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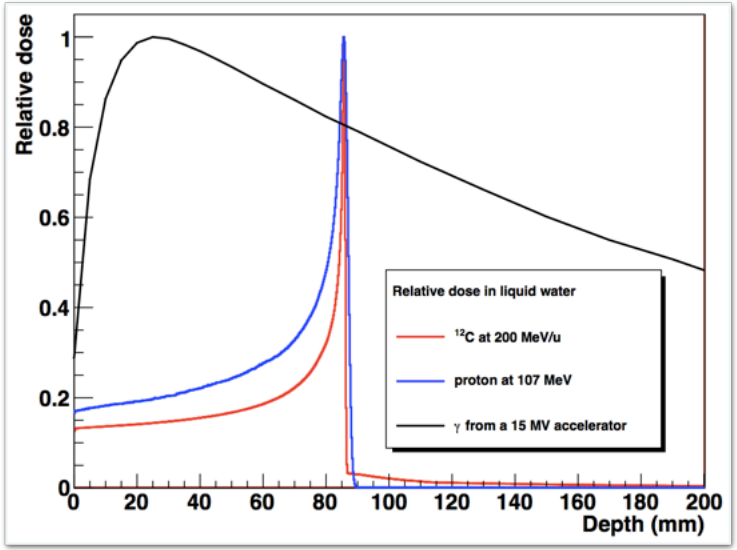
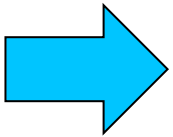
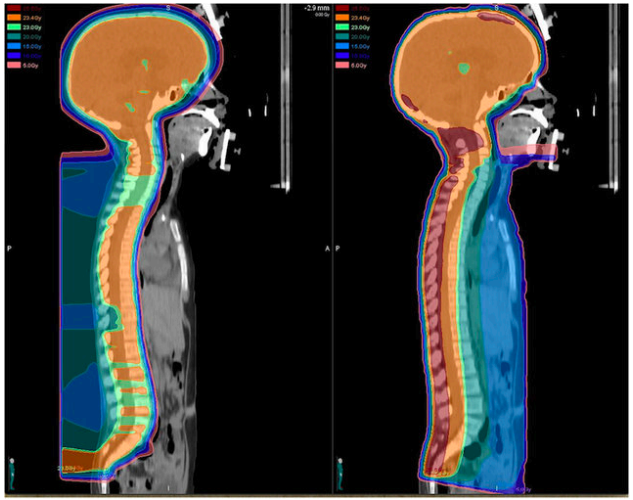
Fisica Nucleare Applicata alla Terapia Medica

Retreat di Fisica delle Particelle Elementari

A very short introduction to Particle Therapy







Dose distributions for a proton (left) and photon (right) craniospinal plan prescribed to 23.4 Gy (relative biological equivalents)

… Last but not least..
RBE! (you can achieve the same damage with less dose using heavily ionising particles → interest for ^{12}C)

Why are we still debating about PT & RT?

PTCOG 2018
[still being debated in 2019]

Friday, May 25, 2018	Title
08.00-08.30	Clinics Slam: Protons There or Photons Here

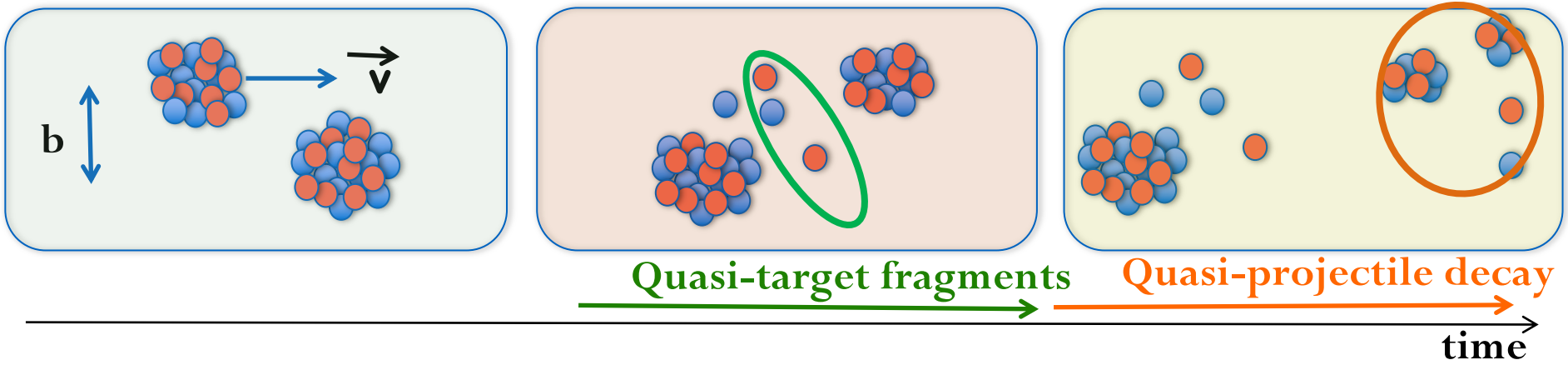
When comparing with RT (photons) you really need to prove that you have ‘everything under control’ to gain the Oncologists/Medical Physicists trust (PT is born ~ 1950.. Protons have been added to the LEA in Italy in 09/2016)

