# Preliminary tests of Plastic Scintillator Detector for the High Energy cosmic-Radiation Detection (HERD) experiment

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- As a part of the design of the components of the HERD mission, measurements were carried out on the plastic scintillator elements that will be used for the veto system and charge measurement (PSD)
- The test has been performed using both $\beta^-$ source (m.i.p.) and hadron/ion beam, to cover a wide range of ionization densities
- The results allow to characterize the behavior of the used components, in order to optimize the construction of the detector

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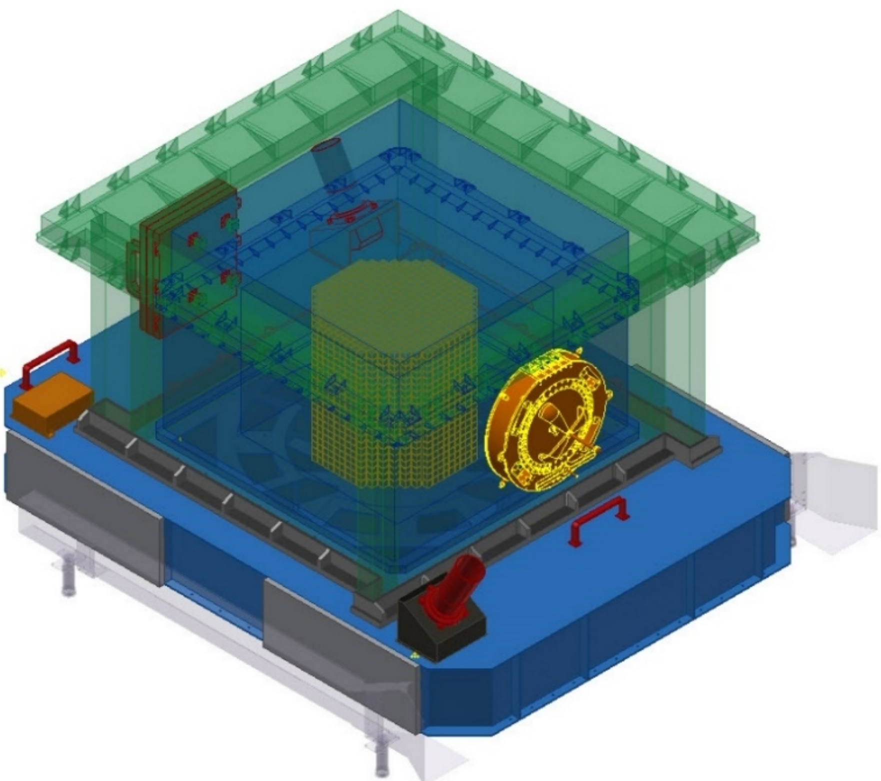
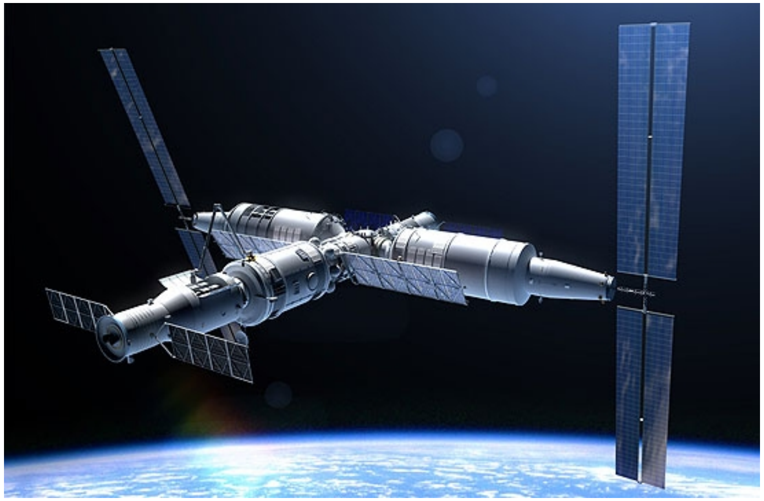
# High Energy cosmic-Ray Detection (HERD)

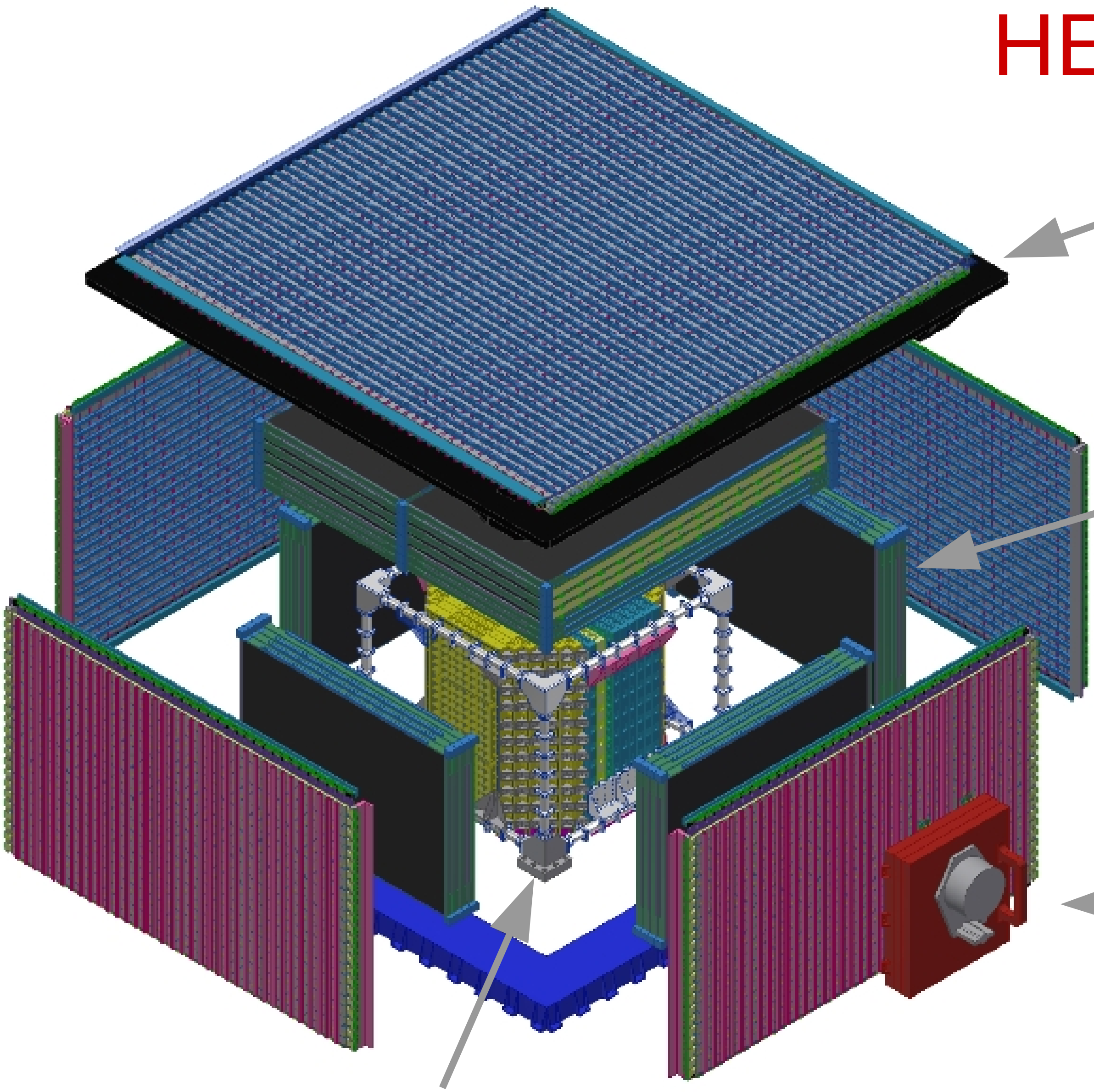
- HERD is an international space mission that will operate on the Chinese space station (currently being assembled)
- Main Scientific Objectives:
  - Dark matter: dark matter search with unprecedented sensitivity
  - Cosmic-ray: precise cosmic ray spectrum and composition measurements up to the knee energy (1 PeV)
  - Gamma-ray: gamma-ray monitoring and full sky survey





planned for launch ~ 2025
operation for ~ 10 years

# HERD payload



PSD (Plastic Scintillator Detector)
Gamma identification (veto)
Charge measurement

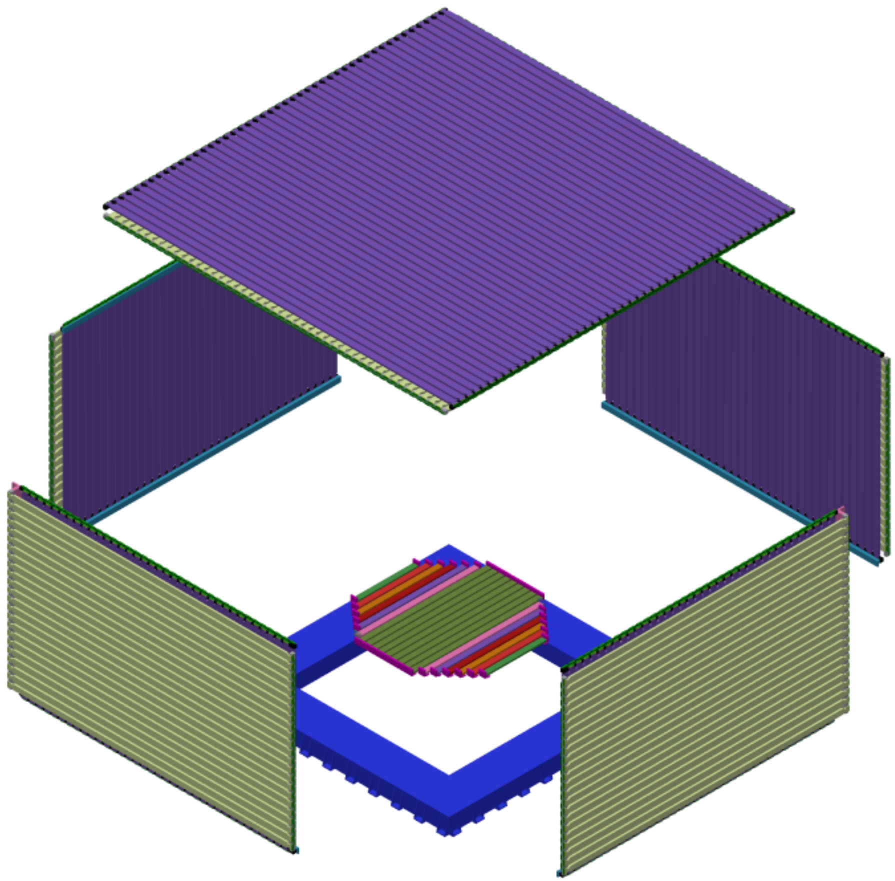
Tracker
Charge measurement
CR trajectory
Gamma converting & tracking

