Study on larger tile using test beam data

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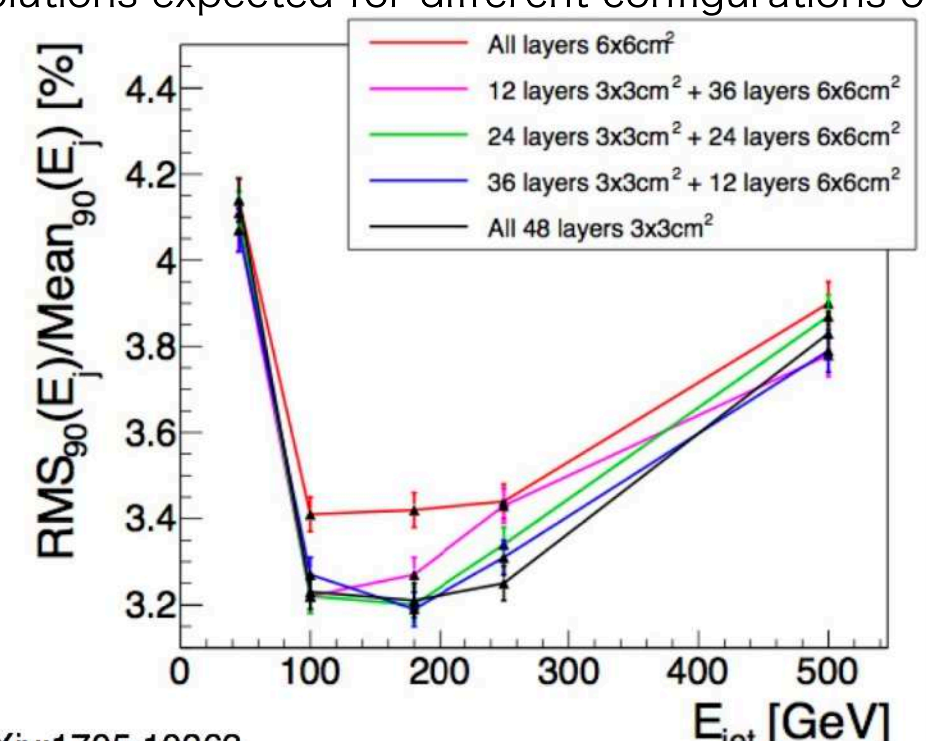
Motivation of This Study

- Toward the construction of ILC, it is necessary to make a more realistic design of ILD detector.
- Granularity of AHCAL is revisited.
- Possibility of mixed granularity with larger scintillator tile at outer layers is under study.
  - We can reduce the number of readout channels, and thus reduce cost.
  - For example 60mm × 60mm tile, 1/4 number of channels and ASICs, more efficient assembly
- Previous simulation studies showed that 30mmx30mm tile can be replaced with 60mmx60mm tile at least up to latter half of layers without significant performance degradation.

Jet energy resolutions expected for different configurations of granularity

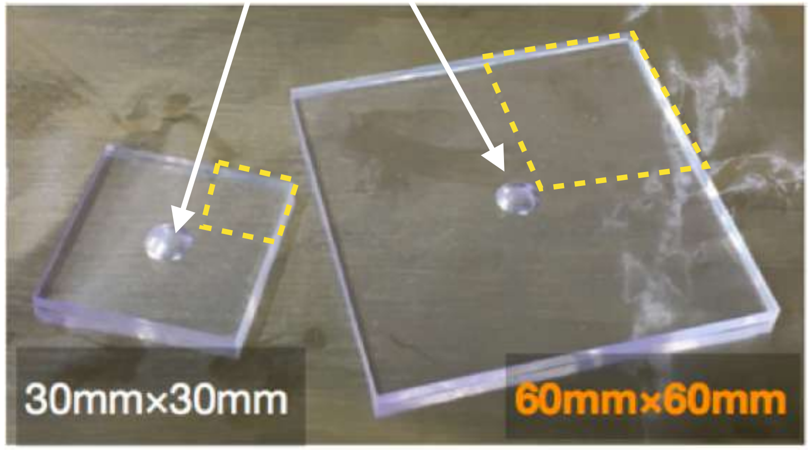


arXiv:1705.10363

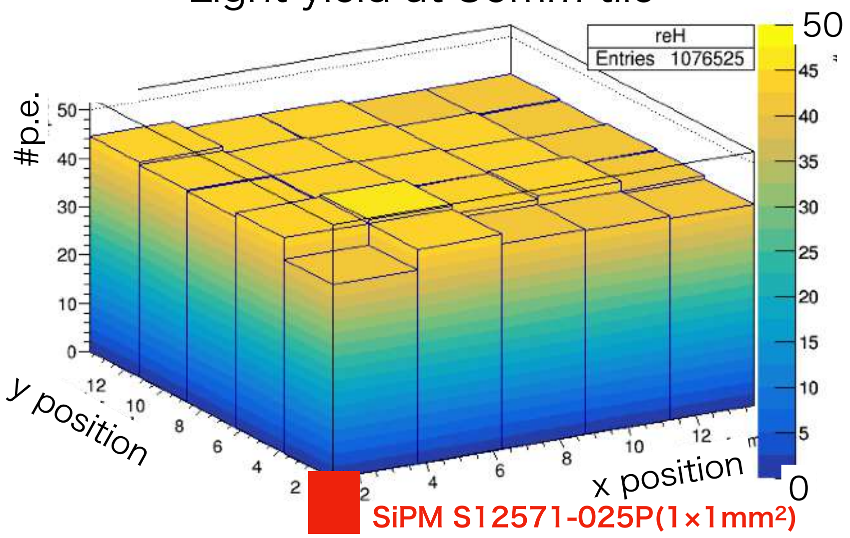
RMS(Ej)/Mean(Ej)
=Jet energy resolution

HBUs with 60mm Tiles

- Larger tile is technically more difficult in terms of lower light collection efficiency.
- Light yield measurement with single tile by using ^{90}Sr
  - Light yield : (60×60mm^2) 18.2 p.e. (30×30mm^2) 43.1 p.e.
  - Excellent uniformity in tile response at 60×60mm^2 tile
- Detection layers with special HBUs with 60mm tiles instead of default 30mm tiles were constructed.
  - Light yield degradation is compensated with larger SiPM (1.3×1.3mm$^2\rightarrow2\times2$mm^2)
  - 4 HBUs with 144 × 60mm-tiles in total



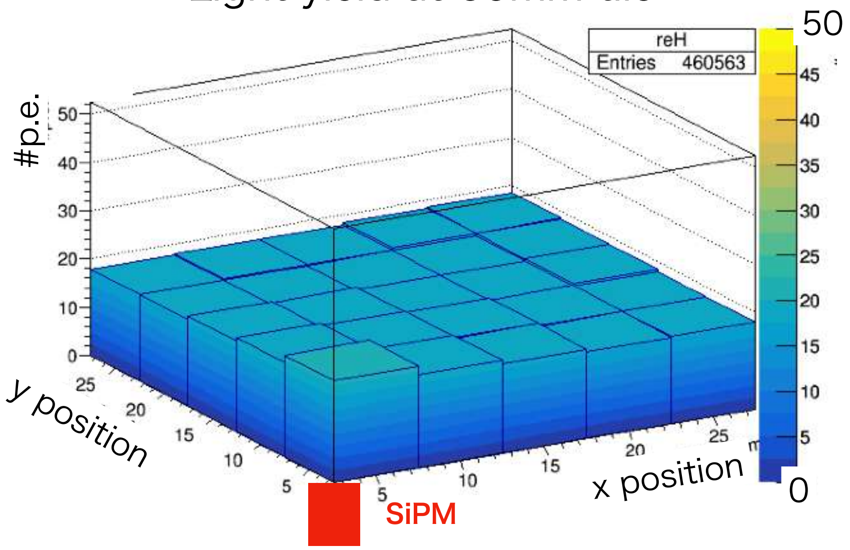
Light yield at 30mm tile



Mean : 43.1

RMS : 3.6%

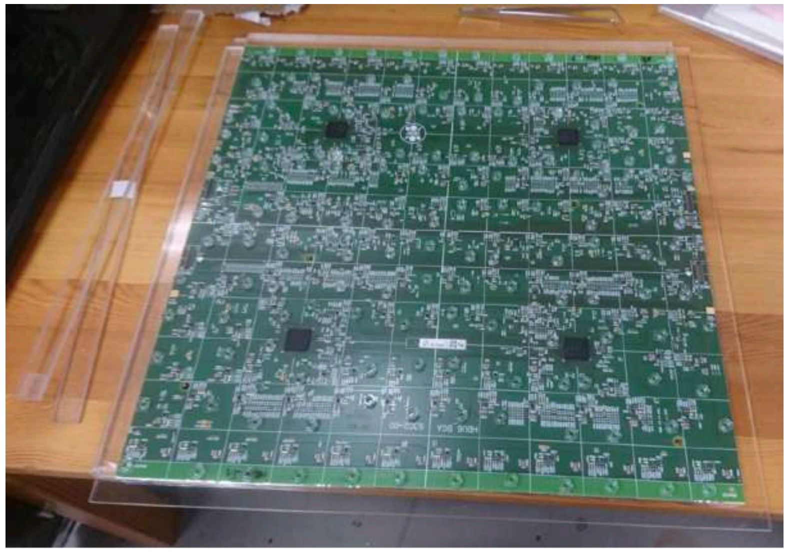
Light yield at 60mm tile



Mean : 18.2

RMS : 2.0%

Front view



Back view

Installation to the large prototype

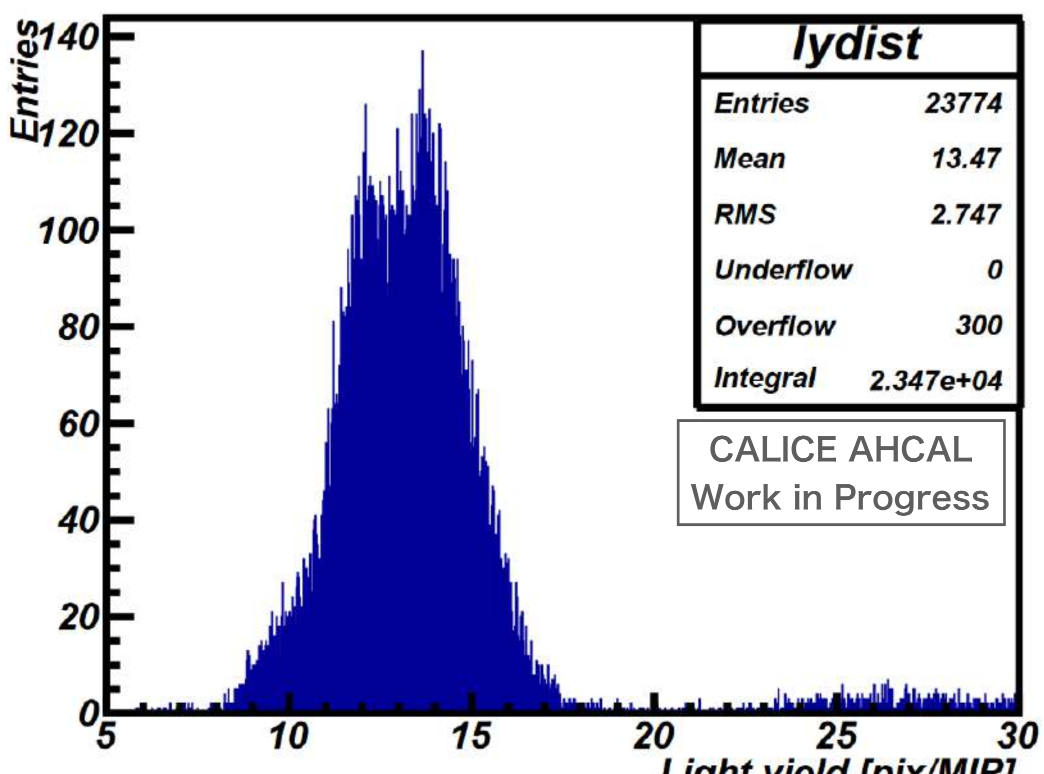
- Installed into the large prototype at June test beam.
  - Called Tokyo Module
  - Installed as 38th layer
- Demonstrate the performance by using beam such as muon, e-, pion
- **Evaluate the performance of mixed granularity by using test beam data**

- Starting data analysis
  - Results shown here are all preliminary

Calibrations

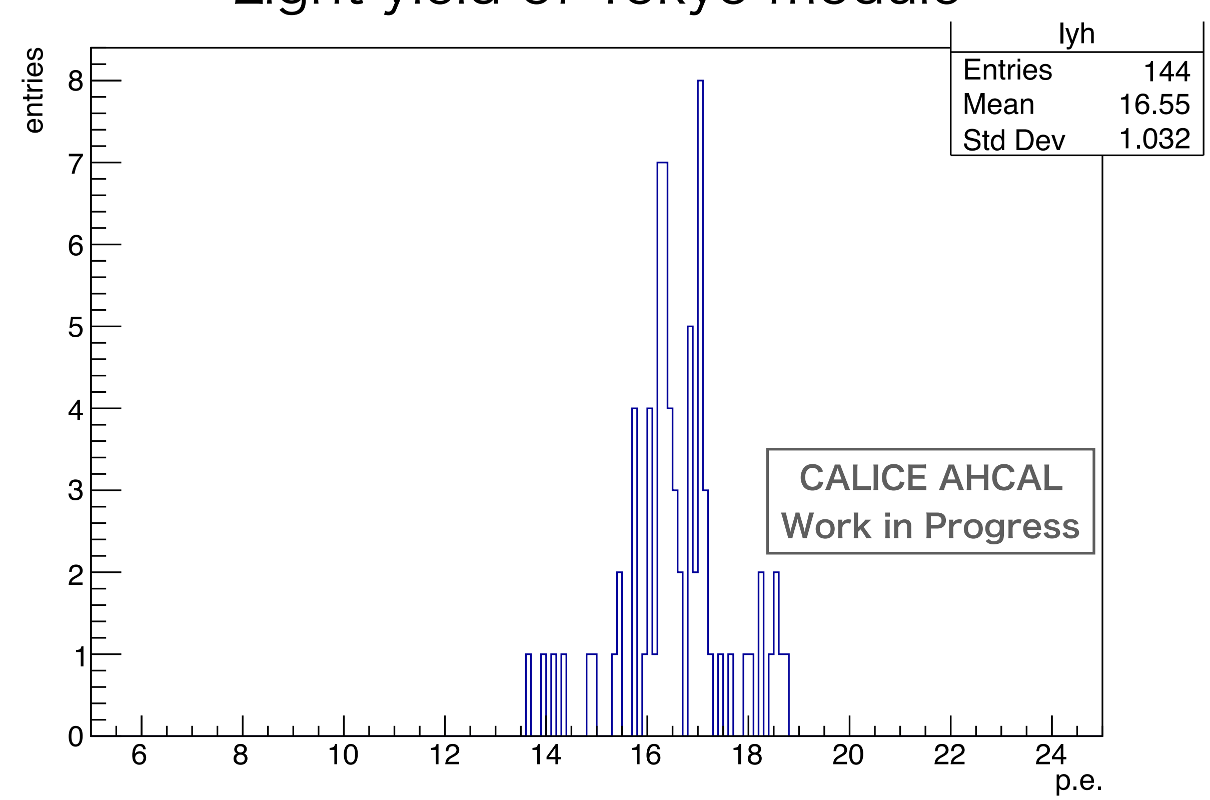
- Calibrations for MIP, gain and pedestal were successfully done for Tokyo module
  - See talks by O. Pinto and D. Heuchel for calibrations
  - Calibration constants are reasonably consistent with those for standard module.
- Light yield
  - Tokyo module : 16.6 p.e.
  - Standard module : 13.5 p.e.
- **All channels on Tokyo module work fine, and have enough light yield.**

