CALICE → FUTURE CIRCULAR COLLIDER -ee

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CNRS IN2P3 Les deux infinis
l'X École Polytechnique
Institut Polytechnique de Paris

Particle Flow Approach

See Gerald's talk for more details

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 $\sigma_{x,y,z} \sim 10\ \mu m$

+ timing

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

Full Reconstruction of single particles

- Charged mostly from tracker
- Neutrals only from calorimeters

Large Tracker

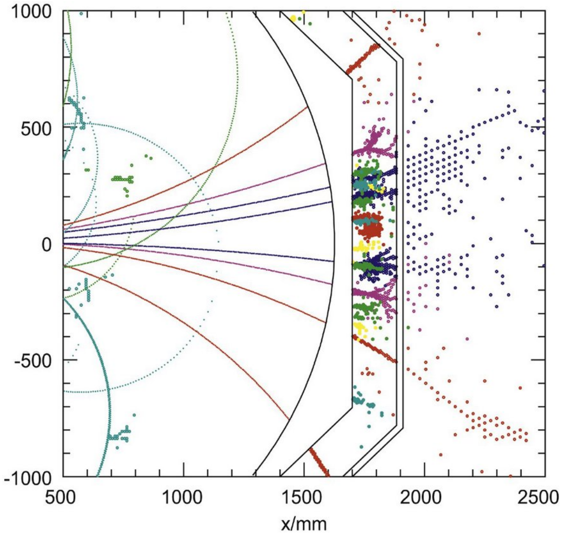
- Precision and low X_0 budget
- Pattern recognition

High precision on Si trackers

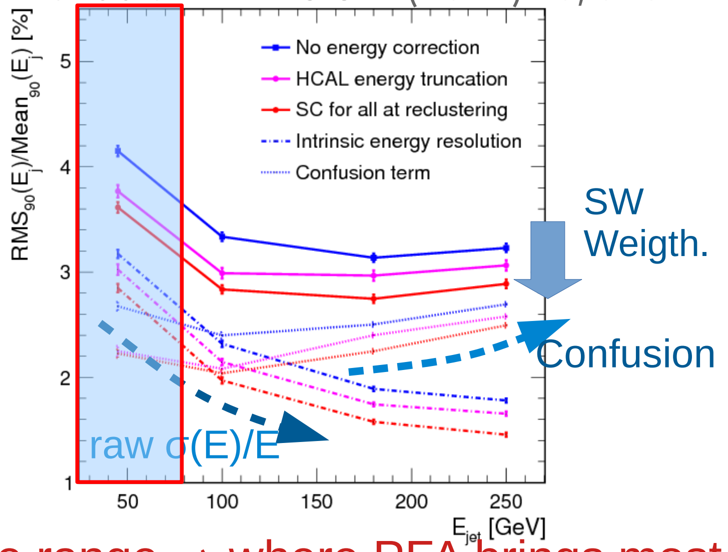
- Tagging of beauty and charm

Large acceptance

HG Imaging Calorimetry



Pandora PFA: EPJ C77 (2017) 10, 698



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 Tracker (system)

  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 ⊃(esp) in jets, τ, …

  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)

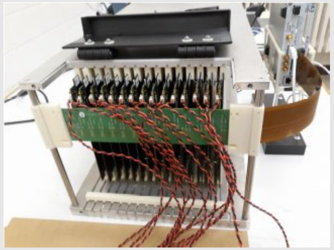
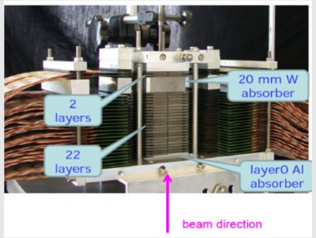
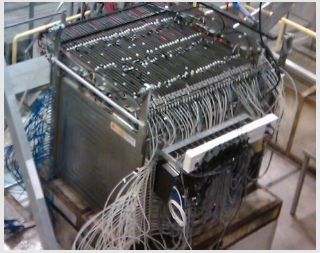
SiD, ILD, CLICdet, CECP$_{\textbf{Baseline}}$ = detector concepts implementing CALICE

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

State of the Art

4,5 prototypes, 15⁺ years of R&D, all tested

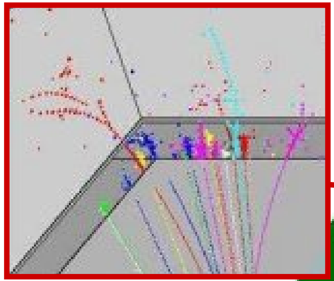
personal opinion, not the collaboration's

