UNIVERSITÀ DEGLI STUDI DI TORINO

HoVe IT
INFN project

INFN
Istituto Nazionale di Fisica Nucleare

LGAD-based detectors for monitoring therapeutic proton beams

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**Fondazione Bruno Kessler (FBK)*

12th International Conference on
POSITION SENSITIVE DETECTORS

Hosted by
UNIVERSITY OF BIRMINGHAM

Acknowledgments

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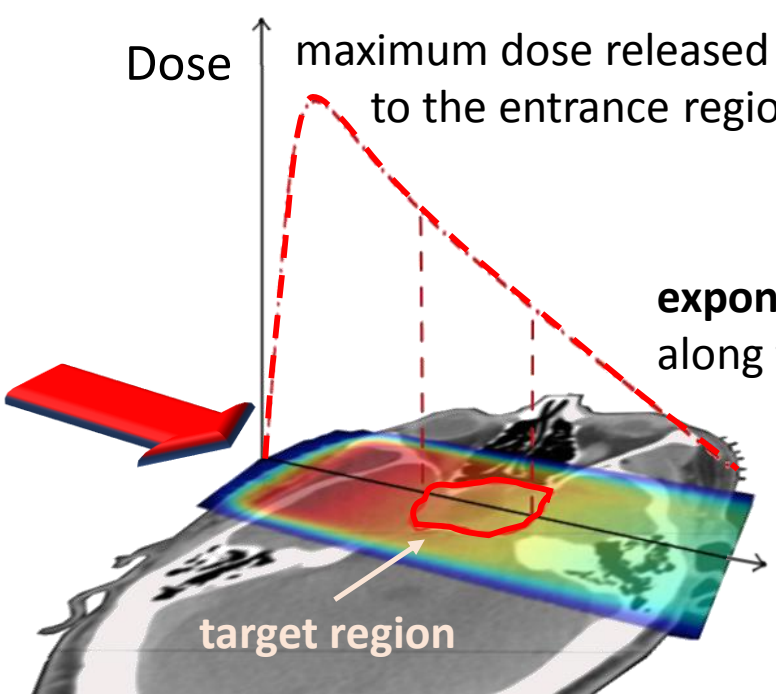
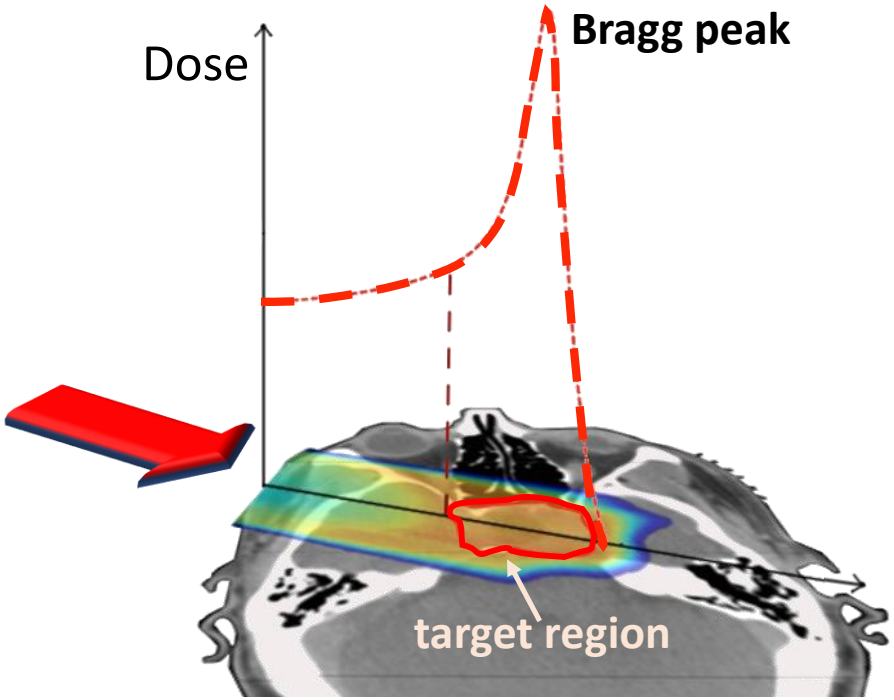
Particle Therapy



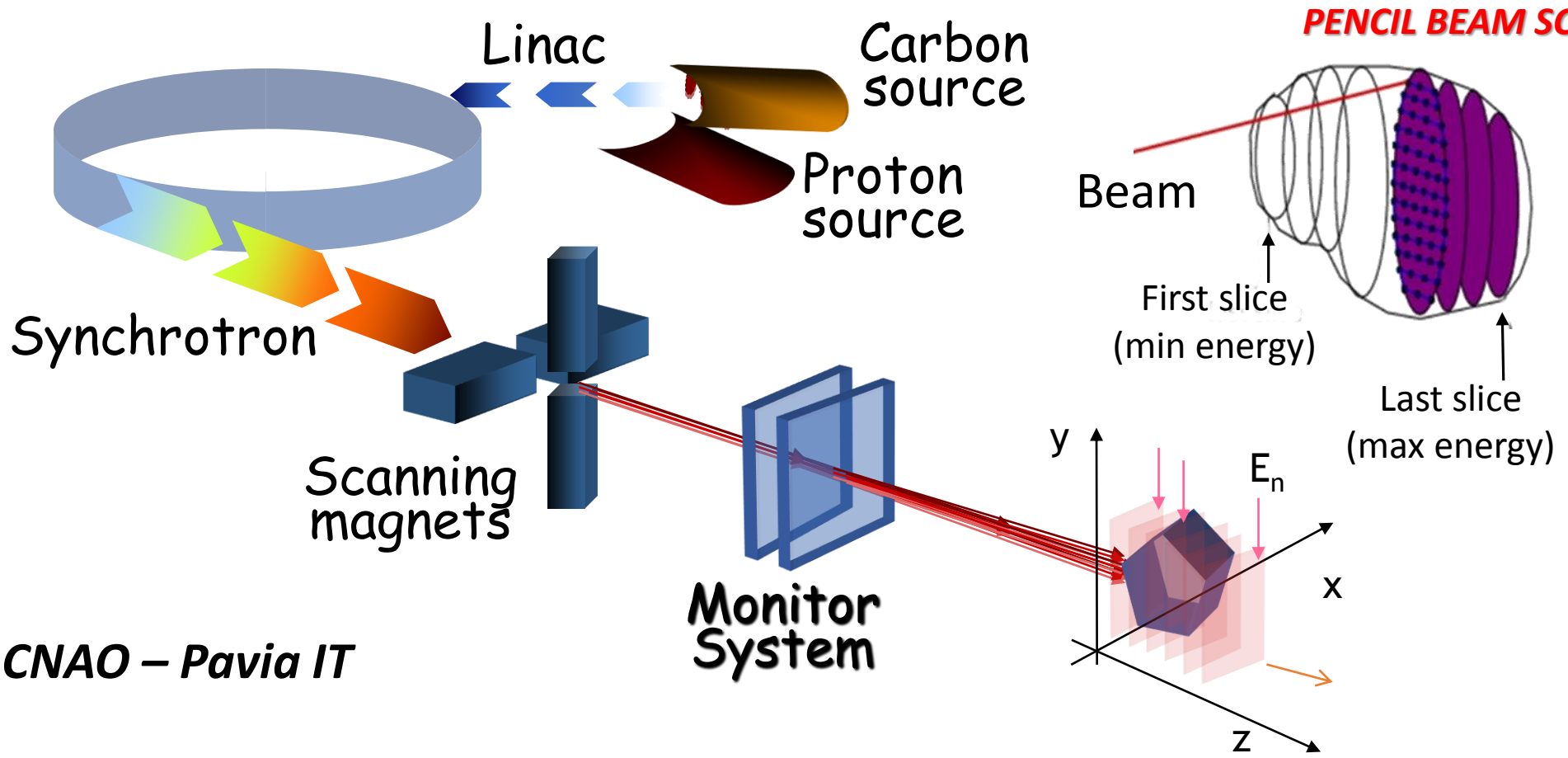
maximum dose released close to the entrance region

exponential decay of the dose along the beam path



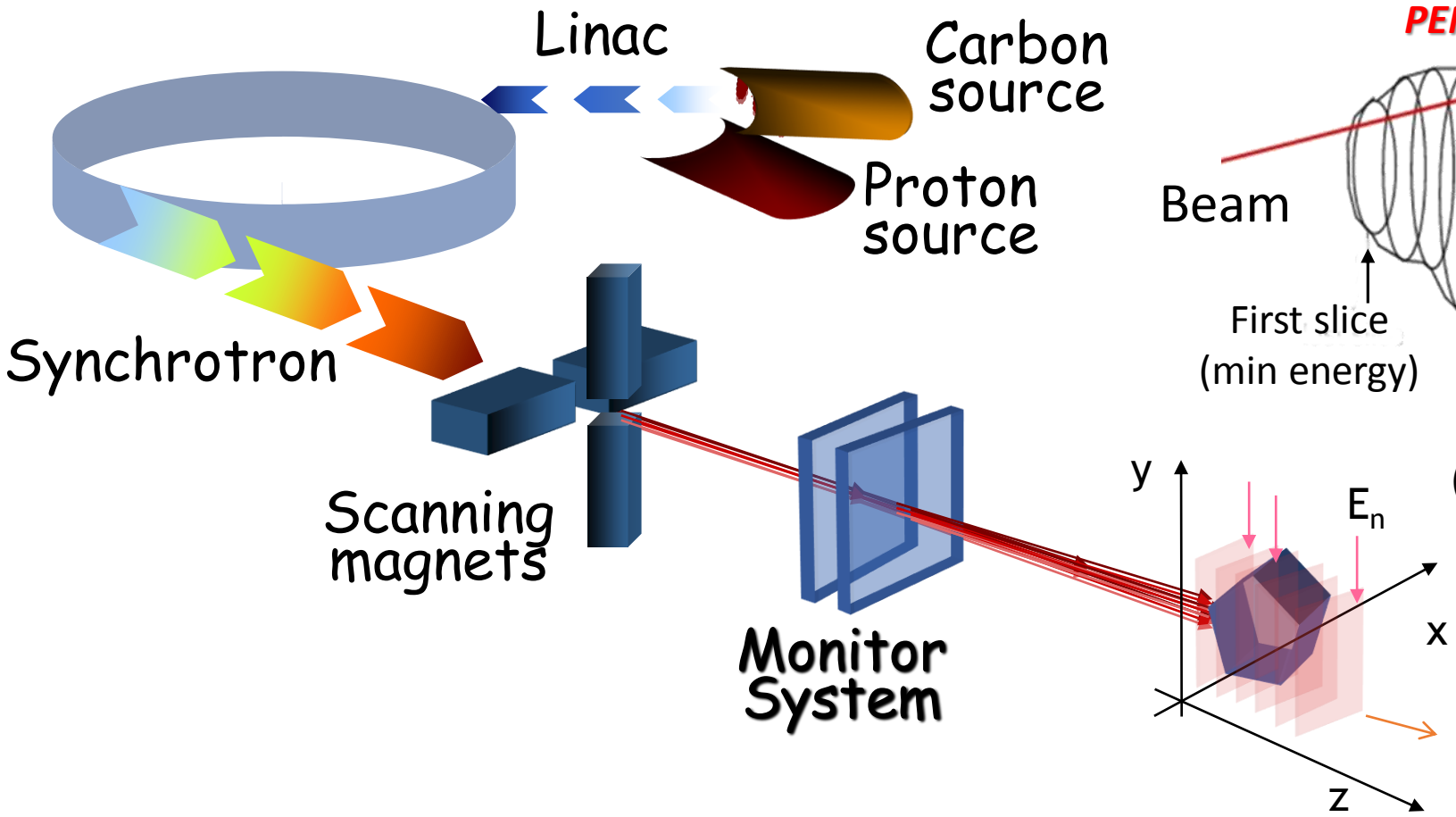
dose released to the tissues

Dose Delivery System

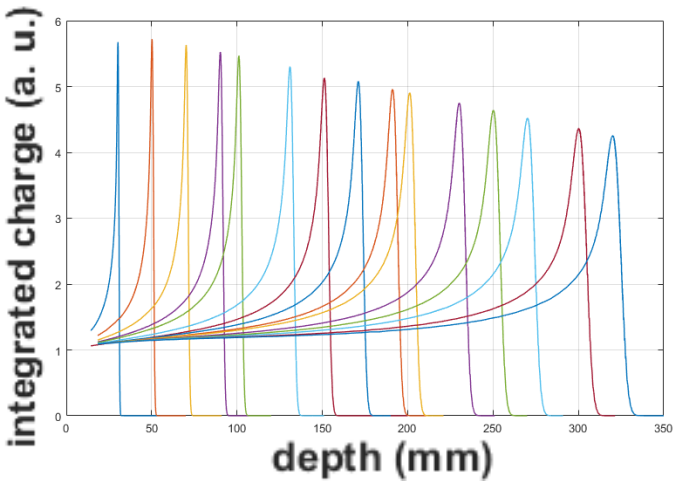


CNAO – Pavia IT

Dose Delivery System



PENCIL BEAM SCANNING



A correct dose distribution needs a precise **monitoring** of the beam parameters:

fluence, position, shape, energy

MoVe IT
INFN project

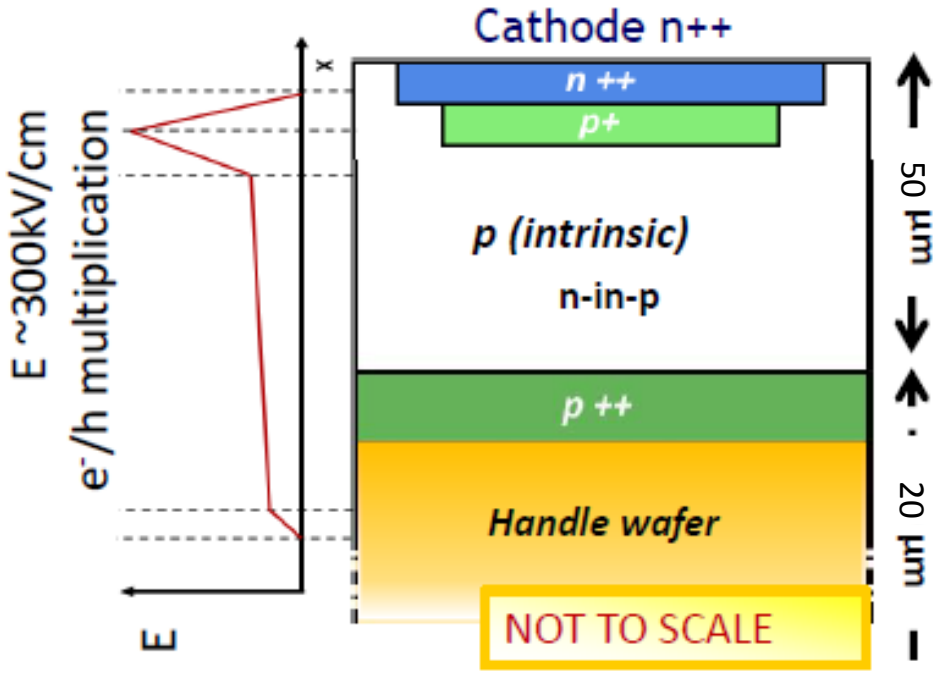
Modelling and **Ve**rification for **I**on beam **T**reatment planning

