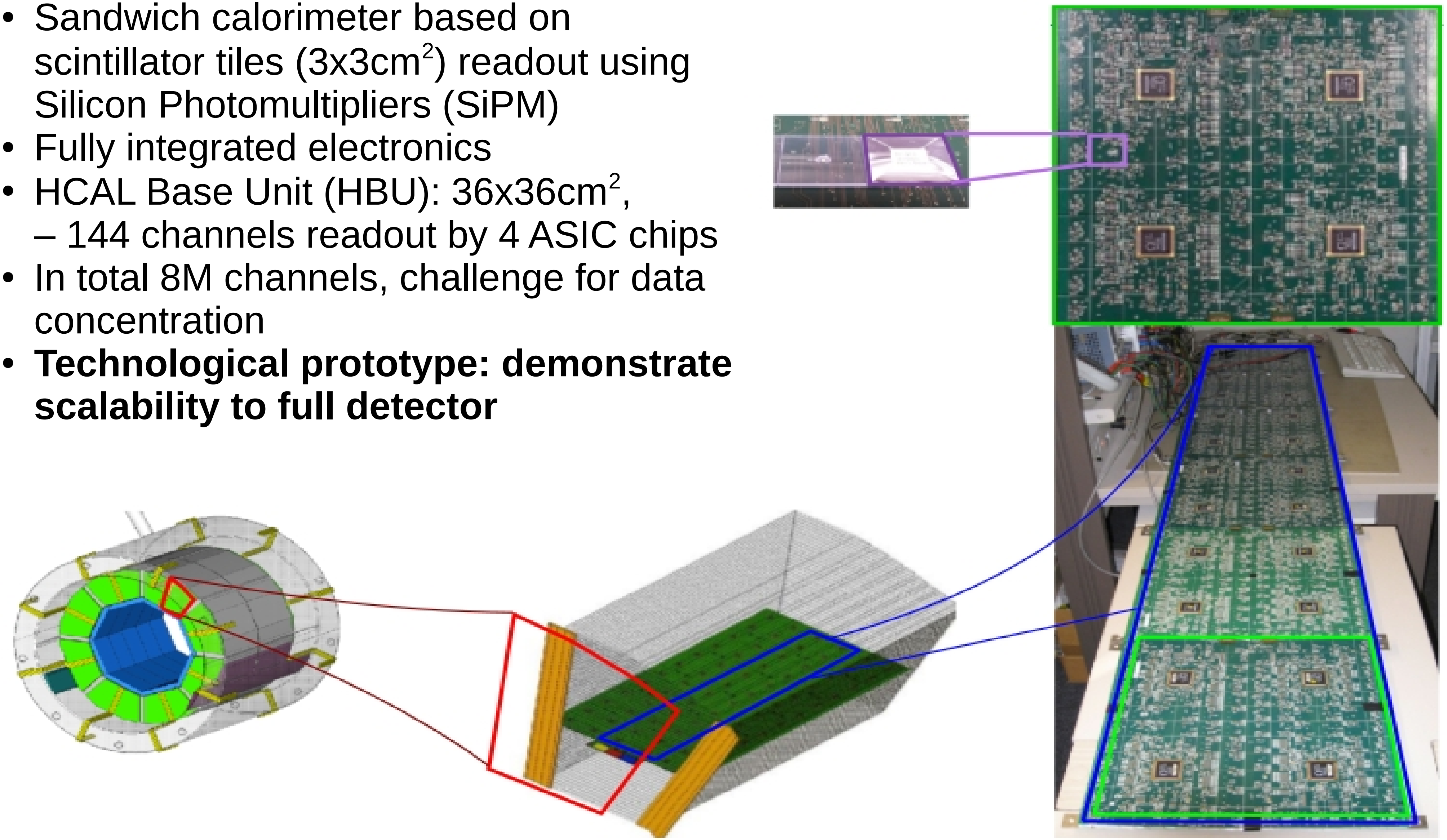
# Study of the nonuniformity of scintillator tiles for highly granular calorimeters

B. Bobchenko (MEPhI/ITEP), M. Chadeeva (MEPhI/LPI), S. Korpachev (MEPhI/LPI), V. Rusinov (MEPhI/ITEP) and E. Tarkovskii (MEPhI/ITEP)

AYSS-2018, 23 - 27 April 2018

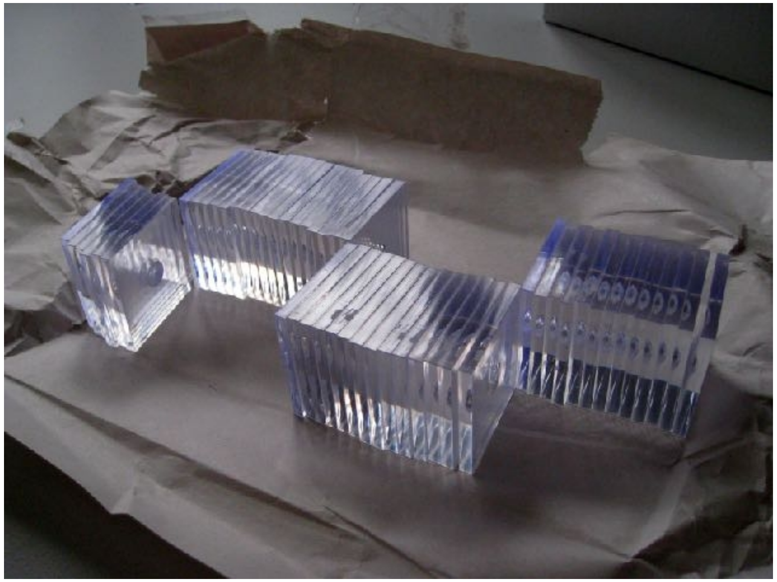
# Hadron calorimeter for ILD detector at ILC

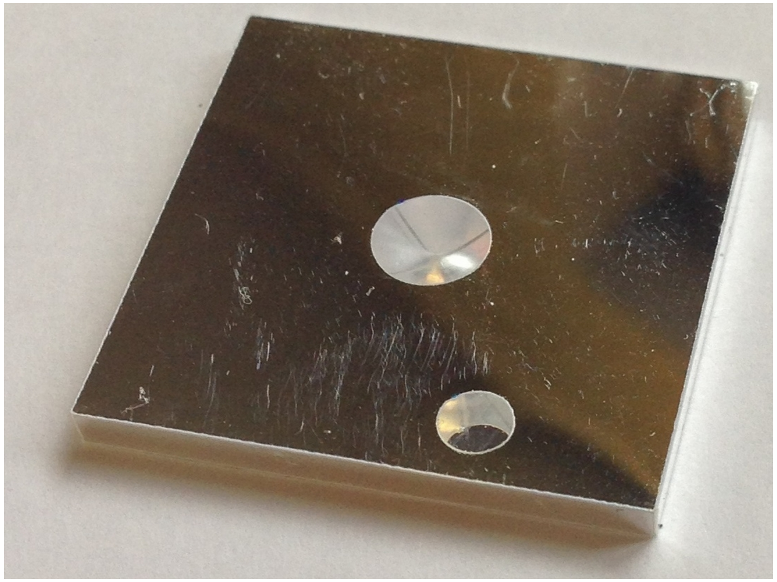
- Sandwich calorimeter based on scintillator tiles ($3x3cm^2$) readout using Silicon Photomultipliers (SiPM)
- Fully integrated electronics
- HCAL Base Unit (HBU): $36x36cm^2$,
  – 144 channels readout by 4 ASIC chips
- In total 8M channels, challenge for data concentration
- **Technological prototype: demonstrate scalability to full detector**

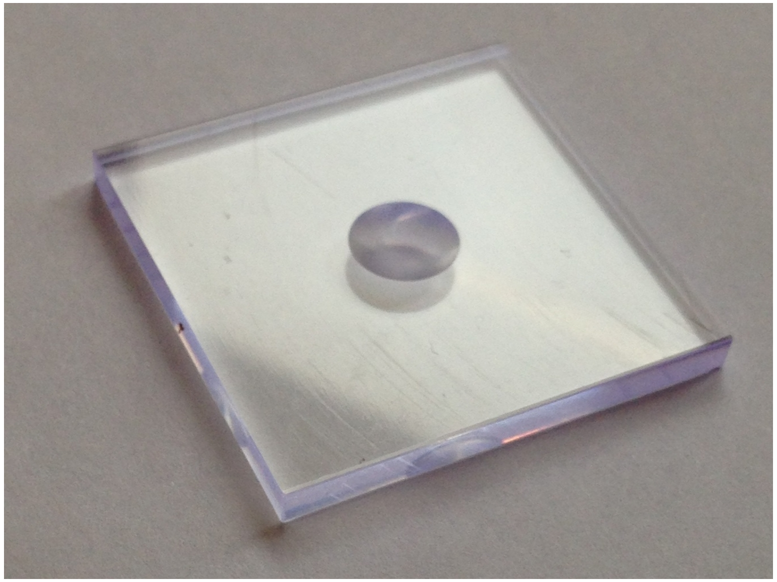


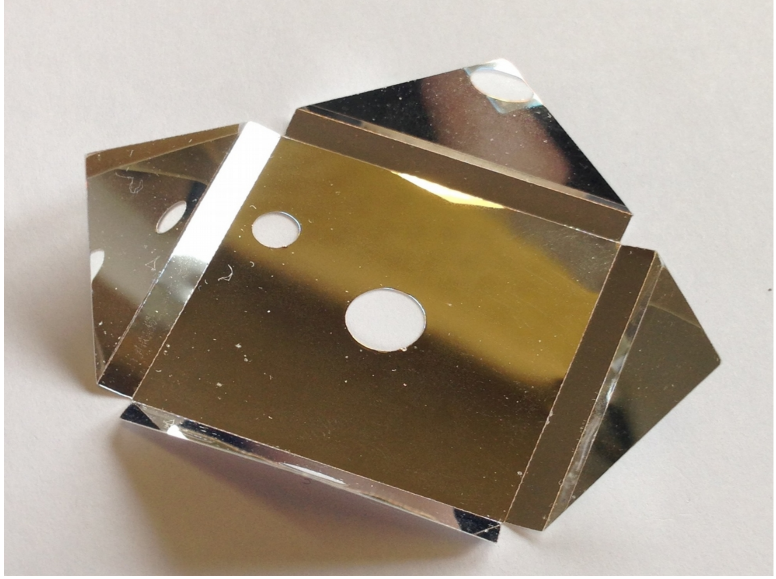
Slide from CALICE collaboration meeting (22-24 March 2017) by Felix Sefkow

# Tiles for CALICE technological prototype







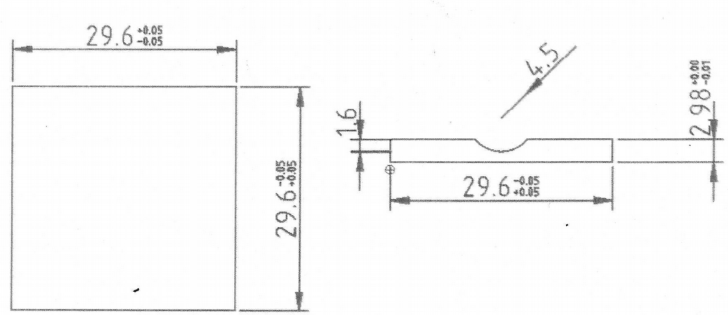


# Cell model with direct readout

Dimple design is aimed to improve uniformity of response for direct readout approach.