Light yield of all layers



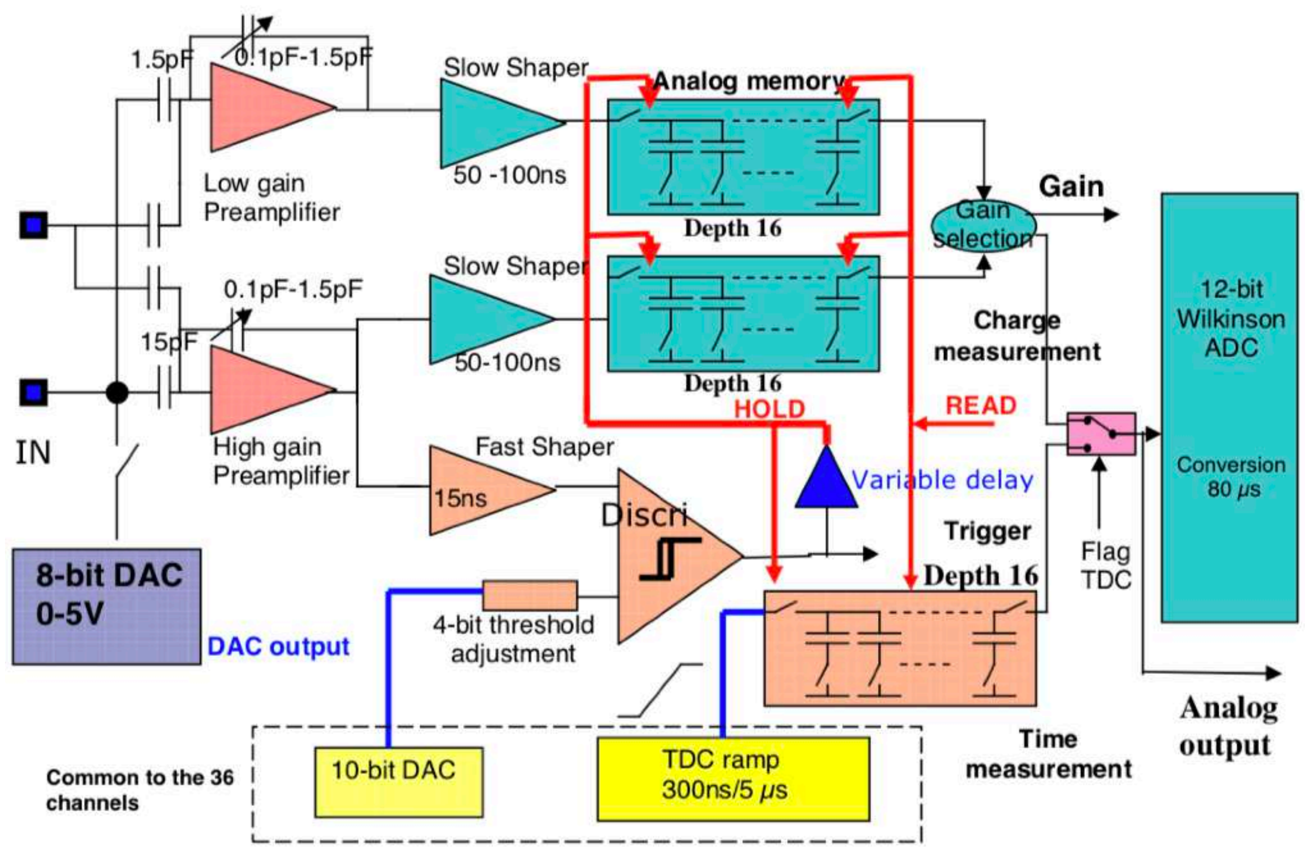
Olin Pinto, Presentation at AHCAL main meeting, 2018

Light yield of Tokyo module



Saturation

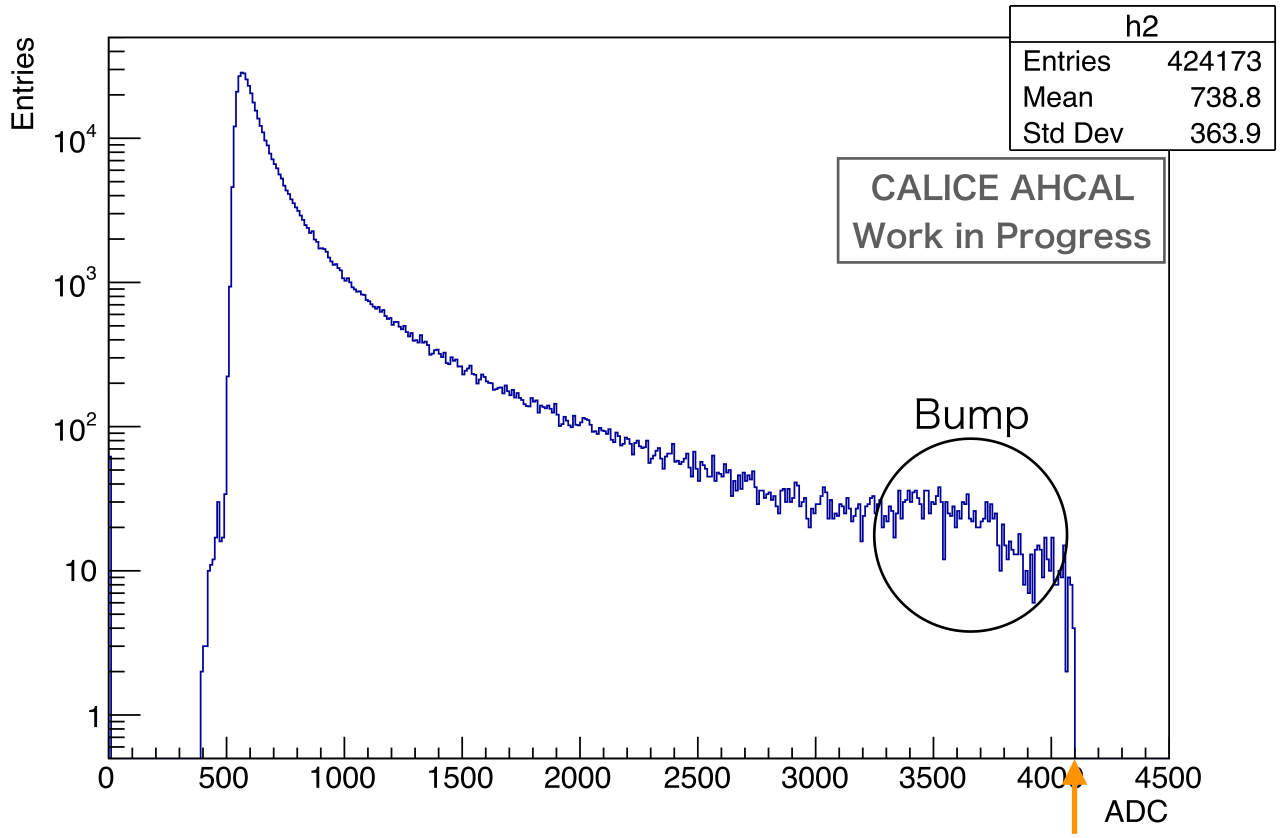
- Saturation would be an issue for 60×60mm² tile with 2×2mm² MPPC
- Number of photoelectrons per MIP is the same, but hit multiplicity can be ~ four times higher because of larger size → Greater Npe
- Possible saturations due to greater Npe
  - MPPC saturation
    - 6400 cells for 2×2mm² MPPC for 60mm tile ↔ 2700 cells for 1.3×1.3mm² MPPC for 30mm tile
  - ADC saturation
    - 12bit ADC : 0 - 4095 ADC counts



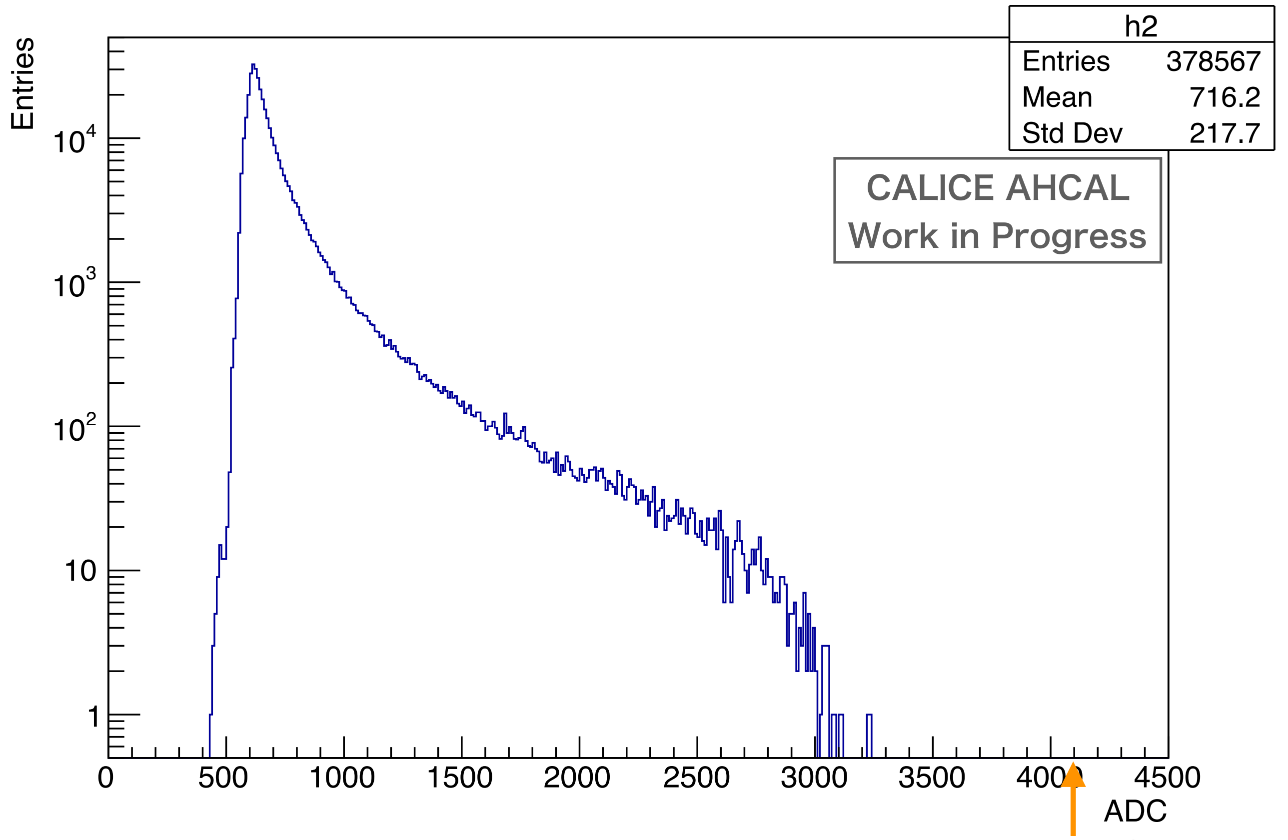
ADC Distribution per Layer for Pion

- Small saturation observed for Tokyo module only at the highest energy of 350 GeV
  - ADC saturation : 0.08% of tile hits exceeds ADC limit
  - MPPC saturation : bump around 3500-4000 ADC counts
  - ※ No MPPC saturation correction
- Note that Hadron energy in experiment is lower than 350GeV

Tokyo module



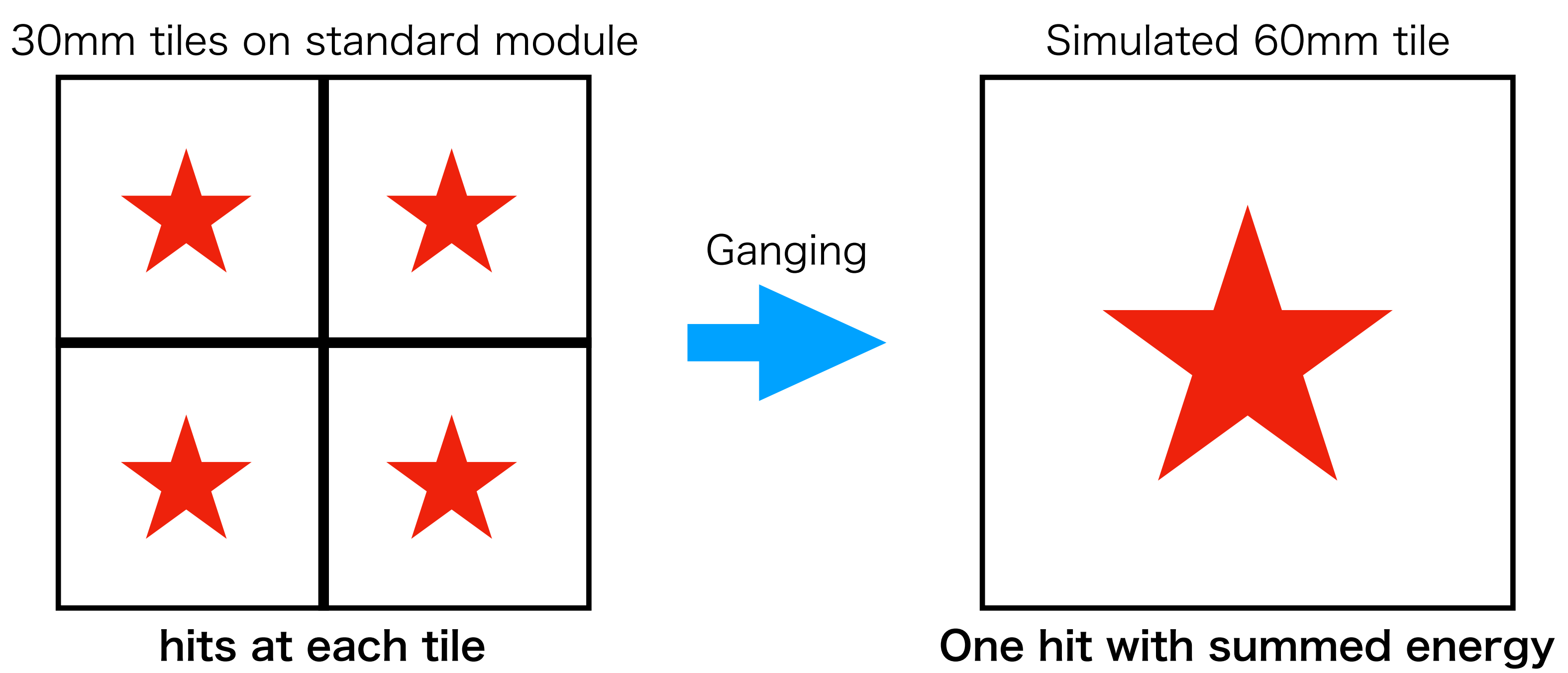
Standard layer with 30mm tile (layer 37)



Ganging Tile Study

- Only one 60mm module in AHCAL large prototype
  - Unable to check 60mm tile response at different shower depth
- **Simulate 60mm tile by combining hits from 2×2 adjacent 30mm tiles**
  - Summarize the energies of hits at 2×2 tiles

