EPDET: an SiW-ECAL optimized for e^+e^- collisions

Vincent Boudry & Manqi Ruan

Institut Polytechnique de Paris

Institute of High Energy Physics, Beijing, China

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

1) **Technological with the production and testing of prototypes in beam (DESY and CERN)**

Status of prototype. CALICE → DRD6

2) **Design of a complete detector including all the constraints (performance, readout, power and cooling, and costing);**

CaloFlux: a new tool for estimation for fluxes in calorimeters

3) **Reconstruction software and methods adapted to this new type of devices;**

   1) “Cluster time measurement with CEPC calorimeter”, Eur. Phys. J. C (2023) 83:93
   2) ParticleFlow optimized ARBOR Covered in CEPC session by M.R.

4) **Estimation of the physics potential using all the above (prototypes, design, and methods).**

Covered in CEPC session by M.R.

Highly-Granular ECAL at Higgs Factories for Particle Flow Approach 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

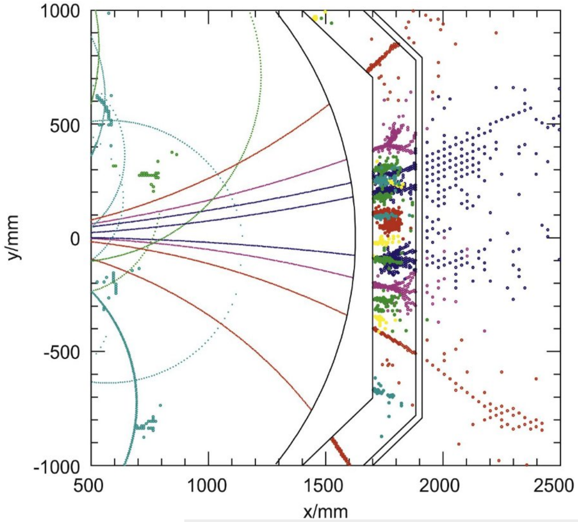
→ Highly Granular Imaging Calorimetry + Particle Flow software

ECAL

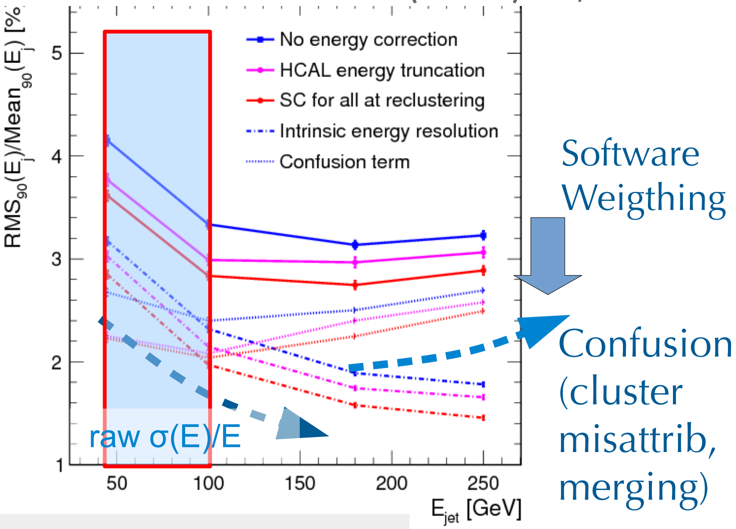
Particle Flow Algorithms :

- **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



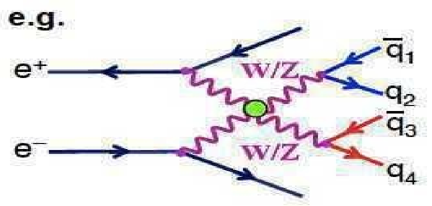
Low E jets ⇒ where PFA brings most

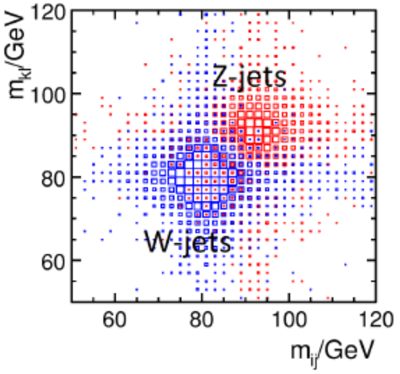
Particle Flow Detectors at Higgs Factories

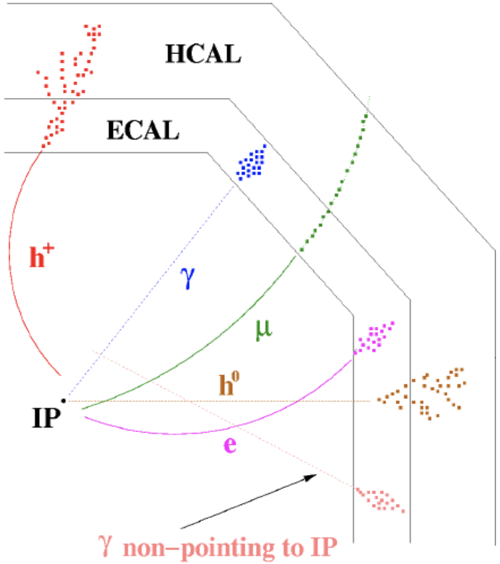
Basis: sep of H → WW/ZZ → 4j

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

⇒ σ_E/E (jets) < 3.8%







Particle Flow ECAL should :

spot tracks & showers from charged (h±, e±)

→ Dynamic range from 1/3 MIP

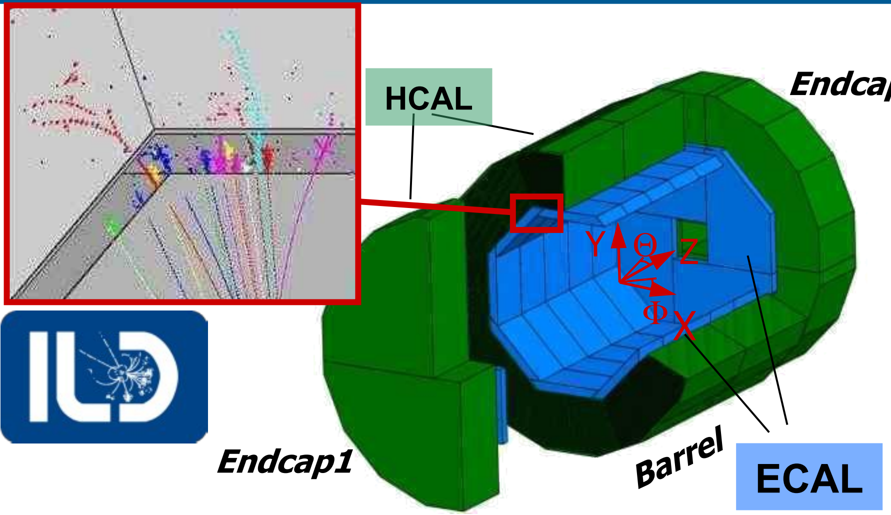
measure Photons in jets & Tau physics (γ vs π_0)

up to 3000 MIPs

measure 2/3 of neutral hadrons interacting in the ECAL

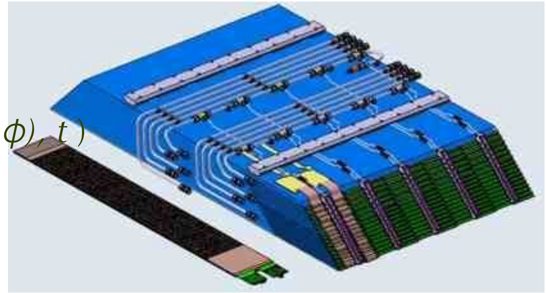
measure Time-of-Flight (10's ps)

An Ultra-Granular SiW-ECAL for experiments



Particle Flow optimised calorimetry

- Standard requirements
  - Hermeticity, Resolution, Uniformity & Stability (E, (θ,ϕ), t)
- PFlow requirements:
  - Extremely high granularity
  - Compacity (density)

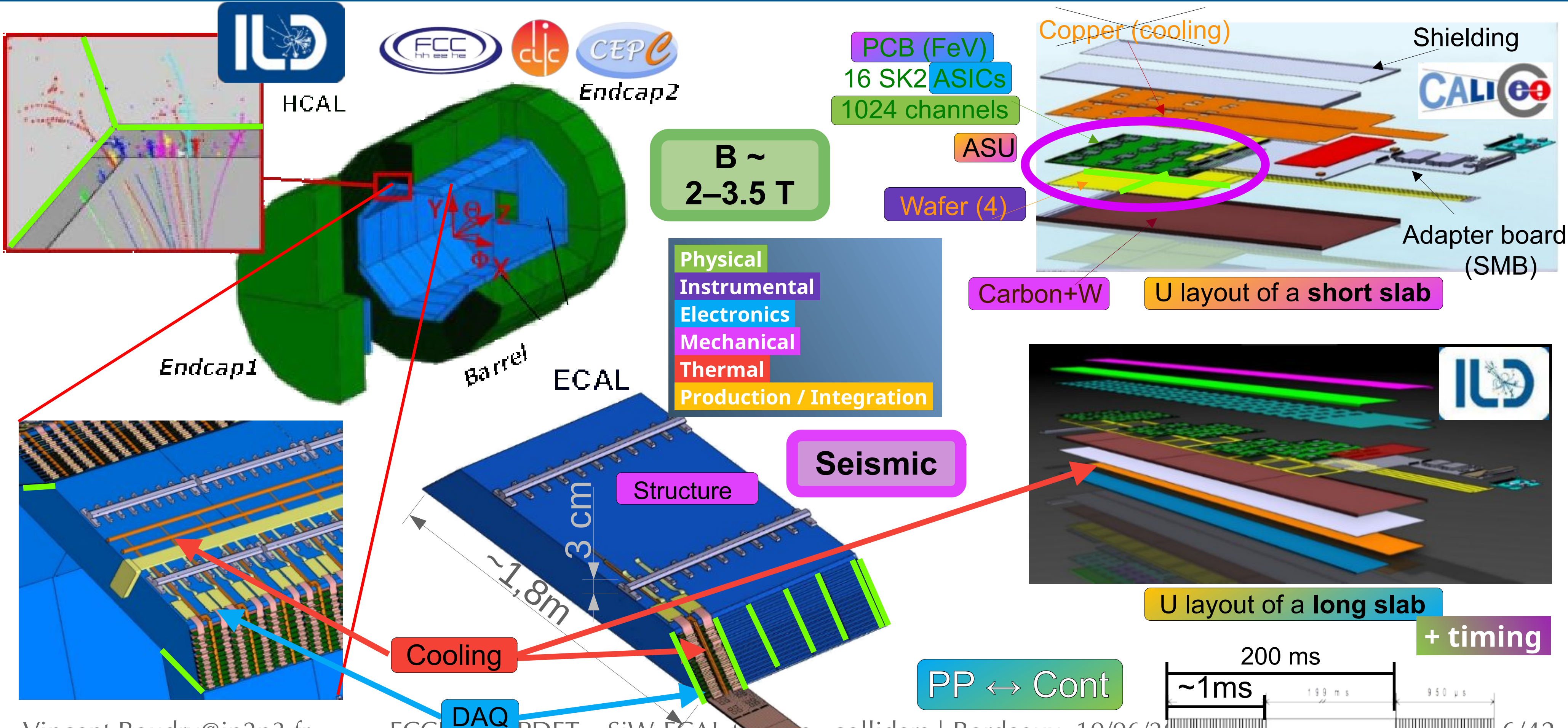


SiW+CFRC baseline choice for future Lepton Colliders:

- Tungsten as absorber material
  - X_0 = 3.5 mm, R_M = 9 mm, λ_I = 96 mm
  - Narrow showers
  - Assures compact design
- Silicon as active material
  - **Support compact design: Sensor+RO≤2mm**
  - Allows for ~any pixelisation
  - Robust technology
  - **Excellent signal/noise ratio: ≥10**
  - **Intrinsic stability (vs environment, aging)**
  - **Albeit expensive…**
- Tungsten–Carbon alveolar structure
  - **Minimal structural dead-spaces**
  - **Scalability**

To be assessed by prototypes

Modular & Transverse Constraints



SiW-ECAL

DRD6

Place your logo here

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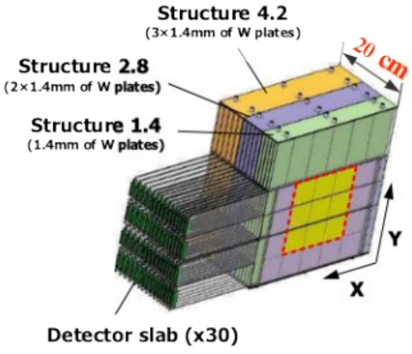
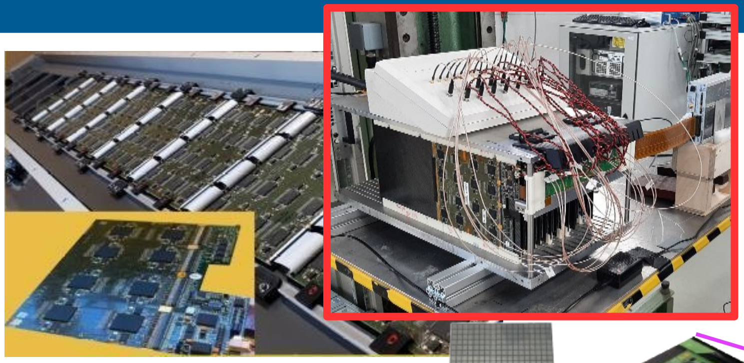
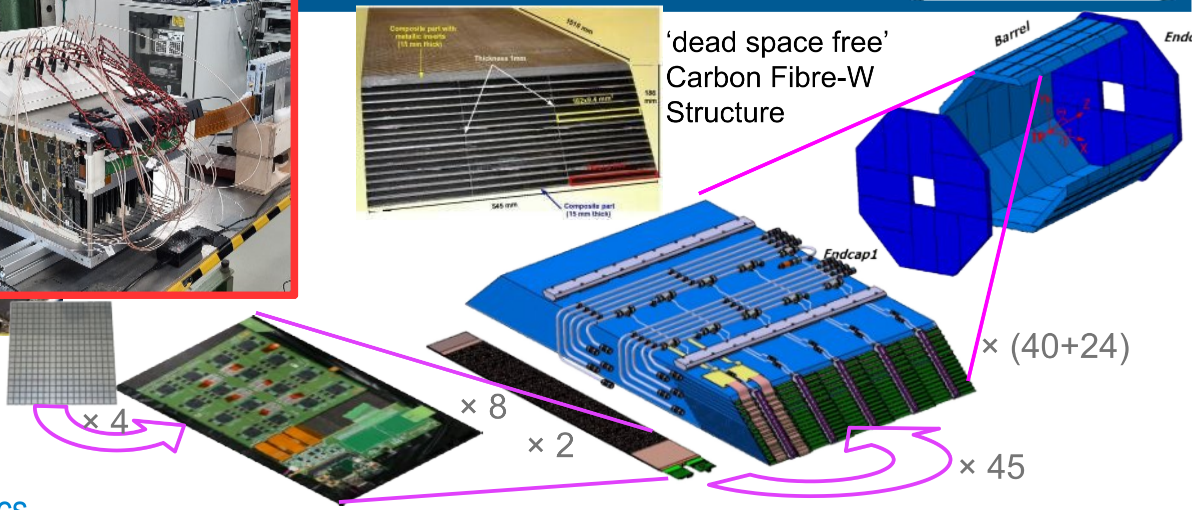
Timeline of SiW-ECAL Prototypes







