The ILD for a future linear or circular e^+e^- collider

Antoine Laudrain (he/him)
for the ILD concept group

ICHEP 2024, Prague

Session: Detectors for Future Facilities, R&D, Novel Techniques — 20.07.2024

CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

DESY.

HELMHOLTZ

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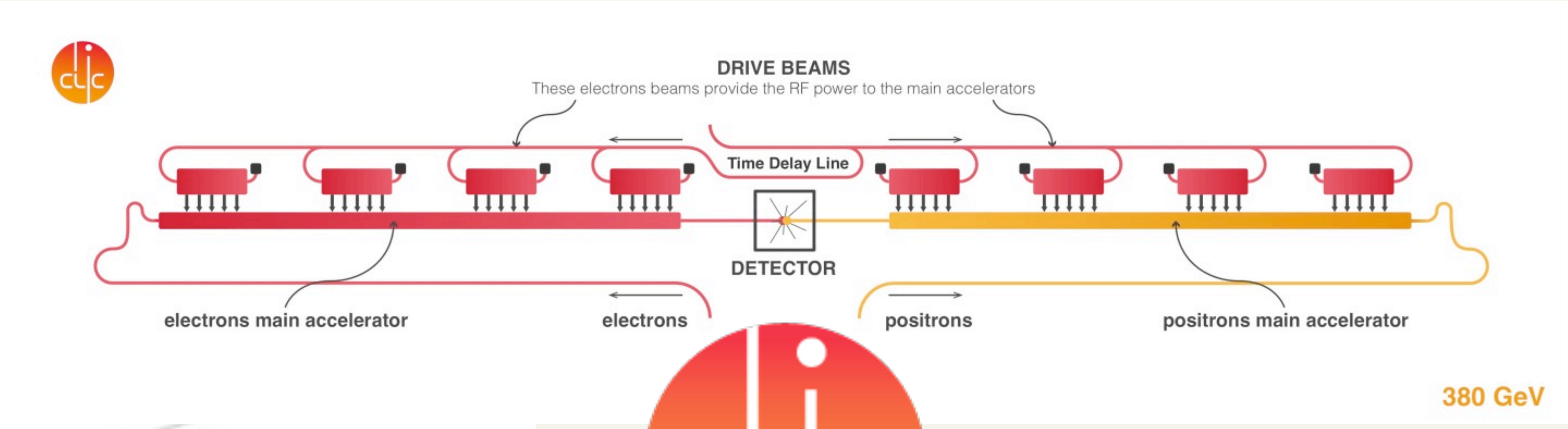
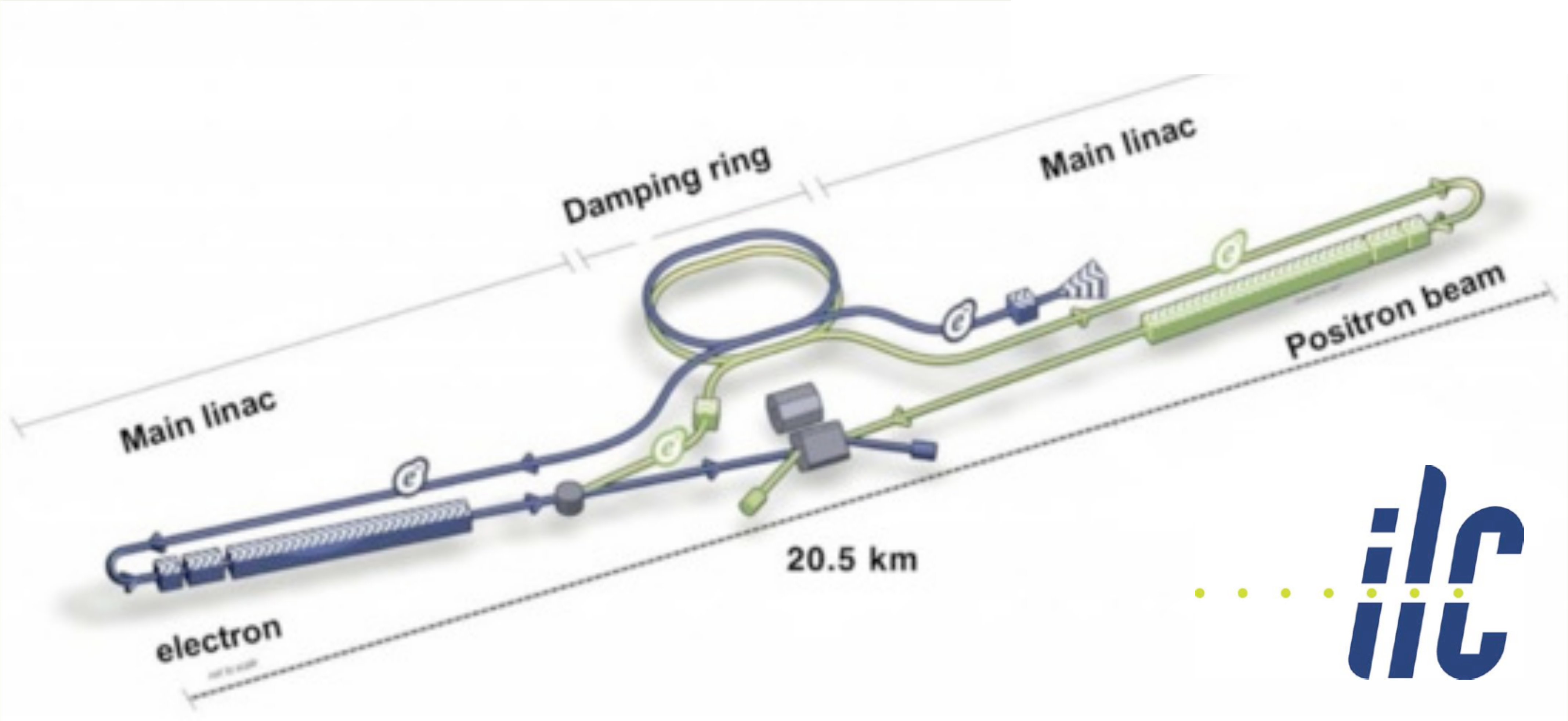
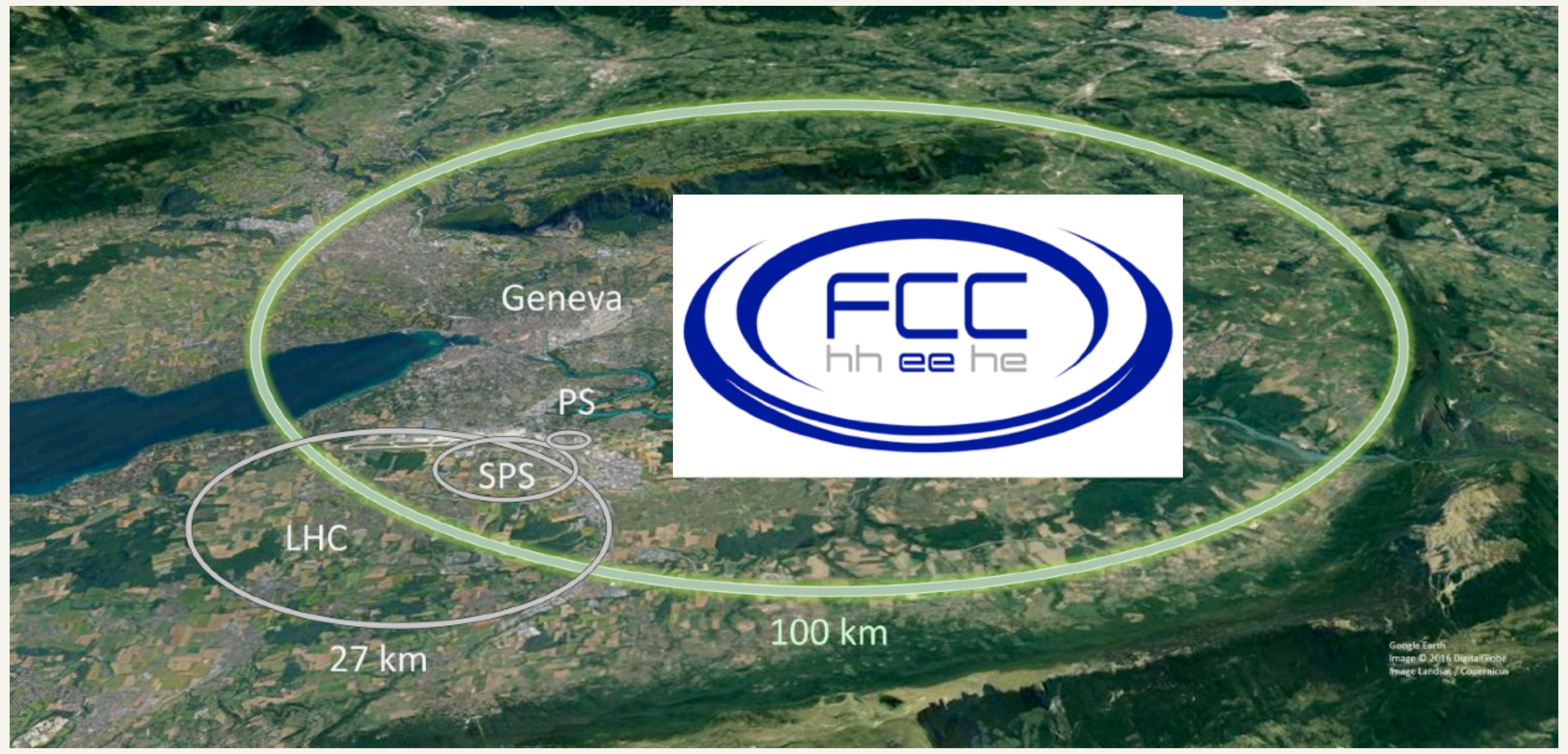
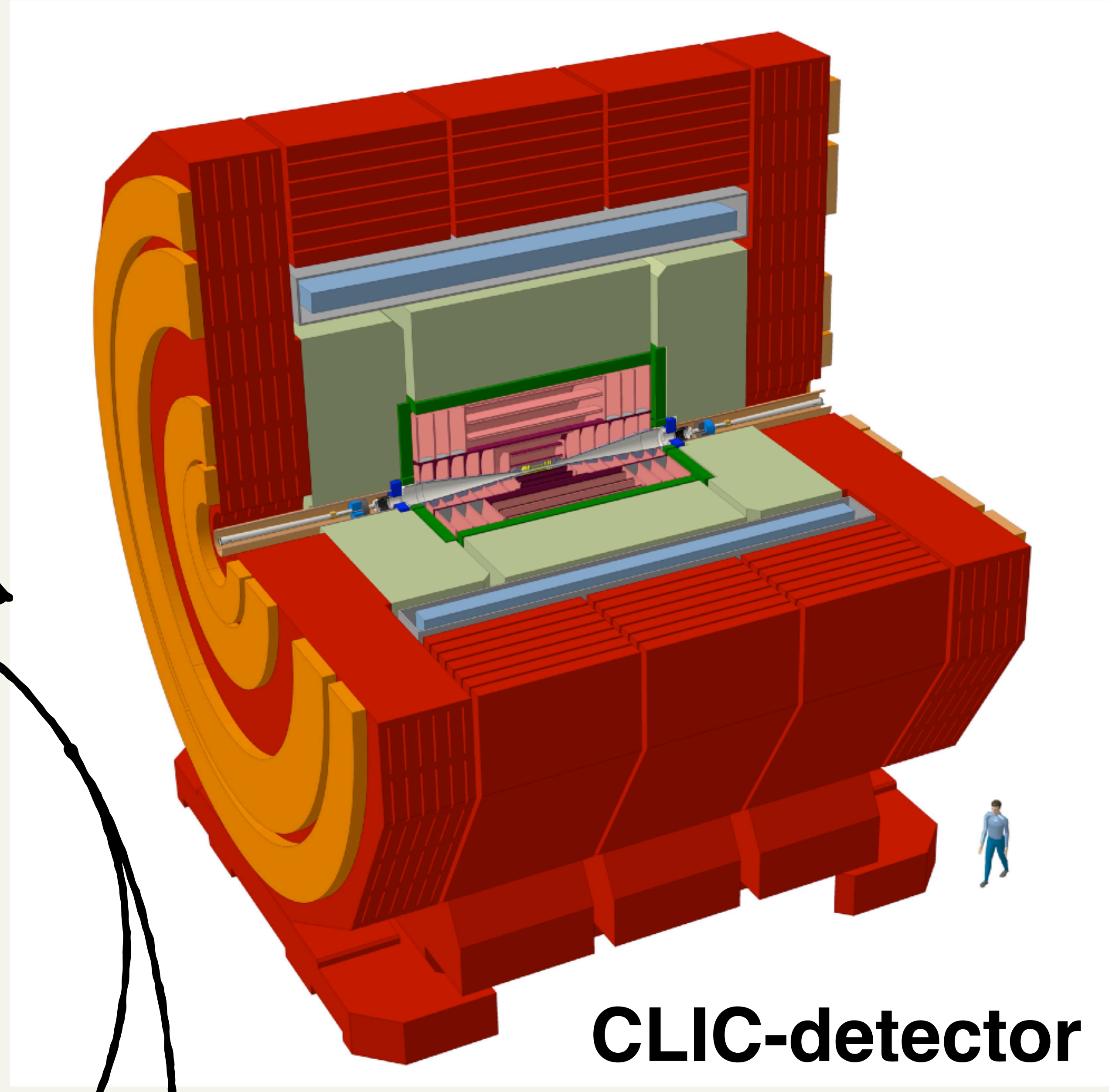
Landscape of possible future e+e- colliders

