Physics motivation and development of the Projectile Spectator Detector (PSD) for the CPOD program of NA61/SHINE experiment at the CERN SPS

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I Introduction to PSD

II Motivations for PSD use in NA61

III Design and readout

IV Beam test of PSD prototype

V Summary

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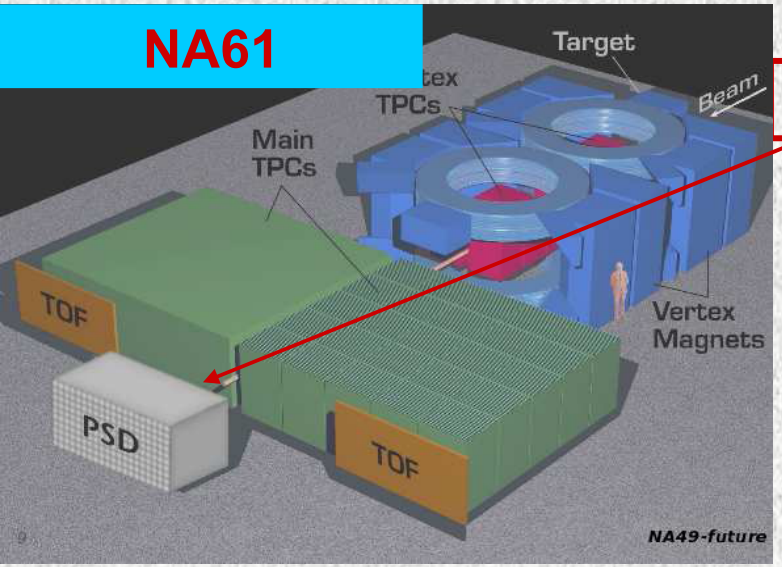
PSD in NA61 setup.



PSD

Very Forward Hadron Calorimeter for detection of projectile spectators

(Projectile Spectators are non-interacting nucleons in beam ions.)

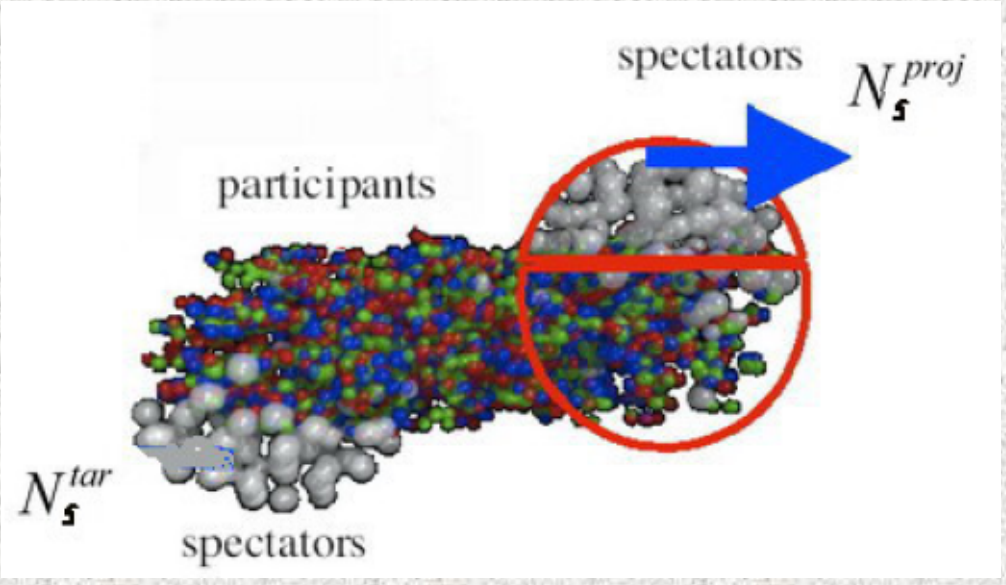
Experimental tasks:

1. Measurement of centrality;
2. Measurement of participant number fluctuations;
3. Reconstruction of the reaction plane.

1. Measurement of centrality

Impact parameter:

$b \sim N_p$, N_p is number of interacting (participant) nucleons.

