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Data acquisition system for a proton imaging apparatus

V.Sipala[a,b], D.LoPresti[a,b], N.Randazzo[b], M.Bruzzi[d,e], D.Menichelli[e,d], C.Civinini[d], M. Brianzi[d], M.Bucciolini[c,d], C.Talamonti[c,d], M.Tesi[e], L.Marrazzo[c,d], L.Capineri[f], S.Valentini[d,f] G.Cuttone[g], G.A.P.Cirrone[g], G.Candiano[g], E.Mazzaglia[g]

a) Dipartimento di Fisica, Università degli Studi di Catania
b) INFN, sezione di Catania
c) Dipartimento di Fisiopatologia Clinica, Università degli Studi di Firenze
d) INFN, sezione di Firenze
e) Dipartimento di Energetica, Università degli Studi di Firenze
f) Dipartimento di Elettronica e Telecomunicazioni, Università degli Studi di Firenze
g) Laboratori Nazionali del Sud-INFN, Catania.

Outline

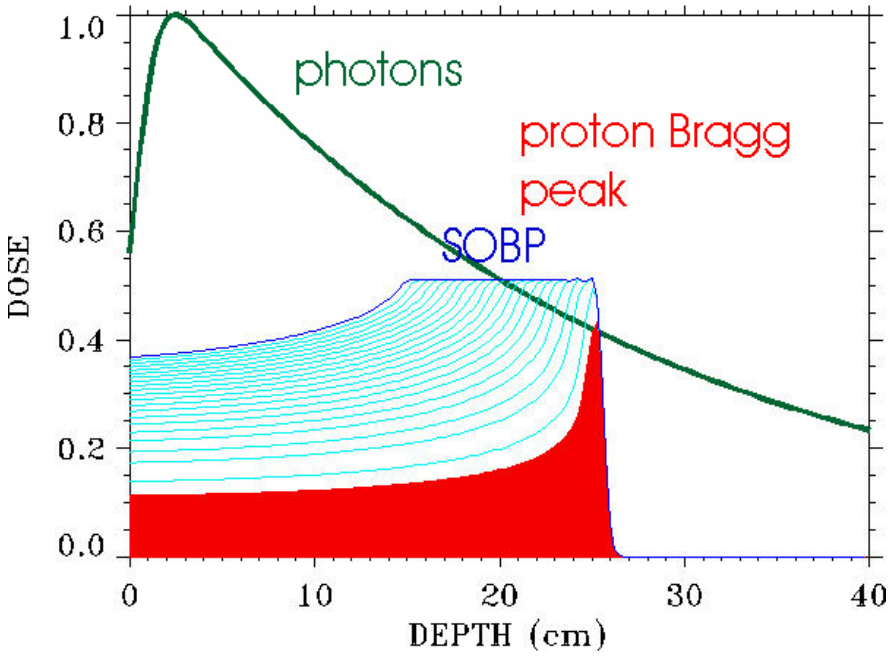
- Proton therapy and proton imaging
- Proton imaging apparatus
- Data acquisition system
  - Tracker
    - Single module architecture
    - Detector
    - VLSI front-end
  - Calorimeter
    - Crystal YAG:Ce
    - Electronic readout
    - Trigger system
- First results with proton beam
- Conclusions

Proton therapy

The proton therapy is a good clinical treatment for cancer as it permits to obtain a dose distribution extremely conform to the target volume.

The Bragg peak shape ensures that healthy tissues in front of and beyond the tumor are not damaged.

Through the weighted superposition of proton beams of different energies it is possible to deposit a homogenous dose in the target region using only a single proton beam direction.
(Spread Out Bragg Peak -SOBP).



proton Computed Tomography – pCT

Proton imaging

Main issues in the quality of treatment in proton therapy are:

- Patient positioning
- Dose planning

Actually X-rays radiography and X-CT are used but…

photons and protons are
a different interaction with the matter

By the pCT it's possible to obtain:

- Directly measurements of the stopping power distribution using the same therapeutic beam
- In a single phase the patient positioning and the treatment

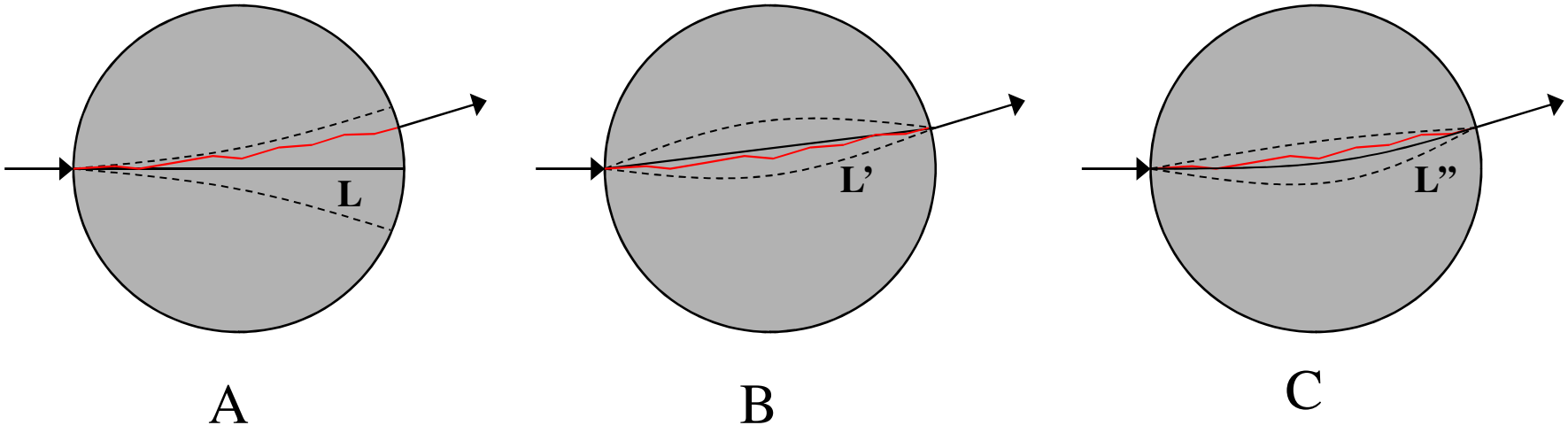
pCT parameters

PARAMETER	VALUE
Proton beam energy	250-270MeV
Proton beam rate	1MHz
Spatial resolution	<1mm
Electronic density resolution	<1%
Detector radiation hardness	> 1000 Gy
Dose per scan	< 5 cGy

Critical parameters:

- Proton beam rate → Data acquisition system
- Spatial resolution → Multiple Coulomb Scattering

Reconstruct principle: Most Likely Path



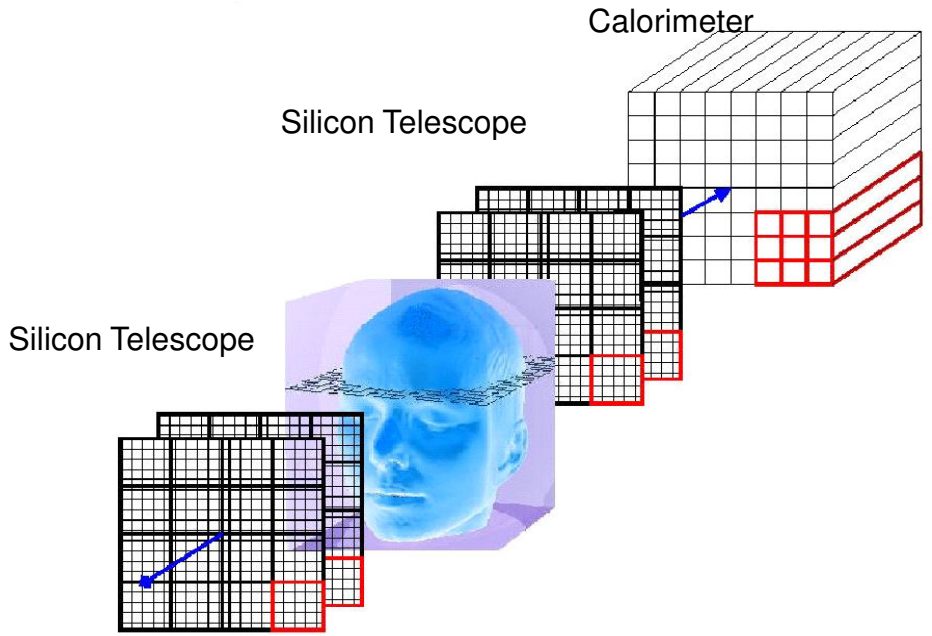
A: Only entry position & direction known: straight line L

B: Entry position & direction + exit position known: straight line L'

C: Entry position & direction + exit position & direction known: curved path L'', "banana-shaped", narrow confidence limits

proton Computed Tomography concept

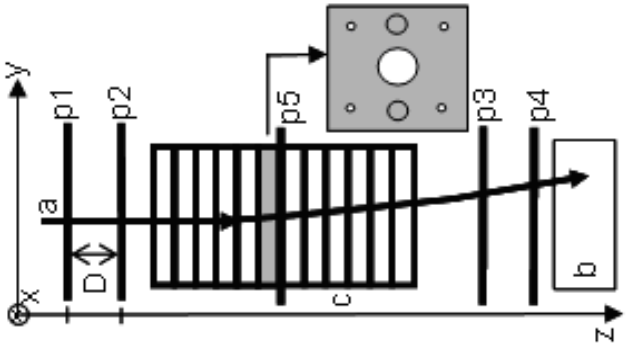
- Reveal the trace of the single proton using a silicon telescope
- Measure the residual energy of the proton using a calorimeter
- Reconstruct the most likely path of the single proton
- Reconstruct the imagine



