A new detector for studying cumulative processes in hadronic collisions

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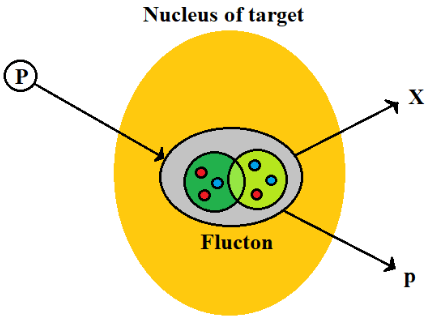
Outline:

Introduction

Cumulative effect – production of particles from nuclei in a region, kinematically forbidden for reactions with free nucleons.



- 1957 – D.I. Blochintzev
- 1971 – A.M. Baldin
- 1971 – experimental discovery of cumulative effect by group of A.M. Baldin and V.S. Stavinsky

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a D.I. Blochintzev. In: ZhETF 33 (1957), p. 1295.

b M.A.Baldin, Kratkie soobshchenia po fizike, 1971, No1, p35.

Cumulative effect

Main features

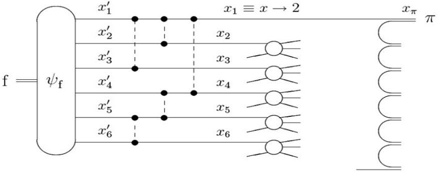
- Scaling law
- Exponential dependence of inclusive cross section on the cumulative particle momentum
- Inclusive cross section decrease with emission angle growth
- Inclusive cross section decrease with cumulative number* growth

**Cumulative number — number of participants.*

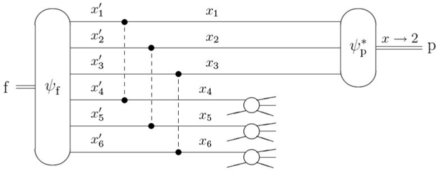
[a] V.S. Stavinsky, Physics of Elementary Particles and Atomic Nuclei, 1979, v.10

Theoretical description of cumulative effect

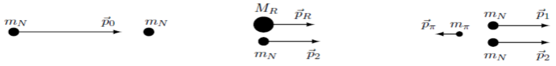
Fast quark fragmentation



Coherent quark coalescence



Resonance mechanism of cumulative particles production



(a) (b) (c)

Event generators:

HIJING, URQMD, FRITIOF model.

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[a] Braun M.A, Vechernin V. V. //Sov. J. Nucl. Phys. 1984. v.40. , 1986. v.43, 1988. v.47 //J. Phys. G . 1990. v.16., 1993. v.19.; //Phys.Atom.Nucl. 1997. v. 60., 2000. v. 63.

Motornenko A., Gorenstein M.I.//2016. arXiv:1604.04308 [hep-ph]

Area of interest

Development of a new detector system for experiments at fixed target:

- Investigations of cumulative spectra at the area of high momentum (1.5 – 4 GeV/c)
- Investigations of possible correlation in cumulative and non cumulative regions
- Investigations of heavy-flavour production in cumulative processes

Calculation of cumulative particle yield

$$E \cdot \frac{d^3\sigma}{dp^3} = \frac{E}{p^2}\frac{d^2\sigma}{dpd\Omega} = \frac{E}{p^2}\frac{A}{N_A \cdot \rho \cdot t}\frac{1}{\varepsilon \cdot \Delta P \cdot \Delta \Omega}\frac{1}{N_{prot}} \cdot N, \qquad (1)$$

A – atomic mass;
N_a –Avogadro constant;
ρ, t – target density, target thickness;
ΔP, $\Delta\Omega$ – setup momentum and solid angle acceptances;
N_{prot} – total number of protons passed through the target;
ε – detector efficiency (here 100%);
$E \cdot \frac{d^3\sigma}{dp^3}$ – should be taken from the experimental data;
N – number of registered particles at the given momentum

a V.V.Ammosov et al.Yadernaya Fizika I Inzhiniring 4 (2013)773-778

Inclusive cross section depends on momentum as: $b \cdot exp(\frac{p}{p_0})$;
Inclusive cross section weakly depends on A;
Inclusive cross section depends on emission angle as: $a \cdot exp(w \cdot cos(\theta))$;
Target: ^{208}Pb, t=1mm;
$N_{prot} = 10^6$;
All parameters obtained from experimental distributions , .

