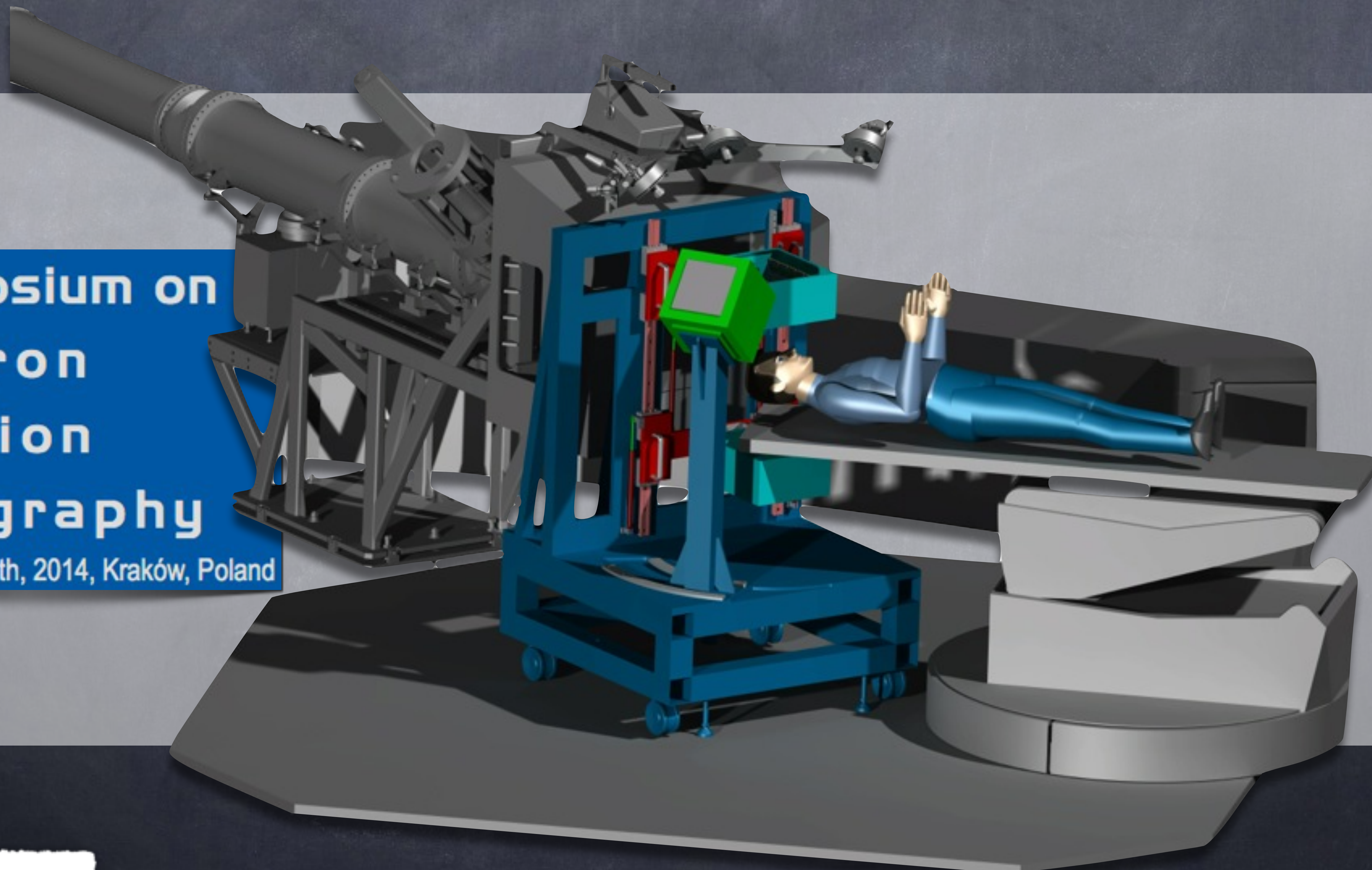
INSIDE Project

Michela Marafini on behalf of the INSIDE Collaboration



II Symposium on
Positron
Emission
Tomography
September 21st - 24th, 2014, Kraków, Poland

INSIDE

PRIN MIUR 2010-2011 -2010P98A75

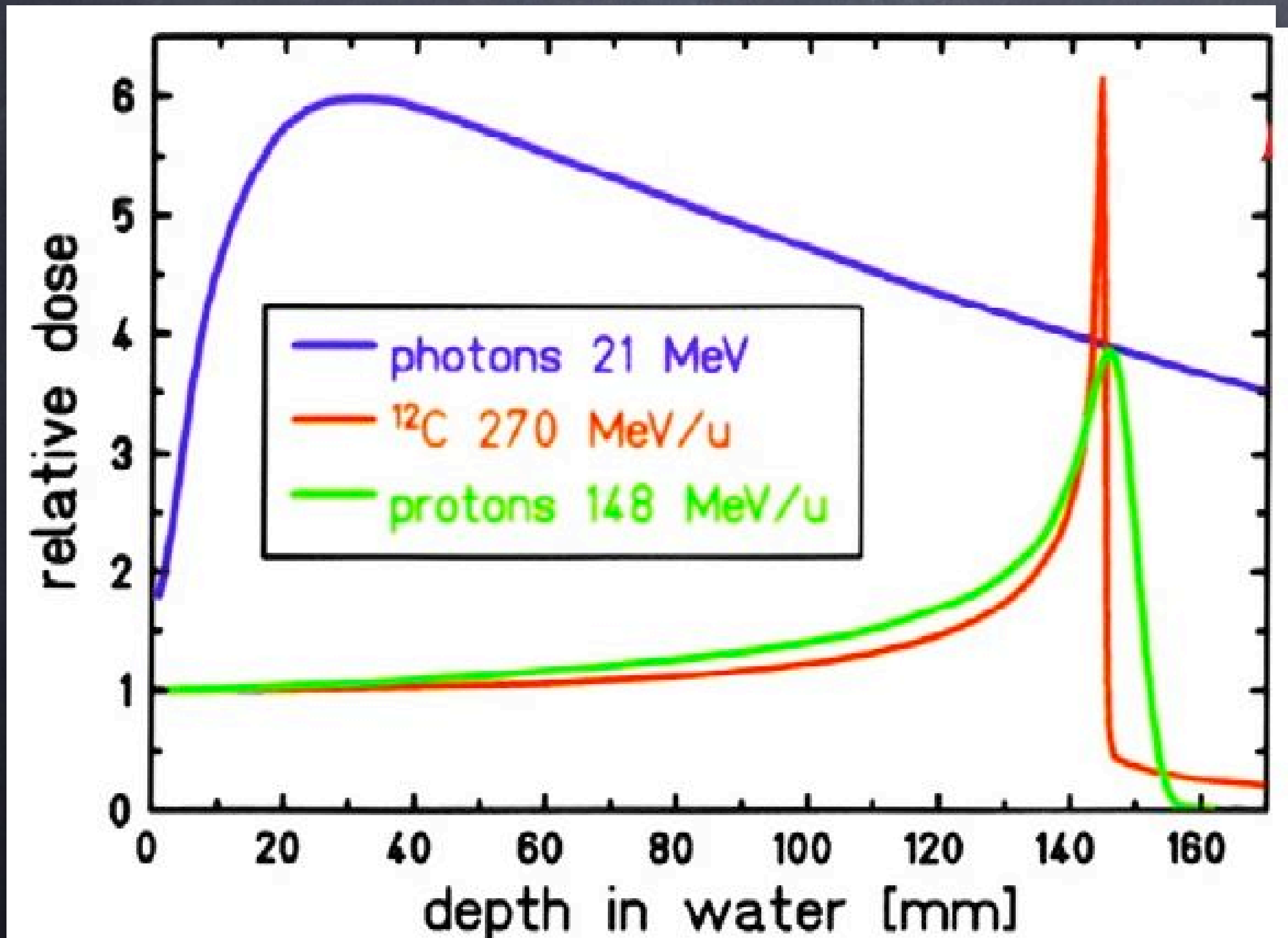
INFN RDH project

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

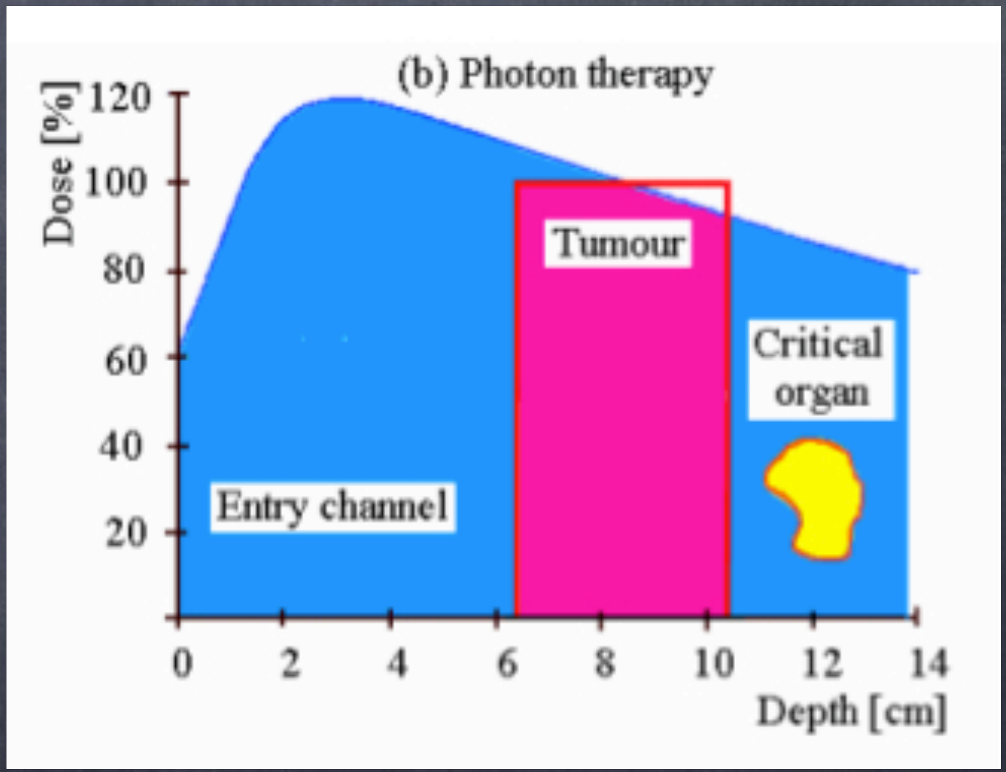
Centro Fermi project

PARTICLE THERAPY

The dose delivered by hadrons in materials fallows the Bragg Peak distribution => PT is particularly suitable for deep and localized tumors.

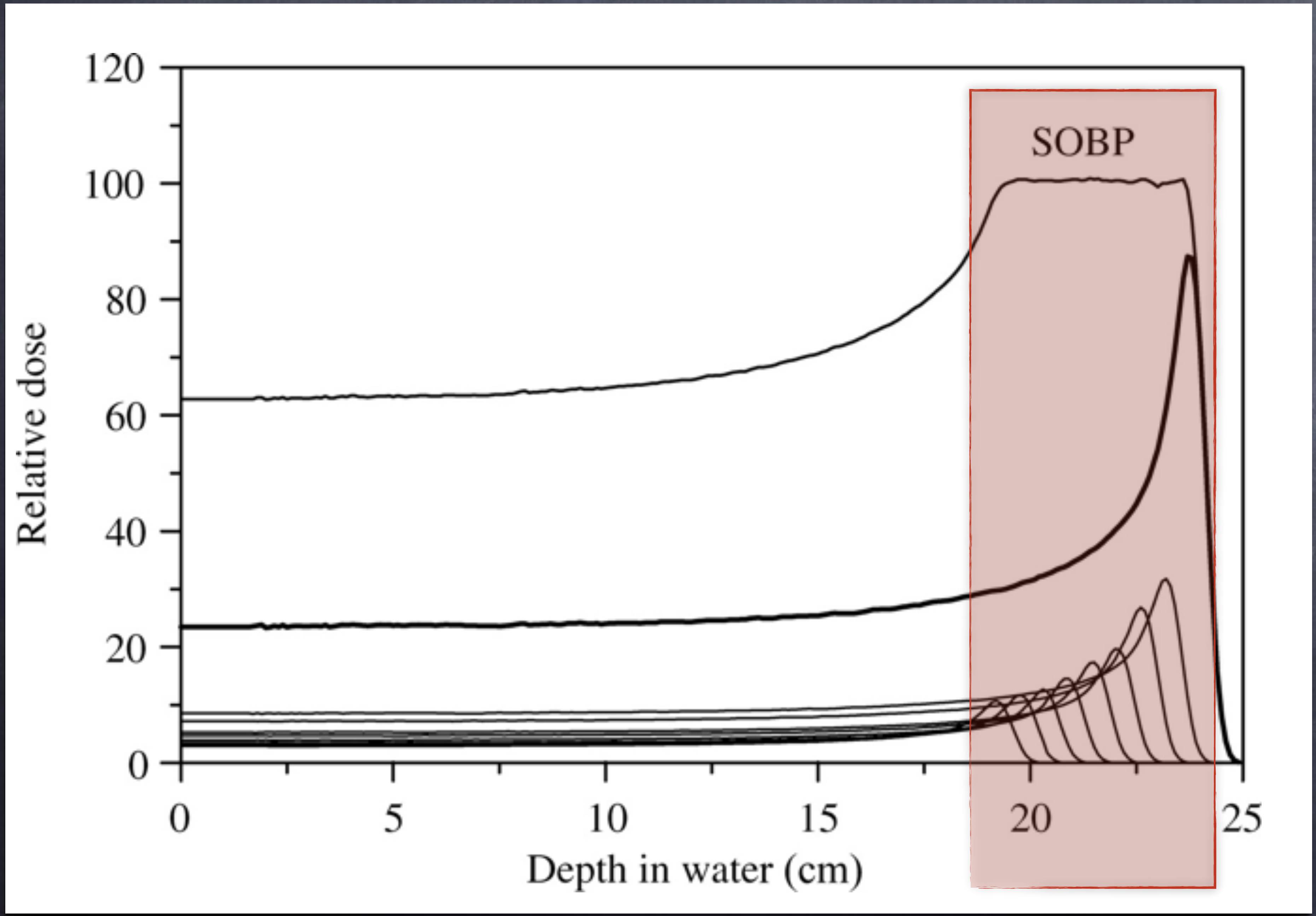


Standar therapy



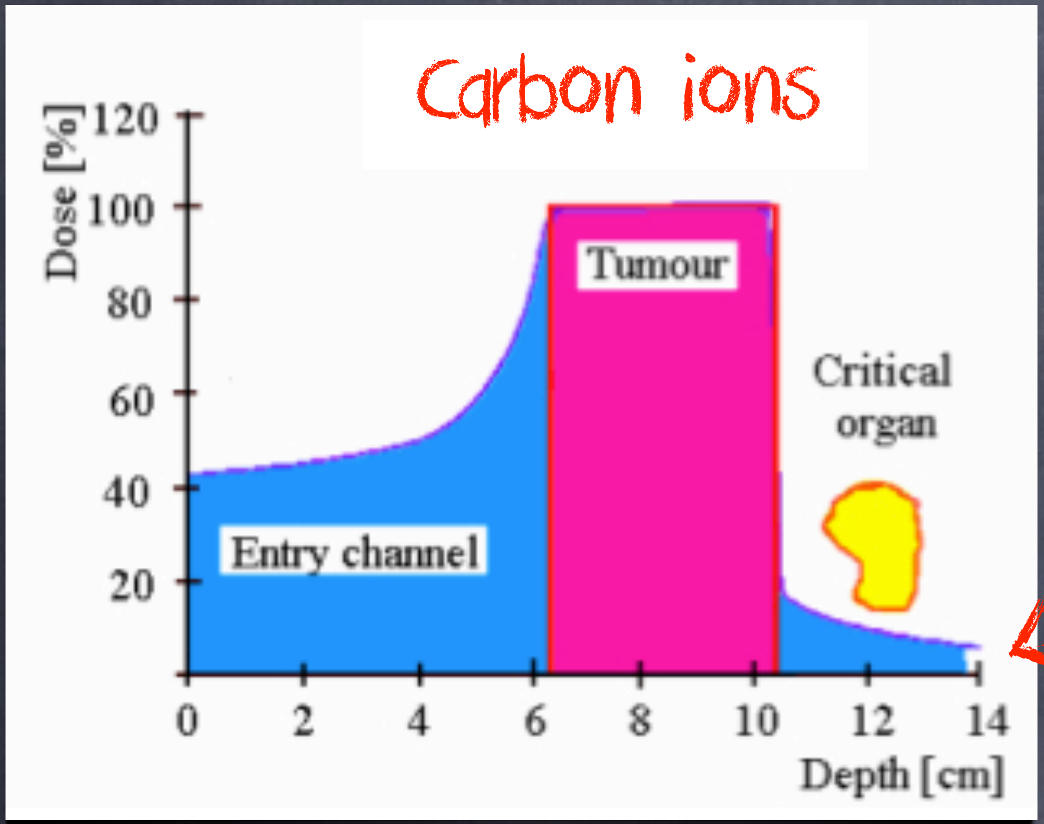
PARTICLE THERAPY

Several pencil beams can be combined in order to "shape" the maximum dose release region.



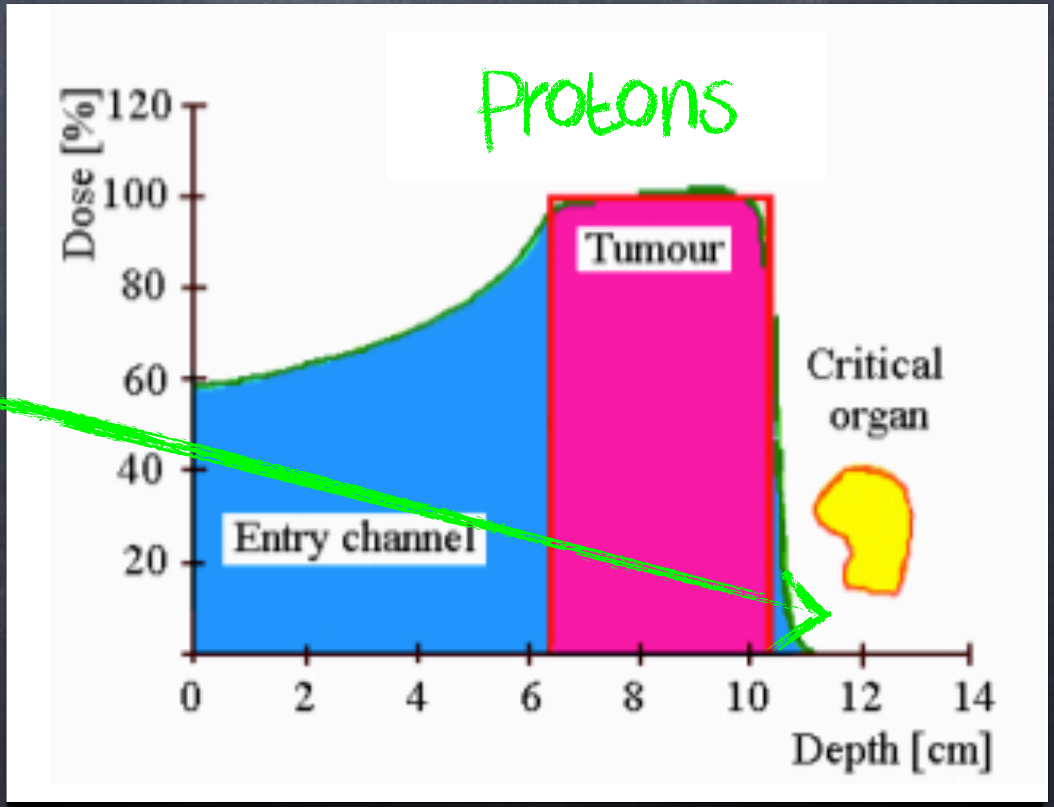
Spread-out-Bragg Peak

PARTICLE THERAPY



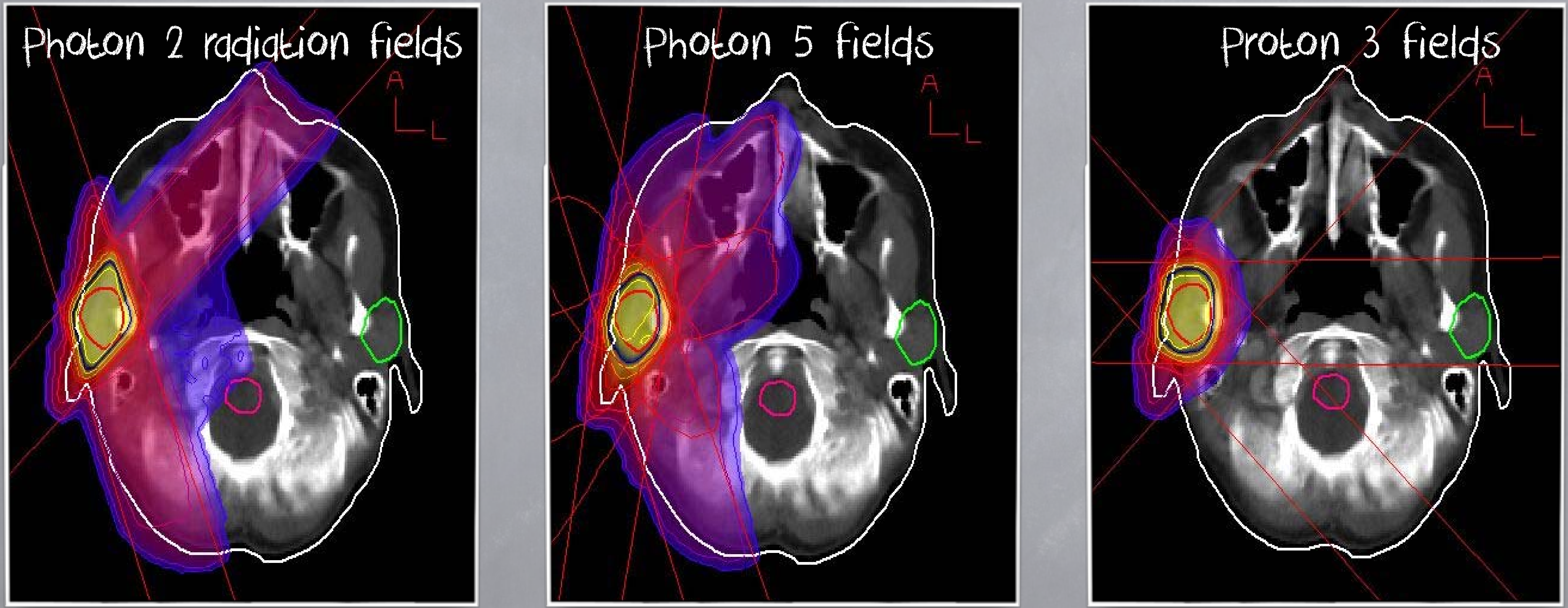
- Reduced Multiple Scattering
- More affected by fragmentation

- Reduced fragmentation
- More affected by Multiple Scattering



PARTICLE THERAPY

The combination of many radiation fields allows improving the performances for loco-regional tumors. The combination of few proton beams is extremely powerful in preserving the healthy tissues.