The challenges wrt conventional Radio Therapy:

- Plan the treatment
- Accelerate/deliver the particles
- Control the beam ‘online’

Both topics, covered hereafter, are deeply related to nuclear physics

Nuclear interactions & applications to Particle Therapy

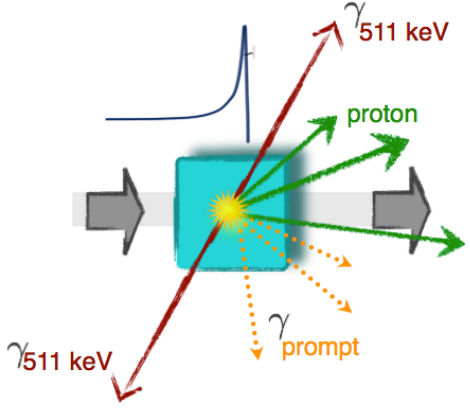


Nuclear fragmentation/interactions occurring in the energy range between tens and hundreds of MeV/u [E.g. 10 - 400] is what we have to better understand to improve…

A. .. treatment planning: Better understanding of the interactions, Study of the fragmentation (projectile and target), damage prediction

B. .. treatment monitoring: 'online' control of the delivered dose

Many different particles are 'around' depending on the beam energy, projectile, target density… Whether it ends up in A or B depends if the particles exits or not

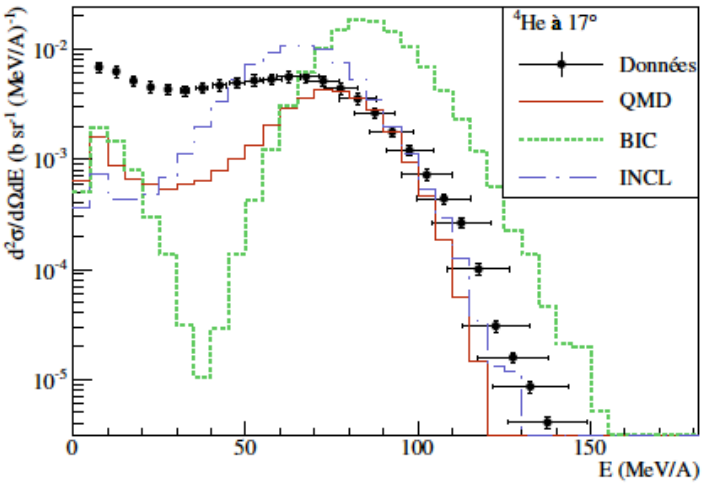


Treatment planning

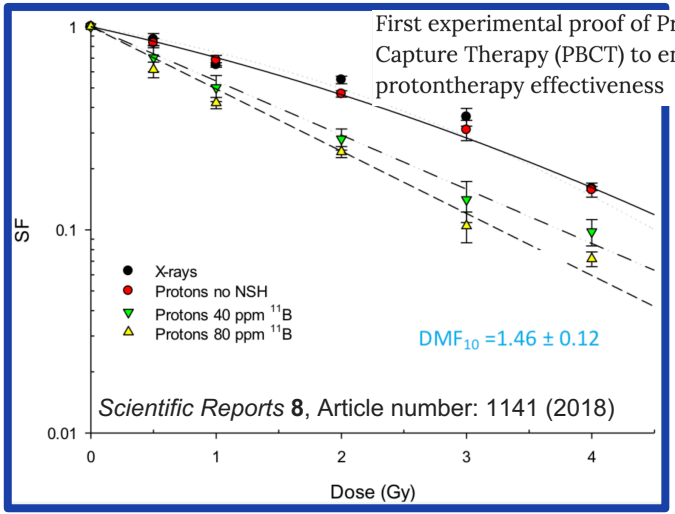
Everything boils down to improving the MC.. (and convince people to use it!) But it's not an easy task at all… need to implement tools that provide a % accuracy [and calibrate it against high precision measurements]!

Different paths can be traveled towards the aforementioned goal..