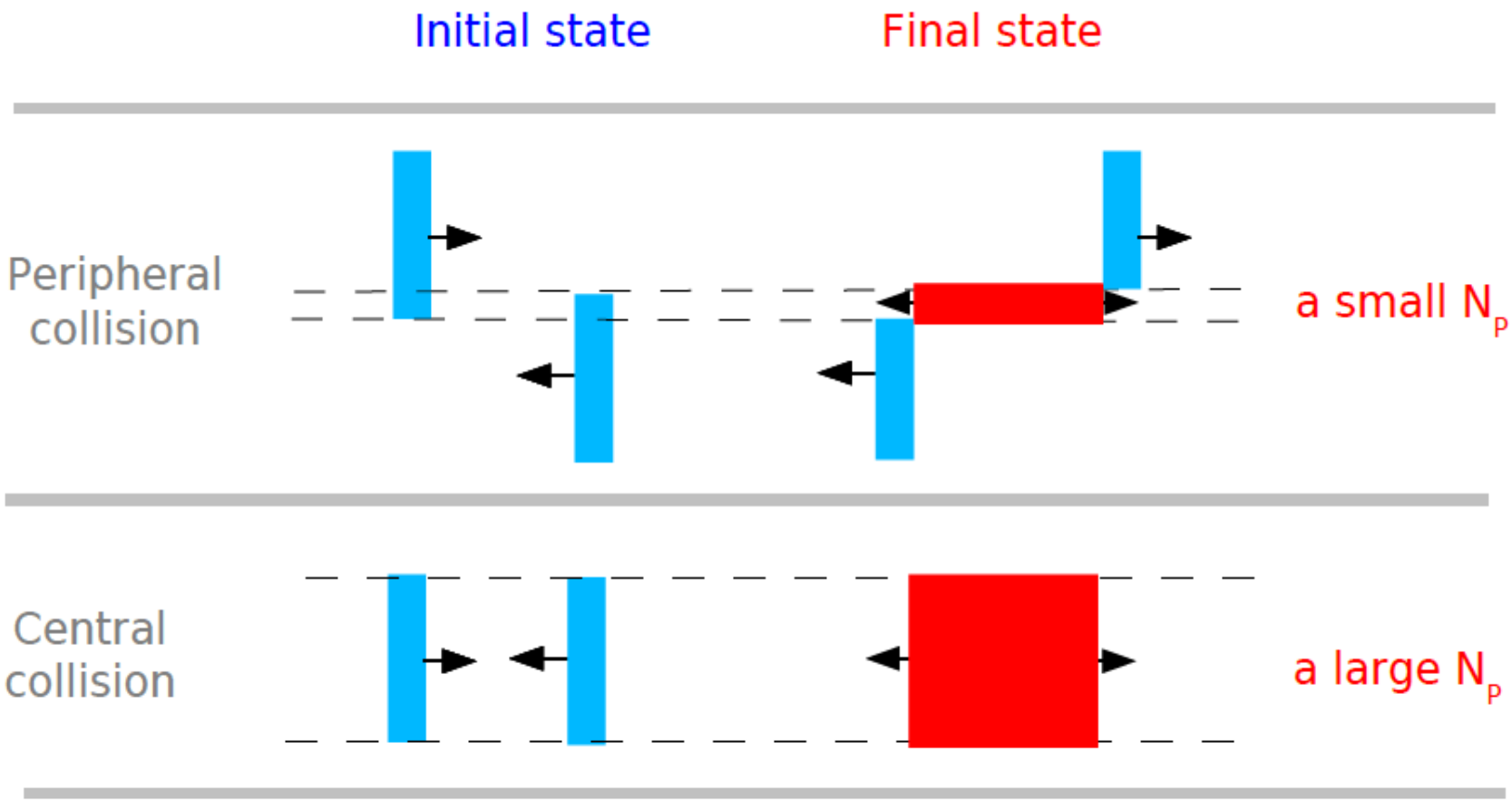


Experimental method:

$N_p = A - N_{spect} = A - E_{meas}/E_{beam}$,

E_{meas} is measured by hadron calorimeter the summary energies of detected spectators

2. Participant number fluctuation



Fluctuations in the collision geometry lead to a large fluctuations in the number participants and are a dominant source of fluctuations

2.Event-by-event fluctuations

Total multiplicity : $N = \sum_{i=1}^{Ns} m_i$ N_s- number of sources,

m_i- multiplicity from a single source.

$$< N > = < N_s > \cdot < m >$$

Physics! QGP?

Geometry of collision

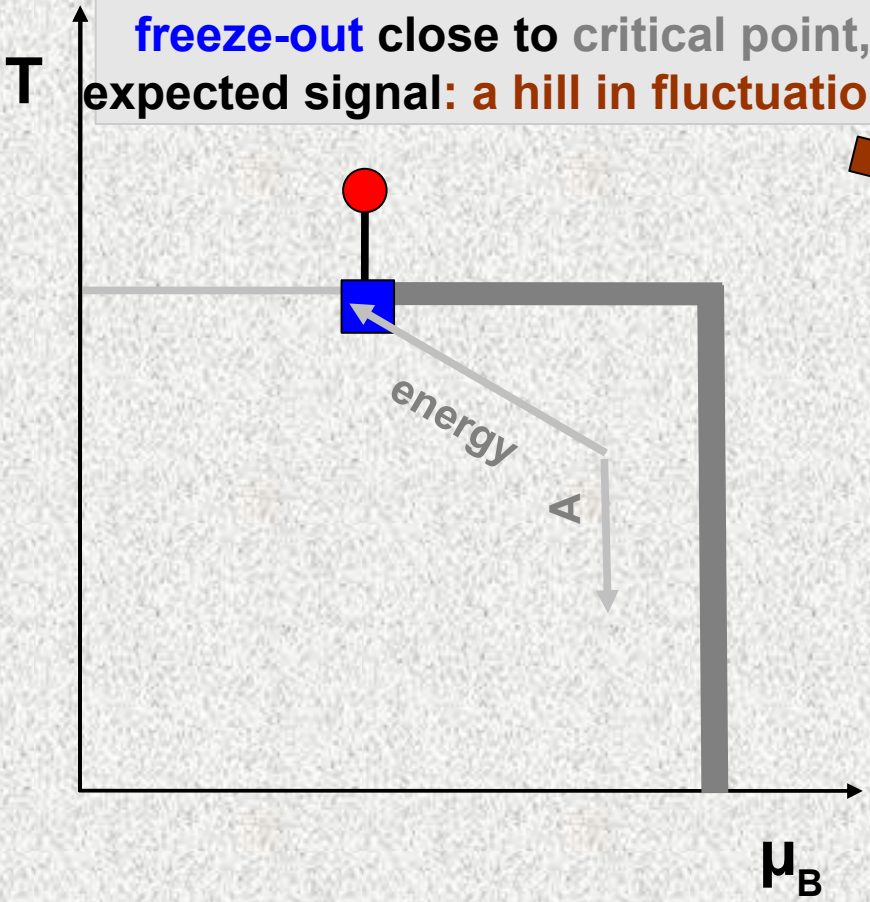
$$\frac{\sigma^2_N}{< N >} = \frac{\sigma^2_m}{< m >} + < m > \frac{\sigma^2_{N_s}}{< N_s >}$$

