Introduction to the CALICE/ILD SiW ECAL and recent testbeam results

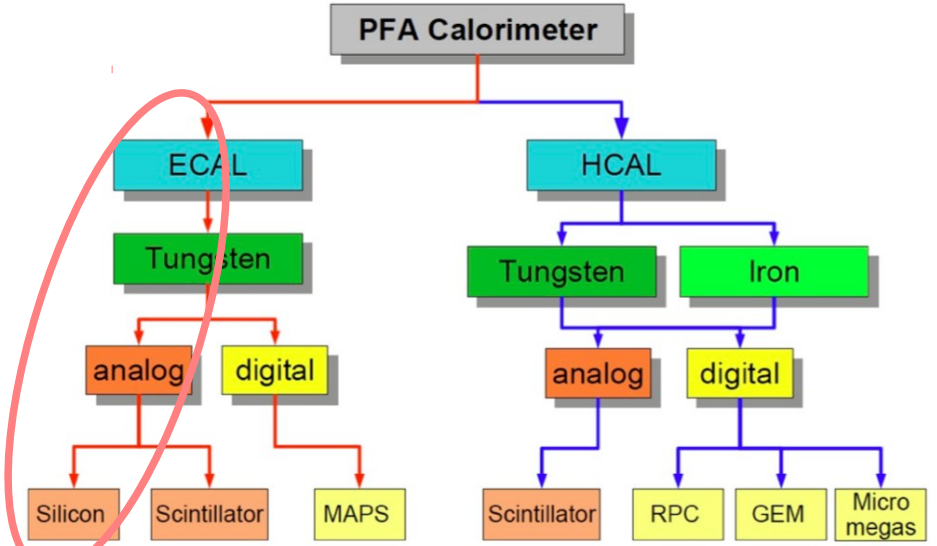
A. Irles (LAL-IN2P3/CNRS) on behalf the SiW-ECAL

23rd October 2018, LCWS2018

Outline of the talk

- The SiW-ECAL technological prototype

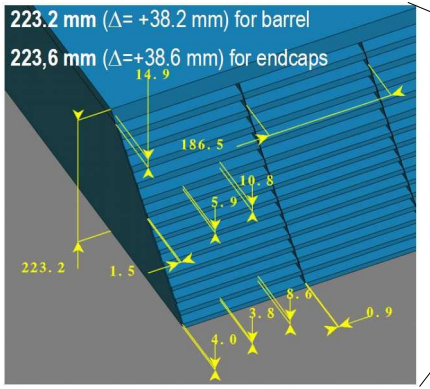
- Beam Test 2017 – DESY TB24
- Beam Test 2018 – DESY TB21 and TB24
- Beam Test 2018 – CERN H24

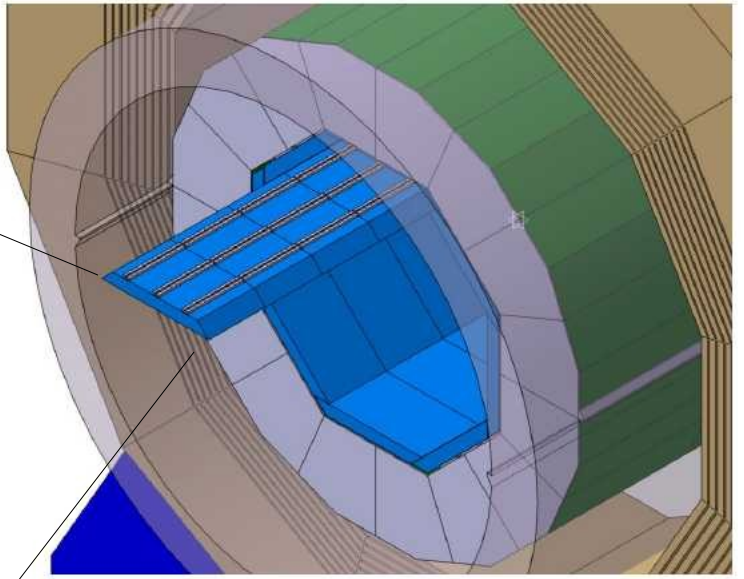


Basic requirements of a **PF calorimeter** for future linear colliders

- Extreme high granularity
- Compact and hermetic (inside magnetic coil)

- **Tungsten** as absorber material
  - Narrow showers
  - Assures compact design
  - Low radiation levels foreseen at LC
  - X_0=3.5 mm, R_M=9mm, I_L=96mm
- **Silicon** as active material
  - Support compact designs
  - Allows pixelisation
  - Robust technology
  - Excellent signal/noise ratio

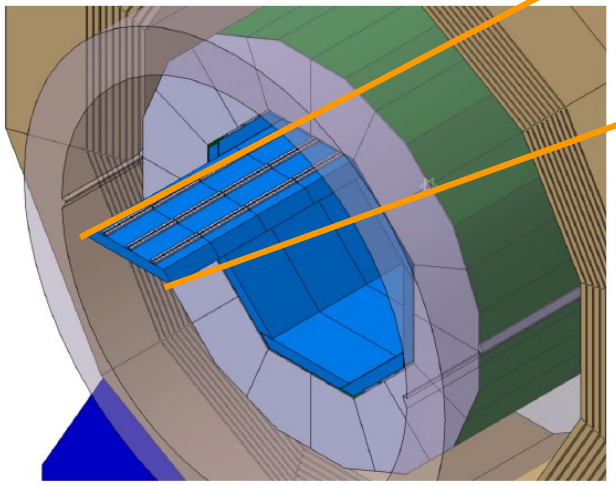




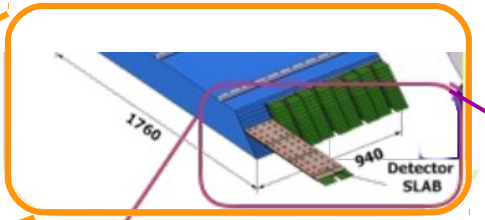
The SiW ECAL in the ILD Detector

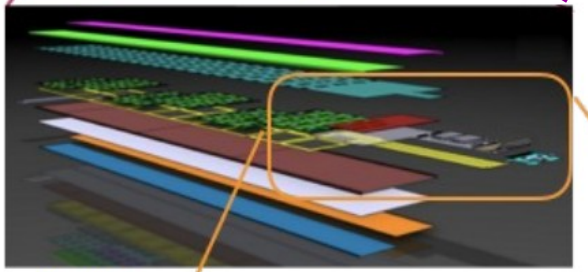
The **SiW ECAL R&D** is tailored to meet the specifications for the **ILD** ECAL proposal

