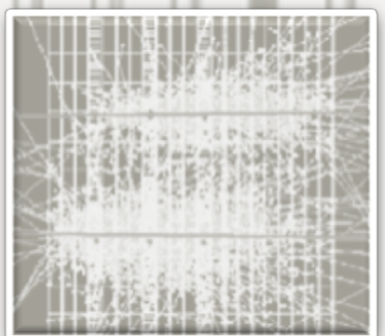
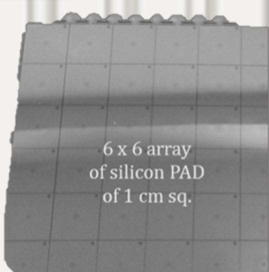
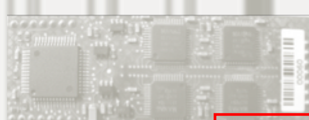
Forward Calorimeter for the ALICE Experiment

Sanjib Muhuri
VECC







- Physics Motivation
- Feasibility and requirements
- Design and Geometry
- Hardware development
- Time-Line

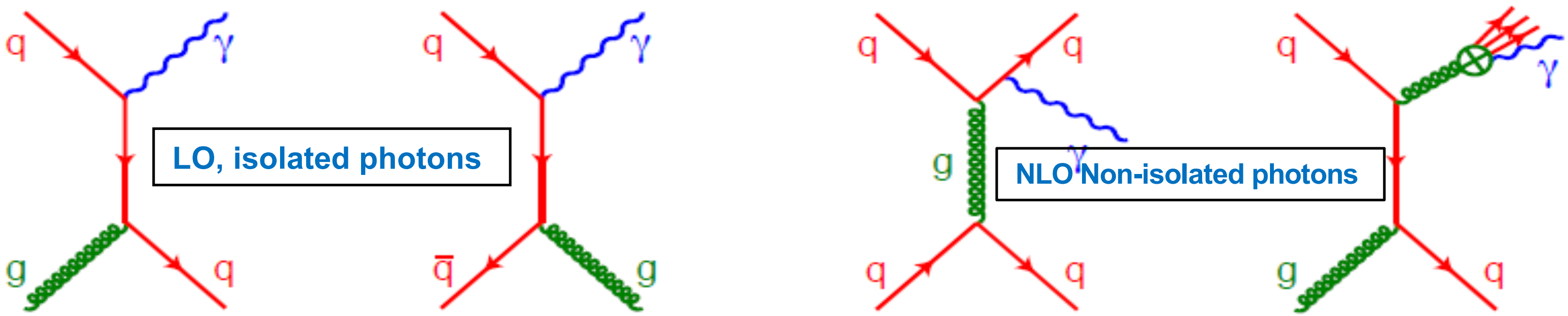
Physics Motivation

pp collision (Test of pQCD)	pA collision (probing initial condition)	AA collision (Final state effects)
Particle production	Distribution of Gluon density at small-x (10^{-4} to 10^{-6})	Opacity and Response of the medium: gamma-jets correlations.
Effect of small-x contribution	Study of Color Glass Condensate	Parton energy loss in dense partonic matter.

Physics Motivation

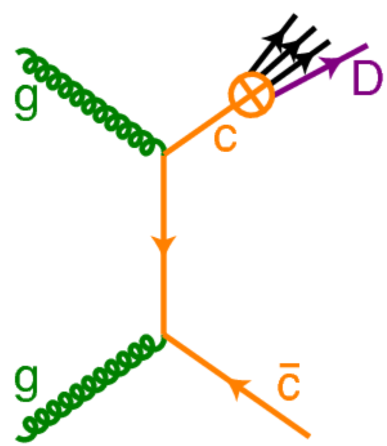
Experimental Observables: Photons, neutral pions, J/Y, Jets

Sources of direct photons



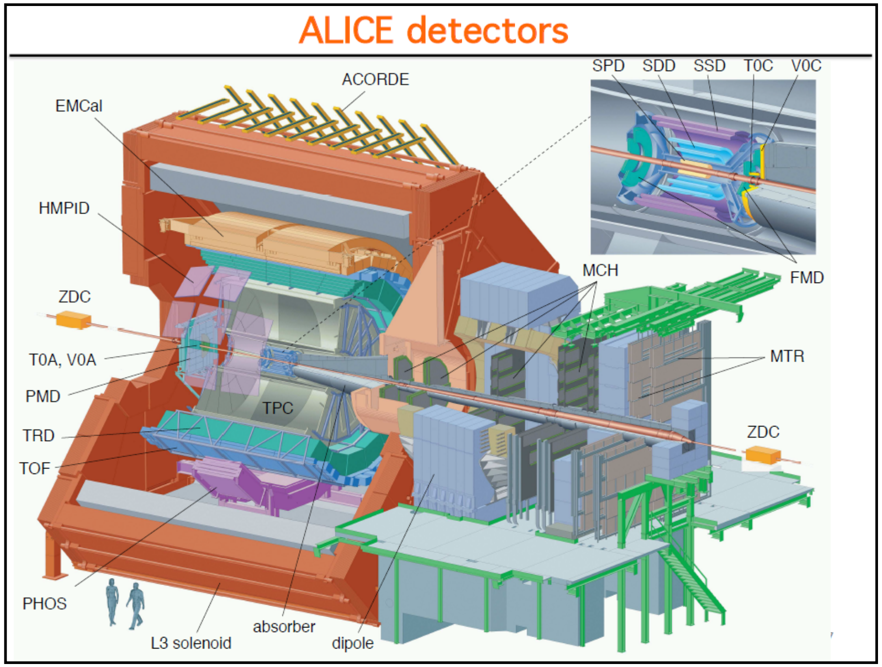
a) Compton b) annihilation c) bremsstrahlung d) fragmentation

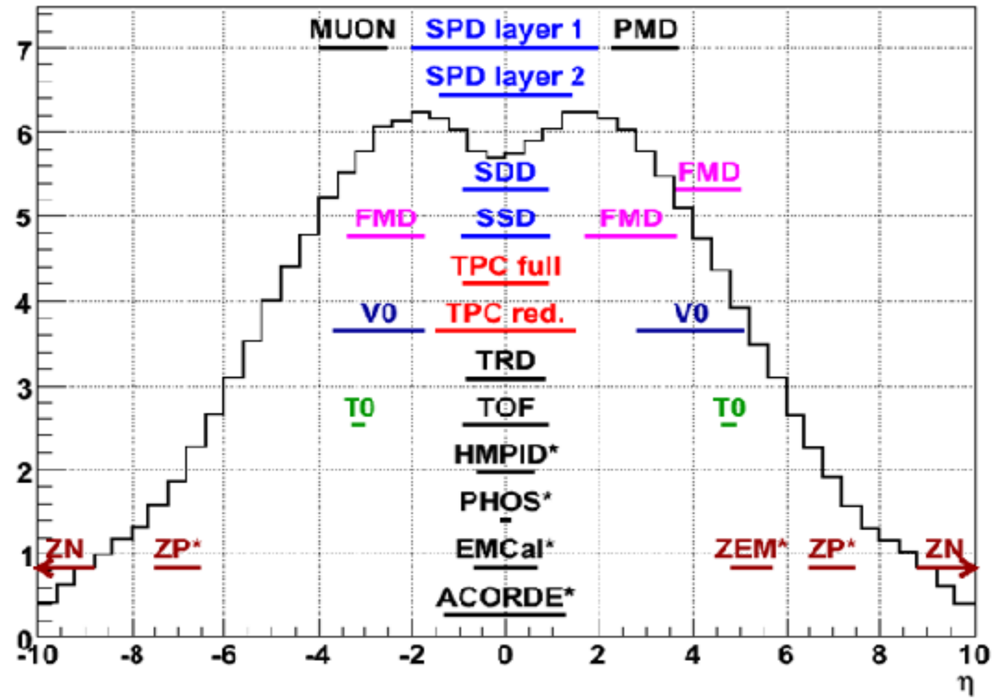
Heavy Flavour Jets



Feasibility and requirements

ALICE Experiment in Present scenario





Measurement in forward rapidity could complement and enhance ALICE physics capabilities.

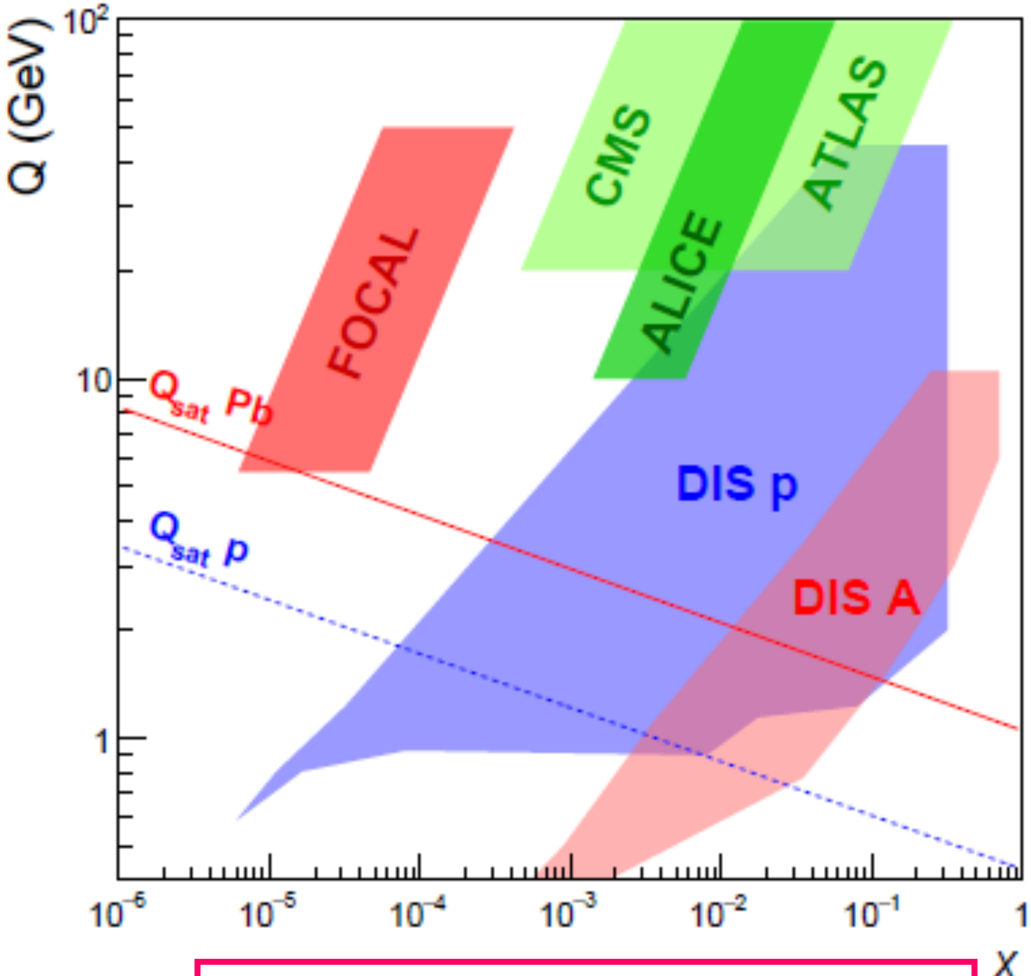
✓ **Excellent coverage in mid-rapidity.**