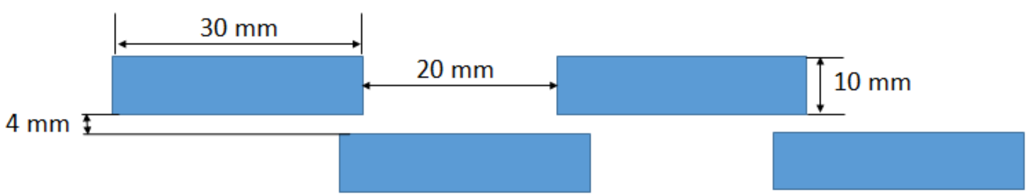
TRD
TeV CR calibration

CALO: 3D imaging calorimeter: energy measurement & particle identification

The novel design of 3D imaging calorimeter could significantly increase GF, improve particle discrimination and reduce systemic error

# PSD structure





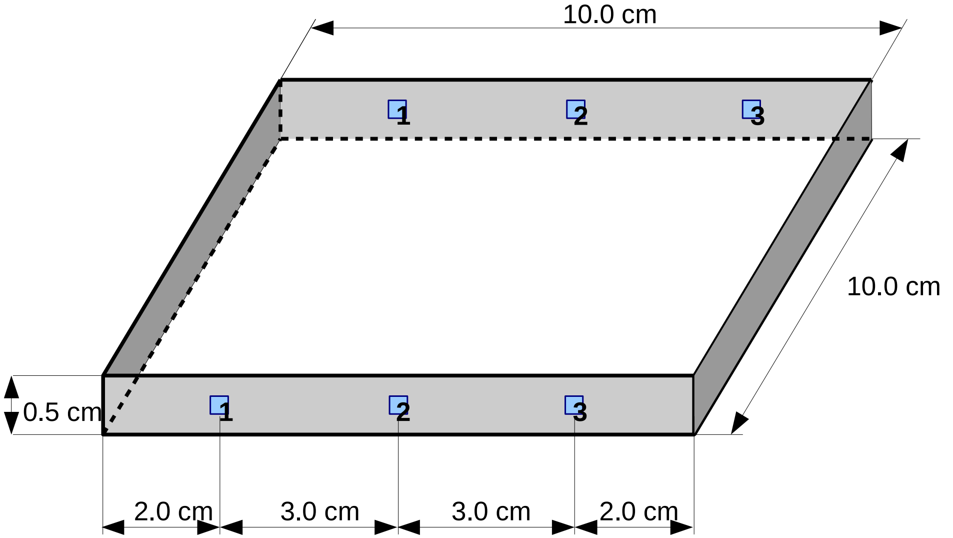

bars are overlapped by 5 mm to avoid “dead zone”
space between two overlapped layers: 4 mm

| | |
|---|---|
| Coverage ratio | > 99.95% |
| Layers(top & side) | 1 x/y layers |
| Layers (bottom) | 1 x |
| Z measurement | 1 - 26 |
| Veto time | < 100 ns |
| Dead time | < 10 μs |
| Eff. Area (top) | $2.0 \times 2.0\ m^2$ |
| Eff. Area (side) | $1.6 \times 1.1\ m^2$ |
| Number of bars | ~ 700 |
| Readout channels | 4.2 k |

**Alternative approach: tile geometry**

# Testing the tile geometry

| Geometry | Advantages |
|---|---|
| Bars | Less readout channels<br>Simpler mechanics |
| Tiles | Better id of backscattered particles<br>More flexible trigger logic |

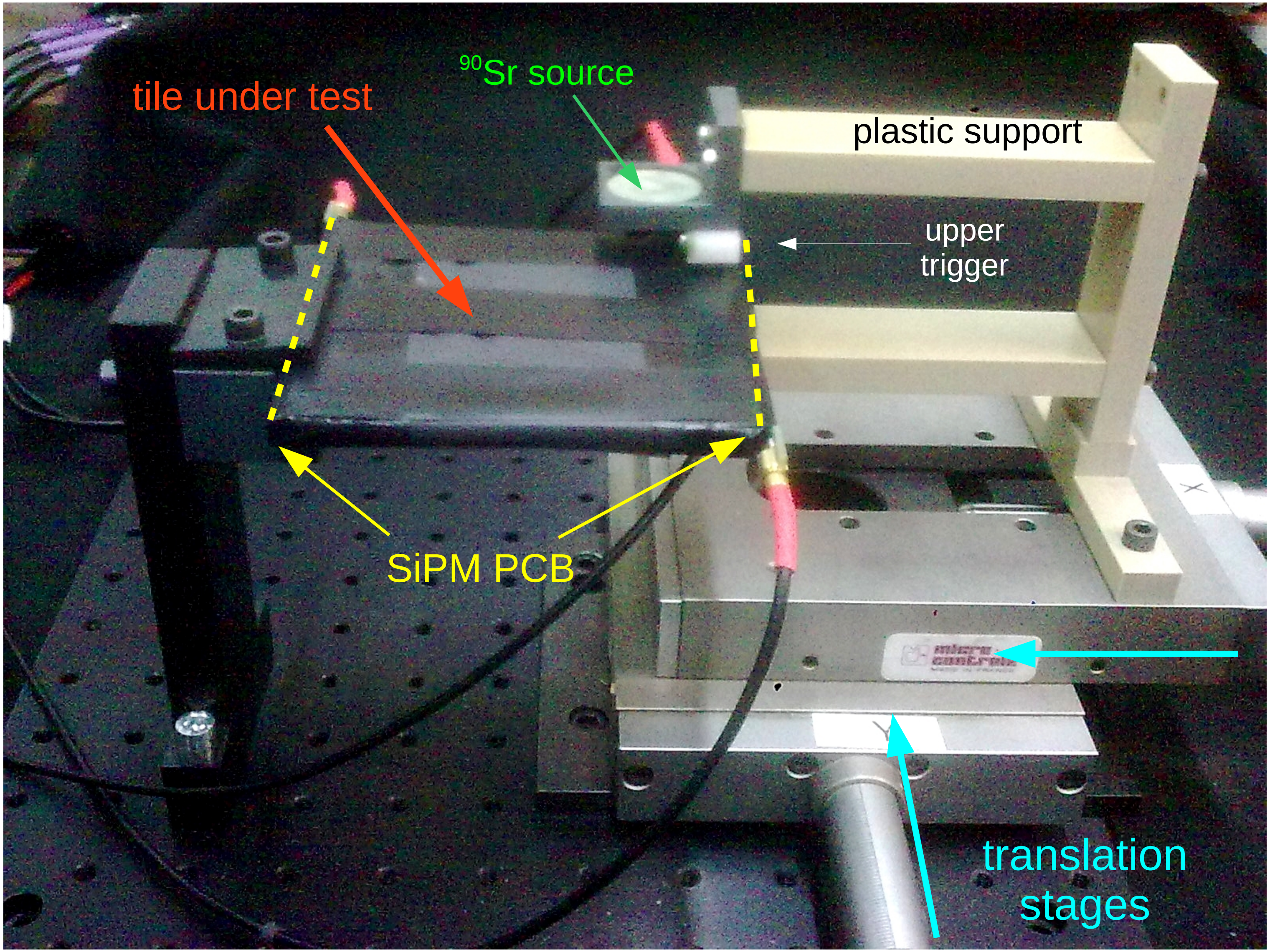



Test performed on a 10x10x0.5 $cm^3$ plastic scintillator tile (EJ200 type)

