Review of the EPS'15 Conference

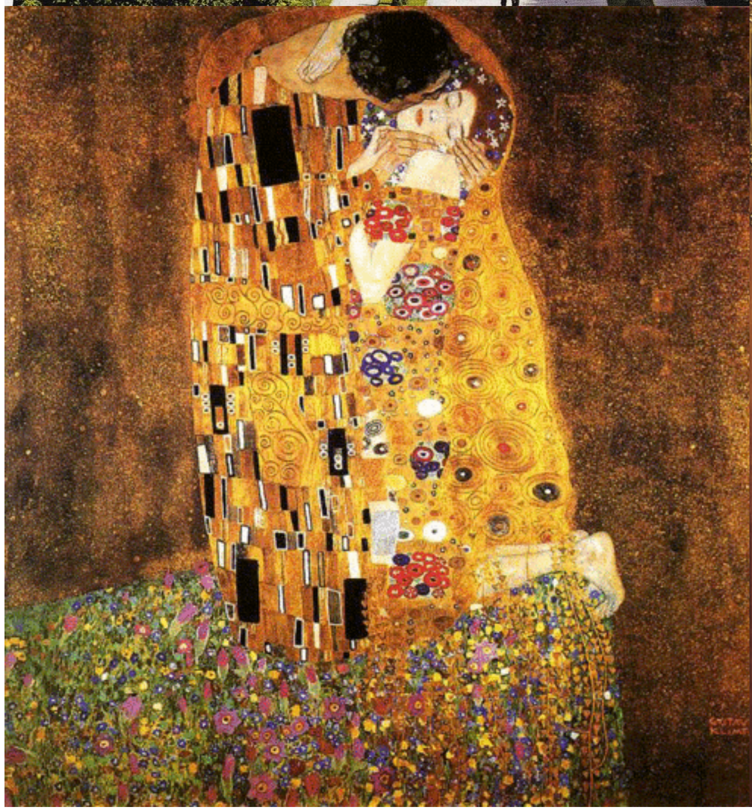
UNIVERSITY OF BIRMINGHAM

Paul Newman, Group Seminar, 14 October 2015

- Almost all material taken from slides in plenary sessions
- PERSONAL SELECTION (with apologies for obvoius bias ...)

Vienna is Nice …

The Belvedere



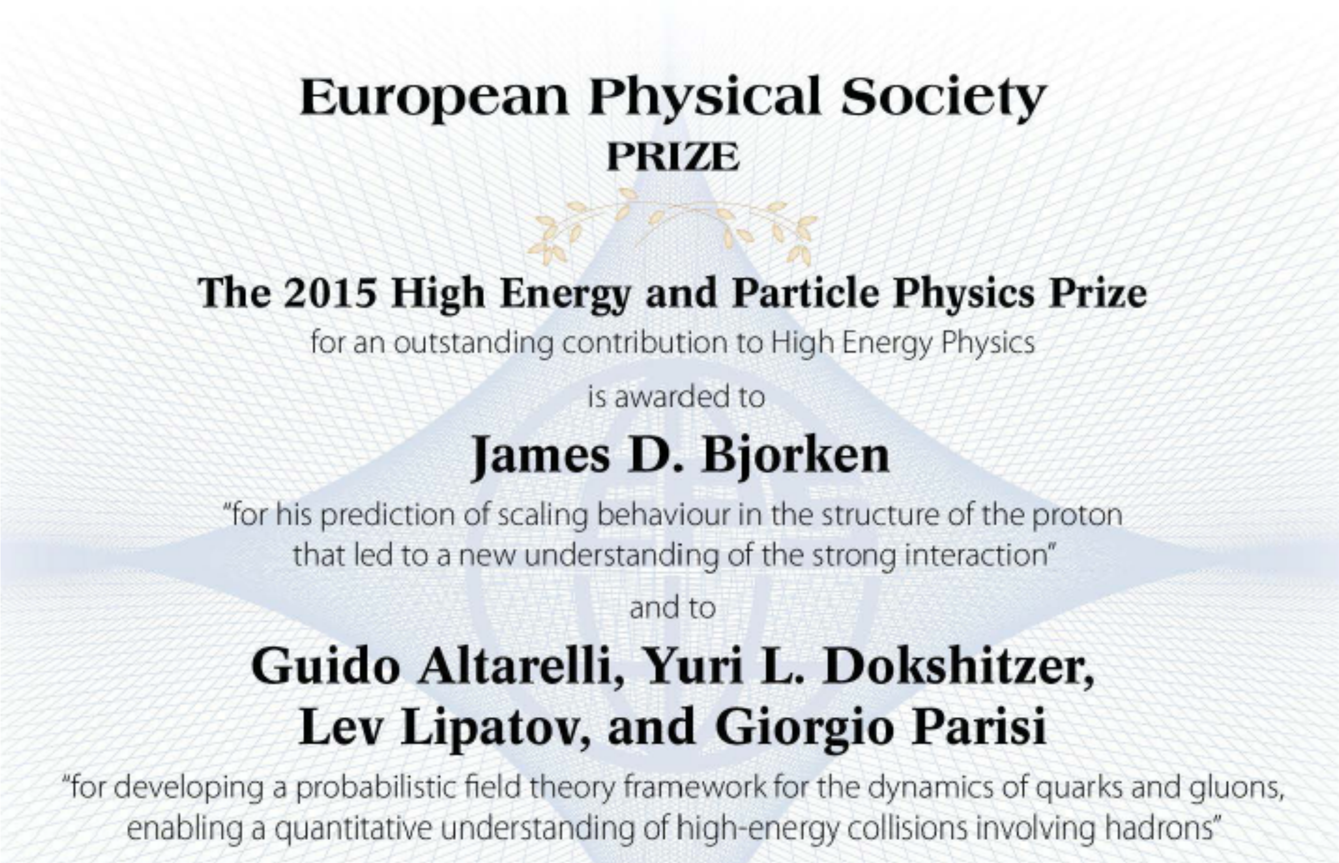
The Conference

Vienna University

“Seven Pillars of Wisdom” on ceiling of Grosse Festsaal

Last of the Culture Slides

Prizes



European Physical Society

PRIZE

The 2015 High Energy and Particle Physics Prize

for an outstanding contribution to High Energy Physics

is awarded to

James D. Bjorken

"for his prediction of scaling behaviour in the structure of the proton that led to a new understanding of the strong interaction"

and to

Guido Altarelli, Yuri L. Dokshitzer, Lev Lipatov, and Giorgio Parisi

"for developing a probabilistic field theory framework for the dynamics of quarks and gluons, enabling a quantitative understanding of high-energy collisions involving hadrons"

Altarelli Acceptance Speech

I was very happy, surprised and grateful when this highly prestigious Prize was announced to me.

I most warmly thank Prof. Lohse (Chair) and all the Members of the EPS - HEPP Board for this great honour

Thomas Lohse (chair)
Yves Sirois (secretary)
Halina Abramowicz (ECFA)
Roger Barlow
Stan Bentvelsen
Thomas Gehrmann
Paula Eerola
Barbara Erazmus
Luis Ibáñez
Karl Jakobs
John Jowett
Elias Kiritsis
Peter Krizan
Mauro Mezzetto
Yosef Nir
Jochen Schieck (HEP2015 LOC)
Igor Tkachev
Zoltan Trocsanyi
Bob van Eijk
Walter Van Doninck
Joao Varela
Claudia-Elisabeth Wulz

The Prize refers to works done some 40 years ago.
Thus, some telegraphic historical introduction is appropriate

Altarelli Acceptance Speech

The evolution equations

a French paper!

ASYMPTOTIC FREEDOM IN PARTON LANGUAGE

G. ALTARELLI *
Laboratoire de Physique Théorique de l'Ecole Normale Supérieure **, *Paris, France*

G. PARISI ***
Institut des Hautes Etudes Scientifiques, Bures-sur-Yvette, France

Received 12 April 1977

$$\frac{dq^i(x,t)}{dt} = \frac{\alpha(t)}{2\pi}\int_x^1 \frac{dy}{y}\left[\sum_j^{2f} q^j(y,t)\, P_{q^iq^j}\!\left(\frac{x}{y}\right) + G(y,t)\, P_{q^iG}\!\left(\frac{x}{y}\right)\right] \tag{22}$$

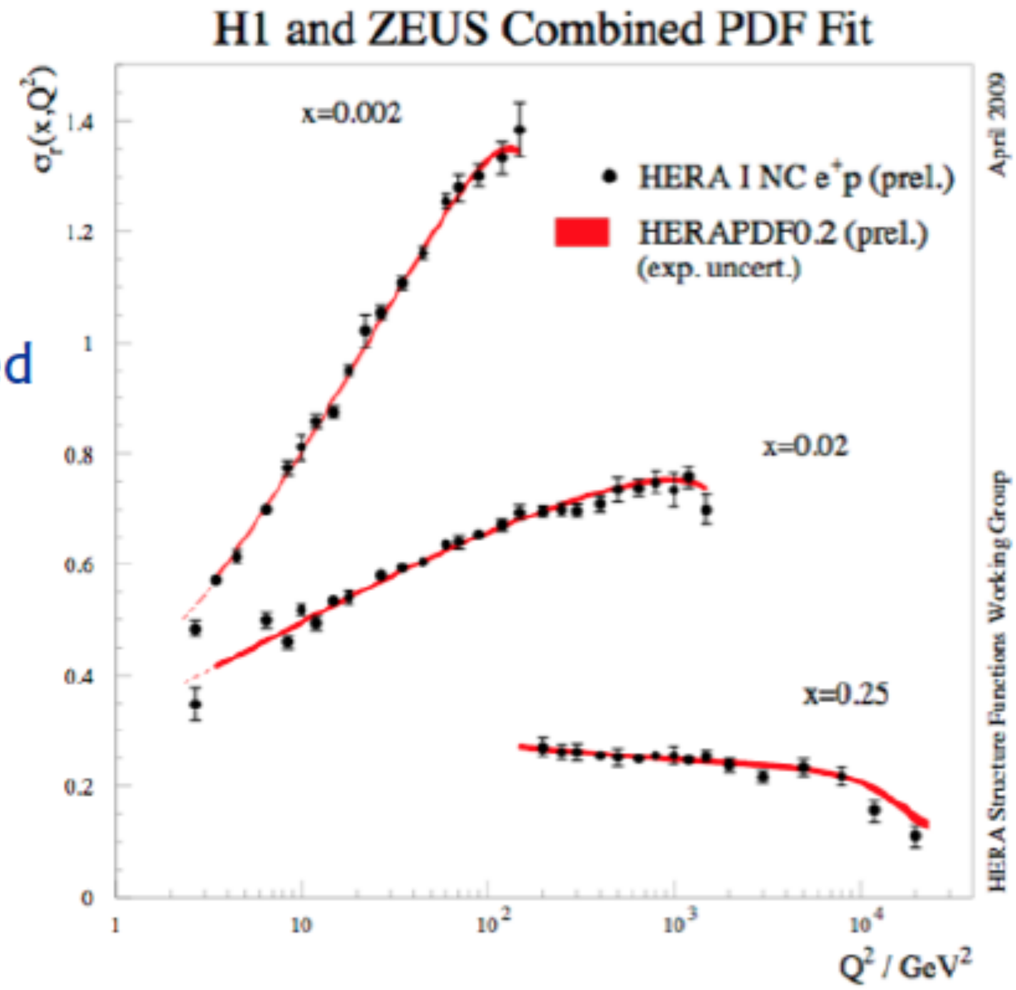
$t = \ln Q^2/\mu^2$

$$\frac{dG(x,t)}{dt} = \frac{\alpha(t)}{2\pi}\int_x^1 \frac{dy}{y}\left[\sum_j^{2f} q^j(y,t)\, P_{Gq^j}\!\left(\frac{x}{y}\right) + G(y,t)\, P_{GG}\!\left(\frac{x}{y}\right)\right] \tag{23}$$

The QCD evolution equations hand-written by me on the '77 preprint

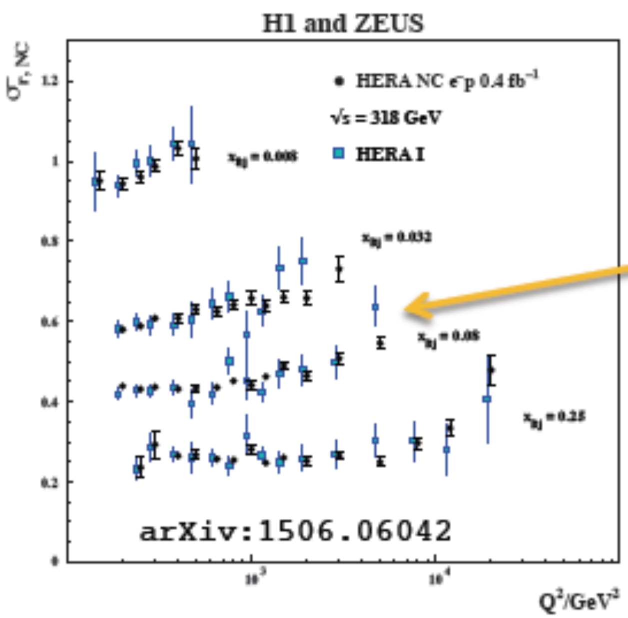
Altarelli Acceptance Speech

This is how the scaling violations are compared with QCD evolution in 2015 after 46 years

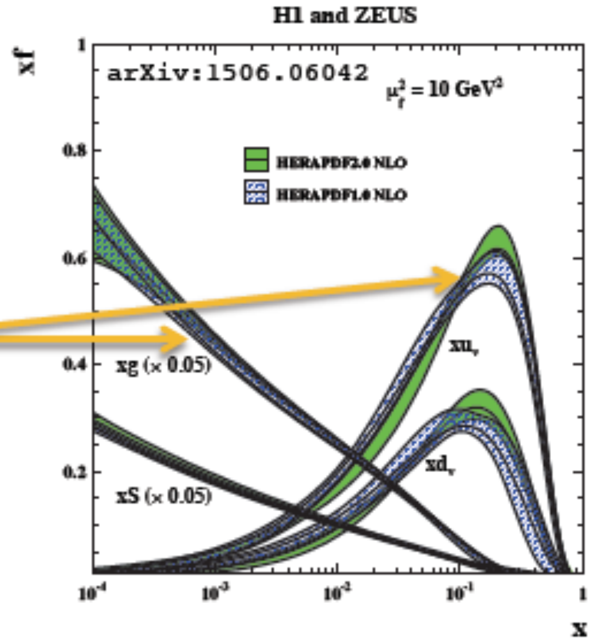


Parton Densities

- HERA provides most important dataset to measure PDF
- HERA II yields significant improvements in precision at high x-Q^2 region
  - Combination of H1 and ZEUS inclusive DIS NC and CC cross-sections in HERA I and II
  - QCD analysis at LO, NLO and NNLO => **HERAPDF2.0**
  - Simultaneous measurement of **gluon-PDF and $\alpha_S(M_Z)$** after inclusion of HERA jet and charm data



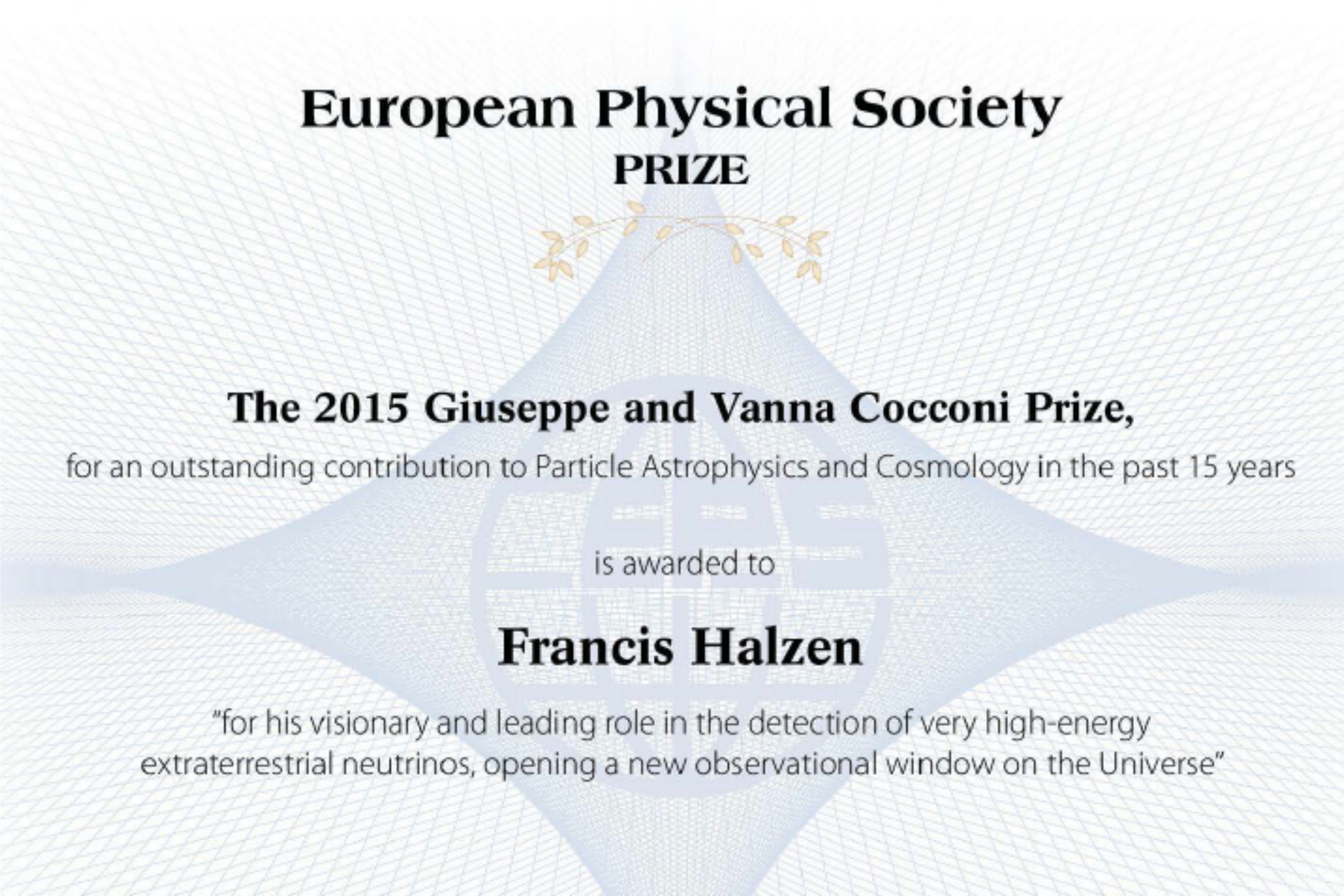
- **Large kinematic range and unprecedented precision (up to few%)**
- **Valence quark and gluon PDF become slightly harder**



Crucial new precision for future

➢ Important input for LHC Run-II predictions => HERA Legacy

Prizes



European Physical Society
PRIZE

The 2015 Giuseppe and Vanna Cocconi Prize,
for an outstanding contribution to Particle Astrophysics and Cosmology in the past 15 years

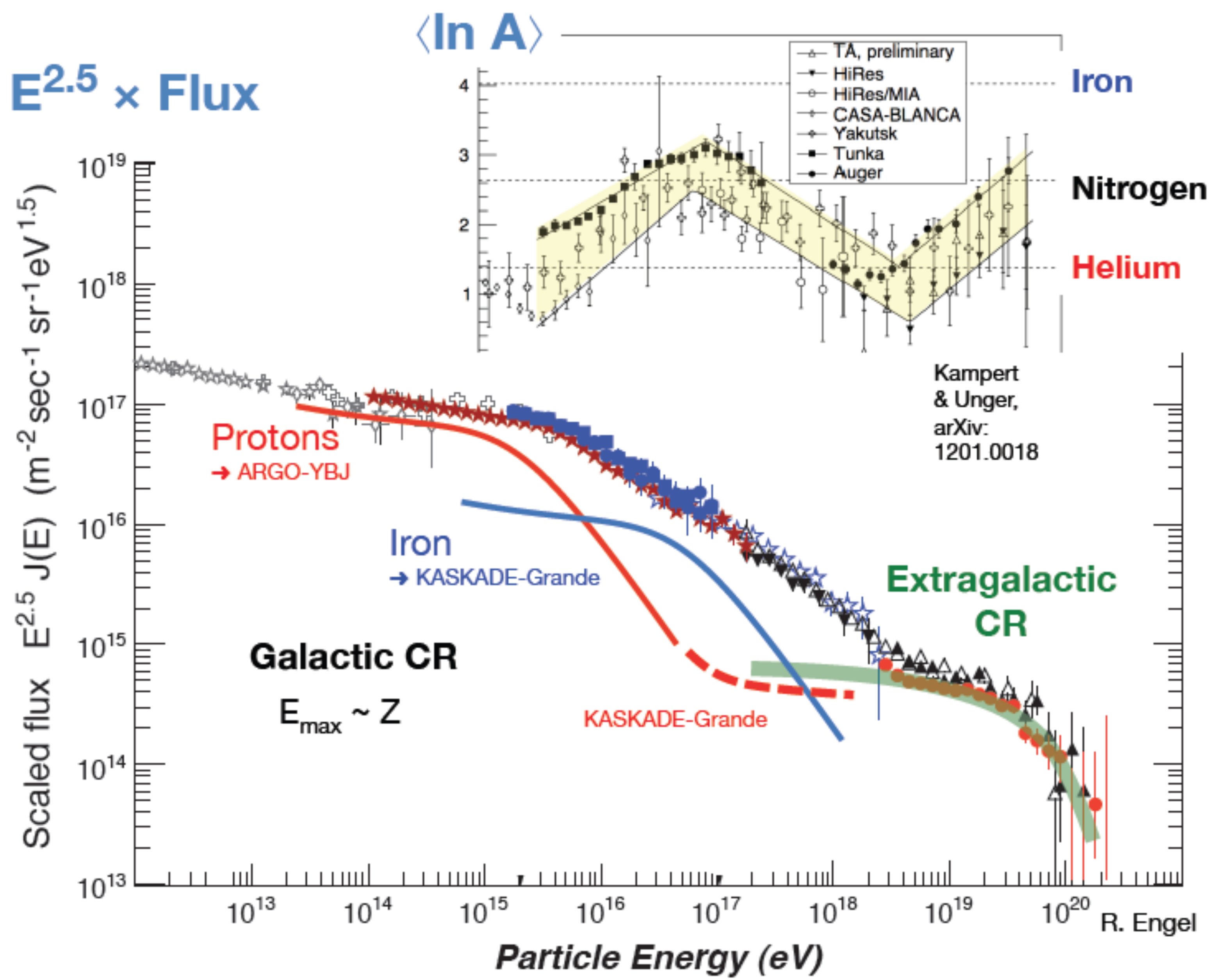
is awarded to

Francis Halzen

"for his visionary and leading role in the detection of very high-energy extraterrestrial neutrinos, opening a new observational window on the Universe"

… a few slides on high energy windows on the universe …

Cosmic Ray Flux (Hofman)



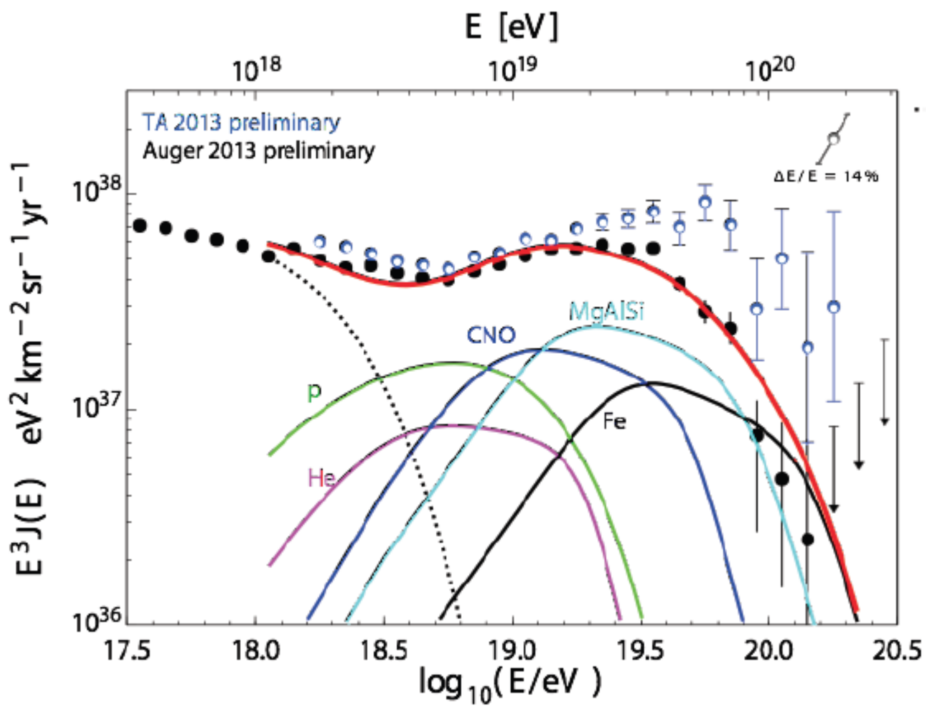
Ultimate Limit to Cosmic Ray Energies?

THE TOP END:
ULTRA HIGH ENERGY COSMIC RAYS

UHECR SPECTRUM: AUGER & TA
ACCELERATORS RUNNING OUT OF STEAM?

Auger:
Argentina, **-35º South**
3000 km² with 1600 SD
4 FD stations
~ 10 years of data

Telescope Array:
Utah, **39º North**
700 km² with 507 SD
3 FD stations
~ 6 years of data

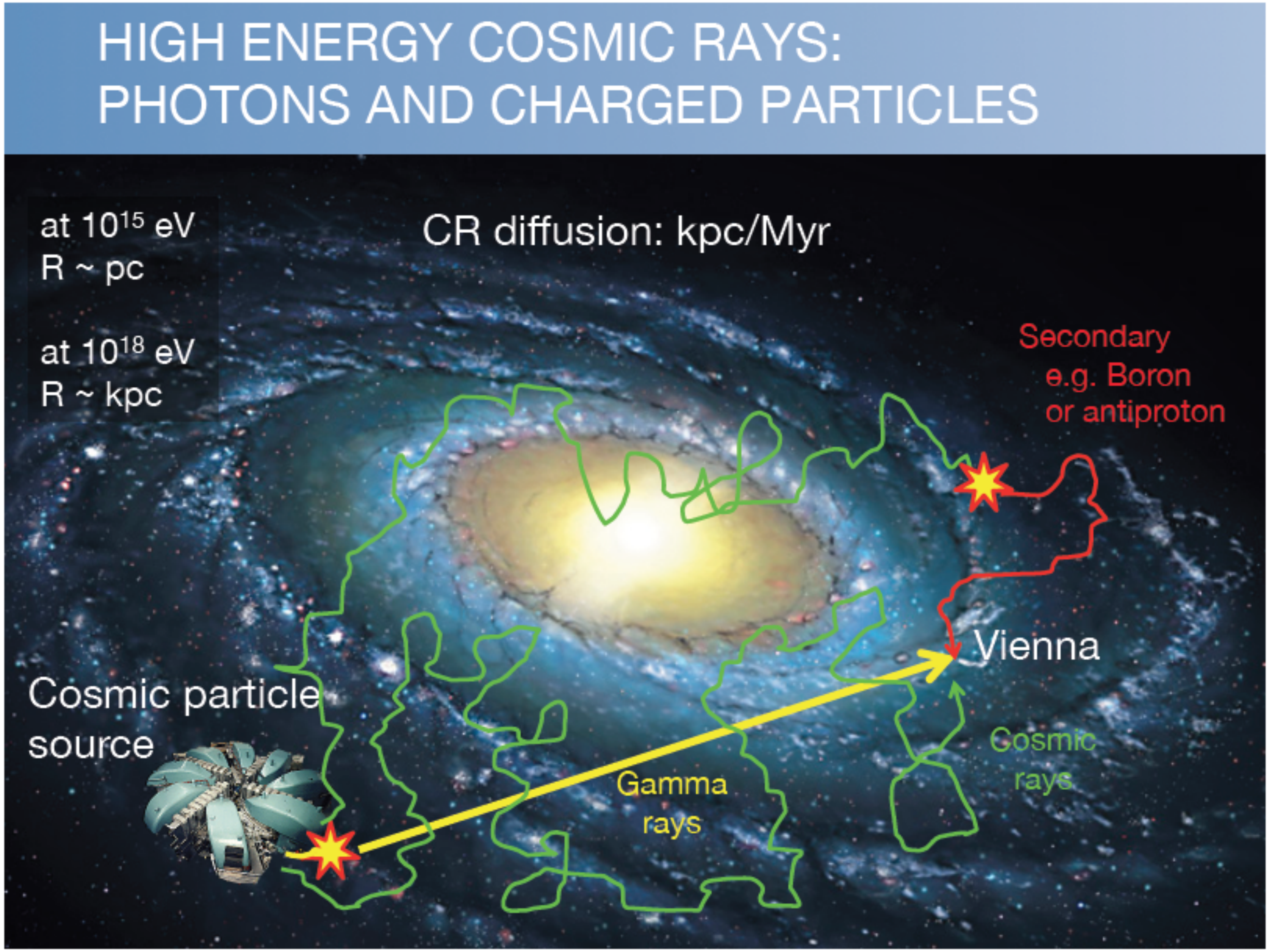


E_{max} ~ Z

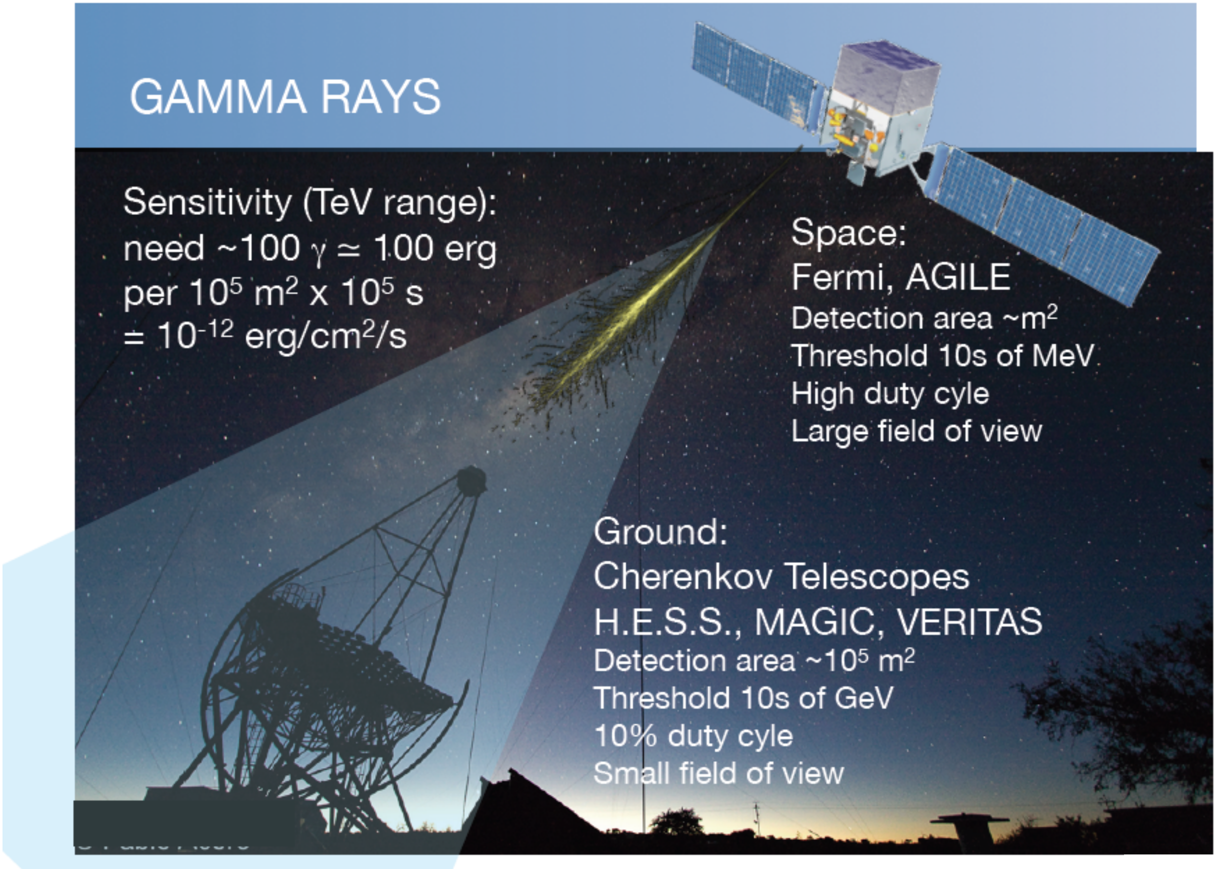
Fit by Aloisio et al.
arXiv:1312.7459v1

cf GZK cut-off ~ 5.10^{19}eV, due to CMB interactions over long distances/.

