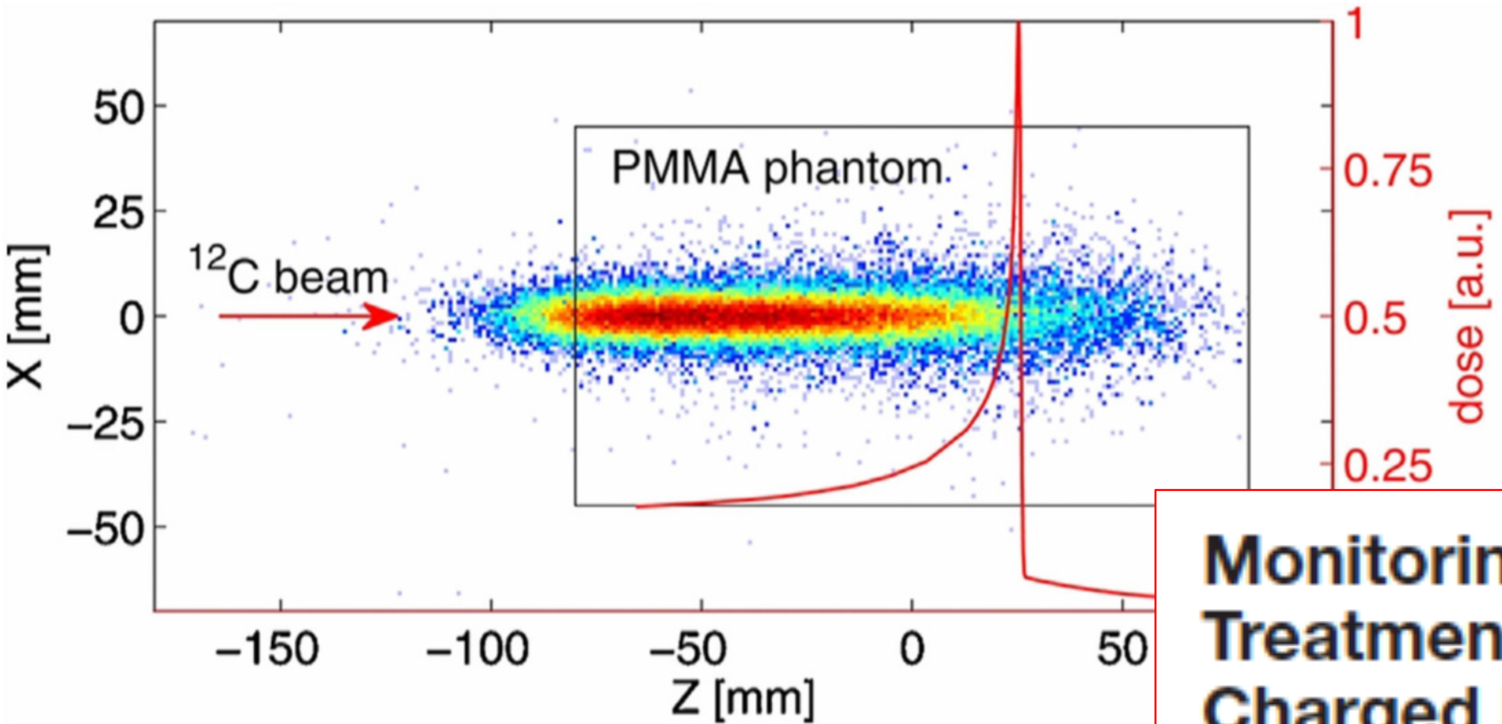
Range monitoring with charged particles

Giacomo Traini

RDH Meeting - Roma, 1st February 2017

12C beam range monitoring with secondary charged particles



Measured emission shape of protons outside a 5 cm thick PMMA at 90^0 wrt the direction of 220 AMeV ^{12}C beam
L.Piersanti et al. PMB, 2014

Front. Oncol. 6:177.
doi: 10.3389/fonc.2016.00177

Monitoring of Hadrontherapy Treatments by Means of Charged Particle Detection

Silvia Muraro[1], Giuseppe Battistoni[1], Francesco Collamati[2], Erika De Lucia[2], Riccardo Faccini[3,4], Fernando Ferroni[3,4], Salvatore Fiore[4,5], Paola Frallicciardi[6,7], Michela Marafini[4,8], Ilaria Mattei[1], Silvio Morganti[3,4], Riccardo Paramatti[4], Luca Piersanti[2], Davide Pinci[4], Antoni Rucinski[4,6], Andrea Russomando[3,4], Alessio Sarti[4,6,9], Adalberto Sciubba[4,6,9], Elena Solfaroli-Camillocci[3,4], Marco Toppi[2], Giacomo Traini[3,4], Cecilia Voena[4] and Vincenzo Patera[4,6,9]*

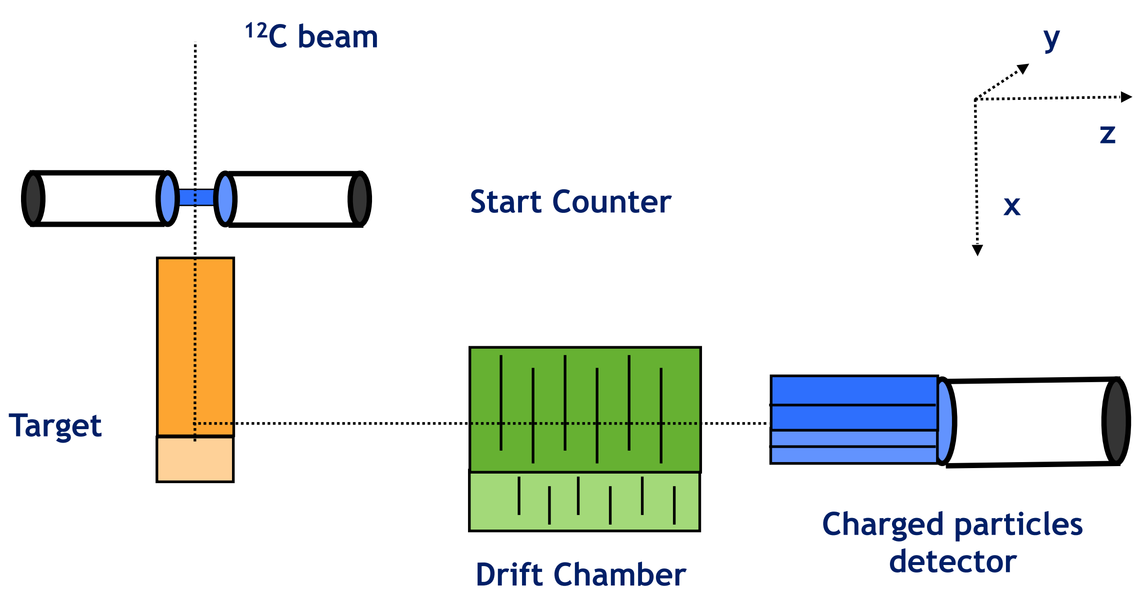
- Detection efficiency ~ 1
- Can be easily tracked to the emission point => correlation with the beam profile
- Forward peaked

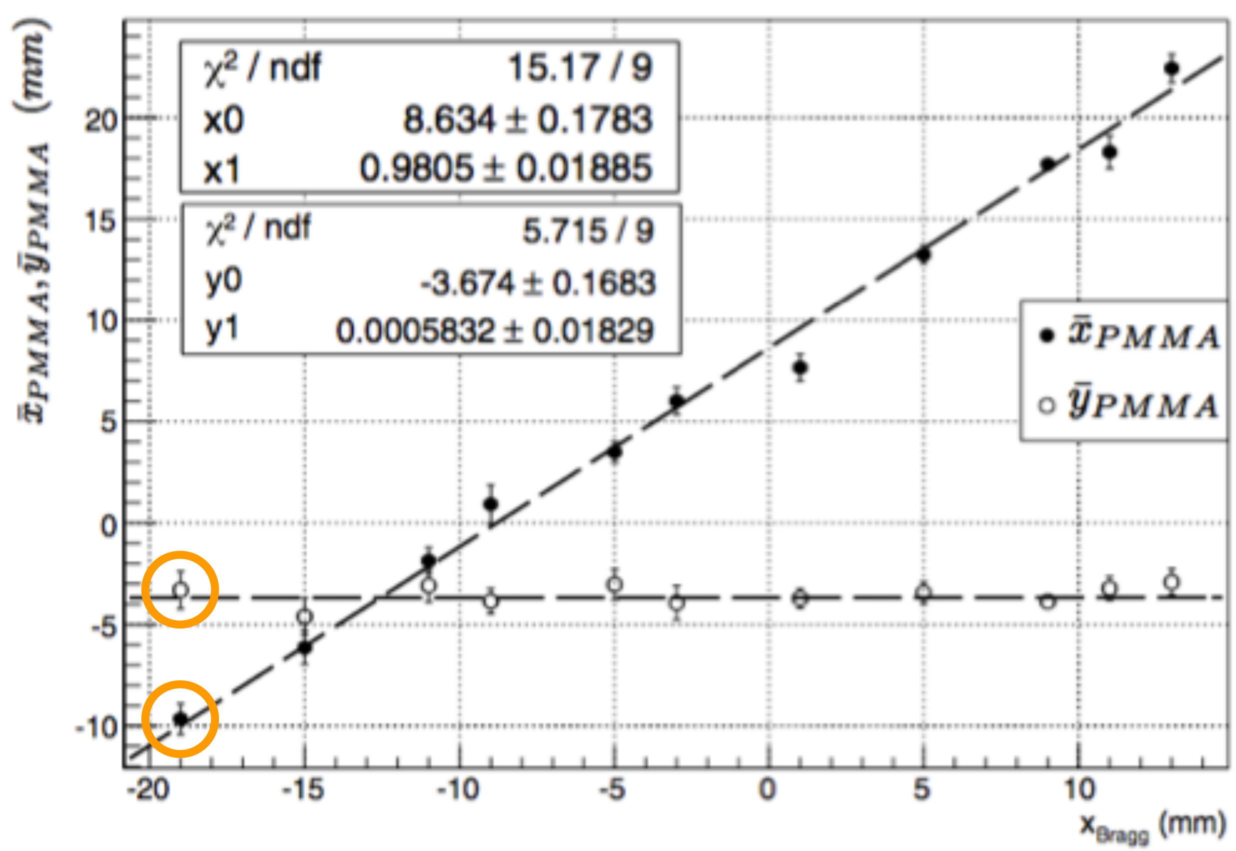
- Energy threshold to escape from the patient
- Multiple scattering worsen the back-pointing resolution

Charged secondary emitted from BP?

- Measurements **@LNS (Catania)** in 2011 with ^{12}C beam @ 80 MeV/u. Range in PMMA phantom ~ 1cm
- Correspond to the last part of the path in the patient of higher energy, longer range pencil beam
- Moving the target the charged particles signal follows

Agodi et al. PMB (2012)





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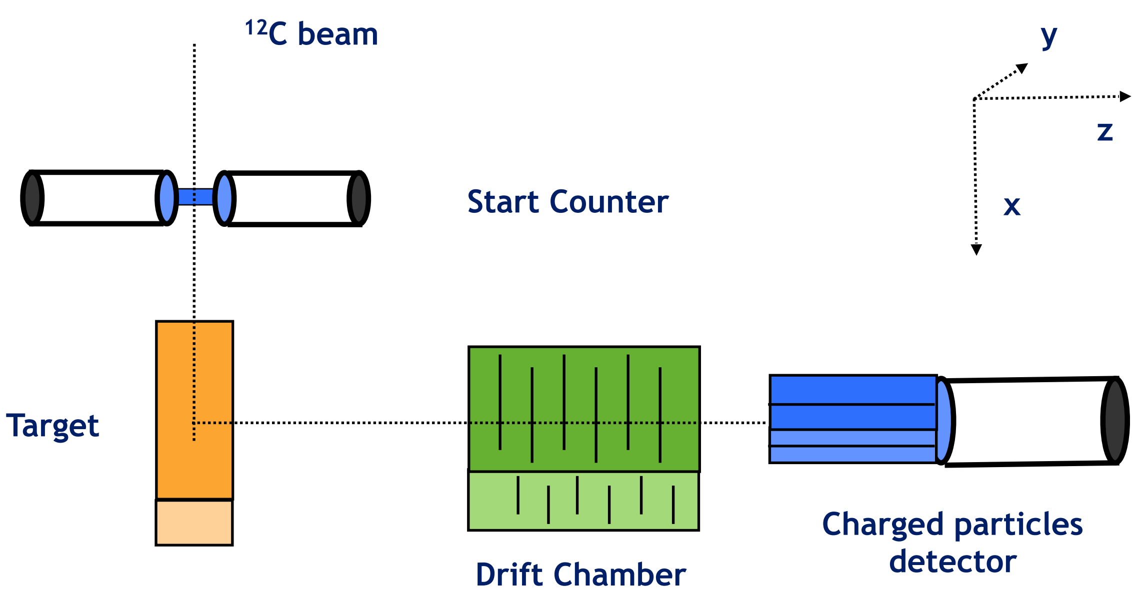

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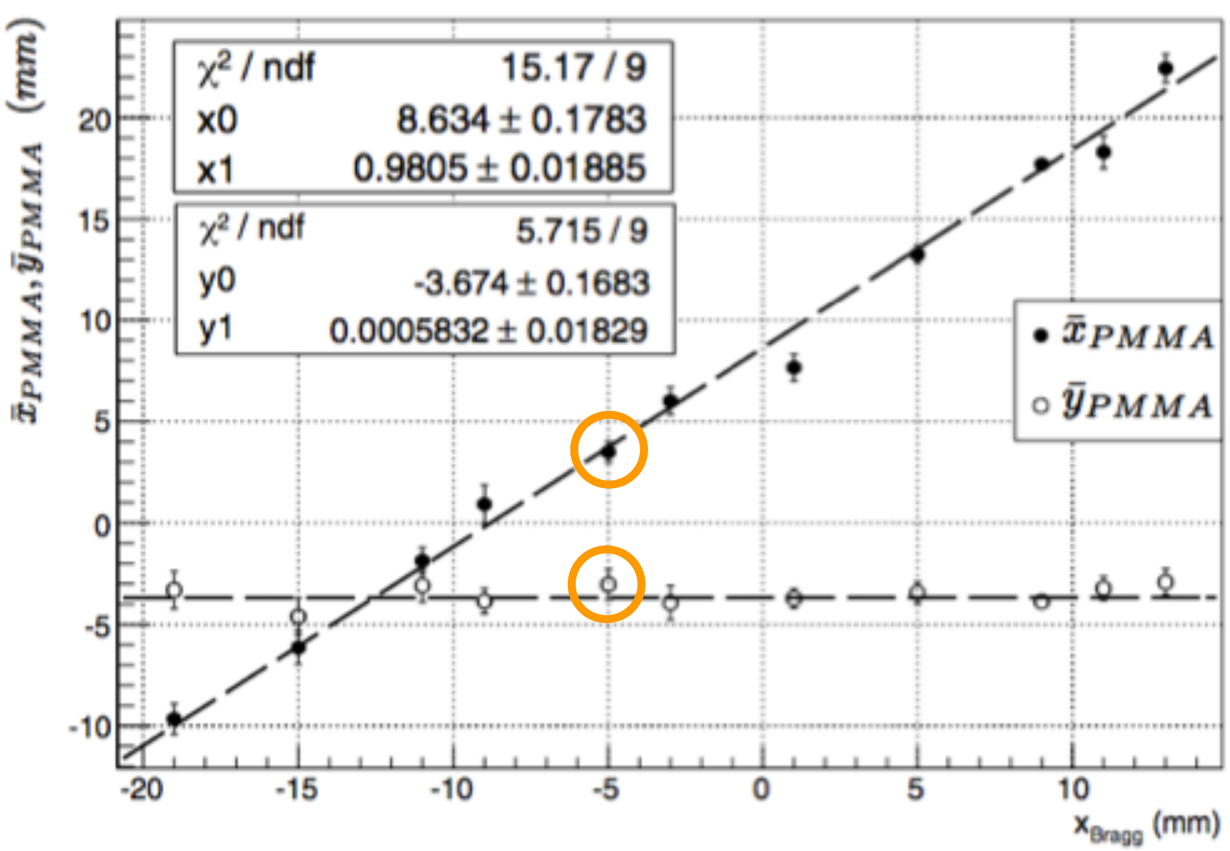

