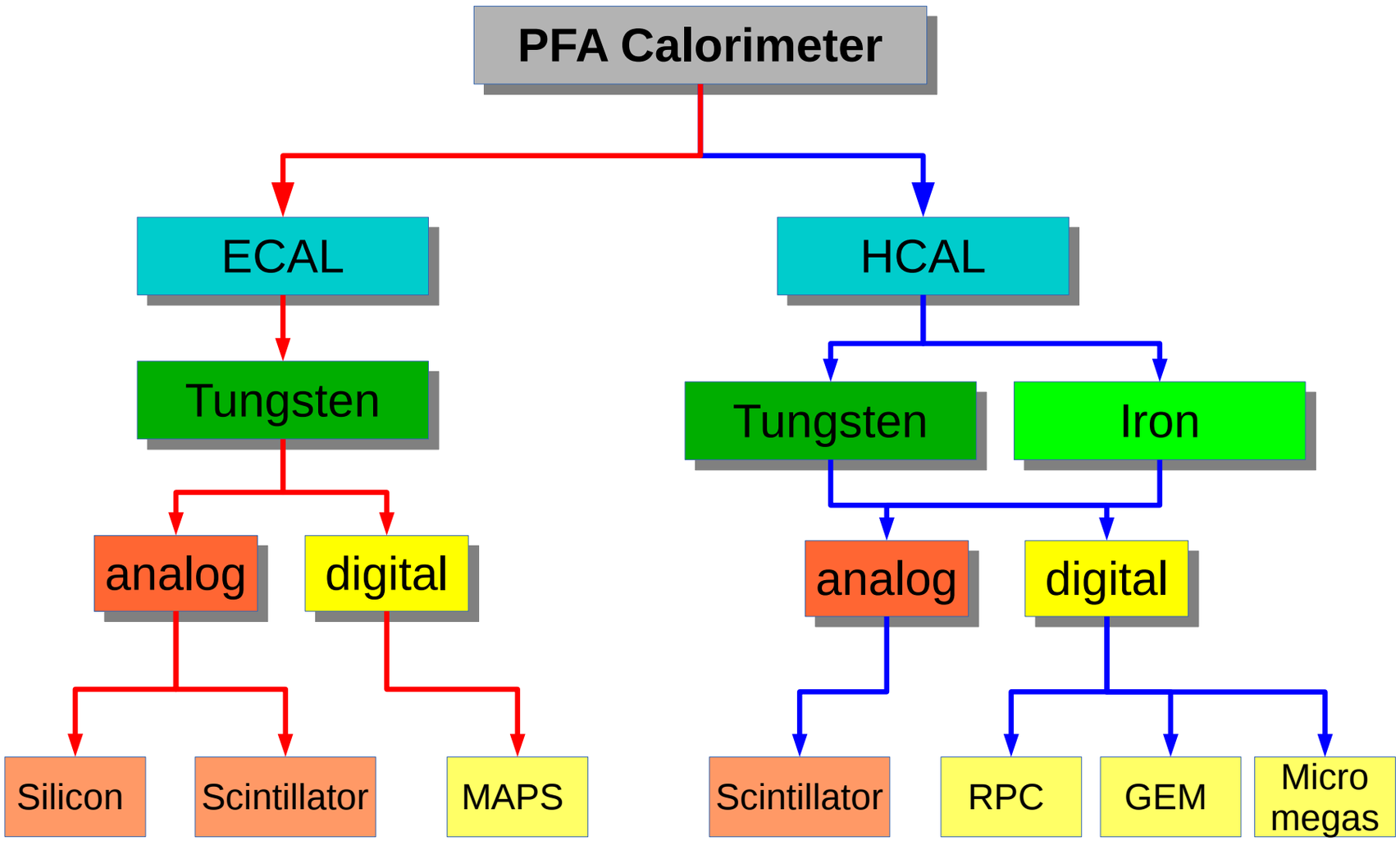
ECAL

Status and Perspectives

J-C. Brient and W. Ootani
ILD meeting 2019, Feb. 26-27, 2019, KEK



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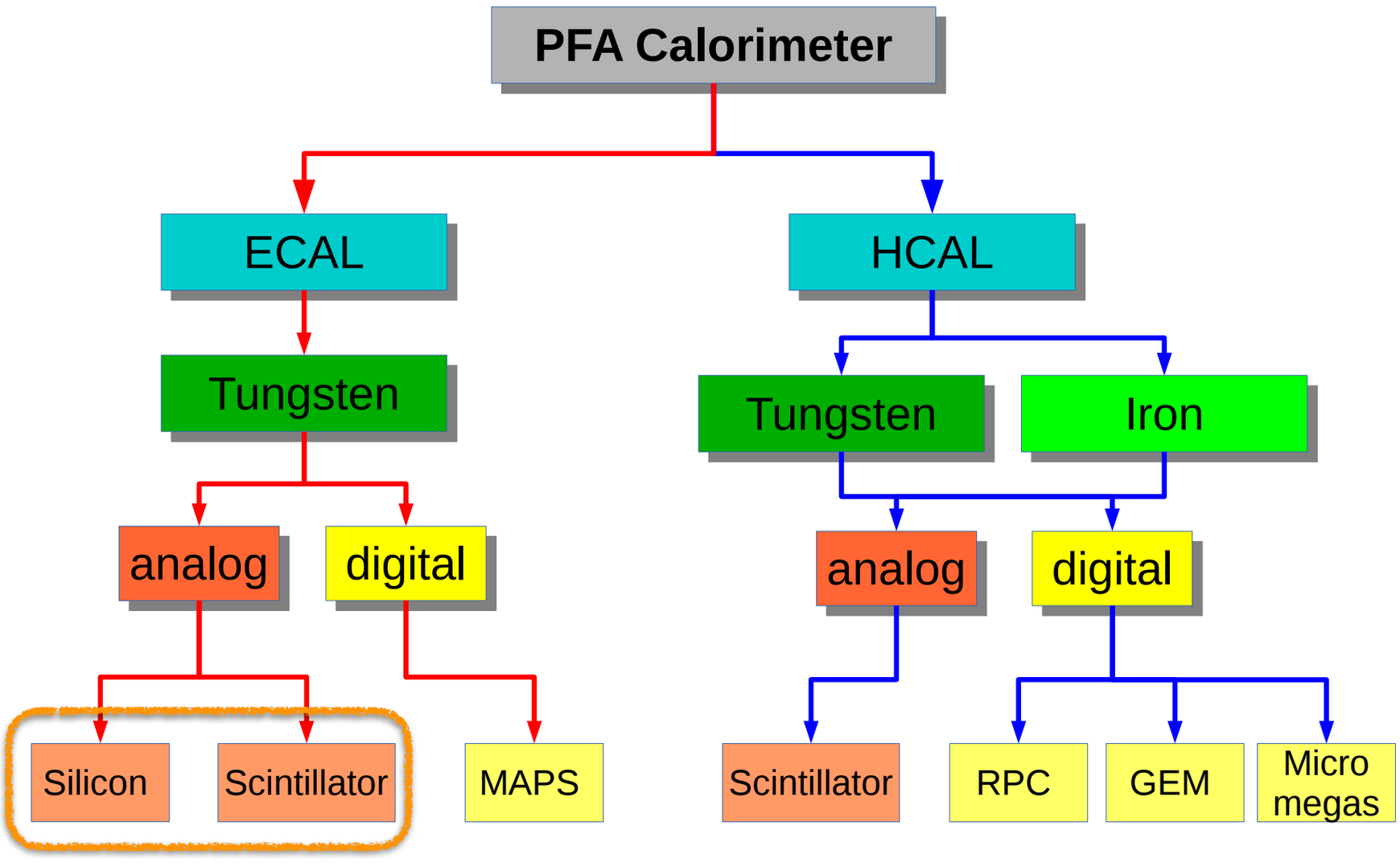
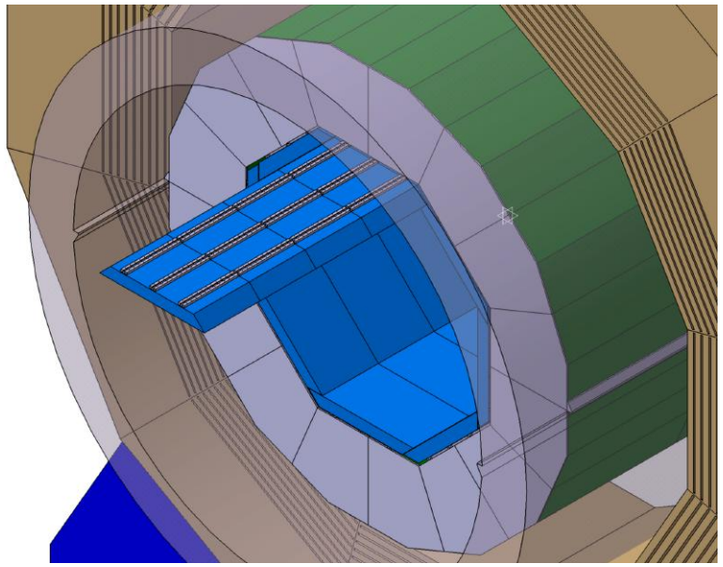
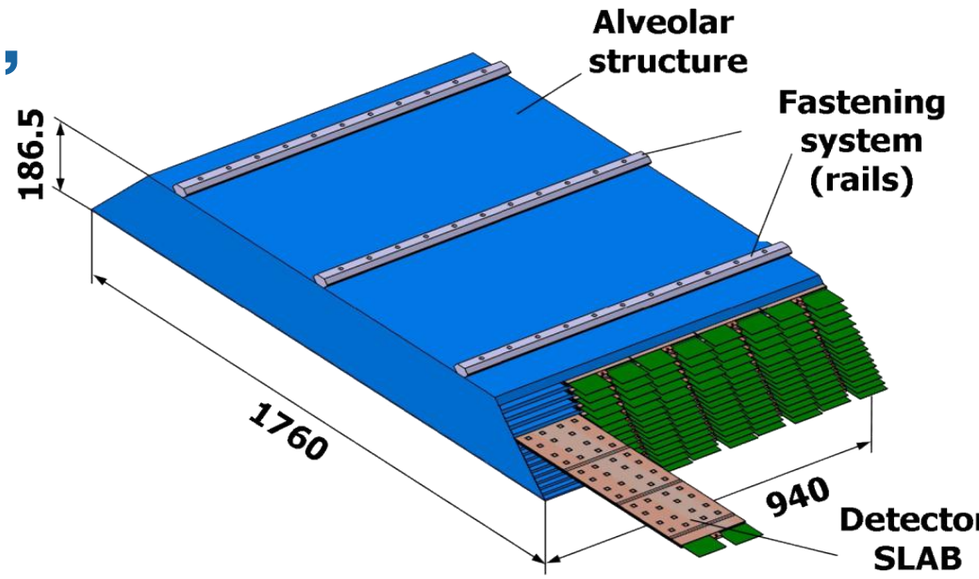


SiW-ECAL

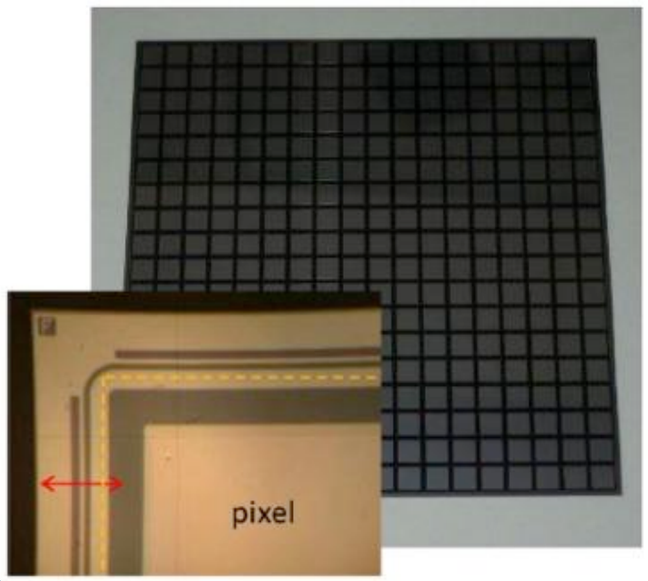
SiW-ECAL



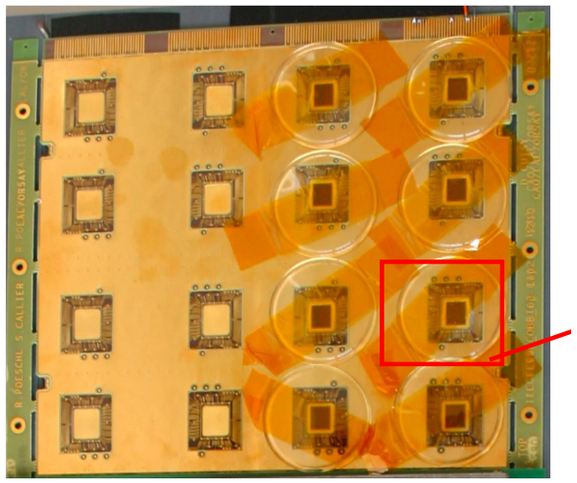
- **Based on Si sensor**
  - Excellent S/N
  - Compact
  - High stability, easy calibration
- **Tungsten absorber (X_0=3.5mm, λ_{int}=96mm, R_M=9mm), ~24X_0**
- **Transverse segmentation: 5×5mm²**
- **Longitudinal segmentation: ~30**
- **# readout channels: 10^8**

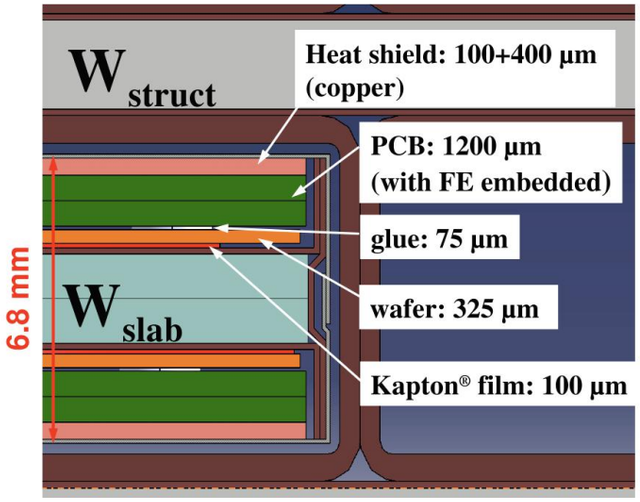


Si sensor



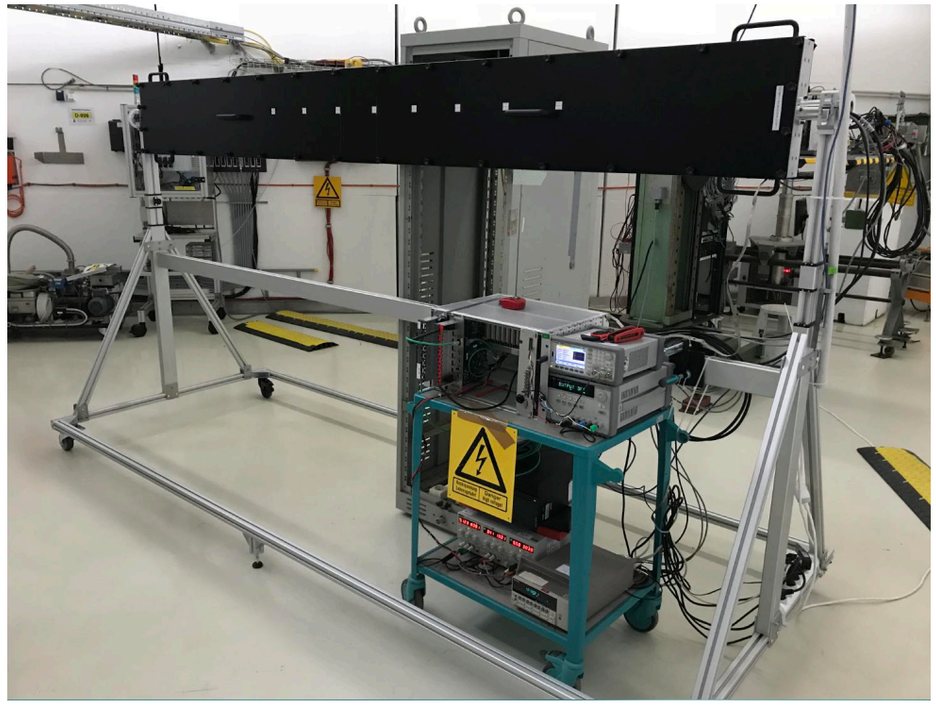
Readout ASIC





Technological Prototypes

- **Short slab**
  - Technological prototype with short slab (single ASU) stack
  - Test beam at DESY (8 layers), at CERN (10 layers)
- **Long slab**
  - Electrical prototype for full-scale ILD slab: 8-ASUs long

