CALICE for FCC-ee

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Particle Flow Approach

Full Reconstruction of single particles

- Charged measured mostly from trackers
- Neutrals only measured from calorimeters

➡ **Large Tracker**

- Precision and low X_0 budget
- Pattern recognition

➡ **High precision on Si trackers**

- Tagging of beauty and charm

Large acceptance

➡ **Highly Granular Imaging Calorimetry**

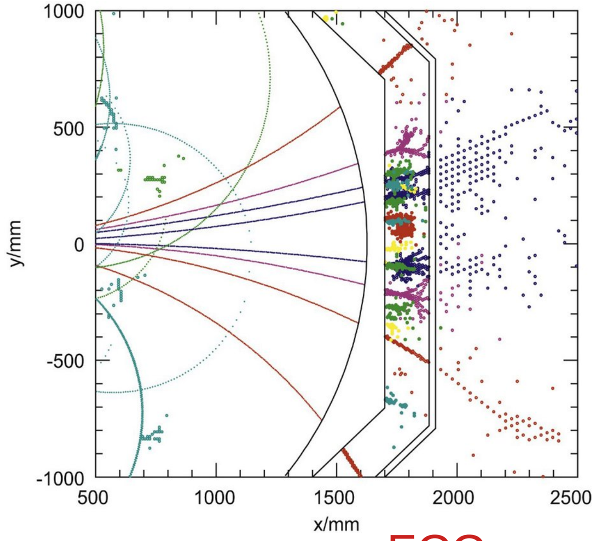
Particle Flow Algorithms :

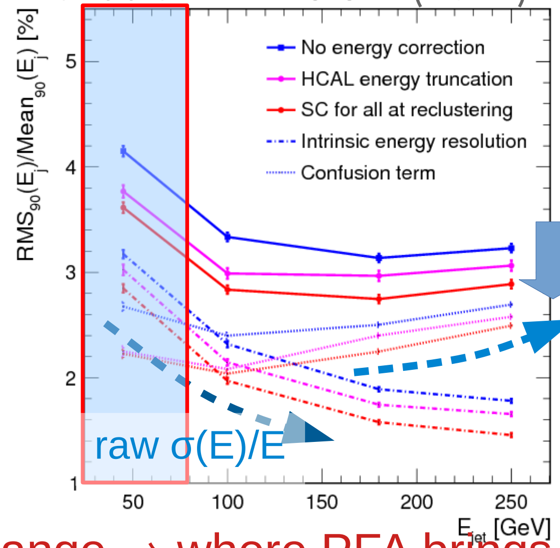
- Jets = 65% charged Tracks + 25% γ ECAL + 10% h^0 E+HCAL
- TPC $\delta p/p \sim 5 \cdot 10^{-5}$; VTX $\sigma_{x,y,z} \sim 10$ µm

+ timing

H. Videau and J. C. Brient, “Calorimetry optimised for jets,” (CALOR 2002)

Pandora PFA: EPJ C77 (2017) 10, 698





Software Weigthing

Confusion (cluster misattrib, merging)

FCC–ee range ⇒ where PFA brings most

What is a 'CALICE' calorimeter ?

1) It is not a single calorimeter

- Calorimetric system : **ECAL+HCAL** + (X_0-thin) High Performance Trackers

  complementary and well associated → small distance (NO MAGNET on the way)

2) Optimised for Particle Flow

- NOT the best calorimeter system (= Best Raw Energy measurement of single part.)
- Measurement and Identification of all particles ⊃ (especially) in jets, τ's, …

  best Boson mass measurement $H \to ZZ, WW; Z, W \to jj$.

  $\Delta(M_Z, M_W) \Rightarrow \sigma(E_j)/E_j \sim 30\%/\sqrt{E} \sim 3.5\text{–}5\ \%$

3) CALICE = R&D on detectors (prototypes)

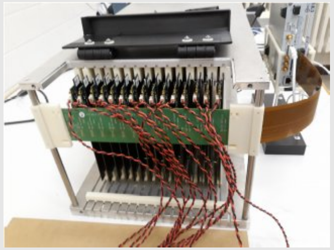
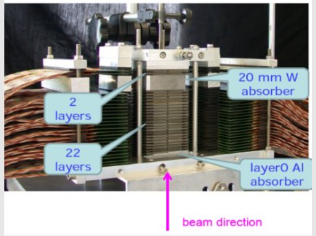
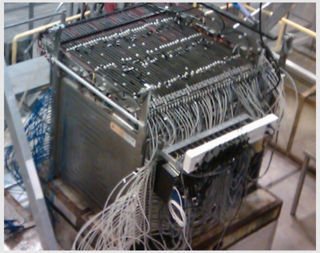
SiD, ILD, CLICdp, CECP$_{\textbf{Baseline}}$ = detector concepts implementing CALICE

physics performances, ⊃ PFA ('physics' prototypes) ⇒ 'technological' prototypes

State of the Art

4,5 prototypes, 15⁺ years of R&D, all [to be] tested

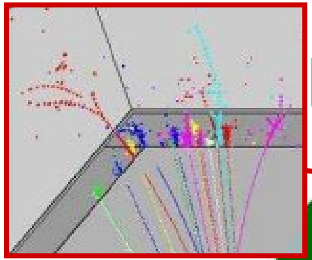
personal opinion, not the collaboration's

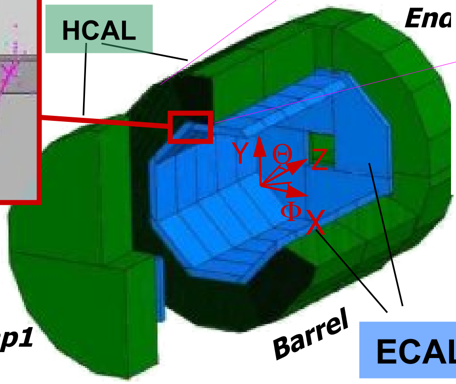
Si-W ECAL	(ALICE FoCAL)	[Scint-W ECAL]	AHCAL	SDHCAL
				
