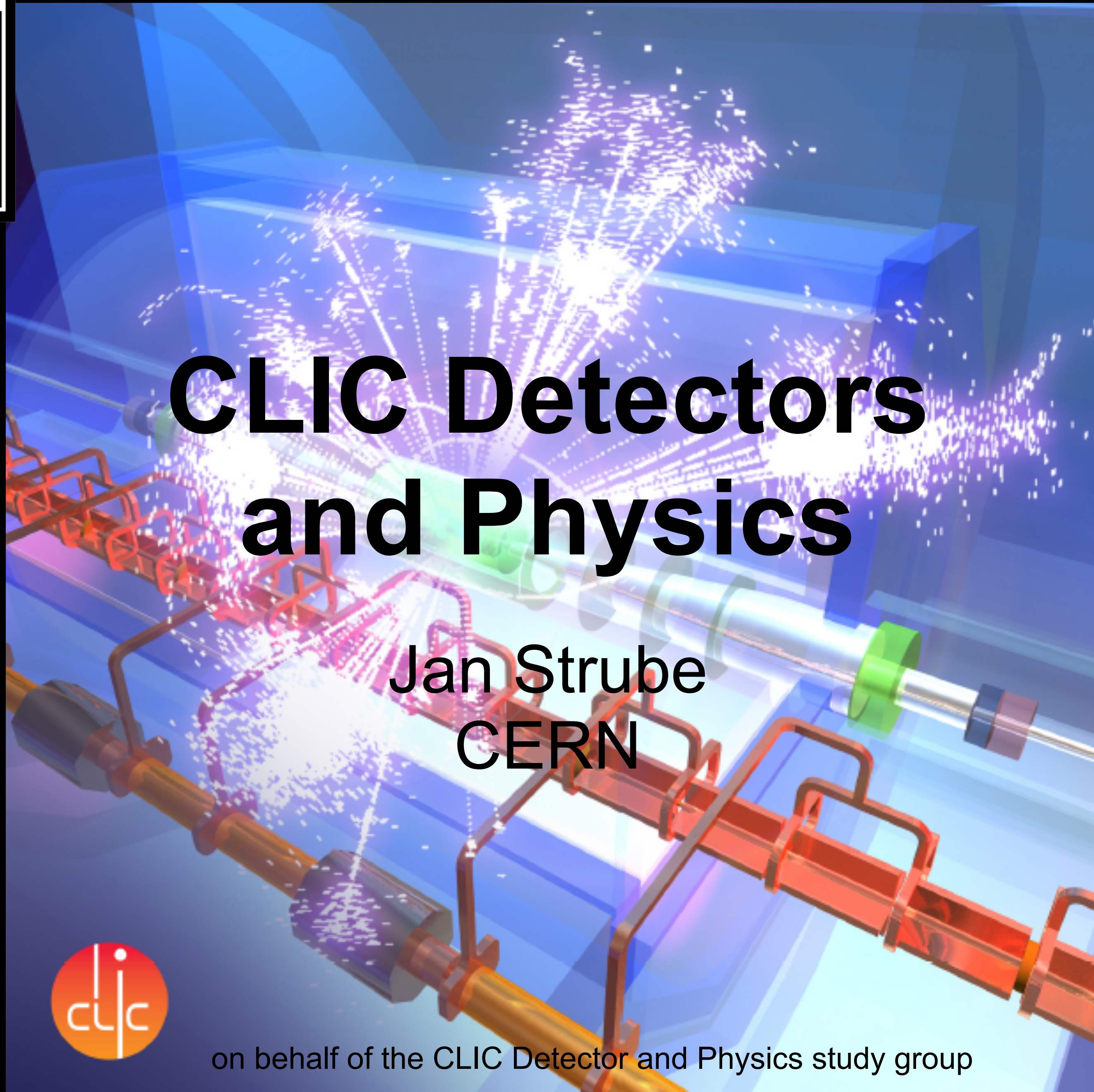


CLIC Detectors and Physics

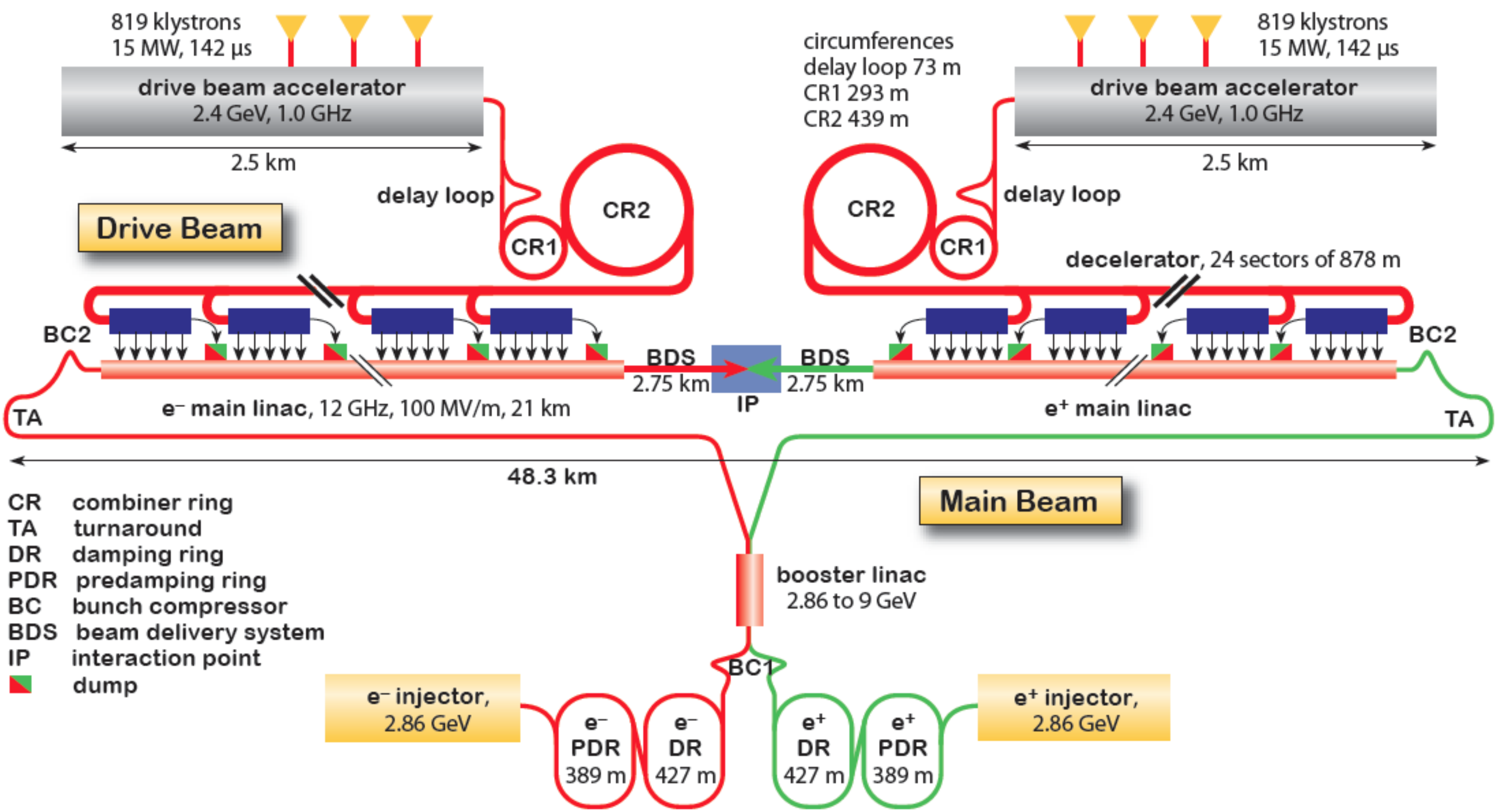
Jan Strube
CERN

on behalf of the CLIC Detector and Physics study group

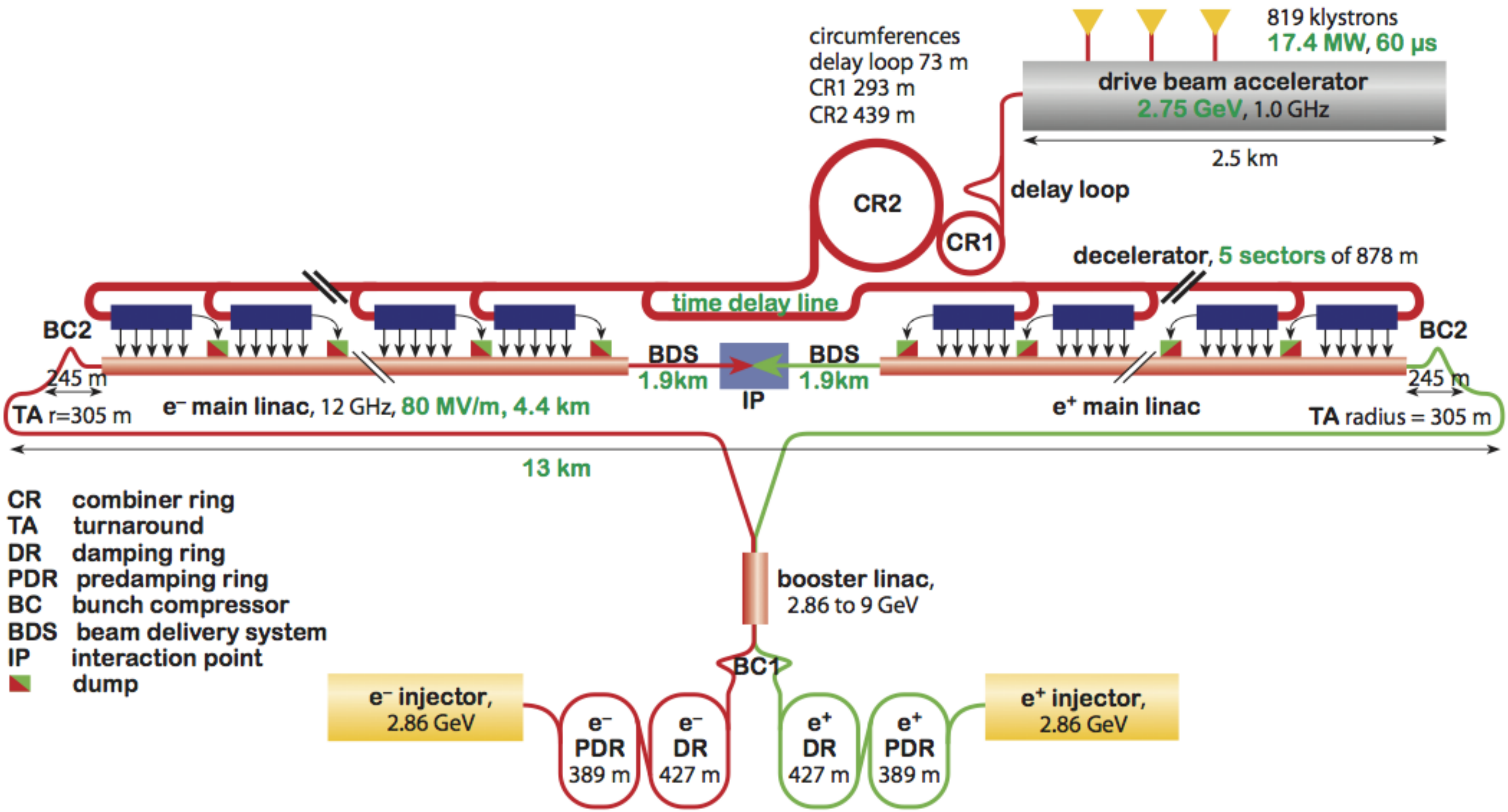
Outline

- The CLIC Accelerator
- Challenges for Detector Design
- The CLIC Detector and Physics Program
  - Simulation Studies
  - Detector Development
- Future Plans
- Summary

CLIC Layout at 3 TeV



CLIC Layout at 500 GeV

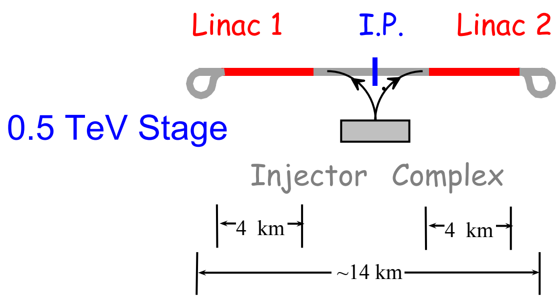


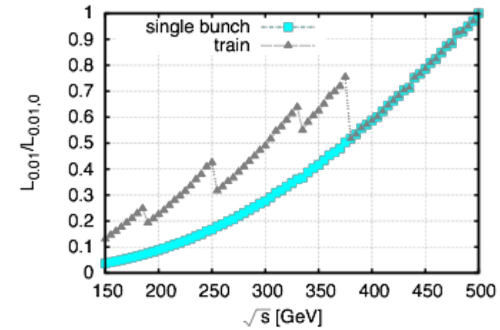
CLIC Staging Scenario

CLIC two-beam scheme compatible with energy staging to provide the optimal machine for a large energy range

Lower energy machine can run most of the time during the construction of the next stage.

Physics results will determine the energies of the stages





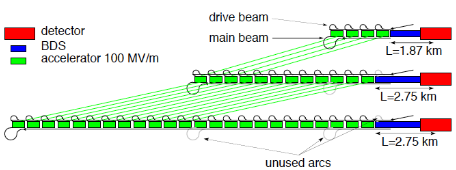
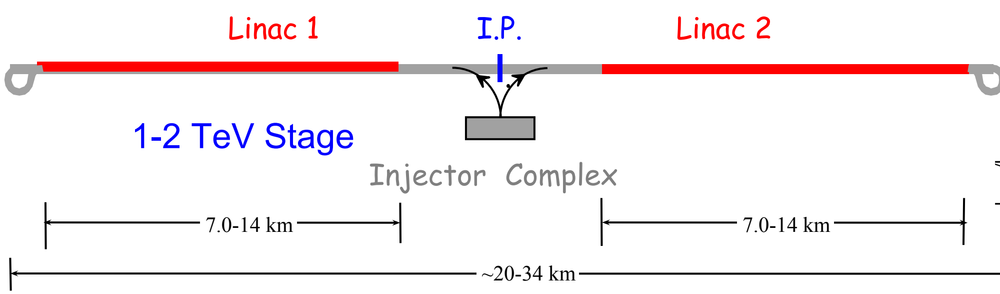
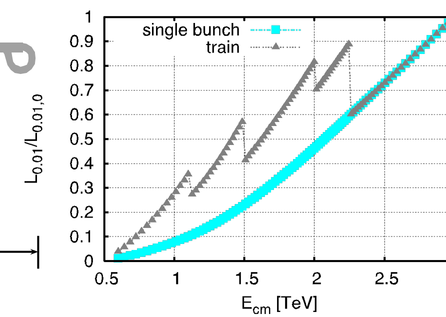
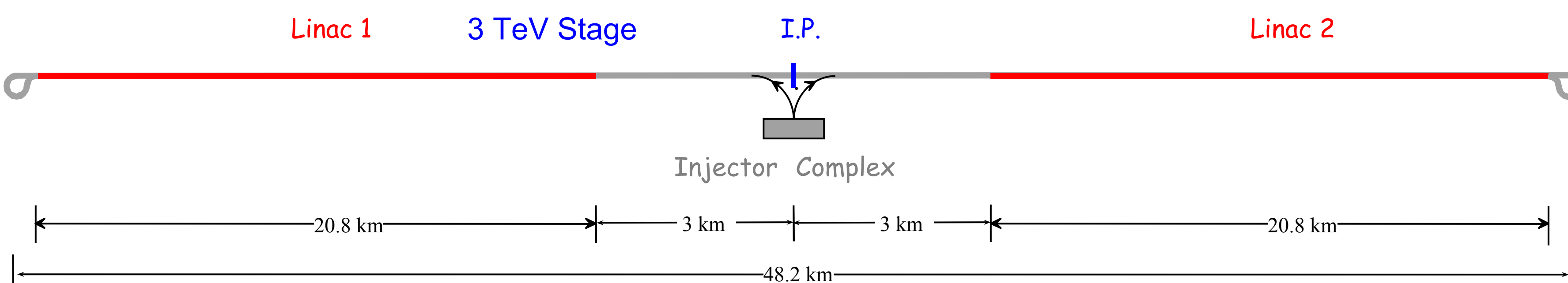
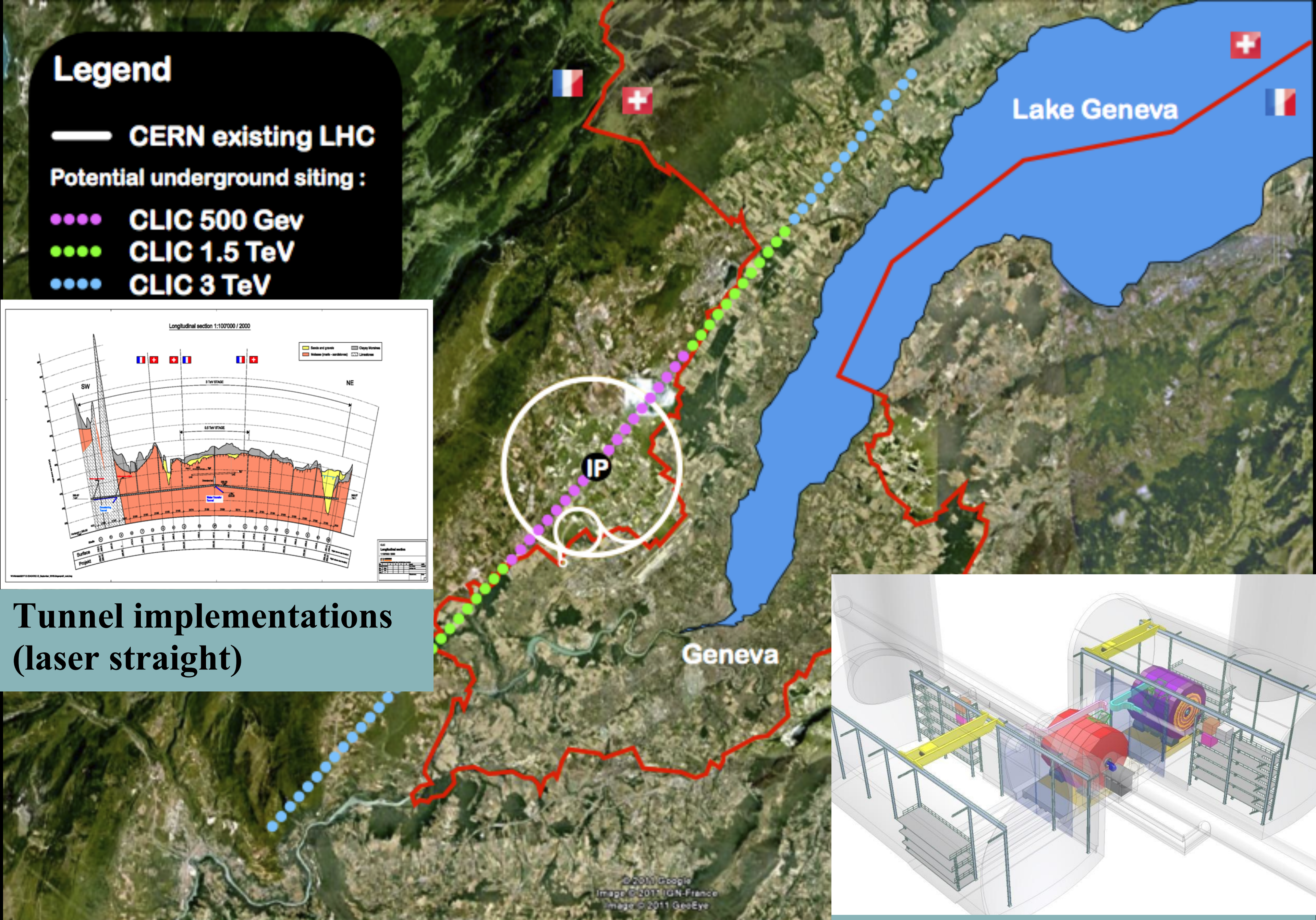


Fig. 3.6: Simplified upgrade scheme for CLIC staging scenario B.