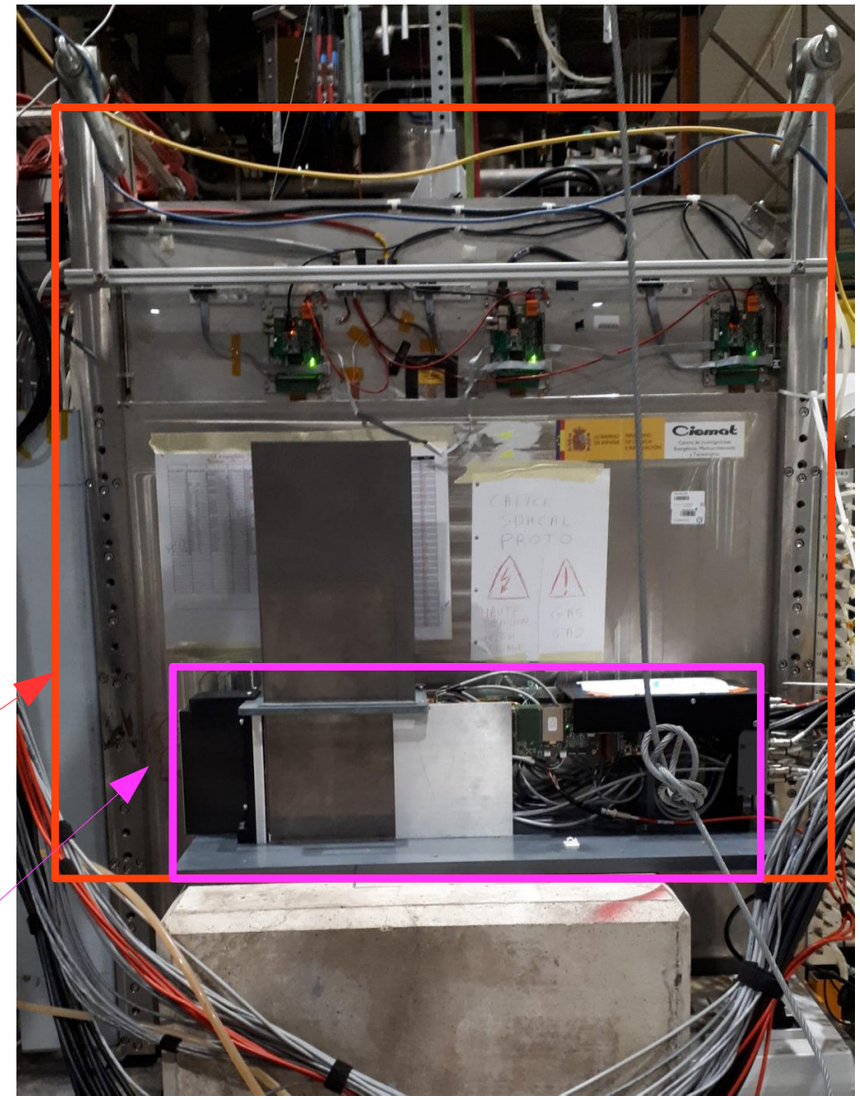


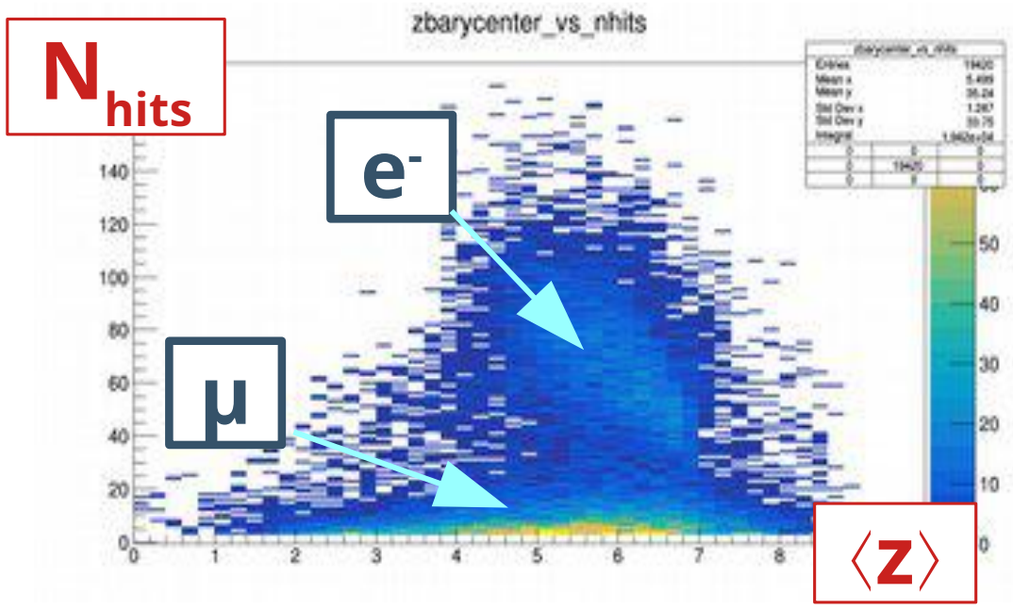
Test Beams with Short Slab Prototype

- **12/2012 : ASU 8 @ DESY :** New DAQ system, first full slab testbeam
- **07/2013 : ASU 8 @ DESY :** New configuration system, Full scans
- **11/2015 : ASU 11 @ CERN :** first test of ASU11 on plateau
- **06/2016 : ASU 11 slabs @ CERN :** first test with ASU11 slabs, common with SDHCal
- **06/2017 : ASU 11 @ DESY :** first test with 7 layers with ASU11, scans and calibrations
- **07/2018 : ASU 11+13 + long slab @ DESY :** first test with ASU13 layers, first test with long slab
- **09/2018 : ASU 11+13 @ CERN :** high intensity for ASU11/13 stack, common with SDHCal

Si-ECAL and SDHCAL Combined Test Beam

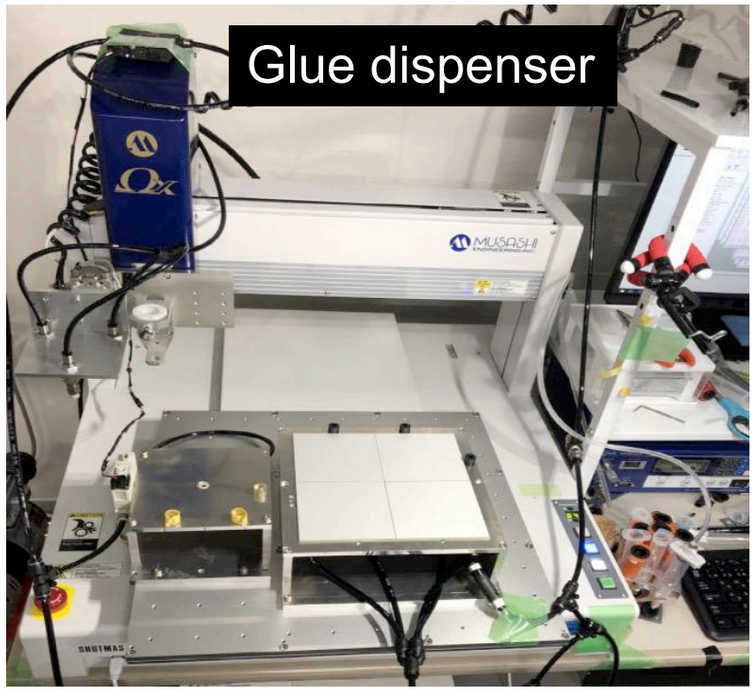
- **Test beam at CERN SPS**
  - DAQ: Sep.26-Oct.6, 2018
  - 6×FEV11+4×FEV13(320&650μm) + 24X_0-W
  - Common running with SDHCAL for one week
    - Independent clocks, common spills with common start acquisition with busy signal from SDHCAL
  - Analysis in progress

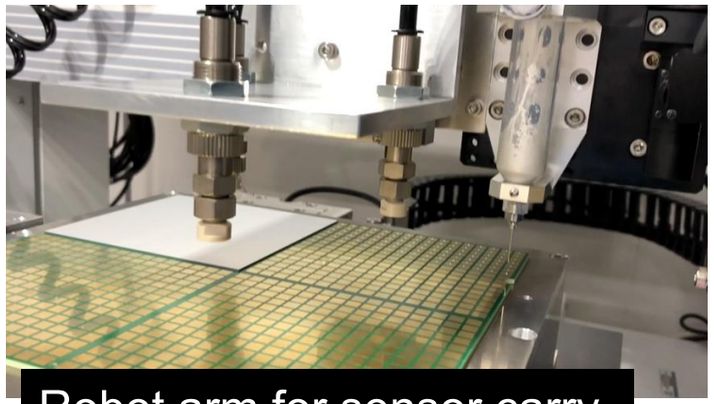


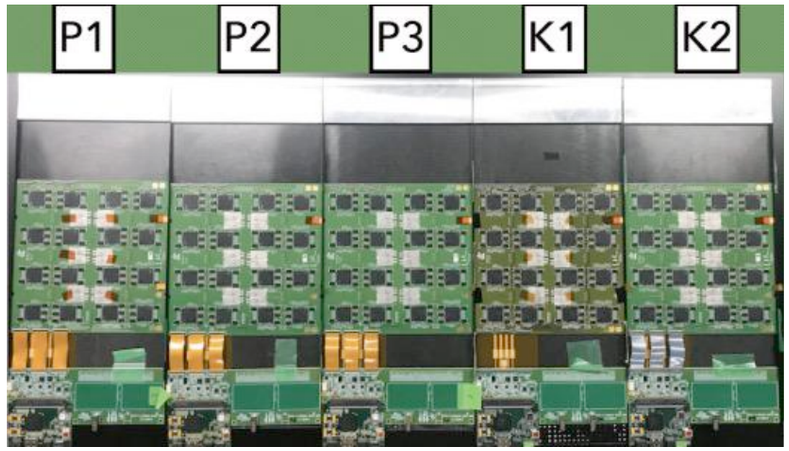


Slab Assembly in Japan

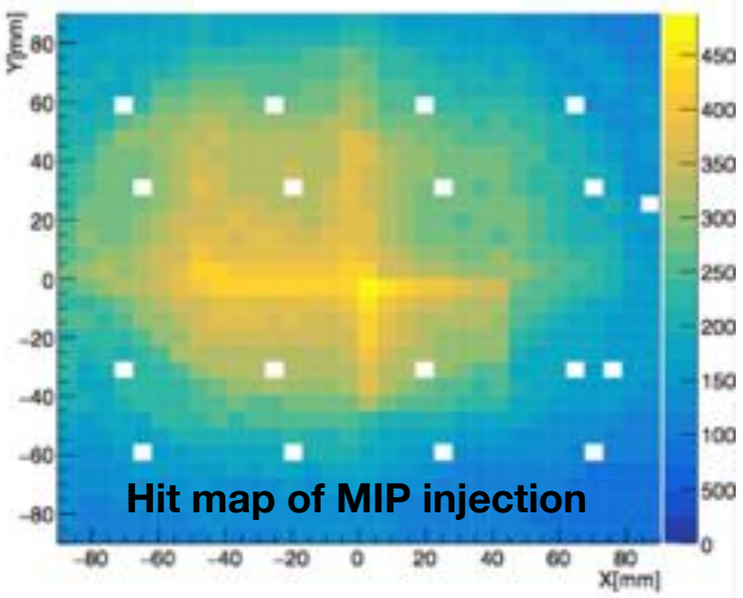
- **Slab assembly in Kyushu has been performed**
  - 5 short slabs of FEV13/SMBv5
  - 4 FEV13s tested at CERN test beam and only 1 or 2 slabs show good MIP separation due to HV connection problem

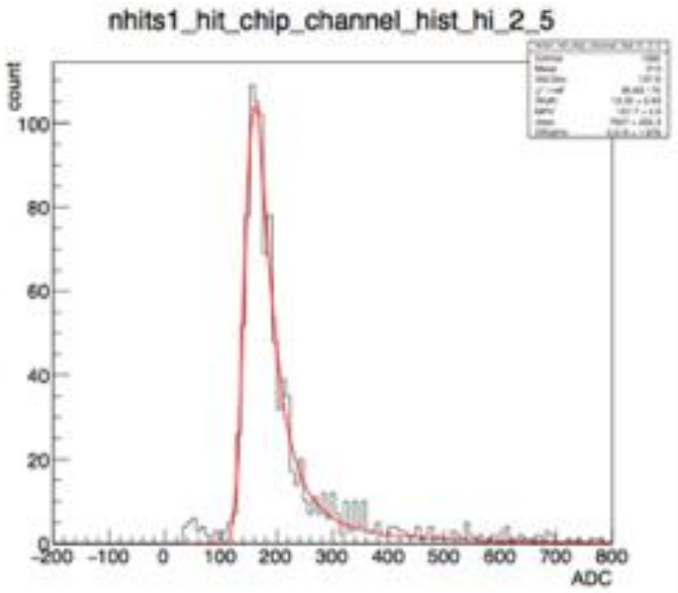






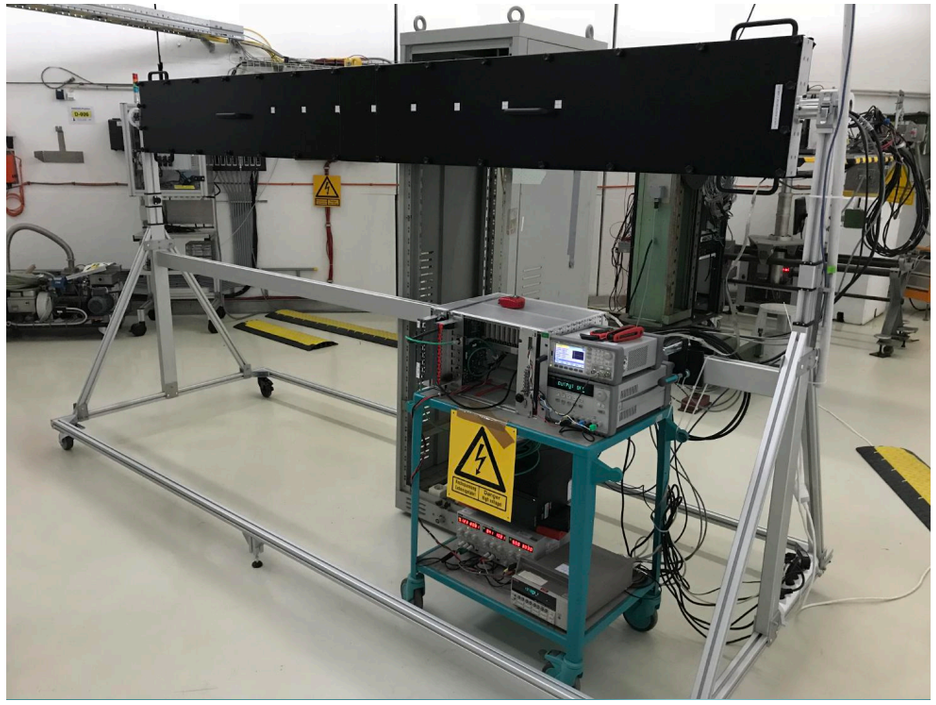
FEV13 P2

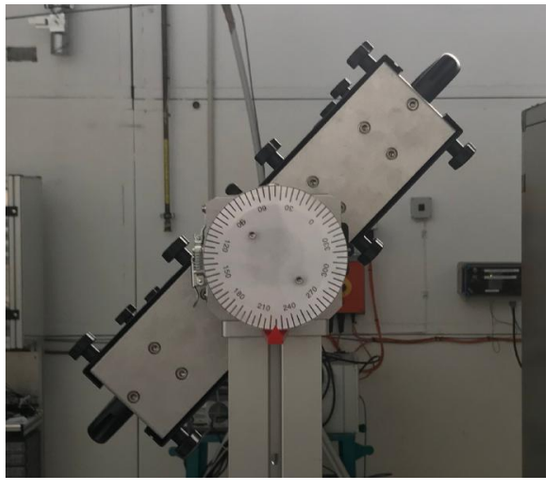


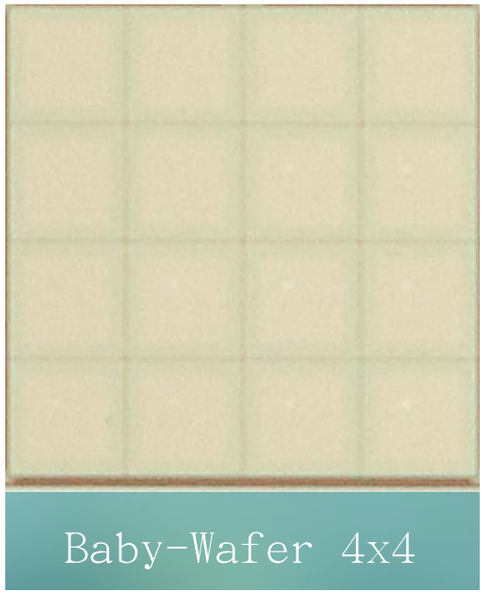


Long Slab Prototype

- **SiW-ECAL full-scale prototype**
  - Assembly of 8 ASU (180×180mm^2 each)
  - Typical size of detecting layer in the SW-ECAL barrel
  - Equipped with baby wafer (4×4 silicon pads)
- **Dedicated mechanical structure**
  - Rotation system with 1° precision
  - Light tight black hood
- **Tested with cosmics, checking source, 3GeV-electrons@DESY**

