CALICE SiW ECAL
Beam test performance of a technical prototype of a highly granular silicon tungsten calorimeter

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The SiW-ECAL team

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Outline

The SiW Electromagnetic Calorimeter for ILD

The 2017 prototype: Test Beam

Digitization for the SiW ECAL

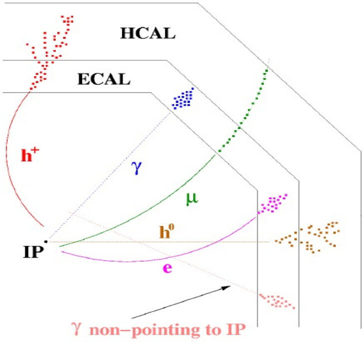
Current prototype

Particle Flow detectors

Particle Flow Detector

Jet energy measurement by measurement of **individual particles**
Maximal exploitation of precise tracking measurement

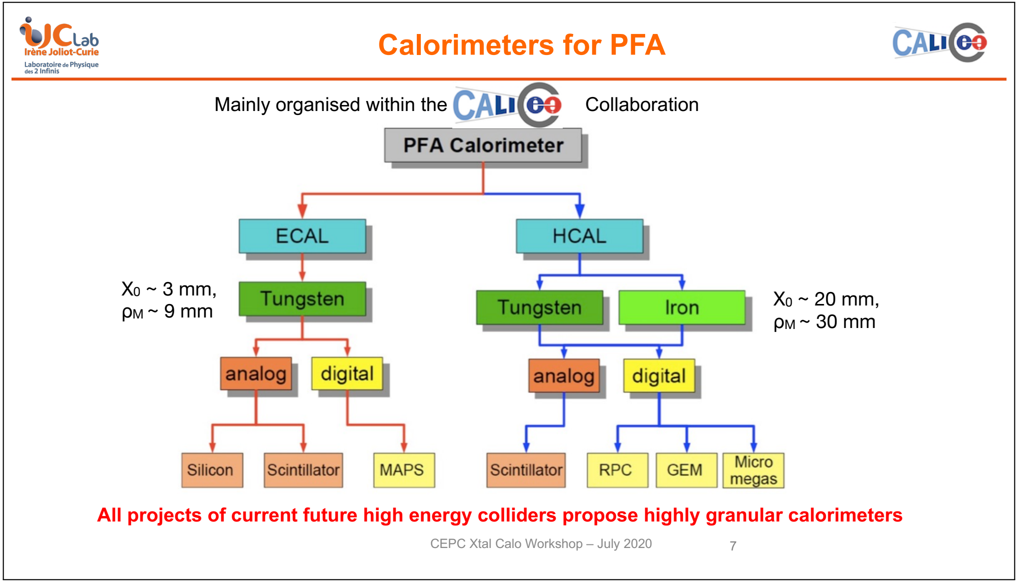
- large radius and length
  - → to separate the particles
- large magnetic field
  - → to sweep out charged tracks
- "no" material in front of calorimeters
  - → stay inside coil
- small Molière radius of calorimeters
  - → to minimize shower overlap
- **high granularity of calorimeters**
  - → to separate overlapping showers



Particle flow as privileged solution for experimental challenges
=> Highly granular calorimeters!!!
Emphasis on tracking capabilities of calorimeters

CEPC Xtal Calo Workshop – July 2020 5

Calorimeters for PFA



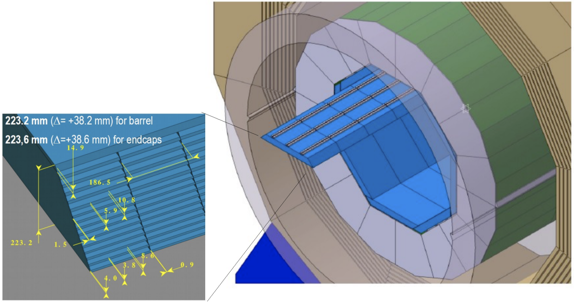
The SiW Electromagnetic Calorimeter for the ILD

Tungsten as absorber material

- Narrow showers
- Assures compact design
- Low radiation levels forseen at LC
- X_0=3.5 mm, R_M=9mm, I_L=96mm

Silicon as active material

- Support compact designs
- Allows pixelization
- Robust technology
- Excellent signal/noise ratio

