Research and development for the Forward Calorimeter as an ALICE upgrade project to study forward physics

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For ALICE FoCal collaboration

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WORKSHOP ON FORWARD PHYSICS AND HIGH-ENERGY SCATTERING AT ZERO DEGREES AT NAGOYA

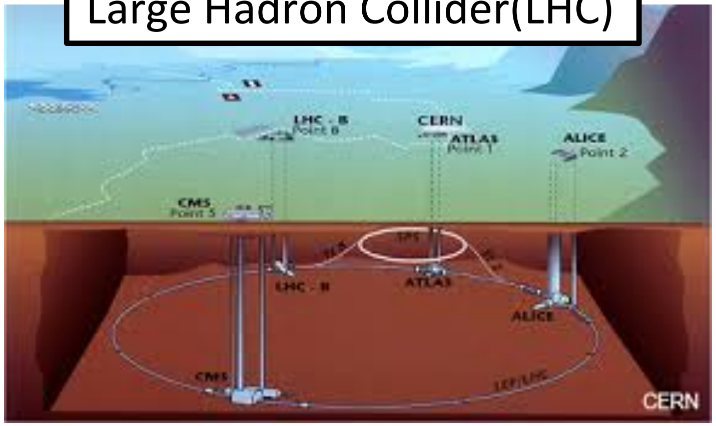
Outline

- Introduction
  - ALICE experiment at LHC
  - Forward physics
  - ALICE upgrade plan
  - FoCal project in ALICE
- Simulation result
  - π^0 detection efficiency
  - Direct photon selection
  - Pb-Pb π^0 performance
- Test beam in 2014
  - LGL result at test beam in 2014
  - HGL result at test beam in 2014
- Summary & next

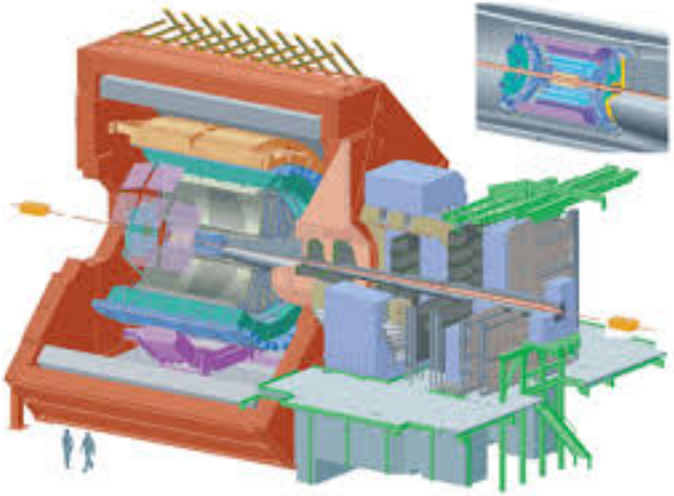
Introduction

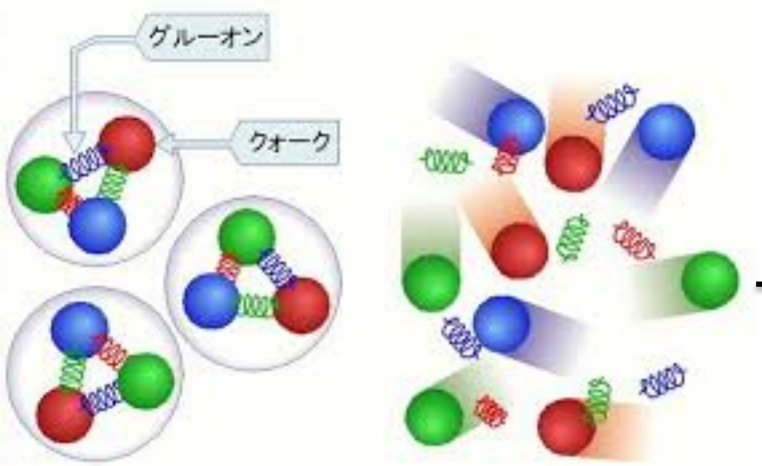
ALICE experiment at LHC

Large Hadron Collider(LHC)



ALICE experiment
- <u>To study QGP(Quark Gluon Plasma)</u>

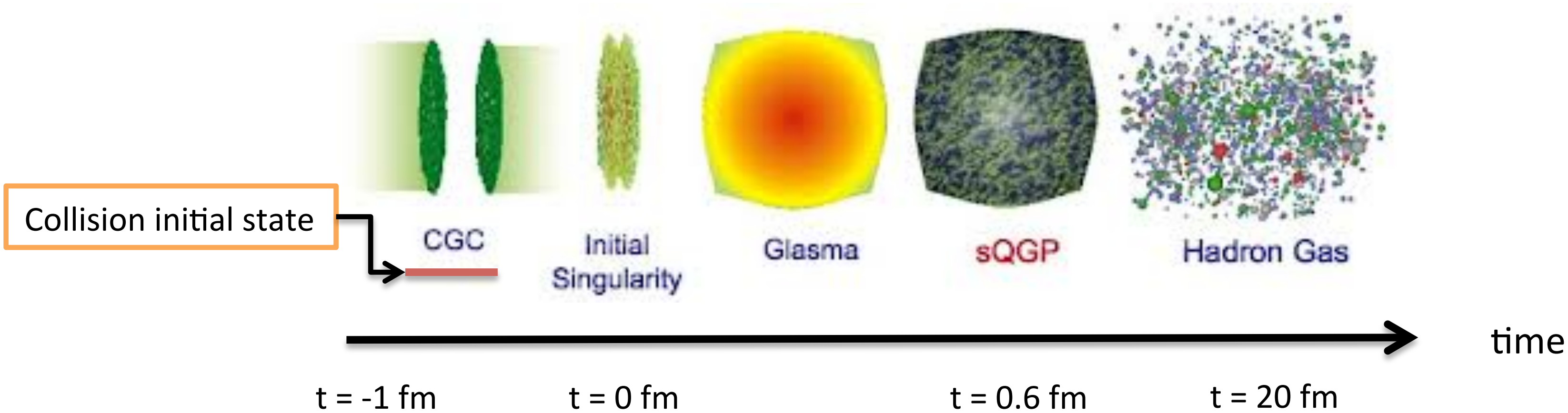




Quark Gluon Plasma
- The state of early universe
- Quarks and gluons move freely

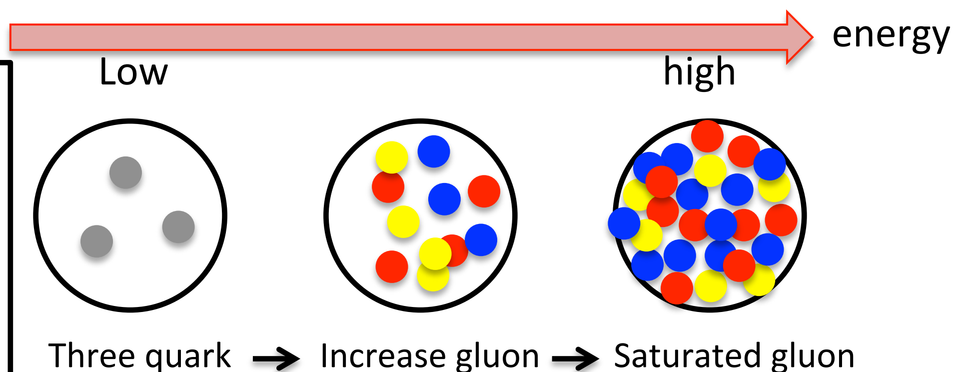
Color Grass Condensate(CGC)

Initial state of nuclear at high energy : gluon is high-density and saturated



Prediction by QCD at high energy
This phenomenon is expected in the forward region

Perform experiment to study it



Forward physics

- Bjorken-x

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

High energy : √s (large)
Forward region : y (small)

↓

<u>small-x</u>

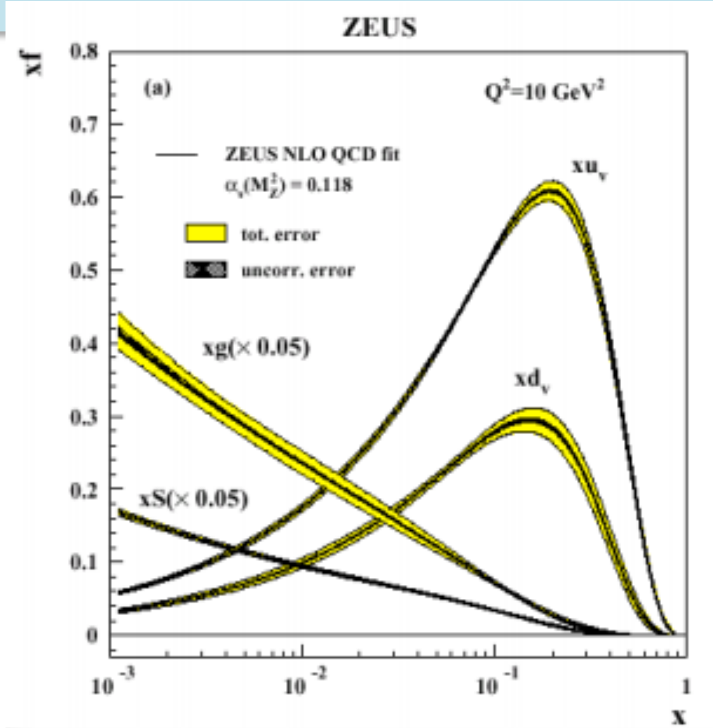
↓

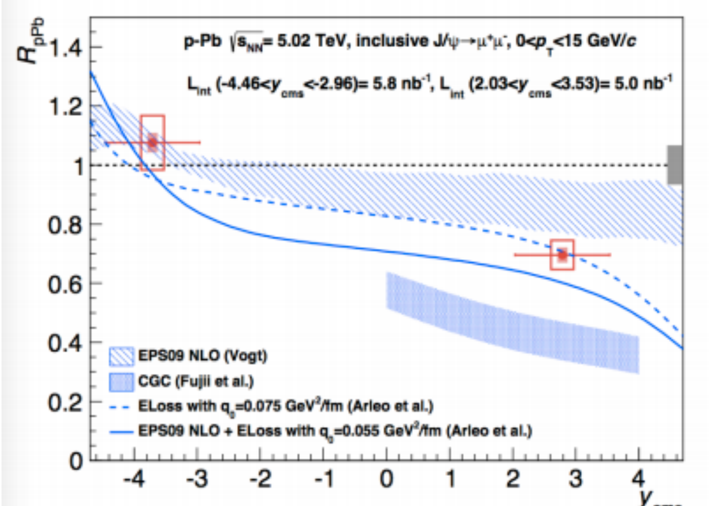
Accessible in LHC experiments

Study by hadron : including the final state

↓

<u>Study by photon : only initial state</u>





CERN-PH-EP-2013-156

ALICE upgrade plan

Upgrade of various detectors are planned for LHC Long Shutdown

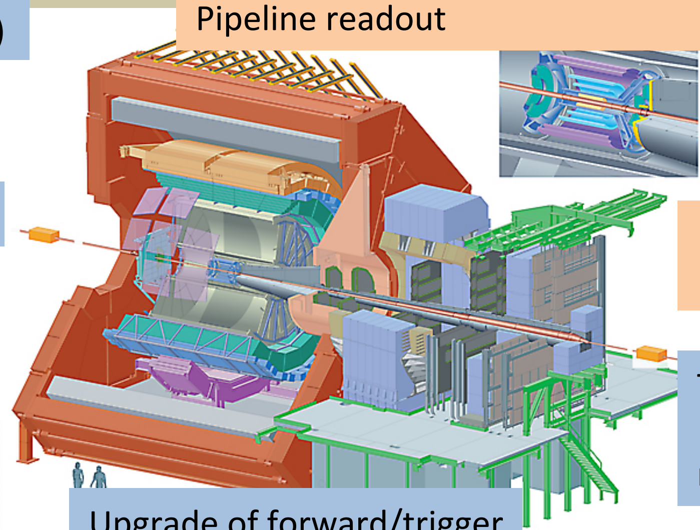
EMCal : extension by DCAL(LS1)

FoCal project

New beam pipe : smaller diameter

TPC : new GEM readout chambers, Pipeline readout

(blue/orange)	approved
(red)	submitted
(green)	under internal review

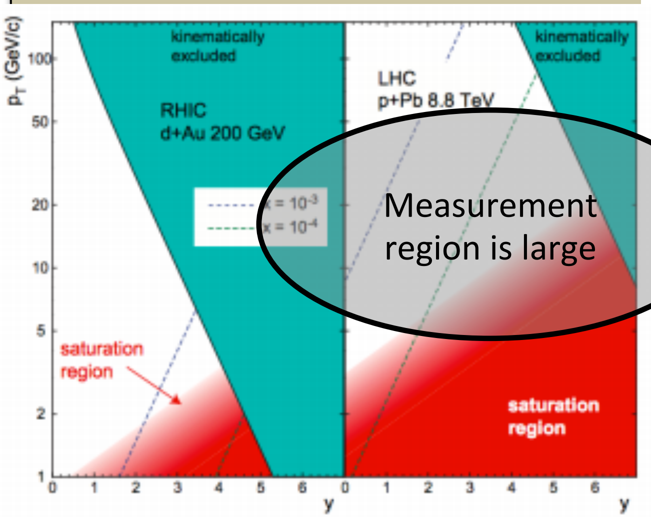


New ITS : high resolution, Low material budget

TRD, TOF, PHOS, EMCal, Muon spectrometer : new readout electronics

Upgrade of forward/trigger detectors (ZDC, VZERO, T0)

MFT project



Measurement region is large

Useable of high energy of LHC
→inspection of CGC, solution of early stage fever, etc…

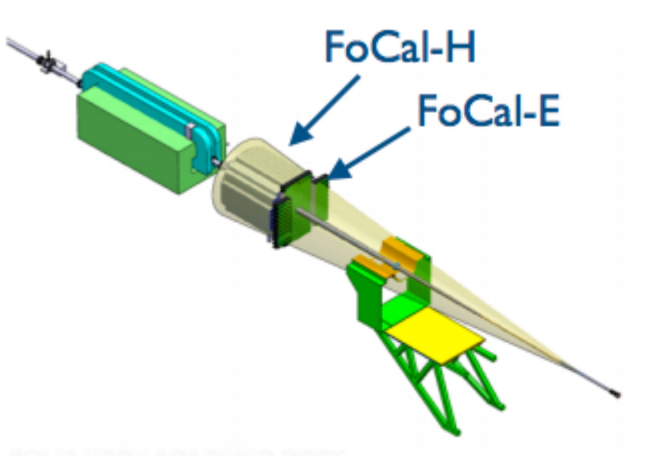
All approved upgrades are for LS2(2019 ~ 2020) and the focal proposal is for LS3.

FoCal project in ALICE

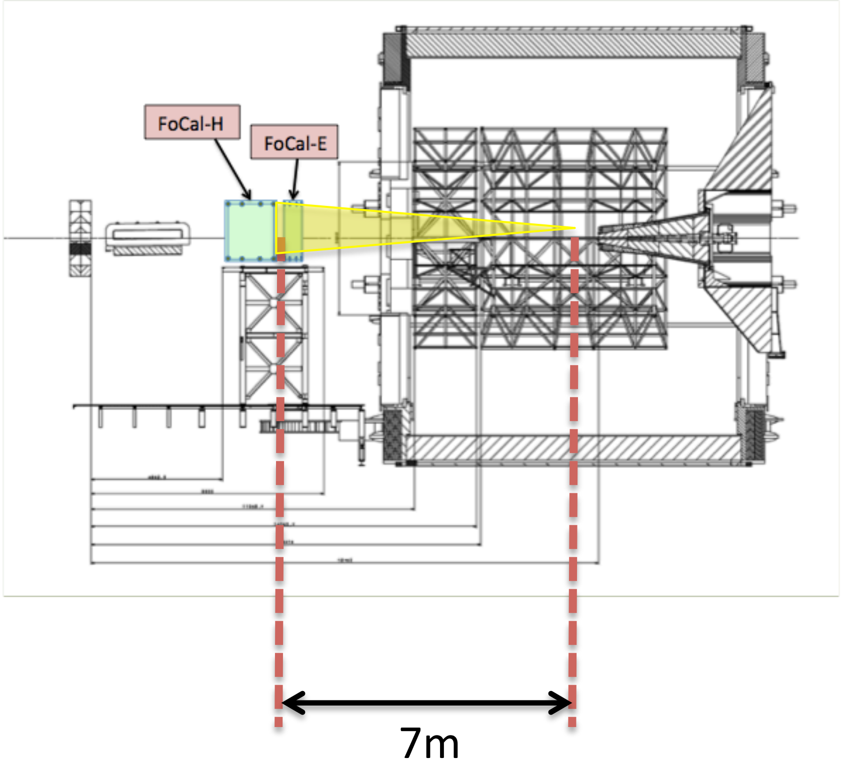
▪FoCal : Forward Calormeter
- One of the upgrade plan in ALICE experiment

▪Components
- Electromagnetic Calorimeter : FoCal-E
- Hadron Calorimeter : FoCal-H