Cosmic Rays (Hofman)



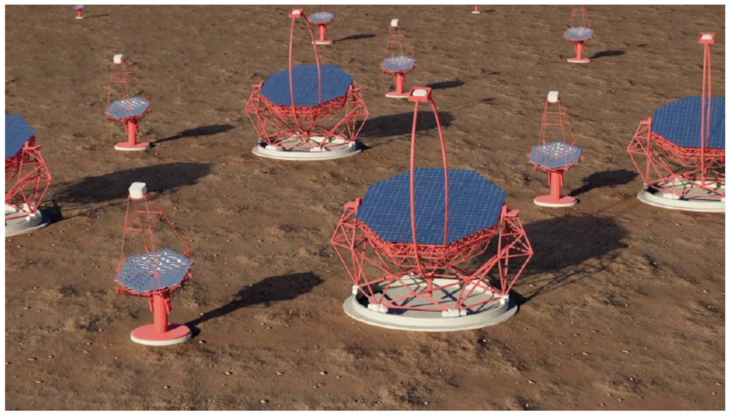
… charged particles not very useful for directional information



Gamma Ray Astronomy

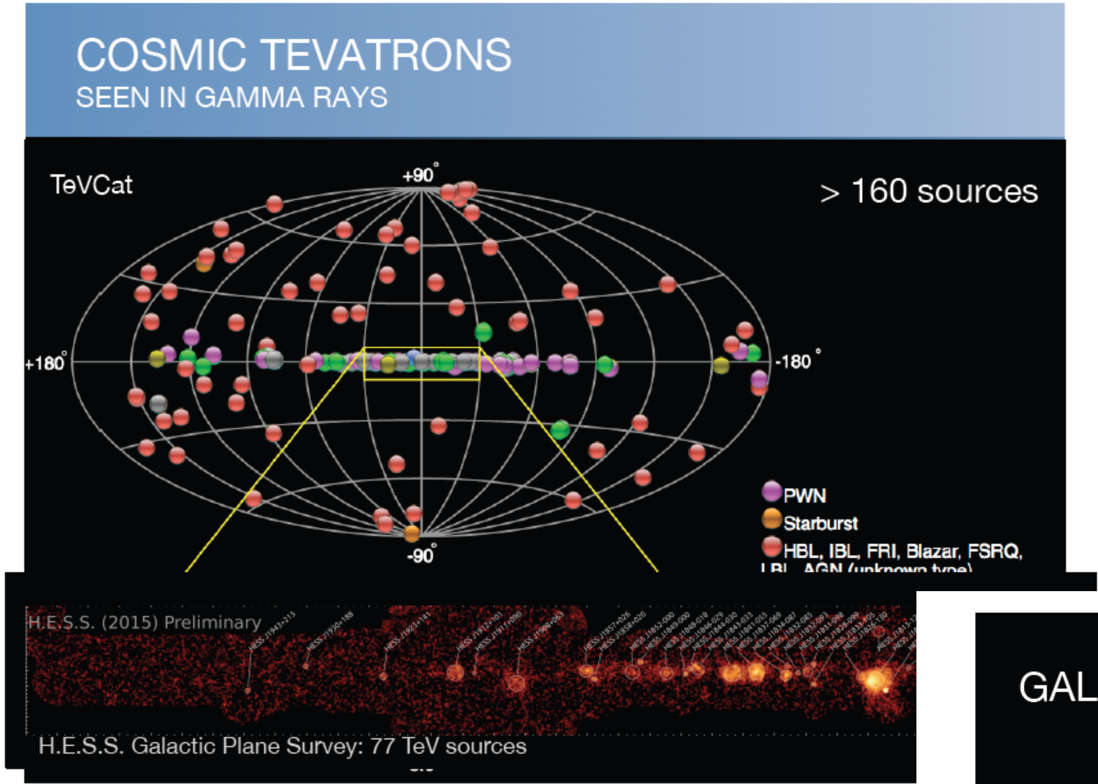
γ-RAYS - THE NEXT GENERATION: CTA

JULY 2015: FOCUS ON SITES AT ESO/CHILE AND LA PALMA



Credit: Multimedia Service,
Institute of Astrophysics of Canary Islands

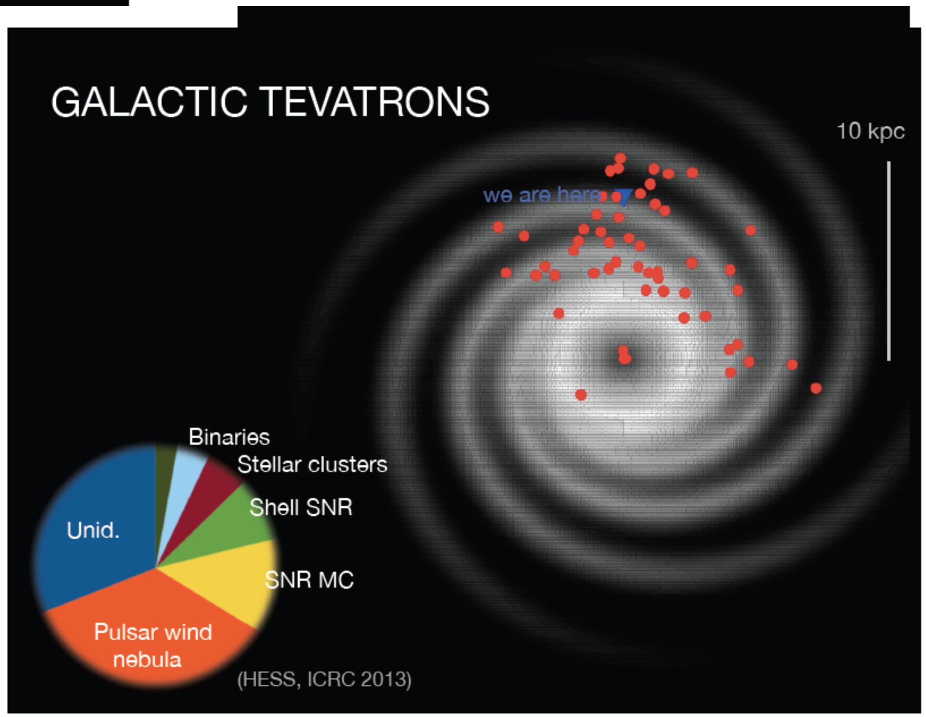
Gamma Ray Astronomy



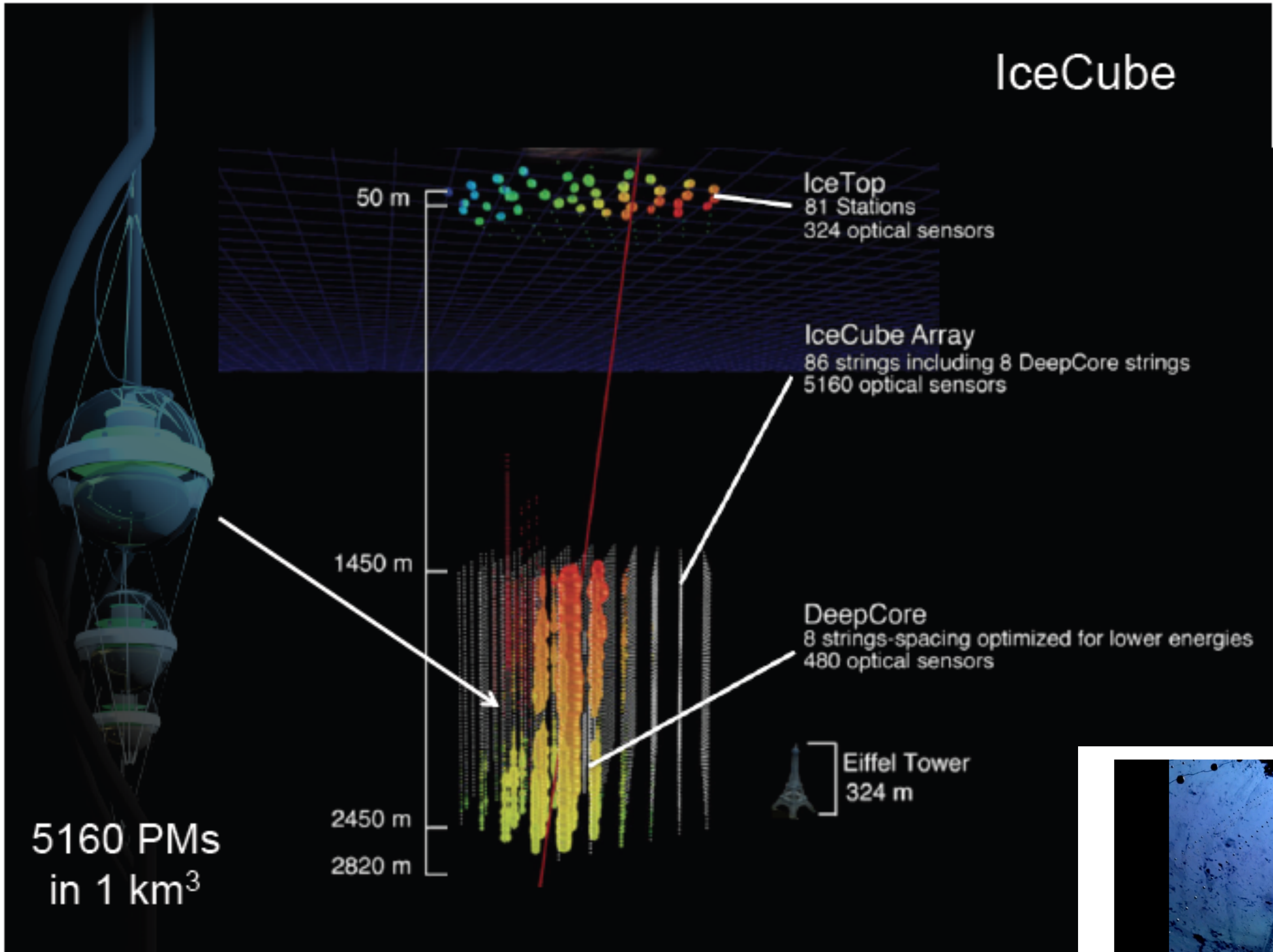
... reliable directional information

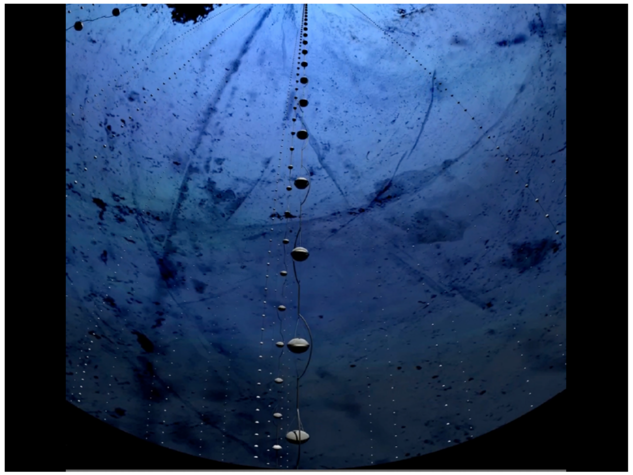
... lots of TeV-scale sources inside and outside the galaxy

... but no cosmic PeVatron observed yet



Halzen: IceCube neutrino telescope





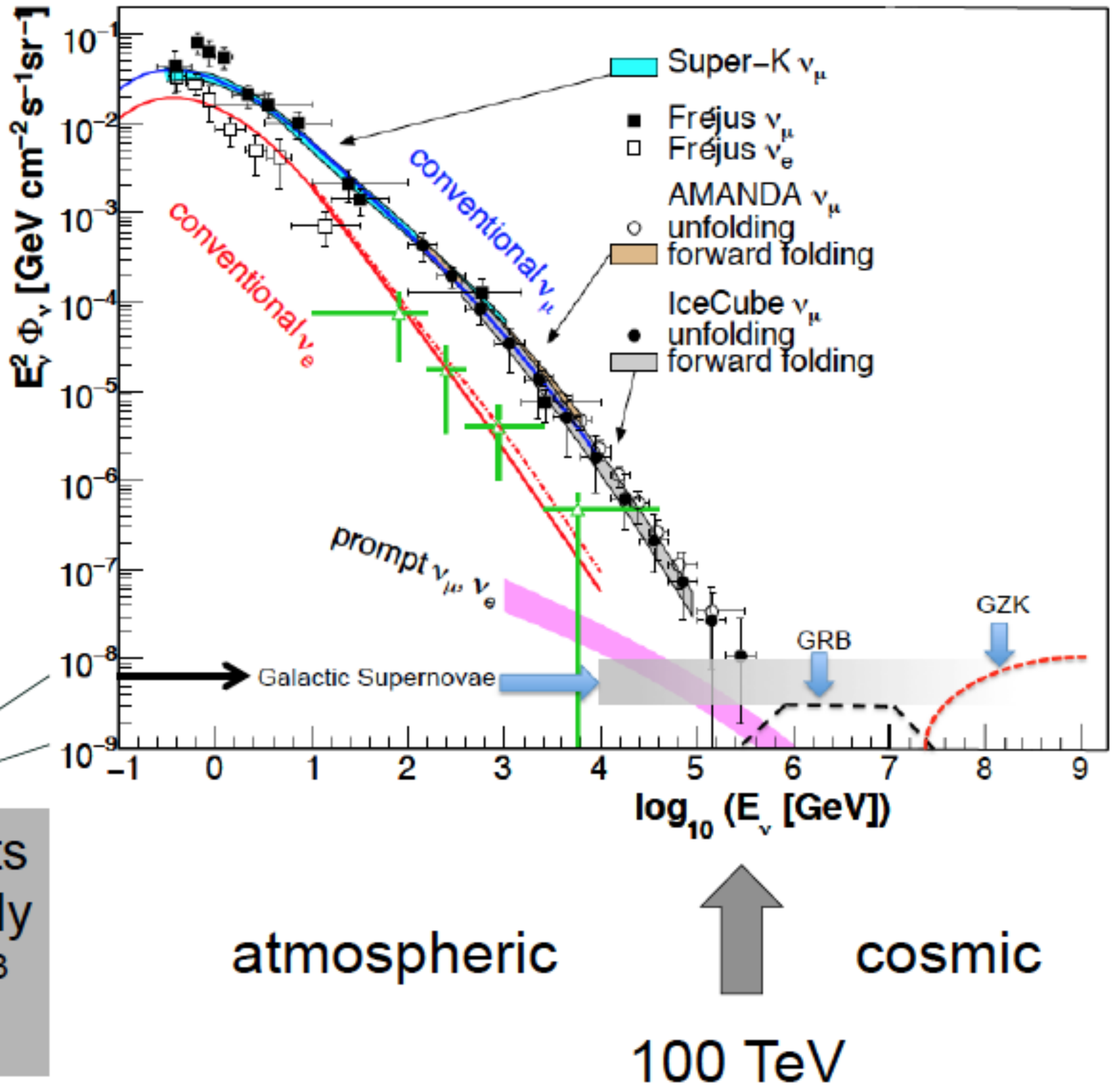
Halzen: Neutrino Astrophysics

above 100 TeV

- cosmic neutrinos:
- atmospheric background disappears

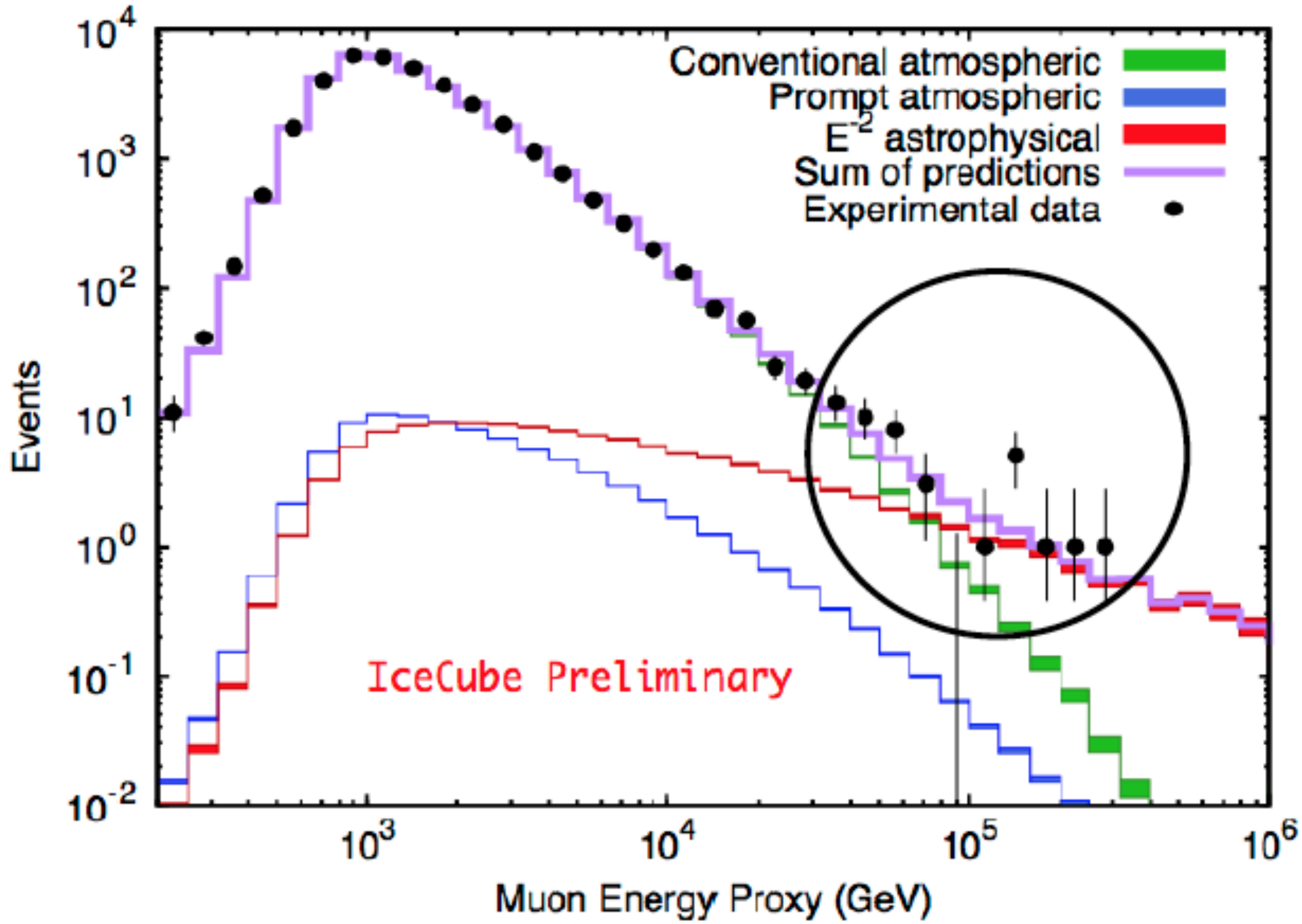
$dN/dE \sim E^{-2}$

10—100 events per year for fully efficient 1 km³ detector

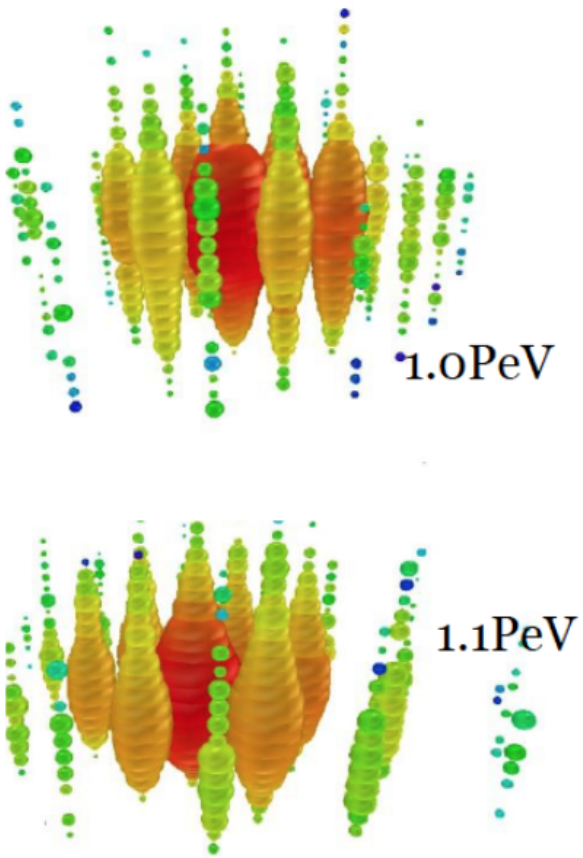


Halzen: Neutrino Astrophysics

cosmic neutrinos in 2 years of data at 3.7 sigma



Halzen: Neutrino Astrophysics



• energy

1,041 TeV
1,141 TeV
(15% resolution)

• not atmospheric: probability of no accompanying muon is 10^{-3} per event

→ flux at present level of diffuse limit

- we observe a diffuse extragalactic flux
- a subdominant Galactic component cannot be excluded
- where are the PeV gamma rays that accompany PeV neutrinos?

Prizes

One other of note …

European Physical Society
PRIZE

The 2015 Outreach Prize

for outstanding outreach achievement connected with High Energy Physics and/or Particle Astrophysics

is awarded to

Kate Shaw

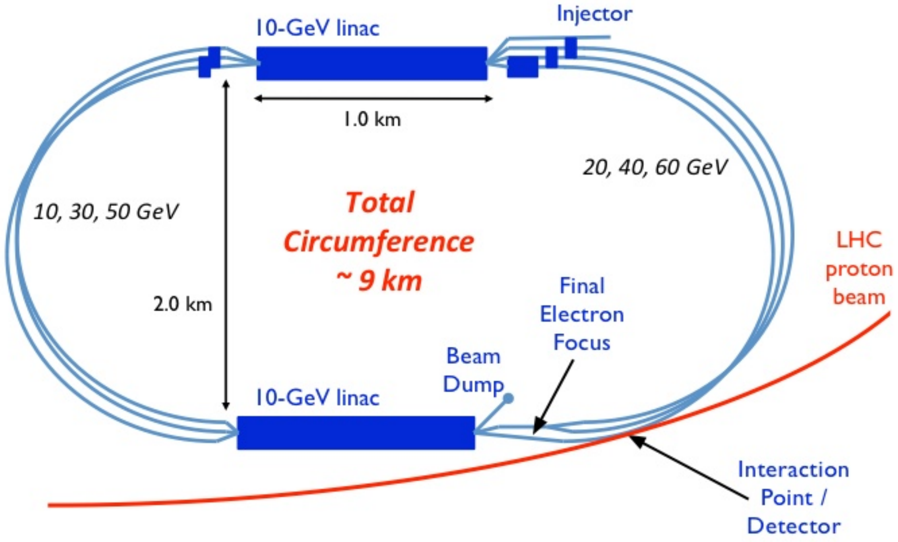
"for her contributions to the International Masterclasses and for her pioneering role in bringing them to countries with no strong tradition in particle physics"

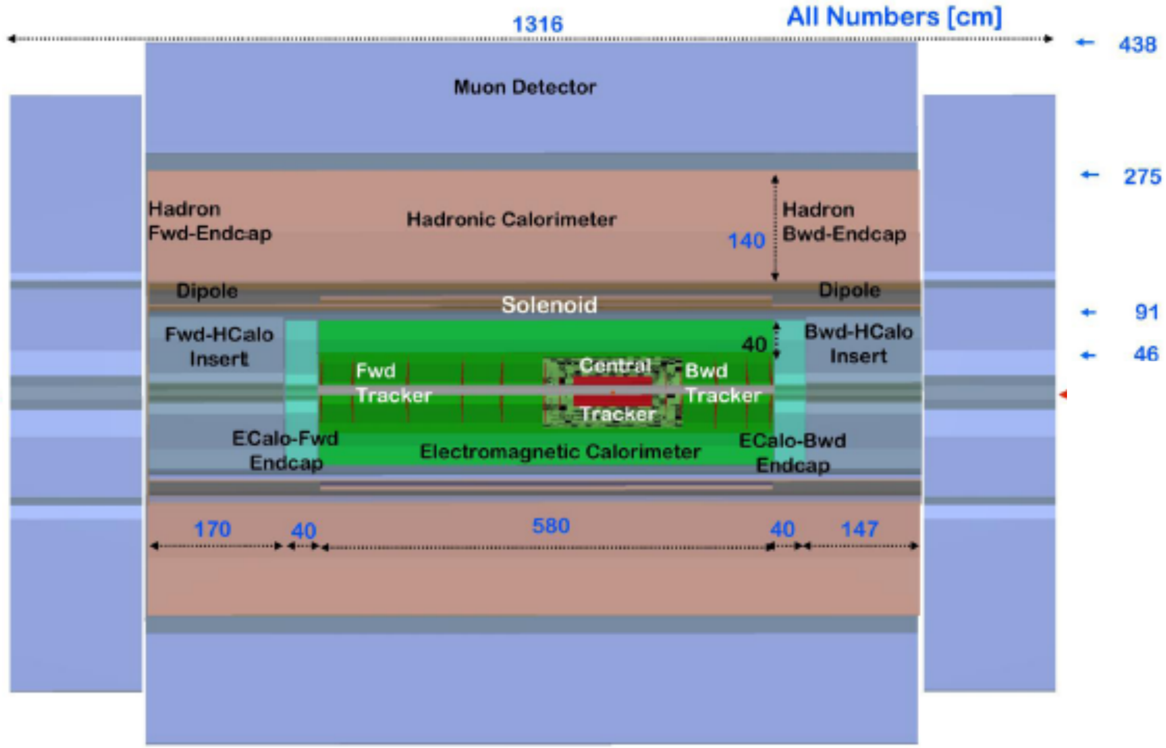
… and so on to the new results …

A Detector(*) for the Large Hadron-electron Collider

Paul Newman
Birmingham University

EPS 2015
Vienna
24 July 2015

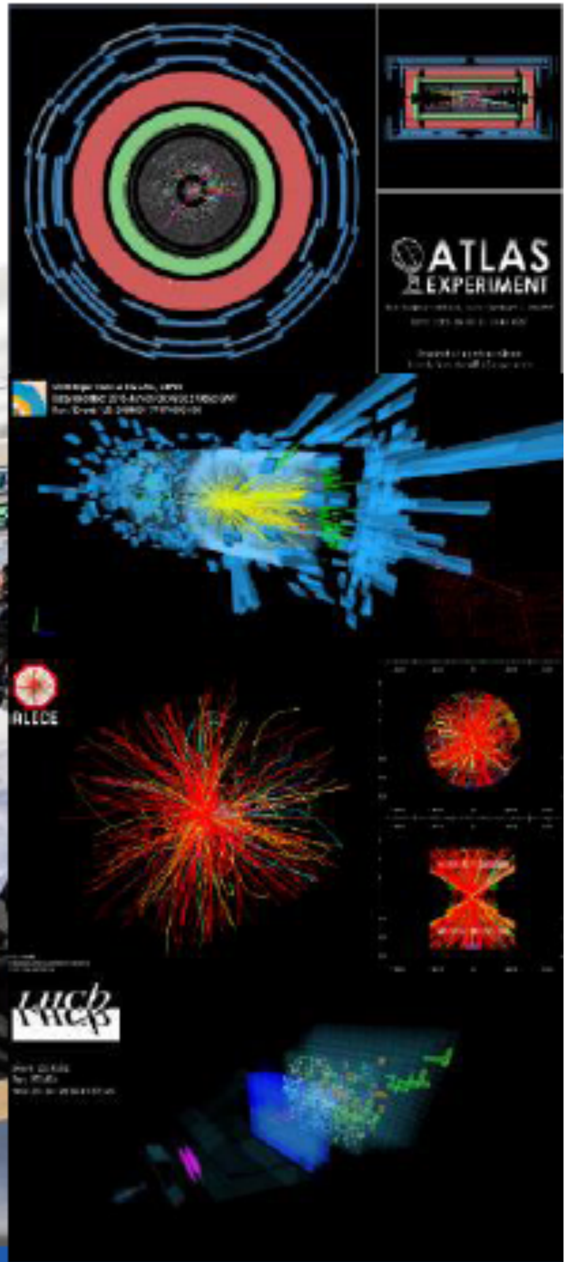




(*) Current Baseline Linac-Ring Version

LHC experiments are back in business at a new record energy 13 TeV

3rd June 2015



Luminosity Snapshot (Hoecker)

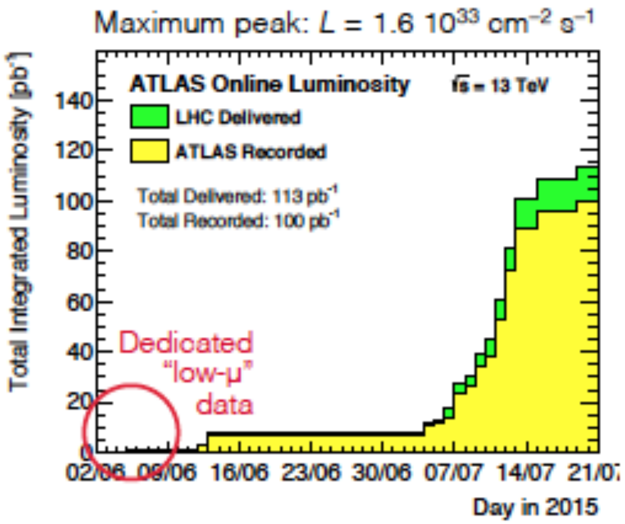
Some EPS'15 results were superseded by new releases at Lepton Photon (Ljubljana) and LHCP (St Petersburg) in August / September

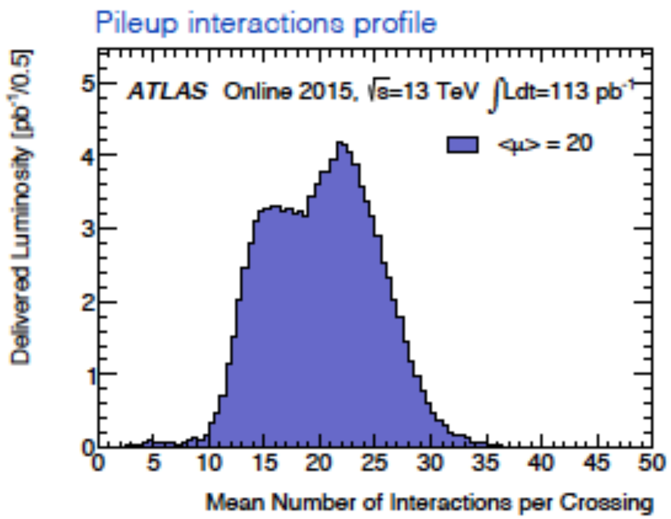
13 TeV data summaries

I will show results between 170 μb⁻¹ and 85 pb⁻¹ today

Luminosity

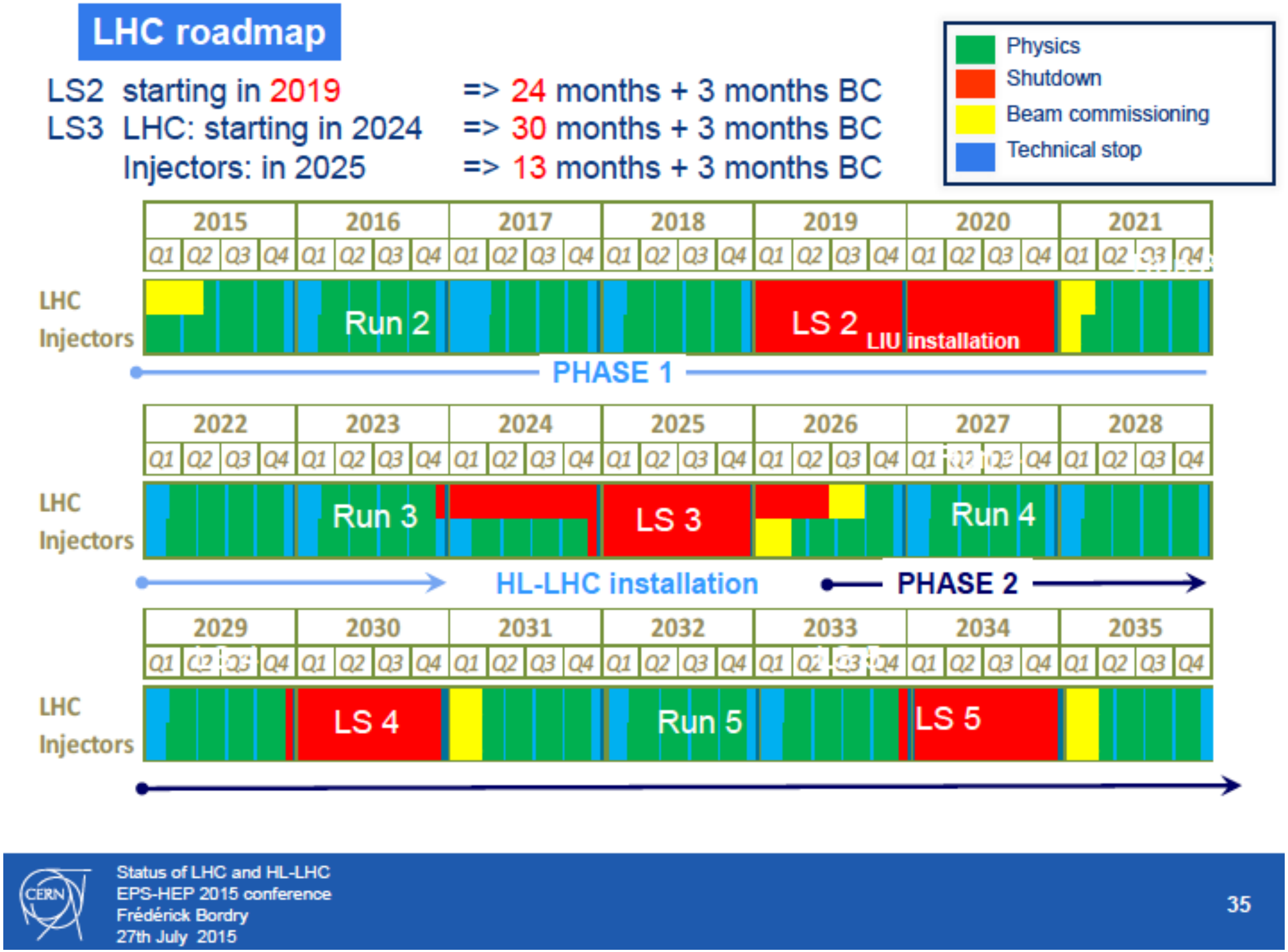
Measured with forward detectors, calibrated with "mini van-der-Meer" scan during low-μ run to 9% precision





cf: sample of 200 pb^{-1} shown at LHCP

cf: >2 fb^{-1} of 13 TeV data have been collected in 2015



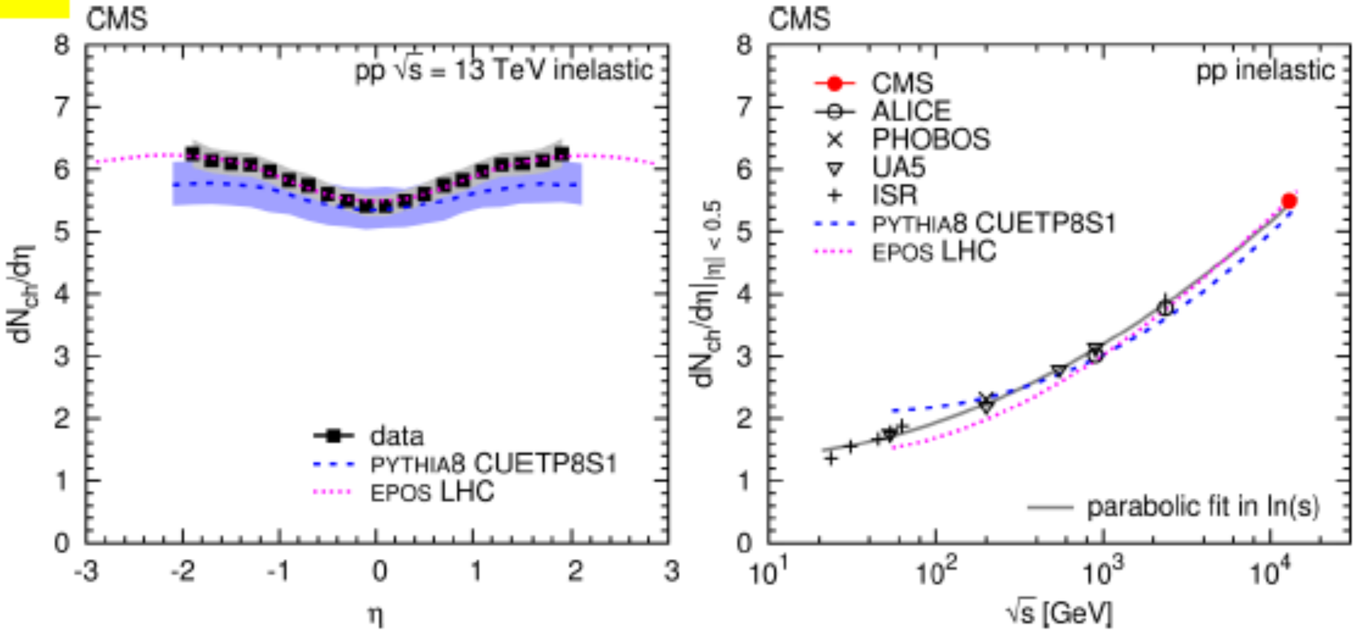
Start of a 20 year, 3000 fb^{-1} programme of pp at 13-14 TeV

