Performance evaluation of a Forward Calorimeter for the ALICE upgrade

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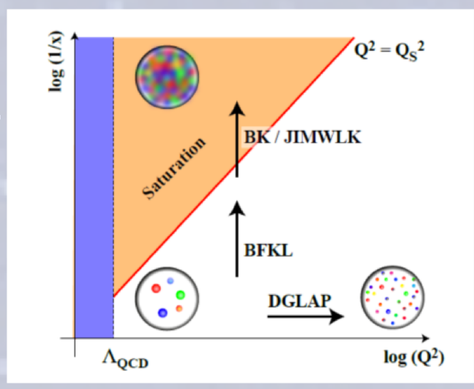
Physics Motivation

- Direct photons at forward rapidity are a key to investigate the high-density parton distribution functions and to understand the initial state of nuclear collisions.
- Gluon density at very small x (< 10^{-4}) may reach saturation of the phase space.
- The Color Glass Condensate(CGC) is a theoretical framework that describes the coherent dynamics of this saturated regime of QCD.
- Goal: measure direct photons at forward rapidity; background comes mainly from π^0 decays into two photons.

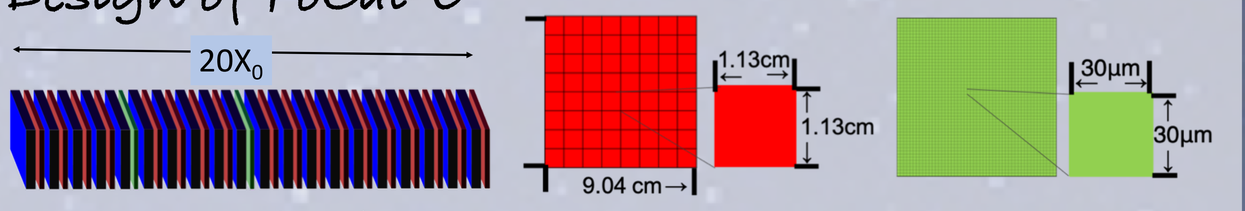


gluon saturation[1]
[1] arXiv:1607.01673

Forward Calorimeter

- **FoCal-E Electromagnetic sampling calorimeter**
- **Rapidity : 3.2 < η < 5.8 ●Dynamic range : 1GeV～1000 GeV**
- **Energy resolution : better than 5 % for p_T > 150 GeV/c**
- **Plan to install during 2024 (ALICE Long Shut Down 3)**

Design of FoCal-E



Focal-E strawman design↑

20 tungsten(W) absorbers

20 Si detectors
∗ two kinds of Si detectors
∗ Measurement of energy deposited in each layer

Low-Granularity Layers (LGL)
measure energy of photon with good resolution
∗ 8x8 Si sensors
∗ thickness : 320 μm

High-Granularity Layers (HGL)
measure position of photon
distinguish direct photons from decay photons in the order of mm.

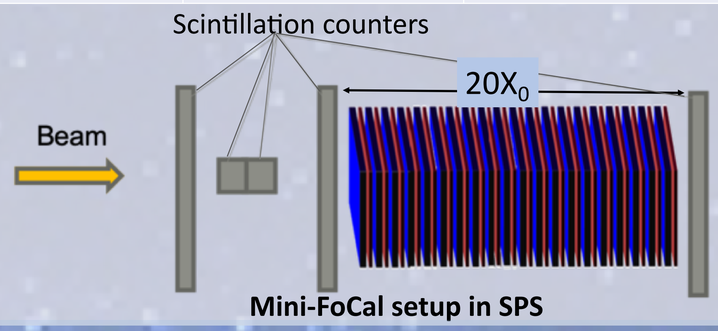
Beam Tests at PS and SPS in 2018

- Prepare the new FoCal prototype, **Mini-FoCal** composed of 20 LGL layers and W in 2018
- **Performance Evaluation of Mini-FoCal**

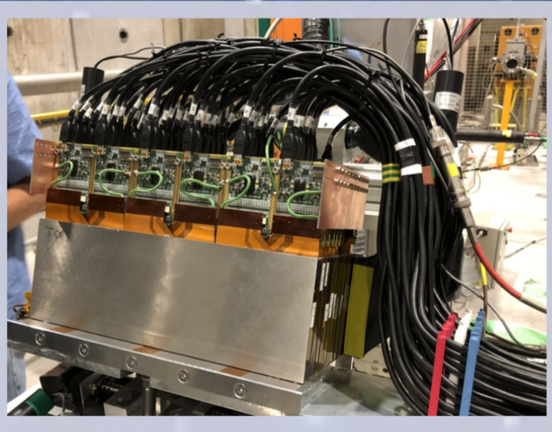
PS Test Beam at CERN
Measurement of ADC corresponding to MIP signal