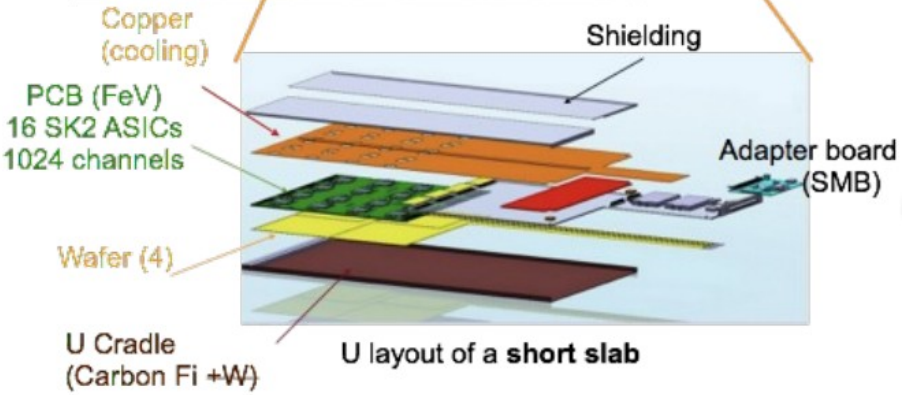
SiW-ECAL for the ILD



The SiW ECAL in the ILD Detector

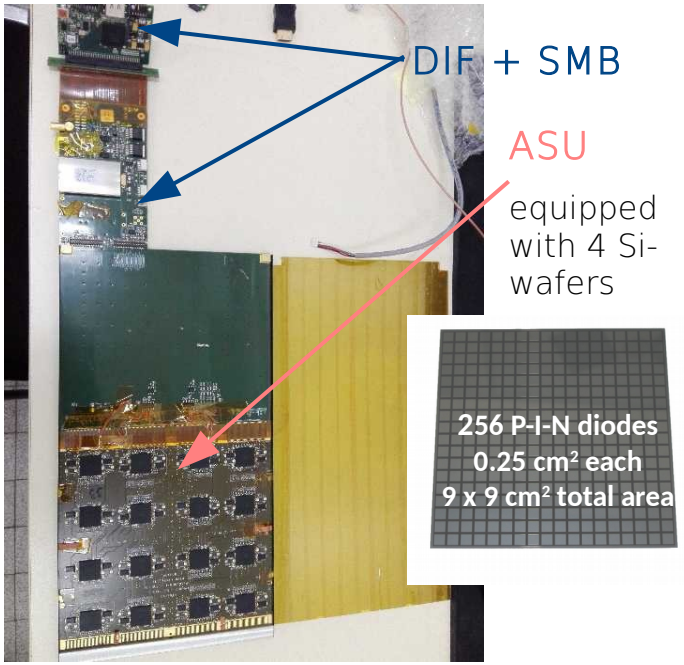






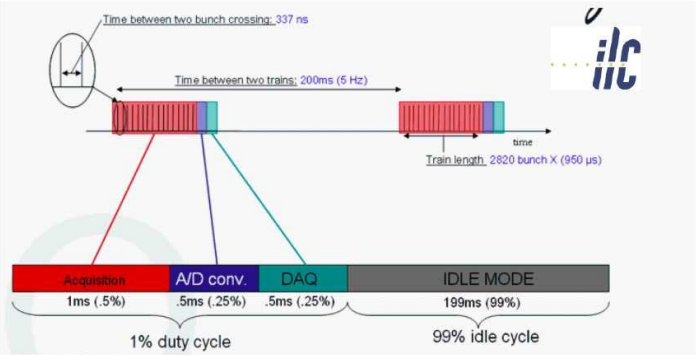
U layout of a **short slab**

SiW-ECAL technological prototype



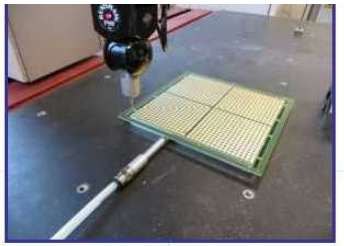
Short slab:

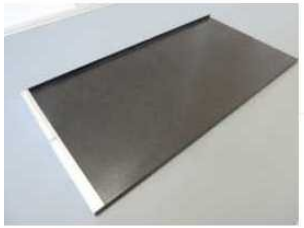
- Adapter board (**SMB**) and Detector Interface (**DIF**)
- **ASU (Active Sensor Unit)**,
  - PCBs (FEV10/11) with silicon P-I-N diodes as active material (325um, 4 kΩcm, N-type)
  - 1024 channels per slab
- VFE electronics: 16 **Skiroc2 ASICS** (in the ASU)
  - Auto trigger, double gain ADC
  - Low power consumption & **power pulsing** (25µW/ch)

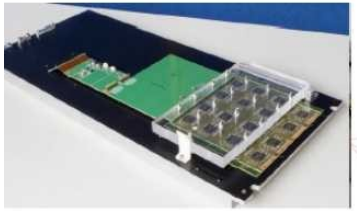


N.B. Final numbers may vary

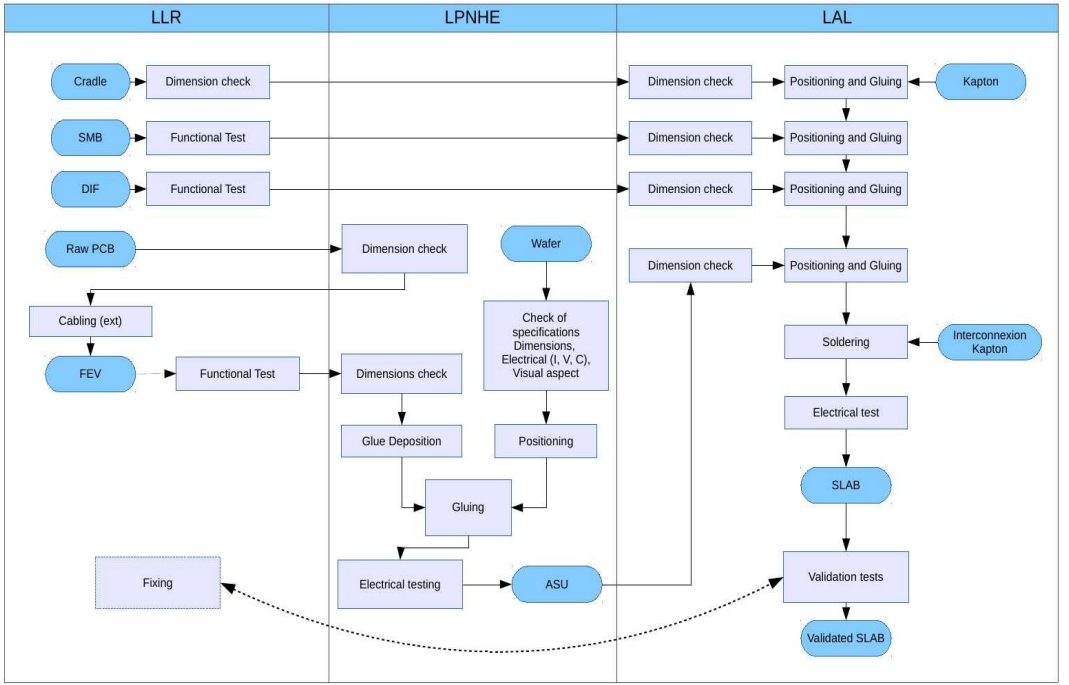
Assembly chain







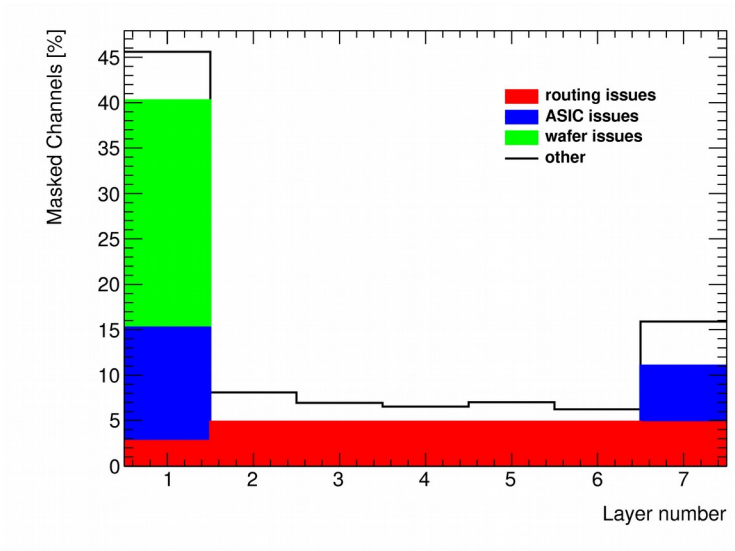
'Simplified view'



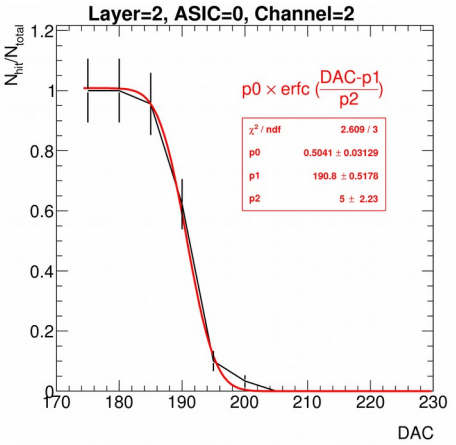
'Assembly and QA chain demonstrator report` on https://cds.cern.ch/record/2166513

Commissioning & Passport delivery

- **Noise control → noisy channels**: **7-8%**: very conservative approach.
  - Found a pattern on the spatial distribution of ~4% some noisy channels



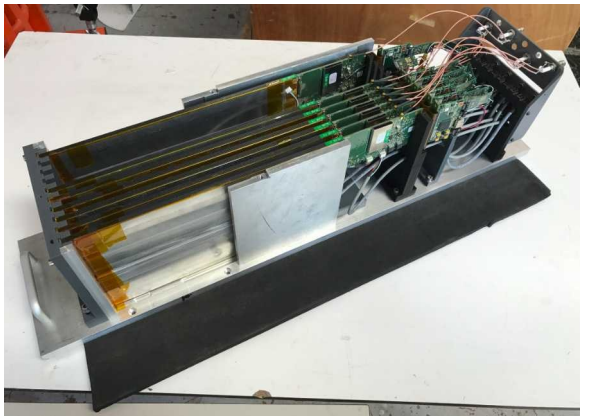
- **Autotrigger** optimization
  - Threshold scans made for all channels → one optimal threshold found for each ASIC

