The CLIC detector

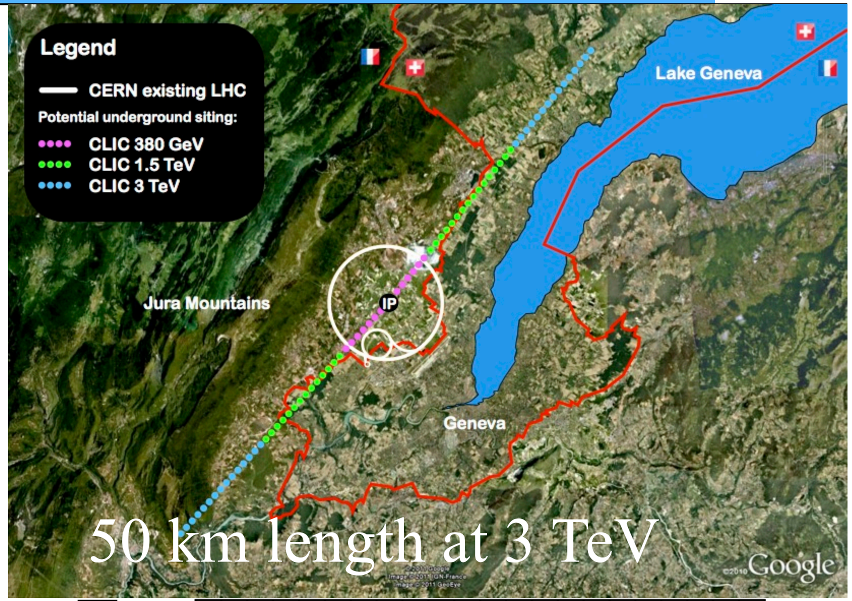
Matthias Weber (CERN)

on behalf of the CLIC detector and physics (CLICdp) collaboration

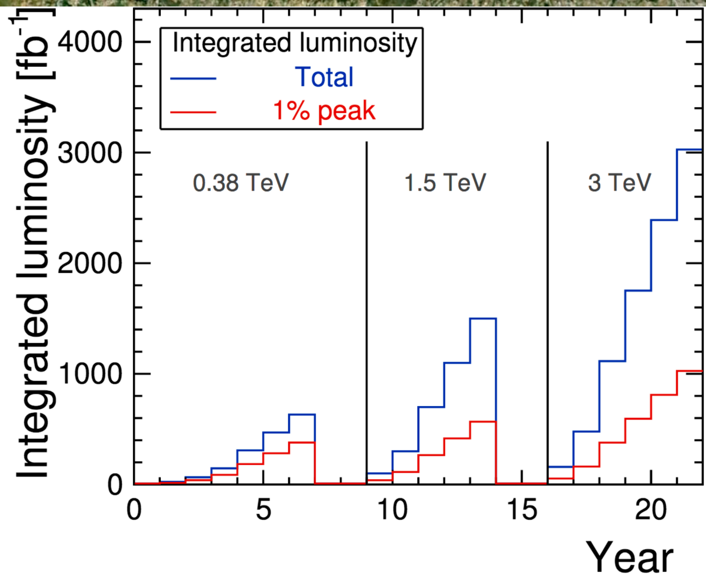
Compact Linear Collider

Proposed e^+e^- linear collider

- Two beam acceleration scheme
- High acceleration gradient (100 MV/m)
- Staged construction up to 3 TeV
  - High precision physics
  - Higgs, top, BSM



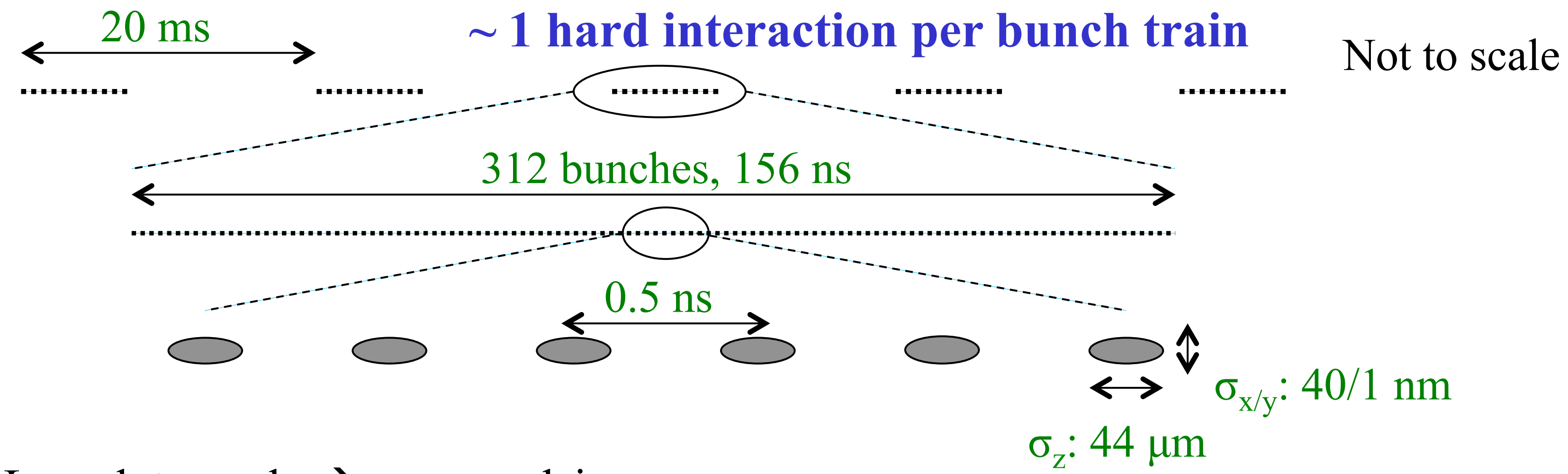
Stage	$\sqrt{s}$ (GeV)	$\mathscr{L}_{\text{int}}$ (fb^{-1})
1	380 350	500 100
2	1500	1500
3	3000	3000



Detector design driven by physics and experimental constraints

CLIC Accelerator talk #203 by P Skowronski

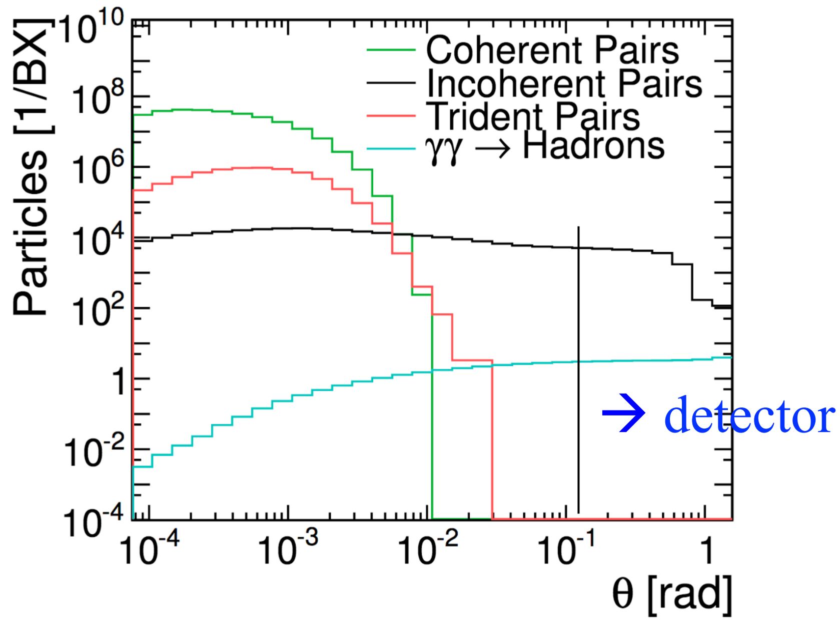
CLIC beam environment



Low duty cycle → power pulsing
High luminosity
Very small bunch size at IP
Very strong electromagnetic field from opposite beam → Beamstrahlung

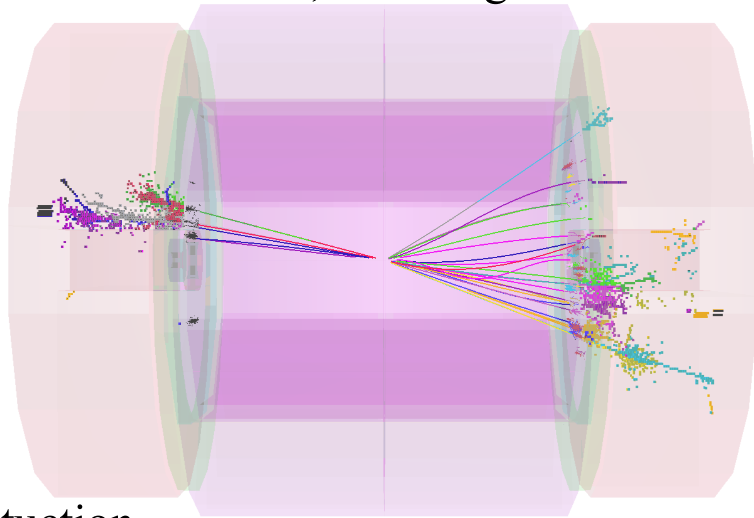
- **Coherent** and **trident** e^+e^- pairs very forward
- Contribution from **incoherent** e^+e^- pairs (3×10^5 per BX) in detector region
- Main background in calorimeters and tracker from **$\gamma\gamma$→hadrons** (3.2 evts per BX at 3 TeV)