CMS Run 2 Highlights

Charged Hadron Multiplicity @ 13 TeV

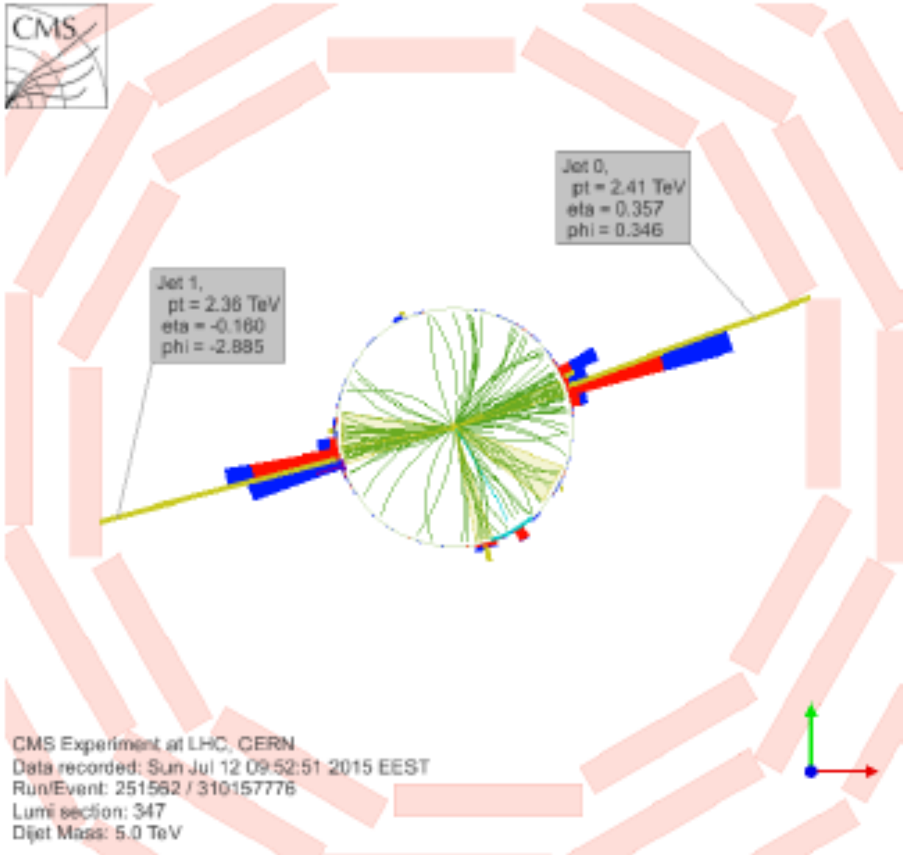
B=0

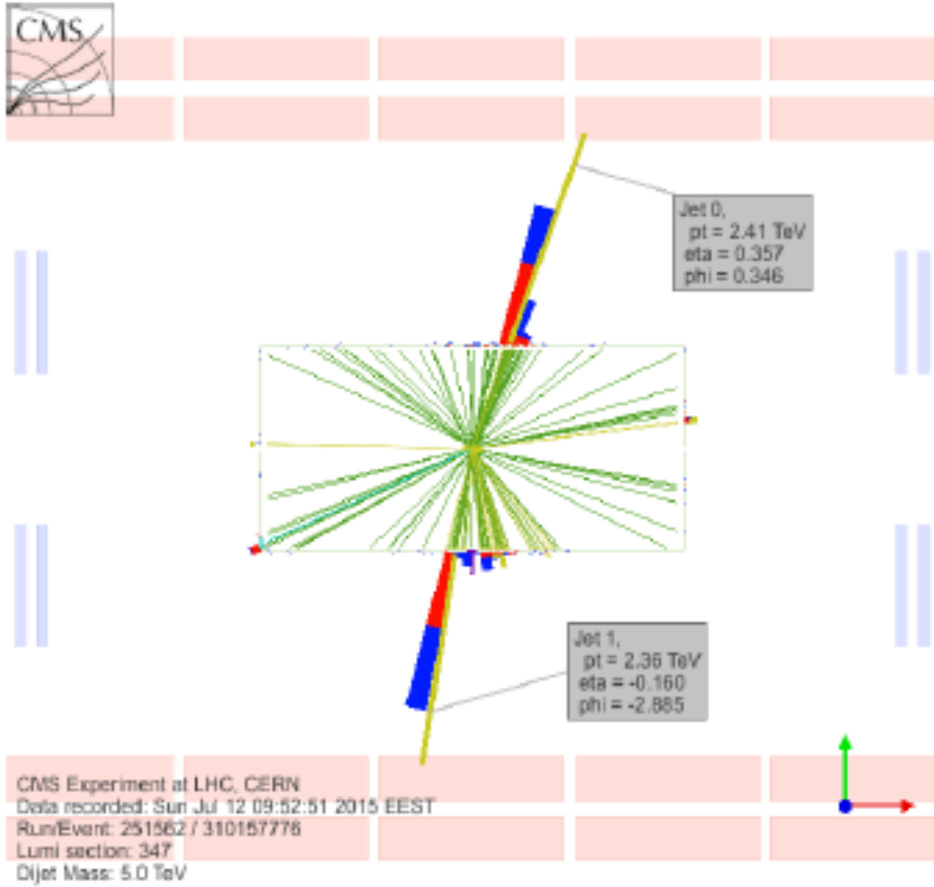
$$dn_{ch}/d\eta|_{|\eta|<0.5} = 5.49 \pm 0.01\,(stat) \pm 0.17\,(syst)$$



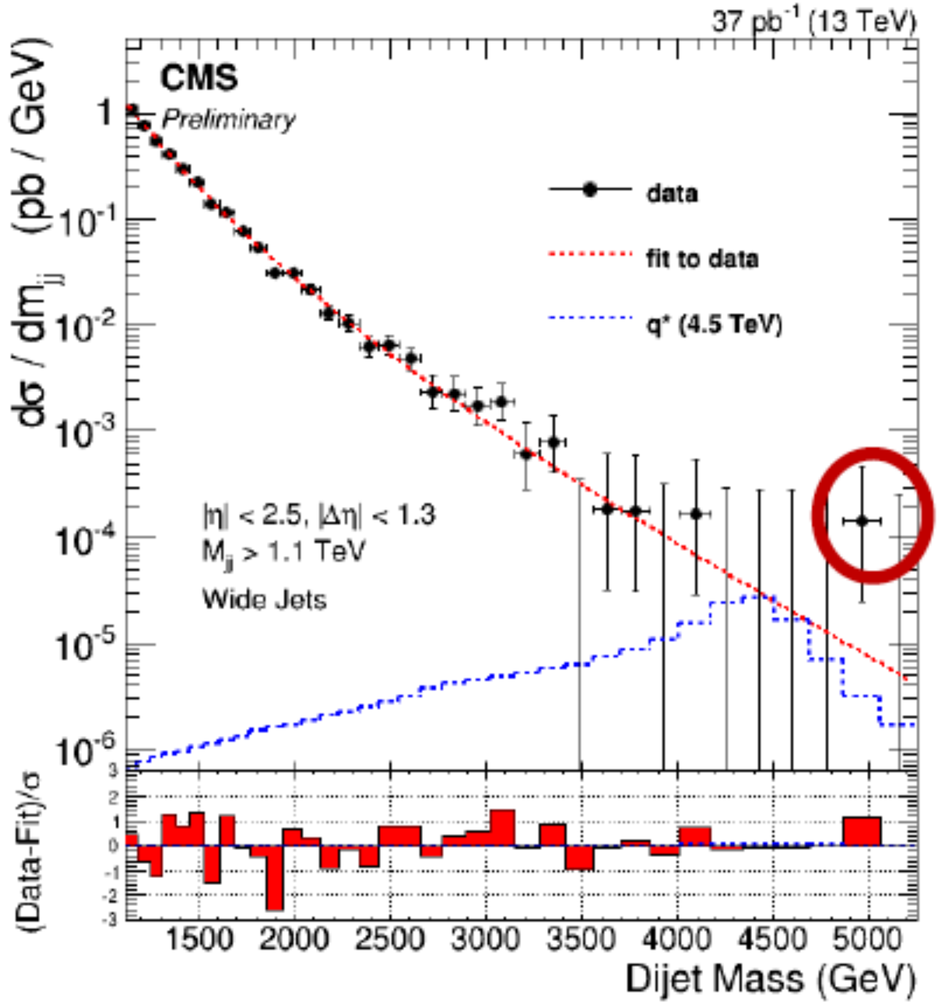
- First measurement of inelastic $dN_{ch}/d\eta$ at 13 TeV pp collisons.
- Mid-rapidity: EPOS LHC and PYTHIA8 CUETP8M1 consistent with data.
- Rapidity dependence better described by EPOS LHC

Di-Jet Event with Mjj = 5 TeV

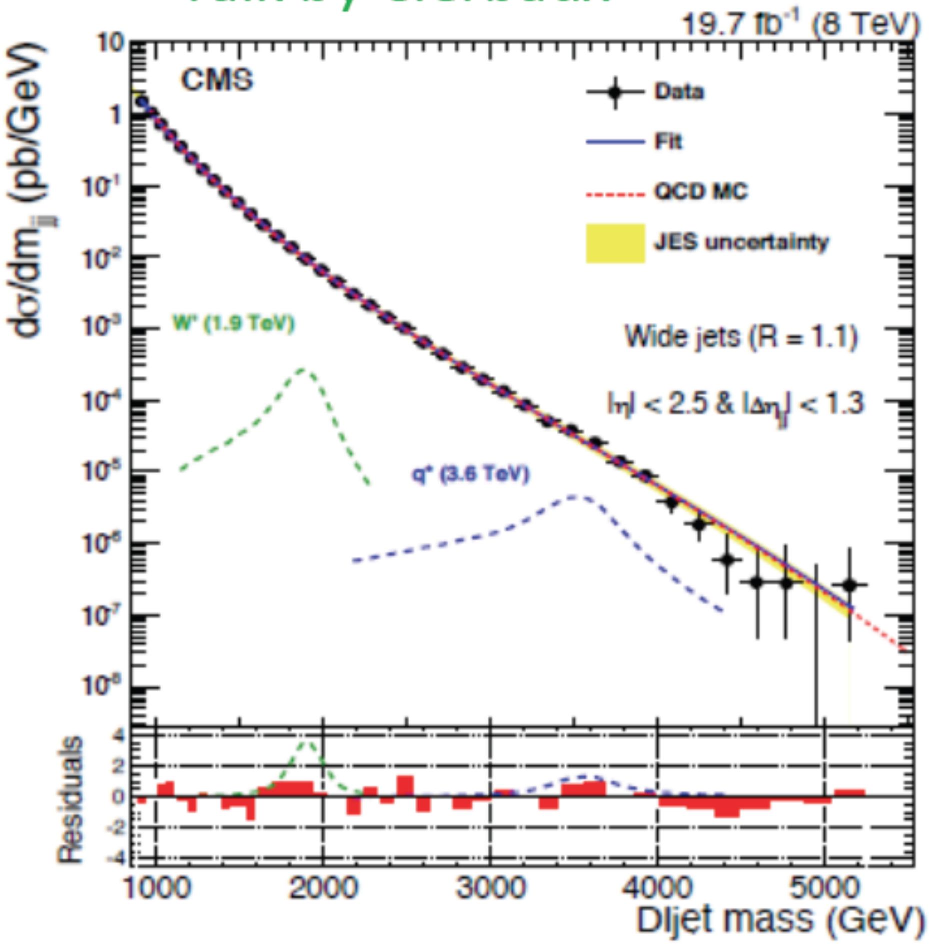




Run 1 v Run 2



Talk by Clerbaux

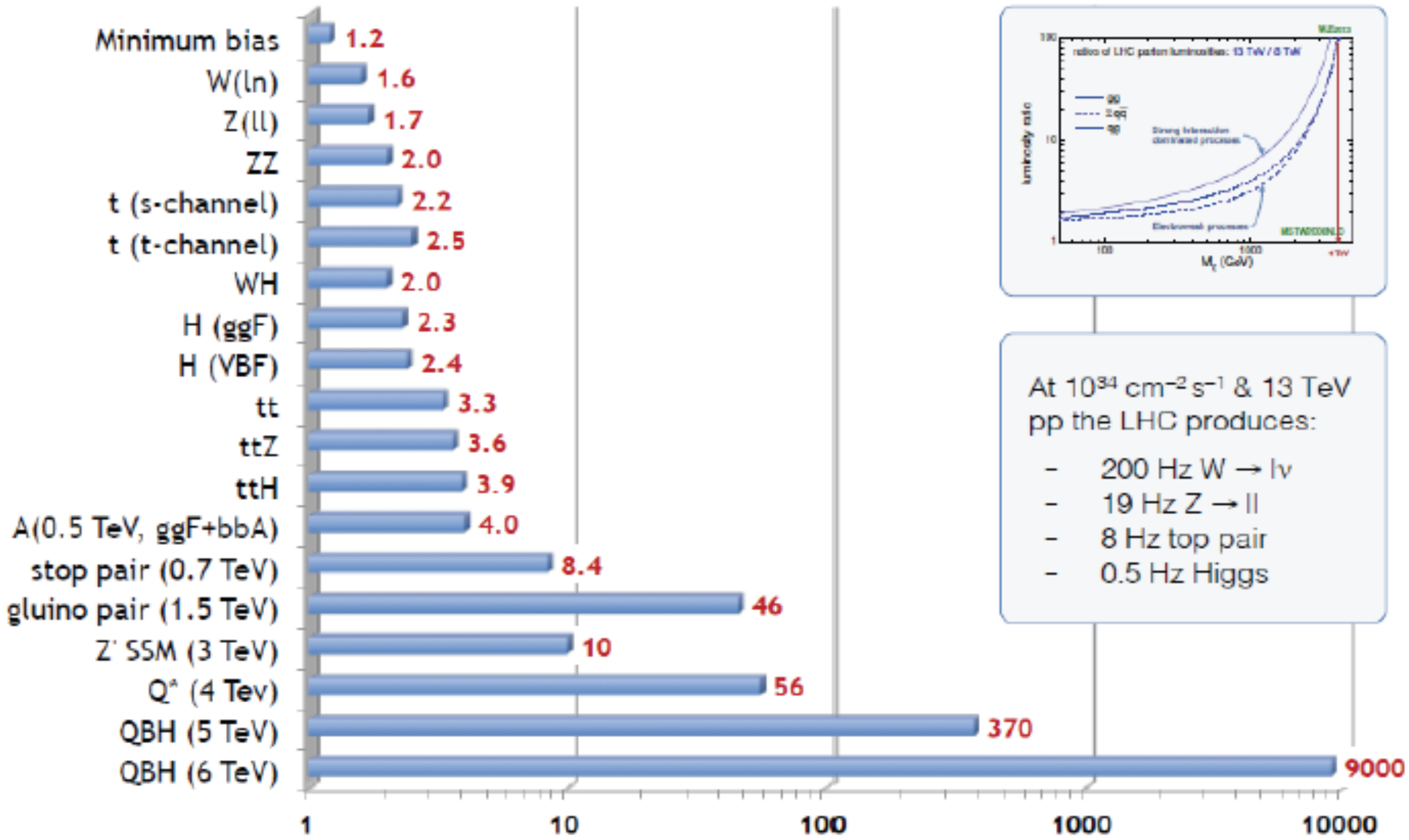


5 TeV dijet resonances not completely excluded at Run 1

Run 1 v Run 2 Sensitivity

Hoecker

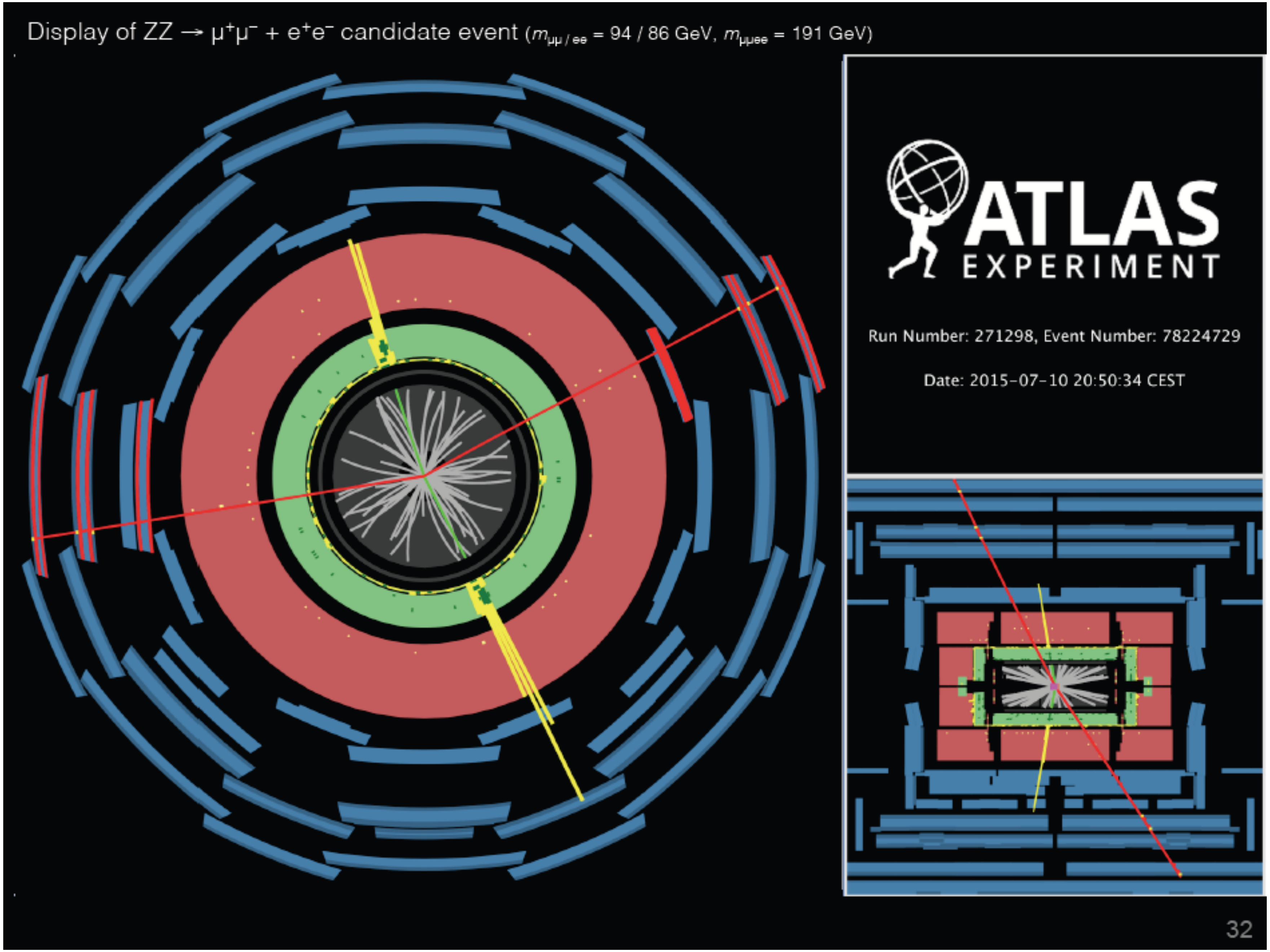
13 TeV / 8 TeV inclusive pp cross-section ratio

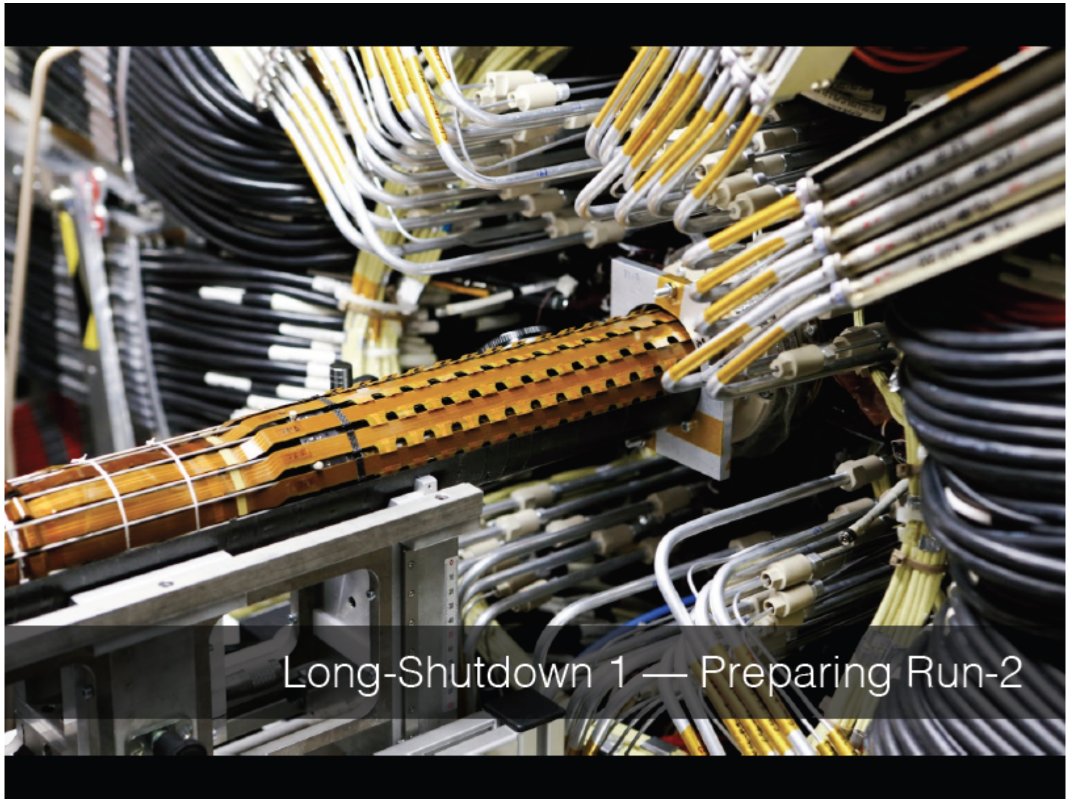


At 10^{34} $cm^{-2}s^{-1}$ & 13 TeV pp the LHC produces:

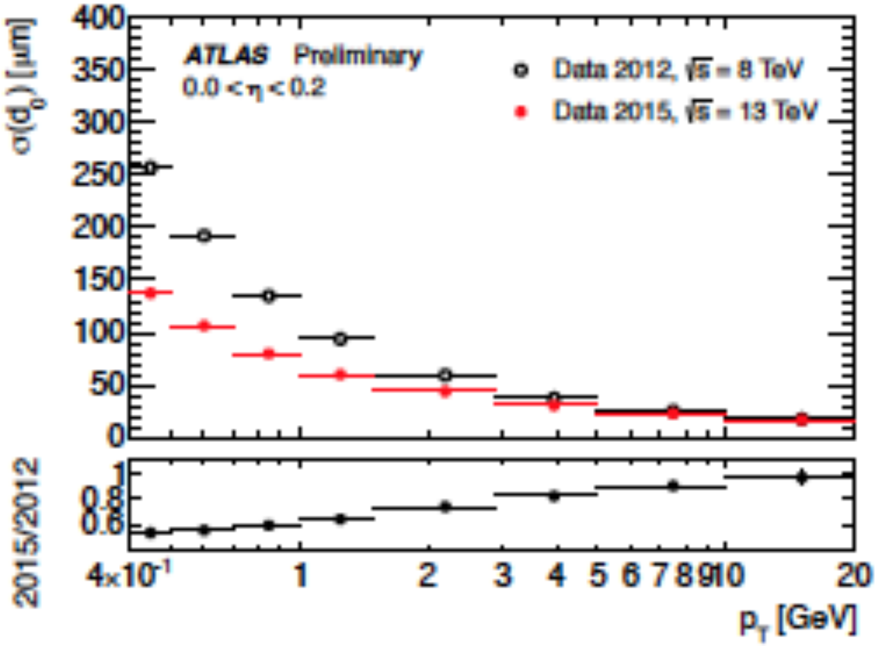
- 200 Hz W → lν
- 19 Hz Z → ll
- 8 Hz top pair
- 0.5 Hz Higgs

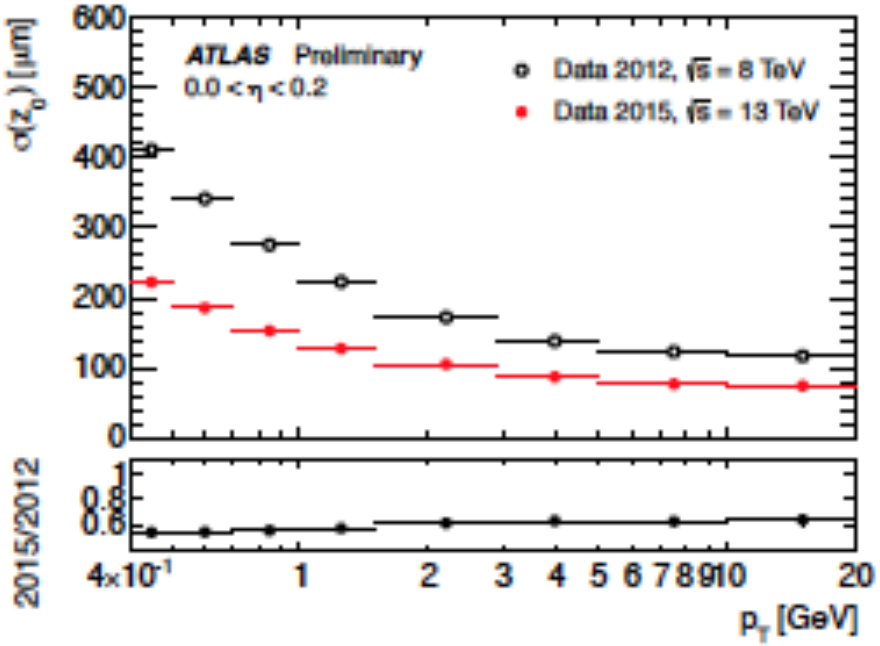
ATLAS Run 2 Highlights





Insertable B Layer





ATLAS Run 2 Highlights

Long-range two-charged-particle angular correlations

In high-multiplicity pp collisions using low-μ data

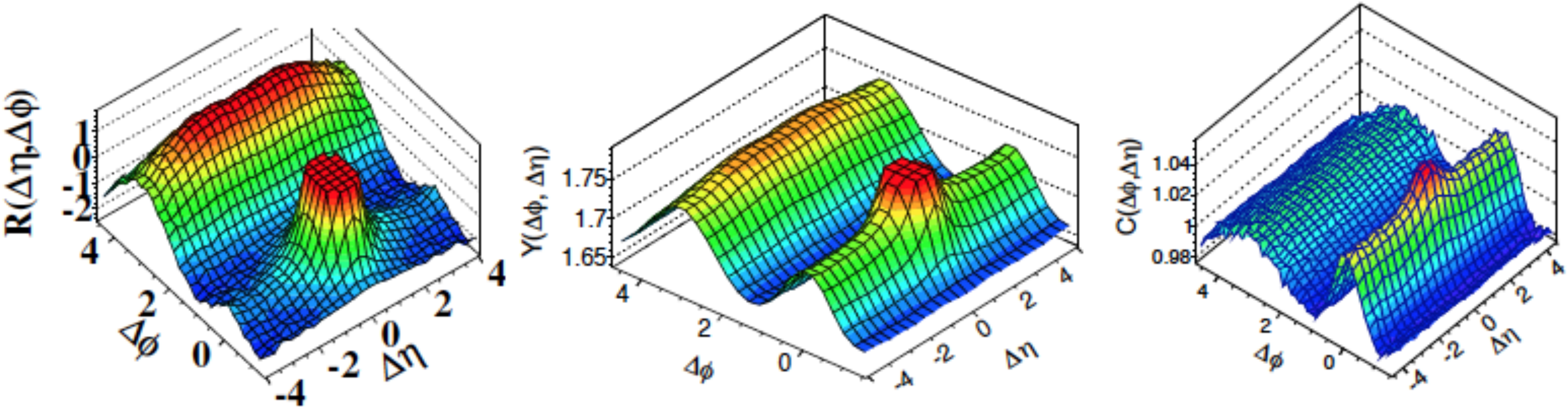
Near-side ($\Delta\phi \sim 0$) “ridge” shape along $\Delta\eta$ seen in pp, pPb and PbPb collisions