- **Lack of experimental data → measure Xsections (e.g. FOOT)**
- **Improve planning software –> Quest for improved MC tools (Geniale)**
- **Allow full MC use in clinical routine → Go for fast (GPU-based) MC implementations (FRED)**
- **Understanding what's behind PT → Production of high LET particles (NEPTUNE), explore other ways for local 'beam activation' (^{19}F)**

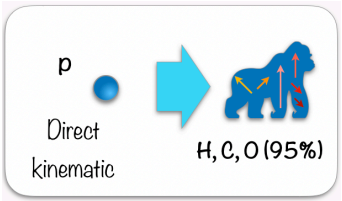


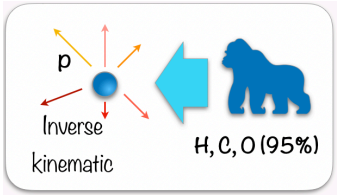
(b) ^{4}He à 17°



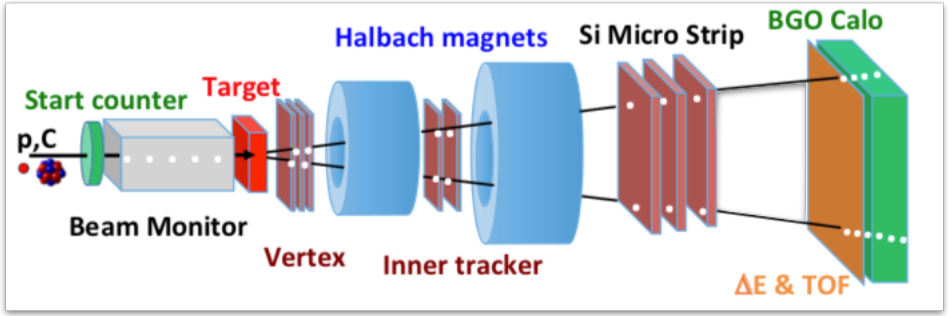
Experimental effort: FOOT

In proton therapy → only target fragmentation
SO FAR NOT ACCOUNTED! (even worse.. Treating O(10^{4-5}) patients still with analytical models)
Fragments have small range/high LET can contribute significantly to **dose outside TGT volume**

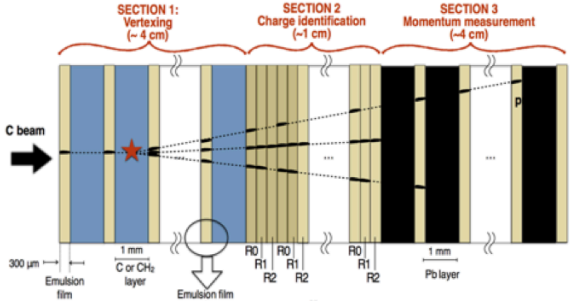




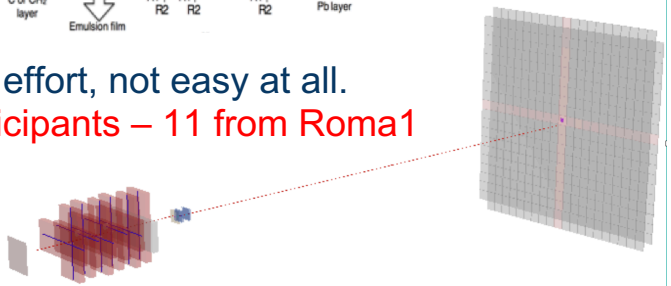
Inverse kinematics
+



Fragment	E (MeV)	LET (keV/μm)	Range (μm)
^{15}O	1.0	983	2.3
^{15}N	1.0	925	2.5
^{14}N	2.0	1137	3.6
^{13}C	3.0	951	5.4
^{12}C	3.8	912	6.2
^{11}C	4.6	878	7.0
^{10}B	5.4	643	9.9
^{8}Be	6.4	400	15.7
^{6}Li	6.8	215	26.7
^{4}He	6.0	77	48.5
^{3}He	4.7	89	38.8
^{2}H	2.5	14	68.9



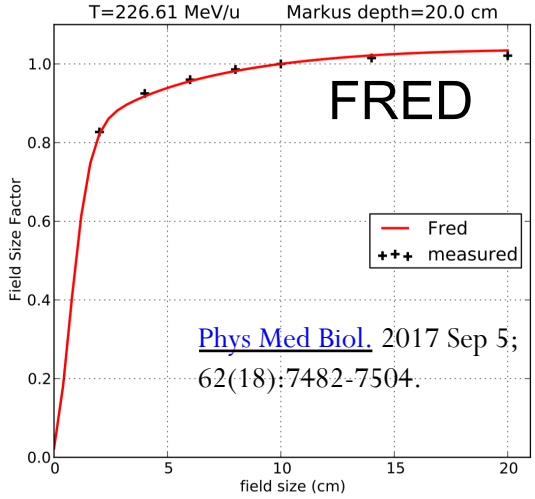
Exp effort, not easy at all.
100 participants – 11 from Roma1



