A Si-PAD and Tungsten based electromagnetic calorimeter for the forward direct photon measurement at LHC

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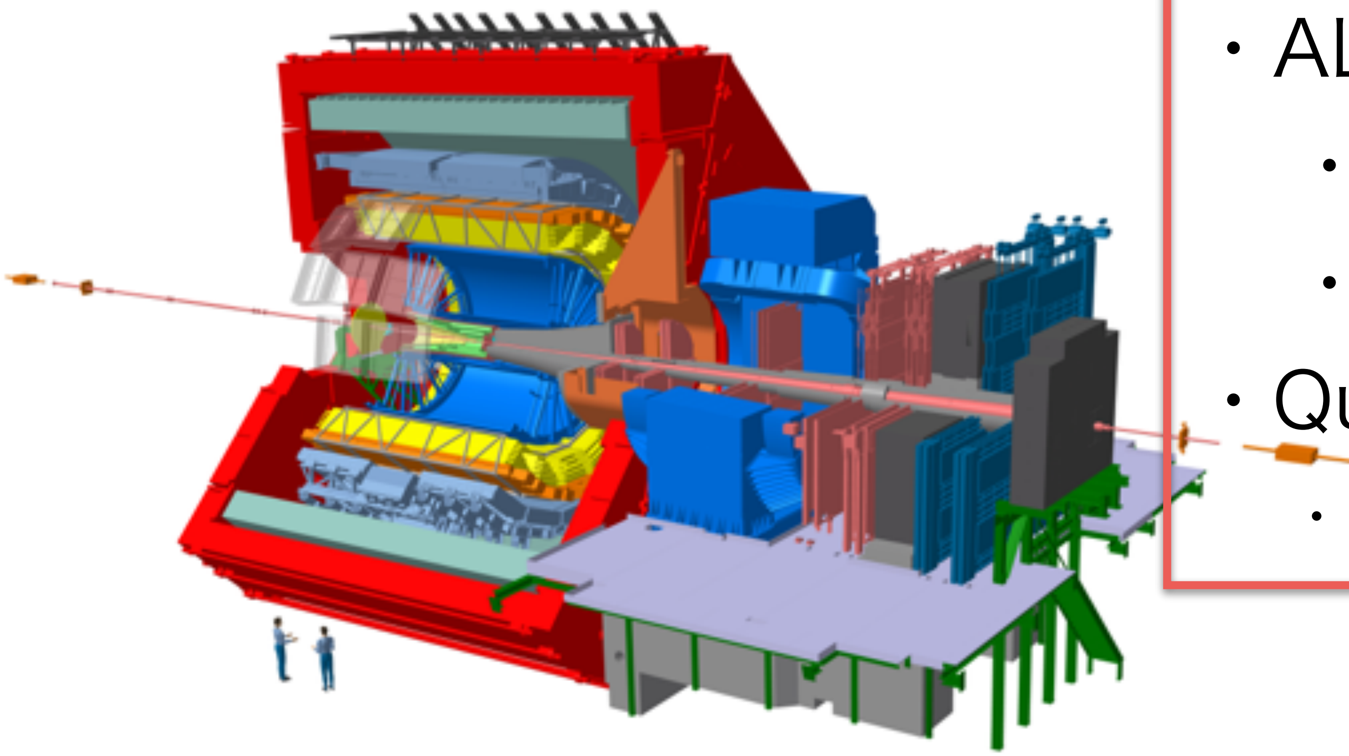
Outline

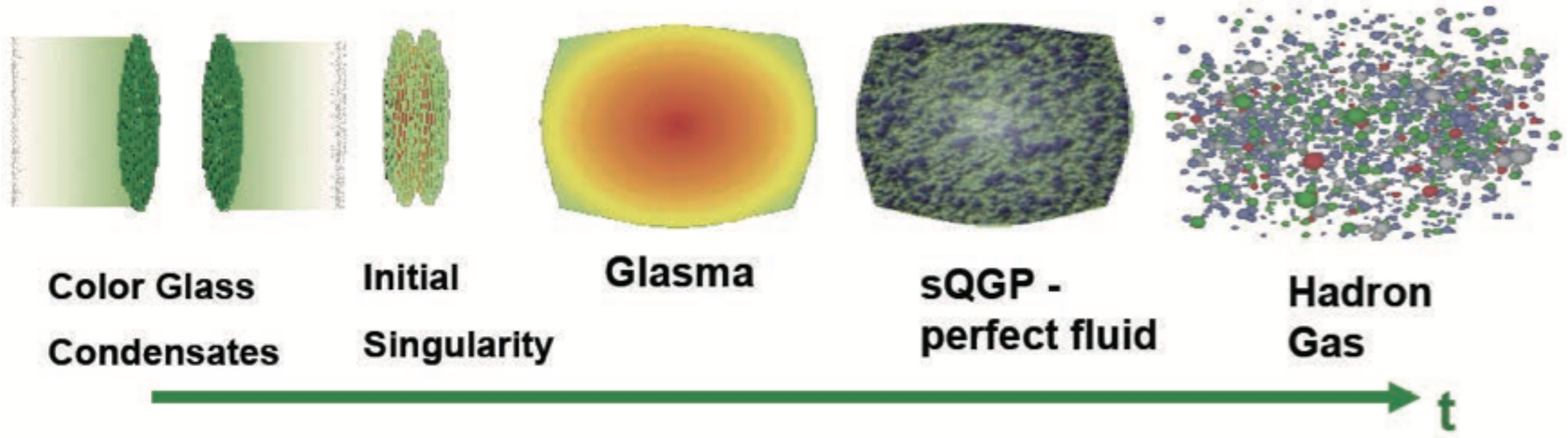
- Introduction
  - ALICE experiment at LHC
  - Motivation
- FoCal Project
  - FoCal-E prototype
- Our development of FoCal-E
  - Performance of Si PAD detector
  - Performance of the integrated system (Low granularity and High granularity detectors)
- Summary & Outlook

ALICE Experiment



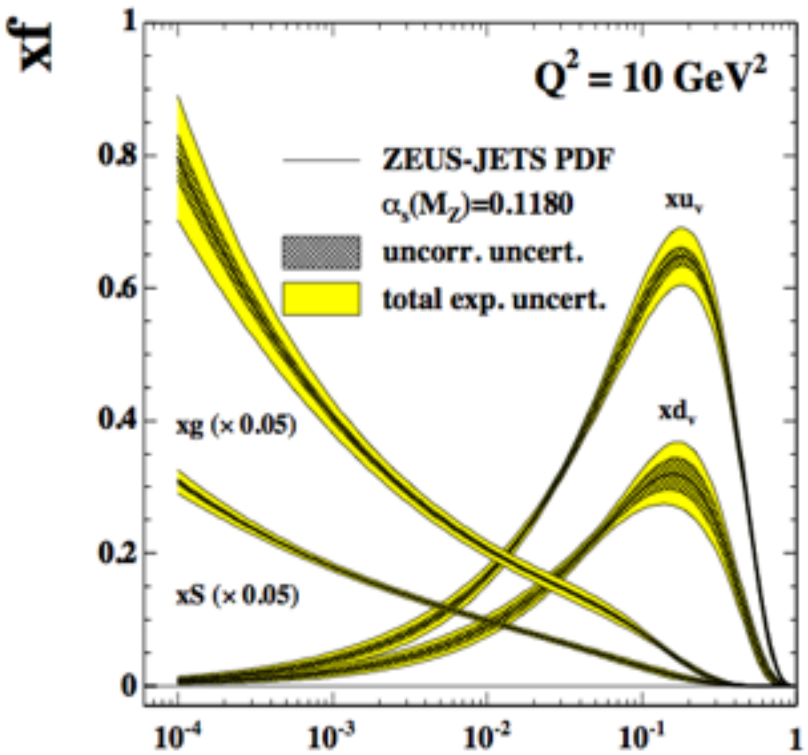
- ALICE experiment at LHC
  - Specialize in heavy ion collisions
  - Study **Quark Gluon Plasma**
- Quark Gluon Plasma (QGP)
  - **Quarks and gluons move freely**

Crucial input to QGP study:**properties of initial state of collision**

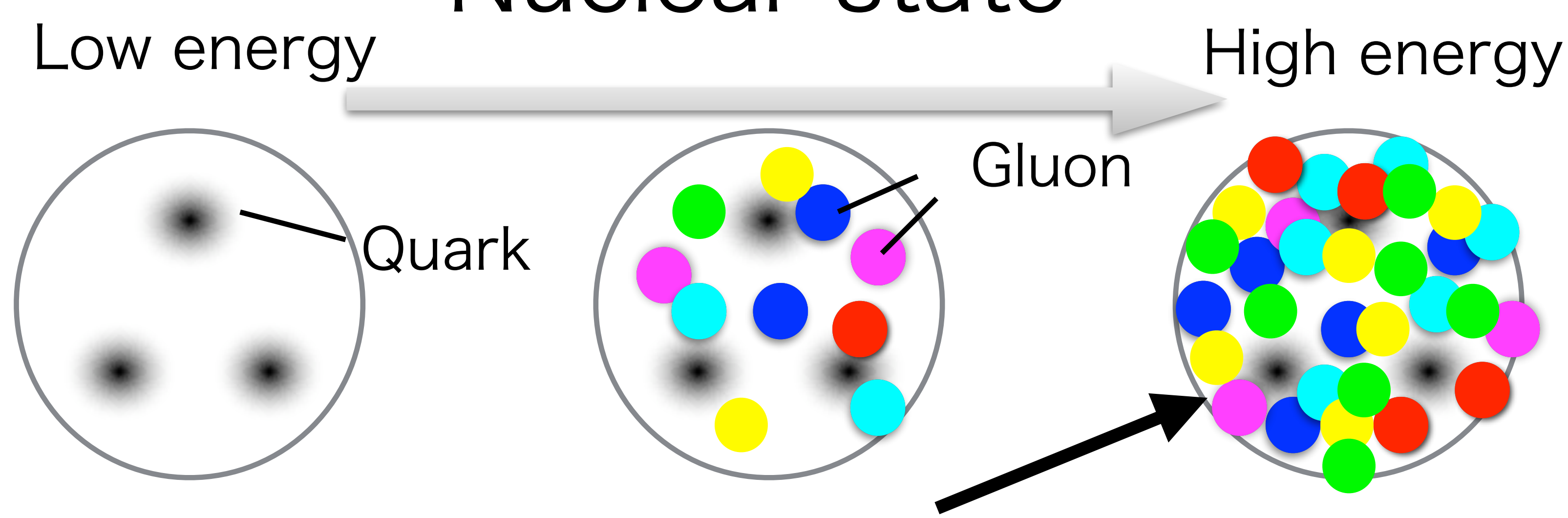


Motivation

Color Glass Condensate(CGC)



Nuclear state



Gluon saturation(CGC)

