CENTRO FERMI
Enrico Fermi
MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE ENRICO FERMI

Dose Profiler

Coordinator: Vincenzo Patera

Participants:

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

Dipendenti/Associati CF

- Michela Marafini, *CF, INFN, RTD (02/2016 => 23/03/2019);*
- Riccardo Mirabelli, Università Roma, INFN Roma, CF, Dottorando *(01/11/2016 => 30/10/2019);*
- **Vincenzo Patera, *SBAI, INFN, CF, Professore Ordinario;***
- Alessio Sarti, *SBAI, LNF, CF, Professore Associato;*
- Adalberto Sciubba, *SBAI, INFN, CF, Professore Ordinario;*
- Giacomo Traini, *Università Roma, INFN Roma, CF, Post Doc;*

Collaboratori

- Micol De Simoni, Università Roma, INFN Roma, Dottorando;
- Marta Fischetti, Università Roma, INFN Roma, Dottorando;;
- Giuseppe Battistoni, INFN Milano, Primo Ricercatore;
- Ilaria Mattei, INFN Milano, Post.Doc;
- Yun Dong, UniMi, INFN Milano, Dottorando;
- Serena Marta Valle, UniMi, INFN Milano, Dottorando.

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- Ilaria Mattei, INFN Milano, Po
- Yun Dong, UniMi, INFN Milan
- Serena Marta Valle, UniMi, IN

Work Institution & Collaborations:

Host Institution: CENTRO FERMI and CNAO

Laboratory: SBAI

Collaborations:

- TIFPA - Proton Therapy Centre, Trento
- CNAO - Centro Nazionale di Adroterapia Oncologica, Pavia
- INFN – Sezione di Roma

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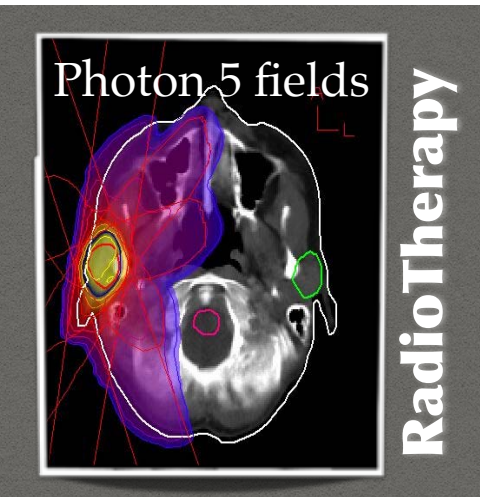
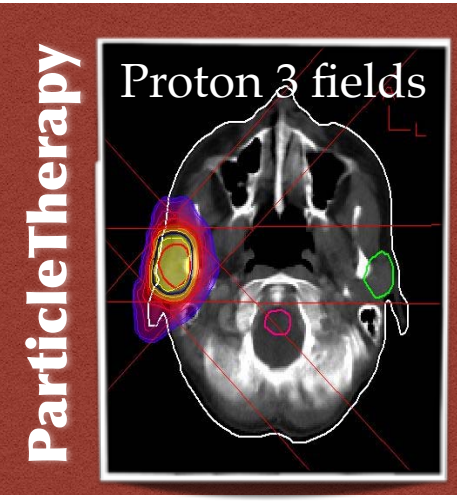
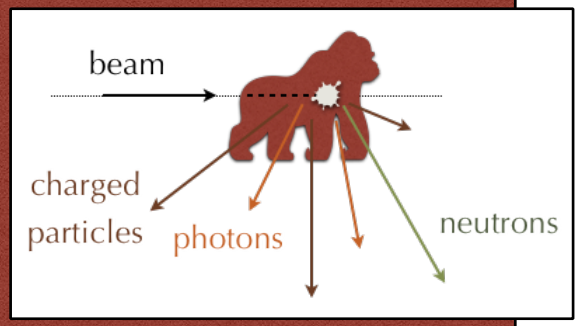
Particle Therapy: range monitoring