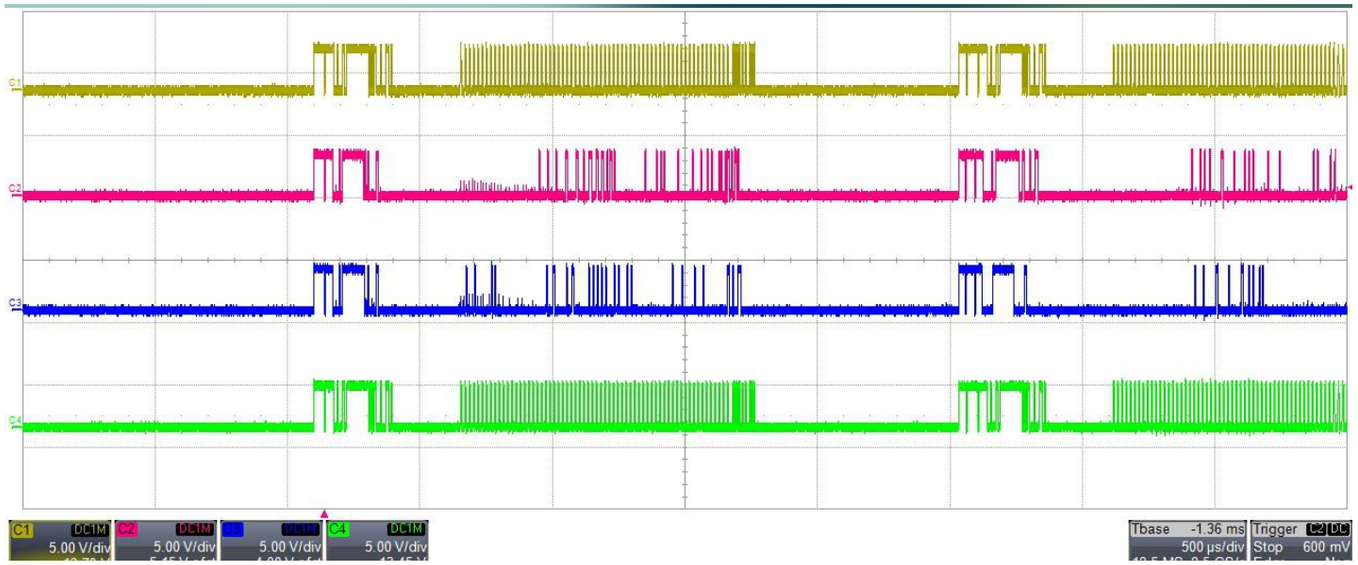


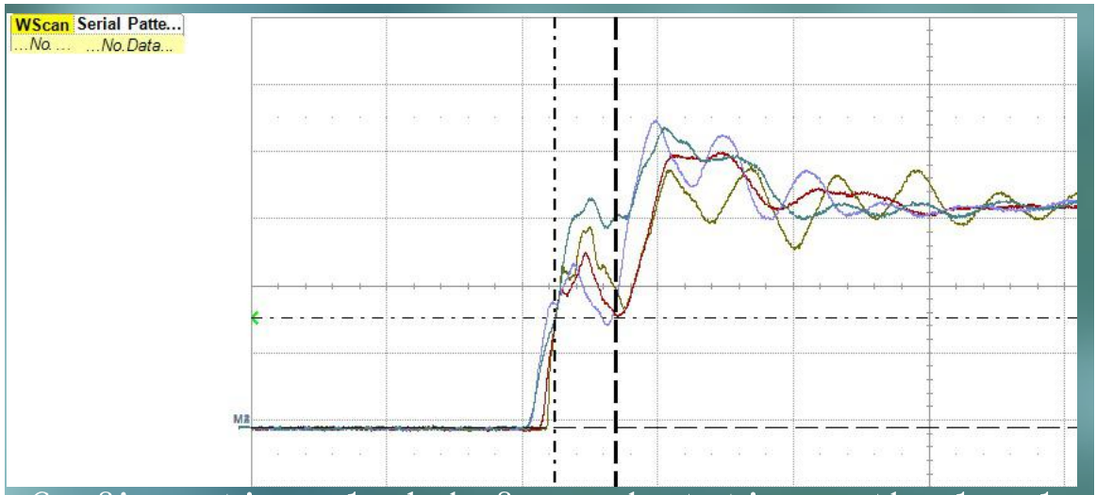




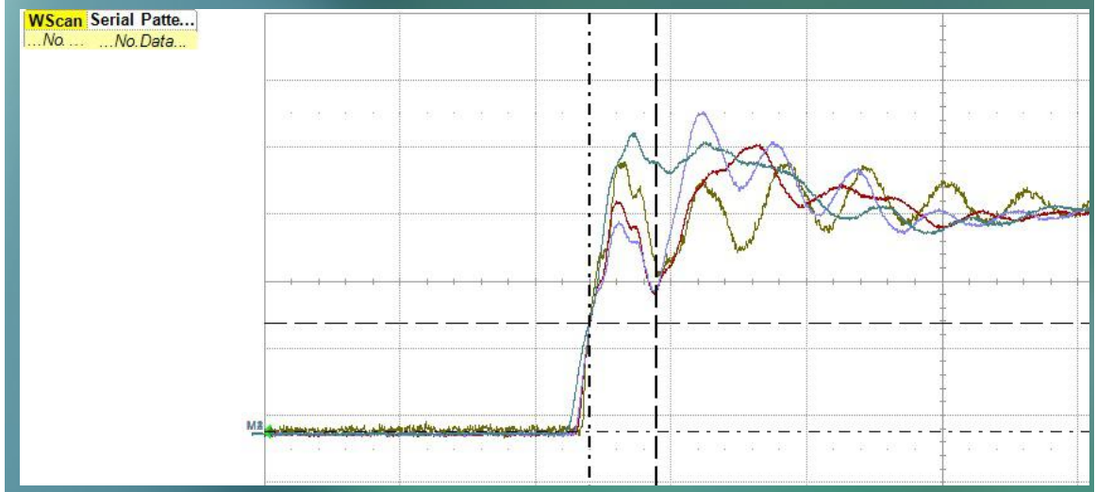
Long Slab Prototype

- **Reflections observed especially on clock lines**
  - Mitigated with RC filter
- **Possible improvements**
  - Optimise clock lines to avoid reflection
  - Adaptable impedance depending on length
  - Use 4 partitions
  - Optimise power distribution to avoid attenuation





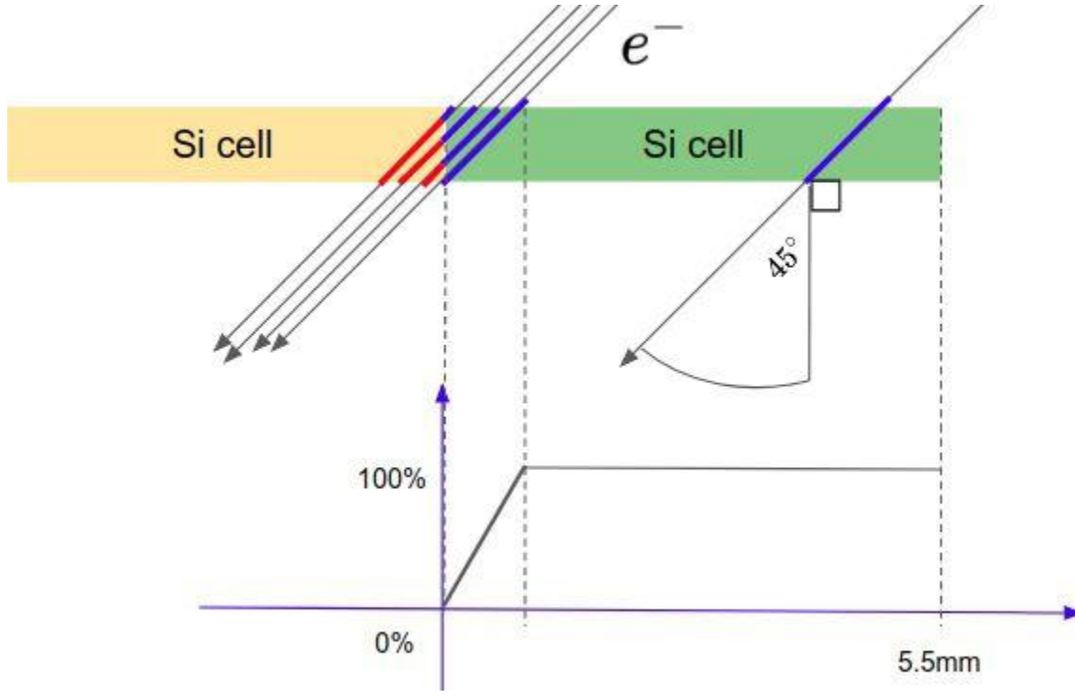
Configuration clock before adaptation : the level is oscillating around the mid-level

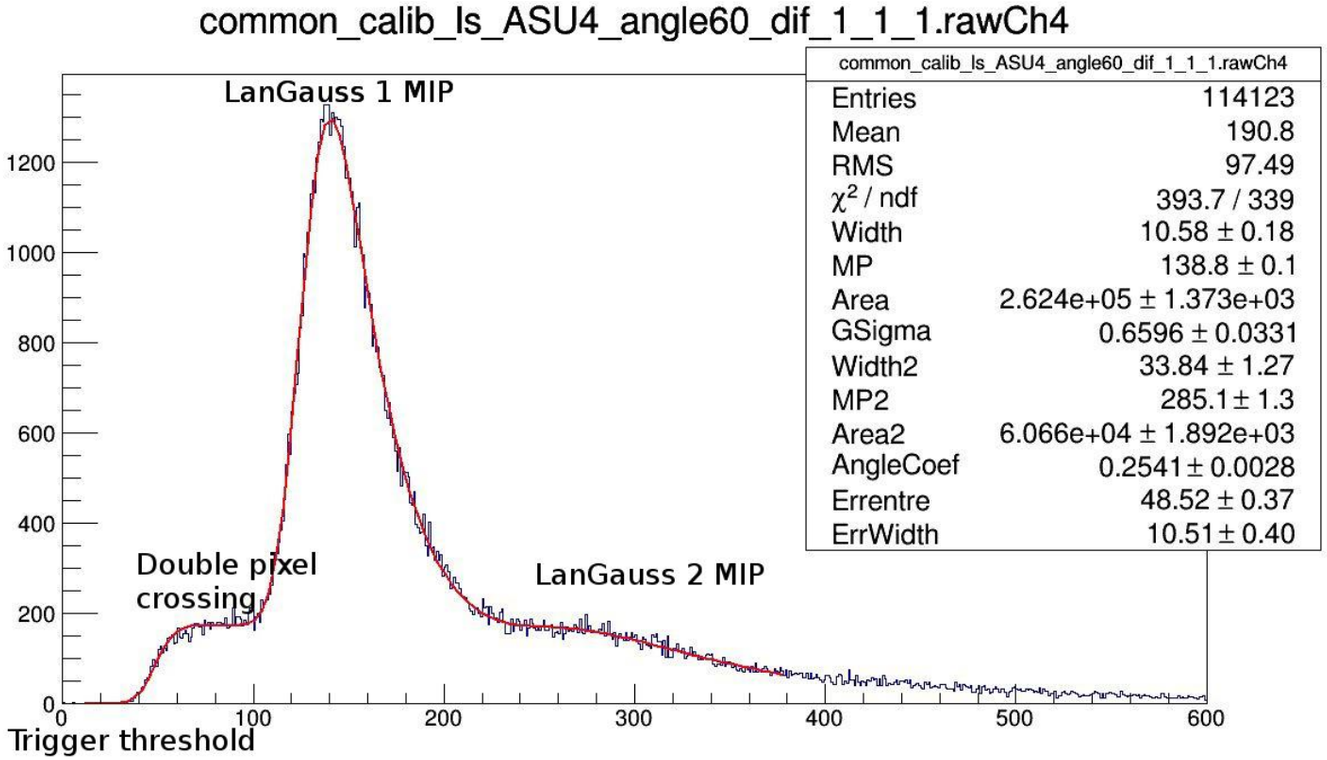


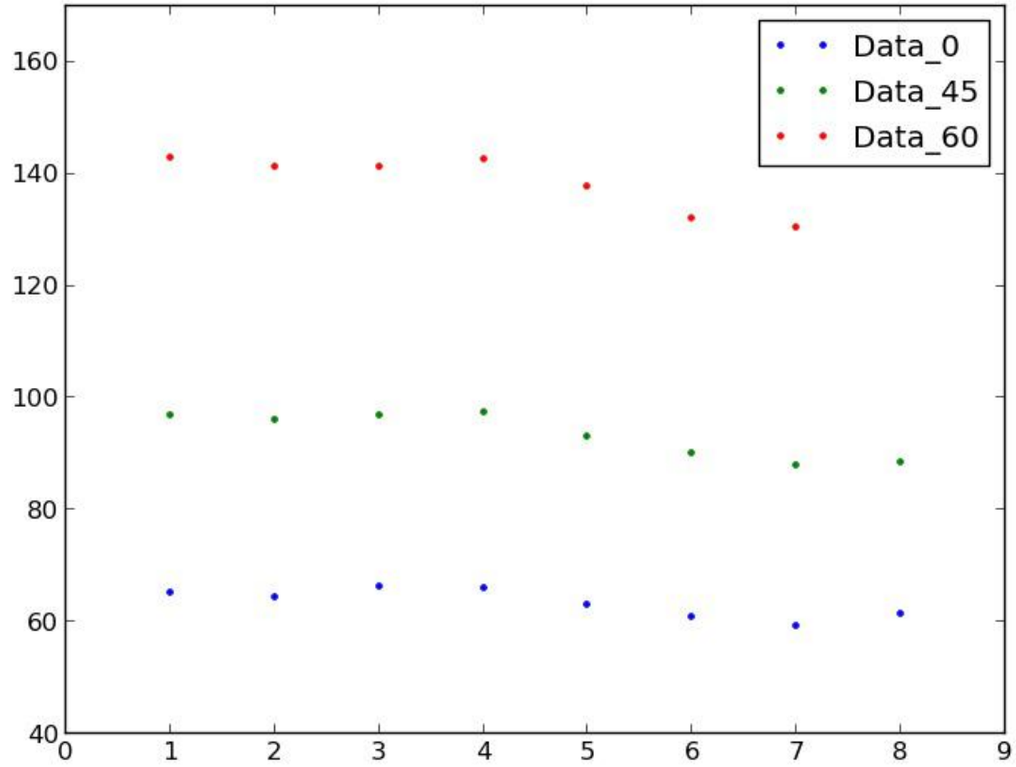
Clock line after adaptation with a RC filter : the oscillations are shifted above the mid-level

Long Slab Prototype

- **MIP response**
  - MIP charge depending on angle (cosθ)
  - Left-side tail from particle going through two adjacent pixels
  - Common inflexion depending on length (~10% of MIP value)