→beam background reduced by p_T and timing cuts

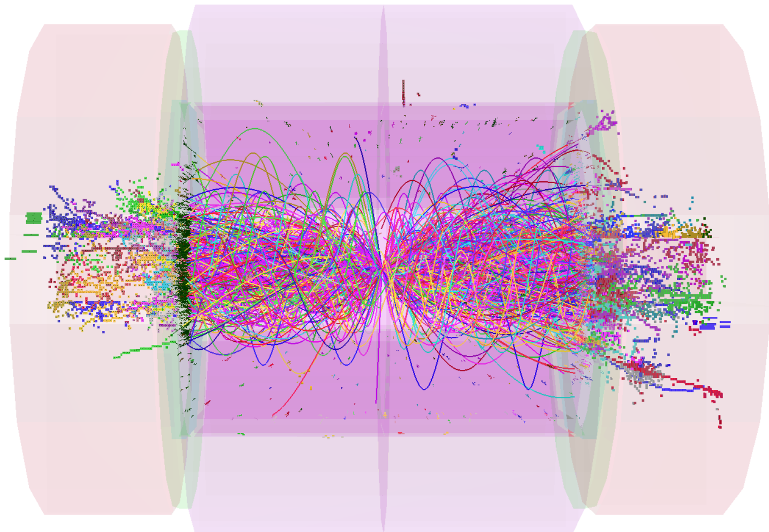


Example: Beamstrahlung background reduction

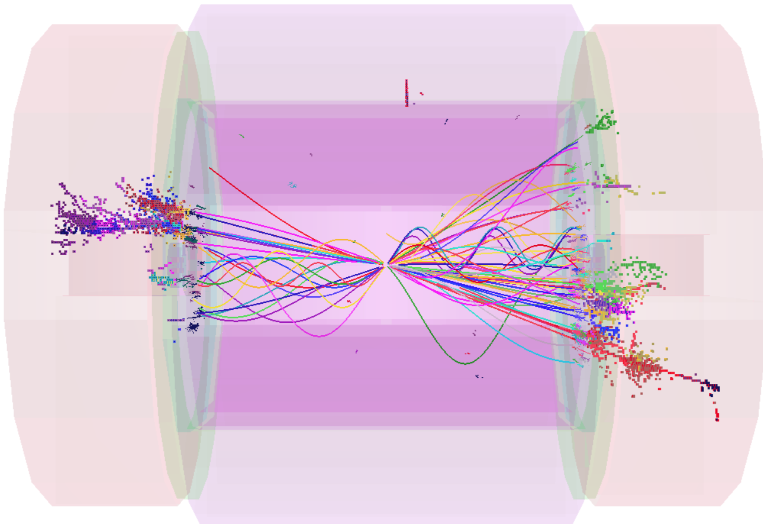
Forward WW, no background



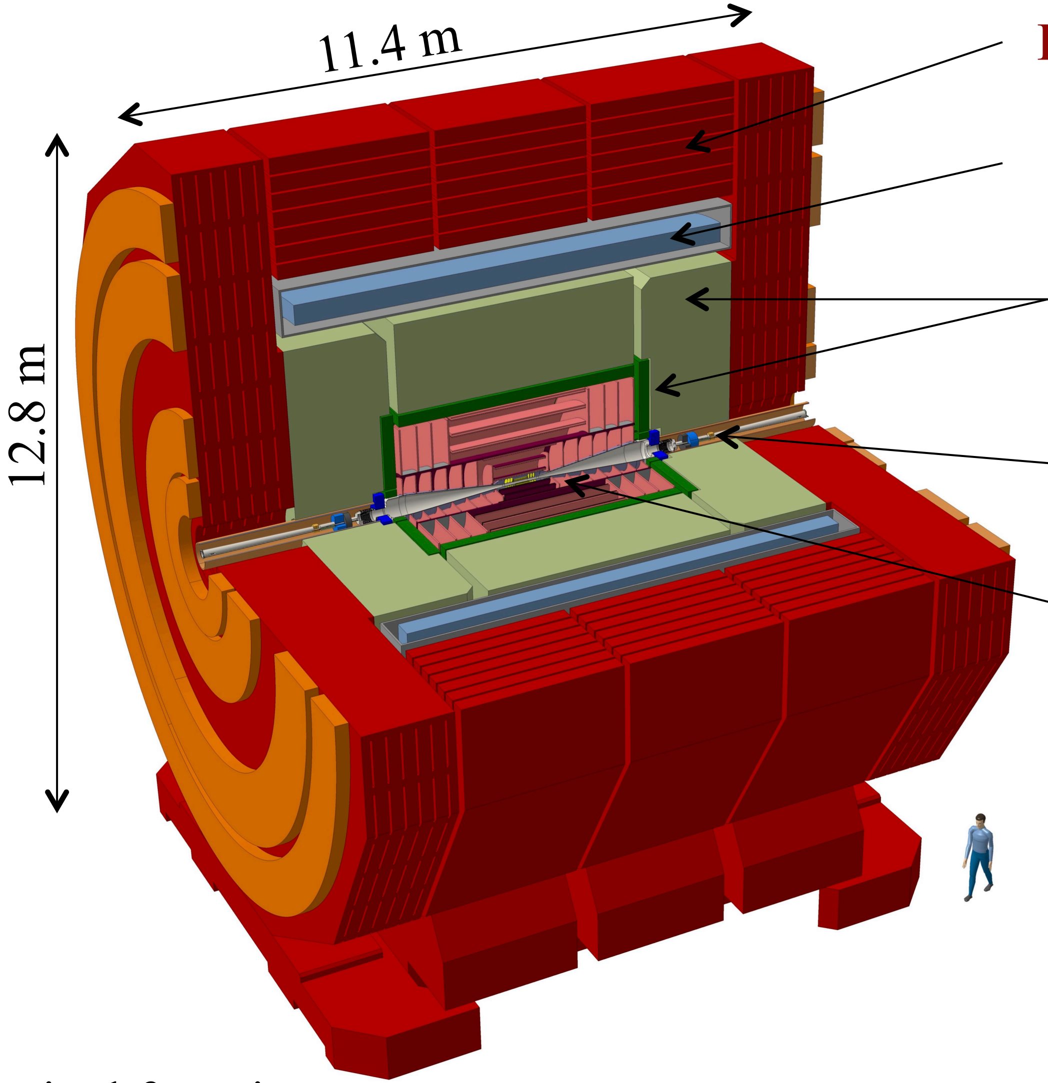
with background in reconstuction
time window ~1.2 TeV



after timing and p_T cuts: ~ 100 GeV remain



CLICdet



Return yoke and muon chambers

4T solenoid (R_{in} = 3.4 m)

Fine grain calorimeters (**HCAL**) and (**ECAL**) for particle flow reconstuction

Forward EM Calorimeters (LumiCal & BeamCal)

Ultra light **Tracker** and **Vertex**

Power pulsed operation (switch off between bunch trains)
Trigger less readout

Final focusing magnet outside of detector

CLICdp-Note-2017-001

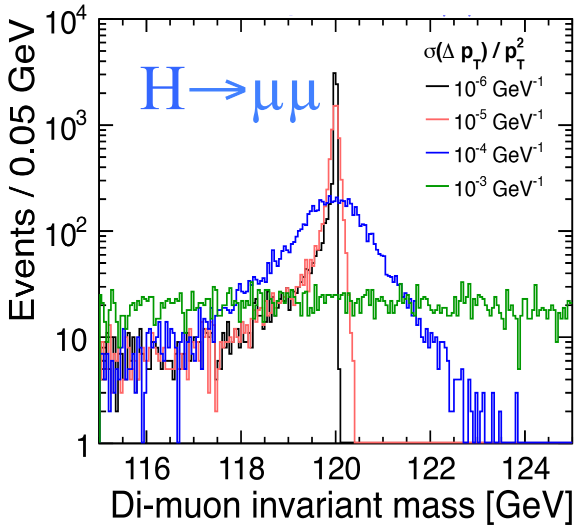
CLICdet: physics requirements

Vertex: excellent identification of secondary vertices for b/c-tagging → excellent impact parameter resolution

Tracker: excellent momentum resolution for high p_T tracks (> 100 GeV), e.g. for Higgs couplings to muons

$$\sigma_{p_T}/p_T^2 \sim 2\times10^{-5}\ \mathrm{GeV}^{-1}$$

O(10) better than LHC experiments

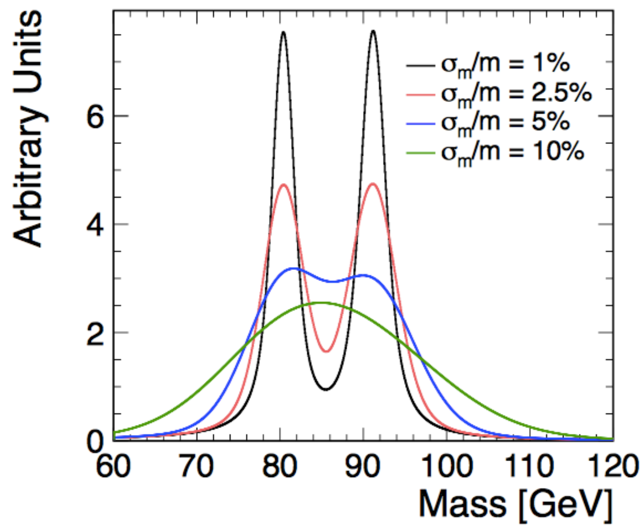


ECAL: excellent photon resolution below 1% for photons at 1.5 TeV

Calorimeters (ECAL+HCAL): Excellent jet energy resolution O(10-1500 GeV)

$$\frac{\sigma_E}{E} \sim 5 - 3.5\%$$

Allows separation of W and Z masses in dijets



Vertex & Tracker optimisation

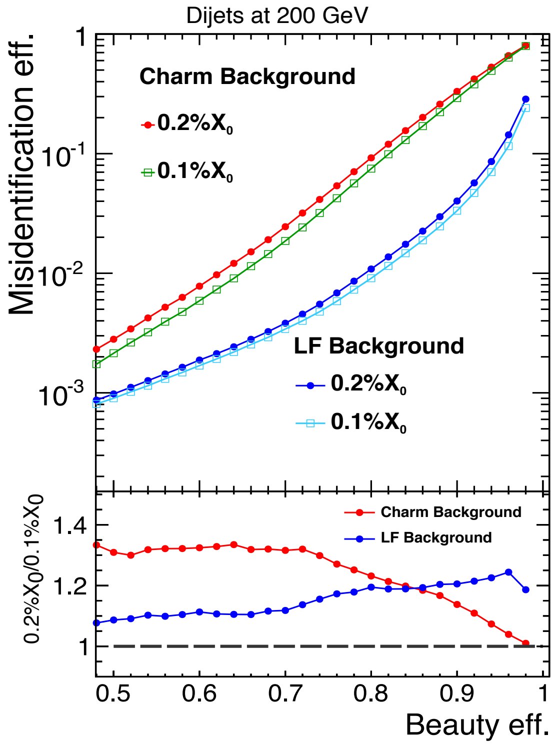
3 double Vertex layers with spiral geometry to allow air flow for cooling + power pulsing

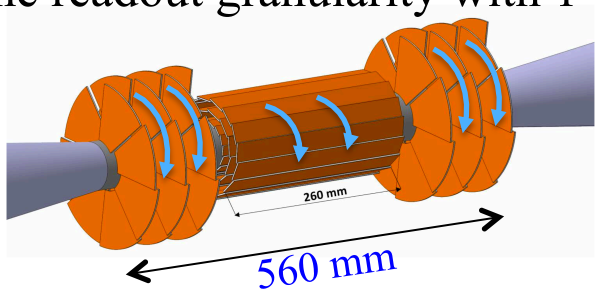
- Ultra light and ultra-thin (0.2%X_0 per detection layer, 10x less than CMS) with $25\times25\mu m^2$ pixels (24x finer than CMS) → achieve single point resolution of 3 μm