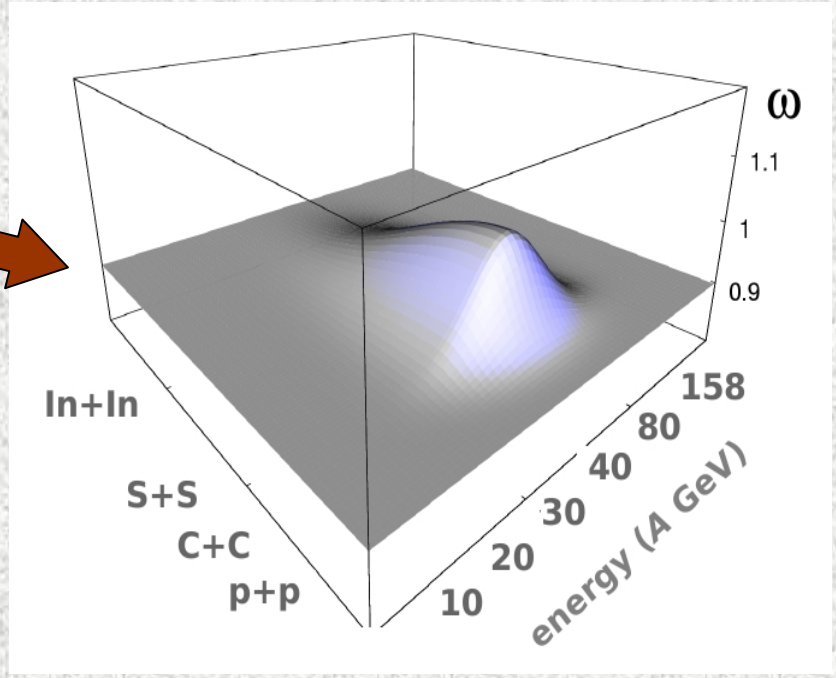
Second component is not interesting and must <u>be fixed</u>

Number of interacting nucleons must be known!

2. Study of dynamical fluctuations.

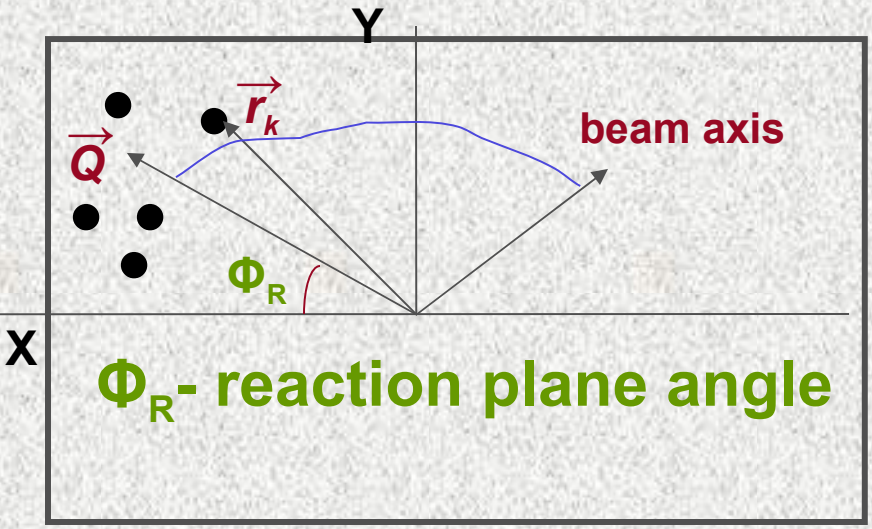
Critical Point:
freeze-out close to critical point,
expected signal: a hill in fluctuations





PSD is the critical tool for search of critical point.
The number of projectile spectators has to be measured by PSD!

3. Reaction plane reconstruction



Reaction plane angle Φ_R is determined by the beam direction and the vector Q:

$$\vec{Q} = \sum_{k=1}^{n} \frac{\vec{r}_k}{|\vec{r}_k|}$$

$\vec{r}_k$ – position vector of the spectator k in the transverse plane to the beam axis

n – number of spectators in event used for reconstruction

Projectile Spectator Detector (PSD) with high transverse granularity and good position resolution is requested!

Requirements to PSD calorimeter:

- **Good energy resolution and its transverse uniformity;**
- **Gaussian shape of the detector response (no nuclear counter effect, no spurious radiation);**
- **Good transverse segmentation.**

Concept of design:

I. <u>Compensation</u>:

$\varepsilon_e / \varepsilon_h = 1$ -- compensated calorimeter.

$\sigma(E)/E = a/\sqrt{E} + b \cdot |1 - \varepsilon_e / \varepsilon_h|$ -- constant term near to zero.

II. <u>Lead/Scintillator sandwich</u>: Compensation at Pb:Scint=4:1.
For thickness δ_{Pb}=16 mm and δ_{Scint}=4 mm **$\sigma_E/E \sim 50\%/\sqrt{E}$** .

