PSD11
The 11th International Conference on Position Sensitive Detectors

Silicon Detectors for Beam Characterization

VIGNATI A (INFN - National Institute for Nuclear Physics - Torino - IT),
MONACO V, ATTILI A, CARTIGLIA N, DONETTI M, FADAVI MAZINANI M, FAUSTI F, FERRERO M, GIORDANENGO S, HAMMAD ALI O, MANDURRINO M, MANGANARO L, MAZZA G, SACCHI R, SOLA V, STAIANO A, CIRIO R.

Introduction

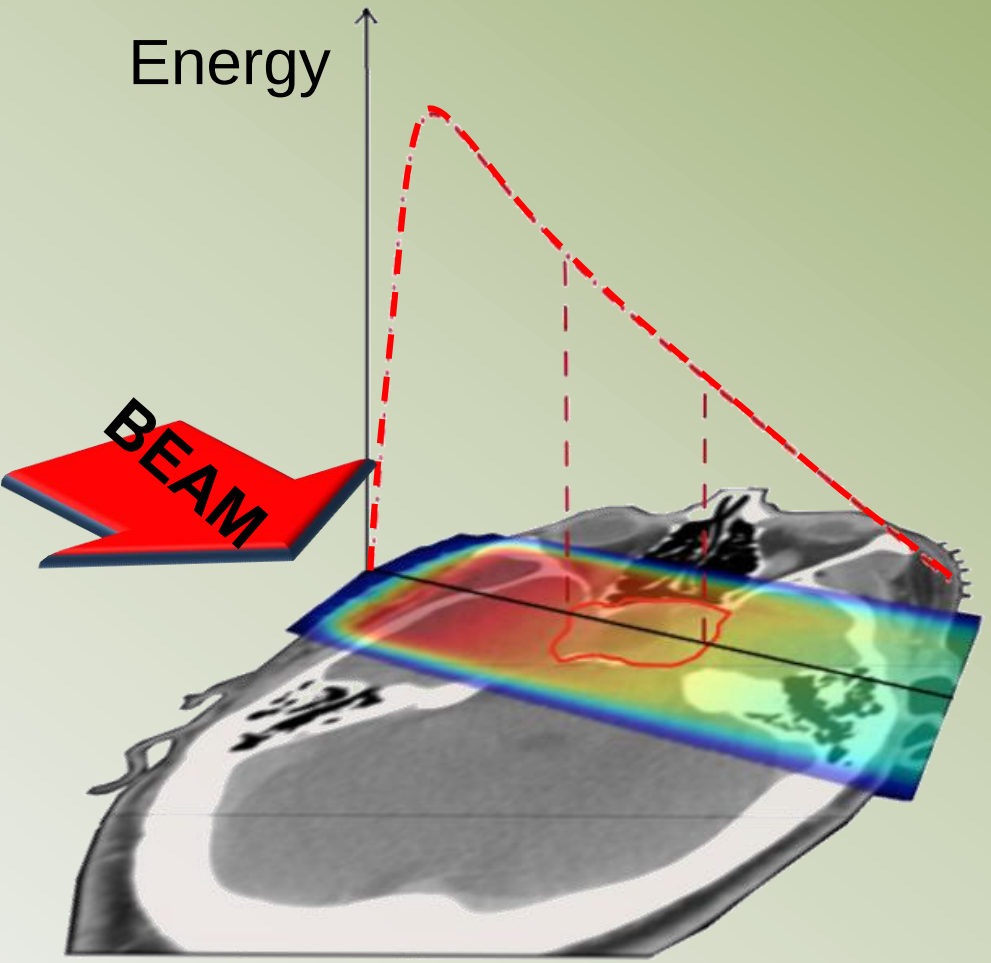
Modeling and Verification for Ion beam Treatment planning

Interdisciplinary project involving the collaboration of various INFN groups and the three Italian hadron therapy facilities (CNAO, LNS, TIFPA).

TASK 4.3

Developing innovative silicon detectors optimized for excellent time resolutions (Ultra Fast Silicon Detectors, UFSDs) to characterize and monitor therapeutic ion beams, overcoming the limits of ionization chambers.

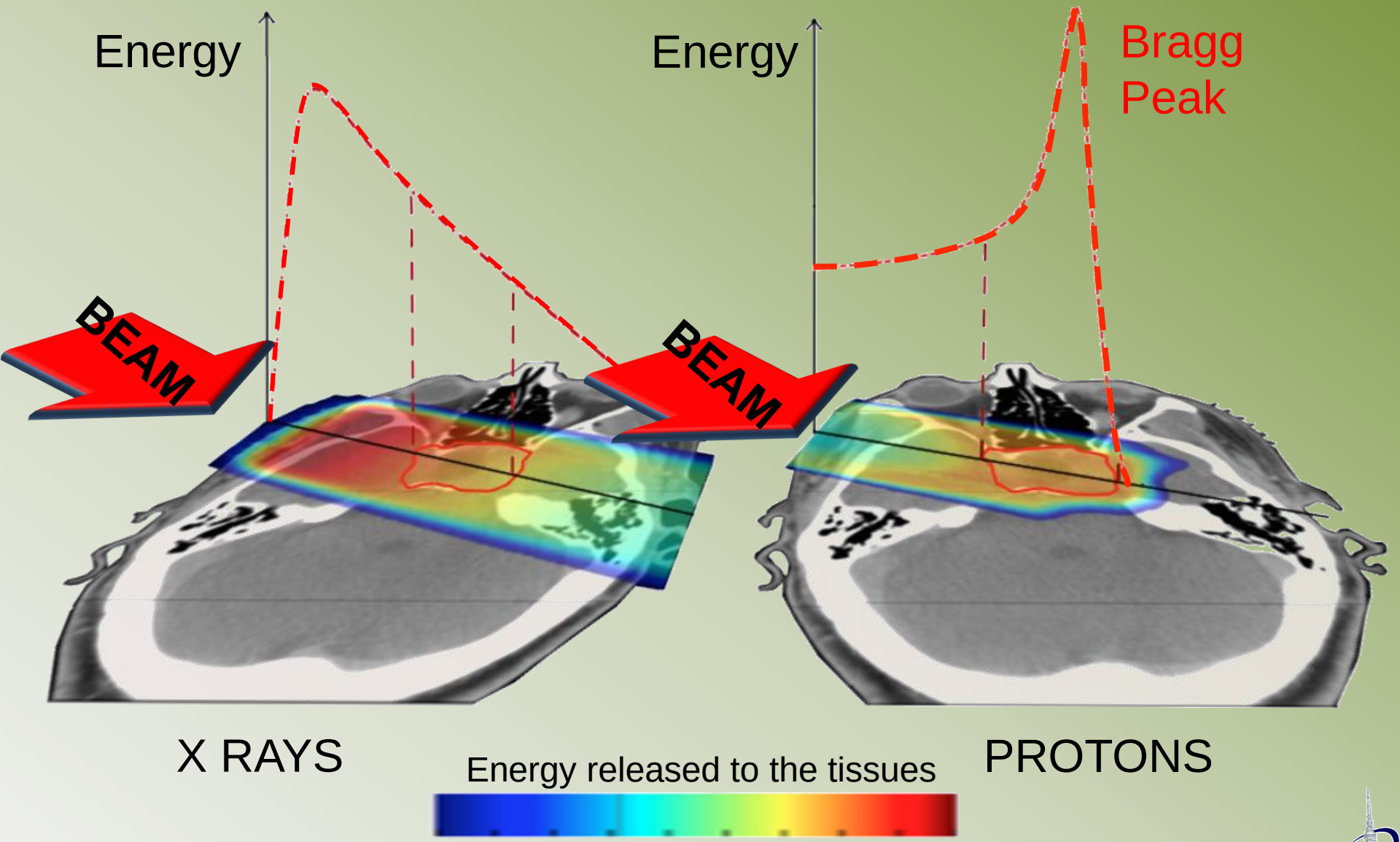
Introduction – Charged Particle Therapy



X RAYS

Energy released to the tissues

Introduction – Charged Particle Therapy



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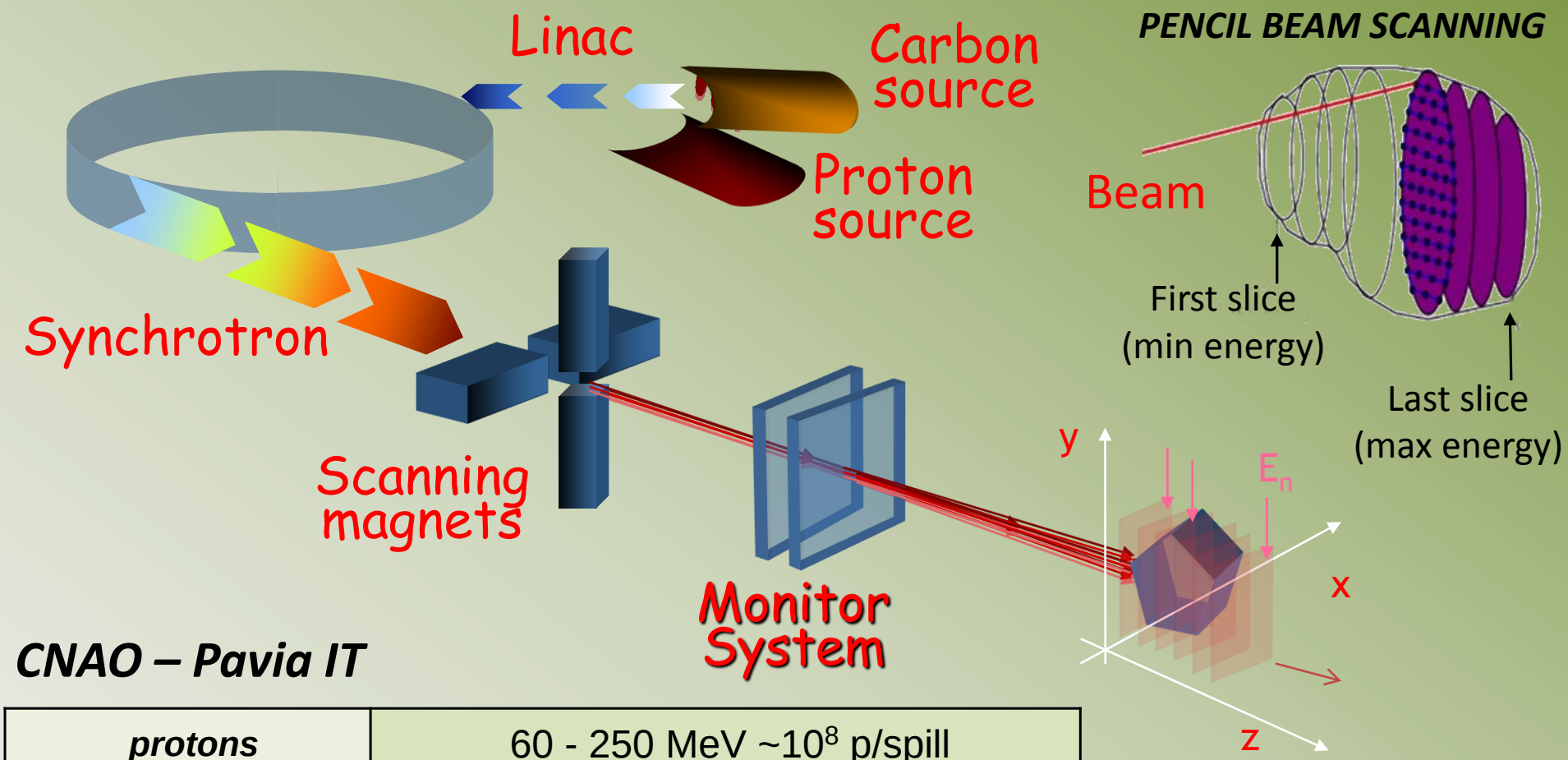
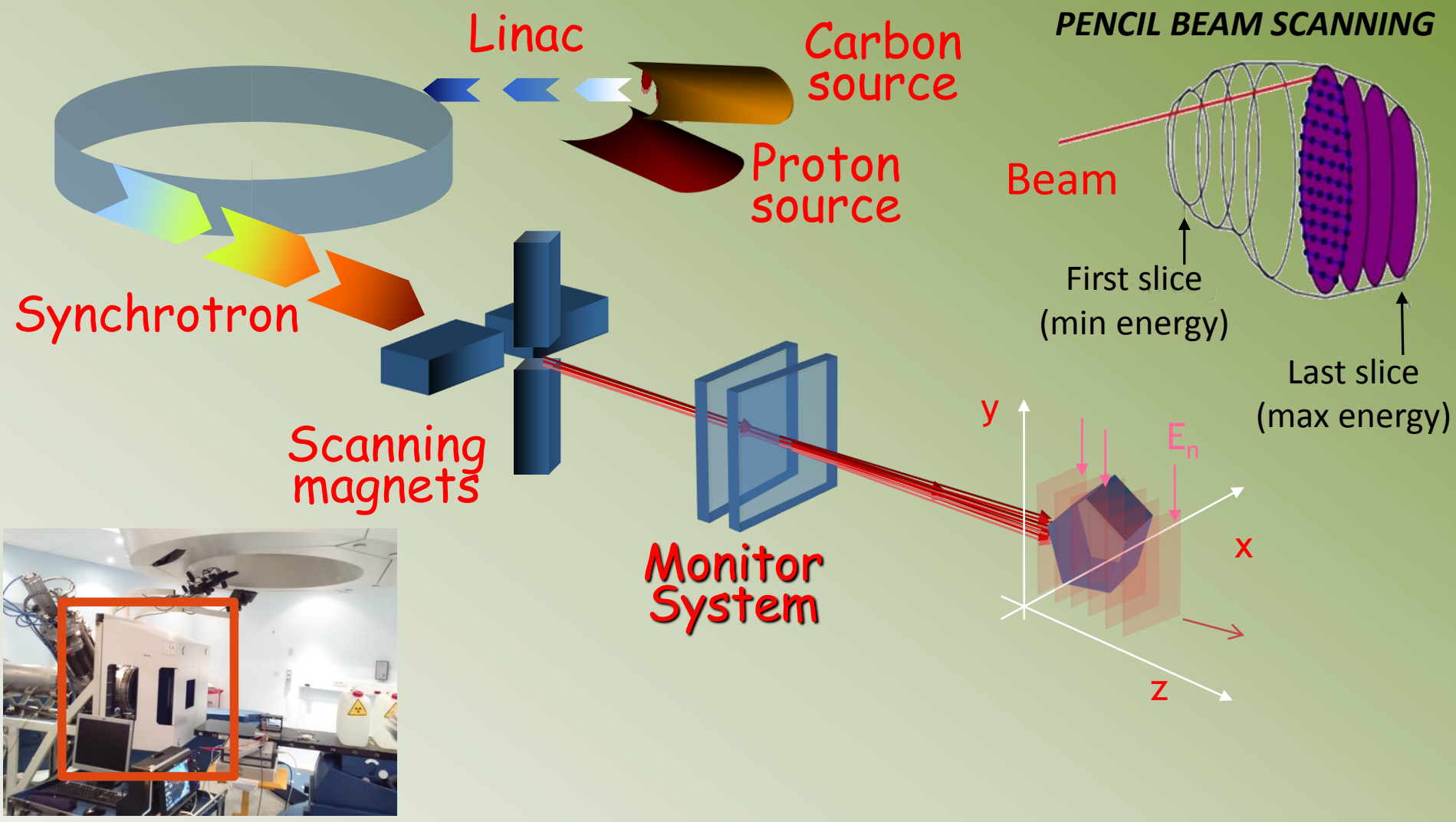


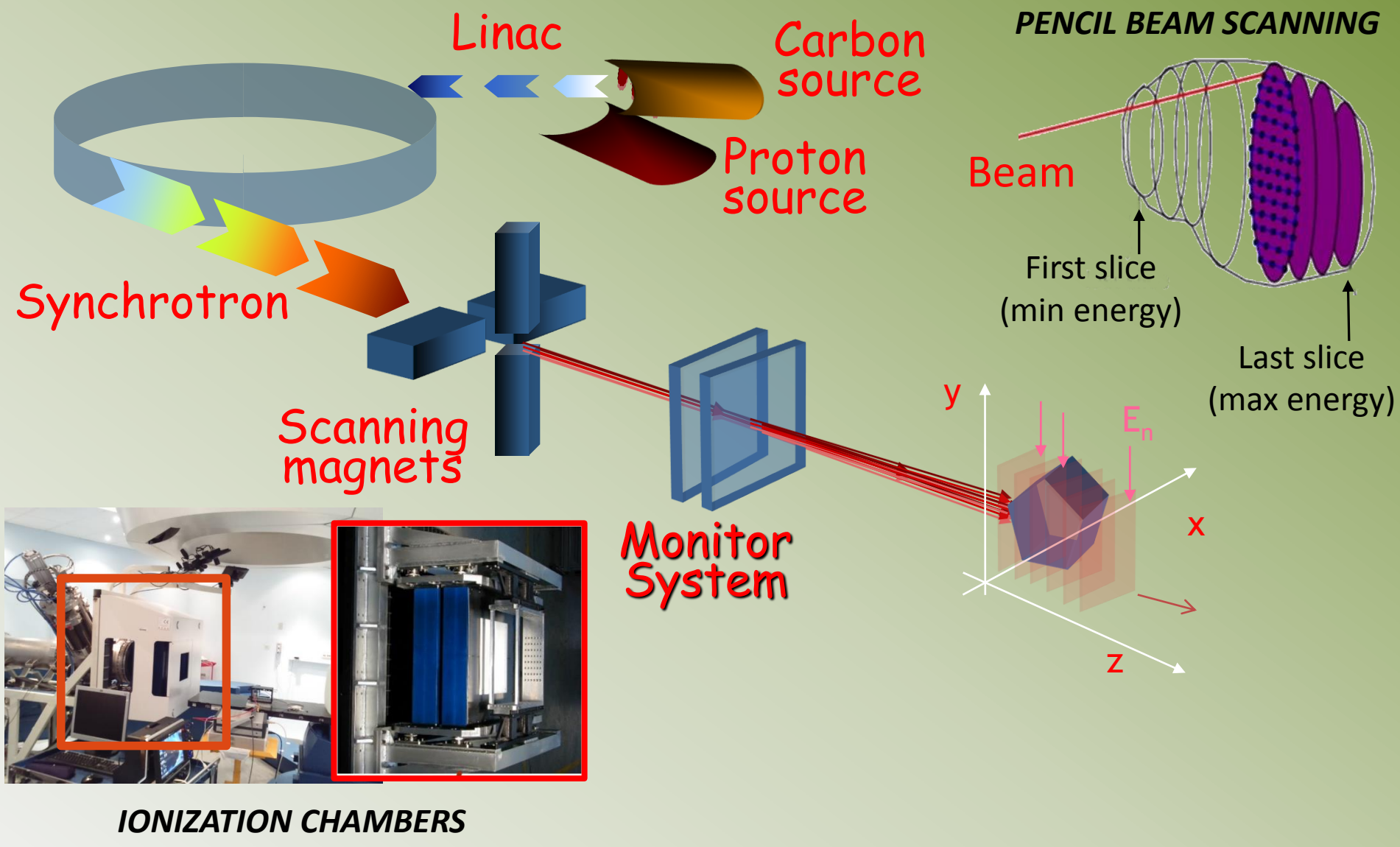
CNAO – Pavia IT

protons	60 - 250 MeV ~10^8 p/spill
C^{6+}	120 - 400 MeV/u ~10^9 - 10^{10} p/spill
Range in water	3 - 27 cm

