/ DRD6

T1.1.1 : an SiW-ECAL for HET factories

Vincent Boudry for the SiW-ECAL groups

Institut Polytechnique de Paris

DI2I Presentation projet IN2P3 DRD6
04/03/2025

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

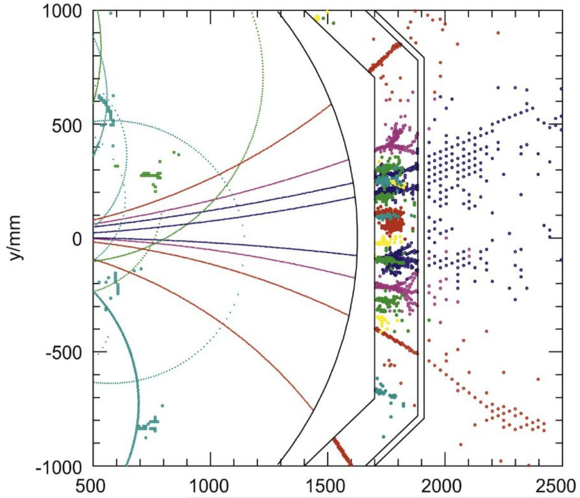
→ Highly Granular Imaging Calorimetry + Particle Flow Software

ECAL

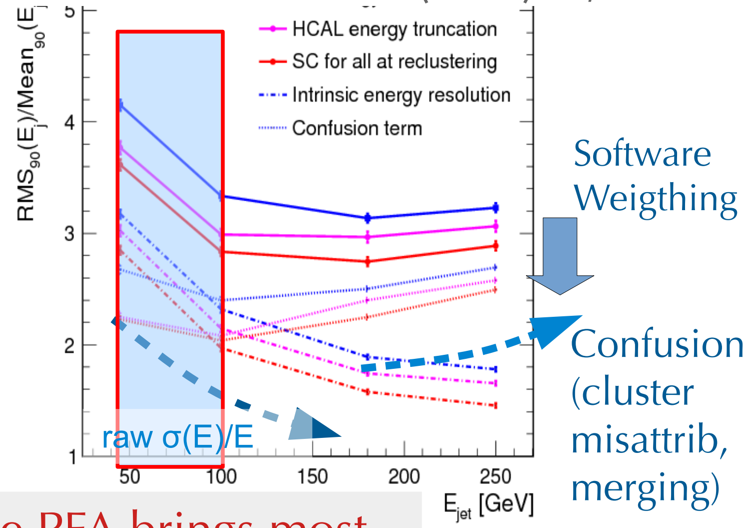
Particle Flow Algorithms :

- **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



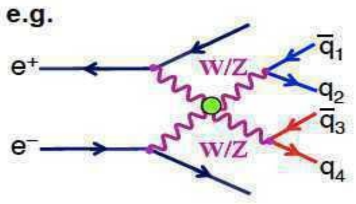
Low E jets ⇒ where PFA brings most

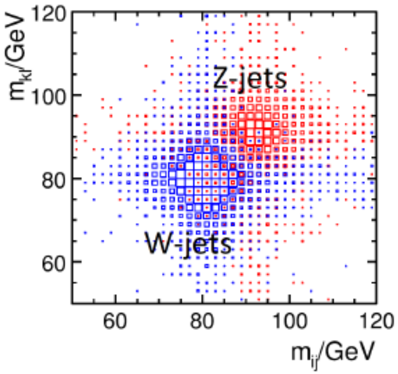
Particle Flow Detectors at Higgs Factories

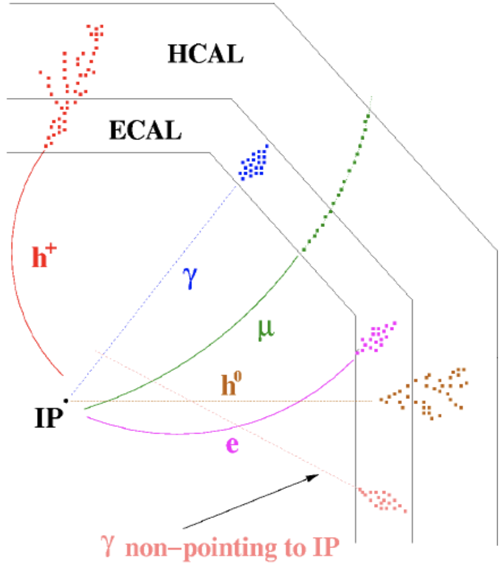
Basis: sep of H → WW/ZZ → 4j

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

⇒ σ_E/E (jets) < 3.8%







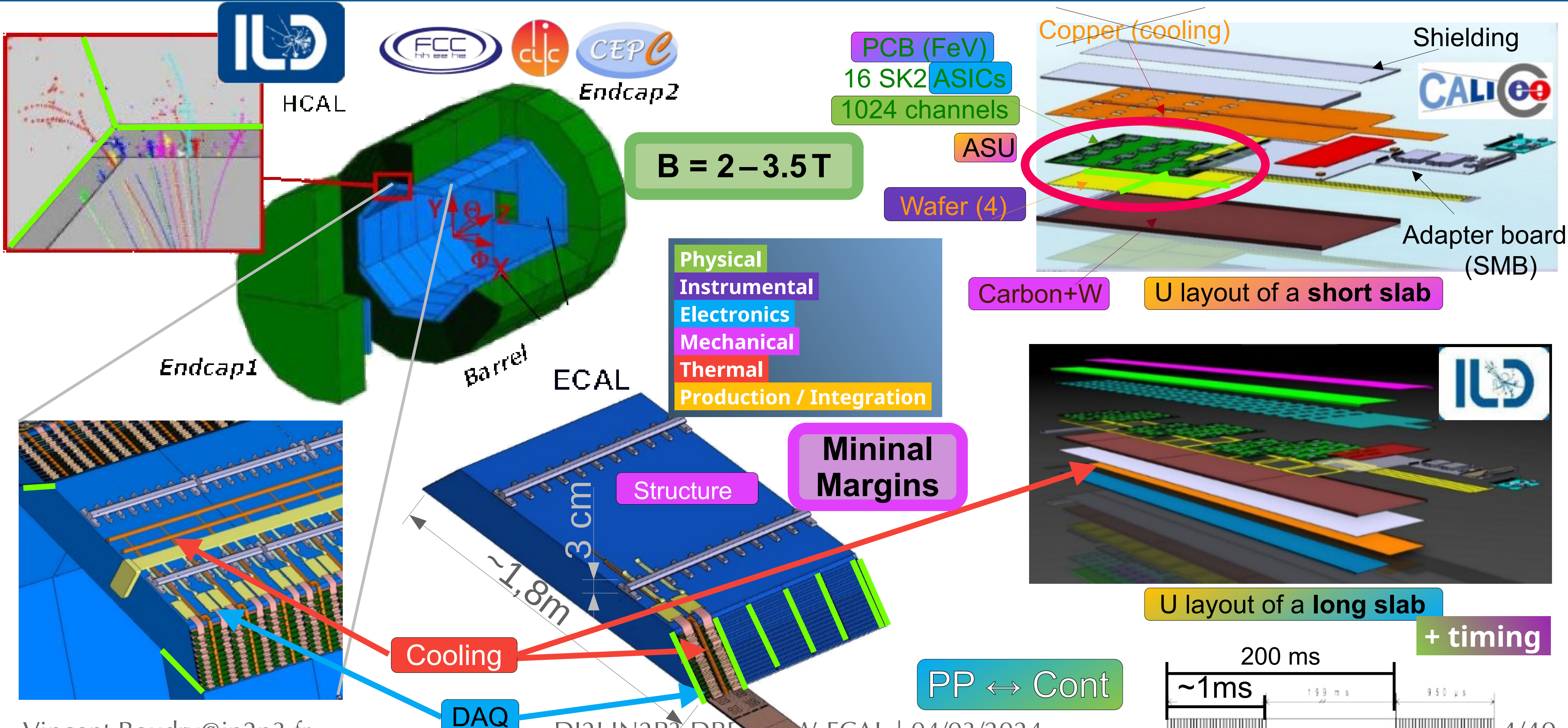
Particle Flow ECAL should :

- **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

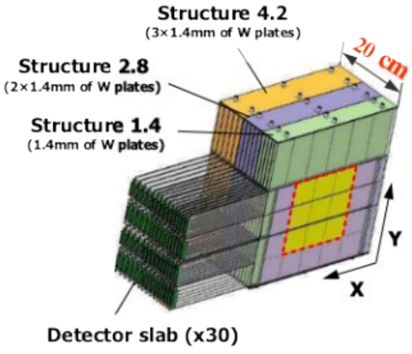
- **track particles & shower with centrimetric timing**