➡Study on mixed granularity by using test beam data



80 GeV Pion

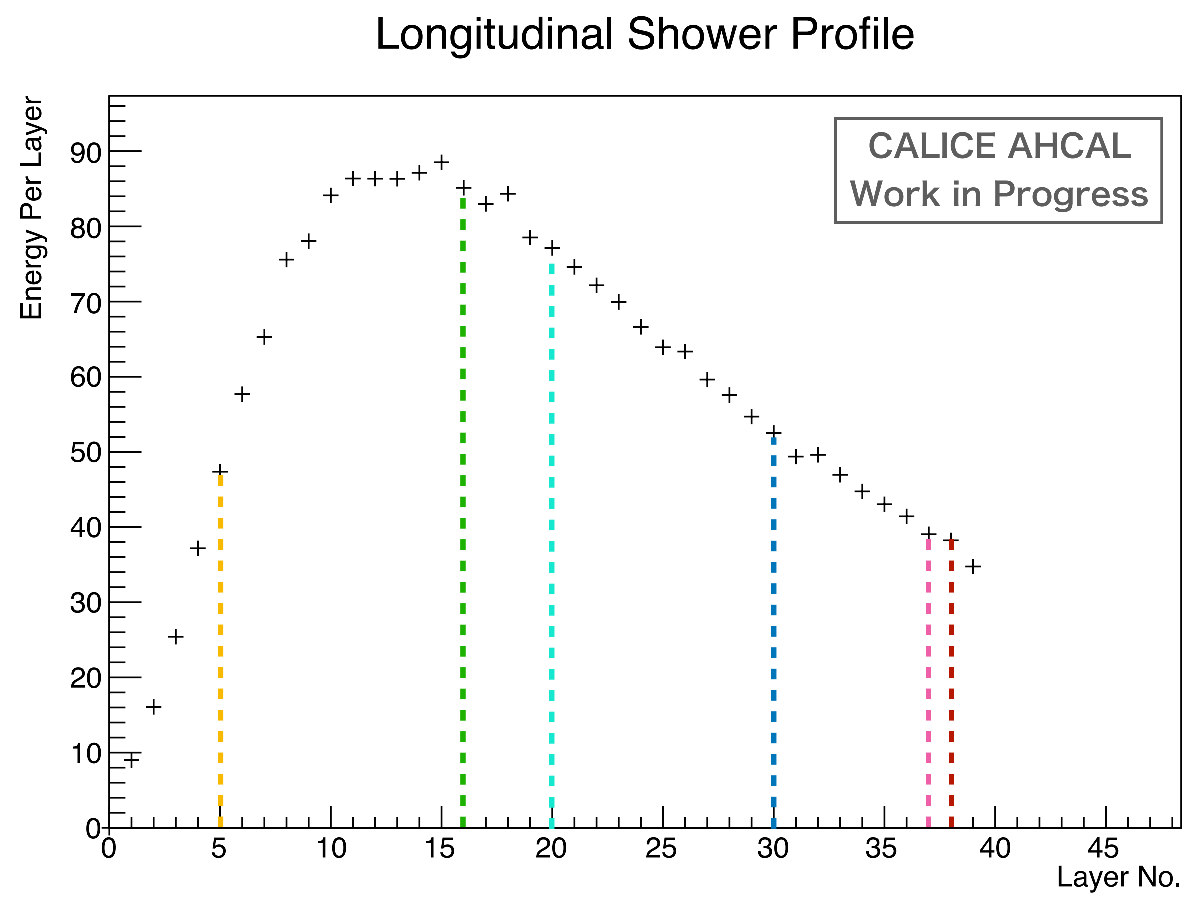
- hitEnergy : MIP-equivalent energy go single hit

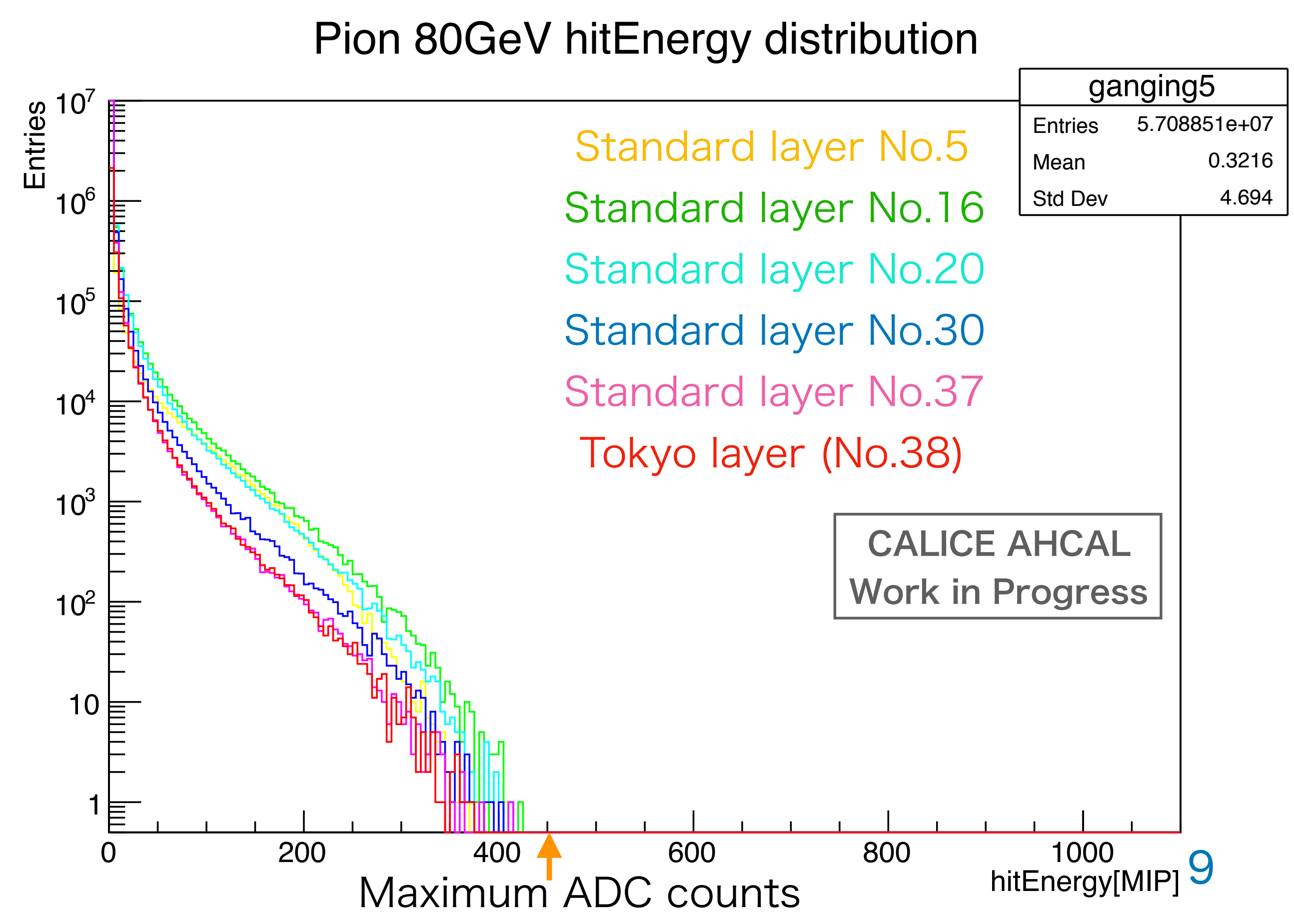
  ※ MPPC saturation correction done

- Almost the same behavior between 60mm tile of Tokyo module (layer No.38) and ganging tile of standard layer No.37

➡**Distribution for Tokyo module is successfully reproduced by ganging tiles**

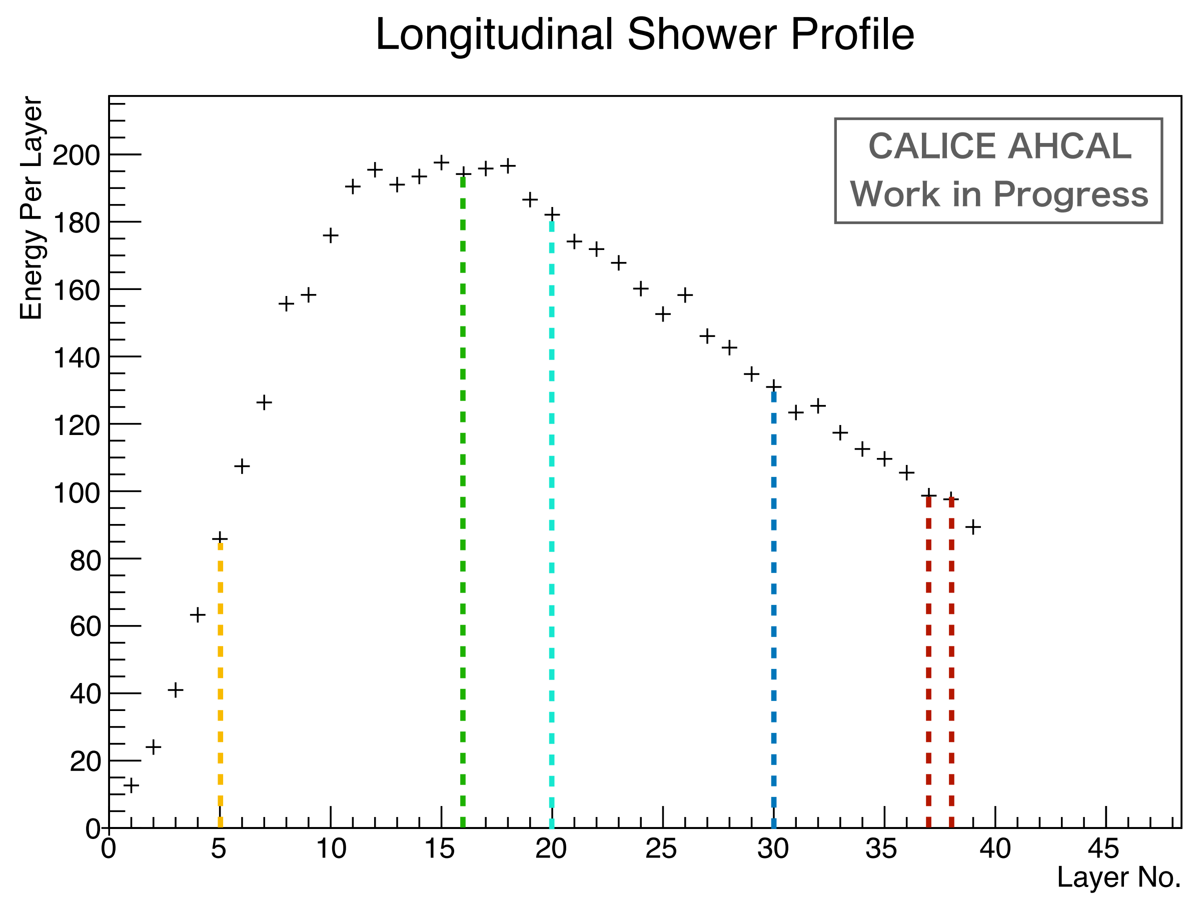
- No saturation for 60mm tile even at shower maximum

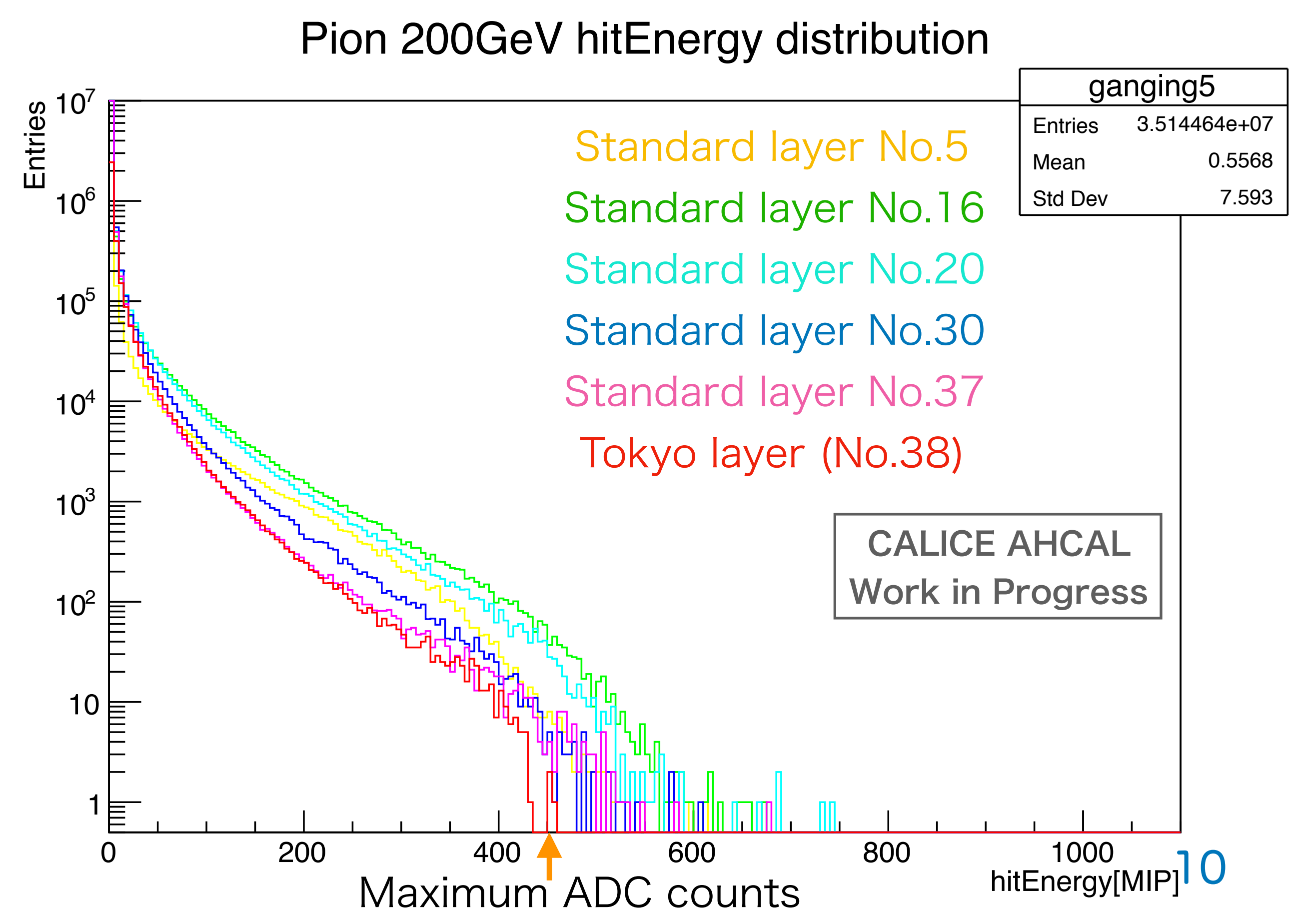




200 GeV Pion

- Starting to saturate at shower maximum
  - 0.16% of the events suffer saturation