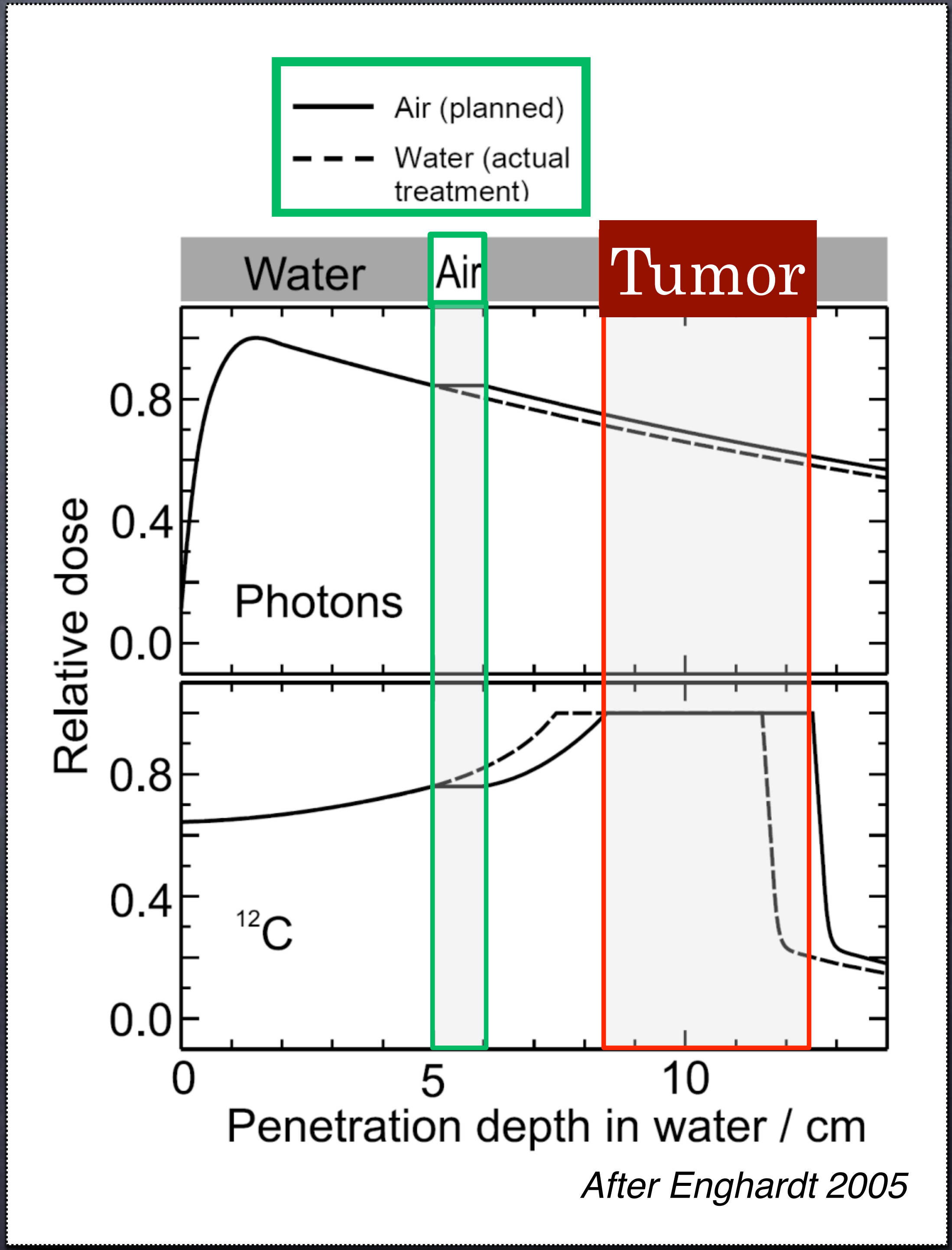
Universitätsklinik für Strahlentherapie und Strahlenbiologie, AKH, Wien

This dose distribution allows to irradiate the cancer reducing the damages for the surrounding volumes

PARTICLE THERAPY

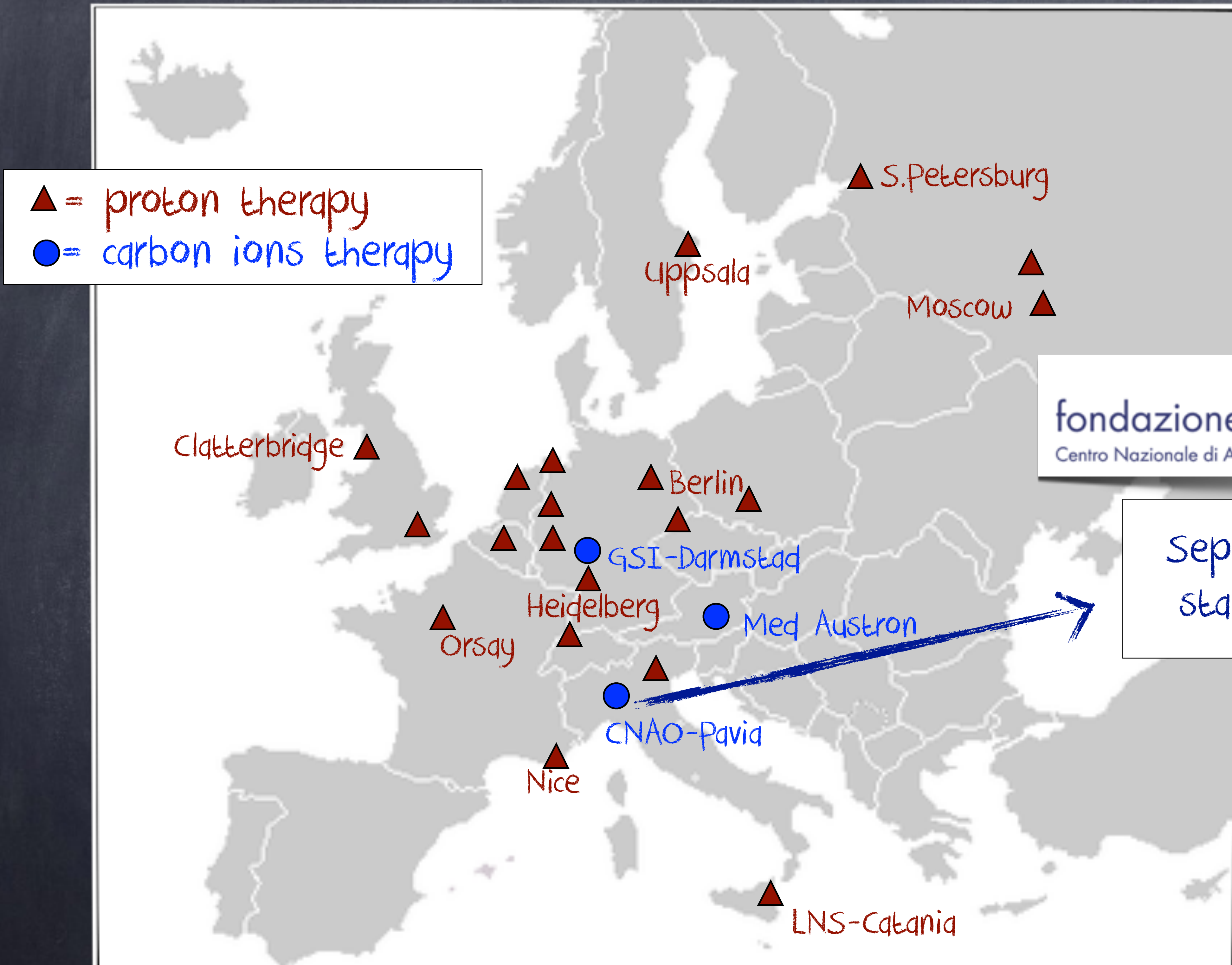
TREATMENT UNCERTAINTIES IN ION BEAM THERAPY

- TPS dose calculation errors
  - Inhomogeneities, metallic implants
  - Conversion HU ion range
  - CT artifacts
- Difference TP/ delivery
  - Daily setup variation
  - Internal organ motion
  - Anatomical/physiological changes
- Daily practice of compromising dose conformity for safe delivery



Courtesy of K.Parodi

Particle Therapy in EUROPE



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

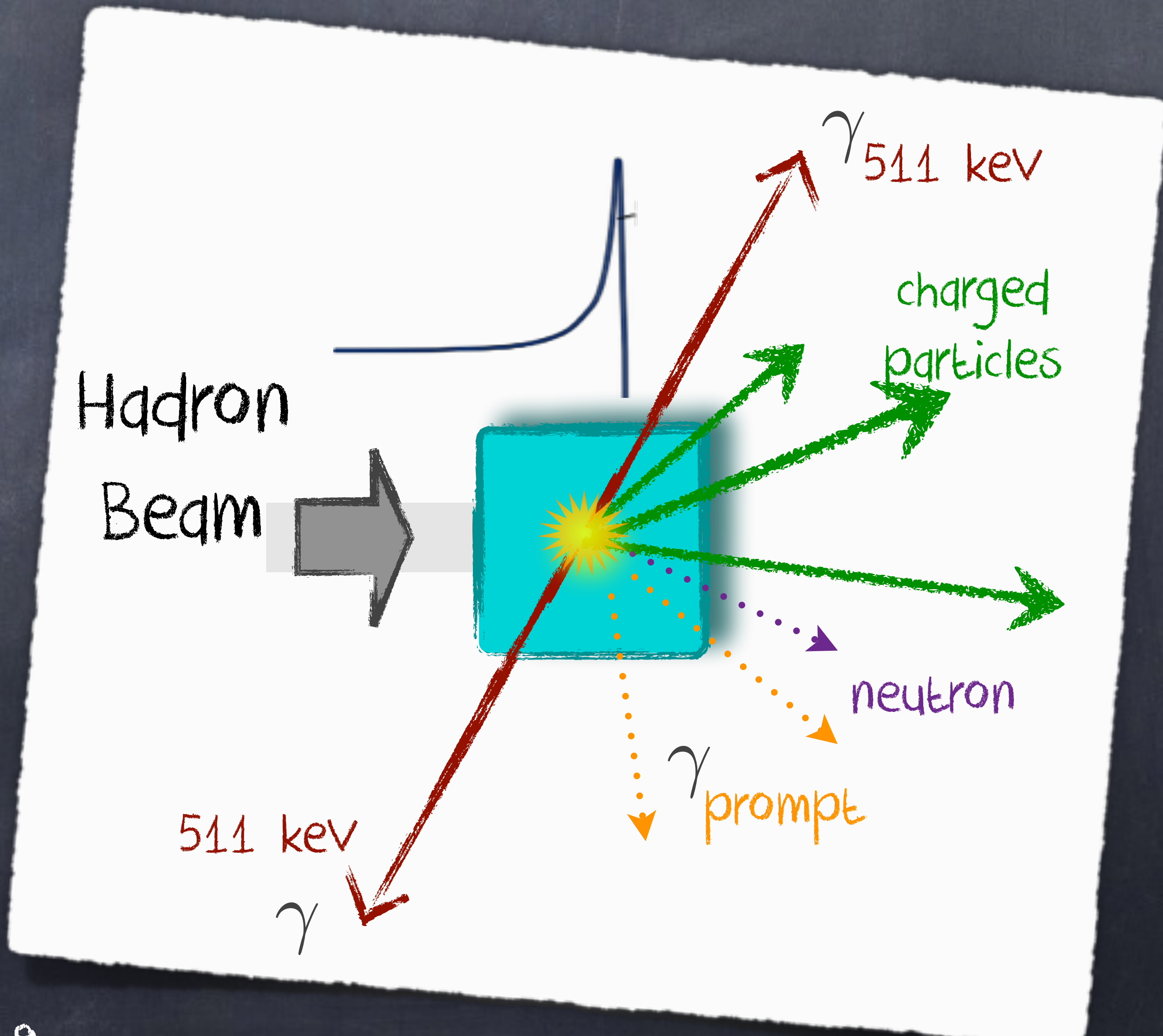
September 22nd 2011 start clinical activity.

PARTICLE THERAPY ⇨ MONITORING

In conventional RT (i.e. with photons), the beam crosses the patient body and can be used for monitoring. In PT the beam is absorbed inside the patient.

An ideal PT monitor device should:

- Check shape (compulsory) and absolute value (desirable);
- Exploit as signal the secondary particles, generated by the beam, coming out from the patient, dealing with the background of the other secondaries;

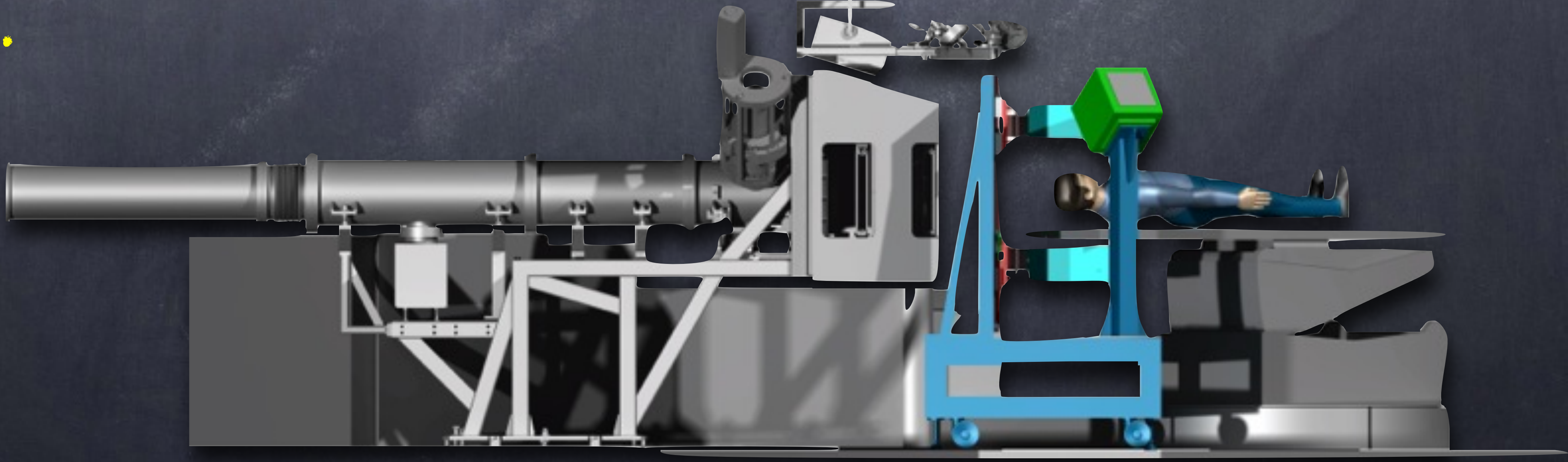


PARTICLE THERAPY ⇨ MONITORING

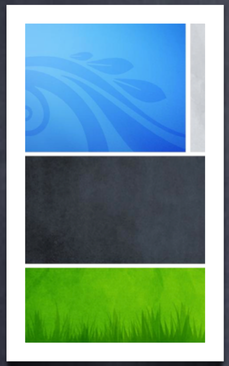
In conventional RT (i.e. with photons), the beam crosses the patient body and can be used for monitoring. In PT the beam is absorbed inside the patient.

An ideal PT monitor device should:

- Measurements and feed-back should be provided during the treatment (in-beam). Best, in active system, if the monitor can follow "on line" the irradiation scan (!)
- Must be integrated in the treatment environment and work-flow: nozzle, couch, positioning system, controls...

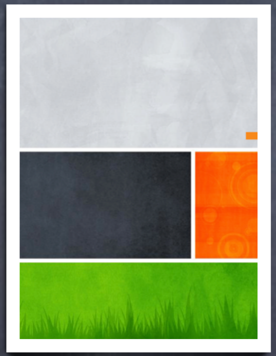


INSIDE



PET HEADS

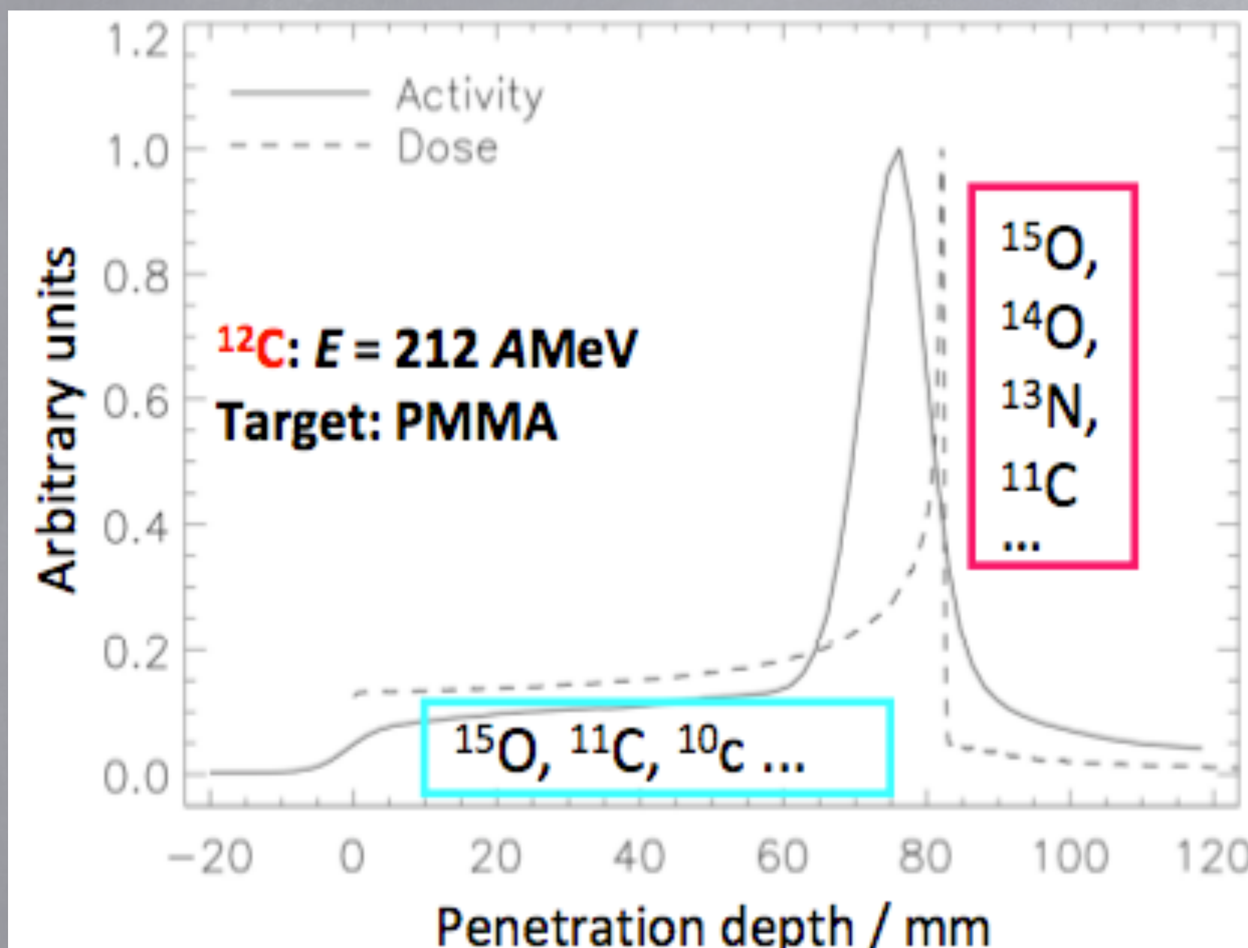
DOSE PROFILER

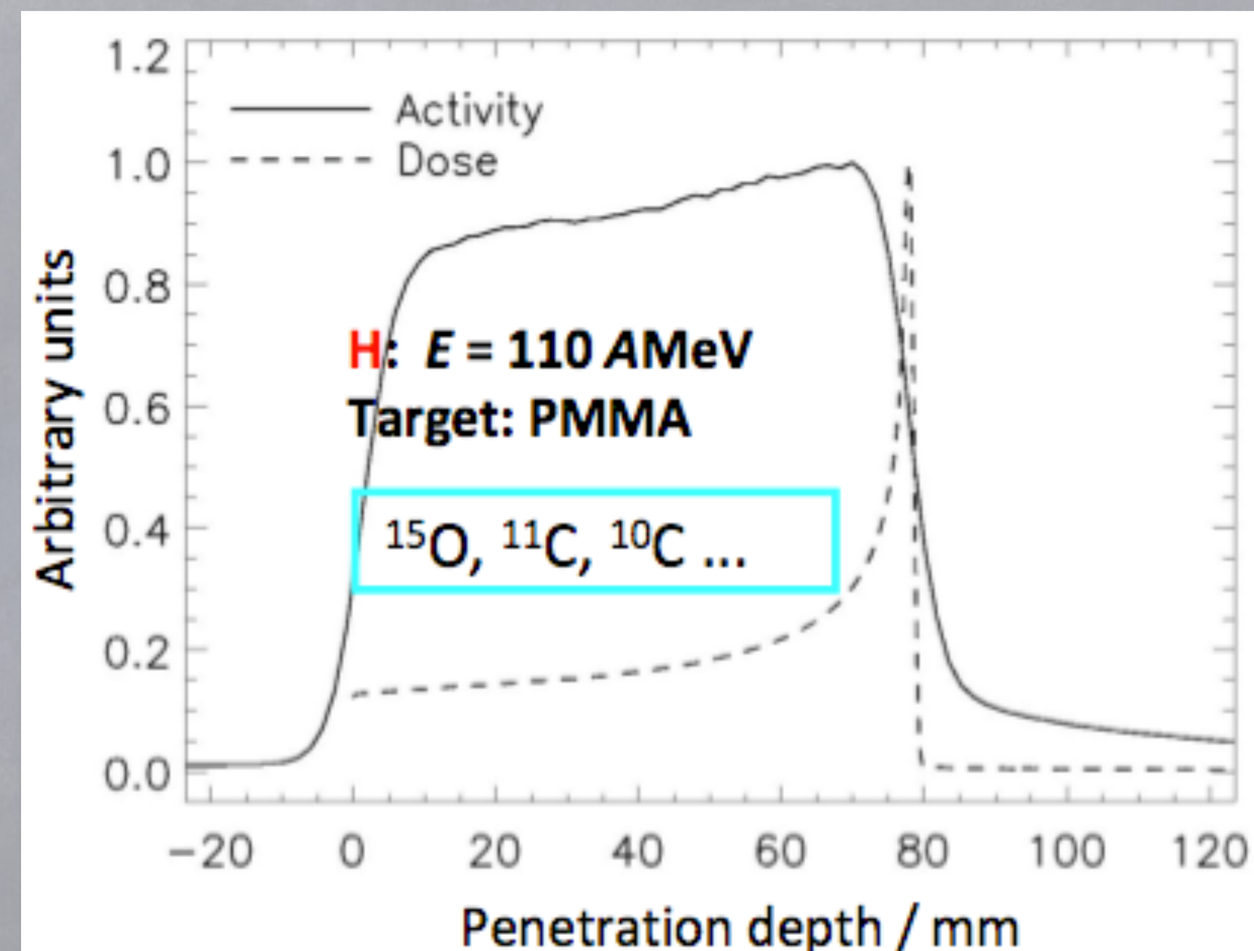


Exploiting beta+ and charged secondary particles emitted during the treatments we want to monitor ONLINE:

- the dose released on the patient ;
- the beam positioning;

PET HEADS

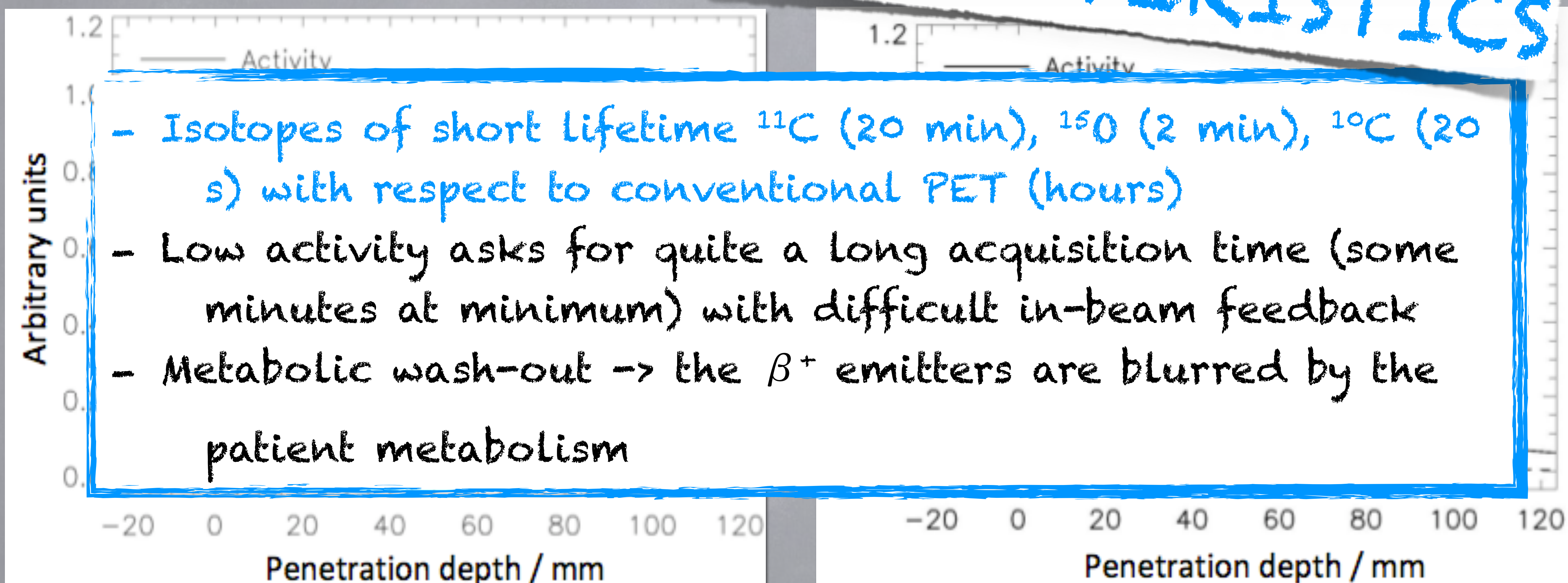




- The beta+ activity emission shape is correlated with the Bragg Peak position for hadron beams;

PET HEADS

CHARACTERISTICS

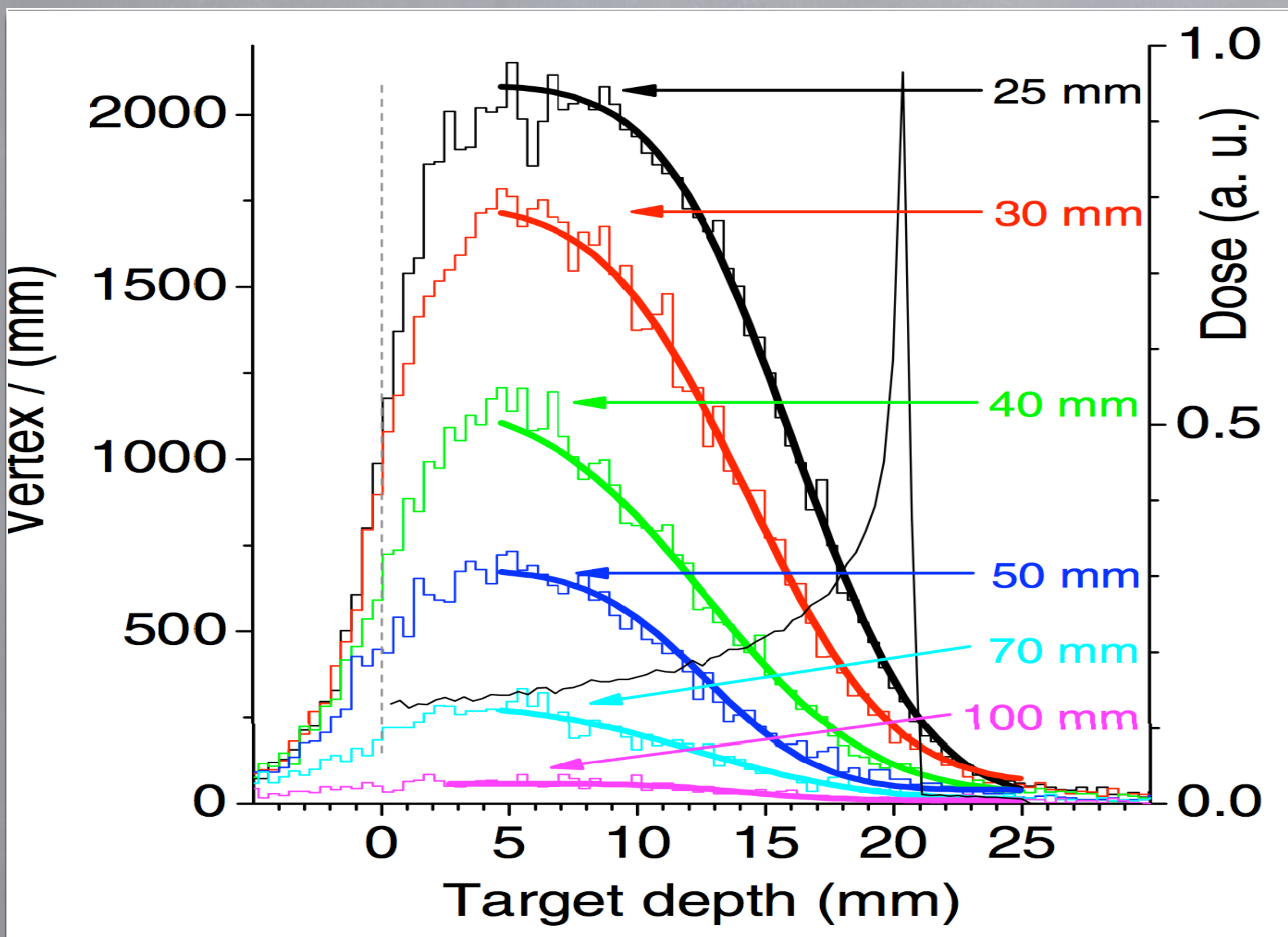


- Isotopes of short lifetime ^{11}C (20 min), ^{15}O (2 min), ^{10}C (20 s) with respect to conventional PET (hours)
- Low activity asks for quite a long acquisition time (some minutes at minimum) with difficult in-beam feedback
- Metabolic wash-out -> the β^+ emitters are blurred by the patient metabolism