0,5×0,5 cm² ×15 (➞30) Si layers + W	0,003×0,003 cm² × 24 MIMOSA layers + W	0,5×4,5 cm² ×30 Scint+SiPM lay. + SS	3×3 cm² × 38 Scint+SiPM lay. + SS	1×1 cm² × 48 layers GRPC + SS
Resolution – R_M ✔ Intégration ✔ Cost – Calibration ✔	Resolution ✔ R_M ✔✔ Intégration **??** Cost **??** Calibration **?**	Resolution ✔ R_M **?** Intégration ✔ Cost ✔ Calibration –	Resolution ✔ λ ✔ Intégration ✔ Cost ✔ Calibration –	Resolution ✔ λ ✔ Intégration (Gaz) – Cost ✔ Calibration –
LLR, IJCLab, LPNHE, (LPSC) IFIC, Kyushu, KEK, **Ω**	NIKHEF, EMMEΦ, CERN, Bergen, **IPHC**	Shinshu U, U. Tokyo, IHEP (CN), USTC, **Ω**	DESY, HH, MPI, Mainz, Wuppertalm, Heidelberg, IPASCR, Bergen, **Ω**	IP2I, LPC, Ghent,(LAPP) CIEMAT, SJTU, **Ω**

Geometries & Services

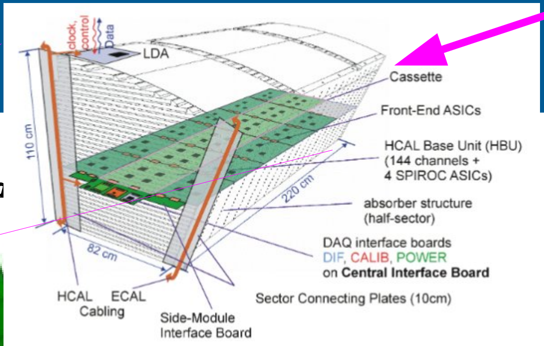
HCAL elec 'accessibilty'

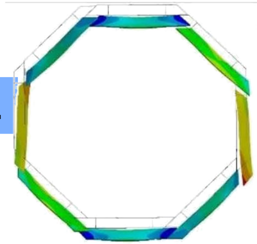
Prism vs diapragm

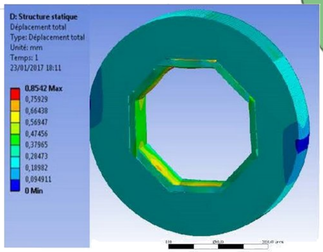


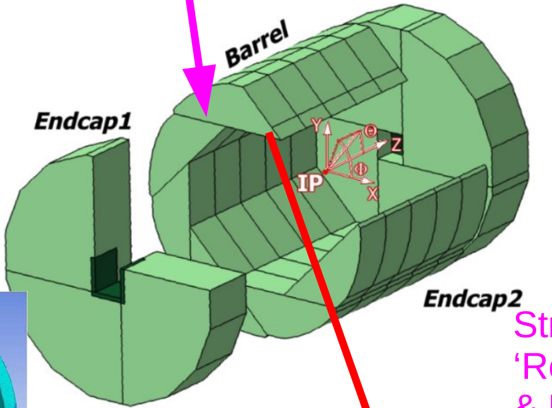


(SiD = 12 fold)

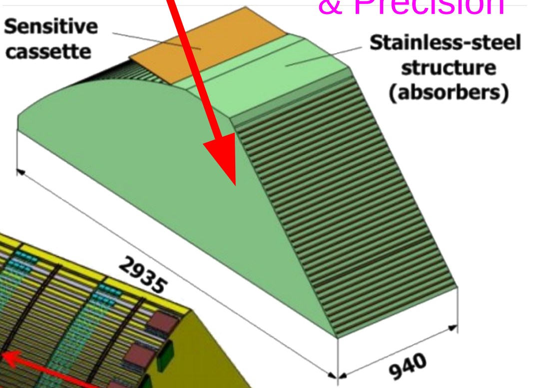


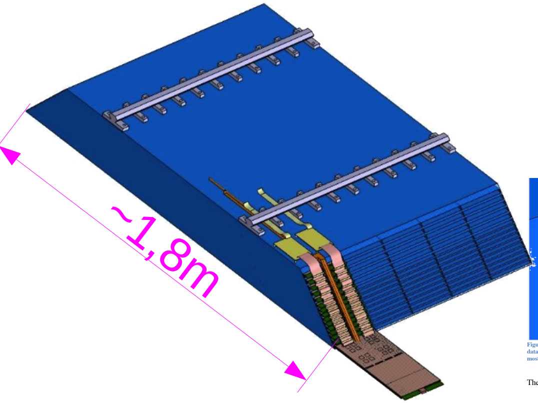






Structural 'Robusteness & Precision'





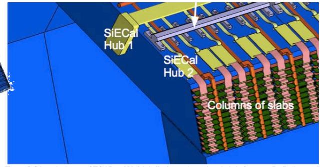
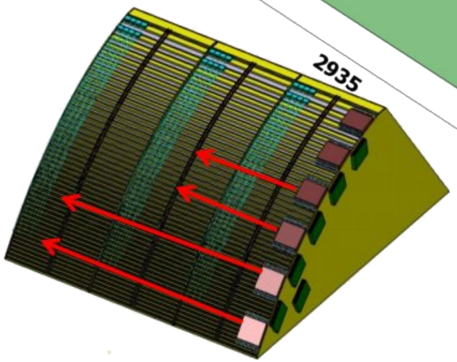


Figure 17: Schematic view onto SiECal Barrel Module indicating services such as the hubs for power distribution as wel data concentration and distribution of readout commands. Note that the size of the hub may still vary (In particule Hub most presumably too small). Shown are also parts of the cooling system that is described below.