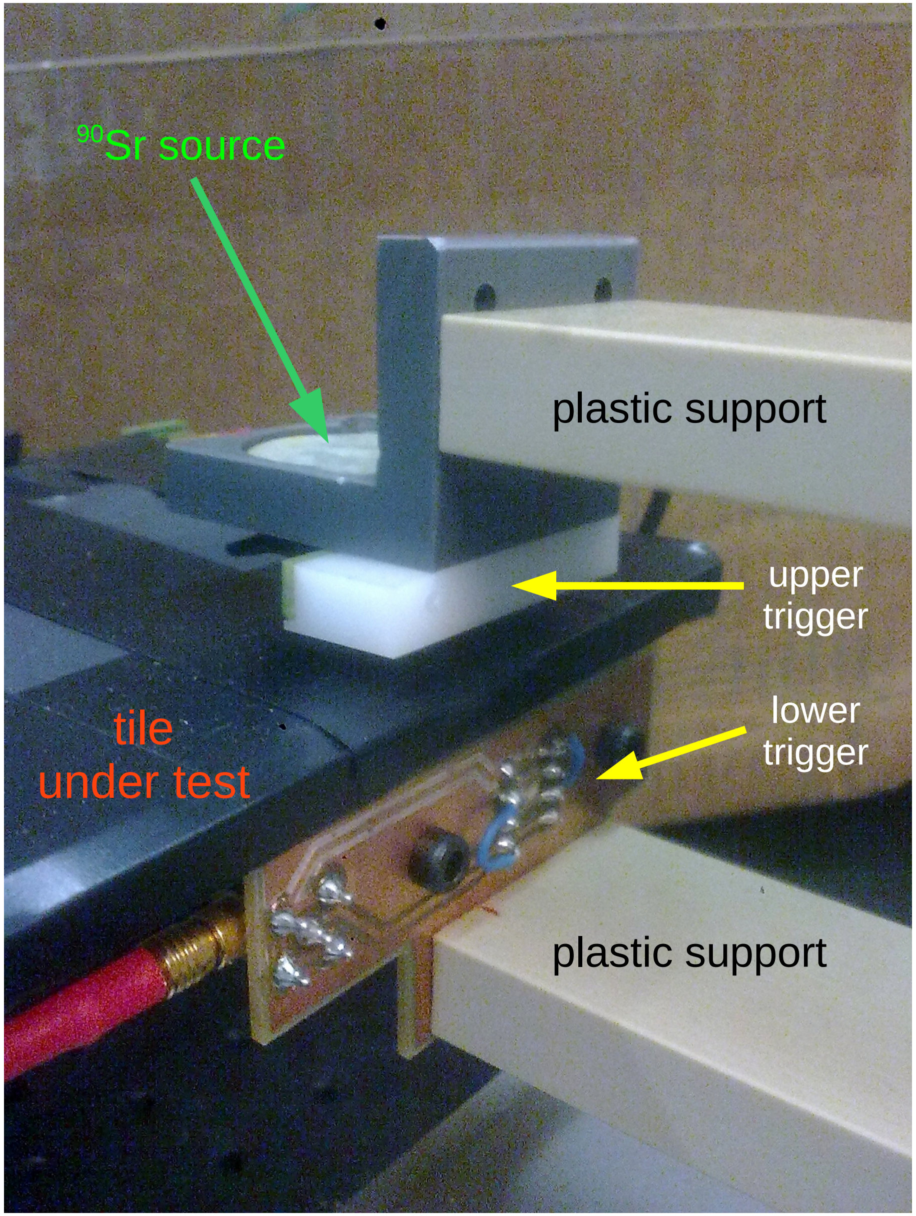
Equipped with 6 Ham. S12572 SiPMs, 50 $\mu$m, 3x3 $mm^2$ (mounted on 2 PCB, placed on opposite sides)

The SiPM signals are acquired with a Tektronix MSO64 oscilloscope without amplification

# Test performed with a $^{90}$Sr source



# Test performed with a $^{90}$Sr source

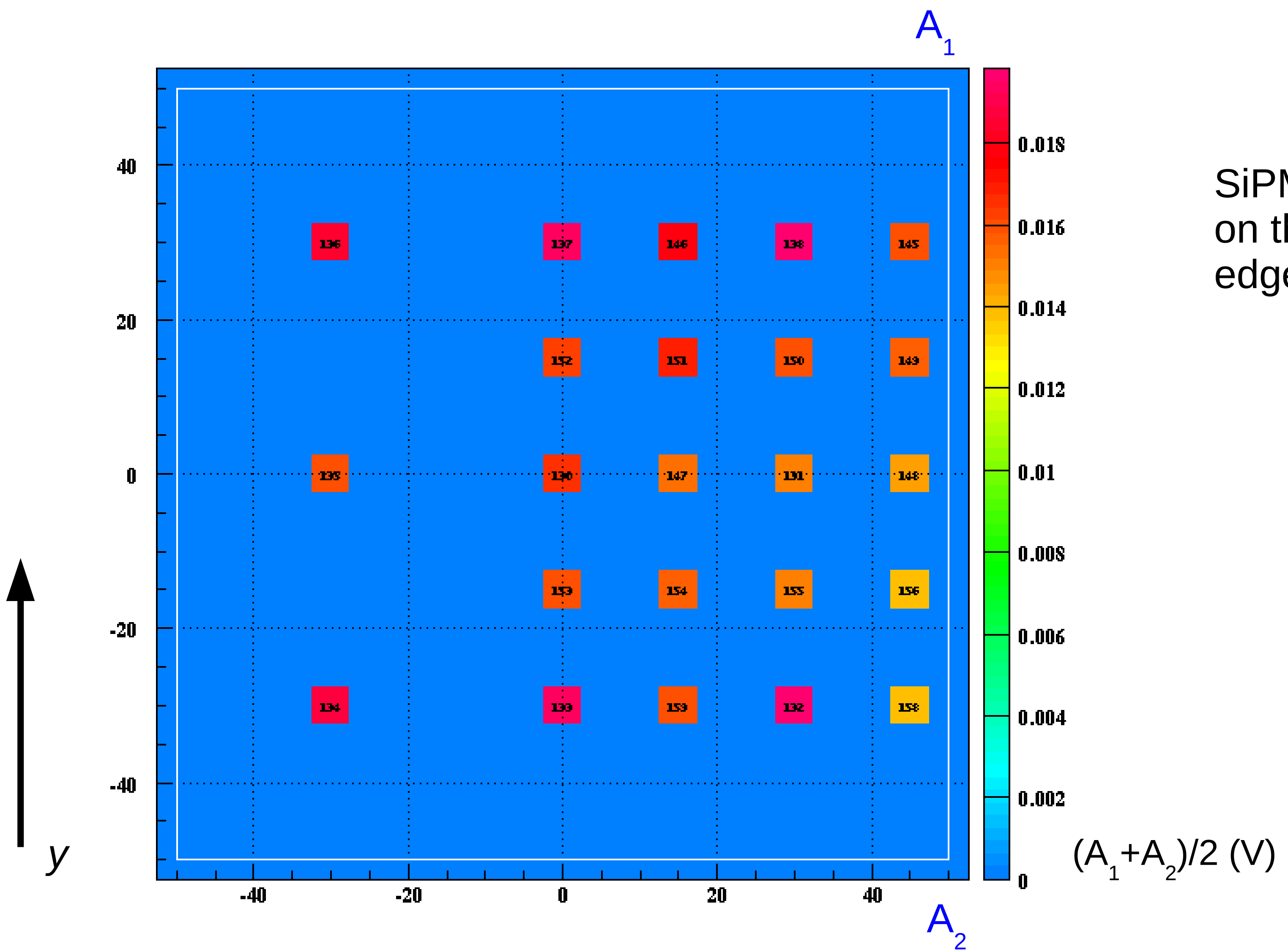



the trigger is given by a small telescope (2 x 1cm scintillators)

# Signal amplitude uniformity

The sum of the signals taken from the two side ($A_1$+$A_2$) is considered

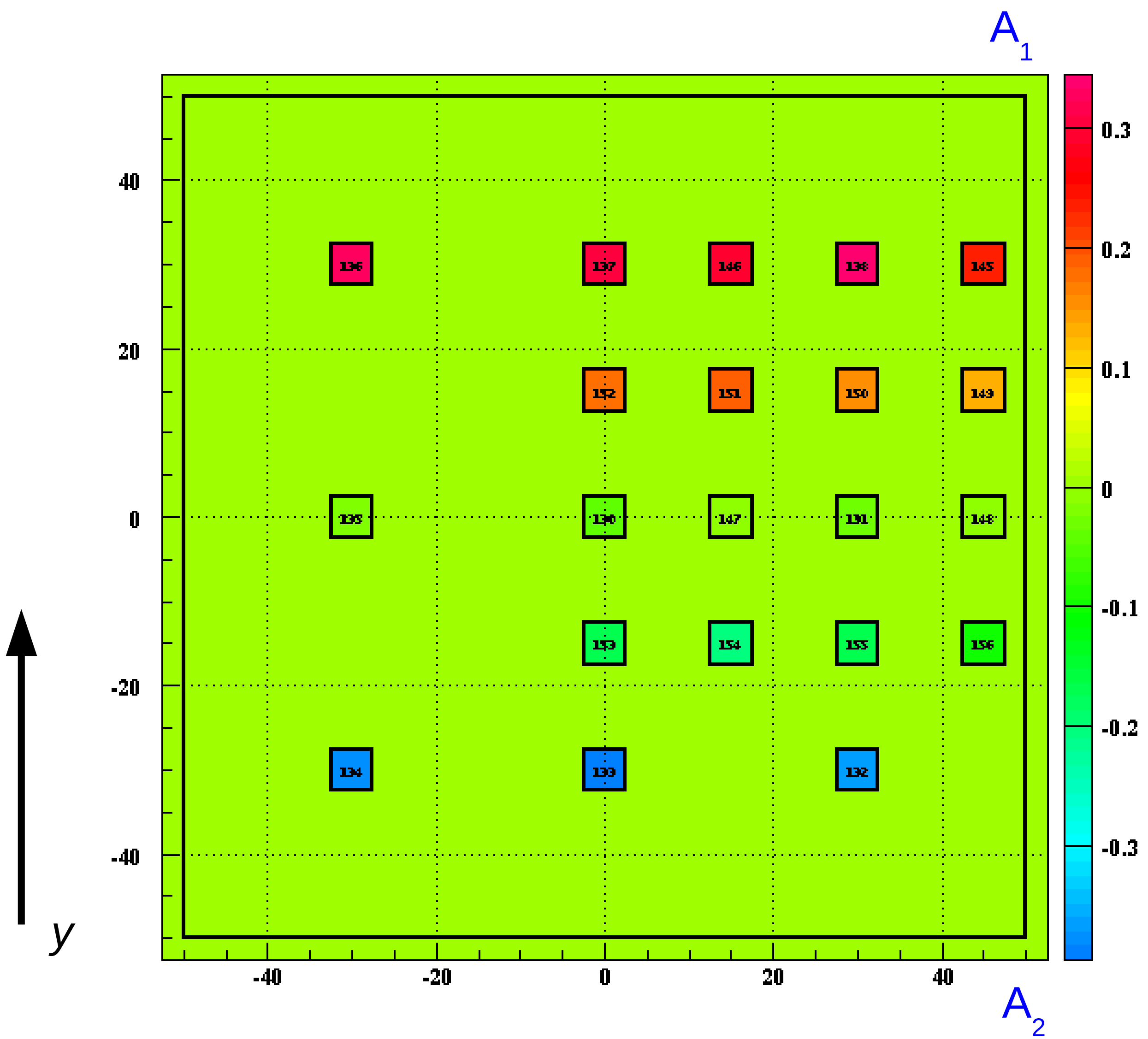
A good uniformity is observed




SiPM PCBs are placed on the upper and lower edge of the tile

# Signal amplitude asymmetry

Considering the asimmetry parameter $(A_1\text{-}A_2)/(A_1\text{+}A_2)$
a regular dependence from the *y* (only) coordinate is observed