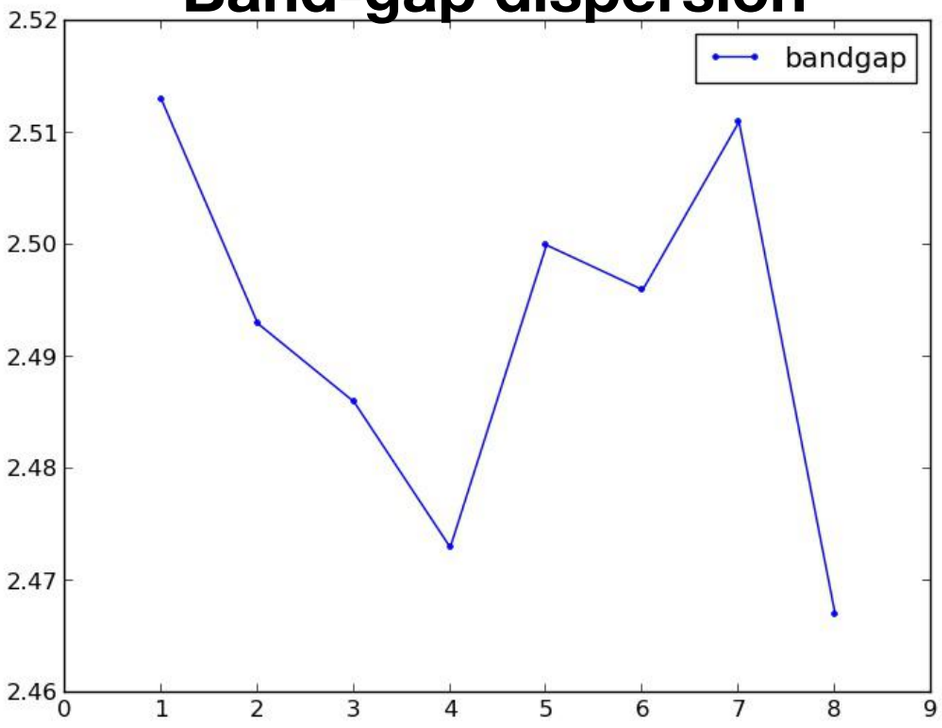




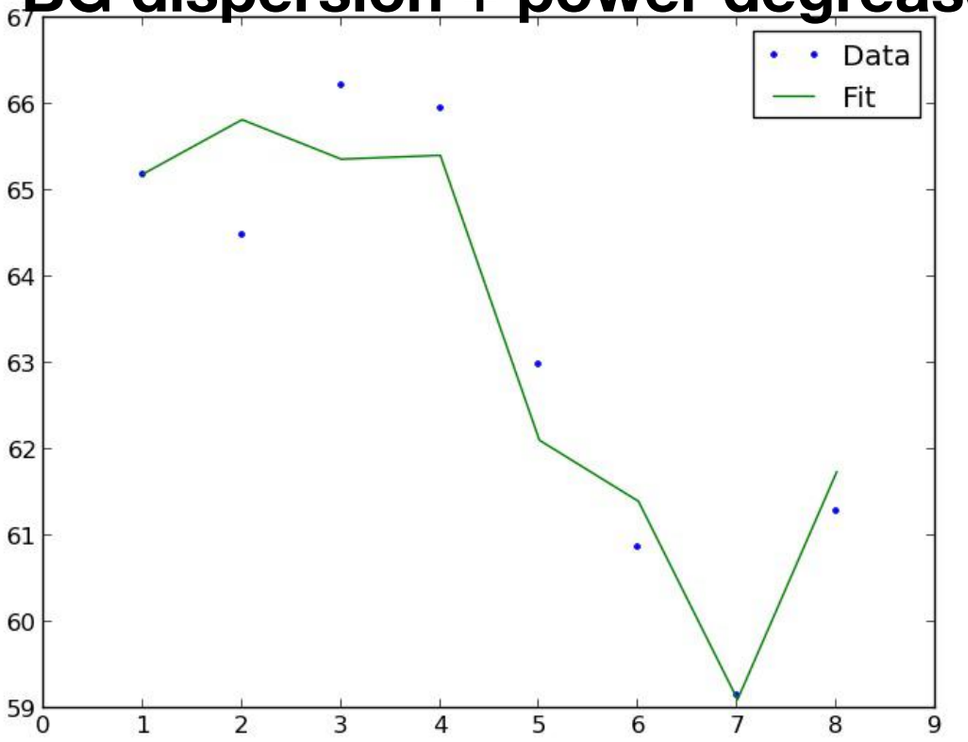
Long Slab Prototype

- **Inflexion is a sum of two effects**
  - Power supply weakening along line
  - Band-gap dispersion (random)
- **Possible improvements at next version**
  - Same length for power line for all ASU →octopus power-supply
  - Need better band-gap dispersion or software compensation

Band-gap dispersion



BG dispersion + power degrease

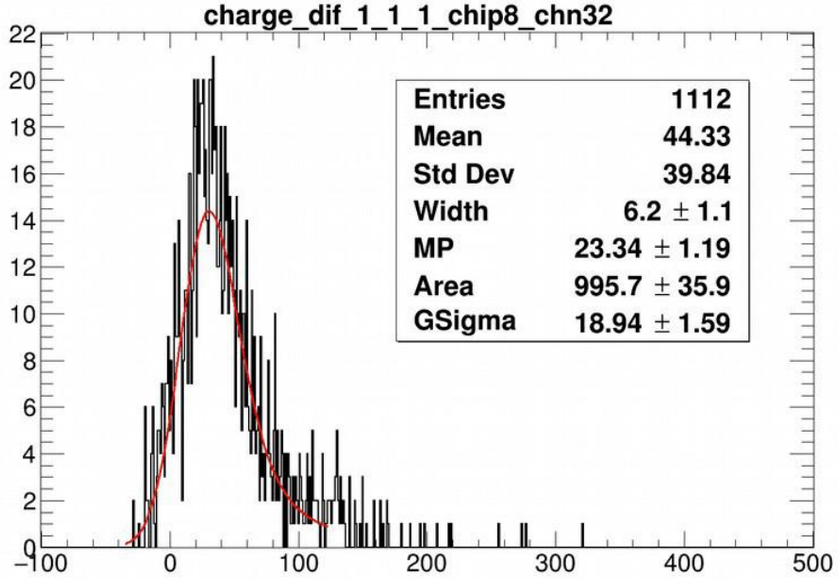


Ultra-thin PCB with COB

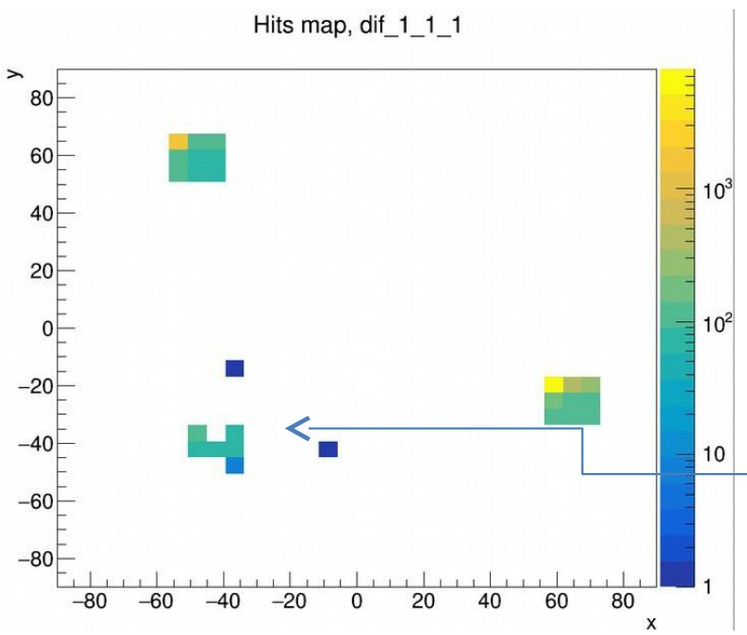
- **Investigating ultra thin PCB with chip-on-board (COB)**
- **LAL/OMEGA collaboration with Korean Group of SKKU**
  - FEV11_COB: 10 boards, 1.2mm-thick
  - Good planarity and good electrical response
  - SKIROC2a wire-bonded at CERN

Ultra-thin PCB with COB

- **Successful debugging w/o sensors**
  - ~4% of noisy channels, good response to injected signals
- **Debugging with sensors (baby-wafers 3×3 pixels)**
  - 3 baby wafers characterised



A. Example of MIP spectrum from cosmic rays.



A. Hit map with for cosmic runs.

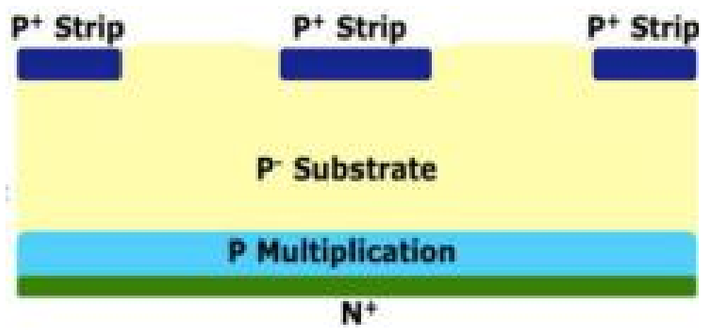
B. (different mapping to BGA versions)

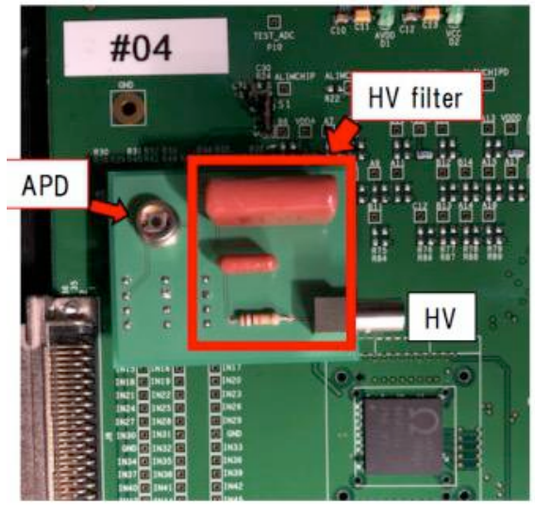
C. Baby wafer tested in DESY. Some glue is spilled.

New Sensor Development

- **LGAD for timing detector**
  - Testing inverse APD with SKIROC2 testbaord
  - Successfully observed Sr-90 signal (estimated active layer thickness of a few 10μm)
- **PSD for position detector**
  - Charge sharing for position determination
  - Laser test with high resistivity gives good dynamic range

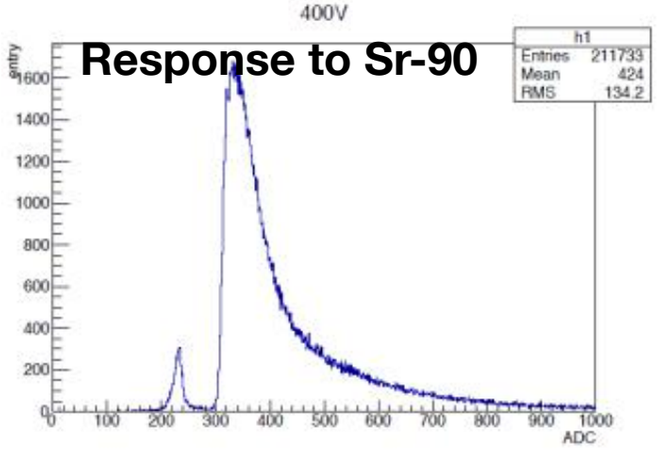
Inverse LGAD



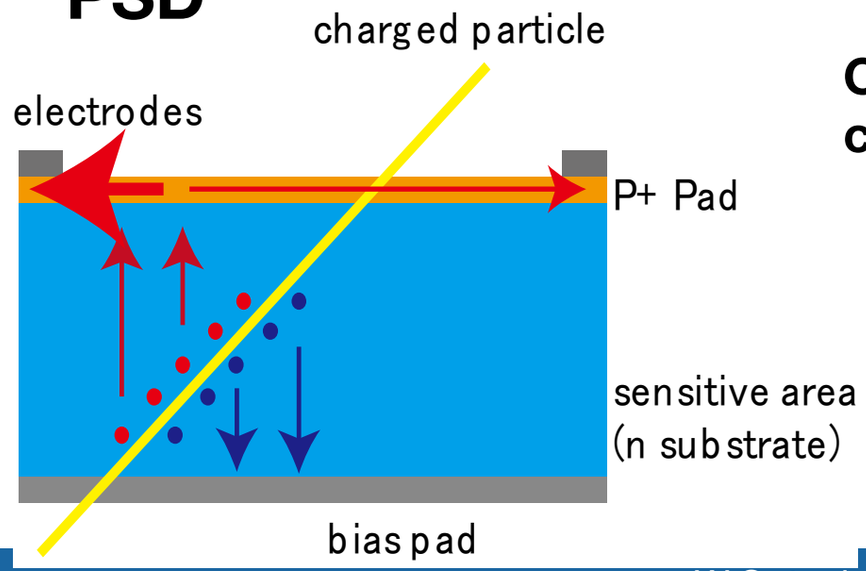


400V

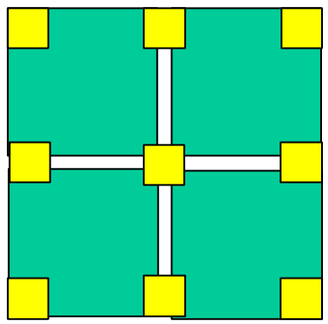
Response to Sr-90



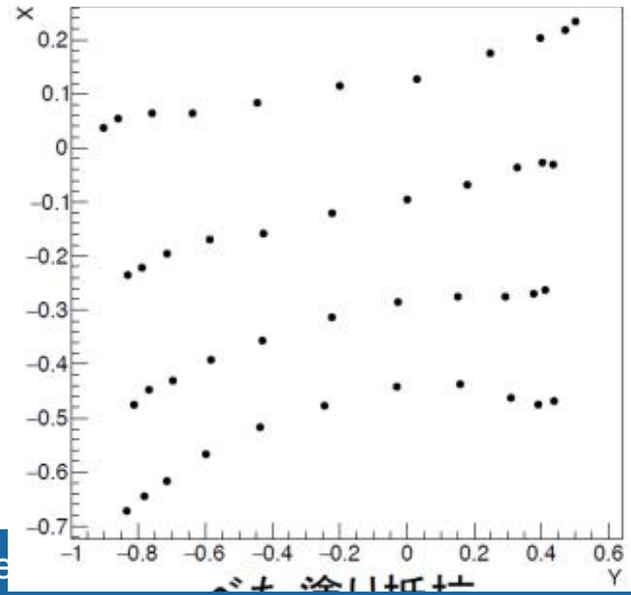
PSD



Combine neighbouring ch to reduce # readout



Good dynamic range with high resistivity (laster test)



AOB

- **Calibration**
  - **Strategy for calibration**
    - Calibrate at construction
    - No need for re-calibration
  - **Silicon PIN diode is “an example of stability”.**
    - The depleted zone will not change in time. In addition, running in over depleted regime avoids gain variation with temperature or pressure or water air content
    - The tungsten thickness will not change with time
    - The gain of the VFE preamplifier can be easily under control by charge injection
  - **Calibration precision at per-mil level or better foreseen**
    - $1\%/\sqrt{N_{cell}}$ with N_{cell}~50 per GeV for EM shower and N_{cell}~30 ($=N_{layer}$) for MIP
    - Could be even better than per-mil for electron >10GeV
    - With a reasonable hypothesis without correlation btw channels
- **Topic for IDR**
  - **Study with long slab prototype**

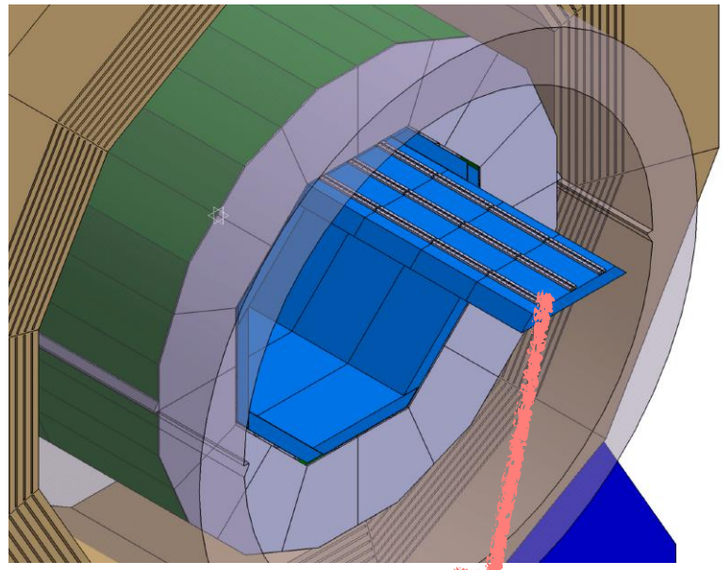
Perspective

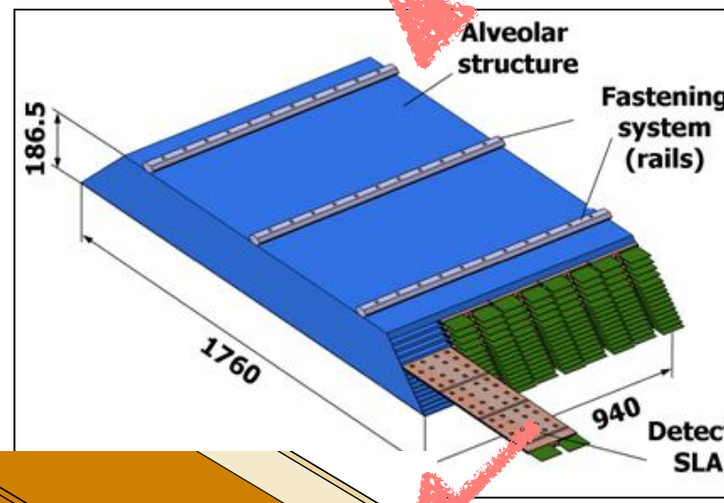
- **Review design of long slab prototype**
  - 750μm wafers, 8” wafers
  - HV distribution
  - DAQ: HW+SW
- **Build prototype with double layered LS**
  - Demonstrator for industry
- **Build a module-0**
  - ~13× DL-Long slabs × 3-5
- **…Build a SiW-ECAL**

