TDAR: Technologies for hadrontherapy

Online Monitoring and MONDO

CENTRO FERMI
Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi

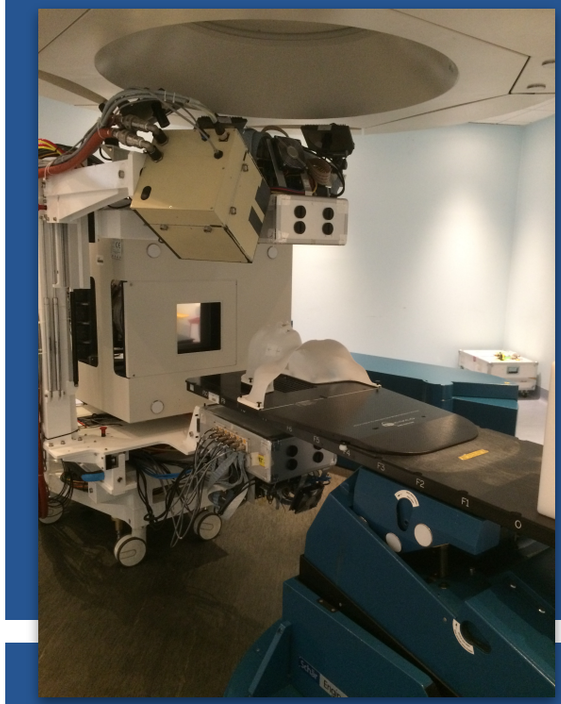
Michela Marafini

Particle Therapy

Dipendenti CF:
-Michela Marafini, *CF, INFN, RTI;*

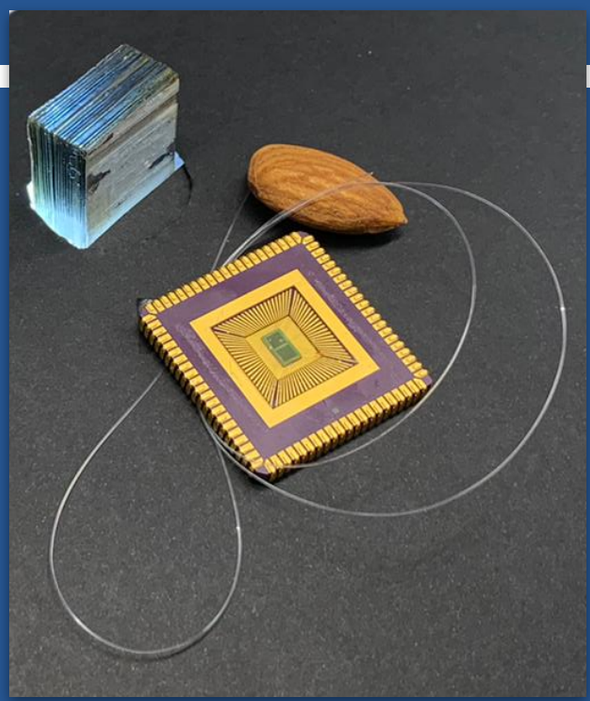
Associati CF:
- Alessandro Bochetti*, Università Roma, INFN Roma, CF, Laureando;*
- Riccardo Mirabelli, INFN Roma, CF, Post Doc*;*
- Vincenzo Patera, *SBAI, INFN, CF, Professore Ordinario;*
- Alessio Sarti, *SBAI, LNF, CF, Professore Associato;*
- Adalberto Sciubba, *SBAI, INFN, CF, Professore Ordinario;*
- Giacomo Traini*, INFN Roma, CF, RTI;*

Collaboratori:
- Micol De Simoni, Università Roma, INFN Roma, Dottorando;
- Marta Fischetti, SBAI, INFN Roma, Dottorando;
- Gaia Franciosini, Università Roma, INFN Roma, Dottorando;
- Giuseppe Battistoni, INFN Milano, Primo Ricercatore;
- Ilaria Mattei, INFN Milano, RTI;
- Silvia Muraro, INFN Milano, RTD;
- Yungsten Dong, UniMi, INFN Milano, Dottorando;
- Serena Marta Valle, UniMi, INFN Milano, Dottorando.



Monitoring with charged secondary particles for Carbon ion therapy and PET photons for proton ion therapy: Dose Profiler (INSIDE) at CNAO.

Characterisation of secondary neutron production in PT treatments



- ***CF*** = Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi
- ***INFN*** = Instituto Nazionale di Fisica Nucleare
- ***SBAI*** = Università degli Studi di Roma *La Sapienza,* Dipartimento di Scienze di Base e Applicate per l'Ingegneria
- **Università Roma** = Università degli Studi di Roma *La Sapienza, Dipartimento di Fisica*
- **LNF** = Laboratori Nazionali di Frascati
- **UniMi**= Università degli Studi di Milano

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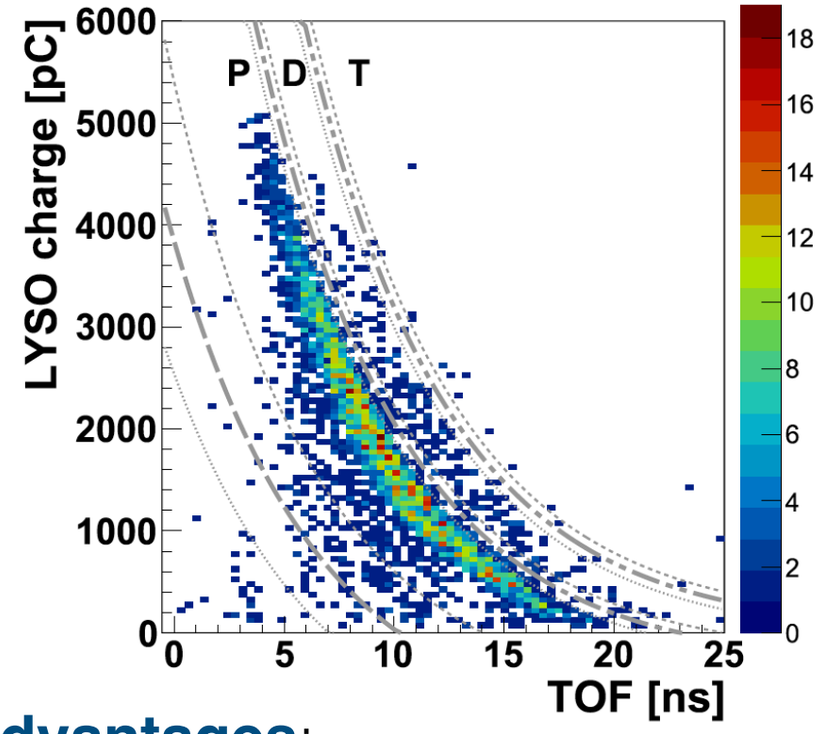
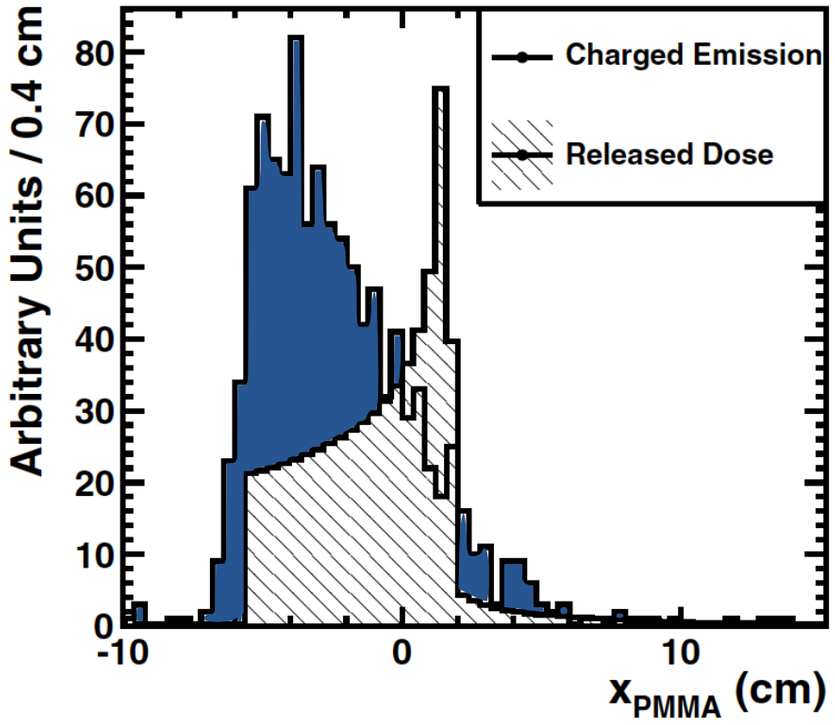
Online Monitoring in PT

In Particle Therapy (PT) the beam interacts with the patient producing secondary particles.
A **significant emission of secondary charged fragments** occurs when using **Z>1** ions.