▪Acceptance : 3.3 < η < 5.3



FoCal installation plan

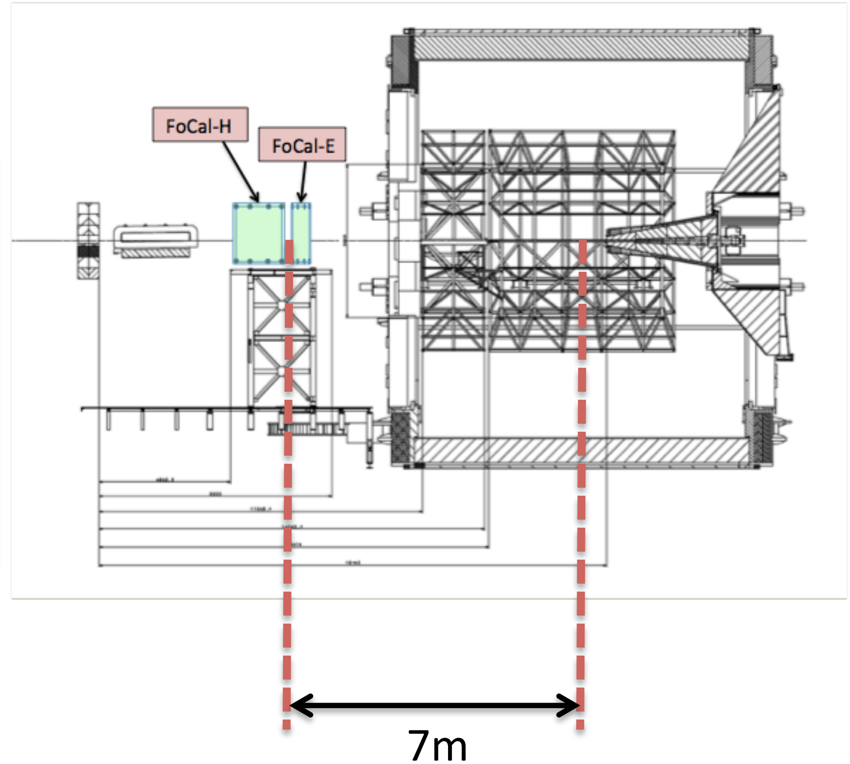


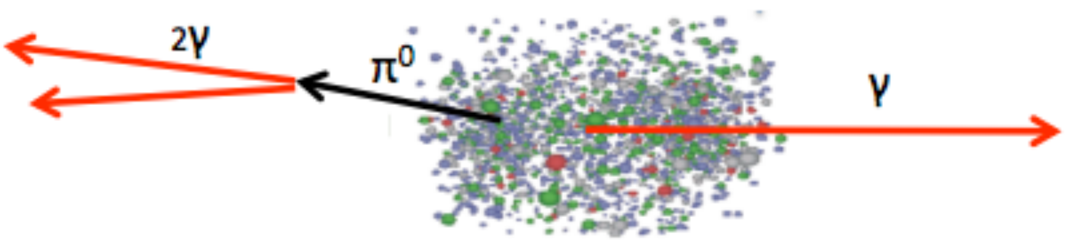
FoCal project in ALICE

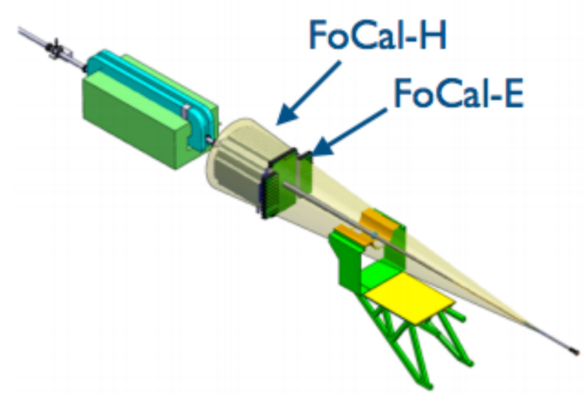
Observables:
- $\pi^0 \rightarrow 2\gamma$
- direct(isolated) photons

- J/Ψ
- Jets

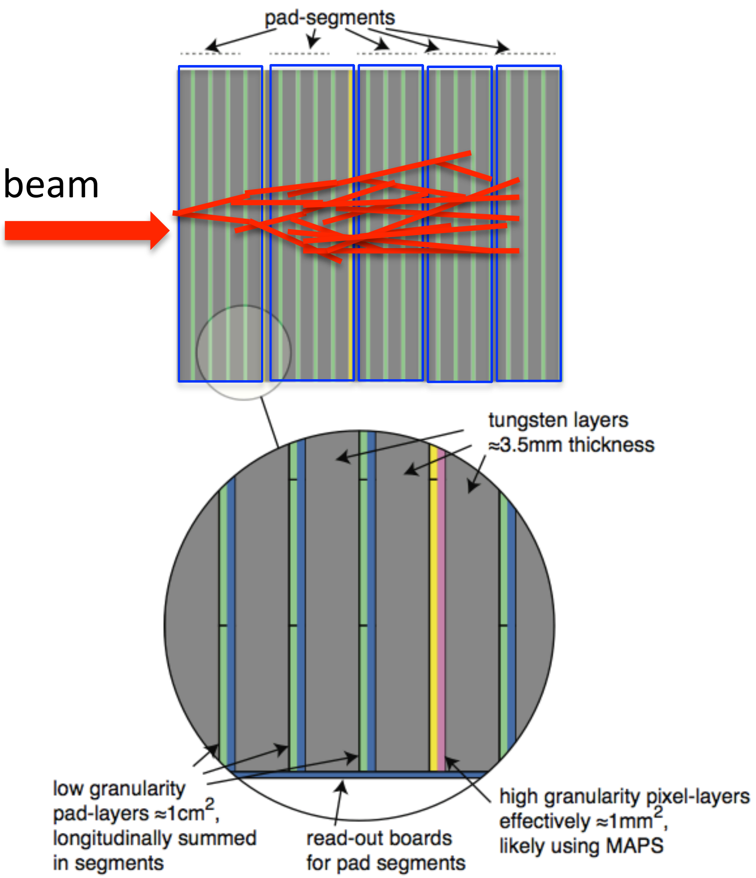
FoCal-E subject (identification of γ/π^0)





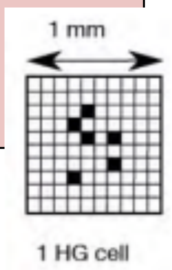


FoCal-E strawman design

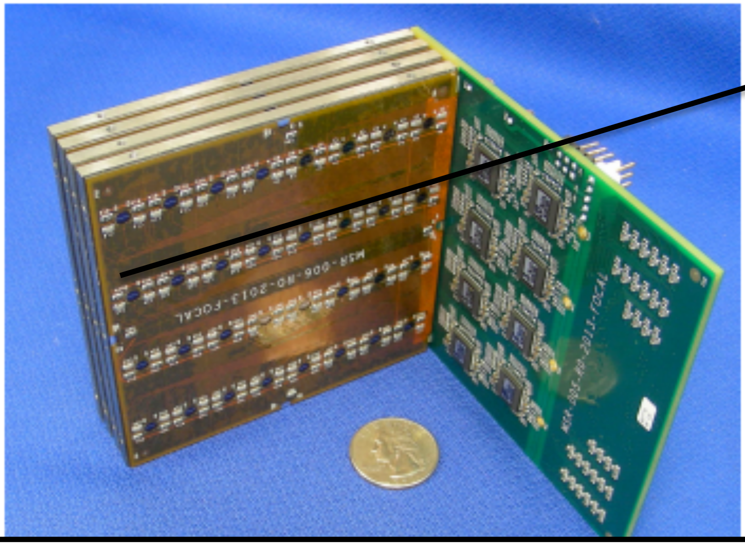


- W/Si sandwich calorimeter
  - W absorber + Si sensors
    - Moliere radius : R_M = 9.3mm
    - Radiation length : X_0 = 3.5mm(1 layer)

- Longitudinal segmentation : two different module
  - Low Granularity Layer(LGL) : 5 segments
    - 1 segment = 4 layers of Si/W
    - 1 layer = 64 PADs(8 × 8)
    - Silicon PAD size : 1 × 1 cm^2
    - Signals are longitudinally summed
  - High Granularity Layer(HGL) : 2 segments
    - CMOS-pixel
    - Pixel size : 30 × 30 μm^2
    - Digital signals are summed in 1 mm^2 cells

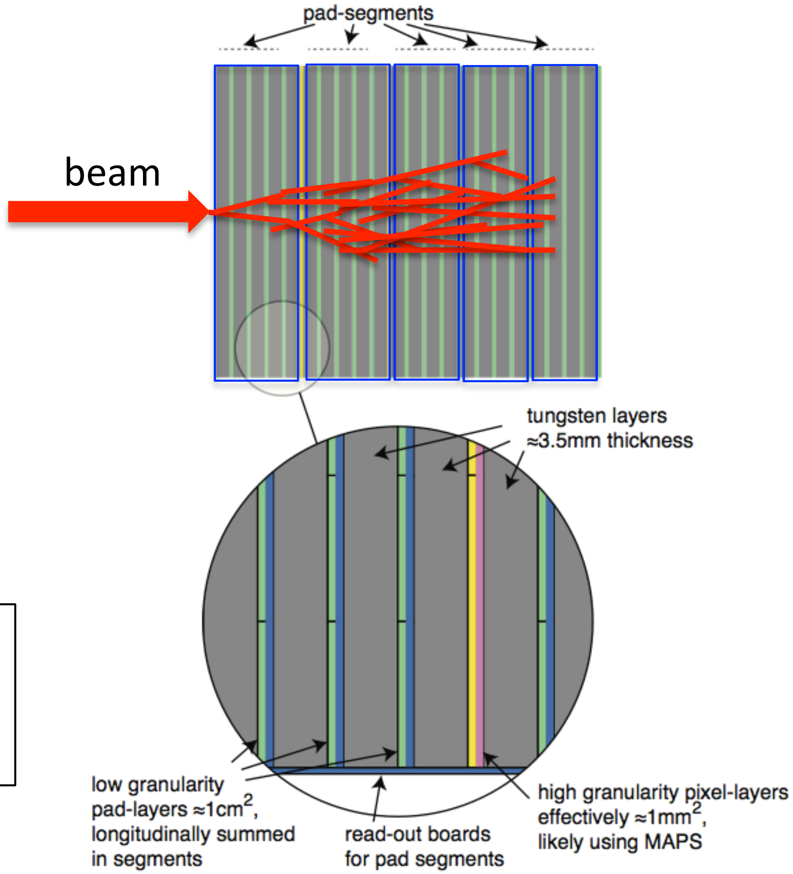


Low Granularity Layer(LGL)



Prototype(made by Oak Ridge National Laboratory)

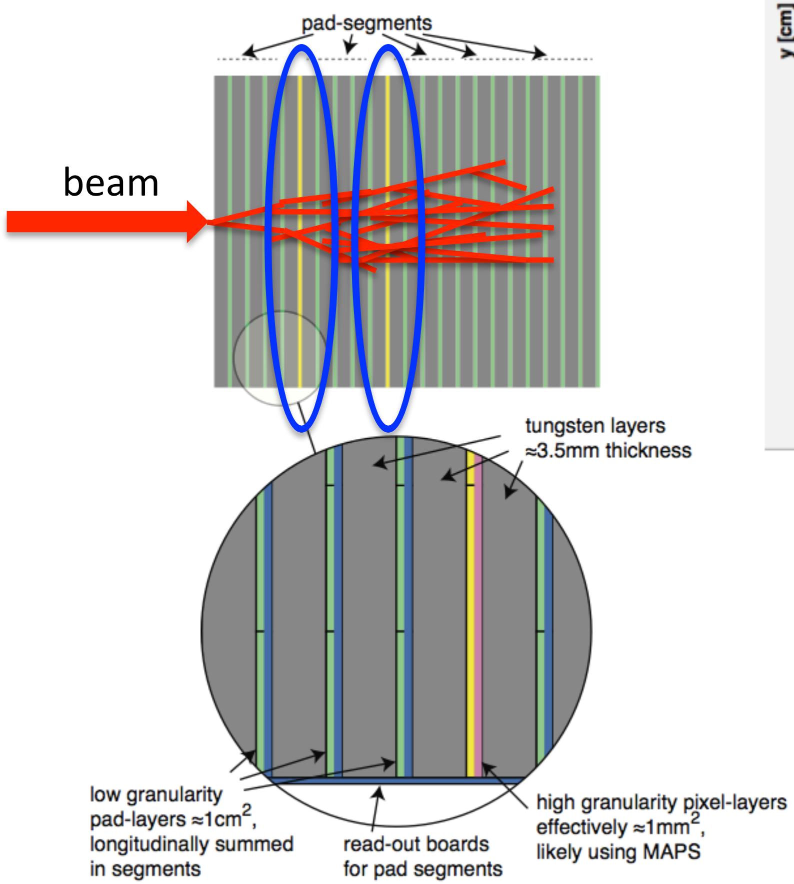
Silicon(Hamamatsu S10938-9959(X))

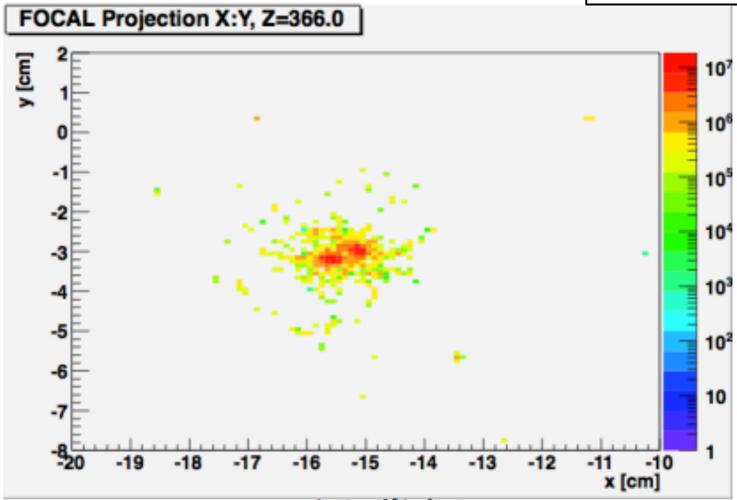


- Summing board has 128 channel output
- 1/1(high gain) positive output : 0ch 〜 63ch
- 1/16(low gain) negative output : 64ch 〜 127ch

We can change the gain by changing reading polarity

High Granularity Layer(HGL)





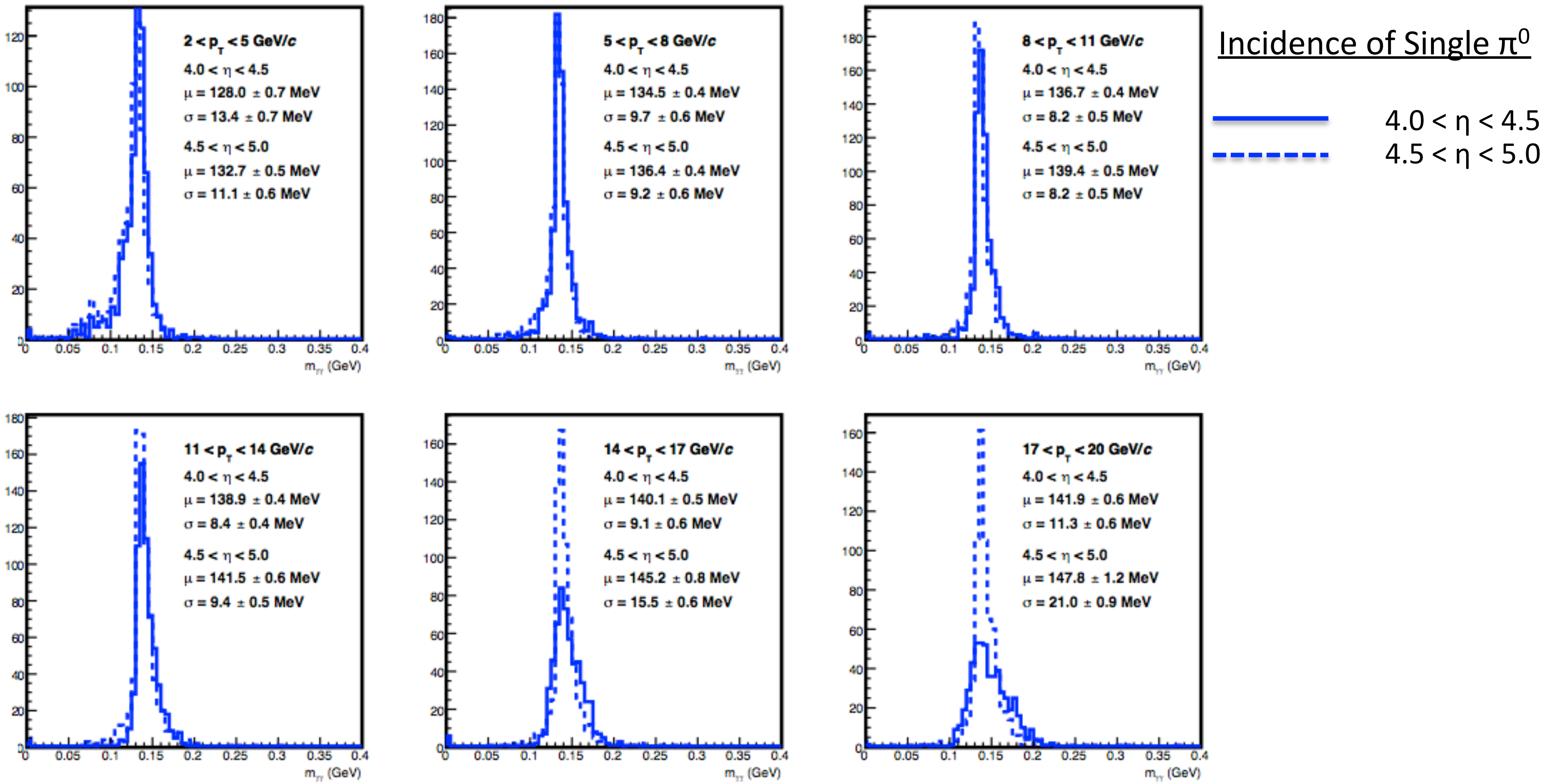
Letter of Indent
A Forward Calorimeter(FoCal) for the ALICE experiment
200GeV/c π^0 simulation

