Towards ILD geometry and reconstruction adaptation for FCC-ee Tera-Z

A. Irles, **IFIC, CSIC-UV**







- Disclaimer, this is a propaganda talk



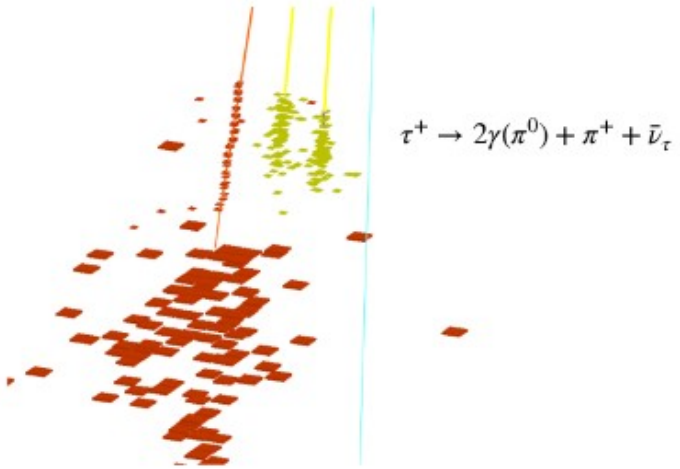


ILD

FUTURE CIRCULAR COLLIDER

e+e- → Z → tau+tau-

Decay channels

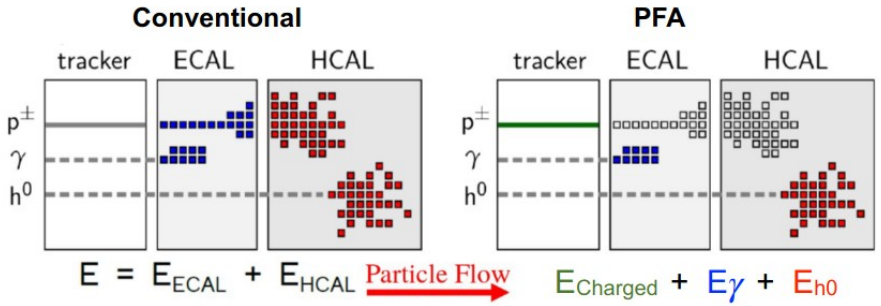


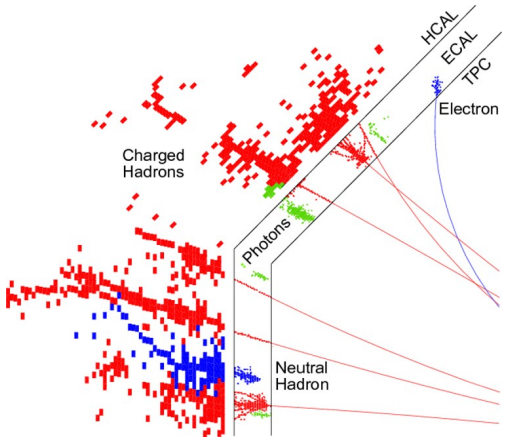
- The tau is interesting enough (see next talk) and rich enough in is topology to be a perfect candidate for detector benchmark.
  - Perfect testbench to try new geometries, new algorithms, new implementations.

Decay del τ^-	BR aprox.	Partículas finales visibles
$\pi^-\pi^0\nu_\tau$	25.49%	$\pi^- + 2\gamma$
$e^-\bar{\nu}_e\nu_\tau$	17.85%	e^-
$\mu^-\bar{\nu}_\mu\nu_\tau$	17.37%	μ^-
$\pi^-\nu_\tau$	10.82%	π^-
$\pi^-2\pi^0\nu_\tau$	9.26%	$\pi^- + 4\gamma$
$\pi^-\pi^+\pi^-\nu_\tau$	8.99%	$\pi^-\pi^+\pi^-$
$\pi^-\pi^+\pi^-\pi^0\nu_\tau$	4.49%	$\pi^-\pi^+\pi^- + 2\gamma$
$\pi^-3\pi^0\nu_\tau$	1.04%	$\pi^- + 6\gamma$
$\pi^-K^0\nu_\tau$	0.838%	$\pi^- + K^0_S/K^0_L$
$K^-\nu_\tau$	0.697%	K^-
$K^-\pi^0\nu_\tau$	0.433%	$K^- + 2\gamma$
$\pi^-K^0\pi^0\nu_\tau$	0.382%	$\pi^- + K^0_S/K^0_L + 2\gamma$
$K^-\pi^+\pi^-\nu_\tau$	0.293%	$K^-\pi^+\pi^-$
$\pi^-K^0K^0\nu_\tau$	0.155%	$\pi^- + 2K^0_{S/L}$
$K^-K^0\pi^0\nu_\tau$	0.150%	$K^- + K^0_S/K^0_L + 2\gamma$

At least ~4$ of events have a kaon in the final state

Particle Flow detector





Aim: perform single particle reconstruction and use the best information in our detector estimate the energy