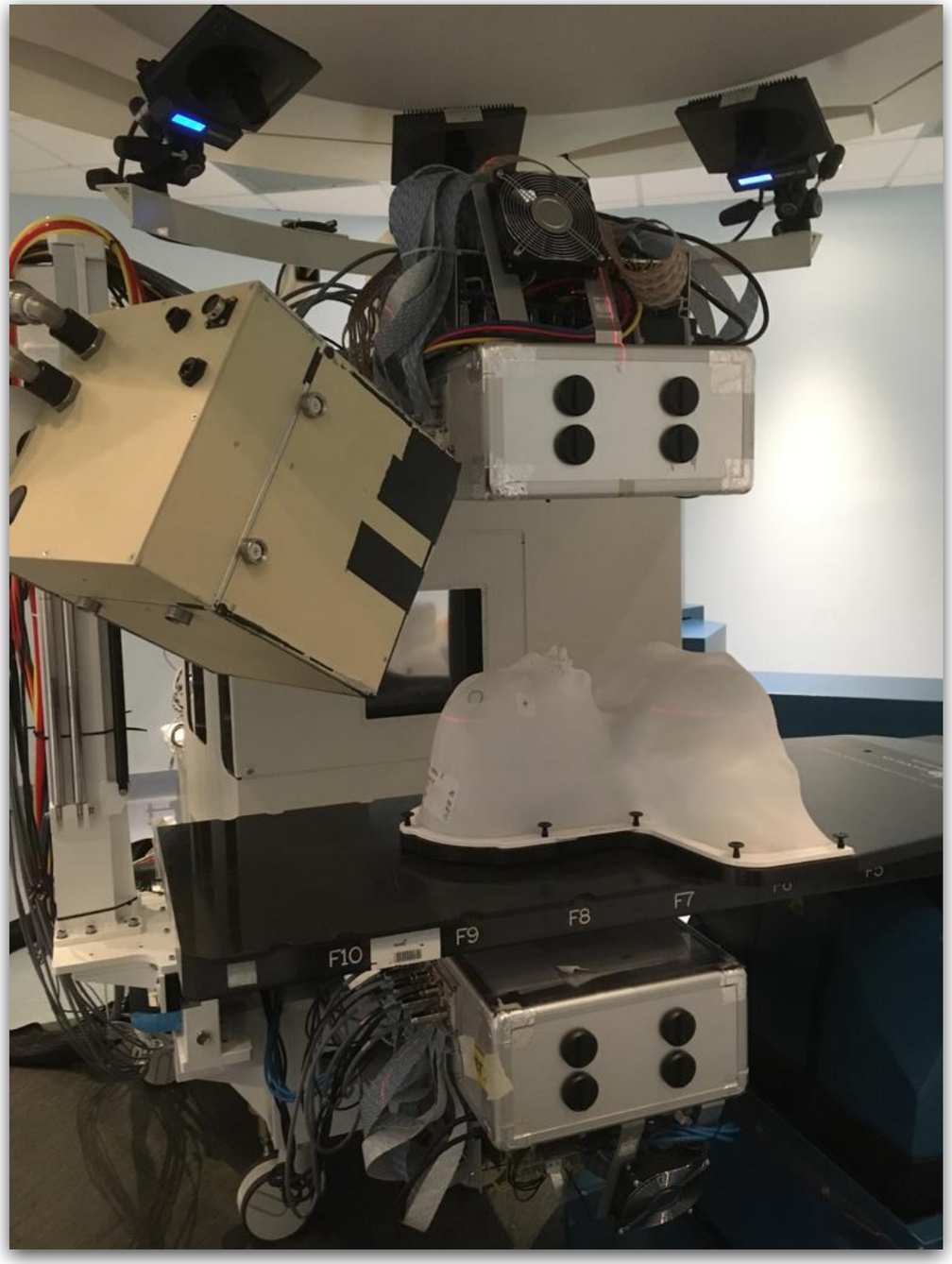
^{12}C @ 220 MeV/u, PMMA target, @90° detection

The fragment emission can be correlated with the Bragg Peak position



- **Advantages**:
  - Easy to detect (high detection efficiency, small background)
  - Easy reconstruction of the production vertex with tracking devices
- **Drawbacks**:
  - Patient-dependent fragment absorption —> non trivial correlation with the Bragg peak
  - Resolution limited by the multiple scattering

Online Monitoring in PT

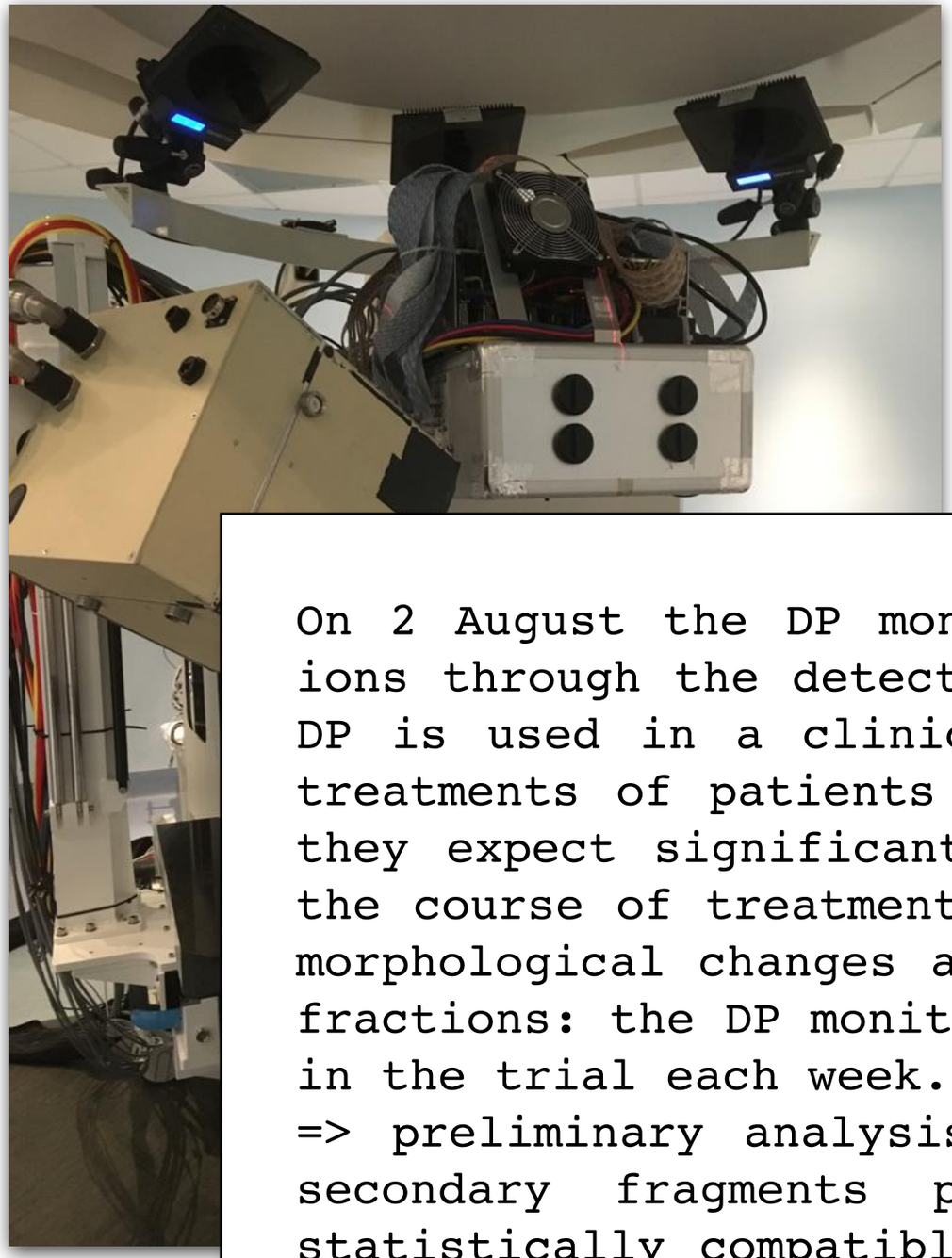


The Dose Profiler is a tracker of charged secondary particles. DP is now installed at CNAO and a clinical trial started in Summer 2019 to evaluate the detector sensitivity to range variations in the context on the INSIDE project.

- Four selected pathologies have been identified: meningioma and nasopharynx cancer treated with proton beams, Adenoid Cystic Carcinoma (ACC) and clival chordoma treated with carbon ion beams
- The system can be used with minimum impact in the treatment time workflow in the clinical routine

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

Online Monitoring in PT



The Dose Profiler is a tracker of charged secondary particles. DP is now installed at CNAO and a clinical trial started in Summer 2019 to evaluate the detector sensitivity to range variation in the context on the INSIDE project.

- Four selected pathologies have been identified: meningioma and nasopharynx cancer treated

On 2 August the DP monitored the first patient treated with carbon ions through the detection of charged fragments. Starting in August, DP is used in a clinical trial that involves the monitoring of 20 treatments of patients with Adenoid Cystic Carcinoma (ACC) in which they expect significant morphological changes in the patient during the course of treatment and Clival Chordoma, in which no appreciable morphological changes are expected. Each treatment includes 20 to 30 fractions: the DP monitors 2 to 3 fractions for each patient enrolled in the trial each week.

=> preliminary analysis: the distributions of the positions of the secondary fragments produced during the various fractions are statistically compatible in cases where no significant morphological changes are expected in the patient. The study of the first clinical case in which changes are expected (confirmed by the CT of revaluation carried out after 9 fractions) is in progress.