$(A_1\text{-}A_2)/(A_1\text{+}A_2)$

SiPM PCBs are placed on the upper and lower edge of the tile

# Test performed on the hadronic beam

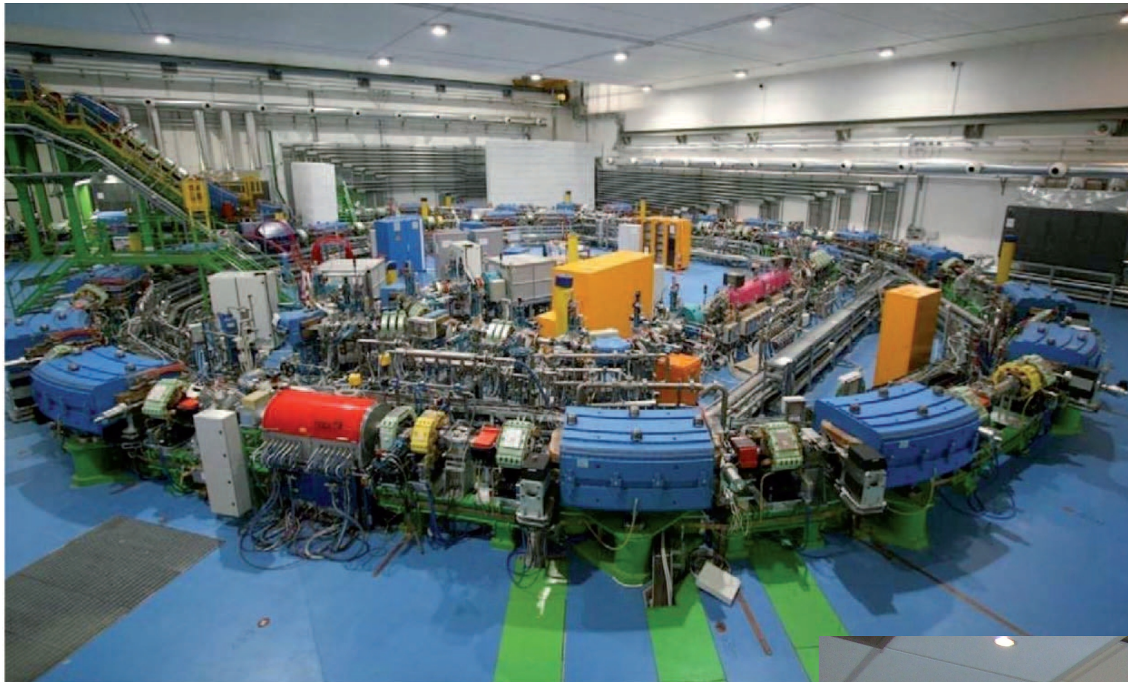
The CNAO (Centro Nazionale di Adroterapia Oncologica) is an accelerator facility dedicated to hadron radiotherapy to treat cancer

At present it uses proton beam with kinetic energy in the range 60-250 MeV and C ion beam with energy in the range 120-400 MeV/u

The particle rate available is up $10^{10}$ p/s or $4 \cdot 10^{8}$ C/s and can be scaled down by several orders of magnitude by intervening on the operating parameters of the accelerator

The beam shape is gaussian with size $s_{x,y} = 0.2 \div 0.8$ cm, depending on energy and beam type