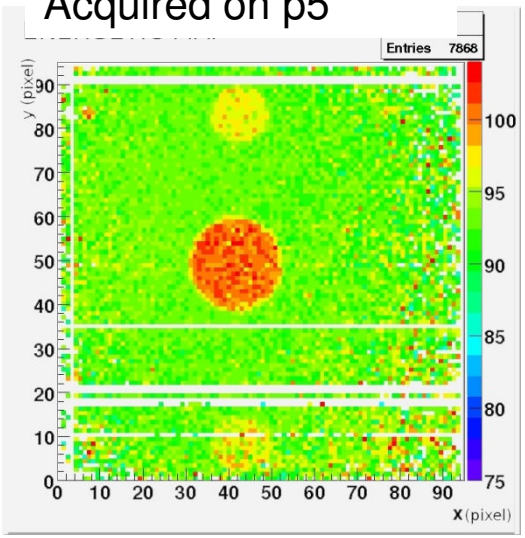
Validation of semi-analytical algorithms with pre-existing data

Data acquired at LLUMC
Proton beam 201MeV

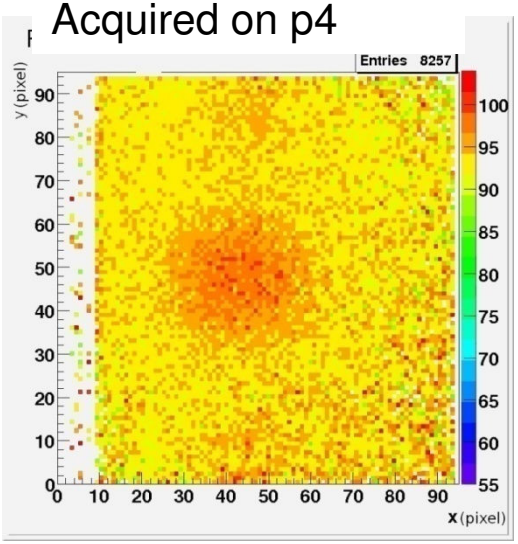
Silicon tracker UCSC CsI(Tl) calorimeter