Bjorken-x

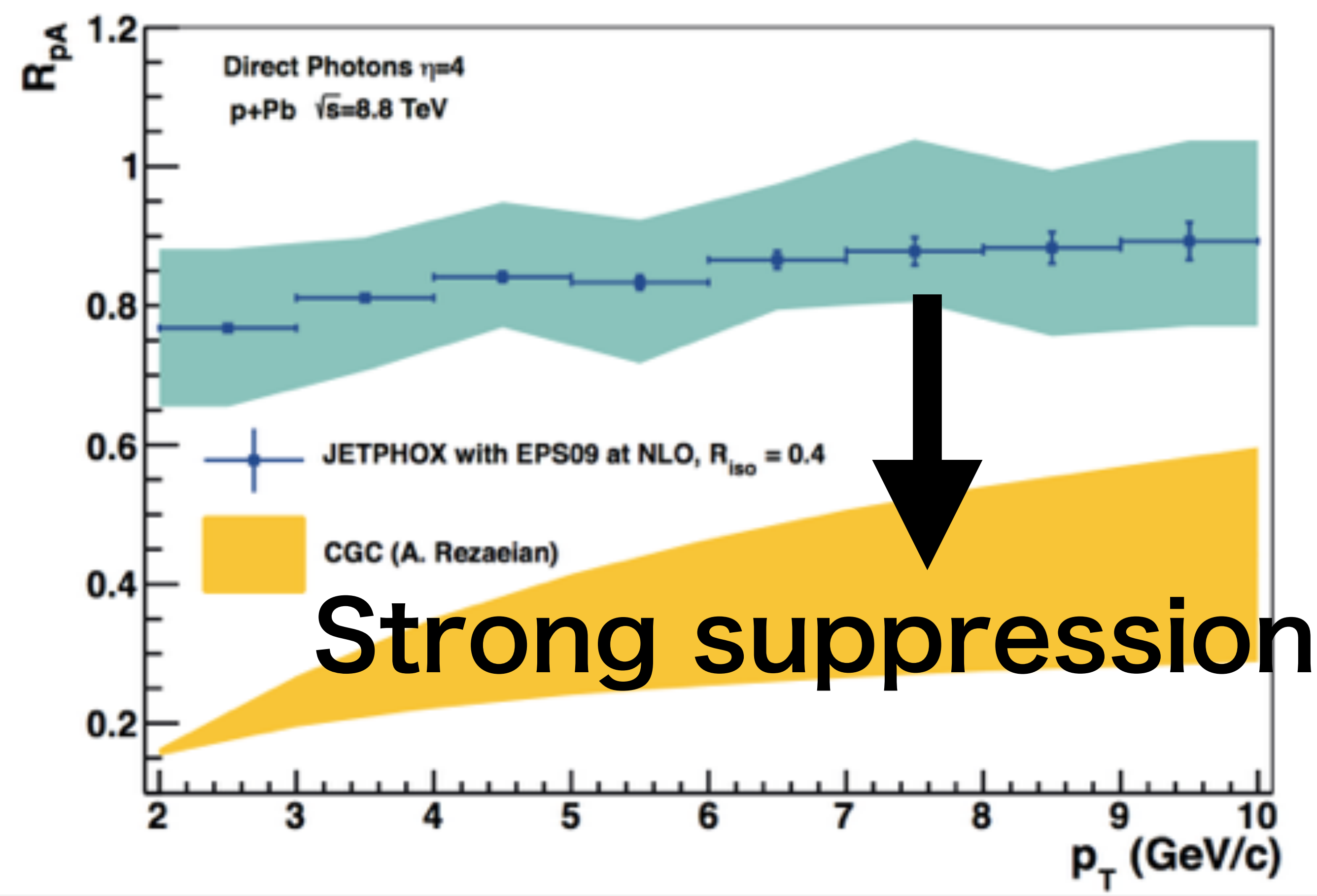
$$x = \frac{2p_T}{\sqrt{s}} e^{-y}$$

Small-x

$x \leq 10^{-4}$ · · CGC occurs

Experimental validation probe

Direct photon



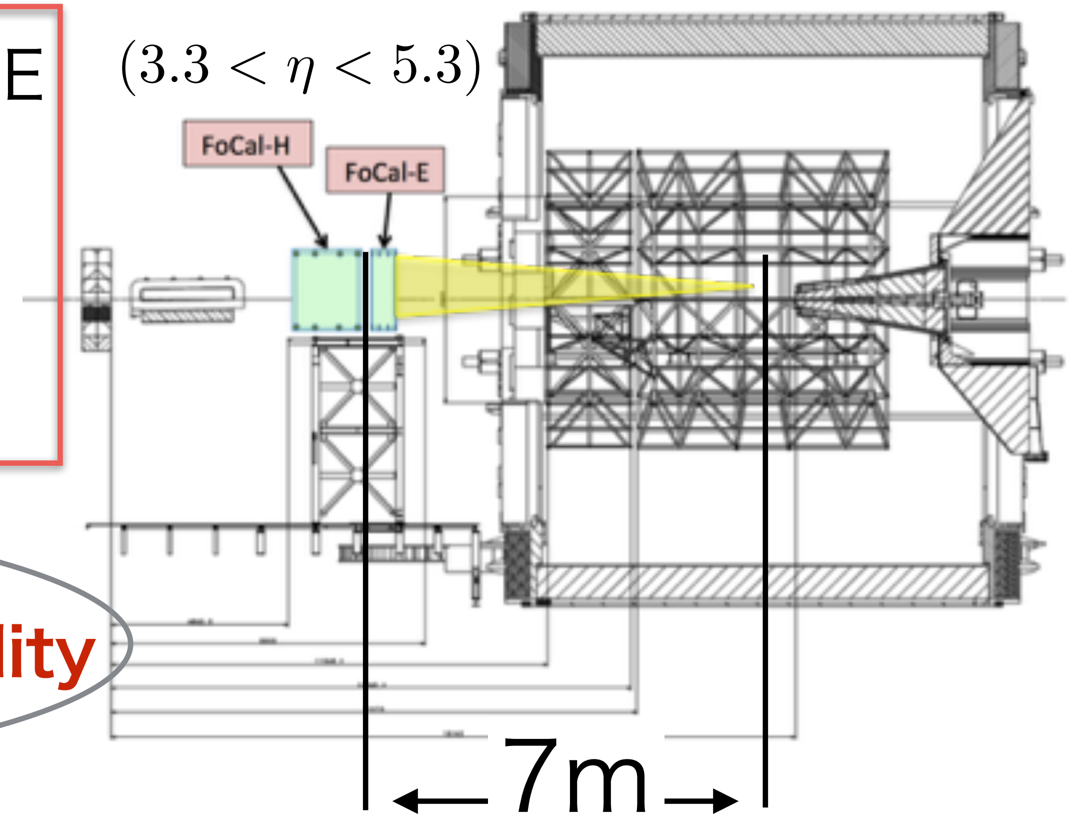
FoCal project

FoCal: detector upgrade proposed within ALICE

Components

FoCal-E : Electromagnetic calorimeter

FoCal-H : Hadron calorimeter



FoCal in ALICE detector

Main purpose

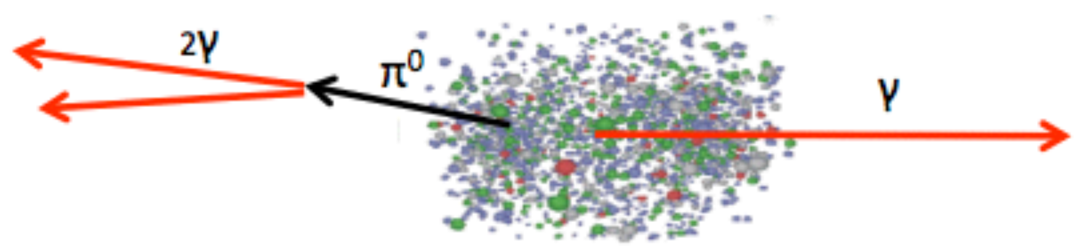
Measurement of direct photons at large rapidity

Explore small-x structure

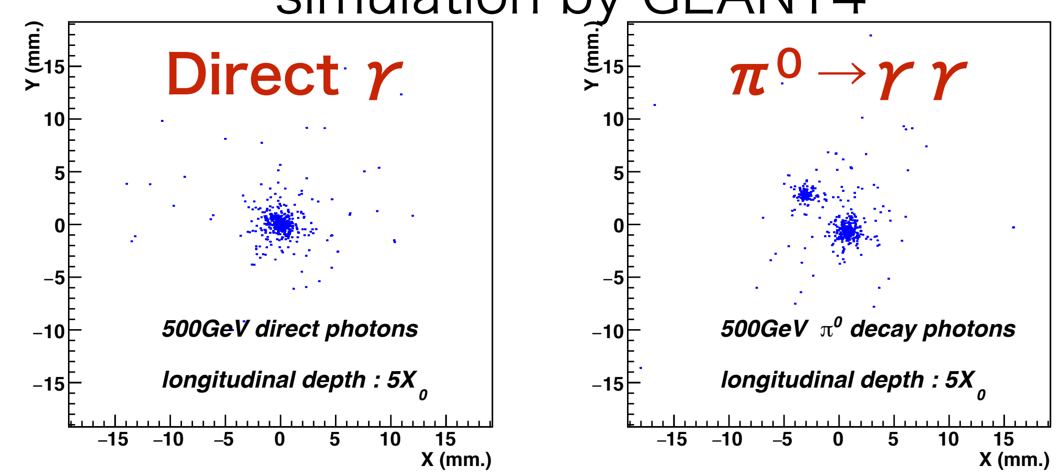
(initial state, CGC, etc・・)

Detector requirements

γ/π^0 separation



simulation by GEANT4



Excellent position resolution is required to separate two clusters

FoCal-E strawman design

Si-W sampling calorimeter

W:absorber

$1X_0 = 3.5\ \mathrm{mm}(1\mathrm{layer})$

$R_\mathrm{M} = 9.3\ \mathrm{mm}$

Si:detection layer

Two types of sensors

1. LGL(Low Granularity Layer)

Si Pad

$1\mathrm{Pad} = 1 \times 1\ \mathrm{cm}^2$

$1\mathrm{layer} = 64\ \mathrm{Pads}(8 \times 8)$

Energy measurement

2. HGL(High Granularity layer)

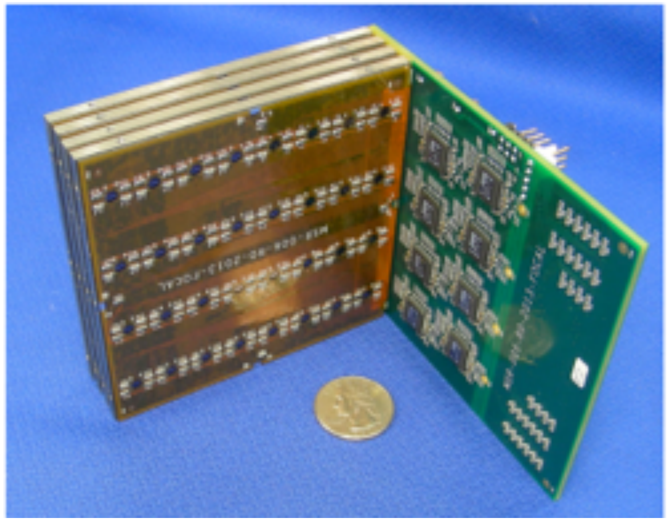
Monolithic Active Pixel Sensors (MAPS)

$1\mathrm{pixel} = 30 \times 30\ \mu\mathrm{m}^2$

digital readout

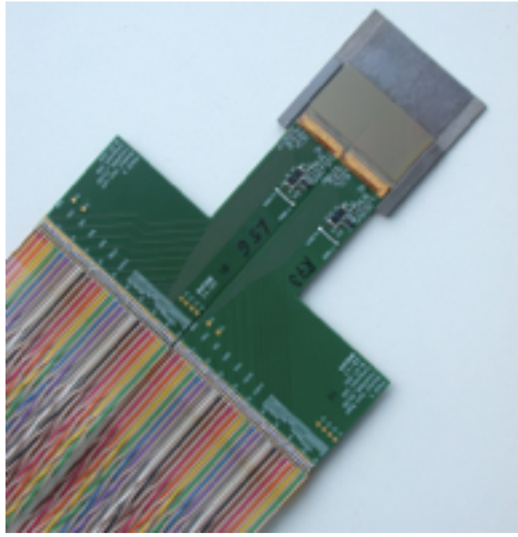
High position resolution

LGL

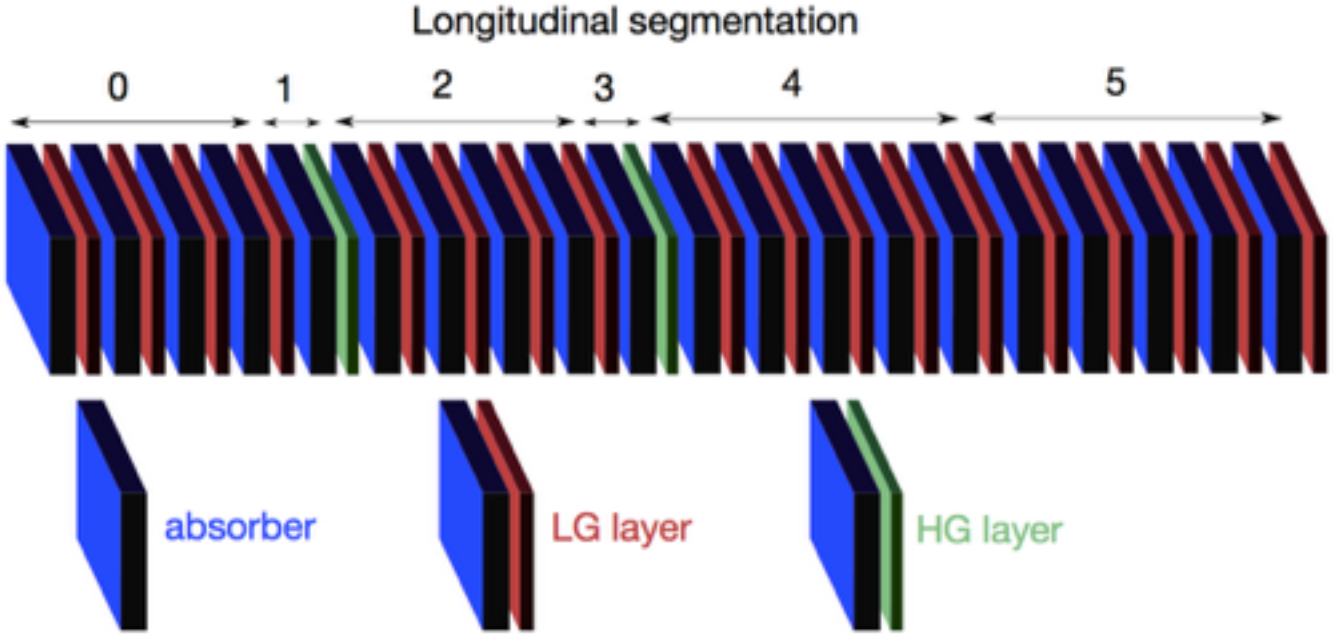


(Oak Ridge National Laboratory &Tsukuba Univ.)

HGL

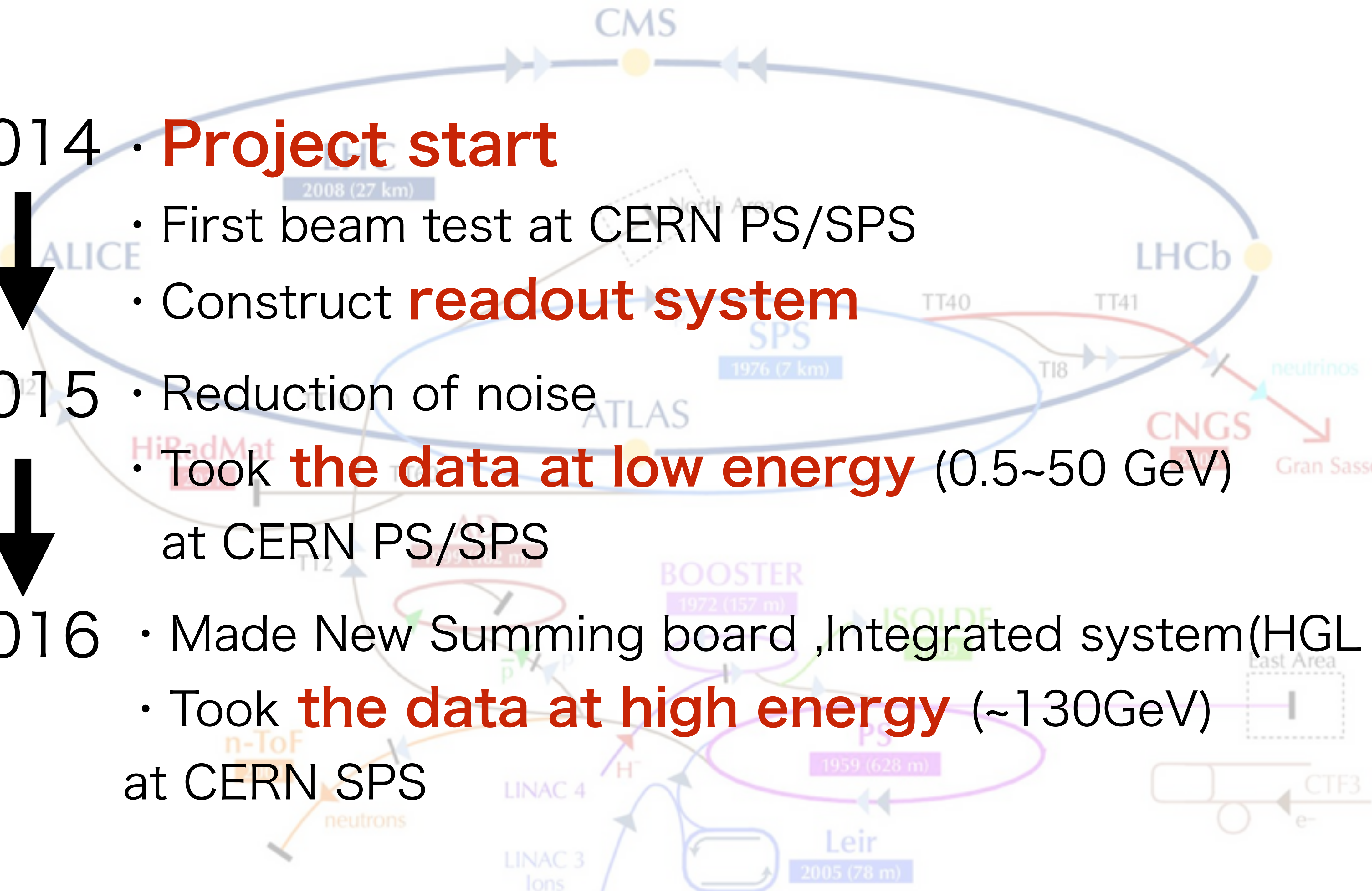


(Utrecht Univ.)



