Use of Micropixel APDs for NA61/CBM Calorimetrers and CBM TOF-Wall

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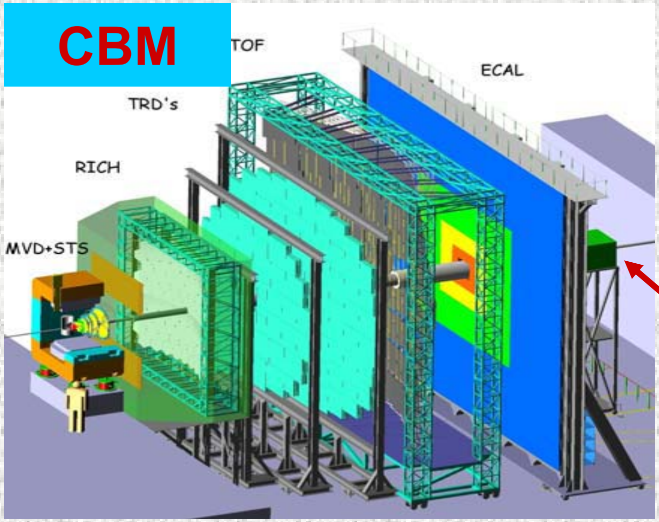
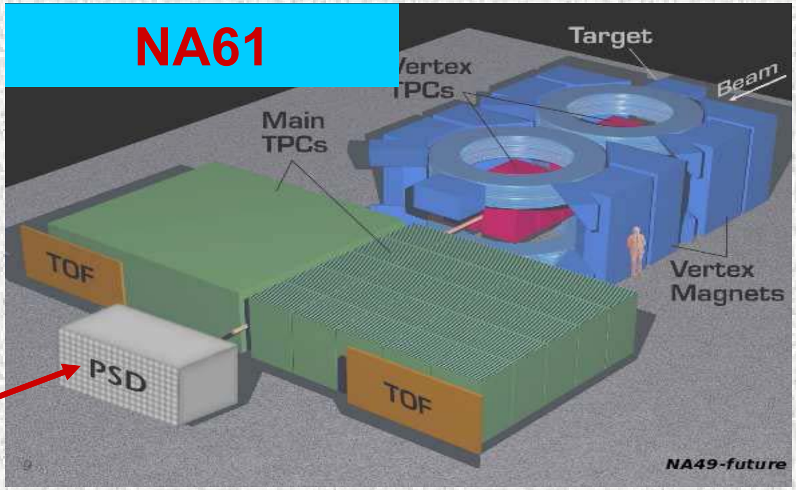
I. Hadron calorimeters for CBM/NA61 experiments.

1. Structure of calorimeter.
2. Readout with micropixel APDs.
3. Properties of MAPDs.
3. Calorimeter performance.

II. MAPD application for granulated TOF-wall.

Hadron calorimeters for
CBM (Darmstadt) and NA61 (CERN)

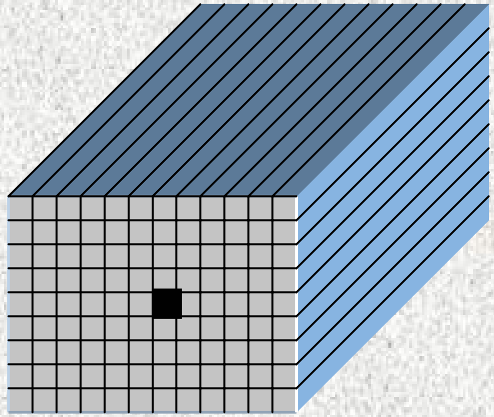




Very forward calorimeter

Main features of the calorimeters:

-high granularity: array of ~100 individual modules
transverse homogeneity of response and energy resolution,



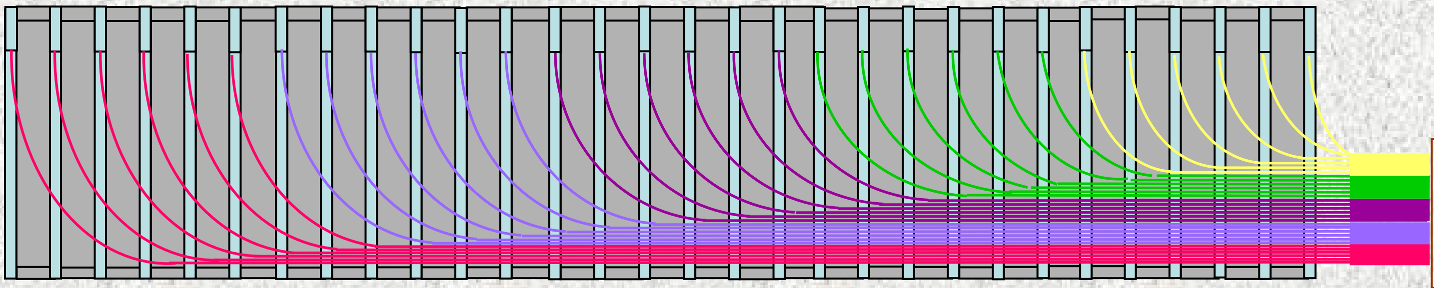
-compensated calorimeter (e/h = 1), lead/scintillator sampling ratio 4:1
high energy resolution ~55%/sqrt(E)