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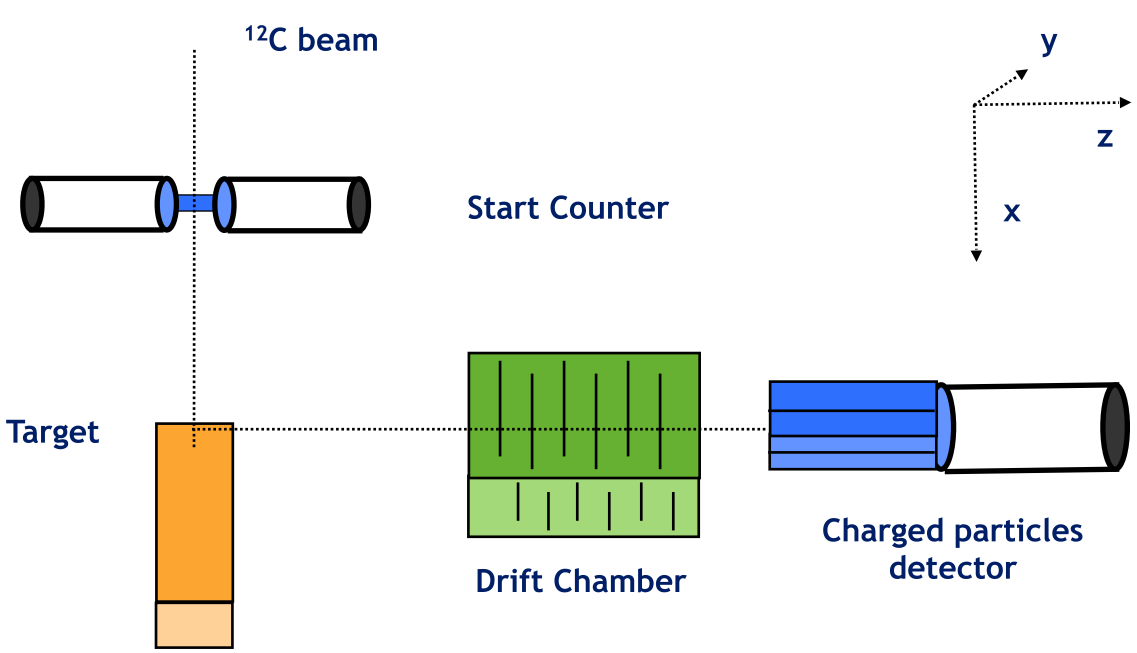

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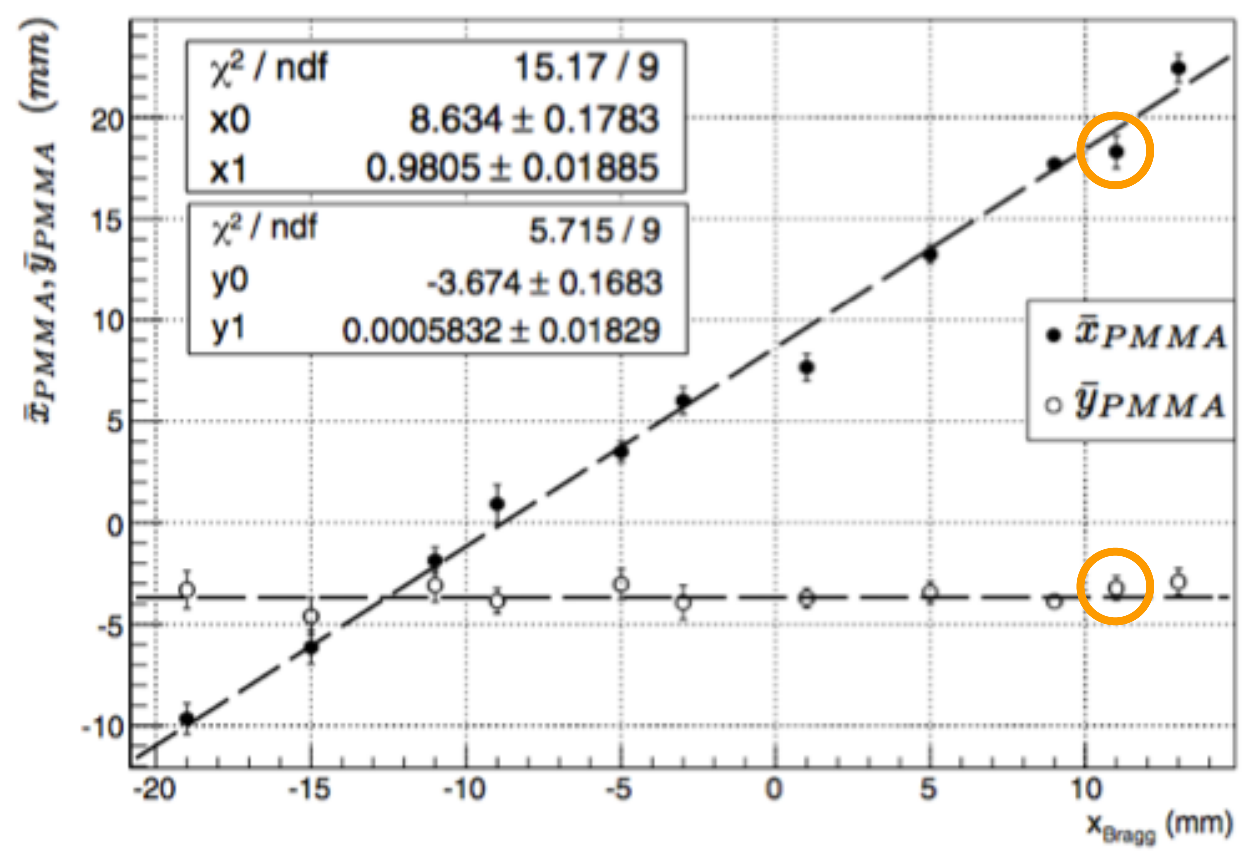
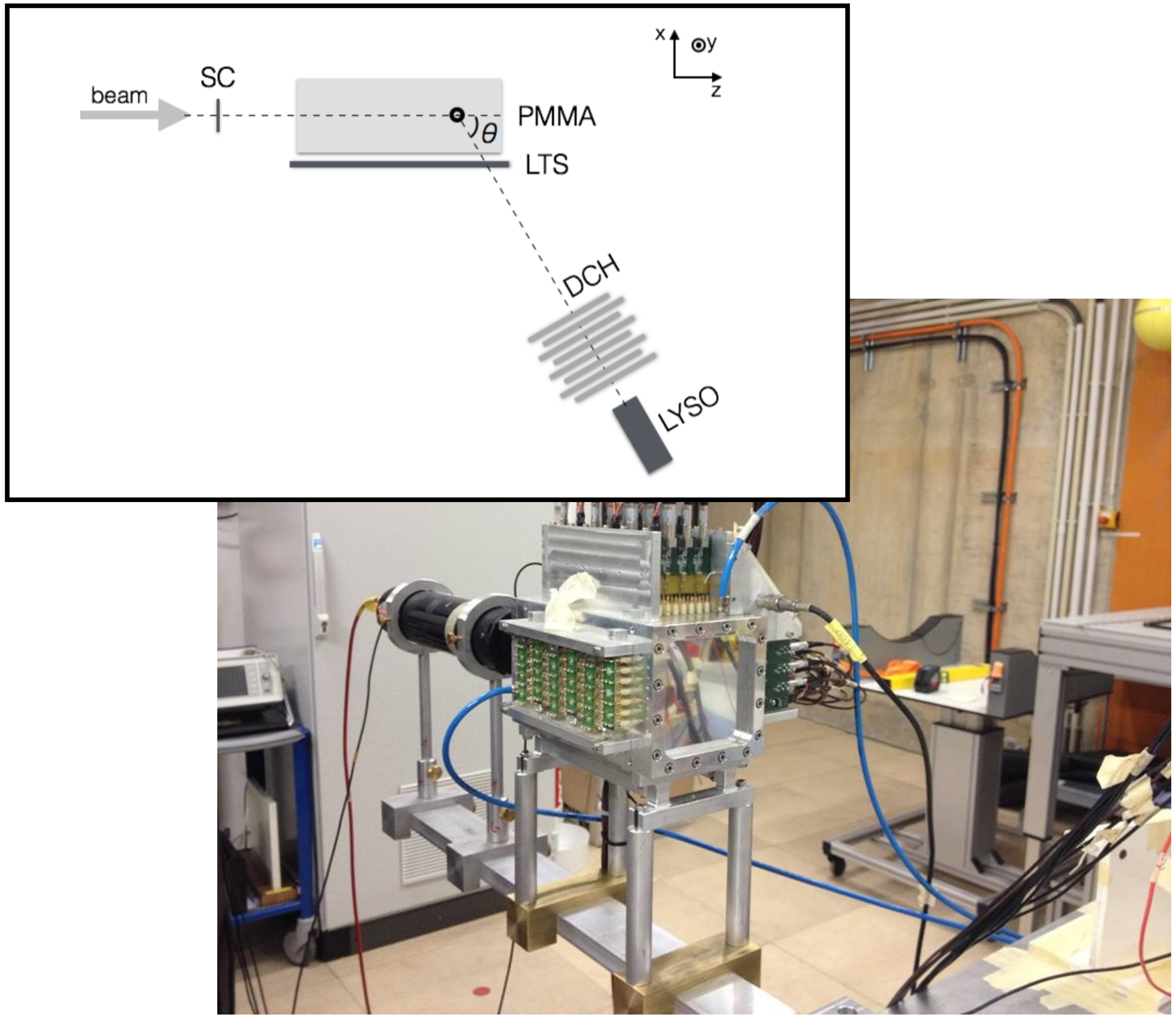
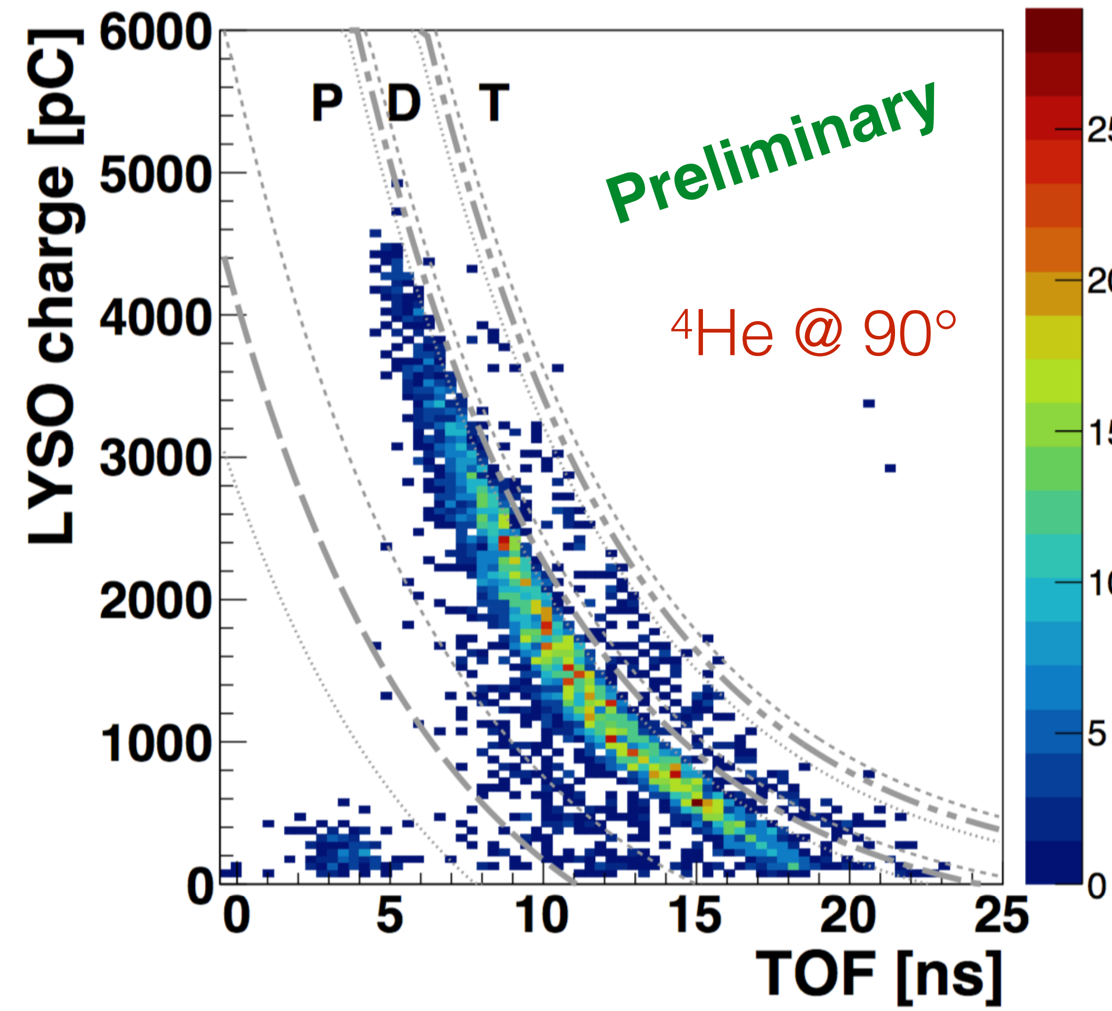


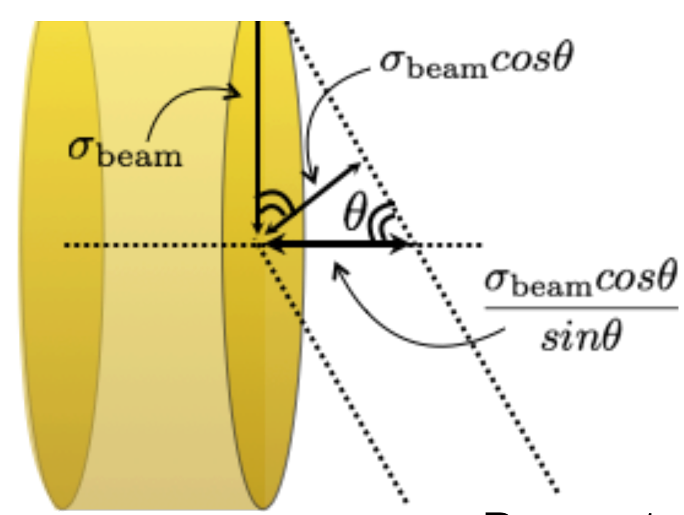
Charged particles production at large angle

- Study of secondary charged particles production at large angle (60°, 90°) **@GSI** (2012) with ^{12}C beam, and **@HIT** (2014) with ^{12}C, ^{4}He, ^{16}O