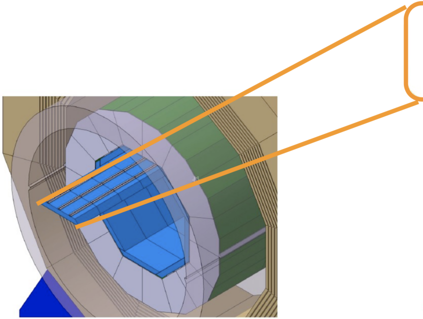


The SiW ECAL in the ILD Detector

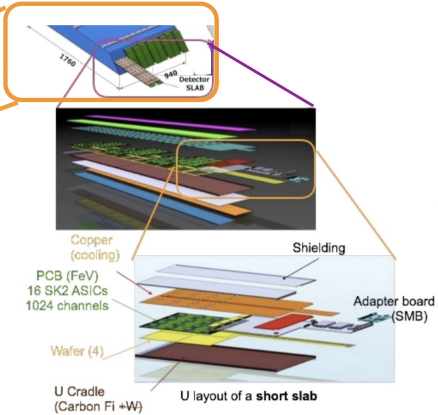
Our R&D is tailored to meet the specifications for the ILD ECAL baseline proposal

The SiW Electromagnetic Calorimeter for the ILD

- Compact design: Thickness of 23 cm for 26-30 active layers + $24X_0$ tungsten
- Limited space for inactive material (PCB, electronics)→Power Pulsing, no active cooling



The SiW ECAL in the ILD Detector

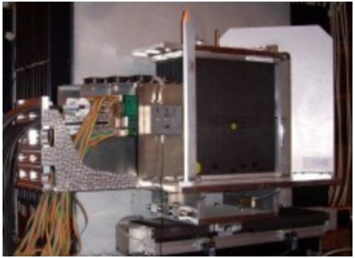


U layout of a **short slab**

The SiW Electromagnetic Calorimeter for ILD

Physics prototype

Proof of principle 2003 - 2011



N channels: 9720

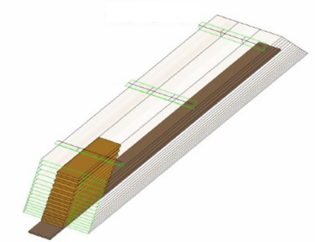
Pixel size: 1x1 cm^2

$R_{M,\mathrm{eff}}$: $\sim$1.5 cm

Weight: $\sim$ 200 kg

Technological prototype

Engineering challenge 2010 -



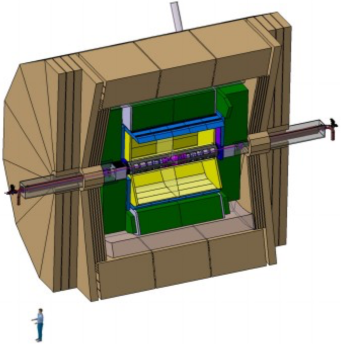
N channels: 45360

Pixel size: 0.55x0.55 cm^2

$R_{M,\mathrm{eff}}$: $\sim$1.5 cm

Weight: $\sim$ 700 kg

LC detector

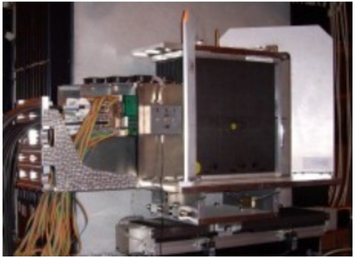


N channels: $\sim$ 100M

Total weight: $\sim$130 t

The SiW Electromagnetic Calorimeter for ILD

Physics prototype
Proof of principle 2003 - 2011



N channels: 9720
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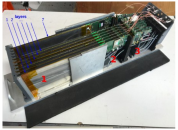
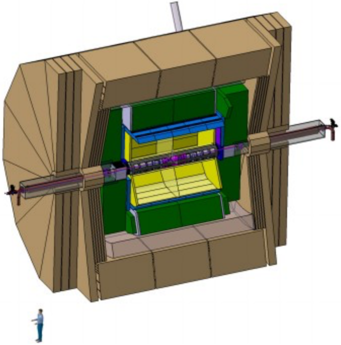
Weight: $\sim$ 200 kg