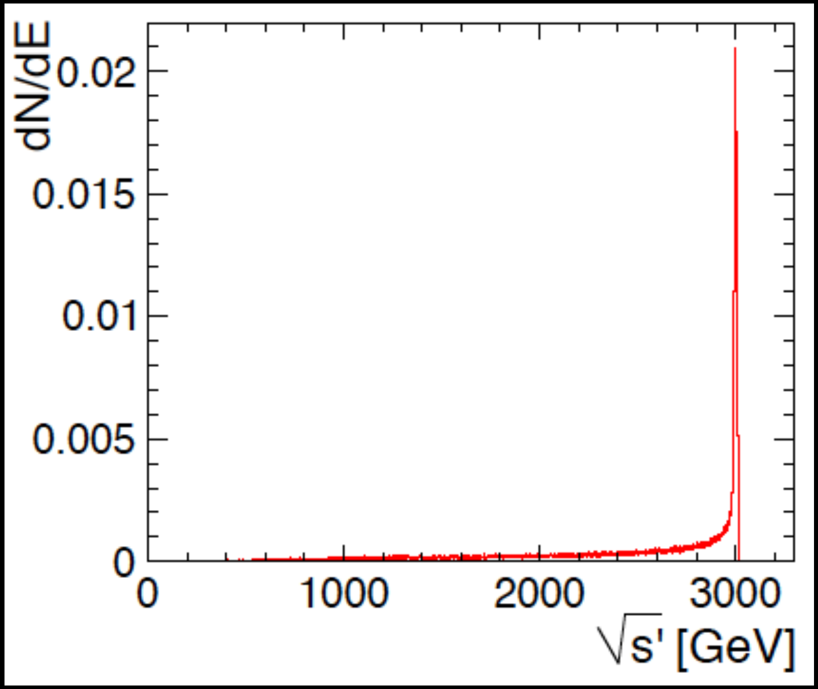


Tunnel implementations (laser straight)

Central MDI & Interaction Region

The CLIC Beams

Parameter	CLIC at 3 TeV
L ($cm^{-2}s^{-1}$)	5.9×10^{34}
BX separation	0.5 ns
#BX / train	312
Train duration (ns)	156
Rep. rate	50 Hz
σ_x / σ_y (nm)	≈ 45 / 1
σ_z (μm)	44

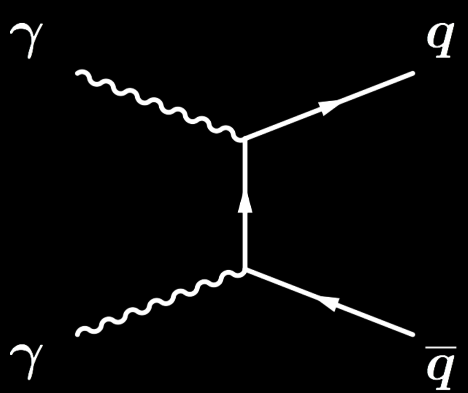


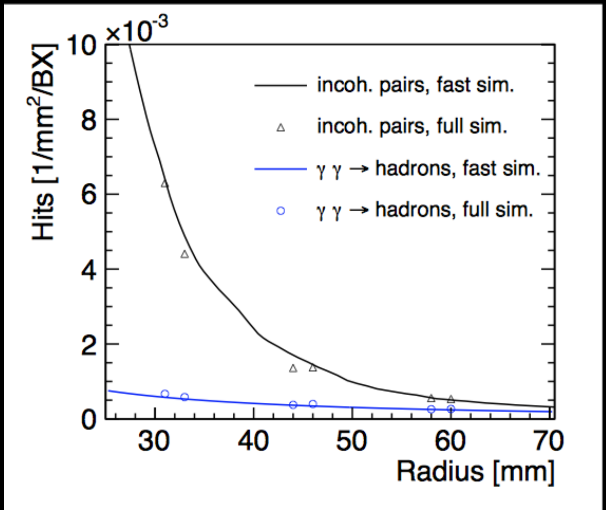
Finite spread of beam energy
Reduction of luminosity
(small effect for processes far from threshold)

Systematic effect on reconstruction,
for example, slepton reconstruction

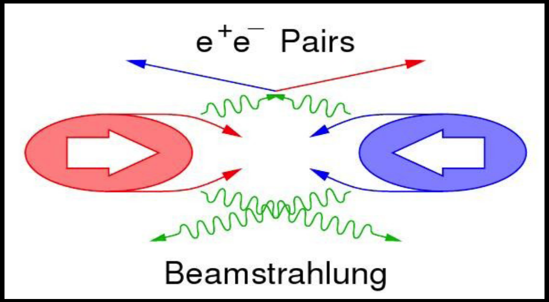
$\sqrt{s'}$ / $\sqrt{s}$	0.5 TeV	3 TeV
> 99 %	62 %	35 %
> 90 %	89 %	54 %
> 70 %	99 %	76 %
> 50 %	~100 %	88 %

Background to Physics studies





Coherent e^+e^- pairs:
7×10^8 per BX, very forward
Incoherent e^+e^- pairs:
3×10^5 per BX, rather forward



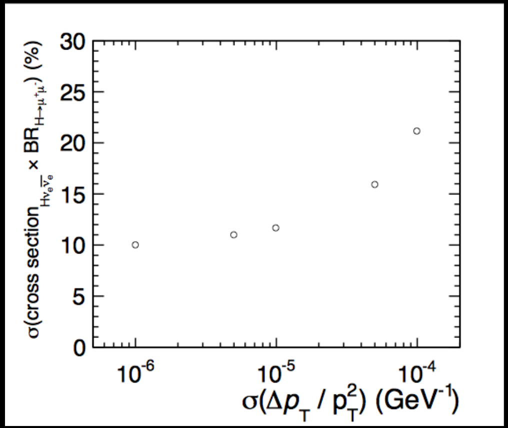
$\sqrt{s}$ (GeV)	N(γγ→hadrons) per BX
350	0.05
500	0.3
1400	1.3
3000	3.2

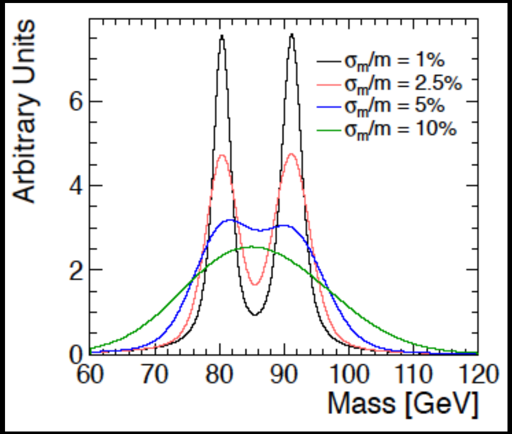
Incoherent pair production:
Increases occupancy in inner tracker layers and forward region
→ impact on detector segmentation and pattern recognition

γγ → hadrons (at 3 TeV):
Deposit up to 19 TeV of energy in the calorimeters
~ 5000 Tracks with 7.3 TeV
Impact is minimized by using advanced reconstruction techniques

Physics Goals Drive Detector Requirements

h → μ⁺μ⁻ measurement uncertainty vs. momentum resolution





W-Z separation

Momentum resolution

Higgs Recoil, $h \to \mu^+\mu^-$:

$\sigma(p_T)/p_T^2 \sim 2\text{x}10^{-5}$ GeV^{-1}

Jet Energy Resolution

Separation of heavy bosons, Gaugino, Triple Gauge Coupling

$\sigma(E)/E$ = 3.5%-5%

Flavor Tagging

$$\sigma_{r\phi} \approx 5\,\mu\text{m} \oplus 15\,\mu\text{m}/(p[\textbf{GeV}]\sin^{\frac{3}{2}}\theta)$$

Challenges for Detector Design

PFA calorimetry

Calorimeters inside coil (track-shower matching)

Full shower containment for operation at 3 TeV

Tracking

Low material budget

Excellent impact parameter resolution

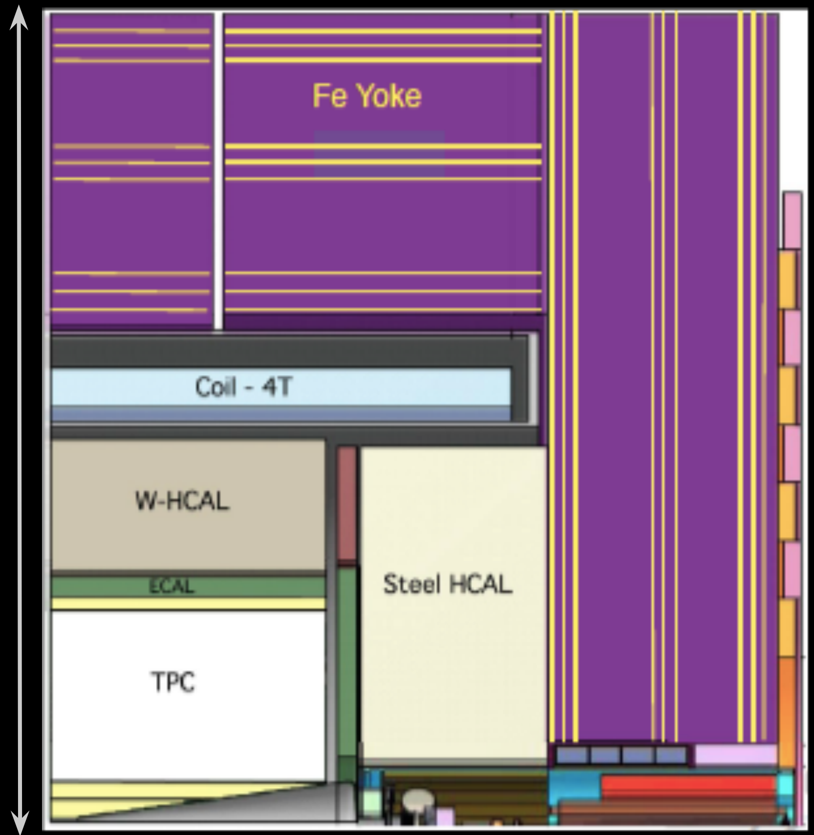
Forward region

QD0 inside detector ↔ compact design ↔ 4π coverage

Detector Concepts for CLIC

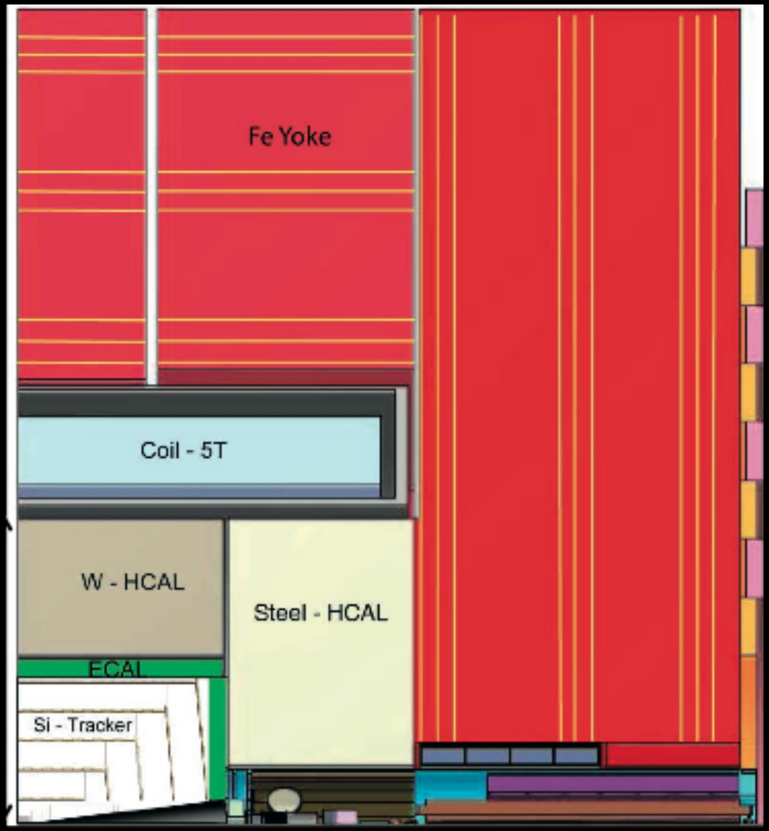
CLIC_ILD

~7 m



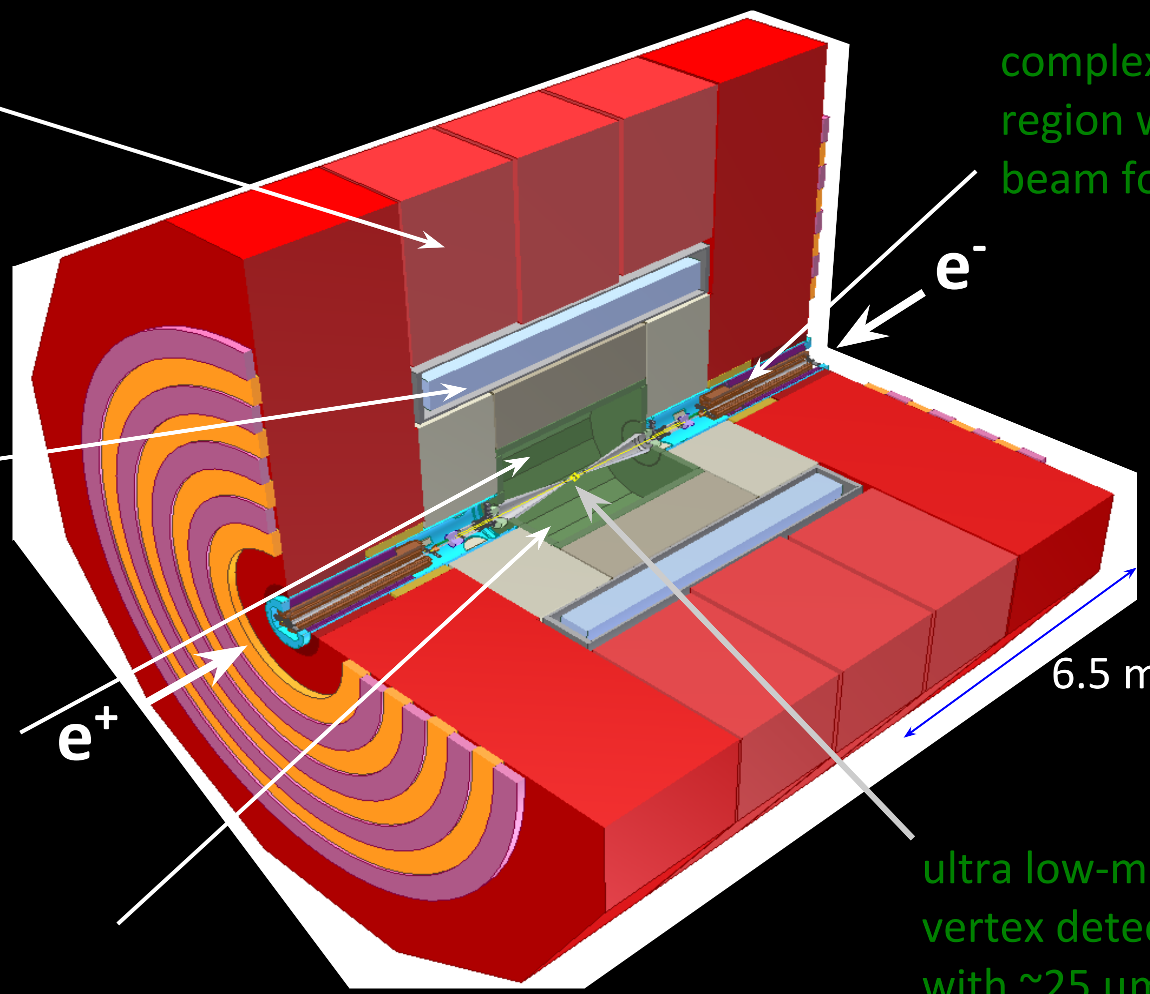
Gaseous Tracking
4 T Field

CLIC_SiD



All- Silicon Tracker
5 T Field
Cost-constrained Design

CLIC detector concepts



CLIC Detector Concepts Summary

	CLIC_ILD	CLIC_SiD
Vertex Tracker	3 double layers r_i = 31 mm	5 layers r_i = 27 mm
Tracker	TPC, r_o = 1.8 m Silicon envelope	Silicon, r_o = 1.2 m
B-field	4 T	5 T
ECAL	SiW 23 X_0	SiW 26 X_0
HCAL barrel	W-Scint, 3x3 mm^2 **7.5** λ	W-Scint, 3x3 mm^2 **7.5** λ
HCAL endcap	Steel-Scint **7.5** λ	Steel-Scint **7.5** λ

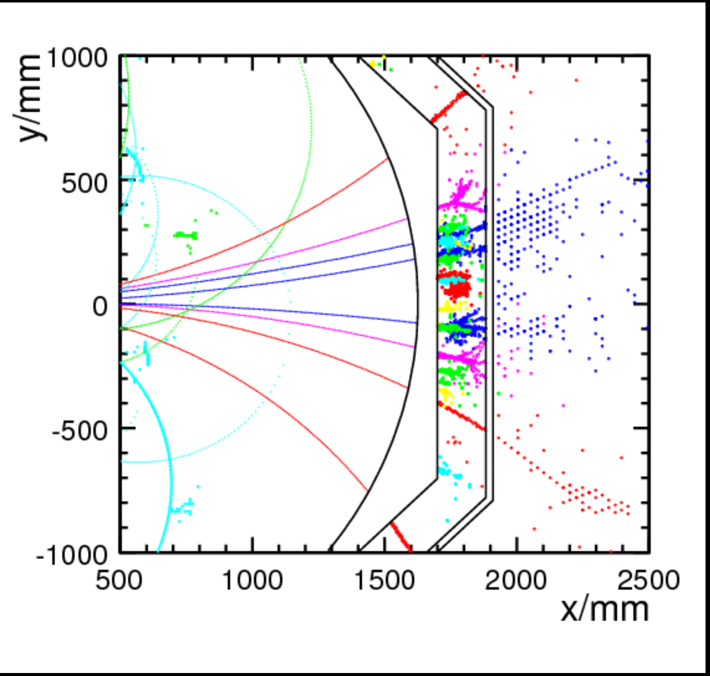
Introduction to Particle Flow Reconstruction

Typical jet contents:

60% charged particles $\sigma(p_T)/p_T^2 \sim 2\text{x}10^{-5}\ \text{GeV}^{-1}$

30% photons $\sigma(E)/E < 20\% / \sqrt{E}$

10% neutral hadrons $\sigma(E)/E > 50\% / \sqrt{E}$



Ideally, fully reconstruct the shower for each particle and match tracks to showers.