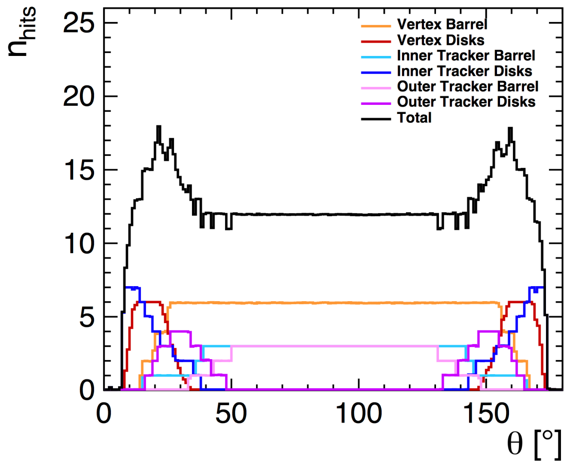
Very light tracker with 1-1.5 % X_0 per layer, liquid cooling

Elongated pixels/short strips so achieve single point resolution of 7 μm, occupancies from beam-beam interactions define readout granularity with 1-10 mm maximum strip length

Flavor tagging performance

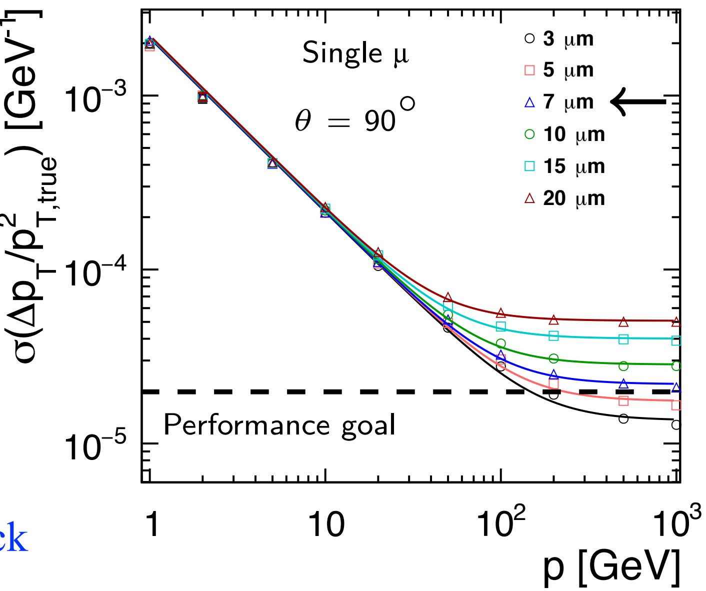






at least eight recorded hits per track down to polar angles of 8 degrees

p_T resolution for different tracker plane resolutions

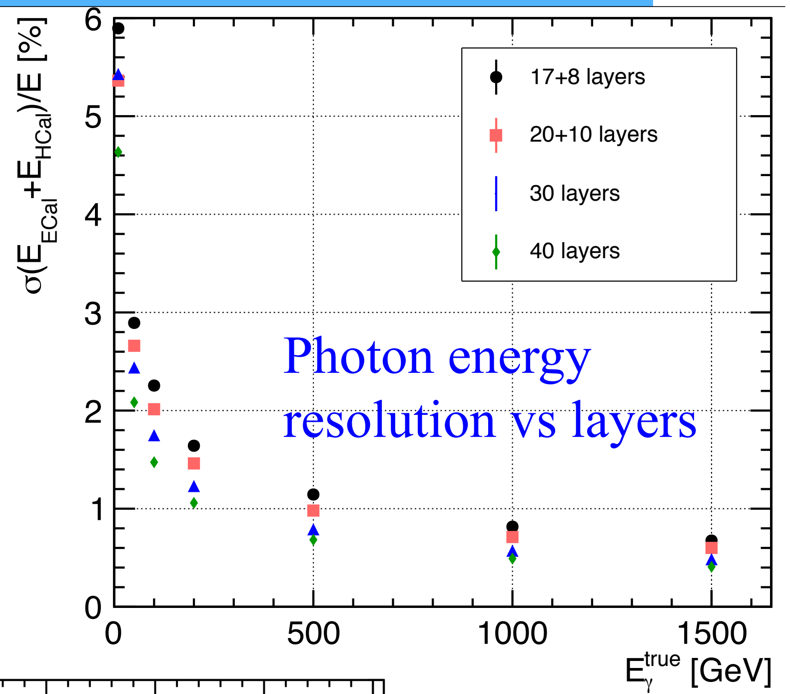


ECAL optimisation

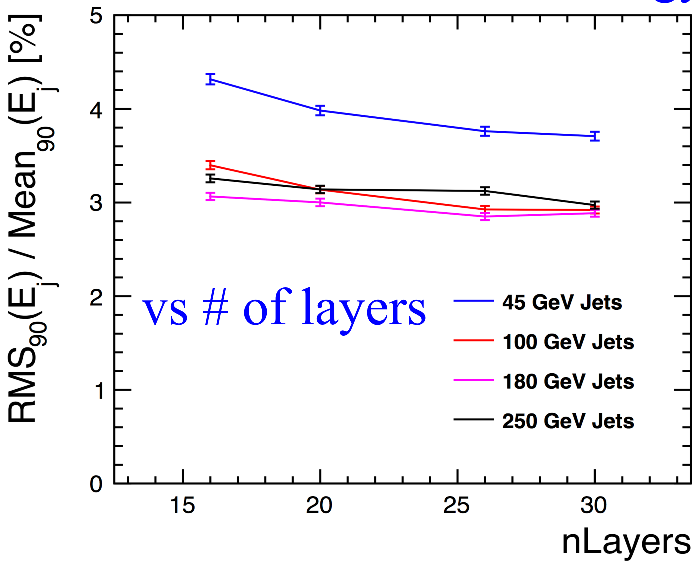
ECAL optimised to for best performance in isolated photon energy resolution

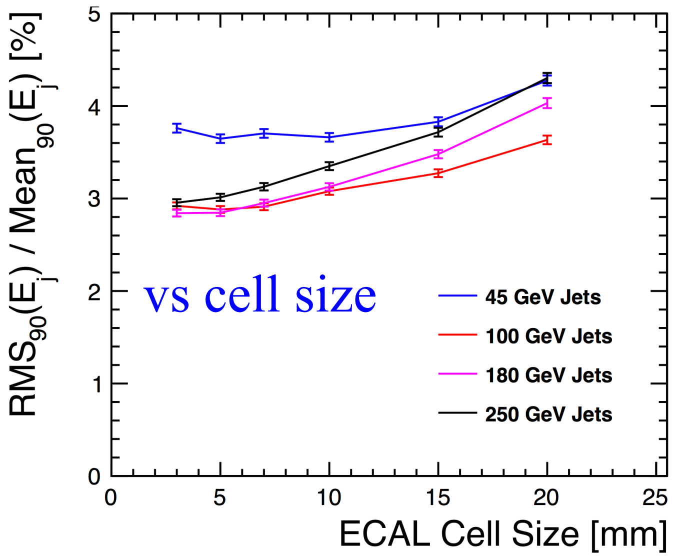
- Test several configuration of absorber layer thicknesses → uniform 40 layer configuration best at higher photon energies
- Increased number of layers slight improvement on jet energy resolution

→ 40 SiW layers with 22 X_0 and cell size of 5x5 mm^2



Jet energy resolution





HCAL optimisation

HCAL optimization using jet observables

- Tungsten and steel show a similar performance
  → use steel as absorber
- Reduce inner HCAL endcap radius from 36 to 24 cm

Small calorimeter cell size to minimize confusion

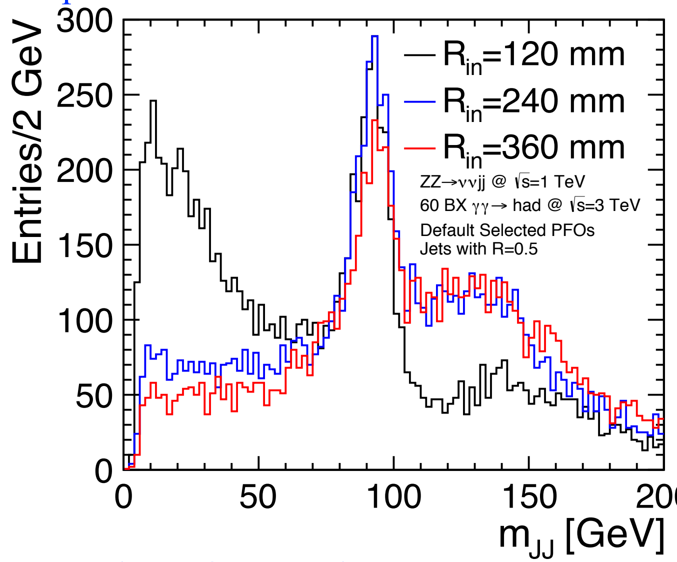
ECAL cell size: **5×5mm²** **~ 20x finer than CMS**

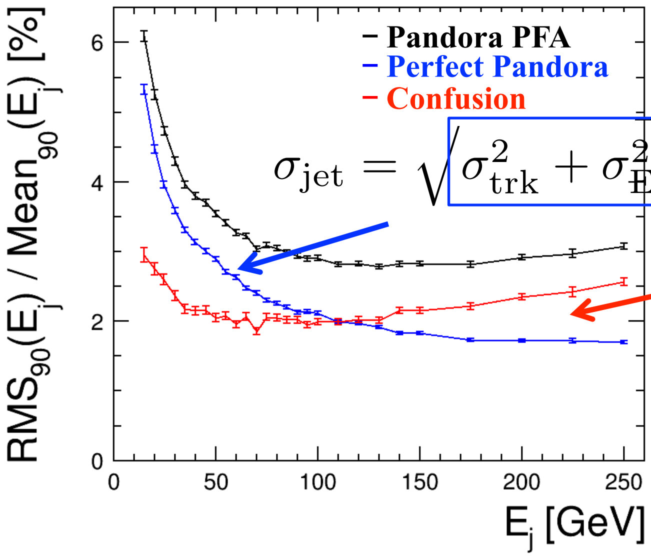
→ crystal front face 22x22cm (EB)

HCAL cell size: **30×30mm²**

→ $\Delta\varphi\times\Delta\eta$ = 0.087x0.087 **~ 3000x finer than CMS**

Physics performance for different HCAL EC radii

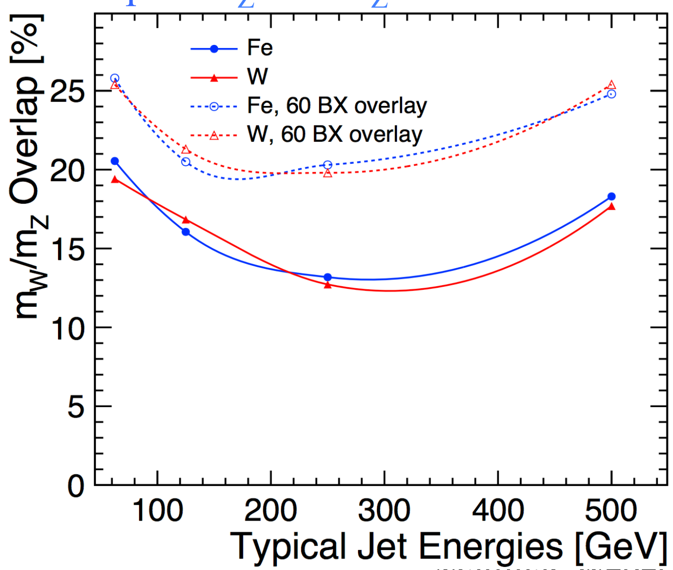




$$\sigma_{\mathrm{jet}} = \sqrt{\boxed{\sigma^2_{\mathrm{trk}} + \sigma^2_{\mathrm{ECAL}} + \sigma^2_{\mathrm{HCAL}}} + \boxed{\sigma^2_{\mathrm{conf}}}}$$