Development of two prototypes of innovative detectors based on silicon (UFSDs) for beam monitoring:

1. to **directly count** individual protons

2. to measure the **beam energy** with time-of-flight techniques

Ultra Fast Silicon Detectors (UFSD)

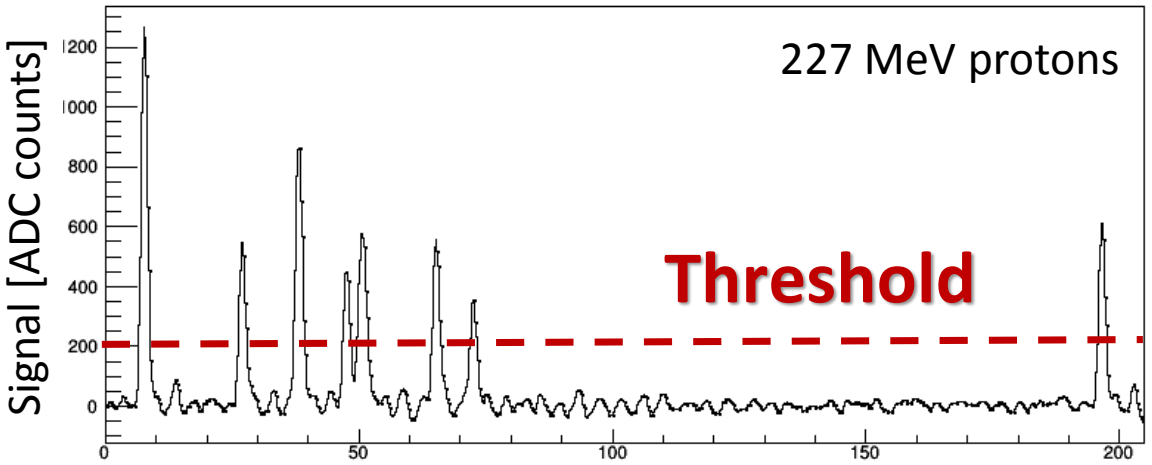


Based on the Low Gain Avalanche Diode (LGAD) techonology

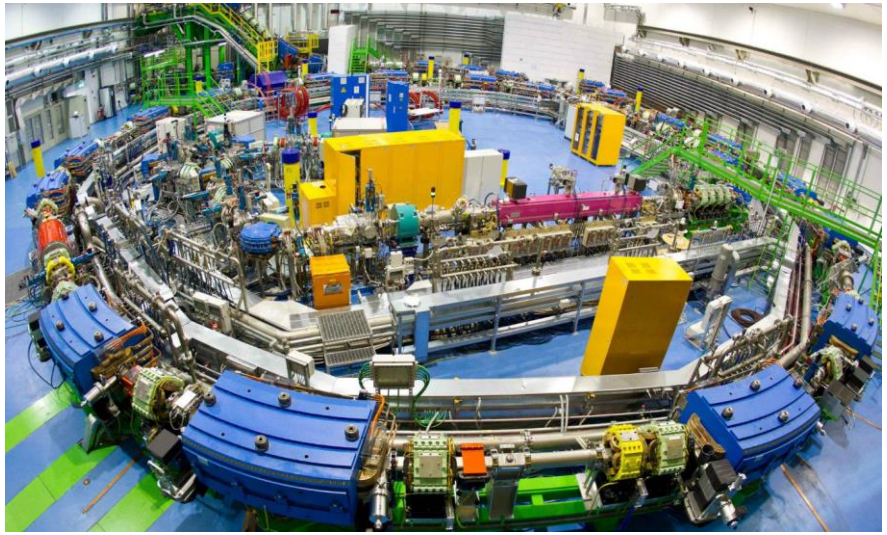
- Thin p^+ gain layer implanted under the n^{++} cathode
  - → Controlled low gain (~ 10-30)
  - → Gain increases with bias voltage
  - → High Signal/Noise ratio
- Small thickness of active volume 50 µm
  - → Reduced beam perturbation, signal steepness
  - → Loss of signal due to reduced thickness compensanted by the internal gain

N Cartiglia (Talk on Tuesday)

Short signal duration (< 2 ns)
→ particle counting
Excellent time resolution (tens of ps)
→ beam energy measurement from time-of-flight



fondazione CNAO
Centro Nazionale di Adroterapia Oncologica per il trattamento dei tumori



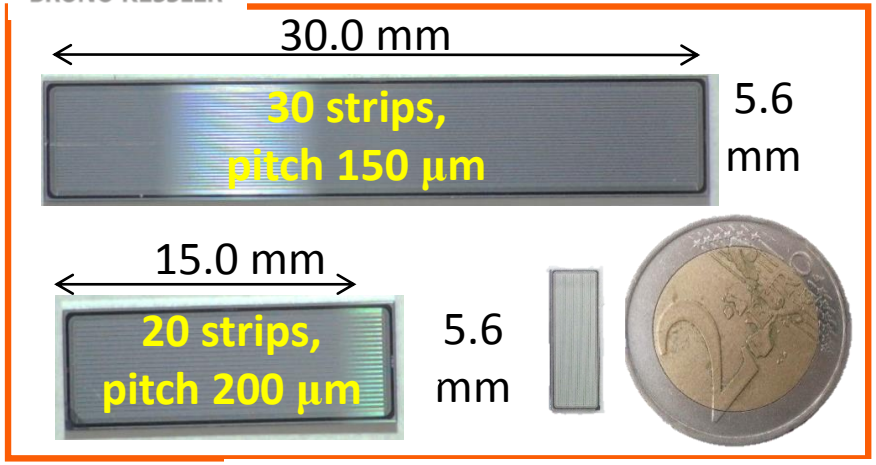
Synchrotron
FWHM 10 mm
Flux 10^8 - 10^9 p/s in spills
Intensity 20 - 50 - 100%
Energy 62 - 227 MeV

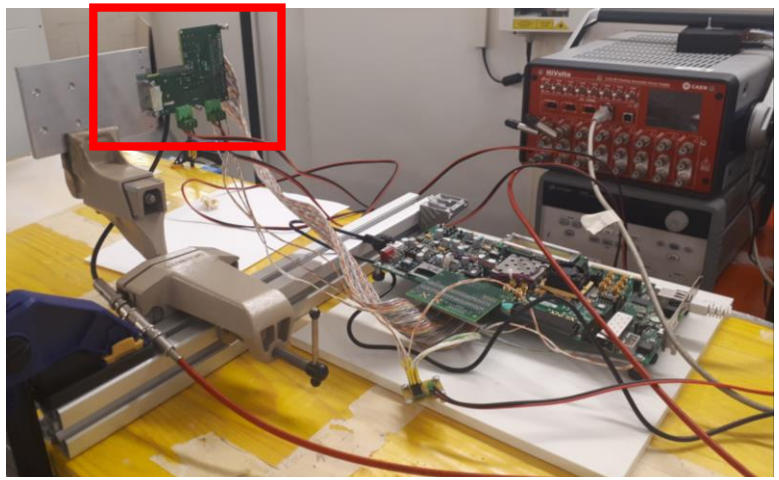
TIFPA
Trento Institute for Fundamental Physics and Applications
PROTONTERAPIA TRENTO

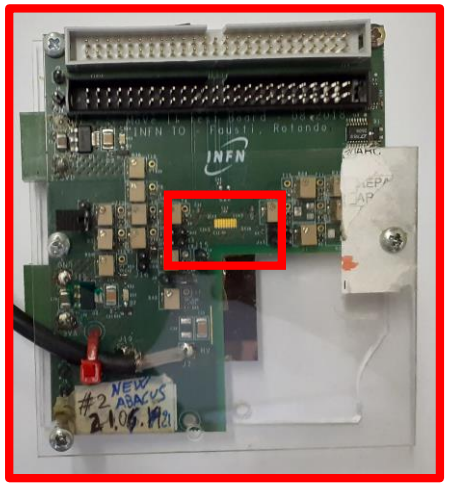
Cyclotron
FWHM 3 - 7 mm
Flux 10^6 - 10^{10} p/s
Current 1 - 320 nA
Energy 68 - 228 MeV

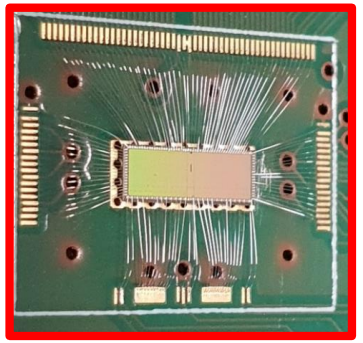
Particle Counting

Counting Prototypes and Readout

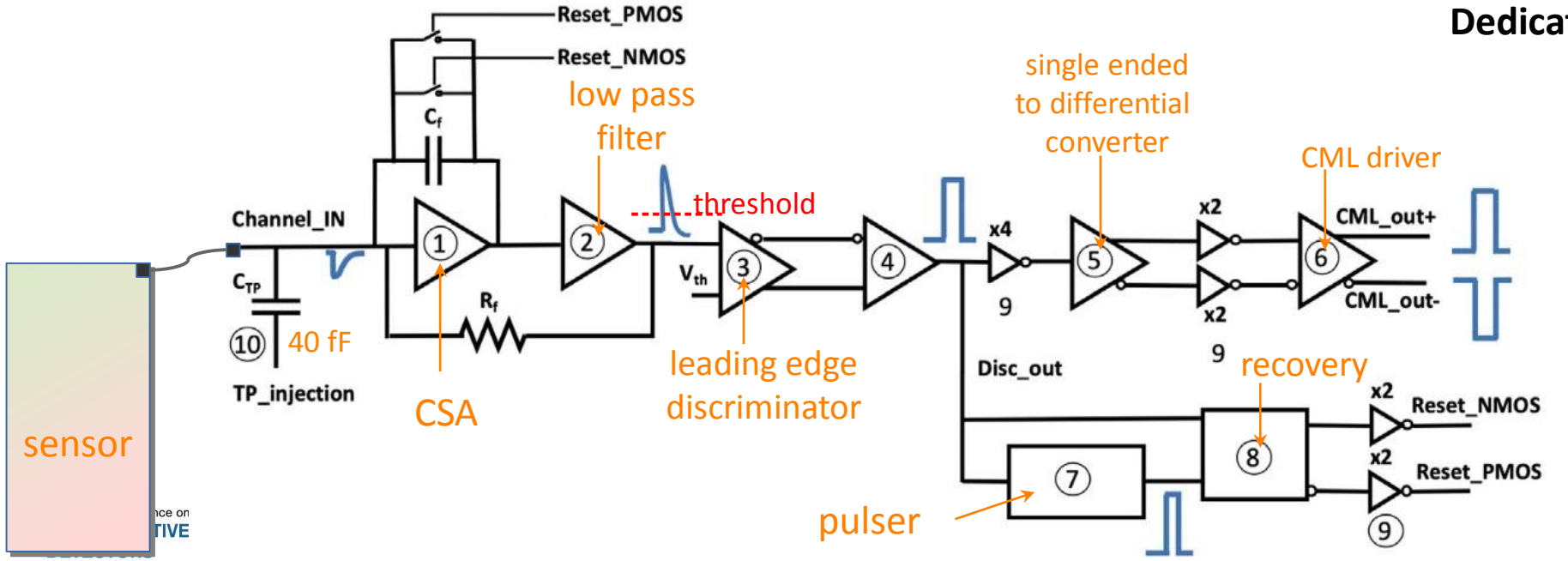








Dedicated fast ASIC chip (ABACUS)