a V.S. Stavinsky, Physics of Elementary Particles and Atomic Nuclei, 1979, v.10

b Y.D Bayukov, Phys.Rev.C, 1979, v.20, iss.2

Results of the rough estimation of the cumulative protons yield

10^6 protons $\rightarrow$ 1mm Pb target

Emission angle (degree)	Total number of cumulative protons
70 ± 4	3.2 ± 0.2
90 ± 4	0.3 ± 0.02
119 ± 4	0.038 ± 0.003
137 ± 4	0.0121 ± 0.0009
160 ± 4	0.0053 ± 0.0003

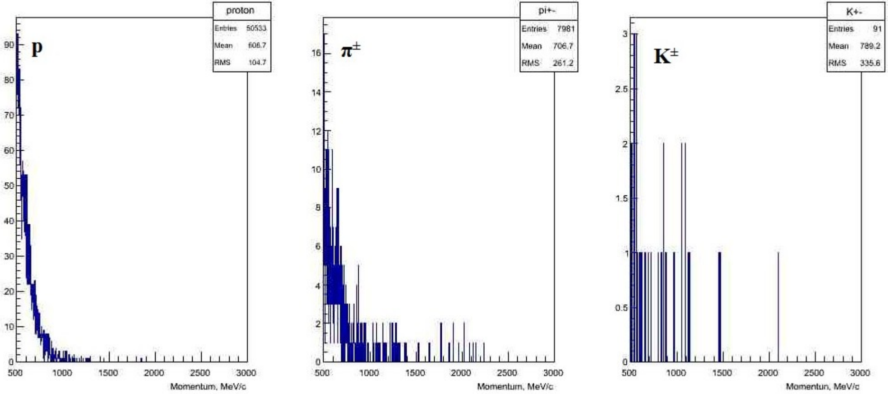
Calculation for the momentum range 1.5 – 4 Gev/c

Momentum, GeV/c	Total number of cumulative protons
2	1.6 ± 0.2
3	$(8.9 \pm 0.1) \cdot 10^{-2}$
4	$(4.87 \pm 0.05) \cdot 10^{-3}$

Calculation of the cumulative proton yield in the angular range between $20°$ and $175°$

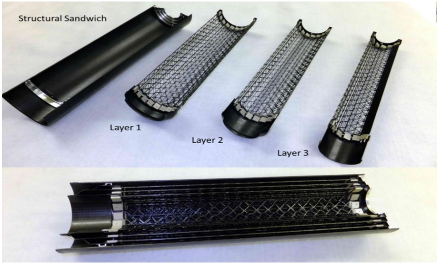
Simulations using FRITIOF model

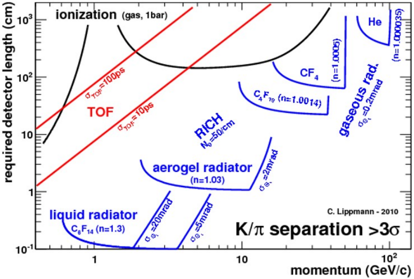
FRITIOF+Geant4 simulation of momentum distribution in the backward cumulative region for the reaction p+Pb for 10^6 protons in a collision at 400 GeV/c.Target thickness 1mm.