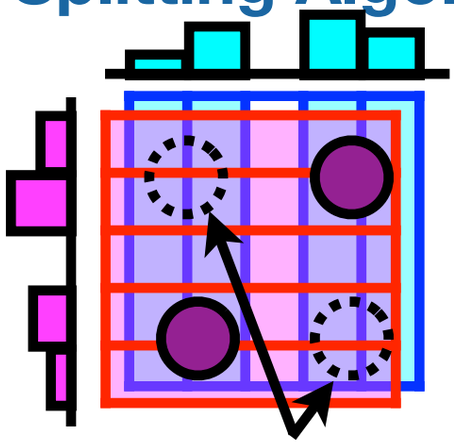
ScW-ECAL

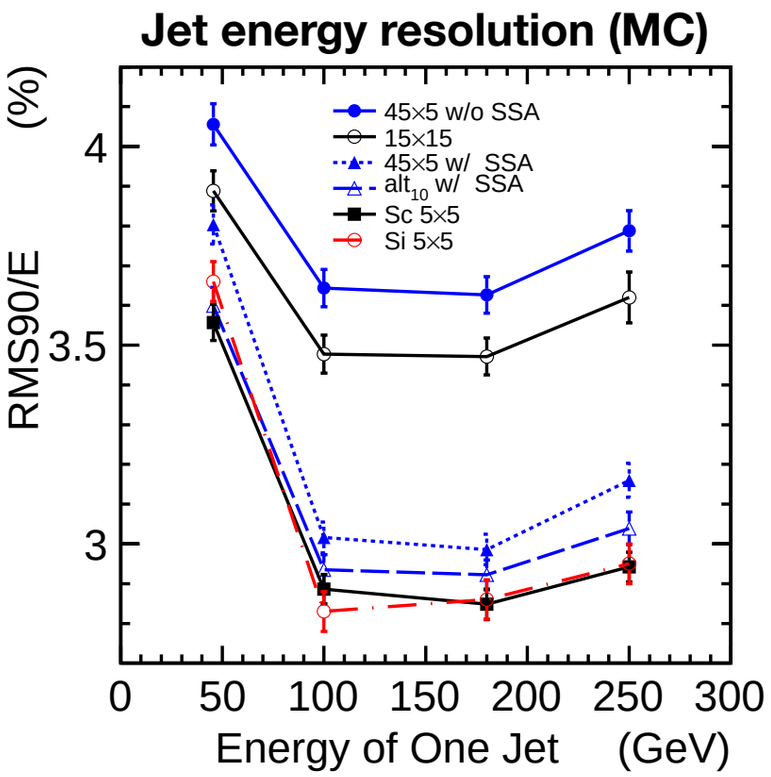
ScW-ECAL

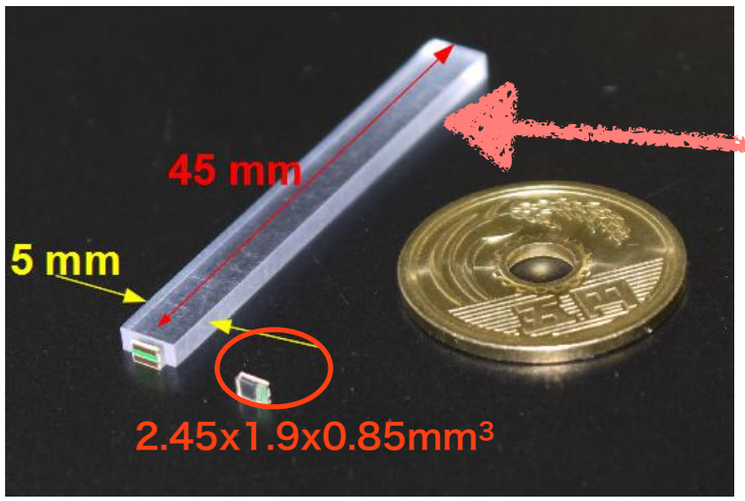
- Based on scintillator strips readout by SiPM (MPPC)
- Virtual segmentation: ~5mm×5mm with strips in x-y configuration
- Significant reduction of readout channels: $10^8 \rightarrow 10^7$
- Reconstruction algorithm: Strip Splitting Algorithm (SSA)
- Timing resolution <1ns
- Low cost

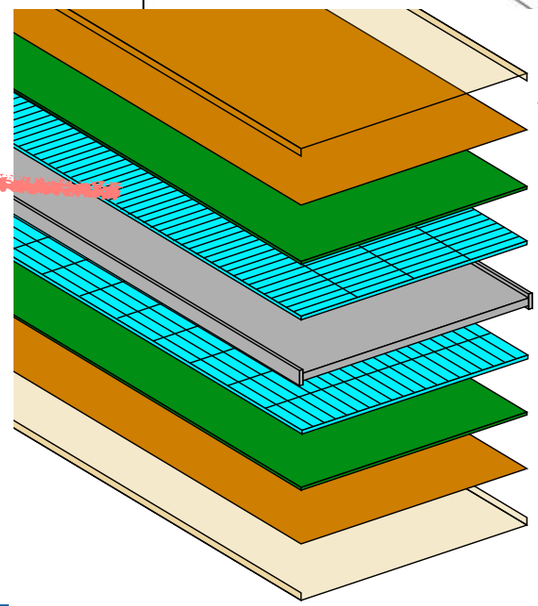






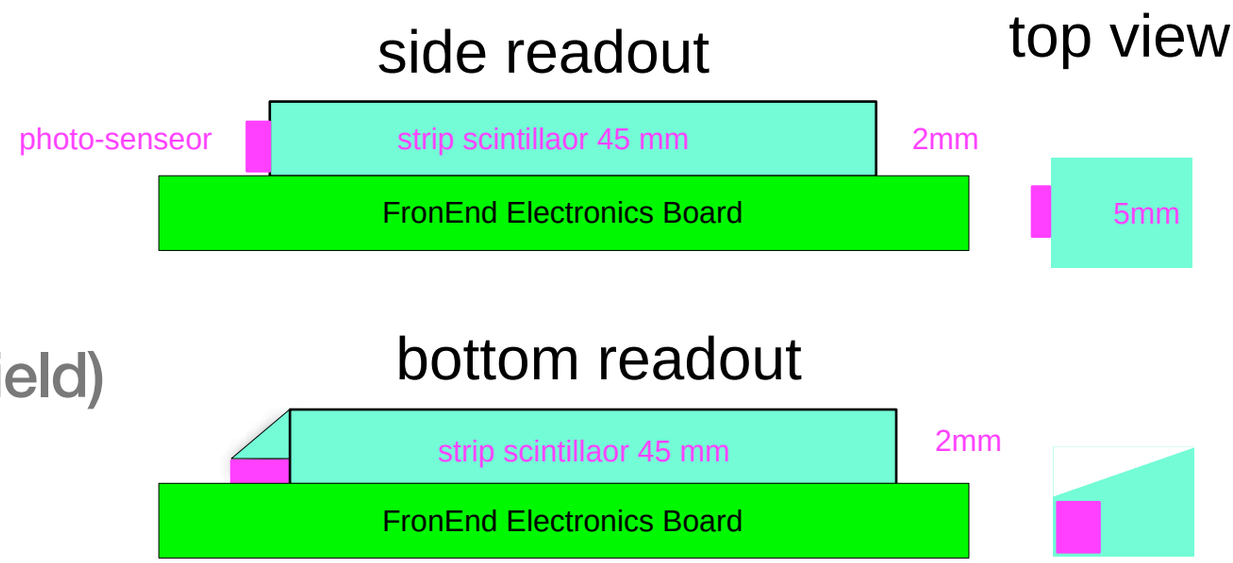


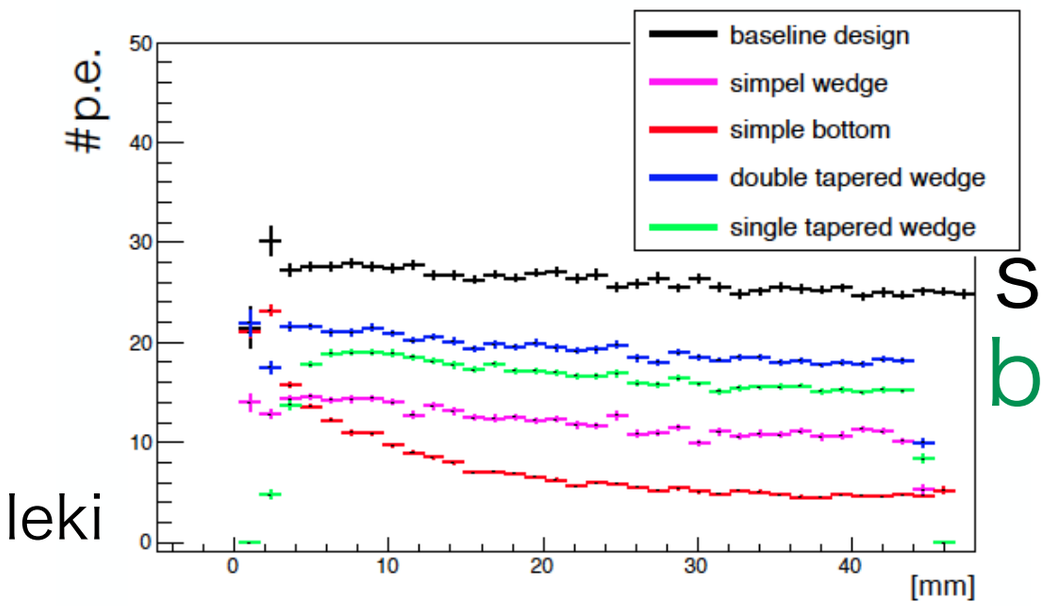


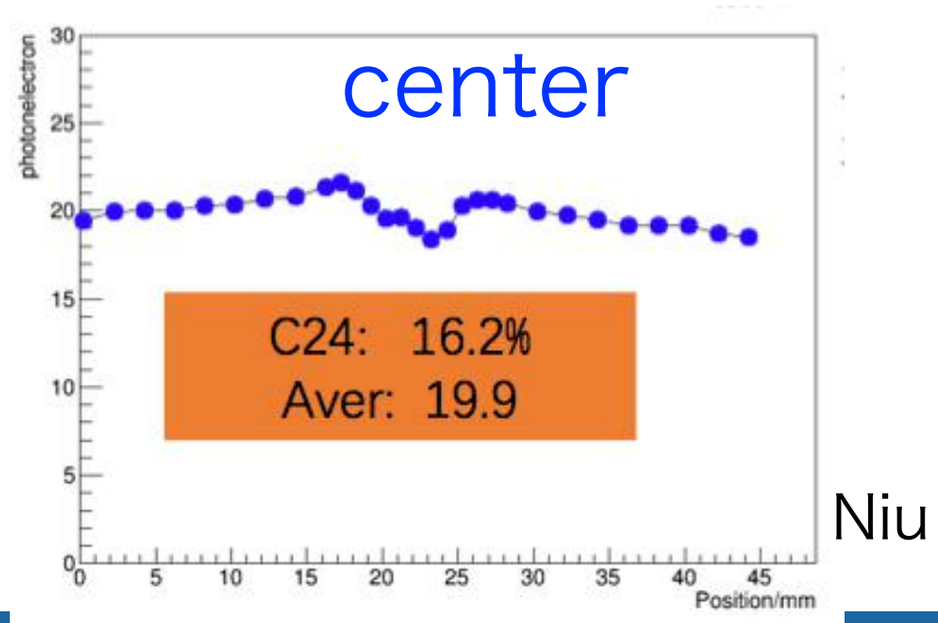


SiPM Readout Scheme

- **Requirements for SiPM readout scheme**
  - Light yield
  - Uniformity (position dependence of light yield)
  - Minimum dead area
  - Compatibility with large scale production
- **New scheme proposed**
  - Central readout with dimple (à la AHCAL SiPM-on-tile) proposed by Chinese group
  - Promising performance





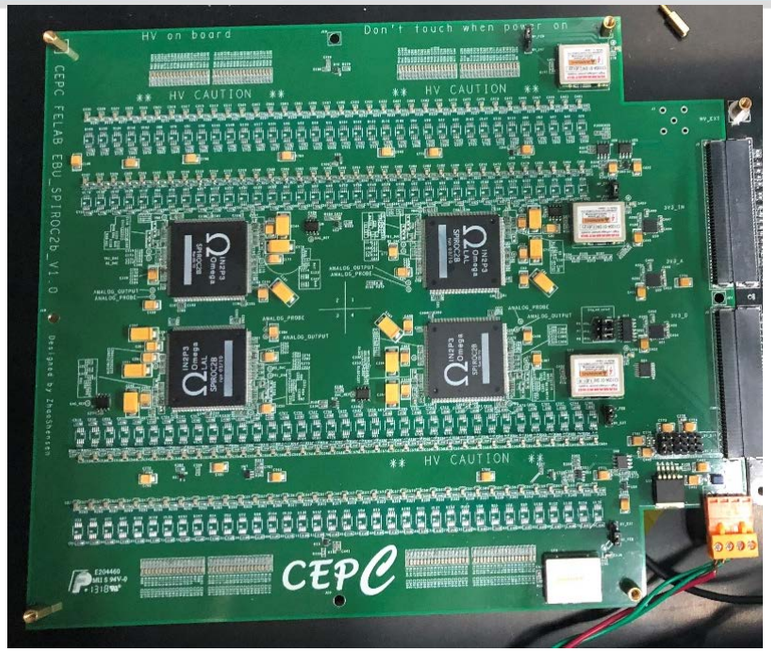


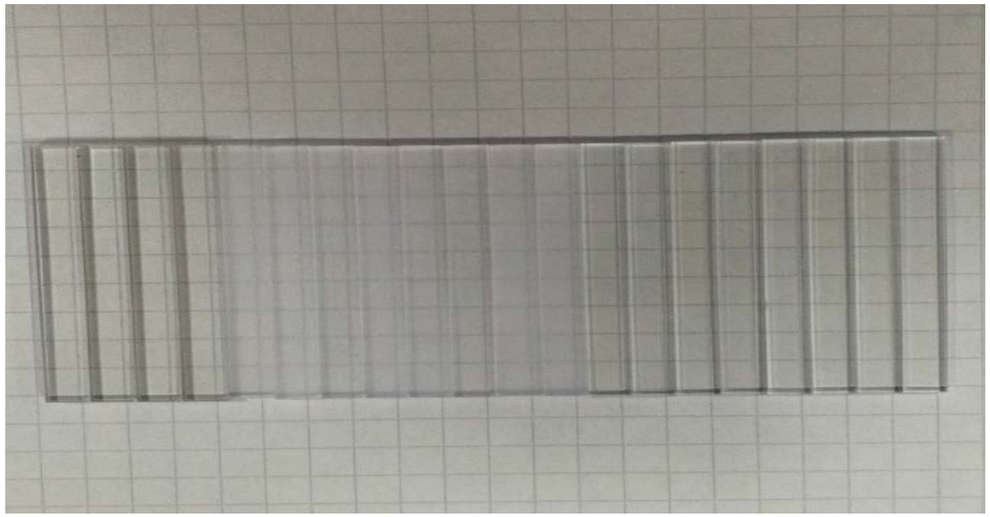
Central Readout with Dimple

Single Layer Prototype

中国科学技术大学
University of Science and Technology of China

- 4 SPIROCs ASIC consist one EBU
- $18cm \times 18cm$ one EBU with 144 scintillator strips
- Scintillator strips are processed and wrapped in the Shanghai institute of Ceramics (SIC)