- longitudinal segmentation (10 sections per module)
  particle identification, calibration, improve energy resolution

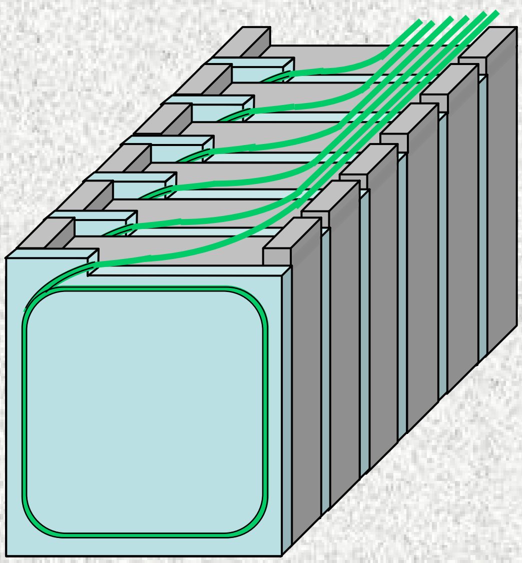
- light readout from each sections
  compactness of photodetectors,
  no nuclear counting effect

Are micropixel APDs ideal solution?

Structure of calorimeter module



MAPDs and amplifiers.



- 60 lead/scintillator sandwiches
- 10 longitudinal sections
- 6 WLS-fiber/MAPD
- 10 MAPDs/module
- 10 Amplifiers/module

Why micropixel APDs in calorimeter?

Requirements to photodetectors for NA61/CBM hadron calorimeters.

1. Compactness (10 photodetectors at area 10x10 cm^2).
2. Small active area (<10 mm^2).
3. No nuclear counter effect. (!)
4. Detection of low (~10 ph.e.) signal for the calibration of the individual sections with the muons.
5. Dynamical range up to 10^4 ph.el. – determined by the energy deposition of heavy ions.
6. Radiation hardness to neutrons (~10^{13} n/cm^2 for CBM).
7. Reasonable price.

Geiger-mode APDs are ideal choice. But…:

MAPDs have non-trivial response:

Linearity depends on number of pixels

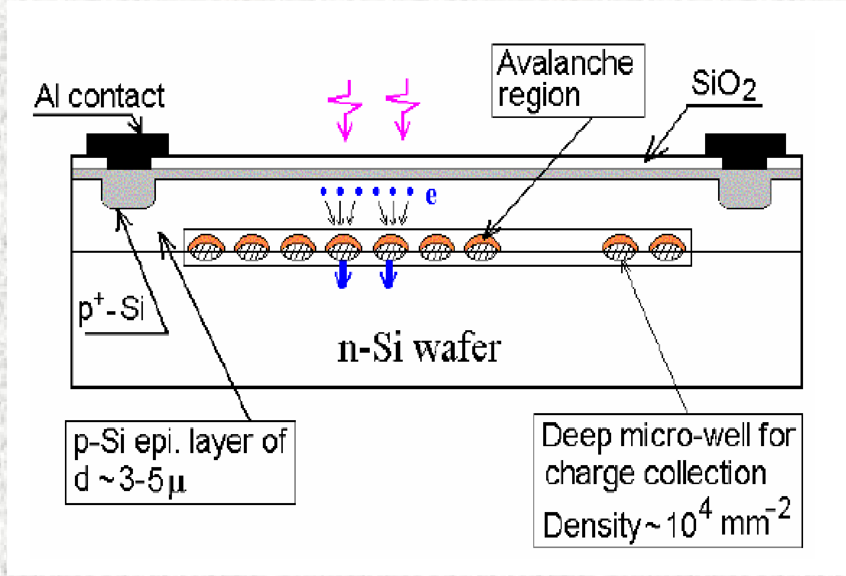
$$N_{fired} = N_{total}(1 - e^{\frac{-N_{photons}PDE}{N_{total}}})$$