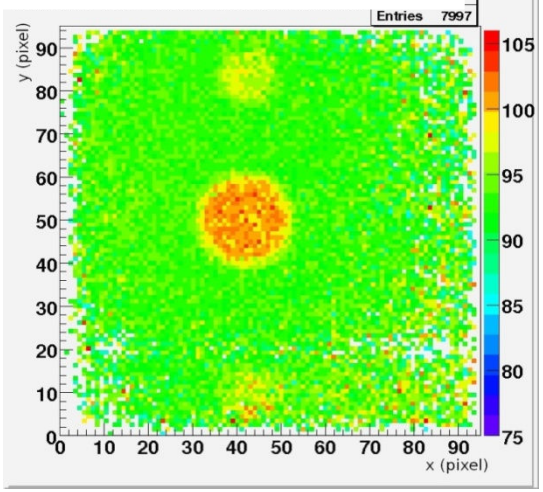
Acquired on p5



Acquired on p4



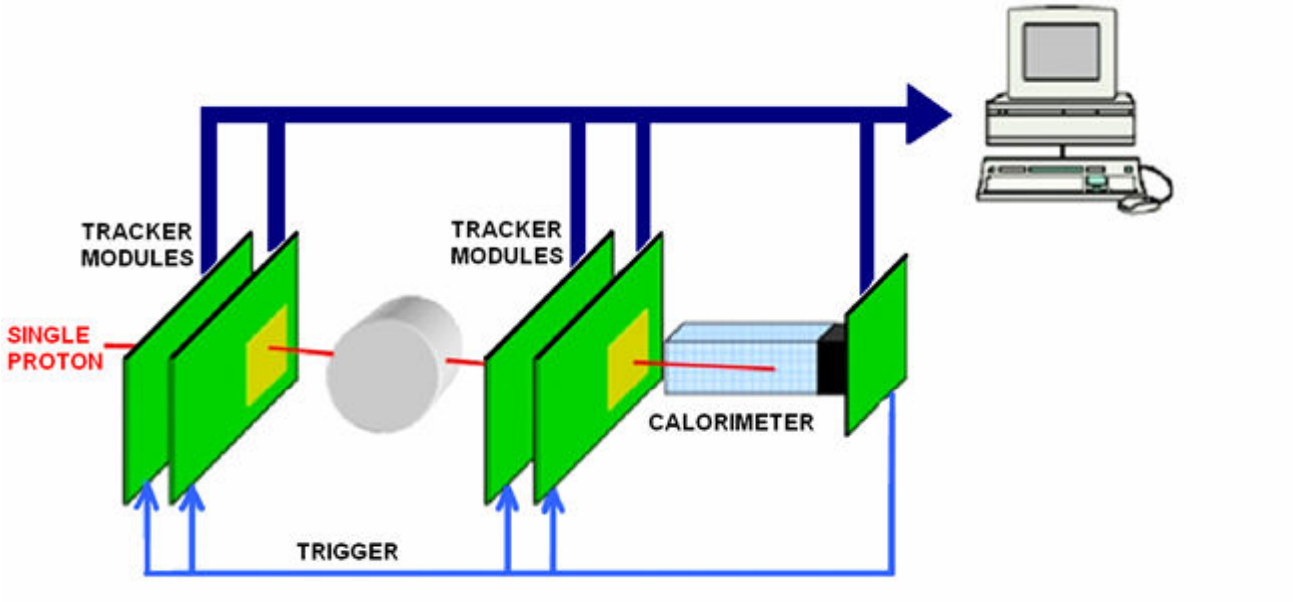
Reconstructed on p5



C. Talamonti et al., "Proton Radiography for clinical applications," NIM A, in press.

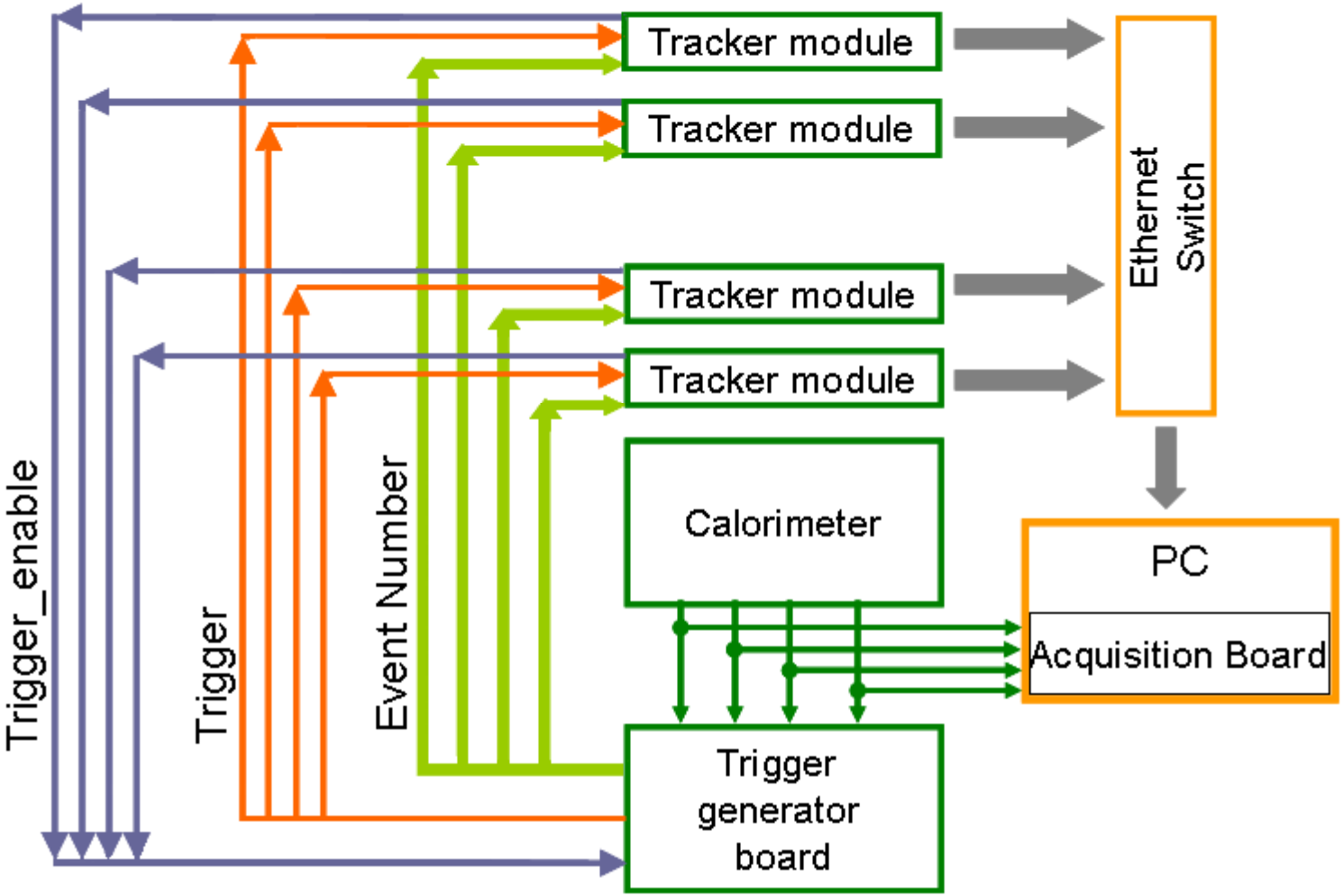
Proton imaging apparatus

First step in the realization of pCT device

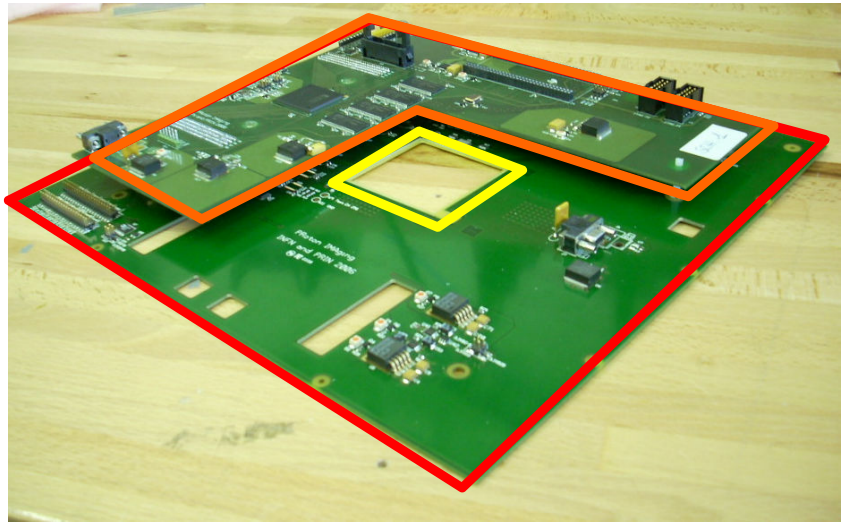


- 4 x-y TRACKER MODULES → **Entry and Exit position and direction**
- 1 CALORIMETER → **Residual Energy**

Data acquisition system



Single Tracker Module

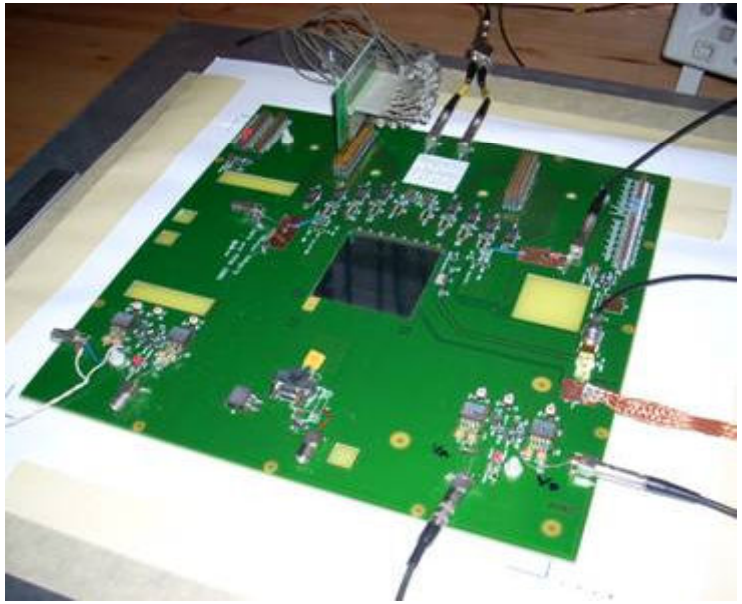


Front-end board

Detector location

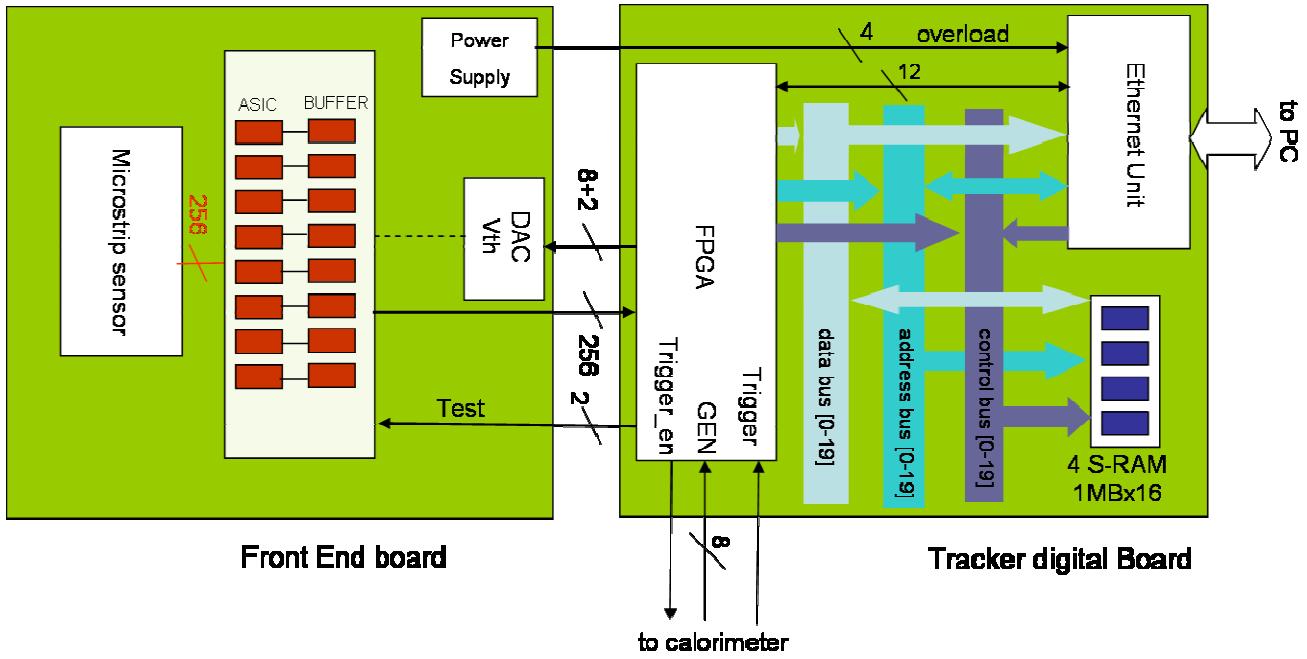
Digital board

Detector board with a detector and 8 chips containing the electronic front-end.



