MediNet

Range monitoring with DoseProfiler in Carbon ion therapeutic beam

and future perspective with proton and neutron secondary products

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CENTRO FERMI

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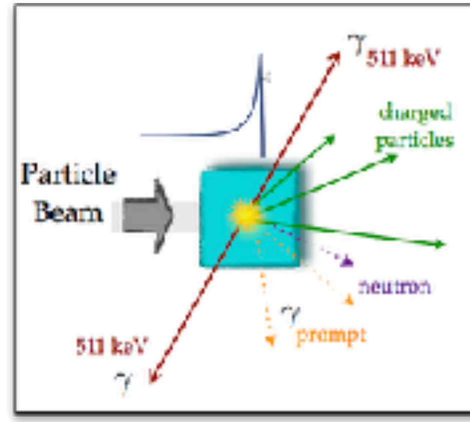
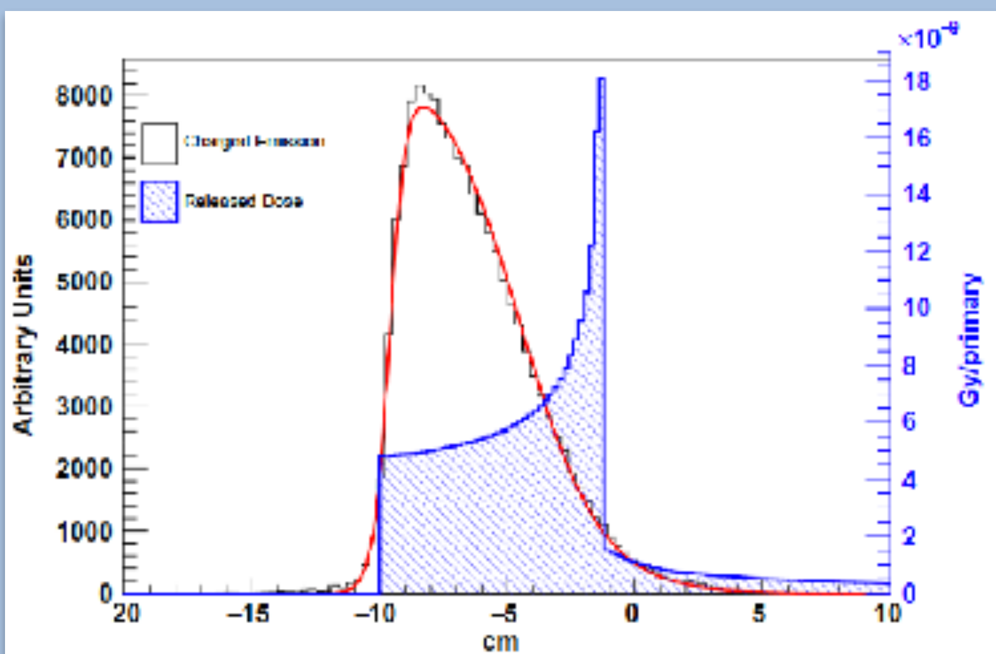
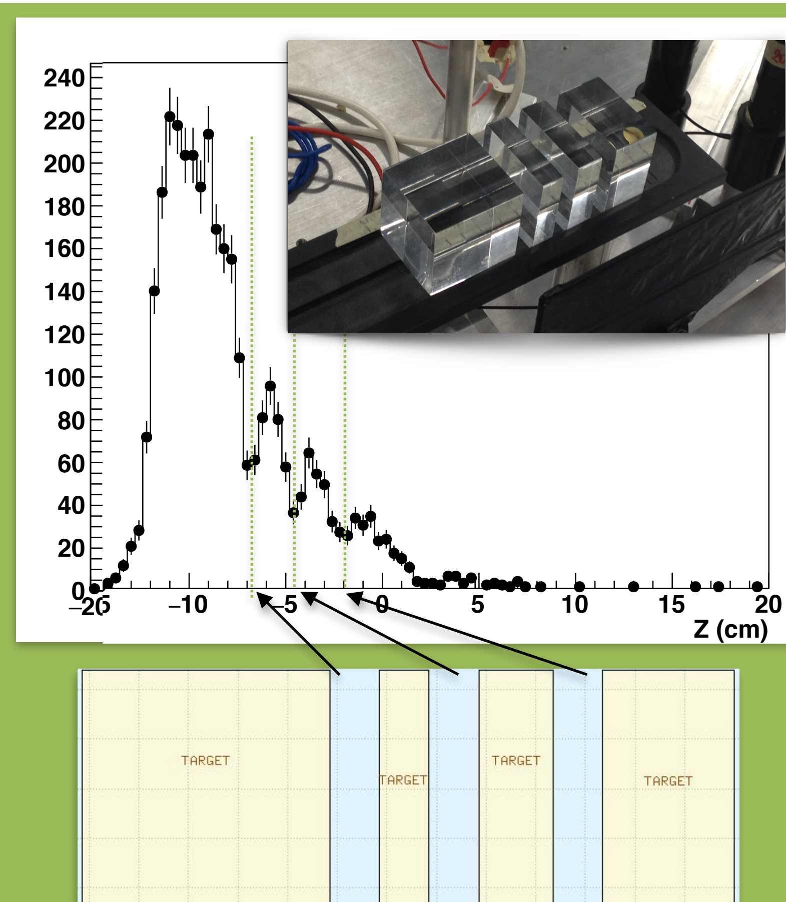
Medinet-WP5

Monitoring technique with p

- Exploits **charged** secondary particles: produced by projectiles or target fragmentation and emitted at large angles (60°-90°) in Z>1 PT treatments (C, He, O);
- Charged emission is correlated to the dose release
- Capable of detecting ‘target’ dis-homogeneities







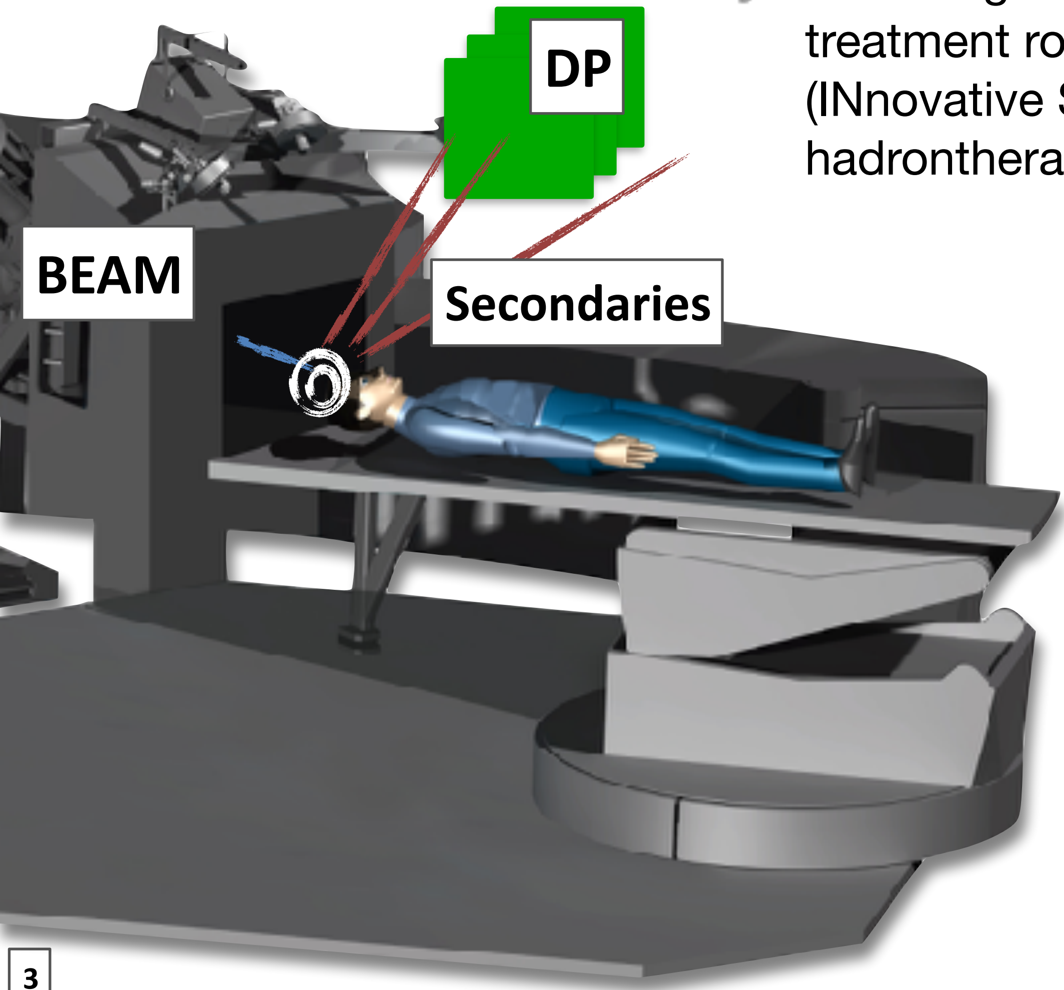
G.Traini et al., Phys. Med. 34 2017, 18-27, doi: 10.1016/j.ejmp.2017.01.004

Monitoring technique: Dose Profiler

- **Dose Profiler**: designed to monitor the beam range by means of the on-line reconstruction of the charged secondary particles tracks

- It is designed to be integrated in the CNAO treatment room, in the framework of the **INSIDE** (INnovative Solution for In-beam DosimEtry in hadrontherapy) project.

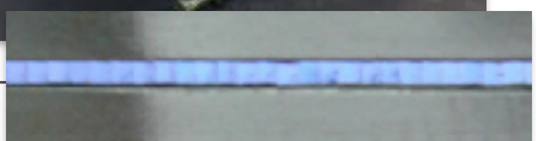
Giusy's Talk



The DP objective is to track protons=> with backtracking we reconstruct proton emission point, thus BP.

G.Traini's Poster: more details!

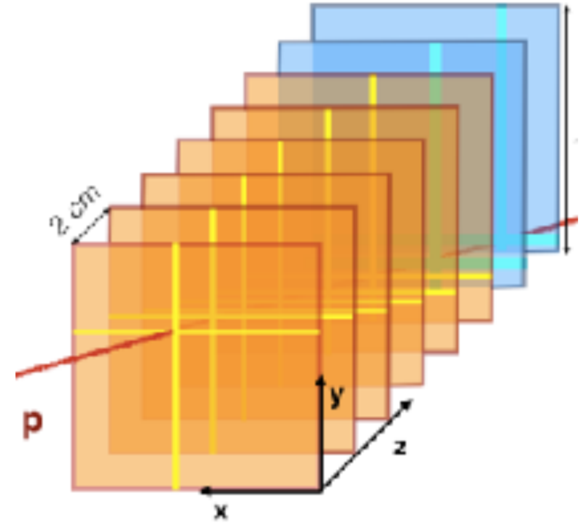
Dose Profiler



- Saint Gobain BCF-12
- Squared, 500 μm²
- Double cladding layer (4%)
- Trapping efficiency 7.2%

G.Traini's Poster: more details!