Dead time → ~ 10 ns

Counting accuracy at 1%

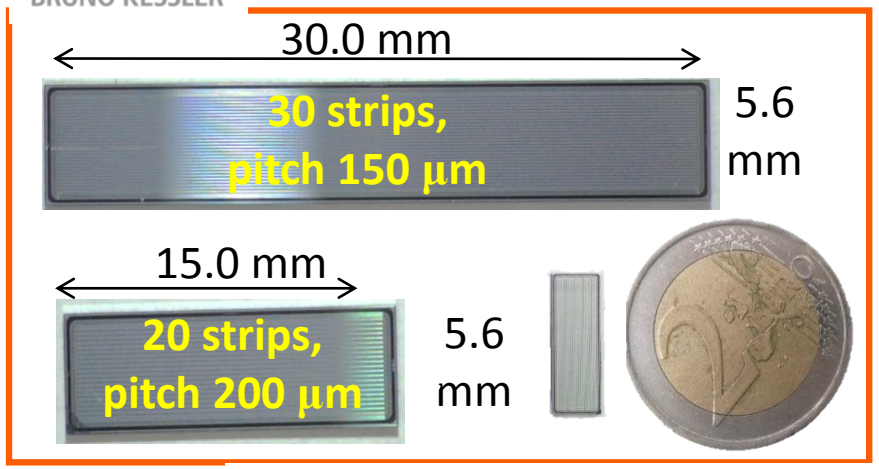
110 nm CMOS technology

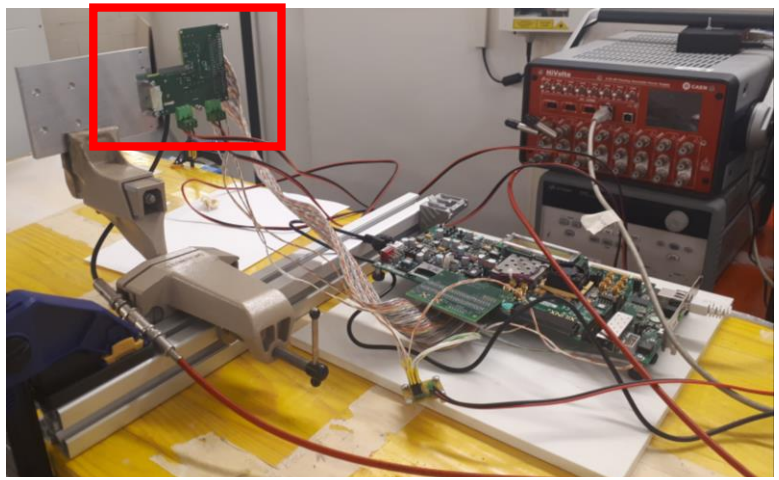
Chip area = 2 × 5 mm^2

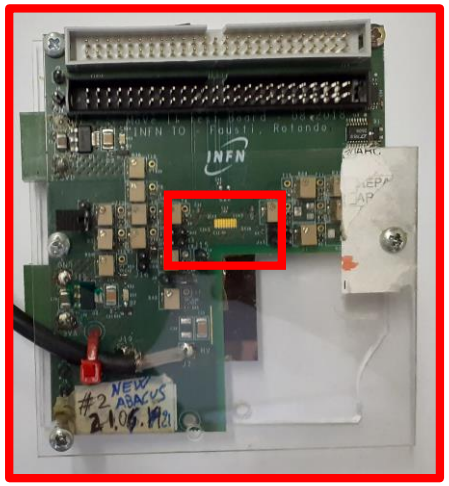
24 channels

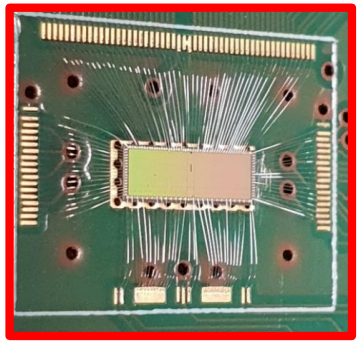
CSA dynamic range: 4 - 150 fC

Counting Prototypes and Readout









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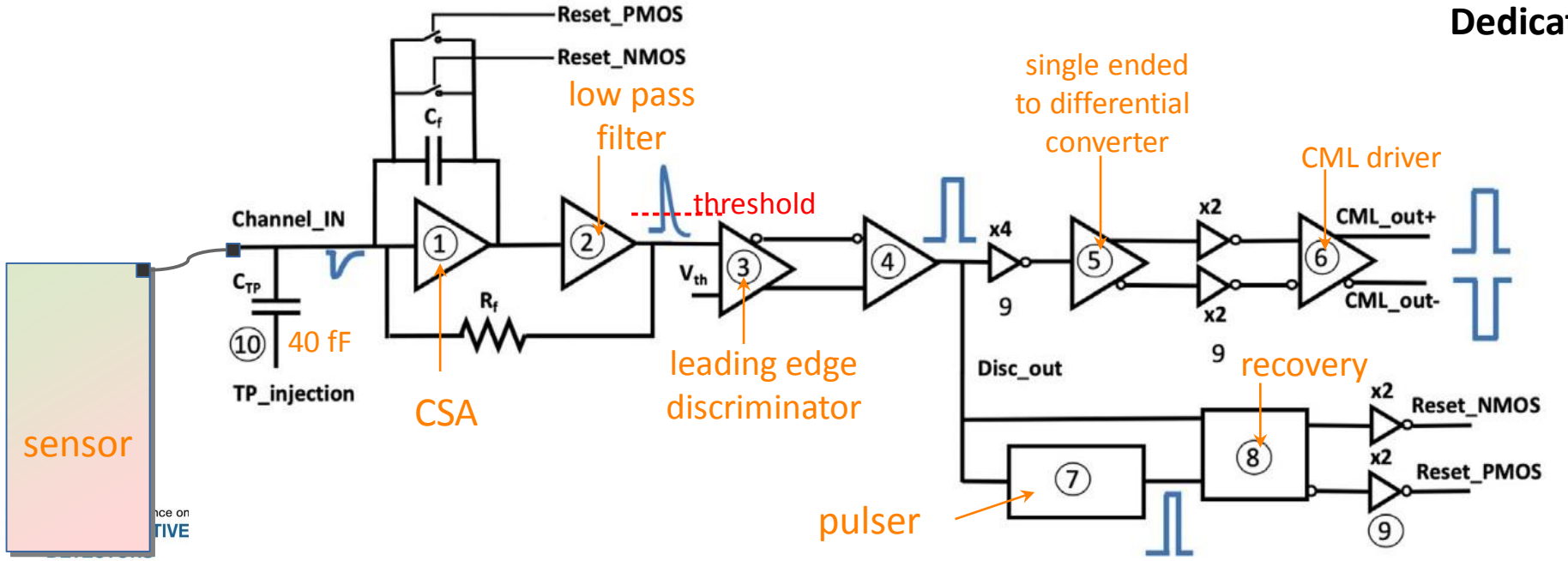


Dead time → ~ 10 ns

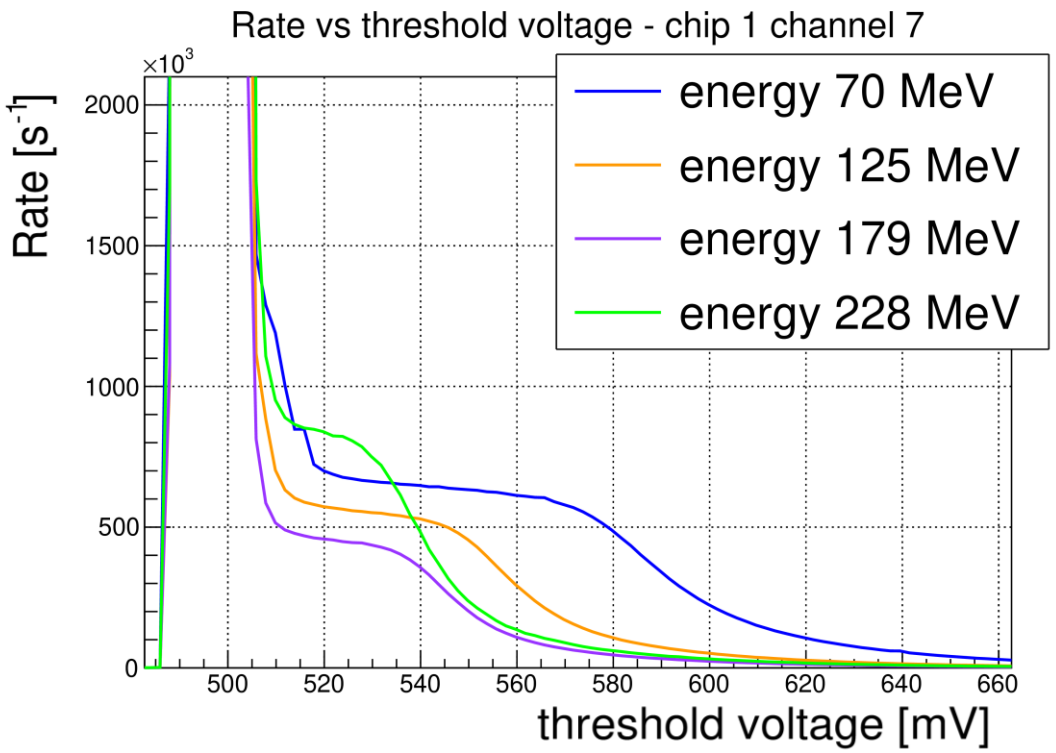
FPGA

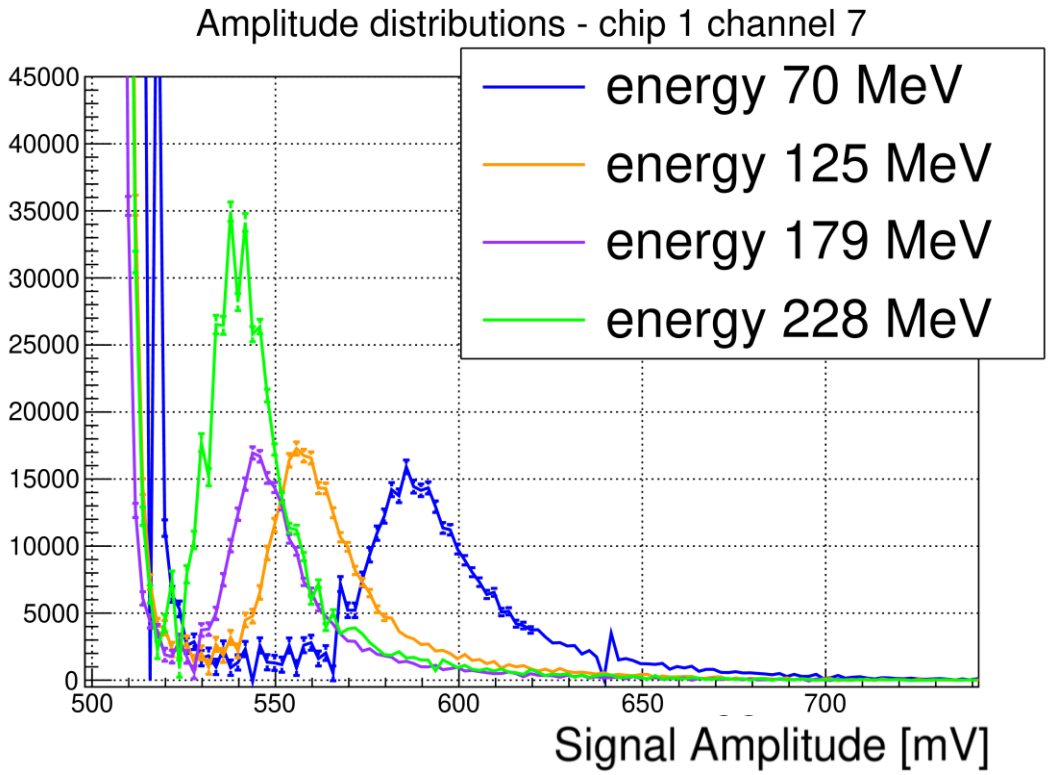
- **FE inizialization**
- **Pulse counting**
- **Pileup correction**

CSA dynamic range: 4 - 150 fC

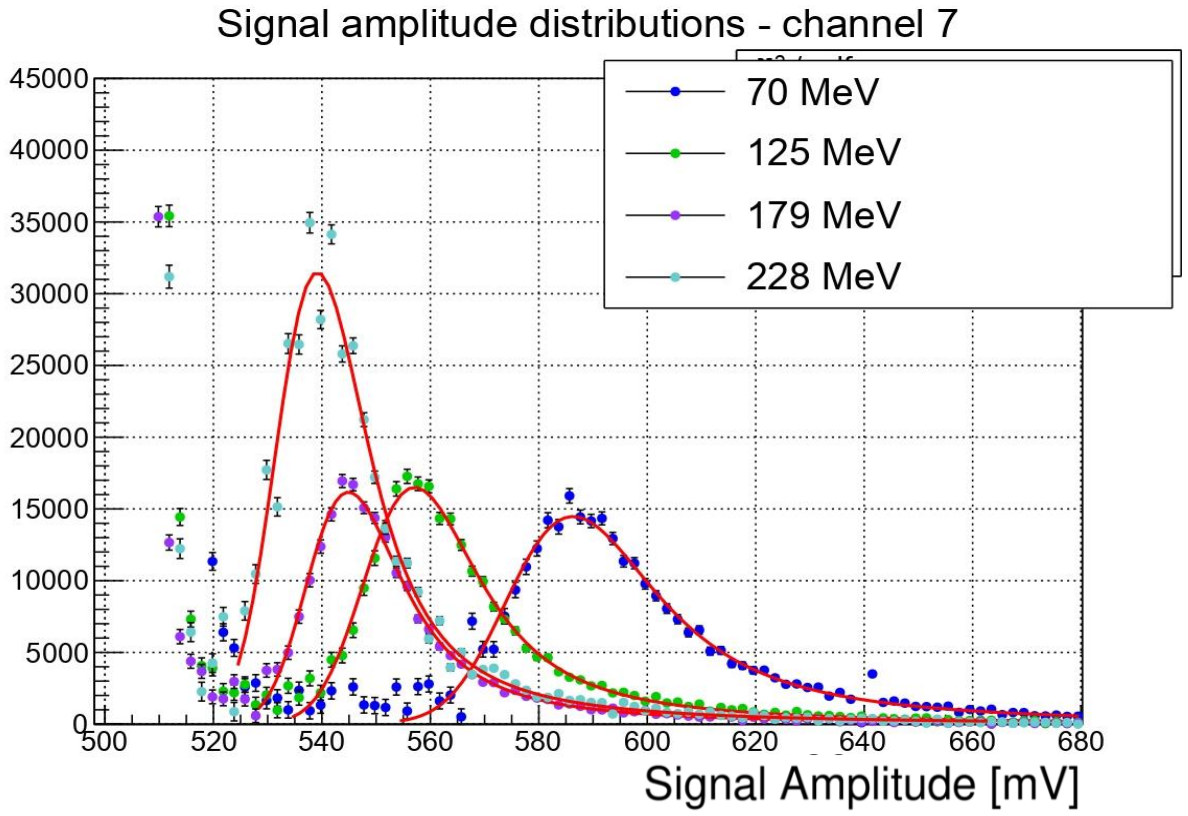
Tests with the ABACUS testboard at TIFPA