1 x-y plane consists of 2 single tracker modules

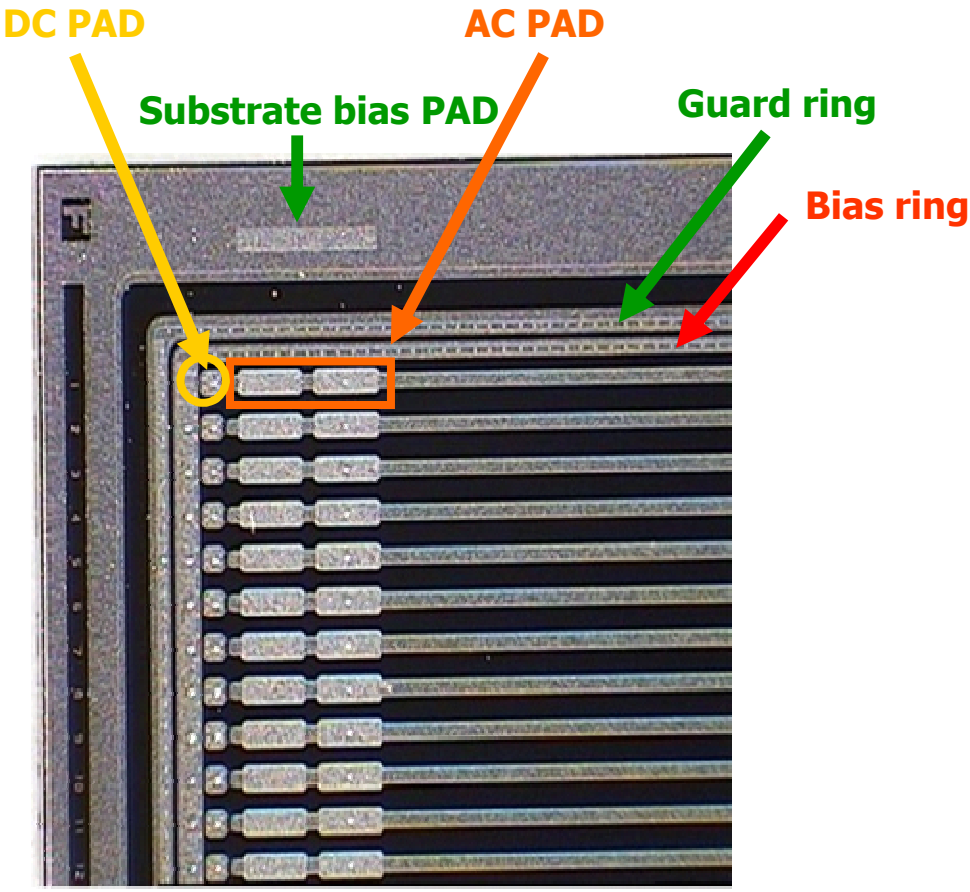
Tracker module architecture



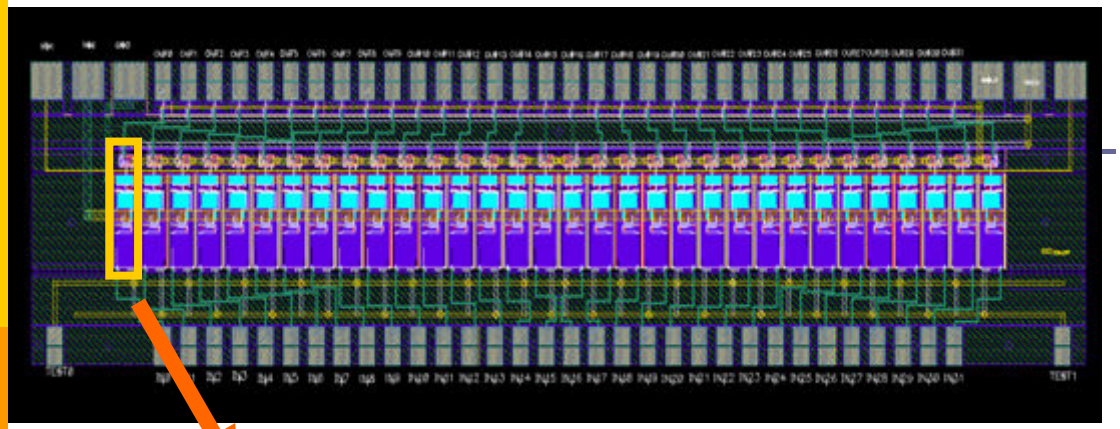
- To achieve a read-out rate of 1MHz a fully parallel digital strip readout system has been developed
- Eight 32-channel VLSI front-end chips acquire the detector signals and sends data in parallel to an FPGA (Xlinx Spartan-3AN) which performs zero suppression and moves data to a buffer memory (~$5x10^5$ events).
- An Ethernet commercial module is used both for data transfer to the central acquisition PC and to control the tracker module DAQ parameters

Detector Description

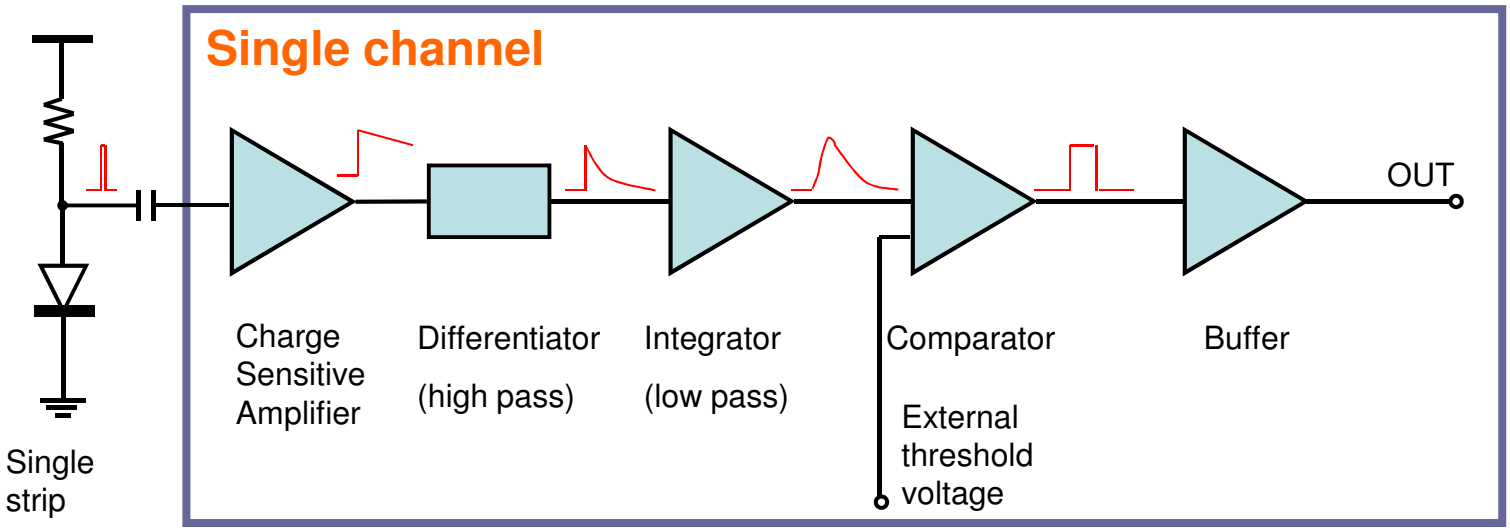
- 53 mm x 53 mm
- n-type substrate with p-type implants
- 200 µm thickness
- 256 strips, each 57 µm thick
- 200 µm pitch
- Integrated resistance for bias 1.5MOhm



VLSI front-end description



- AMS 0.35u CMOS Technologie
- 1.6 mm x 6 mm
- 32 channels
- Power dissipation = 14,5 mW @ chan
- Vcc = +3.3 V

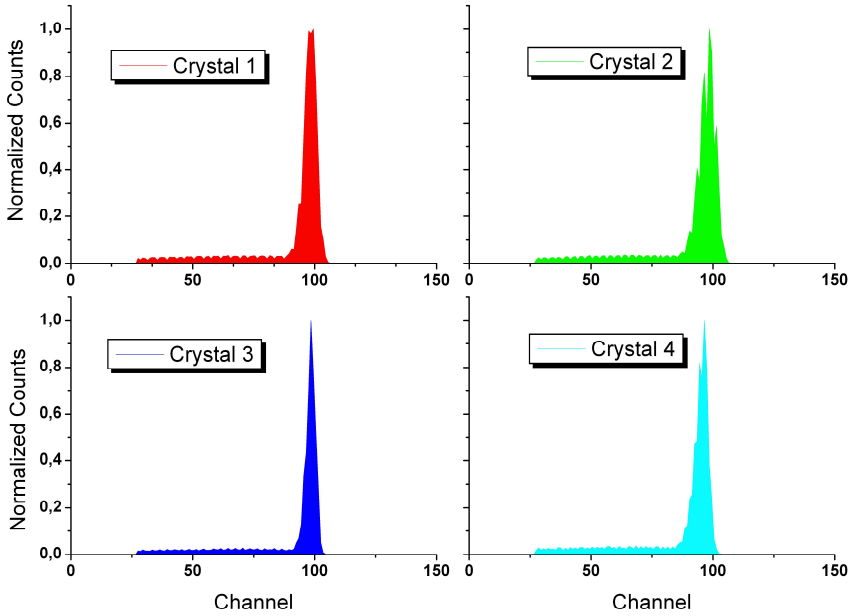


Calorimeter

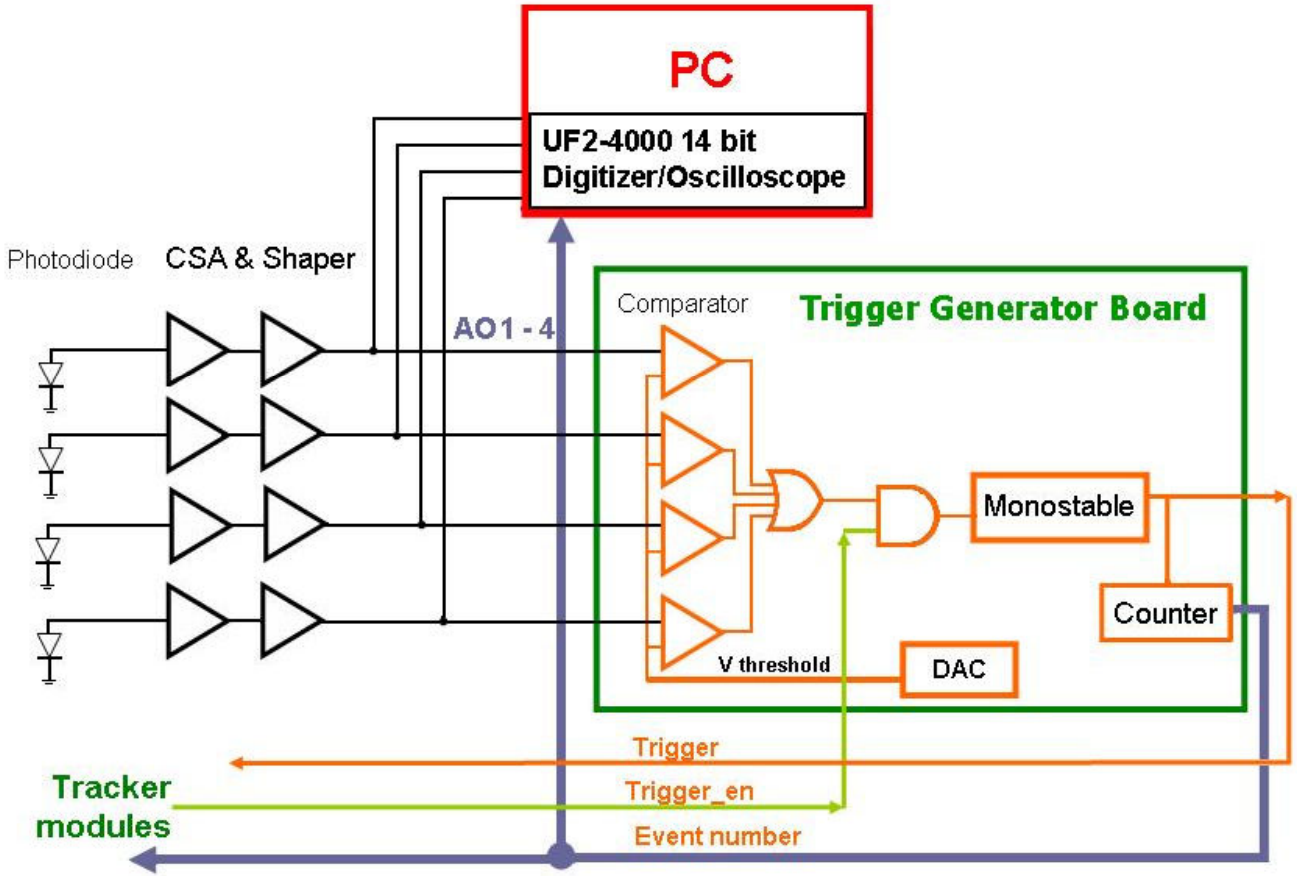
- 4 YAG:Ce scintillating crystals
  Each crystal 30 x 30 mm^2 x 100mm
- 4 Photodiode 18 mm x 18 mm
- 4 commercial front-end
  (Charge Sensitive Amplifier & shaper)