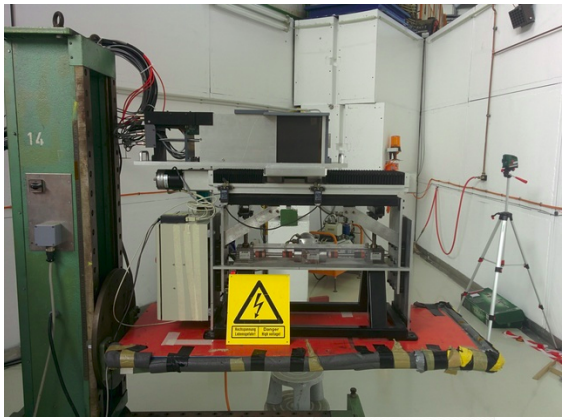


Threshold scan curves with noise

DESY@2017 – Setup & program

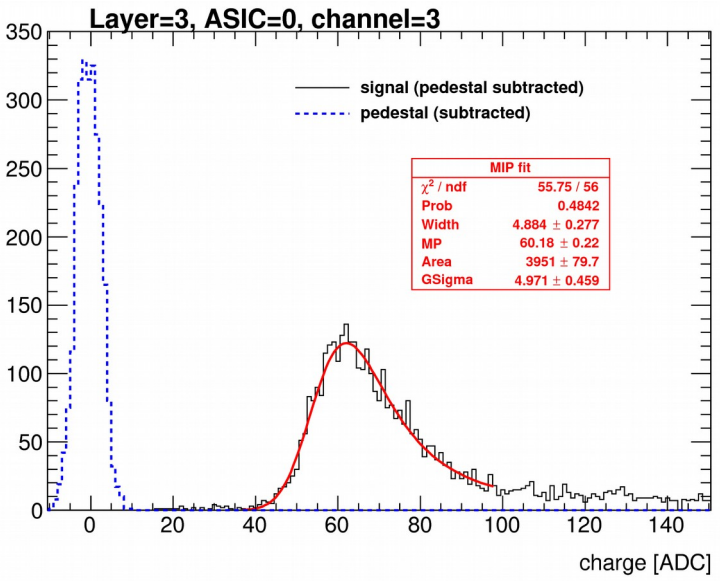
- **Setup** :
  - 7 FEV11 each equipped with 4 325um Si wafers and 16 Skiroc2
  - Power pulsing and ILC mode (emulated ILC spill conditions)
- **Physics program:**
  - Calibration run with 3 GeV positrons perpendicular beam without tungsten absorber plates
  - Electromagnetic showers program.
  - Calibration run with 3 GeV positrons in ~45 degrees (6 slabs)
  - Magnetic field tests with 1 slab (up to 1 T)

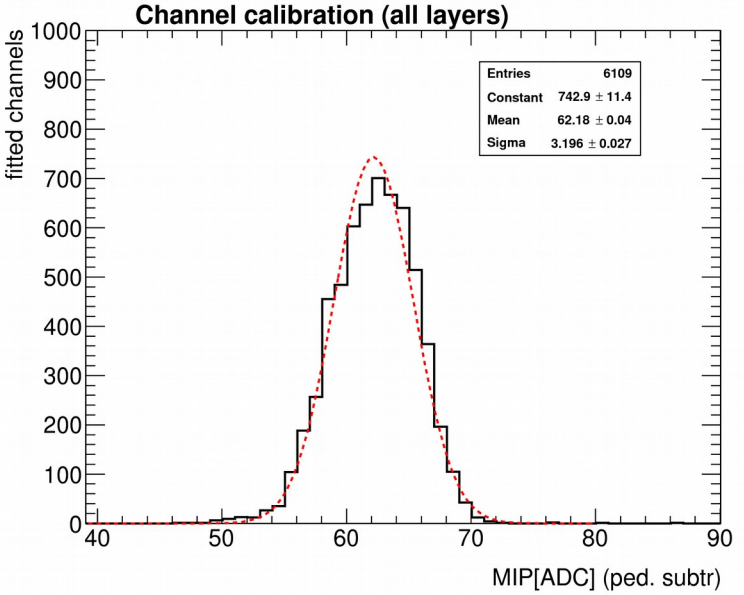




DESY@2017 – MIP calibration

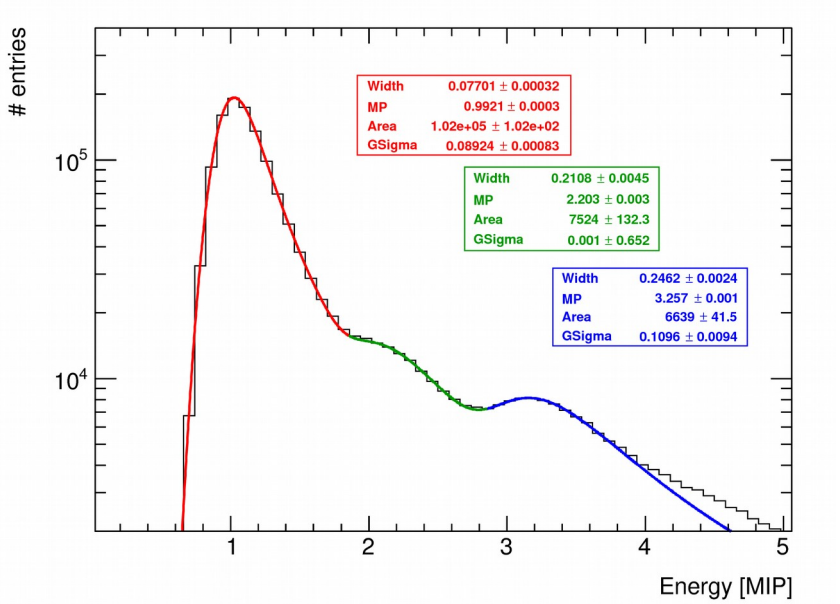
- MIP scan: Si - ECAL **(w/o the W)**
  - Positrons of 3 GeV (~2 kHz rate, beam spot with slightly irregular shape and size <2cm diameter)
  - Simple analysis done module by module
  - Pedestal correction done chip/channel/sca wise, Energy calibration done chip/channel wise
  - MIP: We fit the 98% of available channels → MPV = 62.2 ADC, sigma= 3.2 ADC (dispersion of 5.1 %)



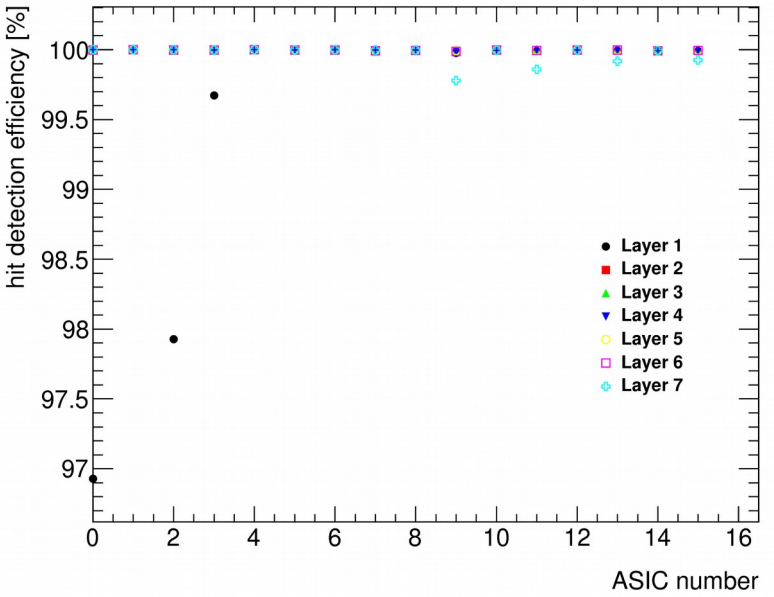


DESY@2017 – Hit detection efficiency in tracks

- After calibration we performed the track reconstruction.



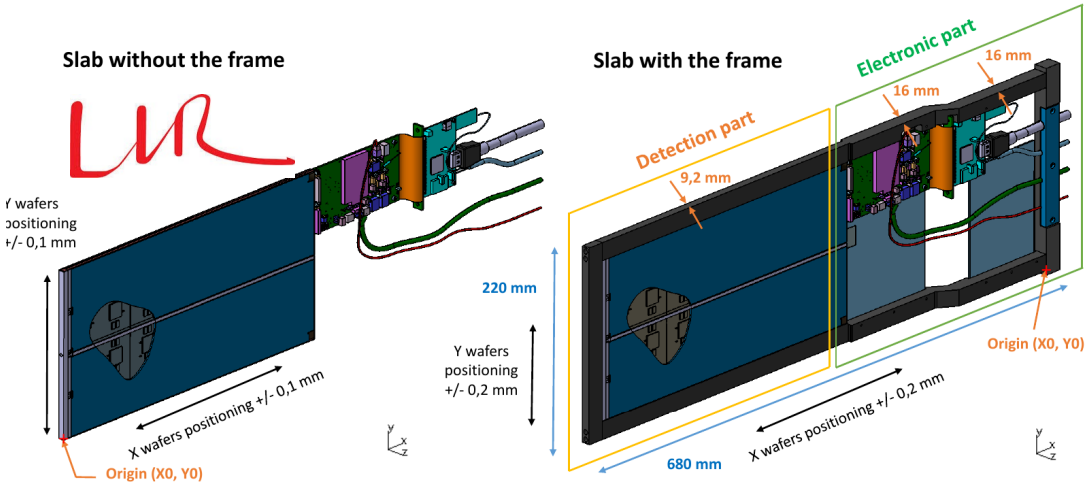
Hit energy distribution in tracks for all calibrated cells