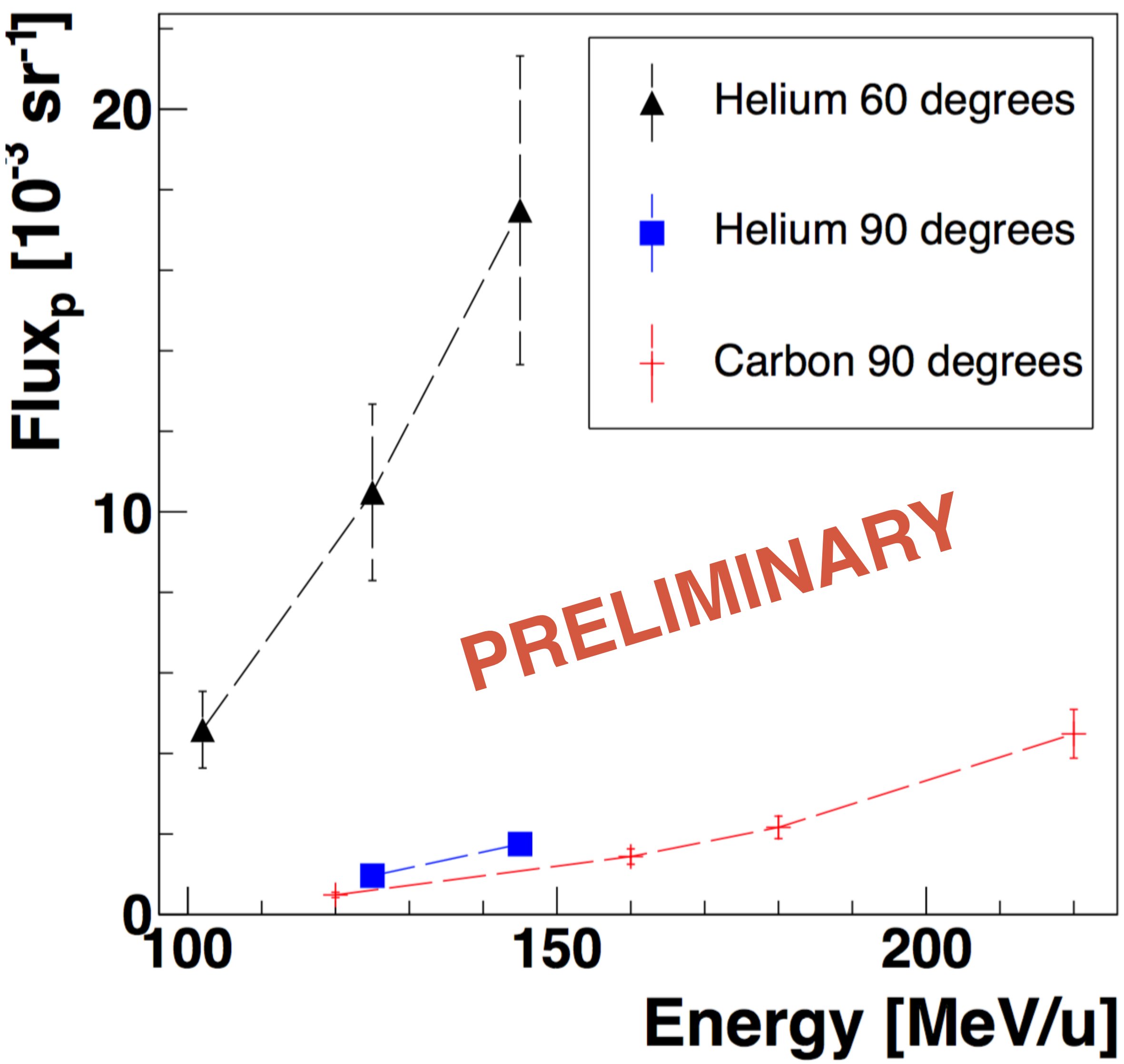
Space resolution and detection angle

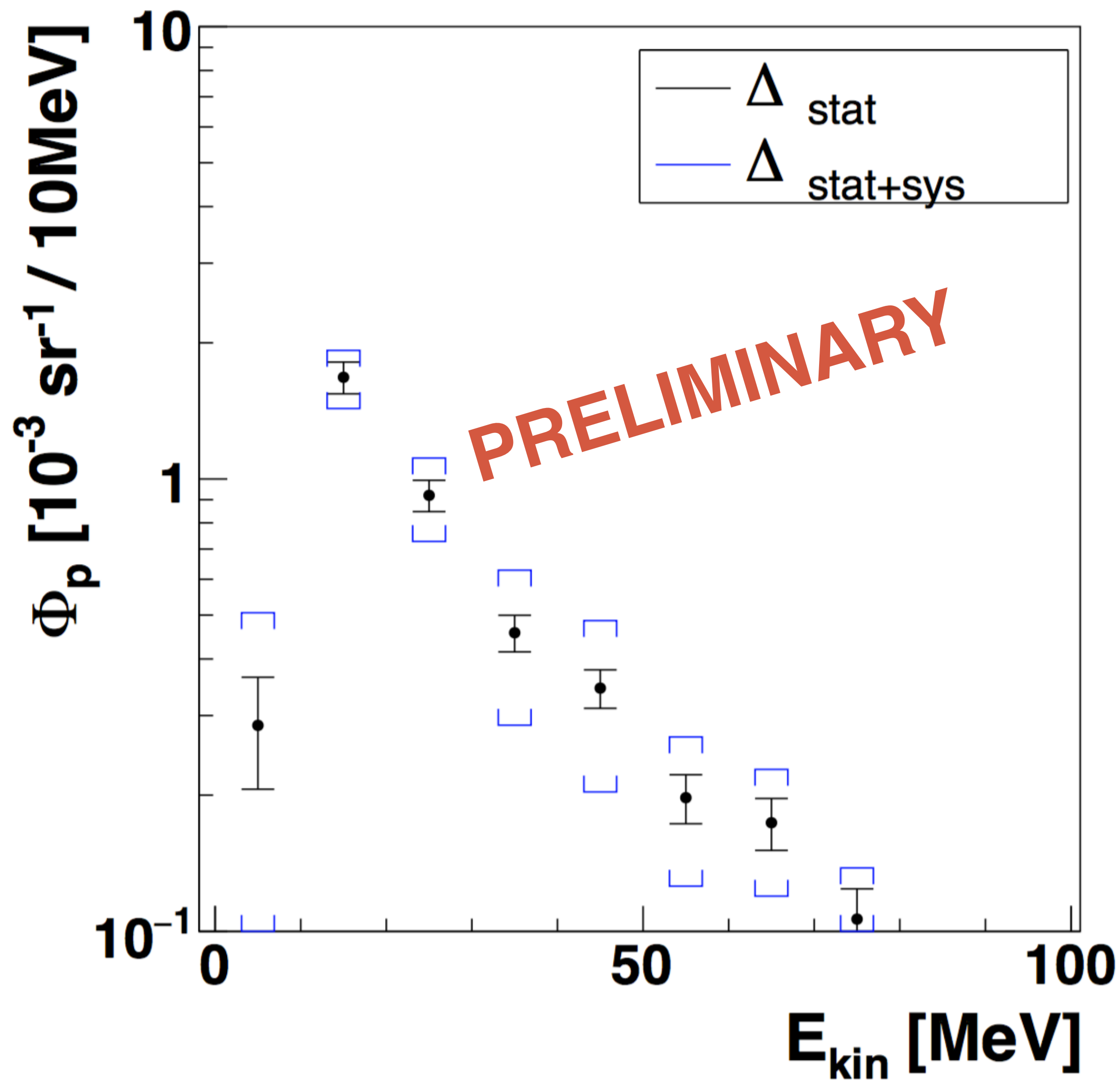


Charged particles production: fluxes and energy spectra

- A not negligible production of charged particles at large angles is observed for all beam types

Secondary charged particles measured @HIT



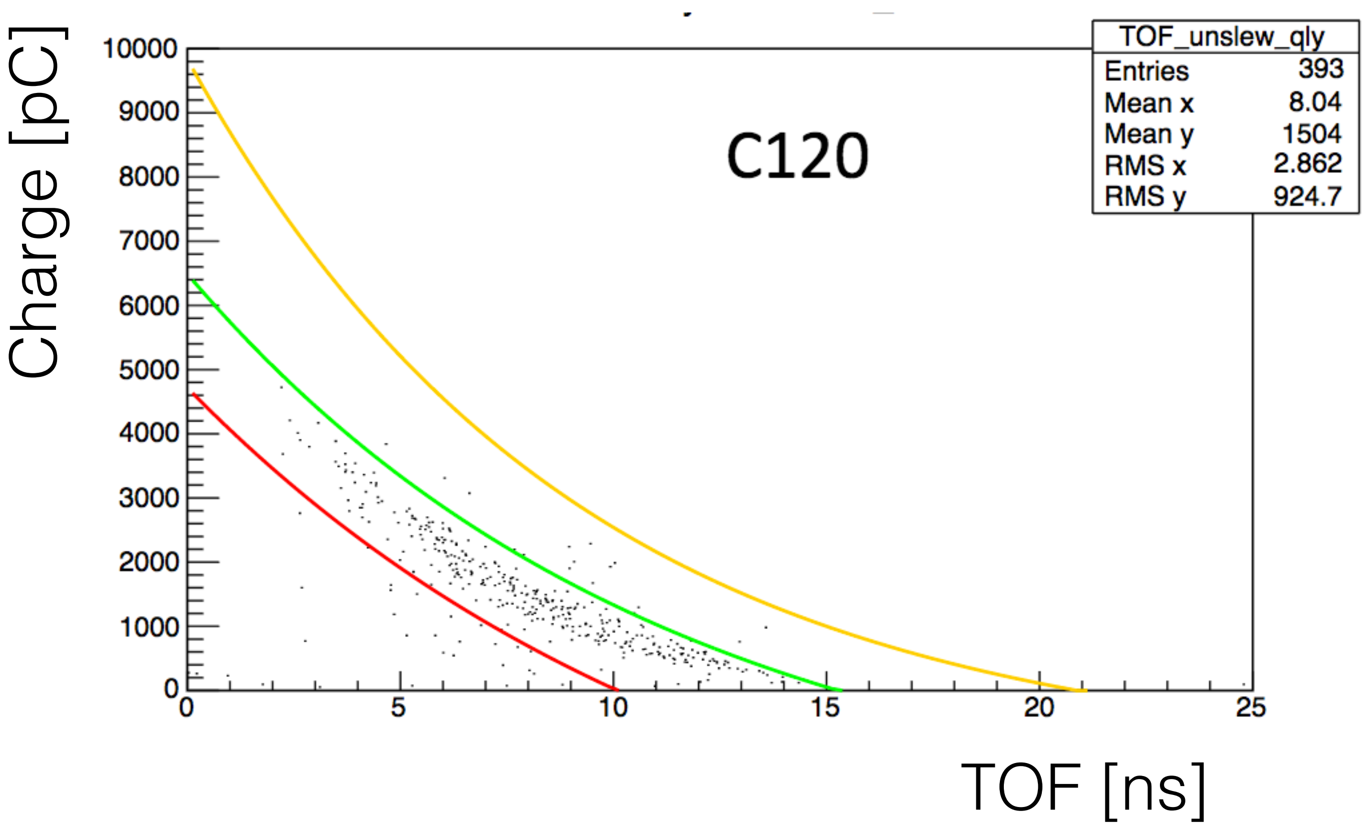


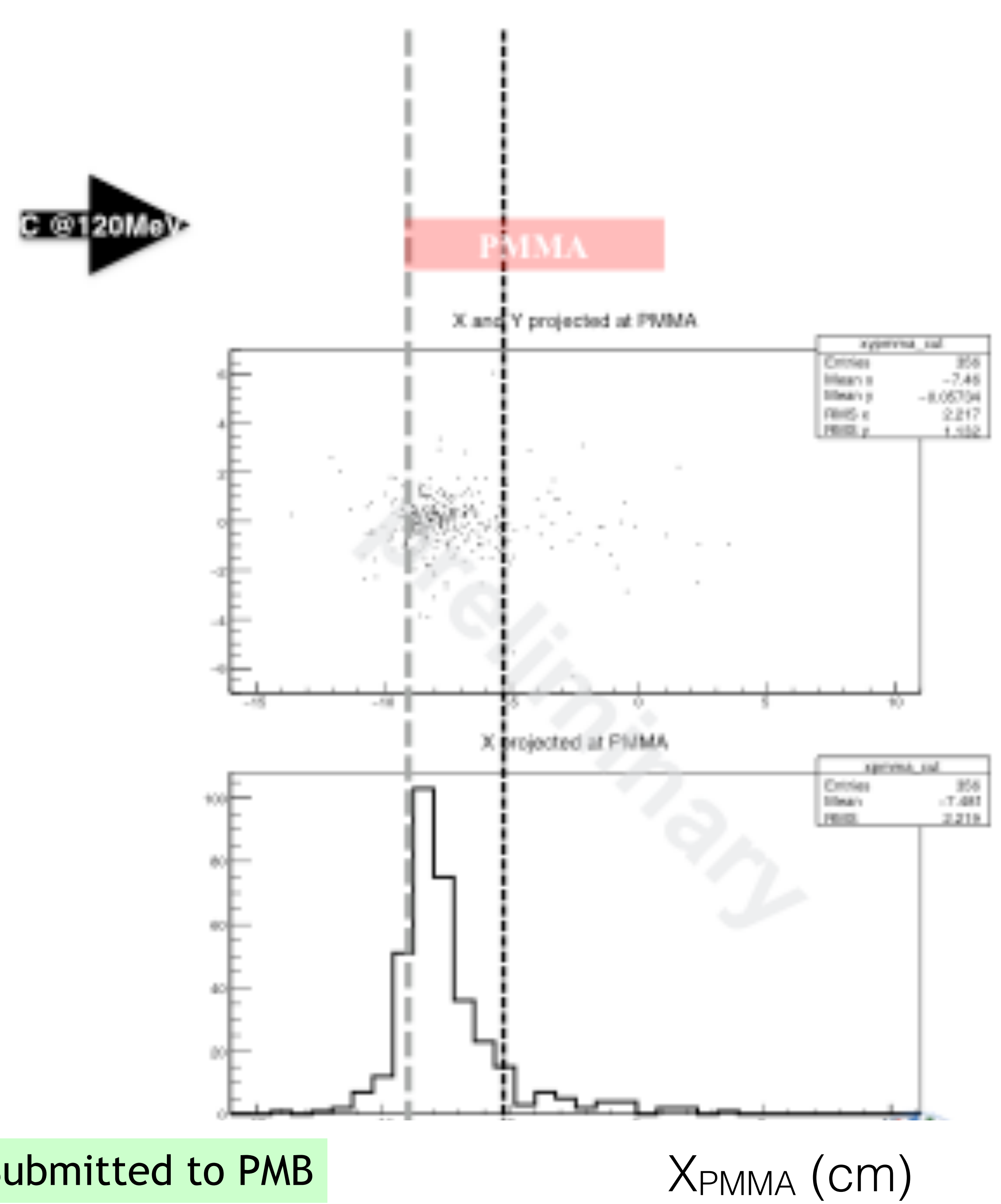
arXiv:1608.04624 Submitted to PMB

Correlation of range (BP position) and emission profile

Secondary charged particles measured @HIT

- The emission shape is correlated to the beam entrance face and BP position as already measured @ GSI with ^{12}C, [Piersanti et al., PMB 59 (2014)]





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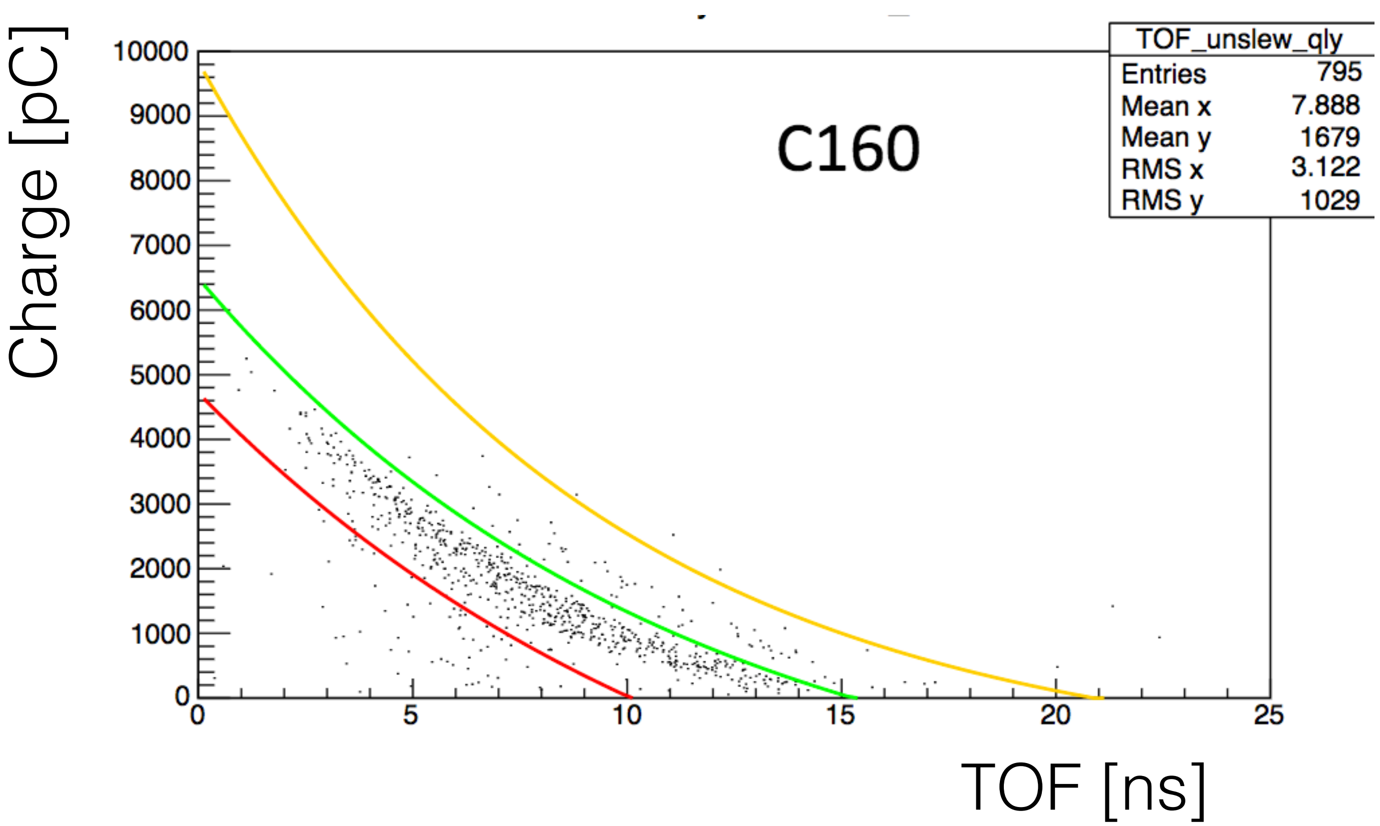