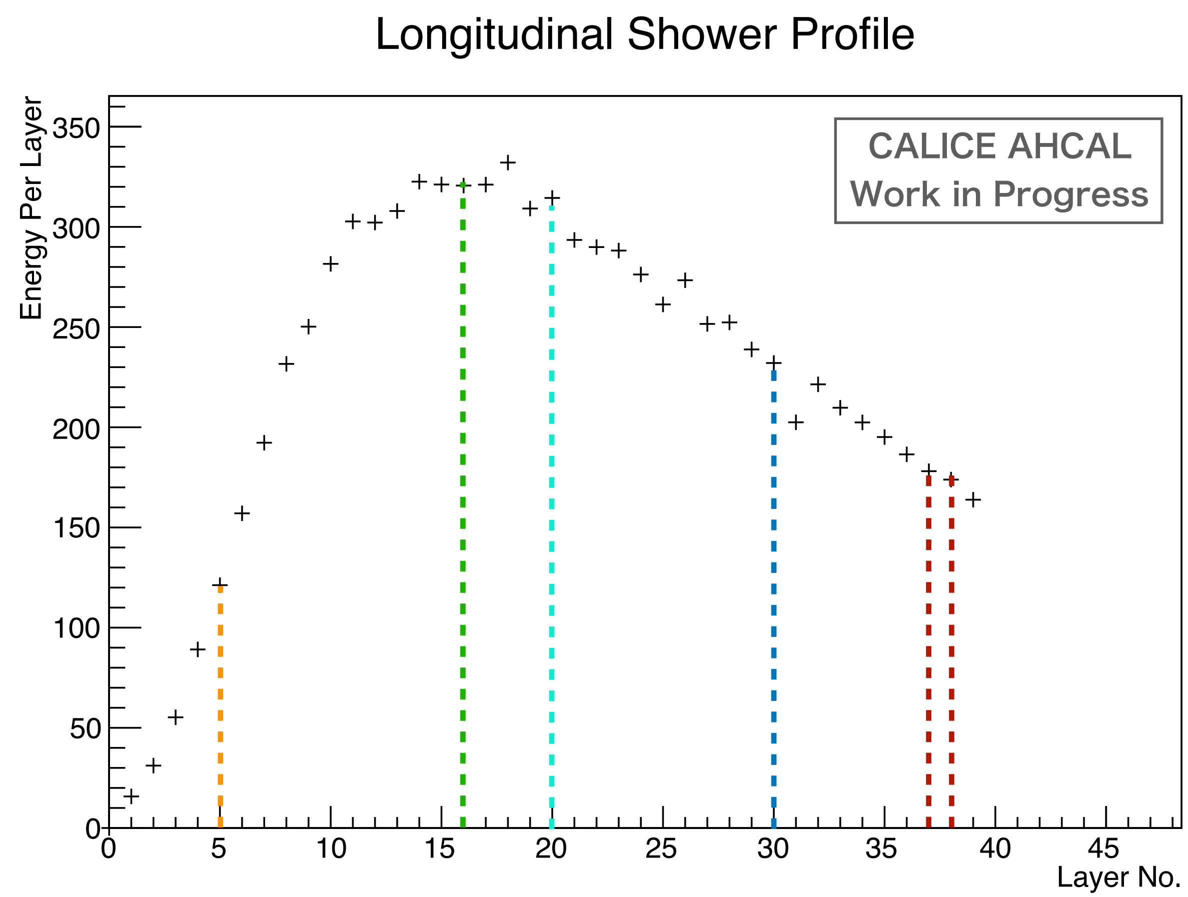


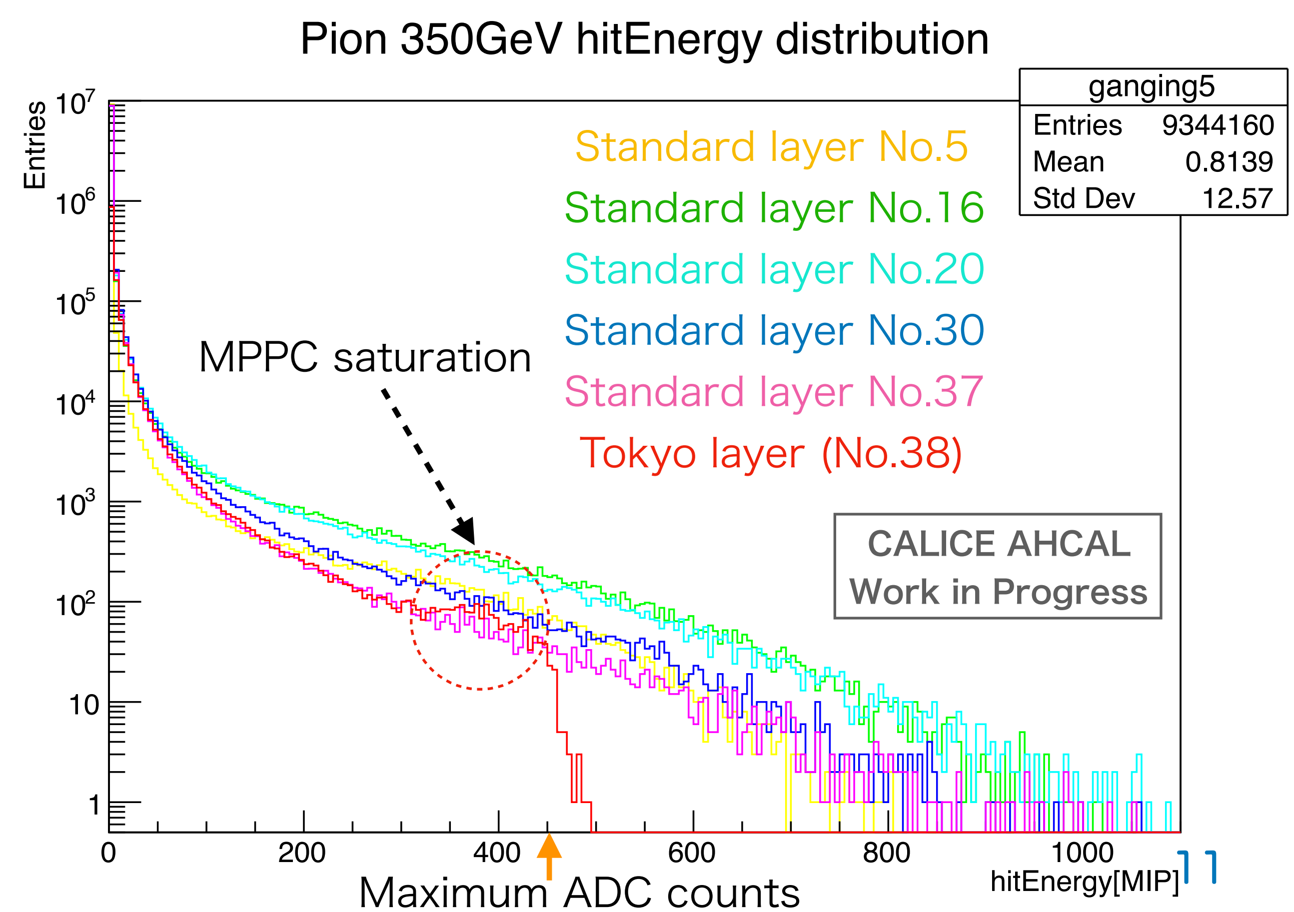


350 GeV Pion

- Effect of saturation is clearly seen at pion 350 GeV for (simulated) 60mm tile response with ganging tile response
    - 7.2% of the events suffer saturation at shower maximum
    - 1.3% of the events suffer saturation just before Tokyo module
- MPPC saturation : bump around 400 MIPs
    - Improved by saturation correction, but incompletely

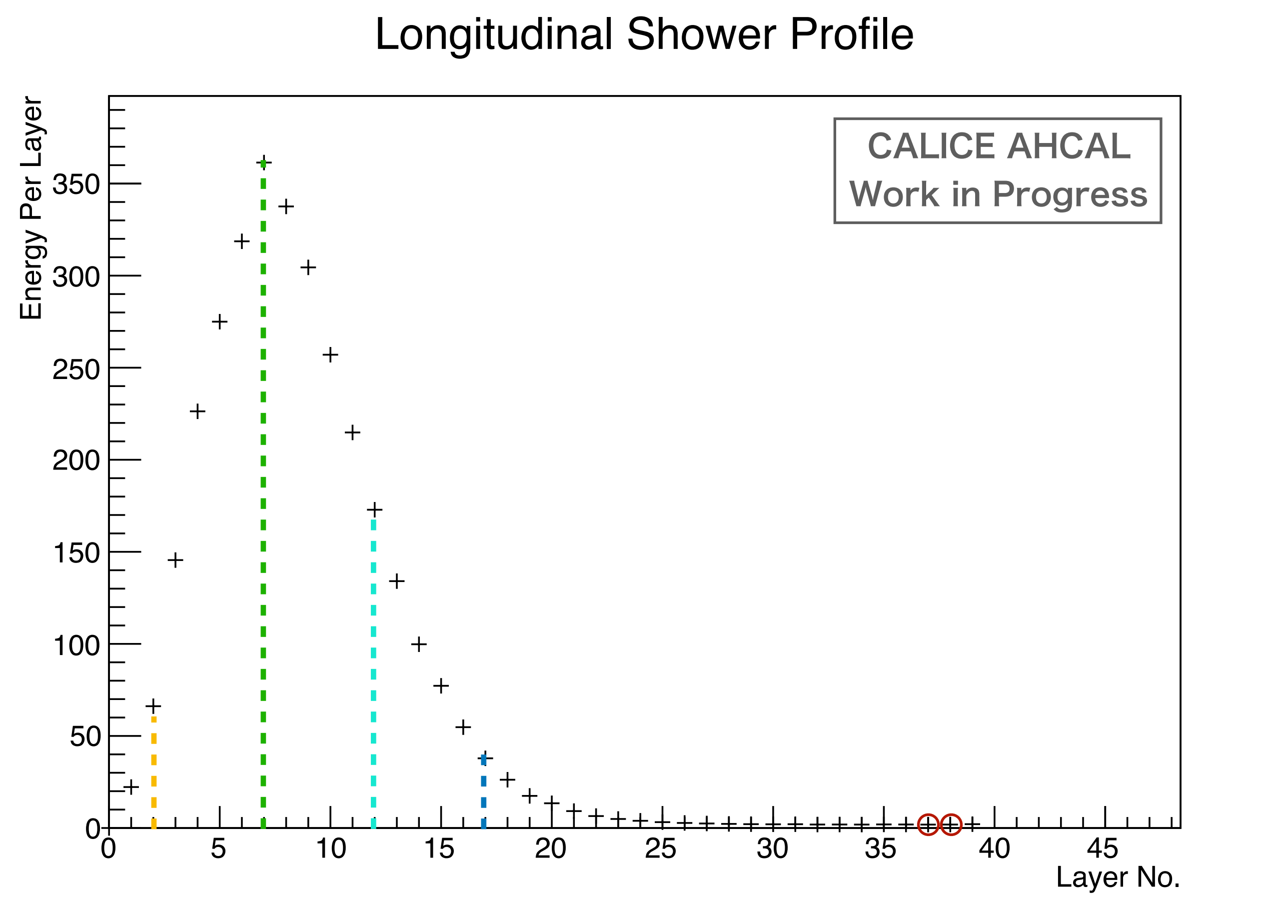
※ Note that Hadron energy in experiment is lower than 350GeV.

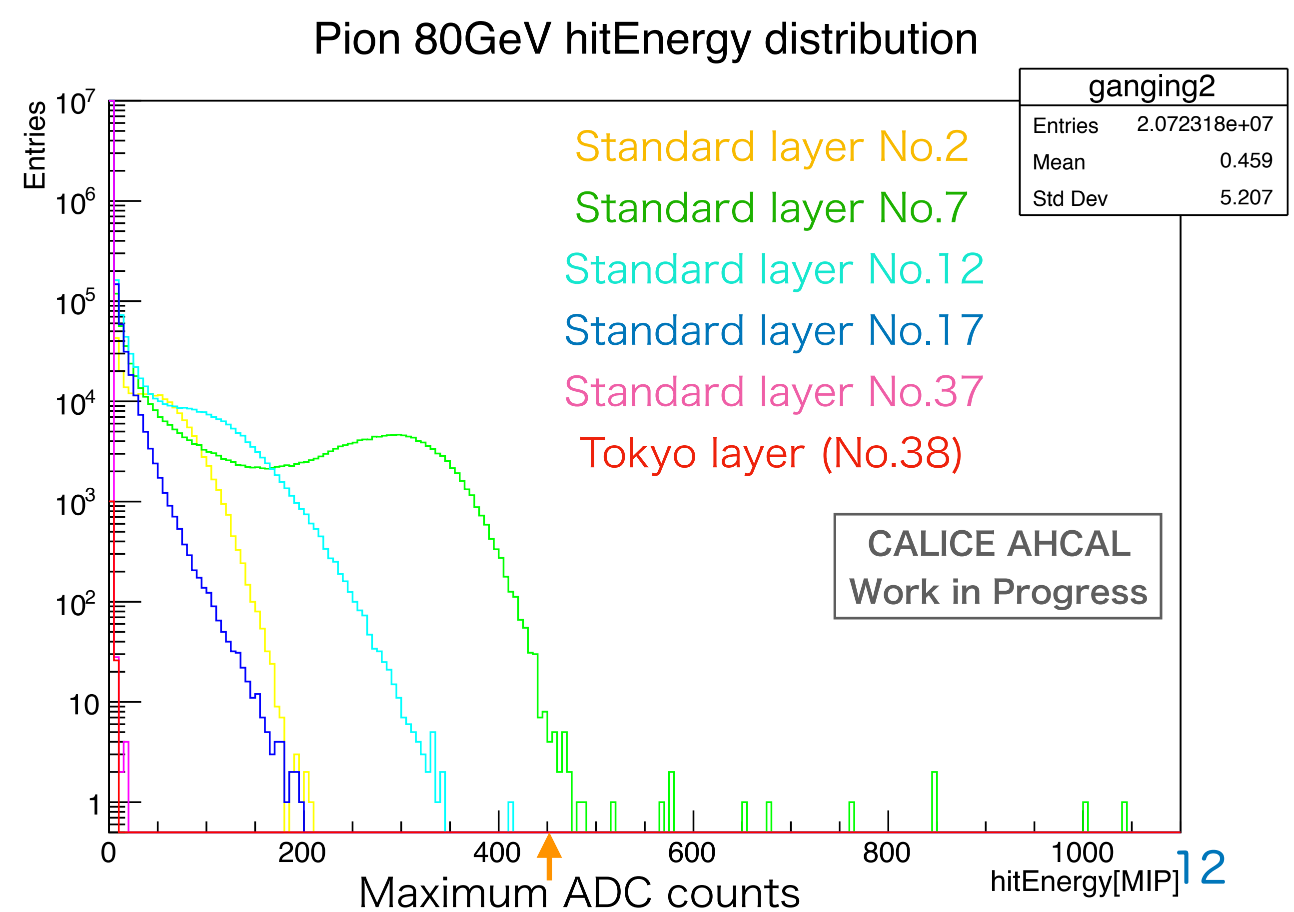




80 GeV e-

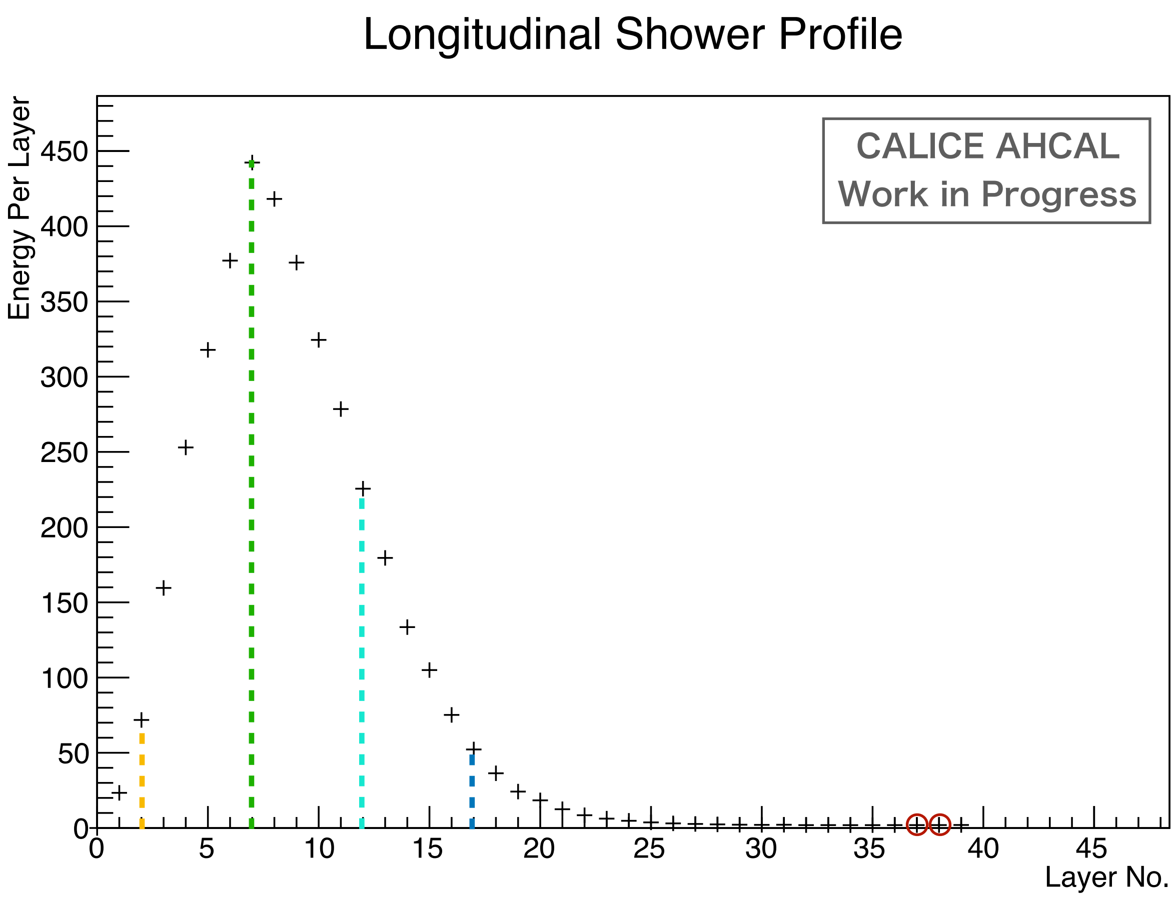
- Electron shower vanishes before first 15-20 layer
  - Cannot reach the latter half of the layers where we are considering the possible replacement with 60mm tiles
  - Nevertheless, tried to check the saturation at inner region
- Starting to saturate at shower maximum
  - 0.03% of the events suffer saturation