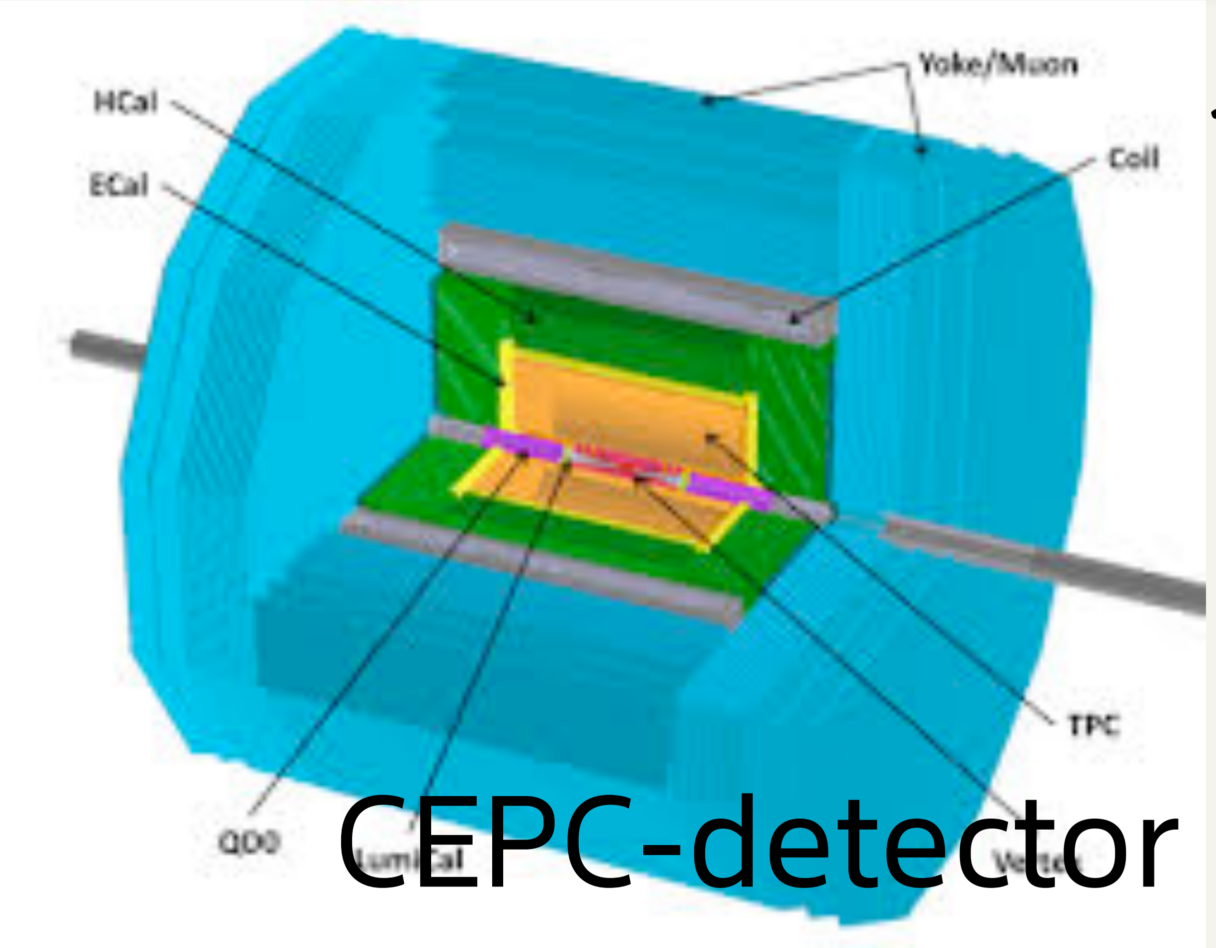


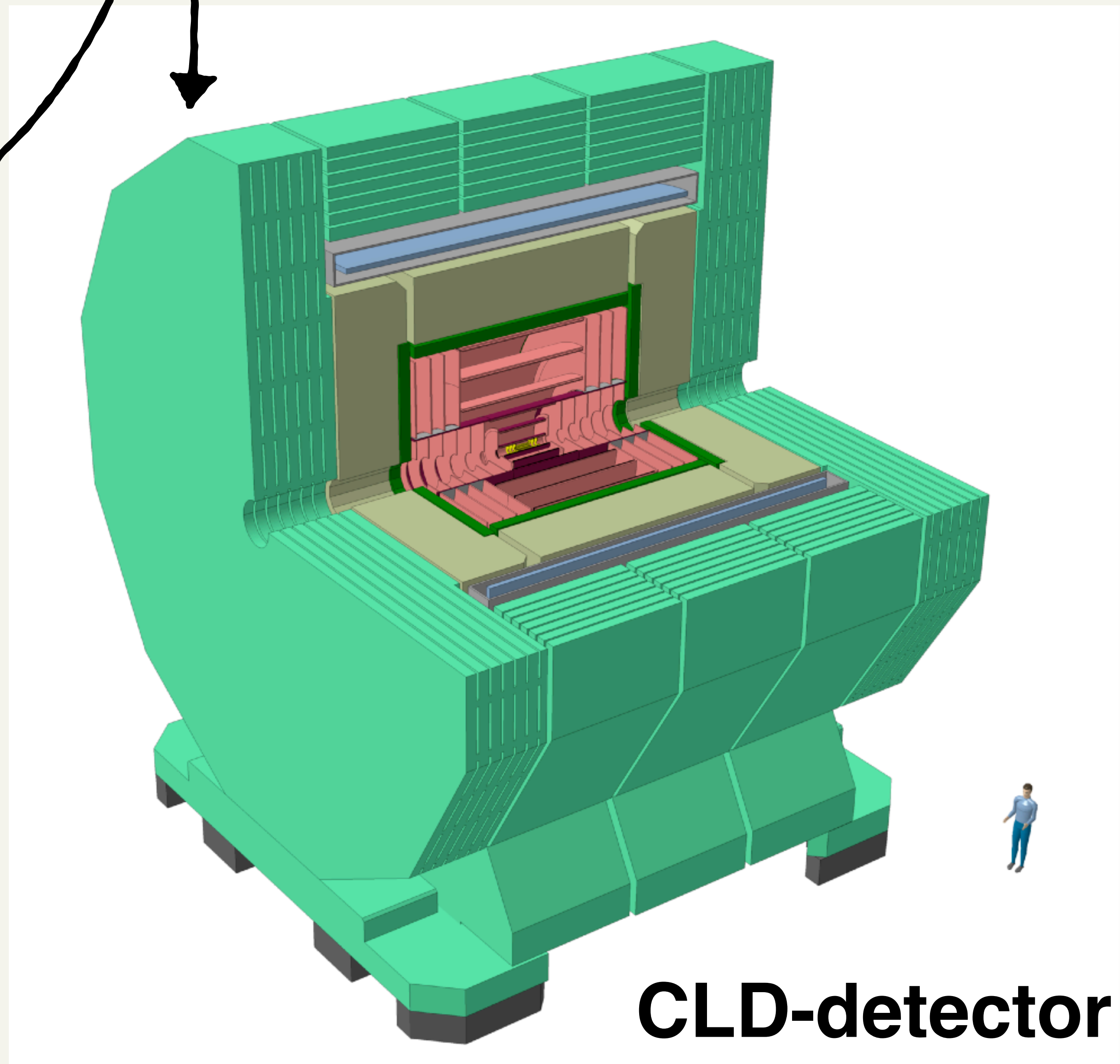




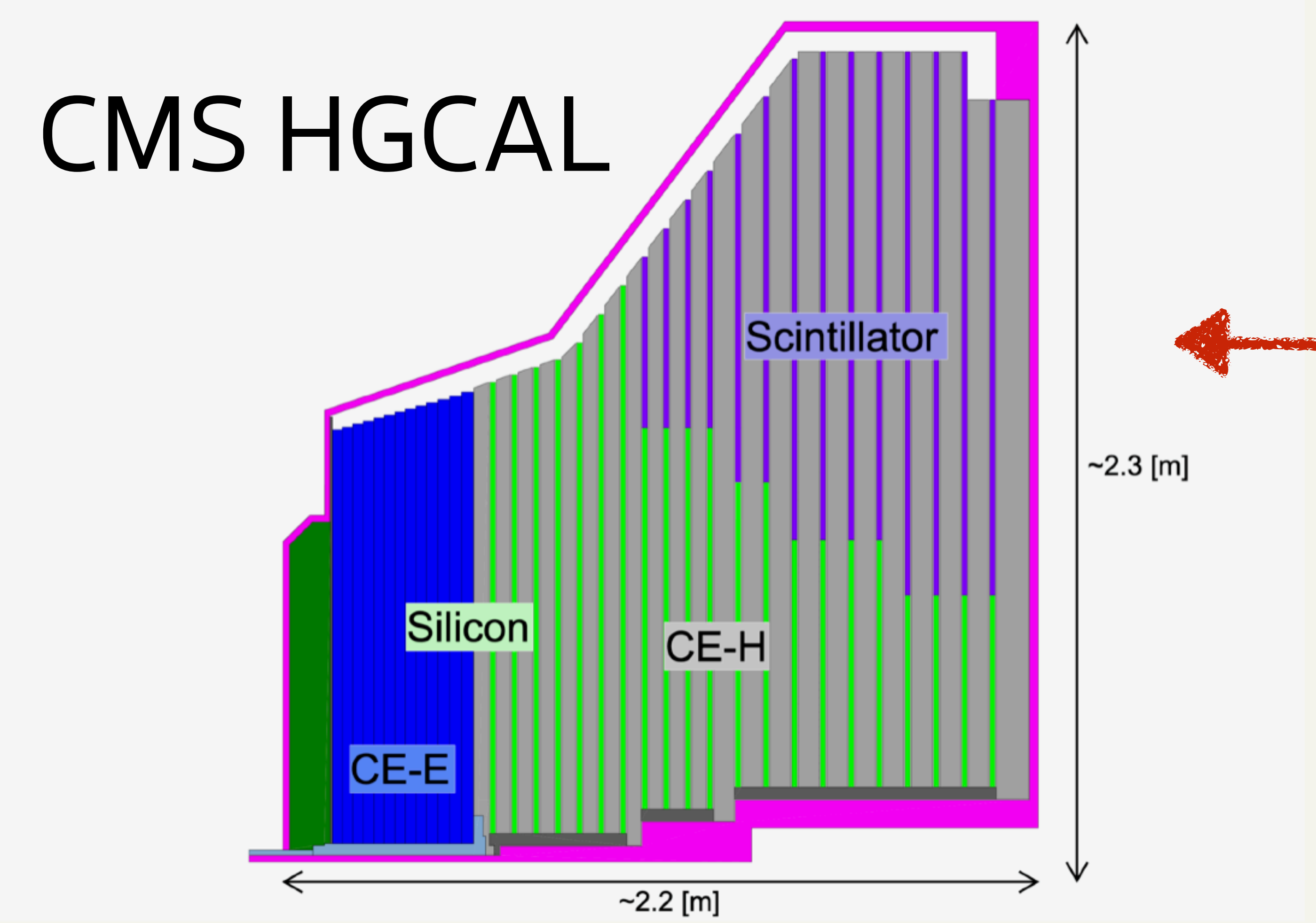
ILD-based concepts already proposed!

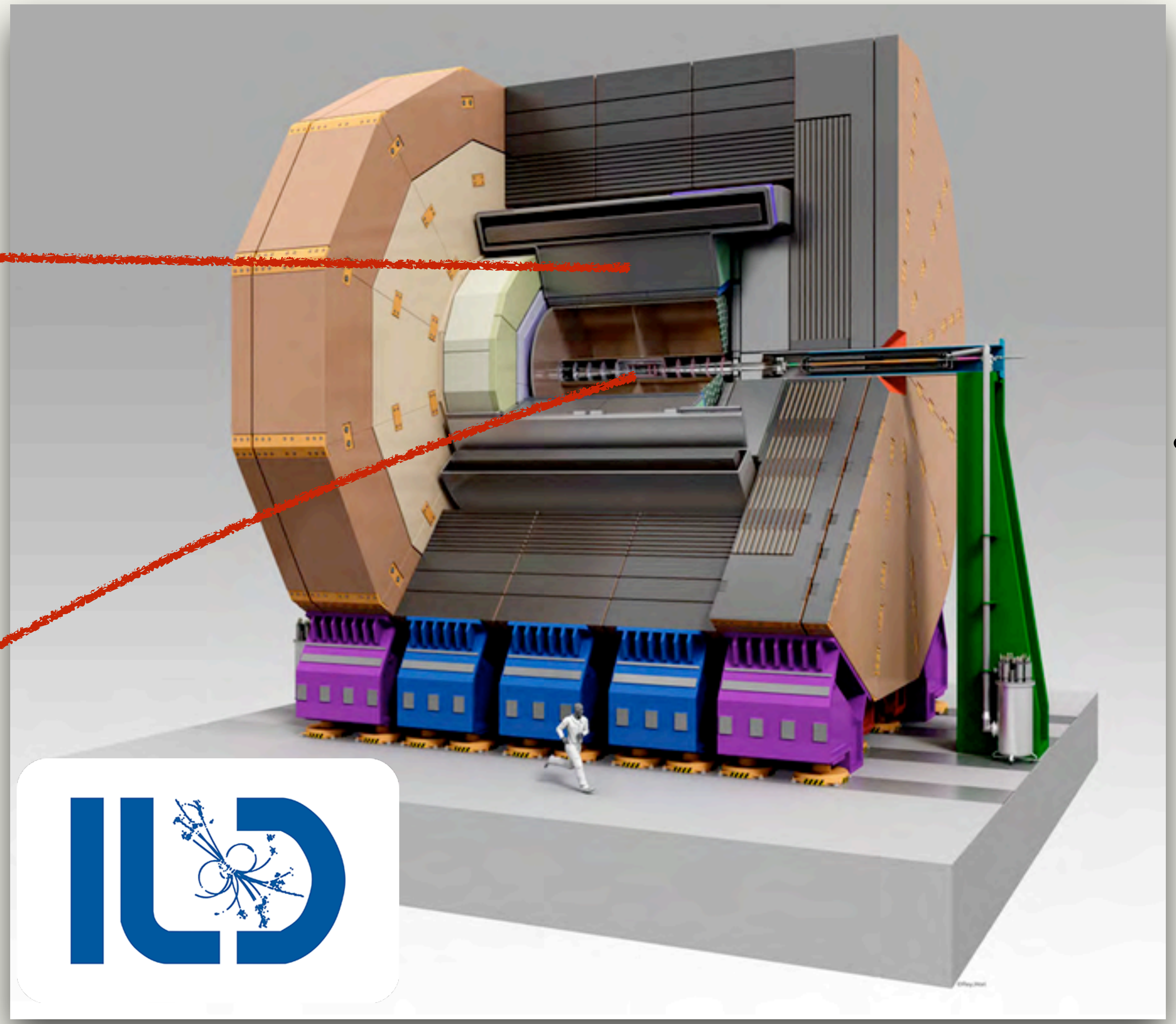


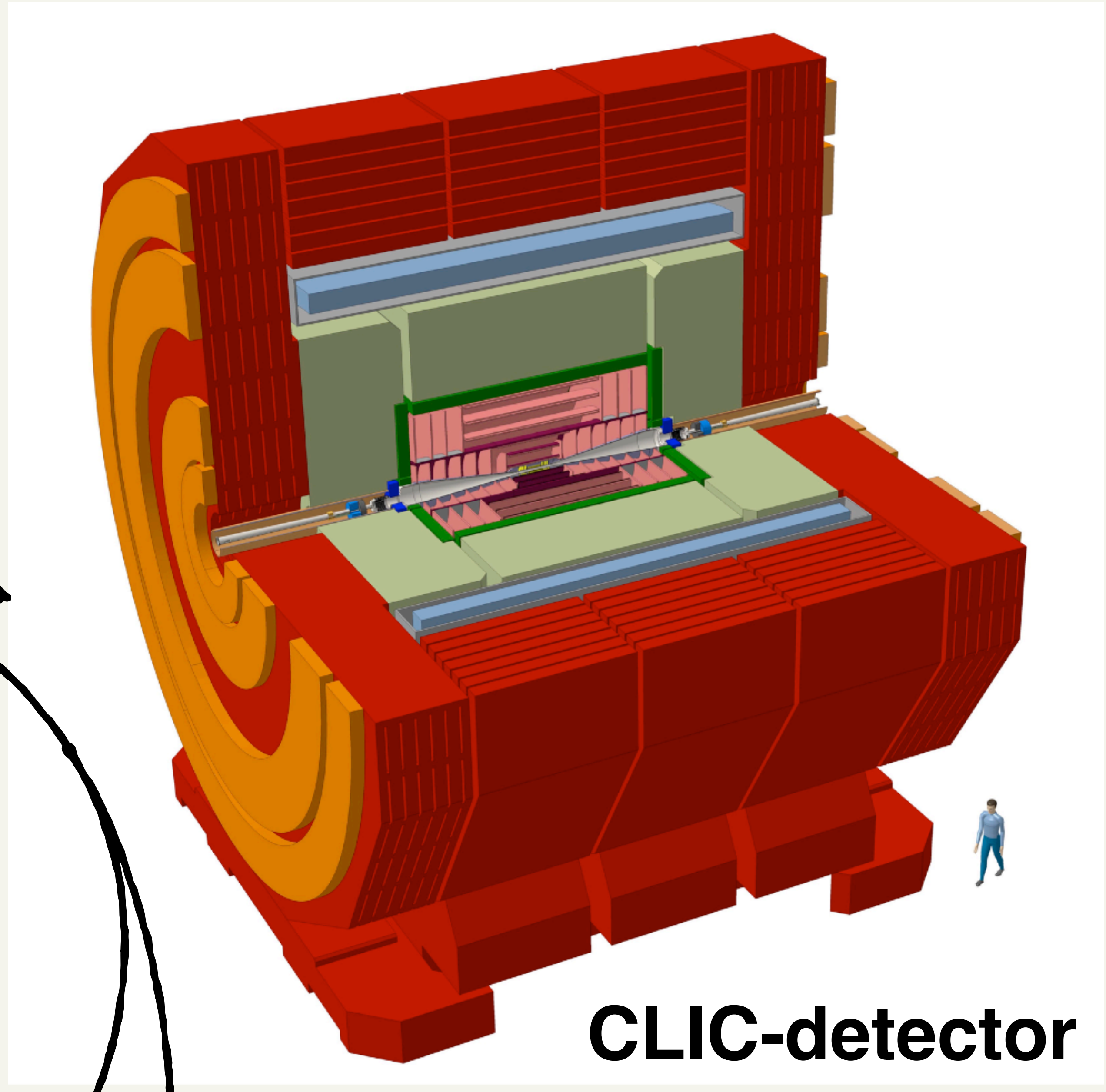




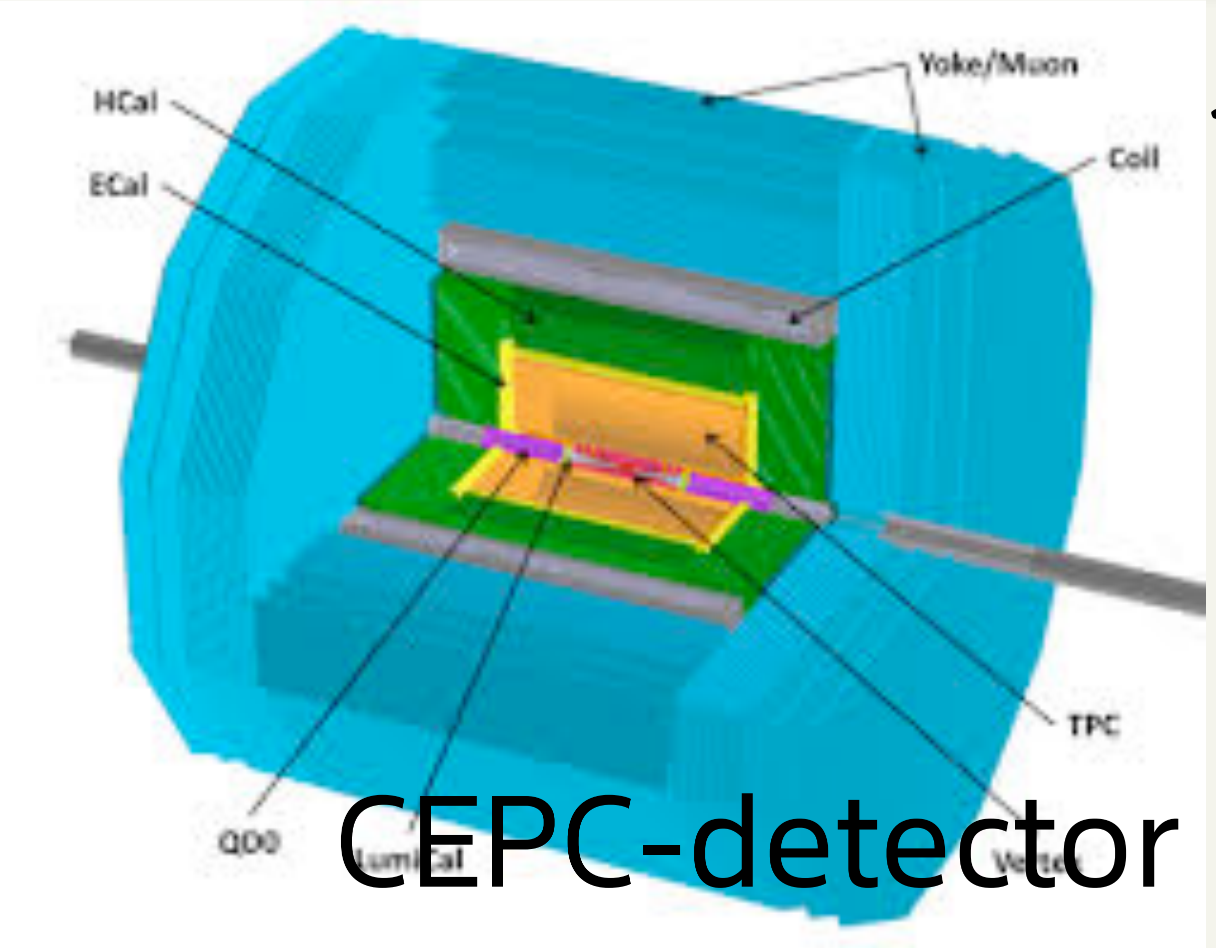
ILD sub-systems at live experiments!