- **6 planes,** each one composed of 2 orthogonally oriented **scintillating fibres** layers, providing the x-y views coordinate
- **2 planes**, each one composed of 2 segmented thicker **plastic scintillators (6 mm),** for trigger purposes and a high resolution energy measurement

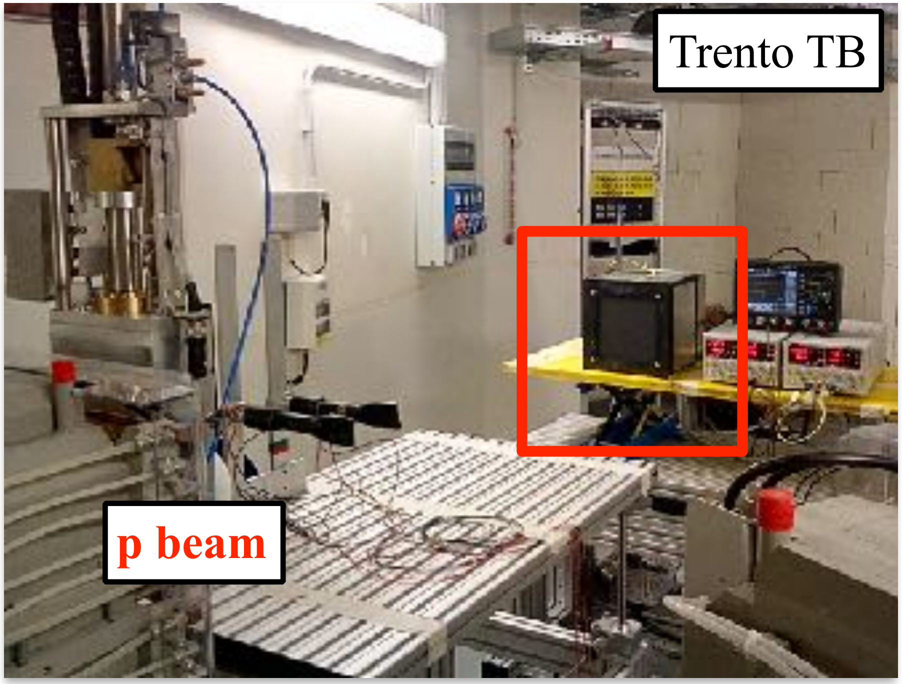


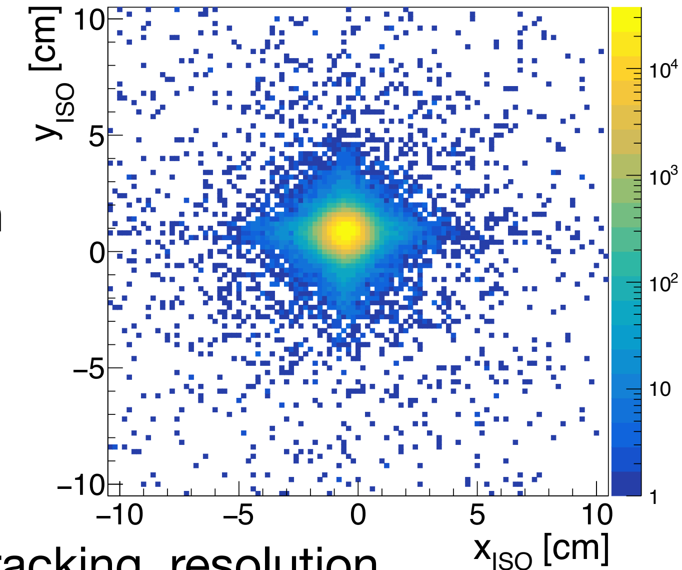
READOUT System

- 32 channels **BASIC_32_ADC**
- **Self-triggering**
- Zero suppression
- Charge amplifier with adjustable shaping

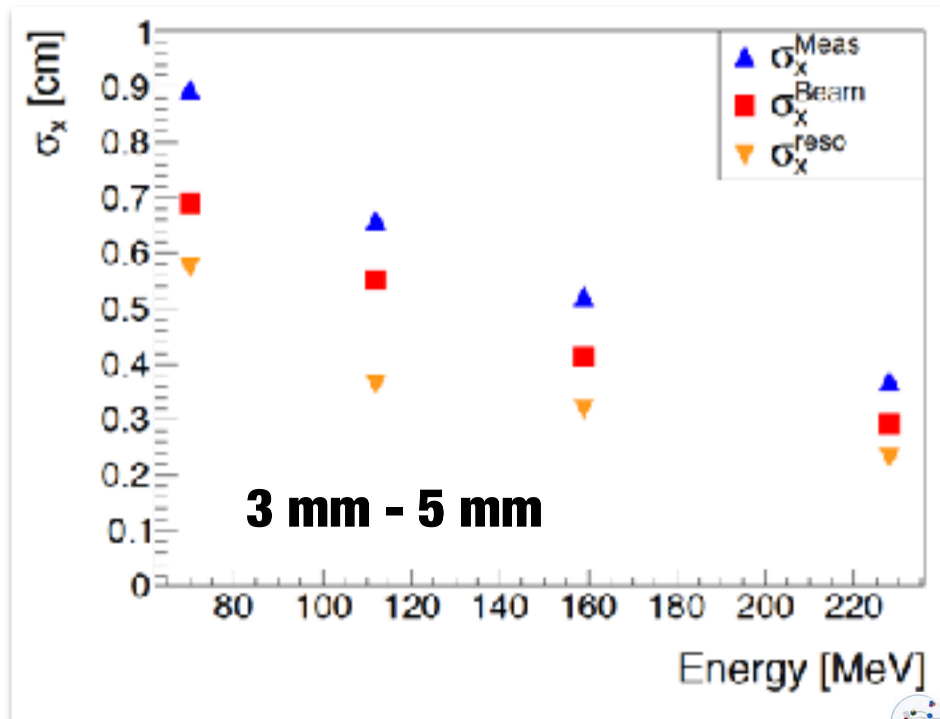
Silicon Photomultipliers (1 mm² area), resulting in a ~300 um spatial resolution

Dose Profiler@TestBeams: PROTONS





- Proton Beam Spot
- Backtracking resolution

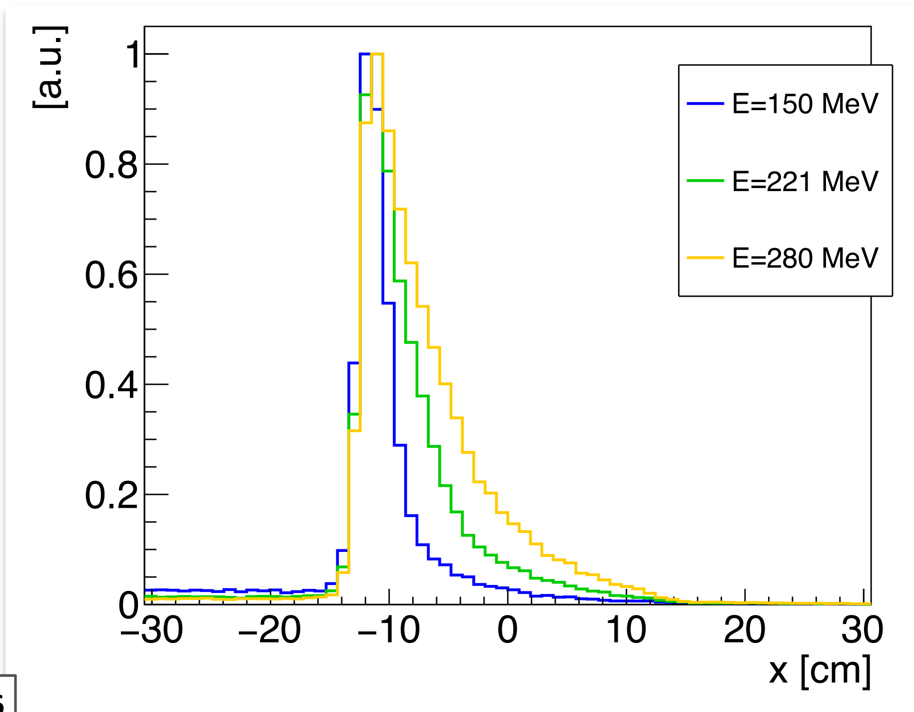


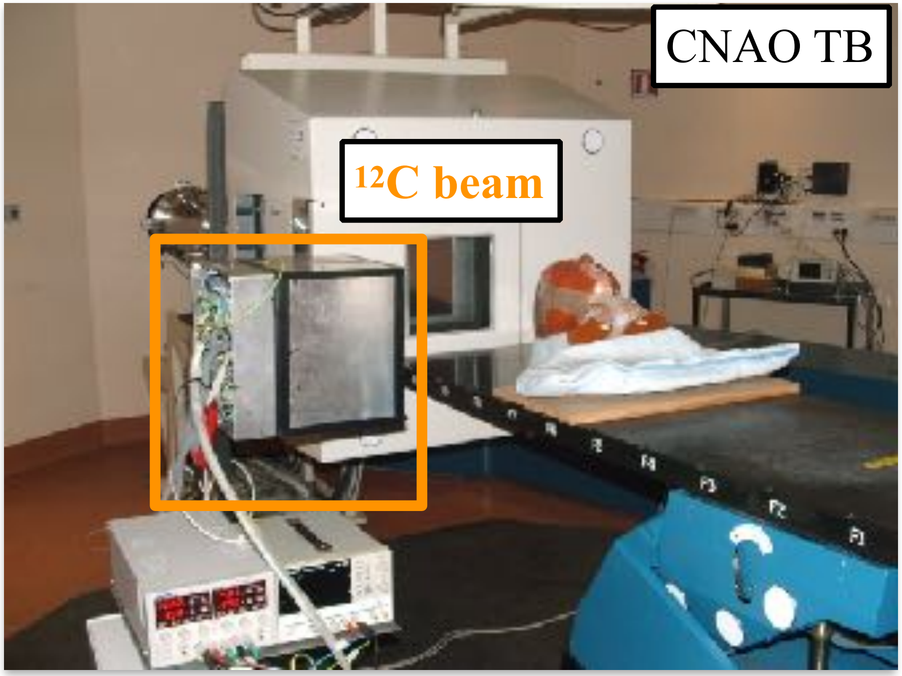
- Mono-energetic proton beams have been used to measure DP efficiency and resolution;
- Plastic scintillator detectors have been exploited for external trigger purposes;

Dose Profiler@TestBeams: CARBON

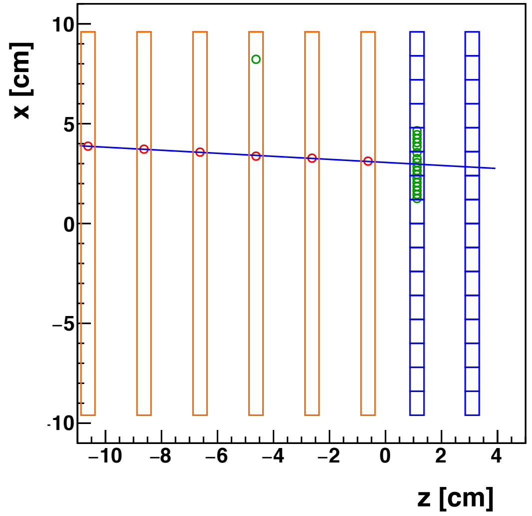
- Secondary protons have been measured with different targets (thin, thick, anthropomorphic) and configurations (60 and 90 degrees)

