An SiW-ECAL for the Future Circular Colliders

Vincent Boudry for the SiW-ECAL groups

Institut Polytechnique de Paris

CEPC WS at Ghangzhou, 07/11/2025

An Highly Granular ECAL at Higgs/E-W/Top Factories for Particle Flow based detectors

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

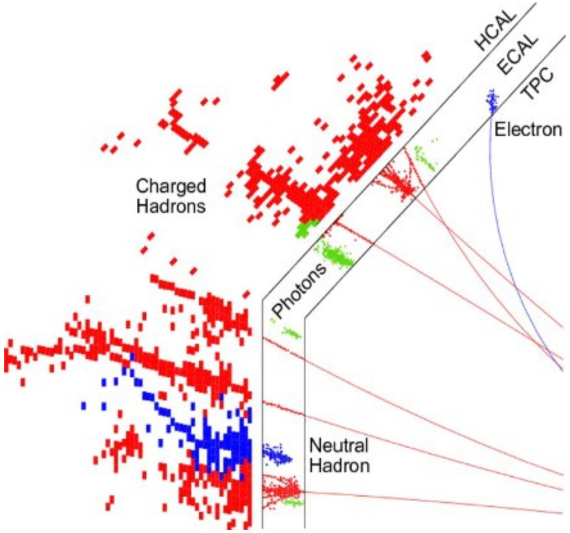
→ Highly Granular Imaging Calorimetry + Particle Flow Software

ECAL

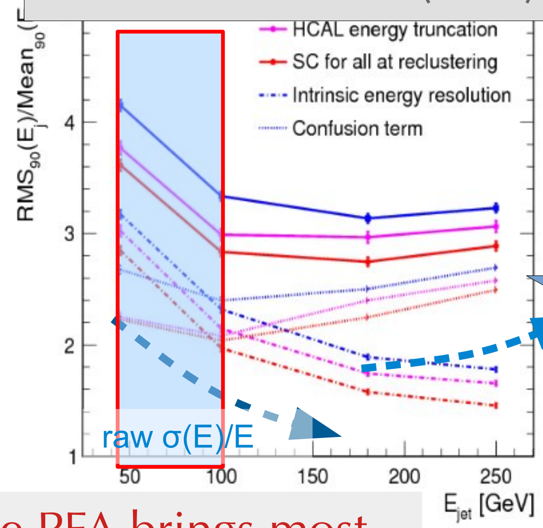
Particle Flow Algorithms :

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

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)

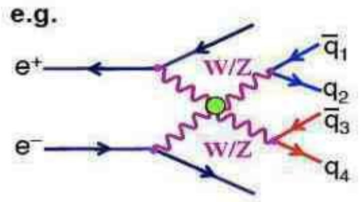
Low E jets ⇒ where PFA brings most

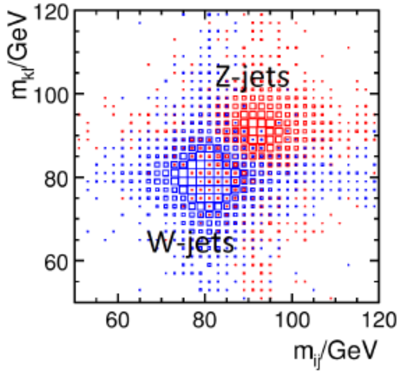
Particle Flow Detectors at Higgs Factories

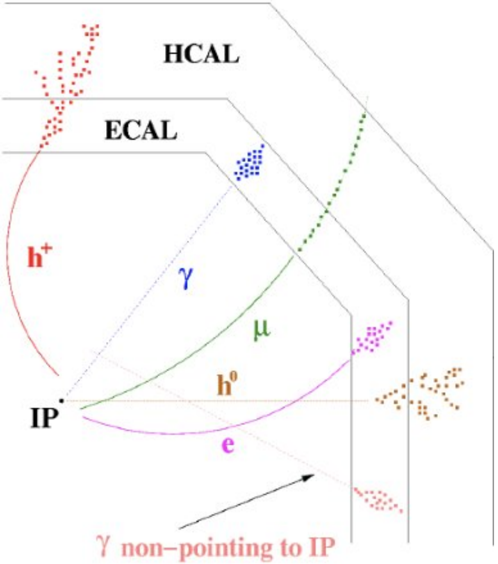
Basis: sep of H → WW/ZZ → 4j

– $\sigma_Z/M_Z \tilde{=} \sigma_W/M_W \tilde{=} 2.7\%\ \sigma_{sep}\ 2.75$

⇒ σ_E/E (jets) < 3.8%







Particle Flow ECAL should :

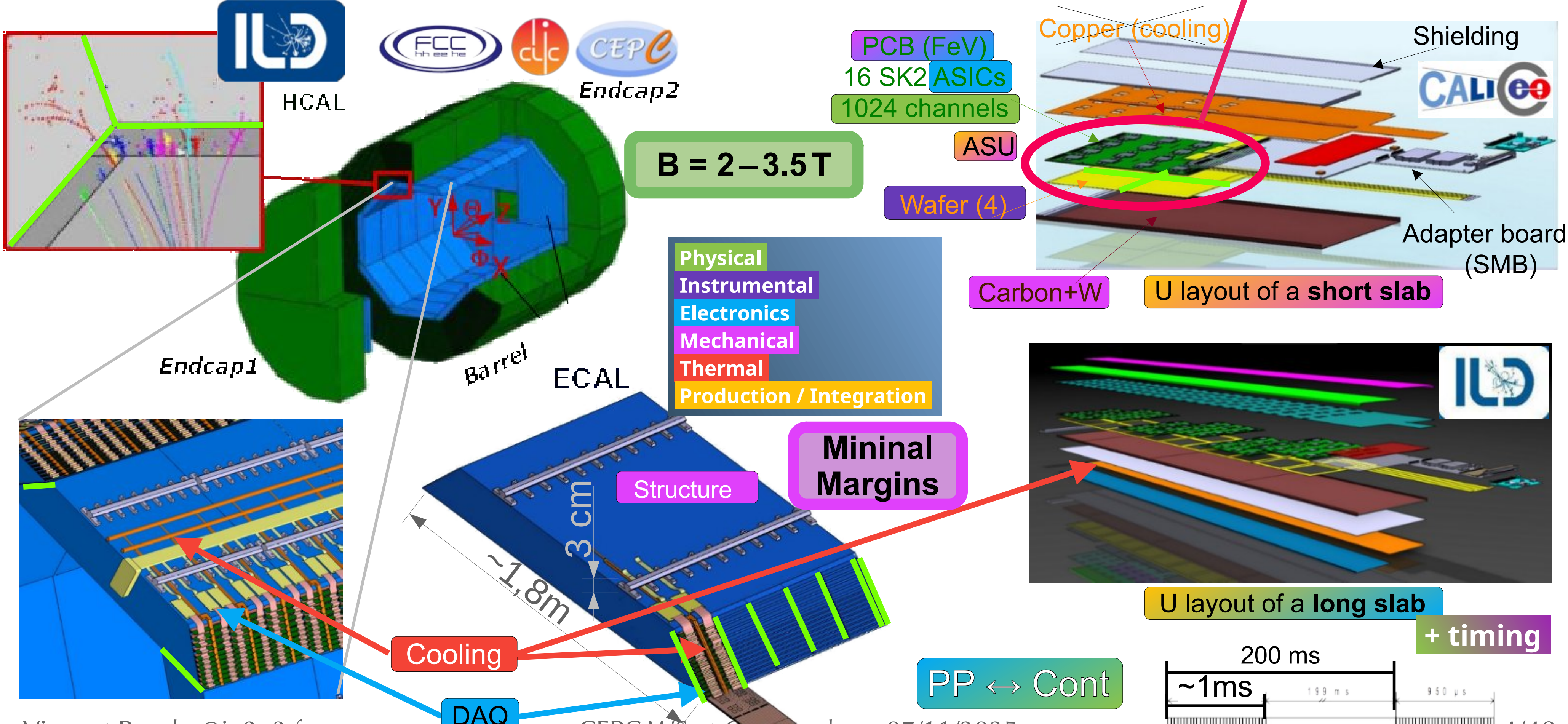
- **spot tracks & showers from charged ($h^\pm$, $e^\pm$)**
  - → Dynamic range from 1/3 MIP
- **measure Photons in jets & Tau physics (vs π^0)**
  - up to ~3000 MIPs
- **measure 2/3 of neutral hadrons interacting in the ECAL**
- **measure Time-of-Flight (10's ps) for improved PID**

Could also

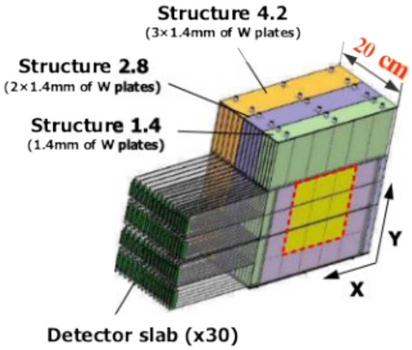
- **track particles & shower with centrimetric timing**

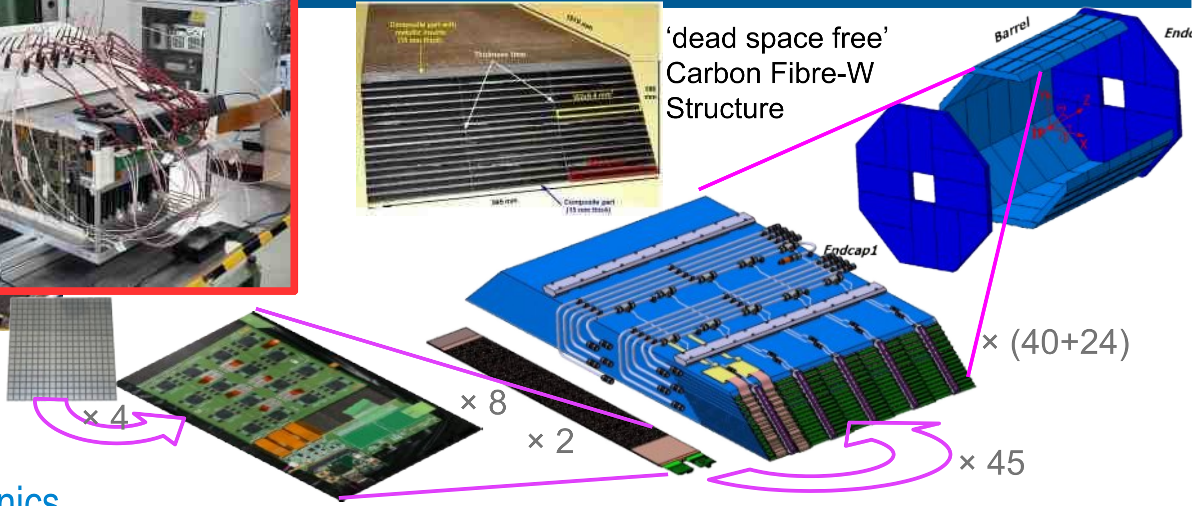
SiW-ECAL Design Constraints LC vs CC

ASU = most critical element



Timeline of SiW-ECAL Prototypes





Physical (2005-11)

- 1×1 cm² on 500μm 6×6 cm²
  Pad glued on PCB
  Floating GR
- × 30 layers (10k chan).
- External readout
- Proof of principe

Technological (now)

- Embedded electronics
  - Power-Pulsed, Auto-Trig, delayed RO
  - S/N = (MPV/σ_{Noise}) ≥ ~12 (trig)
- Compatible w/ 8+ modules-slab
- 5×5 mm² on 320–650m 9×9 cm²
  × 26–30 layers
  - 8k (slab) ~ 30k (calo) channels

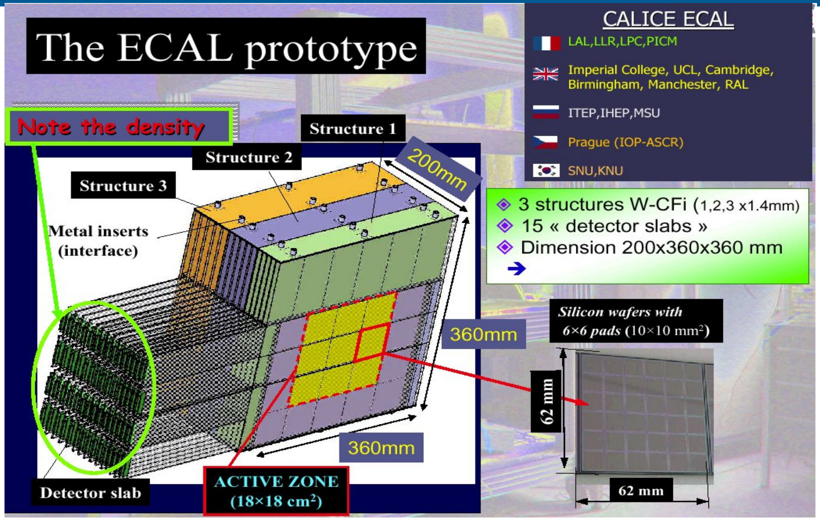
We are here

Pilote ➡ Full Detector

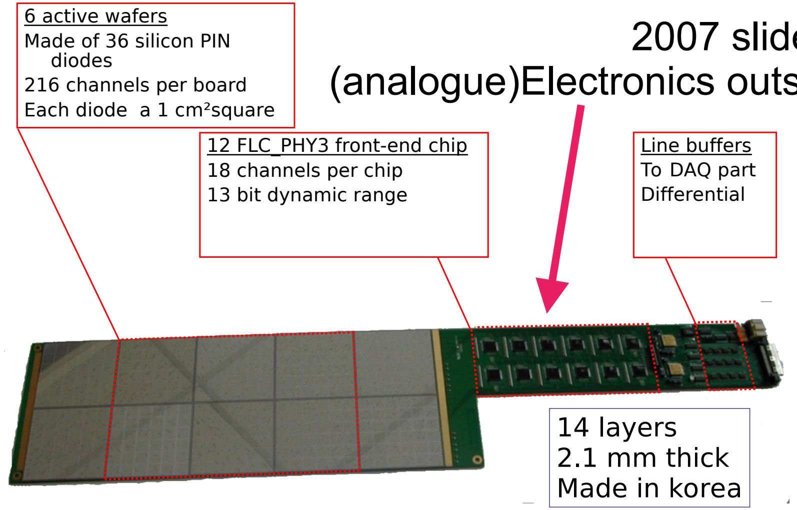
- 1M ➡ 70M channels
- on 725μm 12×12 cm² 8'' Wafers ?
- Pre-industrial building
- Full integration (⊃ cooling)
- **Final ASIC**

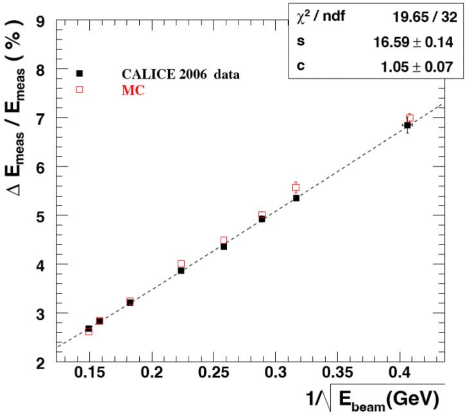
'Almost ready' for LC
Being revisited for CC

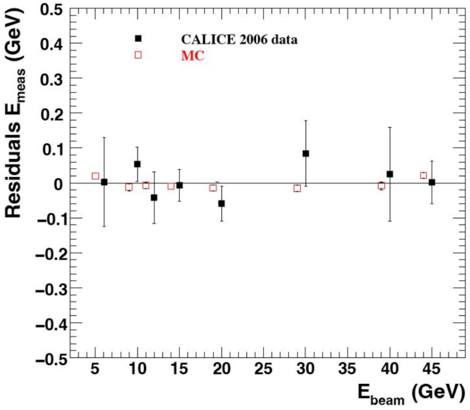
Physics Prototype: classical calorimetry with HG-SIW-ECAL



2007 slides !
(analogue)Electronics outside







Energy, Position, Direction responses

- Using standard methods
- 200M events sample

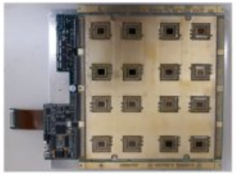
Less classical:

- Hadronic interaction track multiplicity !

