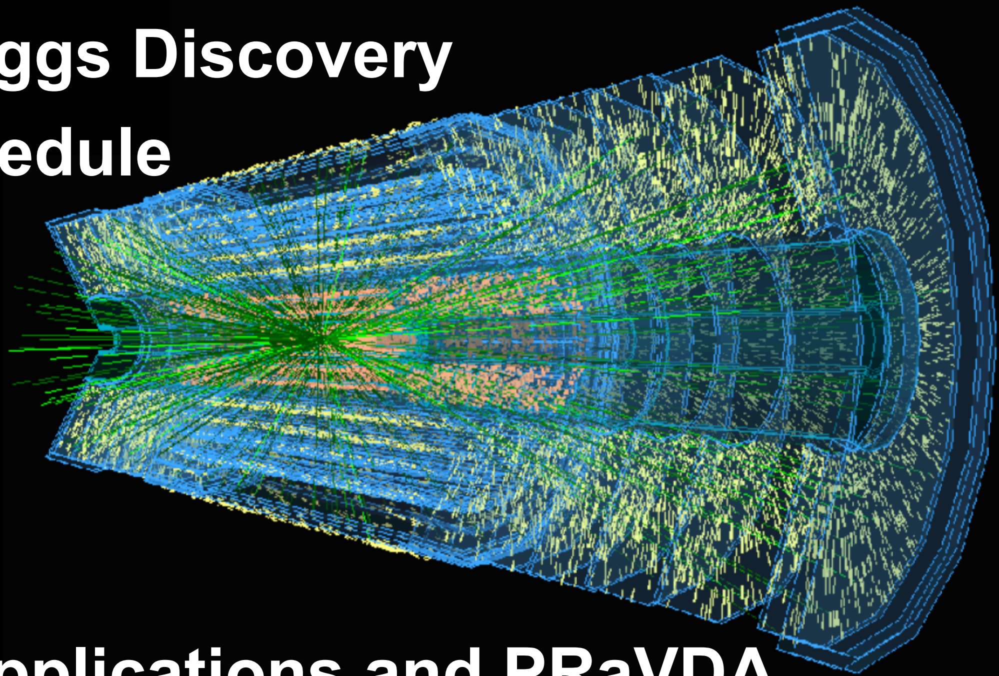
From Higgs to Healthcare

Detector Developments in Particle Tracking for the HL-LHC
and their Applications in Proton Therapy

Phil Allport
ATLAS Upgrade Coordinator
Birmingham University 17/7/14

- **ATLAS and the Higgs Discovery**
- **LHC Upgrade Schedule**
- **ATLAS Upgrades**
  - **Physics Potential**
  - **New Tracker**
    - **Pixels**
    - **Strips**
    - **HV/HR-CMOS**



- **Proton Therapy Applications and PRaVDA**
- **Conclusions**

Silicon Detector Trackers in Particle Physics

- Highly segmented silicon detectors have been used in high energy and nuclear physics experiments for nearly 40 years
- **The principle application has been to detect the passage of ionising radiation with high <u>spatial</u> resolution and good efficiency.**

- **Segmentation → position**
- **Depletion depth → efficiency**
- $\left(W_{Depletion} = \{2\rho\mu\varepsilon(V_{ext} + V_{bi})\}^{1/2} \right)$

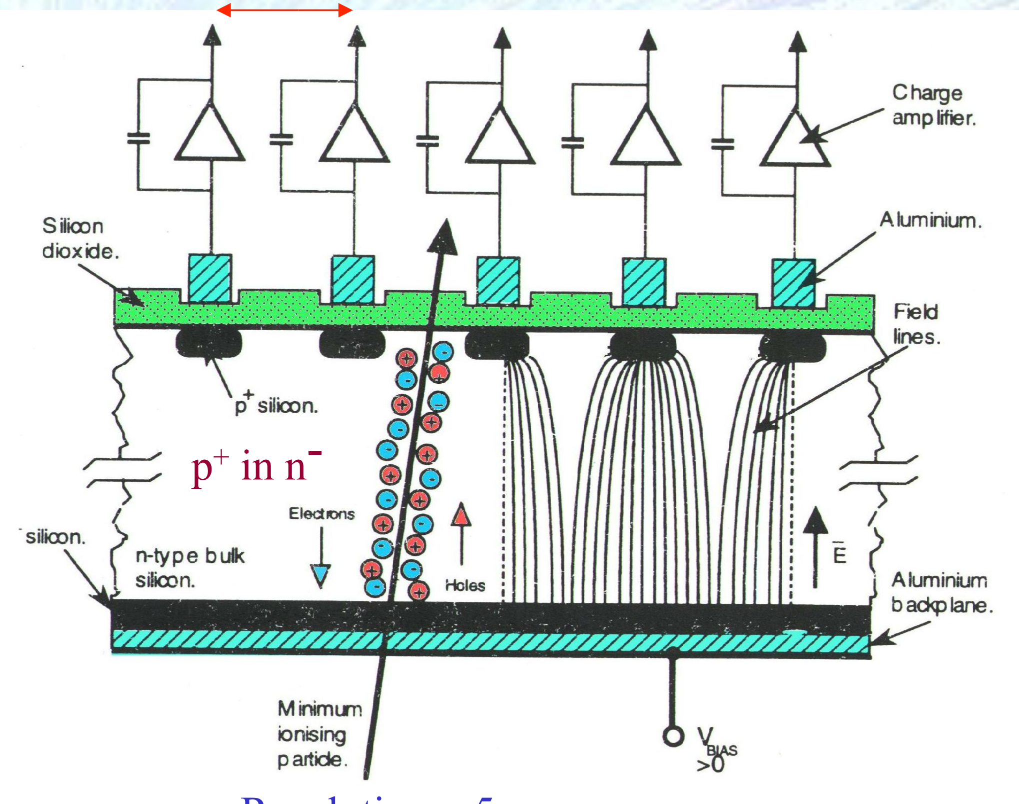
Resistivity

Mobility

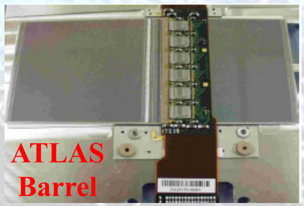
Applied Voltage

- **~80e/h pairs/μm produced by passage of minimum ionising particle, 'mip'**

Pitch ~ 50μm

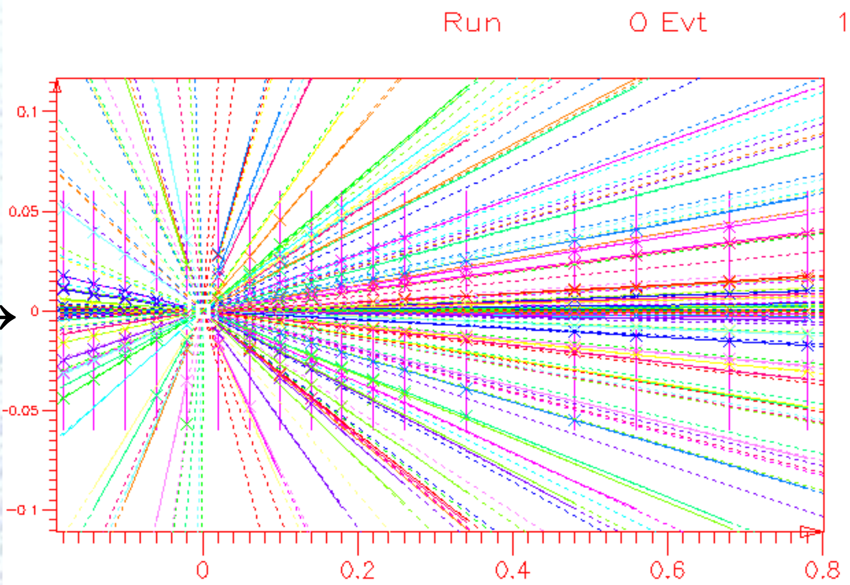


Resolution ~ 5μm

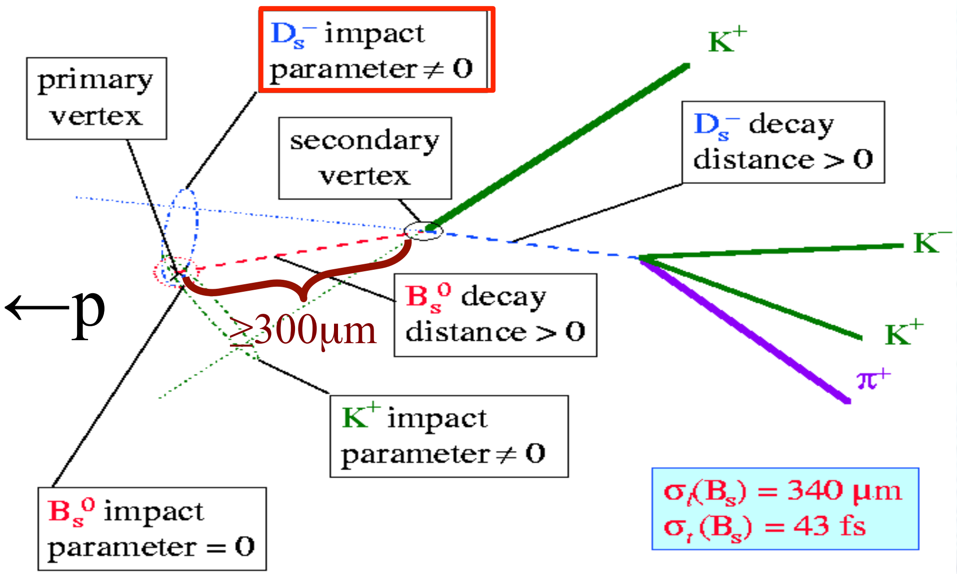


Silicon Sensors as Vertex Detectors

- Nearly all early particle physics applications of silicon micro-strip detectors were to detect and measure particles with pico-second (10^{-12}) lifetimes such that (taking account of special relativity) $\beta\gamma c\tau \geq 300\mu m$
- This meant the primary goal was to locate primary (collision) and secondary vertices (illustrated below in the case of the LHCb VErtex LOcator)



Side on view of 7 TeV on 7 TeV proton collision

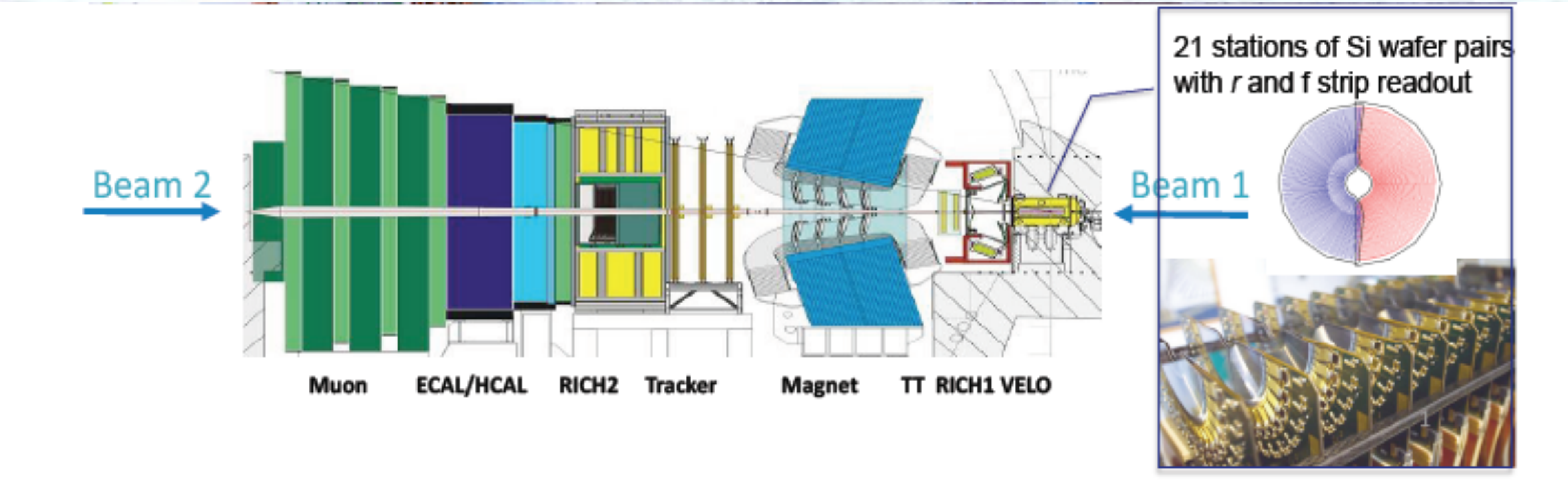


Zoom in showing just particles from B_S-meson decay

- **In most recent experiments, and for the LHCb upgrade, the technology moves from micro-strips to pixel sensors, with much higher channel count**

Silicon Sensors as Vertex Detectors

- Nearly all early particle physics applications of silicon micro-strip detectors were to detect and measure particles with pico-second (10^{-12}) lifetimes such that (taking account of special relativity) $\beta\gamma c\tau \geq 300\mu m$
- This meant the primary goal was to locate primary (collision) and secondary vertices (illustrated below in the case of the LHCb VErtex LOcator)



- **Silicon micro-strip detectors are now used primarily for charged particle tracking detectors at experiments with high radiation environments**

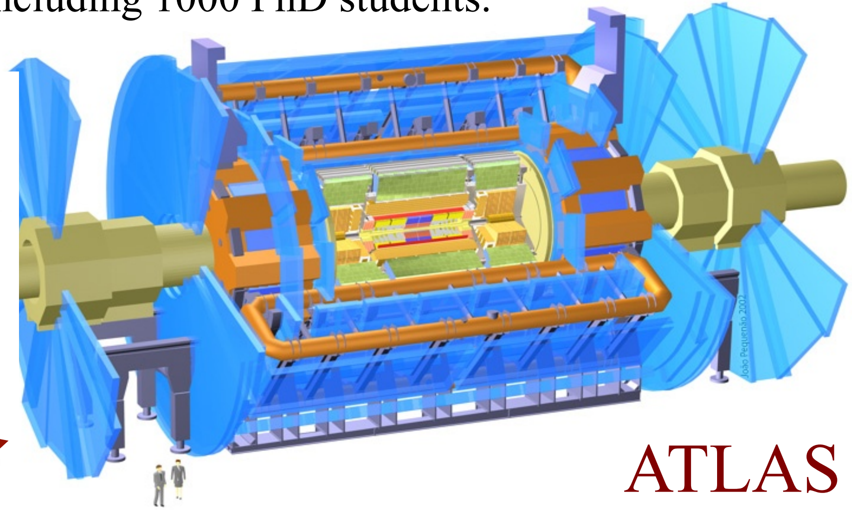
The ATLAS Experiment at the LHC

CERN has 4 Giant Collider Experiments: ALICE, CMS, ATLAS and LHCb

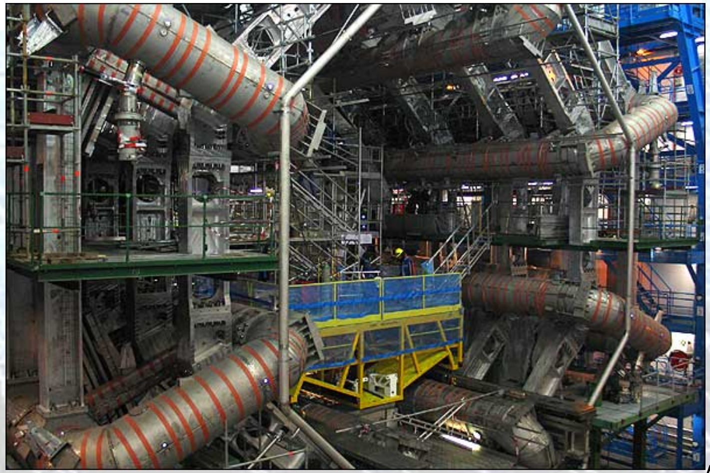
CERN Geneva

The Large Hadron Collider: 7TeV protons on 7TeV protons
or 2.8TeV per nuclean Lead-Lead nuclei Collisions

ATLAS is a collaboration of 3000 physicists from 177 universities and laboratories in 38 countries including 1000 PhD students.



ATLAS

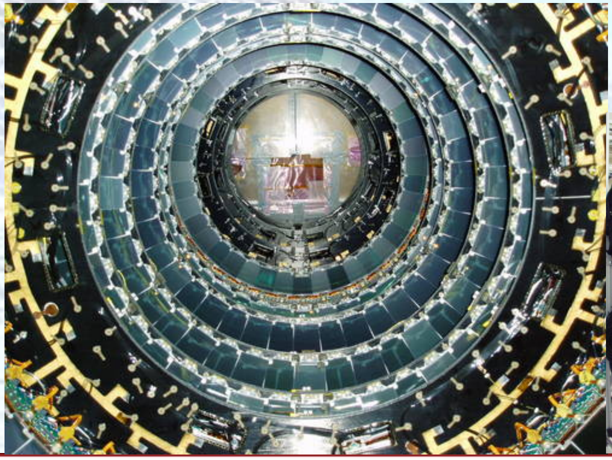


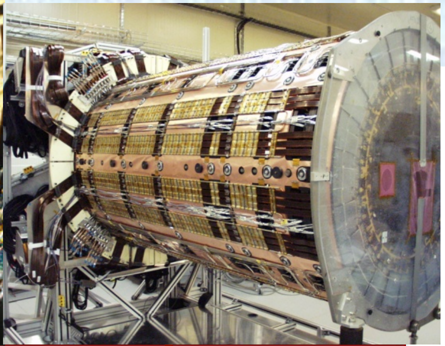
High Speed, High Precision Silicon Tracking

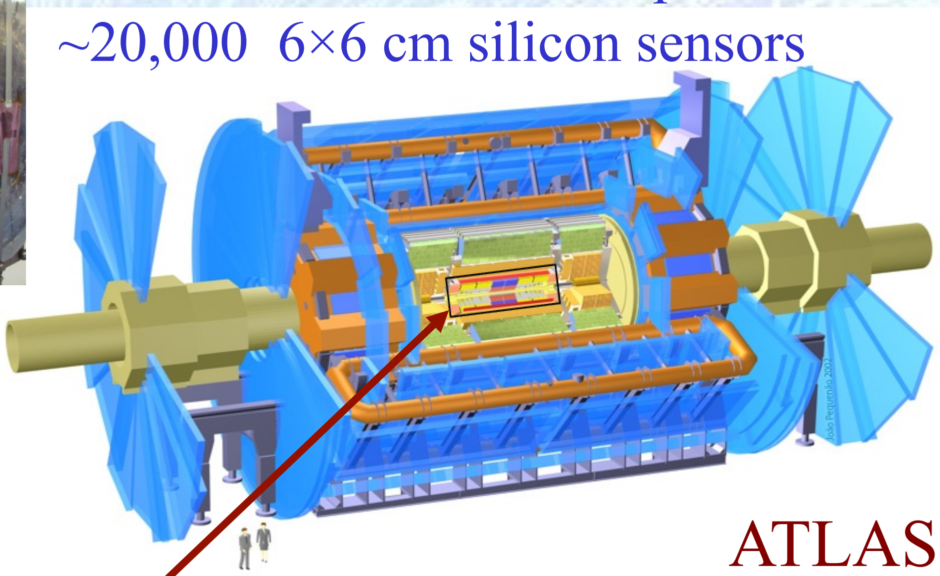
Designed to record and process each collision at 40 million bunch crossings per second.
Measure particle trajectories to 10µm precision (15 million strips).
Has to withstand radiation doses up to hundreds of kGy (Mrads).

61m^2 of silicon micro-strip detectors

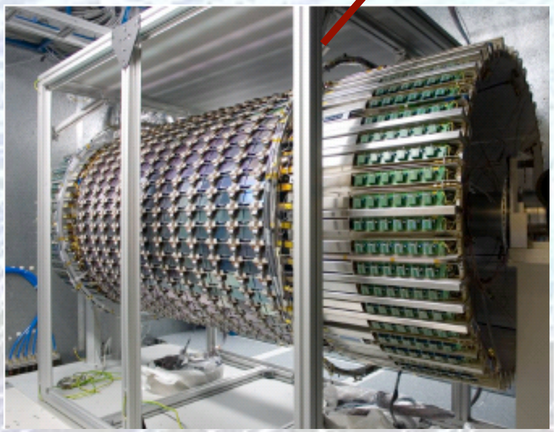
~20,000 6×6 cm silicon sensors

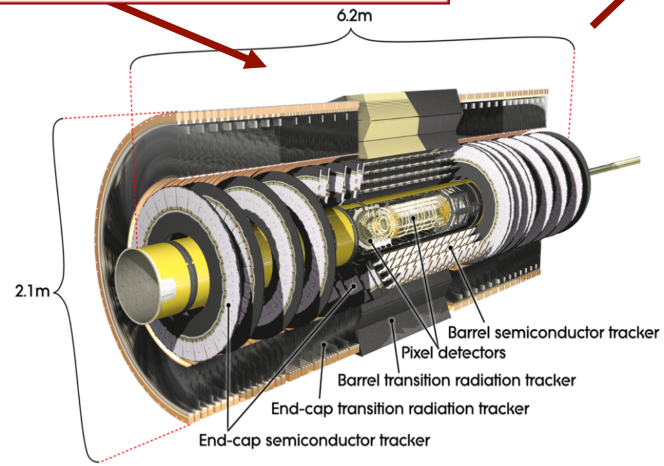






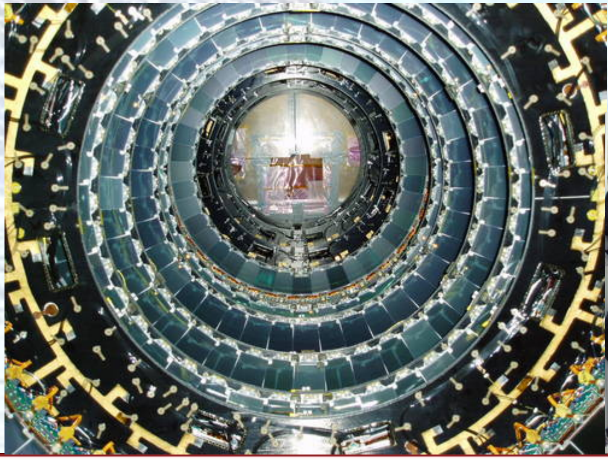
ATLAS

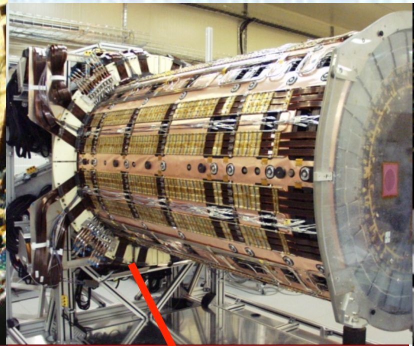


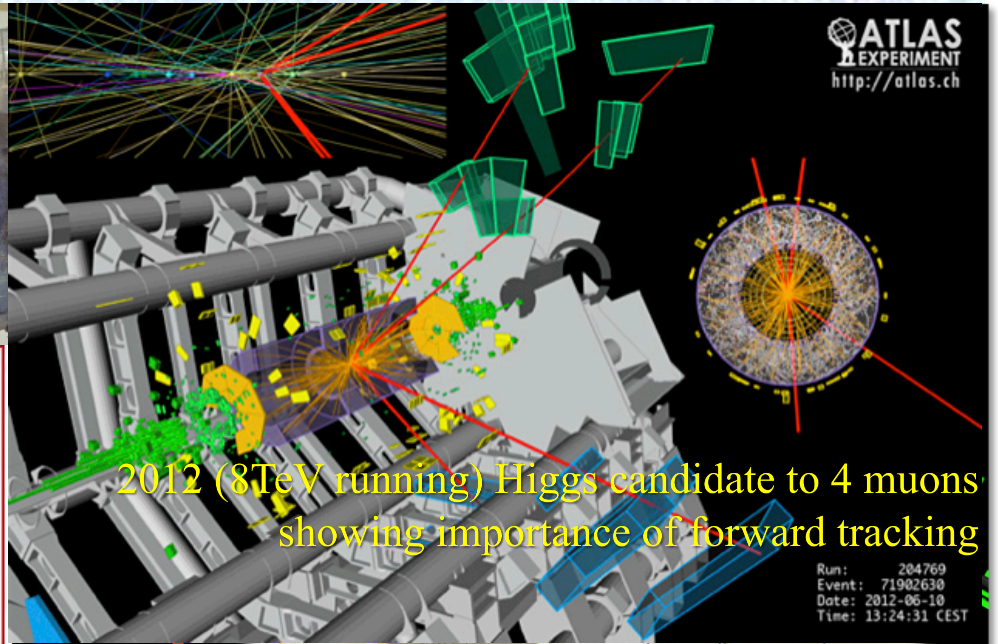


High Speed, High Precision Silicon Tracking

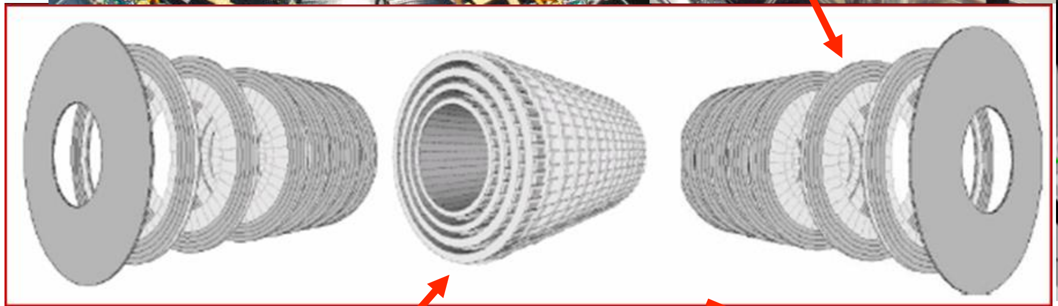
Designed to record and process each collision at 40 million bunch crossings per second.
Measure particle trajectories to 10µm precision (15 million strips).
Has to withstand radiation doses up to hundreds of kGy (Mrads).

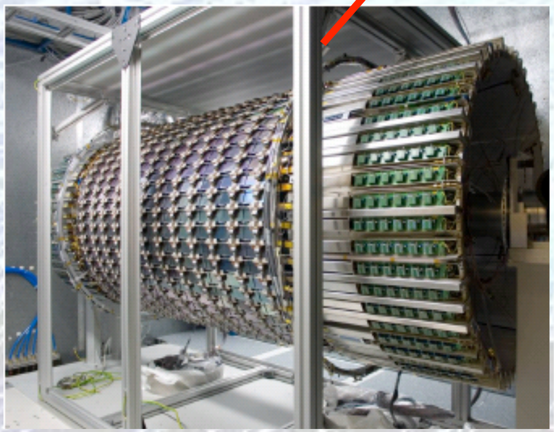


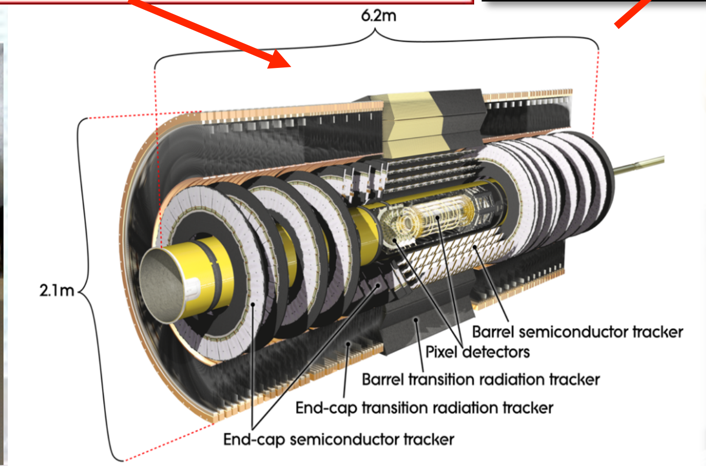


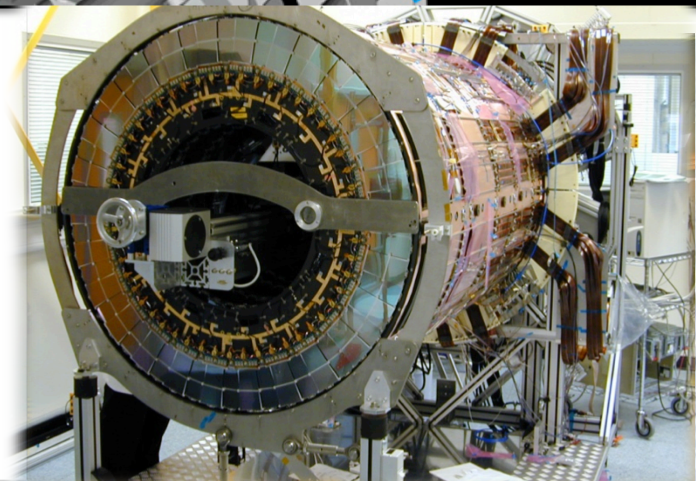


2012 (8TeV running) Higgs candidate to 4 muons
showing importance of forward tracking





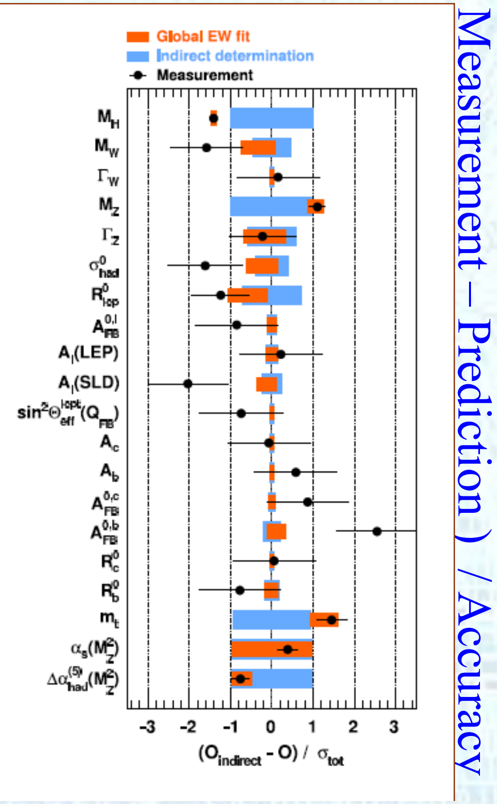




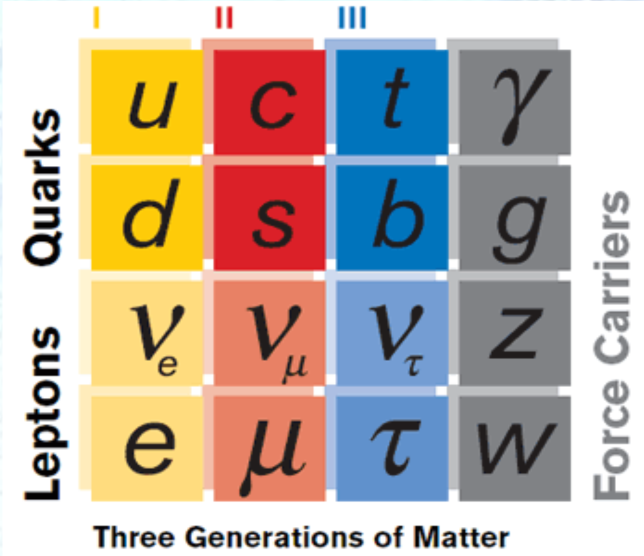
The Standard Model

- **Matter is made out of spin-half particles:**
  - **3 generations of quarks and leptons**
- **Forces are carried by spin-one particles:**
  - **Electro-weak: γ,W,Z**
  - **Strong: gluons**

Quantity	Value	Standard Model	Pull	Dev.
M_Z [GeV]	91.1876 ± 0.0021	91.1874 ± 0.0021	0.1	0.0
Γ_Z [GeV]	2.4952 ± 0.0023	2.4961 ± 0.0010	−0.4	−0.2
$\Gamma(\text{had})$ [GeV]	1.7444 ± 0.0020	1.7426 ± 0.0010	—	—
$\Gamma(\text{inv})$ [MeV]	499.0 ± 1.5	501.69 ± 0.06	—	—
$\Gamma(\ell^+\ell^-)$ [MeV]	83.984 ± 0.086	84.005 ± 0.015	—	—
σ_{had}[nb]	41.541 ± 0.037	41.477 ± 0.009	1.7	1.7
R_e	20.804 ± 0.050	20.744 ± 0.011	1.2	1.3
R_μ	20.785 ± 0.033	20.744 ± 0.011	1.2	1.3
R_τ	20.764 ± 0.045	20.789 ± 0.011	−0.6	−0.5
R_b	0.21629 ± 0.00066	0.21576 ± 0.00004	0.8	0.8
R_c	0.1721 ± 0.0030	0.17227 ± 0.00004	−0.1	−0.1
$A_{FB}^{(0,e)}$	0.0145 ± 0.0025	0.01633 ± 0.00021	−0.7	−0.7
$A_{FB}^{(0,\mu)}$	0.0169 ± 0.0013		0.4	0.6
$A_{FB}^{(0,\tau)}$	0.0188 ± 0.0017		1.5	1.6
$A_{FB}^{(0,b)}$	0.0992 ± 0.0016	0.1034 ± 0.0007	−2.6	−2.3
$A_{FB}^{(0,c)}$	0.0707 ± 0.0035	0.0739 ± 0.0005	−0.9	−0.8
$A_{FB}^{(0,s)}$	0.0976 ± 0.0114	0.1035 ± 0.0007	−0.5	−0.5
$\bar{s}_\ell^2(A_{FB}^{(0,q)})$	0.2324 ± 0.0012	0.23146 ± 0.00012	0.8	0.7
	0.23200 ± 0.00076		0.7	0.6
	0.2287 ± 0.0032		−0.9	−0.9
A_e	0.15138 ± 0.00216	0.1475 ± 0.0010	1.8	2.1
	0.1544 ± 0.0060		1.1	1.3
	0.1498 ± 0.0049		0.5	0.6
A_μ	0.142 ± 0.015		−0.4	−0.3
A_τ	0.136 ± 0.015		−0.8	−0.7
	0.1439 ± 0.0043		−0.8	−0.7
A_b	0.923 ± 0.020	0.9348 ± 0.0001	−0.6	−0.6
A_c	0.670 ± 0.027	0.6680 ± 0.0004	0.1	0.1
A_s	0.895 ± 0.091	0.9357 ± 0.0001	−0.4	− 0.4



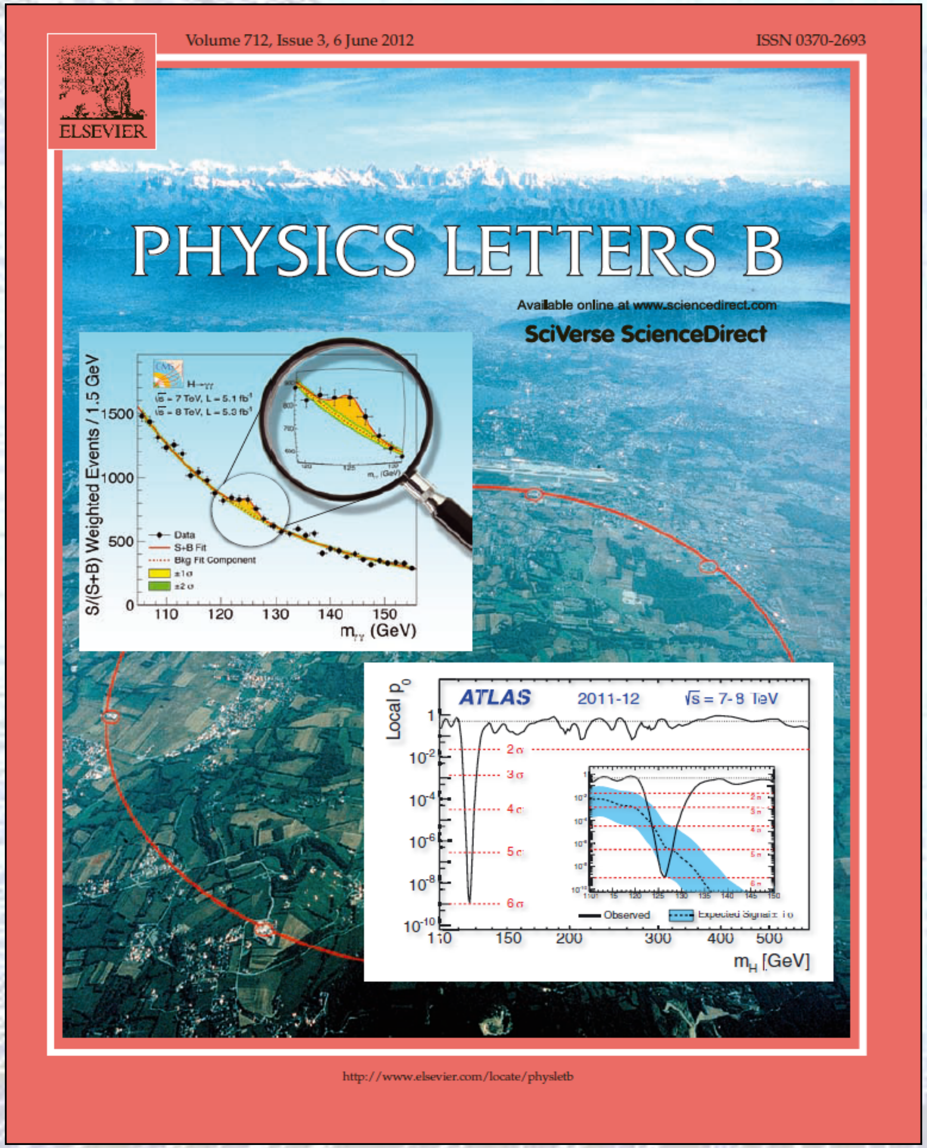
Examples of electro-weak fits to different measurements (http://pdg.lbl.gov/index.html)



Remarkably successful description of known phenomena:

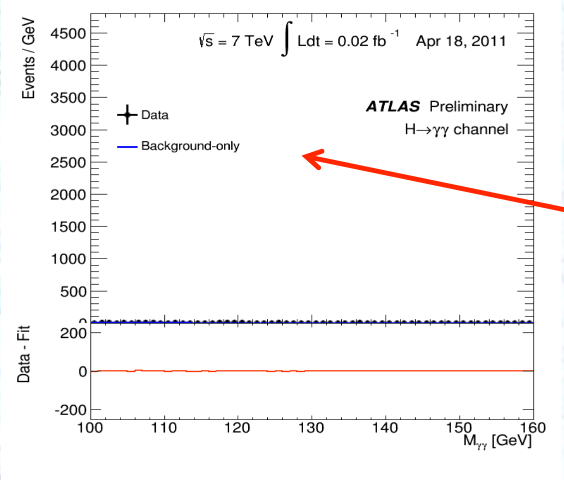
- **predicted the existence of charm, bottom, top quarks, tau neutrino, W and Z bosons.**
- **very good fit to the experimental data so far**
- **but without one crucial ingredient it remains a theory of massless fundamental bosons and fermions**

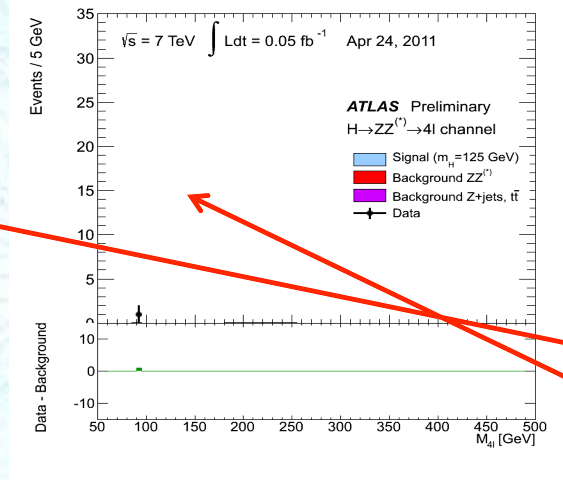
Discovery of the Higgs at the LHC

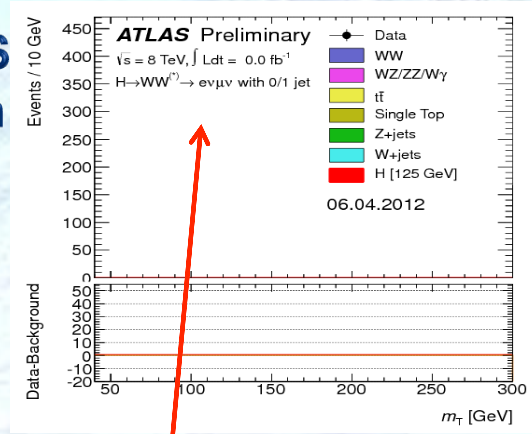


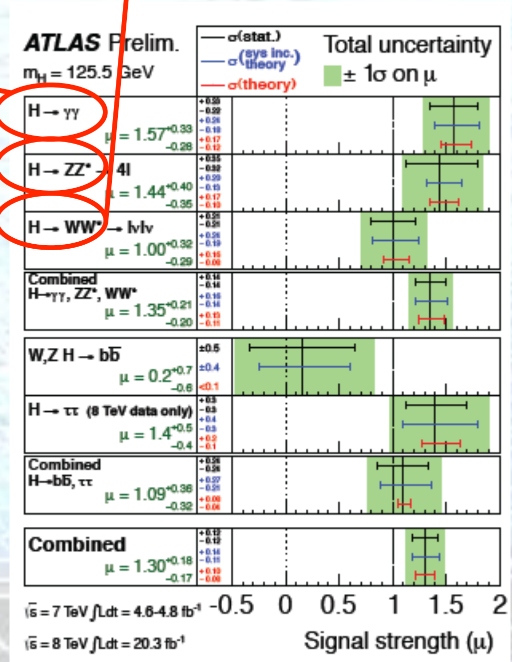
Discovery of the Higgs at the LHC

- Prior to the LHC start-up all we knew: Higgs mass > 114 GeV
- After 2 years of successful LHC operation, in July 2012 ATLAS and CMS announced the discovery of a new Higgs-like boson
- Clearest in γγ, ZZ







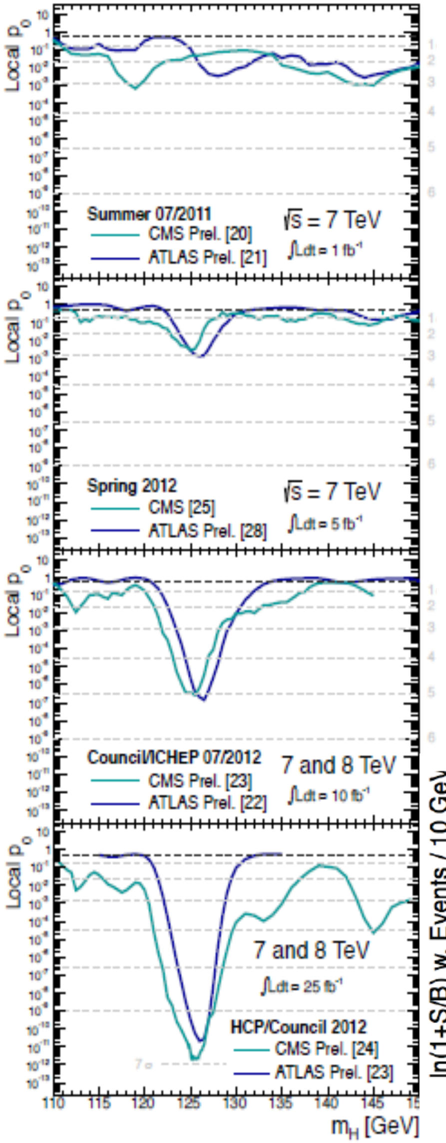


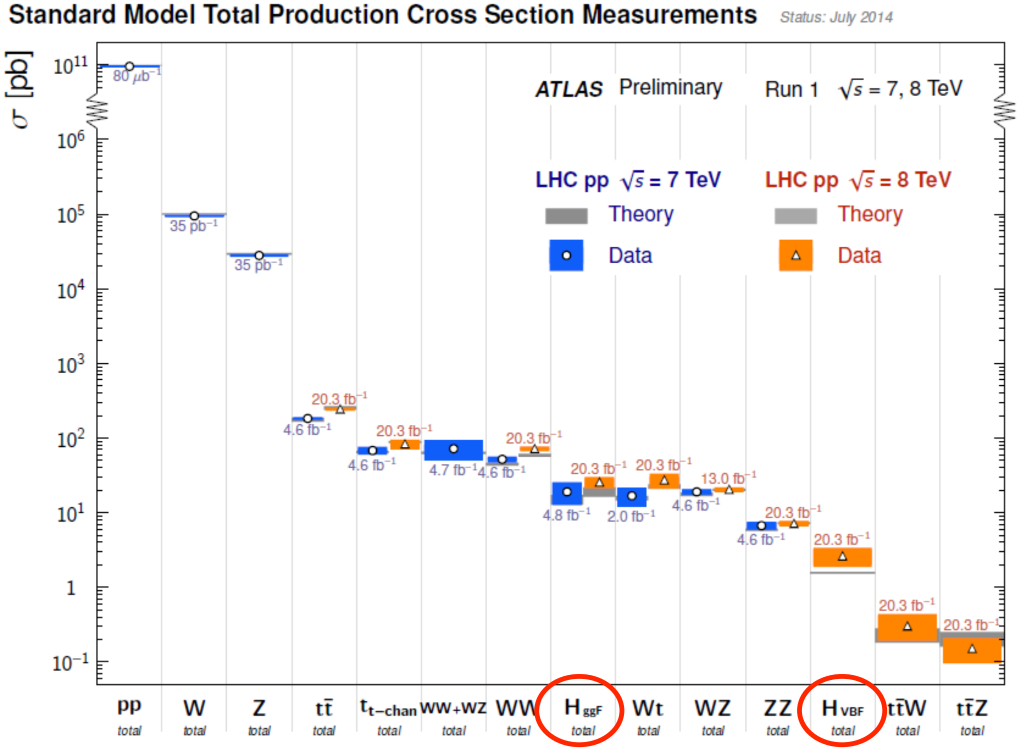
Latest ATLAS m_H fit: ($125.36 \pm 0.37\ (\text{stat}) \pm 0.18\ (\text{syst})$ GeV
http://indico.ific.uv.es/indico/contributionDisplay.py?contribId=78&confId=2025)