Confusion term from wrong identification in pattern recognition dominates for high energetic jets

Overlap of m_Z and m_Z measurements

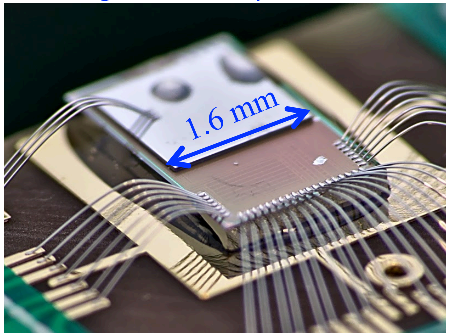


Vertex detector R&D

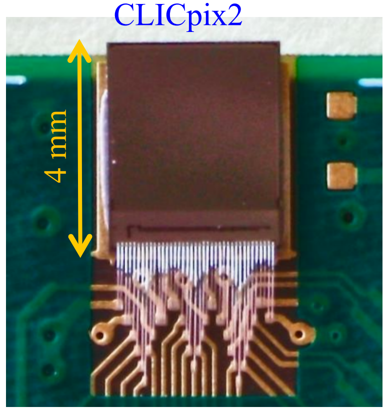
Vertex-detector requirements:
- Ultra-thin (50 µm active silicon)
- High spatial resolution (~3 µm → ~25x25 µm^2 pitch)
- Precise timing (~10 ns)

- Broad R&D program on sensors, readout, powering, interconnects, mechanical integration and cooling
- Beam tests of 65 nm readout ASICs with ultra-thin fine-pitch active-edge and HV-CMOS sensors
- Prototypes of Light-weight mechanical supports and air cooling
- Second generation of sensors and r/o ASICs with improved performance currently under test
- Most challenging: position-resolution target

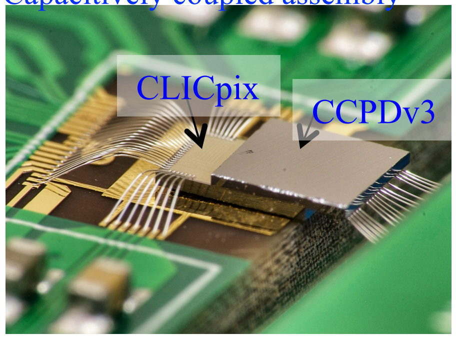
CLICpix with 50 µm sensor



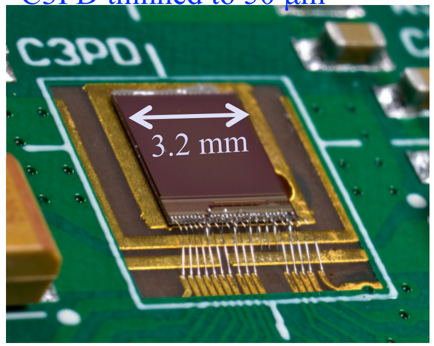
CLICpix2



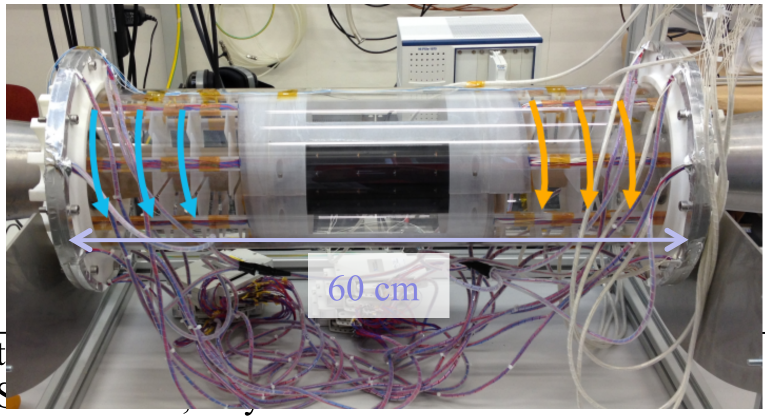
Capacitively coupled assembly



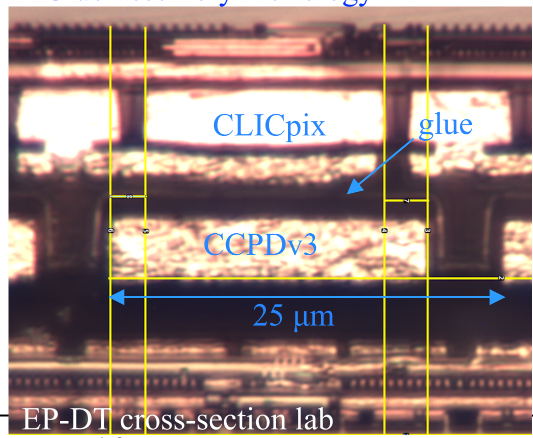
C3PD thinned to 50 µm



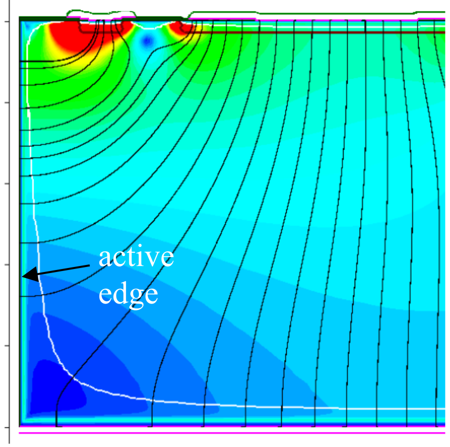
1:1 scale air cooling thermal test setup



Glue-assembly metrology



TCAD simulation



Tracker R&D

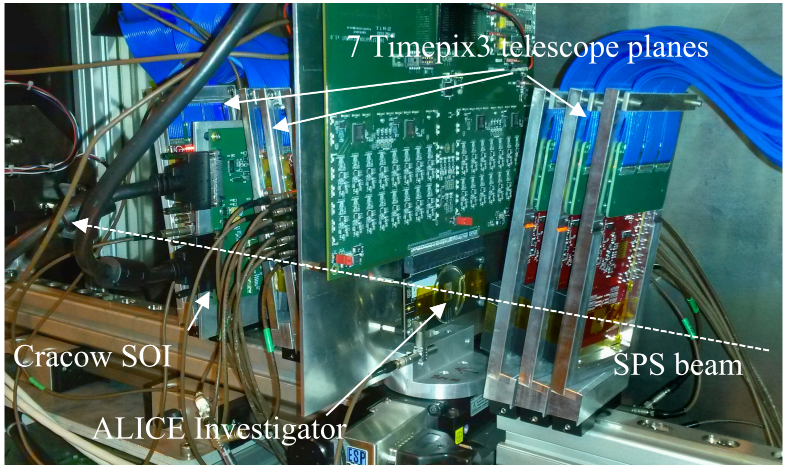
Tracker requirements:

- Material budget 1-1.5% X0 / layer
- Spatial resolution ~7 µm
- fast timing (~10 ns)
- Has to cover ~100 m^2 surface area
  → integrated sensors w. large pixels (≲ 30 µm × 1 mm)

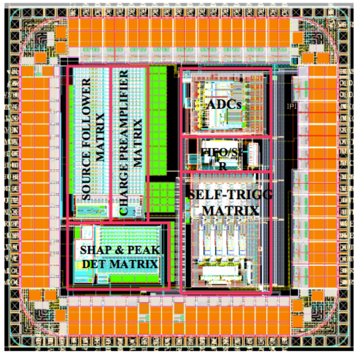
- Evaluating prototypes in different technologies: SOI; depleted monolithic CMOS
- Collaboration with HL-LHC tracker upgrade projects
- Most challenging: maintain efficiency and good timing, despite large pixel area

- Mechanical integration and cooling concept for full tracker
- Prototypes for support frames constructed

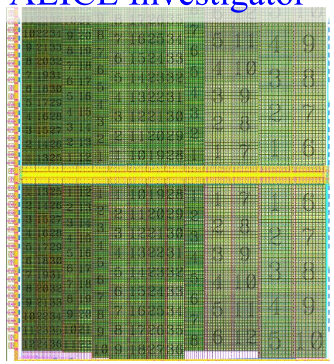
August 2016 test-beam setup in SPS-H6



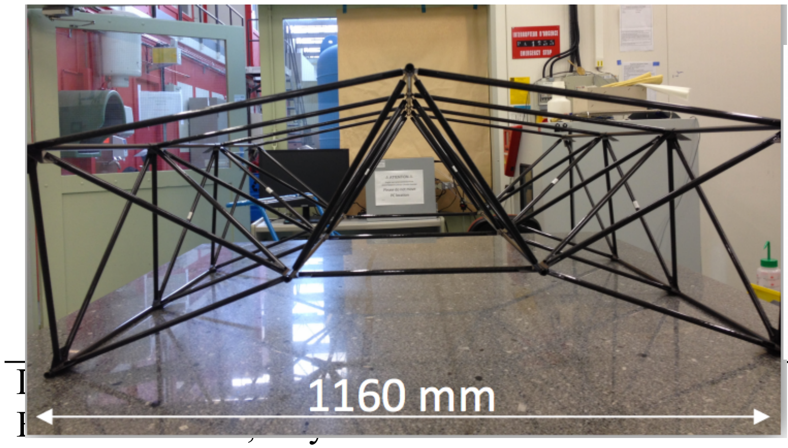
AGH SOI test chip

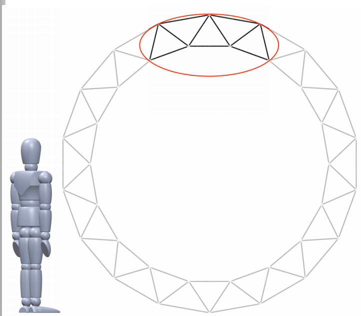


ALICE Investigator



Prototype of outer barrel tracker support structure





Calorimetry R&D: CALICE

ECAL/HCAL R&D for CLIC performed within the **CALICE** collaboration with a comprehensive comparison of various technologies

Silicon-Tungsten **ECAL**

- Finalizing analysis of 1^{st} generation prototypes, 2^{nd} generation under construction with improved r/o technologies