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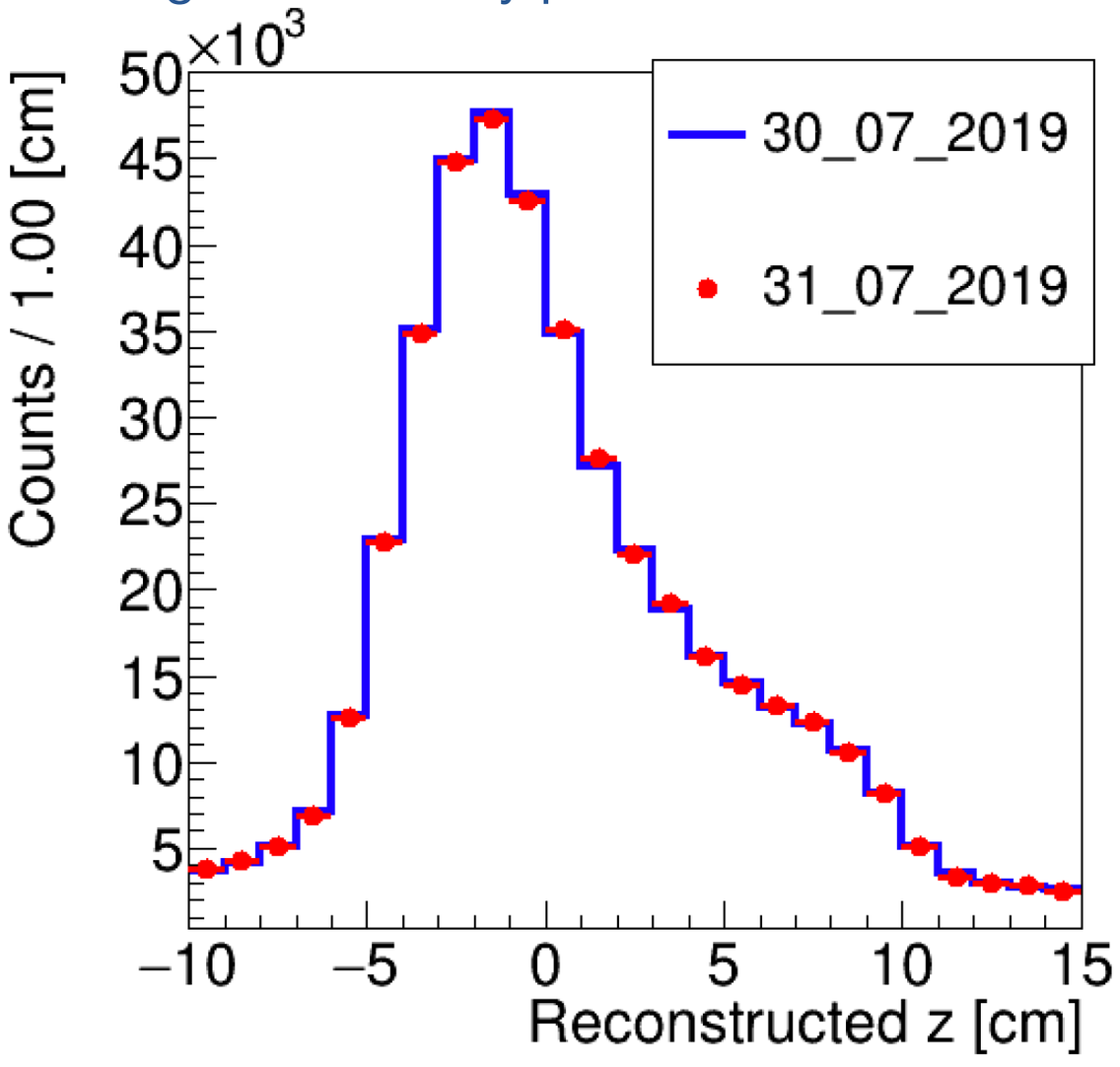
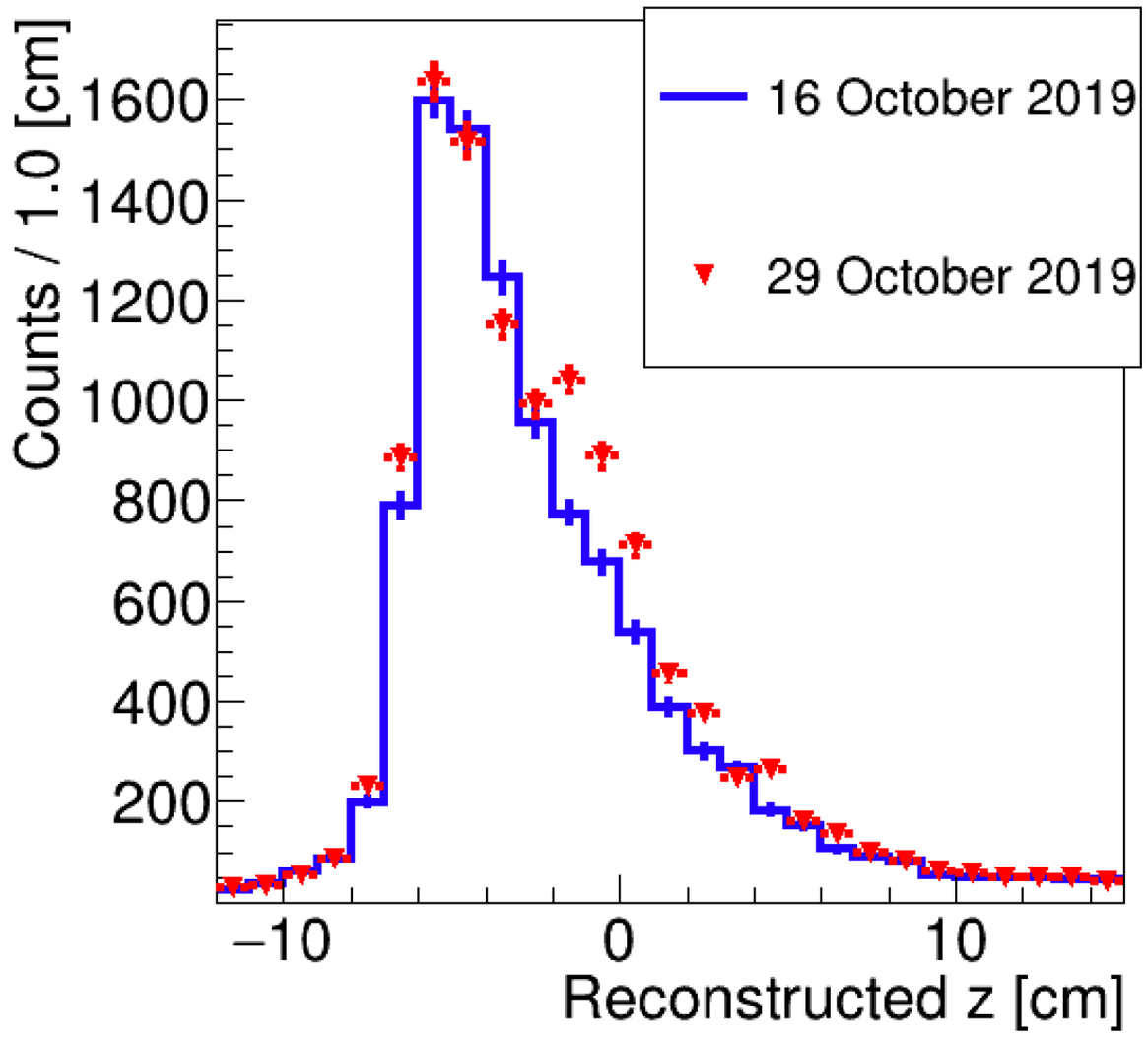
Online Monitoring in PT

Currently in the clinical routine a re-evaluation CT is performed after a fixed number of fractions when a morphological change is expected. The aim of the study with the DP is to understand if exploiting the charged secondary protons information we are sensitive to the morphological changes.





- ☐ No difference was expected
- ☑ No difference is visible in the DP outcome

- ☑ A difference was expected
- ☑ A difference is visible in the DP outcome.

Online Monitoring in PT

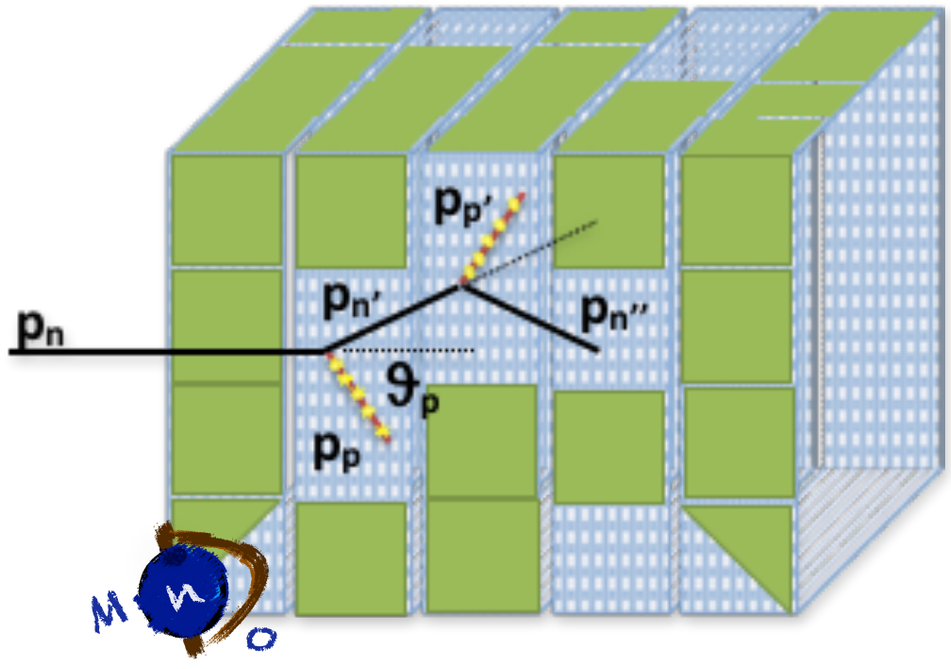
What's next (2020-2022)

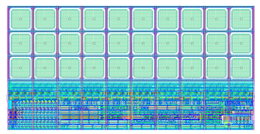
- **Next year (2020) will be dedicated to finish the trial with patients at CNAO (the therapy center is strongly supporting the trial with dedicated funding)**
- In the following years (2021, ..) angular and distance evaluation studies will be performed in order to understand what is the ultimate sensitivity that is reachable with the charged particles based monitoring technique;
- The feasibility of a compact monitor exploiting the SBAM readout (see MONDO readout in the following), using as input the measured proton fluxes and the measured real detector performances, will be explored.

Secondary Neutron in PT

In Particle Therapy (PT) the beam interacts with the patient producing secondary particles. Secondary neutrons can release **additional dose** also far away from the volume under treatment. The incidence (also years after the treatment) of SMNs (**Secondary Malignant Neoplasm**) impacts directly on the quality and life expectation of the patient.

MONDO: 16 x 16 x 20 cm^3





= Chip (SBAM_1)

= Tile (4 x 4 chips)