ASU Technological Prototype Beam test at DESY & CERN

FEV10, 11, 12

- BGA packaging
- Incremental modifications
- From v10 -> v12
- Main "Working horses" since 2014



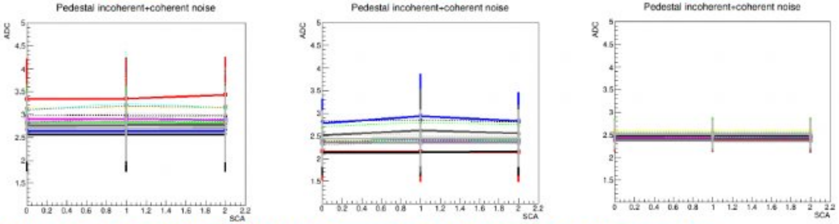
FEV-COB

- Chip-On-Board : ASICs wirebonded in cavities
  - Thinner than FEV with BGA
- Based on FEV11
  - External connectivity compatible

FEV13

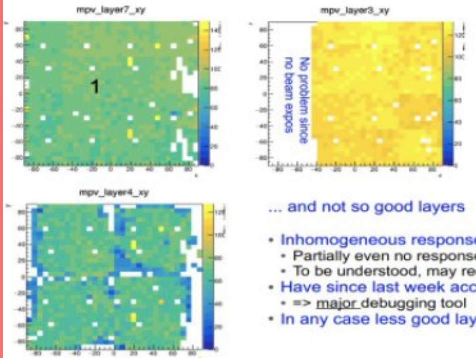
- BGA packaging
  - Improved routing
  - Local power storage
  - Different external connectivity

Pedestal widths, 1st memory cells, per asic



- (Average ± Standard Deviation) of Sigmas for all 64 channels in the same chip
- Latest PCBs, with optimized routing of power distribution shows better behavior
- Slightly larger spread on COB due to a near lack of decoupling capacitors

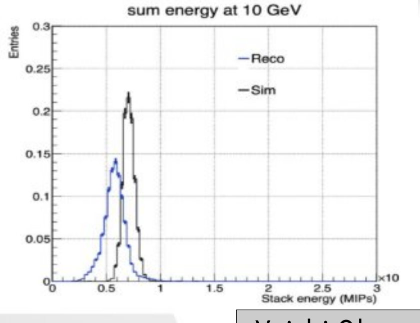
2022 DESY & CERN BT



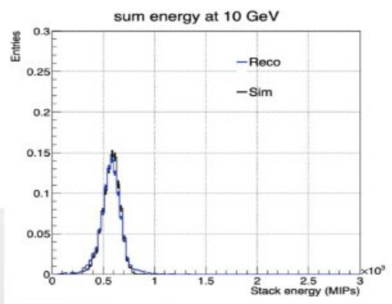
- We have good layers …
  - Homogeneous response to MIPs over layer surface
  - Here white cells are masked cells due to PCB routing
    - Understood and will be corrected

… and not so good layers

- Inhomogeneous response to MIPs
  - Partially even no response at all, in particular at the wafer boundaries
  - To be understood, may require dedicated aging studies
- Have since last week access to the different stages of the ASICs
  - => major debugging tool
- In any case less good layers will be replaced in coming months



Masking
Beam profiling



Yuichi Okugawa (PhD in Feb. 2024)

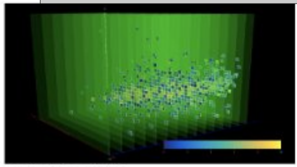


Fig. Simulation e- 100 GeV

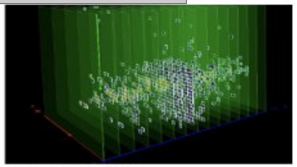
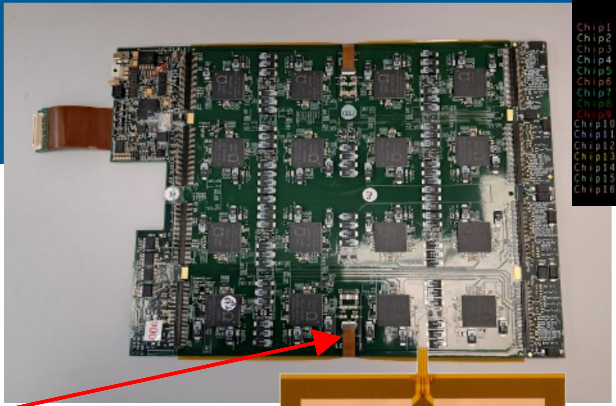


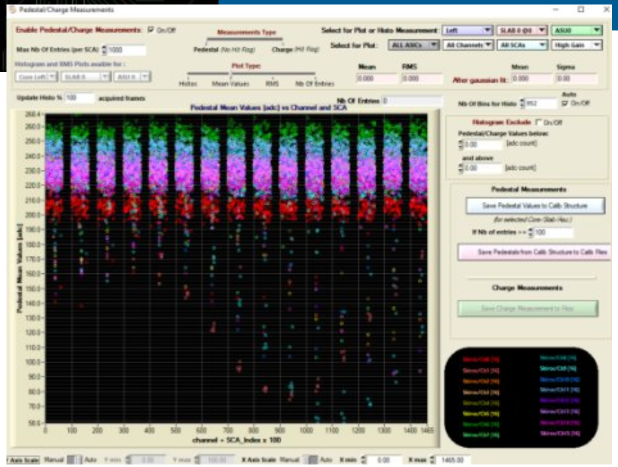
Fig. Reconstructed e- 100 GeV

ASU2.1 (2023–…)



Improvements wrt FEV11/12/13

- Power distributions
  - Local LV power regulation: LDO's
  - Local HV filtering & Supply
- Signal distribution (buffering), data paths
- Monitoring (single ID, temp, probe analogue line)
- ASIC shielding/routing streamlined
- Stand-alone HV distribution ➞ flexibility (testing, set-ups)

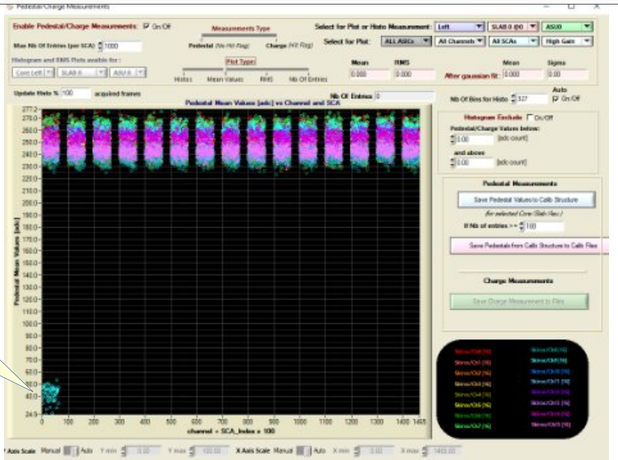


Pedestal measurements vs. Ch# + Mem#×100)

Status:

- Noise uniformity dramatically improved (ex: outliers in thr. / 20)
- version 2.1 produced
  - 15 cabled, 2nd metrology, 2 equipped with sensors (Fev'25)

SIngle channel ➞ the fault on the ASIC/packaging

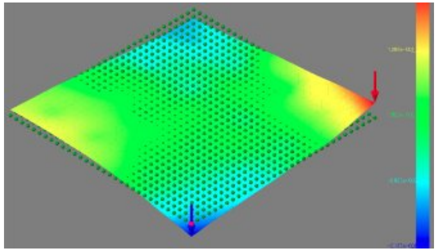


Hybridization studies (2024): How to assemble silicon sensors & PCB ?

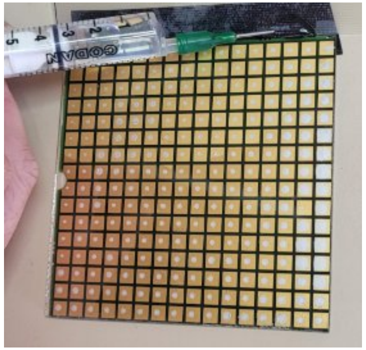
Revisiting gluing (IFIC, IJClab, DMLAB)

- PCB metrology
  - Bef. & After curing & soldering
- Glue formula & preparation
- Gluing methods
  - Robot
  - Stencil
- Reenforcement
  - Filling glue
  - Adhesive films

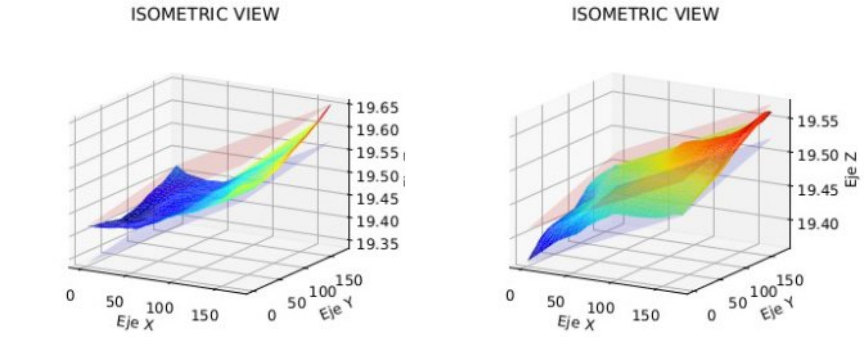
IJClab (méca)



Conductive glue + filling (~invisible) on a glass plate

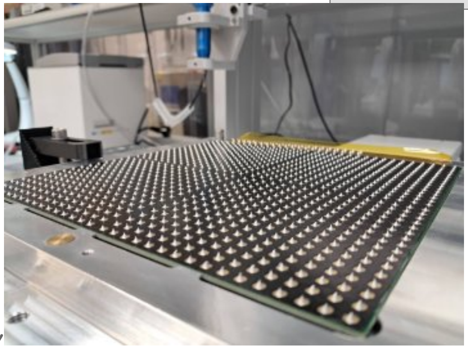


Flatness of PCB



Same PCB before / after 10-day dry storage

Measurements by C. Orero, IFIC



Puncturated adhesive film (**DMLab**)
+
conductive glue dots

Assembly chain:

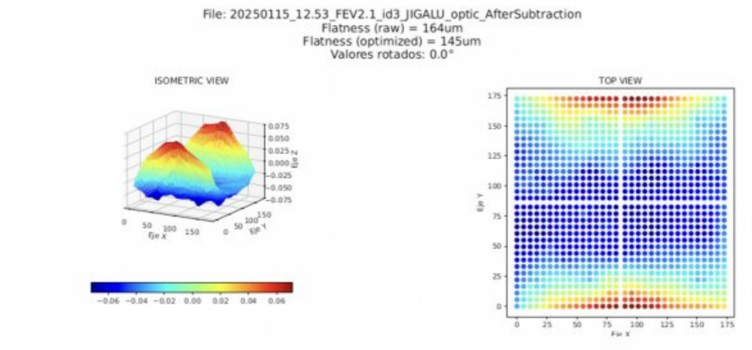
Metrology of PCBs

IFIC

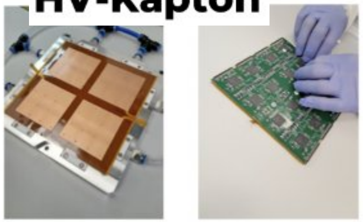
▷ **We could not do conclusive metrologies of the PCBs upon reception**

- Small differences between FEV2.0 and 2.1 and w/ w/o components which make the tools available not suitable... we aim for precision mechanics, we require detailed mechanics models and designs
- At arrival + after drying, requires at least 1 month of time for the full process. → so we decided to dry them before having the definitive tooling (which took some time to be produced)

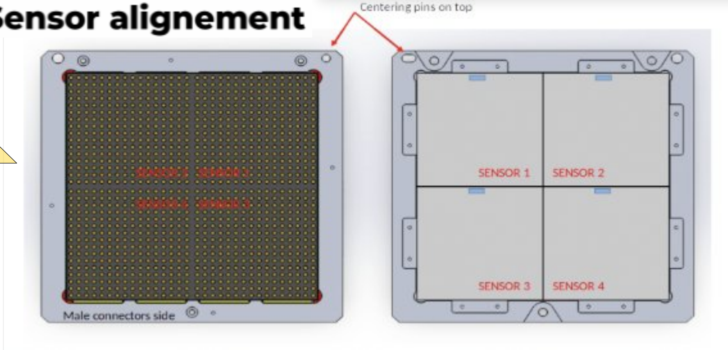
▷ **Metrologies after drying them – FEV2.1 id3 – "flatness" of 145um**