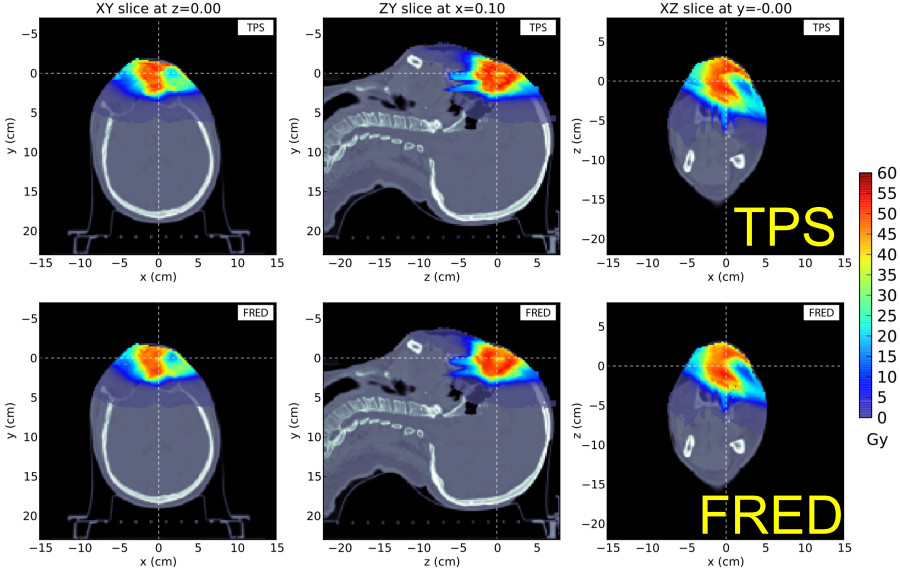
Took first data in 04/2019

Software effort: MC

- Improving the software tools. Ex: improving Geant4 implementing one [data driven] of the following models: Boltzmann-Uehling-Uhlenbeck (BUU); Boltzmann-Langevin (BL) or Antisymmetrized Molecular Dynamics (AMD). **GeNIALE**
- Improving the timing: accurate (MC based) tools take hours for each treatment optimization→ Lots of treatment centres are still using analytical models for this task



protons

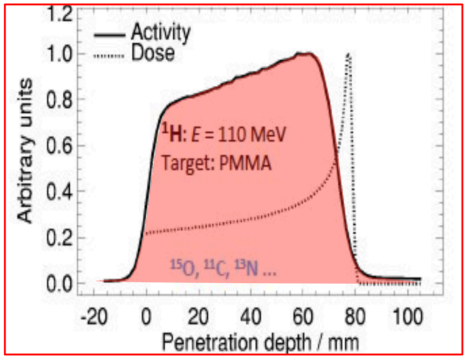


Using FRED: a typical proton run of about 72 h/core (Mairani et al 2013) can now be delivered in less than 2 min on a GPU-fitted workstation.

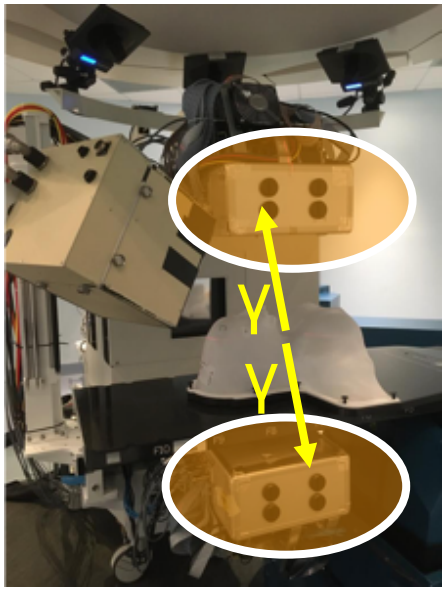
- Model under constant development (need to implement particles production cross sections: ions, electrons, photons…)

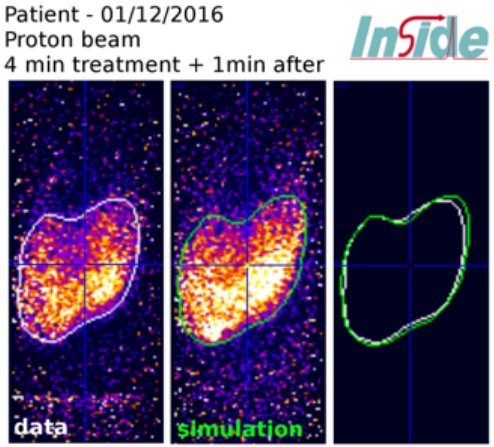
Treatment monitoring

- Awaited since the birth of PT, **still lacking a solution that fulfils the requirements posed by the clinical implementation**.
- Several solutions are being explored.. related to production of secondary particles:
  - γ (prompt || β^+): INSIDE, PAPRICA
  - Charged fragments / Neutrons: next slides