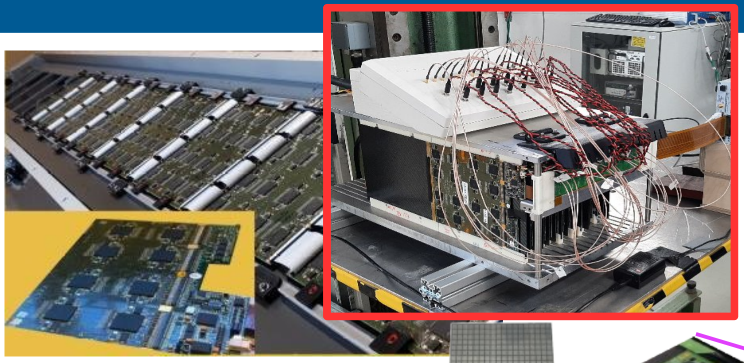
Design Constraints

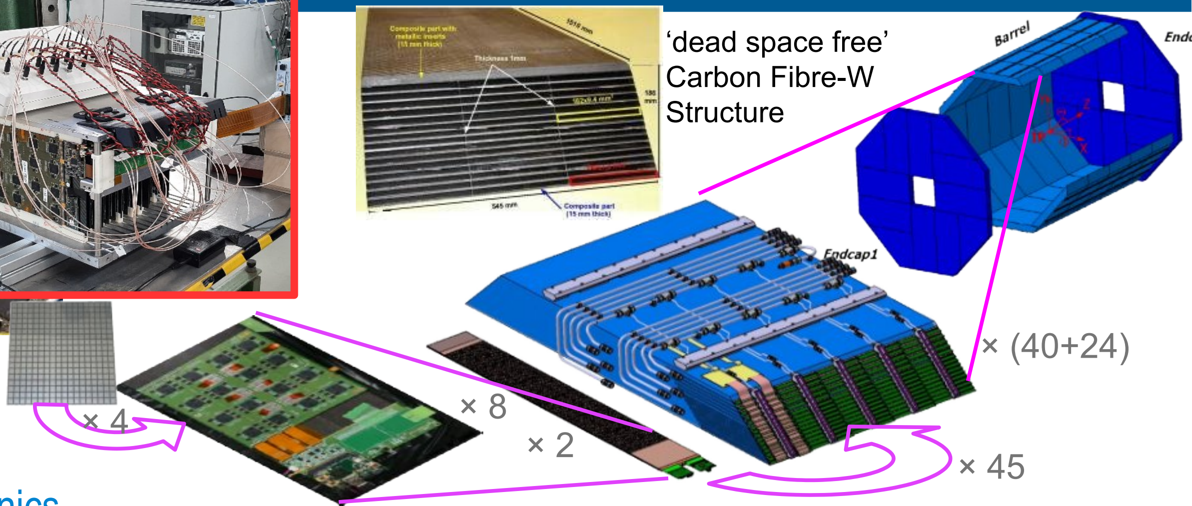


Prototyping and Testing

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

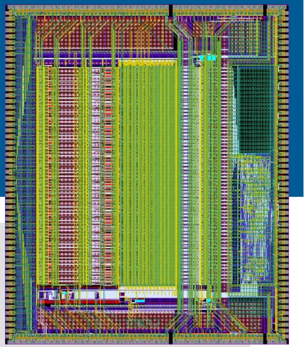
We are here

Pilote ➡ Full Detector

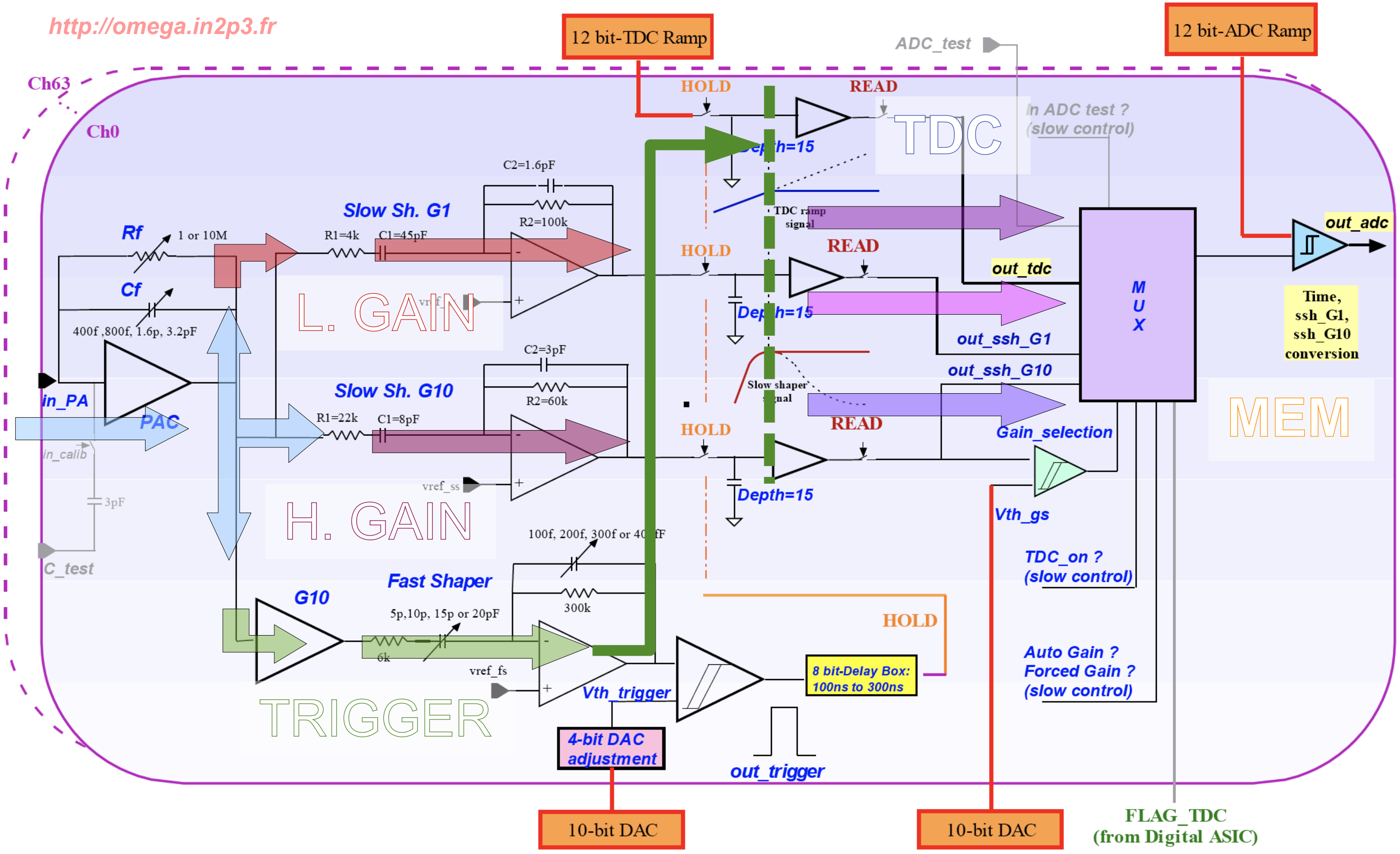
- 1M ➡ 70M channels
- on 725μm 12×12 cm² 8" Wafers ?
- Pre-industrial building
- Full integration (⊃ cooling)
- **Final ASIC**

'Almost ready' for LC
To be revisited for CC

SKIROC2/2A Analogue core for ILC (2012)

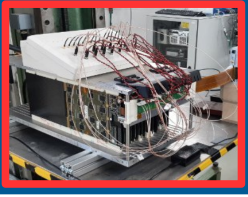


http://omega.in2p3.fr



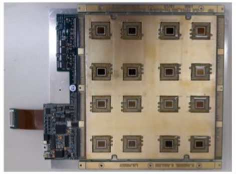
- **64 channels**
- **Auto-triggered**
  - per cell adj.
  - 1 cell triggers all
- Preamp
  + **2 Gains** + Auto-select
  + **TDC** (~1.4ns)
- 15 (×2) analogue memories
- Dyn range 0.1 ~ 2500 mips
  - mip in 320 µm (4 fC)
  - 12 bits ADC's
- *616 config bits*
- Low consumption
  - 25 µW/ch with 0.5% ILC-like duty cycle
- Power-Pulsed

Technological Prototype Beam test at DESY & CERN



FEV10, 11, 12

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



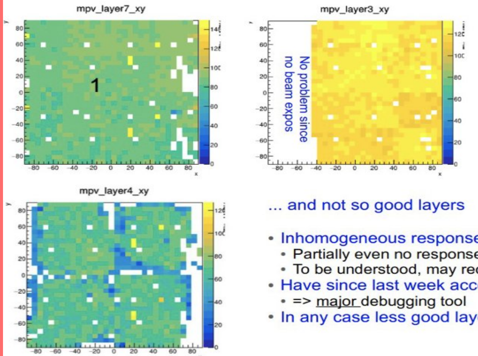
FEV-COB

- 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

2022 DESY & CERN BT

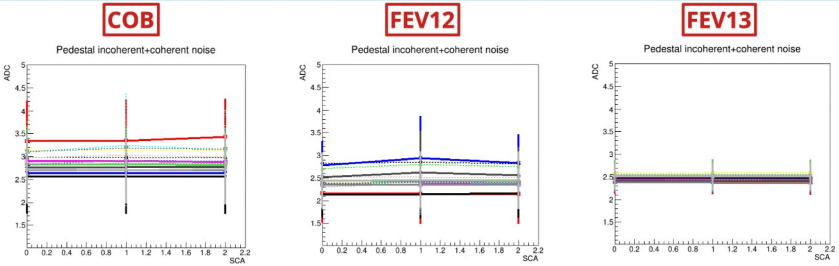


- We have good layers …
  - Homogeneous response to MIPs over layer surface
  - Here white cells are masked cells due to PCB routing
    - Understood and will be corrected

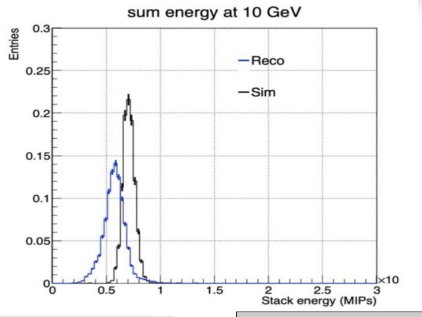
… and not so good layers

- 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

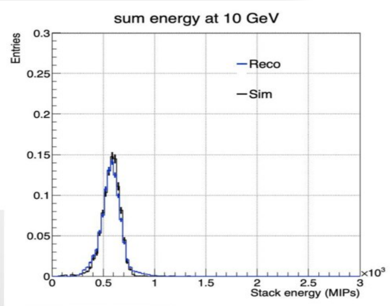
Pedestal widths, 1st memory cells, per asic



- (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



Masking Beam profiling



Yuichi Okugawa (PhD in Feb. 2024)

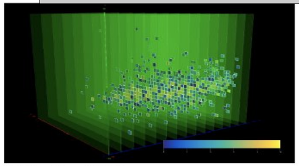


Fig. Simulation e- 100 GeV

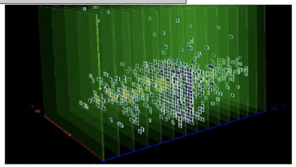
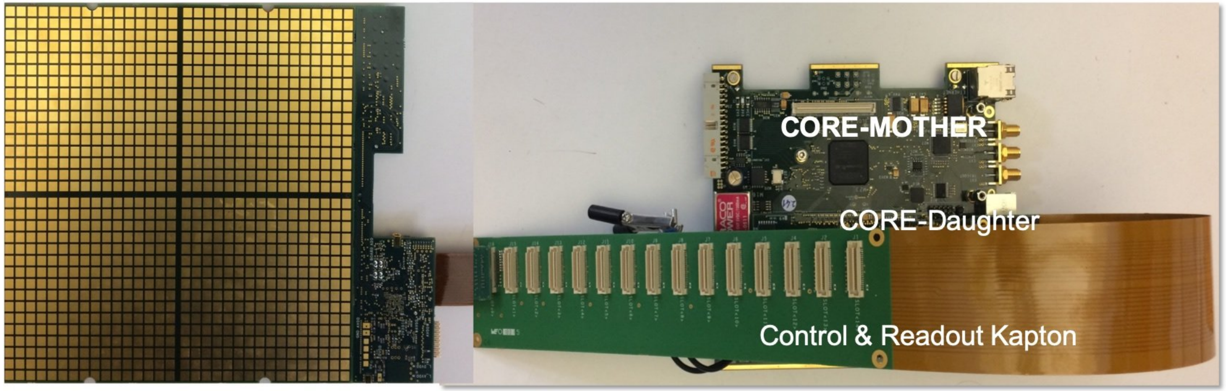


Fig. Reconstructed e- 100 GeV

Compact DAQ readout

D. Breton, D. Zerwas, J. Maalmi, J. Jeglot

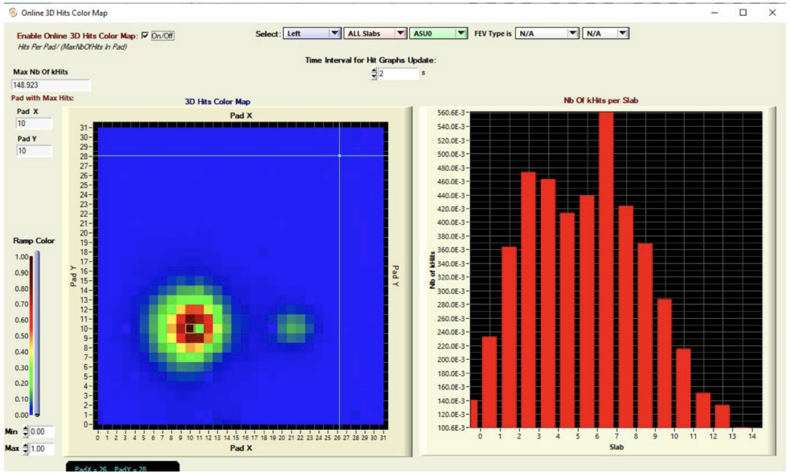


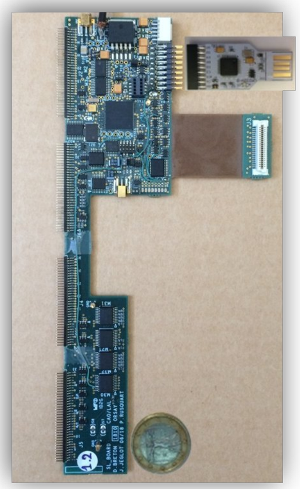
"Dead space free" granular calorimeters → ~ 30 mm space ECAL–HCAL

- Compact DAQ
- in use in BT since 2019

LabWindows + scriptings

- Full debug system
- ↔ EUDAQ
  - Combined running





AIDA innova

Acquisition software

Jihane Maalmi, Crystal
CNRS 2022

Written in C under Labwindows CVI

- Handle whole detector
- Two sides with 15 SLABs
- 5 ASU per SLAB

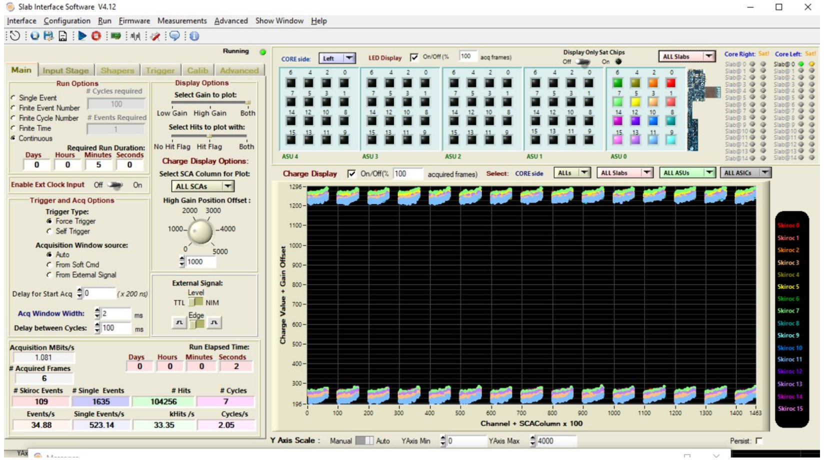
Make advanced measurements

Hardware automatically detected

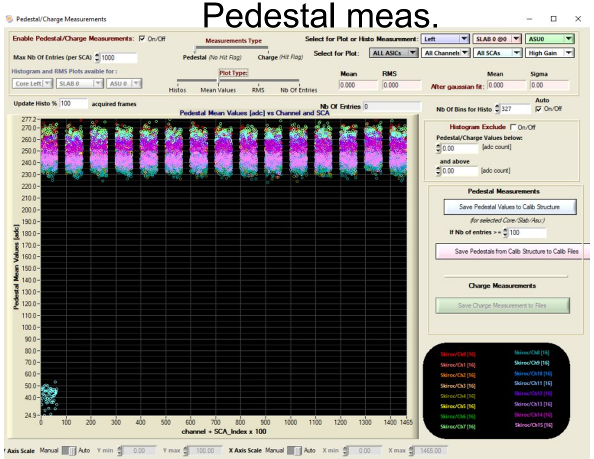
- Number of SLAB
- FEV type + number of ASU

Slow Control:

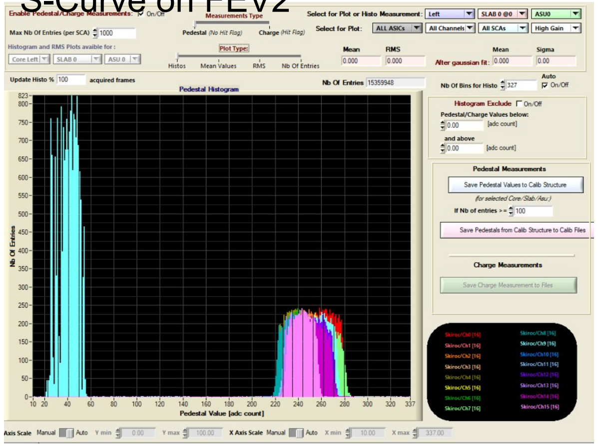
- All parameters programmable
- Integrated analysis



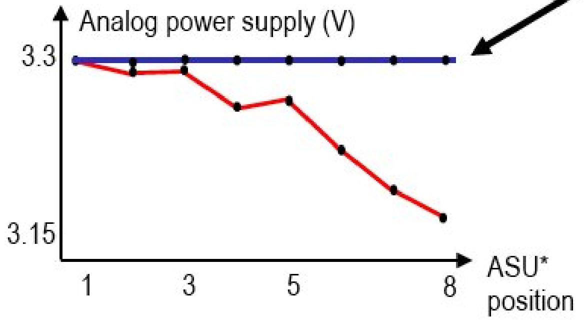
Pedestal meas.