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 320–650µm 9×9 cm²
  × 26–30 layers
  - 8k (slab) ~ 30k (calo) channels

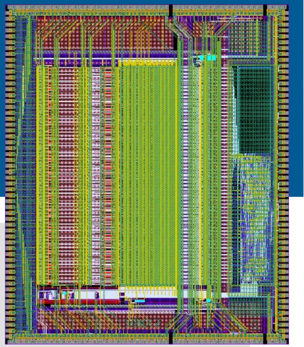
We are here

Pilote ➡ Full Detector

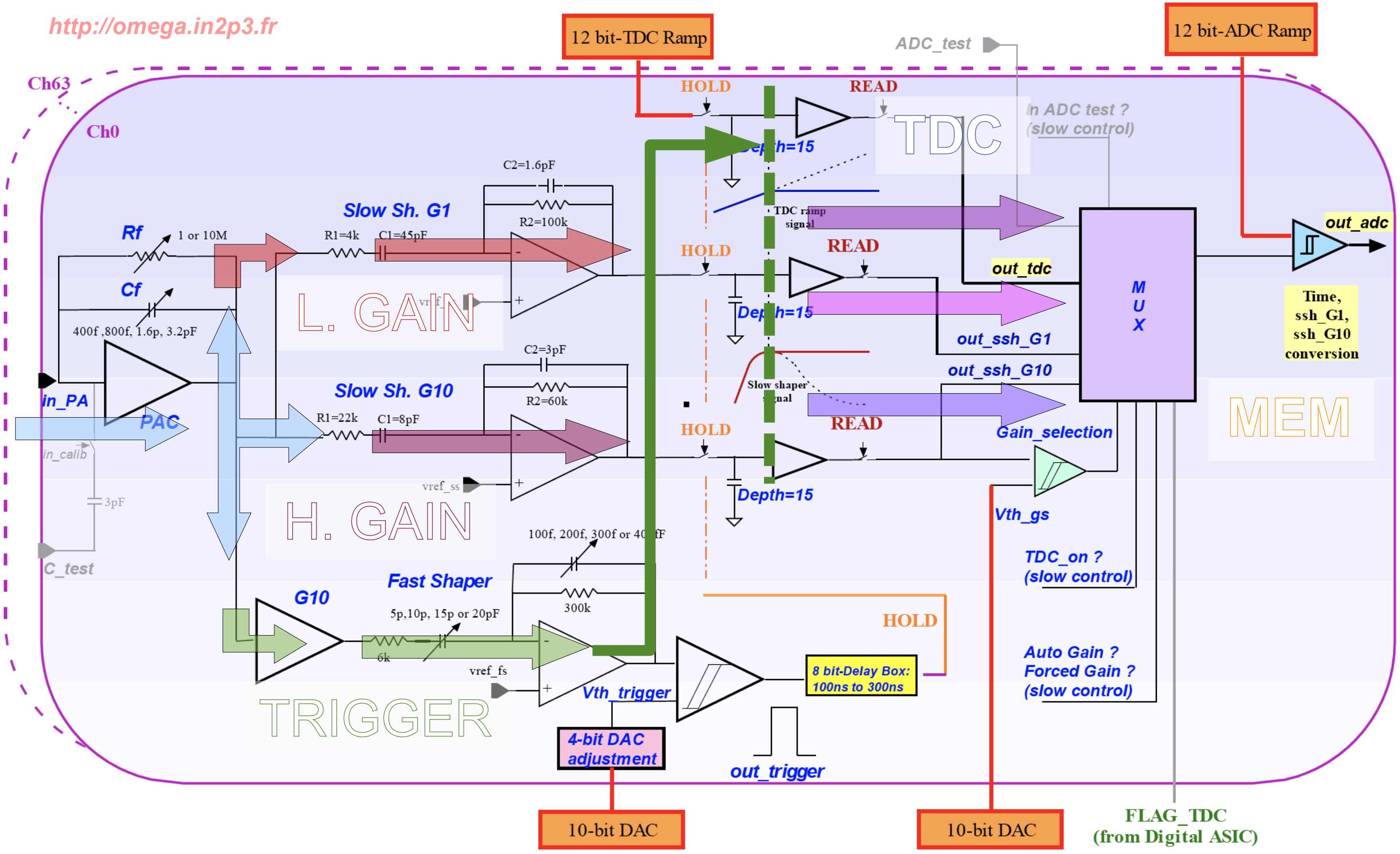
- 1M ➡ 70M channels
- on 750µm 12×12 cm² 8'' Wafers ?
- Pre-industrial building
- Full integration (⊃ cooling)
- Final ASIC

OMEGA Microelectronics

SKIROC2 / 2A Analogue core



http://omega.in2p3.fr

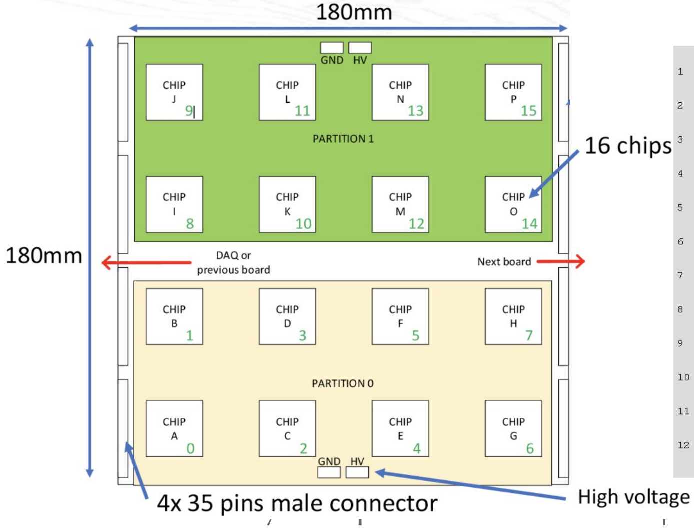


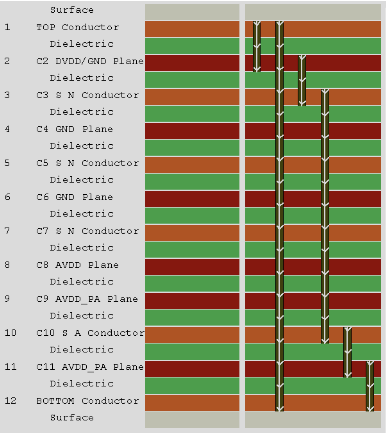
- **64 channels**
- **Auto-triggered**
  - per cell adj.
  - 1 cell triggers all
- Preamp
  + **2 Gains** + Auto-select
  + TDC (~1.4ns)
- 15 (×2) analogue memories
- Dyn range 0.1 ~ 2500 mips
  - mip in 320 µm (4 fC)
  - 12 bits ADC's
- *616 config bits*
- Low consumption
  - 25 µW/ch with 0.5% ILC-like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

FEV's : 15 years of R&D

Most complex element: electrical-mechanical integration

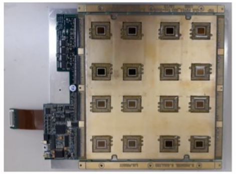
- Powering, Distrib / Collect signals from ASICs, Analog & Digital with dyn. range ≥ 7500
  - Single End operation → Chaining for 8–10 boards
- **Mechanical** placer & holder for Wafers
  → ≤ 50µm lateral precision, flatness
- **Thickness** constraints → Calorimeter Compactness





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)$_{Trig,}$ 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

Technological Prototype Beam test at DESY & CERN



FEV10, 11, 12

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

FEV-COB

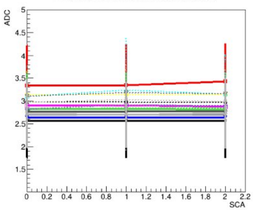
- Chip-On-Board : ASICs wirebonded in cavities
  - Thinner than FEV with BGA
- Based on FEV11
  - External connectivity compatible

FEV13

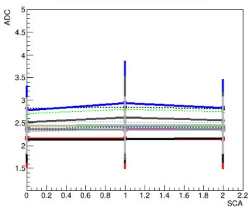
- BGA packaging
  - Improved routing
  - Local power storage
  - Different external connectivity

Pedestal widths, 1st memory cells, per asic

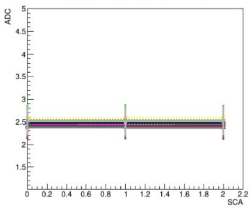
COB



FEV12

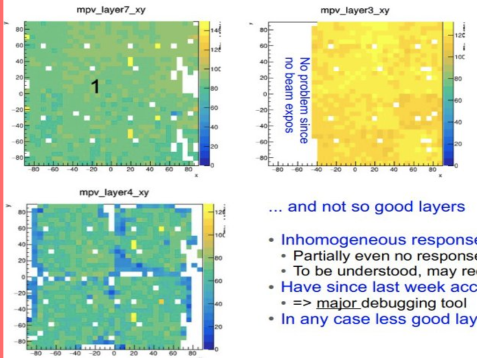


FEV13



- (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

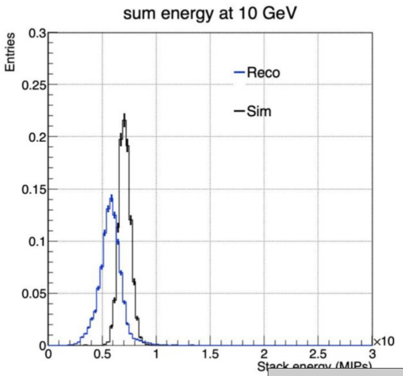
2022 BT



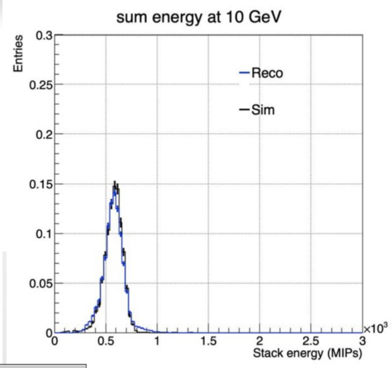
- We have good layers ...
  - Homogeneous response to MIPs over layer surface
  - Here white cells are masked cells due to PCB routing
    - Understood and will be corrected

... 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.)

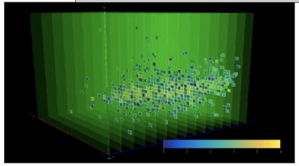


Fig. Simulation e- 100 GeV

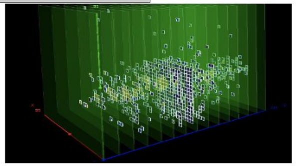


Fig. Reconstructed e- 100 GeV

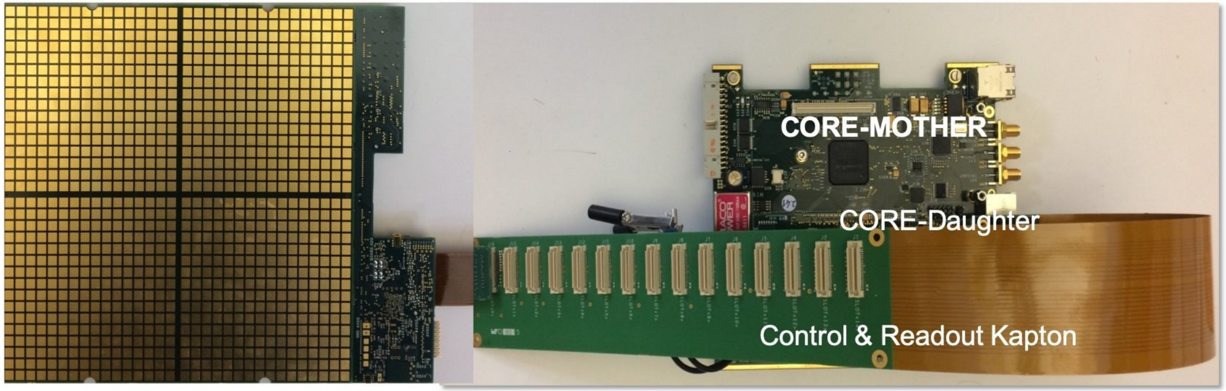
Compact DAQ readout

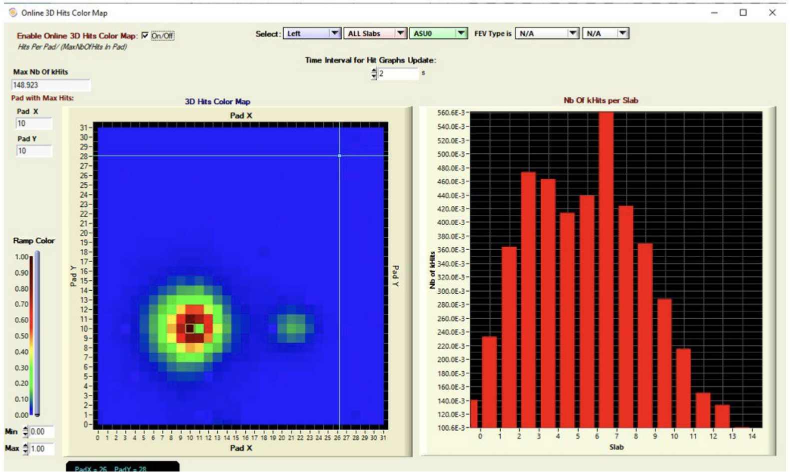
“Dead space free” granular calorimeters
→ ~ 30 mm space ECAL–HCAL