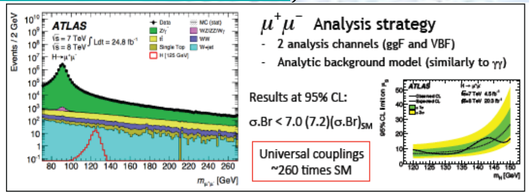
- It is unique amongst the fundamental particles we know (zero spin: so neither a force or matter particle)
- It is key to the way the universe works
- It is stepping stone to a deeper understanding
- Priority is detailed measurements of its properties

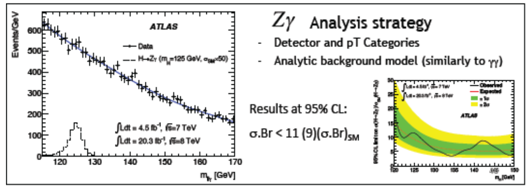
Some Examples of Higgs Physics in ATLAS

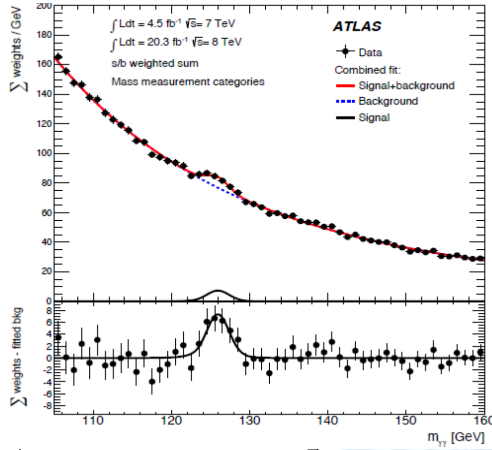
Marumi Kado on behalf of the ATLAS Collaboration at ICHEP 2014 (http://indico.ific.uv.es/indico/contributionDisplay.py?contribId=78&confId=2025)

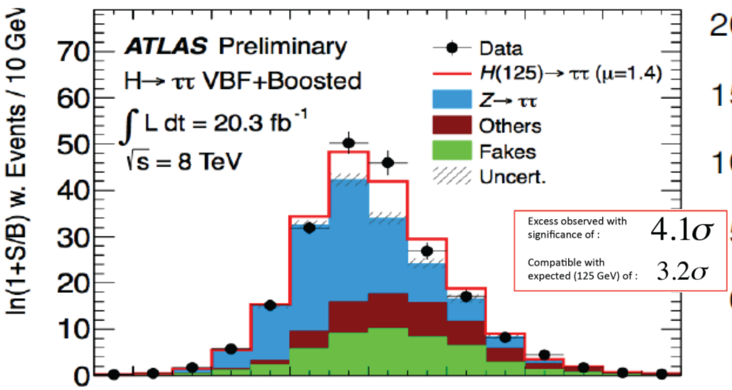


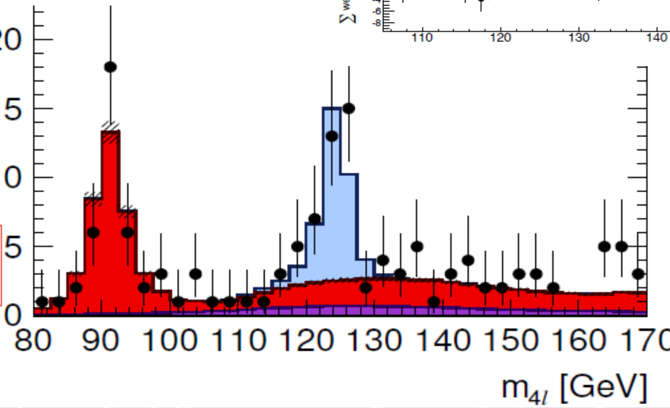






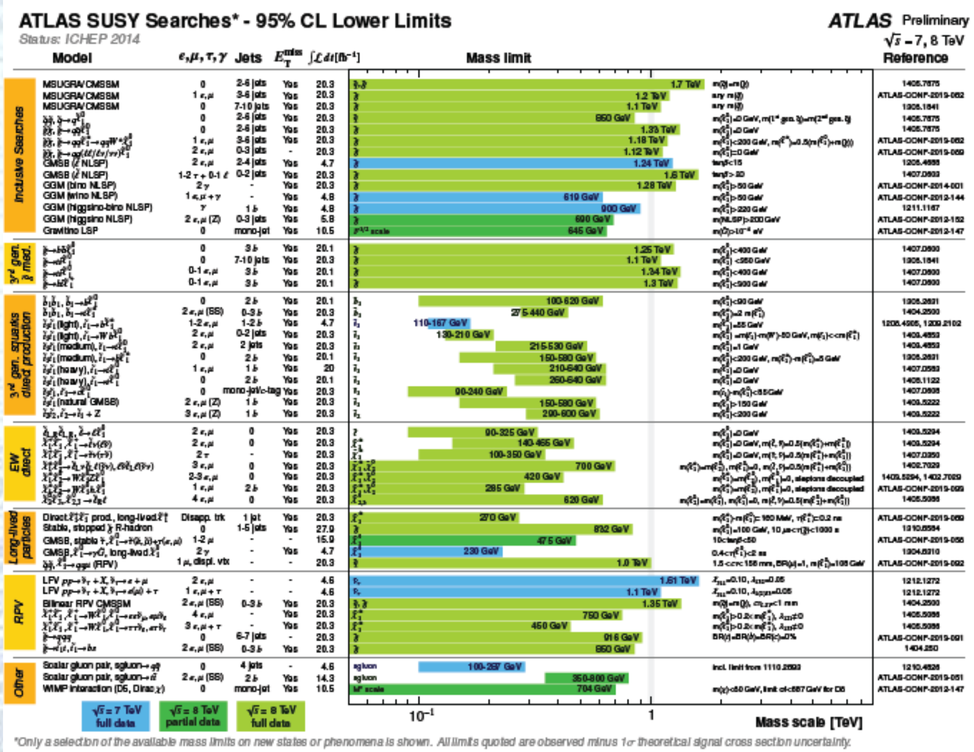


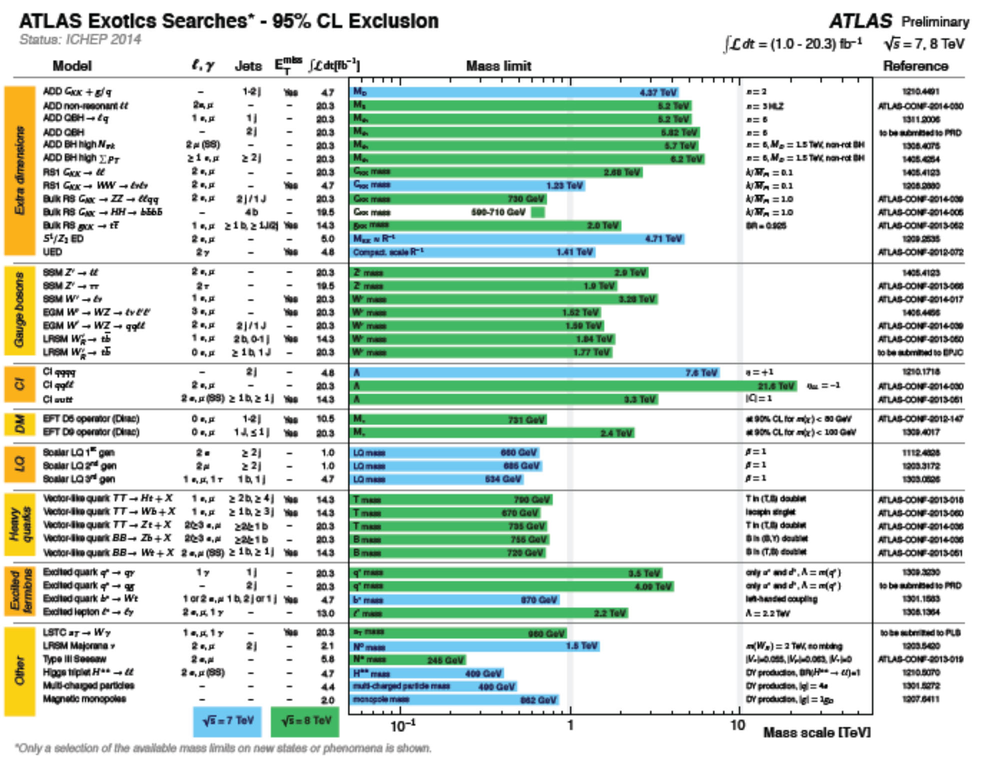




Searches for Beyond the Standard Model

- So far searches up to 8 TeV in energy have only given limits on physics beyond the Standard Model but still early days with 13-14 TeV running to come and up to 100 times more statistics (HL-LHC)





http://indico.ific.uv.es/indico/getFile.py/access?contribId=80&sessionId=17&resId=0&materialId=slides&confId=2025

Particle Physics Planning

- **The main particle physics strategy document for Europe and adopted by CERN Council in May 2013 states:** "The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors*" (http://council.web.cern.ch/council/en/EuropeanStrategy/esc-e-106.pdf);

  while that for the US in May 2014 has: "*The HL-LHC is strongly supported and is the first high-priority large-category project in our recommended program*" (http://science.energy.gov/~/media/hep/hepap/pdf/May%202014/FINAL_DRAFT2_P5Report_WEB_052114.pdf)
- **All 4 experiments, the accelerator and the theory community were represented at the October 2013 ECFA HL-LHC Experiments Workshop at Aix-les-Bains** http://indico.cern.ch/conferenceDisplay.py?confId=252045 **with report at at** https://cds.cern.ch/record/1631032 **which focusses on the detector requirements and discusses the physics reach with 3000fb^{-1}**
- **Accelerator upgrade preparations are discussed in detail at:**
  - "The Review of LHC and Injector Upgrade Plans Workshop" from 29th to 31st October at Archamps, France (**RLUIP**: https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=260492)
  - "The 3rd **Joint HiLumi LHC_LARP** Annual Workshop" from 11th to 15th November at Daresbury (STFC) Laboratory, UK (https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=257368)
- **The next in the ECFA HL-LHC workshop is planned for 21st-23rd October 2014**

ECFA High Luminosity LHC
Experiments Workshop
Physics and technology challenges
1st – 3rd October
Aix-les-Bains
France
2013 Workshop
https://indico.cern.ch/conferenceDisplay.py?confId=252045
Programme Committee
P. Allport
A. Ball
S. Bertolucci
P. Campana
D. Charlton
D. Contardo
B. Di Girolamo
P. Giubellino
J. Incandela
P. Jenni
M. Krammer
M. Mangano
S. Myers
B. Schmidt
T. Virdee
H. Wessels
Local Organising Committee
P. Allport, D. Contardo, D. Hudson, C. Potter
Picture Credit: OT Aix-les-Bains / Gilles Lansard
aix-les-bains centre des congrès
ECFA
High Luminosity LHC
ALICE
ATLAS
CMS
LHCb
CERN

2nd ECFA
HIGH LUMINOSITY
Experiments LHC Workshop
Physics and technology developments
21st - 23rd
OCTOBER 2014
Aix-les-Bains | France
Programme Committee:
P. Allport | A. Ball | S. Bertolucci | F. Bordry | T. Camporesi | D. Charlton | D. Contardo | B. Di Girolamo
P. Giubellino | M. Krammer | M. Mangano | L. Rossi | B. Schmidt | T. Virdee | J.P. Wessels | G. Wilkinson
Organising Committee:
P. Allport | D. Contardo | D. Hudson | C. Potter
Registration and further information at https://indico.cern.ch/event/315626/
or
dawn.hudson@cern.ch and connie.potter@cern.ch
ALICE

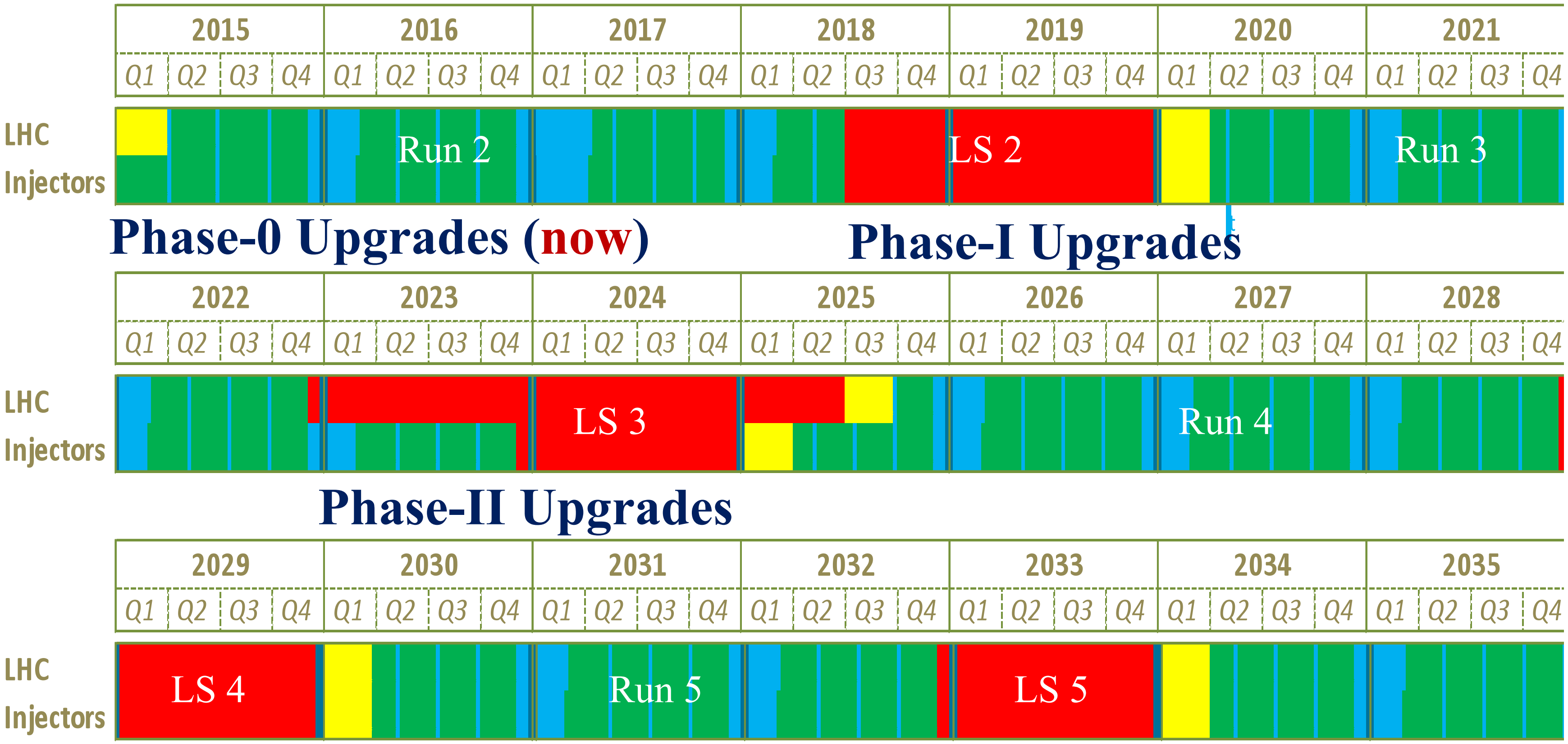
New LHC schedule beyond LS1

Only EYETS (19 weeks)   (no Linac4 connection during Run2)

LS2   starting in 2018 (July)   18 months + 3months BC (Beam Commissioning)

LS3   LHC: starting in 2023 =>   30 months + 3 BC

   injectors: in 2024   =>   13 months + 3 BC



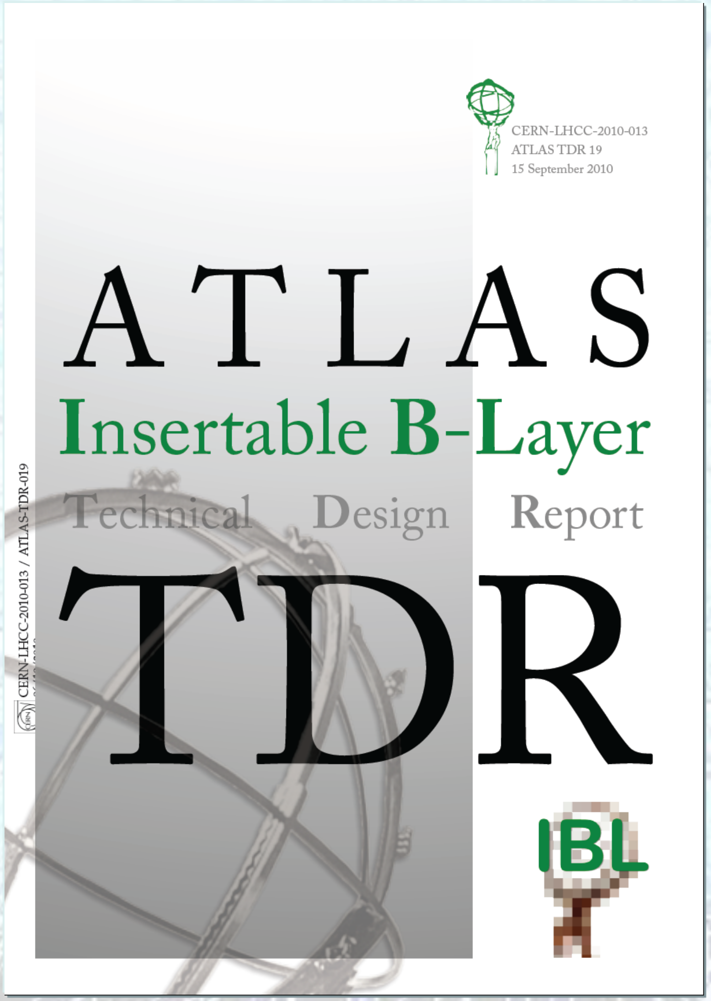
LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators
Monday 2nd December 2013

Current Shutdown Phase-0

- New insertable pixel b-layer (IBL) + new pixel services (nSQP) + new small Be pipe
- New Aluminum beam pipes to prevent activation problem and reduce muon BG
- New evaporative cooling plant for Pixel and SCT + IBL CO_2 cooling plant
- Replace all calorimeter Low Voltage Power Supplies
- Finish the installation of the EE muon chambers staged in 2003 + additional chambers in the feet and elevators region + RPC gas consolidation
- Upgrade the magnets cryogenics and decouple toroid and solenoid cryogenics
- Add specific neutron shielding where necessary (behind endcap toroid, USA15)
- Revisit the entire electricity supply network (UPS in particular)
- Where possible prepare Phase 1 upgrade (services, AFP, ZDC, FTK, ….)
- Re-align the barrel calorimeter and ID + consolidation of infrastructure and services + general maintenance
- Some early installation of (Phase-I) trigger upgrades which are required for above design luminosity operation are being anticipated for Run 2
  - CTP: CTPCore and CTPOut
  - Muon endcap trigger with current small wheel (reduce fake rate)
  - Tile outer layer trigger (to help L1 muon in transition region)
  - nMCM (needed for bunch train correction)
  - CMX and L1Topo
  - Dual output HOLAs for FTK

Current Shutdown
Phase-0

- New insertable pixel b-layer (IBL) + new pixel services (nSQP) + new small Be pipe



ATLAS COLLABORATION CERN-RRB-2012-028-Appendix 1

Addendum No. 01

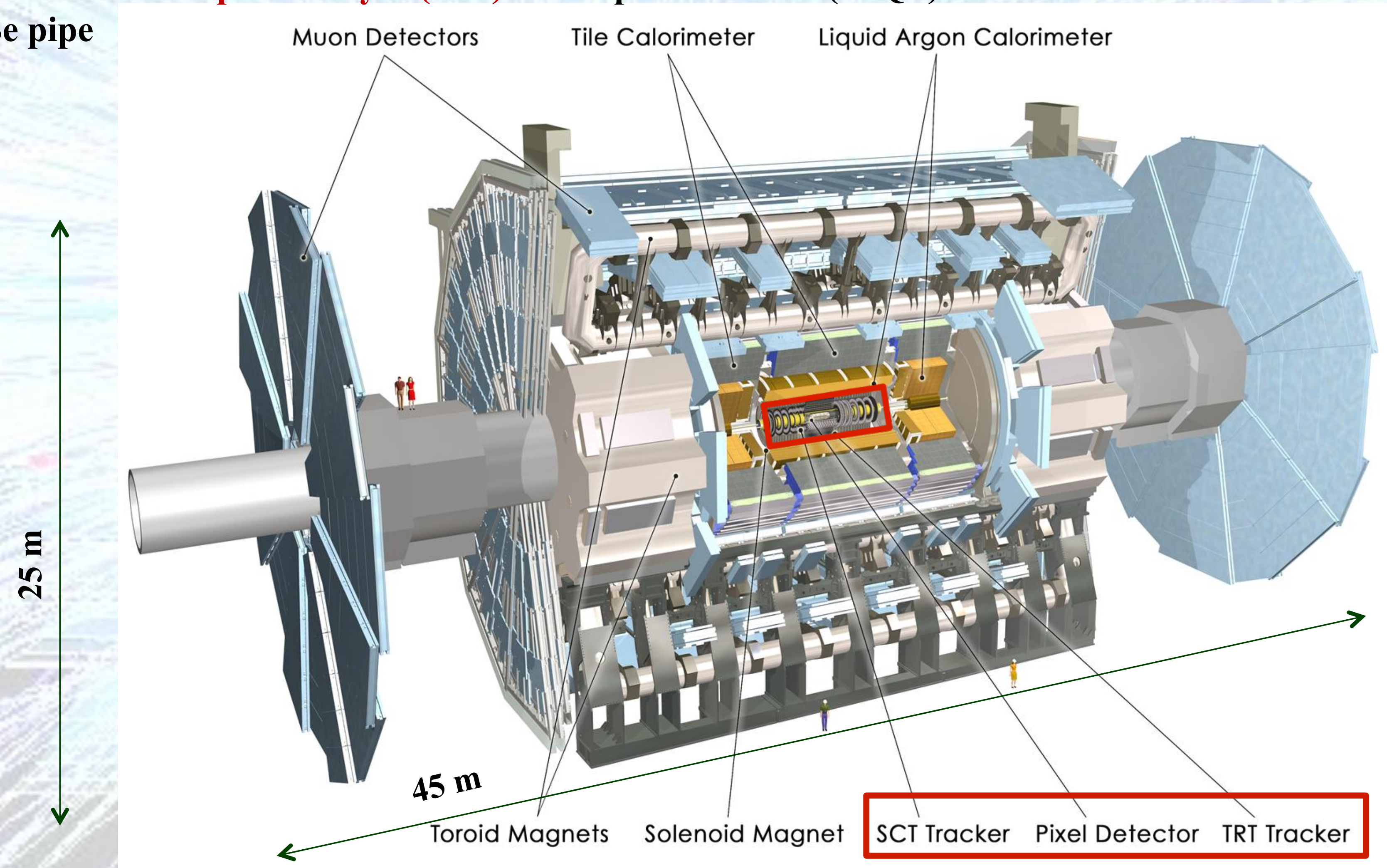
to the
Memorandum of Understanding
for Collaboration in the Construction of the
ATLAS Detector

Construction of the ATLAS Insertable B-Layer (IBL)
Sub-Detector

Work Responsibility	
Barcelona	Prototype: 3D, Planar; Production: contribution
Bonn	Prototype: 3D, Planar, Diamond; Production: contribution
CERN	Prototype: 3D, Planar, Diamond; Production: contribution
Dortmund (/MPI)	Prototype: Planar; production: wafer QC
KEK	Prototype: Planar; Production: contribution
Liverpool	Prototype: Planar; Production: contribution
Ljubljana	Prototype: Diamond
LPNHE/Orsay	Prototype: Planar; Production: contribution
Manchester/Glasgow	Prototype: 3D; Production: contribution; QC supervision (Manchester)
New Mexico	Prototype: 3D, Planar, Diamond; Production (silicon): contribution
Ohio SU	Prototype: Diamond
Oslo/Bergen	Prototype: 3D; Production: contribution
Prague AS	Prototype: Planar; Production: contribution
Santa Cruz	Prototype: Planar, (3D); Production: contribution
SLAC/Stony Brook	Prototype: 3D; Production: contribution
Toronto(/Carleton)	Prototype: Diamond
Udine(/Trento)	Prototype: 3D, Planar; Production: contribution

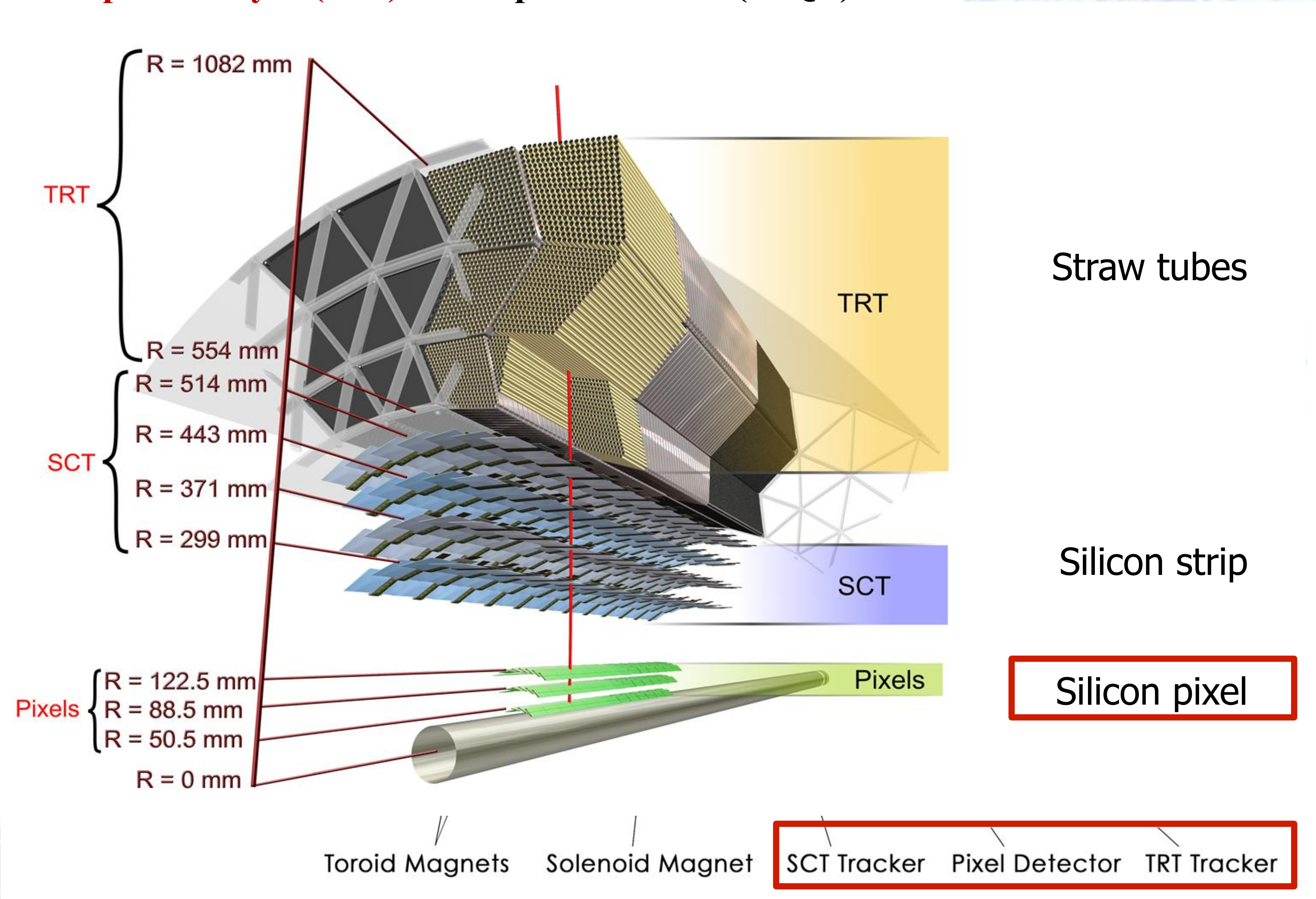
Current Shutdown Phase-0

- New insertable pixel b-layer (IBL) + new pixel services (nSQP) + new small Be pipe

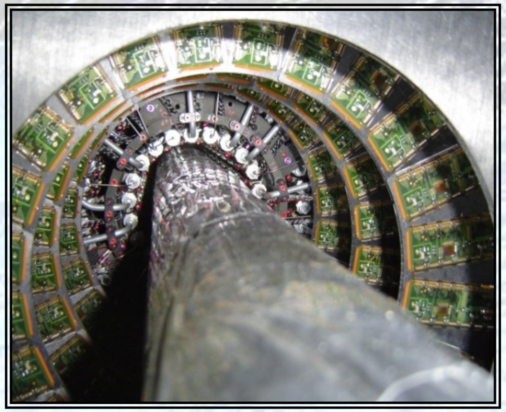


Current Shutdown Phase-0

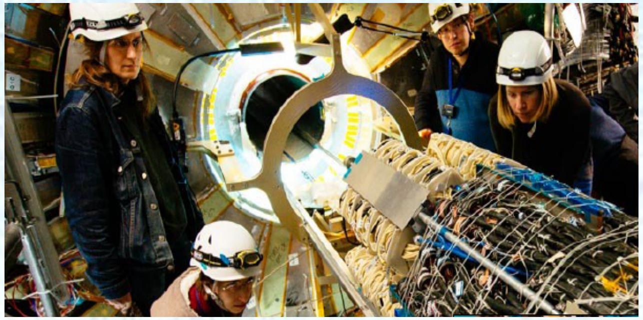
- **New insertable pixel b-layer (IBL) + new pixel services (nSQP) + new small Be pipe**

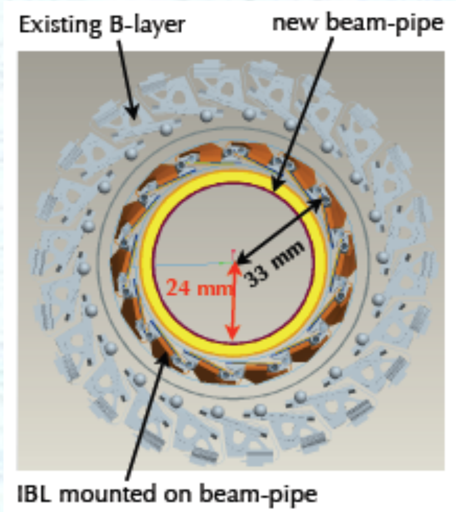


Insertable B-Layer

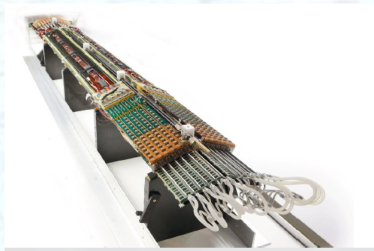


- New inner pixel layer around new smaller beam pipe
- Current pixel package was brought to surface allowing:
  - IBL support tube insertion at surface
  - New services installed to fix problems and improve R/O bandwidth (nSQP)
  - New diamond beam monitors with IBL (FE-I4) ASICs



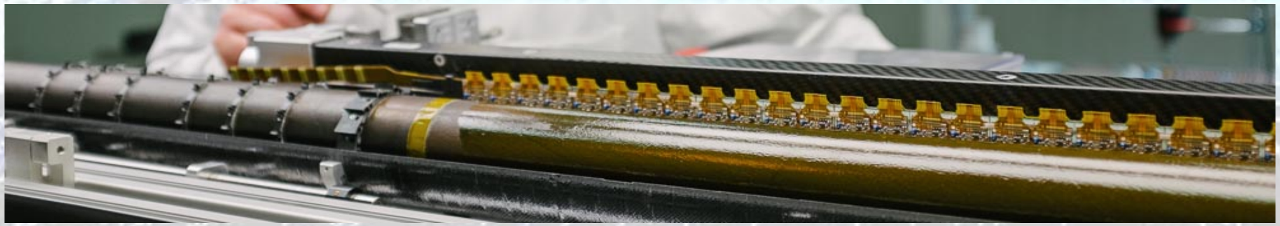


- Reinserted and reconnected
- IBL Inserted into ATLAS on 7th May
  - 27th June service connection completed
  - Final testing and commissioning underway

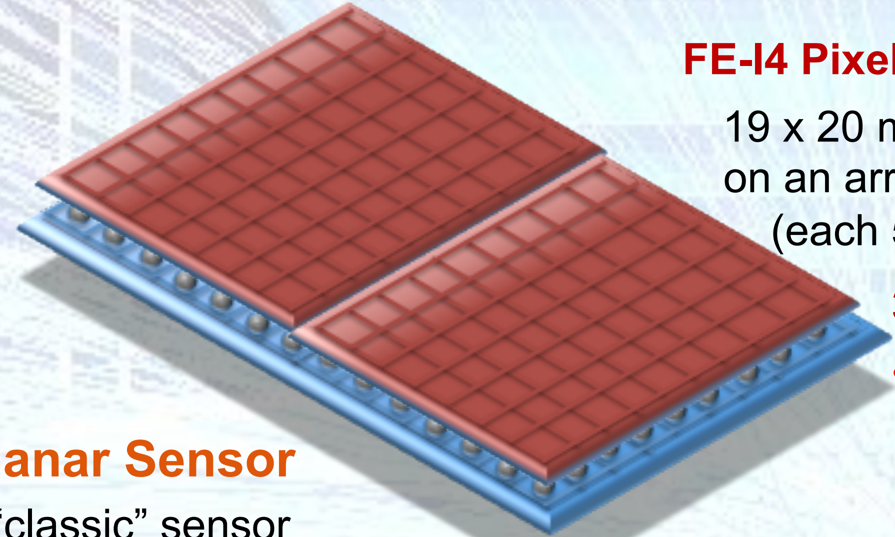


- Off-detector

– New RODs can read-out 32 FE-I4 ASICs at a rate of 160 Mbit/s using 4 S-Links (also supports the dual output required for FTK)

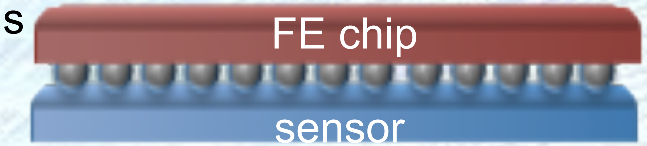


Insertable B-Layer



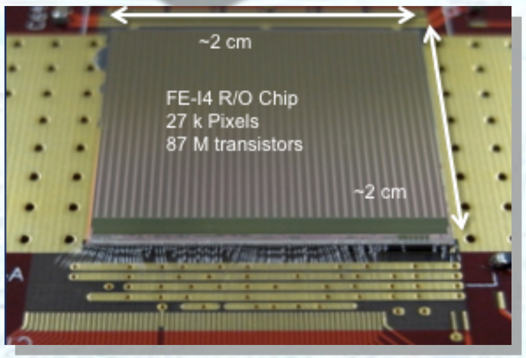
FE-I4 Pixel Chip (26880 channels)

19 x 20 mm^2 130 nm CMOS process, based on an array of 80 by 336 pixels (each 50 x 250 µm^2)



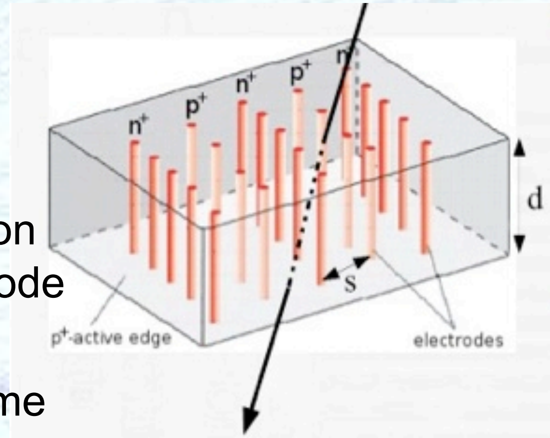
Planar Sensor

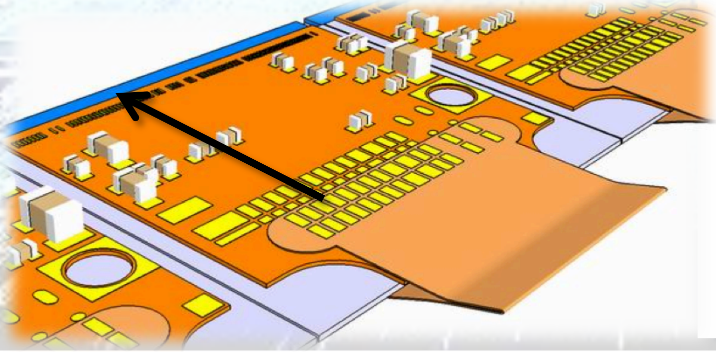
- “classic” sensor design
- oxygenated n-in-n
- 200µm thick
- Minimize inactive edge by shifting guard-ring under pixels (215 µm)
- Radiation hardness proven up to 2.4×10^{16} p/cm^2

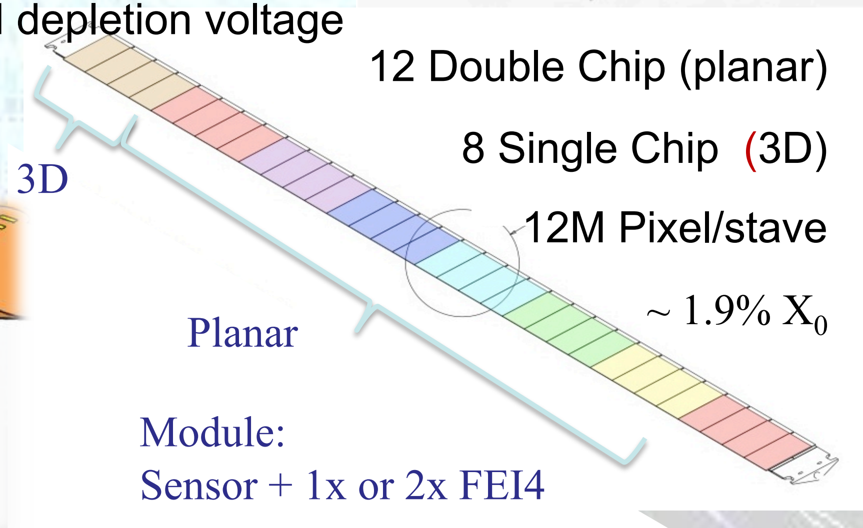


3D Sensor

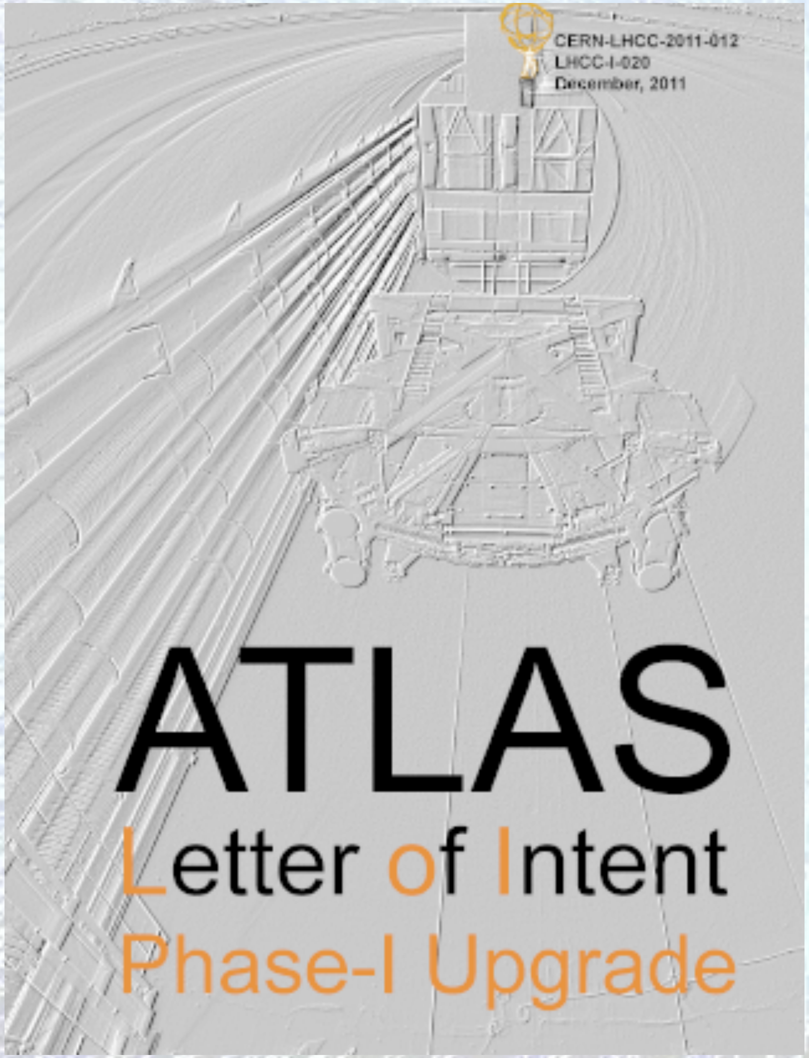
- Both electrode types are processed inside the detector bulk
- Max. drift and depletion distance set by electrode spacing
- Reduced collection time and depletion voltage

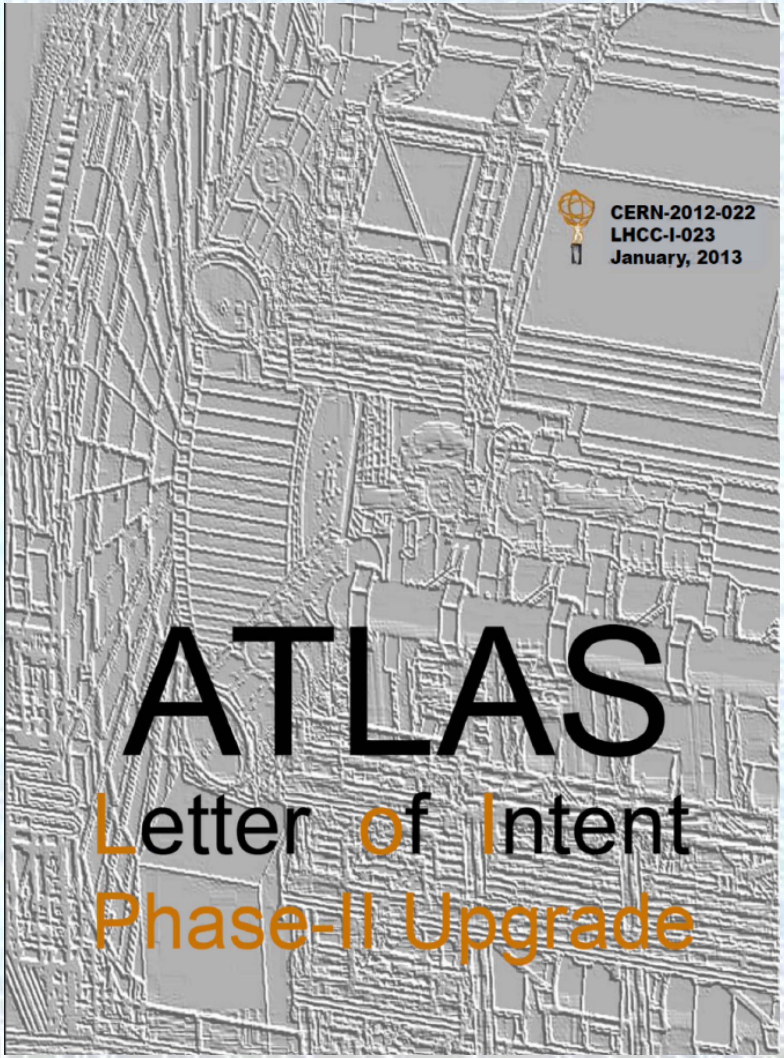




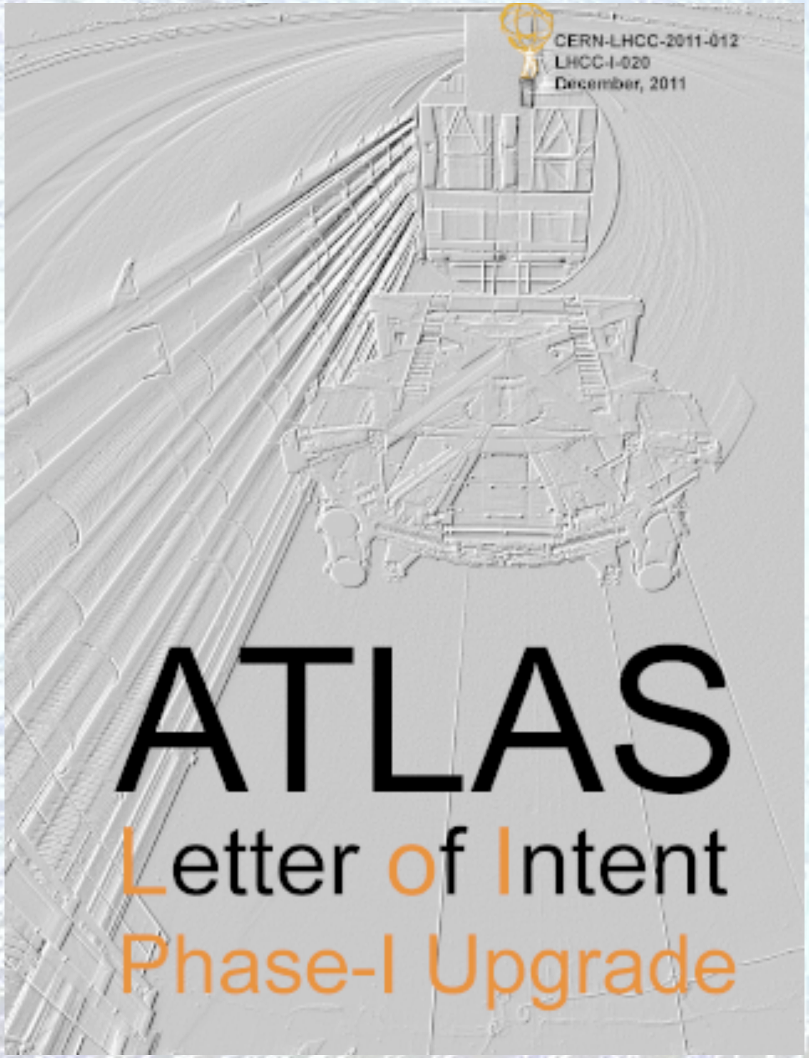


Future Upgrade Planning





Future Upgrade Planning



Phase-I Upgrade

(LS2)