- The beta+ activity emission shape is correlated with the Bragg Peak position for hadron beams;

DOSE PROFILER

Trained Geant4 MC E. Testa et al Phys. Med. Biol. 57 4655

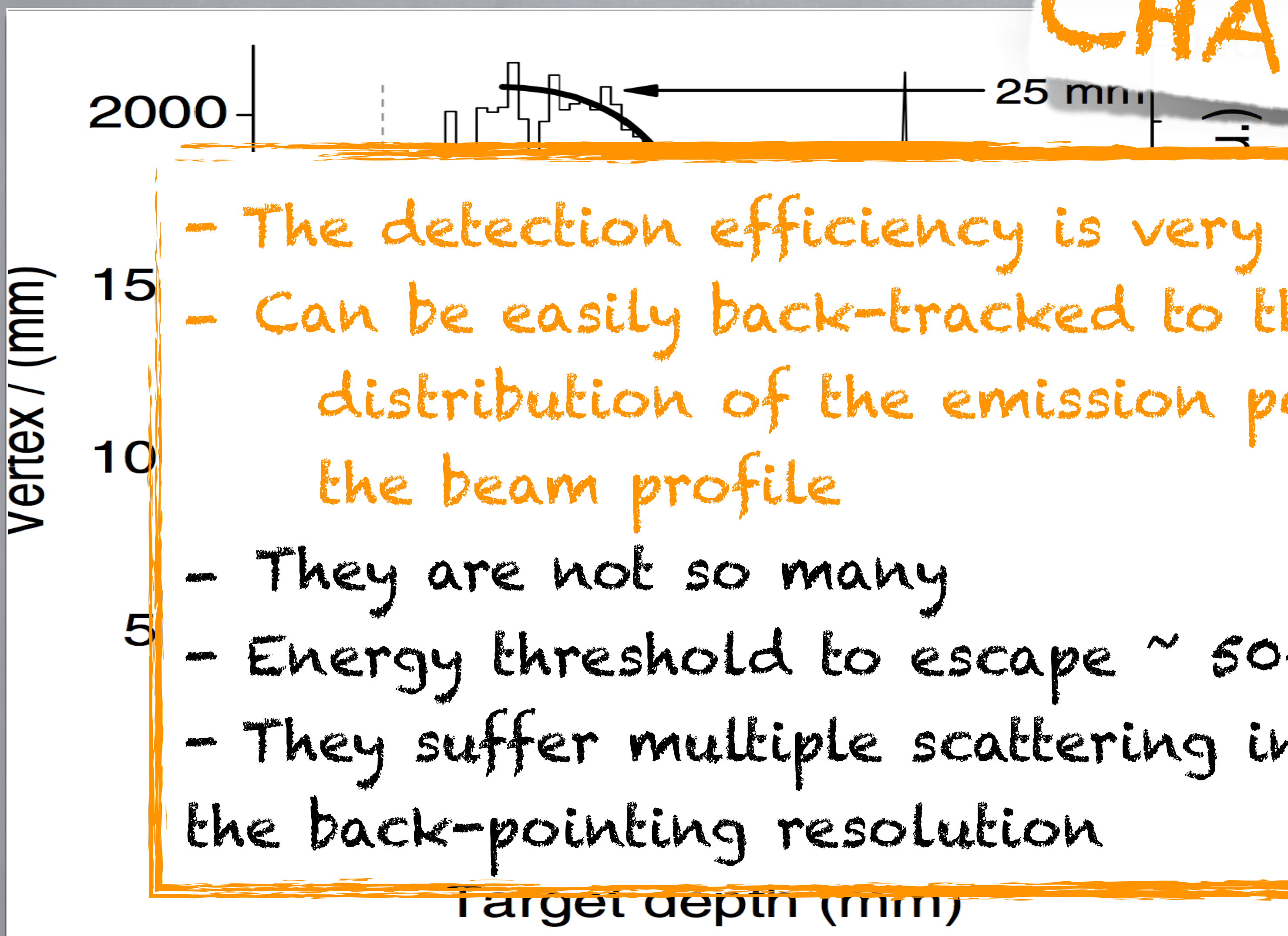


Emission distribution shape of protons as detected outside different PMMA thickness at 30⁰ wrt the direction of 95 MeV/u ^{12}C beam

- The charged secondary particles emission shape is correlated with the Bragg Peak position;

DOSE PROFILER

Trained Geant4 MC E. Testa et al Phys. Med. Biol.



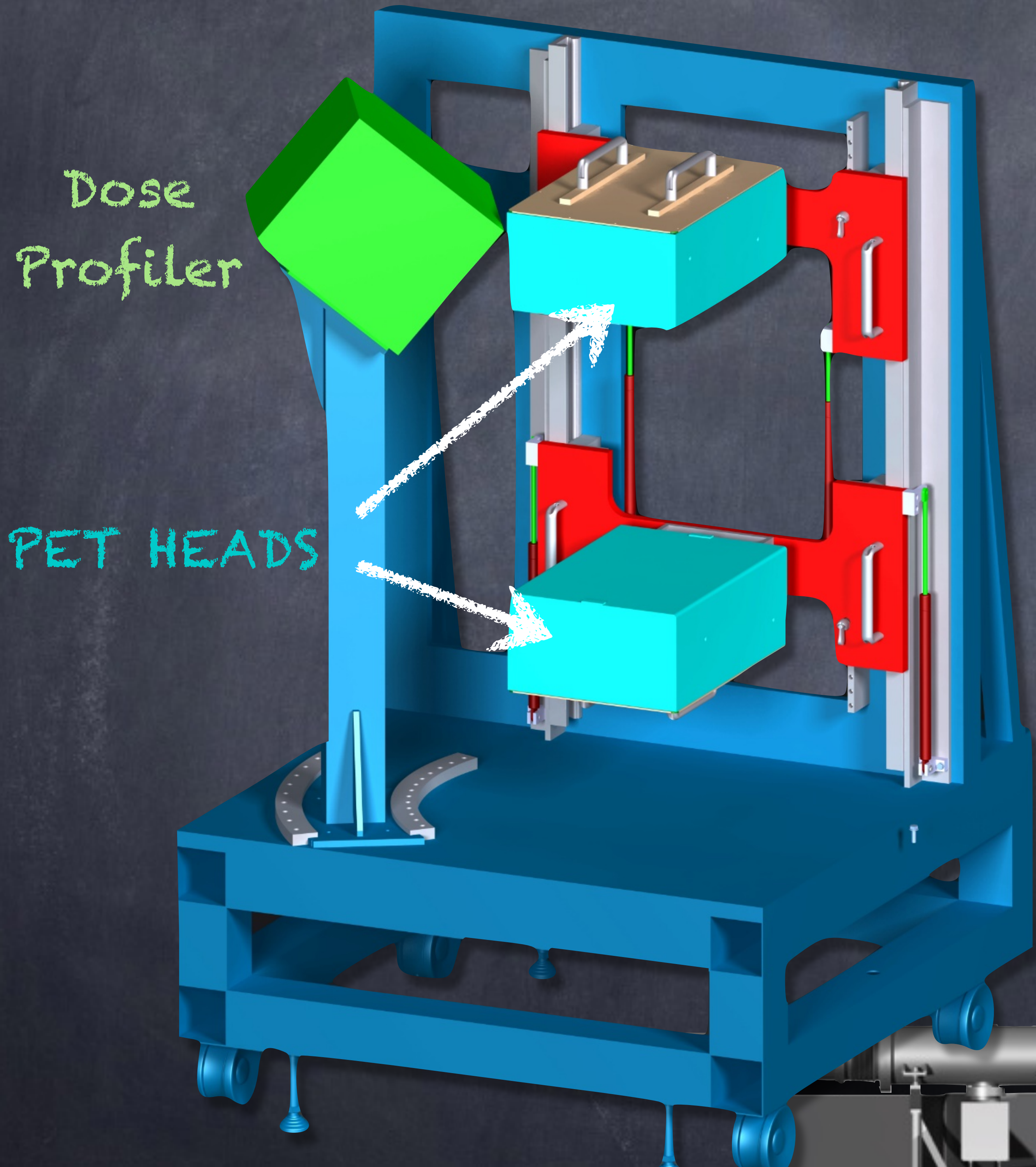
Emission distribution shape of protons as detected outside different PMMA thickness at 30° wrt the direction of 95 MeV/u ^{12}C beam

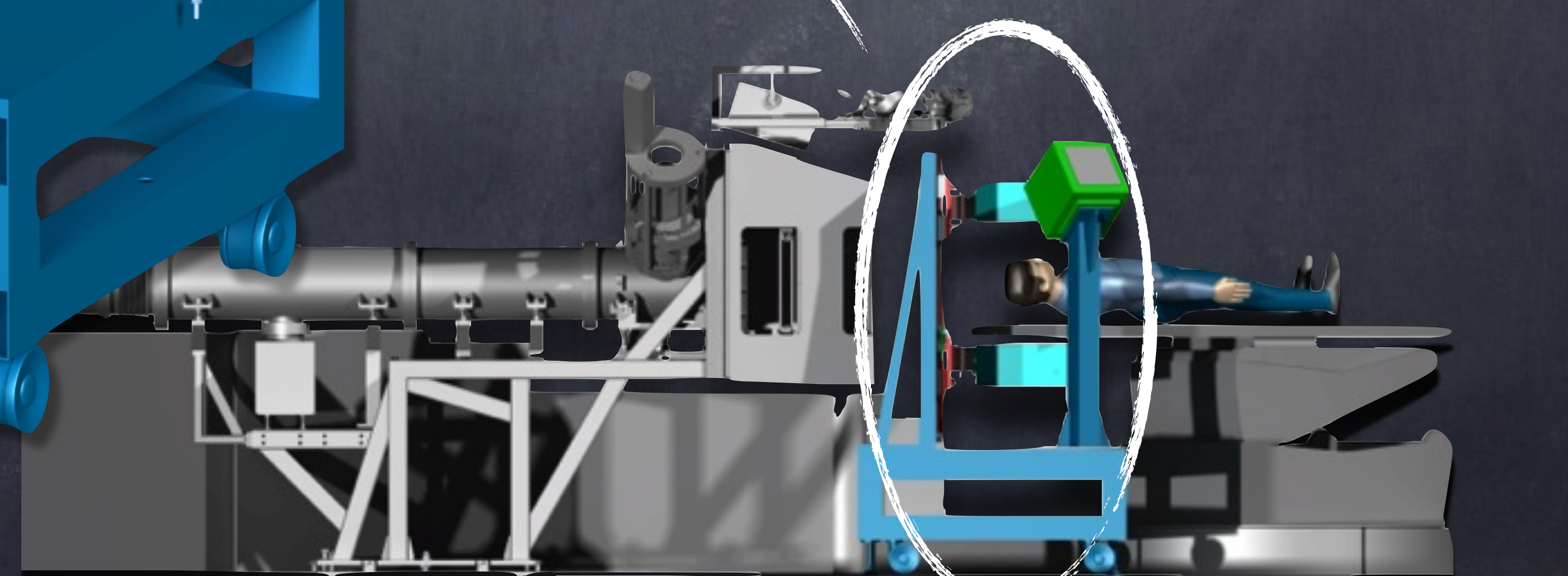
CHARACTERISTICS

- The detection efficiency is very high
- Can be easily back-tracked to the emission point => the distribution of the emission points can be correlated to the beam profile
- They are not so many
- Energy threshold to escape ~ 50-100 MeV
- They suffer multiple scattering inside the patient -> worsen the back-pointing resolution

CNAO SetUp

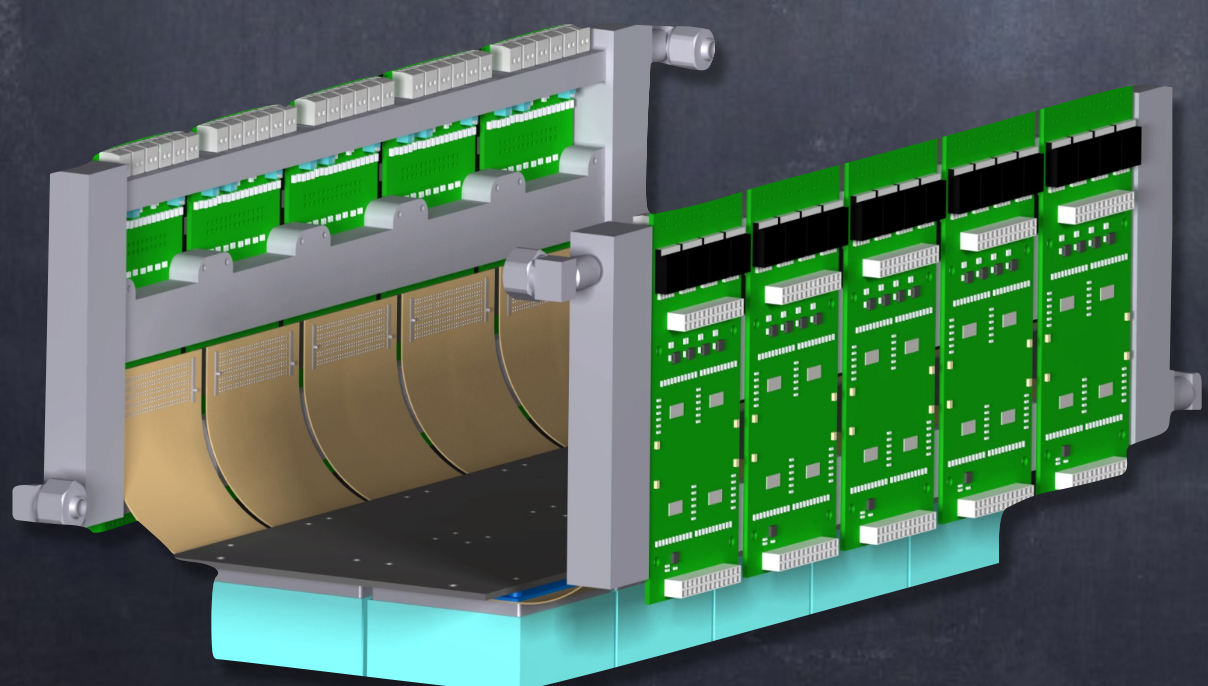
For the CNAO measurements we design a cart in order to hold up the detectors reducing any possible interference with the therapy procedures

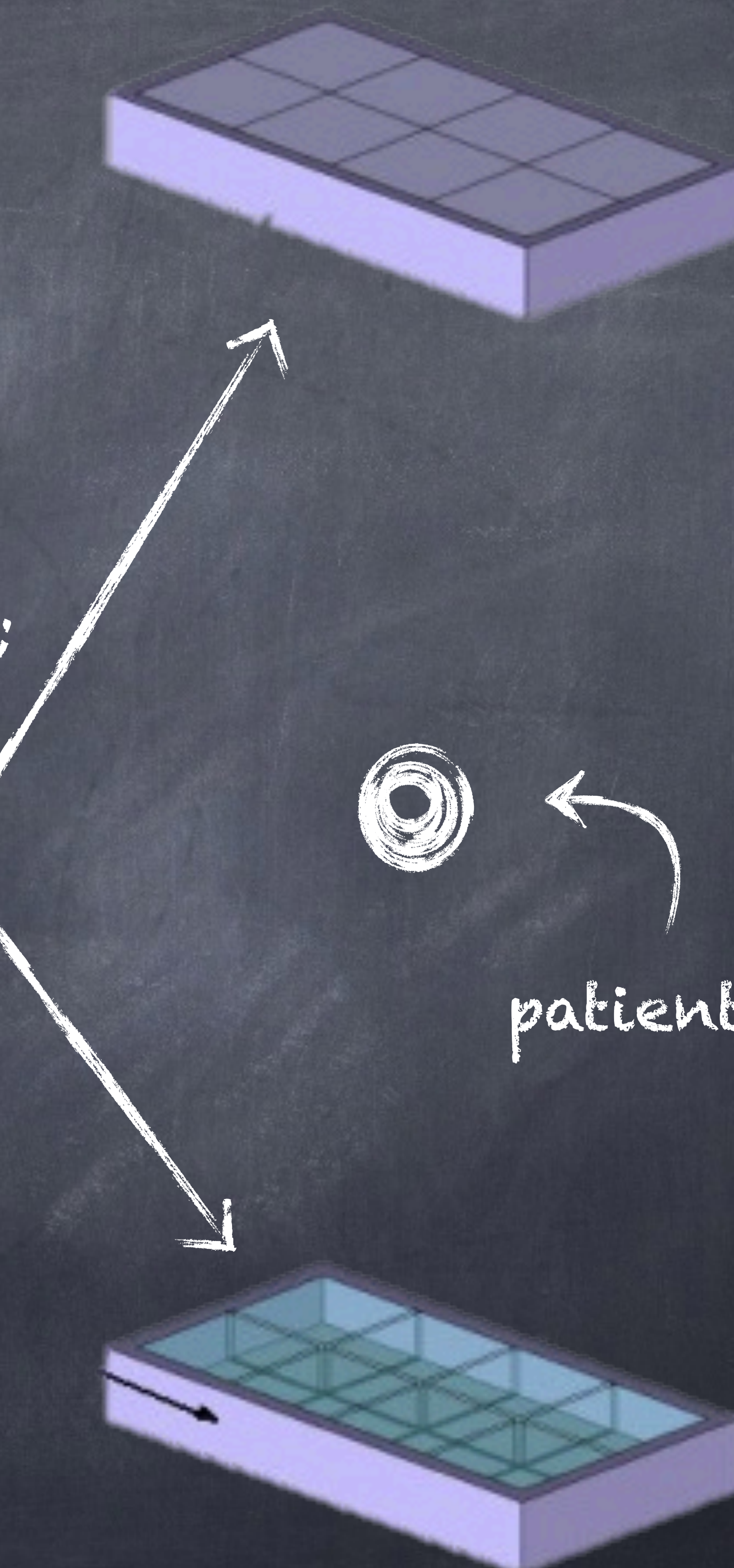




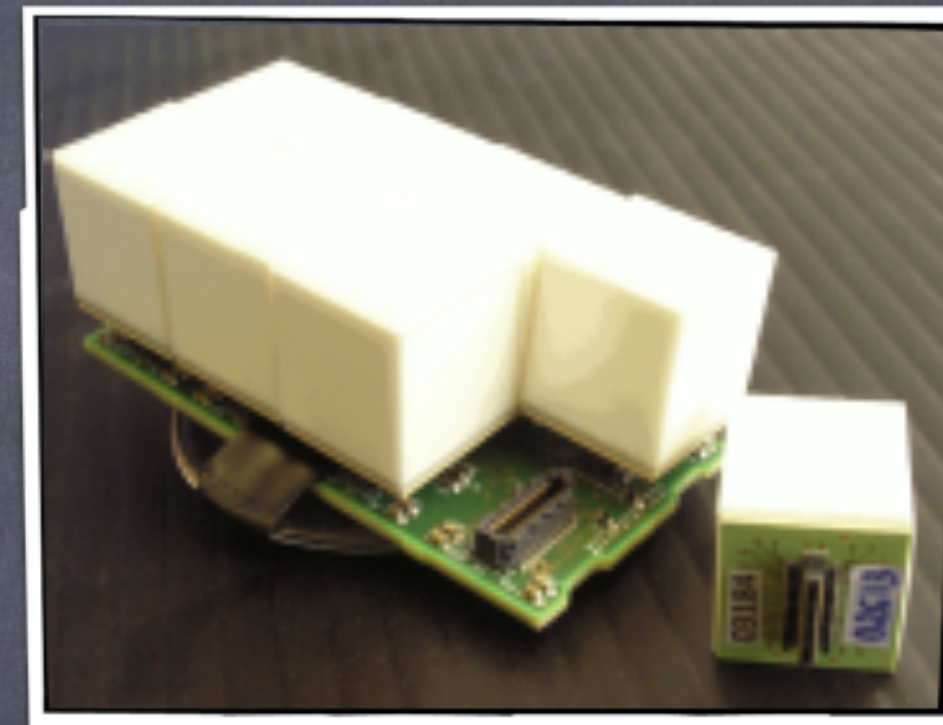
PET HEADS

- Full in-beam PET system able to sustain annihilation, prompt photon and neutron rates during the beam irradiation (in-beam and inter-spill);
- Two planar panels: 10 cm x 20 cm wide => 2 x 4 detection modules;



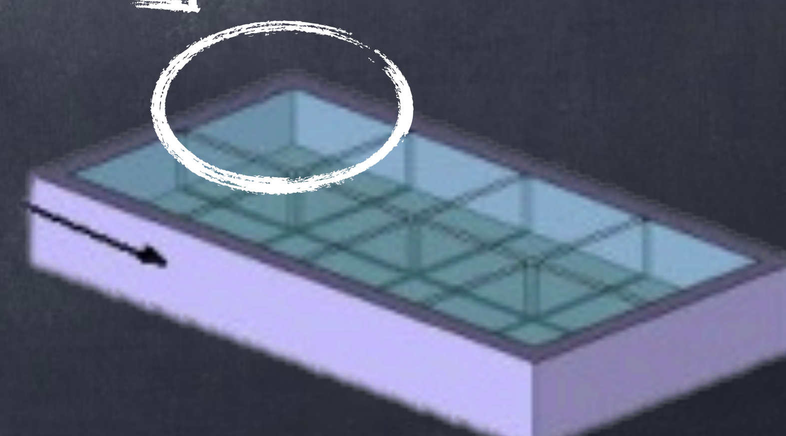


PET HEADS



- Two planar panels: 10 cm x 20 cm wide => 2 x 4 detection modules;
  - Each module is composed of a pixelated LYSO matrix 16 x 16 pixels, 3 mm x 3 mm crystals (pitch 3.1mm).
  - Total sensitive area of a module: 5 cm x 5 cm.

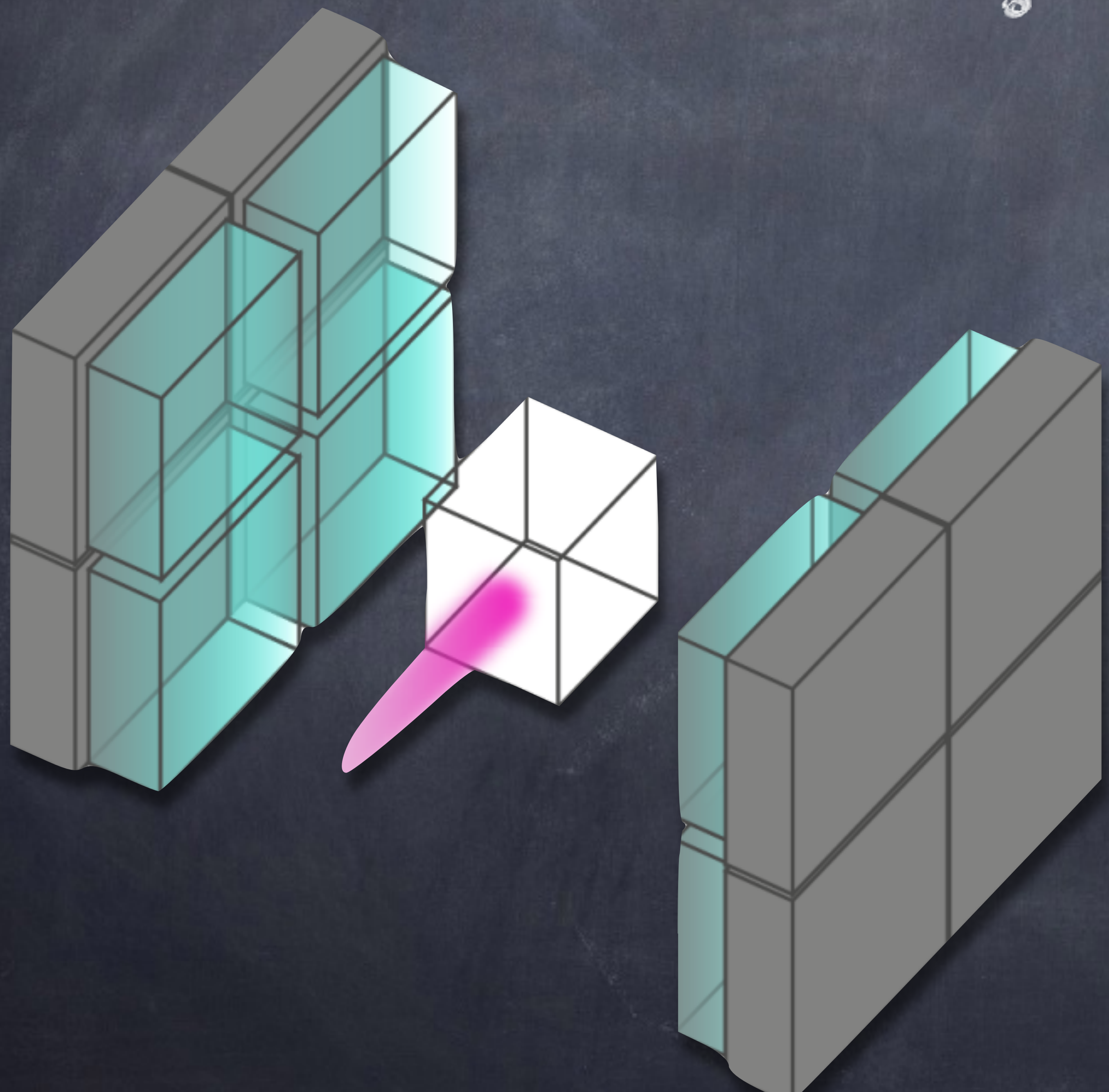
LYSO matrix readout: array of SiPM (16x16 pixels) coupled one-to-one.