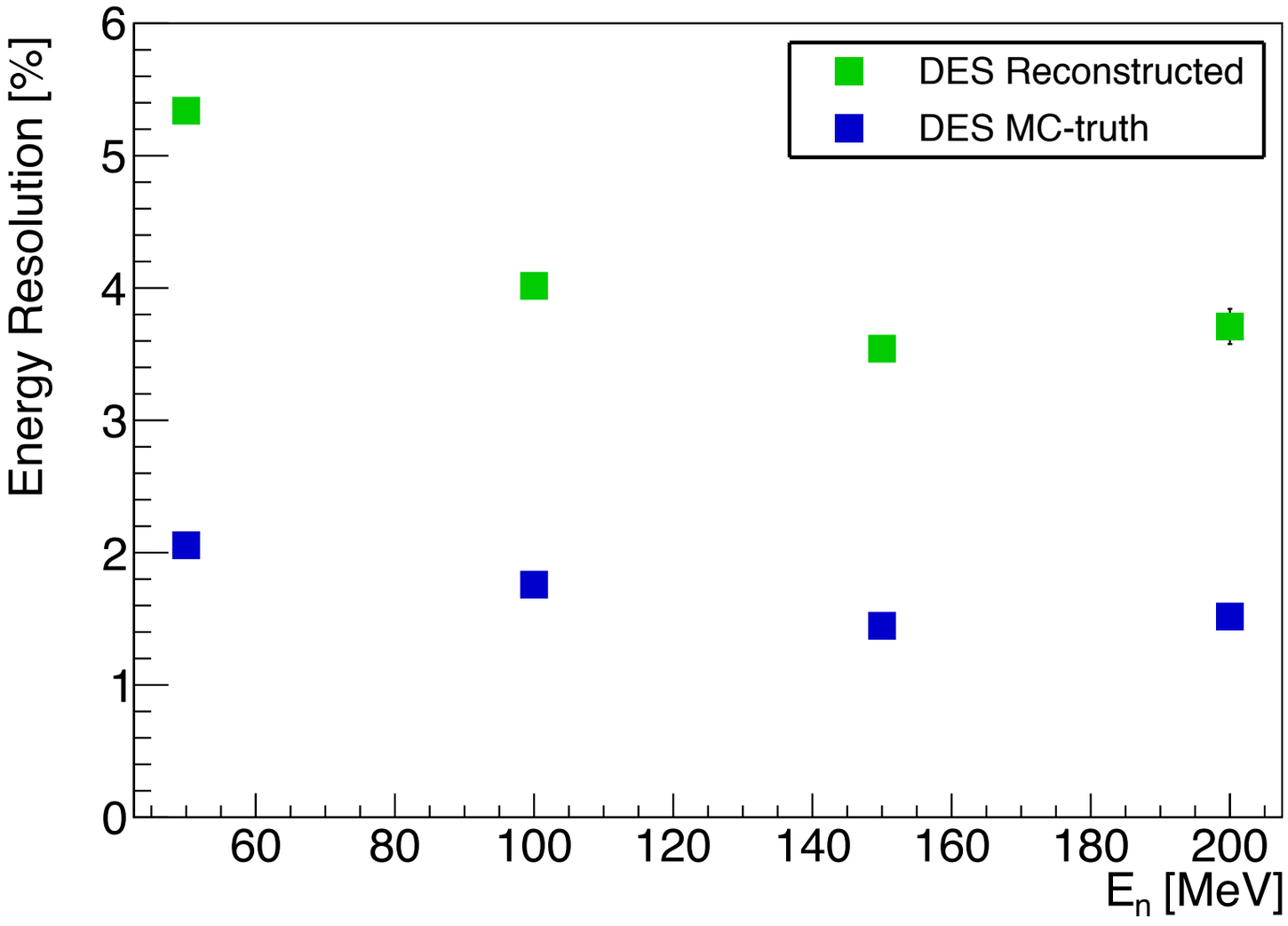
= Modulo Fibre

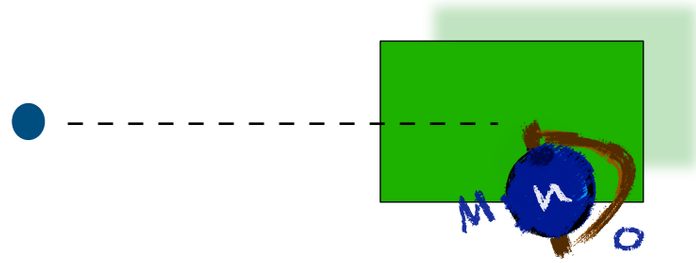
Detection efficiency for Double Elastic Scattering (DES) ~ 10^{-3} and ~ 10^{-1} for Single Elastic Scattering (ES)

$$E_n = \frac{2*E_p*m_p}{\cos^2\theta*(E_p+2*m_p-(E_p/\cos^2\theta))}; \sim \frac{E_p}{\cos^2\theta} \quad [\text{if } E_n << m_n]$$

Secondary Neutron in PT

Reconstructed neutron energy: resolution evaluation. The resolution is dominated by the capability of reconstructing the recoil proton angle.

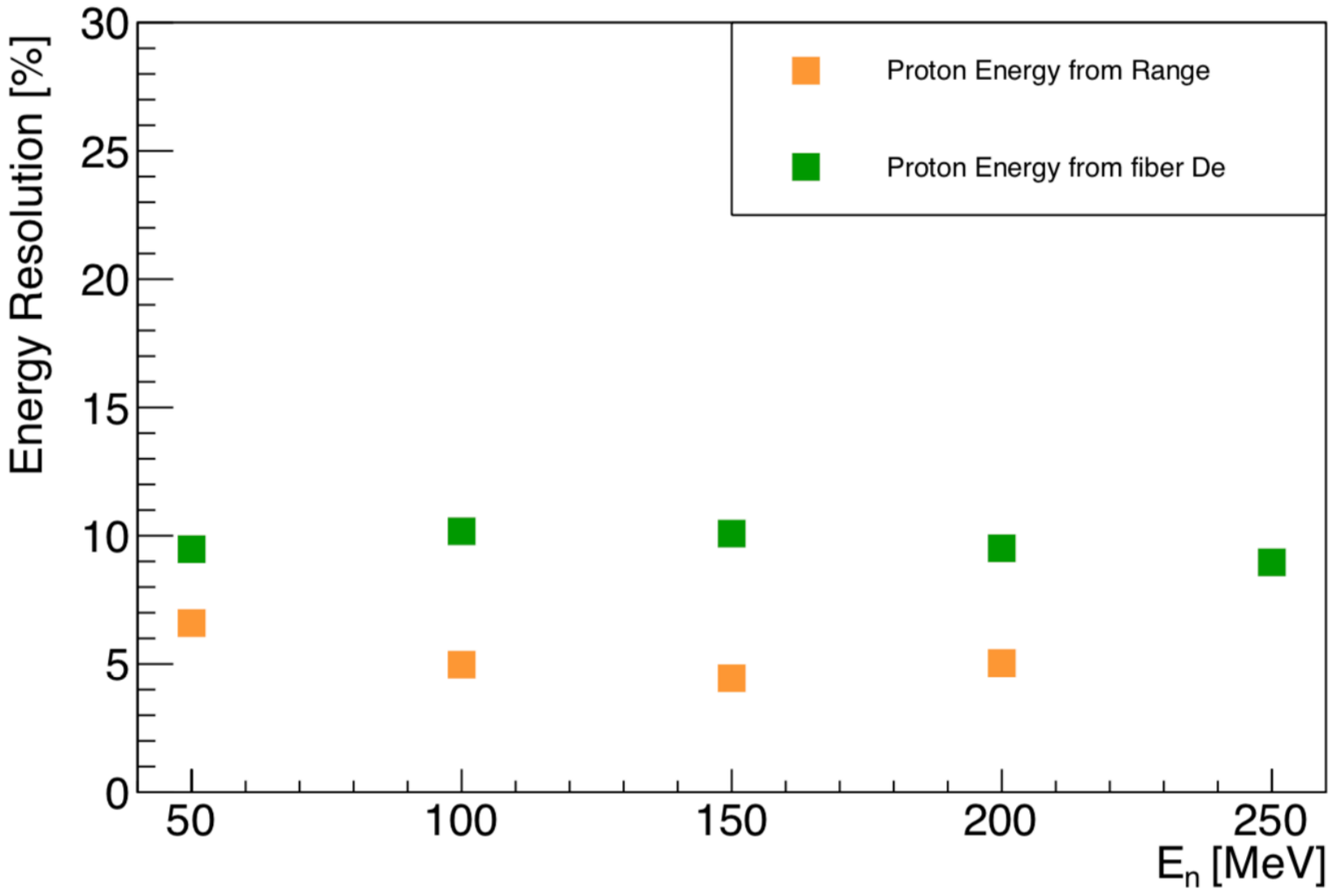


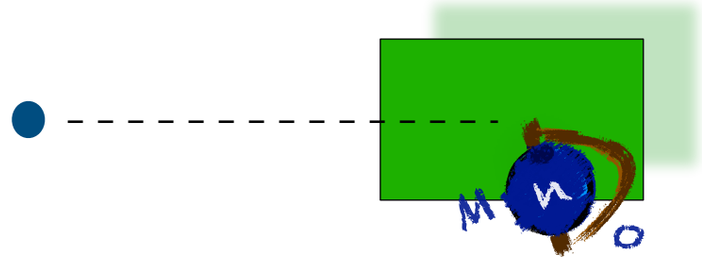


Full contained events

Secondary Neutron in PT

Reconstructed neutron energy: resolution evaluation. The resolution is dominated by the capability of reconstructing the recoil proton angle.





