Hadron calorimeter with MAPD readout in the NA61/SHINE experiment

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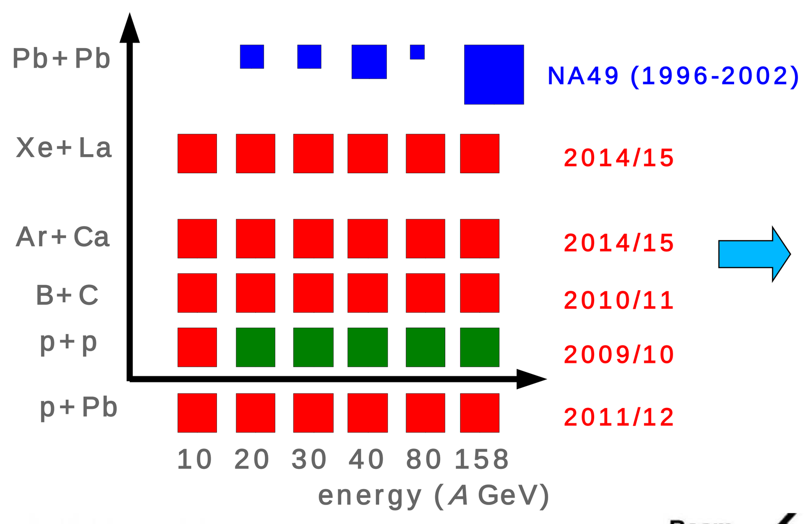
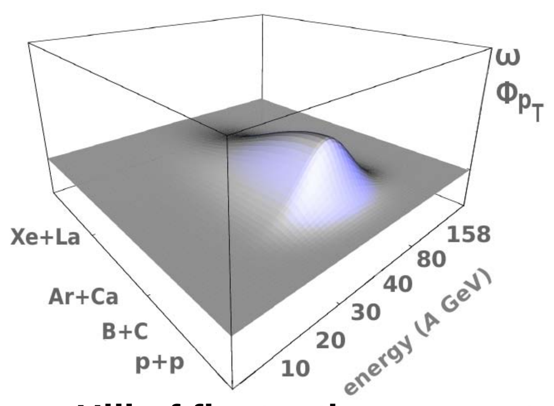
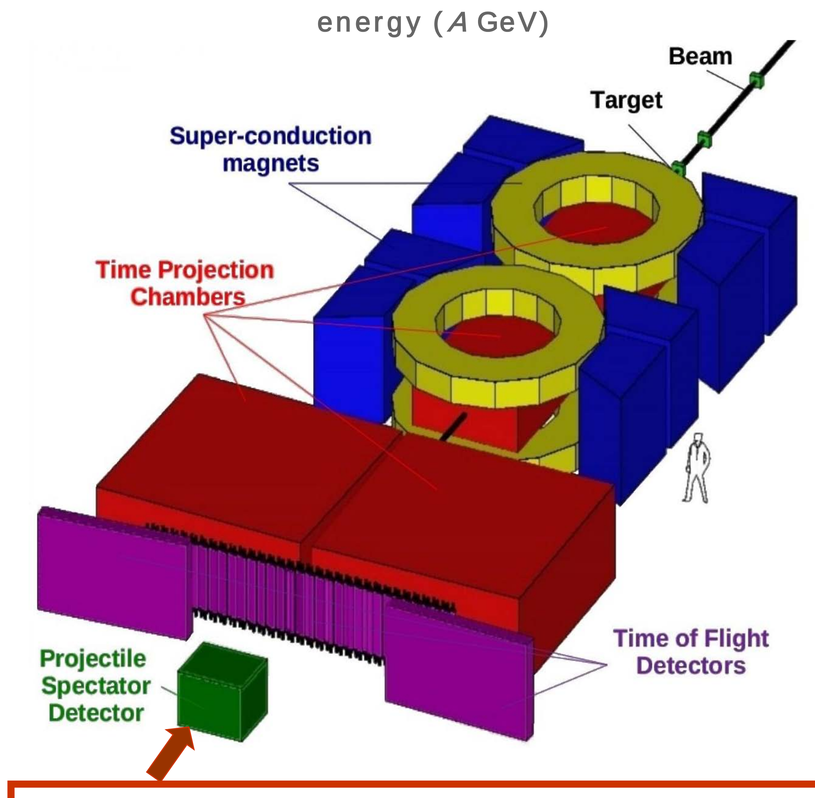
The goal of the NA61/SHINE experiment at CERN is the search for the critical end-point and the onset of deconfinement in ion-ion collisions. A two dimentional scan of the phase diagram of strongly interacting matter will be done by changing the ion beam energy at the SPS (13A – 158A GeV) and the size of the colliding systems. The critical point would be indicated by a maximum in the fluctuation of the particle multiplicity and other physical observables. The onset of deconfinement is revealed by rapid changes in the hadron production properties.