Effect increases with particle multiplicity and moderate p_T

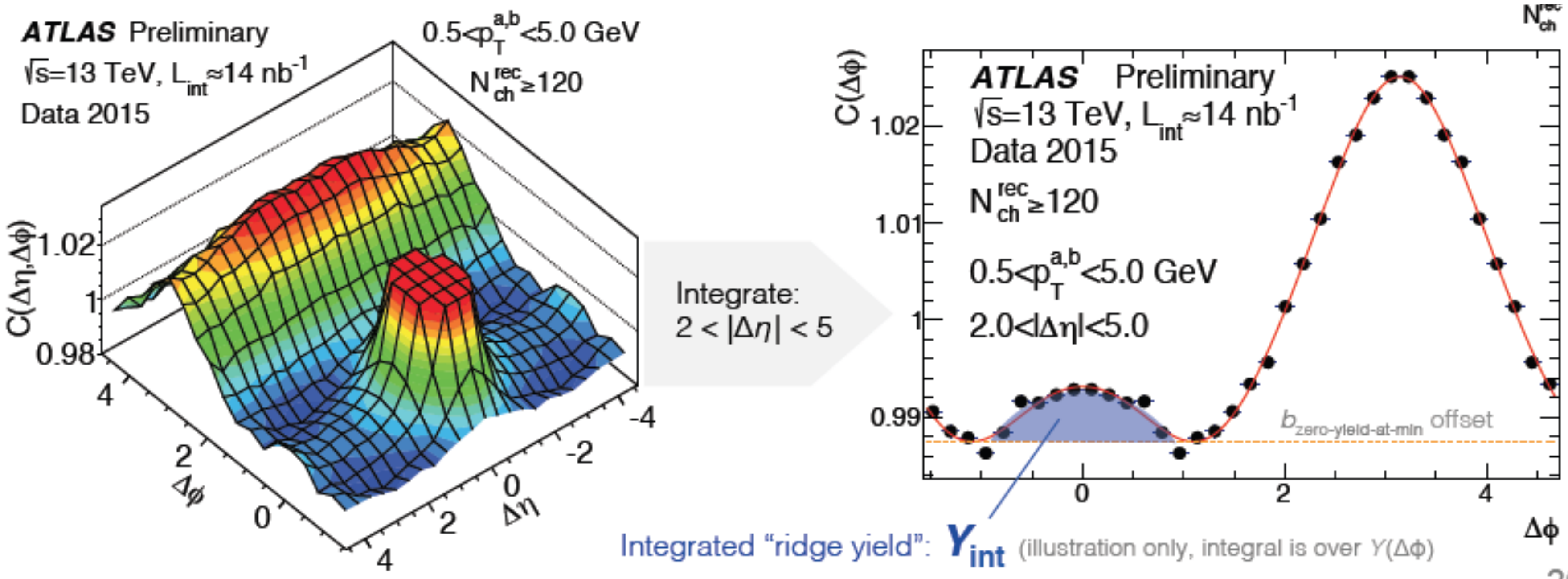
CMS, pp at 7 TeV:
$N_{ch} > 110$, $1.0 < p_T < 3.0$ GeV

ATLAS, pPb at 5.02 TeV:
$N_{ch} > 220$, $1.0 < p_T < 3.0$ GeV

ATLAS, PbPb at 2.76 TeV:
Centrality 0–5%



High charged multiplicity

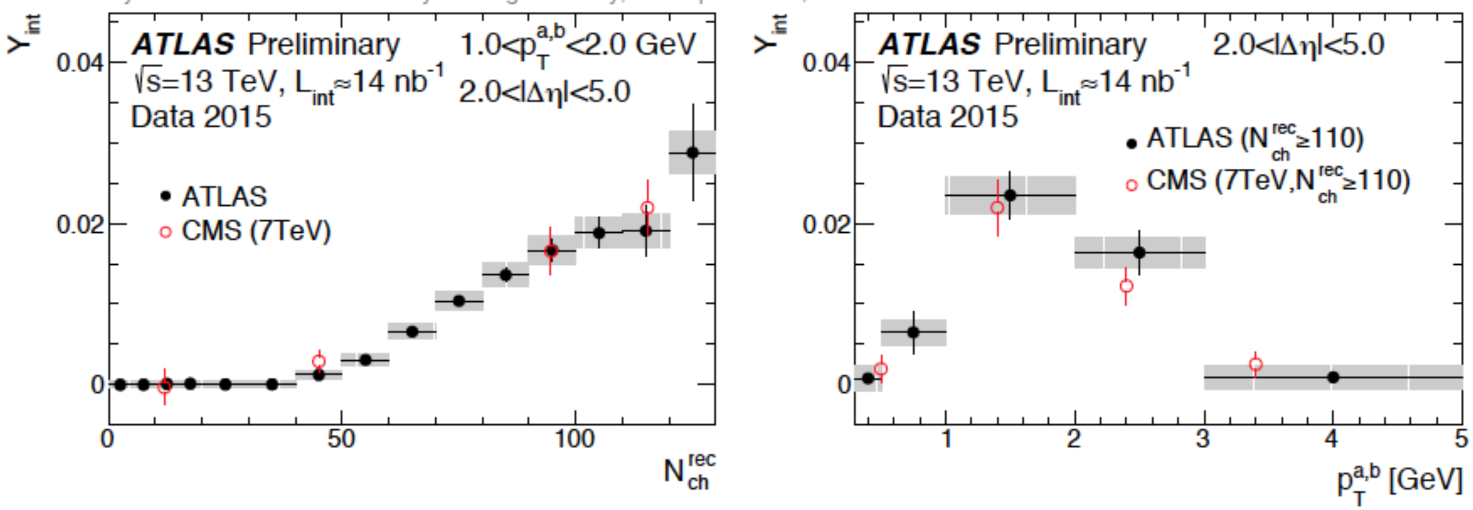


20

Integrated "ridge yield" versus charged multiplicity and p_T range

$\boldsymbol{Y}_{\mathbf{int}}$ = integral of $Y(\Delta\phi) - b_{\mathrm{ZYAM}}$ between ridge minima in $\Delta\phi$ (b_{ZYAM} is simple Y offset correction at minima)

Systematic effects dominated by tracking efficiency, ZYAM procedure, MC closure



→ Compatible yield at different CM energies

ATLAS Run 2 Highlights

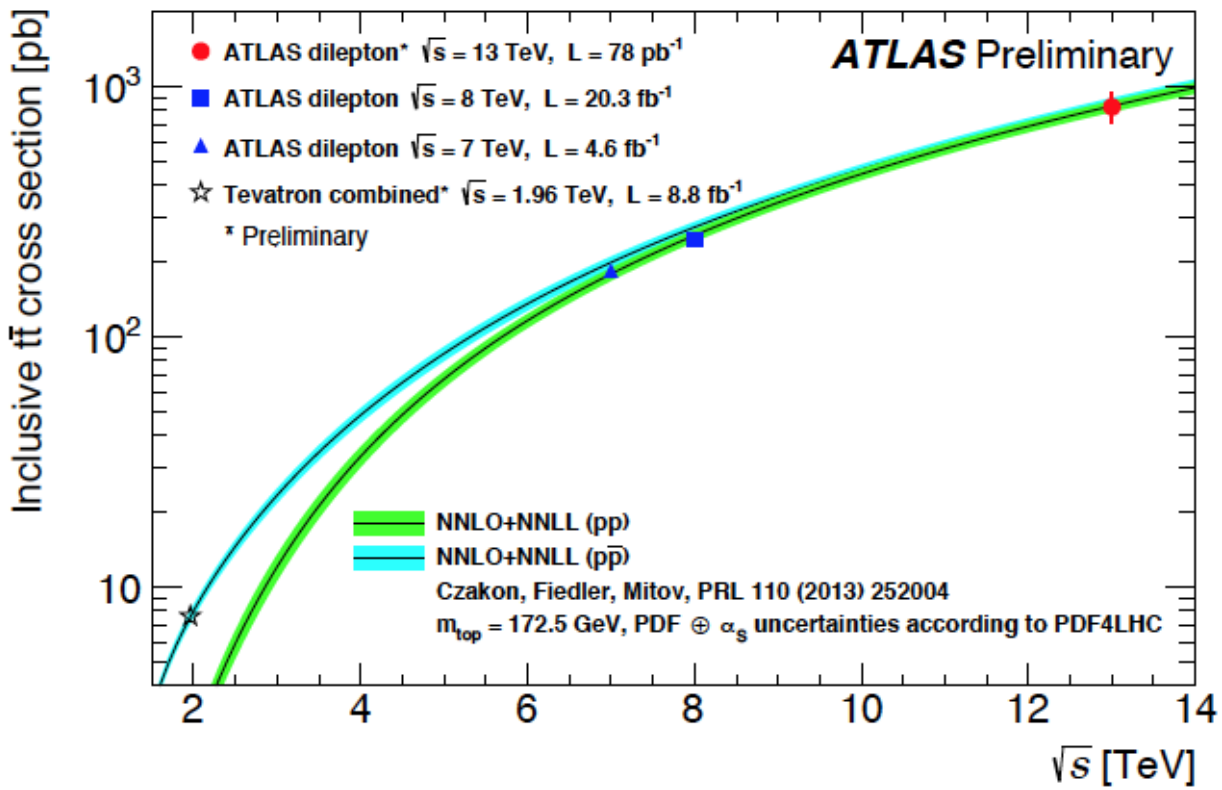
Top-antitop production at 13 TeV

Extraction of top-pair cross section

[ATLAS-CONF-2015-033]

Solving the equation gives the following 13 TeV pp → tt + X cross section

σ_{tt} (13 TeV) = 825 ± 49 (stat) ± 60 (syst) ± 83 (lumi) pb



… and a couple from later conferences (Eric Torrence, LHCP)

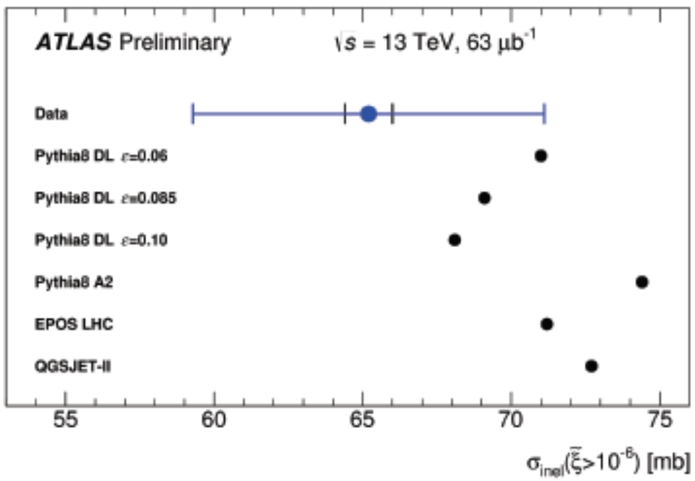
Inelastic pp Cross-Section

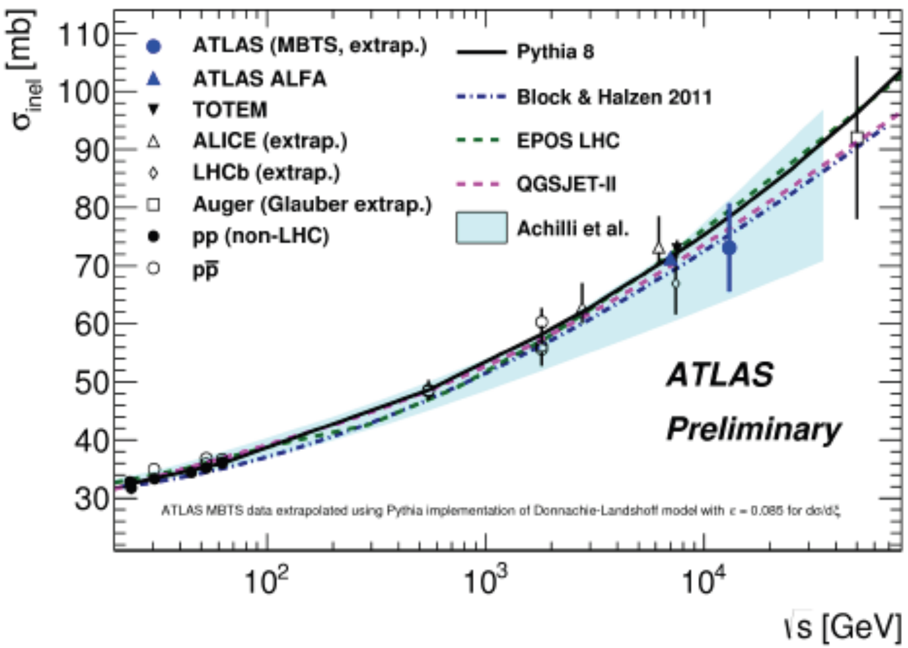
ATLAS-CONF-2015-038

- Using low-pileup data set ($\mu < 0.05$)
- Analysis w/ new MBTS scintillators ($2.1 < |\eta| < 3.9$)
- Result dominated by luminosity uncertainty

Fiducial cross-section:
65.2 ± 0.8 (exp) ± 5.9 (lum) mb

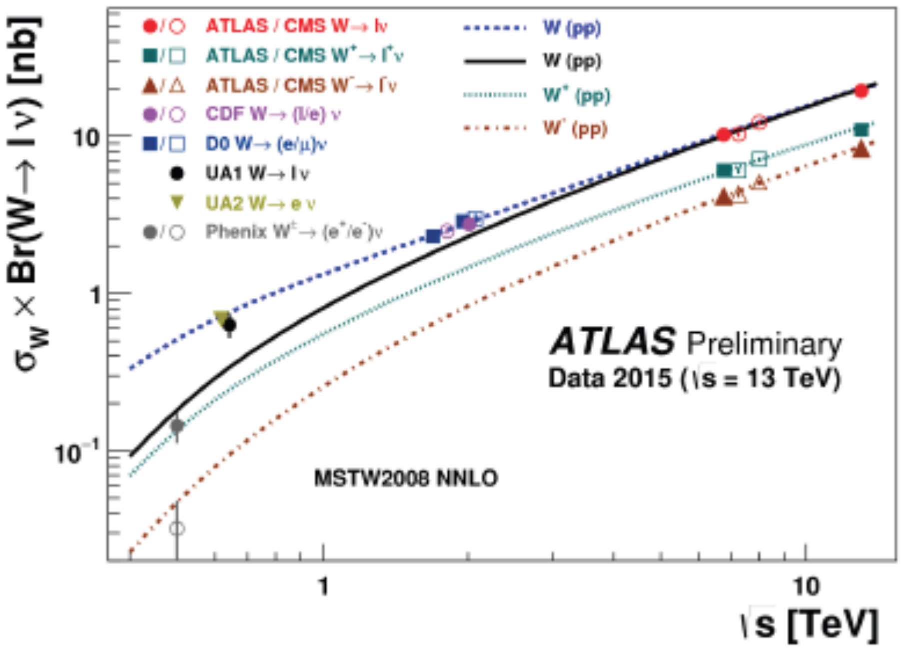
4.2M events selected in 63 μb^{-1}
Estimated 1% background

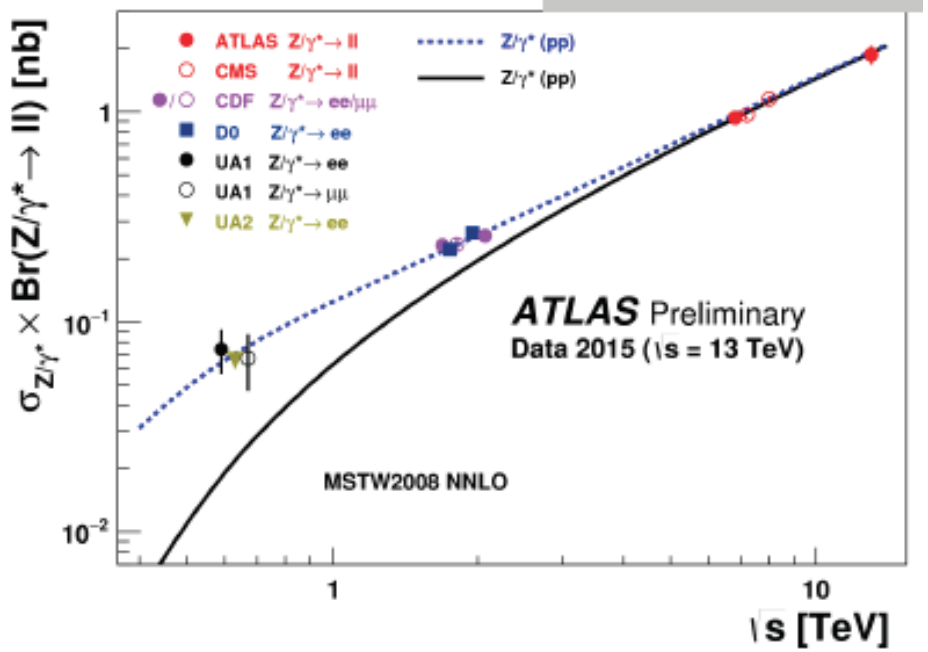




W/Z Cross-Section

ATLAS-CONF-2015-039



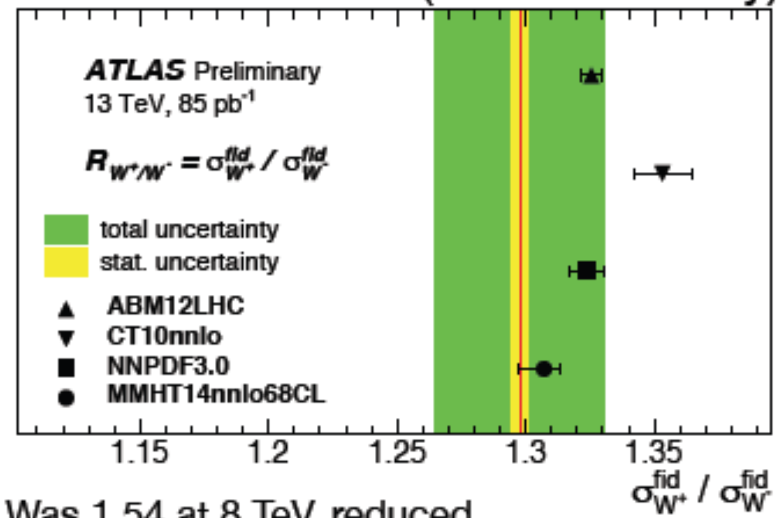


Fiducial cross-sections

Channel	value ± stat ± syst ± lumi [pb]
W^-	$3344 \pm 6 \pm 113 \pm 301$
W^+	$4340 \pm 7 \pm 138 \pm 391$
$W^\pm$	$7684 \pm 9 \pm 232 \pm 692$
Z	$746 \pm 3 \pm 13 \pm 67$

Currently dominated by
lumi uncertainty

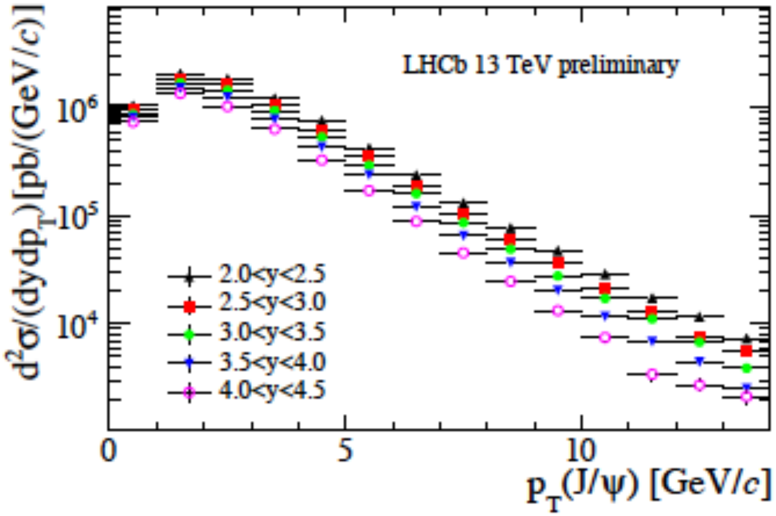
W+/W- Fiducial Ratio (2.5% accuracy)



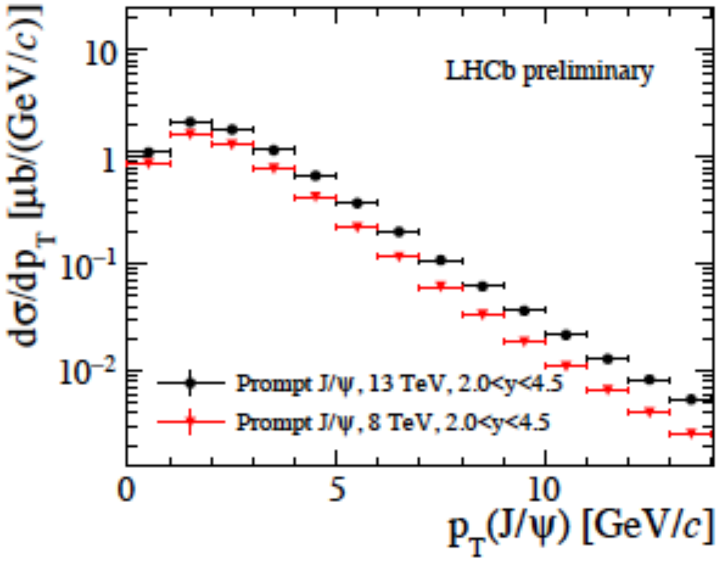
Was 1.54 at 8 TeV, reduced
valence quark asymmetry at 13 TeV

[LHCb, LHCb-PAPER-2015-037, in preparation]

J/ψ CROSS SECTION AT $\sqrt{s} = 13$ TEV



LHCb at Run 2



Double-differential cross-sections are determined in J/ψ $p_T < 14$ GeV/c and $2 < y < 4.5$

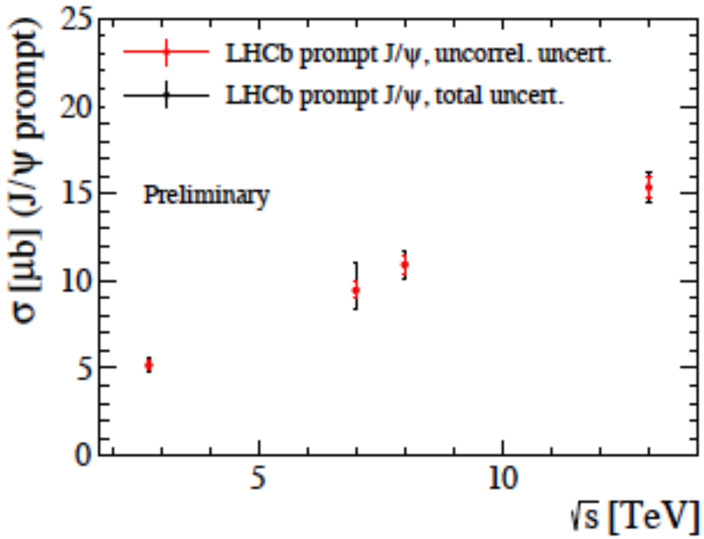
- which are integrated over y
- Ratios of 13 to 8 TeV cross-sections are determined

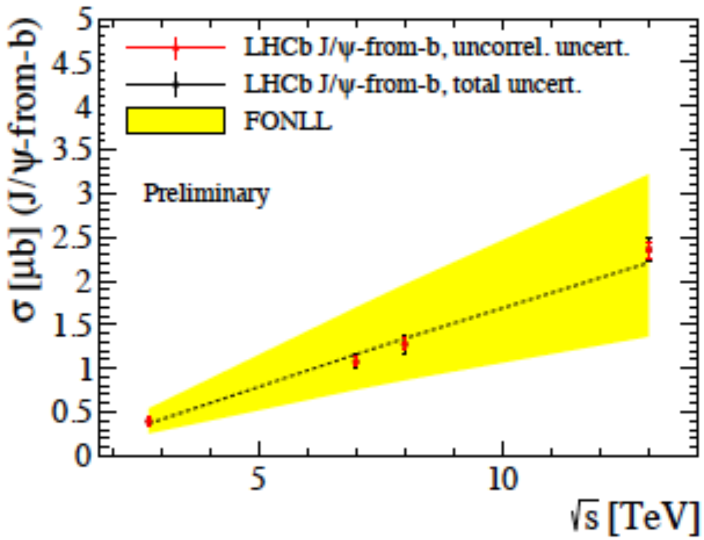
[Shao et al., JHEP05 (2015) 103, arXiv:1411.3300]

[Cacciari, Mangano, Nason, arXiv:1507.06197]

[LHCb, LHCb-PAPER-2015-037, in preparation]

J/ψ cross section at $\sqrt{s} = 13$ TeV





Double-differential cross-sections are determined in J/ψ $p_{\mathrm{T}} < 14$ GeV/c and $2 < y < 4.5$

Preliminary cross-sections :

$$\sigma_{J/\psi}(\mathrm{LHCb}) = 15.35 \pm 0.03 \pm 0.85\,\mu\mathrm{b}$$

$$\sigma_{J/\psi/b}(\mathrm{LHCb}) = 2.36 \pm 0.01 \pm 0.13\,\mu\mathrm{b}$$

where the systematic uncertainty is dominated by the luminosity

Naively applying a factor 5.2 from Pythia:

$$\sigma_{b\overline{b}}(4\pi) = 518 \pm 2 \pm 53\,\mu\mathrm{b}$$

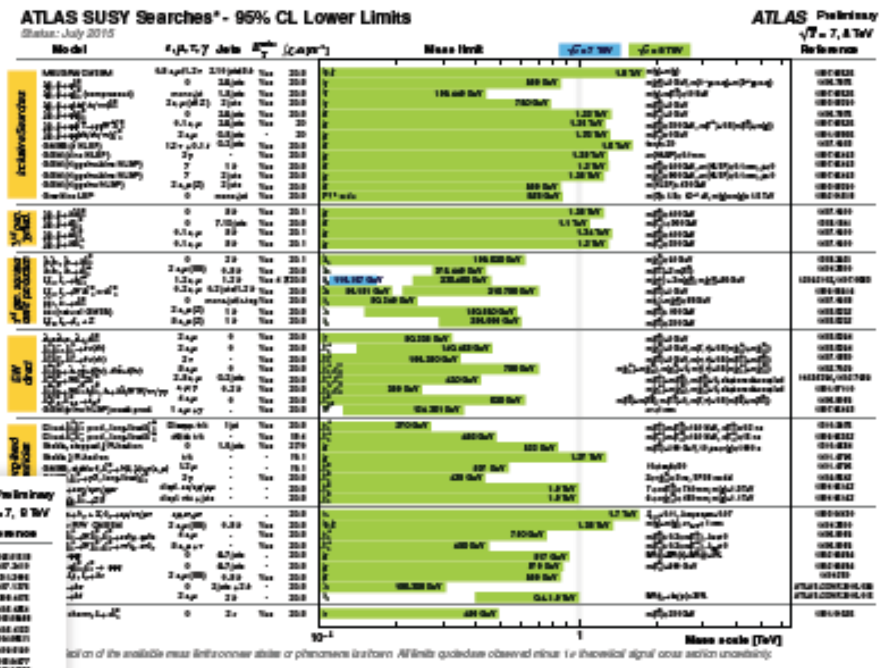
where there's no uncertainty for the extrapolation

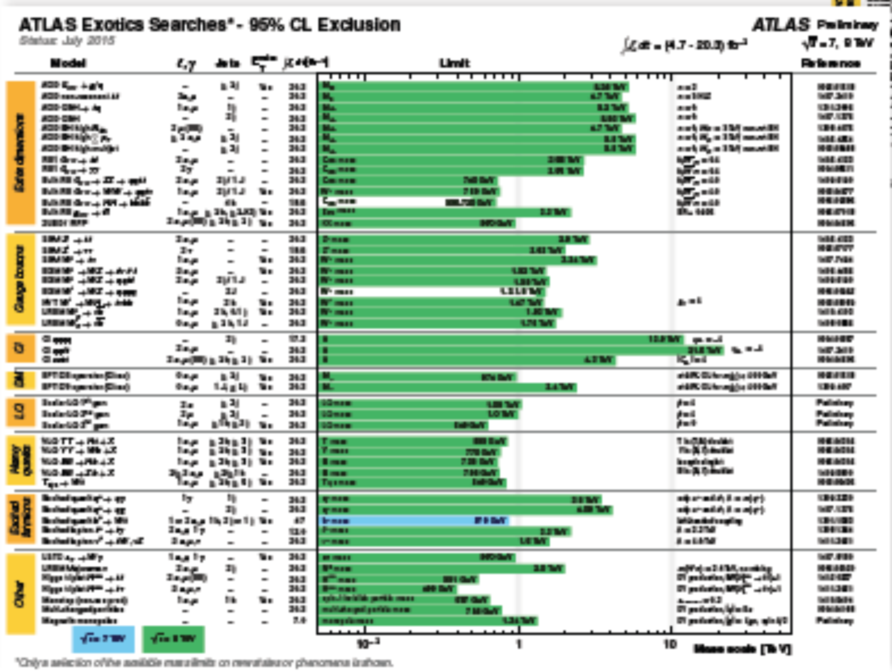
LHC Run 1: Searches at the GPDs

We also did a vast amount of BSM searches — with no significant anomaly seen so far

Theory-agnostic, signature based searches, as well as highly targeted model-dependent ones

→ Covered by plenary speakers: Ivan Mikulec, Anna Sfyrla



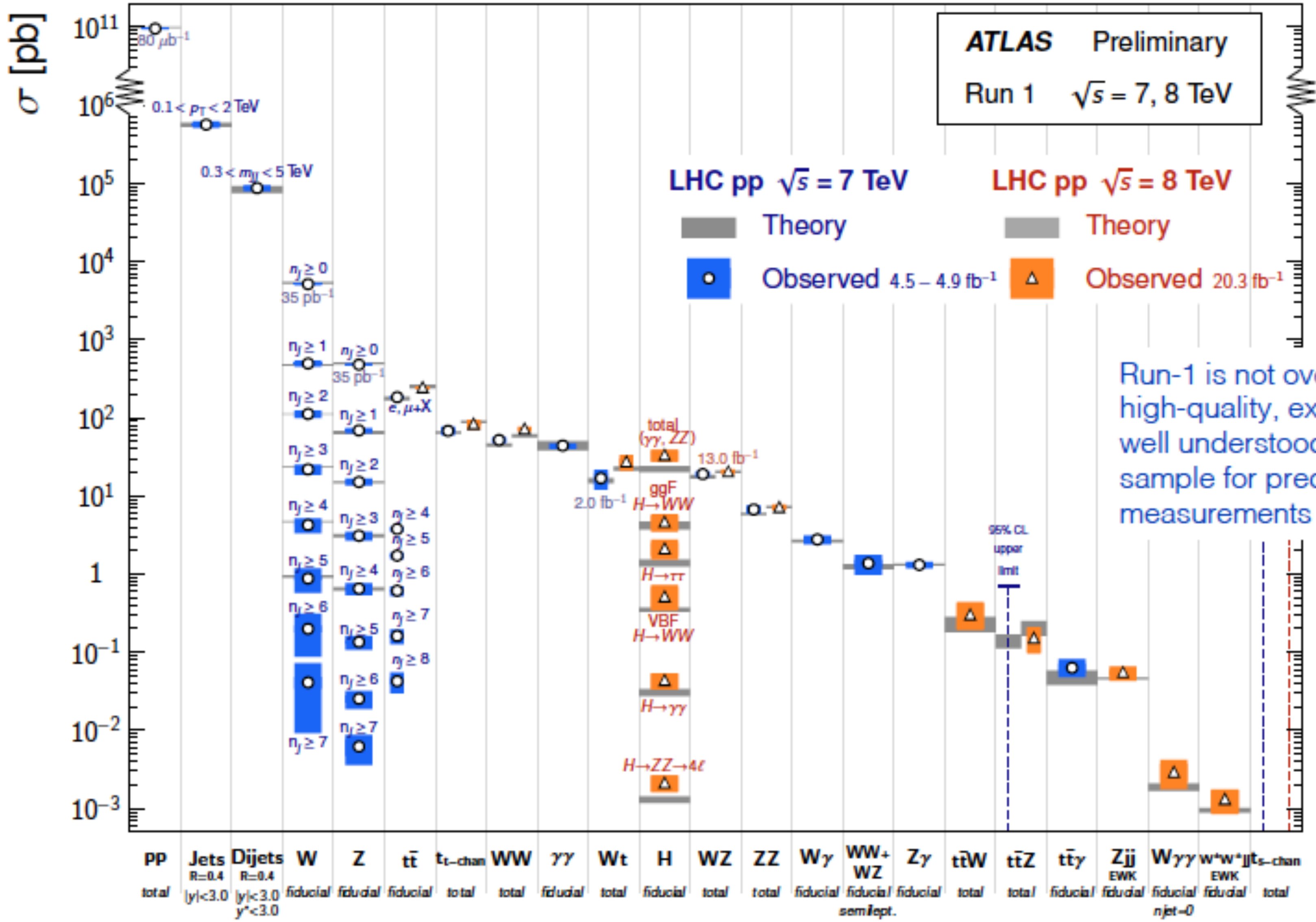


Not unexpectedly, a few of these searches ended up showing some anomaly, a legacy to check in Run-2