S-Curve on FEV2

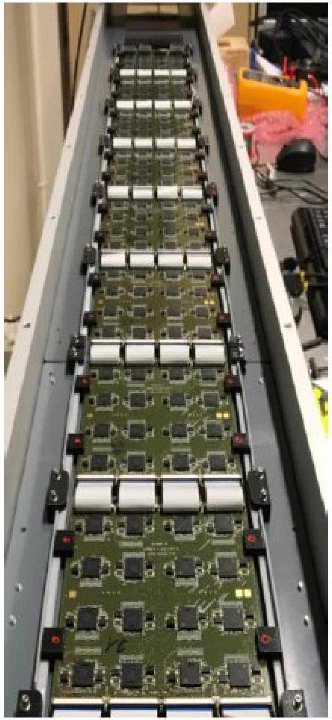


Power distribution dedicated for LONG SLAB (2018)

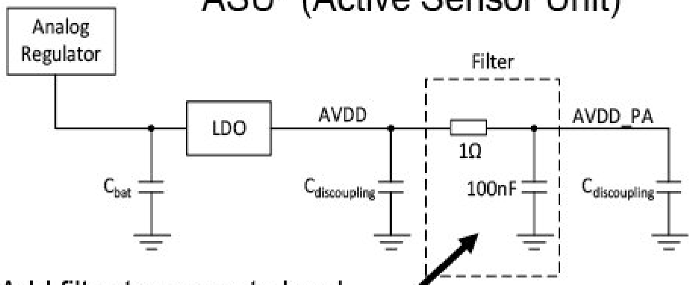


Expected results

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.



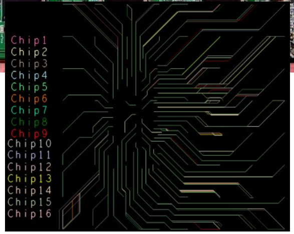
ASU* (Active Sensor Unit)



Add filter to generate local preamplifier power supply

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

New FE boards

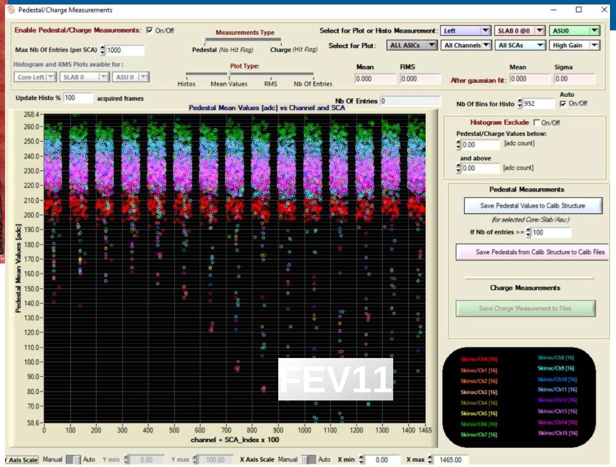


Improvements:

- 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

Status:

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



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

SIngle channel → the fault on the ASIC/packaging

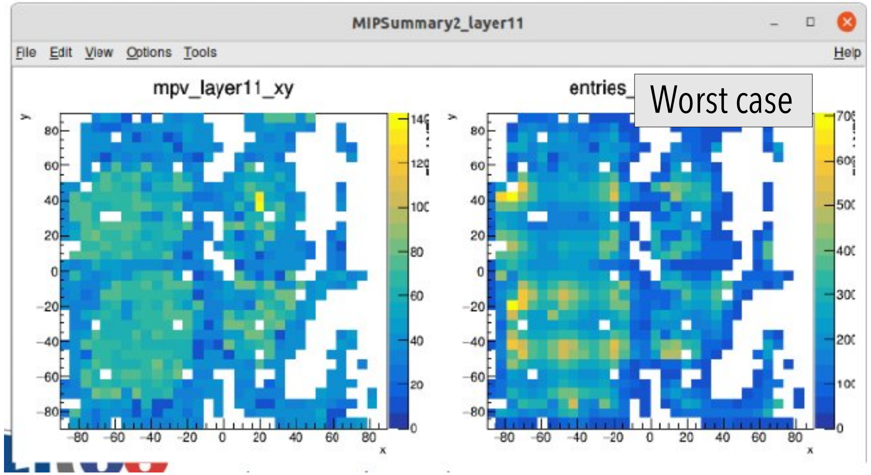
→ Homogenous prototype

Goal:

- 15 layers of FEV2.1 with 500 µm wafers
  - Uniform and more performant electronics
  - Could be used for Non-Lin. QED & Dark Photons experiments:
    - LUXE@XFEL (See Compact Calo pres.)
    - EBES@KEK
    - Lohengrin@ELSA
- All material available

Main issue: failing contacts PCB–Sensor

- Conductive glue dots of ⌀2–3mm
  - Strength ~ 1/5th of classical epoxy
- ~~Aging, mechanical stress, manipulations,~~ glue formula, small series, …

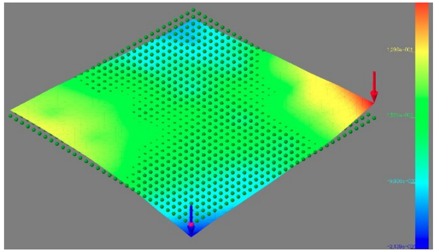


Hybridization studies :
How to assemble silicon sensors & PCB ?

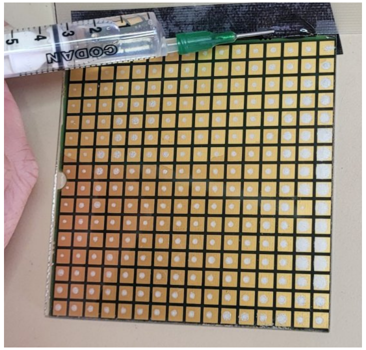
Revisiting gluing (IFIC, IJClab, DMLAB)

- 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

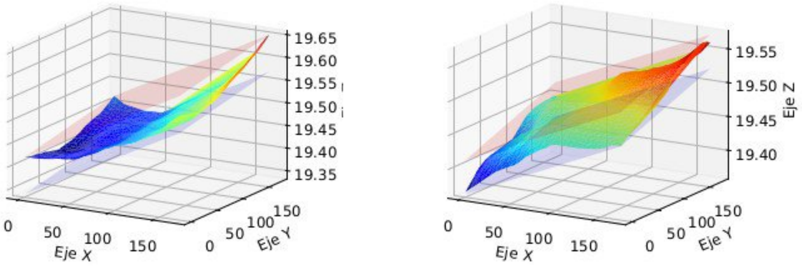


Flatness of PCB

ISOMETRIC VIEW

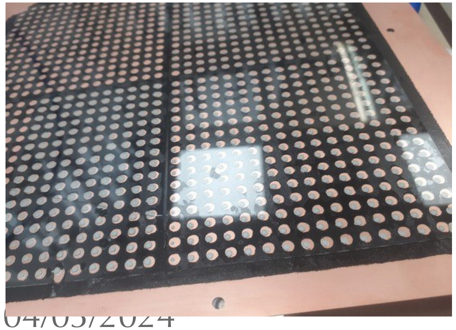
ISOMETRIC VIEW

IFIC (optical)



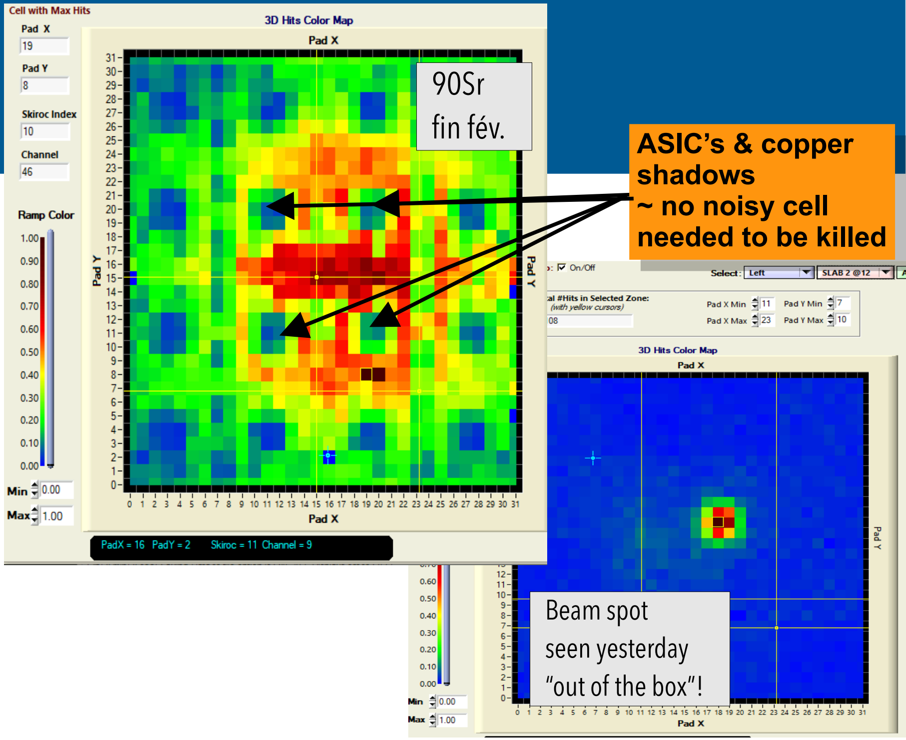
Same PCB before / after 10-day dry storage

Measurements by C. Orero, IFIC



Puncturated adhesive film and condutive glue dots

Beam Tests and Planning for 2025



First CALICE/DRD6 SiW-ECAL beam tests:

- Initially scheduled for June at DESY
- Moved from ~~Fall 2024~~, Spring 2025: **Started yesterday !**

Reason: careful revisitation of the gluing (hydridization) procedure:

- Deformation of the FEV under
  - Heat : expected
  - Humidity : Not expected
- Need to understand before gluing expensive sensors on them

DRD 6: Calorimetry

Proposal Team for DRD-on-Calorimetry

November 15, 2023

	Milestone	Deliverable	Description	Due date
Task 1.1: Highly pixelised electromagnetic section				
Subtask 1.1.1: SiW ECAL		D1.1	Revised 15 layer stack	2024 +1
	M1.1		Specifications for timing and cooling	2025 +1
		D1.2	Engineering module for Higgs factory	>2026 +1

SiW-ECAL for circular EW/Higgs Factories

Linear → Circular Collider's Conditions

Linear (ILC, HL-ILC…)

- 250 GeV (ZH), 365 GeV (tt), 500 GeV (ZHH) + [1000 GeV], $\mathscr{L}$ ~ cst.
- Power pulsing : 5 [10–15]Hz × 1 [2] ms   Power ~ $\mathscr{L}$.

More diverse et stringent conditions:

- 90GeV × 10^7 fb × $5{\cdot}10^{36}$ cm^{-2} s^{-1} (qq × 20,000 ILC @ 250)
- 150 GeV (WW) + 250 GeV (ZH)+ 365 GeV (tt) ~10^4 fb × $5{\cdot}10^{35}$ cm^{-2} s^{-1} (qq × 5–10 ILC @ 250)

From Pulsed to Continuous operation

- Power = cst + convertion+RO × local rates (P_{Conv}+P_{RO} ~ 40% P_{ACQ})
- ASIC, Power/Cooling, DAQ, *Granularity, Precisions (E, t)*, New ideas…

HL-ILC:

- $\mathscr{L}$ ×4 (6)
- $N_{bunches}$ ×2 : $\tau_{Train:}$ 1 → 2 ms
- f_{rep} ×2 (3): 5 → 15 Hz

Dominated by ACQ time: P(~25μW/ch) × 6

HL-CLIC:

- $\mathscr{L}$ ×2
- $N_{bunches}$ → : $\tau_{Train:}$ 176 ns
- f_{rep} ×2 : 50 → 100 Hz

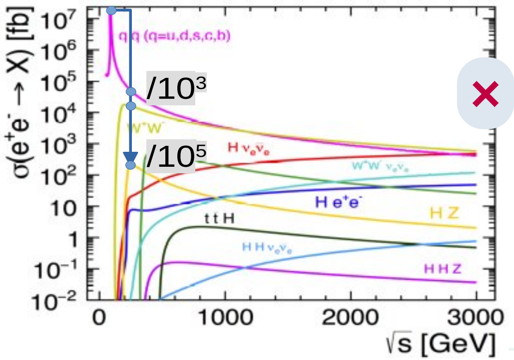
Dominated by Set-up & Conversion time: P (~82μW/ch) ×2

FCC-ee parameters		Z	W⁺W⁻	ZH	ttbar
√s	GeV	91.2	160	240	350-365
Luminosity / IP	10^{34} cm^{-2} s^{-1}	230	28	8.5	1.7
Bunch spacing	ns	19.6	163	994	3000
"Physics" cross section	pb	35,000	10	0.2	0.5
Total cross section (Z)	pb	40,000	30	10	8
Event rate	Hz	92,000	8.4	1	0.1
"Pile up" parameter [μ]	10^{-6}	1,800	1	1	1

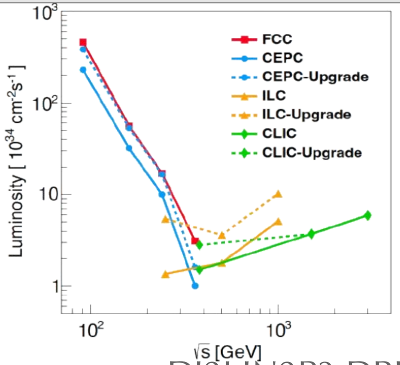
Experimentally, Z pole most challenging

- Extremely large statistics
- Physics event rates up to 100 kHz
- Bunch spacing at 20 ns
  - "Continuous" beams, no bunch trains, no power pulsing
- No pileup, no underlying event …
  - …well, pileup of 2 x 10^{-3} at Z pole

https://indico.cern.ch/event/1064327/contributions/4893208/
Mogens Dam @ FCC Week, 10/06/2022