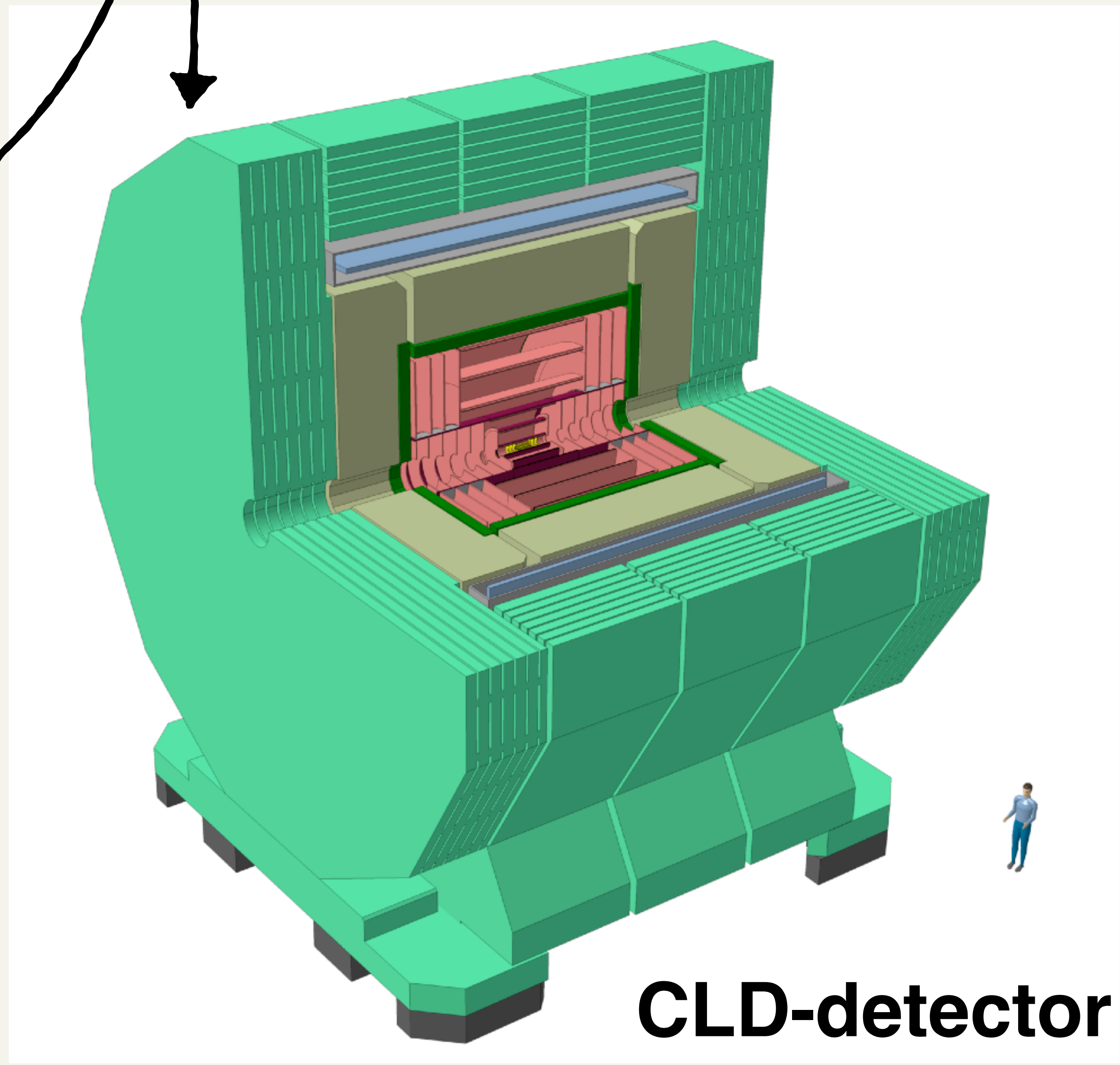


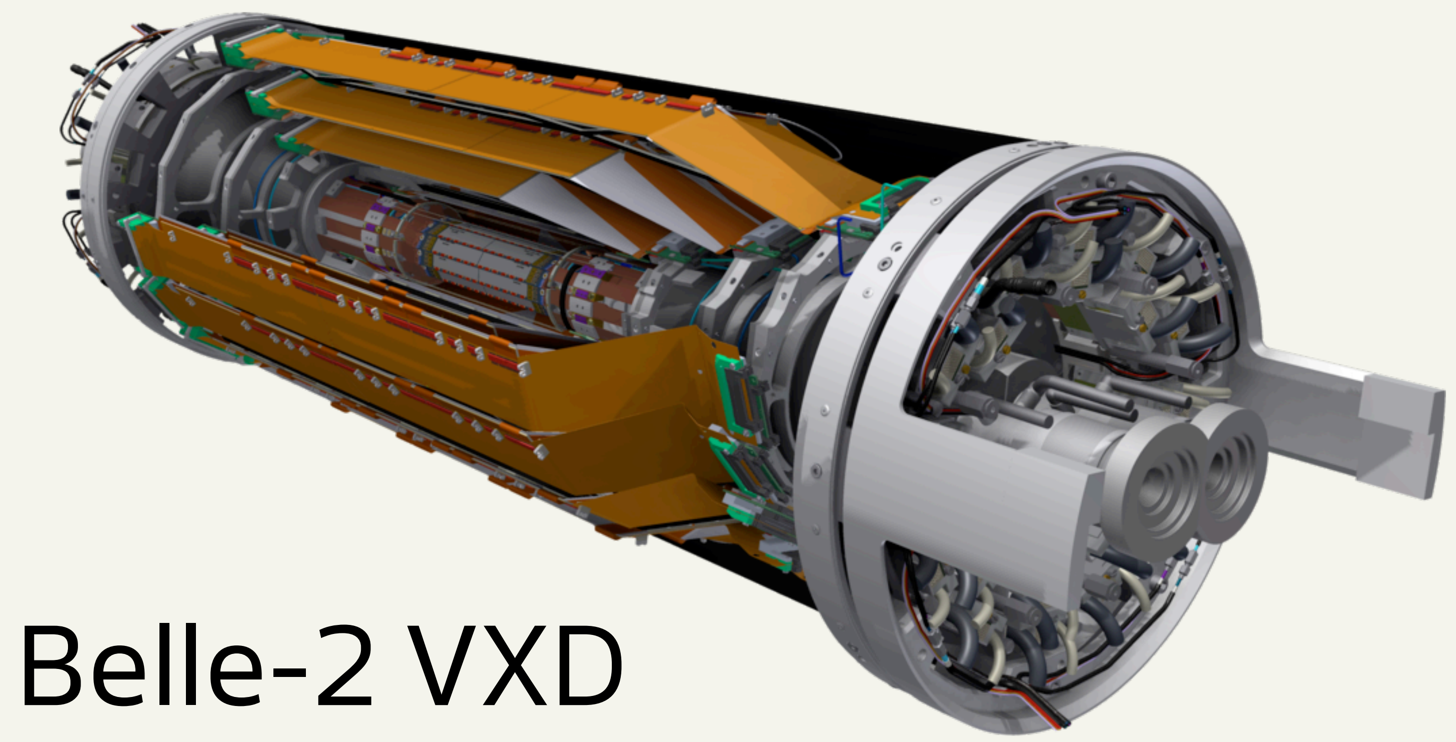




and more...







The ILD at linear e+e- colliders

Contents

- Overview
- Tracking
- Calorimetry
- Forward detectors

ILD IDR: https://arxiv.org/abs/2003.01116

ILD overview

ILD Interim Design Report (2020)

- Multi-purpose detector, original design for the ILC (250 GeV, 500 GeV and 1000 GeV)
  - **Optimised for particle flow**, with minimal material budget in front of ECAL.
  - **3.5 T solenoid** outside of calorimeters.
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  - **Power pulsing** => low heat dissipation => **lightweight** (or no-) **cooling**

~ LHC / 3

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  - e.g.: silicon-W ECAL + scintillator-steel HCAL
  - Jet energy resolution (for a 100 GeV jet): $\sigma_E/E \approx 3-4\,\%$ — **~ LHC / 2**

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- **PID** provided by the TPC (dE/dx) $\sigma_{dE/dx}/\mu_{dE/dx} \sim 5\ \%$ — **~ ALICE**

Vertex detector and silicon tracking

- **Current technologies**:
  - CMOS (well known)
  - DEPFET (Depleted FET)
  - FPCCD (Fine Pixel CCD)

Target: low material budget
~ 0.15% X_0 / layer (3 layers planned)

- **Future technologies**:

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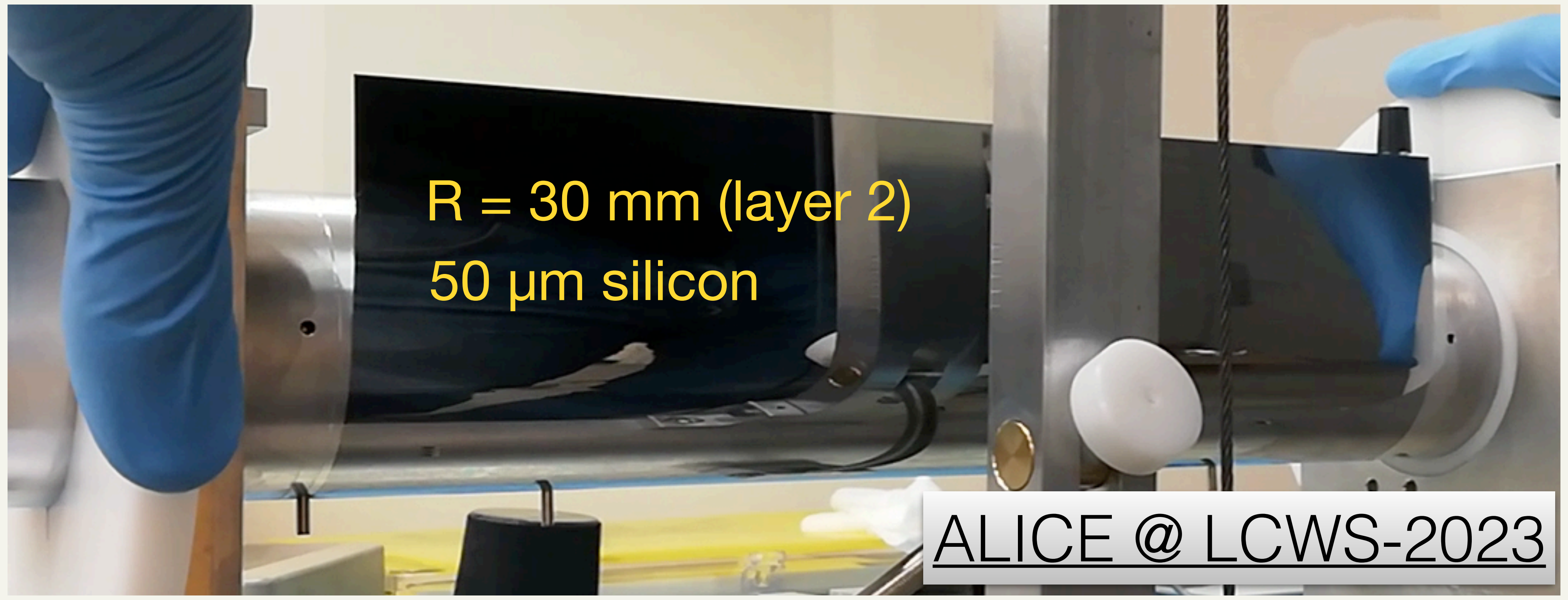

- **Future technologies**:
  - **MAPS** (ALICE ITS-3):
    - Bendable wafers!
    - Ultra-low material: 0.05% X0 / layer
    - Working toward sub-ns timing resolution [Caterina Vernieri LCWS'24]
    - Pixel pitch < 25 µm
    - low power ~ 20 mW/cm2

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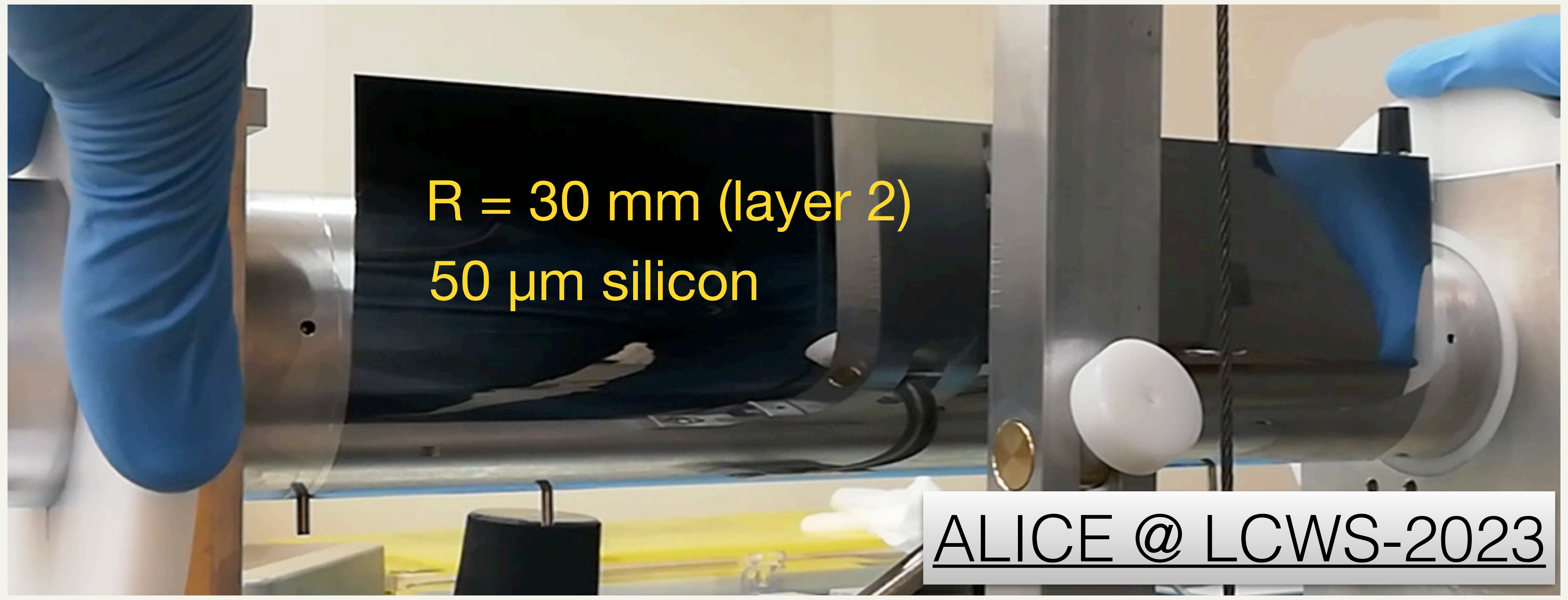
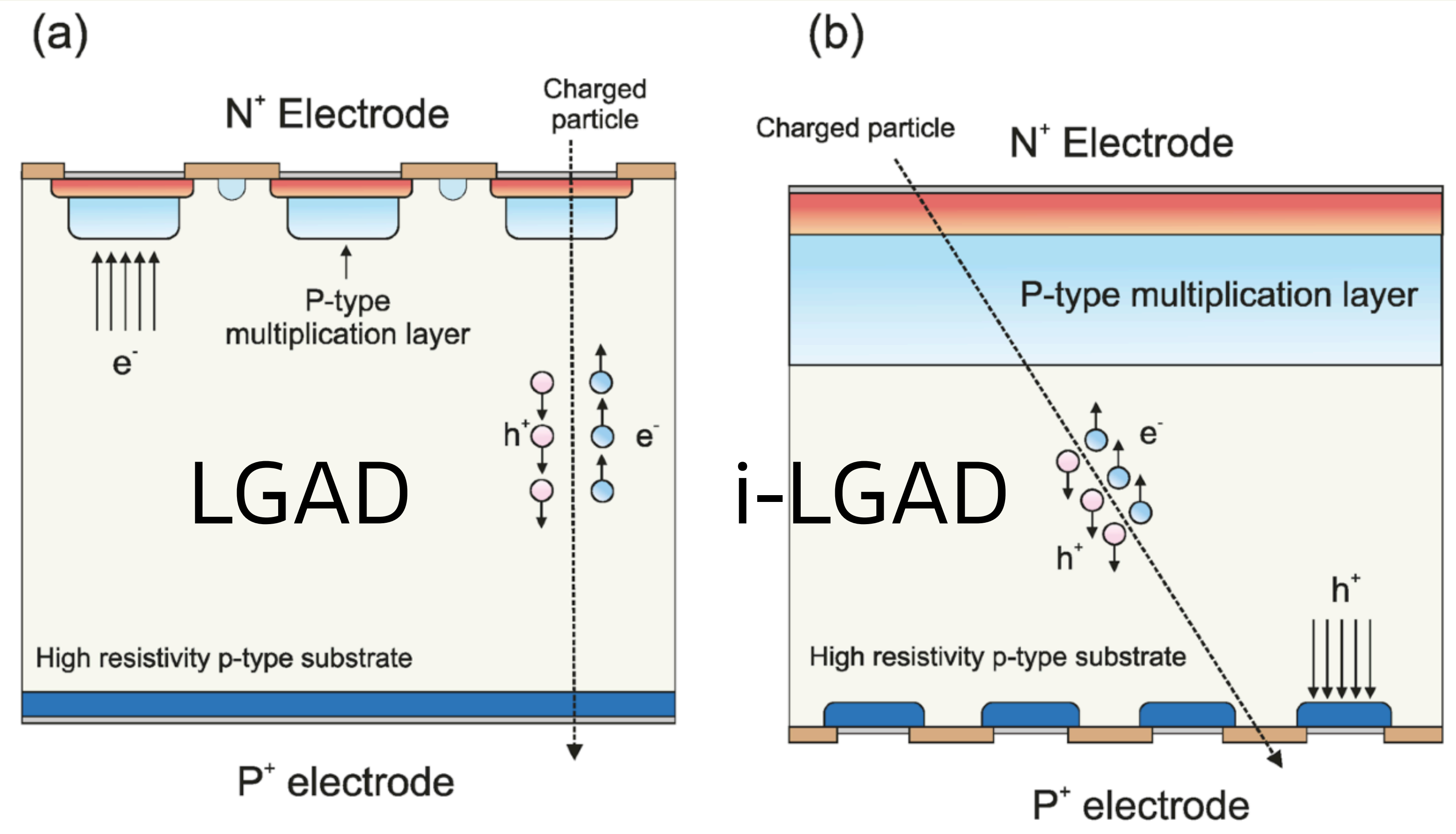
  - Inverted-LGAD (**iLGAD**)
    - 20 ps timing resolution
    - 100% fill factor





https://doi.org/10.3390/s23073450

Tracking: TPC or full-silicon?