Starts Middle 2018

Future Upgrade Planning

In 2013, 4 TDRs for Phase-I construction projects were prepared within ATLAS, submitted to and are now all approved by CERN's LHC Committee

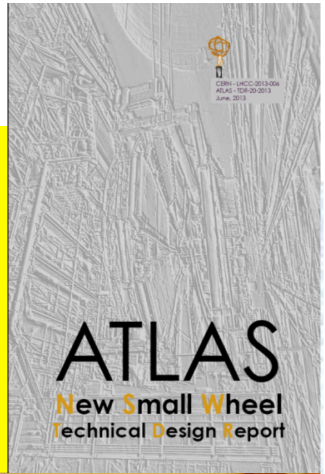
Memoranda of Understanding now in circulation to Funding Agencies

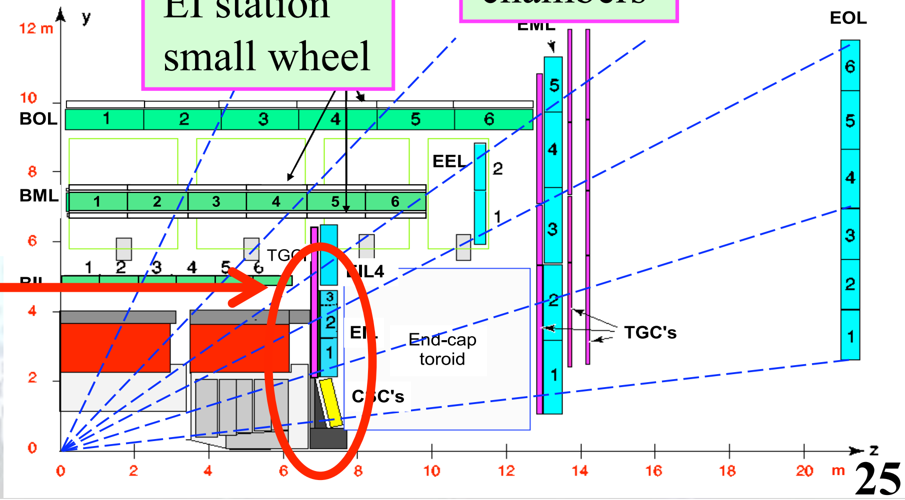
New Small Muon Wheels

(CERN-LHCC-2013-006)

The innermost station of the muon end-cap

Located between end-cap calorimeter and end-cap toroid





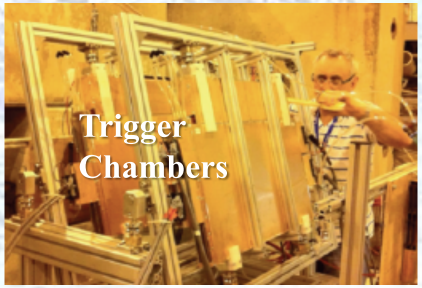
- In furthest forward direction, chamber efficiencies fall with hit rate as luminosity goes well above the design values
- Rate of L1 muon triggers exceeds available bandwidth unless thresholds raised

→ Replace “small“ muon wheels

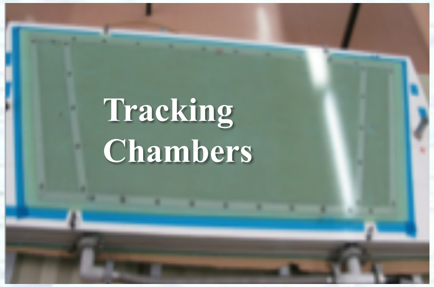
- Kill fake muon triggers by requiring high quality (σ_θ~ 1mrad) pointing to interaction region
- Precision chambers combine sTGC and micromegas technologies for robustness to Phase-II luminosities

New Small Muon Wheels

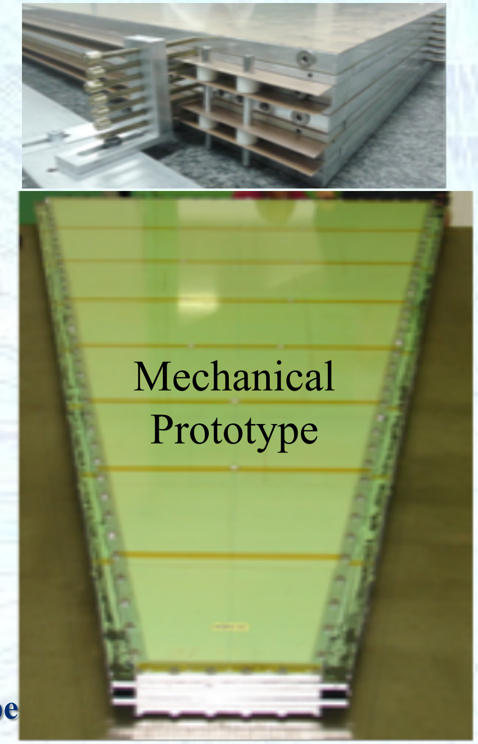
(CERN-LHCC-2013-006)

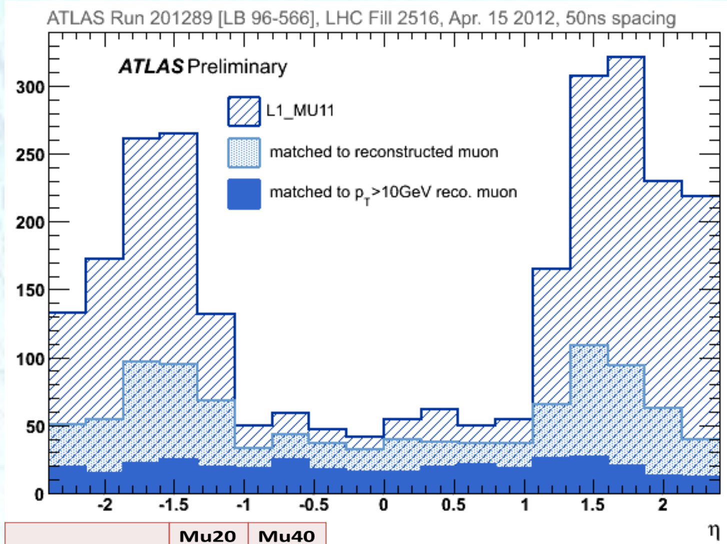


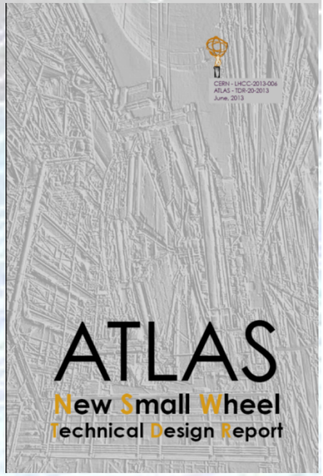
sTGC Prototype

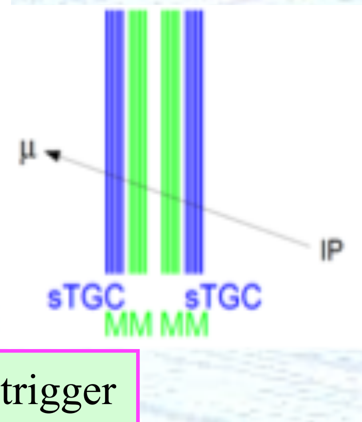


2.4m×1m Micromegas Prototype







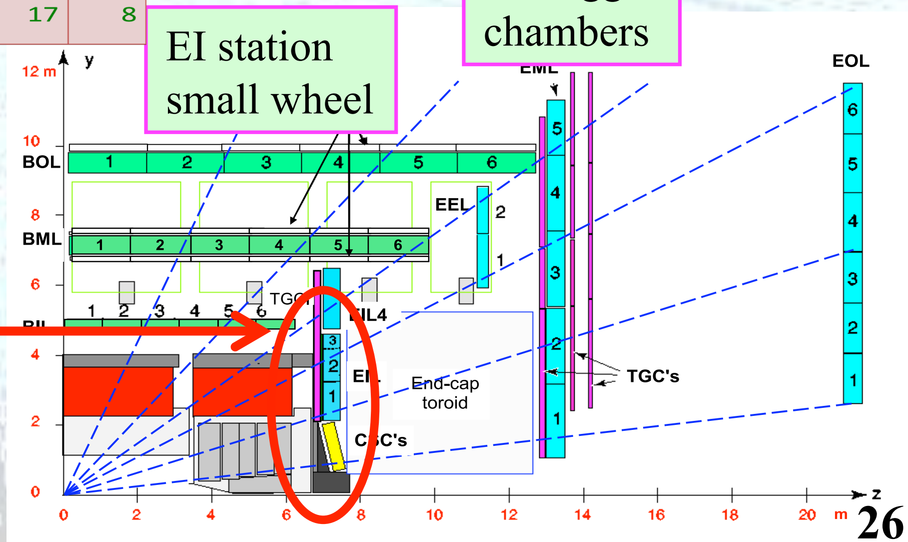


	Mu20	Mu40
Without NSW	60	29
With NSW	22	10
NSW + phase-0	17	8

- **In furthest forward direction, chamber efficiencies fall with hit rate as luminosity goes well above the design values**
- **Rate of L1 muon triggers exceeds available bandwidth unless thresholds raised**

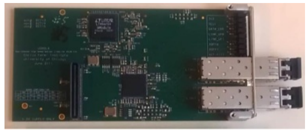
→ Replace "small" muon wheels

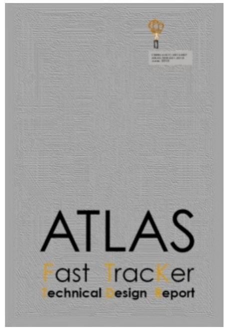
- **Kill fake muon triggers by requiring high quality (σ_θ~ 1mrad) pointing to interaction region**
- **Precision chambers combine sTGC and micromegas technologies for robustness to Phase-II luminosities**



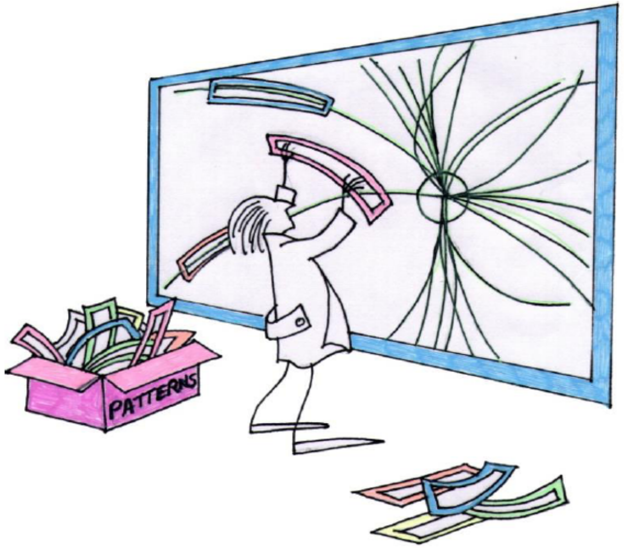
Fast TracKer (FTK)

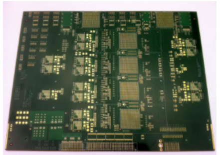
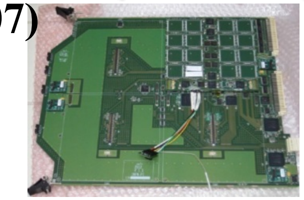
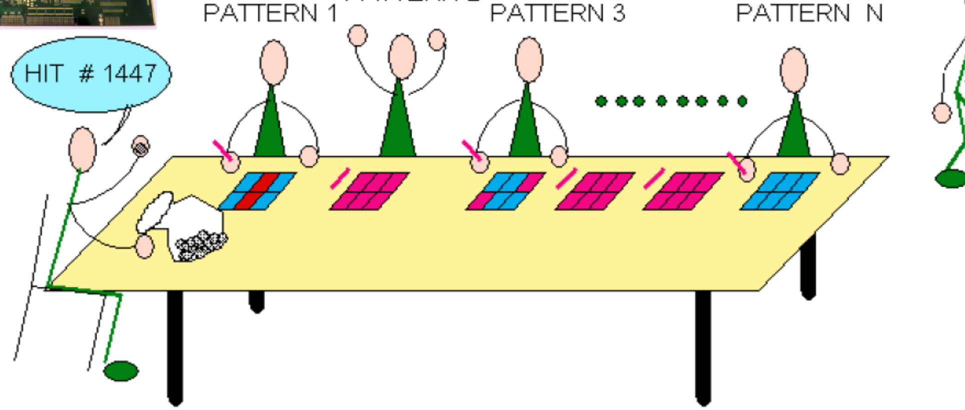
(CERN-LHCC-2013-007)

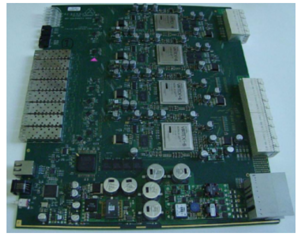




- **Rapid pattern recognition**





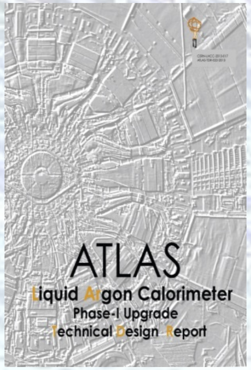
  - **A pattern consists of a Super-Strip in each layer (10s of pixels/strips wide).**
  - **Uses HEP-specific content addressable memory (CAM) custom chip.**
  - **Patterns determined from full ATLAS simulation.**
  - **~ 10^9 patterns see each hit almost simultaneously.**
  - **When hits have all been sent off detector, pattern recognition is ~ done.**

    → This is then followed by FPGA based track fitting (1 fit/ns)

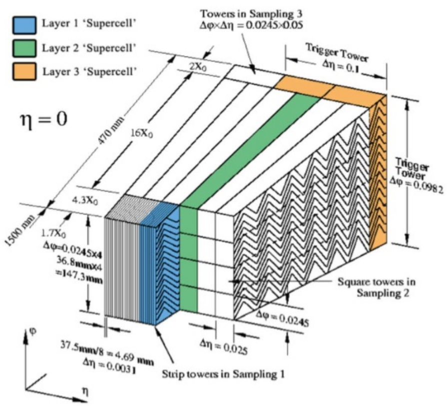
Many boards in pre-production and pre-final CAM chip version submitted
Designed for installation before Phase-I to provide HLT with full tracking at start
(For Phase-II need to speed up to fit tracks as input to Level-1.)

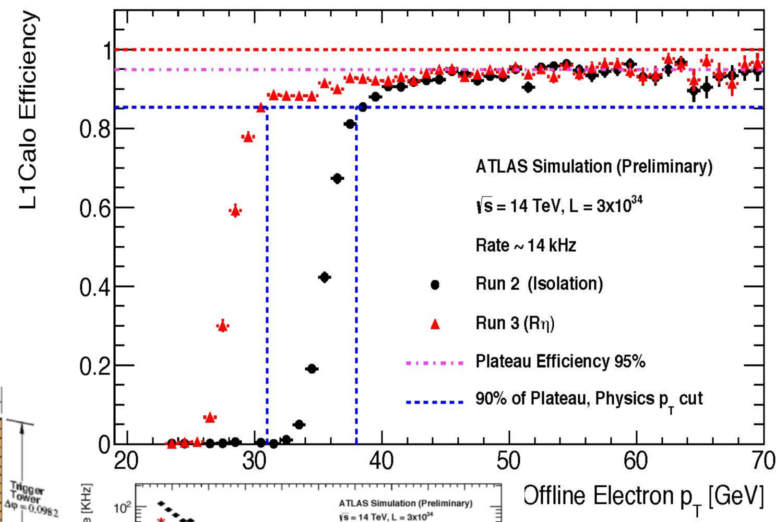
LAr Electronics Upgrades

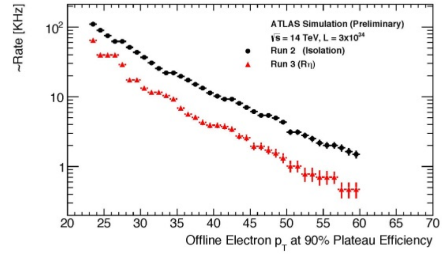
(CERN-LHCC-2013-0017)

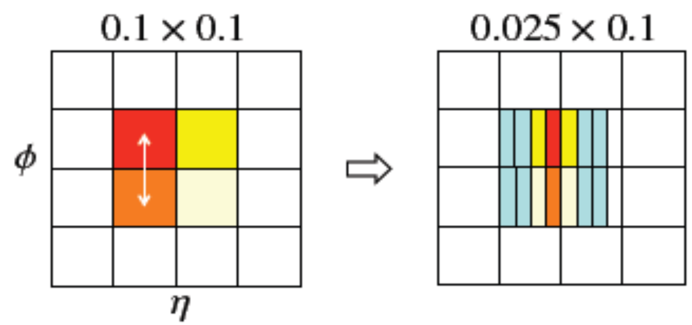


- Key target (as for New Small Wheel) is to maintain high efficiency for Level-1 triggering on low P_T objects (here electrons and photons)
- In the LAr calorimeter this implies changes to the front-end electronics to allow finer granularity to be exploited at Level-1

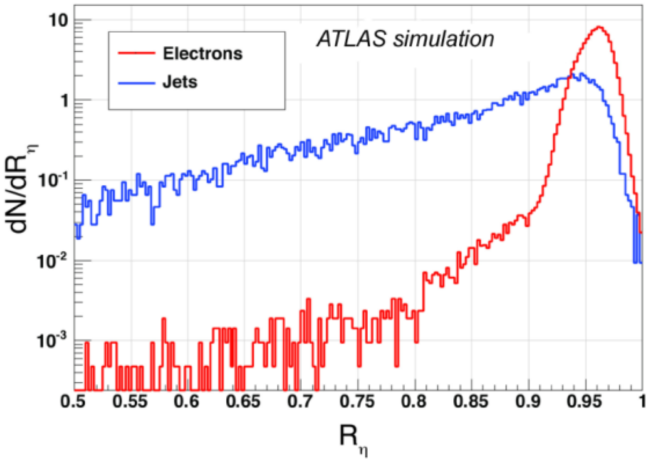




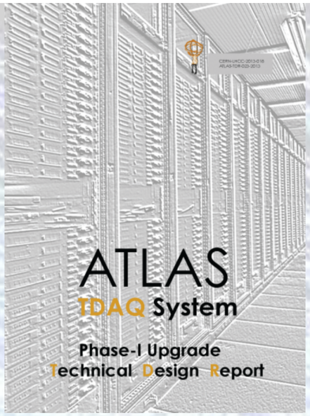




Distribution of the R_η parameter for electrons and jets, defined as the ratio of the energy in the 3x2 over the energy in the 7x2 clusters of the 2nd layer of the EM calorimeter.



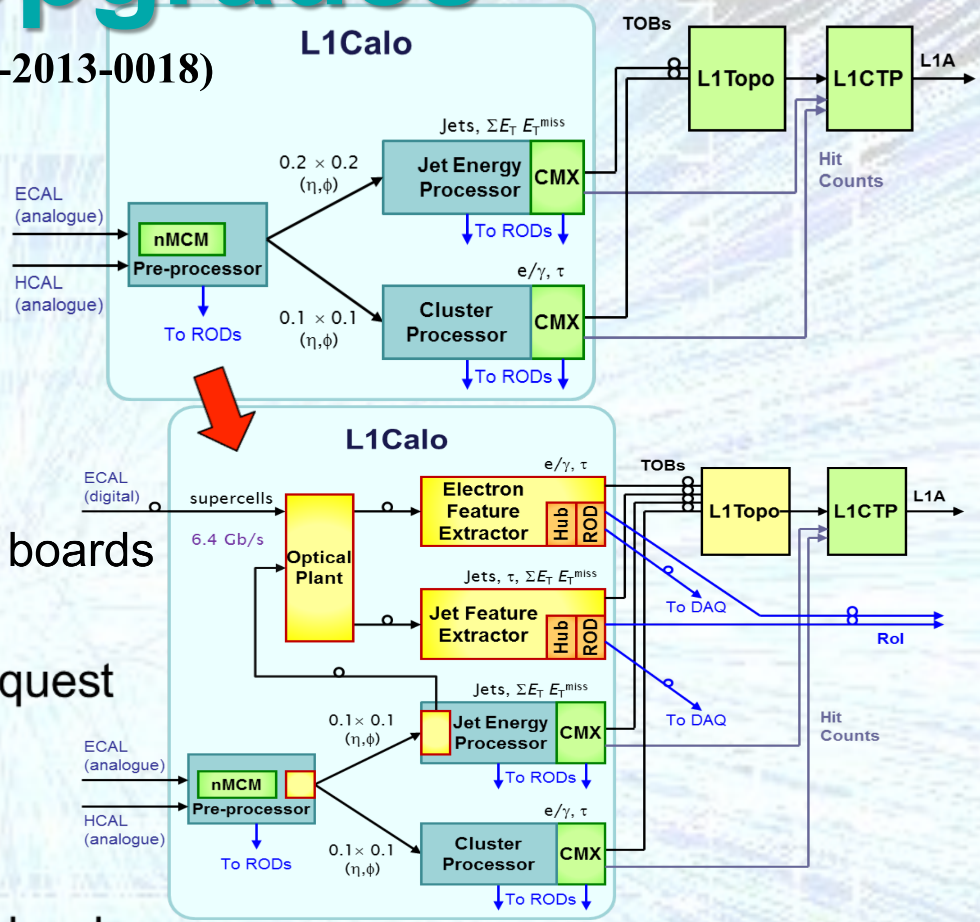
(Phase-I Level-1 designed to be able to become Level-0 at Phase-II.)



TDAQ Upgrades

Level-1: (CERN-LHCC-2013-0018)

- Phase I: completely new L1 electron and jet triggers.
- Very complex ATCA modules. Requires mastery of 6-10 Gb/s signal handling. R&D with demonstrator to check simulations of distribution on boards



HLT:

- Increase DataFlow throughput
  => higher request rates, more data per request
- Maintain rejection & limit rise of CPU times
- Provide for new detectors: FTK, IBL, NSW

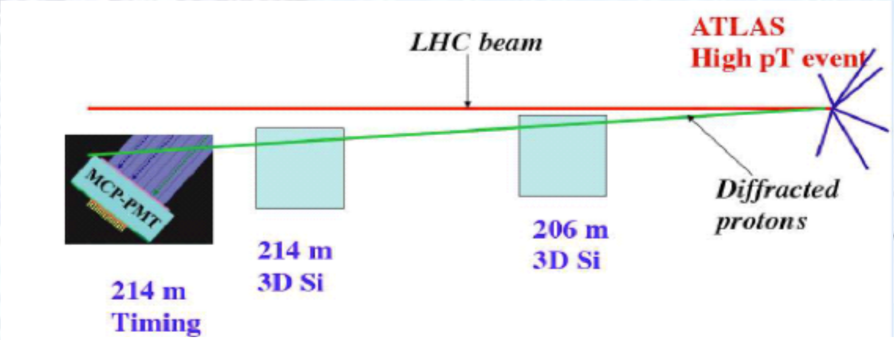
Dataflow:

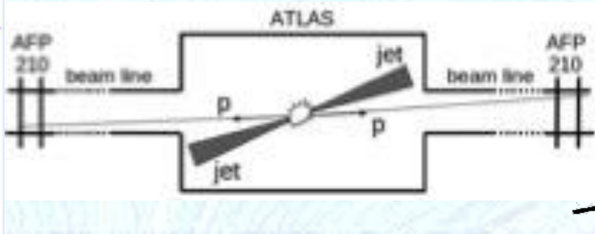
- New ROB being implemented on C-RORC hardware

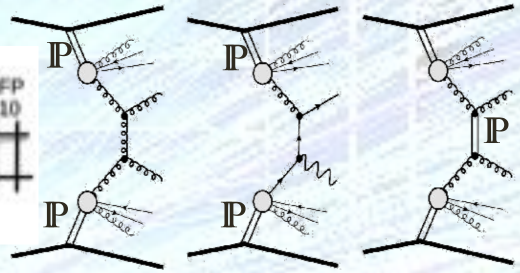
HLT core software:

- Merge L2 & EF:
  - Upgrading HLT Steering software
  - Implementing new chains in Trigger menu

ATLAS Forward Proton (AFP)







- ATLAS review process

1. Initial design review
2. Kick off Institutes meeting
3. EB approval
4. CB endorsement
5. IMOU TDR
6. LHCC and RRB approval

- AFP physics review looked at capabilities in dedicated low <μ> short runs and concluded in January 2014:

  The proposed physics programme of AFP special runs to take place between LS1 and LS2 includes some diffractive and QCD physics topics which cannot otherwise be covered by ATLAS and which will be of substantial interest to a sizable external community. These include dijet and W boson production in single diffractive dissociation and Double Pomeron Exchange dijet production with double proton tags.

  Technical review report (May 2014) encouraged AFP to proceed to seek full collaboration approval subject to resources being identified.

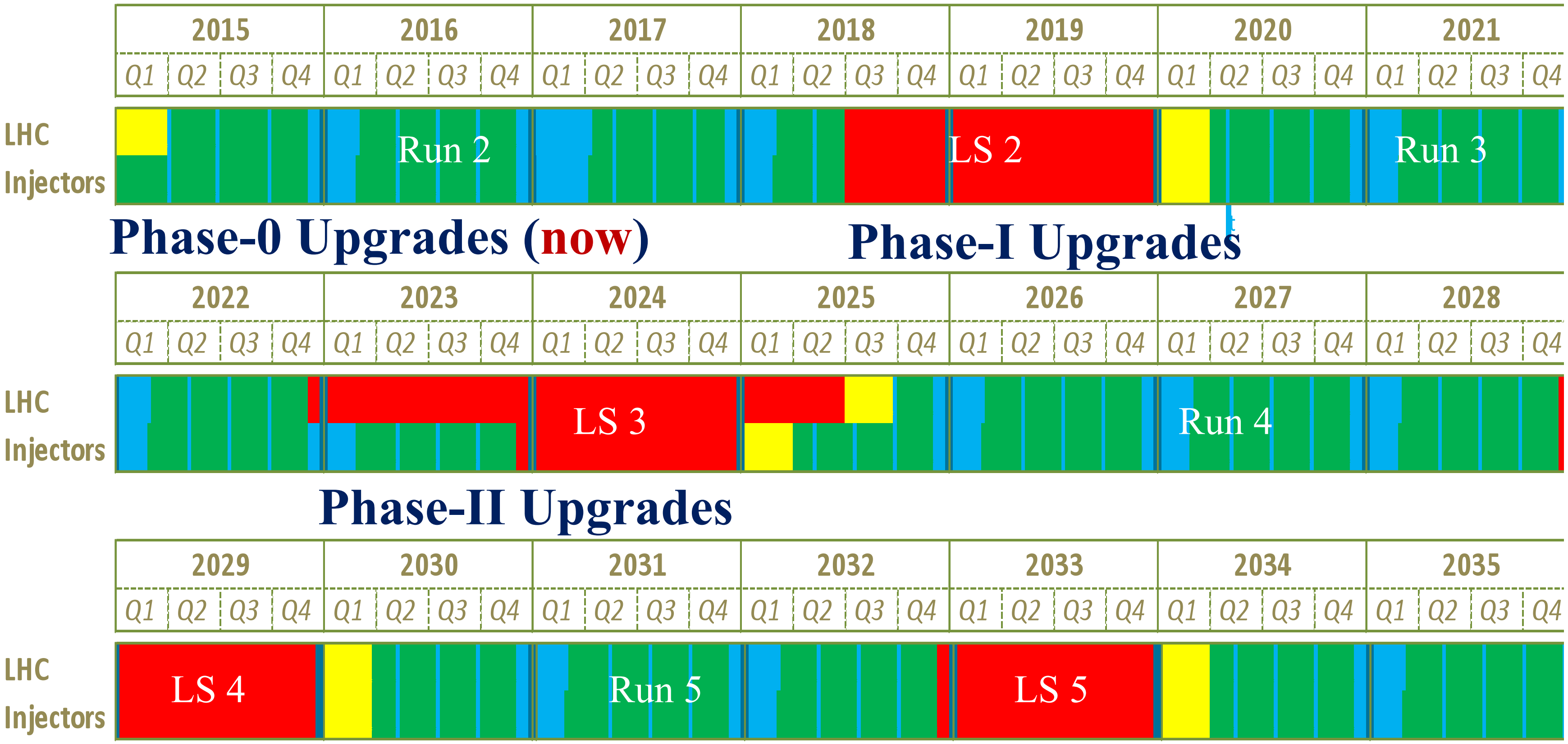
New LHC schedule beyond LS1

Only EYETS (19 weeks)   (no Linac4 connection during Run2)

LS2 starting in 2018 (July) 18 months + 3months BC (Beam Commissioning)

LS3 LHC: starting in 2023 => 30 months + 3 BC

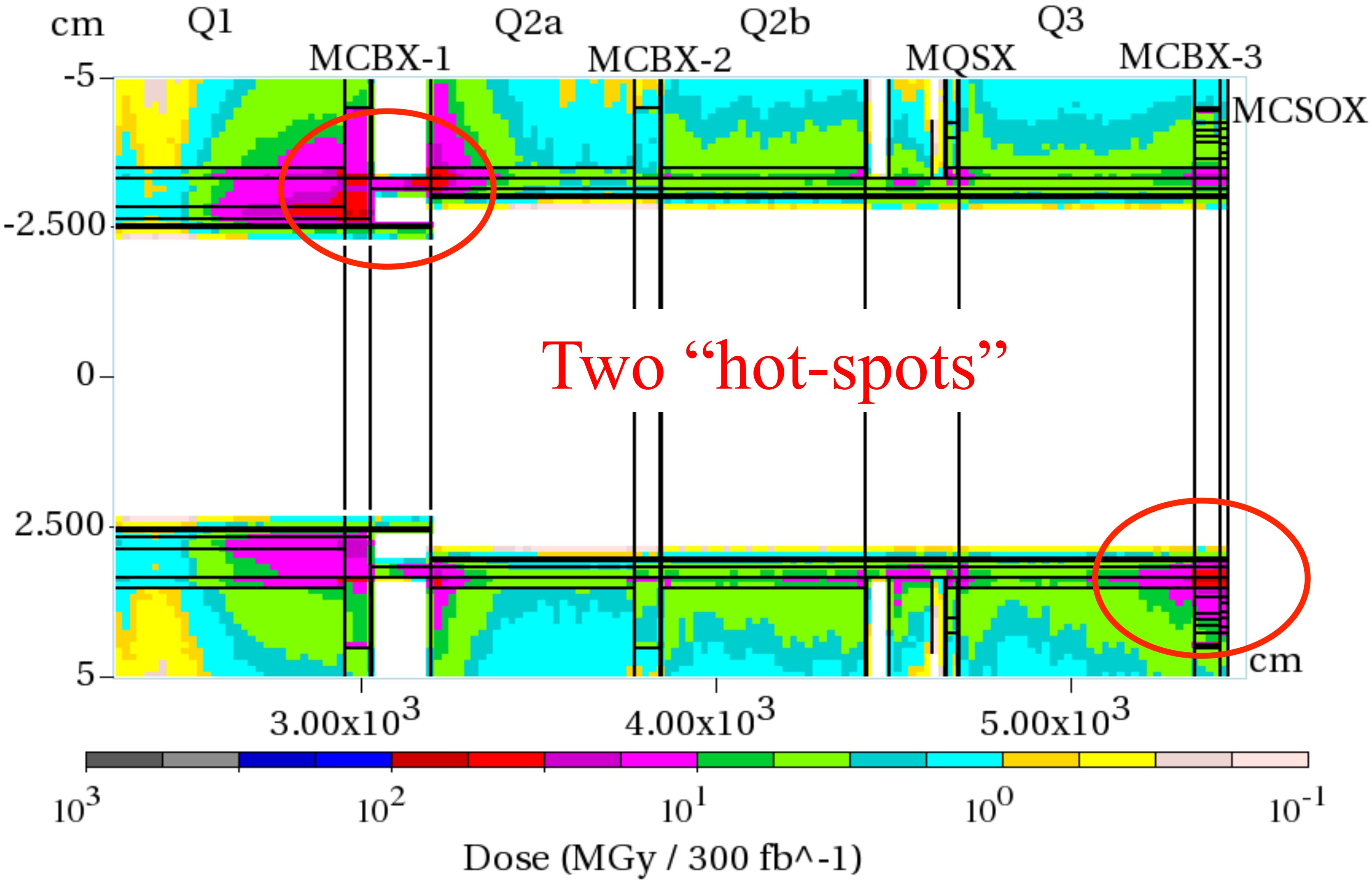
injectors: in 2024 => 13 months + 3 BC



LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators
Monday 2nd December 2013

Radiation dose in the present triplet (300 fb^{-1})

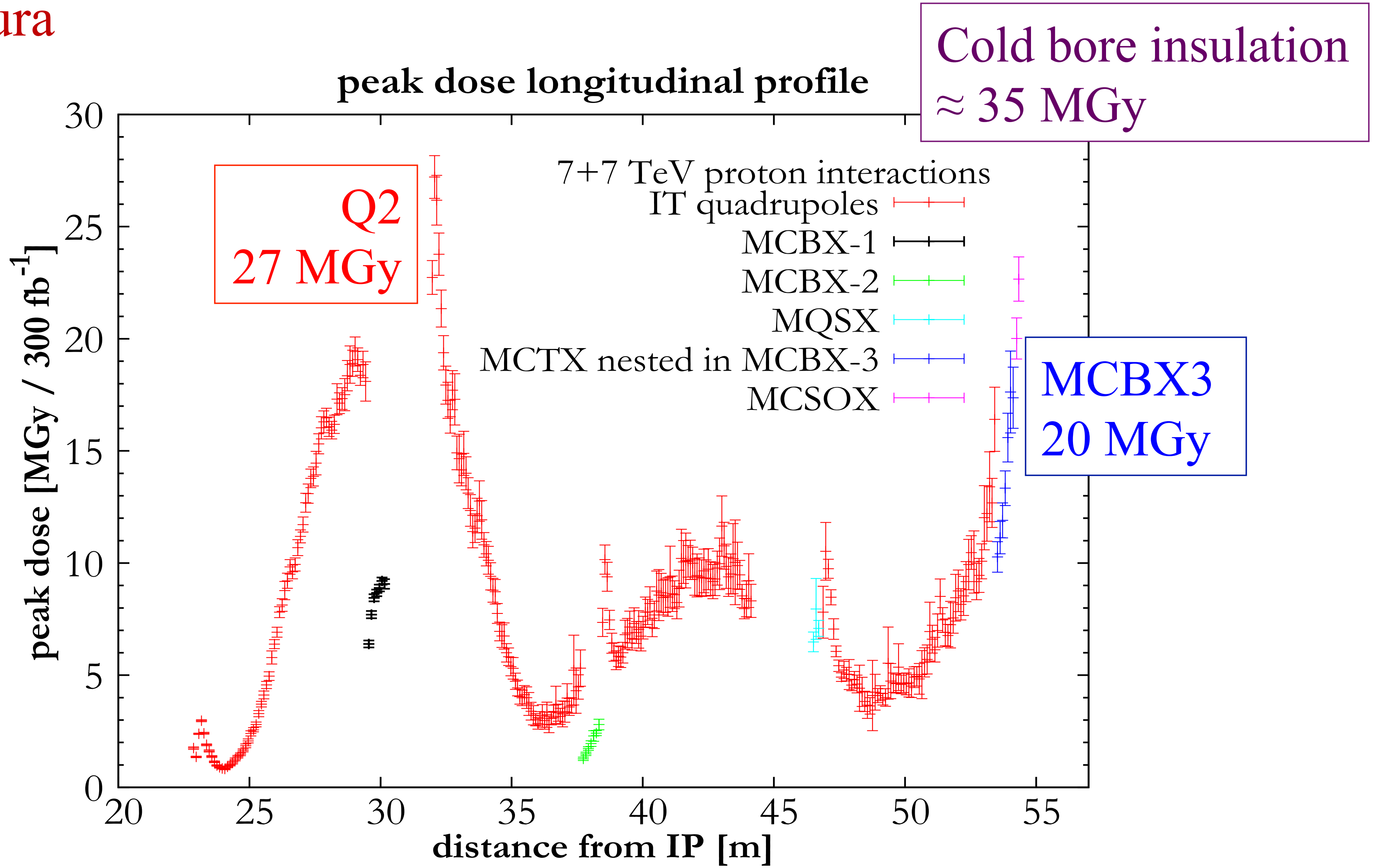
L. Bottura



F. Cerutti, et al., WP10: Energy Deposition and Radiation Damage in Triplet Magnets, April 2013
https://indico.fnal.gov/conferenceDisplay.py?confId=6164

Radiation dose in the present triplet (300 fb^{-1})

L. Bottura



F. Cerutti, et al., WP10: Energy Deposition and Radiation Damage in Triplet Magnets, April 2013
https://indico.fnal.gov/conferenceDisplay.py?confId=6164

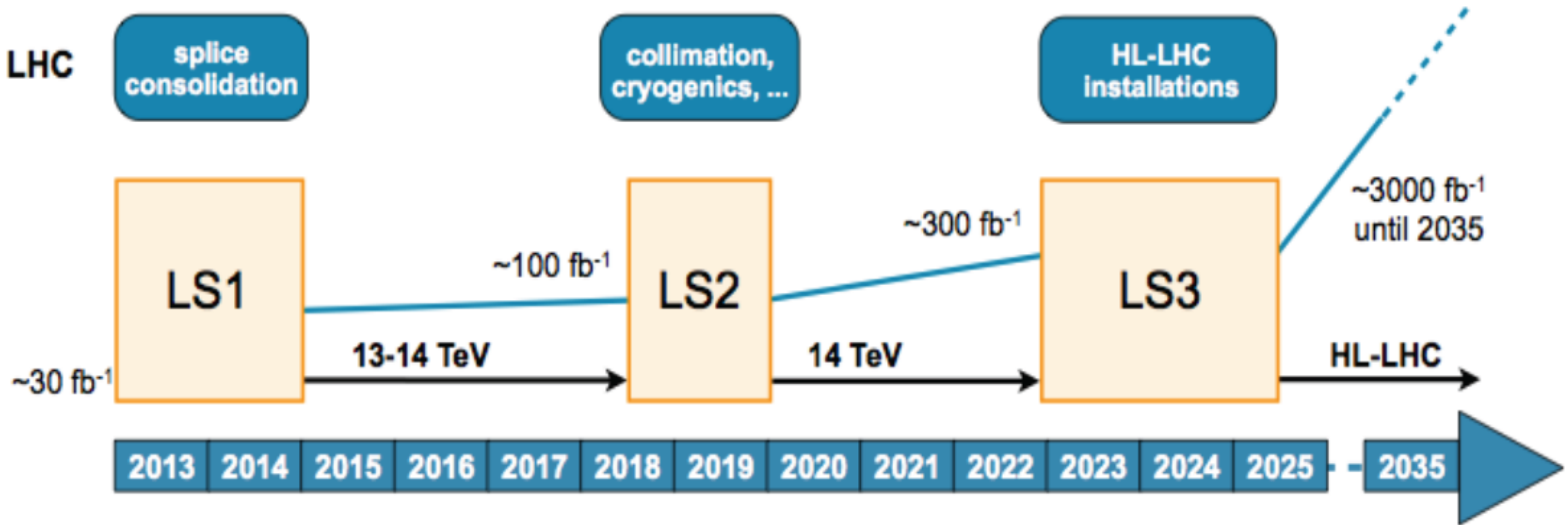
RLIUP Summary on LHC Inner Triplets

L. Bottura https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=260492

- Expected dose by LS3 (300 fb^{-1}) with 50 % uncertainty(3)
  - Range of 27 [18…40] MGy in the Q2
  - Range of 20 [13…30] MGy in the MCBX
- Bonding strength (shear) of epoxies is strongly degraded (80 %) above 20 MGy
- Fracture strength of insulating materials degrades by about 50 % in the range of 20 MGy (G11) to 50 MGy (epoxies, kapton)
- Insulations (polyimide) become brittle above 50 MGy
- Triplet magnets may experience mechanically-induced insulation failure in the range of 300 fb^{-1} (LS3 ± 1 year)
  - Premature quenches (cracks in end spacers)
  - Insulation degradation (monitor on line(4))
  - Mechanical failure (nested coils in MCBX)

RLIUP Summary on LHC Inner Triplets

L. Bottura https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=260492



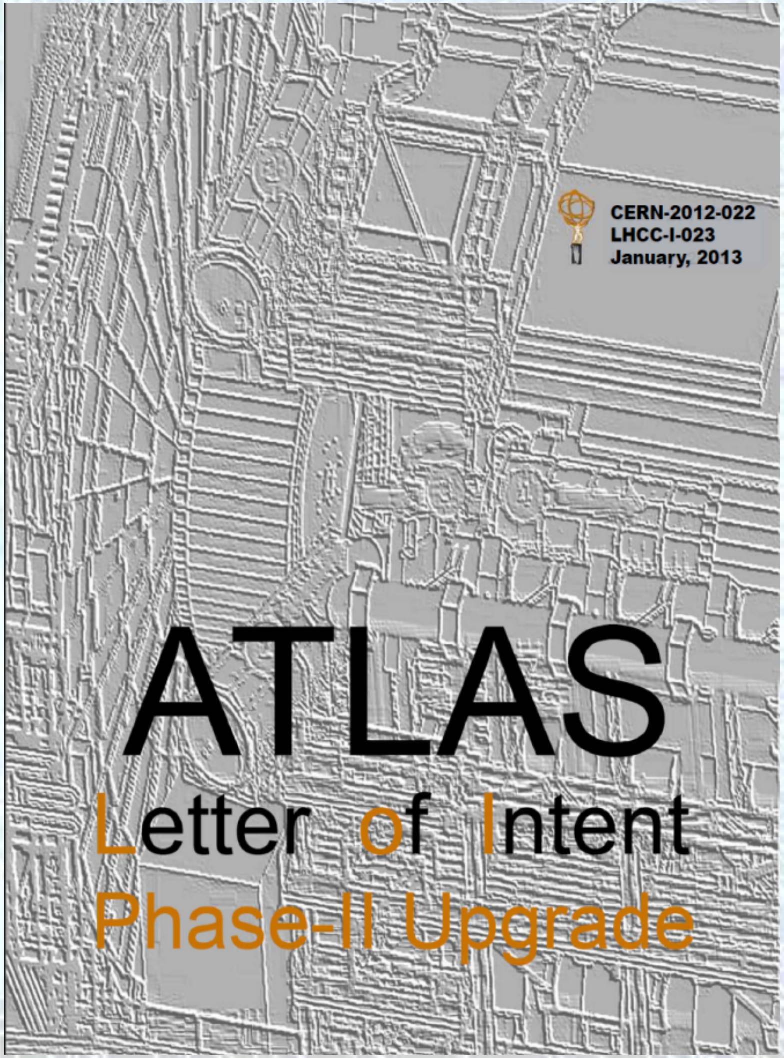
- Triplet magnets may experience mechanically-induced insulation failure in the range of 300 fb^{-1} (LS3 ± 1 year)
  - Premature quenches (cracks in end spacers)
  - Insulation degradation (monitor on line[4])
  - Mechanical failure (nested coils in MCBX)