Requirements for tile production

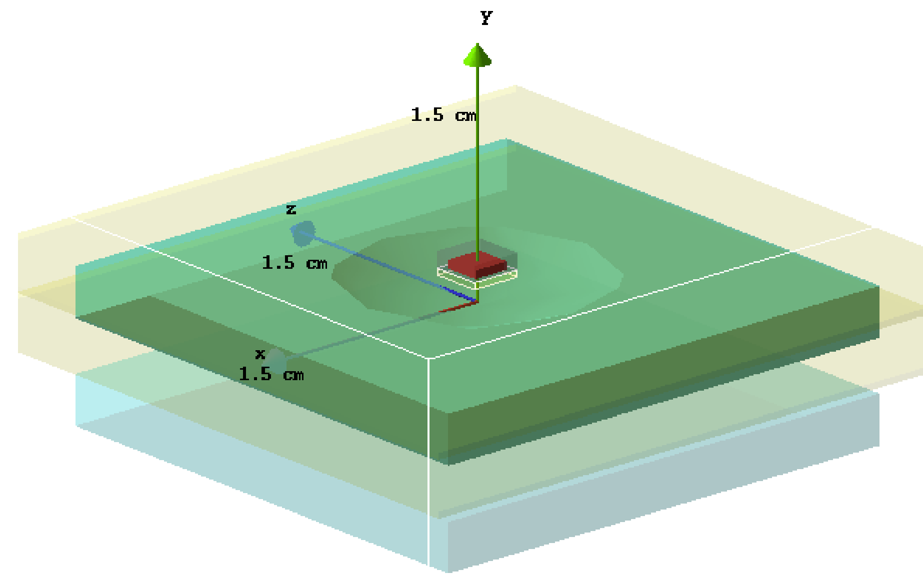
(production mode: injection moulding)




SiPM box: 3.8 x 1 x 3.8 $mm^3$
SiPM KETEK: 2.2 x 1.0 x 2.2 $mm^3$
SiPM working point:
T: 25.5 C; Gain: 23.11 ADC/p.e.; 28 V;

Aluminium-based 3M wrapping foil

Isometric view of Geant4 model




Slab: 40 x 0.2 x 40 $mm^3$
Thickness of foil is 65 microns
Epoxy: 3 x 0.4 x 4 $mm^3$
Trigger tile below measured tile
Wrapping foil not shown

The geometry of $^{90}Sr$ source (Ø2mm) and electron energy spectrum were simulated.

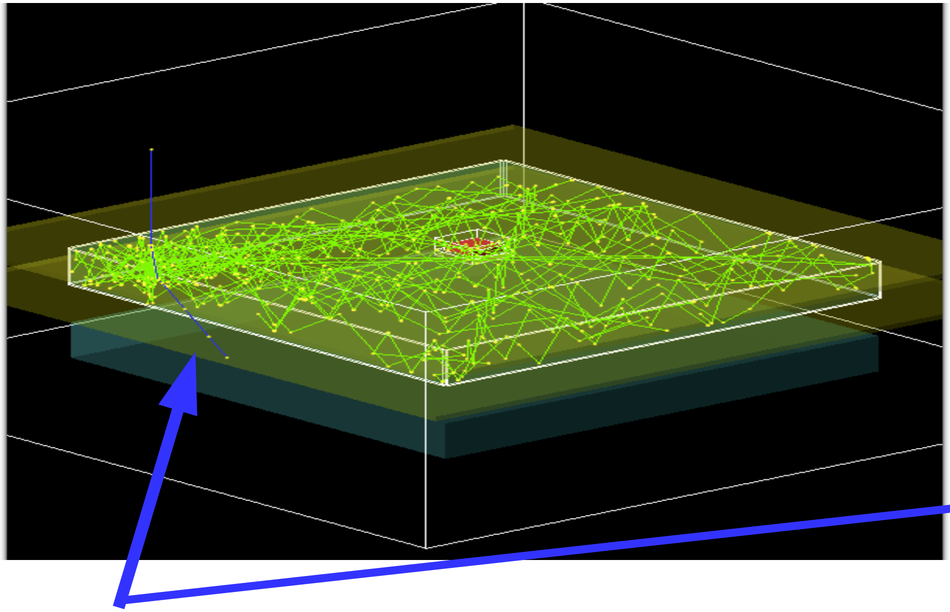
# Properties for BICRON408

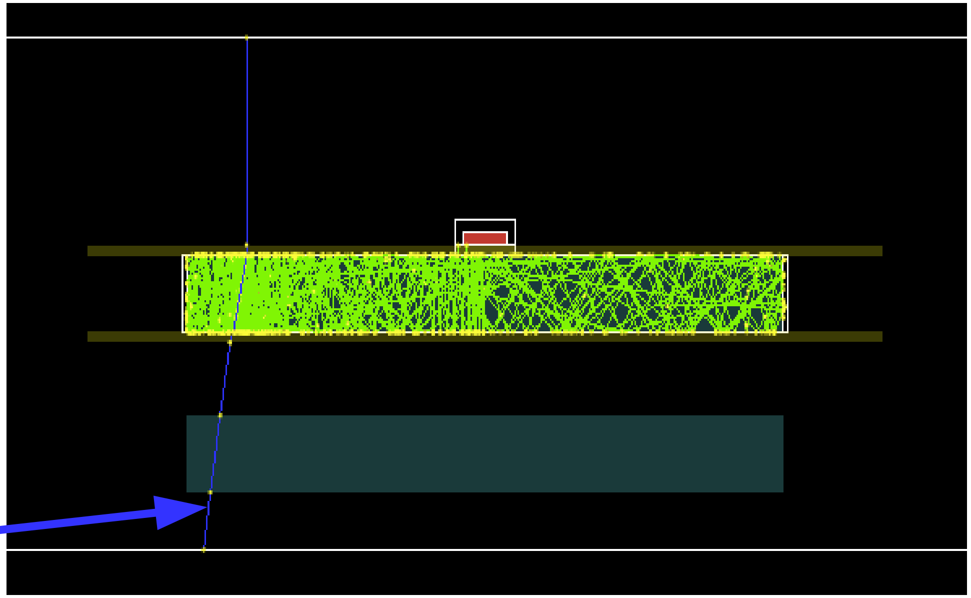
- Light yield of BC408: 10000 photons/MeV
- Refractive index of BC408: 1.58
- Absorption length of BC408: 0.6 meter
- Reflectance of 3M foil:

G4double PE_ESR[15] = {
3.099605*eV, 3.024005*eV, 3.002038*eV, 2.987571*eV,
2.952004*eV, 2.931068*eV, 2.870004*eV, 2.749095*eV,
2.632361*eV, 2.535464*eV, 2.450280*eV, 2.375176*eV,
2.304539*eV, 2.221939*eV, 2.152503*eV };

- The material of tile is BICRON408 ( Polyvinyltoluene ); G4_PLASTIC_SC_VINYLTOLUENE

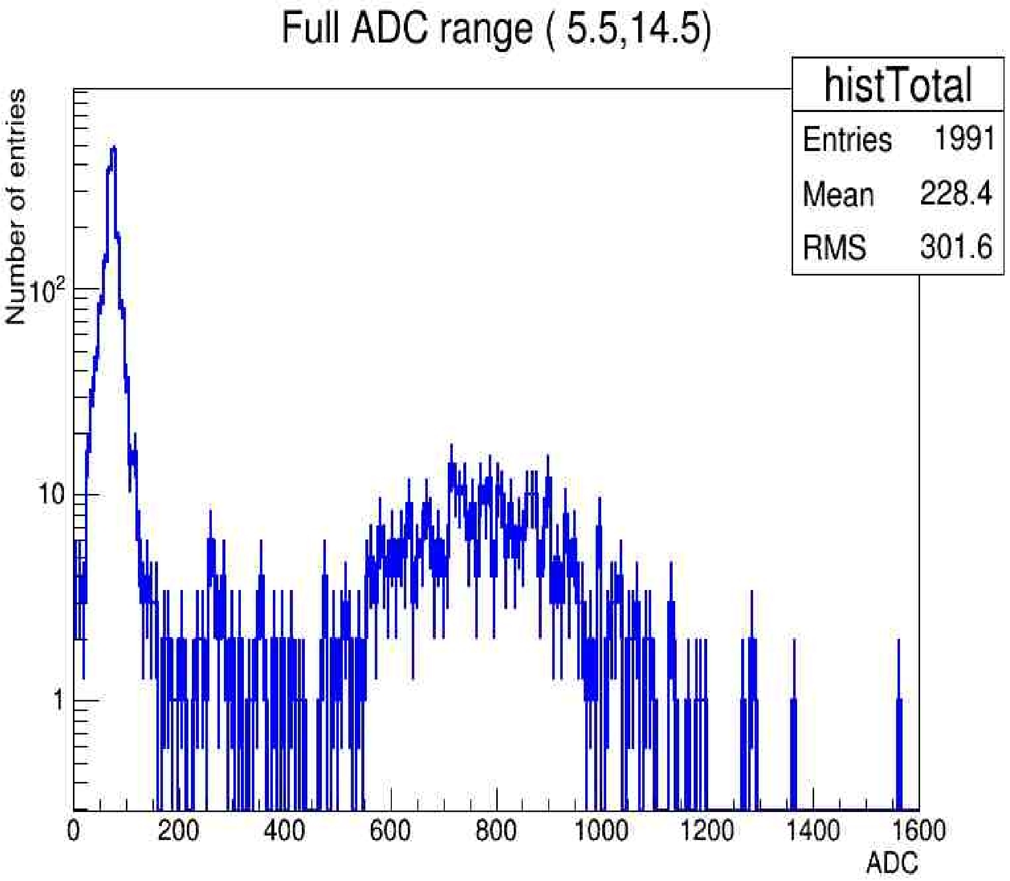
G4double reflect_foil[15] = {
0, 79.99894/100., 85.27812/100., 90.12258/100.,
95.09099/100., 97.82370/100., 99.74816/100., 99.87048/100.,
99.24724/100., 98.06532/100., 98.80880/100., 99.17989/100.,
99.67514/100., 99.67302/100., 99.67117/100. };

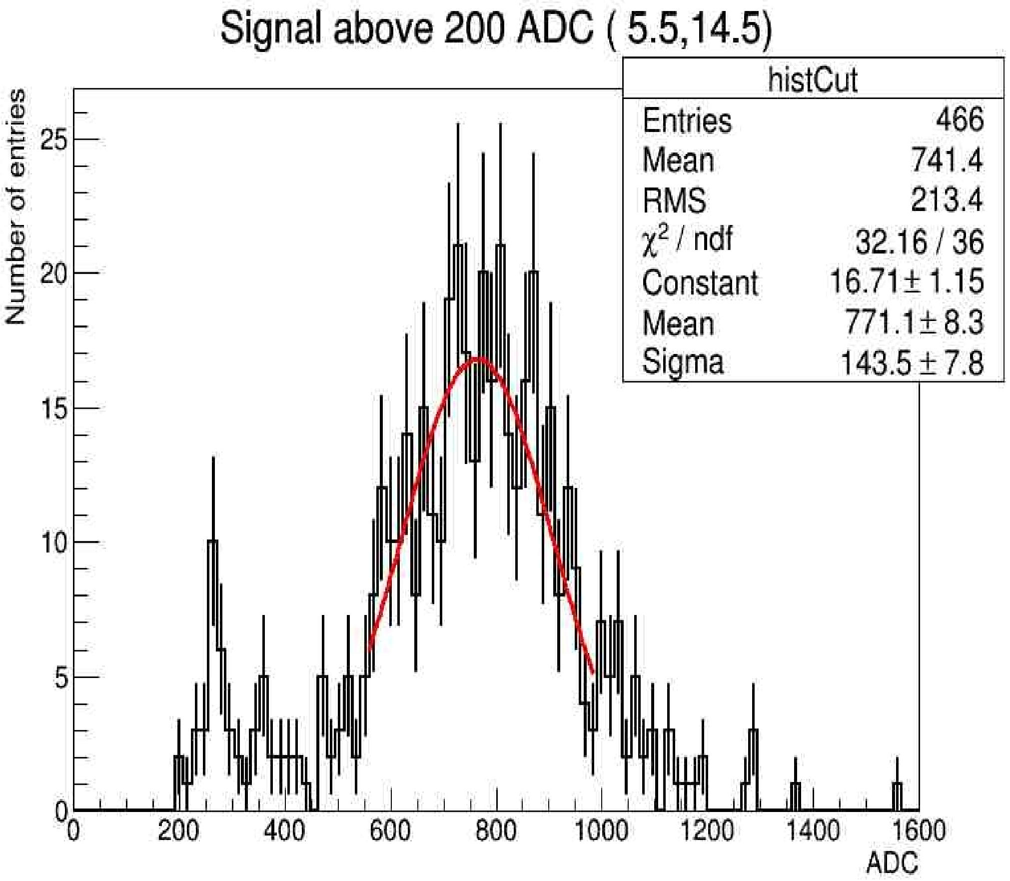




Electron falls vertically. Simulated value of SiPM shift is (0.0, -0.5, -0.95) mm.
Optical photons and SiPM located in the center of the tile.