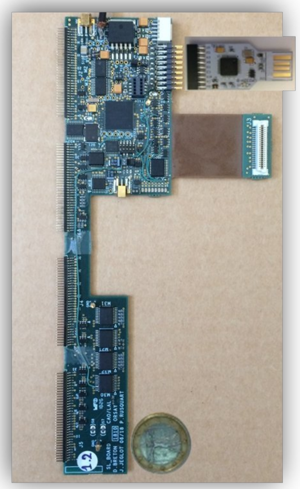
- Compact DAQ
- in use in BT since 2019

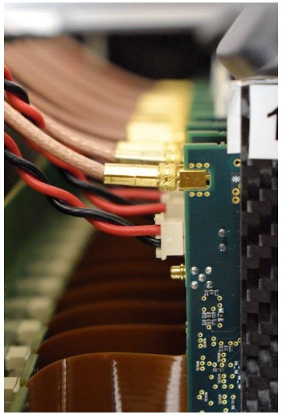
LabWindows + scriptings

- Full debug system
- ↔ EUDAQ
  - Combined running









Acquisition software

Written in C under Labwindows CVI

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

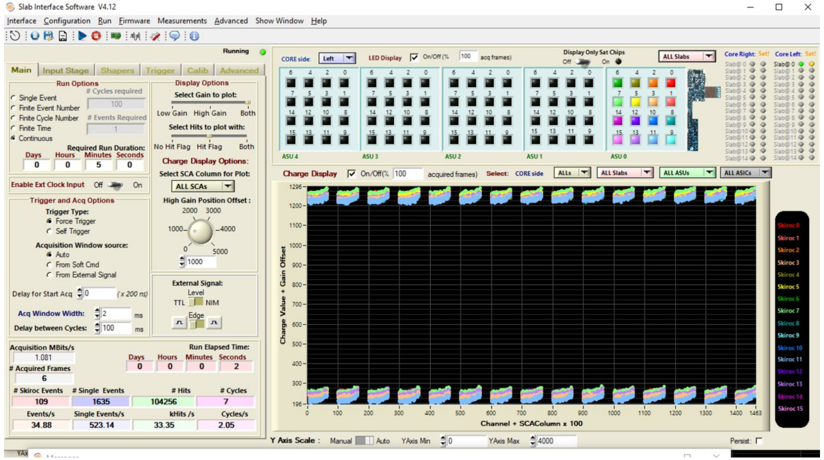
Make advanced measurements

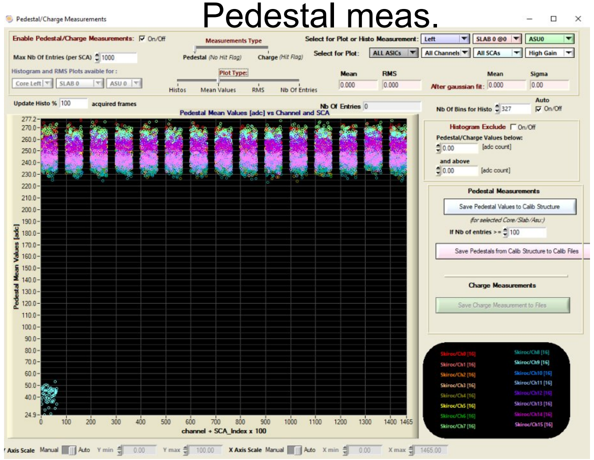
Hardware automatically detected

- Number of SLAB
- FEV type + number of ASU

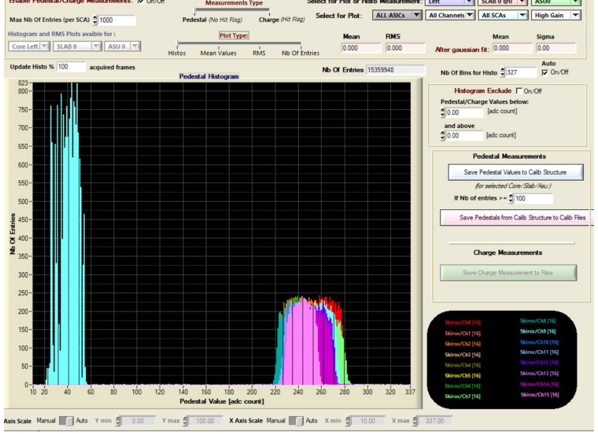
Slowcontrol:

- All parameters programmable
- Integrated analysis



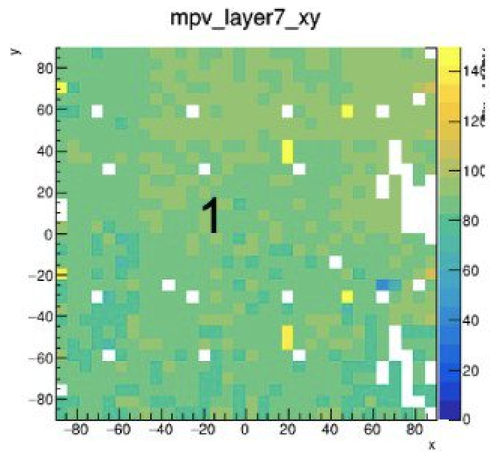


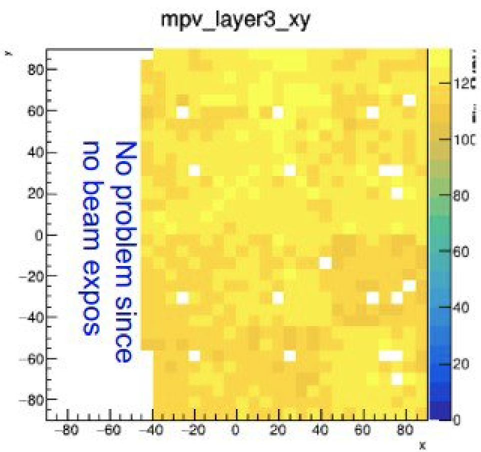
Pedestal meas.



S-Curve on FEV2

MIP calibration





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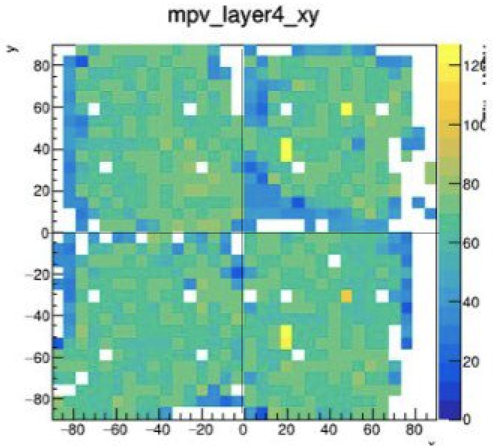

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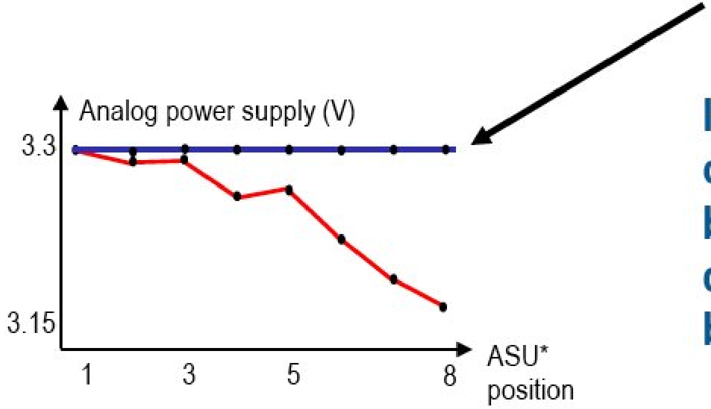
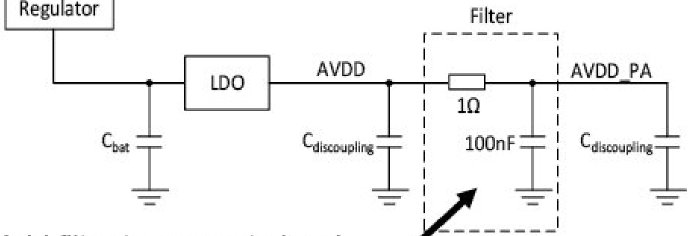
Power distribution dedicated for LONG SLAB



Expected results

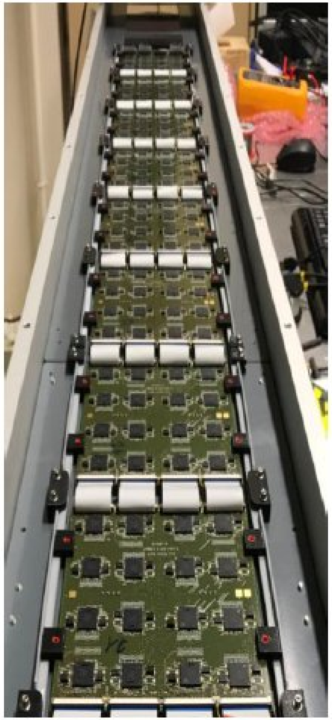
In the electrical long SLAB, 8 boards are chained and due to resistivity of layer per board on analog 3.3V, we measure voltage drop along the long SLAB coupled with bandgap distribution.

ASU* (Active Sensor Unit)

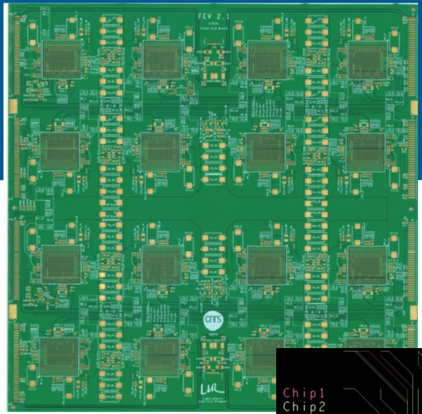


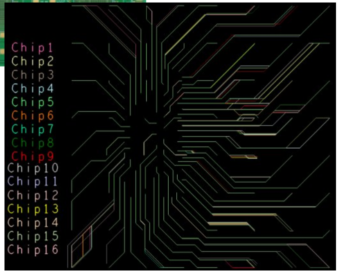
Add filter to generate local preamplifier power supply

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



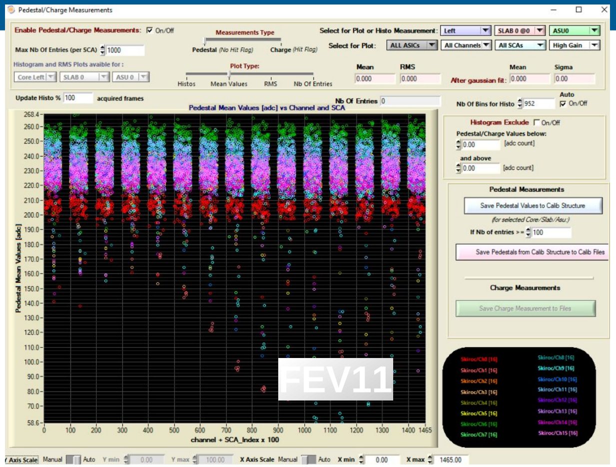
New FE boards





Improvements:

- Power distributions
  - Local power regulation: LDO's
  - Local High Voltage filtering & Supply
- Signal distribution (buffering), data paths
- Monitoring (single ID, temp, probe analogue line)
- ASIC shielding/routing



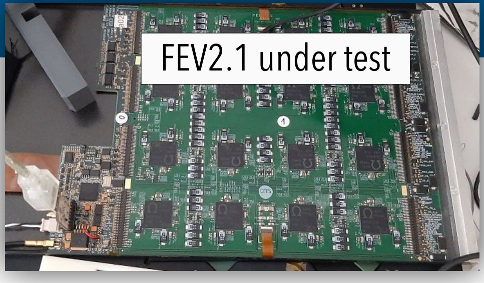
Pedestal measurements vs. Ch# + Mem#×100)

Status:

- pre-version 2.0 tested, minor corrections needed
  - Noise uniformity dramatically improved (ex: outliers in thr. / 20)
- version 2.1 produced
  - before cabling, 2nd metrology, gluing, …

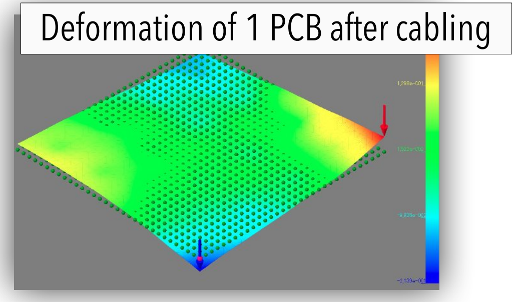
SIngle channel → the fault on the ASIC/packaging