Hit detection efficiency for tracks

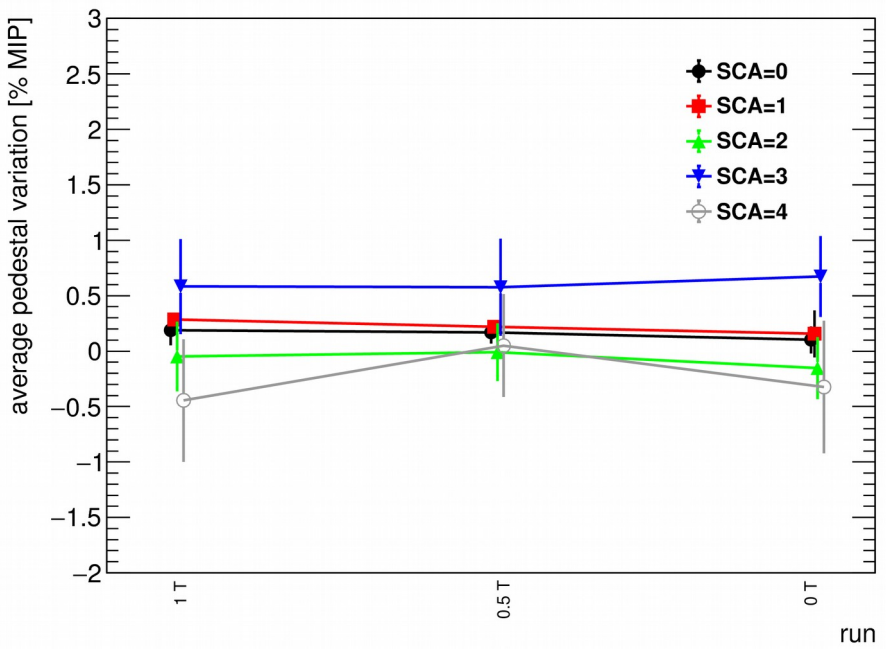
DESY@2017 – Tests under Magnetic Fields

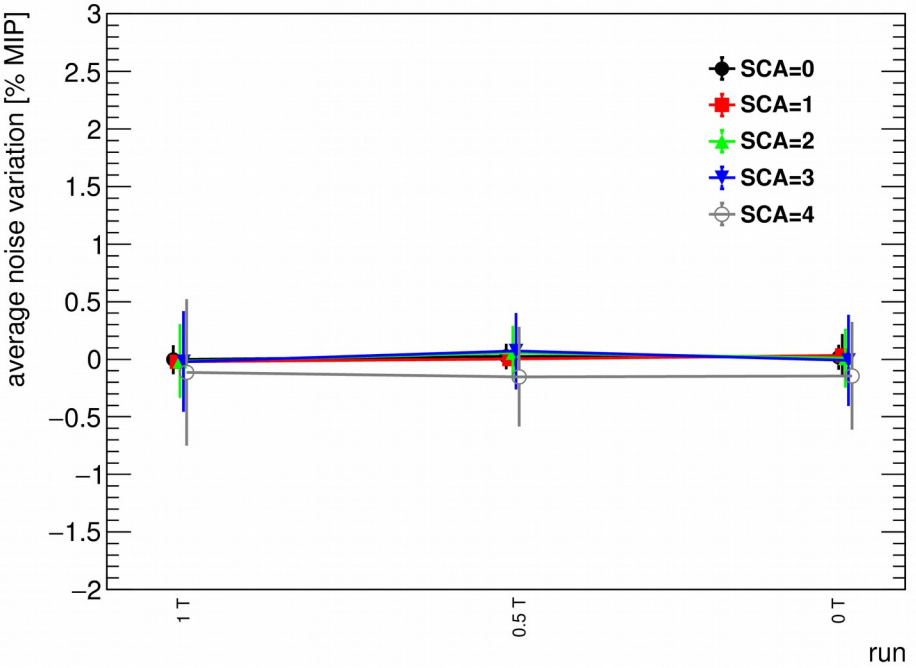
- Magnetic field tests
  - One slab in a special plastic support
  - Magnetic field from 0 to 1 T.
  - With and without beam.
- No failure/loss of performance observed during the operation and after the first analysis.
  - ~20 hours of data in total.



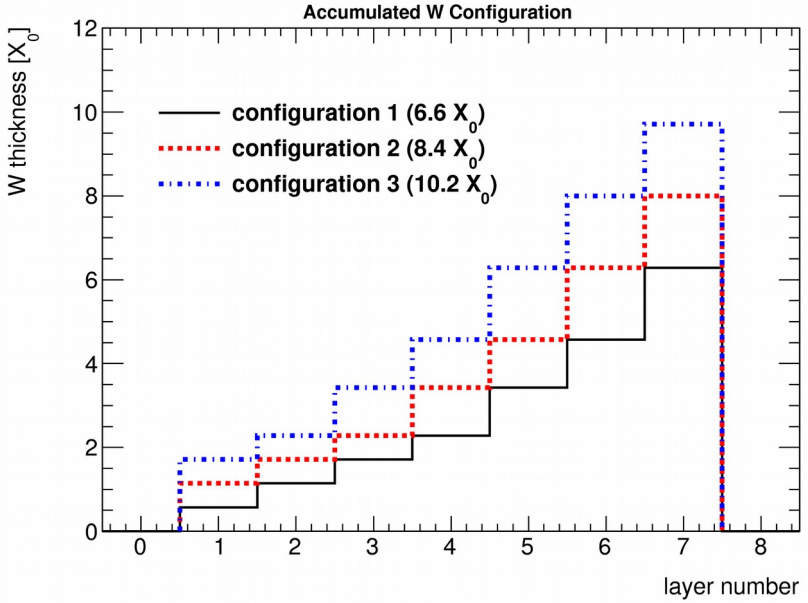
DESY@2017 – Tests under Magnetic Fields

- Very stable noise conditions (note the %MIP scale)



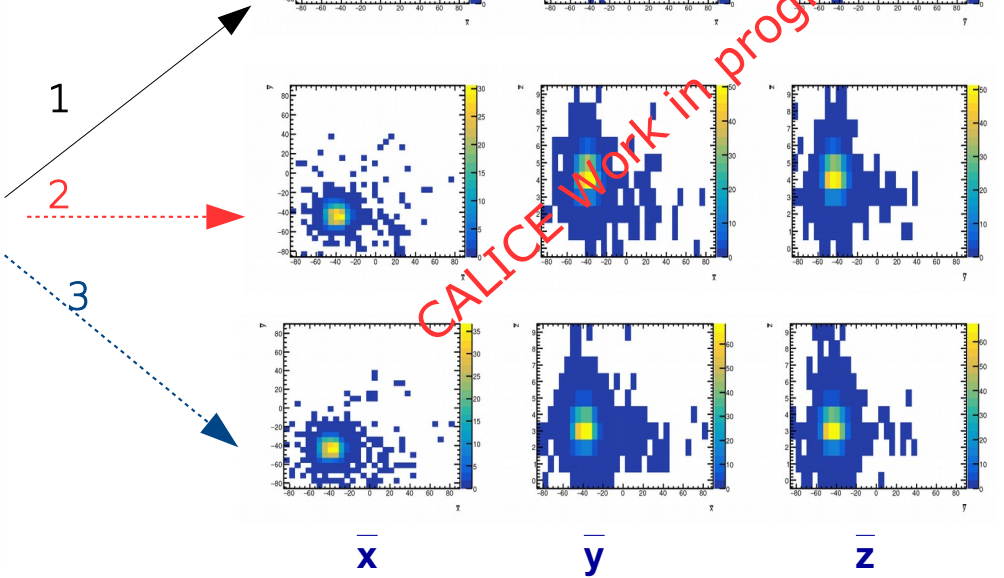


- Tungsten program
  - Scans of various energies (from 1-5.8 GeV).
  - Scan using different tungsten configurations



Raw shower barycenter maps

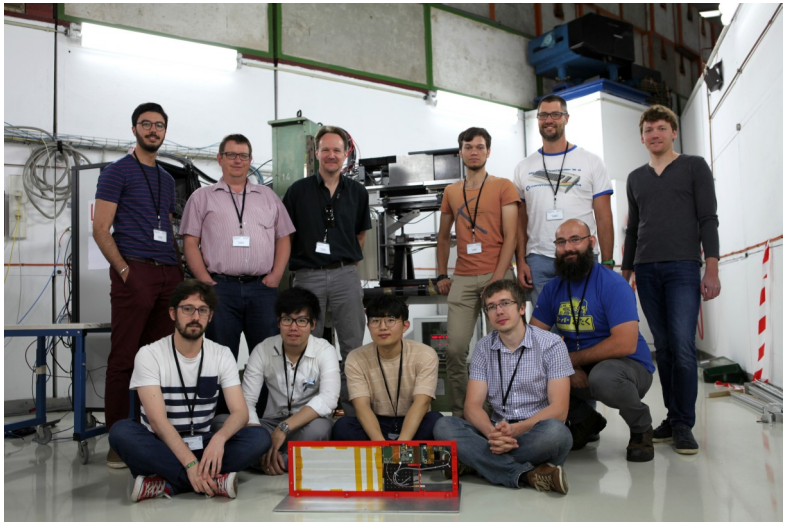
$$\bar{x} = \frac{\sum_{i=cells,\, j=layer\ number} x^i w_0^j E_i}{\sum_{i=cells,\, j=layer\ number} w_0^j E_i}$$



CALICE Work in progress

DESY@2017 – Summary

- Successful beam test of the SiW-ECAL technological prototype.
  - first time with fully assembled detectors elements (first 7 of 10000 needed for ILD)
- MIP calibration achieved at the **5% level.**
- First looks at **shower response are very promising**
- **Operating in 1T magnetic field**
  - Also nice and consistent calibration results



- Presentations + proceedings for **CHEF2017, IEEE2017, LCWS2017**
- Beam test performance **paper ongoing**.