NA61 ion program





Hill of fluctuations expected near the critical point



NA61 experimental setup

Large acceptance ≈ 50%

High momentum resolution $\sigma(p)/p^2 \approx 10^{-4}$ ((GeV/c)$^{-1}$)

Detector efficiency >95%

Event rate ≈ 70 events/sec

PSD is a very forward lead-scintillator hadron calorimeter.

It measures the energy of projectile spectators. This allows to determine the number of projectile nucleons that participate in a collision with a precision of about one nucleon. The requirement energy resolution is better than $80\%/\sqrt{E(\text{GeV})}$

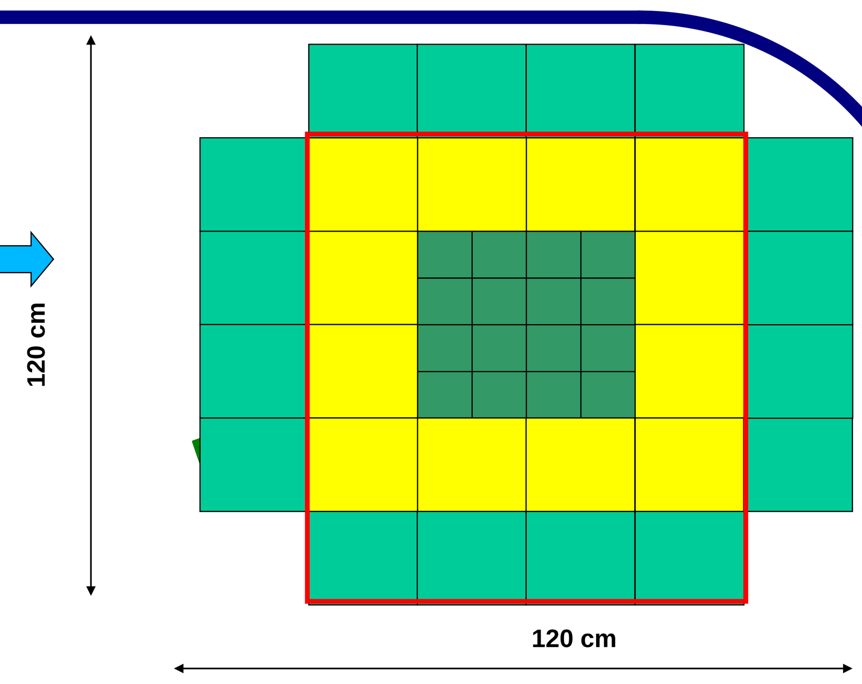
Hadron calorimeter - Projectile Spectator Detector

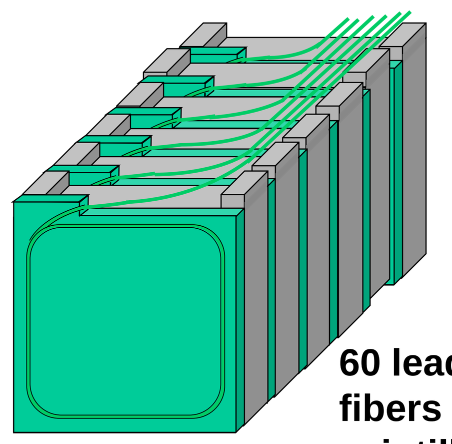
Structure of the PSD:

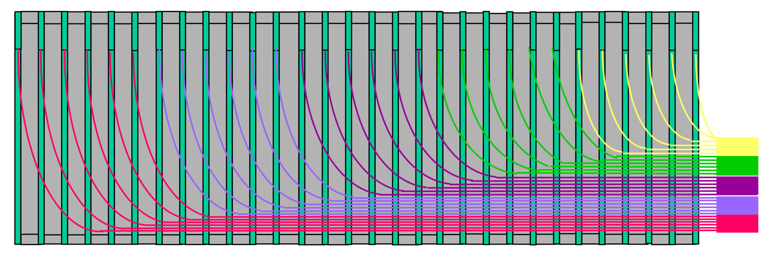
44 individual modules with segmentation into 10 longitudinal sections.