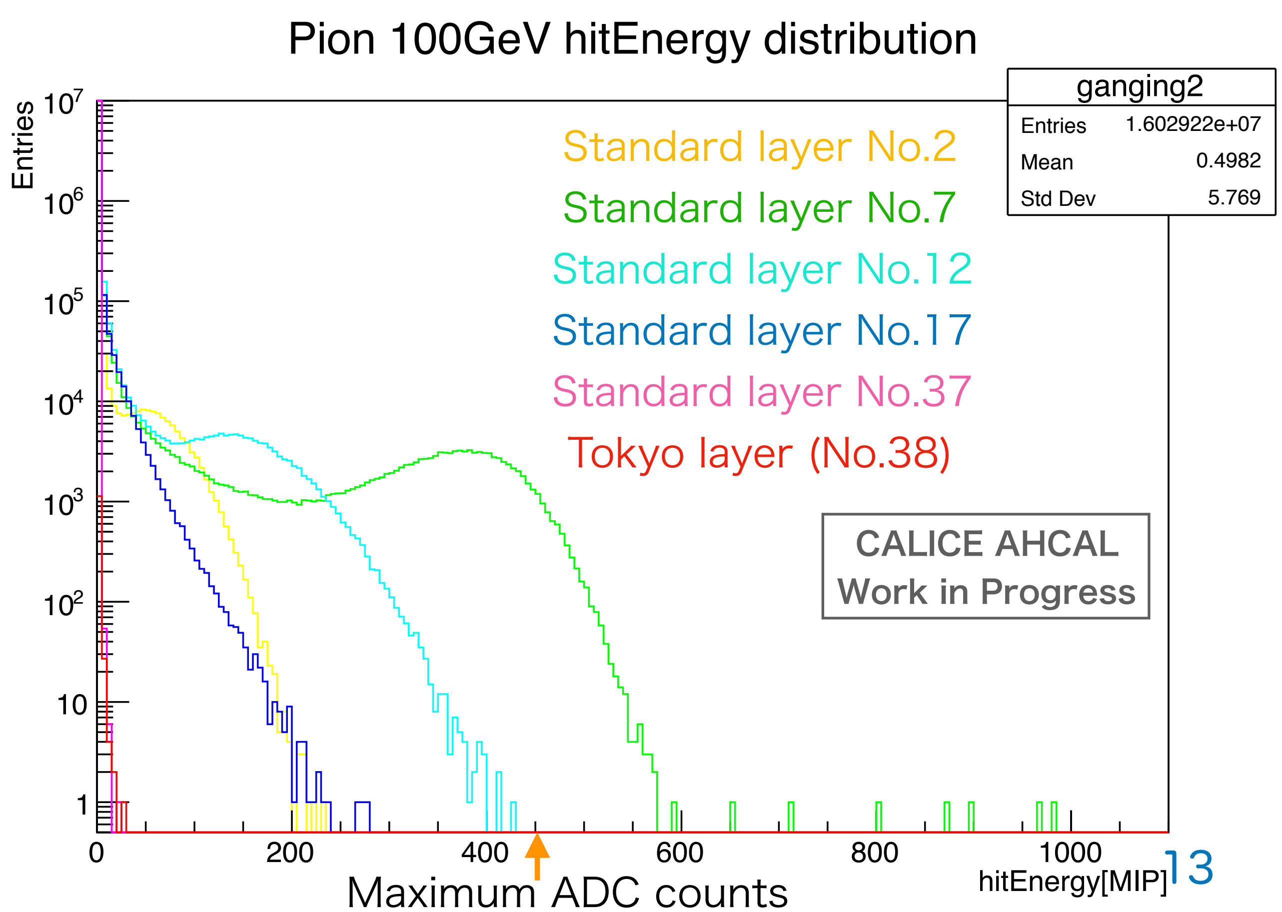




100 GeV e-

- Saturation would occur at shower maximum
  - 5.5% of the events suffer saturation





Summary

- Tokyo module based on 60mm×60mm tiles was developed and installed into the large prototype for June test beam for mixed granularity.
  - It worked fine as expected.
    - Photoelectron peaks are clearly resolved.
    - Sufficient light yield.
- No serious saturation was observed at Tokyo module
  - Small part of tile hits suffers saturation for Tokyo module only at 350 GeV
- Ganging tile study
  - Ganging tiles successfully reproduces 60×60mm^2 tile response.
  - Ganging tile study shows that no serious saturation is expected even at shower maximum for pion below 200 GeV
  - It will be used for further study on mixed granularity.

Prospect

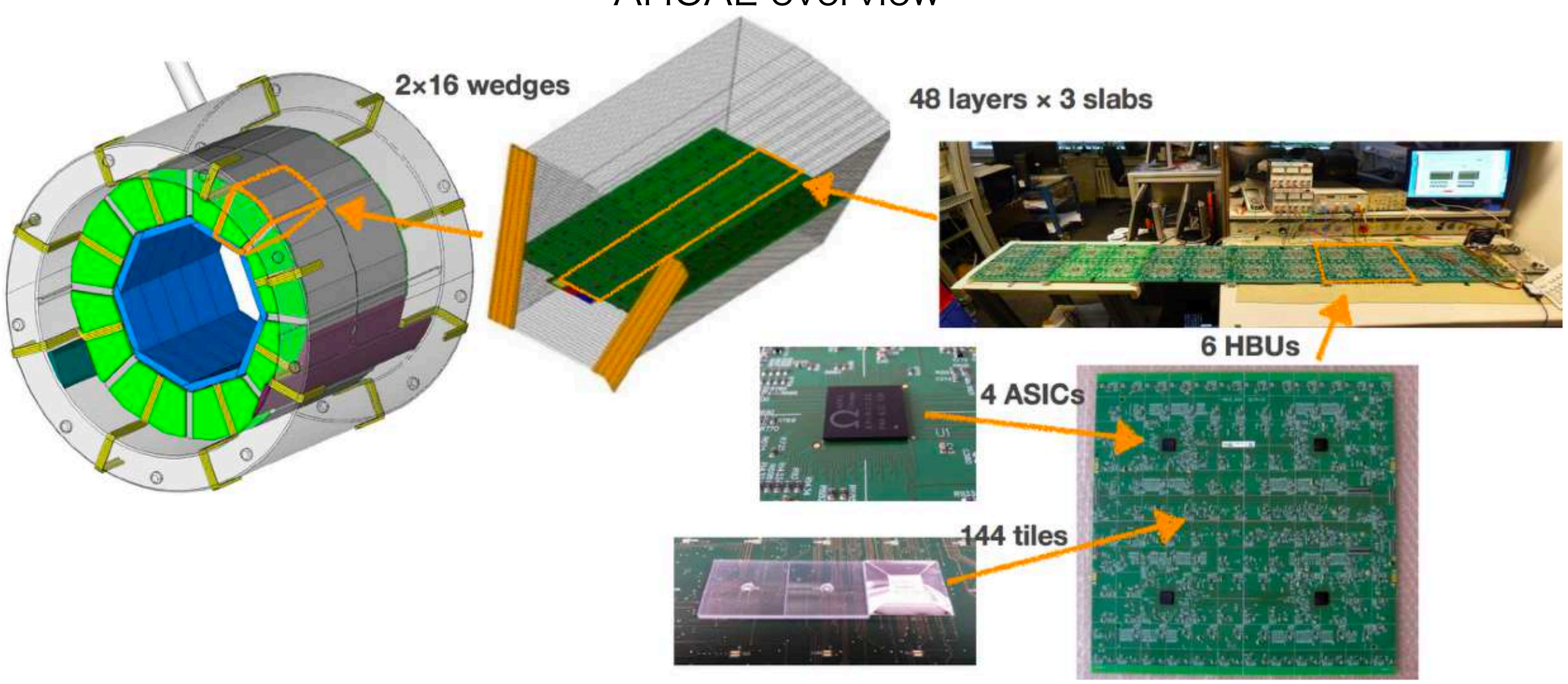
- Evaluate the performance of mixed granularity
  - Reproduce the mixed granularity configuration by applying ganging tile to testbeam data
  - Several cases of mixed granularity changing the ratio of ganging tile layer
  - Analysis testbeam data using ganging tile
    - Particle ID, particle separation, energy resolution,,,
- Simulation study on mixed granularity using ILD_model
  - Evaluate jet energy resolution for mixed granularity
  - Compare ganging tile with MultiSegmentation, and previous study by Lan
  - Apply the software compensation to mixed granularity
    - In the previous study, software compensation was not applied for the case of mixed granularity

Backup

AHCAL (Analogue Hadron CALorimeter)

- 48 layers (scintillator active layer + steel/tungsten absorber layer)
- 8×10^6 scintillator tiles ($30 \times 30 \times 3 mm^3$ each) readout by SiPM (~$1.3 \times 1.3 mm^2$)
- Developed in the framework of the CALICE collaboration
- Large technological prototype
  - 40 layers, 4 HBUs per layer
  - Use the same technology as foreseen in the full scale detector
  - Construction completed
  - **Test beam @CERN SPS in May and June 2018**

AHCAL overview

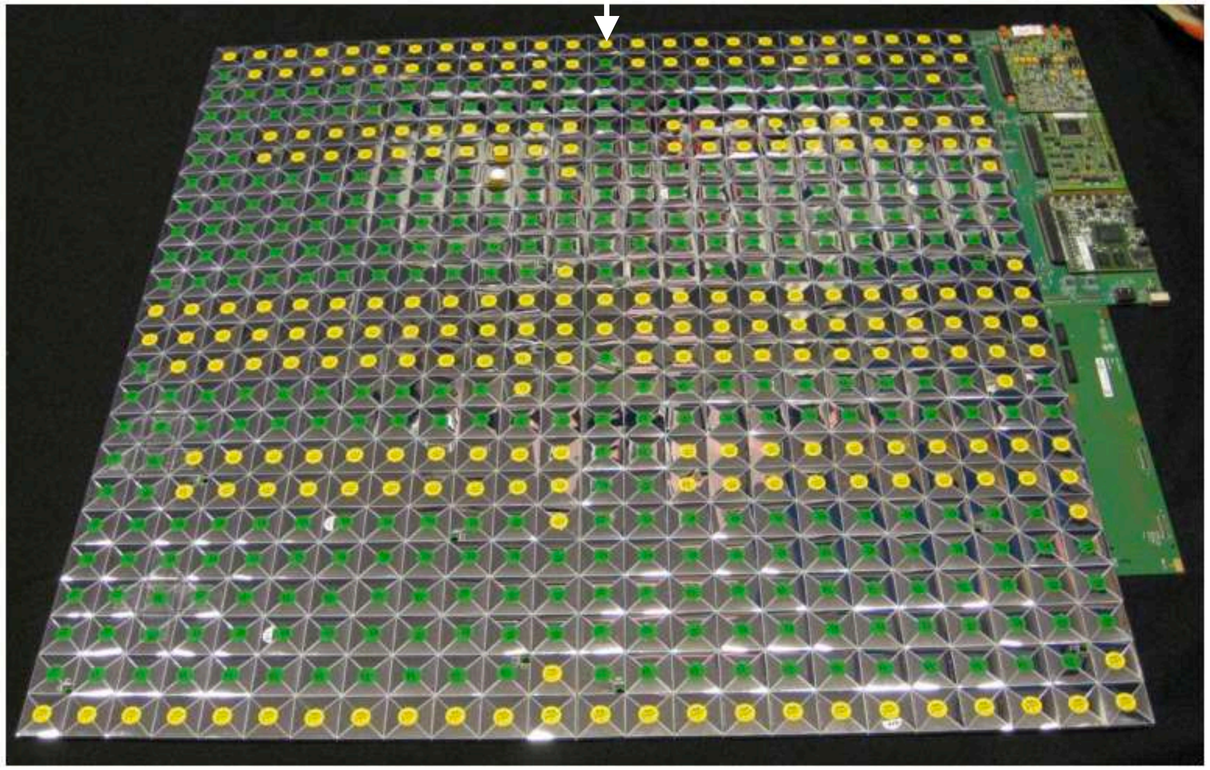


Large technological prototype

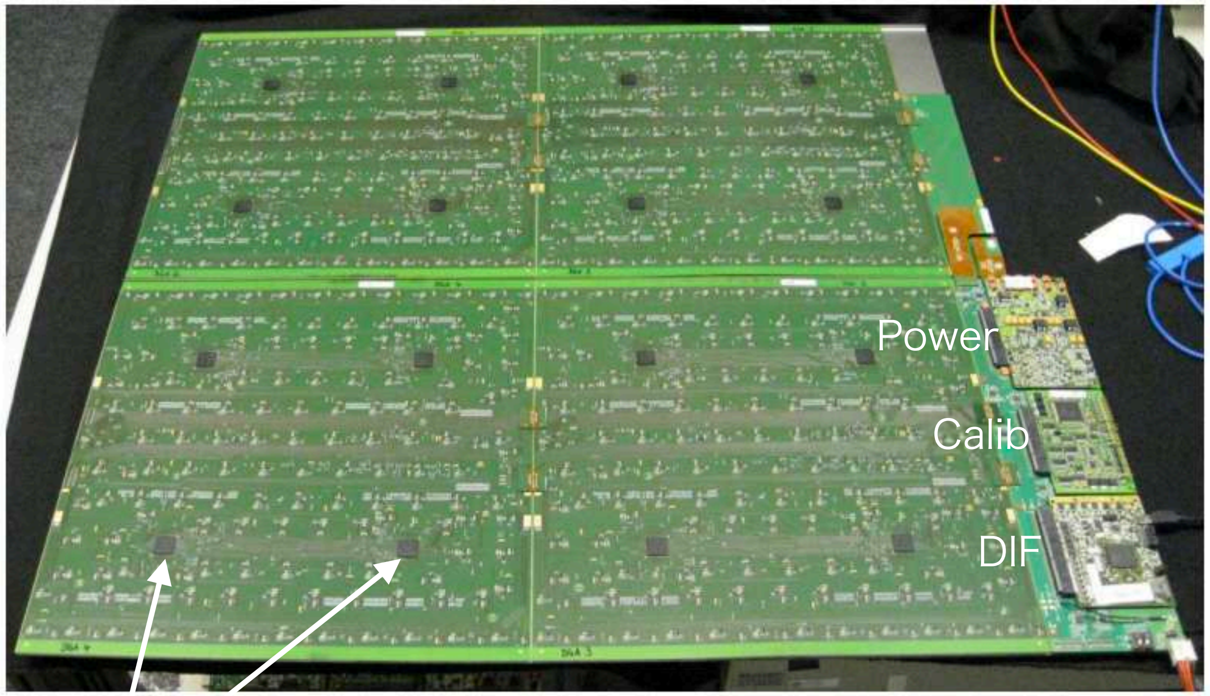
HBUs for large prototype

- 144 tiles (30×30×3mm^2) per one HBU, readout by SiPM (1.3×1.3mm^2)
- Each tile has a dimple for putting a SiPM.
- One LED for each tile for gain calibration.
- 160 HBUs (4 HBUs per layer) for large prototype