pixels

analytical formula

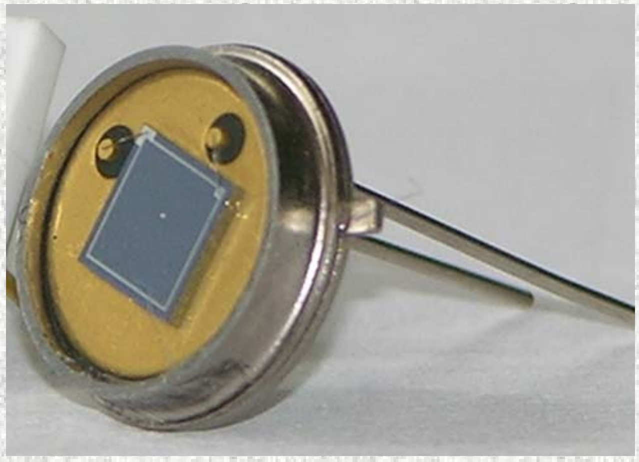
One needs multipixel APDs with the cell density > $10^4/mm^2$!!!

Fortunately, there is one type of Geiger mode APD with the requested pixel density. MAPDs with individual micro-wells.

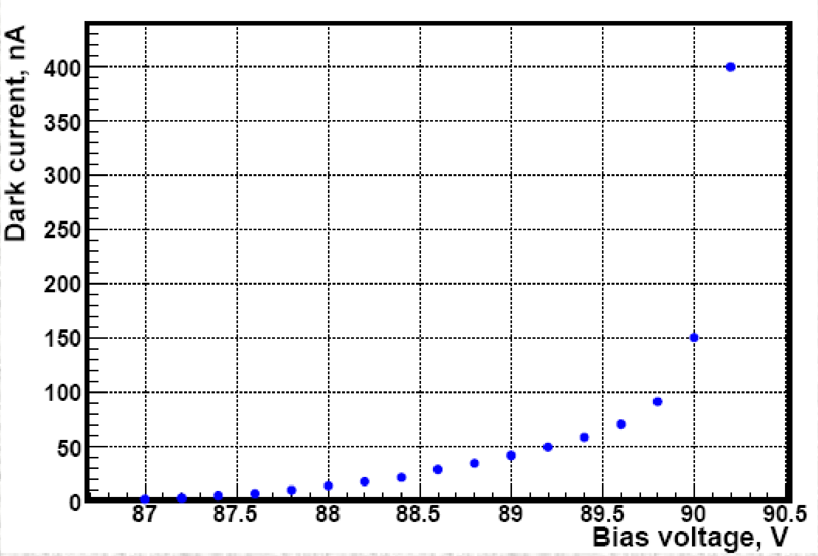


These MAPDs are developed by Prof. Sadygov.
Now they are produced by Zecotek Co. (Singapore).

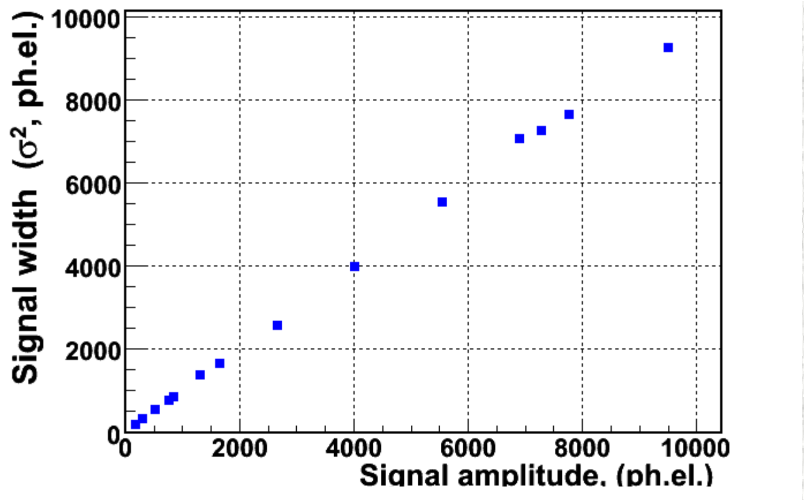
Properties of MAPDs produced by Zecotek Co.



- -Active area: 3x3 mm^2
- - Number of pixel: 15000/mm^2 (up to 40000/mm^2)
- - Gain ~ 10^5
- -Voltage ~ 90 V
- - Dark current < 50 nA
- -PDE ~ 30% for blue-green light
- -Single electron noise ~ 0.3 MHz/mm^2
- - Rise Time ~ 4 ns