Status of the CEPC, October 2022 J. Guimarães da Costa



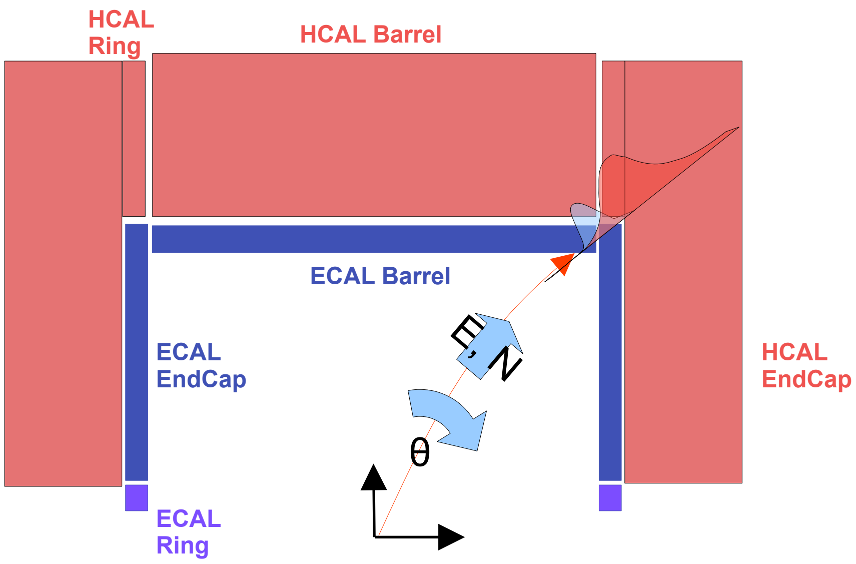
Calorimeter Fluxes from Full Simulations

Quantities useful for self-triggering, low occupancy, Front-End electronics & Design

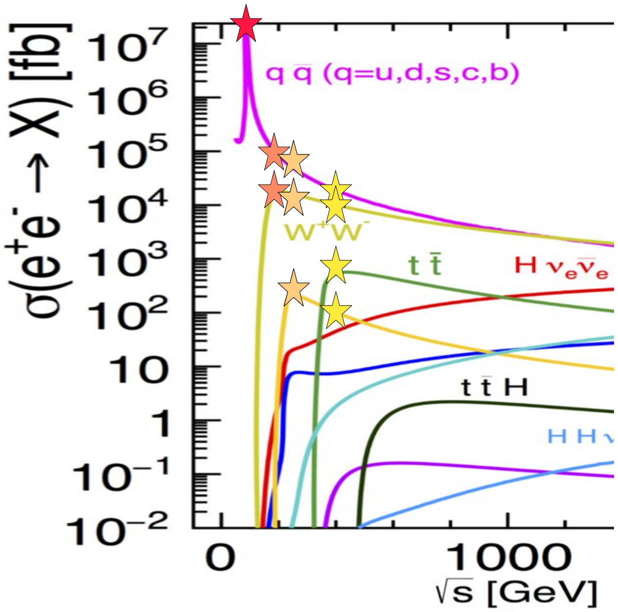
- Number of hits/s per ASICs
  - ➞ Power (Energy per conversion)
  - ➞ Memory size
- Distribution of Energy & Time
  - ➞ Dynamic ranges
  - ➞ Power per conversion
  - ➞ Double hits
- Data output
  - ➞ Data Flux per readout partition (DAQ)
    - ➞ DAQ scheme (Calo trigger to other parts ?)

Other quantities

- Deposited energies
  - ➞ Radiation



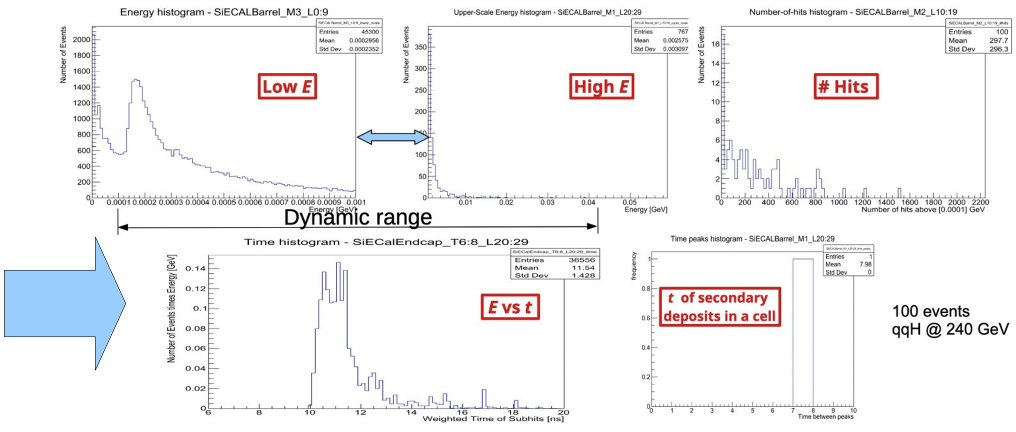
Fluxes in calorimeters



Processes: min. bias

- All
  - ee → qq
  - Ee → $\mu\mu$, $\tau\tau$
  - ee → ee (⊃ Bhabha)
  - →VV
  - Machine background (ee pairs)
- $E_{CM} \geq 160$ GeV
  - ee → WW
- ($E_{CM} \geq 240$ GeV)
  - ee → HZ
- ($E_{CM} \geq 360$ GeV)
  - ee → $t\bar{t}$

Full simulation ILD → statistics per region



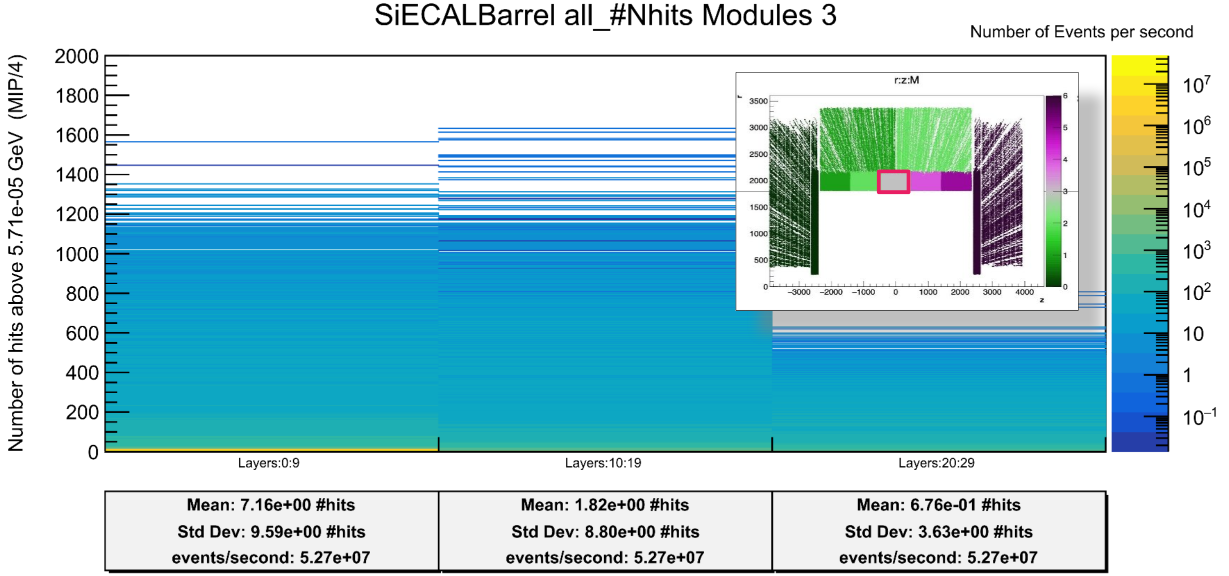
× $\mathcal{L}$ + **Machine background**

→ Fluxes of hits, data, per region

→ Power with ASIC assumptions

Results : Rates in Silicon ECAL Barrel, Central Module vs depth

Similar results for ScECAL, SDHCAL, AHCAL



M3 all staves	L0:9	L10:19	L20:29
Average #hits/s	302E+6 hits/s	65E+6 hits/s	8E+6 hits/s
Max	2000 hits/event	2500 hits/event	1000 hits/event
Data rate	2,11E+9 B/s	458E+6 B/s	54E+6 B/s
Ncells	4 026 764	3 767 273	3 378 036
Occupancy/BX	**1,4 E-06**	**3,3 E-07**	**4,3 E-08**
Base power/W	18,2 E+03	17,1 E+03	15,3 E+03
Conversion power/W	271,4 E+00	58,9 E+00	6,9 E+00
Total power/W	**18,5 E+03**	**17,1 E+03**	**15,3 E+03**
% conv.	1,5 %	0,3 %	0,05 %

cell size	5,5
Bytes/hit	7
powa (W/cell)	4,5 E-03
powb (J/hit)	8,7 E-10
Conv & RO E/hit/μJ	9,0 E-01
Δt/s	19 E-09

Distributions of the number of hits crossing (MIP/4) energy threshold of all the physics processes and machine background at **91.2 GeV (FCC-Z4)**
The z scale is the number of event/s

From the $\langle f_{\text{Nhits}} \rangle$ in one region one can extract :

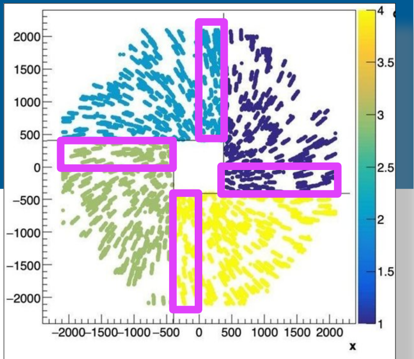
- The data rate, knowing the number of bytes per hits (here 7 as a landmark)
- The occupancy, knowing the number of cell in the region.
- The power dissipated on elec. power (here for SKIROC2 like chip)

- **Most of the hits are in the first third of the calorimeter.**
- **Highest average rates L0:9**
- **Highest max rates in L10:19**

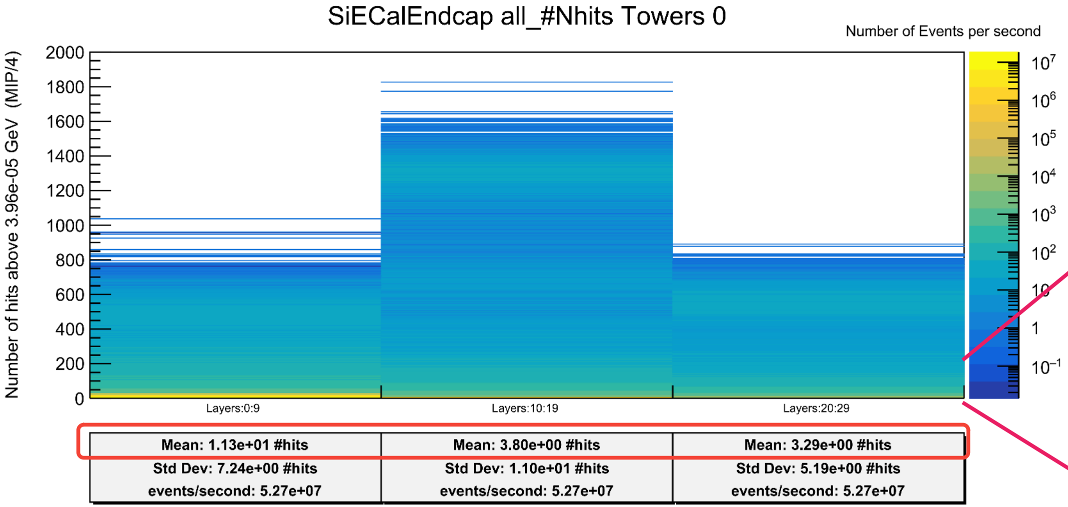
Note 1 : (still) **preliminary**
Note 2 : Rates & Power for all M3 modules
→ 8 per module, 10 per layer for 1 slab
→ ~ 50 W/slab

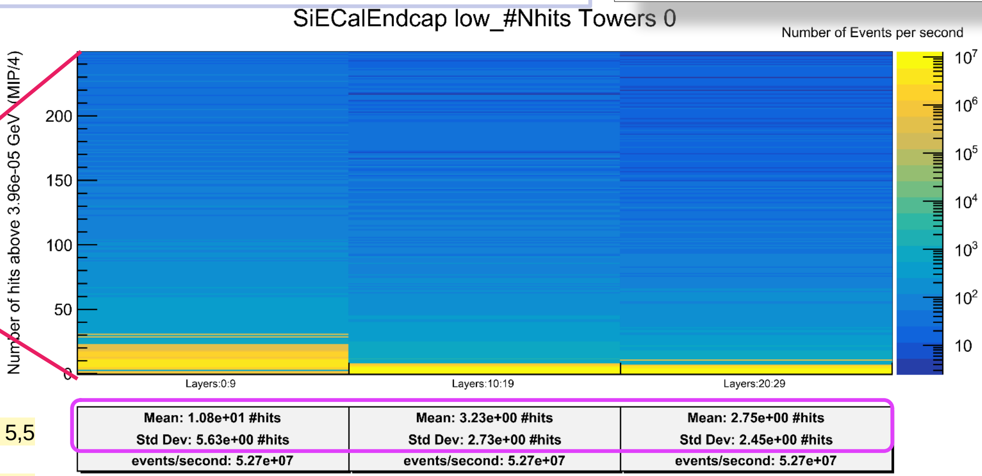
Results: Rates in SiECAL EndCaps, Tower 0 vs depth