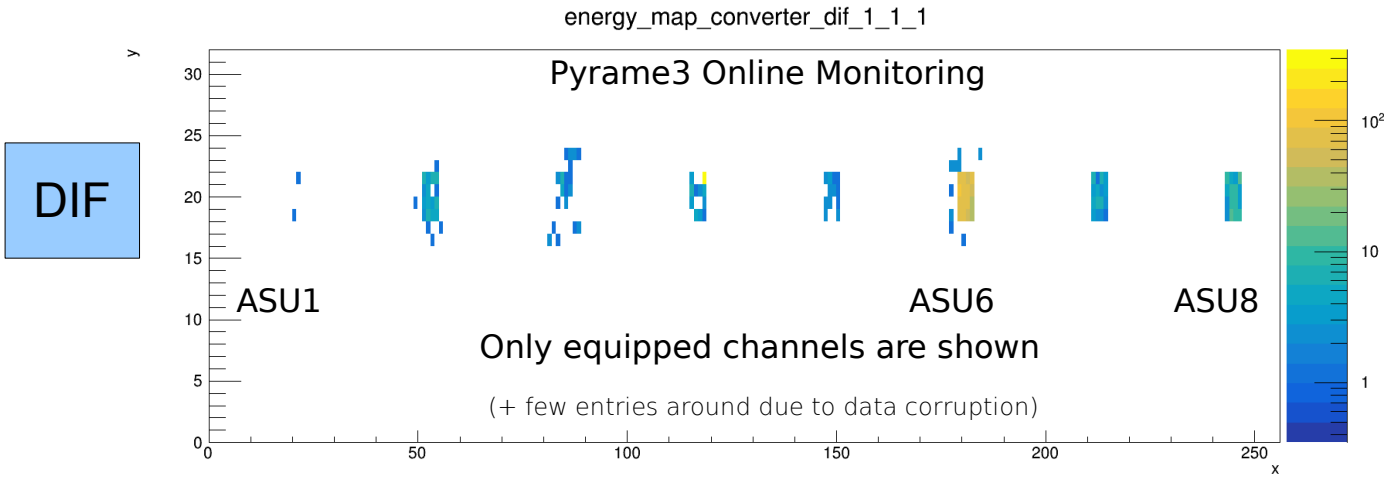
DESY@2018 – Electrical prototype of Long Slab

- Daisy chain of 8 ASU (extendable to 12)
- Corresponding to typical barrel length
- Based on FEV12 ASU & SMBv4 (in stock)
  - FEV12 is an adiabatic modification of FEV11
- No ILC geometrical constraint (thickness)
- Baby-wafer 4x4 pixels on each ASU
- HV filtered by RC circuits to reduce noise
- Adaptation of impedance of any lines (simulations)
- DAQ resizing to cope with chips multiplicity

- **See V. Boudry's talk.**

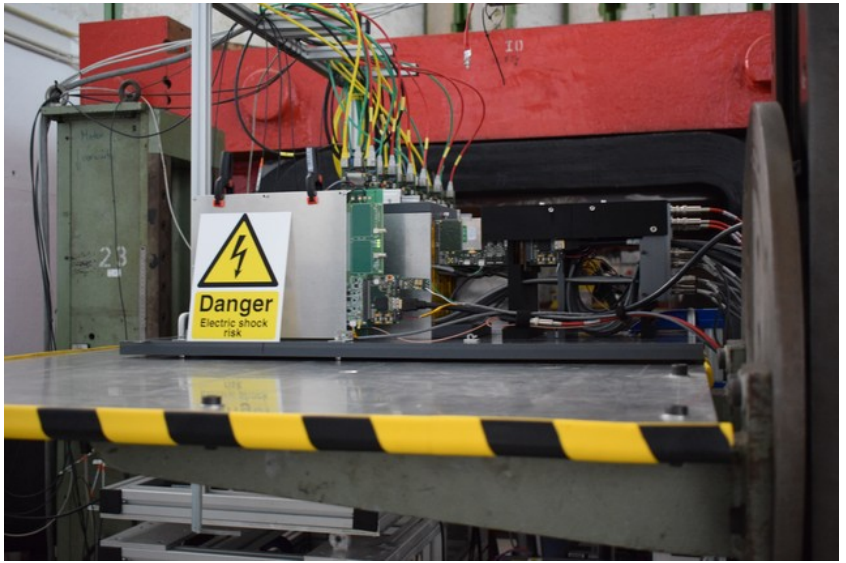
Long Slab performance

- Final commissioning done on site.
- The slab was too noisy for data taking until thursday when more HV RC filters were added: → a total of one every two ASU
- Noise levels became compatibles with short slabs made with FEV11



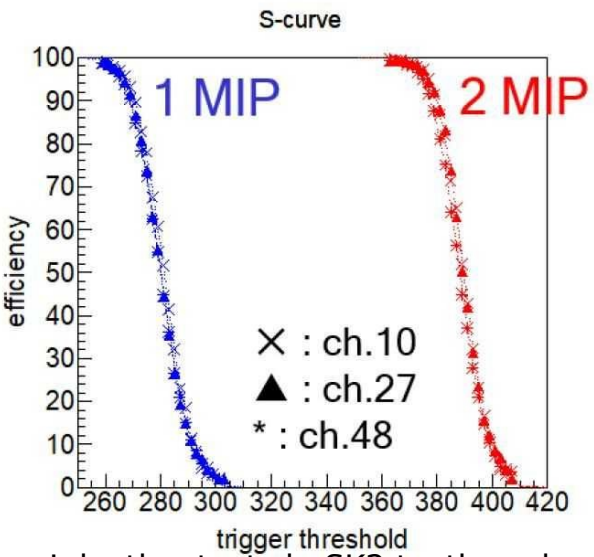
Short slabs stack

- Same configuration than in 2017 for all FEV11.
  - One slab became mute. Being inspected at lab. *Note: It has travelled around the world…*
- New all **plastic structure** to avoid grounding loops
  - Old issue from 2016-17.
  - It is also true that we didn't inserted tungsten plates between all slabs…
- We got enough data for:
  - Crosscheck the calibration of FEV11.
  - Scurves with beam → S/N in the trigger branch.
  - Test the performance of FEV13-Jp.
  - Some simple shower studies (5 X0 of Tungsten in front)
  - Very first tests of new features of the SK2a. (i.e. individual channel trigger threshold, TDC)



S/N in the trigger line

- For the physics prototype, we worked with externally triggered events → the S/N was measured only in the ADC.
- Working in autotrigger, an additional S/N can also defined by the study of the trigger line (fast shaper) → threshold scans
  - The threshold curve is interpreted as the integral of the gaussian distribution of the noise. The width is 1sigma of that gaussian, i.e.: half the difference between the thresholds for 50±34% of the efficiency.