III. <u>Light readout</u> – WLS-fibers to avoid spurious Cherenkov radiation.

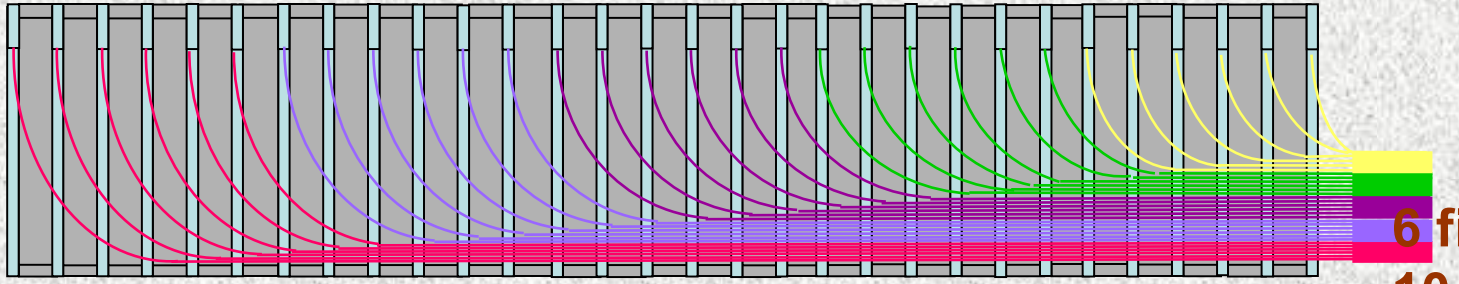
IV. <u>Signal readout</u> – Micropixel APD (MAPD) to avoid nuclear counter effect, detection of a few photons signal, compactness, low cost, new technology.

V. <u>Longitudinal segmentation</u> – for permanent calibration of scintillators in radiation hard conditions, uniformity of light collection from WLS-fibers, rejection of electrons.

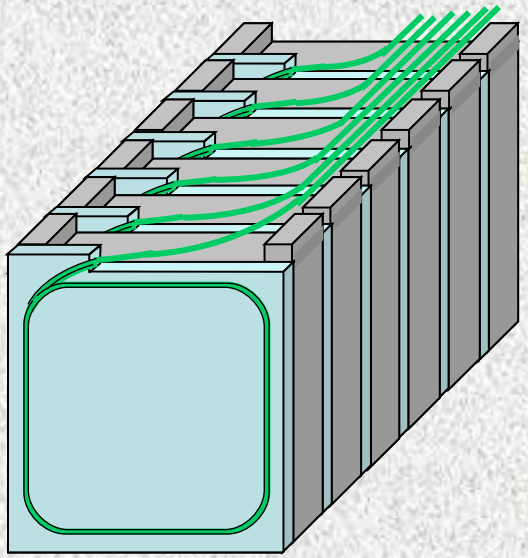
VI. <u>Modular design</u> – transverse uniformity of resolution, flexible geometry, simplicity.

Design of PSD module.

Side view of module.



6 fiber/MAPD
10 MAPDs/module



60 lead/scintillator sandwiches.

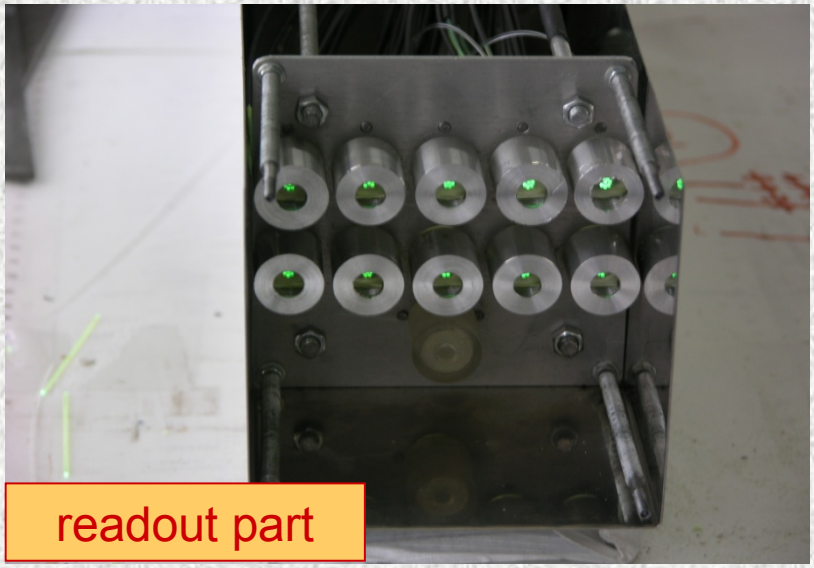
Modular Lead/Scintillator sandwich compensating calorimeter.
Sampling ratio Pb:Scint=4:1.