➢ **Limited in Forward Rapidity**

Forward Rapidity is not instrumented which results an unobstructed view of interaction point

Feasibility and requirements

A comparative Kinematic Coverage for different experiments



DIS and Photon measurement

Feasibility and requirements

Observable: Gamma

Forward rapidity

$$y = \frac{1}{2} ln\left(-\frac{E+p_z}{E-p_z}\right)$$

$3.2 < \eta < 5.3$

P_T Up to 20GeV/c

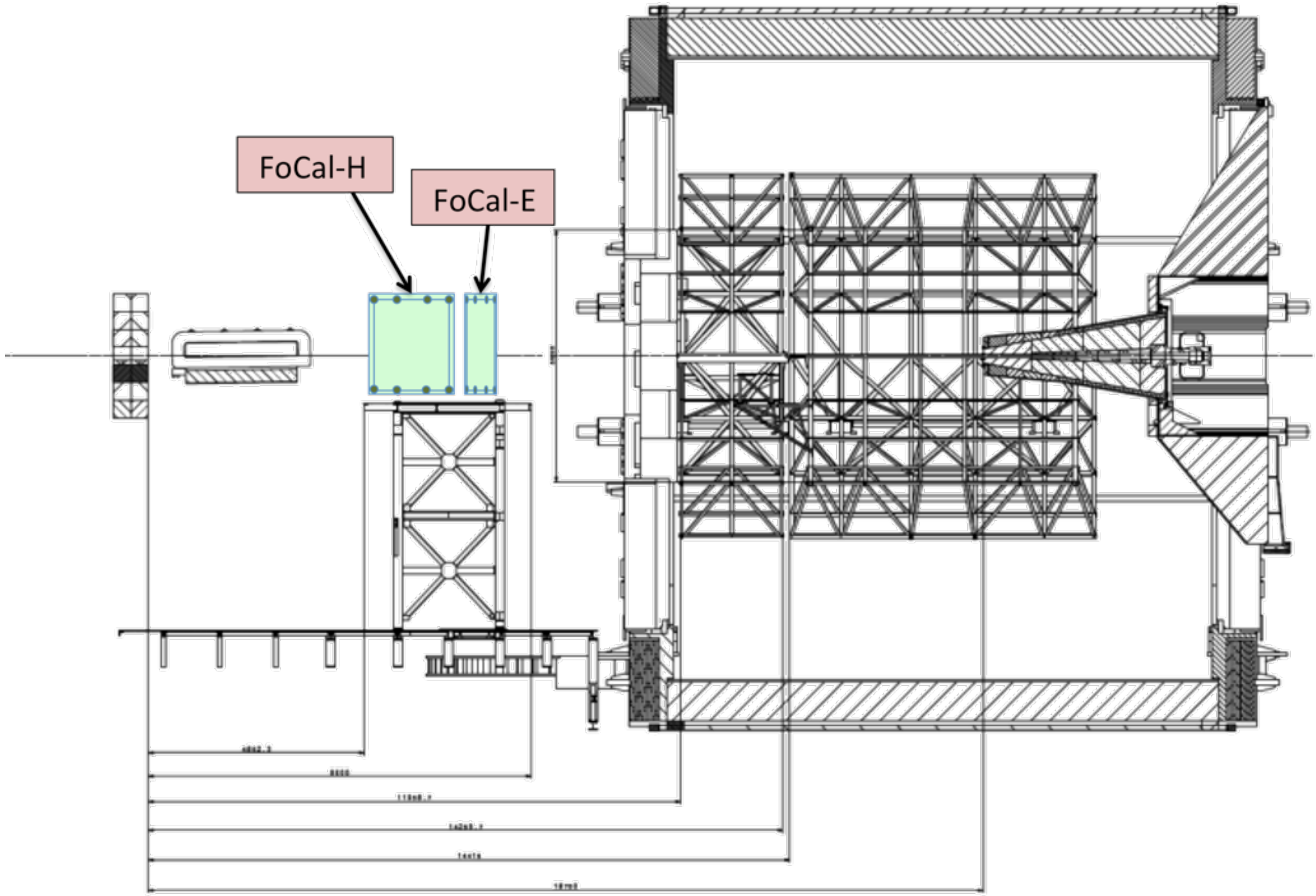
Small-x physics

$$(x = \frac{p_L^{parton}}{p_L^{hadron}}) \leq 10^4,$$

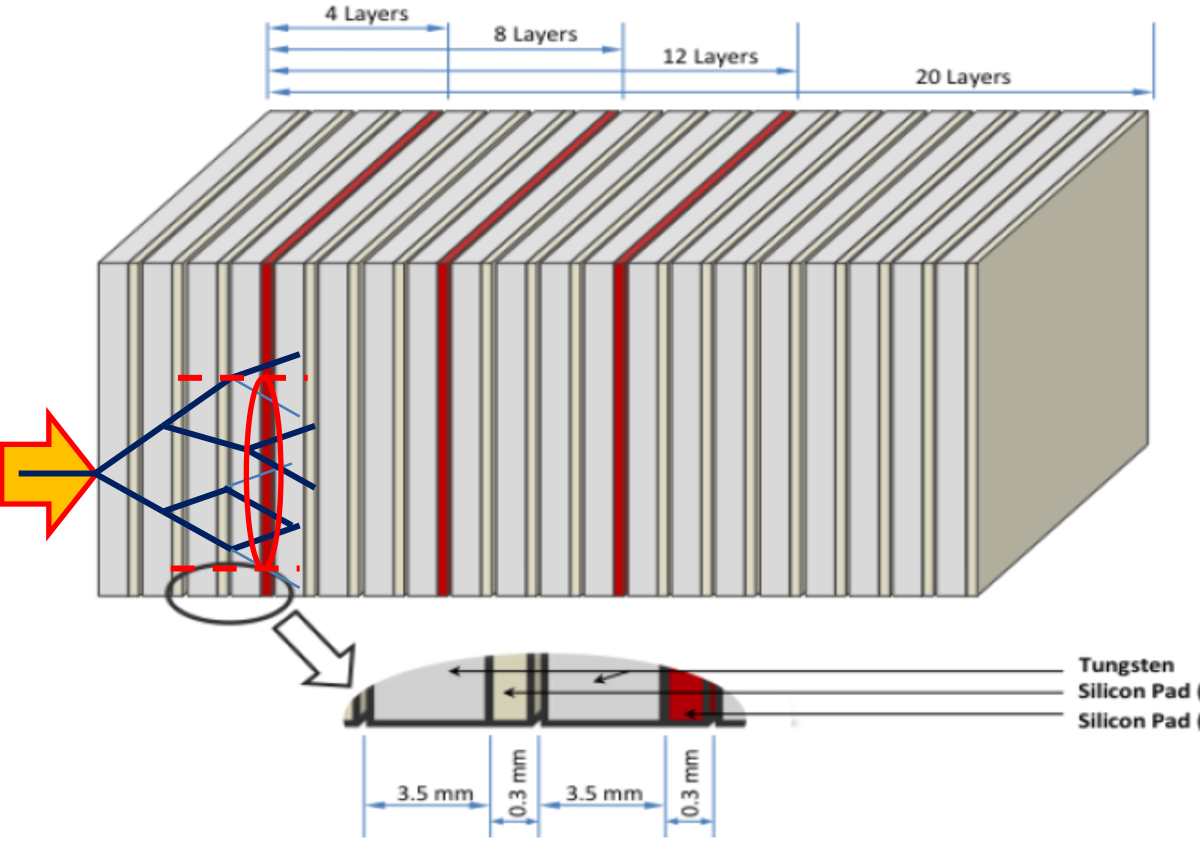
Feasibility in ALICE

- **Distance from IP: 7** m
- **Full azimuthal coverage**
- **Distance from Beam**
  Inner: 6cm (limited by beam pipe)
  Outer: 60cm

Feasibility and requirements



Design and Geometry



	LG	HG
pixel/pad size	≈ 1 cm^2	≈ 30x30 μm^2
total # pixels/pads	≈ 2.5 x 10^5	≈ 2.5 x 10^9
readout channels	≈ 5 x 10^4	≈ 2 x 10^6

assuming ≈ 1m^2 detector surface

- ✓ **Sampling type Hybrid Calorimeter**
- ✓ **Detector : Silicon sensors (LGL: 1cm^2 & HGL: 1mm^2)**
- ✓ **Absorber/Convertor : Tungsten**

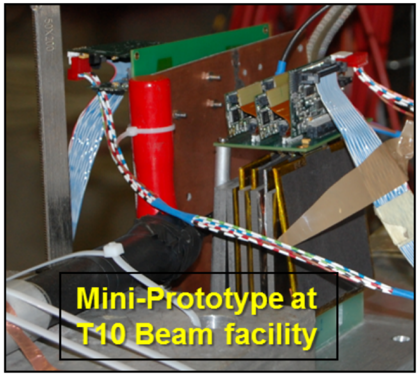
Hardware development

- Development for
  - Low Granular Layer (LGL)
  - High Granular Layer (HGH)
- Readout Electronics

Detector development for LGL

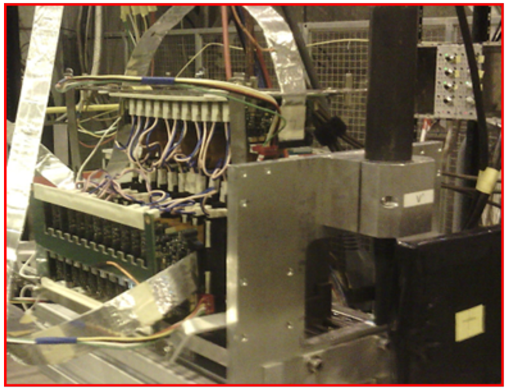
(Efforts in India)

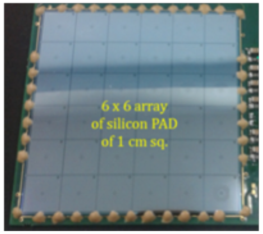
TB-2012



Mini-Prototype

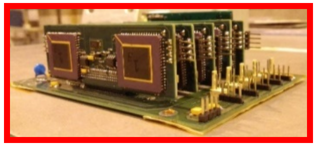
TB-2015





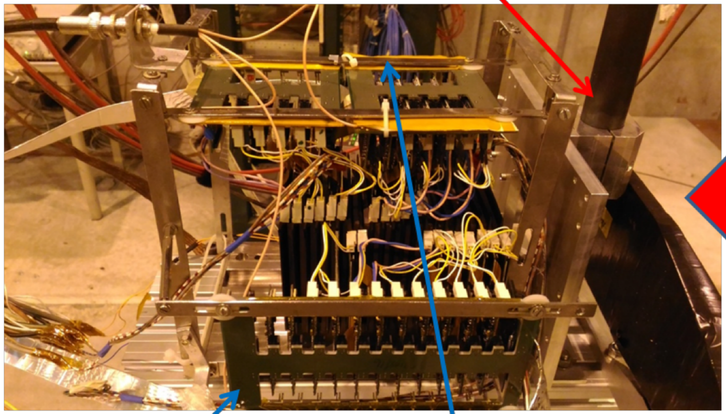
Full-Length-Prototype

TB-2017



6*6 array of 1cm^2 Silicon detector

Trigger system consist of P, H, V Scintillator.