Future Upgrade Planning

Phase-II Upgrade

(LS3)

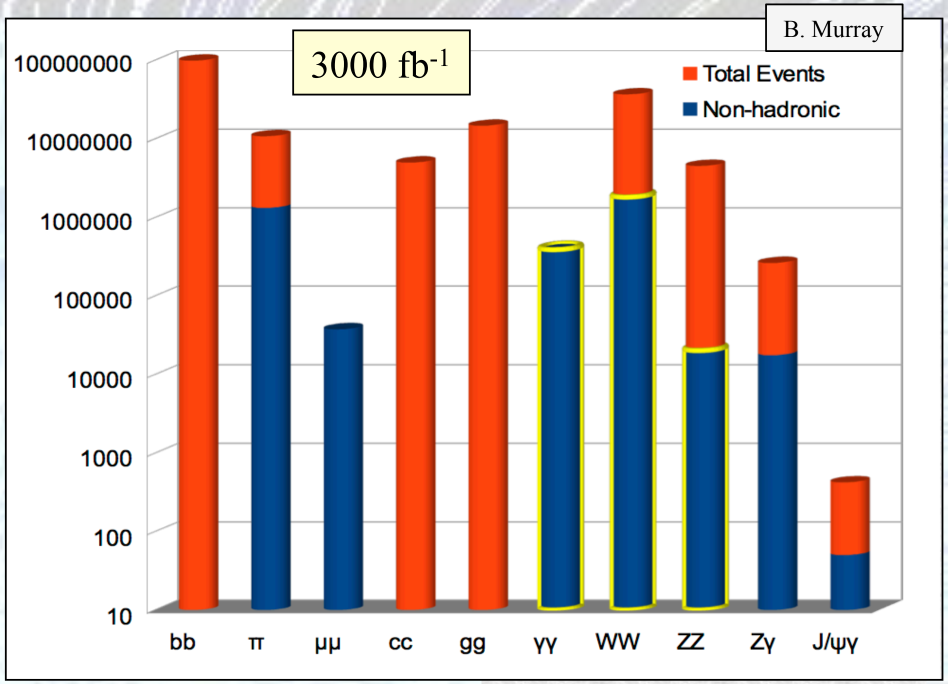
Starts End 2022

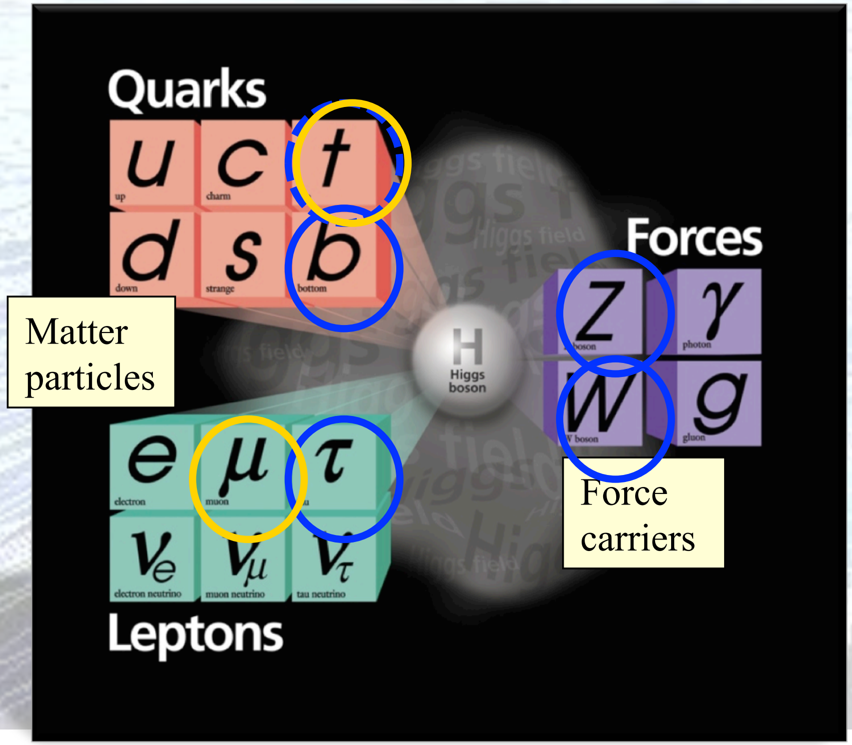


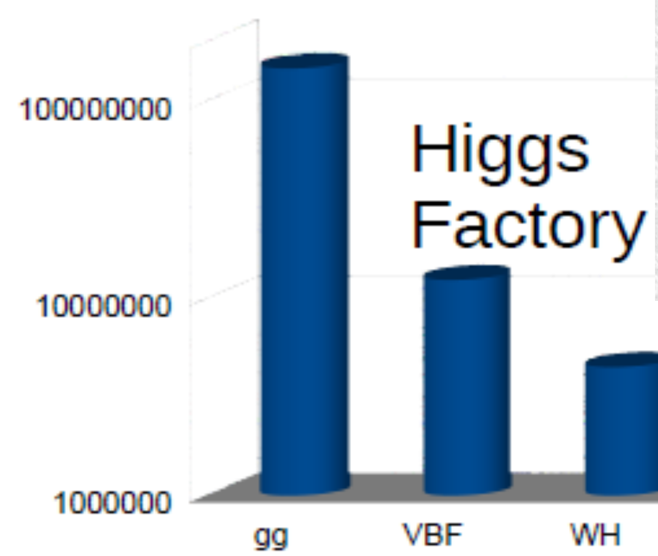
Physics Studies

Aim to measure as many Higgs couplings to fermions and bosons as possible to really test if this is the SM Higgs or a pointer to the BSM physics we know has to exist

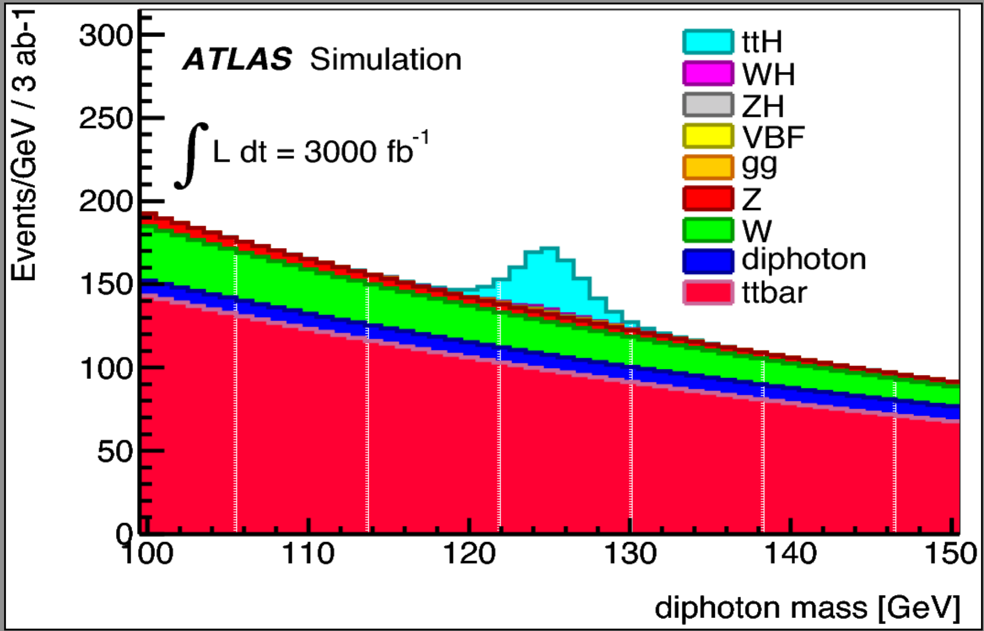
HL-LHC (3000 fb^{-1}): a true Higgs factory:
- > 170M Higgs events produced
- > 3M useful for precise measurements
  (more than or similar to ILC/CLIC/TLEP)
  LHC gg→ H (50pb); e^+e^-→ ZH (0.2-0.3pb)



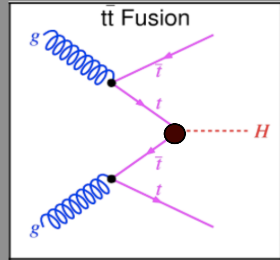




- Over 100M Higgs bosons
- 20K H→ZZ→llll
- 400K γγ
- 50 H→J/ψγ

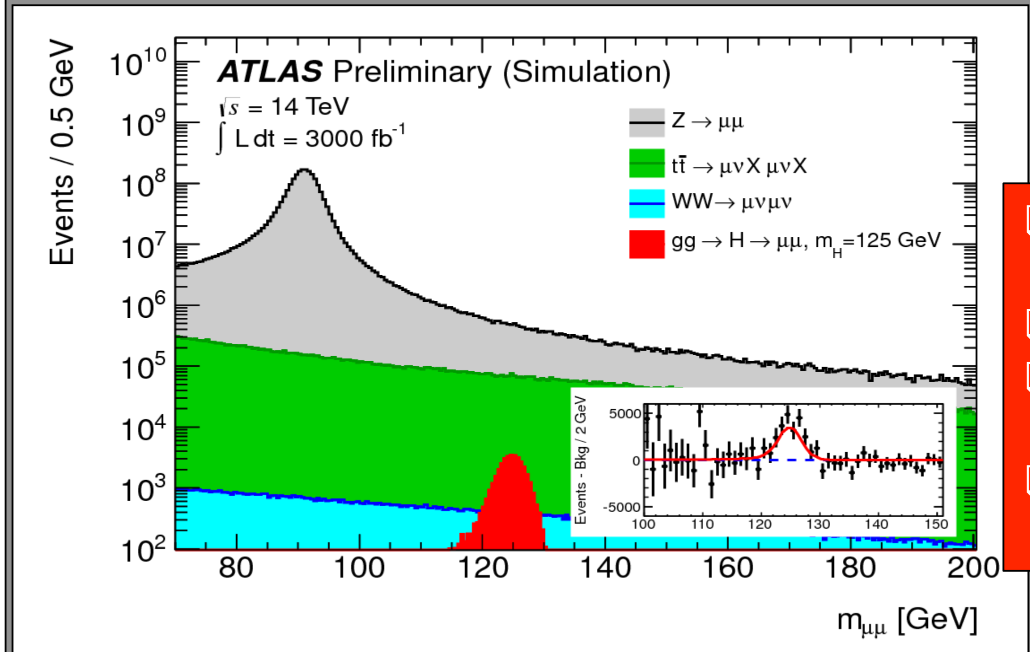


ttH production with H → γγ



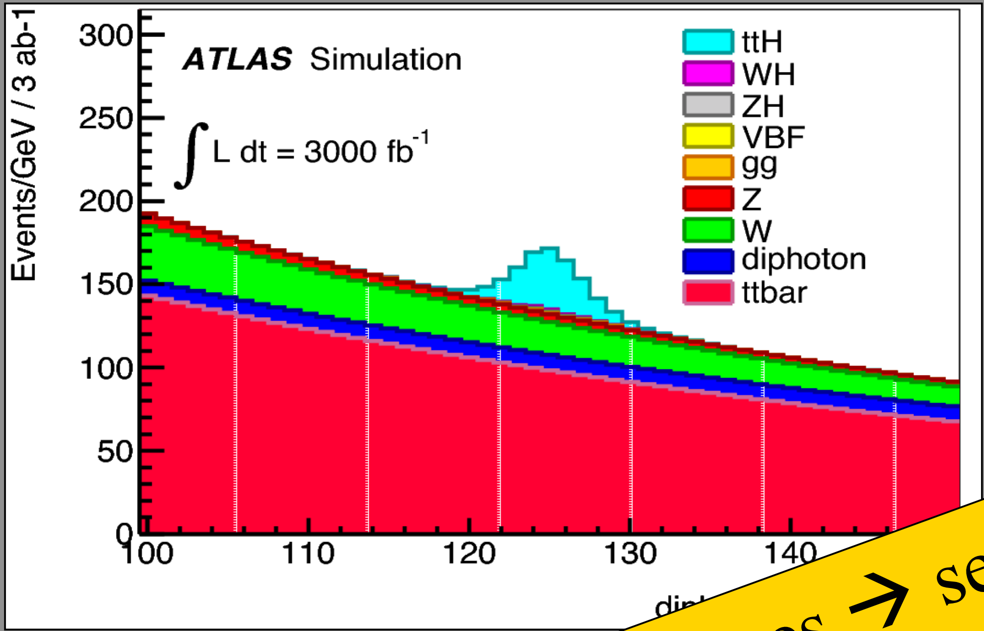
- ❑ Gives direct access to Higgs-top coupling (intriguing as top is heavy)
- ❑ Today's sensitivity: 6xSM cross-section
- ❑ With 3000 fb^{-1} expect ~200 signal events (S/B ~ 0.5) and significance **8.2σ**
- ❑ Higgs-top coupling can be measured to better than 10%

ATL-PHYS-PUB-2014-012

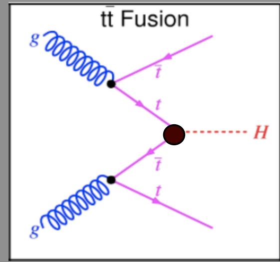


H → μμ

- ❑ Gives direct access to Higgs couplings to fermions of the second generation.
- ❑ Today's sensitivity: 8xSM cross-section
- ❑ With 3000 fb^{-1} expect 17000 signal events (but: S/B ~ 0.3%) and ~ 7σ significance
- ❑ Higgs-muon coupling can be measured to about 10%



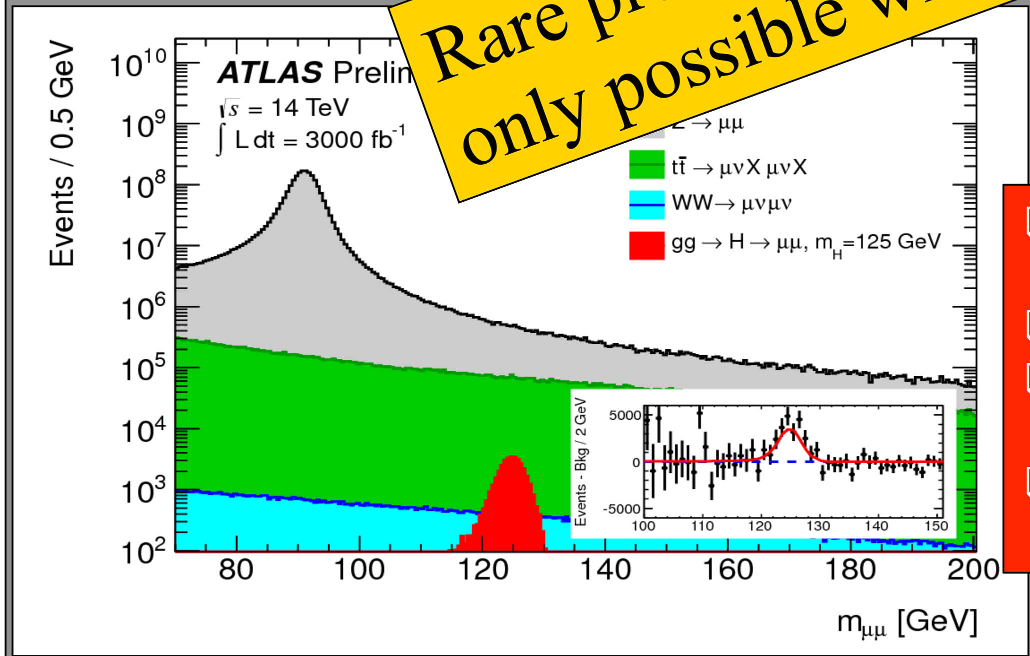
ttH production with H → γγ



- Gives direct access to Higgs-top coupling (intr... as top is heavy)
- Toda... 6xSM cross-section
- ... ~200 signal ... significance **8.2σ**
- ...upling can be ...ured to better than 10%

ATL-PHYS-PUB-2014-012

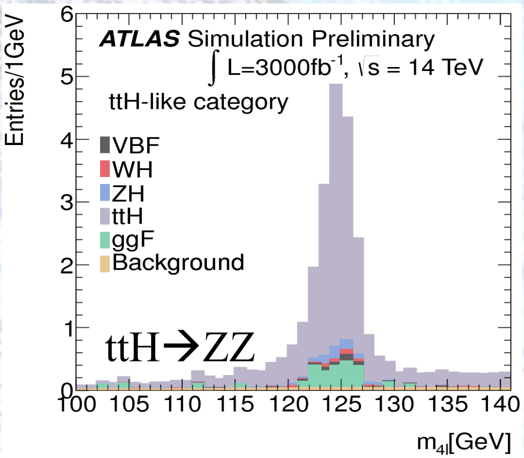
Rare processes → sensitive studies only possible with 3000 fb^{-1}

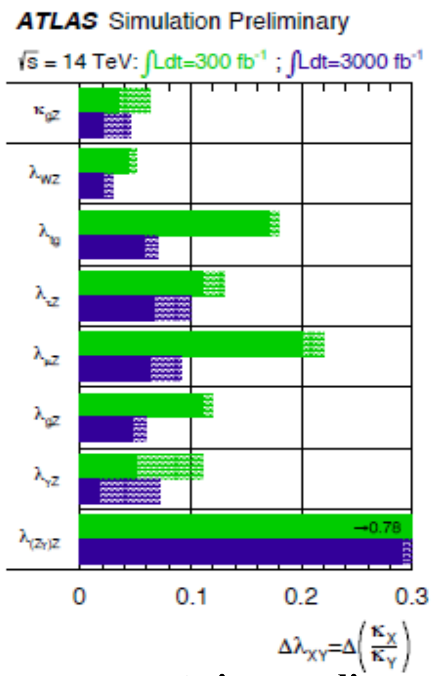


H → μμ

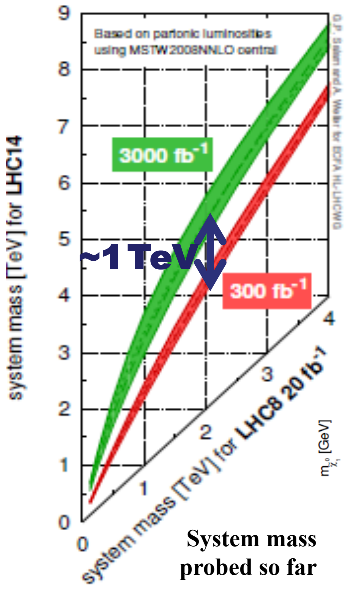
- Gives direct access to Higgs couplings to fermions of the second generation.
- Today's sensitivity: 8xSM cross-section
- With 3000 fb^{-1} expect 17000 signal events (but: S/B ~ 0.3%) and ~ 7σ significance
- Higgs-muon coupling can be measured to about 10%

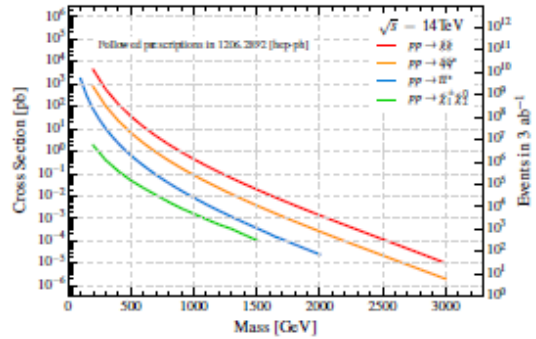
Selected Studies with 3000fb^{-1}



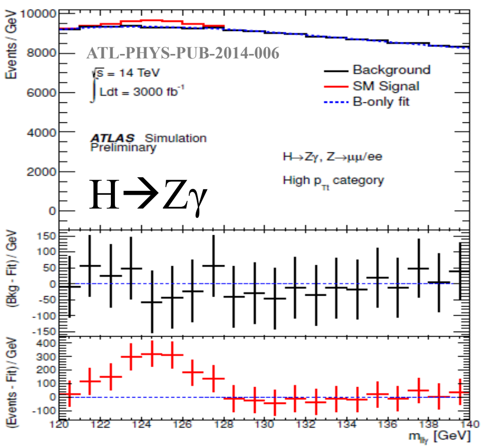


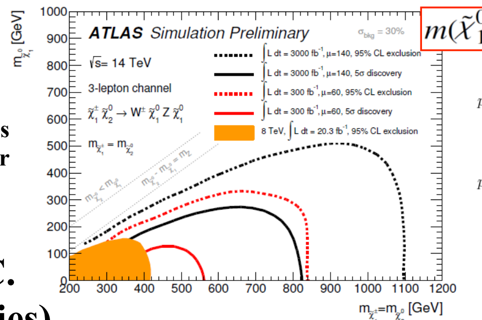
Improvements in coupling ratios with HL-LHC.
(Depends on systematics and theory uncertainties)

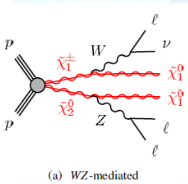




NLO SUSY Cross-section calculations

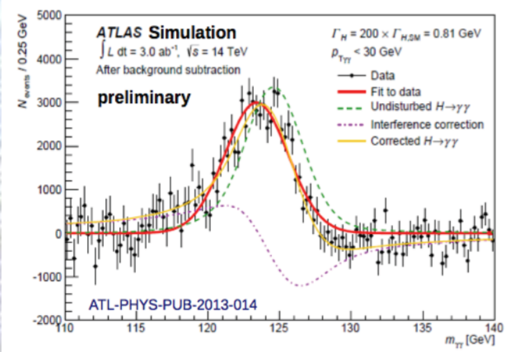




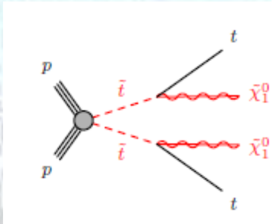


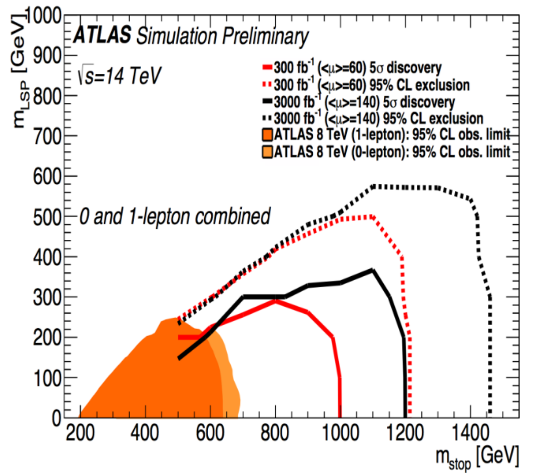
SUSY Limits at 300fb^{-1} and 3000fb^{-1}

ATL-PHYS-PUB-2014-011: H→bb
Combined ZH(H→bb) and WH(H→bb)
300 fb^{-1} <pile-up> of 60 expect 3.9σ
3000 fb^{-1} <pile-up> of 140 expect 8.8σ



Total width from interference in di-photon: reach ~200MeV

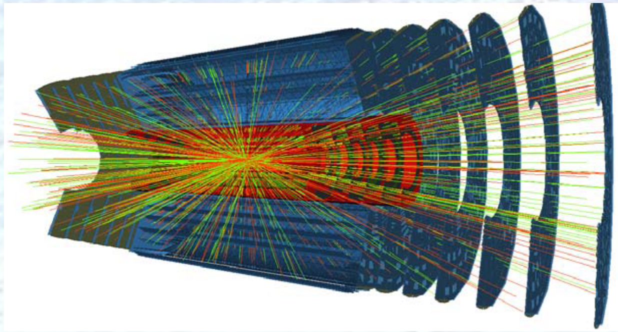




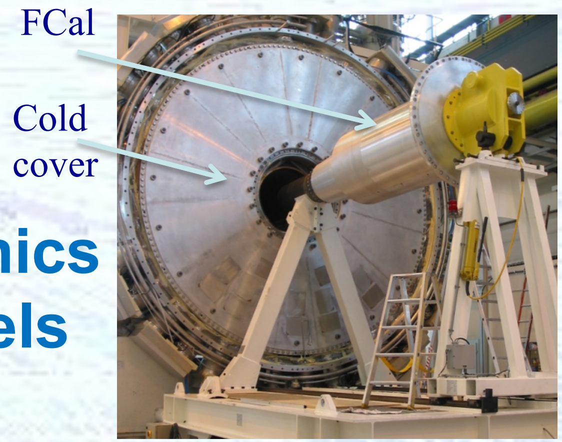
Phase-II Detector Upgrades

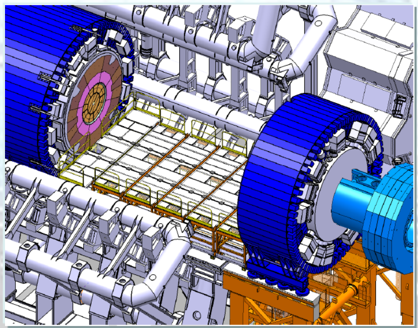
Integrated radiation levels (up to 2-3×$10^{16}n_{eq}/cm^2$) and plan to cope with up to 200 interactions every 25ns

Implications of this include:



- **New Inner Detector (strips and pixels)**
- **Trigger and data acquisition upgrades**
- **L1 Track Trigger**
- **New LAr front-end and back-end electronics**
- **Possible upgrades of HEC and FCal**
- **New Tiles front-end and back-end electronics**
- **Muon Barrel and Large Wheel trigger electronics**
- **Possible upgrades of TGCs in Inner Big Wheels**
- **Forward detector upgrades**
- **TAS and shielding upgrade**
- **Various infrastructure upgrades**
- **Common activities (installation, safety, …)**
- **Software and Computing**



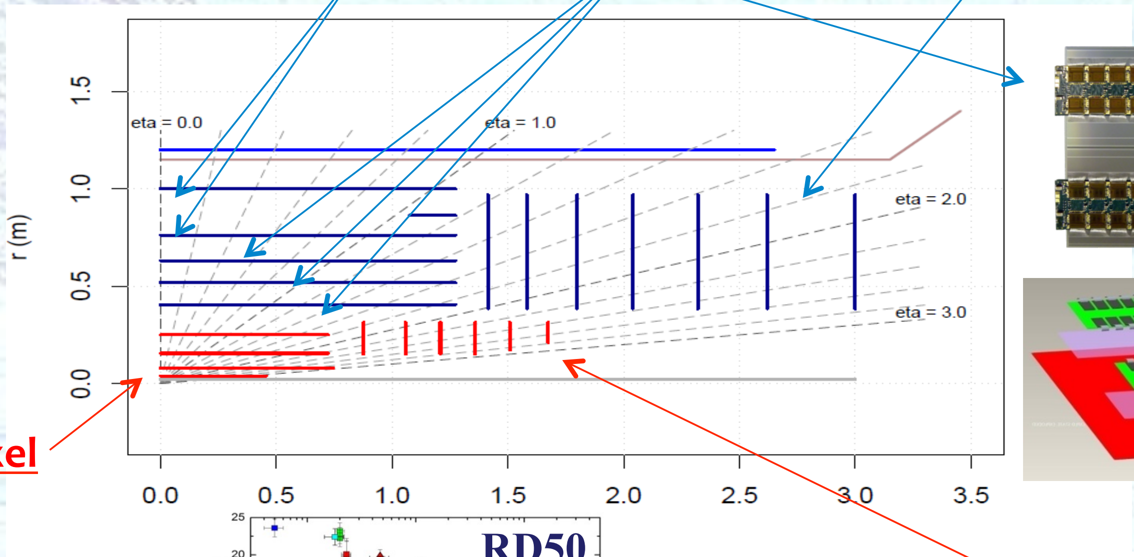


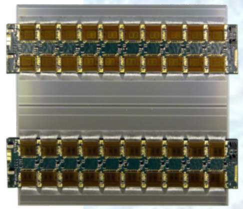
ATLAS: New All-silicon Inner Tracker

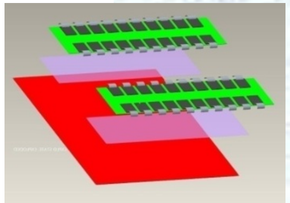
Long Barrel Strips

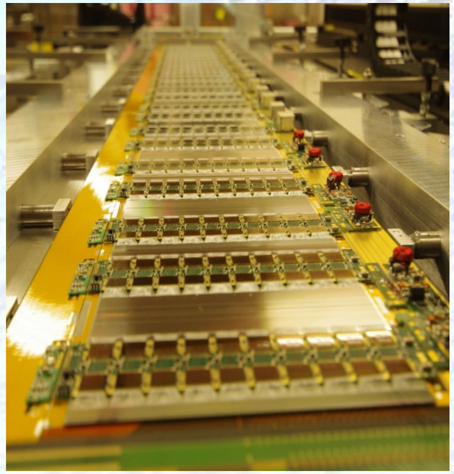
Short Barrel Strips

Forward Strips





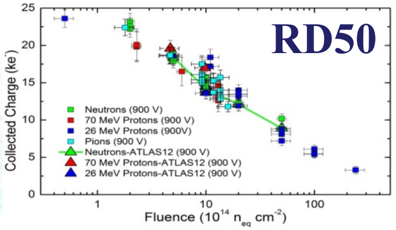




Microstrip Stave Prototype

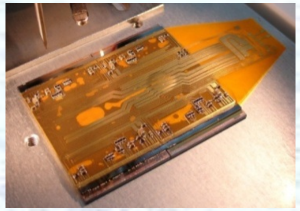
Barrel pixel

Signal vs dose
(1 MeV n equivalent)

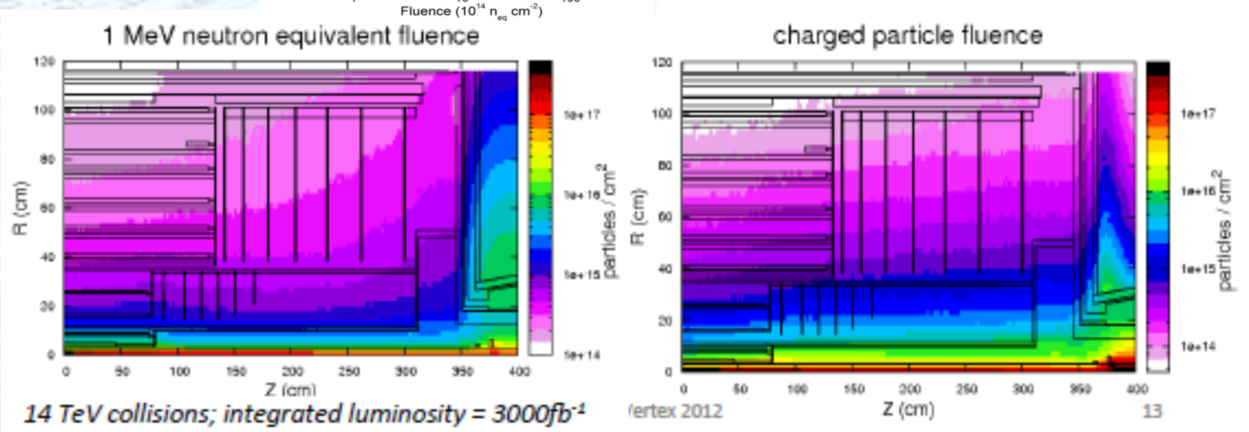


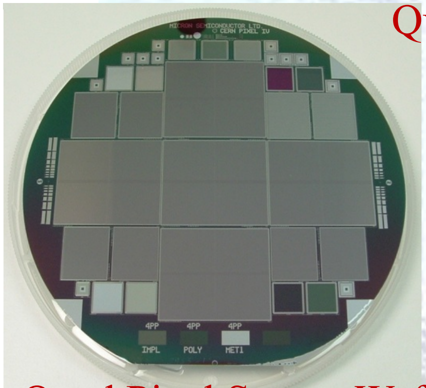
Baseline layout of the new ATLAS inner tracker for HL-LHC Aim to have at least 14 silicon hits

Forward pixel



Quad Pixel Module



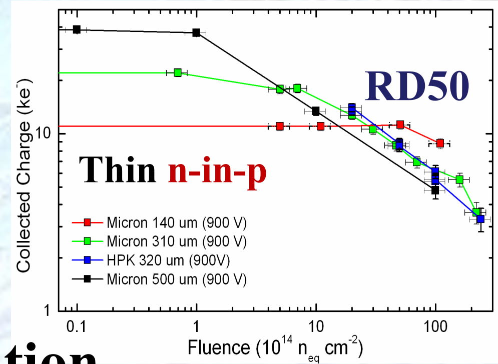


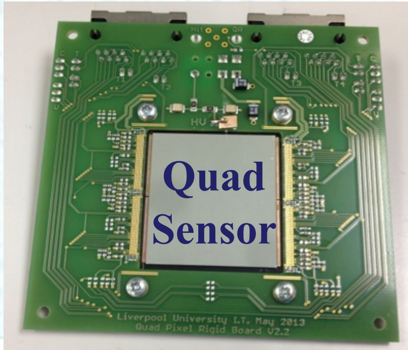
Quad Pixel Sensor Wafer

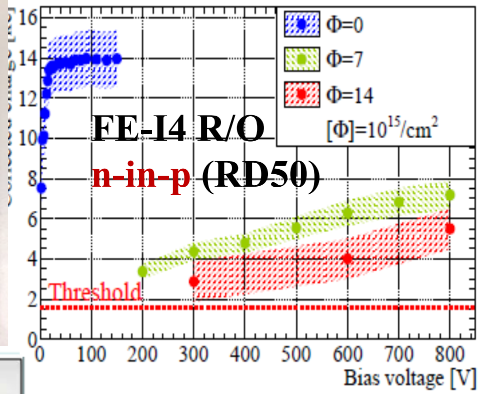
New All-silicon Inner Tracker

Pixel Detector

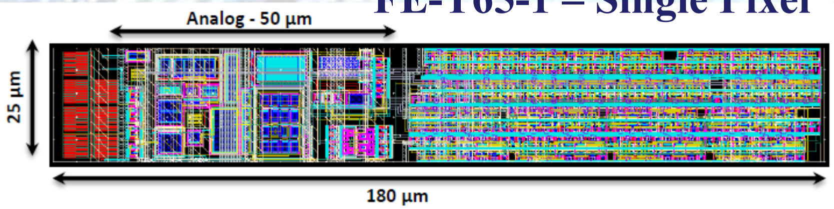
- Thin n-in-n, n-in-p planar, 3D and diamond sensors proved to doses up to $2\times10^{16} n_{eq}/cm^2$ and 1Grad
- Probably use TSMC 65nm technology which should allow pixel sizes down to 50µm×50µm or 25µm×100µm (RD53)
- Test structures in 65nm produced and studied after irradiation
- Larger area sensors (n-in-p) quads/sextuplets produced on 150mm diameter wafers with several foundries
- Irradiated quad pixel modules studied in test-beam with excellent performance
- Prototyping of local supports for various concepts has been carried out
- A number of support designs and service routings have been studied

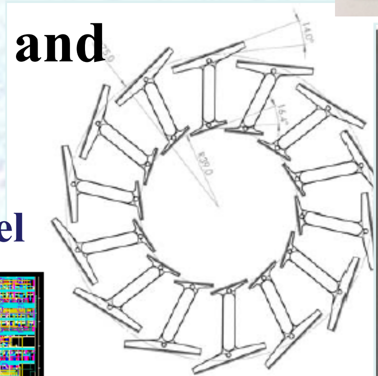




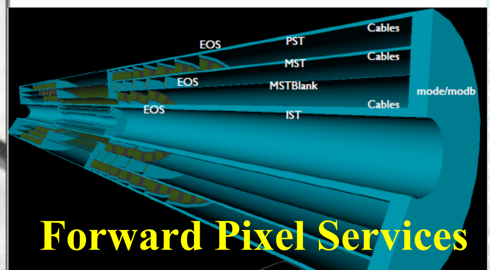


FE-T65-1 – Single Pixel





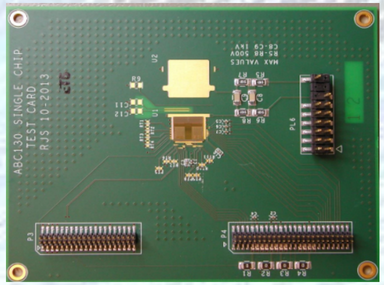
Possible Barrel Support Concept



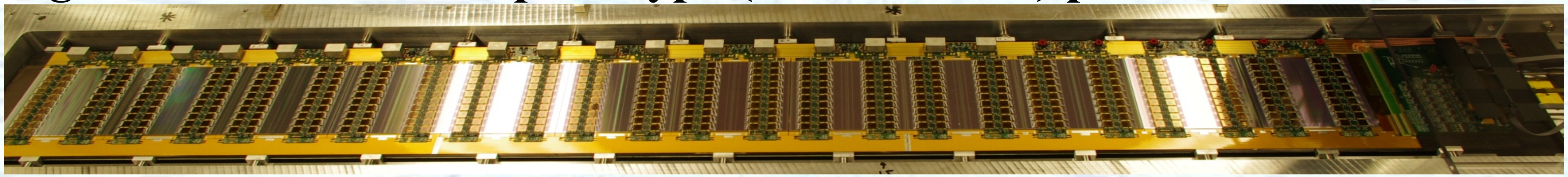
New All-silicon Inner Tracker

Strip Detector

- New prototype n-in-p sensors delivered with 4 rows of 2.4cm long strips at 74.5µm pitch
- New (256 channel) 130nm CMOS ASIC now received after mask corrections

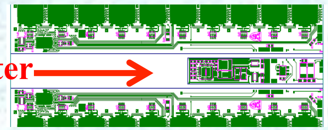


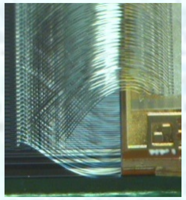
- Many strip modules (single and double sided) prototyped with 250nm ASICs
- Large area stave DC-DC prototype (120cm×10cm) produced and under study



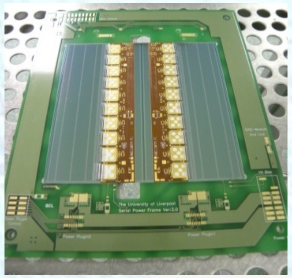
- Serial and DC-DC powering studied in detail on short versions of 250nm stave
- Several other new chips (HCC, HV multiplex, SP, DC-DC,..)
- Hybrid/module designs for these completed

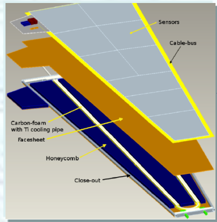
Module with on-board DC-DC converter



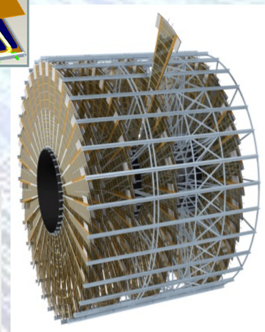


4 row wire bonds





Wedge for Forward Tracker and Global Mechanics

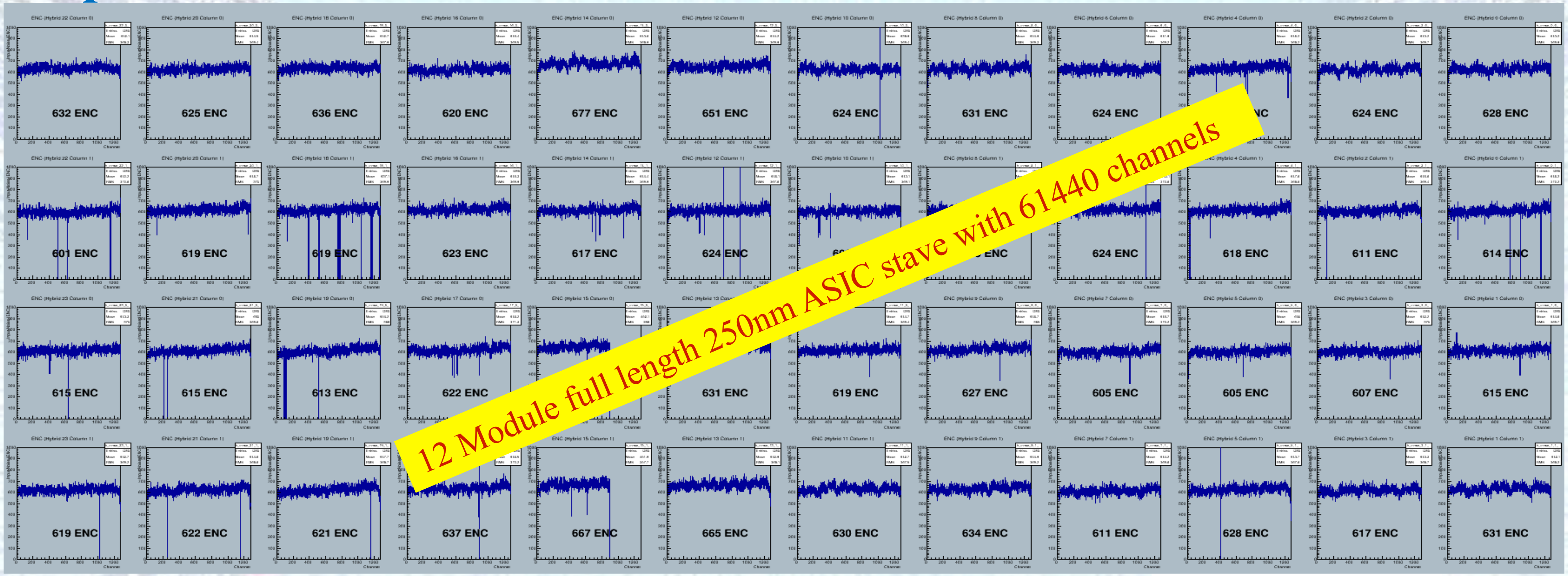


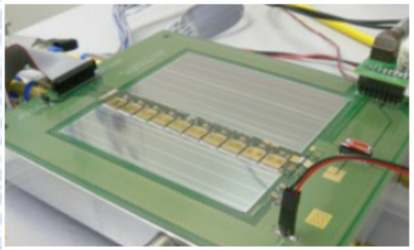
- Local supports extensively prototyped and further material reduction achieved
- Progress in Petal and Stave support designs
- End-of-stave card for 130nm developed

Fully functional forward module

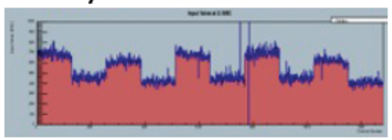
New All-silicon Inner Tracker

Strip Detector



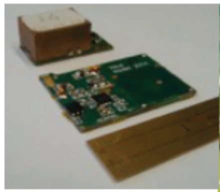


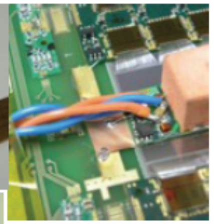
Hybrid with 5+5 ABC130



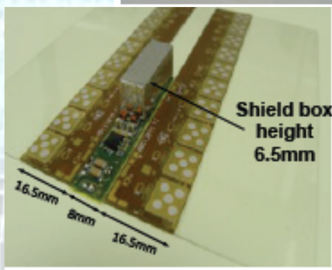
With one of two columns of strips bonded

- Thin build FR4 hybrid made quickly
  - 10 ABC130 attached, 5 off "FIB'd" and 5 off "non-FIB'd"
  - All 10 ABC130s linked serially (for data readout) with common TTC bus
- Wire-bonding much simpler/faster
  - Benefit of collaborating with asic designers to 'fix' geometry
- Hybrid/module behaves as expected:
  - Data Passing at 80MHz RCLK works
  - Hybrid draws ~810mA when configured (PTOTAL~ 1.2W/hybrid)
  - Total power consumption of ~3W/module (inc.HCC)
  - Current ABCN-25 module power consumption is ~20W
  - Output noise as expected and extremely regular