LGL Development from 2014 to 2016

Development since 2014



2014 · **Project start**

- First beam test at CERN PS/SPS
- Construct **readout system**

2015 · Reduction of noise

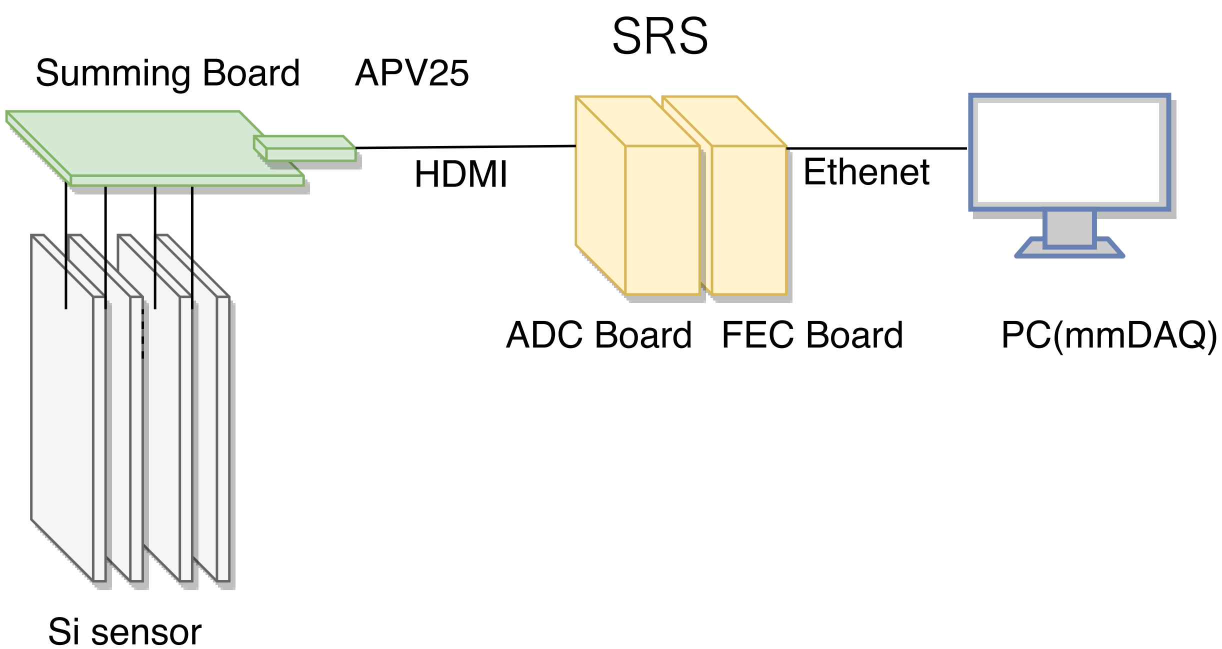
- Took **the data at low energy** (0.5~50 GeV) at CERN PS/SPS

2016 · Made New Summing board ,Integrated system(HGL and LGL)

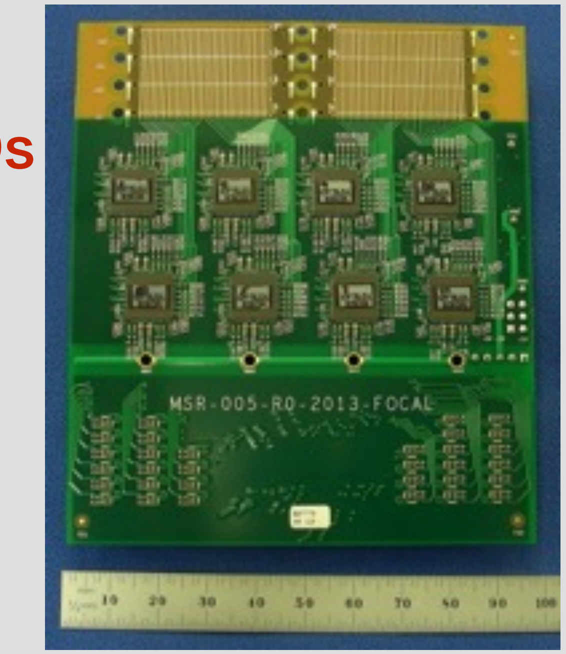
- Took **the data at high energy** (~130GeV) at CERN SPS

LGL readout system (2014~)

readout flow chart



Summing Board(ORNL)



4 sequential Longitudinal PADs

128ch output(2 Gains)

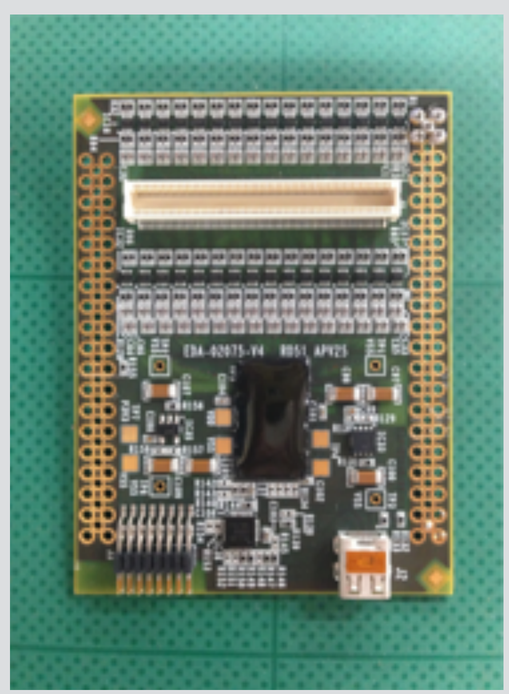
1/1(high gain):positive output

1/16(low gain):negative output

↓

select gain by readout polarity

APV25(CERN RD51)



Read out chip

buffer, preamp, pulse shaper

128:output

Sampling frequency:40MHz

5Gains:80,90,100,110,120%

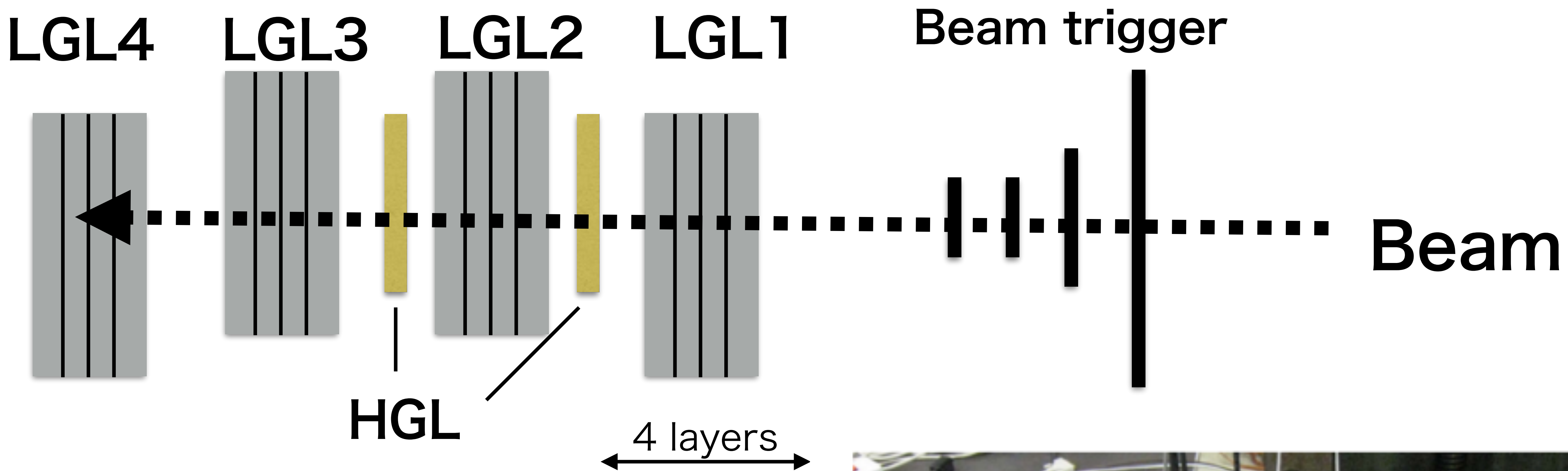
SRS(Scalable Readout System)(CERN RD51)