LHC Run 1: SM at the GPDs

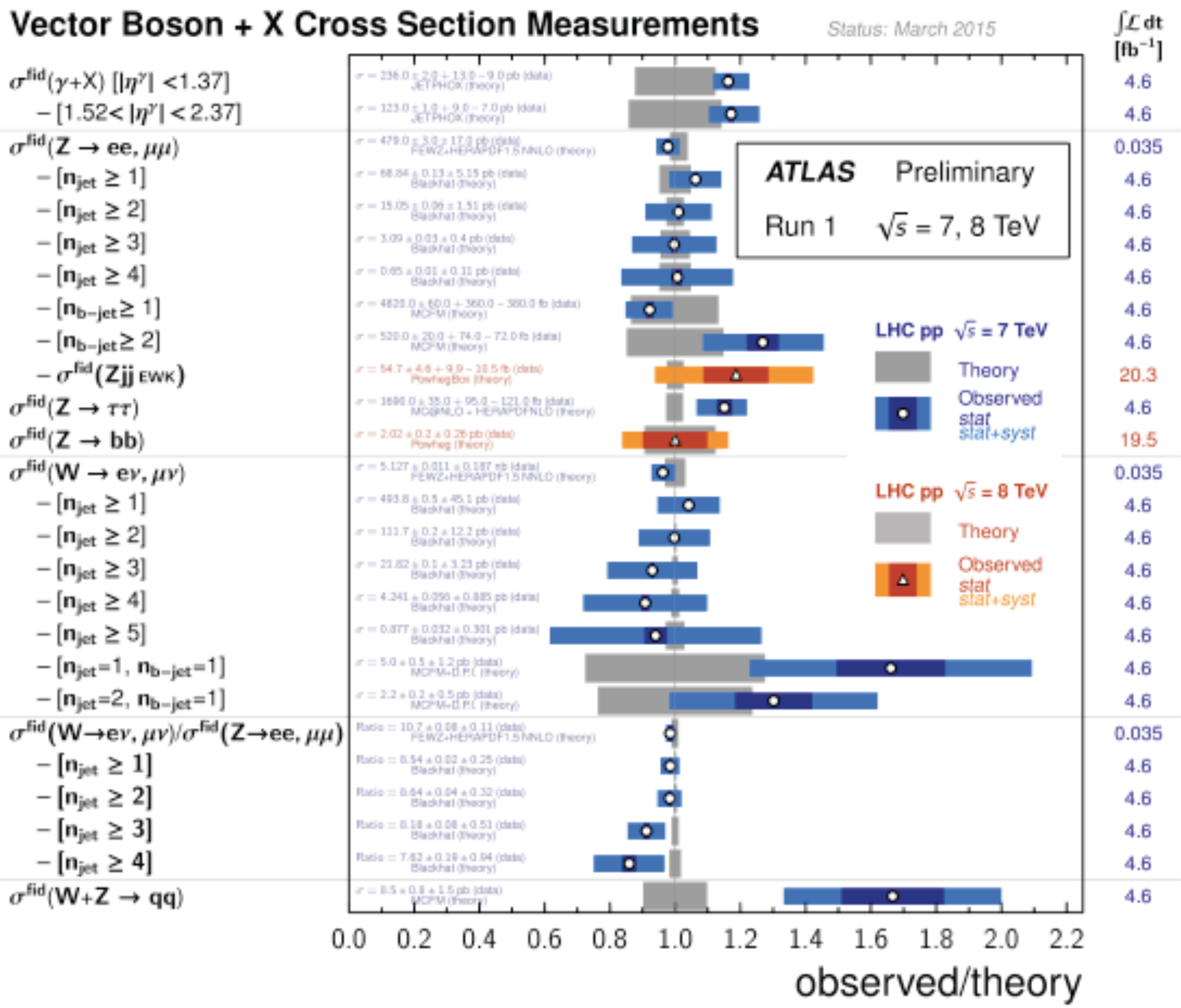
Harvest of results from Run-1 (447 papers to date) confirming predictive power of SM

→ Covered by plenary speakers: Maxime Gouzevitch, Nicholas Hadley, Pierre Savard, Alessandro Tricoli



Run-1 is not over yet: high-quality, extremely well understood data sample for precision measurements

Perturbative QCD: V(+jets)



- V+jets probe different aspects of QCD calculations
- Overall good data-theory agreement over 5 orders of magnitude in cross-sections
- High experimental accuracy exposes discrepancies with predictions

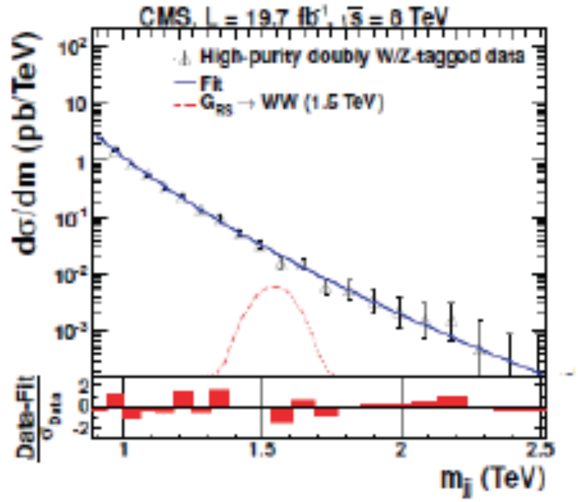
New CMS γγ+jets at 7 TeV
CMS–SMP–14–021
(see backup)

Hints at New Physics? – ATLAS 2 TeV …

VV->qqqq

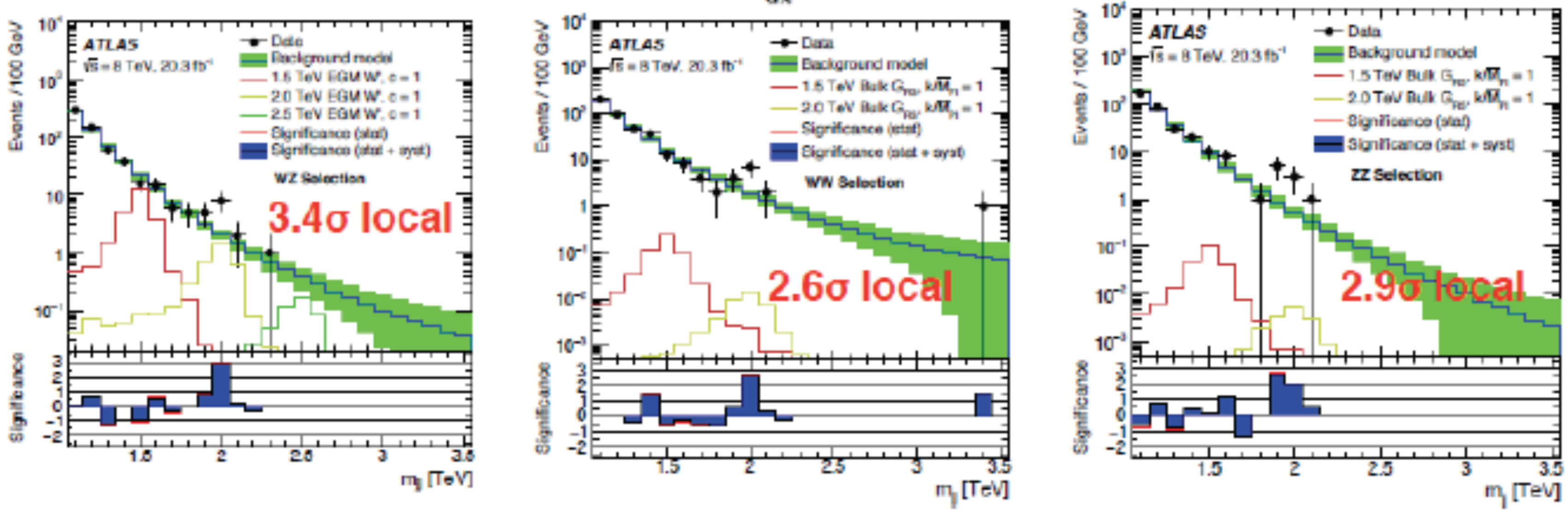
CMS: arxiv:1405.1994

- ATLAS: Trigger on a jet with pt>360 GeV CMS: Trigger on HT
- Only boosted region considered (low mass QCD dominated)
- Select events with Mj within the W/Z mass window
  - ATLAS: $|y_1 - y_2| < 1.2$, Pt Asymmetry <0.15 to reject events where one of the jets is poorly measured
  - 3 overlapping signal regions/non statistically independent
- Additional cuts to reduce QCD (ntrk, nsubjettiness…)
- The background is estimated by fitting the data



ATLAS: arxiv:1506.00962

$$\frac{dn}{dx} = p_1 (1-x)^{p_2 - \xi p_3} x^{p_3},$$

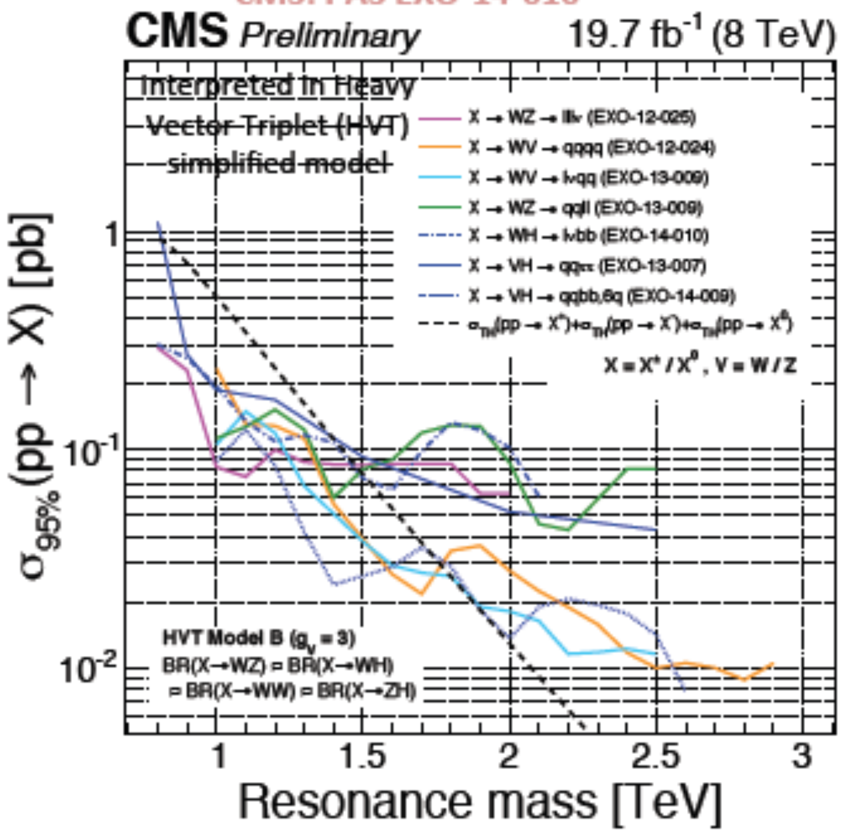


Cavalieri

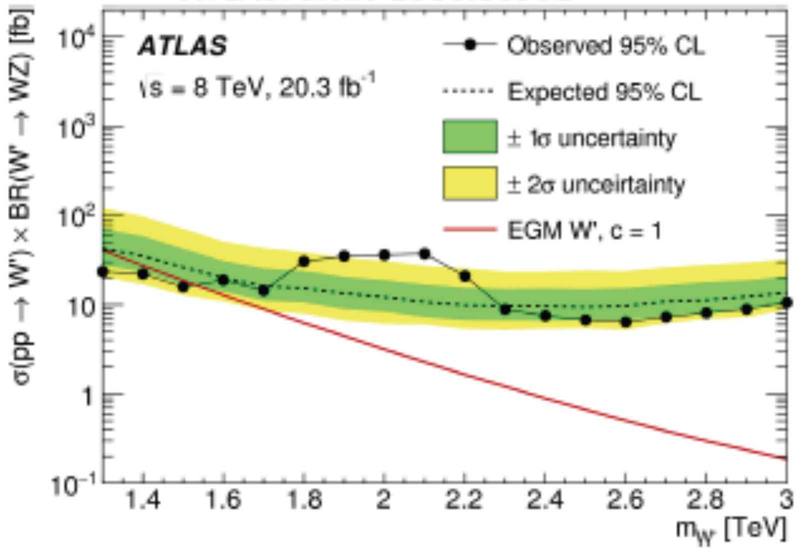
Di-bosons – excess?

- Moderate excesses observed in some channels around 1.8 – 2 TeV
  - Global significance 2 – 2.5 σ
  - Small excesses also in di-jets…
- Excesses of 2σ not unusual, but ATLAS + CMS at similar place = excitement

CMS: PAS EXO-14-010



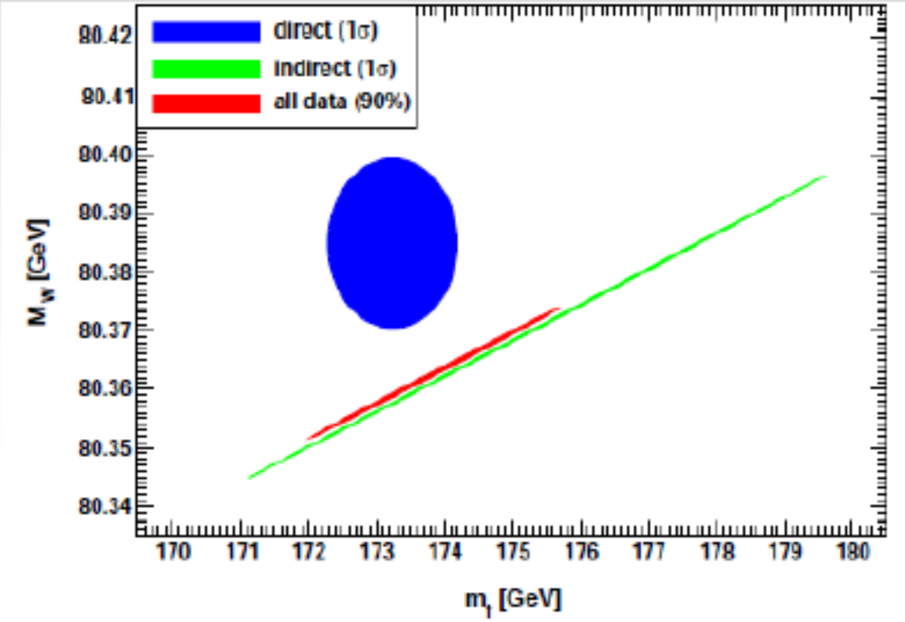
ATLAS: arXiv 1506.00962

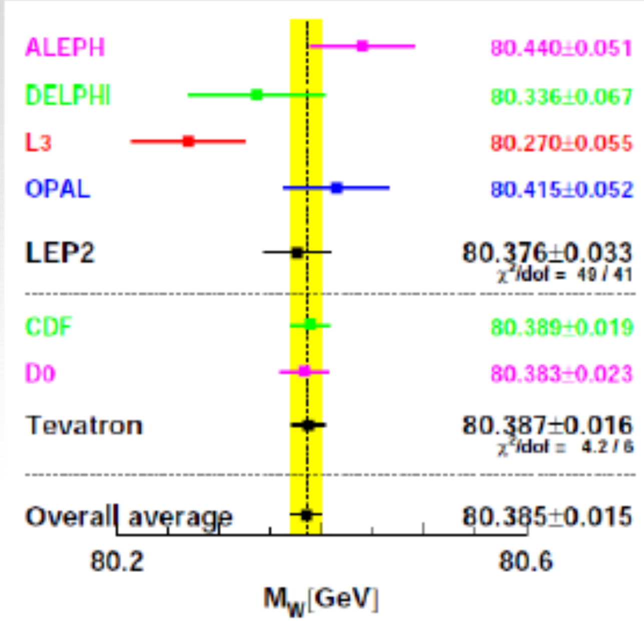


- **Not in all channels…**
- **Will know more after a few first fb^{-1} of Run 2 data**

1.1) High precision W mass

PDG 2015 – CP C38 (2014) 090001

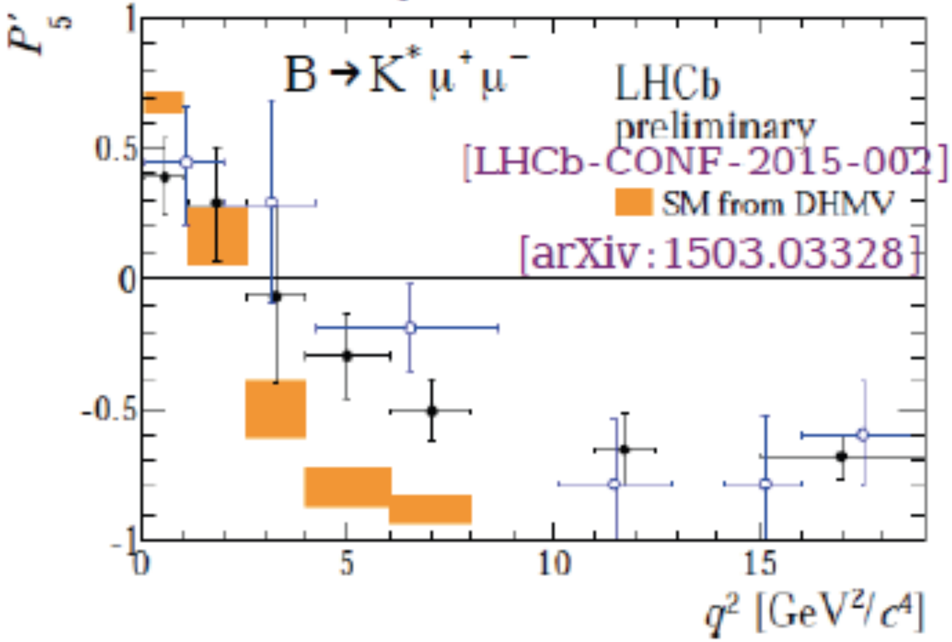




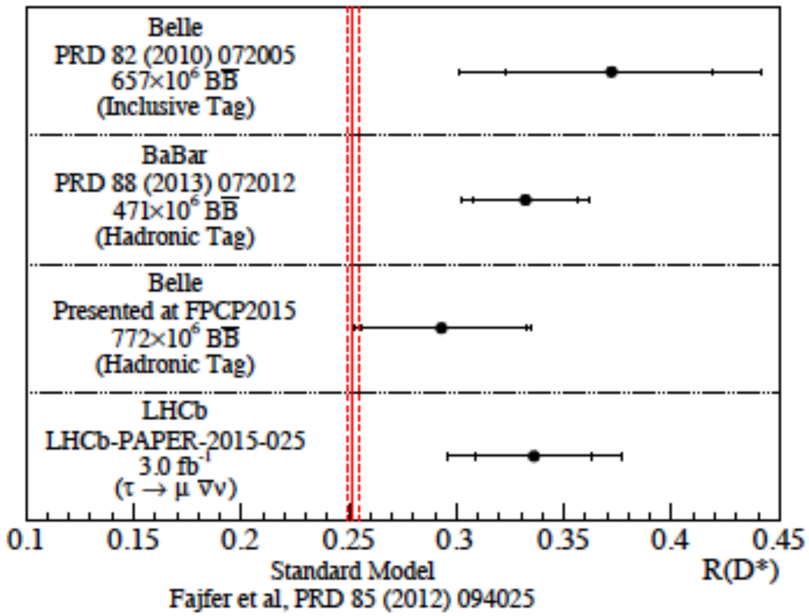
- M_W is the leading uncertainty in SM consistency tests.
- Previous measurements sets a natural goal of O(10 MeV) for the LHC.
  - LEP measurement limited by statistics (N_{WW} = O(40000) events).
  - Tevatron uses DY W → eν/μν events.
  - LHC follow the same trategy: statistics is 100 times larger than LEP one and not a limiting factor.

… motivation for better M_W measurements

⇒ Tension in P'_5 is confirmed with $3fb^{-1}$

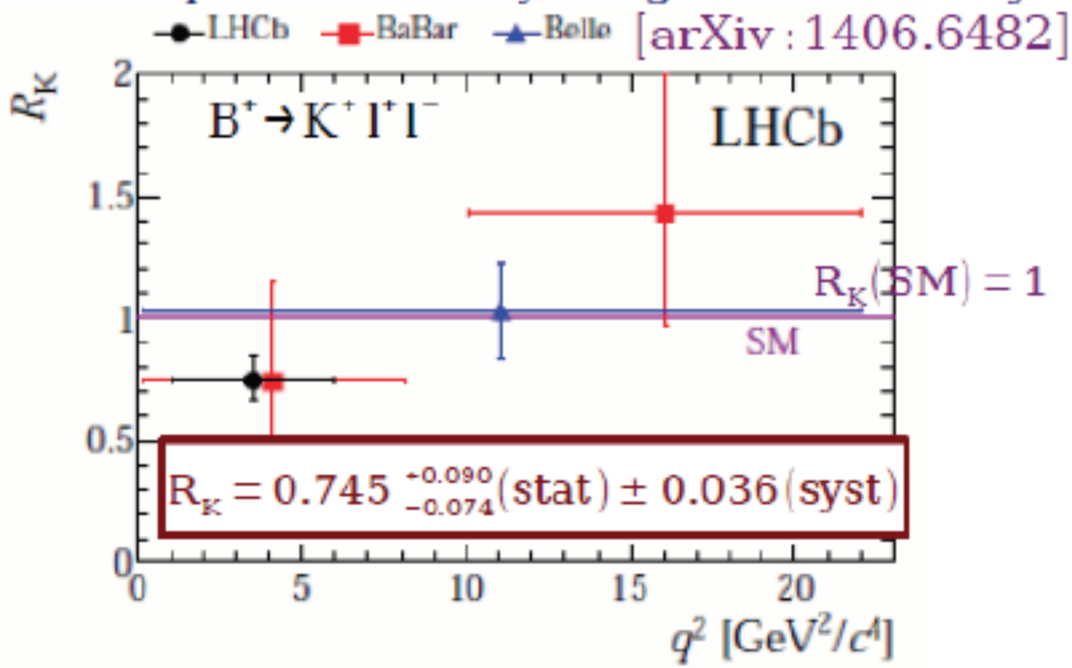


LHCb: “handful of ~3σ anomalies”



$B \to D^* \tau \nu$ [arXiv:1504.06339]

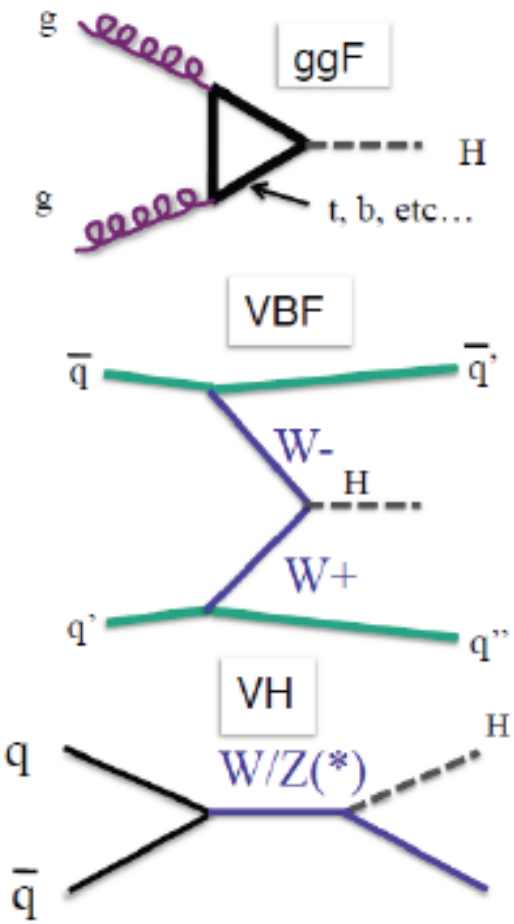
Test of lepton universality using $B^+ \to K^+ l^+ l^-$ decays



LHC Run 1: Higgs

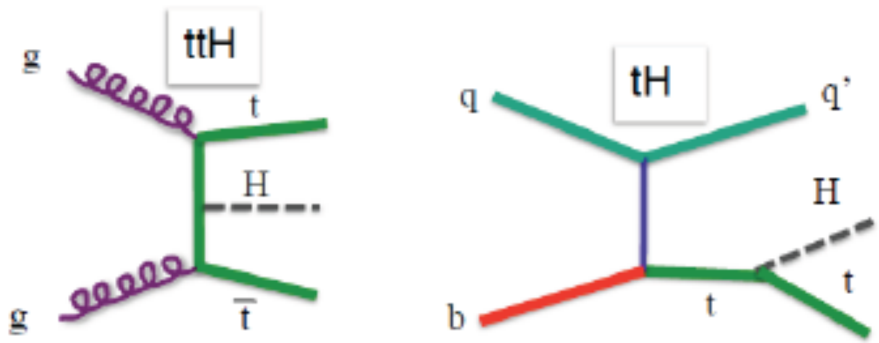
Pierre Savard

Higgs Production at the LHC



	process	8 TeV	13 TeV
ggF	gluon-gluon fusion	19 pb	44 pb
VBF	vector-boson fusion	1.6 pb	3.7 pb
VH	associated production	1.1 pb	2.2 pb
ttH	associated production	0.13 pb	0.51 pb
tH	Associated production	~20 fb	~90 fb

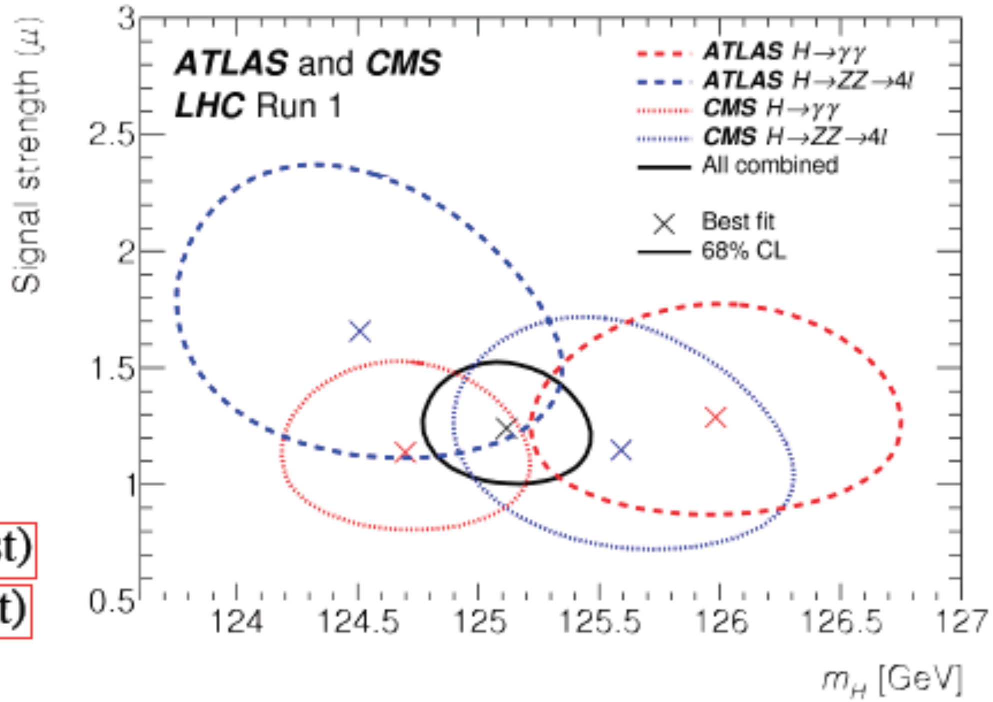
SM Production Modes
(M_H = 125 GeV)



Higgs Mass

The SM does not predict the Higgs boson mass: we need to measure it

Given a mass, we can make predictions* for the production cross section and decay rates



Higgs mass measurements (GeV):

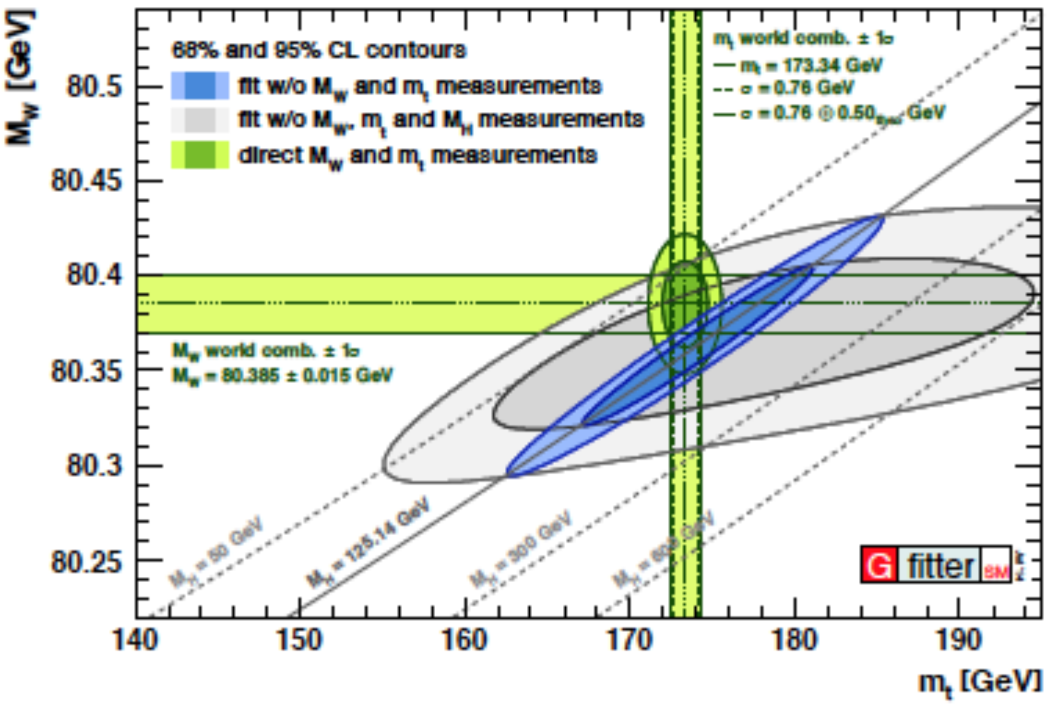
ATLAS: 125.36 ± 0.37 (stat) ± 0.18 (syst)
CMS: 125.02 ± 0.27 (stat) ± 0.15 (syst)

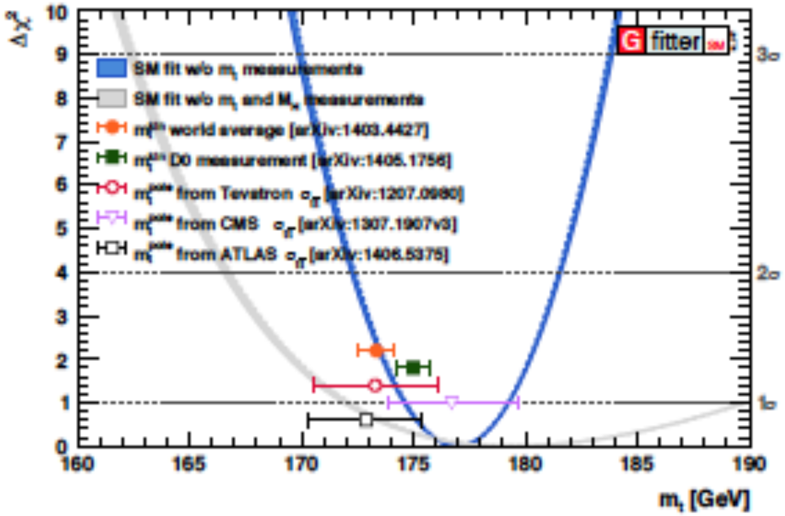
Precision measurement: <0.2%

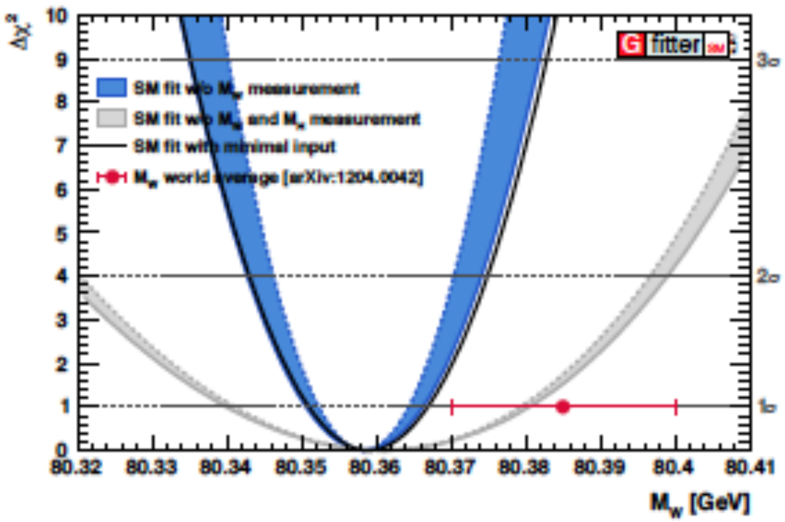
LHC combination:
125.09 ± 0.21 (stat) ± 0.11 (syst)