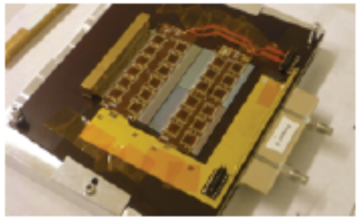


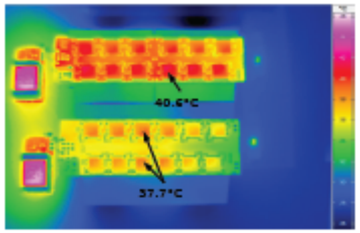


STV10 DC-DC on module



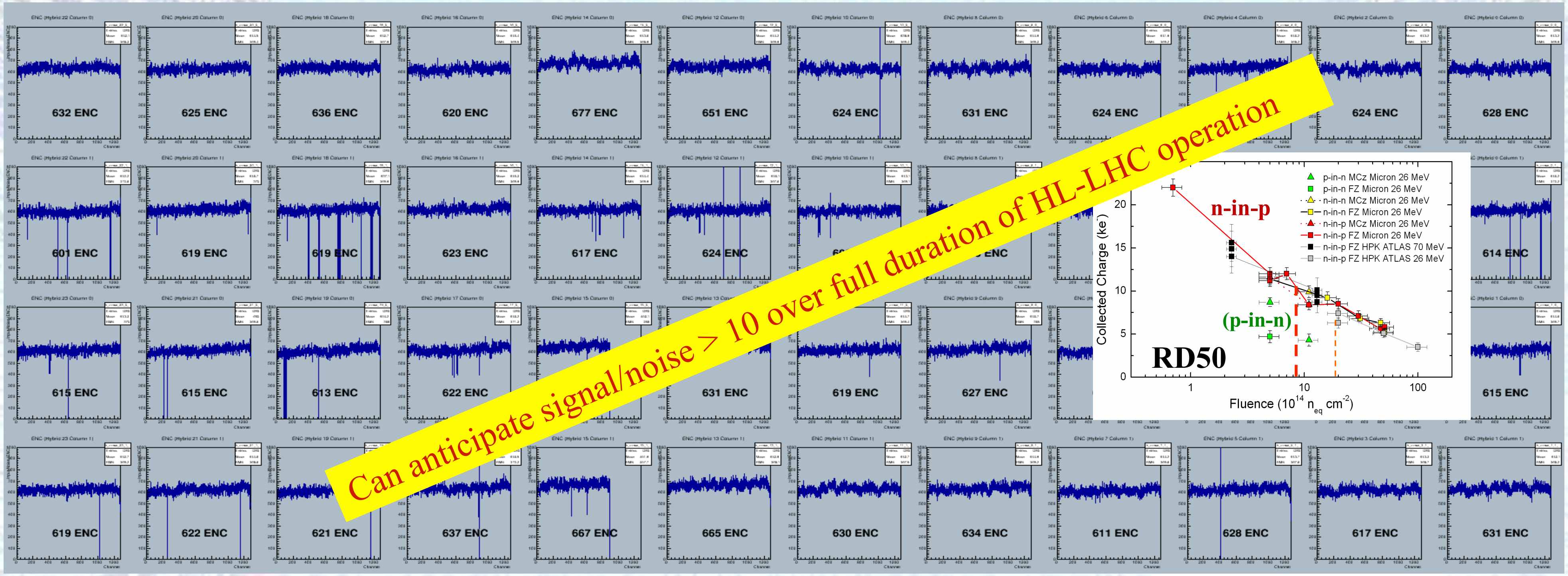
Thermo-Mechanical Module with compact DCDC converter

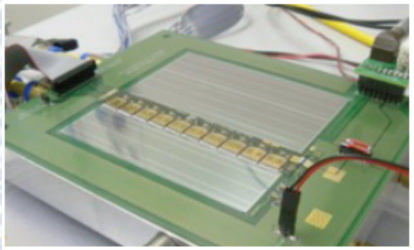




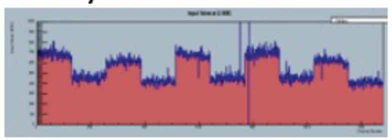
New All-silicon Inner Tracker

Strip Detector



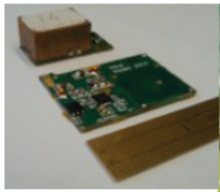


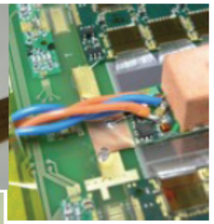
Hybrid with 5+5 ABC130



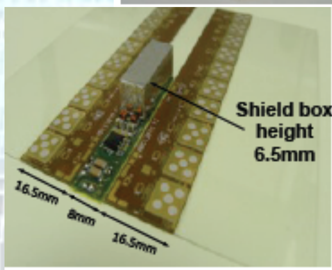
With one of two columns of strips bonded

- Thin build FR4 hybrid made quickly
  - 10 ABC130 attached, 5 off "FIB'd" and 5 off "non-FIB'd"
  - All 10 ABC130s linked serially (for data readout) with common TTC bus
- Wire-bonding much simpler/faster
  - Benefit of collaborating with asic designers to 'fix' geometry
- Hybrid/module behaves as expected:
  - Data Passing at 80MHz RCLK works
  - Hybrid draws ~810mA when configured (PTOTAL~ 1.2W/hybrid)
  - Total power consumption of ~3W/module (inc.HCC)
  - Current ABCN-25 module power consumption is ~20W
  - Output noise as expected and extremely regular

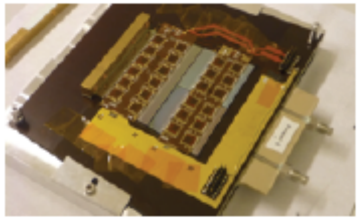


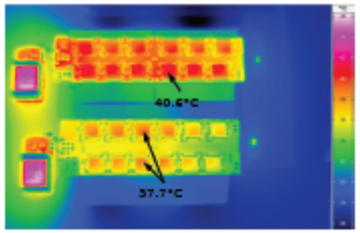


STV10 DC-DC on module



Thermo-Mechanical Module with compact DCDC converter

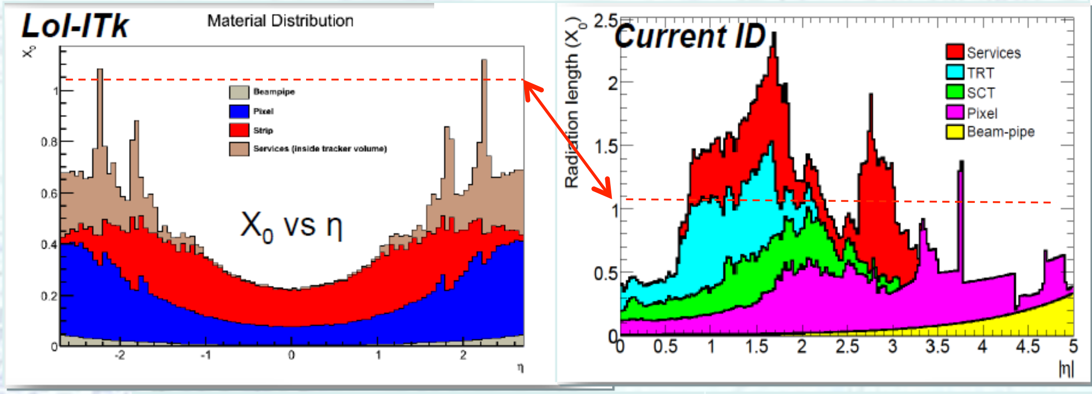


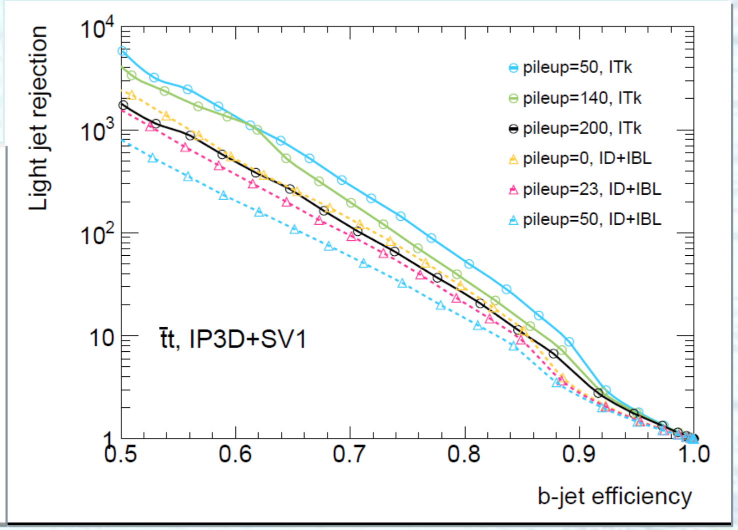


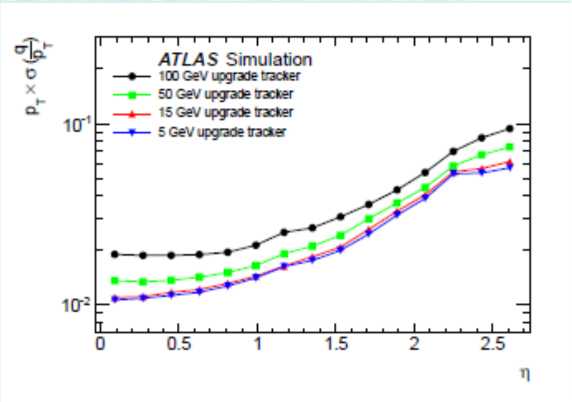
New All-silicon Inner Tracker

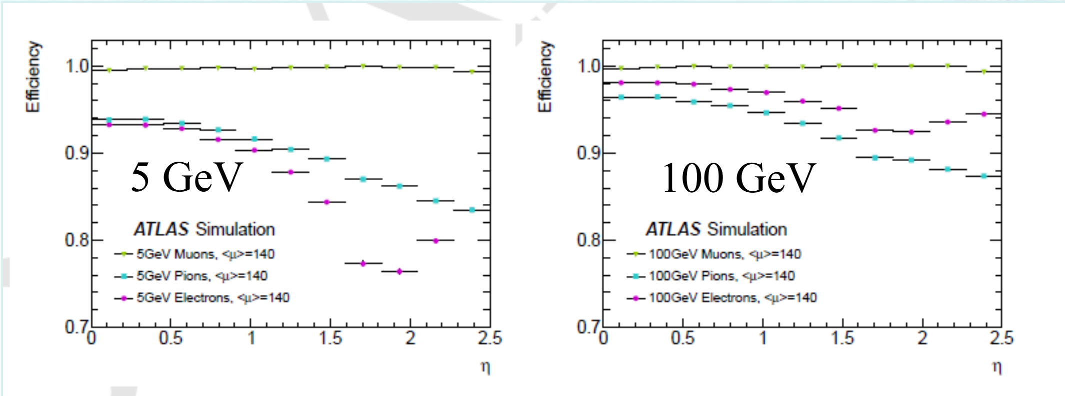
Integration and Performance

- Cooling, services, integration, removal, installation etc all being studied and key is understanding <u>activation</u> issues
- Optoelectronics (GBT) being working on in common with other experiments
- DAQ/DCS exists for prototype operation but not yet designs for final system
- Detailed layout optimisation underway to understand cost/performance trade-offs

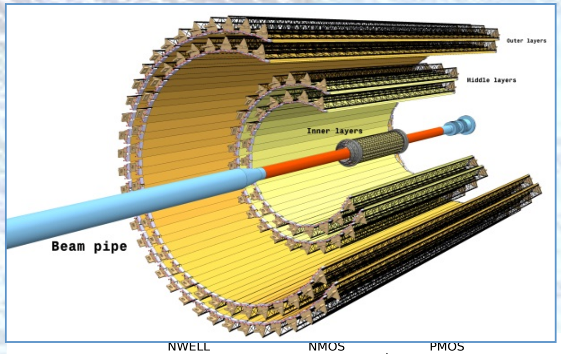


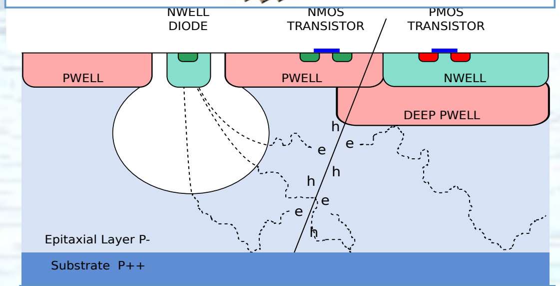


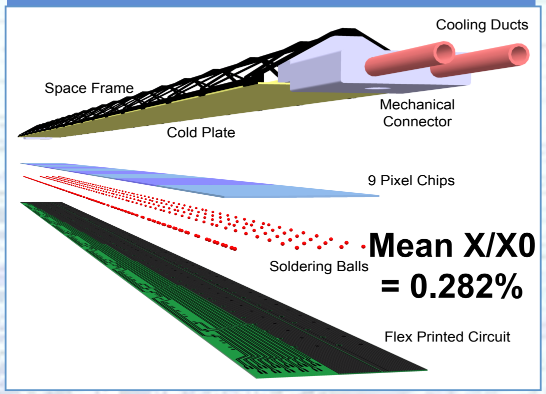




MAPS/CMOS Detector R&D for LHC Upgrades







MAPS installed at STAR (RHIC)

MAPS for ALICE

Priority is ultra-low radiation length due to the low p_T of the decay products of interest.

Target:

Pb-Pb ≥ 10 nb^{-1}

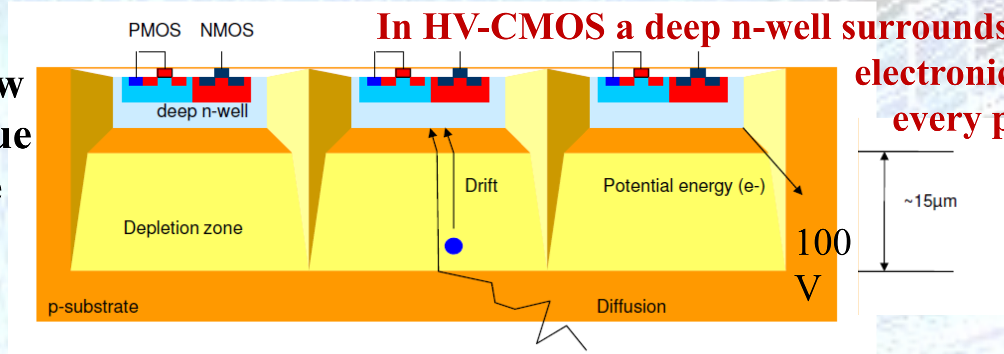
→ 8 x 10^{10} events

pp ≥ 6 pb^{-1}

→14 x 10^{10} events

Read-out all Pb-Pb (50 kHz)

($L = 6 \times 10^{27}\ cm^{-1}s^{-1}$)



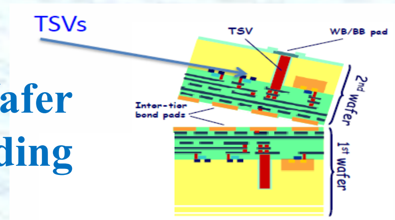
In HV-CMOS a deep n-well surrounds the electronics of every pixel

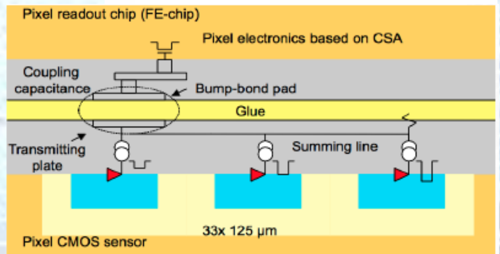
In HR/HV-CMOS charge collection through drift greatly improves radiation hardness and speed

Use at pp collision rates → HL-LHC ATLAS upgrade?

Can consider pixels with complex CMOS-based pixel electronics that process the particle signals or capacitively coupled pixel detectors (CCPDs) based on sensor implemented as a smart diode array with wafer bonding or glue to ASICs (no bumps)

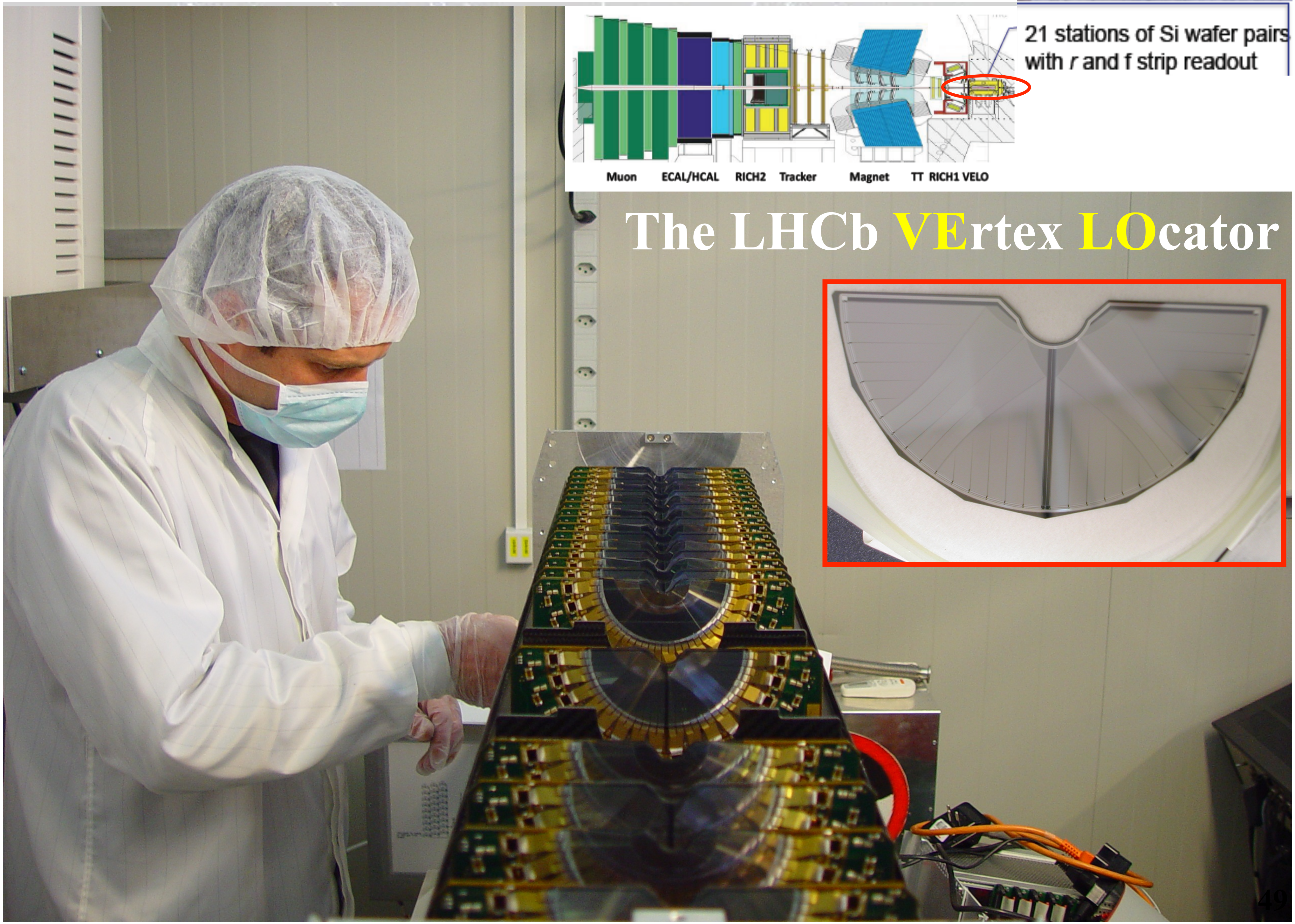
Wafer Bonding





Many different technology options (e.g. can consider "strip sensors" with z-encoding)

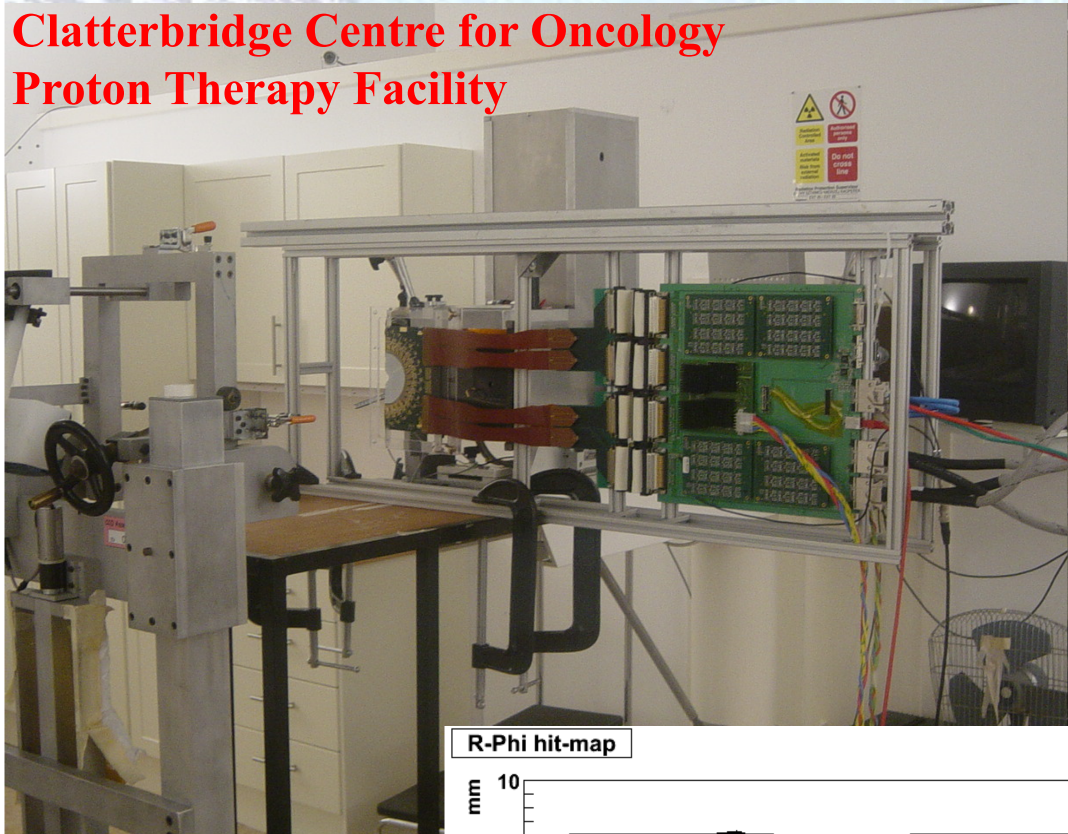
- For HL-LHC need to demonstrate radiation hardness also for large format devices
- HR/HV-CMOS need production experience with large format devices to determine yields and therefore better estimate expected costs

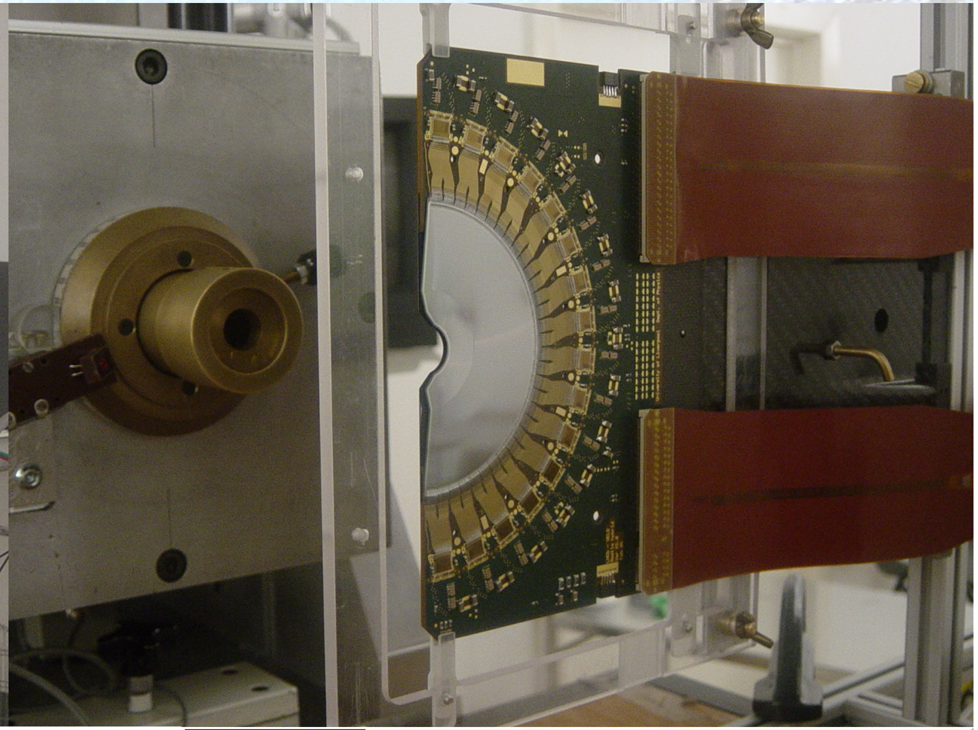


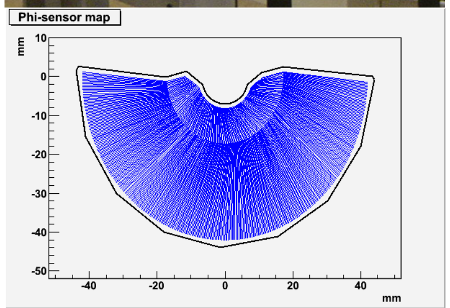
The LHCb VErtex LOcator

LHCb VELO Module as Beam Halo Monitor

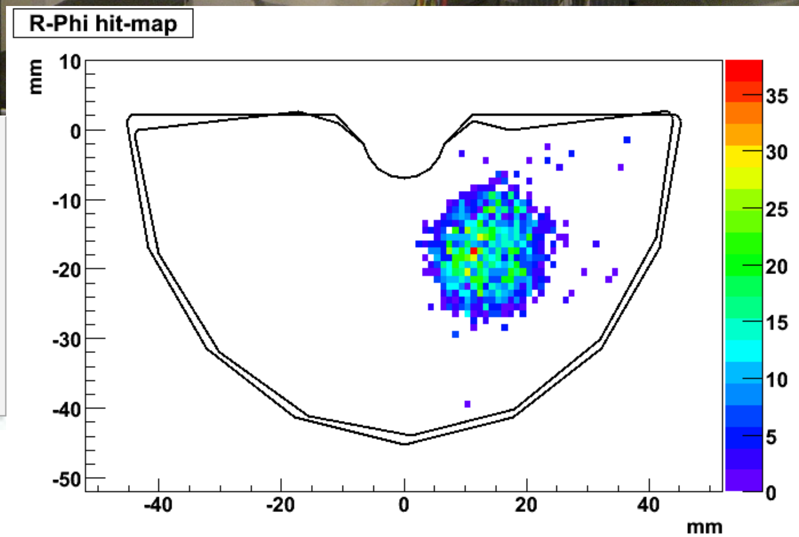
Clatterbridge Centre for Oncology
Proton Therapy Facility

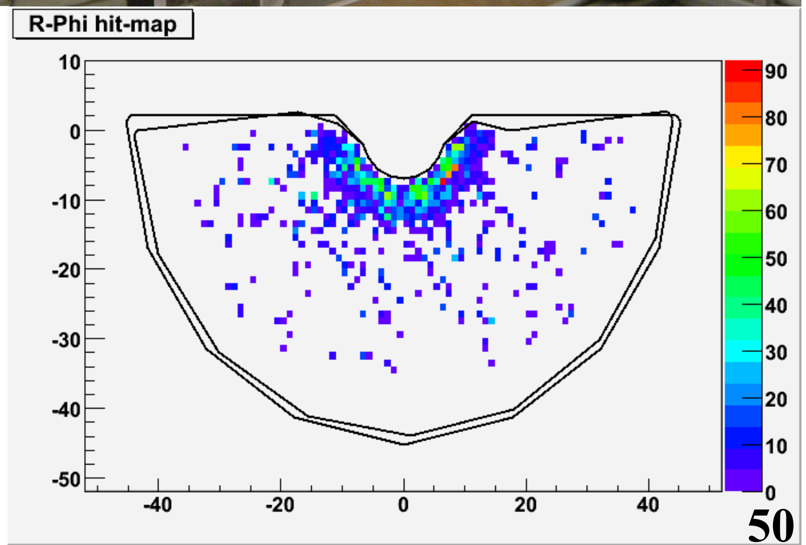






LHCb Back-to-Back
Sensor Module

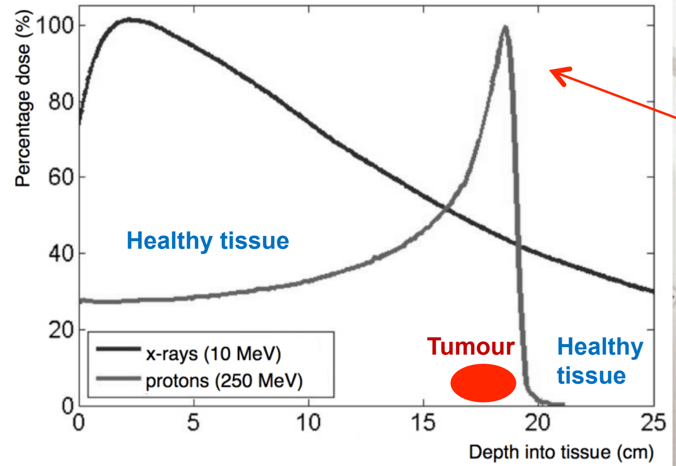




Proton Radiotherapy Verification and Dosimetry Applications

wellcome trust

Integrated computed dosimetry and tomography instrumentation for proton therapy



- **Over 330,000 diagnosed with cancer in the UK each year**
- **Nearly two-thirds of patients will receive radiotherapy as part of their treatment**
- **Half of all patients will receive radiotherapy as part of their curative treatment**
- **Most radiotherapy using external beams of high-energy x-rays**

Can also use proton beams

UNIVERSITY OF LINCOLN
UNIVERSITY OF BIRMINGHAM
UNIVERSITY OF SURREY
UNIVERSITY OF LIVERPOOL

University Hospitals Birmingham NHS
NHS Foundation Trust

University Hospitals Coventry and Warwickshire NHS
NHS Trust

The Christie NHS
NHS Foundation Trust

isdi
IMAGE SENSOR DESIGN & INNOVATION

NRF
National Research Foundation
iThemba LABS
Laboratory for Accelerator Based Sciences

THE UNIVERSITY OF WARWICK

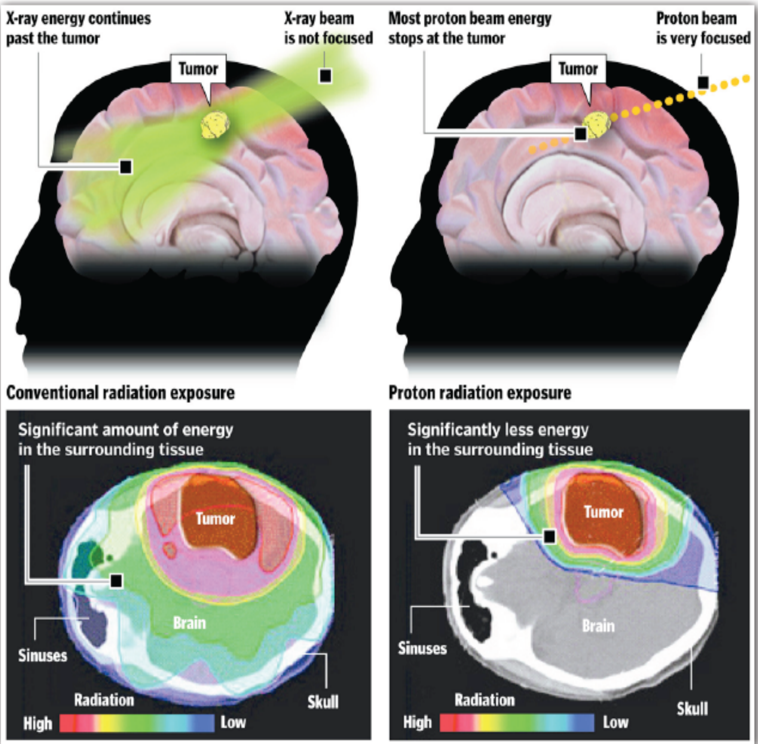
Proton Radiotherapy Verification and Dosimetry Applications

Proton beam therapy offer real benefits

- Tumours in the head and neck region
- Tumours near the spine or other critical organs
- Some types of brain tumours
- Some childhood cancers so the risk of second cancers later in life is greatly reduced
- Shorter treatment lengths
- Less side-effects
- Faster recovery

Proton beam therapy status

- 48 operational centres worldwide
- Further ~30 planned
- Over 70,000 patients treated
- UK Government agreed funding of 2 NHS centres (UCH, London and Christie's, Manchester)



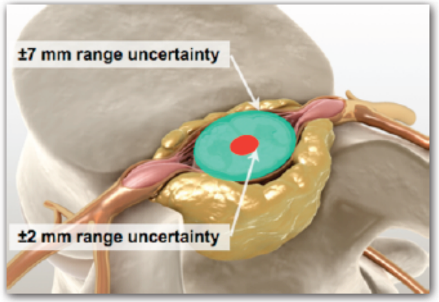
Advantage
Intense dose in small targeted volume

Potential Problem
Intense dose in small healthy volume

Patient planning

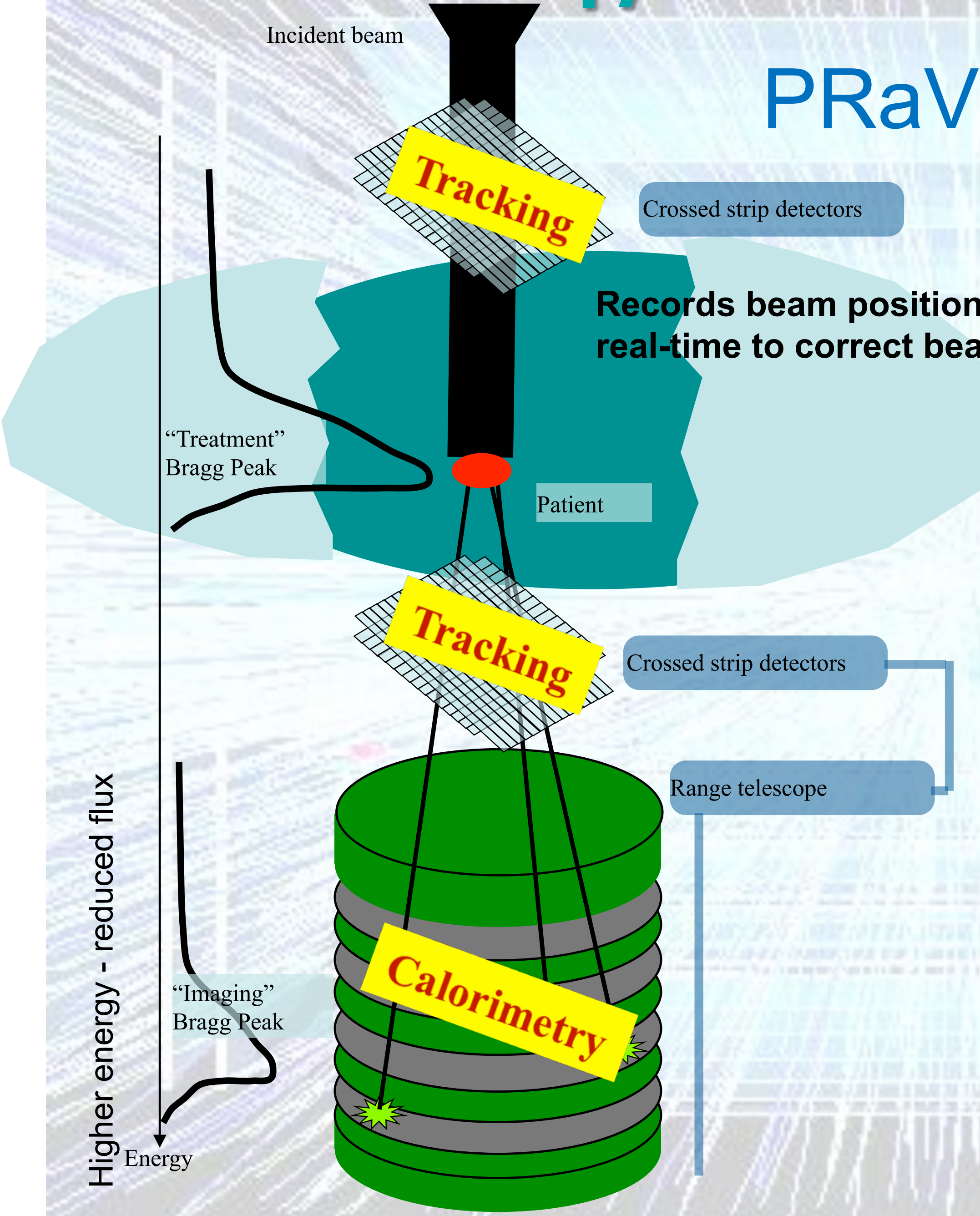
- Perform x-ray CT
- Translate from diagnostic x-rays to treatment protons
- Prone to errors - 1 - 2 cm in soft tissue, greater in bone

- **Need to see the patient using the "same" protons as used in treatment**

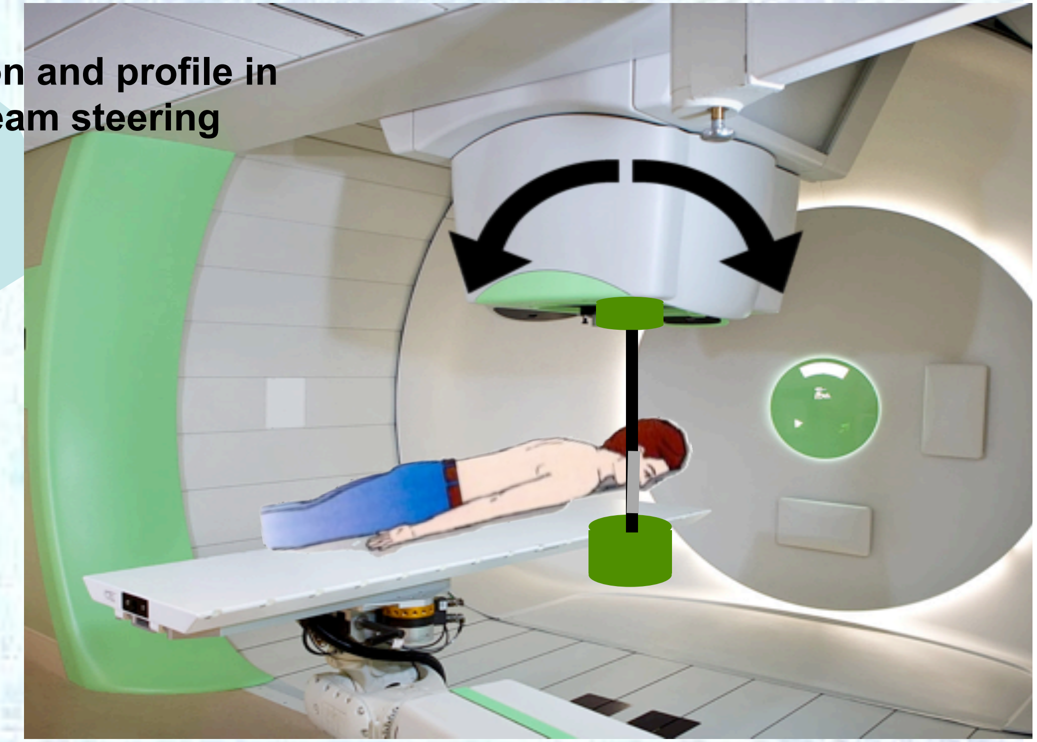


Proton Computed Tomography (pCT) is the key

PRaVDA System Overview



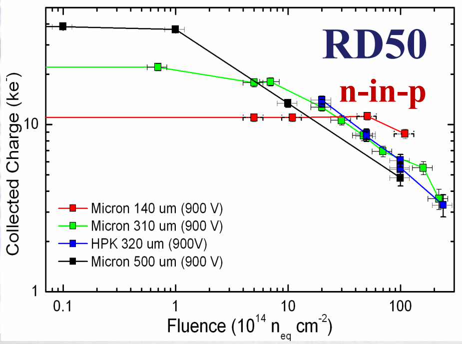
Records beam position and profile in real-time to correct beam steering

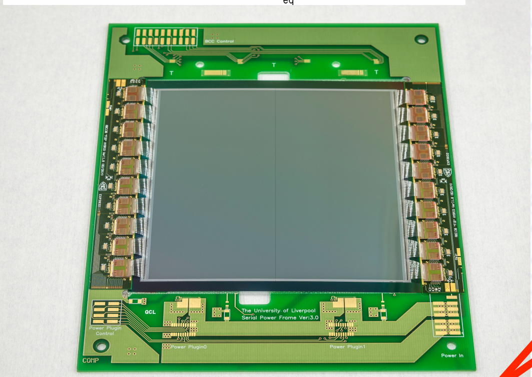


With gantry movement permit full proton-Computed Tomography (pCT) scan using same particle type as for treatment.

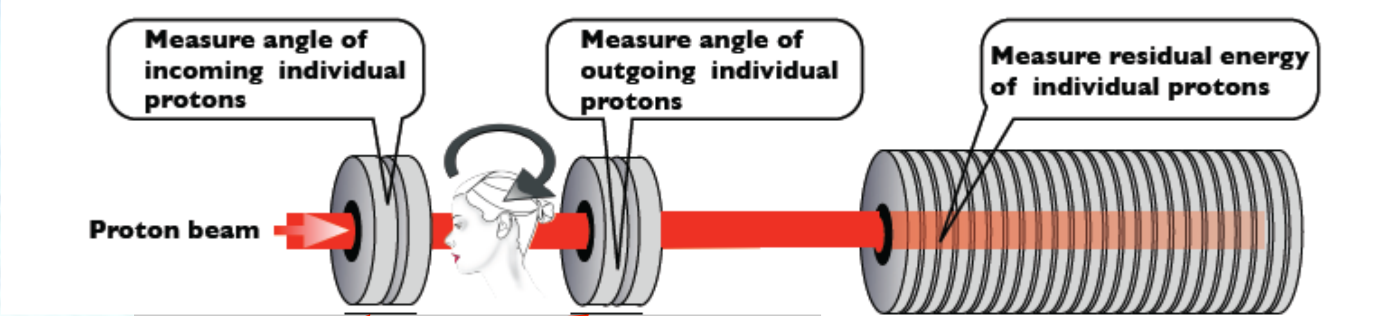
Reduce uncertainties and hence less damage to healthy tissue.

Proton Radiotherapy Verification and Dosimetry Applications

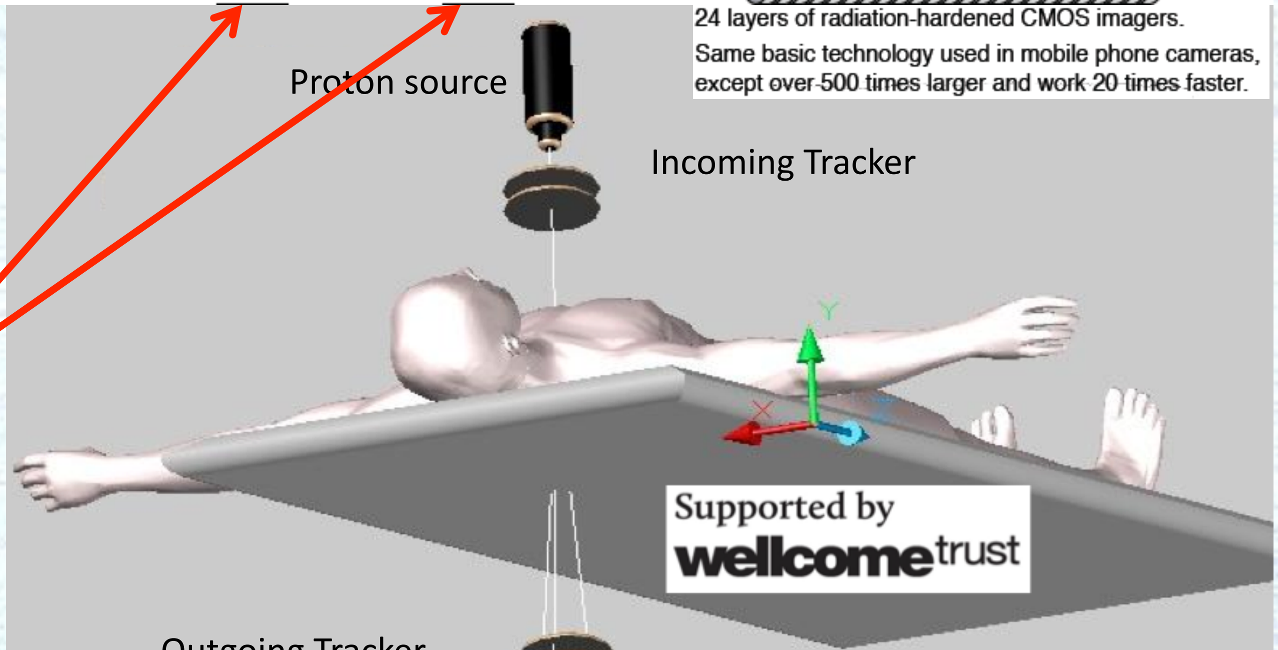


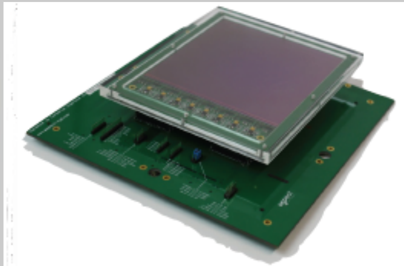


PRaVDA micro-strip detector



24 layers of radiation-hardened CMOS imagers.
Same basic technology used in mobile phone cameras, except over 500 times larger and work 20 times faster.