Introduction – Charged Particle Therapy

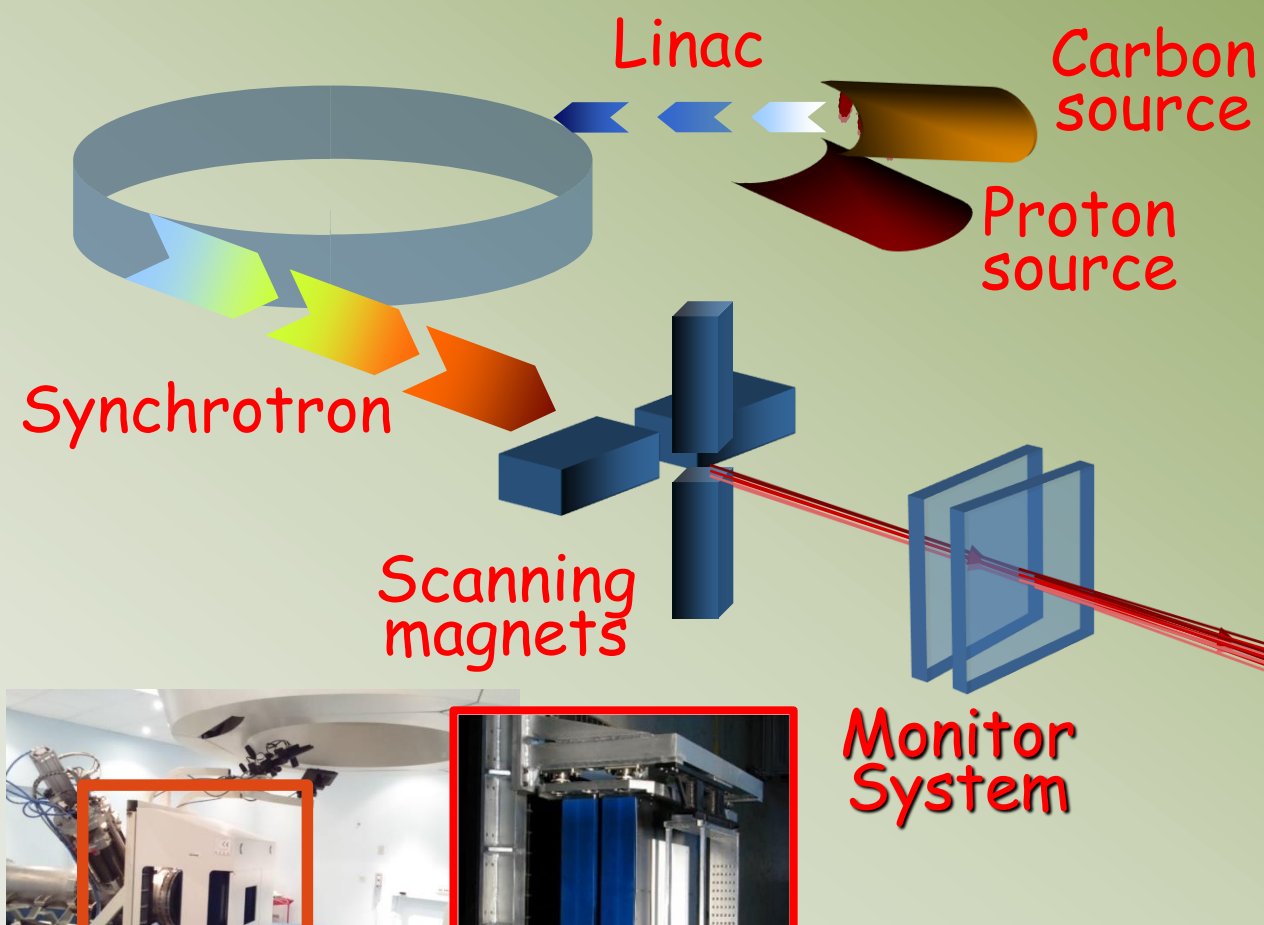


Introduction – Charged Particle Therapy



IONIZATION CHAMBERS

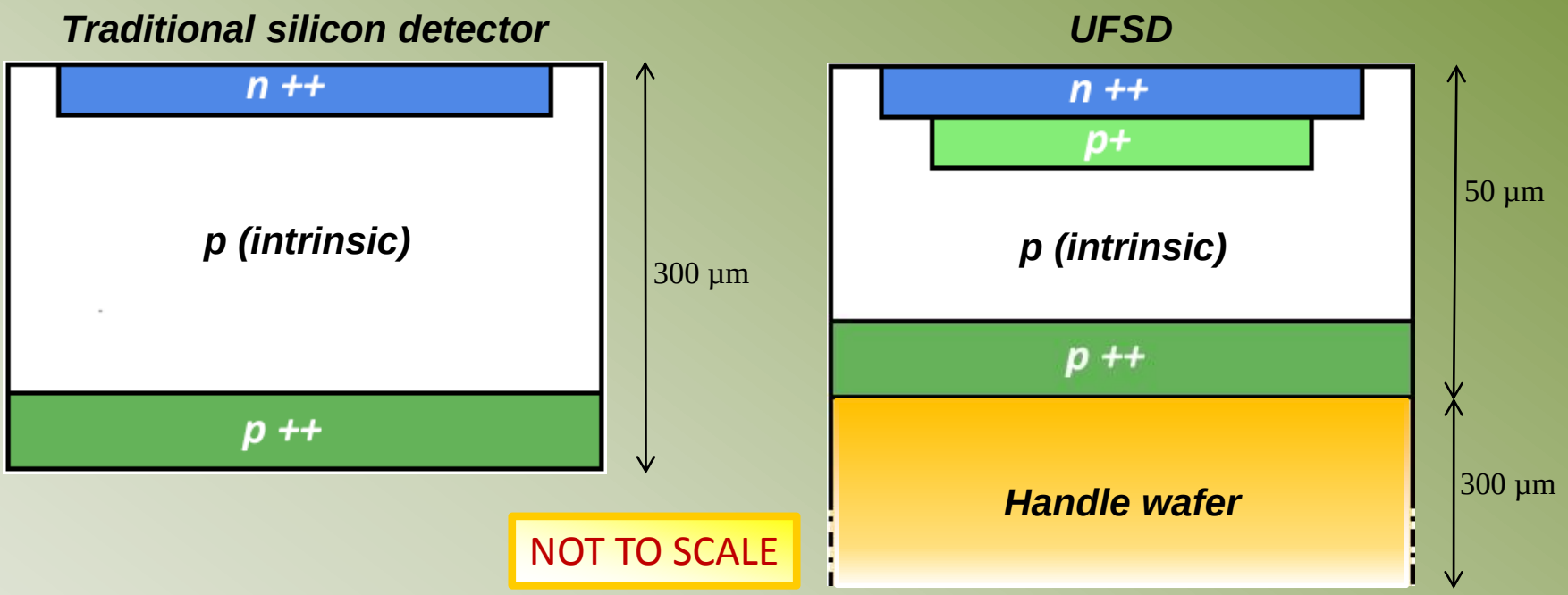
Introduction – Charged Particle Therapy



IONIZATION CHAMBERS

- response dependence on beam energy;
- slow collection time;
- reduced sensitivity.

Introduction: Ultra Fast Silicon Detector (UFSD)



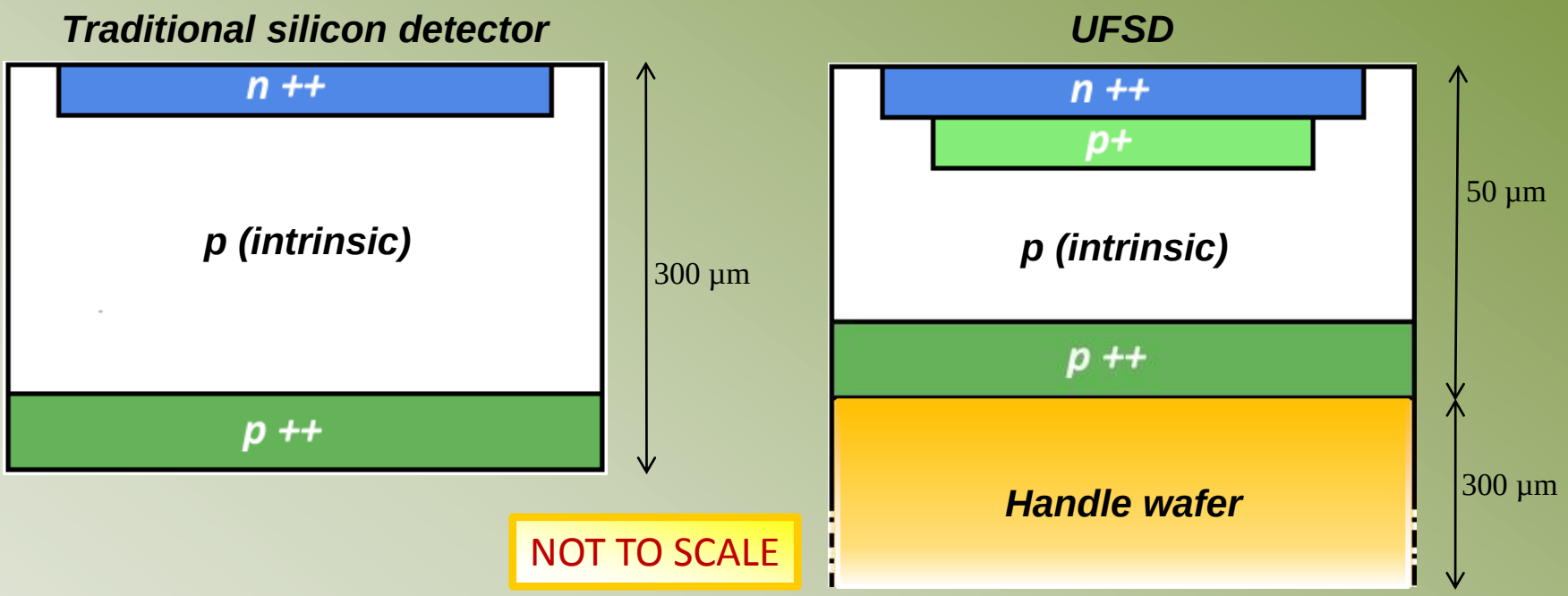
✓ controlled low gain (based on LGAD, Low-Gain Avalanche Detectors);

✓ excellent time resolutions.

H.F.-W. Sadrozinski et al. Ultra-fast silicon detectors (UFSD) Nucl. Instrum. Meth. A831 (2016) 18-23.

V. Sola et al. Ultra-Fast Silicon Detectors for 4D tracking. Journal of Instrumentation (2017), Volume 12.

Introduction: Ultra Fast Silicon Detector (UFSD)



✓ controlled low gain (based on LGAD, Low-Gain Avalanche Detectors);

✓ excellent time resolutions.

Thickness of ~50 micron and gain of ~20 result in optimum performance.

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Aim

Two UFSD devices are being developed:

- ✓ to directly count individual protons at high rates and (thanks to the segmentation in strips) to measure the beam profiles in two orthogonal directions;
- ✓ to measure the beam energy with time-of-flight techniques, using a telescope of two UFSD sensors segmented in a minimum number of pads.

Aim – Near future

…clinical application is very far…

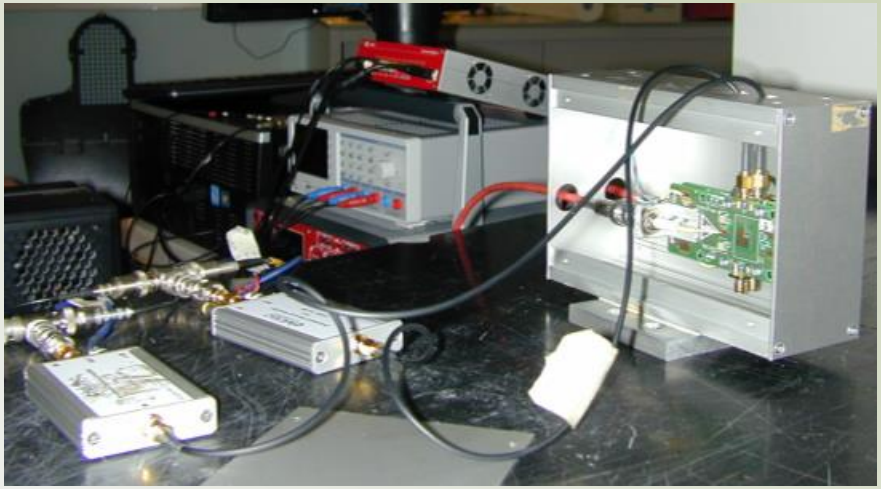
Move IT

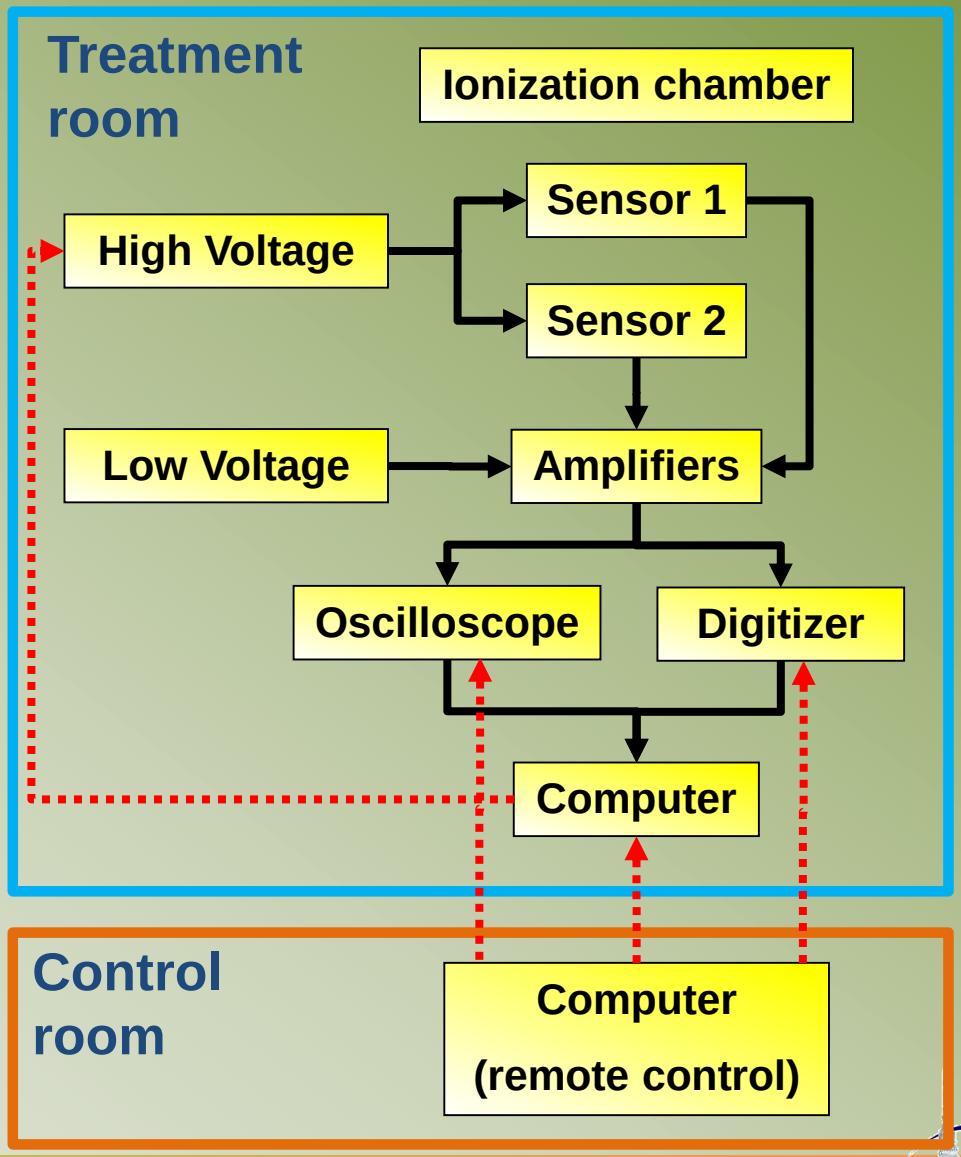
Radiobiological applications:

Passive scattering technique → FOV 3x3 cm^2;

Flux = 10^8 p/s cm^2

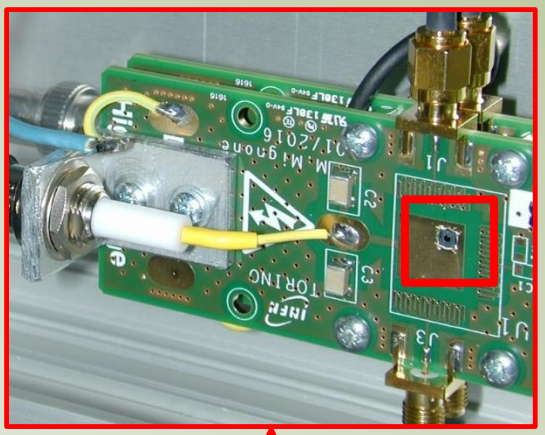
Beam tests

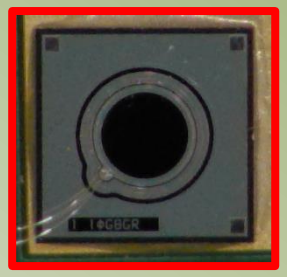


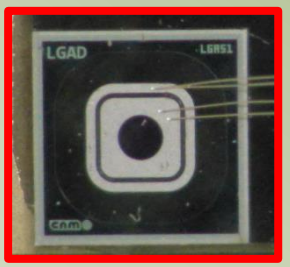

Treatment room
Ionization chamber
Sensor 1
High Voltage
Sensor 2
Low Voltage
Amplifiers
Oscilloscope
Digitizer
Computer
Control room
Computer
(remote control)

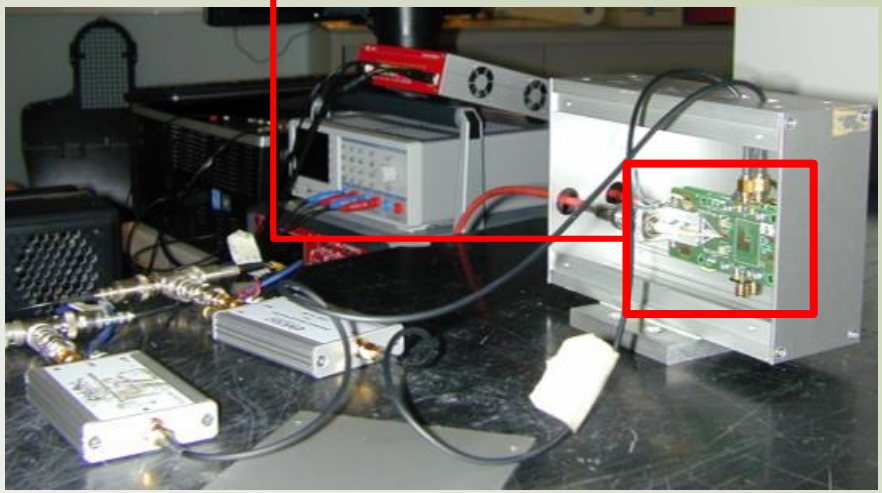
Beam tests

2 detectors of 50 μm:
1. CNM 1,2 x 1,2 mm^2;
2. Hamamatsu Ø 1 mm.