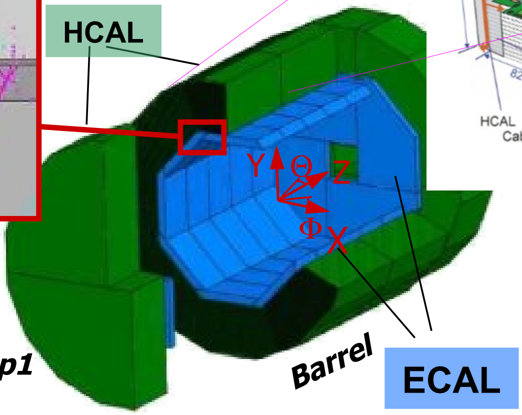
Si-W ECAL	(ALICE FoCAL)	Scint-W ECAL	AHCAL	SDHCAL
				
0,5×0,5 cm² ×15 (→30) Si layers + W	0,003×0,003 cm² × 24 MIMOSA layers + W	0,5×4,5 cm² ×30 Scint+SiPM lay. + SS	3×3 cm² × 38 Scint+SiPM lay. + SS	1×1 cm² × 48 layers GRPC + SS
Resolution – R_M ✔ Intégration ✔ Cost – Calibration ✔	Resolution ✔ R_M ✔✔ 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, ...	DE, NL, CERN	Shinshu, IHEP (CN)	DESY + DE	IP2I, LPC, (LAPP) CIEMAT, Shanghaï

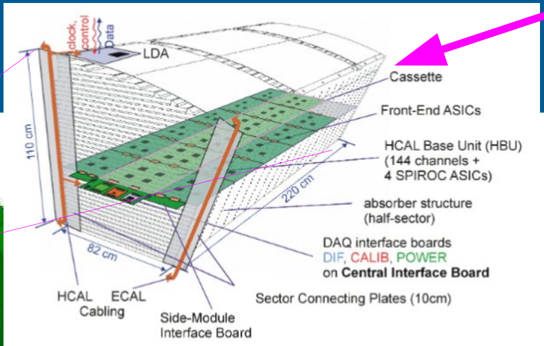
Geometries

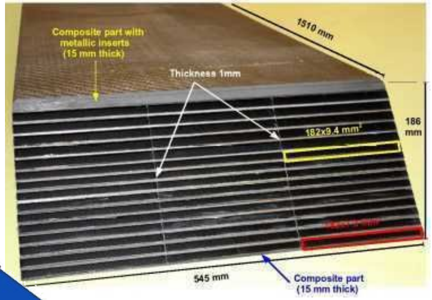
HCAL elec ‘accessibilty’