# Examples of signal distributions in data

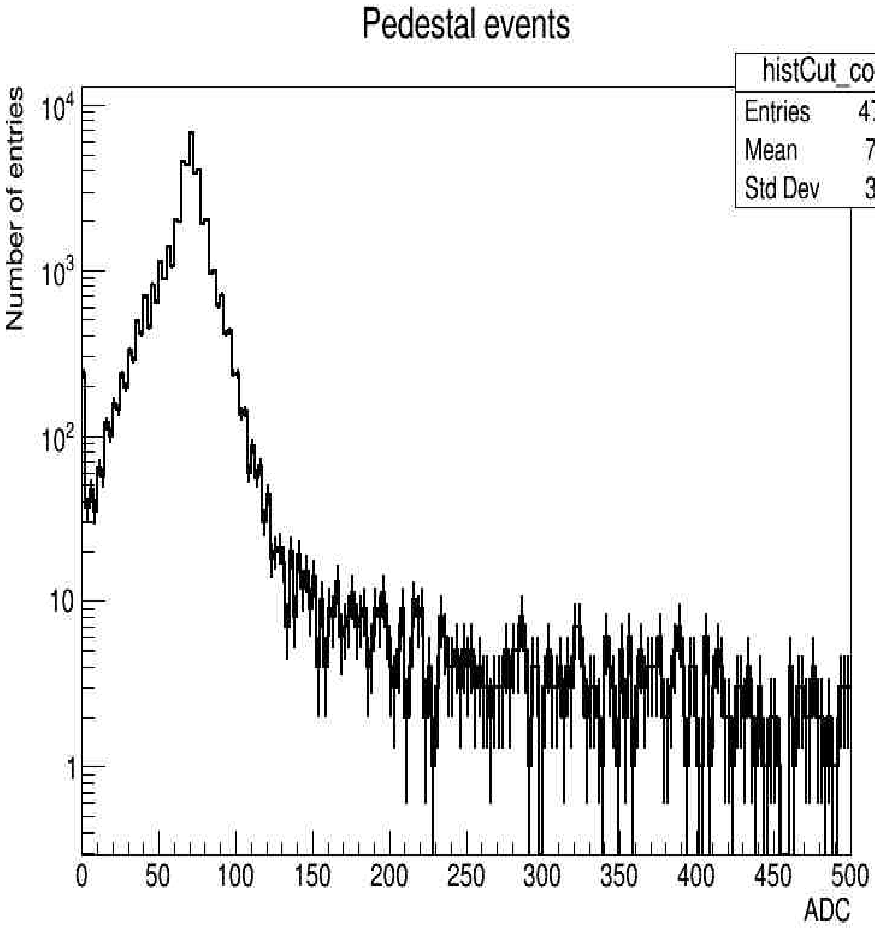


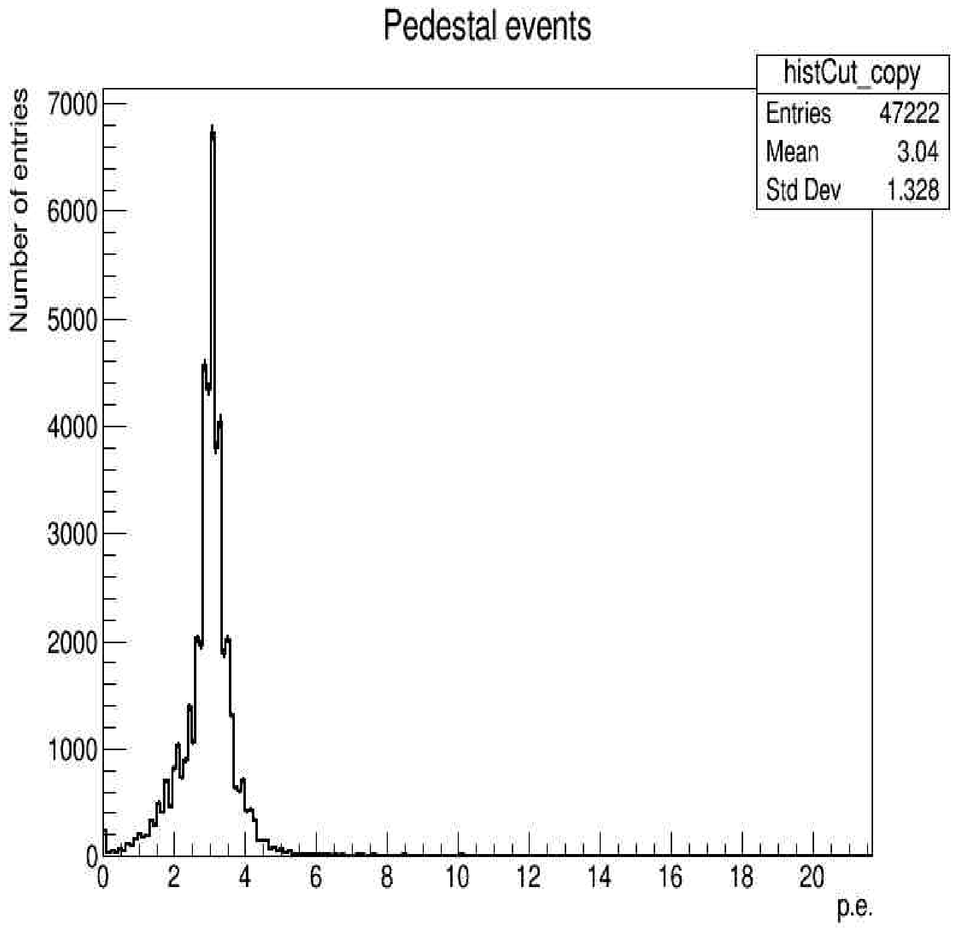




Gaussian fit in the range ± 1.5 RMS

The sophisticated fit procedure was developed to achieve reliable fit results.

# Pedestal events in data




More than 98% of pedestal events are below 200 ADC ( A[p.e.] = A[ADC] / G ).
Measured gain G = 23.11 ADC.

# Digitization of Monte Carlo samples

G4 simulates ionization losses and optical photon transport.
Photon detection in SiPM is not simulated.
The output contains number of photons, which reach SiPM window, $N_{photonsInSipm}$, in each event.

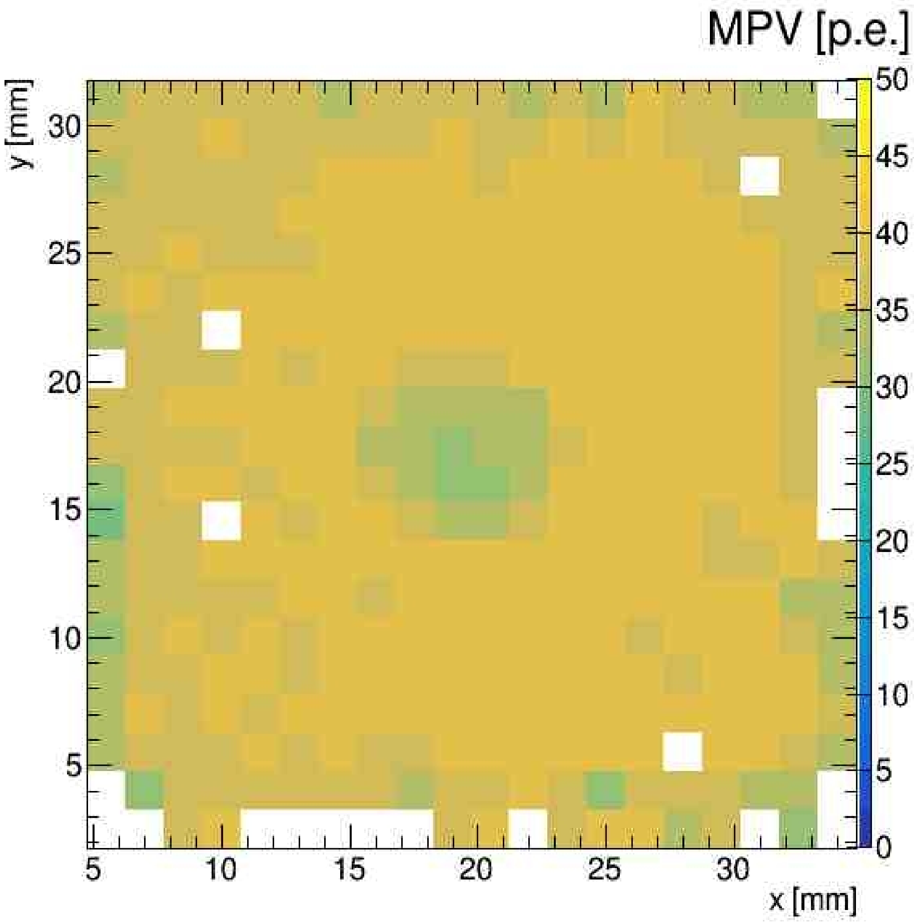
Digitization takes into account quantum efficiency and noise:

- Number of photoelectrons (fired pixels) is calculated as
  $N_{p.e.} = Poisson(QE*N_{photonsInSipm})$
  QE – quantum efficiency (typical values 0.1-0.3)
  QE = 0.15 in this study

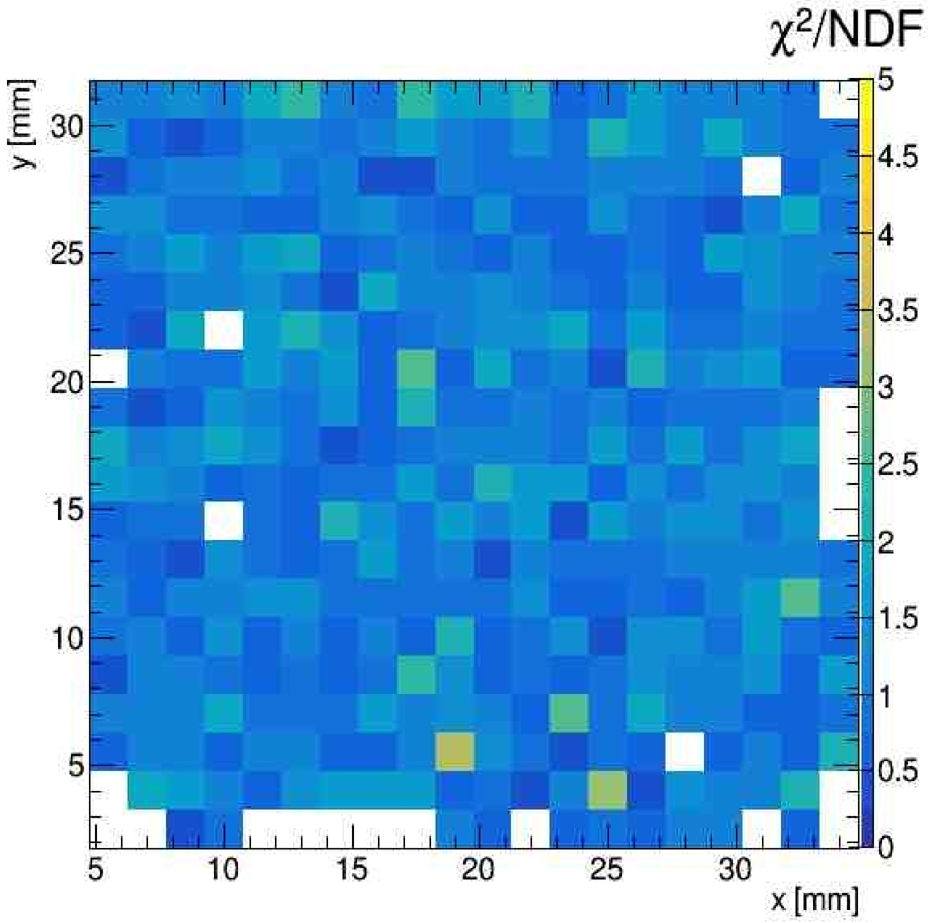
- Gaussian noise is added to signal in each event
  Gaus(mean,sigma)
  Typical mean values 1-3 p.e.
  Gaus(3,1.5) used in this study to emulate noise