- Secondary proton emission shape

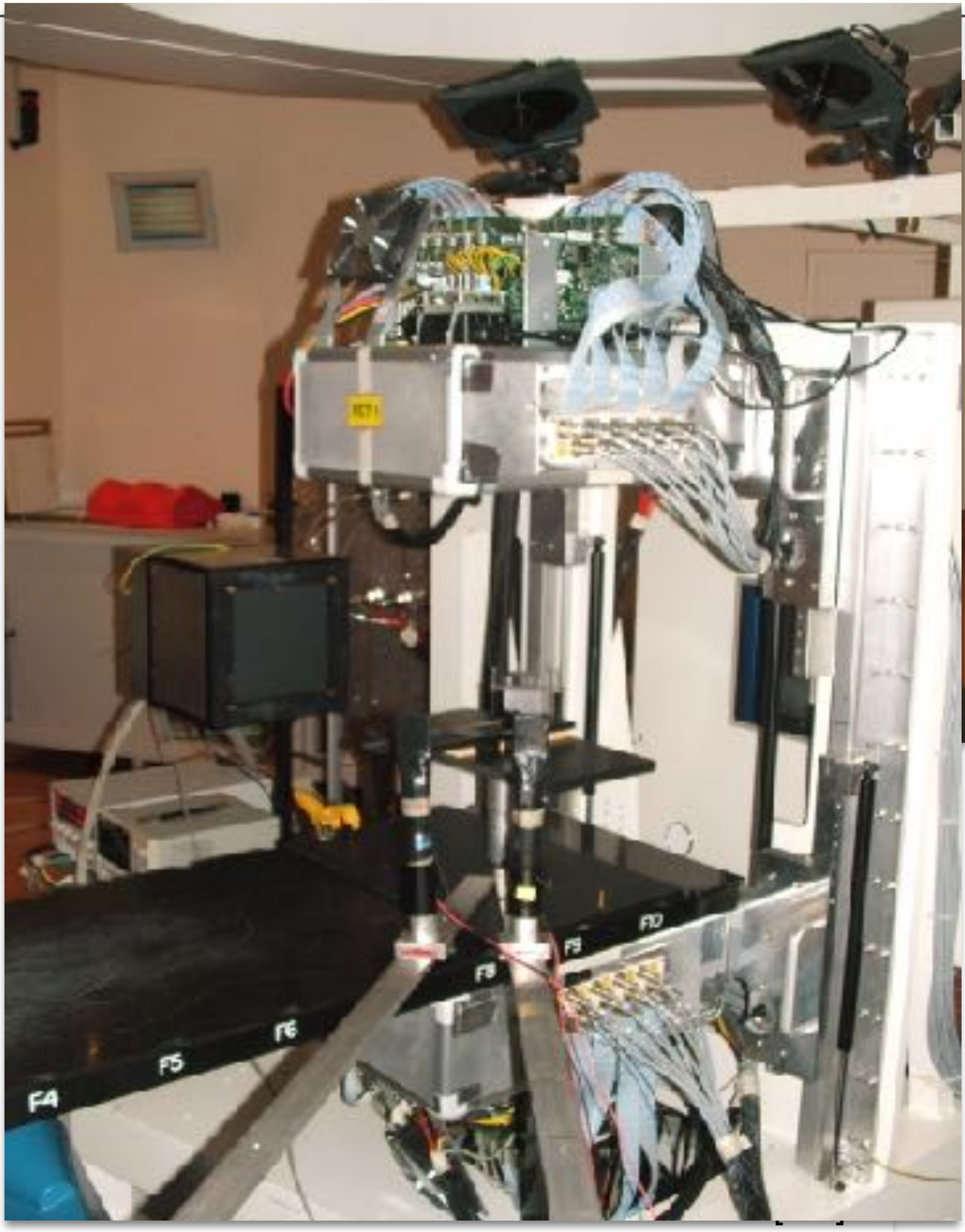




- Event display: tracking of the secondary protons



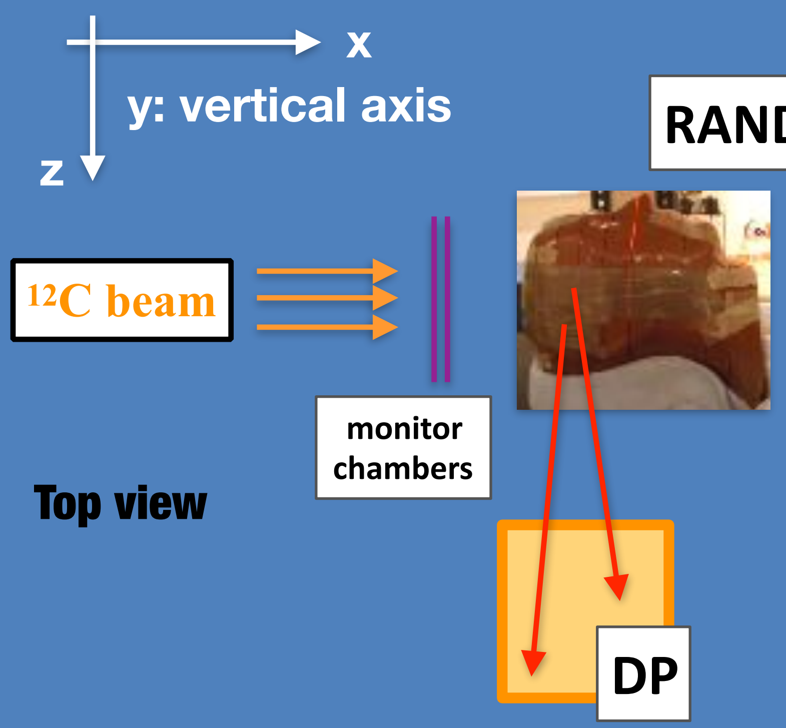
Dose Profiler@TestBeams: CARBON

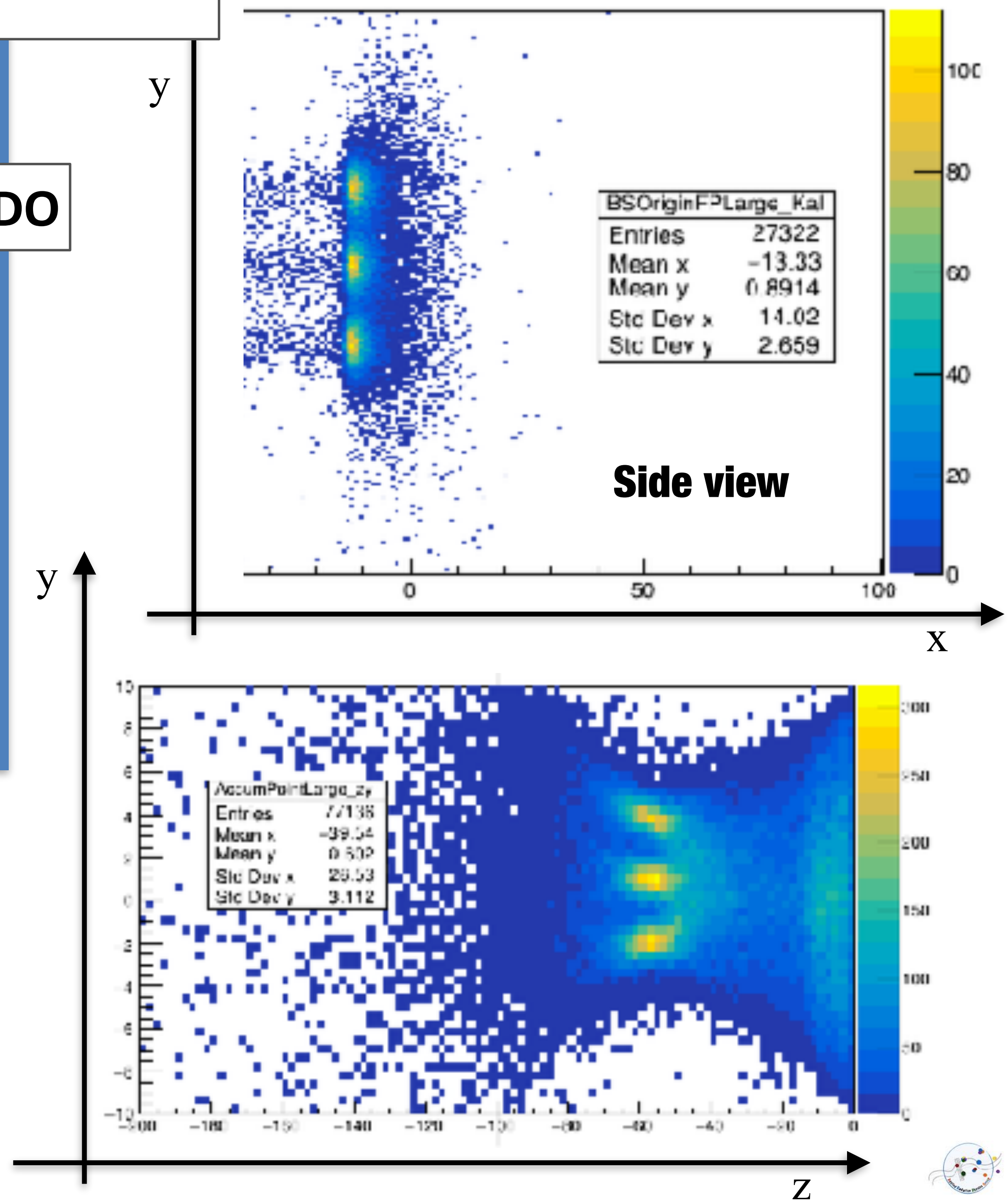


Joint data taking with INSIDE_PET detectors!

