PhD Programme in Physics of the University of Bologna
38th Cycle

Thesis description presentation

“Measurements of nuclear fragmentation differential cross section in an energy range between 200 MeV/n and 400 MeV/n at the FOOT experiment”

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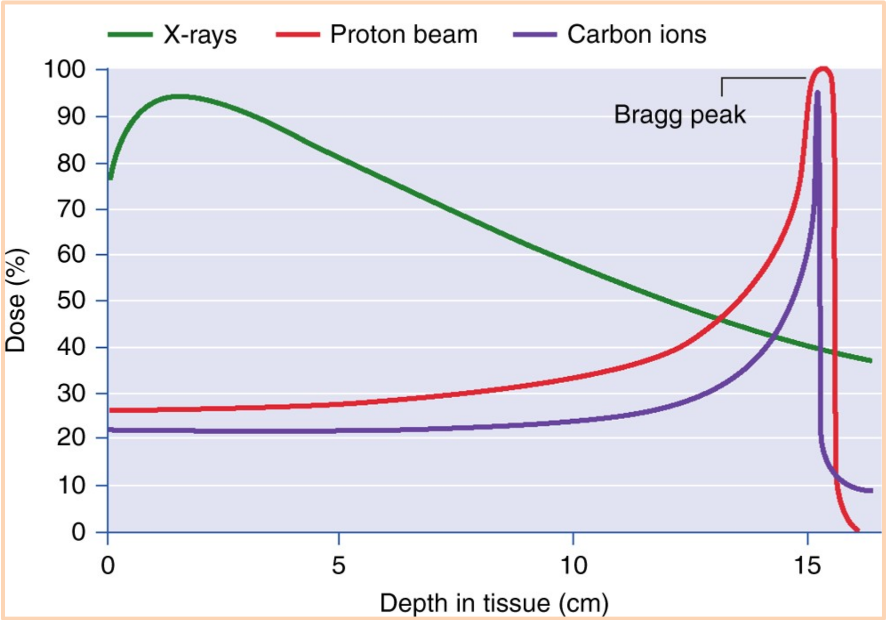
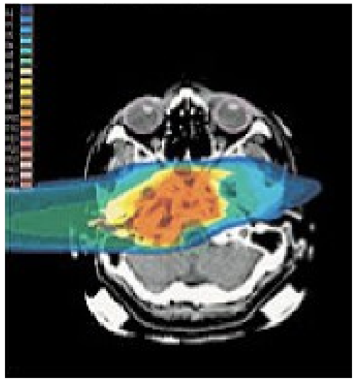
28/06/2022