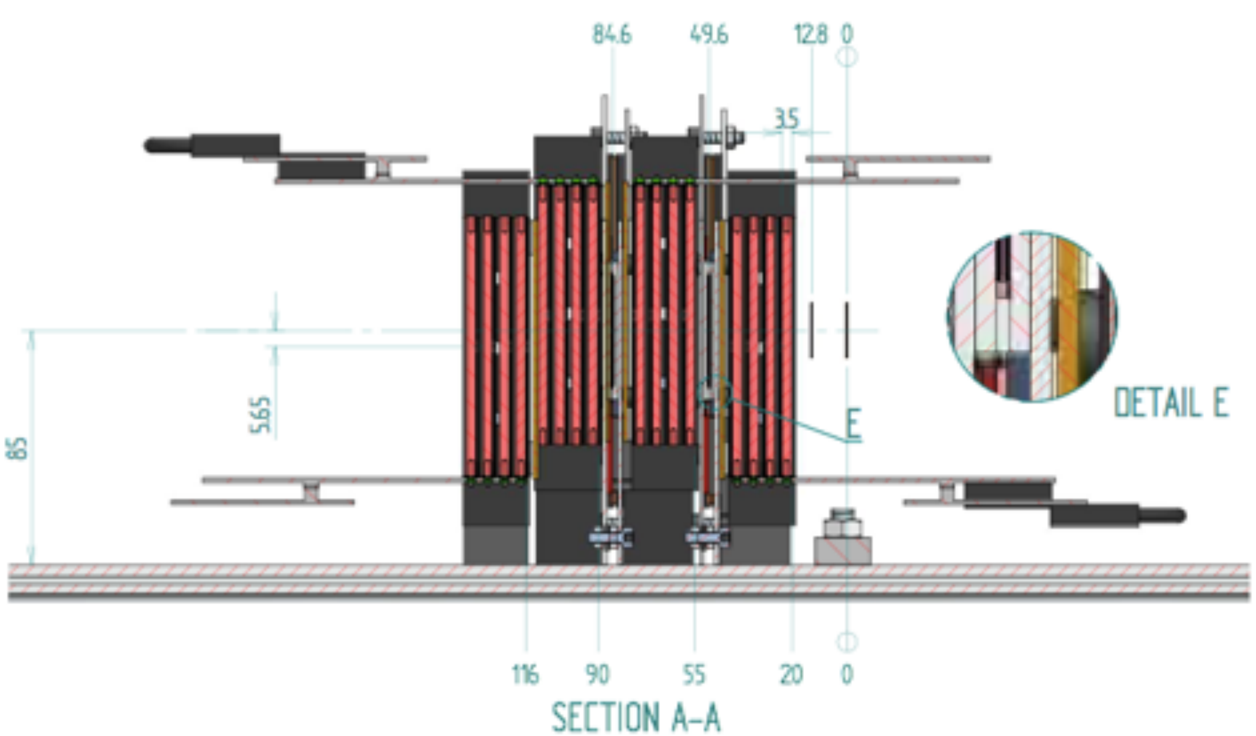
ADC Board:12bit ADC

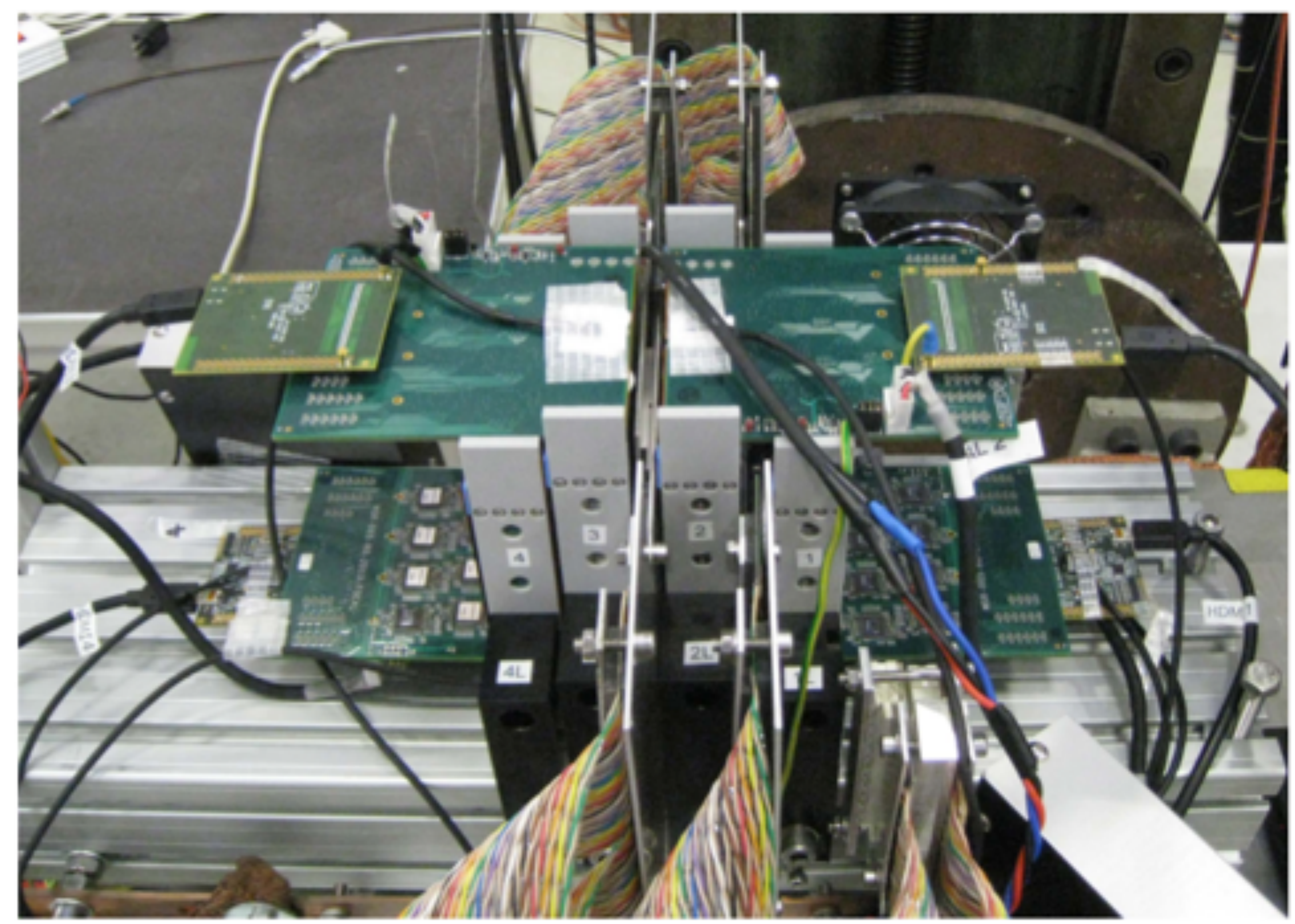
FEC Board:front-end

Send digital data to PC

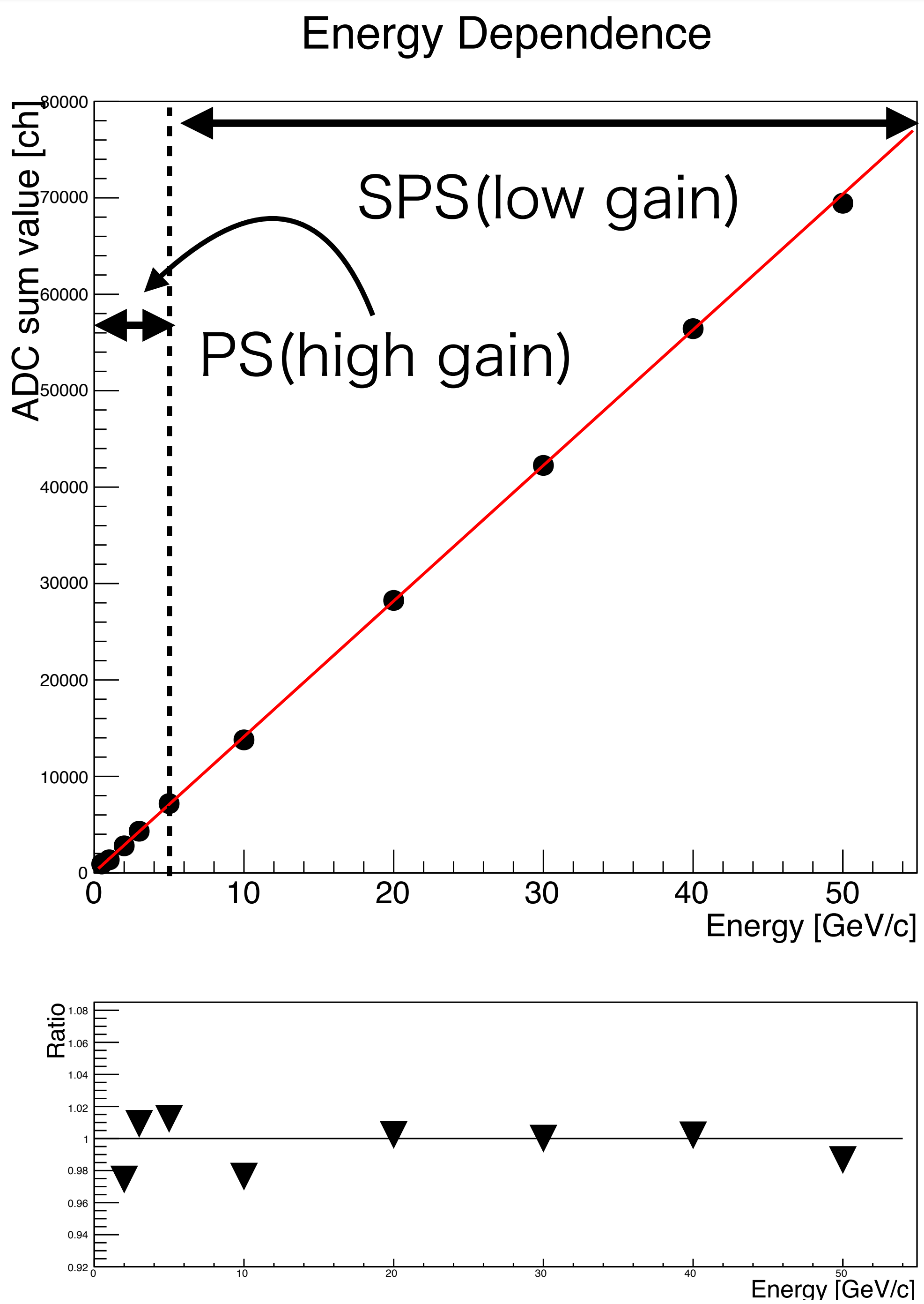
Beam test at CERN PS/SPS in 2015

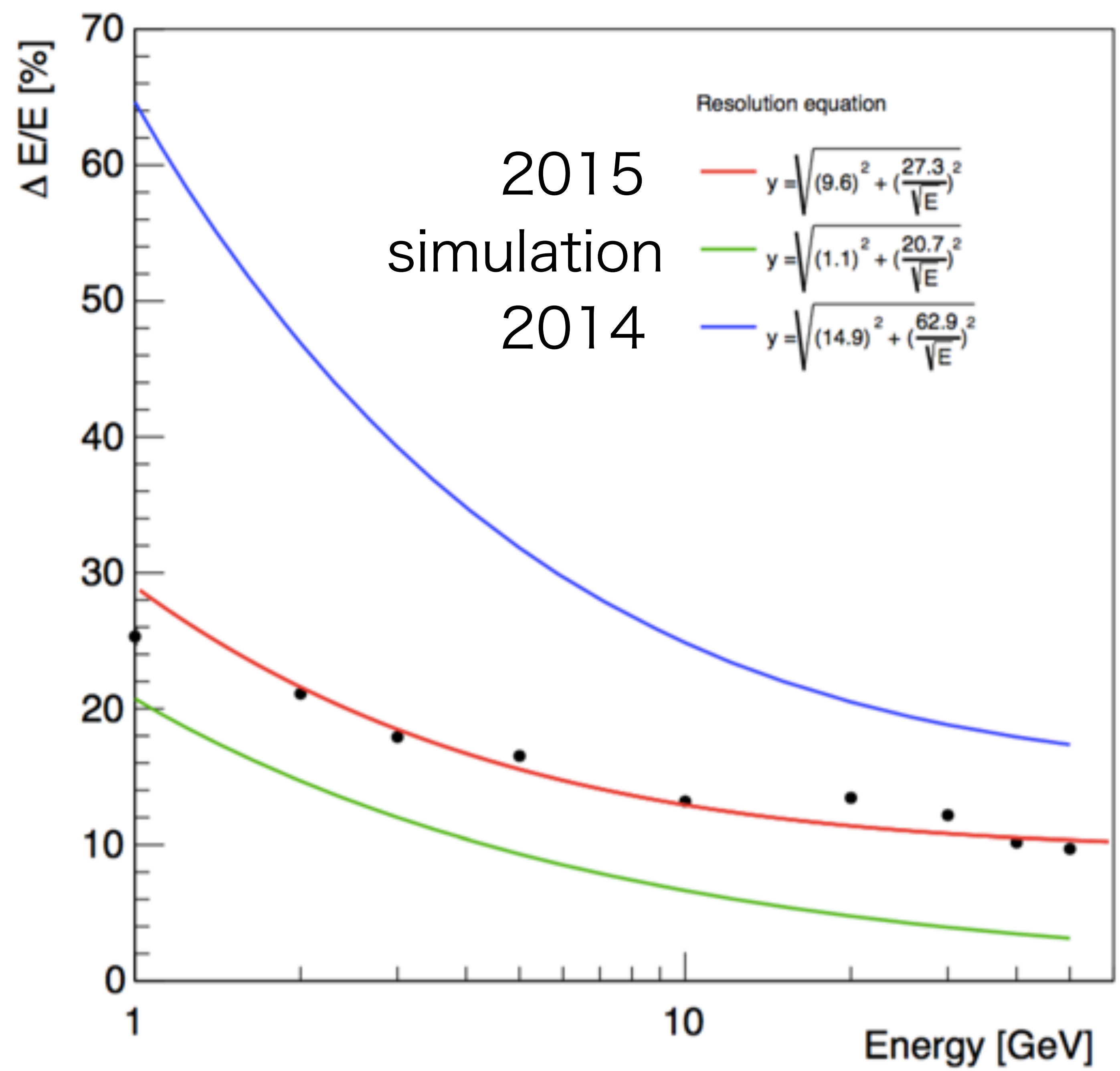






Beam test result in 2015

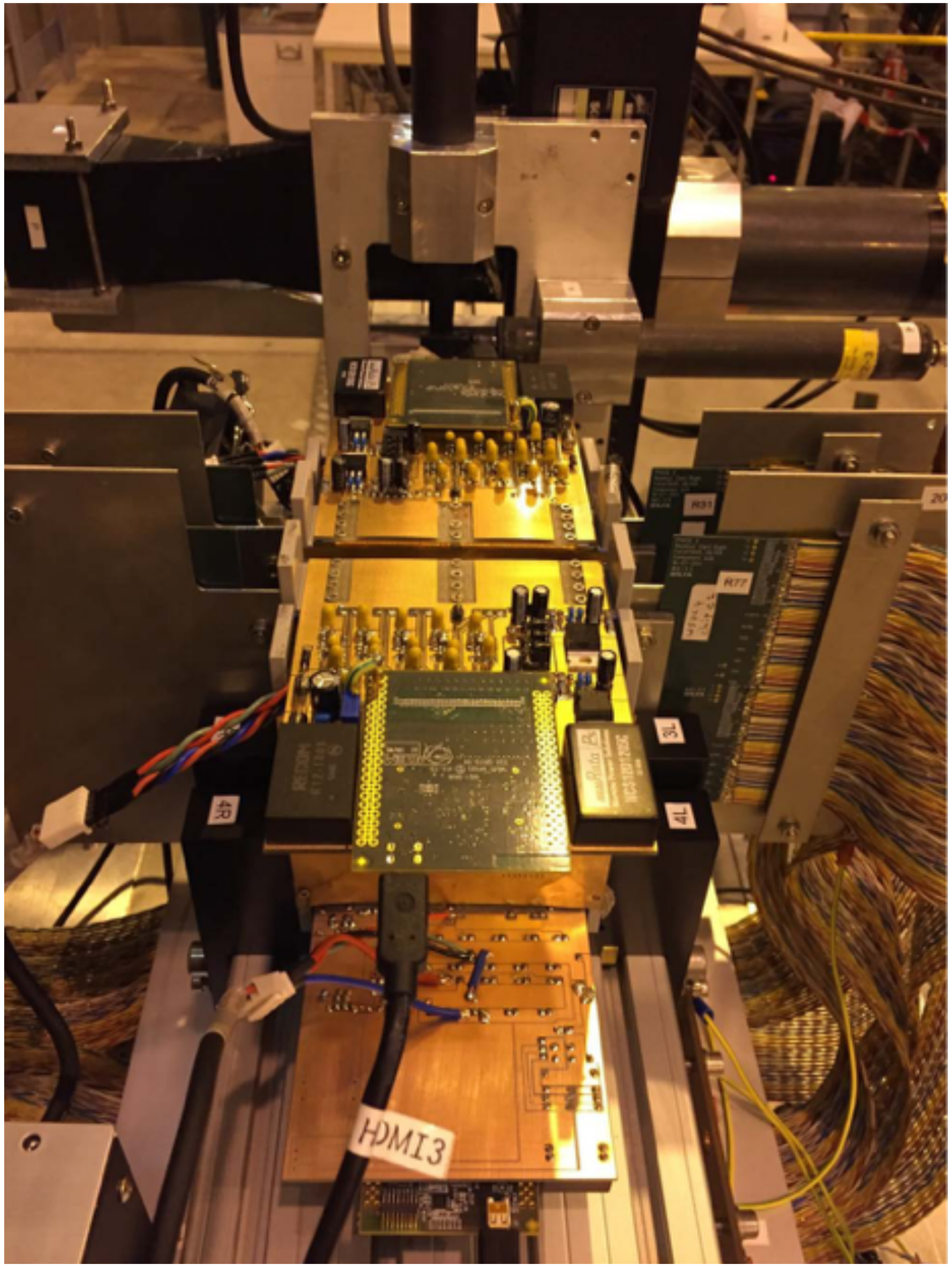


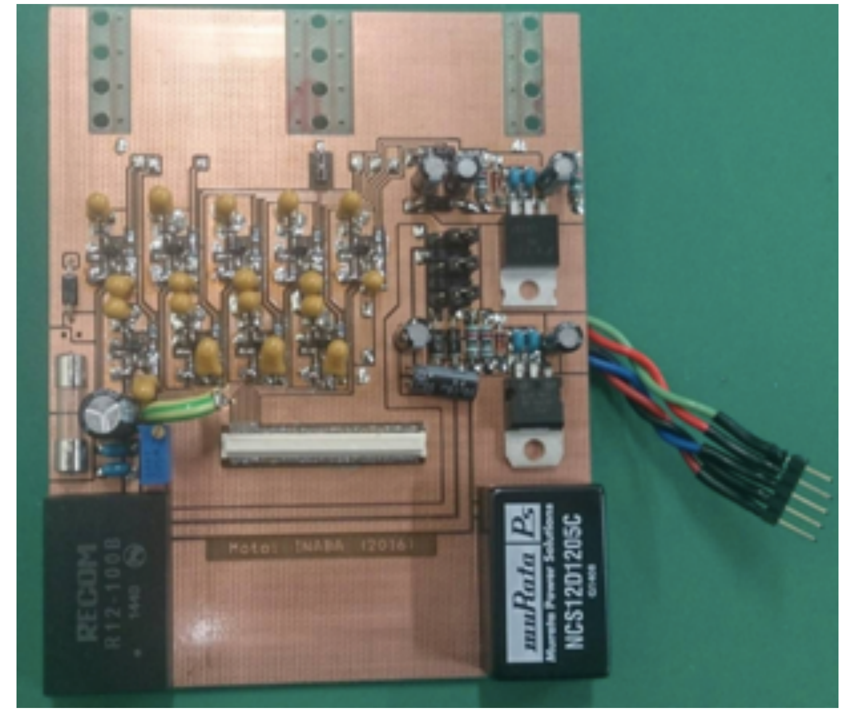


- Good linearity(within ~3%) up to 50 GeV/c

- Achieved ~10% energy resolution at high energy

Test beam at CERN SPS 2016





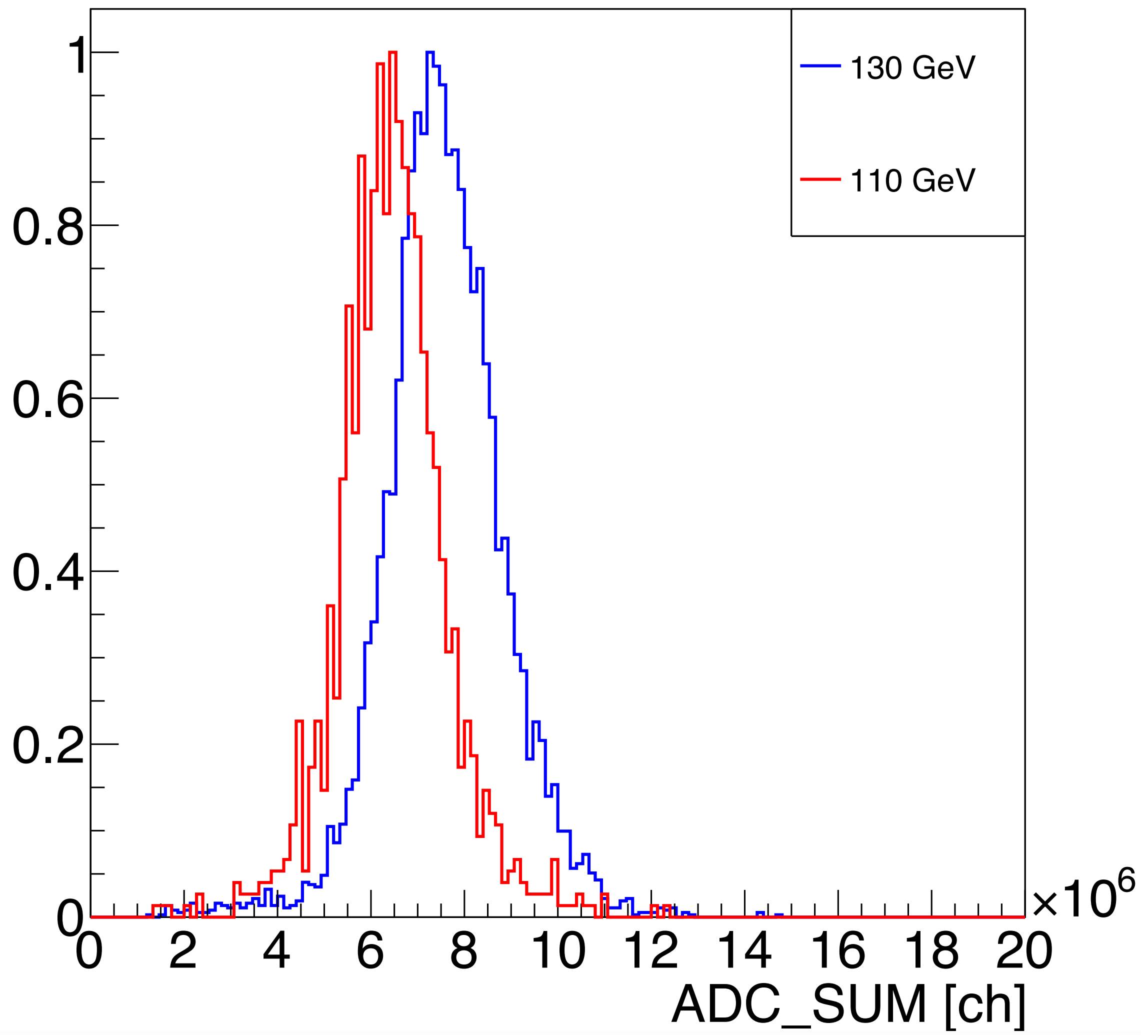
New summing board

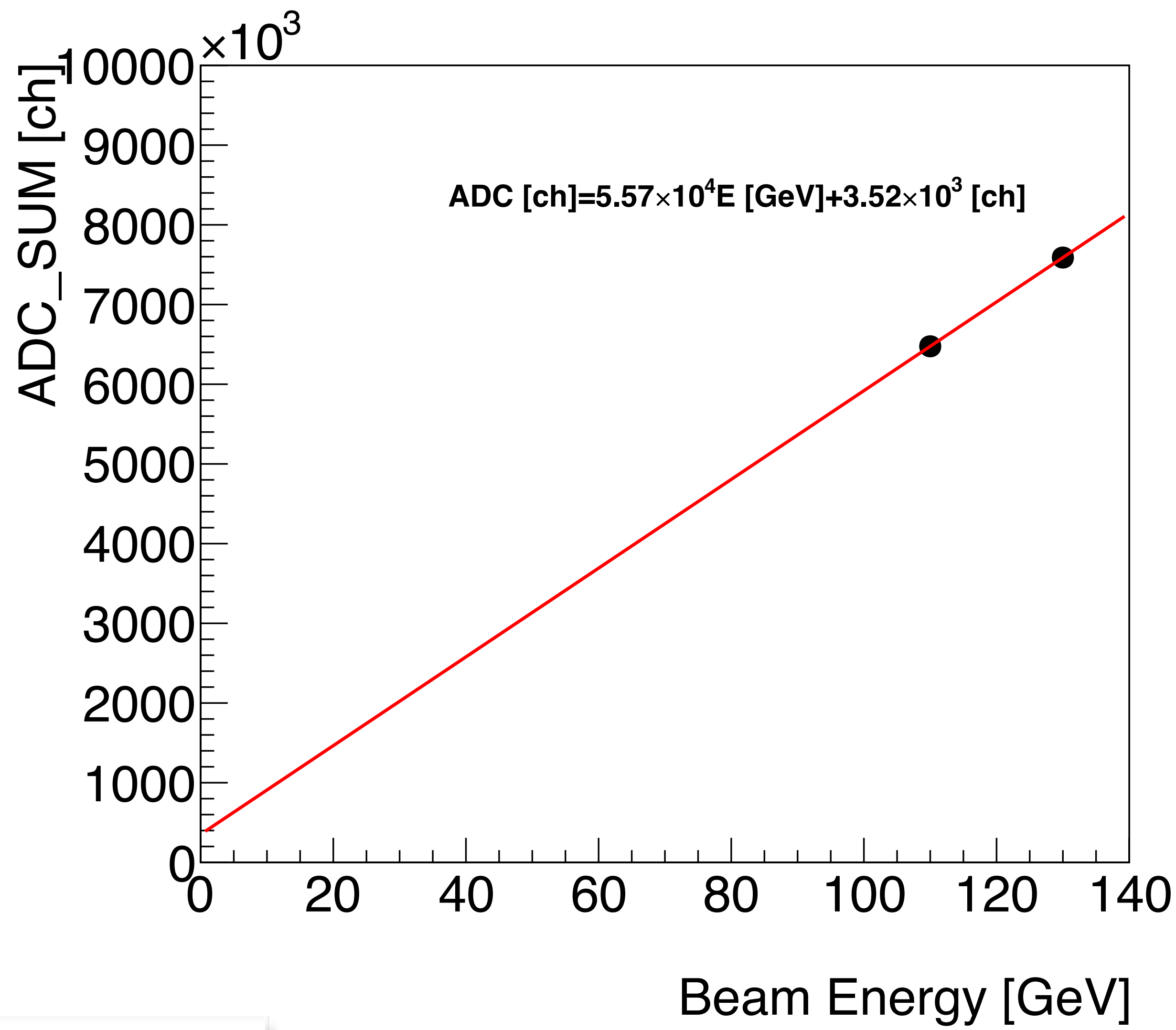
- New Summing board installed
- For noise reduction
- **Attenuate** the signal before readout