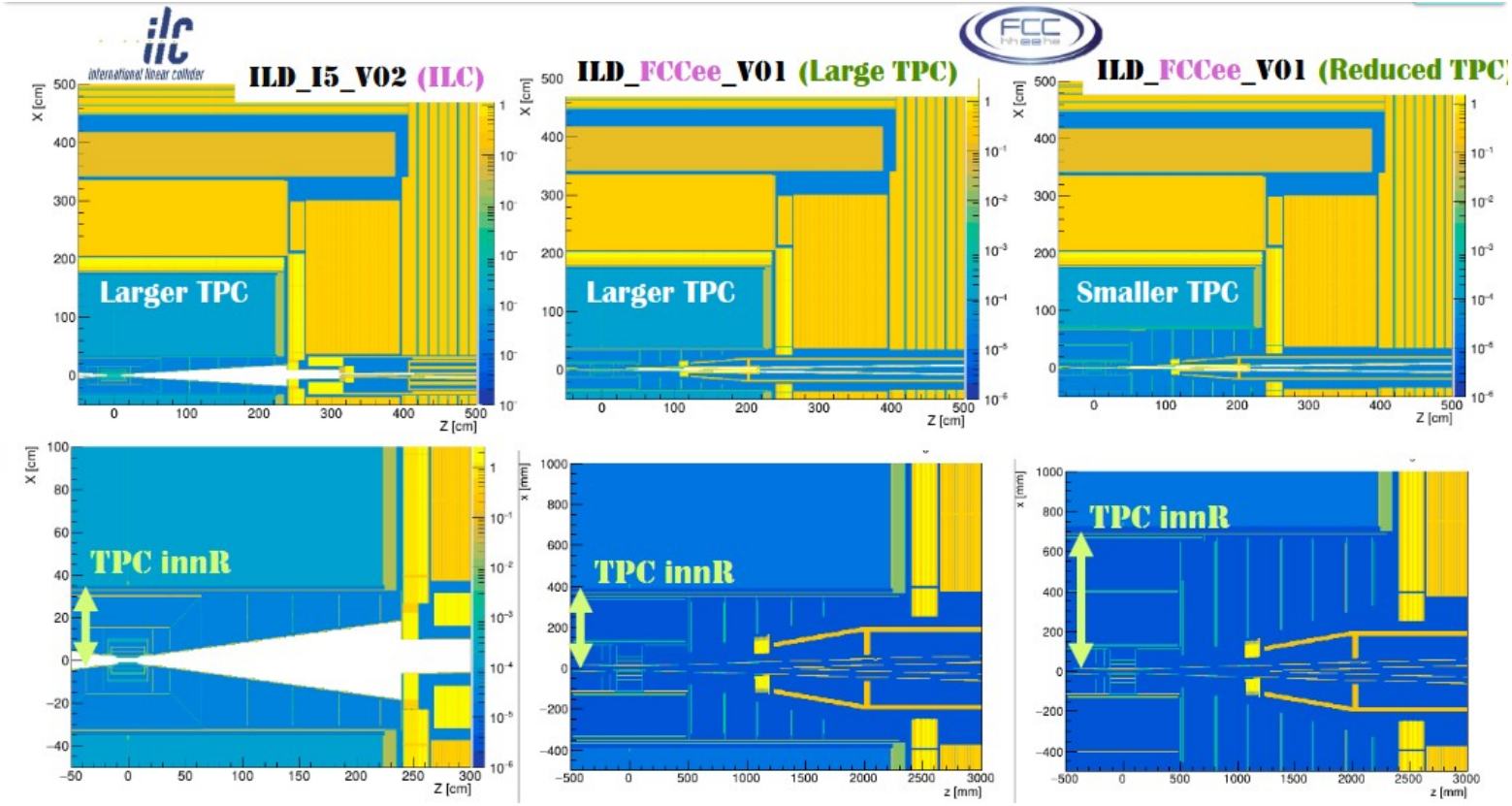
Example: jet created by a proton
"traditional" detector : $(\Delta E)^2 \sim (\Delta E_{ECAL})^2 + (\Delta E_{HCAL})^2$
Particle Flow detector: $\Delta E \sim \Delta E_{track}$

Full detector design oriented to Particle Flow

- **Transparent trackers with PID capabilities**
- **Low material budget and power consumption**
  - Power pulsing electronics
- **Fully embedded electronics**
- **Highly granular and ultra-compact calorimeters**
  - Located inside the coil