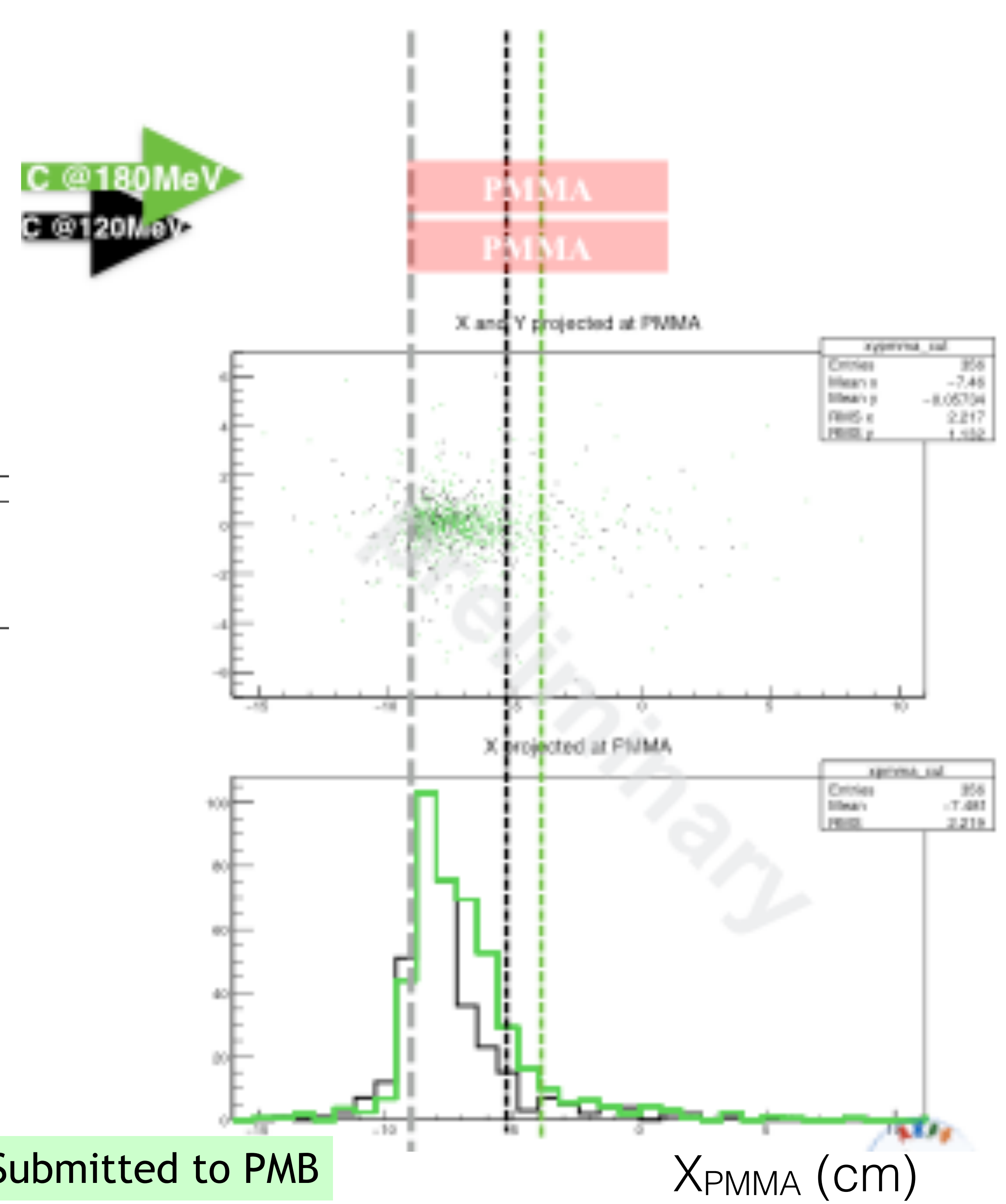

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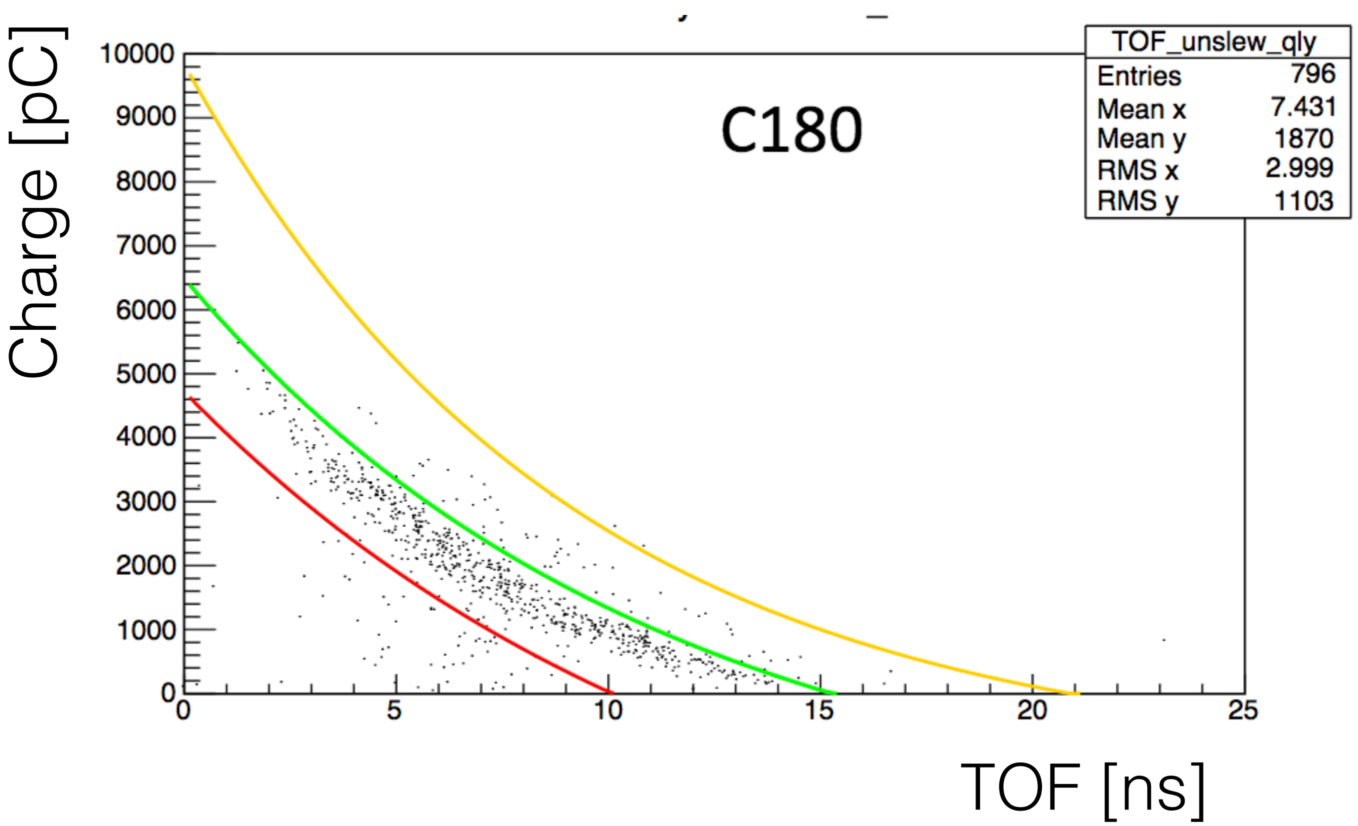

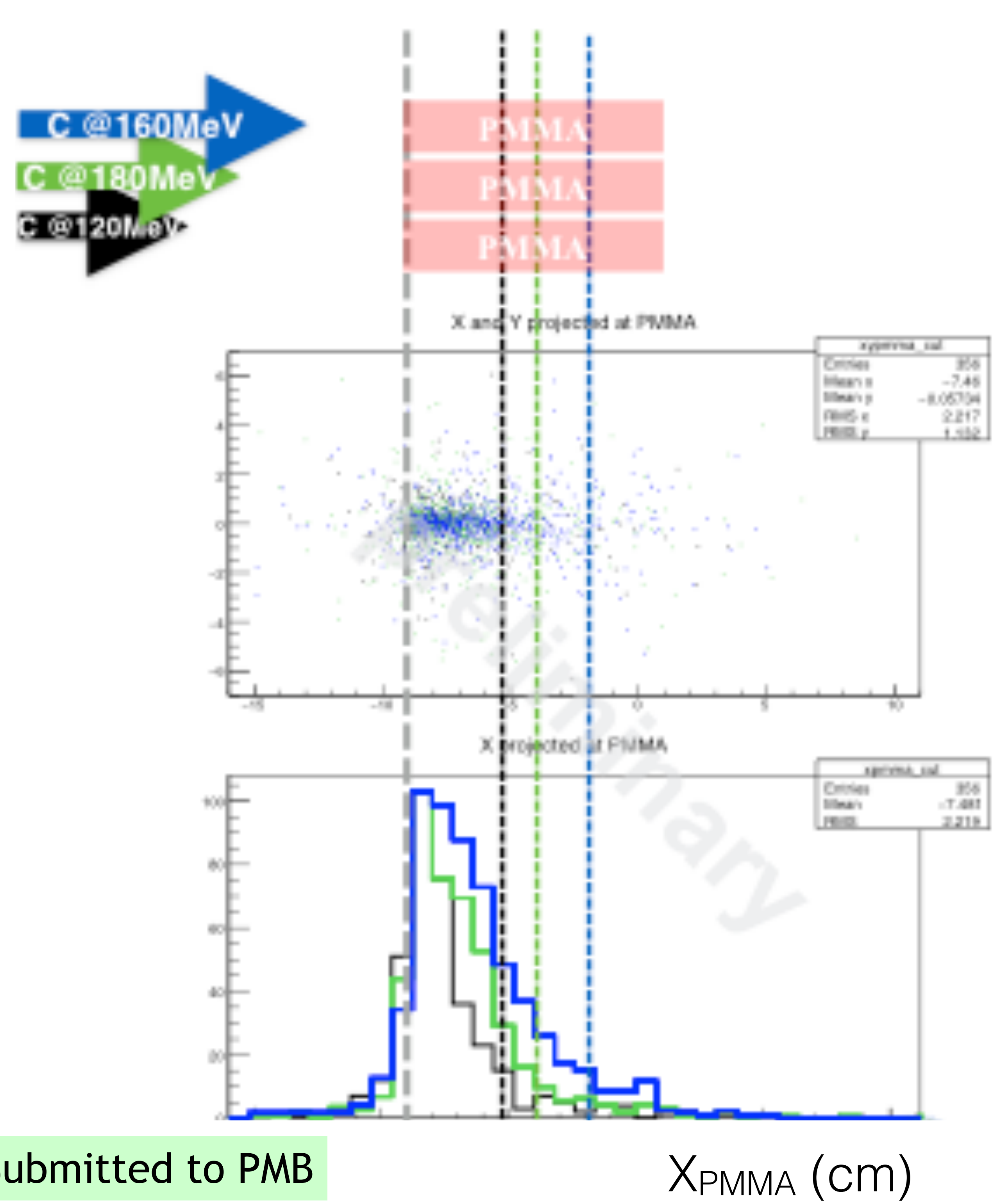

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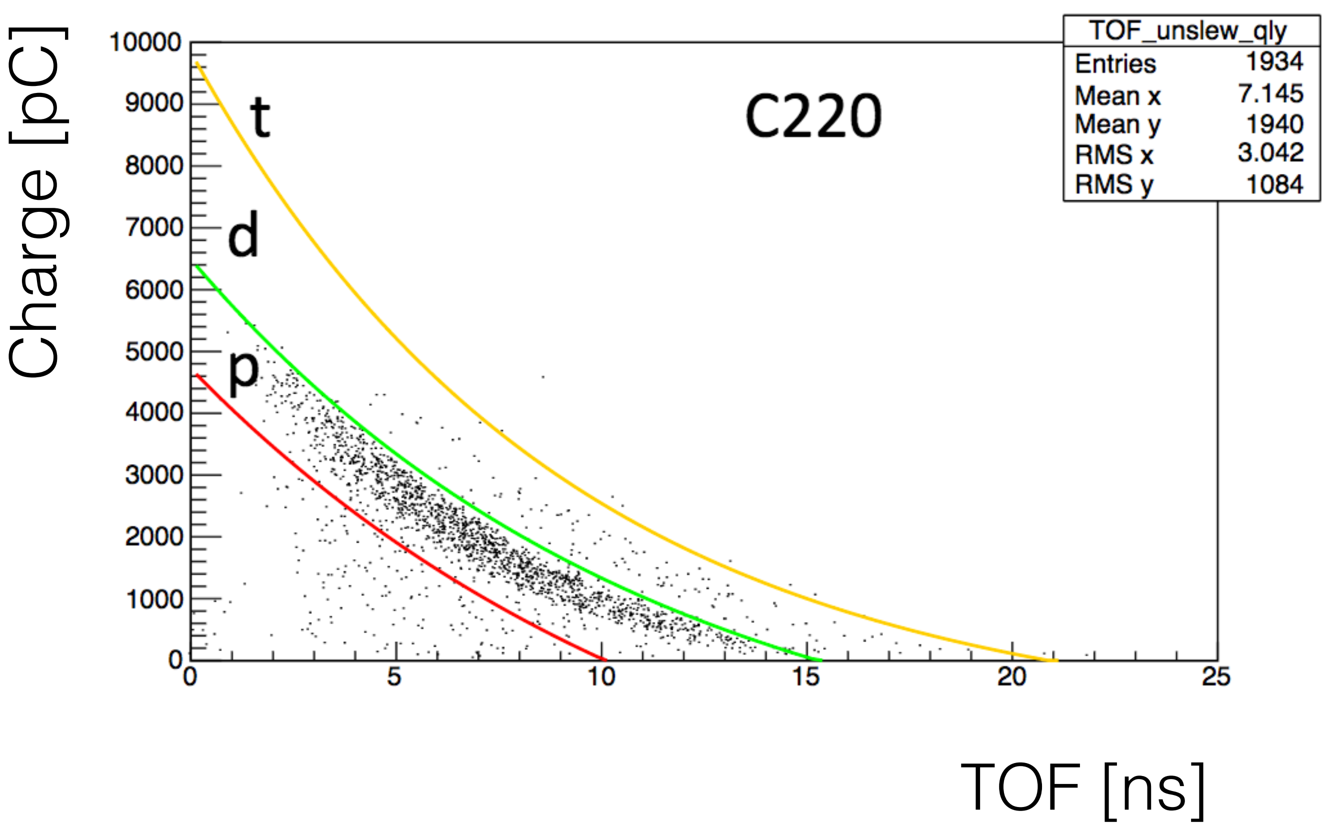