Injection tests in SK2 testboard by Taikan et al (CHEF2017)

- S/N(trig) = 2MIP(50%) - 1MIP(50%) / width =

  12.9 ± 3.4

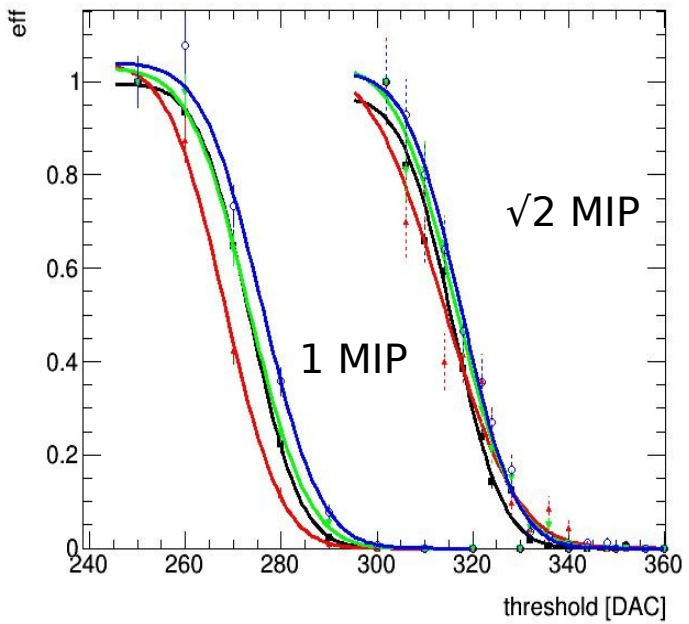
  - *Central value determined by injected signals runs*
  - *Uncertainty estimated using cosmic rays simple studies. Without external references.*

S/N in the trigger line for MIPs: analysis

- Dedicated runs have been taken during last beam test to repeat these s-curves with different size signals (1MIP, 1.4MIP and 2 MIP)
  - For the following results, we use data taken at 1 and 1.4 MIP (45 degrees)
- Run settings
  - The first slab is always at a low threshold → used as reference
  - Single cell calibration is done in all slabs for the lowest threshold run.
  - Event building + filtering is done.
- The S/N is not calculated per cell but per SLAB (since different cells are used in every run).

S/N in the trigger line for MIPs: analysis

- Results for 1 & 1.4 MIP signals.

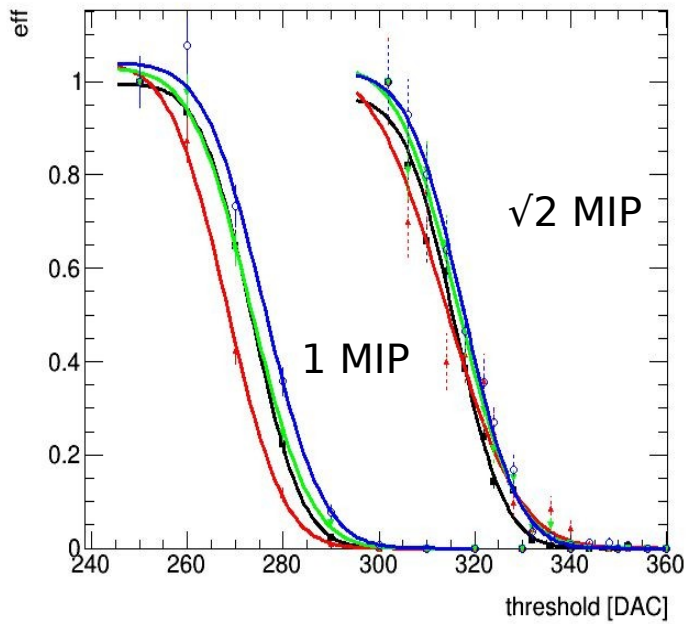


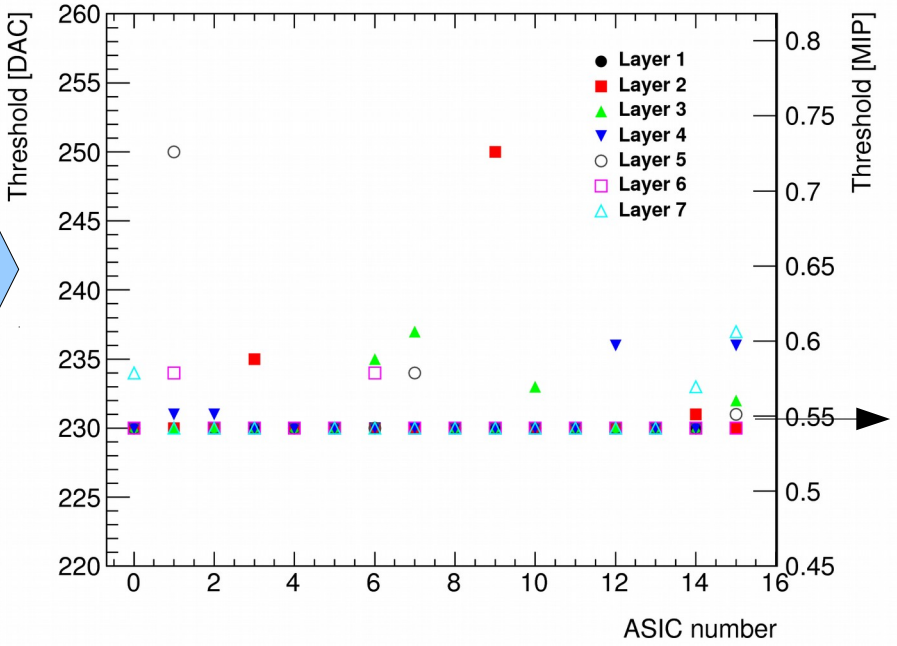
- Slab **17**, **18**, **19**, **20**
- **S/N = 11.6 ± 0.7**

ILD baseline requirements: S/N=10

S/N in the trigger line for MIPs: analysis

- Results for 1 & 1.4 MIP signals.





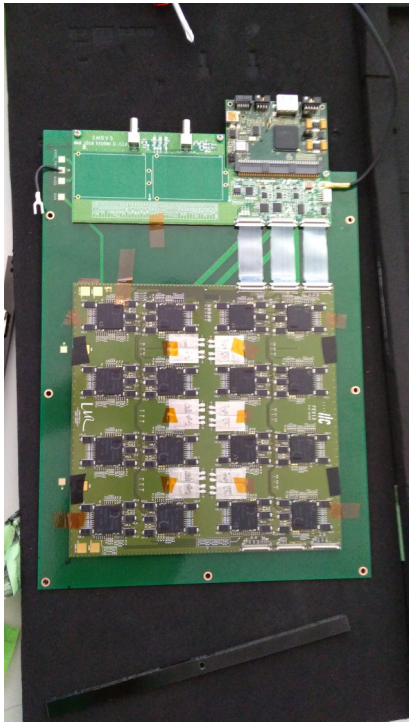
230DAC
≈ 5σ
distance
of the MIP

- Slab **17**, **18**, **19**, **20**
- **S/N = 11.6 ± 0.7**

ILD baseline requirements: S/N=10

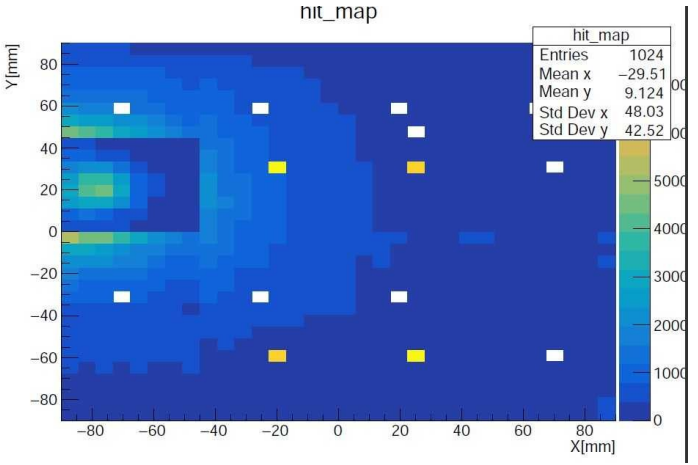
FEV13-Jp test

- Performance of the FEV13-JP + SMBv5 (LLR+Kyushu collab.)
  - See **Taikan's** talk for more details
  - FeV13-Jp developed with the aim of noise level improvement by separating PCB layers for the analogue and digital power of the ASIC and specific re-design of pad-channel routing
  - 4x650 µm wafers (instead of 320µm)
  - Equipped with Sk2a: allows for fine tunning of thresholds + brings the possibility to use the TDC
- Integration in the DAQ worked out-of-the-box.