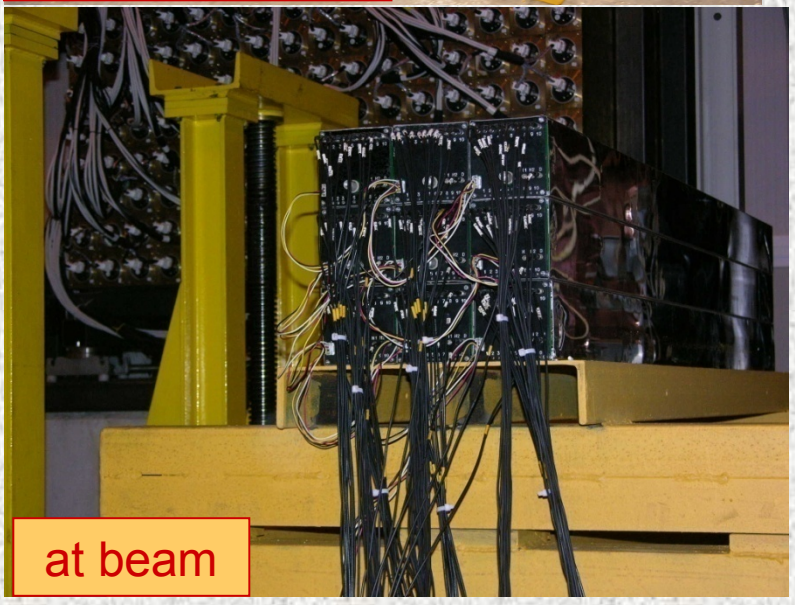
For thickness δ_{Pb}=16 mm and δ_{Scint}=4 mm $\sigma_E/E \sim 50\%/\sqrt{E}$.

Assembling and installation of PSD modules.

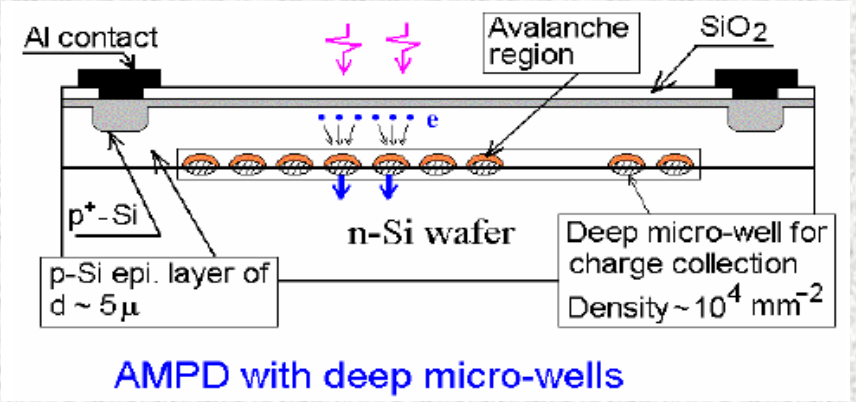

assembling


transportation


readout part


at beam

Light readout with Micro-pixel Avalanche Photodiodes, MAPDs.

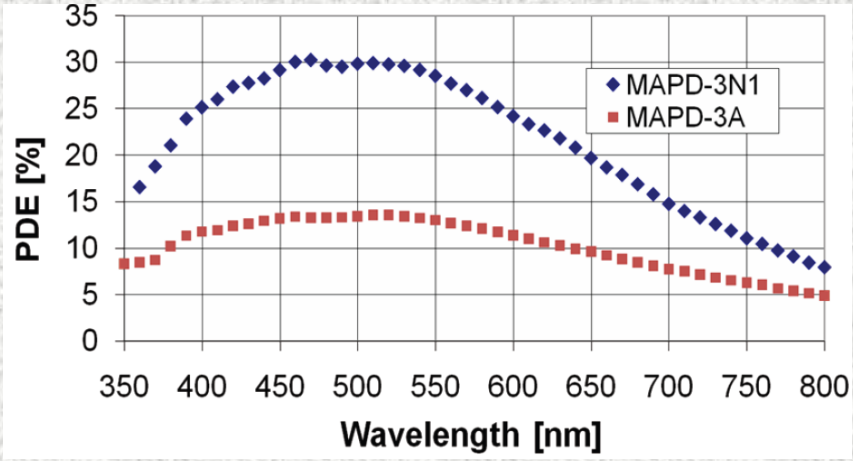


AMPD with deep micro-wells

Type: MAPD-3N.

Size: 3x3 mm^2.

Number of pixels: 1.5x10^4/mm^2.



Photon detection efficiency:~30%.

Gain: 5 x10^4.

Working voltage: ~90V.

Production: Zecotek Co.
Z.Sadygov (Dubna).

Dynamical range of MAPD.