16 central modules – 10x10x125 cm^3
28 outer modules -20x20x125 cm^3

Total weight – 17 tons





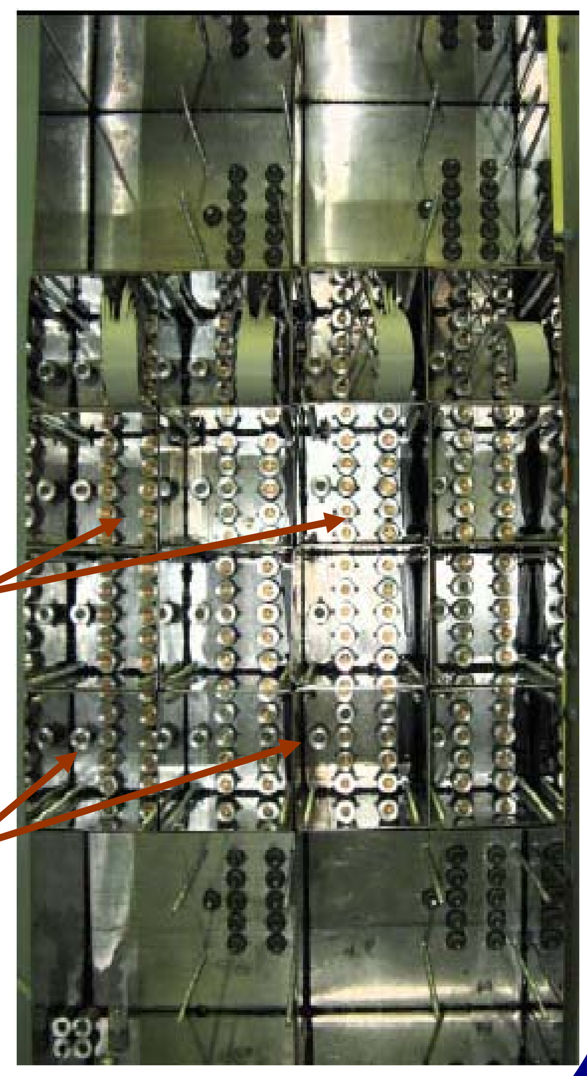


Structure of the module:

60 lead/scintillator sandwiches with WLS-fibers glued in round grooves inside the scintillator.

WLS-fibers of 6 consecutive scintillator plates of each longitudinal section are bundled and readout by 3x3 mm^2 MAPD-3A. 10 longitudinal sections in one module are readout by 10 individual MAPDs.

Photo of rear side of hadron calorimeter during the MAPD installation



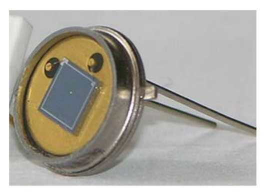
10 MAPDs in each module

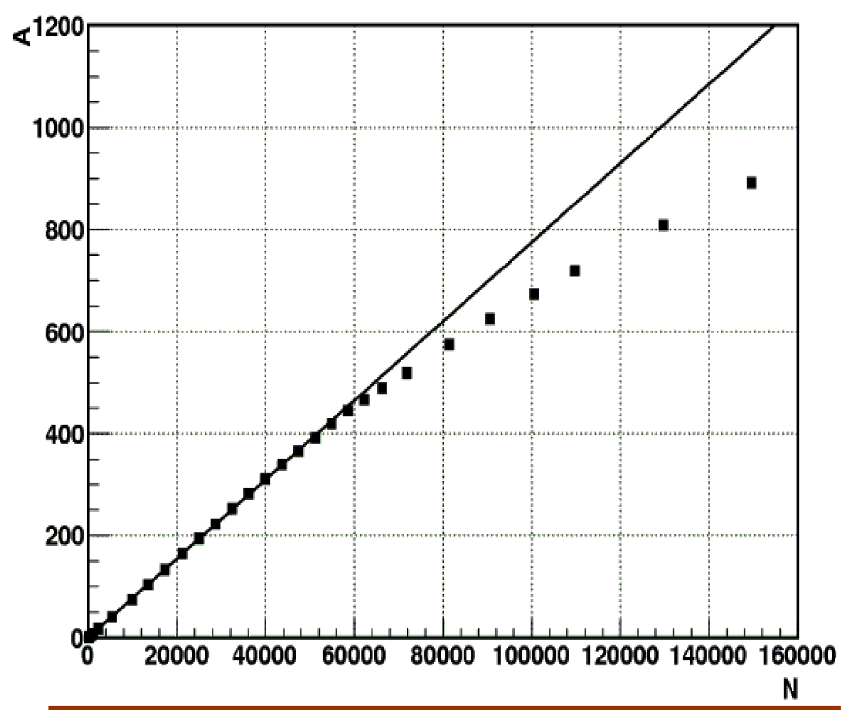
Light emitting diode for the monitoring system

Front view of hadron calorimeter.