Selection of elements of the detector system

1. Detectors with high granularity, efficiency and speed for the tracks and vertices recoconstruction, with low noise for the rare events registration → PIXEL DETECTORS
2. Detectors for the particle identification at low momentum (up to 1.5 GeV/c) → STRIP DETECTORS
3. Compact detector for the particle identification at high momentum (up to 4 GeV/c) →RICH





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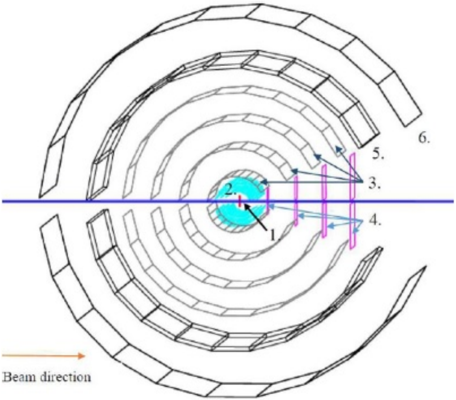
a Abelev B. et al.// J. Phys. G: Nucl. Part. Phys. 2014 v. 41. i.8

b Lippmann C.//Nucl. Instrum. Meth. 2012. v. A666.

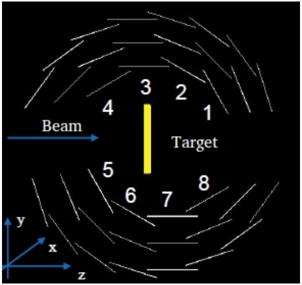
Preliminary geometry layout



3) Strip silicon detectors. Radii of layers(the same as at Vertex Detector(4)):R = 5, 10, 15, 20cm

4) Vertex detector;

5 - 6) Ring Imaging Cherenkov detector: liquid radiator, R=25 cm; photodetector, R=33cm.

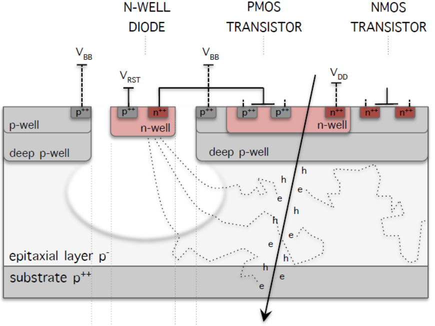


Pixel layers with numeration of the staves of the first layer.

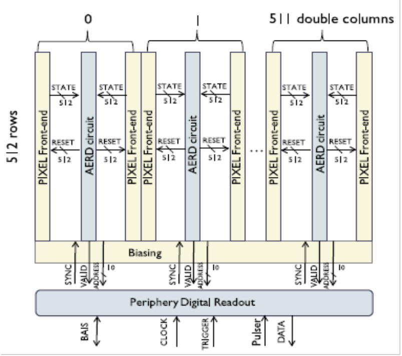
1) Target;

2) Pixel detectors (based on ALICE ITS).Mean radii of layers: R = 2.3, 3.1, 3.9 cm

CMOS* Monolithic Active Pixels Sensors



- Based on 180 nm TowerJazz technology;
- Size of pixel 30×30 μm;
- Matrix: 512×1024 pixels;



- Priority Encoder readout scheme.

*CMOS – Complimentary Metal-Oxide-Semiconductor

a ALICE Collaboration, Technical Design Report for the Upgrade of the ALICE Inner Tracking System, J. Phys. G: Nucl. Part. Phys. 41(2014) 087002

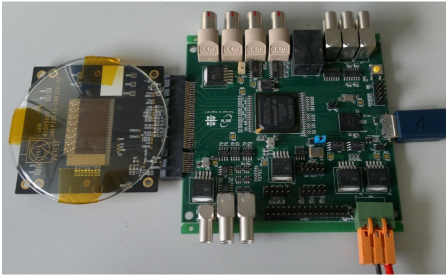
b Jacobus Willem van Hoorne. Study and Development of a novel Silicon Pixel Detector for the Upgrade of the ALICE Inner Tracking System. PhD thesis. CERN-THESIS-2015-255, 2015.

The ALice PIxel DEtector (ALPIDE).