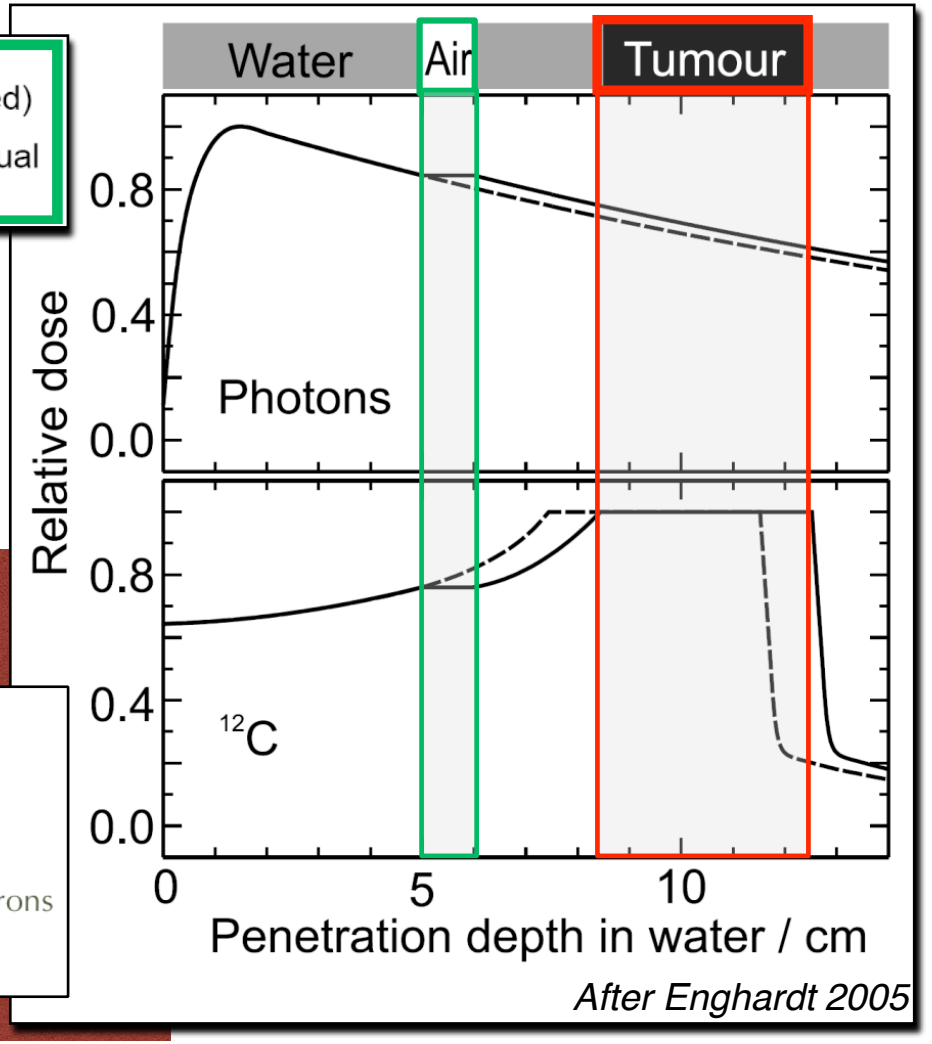
Particle Therapy (PT) treats cancers with light ions (p, ^{12}C, …) exploiting the characteristic hadron dose distribution (dE/dx) peaked at the end of the path inside the patient. Beam range depends on energy, ion and the crossed material.





The beam "position" has to be known with high precision!





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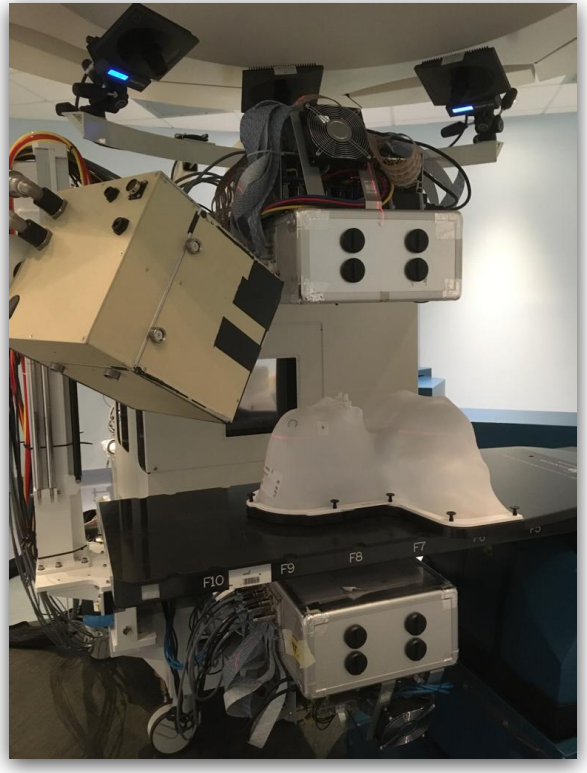
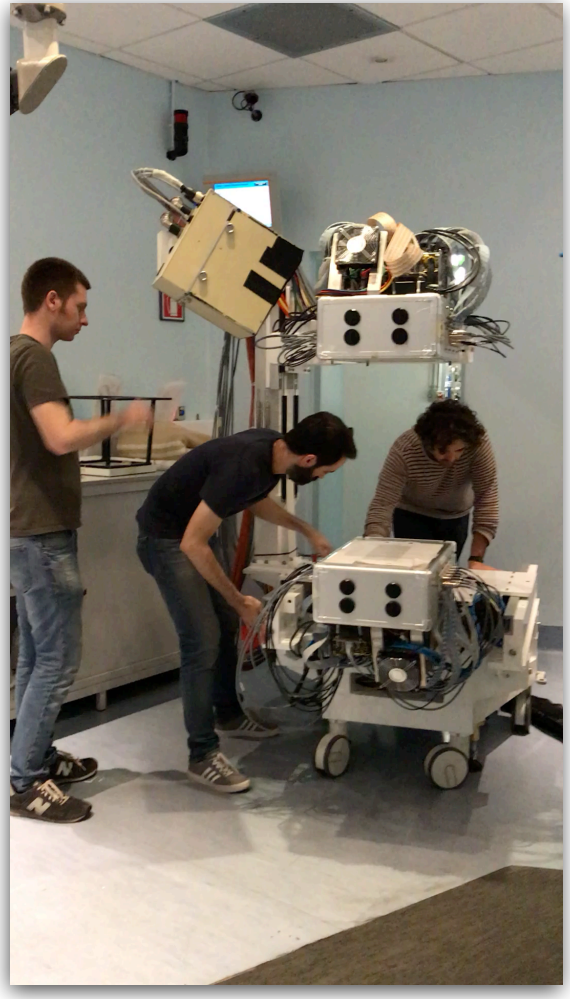
Project main goals and results achieved in 2018

- Characterisation and installation of the DoseProfiler (DP) at CNAO - Centro Nazionale di Adroterapia Oncologica, Pavia;
- **Acquisition with an anthropomorphic phantom;**
- **Installation of the INSIDE cart;**