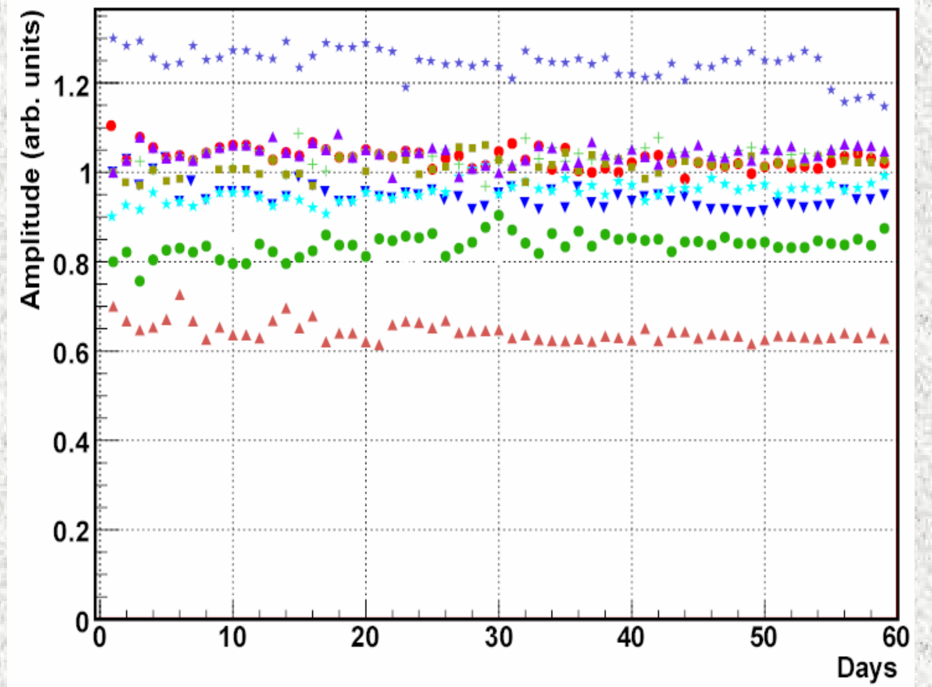
Response to LED signal.
Linearity is preserved up to 10^4 ph.e.



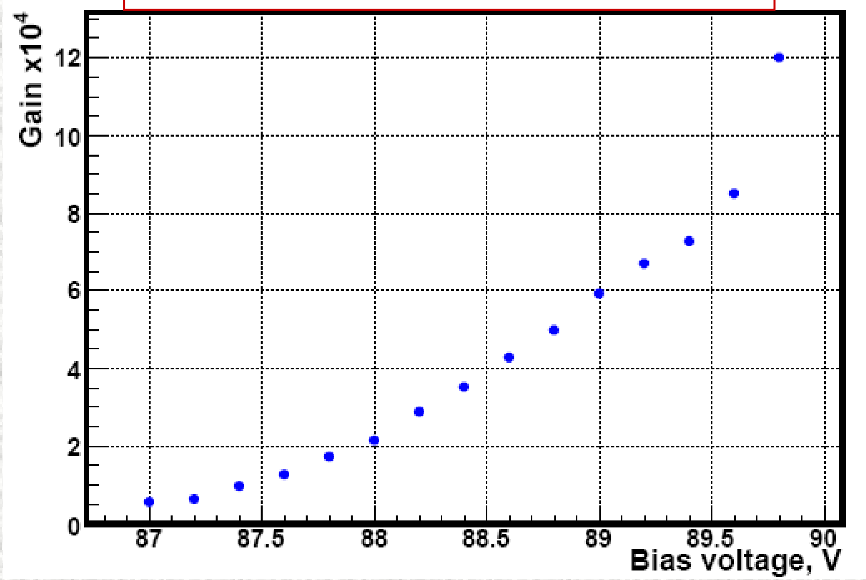
($\sigma^2 \sim N_{ph.el.}$ in linear case)

Stability of MAPDs

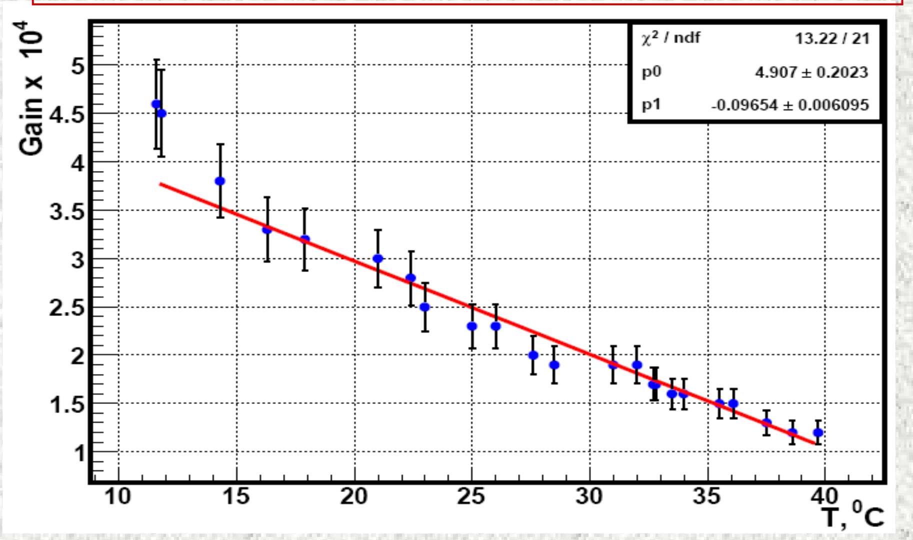
Long-term test: 10 MAPDs were irradiated by LED pulses with f=1 MHz and amplitude ~10^4 ph.e at T~30 ^{0}C during 2 months. No changes in gain and dark current were observed.