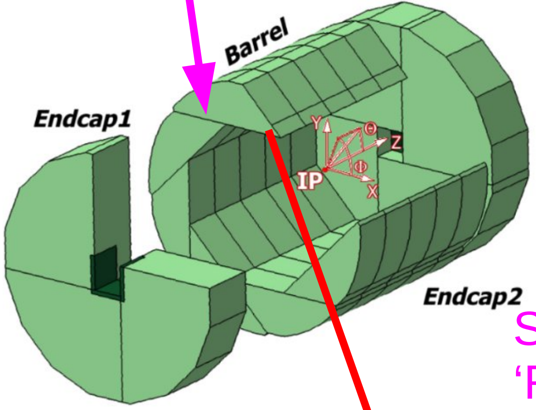
Prism vs diapragm



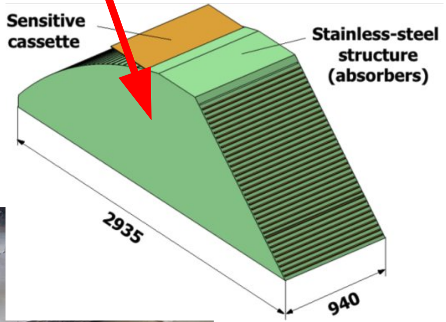


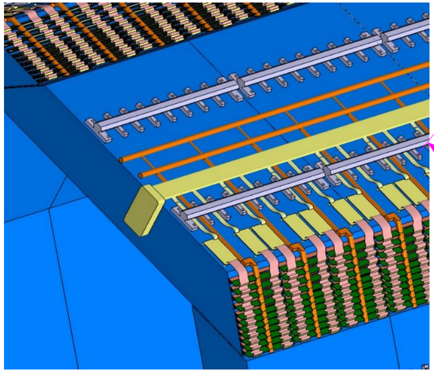


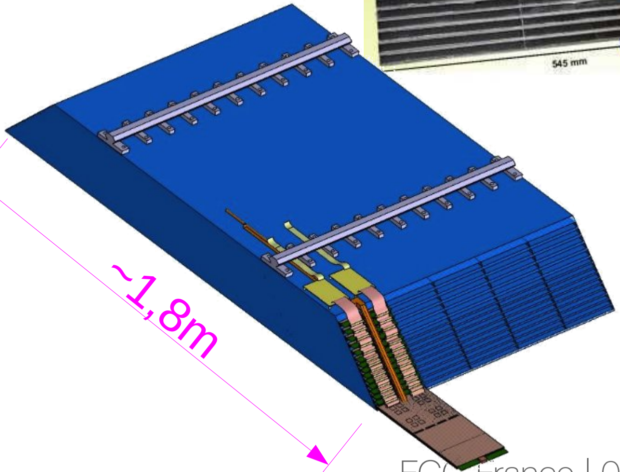


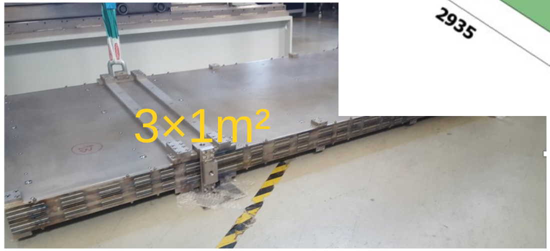


Structural ‘Robusteness & Precision’





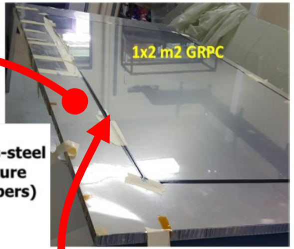


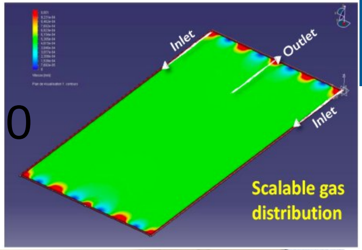


Integratrion R&D (France)

LLR + IJCLab

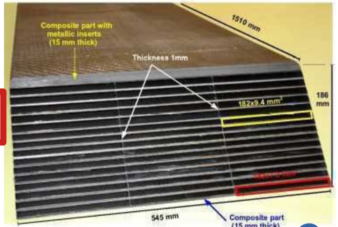
IP2I

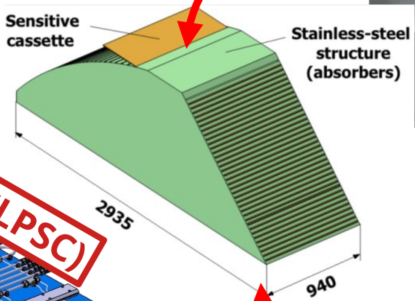


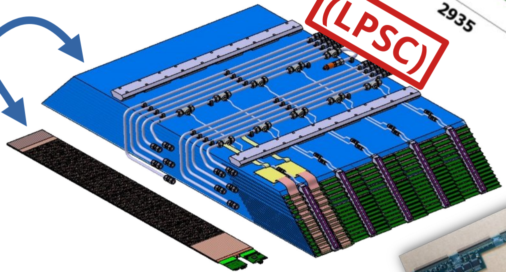


Large technological prototypes

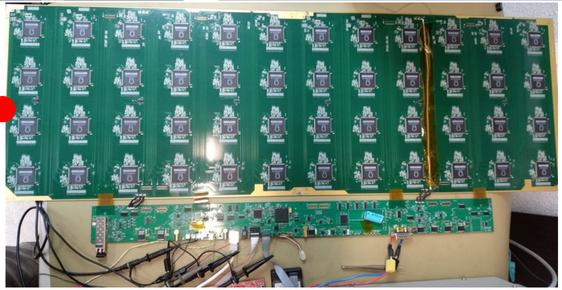
LLR





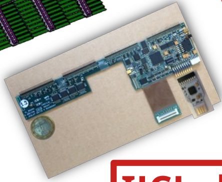


(LPSC)