- Target:
  - Low material budget: 5% X_0
  - Momentum resolution => point resolution: 100 μm.
  - <5% dE/dx resolution for PID.

See "TPC Developments for the ILD" [Huirong Qi, yesterday]

- **Current**: pad-based (**GEM or micromegas**, similar performance) →
  - Test beam prototypes for both readouts.

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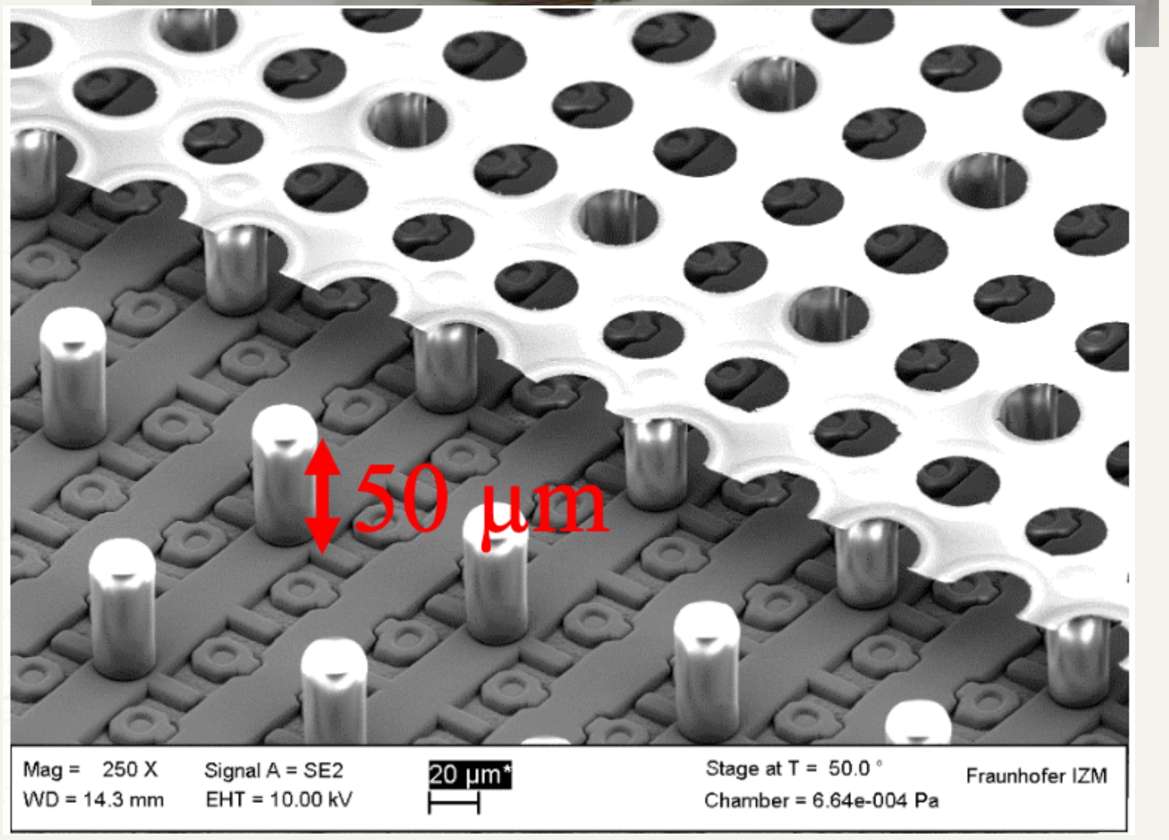
  - Improves momentum resolution (15%) and PID (50%).



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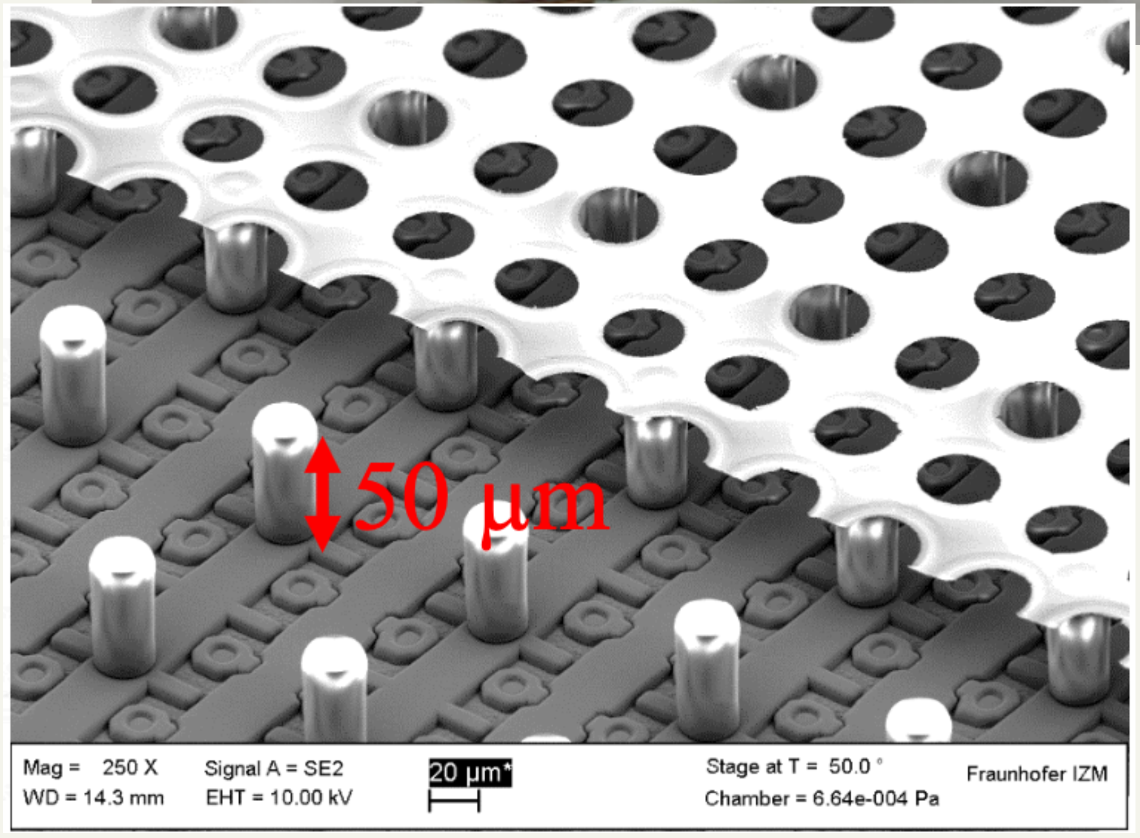


- **Main difference between ILD and CLIC-det** (fusion of ILD and SiD):
  - **full silicon tracking**: 1.5% X_0 / layer
  - 3.5 → 4T

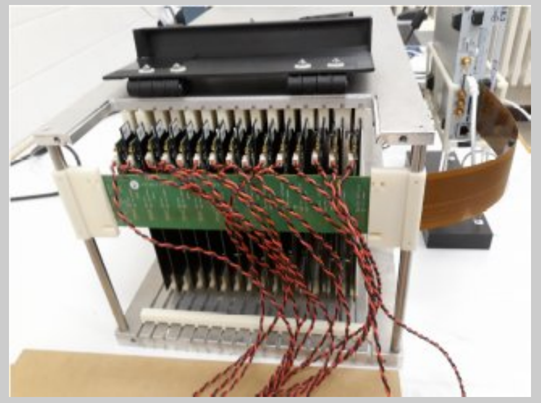
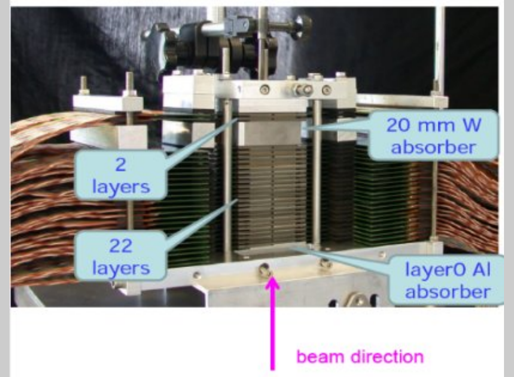
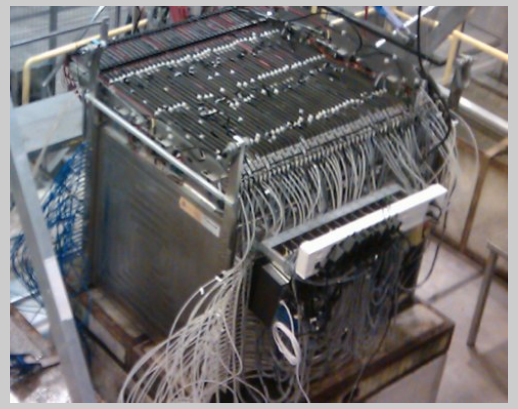
[CLIC-det concept]

Calorimeters

- Calorimeters: developed within CALICE (now DRD-6)
  - High-granularity required for particle-flow reconstruction.

Technological & new Physics Prototypes

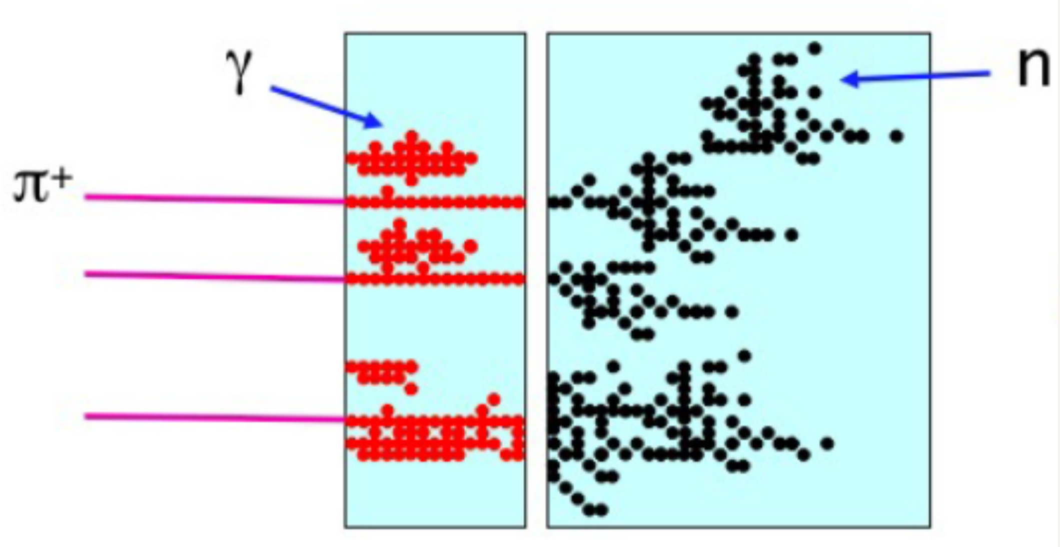
4.5 prototypes, 15+ years of R&D, all tested

Si-W ECAL	(ALICE FoCAL)	Scint-W ECAL	AHCAL	SDHCAL
				
0,5×0,5 cm² ×15 (→30) Si layers + W	0,003×0,003 cm² × 24 MIMOSA layers + W	0,5×4,5 cm² ×30 Scint+SiPM lay. + SS	3×3 cm² × 38 Scint+SiPM lay. + SS	1×1 cm² × 48 layers GRPC + SS

Purposes:

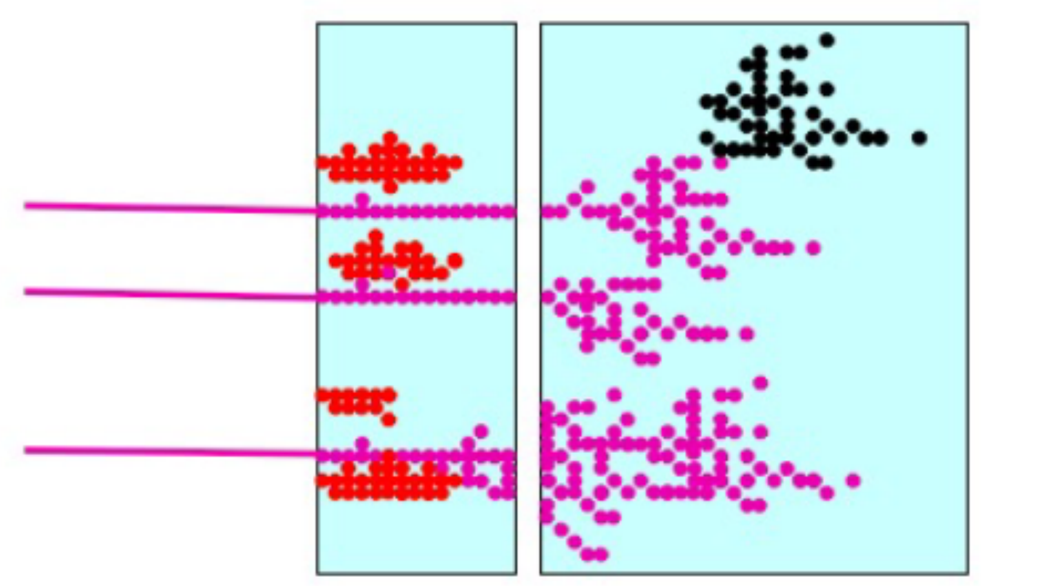
- Prove technological feasibility: electronics inside, thermal capacity, mechanical, DAQ, calibration, …
- Extend physical prototypes : uniformity, "large" production, methods, …

Vincent.Boudry@in2p3.fr CALOR'24 | CALICE, a legacy | 21/05/2024 15/54



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

Particle flow



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

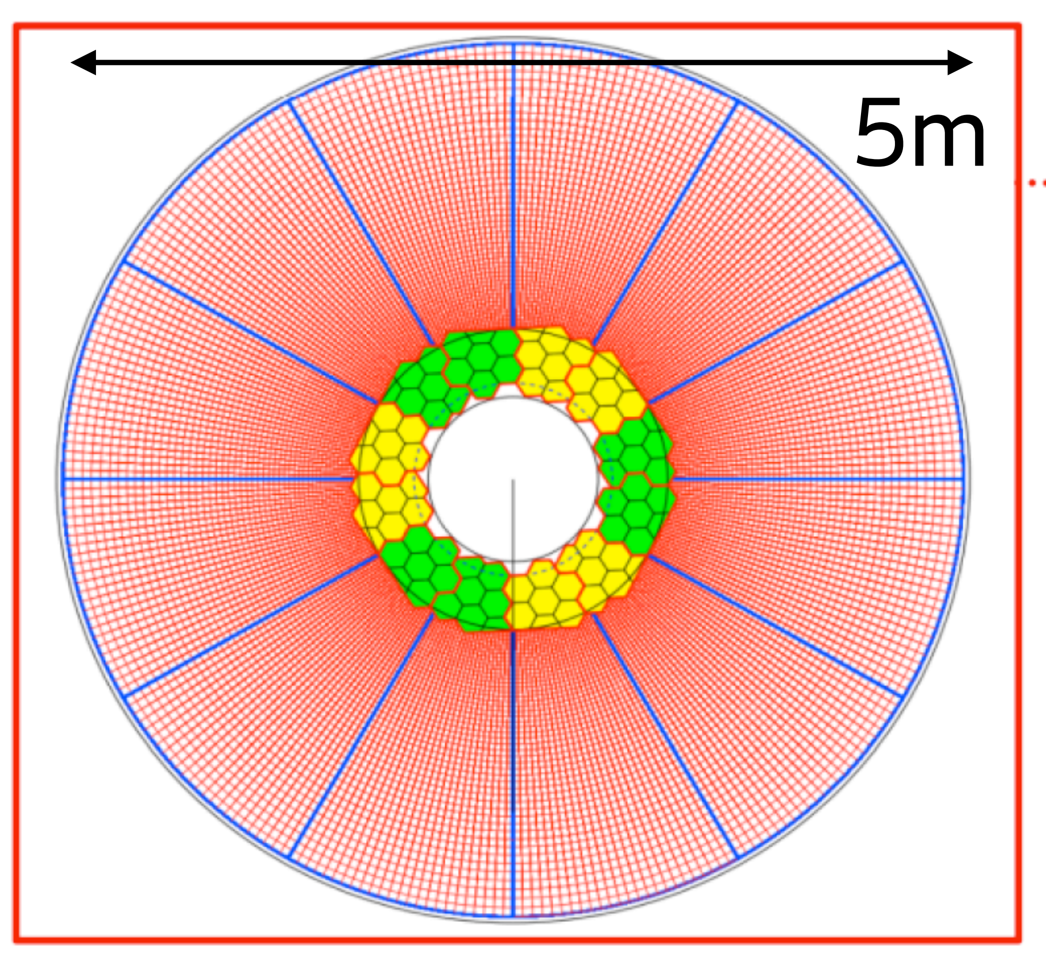
CALICE review talk by Vincent Boudry @ CALOR'24

Calorimetry developments

- **AHCAL**:
  - **Megatiles**: segmented board-sized scintillator in a single piece [Anna Rosmanitz @ AHCAL WS'23].
  - **Fast simulation** development [Julian Uteh @ AHCAL WS'23].

- **SiW ECAL**: Roman Pöschl @ CALOR'24
  - Working on improving hybridisation (gluing of electronics and sensor) and mechanical stress.
  - Test beams in 2022 and 2023.
  - Now building new, improved layers.