Similar results for ScECAL, SDHCAL, AHCAL



Distributions of the number of hits crossing (>MIP/4) energy threshold of all the physics processes and machine background at **91.2 GeV (FCC-Z4)** with the colour bar representing the rate of events





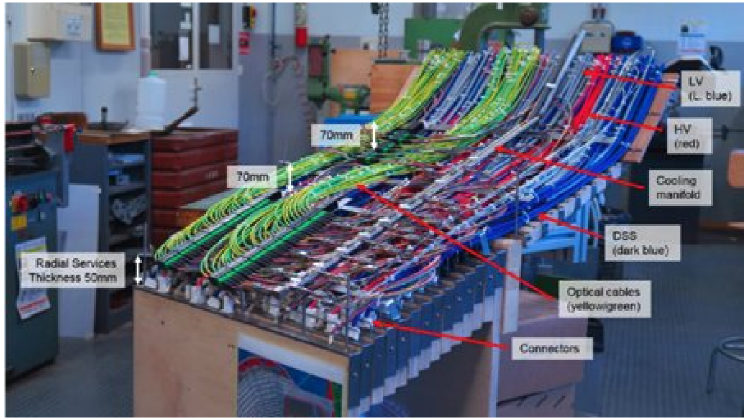
T0 all quadrants	**L0:9**	**L10:19**	**L20:29**
Average #hits/s	572E+6 hits/s	176E+6 hits/s	147E+6 hits/s
Max	2000 hits/event	2500 hits/event	1000 hits/event
Data rate	4,00E+9 B/s	1E+9 B/s	1E+9 B/s
Ncells	1 161 775	1 161 775	1 161 775
Occupancy/BX	**9,4E-06**	**2,9E-06**	**2,4E-06**
Length/Width	2496		565
Base power	5E+03	5E+03	5E+03
Conversion power	515E+00	159E+00	132E+00
Total power	**6E+03**	**5E+03**	**5E+03**
% conv.	8,9 %	2,9 %	2,45 %

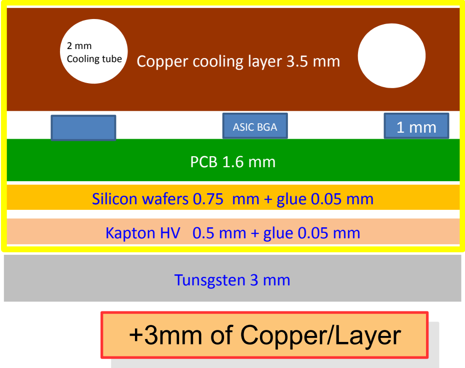
cell size	5,5
Bytes/hit	7
powa (W/cell)	5E-03
powb (J/hit)	870E-12
Conv & RO E/hit/µJ	0,9
Δt	19E-9

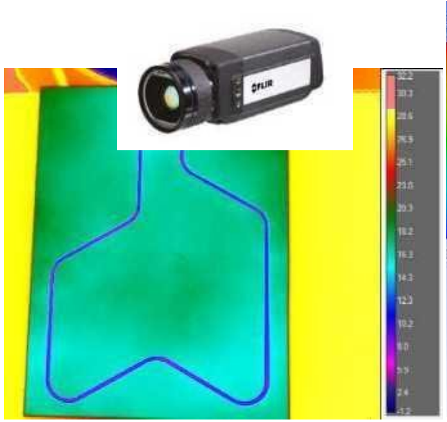
- **Machine background in first layers**
- **High E ee→ee in middle of ECAL**
- **Power driven by the continuous part (Pre-Amps)**

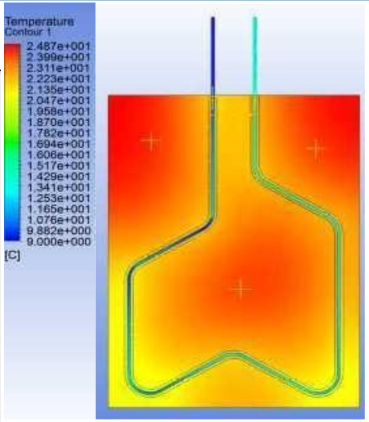
Note 1 : (still) **preliminary**
Note 2 : Rates & Power for all T0 modules
→ /8 per quadrant, *10 per layer for 1 slab* → 75W / slab

Services: integration & cooling : CO_2 à la HGCAL ?



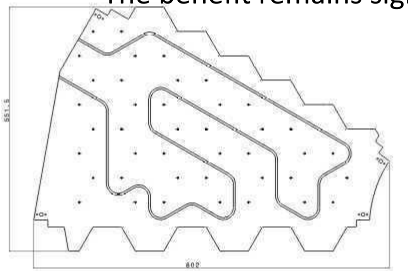


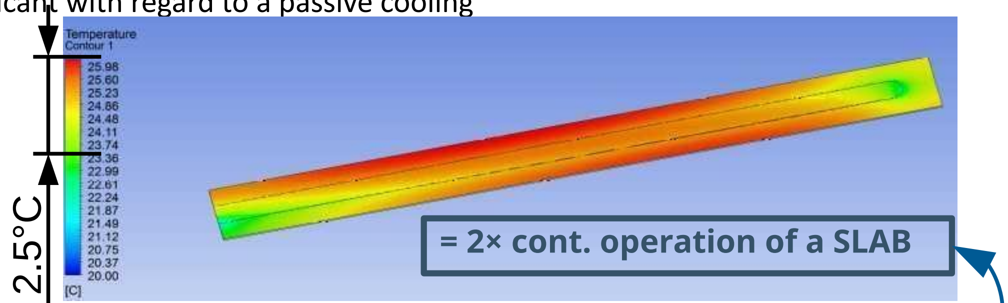




Pipe insertion on a cooling prototype

- Pipe insertion process introduces some efficiency loss due to the thermal contact resistance.
- The benefit remains significant with regard to a passive cooling





Thermal static CFD analysis thermal field example using Fluent with 100W extracted and water mass flow rate of 7g/s through 1,5mm ID

OK, but overkill solution for room temp cooling, and brings non-uniformities

ECAL adaptation : flat water cooling, preliminary thermal studies

Uniform solutions:

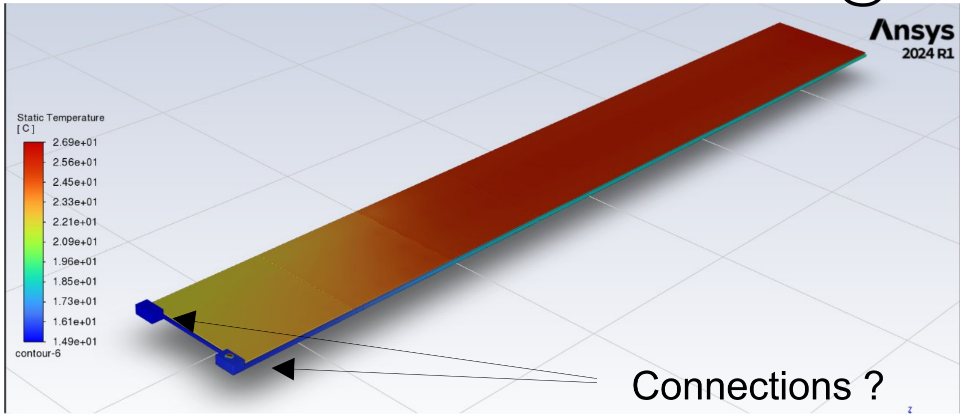
“Standart Slab”:

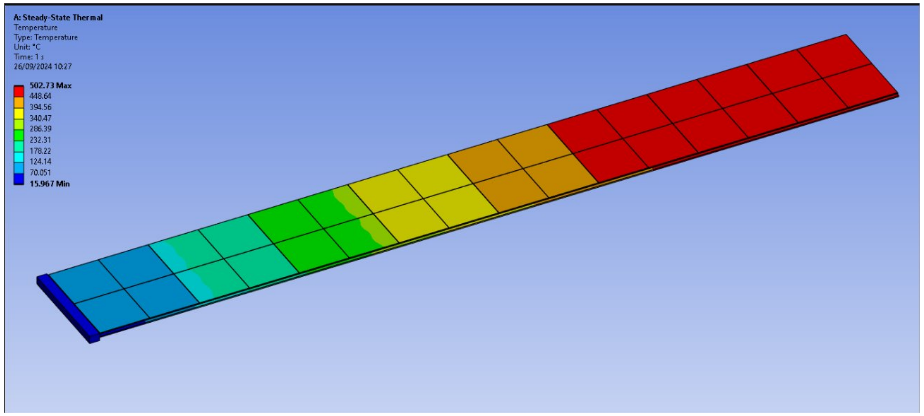
- 8 ASU (1440mm)z, 8192 ch / 128 ASICs
- 100 W

Passive cooling: Cu of 2mm (W, C ignored)

Adiabatic, but for heat bridge at the end

ΔT = 500°C on Wafer surface at *t* = ∞





“Standart Slab”:

- 8 ASU (1440mm), 8192 ch / 128 ASICs
- 128 W (1W/ASIC ~16 mW /ch)

Active cooling:

- Hollowed Cu of 4mm, with 1ℓ/min of water @ 15°C

Adiabatic, but for heat bridge at the end

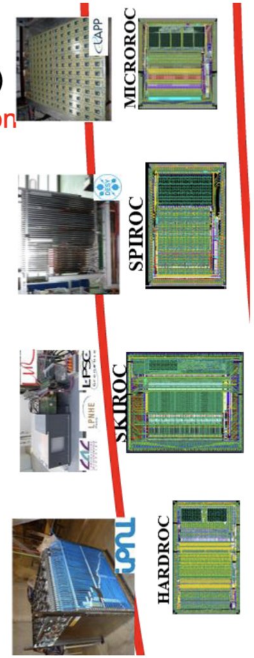
ΔT = 12°C on Wafer surface at *t* = ∞

New ASIC:

DRD6 Common readout ASICs proposal [AGH, Omega, Saclay]

Omega

- Develop readout ASIC family for DRD6 prototype characterization
  - Inspired from CALICE SKIROC/SPIROC/HARDROC/MICROROC family
  - Targeting future experiments as mentionned in ICFA document (EIC, FCC, ILC, CEPC…)
  - Addressing embedded electronics and detector/electronics coexistence + joint optimization
  - Detector specific front-end but common backend
  - ⇒ allows common DAQ and facilitates combined testbeam
- Start from HGCROC / HKROC : Si and SiPM
  - Reduce power from 15 mW/ch to few mW/ch
  - Allows better granularity or LAr operation
  - Extend to LAr (cryogenic operation) and MCPs (PID)
  - Remove HL-LHC-specific digital part and provide flexible auto-triggered data payload
  - Several improvements foreseen in the VFE and digitization parts
- Several other ASICs R/Os also developed in DRD6 and it is good !
  - FLAME/FLAXE, FATIC…
  - Waveform samplers : commercial or specific (e.g. SPIDER)
  - DECAL



CdLT : future chips DRDI 10 jul 23

8

Low Power

- Enough ?
- If Timing ?

Low occupancy

- Self-trigger
- Less memory
  - if continuous readout

Optimized dynamic range (silicon)

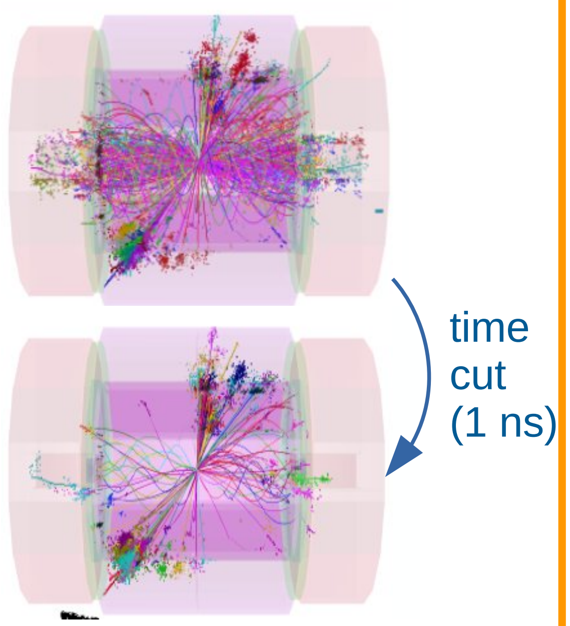
Centimetric Timing

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

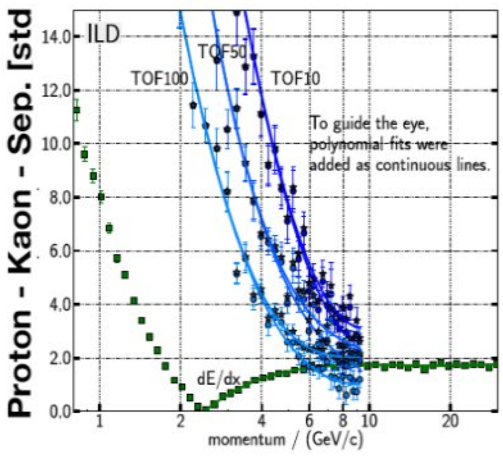
Cleaning of Events



[CLIC CDR: 1202.5940]
adapted from L. Emberger

Particle ID by Time-of-Flight

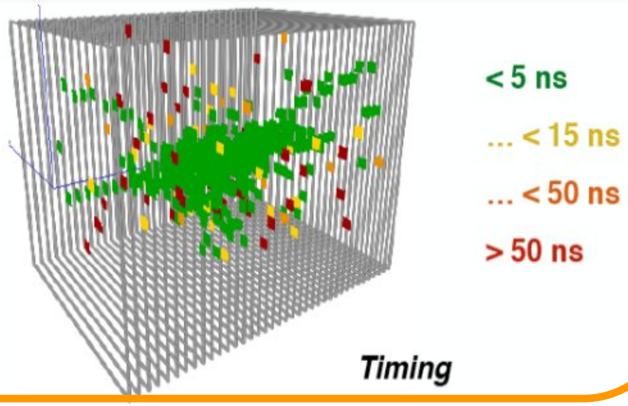
- Complementary to d*E*/dx
  - Here with 100 ps on 10 ECAL hits



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

Conclusions

SiW-ECAL technological prototypes

- **2022:** Heterogeneous 15 layers
  - 1st full calorimeter working [DESY22, CERN22]
    - Shower seen, Detailled simulation ready
    - Analysis on-going ➞ resolutions, ...
  - Numerous emerging issues
    - gluing, HV filtering at high energy
- ~~2024~~ **2025–26:** Uniform 15 layers
  - ➞ New VFE boards
    - Cleaner PS & Clock distributions; more uniform
  - Gluing being revisited
  - Material available.
  - To be tested in 2025
    - ➞ Provide reference sample for GEANT4
    - ➞ With funding ➞ "full" LUXE, EBES, Lohengrin ?, SHiP ?
  - Start FE board on HKROC ?