YAG:Ce properties	
PHYSICAL PROPERTIES	
Density [g/cm^3]	4.57
Hygroscopic	No
Chemical formula	$Y_3Al_5O_{12}$
LUMINESCENCE PROPERTIES	
Wavelength of max. emission [nm]	550
Decay constant [ns]	70
Photon yield at 300k [10^3 Ph/MeV]	40-50

Charge spectrum @100MeV

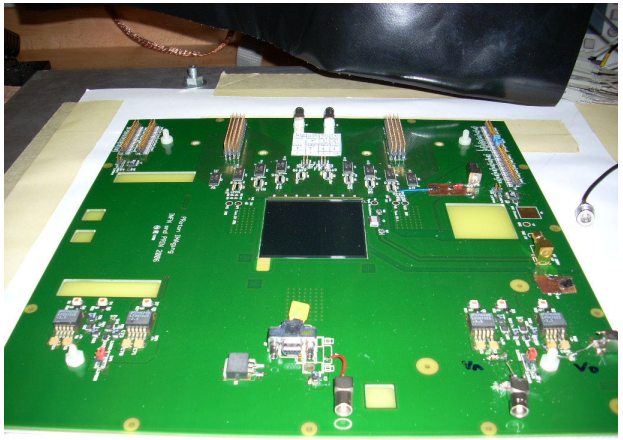


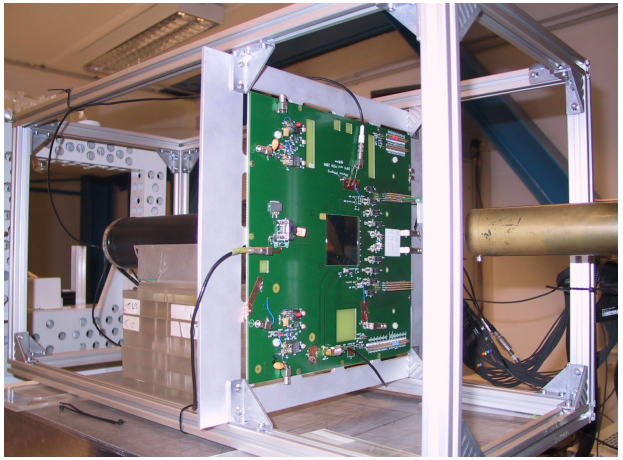
Calorimeter readout & Trigger generator board



Tracker module test

- First results of the beam test at Laboratori Nazionali del Sud with 62MeV protons
- New calibration
- Test with beta source

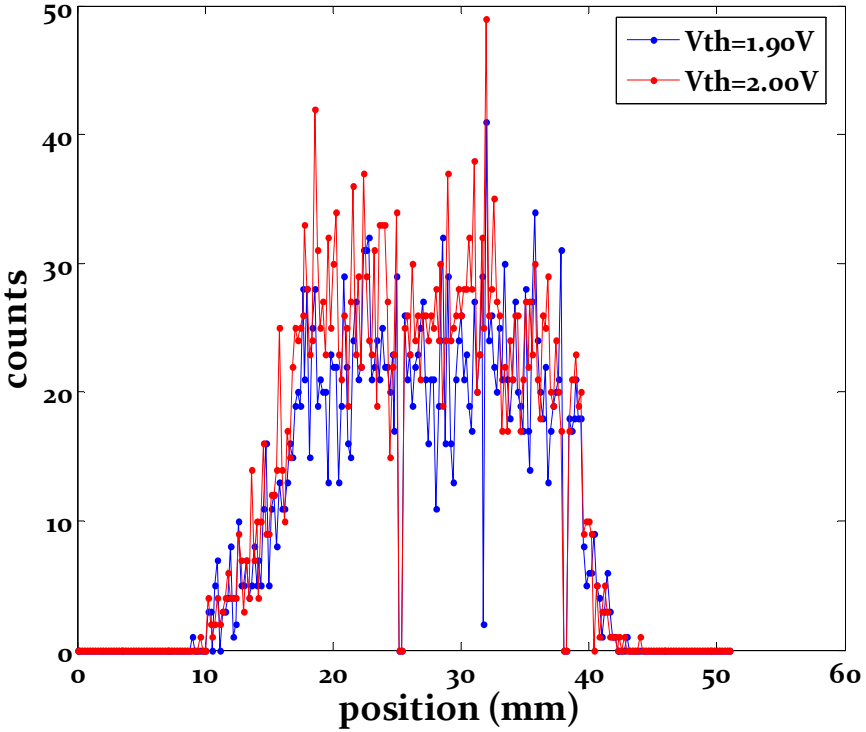


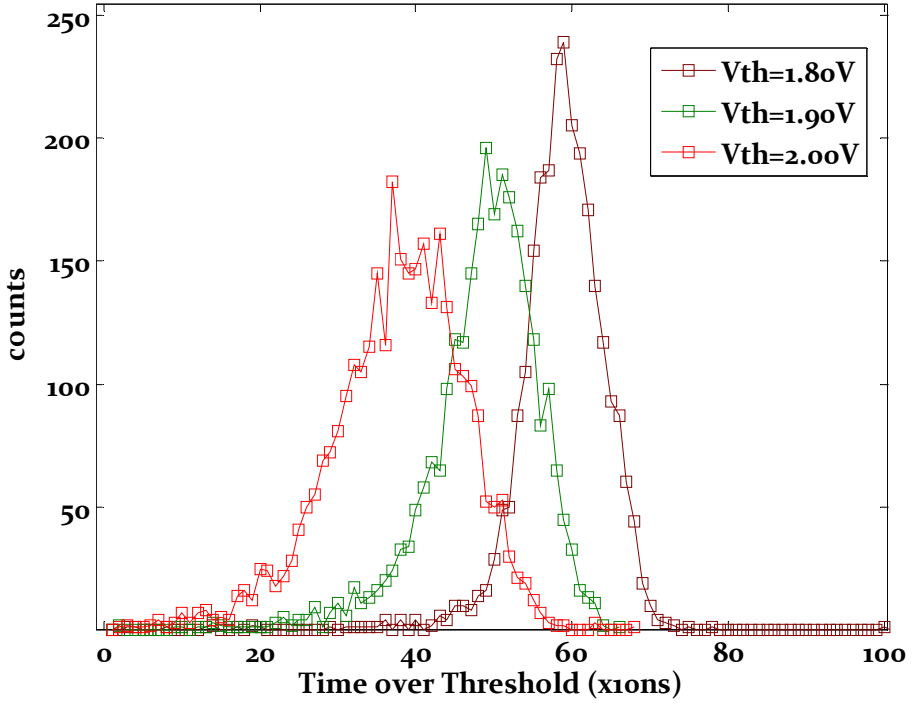


Tracker module:

62MeV proton beam at Laboratori Nazionali del Sud (LNS)

- Front-end board and digital board : beam profile
- Time Over Threshold for different threshold voltage