PET HEADS BACKGROUND

DOPET: an in-beam PET monitor for hadrontherapy

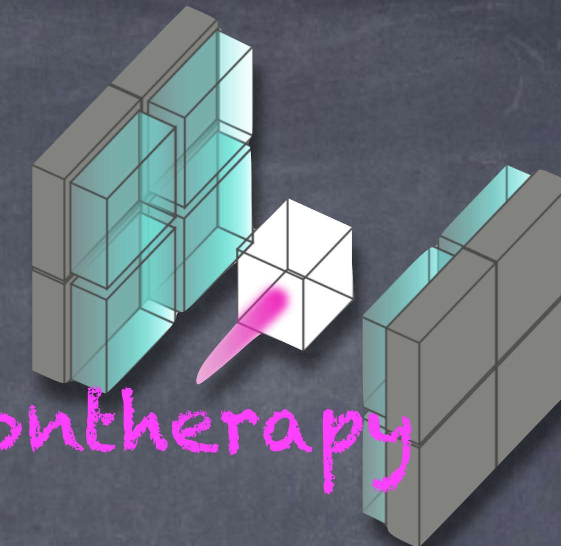
- Two PET heads, each made of 2x2 squared position-sensitive photomultipliers (Hamamatsu H8500) coupled to LYSO:Ce scintillating crystal arrays (2x2x18 mm3 pixel size).



NEW

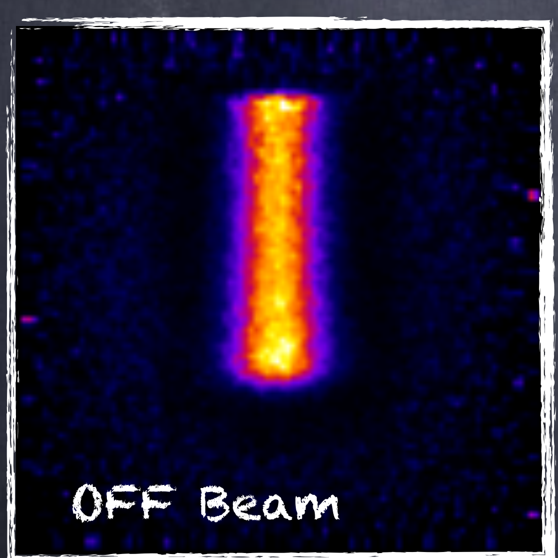
CNAO: 95 MeV proton beam on PMMA in-beam and off-beam acquisition

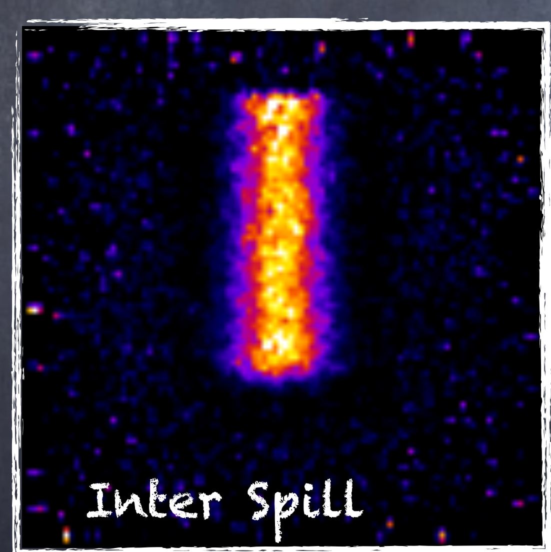
PET HEADS BACKGROUND

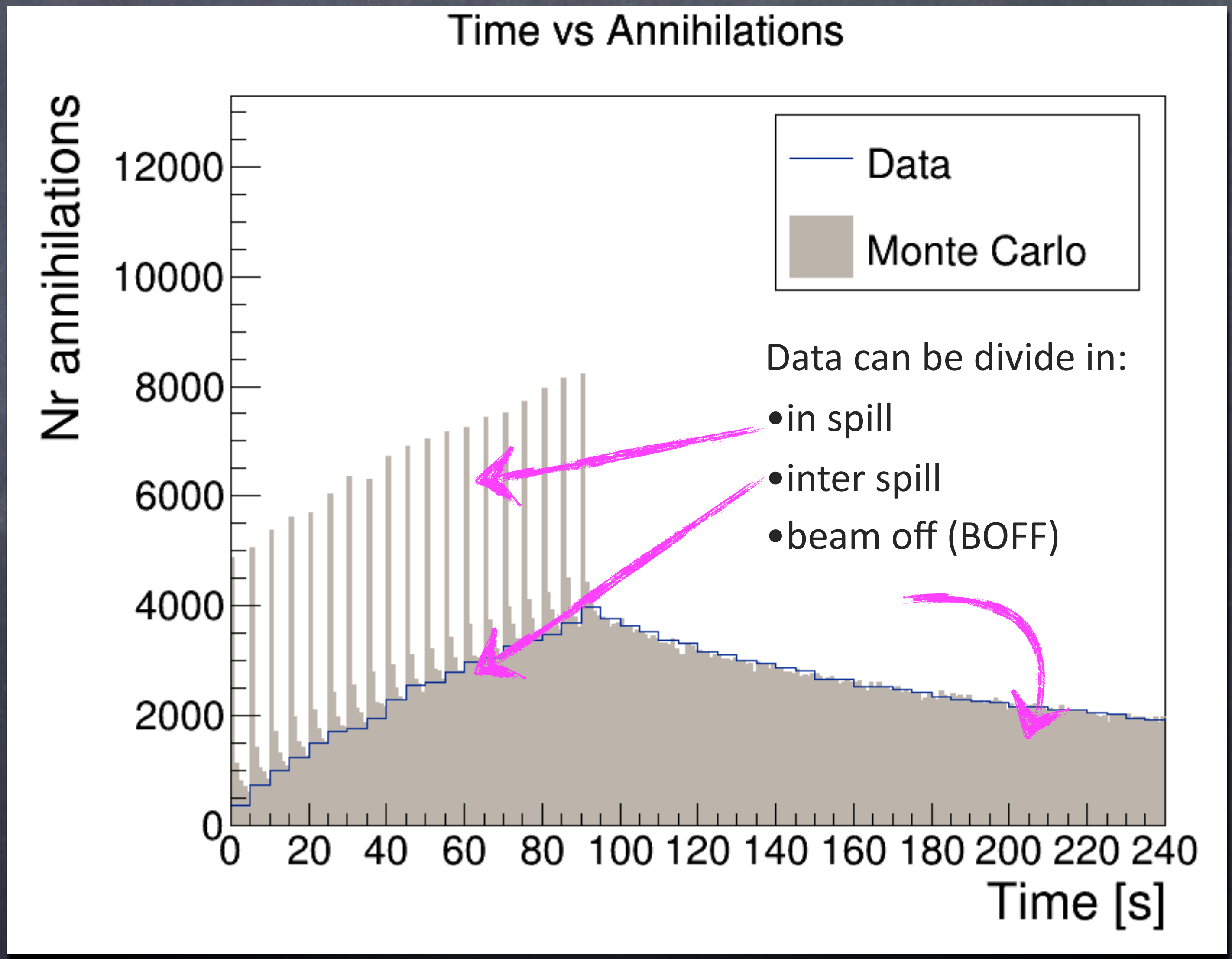


DOPET: an in-beam PET monitor for hadrontherapy

The annihilation map is reconstructed with Maximum Likelihood Estimation Maximization (MLEM) Iterative algorithm







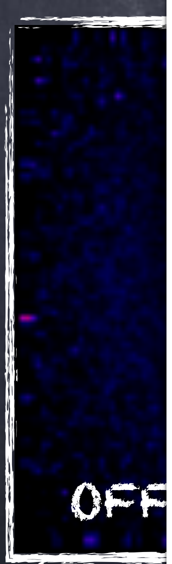
- Beam OFF ~ 550 sec
- Inter-spill ~100 sec
- Beam ON ~120 sec
- In-spill ~20 sec

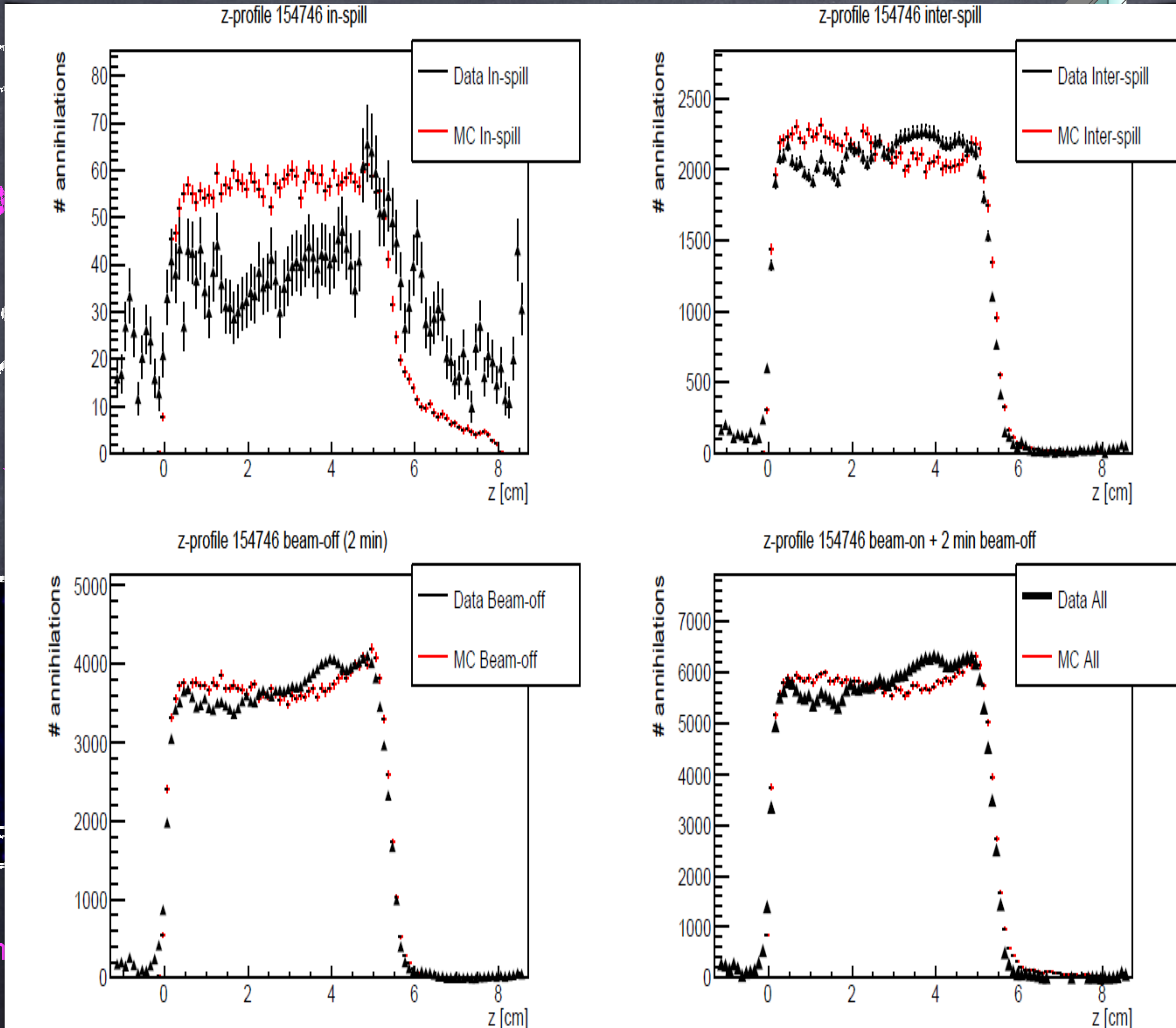
PE

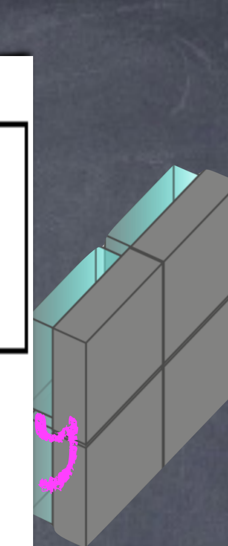
DO y

The hood

Estim





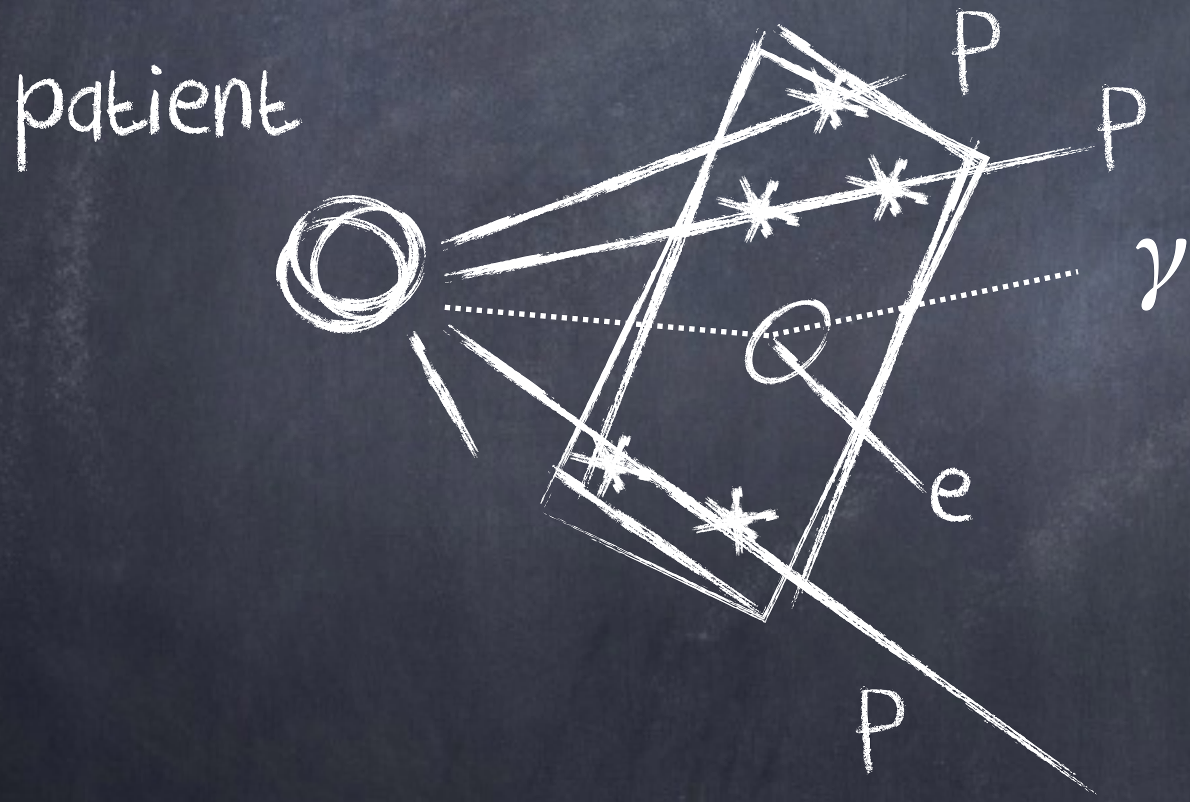


- Bean

DOSE PROFILER

- Detection of photon and charged particles:

  =>reconstruction track and interacting point



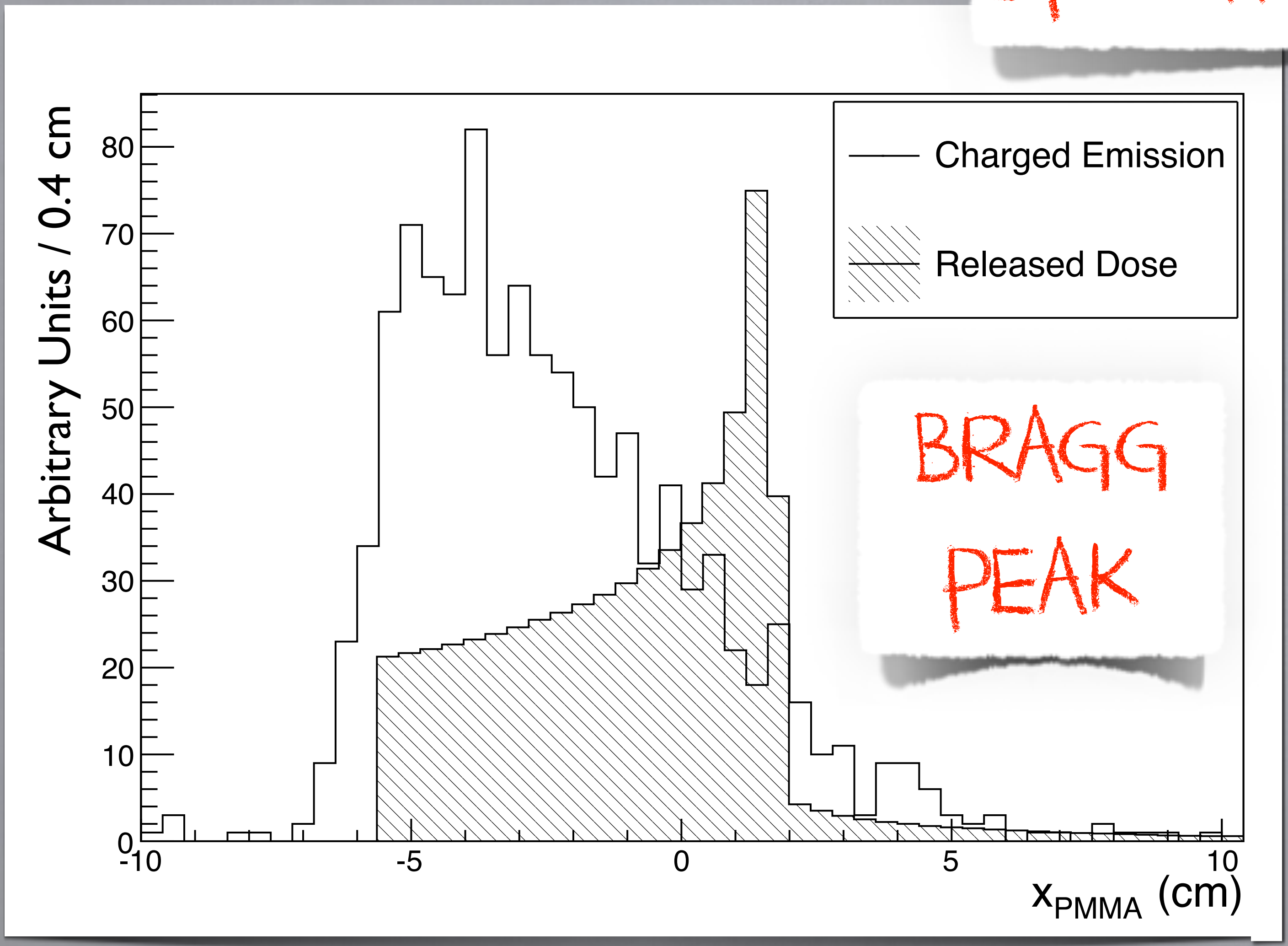
- Back track the charged secondary particles

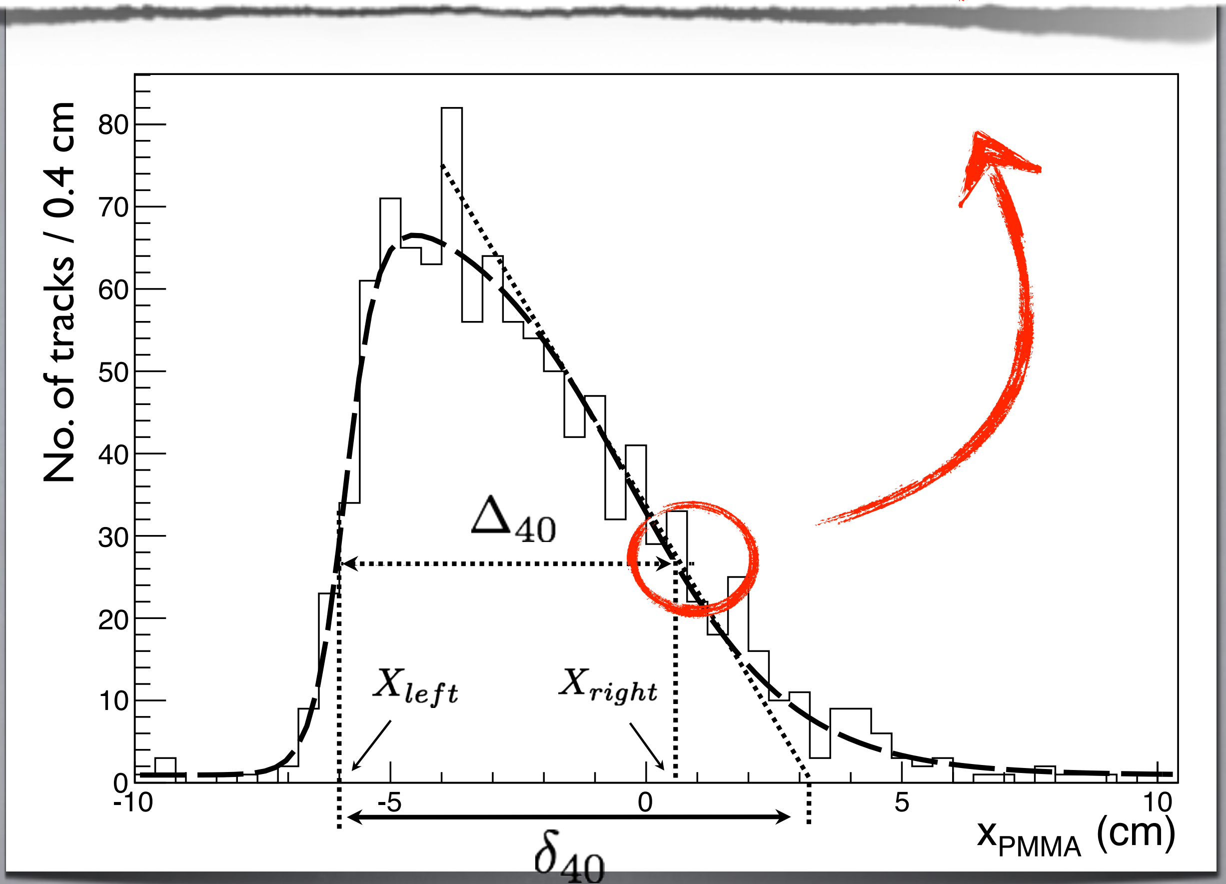
- Detection of a prompt photon via Compton effect and reconstruct its emission point

DOSE PROFILER BACKGROUND

Measured emission profile (¹²C @PMMA)

BP correlation with emission profile



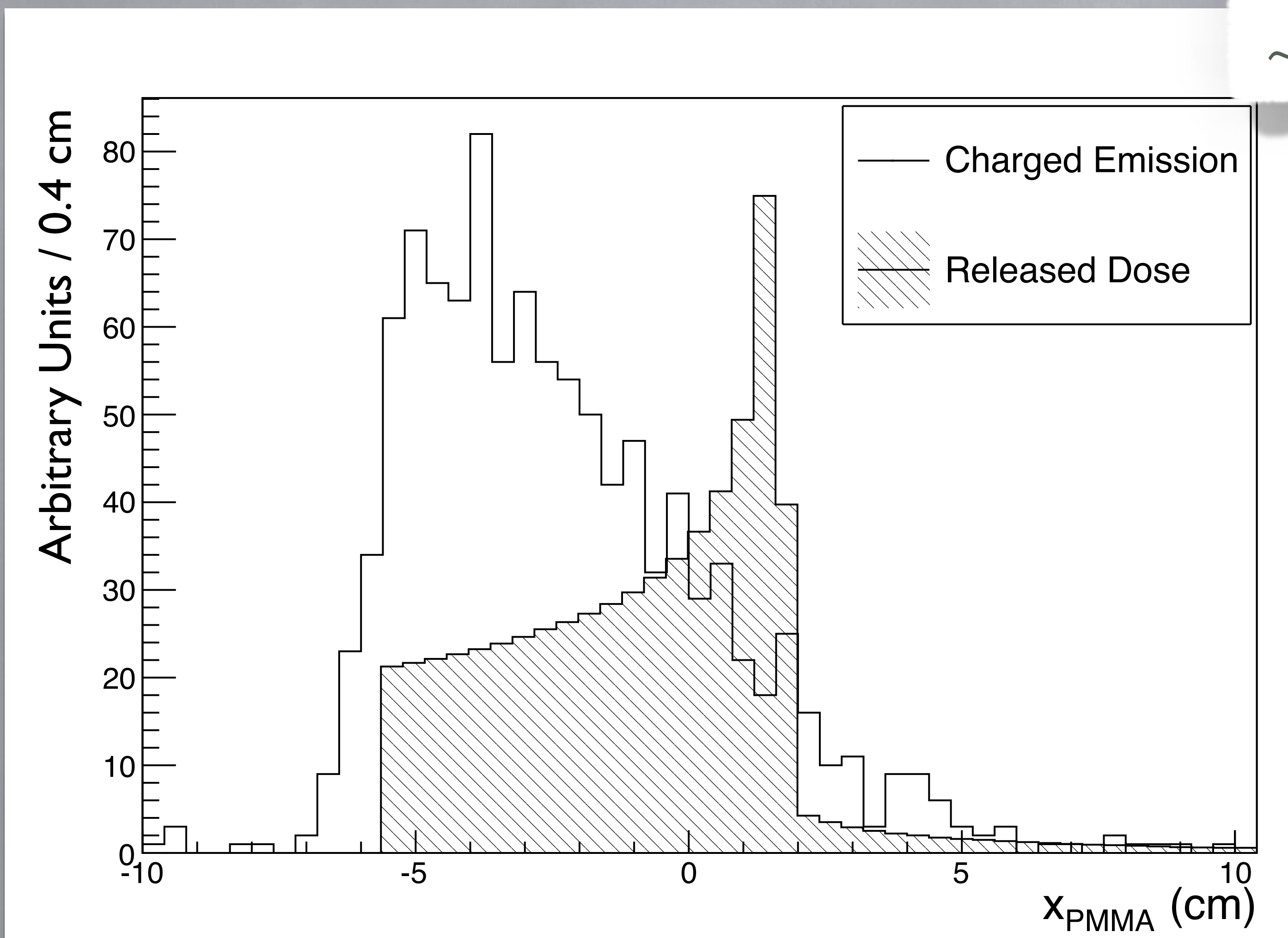


L. Piersanti et al. Phys. Med. Biol. 59 1857

DOSE PROFILER BACKGROUND

Measured fluxes

Measured emission profile (^{12}C @PMMA)