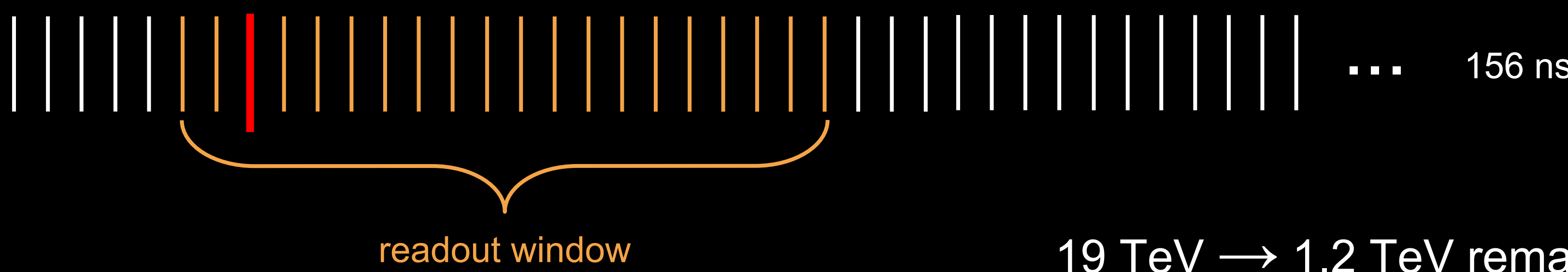
At higher jet energies, confusion (mis-matching of energy depositions and particles) deteriorates the resolution.

At even higher energies, leakages becomes a factor in the jet energy resolution.

PFA possible without high granularity
At CLIC: High granularity essential for background reduction

Detector Readout

Triggerless readout of the whole bunch train
Starting time of Physics event inside the train is identified offline



Subdetector	Reco Window	Hit Resolution
ECAL	10 ns	~ 1 ns
HCAL Endcap	10 ns	~ 1 ns
HCAL Barrel	100 ns	~ 1 ns
Silicon Detectors	10 ns	10 ns / √12
TPC (CLIC_ILD)	Entire train	n/a

19 TeV ⟶ 1.2 TeV remaining in reconstruction window

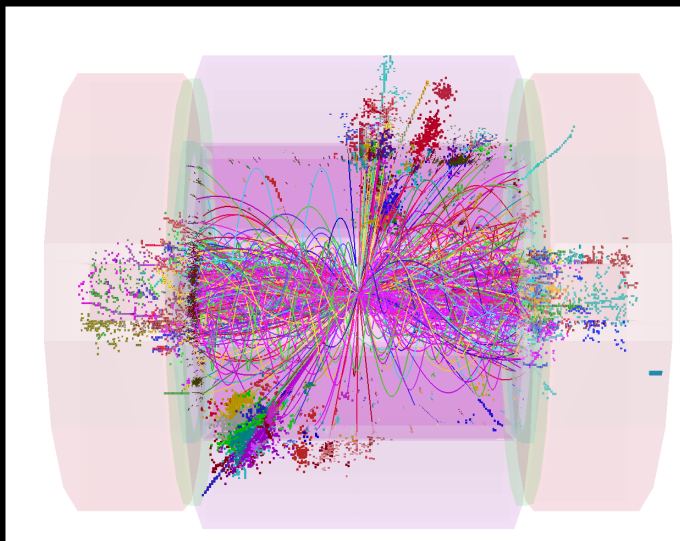
Passed to track finding and PFA reconstruction

necessary for development of shower in tungsten

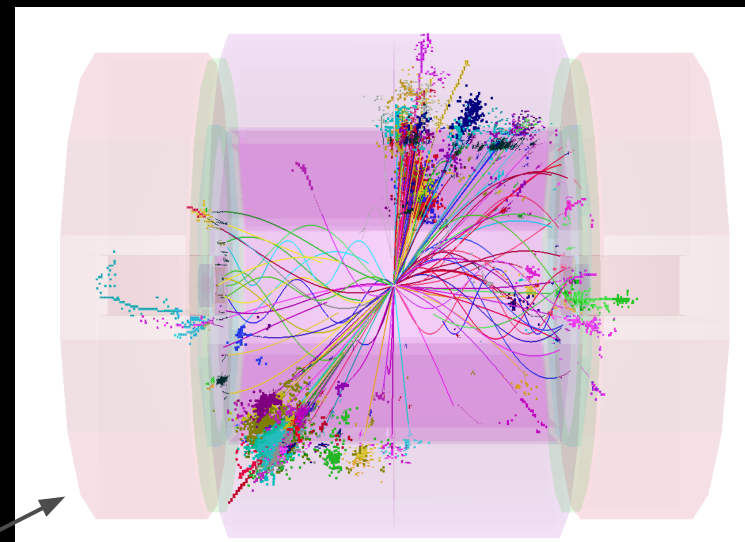
PFA Calorimetry at CLIC

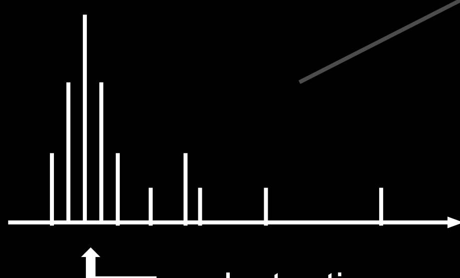
1.2 TeV "extra energy" in reco window

20
BX



100 GeV "extra energy" after timing cuts



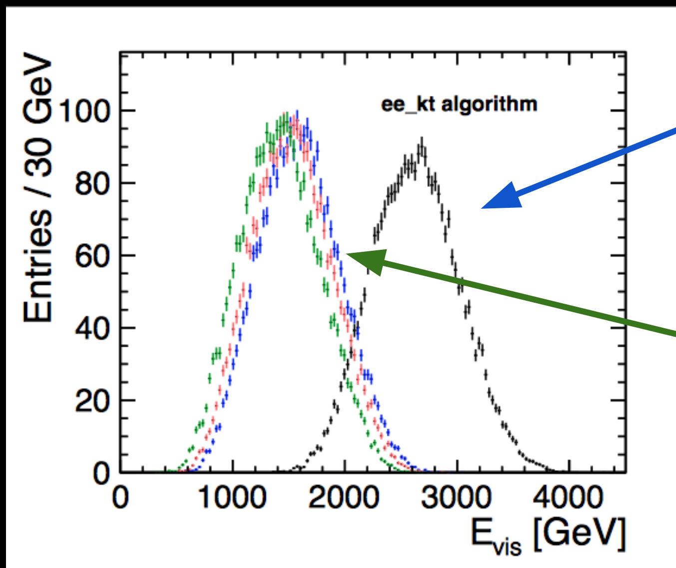


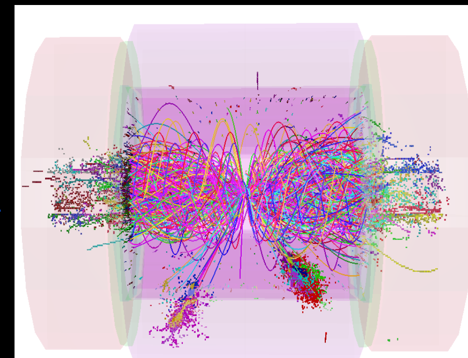
cluster time

Combination of
time and p_T cuts

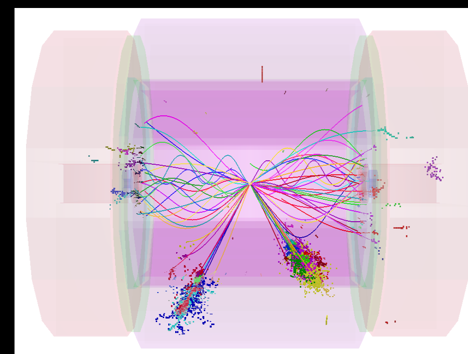
3 sets of cuts defined: loose, default, tight

Jet Finding at CLIC

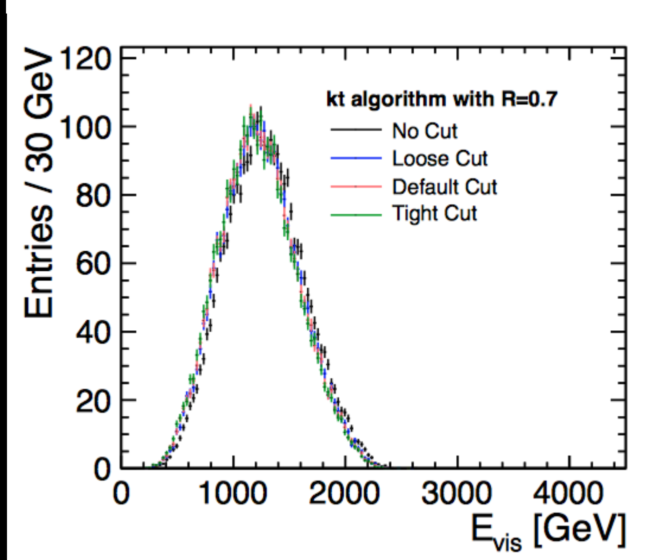


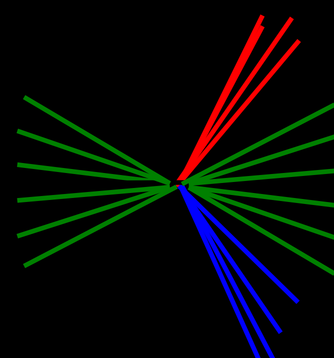


Durham - style jet finders used in exclusive mode



sensitive to background

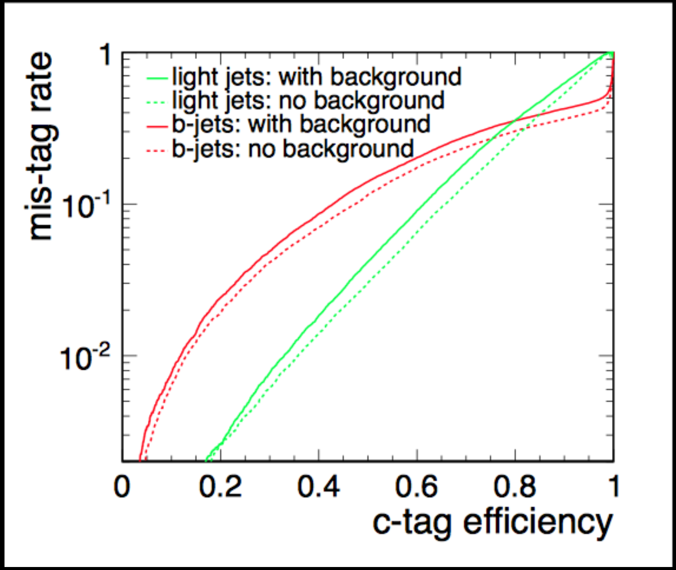


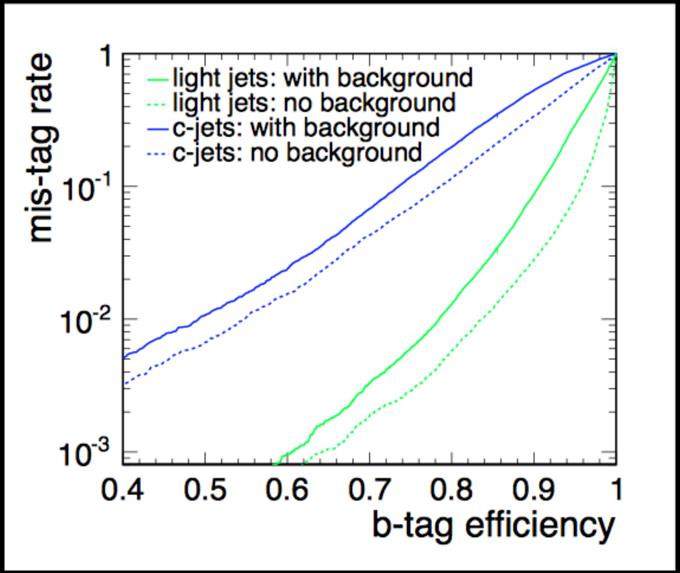


Analyses in CDR used k_T algorithm as implemented in FastJet

"Beam Jets" pick up most of the forward boosted background

Flavor Tagging at CLIC





Efficient tagging of b- and c-jets is a crucial component of the Higgs program at a iinear collider
Using (basically) the ZVTOP algorithm as implemented by the LCFI collaboration

Background somewhat deteriorates the tagging efficiency

Reconstruction Summary

Intense beams at CLIC pose a challenge for the reconstruction:

19 TeV additionally deposited in the calorimeters

Three ways to reduce impact:

1. Reconstruction time slice:

   Identify interesting event offline and remove out-of-time hits

2. Reconstructed particle time:

   Compute the time of the particle from the (energy-weighted) average of the calorimeter hits. Remove low-p_T, late arriving particles

3. Jet reconstruction:

   Beam jets pick up a lot of the forward-boosted background

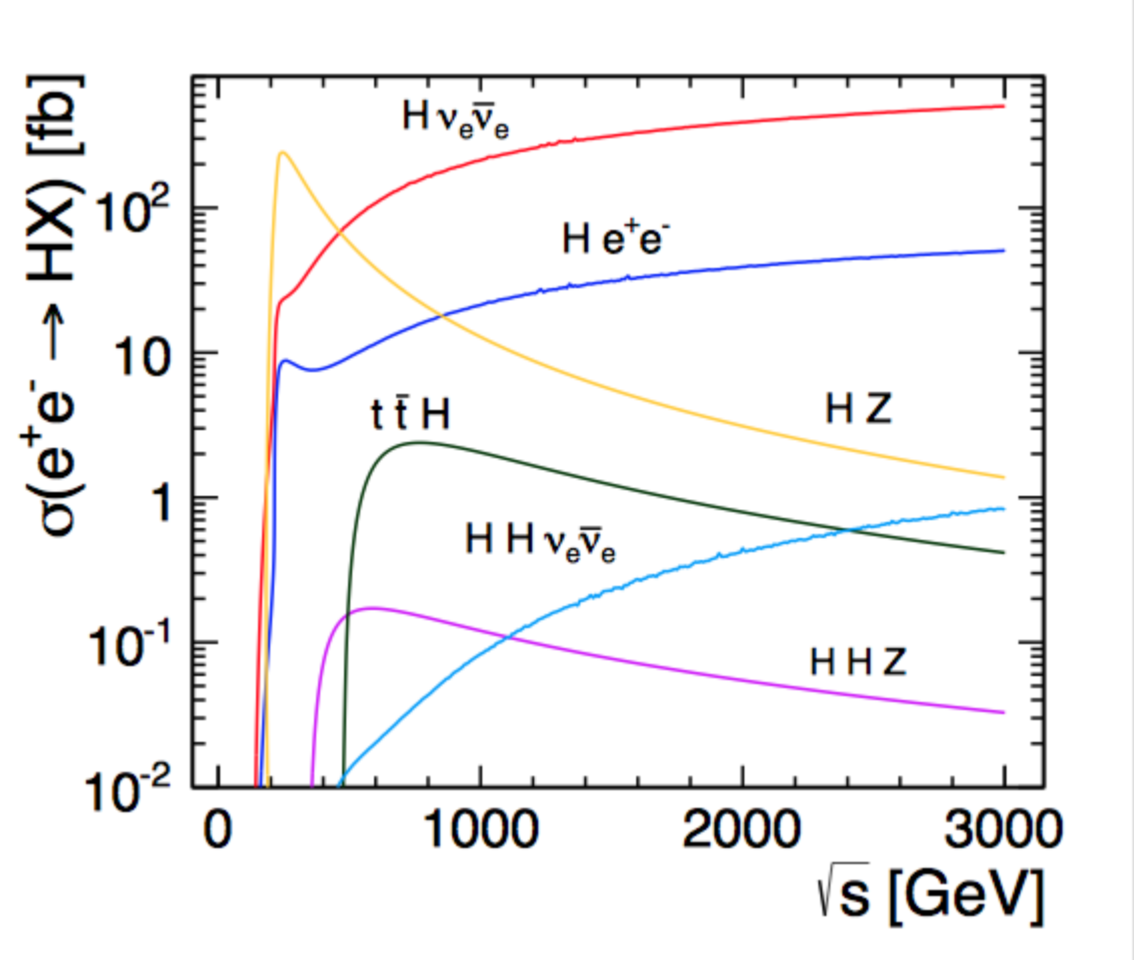
Physics Studies at CLIC

Studies have been done with detailed detector simulation

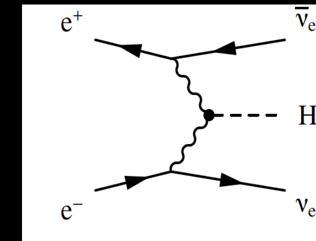
Background taken into account

- (Standard Model) Higgs Studies
- Studies of Physics
  Beyond the Standard Model