↓

Measure higher energy range

Result in 2016: linearity

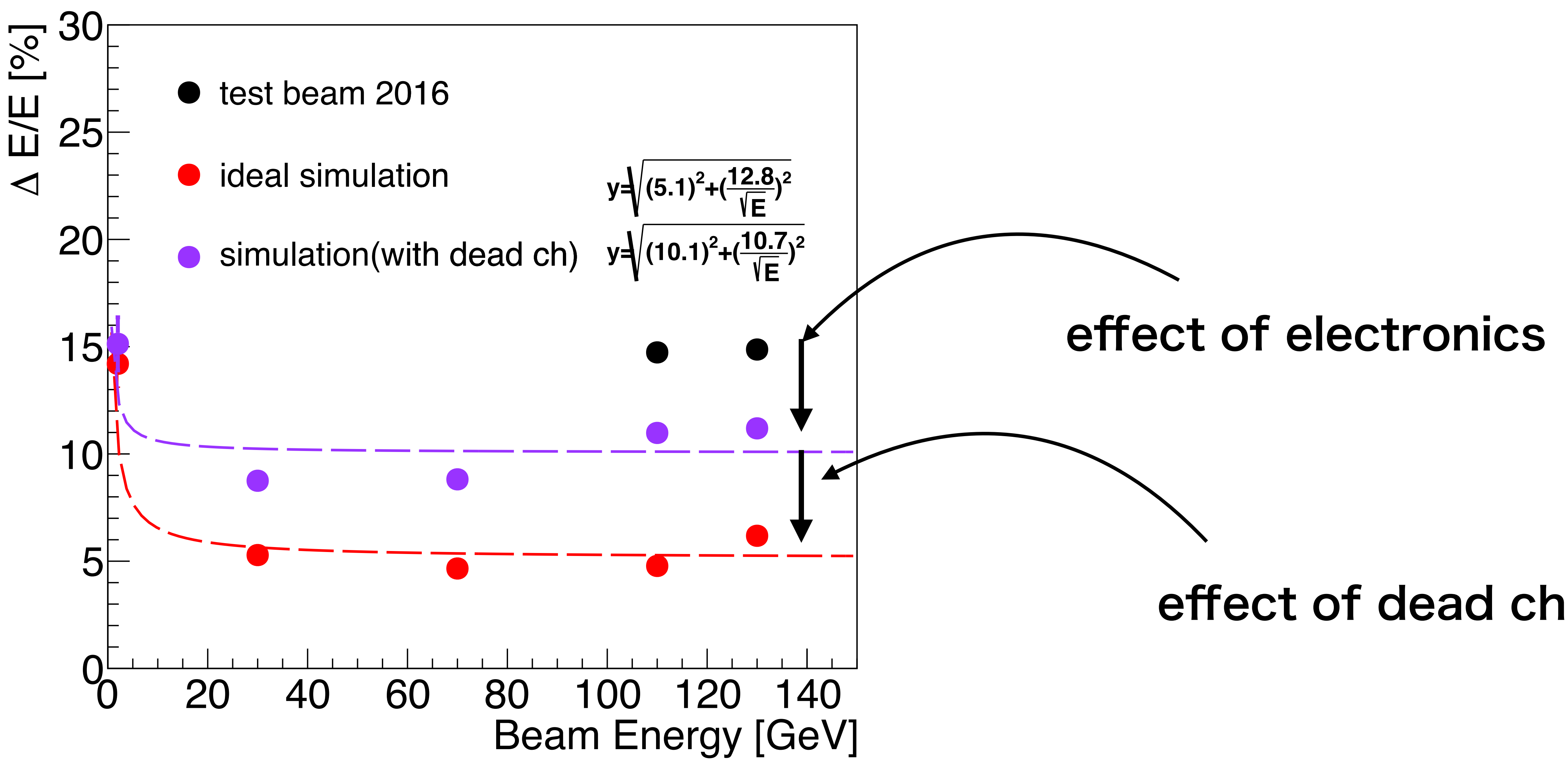




- **Measured 110 GeV and 130 GeV !**

- Took only data at two energies but **linearity is generally good**
- To match the the data in 2015 and those in 2016, need more detail gain **calibration** study.

Result in 2016: resolution



Resolution is worse compared to 2015's fitting data ・・

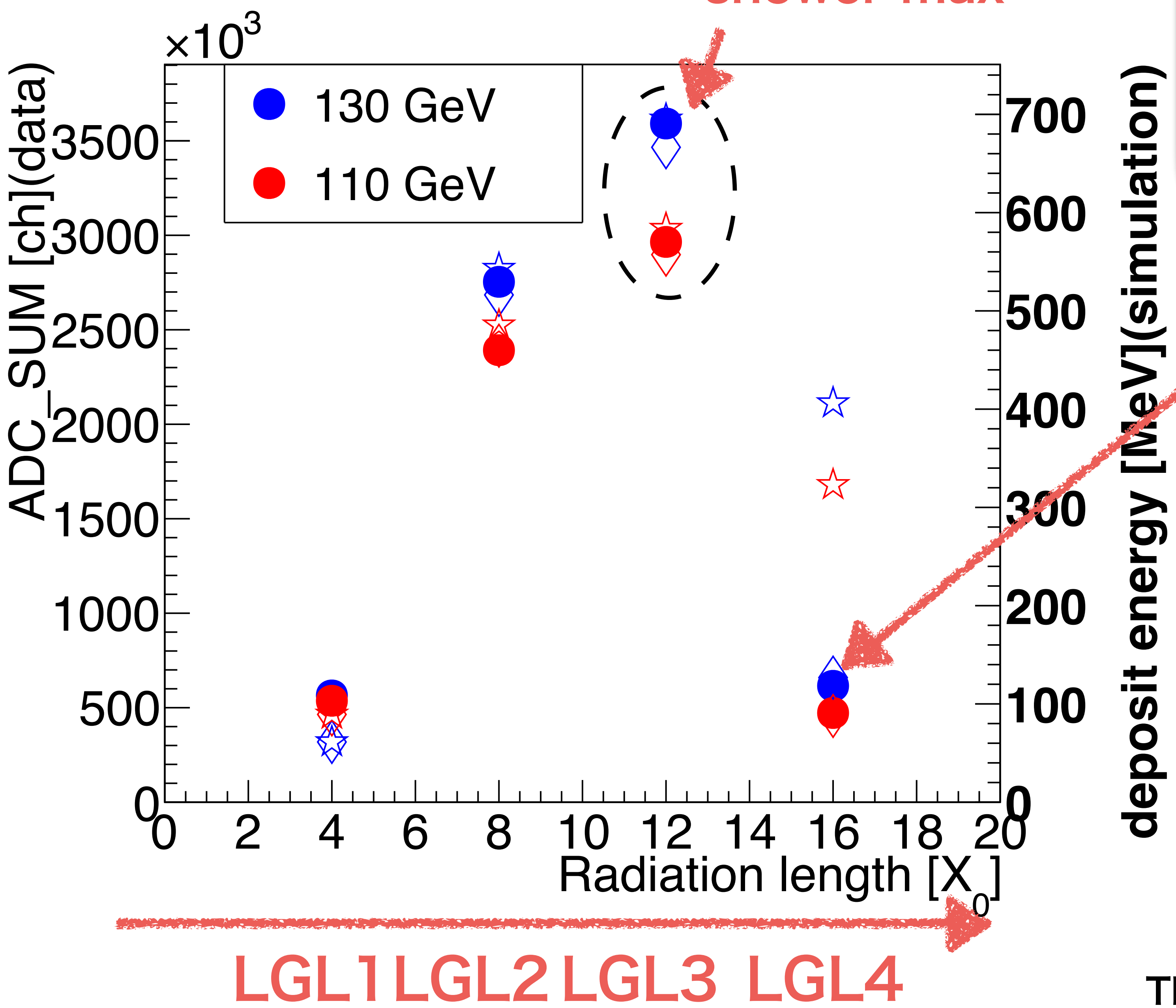
Most likely due to **dead ch** in the center of 4th LGL.

If all channels are working, **better resolution is expected.**

Result in 2016: longitudinal profile

Longitudinal shower profile

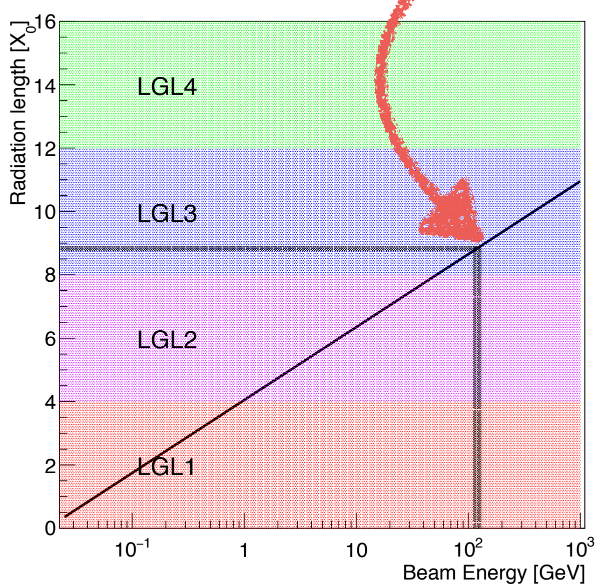
shower max



- ● beam test result
- ◇ simulation (with dead ch)
- ☆ ideal simulation

・ADC values decrease because of dead ch

shower max radiation length



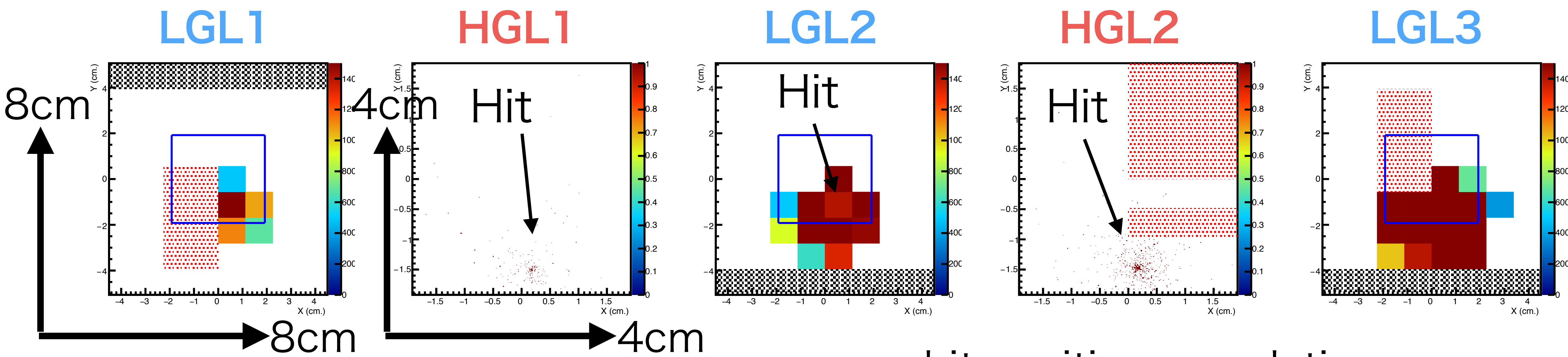
Theoretical value of shower max

110~130 GeV

$9X_0$:LGL3

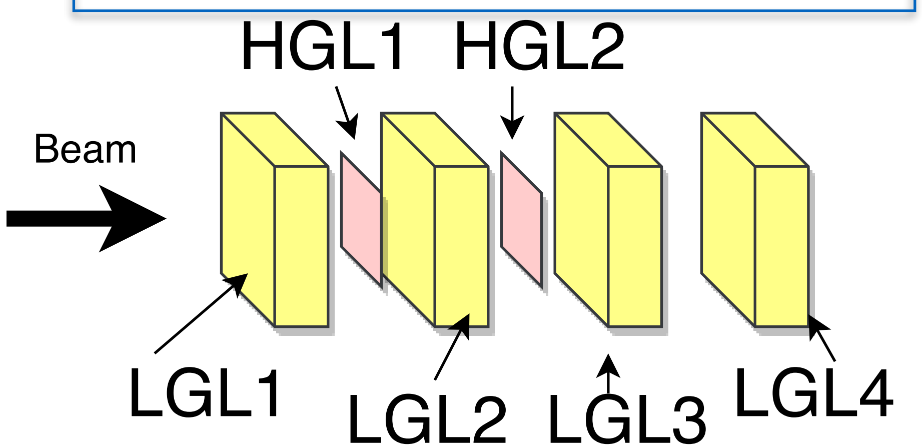
Matched theoretical values and simulation