BEAM

BACK-PLANE PCB for MANAS CHIP

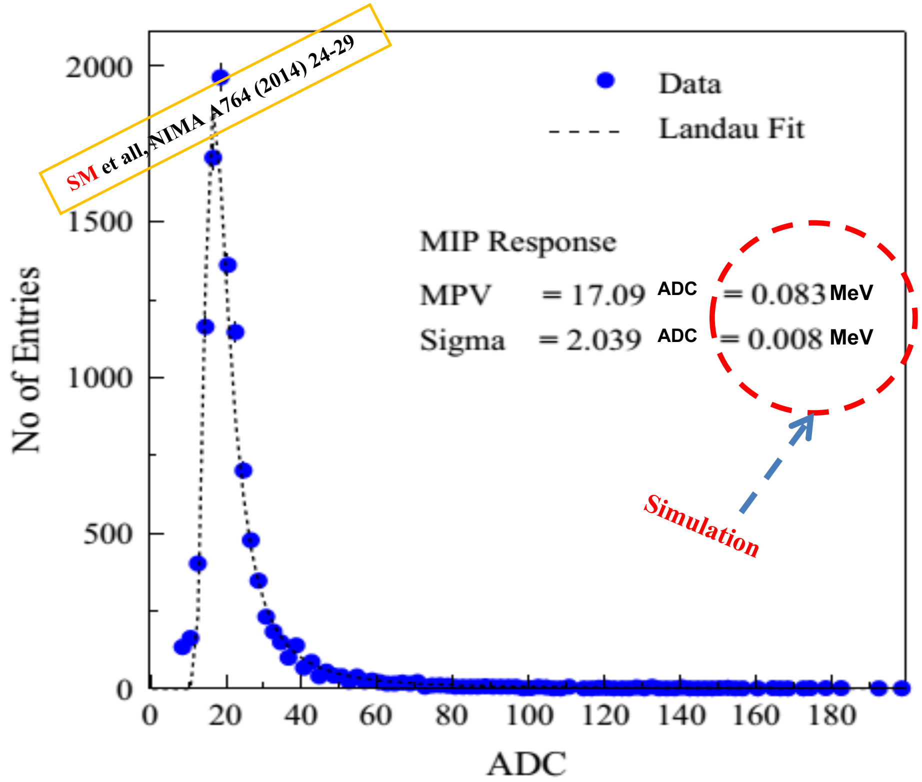
BACK-PLANE PCB for ANUINDRA CHIP

Full-Length-Prototype with ANUINDRA

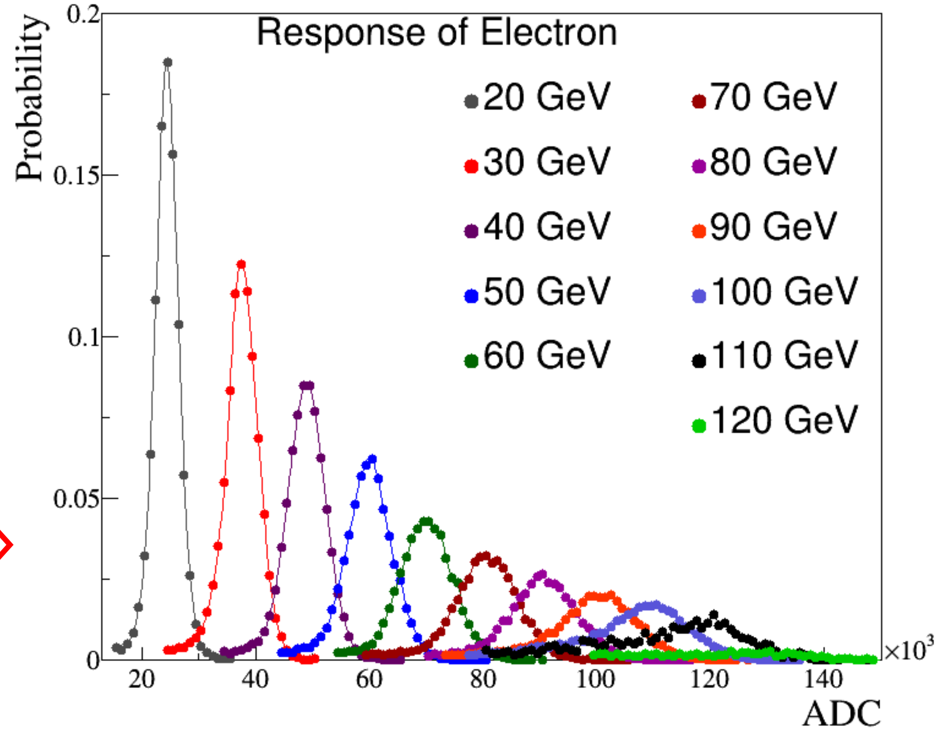
VECC and BARC
With help from
BEL

Detector development for LGL

(Efforts in India)



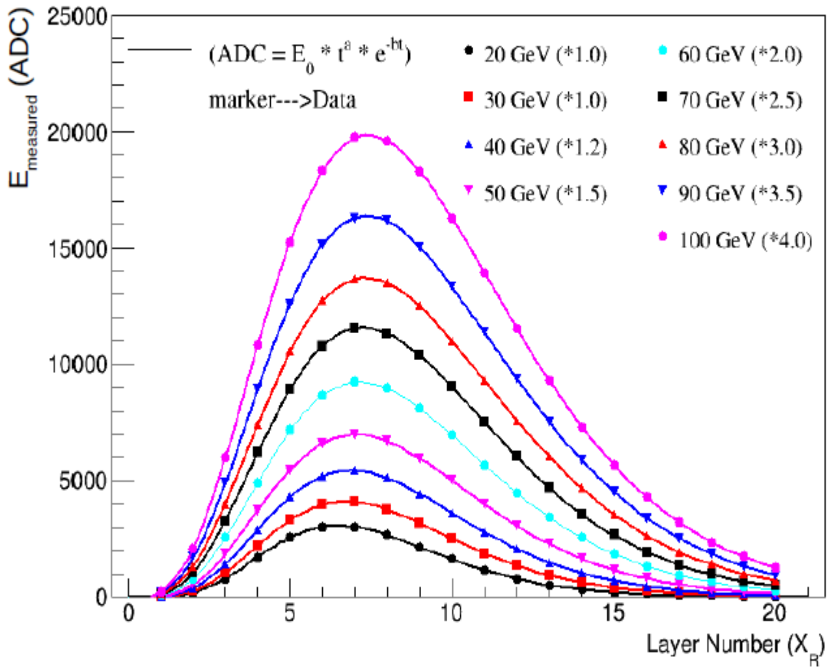
Response of detector to minimum ionizing particle.

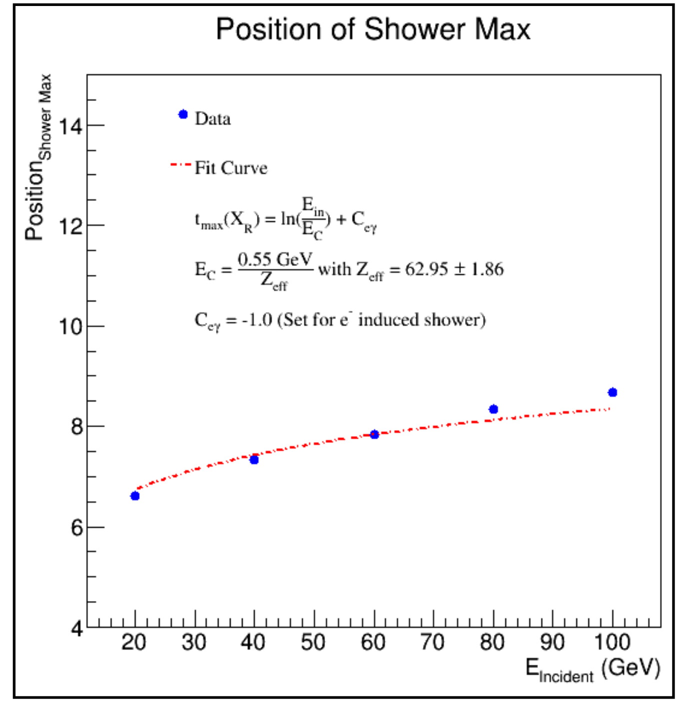


E_{dep} (ADC) by EM-Shower (initiated by electron) for different incident energies.