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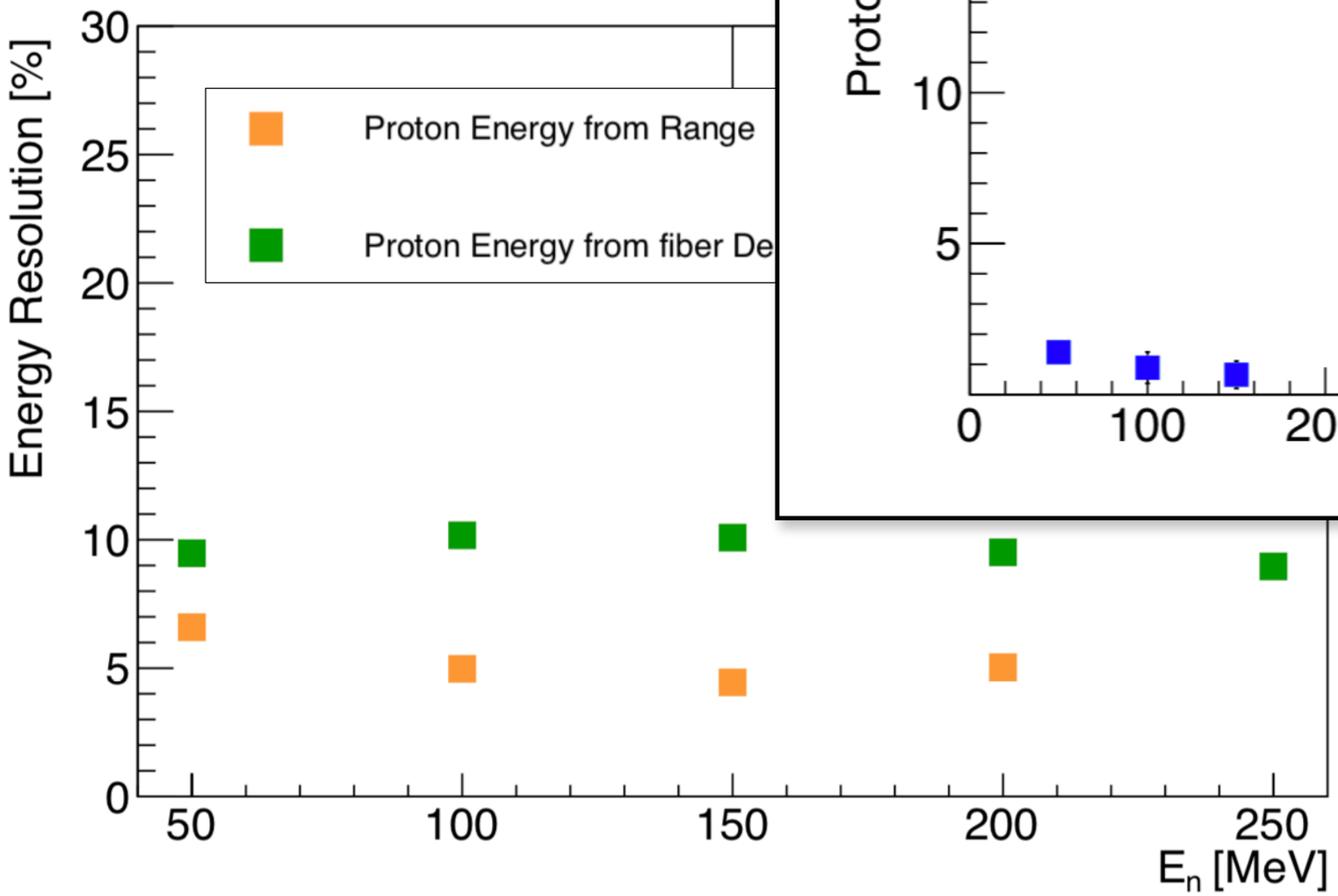
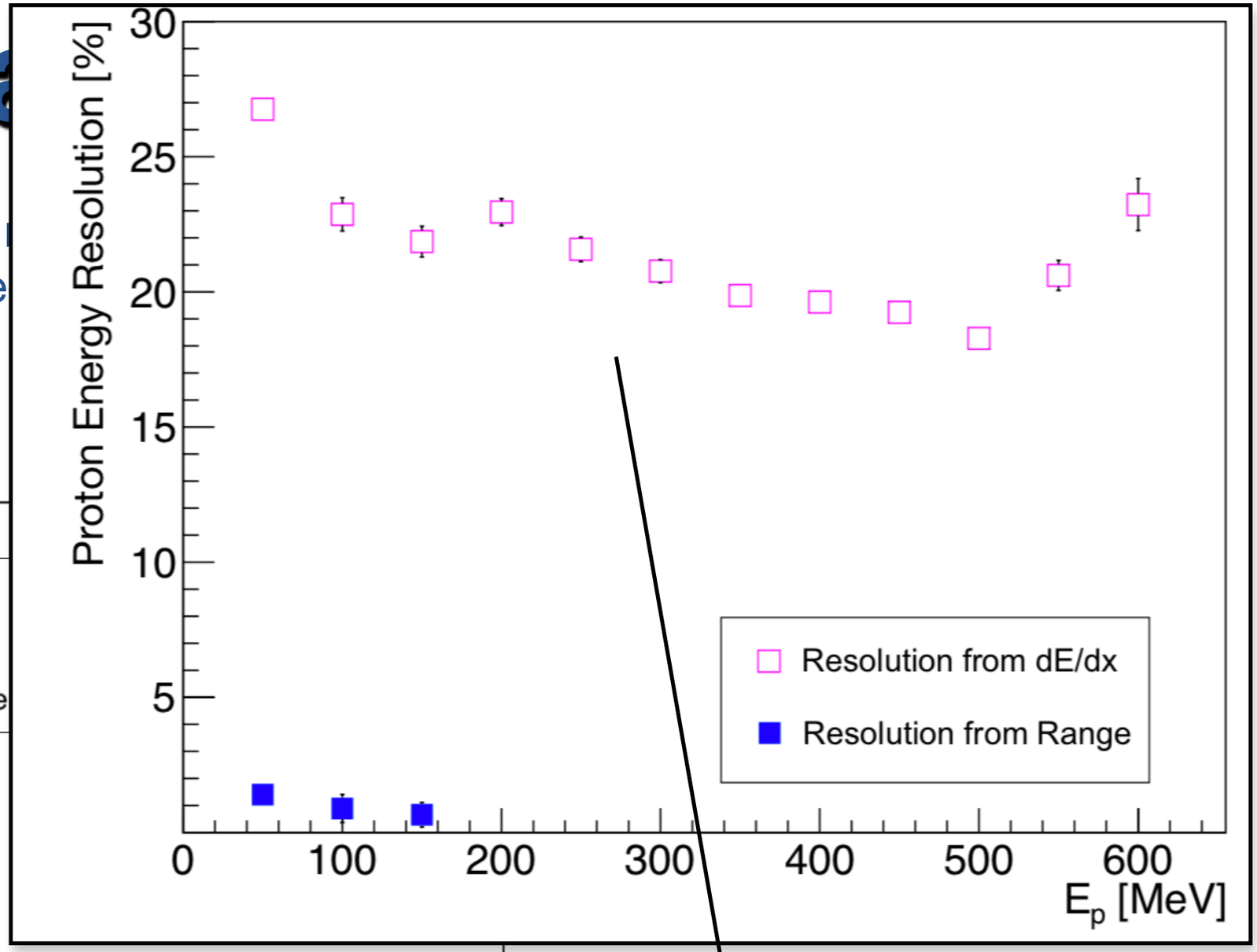
Reconstructed neutron energy: r
capability of reconstructing the re

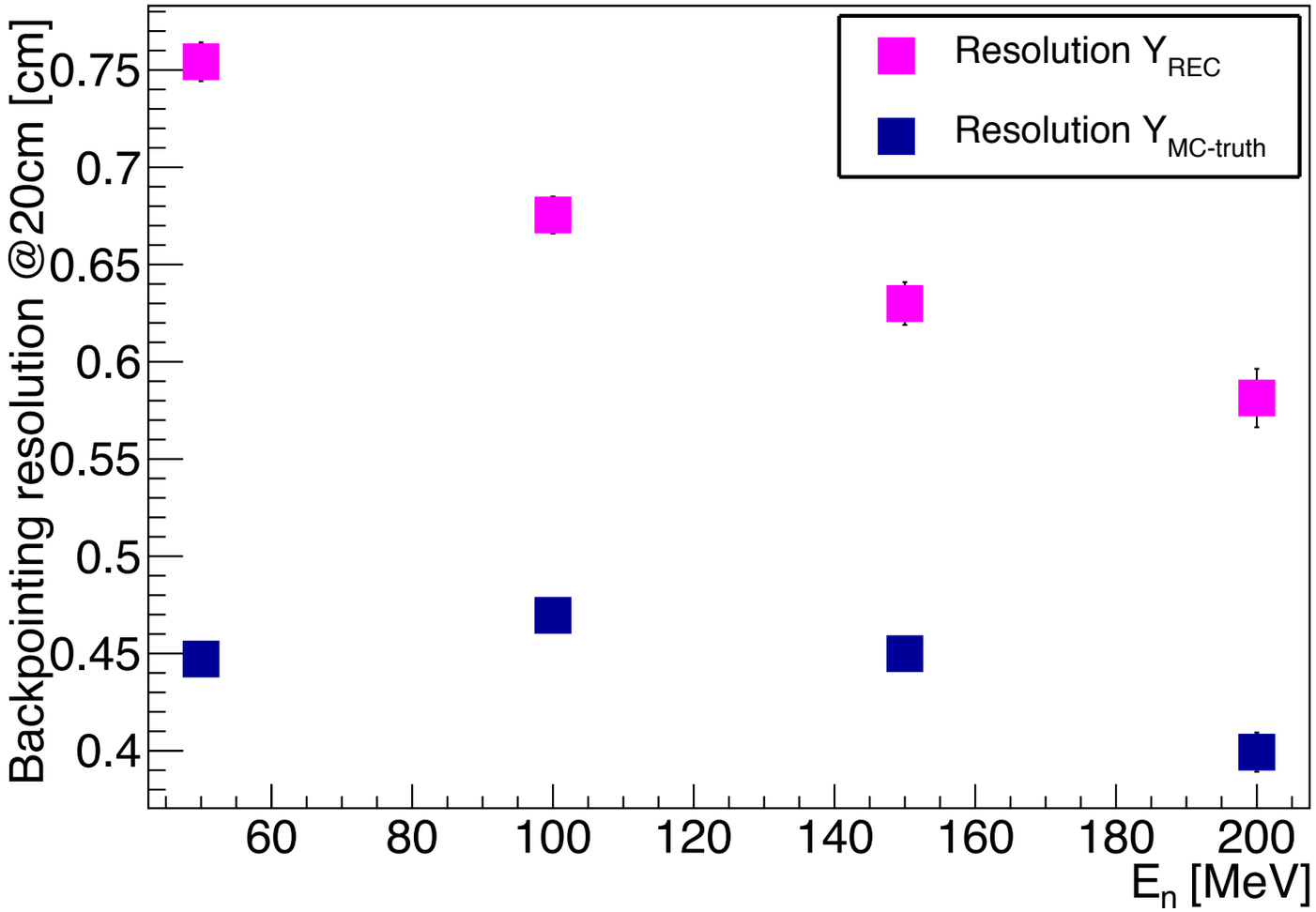


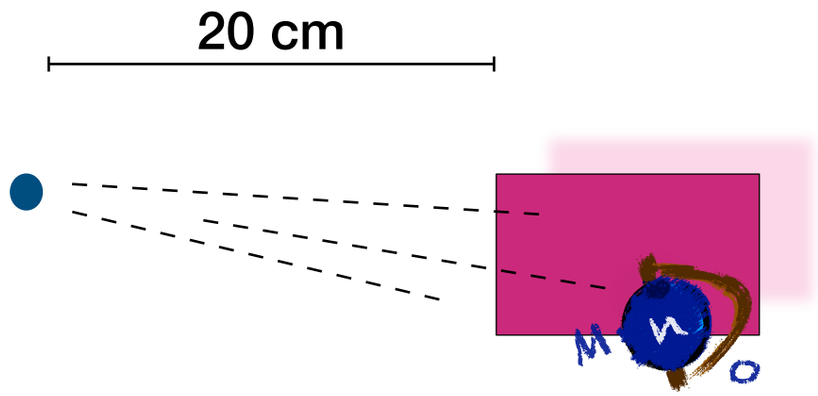


No need of fully contained events

Secondary Neutron in PT

Reconstructed neutron direction: resolution evaluation. The resolution is dominated by the capability of reconstructing the recoil proton angle.