576×30mm-tiles assembled on 4 HBUs

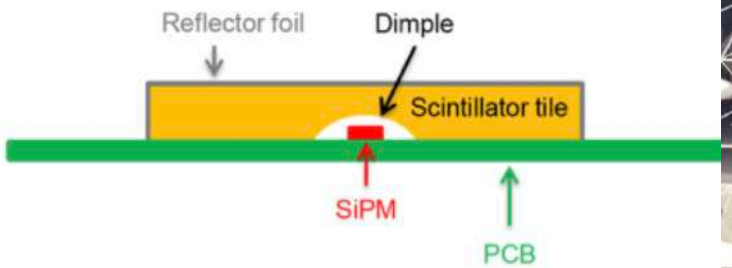


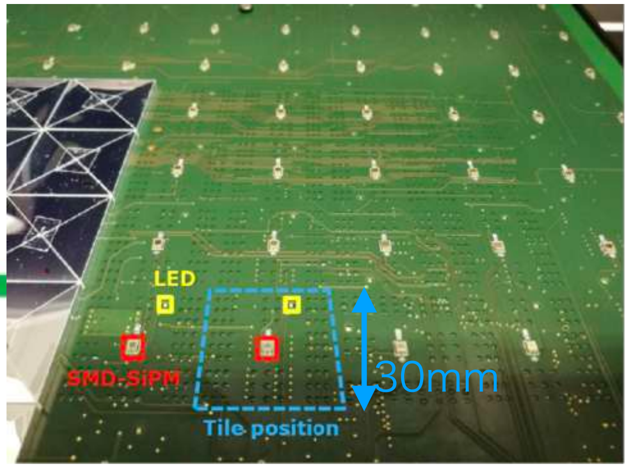
HBUs assembled with 30mm tiles



ASIC

HBUs at ASIC side



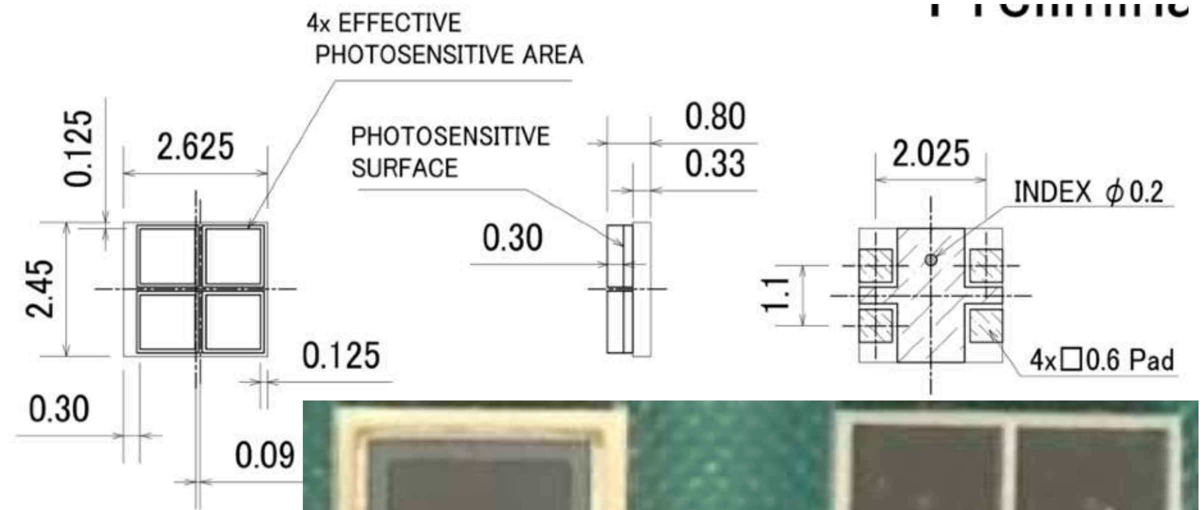


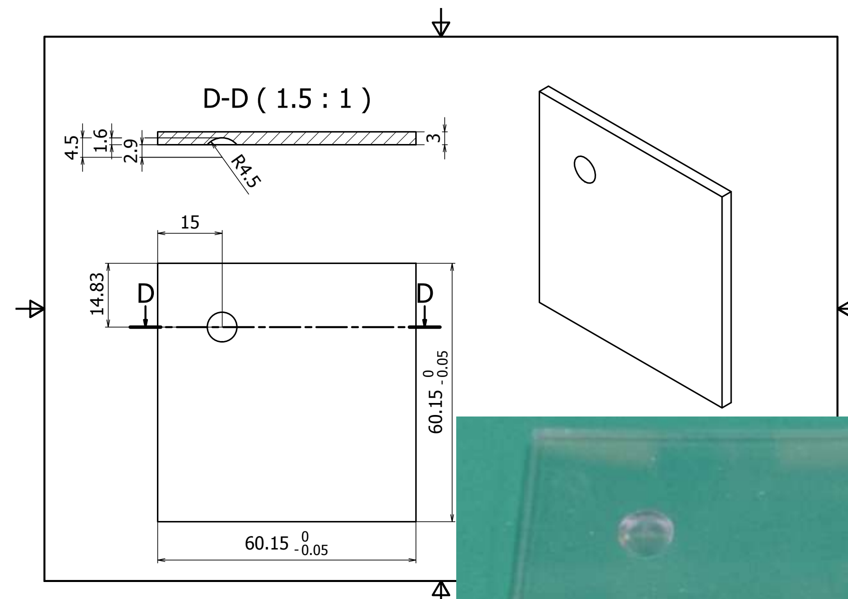
MPPC & Tile

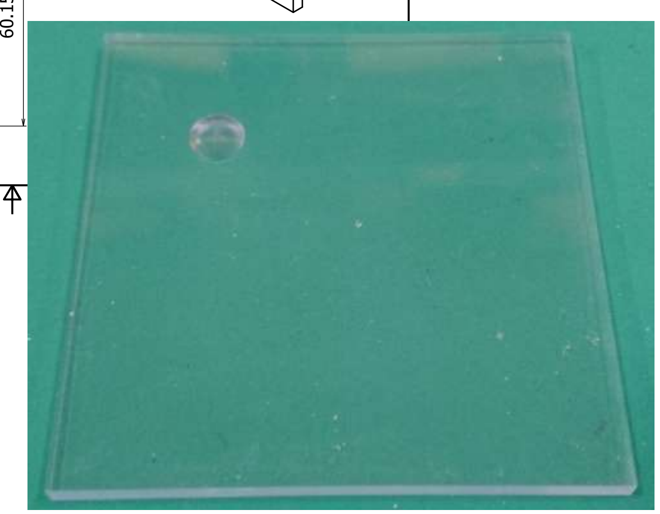
- Hamamatsu produces custom MPPC with an active area of 2×2mm^2 (no standard MPPC with 2×2mm^2 active area and 25μm pixel pitch)
  - Discrete array of 4×TSV MPPC S13615-1025
  - No wire bonding → minimum dead space
  - ➡Almost the same package size
- 2.4 times larger area
  - ➡Large enough to compensate lower light collection efficiency of 60mm tile

- Scintillator tiles are produced by injection moulding, which is suitable for large scale production.
  - The light yield of this polystyrene-based scintillator is 70% of that of commercial PVT scintillator (EJ-212) ➡ Good enough

Hamamatsu Photonics K.K.







HBU with 60mm Tile

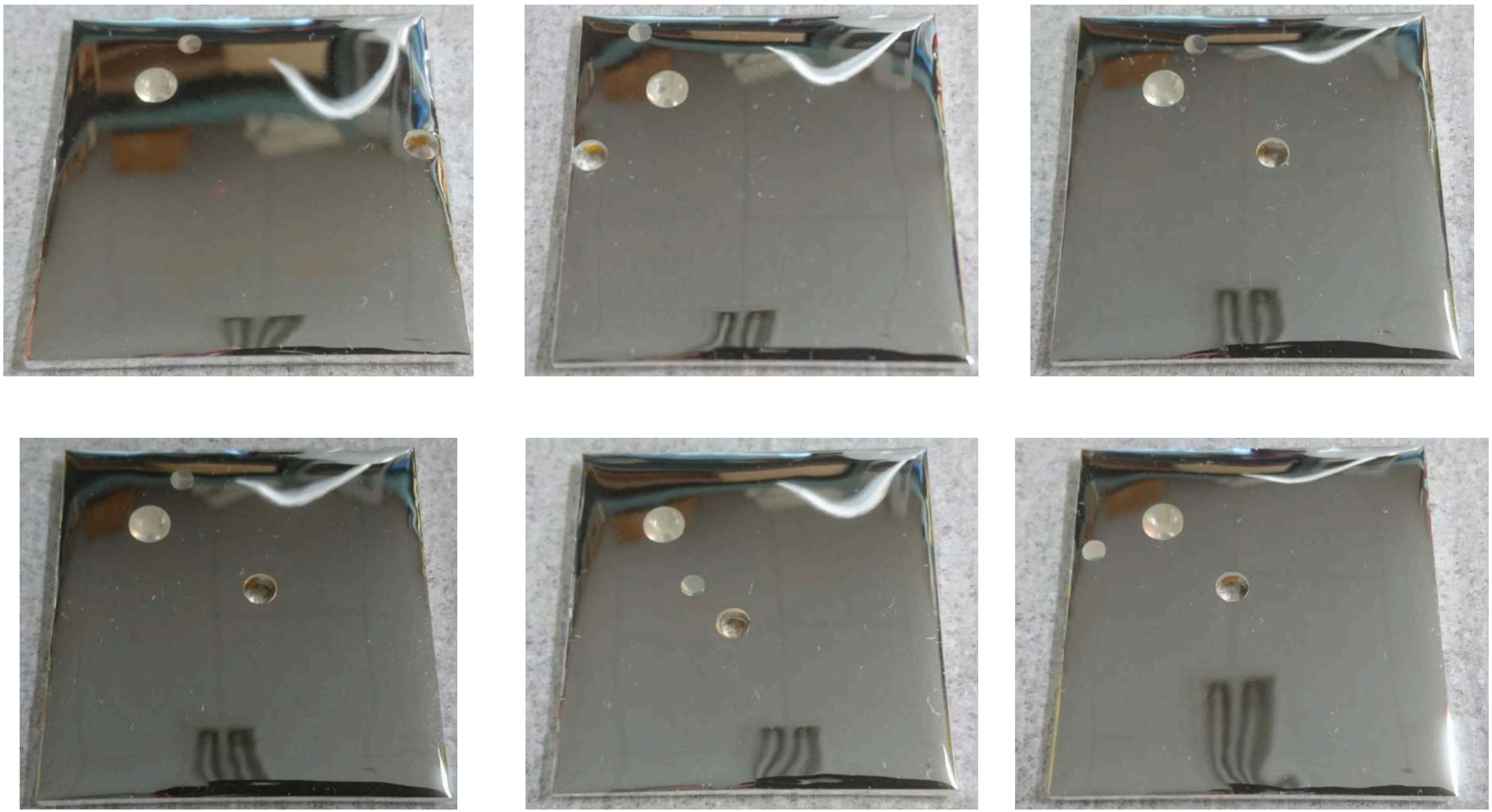
- Design concepts
  - Try to be as consistent with standard 30mm tile HBU as possible.
    - Fair comparison with standard 30mm tile HBU
    - Compatibility with installation to large prototype
  - **Light yield degradation is compensated with larger SiPM** ($1.3\times1.3\mathrm{mm}^2 \rightarrow 2\times2\mathrm{mm}^2$)
  - Use standard HBU (HBU6)
    - Tile is readout by SiPM at shifted position
  - Same design of reflector foil (ESR)
  - Manual tile assembly
- Four HBUs with 144 × 60mm-tiles in total was produced and added to large prototype.
- **Demonstrate the performance for detection layer with 60mm tile**