The following conventions will be used for the identification of the external hubs:

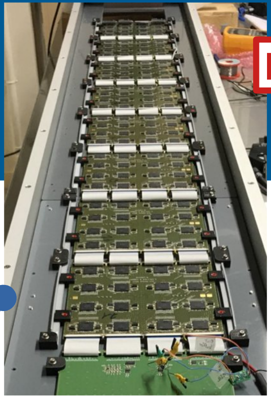
- SiEH1_sn: Here "H1" means that it is an external hub (Concentration Level 1), "s" labels a hub in front of a stave and "n" identifies the stave. In the endcaps the "s" may be replace by a "q"

1.12. Block diagram



Integratrion R&D (France)

LLR + IJCLab

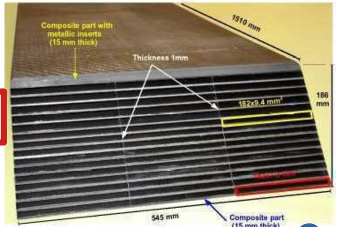


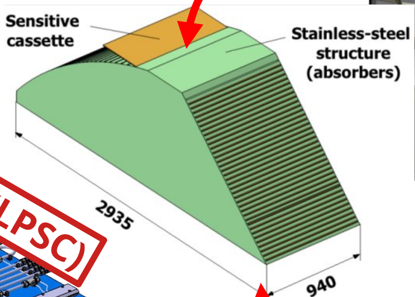
IP2I

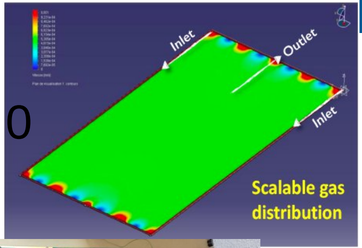
Details in Imad's presentation

Large technological prototypes

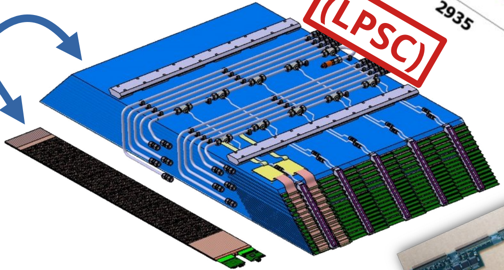
LLR





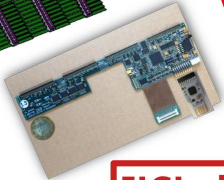


(LPSC)

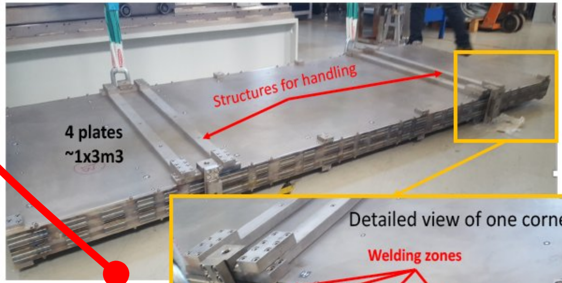


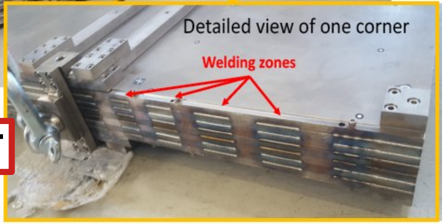
Pilotes (« modules-0 »)

- 3×1m² HCAL's
- 1.5×0.2m² × 3–5 ECAL



IJCLab





CIEMAT

Electron beam welding

Intégration du «timing centimetrique» : 1 cm = 30 ps.

- Bulk ?
- Dedicated layers ?

} Need for detailled studies

Electronics « v3 »

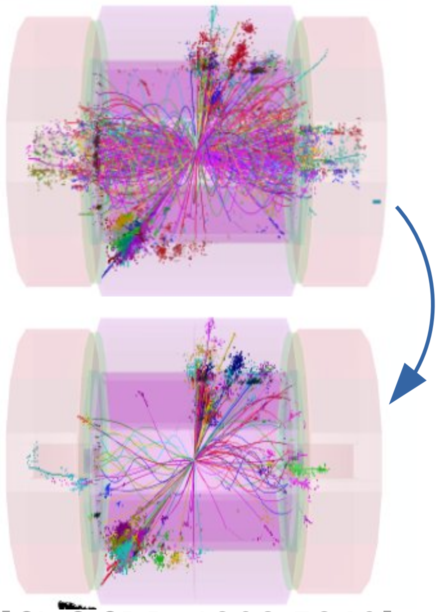
Ωmega

- full 0-suppr, power, timing, nv techno (AMS → TSMC)
- HGCROC → HKROC → ??