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~ 10^{-3} sr^{-1} @ 80MeV/u ^{12}C beam, 90°

~ 10^{-2} sr^{-1} @ 220 MeV/u ^{12}C beam, 90° and 60°

Conservative considerations:

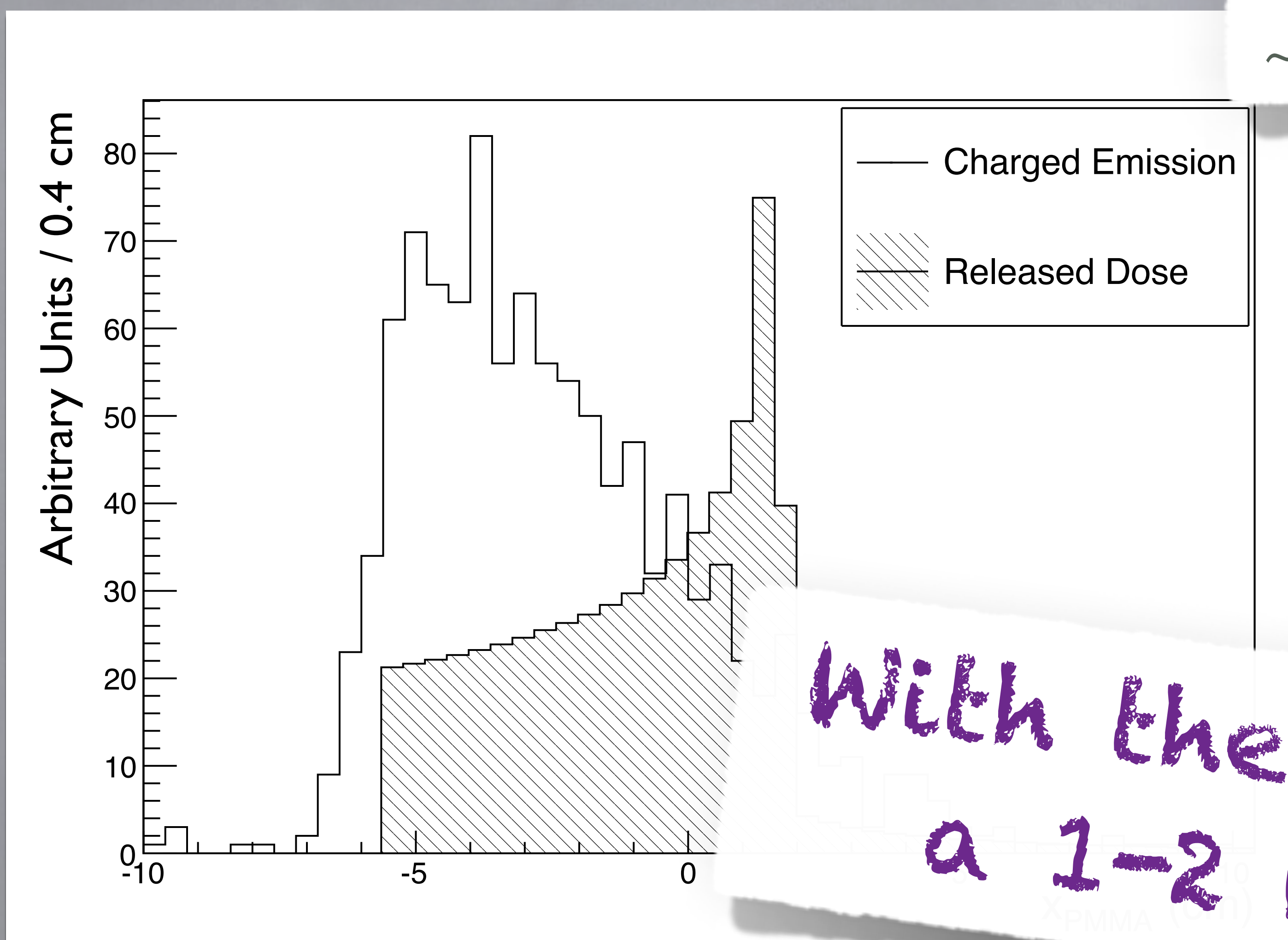
- single pencil beam (2 Gy dose),
- small detector (10x10 cm^2 @ 35 cm)
- deep tumor (MS ϑ ~ 3.16)

⇒ 4 mm resolution

DOSE PROFILER BACKGROUND

Measured fluxes

Measured emission profile (^{12}C @PMMA)



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~ 10^{-3} sr^{-1} @ 80MeV/u ^{12}C beam, 90°

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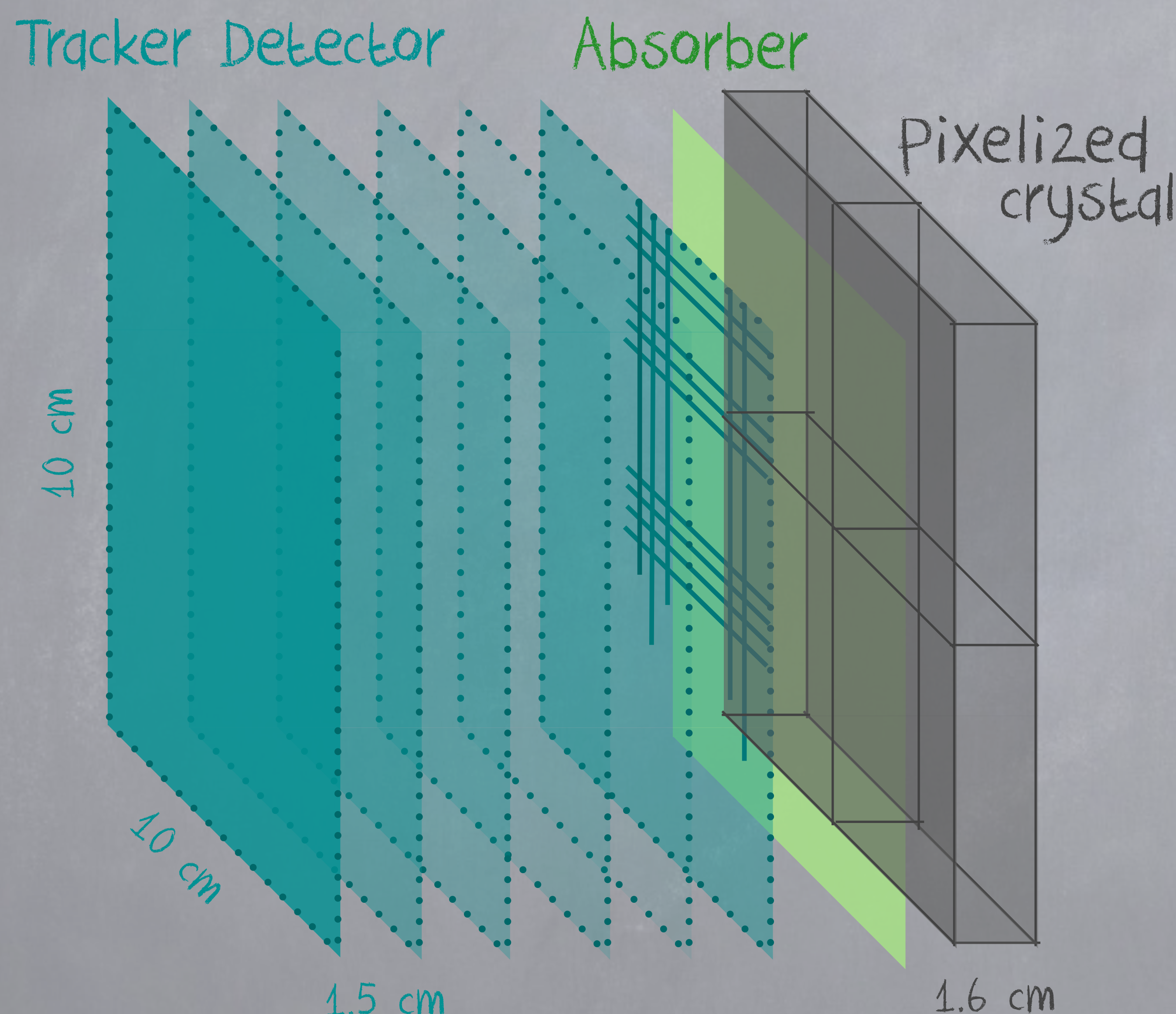
Conservative considerations:

- single pencil beam (2 Gy dose),
- small detector (10x10 cm² @ 35 cm)
- … (MS ϑ ~ 3.16)

With the DP we can reach a 1-2 mm resolution

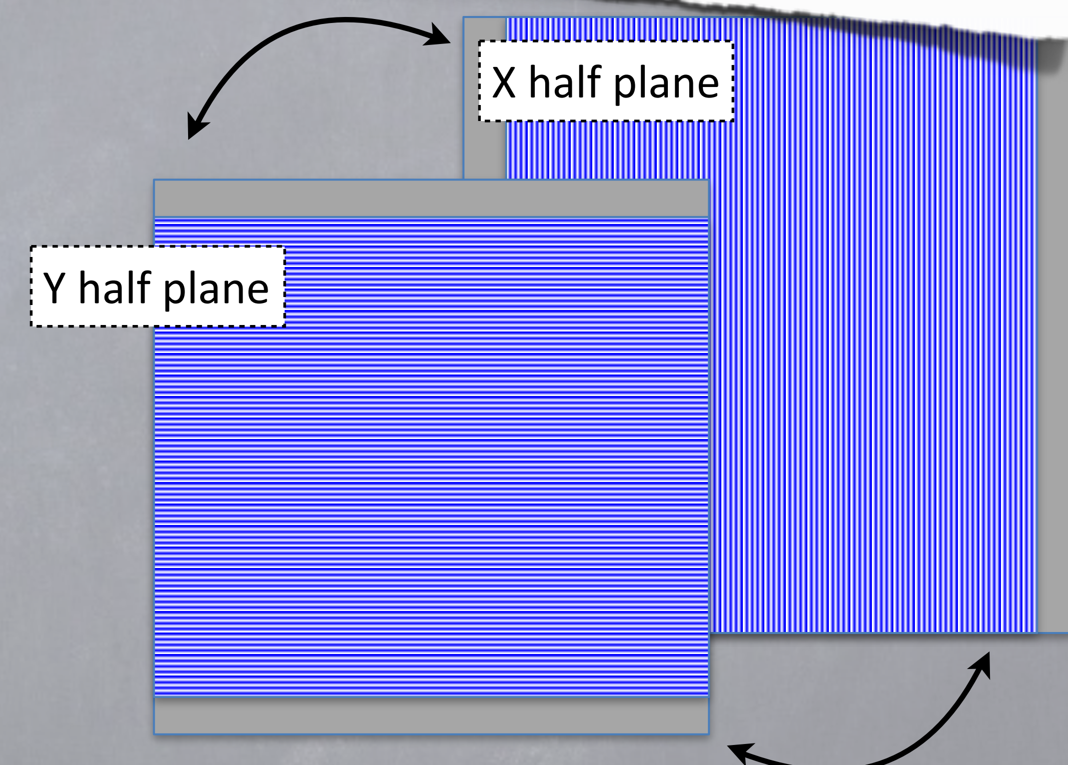
DOSE PROFILER

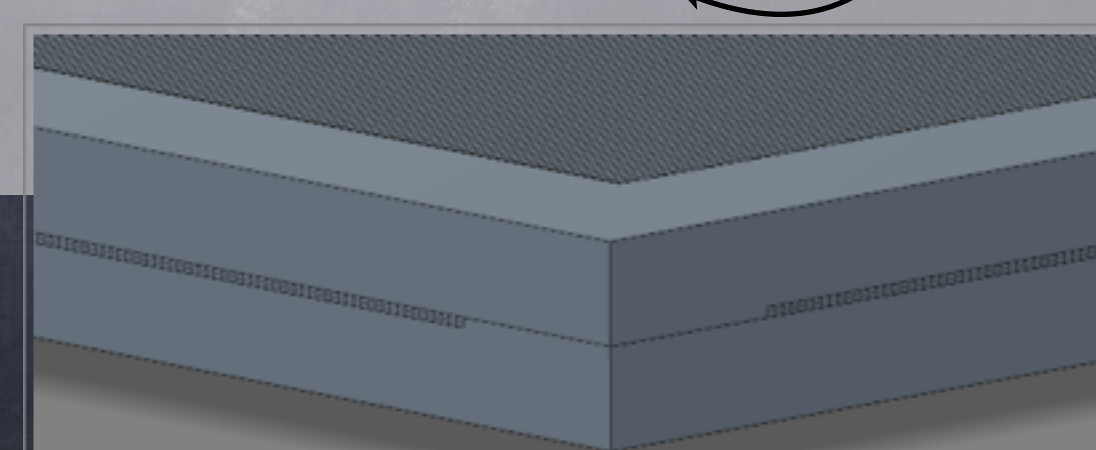


6 planes of fibers:

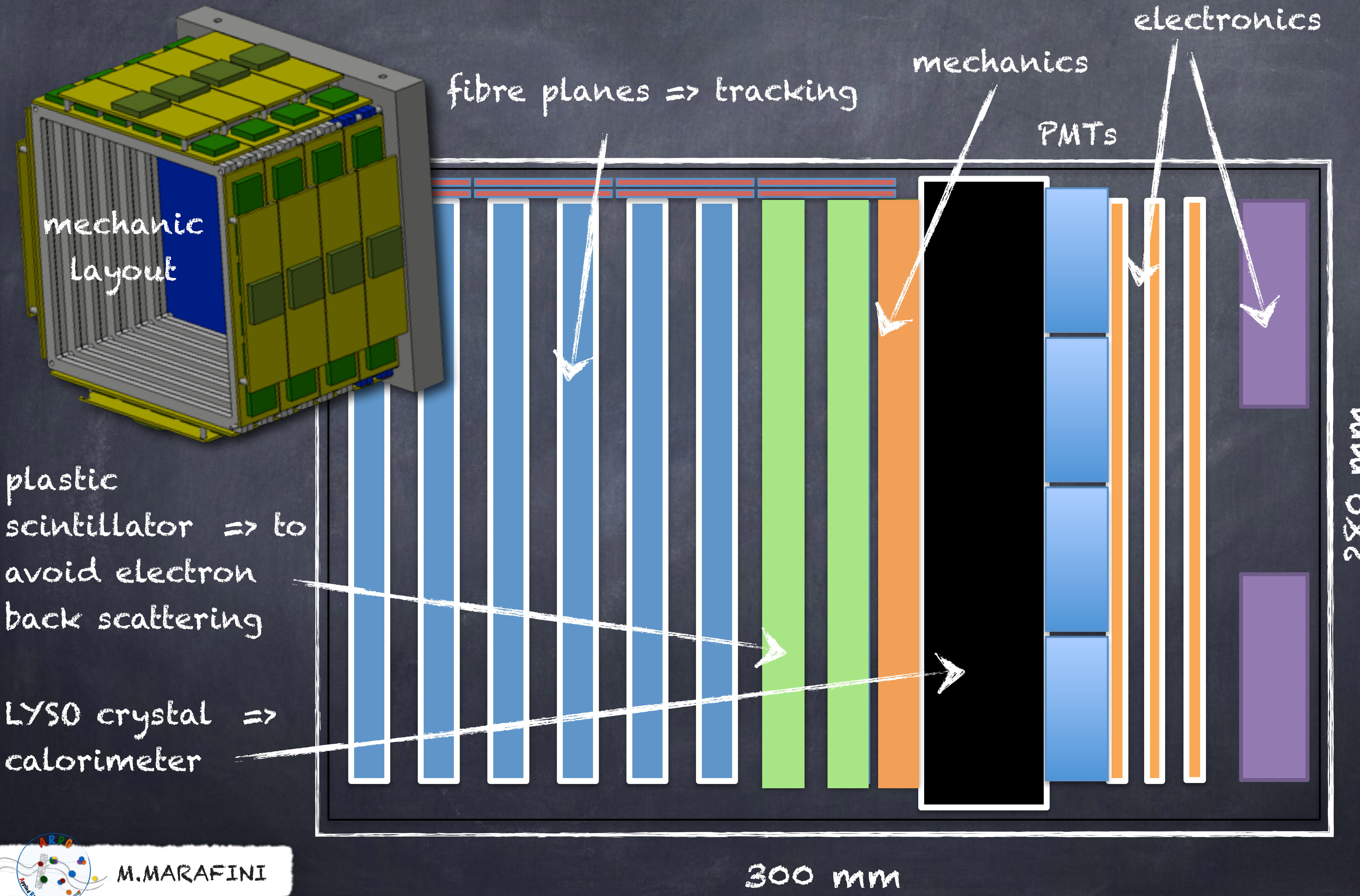
2 layer of fibers each plane

192 fibers each layer (0.5 mm)



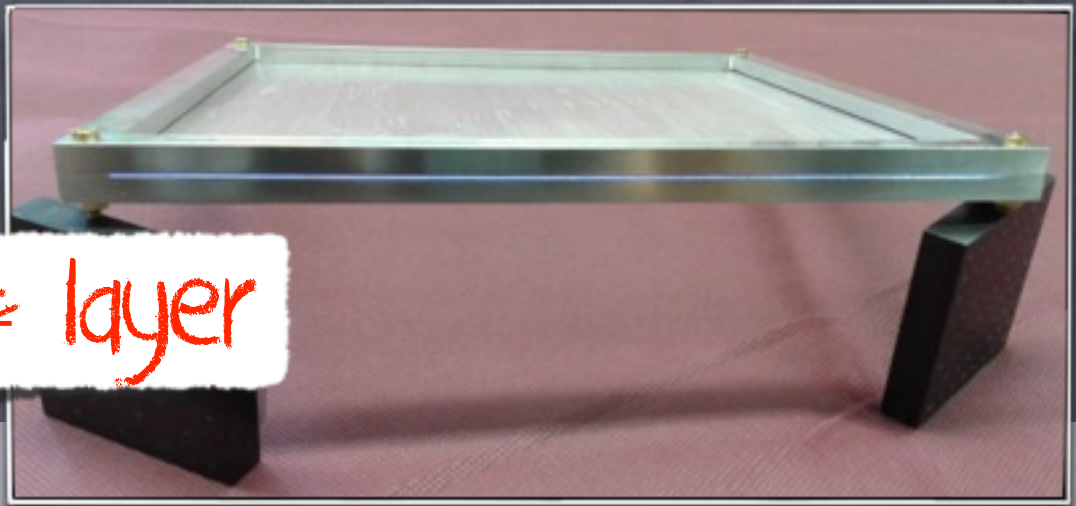


SCHEMATIC SIDE VIEW OF THE DOSE PROFILER

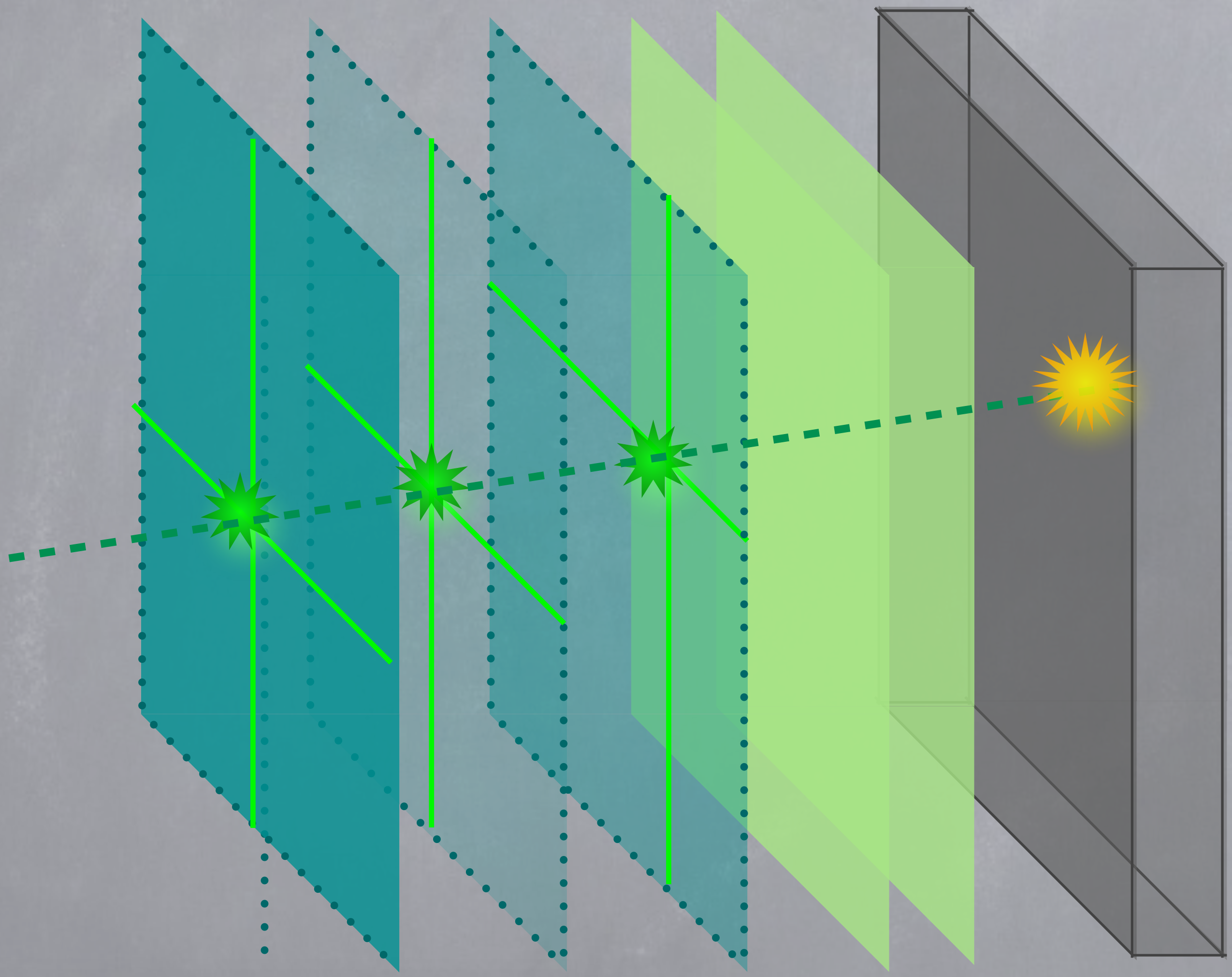


M.MARAFINI

DOSE PROFILER



1st layer

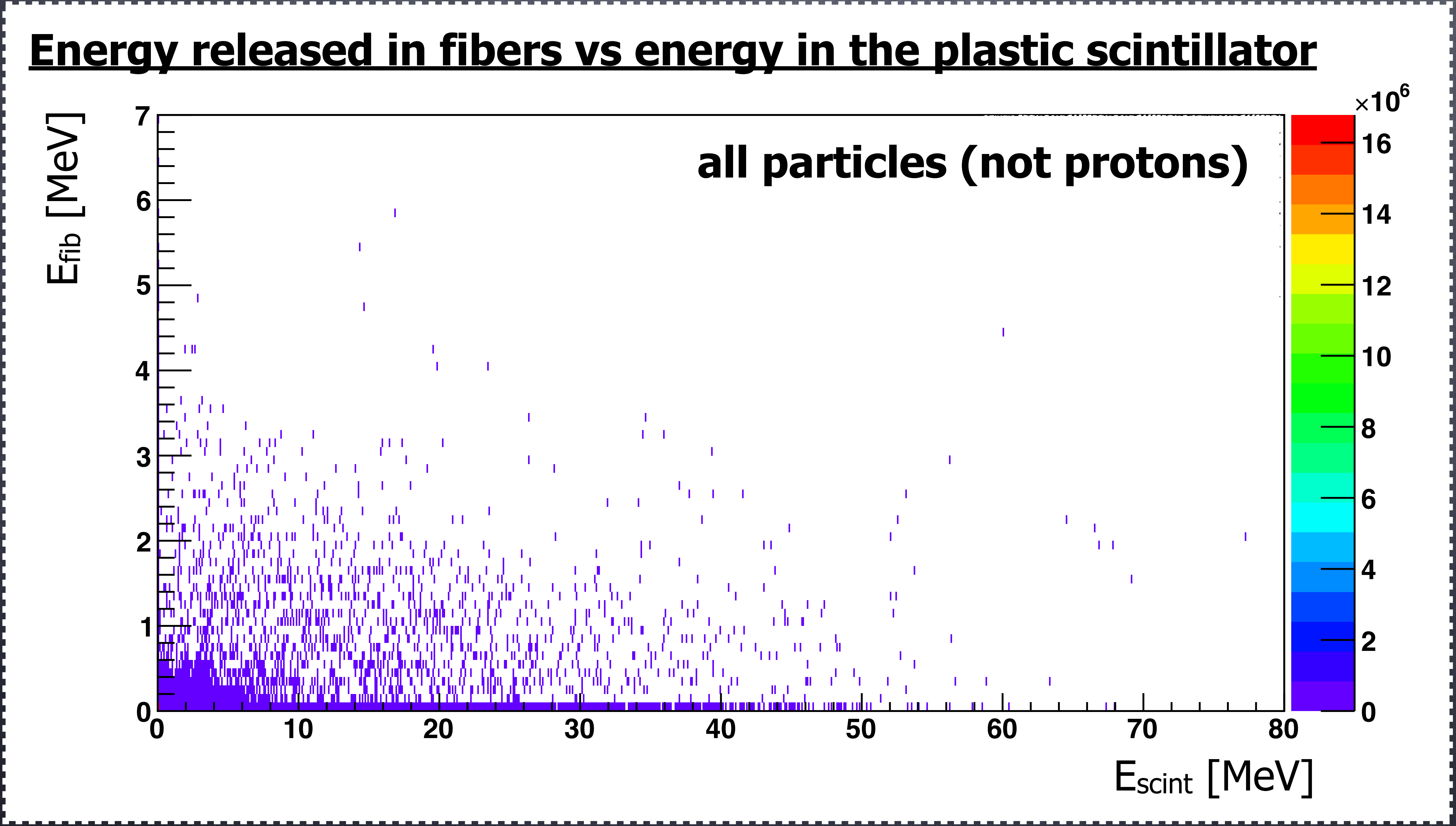


Sketch view

Bragg peak is correlated to the secondary particles emission point (reconstructed by backtracking