Gain gradient ~1%/(0.01V) in working range ΔV~2V



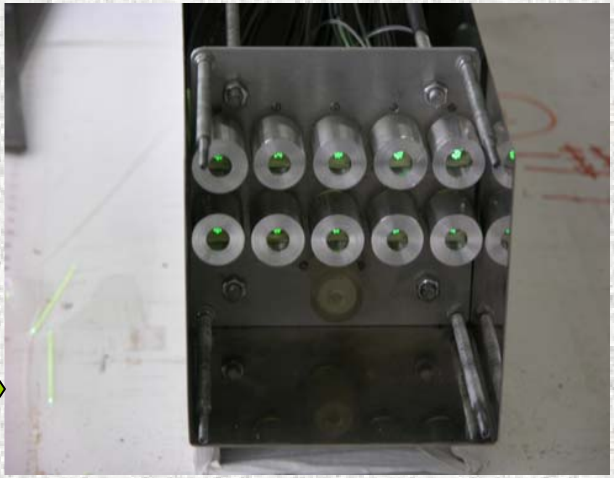
Temperature coefficient is < 3%/^{0}C.



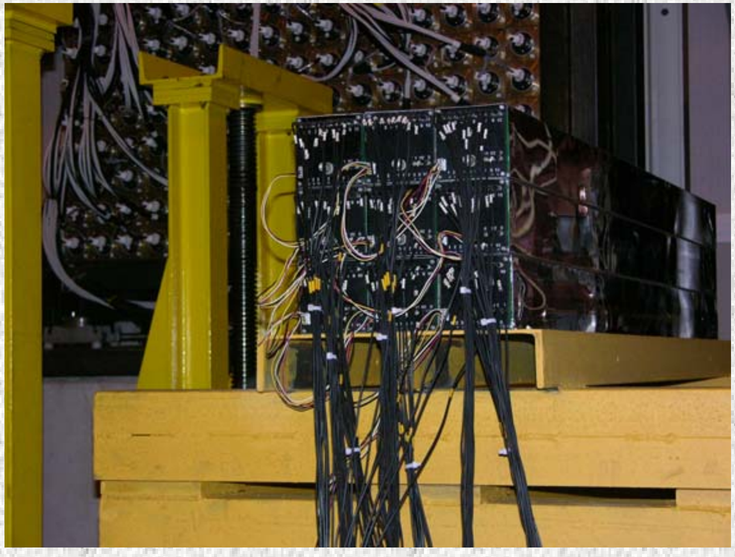
In 2007 first 9 calorimeter modules were assembled at INR