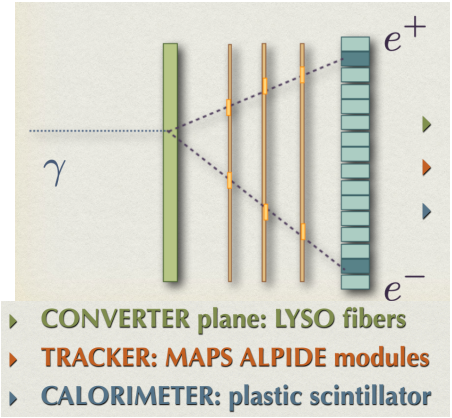
γ 511 keV
in-beam PET

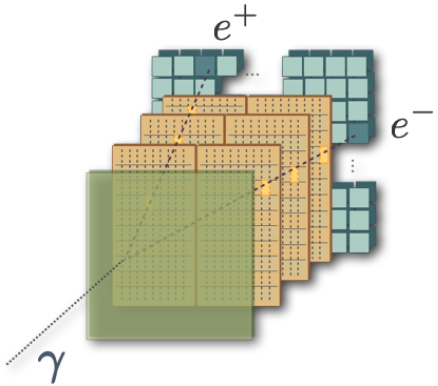




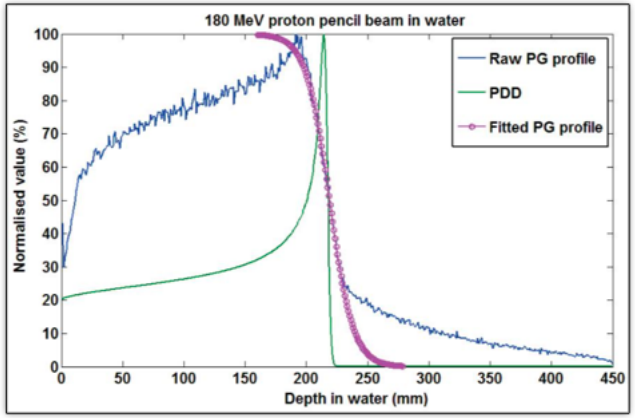
Treatment monitoring

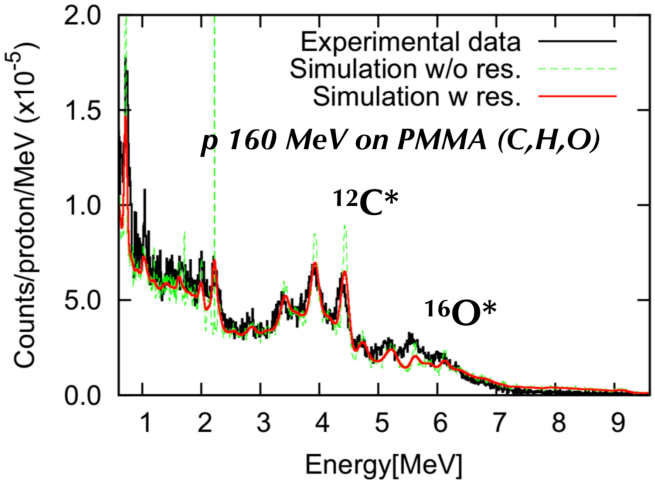
- Prompt photons from nuclear de-excitation can be used as beam range probes as well
- So far, technical proposed solutions were Compton cameras or pixelated readout + collimators.. R&D is still ongoing..
- Tried a different approach: **detect the photons via pair production**.. At the energies of interest for PT applications, detecting pairs is a real challenge (nucleus recoil sets an intrinsic limit on the backtracking precision)





Aim to reach precision *O*(mm) with treatment statistics

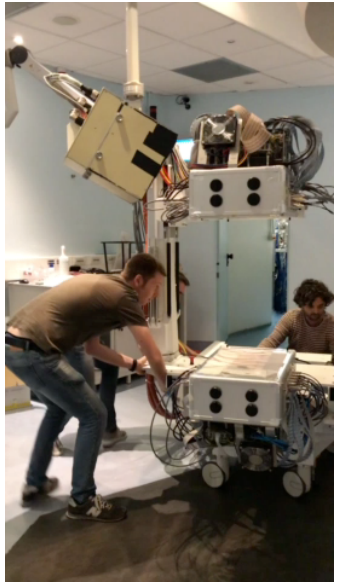


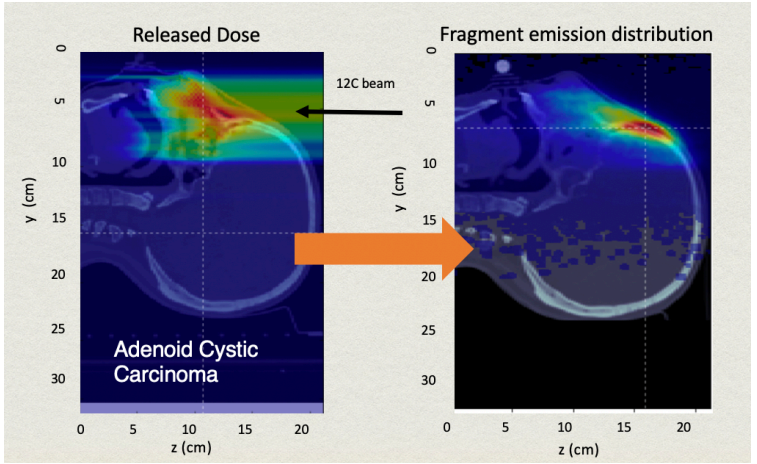


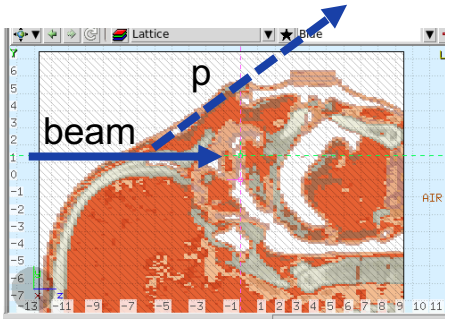
G. Battistoni *et al* 2013, doi: 10.3389/fonc.2016.00116