Prototype(made by Utrecht University)

- This is CMOS-pixel(mimosa23(PHASE 2) : designed in Strasbourg) detector which can readout per 1mm^2 is not quite true; here we read out all pixels individually
- Identification of γ/π^0 is possible because of observing shower shape
- Read out electronics for HGL : provided by Bergen University

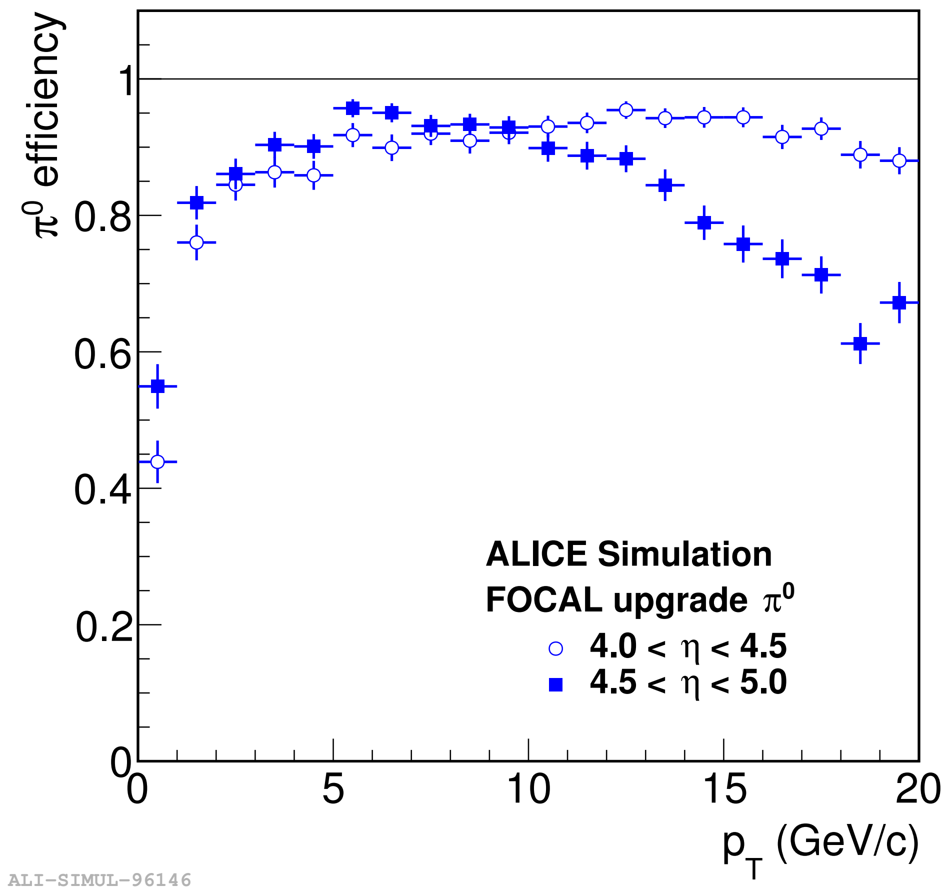
Simulation result

π^0 mass peaks and resolution --simulations; FoCal at 7m--



- Two-photon separation over large momentum range

π^0 detection efficiency



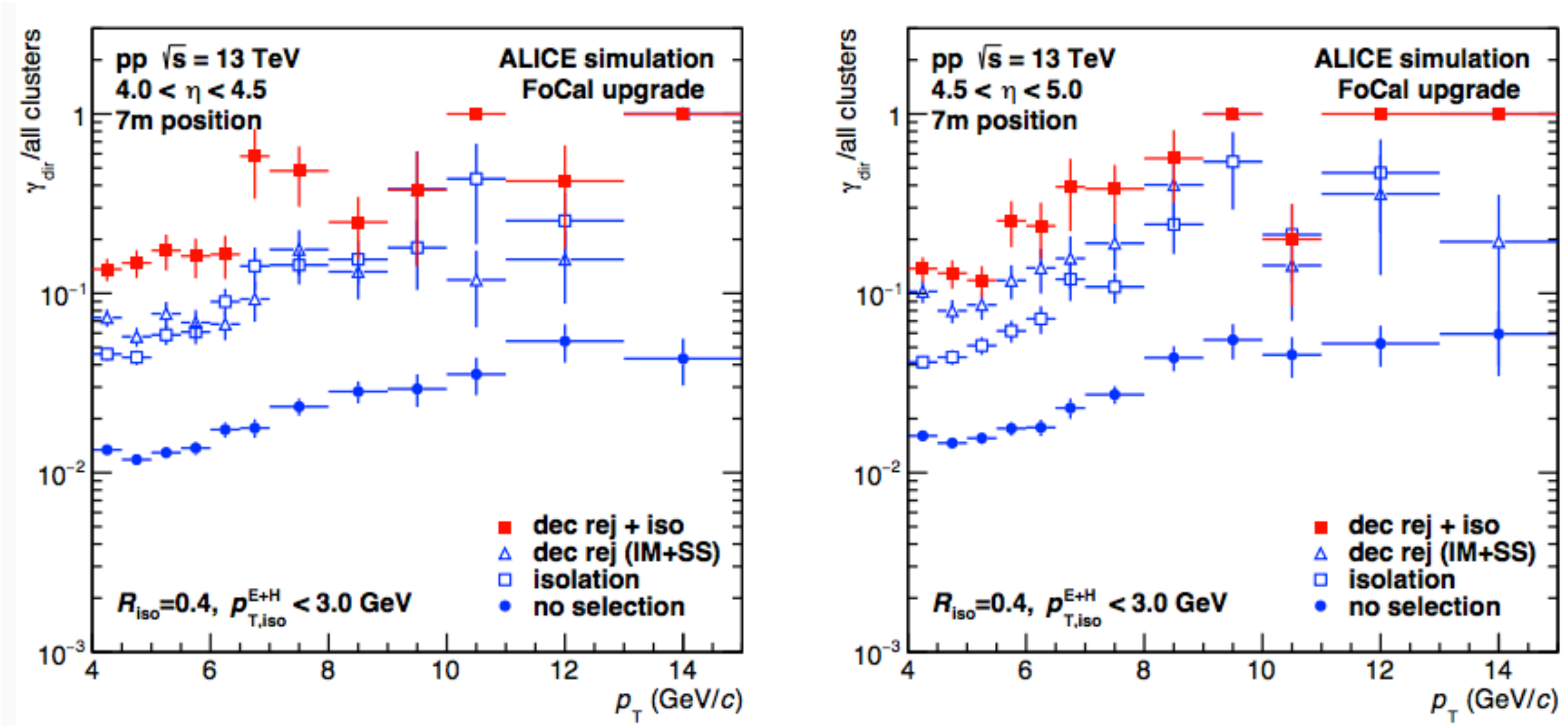
good efficiency

p_T : 2 ~ 18 GeV/c , η = 4.0 ~ 4.5

p_T : 2 ~ 12 GeV/c , η = 4.5 ~ 5.0

Covers the intended range for CGC measurements : low-intermediate Q^2

Direct photon selection

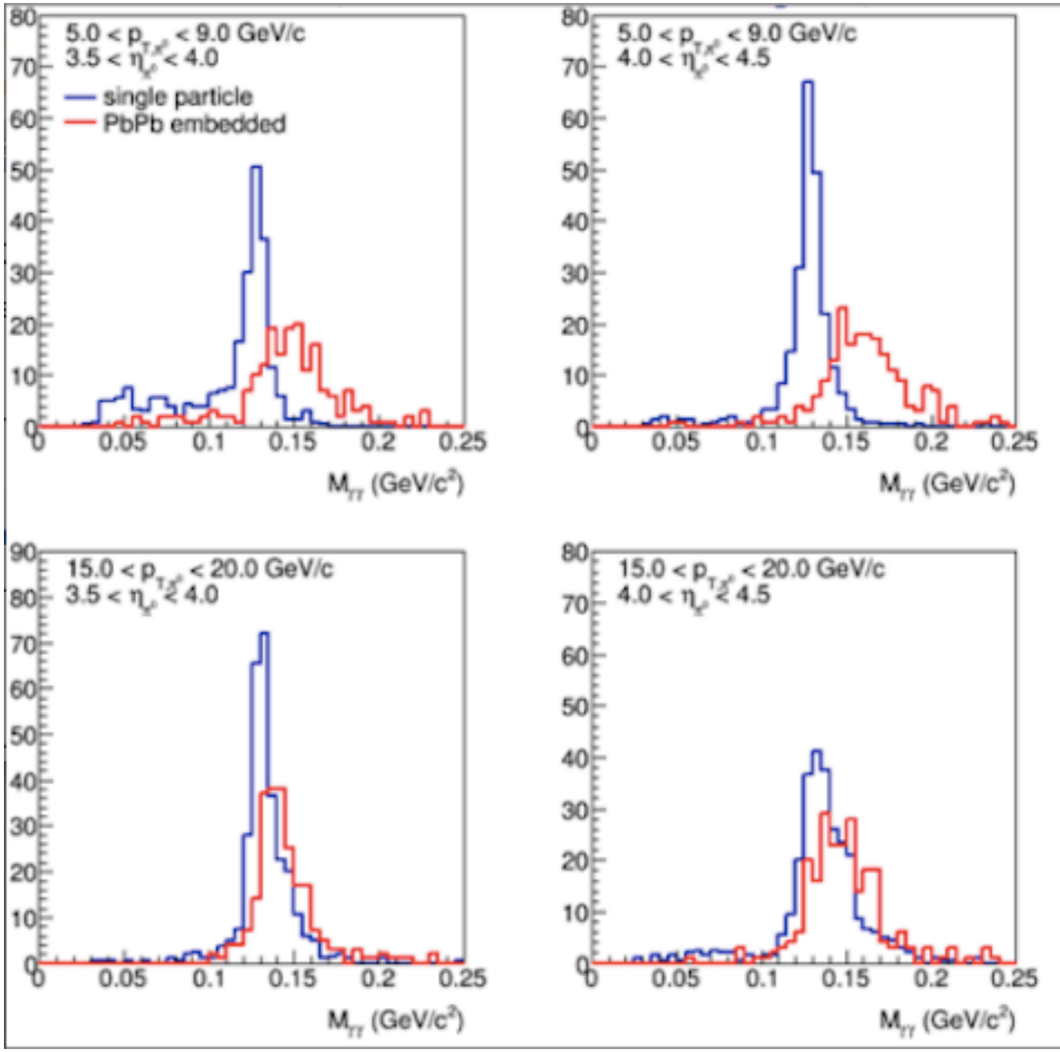


Two handles to select direct gamma : invariant mass , isolation cuts

After selection

Direct gamma fraction > 0.1 (larger at high p_T)

Pb-Pb π^0 performance of invariant mass



Single particle

PbPb embedding(HIJING + single π^0)

Performance worse than pp,
but good enough for p_T > 10 GeV/c

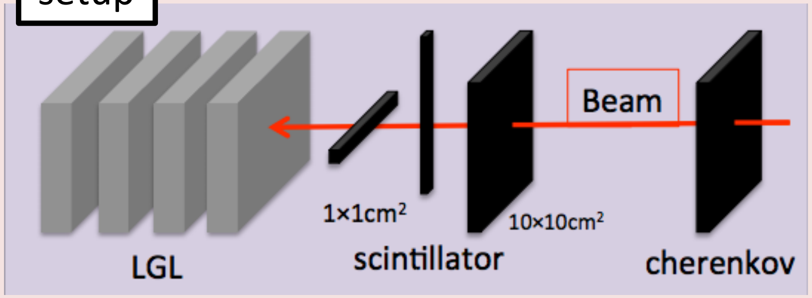
Test beam in 2014

test beam at PS and SPS

This is first test beam experiment for LGL of Tsukuba group!!

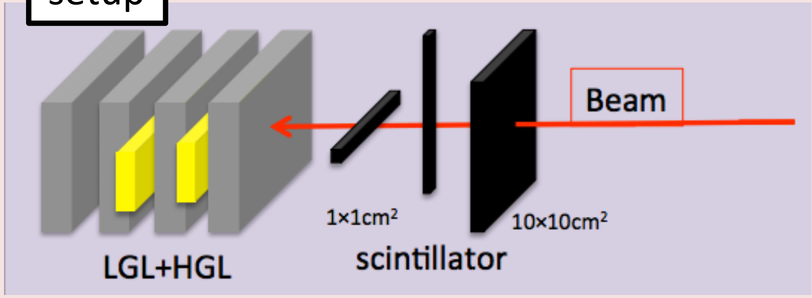
PS
- T9 beam line
- Term : Sep – Oct in 2014
- Energy : 2 〜 10 GeV
- Beam rate : ~100 Hz
- Gain : high gain(1/1)

setup



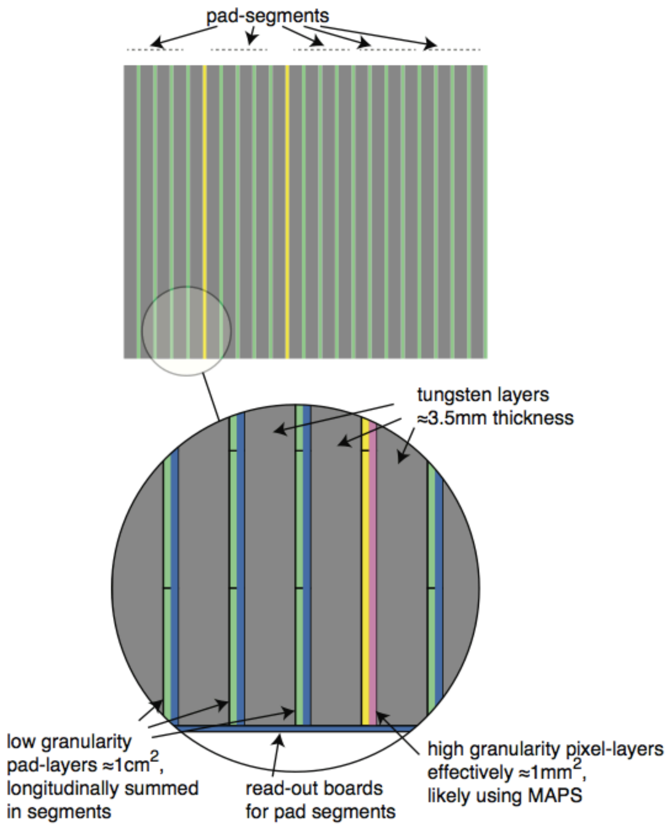
SPS
- T4 – H8 beam line
- Term : Nov in 2014
- Energy : 30 〜 100 GeV
- Beam rate : ~300Hz
- Gain : low gain(1/16)

setup



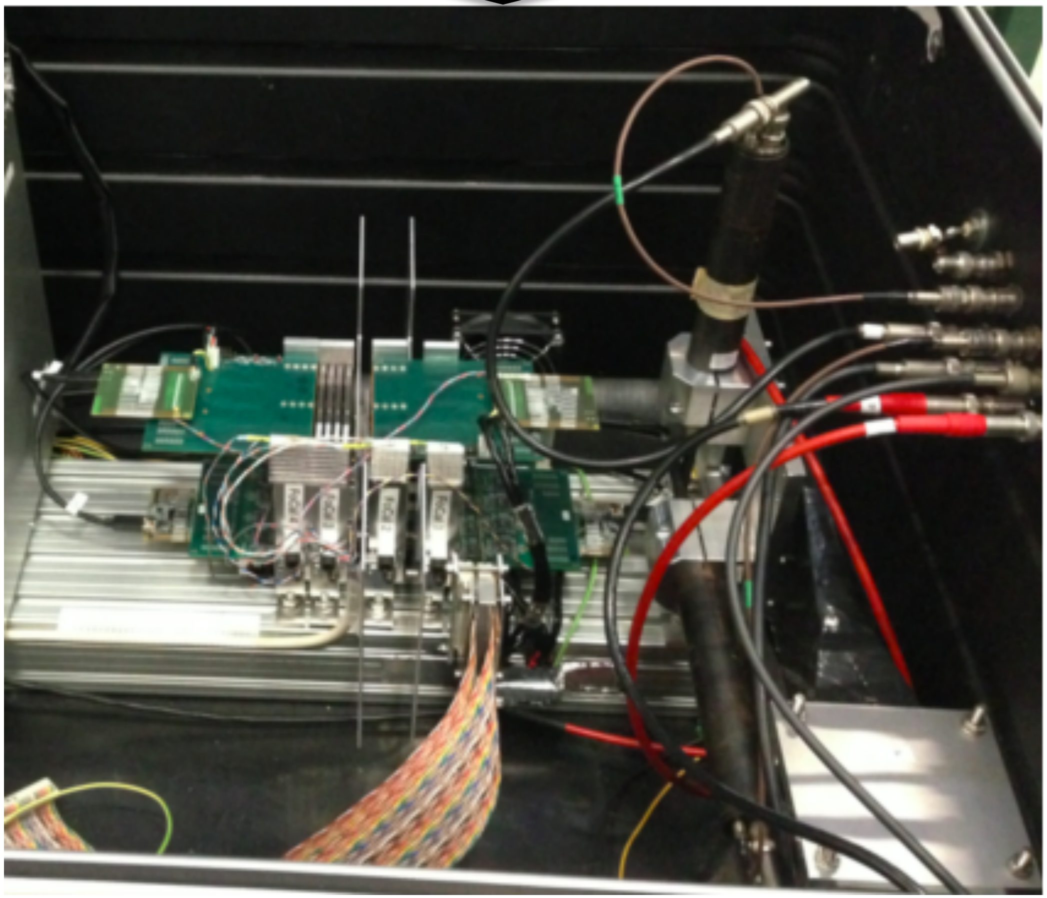
At PS, we use the cherenkov detector to identify electron