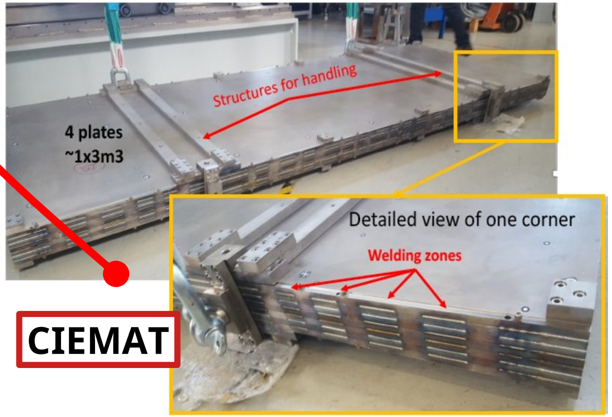


Pilotes (« modules-0 »)

- 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**

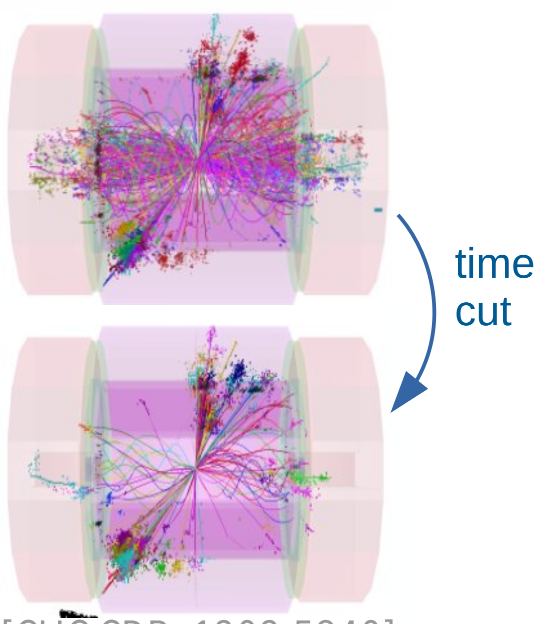
Electronics « v3 » **Ωmega**

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

Timing in calorimeters: 0.1–1ns range

See Roman's talk for more details

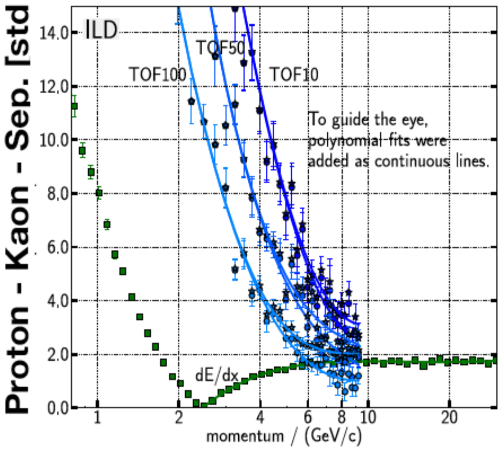
Cleaning of Events



[CLIC CDR: 1202.5940]
adapted from L. Emberger

Particle ID by Time-of-Flight

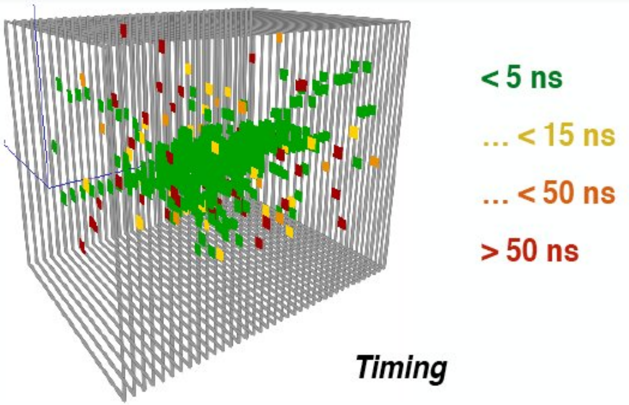
– Complementary to dE/dx
  - here with 100ps on 10 ECAL hits



S. Dharani, U. Einhaus, J. List

Ease Particle Flow:

– Identify primers in showers
– Help against confusion
  better sepration of showers
– Cleaning of late neutrons & back scattering.



Ch. Graf

Electronics & DAQ

Ωmega ASICs:

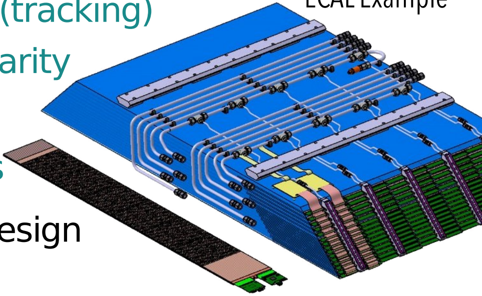
- A set of ASICs adapted for all CALICE large scale prototypes
  - Gradual improvement
  - Purely digital DAQ
- suitable for ILC conditions
  - **low power** consumption using **power-pulsing (~1%)**
  - **low noise** pre-amp, dual gain 12-bits ADC, ns TDC
  - **self-trigger** with local storage, **delayed** 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 req't, feasibile ?