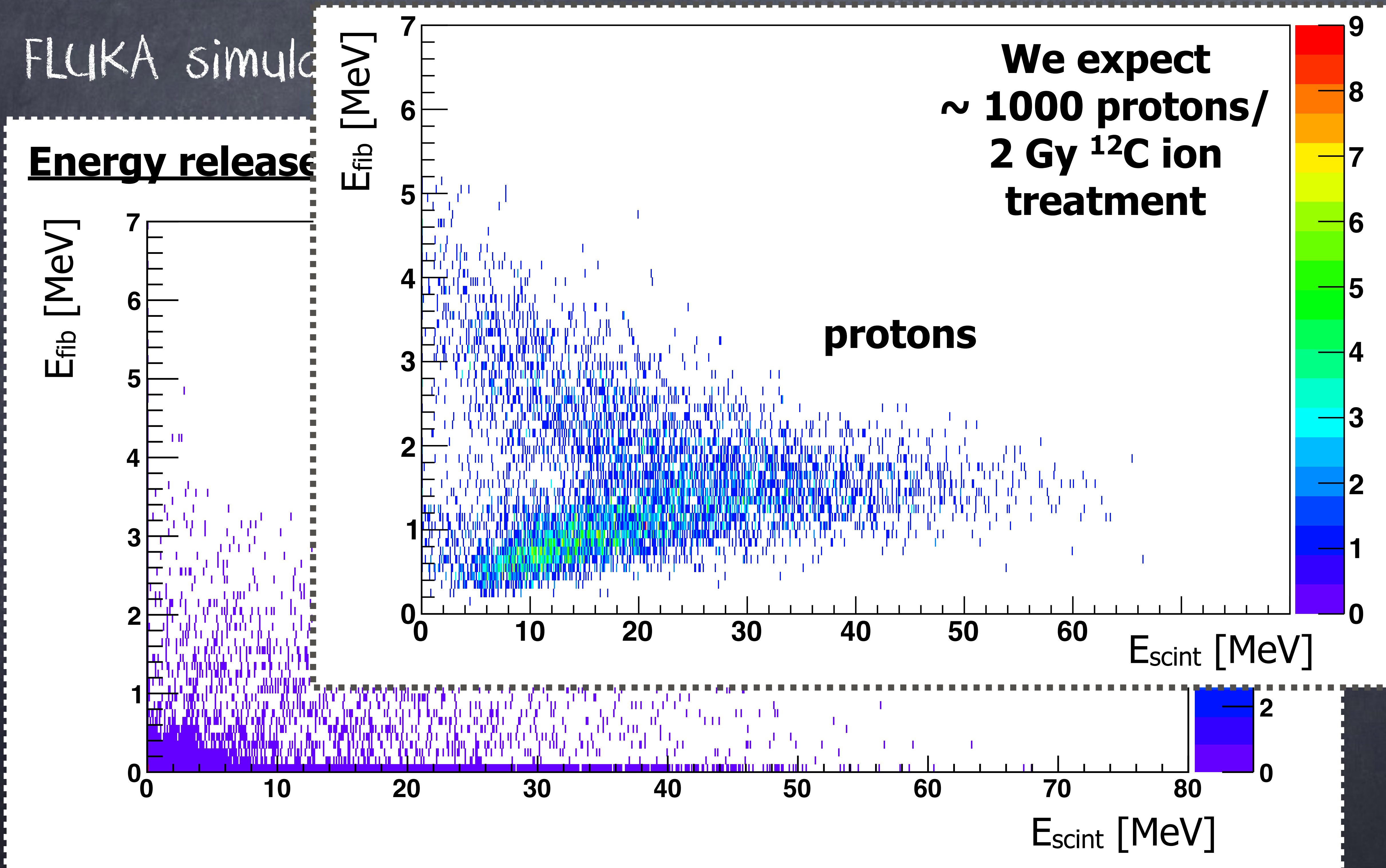
DOSE PROFILER

- FLUKA simulation



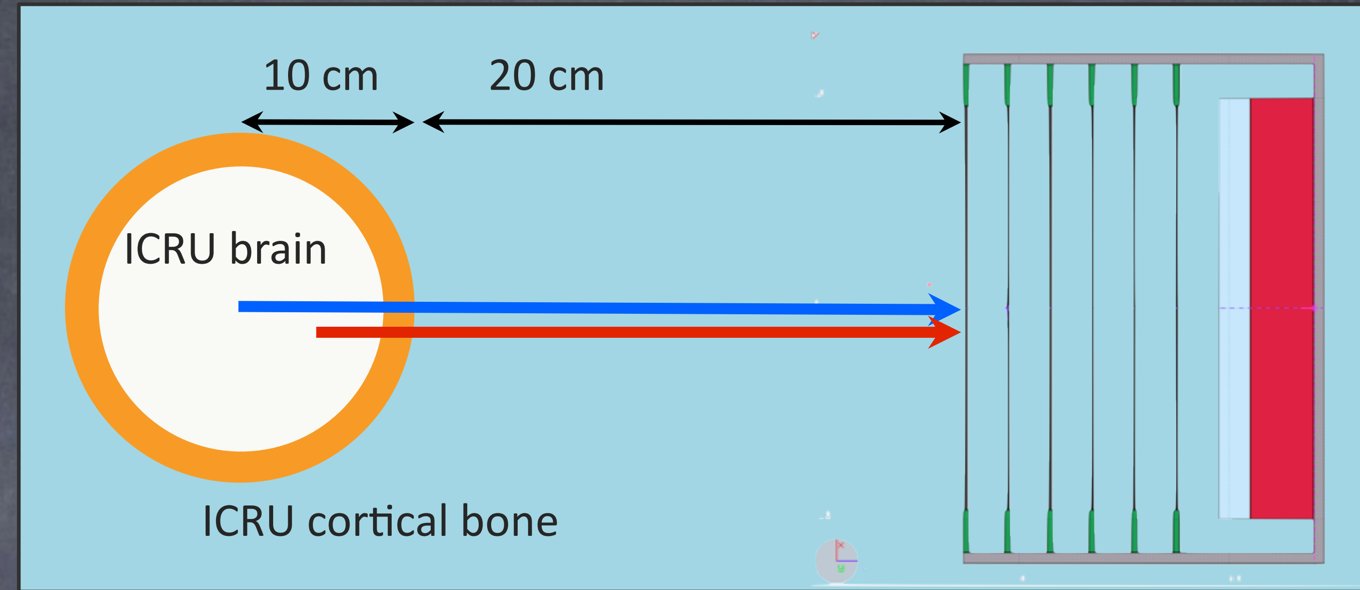
DOSE PROFILER

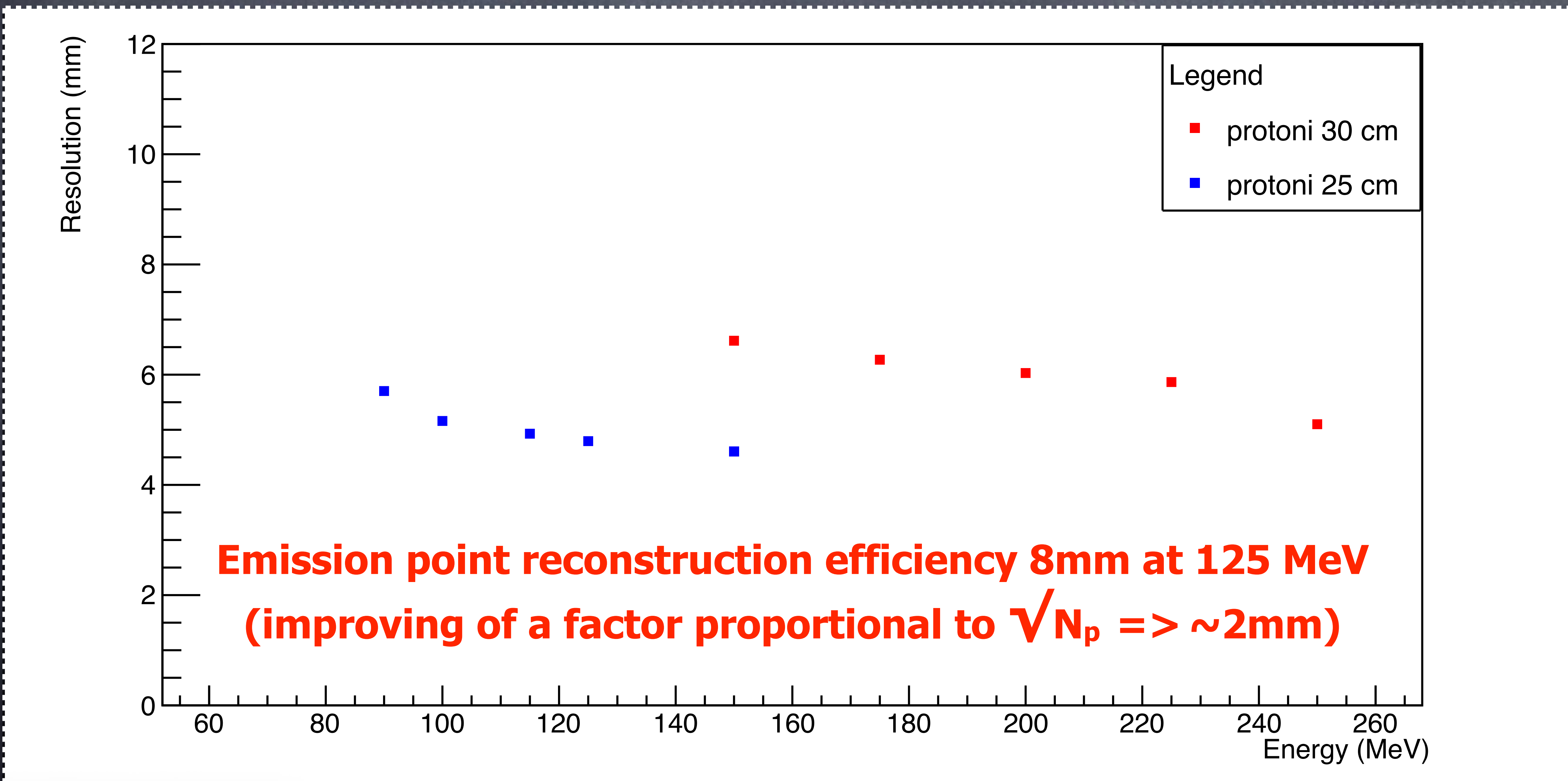
- FLUKA simul



DOSE PROFILER

- Reconstruction software and FLUKA simulation





TimeTable 2015/2016

PET HEADS

1. Electronics, mechanics, DAQ finalization
2. PH(1) PH(2) assembly
3. Software reconstruction implementation
4. Calibration tests

DOSE PROFILER

1. DP assembly (Electronics, mechanics, DAQ)
2. Software reconstruction finalization
3. Integration HW and SW
4. Calibration tests

End 2016 test on phantom

⇨ CNAO

⟹ WORK FOR PATIENT TREATMENTS TEST !

THANKS

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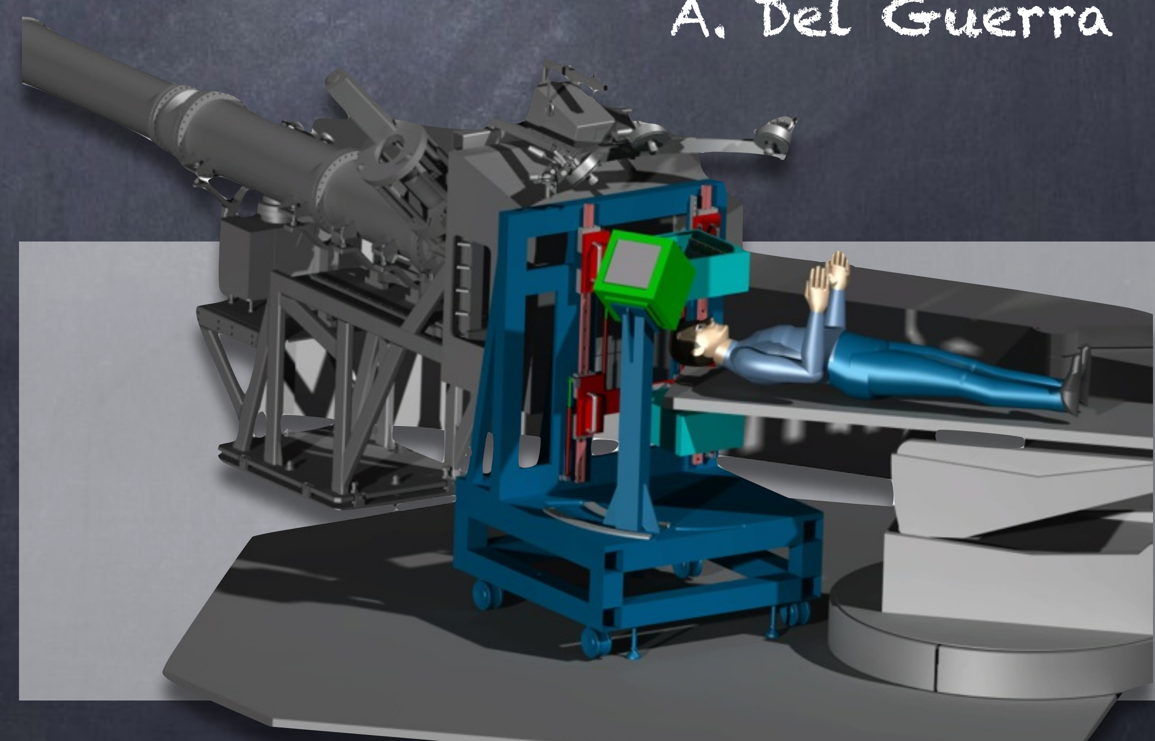
V. Patera
L. Piersanti
A. Sarti
A. Sciubba
C. Voena

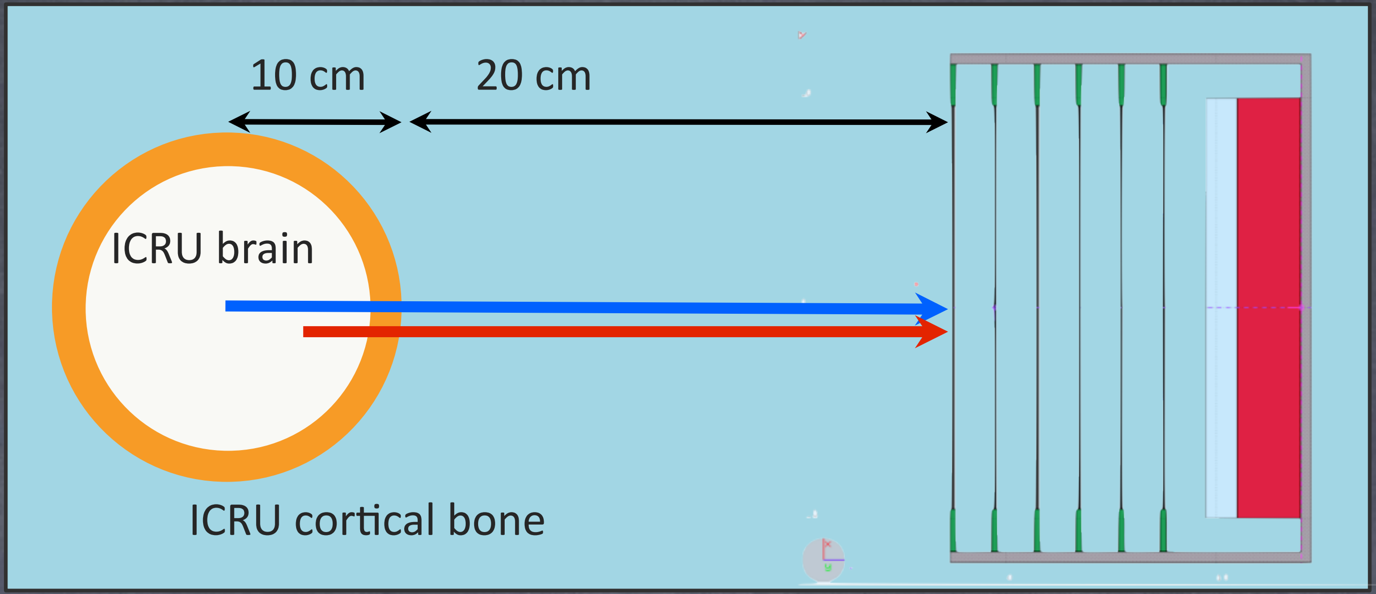
The INSIDE Collaboration
A. Del Guerra



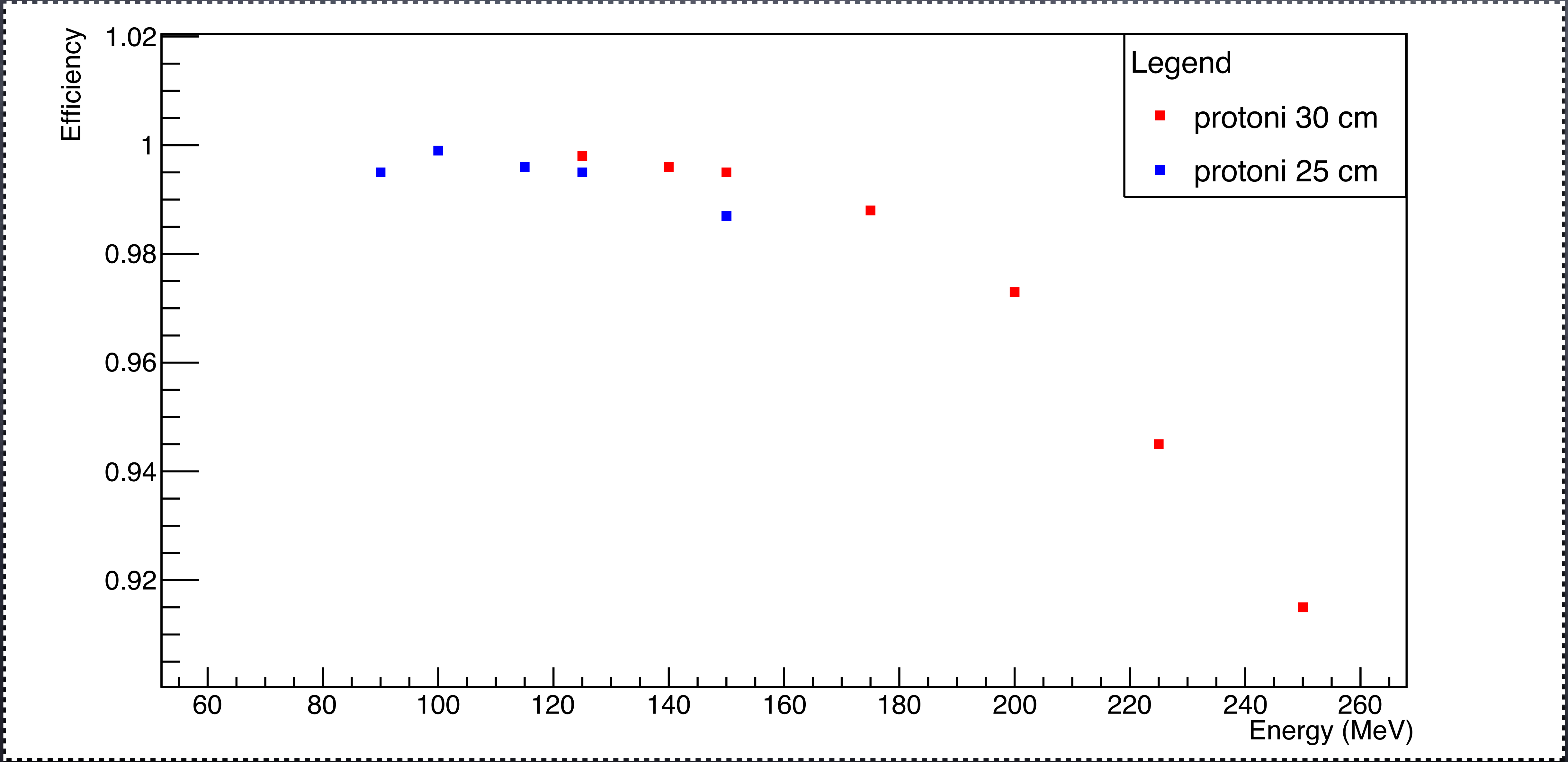
BackUP

DP

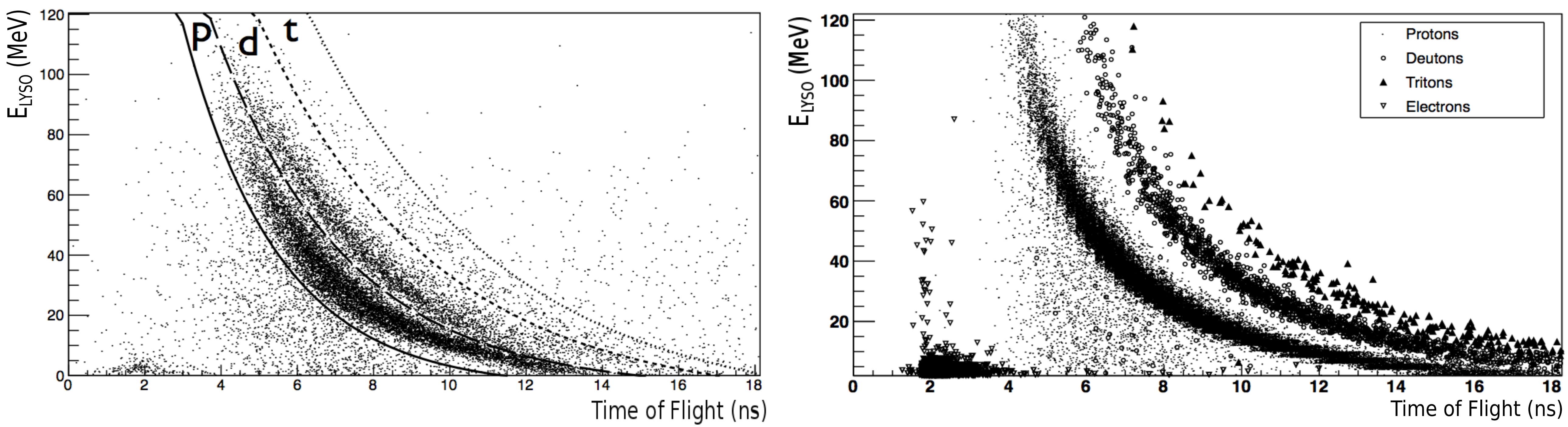
DOSE PROFILER



- Detector resolution



Protons


p
d
t
E_{LYSO} (MeV)
Time of Flight (ns)
Protons
Deutons
Tritons
Electrons
E_{LYSO} (MeV)
Time of Flight (ns)

Protons

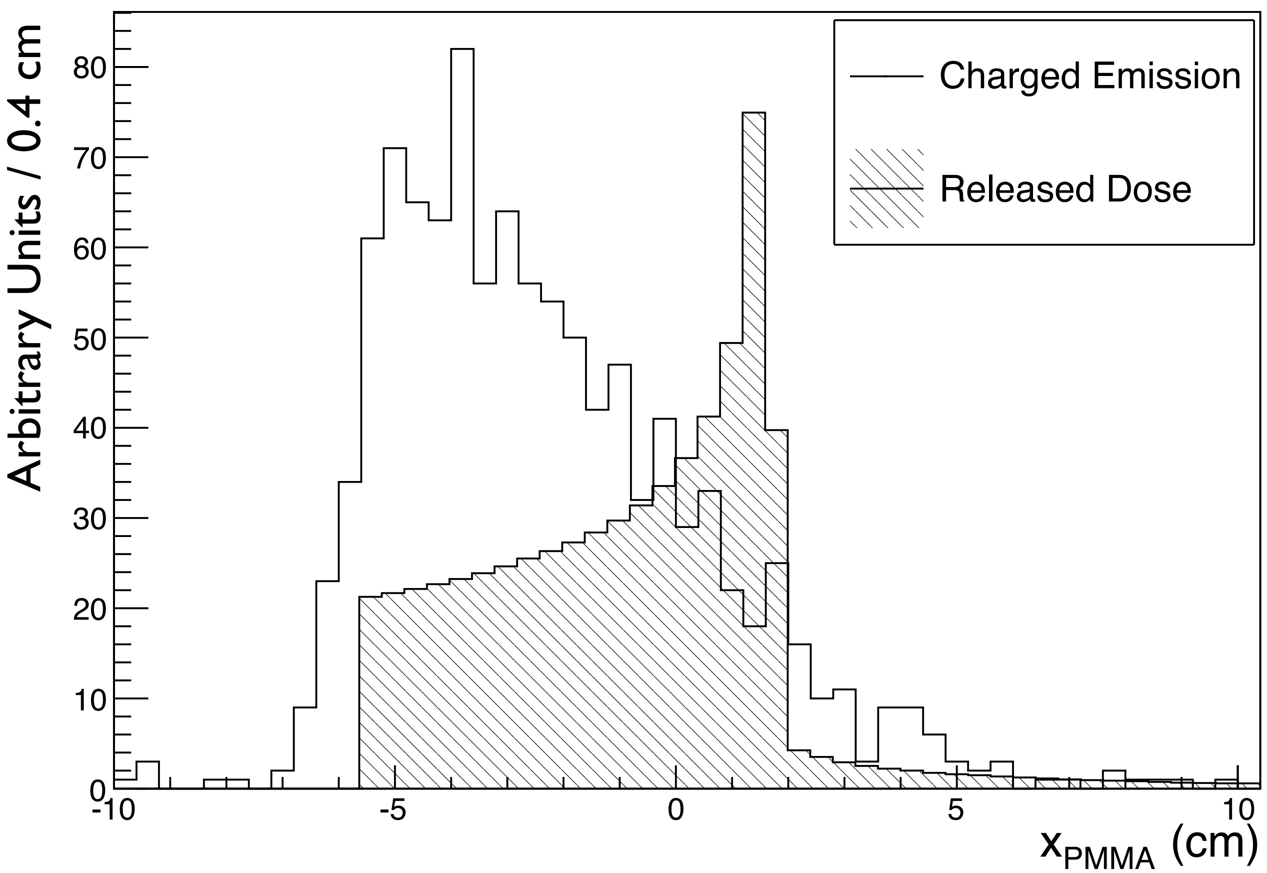
The p, d and t measured *fluxes* for the 60° and 90° experimental configurations are:

$$\frac{dN_\mathrm{p}}{N_\mathrm{C} d\Omega}(\theta = 60^\circ) = (8.78 \pm 0.07_\mathrm{stat} \pm 0.64_\mathrm{sys}) \times 10^{-3}\ sr^{-1}$$
$$\frac{dN_\mathrm{d}}{N_\mathrm{C} d\Omega}(\theta = 60^\circ) = (3.71 \pm 0.04_\mathrm{stat} \pm 0.37_\mathrm{sys}) \times 10^{-3}\ sr^{-1}$$
$$\frac{dN_\mathrm{t}}{N_\mathrm{C} d\Omega}(\theta = 60^\circ) = (0.91 \pm 0.01_\mathrm{stat} \pm 0.21_\mathrm{sys}) \times 10^{-3}\ sr^{-1}$$