ILD design – adapted geometry/layout for FCC

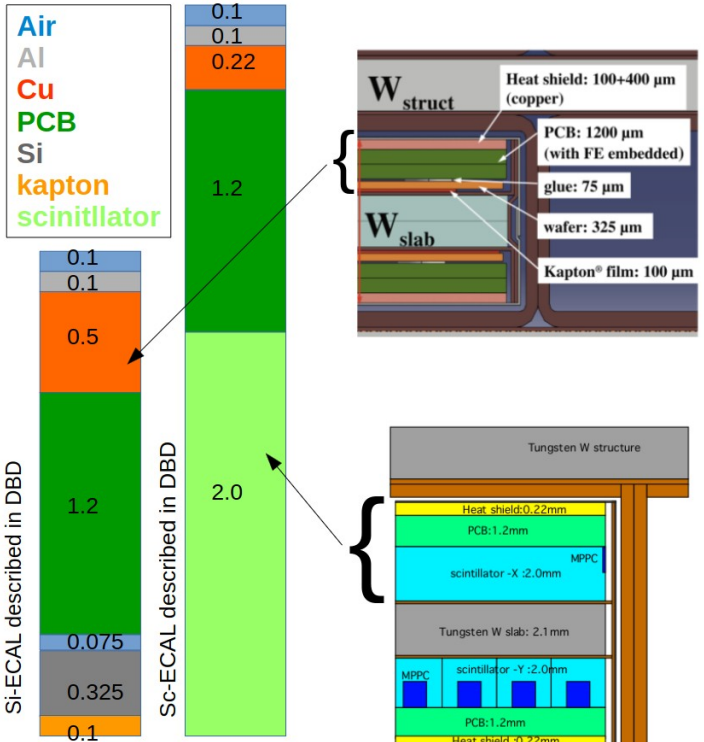
ILD has been optimized (pre-TDR-like documents included) for 250GeV-1TeV.
Intensive campaigns of full simulation studies.



TPC innR=
TPC Inner Radious

Beamstrahlung background decreases with increasing radius.

“Dual simulated” calorimetry



DBD design

2 technological options

Si-ECAL:
service thickness =
2.075 mm/layer

(“service thickness” =
everything that is
not active and
not structural)

Sc-ECAL:
service thickness =
1.62 mm/layer

- All options are included in the default simulation of ILD.
- The reconstruction software uses “your favourite”

ILD contemplates, atm, different technologies for the calos:

- **ECAL -**
  - SiW-ECAL (si pads)
  - ScW-ECAL (sc strips read by single SiPMs)
- **HCAL**
  - AHCAL (Sc tiles readoyut by single SiPMs)
  - Gas RPC semidigital calo

- With Timing/Granularity/etc at different levels of integration in the simulation.

Strategic activities

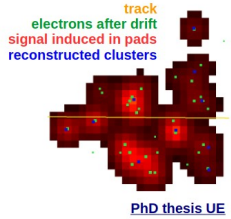
- Software activities are crucial to enable full simulation, validated tracking / calorimetry / PID & Particle Flow / novel AI algorithms.
  - Longstanding expertise for ILC, with full simulation studies https://arxiv.org/abs/2003.01116 + >100 reports/publications (a sample)
  - Adaptation to new conditions (key4hep environment and FCC-TeraZ conditions) is ongoing. to key4hep is ongoing. (See next slide)
- MDI integration. Coordinated by FCC-PED,
  - Understanding the backgrounds (ILD was one of the first addressing this issue)
  - Understanding the geometry, space for services, requirements for LumiCals, etc
  - Can the TPC & trackers cope with it (keeping the high timing/resolution; low power; low material requirements?)

Software and reco activities

- More info here – ILD Meeting, Sept 2026 at CERN
  https://agenda.linearcollider.org/event/11033/contributions/59587/attachments/41058/65494/2026_09_14_ILD_Meeting.pdf

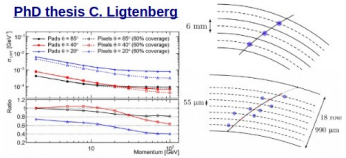
Digitisation - Time Projection Chamber - more detailed implementations

- MarlinTPC by LCTPC
  - individual electrons undergoing drift, amplification and electronics shaping
  - used for detailed simulation and understanding of test beam setups as well as high granularity
  - completely outdated, not part of iLCSoft stack anymore (e.g. still using gear) let alone key4hep stack
- PixelTPC study by C. Ligtenberg
  - full detector simulation with reduced row height (55µm, 990µm)
  - ~ 100 times more compute, still no geant boundaries in phi, unclear if doable for MC productions



PhD thesis UE

PhD thesis C. Ligtenberg



Digitisation – Calorimeter and Muon System

- SiWECal, ScECal and AHCal, all based on `RealisticCaloDigi` and `-Reco`
  - summation of energy contributions deposited in sensitive volume
  - including time window, electronics shaper, noise and SiPM saturation correction
  - detailed timing (first contribution above threshold) available but not used
- SDHCal: `SimDigital`, `SimDigitalToEnergy`
  - ?
- FCal: `SimpleFCalDigi`
  - simple calibrated copy from SimHits, no energy smearing, no electronics, no timing
- Muon system: `DDSimpleMuonDigi`
  - simple calibrated copy from SimHits, no energy smearing, no electronics, detailed timing
- Calo digis live in **`MarlinReco`**, muon digi in **`DDMarlinPandora`**