Technological prototype
Engineering challenge 2010 -

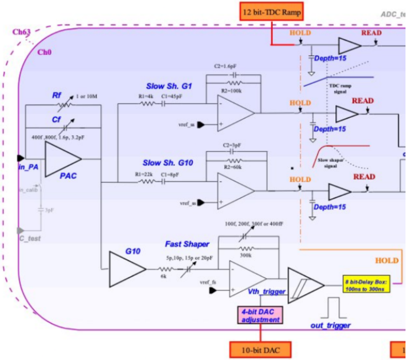


LC detector



N channels: $\sim$ 100M
Total weight: $\sim$130 t

SKIROC2 + PCB



- 64 channels, preamp (+2 gains + TDC)
- Auto-triggered, 15 (x2) analog memories
- Low consumption

- 16 SKIROC2
- FEV: v10 -> v12
  → see Roman's talk for new design
- Slab: ASU (PCB+Wafer) + SMB, carbon + W, shielding

Outline

The SiW Electromagnetic Calorimeter for ILD

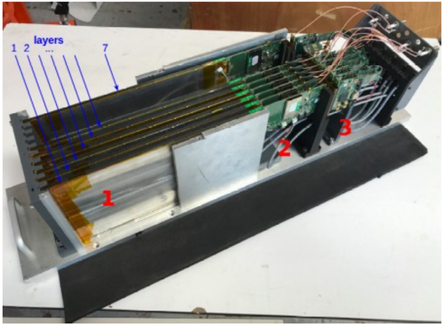
The 2017 prototype: Test Beam

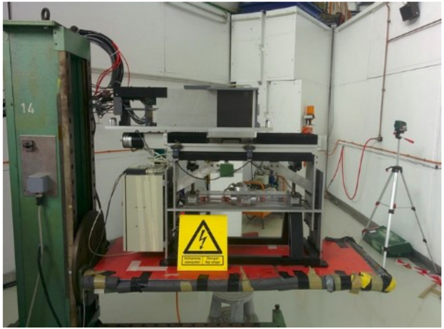
Digitization for the SiW ECAL

Current prototype

The prototype (2017) - Test Beam

- 7 slabs (FEV11), each w/ 4 Si wafers (325 μm)
- Positron beams of 1, 2, 3, 4, 5 and 5.8 GeV.





Varying amounts of W in front of each slab:

Conf	1	2	3
X_0	0.6 - 6.6	1.2 - 8.4	1.8 - 10.2

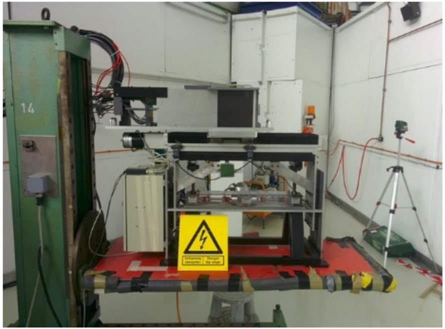
Test Beam - studies

Physics program

- Calibration run with 3 GeV positrons perpendicular beam without tungsten absorber plates
- Electromagnetic showers program.
- Calibration run with 3 GeV positrons in $\sim$ 45 degrees (6 slabs)
- Magnetic field tests with 1 slab (up to 1T)

Results published in NIMA 2019 162969

Studies with simulations including digitization



Test Beam Showers - selection

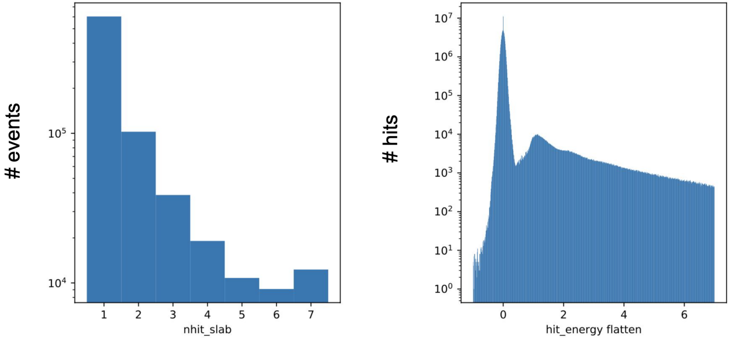
Example: conf 2 @ 2 GeV

Selection:

- At least 5 slabs hit
- $\mu + 6\sigma$ on pedestal gaussian fit
- "Central" slabs hit

Use two criteria

N slabs hit by the shower and hit energy [MIP] in cells



Shower model

Model the longitudinal and transversal energy profile of showers

Transversal (per-layer) model

Double gaussian: shared mean, no corr.