CMS HGCAL
To be installed in 2027



280k + 6M channels

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See earlier talk by Yong Liu

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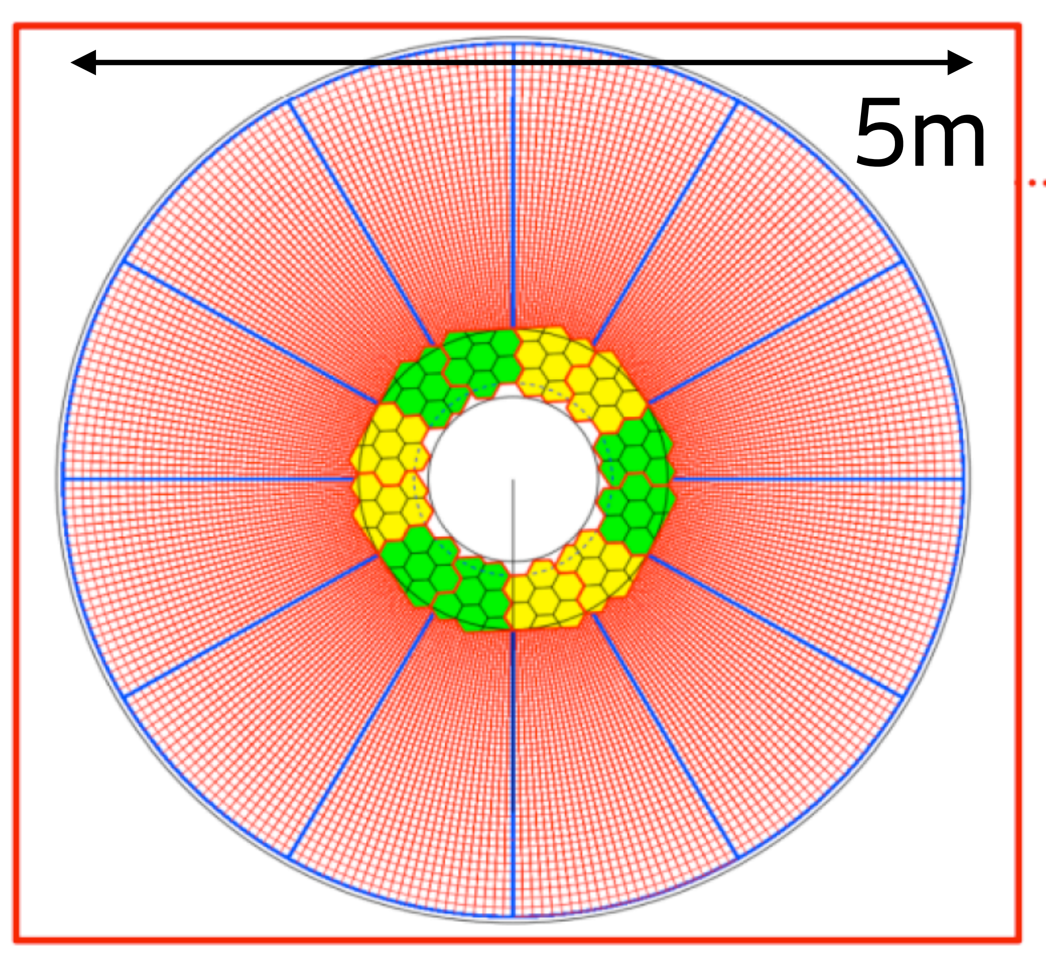

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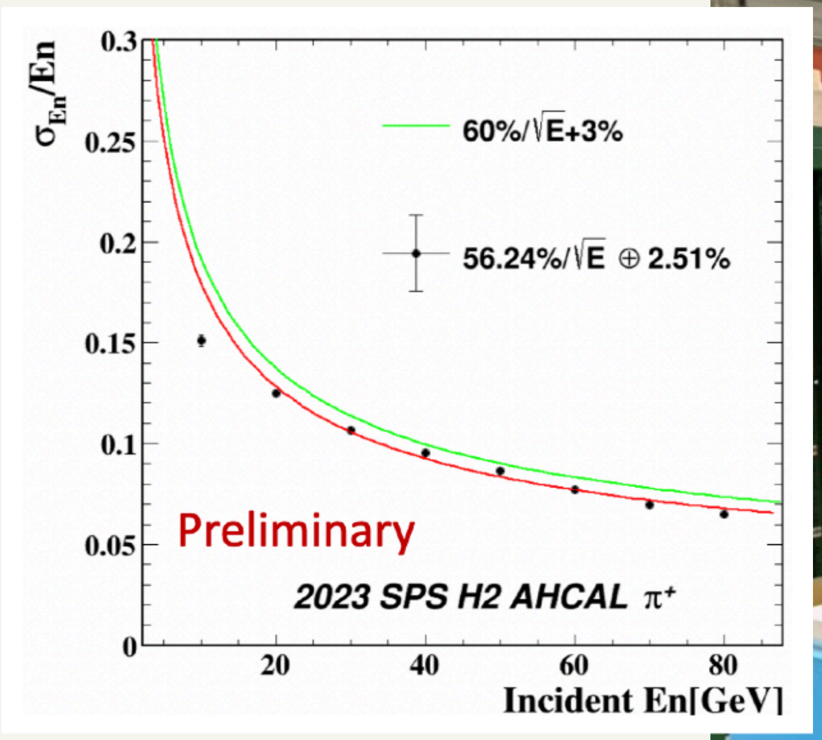

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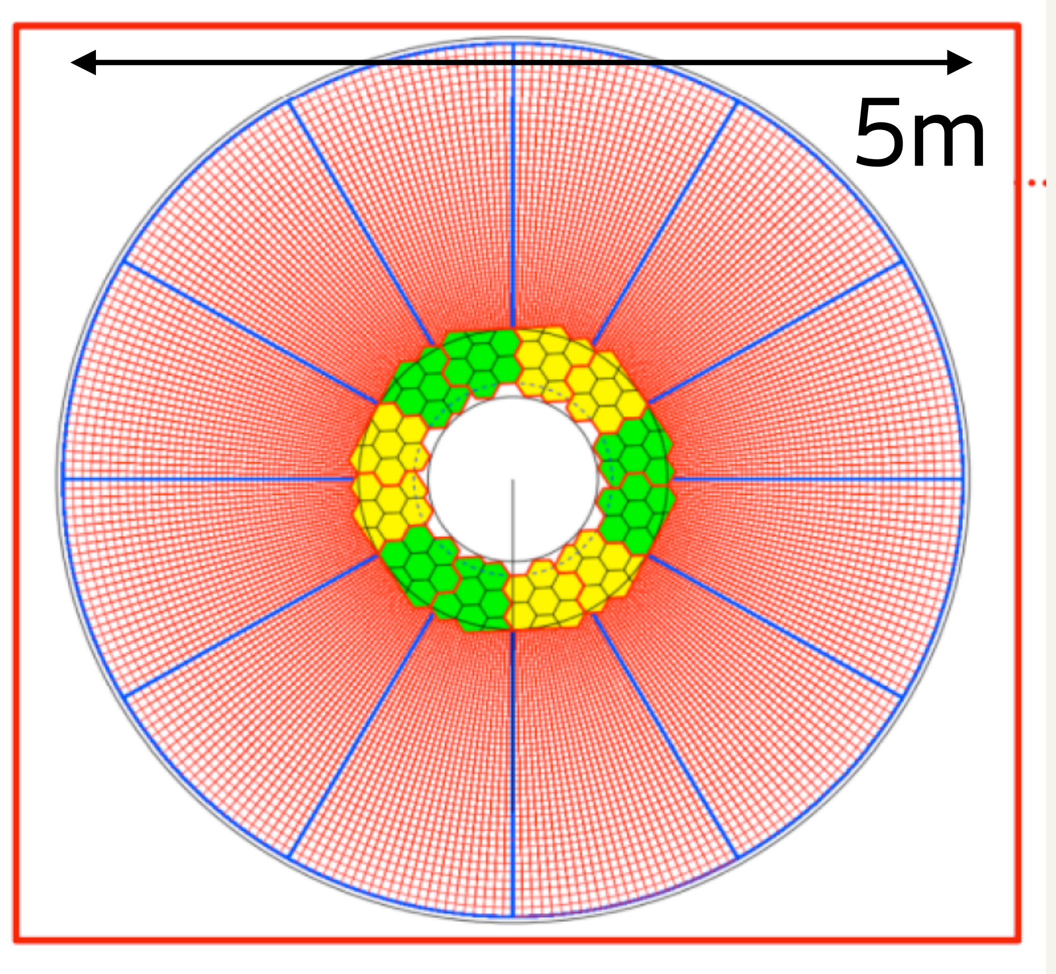

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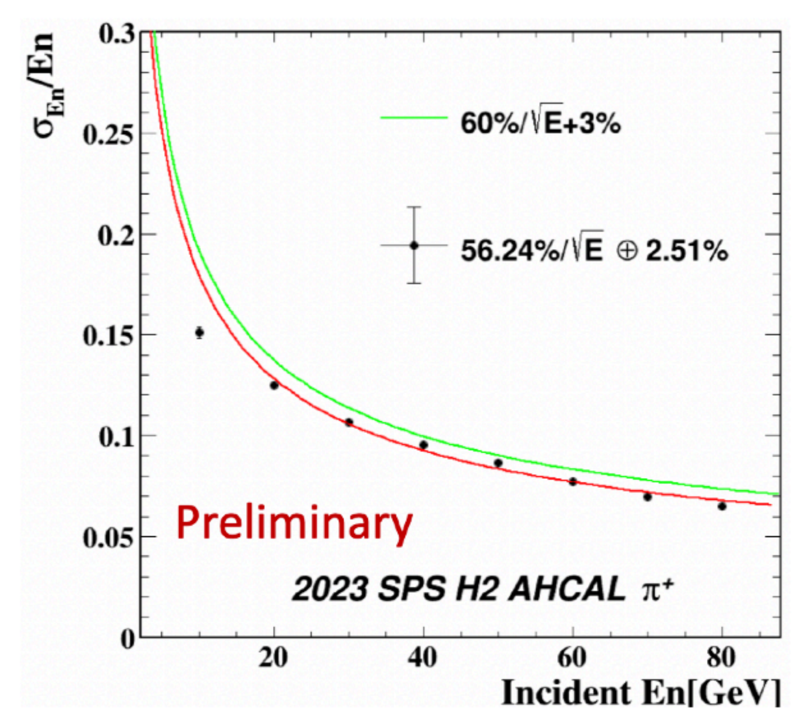


- Digital ECAL using MAPS [Jim Brau @ CALOR'24].

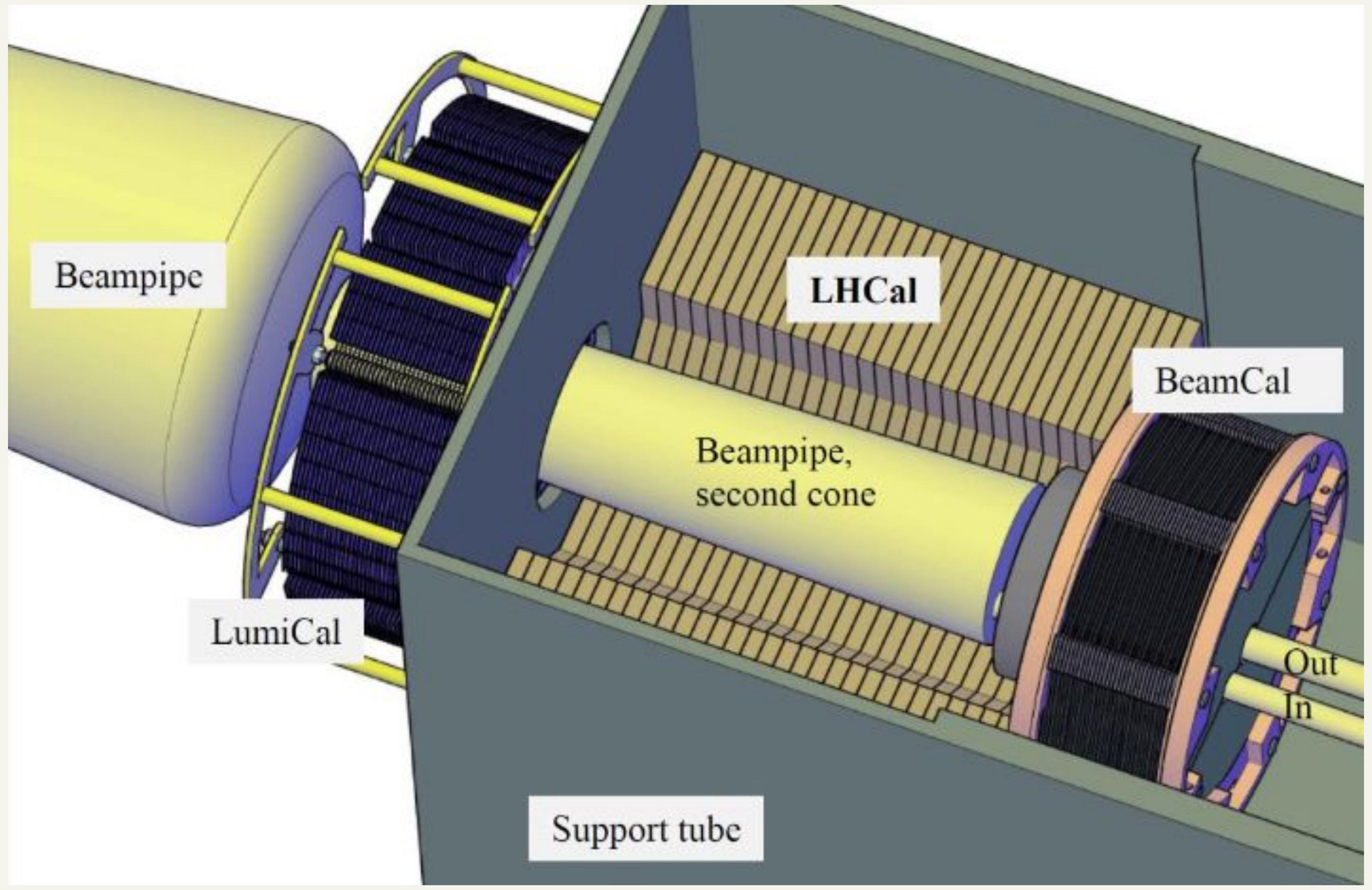
Forward calorimeters

- Down to θ = 6 mrad (η = 5.8).
- No tracker => **high granularity** to provide position resolution.

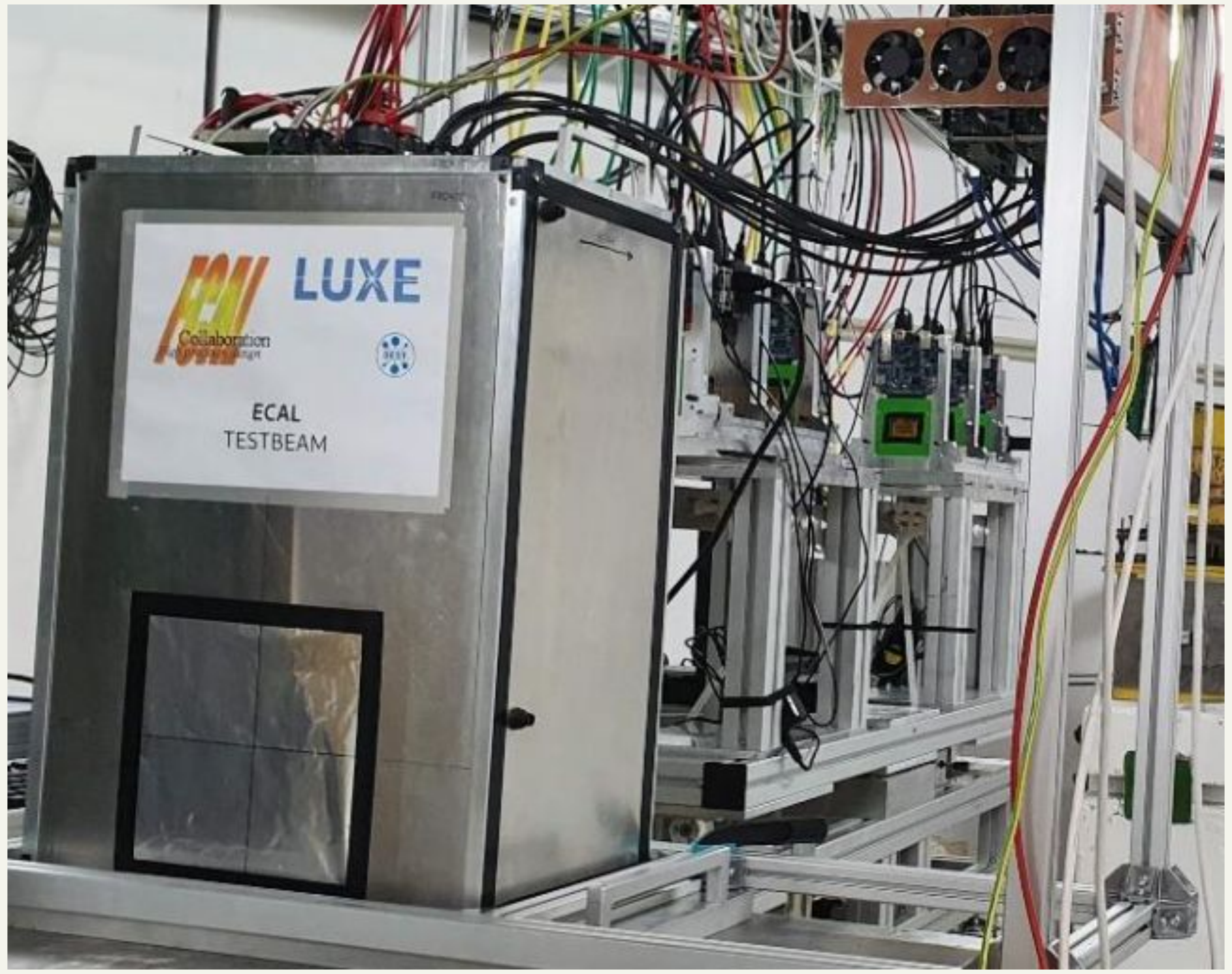
- **BeamCal: per-bunch luminosity** measurement using beam-strahlung
  - GaAs readout + W-absorbers.
  - New GaAs sensors with integrated signal routing.
  - Test beam data analysis ongoing.