CMOS Imager

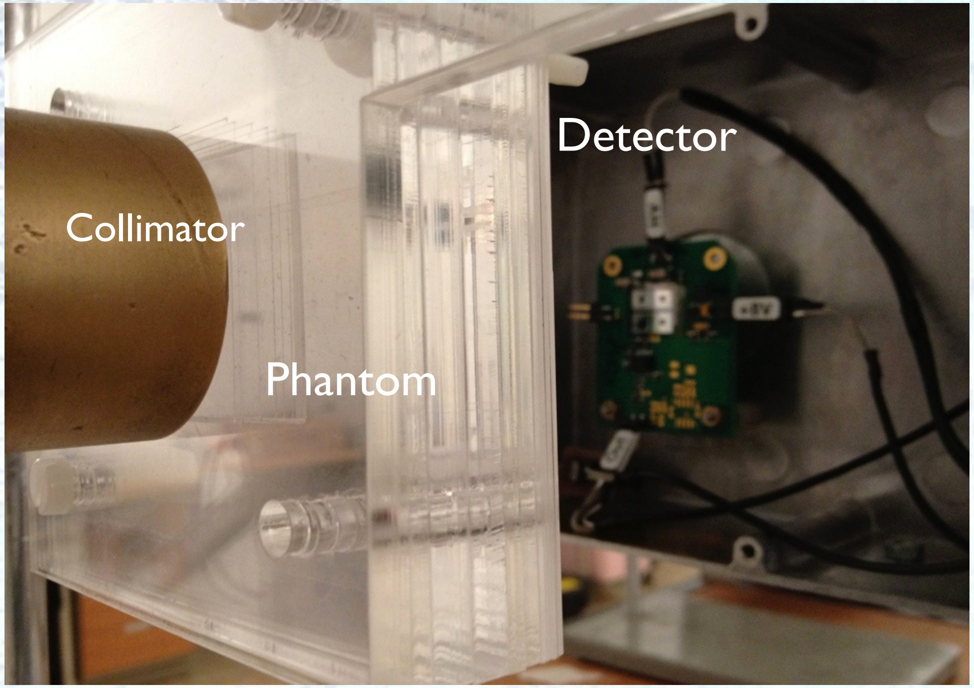
2560 strip silicon sensors using 150µm thick n-in-p technology developed for High Luminosity LHC

12 planes of strips used to make 4 tracking modules, 2 before and 2 after the patient

Each module of strips has three planes crossed at 60° in an (x,u,v) configuration to allow high particle rate

www.pravda.uk.com

Perspex Phantom Measurement at Clatterbridge

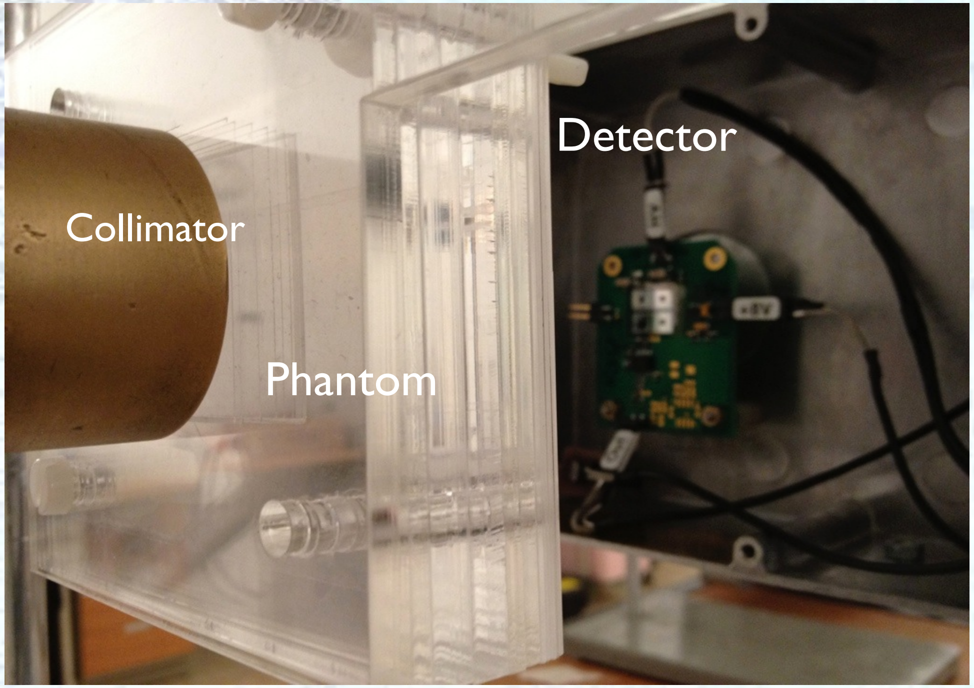


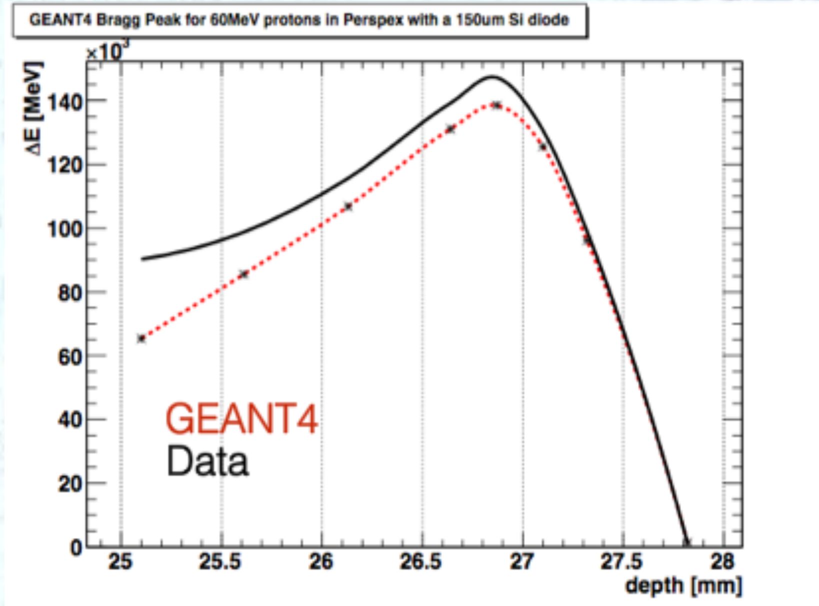
Aim: to reproduce Bragg peak in perspex using silicon detector

Simple detector system comprised of small n-in-p diode and readout with custom built data acquisition

Phantom machined on the laser cutter with sheets of Perspex of varying thickness: 5 - 0.2 mm to allow precise steps to be made

Perspex Phantom Measurement at Clatterbridge





dE/dx plots of 60 MeV protons in Perspex (Differences due to pile-up in detector. Using a strip or pixel detector would eliminate this problem.)

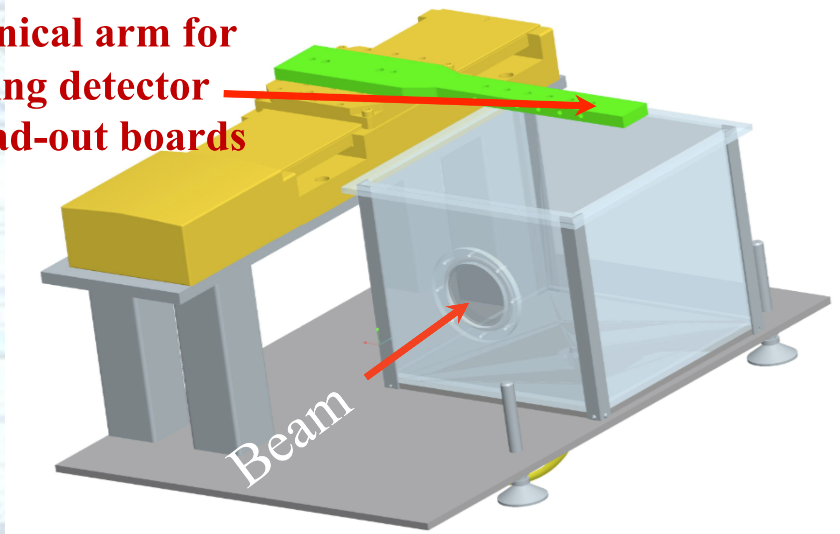
Aim: to reproduce Bragg peak in perspex using silicon detector

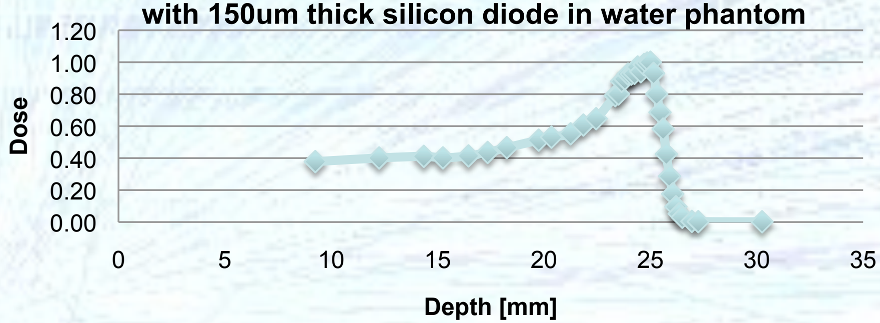
Phantom machined on the laser cutter with sheets of Perspex of varying thickness: 5 - 0.2 mm to allow precise steps to be made

Novel Tissue Equivalent Phantom for Proton Therapy

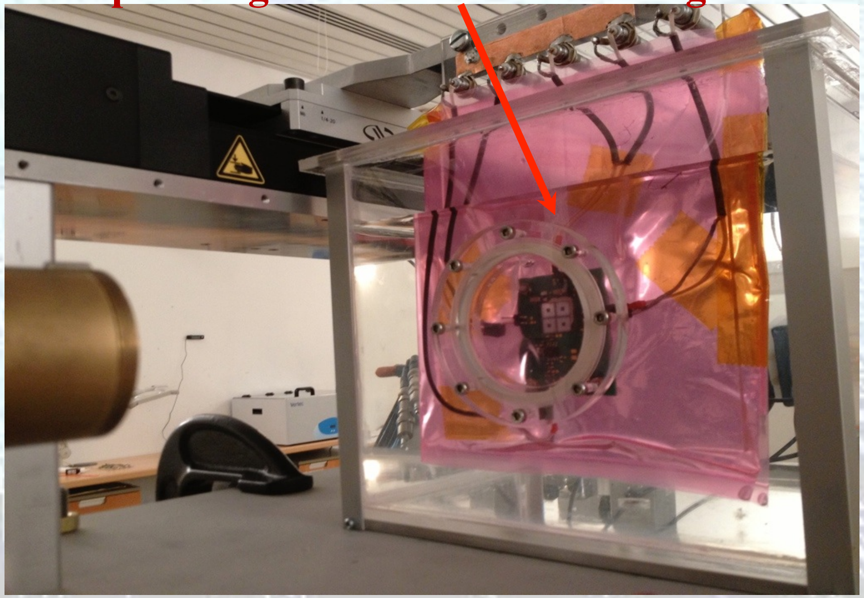
A silicon sensor is rapidly scanned through a tissue equivalent liquid to give the depth-dE/dx profile with high resolution. Silicon diodes (1D), and micro-strip detectors (2D) currently used. **Ideally use a pixel to see full 3D dE/dx distribution for treatment planning and beam quality assurance.**

Mechanical arm for mounting detector and read-out boards





Detector placed inside antistatic bag for waterproofing and electrical shielding



Water Phantom Measurement at Birmingham

With thanks to Jon Taylor, Tony Price, David Parker, Stuart Green, Ilya Tsurin, Gianluigi Casse, Tony Smith

New Detectors have 50um parylene coating as a water barrier. This allows good calibration in depth that cannot be achieved when detectors are inside the antistatic bag (due to air gaps).

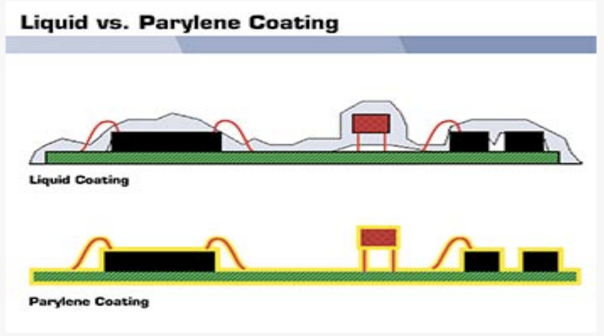
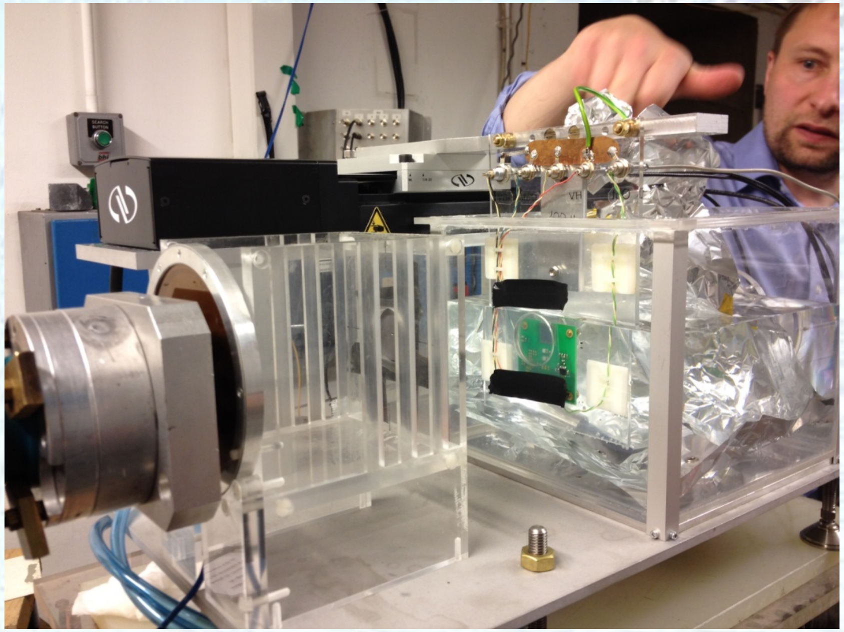
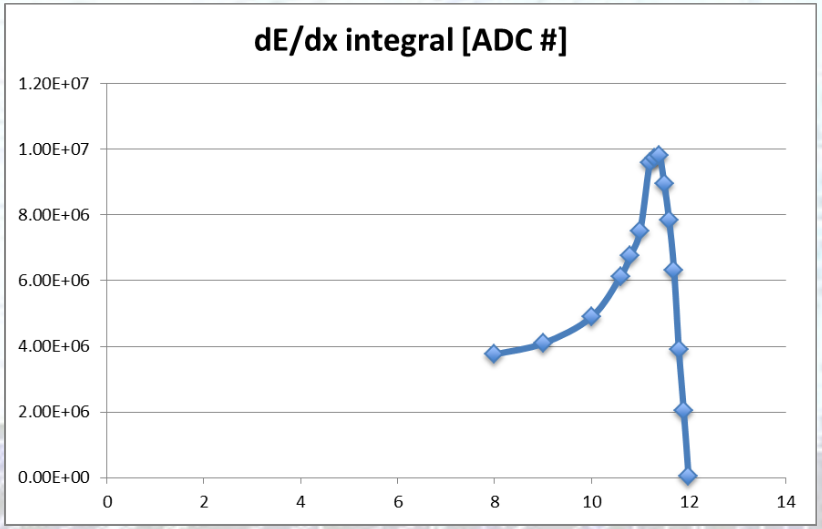
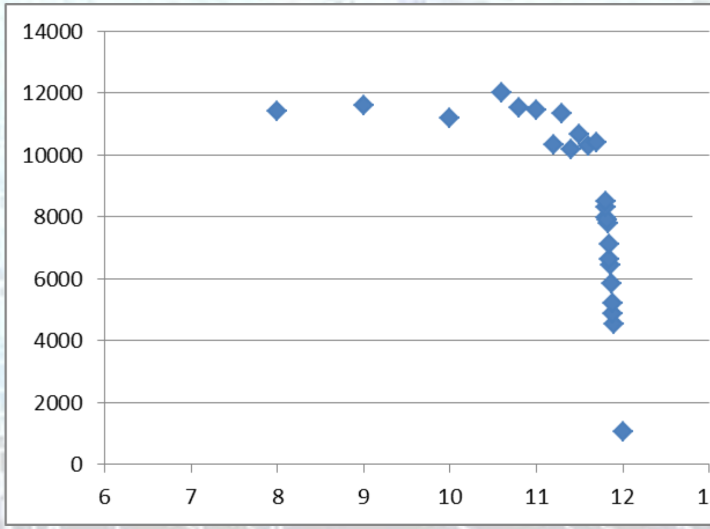


Illustration of liquid coating and Parylene coating







Flux vs Depth

Conclusions

- ATLAS has a coherent plan for upgrades through the coming decade to meet the challenges up to and including the HL-LHC era, which are embodied in the two LoIs and four TDRs which have been through full LHCC approval
- The understanding of the full physics potential of the HL-LHC is advancing rapidly, with greatly increased activity on both detector and accelerator preparations following the adoption by CERN Council of the Updated European Strategy for Particle Physics, with the HL-LHC as its highest priority, and the strong endorsement in the recent P5 report
- There are designs for a replacement tracker that should withstand both the pile-up and radiation conditions at the HL-LHC, with performance able to not just fully recover, but also improve on, the current capabilities at low pile-up.
- In developing these radiation-hard detectors, we have seen a possible application for sensors which would need to permanently sit in a proton beam for years without any need to recalibrate for change in signal with dose

Back-up

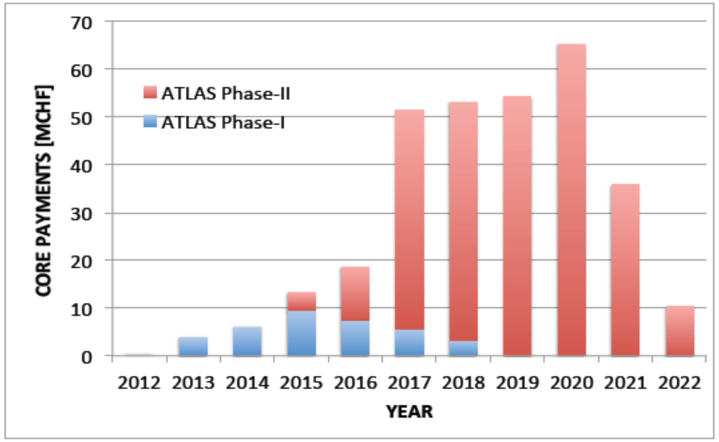
LoI Core Costs

Cost Time Profile

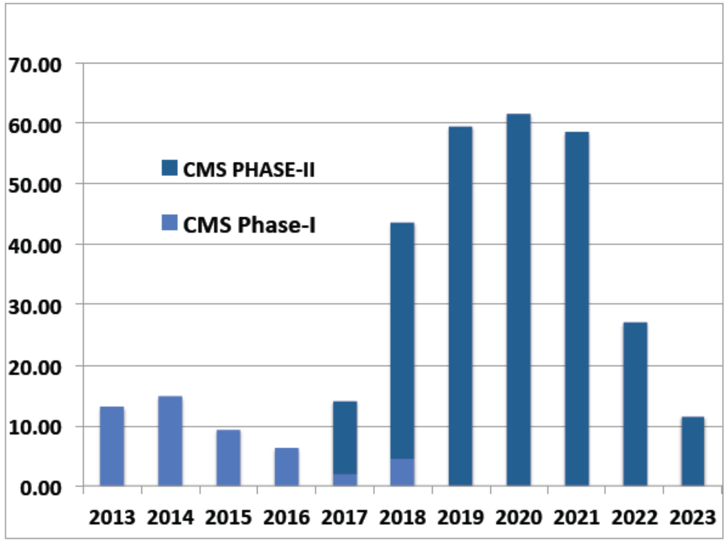
CORE costing

Phase-1 uses TDR costings

Phase-2 uses LoI costings, and includes options



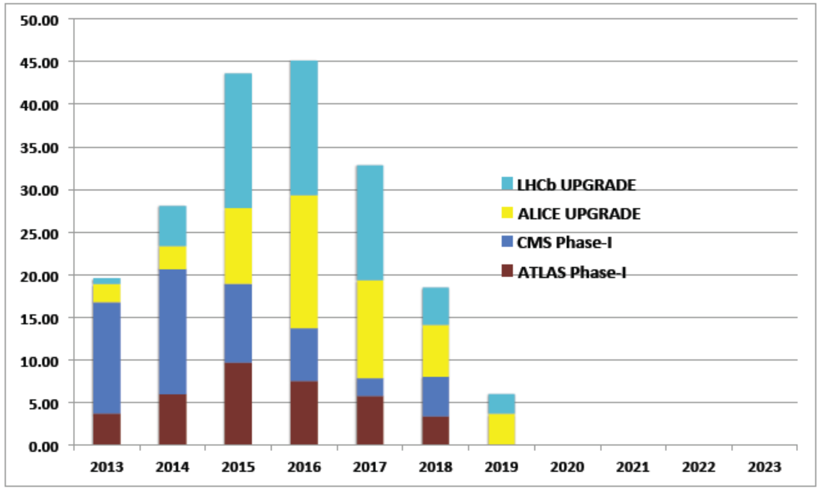
Tracker total: 132 MCHF out of 231M CHF
(plus 45 MCHF of total possible additional costs)



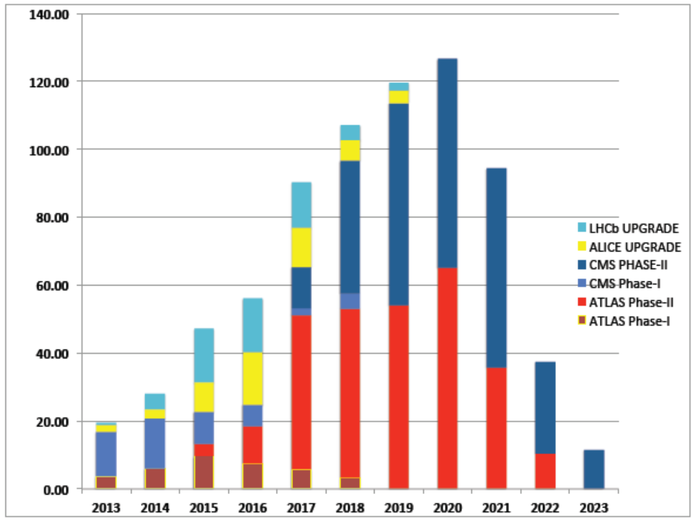
Phase-I LoI Costs see: https://edms.cern.ch/document/1164764

Phase-II LoI Costs see: https://edms.cern.ch/document/1258343

Summary: from now to LS2 (Phase-I)



All Upgrades



New LHC schedule beyond LS1

Only EYETS (19 weeks)   (no Linac4 connection during Run2)

LS2 starting in 2018 (July) — 18 months + 3months BC (Beam Commissioning)

LS3 LHC: starting in 2023 => 30 months + 3 BC

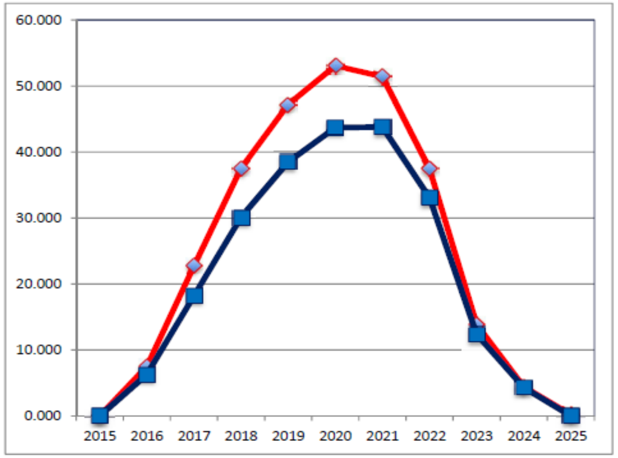
injectors: in 2024 => 13 months + 3 BC

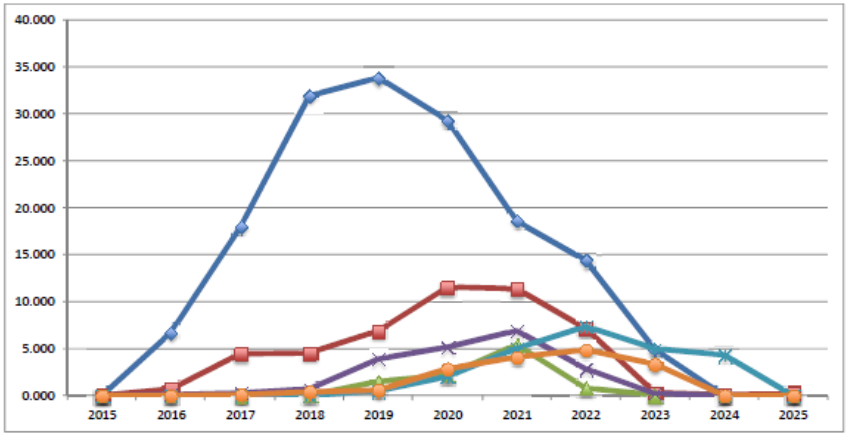
LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators
Monday 2nd December 2013

Re-profiled Phase-II Core Costs

New ATLAS PHASE II upgrade (LS3) with Options Included

		it will happen	it might happen	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	total
		[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]
1	New Inner Detector	131.500	26.000	0.000	6.707	17.906	31.919	33.836	29.284	18.565	14.373	4.911	0.000	0.000	157.500
2	LAr upgrades	32.124	15.096	0.000	0.700	4.458	4.519	6.895	11.554	11.371	7.162	0.289	0.091	0.182	47.220
3	Tiles upgrades	7.483	2.517	0.000	0.000	0.000	0.000	1.499	2.177	5.439	0.804	0.080	0.000	0.000	10.000
4	Muon spectrometer upgrades	19.632	0.500	0.000	0.103	0.282	0.692	3.888	5.169	6.922	2.871	0.205	0.000	0.000	20.132
5	TDAQ upgrades	23.315	0.900	0.000	0.000	0.000	0.000	0.500	2.020	5.020	7.355	5.000	4.320	0.000	24.215
6	Infrastructure items	16.280	0.000	0.000	0.000	0.100	0.400	0.600	2.850	4.100	4.880	3.350	0.000	0.000	16.280
	TOTAL	230.334	45.013	0.000	7.510	22.746	37.530	47.218	53.054	51.416	37.445	13.835	4.411	0.182	275.347

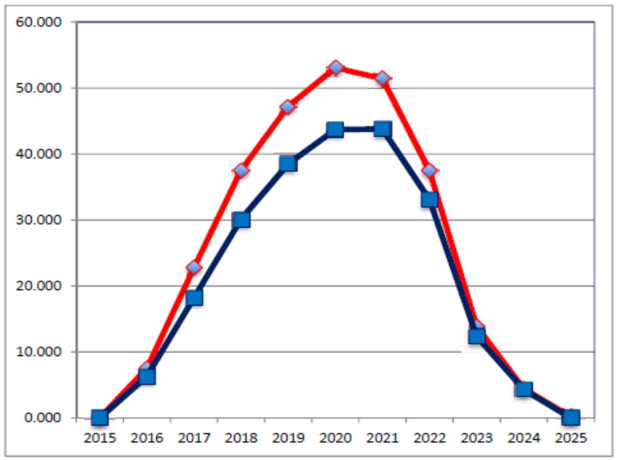




Re-profiled Phase-II Core Costs

New ATLAS PHASE II upgrade (LS3) with Options Included

		it will happen	it might happen	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	total
		[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]	[MCHF]
1	New Inner Detector	*131.500*	*26.000*	0.000	6.707	17.906	31.919	33.836	29.284	18.565	14.373	4.911	0.000	0.000	157.500
2	LAr upgrades	*32.124*	*15.096*	0.000	0.700	4.458	4.519	6.895	11.554	11.371	7.162	0.289	0.091	0.182	47.220
3	Tiles upgrades	*7.483*	*2.517*	0.000	0.000	0.000	0.000	1.499	2.177	5.439	0.804	0.080	0.000	0.000	10.000
4	Muon spectrometer upgrades	*19.632*	*0.500*	0.000	0.103	0.282	0.692	3.888	5.169	6.922	2.871	0.205	0.000	0.000	20.132
5	TDAQ upgrades	*23.315*	*0.900*	0.000	0.000	0.000	0.000	0.500	2.020	5.020	7.355	5.000	4.320	0.000	24.215
6	Infrastructure items	*16.280*	*0.000*	0.000	0.000	0.100	0.400	0.600	2.850	4.100	4.880	3.350	0.000	0.000	16.280
	TOTAL	*230.334*	*45.013*	*0.000*	*7.510*	*22.746*	*37.530*	*47.218*	*53.054*	*51.416*	*37.445*	*13.835*	*4.411*	*0.182*	*275.347*



New Phase-II Profile

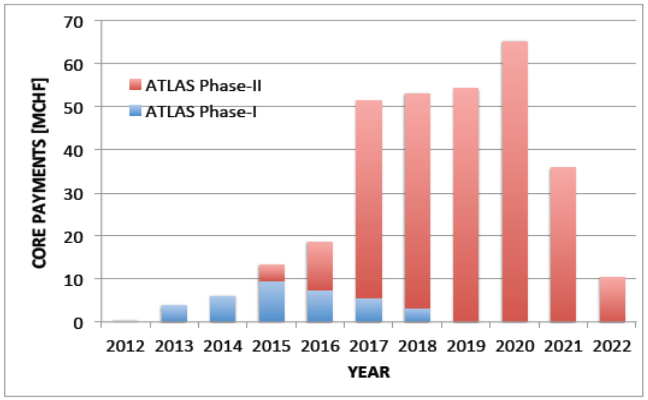
Cost Time Profile

LoI Core Costs

CORE costing

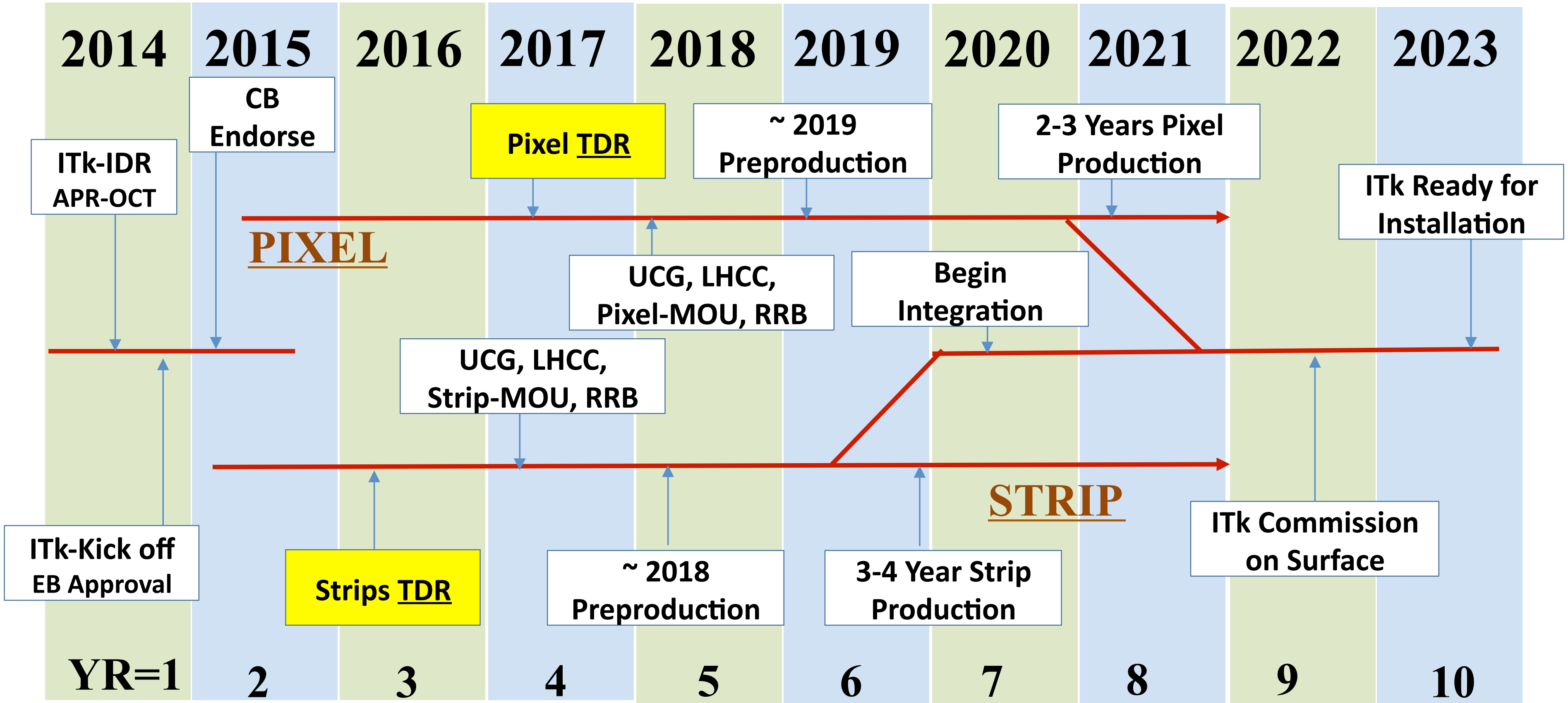
Phase-1 uses TDR costings

Phase-2 uses LoI costings, and includes options



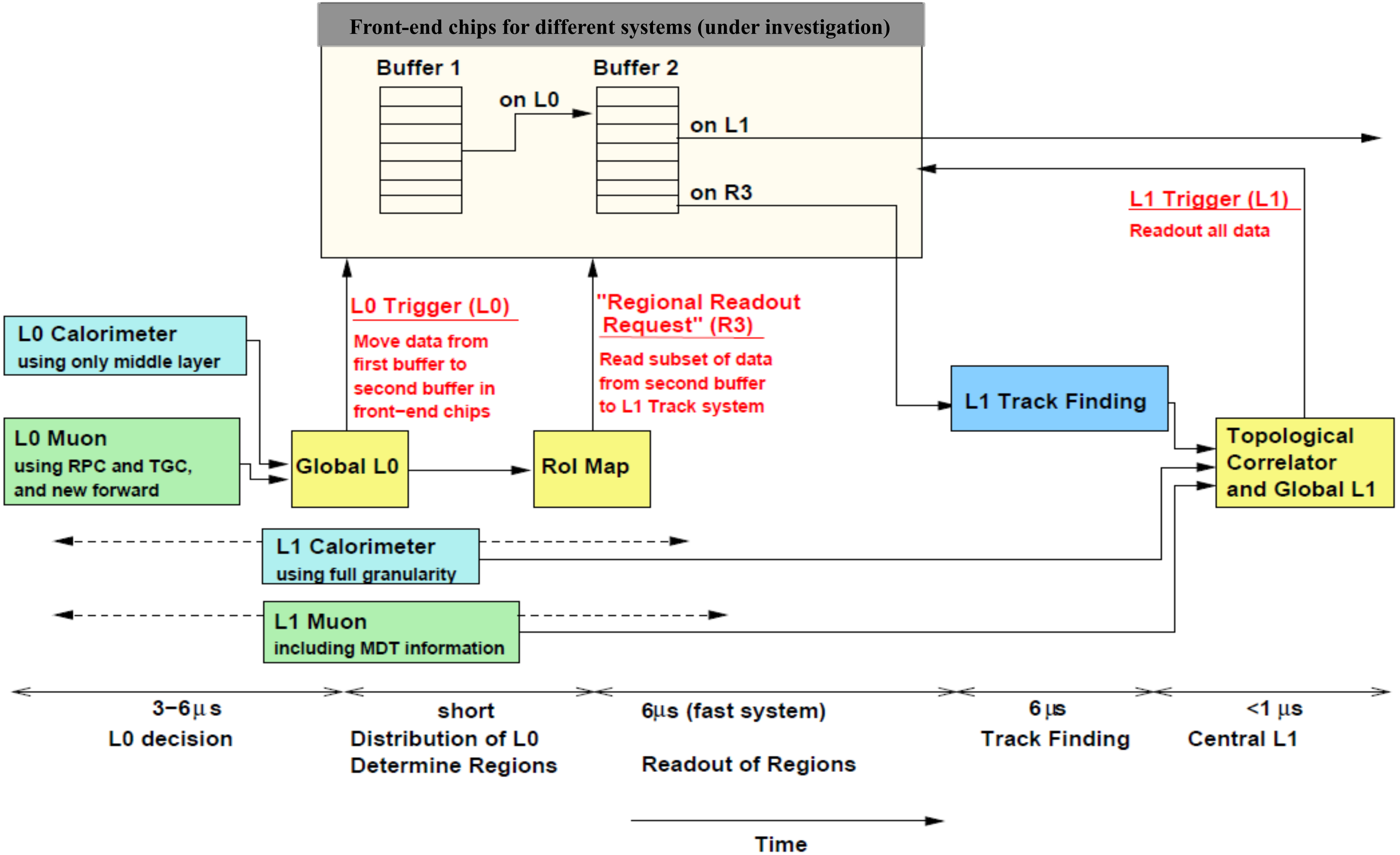
Old LoI Based Profile for Comparison

ITk: Draft Schedule



CB= collaboration board, EB=executive board, IMOU=interim memorandum of understanding, UCG=upgrade cost group, RRB= Resources review board, IDR=initial design review (internal), TDR=technical design report (external)

Phase-II Split TDAQ L1 Scheme



Note latencies, rates and use of R3 read-out are evolving in the light of improved understanding of possible trigger menus for Phase-II and exploration of higher speed data transfer

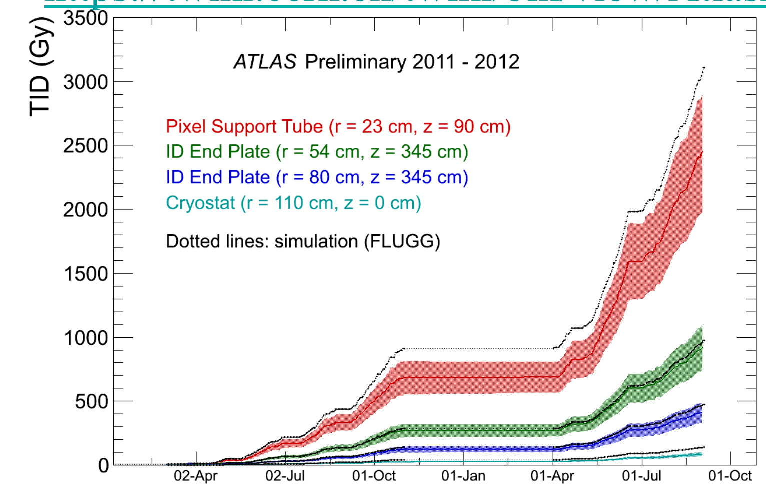
RD53 Summary

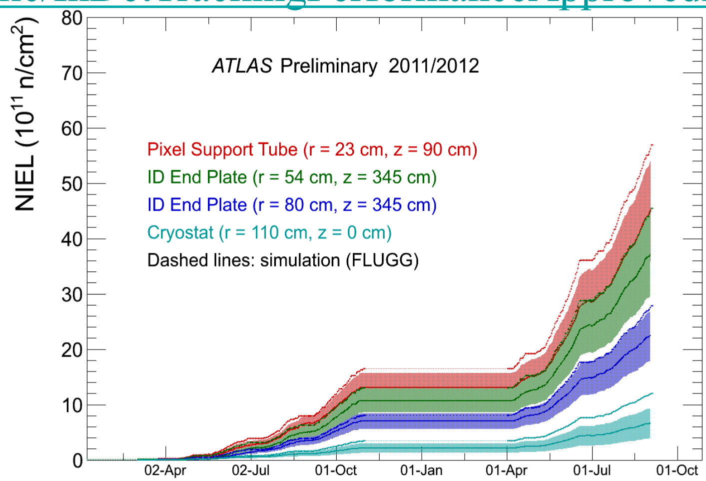
- Highly focused ATLAS-CMS-LCD/CLIC RD collaboration to develop/qualify technology, tools, architecture and building blocks required to build next generation pixel chips for very high rates and radiation
- Synergy with other pixel projects when possible
- Centered on technical working groups
- Baseline technology: 65nm
  - CERN frame contract/NDA/design kit .
  - Will evaluate alternatives ("emergency" plan)
- 17 Institutes, 100 Collaborators
- Initial work program of 3 years
  - Goal: Full pixel chip prototype 2016
  - Working groups have gotten a good start.
  - Common or differentiated final chips to be defined at end of 3 year R&D period

IBM announced (Feb 2014) foundries for sale
New CERN contract with TSMC until end 2017 for both 65 nm and 130 nm - under negotiation
Mixed signal design kit available for the 65 nm
2 metal stacks: 6+1 and 9+1
130 nm could be used as an alternative to IBM
Design kit being developed
Radiation hardness tests to be completed

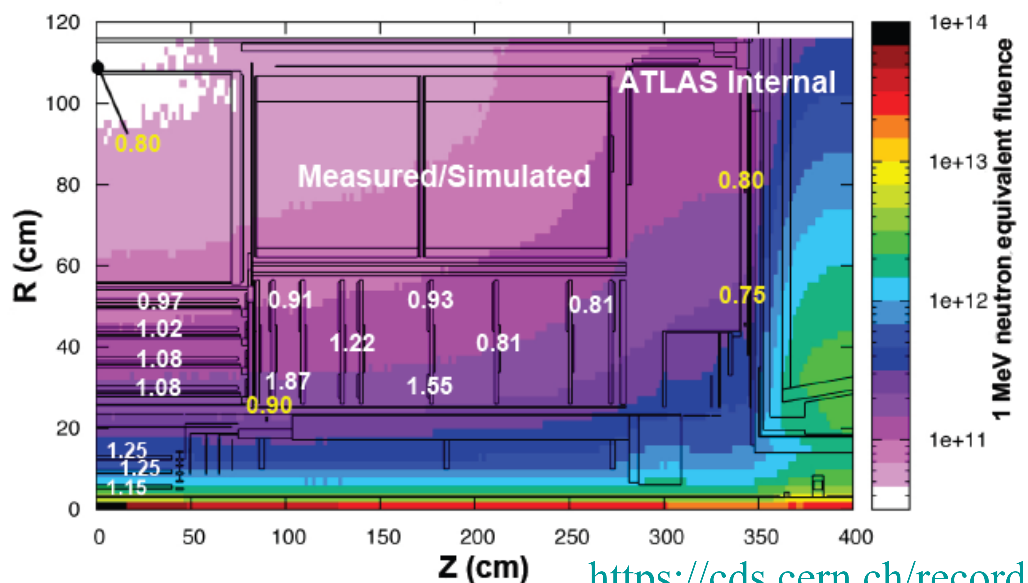
Current Detector Radiation Simulation

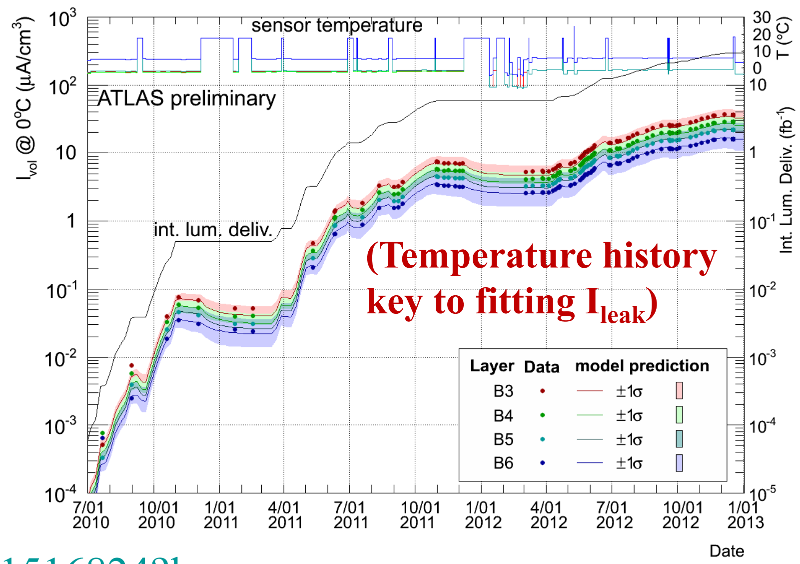
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SCTPublicResults#Figures
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsPixel#Radiation_damage_plots
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/InDetTrackingPerformanceApprovedPlots#Alignment





Simulation results fit with data to much better than a factor of 2 (and safety factor of 2 was assumed in dose specifications)