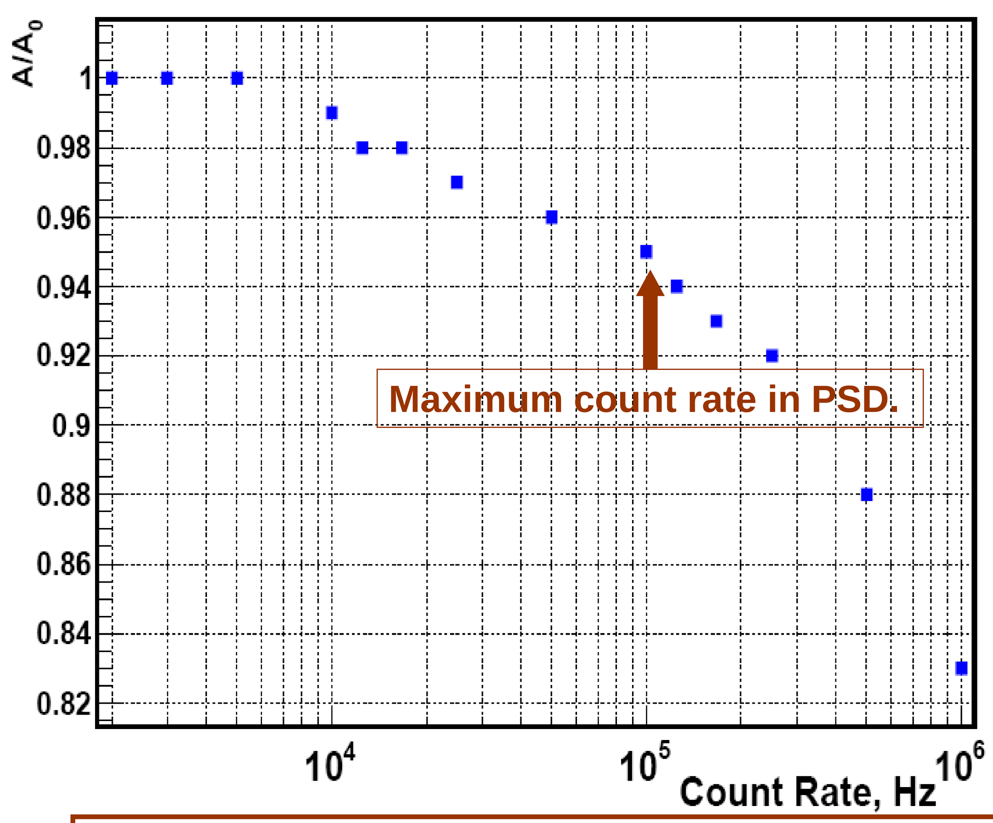
Properties of MAPD-3A photodiodes

The photodetectors in hadron calorimeter must meet a few requirements: linearity of response for signals up to 10^4 photoelectrons, count rate capability up to 10^5 Hz, photon detection efficiency comparable with traditional PMTs, ability to detect signals of a few photons, compactness and reliable long-term operation. The advantages of micropixel avalanche photodiodes (type MAPD-3A) produced by Zecotek Photonics Inc. satisfy the above requirements. They have a pixel density of 10^4/mm^2 due to the specific micro-well structure. The total number of ~10^5 pixels for 3x3 mm^2 active area ensure unique linearity of MAPD response for intensive light pulses. Low dark-noise current ~100 nA and gain ~5x10^4 allow the detection of the signals of a few photoelectrons. Long-term stability tests showed reliable MAPD-3A operation with intense (~10^4 photoelectrons) signals.