# Map of MPV: experimental data

Data



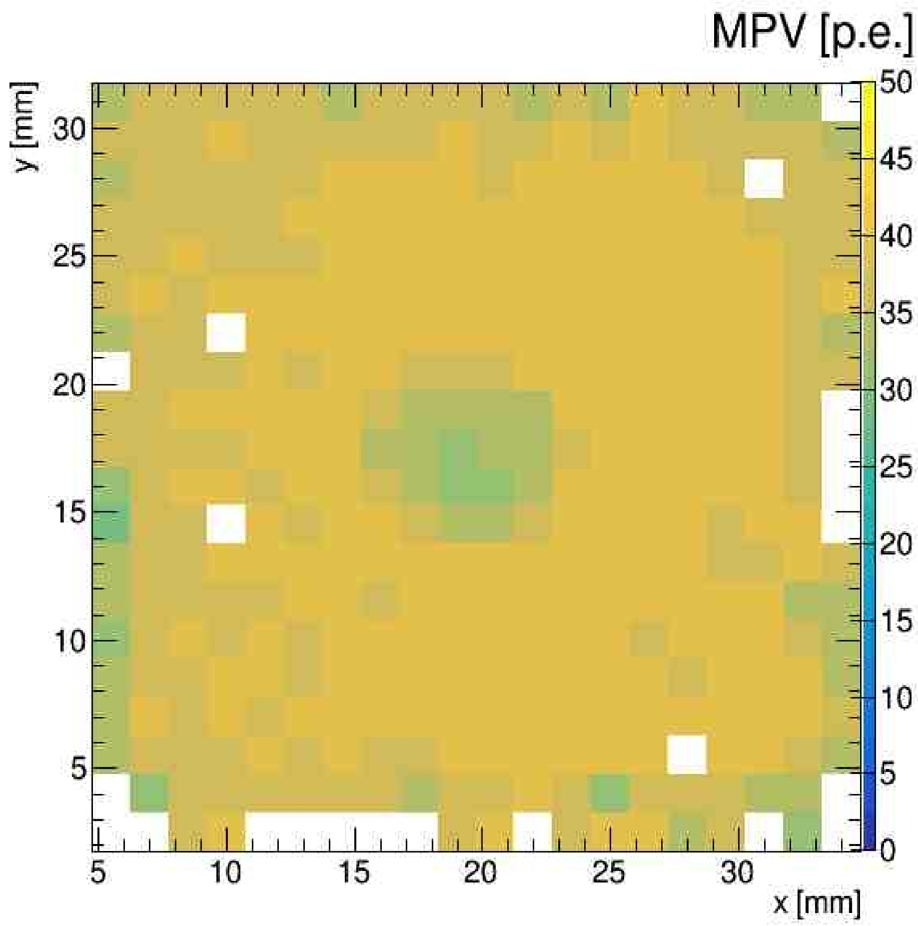

Data




The points w/o reliable fit results (white squares in the Chi2/NDF plot) are excluded from the uniformity estimation.

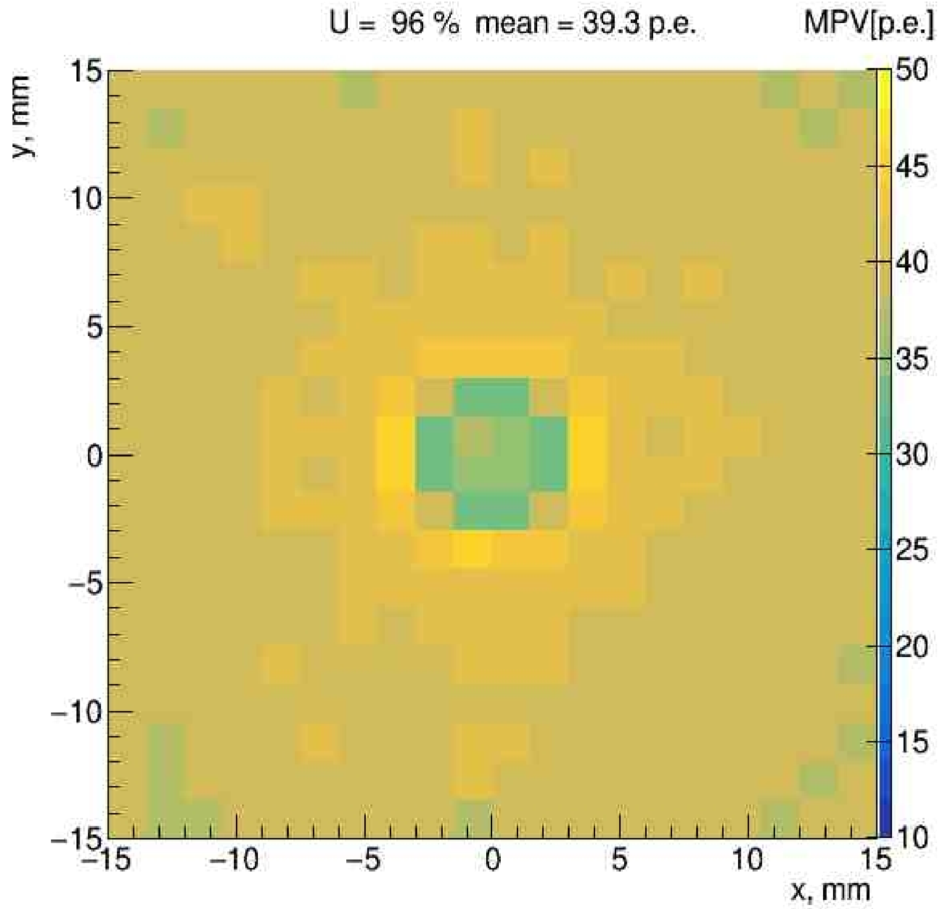
# Comparison of data and MC

**Data**




<p.e.>=37.1; U = 96%

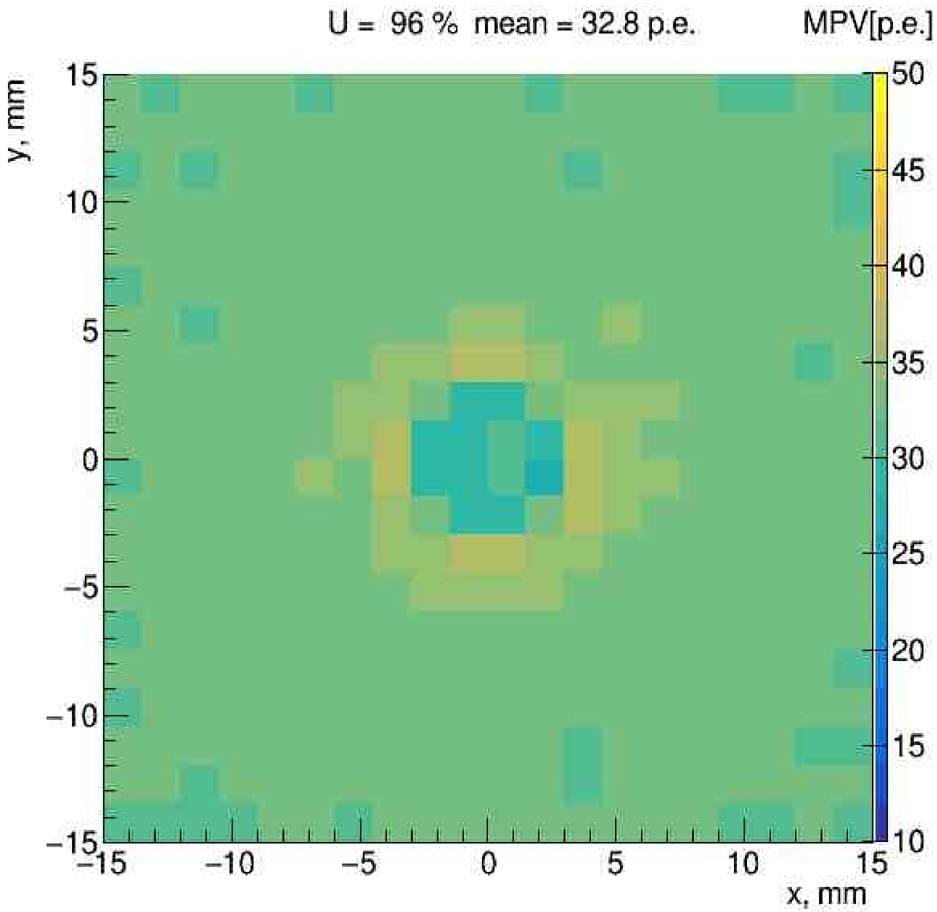
**MC**
-0.5 mm




<p.e.>=39.3; U = 96%

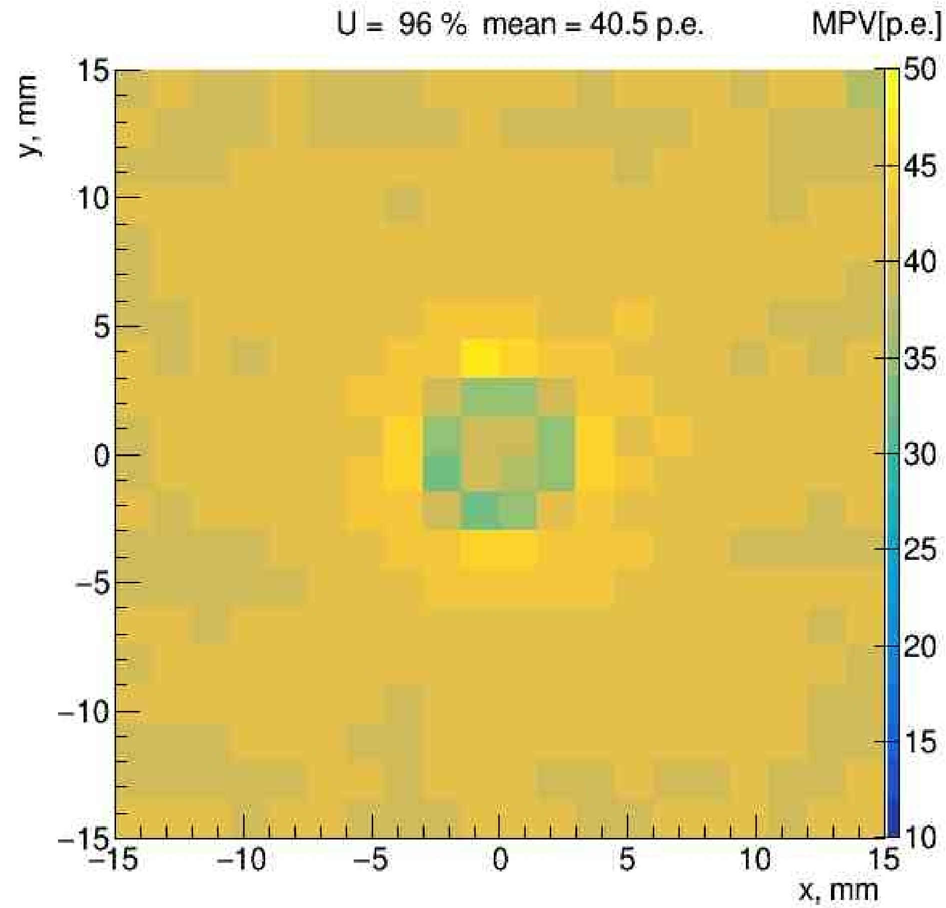
# Comparison data and MC (diff. SiPM position)