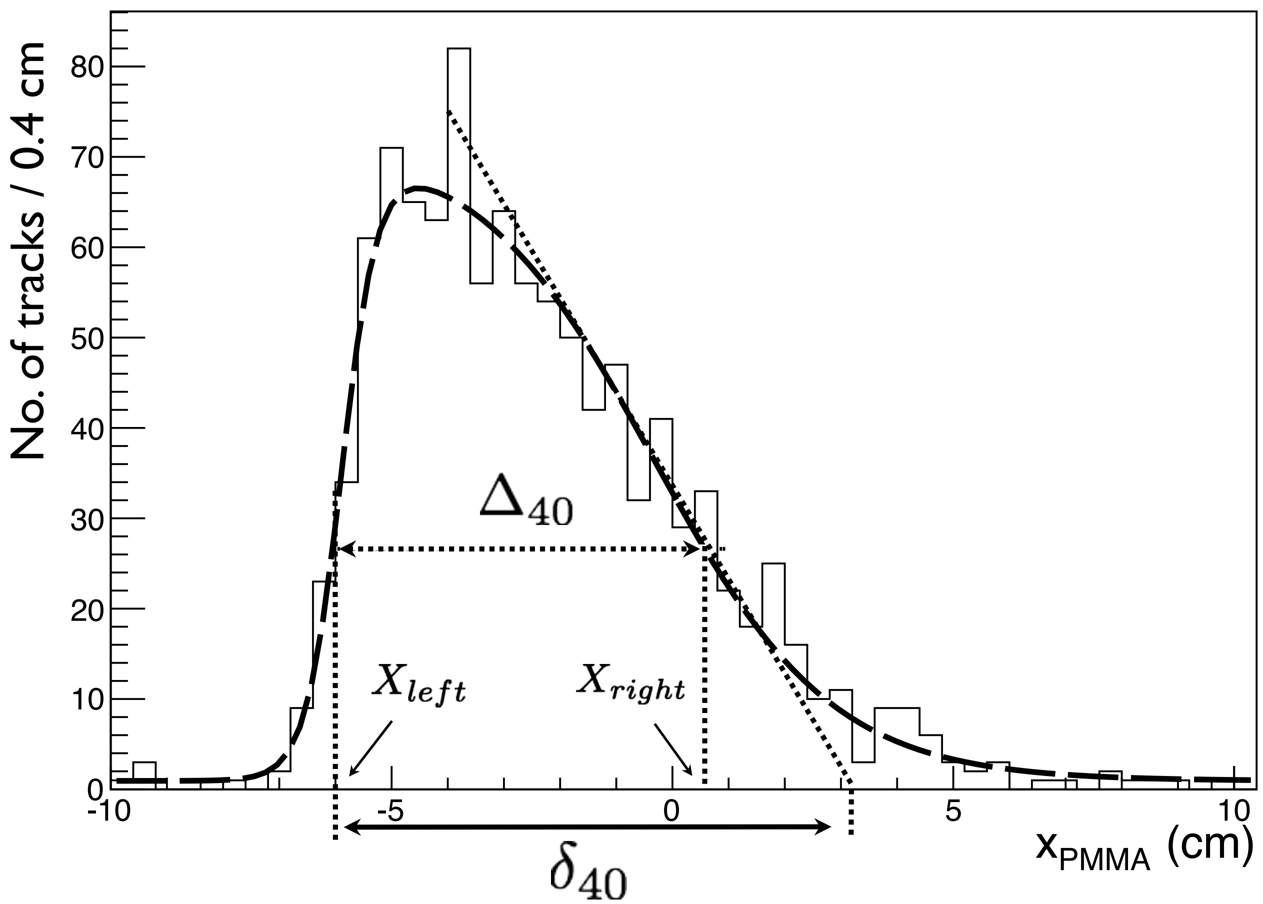
$$\frac{dN_\mathrm{p}}{N_\mathrm{C} d\Omega}(\theta = 90^\circ) = (1.83 \pm 0.02_\mathrm{stat} \pm 0.14_\mathrm{sys}) \times 10^{-3}\ sr^{-1}$$
$$\frac{dN_\mathrm{d}}{N_\mathrm{C} d\Omega}(\theta = 90^\circ) = (0.78 \pm 0.01_\mathrm{stat} \pm 0.09_\mathrm{sys}) \times 10^{-3}\ sr^{-1}$$
$$\frac{dN_\mathrm{t}}{N_\mathrm{C} d\Omega}(\theta = 90^\circ) = (0.128 \pm 0.005_\mathrm{stat} \pm 0.028_\mathrm{sys}) \times 10^{-3}\ sr^{-1}$$

The measurements are systematically dominated, where the leading contributions to the uncertainties are coming from the PID (see section 3.2 for details) and DAQ dead time evaluations.

Protons

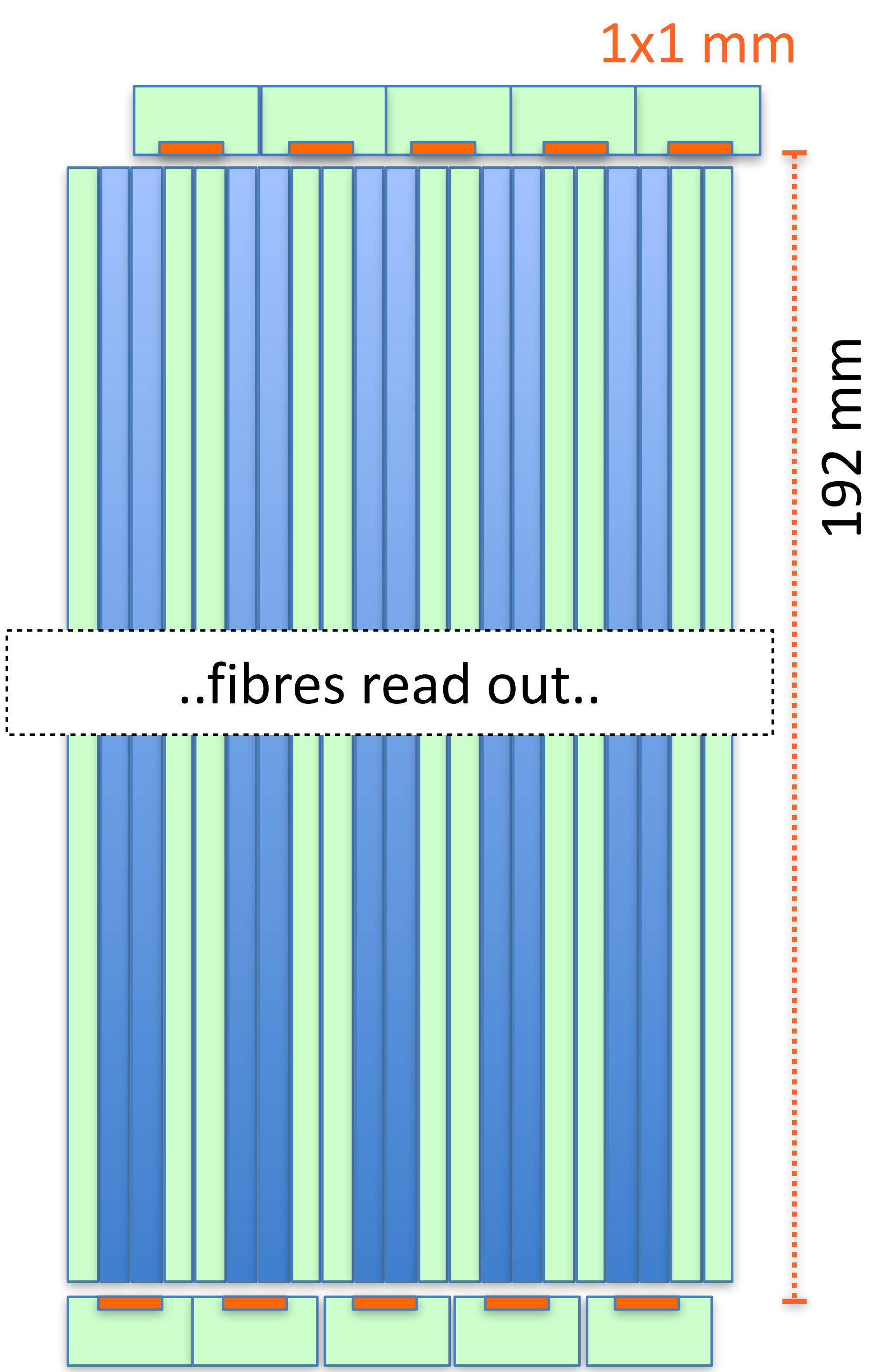


Arbitrary Units / 0.4 cm
Charged Emission
Released Dose
x_{PMMA} (cm)



No. of tracks / 0.4 cm
Δ_{40}
X_{left}
X_{right}
δ_{40}
x_{PMMA} (cm)

TRACKER: planes' readout



- new MPPC (SiPM) => higher efficiency (35%)/noise ratio

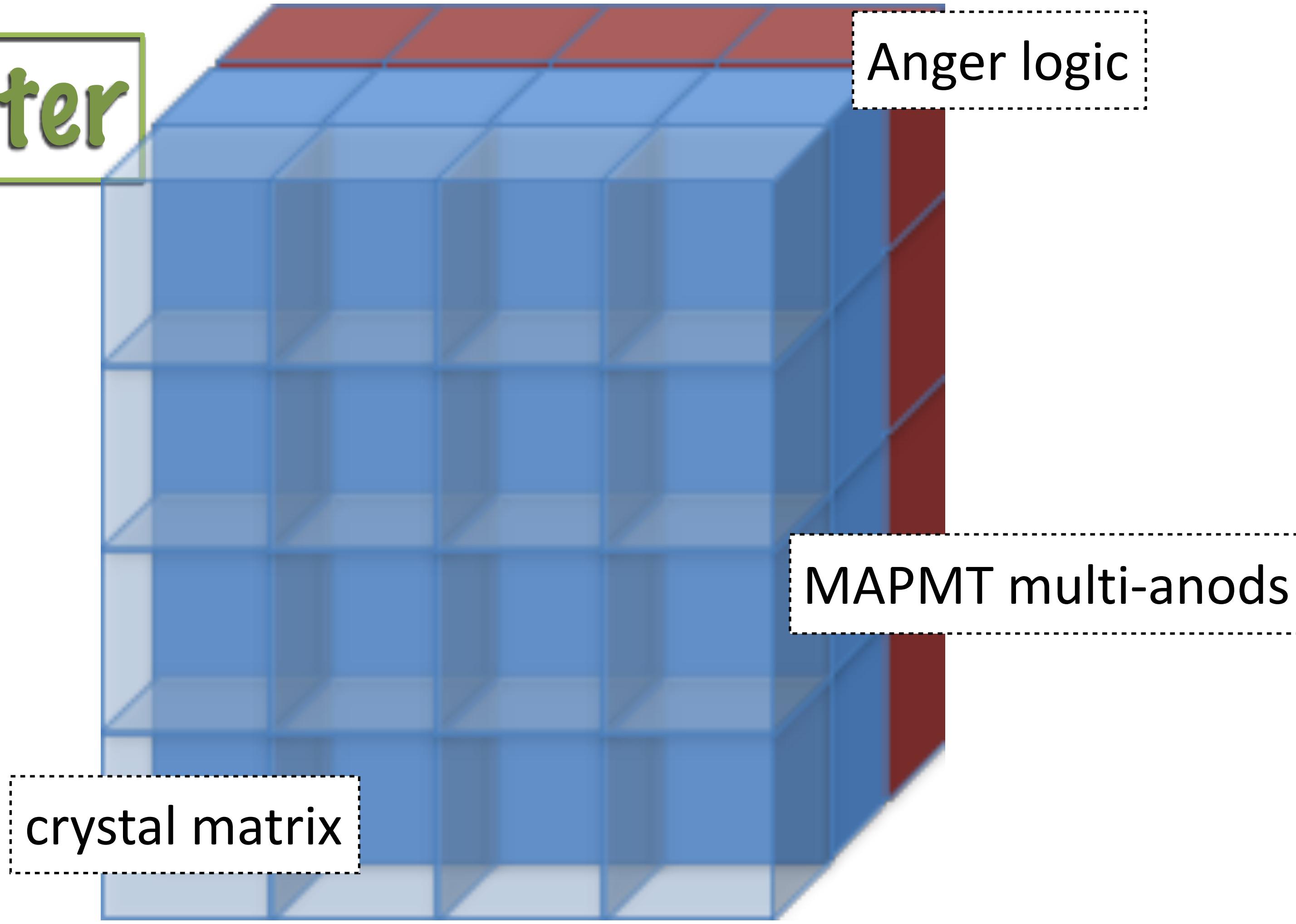
  (two 1mmx1mm pieces now at Milan)

- 20x20 pixel (50μmx50μm) => for one fiber 10x10 pixel

  For a m.i.p.: 2MeV/cm = 20000 ph/cm = 1000 ph/fiber

  => 1000 x 4% x 35% ~ 17 p.e./fiber/m.i.p.

Calorimeter

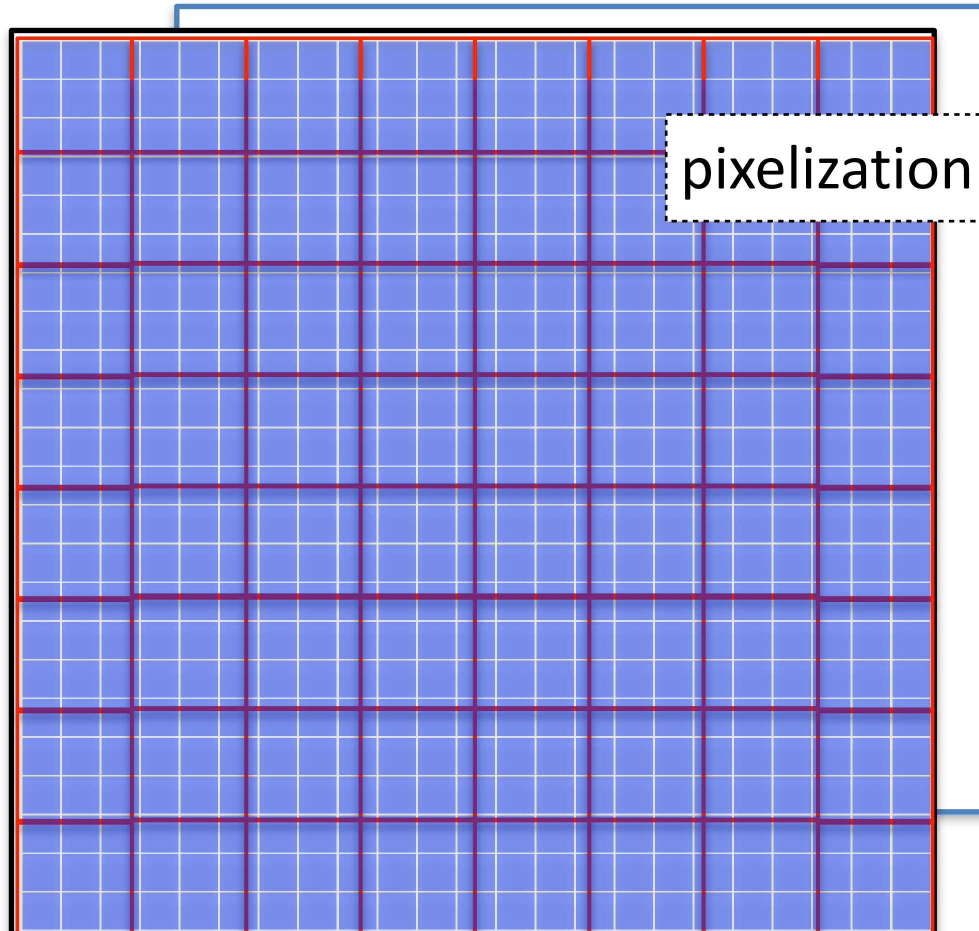


<u>LYSO matrices from ??:</u>

- Hilger "oldPISA"
- Epic "Cina"
- Hamamatsu "PET"

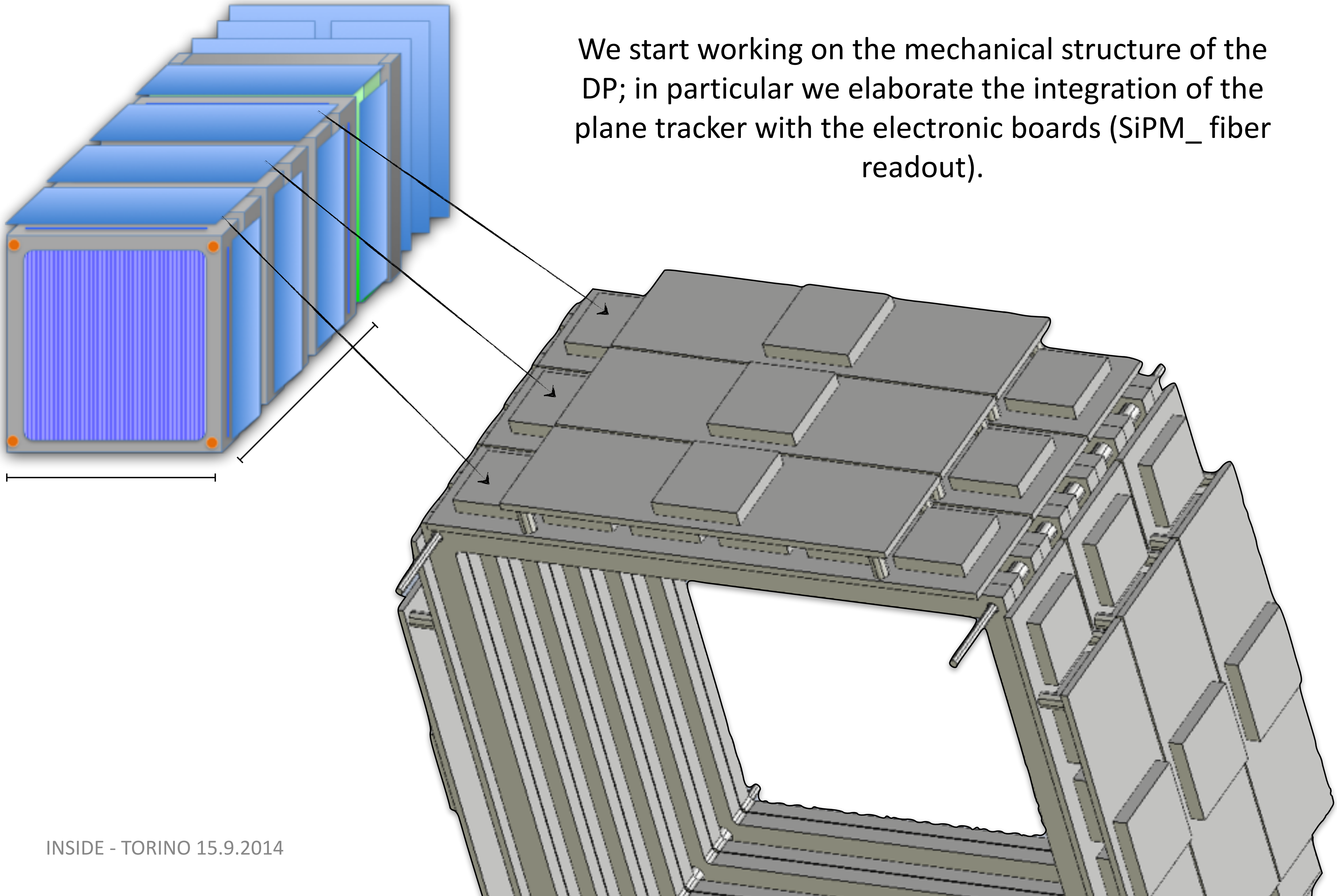
<u>16 MAPMT H8500:</u>

- already purchased
- partially tested



- 8 x 8 pixels PMT
- 23 x 23 pixels crystals

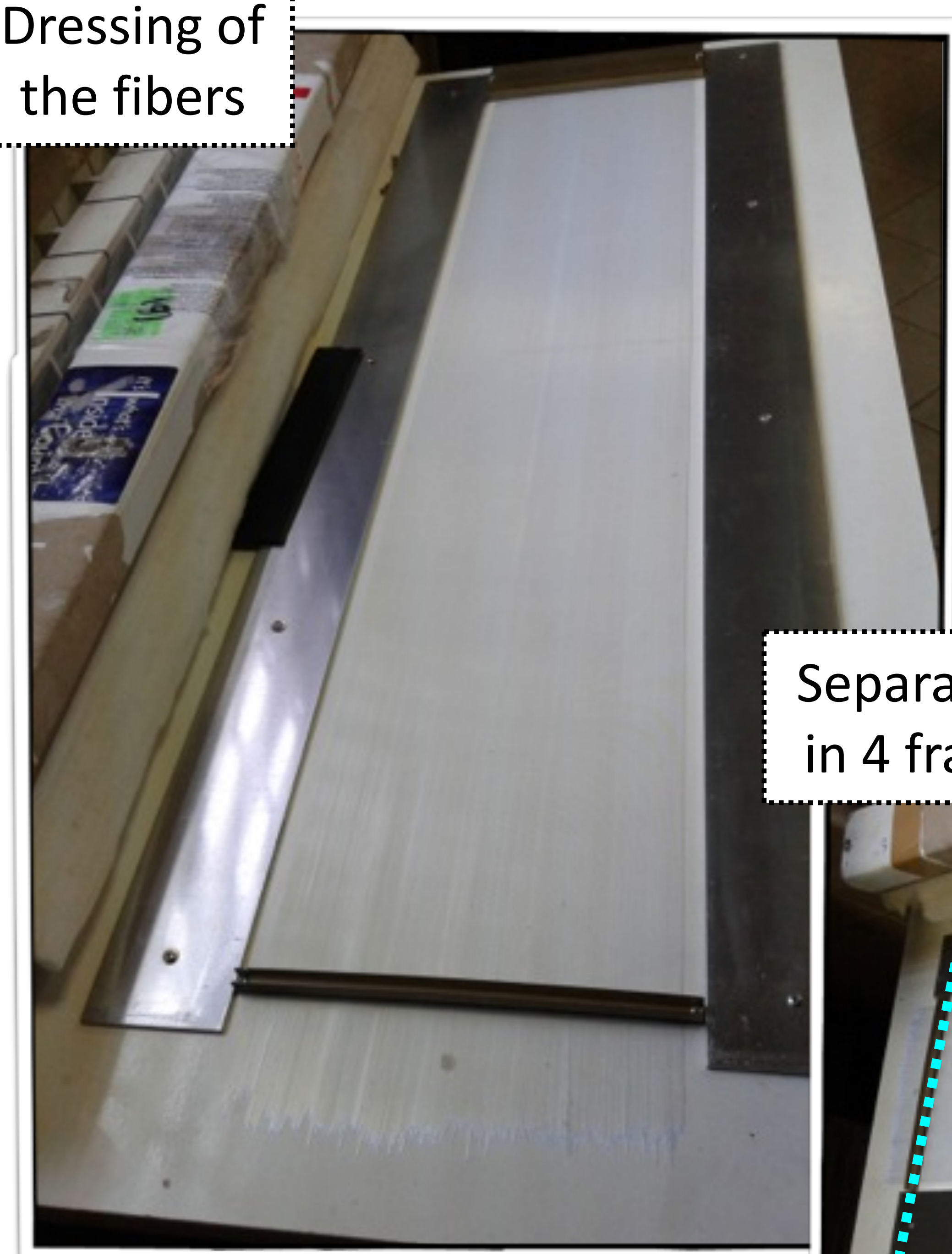
DP: STRUTTURA MECCANICA del TRACKER



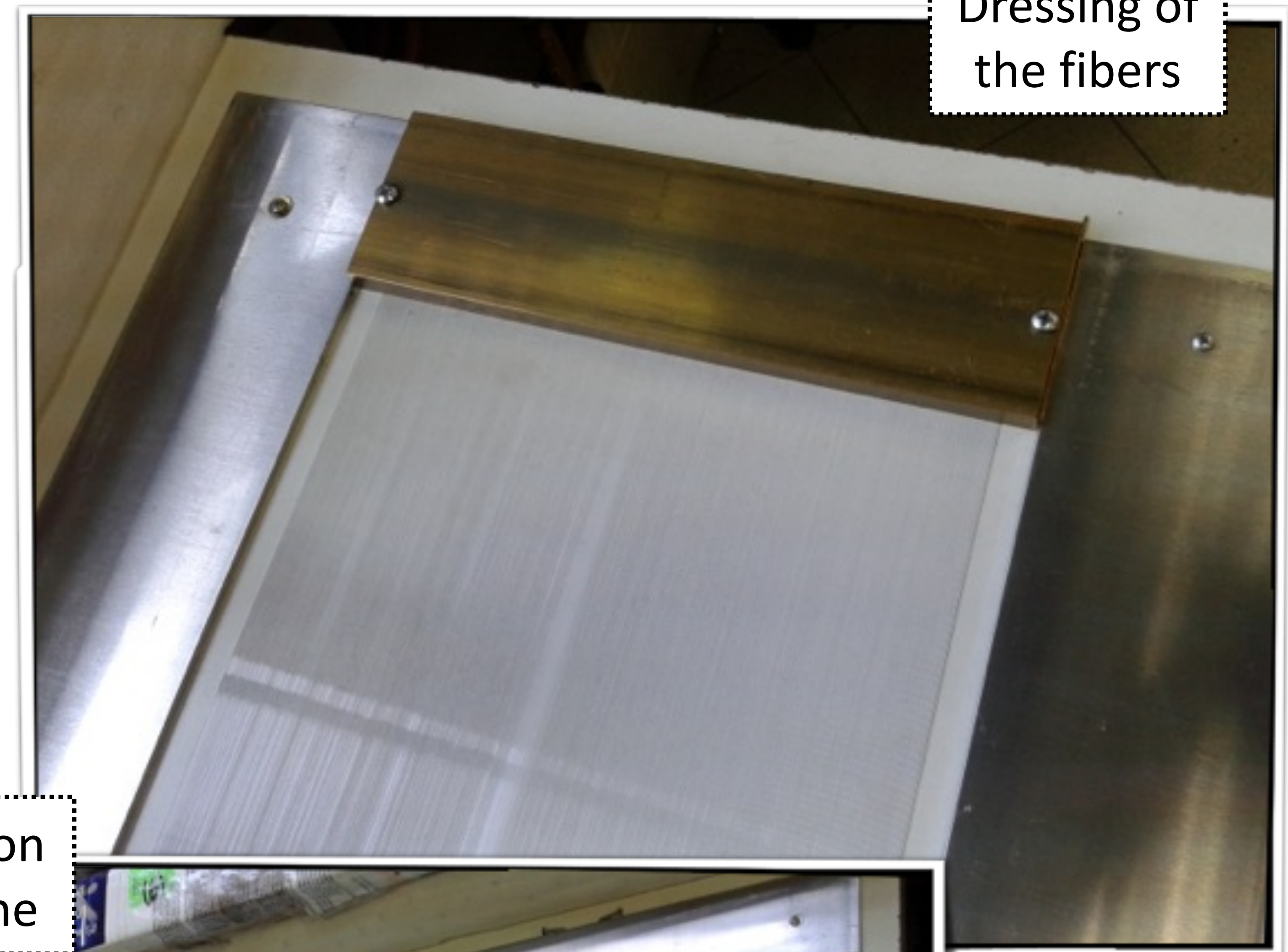
We start working on the mechanical structure of the DP; in particular we elaborate the integration of the plane tracker with the electronic boards (SiPM_ fiber readout).