# The CNAO complex

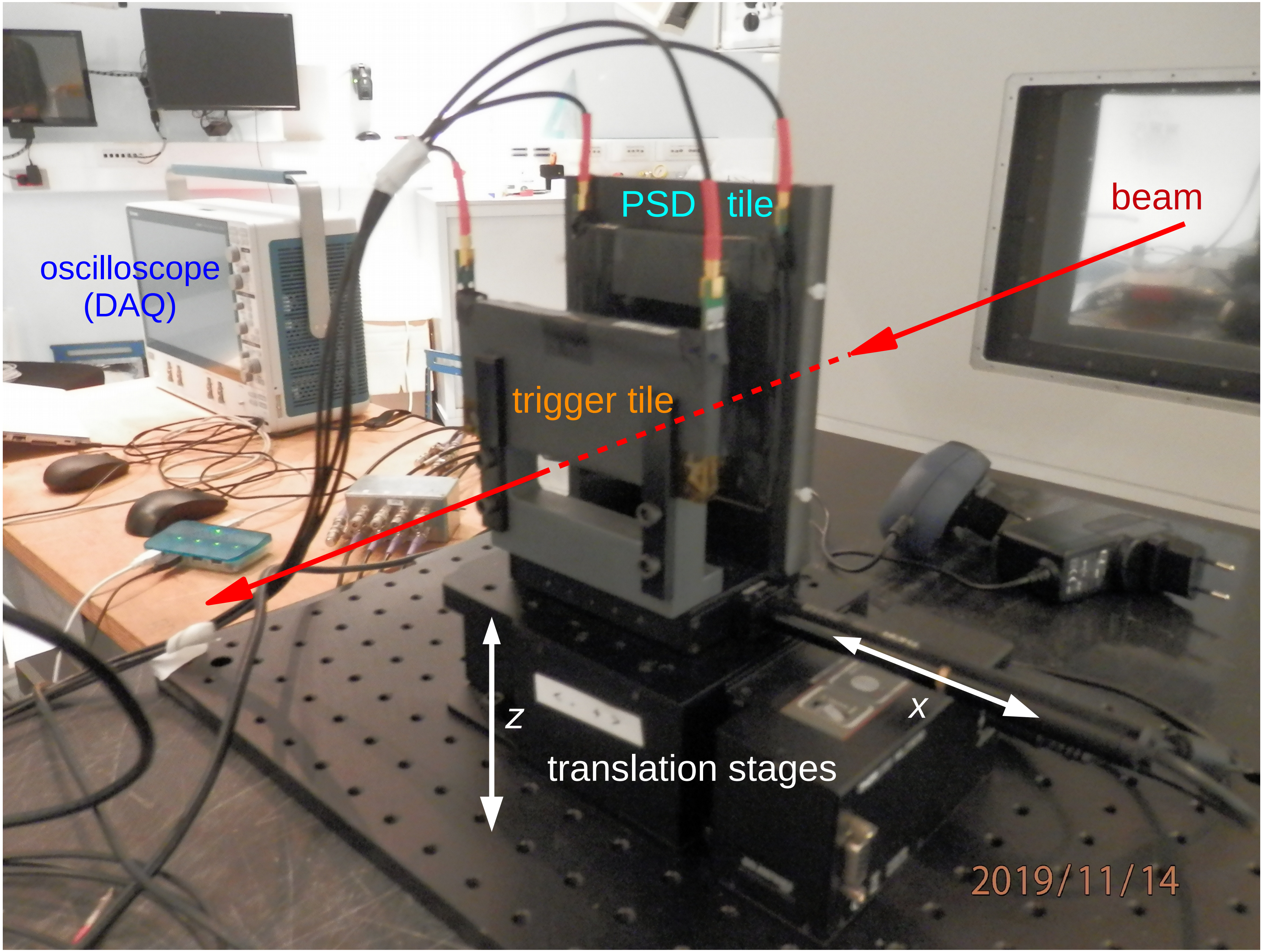


Synchrotron

Treatment rooms


fondazione CNAO

# Beam test setup

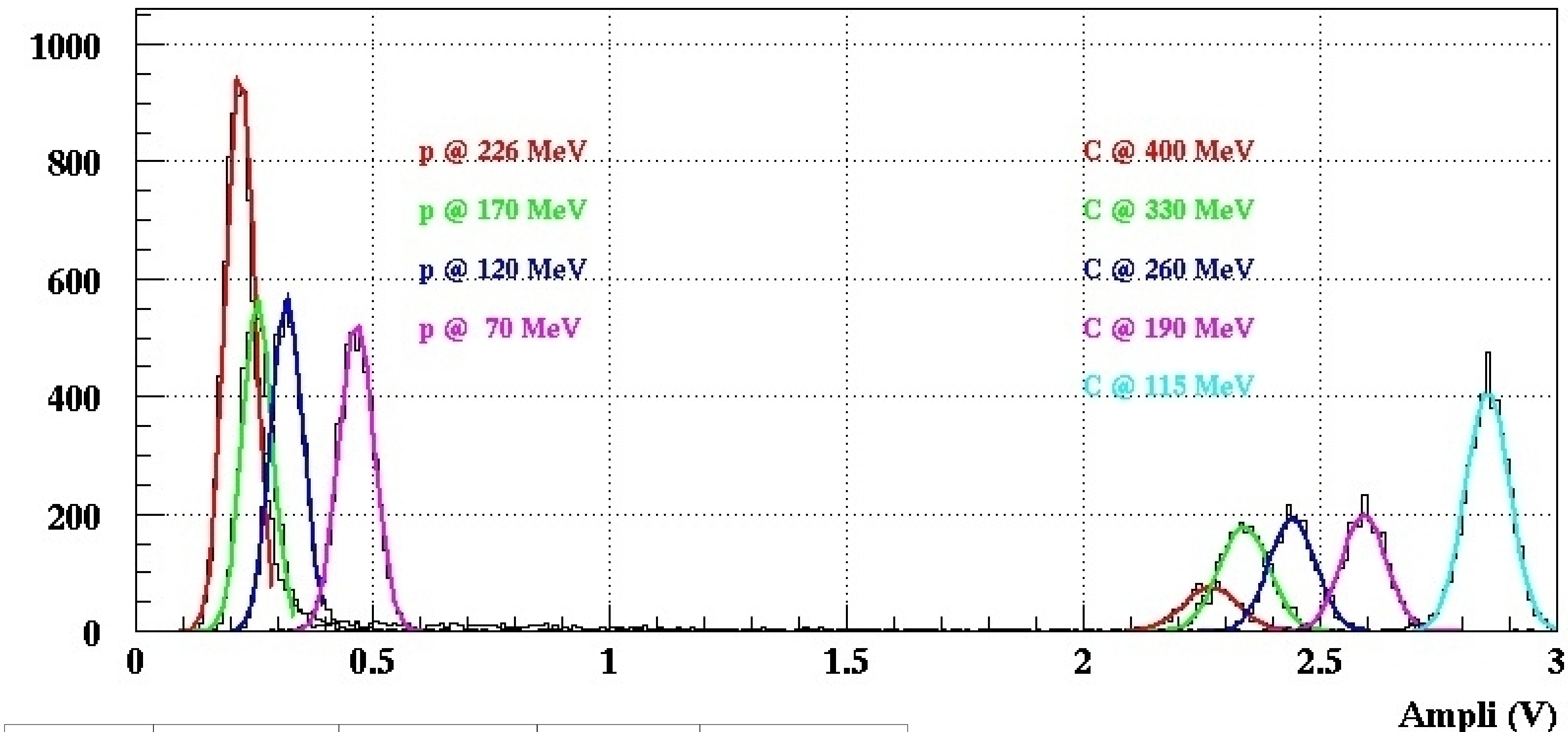


The intresting aspect of using such hadron beams, is that low-β particles can produce high ionization densities (given by the Bethe-Bloch formula), behaving like particles with much higher Z

To perform the PSD tile test, the following beam was used

| Beam | Energy | $\beta$ | $Z/\beta^2$ | Events |
|---|---|---|---|---|
| p | 70 MeV | 0.366 | 7.46 | 5000 |
| p | 120 MeV | 0.462 | 4.68 | 5000 |
| p | 170 MeV | 0.532 | 3.53 | 5000 |
| p | 226 MeV | 0.592 | 2.85 | 18270† |
| C | 115 MeV/u | 0.454 | 174.6 | 20000* |
| C | 190 MeV/u | 0.555 | 116.9 | 2500 |
| C | 260 MeV/u | 0.622 | 93.0 | 2500 |
| C | 330 MeV/u | 0.672 | 79.7 | 2500 |
| C | 400 MeV/u | 0.713 | 70.8 | 1182 |

# Signal amplitude analysis

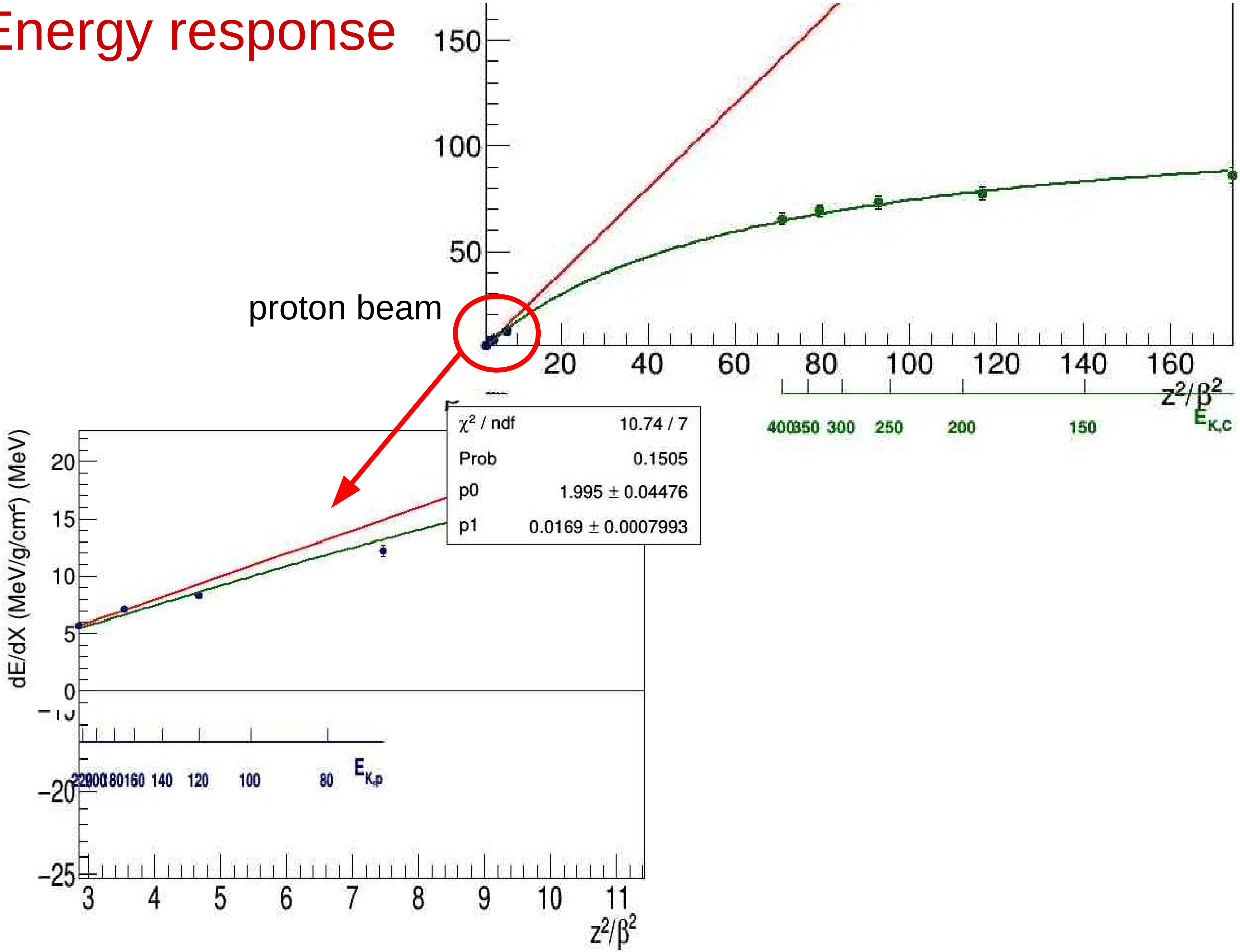



| Beam | Energy (Mev) | Amplitude (V) | Sigma (V) | Resolution (%) |
|---|---|---|---|---|
| p | 226 | 0.218 | 0.031 | 14.2 |
| p | 170 | 0.254 | 0.032 | 12.4 |
| p | 120 | 0.317 | 0.034 | 10.7 |
| p | 70 | 0.465 | 0.038 | 8.08 |
| C | 400 | 2.270 | 0.058 | 2.57 |
| C | 330 | 2.340 | 0.053 | 2.28 |
| C | 260 | 2.442 | 0.049 | 2.03 |
| C | 190 | 2.594 | 0.048 | 1.85 |
| C | 115 | 2.855 | 0.047 | 1.64 |

The amplitude is given by the A parameter of the fit function

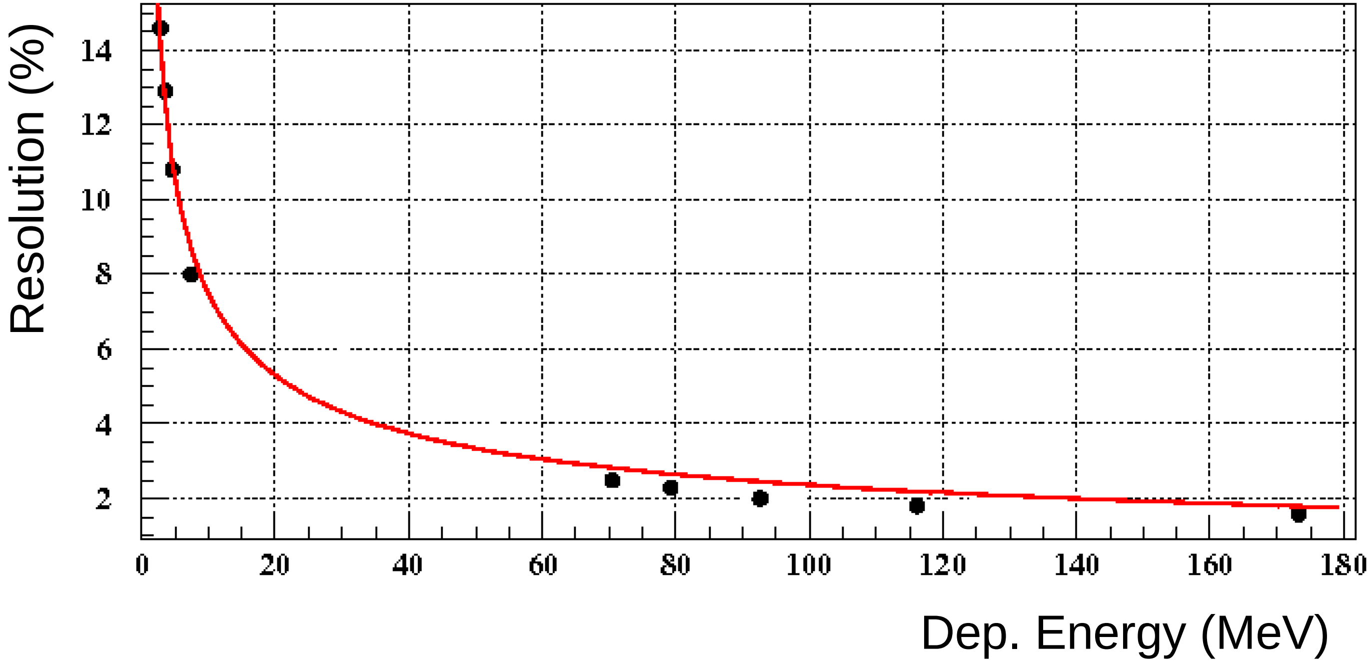
$$f(t) = A \frac{\exp((t_0 - t)/\tau_d)}{1 + \exp((t_0 - t)/\tau_r)}$$