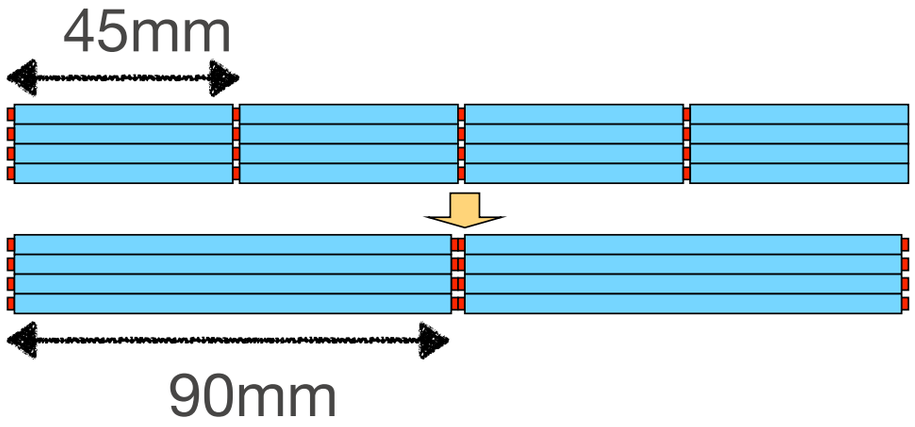


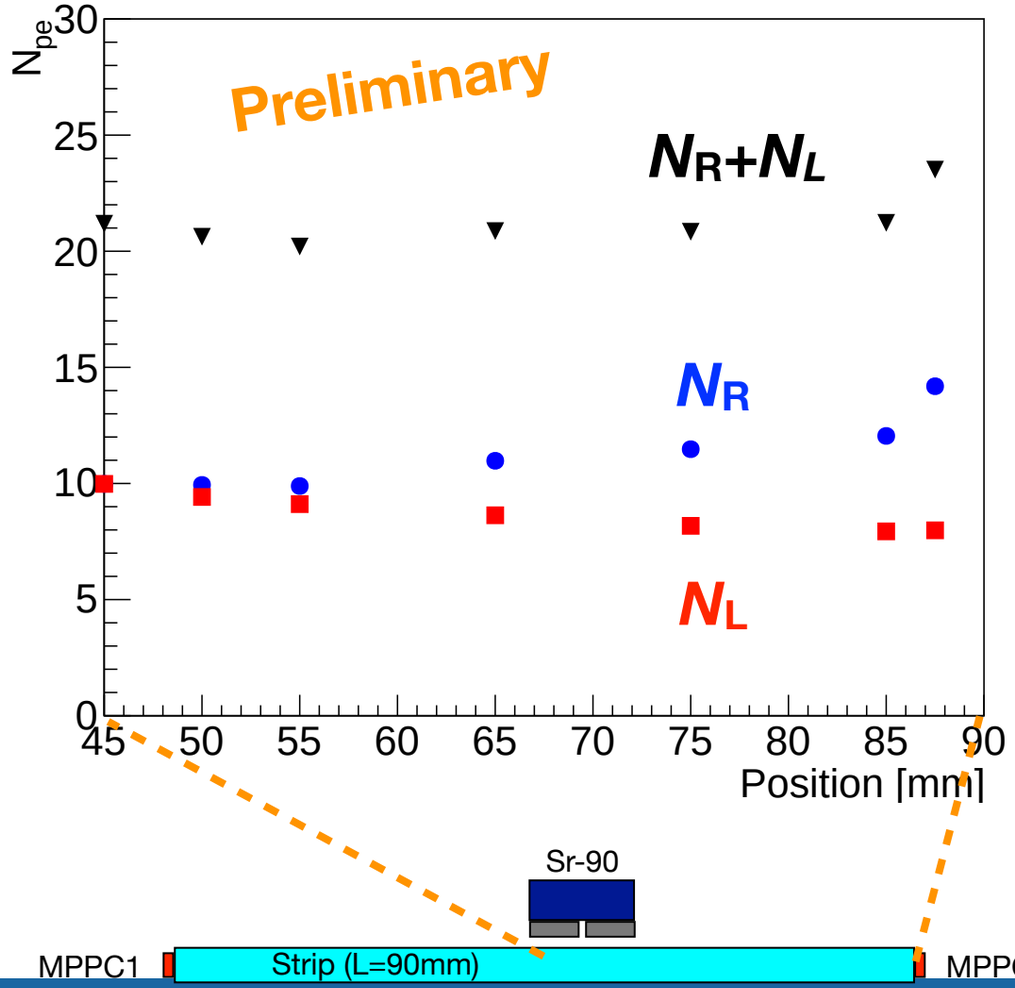


Y. Niu (USTC), CALICE mtg. Shanghai

Double SiPM Readout

- **Advantages**
  - Suppress random noise by taking coincidence
  - More uniform response
  - Higher light yield
  - Scintillation photons shared by two SiPMs → Mitigation of saturation
  - Position reconstruction → Remove ghost hits
- **Promising performance in previous study**
- **Test with double readout + dimple in preparation**





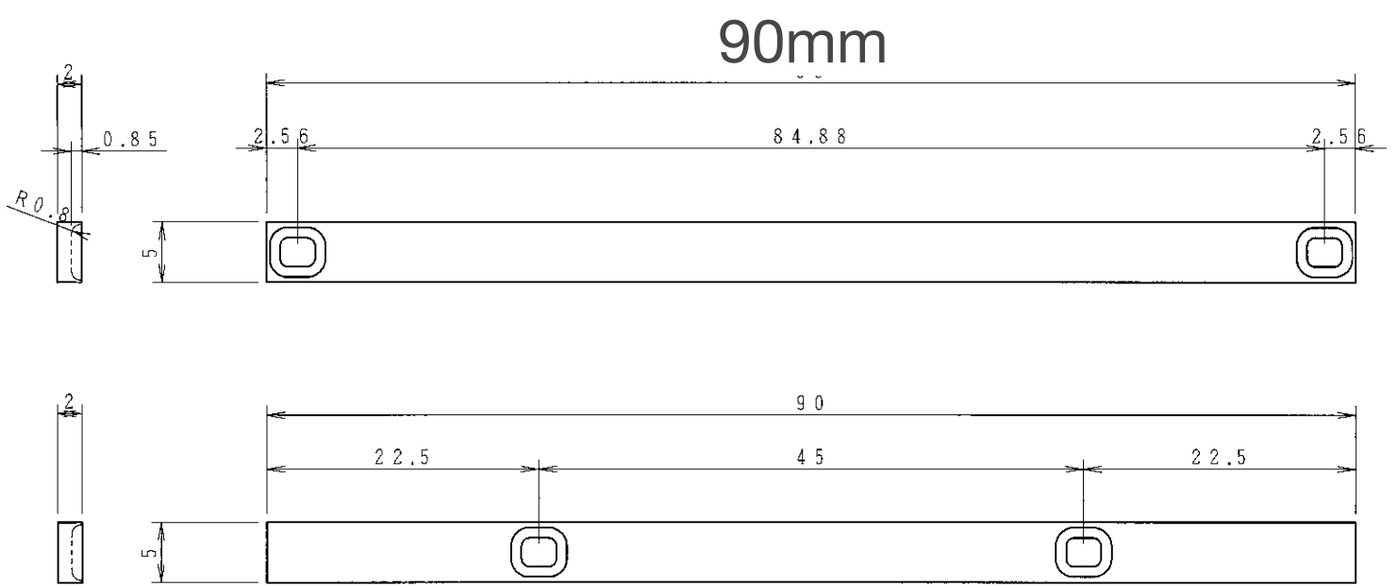
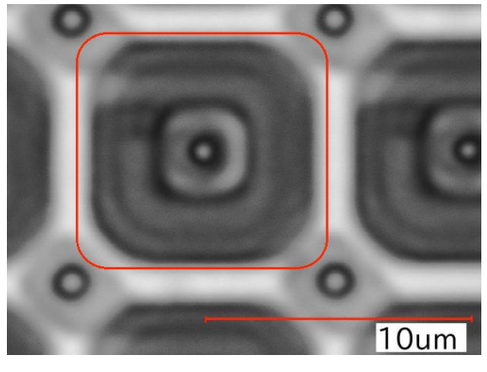


Photo-sensor

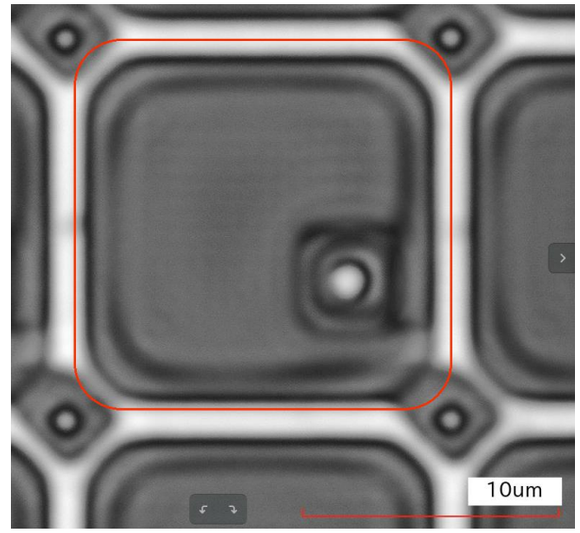
- **Small-pixel SiPM for larger dynamic range**
- **Comparative study between 10μm and 15μm**
- **Currently suggesting 15μm is more preferable**
  - Higher gain and higher PDE

→Developed single layer prototype with 15μm MPPC

10um pitch



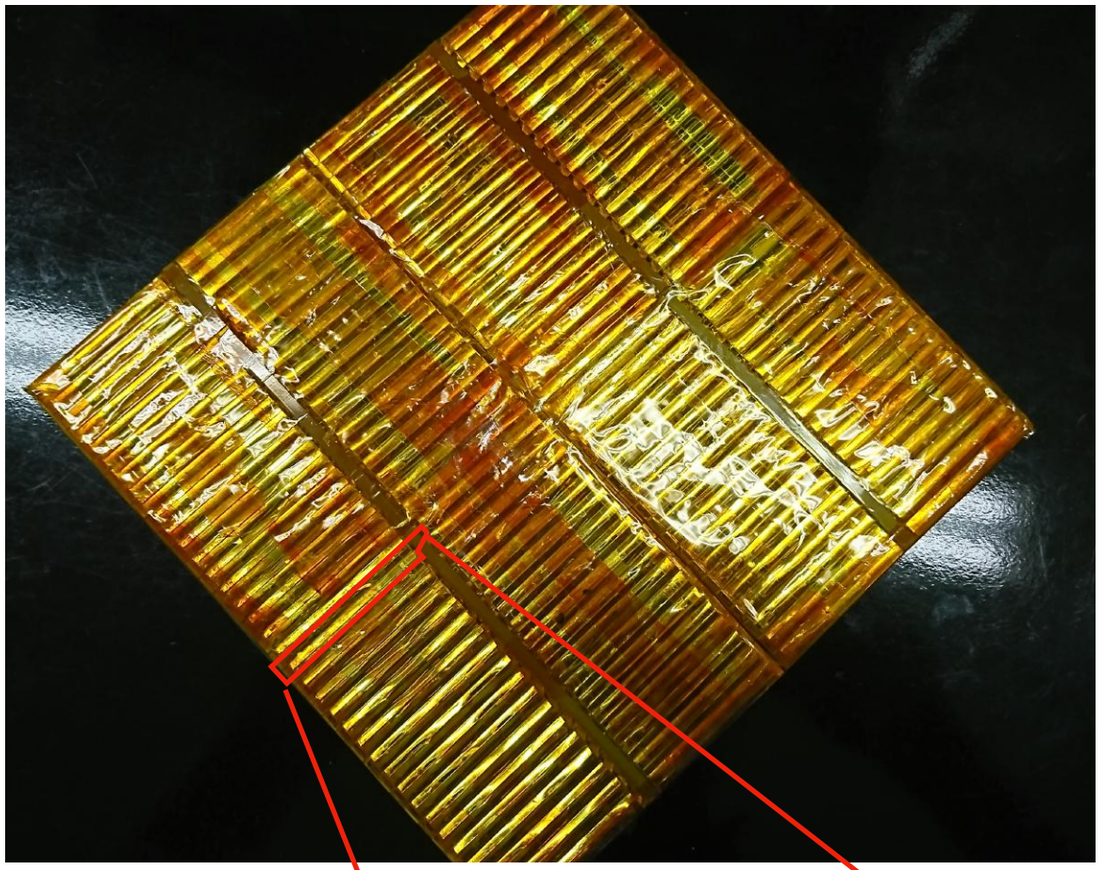
15um pitch

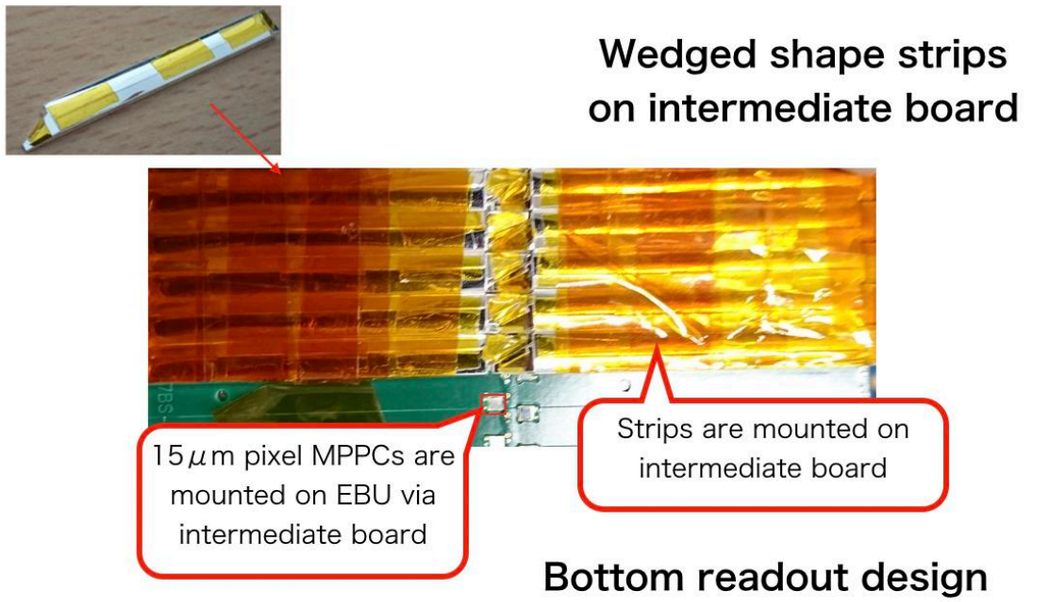


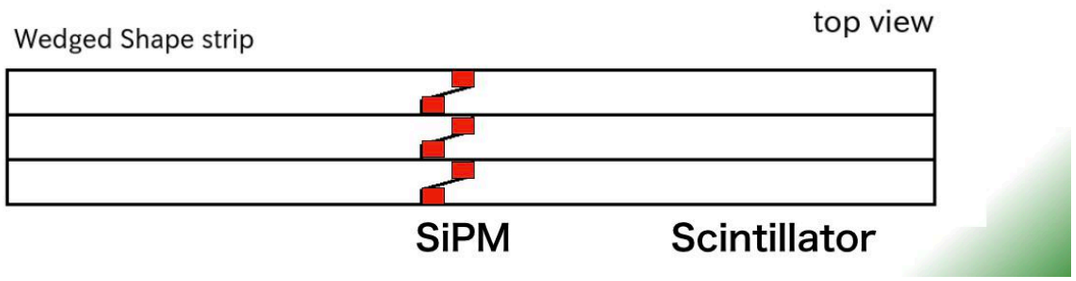
Model Number	S12571-010P	S12571-015P
Photosensitive area	1mm^2	1mm^2
Pixel size	10μm	15μm
Number of pixels	10000	4489
PDE	10%	25%
Gain	1.35x10^5	2.3x10^5
Geometrical fill factor	33%	53%

New Single Layer Prototype

- **New single layer prototype**
  - 144 strips on EBU (18×18cm²)
  - EBU with SPIROC2B
  - 15μm pixel MPPC (S12571-015P, no trench)
  - Bottom readout with wedge-shape