Higgs Physics at CLIC

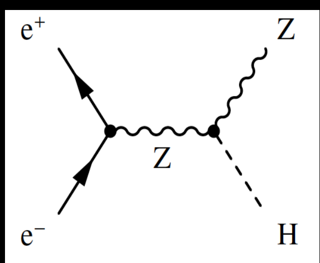


Higgs Physics at CLIC

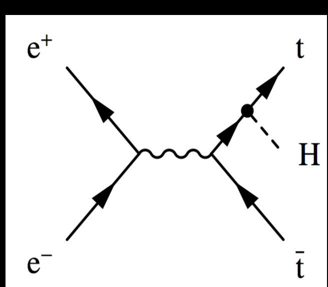


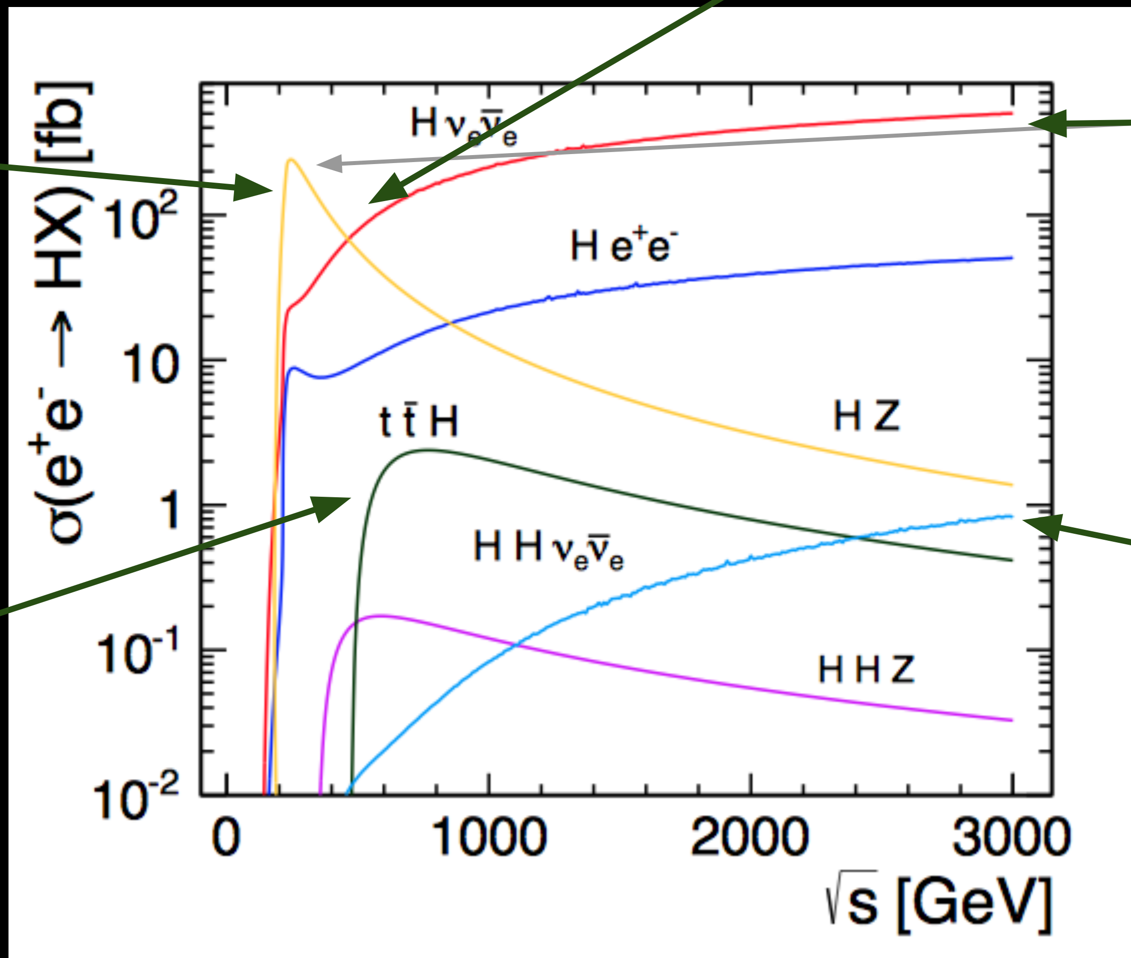
Higgs width

Higgs Recoil method: First sensitivity to invisible decays



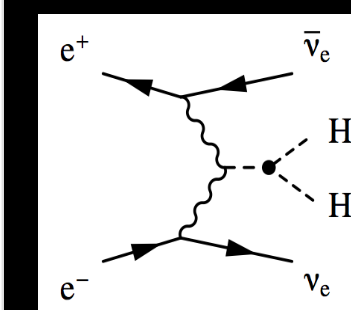
Top Yukawa coupling



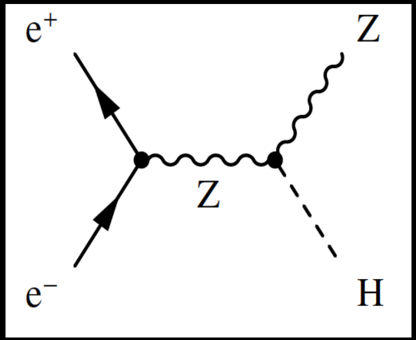


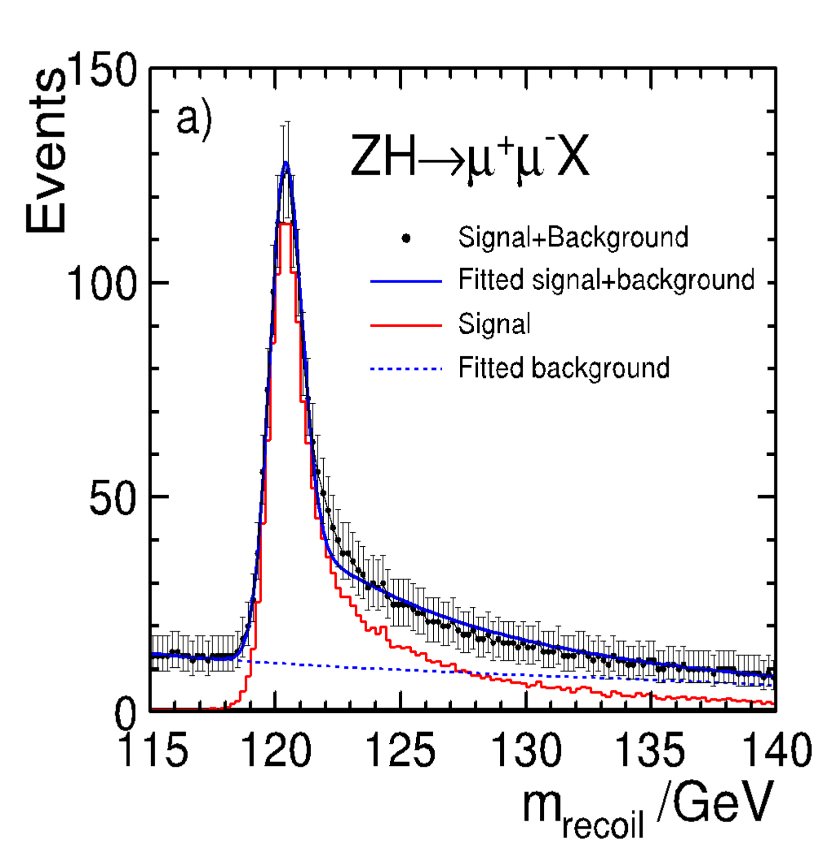
Higgs BR: second generation fermions c quarks, muons

Higgs self-coupling: < 20%



Higgs Recoil Method





Reconstruct the Z in the di-muon channel

Well-known value for E_{CM} allows to plot the recoil against the Z

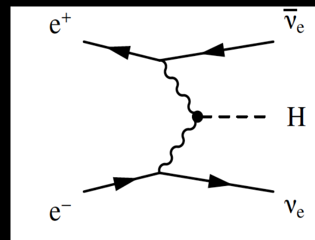
No information about the Higgs decay enters this plot
→ sensitivity to invisible decays

Absolute measurement of gauge coupling, limited only by beamstrahlung

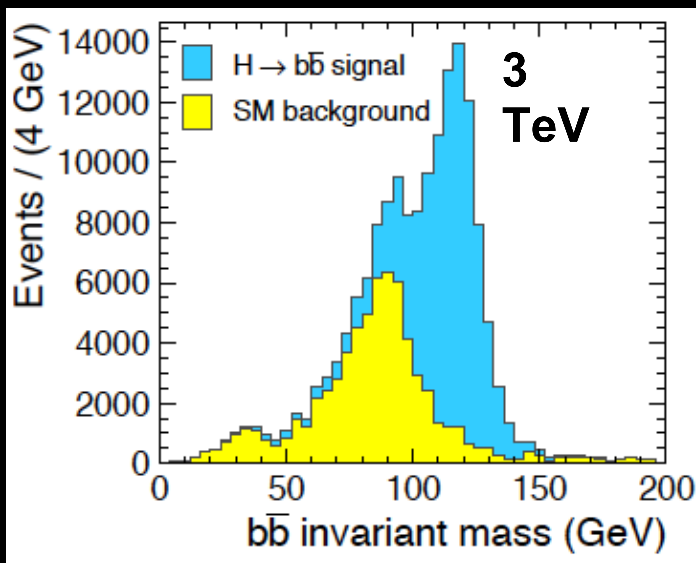
$$\frac{\Delta\sigma}{\sigma} \approx 4\% \qquad \frac{\Delta g_{HZZ}}{g_{HZZ}} \approx 2\%$$

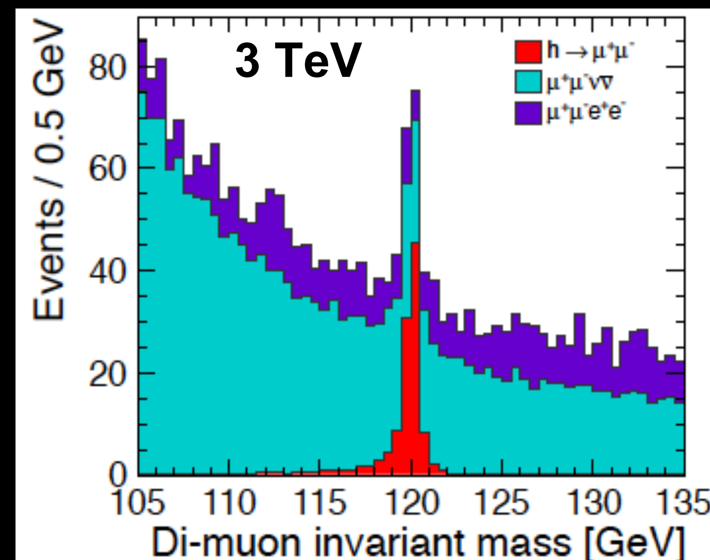
only statistical uncertainty quoted

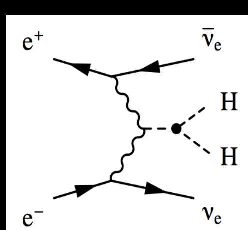
Higgs BR measurements at 3 TeV



GEANT4-based detector simulation studies
Realistic simulation of pile-up background
achievable measurement uncertainty on
h → bb: 0.22%   h → mu mu: 15%
h → cc: 3.2%





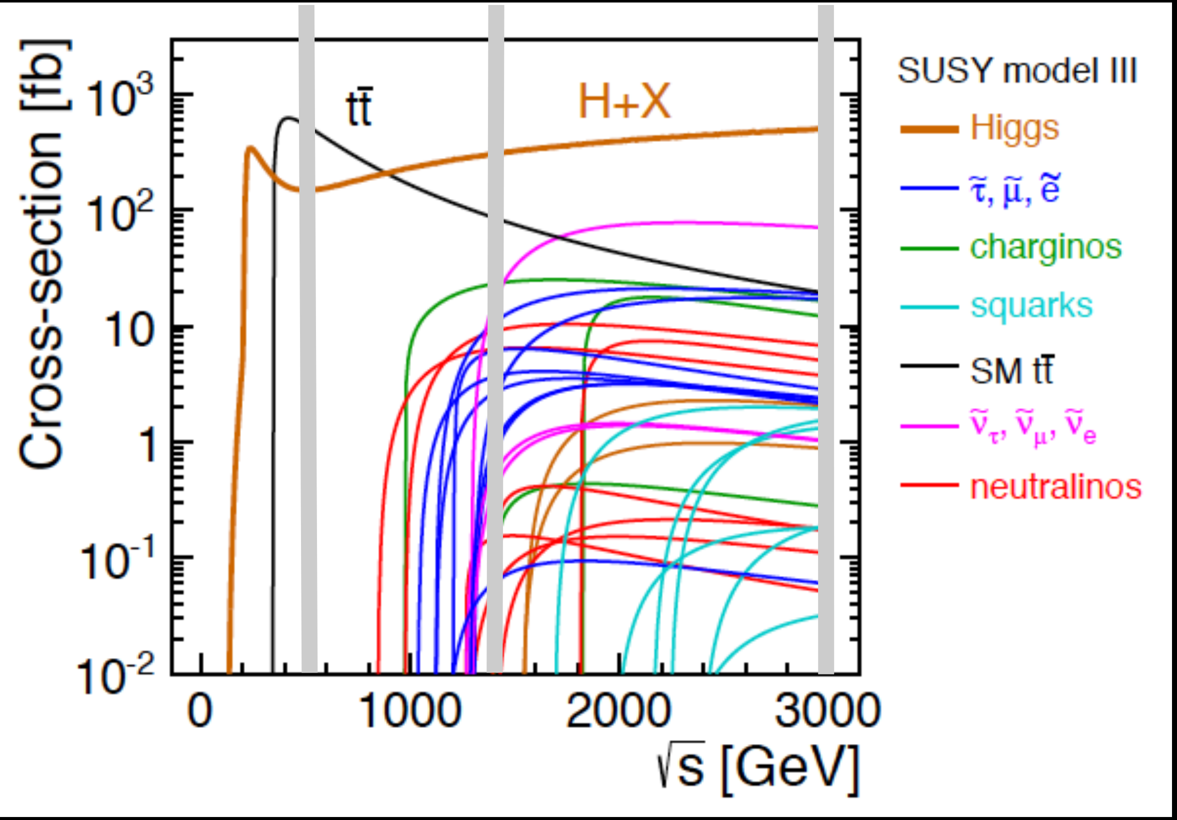


tri-linear self-coupling: ~20% (in progress)

Physics Beyond the Standard Model

First stage defined by physics
350 GeV / 500 GeV
(Higgs, top)