Giusy's team

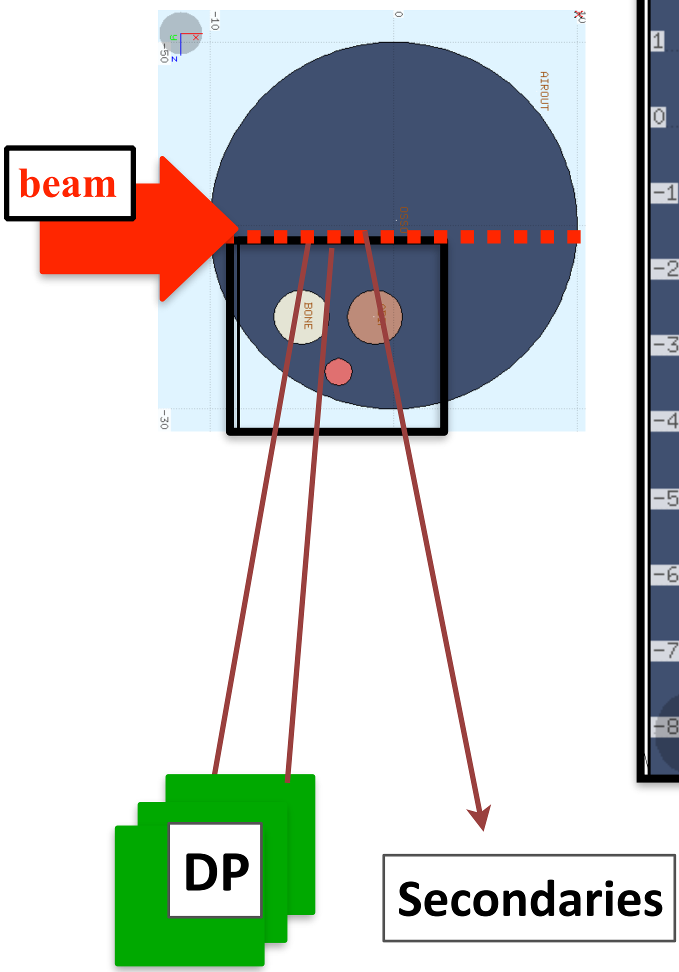
Dose Profiler@TestBeams: CARBON

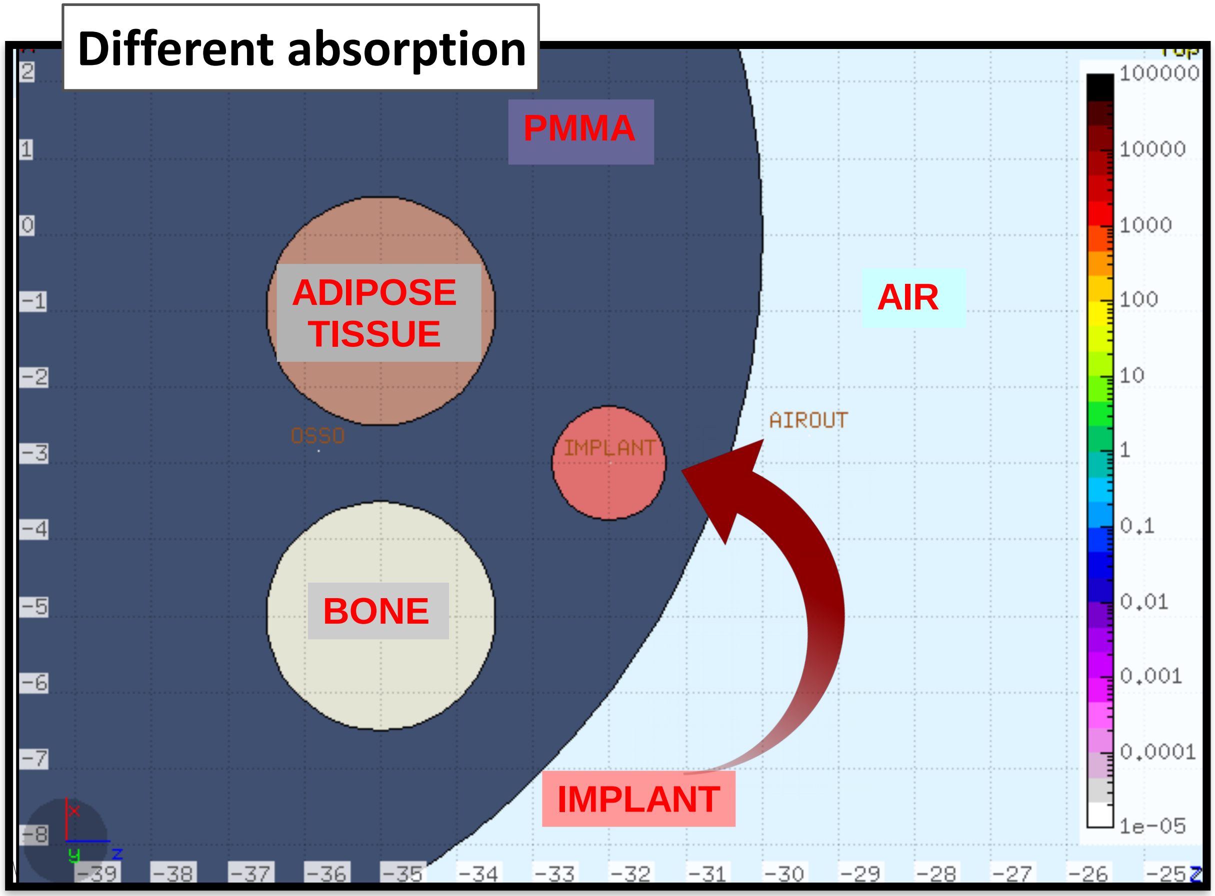




- **Treatment plan, a grid of 9 points, in x,y @ 220MeV**
- Preliminary (rough) attempt of pencil beam standalone reconstruction using *POCA (POint of Closest Approach)* of tracks from consecutive events.

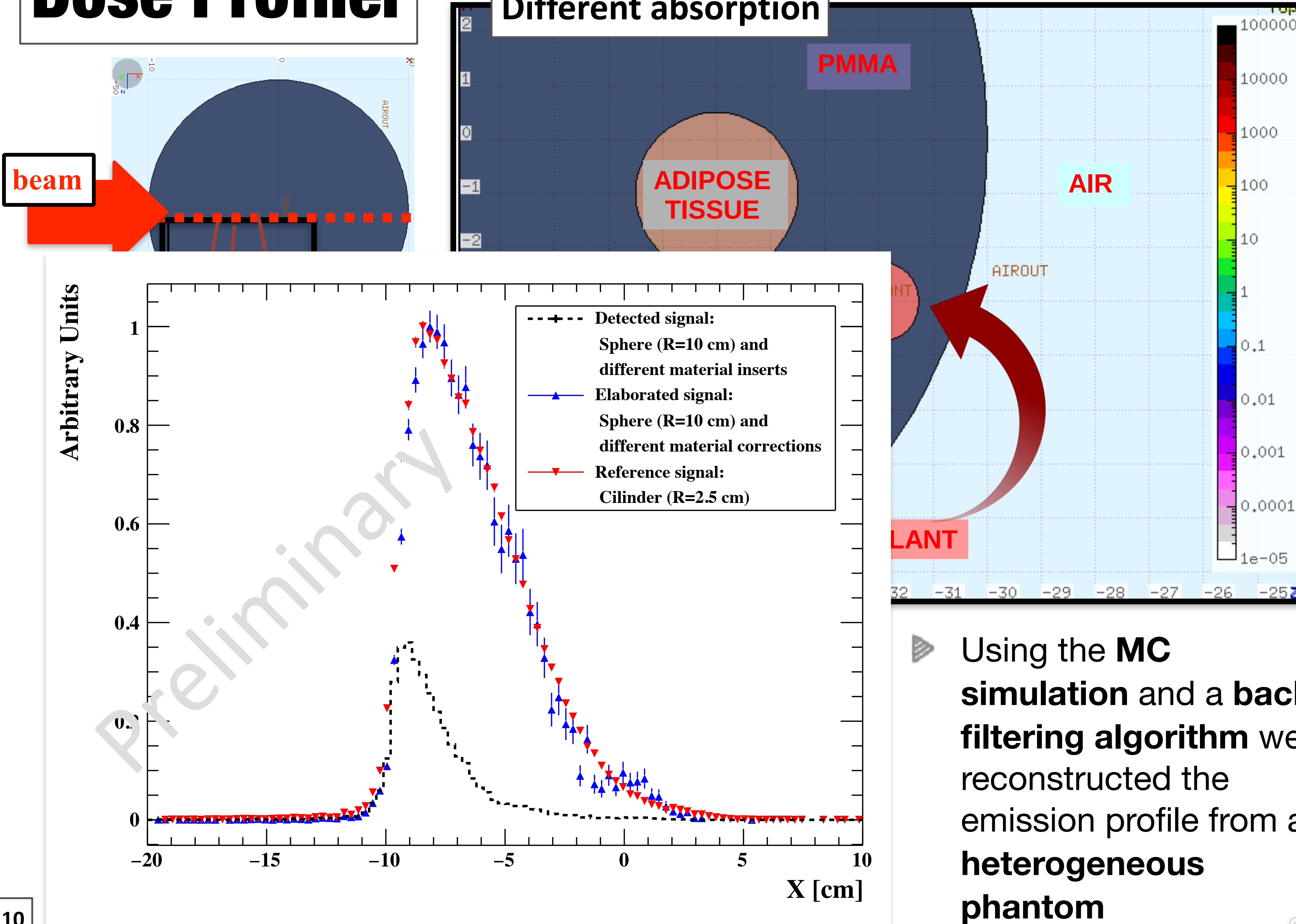
Dose Profiler





- In order to reconstruct the emission profile at production we have to take info account the matter absorption.. many different densities!

Dose Profiler



- Using the **MC simulation** and a **back-filtering algorithm** we reconstructed the emission profile from a **heterogeneous phantom**

Near Future

- Finalise the reconstruction code that takes into account the absorption in the patient of the secondary protons to maximise the precision in correlating the measured spectrum with the BP position;
- Implement communication between DP and the Dose Delivery System of the CNAO treatment room. Needed to:
  - Include the beam direction info in the reconstruction
  - Obtain the start signal for the data transfer when the spill is off

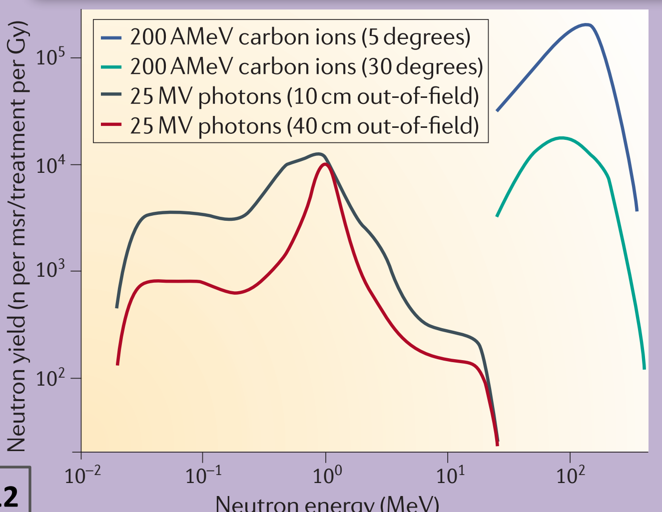
- **Test of the Dose profiler data taking with a patient;**

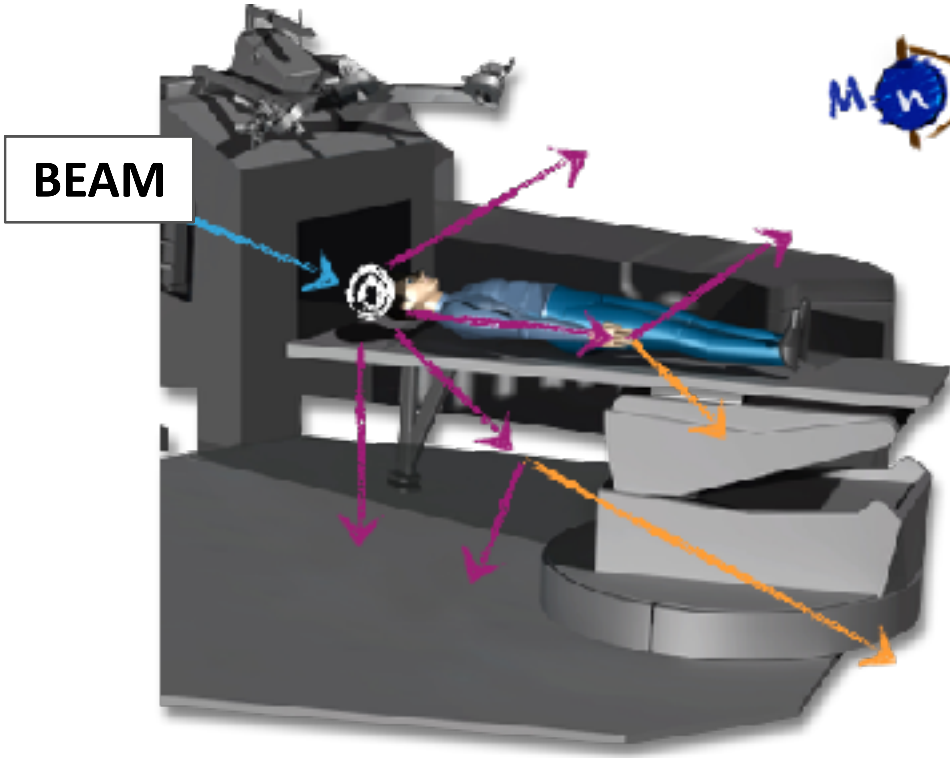
- Porting of the on-line reconstruction code on GPU system
- Optimisation of the operation conditions: distance from patient, angle with respect to the beam
- Evaluation of the performance on selected patients and pathologies;
- Development of a clinical protocol that foresees the use of the profiler feedback in standard treatment;

Neutrons

SMN: Secondary Malignant Neoplasms

Secondary neutrons are the main cause of additional dose to healthy tissues; moreover that dose can be released, in a not well known way, far away from the treated volume. The incidence (years after the treatment) of Secondary Malignant Neoplasms is connected with this phenomenon of additional dose and impacts directly the quality and the expectation of life of the patient.