$$A\,(f\,\mathcal{N}(\mu, \mathbb{1}\sigma_1) + (1-f)\,\mathcal{N}(\mu, \mathbb{1}\sigma_2))$$

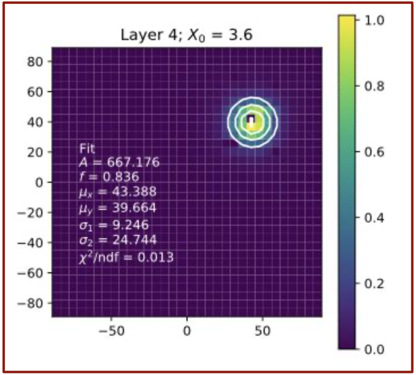
Longitudinal model

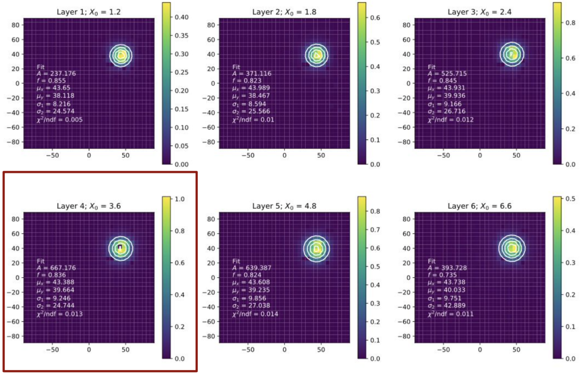
$$\frac{\mathrm{d}E}{\mathrm{d}t} = E_0\, b\, \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

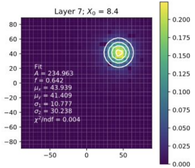
- Fit the longitudinal and transversal parts separately
- Fit the longitudinal part using integral of double gaussian as prompt for E per layer

Shower model for layers

Fit double gaussian per layer







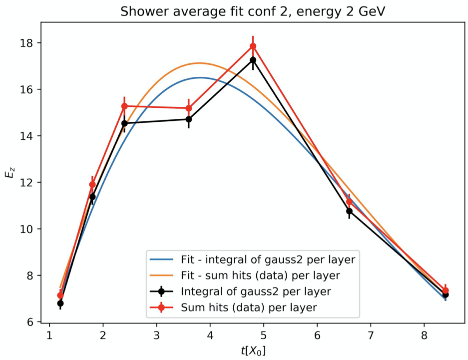
Configuration 2 @ 2 GeV

$$A(f\mathcal{N}(\boldsymbol{\mu}, \mathbb{1}\sigma_1) + (1-f)\mathcal{N}(\boldsymbol{\mu}, \mathbb{1}\sigma_2))$$

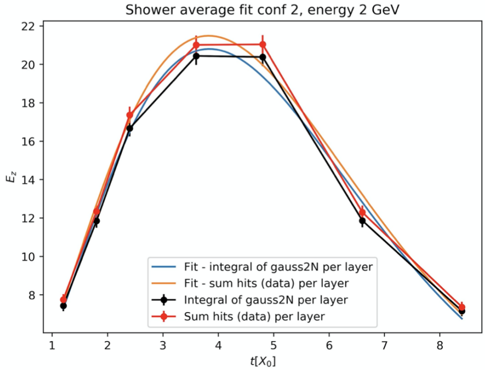
Shower longitudinal profile

$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

No requirement on central slabs



Central slabs hit required



Comments on shower analysis

- First attempt at fitting shower shapes on SiW-ECAL data (7 layers)
  - Help handle masked cells
  - To be checked: issues with calibration mip$\rightarrow$shower ?
- Software in development:
  - Robustness against noise cuts
  - Adapt to individual showers
  - Use integrated (over cell surface) functions
  - Try various lateral shower profiles - Complete with full 3D profiles
- Simulations - Digitization

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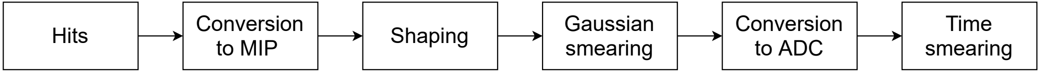
Simulations

- Simulation code of this detector prototype with beam tests are in place
  $\rightarrow$ Daniel Jeans @ cern gitlab, calice_dd4hepTestBeamSim
- We generated samples for the following setups:
  - The 2017 test beam (e^+) as in previous slides, same for e^-.
  - No Tungsten (configuration 0) for e^- and e^+ @ 3 GeV, and μ @ 40 GeV.
- Run and adapted by Adrián Irles.