Parameter	Inner Barrel	Outer Barrel	ALPIDE performance
Silicon thickness	50 μm	100 μm	✓
Spatial resolution	5 μm	10 μm	$\sim$5 μm (both IB and OB)
Chip dimension	15 mm $\times$ 30mm		✓
Power density	<300 mW/cm^2	<100 mW/cm^2	<40 mW/cm^2(IB) <40 mW/cm^2(OB)
Event-time resolution	<30 μs		$\sim$2 μs
Detection efficiency	>99%		✓
Fake Hit Rate	10^{-6} hits/(pixel · event)		<10^{-10} hits/(pixel · event)
TID radiation hardness*	700 krad	100krad	tested at 500 krad
NIEL radiation hardness**	10^{13} (1 MeV n$_{eq}$/cm^2)	3·10^{12} (1 MeV n$_{eq}$/cm^2)	✓

*TID – Total Ionizing Dose (with safety factor 10)
**NIEL – Non Ionizing Energy Losses (with safety factor 10)

Single detector setup



Detectors and carriers for the SPbU were provided by the ALICE collaboration.

Saint-Petersburg laboratory is equipped with setups for the detector characterization tests, temperature measurements and for the work in telescopic mode.

Detector characterisation tests include:

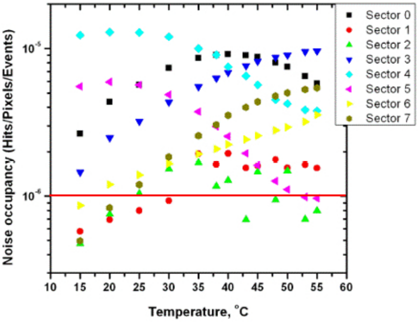
- DAC tests;
- Analogue/digital tests;
- Threshold tests;
- Noise tests;
- Tests with radioactive sources;
- Temperature tests;
- Beam tests

Tests were carried out with four generations of ALPIDE sensors in order to rich the best performance and to find the optimal regime of work.

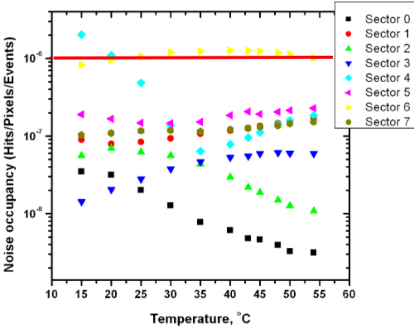
Noise occupancy tests

Figures represent temperature dependences of fake hit rate on temperature for the pALPIDEfs-3 (third generation) sample for Vbb = 0 V and Vbb = -3 V.

NB: sector 5 has stable behaviour!