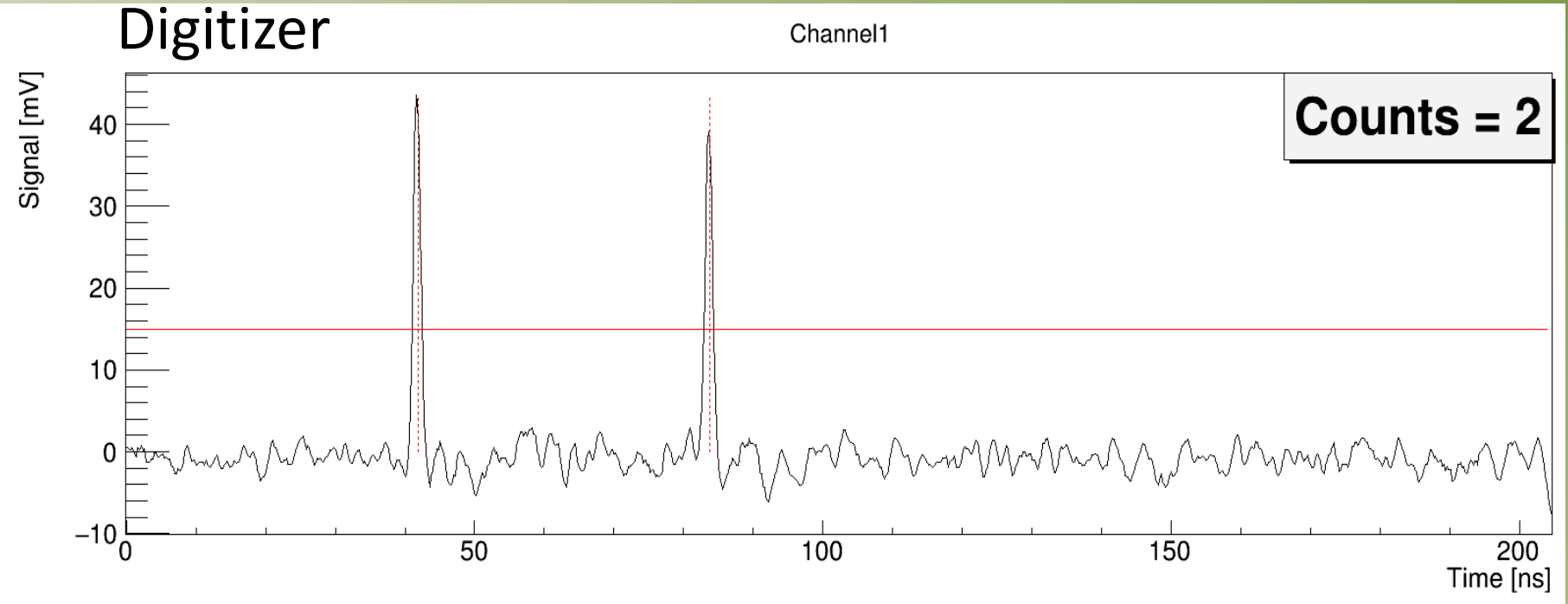






- ✓ CNAO (Pavia);
- ✓ 32 runs;
- ✓ ~ $2*10^{10}$ p each run (FWHM 1 cm);
- ✓ protons (62-227 MeV);
- ✓ Different fluxes (Degrader 20-100).

Results – Signal Duration



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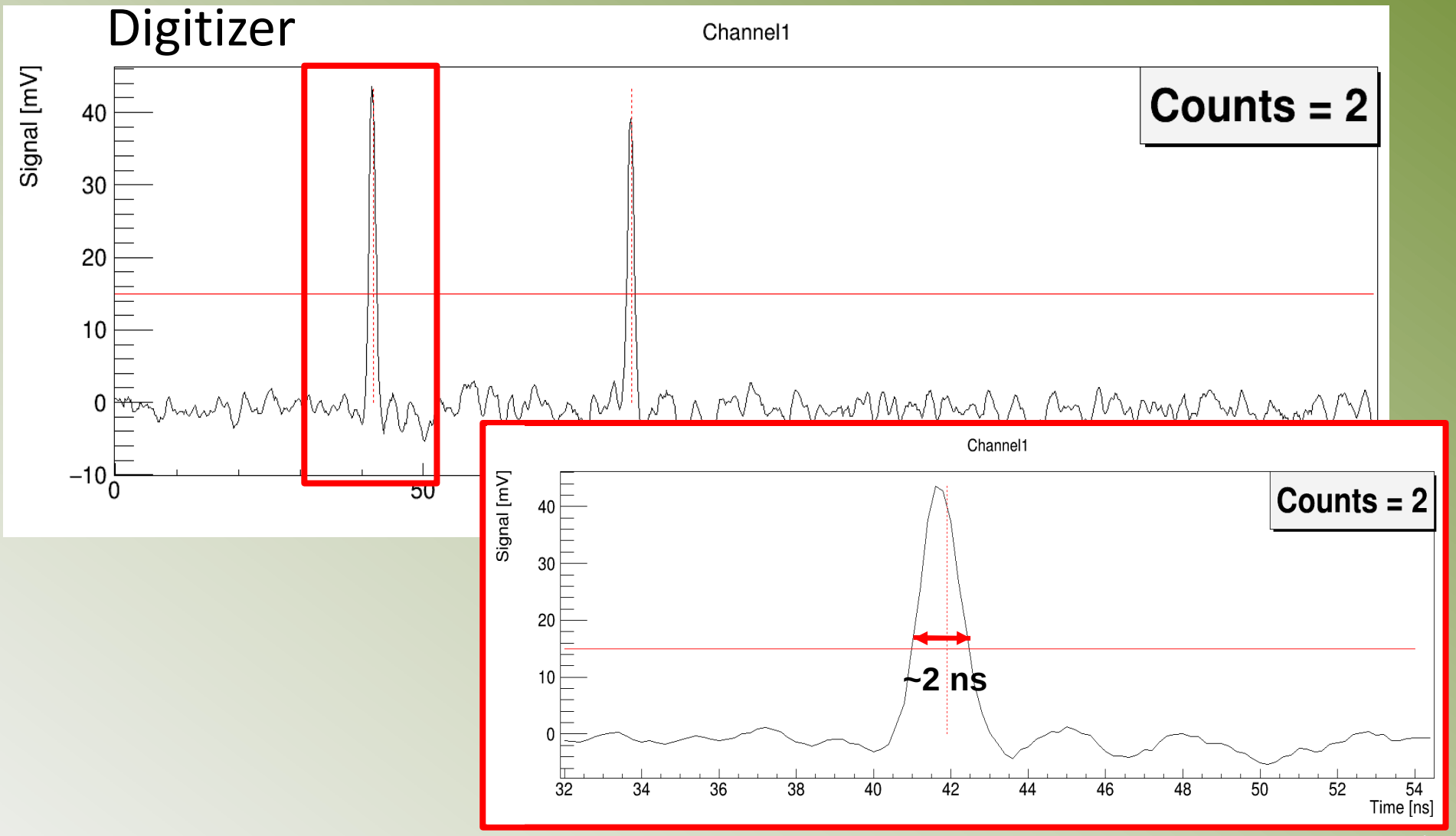
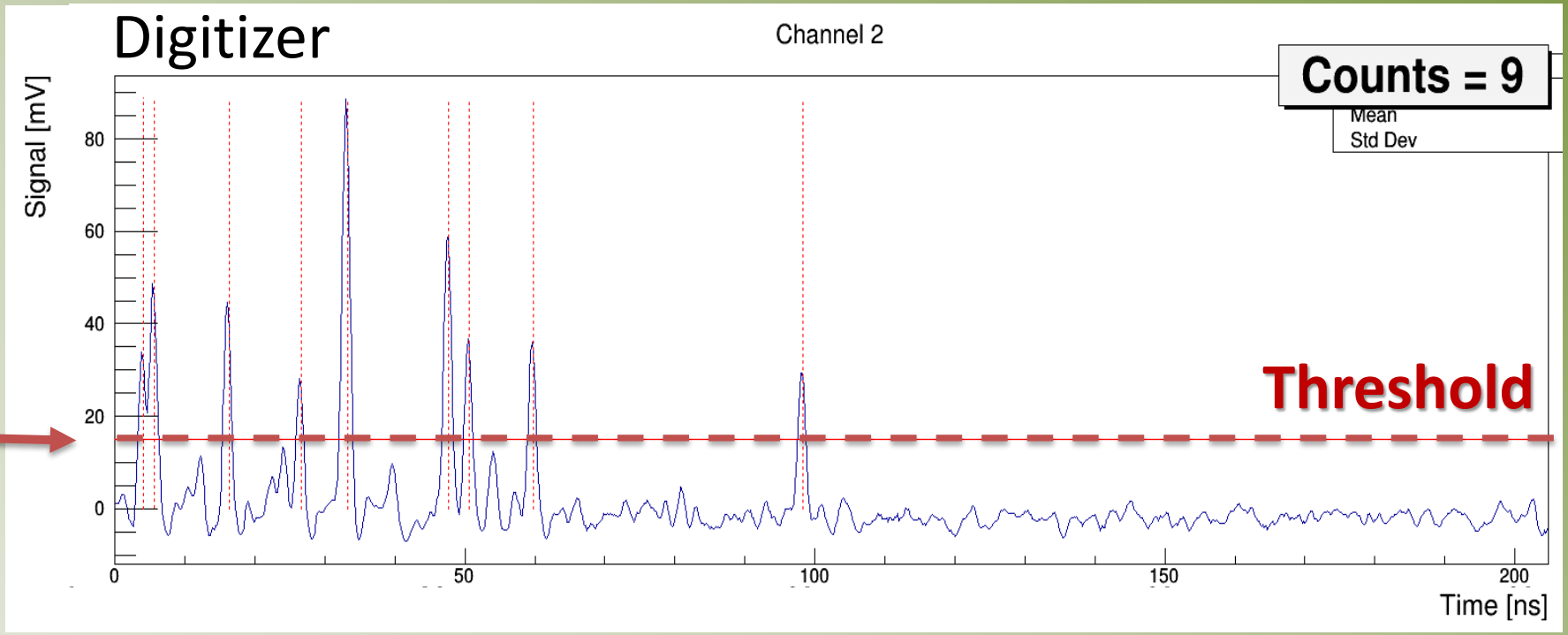
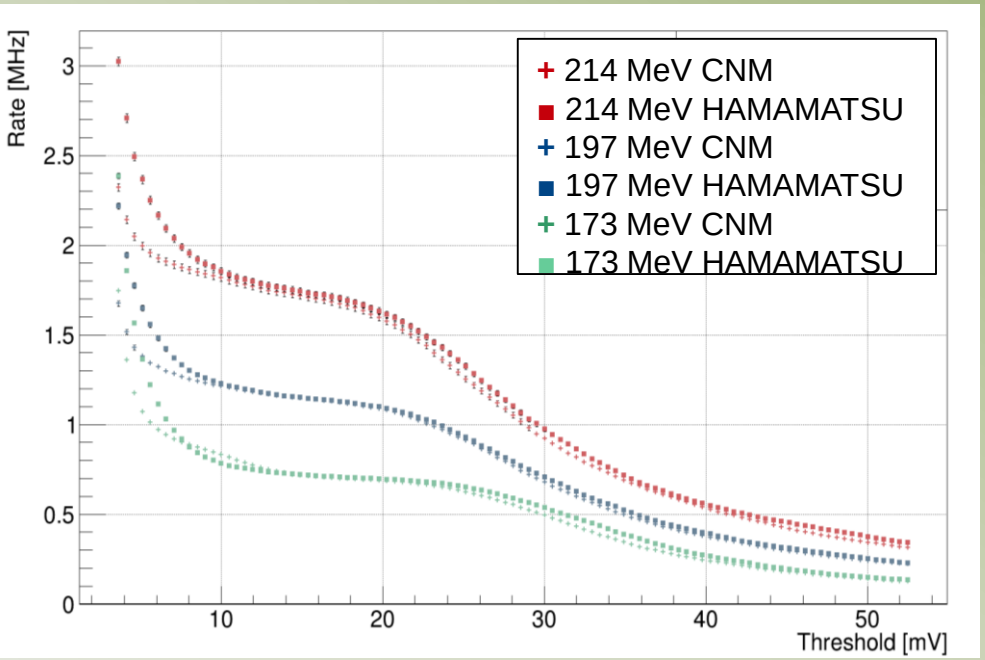