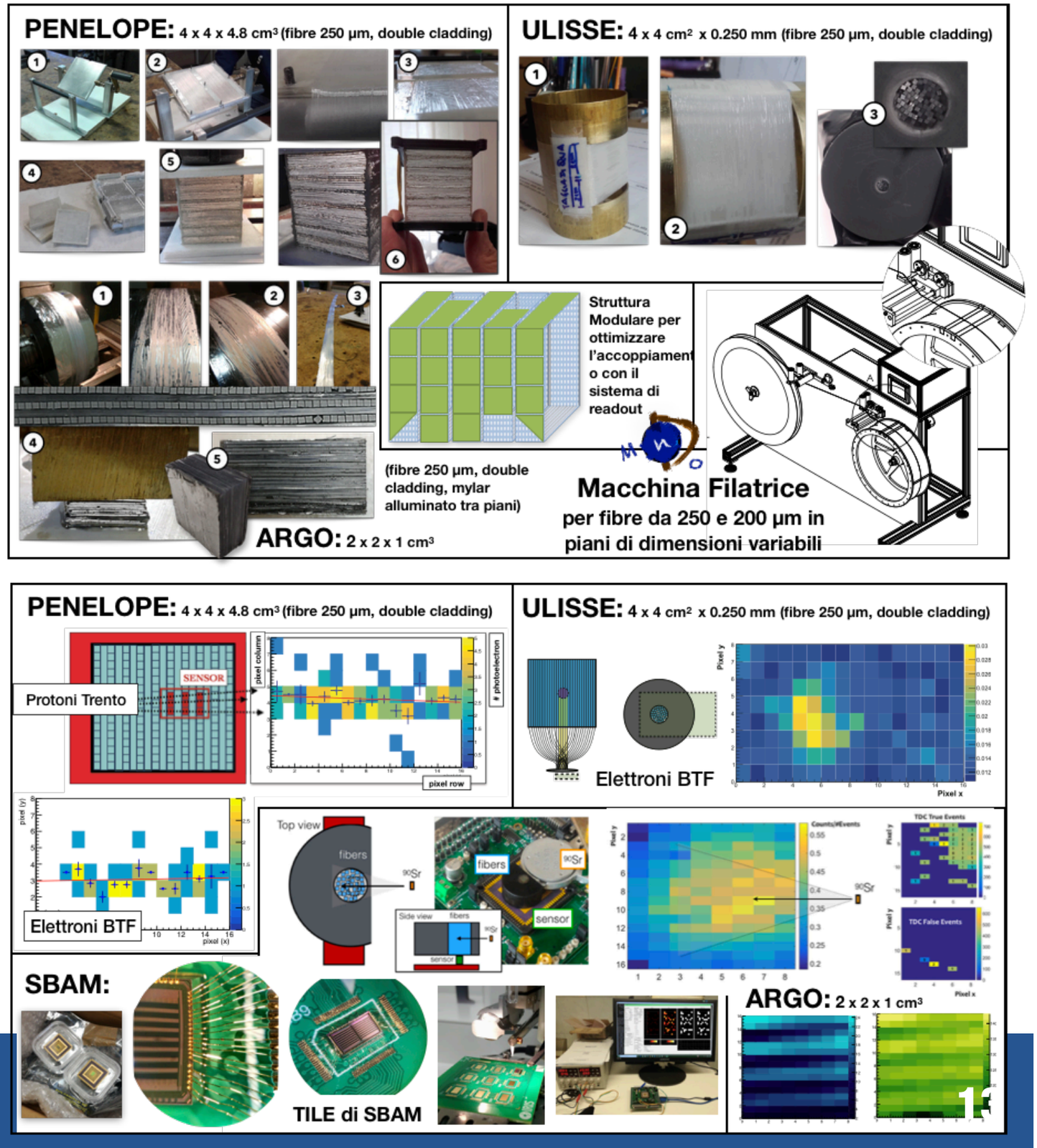




Secondary Neutron in PT

Mondo up to now:

- Mechanical Track Matrix
- Readout of the fibres



Secondary Neutron in PT

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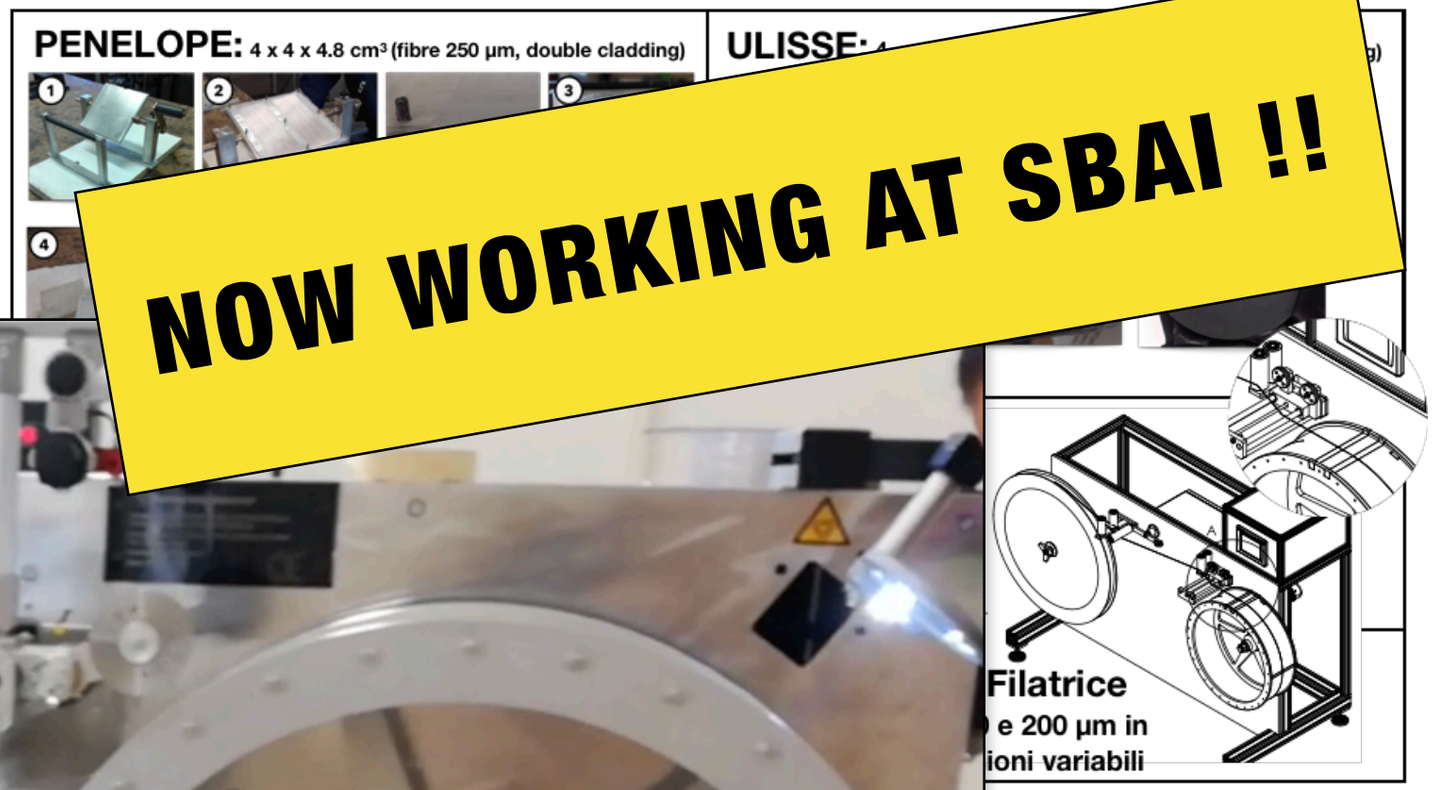
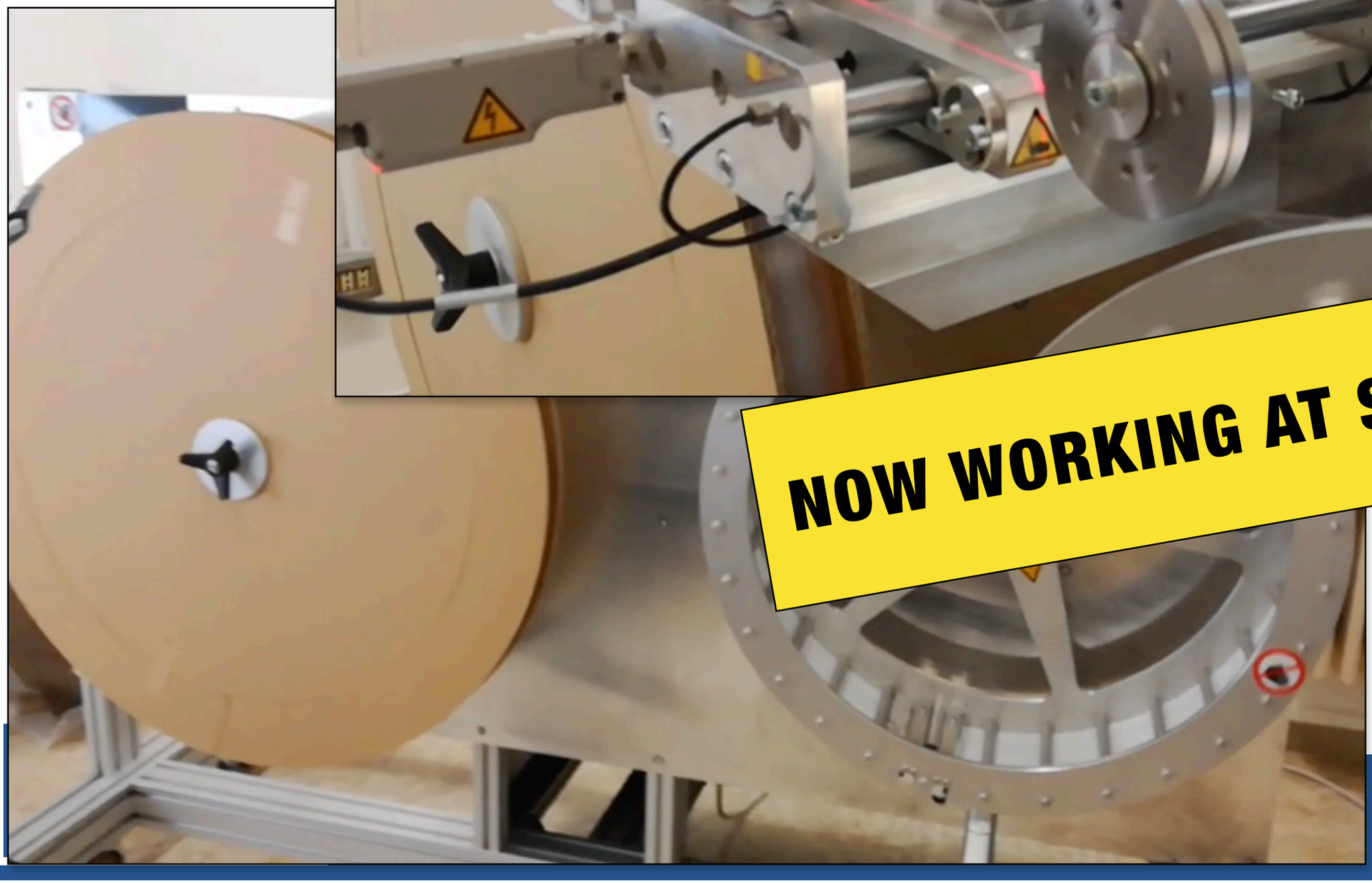


NOW WORKING AT SBAI !!