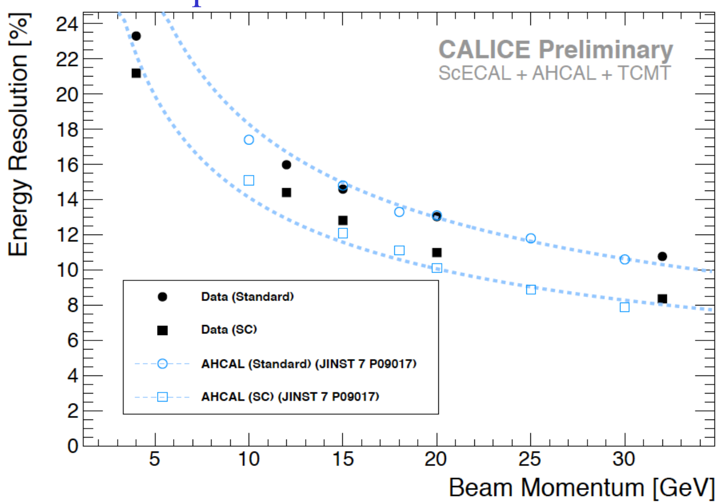
Scintillator sampling analogue **HCAL** with high granularity, optimized for PFA reconstruction

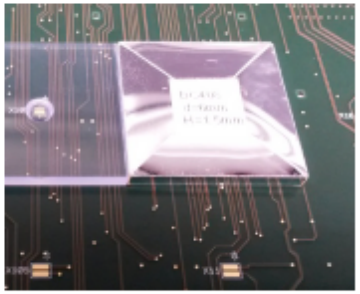
- easy mass assembly: SiPM-on-tile technology
- integrated readout electronics
- scalable to linear collider detector

Recent developments:

- Construction and testing of large 2^{nd} generation prototypes
- larger ~$1m^3$ prototypes under construction with low noise low cross-talk SiPM

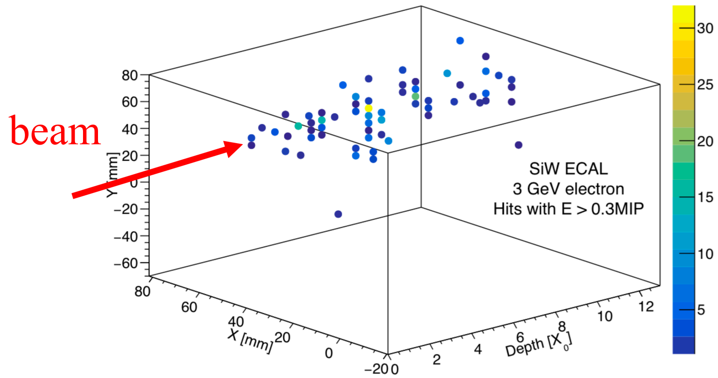
good single particle energy resolution, improved by software compensation (SC) techniques





AHCAL:
SiPM-on-tile technology

3 GeV electron hits in SiW ECAL



CALICE talk #779 by G. Grenier

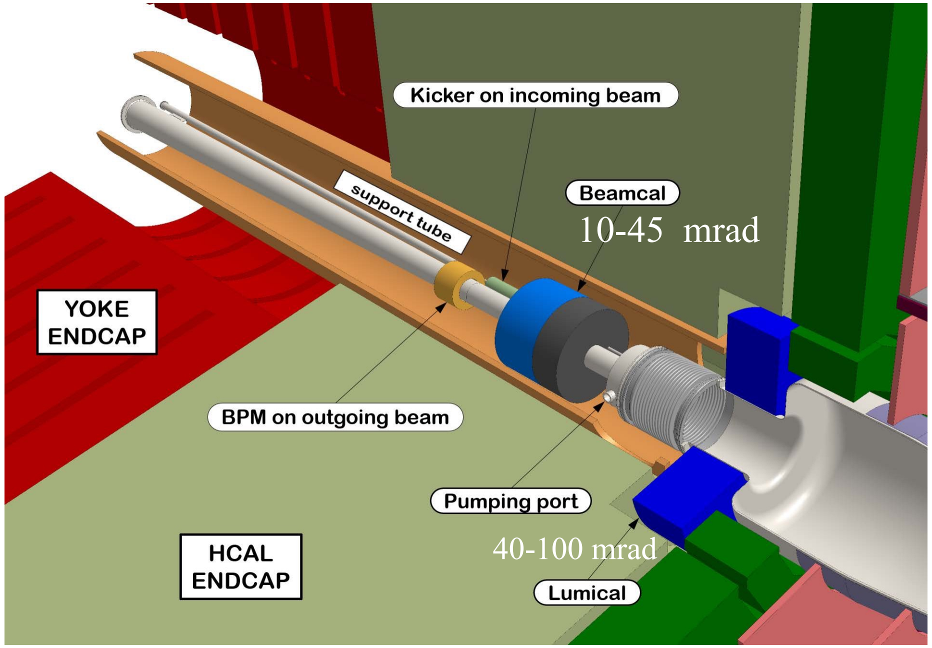
Matthias Weber
CERN

Forward detector R&D

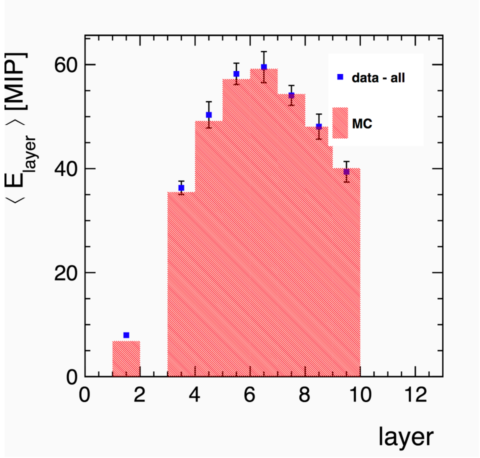
Forward calorimetry R&D for CLIC performed within the **FCAL** collaboration

- LumiCAL for measurement of luminosity (to a few permille as goal)
- BeamCAL for very forward e or γ tagging

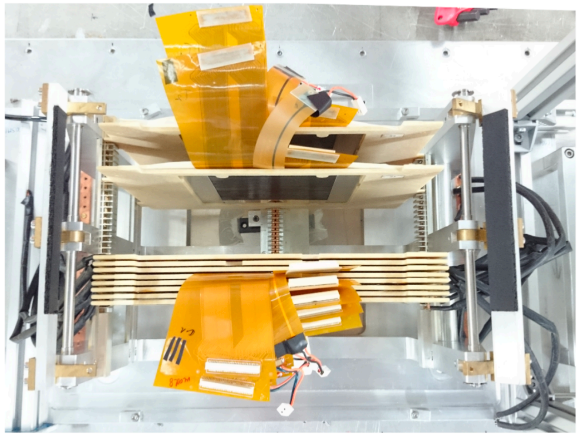
- Evaluating different r/o technologies
  - Radiation hardness
  - Beam tests



LumiCAL prototype
5 GeV electron test beam



LumiCAL test beam prototype



LumiCAL module

FCAL talk #1023 by I. Levy

Summary

The CLIC accelerator provides a unique potential for precision measurements and potential of new discoveries at the TeV scale

New post CDR CLIC detector model CLICdet is proposed, optimised to achieve highest precision over a center of mass energy range from a few hundred GeV up to 3 TeV in a challenging experimental environment

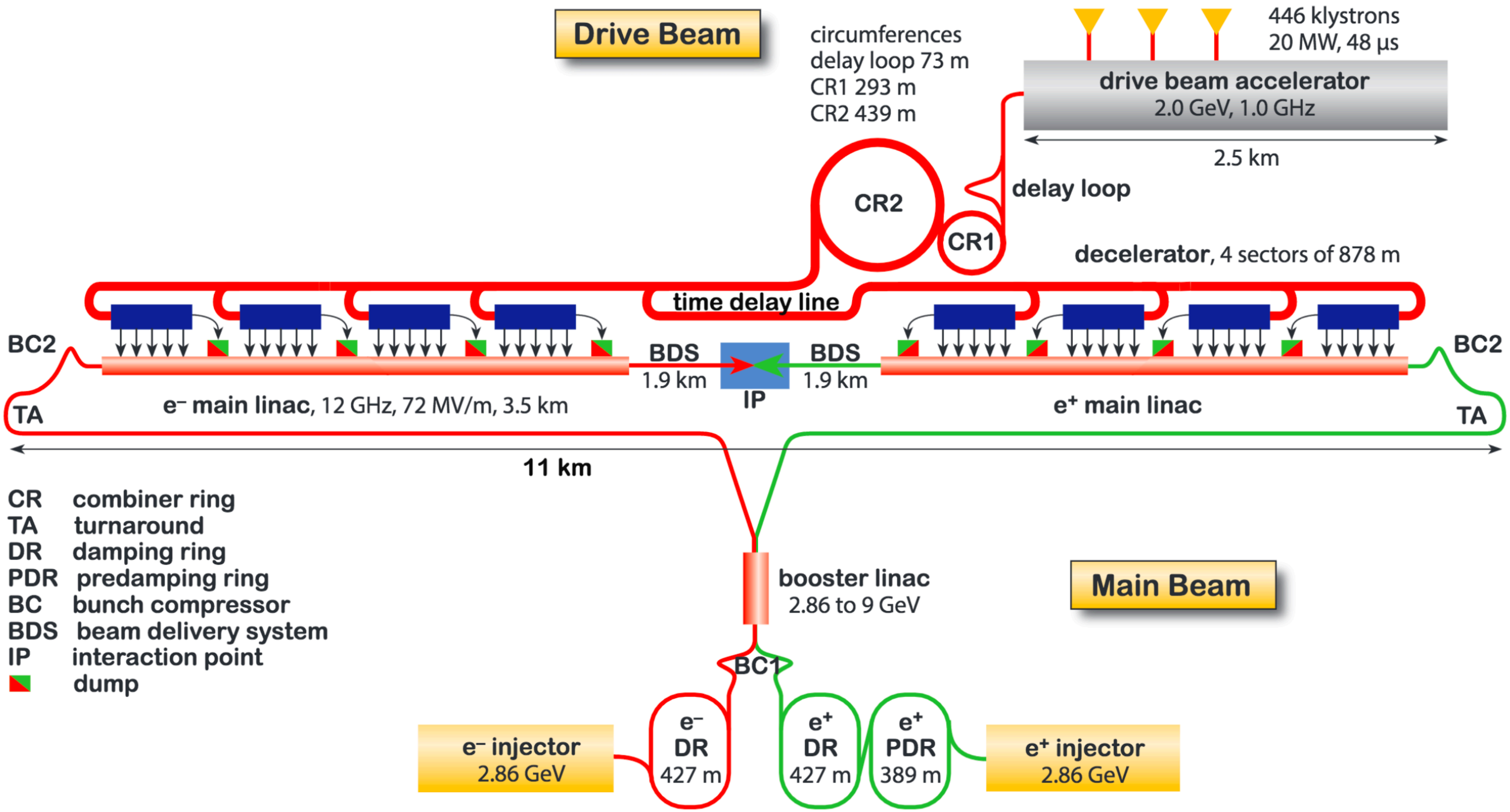
Broad efforts of ongoing R&D on detector technologies meeting the requirements for linear colliders