Results – Threshold and Pile up



Results – Threshold



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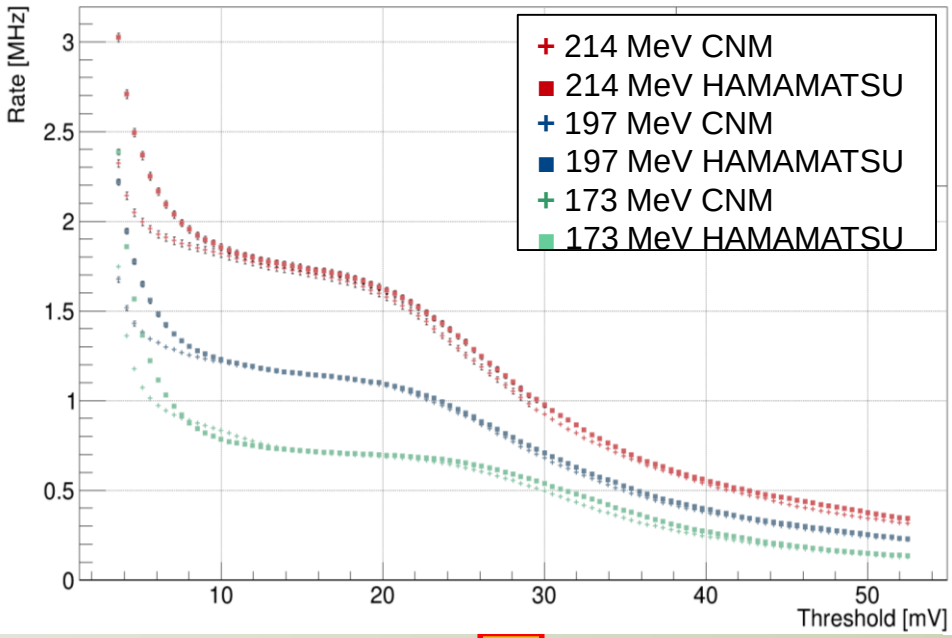
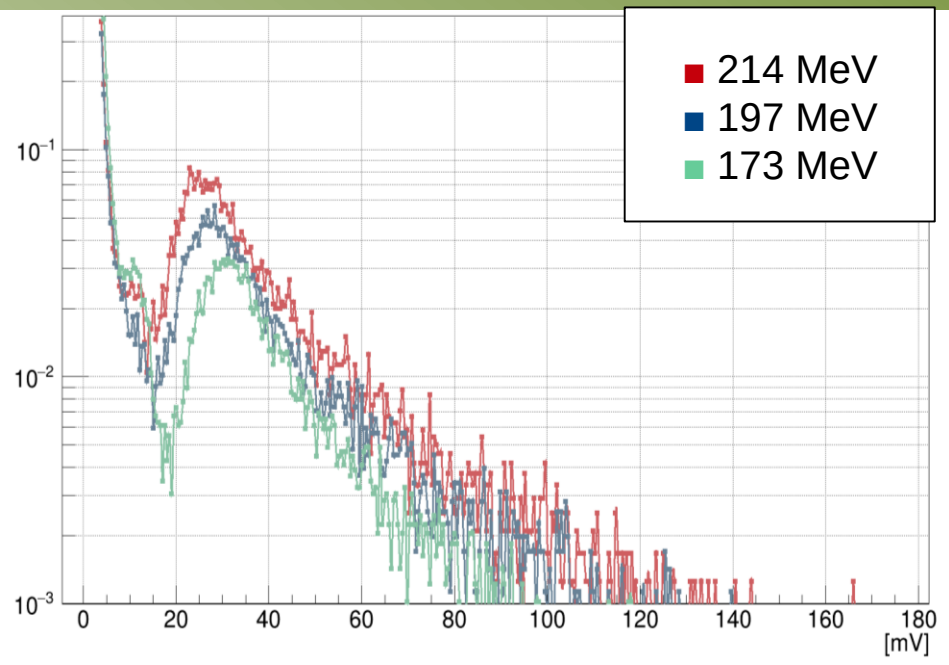
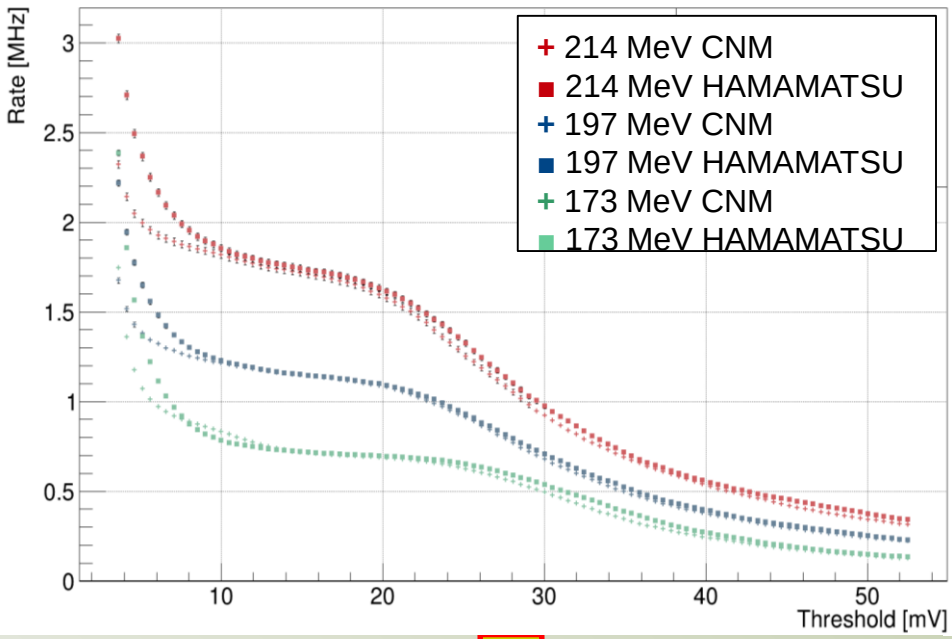
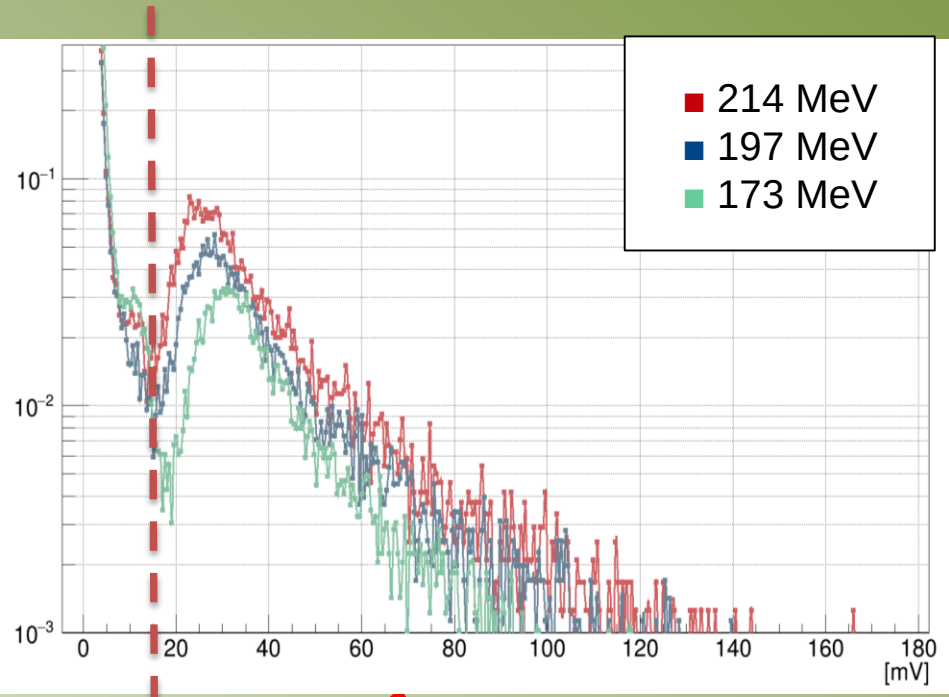




Derivating

Results – Threshold

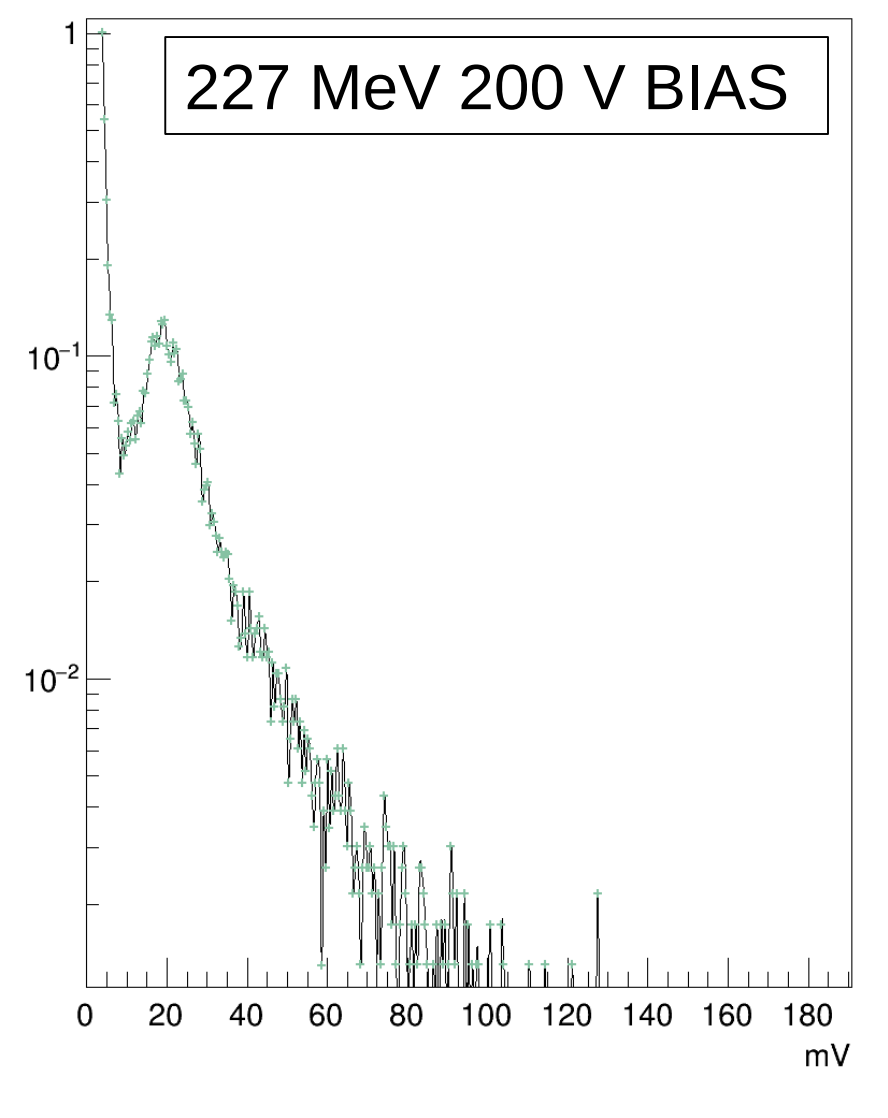


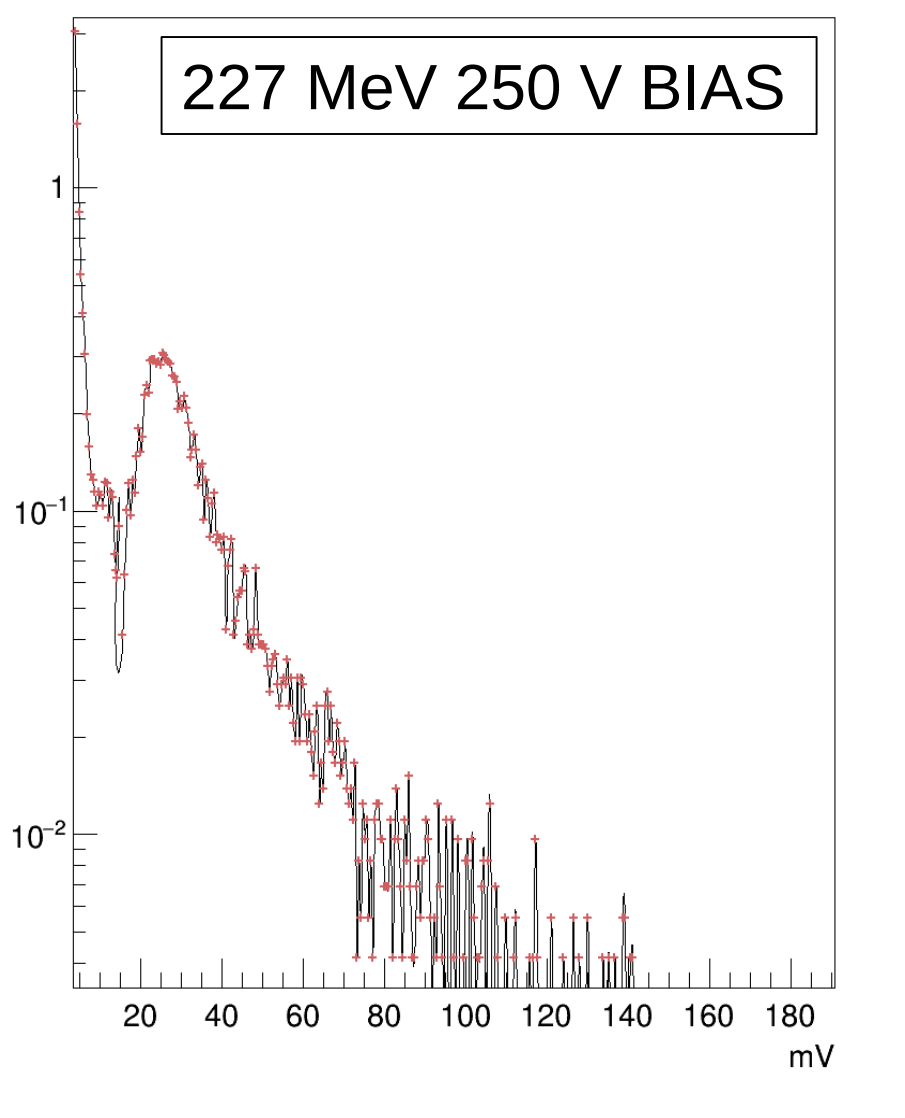


Derivating

Best threshold

Results – Possibility to enhance S/N ratio





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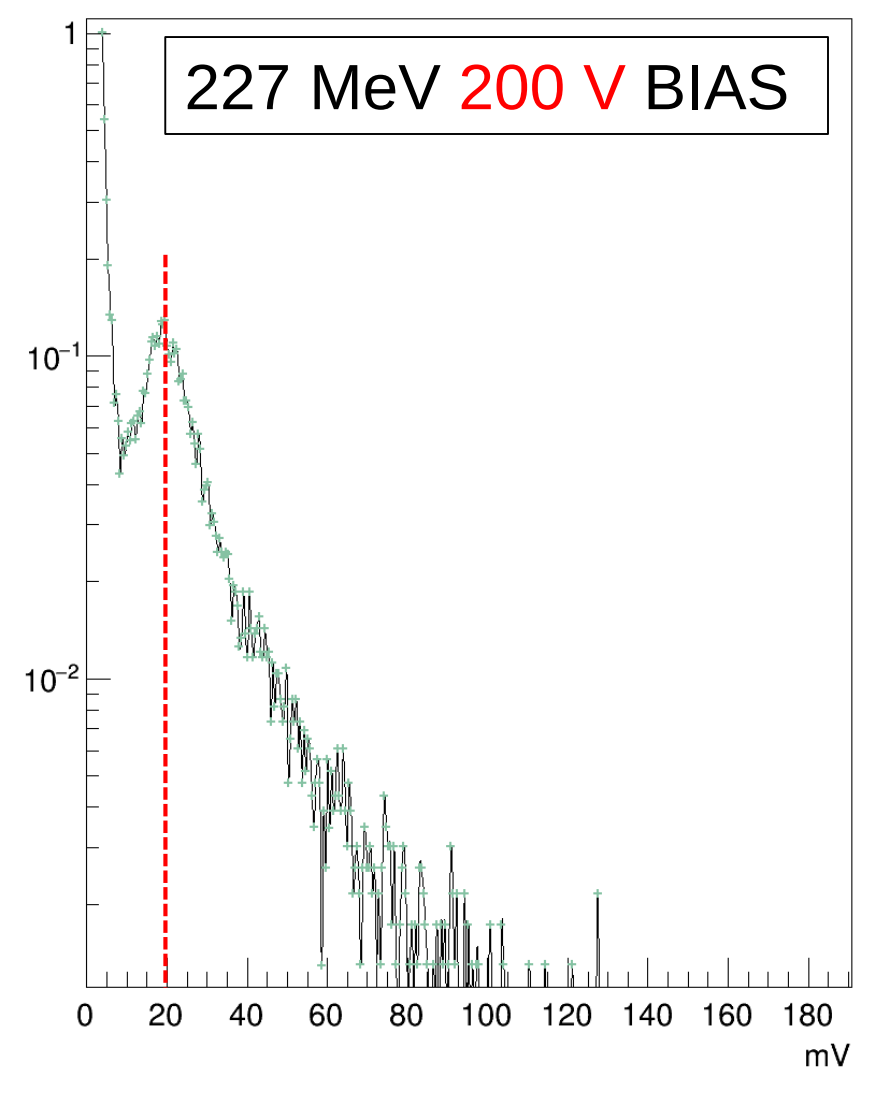