The FOOT experiment

hadrontherapy

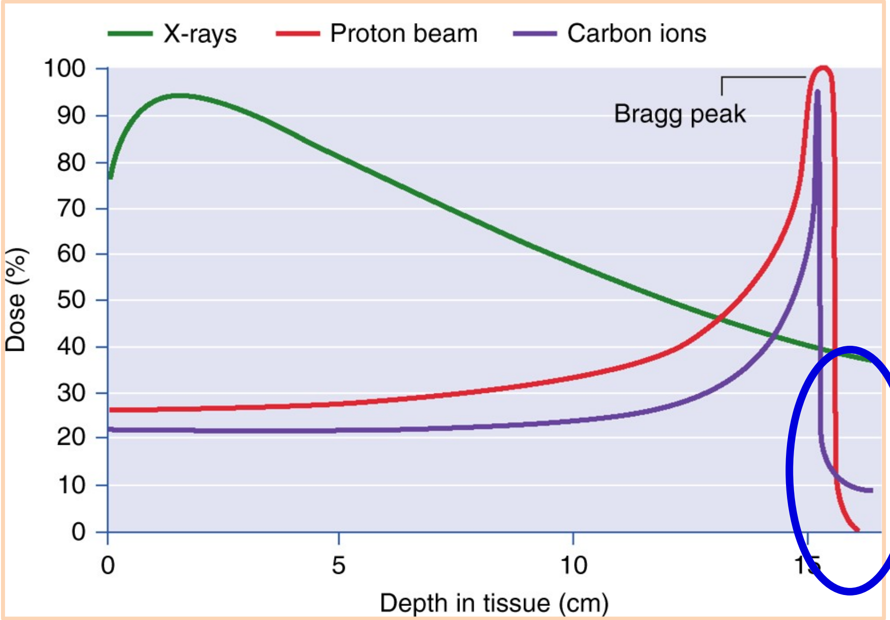


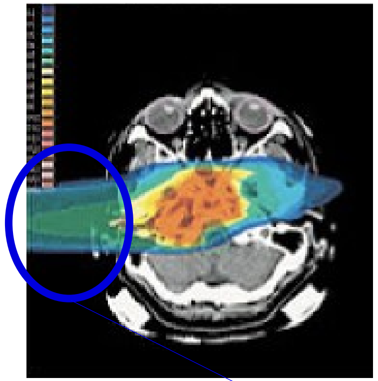


Space radioprotection

The FOOT experiment

hadrontherapy



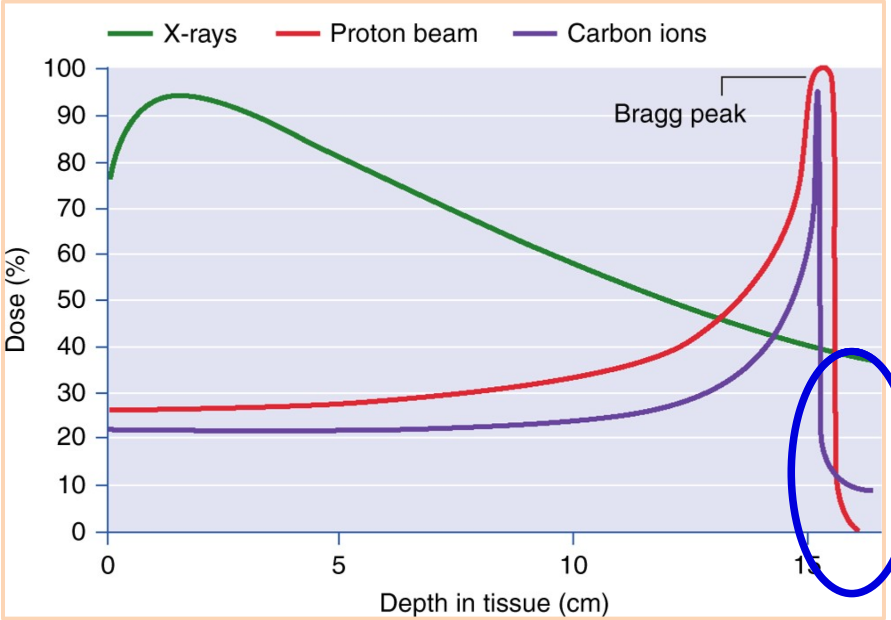


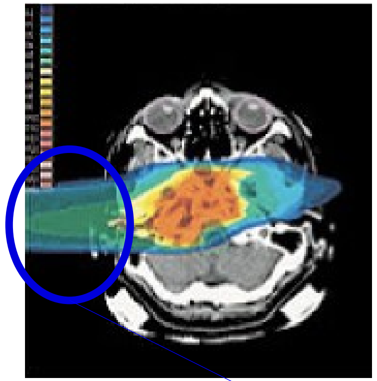
Fragmentation!