- Integration with the PET heads detectors
- Detector calibration performed between March and September 2018

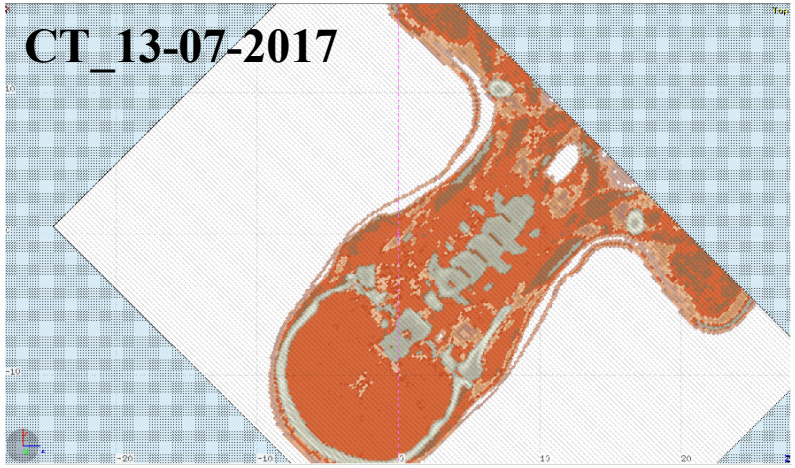


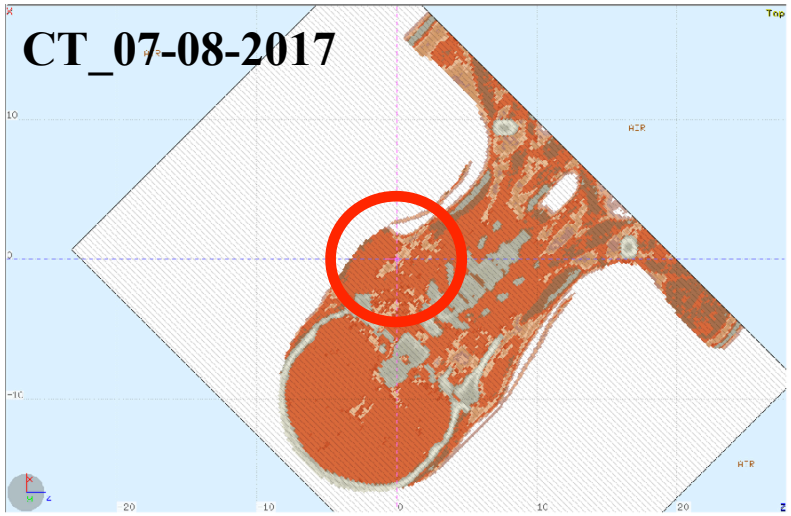
fondazione CNAO
Centro Nazionale di Adroterapia Oncologica per il trattamento dei tumori

DOSE PROFILER

Project main goals and results achieved in 2018

- Software development: implemented fast tracking needed to allow online range monitoring
- Development of MC algorithms to account for the 'matter effect' (fragments multiple scattering and absorption).
  - FLUKA simulation has been implemented to calculate the unfolding correlation matrix.
  - Two approached are being investigated: MLEM & full MonteCarlo based





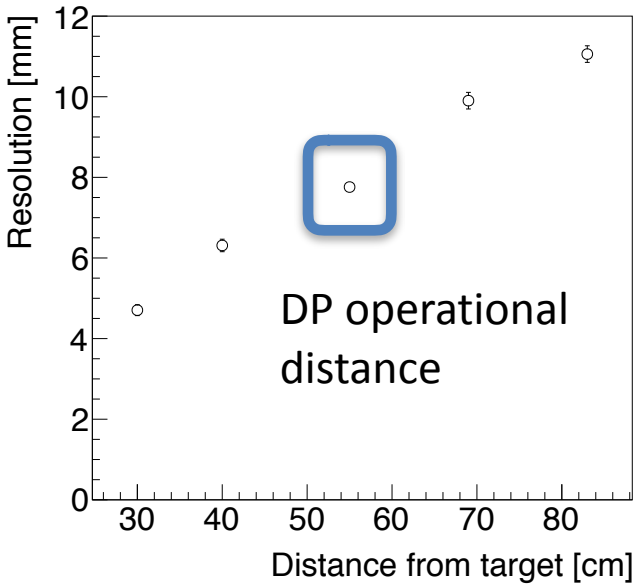
Can we say anything if a large toxicity shows up during a treatment? **Monitoring the patient during the different fractions is a huge priority for CNAO**

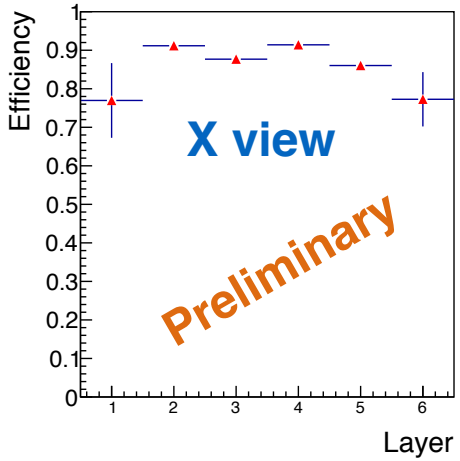
DOSE PROFILER

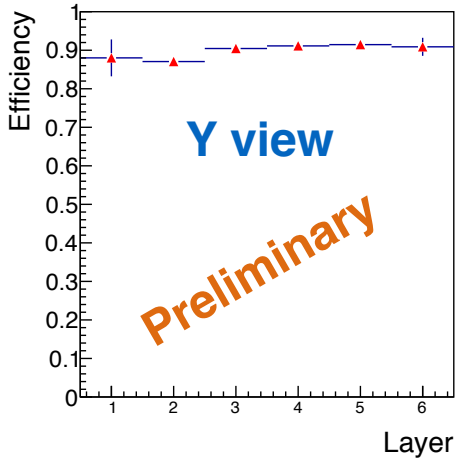
Project main goals and results achieved in 2018