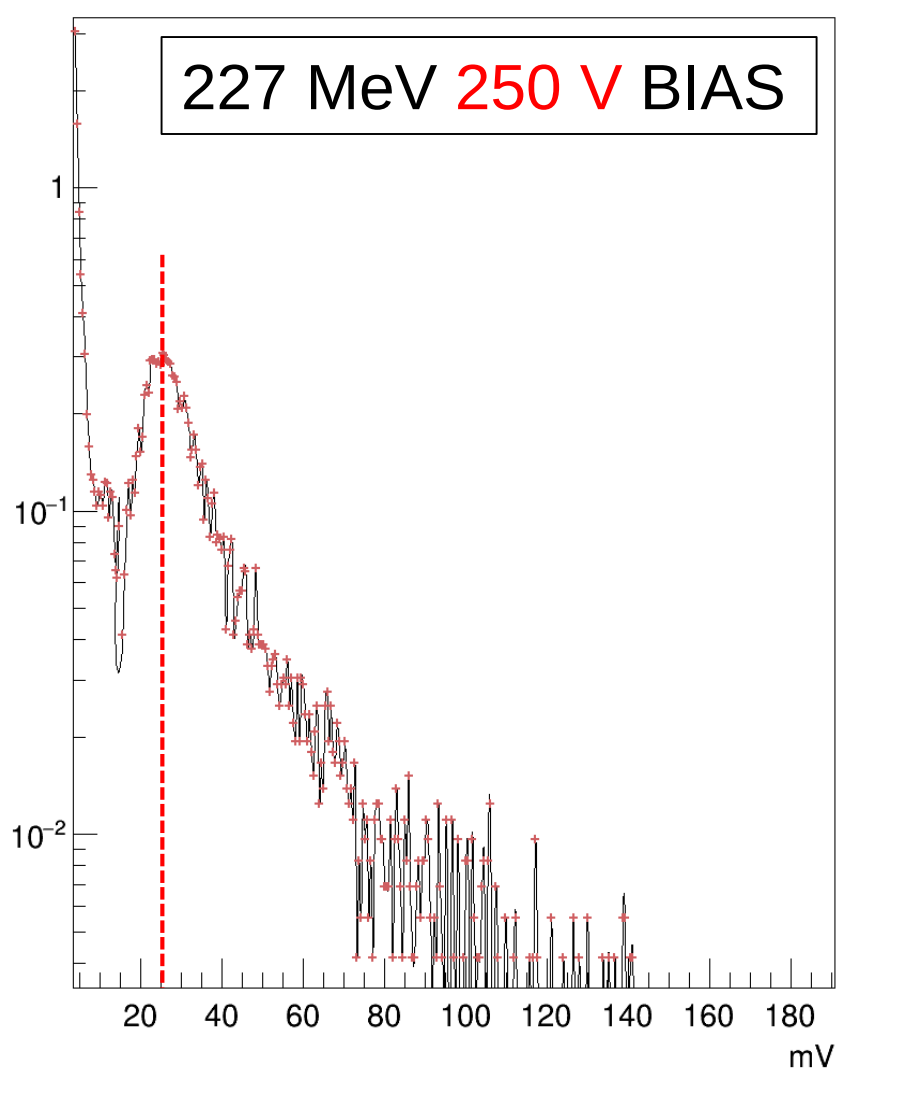

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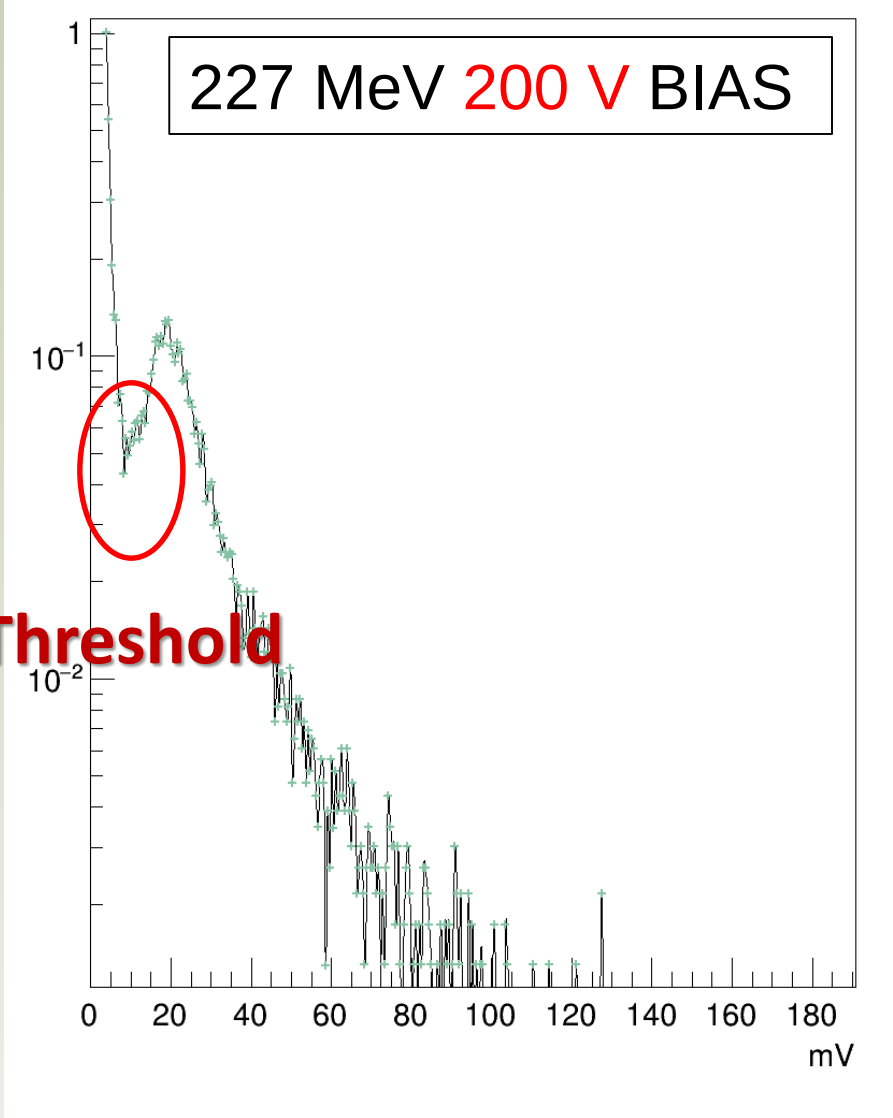
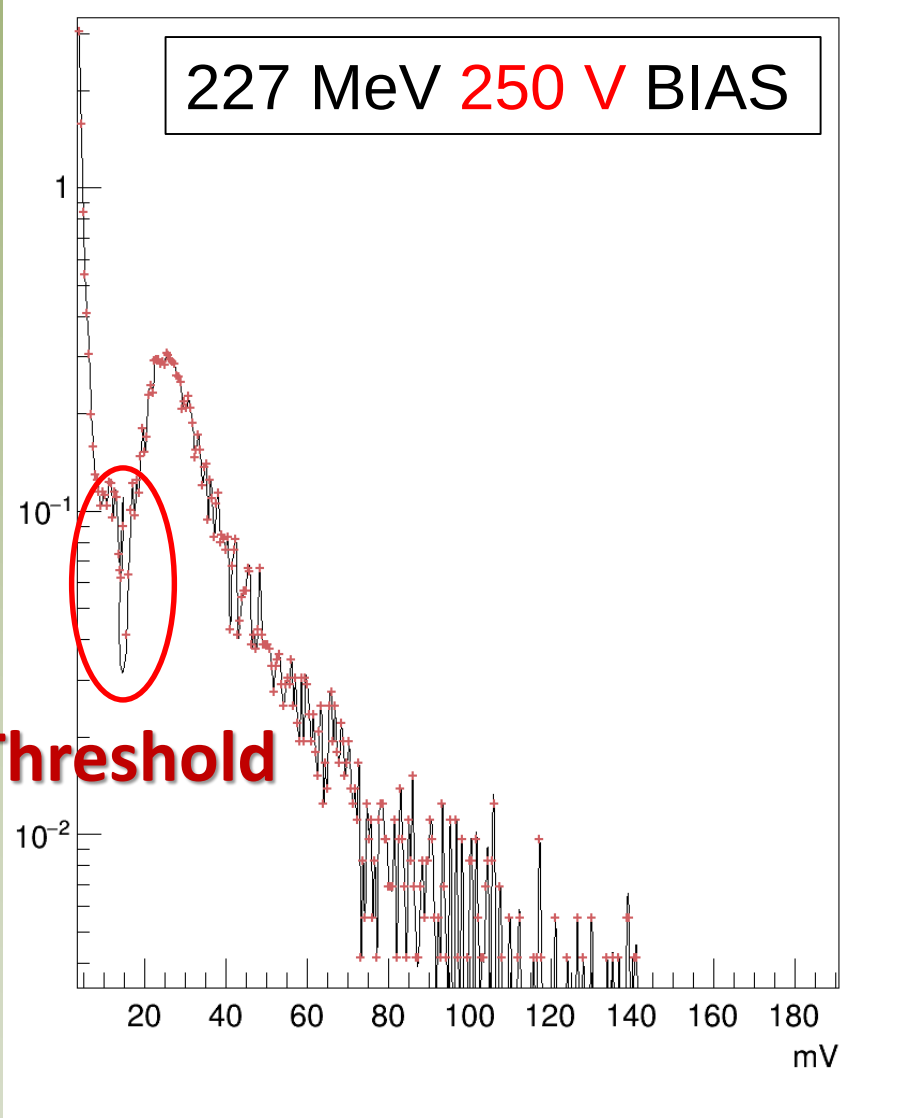
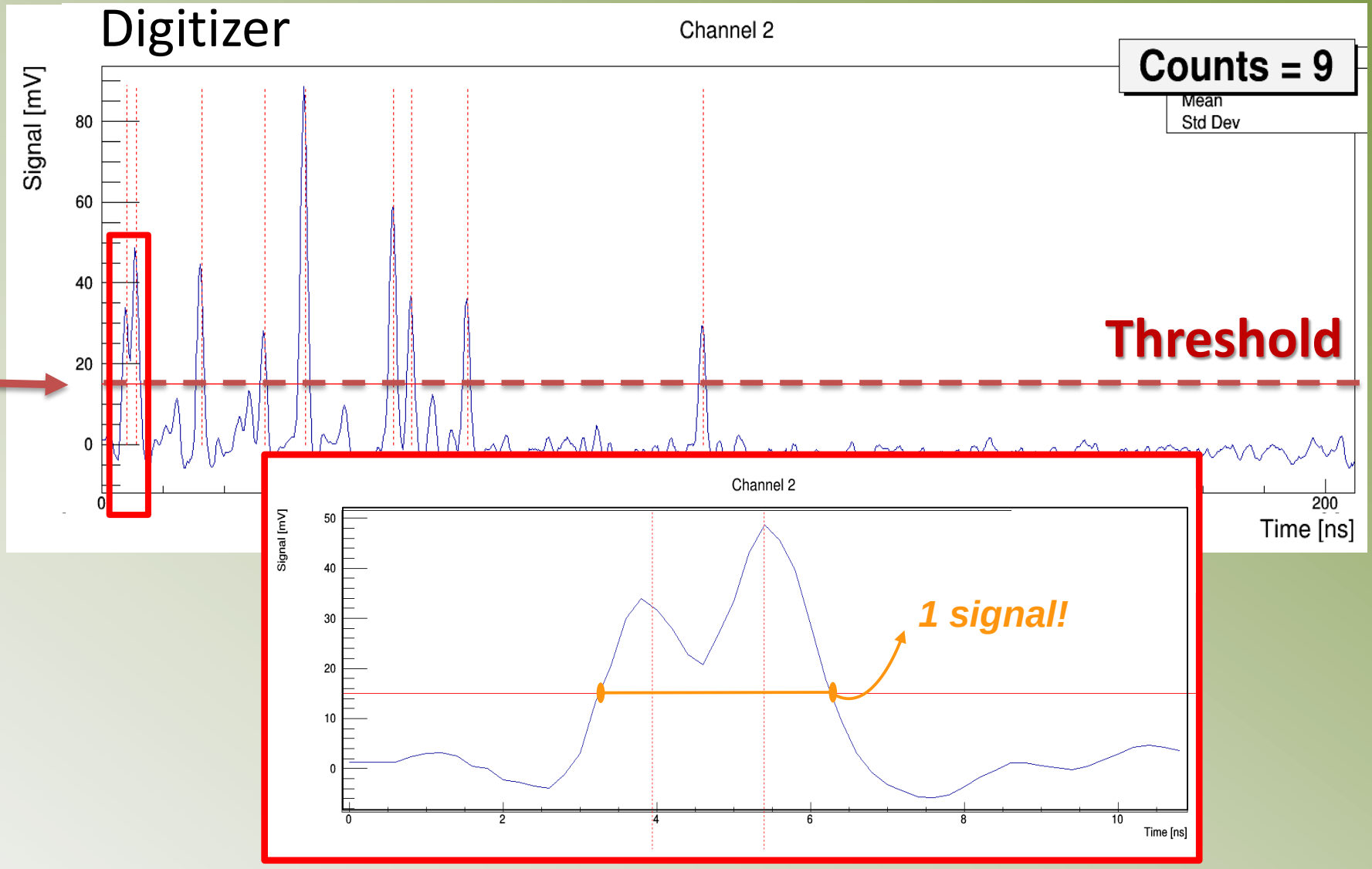
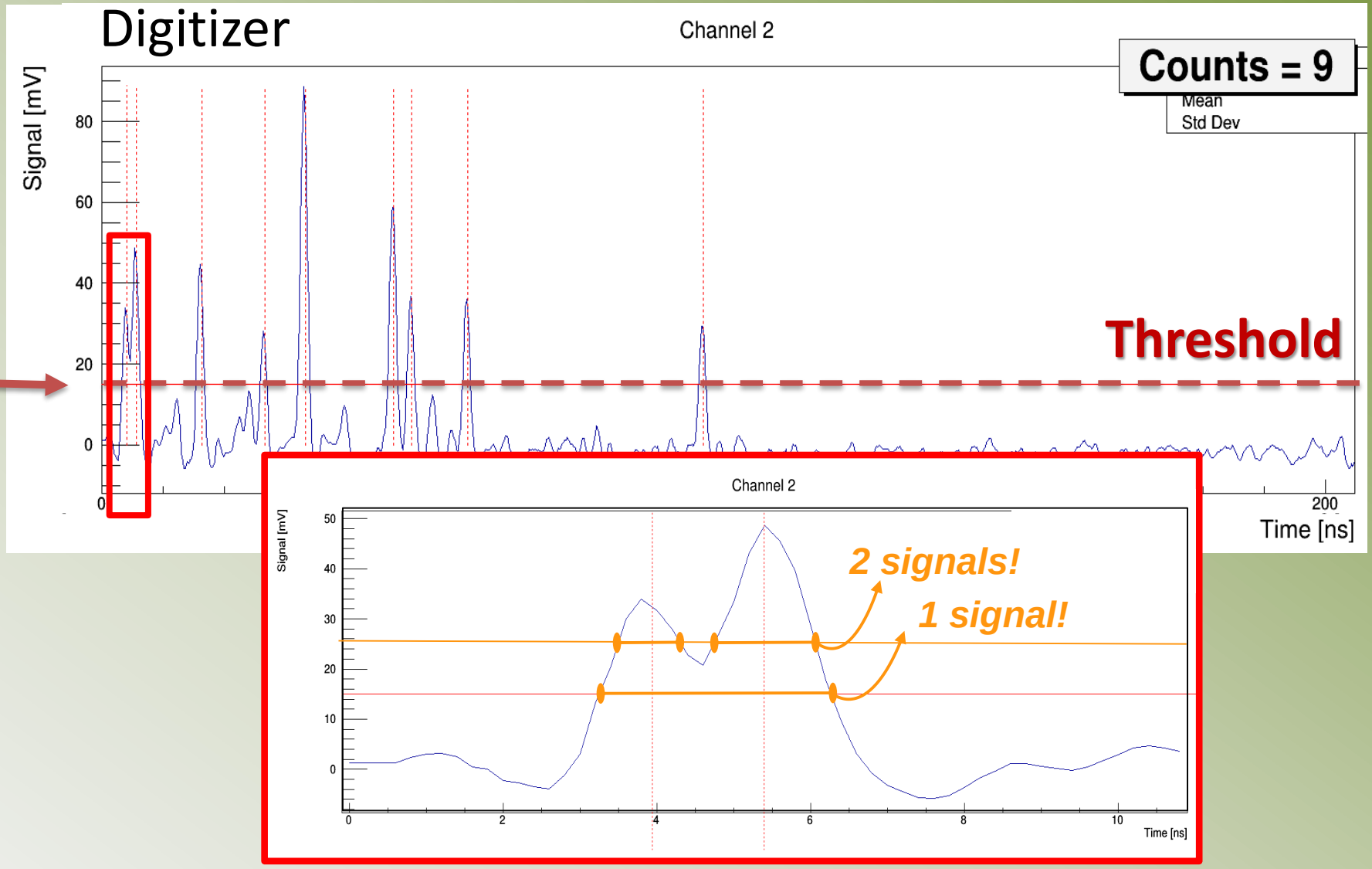




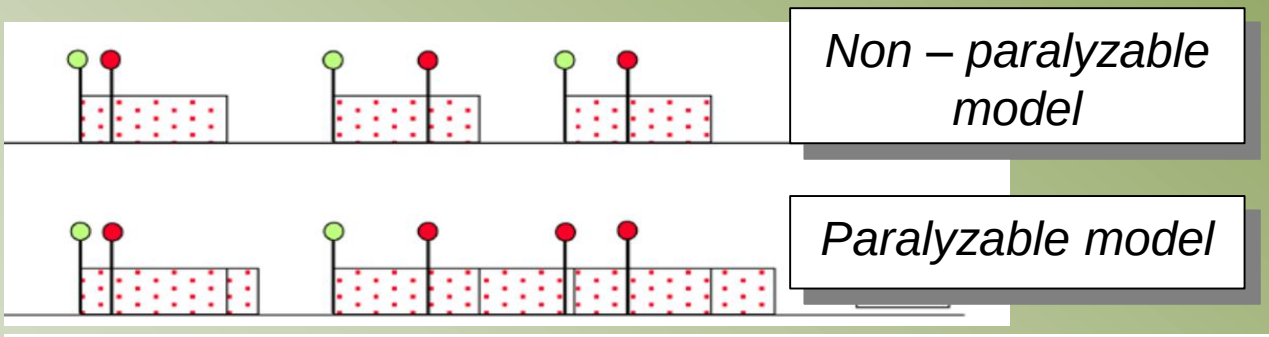
Results – Pile up



Results – Pile up

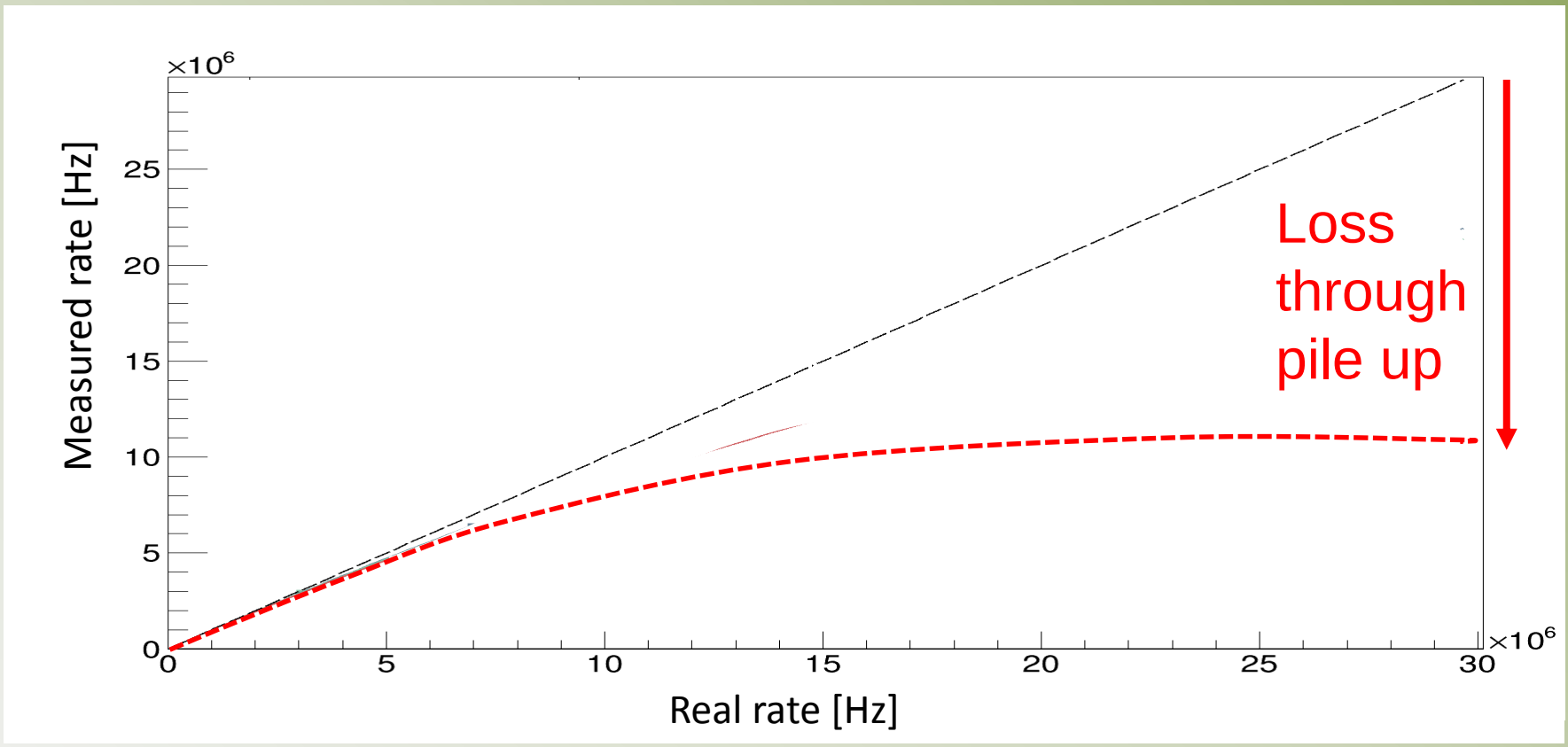


Results – Pile up correction studies ongoing



C (ionization chamber);