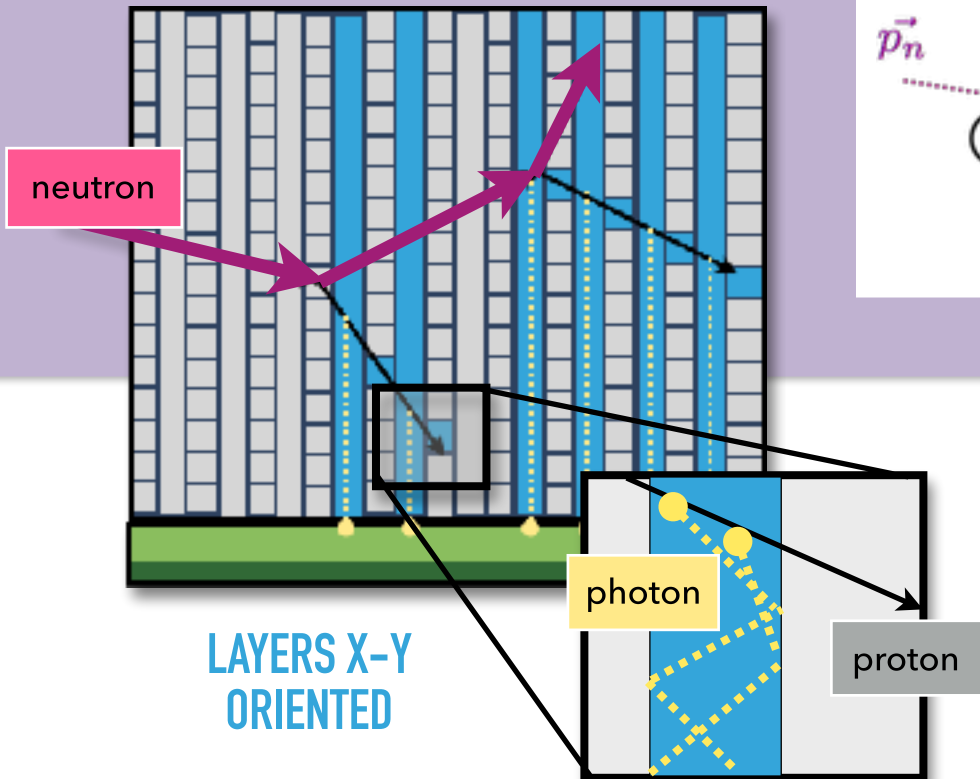




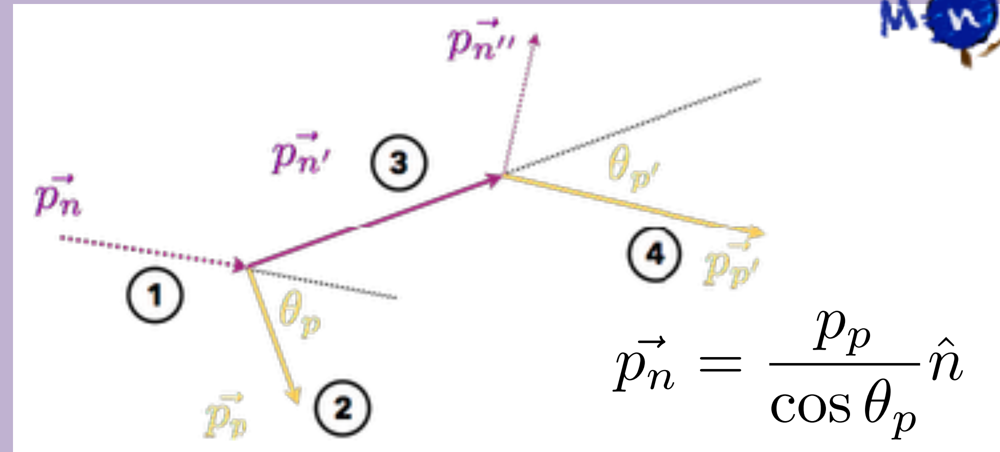
- **Track secondary neutrons**
- **Characterise neutron emission shape and spectra**

[M.Durante W.D. Newhauser doi:10.1038/nrc3069]

Neutrons



LAYERS X-Y ORIENTED



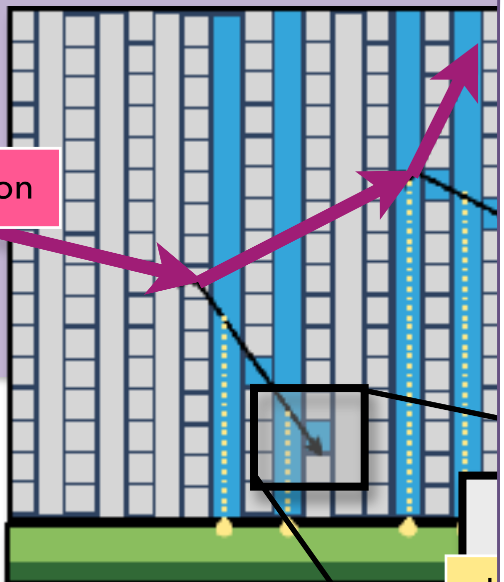
=> Detector size: 10 x 10 x 20 cm³

=> customised readout to collect the scintillation light

Deposited energy per fibre	100 keV in 250 μm
Light yield (BCF-12)	8000 ph. MeV^{-1}
Trapping eff. (double clad.)	7%
$N_{\mathrm{Ph.}}^{\mathrm{prod}}$	60 ph.

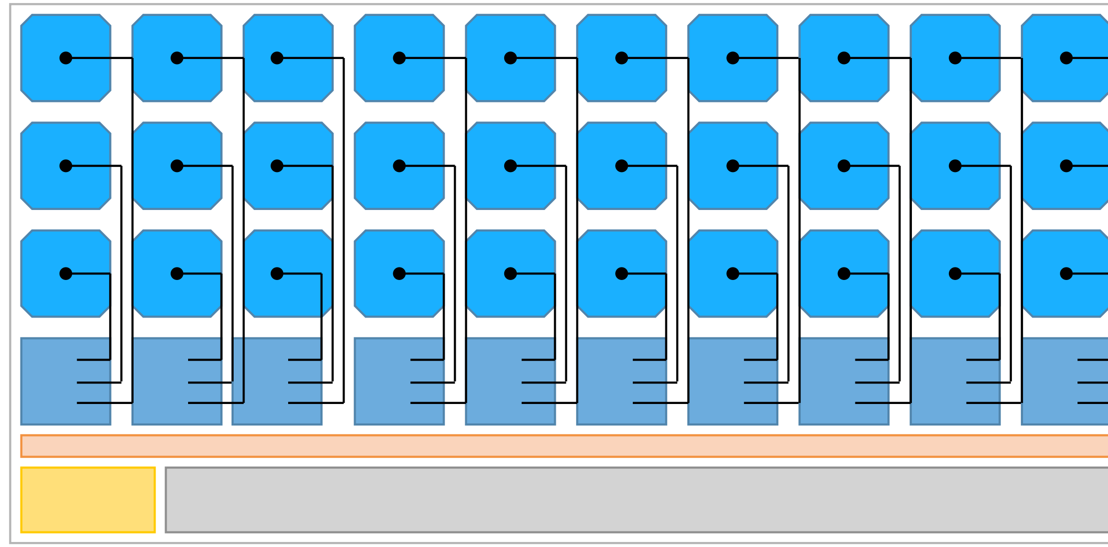
A Single Photon Avalanche Diode **SPAD** Array based **sensor** (CMOS technology) is under development with *Fondazione Bruno Kessler (FBK)*

Neutrons



LAYERS X-Y ORIENTED

Deposited energy per fibre	
Light yield (BCF-12)	
Trapping eff. (double clad.)	7
$N_{\text{Ph.}}^{\text{prod}}$	60 ph.



SPAD
19×19μm² active area
25×25μm² incl. GR and spacing

SRAM, front-end and quenching ×3
25×25μm²

Merging of SPAD signals (OR tree, monostables, …)