Sec

Mondo up t

- Mechanical Tra



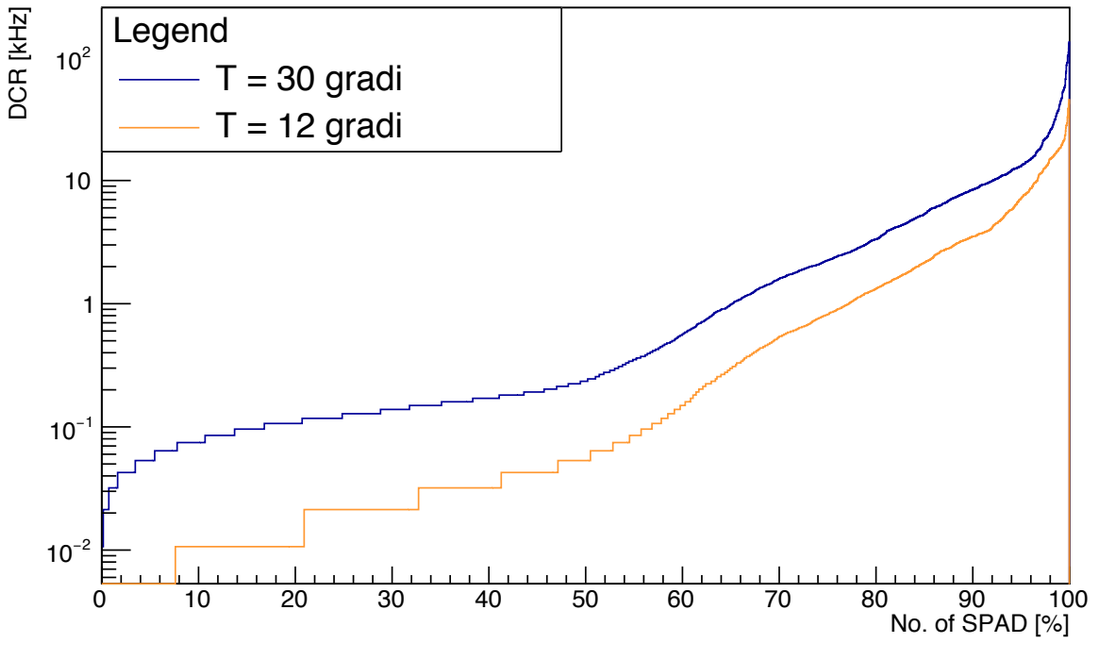
NOW WORKING AT SBAI !!

Secondary Neutron in PT

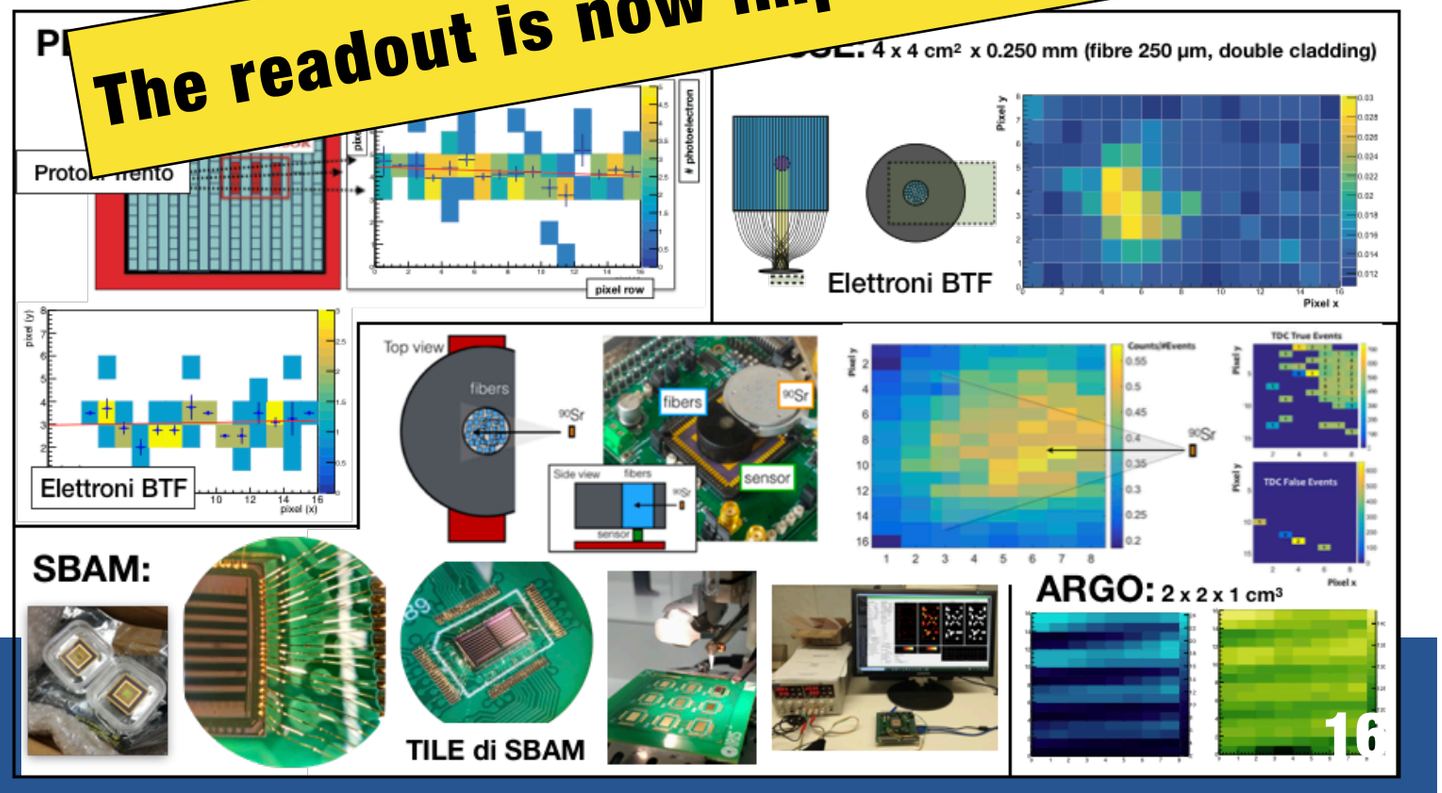
Mondo up to now:

- Mechanical Track Matrix
- Readout of the fibres

The test on the SBAM chip is ongoing



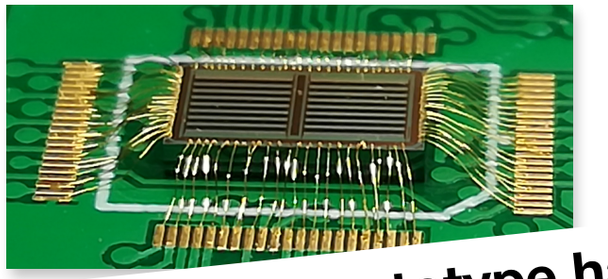
The readout is now implemented in MC !