HV-Kapton



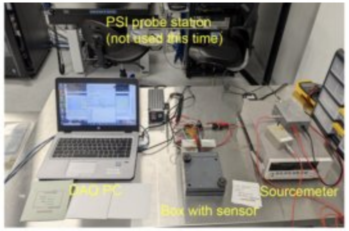
Sensor alignement



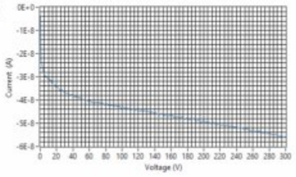
- PROCEDURE - 3D robot and precifluid v0.odt
- PROCEDURE - CALICE ASU gluing_alignment v0.odt
- PROCEDURE - CALICE ASU gluing v0.odt
- PROCEDURE - H20E preparation v2.odt
- PROCEDURE - HV-K... to ASU v0.odt

Sensor characterization

(Simplified) Setup at IJCLab



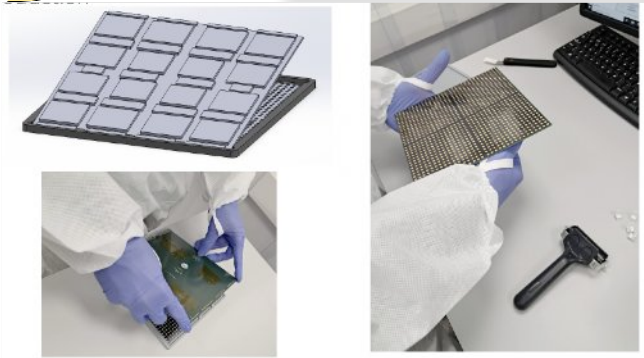
Typical I-V Curve

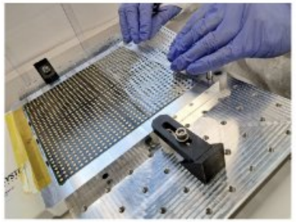


- Reasonable I-V curve though leakage current ~ factor two lower than in HPK data sheet
- Tests allow to validate that there is no major problem with sensors

J. Jeglot, A. Torento, R.P., (R. Cornat)

Sensor and electronics cleaning





3M tape

DESY Beam Tests 2025/03

1 week 3–10/03/2025

SiW-ECAL:

- 2 new ASU FEv2.1 + 1 ASU COB
- No Tungsten

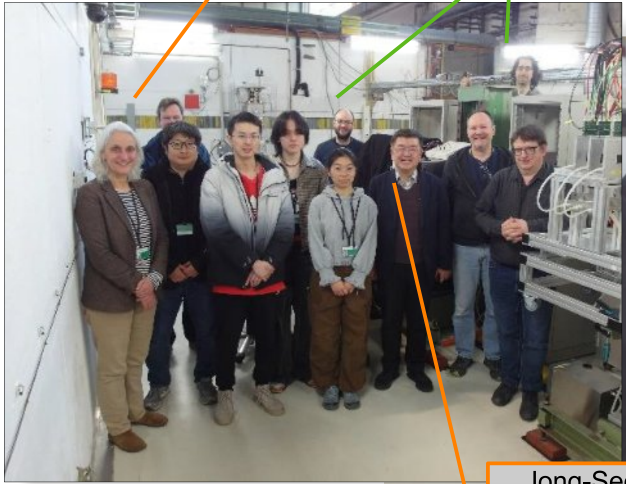
AHCAL:

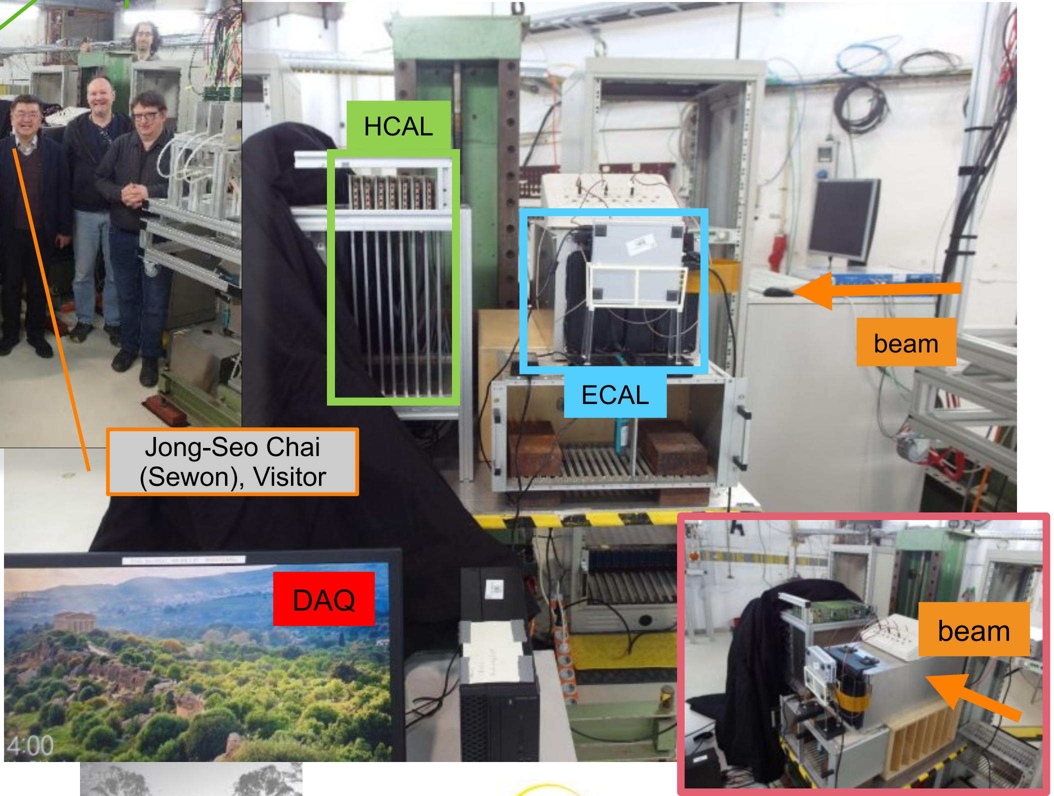
- "Airstack" with 7 short layers

Running:

- 3 days ECAL Stand alone
  - ½ d. install + commissioning
  - Positions scans : uniformity & mip/noise resp.
- 4 days AHCAL
  - ½ d install + repair
  - Scans & TDC runs

"MIPs" only (punch through electrons)



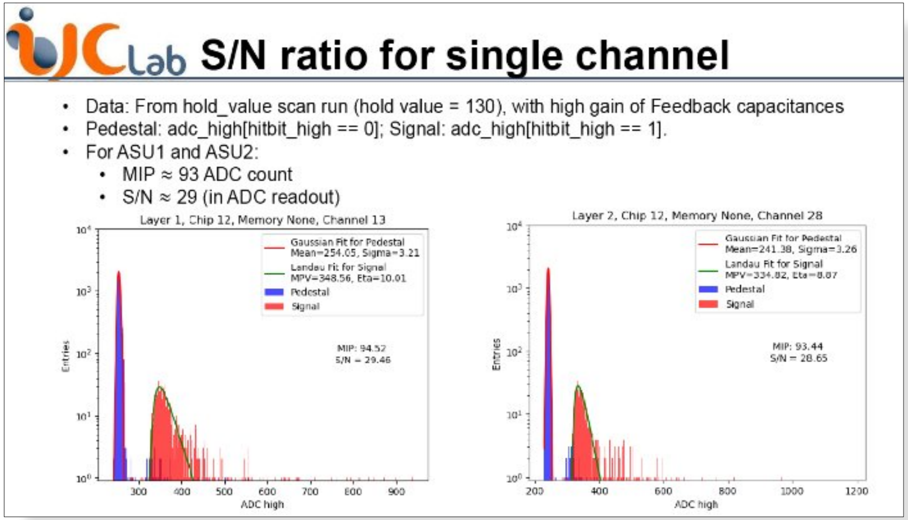


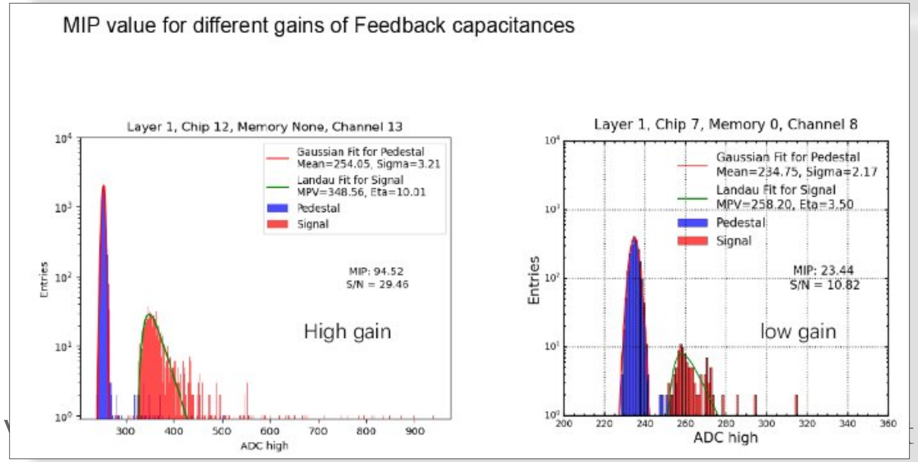
The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)".

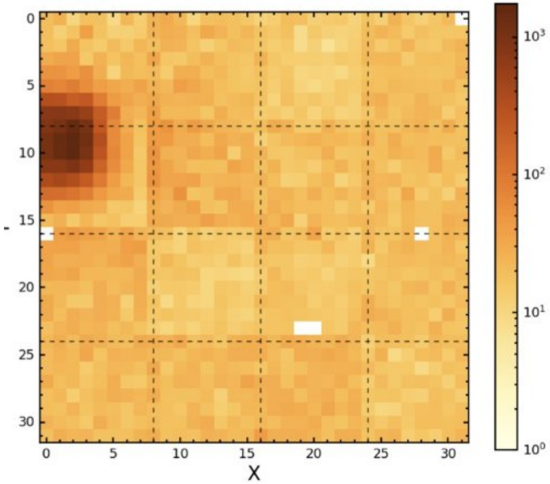
"Toshiko Yuasa"
France Japan
Particle Physics Network
(TYL-FJPPN)

Some results on the SiW-ECAL

Xin XIA (IJCLab)







New FEV2.1 preliminary results:

- High S/N ration (MIP MPV/Noise StdDev) ~ 30 in readout branch
- Run in lower gain mode possible (~ standard for high dynamic range)
- Very few cells masked
- Tentativeof TDC enabling : not conclusive (but was a maybe bit hastly)

'Ultimate' Uniform ILC Prototype

Completion of existing prototype to 15 layers

- based on Ωmega **SKIROC2** (2012, AMS130)
  Ultimated prototype with this tech.
- **2 ASU2.1** tested in March at DESY
- **+13 new ASUs**
  - PCB, ASIC, Components and Wafers available.
    Enginnering & experts time (IFIC) critical
- Go to **BT @ CERN** in June 2026 with a "uniform" full stack (15 layers)
- Same HW can be used for "small" dark photon experiments, e.g.
  EBES@KEK, LUXE@XFEL

Beam Test 2026:

- Goal: reproduce the data set of Physical Proto.
  - Many analysis to be re-established with 4× the lateral granularity
    - Resolutions (E, x, θ)
    - Hadrons interactions track multiplicity
  - New ones to be tried, esp. ML methods
- Make a 2^{nd} reference sample for GEANT4

Students (and Seniors) welcome!

Future Electronics & Design

4 paths of developments for Future Colliders

Circular colliders :

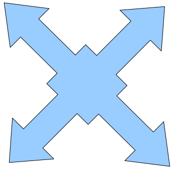
- Continuous readout
- (Much) Higher data flux
- Lower CMS energy wrt Linear Colliders

Reoptimisation:

- PFA with lower granulatity ?
- Revisit the configurations:
  - 20× 2.1 mm W + 10 × 4.2 mm W = 30 layers on 24 X_0
  - 500 μm Si , 5.5×5.5 mm²

Timing:

- "Centrimetric timing" ➞ 30 ps, achievable ?
  - Exp'd : PiD, simplier and more performant PFA



New ASICs

- CALOROC1C
  - Capitalising on SKIROC2A ➞ HGCROC ➞ HKROC

    See pres. from Aimie and Christophe at DRDCalo meeting in Ancona

➞ New FE boards :

- I2C, data concentrator (lpGBT), cont. data flux, improved timing performances
- 1st prototype based on HKROC (~ pin-2-pin compatible CALOROCs)

Active Cooling

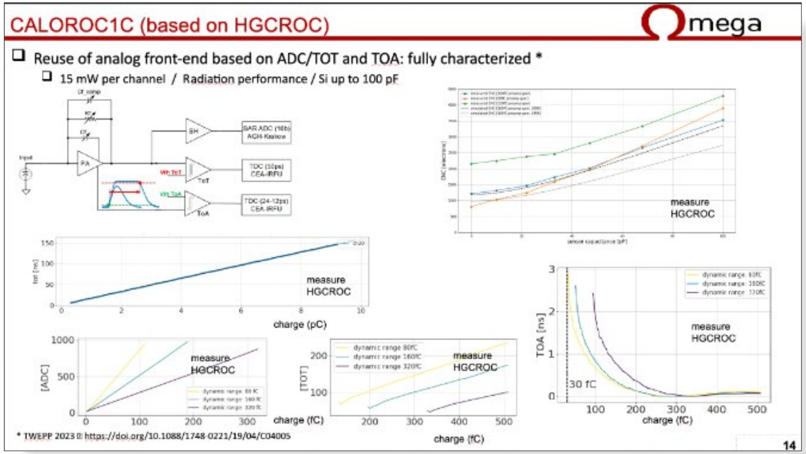
Recent Progress: CALOROC1C design (Si and ℓ Ar) – Ωmega