Detector development for LGL

(Efforts in India)





$$\frac{dE}{dt} = \frac{E_0\beta(\beta t)^{(\alpha-1)} e^{-\beta t}}{\Gamma(\alpha)} \approx E_0 (t)^{\alpha} e^{-\beta t}$$

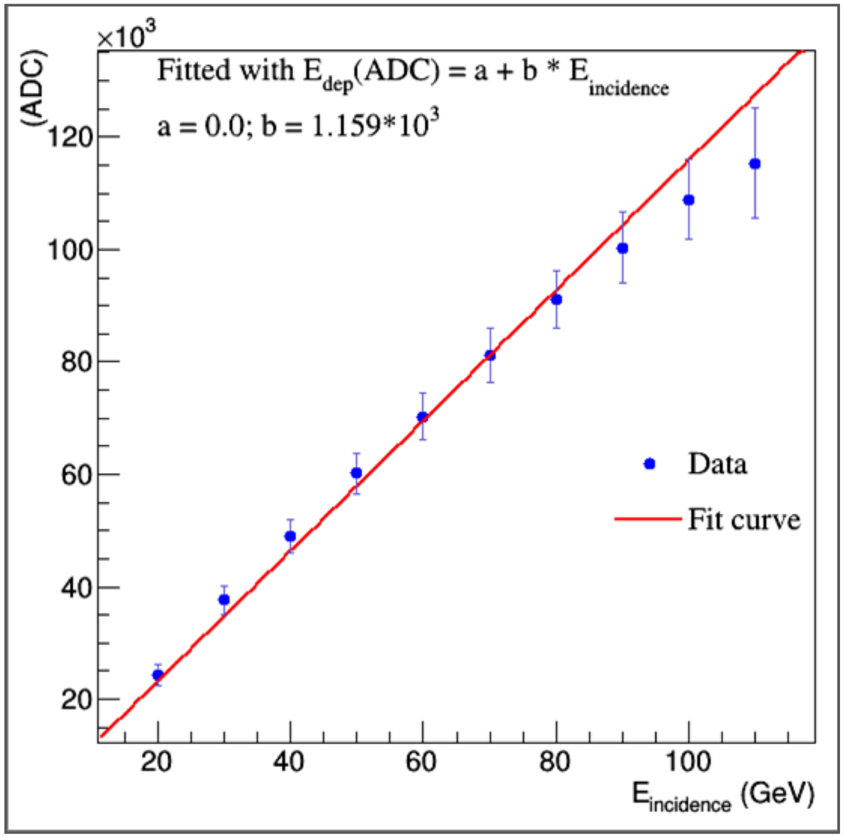
Secondary particle generation at smaller depth

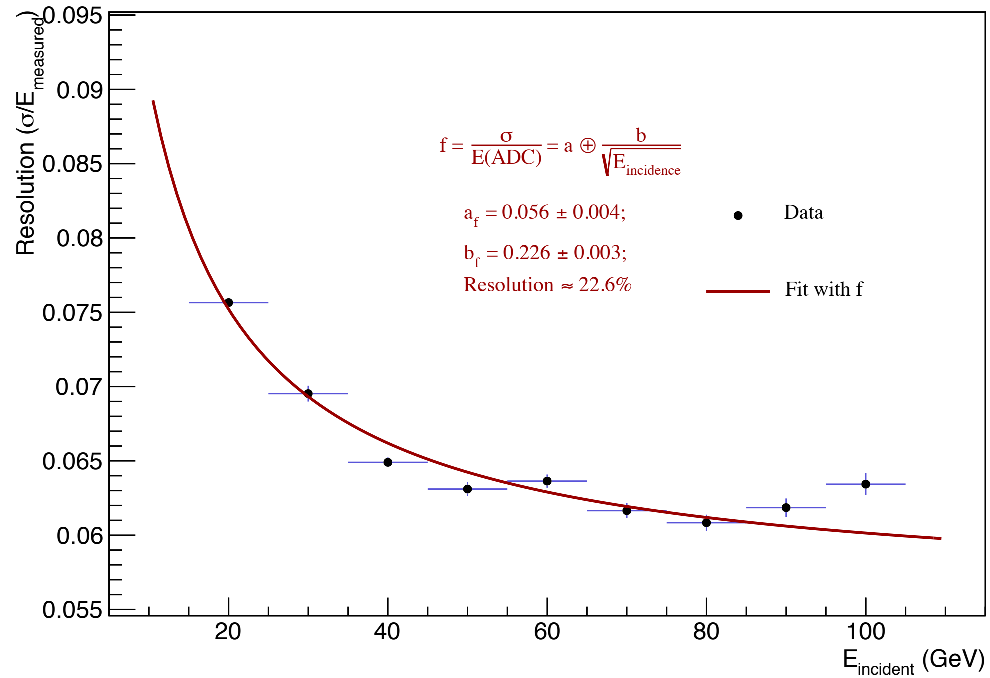
Falling part of the profile due to collisional losses at larger depth

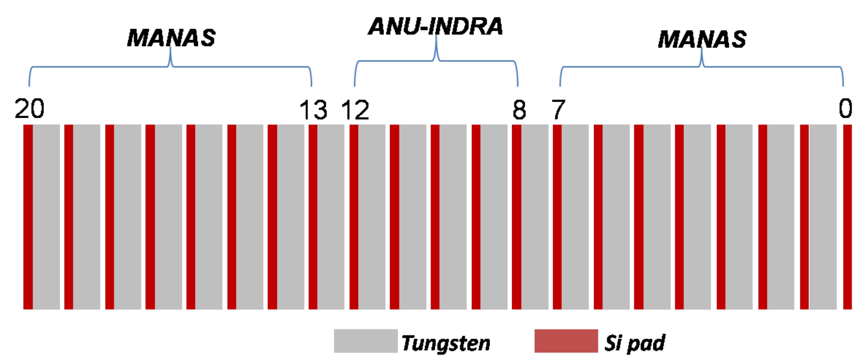
Shower Maximum shift with the increase in incident energy.

Detector development for LGL

(Efforts in India)

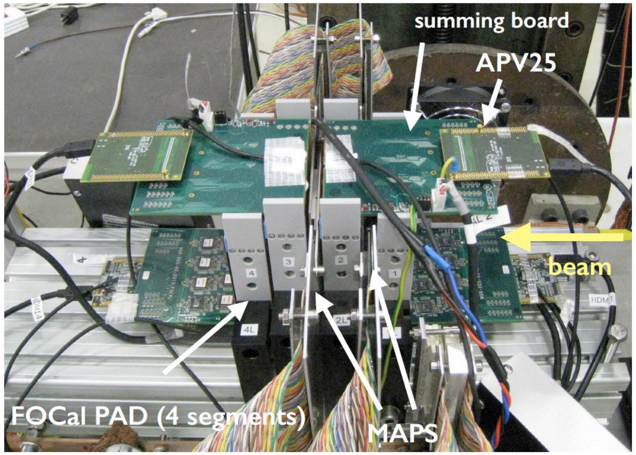




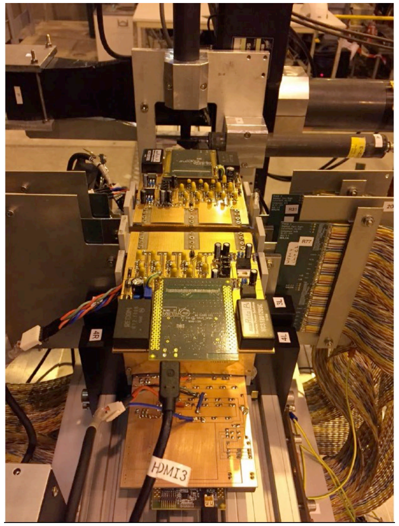


Detector development for LGL

(Efforts in Japan)

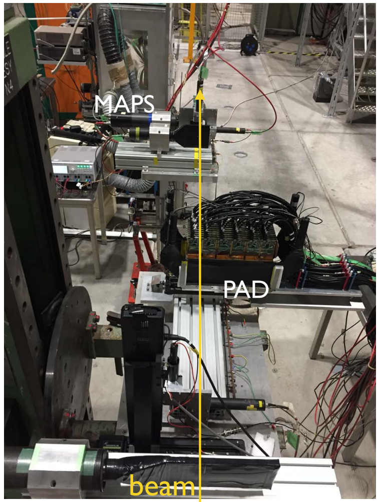


Test beam setup @ PS (same for SPS) in 2015



2016 SPS test beam (Sep. 7-12)

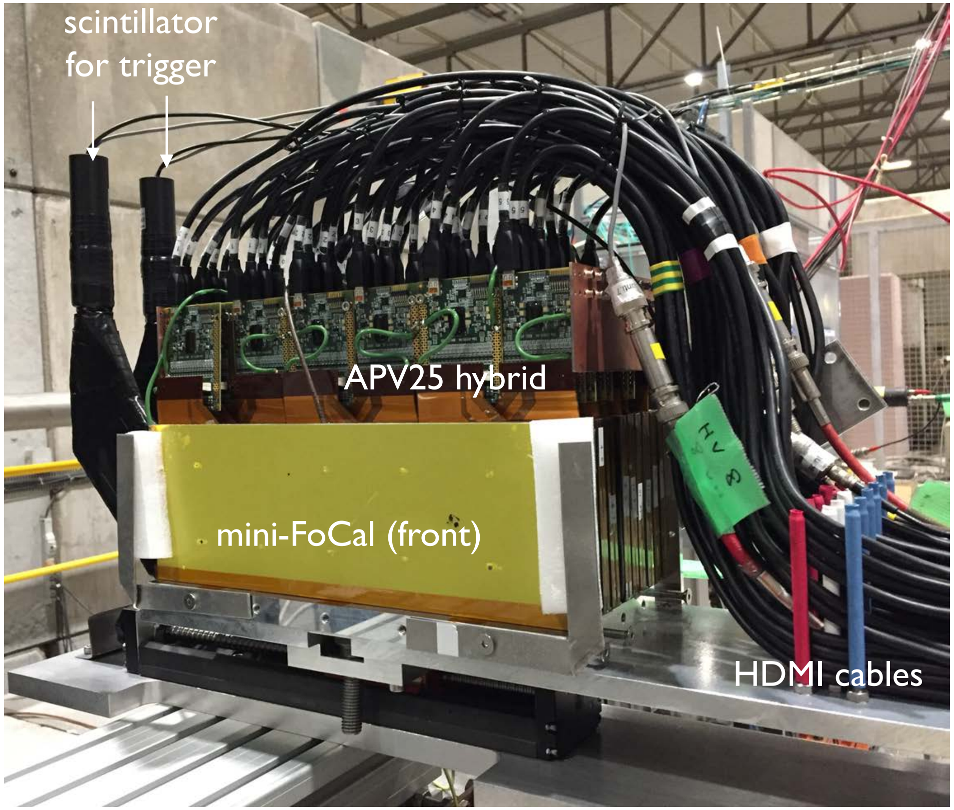
SPS beam test in 2018 (July, Aug)

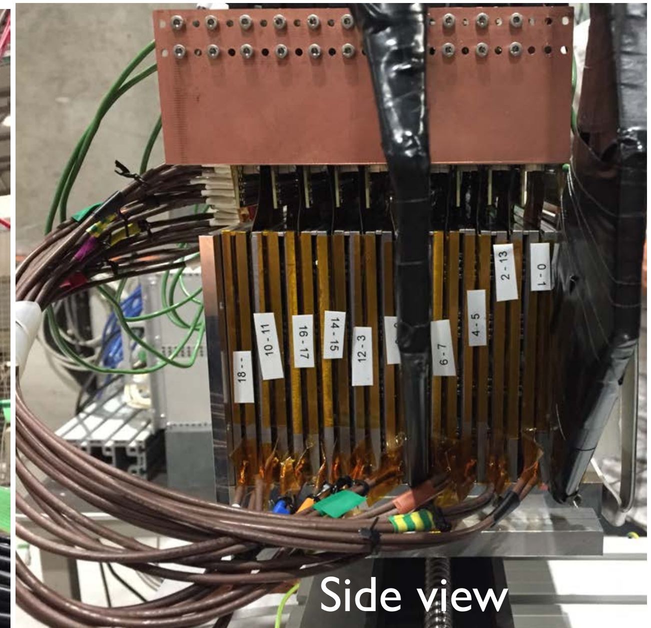


- Two independent setups
  1. PAD
     - APV25 hybrid
     - SRS+DATE software
  2. MAPS
     - ALPIDE (ALICE ITS upgrade)
- Beams @ SPS
  - 100,110,120,150 GeV/c, e^+
  - 250 GeV/c, e-
  - 180 GeV/c, hadrons