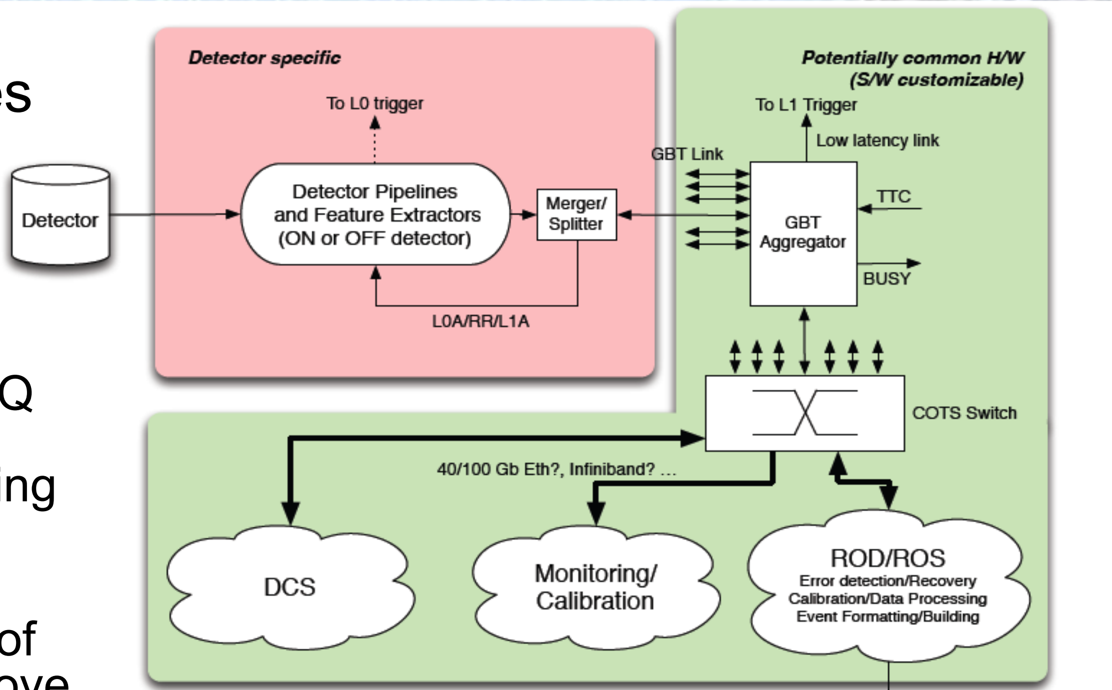


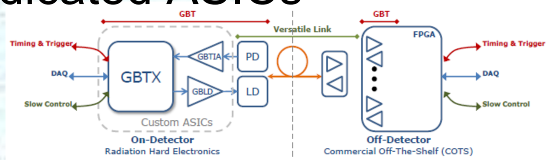


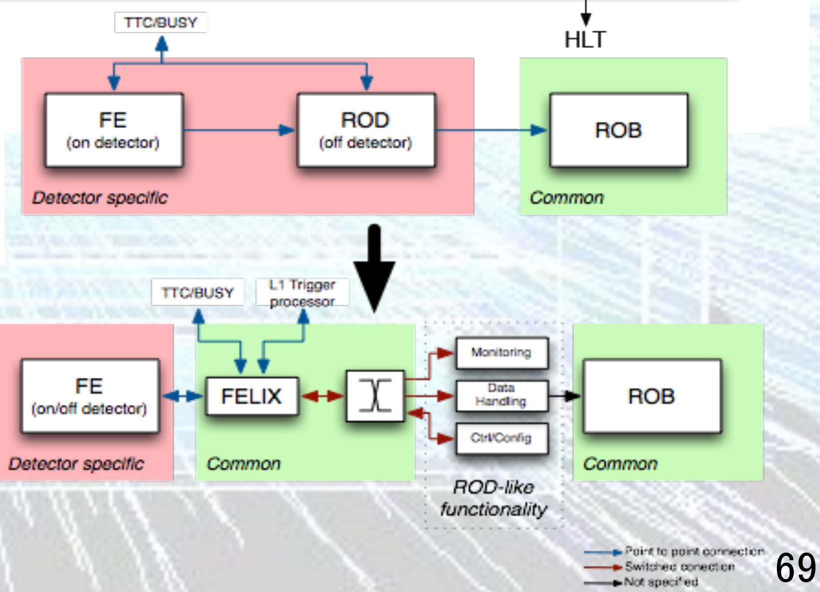
https://cds.cern.ch/record/1516824?ln=en

TDAQ and Detector Readout

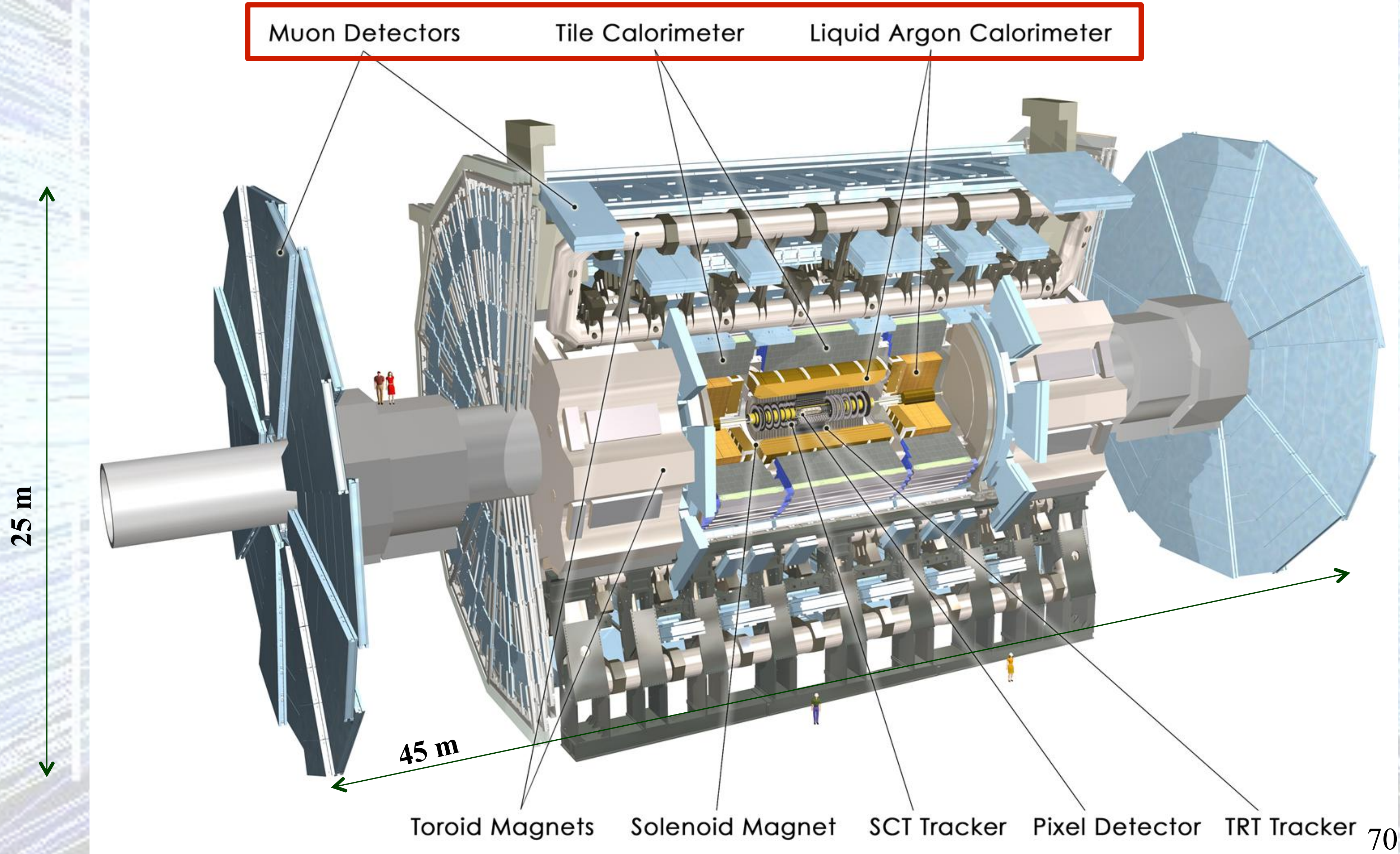
- New TDAQ architecture requires upgrade to readout of detector systems
- General comments on need for upgrades of detector readout:
  - In addition to the changes in TDAQ architecture. Upgraded readout electronics is required due to ageing and radiation damage.
  - More functionality moved to the counting room, taking advantage of large bandwidth optical links to move data off-detector; allows use of FPGAs rather than dedicated ASICs
  - Custom low power (lpGBTx) 4.8Gbps rad-hard ASIC can be reasonably assumed available in low mass custom package (or 9.6 Gbps with similar power as current GBTx)
  - Detectors are evaluating a common readout architecture based on GBTs and common Front-End interface







The ATLAS Experiment



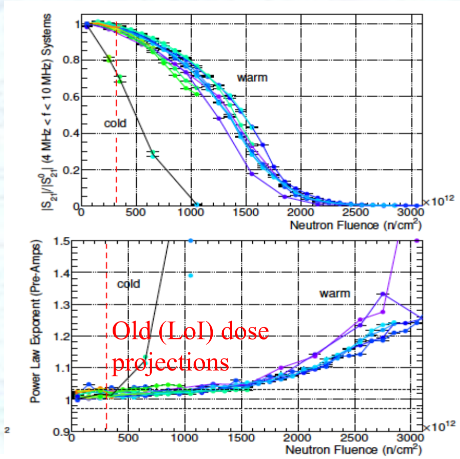
70

Phase-II Upgrades to LAr Electronics

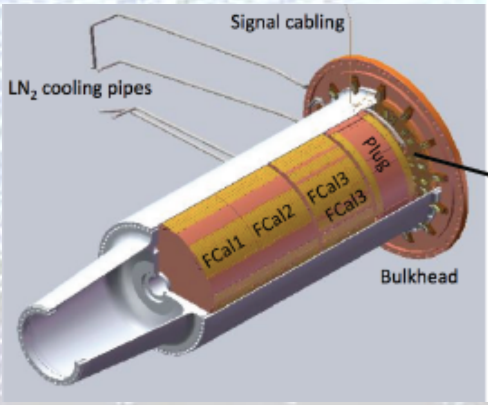
- Replace all FE boards (warm)
  - Gives flexible, free-running architecture sending data off-detector for all bunch-crossings
  - Natural evolution of Phase-I new digital trigger boards
  - Replacement required due to aging and radiation limits
  - Allows implementation of L0/L1 scheme using Phase-I L1 upgrades for Phase-II L0

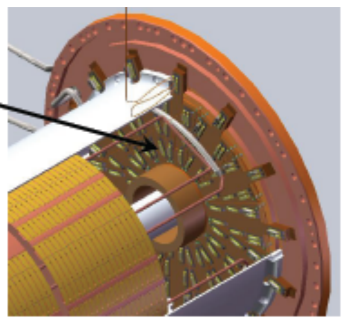
- Replace Hadronic Endcap Calorimeter electronics **if required**
  - Replace HEC cold (GaAs) preamps if significant degradation in performance expected during HL-LHC operation but this requires FCAL removal so new sFCAL would also need to be installed

    (Indications that expected doses are manageable given better dose projections but aging of electronics still needs to be understood)
- Replace just the Forward Calorimeter (FCal) **if required**
  - Install new sFCAL in cryostat or miniFCAL in front of cryostat if significant degradation in current FCAL expected at HL-LHC

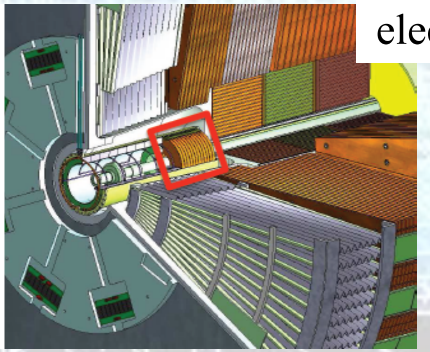


Performance of cold HEC electronics under irradiation





Reduce gap sizes from 269/375/500 μm, new summing boards and cooling loops (to avoid boiling)



miniFCAL absorbs energy upstream of current FCAL Cold Cu/LAr device [100μm LAr gaps]

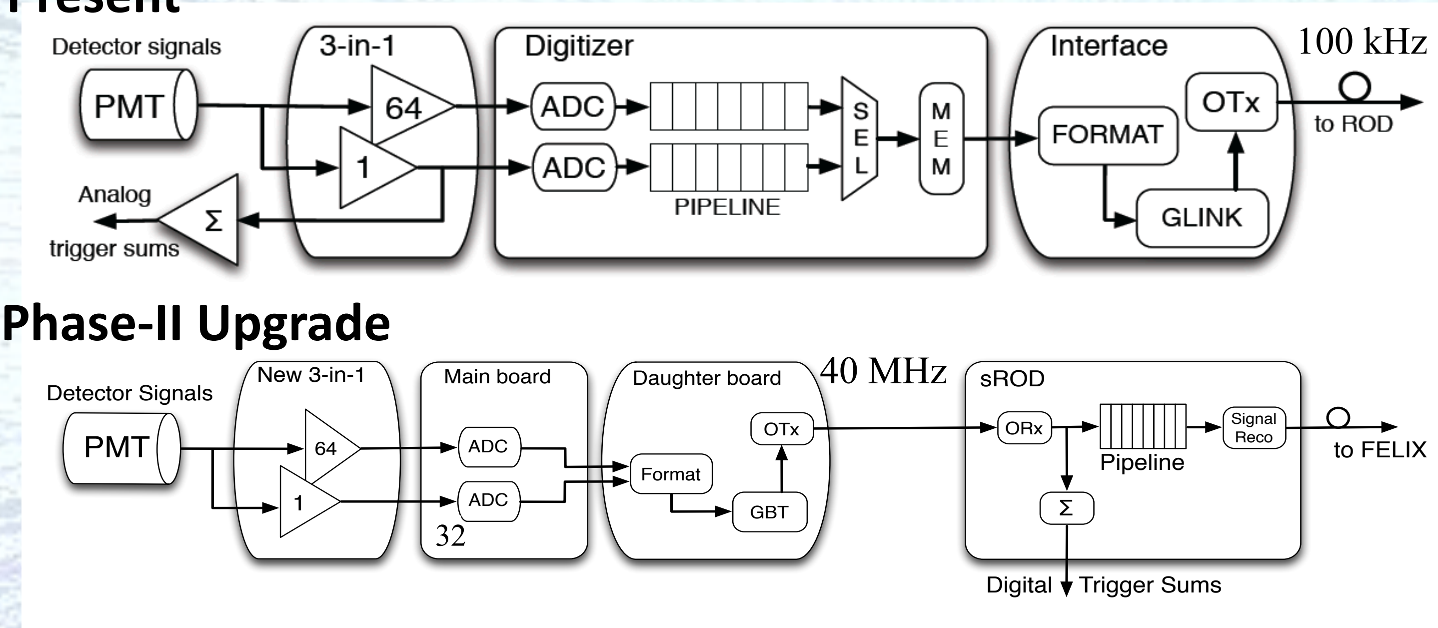
Tile Calorimeter

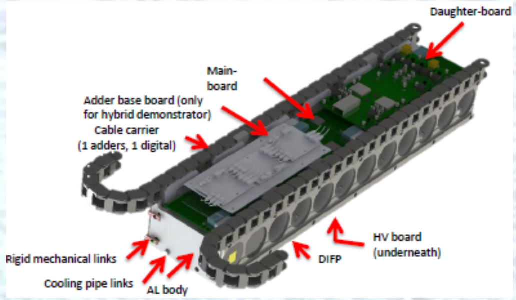
- No major changes foreseen in the readout or trigger during Phase-I
- In Phase-II complete FE&BE electronics replacement.
  - **Full digitization** of data at 40MHz and transmission to off-detector system
  - **Digital** information to L1/L0 **trigger**

Up Link only	Present	Upgrade
Total BW	~ 165 Gbps	~80 Tbps
Nb fibers	256	8192
Fiber BW	640 Mbps	10 Gbps
Nb RODs	32	32?
ROD Crates	4	4
In BW/ROD	5 Gbps	2 Tbps
Out BW/ROD $_{DAQ}$	2,56 Gbps	~ 5 Gbps
Out BW/ROD $_{L1}$	Analog FE	< 80 Gbps

Present

Phase-II Upgrade





- Also significantly improve robustness
  - **Reduce the complexity** and connections inside the front-end drawers. Moving from dependent drawers to independent **mini-drawers** (readout and power).
  - Use a real-complete **redundant readout** – from cell to back-end
  - **Redundant Power** Supply system introducing Point-of-Load regulators

Muon Electronics Upgrade

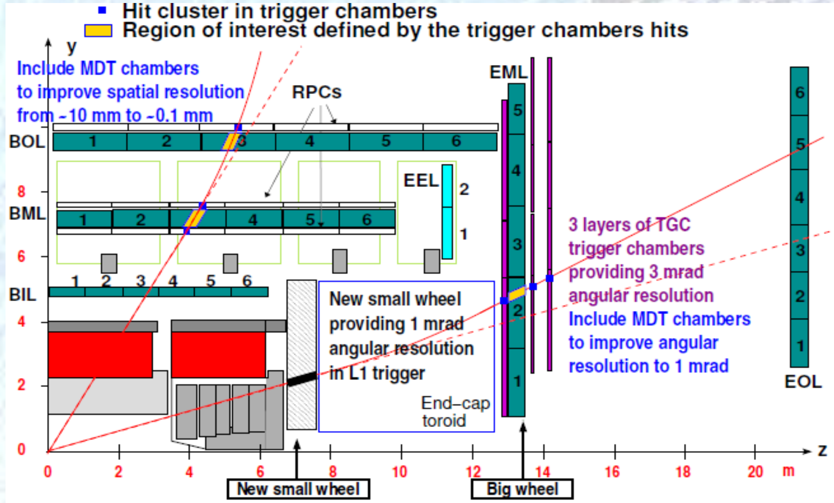
Replace existing electronics to accommodate:

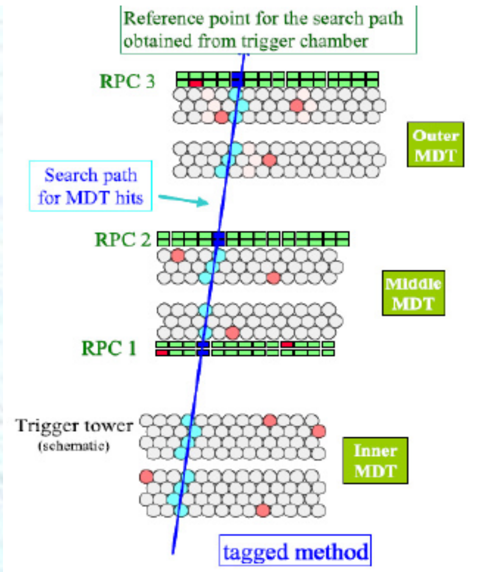
- Increased level-1 trigger latency.
- Need for sharpening the trigger threshold using MDT precision chamber hits at level 0/1.

Features of the new RPC electronics:

- Capable of higher level-1 trigger rate and longer latency.
- Time-over-threshold mode to measure charges deposited on the pick-up strips.

→ Centroid of the charge distribution for improved point resolution.





Features of the new TGC electronics:

- Existing on-chamber ASD pre-ampliers will be kept.
- New TGC read-out electronics chain compatible with HL-LHC requirements with most of the logic functions moved to radiation free zone (USA15).

→ Use of FPGAs for the first level trigger decision

Features of the new MDT electronics:

- Capable of level-1 trigger rate and longer latency in high background regions.
- Additional fast read-out chain for MDT level-0/1 trigger.

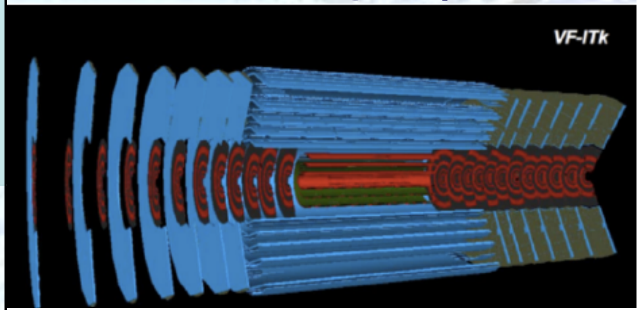
Possible Extensions to Large η

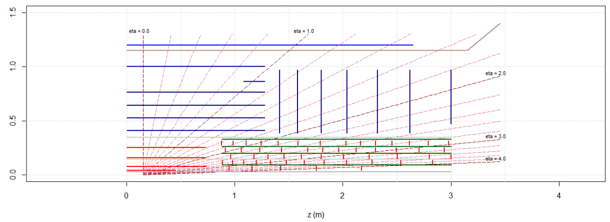
Physics Channels Under Investigation

SM	1) VBS W+W+ for VBF jet reconstruction 2) Tribosons as multi-lepton measurement reference 3) Inclusive W/Z production 4) Exclusive processes ($\gamma\gamma$ ->WW)
SUSY	1) VBF production for EWKinos & optimisation for VBF reconstruction 2) JP determinations for observations of SUSY states 3) t-channel processes for stop production
Higgs	1) Di-Higgs reconstruction/acceptance in bbgg and bb$\tau\tau$. 2) VBF Di-Higgs production modes 3) H->WW for fwd jet veto & b-jet veto optimization 4) H->4l for optimization of lepton coverage 5) H->WW; H->$\tau\tau$ for optimization of VBF reconstruction 6) Higgs invisible and MET requirements 7) t-channel mode for single-top associated H production
Exotics	1) JP determinations for Z' versus KK graviton 2) Single-VLQ t-channel production
top	Single-top modes like t-channel production with very forward topology for light jet and b-jet reconstruction

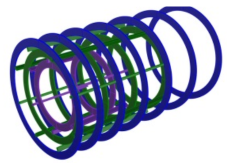
Studies of physics motivations and requirements are proceeding in parallel with studies of possible technical options

- **Extend tracking to η>4?**





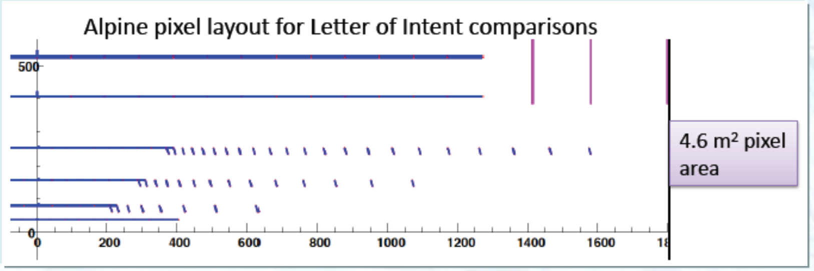
Pixel extension in "ring design"

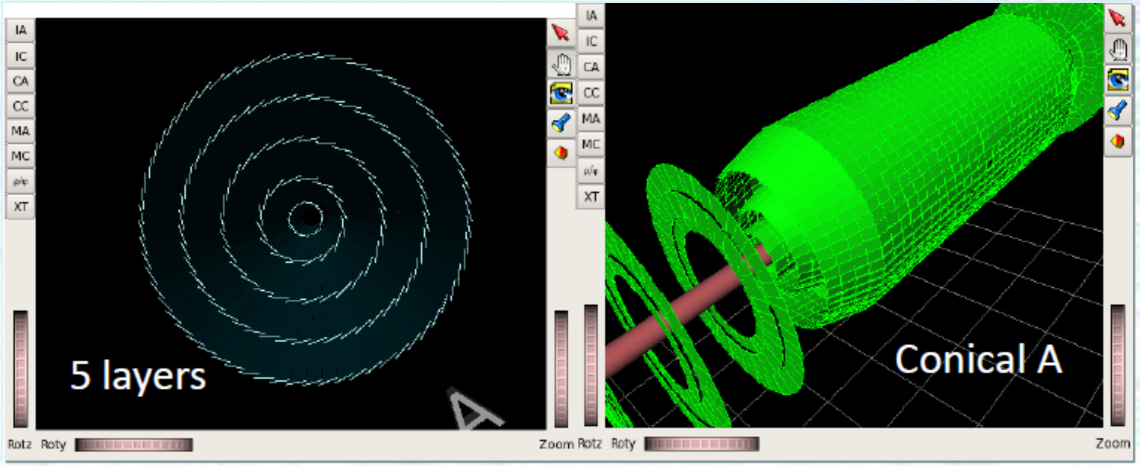


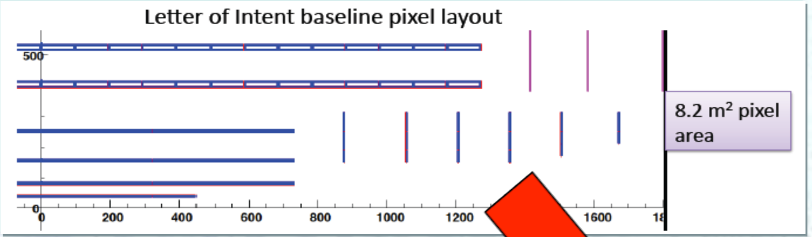
- **Segmented timing detectors at MBTS location?**
- **New FCAL with improved timing and granularity?**
- **Pixelated muon tagger behind ECAL η = 2.7 – 4.5?**
- **Muon spectrometer with magnetized forward shielding?**

New All-silicon Inner Tracker

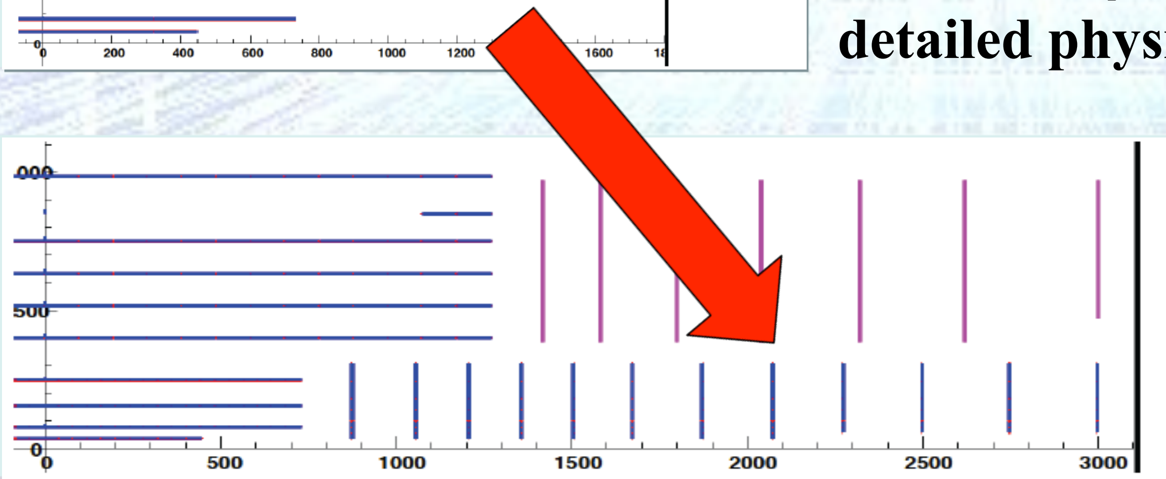
- **Alternative layouts being considered which include either a further pixel layer or inclined pixel sensors attached to the same barrels (Alpine layout)**

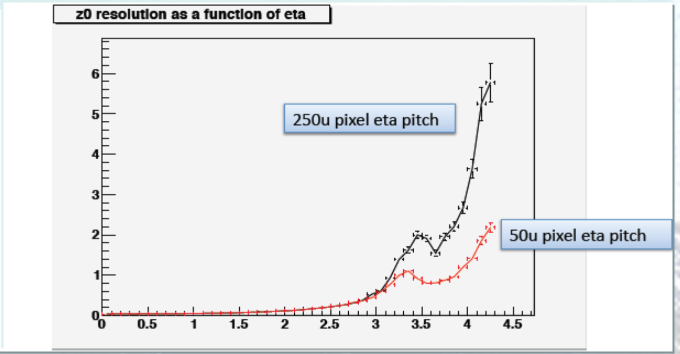






Extended η coverage needs more detailed physics motivation



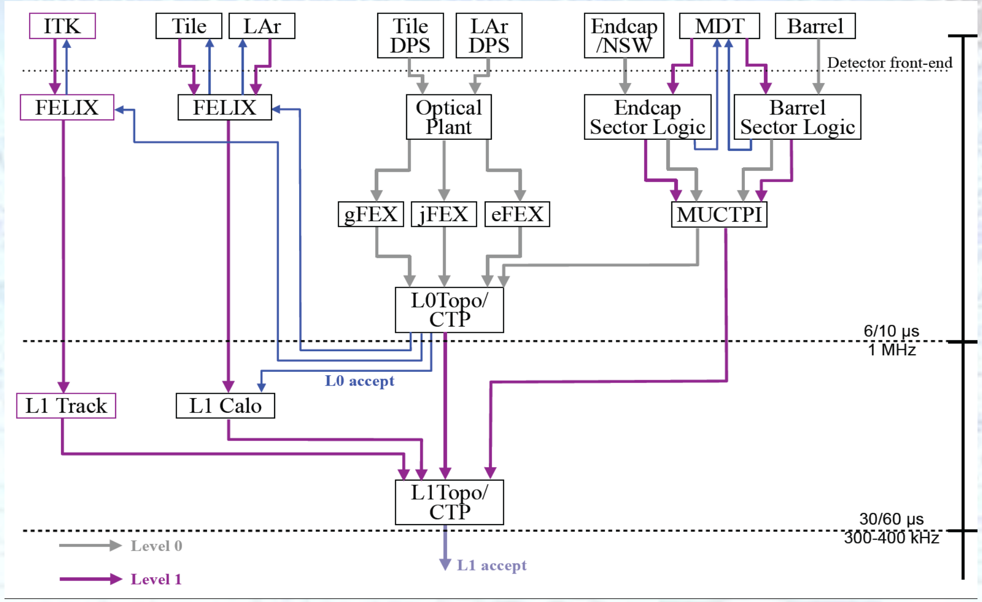


Phase-II Split TDAQ L1 Scheme

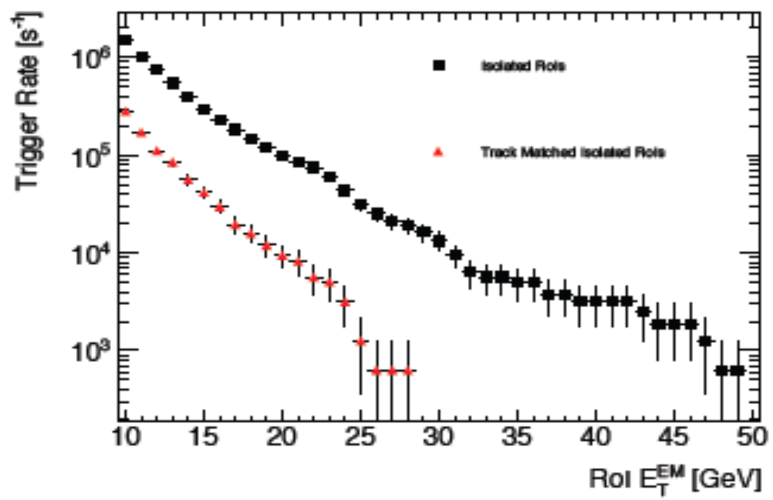
Simulation studies show that including a track trigger complements muon and EM triggers

- Improves muon P_T resolution
- Improves EM identification by matching to track

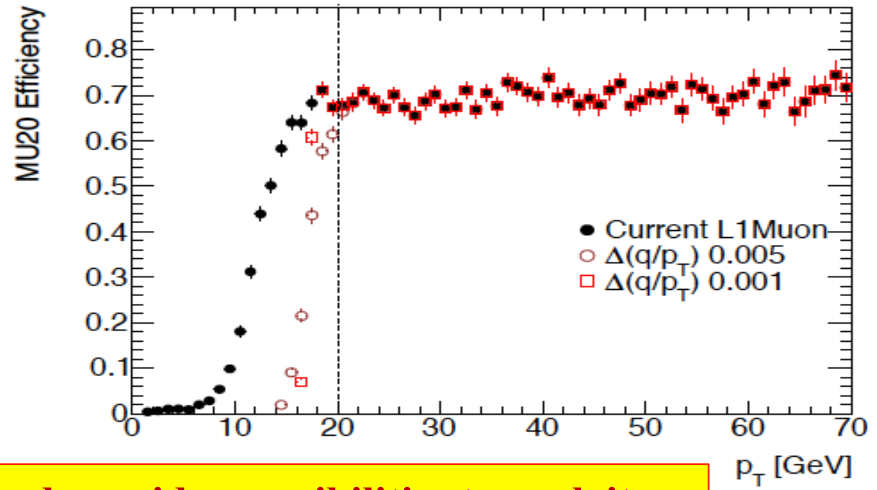
Implemented as 2-level scheme to accommodate legacy electronics and reduce links from strip tracker → reuses Phase-I L1 trigger improvements for new L0



LOA scheme and buffering fully integrated in ABCn130 ASIC



FTK technology could be used to perform fast track fit in L0 defined Region of Interest (RoI)



Note this scheme impacts the electronics in all systems and provides possibilities to exploit the L0/L1 structure to have more extensive information from all sub-detectors at L1

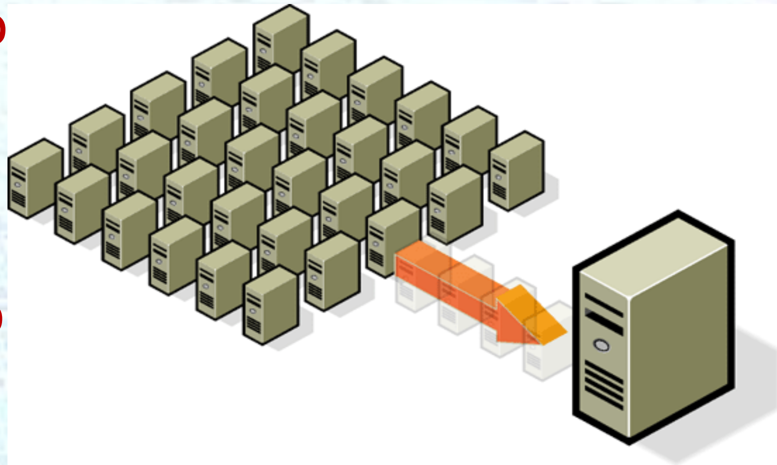
Computing and Software

- Resources needed for computing at HL-LHC are large - but not unprecedented.
  - However, depending on technology assumptions, flat resources can only provide a factor of 2 to 10 times less CPU power than needed
    - Cloud federation may be a way to build the next Grid
    - Possible usage of specialized track processing (eg GPUs as used by ALICE HLT)
    - Multi-core processors will need major software developments to minimize computing demands

➢ The use of more specialized hardware to optimize overall costs implies the need for frameworks able to seamlessly adapt and use much more heterogeneous computing resources

➢ CERN WLCG provides a possible framework for development of future so

➢ All LHC experiments could benefit from better coordinated efforts to develop new programming techniques



Virtualization is the key technology behind the Cloud

CERN-Council-S/106
Original: English
7 May 2013

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE

CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken | *Voting Procedure*

For Approval	**EUROPEAN STRATEGY SESSION OF COUNCIL** 16th Session - 30 May 2013 **European Commission** **Berlaymont Building - Brussels**	Simple Majority of Member States represented and voting

The European Strategy for Particle Physics Update 2013

Having finalised its text by consensus at its Session of 22 March 2013, the Council is now invited to formally adopt the Update of the European Strategy for Particle Physics set out in this document.

1

Higgs working group report

Conveners: Sally Dawson (BNL), Andrei Gritsan (Johns Hopkins), Heather Logan (Carleton), Jianming Qian (Michigan), Chris Tully (Princeton), Rick Van Kooten (Indiana)

Authors: A. Ajaib, A. Anastassov, I. Anderson, O. Bake, V. Barger, T. Barklow, B. Batell, M. Battaglia, S. Berge, A. Blondel, S. Bolognesi, J. Brau, E.Brownson, M. Cahill-Rowley, C. Calancha-Paredes, C.-Y. Chen, W. Chou, R. Clare, D. Cline, N. Craig, K. Cranmer, M. de Gruttola, A. Elagin, R. Essig, L. Everett, E. Feng, K. Fujii, J. Gainer, Y. Gao, I. Gogoladze, S. Gori, R. Goncalo, N. Graf, C. Grojean, S. Guindon, T. Han, G. Hanson, R. Harnik, B. Heinemann, S. Heinemeyer, U. Heintz, J. Hewett, Y. Ilchenko, A. Ismail, V. Jain, P. Janot, S. Kawada, R. Kehoe, M. Klute, A. Kotwal, K. Krueger, G. Kukartsev, K. Kumar, J. Kunkle, I. Lewis, Y. Li, L. Linssen, E. Lipeles, R. Lipton, T. Liss, J. List, T. Liu, Z. Liu, I. Low, T. Ma, P. Mackenzie, B. Mellado, K. Melnikov, G. Moortgat-Pick, G. Mourou, M. Narain, J. Nielsen, N. Okada, H. Okawa, J. Olsen, P. Onyisi, N. Parashar, M. Peskin, F. Petriello, T. Plehn, C. Pollard, C. Potter, K. Prokofiev, M. Rauch, T. Rizzo, T. Robens, V. Rodriguez, P. Roloff, R. Ruiz, V. Sanz, J. Sayre, Q. Shafi, G. Shaughnessy, M. Sher, F. Simon, N. Solyak, J. Stupak, S. Su, T. Tanabe, T. Tajima, V. Telnov, J. Tian, S. Thomas, M. Thomson, C. Un, M. Velasco, C. Wagner, S. Wang, A. Whitbeck, W. Yao, H. Yokoya, S. Zenz, D. Zerwas, Y. Zhang, Y. Zhou

arxiv.org/pdf/1310.8361v1

Snowmass 2013

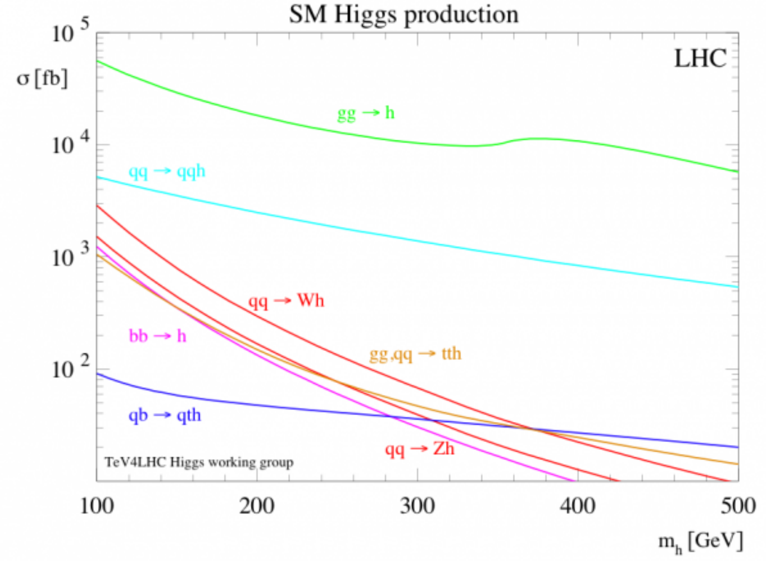
Abstract

This report summarizes the work of the Energy Frontier Higgs Boson working group of the 2013 Community Summer Study (Snowmass). We identify the key elements of a precision Higgs physics program and document the physics potential of future experimental facilities as elucidated during the Snowmass study. We study Higgs couplings to gauge boson and fermion pairs, double Higgs production for the Higgs self-coupling, its quantum numbers and *CP*-mixing in Higgs couplings, the Higgs mass and total width, and prospects for direct searches for additional Higgs bosons in extensions of the Standard Model. Our report includes projections of measurement capabilities from detailed studies of the Compact Linear Collider (CLIC), a Gamma-Gamma Collider, the International Linear Collider (ILC), the Large Hadron Collider High-Luminosity Upgrade (HL-LHC), Very Large Hadron Colliders up to 100 TeV (VLHC), a Muon Collider, and a Triple-Large Electron Positron Collider (TLEP).

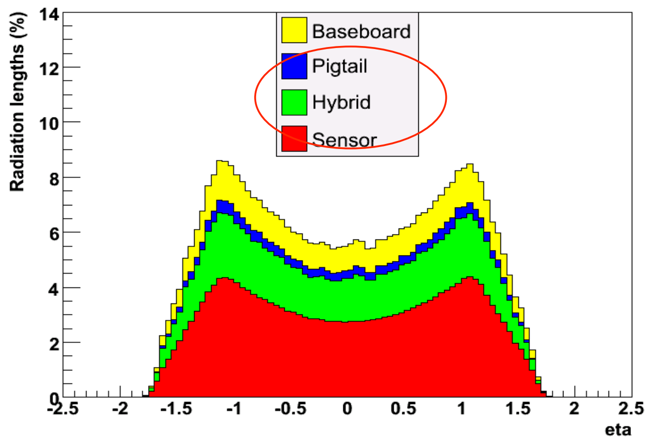
P5 Report May 2014 at http://science.energy.gov/hep/hepap/reports/ . Section 2.2 is particularly relevant. "Recommendation 10: Complete the LHC phase-1 upgrades and continue the strong collaboration in the LHC with the phase-2 (HL-LHC) upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS). The LHC upgrades constitute our highest-priority near-term large project."

Table 1-15. *Dominant Higgs boson production cross sections at various e^+e^- collision energies. Cross sections are calculated [74] including initial-state radiation, but not beamstrahlung effects, for unpolarized beams and the enhancement due to polarized beams ($P(e^-, e^+) = (-0.8, 0.3)$ for 250, 350, and 500 GeV, baseline for the ILC; $(-0.8, 0.2)$ for 1000 GeV, baseline for the ILC; $(-0.8, 0.0)$ for 1.4 and 3.0 TeV, typical for CLIC.)*

Cross sections in fb $m_H = 125$ GeV							
Mode	$\sqrt{s}$ (GeV) =	250	350	500	1000	1400	3000
ZH	unpolar.	211	134	64.5	16.1	8.48	2.00
	polar.	318	198	95.5	22.3	10.0	2.37
$\nu_e\bar{\nu}_e H$	unpolar.	20.8	34.1	71.5	195	278	448
	polar.	36.6	72.5	163	425	496	862
e^+e^-H	unpolar.	7.68	7.36	8.86	20.1	27.3	48.9
	polar.	11.2	10.4	11.7	24.7	32.9	56.5



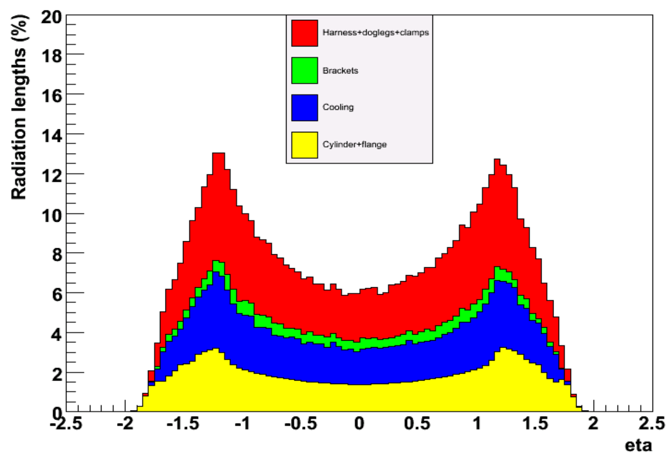
Current Silicon Microstrip (SCT) Material



Current Silicon Tracker
(4 barrel strip layers)

Module Material

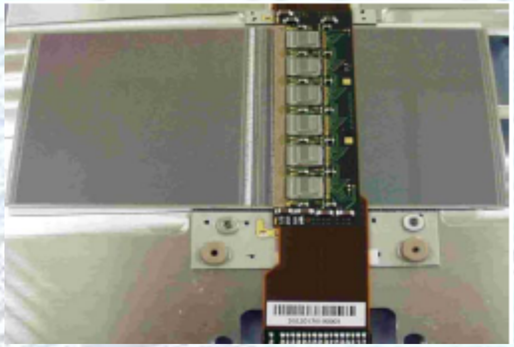
Support Material



Old ATLAS Barrel Module

12 ASIC of 300µm thickness for double-sided module read-out

(*ie* just 6 read-out chips per side)



"The barrel modules of the ATLAS semiconductor tracker". Nucl.Instrum.Meth.A568:642-671,2006.