SiW-ECAL design for HET factories

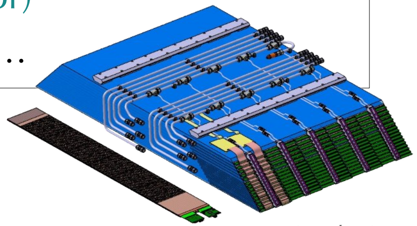
– **2023–25**: Power budget & performances to be re visited

- Occupancy, power, data fluxes (on-going)
  - ➞ Granularity; Passive or Active cooling
  - ➞ new ASIC attributes
- 2025–27: PFA & Timing & Physics performances

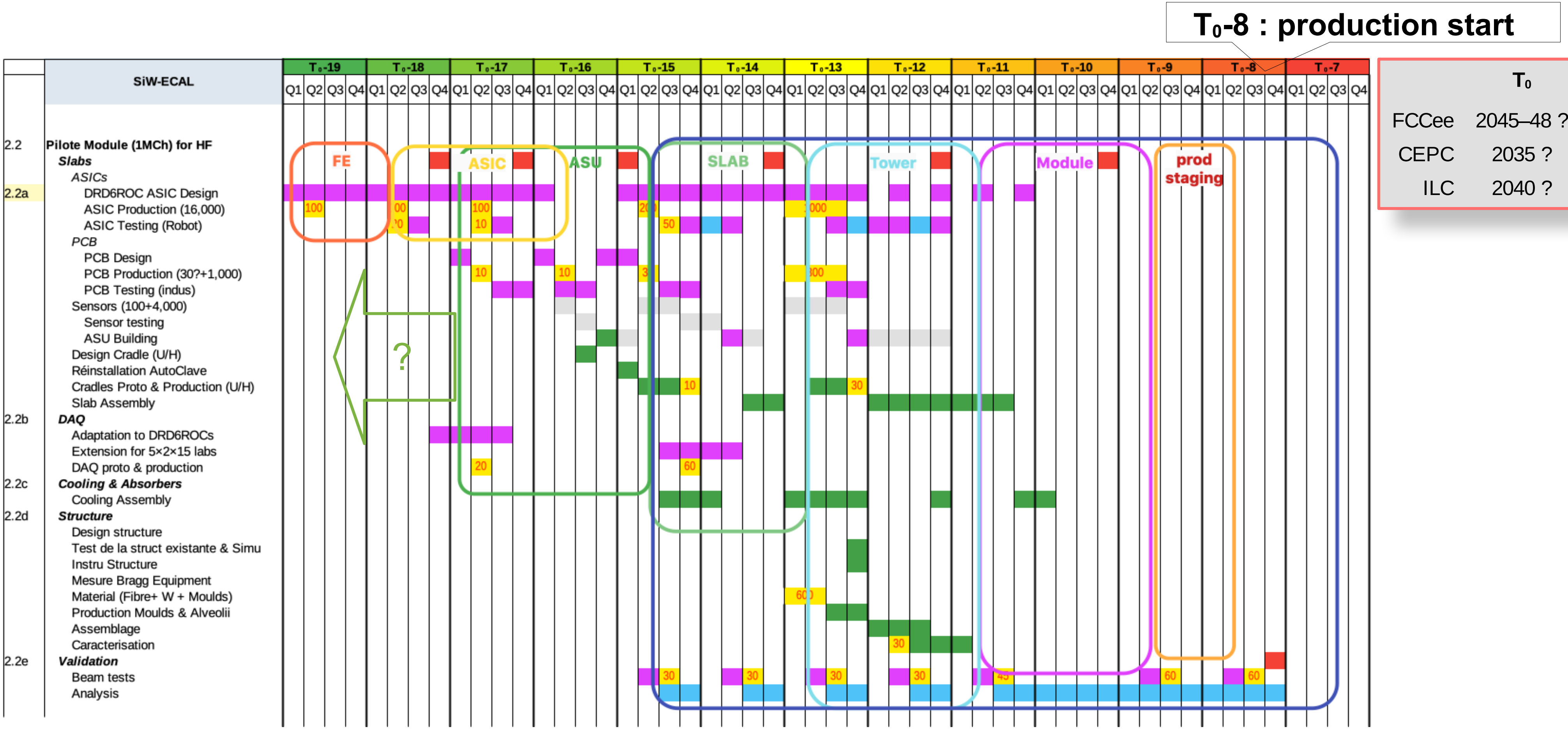
2025–27 : Blue-print for a SiW-ECAL detector for the next ee collider

➡ planning for a **pilote module** @ T_0 collider-8y -5y (1 Mch, 1/60th of real detector)

semi-industrial, quality, ASICs, …



Planning towards a pilot module… *just in case*



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

Liens DRD-Master Projets / Funding

Master Projet IN2P3 SiW-ECAL = DRD6 T 1.1.1 (SiW-ECAL for HET factories)

- *Continuation de CALICE dans une collaboration plus large*
- Prototypage & Tests
- Porteur : V. Boudry (LLR)
  - \+ IJCLab (R. Pöschl), LPNHE (D. Lacour), Omega (Ch. de la Taille), DMLab (D. Zerwas)
  - Actualisation Fiche Projet & Signatures DU: 18/11/2024, ⊃ WP/D DRD6 et ANR's … 1er fond 2025
    - Residu AIDAinnova (sept. 2025)

Master Projet FCC

- Études de physique
- Études détecteur (adaptation ILD pour le FCC-ee)
- Porteur: Gregorio Bernardi (APC)

ANR T-Calo (IP2I–LLR) & ANR-DPG Calo5D (IJCLab–LLR–Mainz–DESY–KIT)

- Études "théoriques" de l'apport du timing "centimétrique" dans les calorimètres
  - Simlation détaillées, PFA Classique et PFA assisté au ML
- FR: PostDocs and Thèses
- Porteurs: G. Grenier (IP2I), R. Pöschl (IJCLab)

Postes de dépense	Remarques	2024	2025	2026	2027	Outlook	Total
Equipements		- €	3 000 €	30 000 €	30 000 €	360 000 €	423 000 €
DRD6 Engineering run ASICs	IN2P3 Share			30 000 €	30 000 €	100 000 €	160 000 €
Prototype mechanics	including W absorber					100 000 €	100 000 €
	and cooling		2 000 €				
PCB production			1 000 €			30 000 €	31 000 €
New compact DAQ						20 000 €	20 000 €
Silicon sensors						100 000 €	100 000 €
Dry cabinet for ASU storage						10 000 €	10 000 €
Fonctionnement		- €	5 500 €	8 500 €	8 500 €	- €	22 500 €
Dry gas			1 500 €	1 500 €	1 500 €		4 500 €
IT Needs (e.g. laptop)			4 000 €	5 000 €	5 000 €		14 000 €
Consumables				2 000 €	2 000 €		4 000 €
							- €
Calcul		- €	- €	- €	- €		- €
Pris en charge par le projet	Report onglet "RC"	- €	- €	- €	- €		- €
Missions		3 200 €	33 000 €	33 000 €	15 000 €	- €	84 200 €
Missions		3 200 €	15 000 €	15 000 €	15 000 €		48 200 €
Beam tests			18 000 €	18 000 €			36 000 €
Personnels		- €	1 000 €	2 000 €	2 000 €	- €	5 000 €
Stages			1 000 €	2 000 €	2 000 €		5 000 €
TOTAL		3 200 €	42 500 €	73 500 €	55 500 €	360 000 €	534 700 €

Nom des personnes	Statut	2024	2025	2026	2027	Total (FTE)
LLR		150%	320%	305%	190%	9,65
V. Boudry	CRCH	90%	90%	90%	90%	3,60
J.C. Brient	DR Emeritus	15%	15%	15%	15%	0,60
H. Videau	DR Emeritus	15%	15%	15%		0,45
Postdoc Calo5D	CDD	15%	100%	100%	85%	3,00
Postdoc T-Calo	CDD	15%	100%	85%		2,00
IJCLab		95%	270%	270%	145%	7,80
R. Pöschl	DR 1	70%	70%	70%	70%	2,80
Postdoc Calo5D	CDD		100%	100%		2,00
Xin Xia	Thésarde	25%	100%	100%	75%	3,00
DMLAB		10%	30%	10%	10%	0,60
D. Zerwas	DR 1 (Directeur)	10%	30%	10%	10%	0,60
LPNHE		10%	10%	10%	10%	0,40
D. Lacour	DR 1	10%	10%	10%	10%	0,40
TOTAL (FTE)		2,65	6,30	5,95	3,55	18,45

Nom des personnes	Statut	2024	2025	2026	2027	Total (FTE)
LLR		20%	25%	60%	70%	1,75
J. Nanni		10%	10%	40%	50%	1,10
O. Ferreira		10%	15%	20%	20%	0,65
IJCLAb		70%	70%			1,40
D. Breton	IRHC	10%	10%			0,20
J. Maalml	IR 1	20%	20%			0,40
J. Jeglot	IE 1	20%	20%			0,40
A. Thiebault	AI	20%	20%			0,40
Omega		100%	100%	100%	100%	4,00
C. de la Taille	IRCH	30%	30%	30%	30%	1,20
D. Thienpont	IR	30%	30%	30%	30%	1,20
F. Duclucq	IR	20%	20%	20%	20%	0,80
L. Raux	IR	20%	20%	20%	20%	0,80
TOTAL (FTE)		1,90	1,95	1,60	1,70	7,15

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:

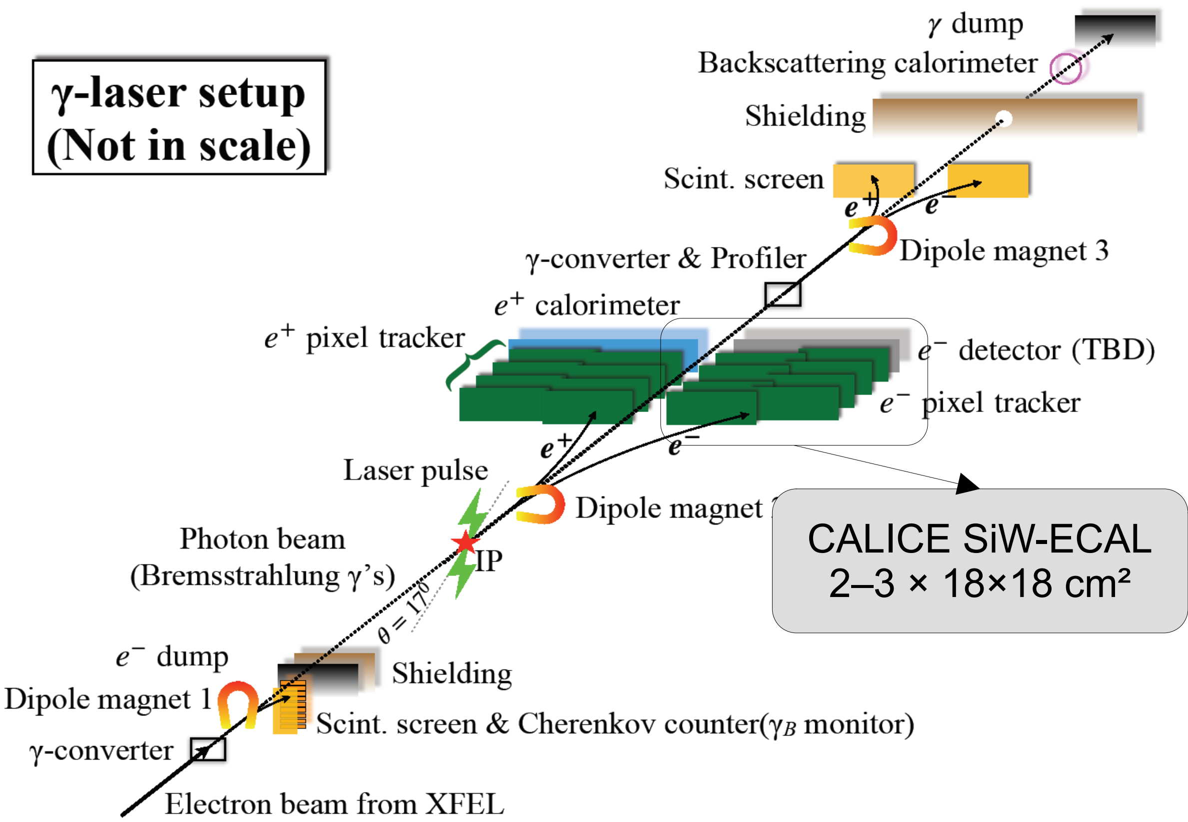
- **XFEL beam 10 Hz,** $1.6{\cdot}10^{9}$ e^{-}, $E_e \leq 17.5$ GeV
- Laser : 40–350 TW, 30 fs, 1 Hz
  → $1.5{\cdot}10^{20}$ W /cm³
- ≥ 2025 at DESY/XFEL

ECAL's:

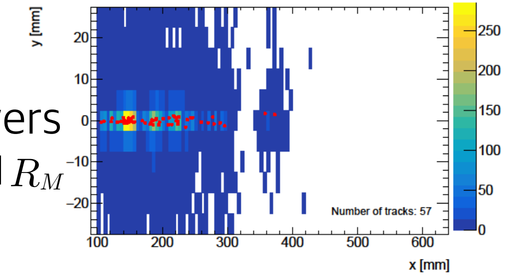
- 5×5 mm² cells, 20 X_0, 12? layers, 20 %/√E
- Si+W or GaAs+W ➞ FCAL and/or CALICE

Q? Optimal sampling for Ee ≤ 17.5 GeV ?