Space radioprotection

The FOOT experiment

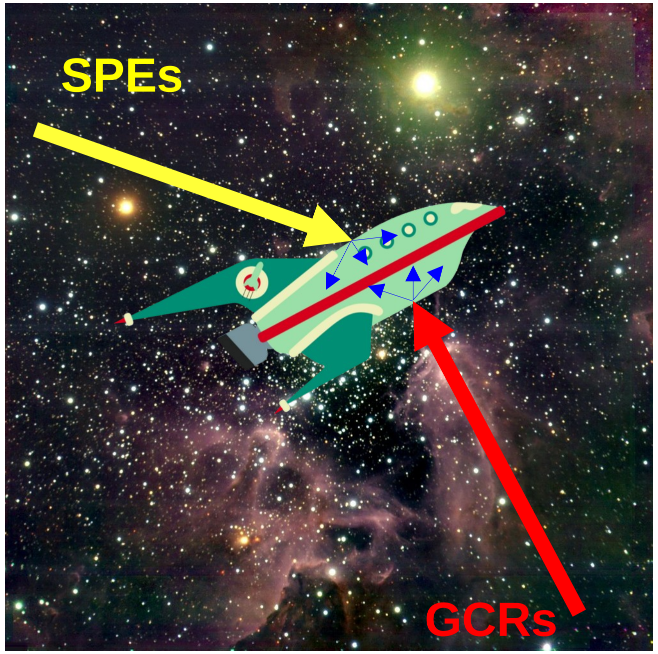
hadrontherapy





Fragmentation!