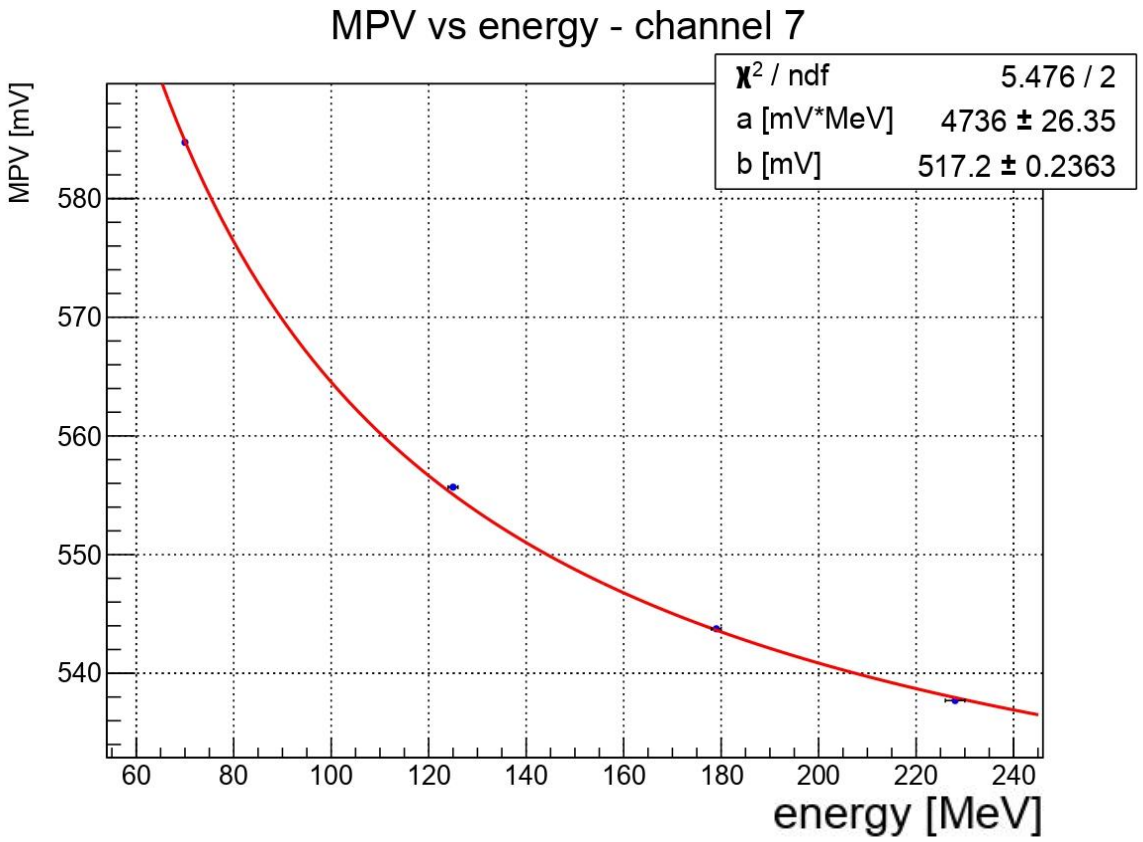
Threshold scans with 4 different proton beam energies (70 MeV, 125 MeV, 179 MeV, 228 MeV





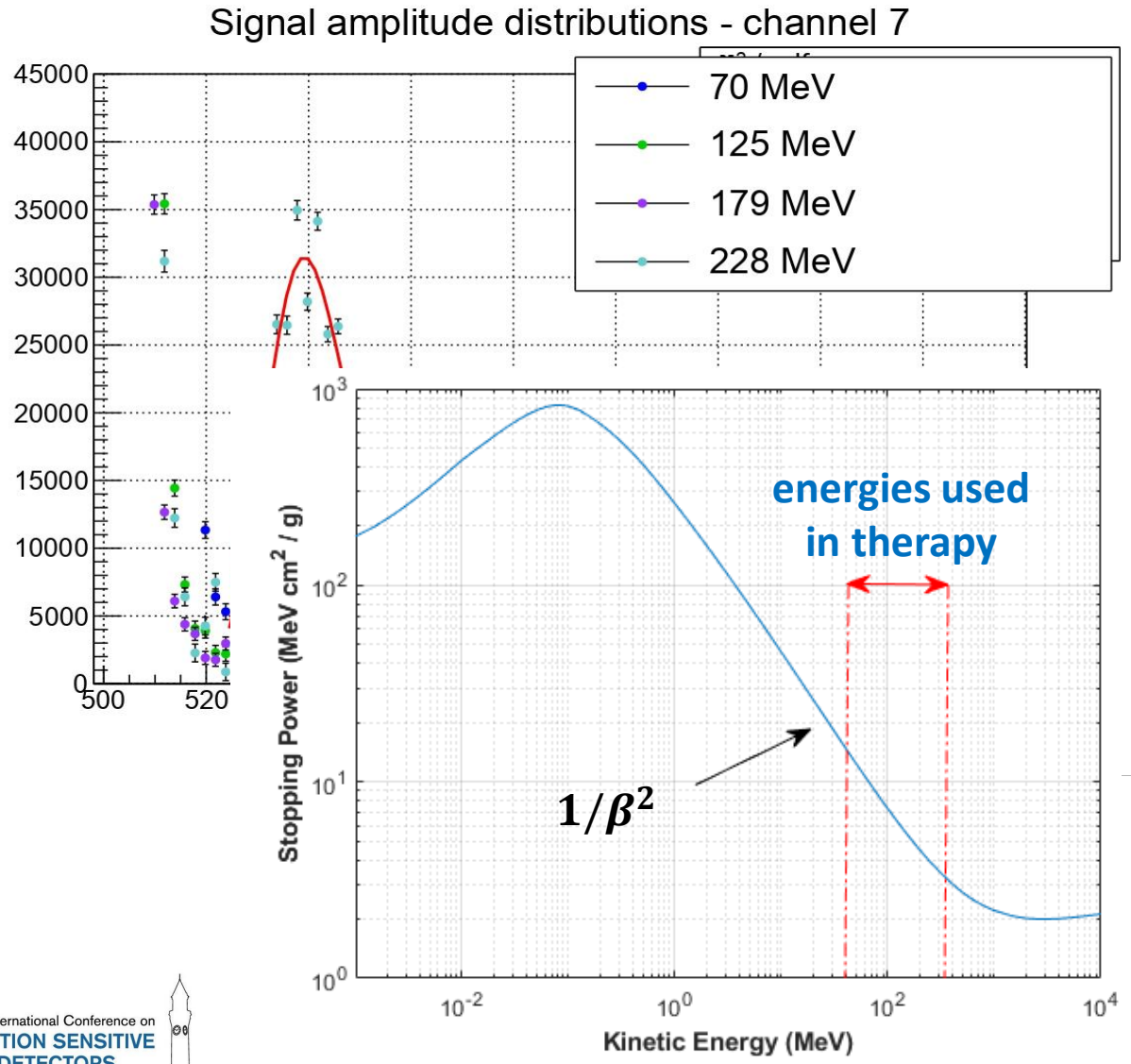
Tests with the ABACUS testboard at TIFPA