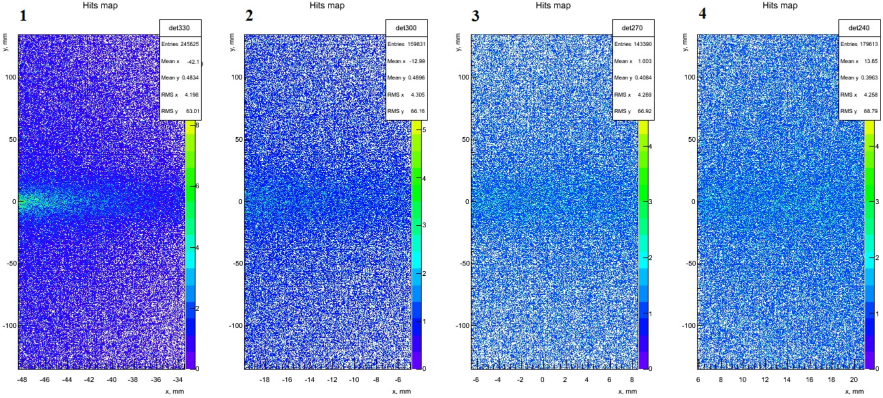
Vbb = 0V



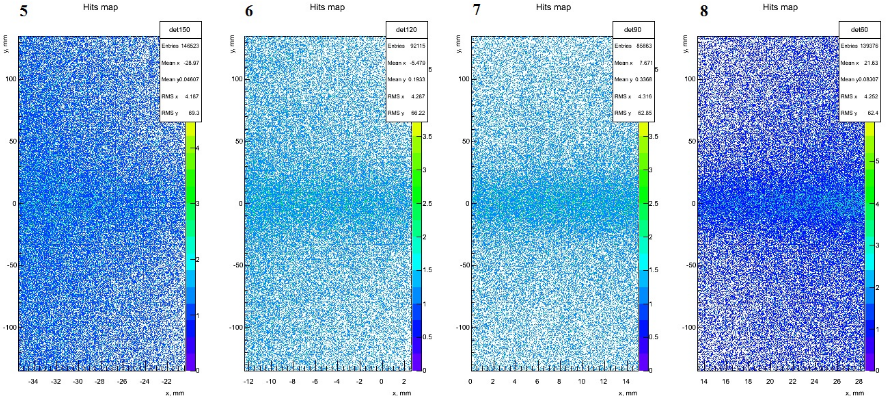
Vbb = -3V

Particle tracking

Geant4 simulation of the first layer pixels response for the reaction p+Pb for 10^6 protons in a collision at 400 GeV/c.
Target thickness 1mm. Magnetic field 1.25 Tl.

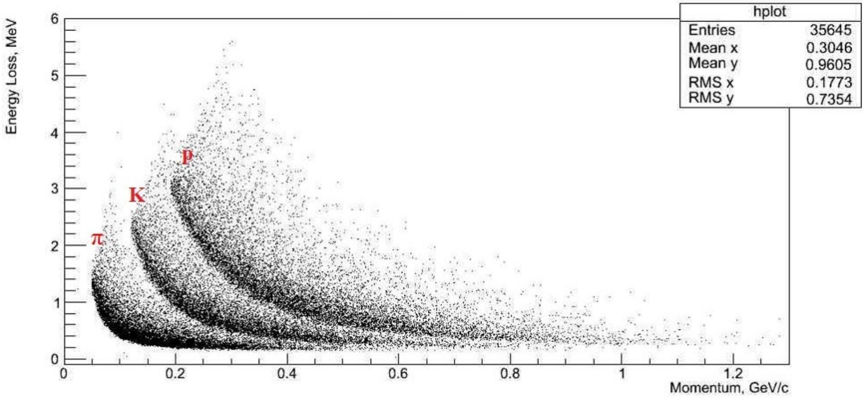


Particle tracking



Particle identification at low momenta

Geant4 simulation of energy losses at the four layers of 150 μm doublesided silicon strip detectors the reaction p+Pb for 10^6 protons in a collision at 400 GeV/c.
Target thickness 1mm. Magnetic field 1.25 Tl.



Conclusions

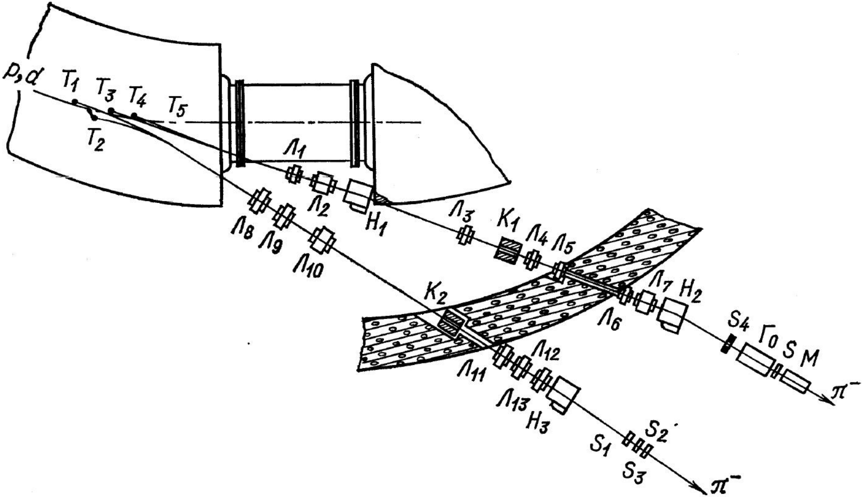
- Experimental studying of cumulative effect can be an instrument for understanding the characteristics of strongly interacting matter
- Compact detector system, proposed in this report, can be used in modern fixed target experiments (NA61/SHINE (SPS, CERN), BM@N (NICA, Dubna), etc.)
- Preliminary results show good expectation for the proposed detector performance