Similar efforts for AHCAL

Timing in calorimeters: 0.1–1 ns range

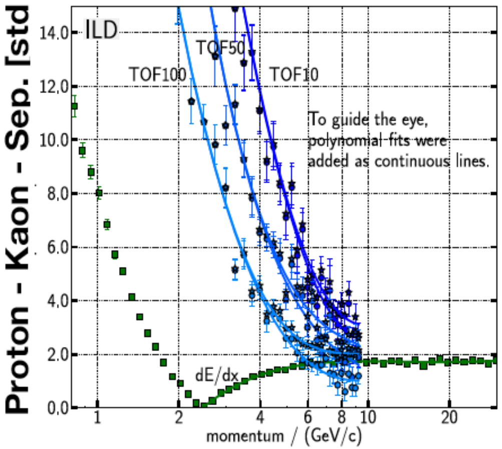
Cleaning of Events



[CLIC CDR: 1202.5940]
adapted from L. Emberger

Particle ID by Time-of-Flight

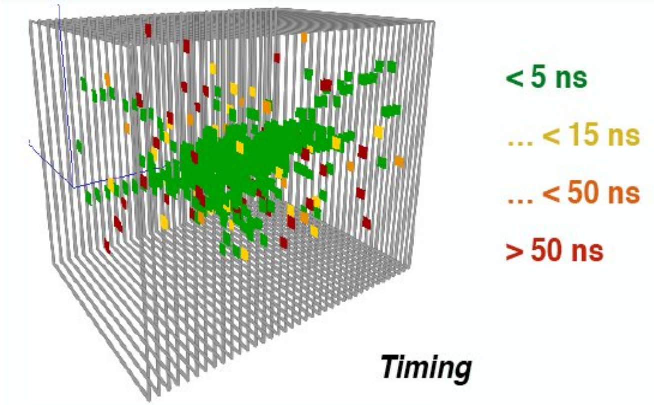
- Complementary to dE/dx
  - here with 100ps on 10 ECAL hits



S. Dharani, U. Einhaus, J. List

Ease Particle Flow:

- Identify primers in showers
- Help against confusion
  better separation of showers
- Cleaning of late neutrons & back scattering.
- Requires 4D clustering



Ch. Graf

Electronics & DAQ

Ωmega ASICs:

- A set of ASICs adapted for all CALICE large scale prototypes
  - Gradual improvement
  - Purely digital DAQ
- suitable for ILC conditions
  - **low power** consumption using **power-pulsing (~1%)**
  - **low noise** pre-amp, dual gain 12-bits ADC, ns TDC
  - **self-trigger** with local storage,
    delayed digitization and read-out
  - **high integration** (36–64 channels), daisy **chaining**

R&D:

- will required update for final integration:

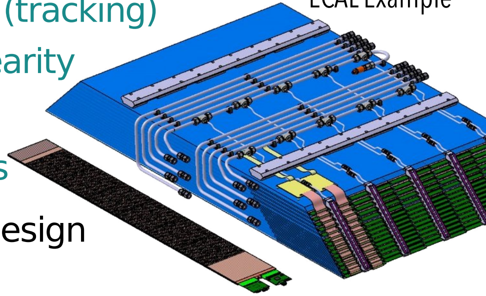
  ~3^{+} years of dev

  - full zero-suppression, I2C bus, new technology
  - Improvement of Timing ? **Learning from CMS-HGCAL ASIC**
- **new scheme needed for circular colliders** (power, readout)
  - **Decision on DAQ Scheme : continous vs triggered ?**

    Central trigger → lower noise requirements, **feasible ?**

Technical requirement on prototypes:

- Integration in cassettes 150 – 300 cm long
- 12k – 27k cells (200–500 ASICs), power pulsed
  - sensitivity to mip signal (tracking)
  - uniformity, stability, linearity
- Reproducibility
  - Typically ~20–50 layers
    - will be ~ 10^4 in final design
- Ex: HGCAL HCAL



DAQ:

- Low power, Small size interfaces
  - ECAL–HCAL = 3 cm, HCAL–Coil or Barrel–Endcap ~ 5-6 cm
- Single side readout

~~**ILC: Pulsed Powering in 2–4T field…**~~

- ~~Passive cooling, local power management~~

Detector Parameters: scaling rules

- Cell lateral size
  - Shower separation (EM~2×cell size)
  - Cell time resolution (1 cm/c ~ 30 ps)
    - Time performance for showers
      - ParticleID, easier reconstruction
- Longitudinal segmentation
  - sampling fraction
    - E resolution (ECAL ~15%/√E)
  - shower separation/start
- ECAL inner radius; Barrel Z_{Start}
- ECAL–HCAL distance
- Barrel–Endcap distance
- Dead-zones sizes (from Mechanics, Cooling)

Number of cells ↗ ⇒ Cost ↗ (1/size²)
Cell density ↗ ⇒ Power consumption ↗
Time resolution ↘ ⇒ Power ↗

threshold, passive vs active cooling
dead-zones ↗

NEED TO BE FULLY RE-EVALUATED for EW region

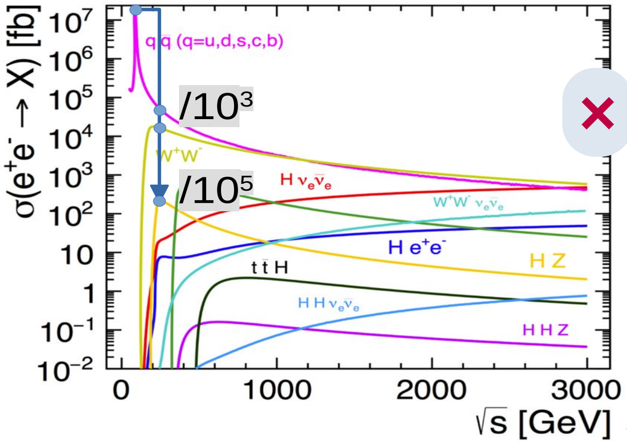
Inner Radius ↗ ⇒ Tracking performance ↗
Cost ↗² (⊃ Magnet, Iron)
Gaps ↗ ⇒ PFlow performances ↘