Later stages guided by future observations



Staging scenario A:
Stage 1: 500 GeV
Stage 2: 1400 GeV
Stage 3: 3000 GeV

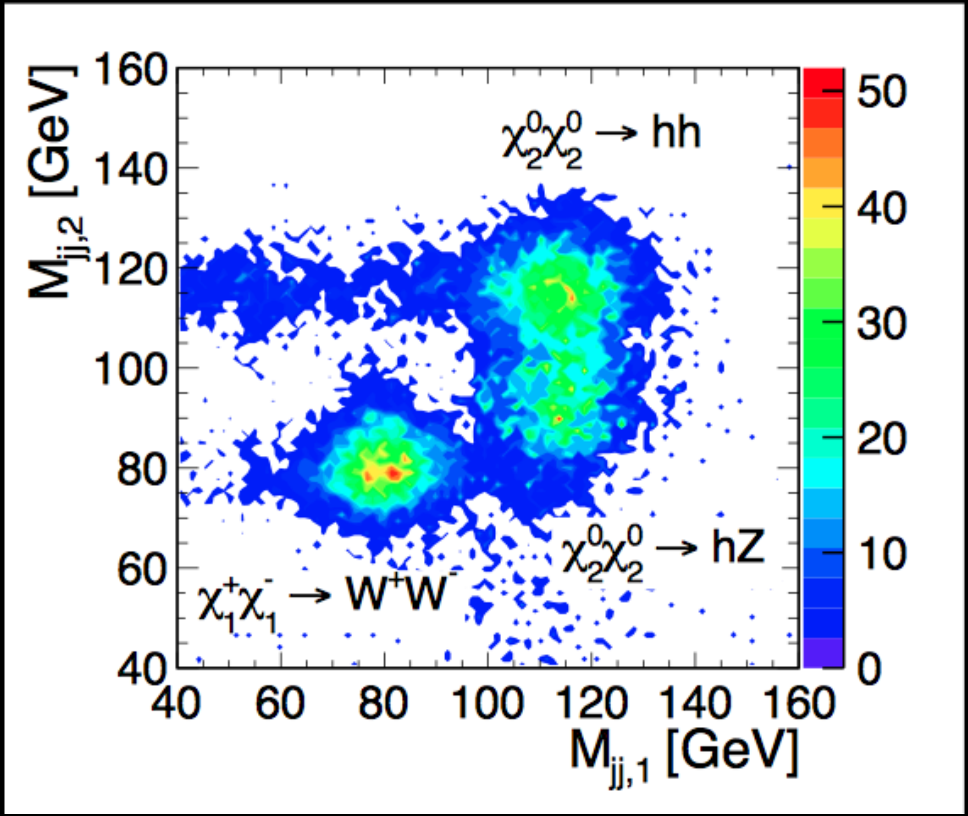
Gaugino Pair Production

$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$$

$$e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0 hh$$

$$e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0 Zh$$

Detailed Detector Simulation including background
3 TeV CLIC



Signature: 4 Jets + missing Energy

Separation of heavy bosons based on reconstructed invariant mass

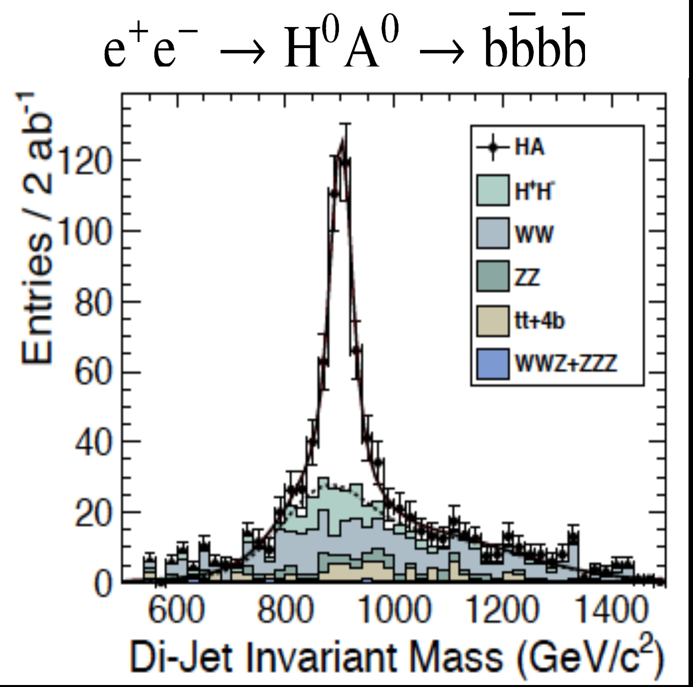
$$\sigma(\tilde{\chi}_1^+\tilde{\chi}_1^-) = 10.6\,\mathrm{fb} \pm 0.25\,\mathrm{fb}$$
$$m(\tilde{\chi}^\pm) = 643.2\,\mathrm{GeV} \pm 7\,\mathrm{GeV}$$

$$\sigma(\tilde{\chi}_2^0\tilde{\chi}_2^0) = 3.3\,\mathrm{fb} \pm 0.11\,\mathrm{fb}$$
$$m(\tilde{\chi}_2^0) = 643.1\,\mathrm{GeV} \pm 10\,\mathrm{GeV}$$

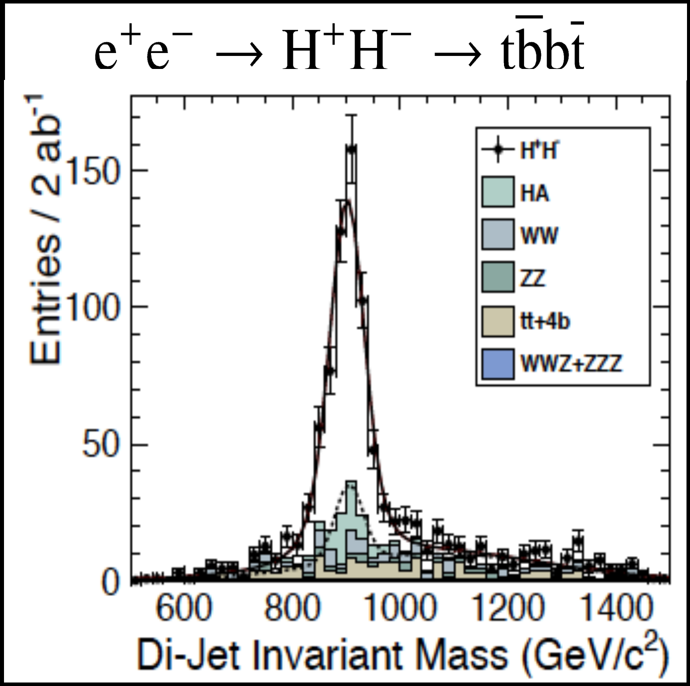
only statistical uncertainty quoted

Heavy Higgs Bosons

Test of flavor tagging in boosted jets and reconstruction of high-energy jets



3 TeV
2 ab^{-1}



$$\mathrm{m}(\mathrm{H}^+/\mathrm{H}^-) = 906.3\,\mathrm{GeV} \pm 2.4\,\mathrm{GeV}$$

1.1 fb

$$\mathrm{m}(\mathrm{A}^0/\mathrm{H}^0) = 902.4\,\mathrm{GeV} \pm 2.8\,\mathrm{GeV}$$

0.5 fb

Sensitivity nearly up to 1/2 √s

only statistical uncertainty quoted

Physics Summary

The CLIC environment at 3 TeV presents a unique opportunity for physics at the TeraScale

Detailed simulation studies show that the impact of the background can be controlled

Excellent detector performance allows precision measurements of heavy objects even at 3 TeV

Hardware R&D

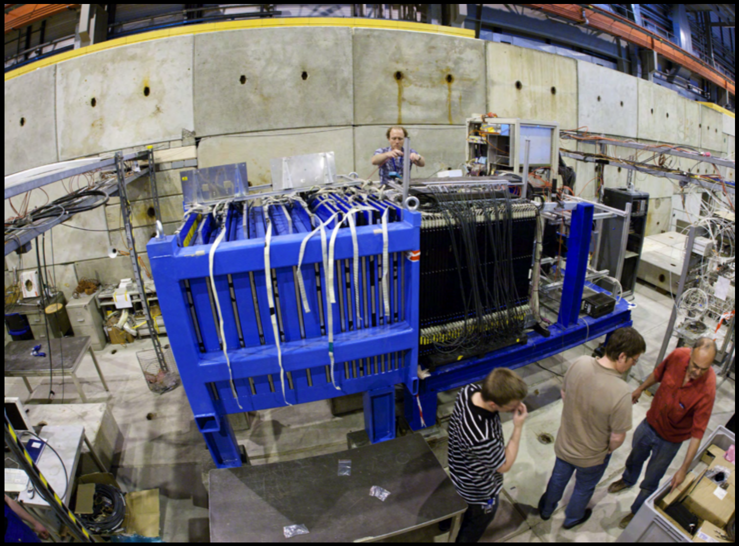
Hadronic Calorimeters

- Scintillator Plates in W absorber structure
- Glass RPC in W absorber structure

Vertex Detector Engineering

Vertex Detector Pixels

Analog HCAL



CERN SPS 2011

Validation of GEANT 4 models in tungsten stack

Good agreement found

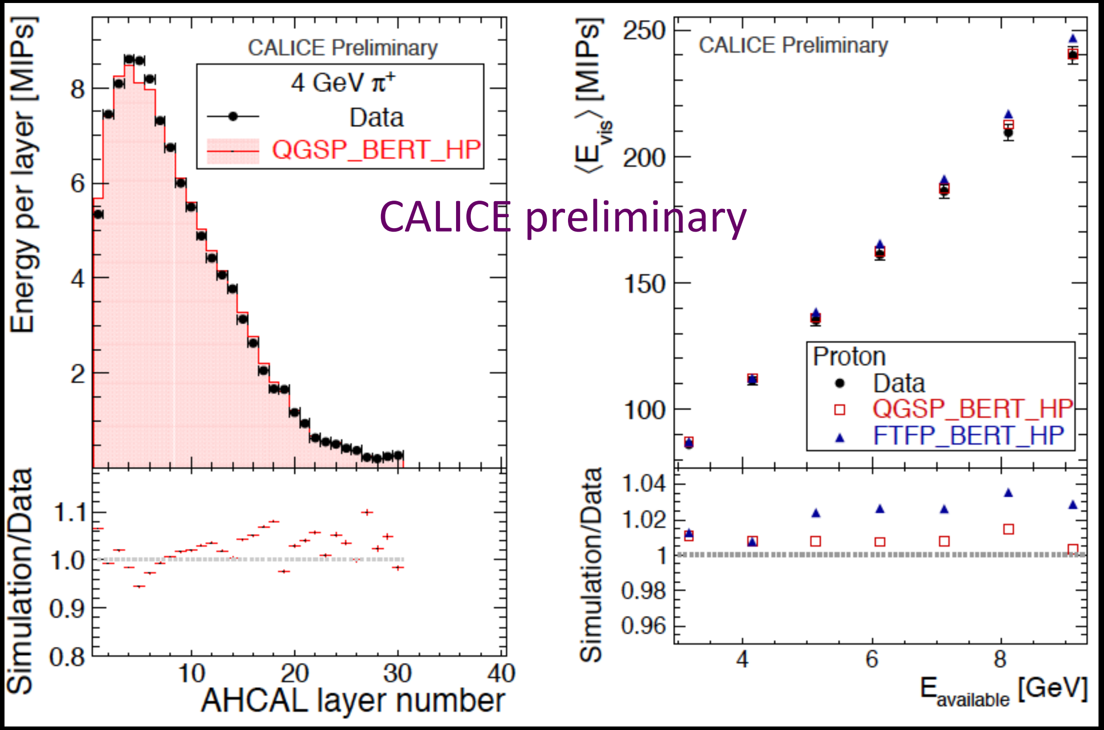
HCAL tests in 2010+2011

10 mm thick **Tungsten absorber** plates

scintillator active layers, 3×3 cm^2 cells

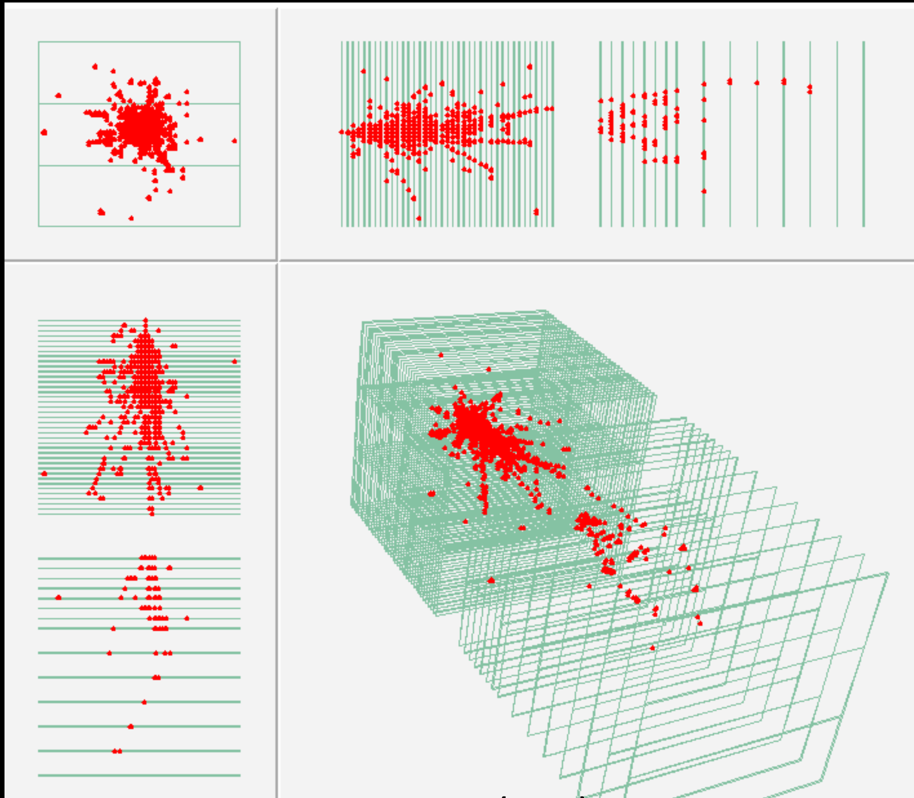
longitudinal shower profile, pions

visible Energy, protons



Digital HCAL

~ 500,000 channels
World record for hadronic calorimetry

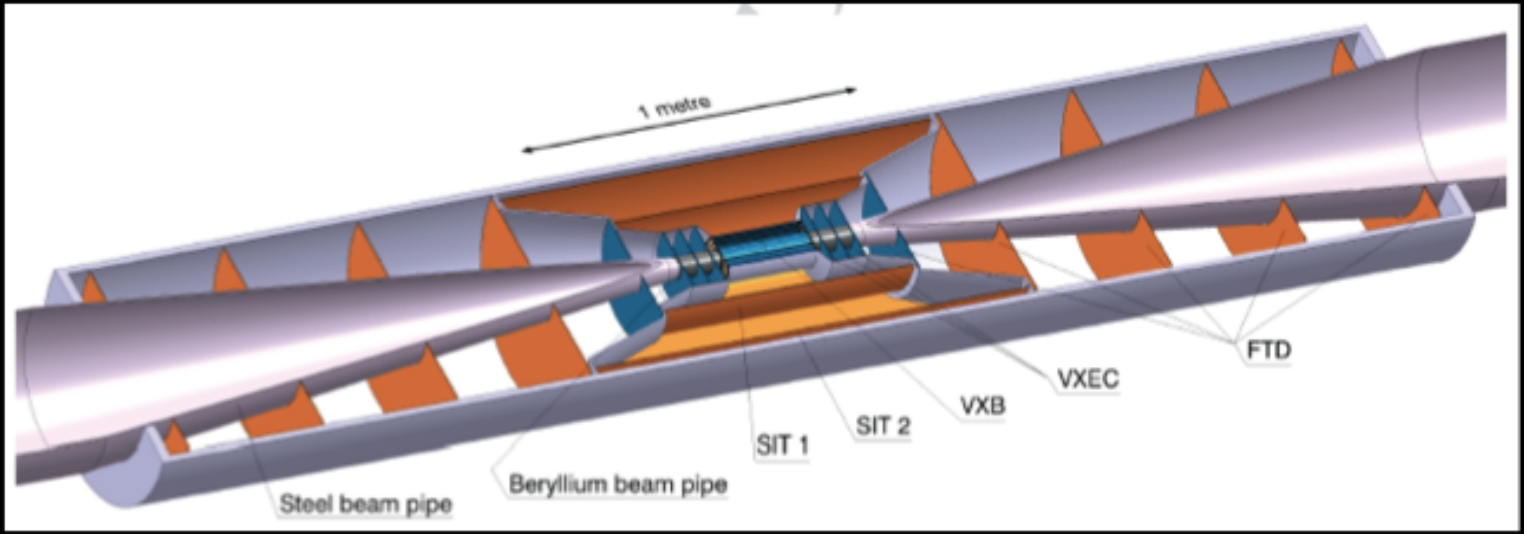


54 glass RPC chambers, 1m^2 each
PAD size 1×1 cm^2
Digital readout (1 threshold)
100 ns time-slicing
Fully integrated electronics
Main DHCAL stack (39) + tail catcher (15)

CERN test setup includes **fast readout RPC (T3B)**

W-DHCAL π^- at 210 GeV (SPS)

Inner Tracking Detectors



R&D

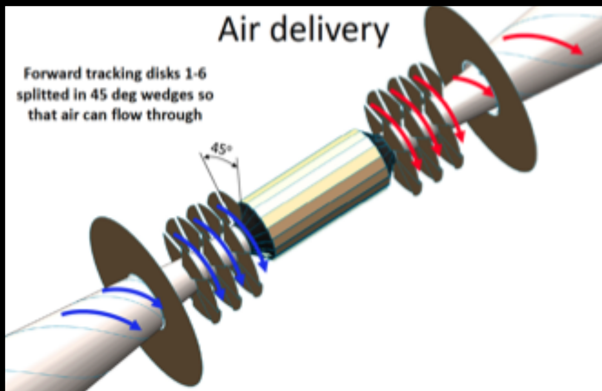
Material budget goal: 0.2% X_0 per layer

Time stamping: 10 ns

Excellent flavor tagging: small pixels ~25x25 μm^2,
small inner radius (2.7 cm)

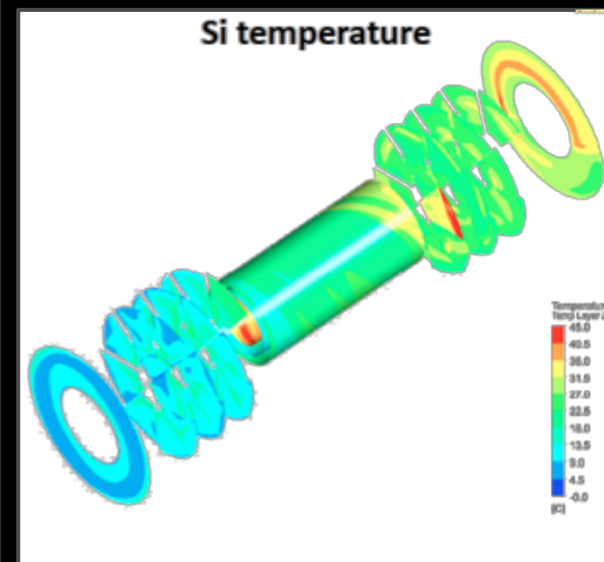
Radiation level < 10^{11} $n_{eq}cm^{-2}year^{-1}$ <= 10^4 lower than LHC