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Reconstruction - Tracking

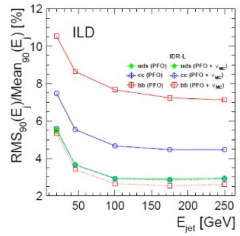
- Old approach, i.e. including with ILD@ILC models in **`ILDReconstruction.py`**:
  - **`Clupatra`** for TPC hits
  - **`SiliconTracking_MarlinTrk`** and **`ForwardTracking`** for Si hits
  - **`FullLDCTracking_MarlinTrk`** for combination → highly tailored to ILD@ILC, not suitable for ILD@FCC adaptation
- New approach 1:
  - **`Clupatra`** with TPC and Si hits; extrapolating TPC to Si, i.e. no merging necessary
  - experimental; needs 3 TPC hits, no coverage below 9° forward
- New approach 2:
  - **`Clupatra`** for TPC hits
  - **`ConformalTracking`** for Si hits
  - Dedicated **`TrackMerger`** to merge → provides 'greedy' and 'ambitious' options for merging; still needs calibration
- Details in talks by V. Schwan in SW/Ana meeting and tomorrow

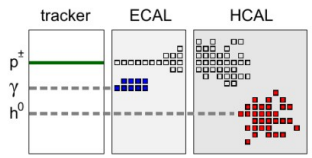
Reconstruction – Particle Flow

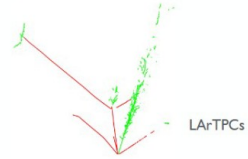
- Pandora is the standard 'conservative' PFlow algorithm
  - works well for ILD@ILC, needs re-calibration for other detectors and ILD@FCC
  - large framework, not easy to adapt or add new approaches
  - currently mostly maintained in LAr TPC community → need active involvement of FC people, but great possibilities to modernise and include ML algorithms, as per J. Marshall



Fine-granularity detectors at future colliders





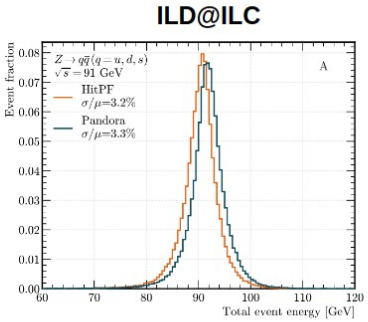


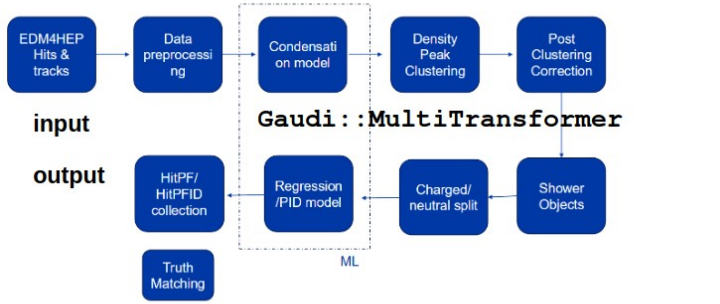
Software and reco activities

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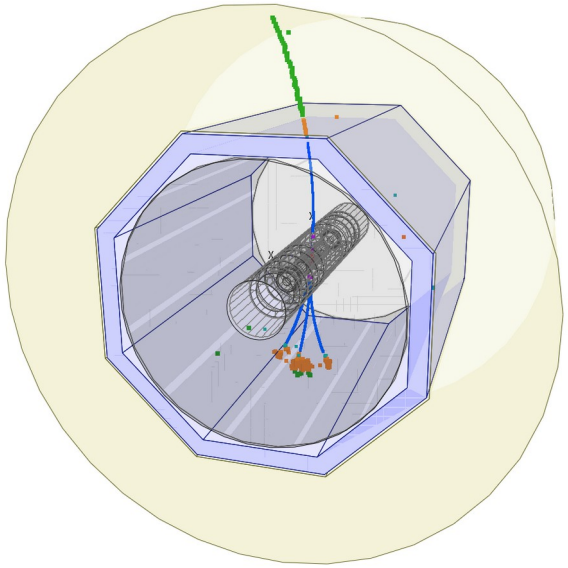
Reconstruction – Particle Flow

- Current focus in PFlow is on (full) ML approaches, see talk by B. Dudar for details
  - several setups/approaches, no clear 'winner' yet
  - common infrastructure and coherence between approaches under development
  - mostly outside key4hep so far, using samples only as input after conversion
  - recent work by L. Herrmann towards implementing `k4PFHitML` inference in CLD reco chain