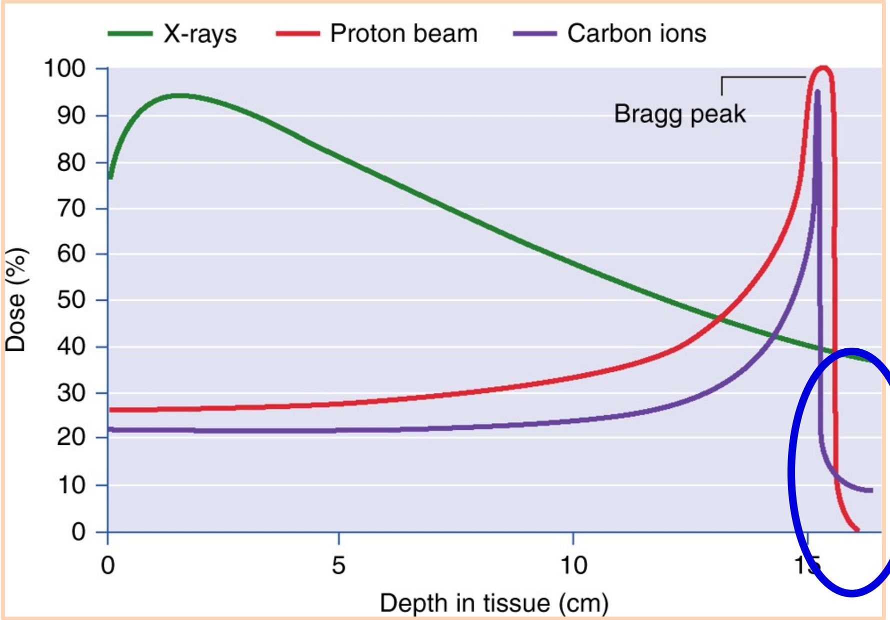
Space radioprotection

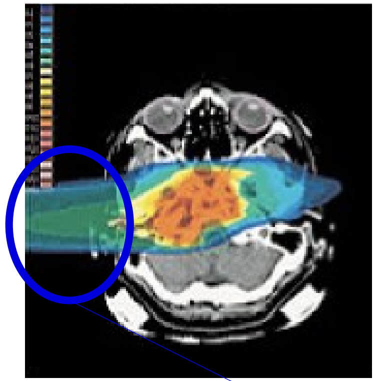


The FOOT experiment

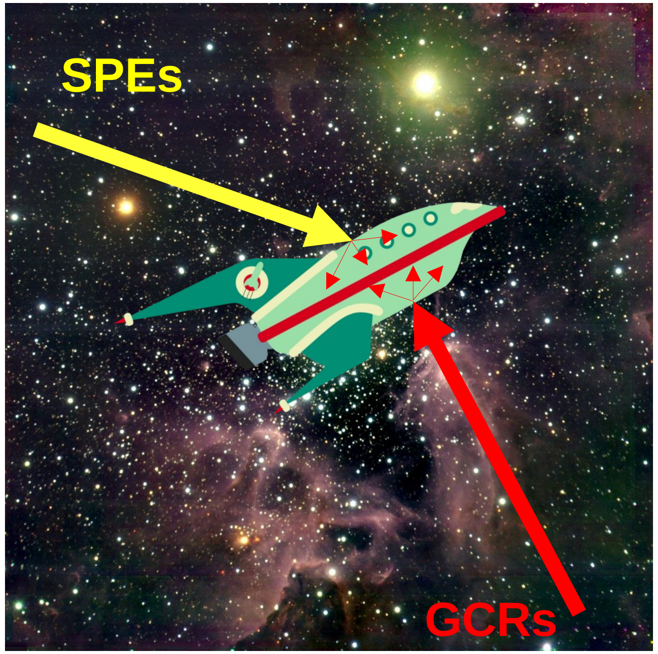
Goal:
double differential projectile and target **nuclear cross sections** mesurements with σ < 5%

- Fixed target collisions
- Beam energies between 200 MeV/u and 700 MeV/u for **hadrontherapy** and **space radioprotection** topics
- **table top setup** to be moved according to beam facility availability
- Particle identification by measuring all kinematic quantities



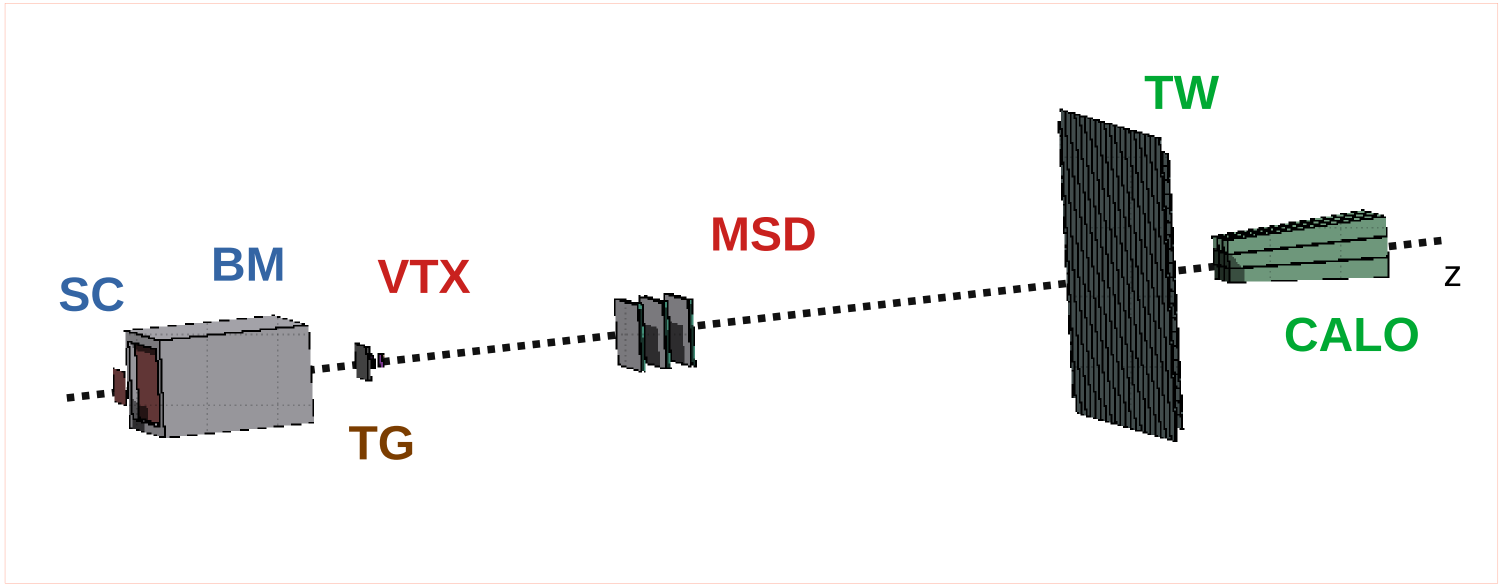


Fragmentation!