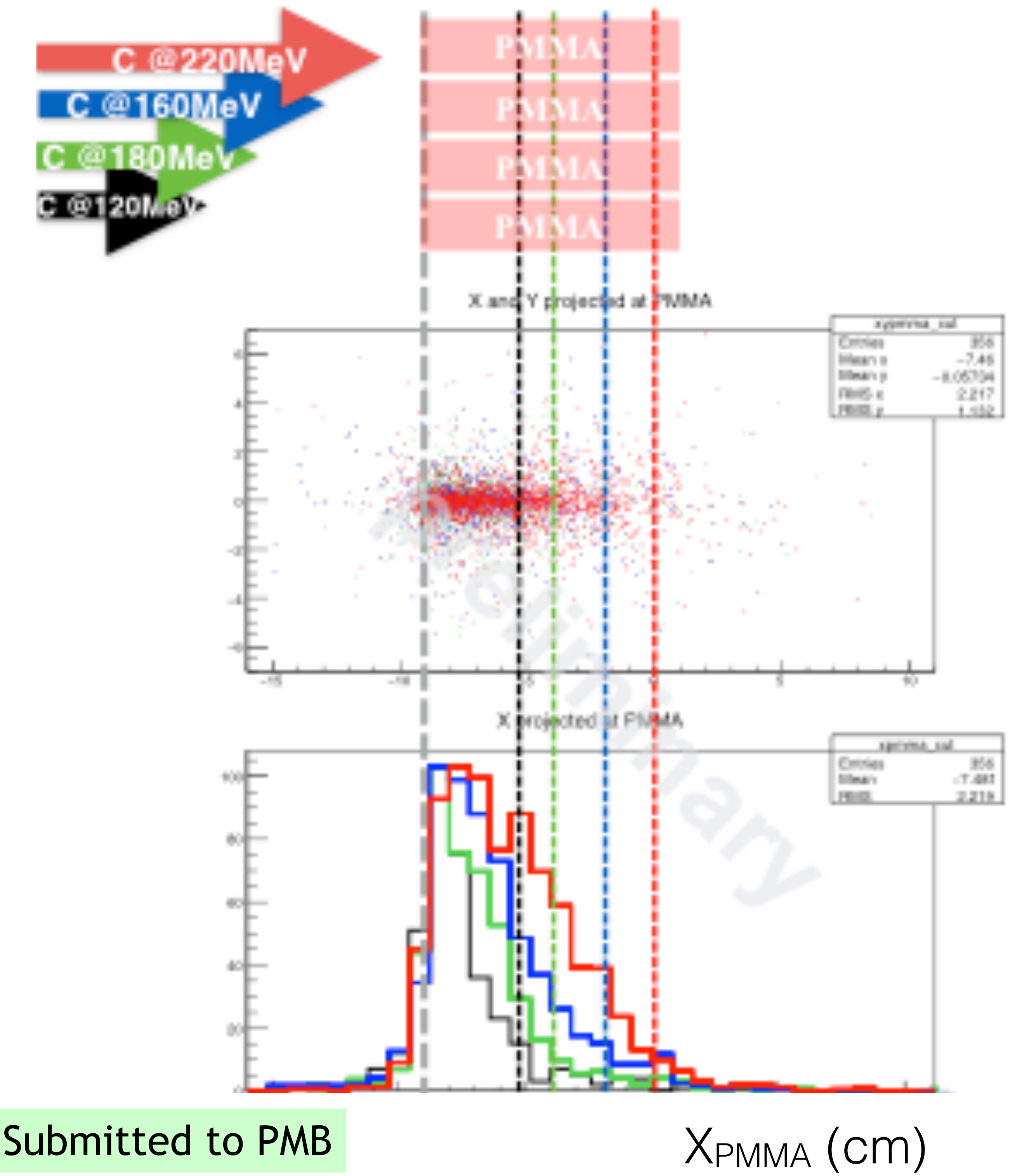

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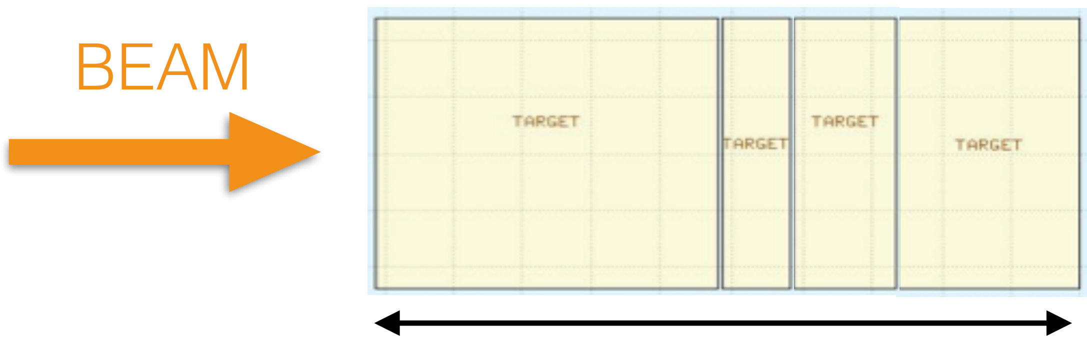
Inhomogeneities

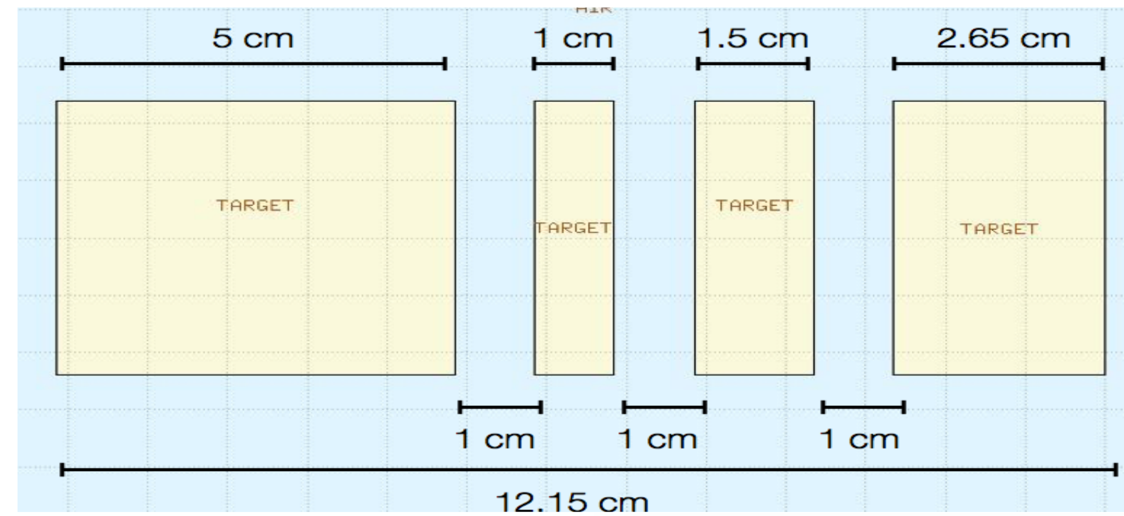
Homogeneous reference target

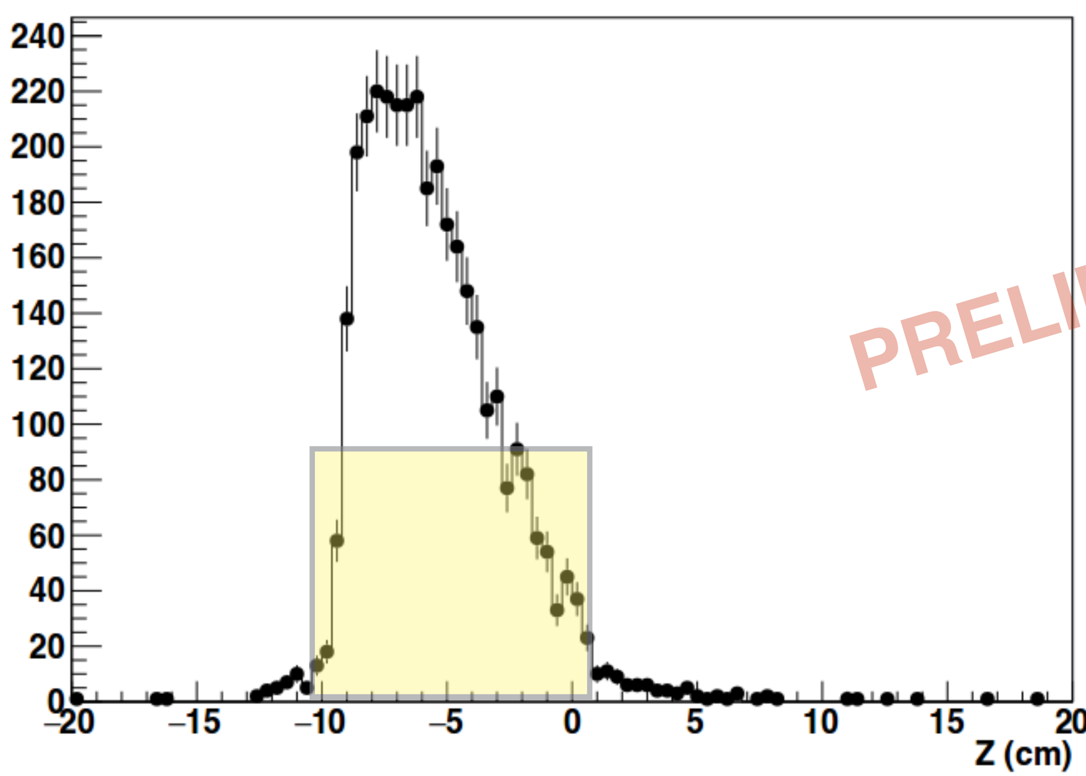
BEAM



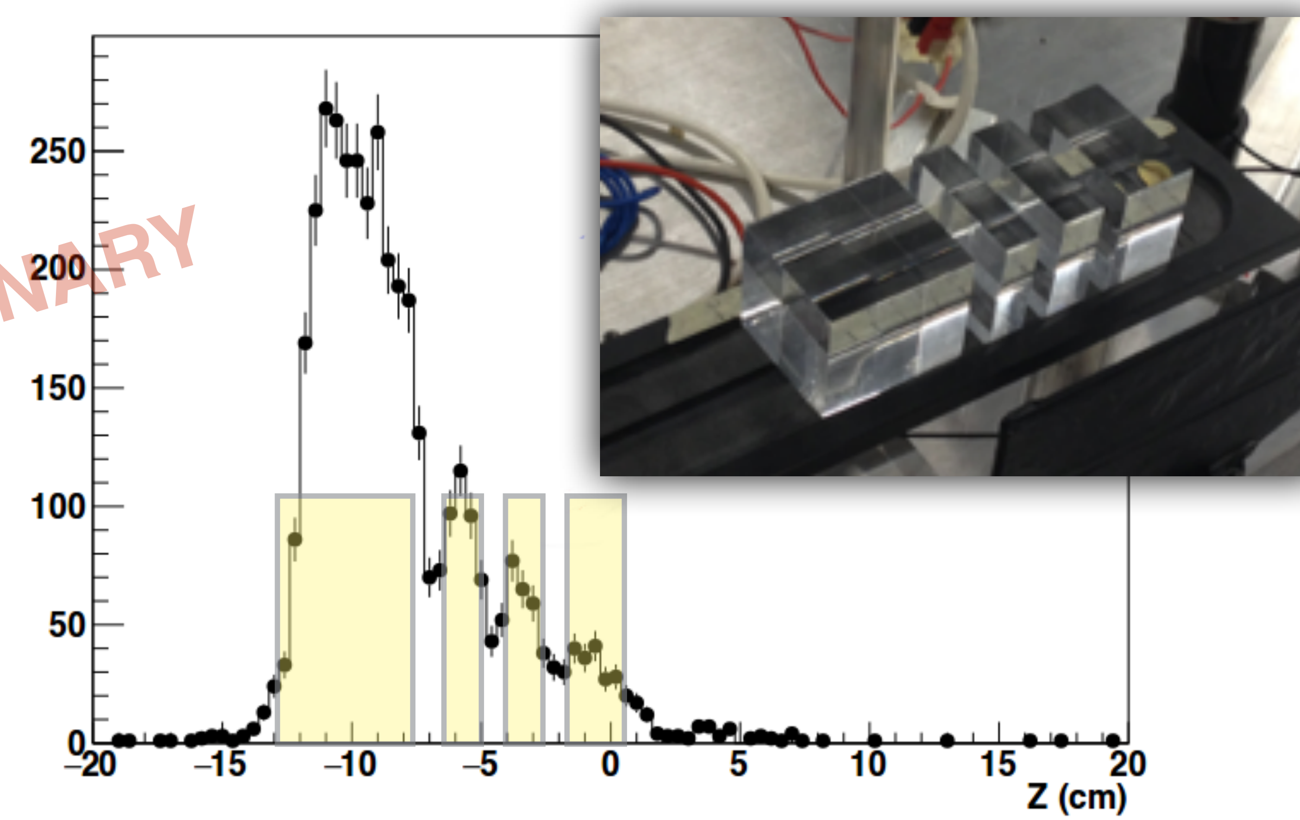
10.15 cm

Segmented target, with air gaps





PRELIMINARY



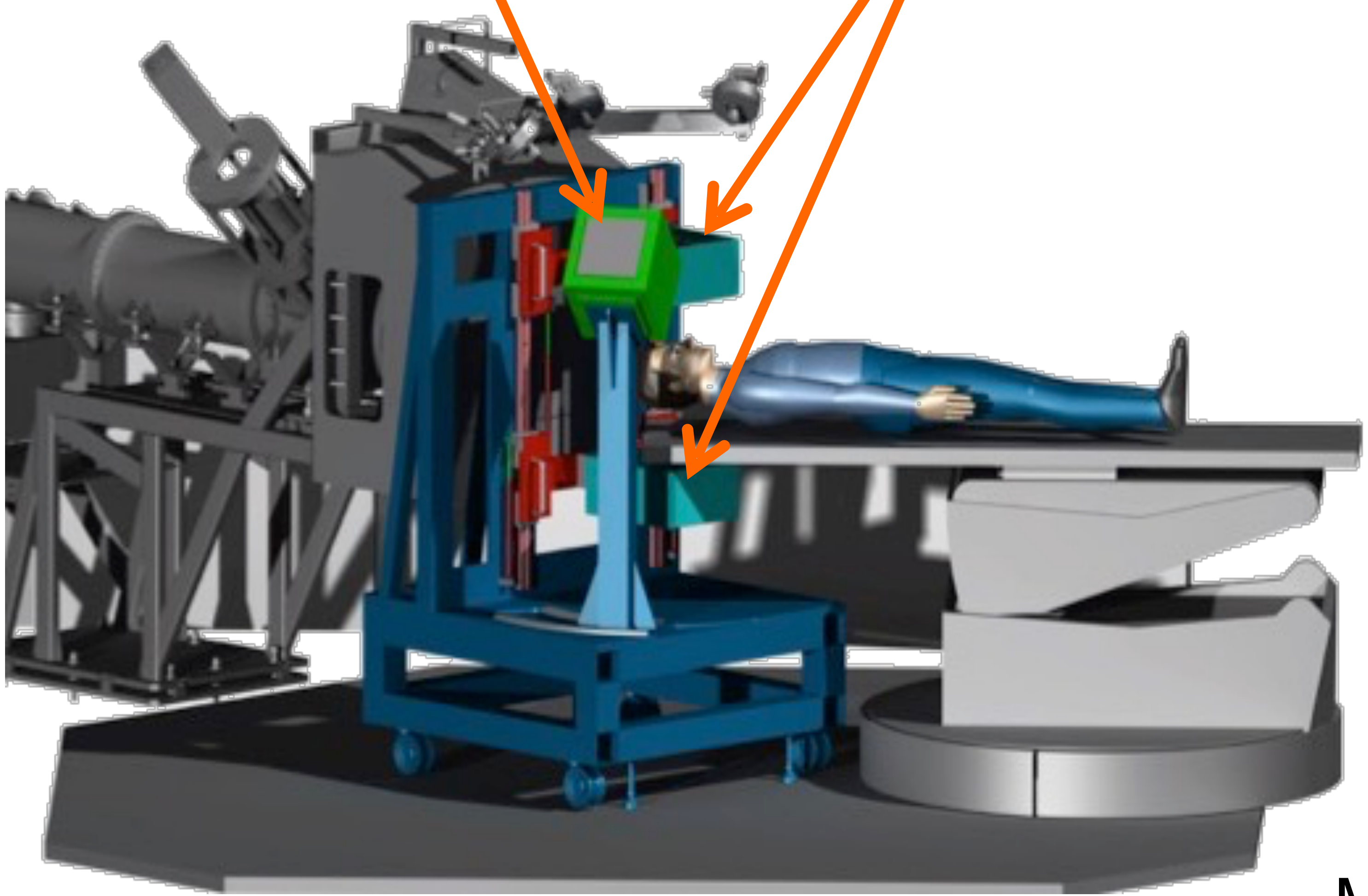
- ^{16}O beam on non homogeneous target: ~ 8 10^8 impinging ^{16}O ion, ~4k tracks reconstructed