Example of FEV13-JP hit map

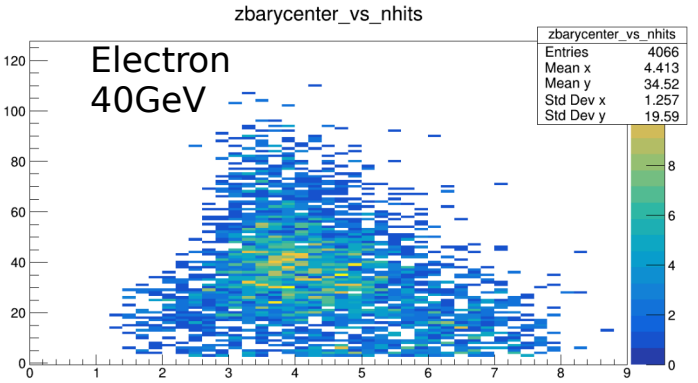
(still some systematically noisy channels)

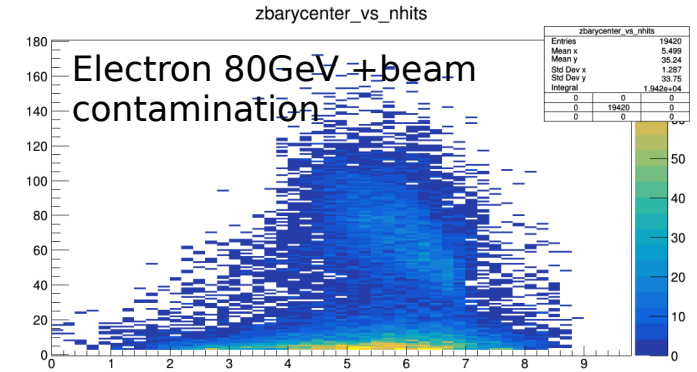


- Two weeks from the 26/09 to 3/10 at CERN with part of the beam time shared on standalone runs and part in common spills with SDHCAL.
  - 10 ECAL slabs in the stack.
  - 6 FeV11 + 4 FeV13-Jp
- Standalone runs with different number of layers (between 7 and 10)
  - muon calibration
  - Electron showers (10,20,40,80,150 GeV)

List of slabs (beam from the bottom)

plane	HDMI#	GDCC:04	GDCC:03	DIF/SLAB	DIF#	Comments
Slab16	9	1		9	dif_1_1_1	
Slab19	2	6		6	dif_1_1_4	
Slab18	4	3		7	dif_1_1_3	
FEV13_K2	1		2	2	dif_1_2_3	650µm
FEV13_P3	5		5	5	dif_1_2_4	320µm
FEV13_P2	3		6	10	dif_1_2_5	650µm
FEV13_K1	8	5		4	dif_1_1_5	650µm
Slab20	10		1	3	dif_1_2_1	
Slab22	6		3	1	dif_1_2_2	was dif_1_2_3 @DESY2017
Slab17	12	2		8	dif_1_1_2	

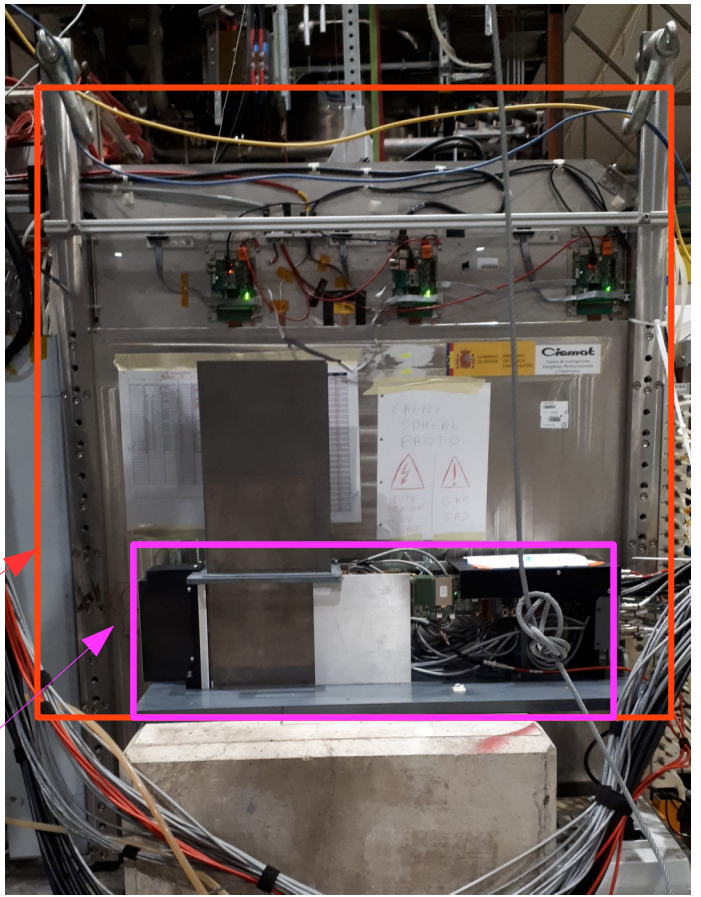




6 FEV11 + 1FEV13-Jp

CERN@2018 SiW-ECAL and SDHCAL

- Two weeks from the 26/09 to 3/10 at CERN with part of the beam time shared on standalone runs and part in common spills with SDHCAL.
- Common running for the last ~ week.
- Independent clocks, common spills with common start acquisition with busy signal from the SDHCAL.
- Common runs:
  - Electrons 150 GeV
  - Muons 200 GeV
  - Pions 40, 50, 60, 70, 80 GeV
  - Data processing and analysis is ongoing.



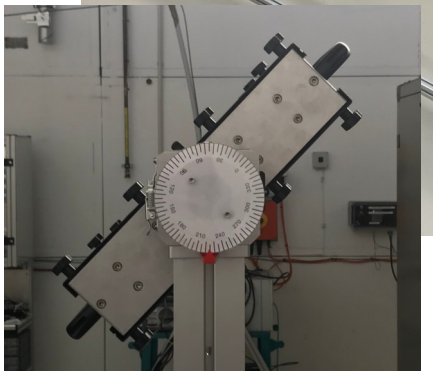
Conclusion

- We are in an exciting R&D phase on SiW-ECAL technollogical prototype with intensive debugging and performance studies in beam test and lot of developments ongoing
  - See talks from V. Boudry, T. Suehara and R. Poeschl

Back-up

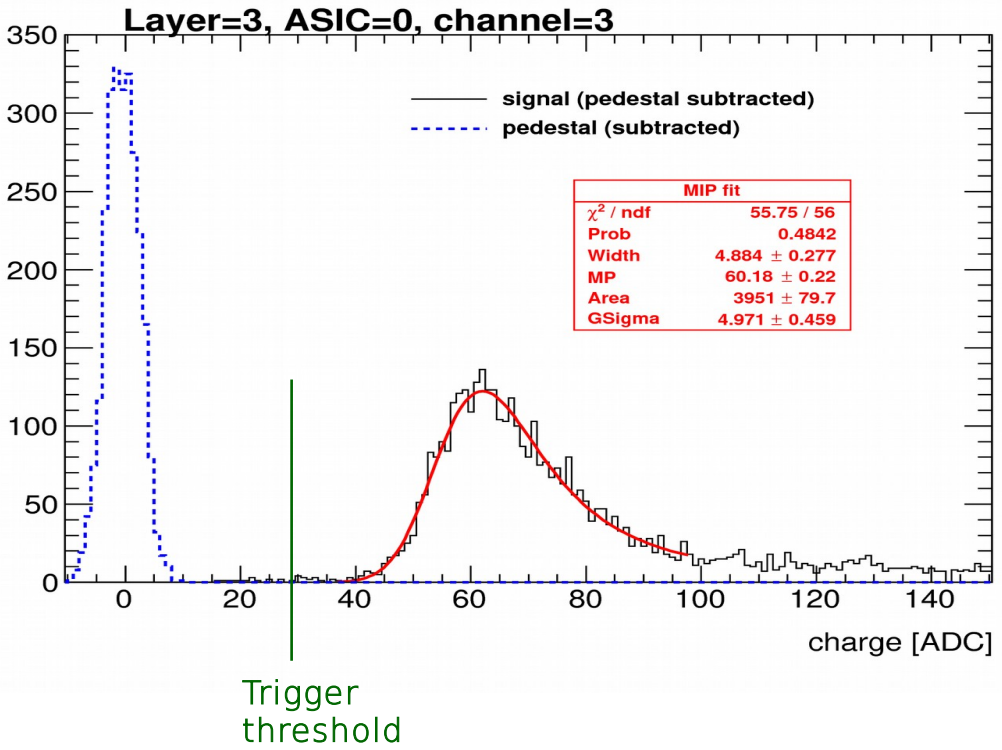
DESY@2018 – Long Slab Setup

- Mechanical structure with mono-directionnal wheels for precise positionning
- Full rotation system with index
- Black cover for light isolation
- Laser alignment with silicon pads
- Compact DAQ on a wheel table
- 3224mm long
- 8 target accessible in zone 21 (beam centered), only 7 in zone 24 (beam on the side)



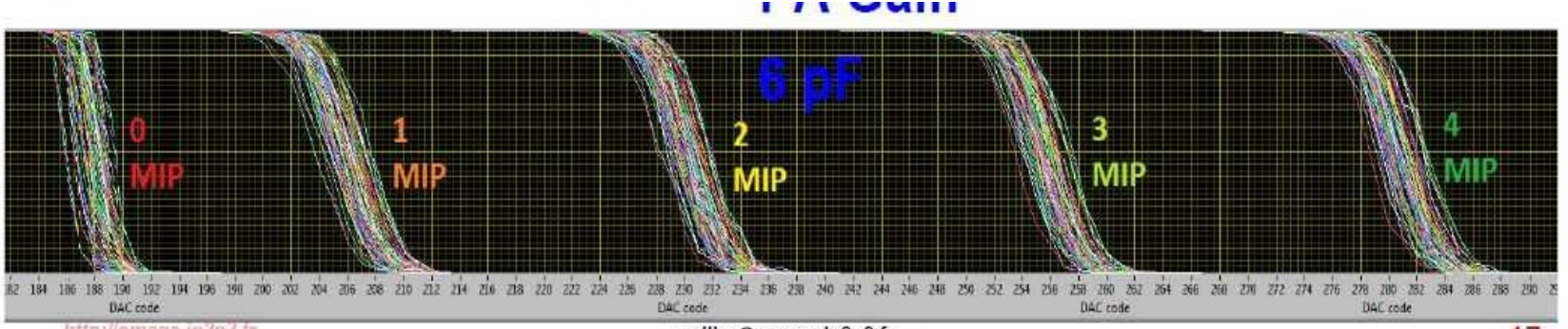
S/N in the ADC

- The high S/N=20 from the ADC is only valid for already triggered cells and **it allows for the filtering of spurious signals (i.e. retriggers)**