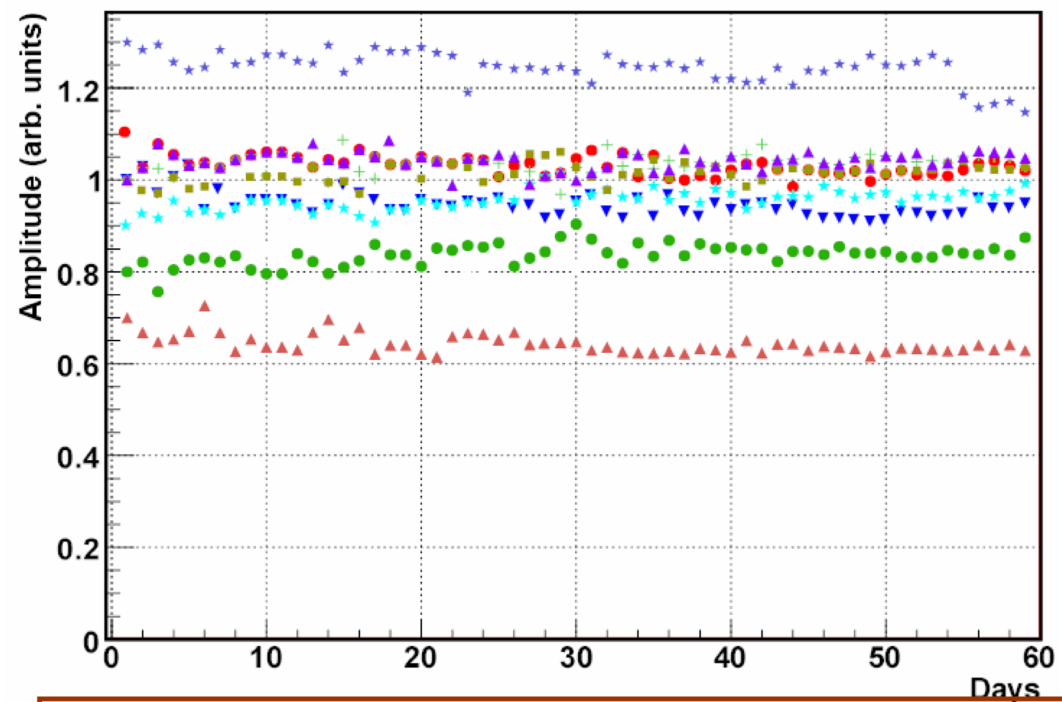




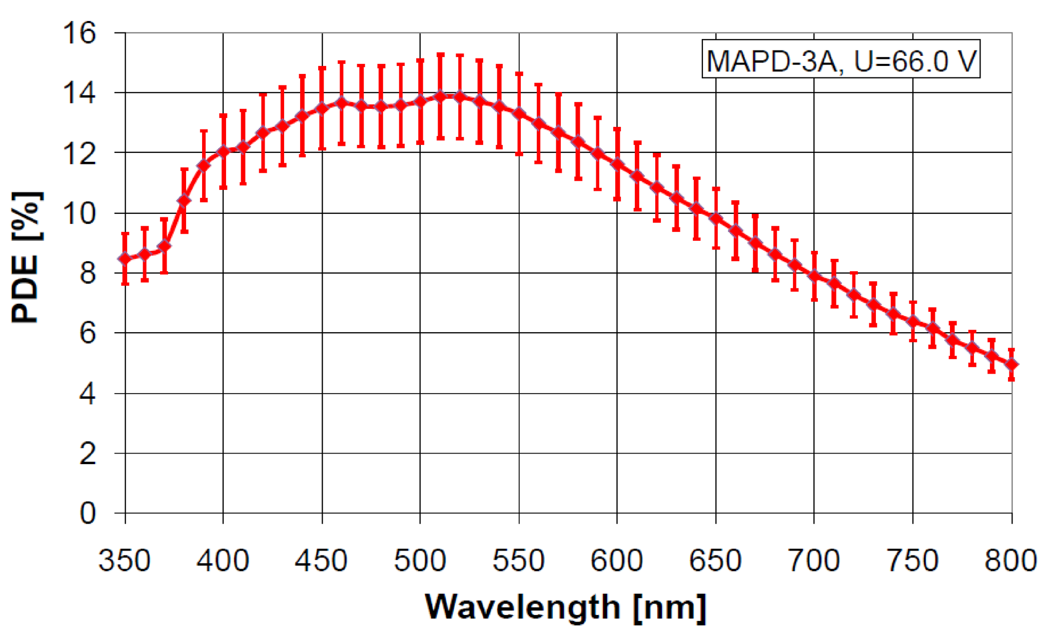
Dependence of MAPD amplitude on the number of falling photons.