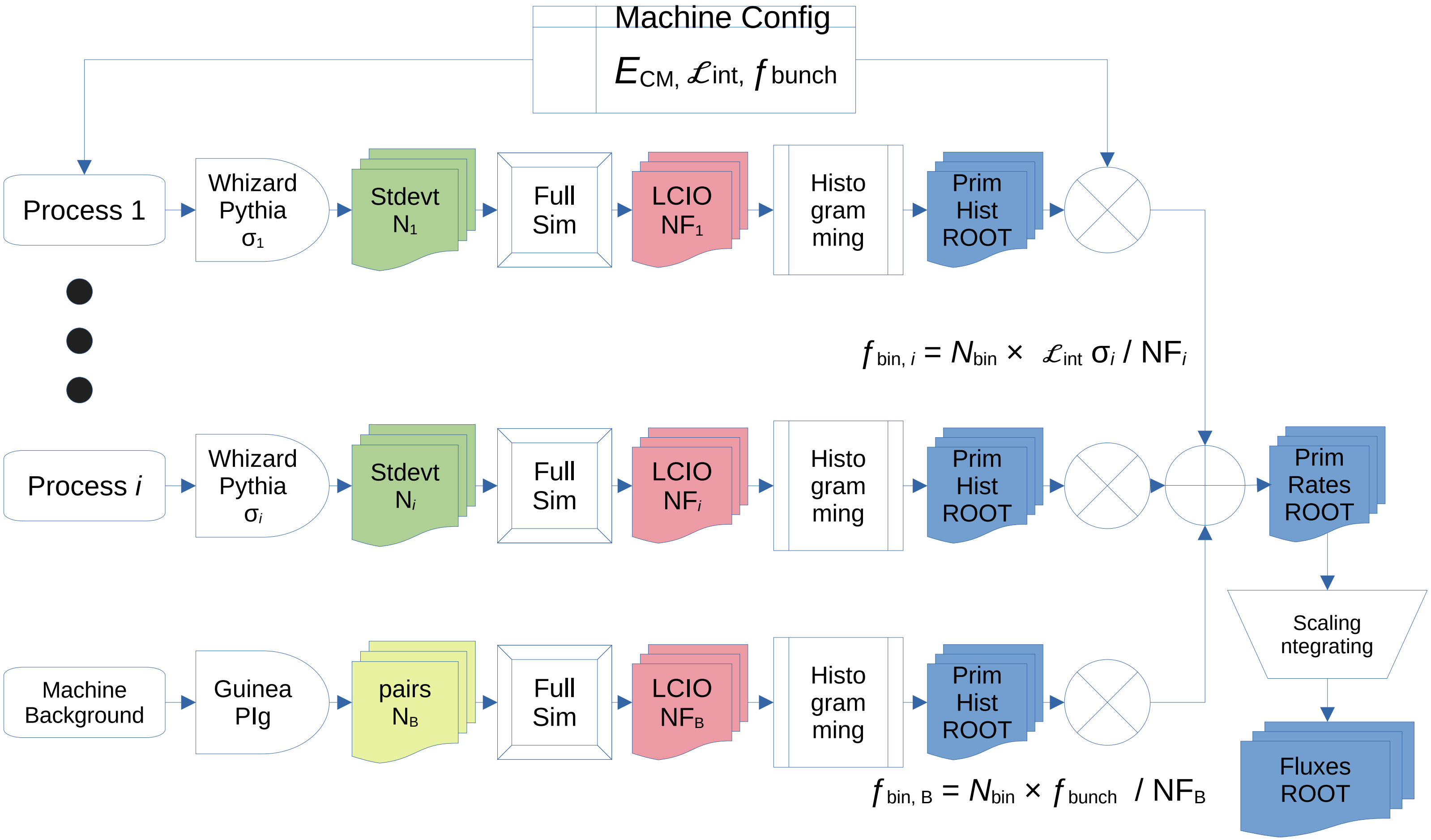
- ⊃ Hit counting, shower separations



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

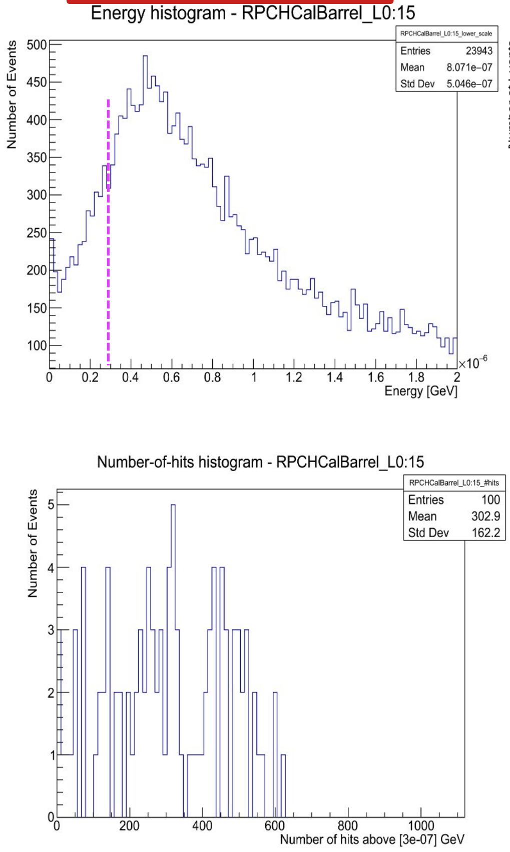


Processes to Fluxes

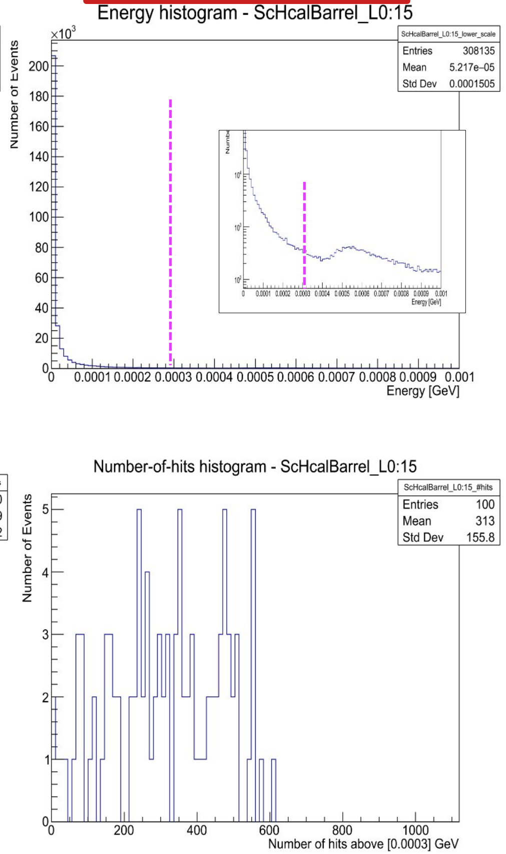


System Low Energy & #hit responses
raw energies (no digitization yet)

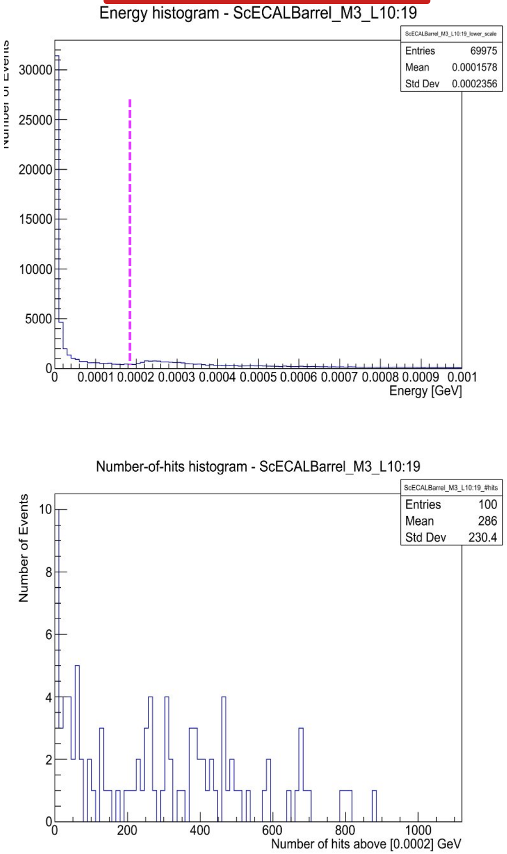
SDHCAL



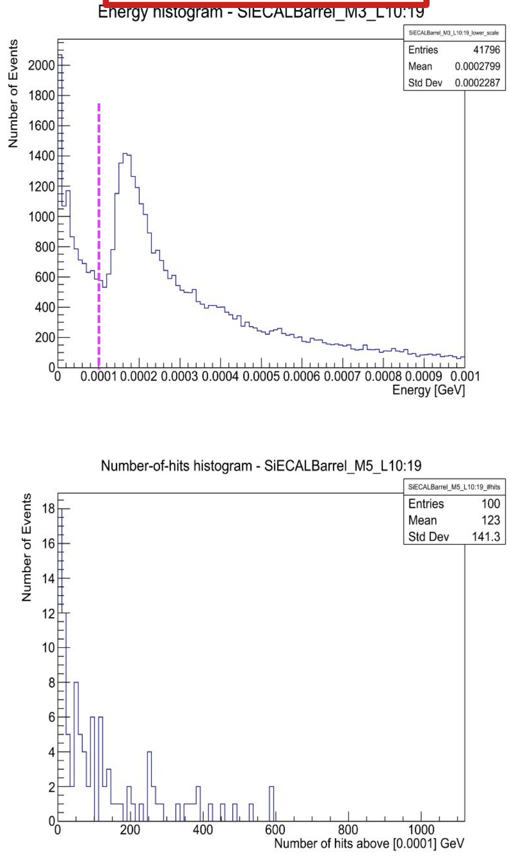
AHCAL



Sc ECAL



Si ECAL



Detector optimization for Higgs Factories

Low energy (90 GeV)

- Lower energy – less focused jets
  - Lower granularity needed (1–2 cm OK ?)
  - Lower dynamic range ? ✘

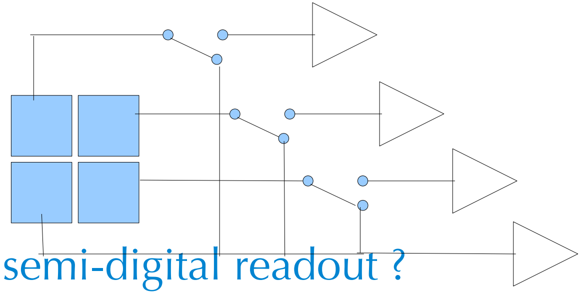
… but not so for the rest (≥ ~250 GeV)

Reduce the number of layers + thicker sensors

- See “Small ILD” model
- 6″×500μm wafers
  ➞ 8″ × 725 μm (resolution $1/\sqrt[5]{d}$)

One size fit all ?

- Have a dynamic granularity ?



- Have a semi-digital readout ?
  - Hit counting for low energy
  - E measurement for high energies

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)

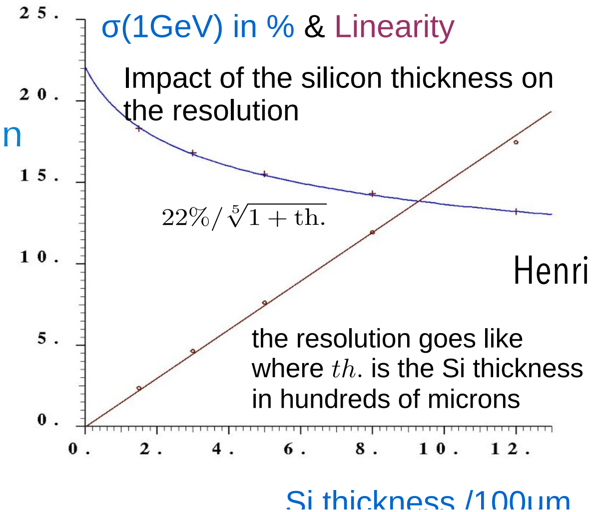
} *near compensation*

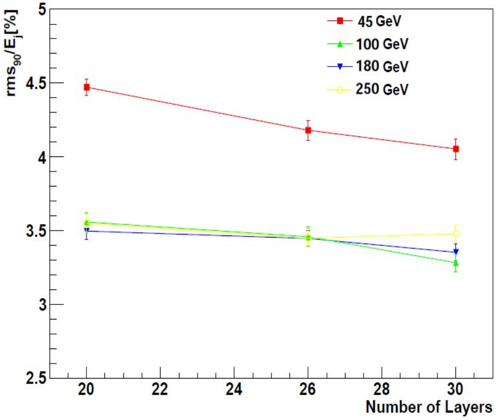
Time Resolution ?