**MC**
0.0 mm



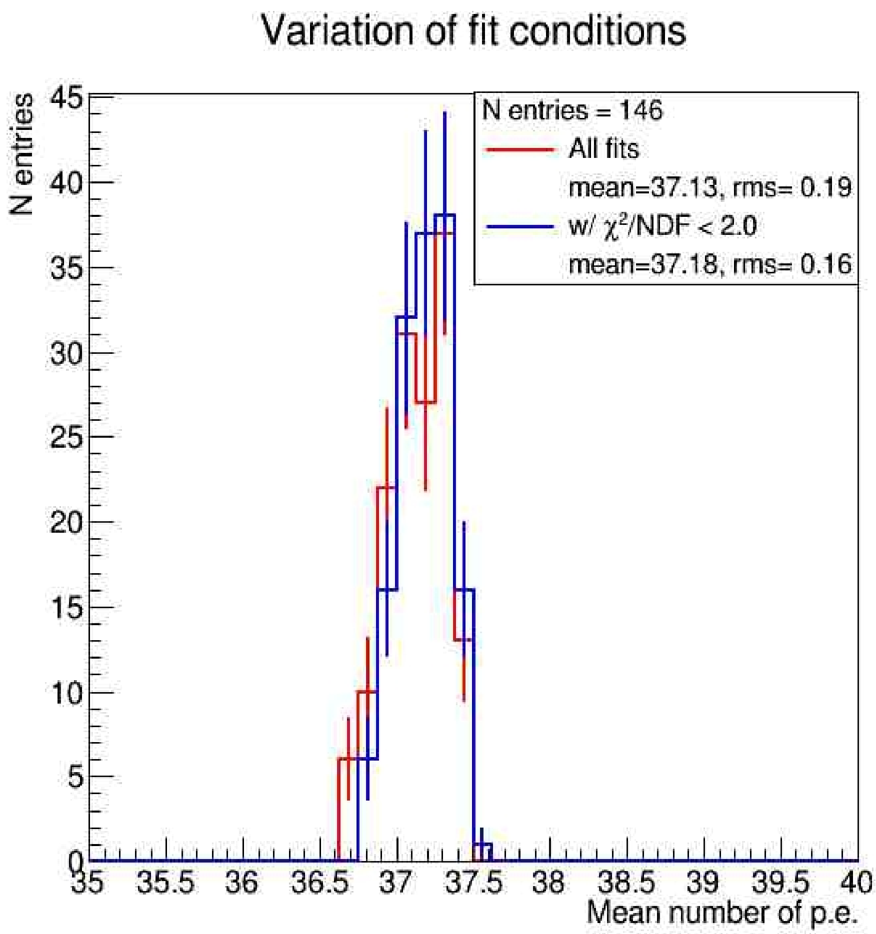

<p.e.>=32.8; U = 96%

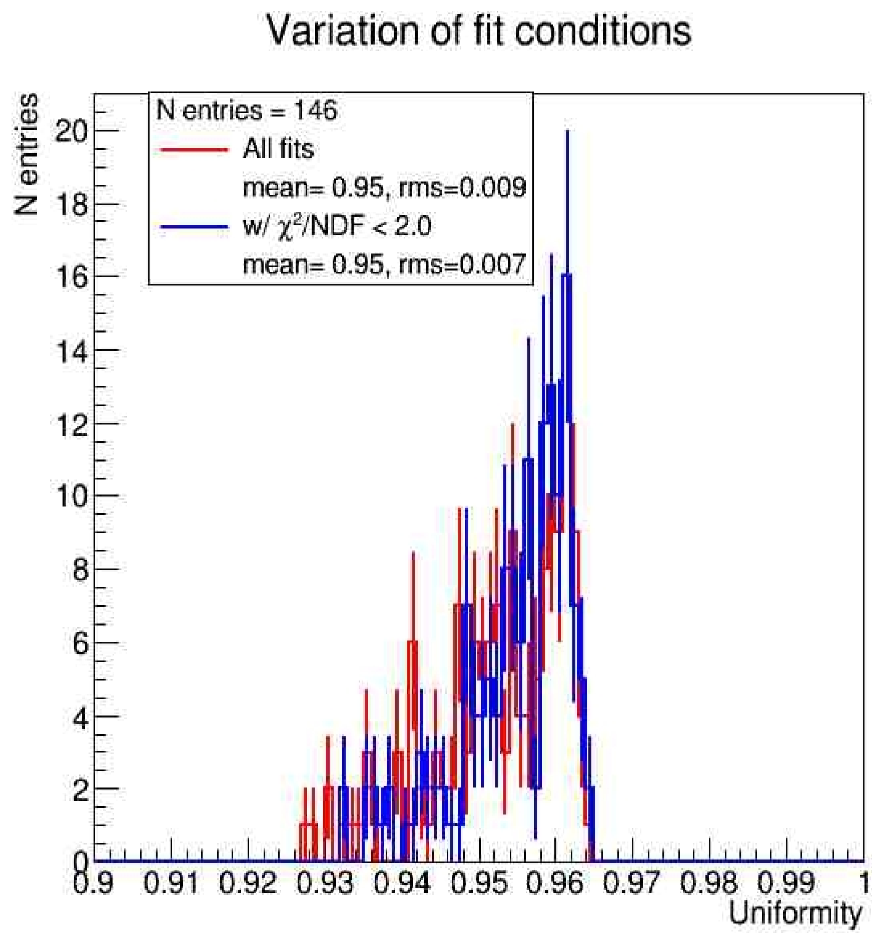
**MC**
-0.95 mm




<p.e.>=40.5; U = 96%

# Systematic uncertainties from fit conditions




Uniformity and <p.e.> were estimated for different fit conditions:

- 1.3 rms ≤ fit range ≤ 2.0
- 300 ≤ upperADCcut ≤ 600
- 7.5 ADC ≤ bin width ≤ 30 ADC

# Results

**Uniformity = 1 – r.m.s. / <MPV>**

| BICRON408 | SiPM position w.r.t. tile plane [mm] | Average MPV [p.e.] | Uniformity |
|---|---|---|---|
| Data | ? | 37.1±0.6 | 95.5±3.6% |
| MC | 0.0<br>-0.5<br>-0.95 | 33±3<br>39±4<br>40±4 | 96.4±3.4%<br>96.2±3.4%<br>96.5±3.4% |

**<MPV>**: uncertainty of data is dominated by the systematic uncertainty in SiPM gain determination; uncertainty of MC is dominated by the systematic uncertainty of our knowledge of quantum efficiency (photon to photoelectron conversion factor).

**Uniformity**: uncertainty is dominated by the statistical uncertainty.

# Conclusions

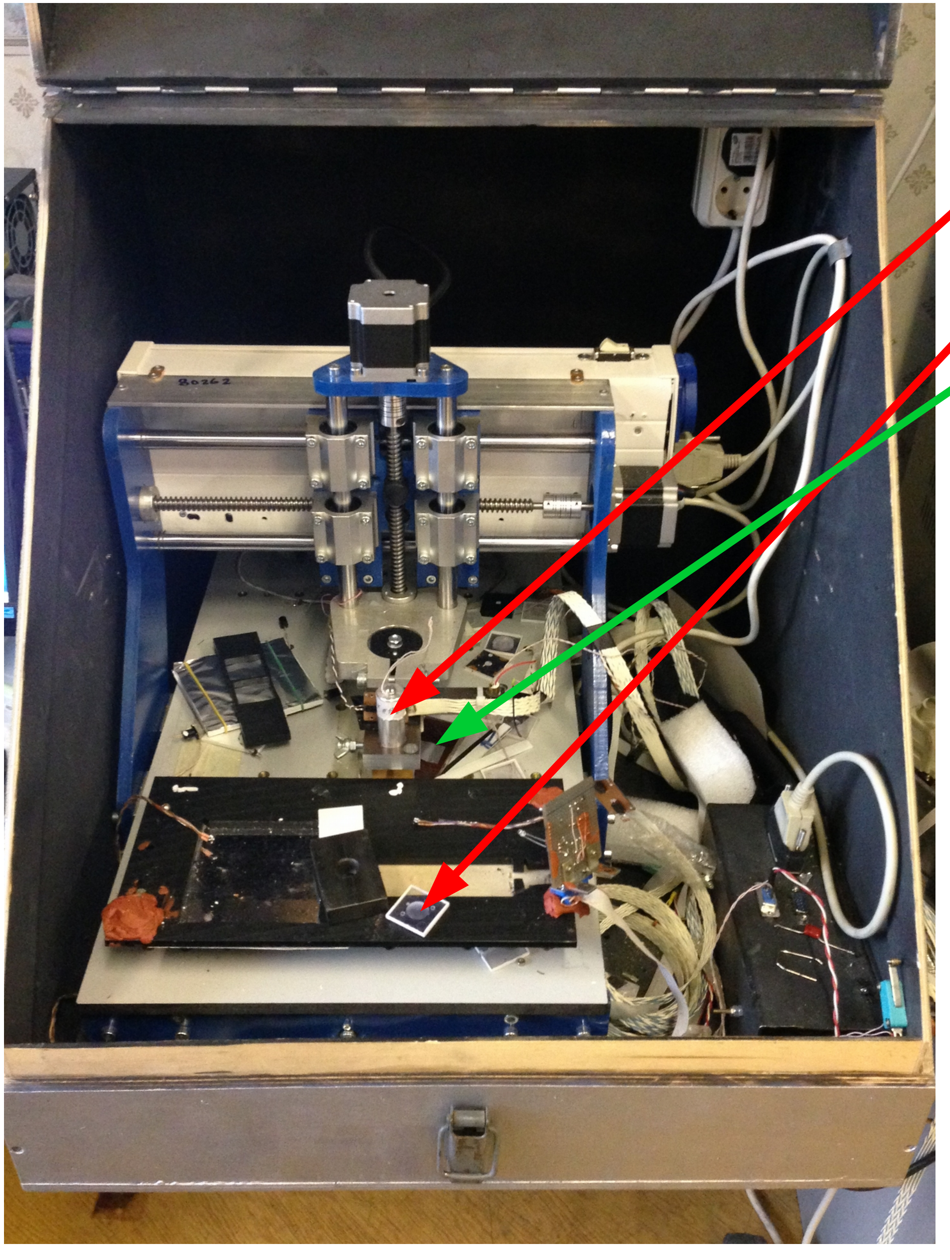
- The response of scintillator tiles (BICRON408) to minimum ionizing particles were measured and simulated using Geant4 package. Good agreement between data and simulations is achieved in the uniformity estimates.

- The simulation were performed for different SiPM positions with respect to the tile surface. The number of collected photons increases with increasing of the SiPM deepening inside the dimple.

- Low number of events at the edge points (tile boarder) in data can be explained by the noisy photodetector of the trigger tile: noticeable fraction of electrons, which partially cross the tile and do not reach the trigger tile, are detected with the signal trigger set.  This effect was not simulated yet.