BACKUP

CLIC related contributions at EPS

- P. Skowronski: Lessons from CTF3 (talk #203, accelerator studies)
- J. Roberts: Energy-staging of the Compact Linear Collider (poster #443)
- G. Milutinovic-Dumbelovic: Higgs and BSM physics at CLIC (talk #401)
- M. Weber: Electroweak precision measurements at CLIC (poster #400)
- N. van der Kolk: Toward Precision Top Quark Measurements in e+e- collisions (talk #468)
- G. Grenier: Technological Prototypes and Result Highlights of Highly Granular (talk #779)
- I. Levy: Measurement of shower development and its Molière radius with a four-plane LumiCal test set-up (talk #1023)

CLIC layout at $\sqrt{s}$ = 380 GeV



CLIC project timeline

2013 - 2019 Development Phase

Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 - 2025 Preparation Phase

Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase

Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2019 - 2020 Decisions

Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

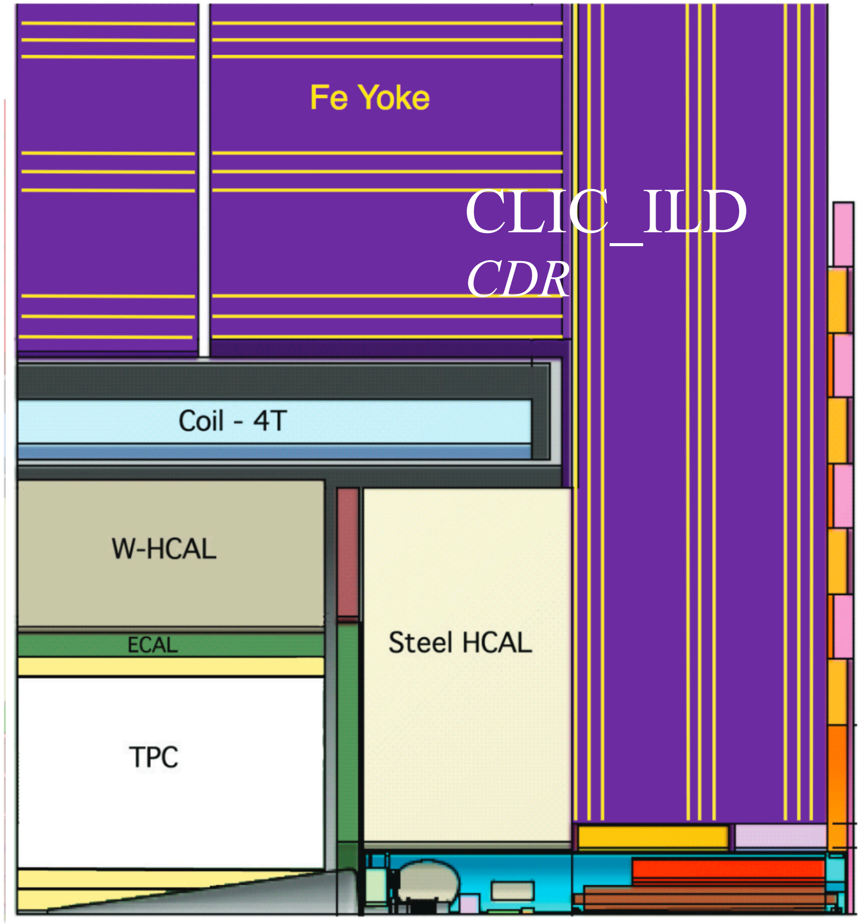
2025 Construction Start

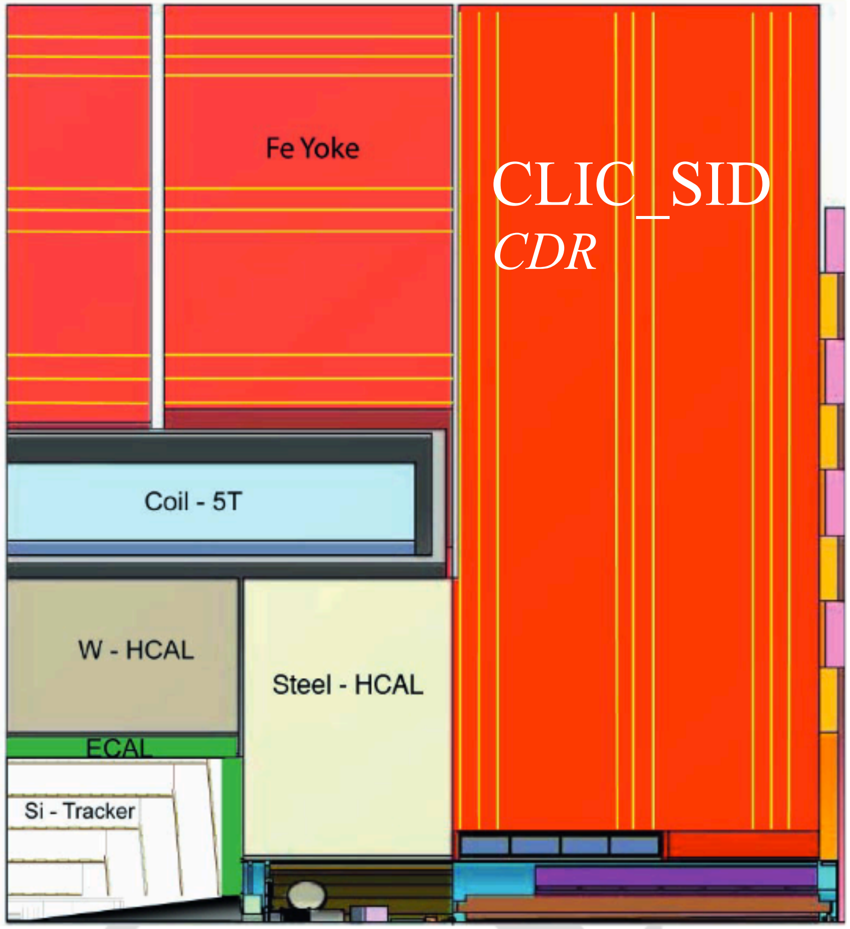
Ready for construction; start of excavations

2035 First Beams

Getting ready for data taking by the time the LHC programme reaches completion

Previous CLIC detector models (CDR)





Former CDR models of CLIC inspired by ILC detectors (CLIC_SID and CLIC_ILD)

CLIC inner detector requirements

Vertex detector physics aim: excellent identification of secondary vertices for b/c-tagging → excellent impact parameter resolution

$$\sigma(d_0) = 5 \oplus 15/(p[GeV]sin^{\frac{3}{2}}\theta)\mu m$$

Affected by single point resolution → **3μm**

Affected by multiple scattering → **0.2% X_0 by detection layer**

Tracker detector physics aim: excellent momentum resolution for high p_T tracks (> 100 GeV), e.g. for Higgs couplings to muons

$$\sigma_{p_T}/p_T^2 \sim 2\times 10^{-5}\ \mathrm{GeV}^{-1}$$

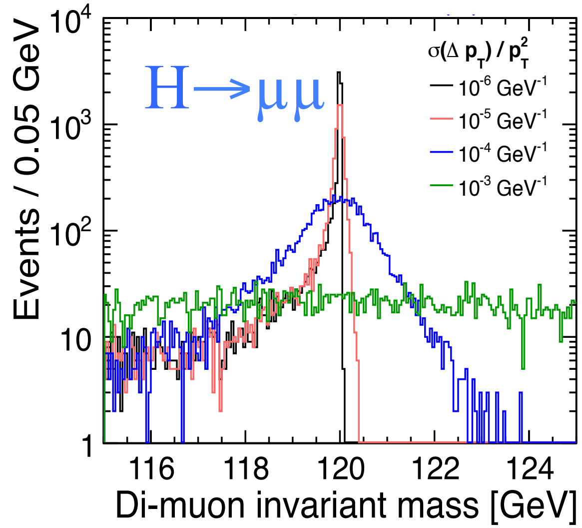
O(10) better than LHC experiments

Position Resolution

$$\frac{\delta p_\mathrm{T}}{p_\mathrm{T}} \propto \frac{\sigma \cdot p_\mathrm{T}}{B \cdot L^2} \cdot \frac{1}{\sqrt{N+4}}$$

Multiple Scattering

$$\frac{\delta p_\mathrm{T}}{p_\mathrm{T}} \propto \frac{1}{B \cdot L} \cdot \sqrt{\frac{X_{tot}}{X_0}}$$



Large and light tracker with good single point resolution, high B Field

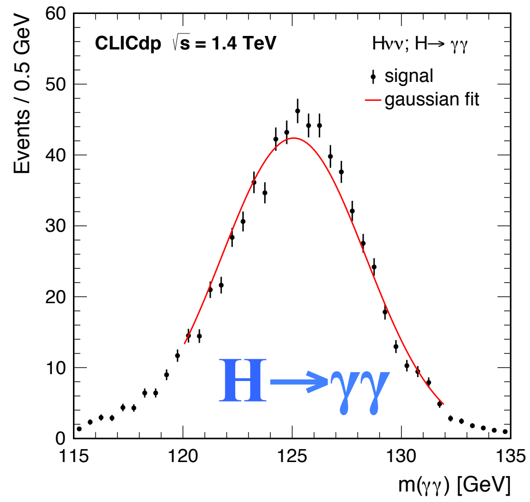
→$\sigma_{R\phi}$ ~ 7μm, ~1-2%X_0 per layer

CLIC calorimeter requirements

Good Photon energy resolution O(10-1500 GeV)

$$\frac{\sigma_E}{E} \sim 4 - 0.4\%$$

Similar to ATLAS



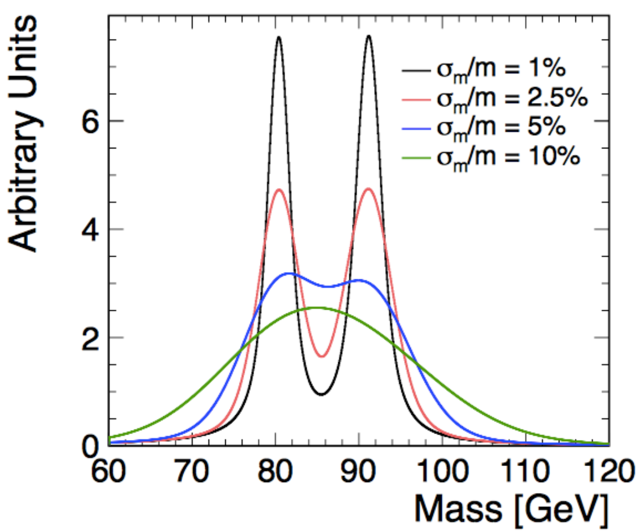
Excellent jet energy resolution O(10-1500 GeV)