FoCal setup

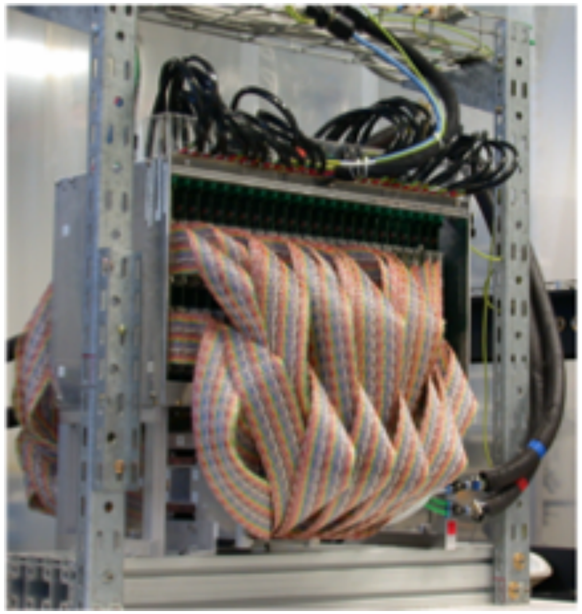


4 segments are stacked on the rail
→fix the position
→attention : summing board inversed

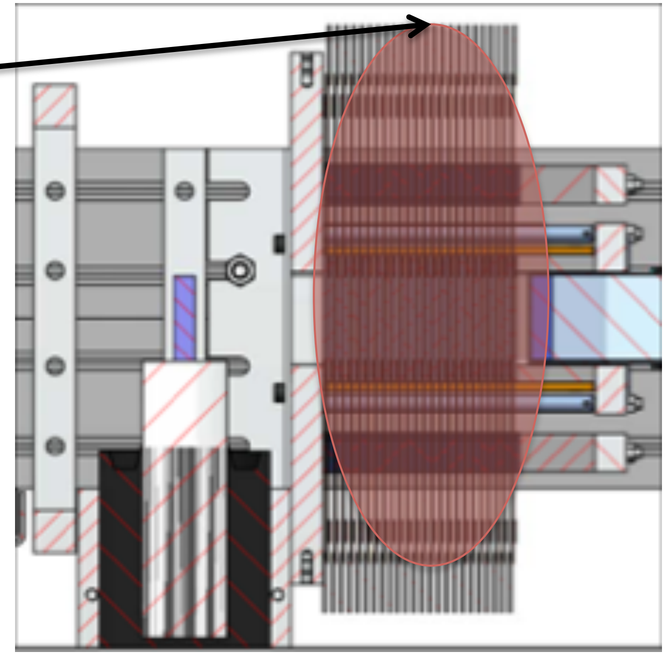
▪Inside black box
4 LGL segments and 2 HGL with trigger scintillator



HGL testbench



MAPS has about 24 layers of HGL with tungsten

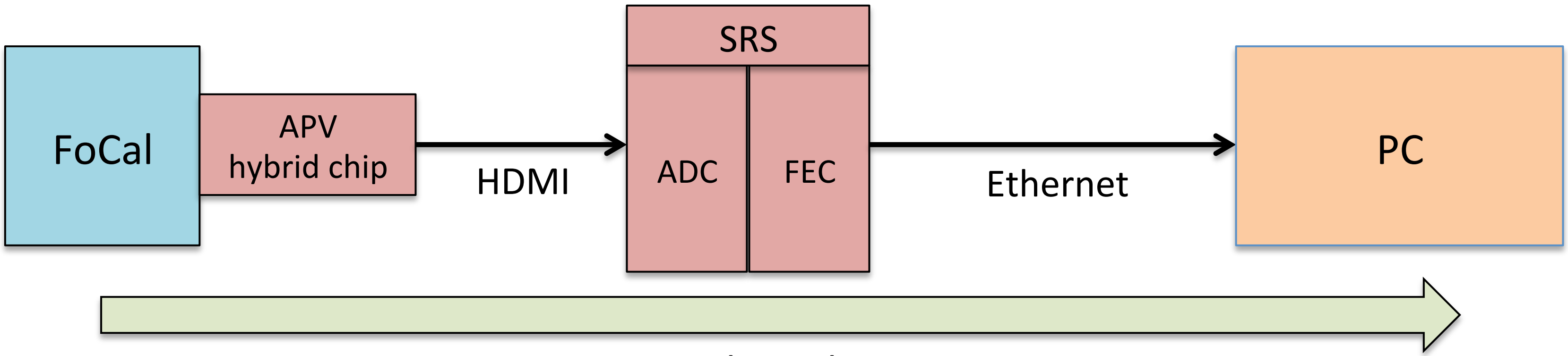


MAPS from the top

This is a special setting for measuring performance of HGL → Measurement of spatial resolution and energy dependence, resolution…

LGL result at test beam in 2014

LGL readout system

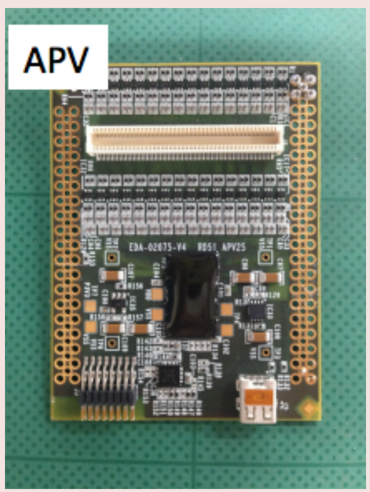


Data Flow Chart

Readout Electronics : developed by CERN RD51 group

▪APV25 hybrid board
Output : 128ch
Sampling speed : 40MHz

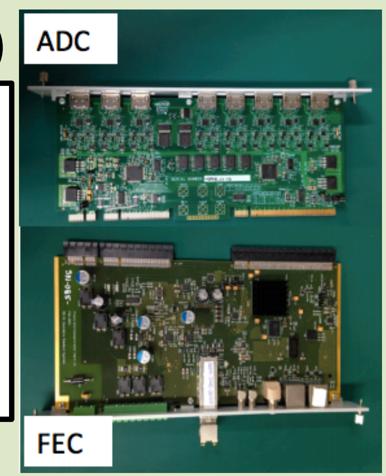
Gain : high gain(1/1) and low gain(1/16)



▪SRS(Scalable Readout System)

- ADC board : 12 bit ADC
Simultaneous readout from 8 APV hybrid board(Master)

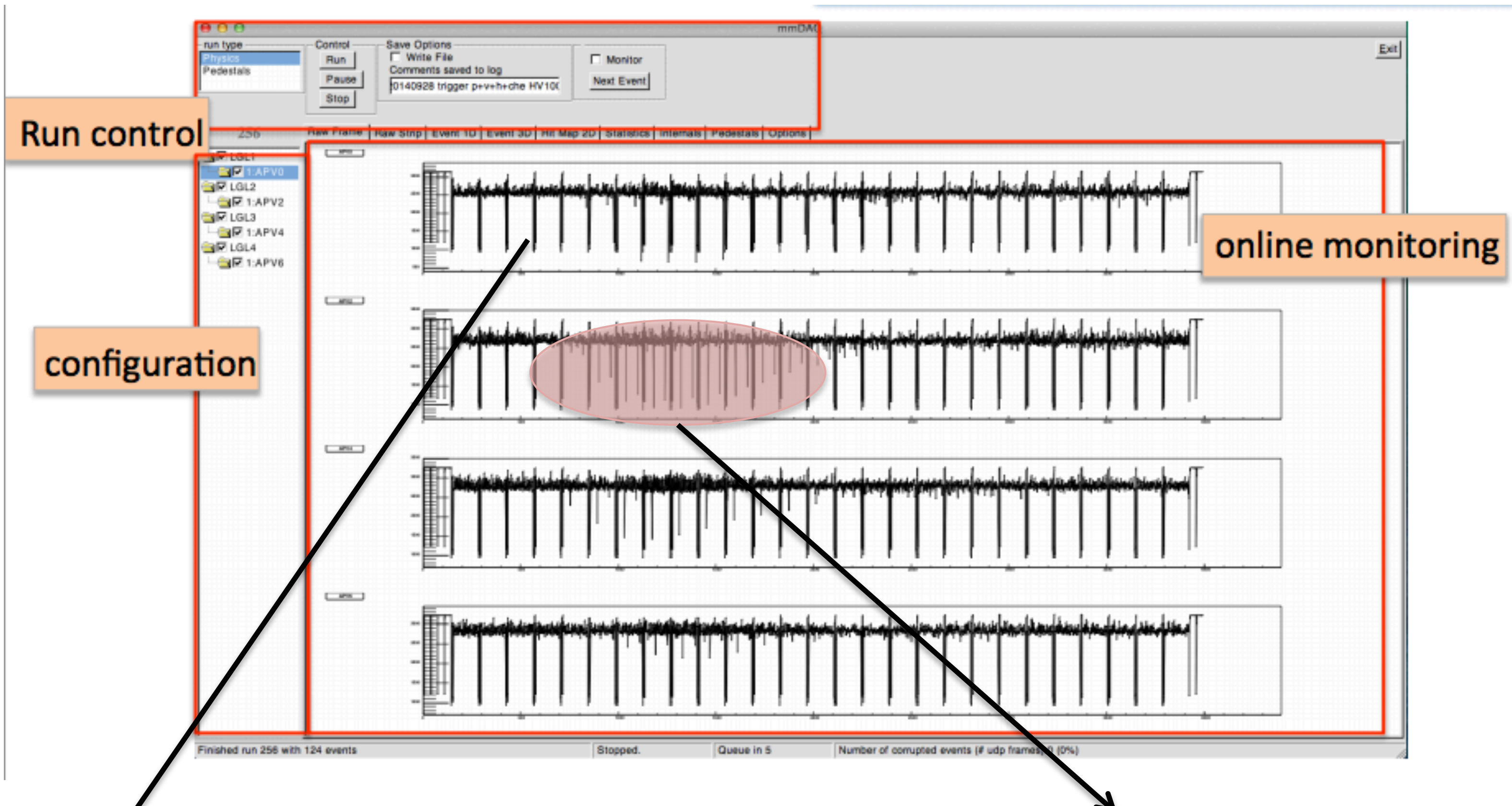
- FEC board : the front-end which processes information from ADC



LGL readout system

DAQsoftware

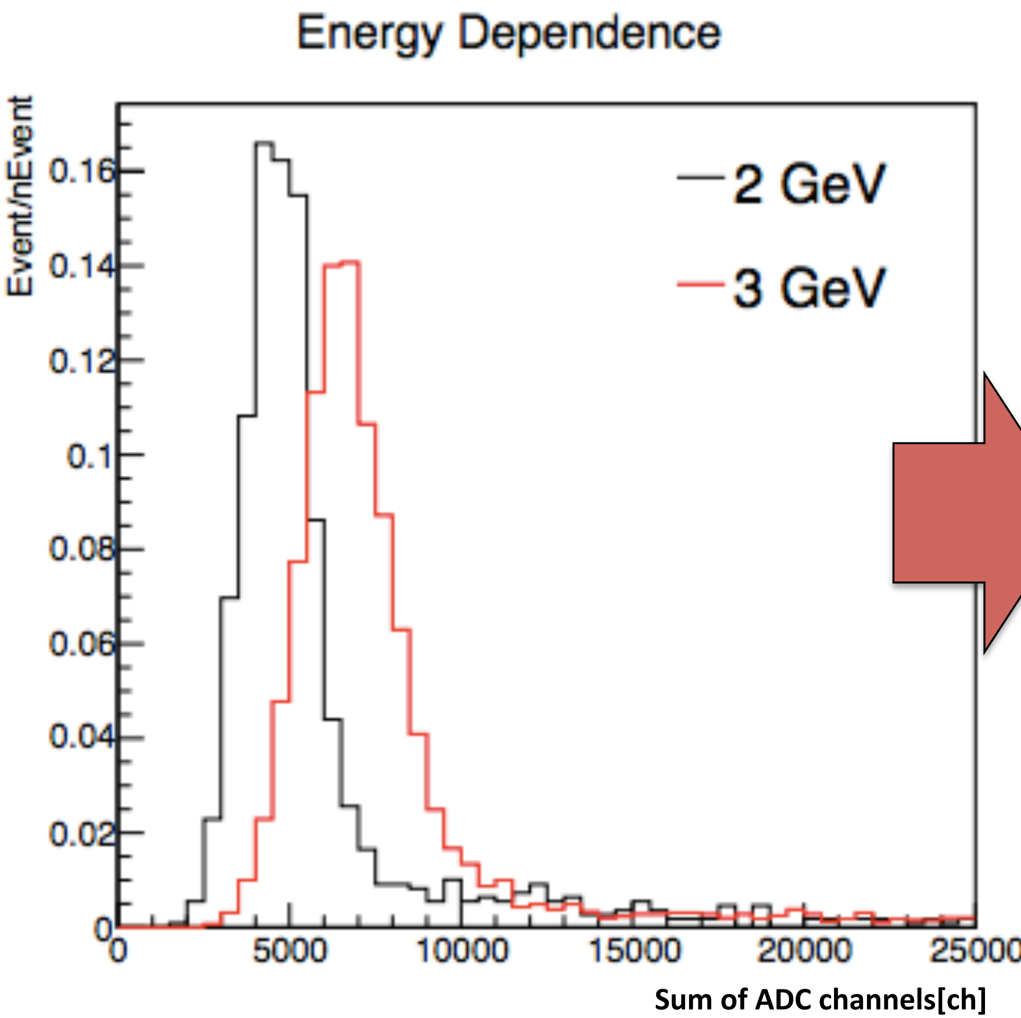
mmDAQ : DAQ system by ATLAS micromegas



signal

Horizontal axis : timebin per 25ns
Vertical axis : ADC channel

PS result



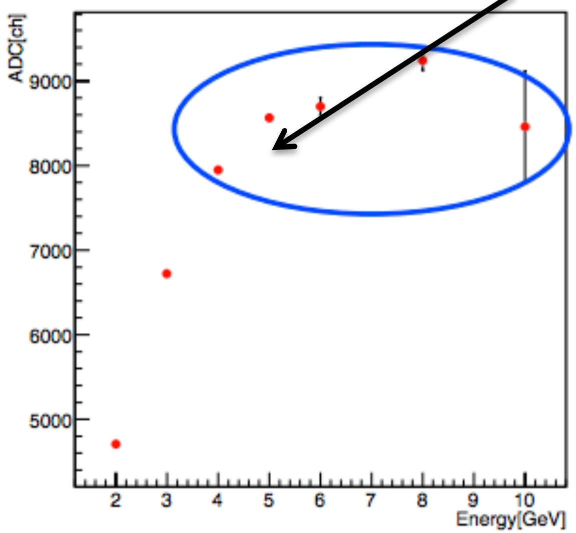
We were able to identify 2GeV and 3GeV beam energy