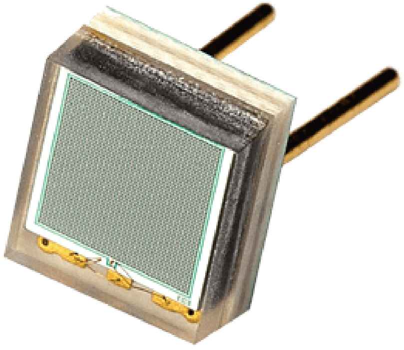
# Backup Slides

# Experimental setup



- Beta - source
- Tile
- Placement of the wrapped tile

# Application of SiPM in HEP experiments



SiPM

Cell of CALICE hadron calorimeter

**Current experiments (scintillator with WLS fiber):**

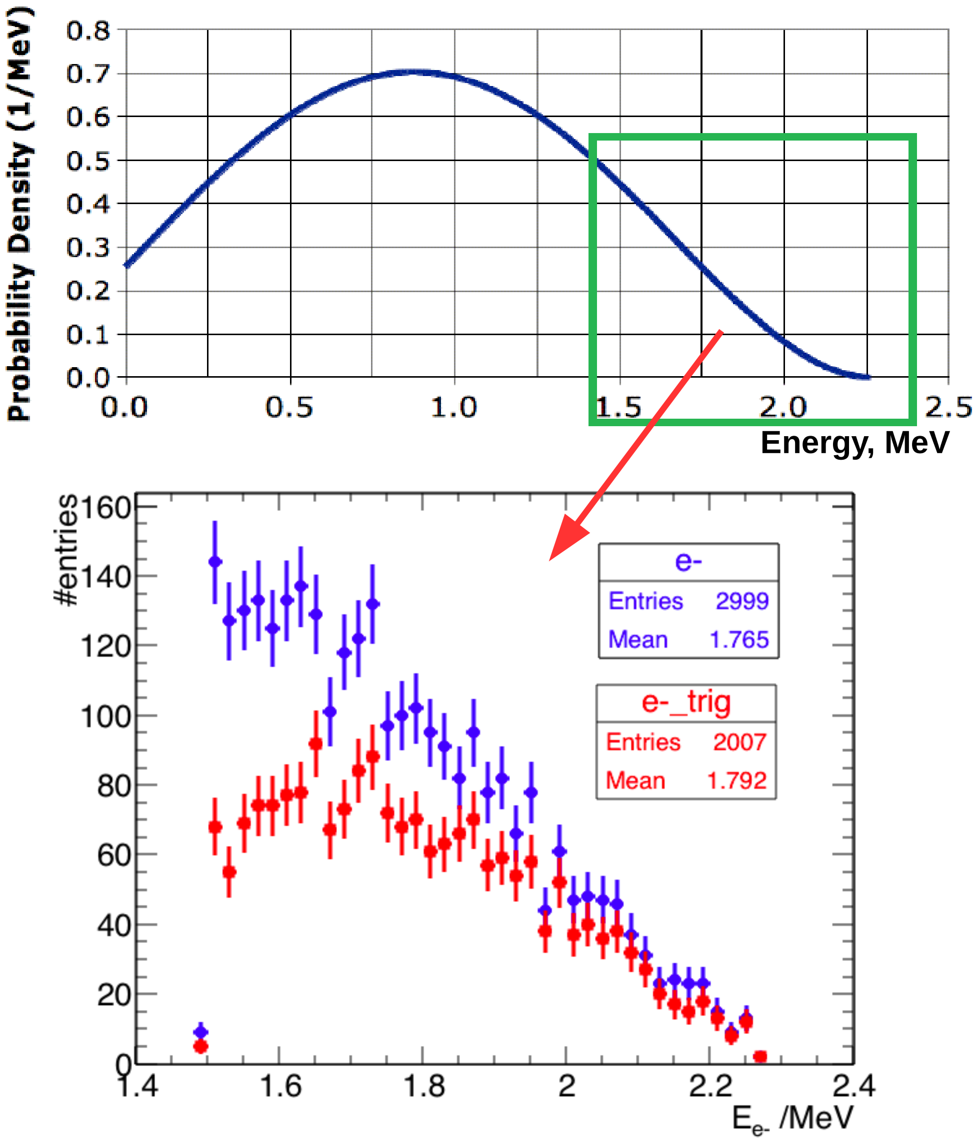
- CALICE: hadron calorimeter prototype (8000 channels, 3x3 $cm^2$ tiles)
- Belle II: muon system (scintillator strips)
- CMS: outer hadron calorimeter (HO)
- T2K: muon system (scintillator plates)

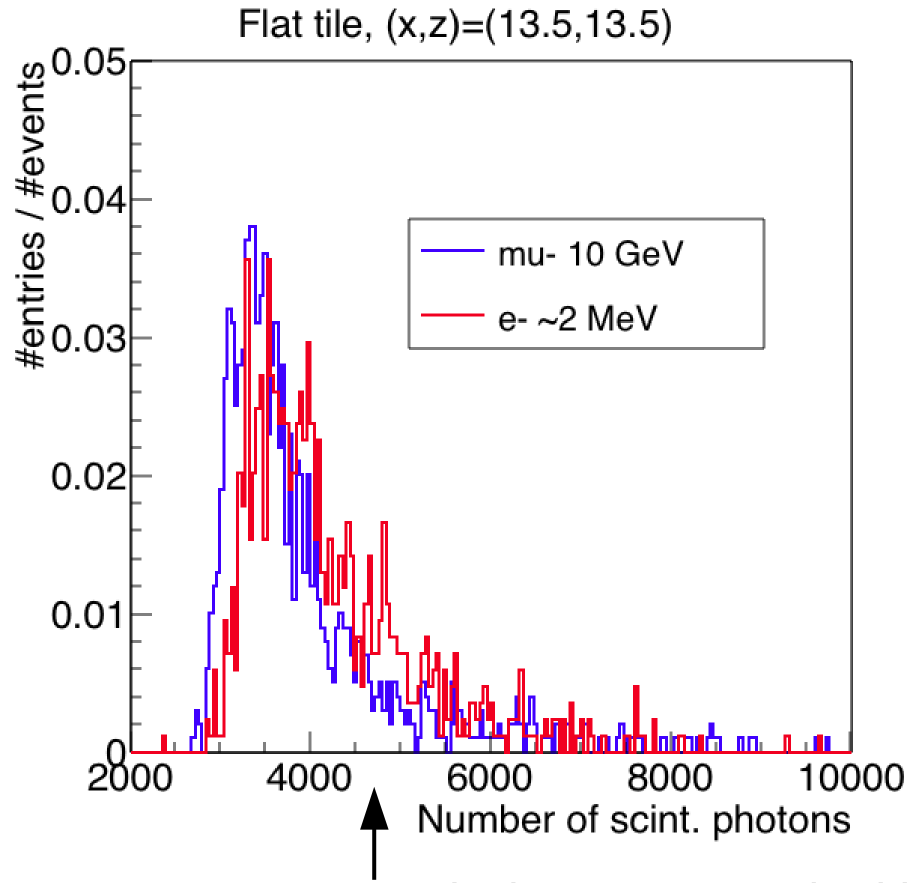
**Planned experiments (scintillator with direct readout):**

- CMS: upgrade of the endcap hadron calorimeter
- ILD: highly granular hadron calorimeter, tiles 3x3 $cm^2$ with direct readout

# Model parameters: source

β-decay of 90Sr: electrons up to 2.28 MeV
To emulate mip we use tail of energy spectrum

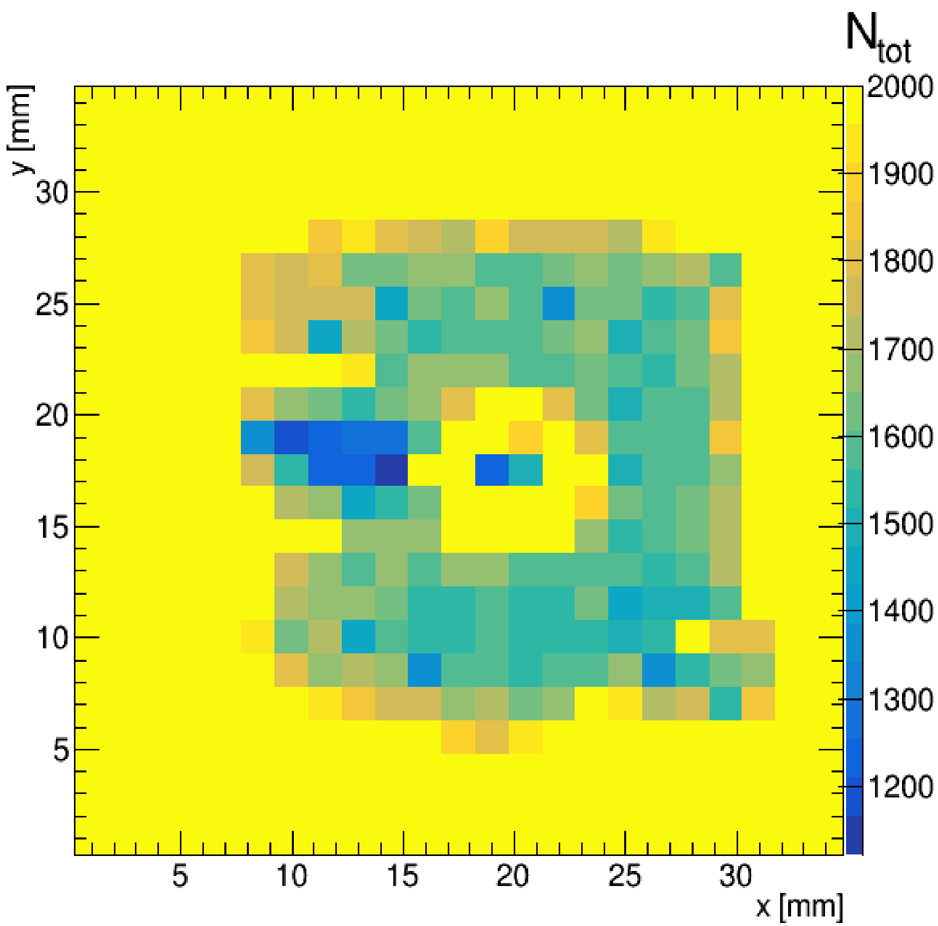


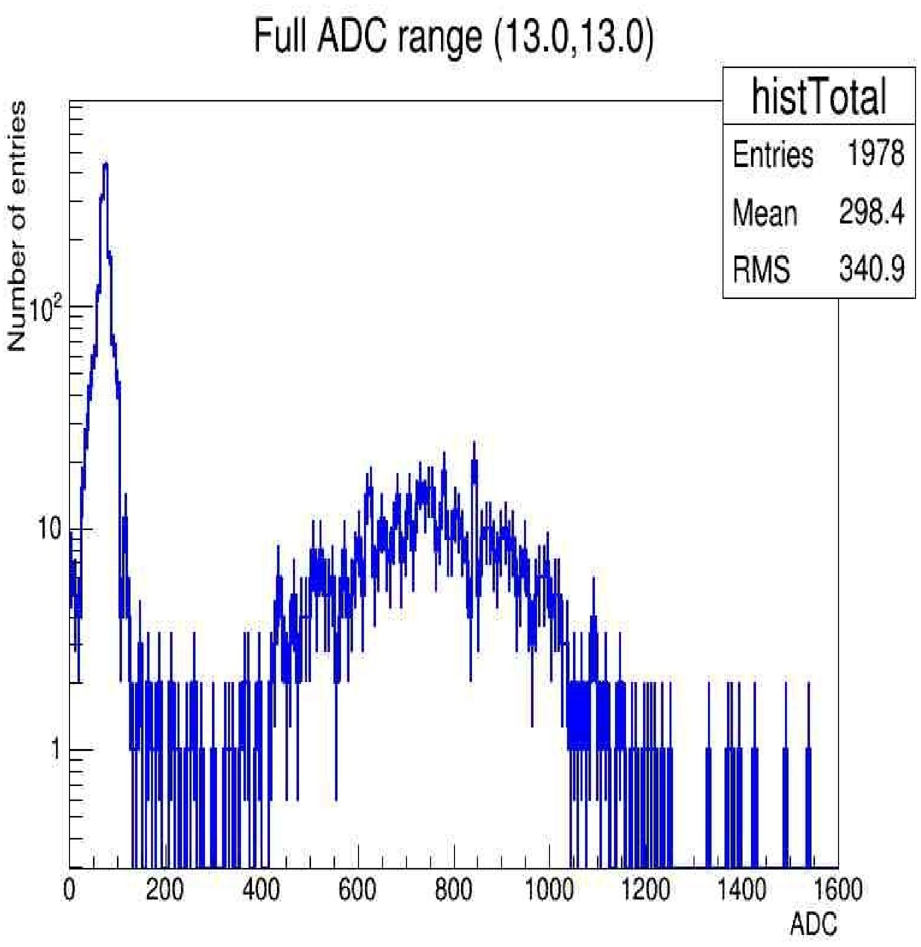




Compare «true» mip (muon 10 GeV) with electron from β-source

In simulation:
plain source 2x2 $mm^2$ (1.4x1.4 $mm^2$)