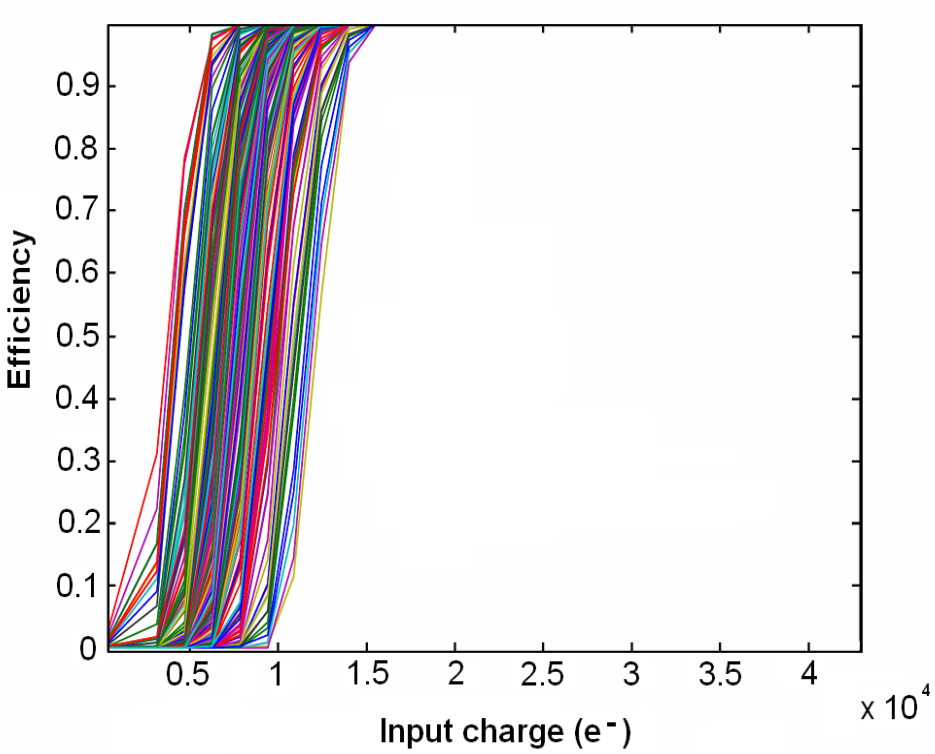
A threshold voltage value for all chips

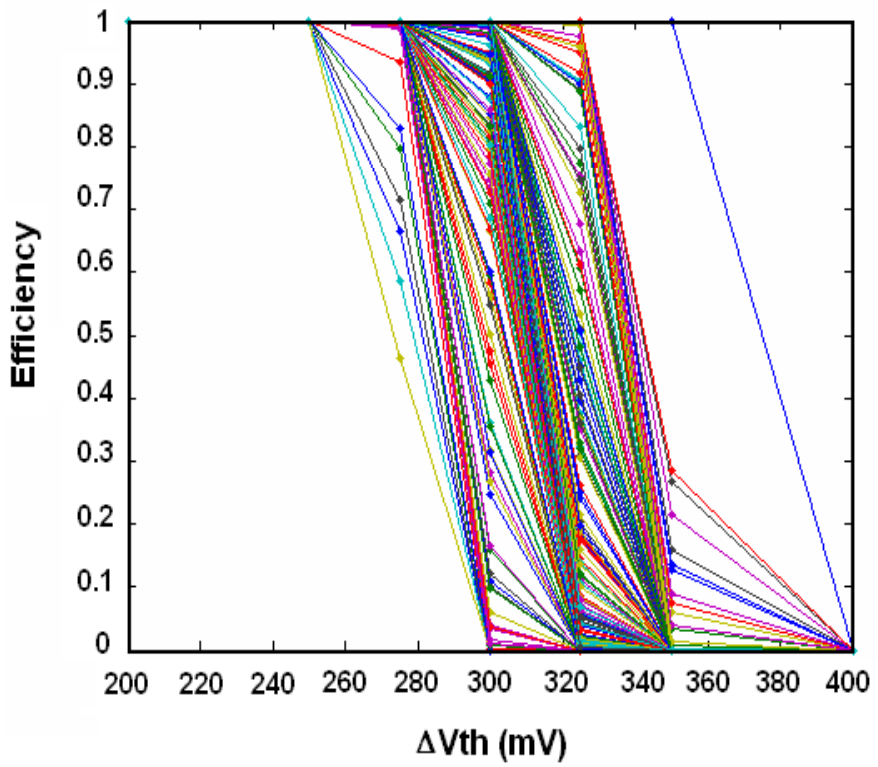
Single tracker module:

New calibration with a threshold voltage value for each chip

Efficiency of all channels vs input charge for fixed threshold voltage: ΔVth=0

Efficiency of all channels vs threshold voltage for fixed input signal: Q= 5MIP

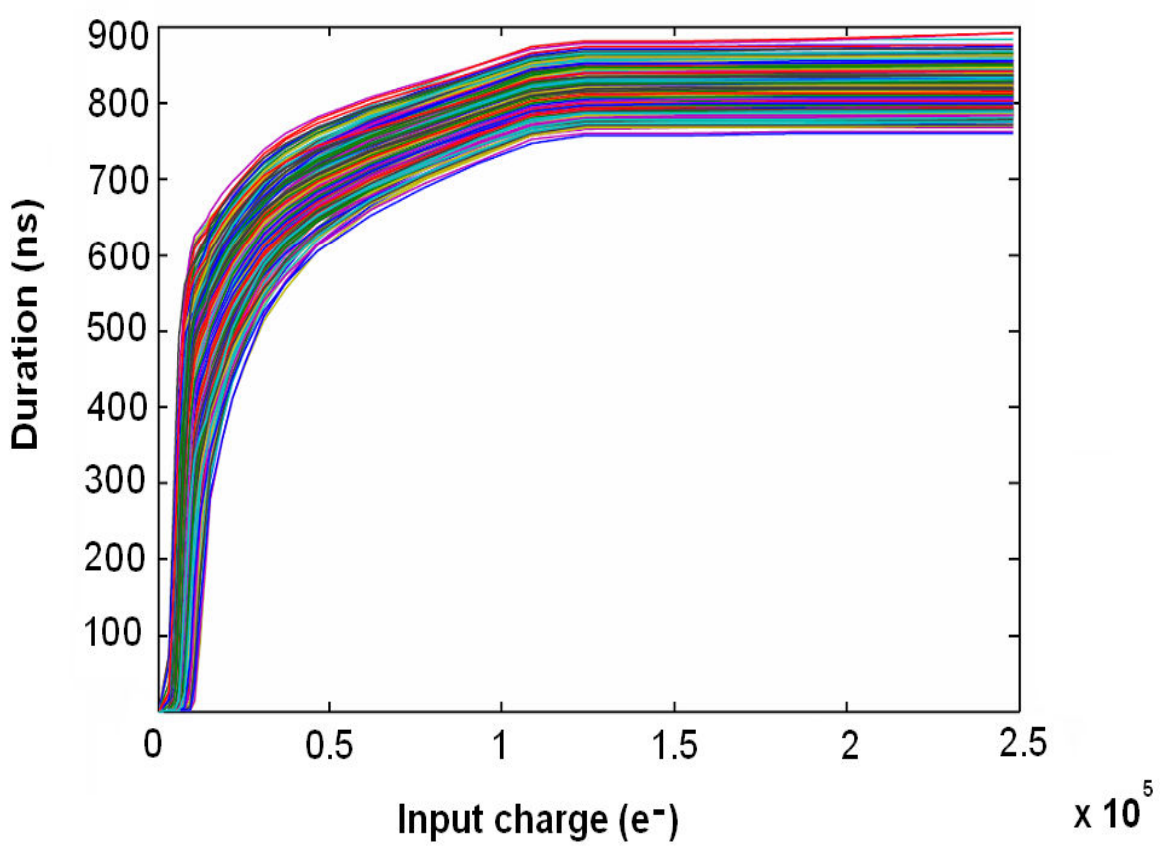




Single tracker module:

New calibration with a threshold voltage value for each chip

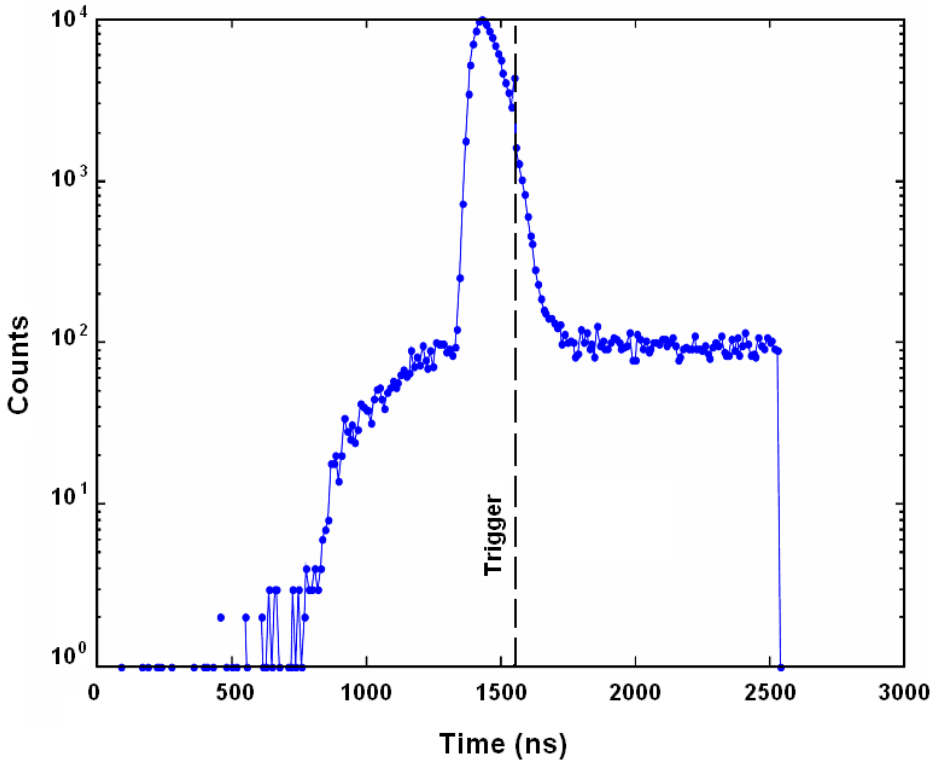
- T(Q) calibration curves: Duration pulse vs input equivalent charge