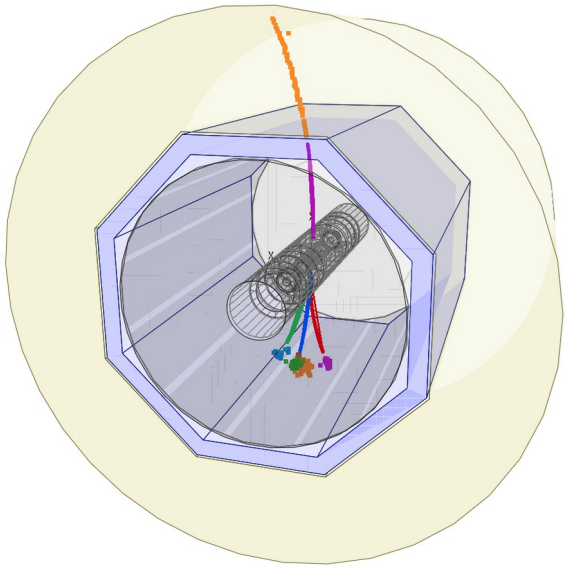




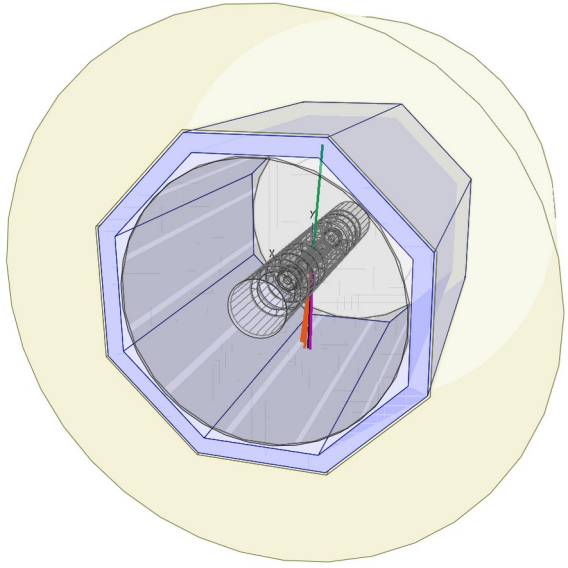
Event displays



hits

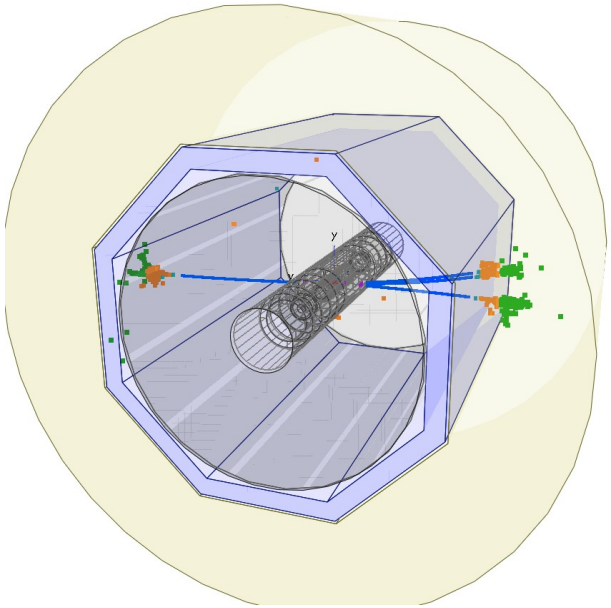


tracks/clusters

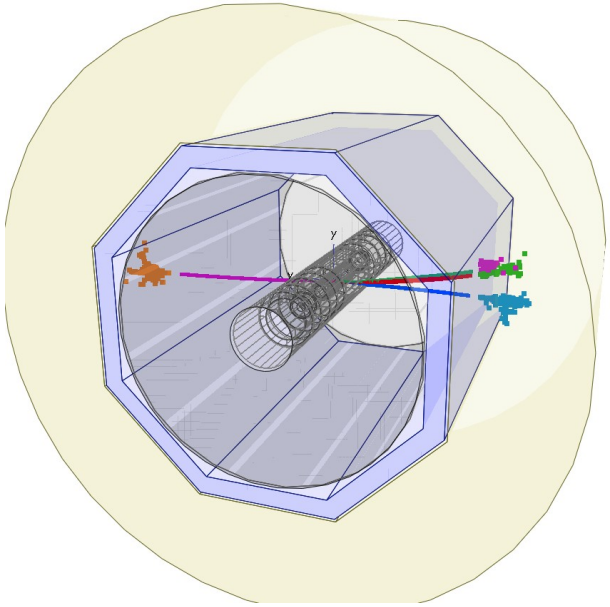


PFOs

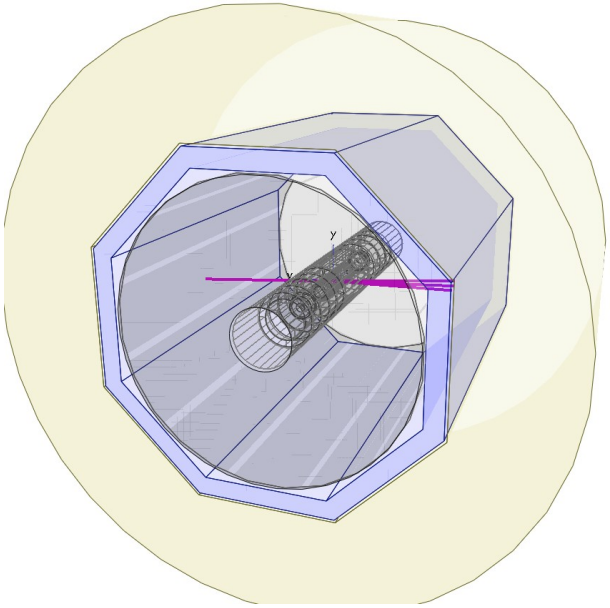
event displays



hits