→We couldn't see the energy dependence from 4GeV to 10GeV
→signals are saturated

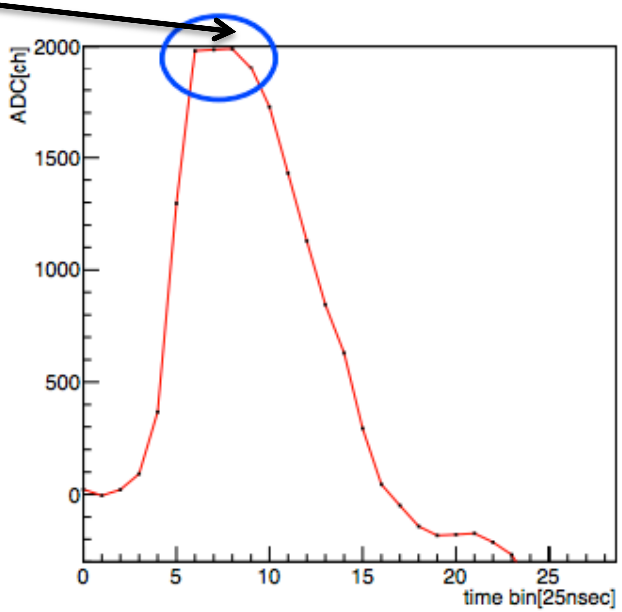
PS result

Saturated signal

Saturated region



Mean of Gaussian fit on each energy



ADC value of Each time bin for 1 LGL

On PS experiment, Noise is large

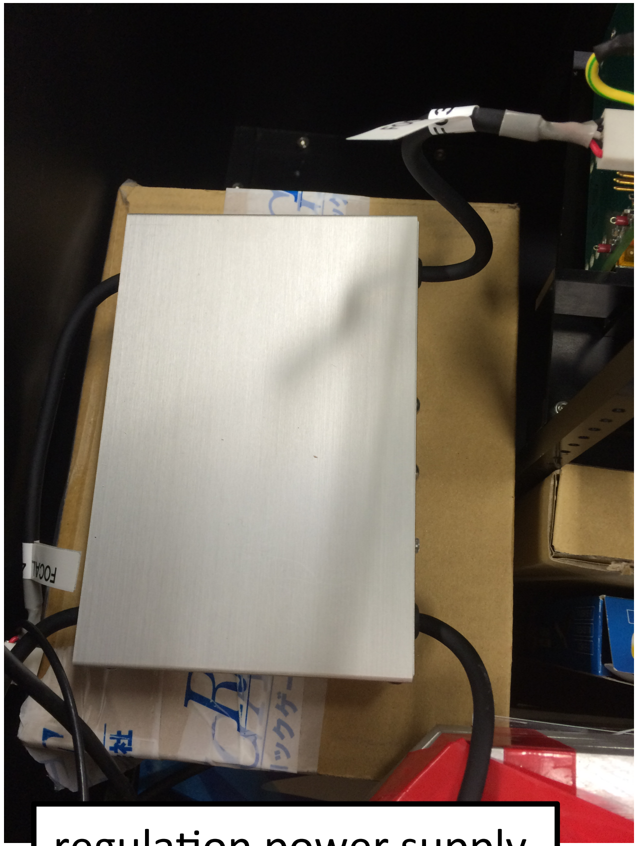
Improvement of noise

Comparison of Noise

	PS		SPS
Pedestal σ	105 ± 10	→	80 ± 7

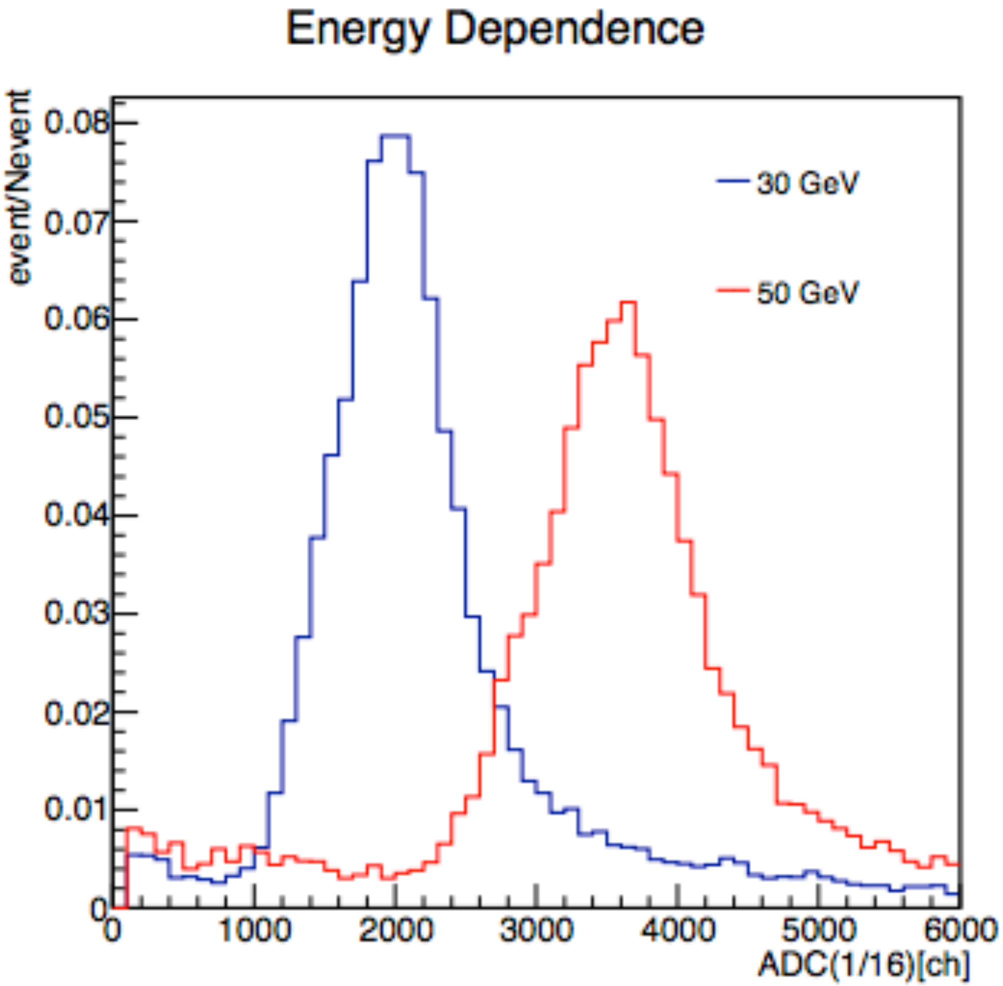
Decrease the noise (about 30%↓)

- Optimization of the GND
- Introduction of regulation power supply



regulation power supply

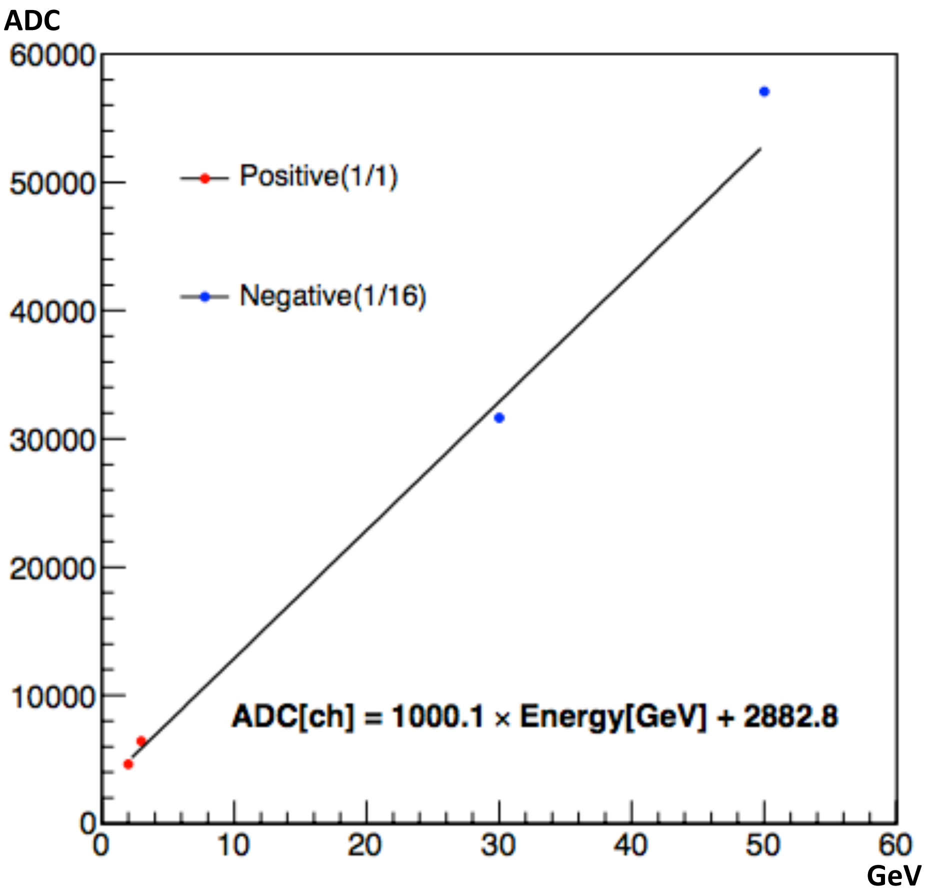
SPS result



Signal : over the pedestal value
Gain : low gain(1/16)
Data taking energy : 30 , 50 GeV

Result : 30 , 50 GeV

Energy dependence (PS and SPS)



Modified ADC channels
→negative output(1/16) × 16

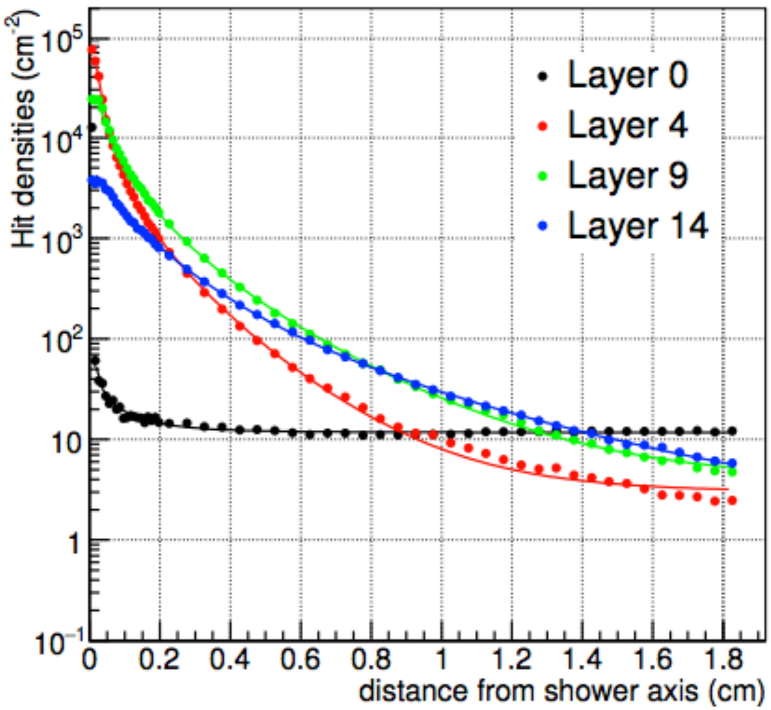
<u>We can see the energy dependence</u>

<u>Next test beam, cover the other energies</u>

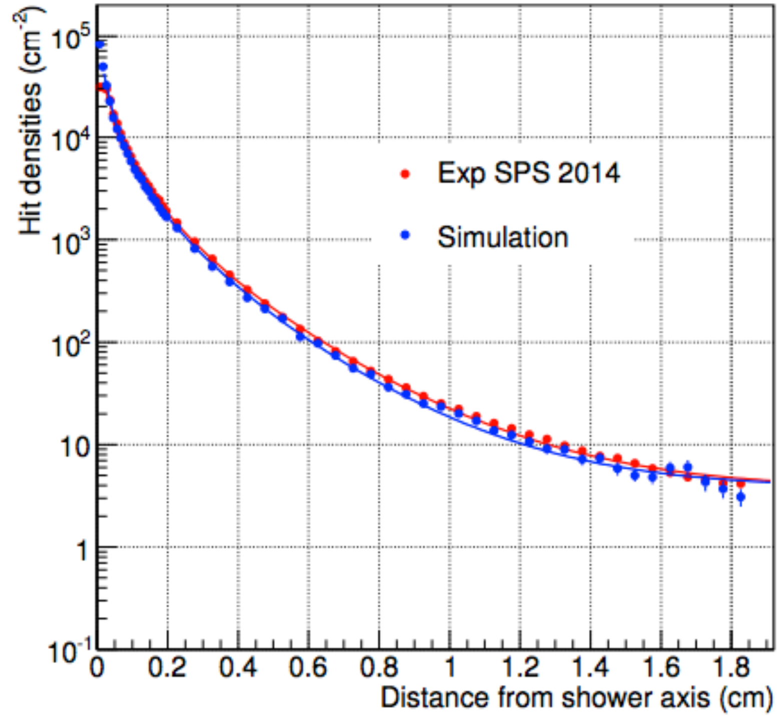
HGL result at test beam experiment

Lateral profiles

Radiation length : X_0 = 3.5mm



Test beam 50GeV e



Extremely good spatial resolution

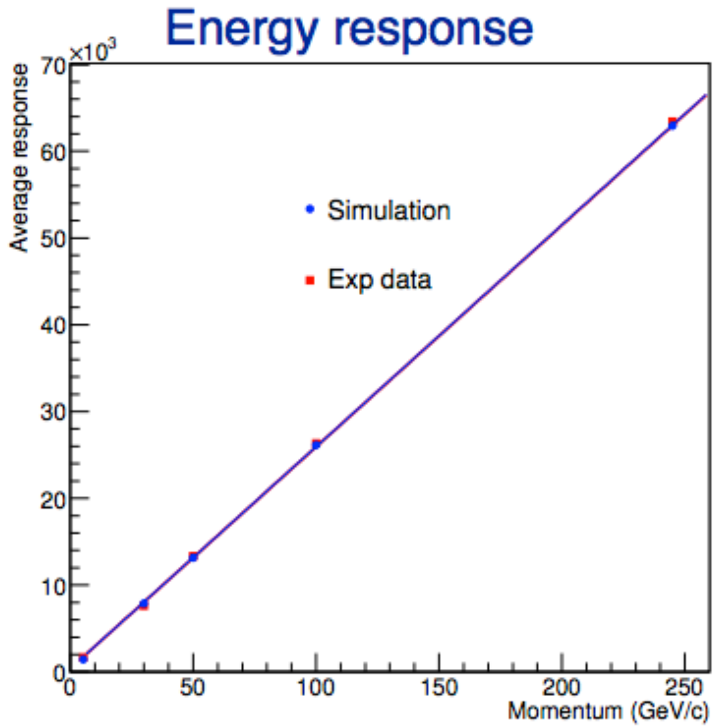
R_M ~ 1 cm

Good agreement with simulations

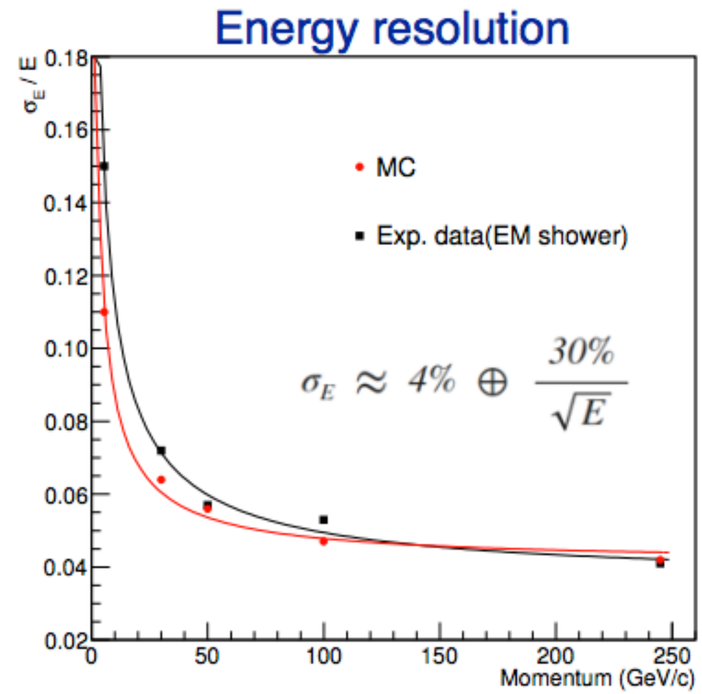
GEANT4 + charge diffusion

Two-photon separation at few mm scale possible

Linearity and energy resolution



Good linearity over full range



Energy resolution in reasonable agreement with MC

HGL is good performance for spatial and energy resolution

HGL : slow readout speed
LGL : fast readout speed

→

HGL : measurement of shower shape
LGL : measurement of shower energy

summary

- Forward Calorimeter in ALICE will be able to observe the unique signal
  - small-x gluons and saturation
  - CGC proving initial condition
  - early thermalization of QGP
- In our first test beam 2014, we were able to see the shower shape and energy dependence

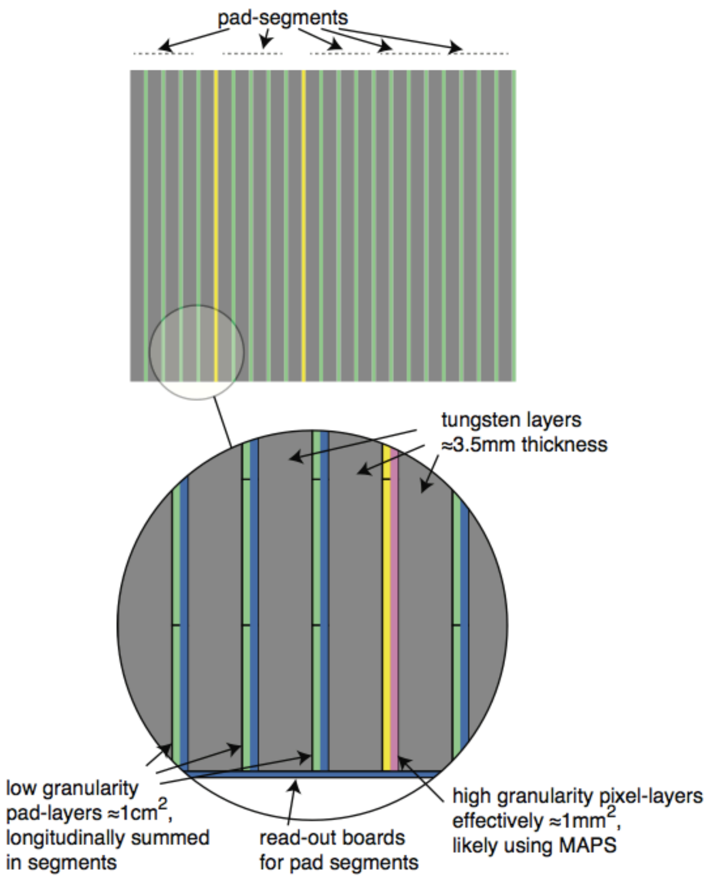
next

- We have the second test beam schedule on Oct – Nov. 2015 at PS and SPS
- For good energy resolution, we need to reduce the noise level and more statistics
- We joined RD51 group and started work of new readout board from this summer
- in this winter, we will aim at ALICE approval. LHCC approval is next step

Thank you for your attention!