Measured Rate;



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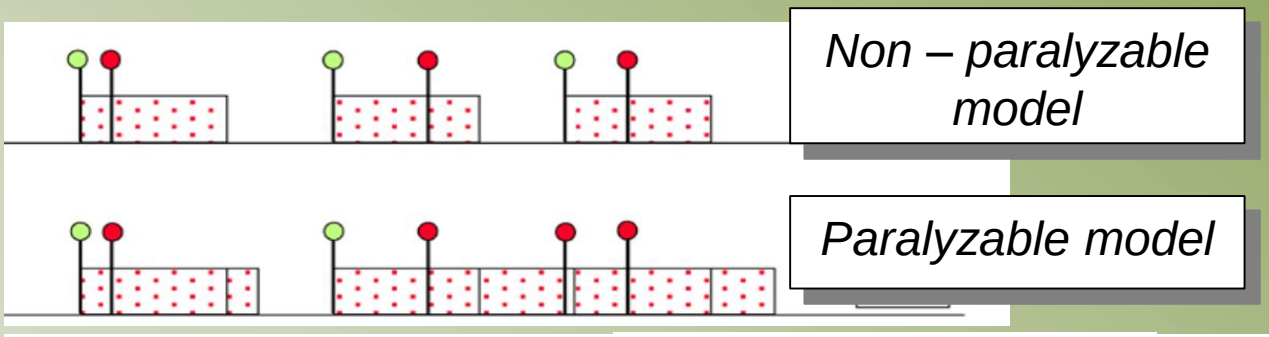

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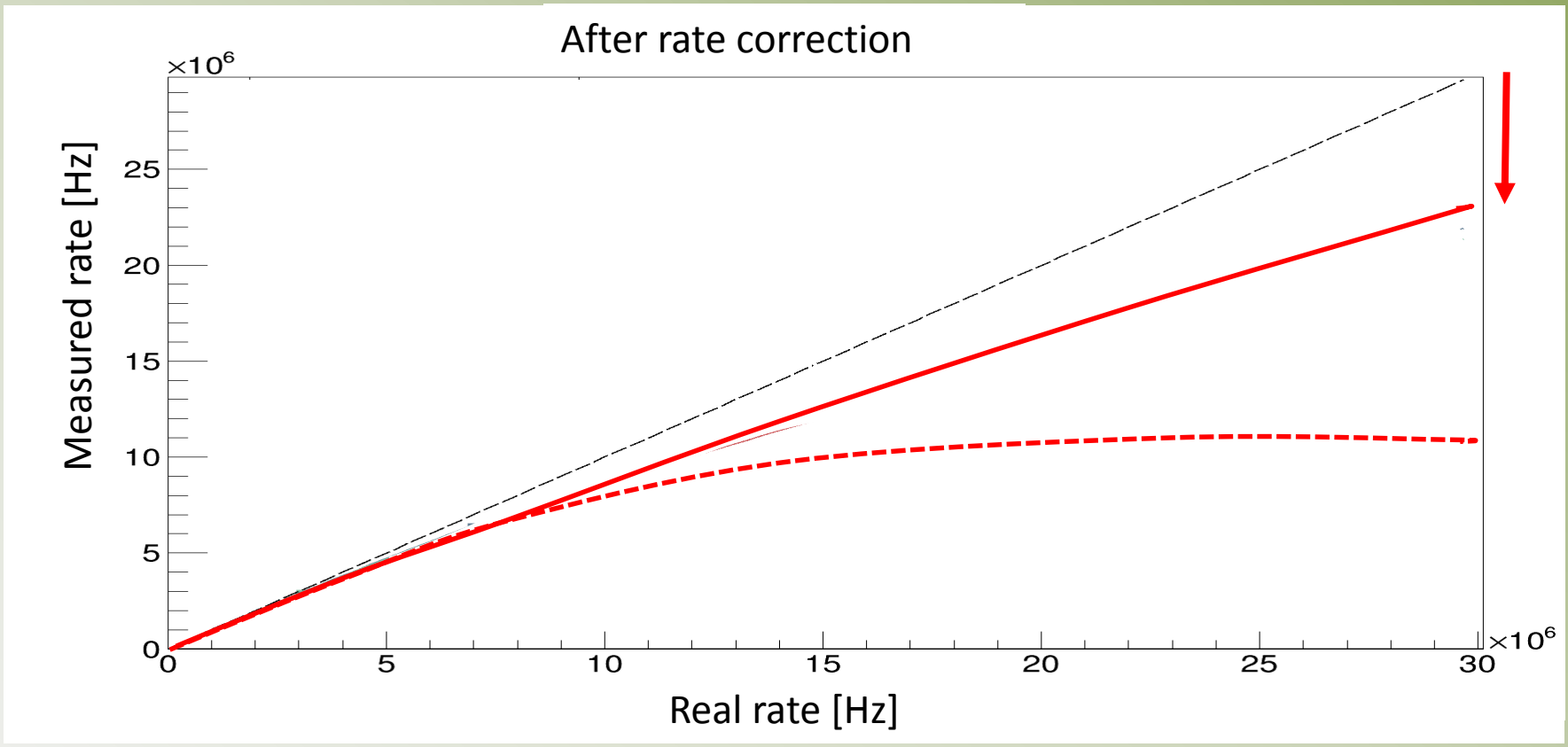
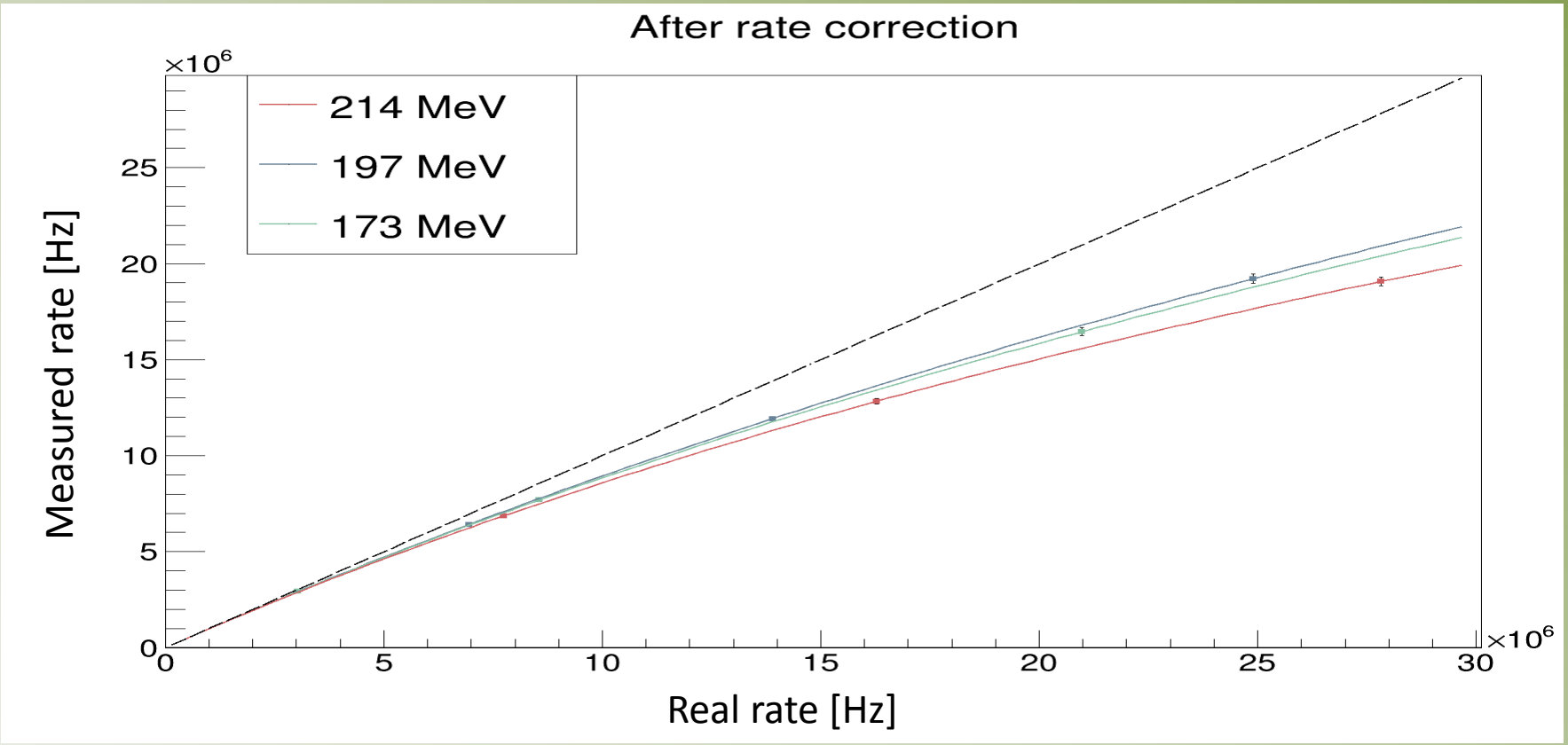


Results – Pile up correction studies ongoing



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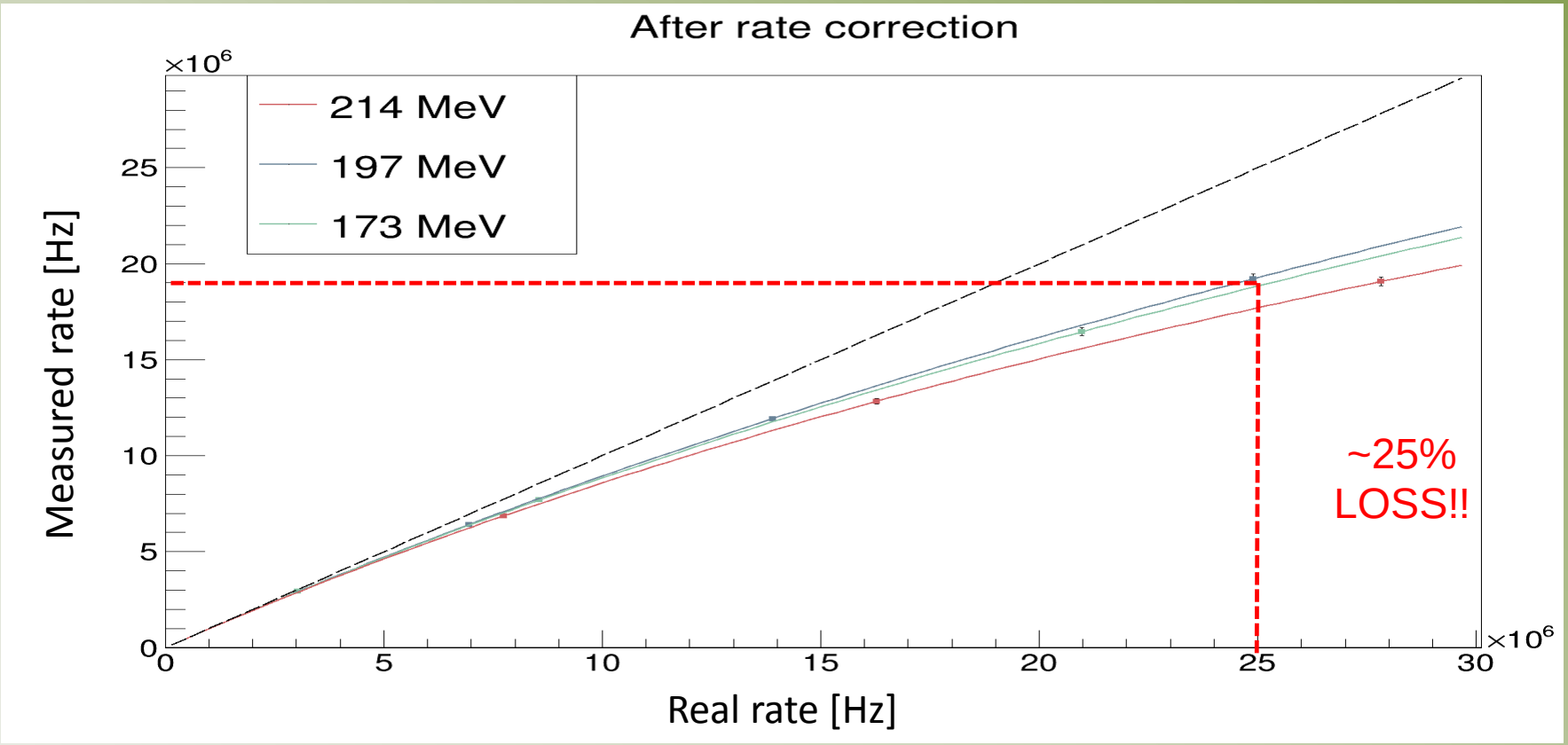
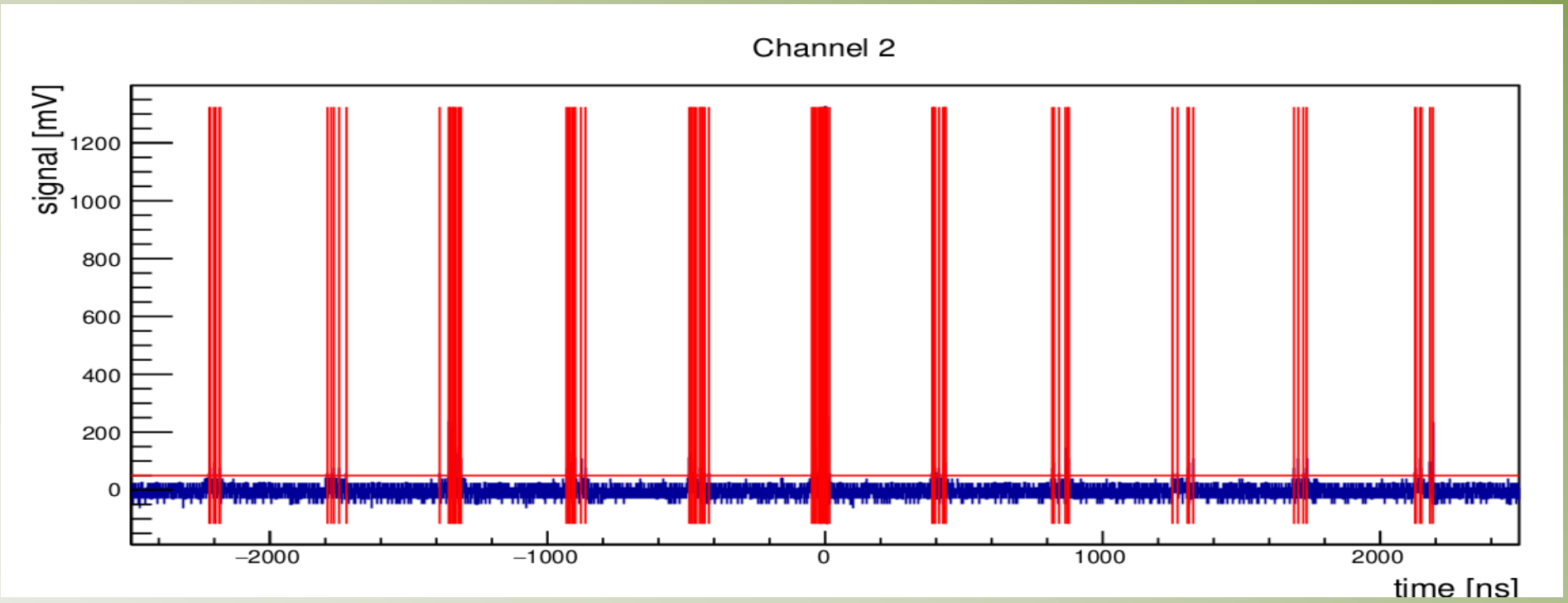