*a lot of progress by theory community, LHCXSWG. Improvements continue…

Impact of Higgs Mass Measurement on Electroweak Fits

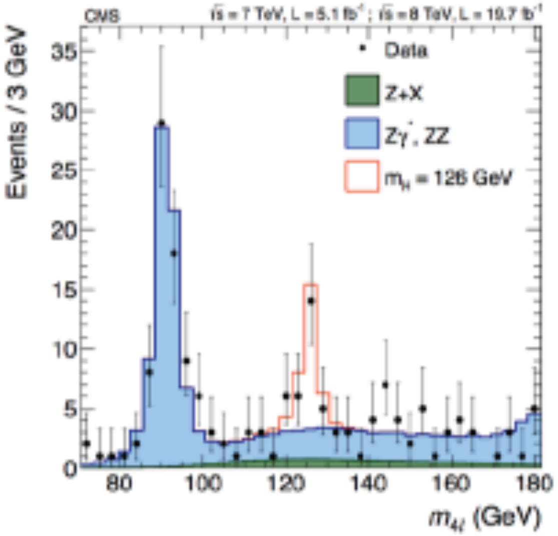


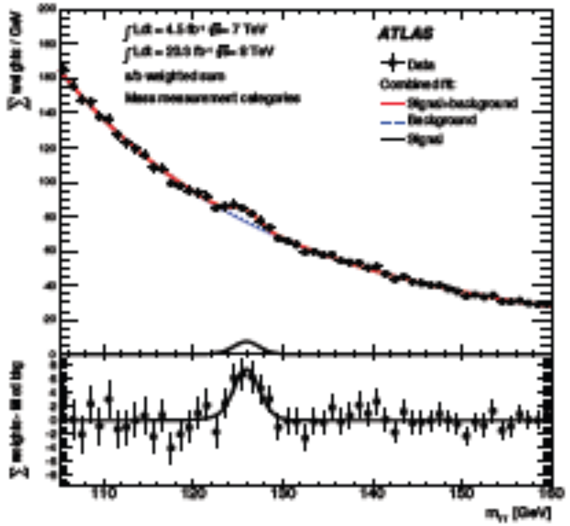


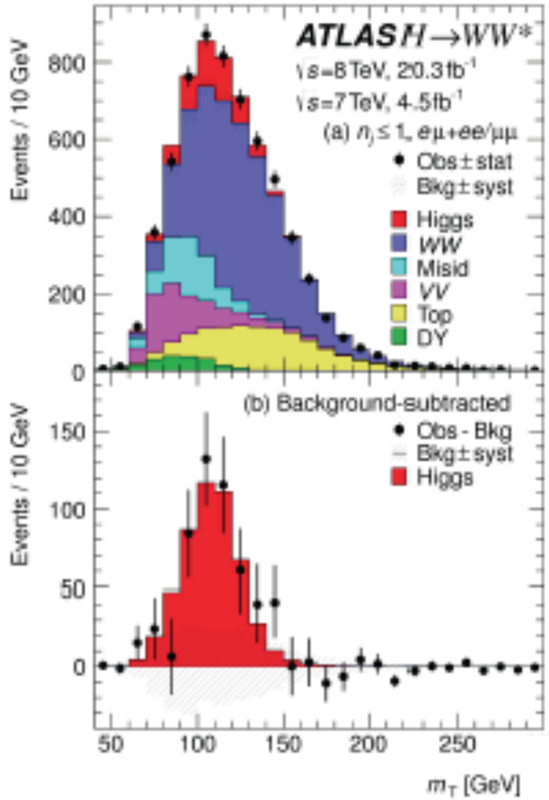


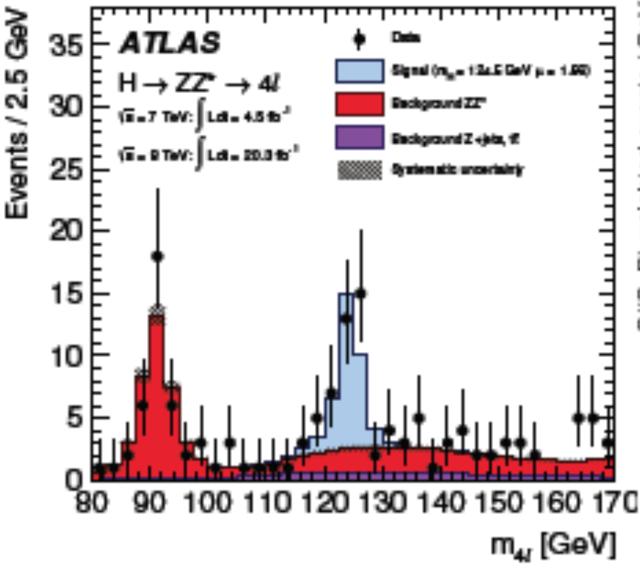
Eur. Phys. J. C 74, 3046 (2014)

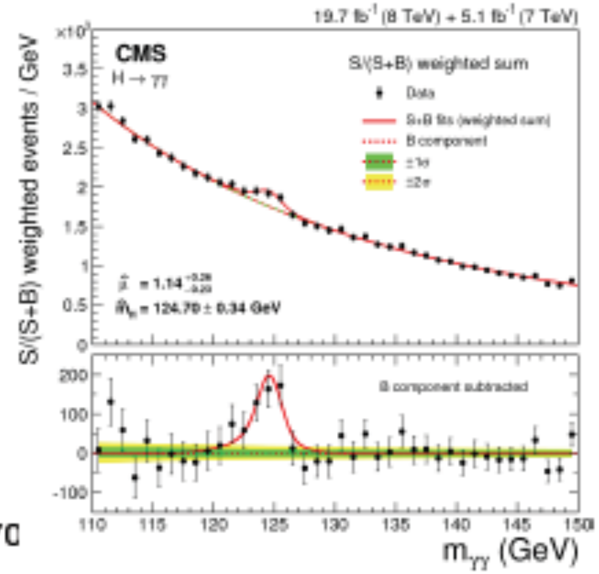
5σ Observation in all Decays to Bosons

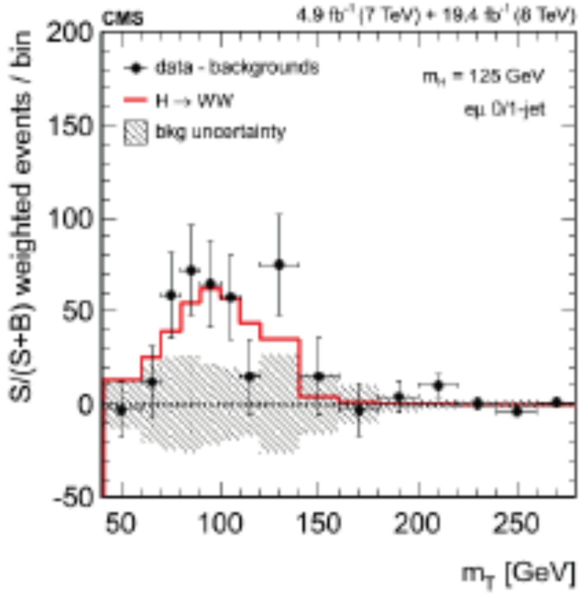










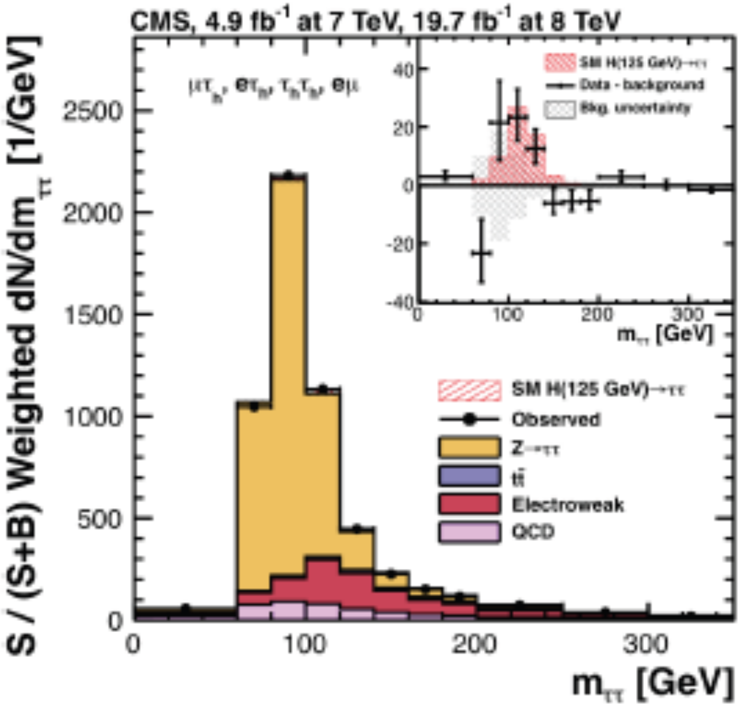


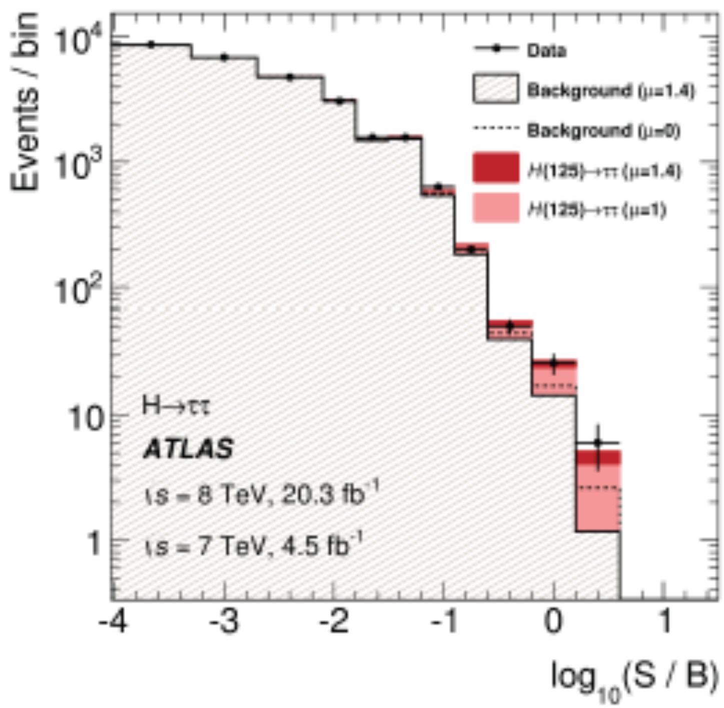
DECAYS TO FERMIONS (ττ)

Significance obs. (exp.)

CMS:
- **3.2 (3.7) σ**

ATLAS:
- **4.5 (3.4) σ**





ττ above 5σ if you do a “naiive combination”

Decays to Fermions (bb)

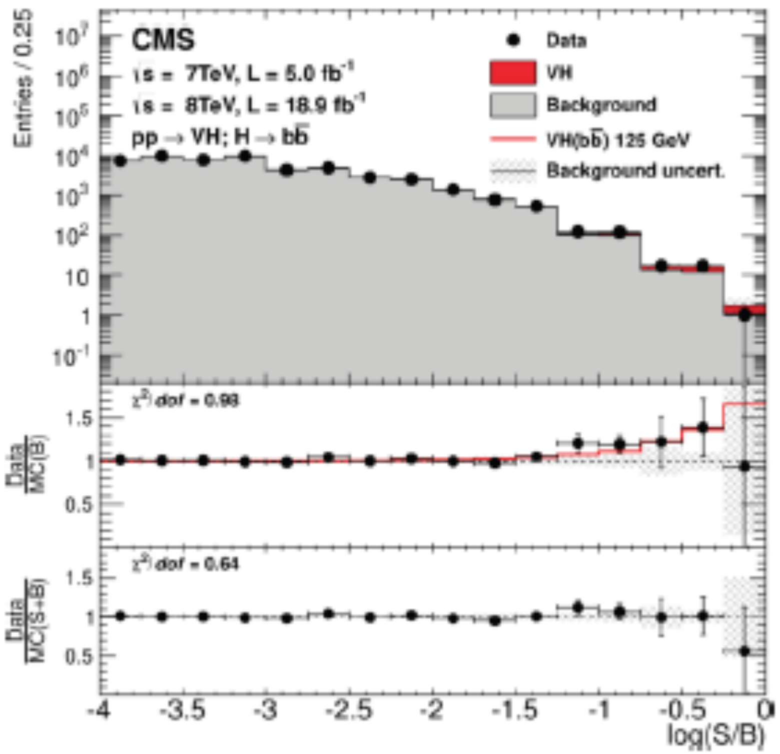
… big target at Run 2

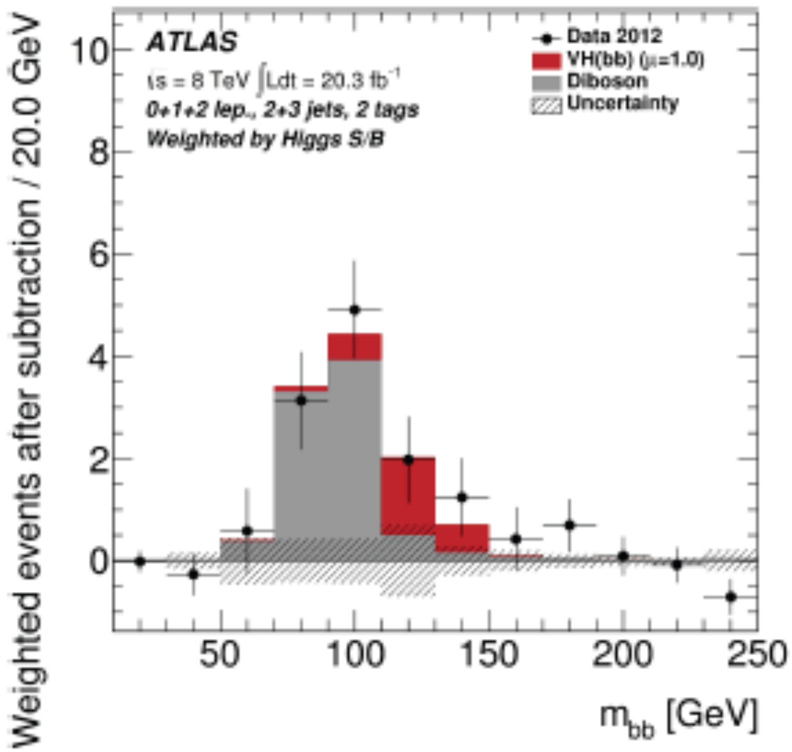
Significance obs. (exp.)

CMS(VH+VBF*+ttH):
- 2.6 (2.7) σ

Tevatron(VH):**
- 2.2 (1.4) σ

ATLAS(VH+ttH):
- 1.8 (2.8) σ





*NEW! arXiv:1506.01010

**my estimate from: Phys. Rev. D 88, 052014 (2013)

Status of SM Rare Decays

Searches for rare decays performed in various channels

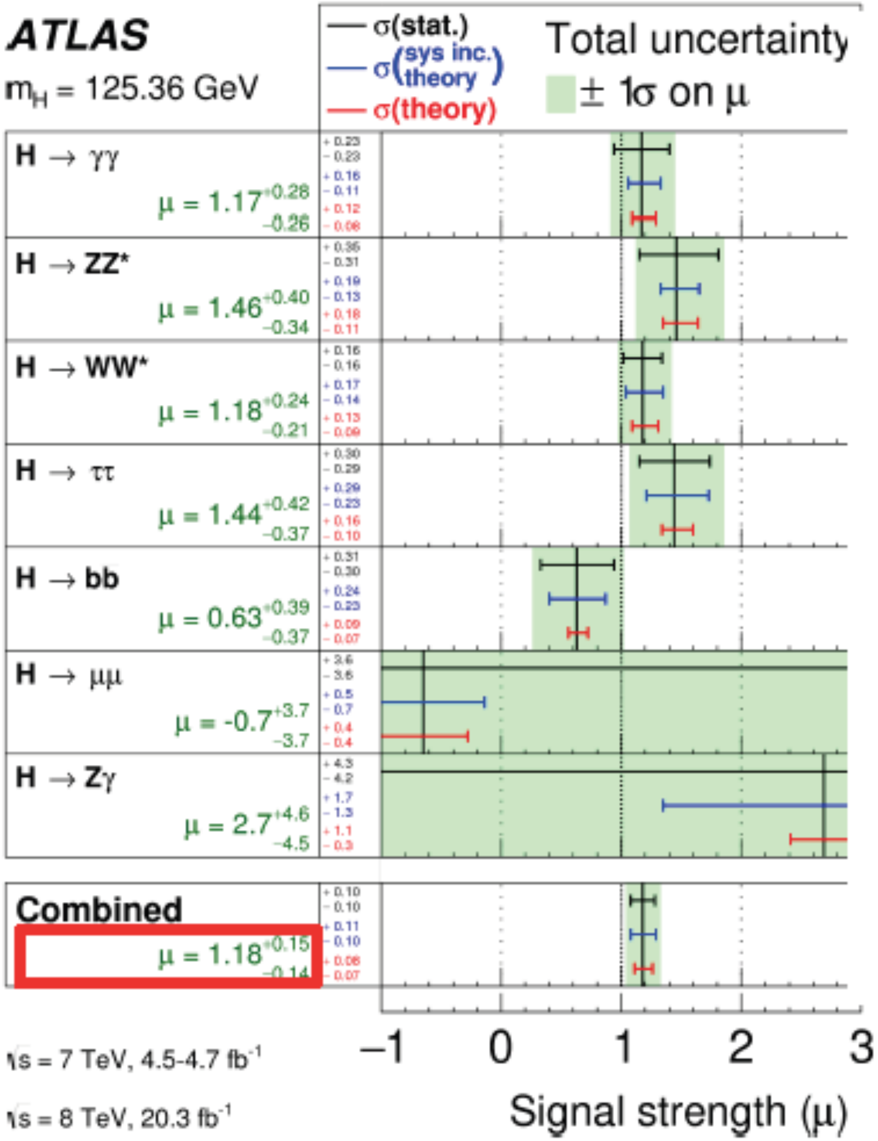
Observation of these decays in Run 1 would signal BSM physics

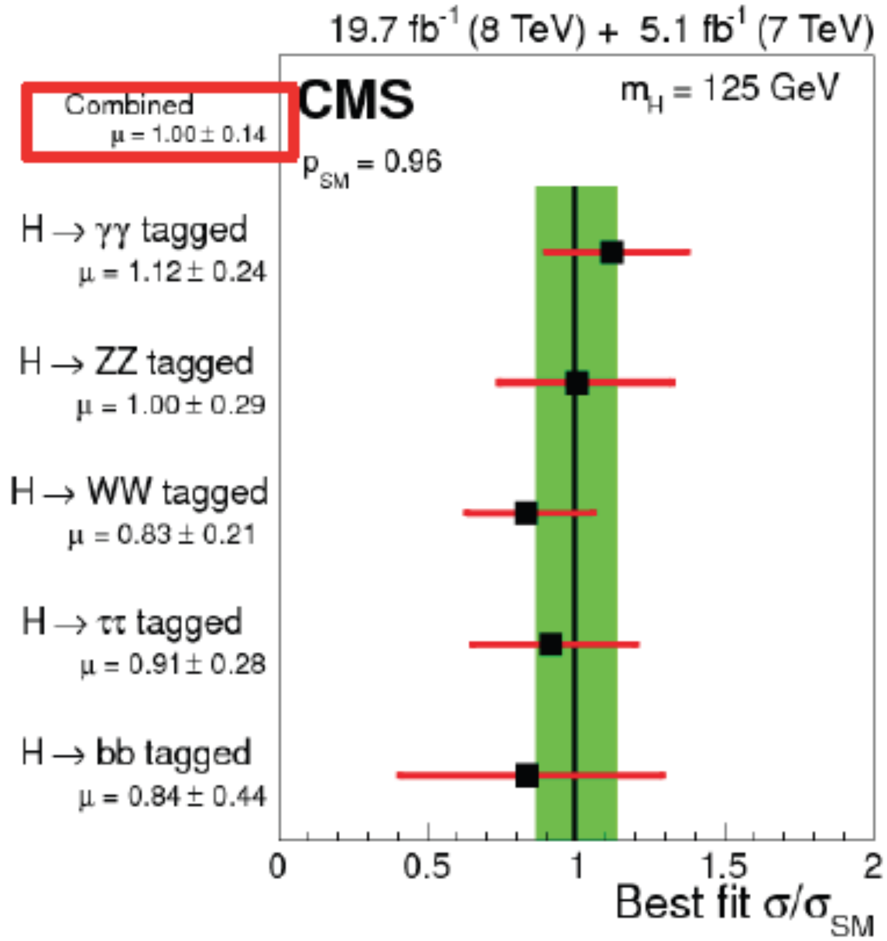
Non-universal coupling of Higgs to leptons:

- $\mu\mu$ signal would be 280 times larger than SM if μ coupling was equal to that of τ

Process	limit (times SM)
$\mu\mu$ (ATLAS)	7.0
$\mu\mu$ (CMS)	7.4
$Z\gamma$ (ATLAS)	11
$Z\gamma$ (CMS)	9
$\gamma\gamma^*$ (CMS)	7.7
$J/\psi\gamma$ (ATLAS)	540
$J/\psi\gamma$ (CMS)	540
ee(CMS)	10^5

Signal Strength for Decay Modes



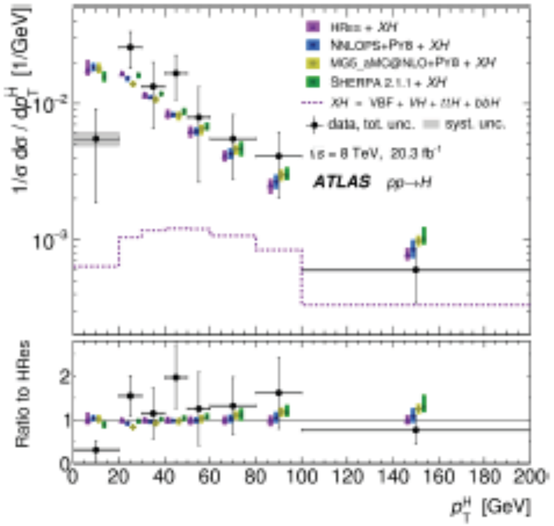


ATLAS: individual μ values from combination of channels
CMS: individual μ values from tagged analyses

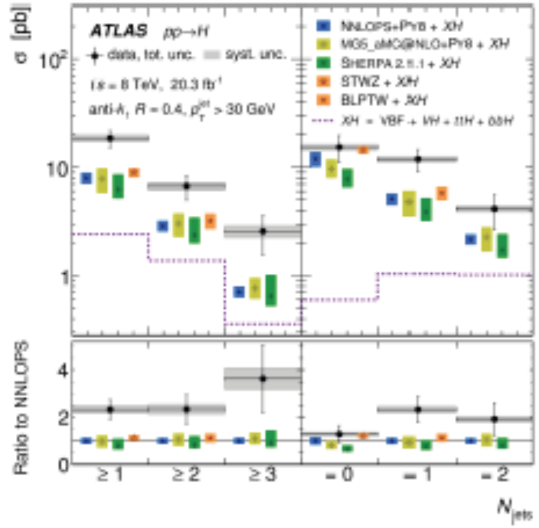
DIFFERENTIAL CROSS SECTIONS (ATLAS)

SM Higgs theory predictions for kinematics: combination of $\gamma\gamma$ and ZZ

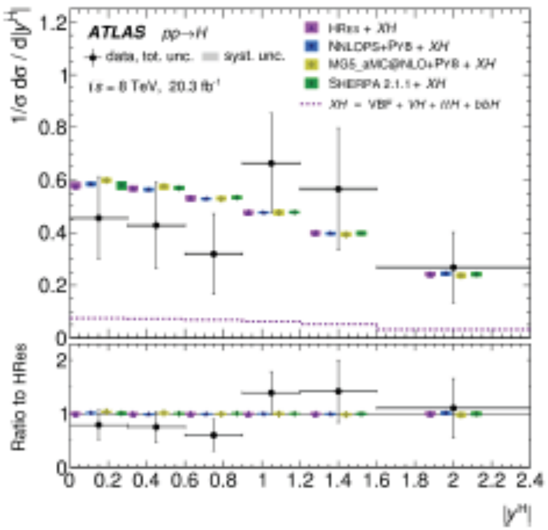
$p_T(H)$



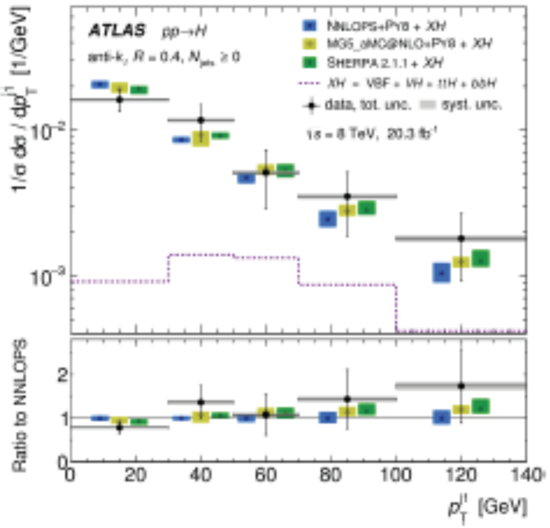
N_{jets}



$|y|(H)$



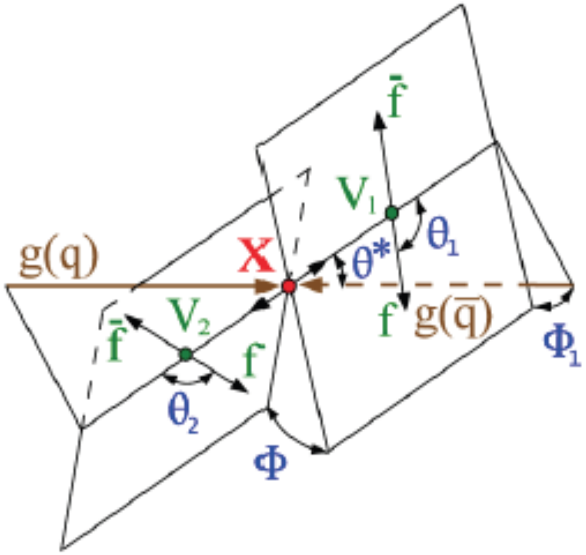
$p_T(j_1)$



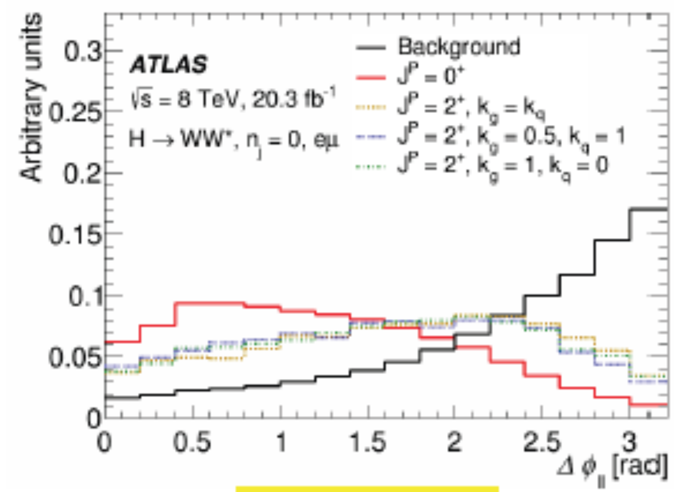
SPIN/CP HYPOTHESES TESTS

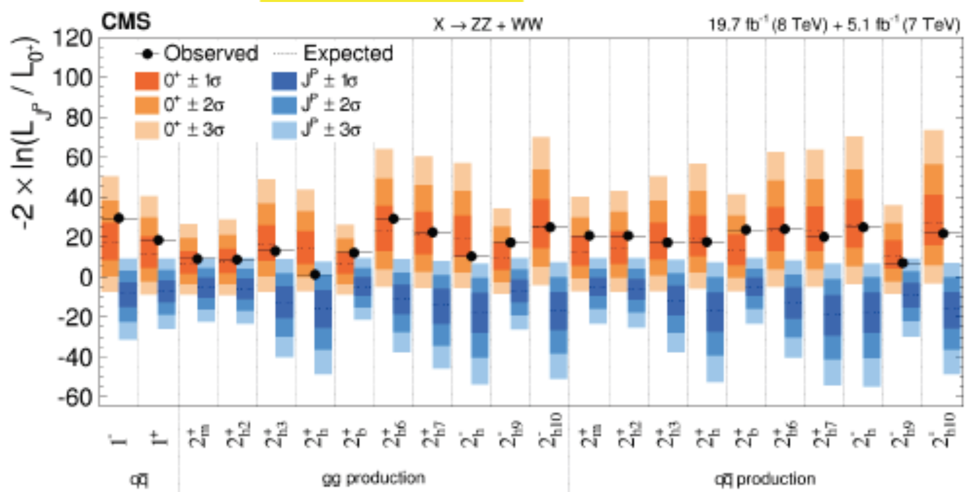
Tests of spin/CP properties performed in ZZ, $\gamma\gamma$, WW channels

ZZ: full kinematic information available for spin/CP determination



WW spin information from kinematic variables



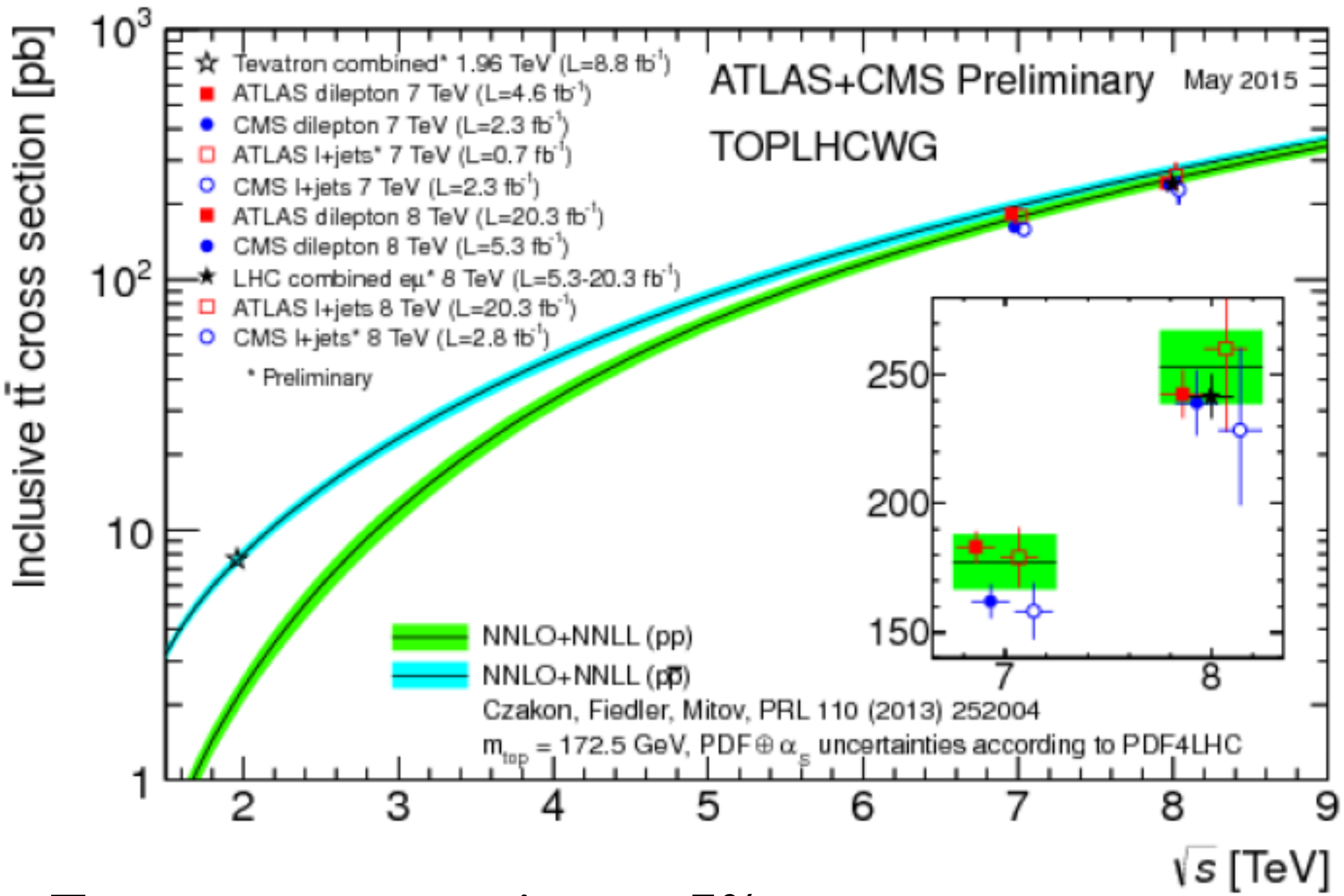


- 0⁺ Higgs is
- favoured over 2⁺
- All other possibilities ruled out at >99.9% confidence

… Higgs is looking very Standard Model-like …

Top Physics (Hadley)

Ttbar Cross Section vs √s



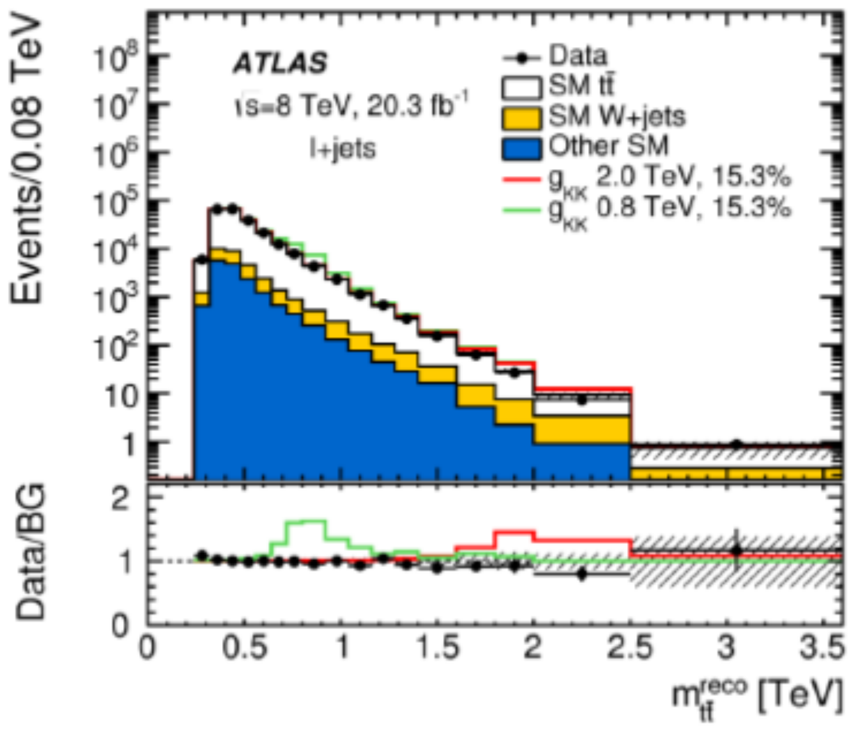
8 TeV
≈ 1.2M – 5M ttbar pairs
Uncertainty 4%