- **LumiCal: integrated luminosity measurement** (Bhabha counting)
  - Based on SiW-ECAL design.
  - applied to CMS lumi cal
  - applied to LUXE ECAL

- **New idea: measure ee → γγ instead of Bhabha**.
  [Graham Wilson @ ILD workshop 2024]
  - Photons at very low angle are difficult, but cleaner!



Wolfang Lohman @ ILD meeting 2022



Adapting the ILD to circular e+e- colliders

Contents

- The CLD detector
- FCCee Machine-Detector Interface (MDI)
- Calorimetry
- Tracking

CLD proposal: https://arxiv.org/abs/1911.12230

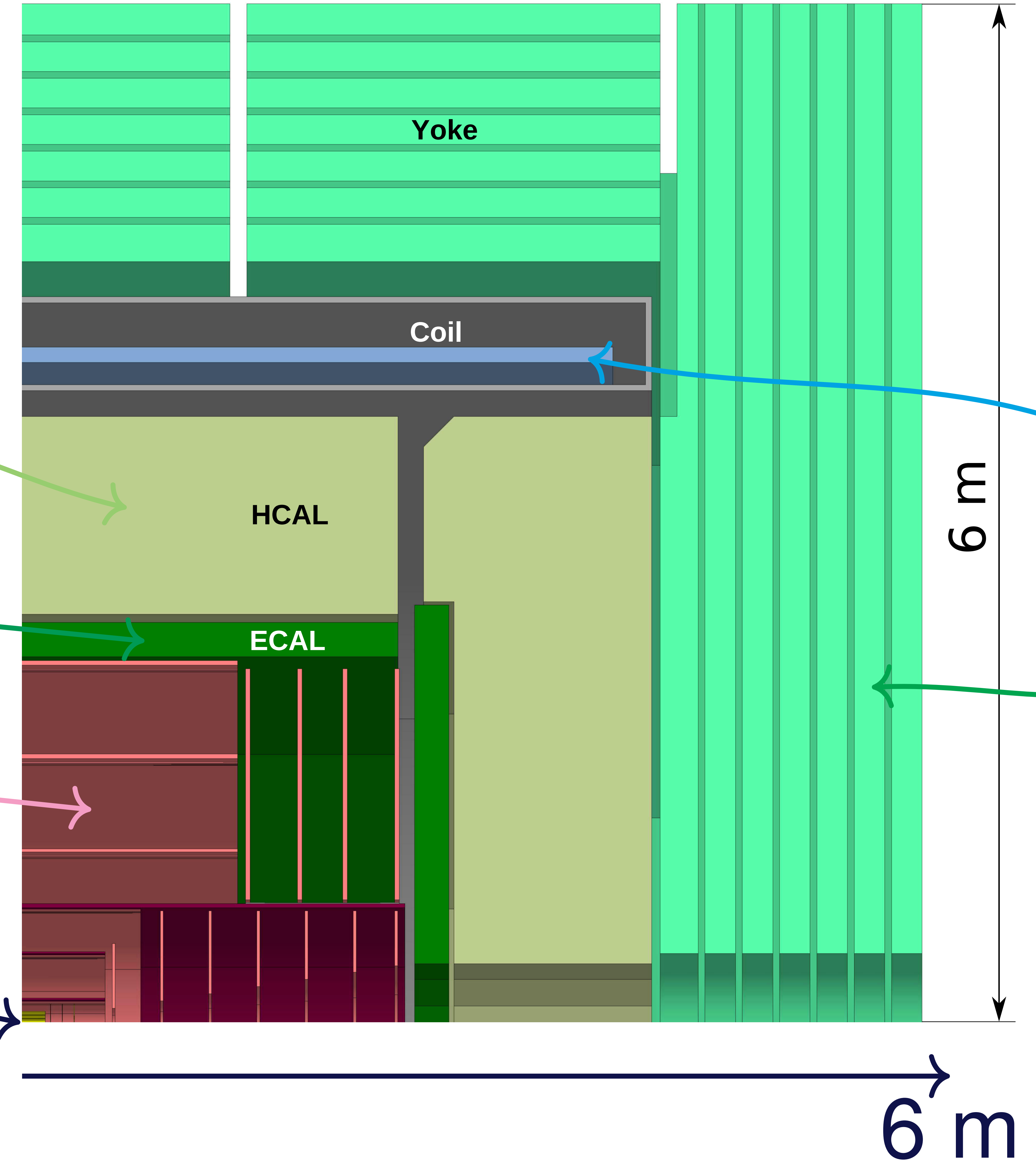
The CLD detector

arxiv:1911.12230

Ancestry: ILD => CLIC-det => CLD

Main changes wrt. ILD

- Steel–Scintillator HCal with 3 cm cell-size
- Silicon–Tungsten ECal with 5 mm cell-size
- Silicon Tracker, mostly 50 µm pitch strips
- Vertex Detector with 25 µm pixels



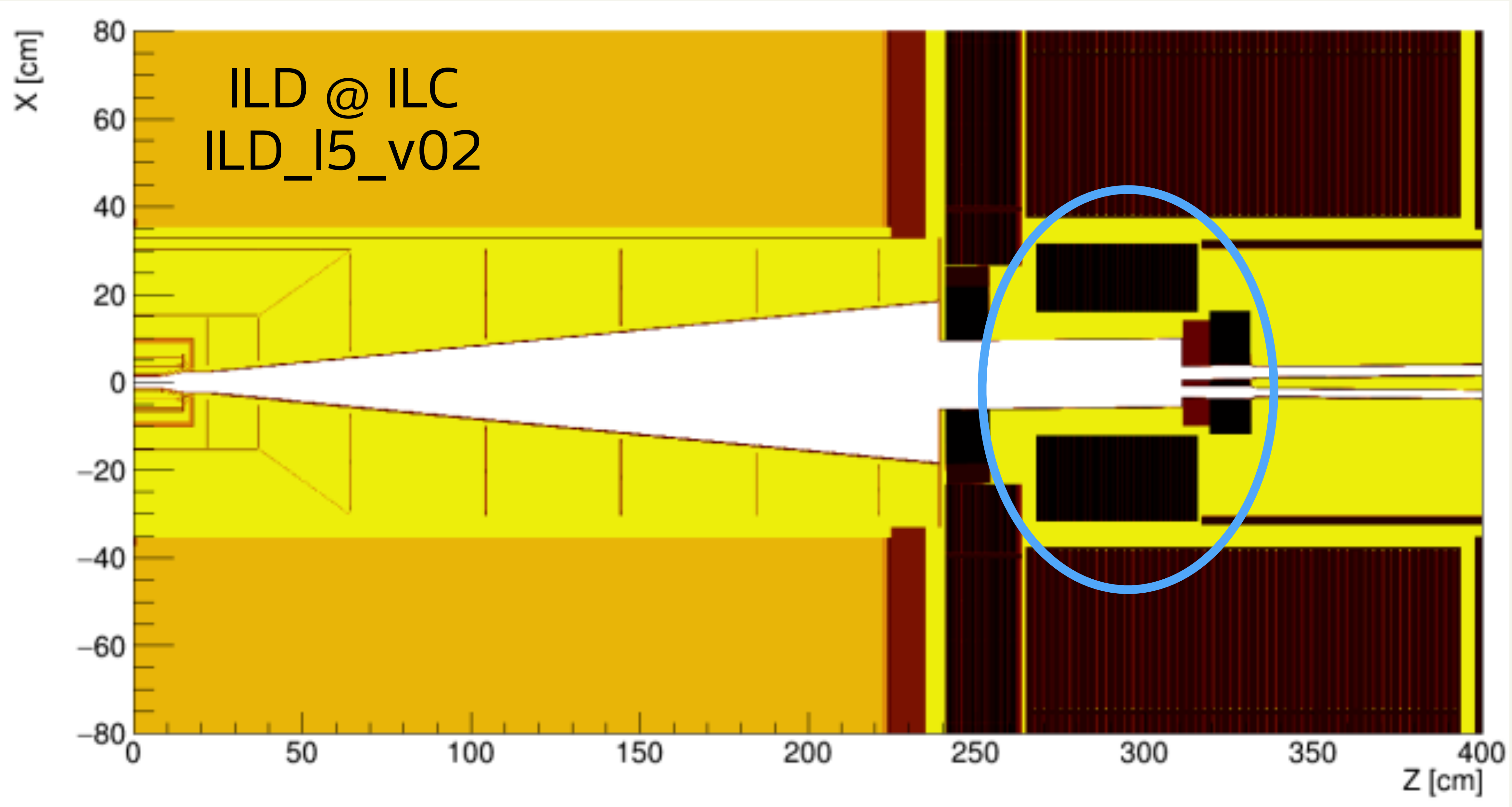
- Superconducting Solenoid of 2 T
- Iron Yoke with RPCs for Muon ID

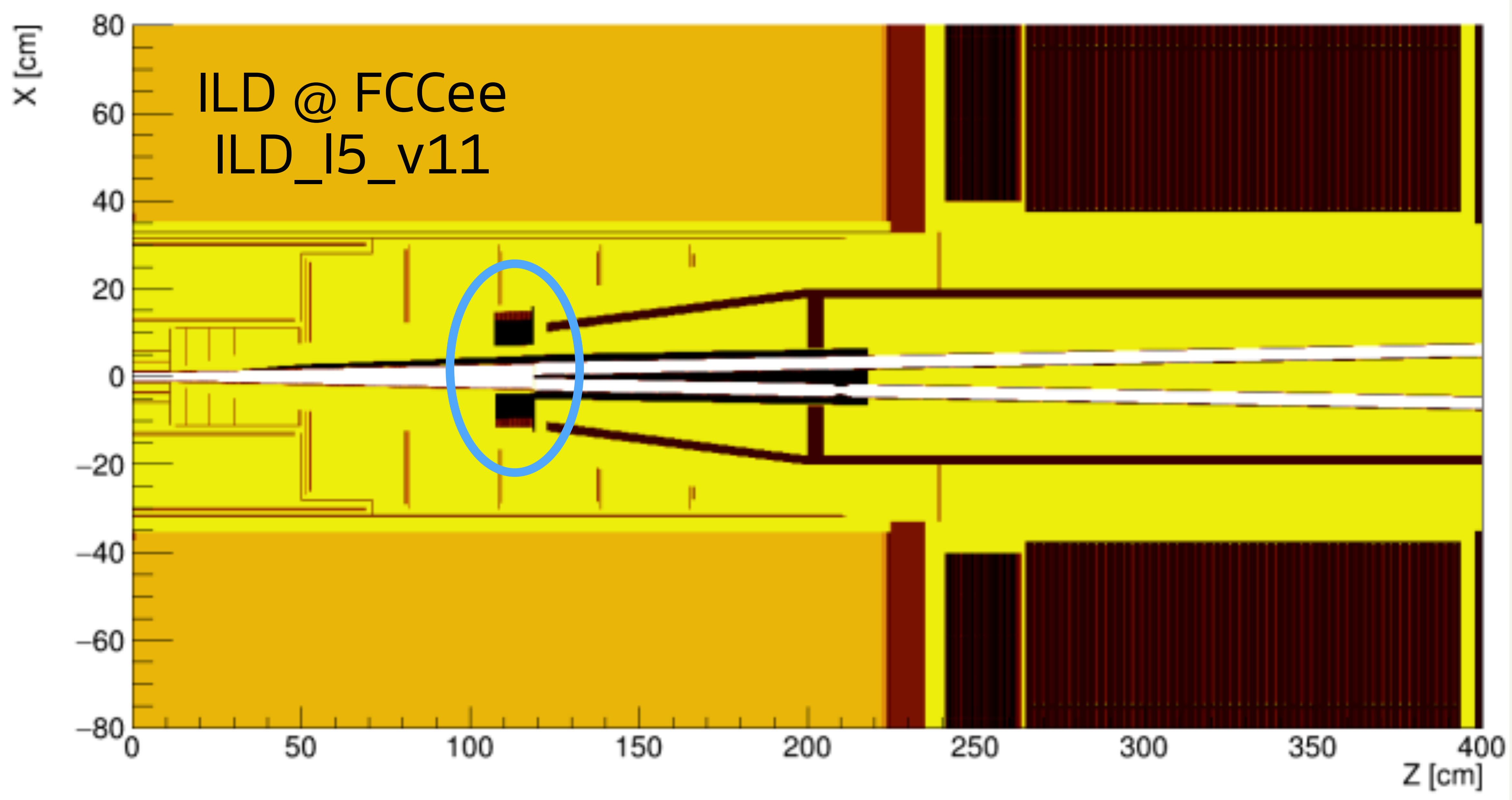
Stolen from Andre Sailer

ILC → FCCee

- Large changes to the Machine-Detector Interface:
  - **Crossing angle** 14 mrad => 30 mrad.
  - **Last focusing quad**: 4 m => 2.2 m
  - **Additional** compensating or screening **coils**.
  - Limits B field to 2 T (at the Z peak).
    - Can be 3 T at lower lumi.

- => Tightly packed forward region.
  - Forward calorimeters pulled back in the tracker area.
  - Background studies needed.



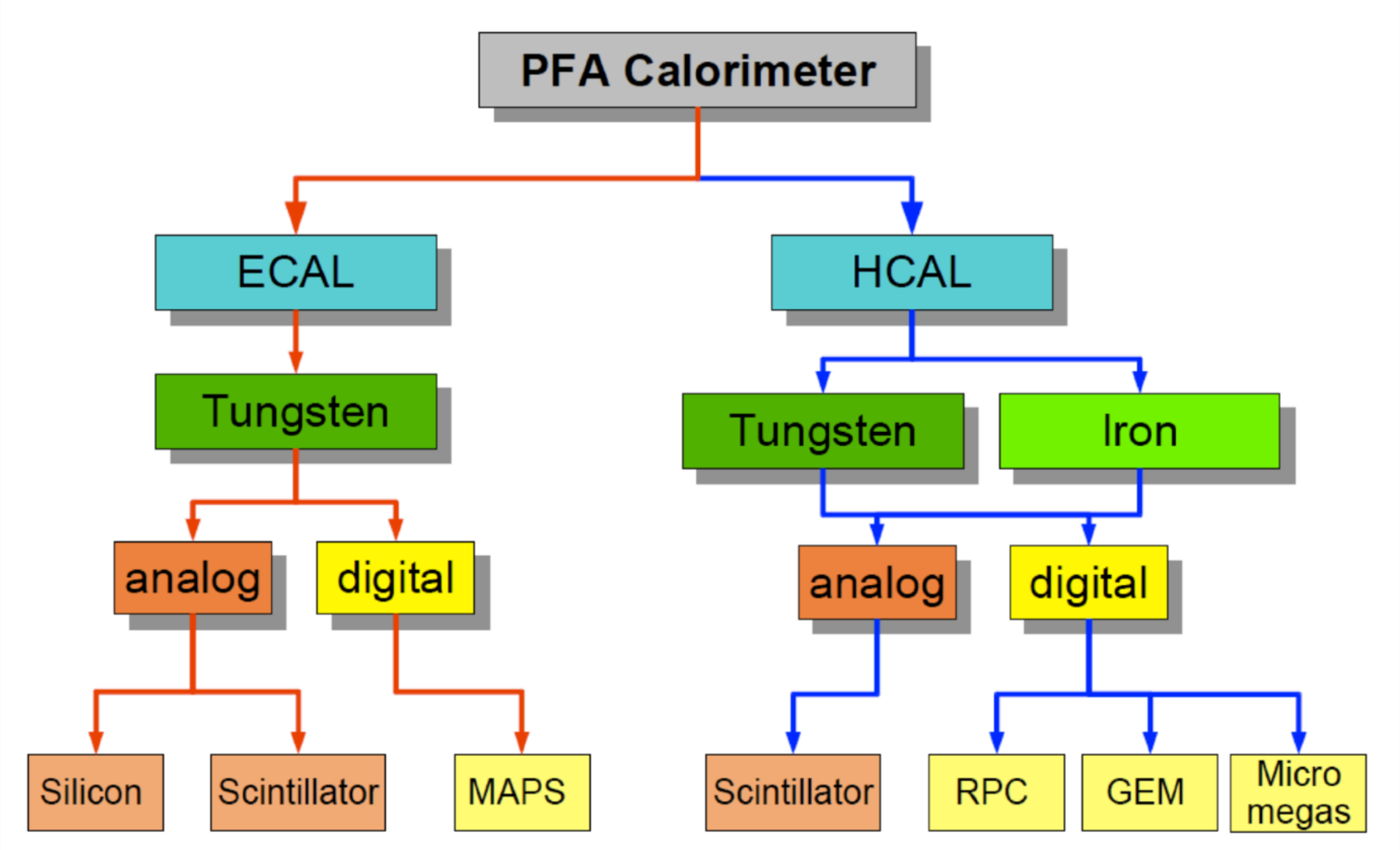


Calorimeters & readout

- **Same technologies** can be reused: high-granularity for **particle-flow**.

- **Real challenge** = "continuous" beam:
  bunch spacing down to < 20 ns
  - => **no power pulsing for electronics**
  - ILC: AHCAL (SPIROC): ~25 μW / channel
  - CMS: HGCAL (HGCROC): ~20 mW / channel

  x800 😱



- Expect physics rate of ~100 kHz at the Z-peak.
  - => **cannot (or hardly) go trigger-less**.
  - Though it might be acceptable at lower lumi (WW / Higgs / ttbar).