New hardware for the SiW-ECAL



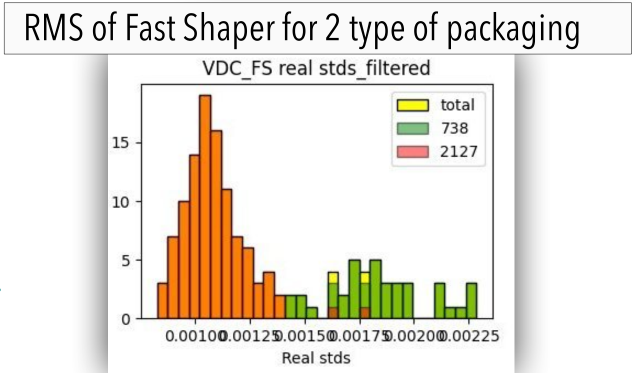
30 PCB of new type FEV2.1 have been produced

- 1st batch of 4 cabled for tests
- 1 equipped with 4 babywafers for HV test
  - Still needs adapatation of Slboard for HV supply (on-going)
- Mechanical test made at IFIC Valencia
  - Not all satisfactory (flatness ±200μm in the corners after the cabling involving heating at 300°C); further investigation on the cabling process foreseen



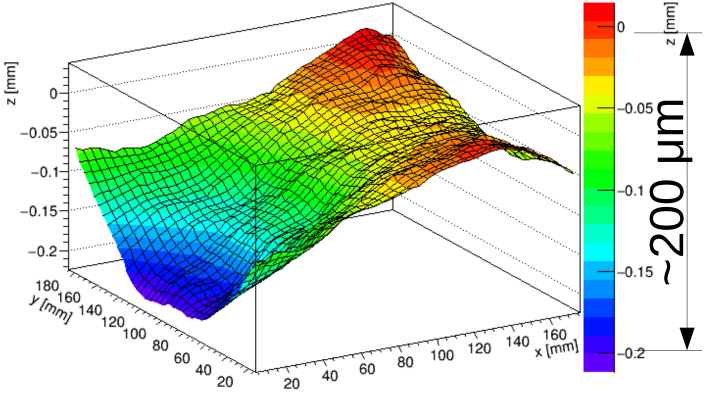
Testing of Skiroc2 ASICs:

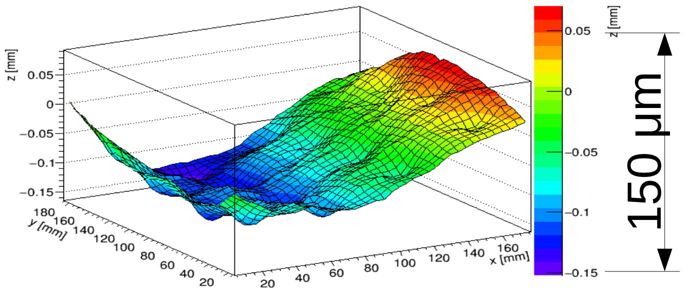
- ~ 1/3 of ASICs tested thoughroughly on dedicated bench at Ωmega lab prior to soldering on PCB's
  - Statistical analysis on-going; testing of the rest will resume soon.
- 64 (4×16) mounted on the FEV2.1
  - Performances (noises, thresholds, …) will be compared with bench results.



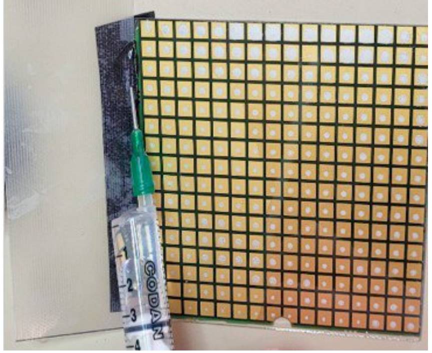
PCB – Sensor gluing studies (on-going at Valencia & IJClab)

PCB planearity @Orsay before / after component soldering

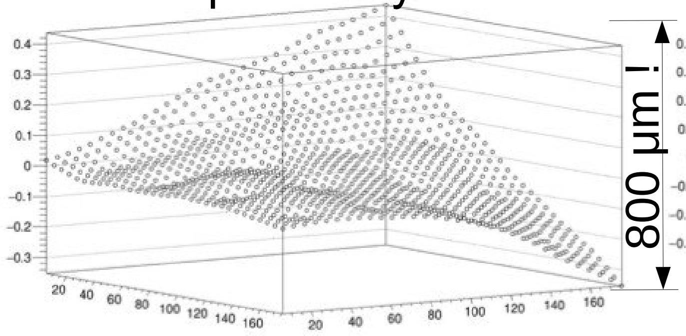


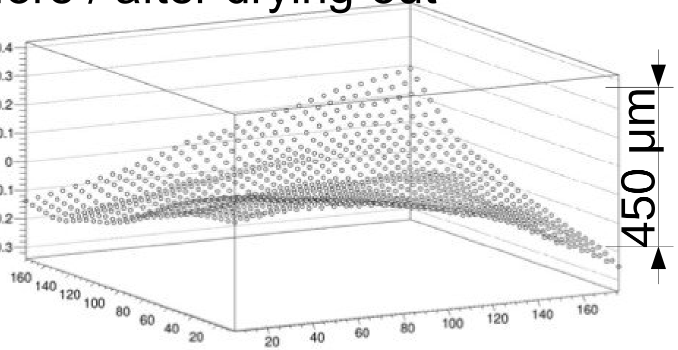


Conductive glue dots + underfill mechanical glue

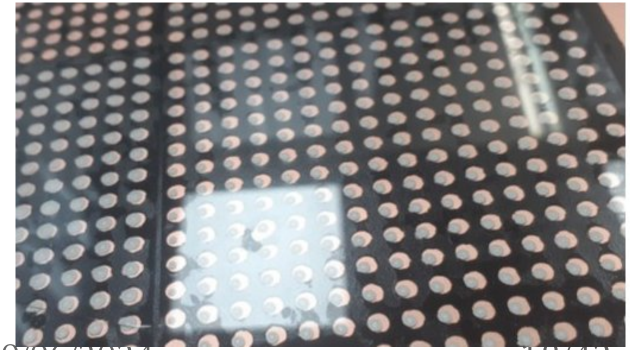


PCB planearity Valencia before / after drying-out





3M conductive glue



Beam Tests and Planning for 2024

First CALICE/DRD6 beam tests

- Initially scheduled for June at DESY
- To be moved in Fall 2024

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
	M1.1		Specifications for timing and cooling	2025
		D1.2	Engineering module for Higgs factory	>2026

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], $\mathcal{L}$ ~ cst.
- Power pulsing : 5 [10–15]Hz × 1 [2] ms   Power ~ $\mathcal{L}$.

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:

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

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

HL-CLIC:

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

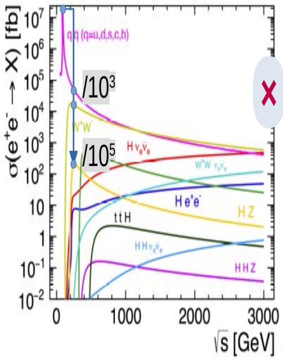
Dominated by Set-up & Conversion time: P (~82µW/ch) ×2

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

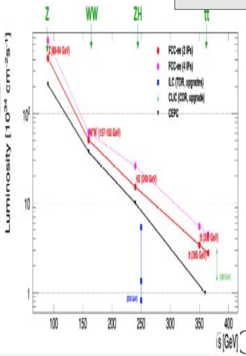
Experimentally, Z pole most challenging

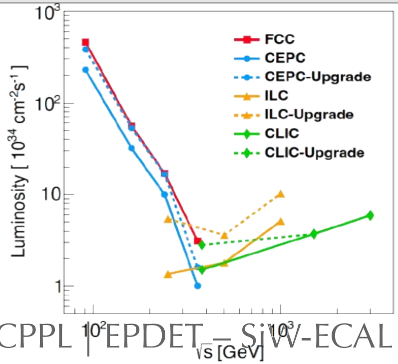
- Extremely large statistics
- Physics event rates up to 100 kHz
- Bunch spacing at 20 ns
  - "Continuous" beams, no bunch trains, no power pulsing
- No pileup, no underlying event …
  - …well, pileup of 2 x 10^{-3} at Z pole

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



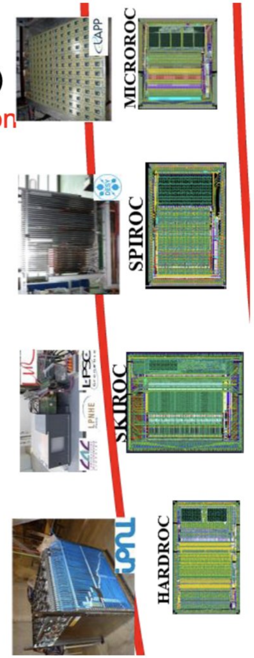


New ASIC:

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

See Christophe's presentation & Disc on Thursday

Low Power

- Enough ?
- If Timing ?

Low occupancy

- Self-trigger
- Less memory
  - if continuous readout

Optimized dynamic range (silicon)

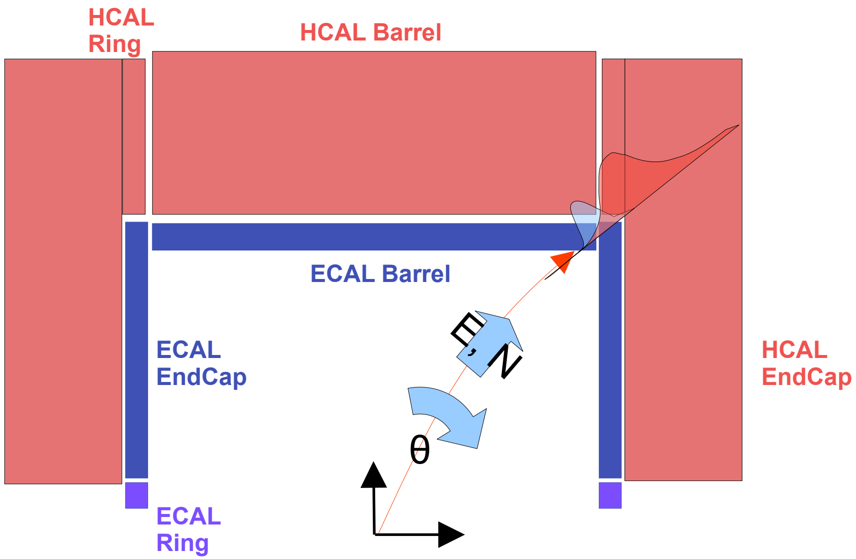
Calorimeter Fluxes from Full Simulations: CaloFlux

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



Processes to Fluxes

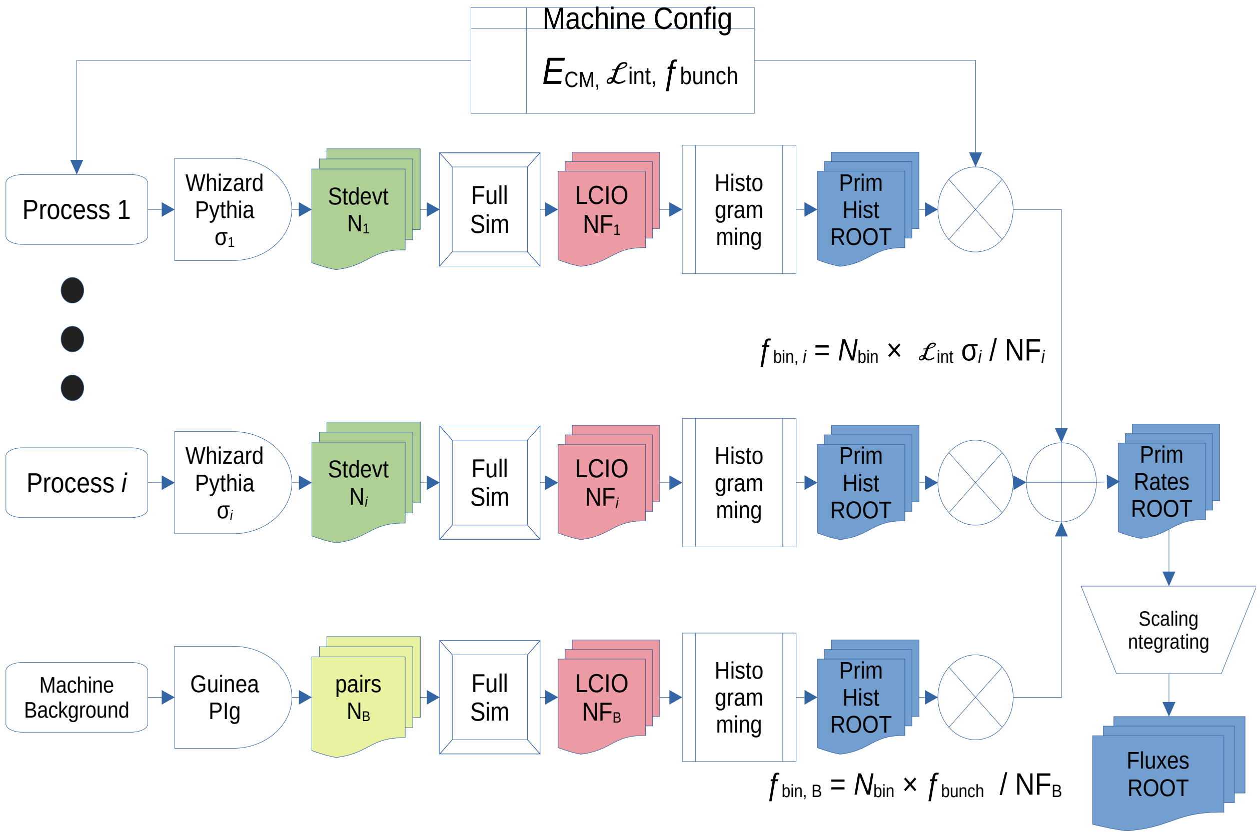


Table 2: 91.2 GeV
($N = 10000$, $\mathcal{L}_{int.} = 1.4 \times 10^{-3}\ \mathrm{fb^{-1}s^{-1}}$)