SPS Test Beam at CERN
Measurement of energy resolution

	Energy (GeV)	Particle	Trigger
PS	9	Electron + Hadron	Cherenkov Counter
SPS	110,150,250	Positron + Hadron	Scintillation Counters



Mini-FoCal setup in SPS



picture of Mini-FoCal

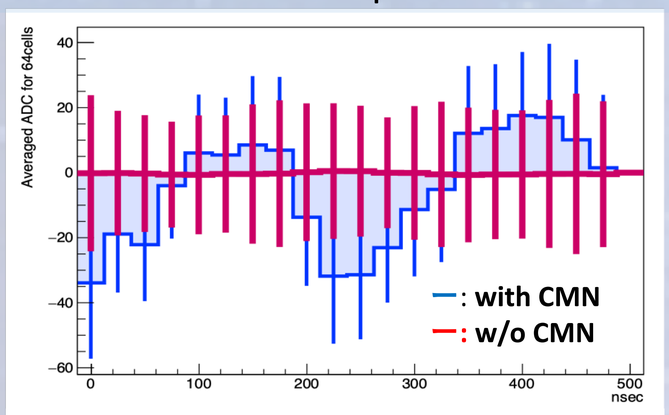
Analysis

Method of analysis

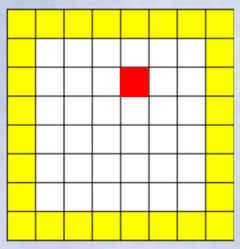
①Subtract Pedestal ②Subtract CMN ③ Clusterise ④Select positron events

Common Mode Noise (CMN)

CMN shows same time period in one LGL



Time dependence of <ADC> of each Si cell



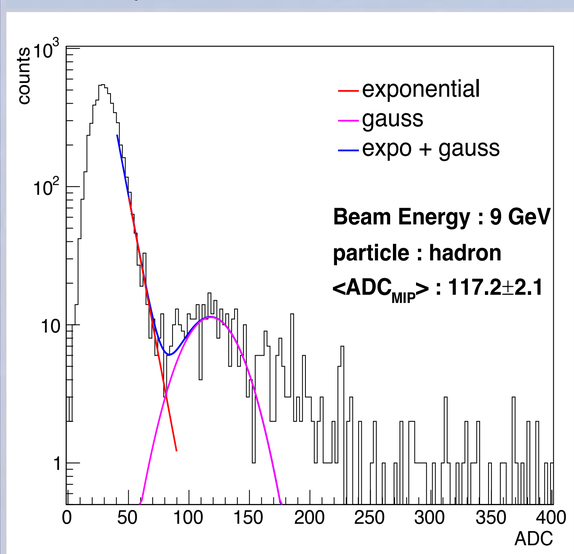
Schematic diagram of one LGL↑

How to Subtract Noise
∗ Consider the average of 28 pads per layer (shown in yellow) as CMN, and subtract CMN from each Si cell.

→ **Noise can be reduced to ～1/100 by subtracting CMN.**

Results of PS test beam

MIP peak distribution with single hadron beam



ADC distribution of one Si cell↑

∗ beam injected onto one cell

∗ $\langle ADC_{MIP} \rangle$: **117.2 ± 2.1**

∗ CF : conversion factor

$$CF = \frac{\langle \text{Energy deposited of MIP in Si with 320 μm} \rangle}{\langle ADC_{MIP} \rangle} = 0.089\ MeV / 117.2 = 7.5 \times 10^{-7}\ \text{GeV / ADC}$$