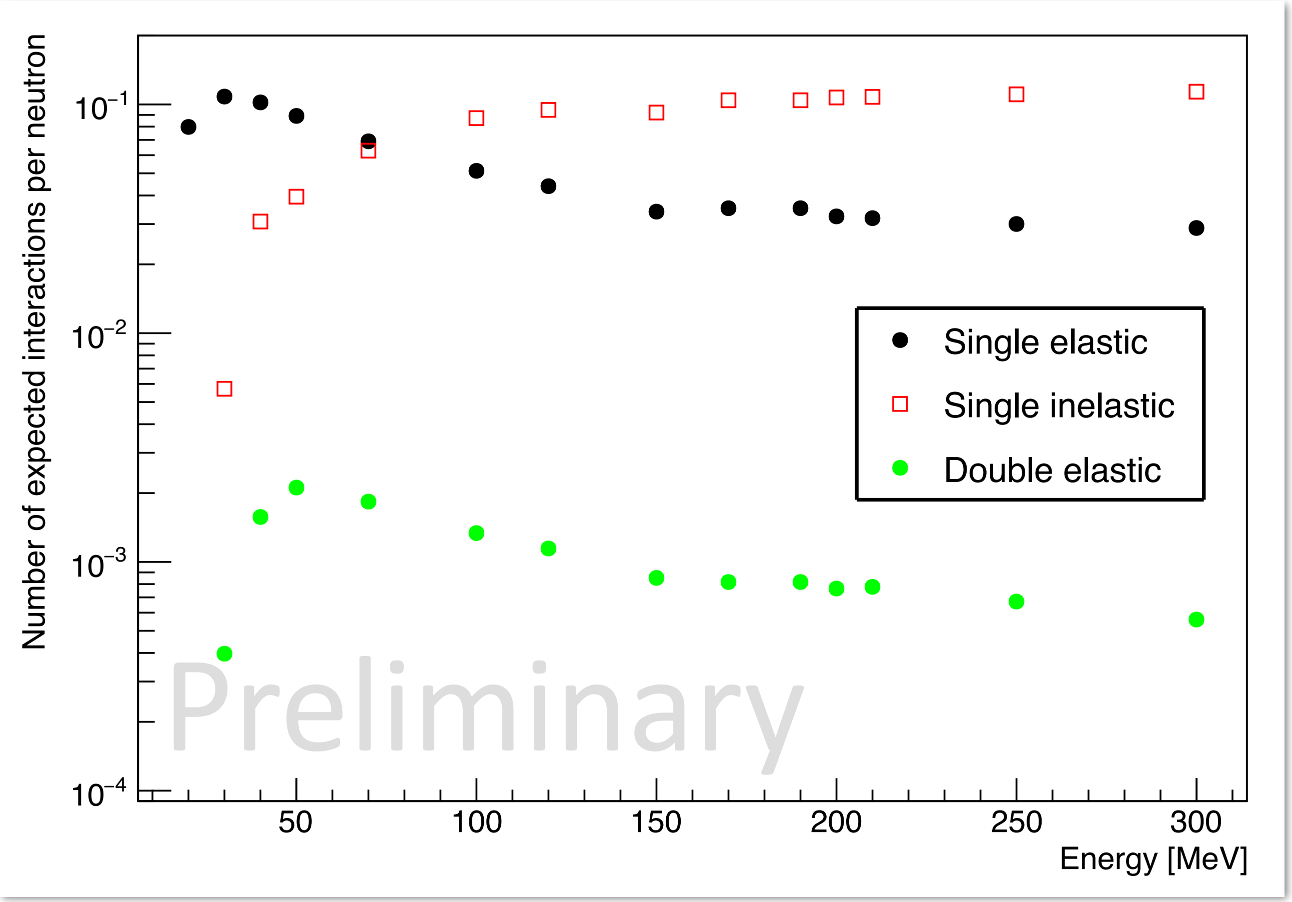
5-bit Digital counter
5bit×6×16μm²

Space left for discriminator

under development with *Fondazione Bruno Kessler (FBK)*

MONDO

- A MONDO detector description in MC FLUKA simulation has been implemented (the readout system has been simulated as well). Elastic and inelastic interaction study:



Detector:

- 10 x 10 x 20 cm^3
- 250 μm fibres

Detection:

- Double Elastic Scattering interaction probability in the detector => about 10^{-3}

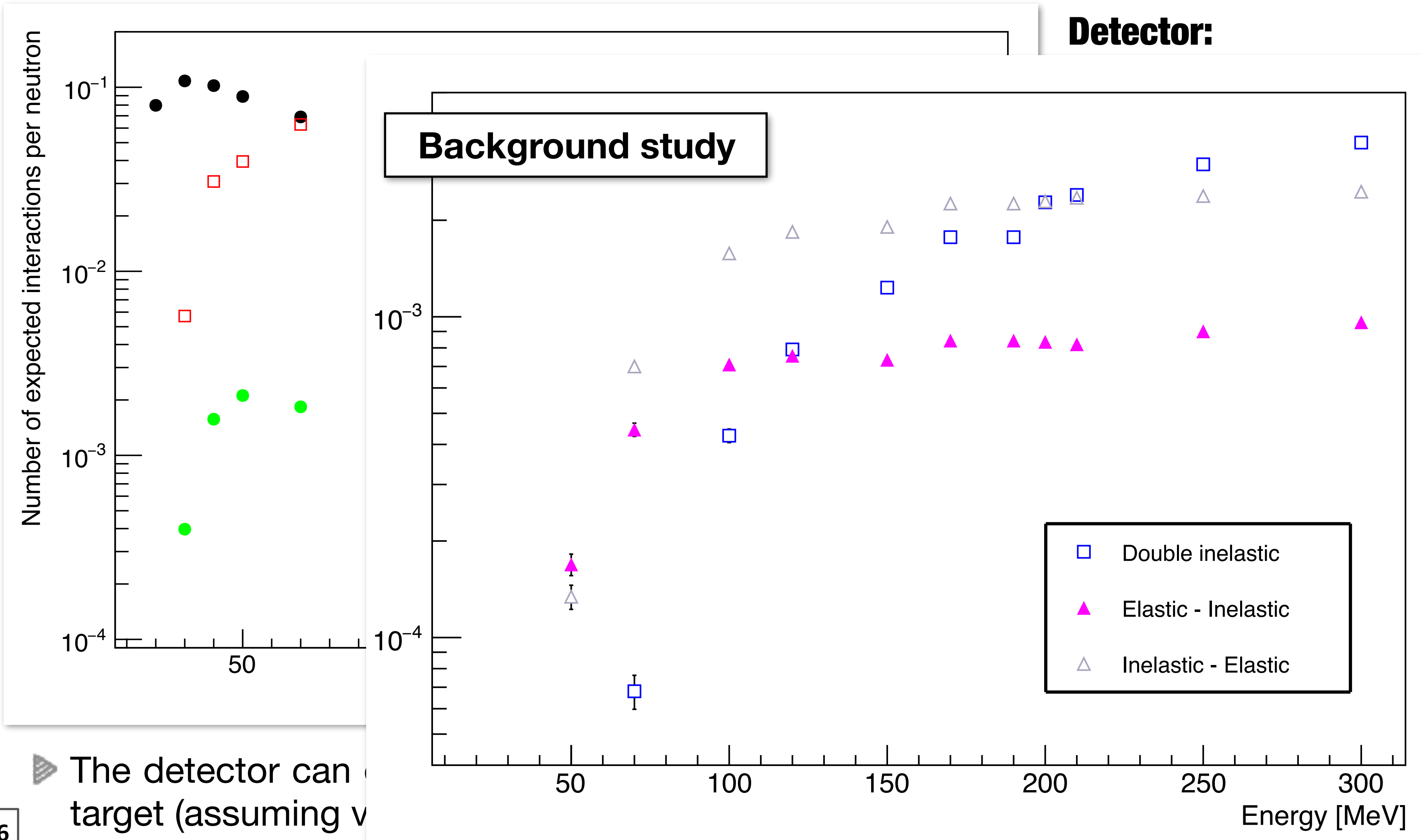
Constraints:

- thr. 12 MeV on protons
- p full containment

- The detector can exploit single ES for neutron cross-section measurements with thin target (assuming vertex position) and for neutron beam monitoring applications.

MONDO

- A MONDO detector description in MC FLUKA simulation has been implemented (the readout system has been simulated as well). Elastic and inelastic interaction study:



Detector:

n

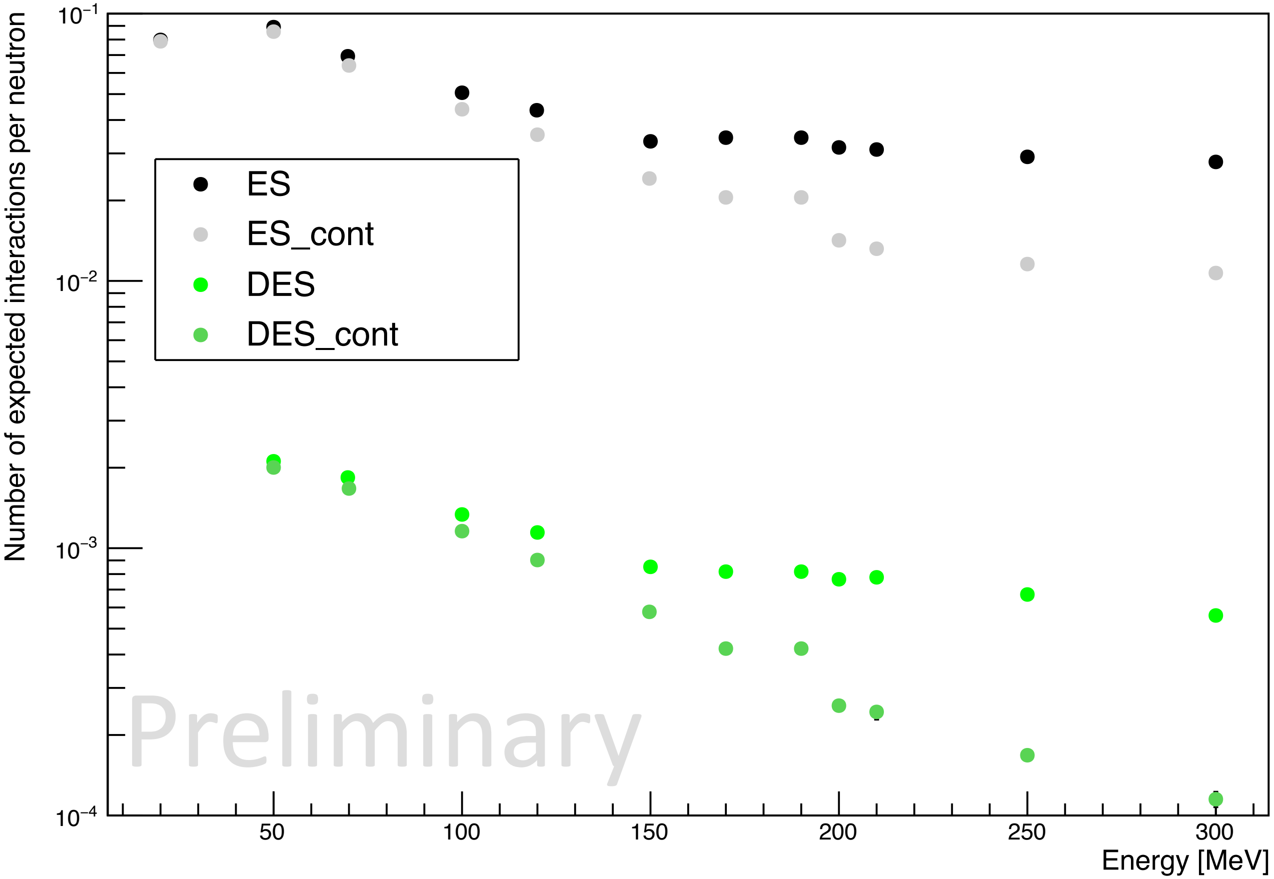
0-3

ns

- The detector can … in target (assuming v…

MONDO

- A dedicated study has been performed in order to understand how full proton containment request impacts on MONDO detection probability:



Detector:

- 10 x 10 x 20 cm^3
- 250 μm fibres

Constraints:

- thr. 12 MeV on protons

Detection:

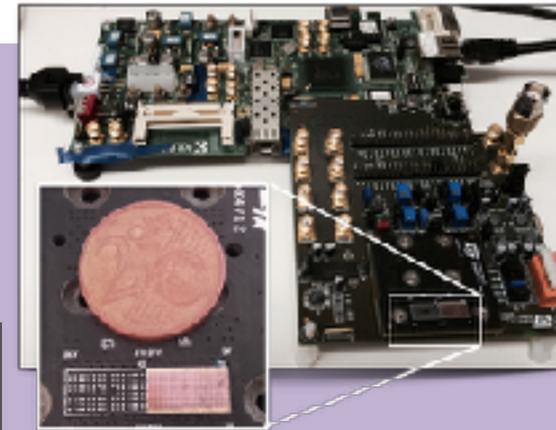
- Detection efficiency of DES interactions, decreases of a factor ~5 for higher energy neutrons (protons), when requiring the full containment

- A different proton recoil kinetic energy measurements has to be introduced in this case: energy loss and timing information are currently under study.