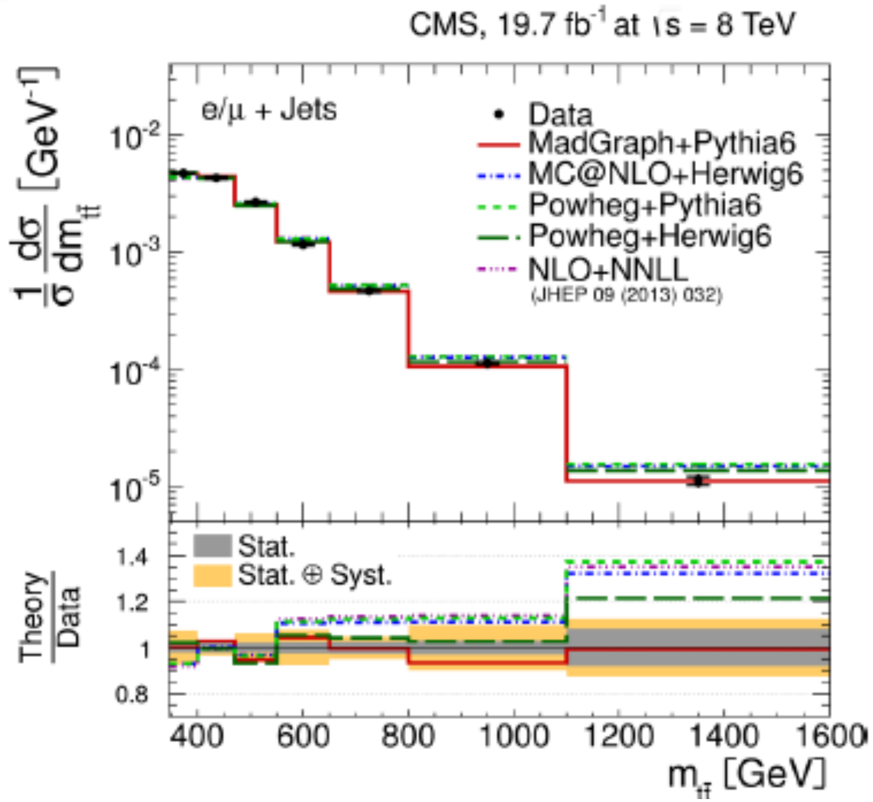
7 TeV
≈170,000 ttbar pairs
Uncertainty 5%

Tevatron uncertainty ~ 5%

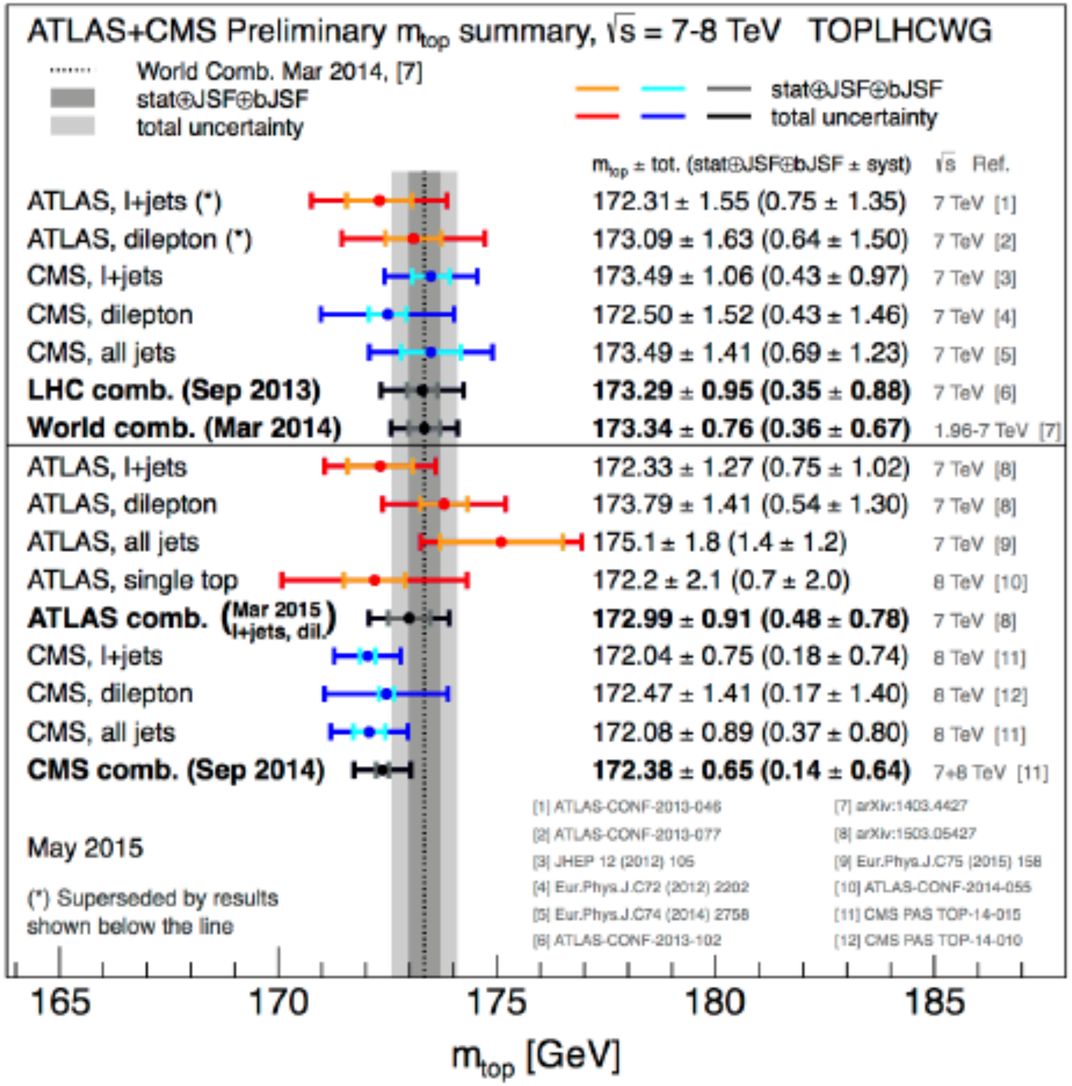
Top Physics at Run 1 (Hadley)

Ttbar differential distributions – LHC





Top Mass LHC



Perhaps some tension

Tevatron 174.34 ± 0.64 GeV

CMS 172.38 ± 0.65 GeV
ATLAS 172.99 ± 0.91 GeV

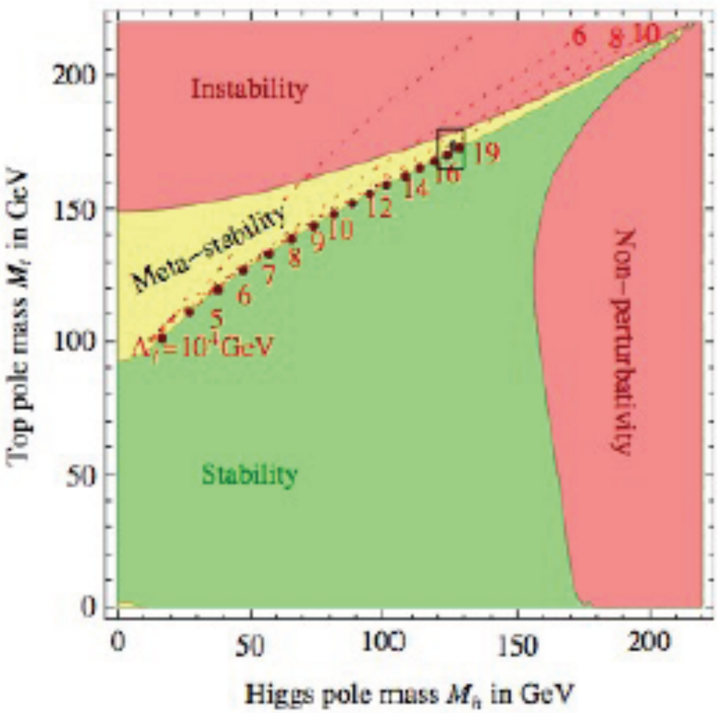
Higgs and Top Masses and the Stability of the Universe

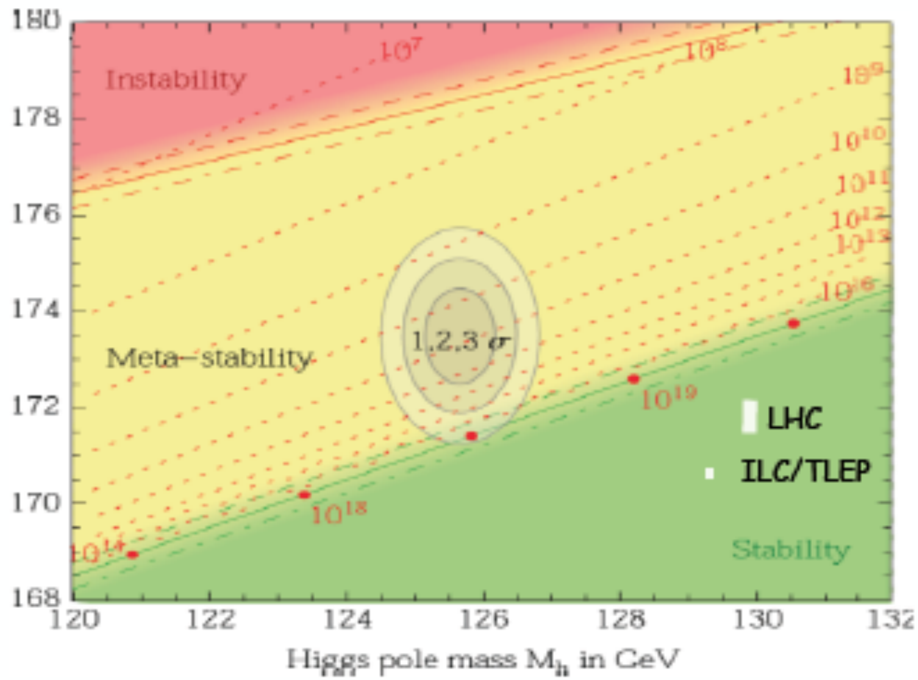
Vacuum Meta-stability

[Buttazzo et al 2013, Bezrukov et al 2013, Degrassi et al 2012]

Naturalness: an explanation waiting for facts.

Meta-stability: a fact waiting for an explanation.





Vacuum meta-stability theory assumes SM works to GUT scale

Special session on Saturday afternoon on PP & Cosmology

	The particle physics / cosmology connection	*Raphael FLAUGER*	*Audi Max*	14:30 - 15:00
15:00	**The Higgs field and the early universe**	*Fedor BEZRUKOV*	*Audi Max*	15:00 - 15:30
	The future of observational cosmology / prospects for understanding dark energy	*Reynald PAIN*	*Audi Max*	15:30 - 16:00

The Higgs field and the early universe

Fedor Bezrukov

University of Connecticut
&
RIKEN-BNL Research Center

EPS HEP 2015
22–29 July 2015
Vienna, Austria

University of Connecticut

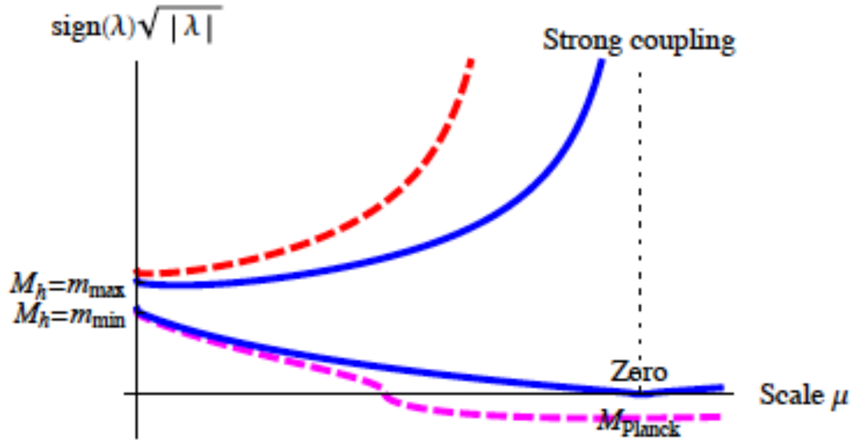
BROOKHAVEN NATIONAL LABORATORY

Probably my favourite talk at the meeting.

… thought I understood it at the time …

Standard Model self-consistency and Radiative Corrections

- Higgs self coupling constant λ changes with energy due to radiative corrections.



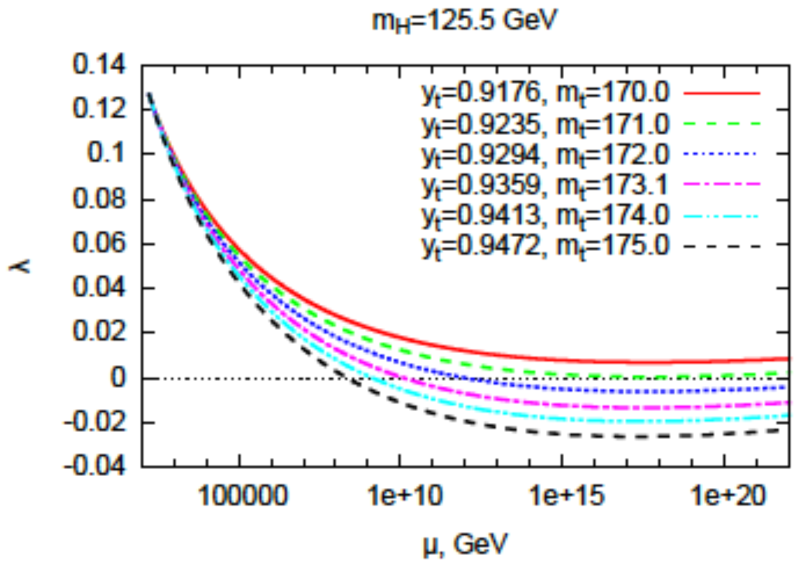
$$(4\pi)^2\beta_\lambda = 24\lambda^2 - 6y_t^4 + \frac{3}{8}(2g_2^4 + (g_2^2 + g_1^2)^2) + (-9g_2^2 - 3g_1^2 + 12y_t^2)\lambda$$

- Behaviour is determined by the masses of the Higgs boson $m_H = \sqrt{2\lambda}v$ and other heavy particles (top quark $m_t = y_t v/\sqrt{2}$)
- If Higgs is heavy $M_H > 170$ GeV – the model enters *strong coupling* at some low energy scale – new physics required.

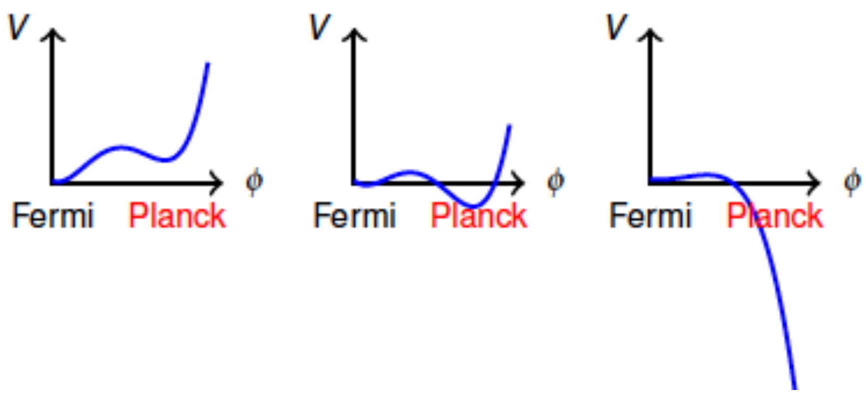
Lower Higgs masses: RG corrections push Higgs coupling to negative values

- For Higgs masses $M_H < M_{\text{critical}}$ coupling constant is negative above some scale μ_0.
- The Higgs potential may become negative!
  - Our world is not in the lowest energy state!
  - Problems at some scale $\mu_0 > 10^{10}$ GeV?

Coupling λ evolution:

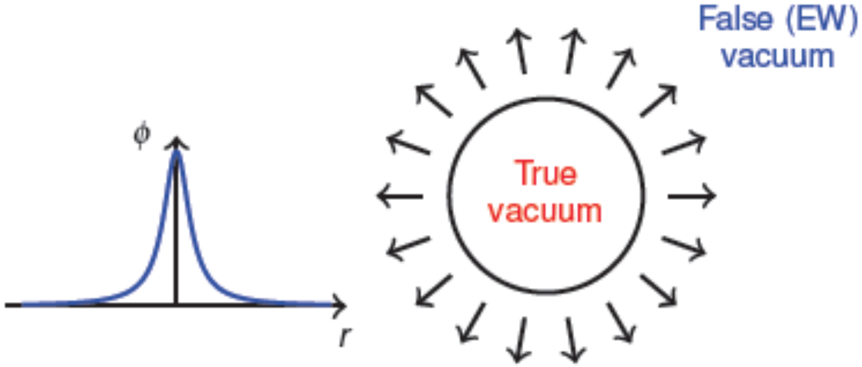


Higgs potential $V(\phi) \simeq \lambda(\phi)\frac{\phi^4}{4}$



What to do if we are metastable?

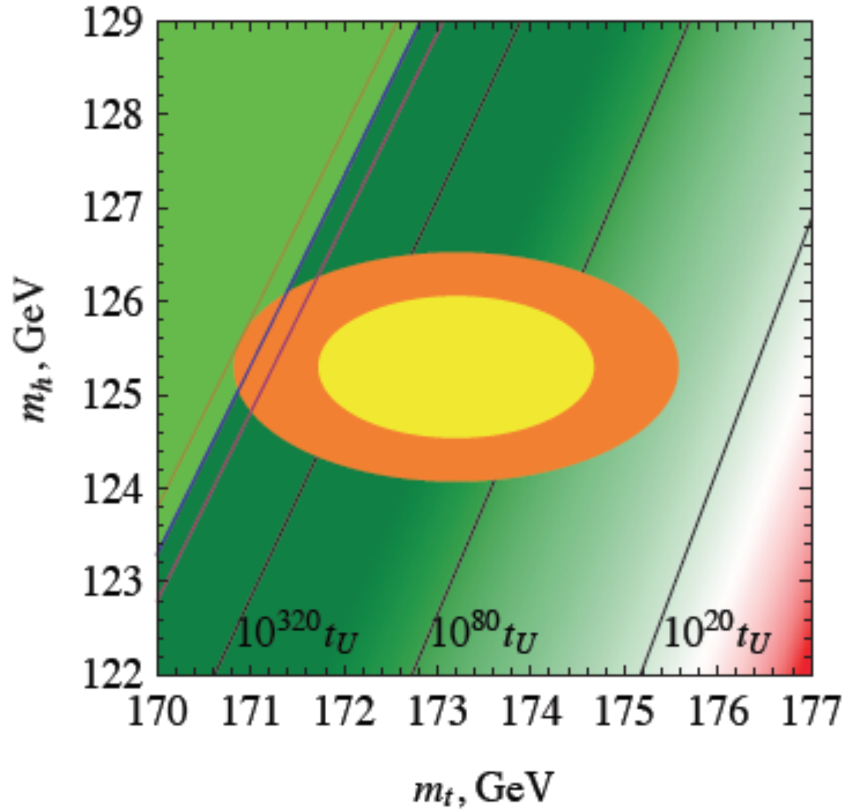
Vacuum decays by creating bubbles of true vacuum, which then expand very fast ($v \to c$)



Tunneling suppression:

$$p_{\text{decay}} \propto e^{-S_{\text{bounce}}} \sim e^{-\frac{8\pi^8}{3\lambda(h)}}$$

Lifetime $\gg$ age of the Universe!

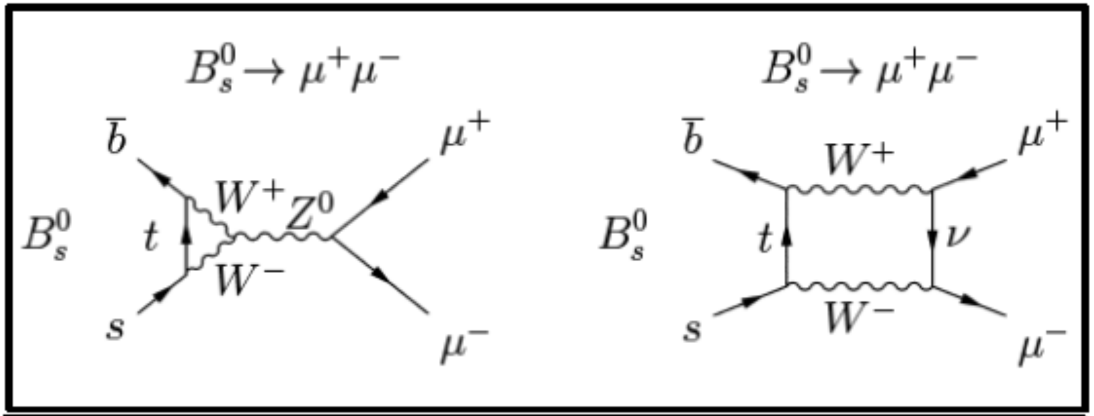


… it appears we're safe, but would be good to know top and Higgs masses more accurately nonetheless ☺

Rare and Exotic Decays / Particles in Flavour Physics (Trabelsi)

$B_{(s)} \to \mu\mu$: ultra rare processes...

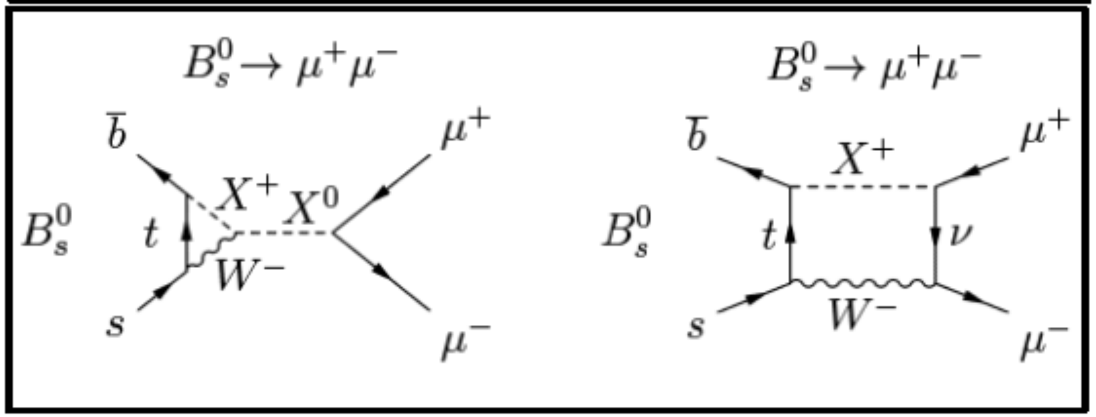
loop diagram + suppressed in SM + theoretically clean =
an excellent place to look for new physics



higher-order FCNC allowed in SM

$\mathcal{B}(B_s \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$
$\mathcal{B}(B_d \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$

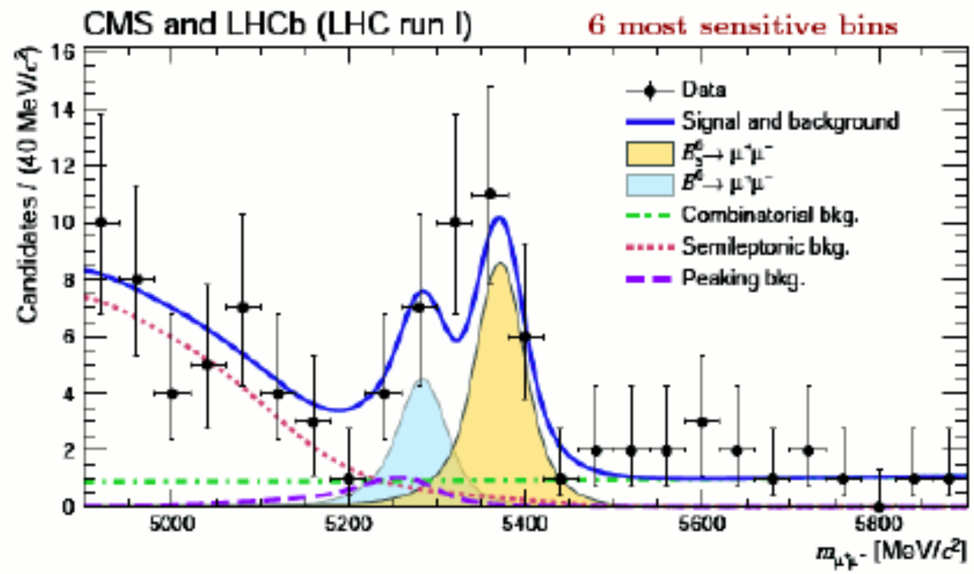
[Bobeth et al, PRL 112 (2014) 101801]



same decay in theories extending the SM (some of NP scenarios may boost the $B \to \mu\mu$ decay rates)

Combination results $B_{(s)} \to \mu^+ \mu^-$ [arXiv:1411.4413]

published in Nature

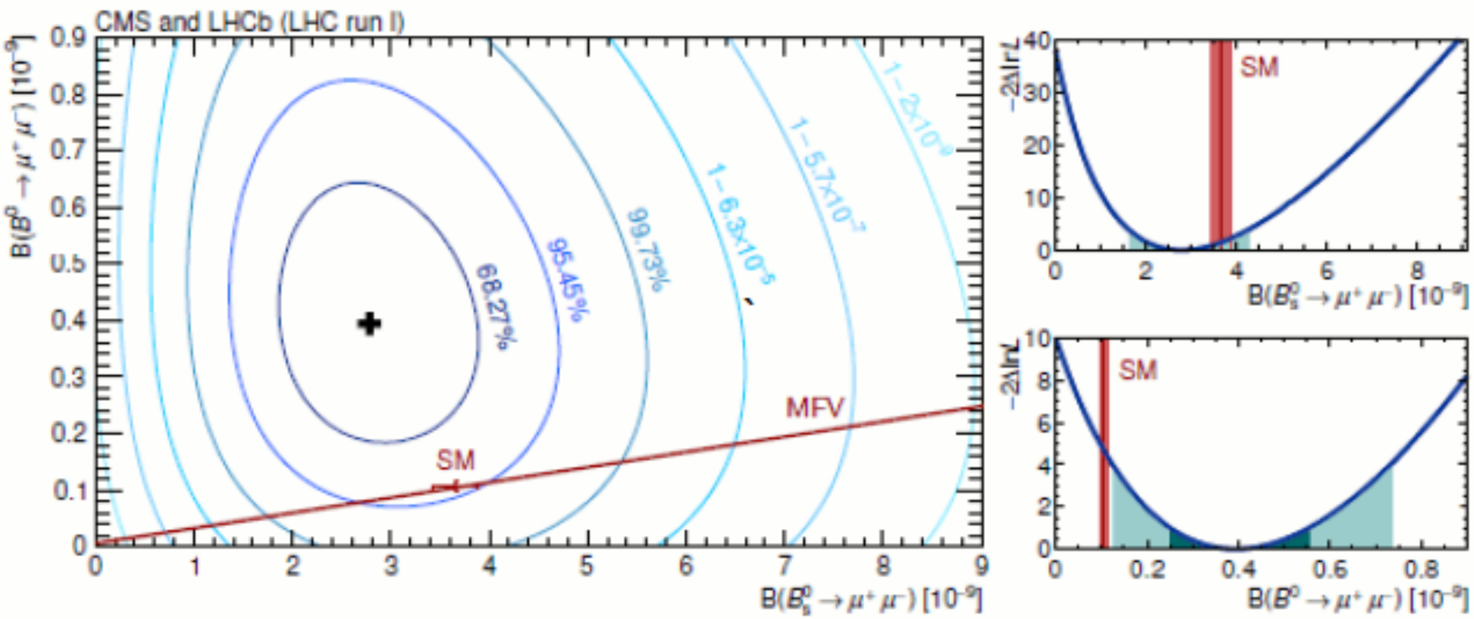


$B(B_s^0 \to \mu^+ \mu^-) = (2.8\,^{+0.7}_{-0.6}) \times 10^{-9}$

first observation: 6.2σ significance

$B(B^0 \to \mu^+ \mu^-) = (3.9\,^{+1.6}_{-1.4}) \times 10^{-10}$

first evidence: 3.0σ significance

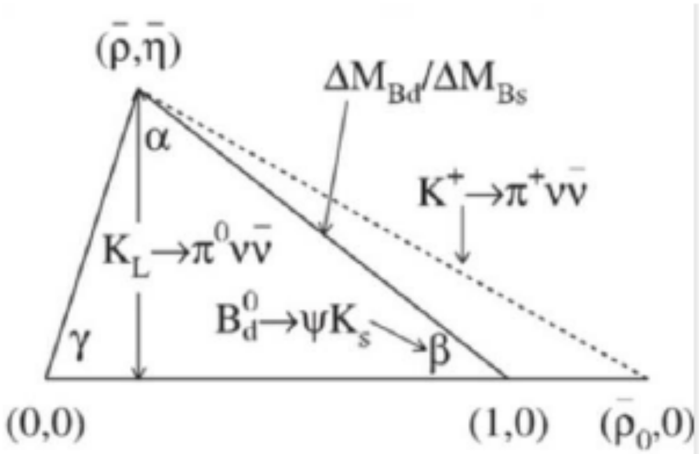


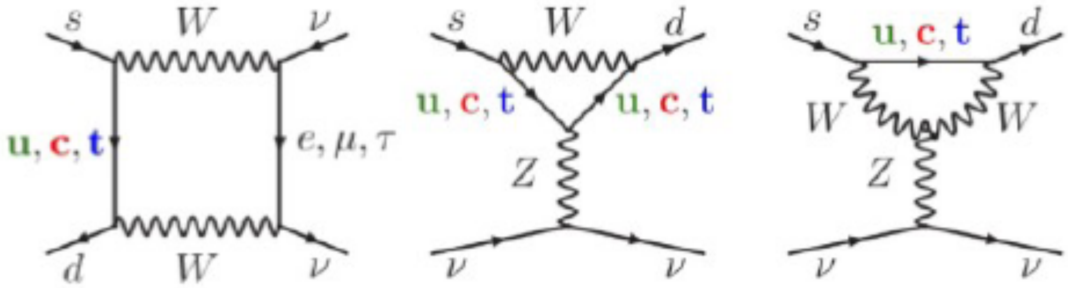
and more to come...