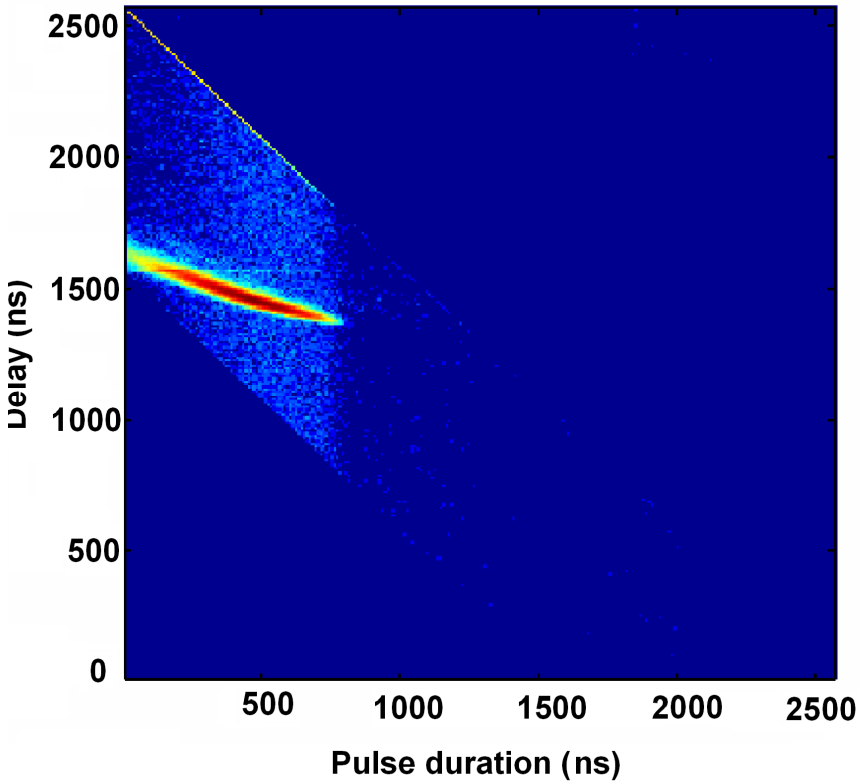


Single tracker module:

Test with beta source 90Sr

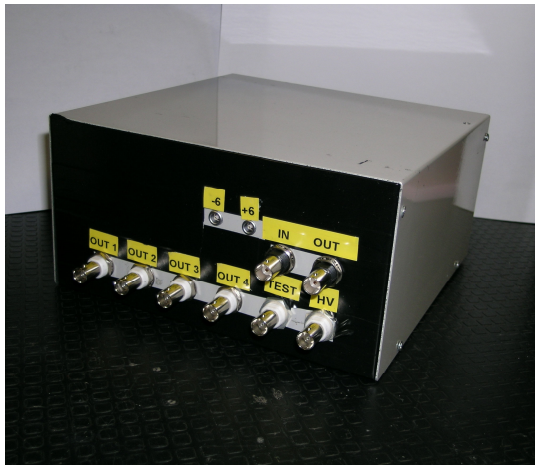
- Acquisition rate = 20kHz
- Total counts =100000 events





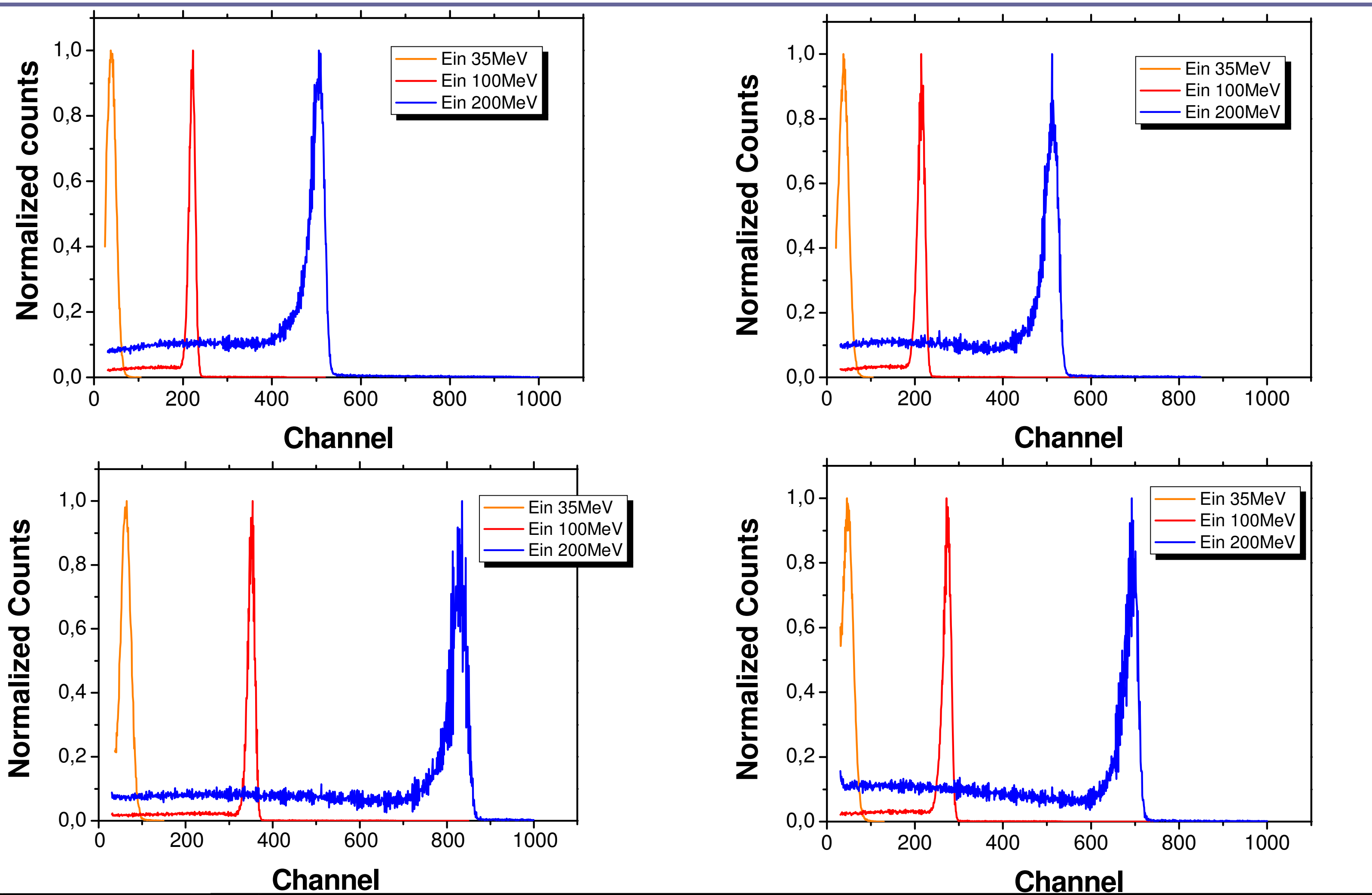
Calorimeter test

- Linearity study
- Homogeneity study
- New electronic readout



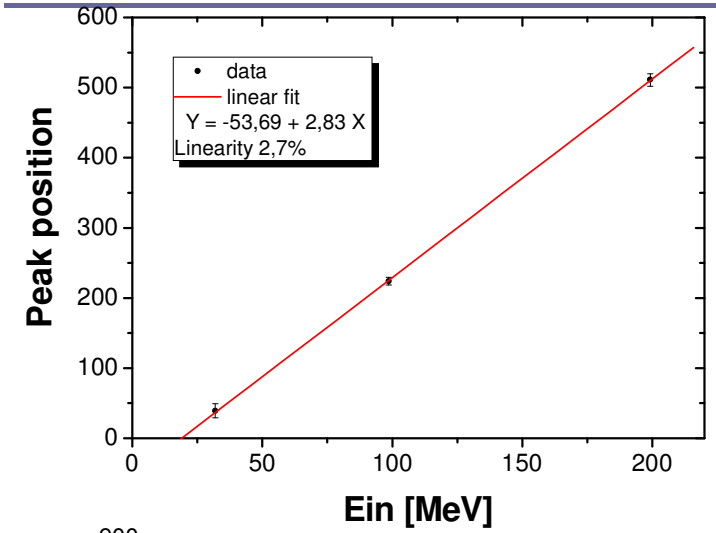
Calorimeter: beam test -Loma Linda Medical Center

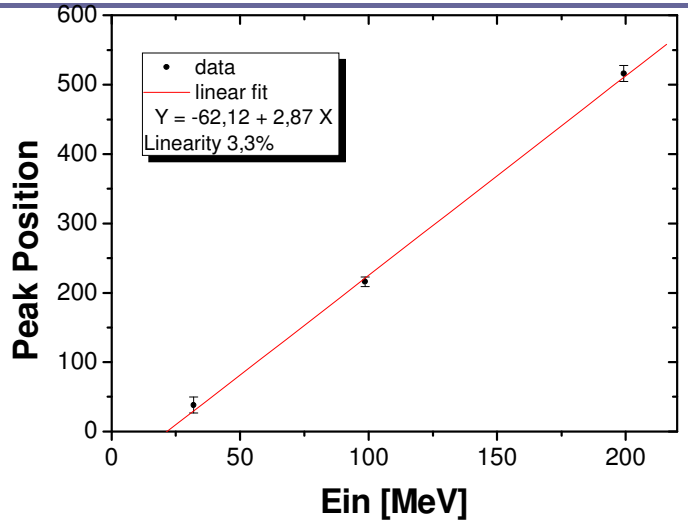
Charge spectrum at different proton energies