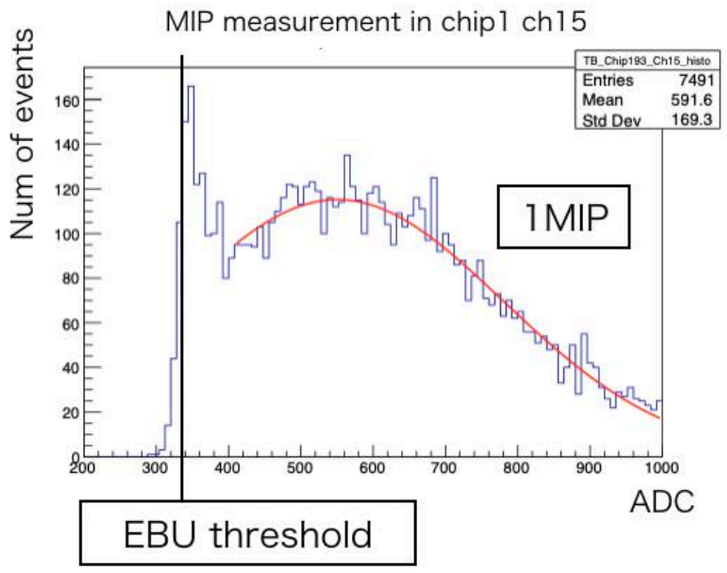


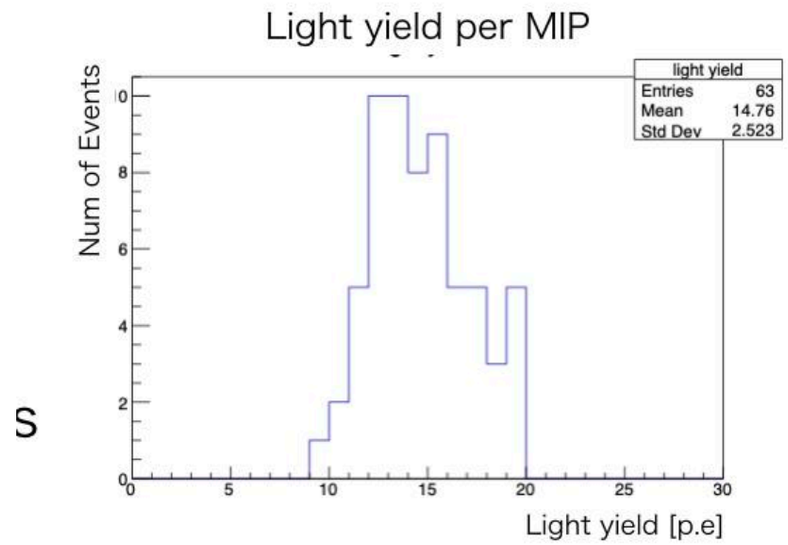


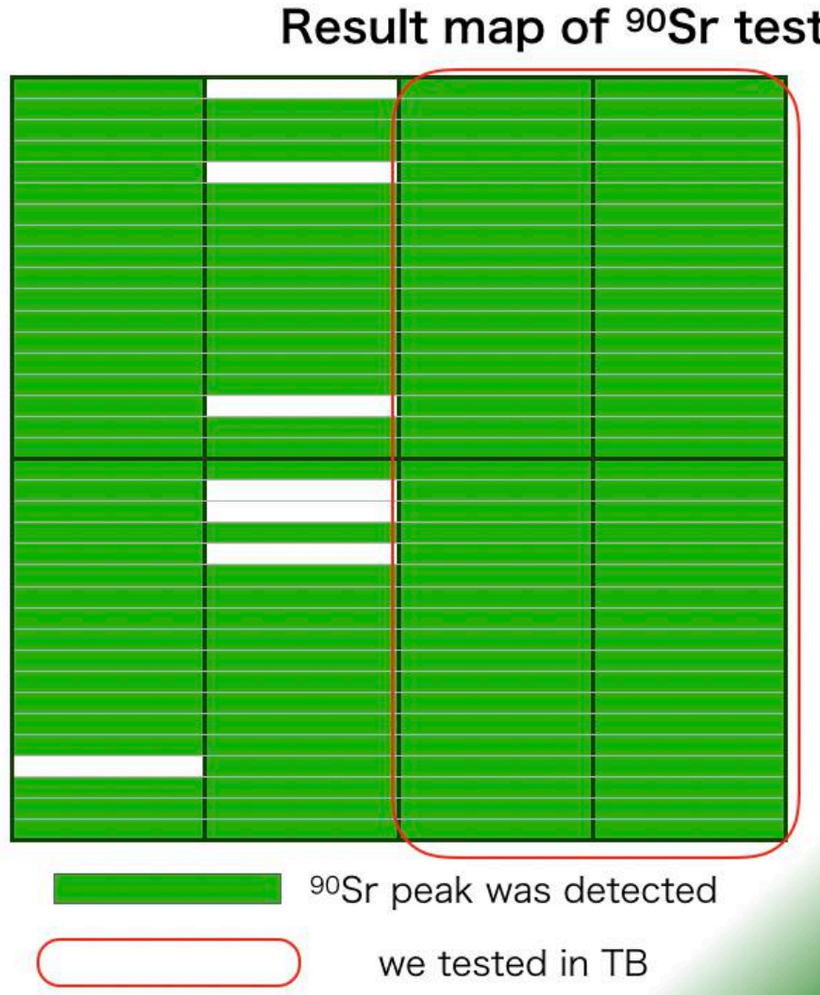


New Single Layer Prototype

- **Lab. test**
  - Calibration with LED
  - Response to electron from Sr-90
    - MIP peak resolved for 137 out of 144
    - Average LY: 14.8pe

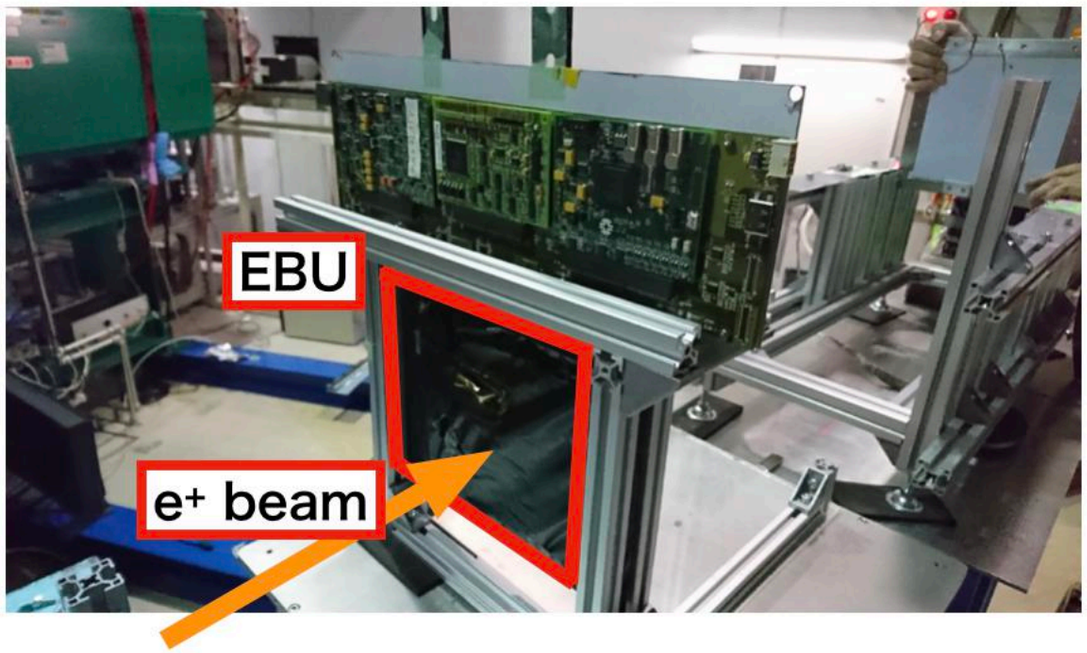




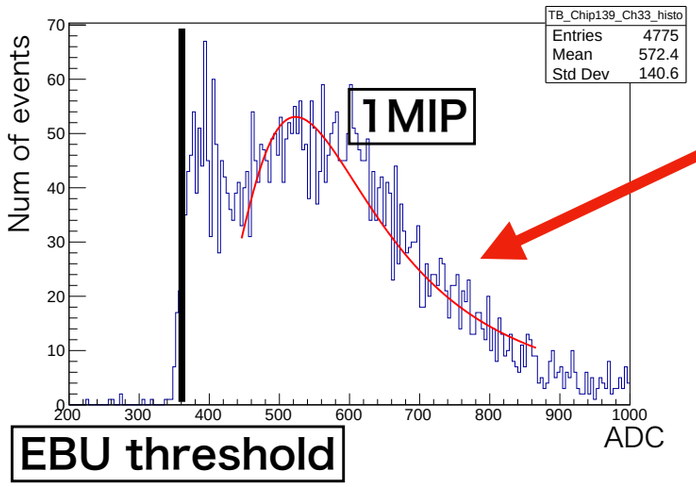


New Single Layer Prototype

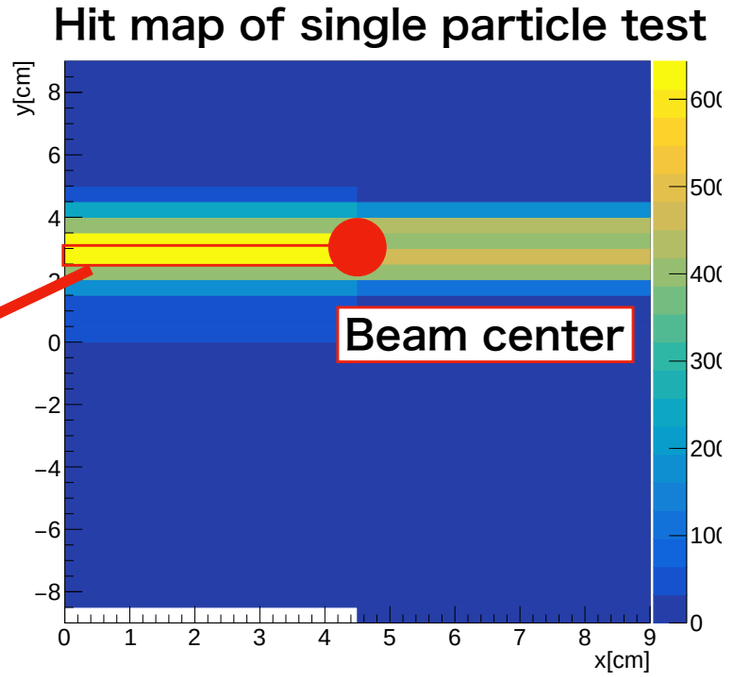
- **Test beam**
  - ELPH@Tohoku University
  - Nov. 22-25, 2018
  - 50-800MeV positron beam
  - as a part of active absorber calorimeter test
  - Single particle + EM shower with material in front of EBU



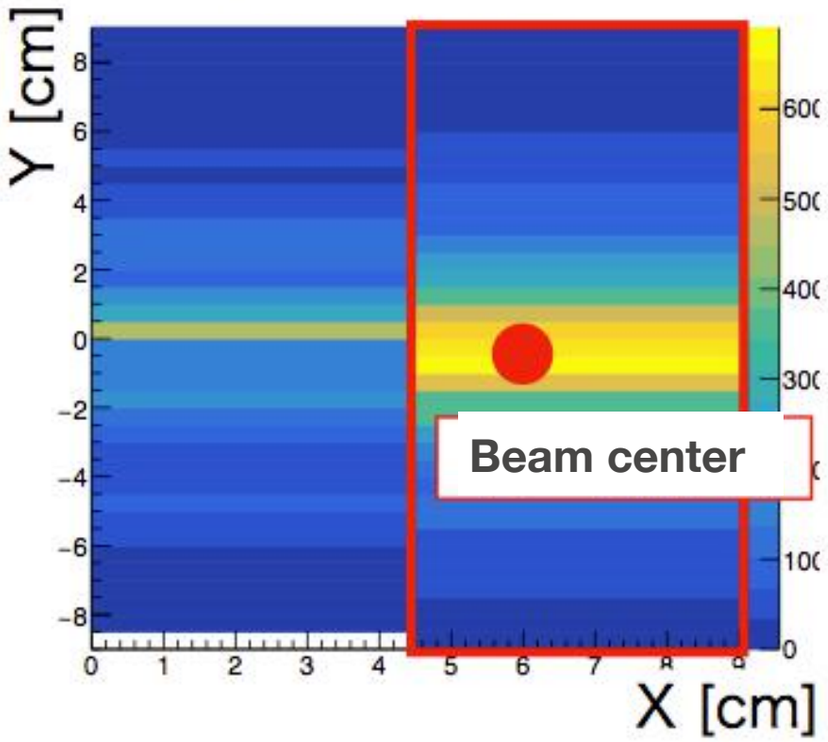
ADC distribution of beam center



Hit map of single particle test



EM shower



New Small-Pixel MPPC

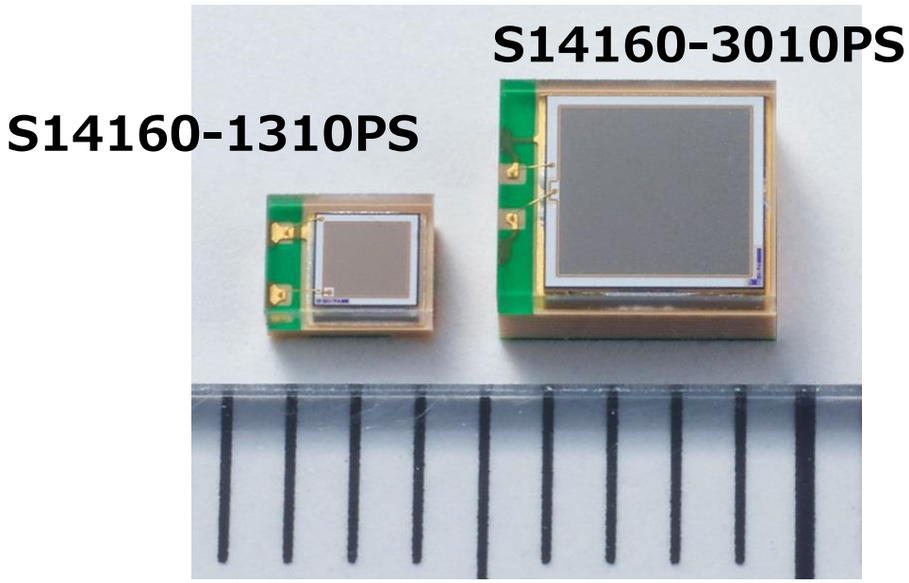
New

HAMAMATSU
PHOTON IS OUR BUSINESS

Small Pixel Size MPPC

S14160-1310PS/-1315PS, -3010PS, -3015PS

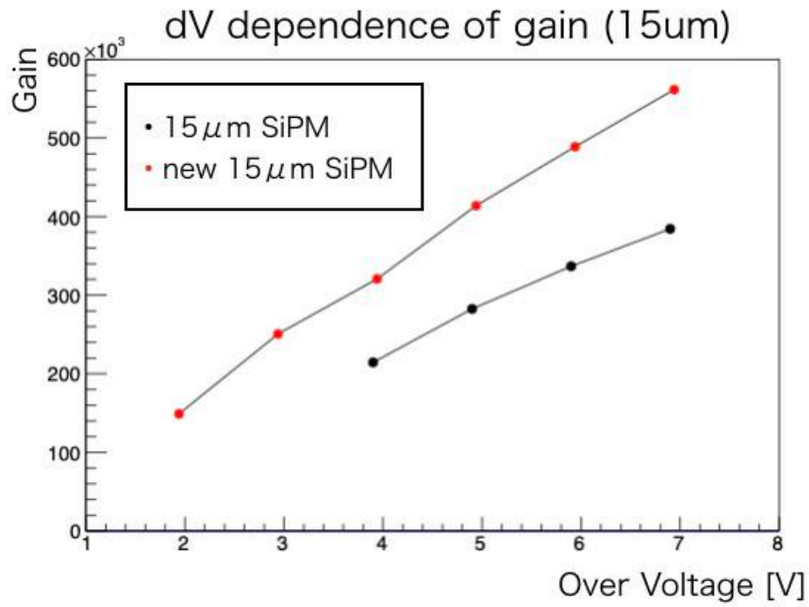
- **High-dense pixels (10/15μm pitch) with trench technique for *Low crosstalk***
- **Break down voltage : 38V (*Low operation voltage*)**
- **Higher PDE & Lower noise**
- **To be a candidate for the hard radiation application**