Detector development for LGL

(Efforts in Japan)

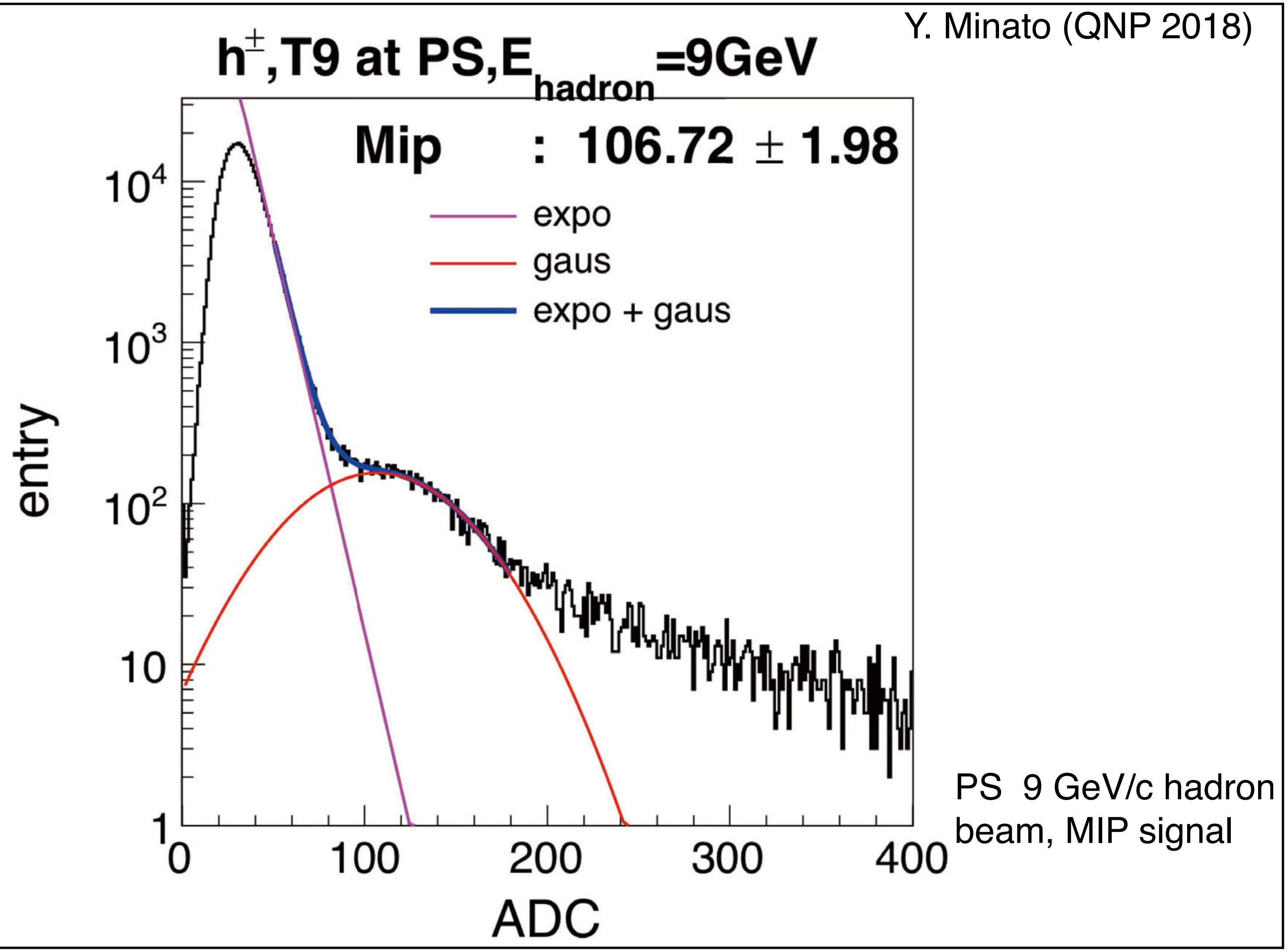




19 layers of Si-W layers

Detector development for LGL

(Efforts in Japan)



PS 9 GeV/c hadron beam, MIP signal

Detector development for LGL

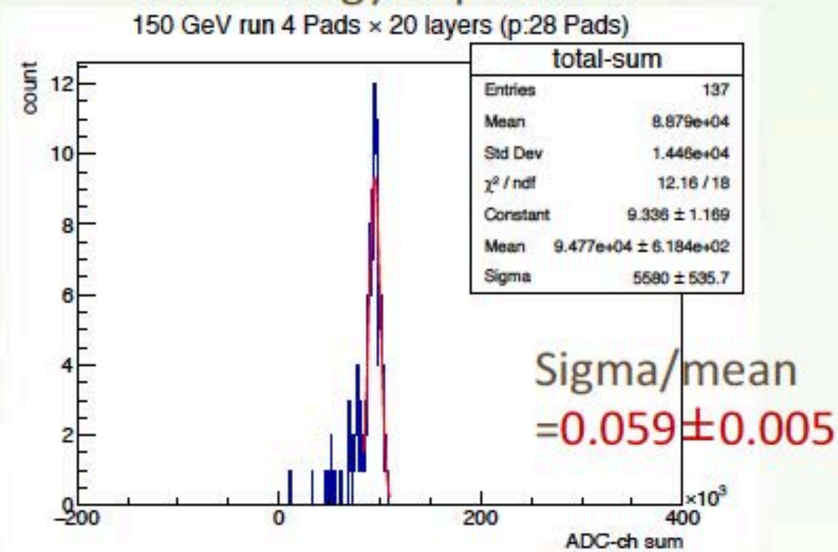
(Efforts in Japan)

S. Takasu

∗ Energy resolution improved a little bit.

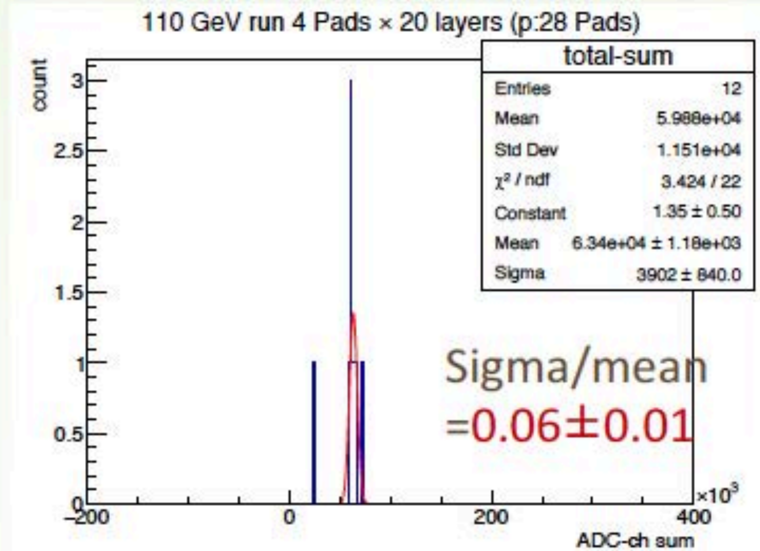
		Simulation expectation
150 GeV: 6.0 ±0.4 % →	5.9 ±0.5 %	(4.0 ±0.1 %)
110 GeV: 20 ±20 % →	6 ± 1 %	(5.0± 0.2 %)

Total energy deposited



150 GeV positron candidates

Total energy deposited

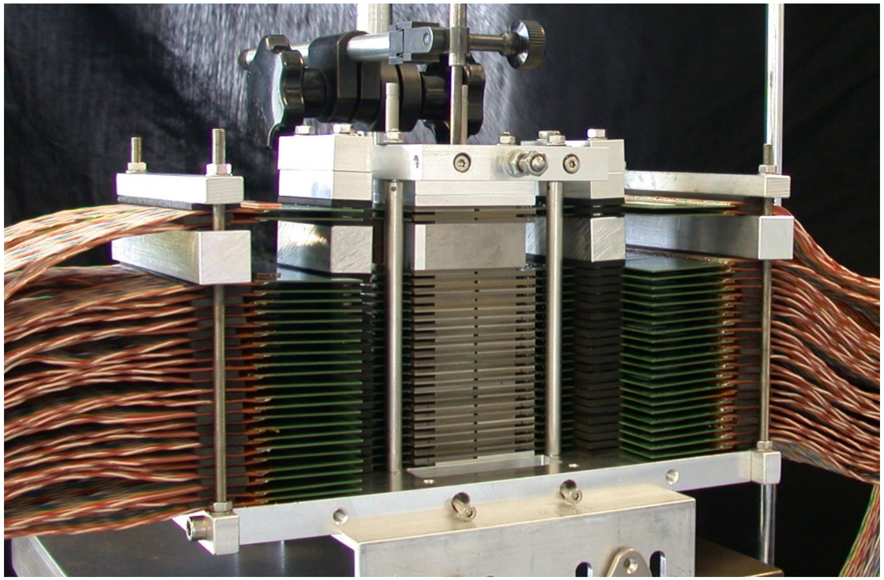


110 GeV positron candidates

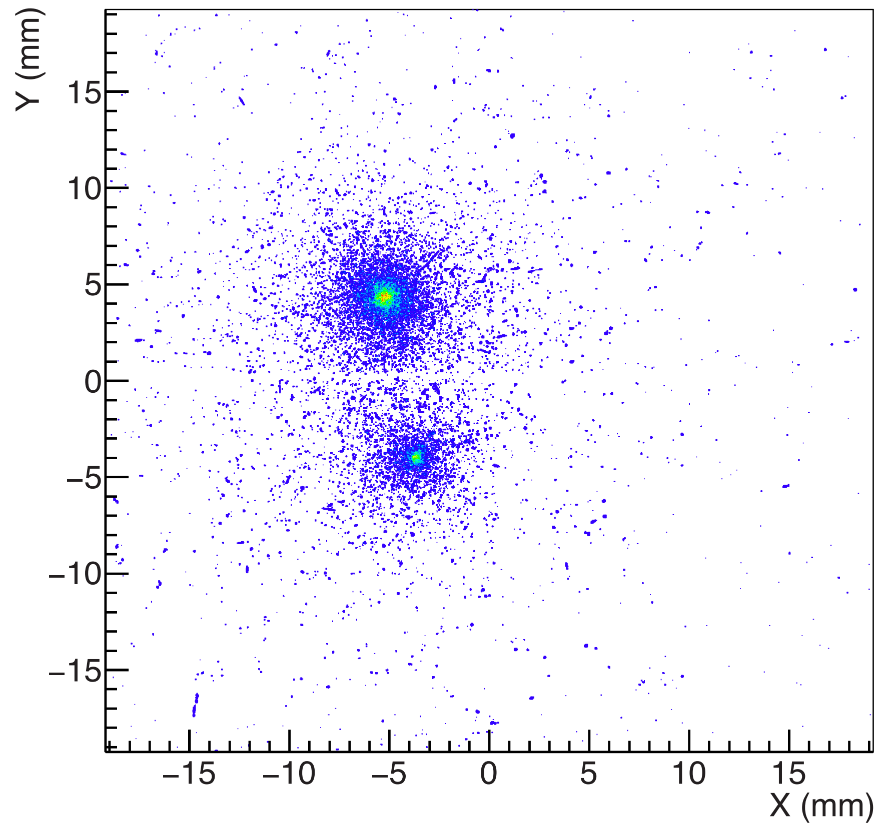
Detector development for HGL

(Efforts in The Netherlands)