S/N in the trigger line

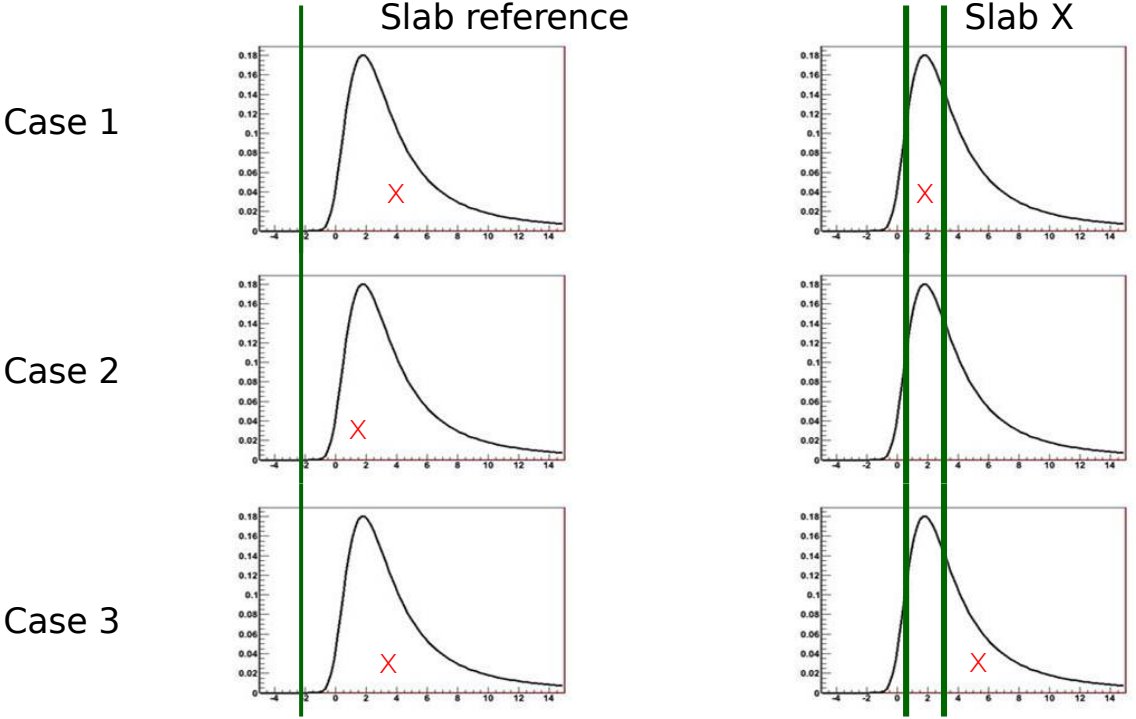
- How this curve looks for real signals measured in fully equipped detector modules ?
  - Similar test was done with ~1MIP cosmics → larger width and slightly different mean value. Using this we can estimate the uncertainty from the previous measurement:
  - S/N = 12.9±3.4 (very large uncertainty!)
- What about using the information of the threshold scan in absence of signal (noise-scurves)
  - The width and 50% position for 0-MIP scurves is not describing only the noise → competing effects between white noise and the sampling on the fast shaper.



Callier, CALICE2016,
Arlington, SK2a

S/N in the trigger line: analysis

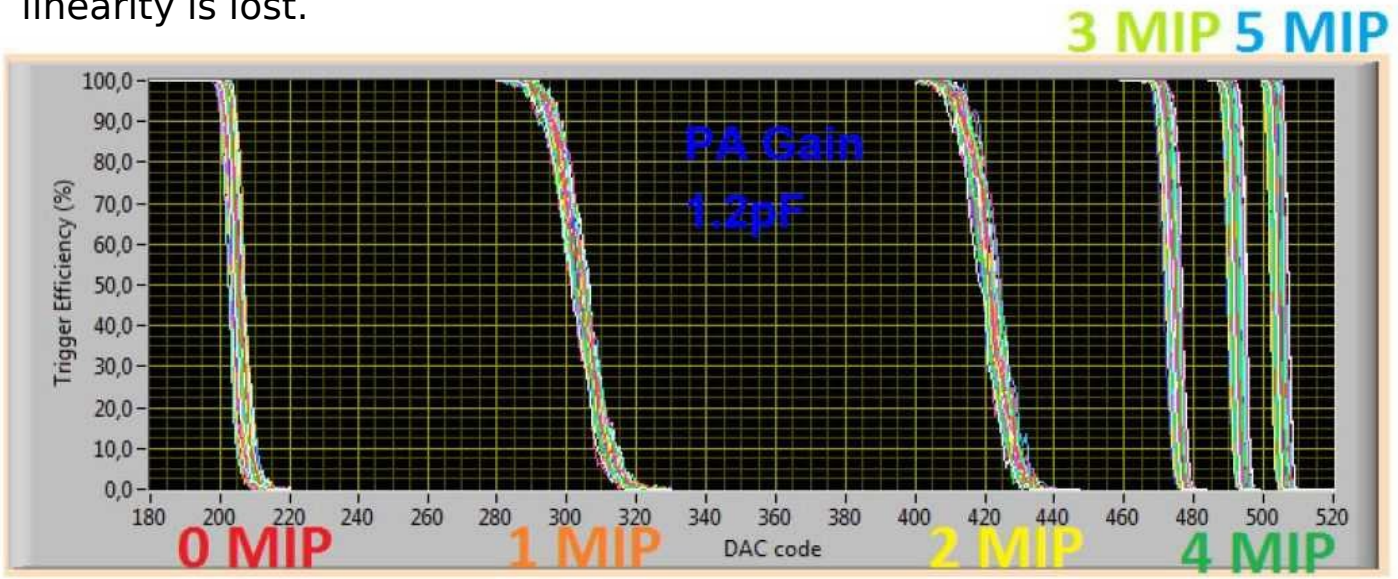
- The analysis is repeated for every slab after the first. An event is accepted if:
  - the first slab has only a hit with E>0.5
  - The studied slab hasn't an event outside (MPV-wLandau,MPV+wLandau)
- Then all events within (MPV-wLandau,MPV+wLandau) are counted for each threshold value



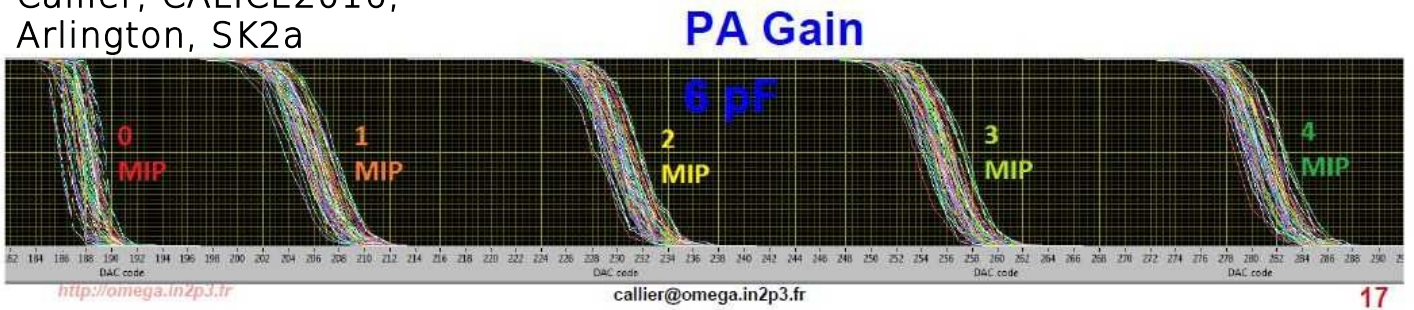
- Accepted and counted as triggered in slab X.
- Accepted and counted as not triggered in slab X
- Vetoed.

S/N in the trigger line

- **SK2a,** position of 0MIP (and width) disagrees with the expected from 1 and 2 MIP. For large signals, the linearity is lost.



Callier, CALICE2016, Arlington, SK2a



- **PA=1.2pF** (high gain for beam test)
  - S/N ~12, (rough estimation from the plot!)
- Similar for **6pF** (ILC gain) since the factor 5 reduction in distance is compensated by a smaller width of the curve → to be evaluated in beam!