# Energy response



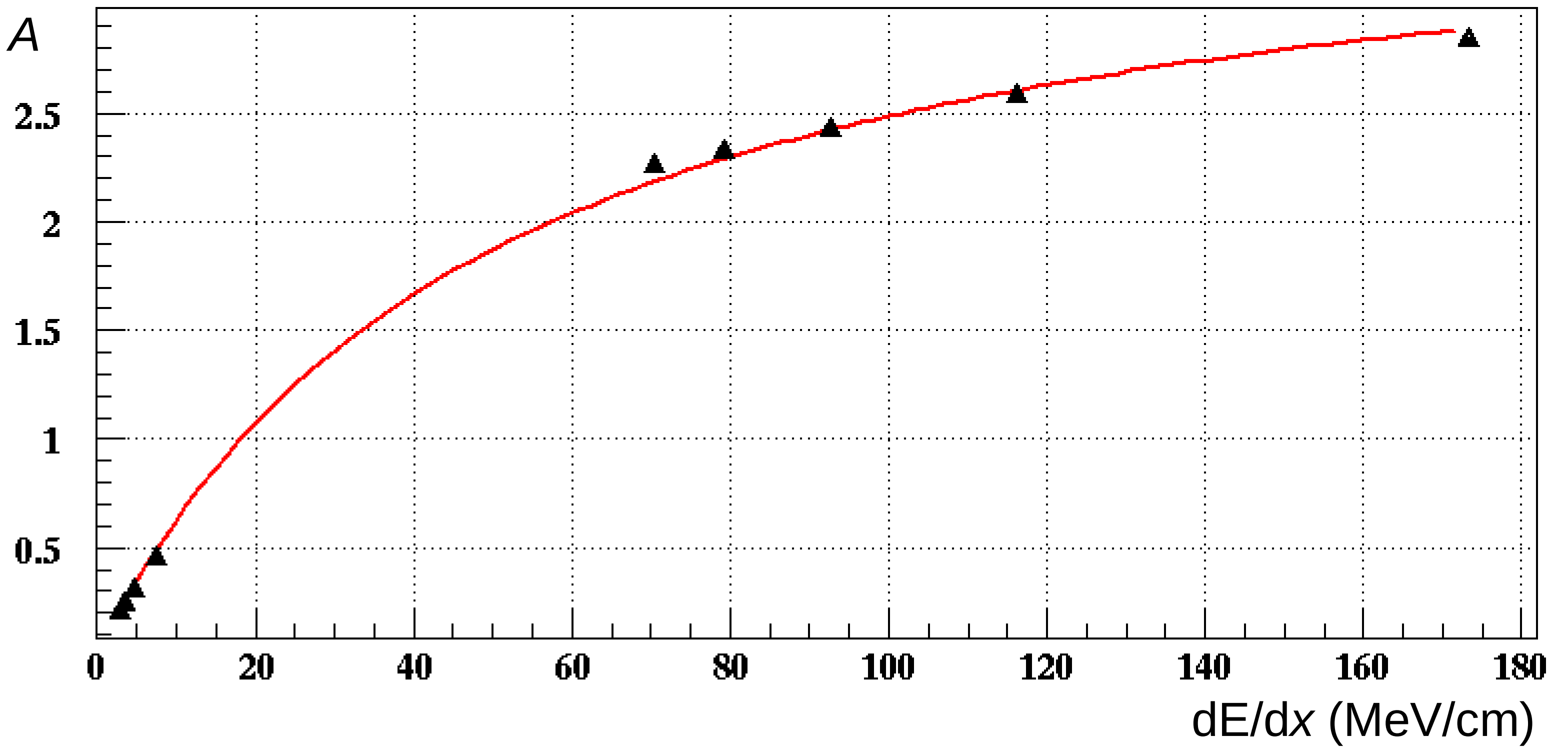
# Energy resolution

considering dE/d*x* = 2 MeV/cm for m.i.p.




$$\frac{\Delta E}{E}(\%) = \frac{22.9}{\sqrt{E}(MeV)}$$

# Birks' law




The correlation between the signal amplitude and the dE/dx is well fitted with a Birks' law (provided the SiPM are not saturated)

$$A = P_1 \frac{dE/dx}{1 + P_2 \, dE/dx}$$

$P_1$ = 0.040 V

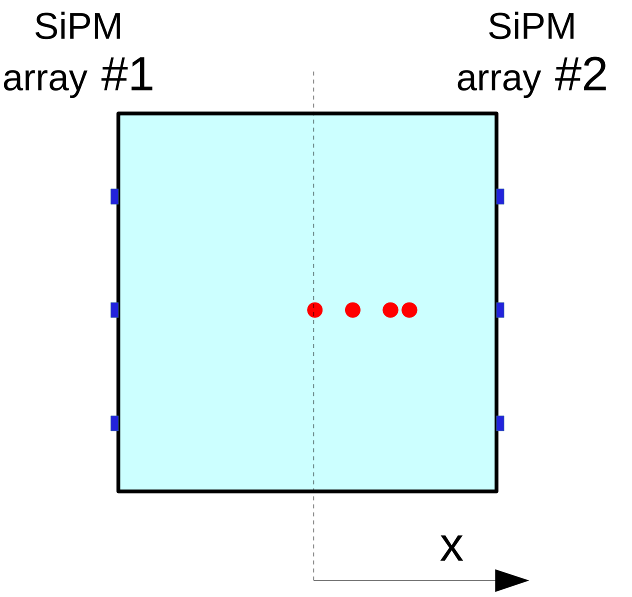
$P_2$ = 0.011 g/(MeV cm$^2$)

The value of $K_b$ coefficient ($P_2$) is in agreement with the ones found in literature: $(1.26 \div 2.07) \cdot 10^{-2}$ g/(MeV cm$^2$)

# Beam position analysis

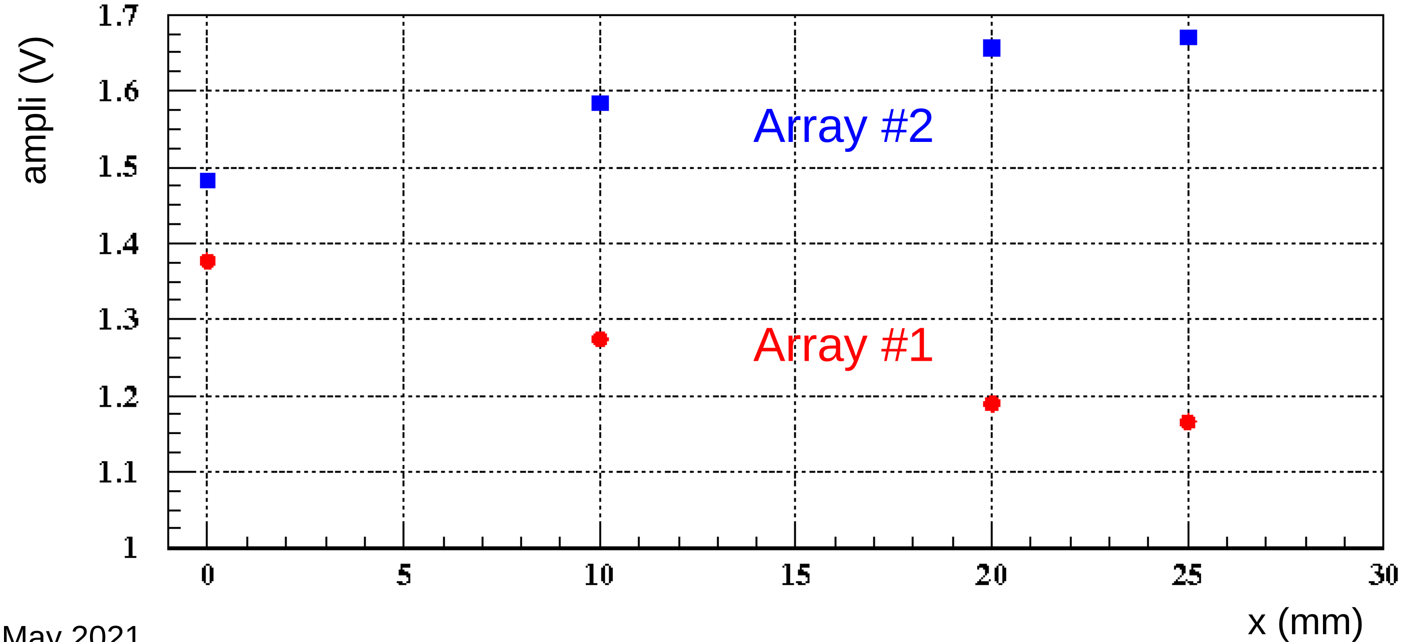
C @ 115 MeV/u

| x (mm) | **A1** (V) | **A2** (V) |
|---|---|---|
| 0.0 | 1.376 | 1.482 |
| 10.0 | 1.274 | 1.583 |
| 20.0 | 1.189 | 1.656 |
| 25.0 | 1.165 | 1.670 |