※ Next time, dedicated HBUs will be produced where

- Tile is readout by SiPM at center

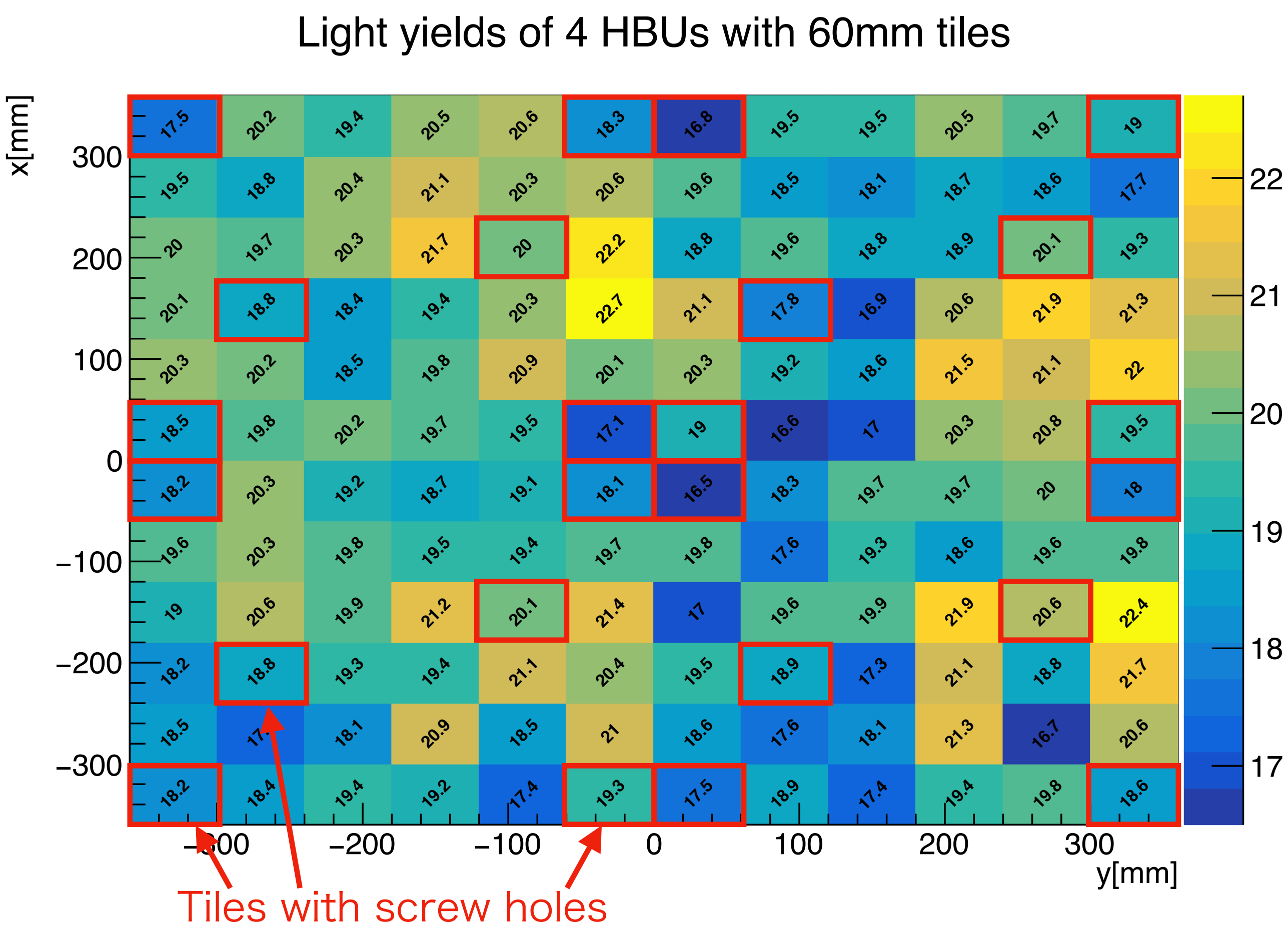
Tiles with screw holes

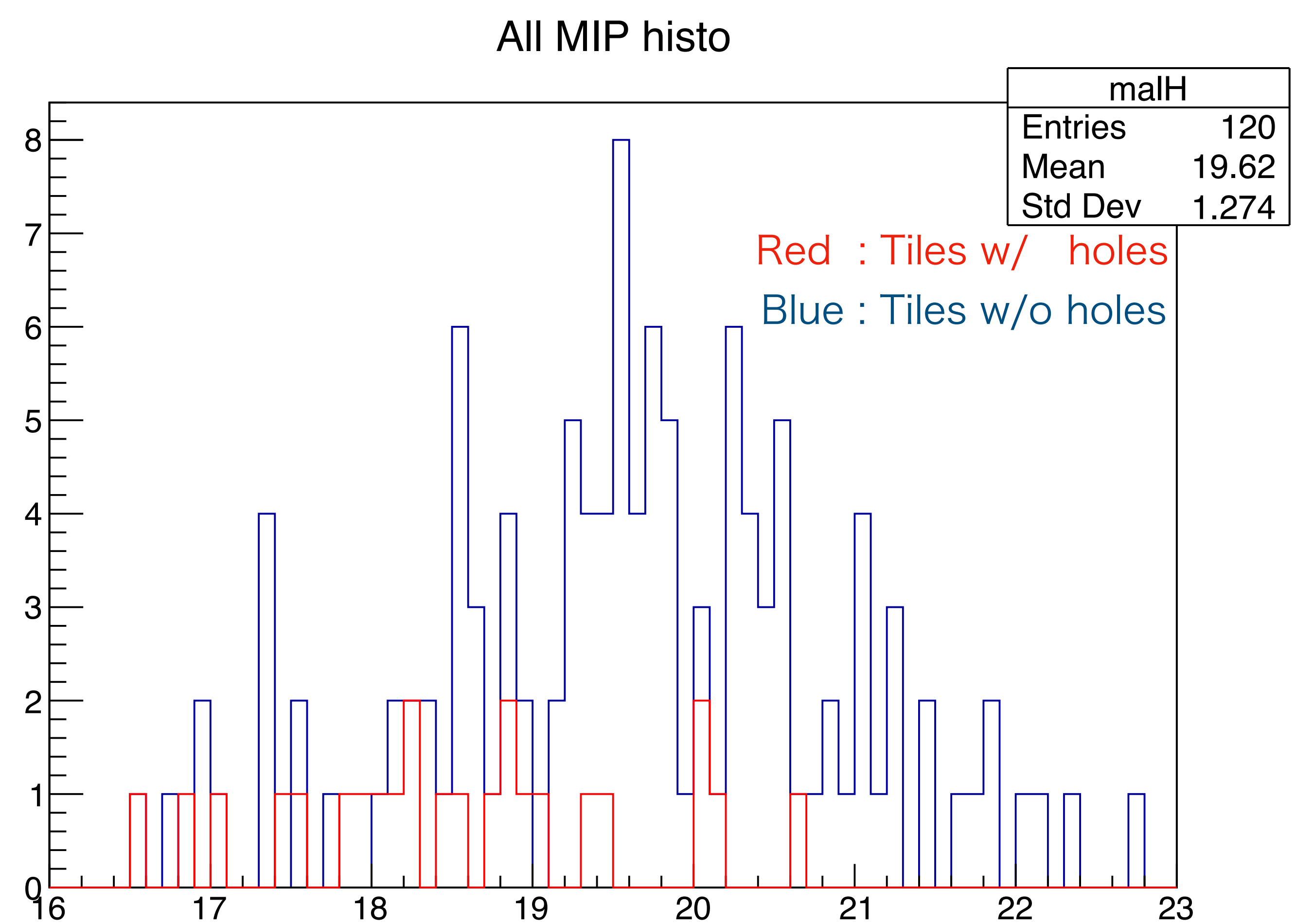
- 24 pieces of tiles (6 per HBU) have screw holes in order to fix HBU with stack.
  - Insert the long reflector and cover the hole.



LY difference about tiles with holes

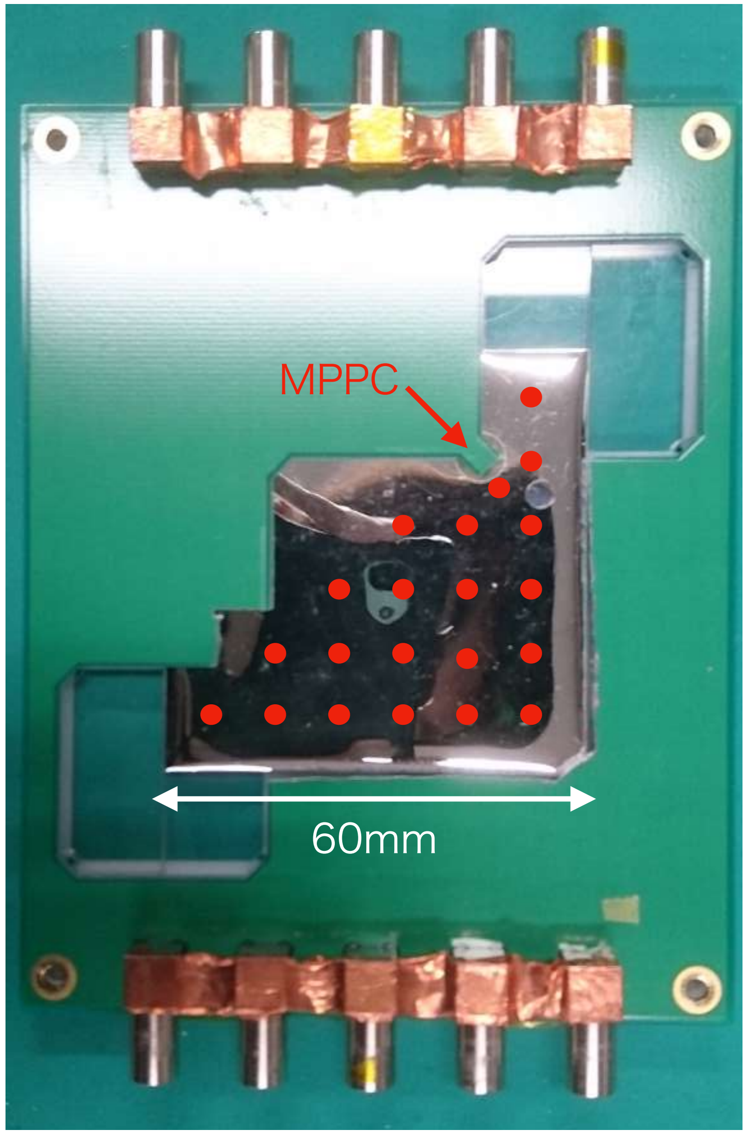
- Tiles with screw holes are worried about light leakage, so compare tiles w/ holes with tiles w/o holes.
- Histogram shows light yields distribution both w/ and w/o screw holes.
  - Average LY w/ holes : 18.6
  - Average LY w/o holes : 19.6
- Tiles w/ holes have a bit lower light yields than w/o holes.

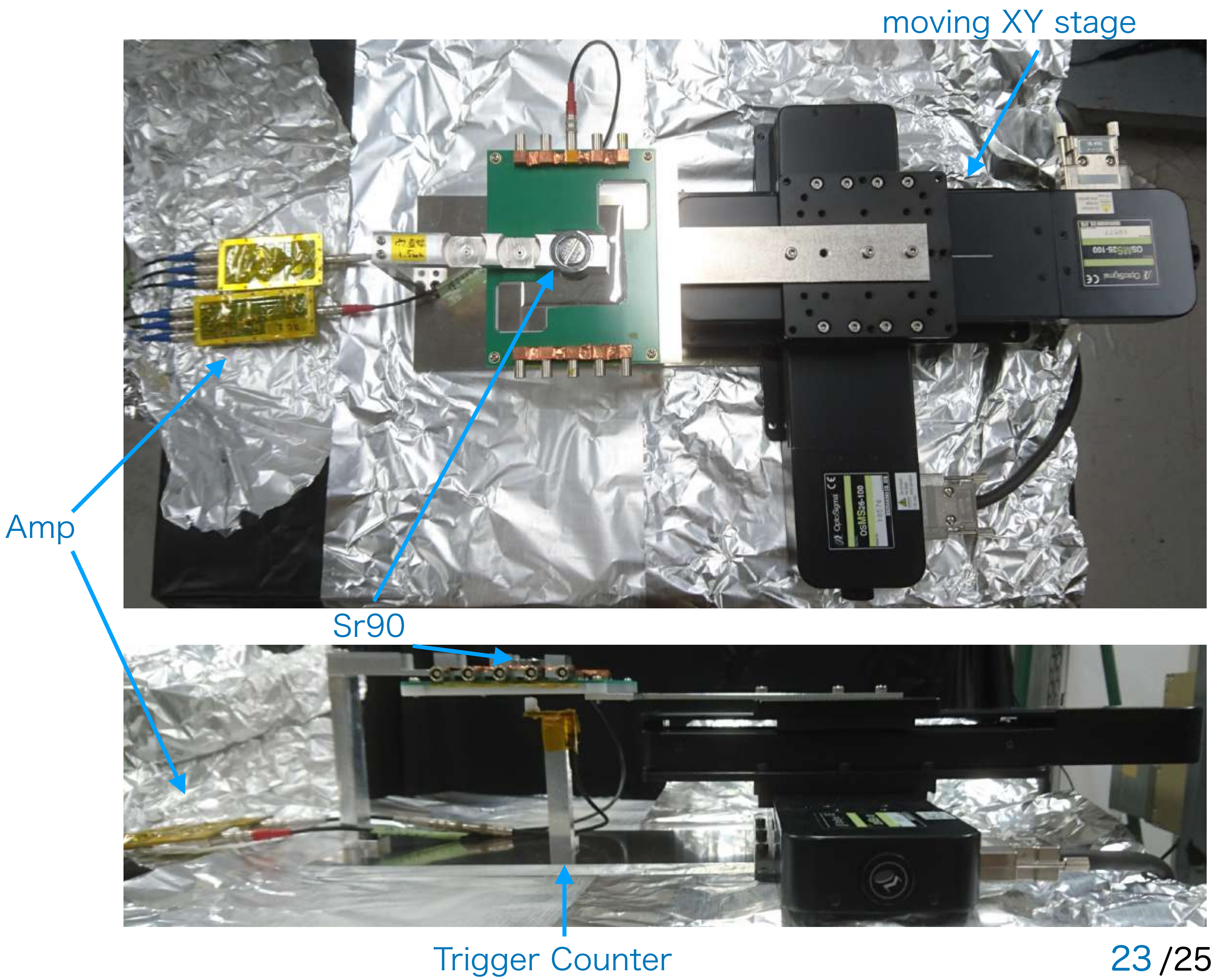




Tile performance test

- Measure the performance of 60mm tile with shifted SiPM readout
  - **Position dependence of light yield**
  - MPPC S13360-1325PE ($1.3 \times 1.3 mm^2$)

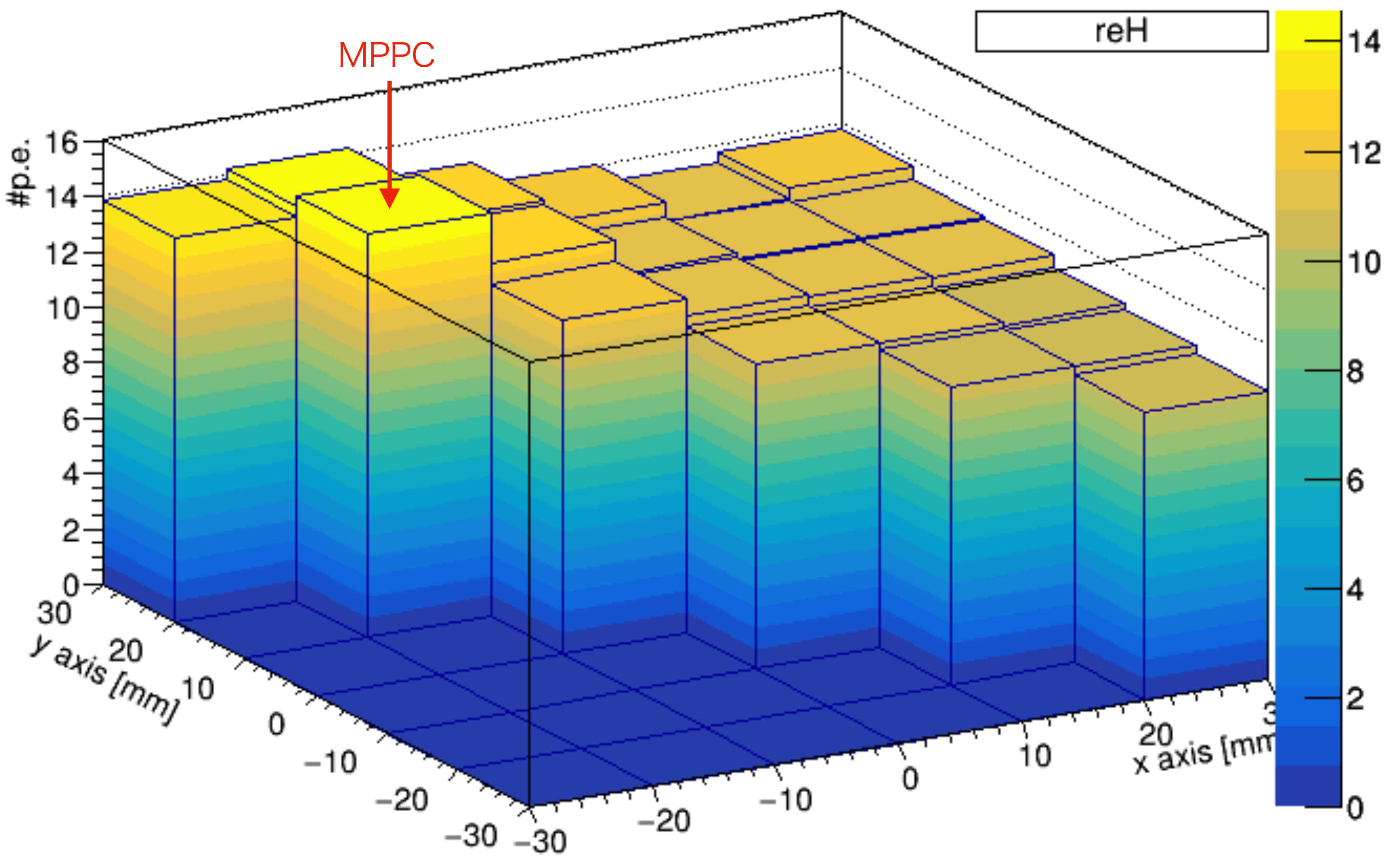




Position dependence of light yield

- Measured light yield (mean) : 11.8
  - ➡27.9 expected with 2×2mm² MPPC
- Non-uniformity ~ 9.8% (RMS)
- **Light yields and uniformity don't change significantly compared to center readout.**