Result in 2016: positioning

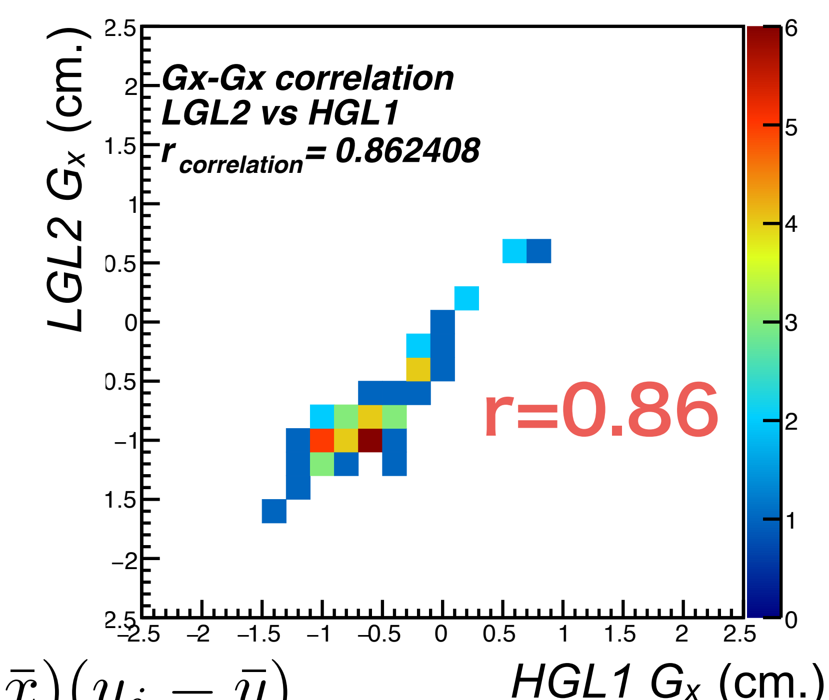


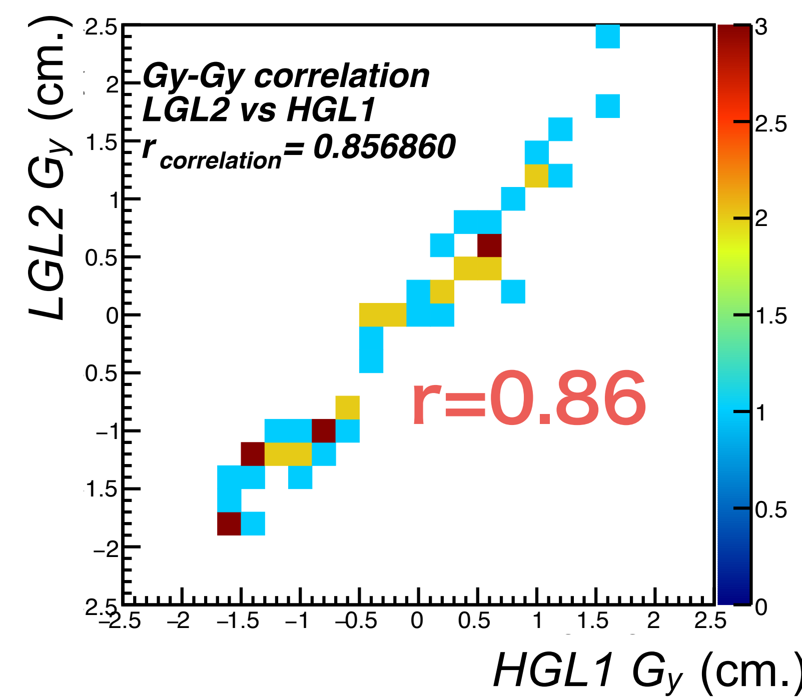
HGL range

dead ch



hit position correlation





$$r_{\mathrm{Correlation}} = \frac{\frac{1}{N}\Sigma_{j=1}^{N}(x_j-\bar{x})(y_j-\bar{y})}{\sqrt{\frac{1}{N}\Sigma_{j=1}^{N}(x_j-\bar{x})^2}\sqrt{\frac{1}{N}\Sigma_{j=1}^{N}(y_j-\bar{y})^2}}$$

$r \to 1$ positive correlation

Observed strong position correlation

Summary & Outlook

Summary

- We have tested Si PAD-W based electromagnetic calorimeter(LGL) for 3 years.
- Good energy linearity **up to 130 GeV is measured**.
- Energy Resolution is ~10% at 50 GeV and 130 GeV (assumed no dead ch).
- **Strong correlation** between LGL & HGL is observed.

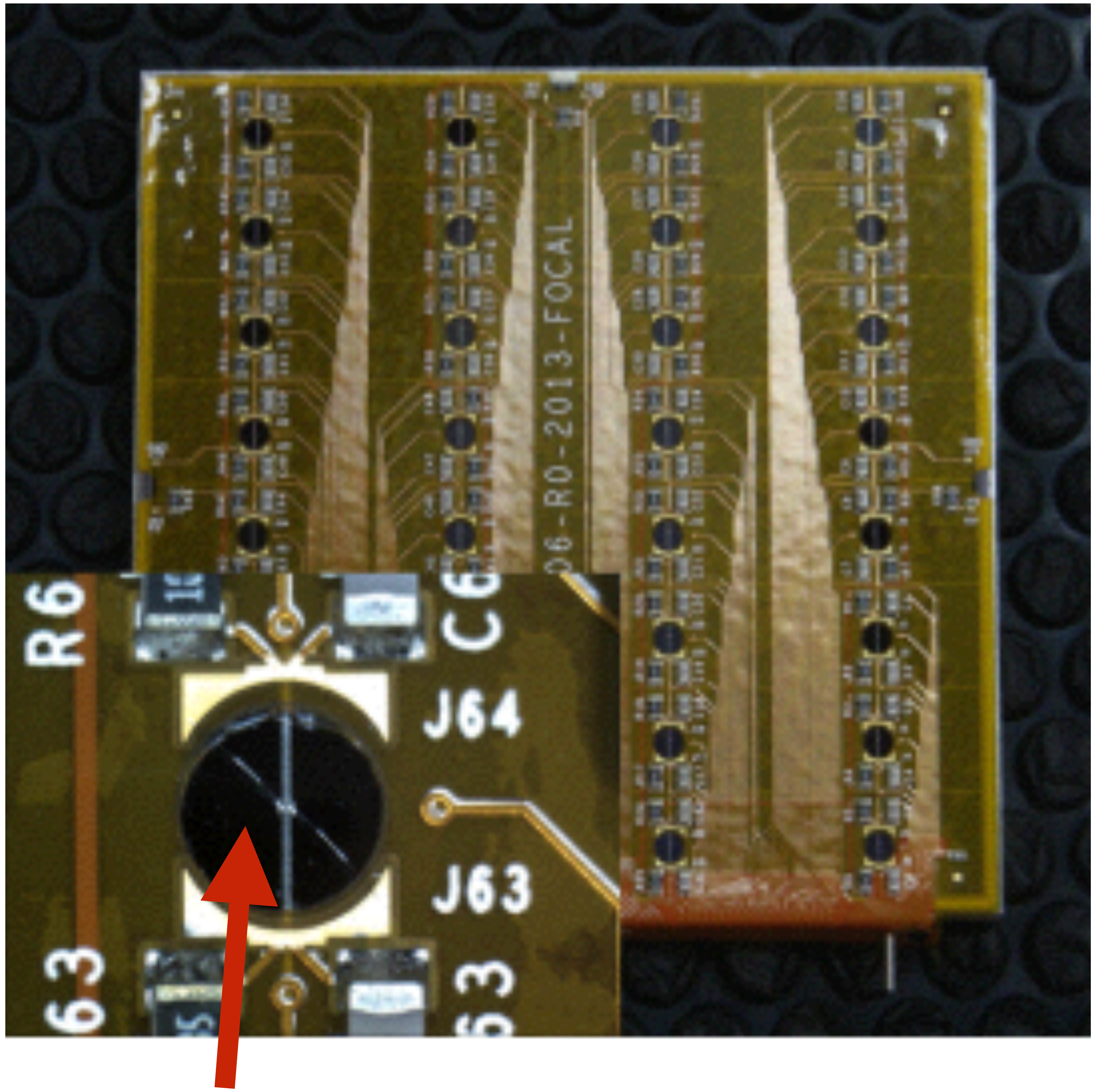
Outlook

- **Noise has to be reduced** to get closer to the performance in the simulation.
- Perform **calibration** by measuring MIP signal and examine current dynamic range.
- Based on those results, **make a new type of FoCal prototype** which fulfills the requirement for the physics measurements.

Thank you very much for your attention !