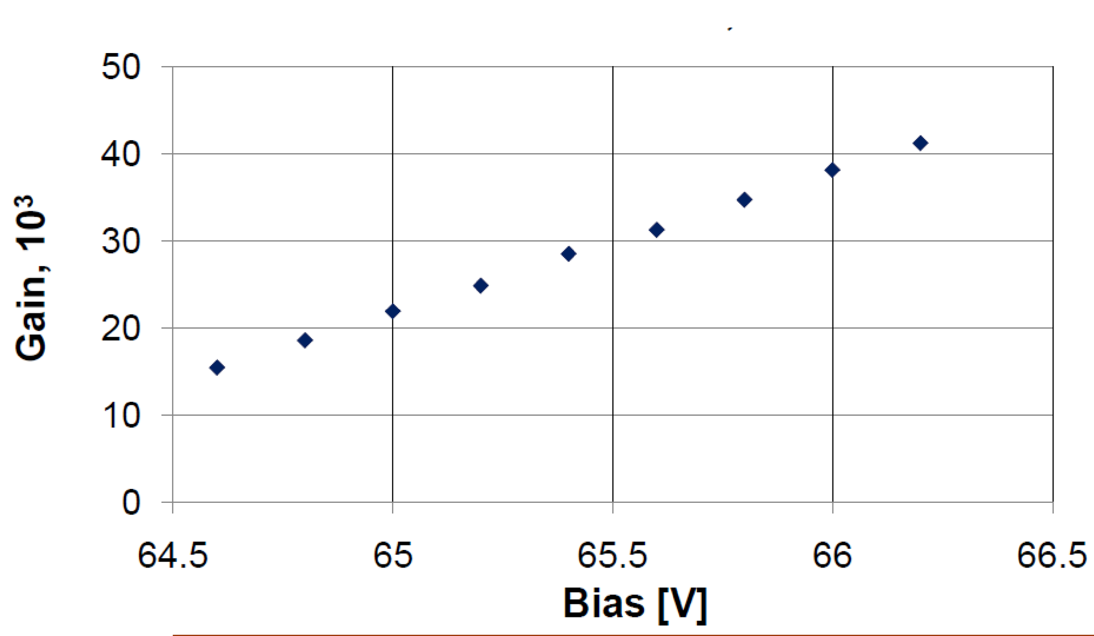
Relative change of MAPD-3A amplitude with the frequency of ~1500 ph.e. signal.



Long-term test: 10 MAPDs were illuminated by LED pulses with f=1 MHz and amplitude ~10^4 ph.e at T~30 ^{0}C during 2 months. No changes in gain and dark current were observed.

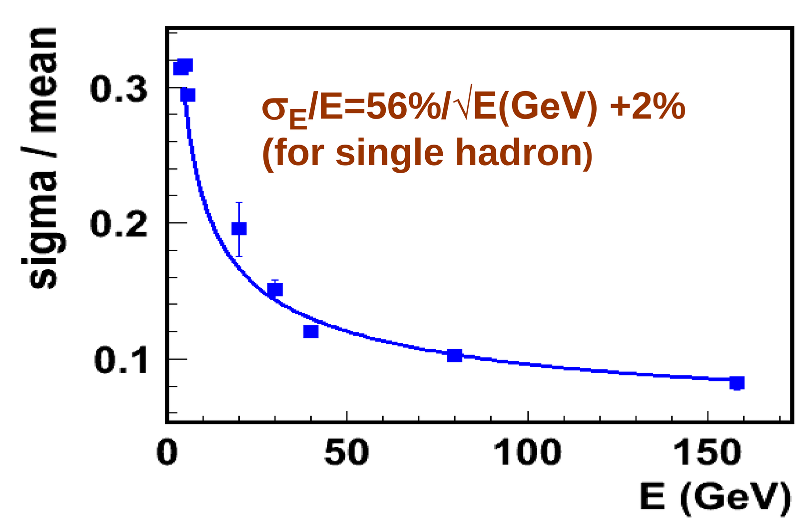


Spectral response of MAPD-3A: dependence of PDE on the wavelength of the light.



Dependence of MAPD-3A gain on the bias voltage.

The performance of the calorimeter supermodule was tested at pion beam of low energies (2-5 GeV) and SPS energies (20-158 GeV). The obtained energy resolution, shown below, is in a good agreement with the MC simulations.



PSD supermodule energy resolution