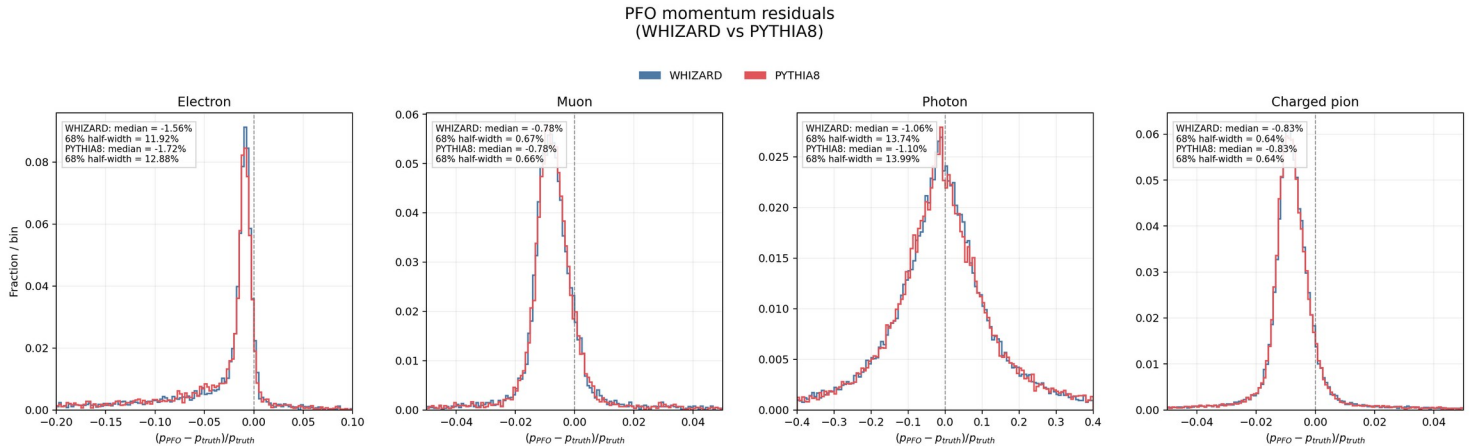


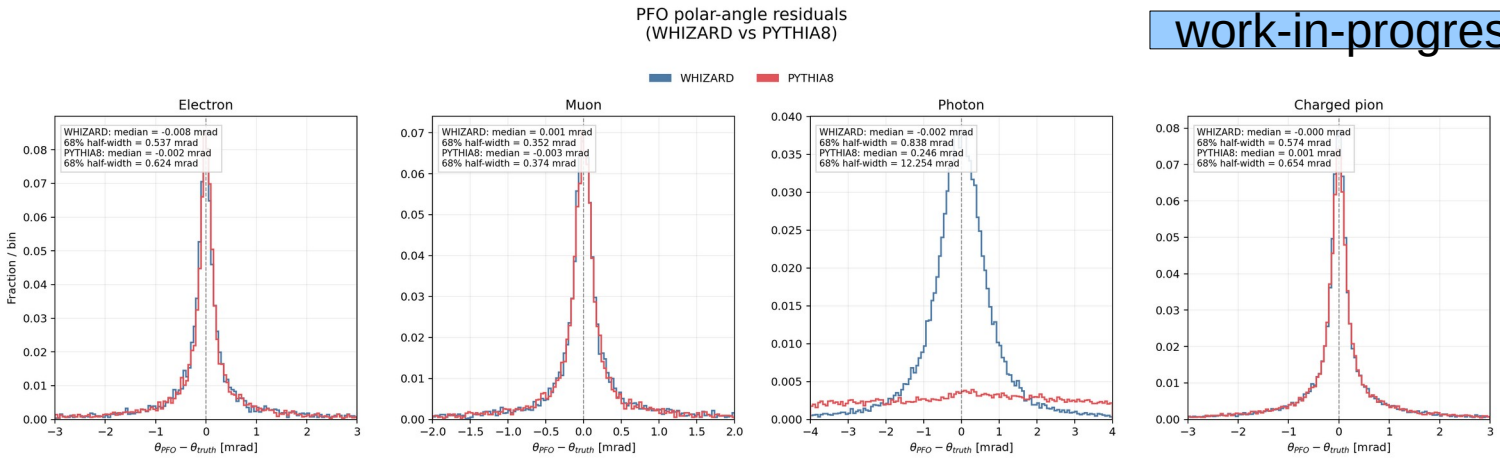
tracks/clusters



PFOs

Basic reco

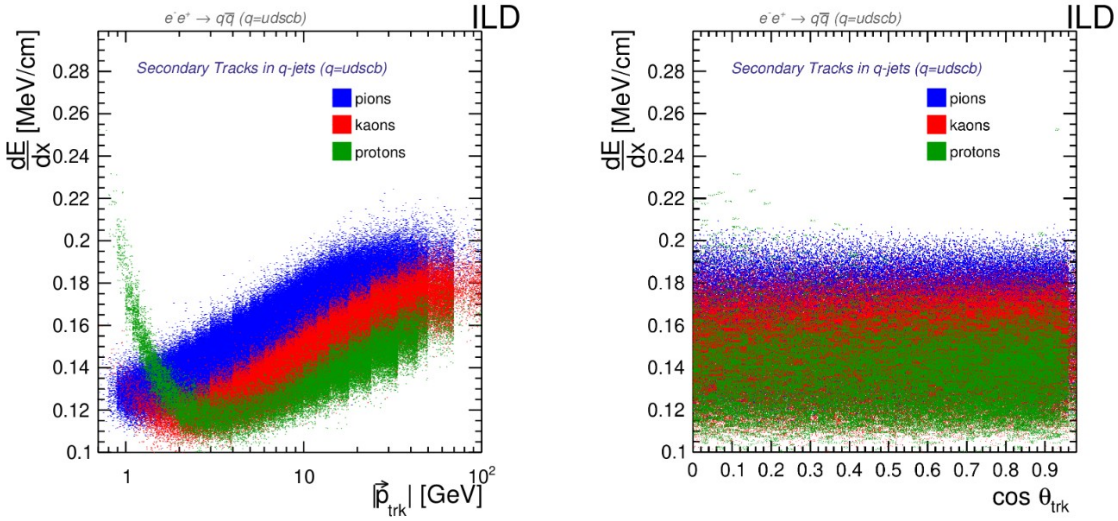


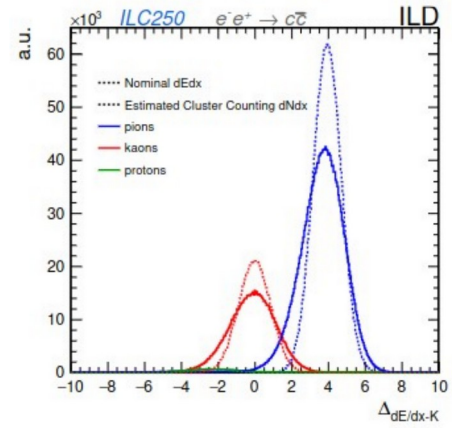


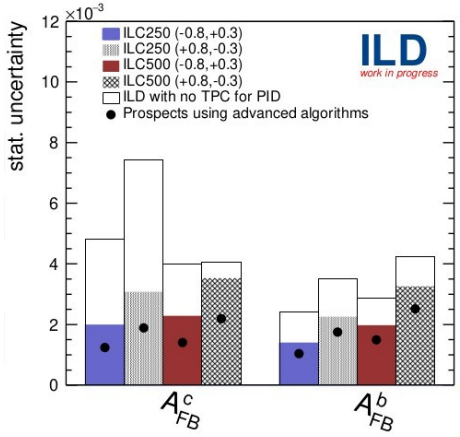
work-in-progress

"trial" reco version. **Not ready for physics discussions**

Charged pi/k separation







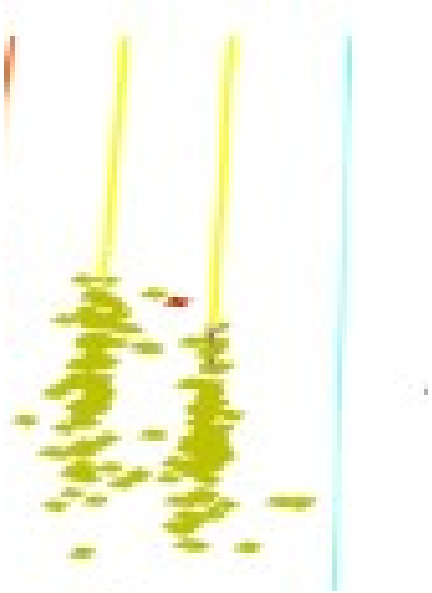
- The TPC faces several challenges to run at the TeraZ run.
- However, it provides unique kaon/pion/proton separation capabilities
  - Flavour physics
  - strange/charm/beauty physics (flavour and EW)
  - tau