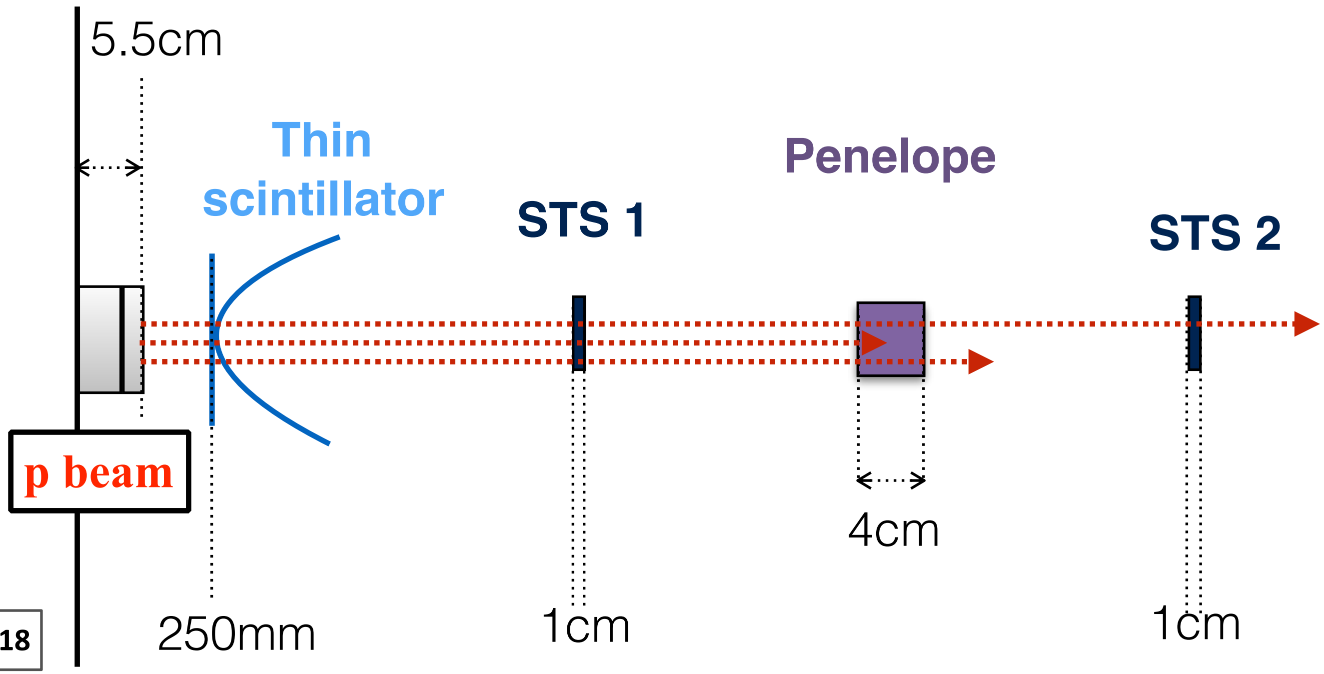
MONDO@TestBeams

=> **PENELOPE detector prototype:**
4 x 4 x 4.8 cm^3
SPADnet sensor is used as readout prototype

16 x 8 pixels of 600 μm, sensor ~0.5 cm^2 FF ~40 %, QE ~ 33%



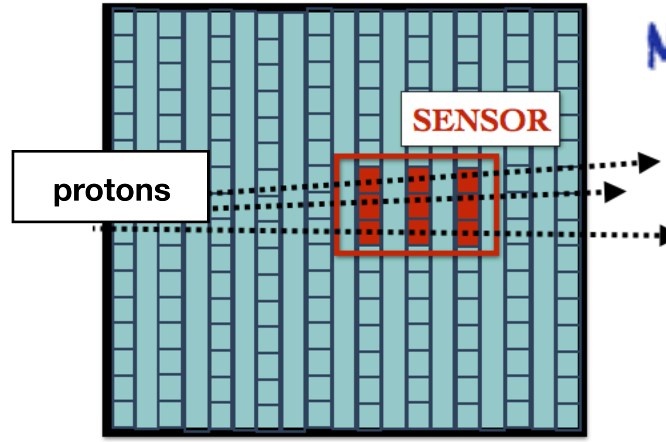
- PENELOPE has been tested at the experimental ASSP facility of Trento with protons



- Two readout: multi-anode commercial PMT and Spad-net silicon sensor;
- Monochromatic beams at different energies [60-220] MeV

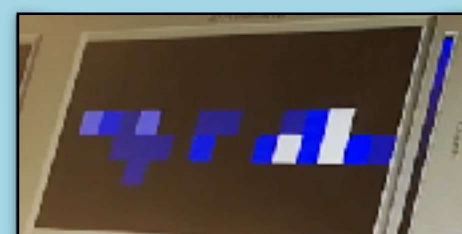
MONDO@TestBeams

1º PENELOPE readout: FBK spadnet sensor (128 ch., 600µm per pixel)



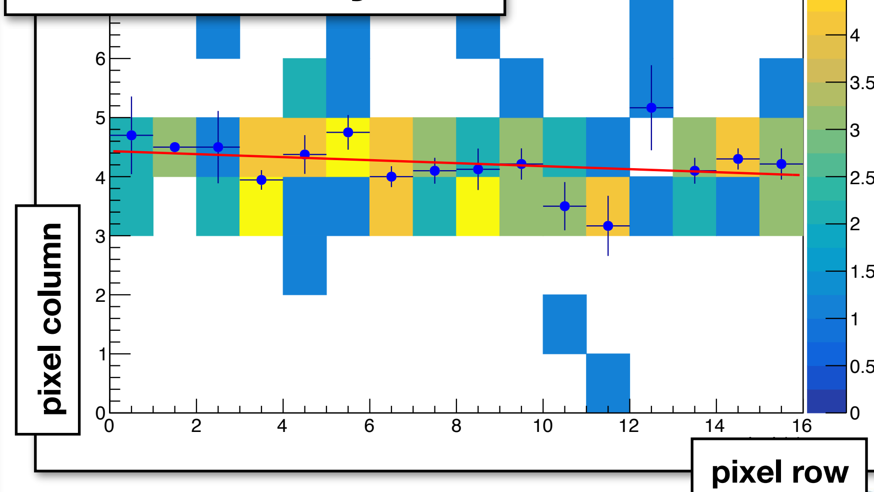
- This readout allowed to understand that protons release enough energy in the fibres to trigger (self trigger) the sensor and acquire the events;

Online readout



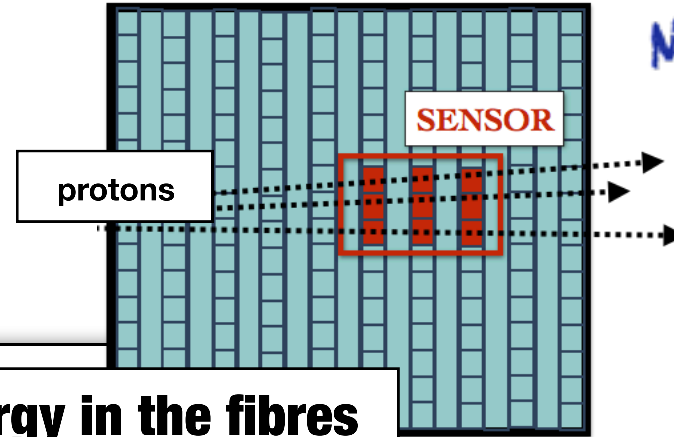
- charge and timing information both inline and offline

Offline analysis

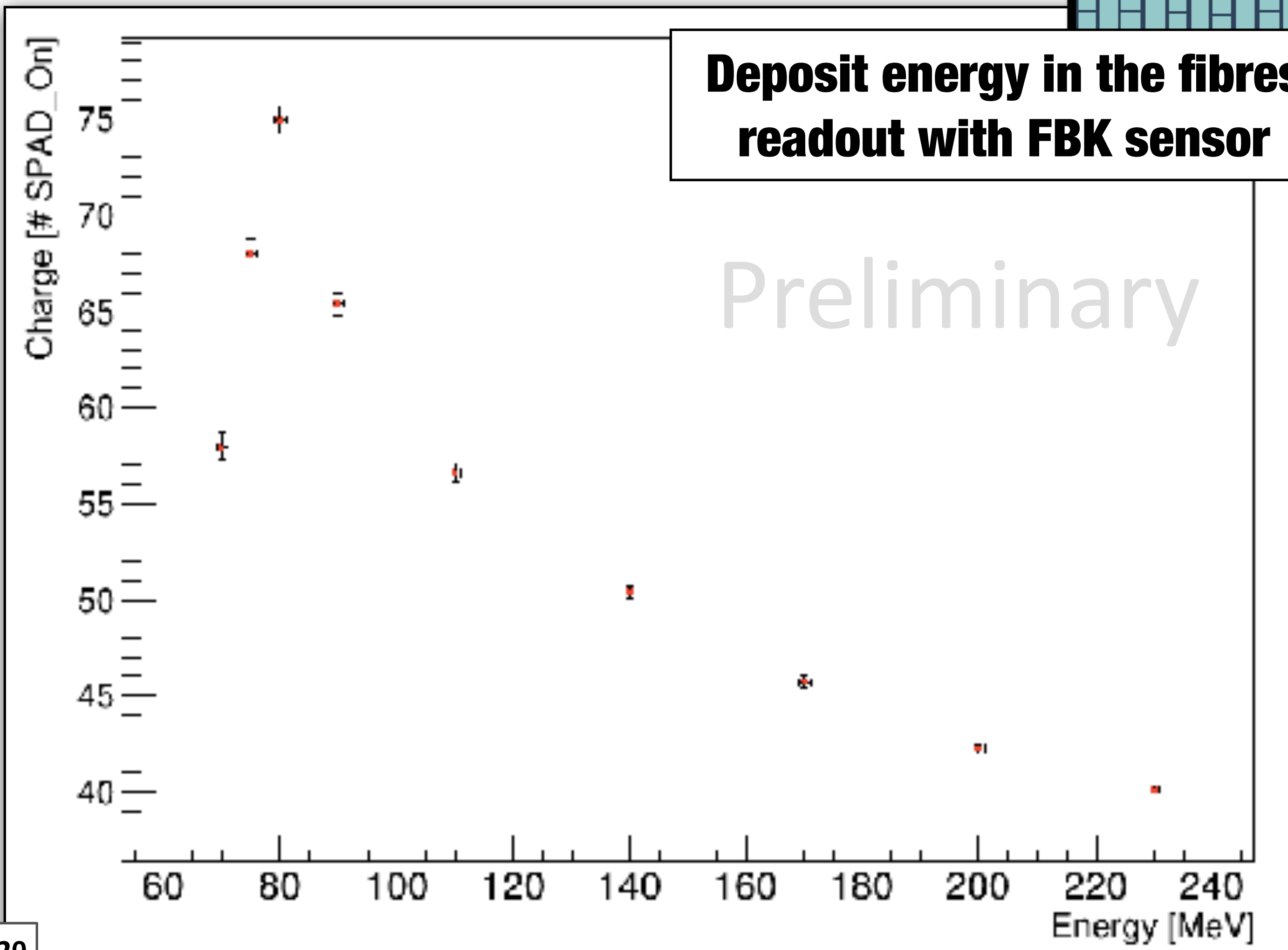


MONDO@TestBeams

1º PENELOPE readout: FBK spadnet sensor (128 ch., 600μm per pixel)