STRUTTURA MECCANICA

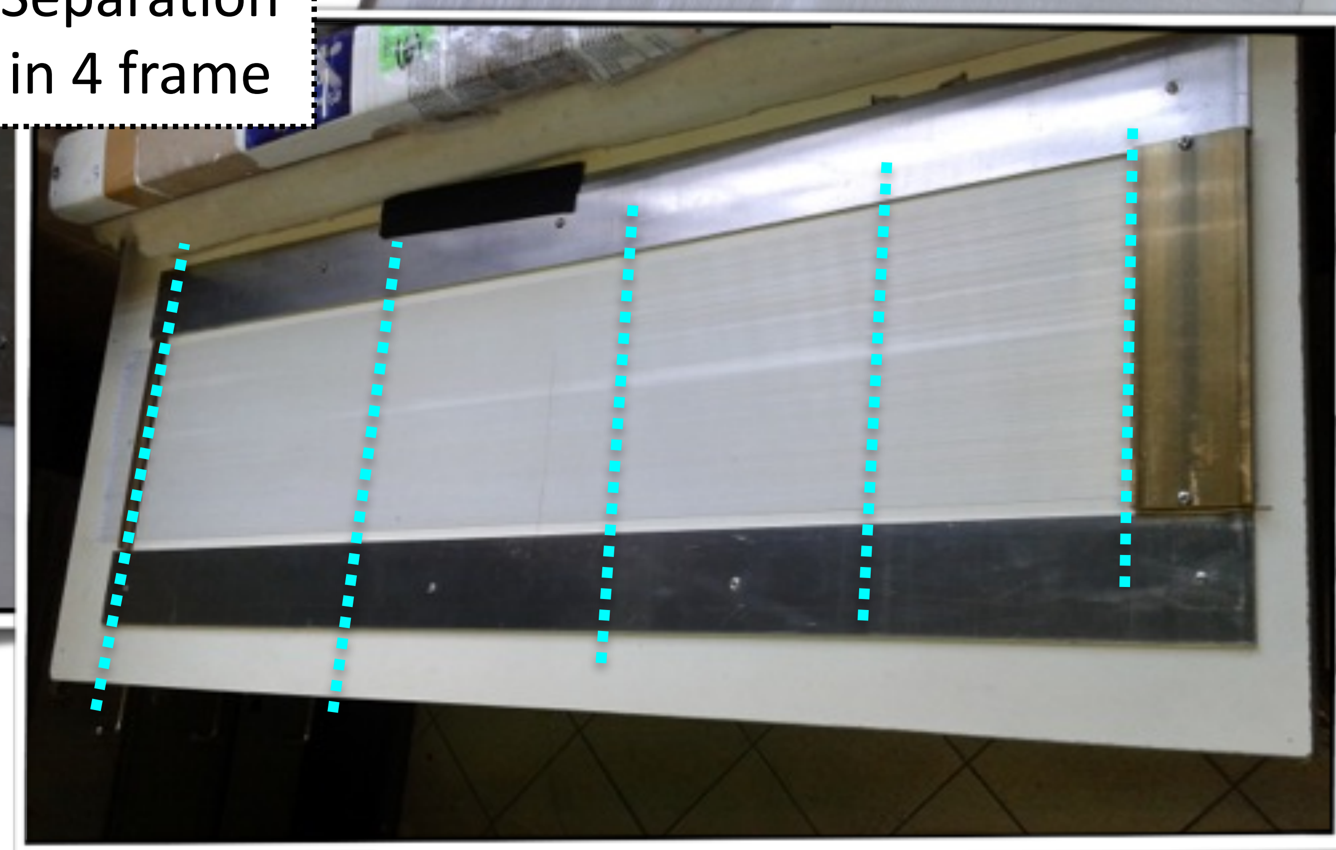
Dressing of the fibers



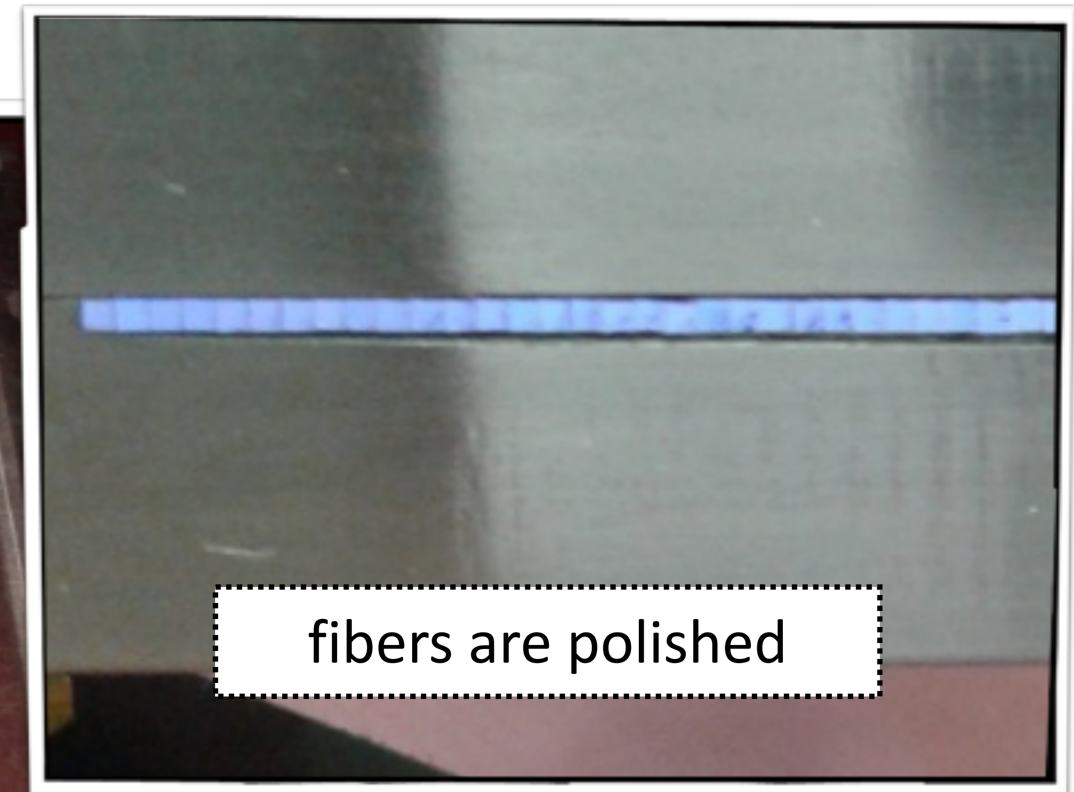
Dressing of the fibers

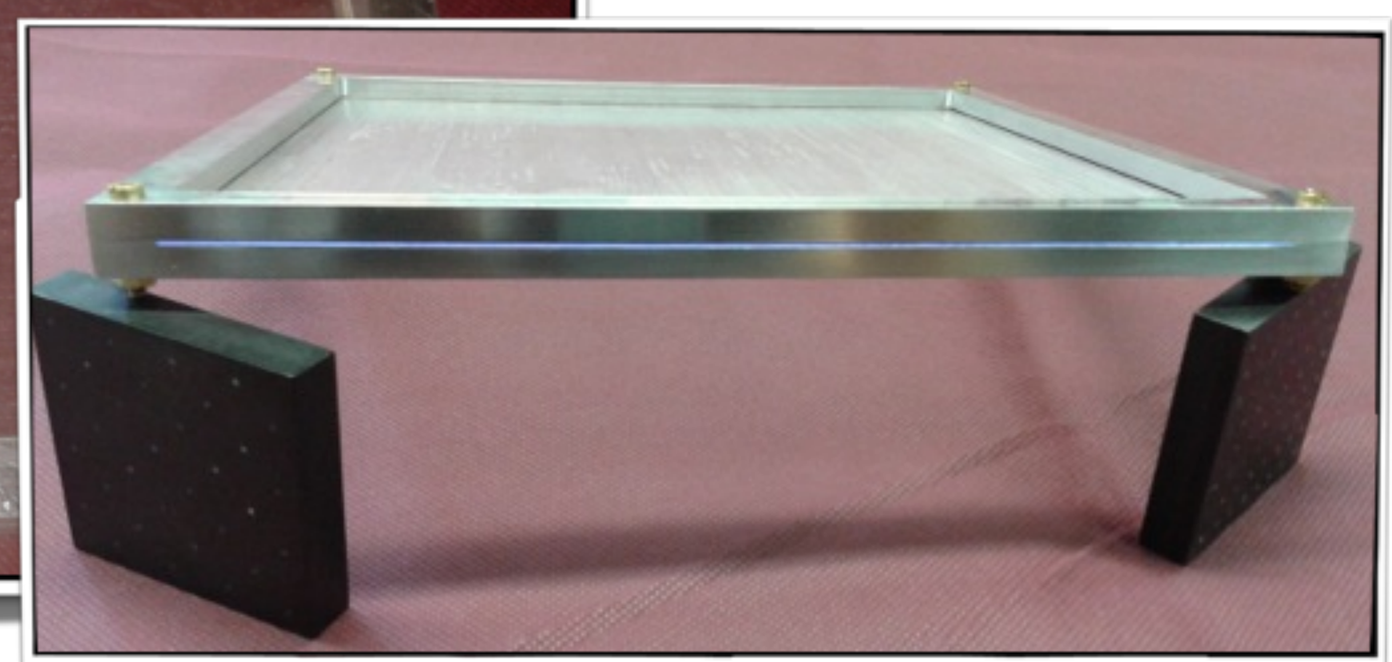


Separation in 4 frame

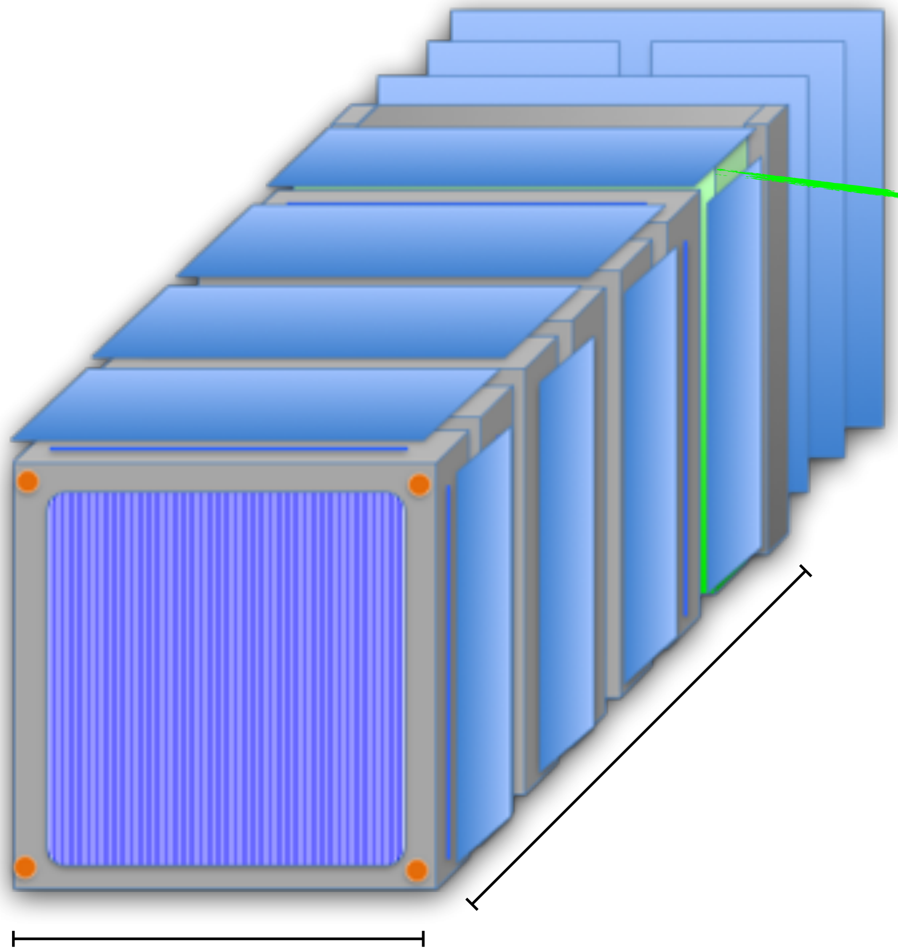


DP: STRUTTURA MECCANICA del TRACKER

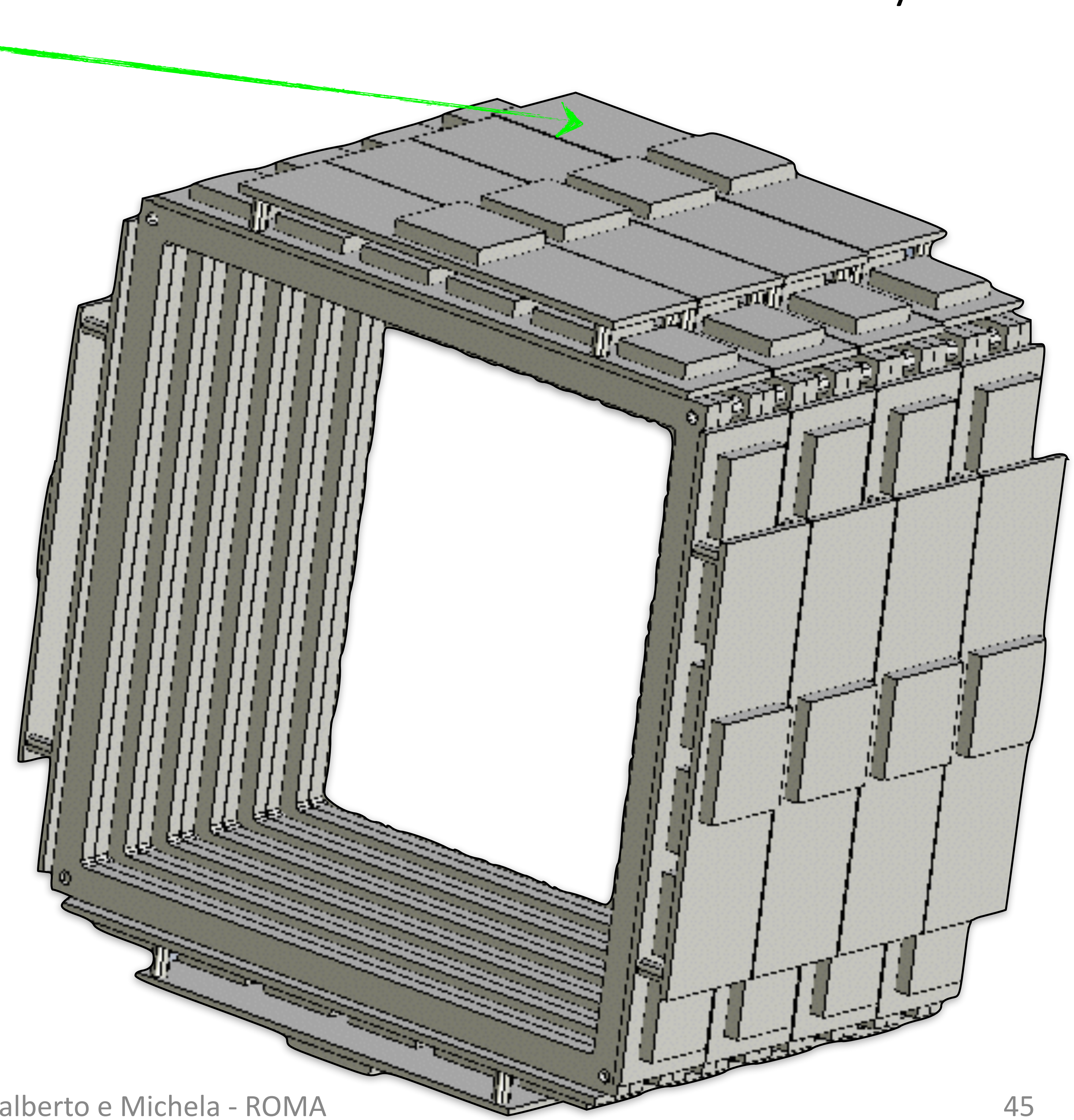




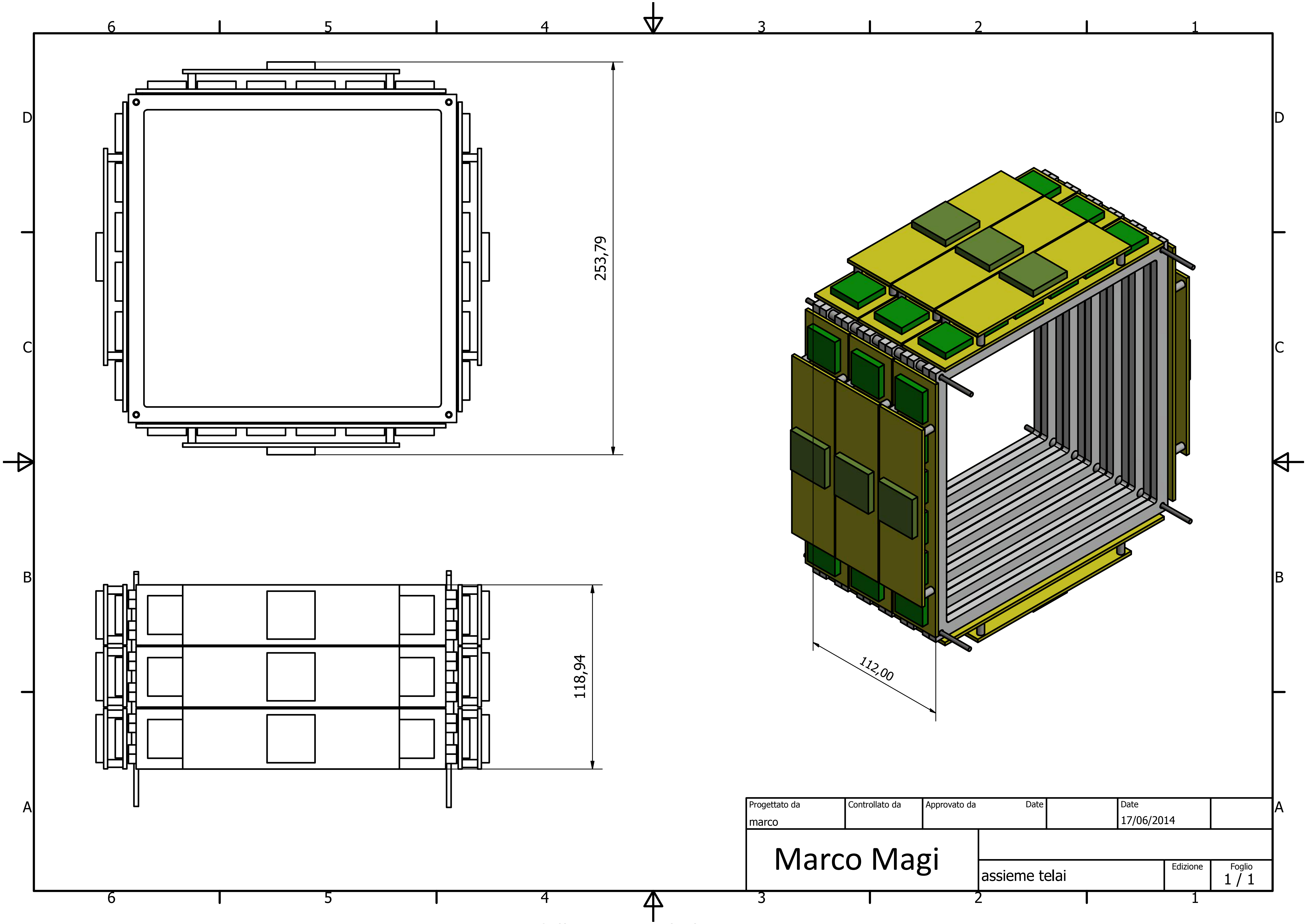
DP: STRUTTURA MECCANICA del TRACKER



The scintillator layer are read out with the same SiPM electronics of the tracker layers.

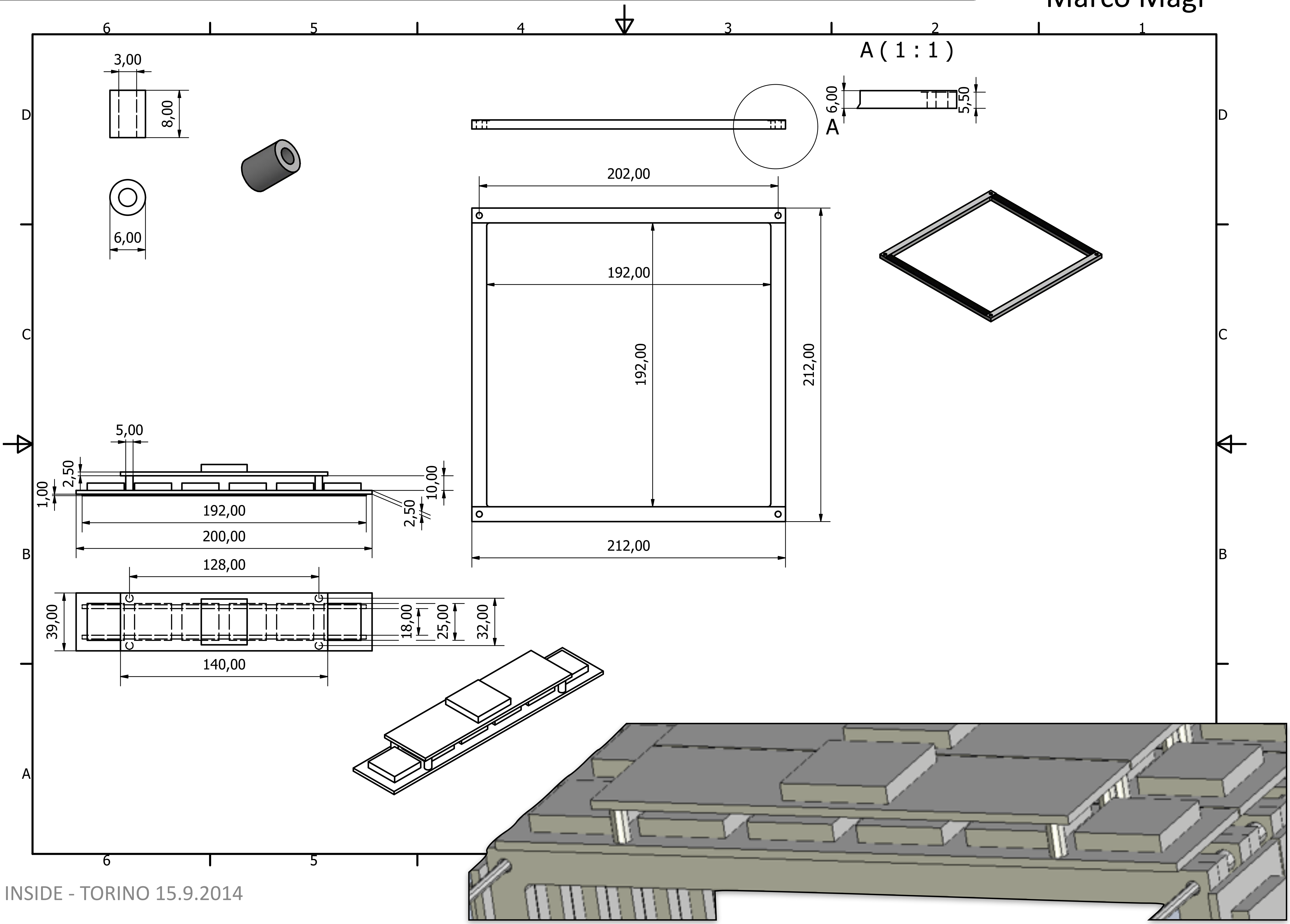


DP: STRUTTURA MECCANICA del TRACKER



DP: STRUTTURA MECCANICA del TRACKER

Marco Magi



Time Schedule

from MILANO March 2014

2013

- profiler **layout optimization** with MC
- reconstruction algorithm development

2014

- fibers test
- electronics and DAQ design
- one plane module assembly => M.Magi
- other planes assembly and tests .. before Christmas!
- stand alone mechanics
- electronics production
- calorimeter realization

Milan is working to the test board
LNF start working effectively from June!

up to now we are here!!

2015

- profiler assembly (mechanics, electronics, DAQ &TRG)
- **integration HW & SW**
- global device test & characterization

PET