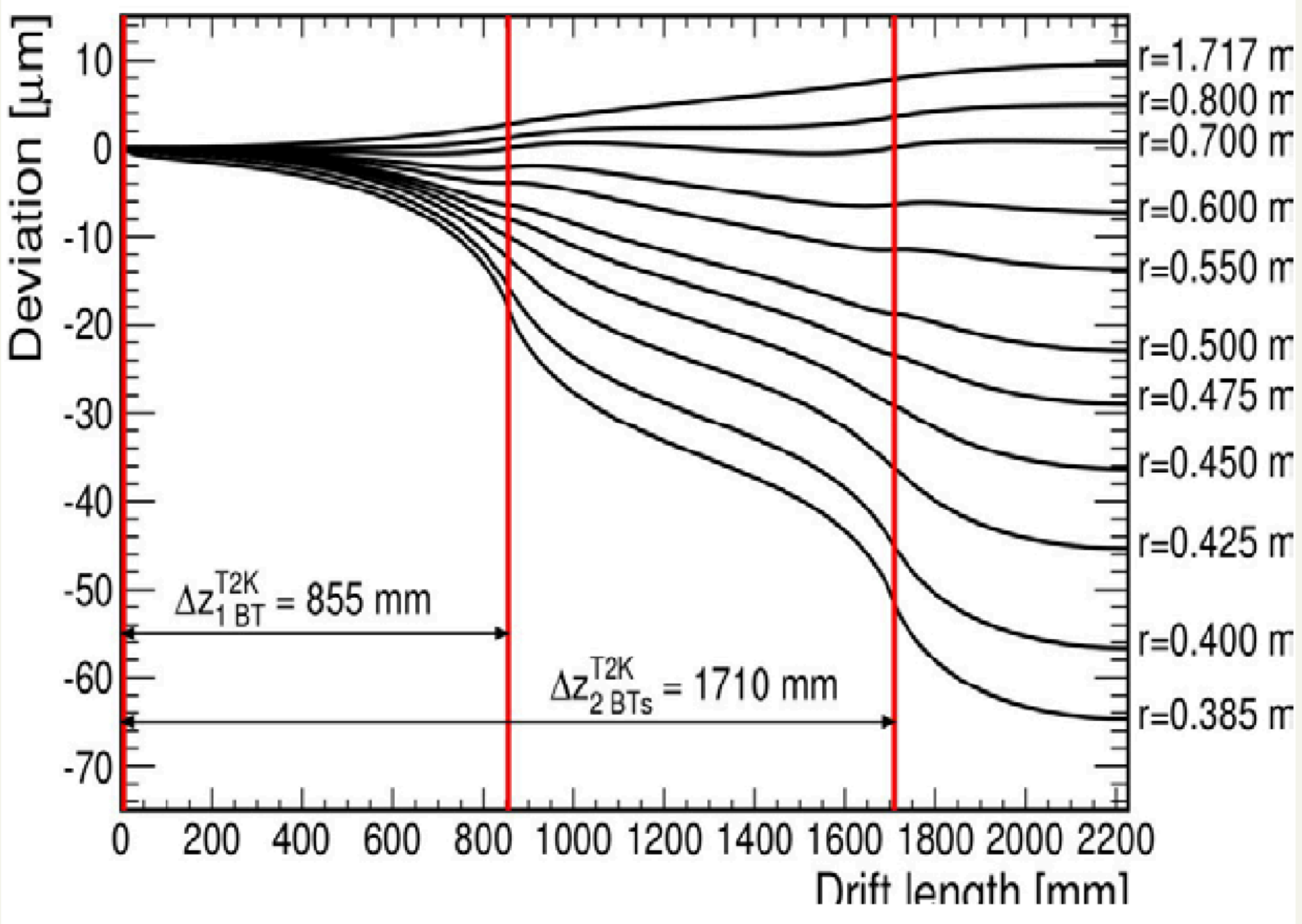
- Note: cooling and trigger requirement also applies to the tracking systems…

A TPC at high-luminosity?

See talk by Huirong Qi yesterday

- **Potential issues**:
  - **BX** much more frequent than at ILC?
    - Electronics speed can cope with that.
  - **Occupancy** due to physics events and backgrounds?
    - Granularity is fine enough.

- **Actual issue: charge build-up in the TPC**.
  - Due to beam-strahlung background*.
  - => **TPC field distortion** due to primary ions and ion back-flow.
    - Distortions at the 100 μm level.



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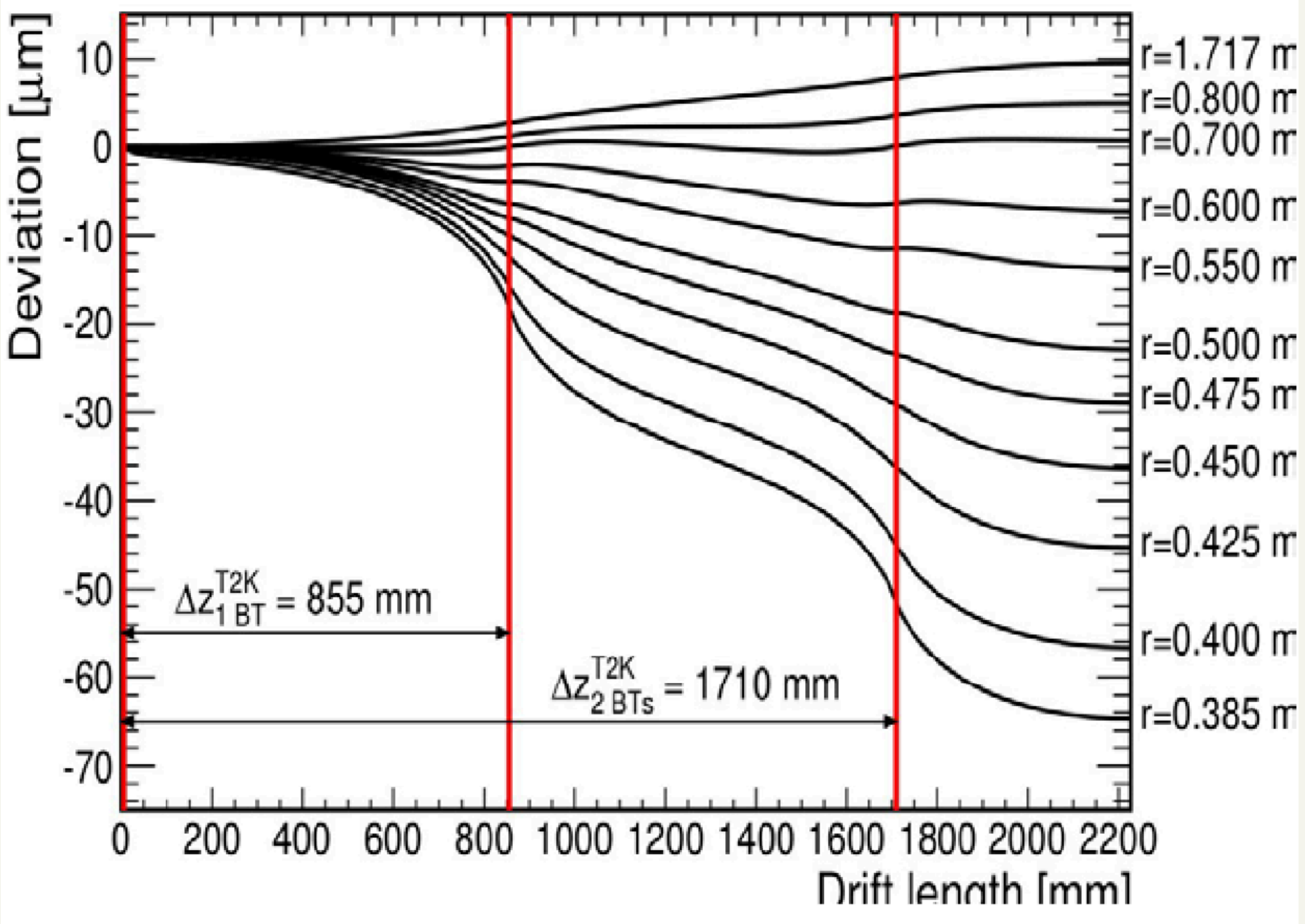

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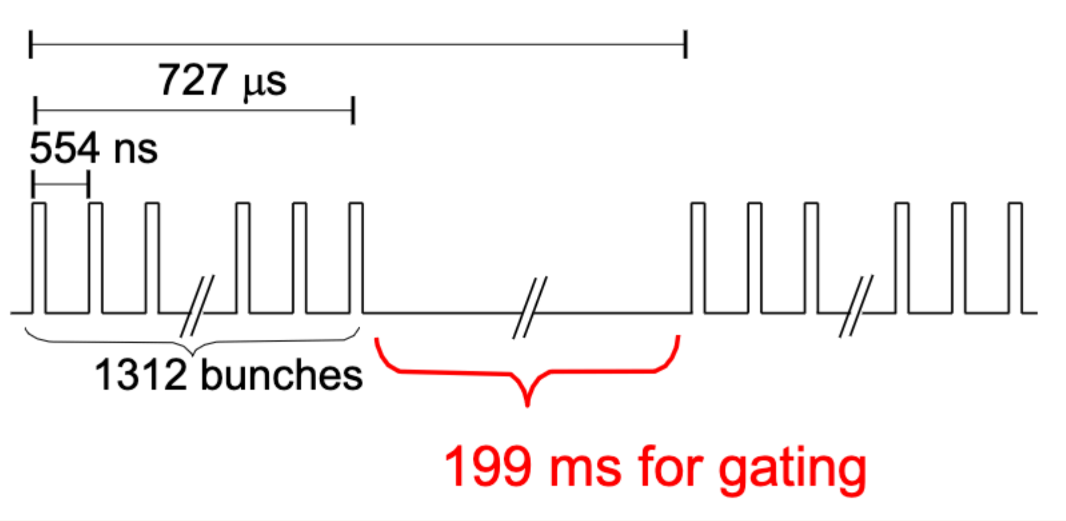
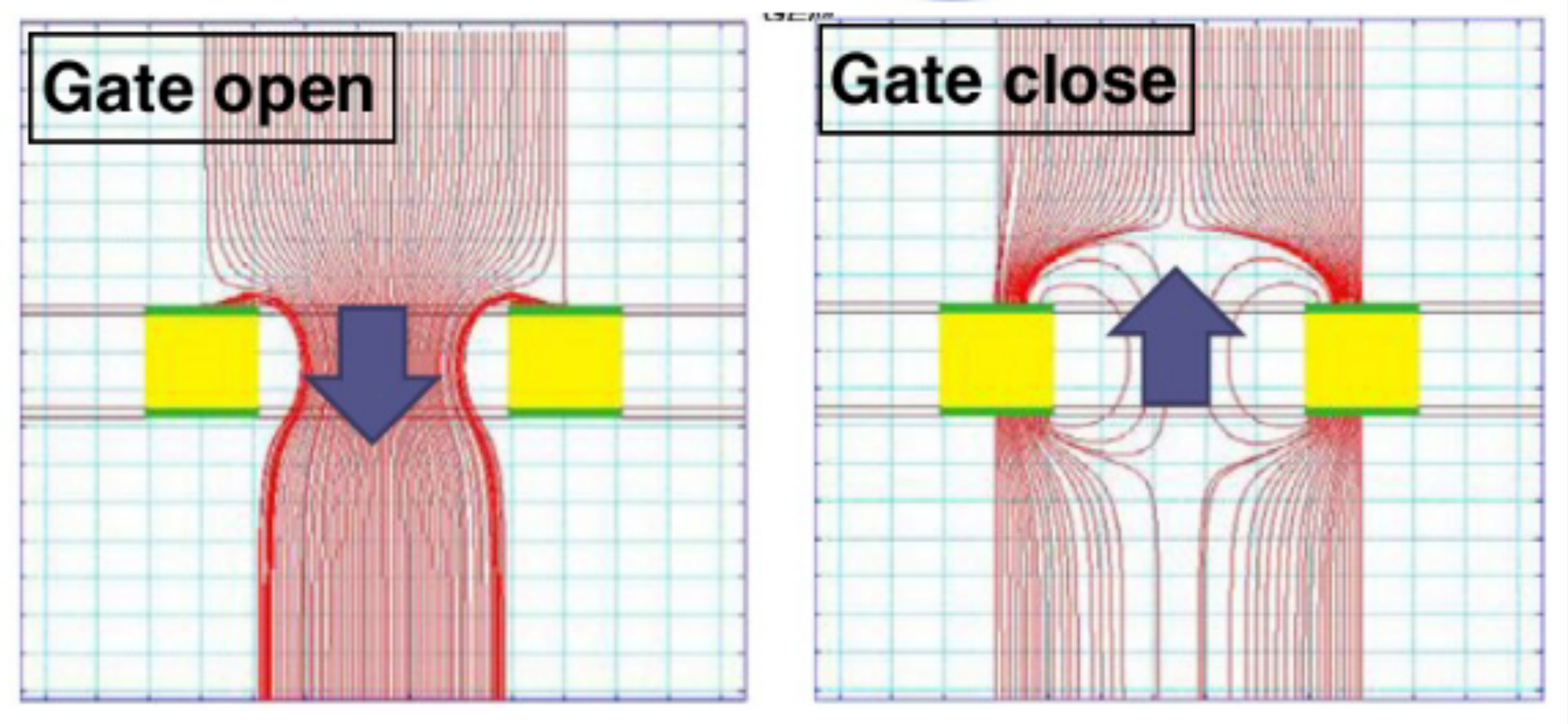
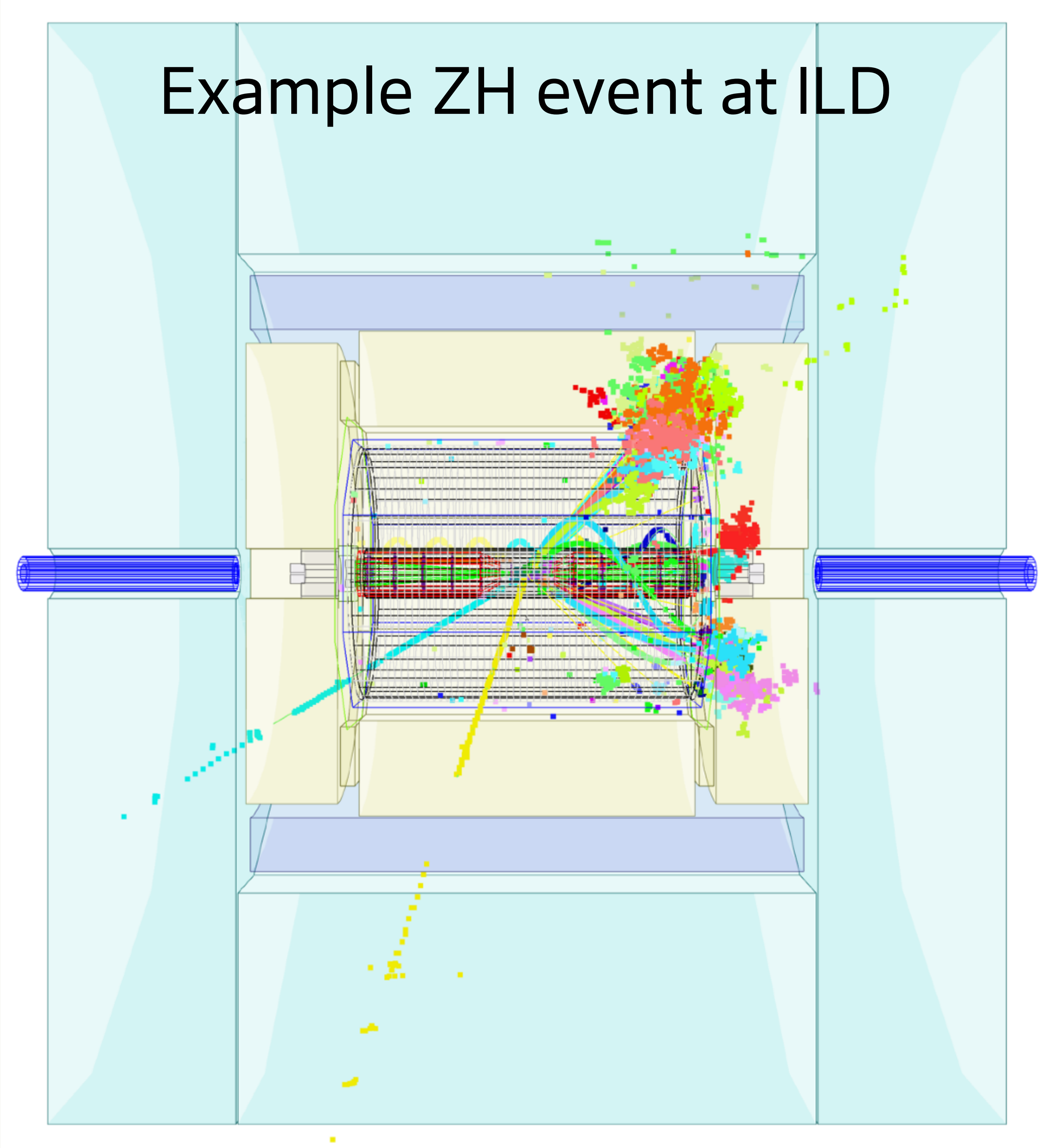
- **Solved at ILC/CLIC by "gating"**
  (reverse polarity of the collection surface outside of bunch crossing to capture the ions).
  - Not straightforward at FCC/CEPC.





Summary

- **ILD** (CLIC-det) for ILC (CLIC) is a **mature detector**.
  - Concepts have been worked on for > 15 years, including simulations, large prototypes, and test beams with real data analysis.
  - **Ideas have been applied** to running or about-to-run detectors (CMS HGCAL, ALICE ITS), and are a **source of inspiration** for other R&D projects (LUXE).
  - **Great playground** for new ideas (pixel readout for TPC, dual readout calorimeters, …)!
  - Software improvements are going on.