- Data taking at CNAO:
  - Carbon ion beams of therapeutical intensity and energy impinging on small homogenous targets: => tracking capability measurements
  - **Carbon ion beams impinging on anthropomorphic phantom (RANDO®), final distance and angle (same as clinical trials).**

- Good performance has been obtained:
  - **sub-millimeter tracking resolution for a sample of 100 tracks**
  - sustainable clinical rate of more than ~ 100 kHz







DOSE PROFILER

Project main goals and results achieved in 2018

- Milestone1. Implementation of correction measurements to reduce the detector readout dead time

  100%

  - Now: DT brought down to 4 μs!

- Milestone 2. **Integration of the DP with the PET-Heads system in the clinical trials program at CNAO**

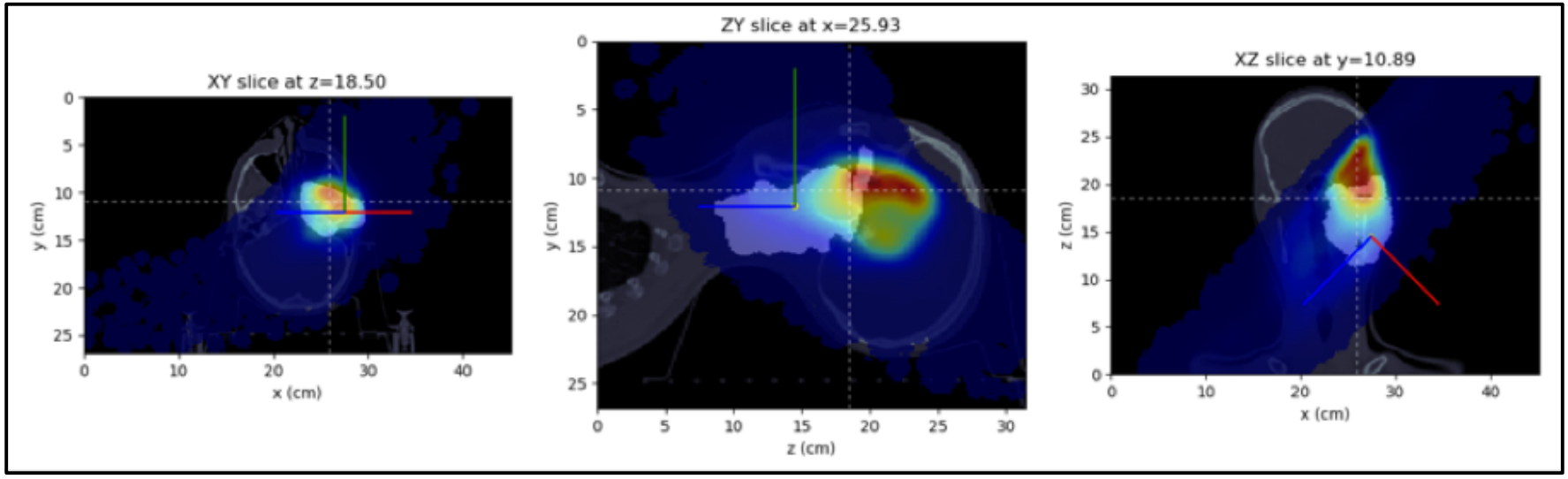
  100%

DOSE PROFILER

Project main goals and results achieved in 2018

- Milestone 3. Development of the software required to implement the matter effect correction in the data analysis

80% - while **the algorithms for the matter effect correction have been developed**, a final decision on the best strategy for online monitoring applications has yet to be made [will be done against clinical trial data]



- Milestone 4. Implementation of online feedback for the BP monitoring

50% - The algorithms needed for the **track reconstruction and range monitoring have been developed within the offline framework**. While the track reconstruction has been already ported to the online environment, the matter effect and display are yet to be implemented.

DOSE PROFILER

Scientific Publication for DP in 2018

A. Rucinski, *et al.*	Secondary radiation measurements for particle therapy applications: charged particles produced by 4He and 12C ion beams in a PMMA target at large angle	Physics in Medicine & Biology	2018	63 055018	doi: 10.1088/1361-6560/aaa36a
I. Mattei, *et al.*	Scintillating Fiber Devices for Particle Therapy Applications	IEEE TRANSACTIONS ON NUCLEAR SCIENCE	2018	65 2054	doi:10.1109/TNS.2018.2843179

Scientific products in 2018

The clinical trial is about to start. Four selected pathologies have been identified:

- Meningioma and nasopharynx cancer treated with proton beams;
- Adenoid Cystic Carcinoma (ACC) and clival chordoma treated with ^{12}C beams;