After this, we need to add digitization effects

Digitization

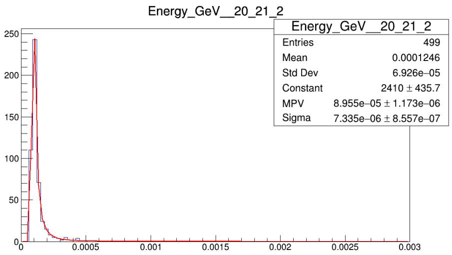
Raw simulation ⇒ info. resembling detector output, including readout effects



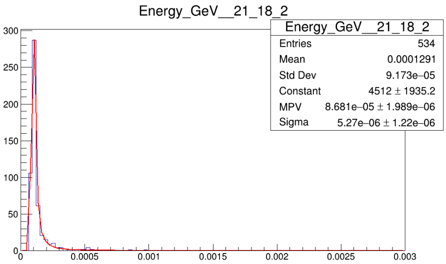
- Hits: starting point from raw simulation.
- Map energy deposited to MIP scale.
- Simulate pulse shaping in the readout electronics + saturation effects.
- Add smearing: noise term in detector cells/readout.
- Conversion to ADC, time smearing

Energy of hits in a cell. No Tungsten, positrons and muons

Take cells with >1k hits (out of 10k events) → fit Landau distribution



Positrons @ 3 GeV



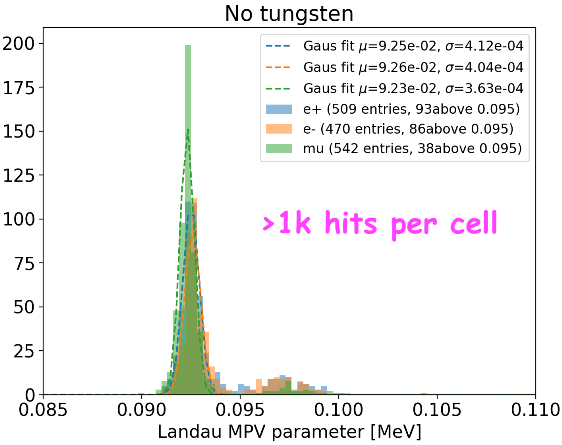
Muons @ 40 GeV

Use Landau location (MPV) as reference for conversion.

MIP conversion

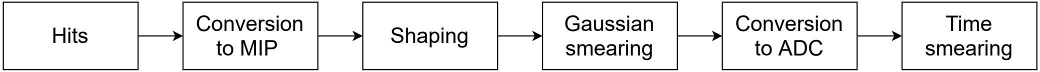
Landau MPV distributions:
e^-, e^+, μ

- Gaussian fit on each case
- Some problematic fits (backup)
- Work in progress
- At the moment: 0.0923 MeV/MIP



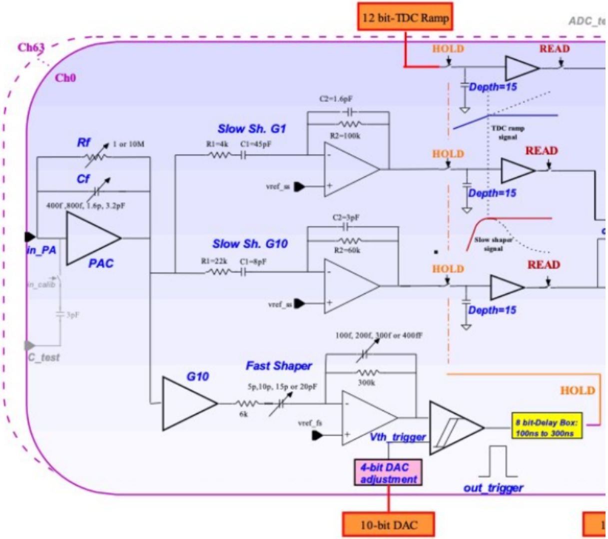
Digitization

Raw simulation ⇒ info. resembling detector output, including readout effects



- Hits: starting point from raw simulation.
- Map energy deposited to MIP scale.
- **Simulate pulse shaping in the readout electronics + saturation effects.**
- Add smearing: noise term in detector cells/readout.
- Conversion to ADC, time smearing