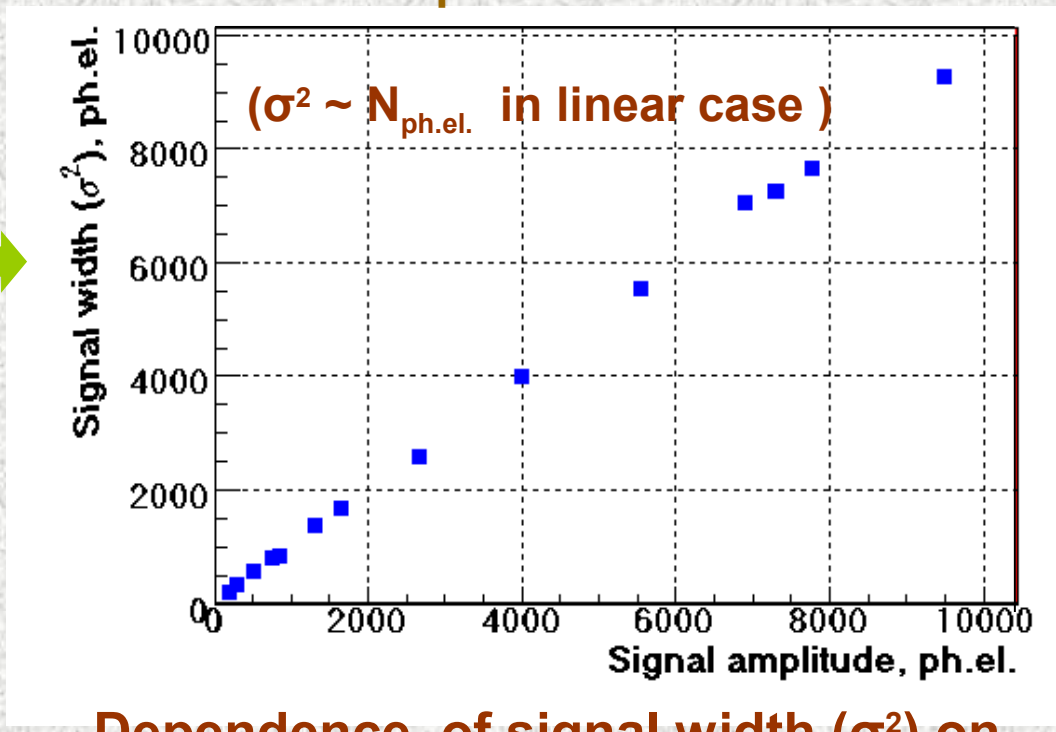
Linearity of response depends on total number of pixels (analytical formula)

$$N_{fired} = N_{total}\left(1 - e^{-\frac{N_{photons} \cdot PDE}{N_{total}}}\right)$$

pixels

3x3 mm² MAPD with pixel density >10⁴/mm² has a linear response.

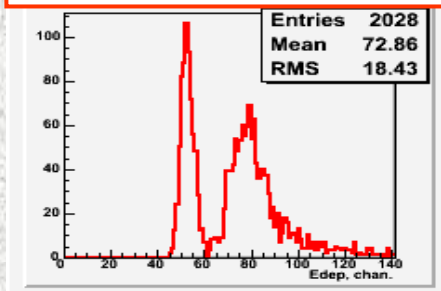
Very fine for calorimetry !

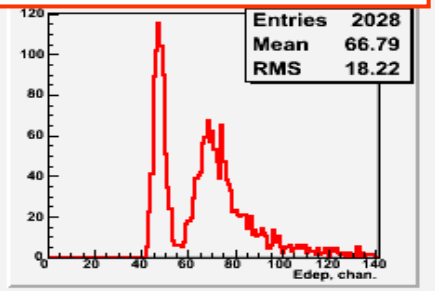


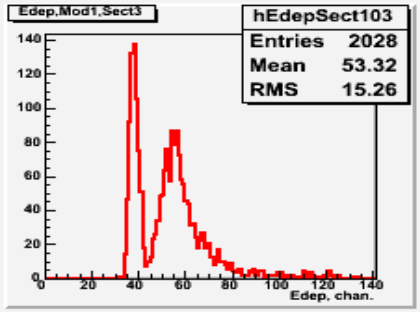
Dependence of signal width (σ²) on signal amplitude $N_{ph.el.}$ in photoelectrons.

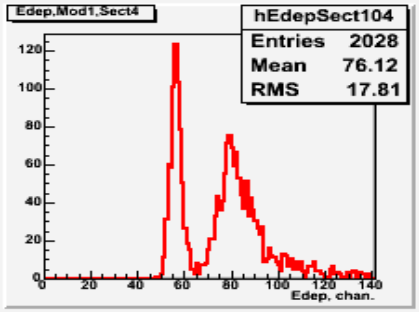
Calibration of longitudinal sections by muon beam