# Response to minimum ionizing particles: tile from BICRON408

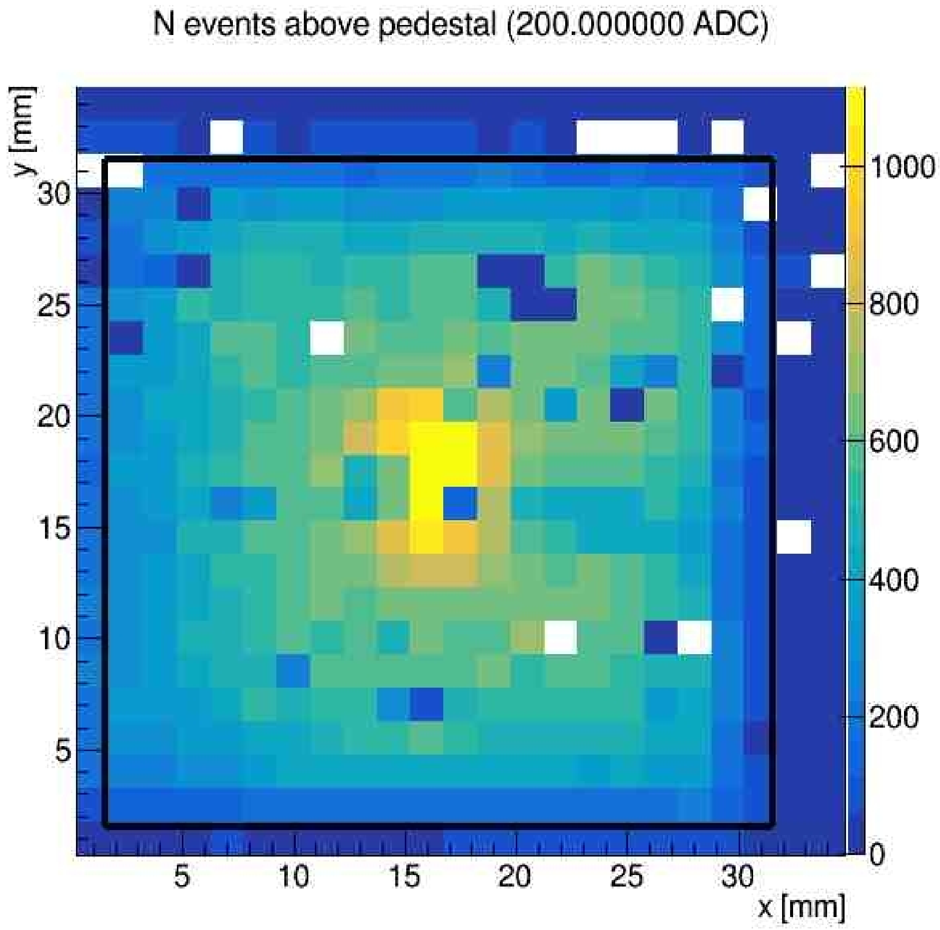



Signal events are above 200 ADC

BICRON408 tile, scan step = 1.5 mm

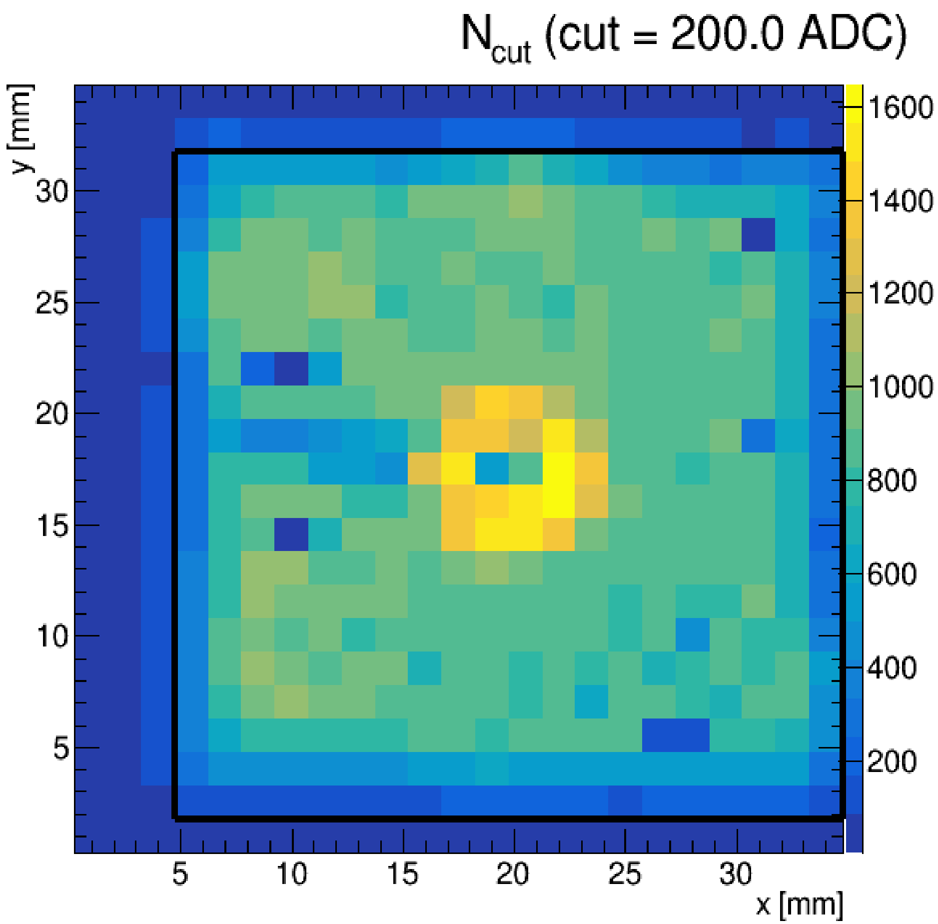
# Identification of tile position

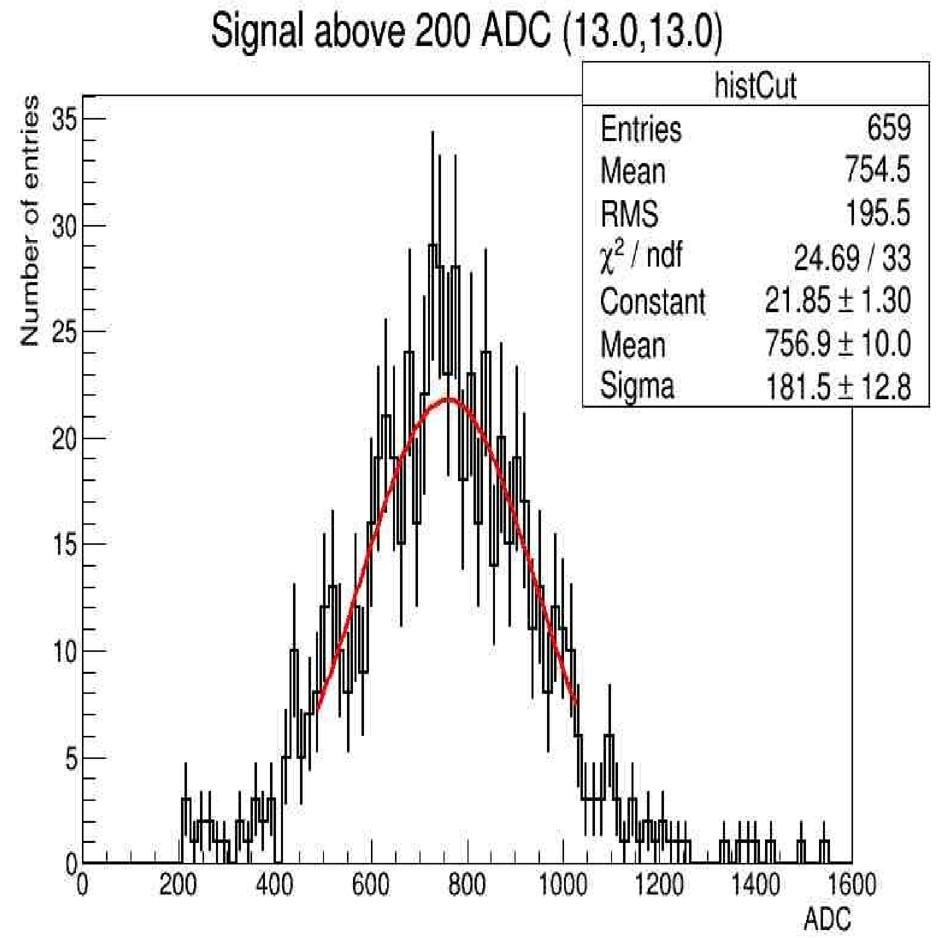



BICRON408 tile
scan step = 1.5 mm

- Tile size: 30x30 $mm^2$
- 20x20 points for 1.5 mm scan
- The measurements over the area greater than tile
- We use the maximum number of events to get border of the tile and calculate uniformity of the tile