R&D for HGL layers based on CMOS- MAPS



display of single event (with pile-up) from 244 GeV mixed beam



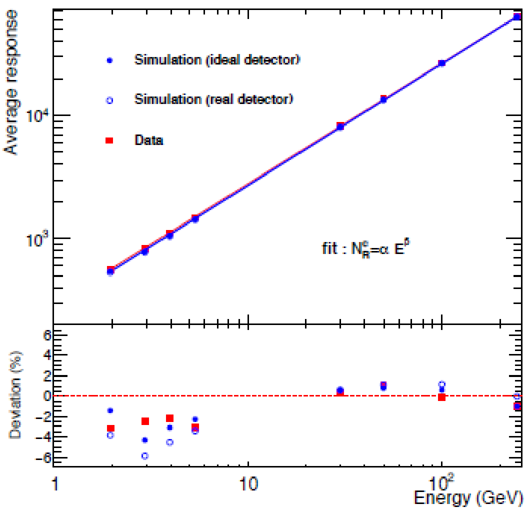
Test with beams at DESY, CERN PS, SPS

4x4 cm^2 cross section
24 layers
30 μm pixels
39 M pixels total

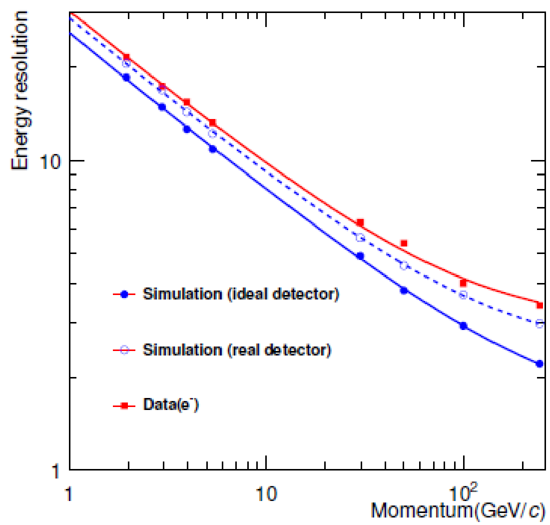
Detector development for HGL

(Efforts in The Netherlands)

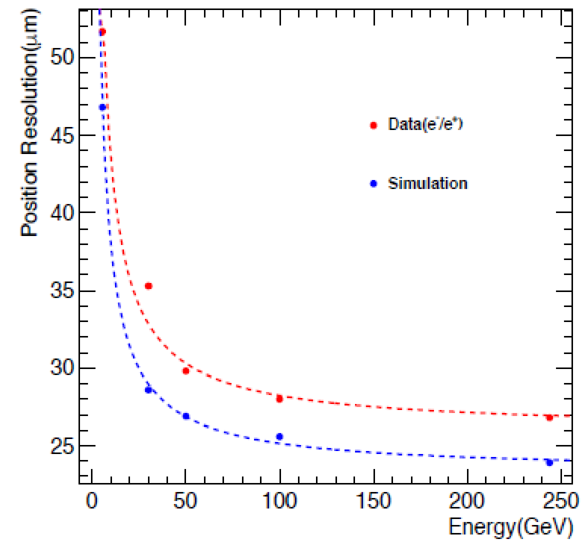
energy linearity



energy resolution



position resolution



$$\frac{\sigma_E}{E} = a \oplus \frac{b}{\sqrt{E/\mathrm{GeV}}} \oplus \frac{c}{E/\mathrm{GeV}}$$

$$a = (2.95 \pm 1.65)\%$$

$$b = (28.5 \pm 3.8)\%$$

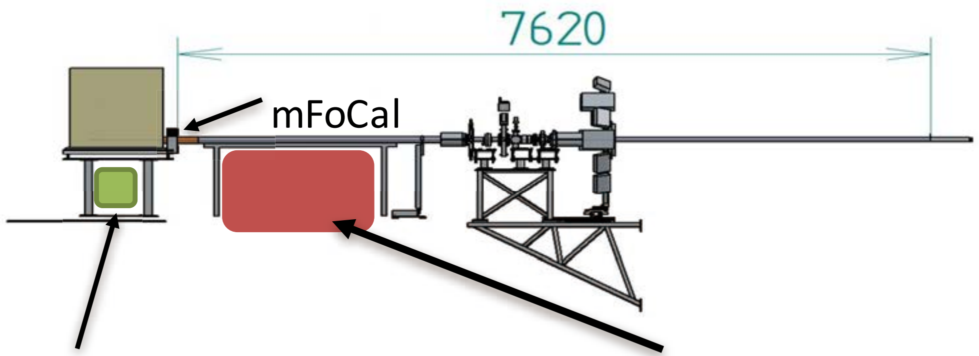
$$c = 6.3\%$$

$$\sigma_x = f \oplus \frac{g}{\sqrt{E}}$$

$f = 25.8 \pm 0.3$ μm and $g = 104 \pm 1$ μm$\sqrt{\mathrm{GeV}}$.

Development of Mini FoCal

(Efforts in Japan)



At z = 7.62 m from IP, in front of ZEM

- Three towers structure.
  - 20 layers of silicon PAD / tower (20 X_0)
  - 3 layers of MAPS / tower
  - Total No. of PD: 64 x 20 x 3 = 3,840
- Combine PAD and MAPS for three towers as one
- Close to the final design of FoCal EM
- No MAPS at this time.
- Optimized to measure 50 - 200 GeV photons.

Development of Mini FoCal

(Efforts in Japan)

Readout Electronics

Requirements

- **Increased data rate capability**, Target: 50kHz in Pb-Pb
- **Radiation Dose**: 1×10^{12} 1 MeV neutron equivalent dose per cm^2 ~ 80-180 krad
- **Dynamic range (D.R)** ~ 1 MIP to >10 pC (?) (~ >70 dB)
- **Noise**: 600 – 2000 e
- **Number of channels**: 64 per detector
- **Power Dissipation**: less than 10 mW /Channel
- Digitization **Resolution** : Min 10 bit, preferred 12 bit
- **DAQ compatibility**: CRU of ALICE

Available Chips

1. **ANUINDRA ASIC:** 16 channel /2.6 pC D.R/ compatible with CROCUS/ functionally same as MANAS / 0.35 um CMOS technology, Triggered DAQ

2. **SAMPA ASIC:** 32 channel/500 fC D.R/compatible with CRU/0.13 um CMOS technology

3. **SKIROC/HGROC:** 64 channel/ 10pC D.R/ADC (150 fC)+ToT (time over threshold)/0.13 um CMOS technology

4. **VMM-3 ASIC:** 64 channel / 2 pC D.R (?) / 0.13 um CMOS technology / very low power

Time-Line

2019	2020	2021	2022	2023	2024
Work out conceptual design	Finalise design		Production	Calibration in test beam	Installation

Thanks

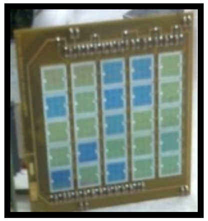
BACKUP SLIDES

Detector development & prototyping

Efforts in India

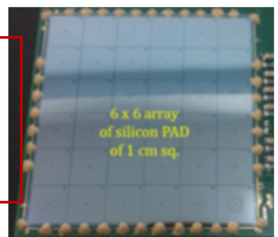
Silicon Pad Detectors

Physically Isolated



2012

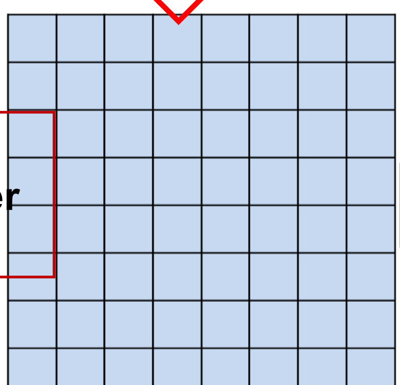
5 x 5 array



On a Single wafer (4 inch)

2015 & 2017

6 x 6 array



On a Single wafer (6 inch)