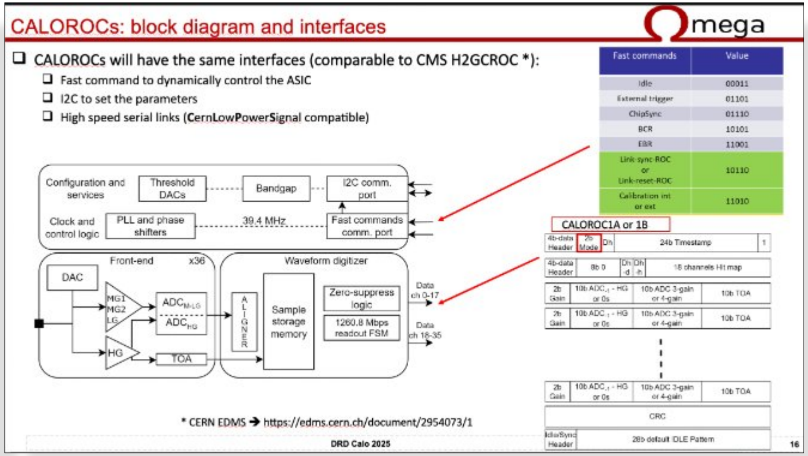
New ASICs

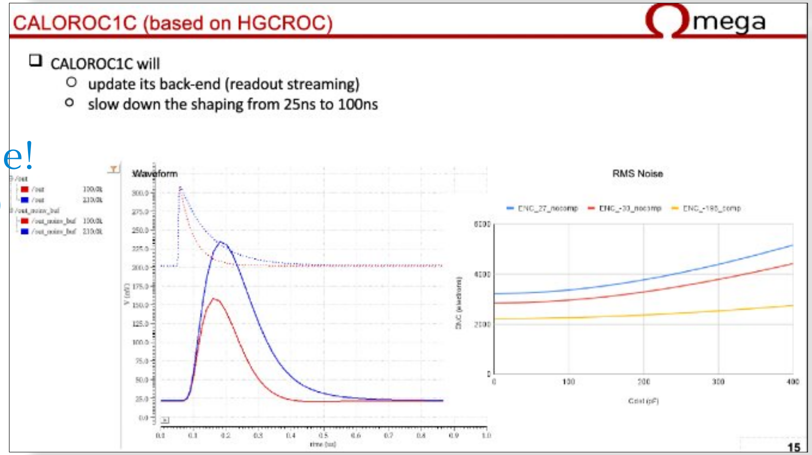
- Based on HGCROC, HKROC

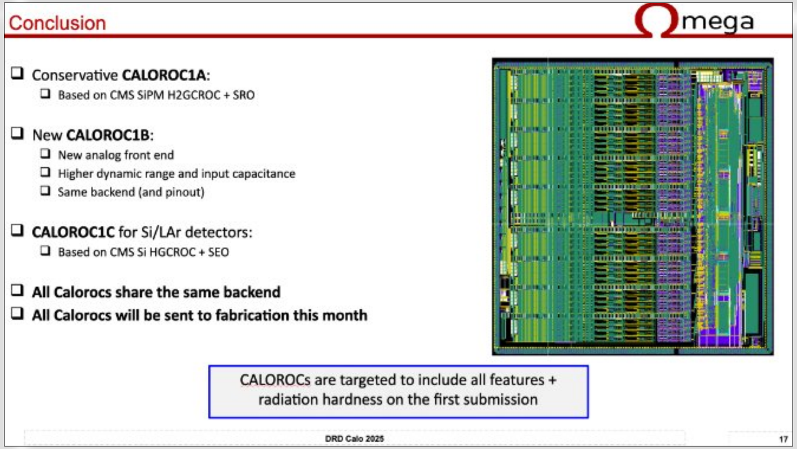
'Almost' Compatible:

- PCB & DAQ work can start with HKROC
- 1st submission done! (6m admin delays)









Towards a Compact cooling system

"Boosted Standard Slab"

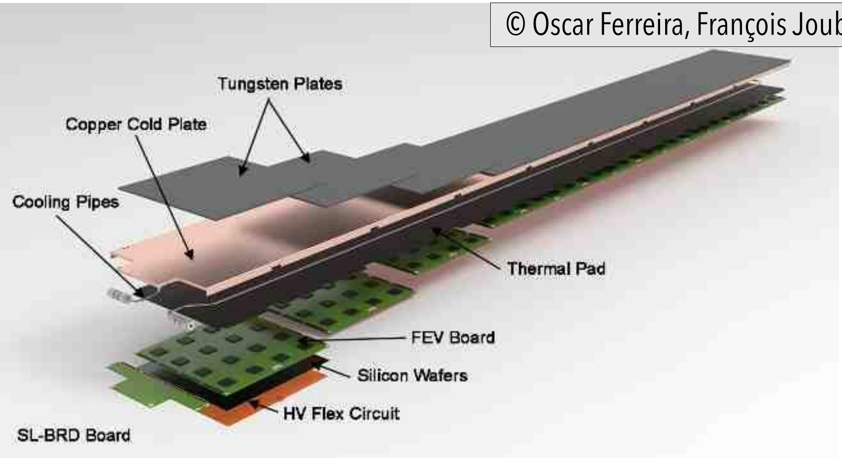
- → 210W (30W/ASU) : ASICs + Concentrators + PS…
  - (ILC like in CC ~ 130W)

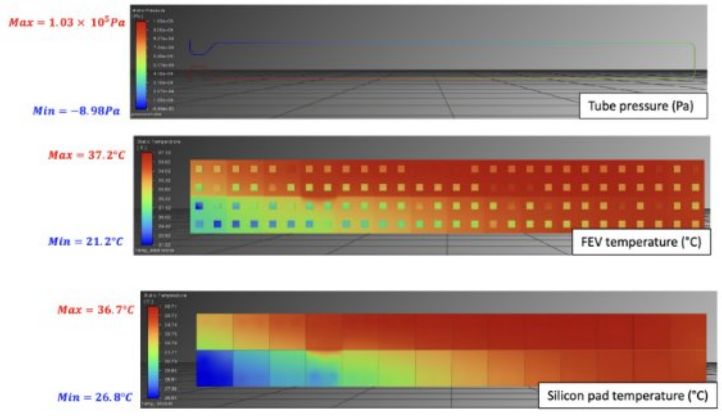
Active cooling:

- 4 mm Cu plate with 1/8″ Stainless Steel Tubing
- 0.2 ℓ /min of water @ 15°C

Simulations
Adiabatic, but for heat bridge at the end, $t = \infty$

© Oscar Ferreira, François Joubert @ LLR





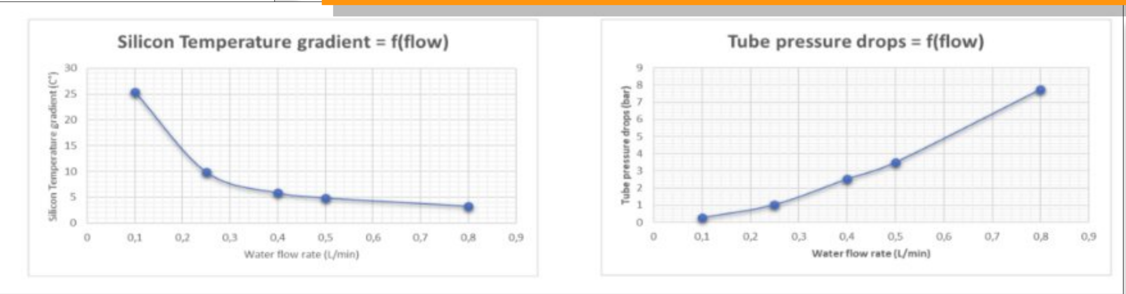
Inlet flow rate : 0.25L/min

Results :

- Pressure drop : 1.03 bar
- **Silicon temperature gradient : 9.87°C**

- Preliminary results resumed in the following graphs.
- Operating point between **0.25 L/min** and **0.45 L/min** for allowable pressure drops.

To be assessed by prototype (2026)



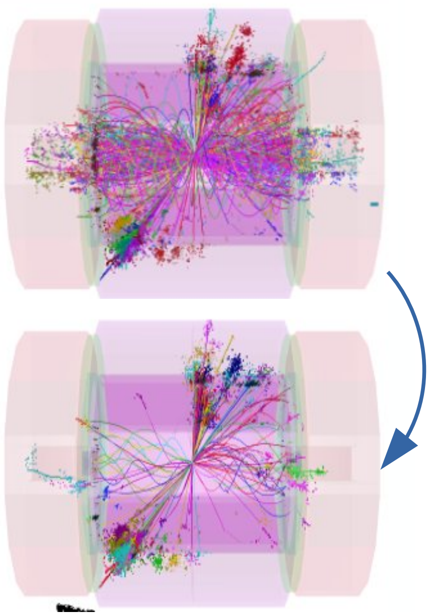
Centimetric Timing

Timing in Calorimeters: 0.1–1 ns range

1 cm/c = 30 ps

Started in KIT, JGU, IJClab, LLR and IP2I (Lyon): Calo5D & T-Calo

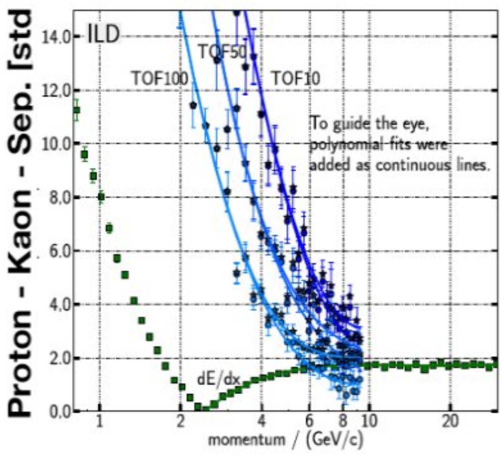
Cleaning of Events



[CLIC CDR: 1202.5940]
adapted from L. Emberger

Particle ID by Time-of-Flight

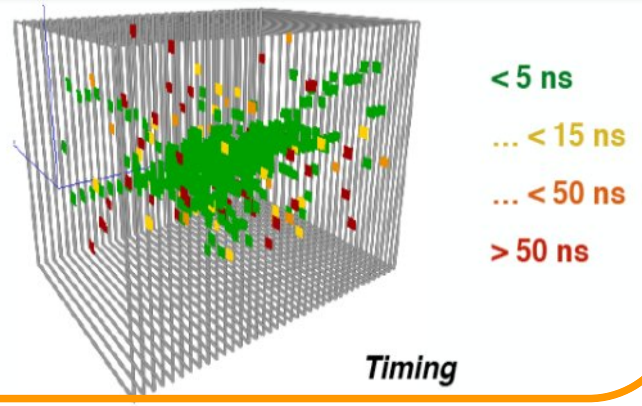
- Complementary to dE/dx
  - Here with 100 ps on 10 ECAL hits



S. Dharani, U. Einhaus, J. List

Ease Particle Flow with $\mathcal{O}(30)$ ps ?

- Cleaning of late neutrons & back scattering (ns)
- $\mathcal{O}(30)$ ps for mips… HGCAL / 100!
- Identify primers in showers
- Help against confusion
  better separation of showers
  - Requires '4D clustering'



Ch. Graf

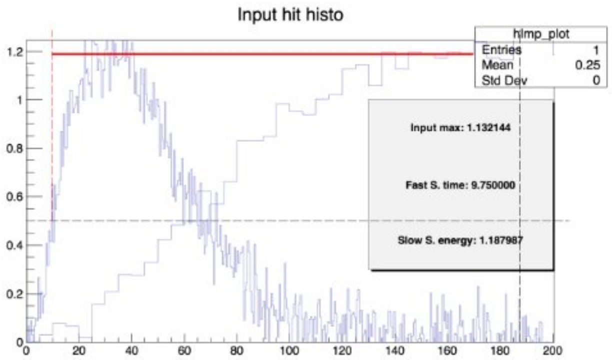
How to implement a realistic timing in the digitization ?

“high level”: simply modelize the slew-time-corrected response

- From HGCAL paper measurements.
  To be adapted for SiW-ECAL:
  - Silicon thickness → capacity S/N ⊗ noise performances

“Low level”:

- From sub-hits collect the amplitude-time,
- simulate pulse-shapes, add noise
- Perform ToA process:
  - Single threshold
  - Pulse shape reconstruction
  - (CFD)



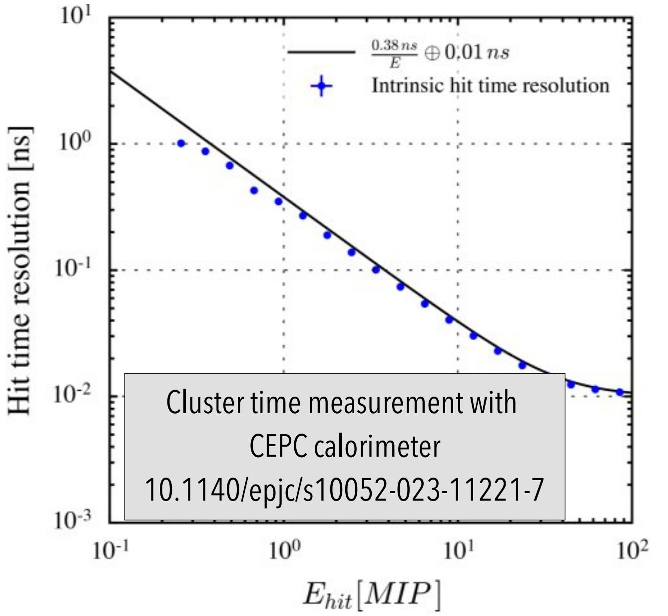


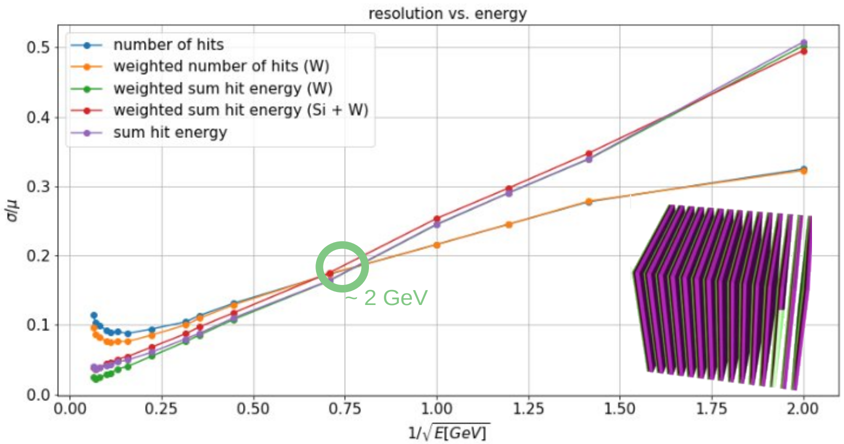
Fig. 6 The intrinsic hit time resolution as a function of the energy deposition in the silicon sensors. The black solid line is the model of CMS measurement [1] and the blue dots are the result of the digitization in the 10 GeV μ^- samples.