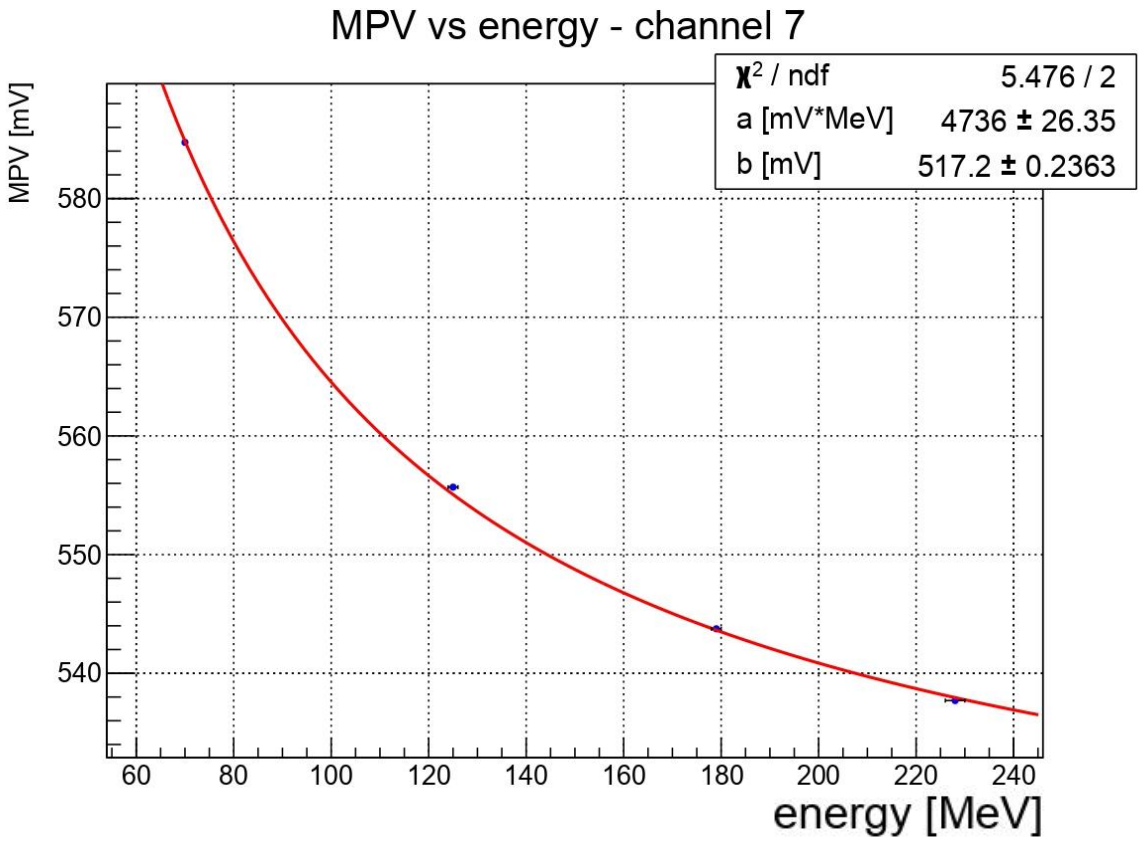




$$E_{beam} \propto \beta^2$$

Tests with the ABACUS testboard at TIFPA

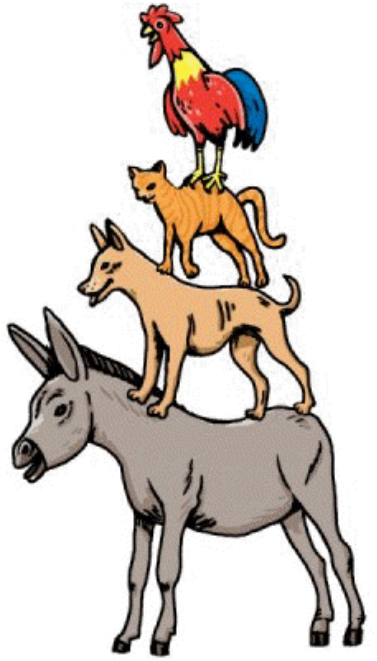




60 MeV – 230 MeV
30 mm – 320 mm

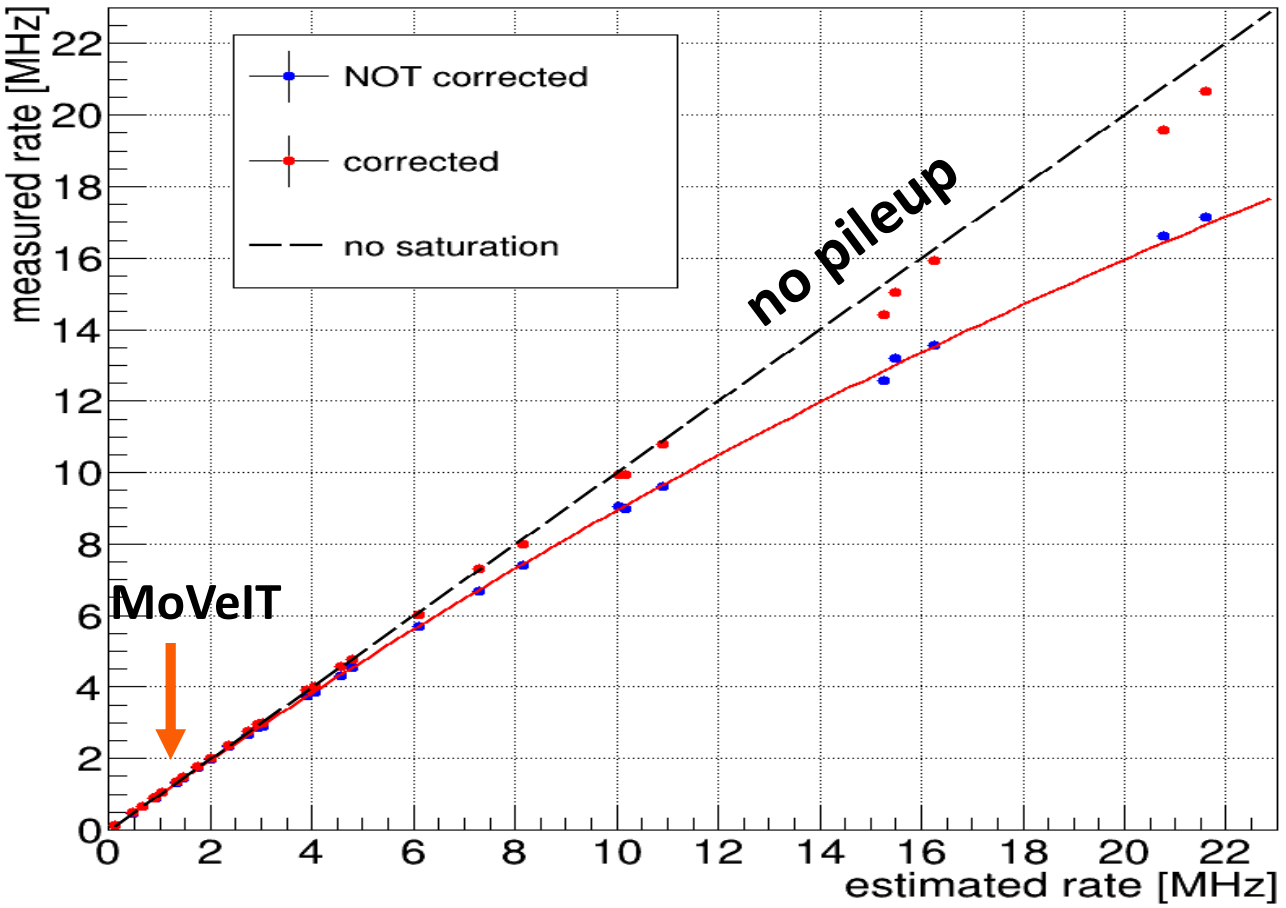
$$E_{beam} \propto \beta^2$$

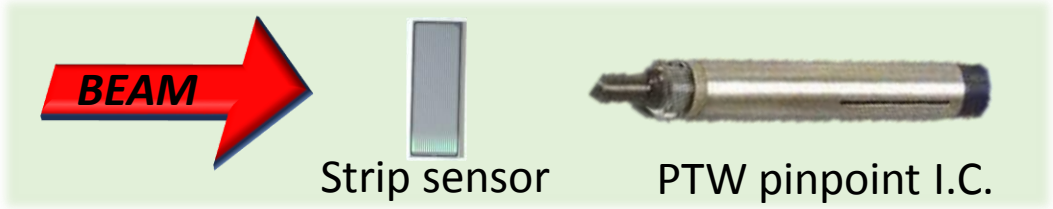
Particle Counting



Pile-up inefficiency

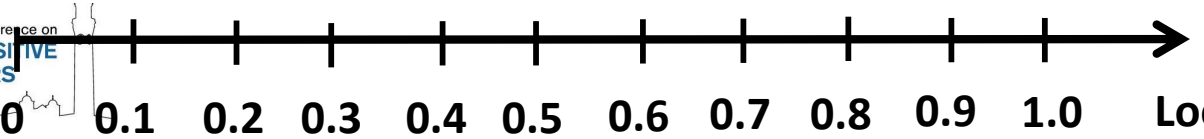
Mitigation of saturation effects





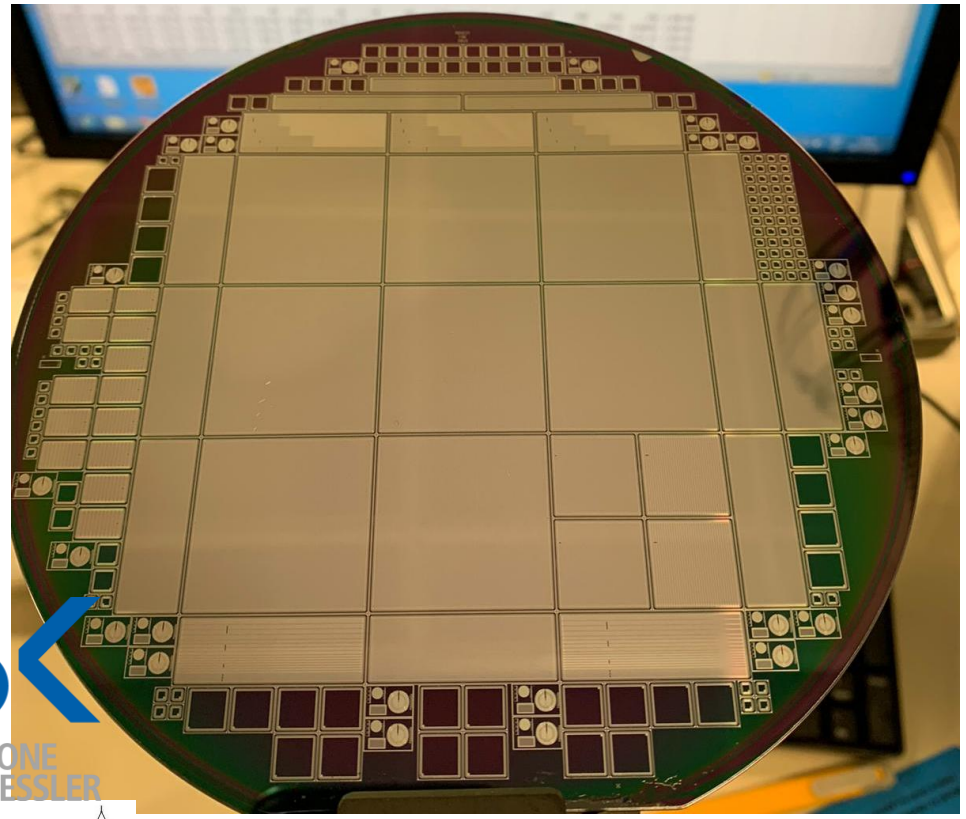
Particle rate estimated using the charge measured with a PTW pin-hole ionization chamber and assuming a paralyzable saturation model.

Correction method based on the correlation of logical pulses from two neighbouring strips (paralyzable model of saturation effects assumed)

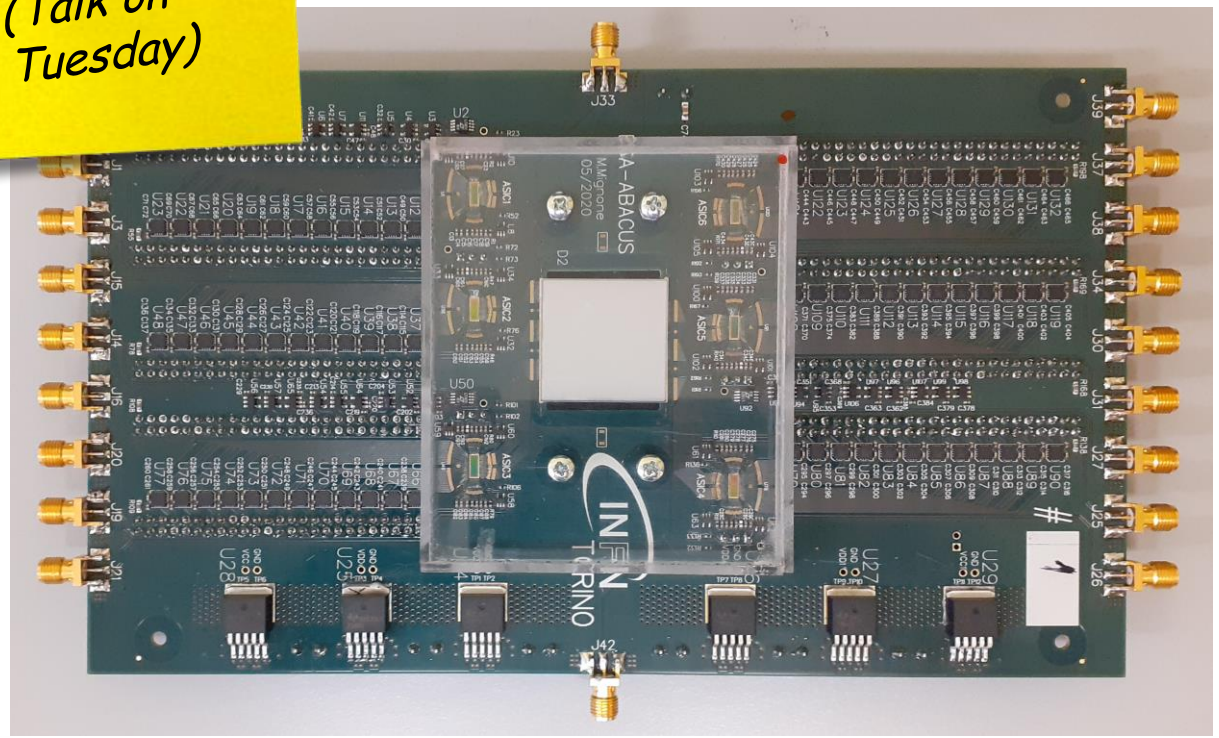


Final Counting Sensor Prototypes

- Strip segmentation (strip area ~ 3 mm^2)
- Area 2.7 × 2.7 cm^2
- 146 strips (144 with gain, 2 no gain)



OA Martì Villarreal (Talk on Tuesday)



FONDAZIONE BRUNO KESSLER

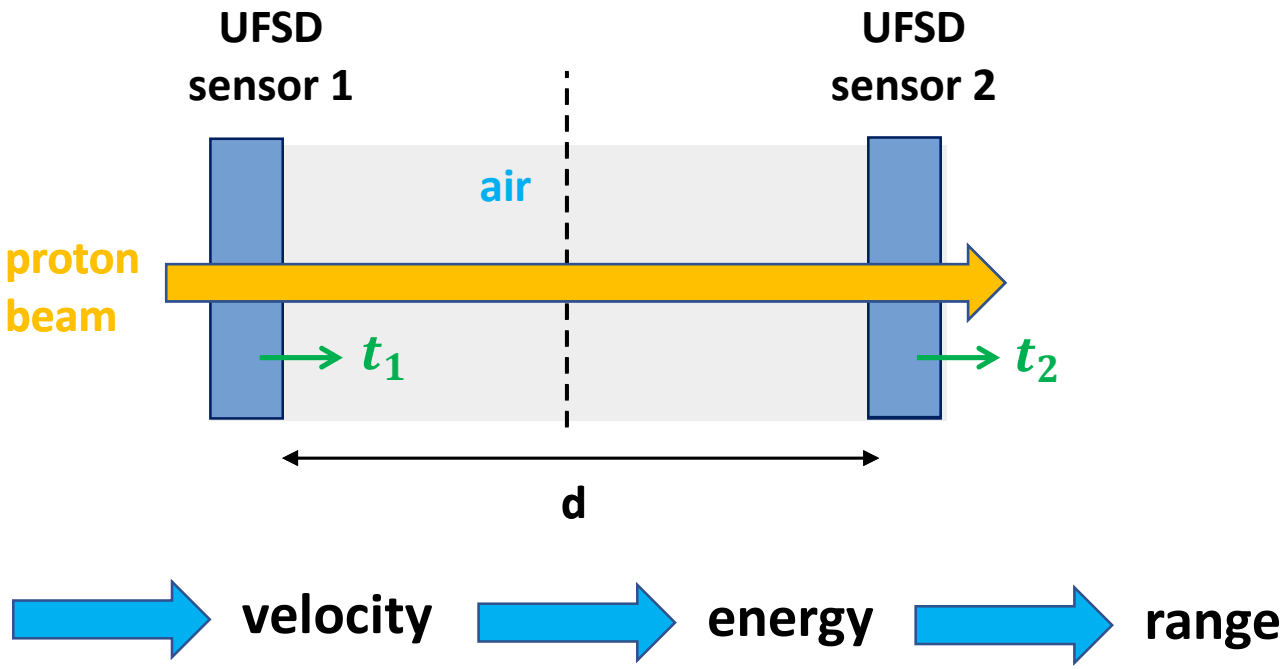
12th International Conference on POSITION SENSITIVE DETECTORS