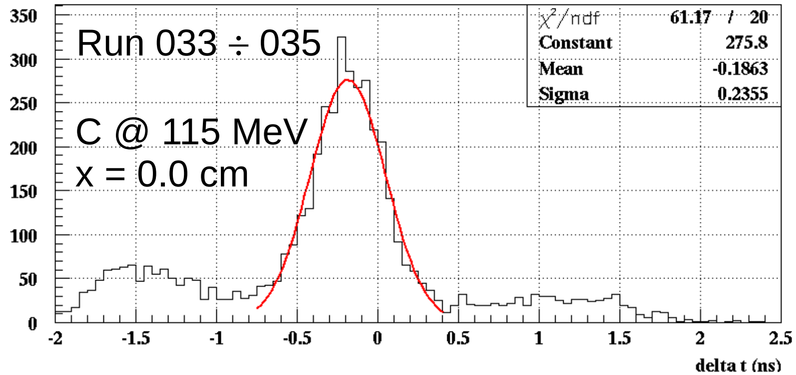


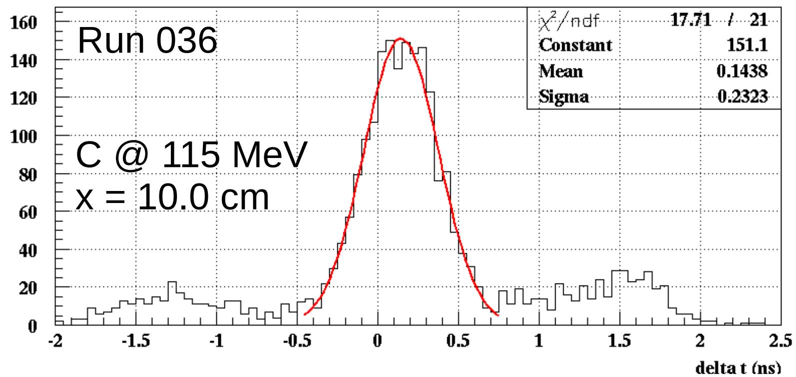

The signal of array #2 SiPM increase with x even at high dE/dx (C ions at 115 MeV/u)

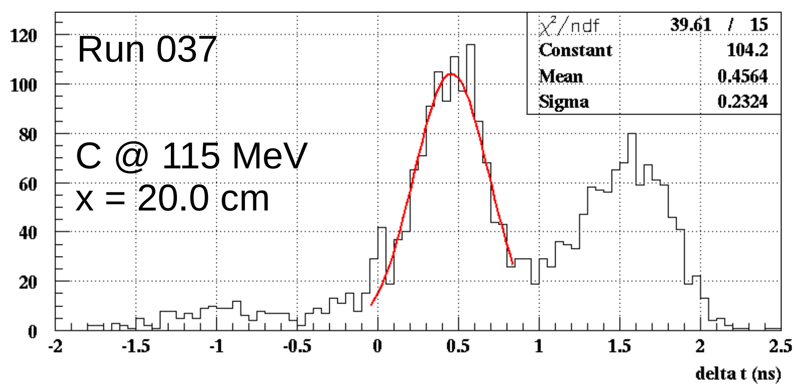
→ SiPM are not saturated

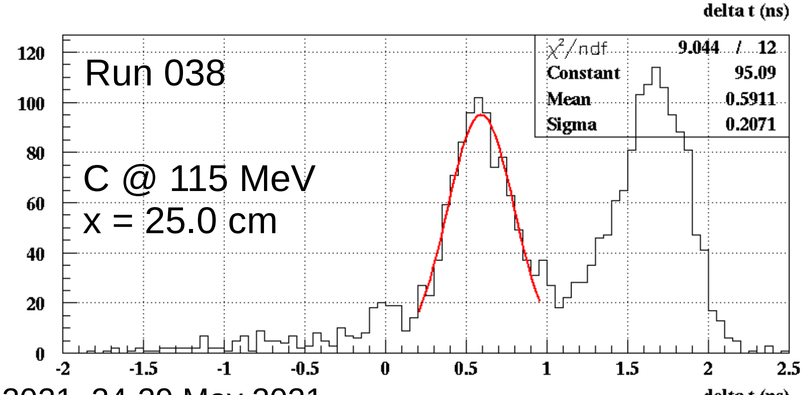


# Time analysis



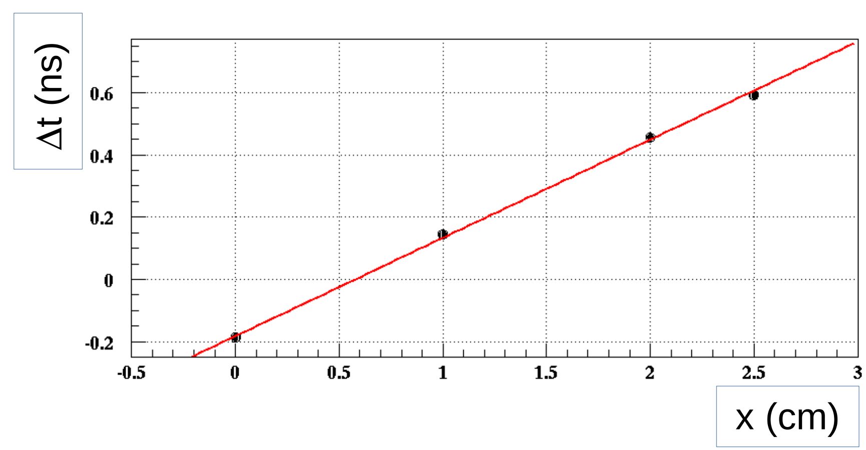



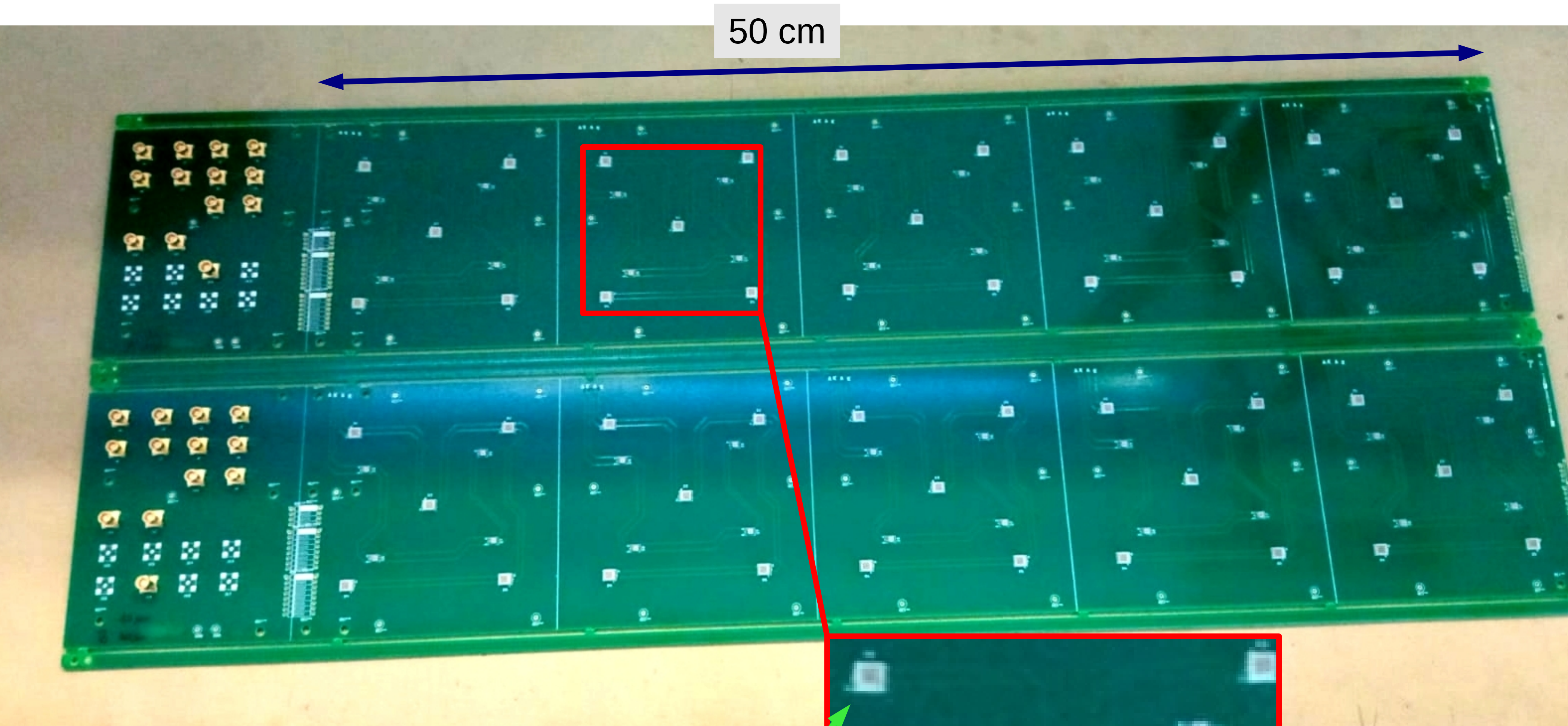

Considering the time difference $\Delta t = t_1 - t_2$

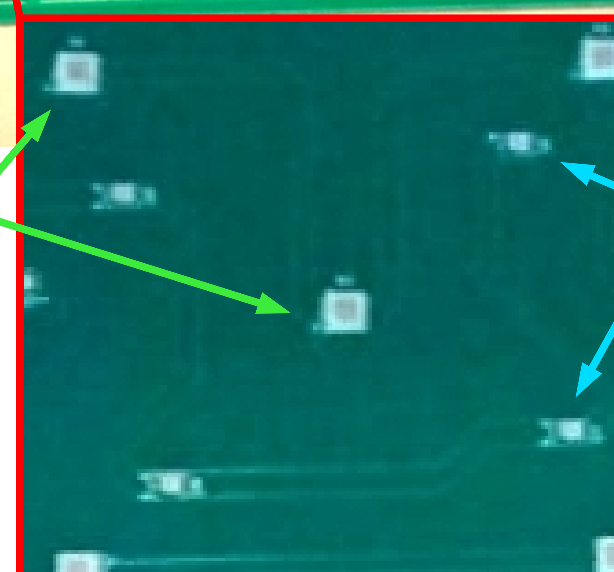
| x (mm) | Δt (ns) |
|---|---|
| 0.0 | -0.18 |
| 10.0 | 0.14 |
| 20.0 | 0.46 |
| 25.0 | 0.59 |




$$\Delta t\,(ns) = 0.32 * x\,(cm) - 0.18$$

# In progress: half-meter long PCB with dual-size SiPM




Readout of 5 adjacent tiles

# Conclusions

- A PSD tile has been tested using a $\beta^-$ ($^{90}Sr$) source, obtaining interesting results on both the uniformity and position dependent signal amplitude
- The tile has also been using the p / C beam at CNAO, reproducing conditions similar to those that occur with much heavier particles, obtaining an estimate of the energy resolution and the loss of linearity due to Birk's law
- Similar tests are planned on a larger PSD prototype (under construction)