The INSIDE project

Prompt secondary particles emission
"DOSE PROFILER" Tracker

β^+ activity distribution
IN-BEAM PET HEADS

BI-MODAL MONITORING SYSTEM

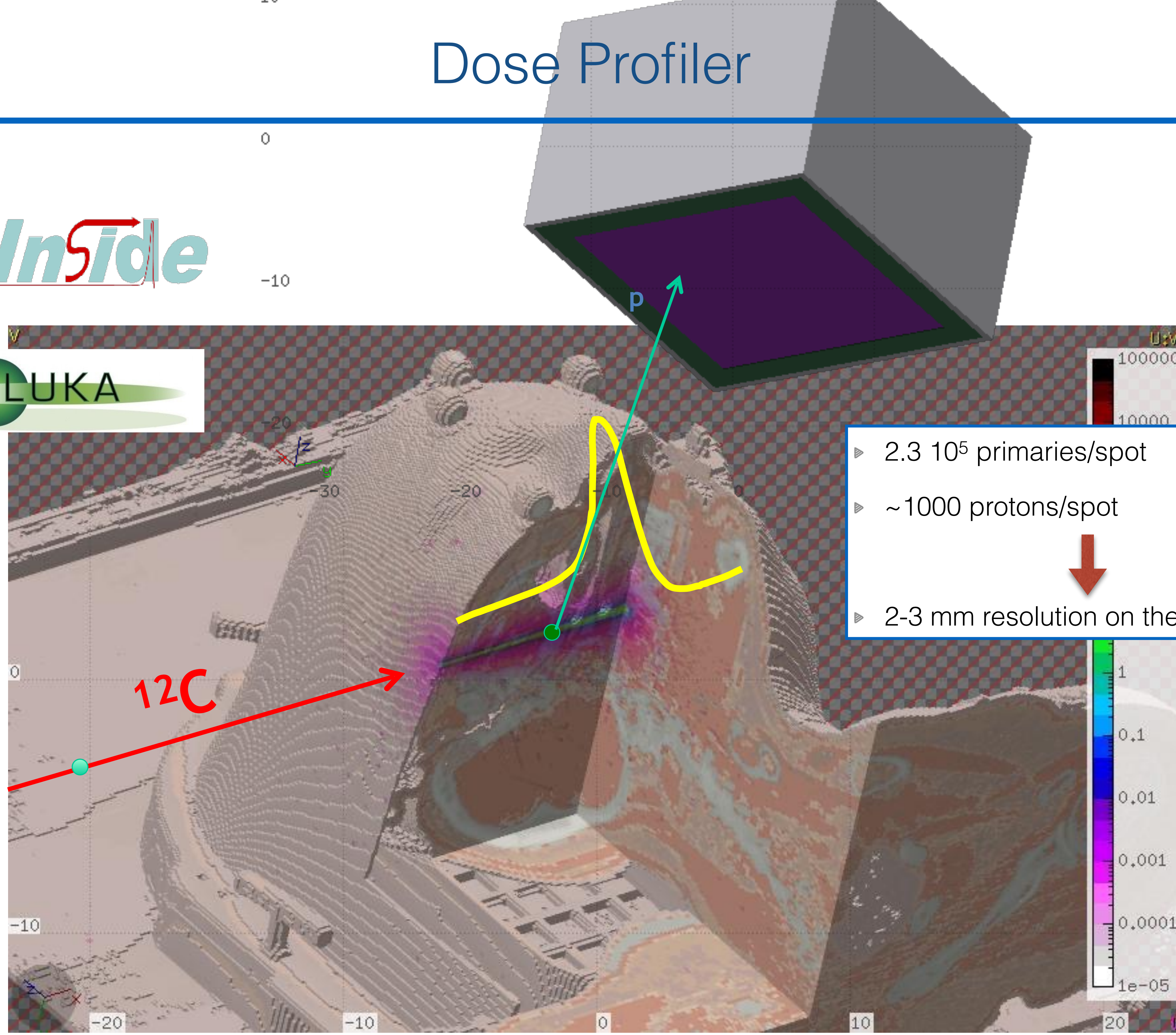


Goals:
- To be integrated in the gantry
- To be operated beam-on
- To provide in vivo particle range on-line

Inside @ CNAO

More on INSIDE
http://131.114.131.146/insidewiki/

Dose Profiler



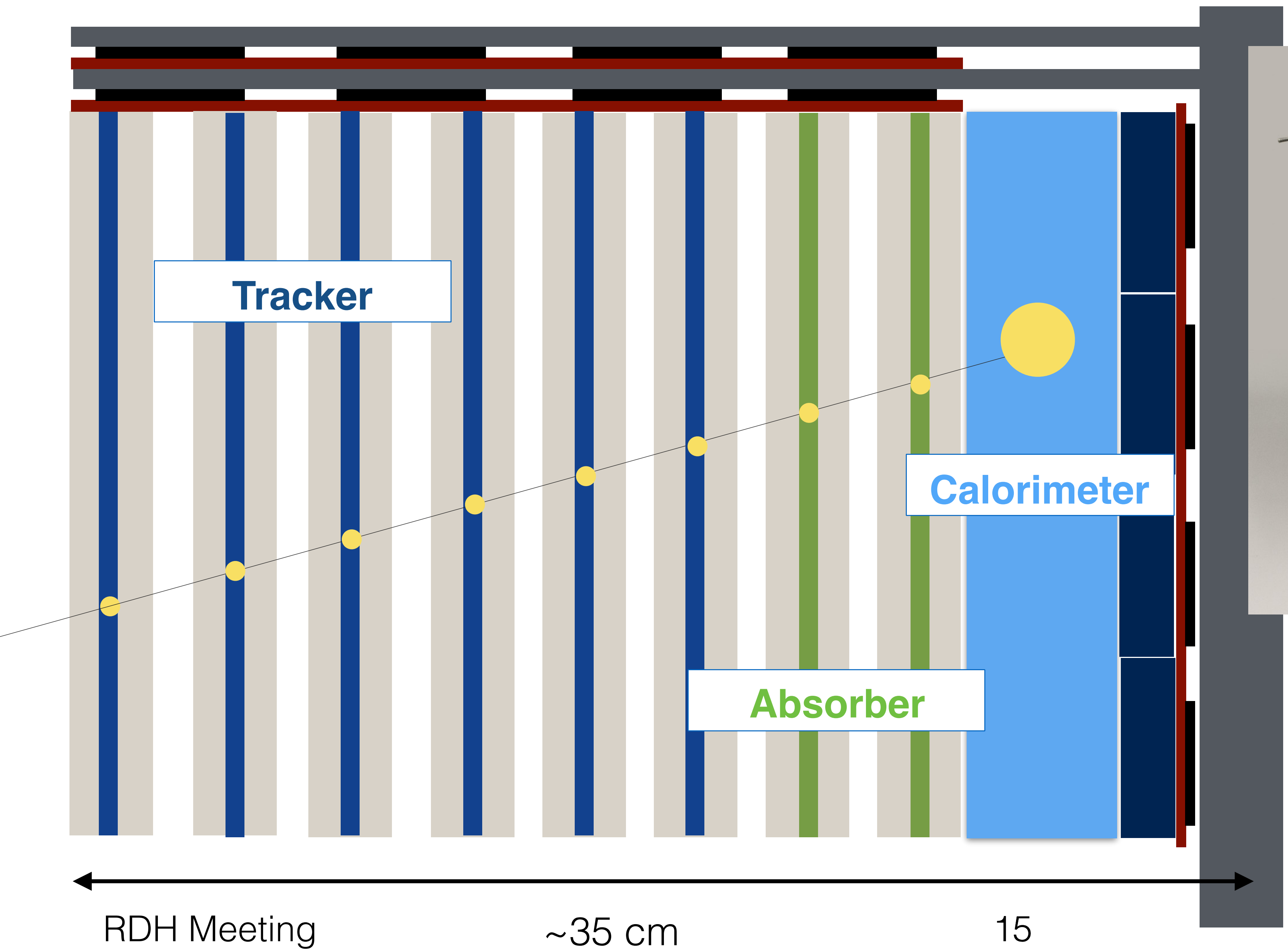
- 2.3 10^5 primaries/spot
- ~1000 protons/spot

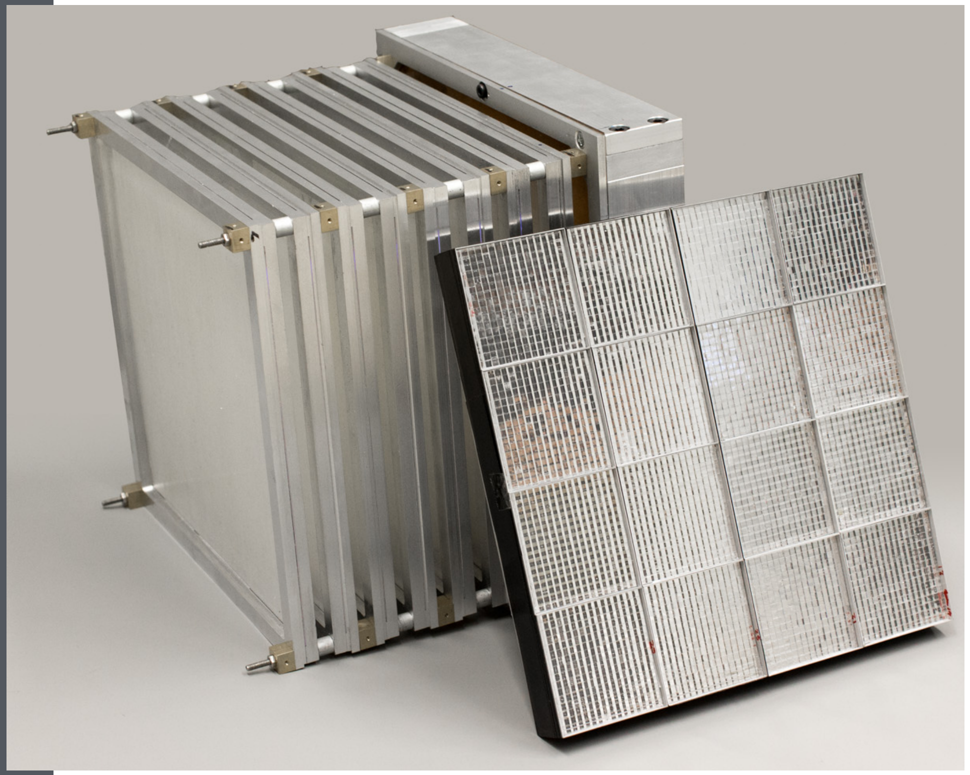
↓

- 2-3 mm resolution on the distal slice

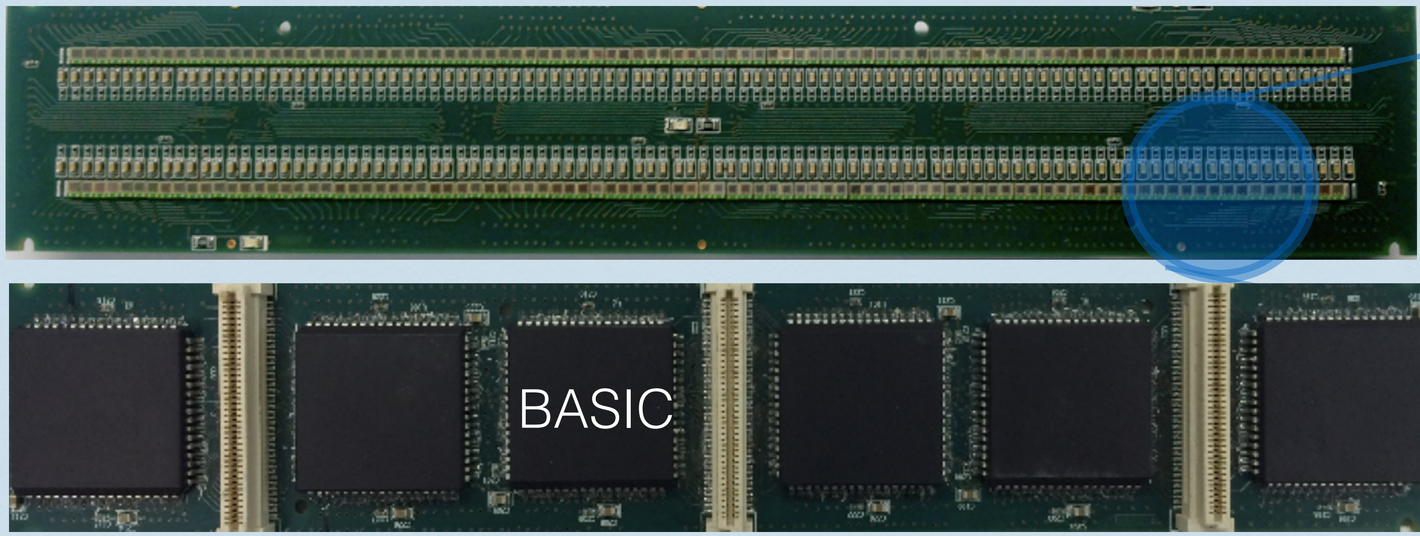
Dose Profiler

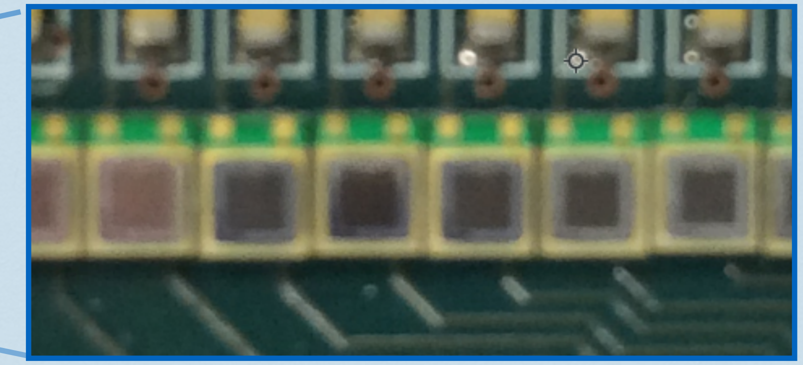
- **Tracker**: 6 xy planes with 2 cm spacing. Each plane is made of 2 stereo layers of 192 0.5x0.5 mm^2 square scintillating fibres. The fibres are read-out by Hamamatsu 1mm^2 SiPM S12571-050P
- **Absorber**: 2 planes made of segmented plastic scintillator 6 mm thick
- **Calorimeter**: LFS crystal read-out by multi-anode PMT Hamamatsu H8500





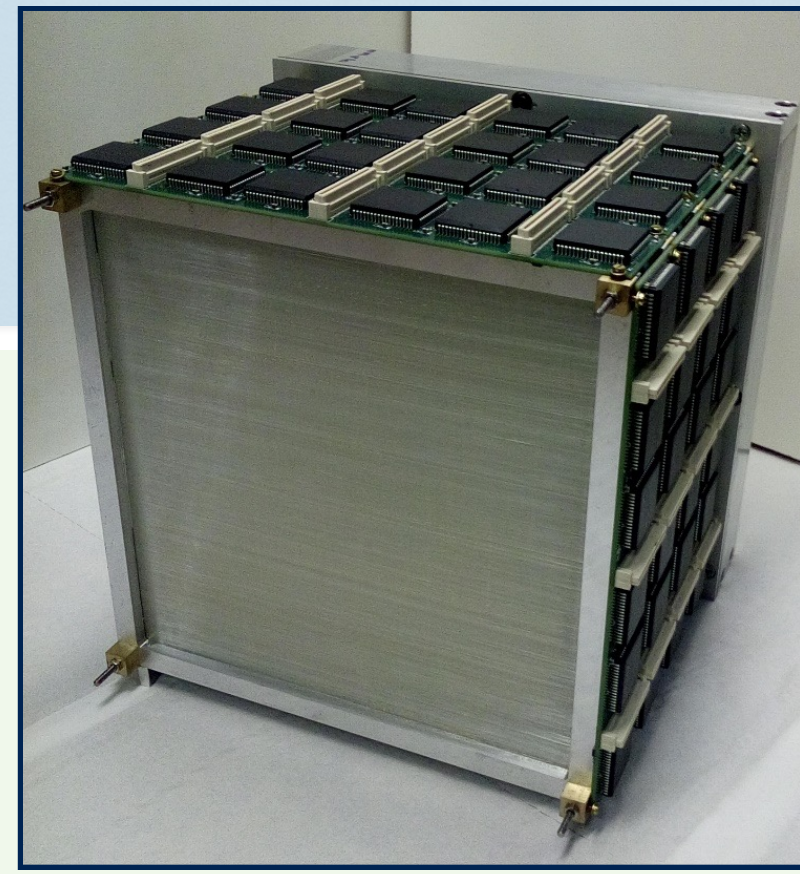
Dose Profiler front-end electronics and DAQ