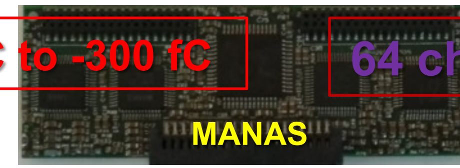
Proposed for 2018

8 x 8 array

ASIC Development

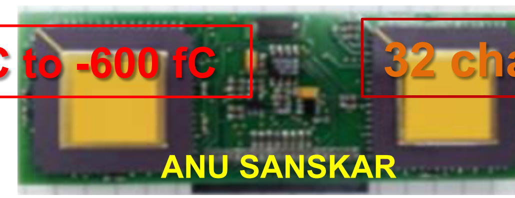
+500 fC to -300 fC

64 channel



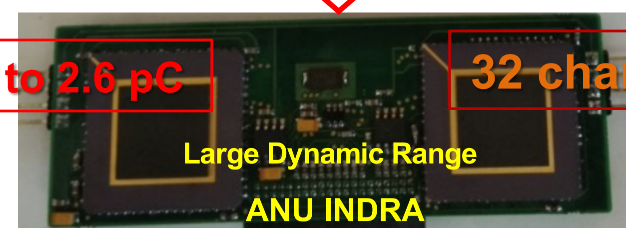
+600fC to -600 fC

32 channel



2.4 to 2.6 pC

32 channel



1000 MIPs

?? channel

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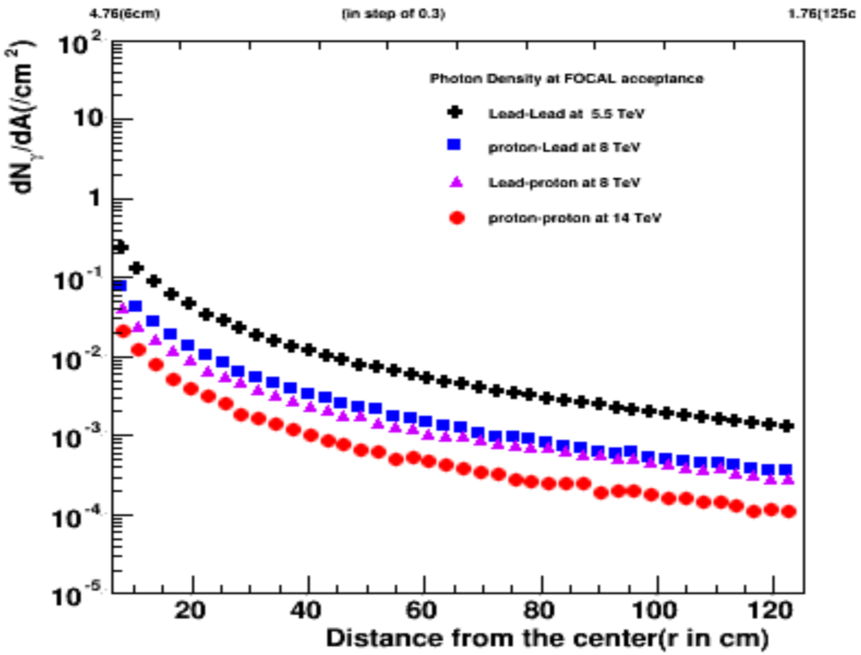
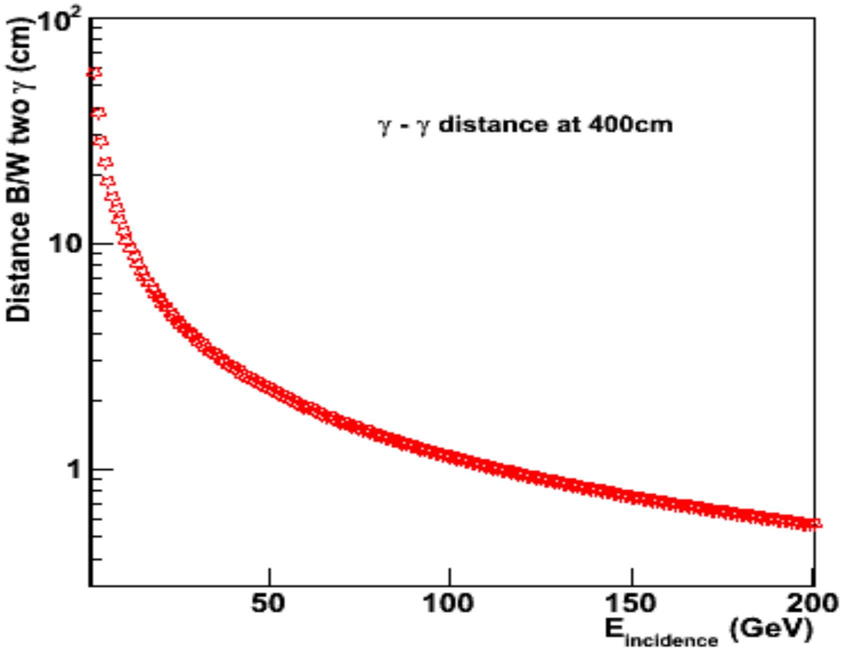
Design and Geometry

Design parameters





Distance from IP: 4m (8m)

Radial distance:

Inner: **6cm (limited by beam pipe)**

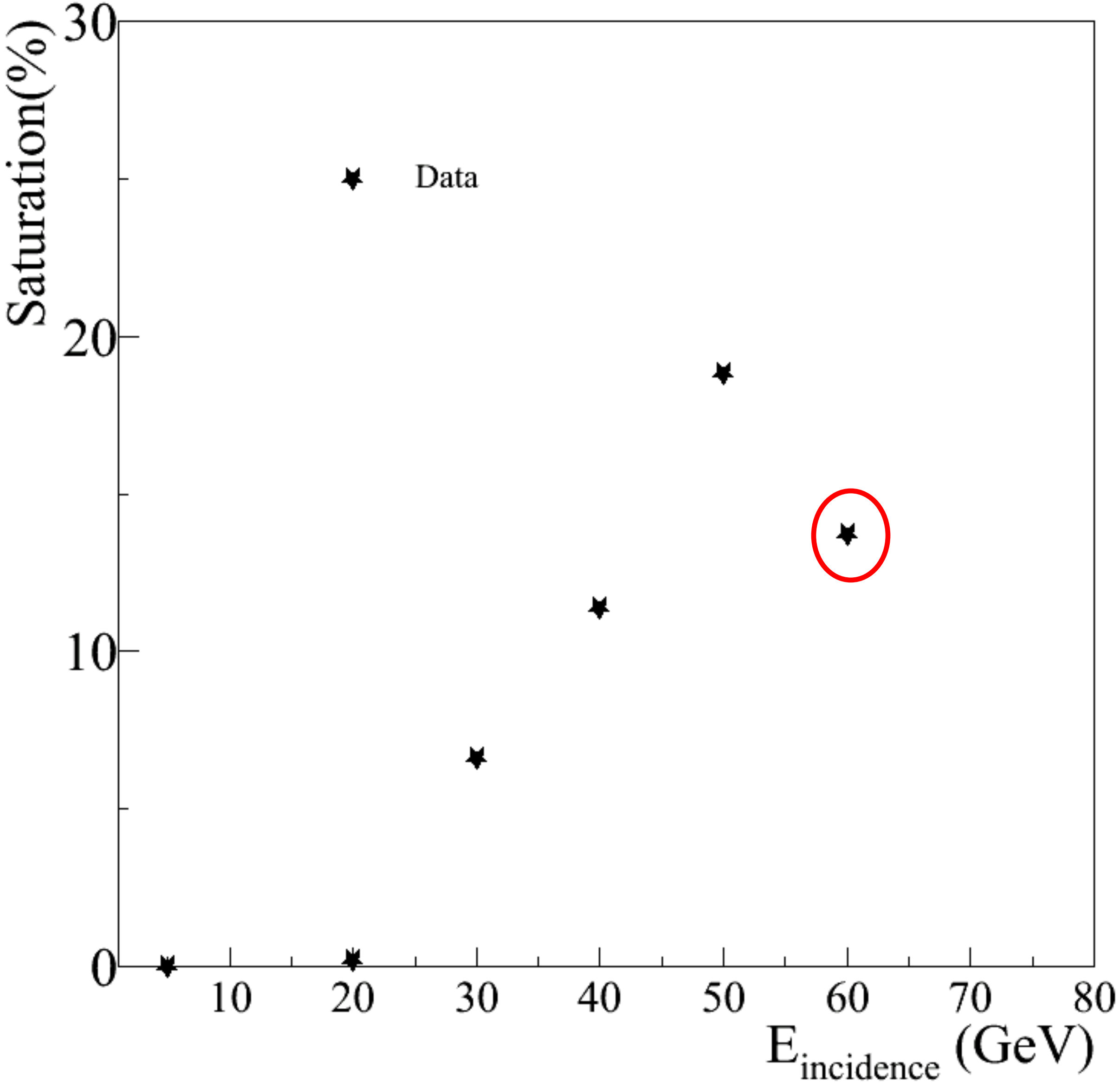
Outer: **80cm**

Rapidity Coverage: **$2.5<\eta<5.5$**

P_T range of particle detection: **Up to 20GeV/c**

- ✓ **Sampling type Hybrid Calorimeter**
- ✓ **Detector : Silicon sensors (LGL: 1cm^2 & HGL: 1mm^2)**
- ✓ **Absorber/Convertor : Tungsten**

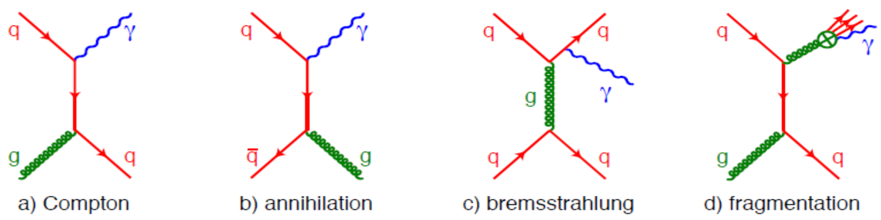
Saturation Effect due limitation of the electronics used for the prototype



Limitation of the readout shows the saturation effect which is appearing after 20 GeV. Maximum Saturation effect found was about 18%. 60GeV case need to be taken more seriously because of it's anomalous behavior.

Experimental Observables: Gamma from different sources

✓ Probing the gluon density with direct photons



Feynman diagrams for photon production:

At leading order, isolated photons from

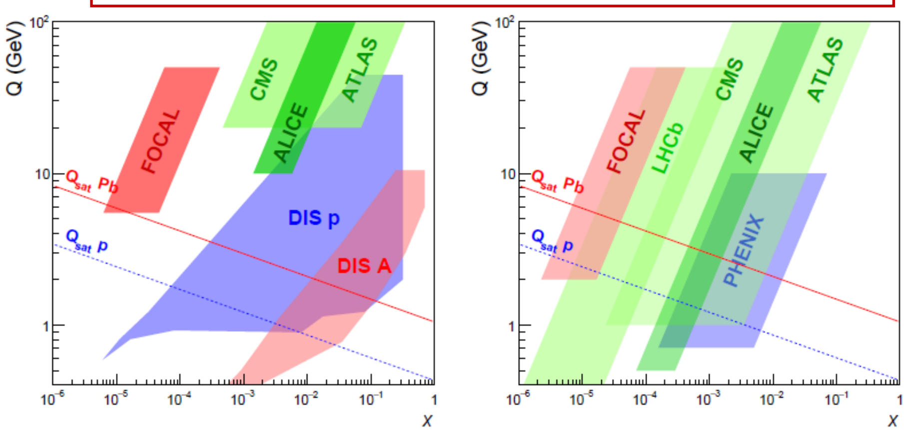
- ✓ **a) quark-gluon Compton process,**
- ✓ **b) quark-antiquark annihilation process.**

Non-isolated photons at next-to-leading order from

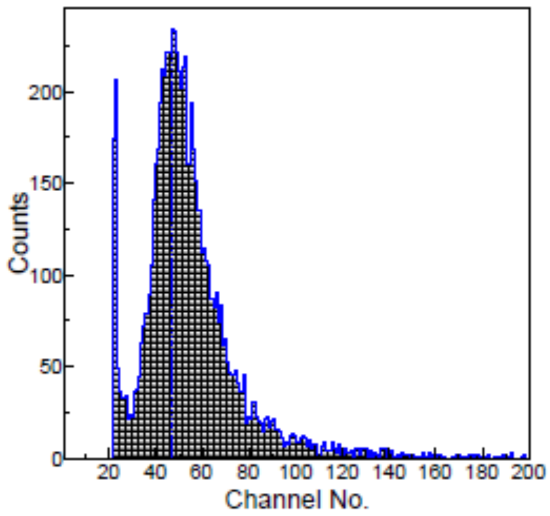
- ✓ **c) bremsstrahlung from a quark,**
- ✓ **d) emission during the gluon fragmentation process.**

x-Q coverage of various experiments and measurements:

- ✓ **Left panel shows DIS measurements and the photon measurements**
- ✓ **Right panel shows the regions covered by hadron measurements**
- ✓ **Clearly, the FOCAL measurements will probe much smaller-x than the existing measurements.**



Hardware Development done so far:

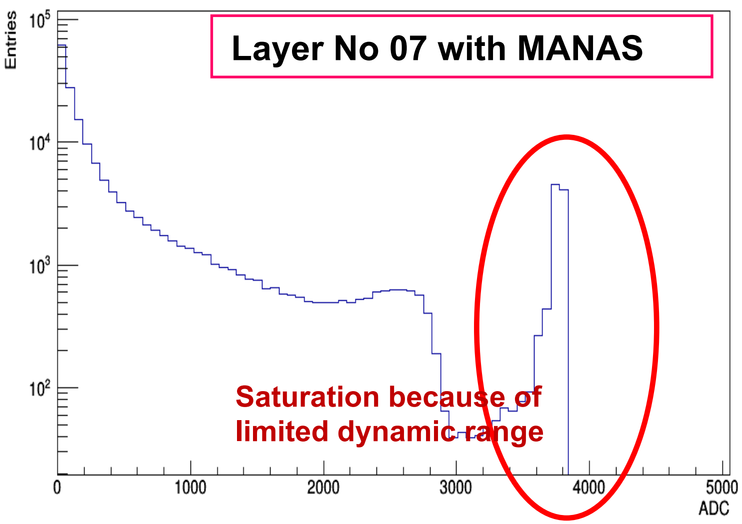


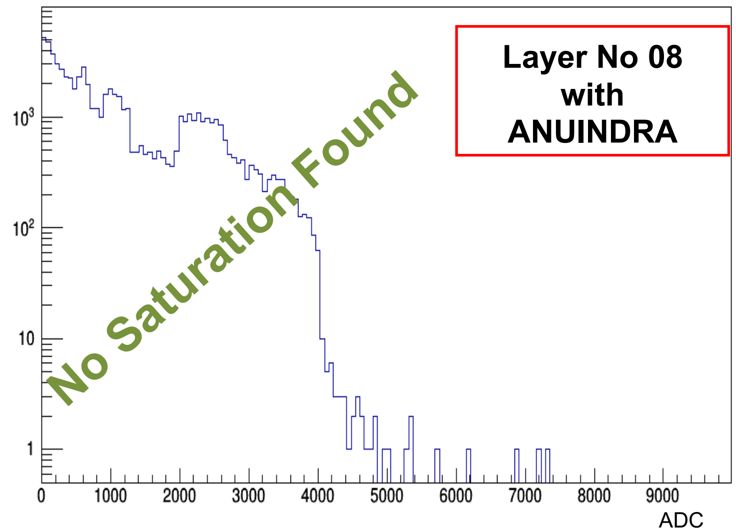
Response of a single silicon pad detector to 90Sr source. A clear peak corresponding to energy of 0.546 MeV is visible on the right, well separated from the noise.

ANUINDRA test board

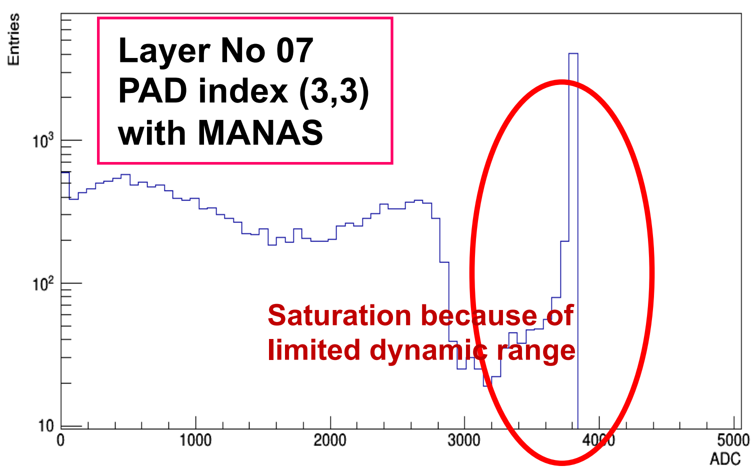
Full-Length Prototype: Testing with ANUINDRA

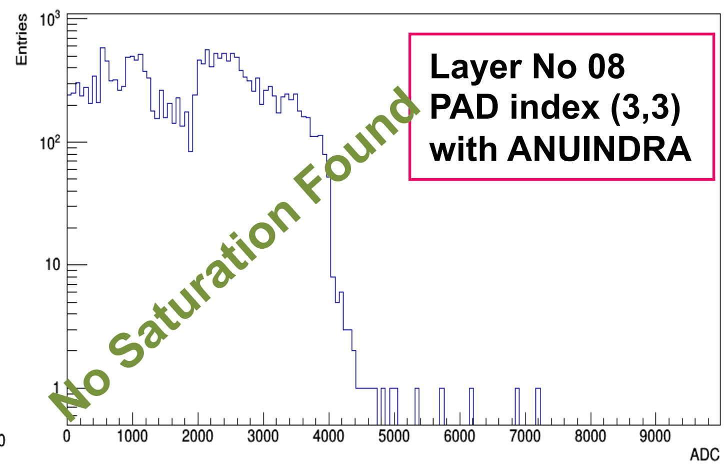
30GeV Electron





Same observations layer wise as well as pad wise!!!



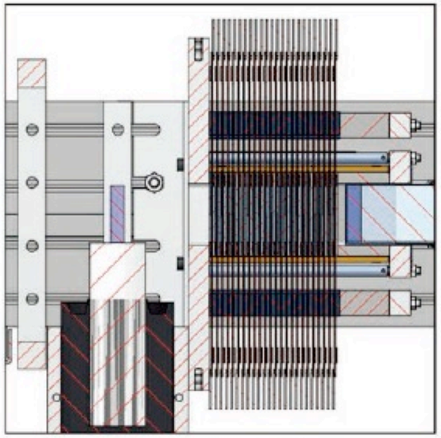


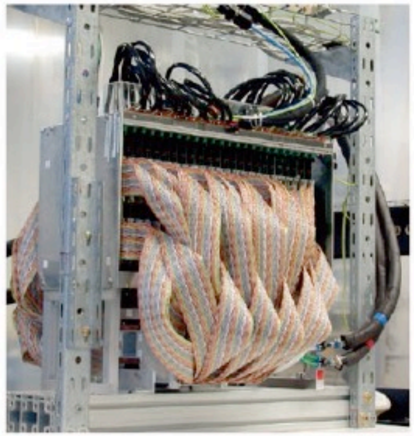
No Saturation up to 100 GeV Electron

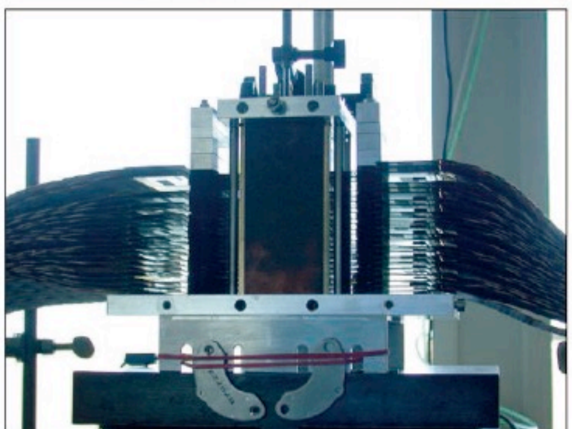
High Granularity (HG) Prototype, MAPS

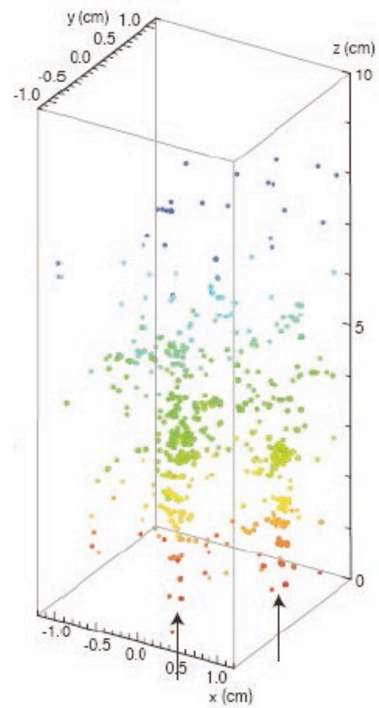
- 4×4 cm^2 cross section, 28 X_0 depth
- 24 layers: W absorber + 4 MAPS each
- MIMOSA PHASE 2 chip (IPHC Strasbourg)
  - 30 μm pixels
  - 640 μs integration time
    (needs upgrade – too slow for experiment)
- 39 M pixels total
- Test with beams at DESY, CERN PS, SPS

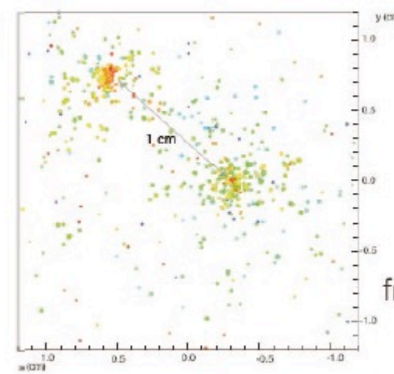
MAPS prototype











front view

Event Display:
measurement (DESY) of pile-up of two 5.4 GeV electrons, demonstrates two-shower separation capabilities

Specification	ANUSANSKAR	MANAS	ANUINDRA
Noise at 0 pF	390 rms electrons	500 rms electrons	700 rms electrons
Noise slope	7 e^-/pf	11.6 e^-/pf	15 e^-/pF
Linear dynamic range	+/- 600 fC	+ 500 fC to -300 fC	~ (2.4 - 2.6) pC
Conversion gain	3.3 mV/fC	3.2 mV/fC	(1-1.25) mV/fC
Peaking time	1.2 μs	1.2 μs	1.2 μs
Baseline recovery	1% after 4 μs	1% after 5 μs	1% after 5 μs
VDD/VSS	+/- 2.5 V	+/- 2.5 V	+5 V/GND
Analogue readout speed	1 MHz	1 MHz	1 MHz
Power consumption	~ 15 mW/channel	~ 9 mW/channel	~ 25 mW/Channel
Die area	4.6 mm x 4.6 mm	4.6 mm x 2.4 mm	~ 5.6 mm x 5.3 mm
Technology	0.7 μm standard CMOS	1.2 μm standard CMOS	0.35 μm standard CMOS
Package	CLCC-68	TQFP-48	CLCC-68