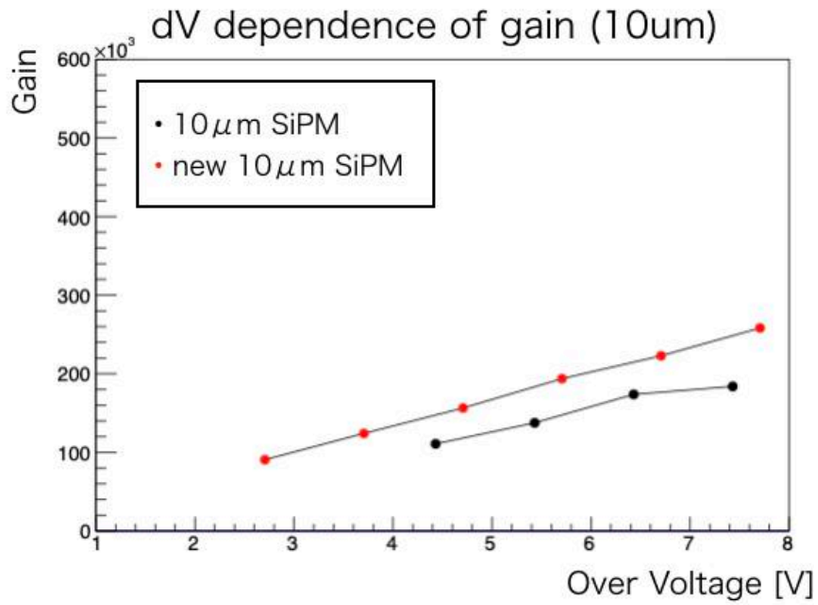


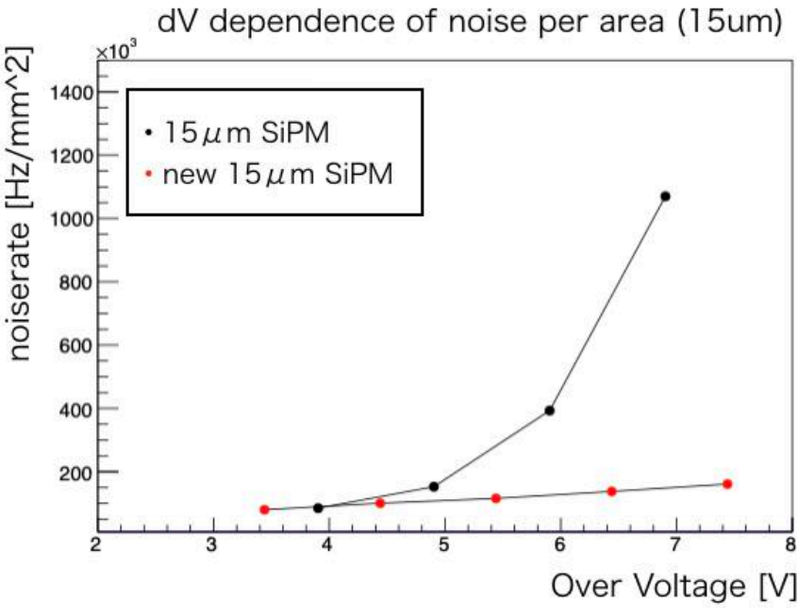
K. Yamamoto, PD18

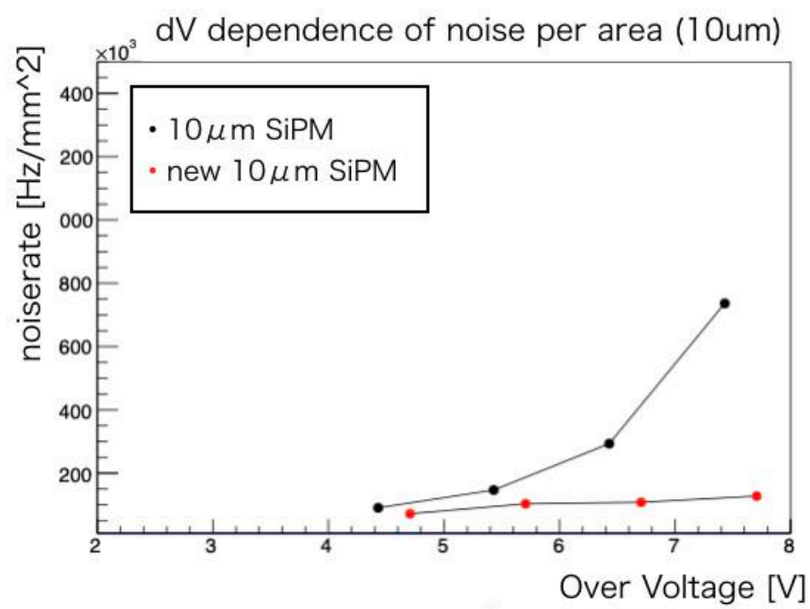
New Small-Pixel MPPC

- **Test with prototypes for new small-pixel MPPC**
  - Sensor area: 1.3×1.3mm^2
  - Pixel size: 10μm, 15μm
  - Tested with dedicated readout electronics based on CAMAC
- **Preliminary results show promising performance**
  - 30% (40%) higher gain for 10μm (15μm)
  - Significantly lower dark noise
- **Further tests in progress**
  - Optical cross talk
  - MIP measurement on EBU



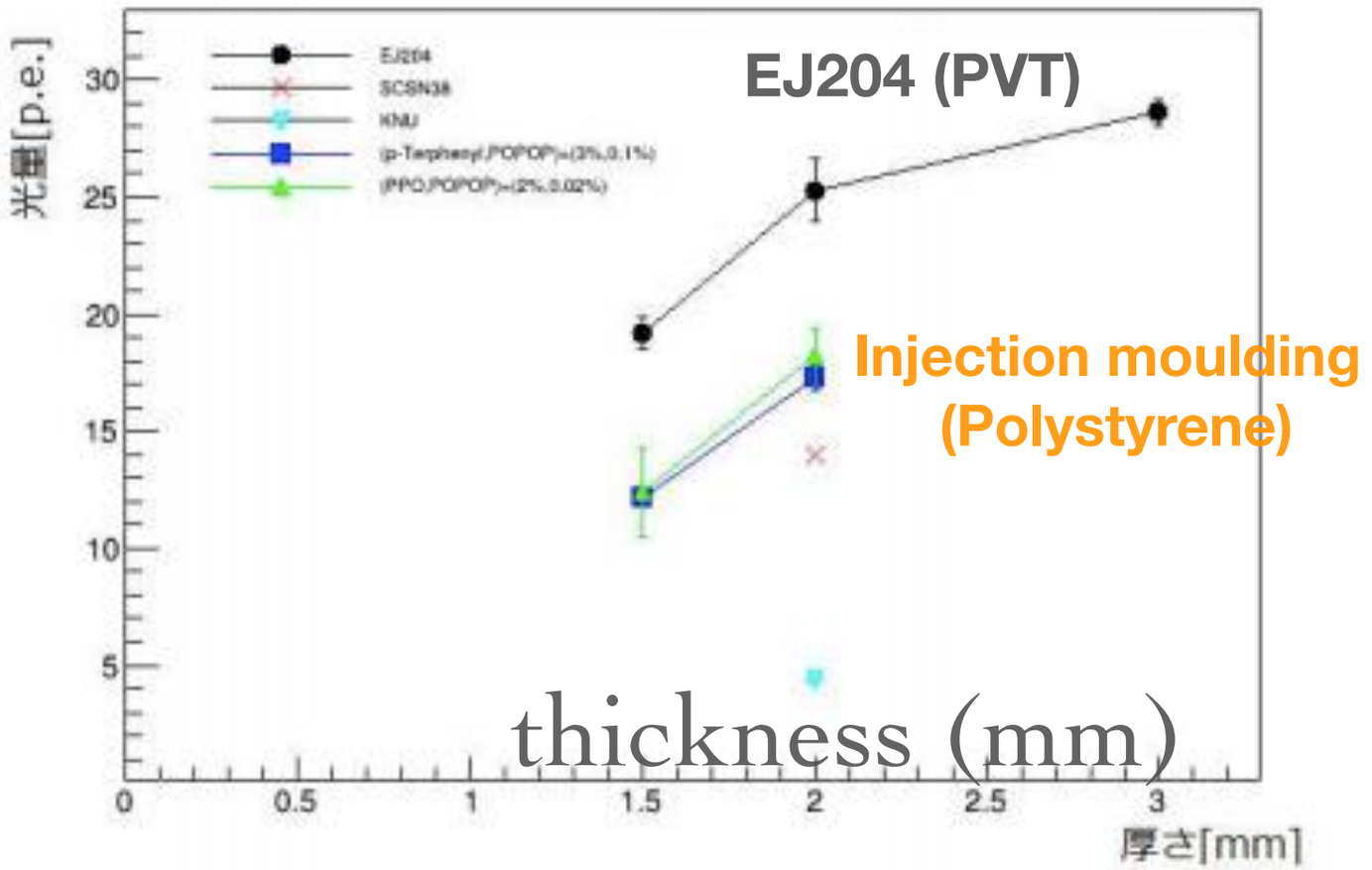






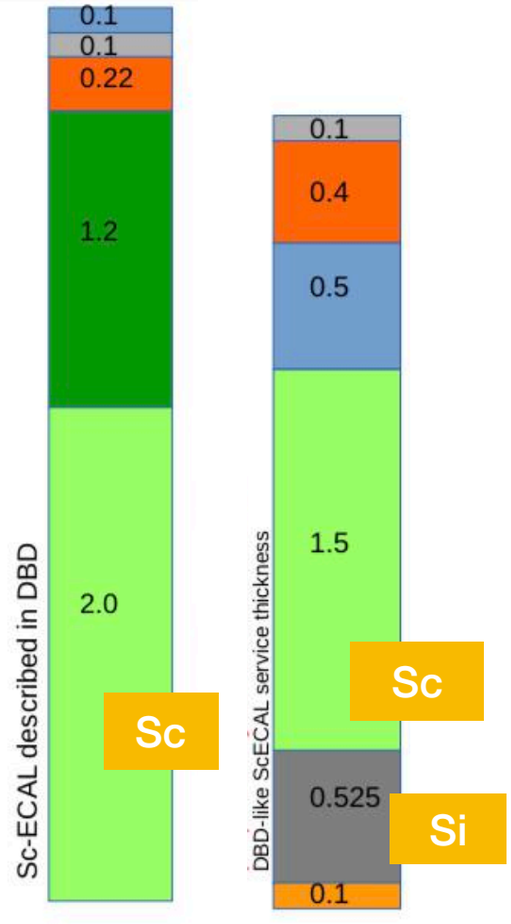
Scintillator Material Study

- **Scintillator production based on injection moulding**
  - Suitable for large scale production
  - Base material: polystyrene (PS) instead of polyvinyl-toluene (PVT) used for commercial scintillator
  - Issue: lower light yield
- **Production parameters optimisation to maximise light yield**
  - Achieved 65-70% of PVT light yield
  - Parameters to be further optimised

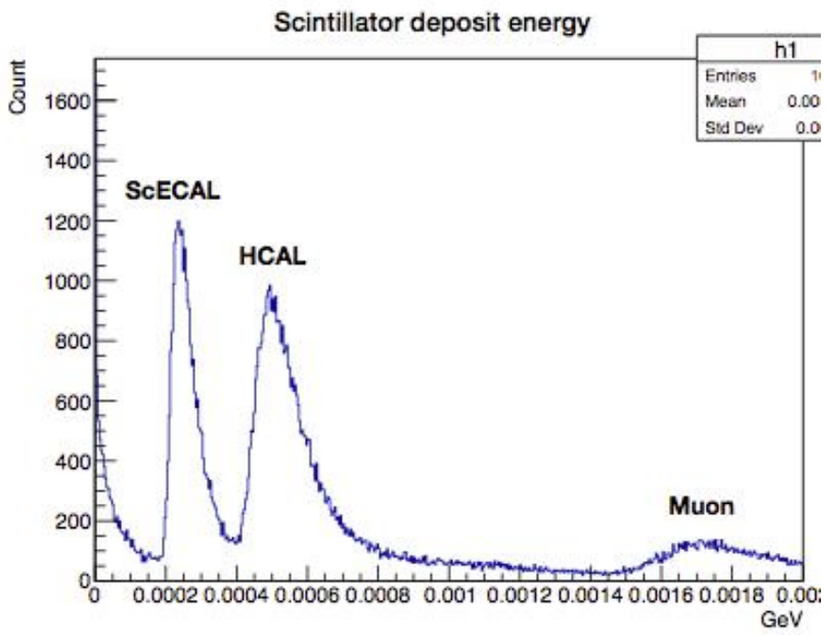


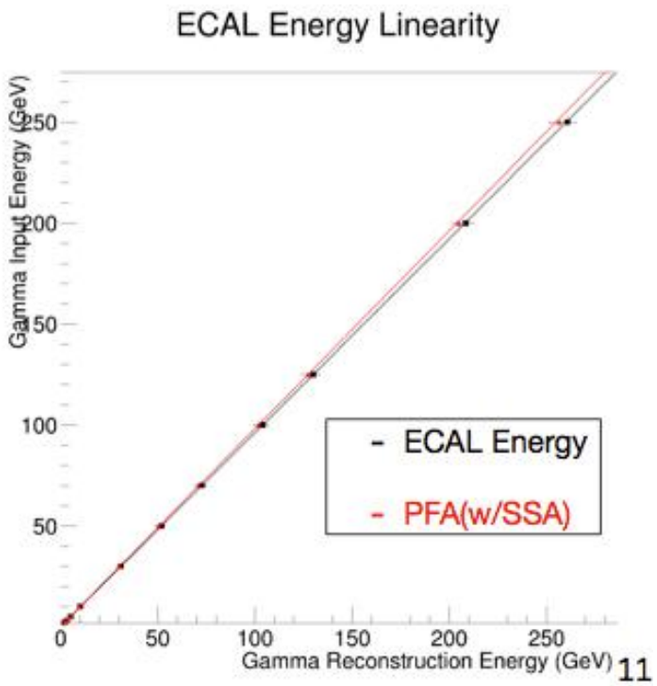
Simulation

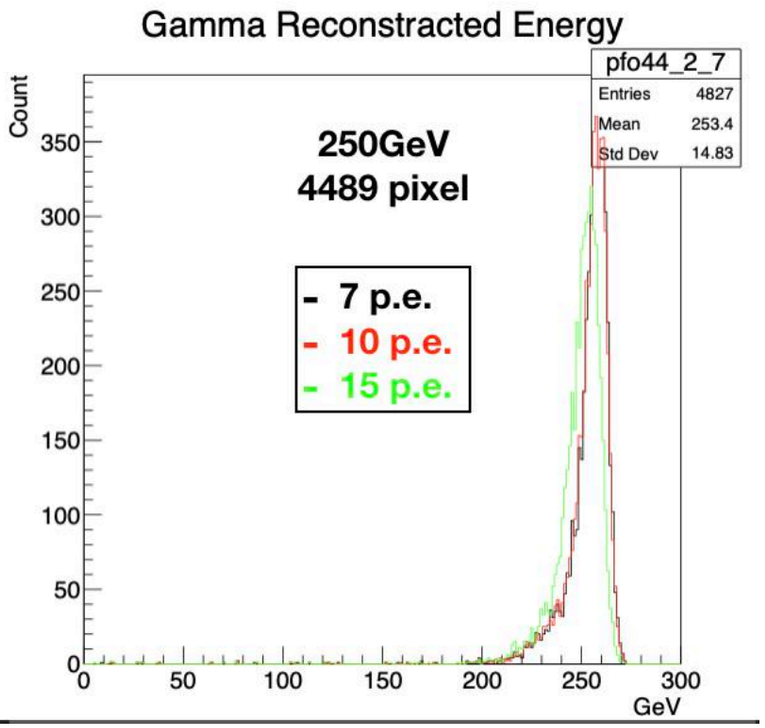
- **Sc-ECAL simulation for DD4hep in progress**
  - Hybrid simulation with Sc+Si
- **Calibration with MIP, photon (10GeV)**
- **Good linearity confirmed**
- **MPPC saturation study**
  - No significant saturation effect with 15μm pixel for 500GeV ILC



Mokka/ DBD **DD4hep**







AOB

- **Calibration**
  - **Strategy**
    - MIP response
      - Any MIP (cosmic, beam halo muon, muon/charged pion in collision data,…)
    - SiPM gain
      - Built-in LED system
    - Electromagnetic and hadronic scales
      - Test beam data
  - **Monitoring**
    - SiPM gain with LED system
    - Temperature with several temp. sensors on each EBU
  - **Precision for calibration**
    - Random strip-by-strip fluctuation on MIP/gain constants is acceptable up to 20-30% in terms of single particle resolution
    - Statistics: 50MIPs per strip necessary to achieve this level of precision
    - Effect on JER under study
- **Topic for IDR**
  - Improved S/N with 15μm pixel MPPC
    - Better separation for single photoelectron and MIP

Perspective

- **EBU with SPIROC2E**
  - Control trigger threshold for each channel
- **Develop scintillator production in lab.**
- **Build EBU with new MPPC (HD-MPPC with trench)**
- **Joint effort with CEPC Sc-ECAL R&D, aiming at**
  - Constructing prototype with ~30 layers
  - Test beam experiments