Results – Bunched structure of the beam



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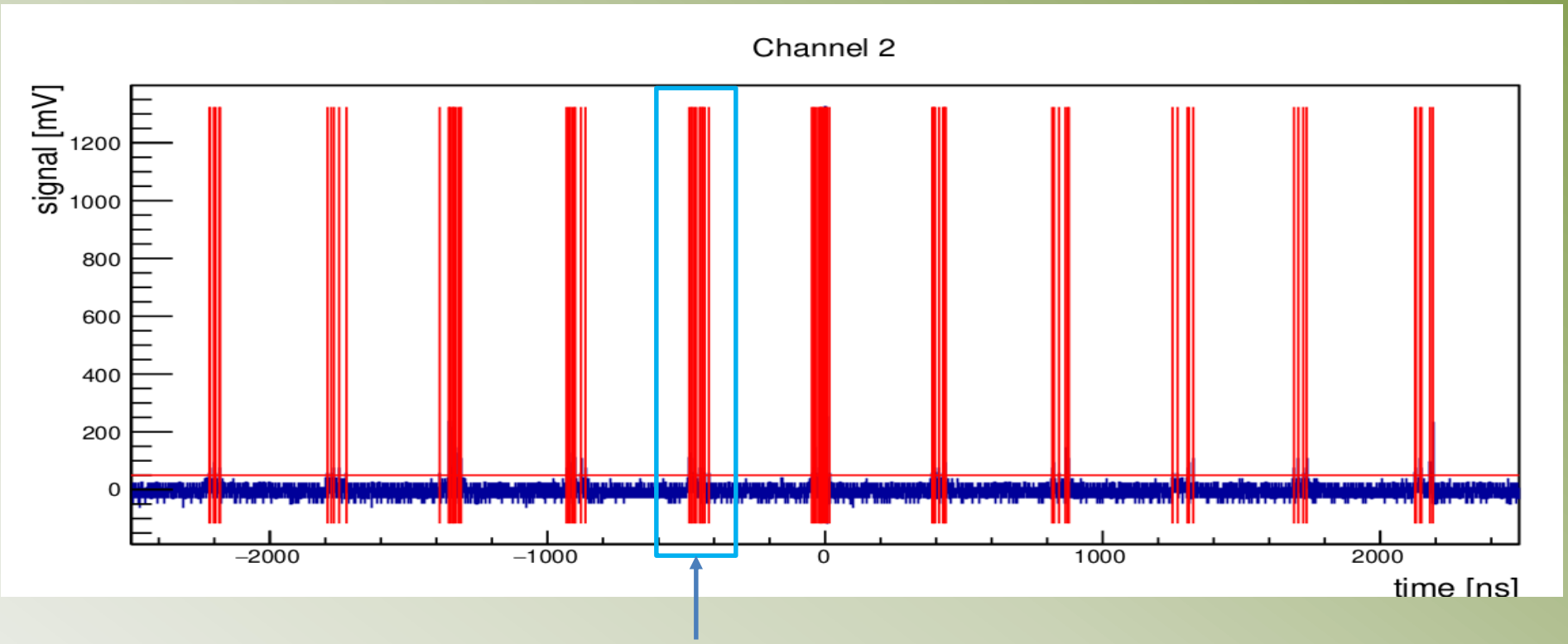
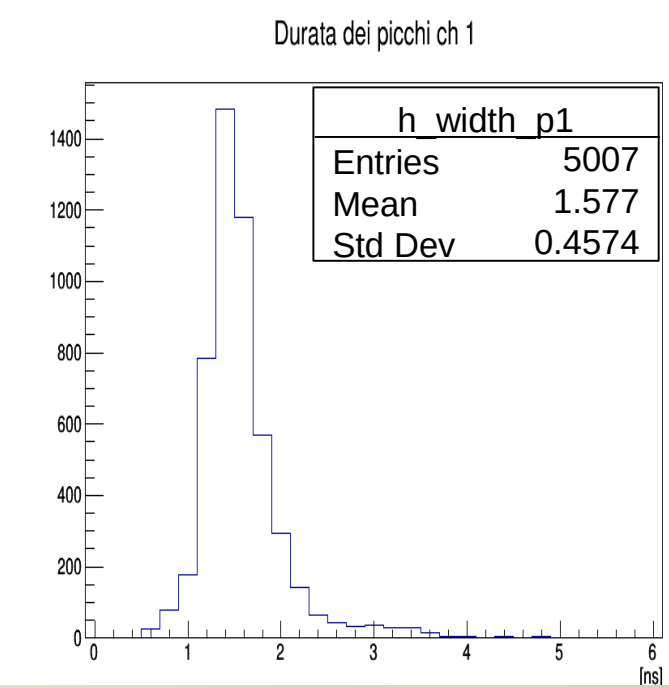
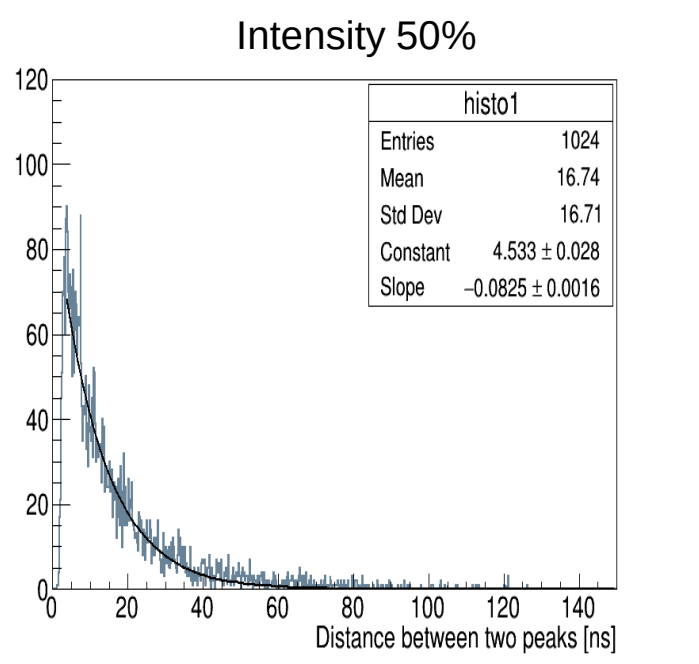


~10^{10} p/s cm^2 !!

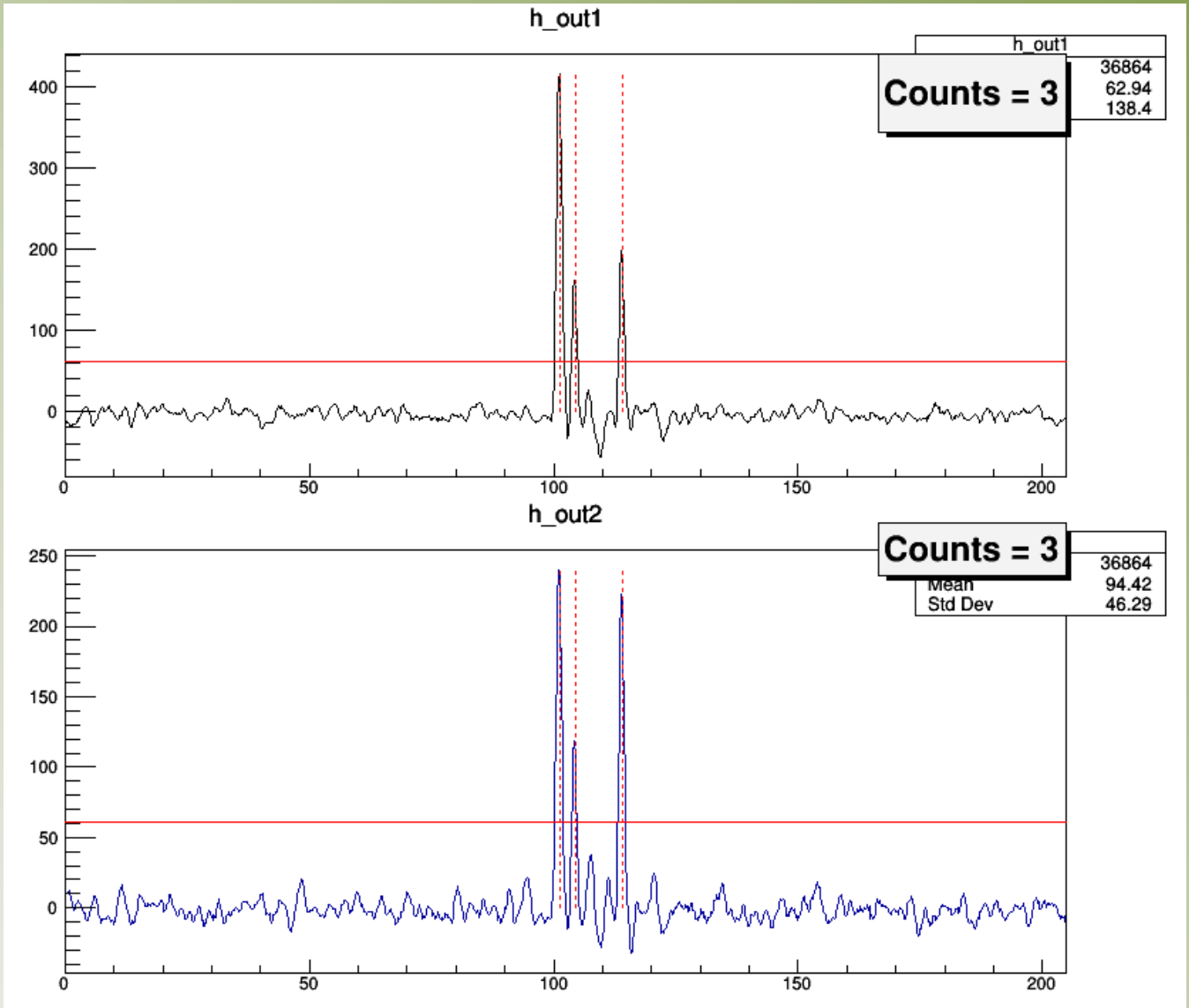
Results – Bunched structure of the beam





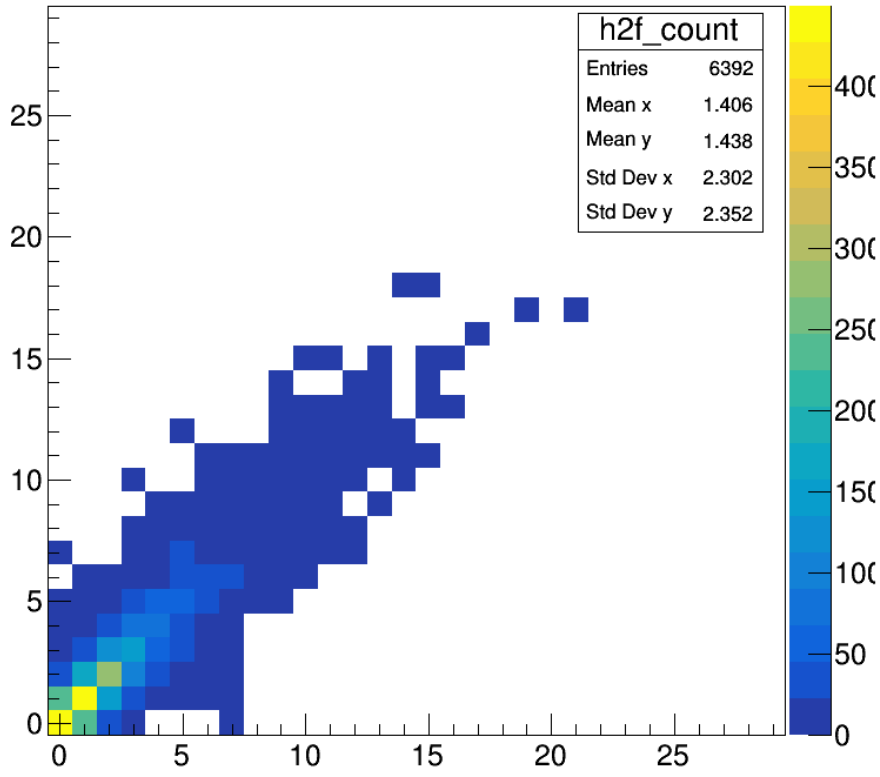
Intensity	Rate (counts) [MHz]	Rate (fit) [MHz]
20%	2.92 ± 0.03	50.7 ± 1.1
50%	7.70 ± 0.09	82.5 ± 1.6
100%	13.57 ± 0.21	127.3 ± 2.6