Skiroc2 readout (from datasheet)



Two signal paths after pre-amp:

- One Fast Shaper
  $\rightarrow$ Trigger threshold, time
- Two Slow Shapers
  $\rightarrow$ Measure energy

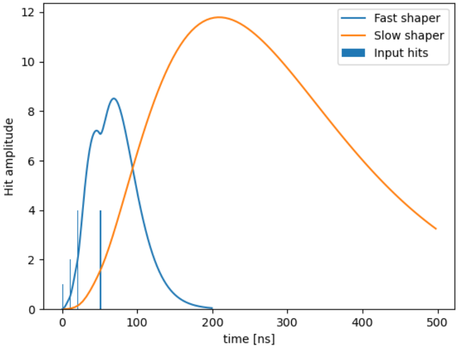
Shaping concept

- n-order CR-RC filter

$$s(t,A) = \frac{A}{n!}\left(\frac{x-t}{\tau}\right)^n \exp\left(-\frac{x-t}{\tau}\right)$$

if $x - t > 0$ (else, $s(t,A) = 0$)

- Fast shaper: $n = 2, \tau = 30$ ns
- Slow shaper: $n = 2, \tau = 180$ ns
- Set of thresholds $\Rightarrow$ retrieve times
- Currently being prototyped...



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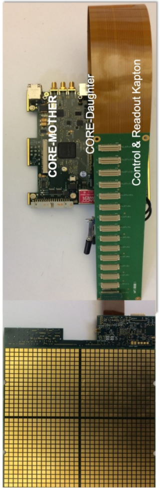
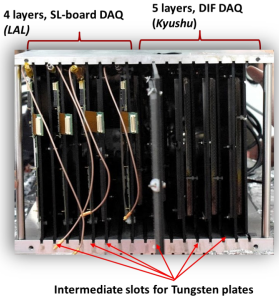
Ready for the 2021 test beam campaign

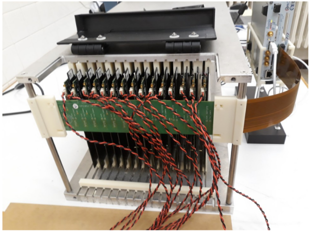
Test bench 2018:



Beam test 4 layers: 2019

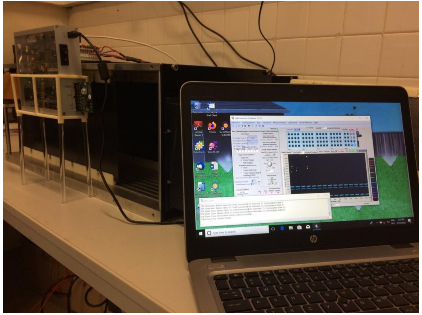


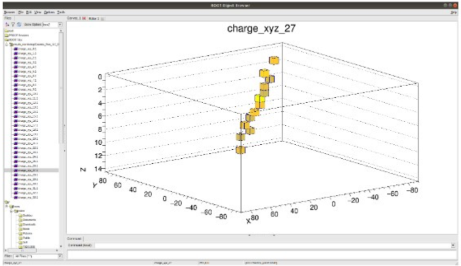
15 layers: 2020
15000 cells in r/o!



- Rapid development of compact r/o electronics
- For the first time we have components at hand that could be installed in a lepton-collider detector
- Ready for beam test in ~~March 2020, December 2020, May 2021~~, Autumn 2021?

Ready for the 2021 test beam campaign





Ready for beam test in ~~March 2020, December 2020, May 2021~~, Autumn 2021?

- >15 layers ready for beam test
- FEV10, 11, 12, 13 and COB

Summary

- High-Granularity Self-Triggered calorimeters:
  - Require high S/N ratio (here S/N $\sim$ 12) $\sim$ noise vs beam rate
  - $\rightarrow$ More layers needed (ready since 2020)
- Shower profile fitting:
  - Encouraging preliminary results
  - Will improve with 3D model (ongoing)
  - Will be better at higher energies (CERN)
- Simulation using DD4HEP model ongoing and mandatory for calibration
- Digitization:
  - Work in progress
  - Mandatory to understand the time in showers