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

- 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 ↗
Cell density ↗ ⇒ Power consumption ↗
Time resolution ↘ ⇒ Power ↗

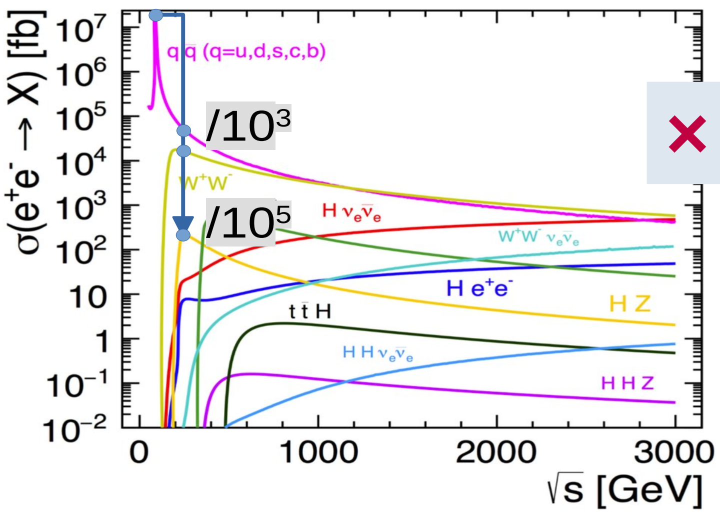
thr. passive vs active cooling
dead-zones ↗

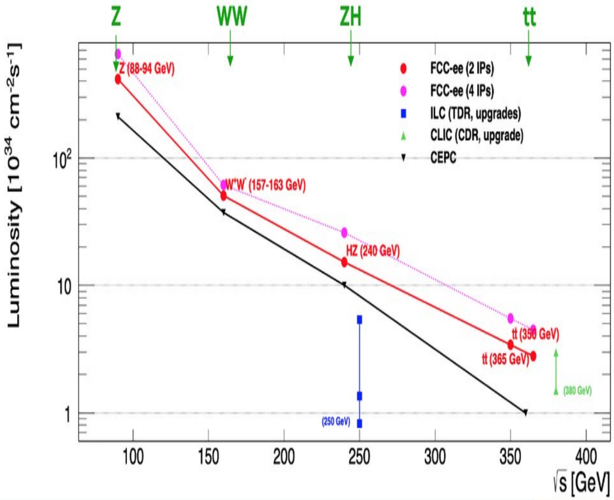
NEED TO BE FULLY RE-EVALUATED for EW region

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)

Conclusion





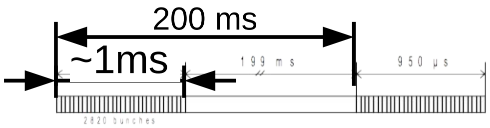
CALICE enters a new phase :

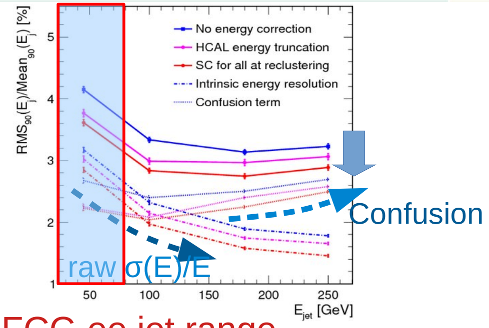
- Construction of 1st large HG calorimeter (HGCAL : 6M voix)
- R&D ``final rush'' for ILC
  - Construction = ~8 years
    → 3 years of R&D +5y for FCC-ee…

Still many element to be tought of

- stability, fiability (MTBF) → redondance
- Power & Cooling (HL scheme)
- Performances (Z peak ≠ WW & Higgs Hill)
  - RAW (single particle) Resolution E, t → (PID, Reco) → Jets, FS

PP ↔ Cont





FCC-ee :

- Need to fix parameters & det. philosophy *for a large range of conditions* → **Think large / complementary**
  - **Technology ↔ Performances :** Trigger/DAQ ↔ noise, noise ↔ detection efficiency, cooling ↔ granularity, …
- Time for new techno: Timing, ML optimisation, other sensors (Crystal), μ-cooling, Digital sensors (dSiPM)
  - Change of constraints ?