Dose Profiler

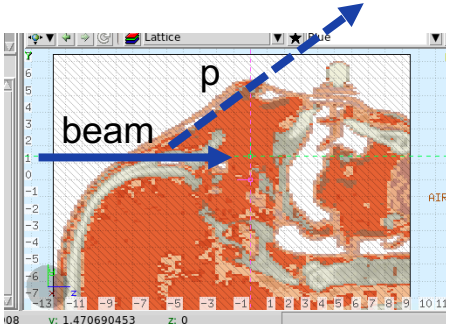
- Built in 2017: **going to take data on patients starting from mid July**!
- Exploits production of secondary charged fragments (mainly protons)
- 8 x-y planes of fibre tracker read by SiPMs



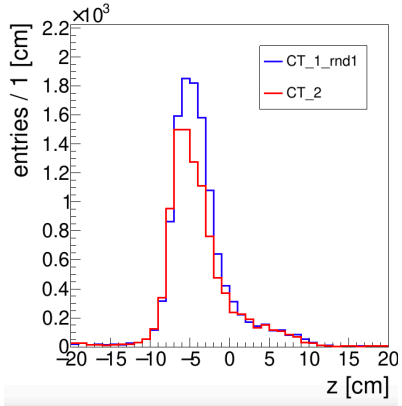


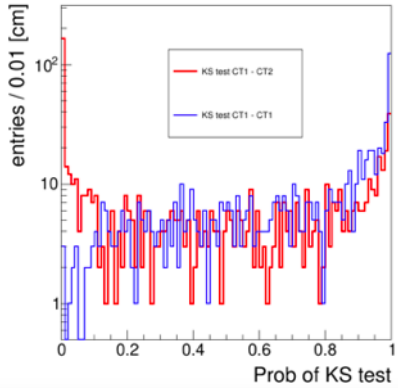


CT1



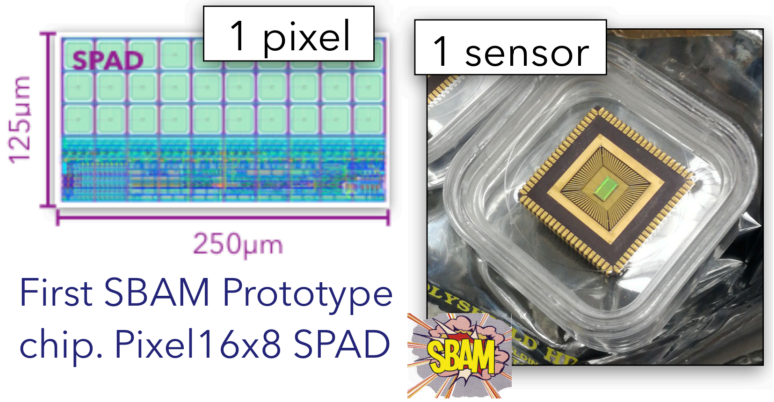
CT2 – after 3 weeks



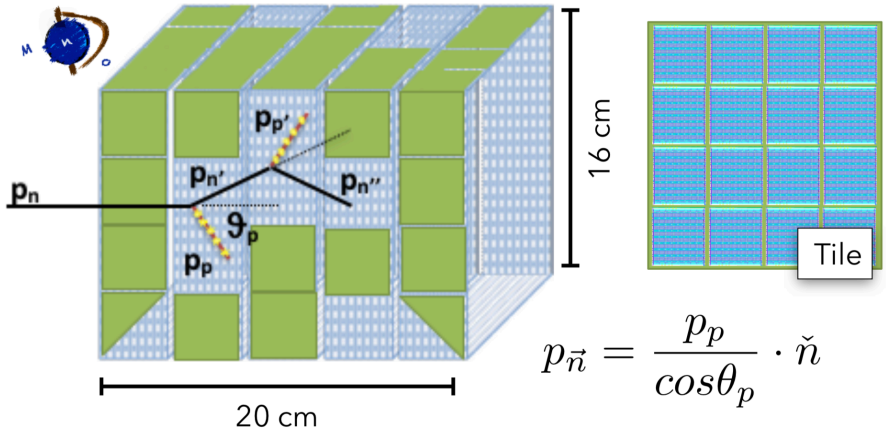


Mondo

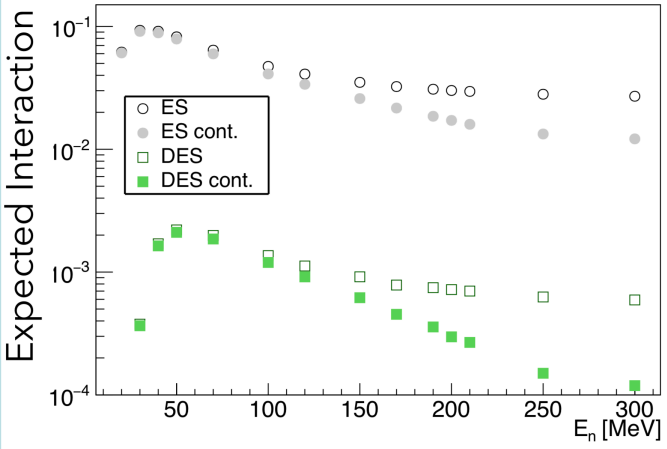
- Neutrons play a crucial role in 'releasing dose far away from the target region' → risk of Secondary Malignant Neoplasms. A neutron tracker is needed.
- @ PT energies: scintillating fibers neutron tracker
- Technological challenge: a pixelated readout, capable of Single photon detection, over a large area is needed (synergy with FBK → implementation of array of SPADs)



First SBAM Prototype chip. Pixel16x8 SPAD



$$p_{\vec{n}} = \frac{p_p}{cos\theta_p} \cdot \check{n}$$

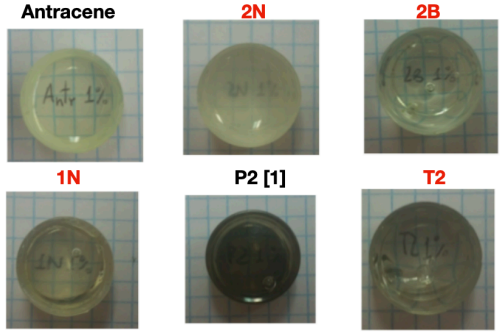


Competences

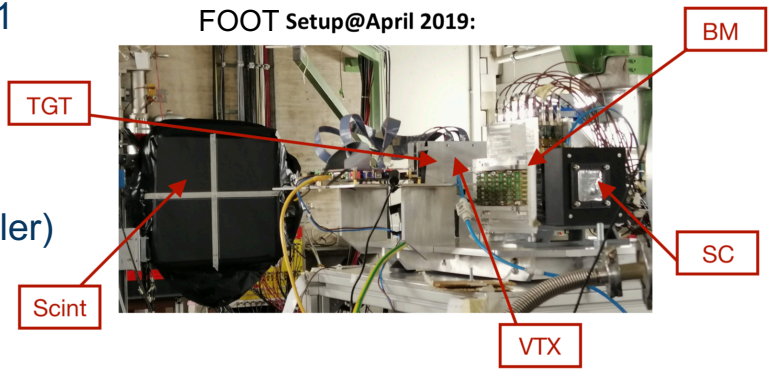
http://arpg-serv.ing2.uniroma1.it