Summary

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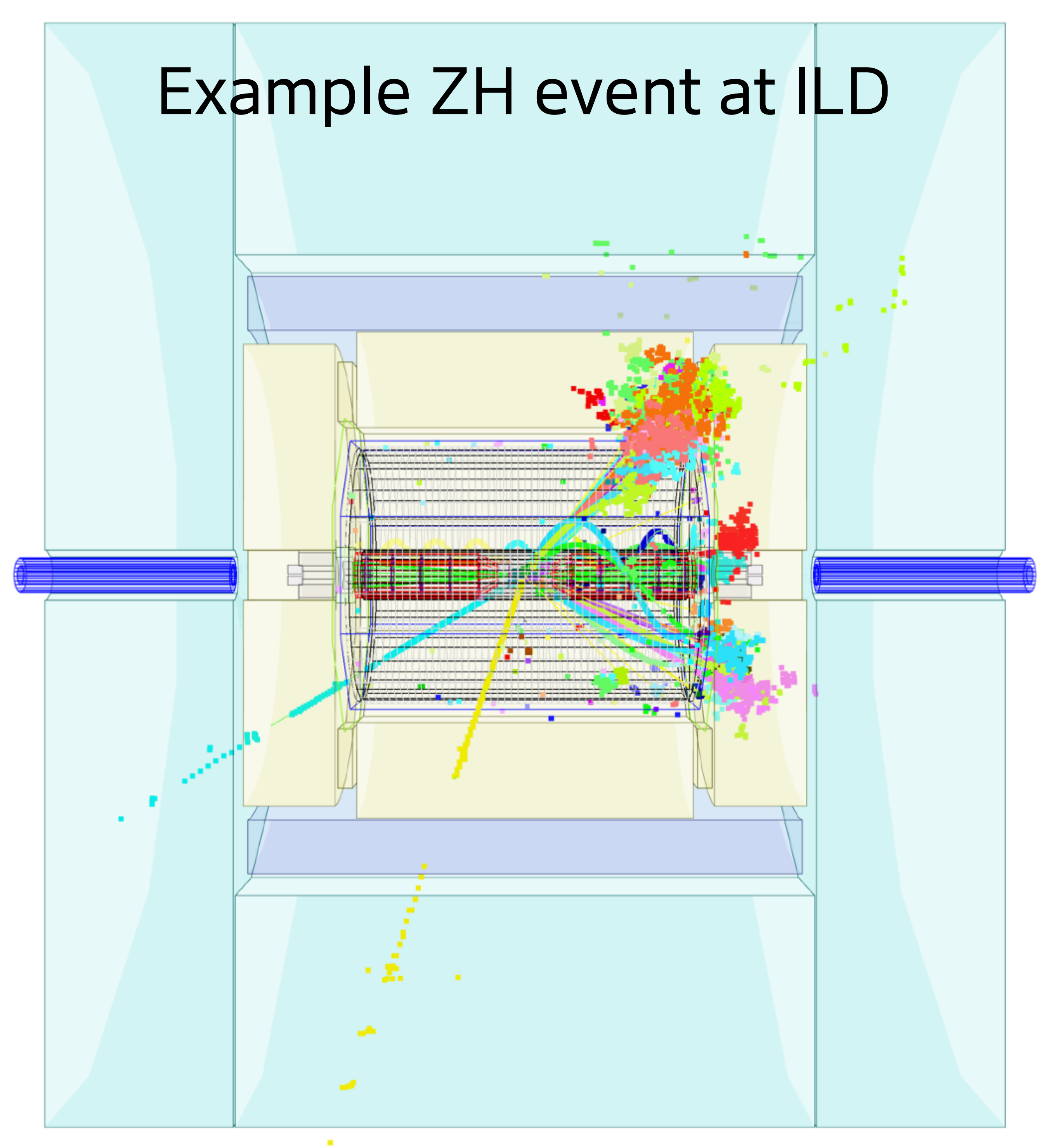
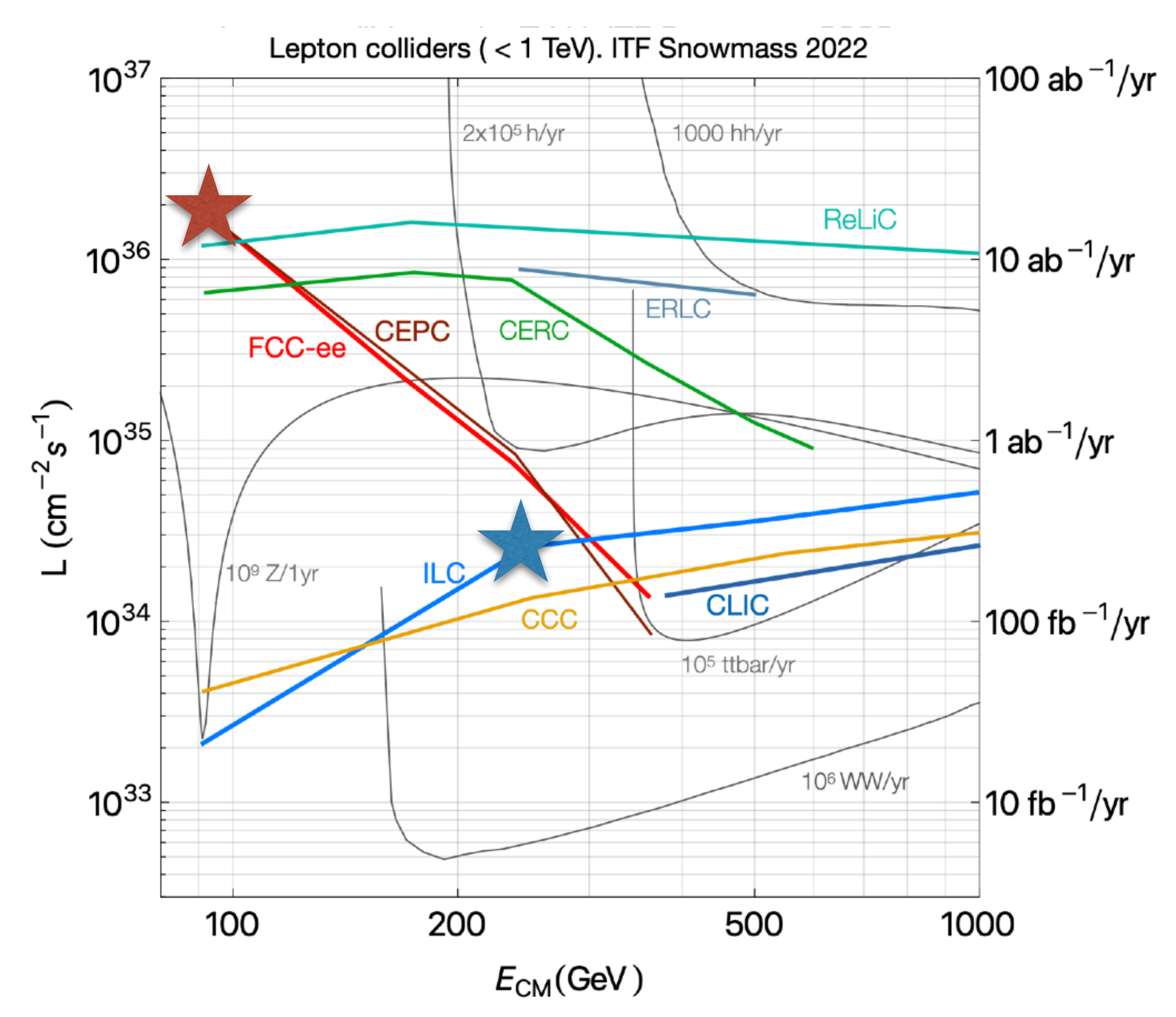
- **ILD at circular colliders requires non-trivial adjustments**.
  - **Continuous running** forbids power-pulsing operation => need for heavier **cooling**
    - => more material, in an already-packed detector.
  - MDI implies major **layout changes**: LumiCAL and forward detectors.
  - **Main challenge from the tracking**: TPC lives at the limits, particularly at the Z peak.
    - Beam-strahlung background leading to large ion back-flow.
  - However **no definitive show-stopper**, with people working on solutions!

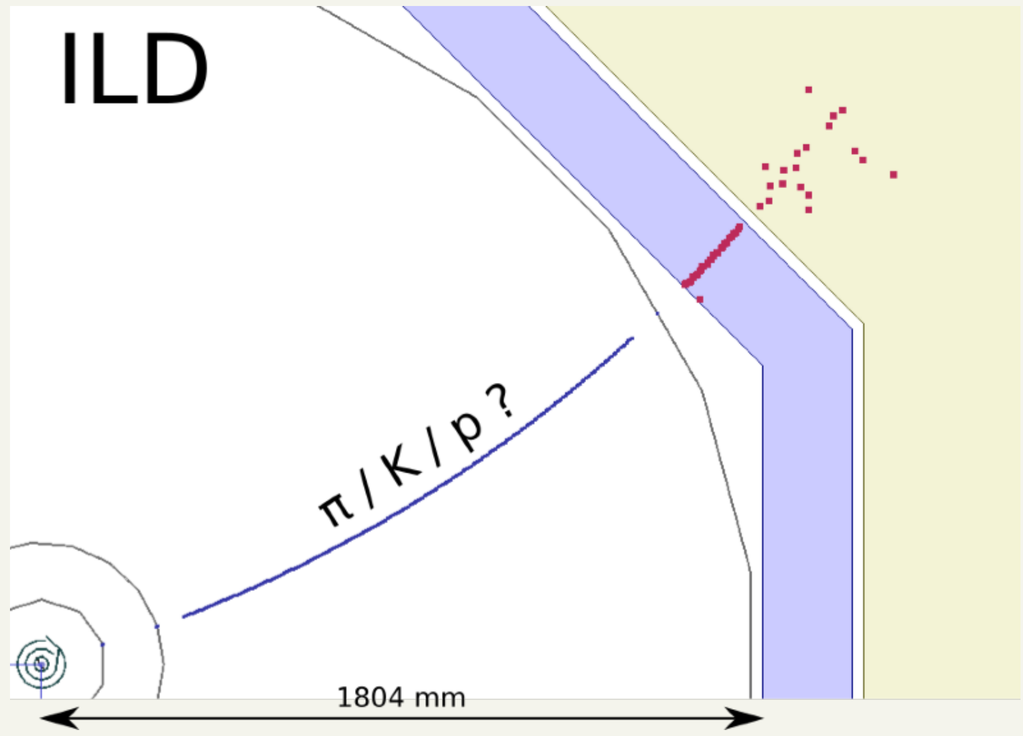


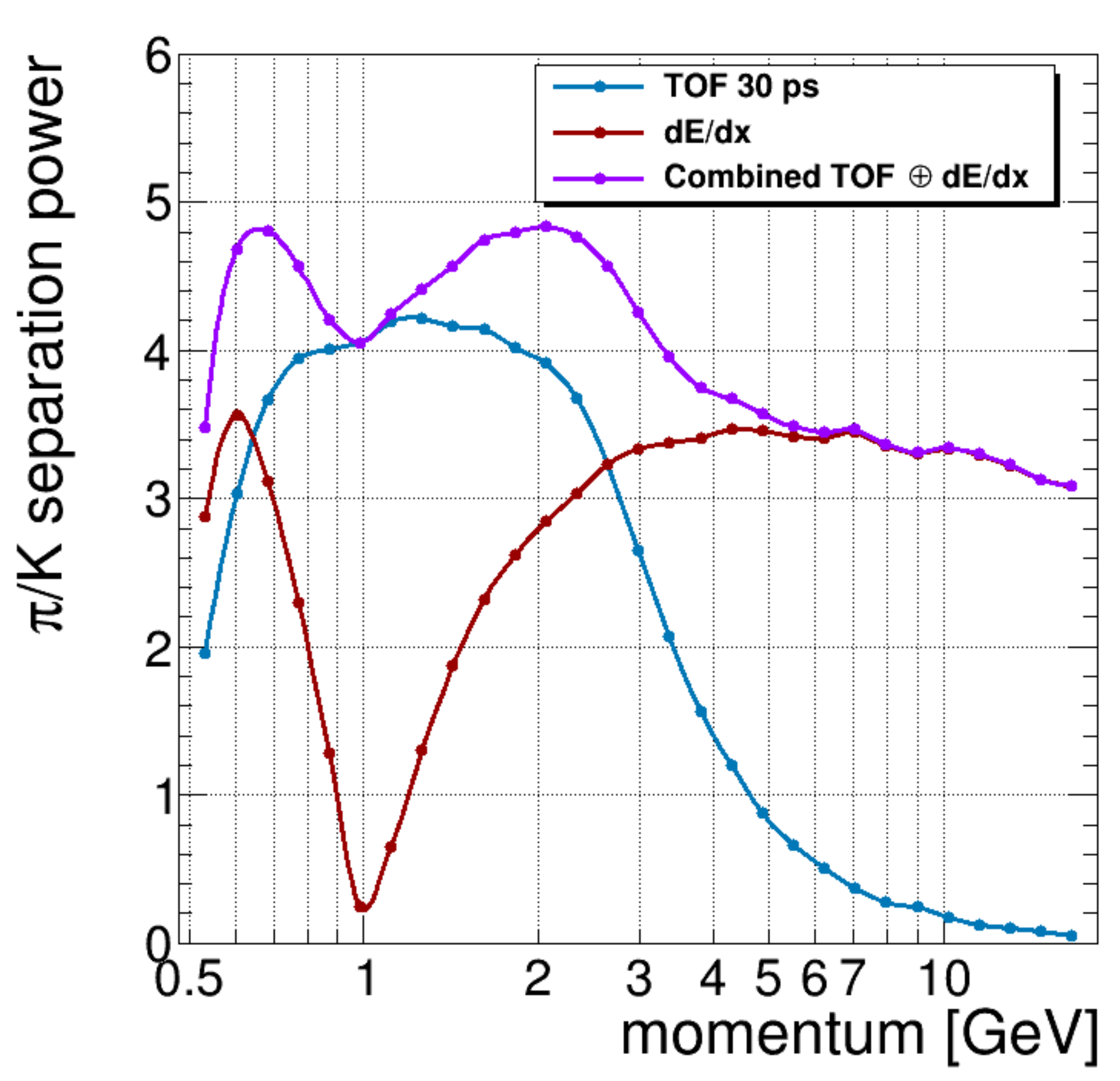


Thanks for your attention!

Questions?

Particle ID improvements



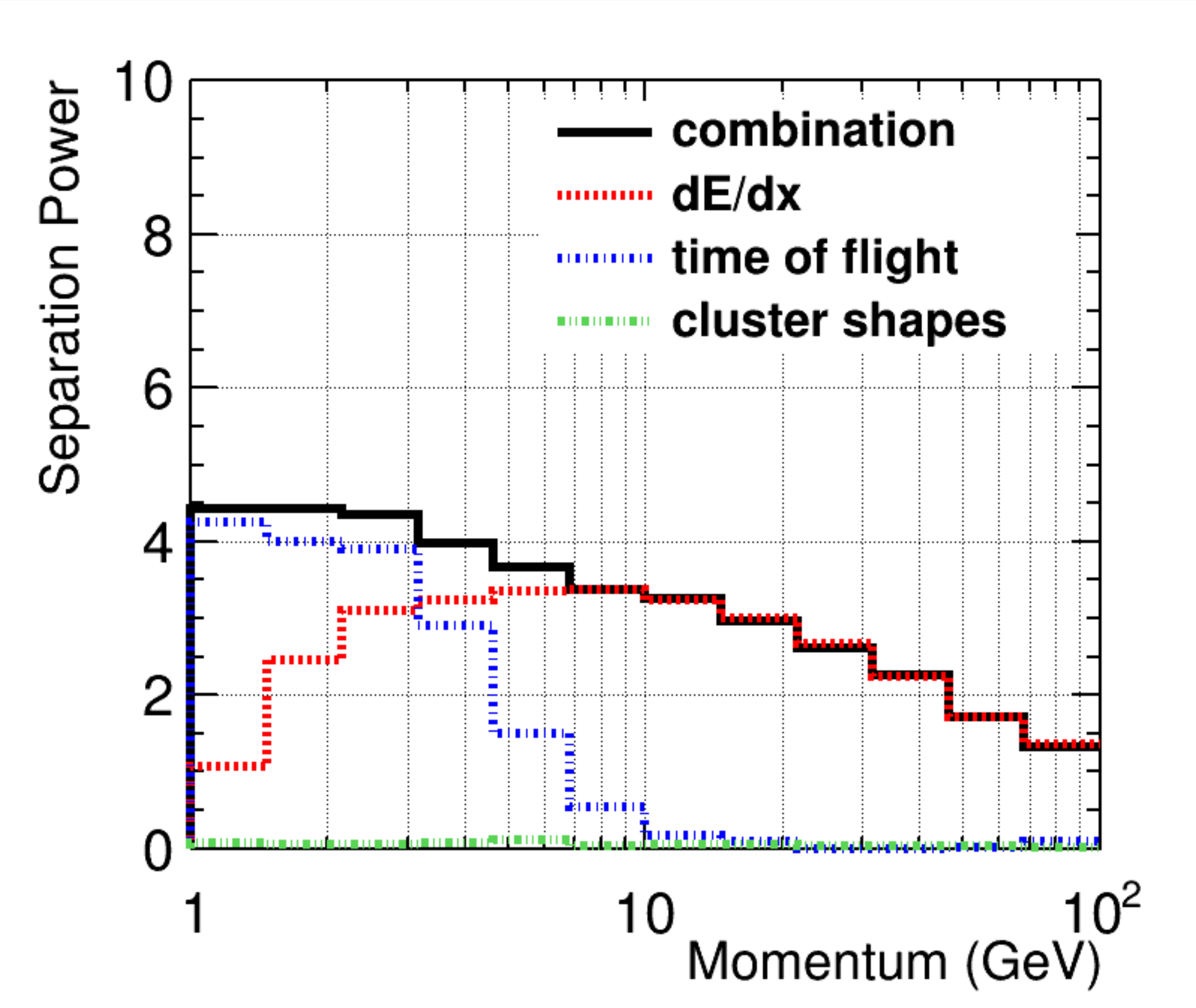


- **PID at ILD**:
  - **energy loss** (dE/dx) from the TPC
  - **cluster shape** from particle flow
  - **Time-of-Flight** (ToF)
- ToF can be improved by using timing information from the ECAL.
  - Improved track length measurement in the TPC.

Bohdan Dudar @ EPS'23

- **Combine all methods using BDT**!
  - => Comprehensive PID framework

Ulrich Einhaus @ ILD Workshop 2024



See also: talk by Taikan Suehara this morning.

Software

See earlier talk by Swathi Sasikumar

- Common software stack: Key4HEP
  - iLCSoft, FCC-SW, CEPC-SW…
  - Detector models included (DD4hep)
    - multiple variations of ILC, CLIC-det, CLD, CEPC-ILD
  - Generators
  - Reconstruction algorithm (eg. Pandora, ACTS)
  - …