Low-mass Cooling



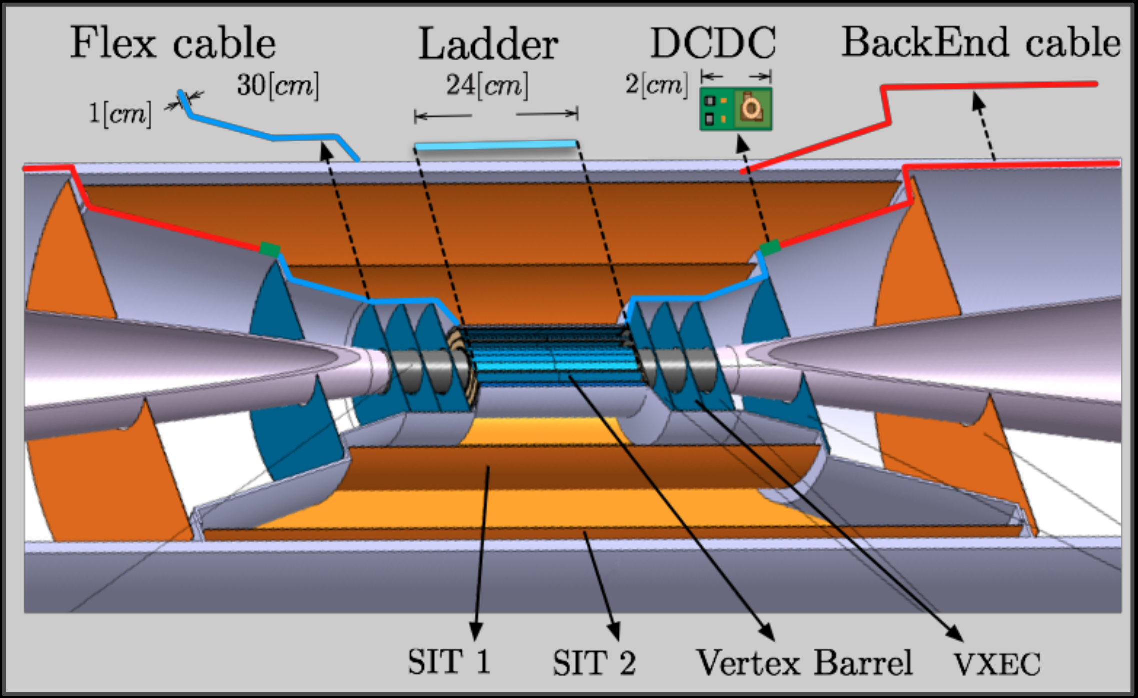
ANSYS finite element simulation
of air-flow cooling:
Spiral disk geometry allows for air flow into barrel
Sufficient heat removal

- Temperature < 30°C
- Except barrel layer 2 (40°C)
- Conduction not taken into account



Mass Flow: 20.1 g/s
Average velocity:
@ inlet: 11.0 m/s
@ z=0: 5.2 m/s
@ outlet: 6.3 m/s

Power Delivery



DC/DC converters outside pixel-sensor area
Flexible Kapton cables with Al conductor for power delivery
Power pulsing @ 50 Hz, reducing avg. power
local energy storage and voltage regulation with
Si capacitors (~10 μF/chip) and LDO regulators

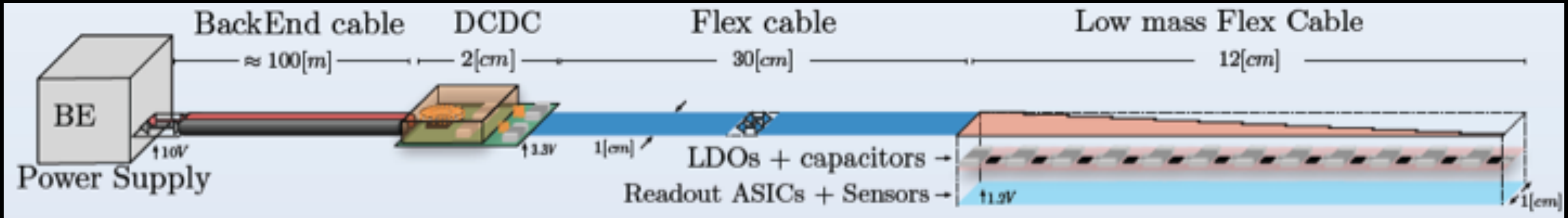
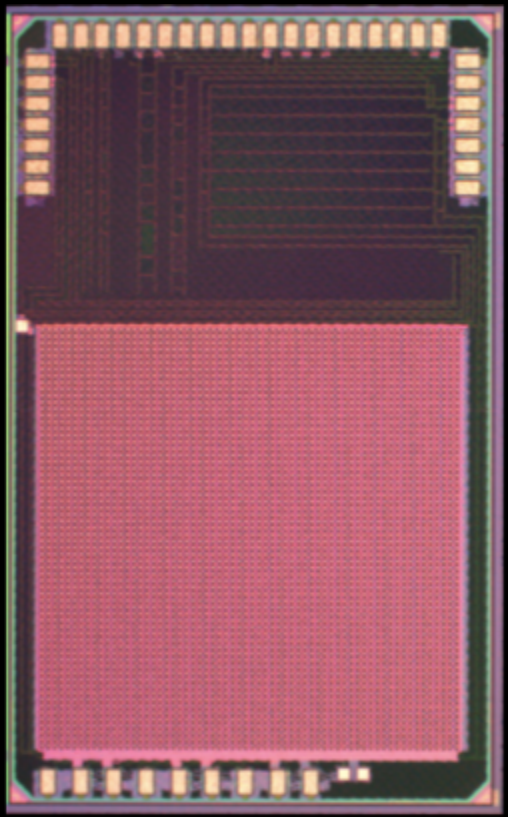
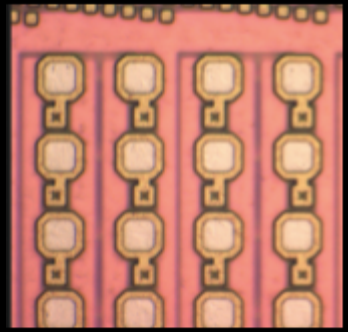


Figure: Half ladder proposed powering scheme

CLICPix demonstrator

Hybrid approach pursued: (<= other options possible)
•Thin (~50 μm) silicon sensors (Micron, CNM, VTT)
•Thinned High density ASIC in very-deep-sub-micron:
•TimePix3, Smallpix <= R&D steps
•CLICpix
•Low-mass interconnect
•Micro-bump-bonding (Cu-pillar option, Advacam)
•Through-Silicon-Vias (R&D with CEA-Leti)
•Chip-stitching





CLICpix

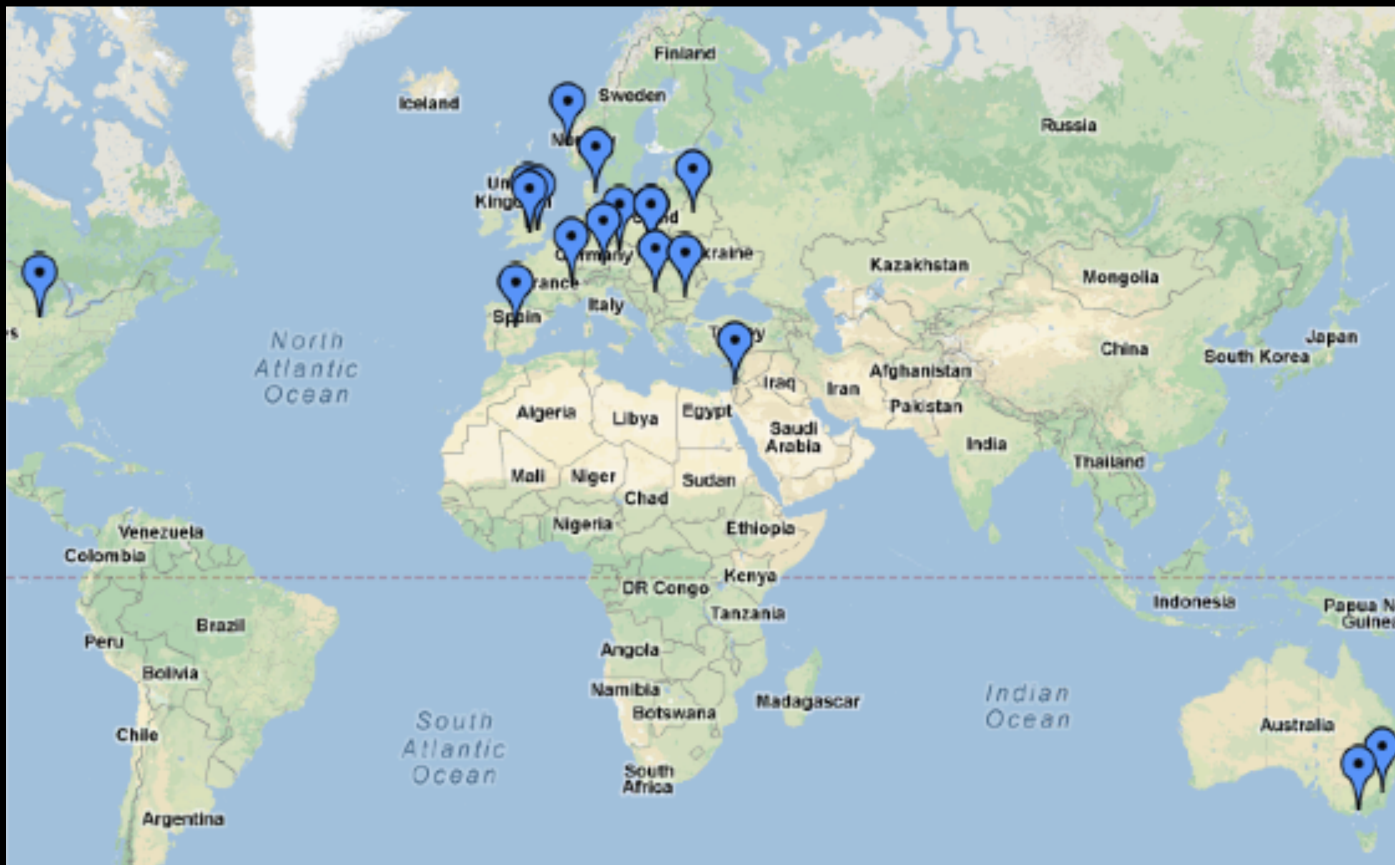
64×64 pixel demonstrator
•65 nm technology
•25×25 μm^2 pixels
•4-bit TOA and TOT information
•10 nsec time-slicing
•Power 2 W/cm^2 (continuous)
With sequential power pulsing 50 mW/cm^2

•**CLIC CDR** (#1), A Multi-TeV Linear Collider based on CLIC Technology, CERN-2012-003, https://edms.cern.ch/document/1234244/

•**CLIC CDR** (#2), Physics and Detectors at CLIC,
CERN-2012-003, arXiv:1202.5940

•**CLIC CDR** (#3), The CLIC Programme: towards a staged e+e- Linear Collider exploring the Terascale, CERN-2012-005, http://arxiv.org/abs/1209.2543

Organisation of CLIC Detector and Physics study

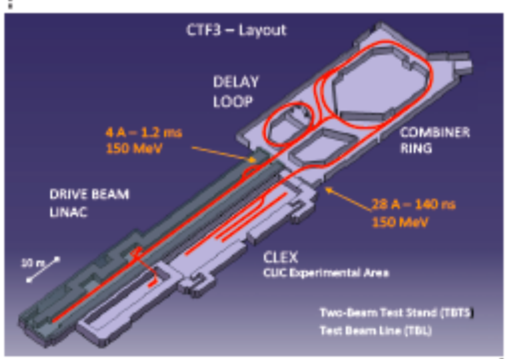


Pre-collaboration structure, based on a "Memorandum on Cooperation"
http://lcd.web.cern.ch/LCD/Home/MoC.html

CLIC strategy and objectives

2012-16 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.



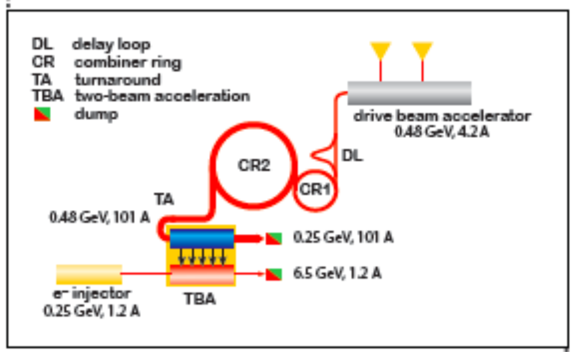
2016-17 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects), take decisions about next project(s) at the Energy Frontier.

2017-22 Preparation Phase

Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

Prepare detailed Technical Proposals for the detector-systems.



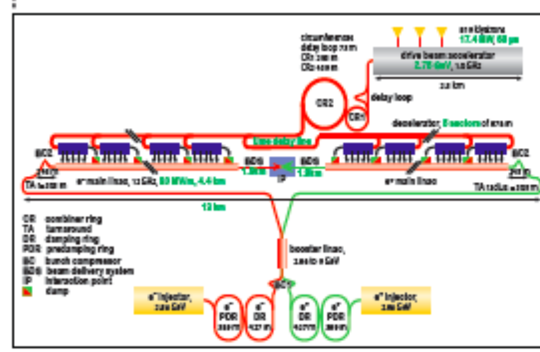
2022-23 Construction Start

Ready for full construction and main tunnel excavation.

2023-2030 Construction Phase

Stage 1 construction of a 500 GeV CLIC, in parallel with detector construction.

Preparation for implementation of further stages.



2030 Commissioning

From 2030, becoming ready for data-taking as the LHC programme reaches completion.

Faster implementation possible, (e.g. for lower-energy Higgs factory): **klystron-based initial stage**

plans for the phase 2013-2016

Further exploration of the physics potential

- Complete picture of Higgs prospects at ~350 GeV, ~1.4 TeV, ~3 TeV
- Discovery reach for BSM physics
- Sensitivity to BSM through high-precision measurements

cf. LHC results

Drives the CLIC staging strategy

Detector Optimisation studies

- Optimisation studies linked to physics (e.g aspect ratio, forward region coverage);
- Interplay between occupancies and reconstruction;
- Interplay between technology R&D and simulation models.

Technology demonstrators

- Many common developments with ILC
- Complemented with CLIC requirements

R&D objectives: 2013-2016

R&D => technology demonstrators

Implementation examples ***demonstrating the required functionality***

Vertex detector

Demonstration module, meeting requirements of high precision, 10 ns time stamp and ultra-low mass

Main tracker

Demonstration modules, including manageable occupancies in the event reconstruction

Calorimeters

Demonstration modules, technological prototypes + addressing control of cost

Electronics

Demonstrators, in particular in view of power pulsing

Magnet systems

Demonstrators of conductor technology, safety systems and moveable service lines

Engineering and detector integration

Engineering design and detector integration harmonized with hardware R&D demonstrators

Challenging and interesting detector technologies
Considered feasible in a 5-year R&D program

summary and outlook

Summary of CLIC detector & physics CDR studies

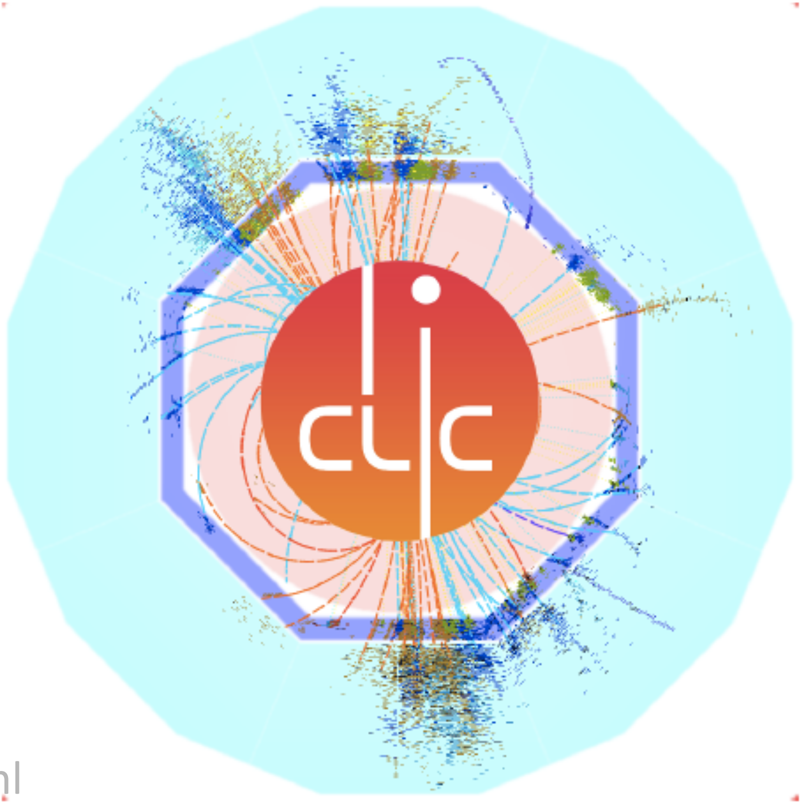
- Feasibility of precision physics measurements demonstrated
- Staged implementation of CLIC => large potential for SM and BSM physics

Good progress with understanding detectors at CLIC

- Based on ILD and SiD concepts
- Detector requirements now well understood
- => challenging, but feasible through realistic R&D

Development program for the next CLIC phases

- Anticipating energy frontier machine choice ~2017
- Anticipating start of construction by ~2023



Welcome to join !