Re-optimisation

Resolution optimisation

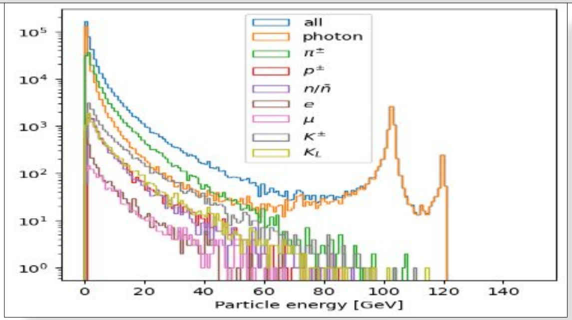
Better $\sigma(E)/E$ for photons from hit-counting for $E\gamma \leq \sim 2$ GeV

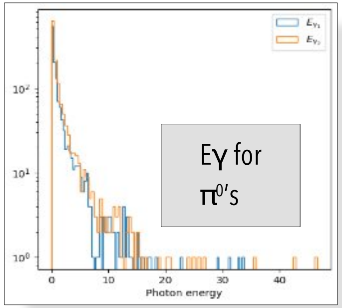
- Results on the simulated 2022 BT set-up [F. Jimenez & summer students]



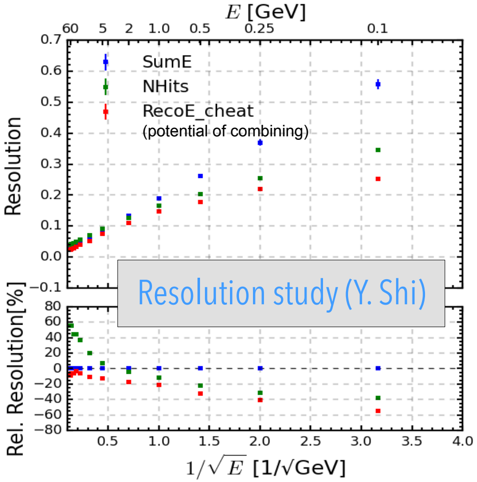
Seen in 2009 (M. Reinhard, PhD) but somehow never integrated in optimization

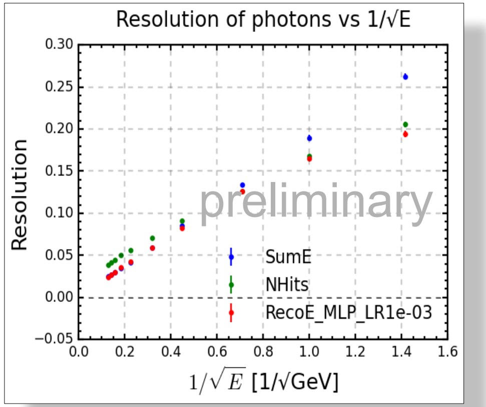
Event composition (ee→ qq @ 240 GeV) [H. Liang]





Re-evaluation on flexible (uniform) toy model





Detector RAW Performances Optimisation

Inclusive Energy Reconstruction Methods

- **Ongoing** : effects of
  - Thresholds (0.1 – 1.5 MPV of a MIP)
  - Silicon thickness (150 – 750 µm)
  - Cell size (1 mm – 20 mm)
  - Sampling fraction (*n* layers with const. W thickness)
  - Total thickness (fixed Sampling fraction)
- **To be done**:
  - Go non-uniform (optimal W thicknesses for *n* layers)
  - Optimal configs for angular resolution
  - Optimal configs for cluster time reconstruction
  - Test other technologies

Possible Outcomes

- Need for dedicated front layers, e.g. LGAD in first *n*~5 layers ?
- Replace the last Si layers by [**技术**]

[技术] = place here your favorite technology!

Overall performances: High-Granularity for some final states

Work by JC. Brient (LLR)**

1. Bs → Ds $\pi^\pm$, Ds $K^\pm$
2. $B^0 \to \pi^0 \pi^0$
3. Transition from quark $b \to s\,\gamma$
4. τ physics rare decays
5. τ polarisation and AFB measurement

Based on fast simulation:
rare events = millions of events needed

Charged tracks reconstruction,
- 100% efficiency above $0.15\,\text{GeV}$ Pt is used
- resolution is taken as $\delta P/P^2 = 10^{-4}$
  (a little bit more pessimistic than ILD official value)
- k/π id. Larger than 3σ up to 15 GeV
- d0 track resolution 15 μm
- vertex (2 tracks) resolution at 20 μm

Photons reconstruction**

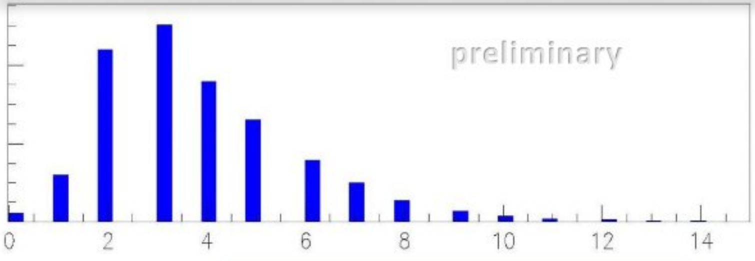
- $\Delta E/E \sim 16\%/\sqrt{E} \oplus 0.5\%$ (standard SiW)
- detector performances based on Full Simulations studies on 5D calo (x,y,z,E,t)
  - Threshold ~ 50 MeV
    ($\varepsilon = 70\,\%$, $100\,\%$ @ 150 MeV)
  - No mis-ID γ/π^0 if dist.>1.5
  - Impact Position resolution < 1mm at $E\gamma$ > 1 GeV

* Detailled report from here:
Performances of ultra granular ECAL for flavor physics at ILC, LCWS25

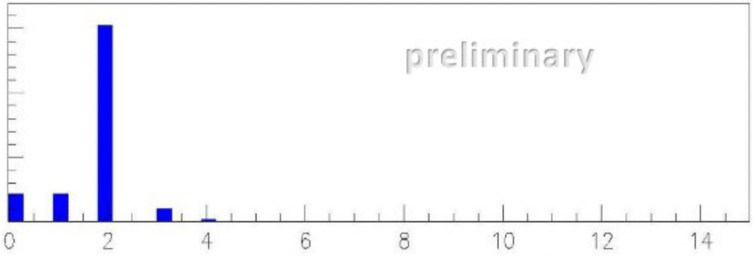
** See details at DRDCalo Ancona meeting

Bs → Ds π±, Ds K± with Ds → φρ → K+K- π±π0

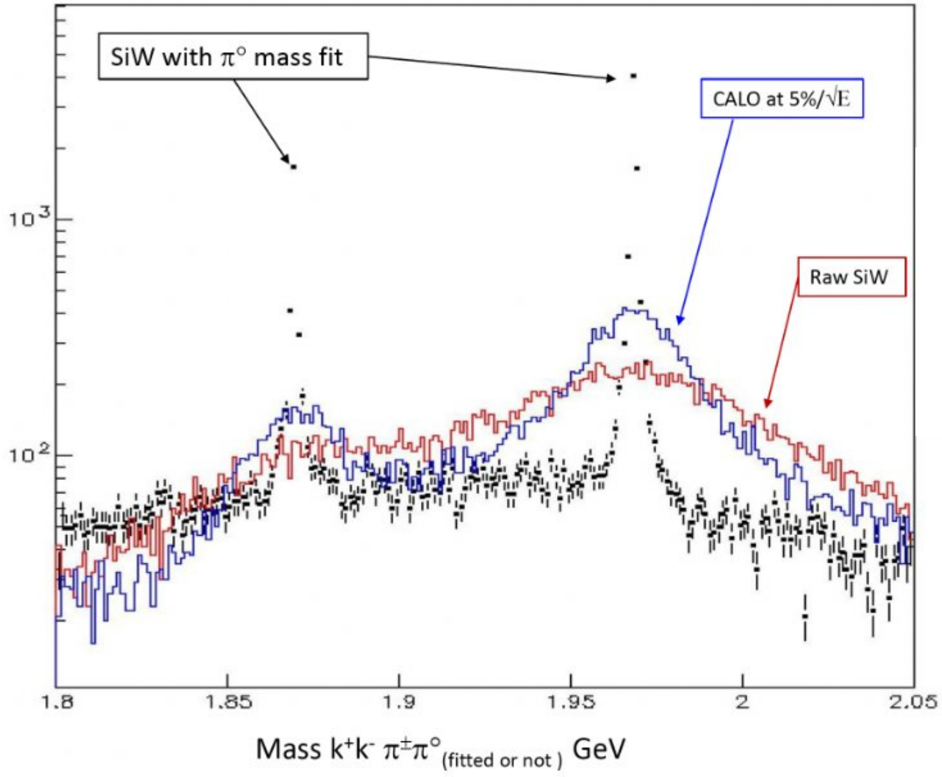
- The events are split in 2 hemisphere with the Thrust axis
- select a displaced vertex with $K^+K^-\pi^\pm$ ($K^\pm$) in one hemisphere
- Select the φ mass region for K^+K^-
- Define the jet direction as the direction of $K^+K^-\pi^\pm$ ($K^\pm$)
- Photon(s) in the cone such cosine(γ/jet)>0.75



Number of photon(s) in the jet



Selected photon(s)



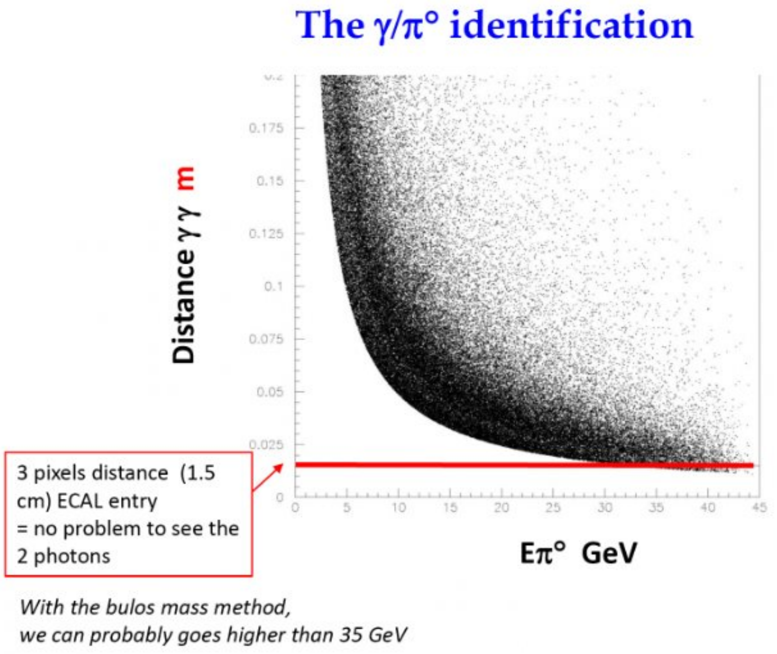
How good is the selection?

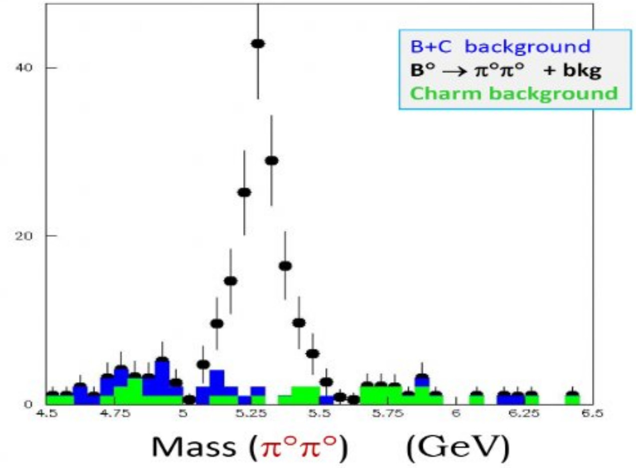
$B^0 \to \pi^0\pi^0$ and $B^0 \to K^*\gamma$

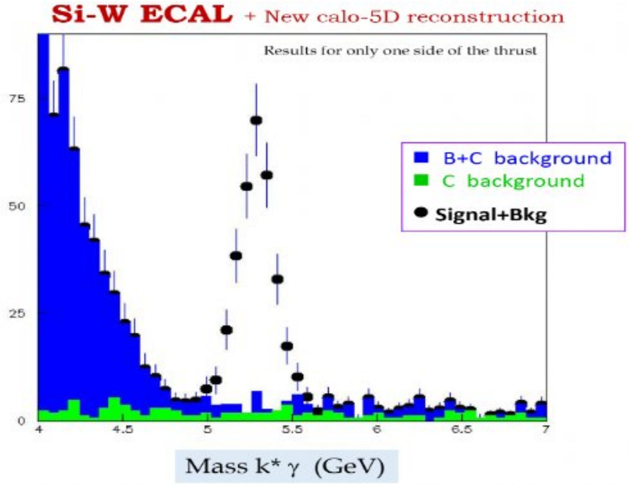
Selection on tracks + γ/π^0 identification:

→ "Background free" (90% purity) measures

- Detailled report from JC.Brient here:
  Performances of ultra granular ECAL for flavor physics at ILC, LCWS25

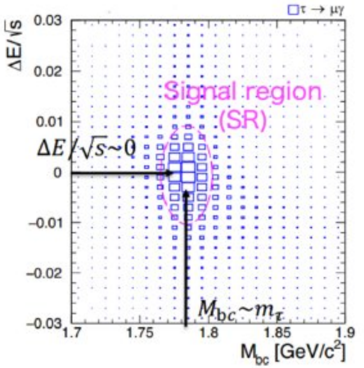






τ physics rare decays

Example: τ ➞ μγ



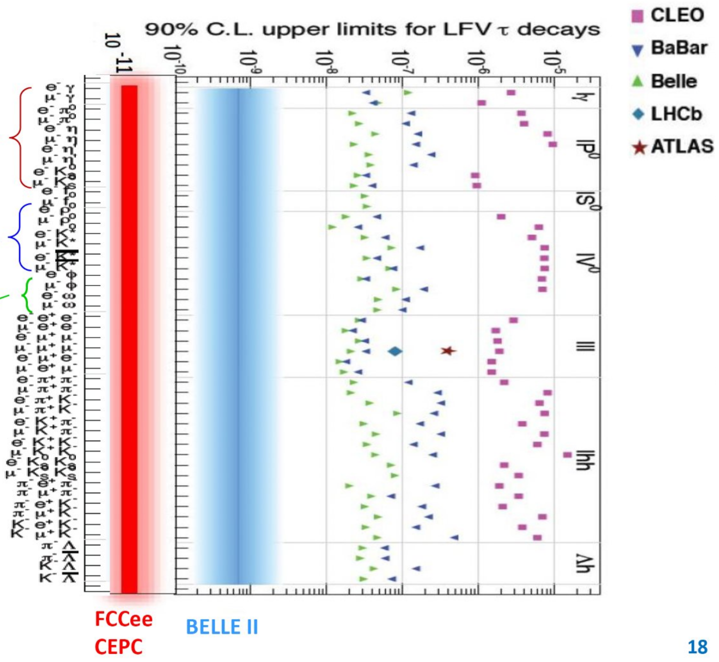
signal region

- $M_{\rm bc} = \sqrt{(E_{\rm beam}^{\rm CM})^2 - \left(p_{\ell\gamma}^{\rm CM}\right)^2} \sim M_\tau$
- $\Delta E = \left(E_{\ell\gamma}^{\rm CM} - E_{\rm beam}^{\rm CM}\right) \sim 0$ GeV
- for background $M_{\rm bc}$ distribution will vary smoothly without peaking
- signal region is blinded during the analysis!