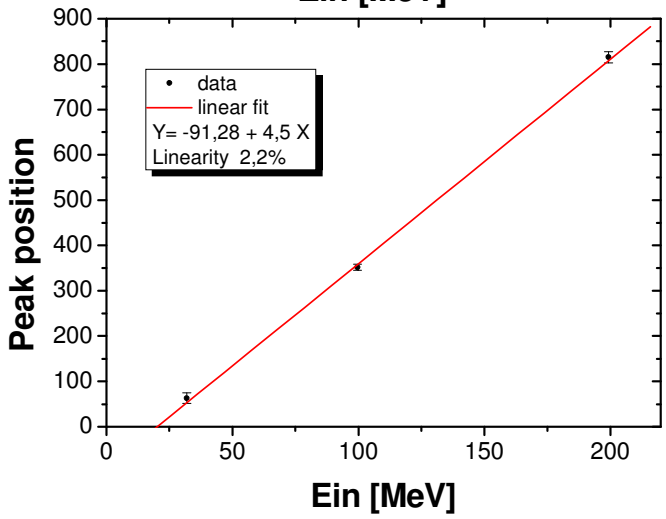


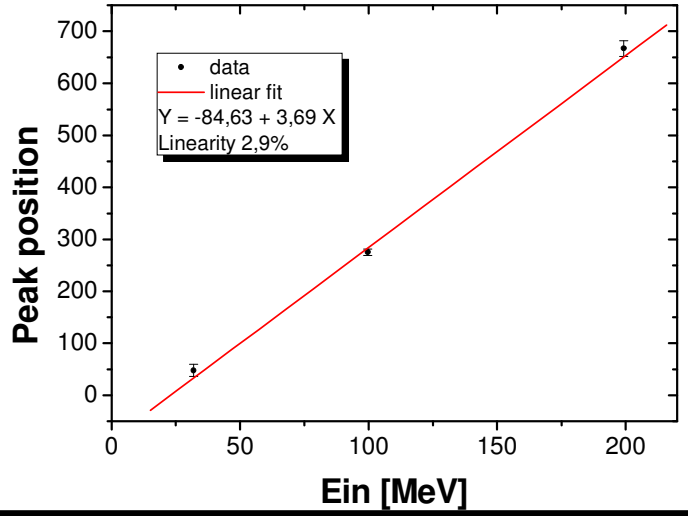
Calorimeter: beam test -Loma Linda Medical Center

Linearity (30-200MeV energy proton range)



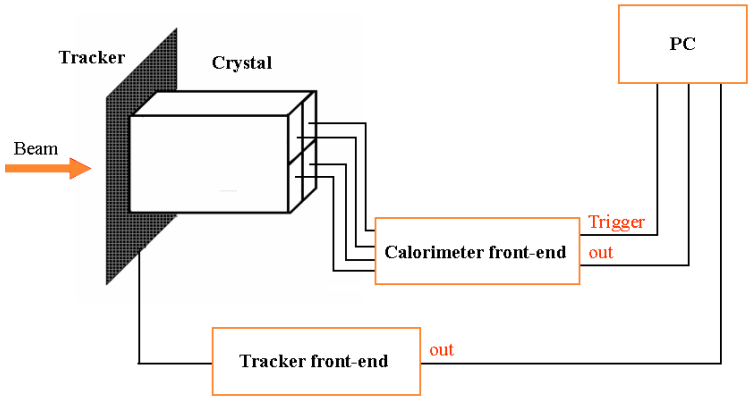






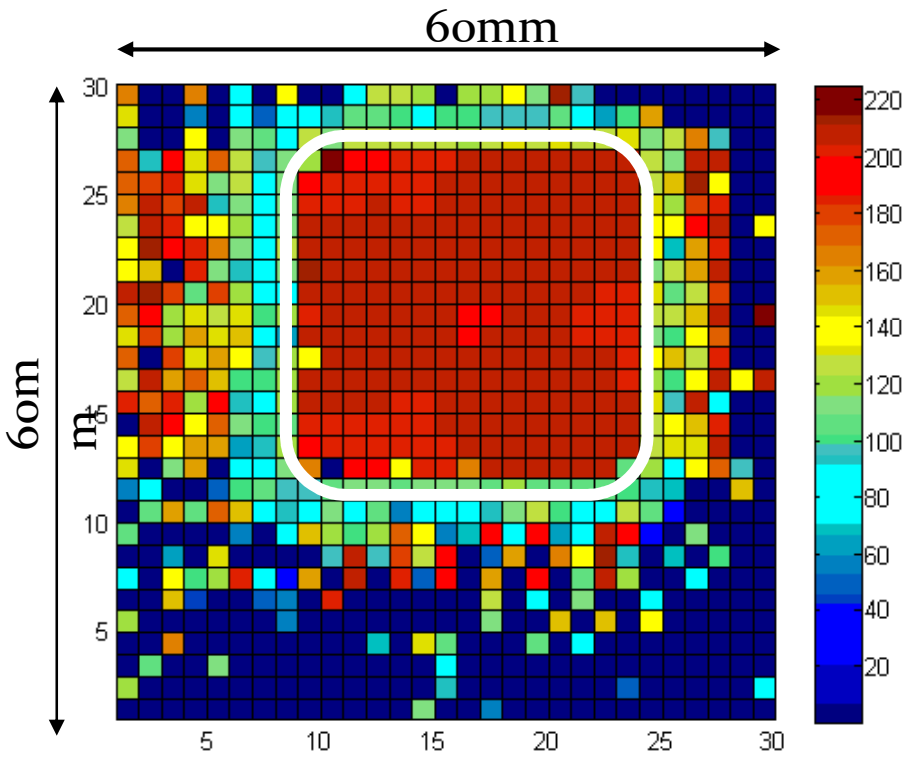
Calorimeter: beam test -Loma Linda Medical Center

Single crystal homogeneity study



The tracker area has been divided into 30x30 squares (area = 2x2mm²). For each square the charge spectrum has been made.

This is the map of the charge spectrum peak value

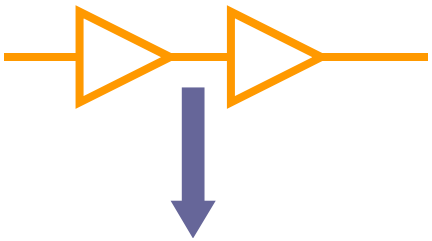


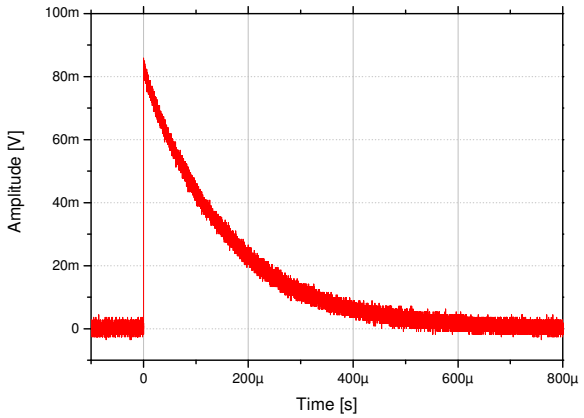
Calorimeter:

New electronic readout

- Yesterday

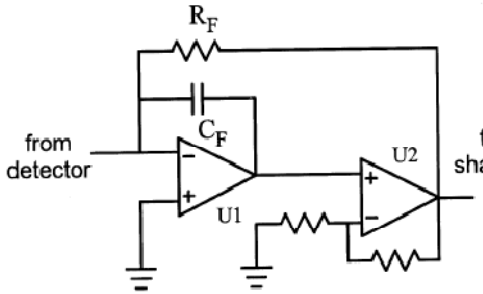
CR110 + CR220-3us





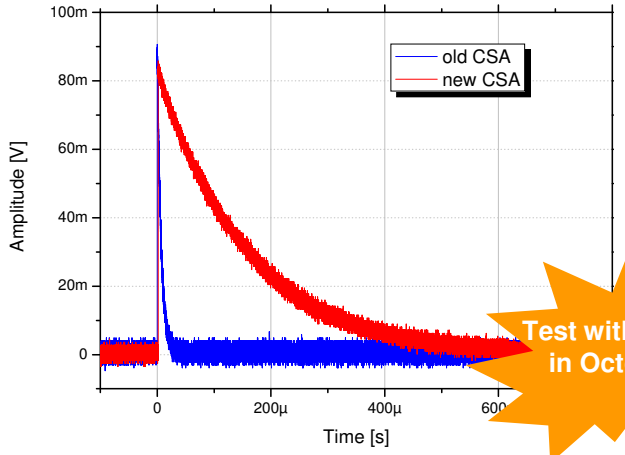
Low acquisition rate

- Today



$$T_d = \frac{R_F \times C_F}{A}.$$

Bassini, Boiano and Pullia IEEE TNS, VOL. 49, NO. 5, OCTOBER 2002



Test with YAG:Ce in October '09

High acquisition rate

Conclusions

A proton imaging device is being built by the Italian collaboration

- Tracker
  - *Single module: assembled and tested at LNS with 62MeV proton beam*
- Calorimeter
  - *YAG calorimeter: completely characterized at LLMC with 30-200MeV proton beam*
  - *Front-end electronics: prototype exists (commercial parts)*
  - *Trigger generator assembled*

Future plans

- Calorimeter with new front-end (higher rate): to be tested with proton beam (by the end of 2009)
- Two tracker modules (one x-y plan) and the calorimeter: to be tested with proton beam (by the end of 2009)
- Complete device built (by the end of 2010)