Back up

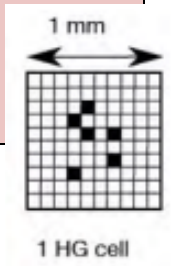
FoCal-E strawman design



・W/Si sandwich calorimeter(prototype : ORNL)
- W absorber + Si sensors
  Moliere radius : R_M = 9mm
  Radiation length : X_0 = 3.5mm(1 layer)

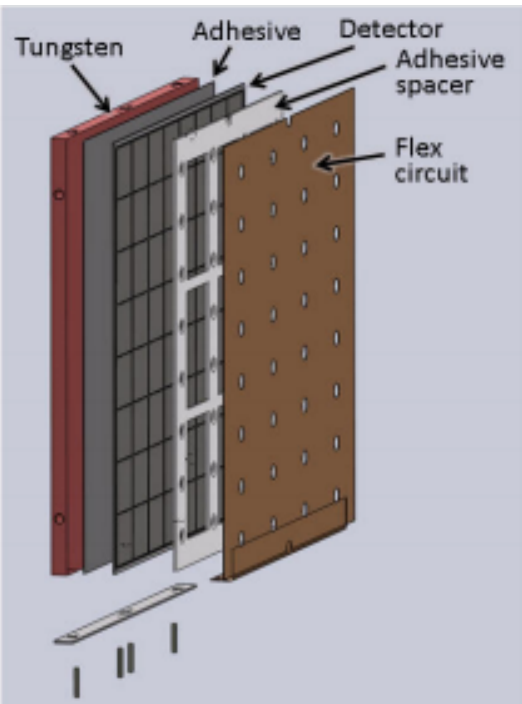
・Longitudinal segmentation : two different module
- Low Granularity Layer(LGL) : 4 segments
  ・4(or5) layers of Si/W per 1 segment
  ・Cell size : 1 × 1 cm^2
  ・1 layer has 64 PADs(8 × 8)
  ・Signals are longitudinally summed

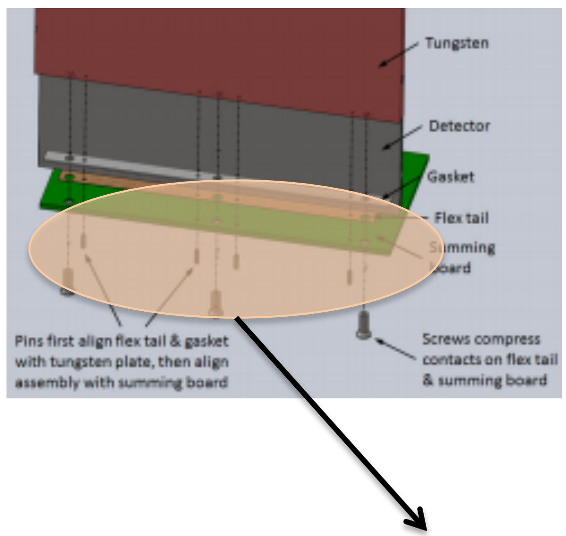
- High Granularity Layer(HGL) : 2 segments
  ・CMOS-pixel
  ・Pixel size : 25 × 25 μm^2
  ・Digital signals are summed in 1 mm^2 cells



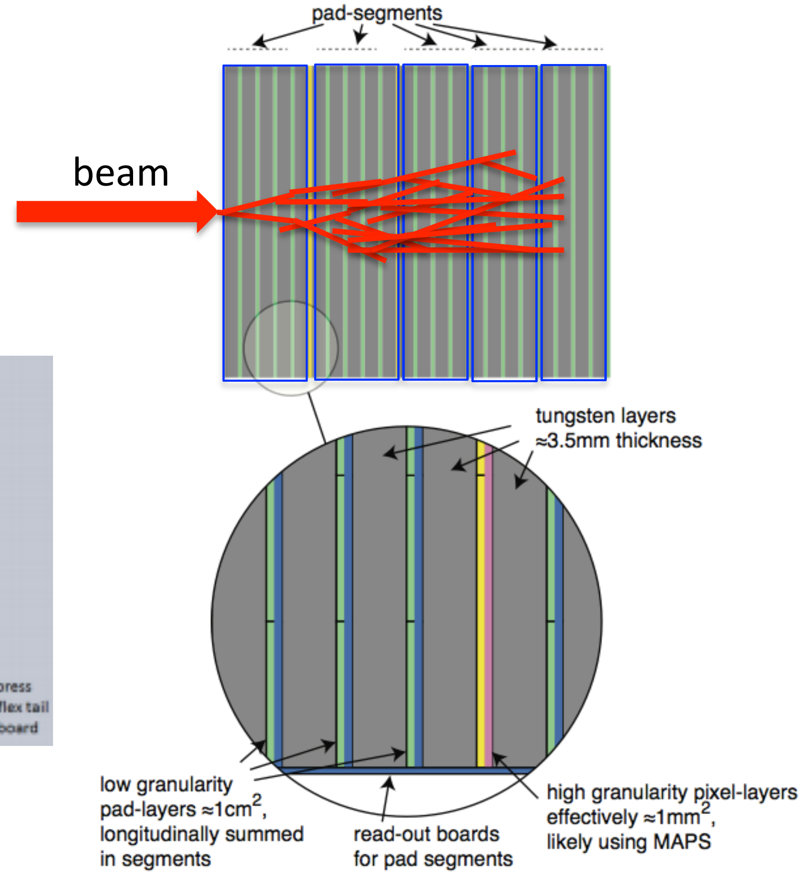
Low Granularity Layer(LGL)

LGL :
measurement of shower produced by tungsten.
1 LGL have 4 layer → signal is summed by 4 layer

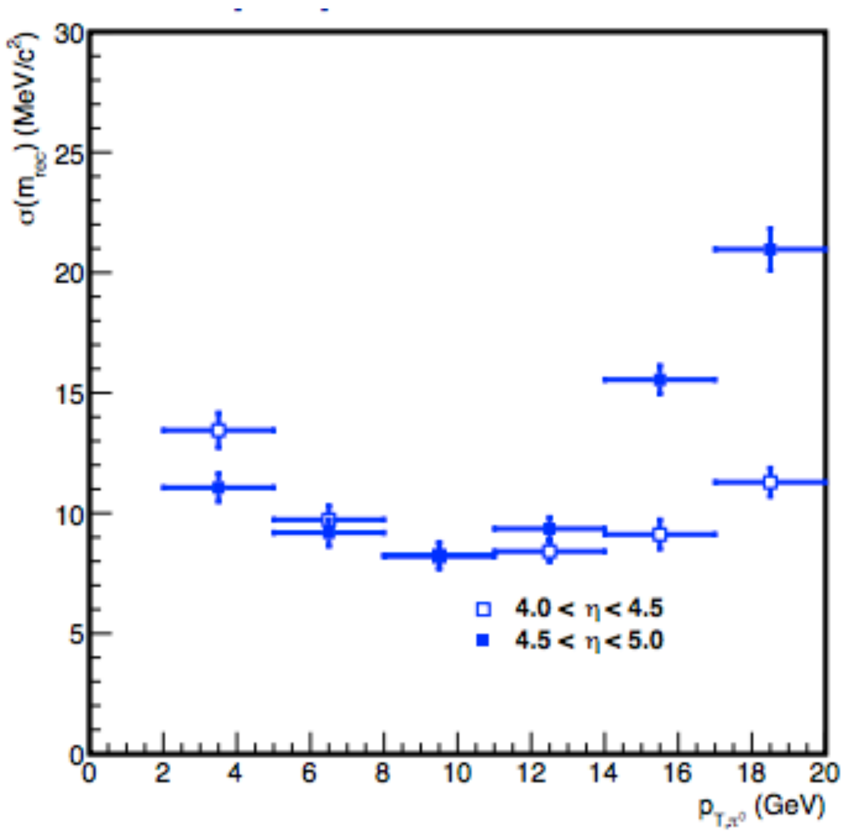




Summing board



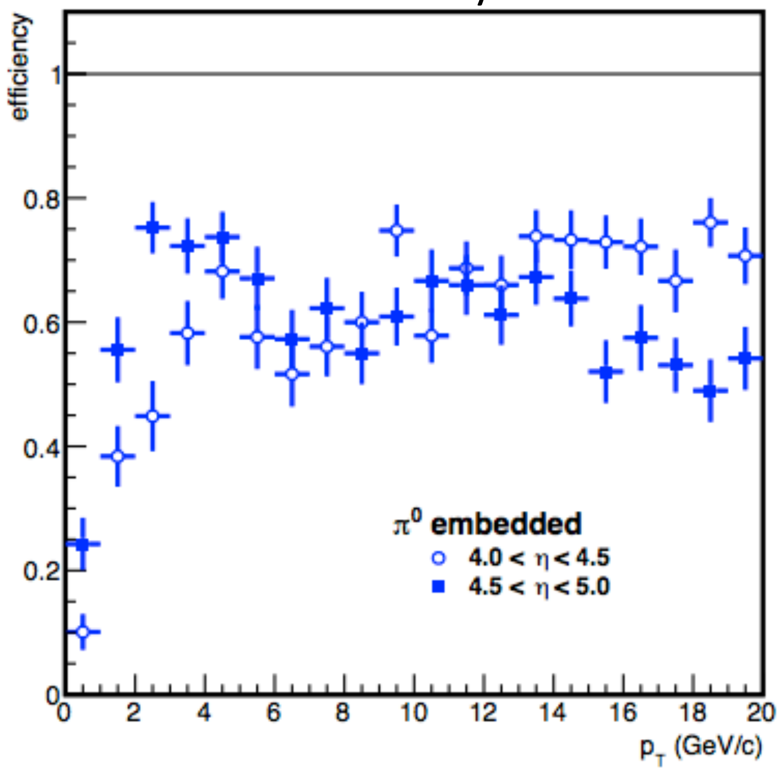
π^0 mass sigma



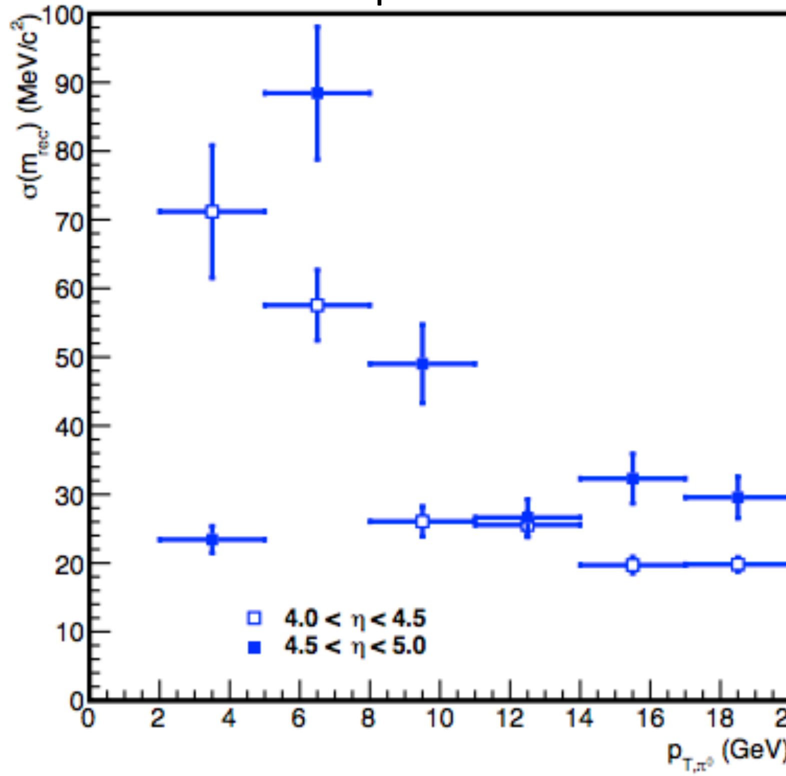
- Peak width ~ 10 MeV over large range in p_T

Pb-Pb efficiency π^0

efficiency



Mass peak width

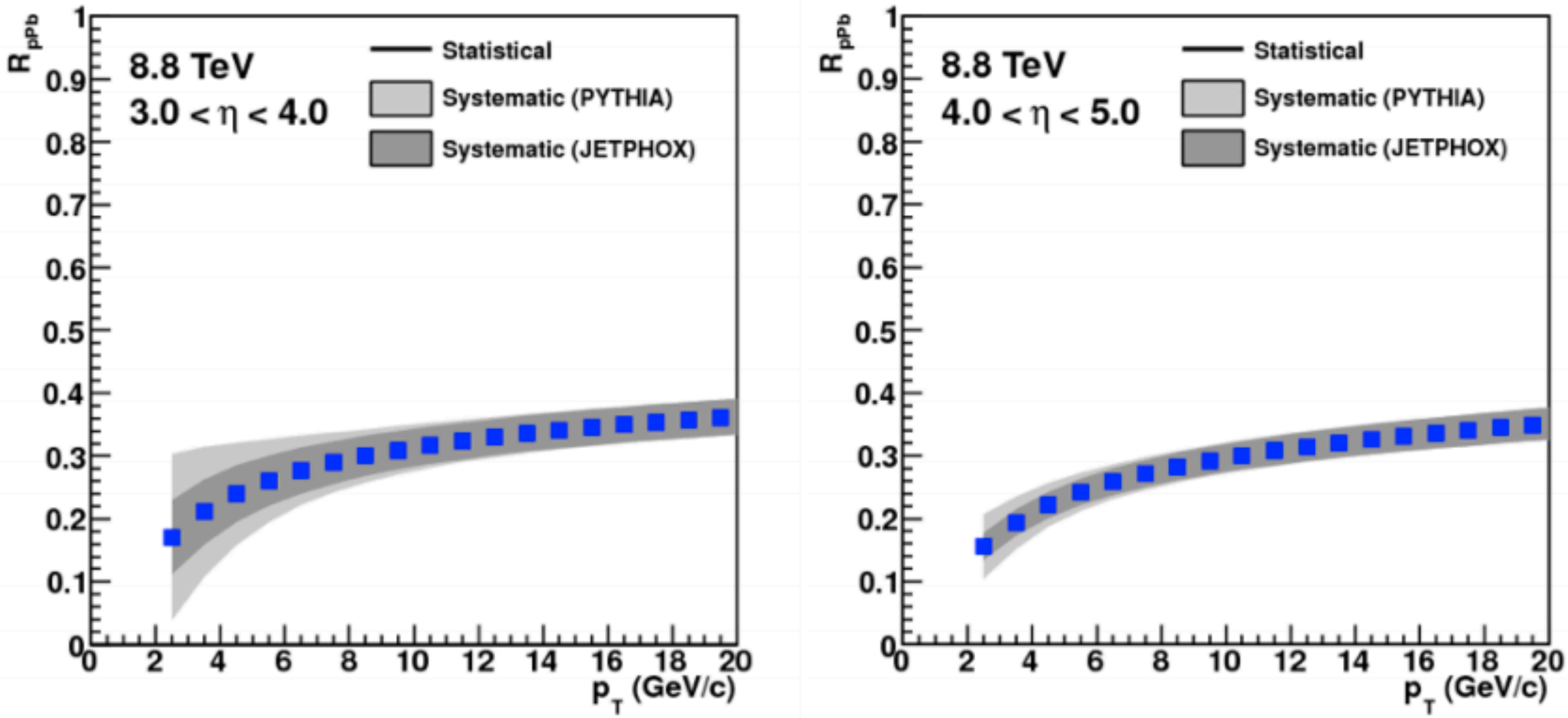


π^0 efficiency ~ 0.6

Mass resolution is good for $p_T > 10$ GeV

FOCAL performance: γ in p-Pb

Old 4m geometry used; will be updated soon



Using same numbers for π^0 identification, isolation eff as 14 TeV

Excellent precision for direct γ R_{pPb}

Lower p_T reach uncertain due to uncertainties on rates
~4-5 GeV should be in reach

$4<\eta<5$ uncertainties smaller; intrinsic S/B better

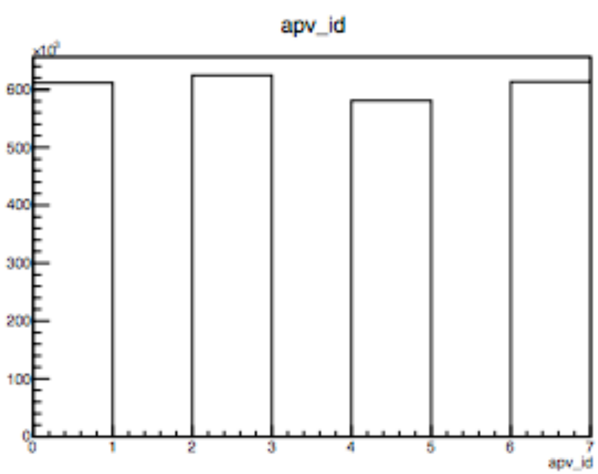
Analysis method

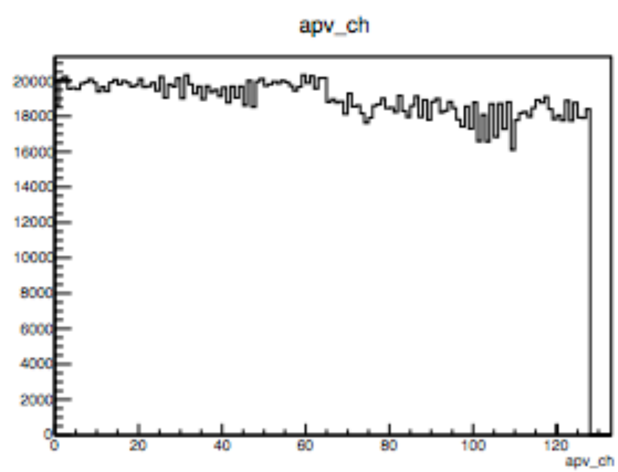
Marge — root — 62×17

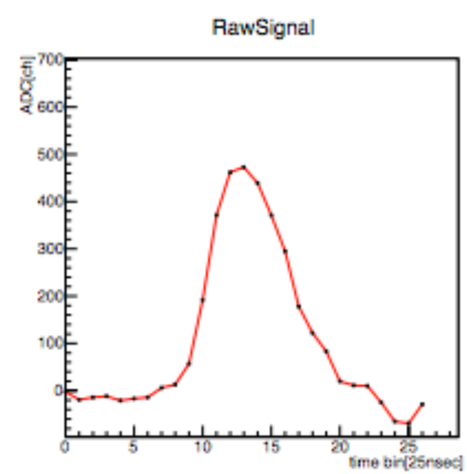
```
hep03:Marge wsato$ root -l run.root
root [0]
Attaching file run.root as _file0...
root [1] raw->Show(0)
======> EVENT:0
 apv_evt         = 1
 time_s          = 1416308254
 time_us         = 277914
 apv_fecNo       = (vector<unsigned int>*)0x7fc963d9e370
 apv_id          = (vector<unsigned int>*)0x7fc963d9f000
 apv_ch          = (vector<unsigned int>*)0x7fc963d9f730
 mm_id           = (vector<string>*)0x7fc963da0140
 mm_readout      = (vector<unsigned int>*)0x7fc963da0940
 mm_strip        = (vector<unsigned int>*)0x7fc963da1210
 apv_q           = (vector<vector<short> >*)0x7fc963da1b50
 apv_presamples  = 0
root [2]
```