DOSE PROFILER

Conference for DP in 2018

M. Fischetti *et al.*	In-room characterization, using an anthropomorphic phantom, of a novel detector for on-line dose monitoring in light ions cancer therapy.	104° Congresso Nazionale della SIF	2018	https://www.sif.it/attivita/congresso/104
M. De Simoni *et al.*	Risultati dei test, fatti in sala di trattamento al CNAO, di un monitor online innovativo del range in trattamenti di terapia con particelle (Dose Profiler)	18° Convegno Nazionale della SIRR	2018	http://www.sirr2.it/sirr2018/
I. Mattei *et al.*	Neutron and charged particle trackers: application to PT	2018 Symposium on Radiation Measurements and Applications	2018	http://rma-symposium.engin.umich.edu/
S. M. Valle *et al.*	Secondary charged fragments tracking detector for on-line Bragg peak monitoring in Particle Therapy	IUPESM 2018 World Congress	2018	http://www.iupesm2018.org/
R. Mirabelli *et al.*	In-room performance evaluation of a novel charged particles monitor of light ions PT treatments	2018 IEEE Nuclear Science Symposium and Medical Imaging Conference	2018	http://www.nssmic.org/2018/
A. Sarti *et al.*	In-room characterisation, using an anthropomorphic phantom, of a novel monitor exploiting secondary charged particles emission in light ion PT treatments	57th Annual Conference of the Particle Therapy Co-operative Group (PTCOG57)	2018	http://ptcog57.org/
V. Patera *et al.*	Vision for: beam tracking with prompt secondary ions	3rd Heidelberg Symposium on Novel Techniques in Ion Beam Radiotherapy	2018	https://www.dkfz.de/en/medphys/novel_detectors_ionbeams/Symposium2018.html

DOSE PROFILER

Milestones 2019

- Operation and performance test of the DP during the clinical trial (clinical conditions, with patients) that will be carried out at the CNAO centre
- **Evaluation of the DP sensitivity to morphological and patient positioning variations (inter-fractional changes)**
- Definition and optimisation of the matter effect unfolding strategy
- Development and test of the online beam range monitoring software

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DOSE PROFILER

Plan of activities 2019 – 2021

- From 2019 the bi-modal INSIDE detector (DP+PET_heads) will be used within the clinical trial to assess the treatments online monitoring capabilities in a realistic scenario;
- The software tools developed over the past three years will be benchmarked against the clinical trial data, adapted for the *on-line* use and implemented in the acquisition software aiming, finally, for a graphic display of the treatment quality;
- systematic exploration of the physical limits, in the clinical field, of the monitoring technology implementing charged particles and of alternative technological solutions. The maximum resolution obtainable in the monitoring of patients with ions at Z> 1, will be studied using secondary charged fragments:
  - different distances wrt iso-centre and angles wrt the beam direction will be systematically explored.
  - Different technological solutions (eg. compact detectors with integrated pixel readout) will be considered in order to take full advantage from all the available physical information.

External funding

- **CNAO** is contributing to the funding of the clinical test and characterisation of the DP with therapeutical beams (protons and carbon ions);

DOSE PROFILER

Expected funding in the 3-year period:

- **Request of funding by Centro Fermi**

- Consumables: 25keuros/year
- Manpower: 1 post.doc contract/year;

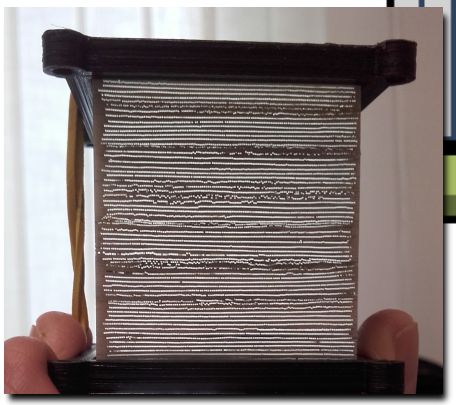
Secondary neutrons in PT

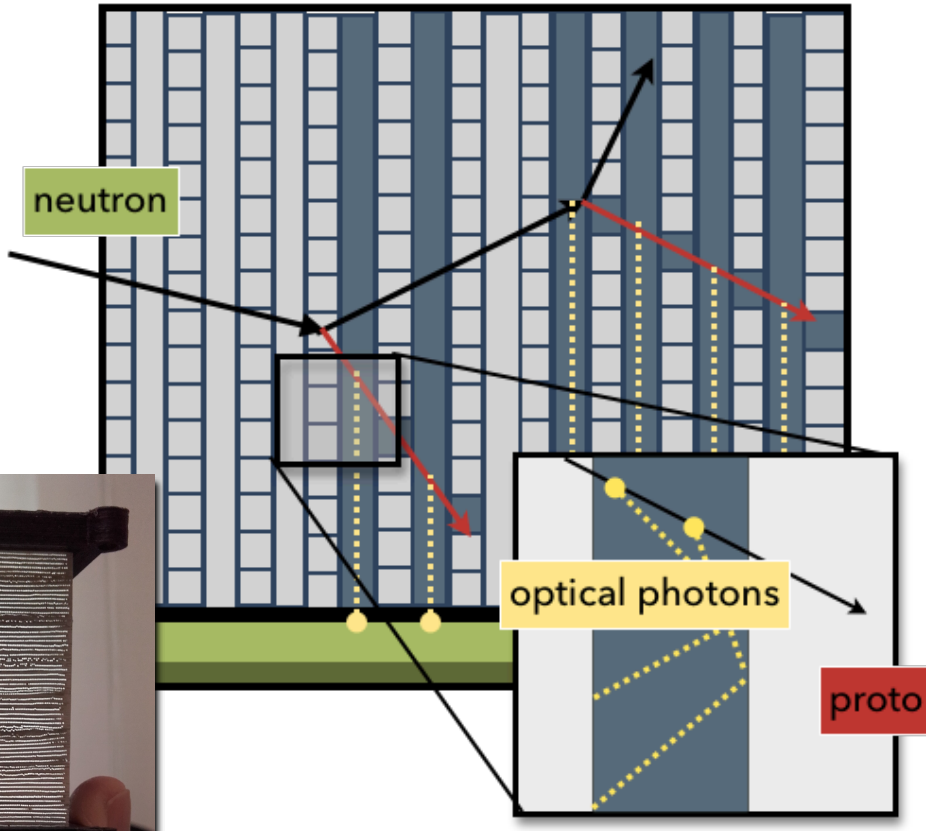
Secondary neutrons production has to be deeply investigated as neutrons can release **additional dose** also far away from the volume under treatment. The incidence (also years after the treatment) of SMNs (**Secondary Malignant Neoplasm**) impacts directly on the quality and life expectation of the patient.