Module assembling

Rear part of module with 10 optical connectors

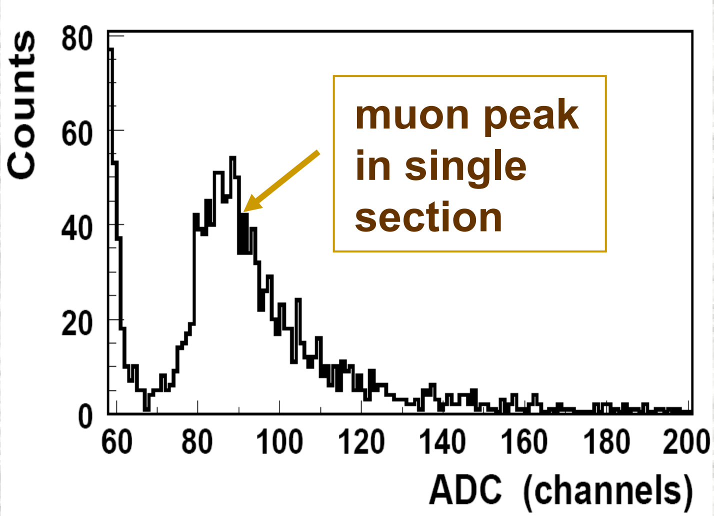


Calorimeter at CERN beam

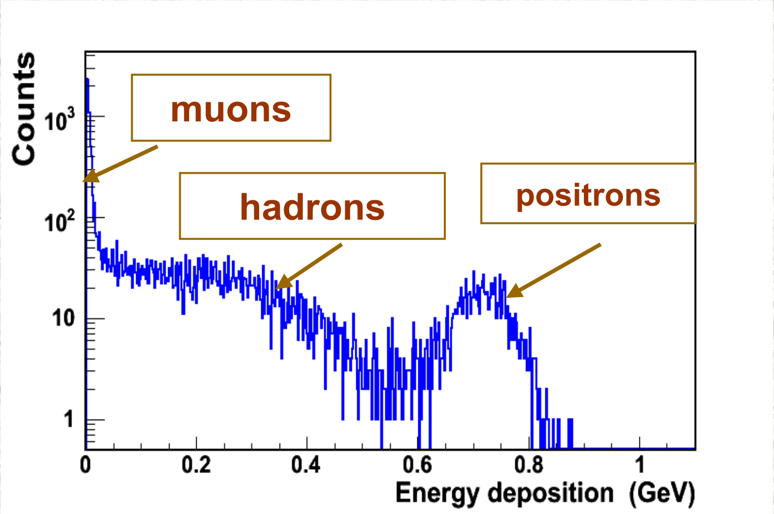


Beam test was performed with earlier version of MAPDs produced by Micron plant. Now they are replaced by Zecotek MAPDs.

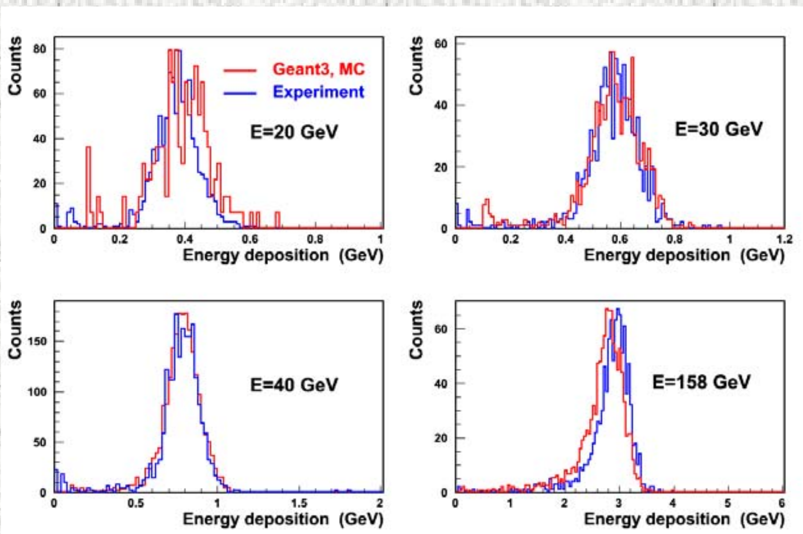
Performance of calorimeter with MAPD readout