Many channels requiring a very good $\gamma/K^0{}_L/n$ and γ/π^0 ID

- BC mass,
- γ/π°,η Identification
- Meson mass fit (π°, η)

- BC mass,
- γ/π°,η and γ/K° Identification
- Meson mass fit (π°, η)



BC for Beam Constraint

18

Idem for τ polarisation: γ counting is critical

➞ low threshold and high granularity as in SiW is a game changer

Conclusion: The end of Adolescence… welcome Adulthood

The SiW-ECAL alteady has long life:

- More than 20 years of development
  - Some children growing : CMS HGCAL

Teen age approaches its end…

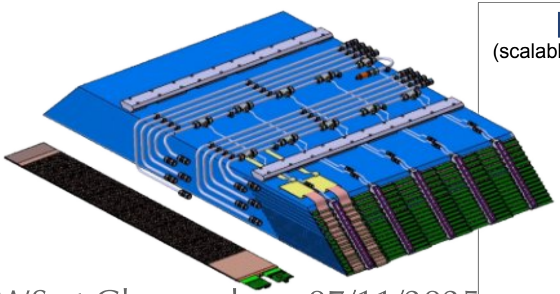
- Technological development in final phase
  - Ultimate Tests with legacy ASICs in 2026
  - New electronics on the making
- Ideal moment to reconsider initial choices
  - Full potential is being re-explored and extended
    - e.g. power of high-granularity for γ/π^0
- 1st 'Real' Job: **EBES, LUXE**, **Lohengrin, SHiP**

Getting ready for large scale prototyping (2029–2032)

Many opening for new ideas:

- New Beam Test data in June 2026
  - Place for classical and Innovative Analyses
- 1st applications
- Usage of 'Centimetric Timing' (~30ps for MIPs)?
- Hybridization with new technologies?
  - e.g. LGAD, MAPS, Crystals, Scintillators, …
- Industrial methods and partners

Join the adventure...



Pilote (scalable proto. in FCC-talk) ➡ **Full Detector**

- 1M ➡ 70M channels
- on 725µm 12×12 cm² 8" Wafers ?
- Pre-industrial building
- Full integration (⊃ cooling)
- **Final ASIC**

Back-up

LUXE

Physics:

- QED in High Fields:
  $e+n\gamma \rightarrow e\gamma,\ \gamma+n\gamma \rightarrow ee$
  - Schwinger's limit
- BSM: Axions Like Pseudo Scalar, …

Beams:

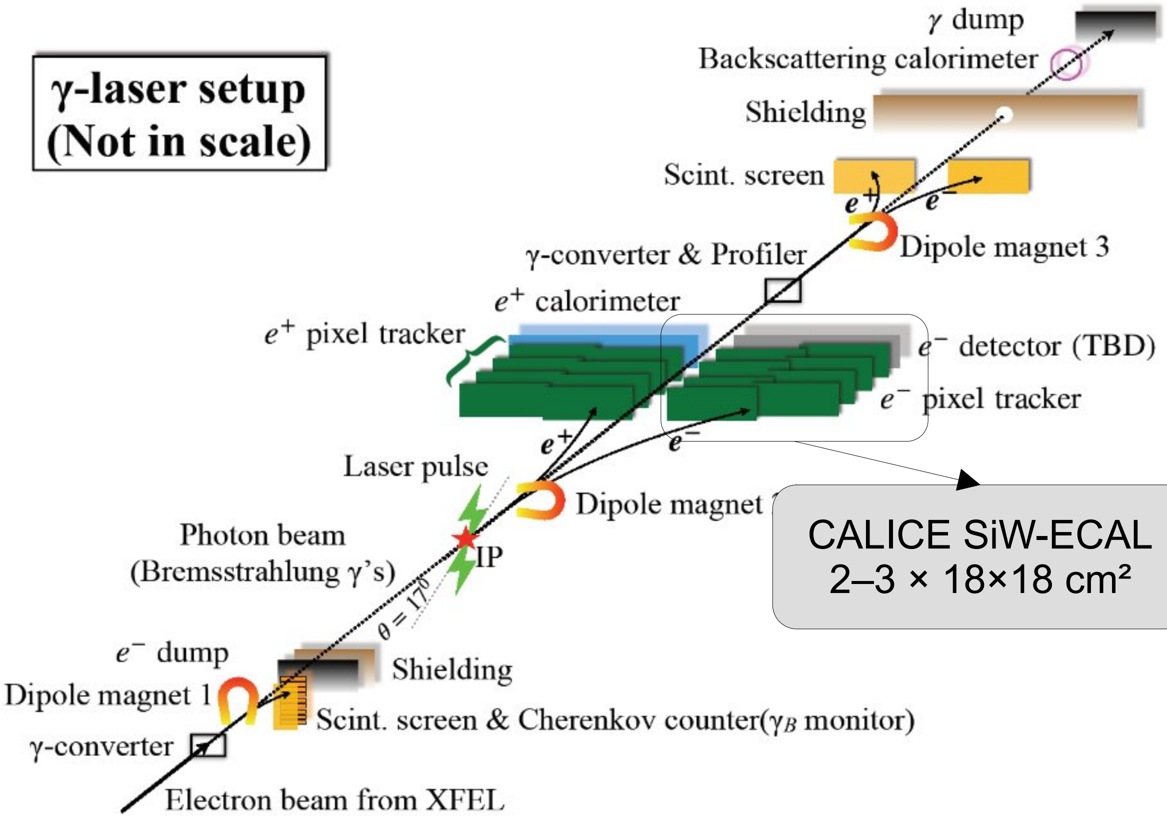
- **XFEL beam 10 Hz,** $1.6{\cdot}10^{9}$ e^{-}, $E_e \leq 17.5$ GeV
- Laser : 40–350 TW, 30 fs, 1 Hz → $1.5{\cdot}10^{20}$ W /cm³
- ≥ 2025 at DESY/XFEL

ECAL's:

- 5×5 mm² cells, 20 X_0, 12? layers, 20 %/√E
- Si+W or GaAs+W → FCAL and/or CALICE

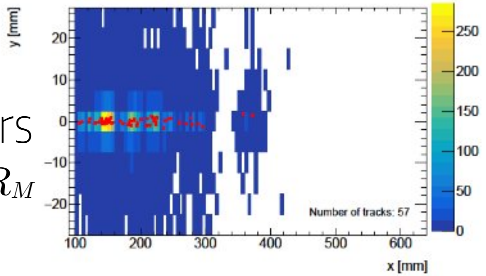
Q? Optimal sampling for Ee ≤ 17.5 GeV ?

- ⊃ Hit counting, shower separations

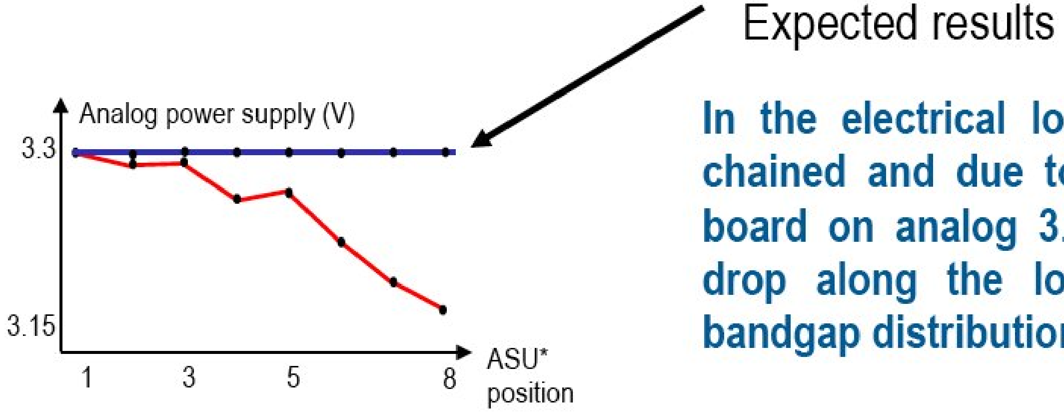


CALICE SiW-ECAL
2–3 × 18×18 cm²

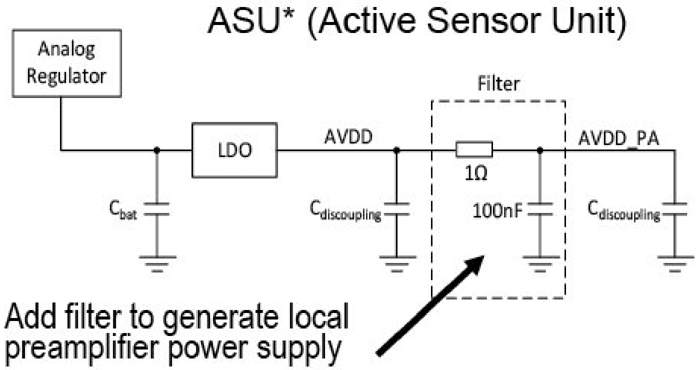
Overlap of showers
$E(x, z) \rightarrow$ Small R_M



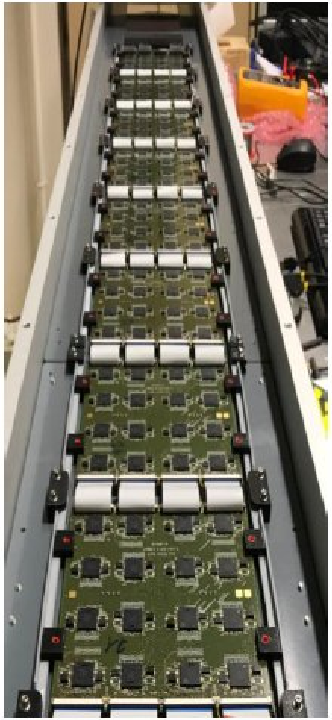
Power distribution dedicated for LONG SLAB (2018)



In the electrical long SLAB, 8 boards are chained and due to resistivity of layer per board on analog 3.3V, we measure voltage drop along the long SLAB coupled with bandgap distribution.



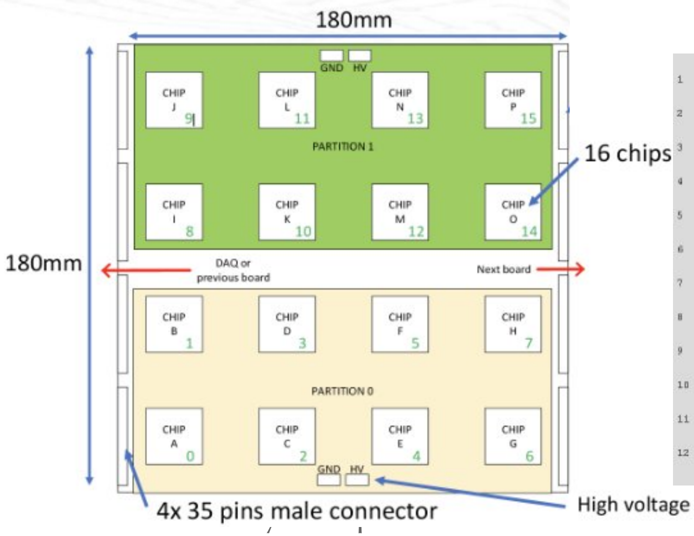
→ We decide to generate local power supply with LDO (Low Drop Out) to cancel voltage drop and reduce common noise.

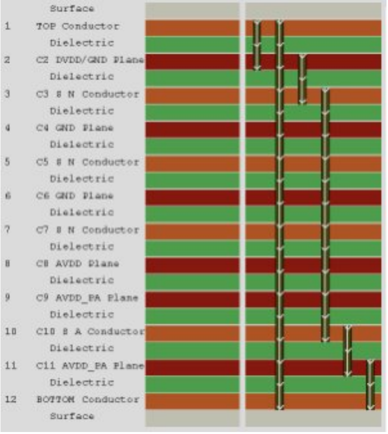


FEV's : 15 years of R&D

Most complex element:
electrical-mechanical integration

- Powering, Distrib / Collect signals from ASICs, Analog & Digital with dyn. range ≥ 7500
  - Single End operation ➞ Chaining for 8–10 boards
- **Mechanical** placer & holder for Wafers
  ➞ ≤ 50µm lateral precision, flatness
- **Thickness** constraints ➞ Calorimeter Compactness





Milestone	Date	Object	Details	REM
1st ASIC proto	**2007**	SK1 on FEV4	36 ch, 5 SCA	proto, ≤ 2000 mips
1st ASIC	2009	SK2	64ch, 15 SCA	3000 mips
1st PCB proto	**2010**	FEV7	8 SK2	COB
1st working PCB	2011	FEV8	16 SK2 (1024 ch)	CIP (QGFP)
1st working ASU in BT	**2012**	FEV8	4 SK2 readout (256ch)	S/N ≤ ~ 14 (H Gain), no Power Pulsing retriggers 50–75%
1st run in PP	2013	FEV8-CIP		BGA, Power Pulsing
1st full ASU	**2015**	FEV10	4 units on test board 1024 channel	S/N ~ 17–18 (H Gain) retrigger ~ 50%
1st SLABs	2016	FEV11	10 units	Noise issues
pre-calo	**2017**	FEV 11	7 units	S/N ~ 20 $(12)_{\text{Trig,}}$ 6–8 % masked
1st technological ECAL	2018	FEV11, 12 13 Compact Calo Long Slab	SK2 & SK2a (⊃timing) 8 ASUs	Improved S/N Timing enabling
1st working COB, new DAQ	2019	FEV-COB	2×1/4 ASUs Cont. power.	Technical
2nd tech ECAL	20–22	5 types FEV's	H. Gain, Cont. Power	320, 500, 650 µm