A. Ciardiello, F. Collamati, M. De Simoni, R. Faccini, M. Fischetti, M. Magi, C. Mancini Terracciano, M. Marafini, R. Mirabelli, S. Morganti, V. Patera, A. Sarti, A. Schiavi, A. Sciubba, E. Solfaroli Camillocci, G. Traini, C. Voena

- Group across 2 departments: Fisica + Scienze di Base applicate per l'ingegneria
- HW
  - Detector development:
    - Scintillators (Margarita, + synergy with chem. section for new scintillators! + pterf → next talk)
    - Fibres (Dose Profiler, MONDO) and related DAQ
    - Calorimetry (NaI, BGO, LYSO)
    - Gas trackers (DCH Beam monitor chamber)
    - ALPIDE pixel detectors (Paprica)
  - DAQ
  - Sinergy with mechanical workshop @ SBAI, Roma1 and LNF electronic service
- SW
  - Simulation (Fluka) GPU-based MC (FRED)
  - DAQ: VME, VHDL FPGA programming (DoseProfiler)
  - Data Analysis



FOOT Setup@April 2019:



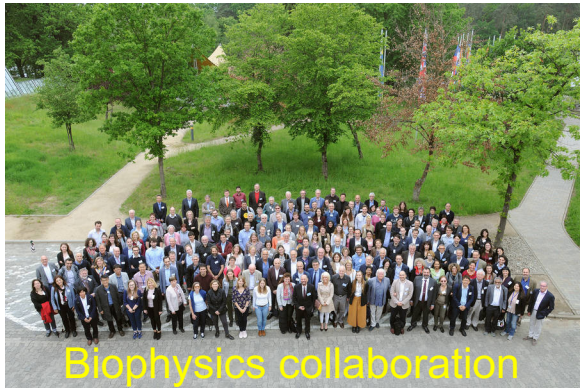
Outlook

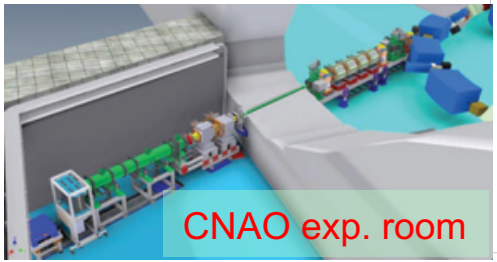
Interest in PT (number of treatment centres) is steadily growing: we are still far from getting the best out of the therapy and to transfer it to the clinical routine