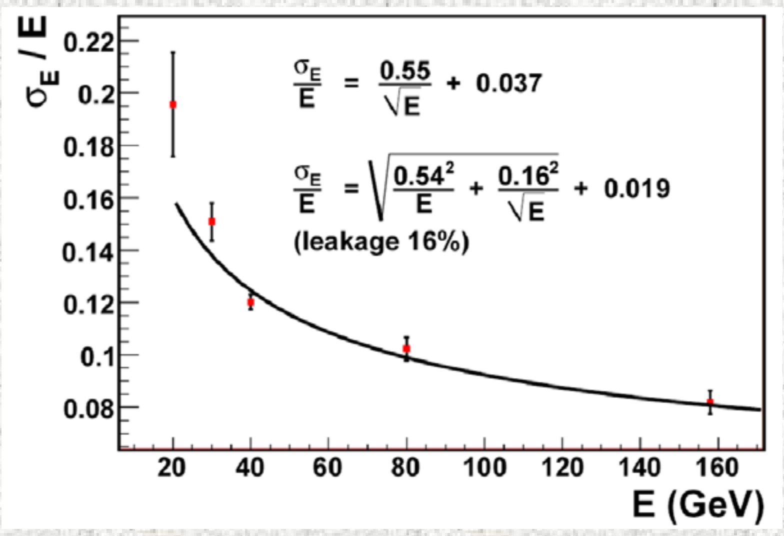
Calibration with 70 GeV muon beam



Response of first section to mixed beam

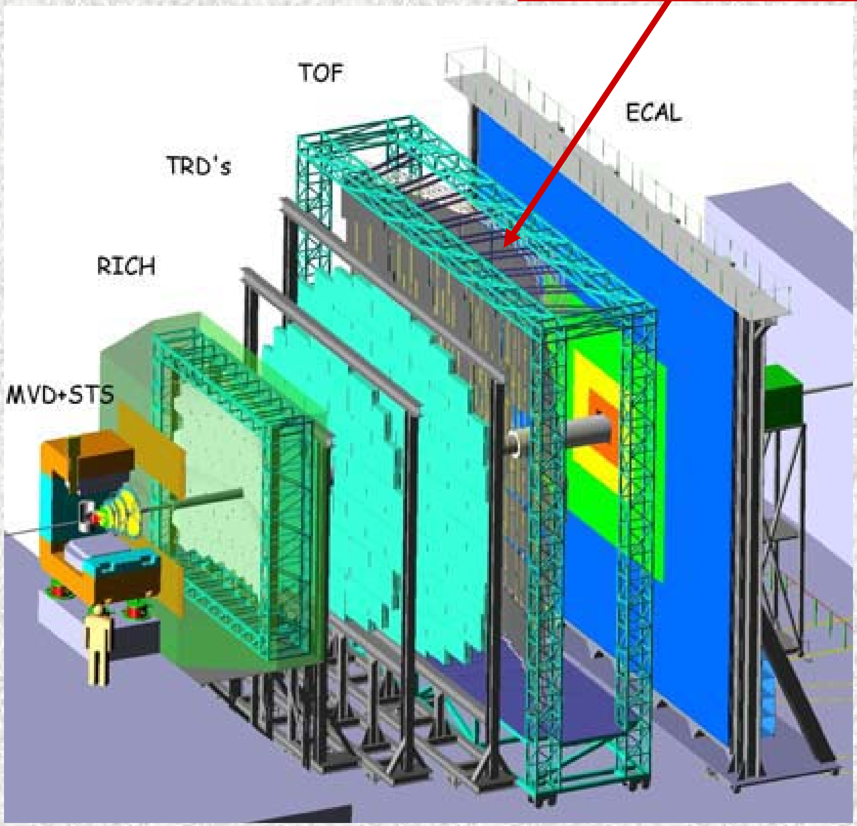


Spectra of energy depositions for different beam energies



Energy resolution of calorimeter

TOF Wall at CBM



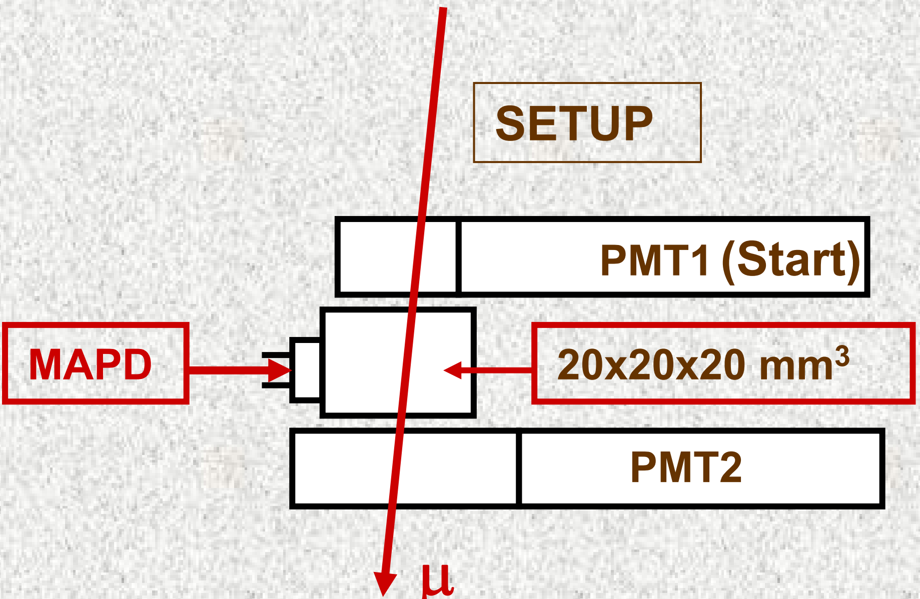
Parameters of TOF wall:

- TOF wall size ~ 15 m x 10 m = 150 m^2
- Overall time resolution σ_t = 80 ps.
- Space resolution ≤ 5 mm x 5 mm.
- Efficiency > 95 %.
- Rate capability > 20 kHz/cm^2.
- Compact and low consuming electronics
- (~65.000 electronic channels).