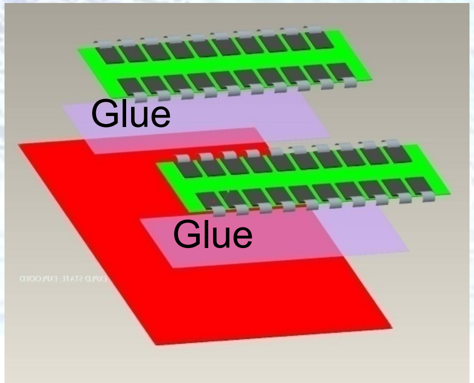
Table 1
Radiation lengths and weights estimated for the SCT barrel module

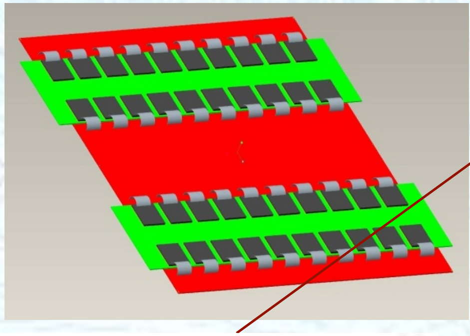
Component	Radiation length [%Xo]	Weight [gr]	Fraction [%]
Silicon sensors and adhesives	0.612	10.9	44
Baseboard and BeO facings	0.194	6.7	27
ASIC's and adhesives	0.063	1.0	4
Cu/Polyimide/CC hybrid	0.221	4.7	19
Surface mount components	0.076	1.6	6
Total	1.17	24.9	100

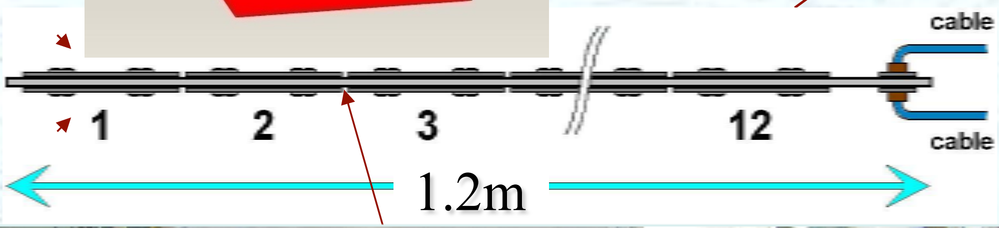
New ATLAS sLHC-Tracker Module will have 80 ASICs in two hybrid fingers for just one-sided read-out

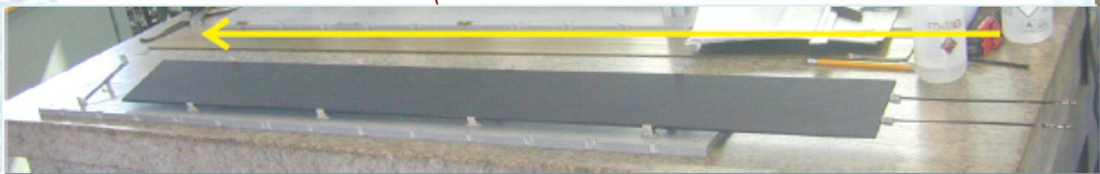
Hybrid area per module roughly ×2 at HL-LHC: much higher R/O granularity

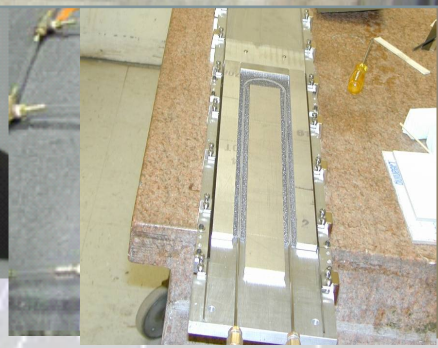
Stave: Hybrids glued to Sensors glued to Bus Tape glued to Cooling Substrate

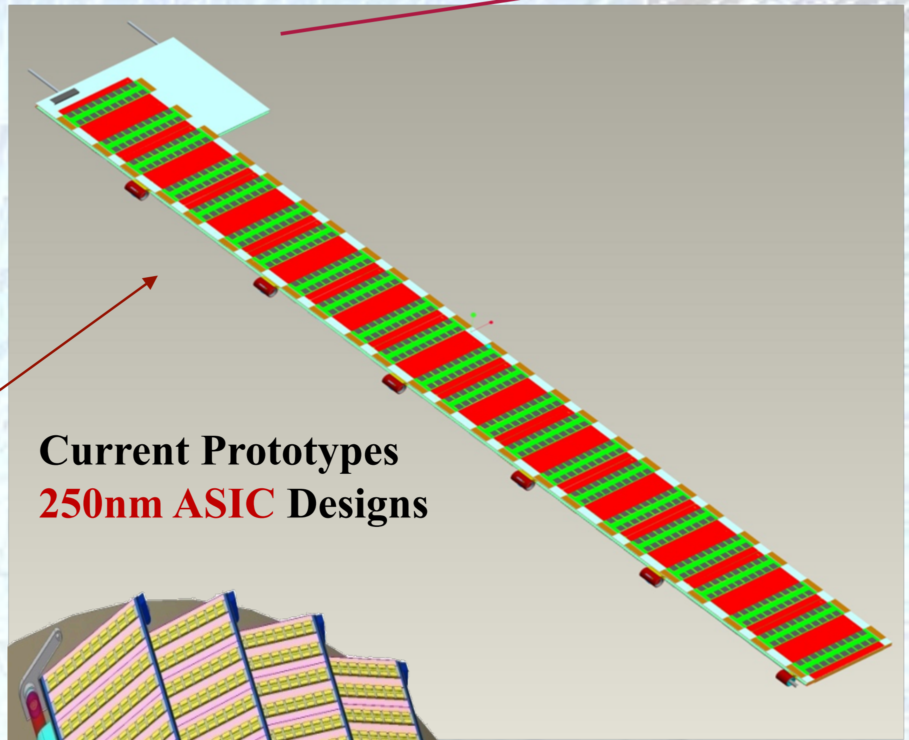




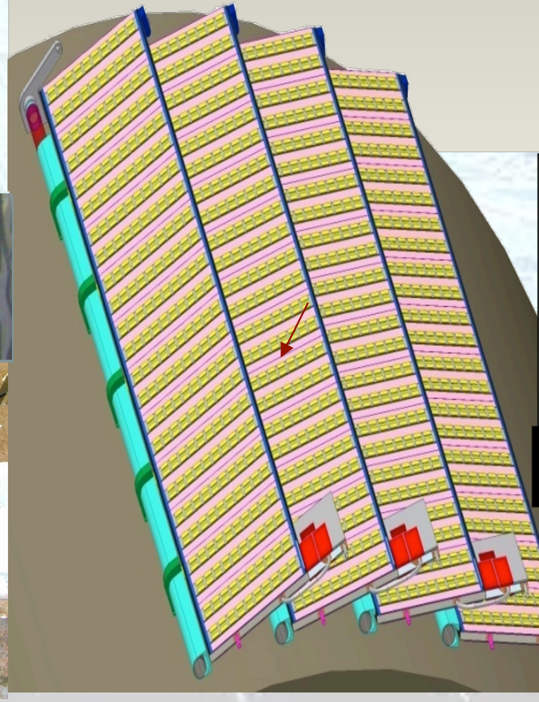


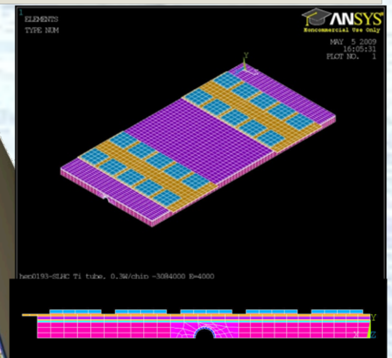


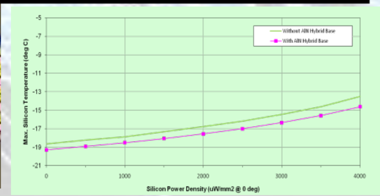




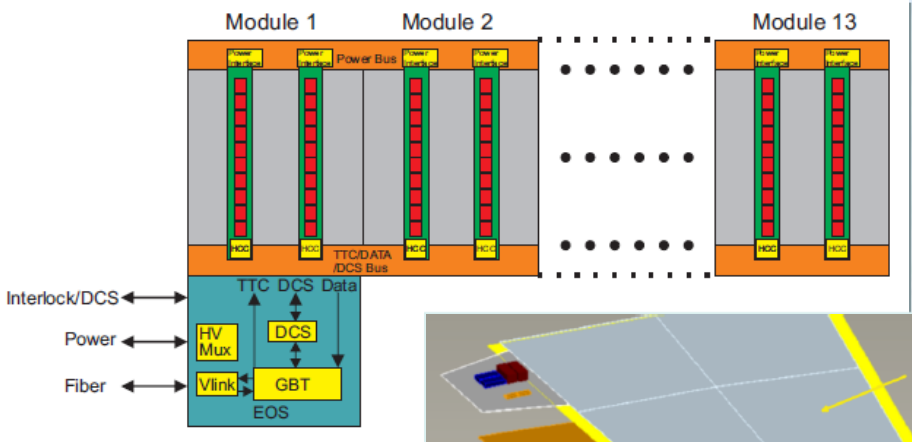
Current Prototypes
250nm ASIC Designs

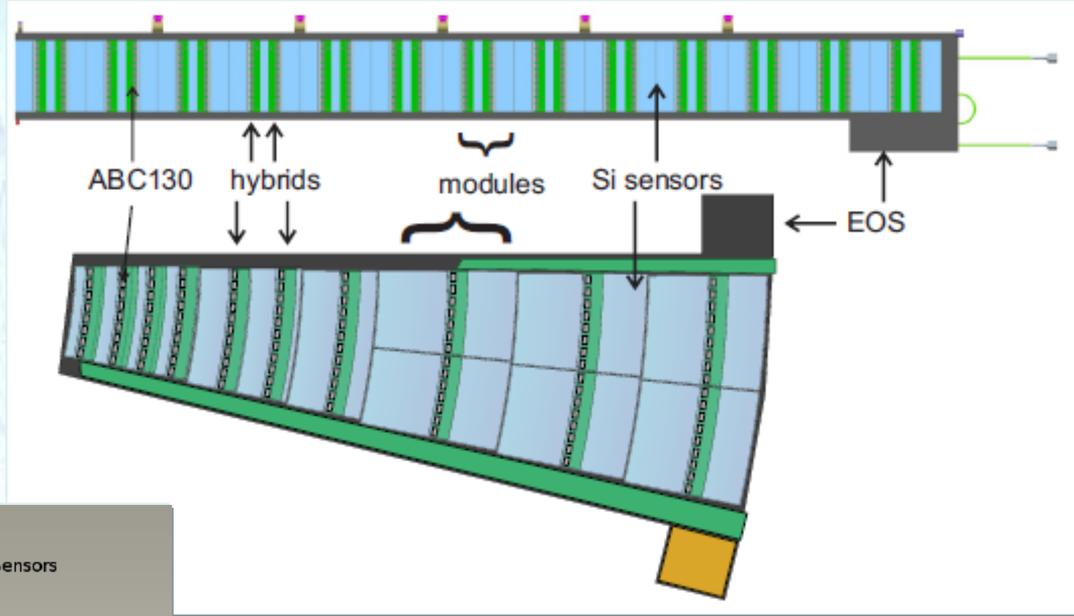




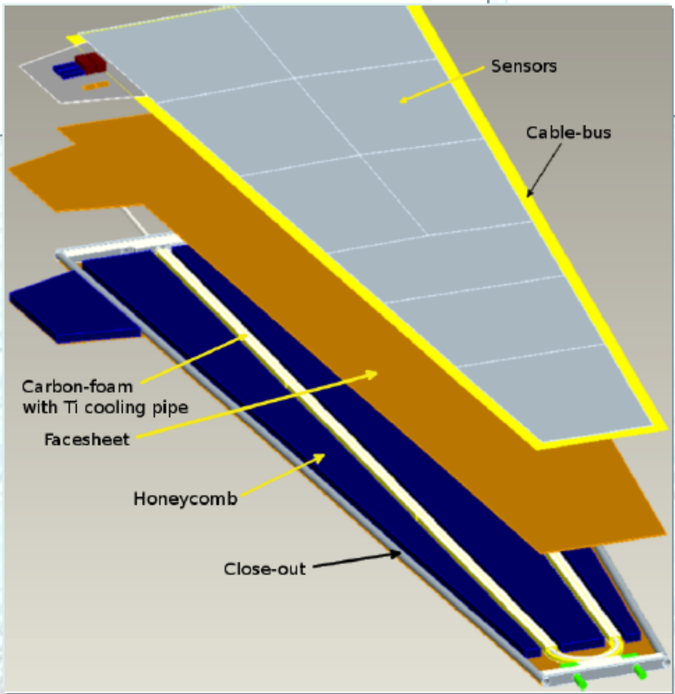


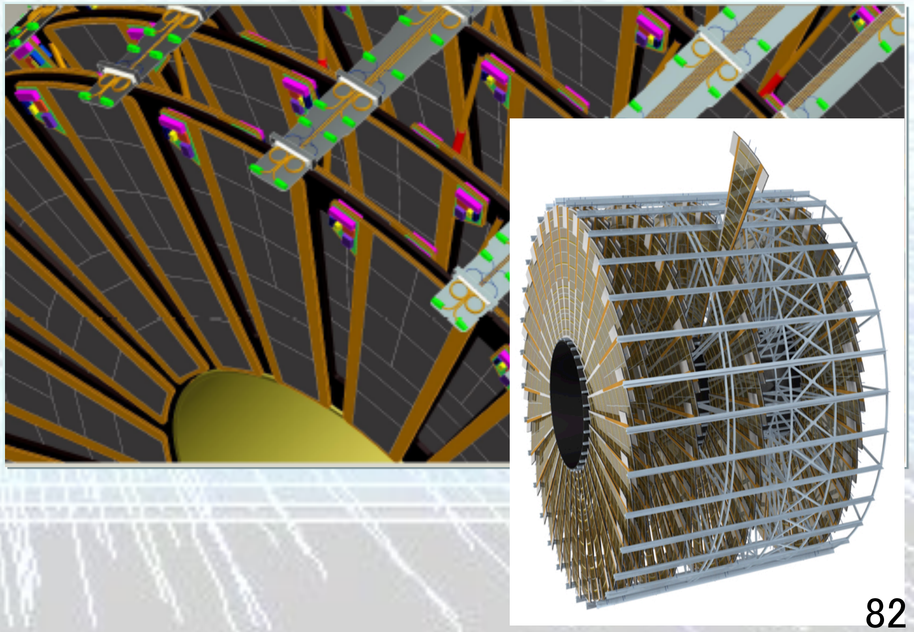
Stave: Hybrids glued to Sensors glued to Bus Tape glued to Cooling Substrate



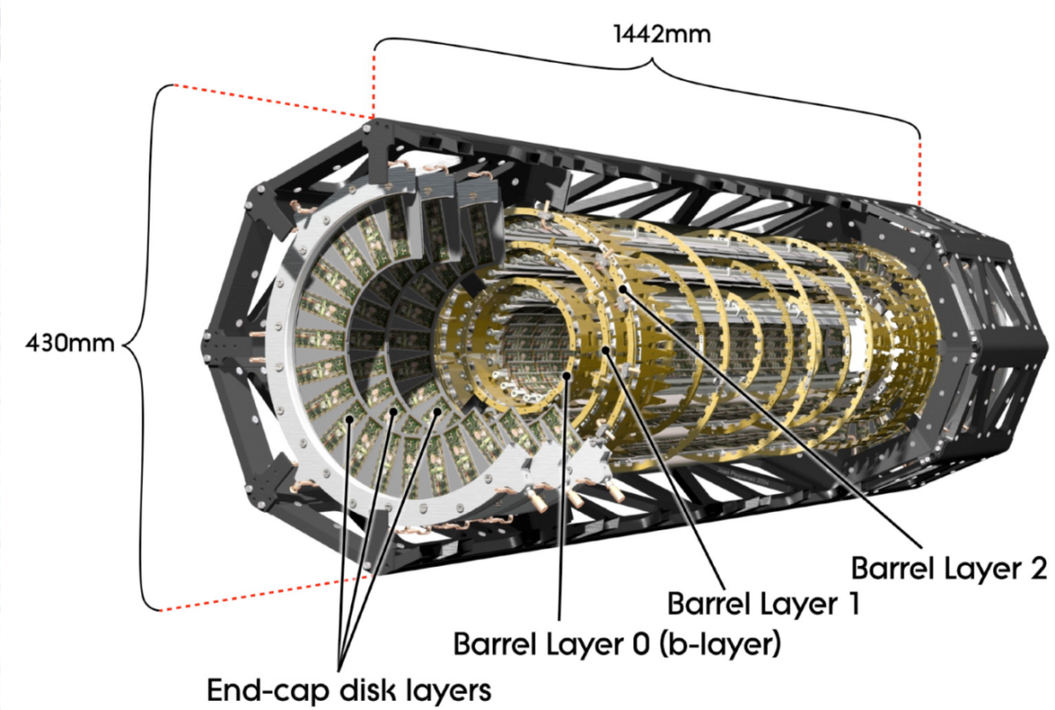


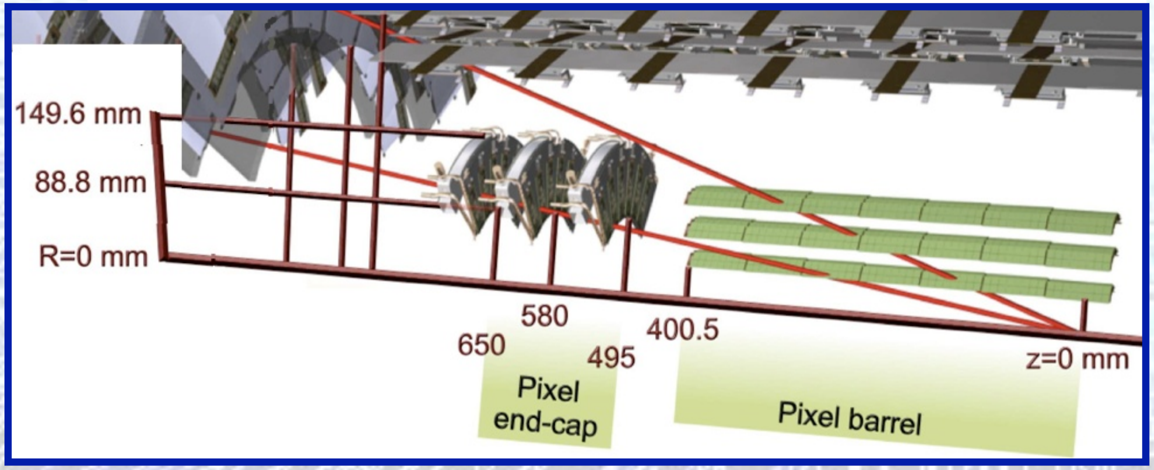
Module, Stave and Petal concepts with 130nm ASIC: 256 channels so each row of ASICs address two rows of strips





The ATLAS Pixel Detector

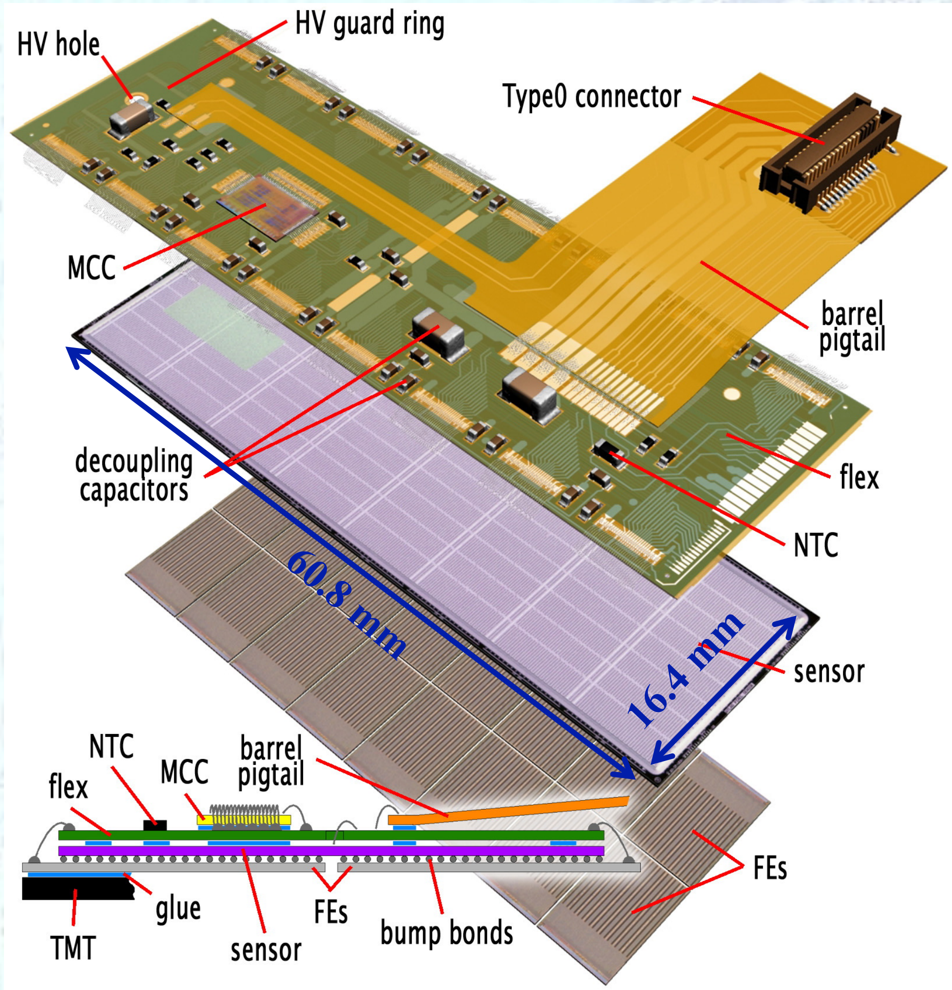




- **Three barrel layers:**
  - R= 5 cm (B-Layer),
    9 cm (Layer-1), 12 cm (Layer-2)
  - modules tilted by 20º in the Rϕ plane to overcompensate the Lorentz angle.
- **Two endcaps:**
  - three disks each
  - 48 modules/disk
- **Three precise measurement points up to $|\eta|$<2.5:**
  - RΦ resolution:10 μm
  - η (R or z) resolution: 115 μm
- 1456 barrel modules and 288 forward modules, for a total of 80 million channels and a sensitive area of 1.7 m^2.
  - Environmental temperature about -10 ºC
  - 2 T solenoidal magnetic field.

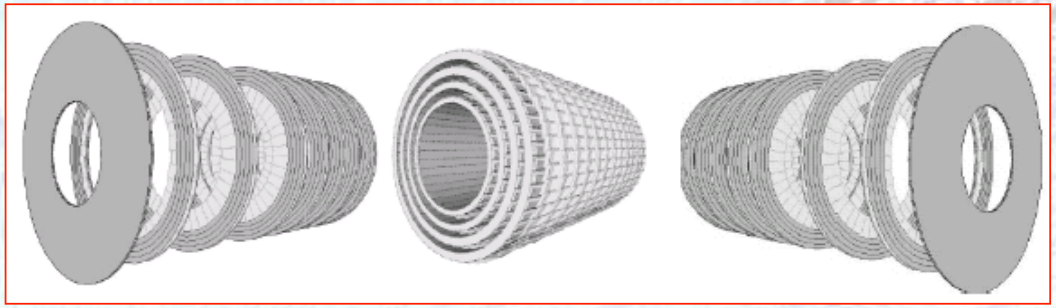
Module Overview

- **Sensor**
  - 47232 n-on-n pixels with moderated p-spray insulation
  - 250 μm thickness
  - 50 μm (RΦ) × 400 μm (η)
  - 328 rows (x_{local}) × 144 columns (y_{local})
- **16 FE chips**
  - bump bonded to sensor
- **Flex Hybrid**
  - passive components
  - Module Controller Chip to perform distribution of commands and event building.
- **Radiation-hard design:**
  - Dose >500 Gy
  - NIEL >10^{15} n_{eq}/cm^2 fluence

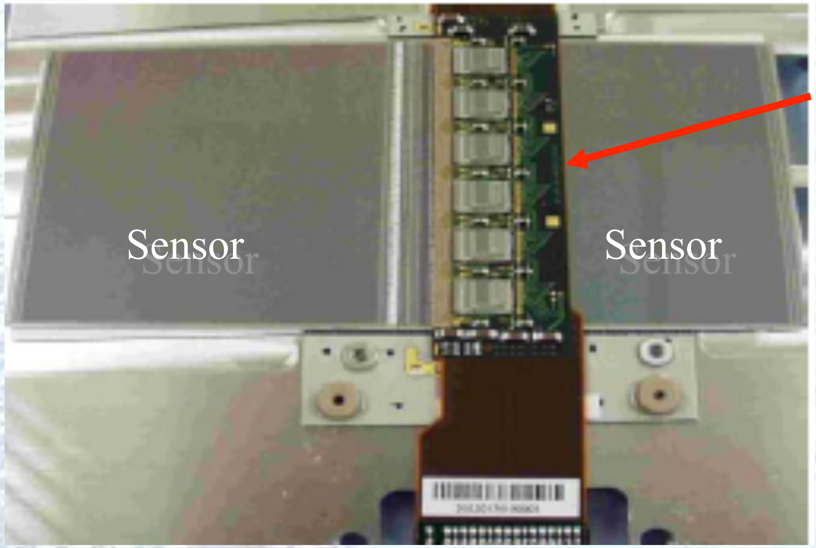


Current SCT ATLAS Module Designs

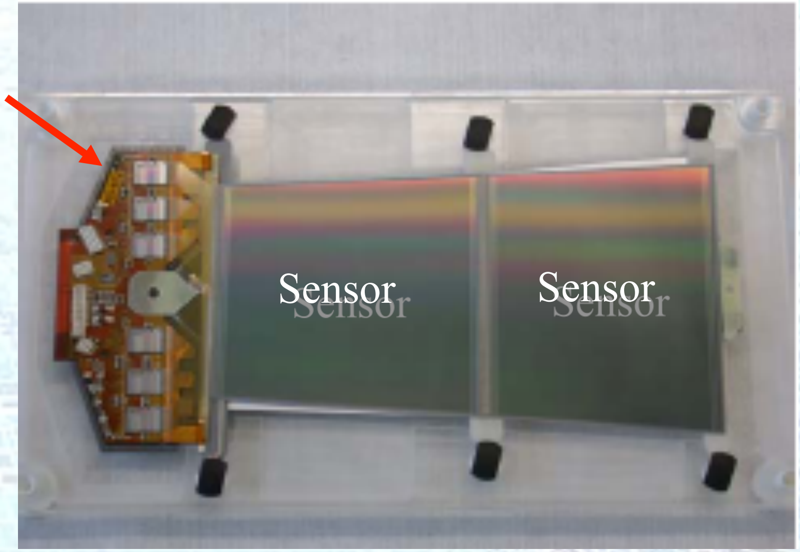
ATLAS Tracker Based on Barrel and Disc Supports



Effectively two styles of double-sided modules (2×6cm long) each sensor ~6cm wide (768 strips of 80μm pitch per side)



Hybrid cards carrying read-out chips and multilayer interconnect circuit

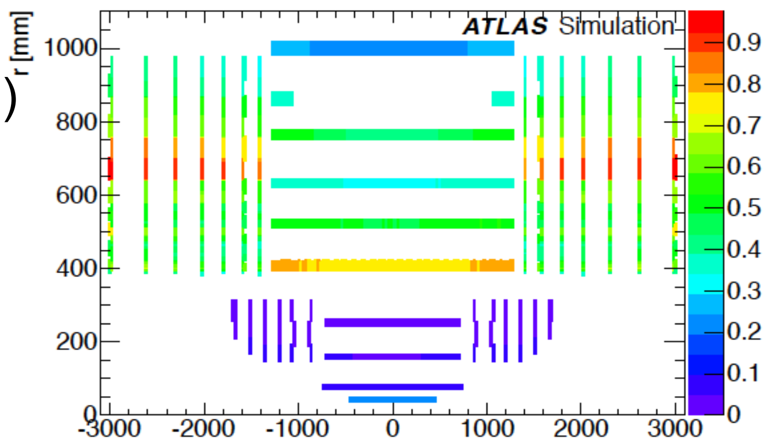


Barrel Modules (Hybrid bridge above sensors)

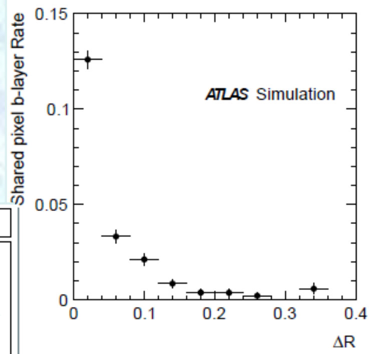
Forward Modules (Hybrid at module end)

Baseline Tracker Performance

- New Inner Detector Improved granularity
  (Smaller pixels and 2.45cm and 4.9cm strips (74.5μm pitch)
  - ➢ Improved radiation hardness
  - ➢ Reduced material
  - ➢ Extended forward coverage
  - ➢ Robust tracking (14 layers)

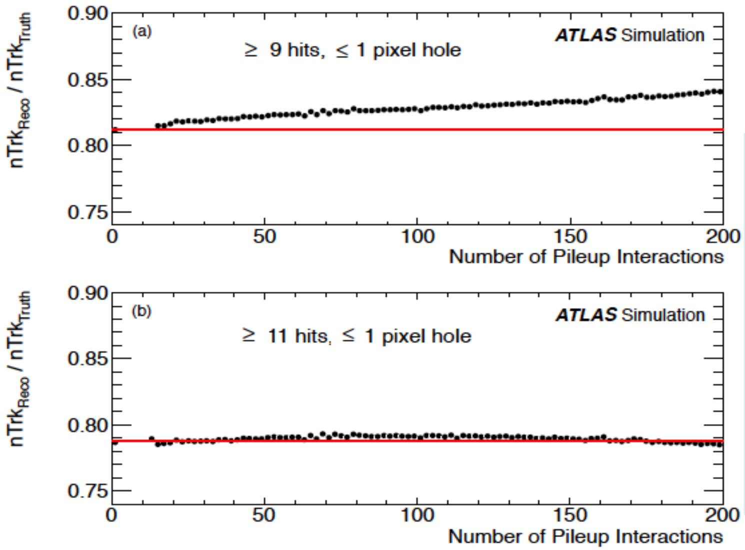


Occupancy for <μ>=200 (in %)

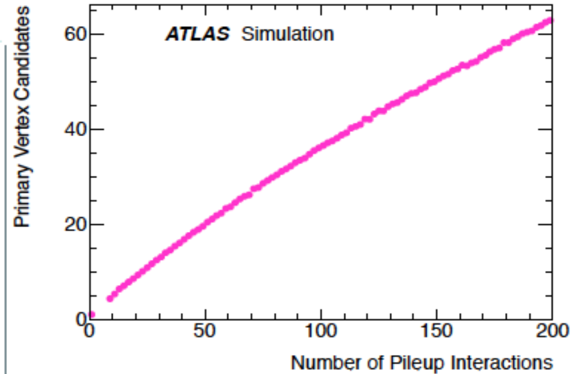


parameter	layer 1	layer 2	layers 3 + 4	disks
chips (ϕ x z)	FE-5 2x1	FE-5 2x2	FE-I4 2x2	FE-I4 2x3
pixel size (μm^2)	25 x 150	25 x 150	50x 250	50x 250
nb of pixels in ϕ	672	1348 +12 ganged	672 + 6 ganged	672 + 6 ganged
nb. of double columns in z	68	68	40	60
length of sensor at gap (μm)	300	300	450	450
distance to module edge (μm)	150	150	500	500
distance active to cut edge (μm)	100	100	100	100
active size (mm^2)	16.8 x 41.1	34.0 x 41.1	33.9 x 40.4	33.9x60.8
physical size (mm^2)	18.8 x 41.3	38.0 x 41.3	38.0 x 41.1	38.0x61.3
power (W)	0.9	1.8	1.8	2.7

Track parameter $\lvert\eta\rvert < 0.5$	Existing ID with IBL no pile-up $\sigma_x(\infty)$	Phase-II tracker 200 events pile-up $\sigma_x(\infty)$
Inverse transverse momentum (q/p_T) [/TeV]	0.3	0.2
Transverse impact parameter (d_0) [μm]	8	8
Longitudinal impact parameter (z_0) [μm]	65	50



Detector:	Silicon area [m^2]	Channels [10^6]
Pixel barrel	5.1	445
Pixel end-cap	3.1	193
Pixel total	**8.2**	**638**
Strip barrel	122	47
Strip end-cap	71	27
Strip total	**193**	**74**



Future Upgrade Planning

Phase-II Upgrade

(LS3)

Starts End 2022

Parameter	25ns
N_b	2.2E+11
n_b	2808
N_{tot}	6.2E+14
beam current [A]	1.11
x-ing angle [μrad]	590
beam separation [σ]	12.5
β^* [m]	0.15
ε_n [μm]	2.50
ε_L [eVs]	2.51
energy spread	1.20E-04
bunch length [m]	7.50E-02
IBS horizontal [h]	18.5
IBS longitudinal [h]	20.4
Piwinski parameter	3.12
Reduction factor 'R1*H1' at full crossing angle (no crabbing)	0.306
Reduction factor 'H0' at zero crossing angle (full crabbing)	0.905
beam-beam / IP without Crab Cavity	3.3E-03
beam-beam / IP with Crab cavity	1.1E-02
Peak Luminosity without levelling [cm^{-2} s^{-1}]	7.4E+34
Virtual Luminosity: Lpeak*H0/R1/H1 [cm^{-2} s^{-1}]	21.9E+34
Events / crossing without levelling	210
Levelled Luminosity [cm^{-2} s^{-1}]	5E+34
Events / crossing (with leveling for HL-LHC)	140
Leveling time [h] (assuming no emittance growth)	9.0

(https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=257368)

HL-LHC matrix: equipment, time, cost

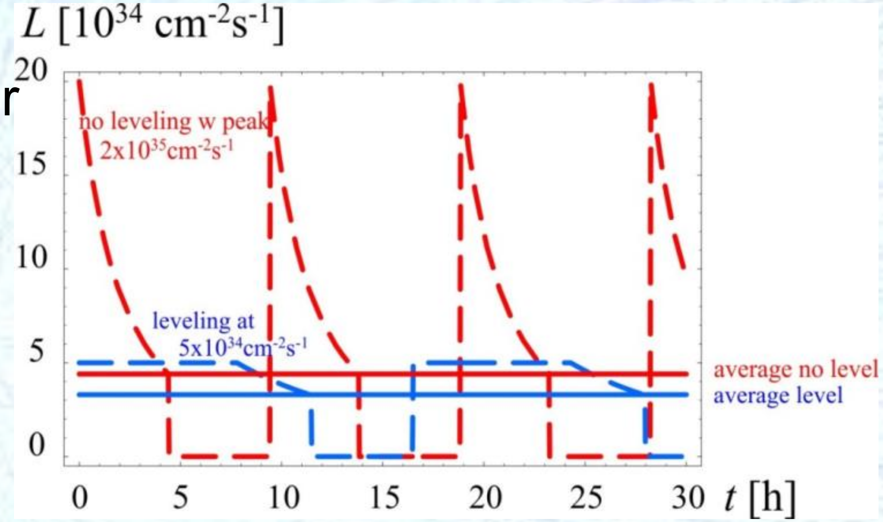
LS2 - 1 y (14 months access)		LS3 - 2 y (26 months access)					
	PIC		US1	US2	Cost (MCHF)		In kind
	LS2	*LS3*	*LS3*	*LS3*			in part
P4 new cryoplant	Y				15		
H SC link P7	Y				5		
IR (IT,D1, TAS)	%	Y			210		YES
P1-P5 cryoplant	%	Y			75		
SC link (EPC&DFBX on surface)	%	Y			40		
Collimators IR		Y			10		
Collimators MoGr	%	Y			15		
Collimators for INJ &TCLA Q4/Q5)		Y			5		
DS cryocoll.(11T) P2	Y				20	395	
LRBB comp.wires			Y		10		
DS cryocoll.(11T) P7			Y		25		
DS cryocoll (11 T) P1-P5			Y		40		
SC link (EPC&DFB on surface) for MS			Y		20	95	
MS new layout (P1-P5) and Q5 in P6				Y	30		YES
Machine & Magnet QPS (Availability)				Y	25		
CC cavity P1-P5				Y	95		YES
SCRF 2nd Harmonic				Y			
Crystal Coll				Y ?			YES ?
Halo control (e-lens)				Y ?			YES
High Band Feedback System				Y ?		150	
Studies					10		
Other systems (Studies, Vacuum,							
Diagnostics, Remote handling					30		
Infrastructure, Logistics,							
Integration,Installation HWC					130	170	
Total					**810**	**810**	

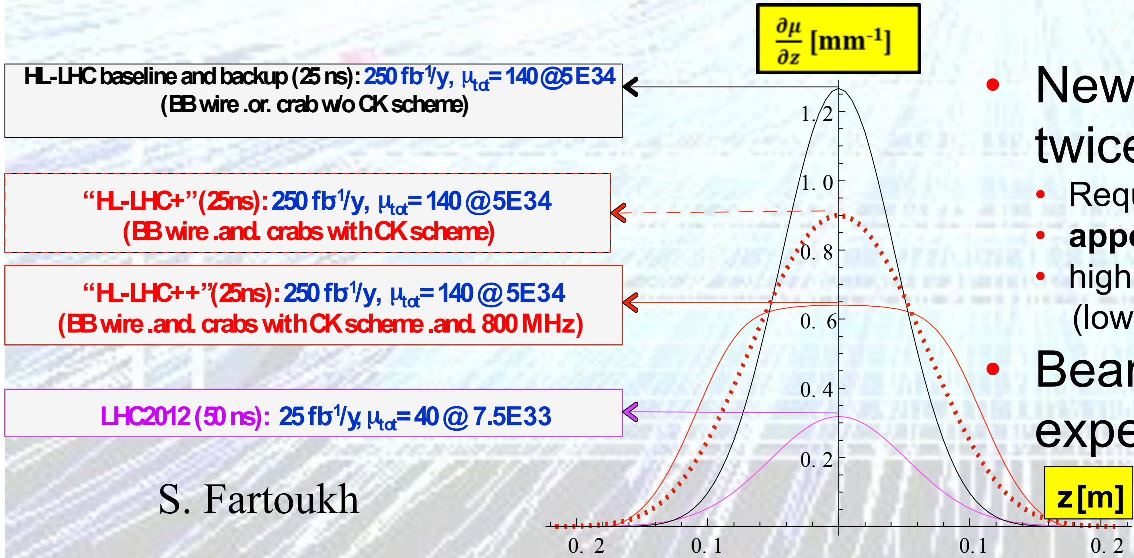
Conclusions

- **The upgrade is robust for 250 (300) fb^{-1}/y**
  - Means to maintain or increase availability are under study
- **All hardware is more robust for 3000 fb^{-1} than it is today for 300 fb^{-1}**
- **Design Study finished by 2015 with the TDR**
- Margins are there and – once established and proved:
  - Possible to decrease pile-up density and/or increase to 350 fb^{-1} ($7 \cdot 10^{34}$ of L_{level}) thanks **to crab kiss (CC in II & ⊥ planes) and β* of 10 cm (large aperture IT & ATS)**
  - **Increase data collection to > 4000 fb^{-1}??**

Interface with Accelerator

- In the context of the 3000fb^{-1} by "around 2030", given that levelling at 5×10^{34} cm^{-2}s^{-1} is based on an effective luminosity of 2×10^{35} cm^{-2}s^{-1}, this raises the question of the ultimate acceptable pile-up (average # collisions each 25ns)
- The "crab-kissing" scheme offers an extended interaction region in z with lower pile-up density (better vertex finding)
- The question arises for mean pile-up, <μ>, = 140 (5×10^{34} cm^{-2}s^{-1}, 25ns); if the vertex density could drop from 1.3/mm to 0.7/mm could <μ> be even higher?



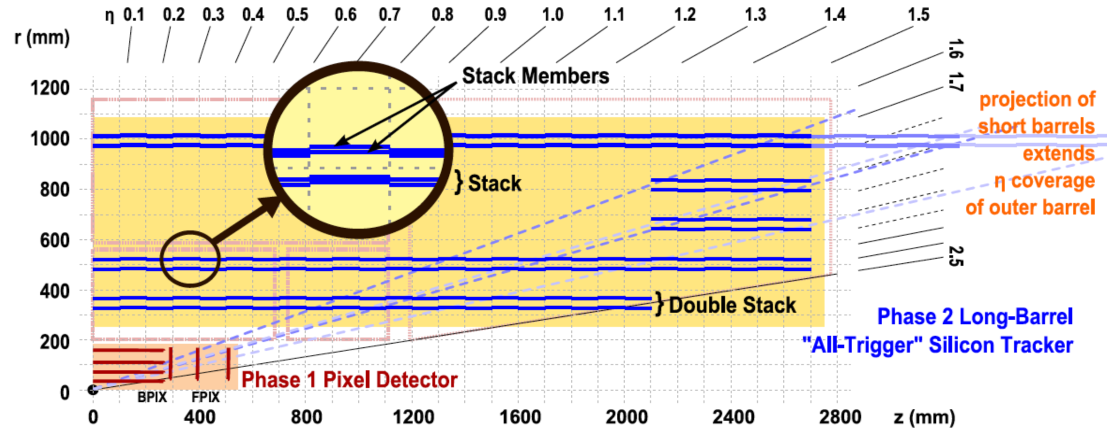


S. Fartoukh

- New Triplets at Interaction Region will have twice present aperture
  - Requires modification of absorbers in the interaction region
  - **appears compatible with small radius beam pipe**
  - highly desirable to anticipate work in LS2 (lower activation - time gained for LS3)
- Beam loss risks (for new crab cavities and experiments)
  - Appear manageable from preliminary studies –
  - More (common) work needed

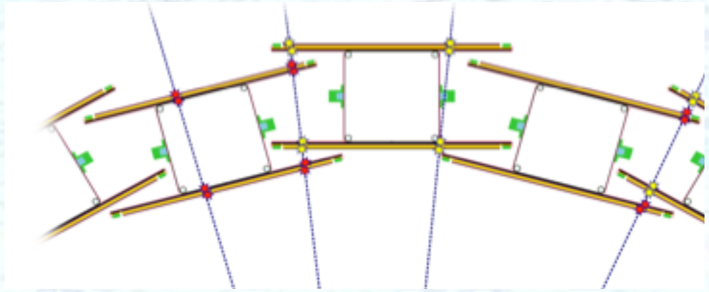
CMS: "Long-Barrel" Double-Stack Concept

- Layout optimized for L1 track finding. Geometry helps to keep problem "local"
- Within double-stack, each lower module is combined with two upper modules to form "Tracklets"
- Tracklets in each "super-layer" are extrapolated to the other two super-layers

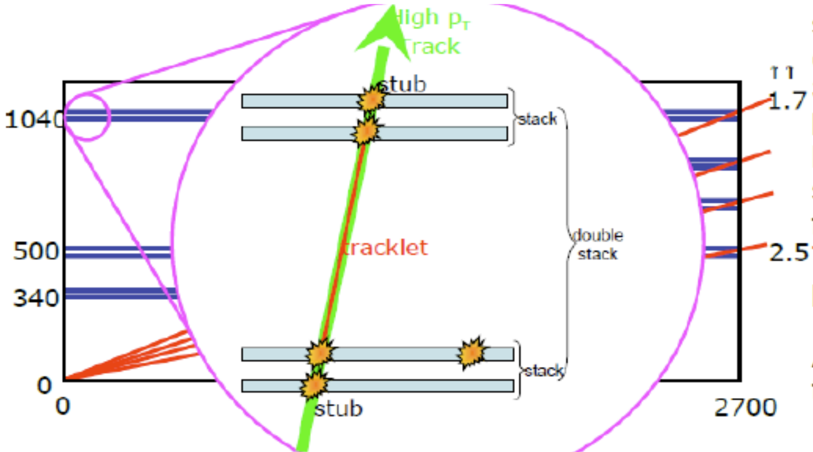


6 long layers = 3 Super layers

ϕ arrangement within double-stack layer

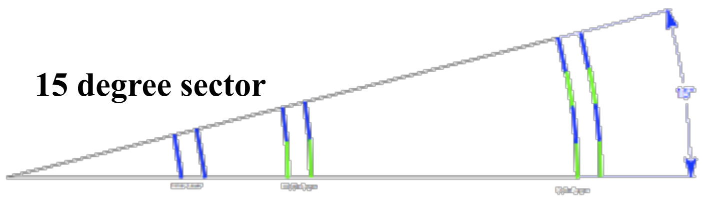


Common supporting mechanics



Pairs of stubs are combined to form "tracklets"

Self-contained ϕ sectors.
Each sector needs to be combined with the two neighbouring sectors (left and right) to "contain" ~2.5 GeV tracks.



CMS: Phase-II Tracker Requirements

- **Radiation hardness**
  - **Ultimate integrated luminosity considered ~ 3000 fb^{-1}**
    - To be compared with original ~ 500 fb^{-1}
- **Resolve up to ~200 collisions per BX, with few % occupancy**
    - Higher granularity
- **Improve tracking performance**
  - **Improve performance @ low p_T ,reduce particle interaction rates**
  - **Reduce material in the tracking volume**
  - **Improve performance @ high p_T**
    - Reduce average pitch
- **Tracker input to Level-1 trigger**
  - **μ, e and jet rates would become unacceptably large at high luminosity**
    - Even considering "phase-1" trigger upgrades
    - Performance of selection algorithms degrades with increasing pile-up
  - **Add tracking information at Level-1**
    - Move part of HLT reconstruction into Level-1!
  - **Objective:**
    - Reconstruct "all" tracks above 2 - 2.5 GeV
    - Identify the origin along the beam axis with ~ 1 mm precision