# Thanks !

# Backup slides

# HERD specifications

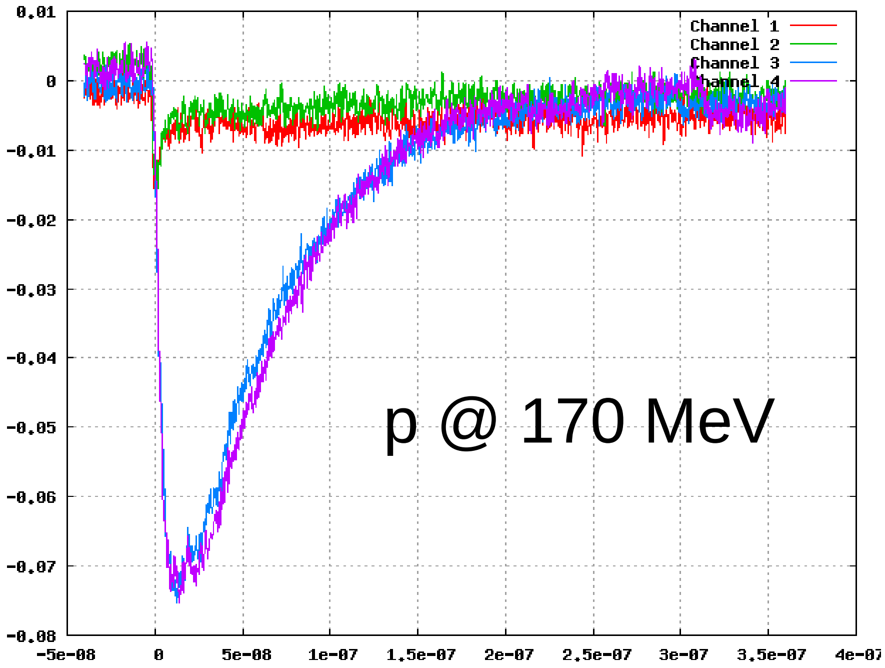
| Item | Value |
|---|---|
| Energy range (e/γ) | 10 GeV - 100 TeV (e); 0.5 GeV - 100 TeV (γ) |
| Energy range (CR) | 30 GeV - 3 PeV |
| Angular resolution | 0.1 deg.@10 GeV |
| Charge resolution | 0.1-0.15 c.u |
| Energy resolution (e) | 1% @ 200 GeV |
| Energy resolution (p) | 20% @ 100 GeV – PeV |
| e/p separation | $\sim 10^{-6}$ |
| G.F. (e) | > 3 $m^2$sr @ 200 GeV |
| G.F. (p) | > 2 $m^2$sr @ 100 TeV |
| Field of View | ± 70 deg (targeting ± 90 deg) |
| Lifetime | > 10 years |
| Mass | ~ 4000 kg |
| Envelope | ~ 300 x 230 x 155 $cm^3$ |

# Acquired signals

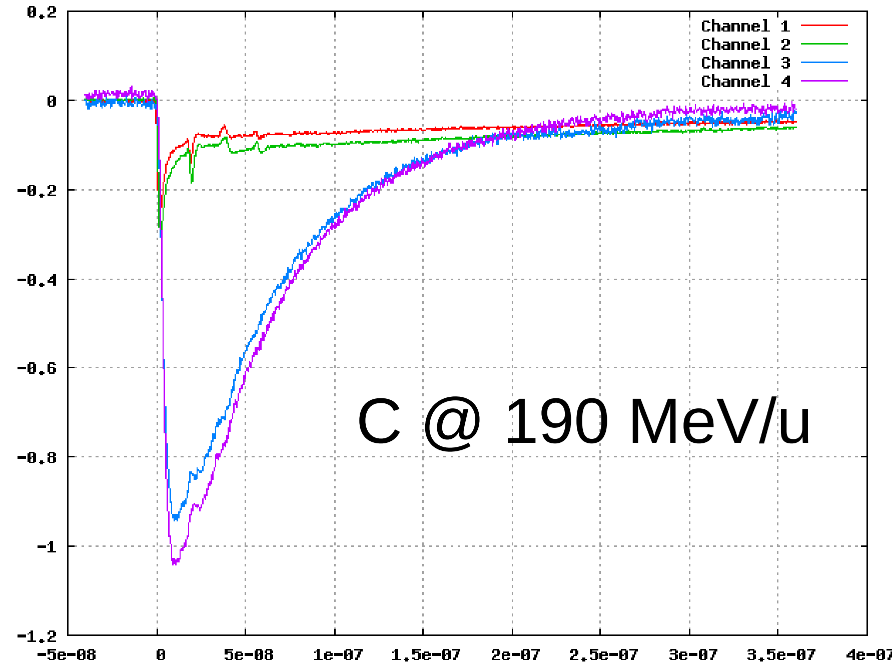
4 channels per *event:*

trigger tile ch1 and ch2 in coincidence gives the trigger

PSD tile ch3 and ch4

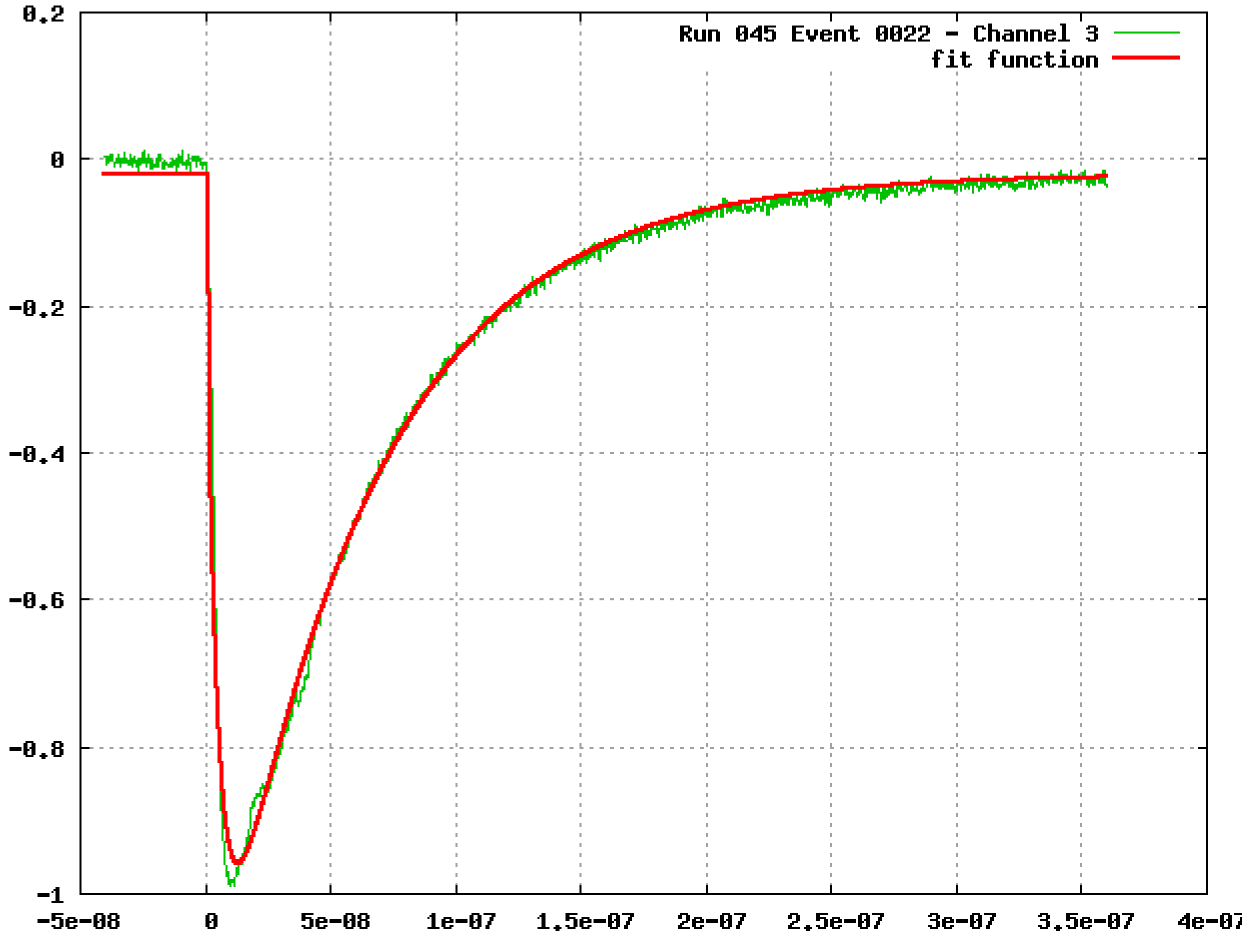



0.4 μs




0.4 μs

# Pulse analysis




5 parameters fit

b baseline

A amplitude

$t_0$ start time

$t_r$ rise time

$t_d$ decay time

$$f(t) = \begin{cases} b & t \le t_0 \\ b + A*(1-\exp(-t/\tau_r))*\exp(-t/\tau_d) & t > t_0 \end{cases}$$

A is used as the signal amplitude