MONDO is a tracking detector that exploits double elastic scattering

- The detector is a compact matrix of plastic scintillating fibres (250 μm). The fibres are readout by a dedicated innovative silicon sensor developed for MONDO in collaboration with FBK (Fondazione Bruno Kessler): **SBAM** - Spad Based Acquisition readout for the Mondo experiment.

10 x 10 x 20 cm^3





MONDO

Coordinator: Michela Marafini

Participants:

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- Riccardo Mirabelli, Università Roma, INFN Roma, CF, Dottorando *(01/11/2016 => 30/10/2019);*
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Coordinator: Michela Marafini

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- Giuseppe Battistoni, INFN Mila
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- Yun Dong, UniMi, INFN Milanc
- Serena Marta Valle, UniMi, INI

Work Institution & Collaborations:

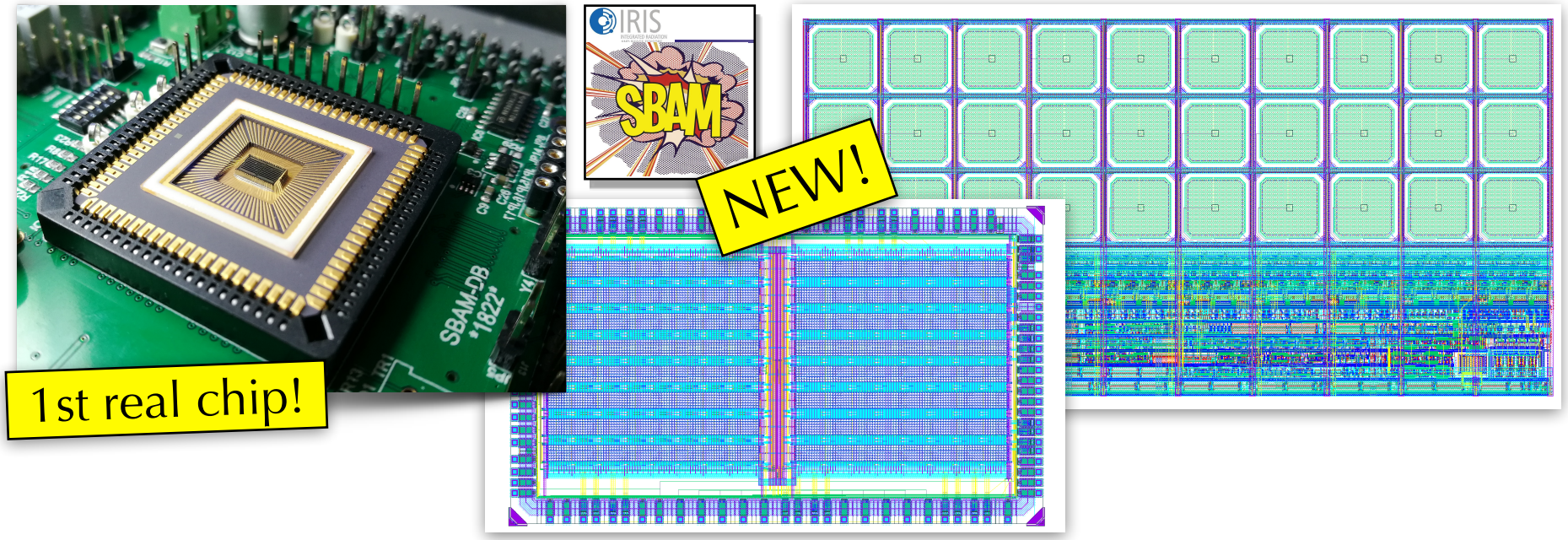
Host Institution: CENTRO FERMI

Laboratory: SBAI

Collaborations:
- TIFPA - Proton Therapy Centre, Trento
- CNAO - Centro Nazionale di Adroterapia Oncologica, Pavia
- **FBK – Fondazione Bruno Kessler, Trento**
- INFN – Sezione di Roma

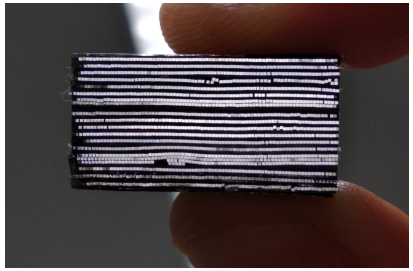
Project main goals and results achieved in 2018

- Finalisation of the architecture of the SBAM readout sensor:



- Feasibility study with two different mechanical companies for the realisation of the weaving frame (scintillating fibres);

- Validation of the operative technique at SBAI mechanical workshop: new prototype of 2 x 2 x 1 cm3