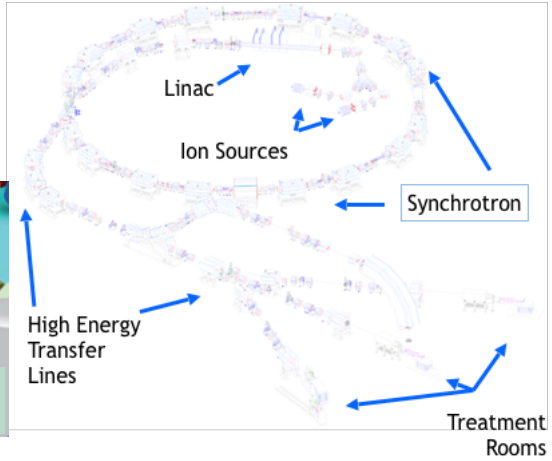
- Opportunity @FAIR just opened: Radio Protection Space + intensity frontier
- European interest is high in the field. An international network has been established → Last may: newborn BioPhysics collaboration (V. Patera spokesman)
- CNAO delivered his first beam to the newly crafted experimental room (may 2019 was an except. month)

Next years will be exciting

- MONDO will become operative: first opportunity to track neutrons/play with the sensor
- Clinical trial will say a final word on the online monitoring feasibility via charged fragments detection (Dose Profiler)
- FOOT/Paprica will take data..


Biophysics collaboration

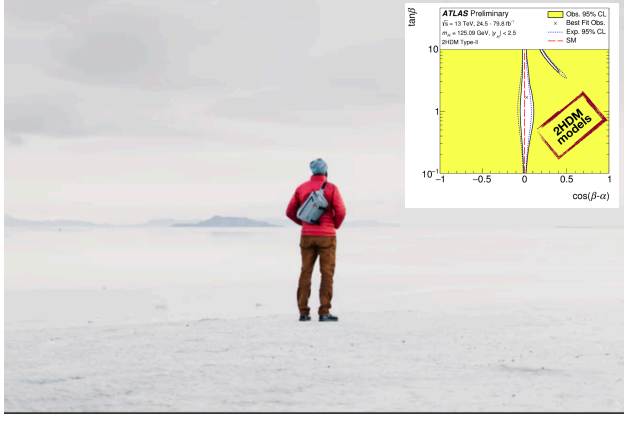

CNAO exp. room



Conclusions

- Talking to you.. My dear ATLAS, CMS or Dark-Whatever friend..

Tired of this?



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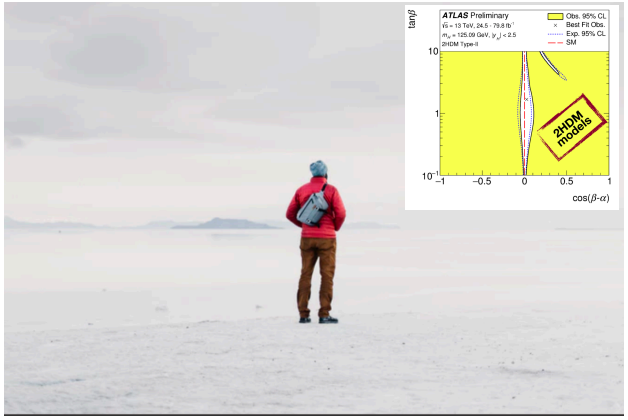

Come and play with us!

Go Applied! It will be fun!

Conclusions

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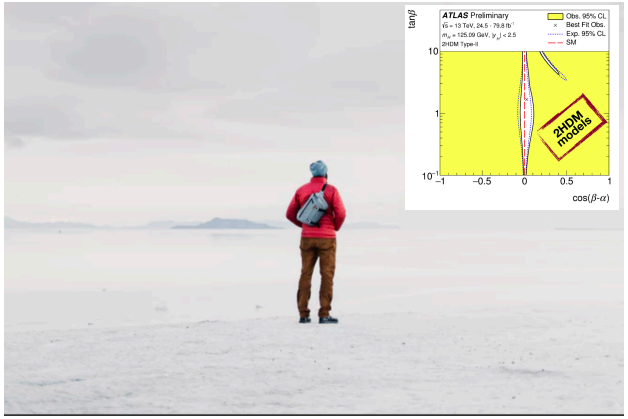

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