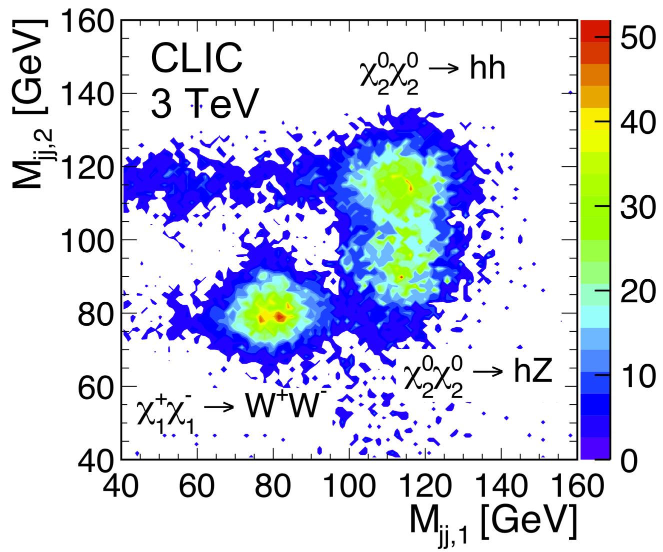
$$\frac{\sigma_E}{E} \sim 5 - 3.5\%$$

ATLAS JER <~ 5% for p_T^{jet} > 1 TeV

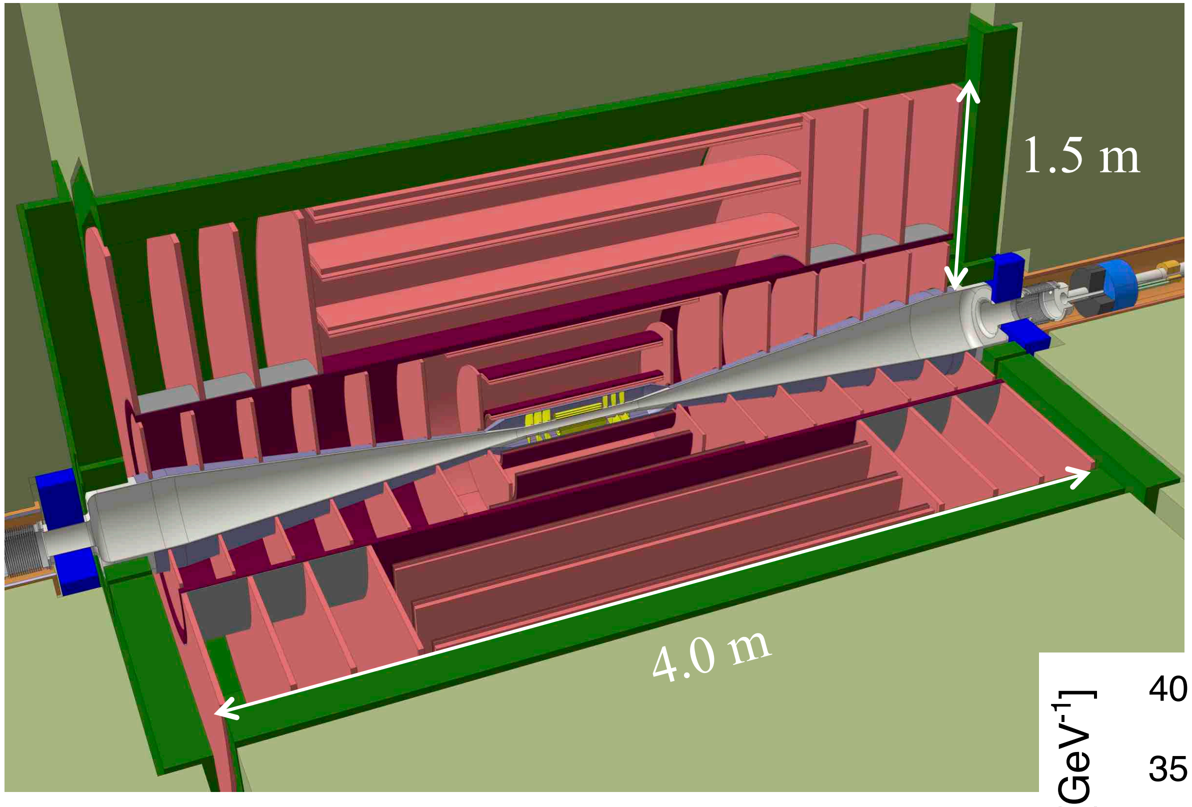
➡ Allows separation of W and Z masses in dijets