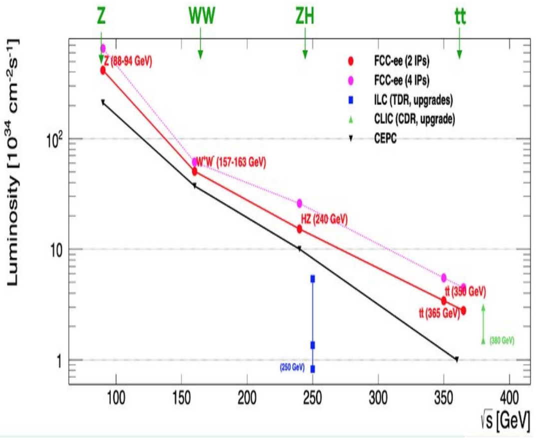
Review of physical implication (from TeV): see Linear collider detector requirements and CLD, F. Simon @ FCC-Now (nov 2020)
Physics Requirement studies @ 250 GeV: see Higgs measurements and others, M. Ruan @ CEPC WS, (nov 2018)

Outlook

CALICE enters a new phase :

- Construction of 1st large HG calorimeter (HGCAL : 6M channels ~ 1/10th of ILD)
- R&D ``final rush'' for ILC (if decided)
  - Construction = ~8 years → 3 years of R&D
  - Still many element to be tought of
    - Final design, pilot's building, industrialisation
    - stability, fiability (MTBF) → redondance
    - Power & Cooling (HL scheme)





FCC-ee :

- Performances (Z peak ≠ WW & Higgs Hill ~10^5 more events)
  - Needed RAW (single particle) resolution E, t → (PID, Reco) → Jets E resolution, Final States identification
- Need to fix parameters & detector philosophy for a large range of conditions → Think large / complementary
  - Technology ↔ Performances : Trigger/DAQ ↔ noise, noise ↔ detection efficiency, cooling ↔ granularity, …
- … but ~ **+5y for R&D for FCC–ee…**
  Time for new technologies: Timing, ML optimisation, other sensors (Crystal, MGRP, ℓAr, DR, …), µ-cooling, projective readout, Digital sensors (dSiPM)

Extras

Validation of prototypes: common goals

⇐ many already achieved with physical prototypes

Scientific goals:

- Energy & Time measurements:
  - Linearity & Resolution to single e, π in 1–200 GeV (⇒ input to jet simulations for PFA)
  - Saturation effects
- 5D Shower profiles
- Particle Flow Algorithm (PFA) tests : shower separation, reconstruction, identification

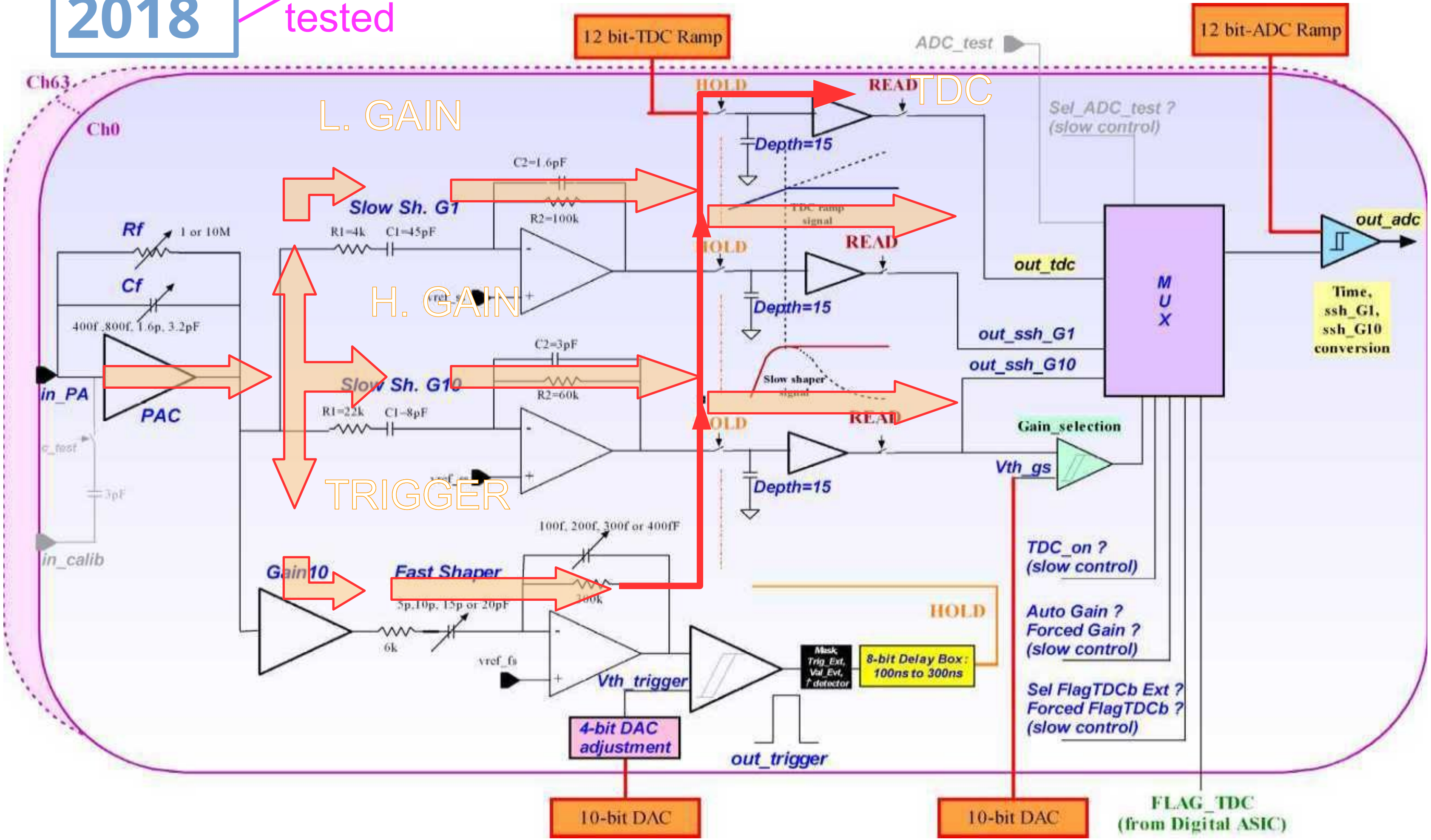
Technical goals:

- Operation of **scalable design** with **power-pulsing**
- **Low-Energy Calibration** with muons **(mips)** position scans, [**High Energy: e, π**]
  - **Signal-to-noise of trigger** (limited memories)
  - **Uniformity**: Efficiency, Mean response (Light Yield, Mip Peak, Multiplicity)
  - Input for **realistic digitization models** ⇒ input to simulation: prototype and Particle Flow
- **Scientific goals (again):** improved granularity, design, etc...
- Running as close as possible to **ILC mode** (200 ns BC), relaxed mode for practical reasons (typ. 4 µs BC)

SKIROC2 / 2A Analogue core

2018

tested



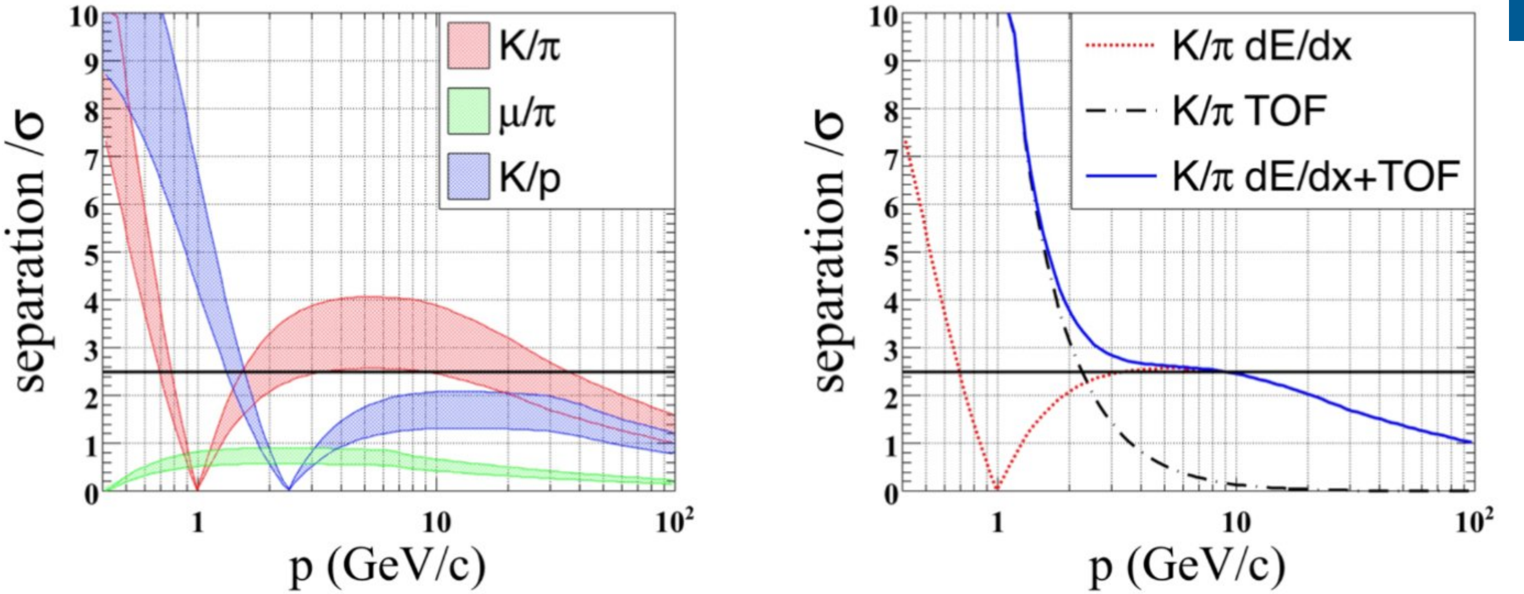
Similar to SiD Kpix

- 64 channels
- Preamp
  + 2 (auto)Gains
  + TDC (~1.4ns)
- Auto-triggered
  - per cell adj.
- 15 (×2) analogue memories
- Low consumption
  - 25 µW/ch
    with 0.5% ILC-like duty cycle
- Power-pulsed

Not final chip
(full 0-suppr.)

ECAL ToF

Kaon



Highly appreciated in flavor physics @ CEPC Z pole
- TPC dEdx + ToF of 50 ps

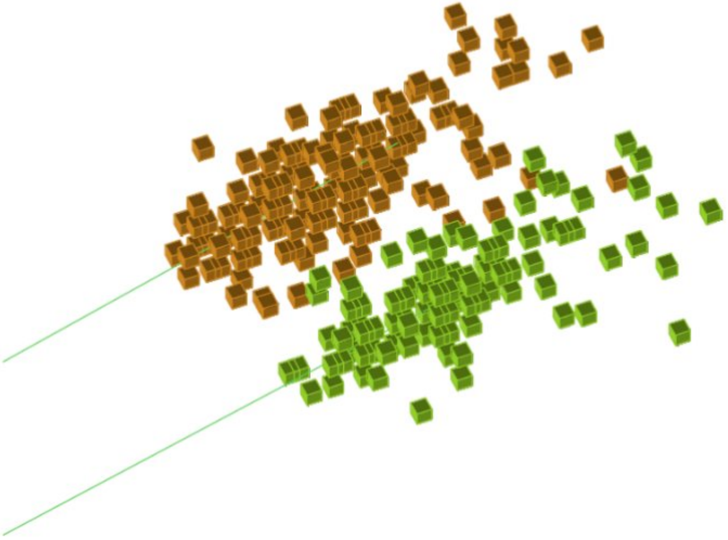
At inclusive Z pole sample:
- Conservative estimation gives efficiency/purity of 91%/94% (2-20 GeV, 50% degrading +50 ps ToF)
- Could be improved to 96%/96% by better detector/DAQ performance (20% degrading + 50 ps ToF)