Channels	σ (10^5 fb)	$\sigma \times \mathcal{L}_{int.}/N$ ($\mathrm{s^{-1}}$)
$e^+e^- \to q\bar{q}$	344	4.82
$e^+e^- \to \ell\bar{\ell}$	34.6	0.484
$e^+e^- \to \ell\bar{\ell}$ ($M_{ee} < 30$ GeV)	1.01	0.0141
$e^+e^- \to \ell\bar{\ell}$ ($M_{ee} > 30$ GeV)	57.8	0.809

Table 3: 162.5 GeV
($N = 10000$, $\mathcal{L}_{int.} = 2.14 \times 10^{-4}\ \mathrm{fb^{-1}s^{-1}}$)

Channels	σ (10^5 fb)	$\sigma \times \mathcal{L}_{int.}/N$ ($\mathrm{s^{-1}}$)
$e^+e^- \to q\bar{q}$	1.55	3.32×10^{-3}
$e^+e^- \to \ell\bar{\ell}$	0.241	5.16×10^{-4}
$e^+e^- \to W^+W^-$	0.0504	1.08×10^{-4}
$e^+e^- \to \ell\bar{\ell}$ ($M_{ee} < 30$ GeV)	0.240	5.14×10^{-4}
$e^+e^- \to \ell\bar{\ell}$ ($M_{ee} > 30$ GeV)	12.9	2.76×10^{-2}

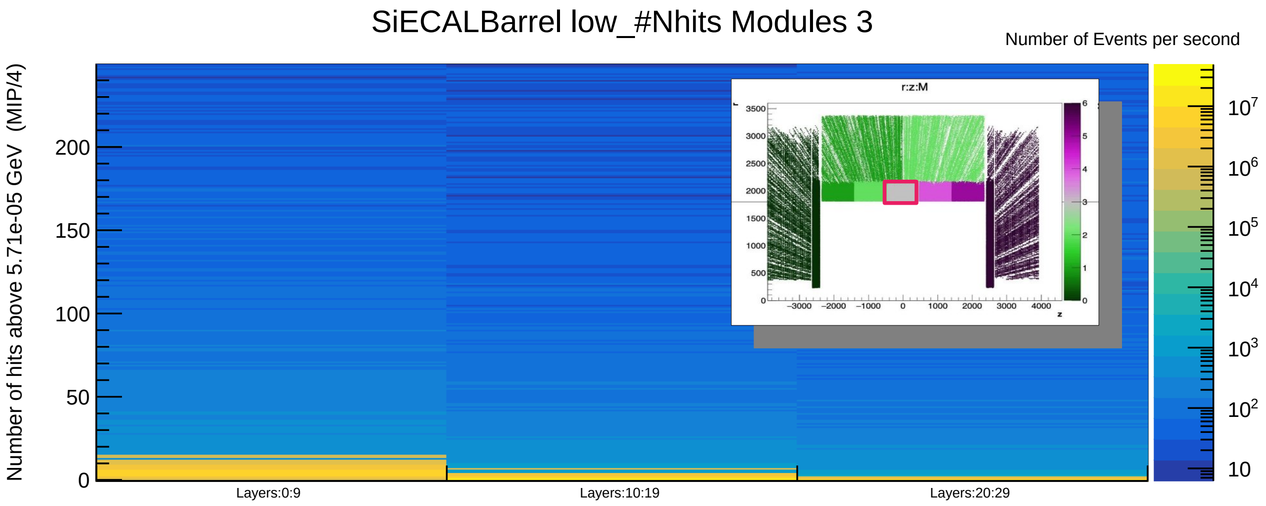
Table 4: 240 GeV
($N = 10000$, $\mathcal{L}_{int.} = 6.9 \times 10^{-5}\ \mathrm{fb^{-1}\ s^{-1}}$)

Channels	σ (10^5 fb)	$\sigma \times \mathcal{L}_{int.}/N$ ($\mathrm{s^{-1}}$)
$e^+e^- \to q\bar{q}$	0.550	3.80×10^{-4}
$e^+e^- \to \ell\bar{\ell}$	0.100	6.88×10^{-5}
$e^+e^- \to W^+W^-$	0.167	1.15×10^{-4}
$e^+e^- \to ZH$	0.00204	1.41×10^{-6}
$e^+e^- \to \ell\bar{\ell}$ ($M_{ee} < 30$ GeV)	0.120	8.29×10^{-5}
$e^+e^- \to \ell\bar{\ell}$ ($M_{ee} > 30$ GeV)	5.92	4.09×10^{-3}

Table 5: 365 GeV
($N = 10000$, $\mathcal{L}_{int.} = 1.2 \times 10^{-5}\ \mathrm{fb^{-1}s^{-1}}$)

Channels	σ (10^5 fb)	$\sigma \times \mathcal{L}_{int.}/N$ ($\mathrm{s^{-1}}$)
$e^+e^- \to q\bar{q}$	0.228	2.74×10^{-5}
$e^+e^- \to \ell\bar{\ell}$	0.0430	5.16×10^{-6}
$e^+e^- \to W^+W^-$	0.111	1.33×10^{-5}
$e^+e^- \to ZH$	0.00123	1.47×10^{-7}
$e^+e^- \to t\bar{t}$	0.00372	4.46×10^{-7}
$e^+e^- \to \ell\bar{\ell}$ ($M_{ee} < 30$ GeV)	0.0499	5.99×10^{-6}
$e^+e^- \to \ell\bar{\ell}$ ($M_{ee} > 30$ GeV)	2.58	4.65×10^{-6}

Results : Silicon ECAL Barrel, Central Module vs depth



Layers:0:9	Layers:10:19	Layers:20:29
Mean: 5.60e+00 #hits	**Mean: 1.13e+00 #hits**	**Mean: 1.21e-01 #hits**
Std Dev: 3.62e+00 #hits	**Std Dev: 2.25e+00 #hits**	**Std Dev: 2.08e+00 #hits**
events/second: 5.27e+07	**events/second: 5.27e+07**	**events/second: 5.27e+07**

Average	302E+6 hits/s	65E+6 hits/s	8E+6 hits/s
Max	2000 hits/event	2500 hits/event	1000 hits/event
for 6B/hits	2,111E+9 B/s	458E+6 B/s	54E+6 B/s
Ncells	4 026 764	3 767 273	3 378 036
Occupancy/BX	1,4E-06	3,3E-07	4,3E-08

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

- Most of the hits are in the first 2 thirds of the calorimeter.
- Highest average rates L0:9
- Highest max rates in L10:19

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

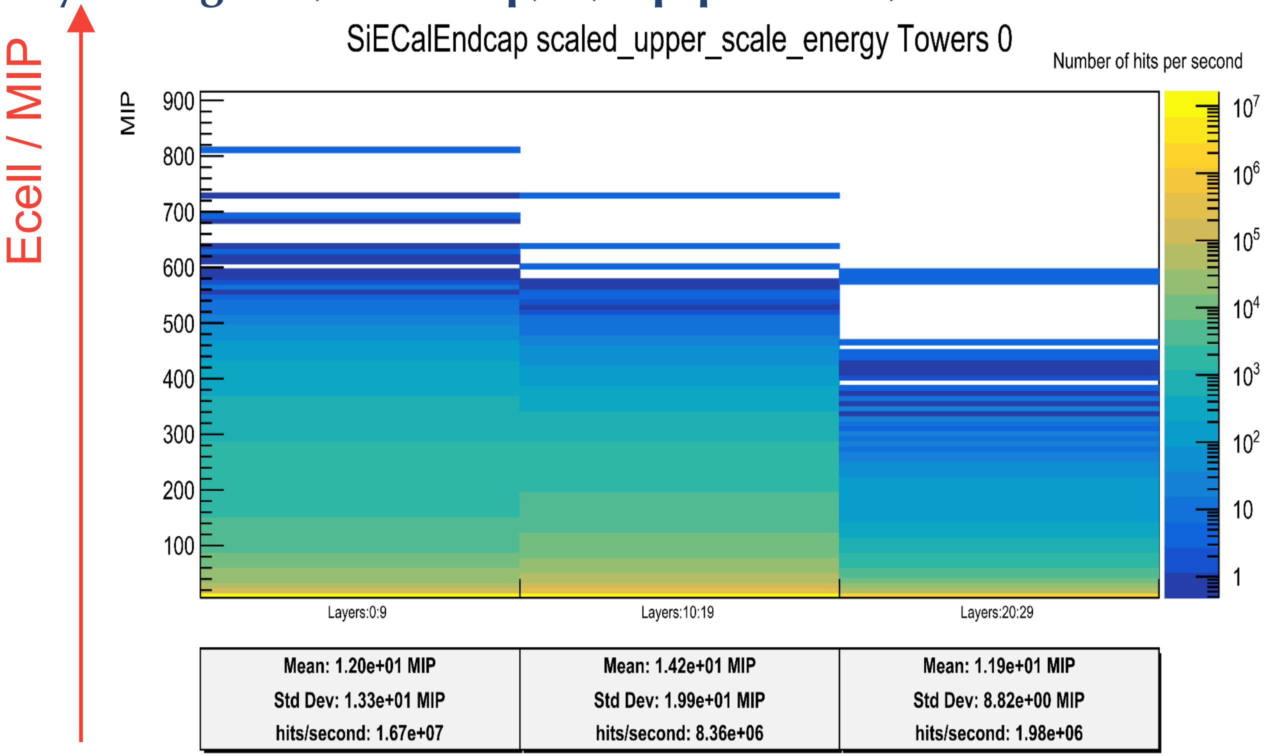
- The data rate, knowing the number of bytes per hits (here 6 as a landmark)
- The occupancy, knowing the number of cell in the region.

Note 1 : **Preliminary**

Note 2 : Rates for all M3 modules ➞ /8 per module, /10 per layer

Dynamic range

Dyn Range ~ (Emax/Mip)/ (Mip/precision)



Similar distributions for

- Time, Nhits, Energy
- SiW-ECAL, ScECAL, AHCAL, SDHCAL
  - All Barrel and Endcaps modules/towers and “Rings”
    - 11 “systems” in total
  - 3 section in depth

Now for ILD

Main processes
@ 91*, 162, 240*, 365 GeV

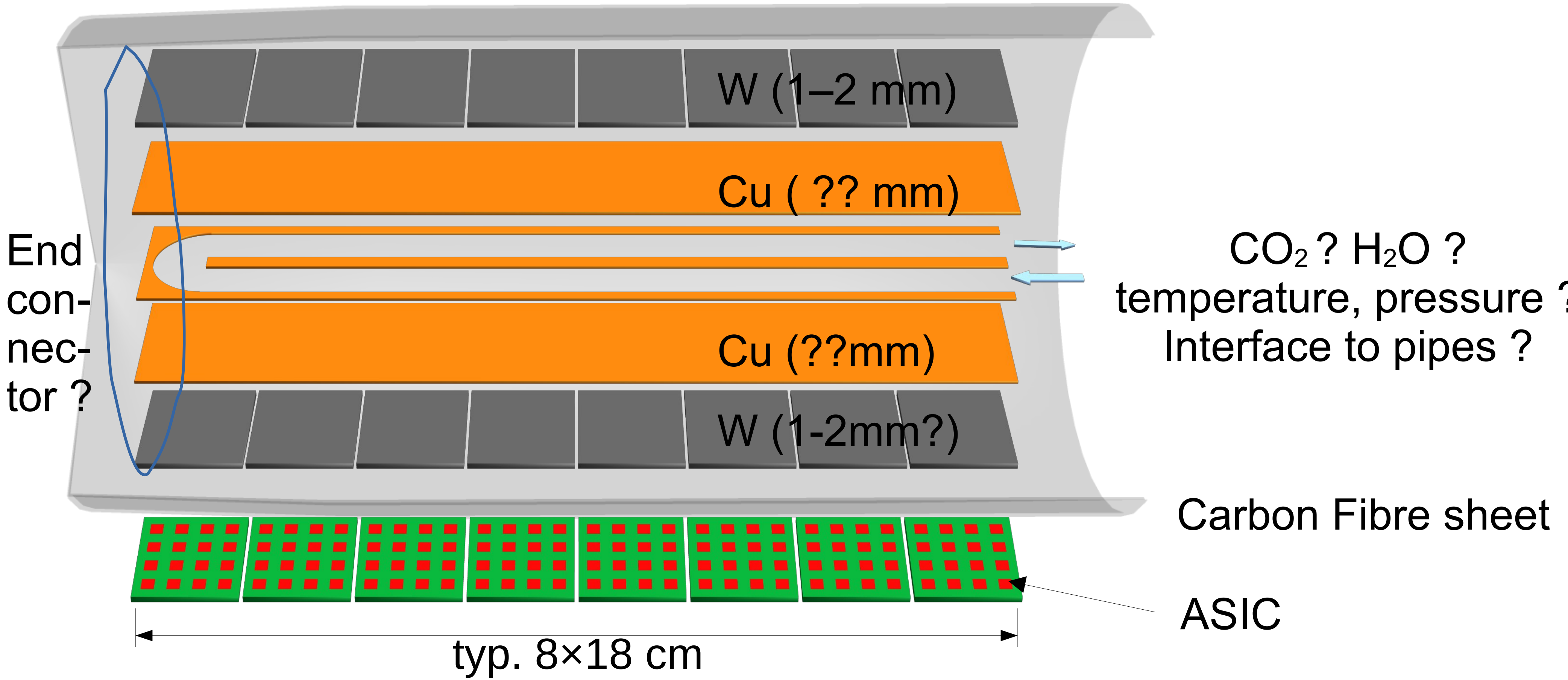
- With machine background

Variant with prelim MDI for FCC

Missing:

- Digitization (esp. for SDHCAL)
- Consolidation
- Play with granularity / electronics / cooling

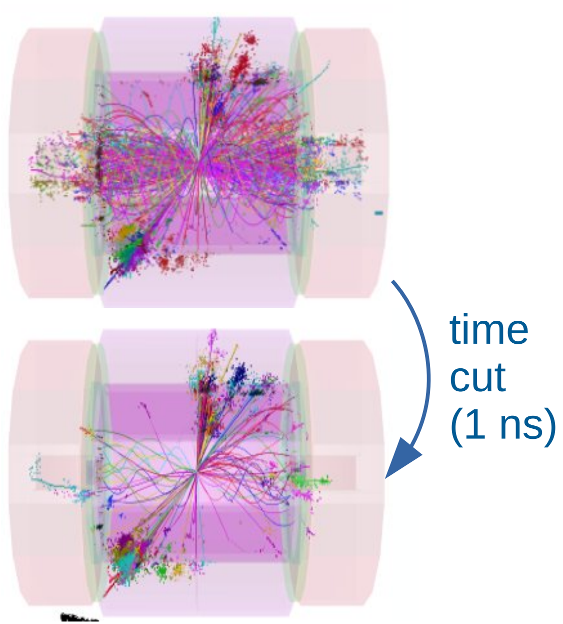
How to Active cool a slab, without degrading uniformity ?