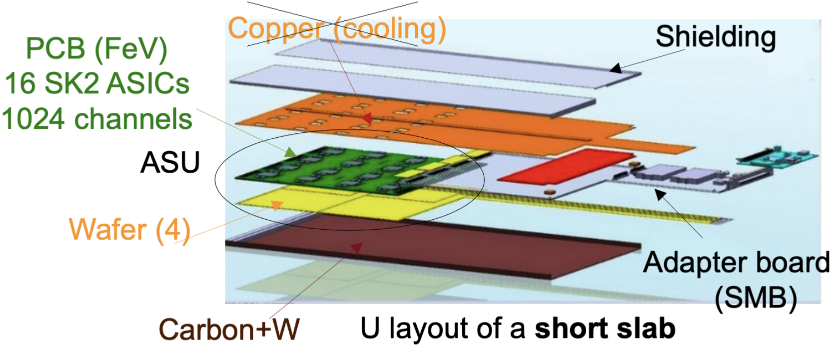
Backup

Resources - acknowledgements

Slides significantly borrow content from:

- Talks from Roman Pöschl:
  - LCWS '21
    https://agenda.linearcollider.org/event/9076/contributions/47664/
- Talks from Adrián Irles:
  - IAS Program on High Energy Physics (HEP 2021)
    https://indico.cern.ch/event/971970/contributions/4172179/
  - LCWS '21 https://indico.cern.ch/event/995633/contributions/4261854/
  - ILD meeting
    https://agenda.linearcollider.org/event/9174/contributions/47746/

Slab layout



U layout of a **short slab**

Test Beam - configurations

The 2017 setup: three configurations with varying amounts of W in front of each slab,

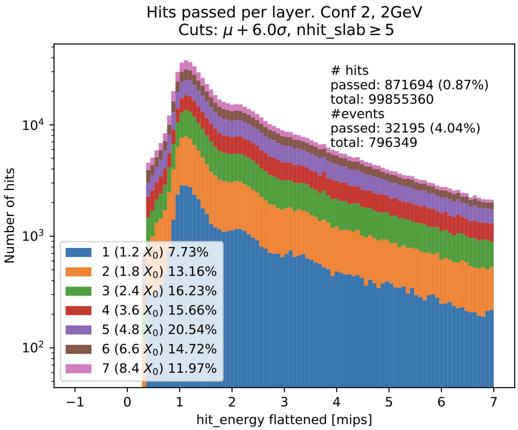
- Conf. 1: 0.6, 1.2, 1.8, 2.4, 3.6, 4.8 and 6.6 X_0,
- Conf. 2: 1.2, 1.8, 2.4, 3.6, 4.8, 6.6 and 8.4 X_0,
- Conf. 3: 1.8, 2.4, 3.6, 4.8, 6.6, 8.4 and 10.2 X_0.

Positron beams of 1, 2, 3, 4, 5 and 5.8 GeV.

- Study of electromagnetic showers.
- Use this setup for comparison with simulations, where the digitization effects will be included.

Test Beam Showers - after selection

After selection



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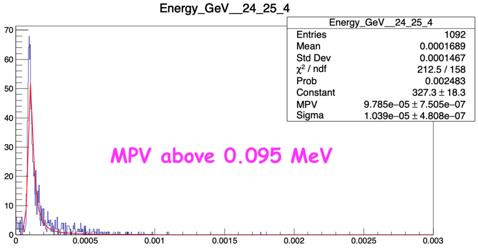
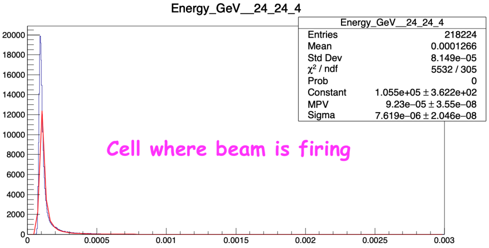
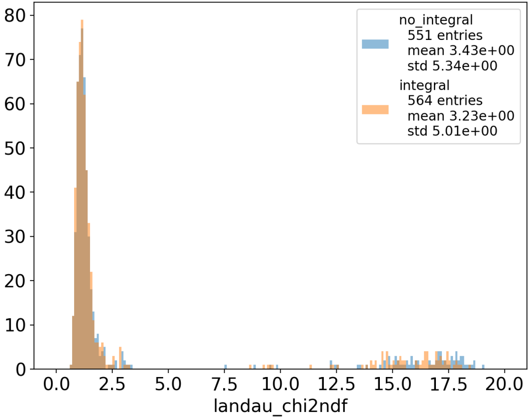
What's going on in the bump?