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

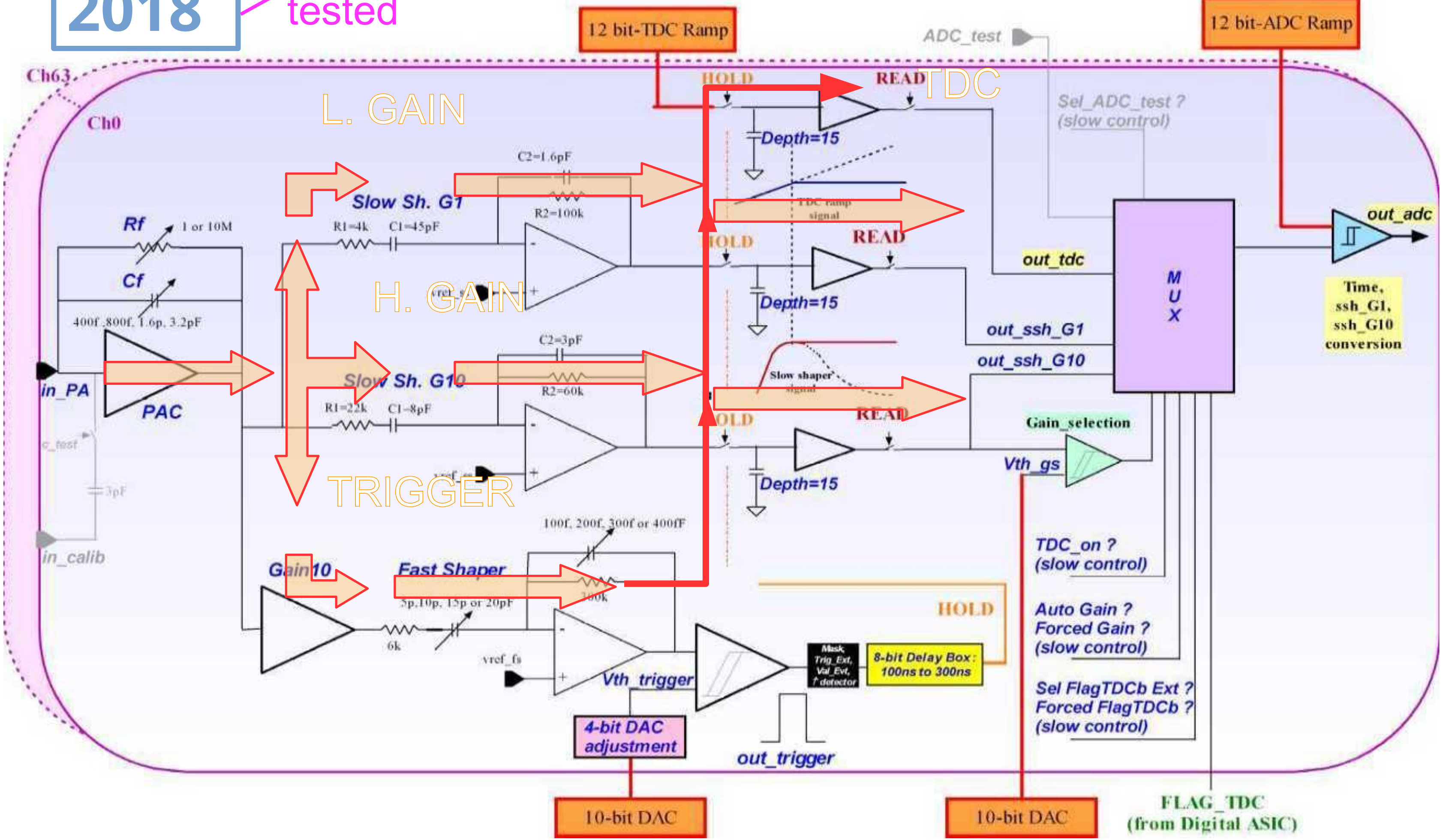
Technical goals:

- 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

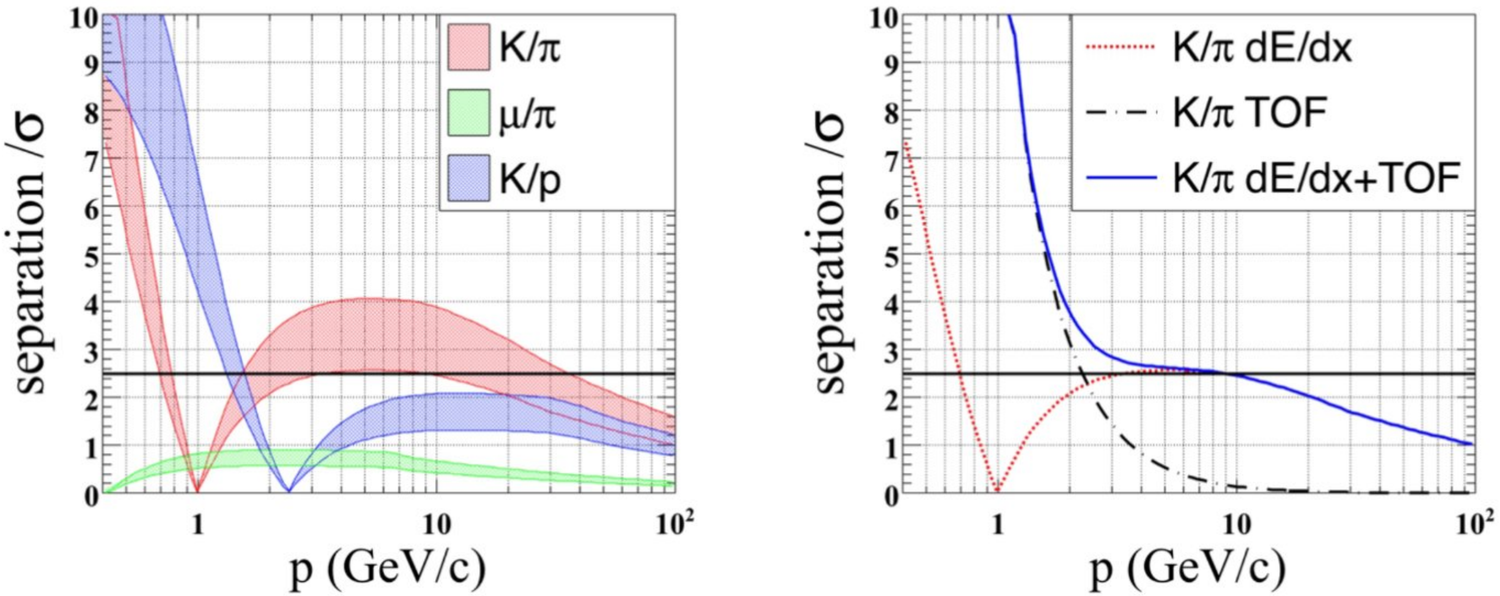


Similar to SiD Kpix

- 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.)

Kaon



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

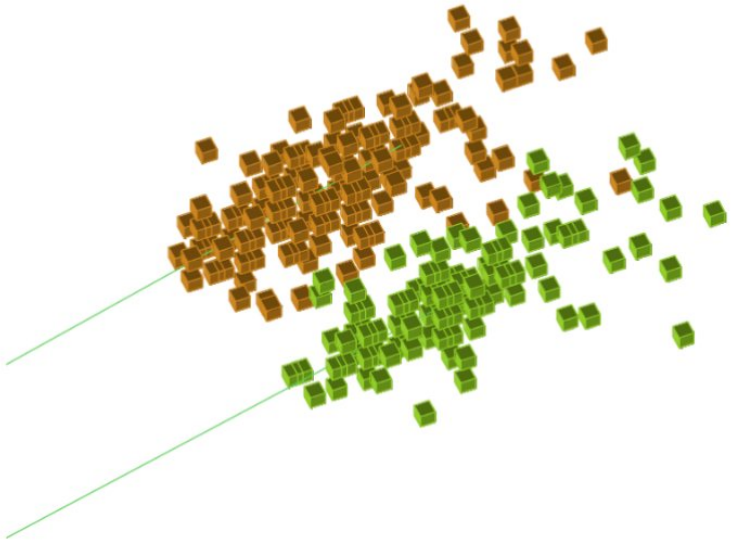
At inclusive Z pole sample:

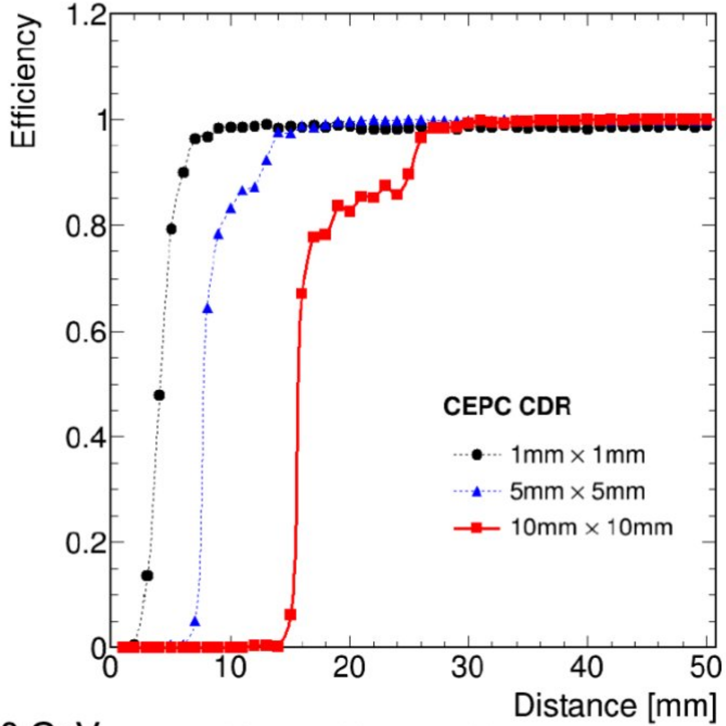
- Conservative estimation gives efficiency/purity of 91%/94% (2-20 GeV, 50% degrading +50 ps ToF)
- Could be improved to 96%/96% by better detector/DAQ performance (20% degrading + 50 ps ToF)

18/11/19 CEPC WS@IHEP CEPC-DocDB-id: 172 https://arxiv.org/abs/1803.05134 Eur. Phys. J. C (2018) 78:464 26

ECAL Separation

Clustering





Critical energy to separate an evenly decay π_0: 30 GeV

See Hang Zhao's talk

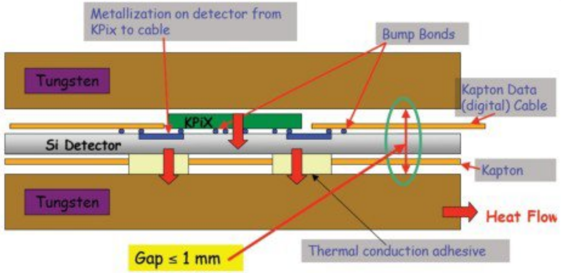
18/11/19 CEPC WS@IHEP 27

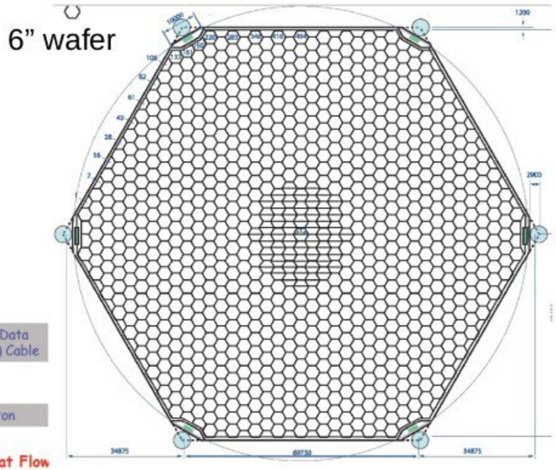
SiD SiW-ECAL (not CALICE, but 'CALICE-like'

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



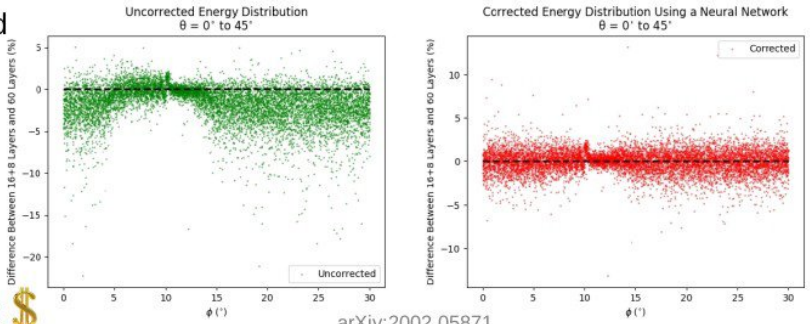


arXiv:1306.8329 - ILC TDR 4: Detectors

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

A crack-less ECAL geometry