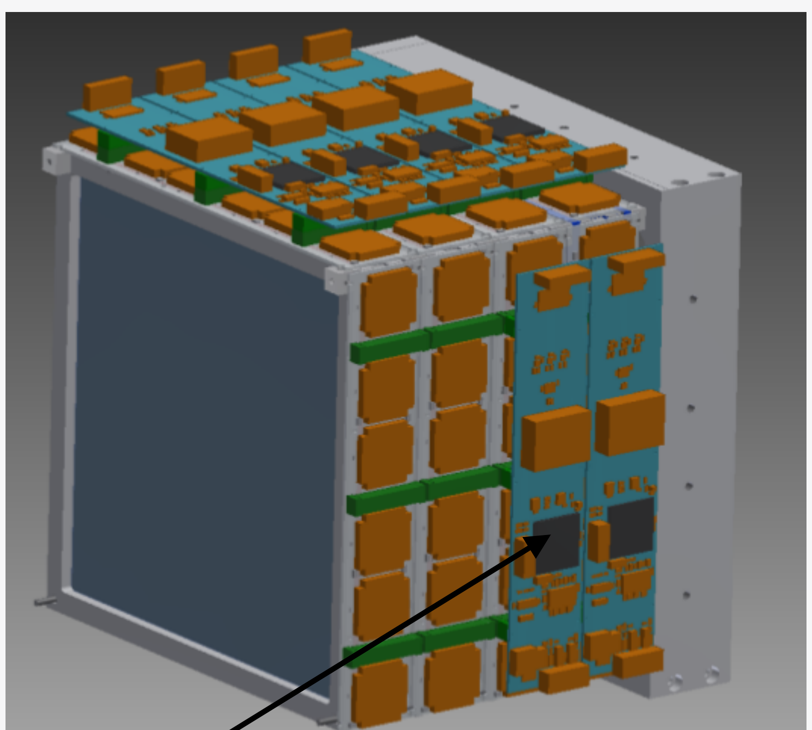




SiPM

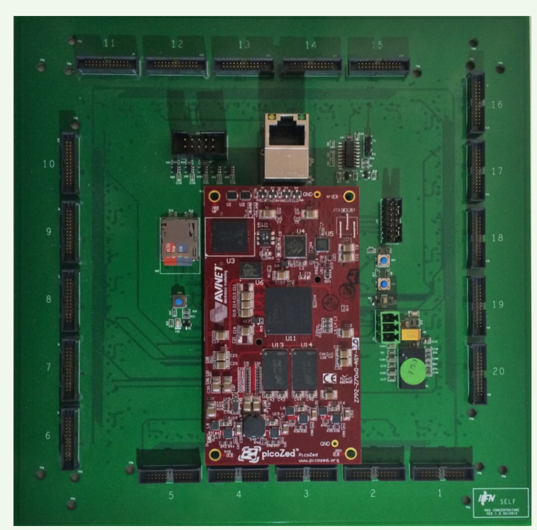
32 SiPM feed a 32-channel ASCI named BASIC32_ADC





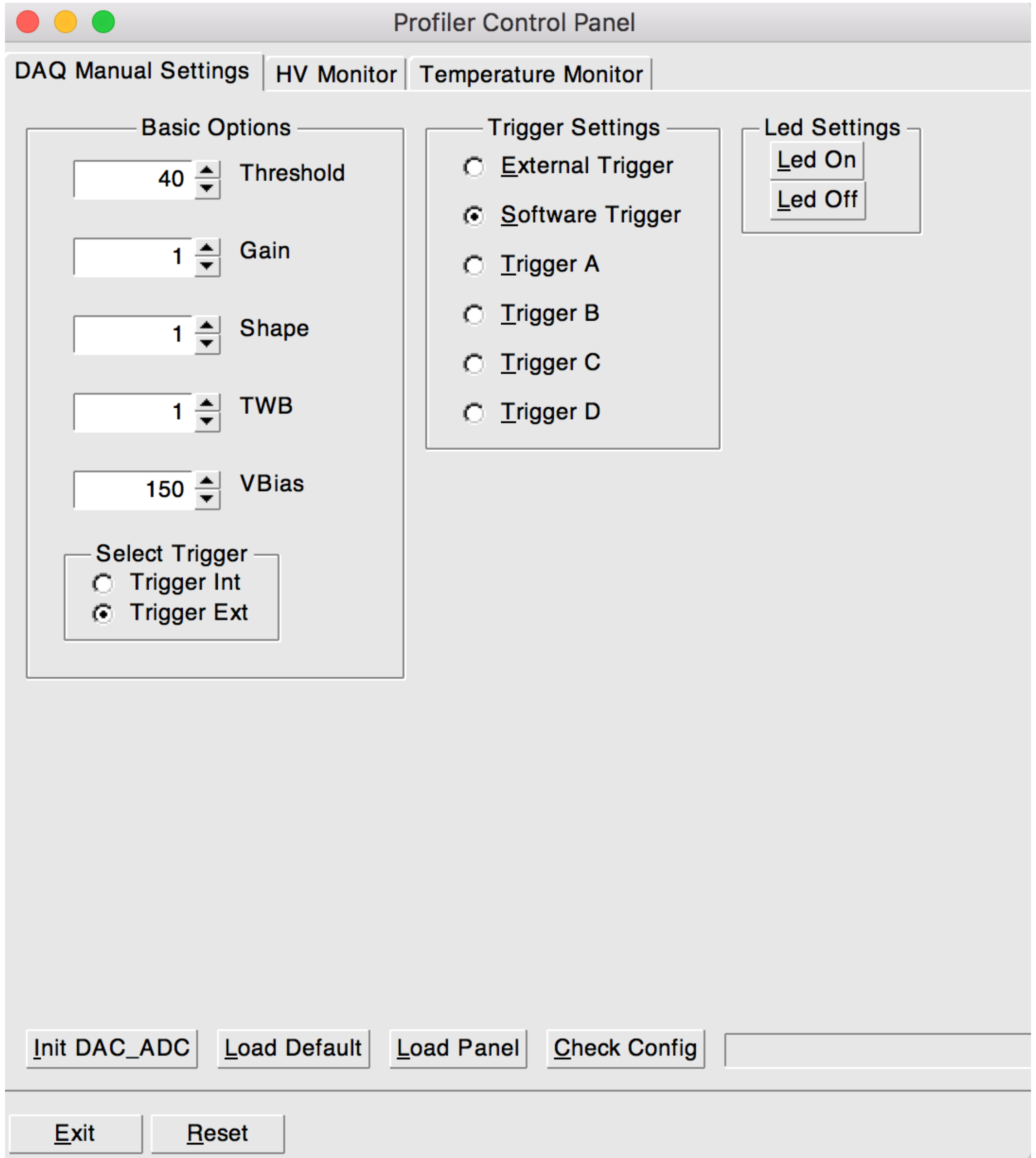
16 FPGA provides the read-out of all ASIC

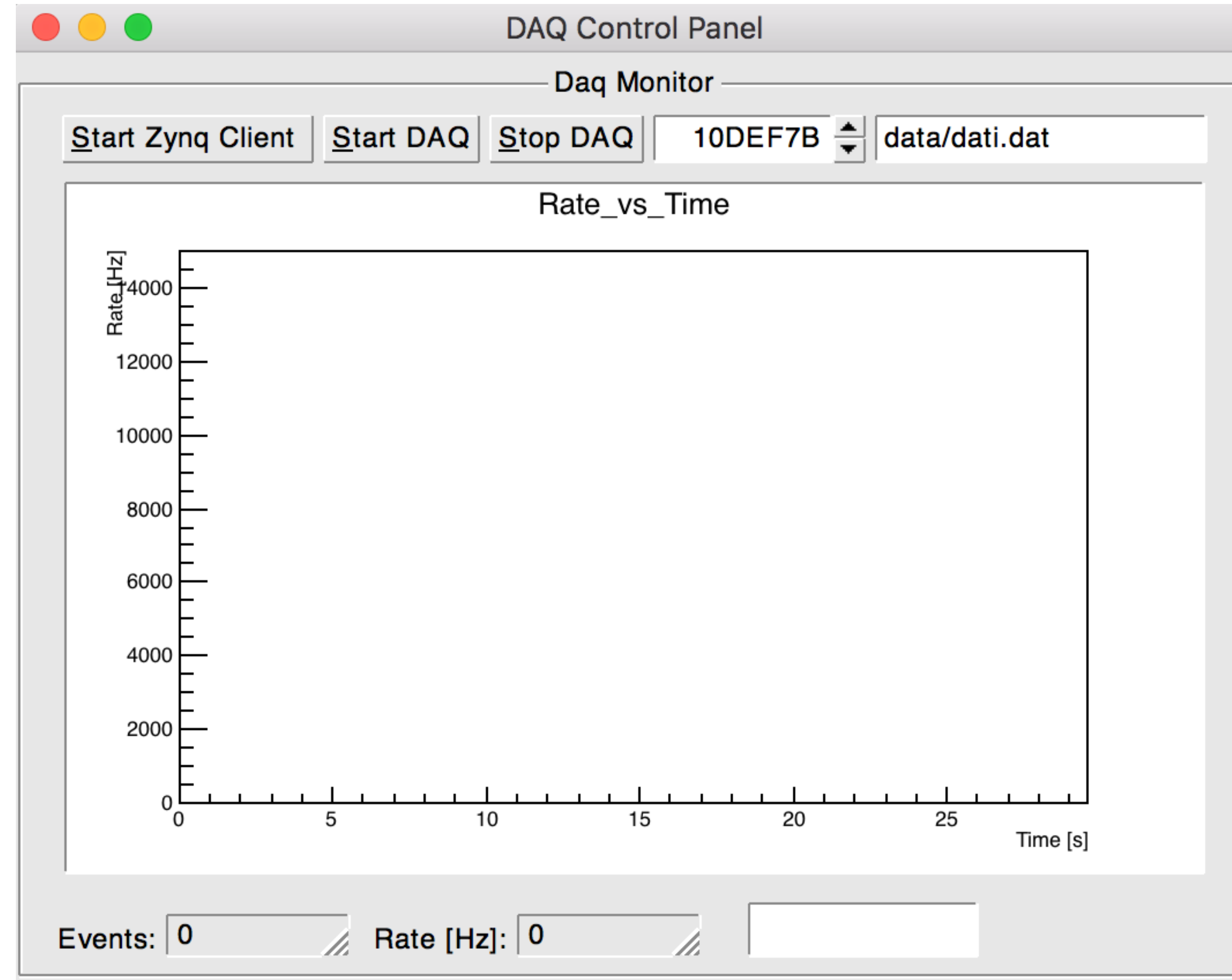
A Concentrator collects the FPGA data and provides the communication via ethernet with a PC



The electronics are fully tested and are going to be assembled

Dose Profiler DAQ software

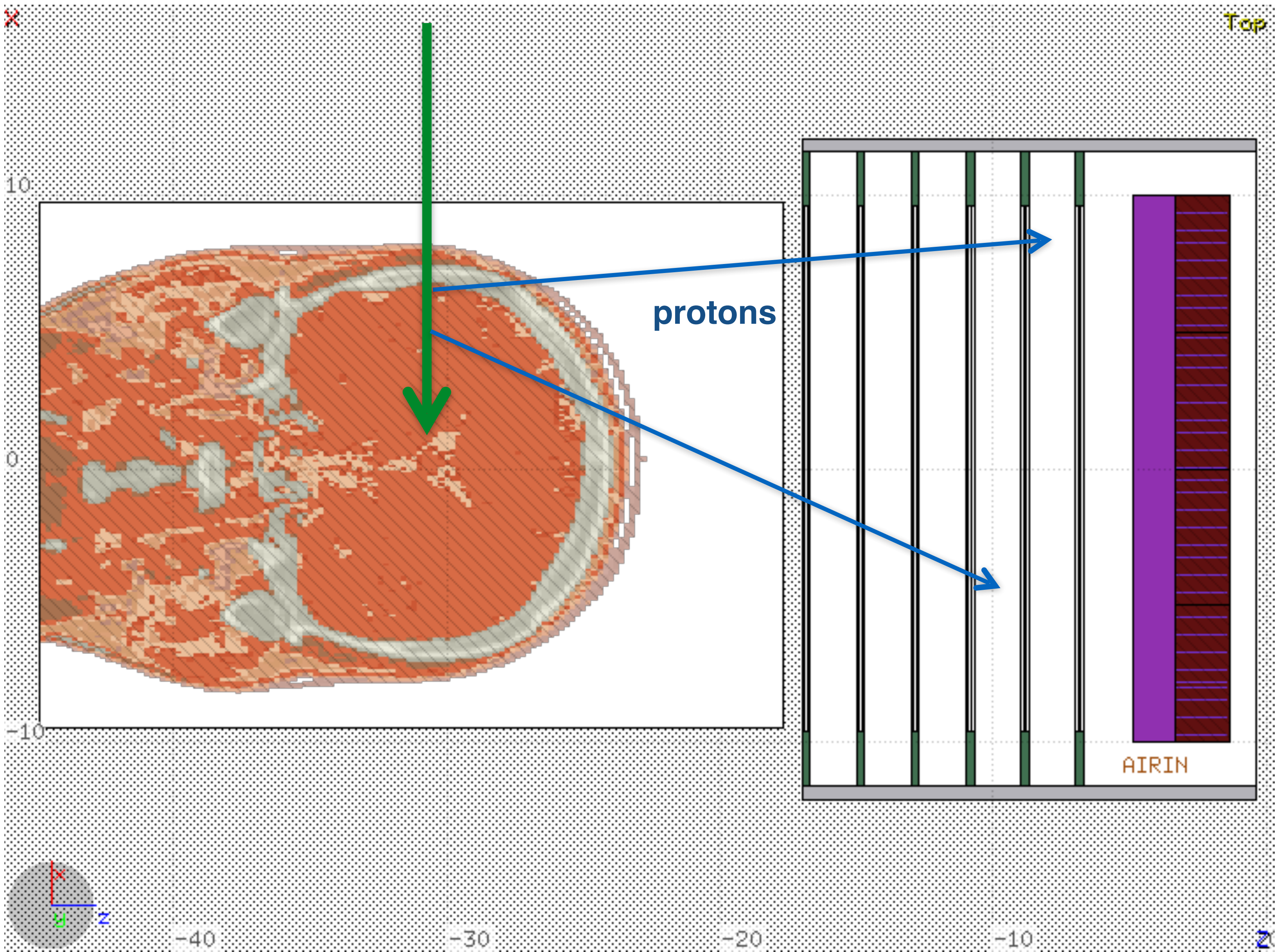




- The acquisition and control software is based on ROOT libraries. It is composed by 2 independent graphic panel, one for setting configuration and monitoring (SiPM voltage, temperature), the other one for data acquisition.