2007 SPS beam - 75 GeV l.y~2ph.e/MeV

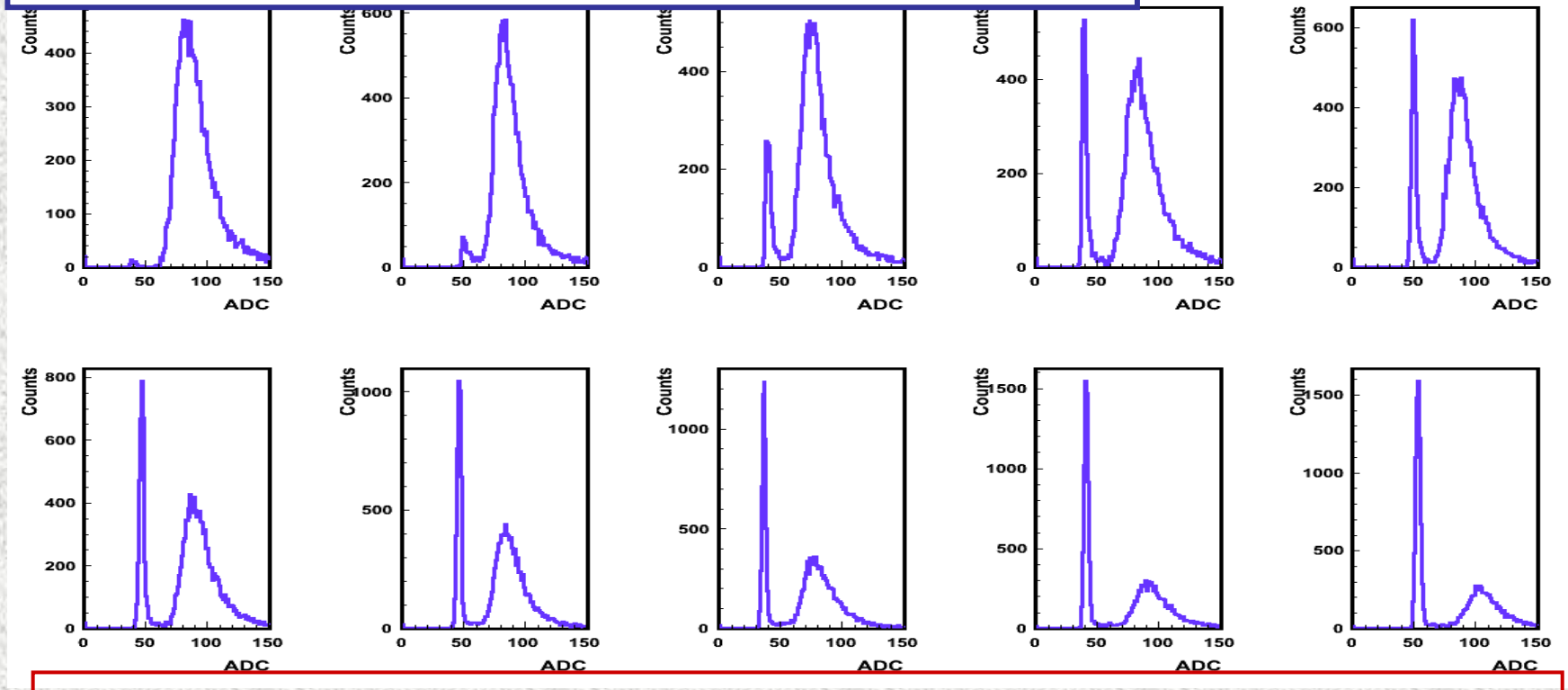








2010 PS-T10 beam E_μ<6 GeV l.y~ 6 ph.e./MeV

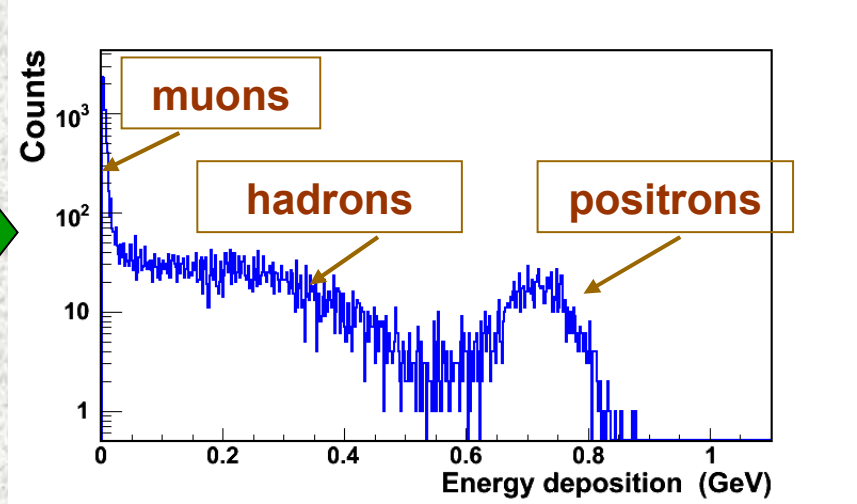


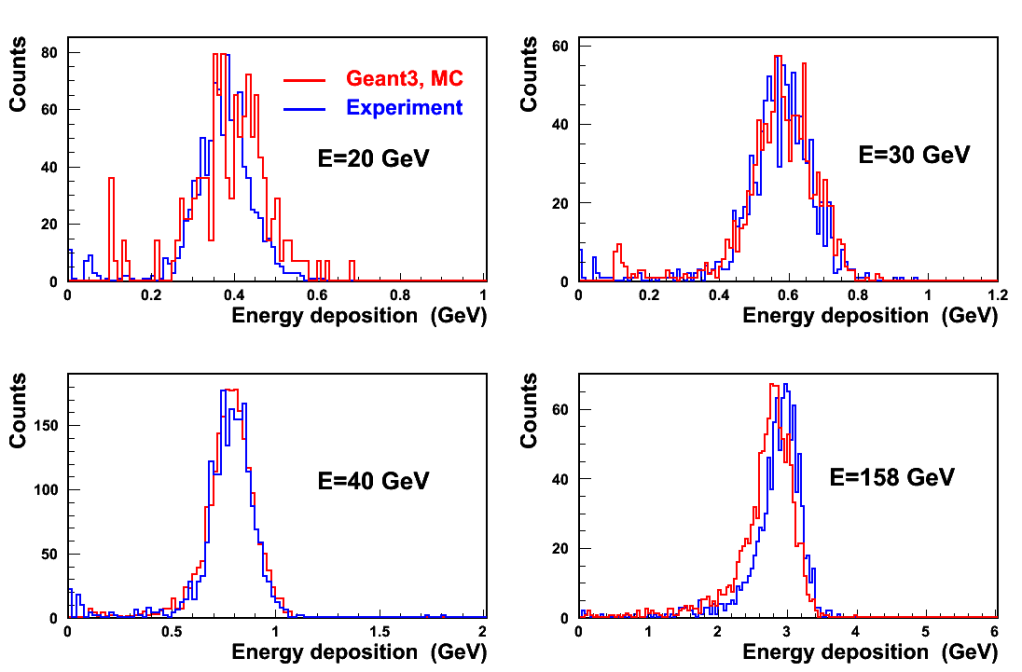
Remarkable improvement of l.y. due to nice PDE of new MAPDs

Performance of PSD calorimeter.