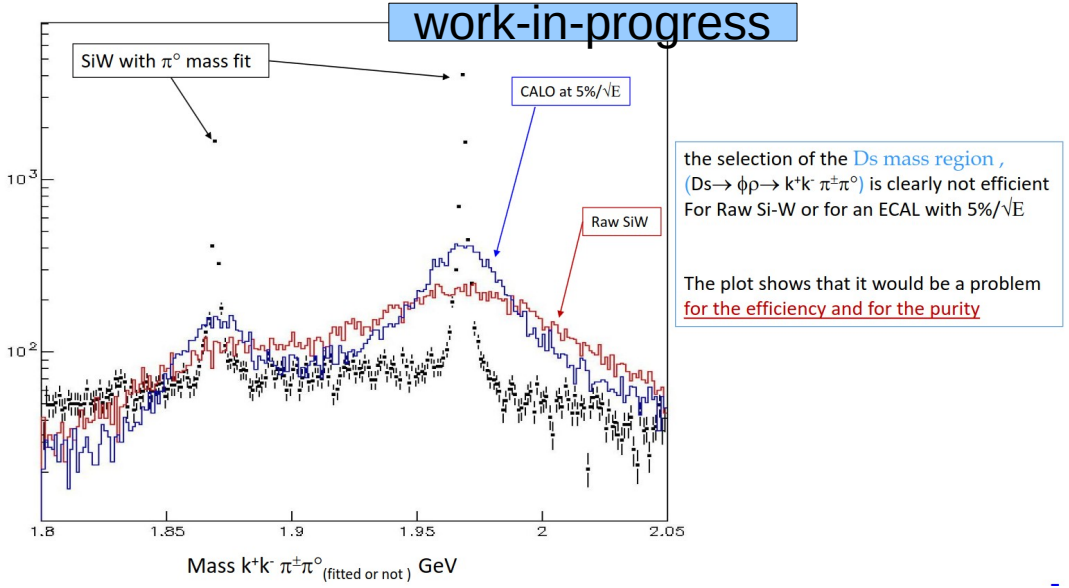
Eur.Phys.J.C 84 (2024) 5, 537

pi0 reconstruction – photon reconstruction

For high precision tau-physics:

Key factors are the efficiency and purity of the photon(s) reconstructed samples at both very low and very high π0 energies





Eur.Phys.J.Plus 141 (2026) 6, 697

Join the effort

- **Are you working in any of the sub-detector technologies and would like to optimize the detector layout and study physics performance?**
  - Whichever your detector is, it will be used for tau/tau reconstruction
  - ILD is open to technologies / ideas.





- **Are you working in software/computing/algorithms**
  - Particle Flow with IA ?
  - Pi0 / photon separation beyond kinematic fits ?
  - …

- **Contact the ILD** team or your favorite **FCC-PED working group** (see Michele's talk yesterday for all the links) or any of the Detector Concepts
  - The flavor of the detector concept will not change the impact of your contribution

backup

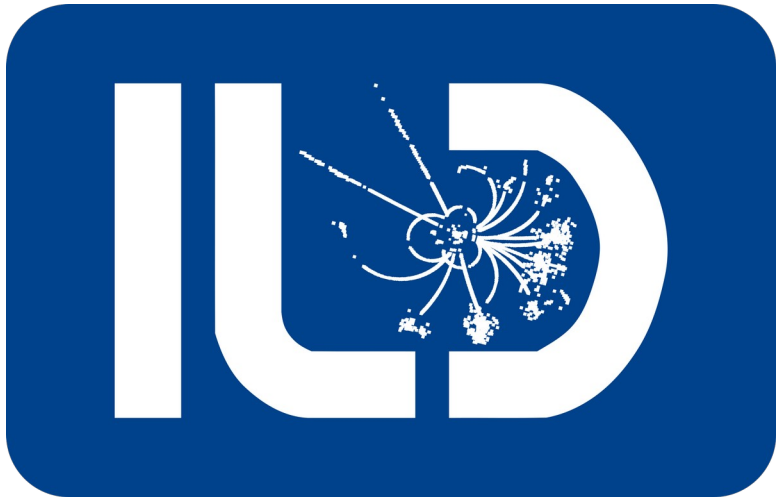
ILD Concept Group



ILD Concept Group – spanish institutes

- **6 institutes, 33 members**

- **CIEMAT – 5 members**
  - Contact: **MC. Fouz → Spokesperson**
- **IFCA – 7 members**
  - Contact A. Ruiz
- **IFIC – 9 members**
  - Contact: **A. Irles → Collaboration Board Chair**
- **IMB-CNM – 2 members**
  - Contact G. Pellegrini
- **ITA – 6 members**
  - Contact F. Arteche
- **UB – 4 members**
  - Contact A. Diequez





ILD Concept Group – for e+e-

https://indico.cern.ch/event/1439855/contributions/6461486/attachments/3045859/5381786/The_ILD_Detector%20submitted.pdf

The ILD Detector: a Versatile Detector for an Electron-Positron Collider at Energies up to 1 TeV

The ILD Concept Group
Contact: T. Behnke, Deutsches Elektronen Synchroton, DESY
(Dated: March 29, 2025)

The International Large Detector, ILD, is a detector concept for an experiment at a future high energy lepton collider. The detector has been optimised for precision physics in a range of energies from 90 GeV to about 1 TeV. ILD features a high precision, large volume combined silicon and gaseous tracking system, together with a high granularity calorimeter, all inside a central solenoidal magnetic field. The paradigm of particle flow has been the guiding principle of the design of ILD. ILD is based mostly on technologies which have been demonstrated by extensive research and test programs. The ILD concept is proposed both for linear and circular lepton collider, be it at CERN or elsewhere. The concept has been developed by a group of nearly 60 institutes from around the world, and offers a well developed and powerful environment for science and technology studies at lepton colliders. In this document, the required performance of the detector, the proposed implementation and the readiness of the different technologies needed for the implementation are discussed.