Reconstruction Methods : timing

Timing in Calorimeters: 0.02–1 ns range

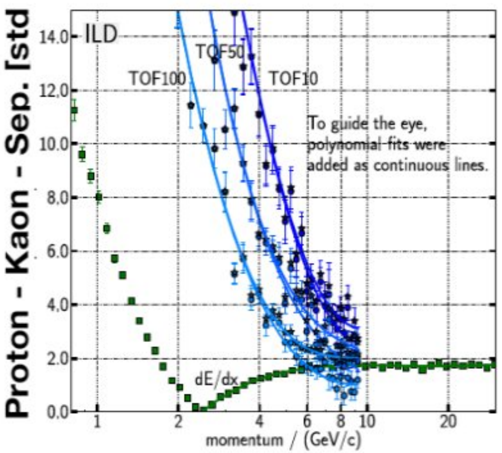
Cleaning of Events



[CLIC CDR: 1202.5940]
adapted from L. Emberger

Particle ID by Time-of-Flight

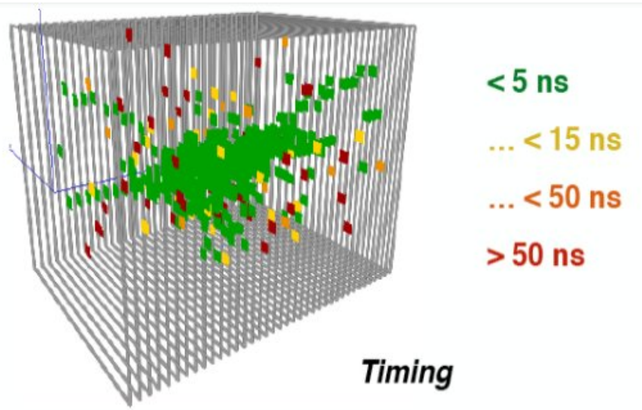
– Complementary to d*E*/dx
  - Here with 100 ps on 10 ECAL hits



S. Dharani, U. Einhaus, J. List

Ease Particle Flow with ps ?

– Cleaning of late neutrons & back scattering (ns)
– Identify primers in showers
– Help against confusion *better separation of showers*
  - Requires '4D clustering'



Ch. Graf

Cluster time measurement with CEPC calorimeter,

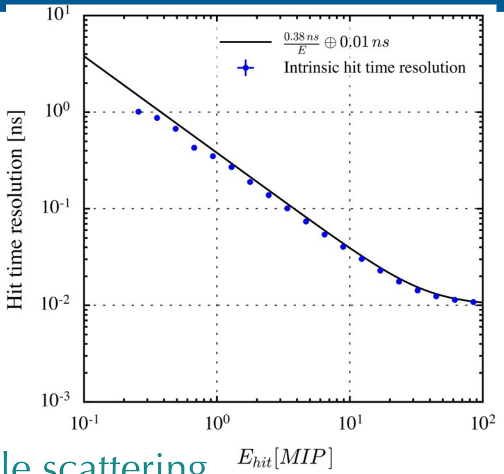
Eur. Phys. J. C (2023) 83:93

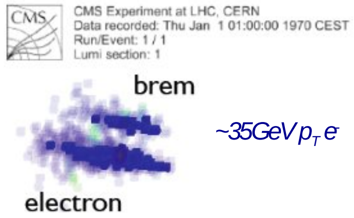
Yuzhi Che[1], Vincent Boudry[2], Henri Videau[2], Muchen He[1], Manqi Ruan[1,a]

Optimal use of timing from a given cluster to estimate the particle Time-of-Flight in ECAL

- "Intrinsic" cell-time resolution vs cell-energy

  CMS resolution type ~10 ps for high E ➞ Digitization

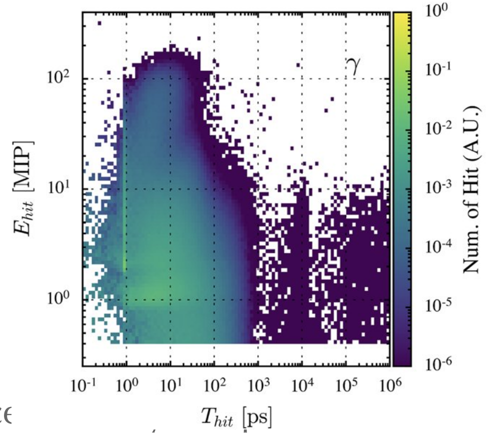




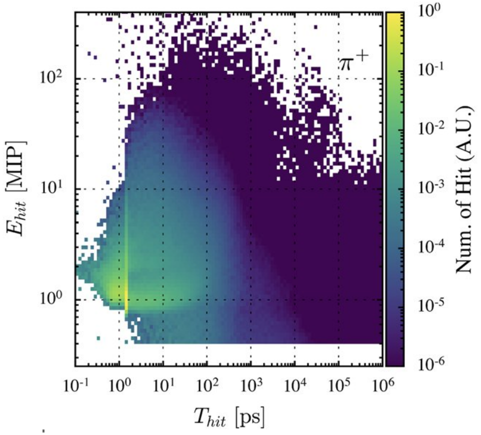
Transparent cells => no timing
Solid cells = > timing information ~50ps

- Low-E cells degrades performances
  - Bad time resolution & Shower-halo ➞ Multiple scattering

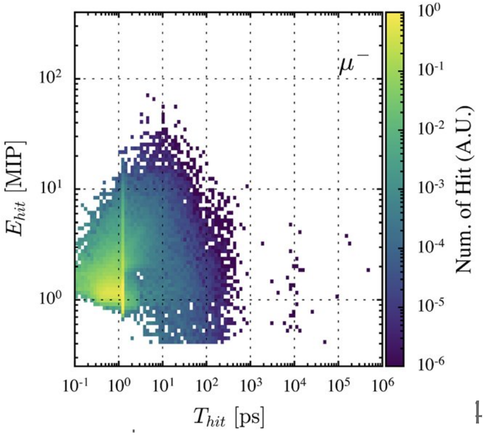
10 GeV γ



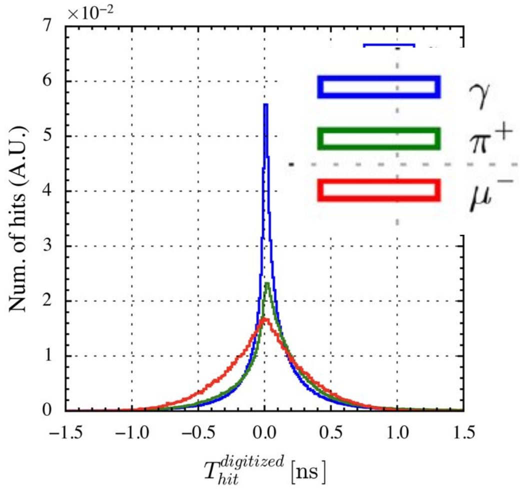
10 GeV π+

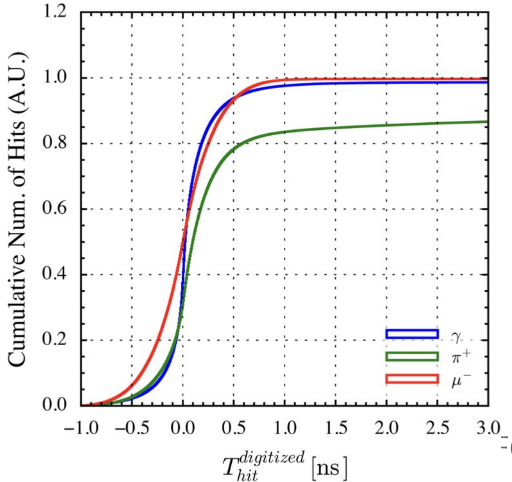


10 GeV μ-



Cluster time measurement with CEPC calorimeter, Eur. Phys. J. C (2023) 83:93



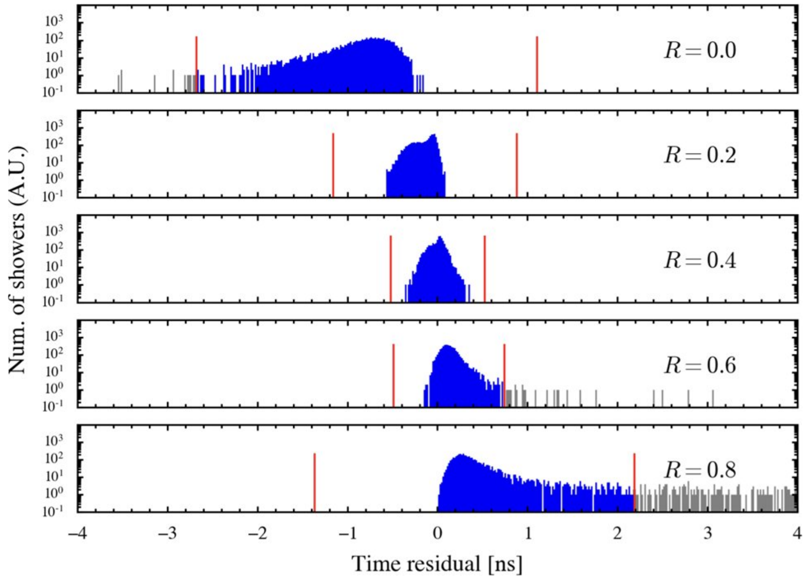


Best ⟨time⟩ from the core, but where does the core stops ?

- Narrow peak around the middle hit-time distribution
  - ➞ use the time of the (R·Nhit)-th time-ordered hit