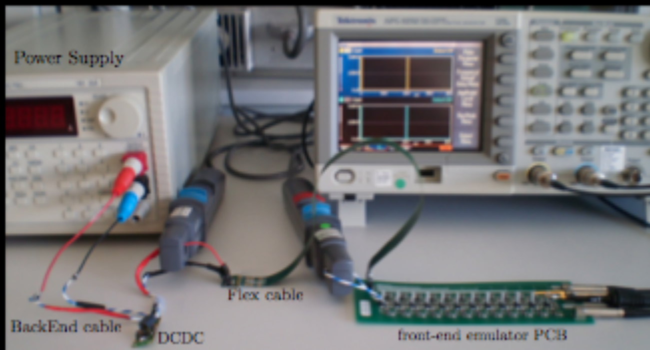
lcd.web.cern.ch/lcd/

http://lcd.web.cern.ch/LCD/Home/MoC.html

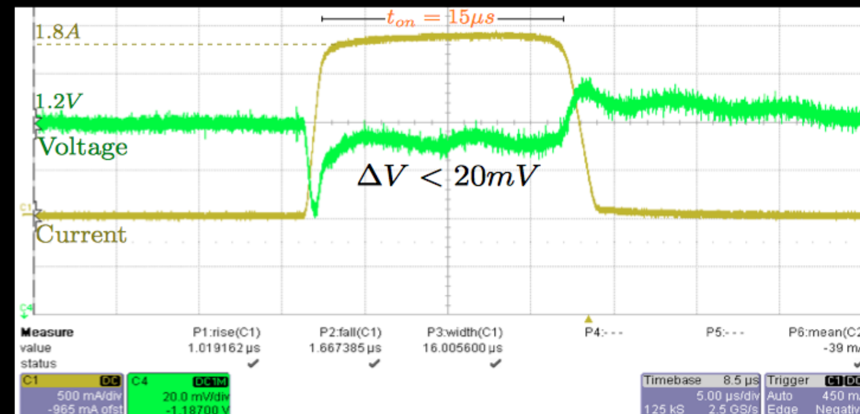
Backup

Power Pulsing Measurements

Test setup with active loads emulating analog pixel F/E:

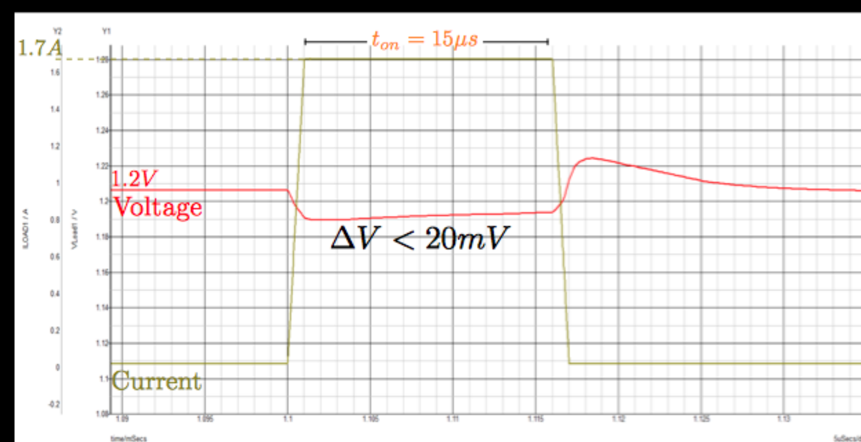


Measurement



- Equivalent thickness cable+LDO+cap.: 0.145% X0 / layer in vtx region
- Power pulsing at 50 Hz
- Load current of 2 A (half ladder) during 15 μs
- Monitor load voltages and currents
- Observed ripple ΔV< 20 mV, acceptable for CLICPix
- Agreement between measurement and simulation

Simulation



Possible luminosity examples

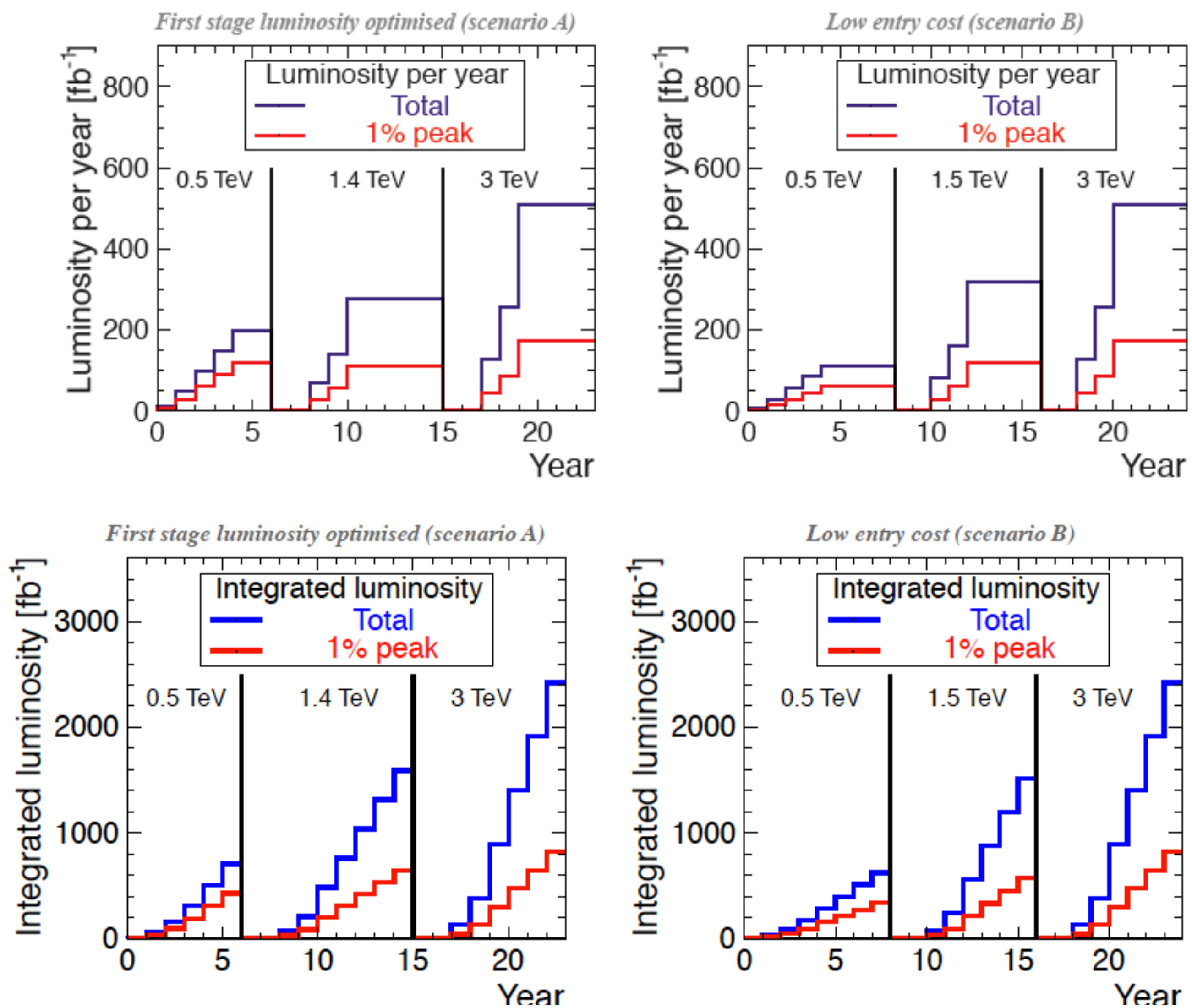
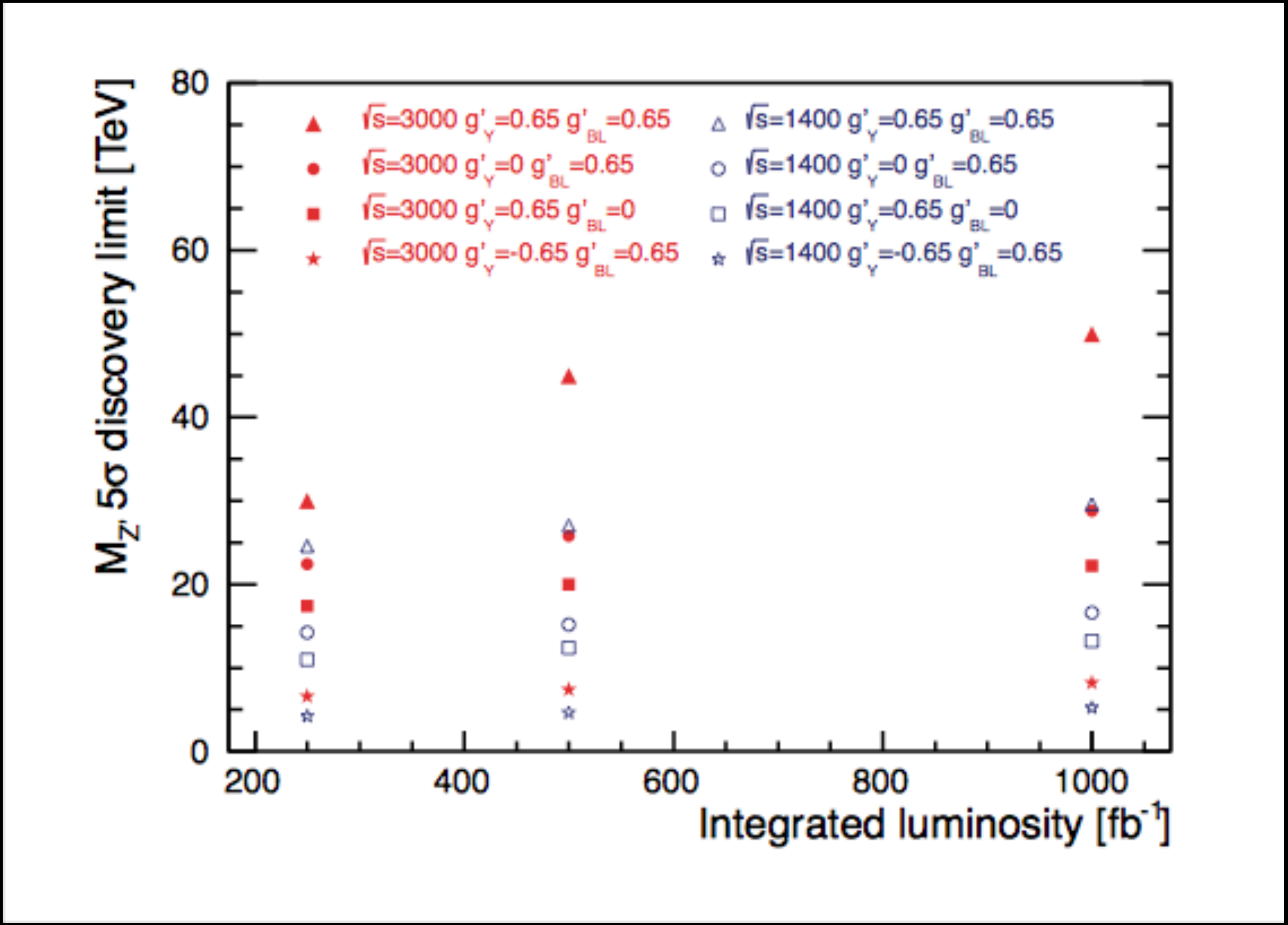


Fig. 5.2: Integrated luminosity in the scenarios optimised for luminosity in the first energy stage (left) and optimised for entry costs (right). Years are counted from the start of beam commissioning. These figures include luminosity ramp-up of four years (5%, 25%, 50%, 75%) in the first stage and two years (25%, 50%) in subsequent stages.

Based on 200 days/year at 50% efficiency (accelerator + data taking combined)

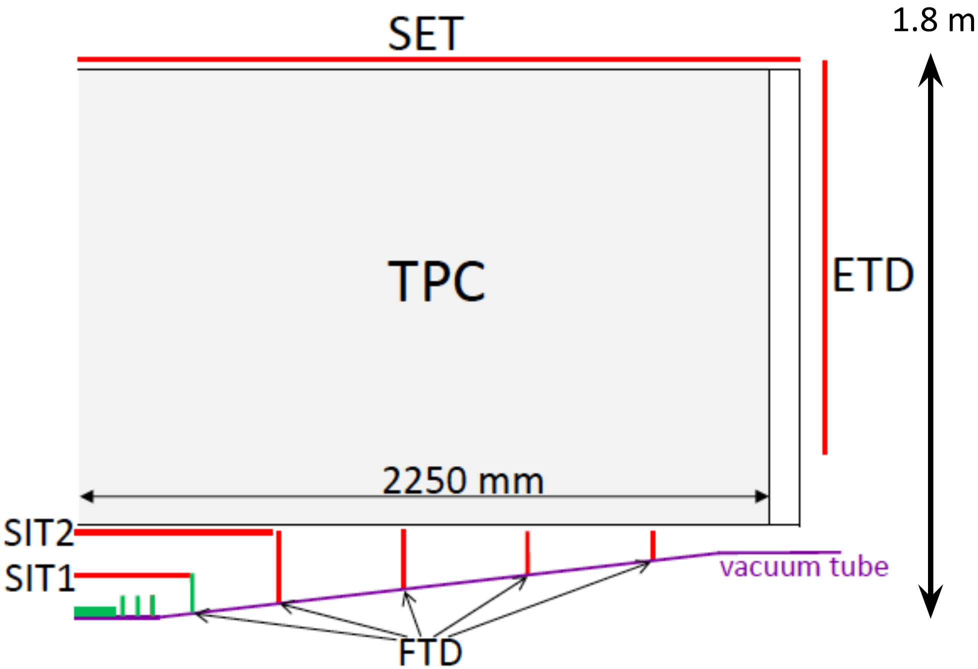
Target figures: >600 fb^{-1} at first stage, 1.5 ab^{-1} at second stage, 2 ab^{-1} at third stage

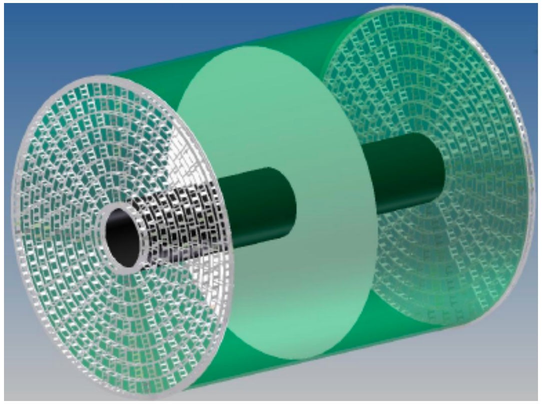
Z' Sensitivity Study



CLIC_ILD ↙ and CLIC_SiD ↘ tracker

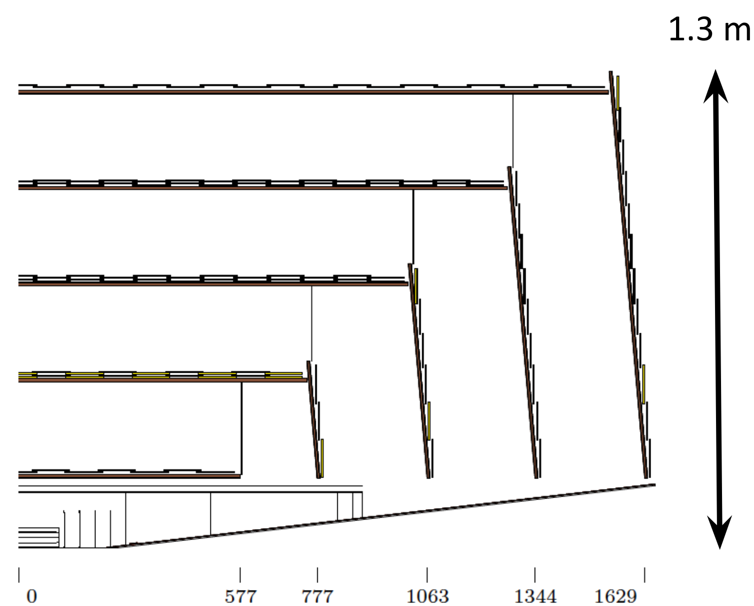
TPC + silicon tracker in 4 Tesla field

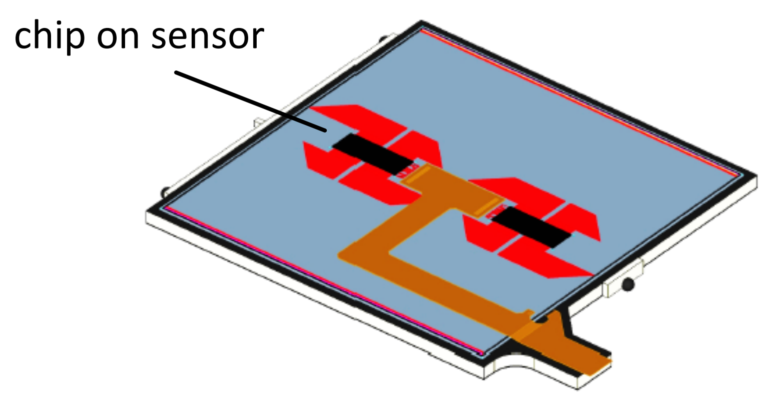




Time Projection Chamber (TPC) with MPGD readout

all-silicon tracker in 5 Tesla field





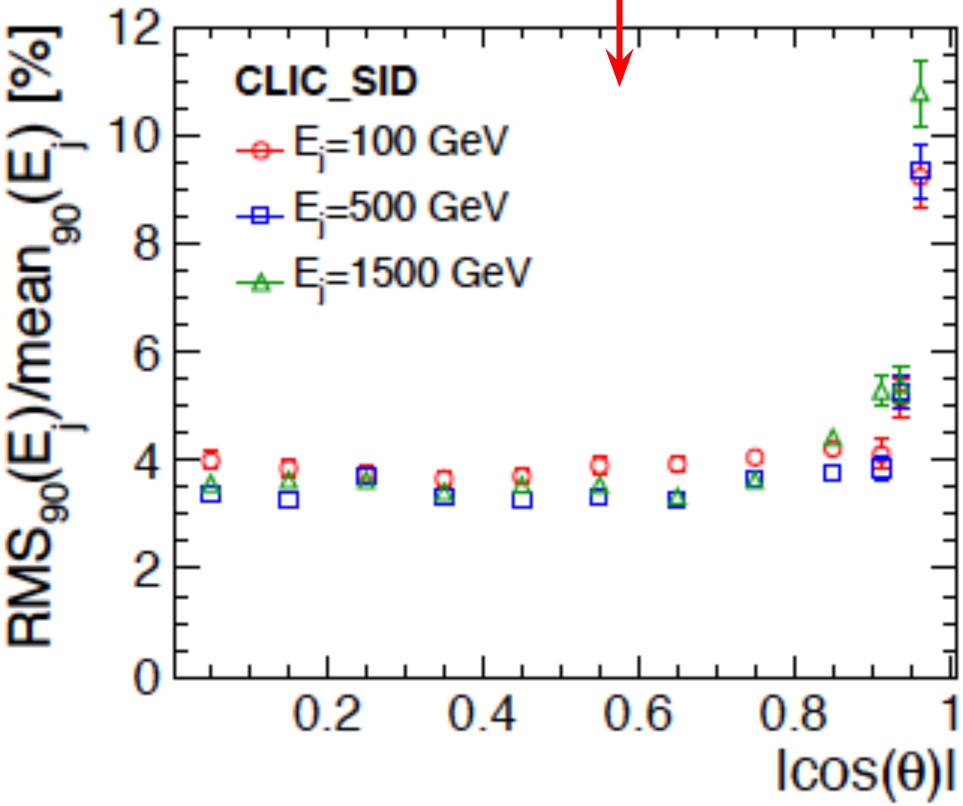
PFA calorimetry at CLIC

ECAL
Si or Scint. (active) + Tungsten (absorber)
cell sizes 13 mm^2 or 25 mm^2
30 layers in depth