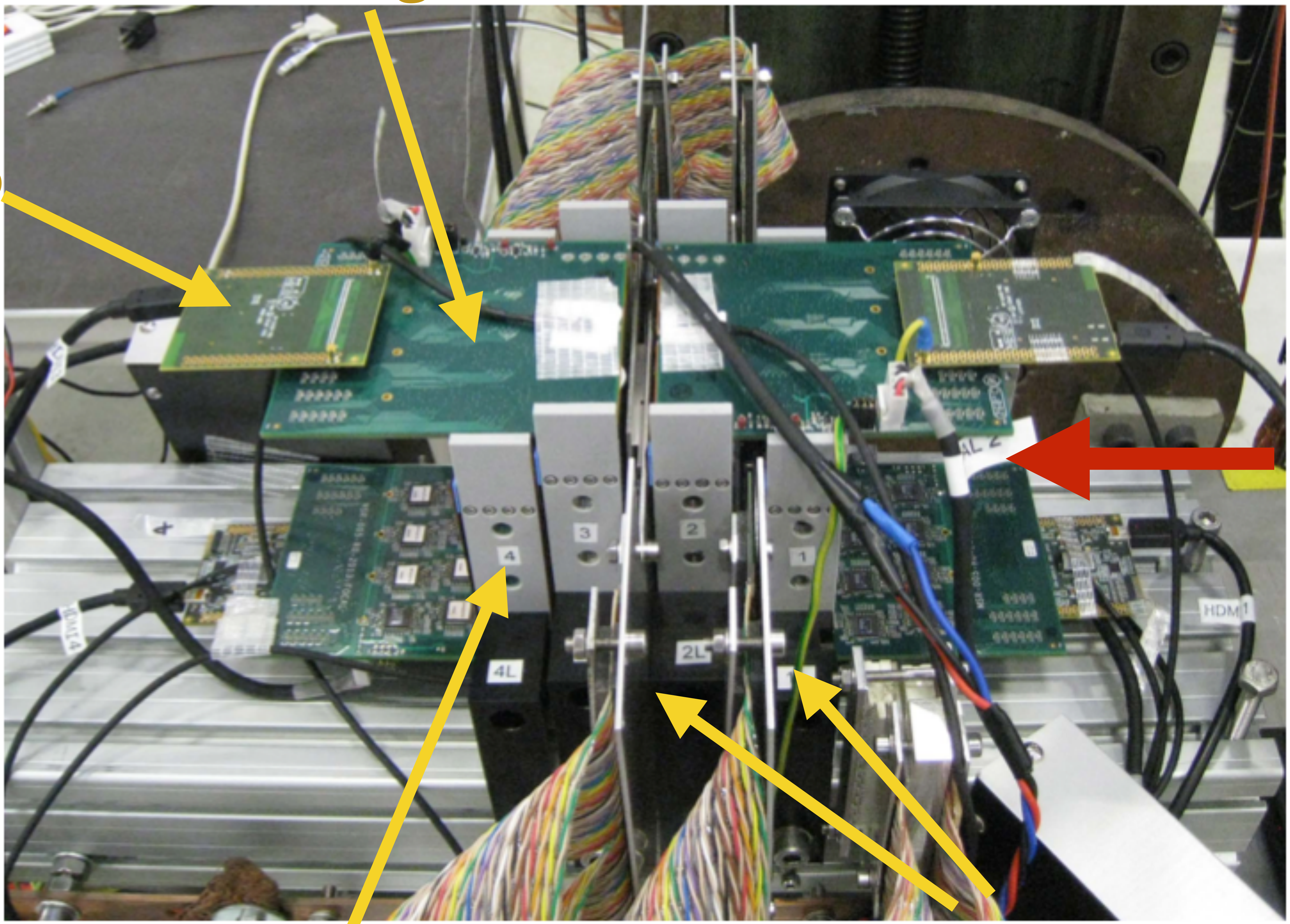
Back up slides

Si wire bonding

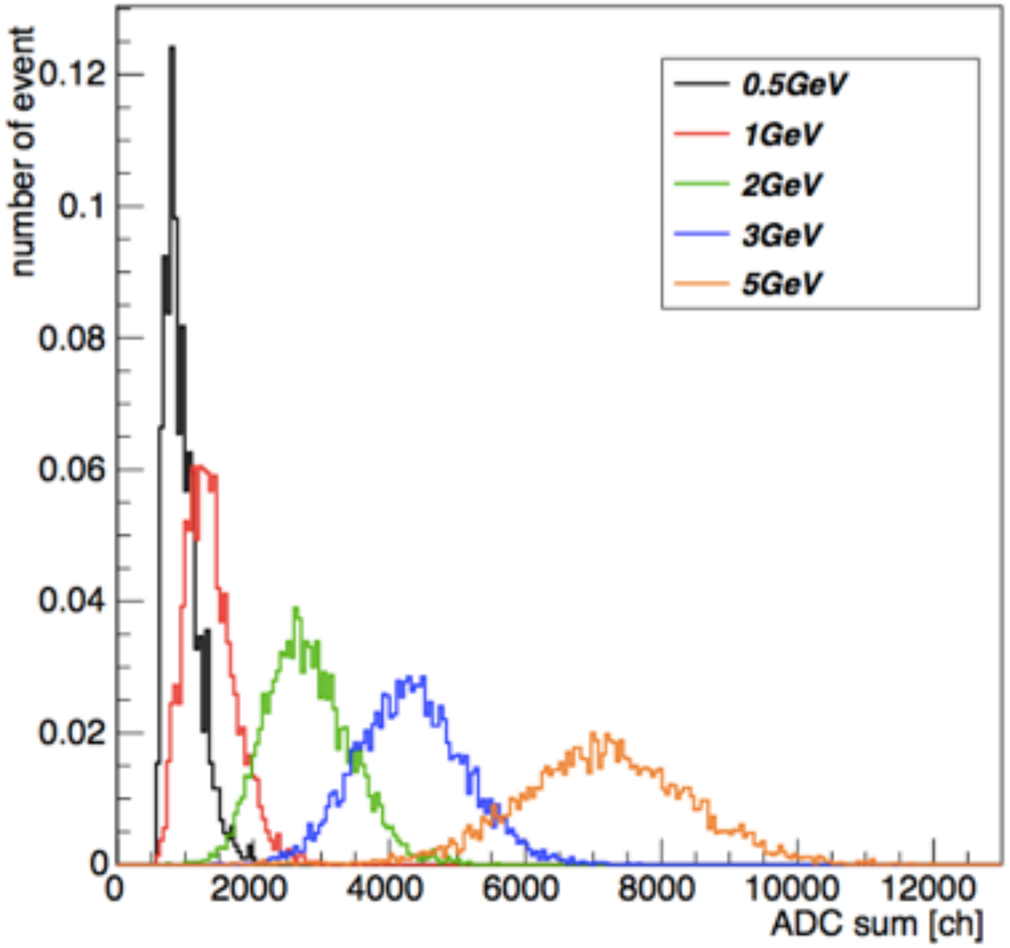


wire bonding

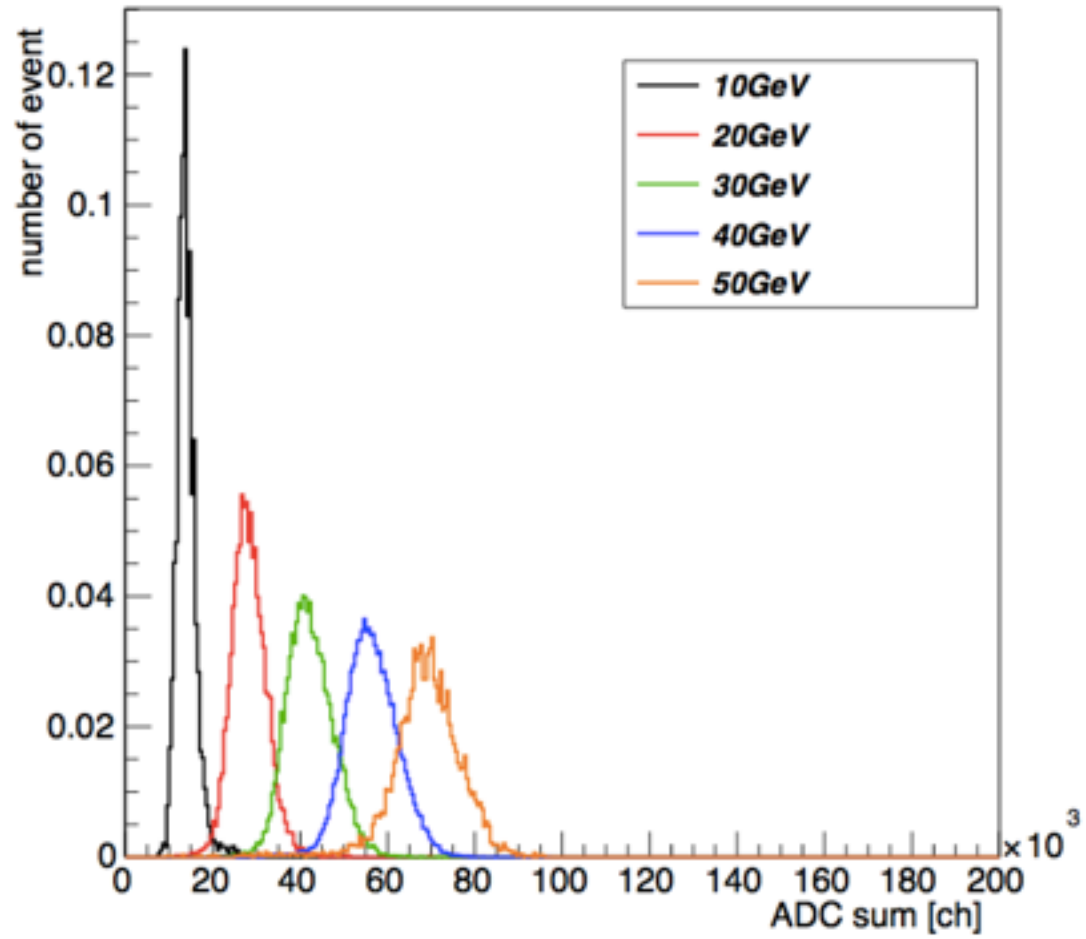
Beam test @CERN PS/SPS in 2015



Spectrum 2015 data

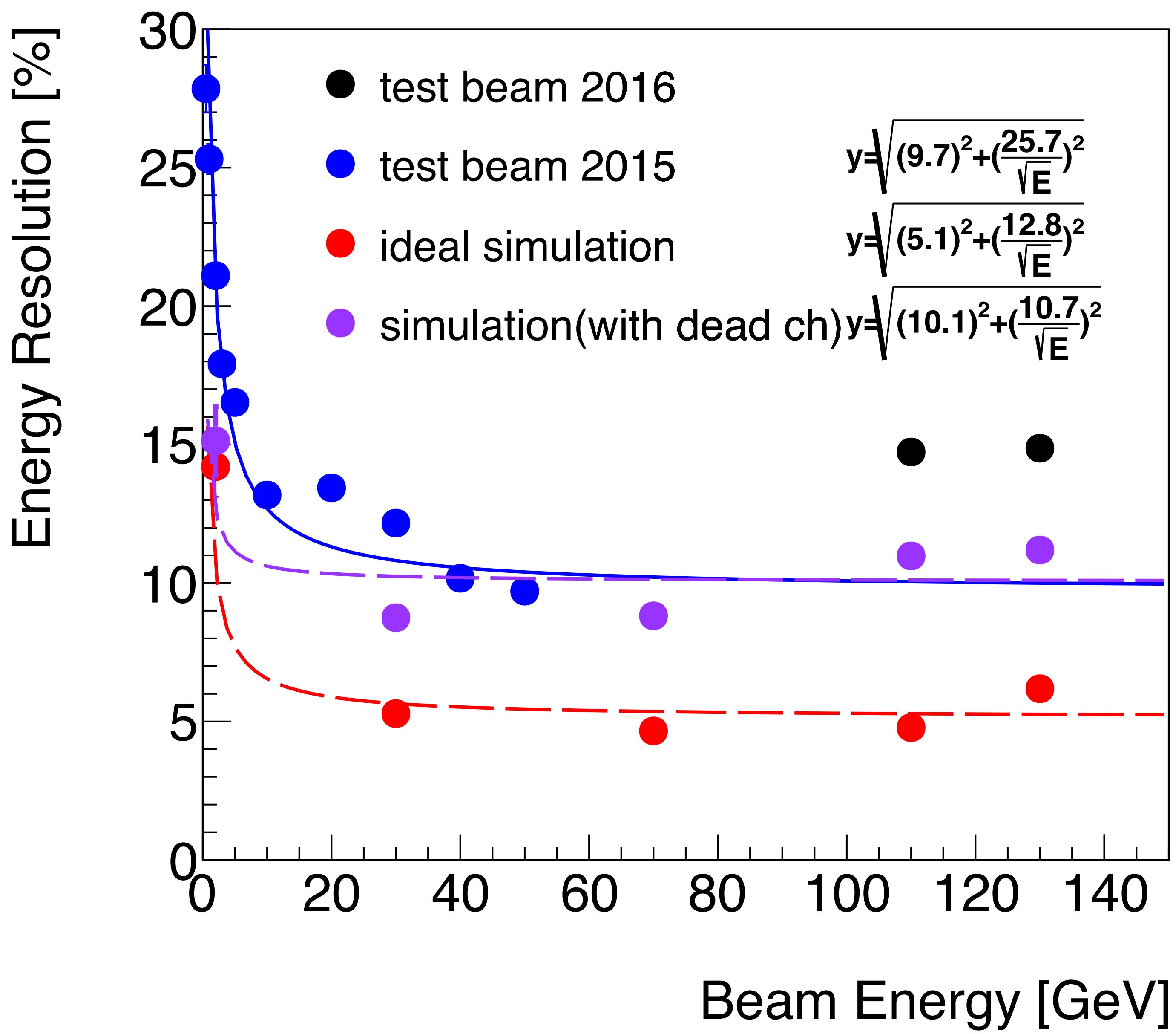


Data at PS in 2015

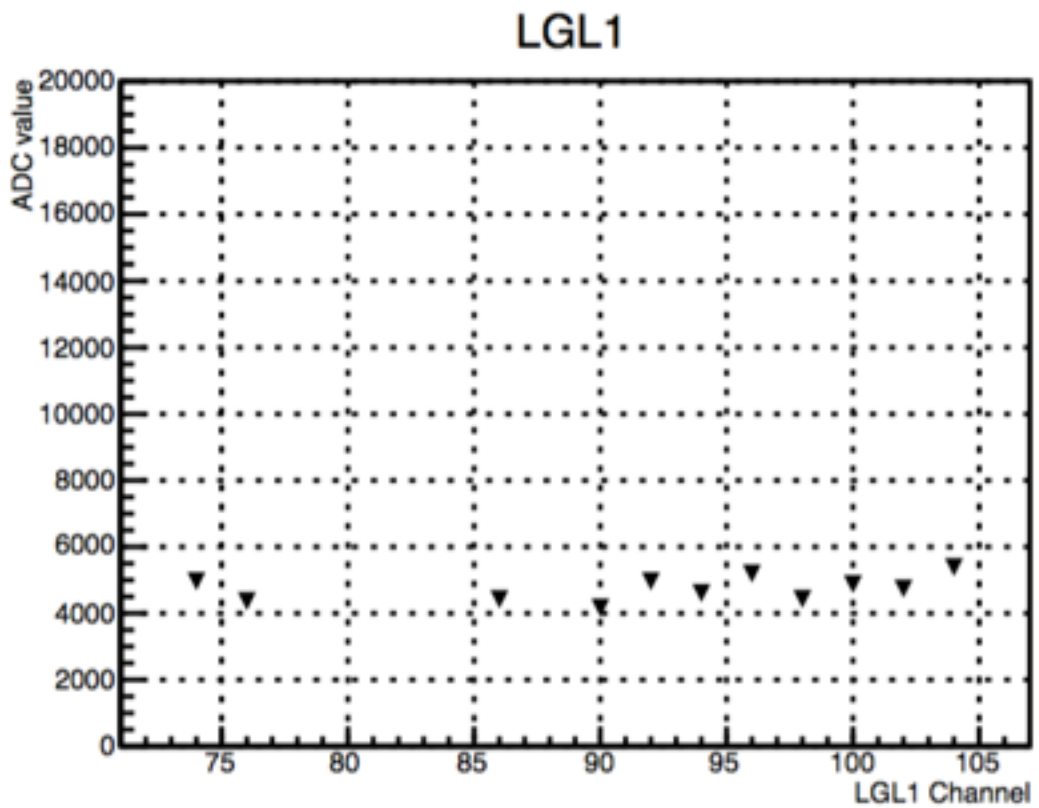


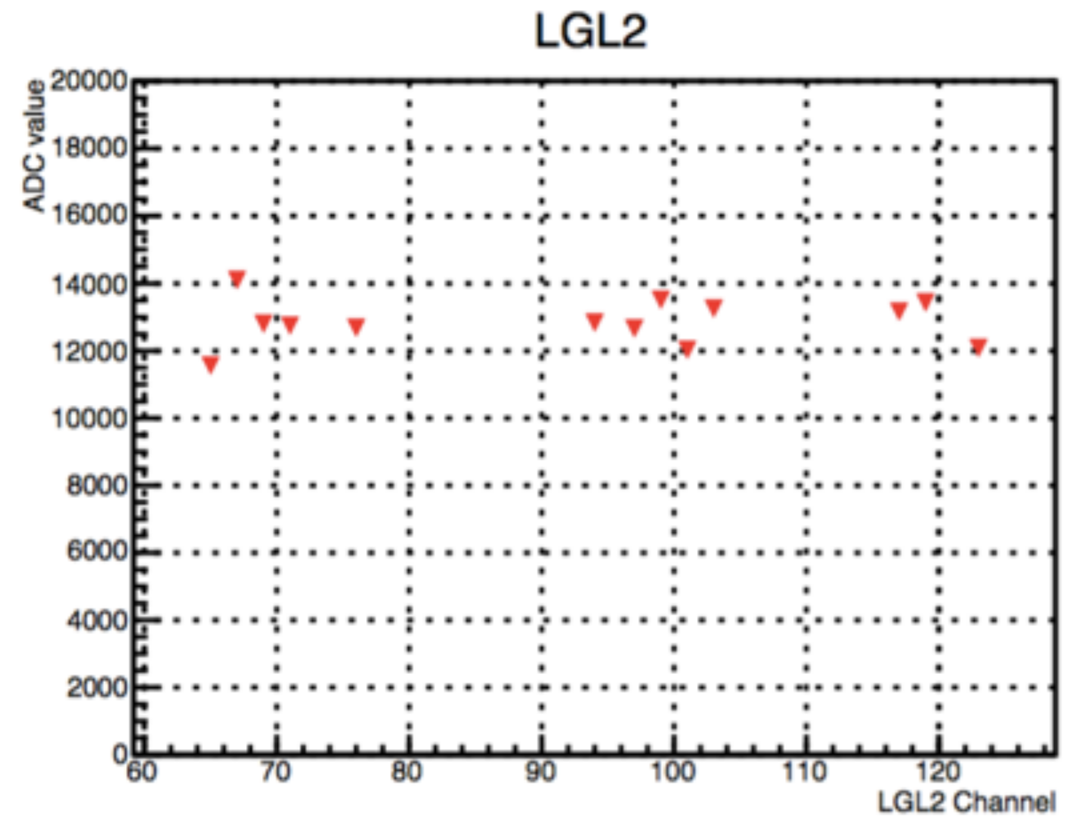
Data at SPS in 2015

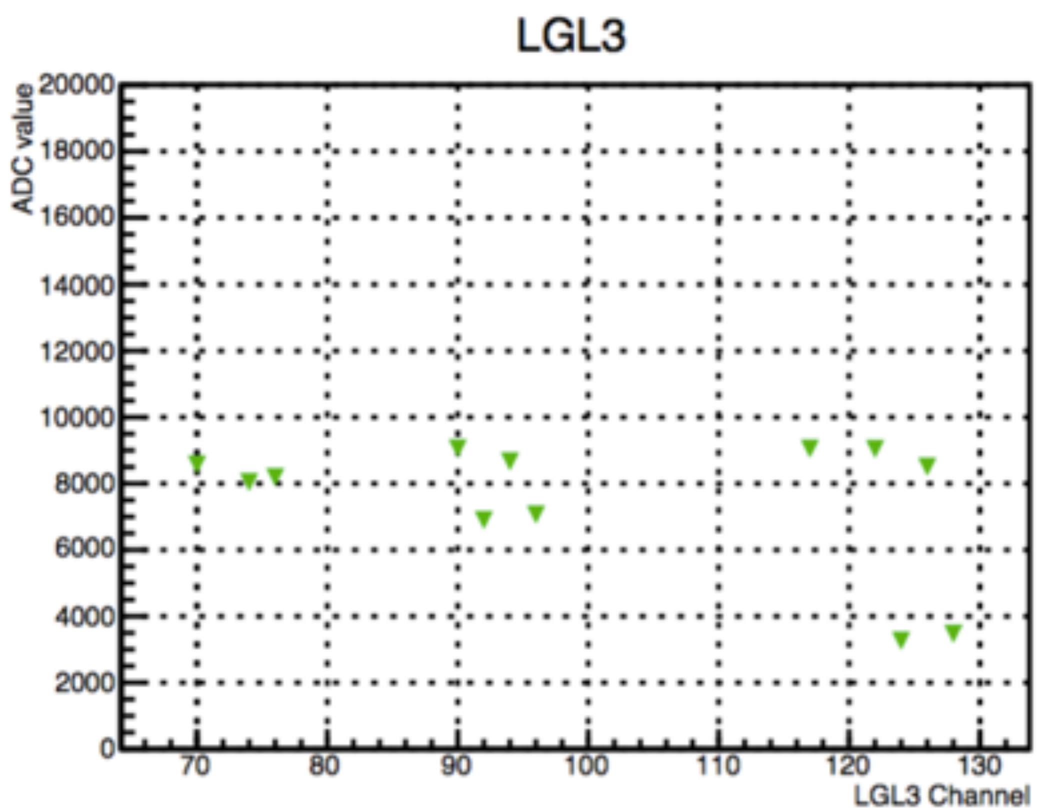
Resolution 2015 and 2016



Channel dependence



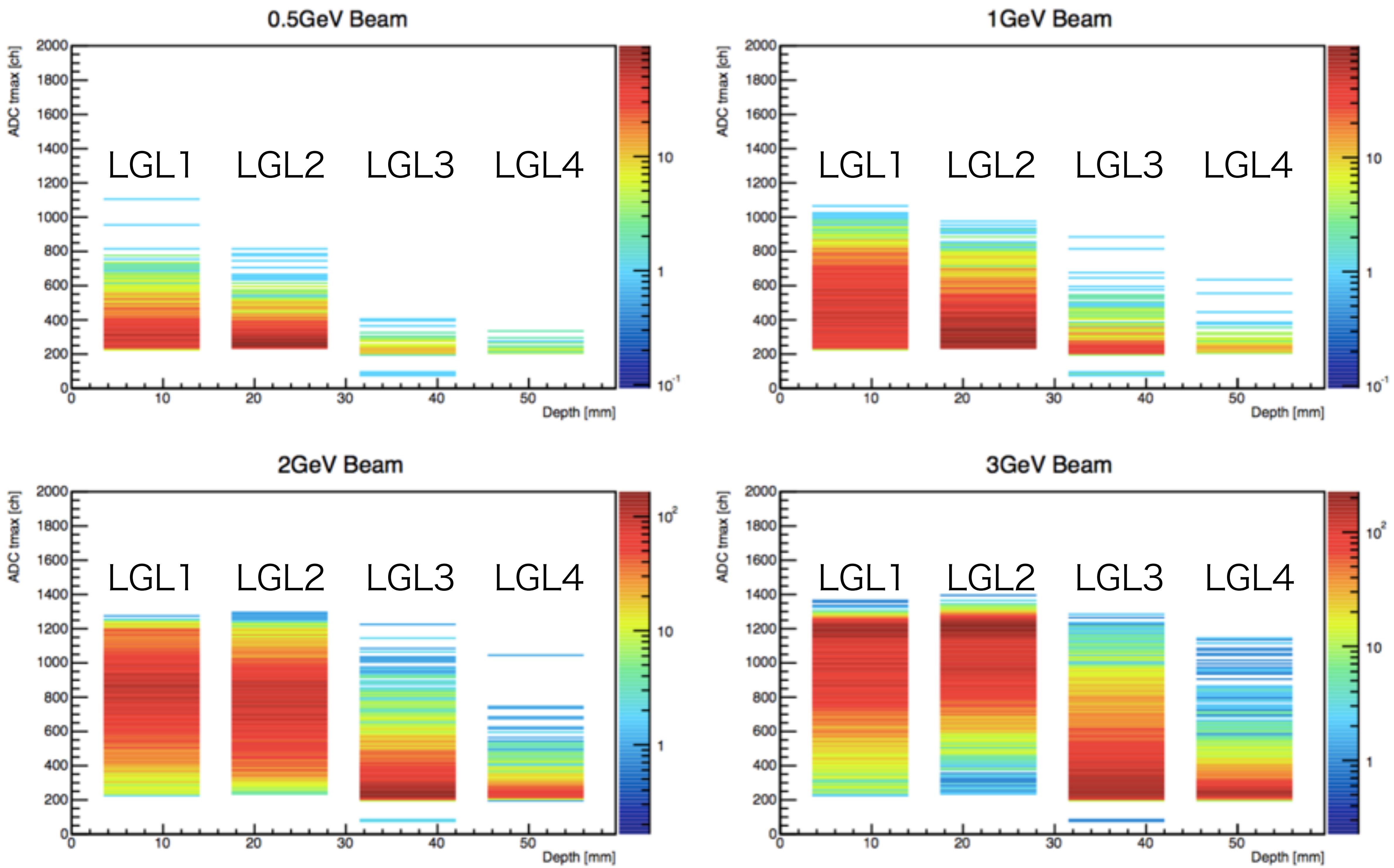




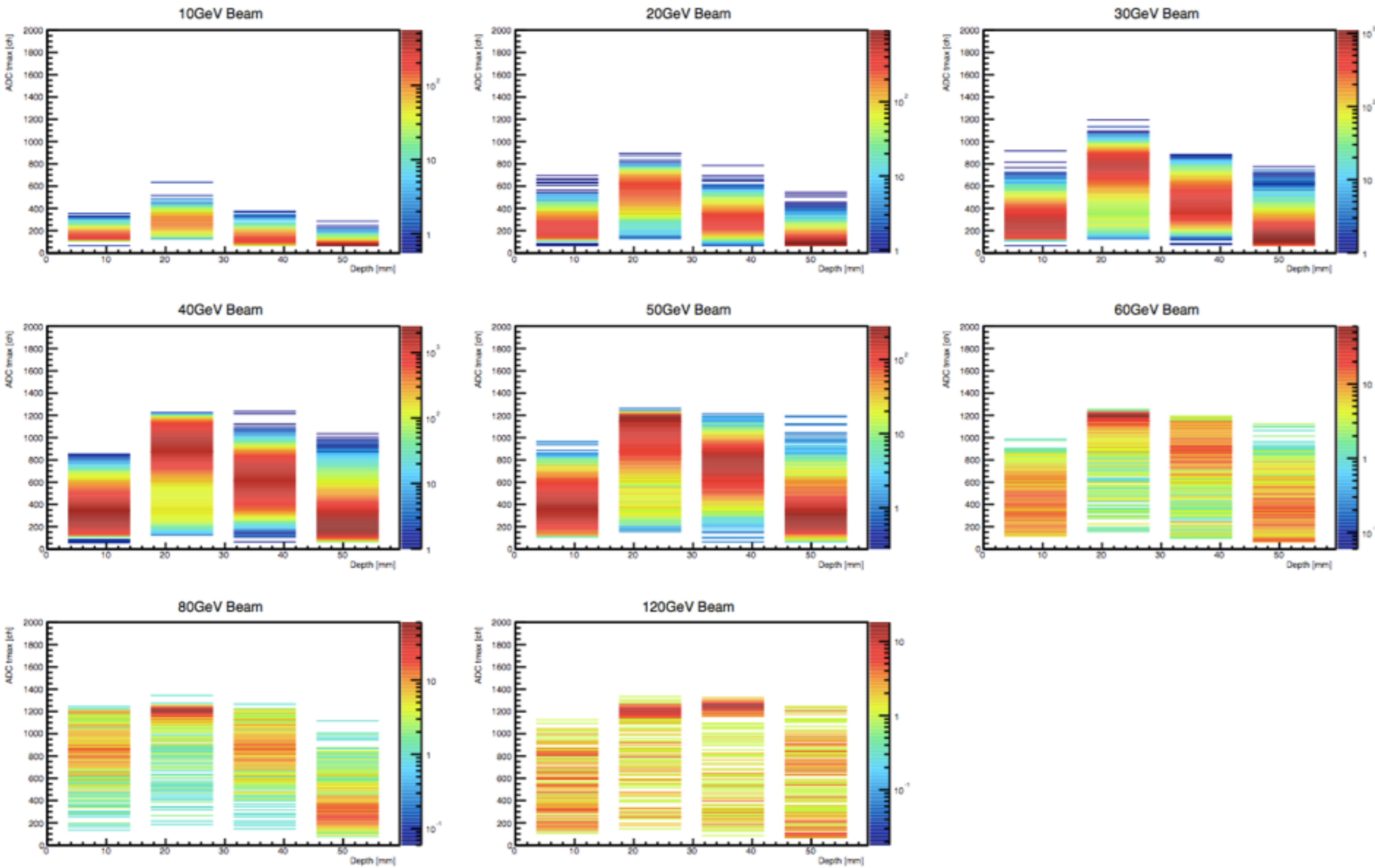
2015 at E = 20 GeV

There are a few difference

Longitudinal shower profile in 2015

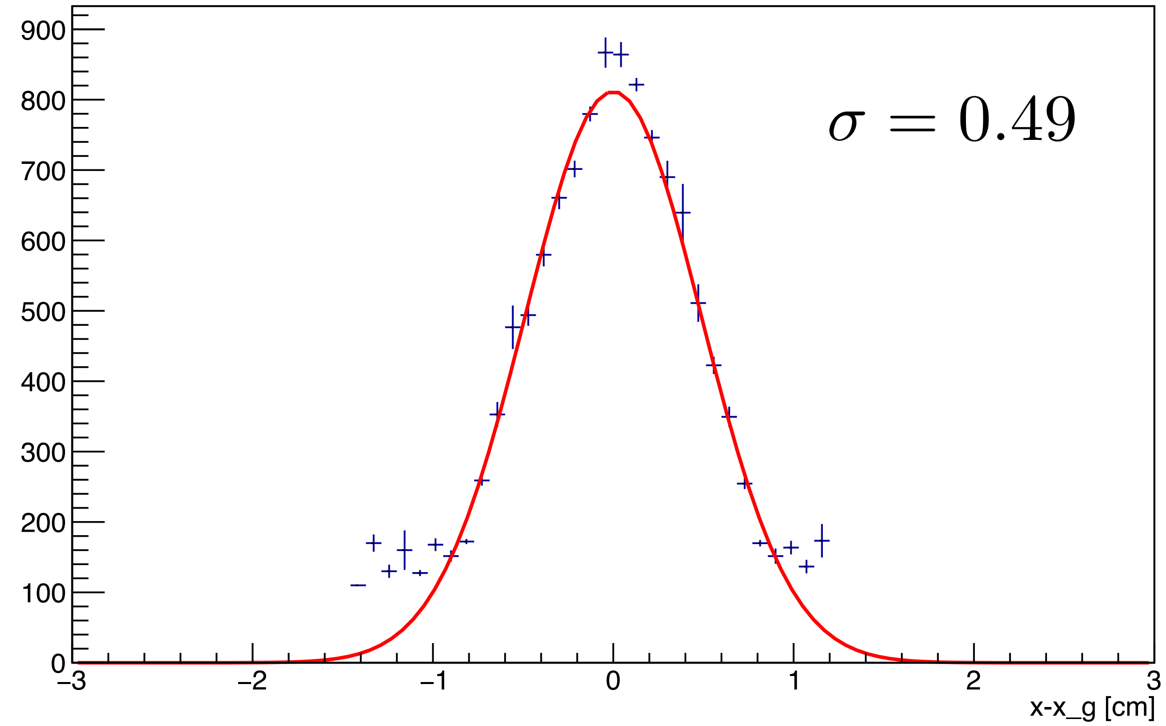


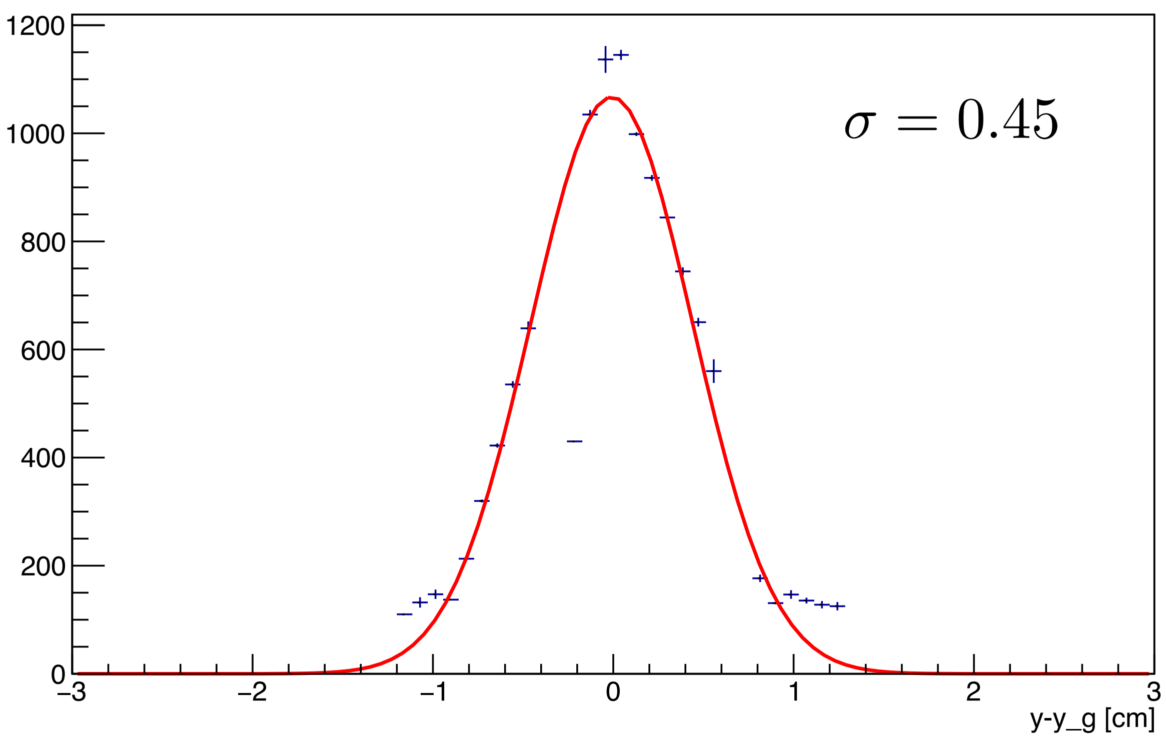
Longitudinal shower profile in 2015



Radius of shower spread

LGL3 130 GeV





- This is the Diagram showing spread of horizontal shower in 130 GeV LGL 3
- ADC Values projection as a function X or Y.
- The width of the distribution represents the magnitude of the spread of the shower