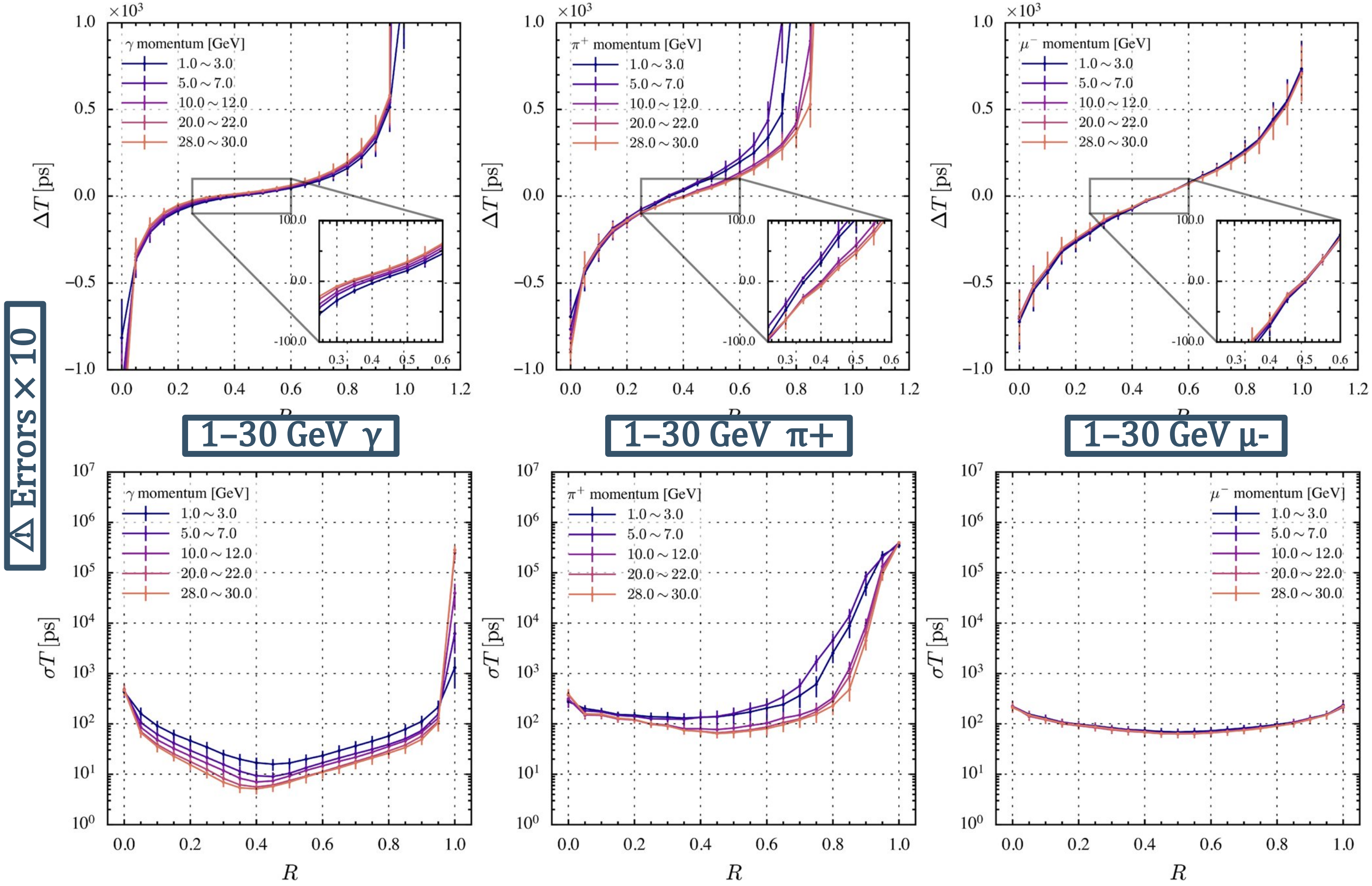
Scan for best R *vs t(PID & E)*

10 GeV π+

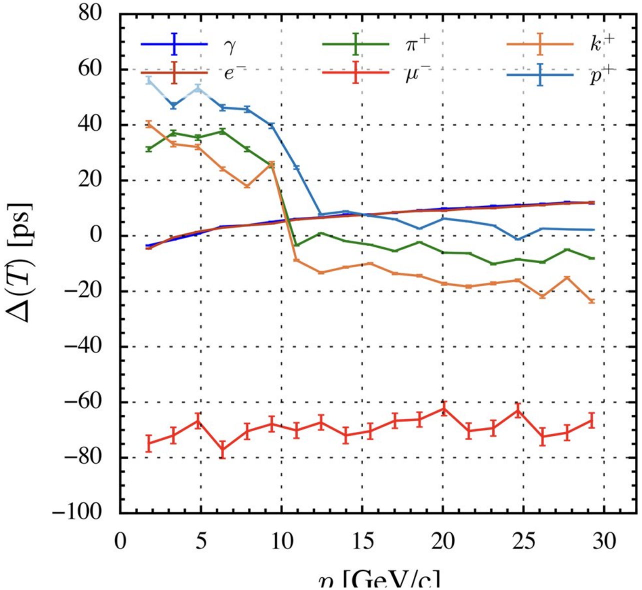


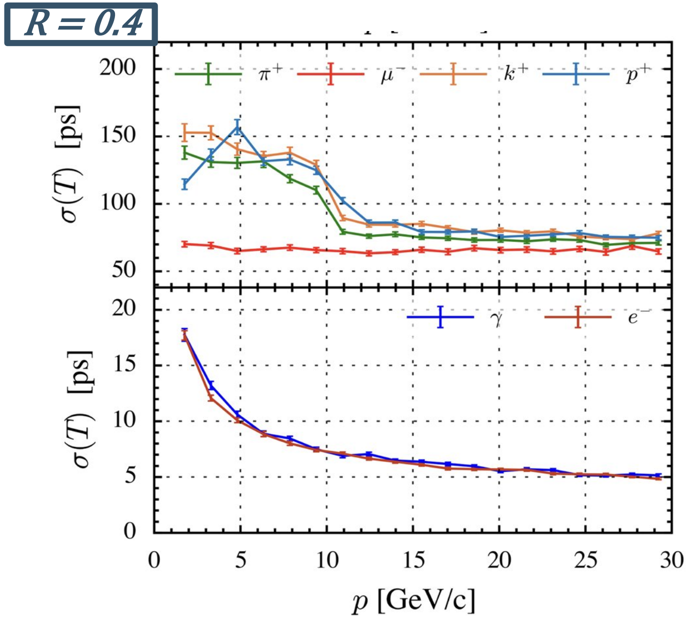
Red lines = outliers quantile-based cut-off

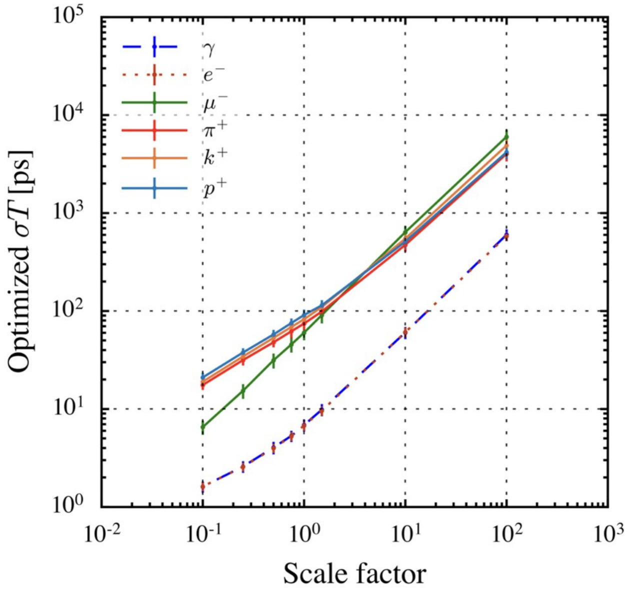
Biases & resolutions



Biases and Resolutions







Hadronics showers (in ECAL only!)

– σ(t) ~ 150–75 ps ; Break at 10 due to GEANT4 hadronic models…

EM showers:

– σ(t) ≤ 20 ps for E > 1 GeV; 5 ps for E > 25 GeV

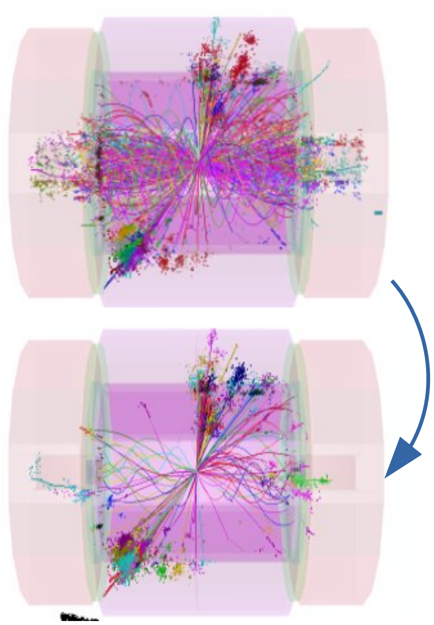
Nlayers, timing layers, Si thickness

Timing in Calorimeters: 0.02–1 ns range

1 cm/c = 30 ps

Recruiting in KIT, JGU, IJClab, LLR and IP2I (Lyon)

Cleaning of Events

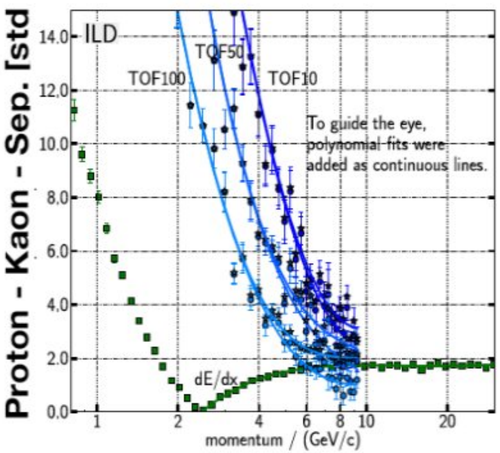


time cut (1 ns)

[CLIC CDR: 1202.5940] adapted from L. Emberger

Particle ID by Time-of-Flight

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



S. Dharani, U. Einhaus, J. List

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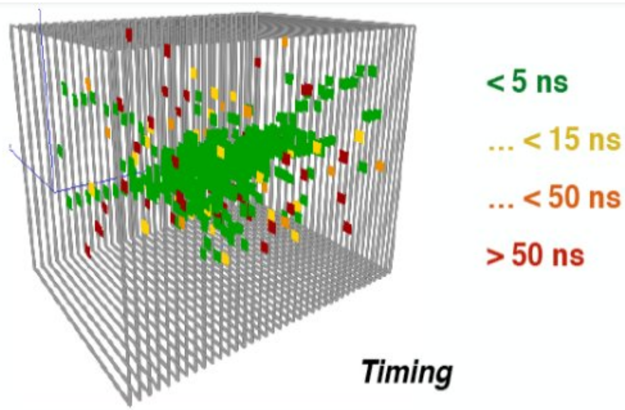


Ch. Graf

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:** Uniform ~~15~~ layers
  - ➞ New VFE boards
    – Cleaner PS & Clock distributions; more uniform
  - Gluing being revisited
  - Material available.
  - To be tested in 2024
    ➞ Provide reference sample for GEANT4
    ➞ With funding ➞ "full" LUXE

SiW-ECAL design for HET factories

– **2023–26**: Power budget & performances to be re visited
  - Occupancy, power, data fluxes (on-going)
    ➞ Granularity; Passive or Active cooling
    ➞ new ASIC attributes
  - 2024–26: **PFA & Physics performances**
  - **Including timing & AI enhenced PFA**

2025–26: Blue-print for a SiW-ECAL detector for the next ee collider

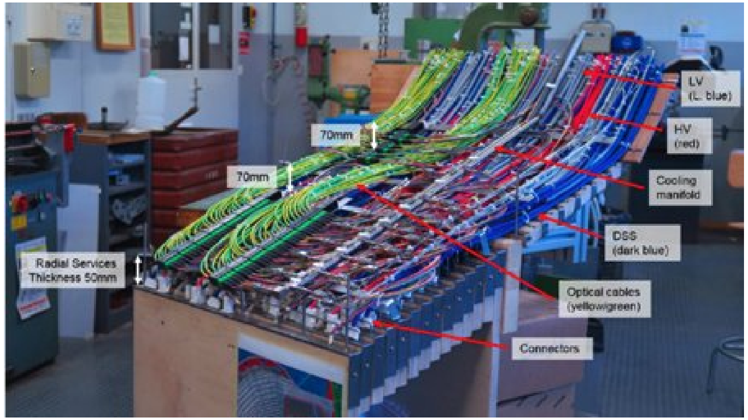
➡ planning for a pilote module @ T_0 collider-8y -5y
(1 Mch, 1/60th of real detector)