HCAL
Several technology options: **scint. or gas**
Tungsten (barrel), steel (endcap)
cell sizes 9 cm^2 (analog) or 1 cm^2 (digital)
60-75 layers in depth
Total depth 7.5 Λ_i

technology

simulated
jet energy resolution



(no jet clustering, without background overlay)

High precision on jets
↓
ECAL +HCAL have to fit inside coil
↓
CLIC needs Tungsten absorber in HCAL
↓
Requires beam tests to validate Geant4

Higgs Summary

Higgs studies for m_H =120 GeV

$\sqrt{s}$ (GeV)	Process	Decay mode	Measured quantity	Unit	Generator value	Stat. error	Comment
350	SM Higgs production	$ZH \to \mu^+\mu^- X$	σ	fb	4.9	4.9%	Model independent, using Z-recoil
			Mass	GeV	120	0.131	
500		$ZH \to q\bar{q}q\bar{q}$	$\sigma\times$ BR	fb	34.4	1.6%	$ZH \to q\bar{q}q\bar{q}$ mass reconstruction
			Mass	GeV	120	0.100	
500		$ZH, H\nu\bar{\nu} \to \nu\bar{\nu}q\bar{q}$	$\sigma\times$ BR	fb	80.7	1.0%	Inclusive sample
			Mass	GeV	120	0.100	
1400	WW fusion	$H \to \tau^+\tau^-$	$\sigma\times$ BR	fb	19.8	<3.7%	
3000		$H \to b\bar{b}$			285	0.22%	
		$H \to c\bar{c}$			13	3.2%	
		$H \to \mu^+\mu^-$			0.12	15.7%	
1400 3000	WW fusion		Higgs tri-linear coupling g_{HHH}			~20% ~20%	

SUSY Summary

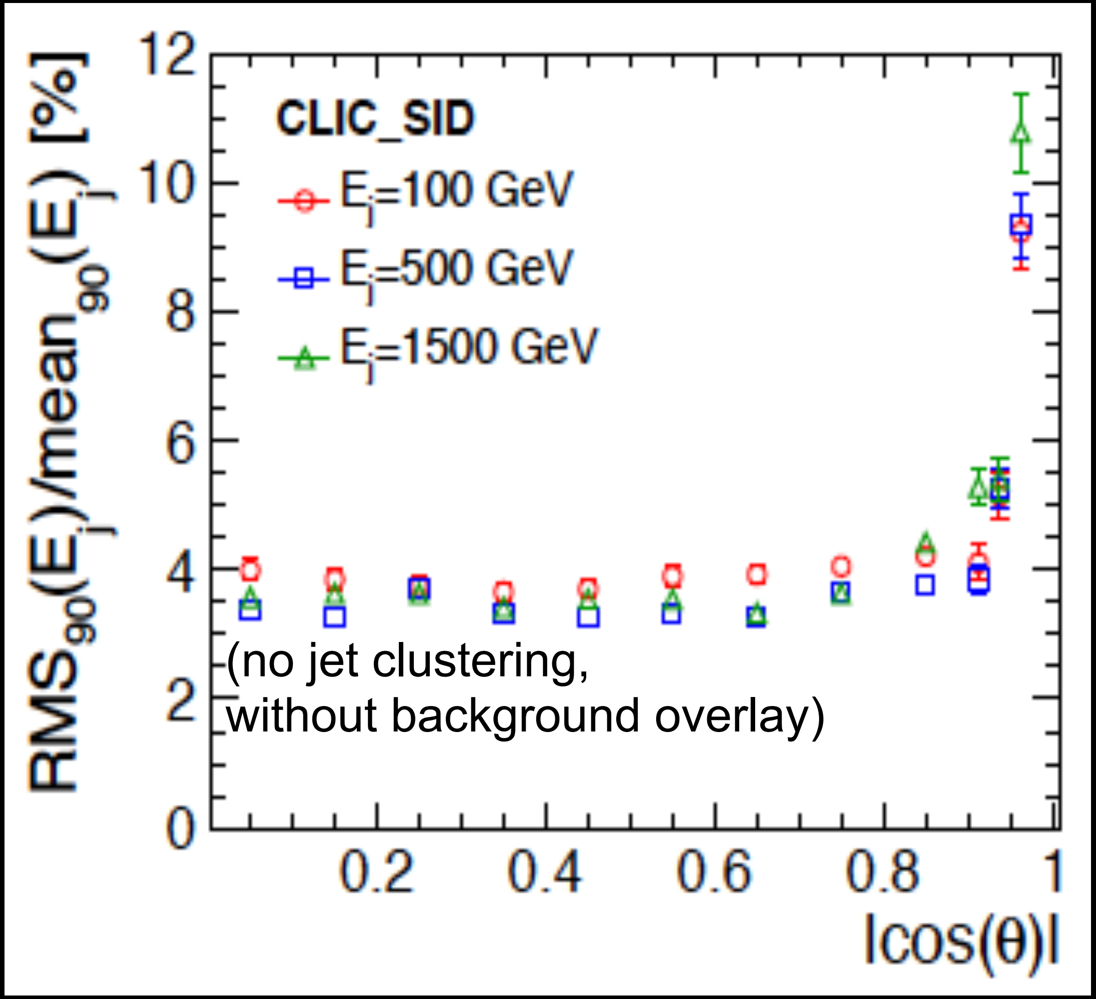
$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Unit	Generator value	Stat. error
1.4	Sleptons production	$\widetilde{\mu}_R^+\widetilde{\mu}_R^- \to \mu^+\mu^-\widetilde{\chi}_1^0\widetilde{\chi}_1^0$	III	σ	fb	1.11	2.7%
				$\tilde{\ell}$ mass	GeV	560.8	0.1%
				$\widetilde{\chi}_1^0$ mass	GeV	357.8	0.1%
		$\widetilde{e}_R^+\widetilde{e}_R^- \to e^+e^-\widetilde{\chi}_1^0\widetilde{\chi}_1^0$		σ	fb	5.7	1.1%
				$\tilde{\ell}$ mass	GeV	558.1	0.1%
				$\widetilde{\chi}_1^0$ mass	GeV	357.1	0.1%
		$\widetilde{\nu}_e\widetilde{\nu}_e \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0 e^+e^-W^+W^-$		σ	fb	5.6	3.6%
				$\tilde{\ell}$ mass	GeV	644.3	2.5%
				$\widetilde{\chi}_1^\pm$ mass	GeV	487.6	2.7%
1.4	Stau production	$\widetilde{\tau}_1^+\widetilde{\tau}_1^- \to \tau^+\tau^-\widetilde{\chi}_1^0\widetilde{\chi}_1^0$	III	$\widetilde{\tau}_1$ mass	GeV	517	2.0%
				σ	fb	2.4	7.5%
1.4	Chargino production	$\widetilde{\chi}_1^+\widetilde{\chi}_1^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0 W^+W^-$	III	$\widetilde{\chi}_1^\pm$ mass	GeV	487	0.2%
				σ	fb	15.3	1.3%
	Neutralino production	$\widetilde{\chi}_2^0\widetilde{\chi}_2^0 \to h/Z^0 h/Z^0 \widetilde{\chi}_1^0\widetilde{\chi}_1^0$		$\widetilde{\chi}_2^0$ mass	GeV	487	0.1%
				σ	fb	5.4	1.2%

Results of detailed simulation study for a given SUSY model (model III)
CLIC operated at 1.4 TeV, 1.5 ab^{-1}
Results from earlier stage(s) not taken into account

Susy models I & II

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Unit	Generator value	Stat. error
3.0	Sleptons production	$\widetilde{\mu}_R^+\widetilde{\mu}_R^- \to \mu^+\mu^-\widetilde{\chi}_1^0\widetilde{\chi}_1^0$	II	σ	fb	0.72	2.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.6%
				$\widetilde{\chi}_1^0$ mass	GeV	340.3	1.9%
		$\widetilde{e}_R^+\widetilde{e}_R^- \to e^+e^-\widetilde{\chi}_1^0\widetilde{\chi}_1^0$		σ	fb	6.05	0.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.3%
				$\widetilde{\chi}_1^0$ mass	GeV	340.3	1.0%
		$\widetilde{e}_L^+\widetilde{e}_L^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0 e^+e^-hh$ $\widetilde{e}_L^+\widetilde{e}_L^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0 e^+e^-Z^0Z^0$		σ	fb	3.07	7.2%
		$\widetilde{\nu}_e\widetilde{\nu}_e \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0 e^+e^-W^+W^-$		σ	fb	13.74	2.4%
				$\tilde{\ell}$ mass	GeV	1097.2	0.4%
				$\widetilde{\chi}_1^\pm$ mass	GeV	643.2	0.6%
3.0	Chargino production	$\widetilde{\chi}_1^+\widetilde{\chi}_1^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0 W^+W^-$	II	$\widetilde{\chi}_1^\pm$ mass	GeV	643.2	1.1%
				σ	fb	10.6	2.4%
	Neutralino production	$\widetilde{\chi}_2^0\widetilde{\chi}_2^0 \to h/Z^0h/Z^0\widetilde{\chi}_1^0\widetilde{\chi}_1^0$		$\widetilde{\chi}_2^0$ mass	GeV	643.1	1.5%
				σ	fb	3.3	3.2%
3.0	Production of right-handed squarks	$\widetilde{q}_R\widetilde{q}_R \to q\bar{q}\widetilde{\chi}_1^0\widetilde{\chi}_1^0$	I	Mass	GeV	1123.7	0.52%
				σ	fb	1.47	4.6%
3.0	Heavy Higgs production	$H^0A^0 \to b\bar{b}b\bar{b}$	I	Mass	GeV	902.4	0.3%
				Width	GeV		31%
		$H^+H^- \to t\bar{b}b\bar{t}$		Mass	GeV	906.3	0.3%
				Width	GeV		27%

PFA Performance w/o background



Detector Costing (no labor)

Table 5.4: Value estimate of the CLIC detectors.

	CLIC_ILD (MCHF)	CLIC_SiD (MCHF)
Vertex	13	15
Tracker	51	17
Electromagnetic calorimeter	197	89
Hadronic calorimeter	144	86
Muon system	28	22
Coil and yoke	117	123
Other	11	12
Total (rounded)	560	360

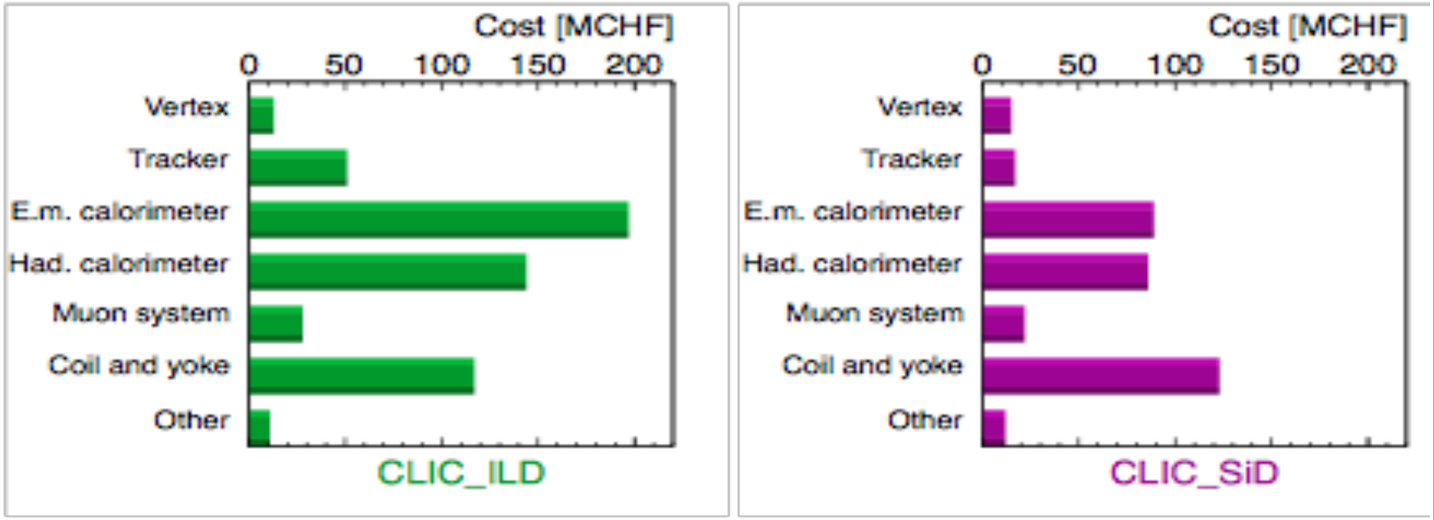
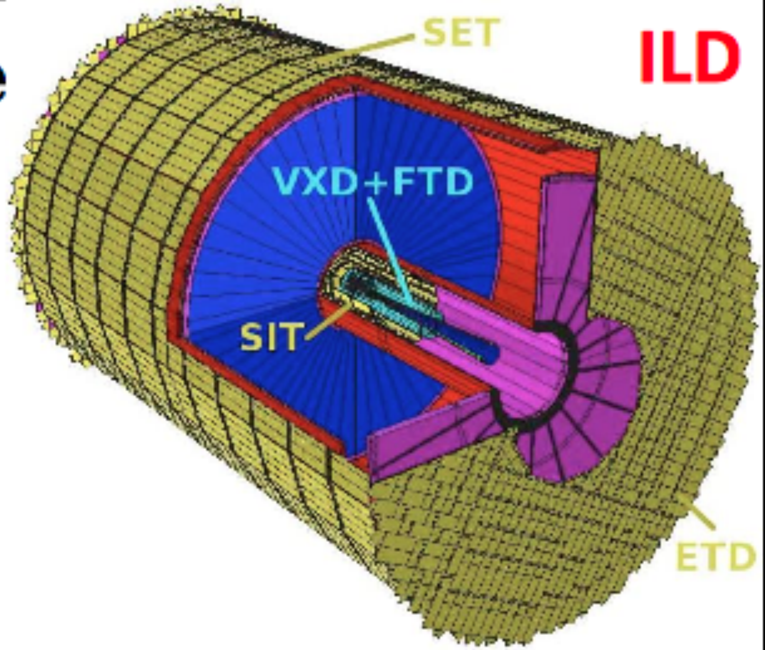


Fig. 5.9: Cost structure of the CLIC detectors.

Vertex Region Layout

	CLIC_ILD	CLIC_SiD
Central beam pipe	Beryllium	
	$R_i = 29.4$ mm	$R_i = 24.5$ mm
	$d = 0.6$ mm	$d = 0.5$ mm
Barrel region	3 double layers	5 single layers
	$\lvert z\rvert < 130$ mm	$\lvert z\rvert < 98.5$ mm
	$R_i = 31,\ 44,\ 58$ mm	$R_i = 27,\ 38,\ 51,\ 64,\ 77$ mm
Forward region	3 double layers	7 single layers
	$z = 160, 207, 255$ mm	$z = 120, 160, 200, 240,$
		$280, 500, 830$ mm
Sensors	$20\ \mu m \times 20\ \mu m$, $\sigma_{sp} \approx 3\ \mu m$	
	$X/X_0 = 0.18\%$	$X/X_0 = 0.11\%$
	per double layer	per single layer
Surface area	$0.736\ m^2$	$1.103\ m^2$
Number of channels	1.84×10^9	2.76×10^9

The Silicon Envelope in numbers (current scheme)



Component	Layer #	# modules	# sensors/ module	# channels	Total surface m2
SIT1	1st layer	33	3	66.000	0.9
	2nd layer	99	1	198.000	0.9
SIT2	1st layer	90	3	180.000	2.7
	2nd layer	270	1	540.000	2.7
SET	1st layer	1260	5	2.520.000	55.2
	2nd layer	1260	5	2.520.000	55.2
ETD_F	X or U or V	82/quad =328/layer =984/ETD	2 or 3 or possibly 4	2.000.000	30
ETD_B	idem	idem	idem	idem	30

Total number of channels:
10^6 (SIT) + $5\text{x}10^6$ (SET) + $4\text{x}10^6$ (2 ETD)
= **$10\ \text{x}10^6$ channels**
Total area:
7 (SIT)+110 (SET) +2x30(ETDs) = **180 m^2**
Total number of modules:
500 (SIT) + 2500 (SET) + 2000 (ETDs)=
5000 modules with unique size sensors
=>Achieved: a unified and simple design for all components (except FTD)

Taken from: Aurore Savoy-Navarro, talk for
Terceras Jornadas sobre la Participación Española en los Futuros
Aceleradores Lineales de Partículas - 7 a 8 Mayo, Barcelona

Key Parameters of the CLIC machine

Parameter	Symbol	Unit	500 GeV	3 TeV
Centre-of-mass energy	$\sqrt{s}$	TeV	0.5	3.0
Repetition frequency	f_{rep}	Hz	50	50
Number of bunches per train	n_b		354	312
Bunch separation	Δt	ns	0.5	0.5
Accelerating gradient	G	MV/m	80	100
Total luminosity	$\mathscr{L}_{total}$	$10^{34}\text{cm}^{-2}\text{s}^{-1}$	2.3	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	$10^{34}\text{cm}^{-2}\text{s}^{-1}$	1.4	2.0
Number of photons per electron/positron	n_γ		1.3	2.1
Average energy loss due to beamstrahlung	$\Delta E/E$		0.07	0.28
Number of coherent pairs per bunch crossing	N_{coh}		2×10^{-2}	6.8×10^8
Energy of coherent pairs per bunch crossing	E_{coh}	TeV	15	2.1×10^8
Number of incoherent pairs per bunch crossing	n_{incoh}	10^6	0.08	0.3
Energy of incoherent pairs per bunch crossing	E_{incoh}	10^6 GeV	0.36	23
Hadronic events per bunch crossing	n_{had}		0.3	3.2

Background Properties