The author of this report from the SPbU acknowledges the support by the Russian Science Foundation research grant 16-12-10176

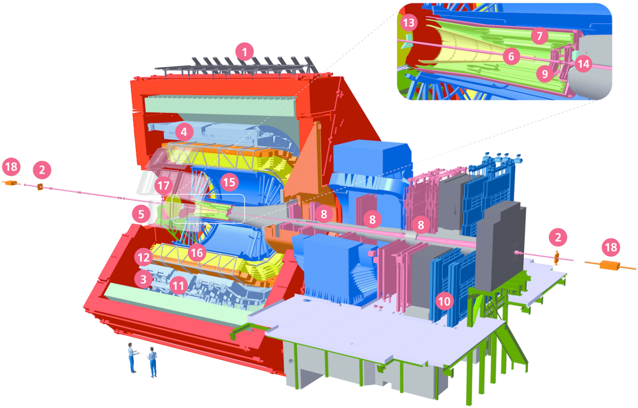
Thank you for your attention!

Back-up slides

The experiment of Baldin and Stavinsky

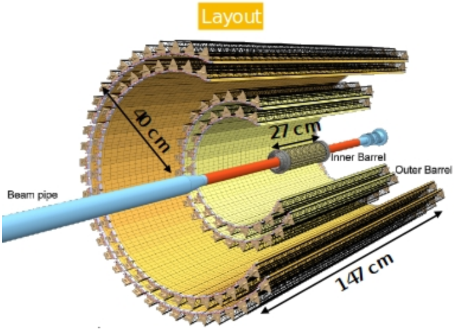


The ALICE experiment

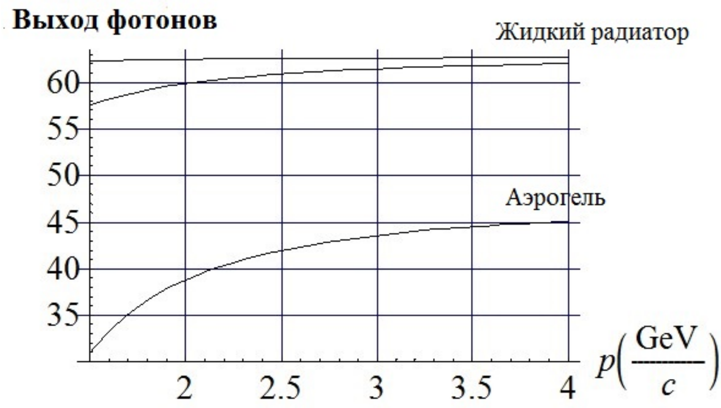


1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter

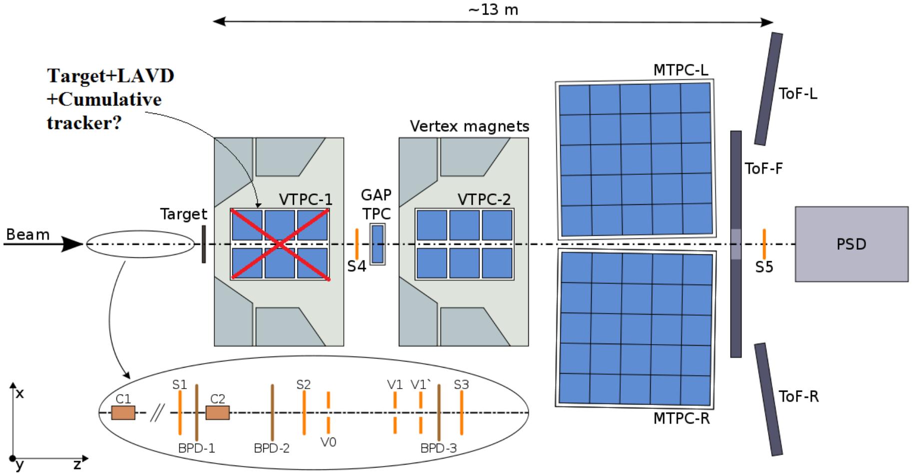
ALICE Inner Tracking System



Photon yield at RICH



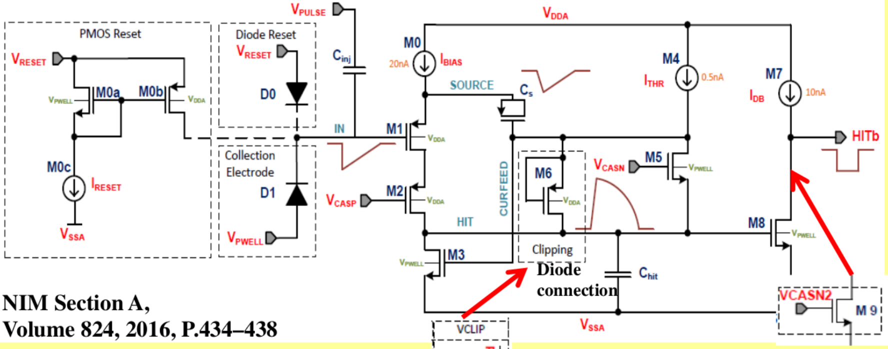
NA61/SHINE


~13 m
Target+LAVD
+Cumulative
tracker?
MTPC-L
ToF-L
Vertex magnets
ToF-F
VTPC-1
GAP
TPC
VTPC-2
Target
Beam
S4
PSD
S5
x
C1
S1
C2
S2
V1
V1`
S3
BPD-1
BPD-2
V0
BPD-3
y
z
MTPC-R
ToF-R

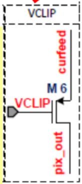
Full-scale Pixel Detector prototypes (pALPIDE -1,2,3)

A comprehensive scheme for the pixel front-end circuit Including all possible variations