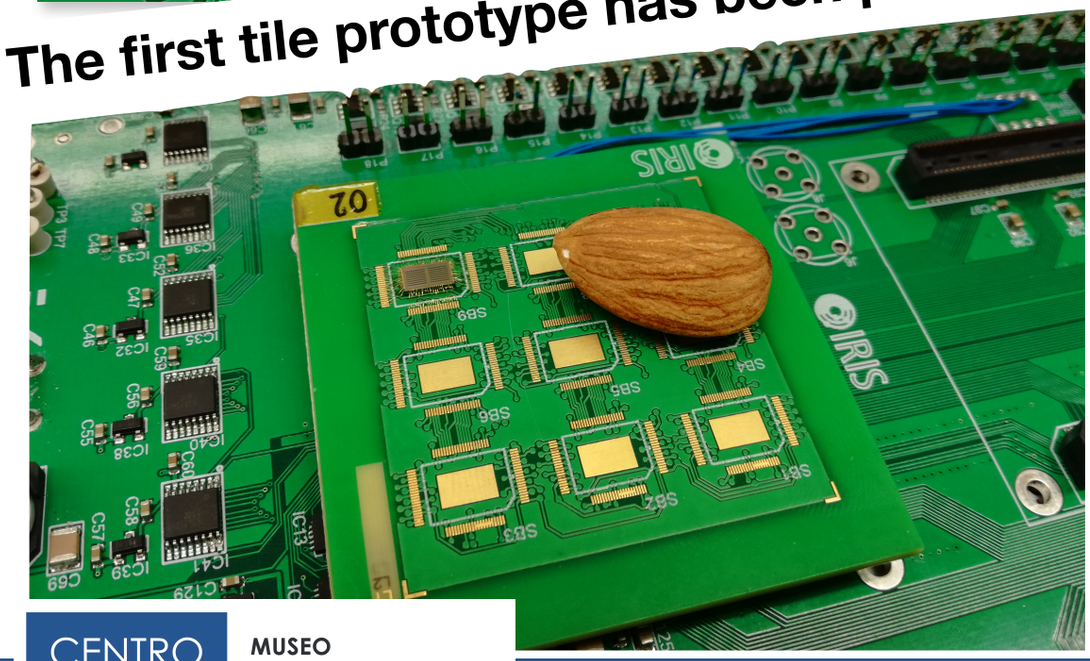
Secondary Neutron in PT

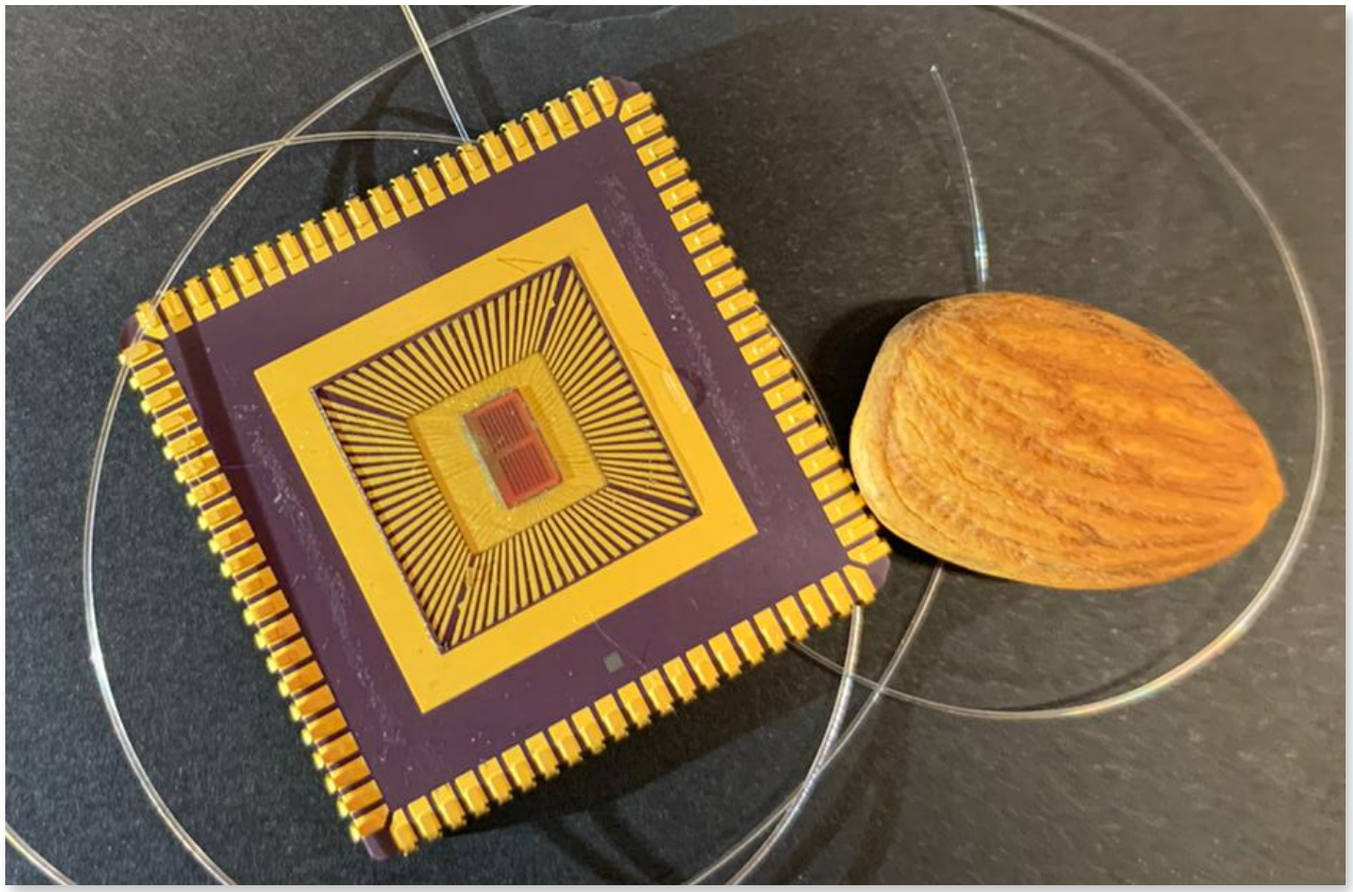
Mondo up to now:

- Mechanical Track Matrix
- Readout of the fibres

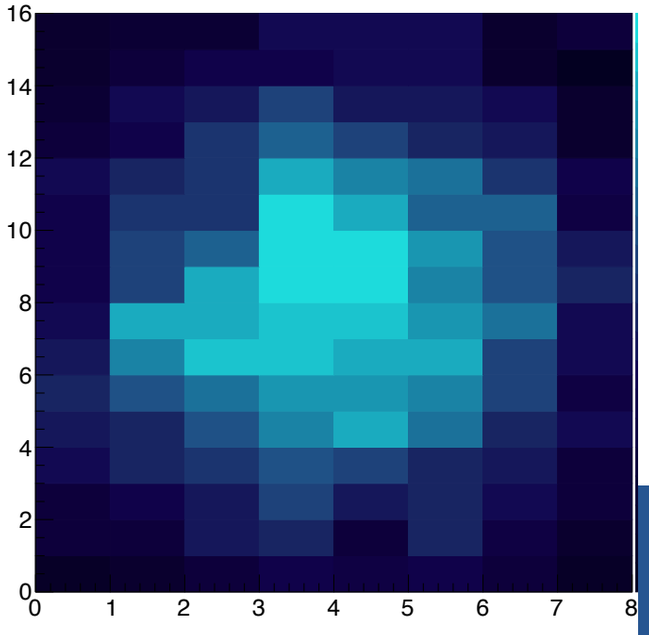


The first tile prototype has been produced





The test on the SBAM chip is ongoing at SBAI



- Fibres readout with SBAM chip: the charge distribution is obtained irradiating the fibres with an electron source (^{90}Sr).

Secondary Neutron in PT

What's next (2020-2022)

- Realisation of the fibre layers (multiple studies on glue, alignment, cross-talk, …)
- Development of the track reconstruction software for the recoil protons and neutrons
- Development of new sensor, SBAM 1.9 exploiting the funding from SPARE (Premiale@CF). We intend to make the step forward for the new chip development scaling in size and optimising the layout;
- For the tile system development: synergy with the paprica project (grant G5 INFN).

Secondary particles in PT

The SBAM sensor development will allow for all secondary PT particles detection.. It is a long way.. but with an important impact for particle therapy applications.

Publications - 2019

Traini G., et al ; Review and performance of the Dose Profiler, a particle therapy treatments online monitor, Physica Medica, Volume 65, September 2019, Pages 84-93, doi: 10.1016/j.ejmp.2019.07.010

De Simoni M., et al.; In-room test results at CNAO of an innovative PT treatments online monitor (Dose Profiler), Nuovo Cimento della Societa Italiana di Fisica, Volume 41, Issue 6, November 2018, Article number 209, doi: 10.1393/ncc/i2018-18209-2

Mirabelli R, et al.; In-room performance evaluation of a novel online charged secondary particles monitor of light ions PT treatments, 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC 2018 - Proceedings November 2018, Article number 8824552, doi: 10.1109/NSSMIC.2018.8824552

Rucinski A., et al. ; Secondary radiation measurements for particle therapy applications: Charged secondaries produced by 16O ion beams in a PMMA target at large angles, Physica Medica Volume 64, August 2019, Pages 45-53, doi: 10.1016/j.ejmp.2019.06.001

E.Gioscio, et al. “Development of a novel neutron tracker for the characterisation of secondary neutrons emitted in Particle Therapy” under press on NIM A (2019) 162862 doi: https://doi.org/10.1016/j.nima.2019.162862

Conferences - 2019

V. Patera, "Nuclear applications in cancer radiotherapy with light ion beams", PARTICLE ACCELERATOR - DEVELOPMENT AND USES IN MEDICAL APPLICATIONS, INDUSTRY, SCIENCE AND THE ENVIRONMENT November 5, 2019, Tel –Aviv, Israel
G. Traini, "Range monitoring in particle therapy: the INSIDE project", Medinet Network final meeting, Wiener Neustadt, 7-9 October, 2019 https://medinet.medaustron.at/index.php/Meeting2019
M. Fischetti, "Inter-fractional monitoring in Carbon ions Particle Therapy treatments with the Dose Profiler detector" OMA, Seville, 2-6 September, 2019 https://indico.cern.ch/event/803528/
G. Traini , "Novel charged particles monitor of light ions PT treatments: results of preliminary tests using a RANDO® phantom" VCI19, Vienna, 18-22 February, 2019 https://vci2019.hephy.at/home/
M. De Simoni, "The Dose Profiler tracker: an online Particle Therapy monitor optimised for the detection of charged fragments produced by the ion beams interactions with matter", International Winter Meeting on Nuclear Physics, Bormio, 21 - 25 Jan, https://indico.mitp.uni-mainz.de/event/188/
M.Fischetti, “Inter-fractional monitoring in Particle Therapy treatments with 12C ions exploiting the detection of charged secondary fragments” YRM, Rome, 18-21 June 2019 http://www.iphysnet.com/wp/yrm/events/10yrm/
G.Traini, “Inter-fractional monitoring in PT with 12C ions: results of a clinical trial performed at CNAO exploiting the detection of charged secondary particle” PTCOG, 2019, https://ptcog58.org/

E.Manuzzato, Design and Electro-optical Characterization of a Novel, Fully Digital CMOS SPAD Array for Ultra-fast Neutron Tracking in Particle Therapy, IEEE, 2019
R.Mirabelli, MONDO TRACKER FOR SECONDARY ULTRA-FAST NEUTRON CHARACTERISATION IN PARTICLE THERAPY, SIF, 2019
E.Gioscio, Development of a novel neutron tracker for the characterisation of secondary neutrons emitted in Particle Therapy, VCI, 2019
M.De Simoni, Spectrum and flux measurements of secondary ultra-fast neutrons produced in Particle Therapy treatments using the innovative MONDO tracker., OMA, 2019
M.Marafini, Characterisation of the secondary neutron production with the MONDO project: an innovative tracker of ultra-fast neutrons optimised for PT applications, PTCOG, 2019, https://ptcog58.org/
E.Manuzzato, Development of the MONDO Ultra-Fast Neutron Tracker for Secondary Neutron Characterisation in Particle Therapy, IEEE, 2019
A.Bochetti, SBAM: A Spad Based Acquisition sensor for the MONDO experiment, SQUAD, 2019

Thanks