- Landau mu > 0.095 MeV (i.e. the bump); fit works well but could be improved?
- χ^2/ndf high for cells 24_24 (where the beam is fired) in all layers
- Few fits not converging



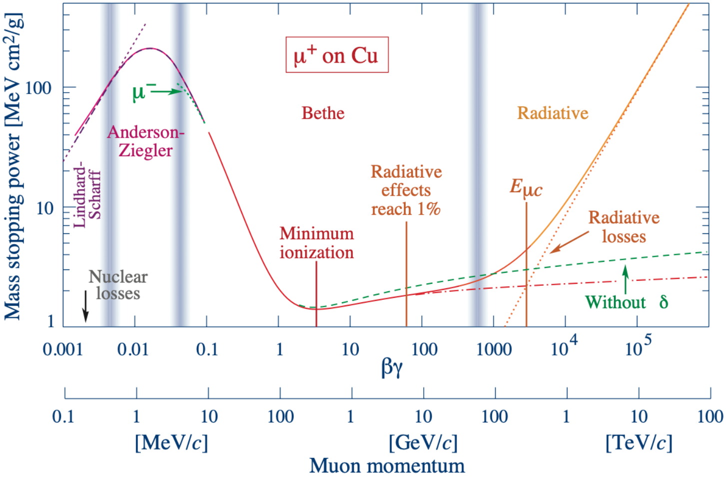


“Integral” option in ROOT - chi2



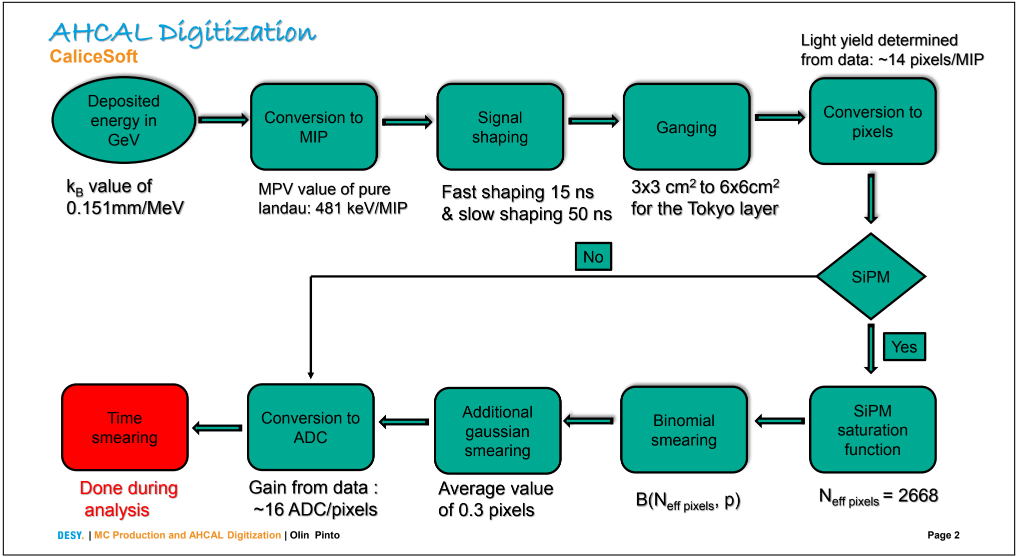
Check this, work in progress...

Mass stopping power for positive muons (PDG)



Muon minimum ionization occurs at $\sim$ 0.4 GeV

AHCAL Digi



AHCAL Digitization
CaliceSoft
Light yield determined from data: ~14 pixels/MIP
Deposited energy in GeV
Conversion to MIP
Signal shaping
Ganging
Conversion to pixels
kB value of 0.151mm/MeV
MPV value of pure landau: 481 keV/MIP
Fast shaping 15 ns & slow shaping 50 ns
3x3 cm2 to 6x6cm2 for the Tokyo layer
No
SiPM
Yes
Time smearing
Conversion to ADC
Additional gaussian smearing
Binomial smearing
SiPM saturation function
Done during analysis
Gain from data : ~16 ADC/pixels
Average value of 0.3 pixels
B(Neff pixels, p)
Neff pixels = 2668
DESY. | MC Production and AHCAL Digitization | Olin Pinto
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