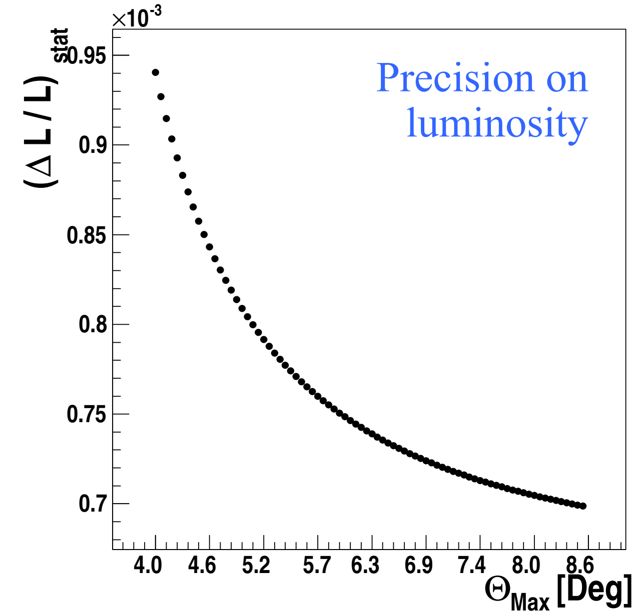
Large Coverage

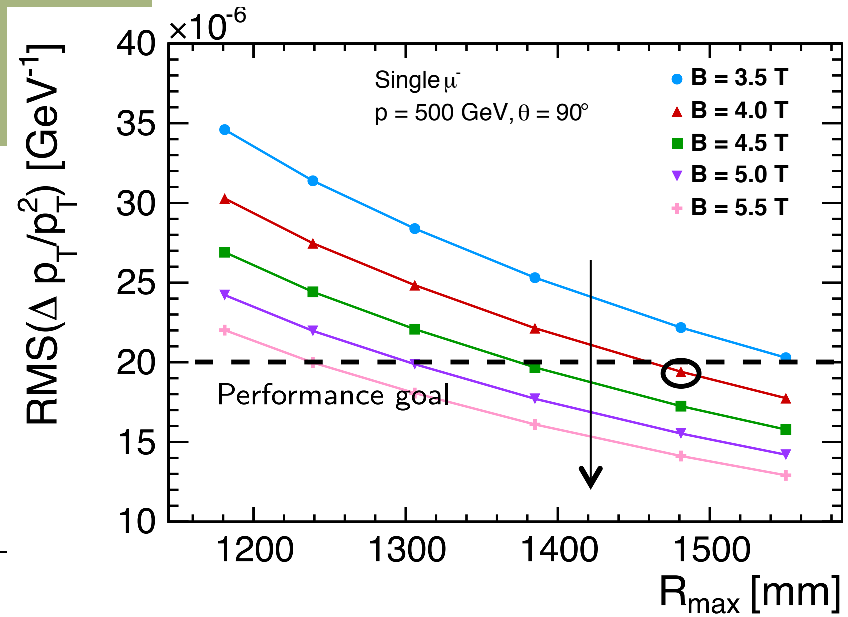




Tracker Optimisation

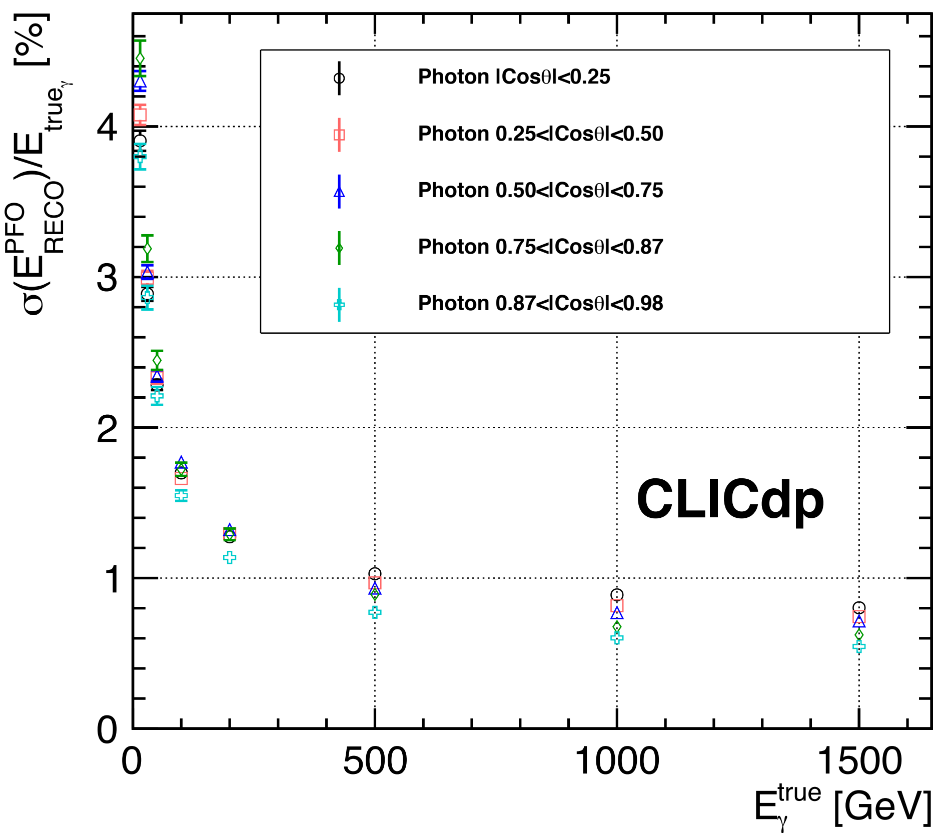




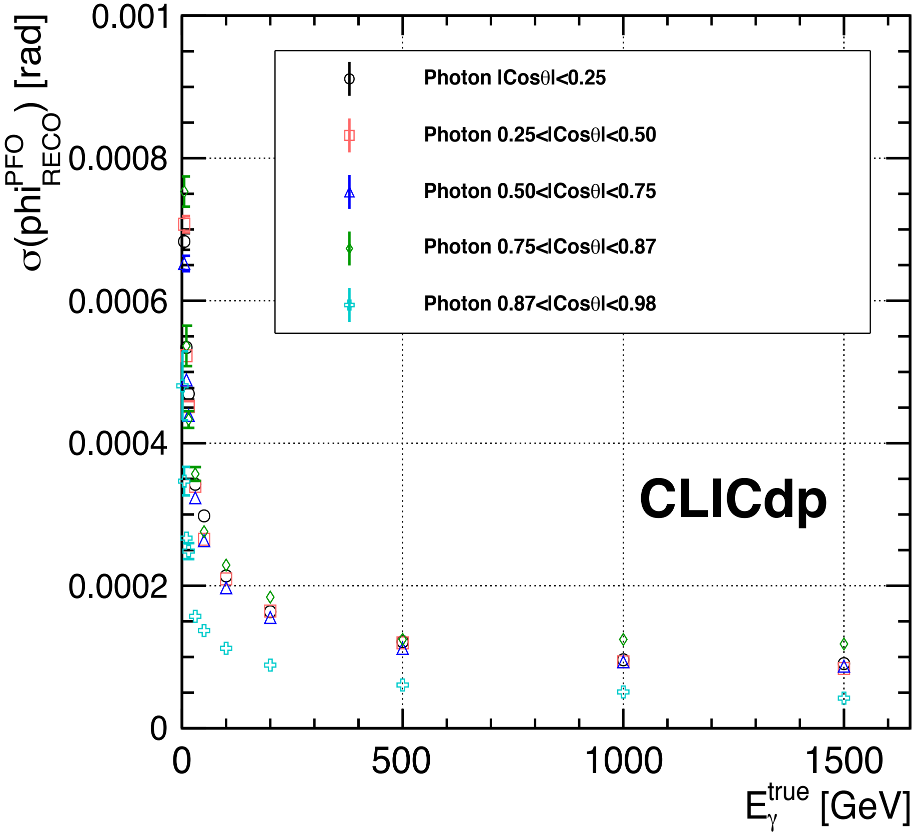


- Tracker overall size and B field
  - Acceptance $|\theta| > 7°$ → $|\eta| > 2.8$
  - B = 4 T
  - 4.4 m x 3 m tracker

Photon Performance



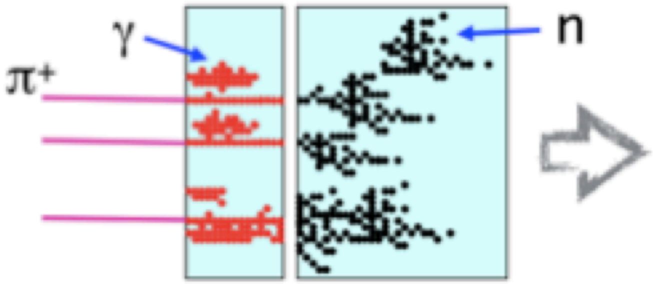
Relative Photon Energy Resolution in different detector regions



Photon phi position resolution in different detector regions as function of true photon energy

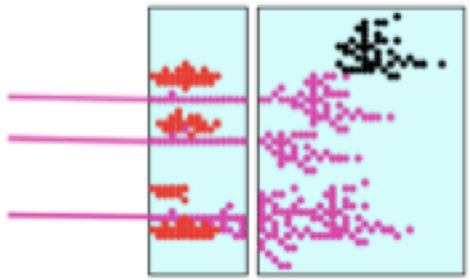
Particle flow calorimeters

Classical approach



$$E_{JET} = E_{ECAL} + E_{HCAL}$$

Particle flow approach

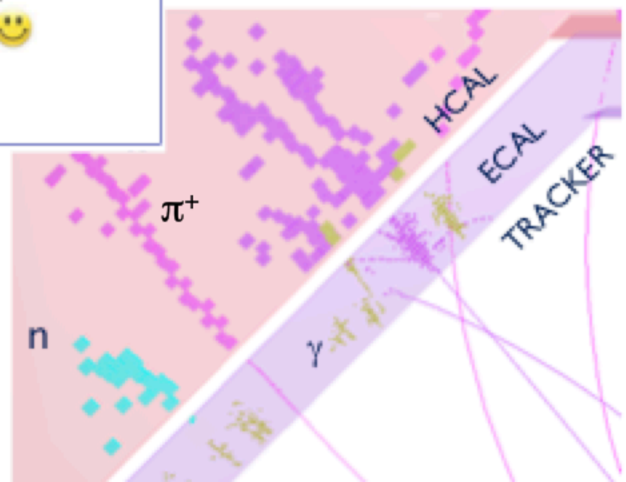


$$E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$$

Typical jet composition:
- 60% charged particles
- 30% photons
- 10% neutrons

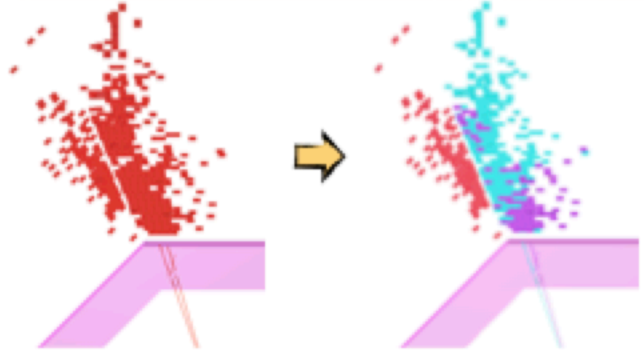
Always use the best info you have:
- 60% => tracker 🙂 🙂
- 30% => ECAL 🙂
- 10% => HCAL 🙁

Requires *highly granular calorimeters* to resolve deposits from different particles and *sophisticated software* to make correct associations

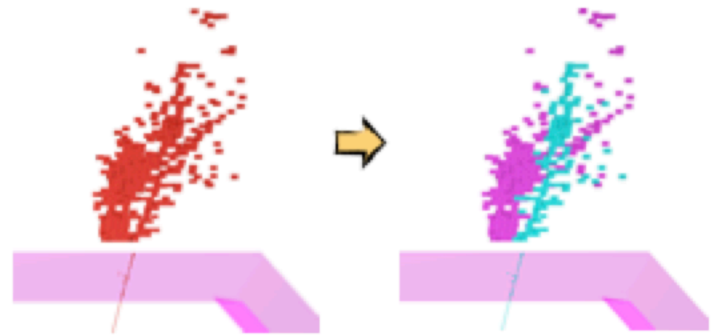


Particle flow algorithms: Pandora

"The Pandora Software Development Kit for Pattern Recognition" → *EPJC.75.439*



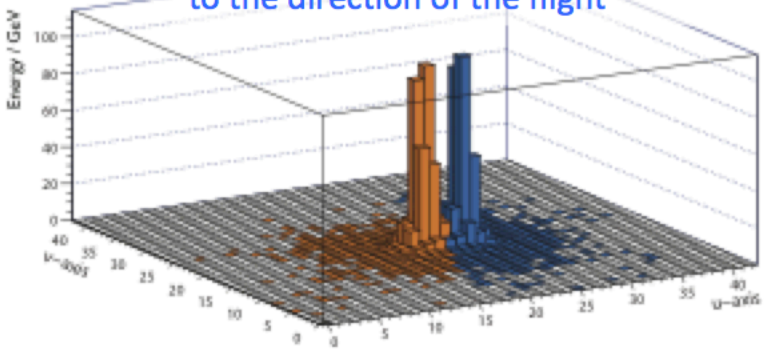
1. Multiple tracks associated to single cluster – split cluster.



2. Cluster energy much greater than track momentum – split cluster.

- Exploit calorimeter granularity to gradually build-up picture of events
- More than 70 algorithms to address specific event topologies, with very few mistakes, and to avoid accidental merging of separate particles

Energy of 2 γ in transverse plane to the direction of the flight

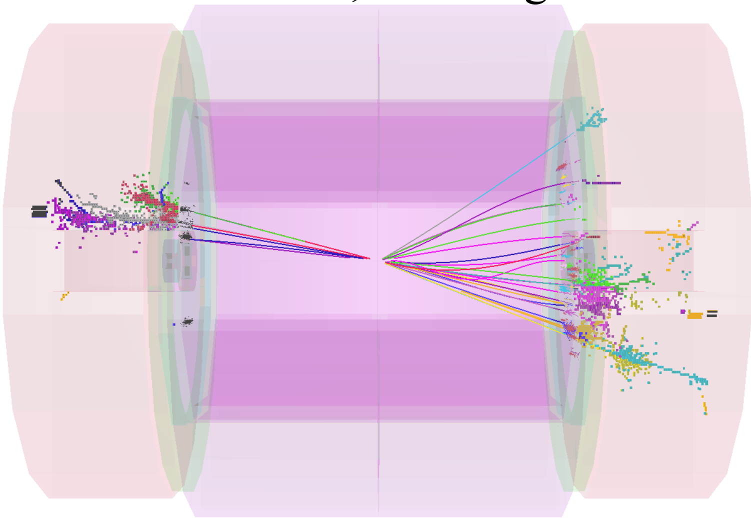


CLIC detector & physics collaboration

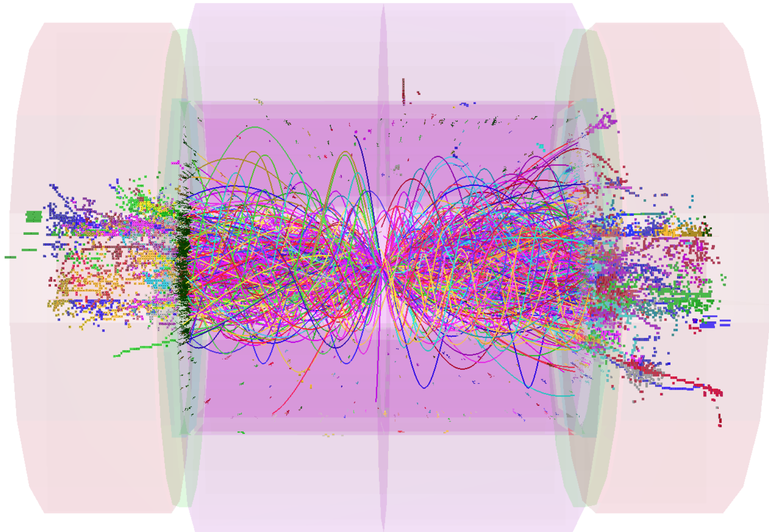
- CLICdp collaboration addresses detector and physics issues for CLIC
- CERN acts as host laboratory
- Currently 29 institutes from 18 countries, ~180 members
  http://clicdp.web.cern.ch/
- Close connection to ILC detector concepts, CALICE, FCAL, AIDA-2020

Example: Beamstrahlung background reduction

Forward WW, no background



with background in reconstuction time window ~1.2 TeV



after timing and p_T cuts: ~ 100 GeV remain:

- Remove neutral hadrons with p_T < 0.5 GeV
- Remove photons with p_T < 0.2 GeV
- For charged hadrons with p_T < 1 GeV, cut on cluster time between -0.25 to 1 ns window (tof corrected)
- For neutral hadrons with p_T < 8 GeV cut on cluster time window of 0 to 2.5 ns
- For photons with p_T < 4 GeV time window of 0 to 1 ns

→ Other particles accepted for default reconstruction time window