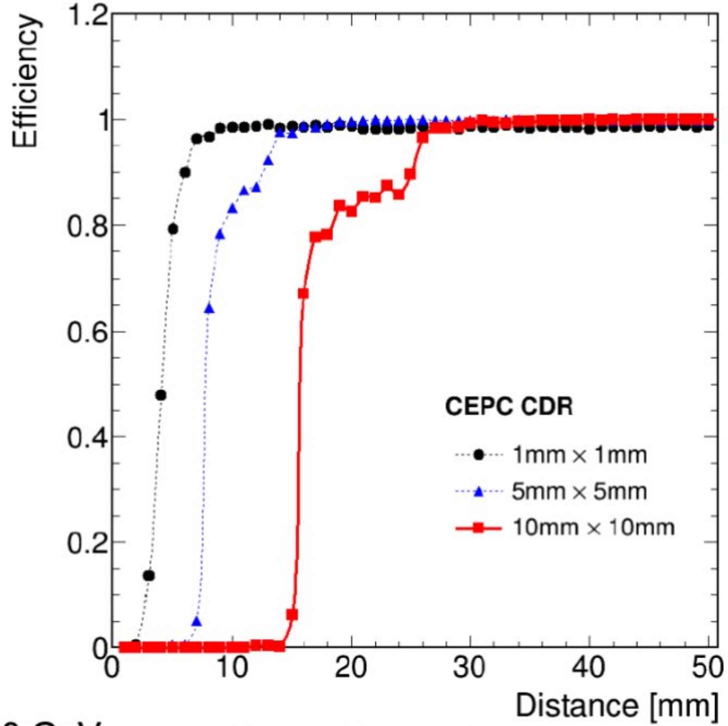
18/11/19 CEPC WS@IHEP 26

CEPC-DocDB-id: 172
https://arxiv.org/abs/1803.05134
Eur. Phys. J. C (2018) 78:464

ECAL Separation

Clustering





Critical energy to separate an evenly decay π_0: 30 GeV

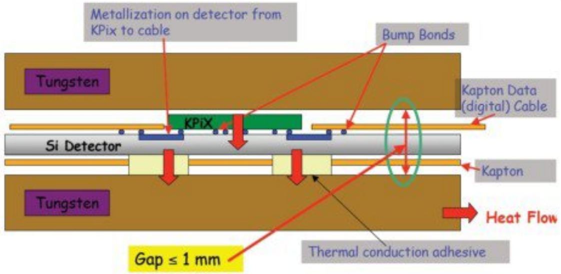
See Hang Zhao's talk

18/11/19 CEPC WS@IHEP 27

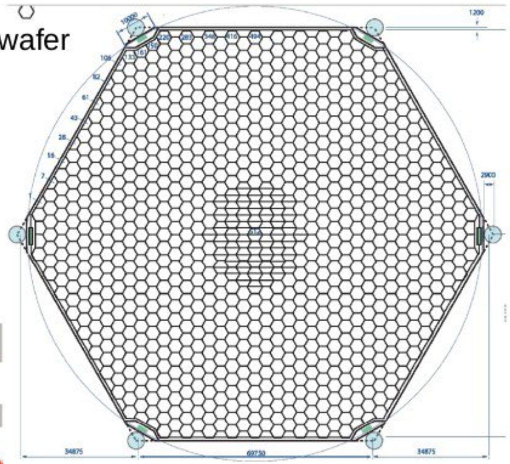
SiD SiW-ECAL (not CALICE, but ‘CALICE-like’)

SiD – Si-W ECAL

Design configuration: “(20+10)”, i.e.
20 thin W layers (2.5 mm)
10 thick W layers (5.0 mm)
+ 30 Si layers



6” wafer

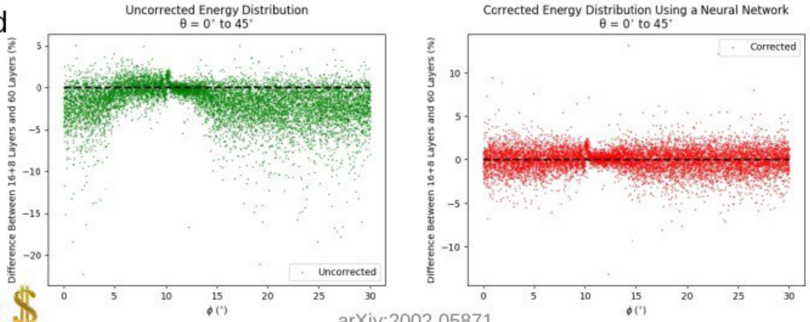


arXiv:1306.8329 - ILC TDR 4: Detectors

Energy leakage of electromagnetic particles estimated by analyzing the patterns in total energy deposition in each layer using neural networks.