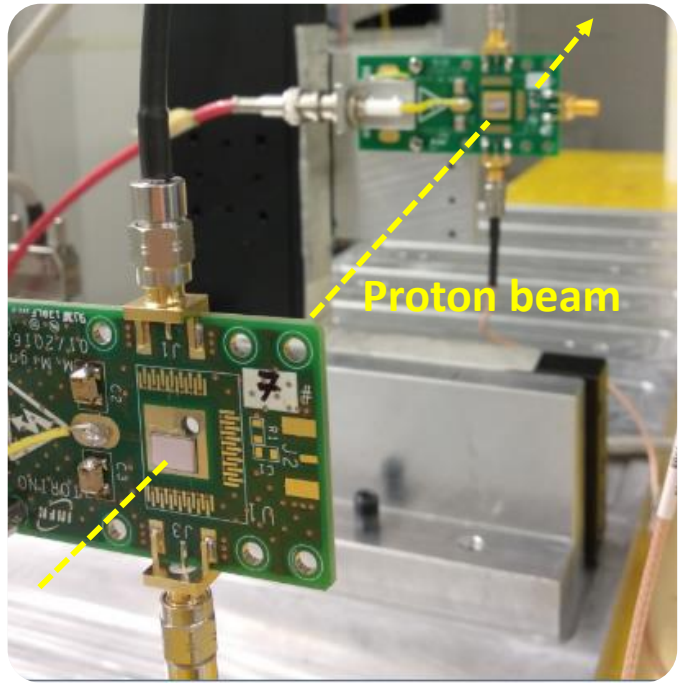
Energy Measurement

Energy Measurement Telescope

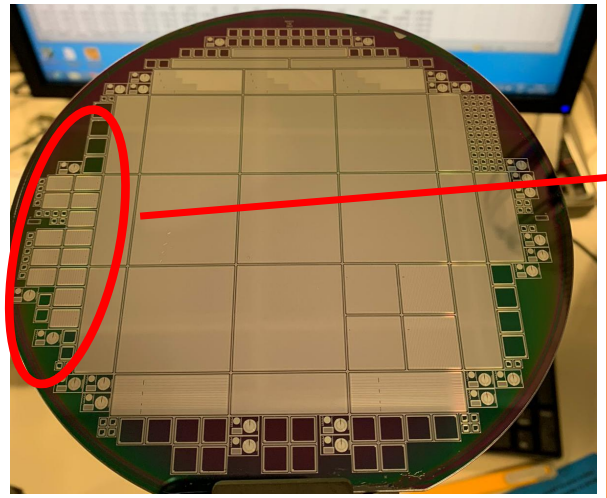
→ Determine the energy through measurements of **time-of-flight** of coincident protons

→ Required tolerance on the range uncertainty in water **< 1mm**, i.e. precision **< 4 ps** needed at 230 MeV at 1 m distance





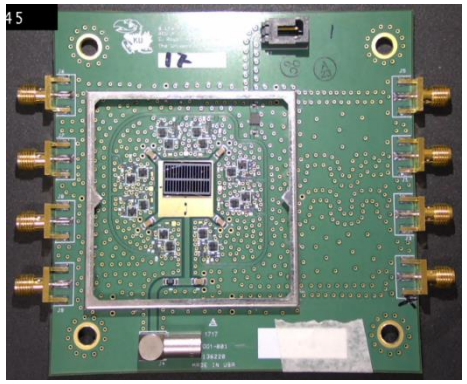
Timing Prototypes and Readout



FONDAZIONE BRUNO KESSLER

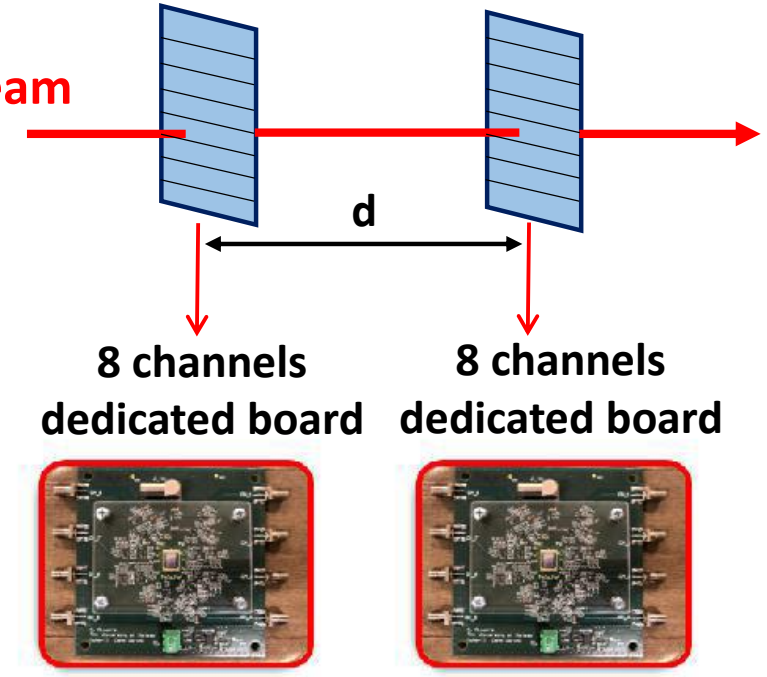
11 strips,
pitch 590 µm
50 µm active thickness
(thinned down to a total thickness of 70 µm)

Dedicated readout board for time measurement



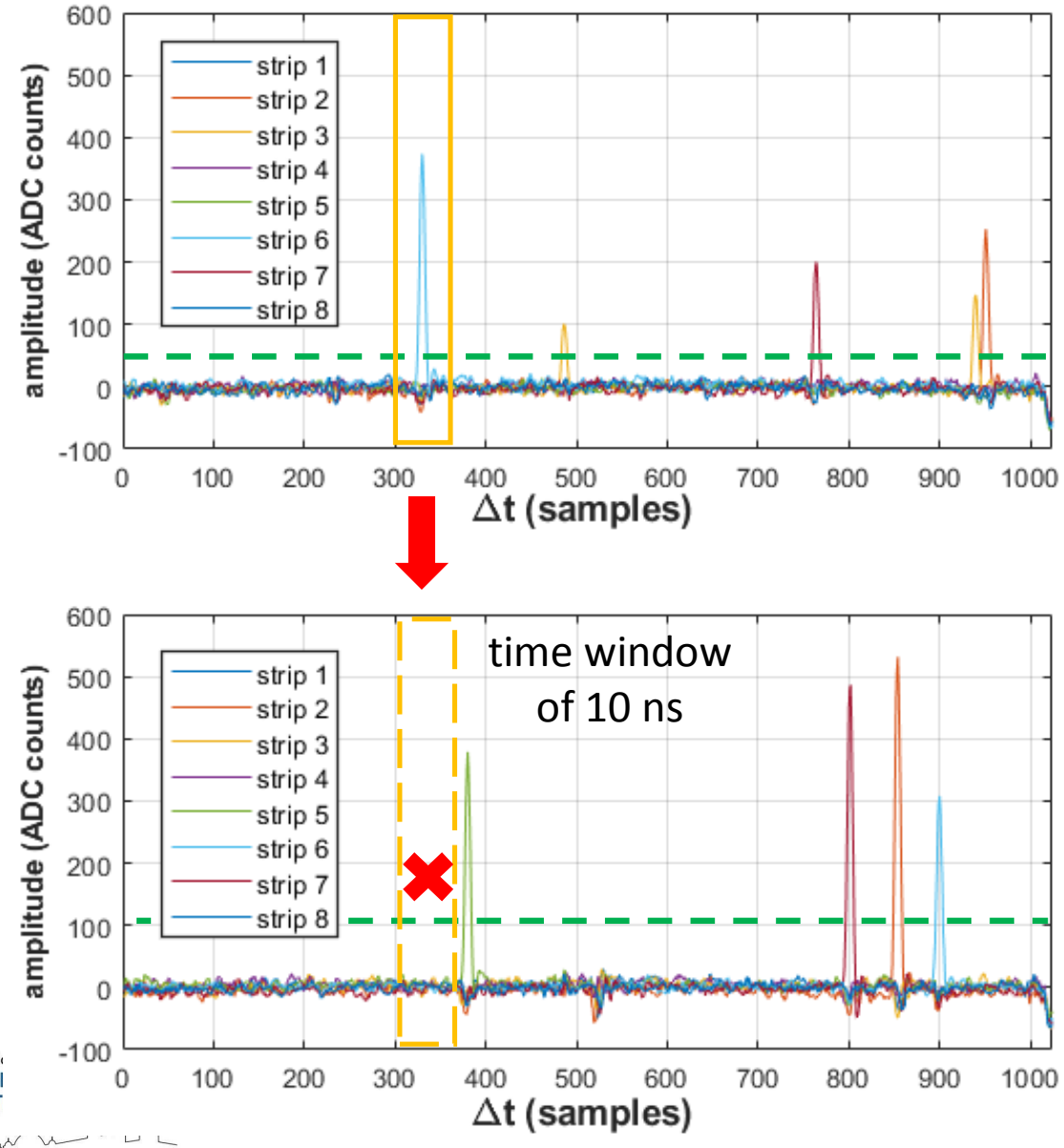
Optical link
80 MB/s

Digitizer 5 GS/s



12th International Conference on POSITION SENSITIVE DETECTORS

Time-of-Flight (TOF) measurement - Coincidences



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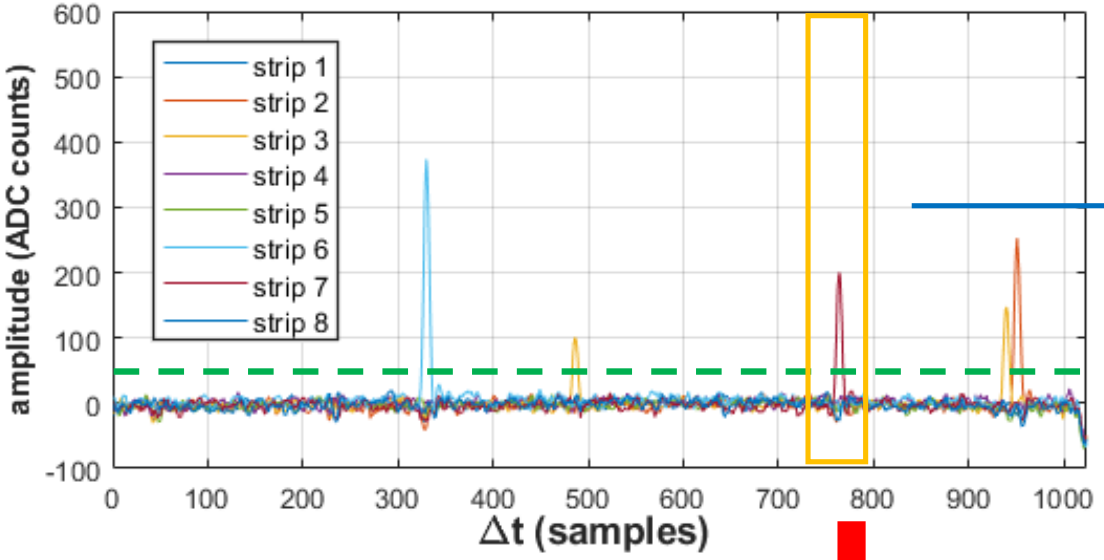
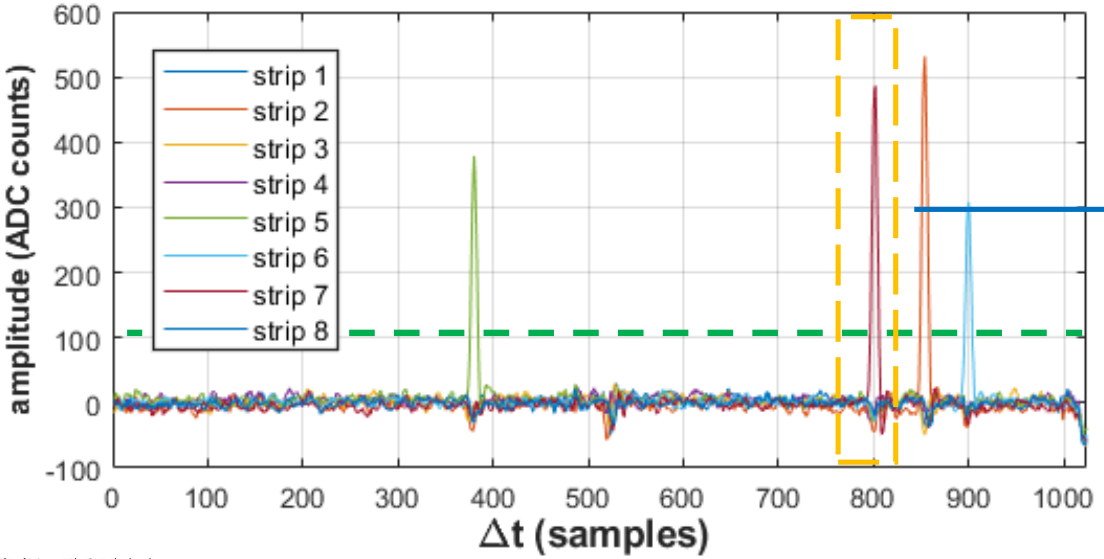