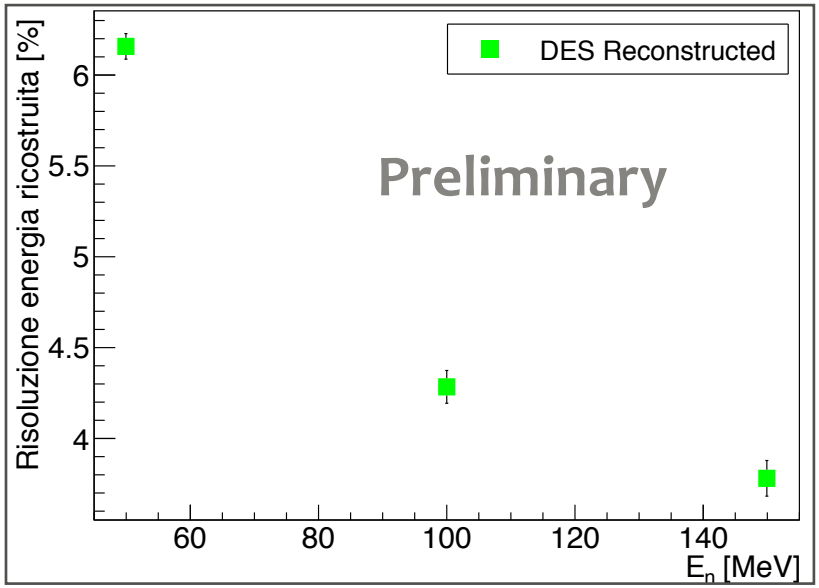


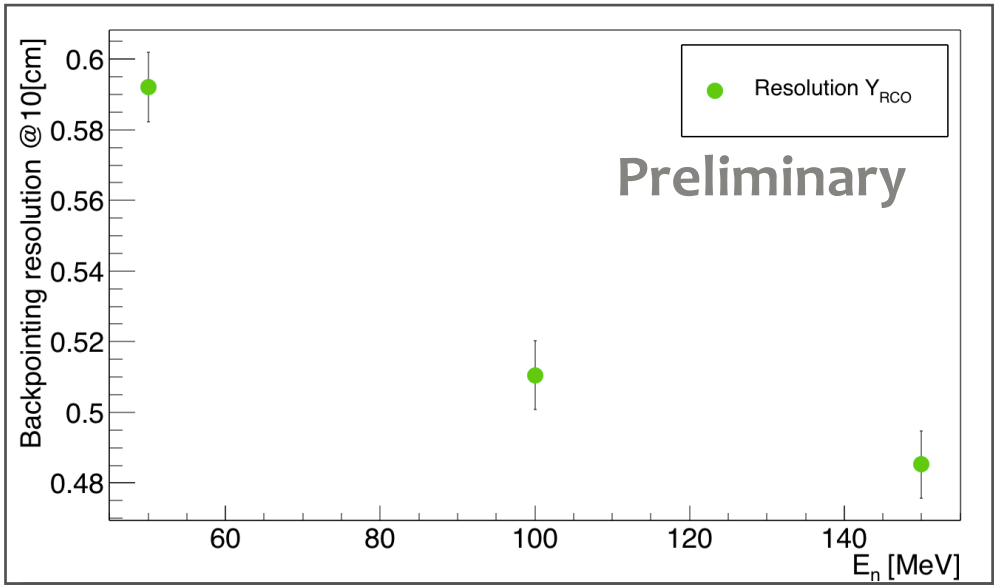
MONDO

Project main goals and results achieved in 2018

- Finalisation of the MC FLUKA code for the MONDO detector simulation. The electronic readout system (details on the pixel size, number of SPAD, trigger, dark count rate, efficiency, fill factor, …) has been integrated in the code.

- ☑ The performance of MONDO detector has been studied in terms of neutron reconstructed energy and back-pointing capability:



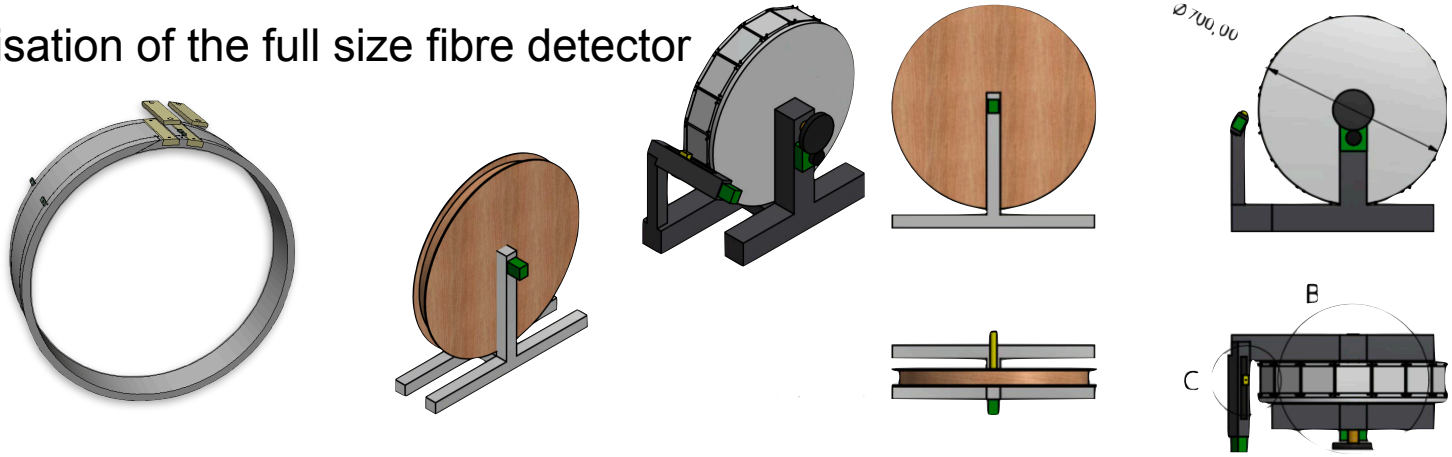


- The potentialities of MONDO exploited as prompt photon detector has been studied (detection via scattering Compton and pair production).