(18+6) vs (60+0) GEANT4 models, with:
- energies range: 20 – 300 GeV
- incidence angles $\theta = 0° - 45°$
- azymuthal angles $\phi = 0° - 30°$

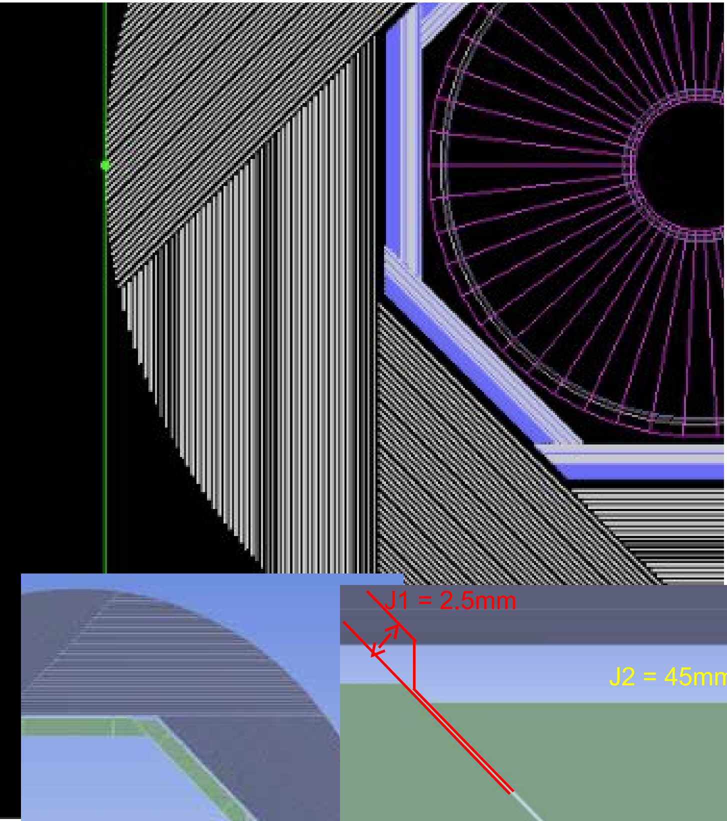
Design performance possible with 16+8 configuration: $

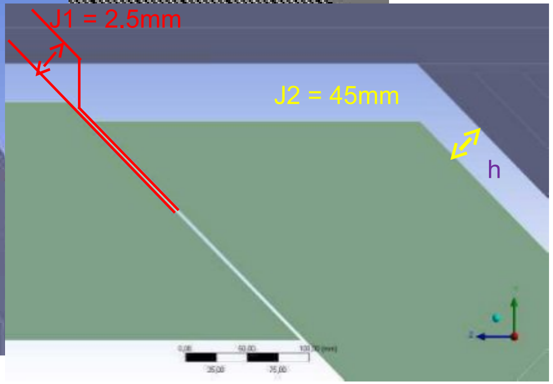


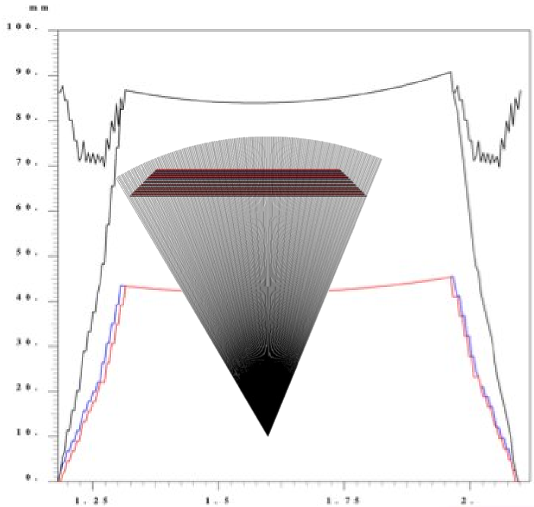
arXiv:2002.05871

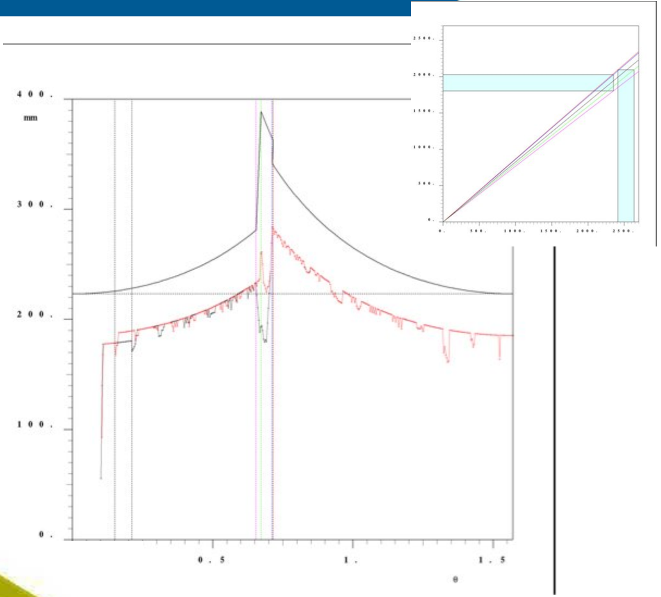
2020.10.21 F.Corriveau (IPP/McGill) - AWLC 2020 - Particle Flow Calorimetry 10

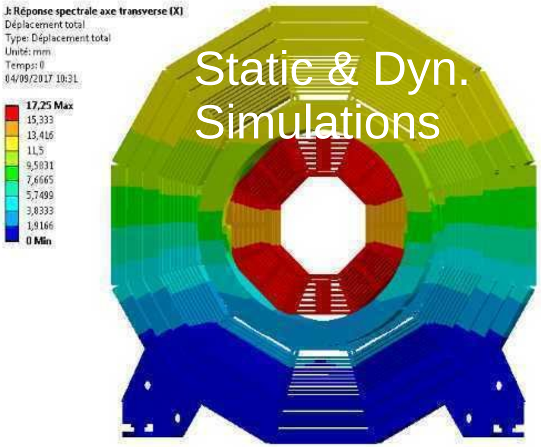
A crack-less ECAL geometry











Static & Dyn.
Simulations