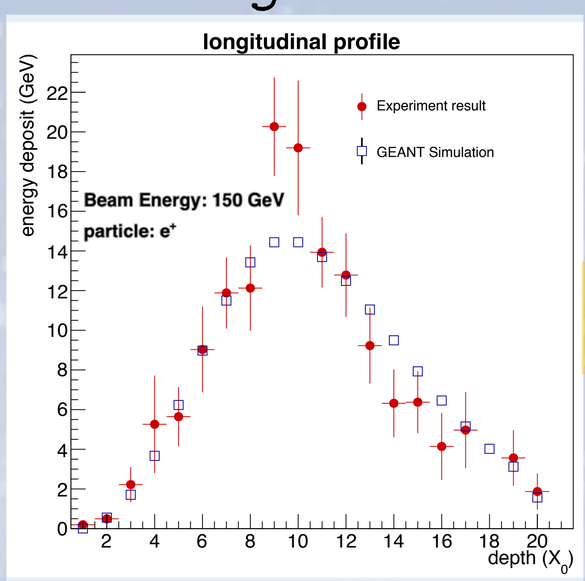
∗ SF: simulated Sampling Fraction

$$SF = \frac{\langle \text{energy deposited in Si} \rangle}{\langle \text{incident energy} \rangle} = 1.7 / 150\ \text{GeV} \quad (2.8 / 250\ \text{GeV})$$

∗ $E_{reco.} = ADC \times CF \times \frac{1}{SF} \times 180$: reconstructed energy from ADC with CF and SF

Results of SPS test beam

Electromagnetic Shower



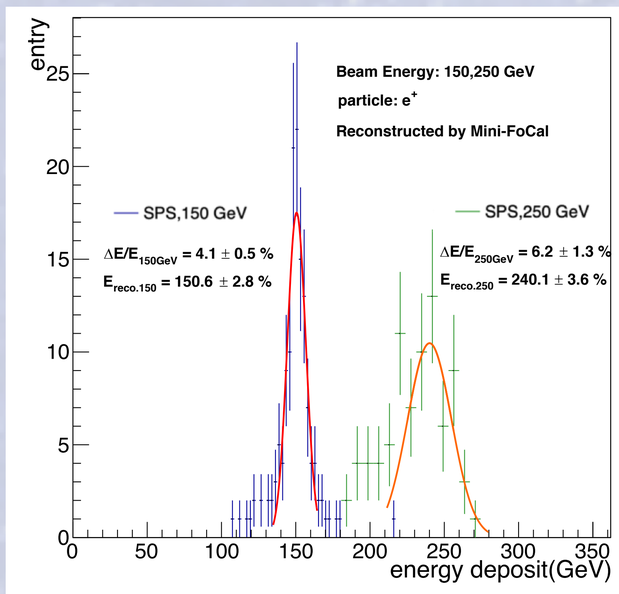
∗ Reconstruct energy deposited in each layer
∗ Maximum of Shower development is in the 9th layer (= $9X_0$)

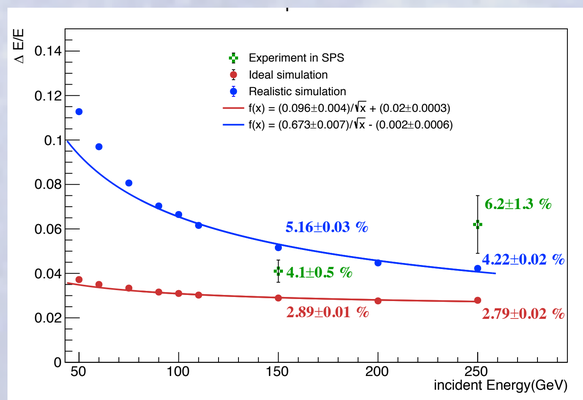
Consistent with the expectation from simulation

(plot from Moe Isshiki [Tsukuba University])

Energy resolution of Mini-FoCal

- Incident positron energy was reconstructed with **<ADC_{MIP}>**
- Energy resolution was evaluated and compared to simulation





∗ Error bars represent only statistical error.
∗ Energy resolution at 150 GeV is evaluated reasonably well.

∗ Due to low intensity positron beams, energy resolution at 250 GeV does not agree with simulation.
∗ Both incident energies are reconstructed within error.

Summary

∗ FoCal is a proposed ALICE upgrade project to study coherent dynamics of the saturated regime of QCD, CGC.
∗ Mini-FoCal is tested with PS and SPS at CERN to evaluate the FoCal performance.
∗ Method of CMN subtraction is established.
∗ ADC corresponding to MIP is evaluated in PS beam test.
∗ Positron energy is reconstructed with <ADC_{MIP}> and energy resolution is evaluated.

Outlook

✓ Performance evaluation of Mini-FoCal will be improved
- Method of selecting positron events will be Improved.
- The FoCal Performance will be evaluated in test-beam experiments with better identification of positron
- Comparison and verification of measurements with realistic simulation

✓ Mini-FoCal was installed in the ALICE cavern during the pp collisions in Run2 at $\sqrt{s}$ =13 TeV for test measurements. The analysis is ongoing.