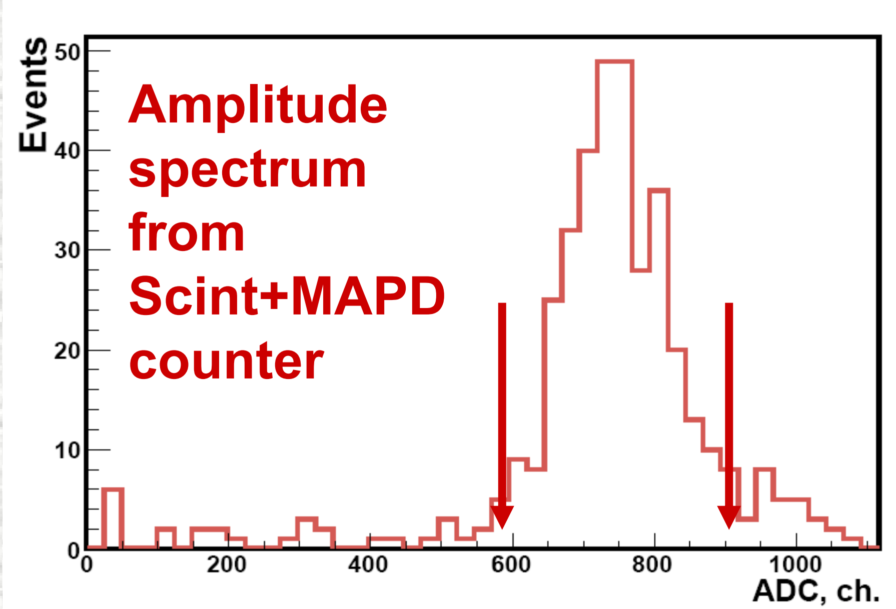
Rate capability of ordinary RPCs is
<1 kHz/cm^2 !
Is it possible to use scintillator TOF counter with MAPD readout as a cheap and reliable solution for central part of wall with the cell size of 20x20 cm^2?

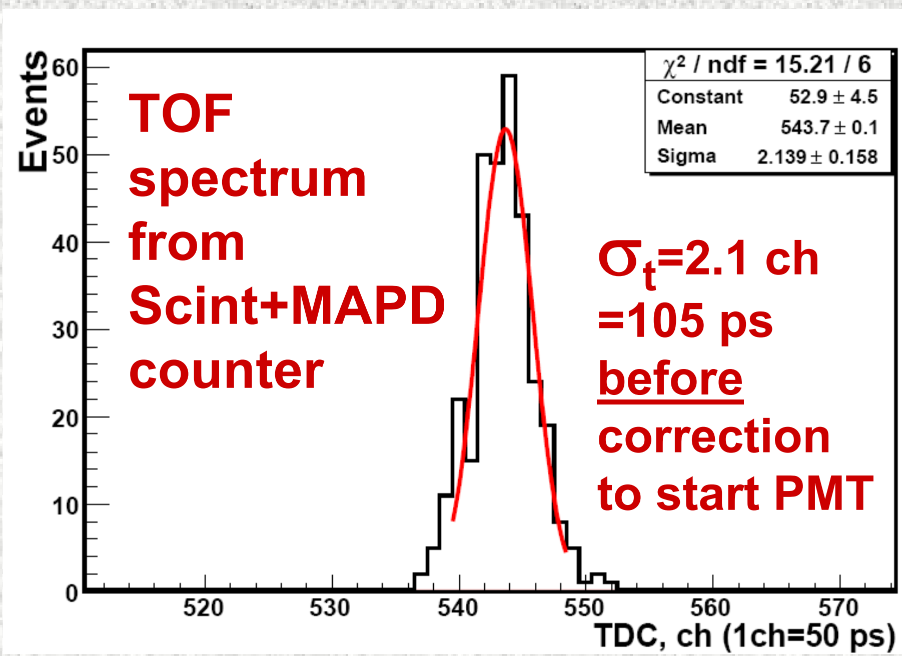
A few types of plastic scintillators (cube of 20x20x20 mm^3) and MAPDs were tested.

Test of TOF with cosmic rays



σ_t(PMT1)=σ_t(PMT2)=70 ps





TOF resolution for scintillator with MAPD readout is ~80 ps!

Is it good for CBM TOF-Wall ?

A few comments to TOF measurements:

- The amplifier with low input impedance (<10 Ohm), gain~120 and bandwidth~300 MHz was used.
- Measurements were done with Leading Edge Discriminator (CAEN, mod.84).
- The discriminator threshold was set to 30 mV.
- The signal amplitude from Scintillator+MAPD counter is one order higher.
- Constant Fraction Discriminator gives ~30% worse results.

- **We see a few ways of improvement for TOF resolution:**

a) shorter rise time (now it is ~4 ns)
b) higher PDE value (now it is ~25% for blue light)
c) larger active area (now it is 9 mm^2)
d) use of a few MAPDs per one scintillator

⇓

Huge potential for improvement !!!

Outlook

- The modular hadron calorimeter with fine longitudinal segmentation is developed.
- The calorimeter has light readout with WLS-fibers and micropixel APDs.
- MAPD with high pixel density ensures the appropriate dynamical range together with the detection of low light signals from single particles.
- The calorimeter performance meets the requirements of NA61/CBM experiments.
- High PDE values (~30%) for blue light and relatively short rise time of ~4 ns make very attractive the use of these MAPDs for granulated TOF systems like CBM TOF-wall.
- Time resolution of σ_t~80 ps for plastic scintillator with MAPD readout is achieved in simple test with cosmic rays.
- We see high potential in further improvement of MAPDs performance and their time properties.