Going from 30 to 26 Layers & 500 →725 µm : performances

Going from 30 to 26 layers

- Reduction of cost; increase of Energy resolution
  - keep $24X_0$ (84mm) of Tungsten

Increasing the Si thickness to 725µm

- GR width ↗ ⇒ go to 8″ wafers, new design

Energy resolution σ(E)/E:

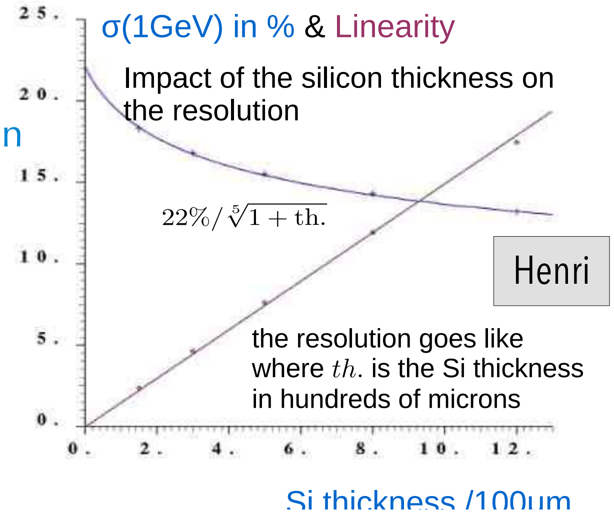
- for 26 layers w.r.t. 30: ↗ +8.5%
- with 725µm w.r.t 500µm : ↘ –6.6% (-8.7% wrt to DBD 300µm)

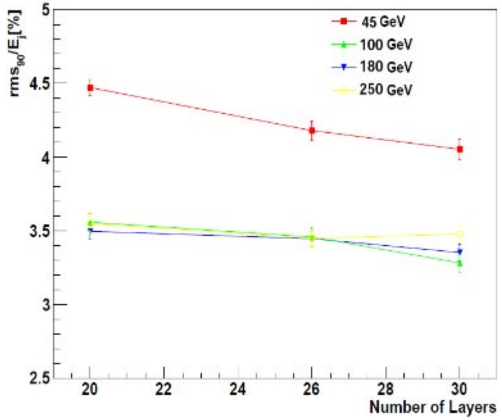
near compensation

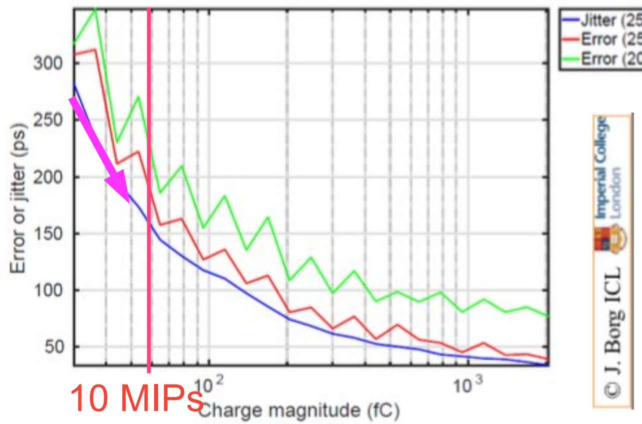
Time Resolution ?

- Noise ~ C_{det} ~ width²/th, Signal ~ th ↗ ➞ S/N ~ th² ~ ×1.5 ?

  ⇒ Improved timing perf (esp. for mips)

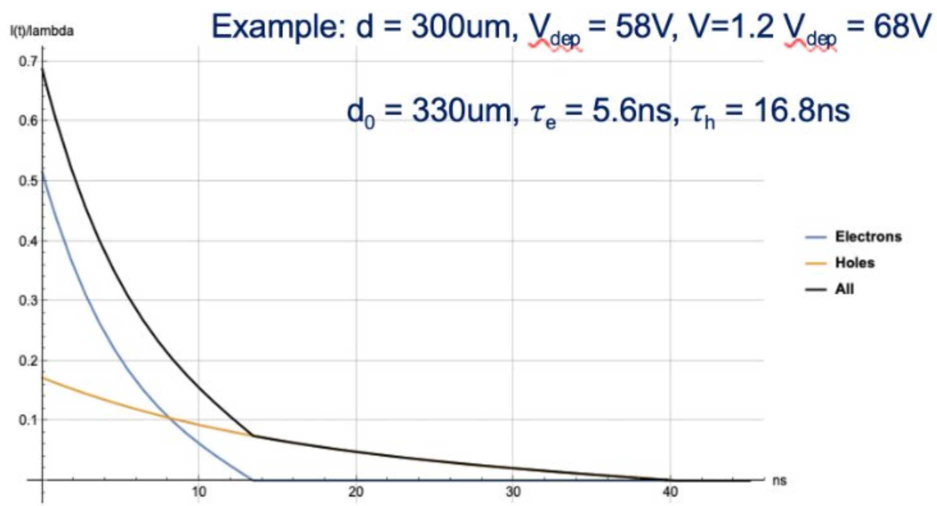


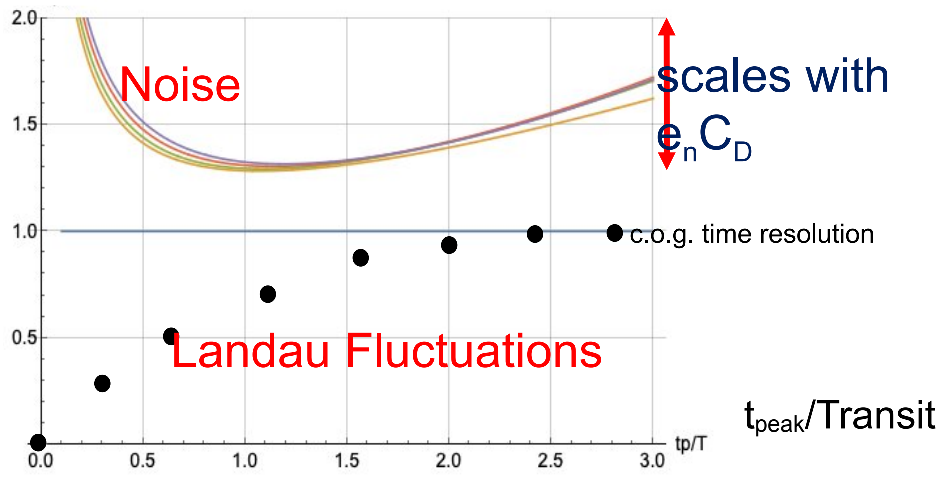




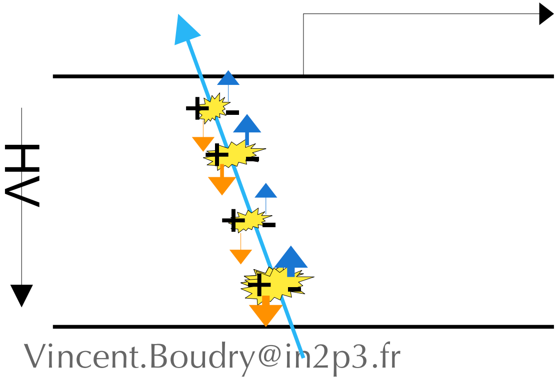
C. de La Taille Front-End elecectronics CHEF 2017

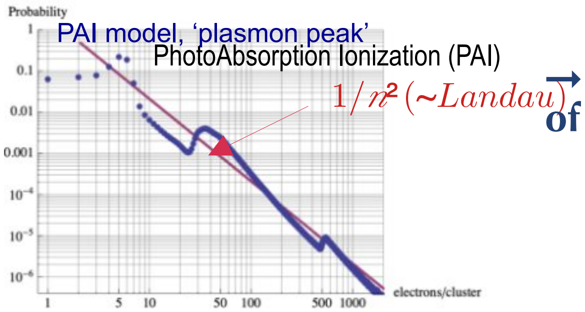
Time measurement *in Silico*





Landau Fluctuations ⊕ Noise





→ optimal thickness of sensors (T ↔ thickness) to be determined

S. Riegler

Going from 30 to 26 Layers: performances

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- Reduction of cost; increase of Energy resolution
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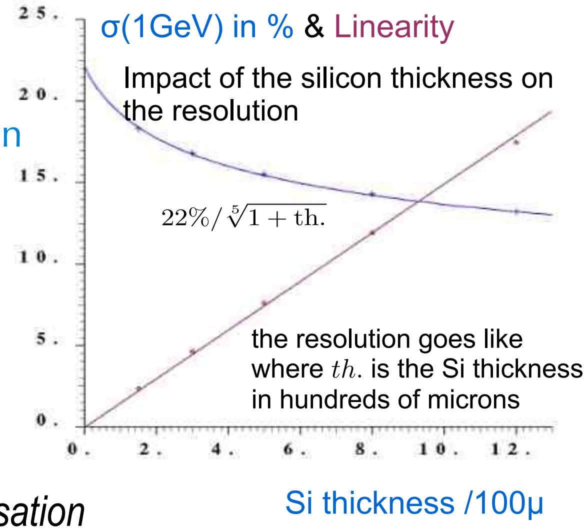
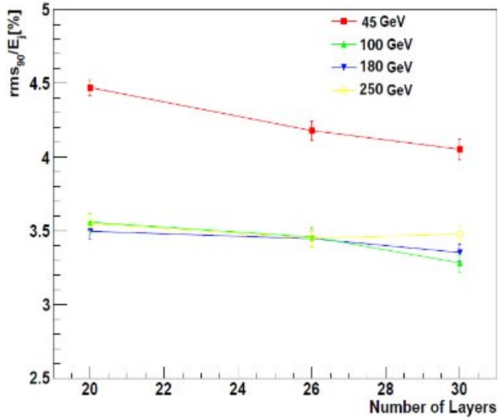
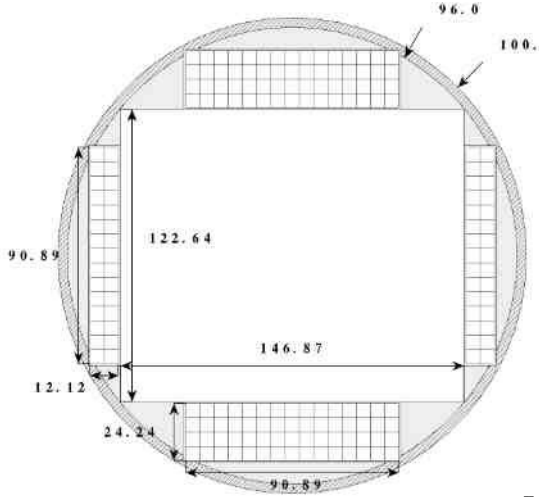




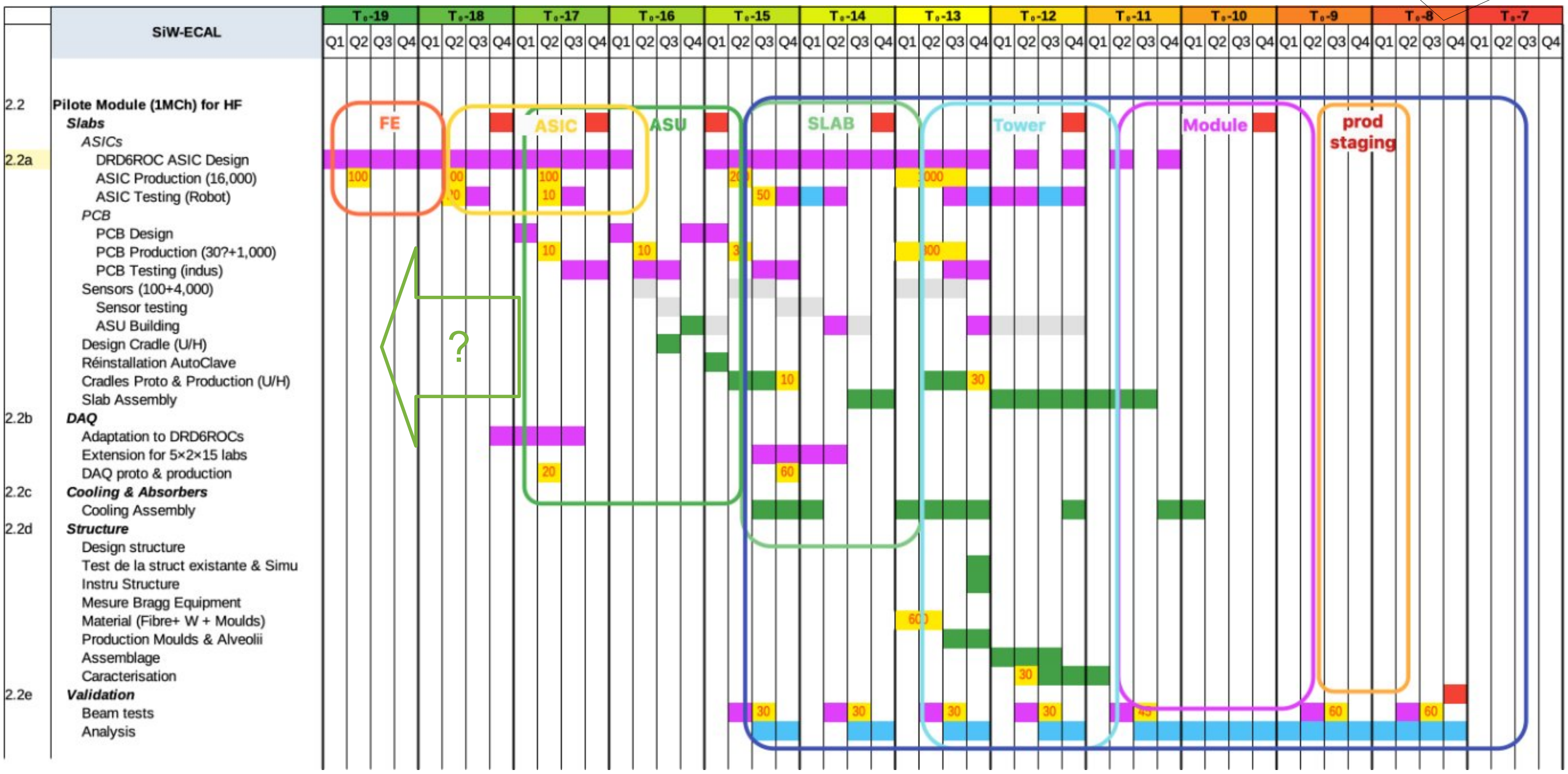


Study needed on dead zones (larger GR...), separation, resolution and efficiency performances at low energy.