Energy spectrum in first section of module for mixed 30 GeV beam of pions, positrons and muons.

PID and rejection of secondary particles are possible.

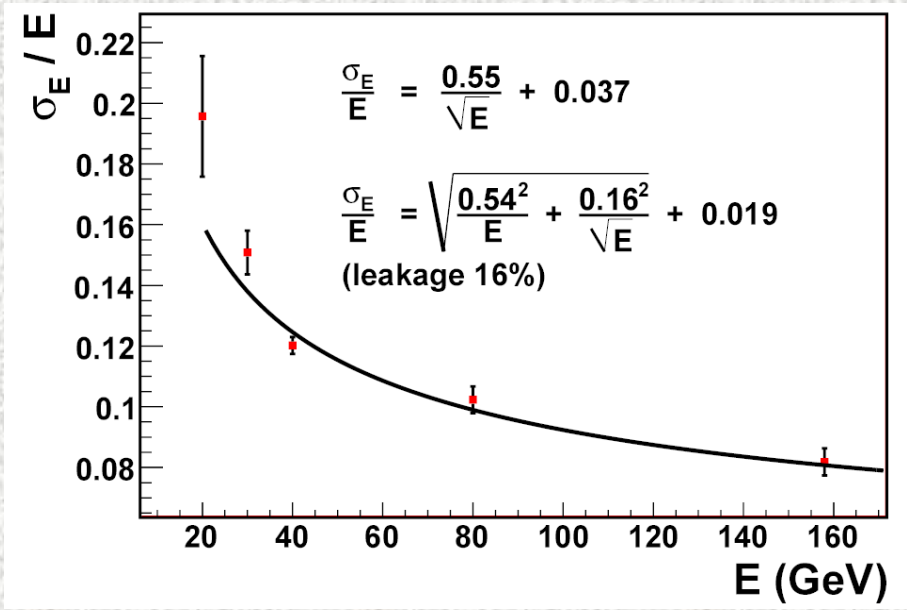




Energy deposition spectra from pions of different energies in PSD prototype: simulation and experiment

Energy resolution at high energies

- The constant term in energy resolution is essential only for energy measurement of single particle.
- It is not very important in case of measurement of total energy from many particles with the same energy.
- The reason is dependence of energy resolution for N spectators as:



$$\frac{\sigma(E)_N}{E_N} = \frac{\sqrt{\Sigma_i \sigma(E)_i^2}}{E_N} = \frac{\sqrt{N}\sigma(E)_1}{NE_1} = \frac{1}{\sqrt{N}} \cdot \frac{\sigma(E)_1}{E_1}$$

Constant term disappears in heavy ions experiments (spectator measurements)!

Correction for the shower leakage improves the resolution as 54% (stochastic term) and 1.9% (constant term).

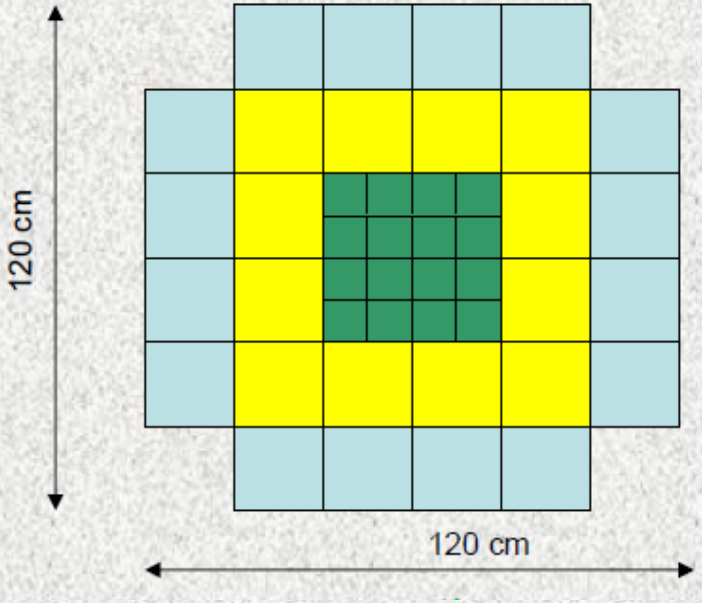
Summary

- PSD calorimeter is new detector element in NA61 experiment and is intended for a few experimental tasks.
- PSD is crucial detector for the search of the critical point.
- The concept and design of PSD calorimeter is well developed now.
- PSD has fine transverse granularity and longitudinal segmentation due to the modular design.
- The readout of PSD modules is done by novel photodetectors, MAPDs with high pixel density.
- 1/3 of PSD modules is installed now at NA61 area. The full construction has to be completed in the nearest months.
- Test of the PSD prototype at beam confirmed the expected performance.

Thank you!

Backup slides

Structure of the PSD



16 modules 100 x 100 mm^2 .
Lead plates – 16 mm
Scint. – 4 mm

12 modules 200 x 200 mm^2 .
Lead plates – 16 mm
Scint. – 4 mm, $L_{int} = 5.7\Lambda_{int}$

16 modules 200 x 200 mm^2 .
4 layers - Al(0.8mm)+Pb(3mm)+Al(0.8mm)
Scint. – 4 mm, $L_{int} = 5.4\Lambda_{int}$

Total weight ~ 17 tons !