Data of mmDAQ is outputted root File

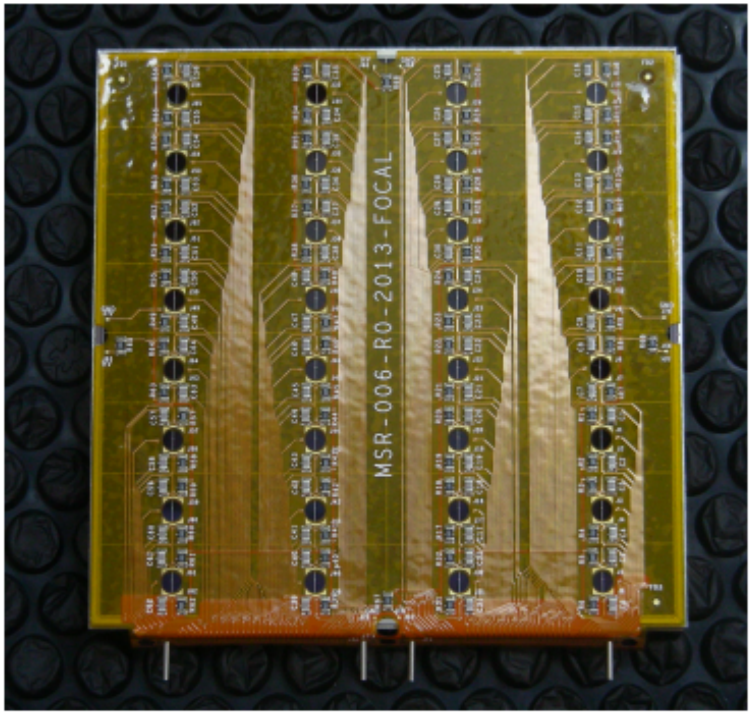
apv_evt : number of event
apv_id : APV ID
apv_ch : APV channel
apv_q : raw data of 27 time bin







Channel mapping



MSR-006-R0-2013-FOCAL

Y ↑

34	36	2	4	63	61	31	29
38	40	6	8	59	17	27	25
42	44	10	12	55	53	23	21
46	48	32	30	33	35	19	17
50	52	28	26	37	39	15	13
64	62	24	22	41	43	1	3
60	58	20	18	45	47	5	7
56	54	16	14	49	51	9	11

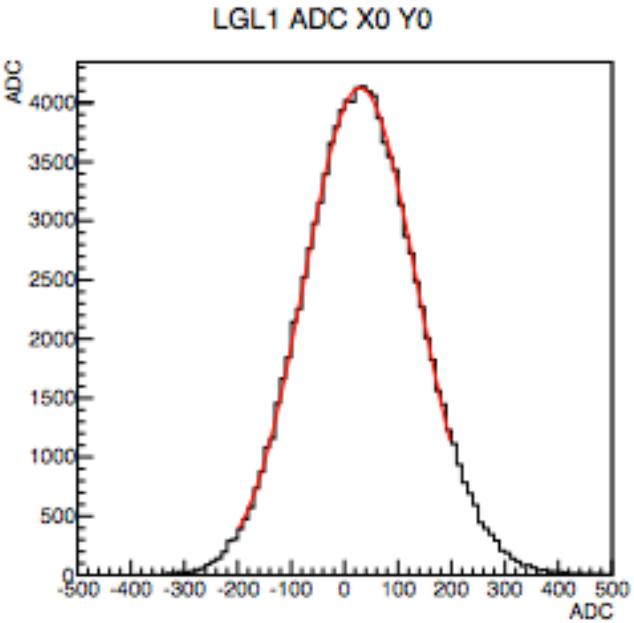
X →

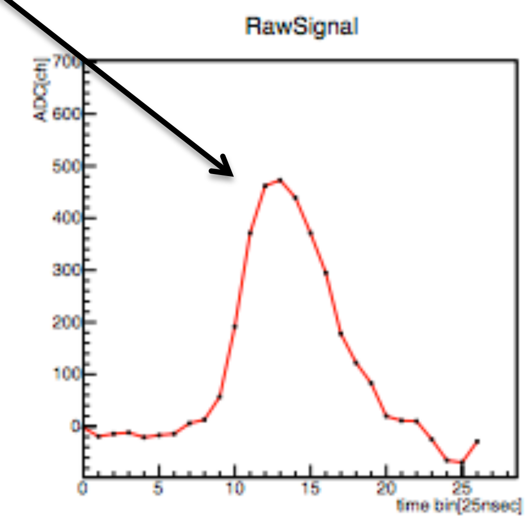
<u>If summing board is inverse, line is symmetry</u>

Define of hit

qmax point

Pedestal histgram





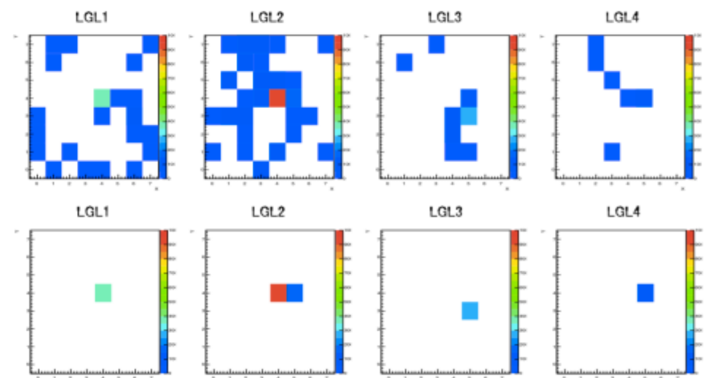
- Gauss fit

$$f(x) = A \bullet \exp\left\{-\frac{(x-\mu)^2}{2\sigma^2}\right\}$$

A : constant
μ : mean
σ : sigma

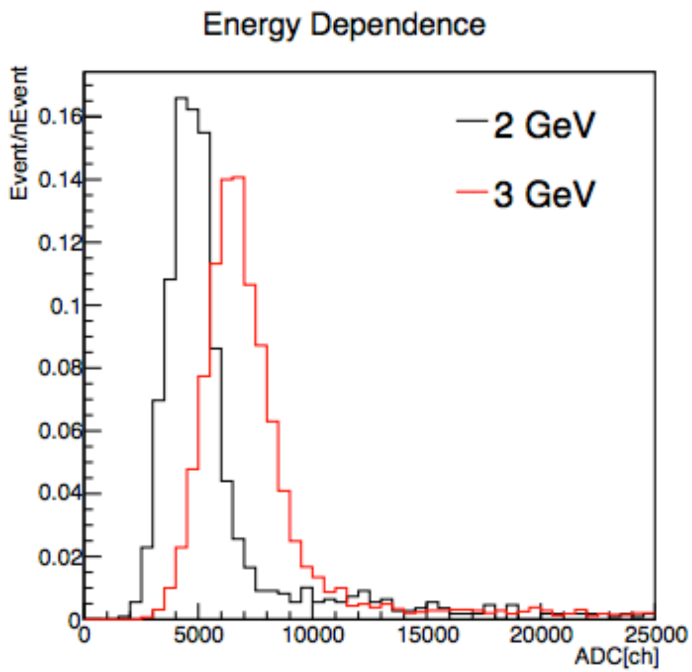
Hit is to meet the following condition

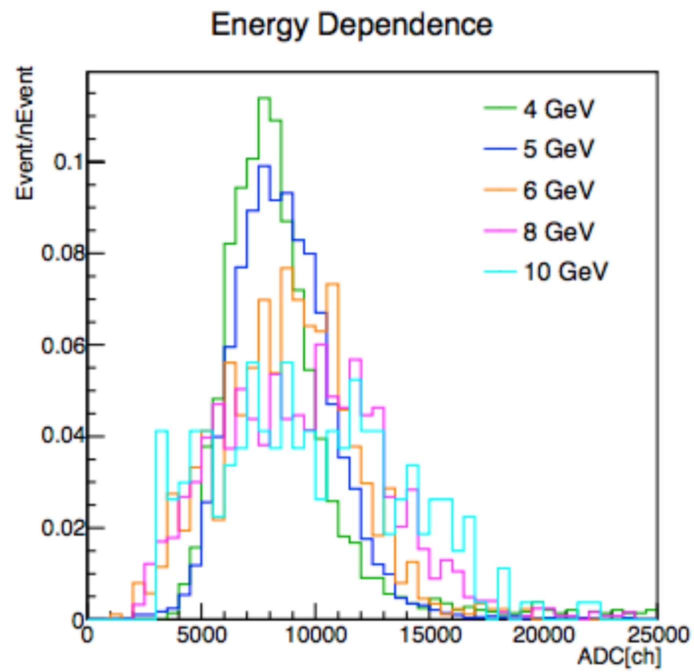
$$apv\_q\max > \mu + 4\sigma$$



PS result

Energy dependence

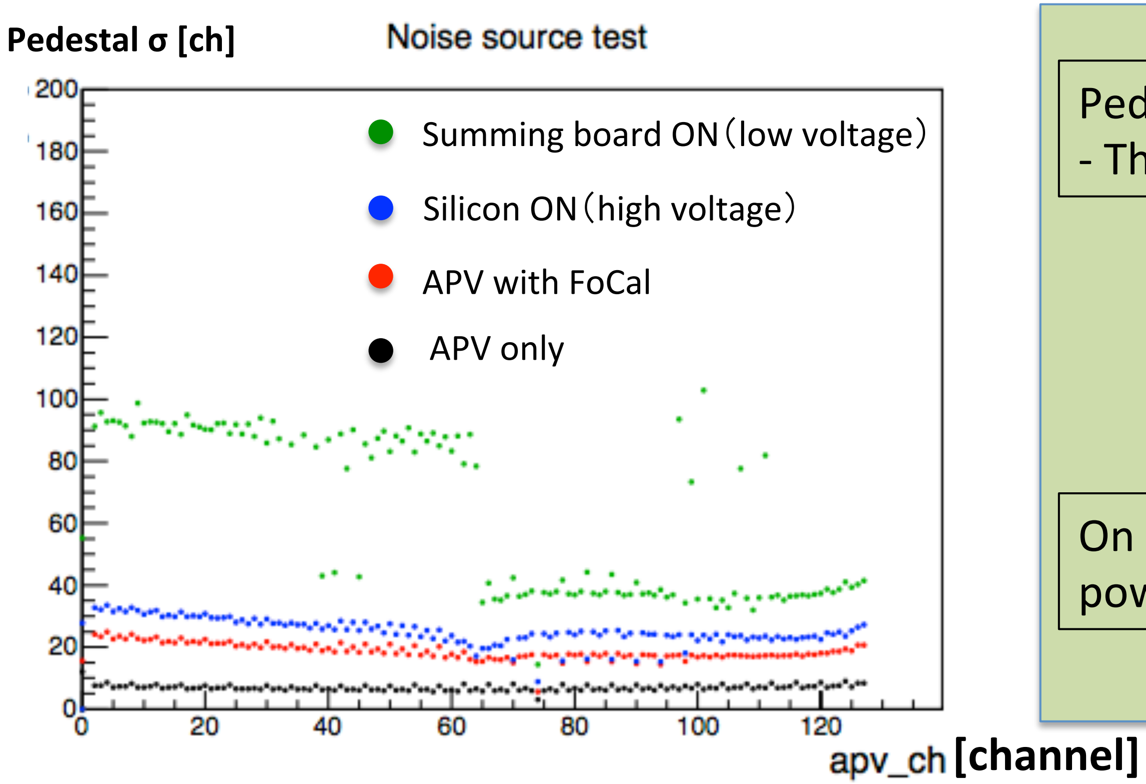




We can identify 2GeV and 3GeV beam energy

Signal is over the pedestal value
→We can't see the energy dependence from 4GeV to 10 GeV
→signals are saturated.

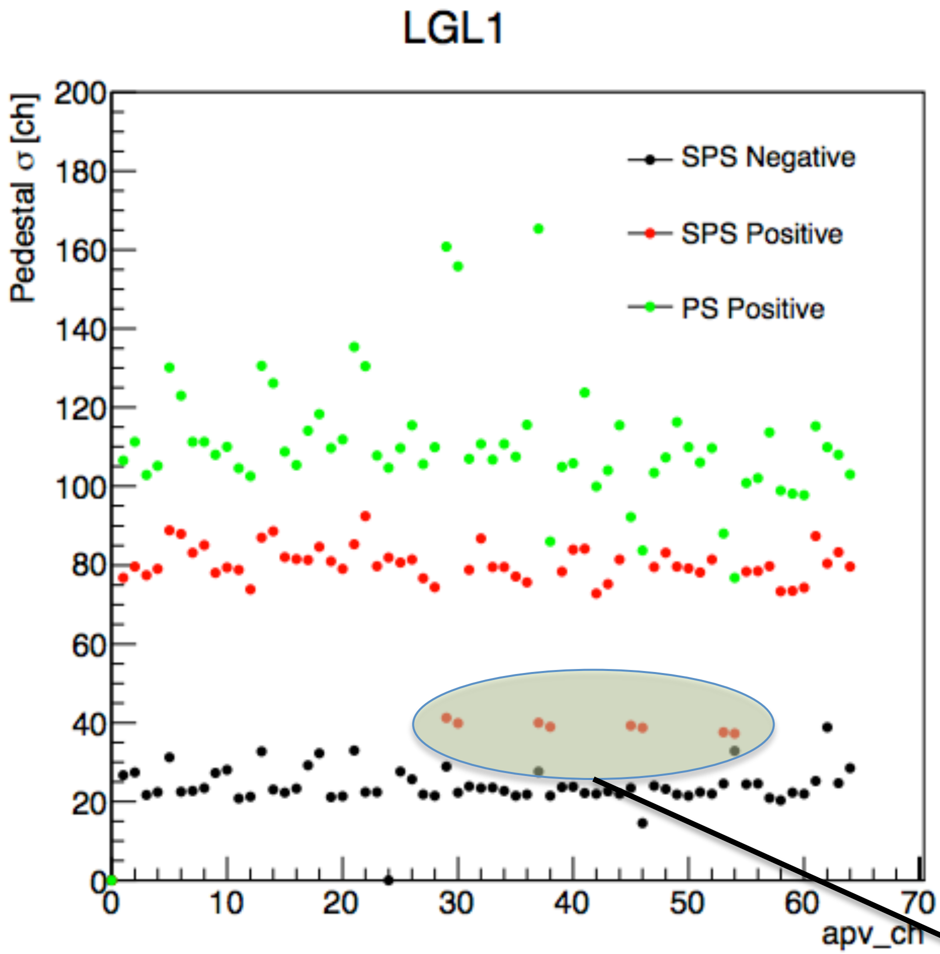
Comparison of Noise



Pedestal value
- The most noise source is low voltage

On SPS, We introduce the stabilization power supply

Comparison of Noise

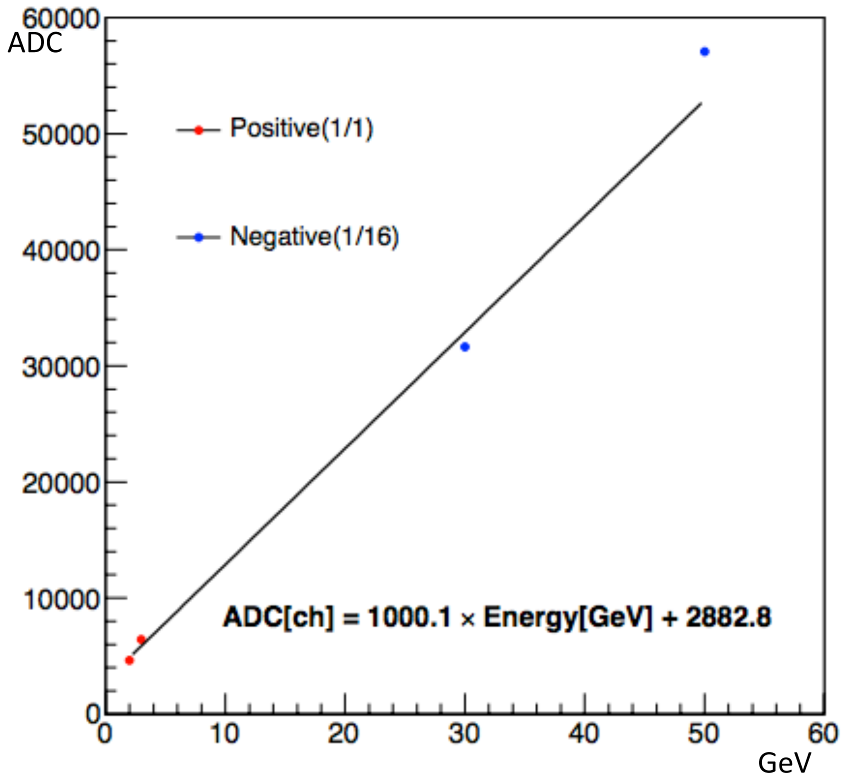


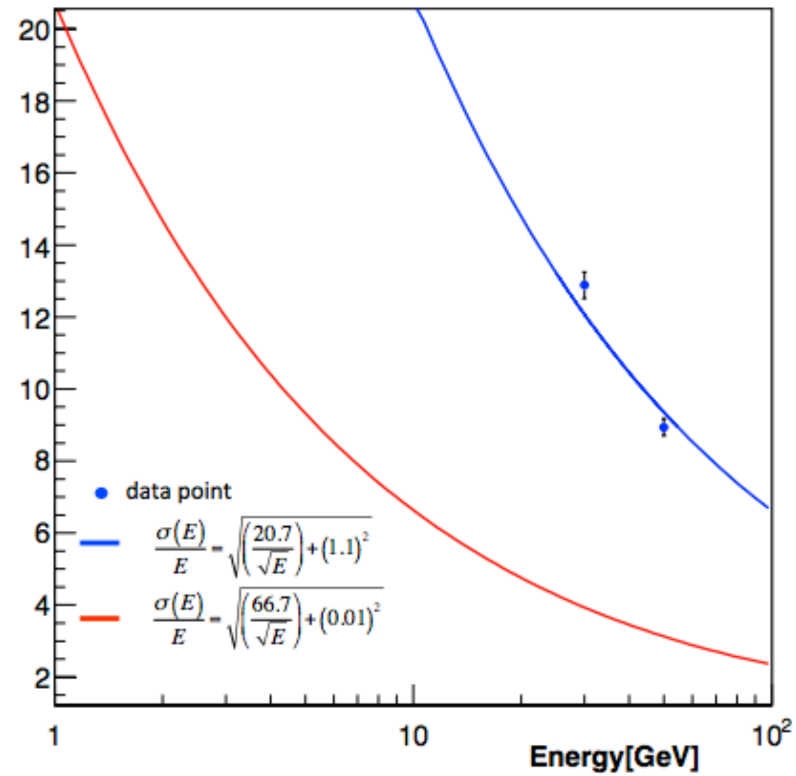
Dead channel

Introduction of stabilization power supply

Decrease the noise (about 30%↓)