Results – Sensors correlation

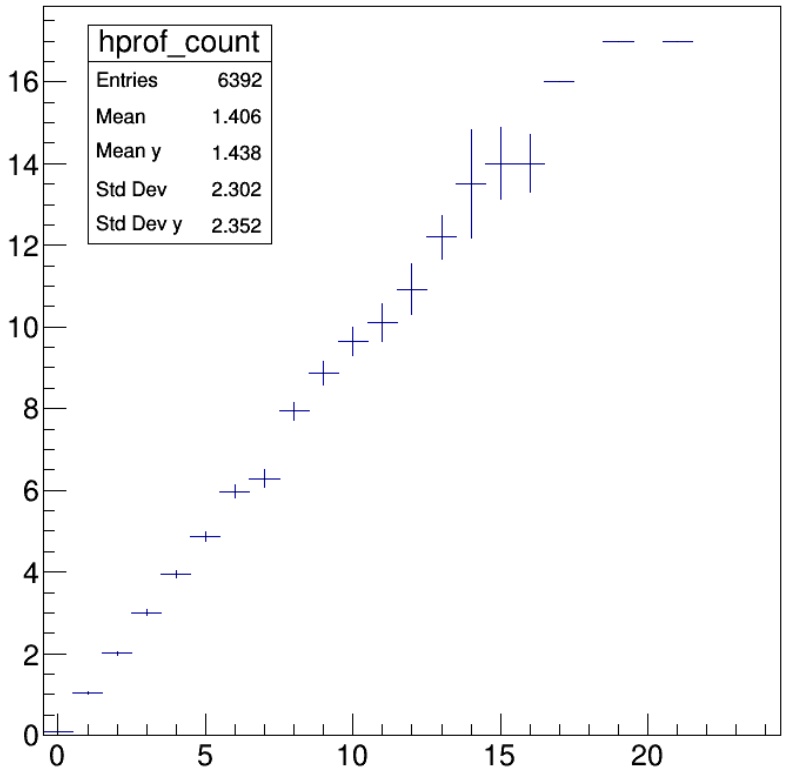


Results – Sensors correlation

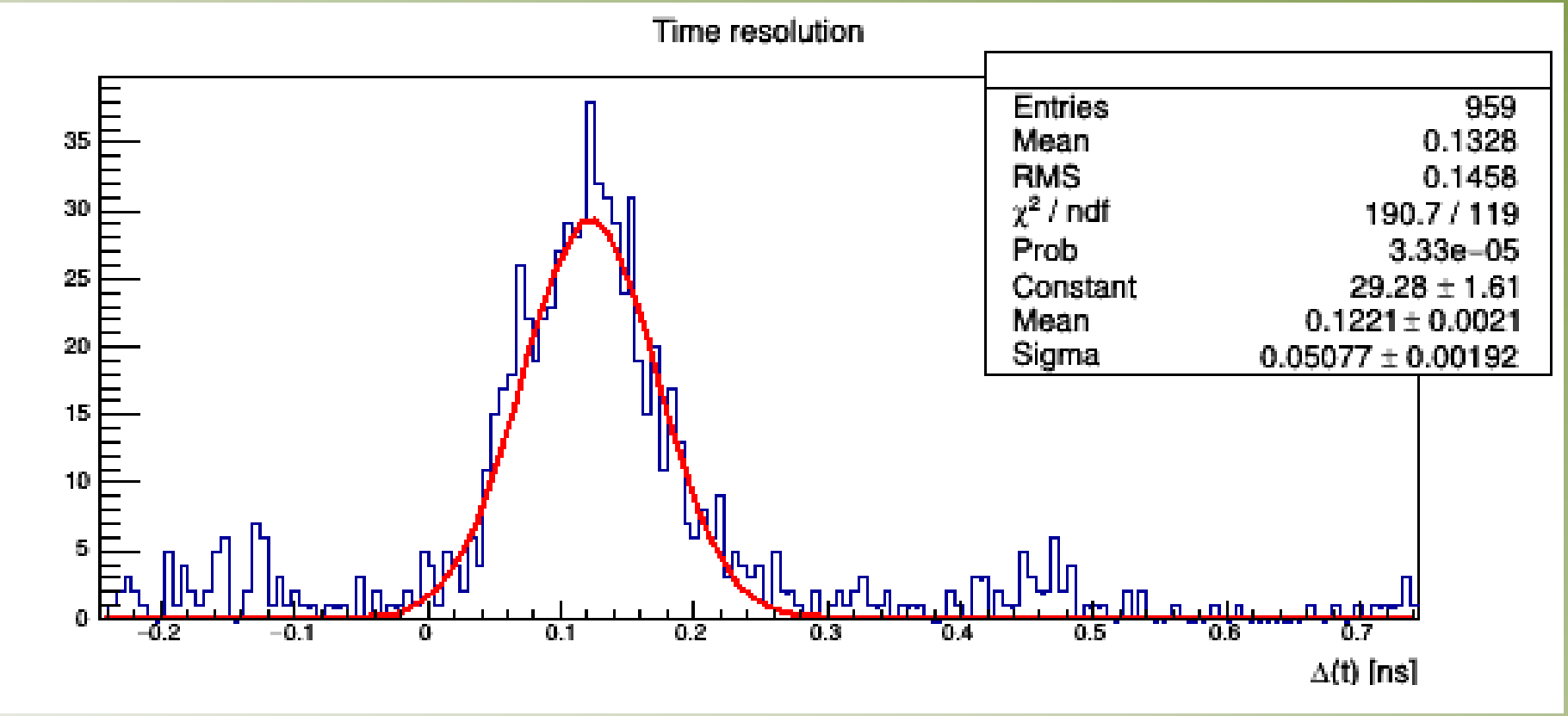
Count on Ch 1 and Ch 2



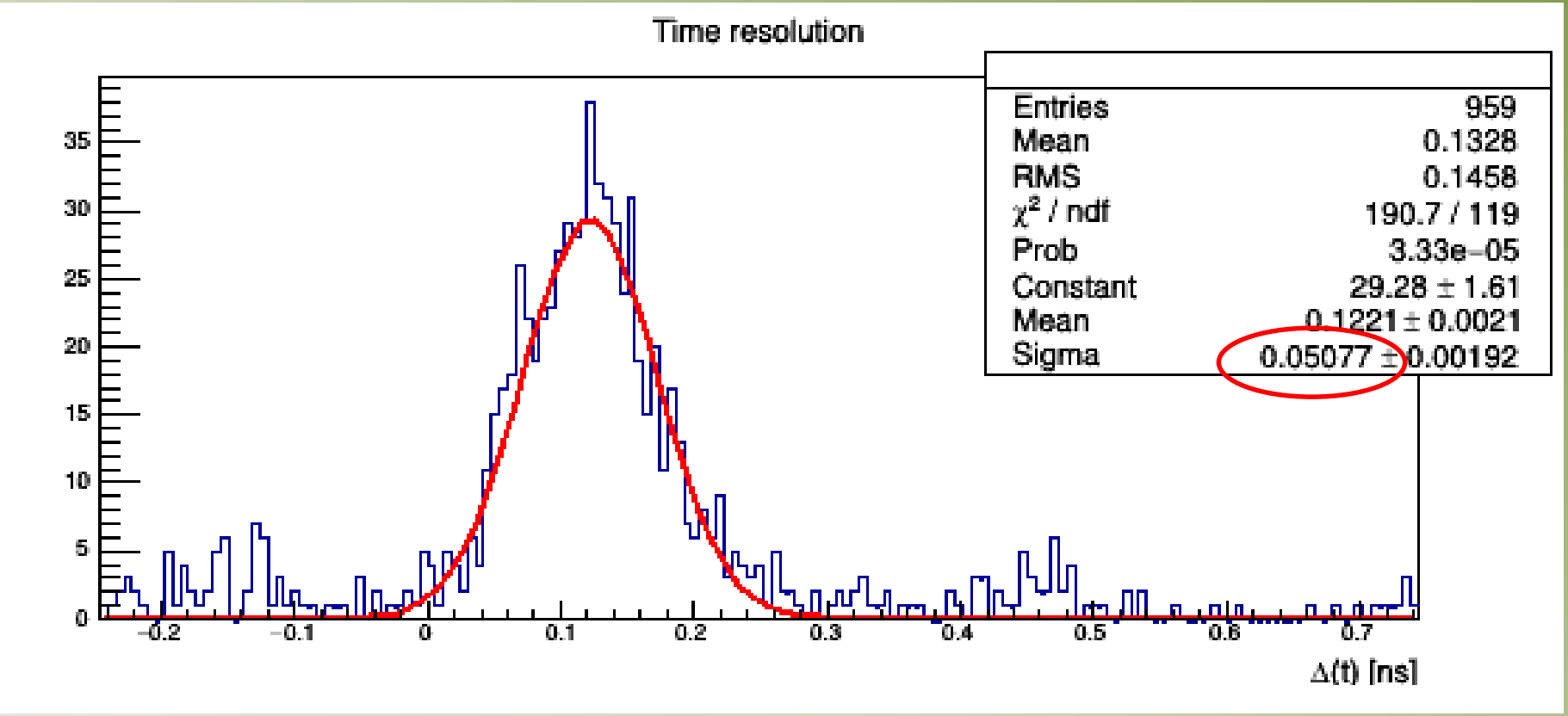
Profile of Ch2 versus Ch1



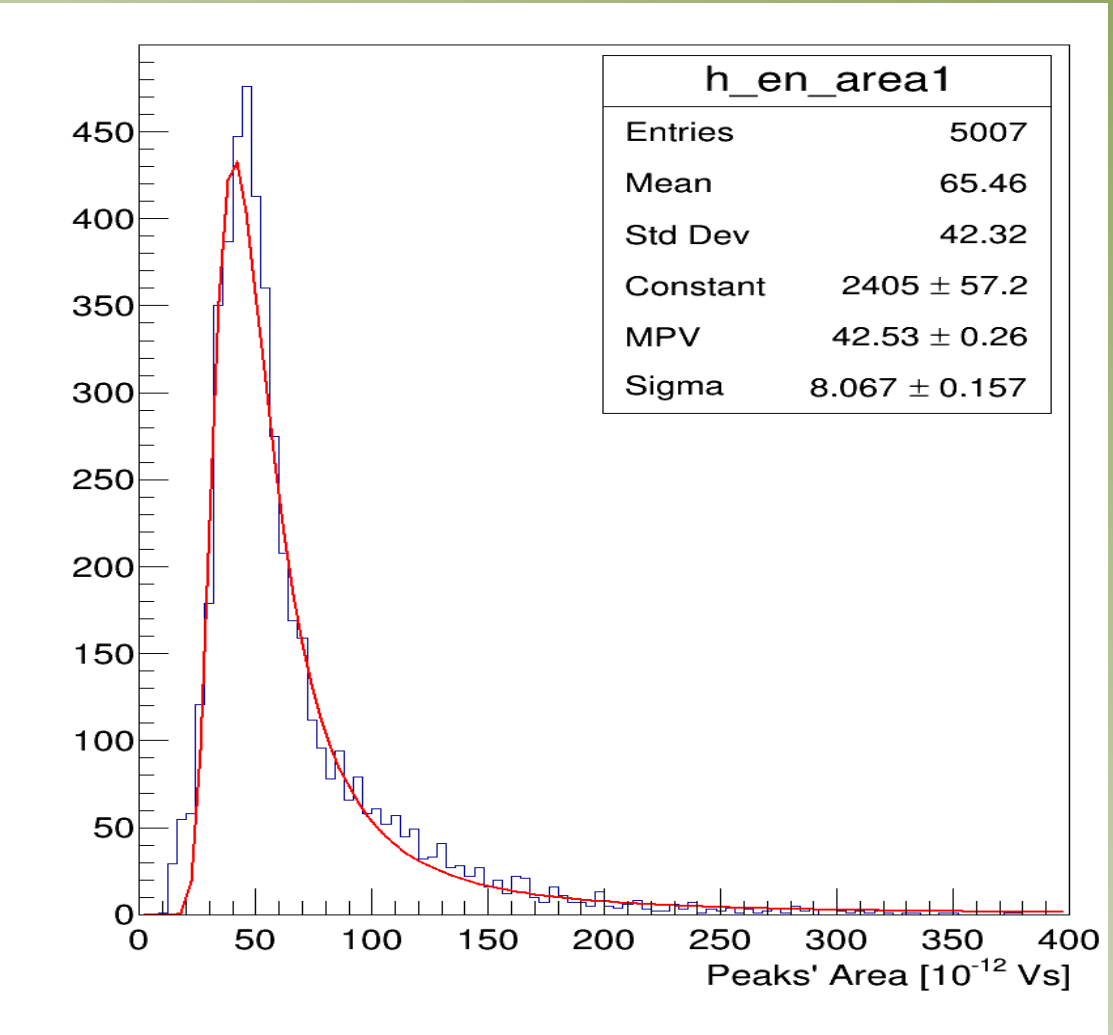
Results – Time resolution



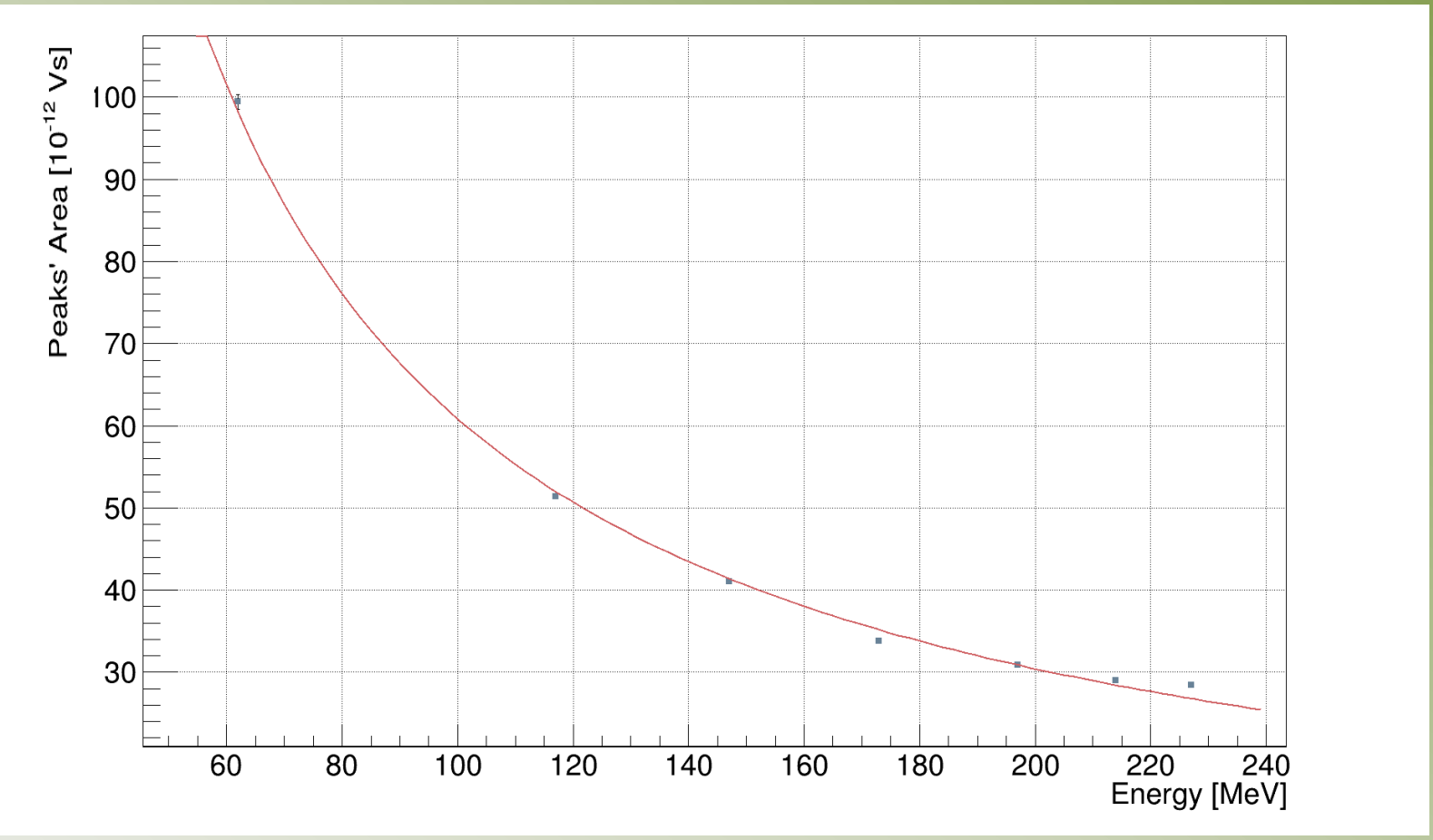
Results – Time resolution



Results – Landau

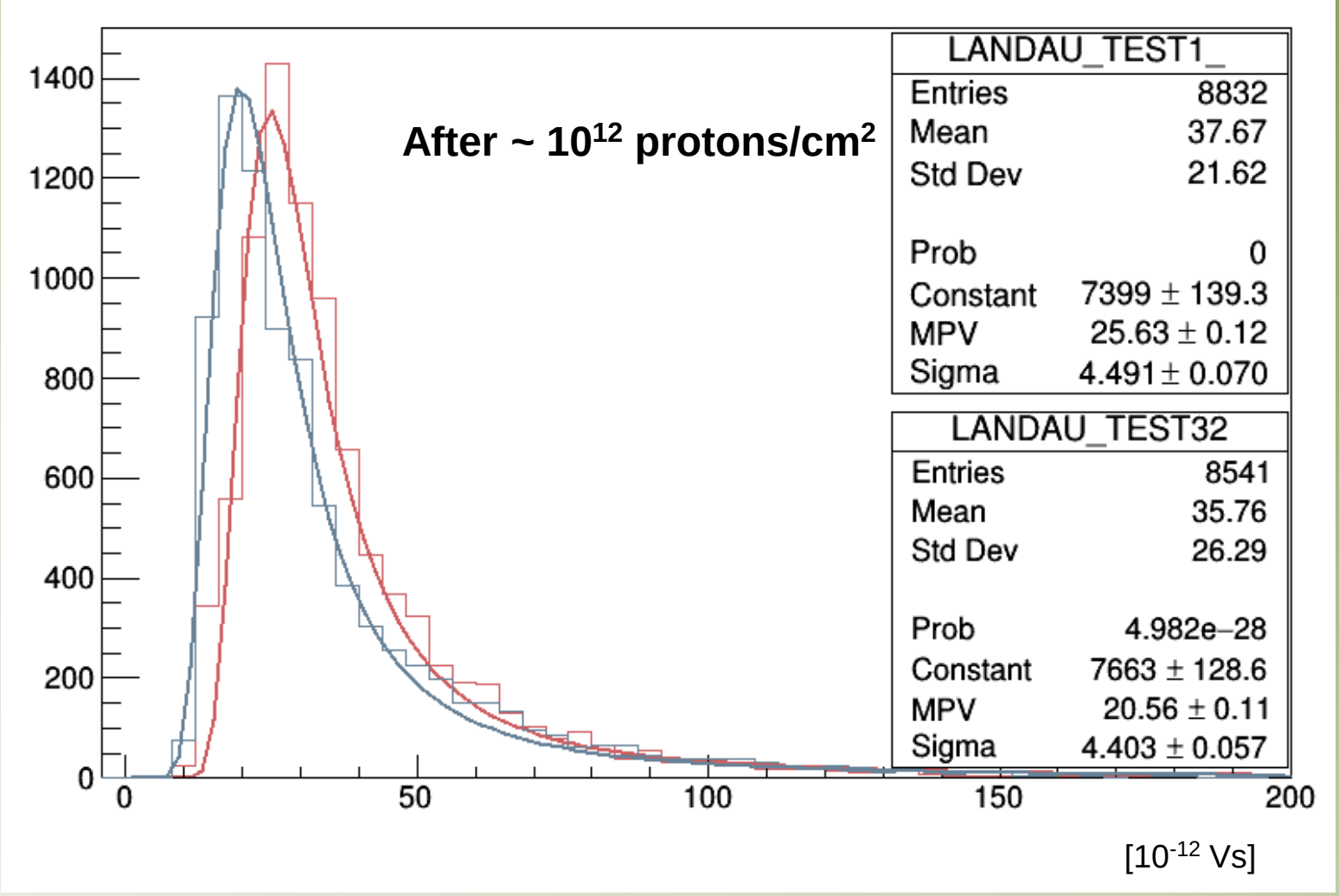


Results – MPV distribution

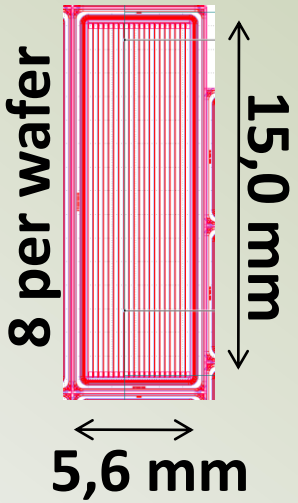


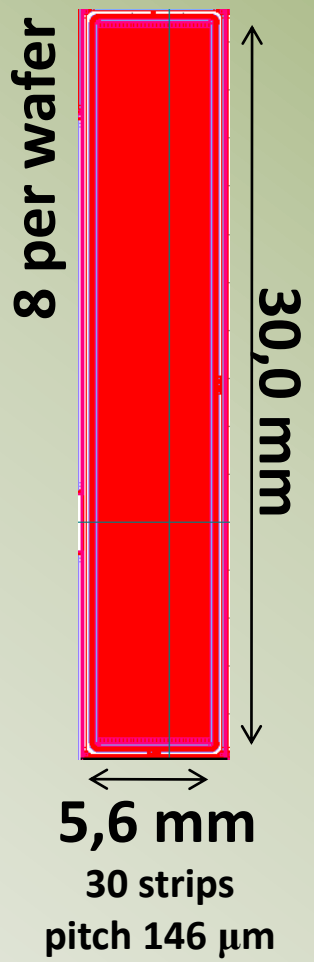
Bethe-Bloch curve's trend

Results – Radiation damage



Ongoing – Strips sensors and doping possibilities

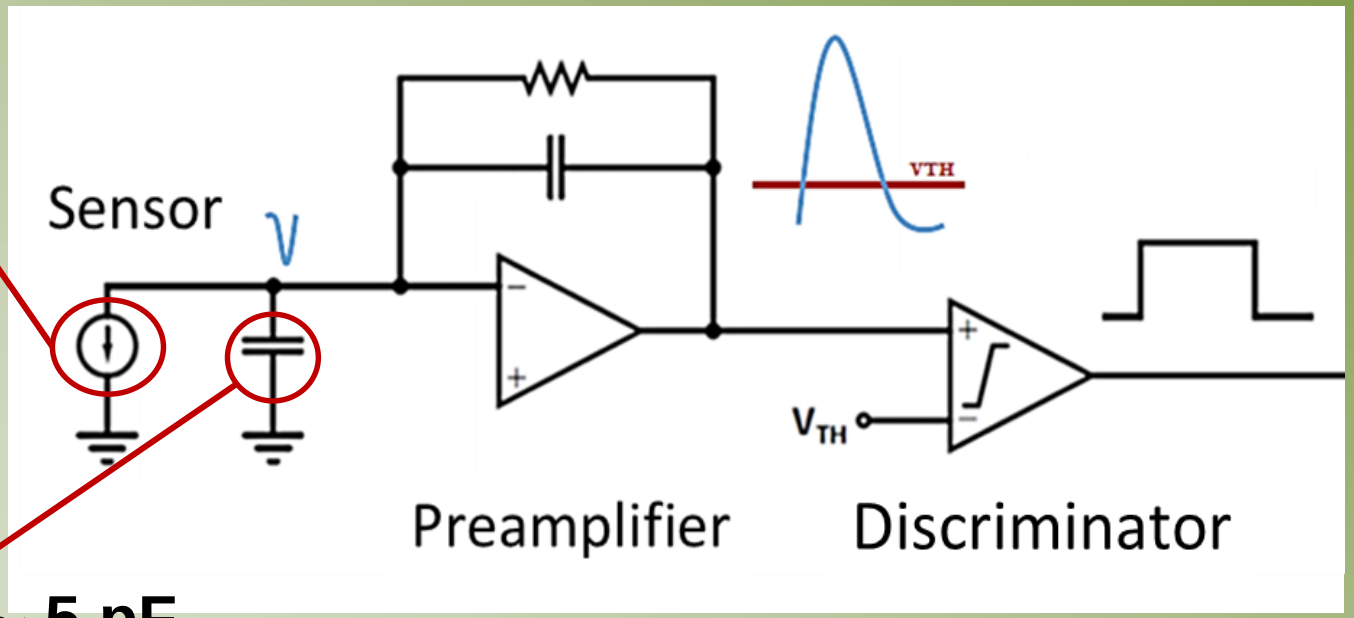




- ✓ Different doping doses;
- ✓ Doping with gallium instead of boron;
- ✓ Treatment with a carbon spray;
- ✓ Varying the thermal cycle for activation.

Ongoing – Fast front-end electronics

Sensor Signal



Sensor Capacitance ~ 5 pF

Proton beam energy range: 60÷250 MeV (6-2 MIPs)
Front-End Input charge range: 3 fC ÷ 130 fC
Fluxes measurements: up to 10^8 p cm^{-2} s^{-1}
Pile-up probability kept < 1 %.

Conclusion

UFSD in charge particle therapy could open new perspectives:

Directly count the number of particles → exploiting the large UFSD S/N ratio and fast collection time in small thicknesses;

Measure the energy of the beam → exploiting the outstanding time resolution.

Move IT

INFN

anna.vignati@to.infn.it