For pALPIDE-1,2



NIM Section A,
Volume 824, 2016, P.434–438



For pALPIDE-3
for sectors: 3,4,5,7
add VCLIP

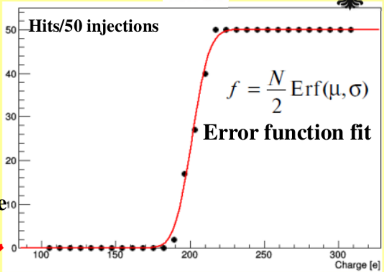
For pALPIDE-3
for sectors: 0,3,4,5,7
add VCASN-2 (M9)

Study of the characteristics of full-scale Pixel Detector prototypes

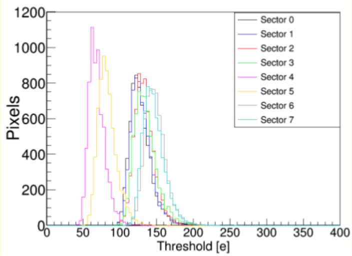
Threshold Scan

The operational thresholds for a certain set of detector's pixels depending on the charge delivered to the chosen pixels was determined

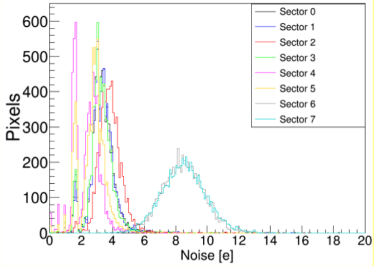
In order to extract threshold a number of charge injections with different amplitude are performed (50 points with 50 injections per point). A probability distribution of fired pixels measuring a pixel response (S-curve) has been obtained.



N - number of injections, μ - threshold value
σ- temporal noise value (threshold dispersion)



Pixel threshold distribution for 8 sectors



Temporal noise values for the pixels for 8 sectors