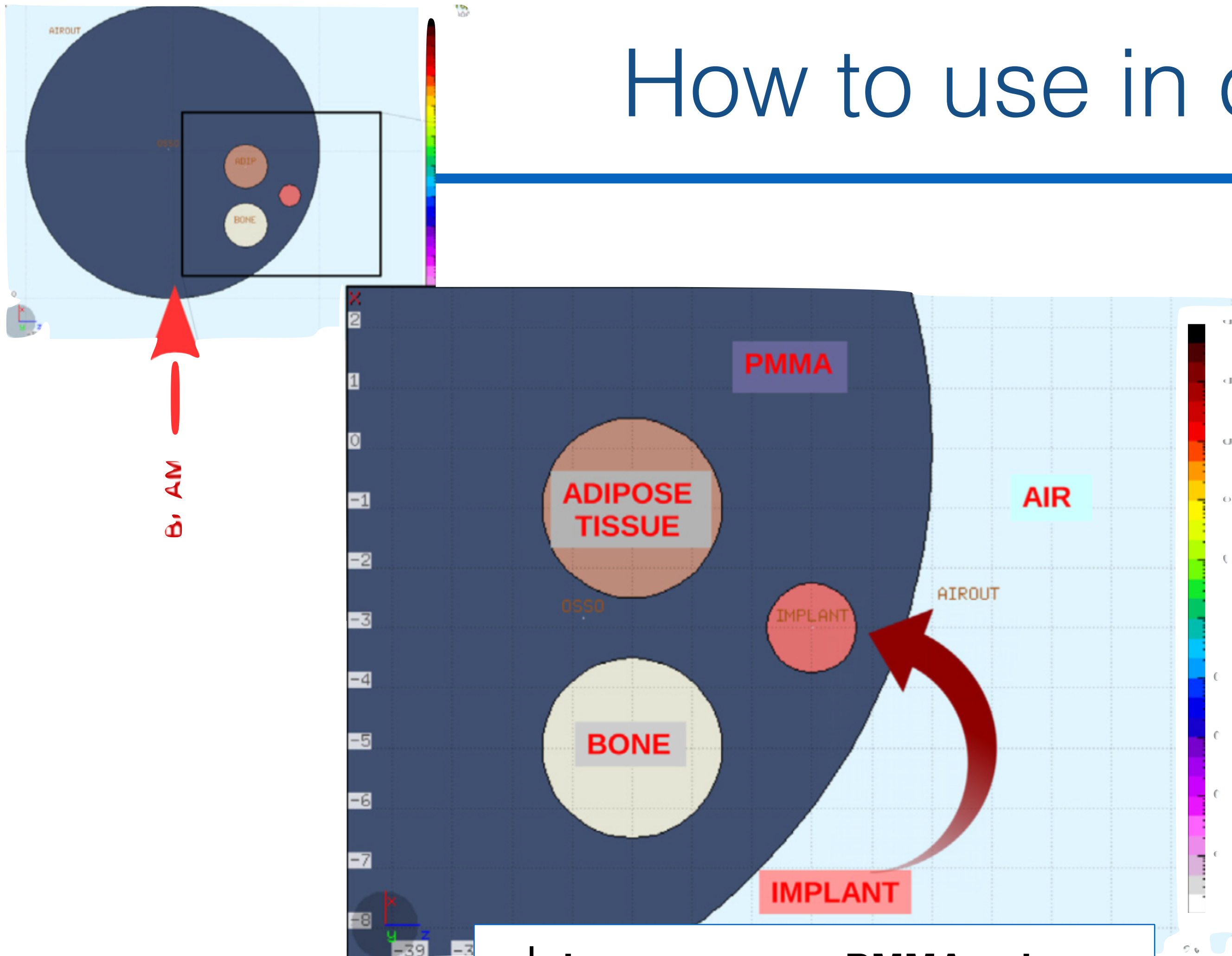
How to use in clinical case - 1

^{12}C-ion BEAM

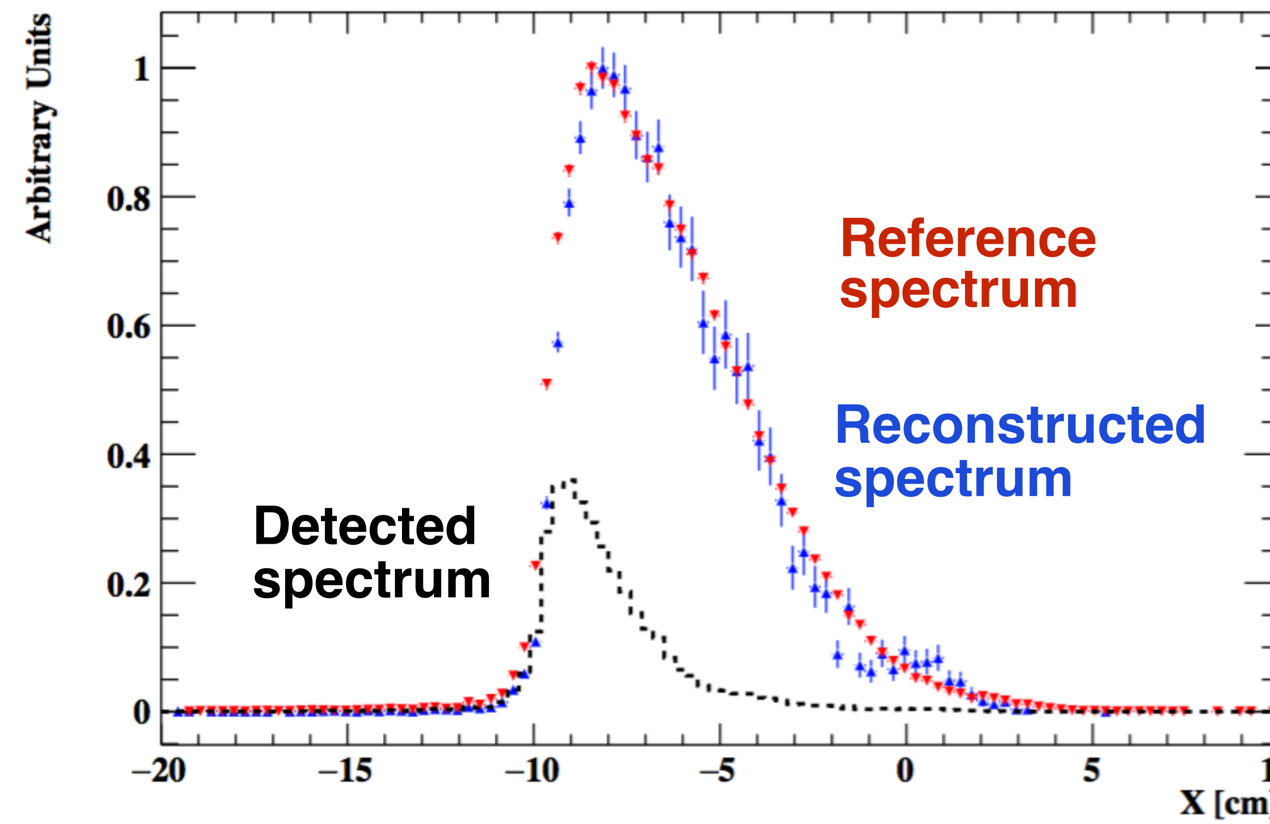


- In order to make use of the measured emission profile, the **absorbing effect due to the different thickness** material MUST be taken into account
- We are able to take into account of this in real time. It can be achieved buy means of a fast GPU-based MC code **back-propagating the reconstructed tracks though a geometry derived from the same CT used for planning.**

How to use in clinical case - 2



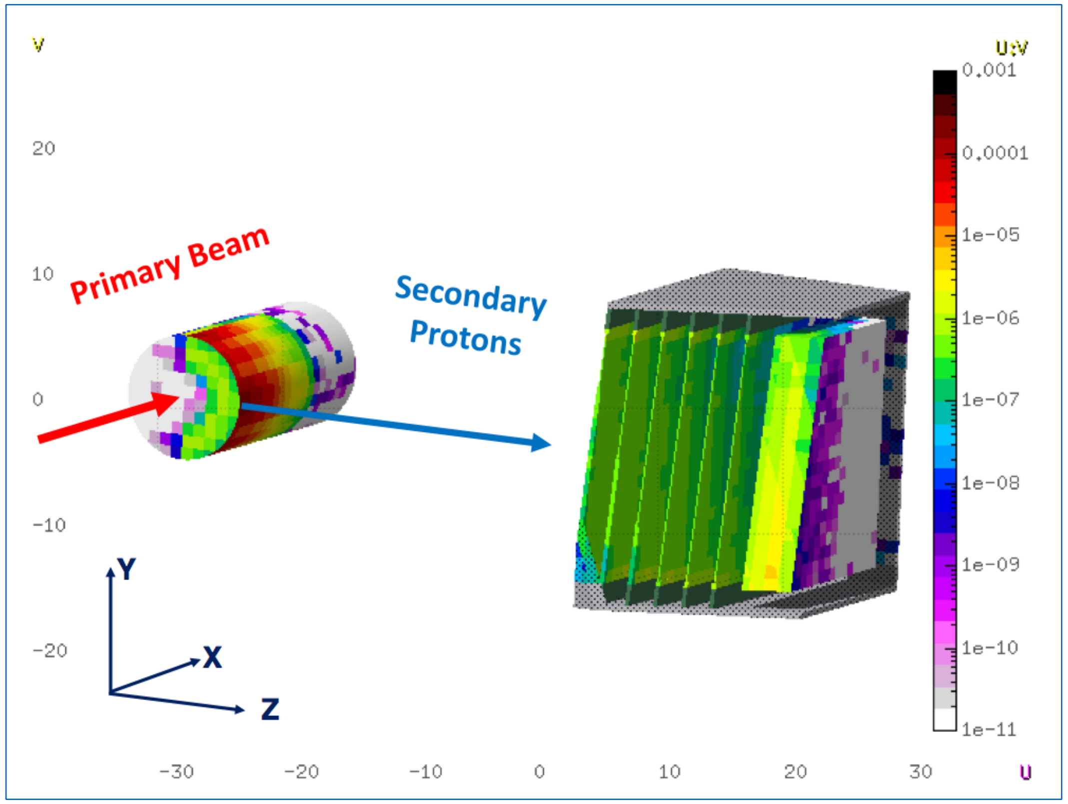
Inhomogeneous PMMA sphere containing smaller spheres of different material



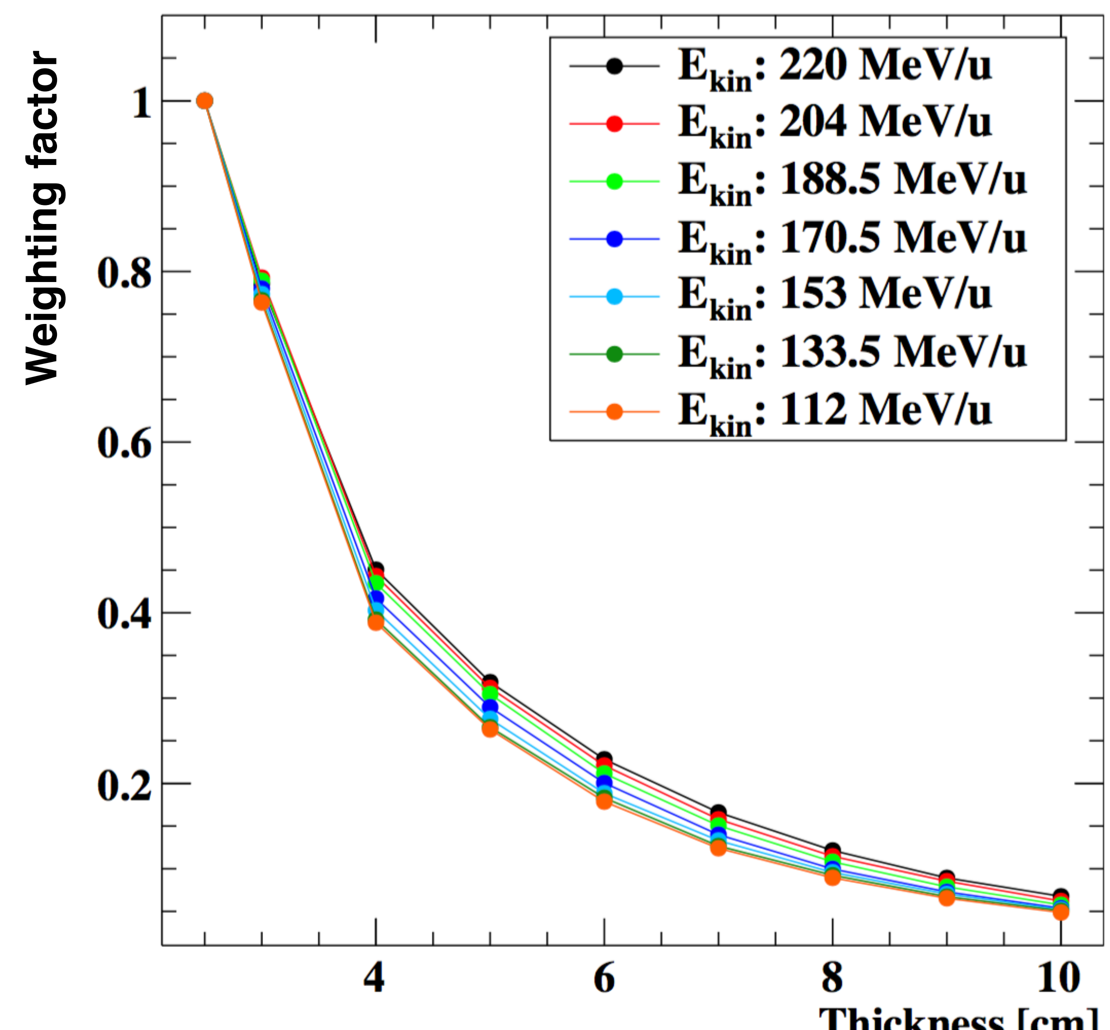
- By means of the attenuation study of the proton emission shape for different material thickness , we get a method to correlate the shape detected by the Dose Profiler coming out from the patient with the BP position
- We apply to each reconstructed track a **weight that takes into account the thickness and the density of the material crossed by the proton**
- **~2-3 mm resolution with a statistical sample for a single port at 1.5 Gy physical dose**

Traini et al. , Physica Medica (2017), DOI: http://dx.doi.org/10.1016/j.ejmp.2017.01.004

How to use in clinical case - 3



- We use FLUKA/FRED to evaluate the absorption of the proton flux with respect to the tissue material crossed
- The procedure heavily relies on secondary E_{kin} modelling in the MC

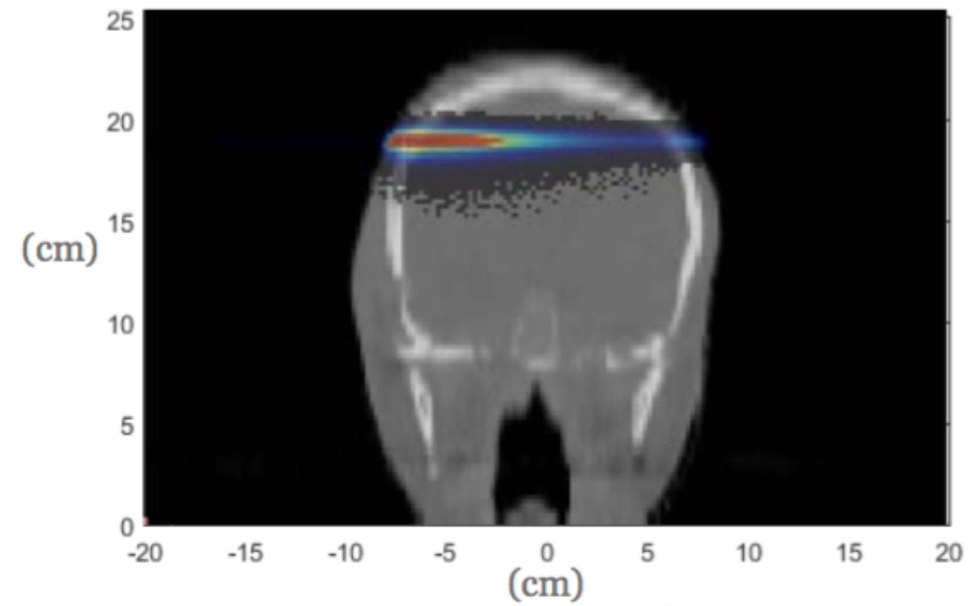


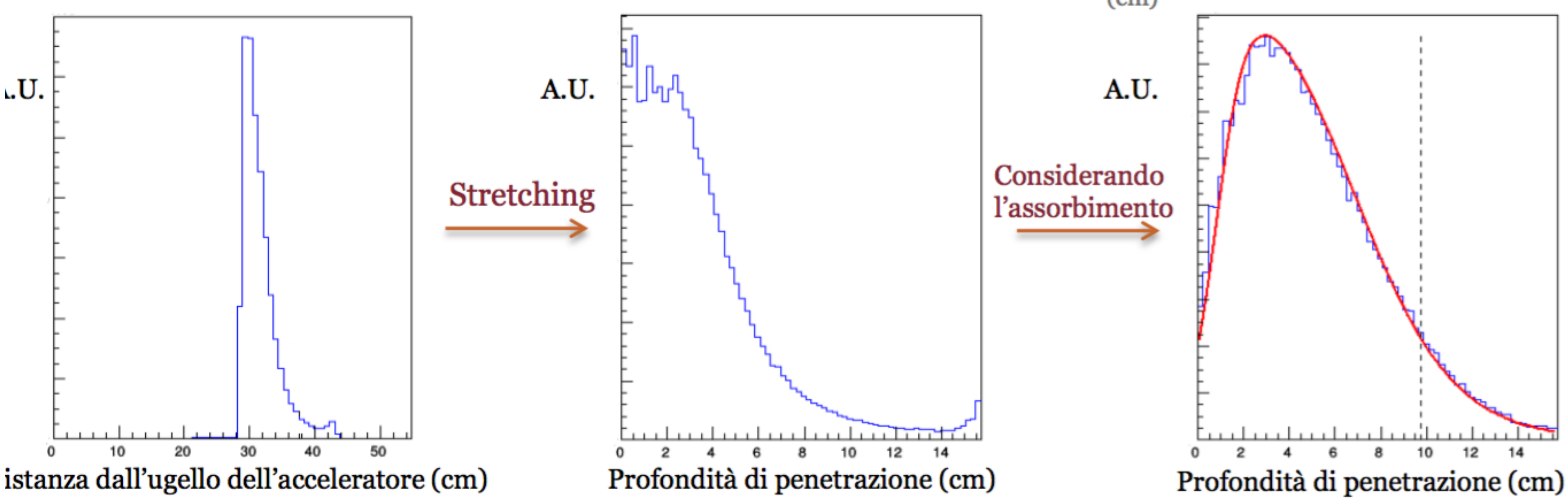
- We are interfacing the FRED MC code with the Profiler reconstruction code. FRED is able to provide weighting factor much faster the maximum daq rate expected (~10 kHz)

Traini et al. , Physica Medica (2017), DOI: http://dx.doi.org/10.1016/j.ejmp.2017.01.004

How to use in clinical case - 4

Ricostruzione di emissione per una CT di un paziente





Correzione dell'effetto della materia sulle particelle primarie

Correzione dell'effetto della materia sulle particelle secondarie

Next steps

- **February 2017**: test with cosmics, efficiency vs temperature measurements
- **March 2017**: test beam @Trento with protons (20-150 MeV). Efficiency measurements, geometrical alignment, beam energy measurements from dE/dx in the fibres and in the absorber
- **June/July 2017**: test beam @CNAO. Thin target measurement to build a database to calibrate the proton absorption. Calibration on phantom
- **October 2017**: first test on patient