Project main goals and results achieved in 2018

- Milestone1. Realisation of the full size fibre detector

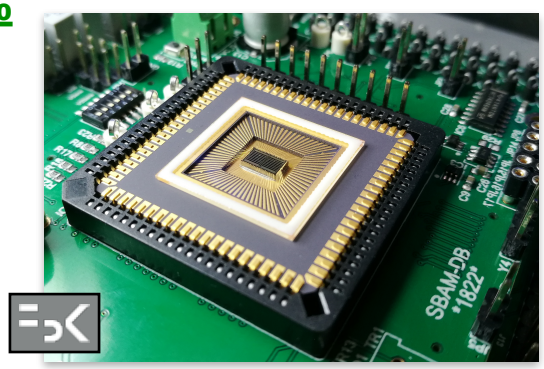
  30%



- Milestone 2.

  60%

  - **Realisation of the first SBAM sensor chip. 100%**
  - Realisation of prototype a sensor in a tile. 20%



- Milestone 3. Coupling between SBAM and fibres
  - Very Soon!I've got the chip yesterday!

- Milestone 4. Implementation of the optical readout system in the MC FLUKA simulation

  100%

MONDO

Scientific Publication for MONDO in 2018

V. Giacometti, *et al.*	*Characterisation of the MONDO detector response to neutrons by means of a FLUKA Monte Carlo simulation*	Radiation Measurements	2018	**119** 144-149	10.1016/j.radmeas.2018.10.006
R. Mirabelli, et al.	*The MONDO Detector Prototype Development and Test: Steps Toward an SPAD-CMOS-Based Integrated Readout (SBAM Sensor)*	IEEE Transactions on Nuclear Science	2018	**65** 2 744-751	10.1109/TNS.2017.2785768
I. Mattei, *et al.*	*Scintillating Fiber Devices for Particle Therapy Applications*	IEEE Transactions on Nuclear Science	2018	65 2054	10.1109/TNS.2018.2843179

Scientific products in 2018

• The FBK and CF developed in collaboration* (*Convenzione Quadro*) the SBAM sensor: the **first chip - SBAM_1 - has been produced at LFoundry** and tested at FBK for the preliminary checks.

* The **intellectual property of the sensor** is shared by the two parts.

MONDO

Conference for MONDO in 2018

R. Mirabelli *et al.*	*Particle Therapy secondary neutrons characterisation with the MONDO project*	IUPESM 2018 World Congress	2018	http://www.iupesm2018.org/
E.Gioscio et al.	*A new compact tracker for the ultrafast secondary neutrons produced in light ions therapy*	PM2018 14º Pisa Meeting on Advanced Detector	2018	https://agenda.infn.it/conferenceDisplay.py?ovw=True&confId=13450
I. Mattei *et al.*	*Neutron and charged particle trackers: application to PT*	2018 Symposium on Radiation Measurements and Applications	2018	http://rma-symposium.engin.umich.edu/
M. Fischetti *et al.*	*Characterisation of secondary neutron production in particle therapy treatment with the MONDO neutron tracking detector*	104° Congresso Nazionale della SIF	2018	https://www.sif.it/attivita/congresso/104
M. Fischetti *et al.*	*Characterisation of secondary neutron production in particle therapy treatment with the MONDO neutron tracking detector*	18° Convegno Nazionale della SIRR	2018	http://www.sirr2.it/sirr2018/

Poster for MONDO in 2018

R. Mirabelli *et al.*	*Poster: Particle Therapy secondary neutrons characterisation with the MONDO project*	NDRA 2018 - Summer School on Neutron Detectors	2018	https://webmagazine.unitn.it/evento/dii/30864/ndra-2018-summer-school-on-neutron-detectors
R. Mirabelli *et al.*	*Poster: The SBAM sensor for the MONDO experiment*	SQUAD 2017 - Advanced School in Quantum Detector	2018	https://webmagazine.unitn.it/evento/dii/21705/squad-2017-advanced-school-on-quantum-detectors

Milestones 2019

- Realisation of the tracker with layers x-y oriented of scintillating fibres.
- Evaluation of the detector performance with inelastic scattering events (intrinsic background)
- Implementation of the SBAM sensor in a Tile-based prototype
- Development of a track reconstruction system

MONDO

Plan of activities 2019 – 2021

- Tracker with 200 and 250 μm scintillating fibres
- Integration of the fibre structure with SBAM
- SBAM sensors on Tile structure
- Reconstruction software (3D)
- Calibration measurements: characterisation of the detector with protons and neutrons
- Measurements of (secondary) neutrons production

(Potential) external funding

- **SPARE** (Space Radiation Shielding) project has been funded (**Premiale 2016** INFN + CF+ASI) and the MONDO detector will be employed for space radio-protection applications;
- **eGIOVE**: Enhancing Gamma Interactions for Online VErification - **PRIN 2017 Under40.** It has been submitted with CF as RU to study the monitoring in PT exploiting Oxygen and Fluorine prompt gamma production;

MONDO

Expected funding in the 3-year period:

- **Request of funding by Centro Fermi**

- Beside the already allocated funding of MONDO (SIR) and SPARE (PREMIALE) no other request will be addressed to CF