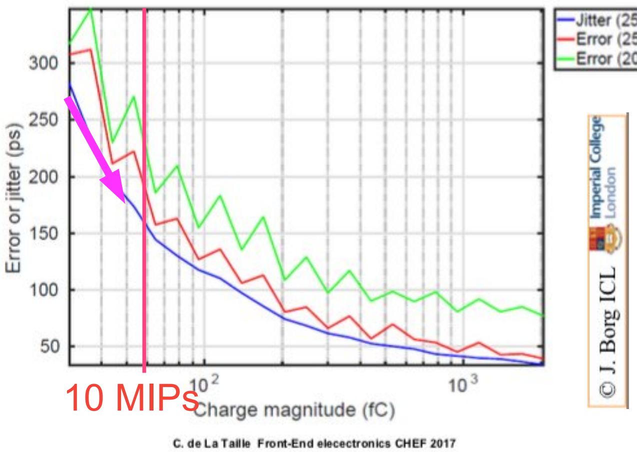
- Noise ~ C_{det} ~ width²/th,
  Signal ~ th ↗ → S/N ~ th² ~ ×1.5 ?

  ⇒

  Improved timing perf (esp. for mips)



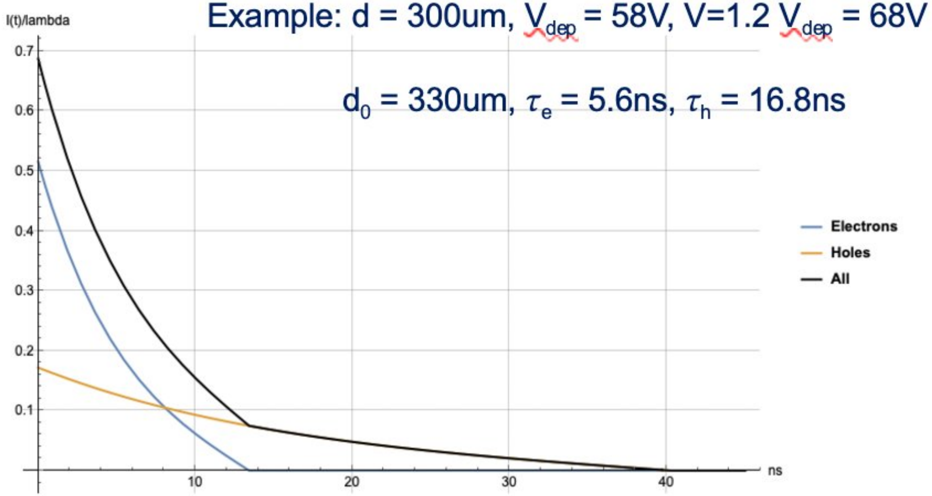


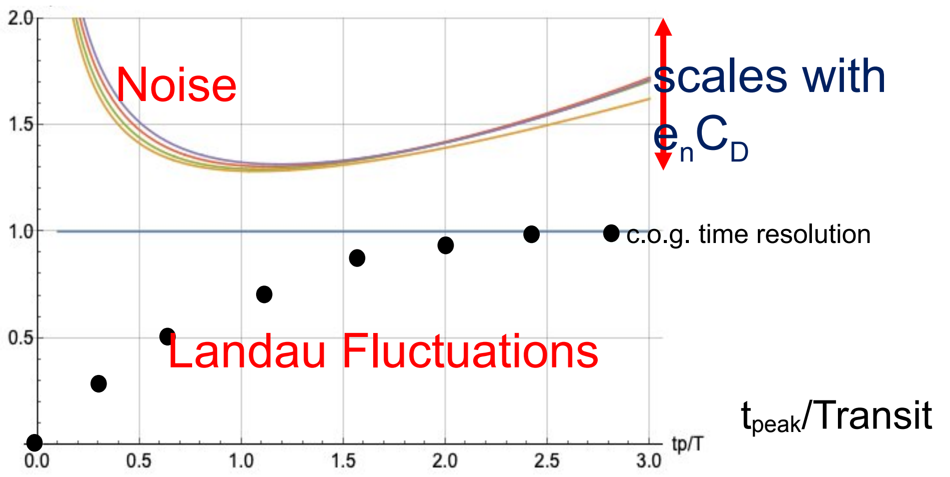


Time measurement *in Silico*

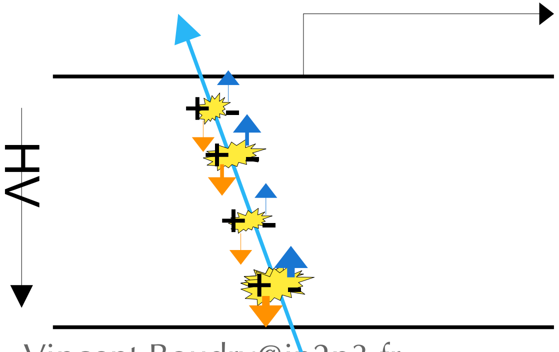
Example: d = 300um, V_{dep} = 58V, V=1.2 V_{dep} = 68V

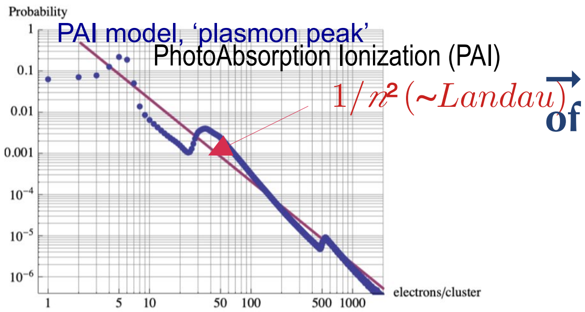
d_0 = 330um, τ_e = 5.6ns, τ_h = 16.8ns





Landau Fluctuations ⊕ Noise

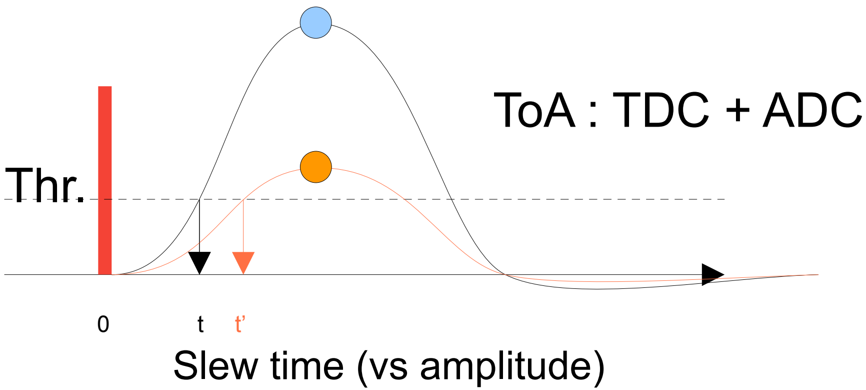


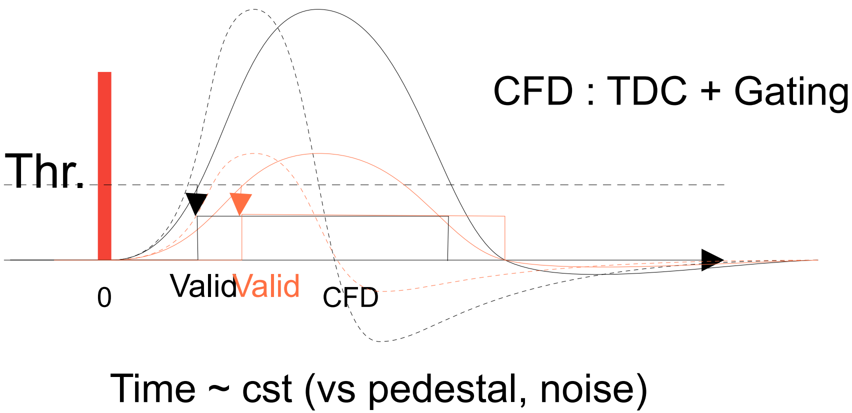


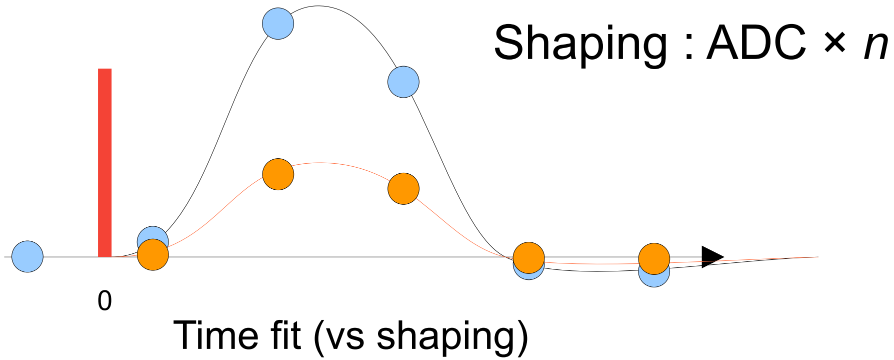
→ optimal thickness of sensors (T ↔ thickness) to be determined

S. Riegler

Time measurement methods



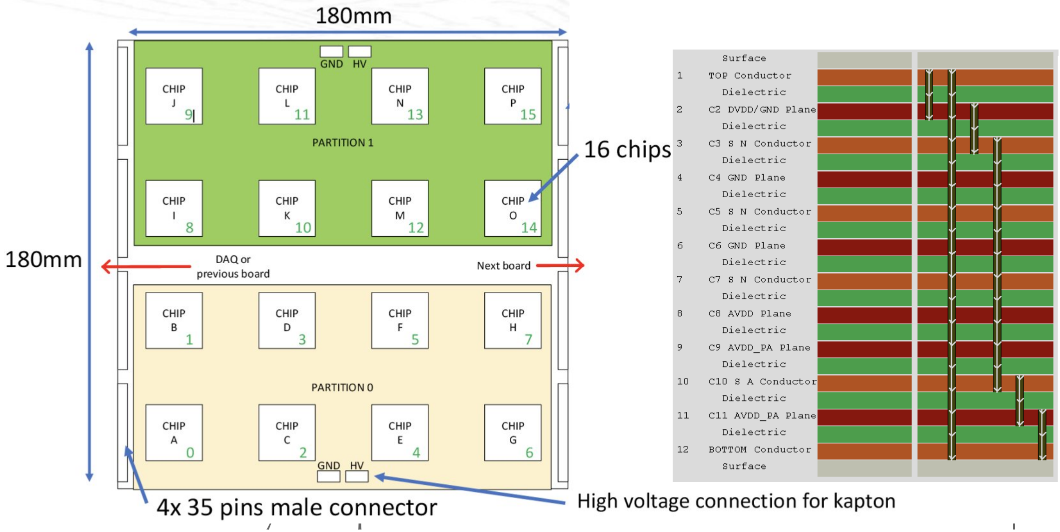




FEV's : 15 years of R&D

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: performances

Going from 30 to 26 layers

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

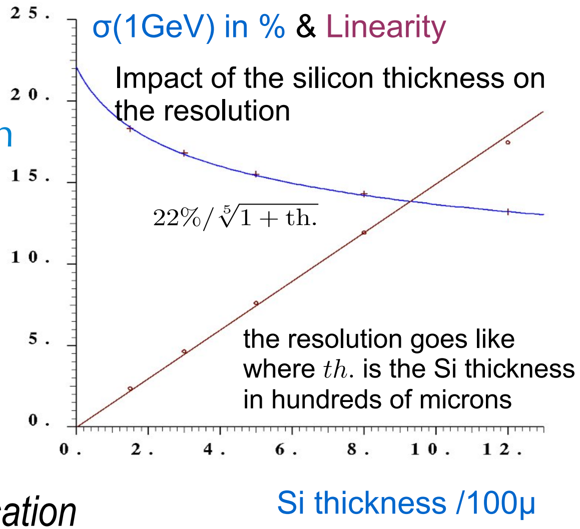
Increasing the Si thickness to 725µm

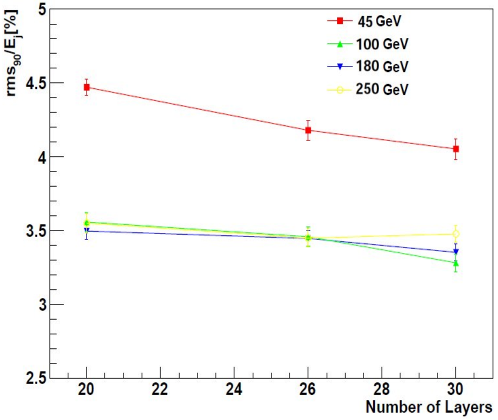
- GR width ↗ ⇒ go to 8″ wafers, new design

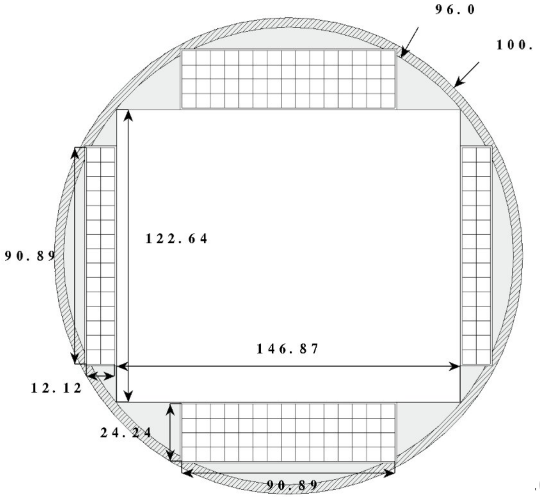
Energy resolution σ(E)/E:

- 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







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]