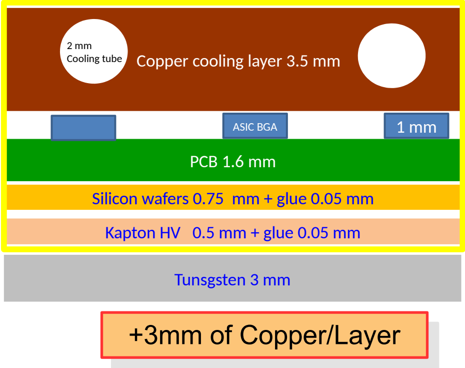
semi-industrial, quality, ASICs, …

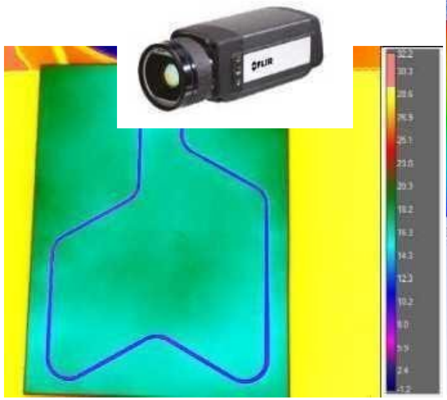
Back-up

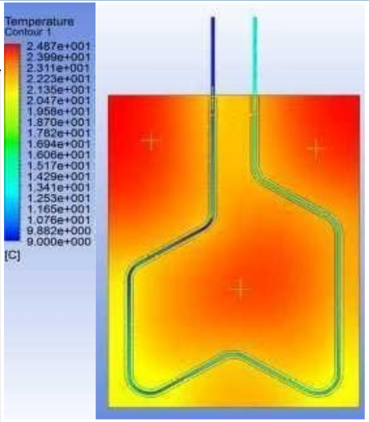
Services: integration & cooling

T. Pierre Emile



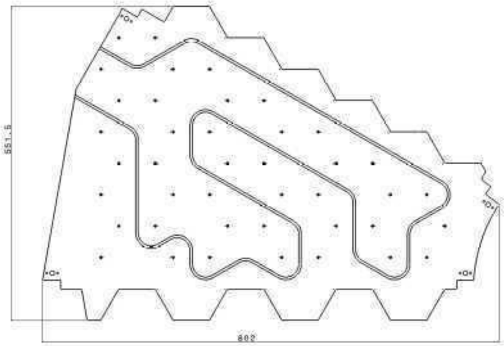


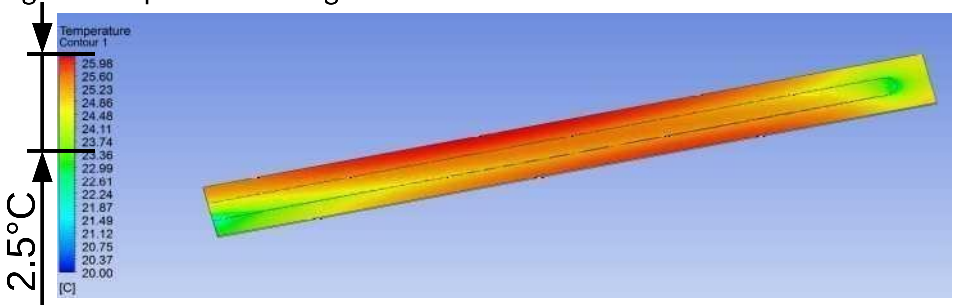




Pipe insertion on a cooling prototype

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

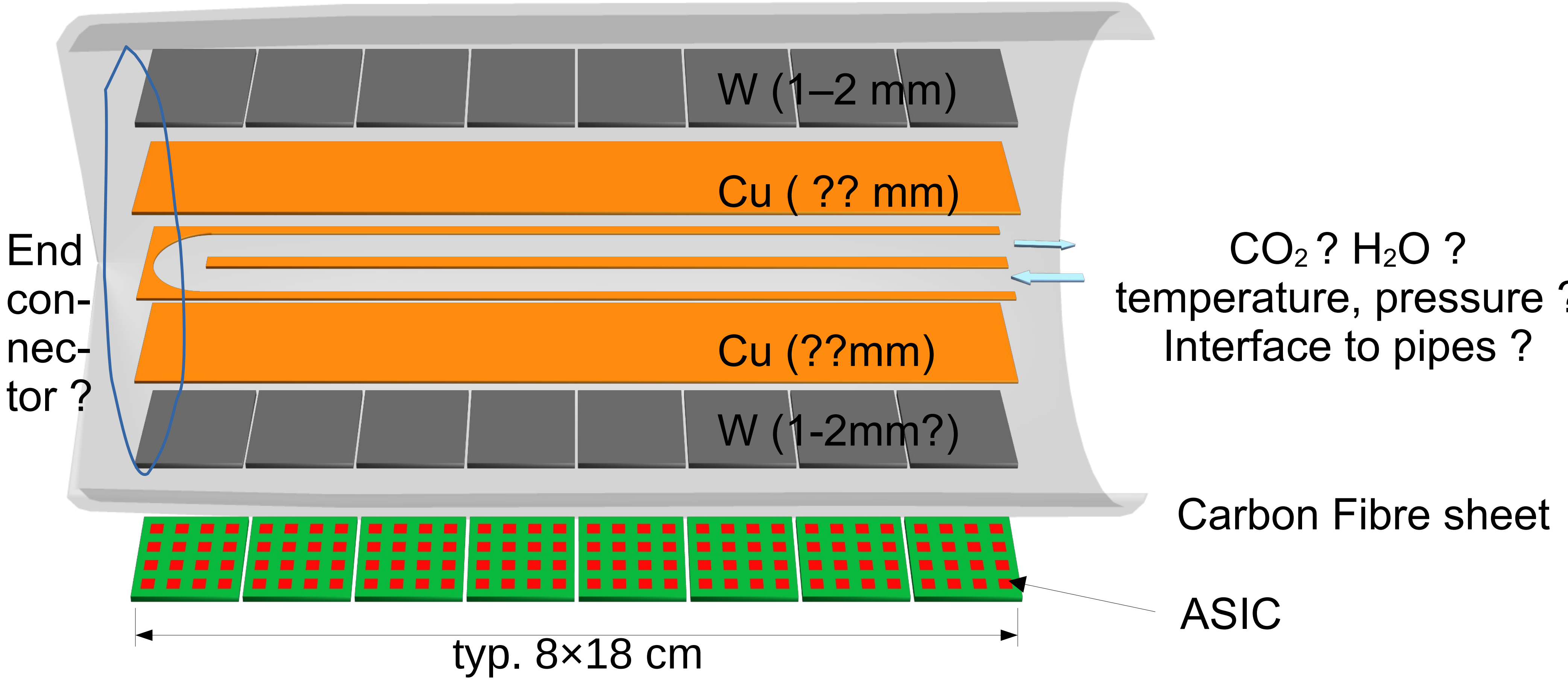




Thermal static CFD analysis thermal field example using Fluent with 100W extracted and water mass flow rate of 7g/s through 1.5mm ID pipe

×2 cont. operation of a SLAB,
with 5 mW/ch × 5×5 mm²

How to Active cool a slab, without degrading uniformity ?



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

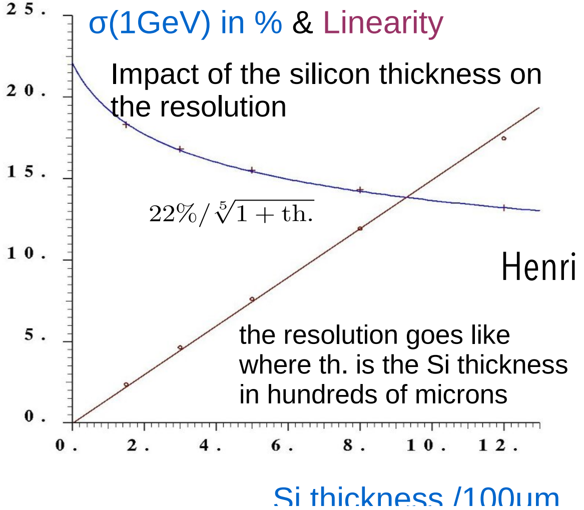
Increasing the Si thickness to 725µm

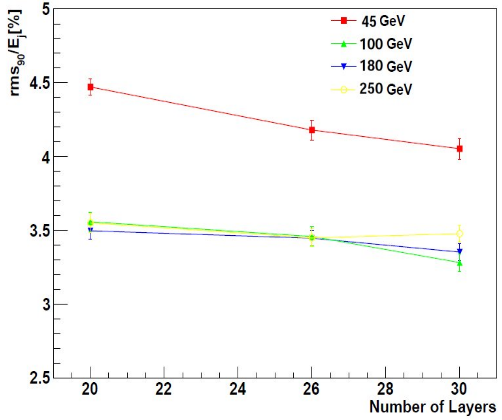
- GR width ↗ ⇒ go to 8″ wafers, new design

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)

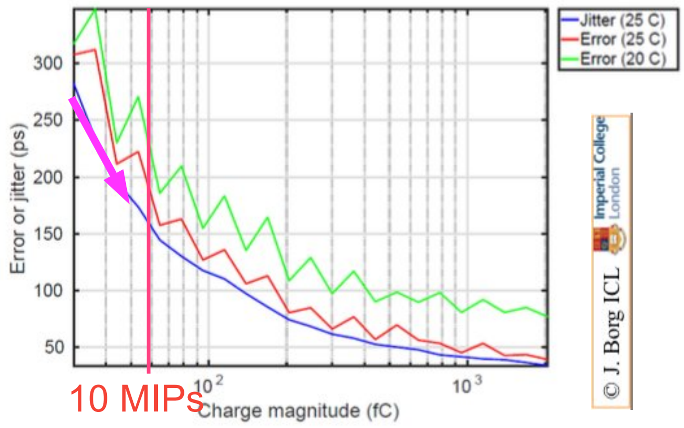
near compensation





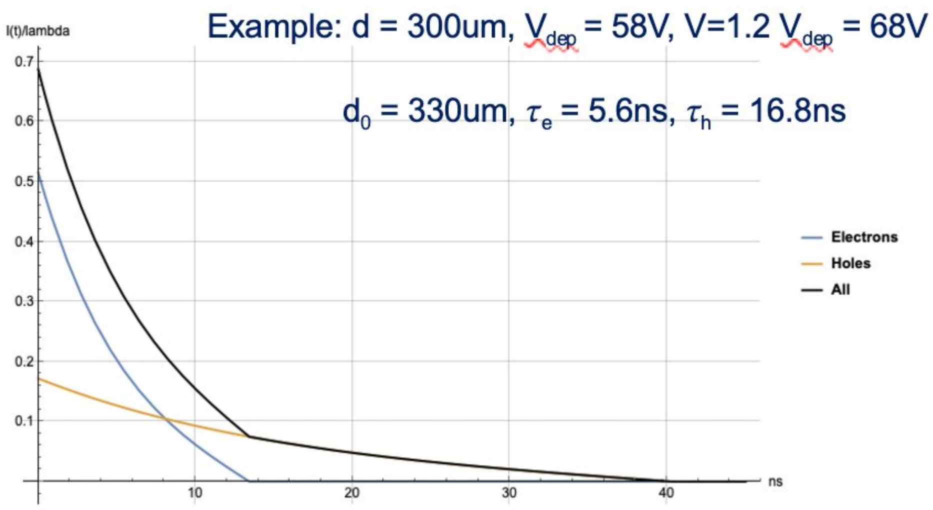
Time Resolution ?

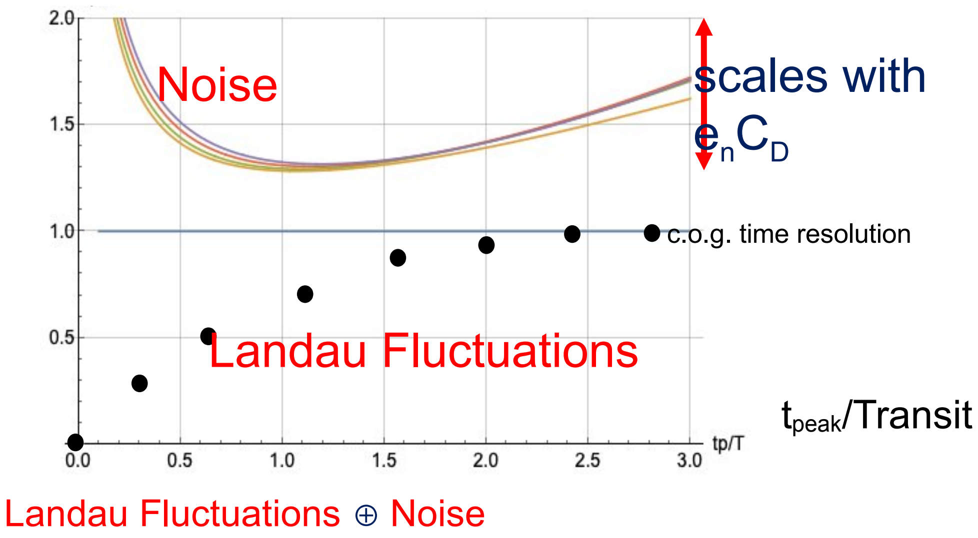
- Noise ~ C_{det} ~ width²/th,
  Signal ~ th ↗ ➞ S/N ~ th² ~ ×1.5
  ⇒ Improved timing perf (esp. for mips)

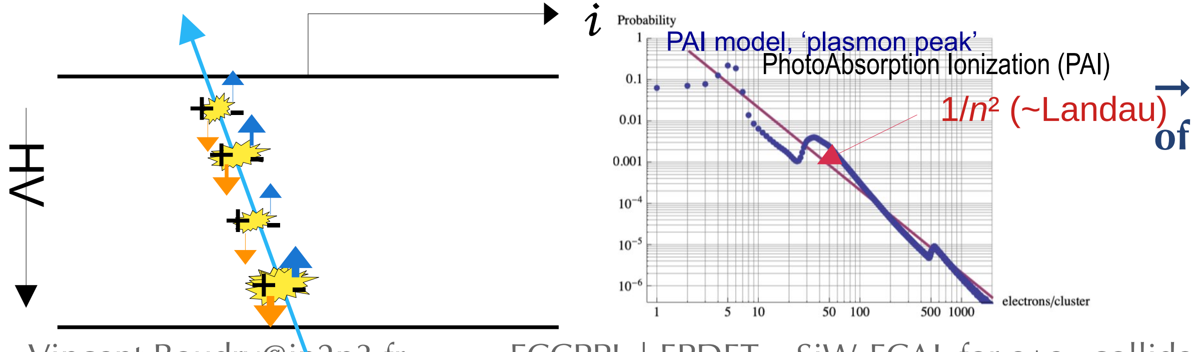


C. de La Taille Front-End elecectronics CHEF 2017

Time measurement *in Silico*



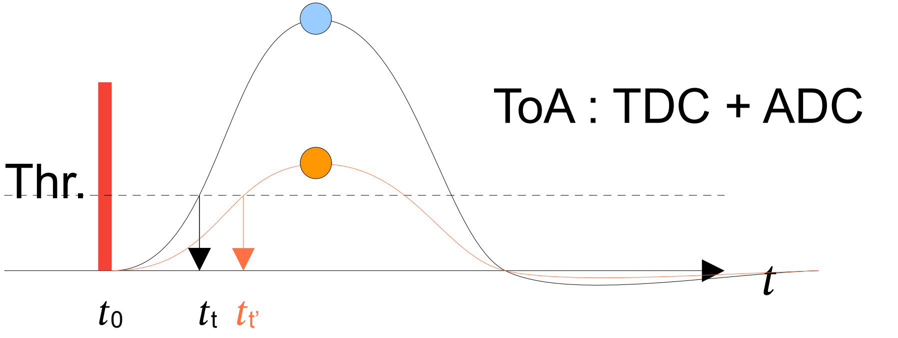




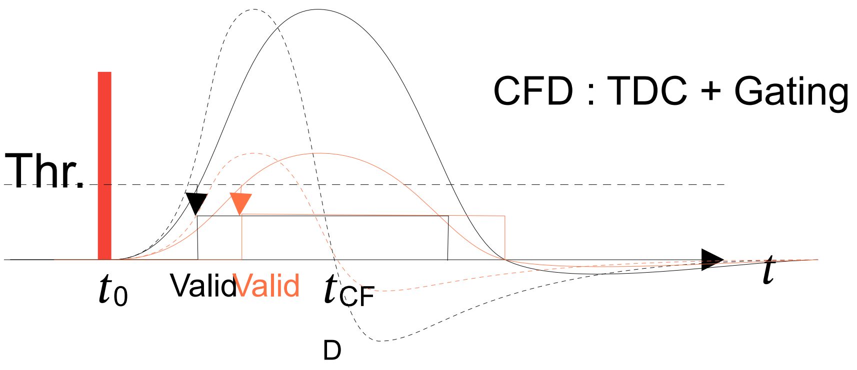
→ optimal thickness of sensors (T ↔ thickness) to be determined

S. Riegler

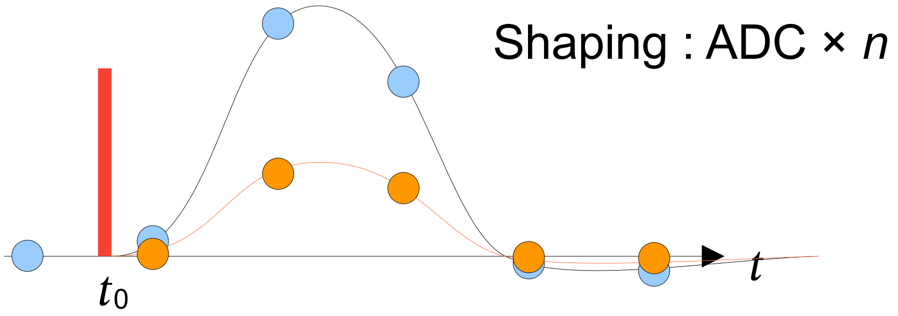
Time measurement methods



Slew time (vs amplitude)



Time ~ cst (vs pedestal, noise)



Time fit (vs shaping)

Time resolution: Quantiles vs Average