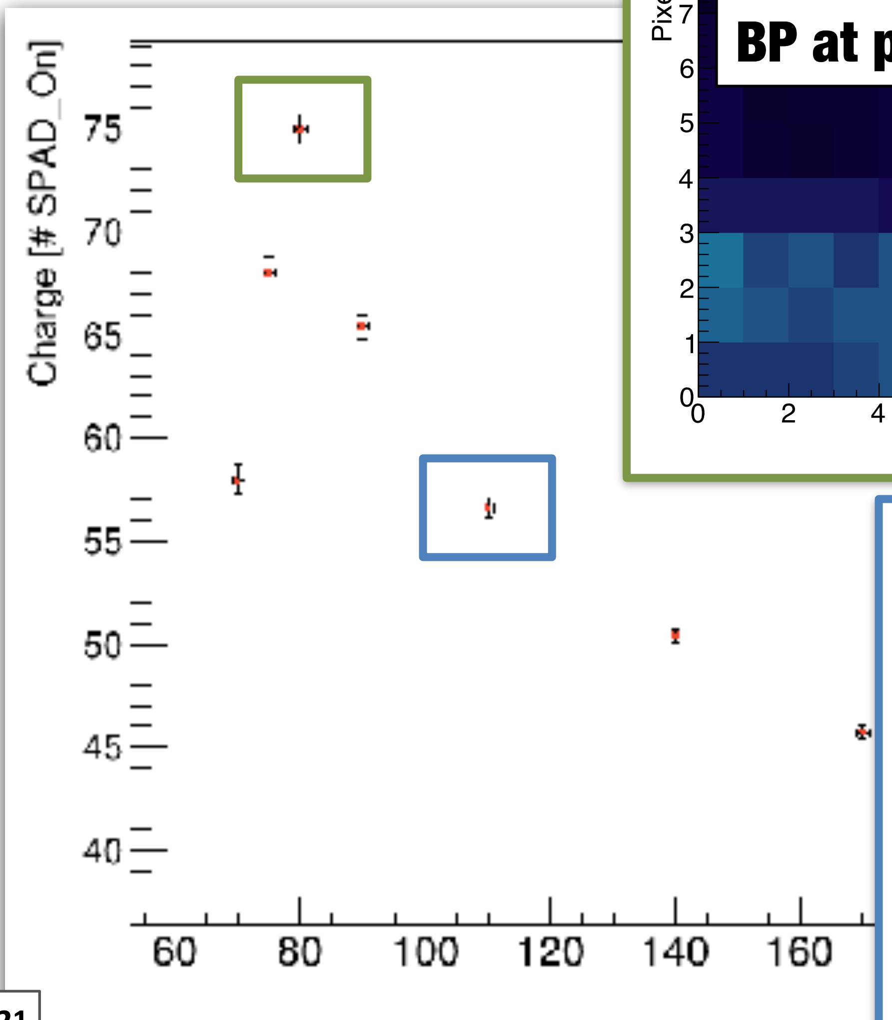


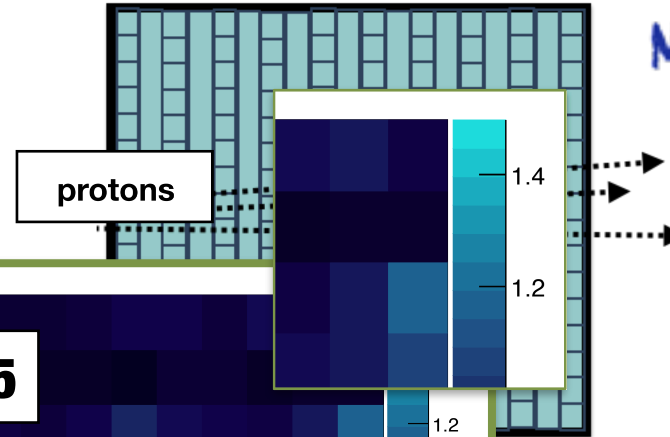
Deposit energy in the fibres readout with FBK sensor

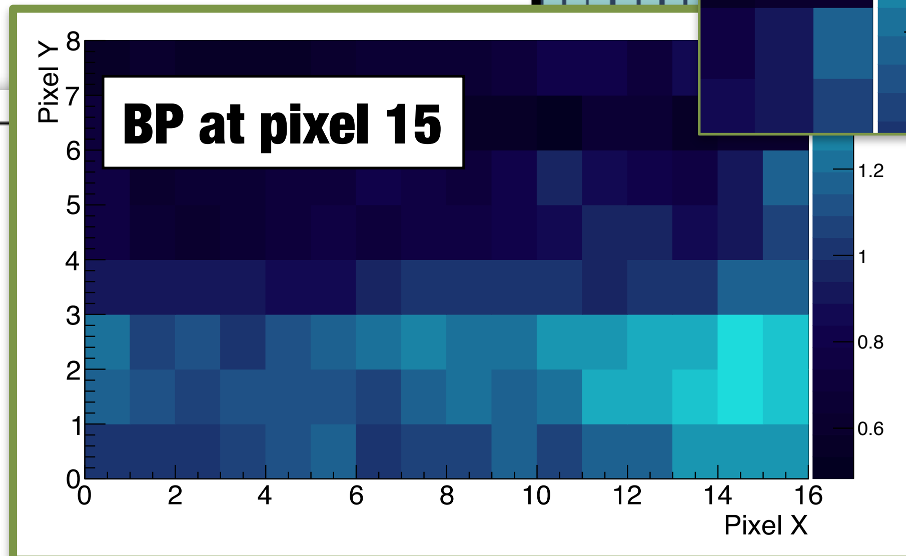


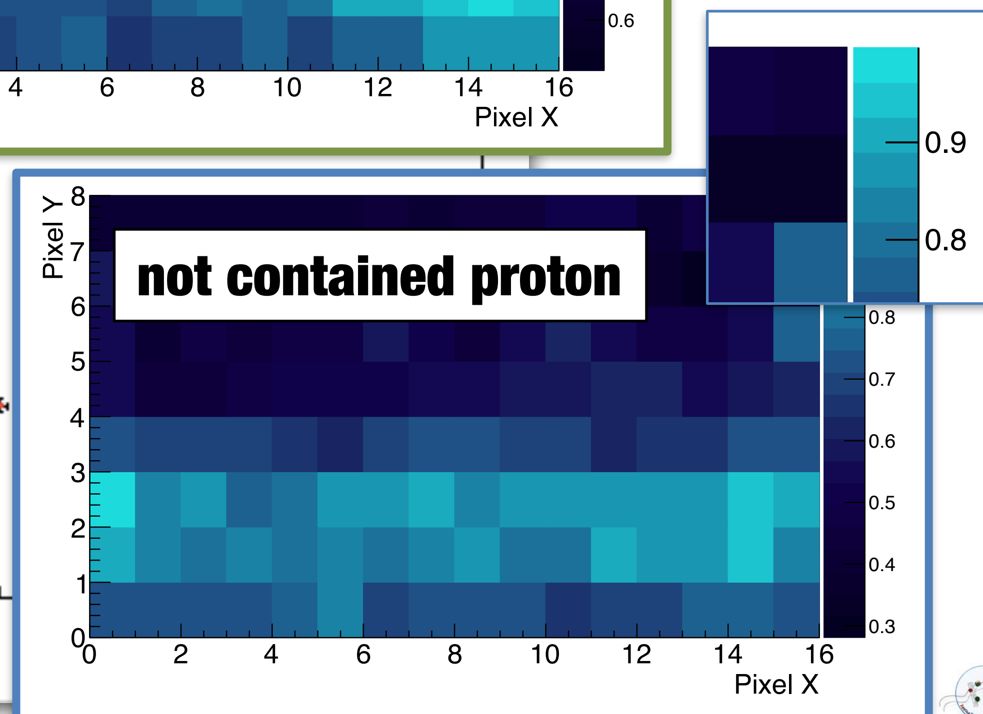
MONDO@TestBeams

1º PENELOPE readout: FBK spadnet sensor (128 ch., 600μm per pixel









Near Future

- Design and construction of the full size detector with scintillating fibres organised in x-y oriented layers: 10 x 10 x 20 cm^3;
- Production of the first SBAM sensor test chip. Realisation of a prototype tile sensor;
- Test measurements with proton beam (Trento) with SBAM sensor test chips
- Reconstruction Software: event display and event reconstruction;

- New SBAM sensors (full run);
- Full detector instrumentation;
- Measurements of neutrons produced in PMMA during Carbon ion (CNAO) and proton (TIFPA) irradiation;

Conclusions

- Our group work in WP2 is focused in **improving the quality** assurance in **Particle Therapy** (PT), especially for **Z>1** PT beams (es. carbon ion);

- The strategy follows a multiple approach:
  - **measurements**
  - **design**
  - **realisation of different devices**

  exploiting the different nuclear interactions;

- The synergy with PT centres is of fundamental importance!

TEAM:

- **Giuseppe Battistoni, INFN Milano;**
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- **Adalberto Sciubba, SBAI, INFN, CF;**
- **Angelo Schiavi, SBAI;**
- Giacomo Traini, Università Roma, INFN;
- Serena Valle, Università Milano, INFN;

Thank you - GRAZIE

Most Recent Scientific Publication (only 2017)

- Battistoni G.et al. “Design of a tracking device for on-line dose monitoring in hadrontherapy” (2017) NIM A 845, pp. 679-683.
- Traini G. et al. “Design of a new tracking device for on-line beam range monitor in carbon therapy” (2017) Physica Medica, 34, pp. 18-27

- Mattei I. et al. “Secondary radiation measurements for particle therapy applications: Prompt photons produced by 4He, 12C and 16O ion beams in a PMMA target” (2017) PMB, 62 (4), pp. 1438-1455
- Marafini M. et al. “Secondary radiation measurements for particle therapy applications: Nuclear fragmentation produced by 4He ion beams in a PMMA target “(2017) PMB, 62 (4), pp. 1291-1309

- Marafini M et al. *“MONDO: a neutron tracker for Particle Therapy secondary emission characterization” PMB 62 (2017) 32993312 doi: 10.1088/1361-6560/aa623a*
- Mirabelli R et al. *“The MONDO detector prototype development and test: steps towards a SPAD-CMOS based integrated readout (SBAM sensor)”* TNS PP (2017) 99 1-1 doi: 10.1109/TNS.2017.2785768
- S.Valle, et al. *‘’The MONDO project: A secondary neutron tracker detector for particle therapy*'' NIMA 845, 556–559 (2017) DOI: 10.1016/j.nima.2016.05.001