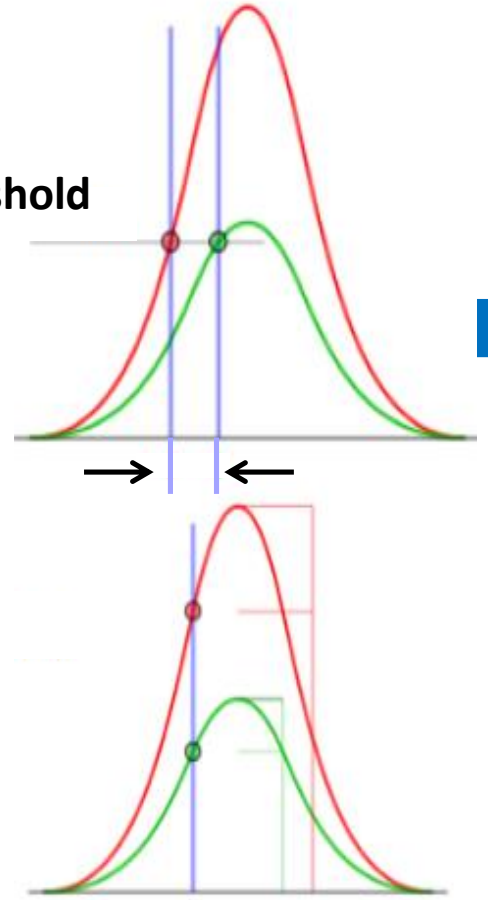
t_1



t_2

constant fraction algorithm to reduce the time walk effect

threshold

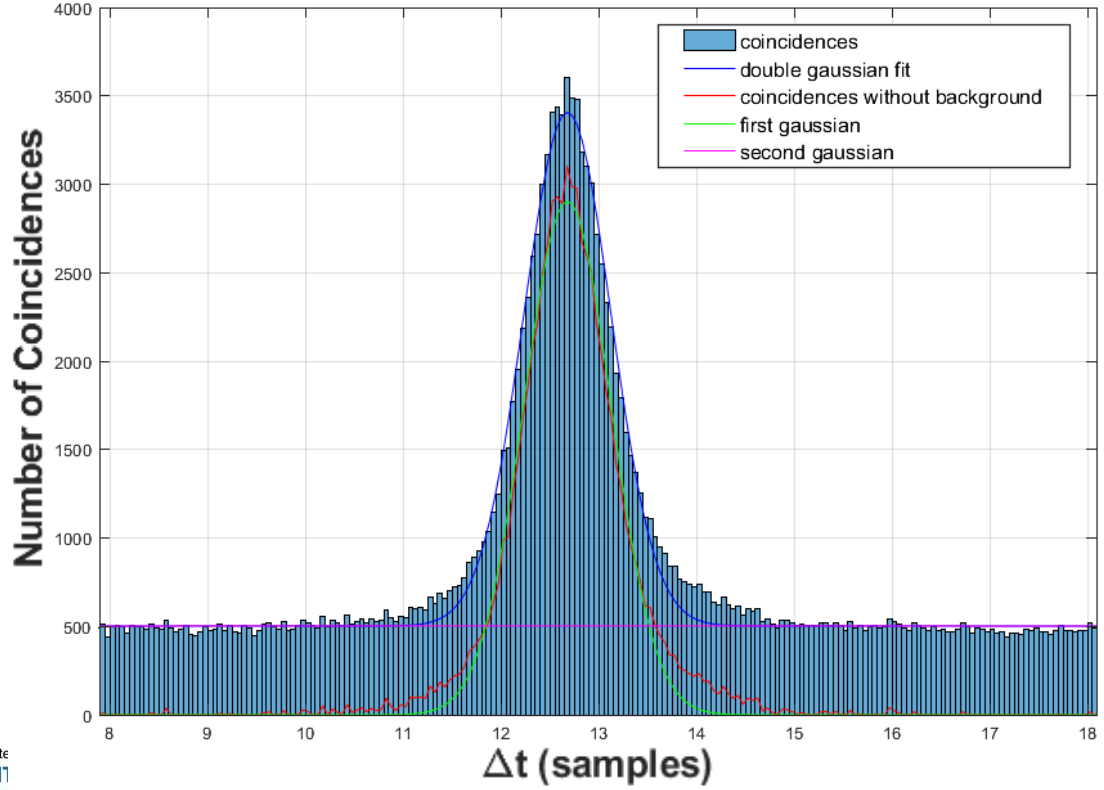


$\Delta t = t_1 - t_2$

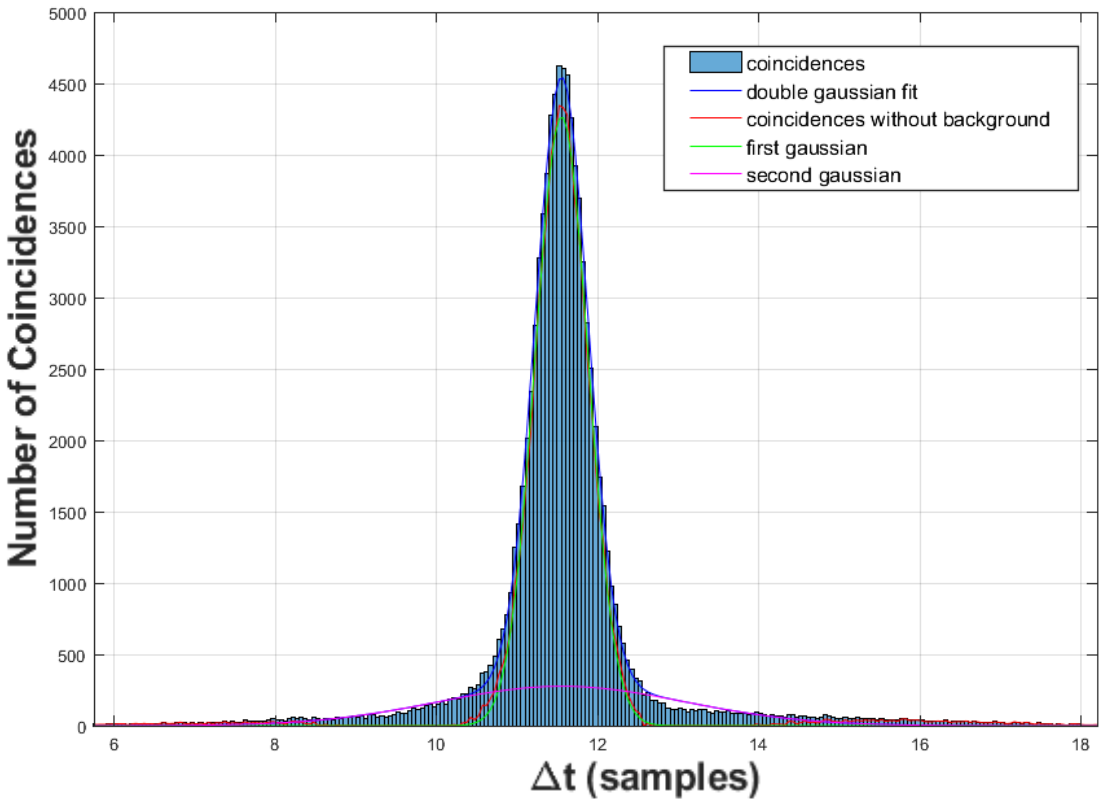
Distribution of Δt

- Double gaussian fit to identify the peak of true coincidences from the combinatorial background

181.68 MeV @ 400 mm



182.8 MeV @ 400 mm



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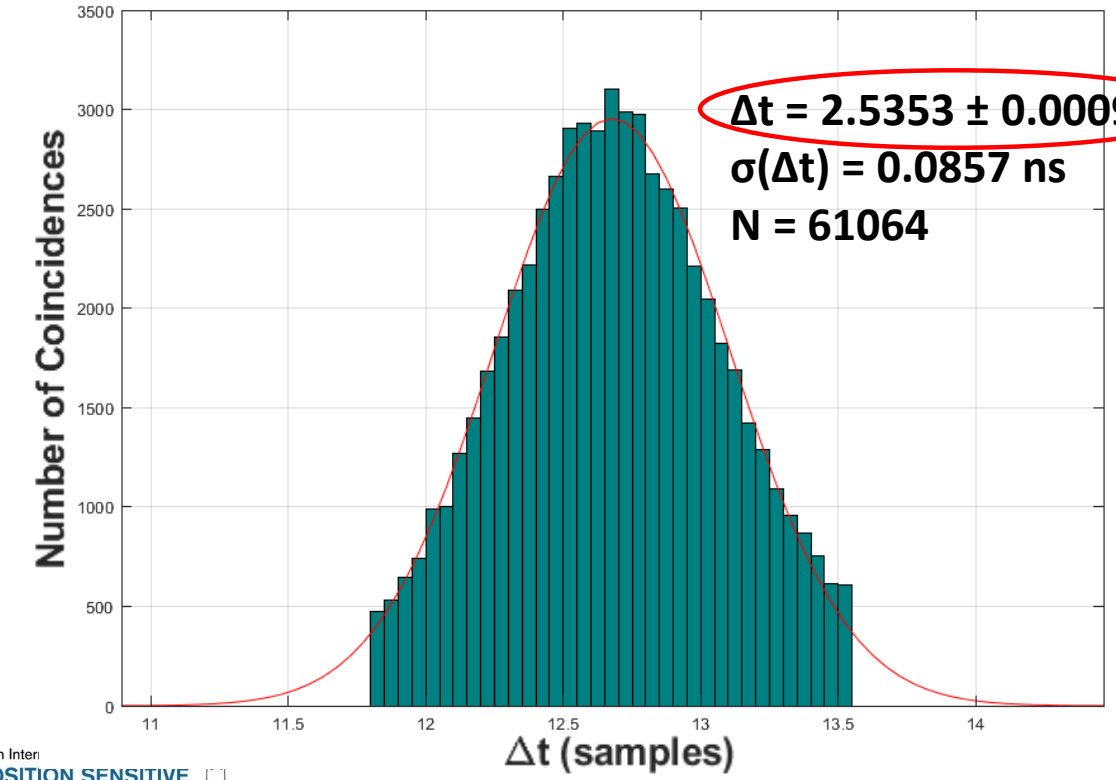