[Talk by Kai-Feng Chen for CMS, arXiv:1208.3355 for LHCb]

Rare Kaon Decays: $K^+ \to \pi^+ \nu \bar{\nu}$ [Talk by Vito Palladino]

$$B_{SM}(K^+ \to \pi^+ \nu \bar{\nu}) = (9.1 \pm 0.7) \times 10^{-11}$$





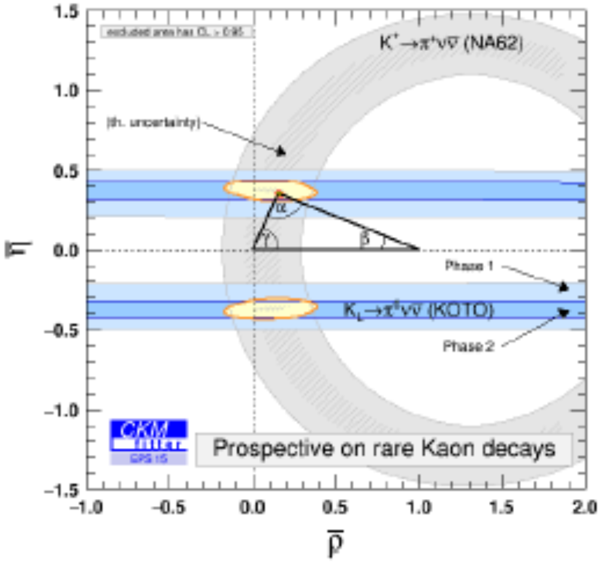
BNL E787/949

$$B(K^+ \to \pi^+ \nu \bar{\nu}) = (1.73^{+1.15}_{-1.15}) \times 10^{-10}$$

– NA62 goal

Aim to collect o(100) events in 2 years of data

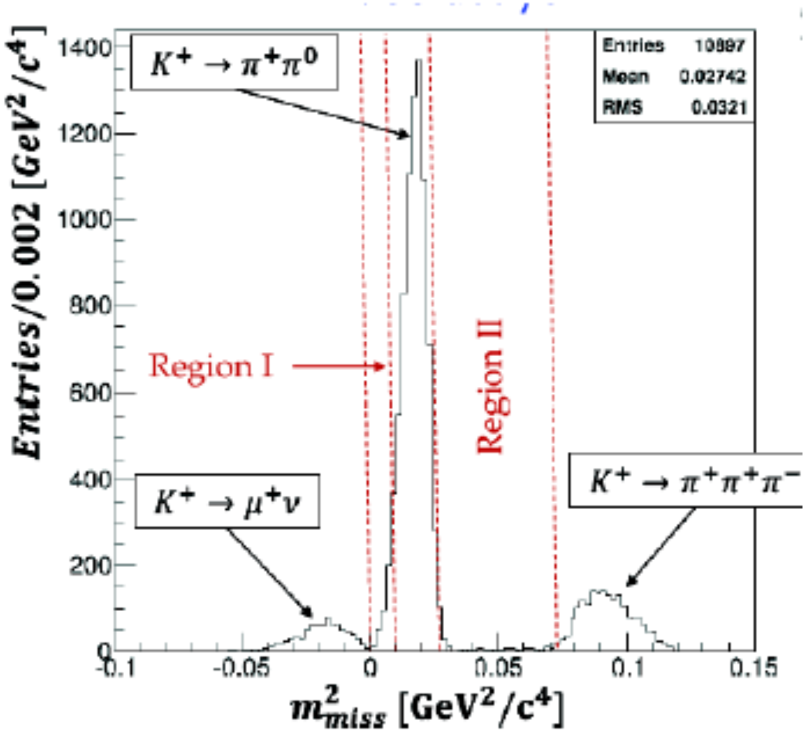
⇒ 10% precision



– NA62 status 2014 pilot run (Oct-Dec 2014)

5-20% of nominal beam intensity

almost all detectors fully commissioned



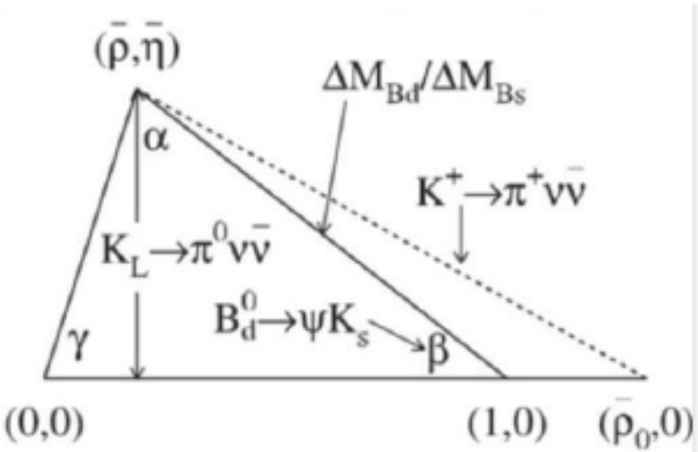
first look at 2014 data

reprocessing data withcomplete calibration

⇒ 2015 run: July to November

Rare Kaon Decays: $K_L \to \pi^0 \nu \bar{\nu}$

$B_{SM}(K_L^0 \to \pi^0 \nu \bar{\nu}) = (3.0 \pm 0.3) \times 10^{-11}$

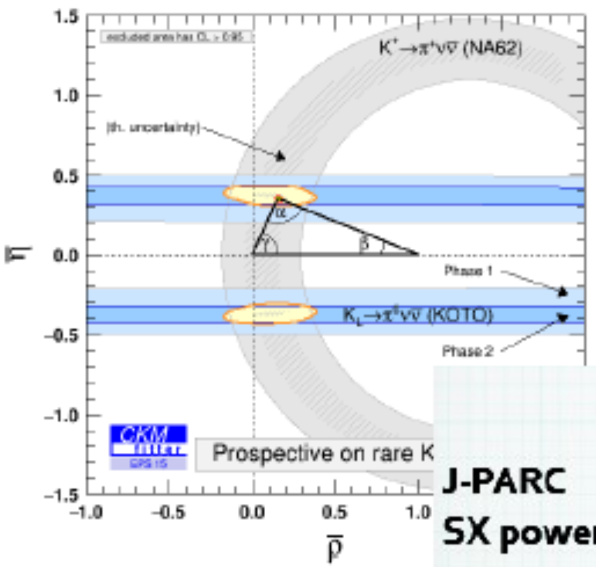


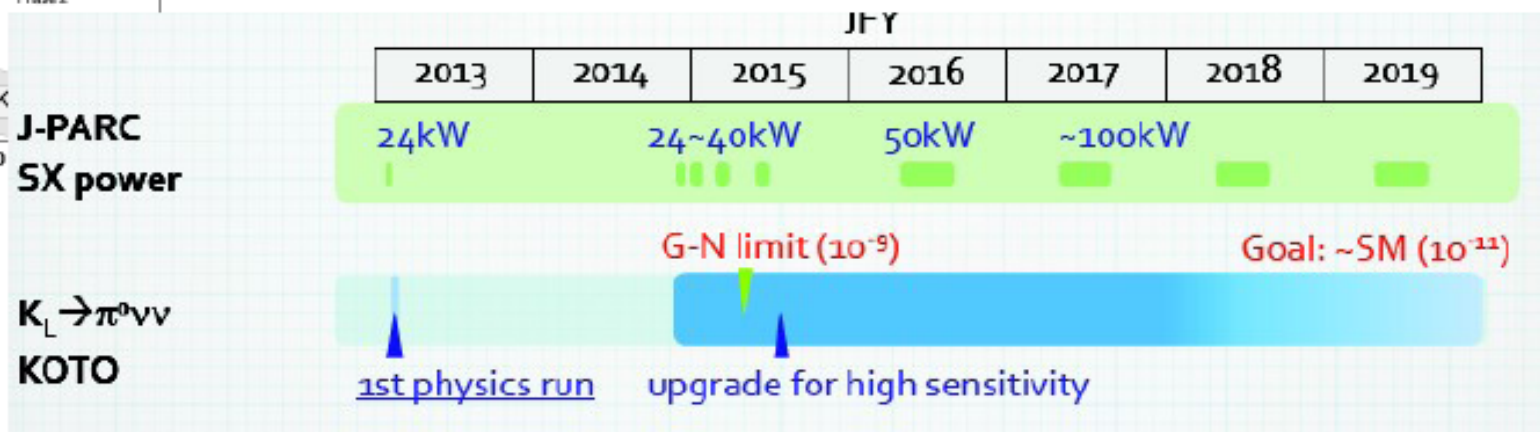
previous result: $B(K_L^0 \to \pi^0 \nu \bar{\nu}) < 2.6 \times 10^{-8}$ at 90% C.L.
KEK E391a

KOTO status

1st physics run in May 2013
100 hours of data taking, 24 kW
1 evt observed (consistent with BG) [CKM2014]
upgraded to reduce background,
⇒ took data (April, June 2015), 27 kW, more in Fall
Target sensitivity: $o(10^{-9})$, Grossman Nir limit

[see Talk by George WS Hou for $K_L \to \pi^0 Z'$]



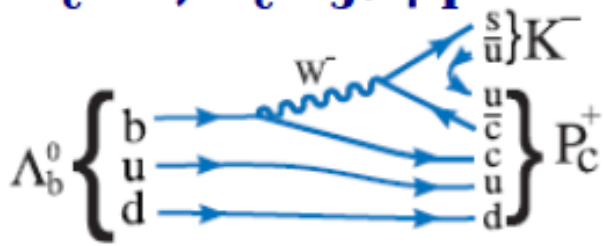


Observation of $J/\psi\, p$ resonances consistent with pentaquark states in $\Lambda_b^0 \to J/\psi K^- p$ decays [NEW]

[arXiv:1507.03414]

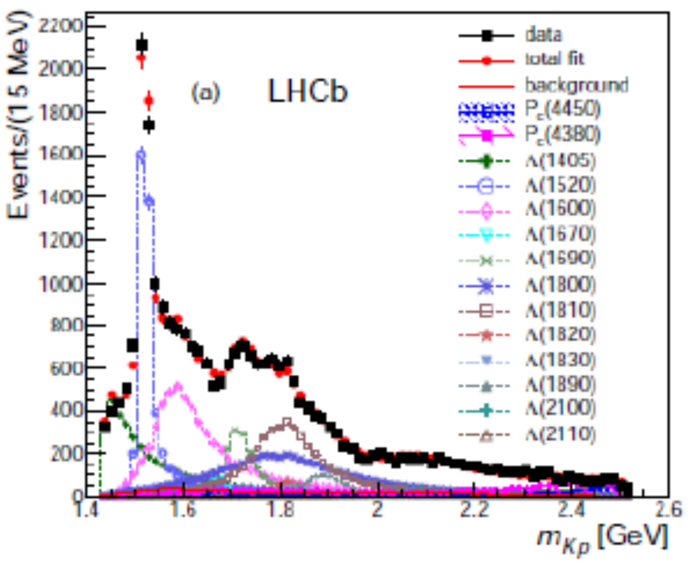
decay amplitude analysis incorporating both decay sequences: $\Lambda_b \to J/\psi \Lambda^*$, $\Lambda^* \to K^- p$ and $\Lambda_b \to P_c^+ K^-$, $P_c^+ \to J/\psi\, p$

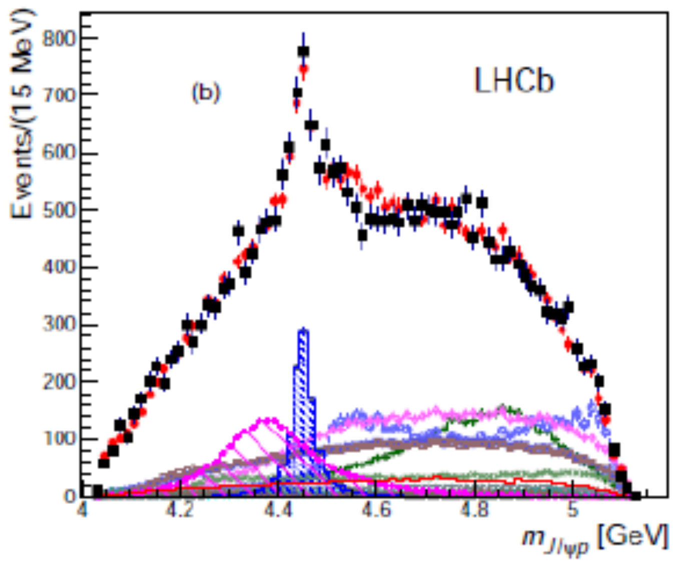
use m(Kp) and 5 decay angles as fit parameters

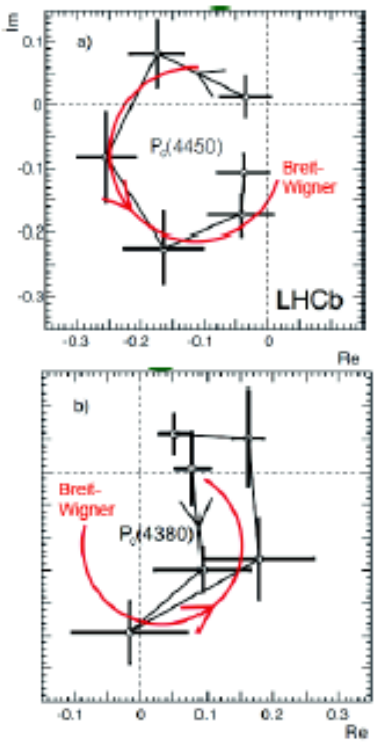


⇒ Best fit with $J^P = (3/2^-, 5/2^+)$

(also $(3/2^+, 5/2^-)$ and $((5/2^+, 3/2^-))$)







Mass (MeV)	Width (MeV)	fit fraction (%)	Σ
4380±8±29	205±18±86	8.4±0.7±4.2	9σ
4449.8±1.7±2.5	39±5±19	4.1±0.5±1.1	12σ

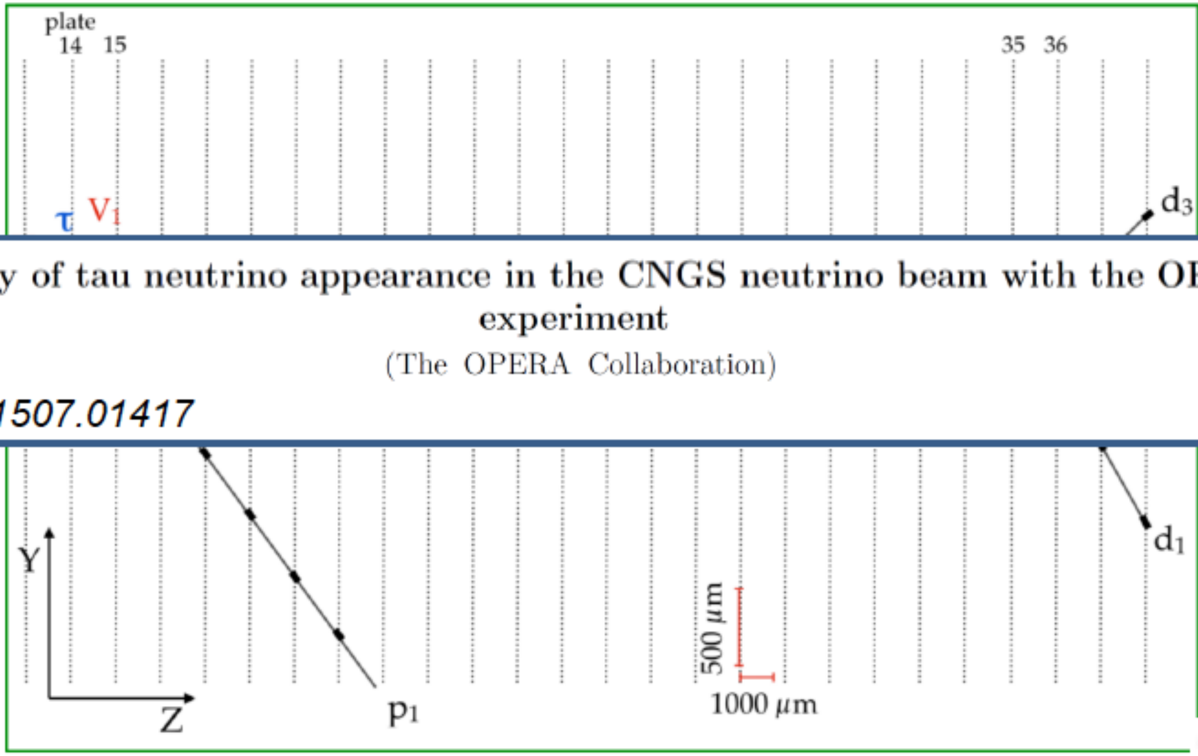
⇒ already 11 citations from theorists

Neutrinos (Caccianiga)

Accelerator neutrinos: OPERA

NEWS: the 5-th ν_τ!

Null hypothesis excluded at 5.1 σ



Discovery of tau neutrino appearance in the CNGS neutrino beam with the OPERA experiment

(The OPERA Collaboration)

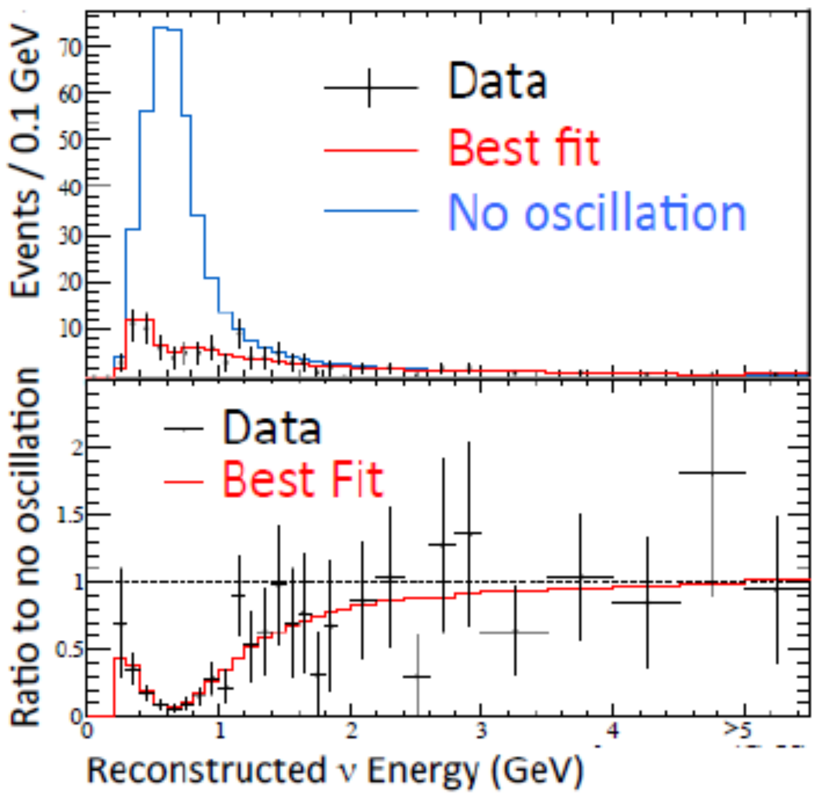
arXiV:1507.01417

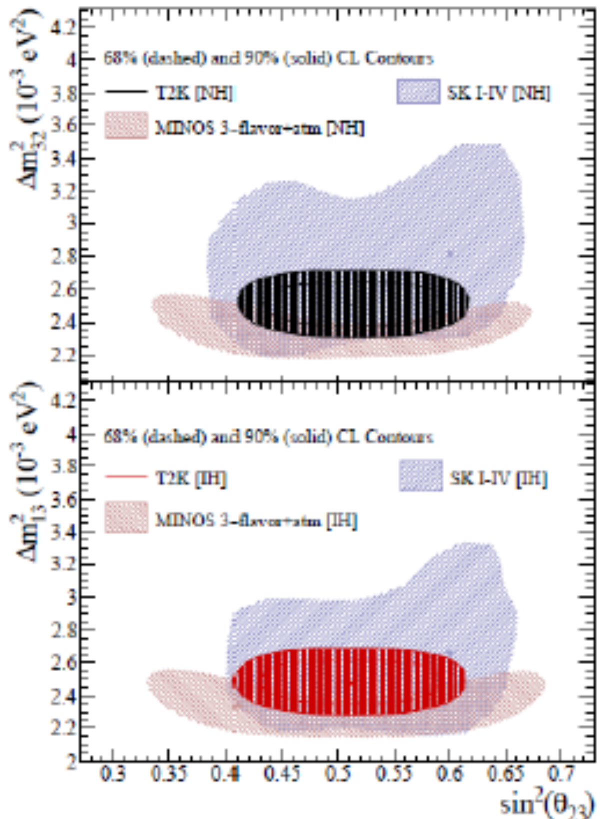
Accelerator neutrinos: LBL experiments

ν_τ appearance: sensitive to $(\Delta m^2)_{23} + \theta_{23}$

Accelerator neutrinos: T2K

Results on ν_μ disappearance: sensitive to $(\Delta m^2)_{23} + \theta_{23}$





$$\sin^2\theta_{23} = 0.514^{+0.0055}_{-0.0056} \text{ (N.H.)}$$
$$\sin^2\theta_{23} = 0.511^{+0.0055}_{-0.0055} \text{ (I.H.)}$$

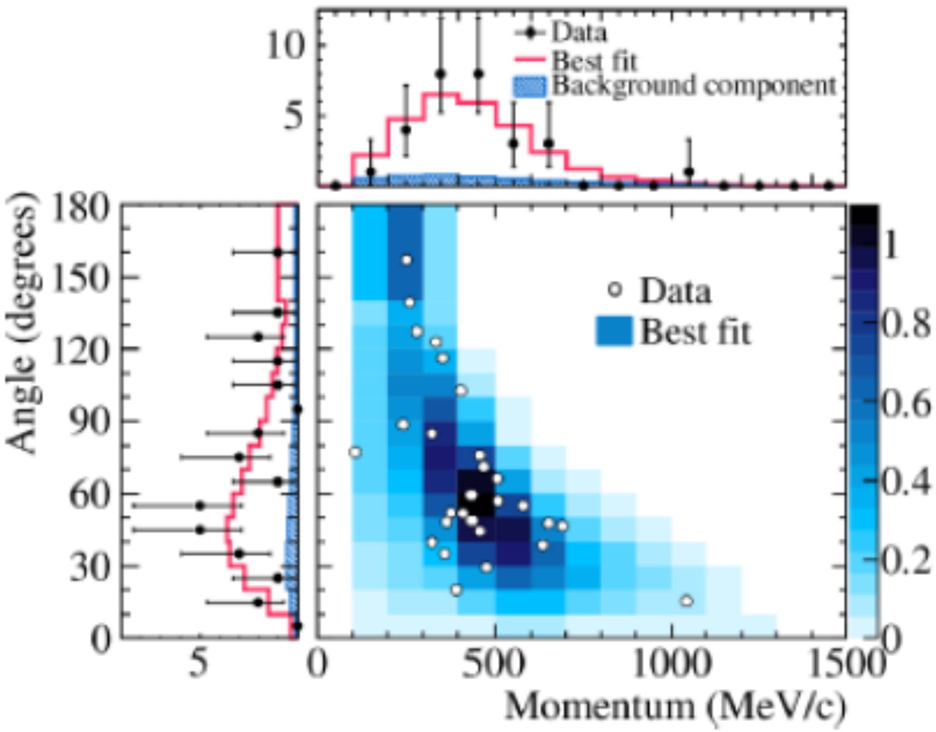
- Most precise measurement of θ_{23} (11%)
- *Phys.Rev.Lett.* **112**,181801 (2014)

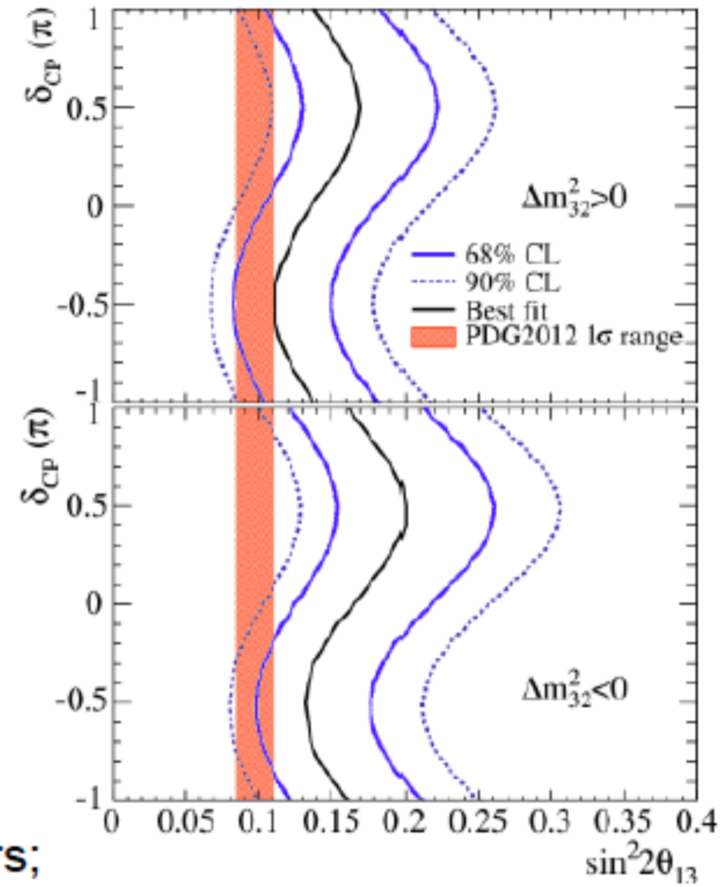
Accelerator neutrinos: T2K

θ_{23} Δm^2_{23} θ_{13} δ_{CP}

Results on ν_e appearance: sensitive to $(\Delta m^2)_{23}$+ θ_{23}+ θ_{13}

Phys.Rev.Lett. **112**,061802 (2014)



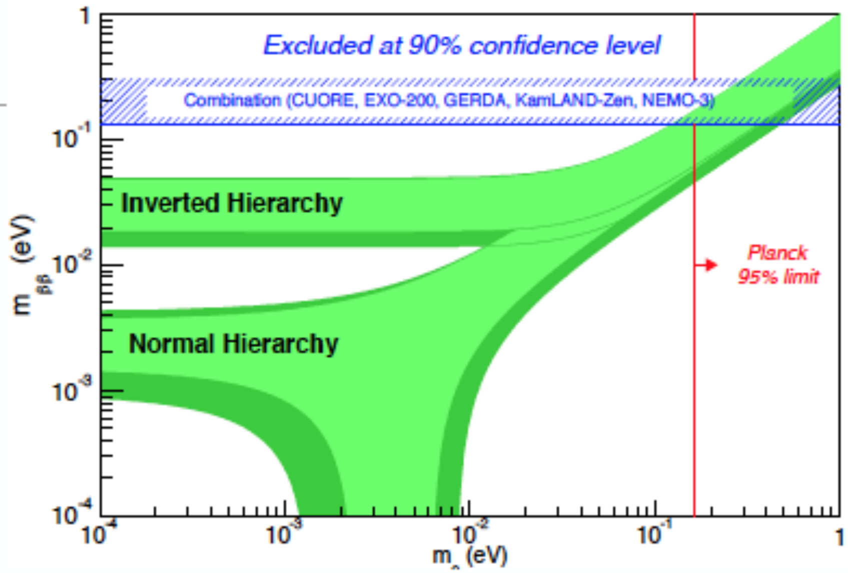


- Discovery of $\nu_\mu \rightarrow \nu_e$ at 7.3 σ (28 ν_e)
- T2K finds a value of θ_{13} slightly larger than reactors;
- This small tension provides early sensitivity to $\delta_{CP;}$

Neutrinoless Double β Decay (Cadenas)

Where are we?

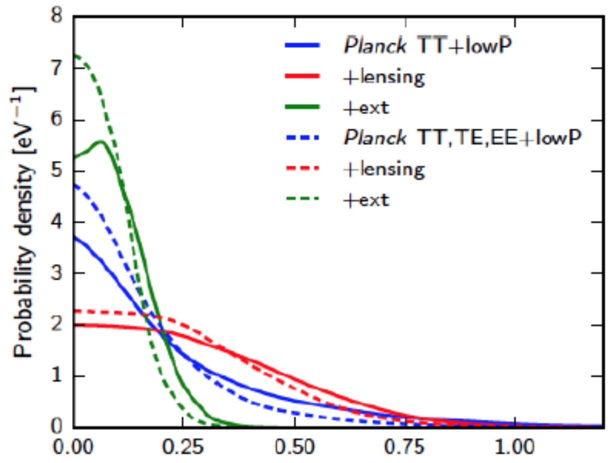
- In spite of the enormous experimental progress over the last decade, ββ0ν experiments are not even getting close to the IH region
- We need to go from ~200 meV to ~20 meV.
- A factor 10 in mββ is a factor 100 in $T_{1/2}$



- It appears possible for most of the techniques to reach 10^{26} y (ton scale target mass, improvements in technology)
- Instead reaching 10^{27} y seems very difficult.

Absolute Neutrino Mass Scale (Flauger / Lahav)

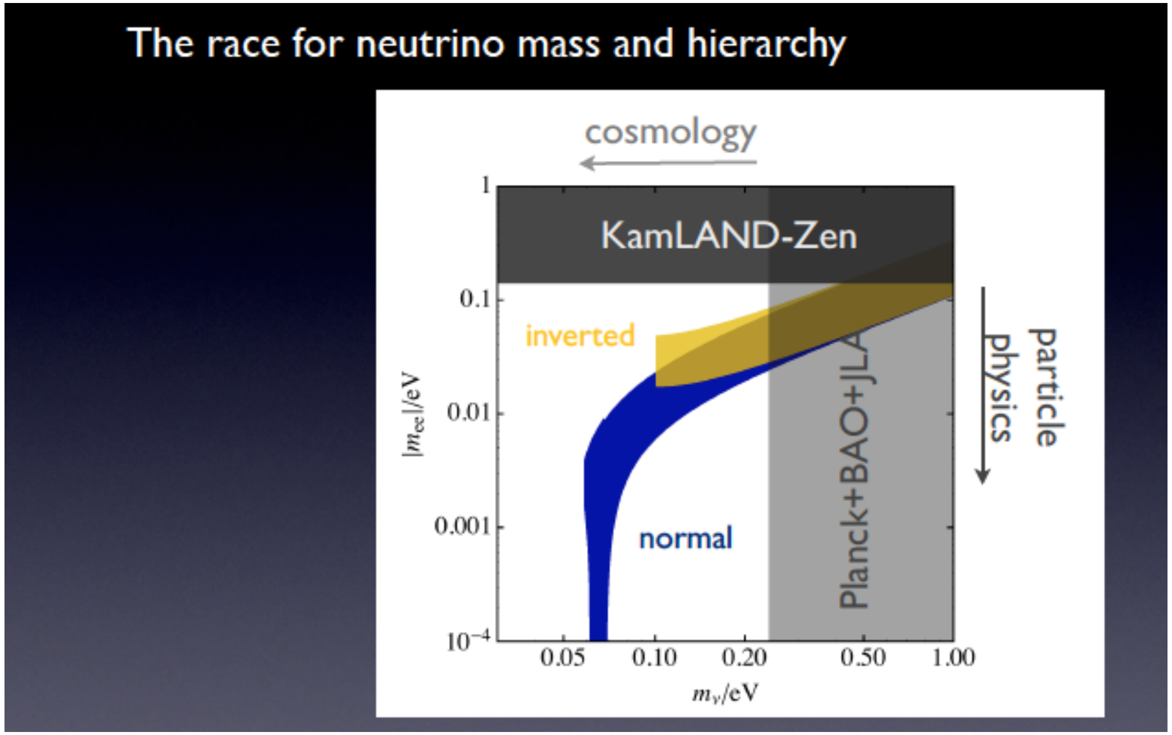
Neutrino mass upper limit
(note lower bound of 0.06 eV)



$$\left.\begin{array}{l}\sum m_\nu < 0.23\ \mathrm{eV} \\ \Omega_\nu h^2 < 0.0025\end{array}\right\} \text{95\%, } \textit{Planck}\ \text{TT+lowP+lensing+ext.}$$

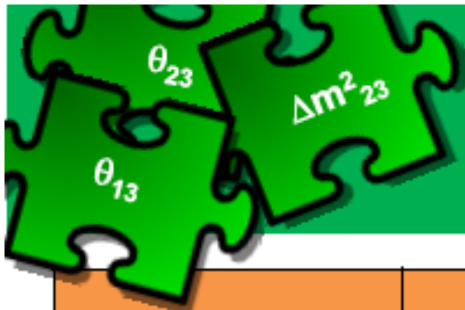
10

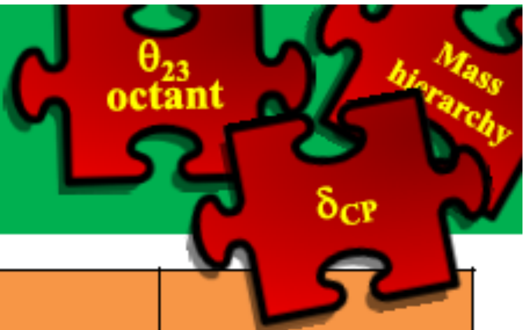
Planck collaboration 2015



[Sum of neutrino masses]

Accelerator neutrinos: future LBL experiments





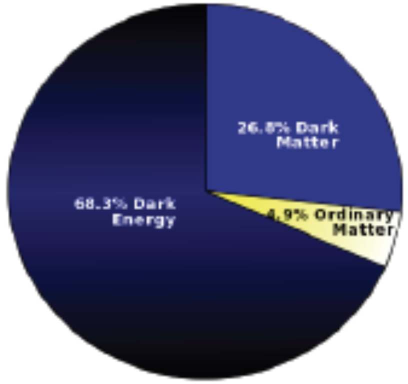
Goals of future LBL experiments

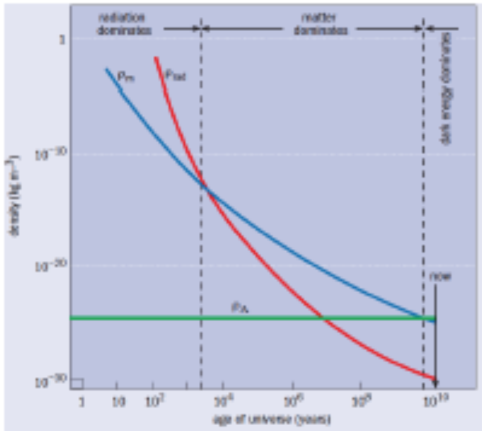
- Collect high statistics of disappearance (~10000 ν_μ) and appearance (~1000 ν_e) samples;
- Search for CP-invariance/violation;
- Determine neutrino mass hierarchy;
- Significantly improve precision of neutrino mixing parameters;
- Test the three neutrino mixing hypothesis;

Experiment	Status	E_ν (GeV)	L (Km)	E/L (eV^2)	ν beam	ν type
DUNE	Future (end of 2020s)	5	1300	3.8×10^{-3}	Fermilab newbeam	ν_μ /anti-ν_μ
HYPERK	Future (end of 2020s)	0.6	295	2×10^{-3}	KEK J-PARC (improved)	ν_μ /anti-ν_μ

What I probably should have talked about

What accelerates the Universe?





"a simple but strange universe"

Dark matter and (particularly) dark energy and their relation to particle physics was possibly ***the*** major theme

Assuming SM (νMSM), the only "subtleties" left are the Higgs boson potential and inflation

Higgs potential stability

- Absolutely stable Electroweak vacuum
- Metastable EW vacuum (true vacuum at/above Planck scale)

Higgs and inflation

- Higgs boson *completely unrelated* to inflation
- Higgs boson "feels" inflation
  - interacts with inflaton field (e.g. changes mass depending in inflaton background)
  - non-minimal coupling with gravitational background (changes properties in curved background)
- Higgs boson drives inflation itself (Higgs inflation from non-minimal couplign to gravity)