# Examples of signal distributions

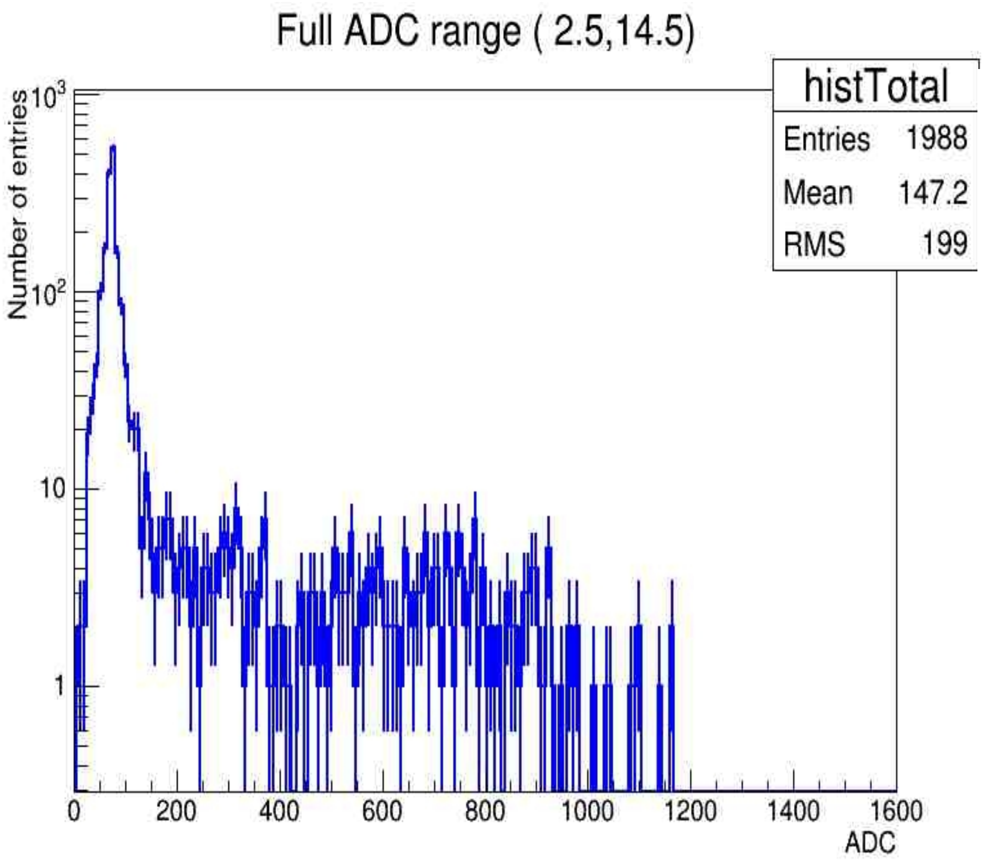


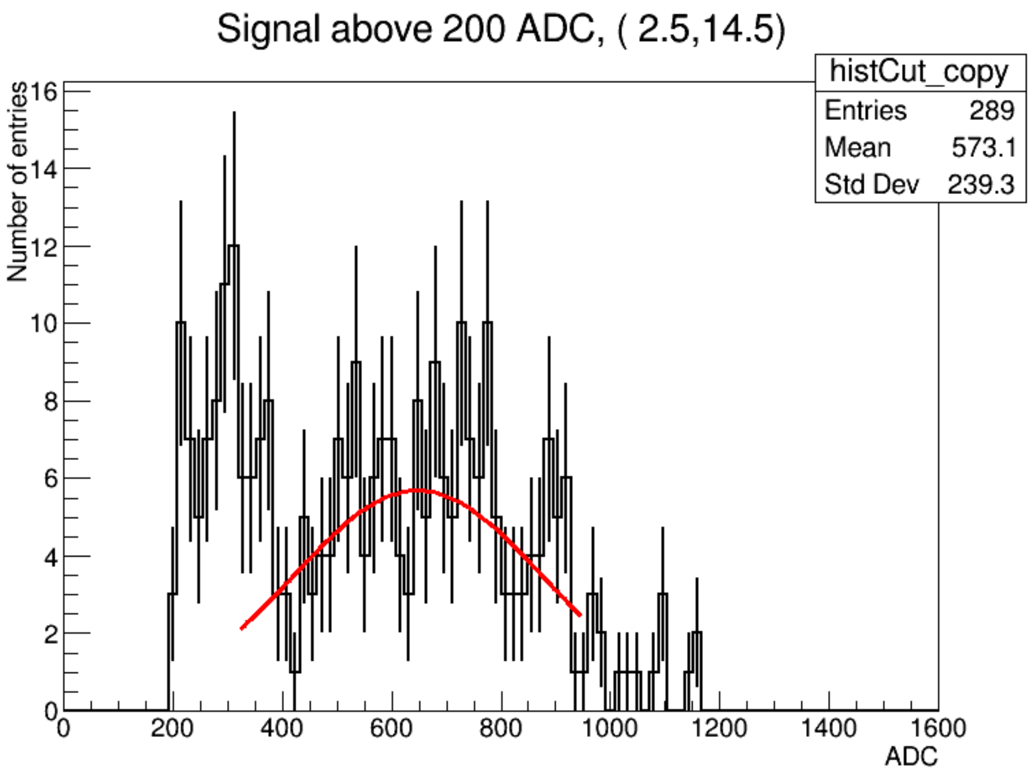




Number of events after pedestal rejection

Good Gaussian fit

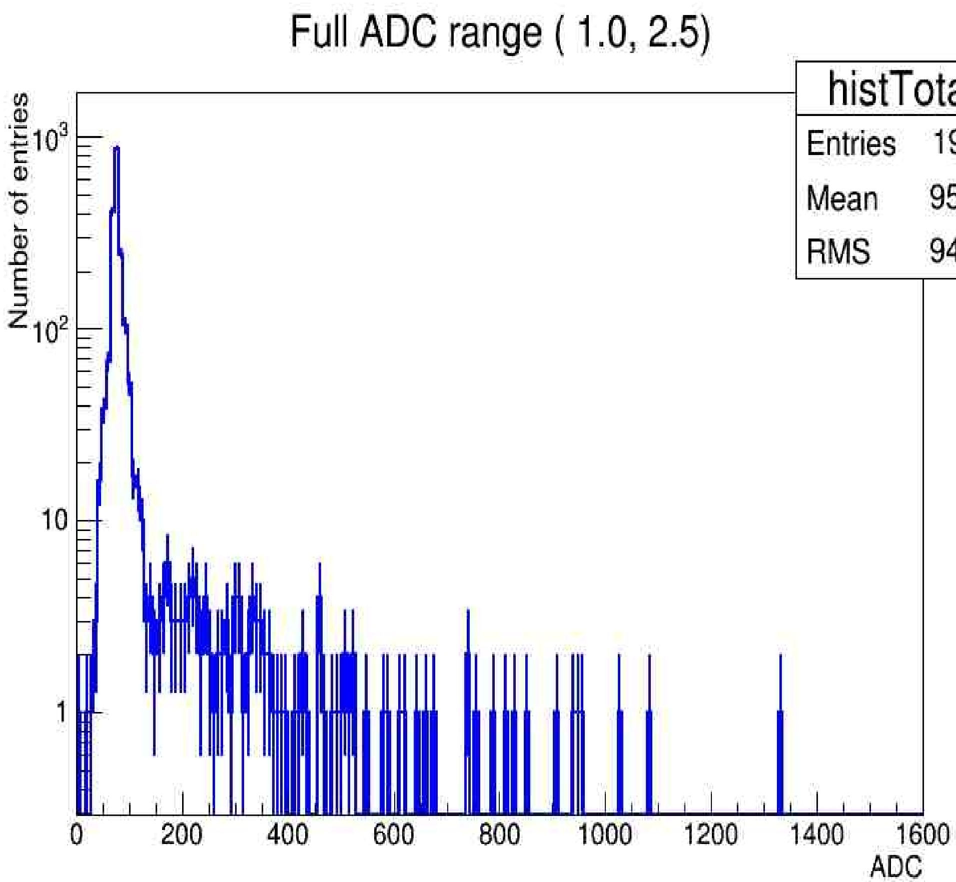
# Examples of signal distributions

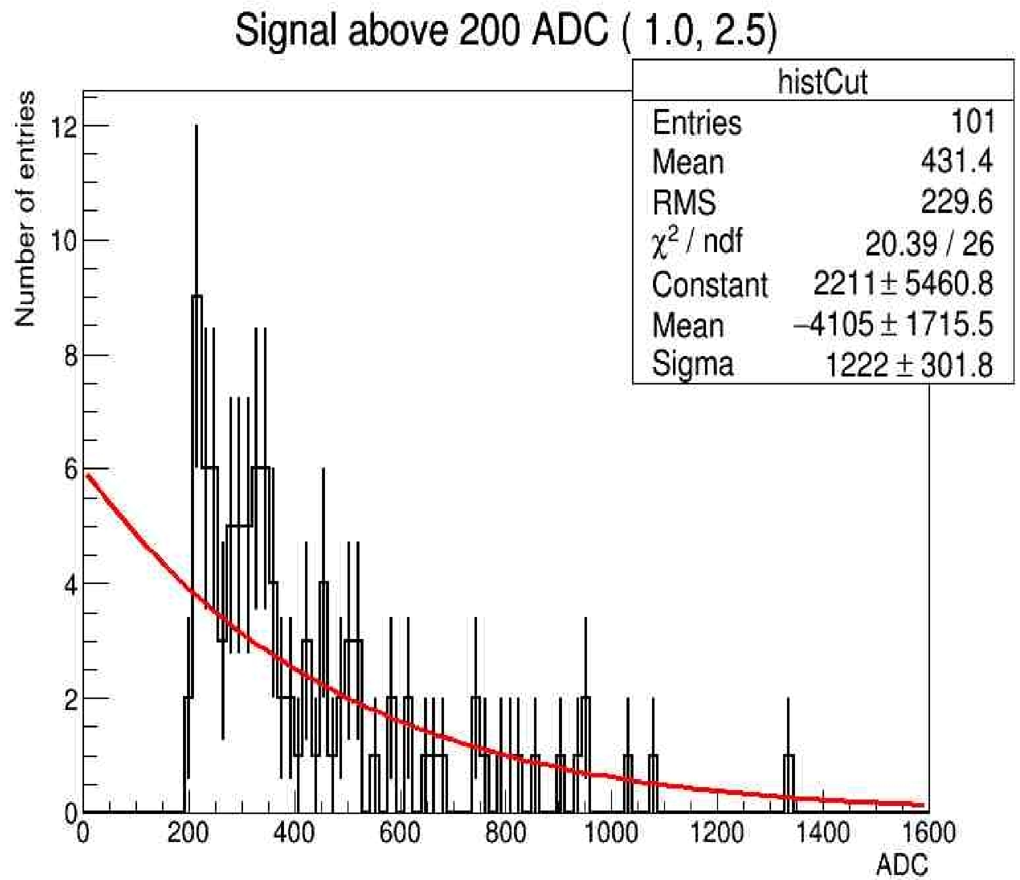



We take mean of signal sample instead of fit if the fit is bad

# Examples of signal distributions

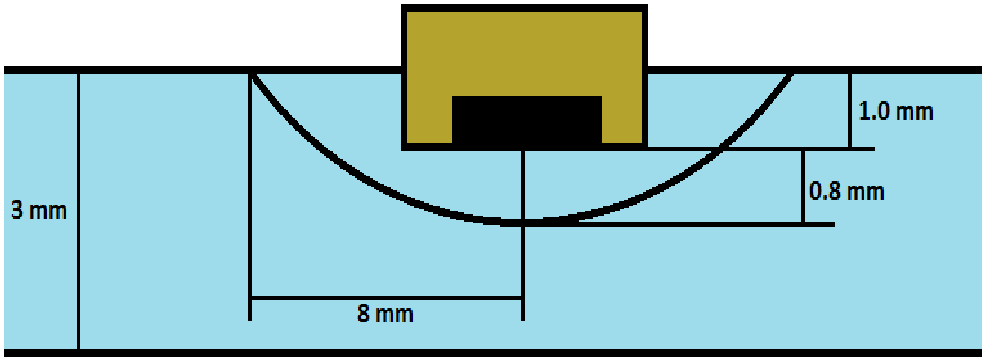



Samples with small number of signal events are outside the tile border

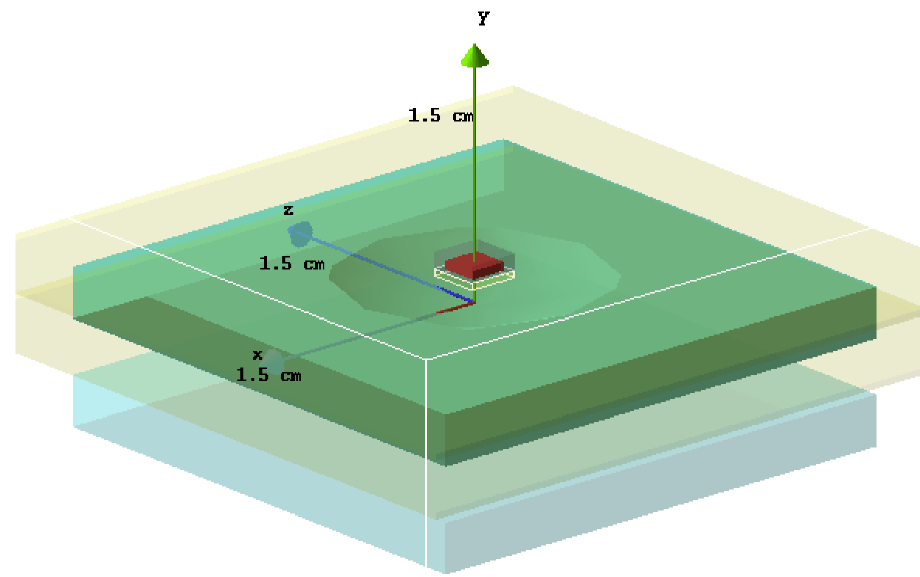
# Cell model with direct readout

- We simulated flat tile and tile with dimple ( spherical and parabolic shapes )
- For direct readout approach the shape of tile surface need to be modified to improve the uniformity of response




Tile: 30 x 3 x 30 mm$^3$
SiPM box: 3.8 x 1 x 3.8 mm$^3$
SiPM: 2.2 x 0.5 x 2.2 mm$^3$
(schema not to scale)

Isometric view of tile with dimple




Reflective foil: 40 x 0.4 x 40 mm$^3$
Side cover: 0.2 x 3 x 30 mm$^3$
Epoxy: 3 x 0.4 x 4 mm$^3$
Trigger tile below measured tile

Geometry parameters are the same as in experimental work **NIM A572 (2015) 45**

# Optical properties for BICRON408

- Light yield of 408: 10000 photons per MeV
- Refractive index of 408: 1.58
- Absorption length of PS: 0.6 meter
- Reflectance of mylar: 0.99
- Reflectance of foil:
  0.00 (3.01 eV) – 0.99 (2.15 eV)

- Signal = number of photons in SiPM
- Quantum efficiency = 0.15
- SiPM internal structure not modelled