- eg: JER : $\sigma(E_J)/E_J$ +6% for 26 layers (500 µm) to be redone...
  Shown @ 6th ILD Optim meeting (16/07/2014) [link]

Planning towards a pilot module… *just in case*

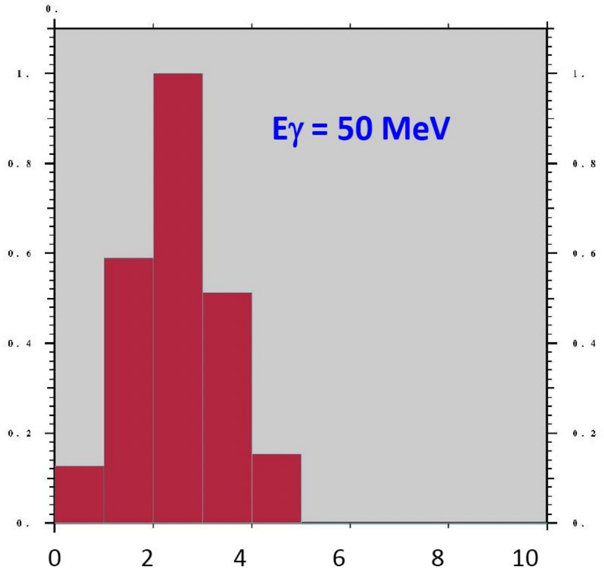
T_0-8 : production start



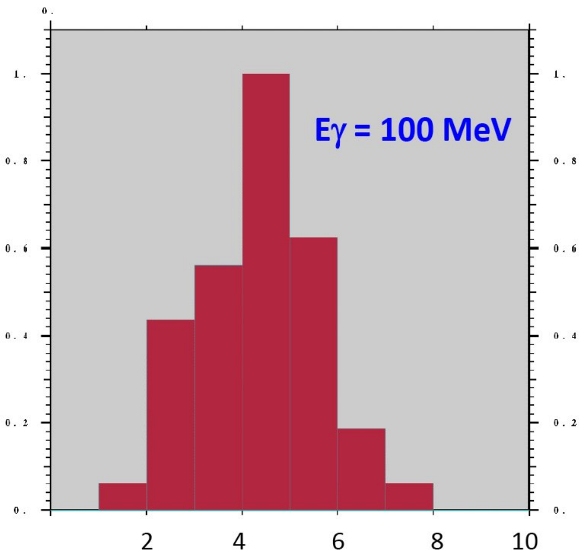
	T_0
FCCee	2045–48 ?
CEPC	2035 ?
ILC	2040 ?

Low-E Photon response (ILD standard SiW-ECAL)

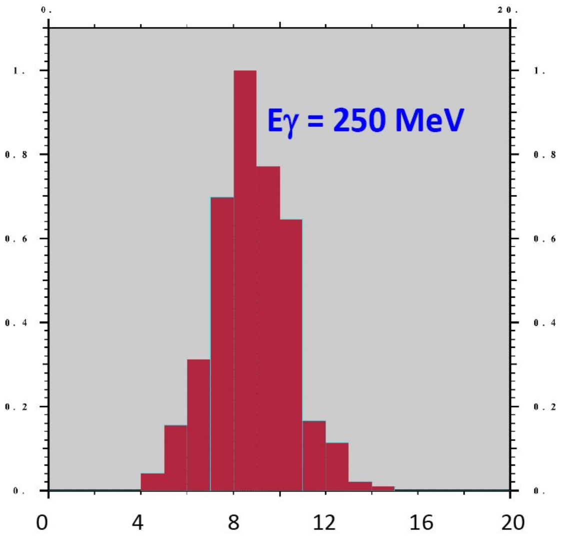
Number of layer(s) for e.m. shower in SiW ECAL



70% with 2 or more layers



90% with 2 or more layers

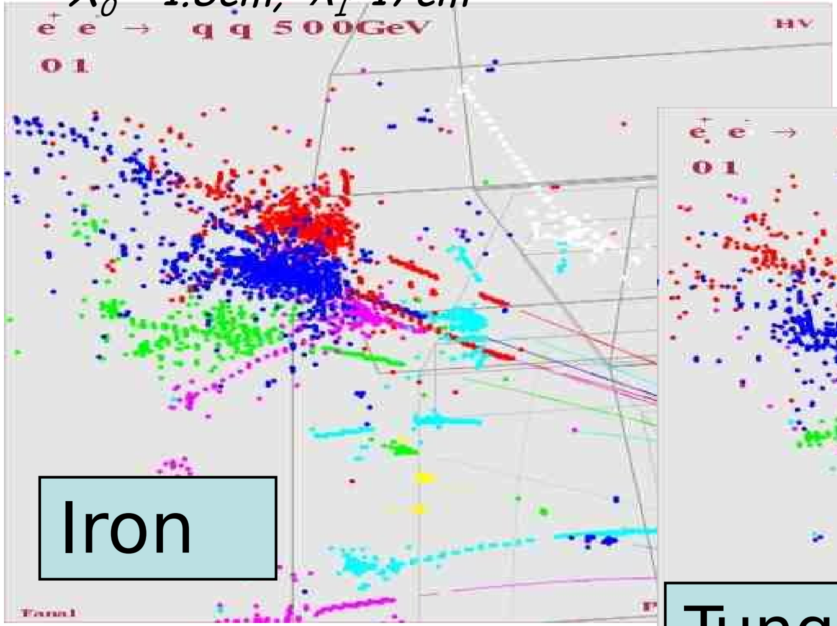


100% with 2 or more layers

Choice of Absorber Material - Tungsten vs. Iron

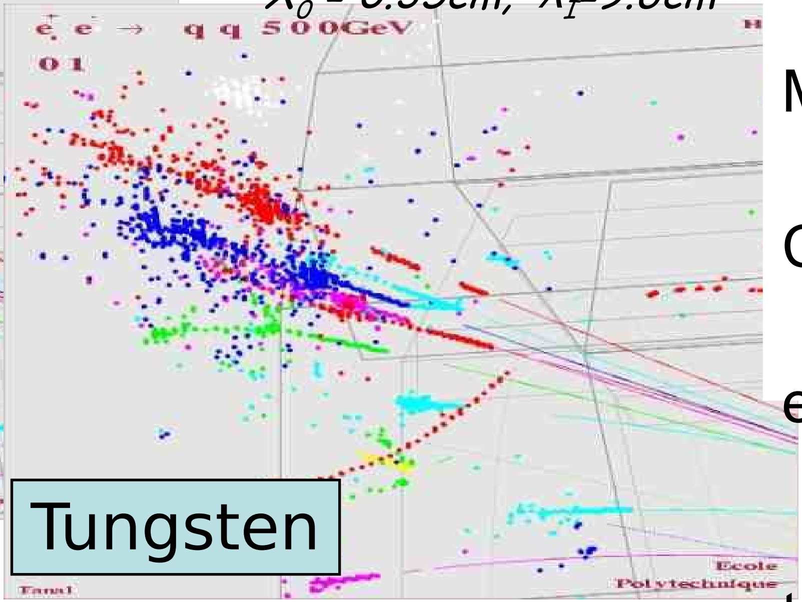
elm./had separation:
keep X_0 / λ_I small

X_0 = 1.8cm, λ_I=17cm



(images courtesy H.Videau)

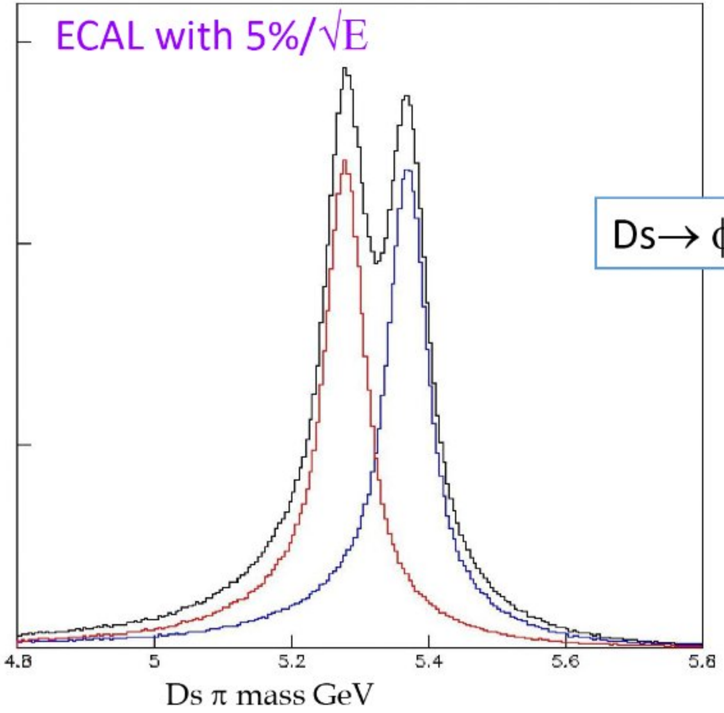
X_0 = 0.35cm, λ_I=9.6cm



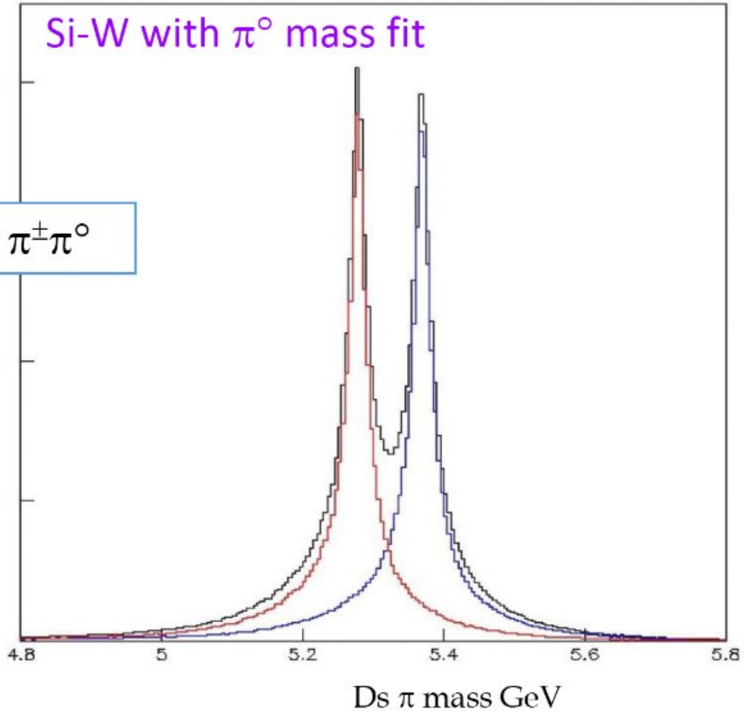
- Molière Radius for W: R_M = 0.9cm
- Cell Size need to match R_M !
- effectively a factor (1 + Gap /2.5mm) more
- technology challenge: thin readout gap

How it affect B°- Bs separation

Full sim. + Recons. ECAL-5D + Fast Sim.



Ds→ ϕρ→ k^+k^- $\pi^{\pm}\pi^{\circ}$



For final state Ds π, B^0 vs Bs ,

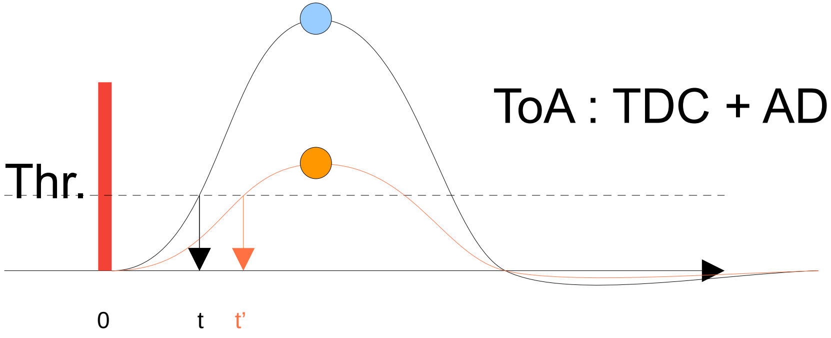
the separability is **0.7σ** when using ECAL with ΔE/E= 5% / √E (crystal like)

This value become 1.6 σ , when using ultragranular +fit π°

$\sigma^2 = \sigma_1{}^2 + \sigma_2{}^2$, σ_1 (σ_2) is the resolution on the Ds π mass for B0 (Bs)

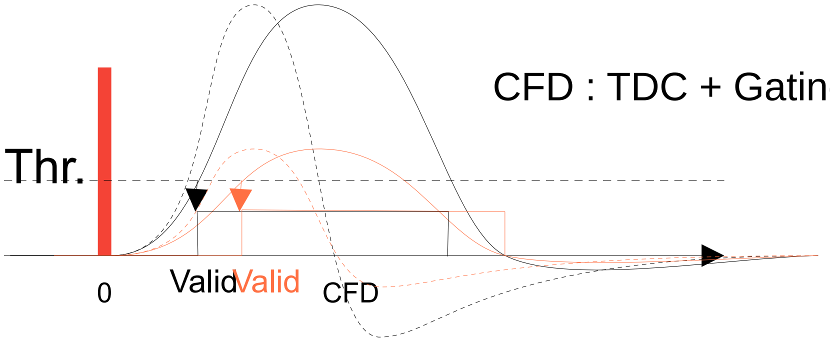
Time measurement methods

ToA : TDC + ADC



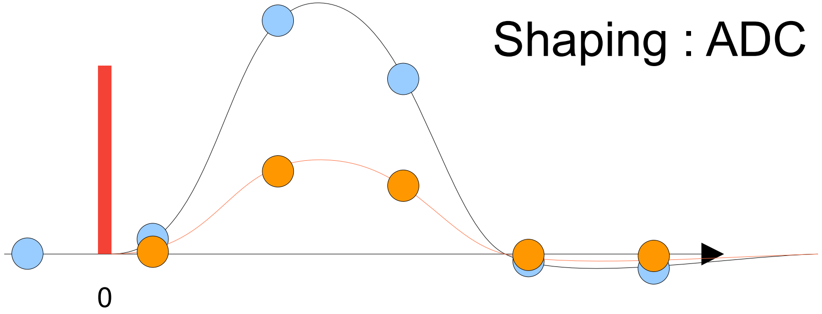
Slew time (vs amplitude)

CFD : TDC + Gating



Time ~ cst (vs pedestal, noise)

Shaping : ADC × *n*



Time fit (vs shaping)

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