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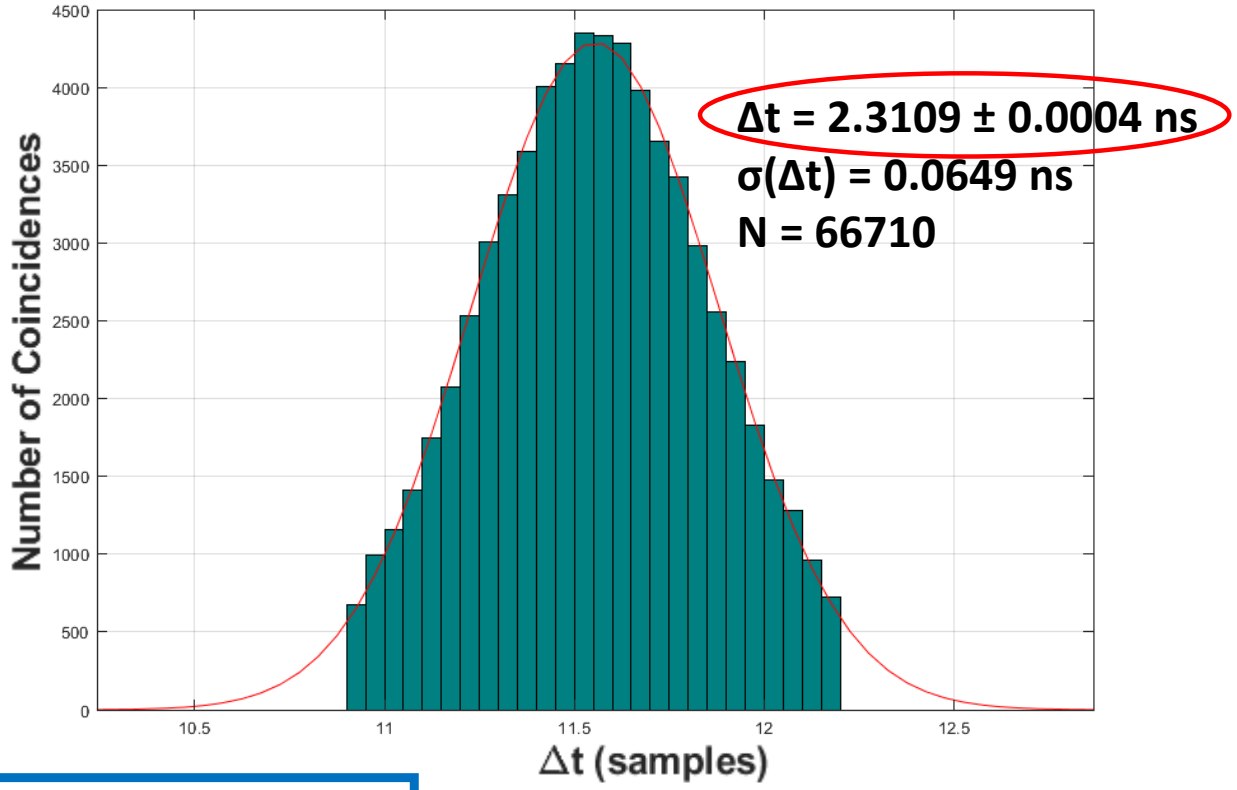
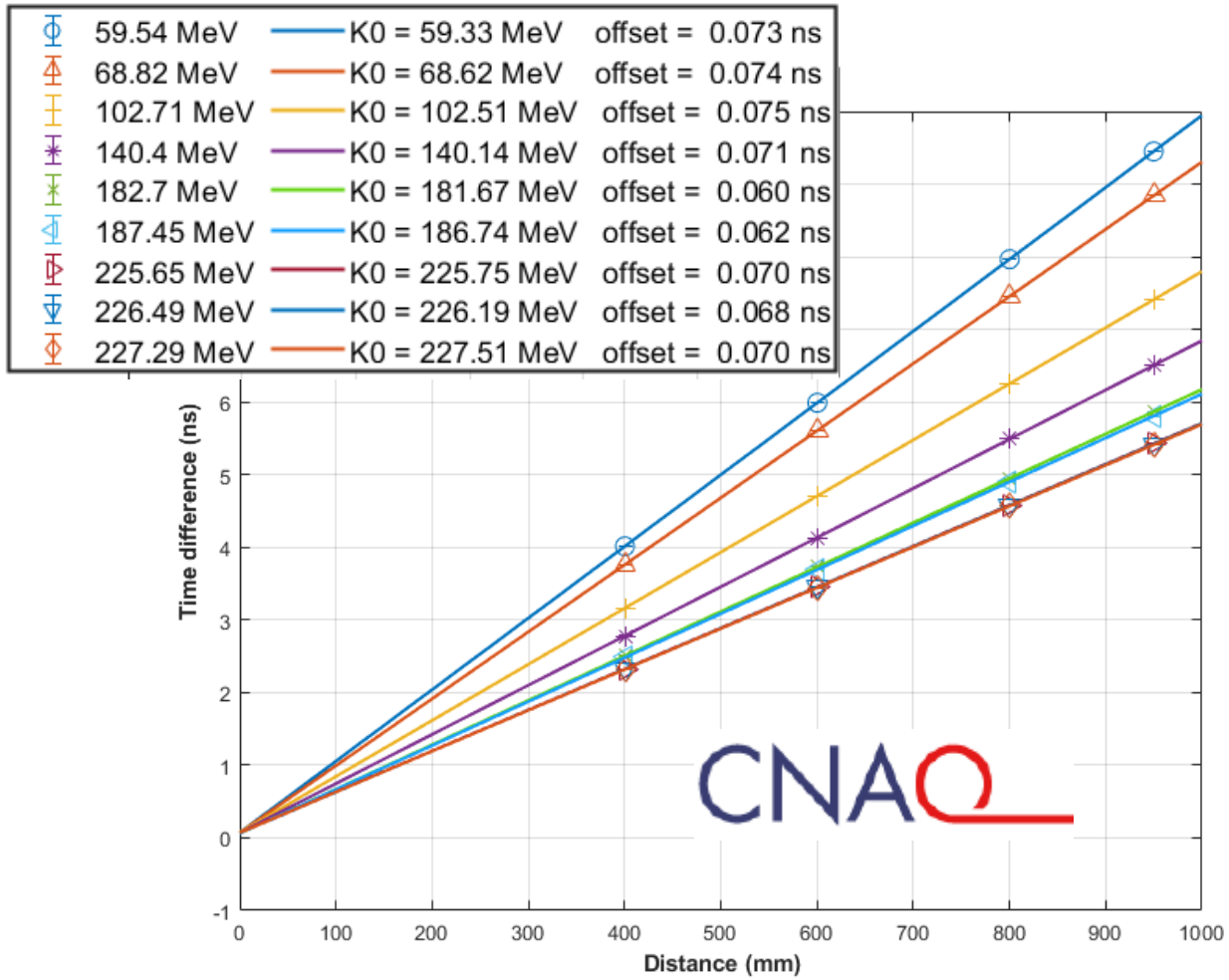
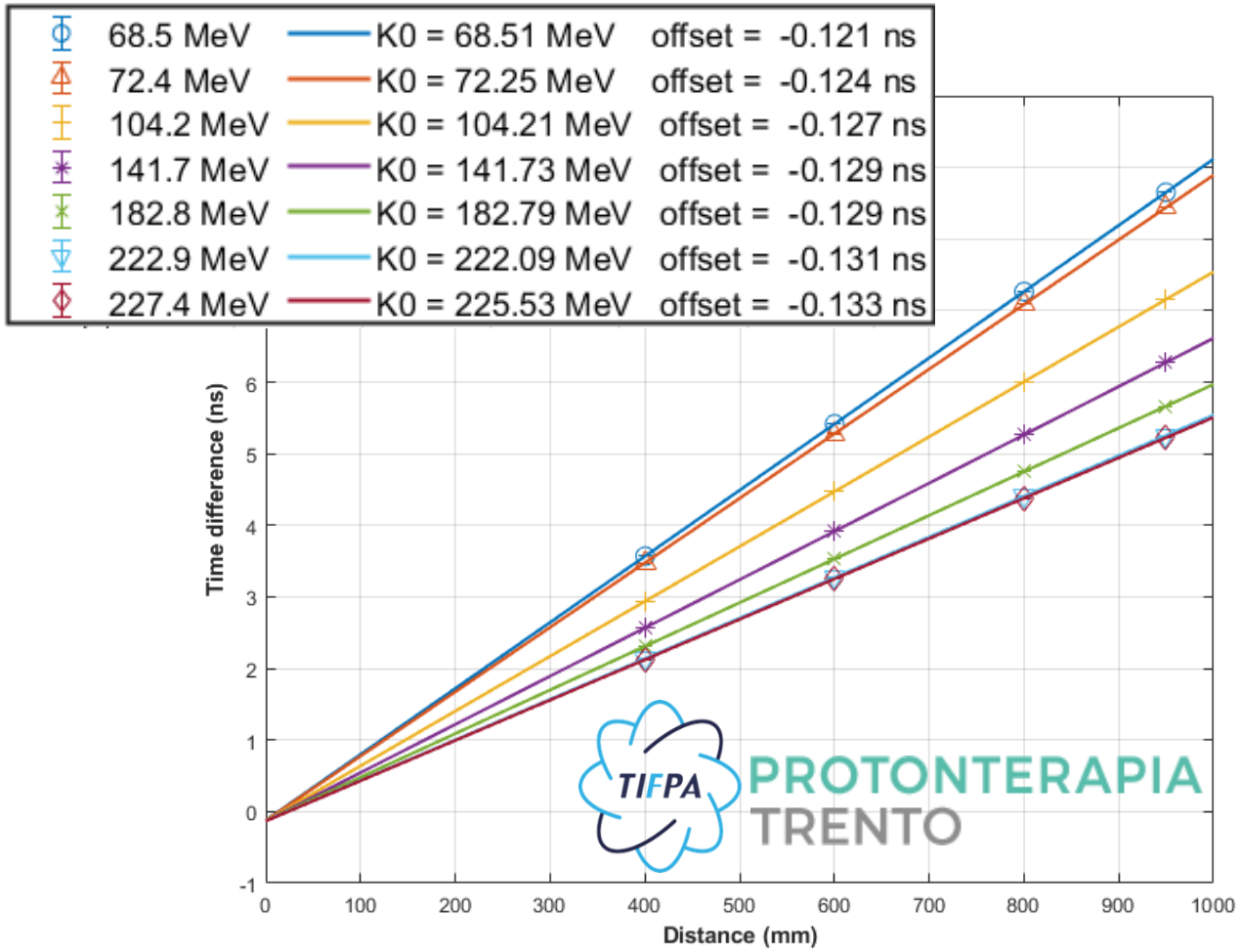


- **time resolution for single crossing** ~40 ps < σ < ~65 ps

Energy measurement from TOF

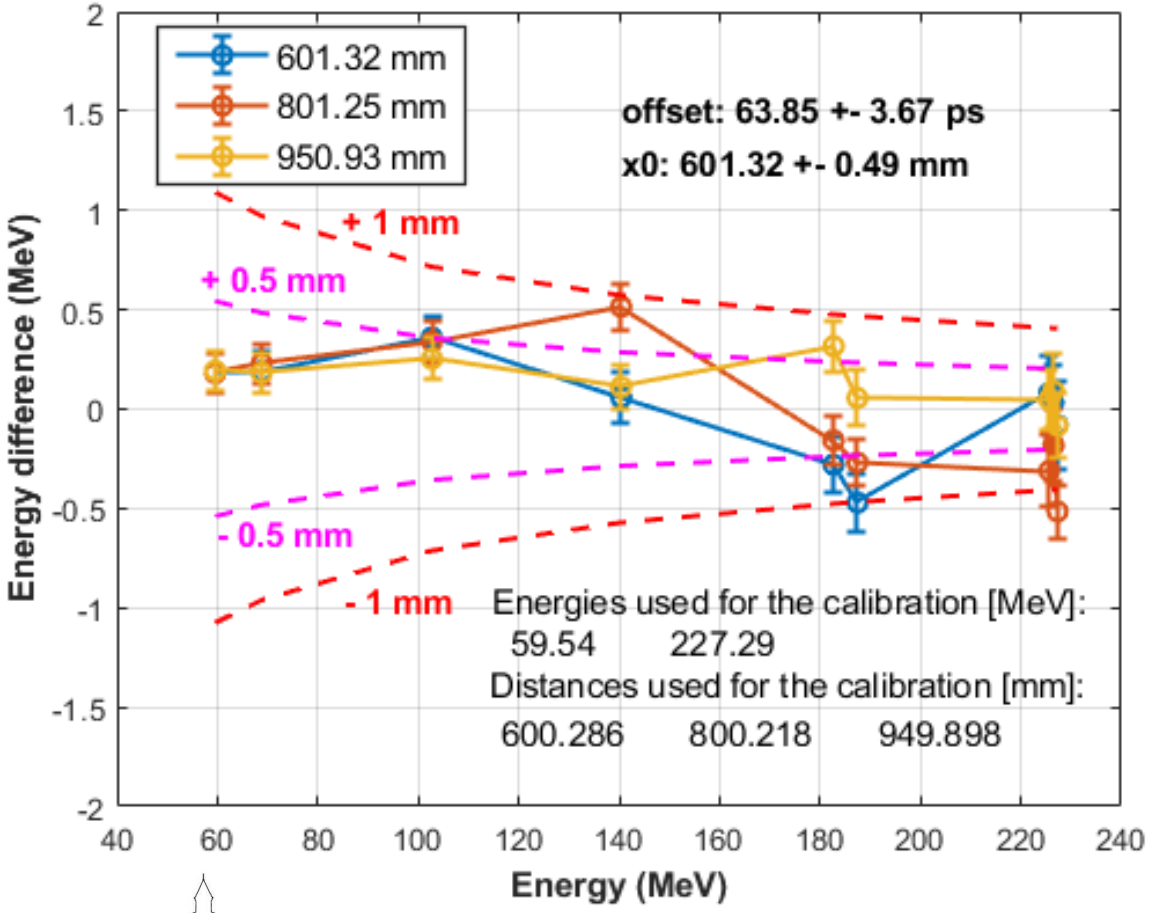
→ Interpolation of the measured time difference as a function of the distance with K_0 and $time\ offset$ as parameters

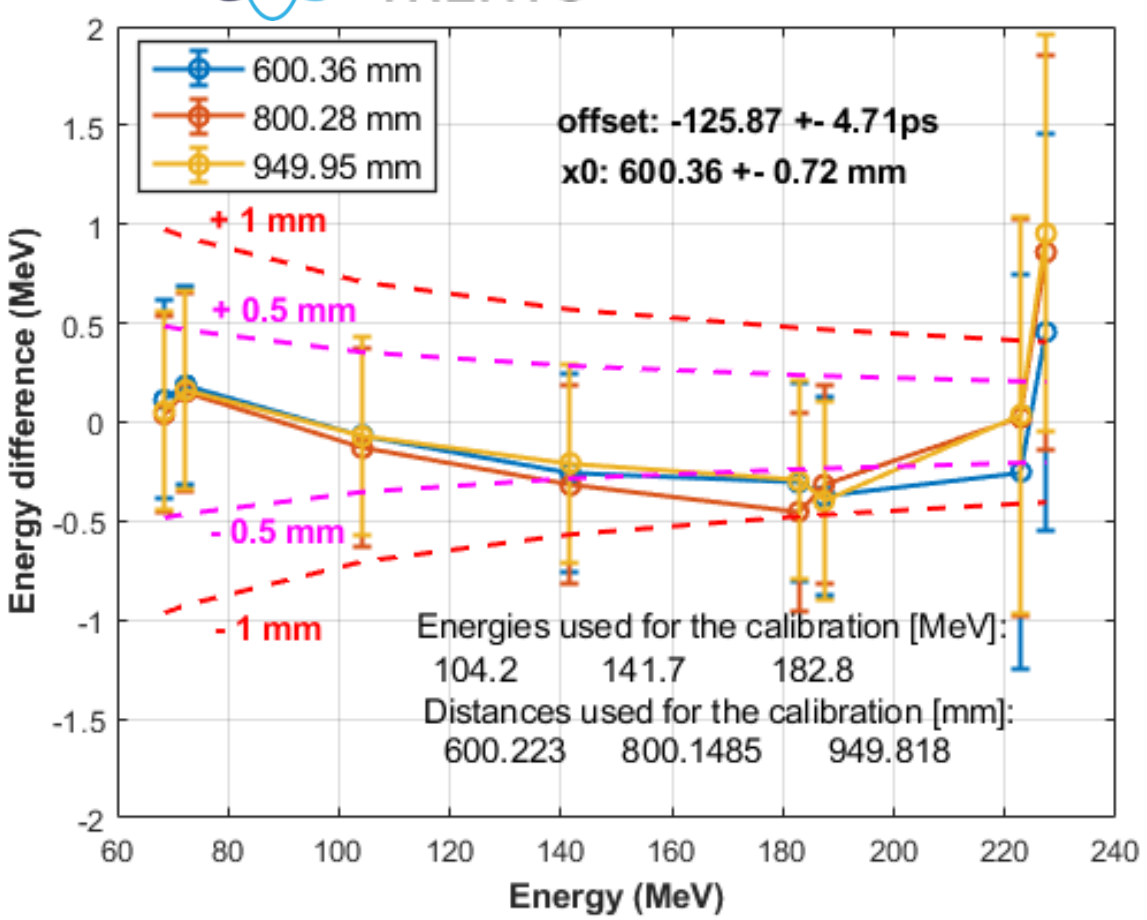




A **calibration** is needed to remove the systematic errors due to the experimental setup

Preliminary Results





Conclusions

UFSD are a promising technology for beam qualification and monitoring in Particle Therapy

- Excellent time resolution: **real-time measurement of the beam energy**
- Short signal duration: **single particle counting**

→ *Patent for energy measurement prototype*

→ *Final readout electronics for counting prototype*

→ *Radiation hardness*

→ Radiobiological experiments

→ Aiming at clinics!

Thank you