Prototype test(1.3×1.3mm² SiPM)



Simulation Study on Mixed Granularity

- Evaluate jet energy resolution for mixed granularity with software compensation
  - In the previous study by Lan, software compensation was not applied for the case of mixed granularity
- For mixed granularity, ideally SC parameters should be optimized layer by layer.
  - Need to modify iLCSoft for doing this

- Check reproducibility from previous study.
- Study with using common SC parameters for whole layers

/cvmfs/ilc.desy.de/sw/ILDConfig/v02-00-01/StandardConfig/production/PandoraSettings/PandoraSettingsDefault.xml

$$\omega(\rho) = p_1 \exp(p_2 \rho) + p_3,$$

$$p_1 = p_{10} + p_{11} \times \mathrm{E}_{sum} + p_{12} \times \mathrm{E}_{sum}^2$$

$$p_2 = p_{20} + p_{21} \times \mathrm{E}_{sum} + p_{22} \times \mathrm{E}_{sum}^2$$

$$p_3 = \frac{p_{30}}{p_{31} + e^{p_{32} \times \mathrm{E}_{sum}}},$$

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    <!-- PLUGIN SETTINGS -->
    <HadronicEnergyCorrectionPlugins>SoftwareCompensation</HadronicEnergyCorrectionPlugins>
    <SoftwareCompensation>
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    </SoftwareCompensation>
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    <PhotonPlugin>LCPhotonId</PhotonPlugin>
    <ElectronPlugin>LCElectronId</ElectronPlugin>
    <MuonPlugin>LCMuonId</MuonPlugin>
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Procedure

- ILCSoft version : v02-00-01, ILD model : ILD_l5_v02
- Prepare the geometries
  - All 30×30mm²
  - Inside 24 layers 30×30mm², outside 24 layers 60×60mm²
  - All 60×60mm²
- Calibration by using muon, electron and kaon events
- Software compensation training or not
- Simulate di-jet events form quark pairs in DD4hep

/cvmfs/ilc.desy.de/sw/x86_64_gcc49_sl6/v02-00-01/lcgeo/v00-16-01/ILD/compact/ILD_common_v02/SHcalSc04_Barrel_v04.xml

All 30mm
(All 60mm replaced grid_size 3 → 6)

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      <segmentation name="Scigrid" type="TiledLayerGridXY"  key_value="3"  grid_size_x="3" grid_size_y="3.03248"/>
    </segmentation>
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      <hits_collection name="HcalBarrelRegCollection"  key="slice" key_value="3"/>
    </hits_collections>
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  </readout>
</readouts>
```

Half by half of
30mm and 60mm

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      <segmentation name="ScigridOuterLayer"   type="CartesianGridXY"   key_min="25" key_max="0xFF" grid_size_x="60.0*mm" grid_size_y="60.0*mm" />
    </segmentation>
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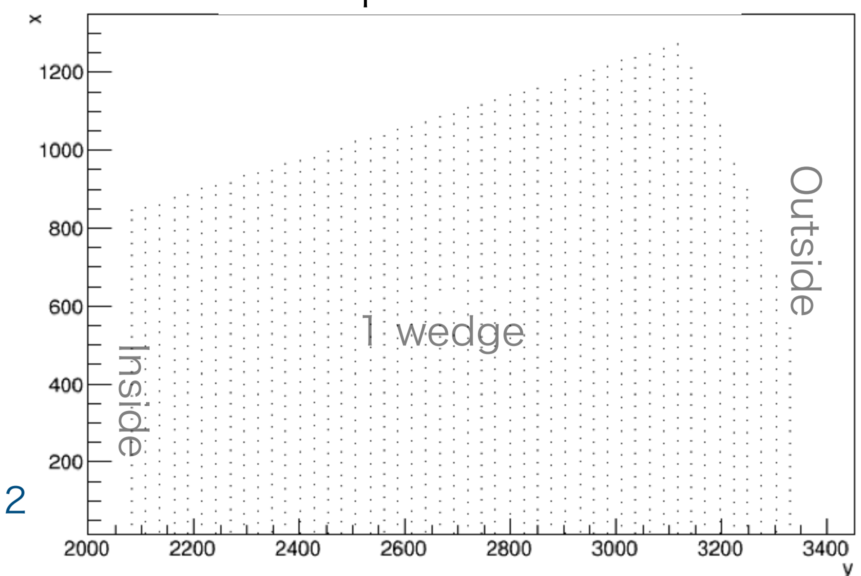
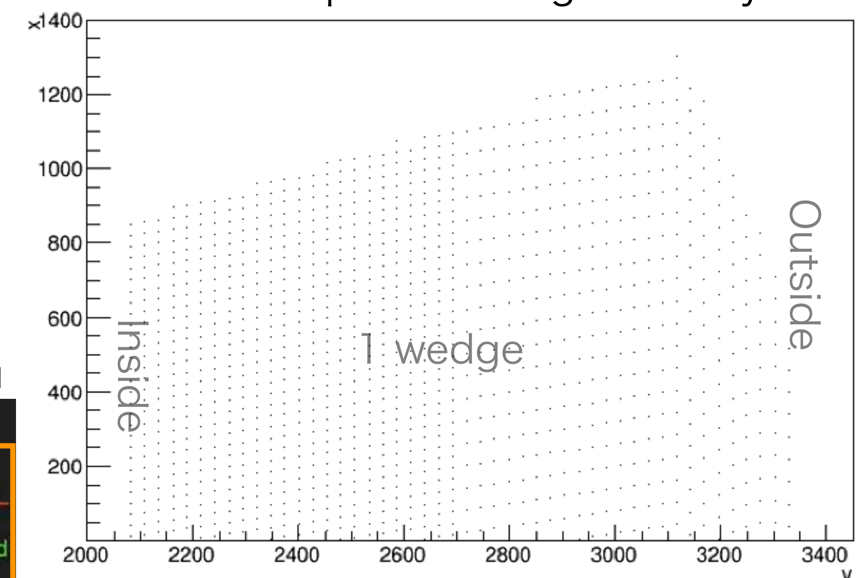
↓z is beam axis, x and y are its vertical axes

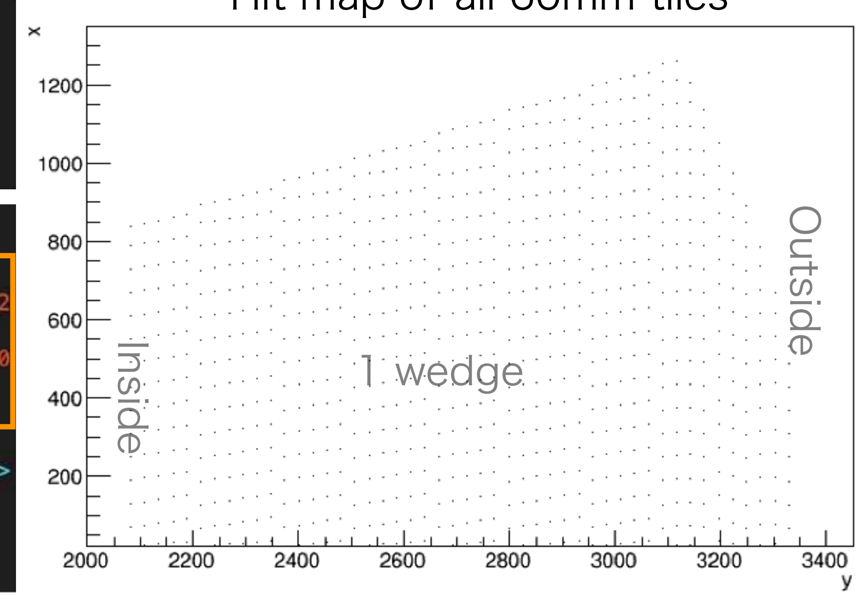
Hit map of all 30mm tiles



Hit map of mixed granularity



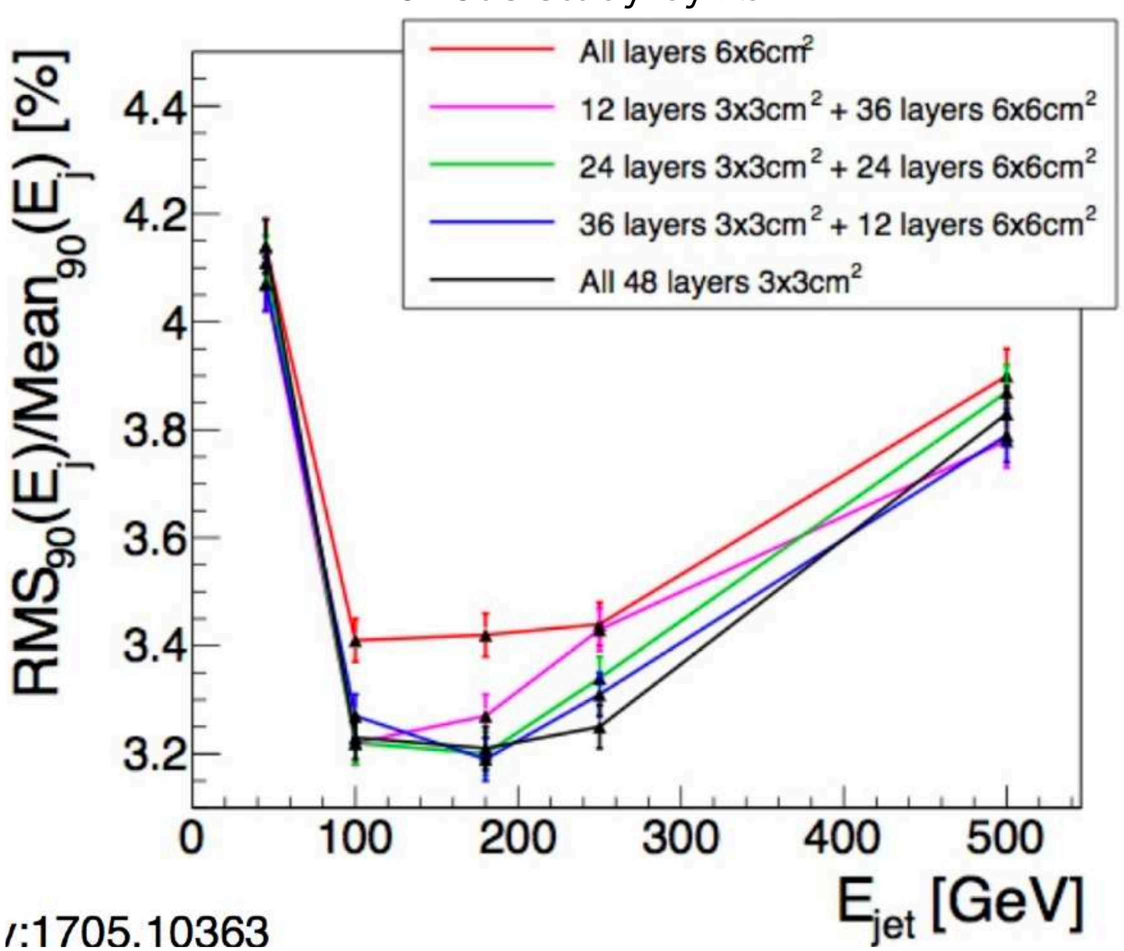
Hit map of all 60mm tiles



Results w/o SC

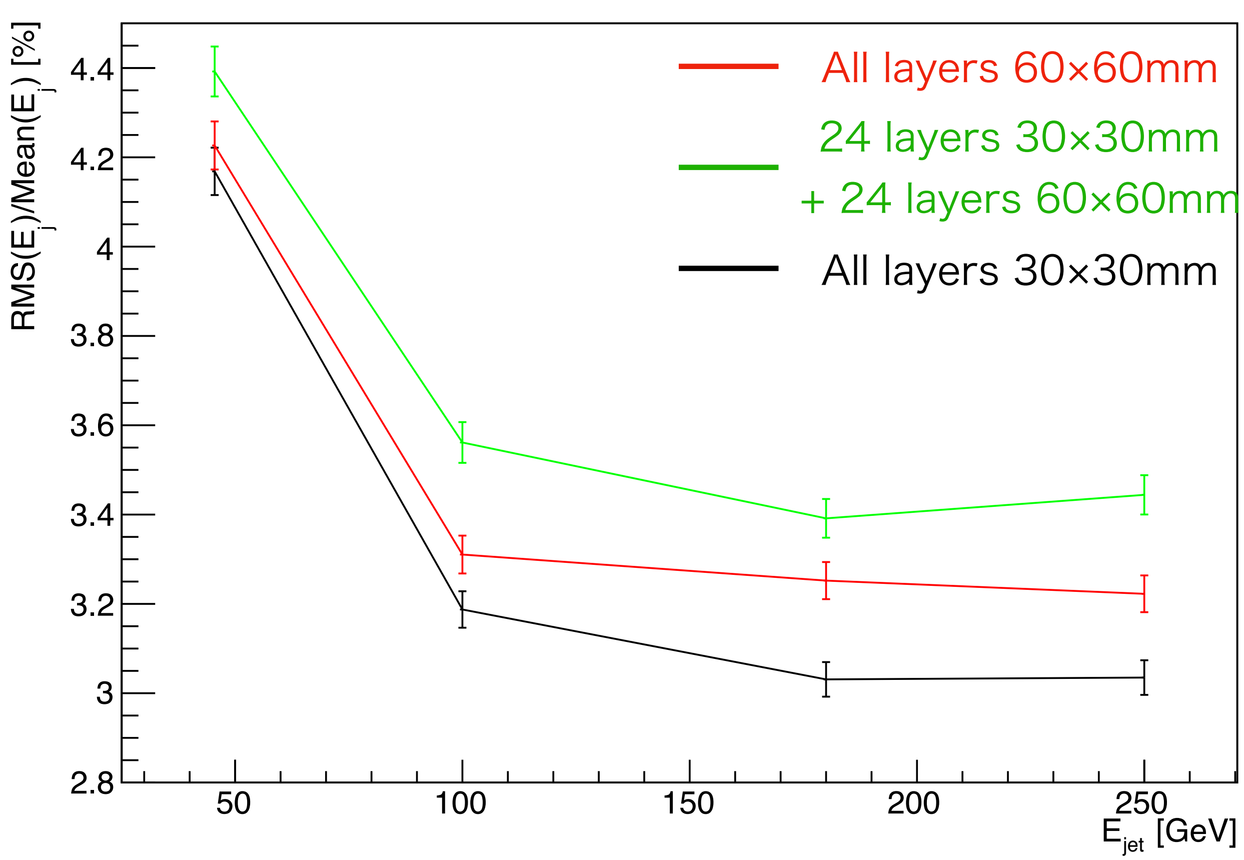
- New geometry of all layers 30×30mm² and all layers 60×60mm² has almost the same results compared to previous study.
- Half by half of 30mm and 60mm gets worse.
  - Due to the difference of iLCSoft or ILD model version?
  - Due to something wrong with multi segmentation?

Jet energy resolutions for different granularity (w/o SC)
Previous study by Lan



/:1705.10363

Jet energy resolutions for different granularity (w/o SC)
New geometry



Results of new geometries

- Reasonable improvement for all 30×30mm² tiles configuration with SC.
- Slight improvement for half 30×30mm² and half 60×60mm² configuration with SC.
- Even worse for all 60×60mm² configuration with SC

➡It seems that SC is not correctly working for 60×60mm² tiles

➡Need to apply different SC parameter layer-by-layer and to optimize SC parameter for 60×60mm² layer.

Jet energy resolutions for different granularity(w/ and w/o SC)