$$R_{\mathrm{M}} = 9.3\ \mathrm{mm}$$

(90% of the shower fall within this radius)

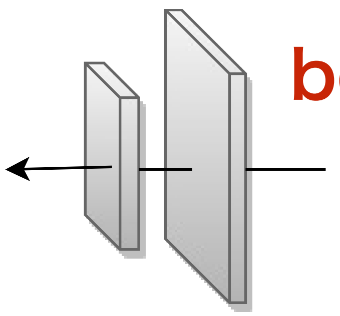
$$1.65\sigma = 0.8 \pm 0.0013\ \mathrm{cm}$$

The shower radius on the LGL 3 module is within the range of the theory

Integrate System

Integrate system

Purpose: Share the same event with different detectors



beam trigger

10 bit trigger ID (Digital)

- HGL DAQ has **trigger scaler** information.
- Trigger circuit generates **analog pulse.** corresponding to 10 bit trigger scalar number.
- LGL DAQ reads out both Pad signal and trigger scalar number as analog data.

Trigger scaler

(FPGA Box)

HGL DAQ

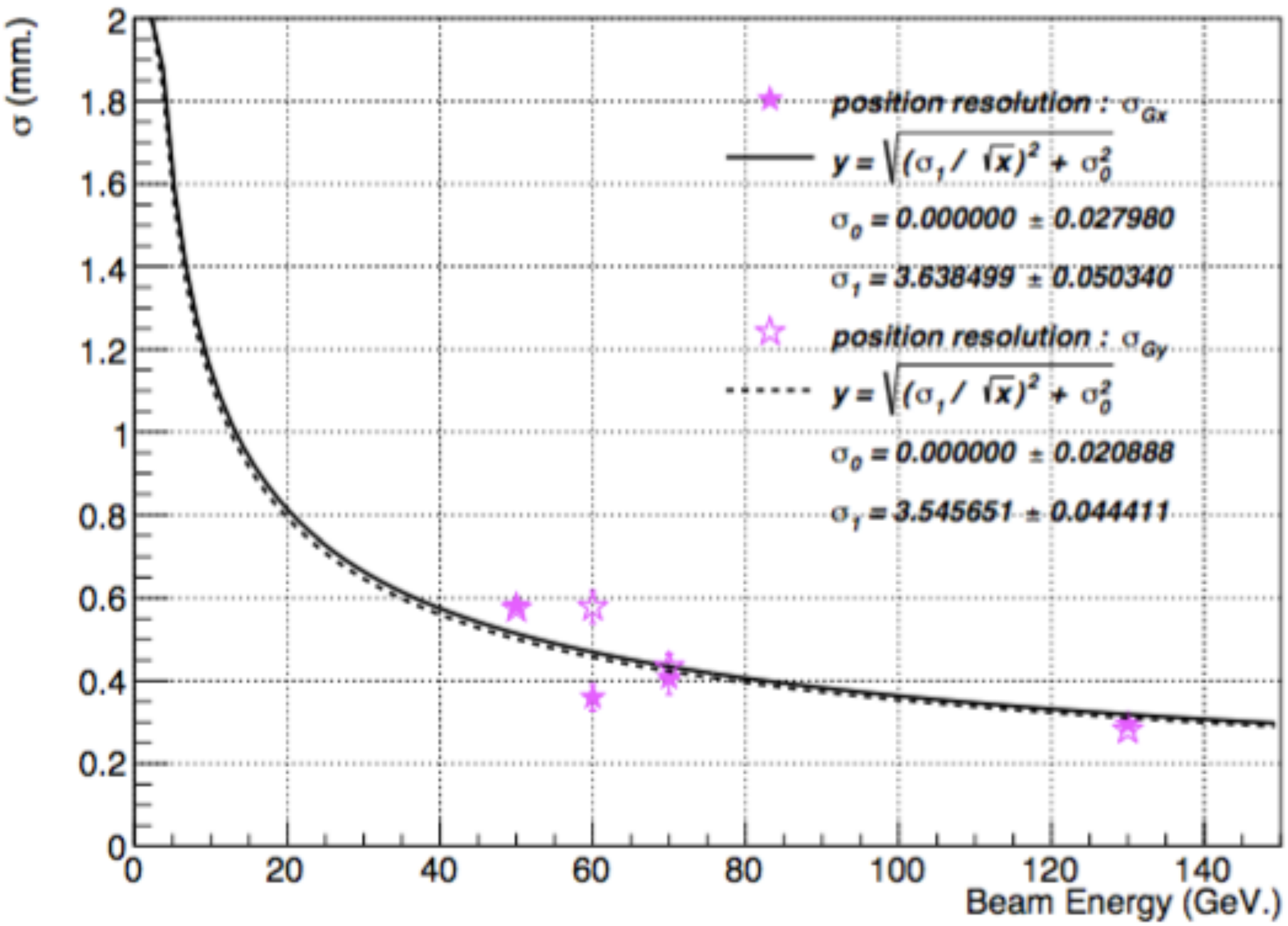
trigger circuit

10ch trigger Pulse (Analog)

LGL DAQ

HGL position resolution

The center of gravity of position resolution



$$\sigma_{G_x} = \frac{(3.638 \pm 0.050)\mathrm{mm}}{\sqrt{E}} \oplus (0.000 \pm 0.028)\mathrm{mm}$$

$$\sigma_{G_y} = \frac{(3.546 \pm 0.044)\mathrm{mm}}{\sqrt{E}} \oplus (0.000 \pm 0.021)\mathrm{mm}$$