Energy dependence (PS and SPS)





Modified ADC value
→negative output(1/16) × 16

Different from simulation result
→More statics and decreasing noise

FoCal group goal for FoCal-E

Each

LGL
- Measurement of shower energy
- Measurement of energy resolution
- Development of speedy readout system

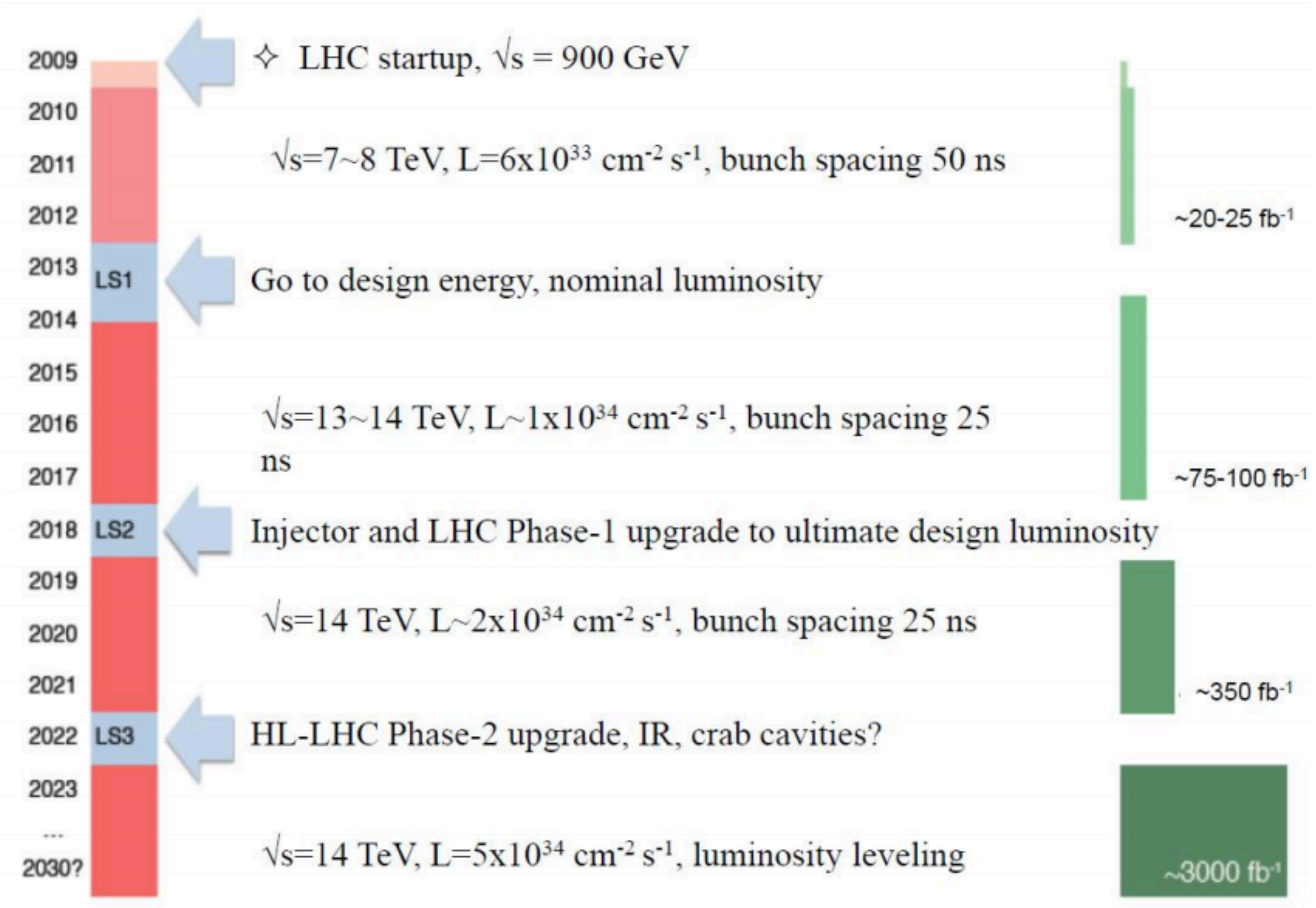
HGL
- Separation of shower shape
- Measurement of spatial resolution

And so on…

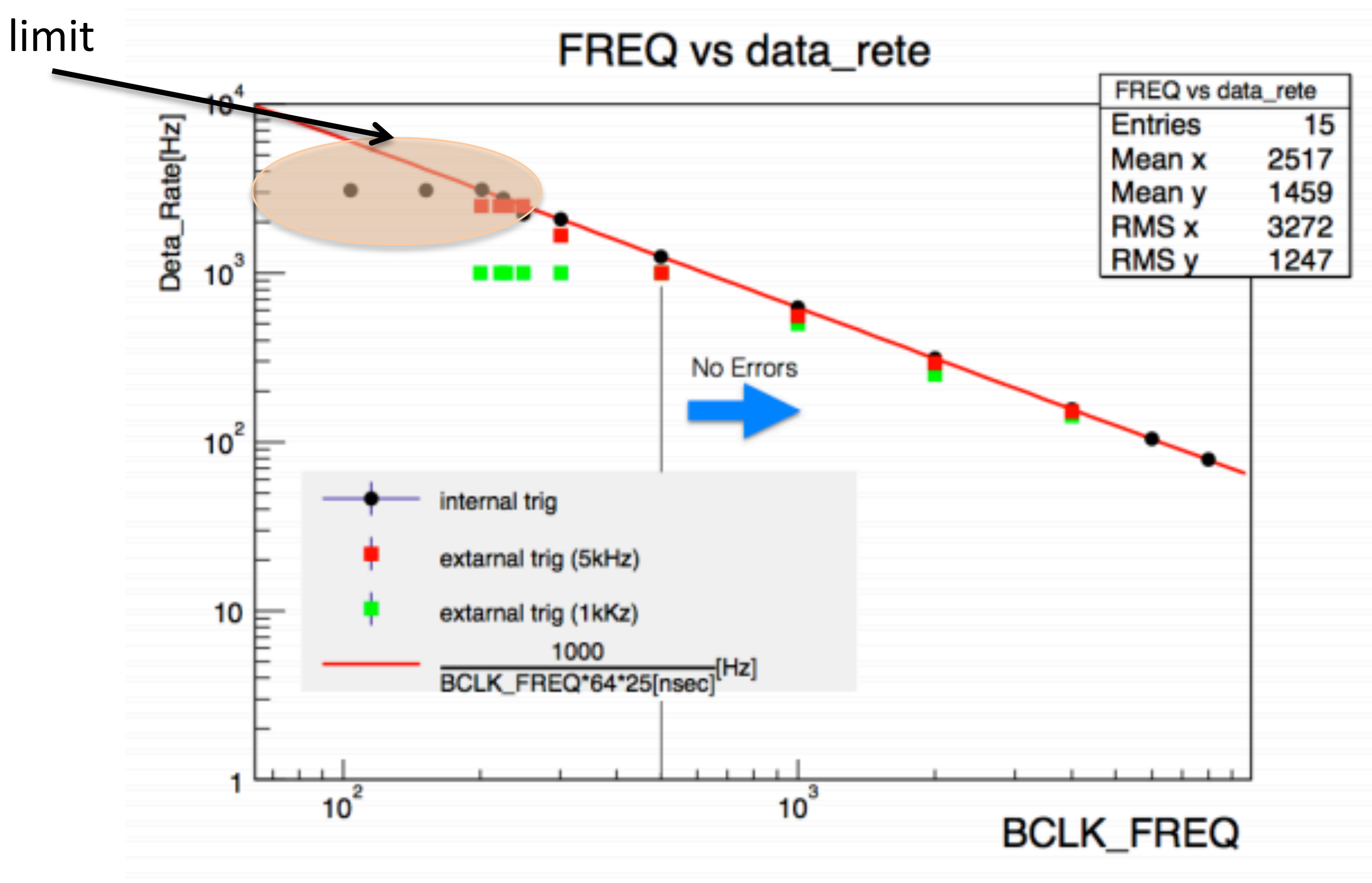
total

- Trigger merge of HGL and LGL
- radiation damage study
- LoI accepted
- Future plan
  - Mini-FoCal installation after LS2
  - Full FoCal installation after LS3

LHC Timeline

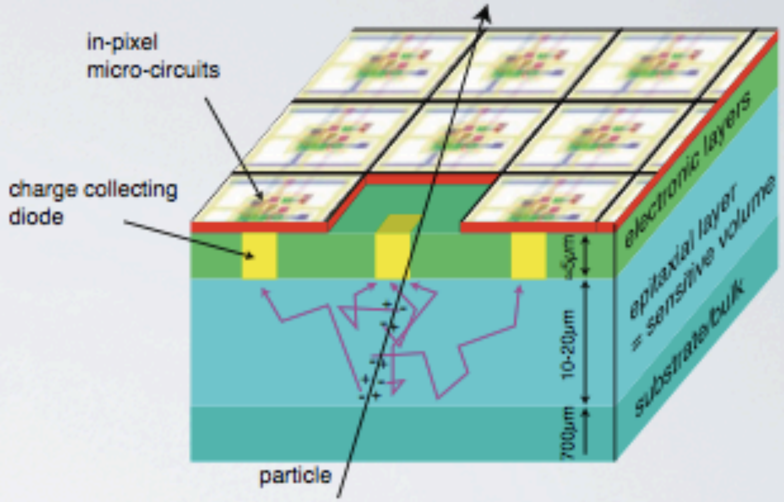


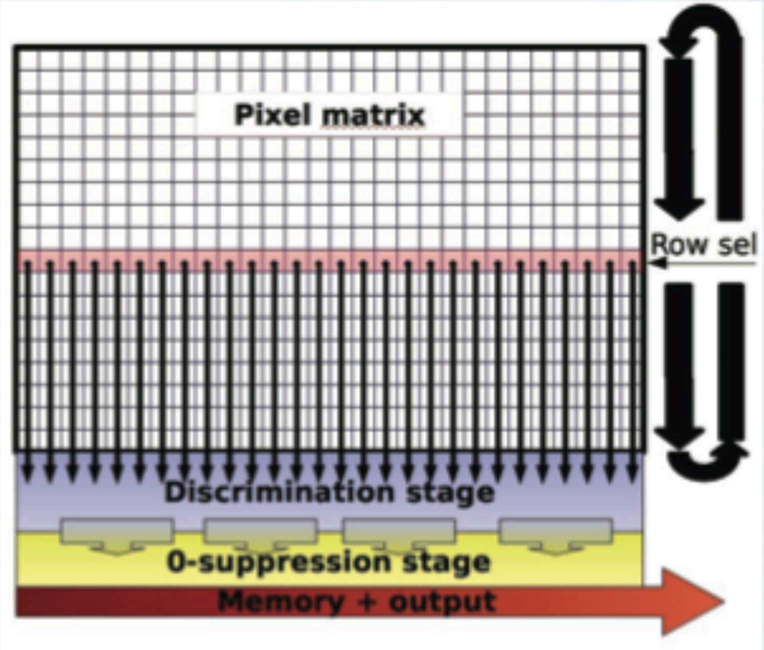
DAQ rate


limit
FREQ vs data_rete
FREQ vs data_rete
Entries 15
Mean x 2517
Mean y 1459
RMS x 3272
RMS y 1247
Deta_Rate[Hz]
No Errors
internal trig
extarnal trig (5kHz)
extarnal trig (1kKz)
1000 / BCLK_FREQ*64*25[nsec] [Hz]
BCLK_FREQ

MIMOSA Sensors

- Monolithic Active Pixel Sensors (MAPS)
  - Si-sensors + electronics in CMOS on single substrate
  - thin sensitive layer (≈20μm)
  - charge collection by diffusion
- existing chips
  - readout of analog signals by rolling shutter
    - slow: 640μs readout time
  - 0.35μm technology





M.Winter et al., IPHC Strasbourg

HAMAMATSU

シリコンフォトダイオード
S10938-9959(X)

■ 材料仕様

項　目	値	単 位
結晶面方位	（1，０，０）	
厚さ	500±15	μm
裏面不感層	20	μm

■ 外形仕様

項　目	値	単 位
chip size	93 × 93	mm
Number of PDs	64（8 × 8）	ch
PD pitch(X)	11300	μm
PD pitch(Y)	11300	μm
Single P+ size	11250 × 11250	μm
Single Al size	11280 × 11280	μm
PAD size	100 × 200	μm
Number of PADs	4	/ch

■ 特性仕様

項　目	値	単 位
Vfd	＜ 220	V
Id	＜ 20	nA/ch(VR=Vfd)
Ct	30	pF/ch(VR=Vfd)
NG ch	＜ 2	%(1ch MAX)

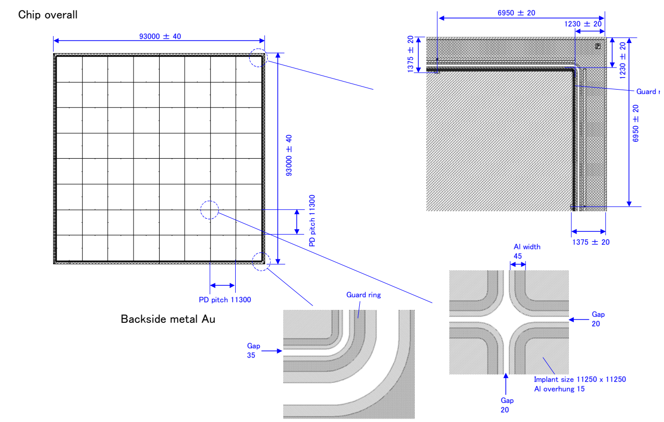
■ 検査仕様

項　目	内容
Id	各 ch の Id、Vr=100V、150V、200V、250V
Ct	各 ch の Ct、Vr=100V、150V、200V、250V
Vfd	モニタ PD での Ct 測定値より換算

浜松ホトニクス株式会社

シリコンフォトダイオード S10938-9339(X)

■外形寸法図（単位：μm）



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HAMAMATSU

Shower profile

To observe expanse of the shower, we use the following equation

<u>The center of gravity 's equation</u>

$$x^{(s)} \equiv < x^{(s)} > \equiv \frac{\sum_{i,j} ADC^{(s)}_{i,j} \cdot x^{(s)}_i}{\sum_{i,j} ADC^{(s)}_{i,j}} \qquad s = 1,2,3,4 \quad i,j = 1, \cdot \cdot, 8$$

$$y^{(s)} \equiv < y^{(s)} > \equiv \frac{\sum_{i,j} ADC^{(s)}_{i,j} \cdot y^{(s)}_j}{\sum_{i,j} ADC^{(s)}_{i,j}} \qquad s = 1,2,3,4 \quad i,j = 1, \cdot \cdot, 8$$

s : which LGL
i , j : PAD of x & y axis

Shower profile

- beam : 2GeV electron
- Longitudinal shower profile
  - shower max d (for W) = 19.27mm ← 2nd LGL

$$d = 0.35 ln(\frac{E_{incident}}{8.11[MeV]} - 0.5)[cm]$$

- Transverse shower profile
  - re-calculate shower center (centroid)
  - Moliere radius (for W) : 9.16mm
- longitudinal and transverse shower profiles are consistent with the expectation

Gap of center of gravity for the hit