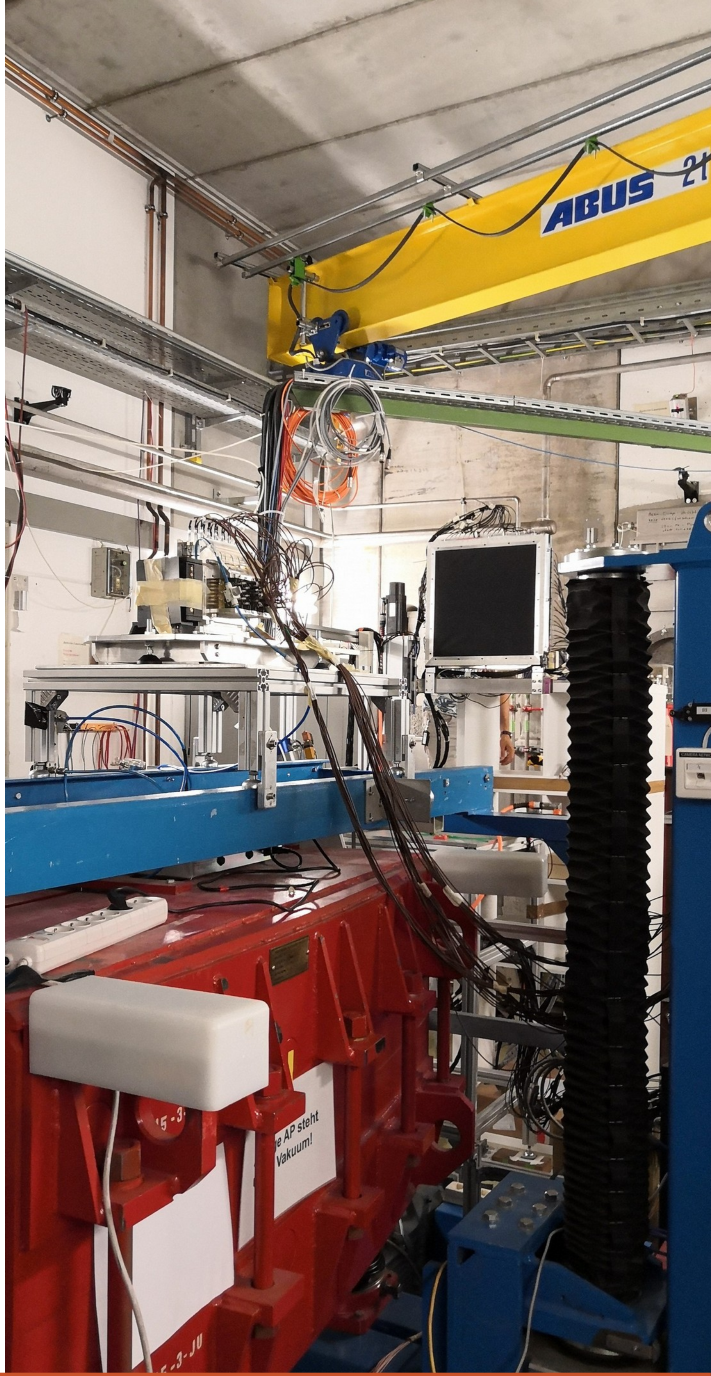


GSI 2021 analysis

- ^{16}O 400 MeV/u on 5 mm C target
- Real data taken at GSI in 2021
- Analysis implemented in **SHOE**
- Partial setup: no tracker, only one module of calorimeter



First preliminary goal:
charge changing angular differential cross section



Differential cross section

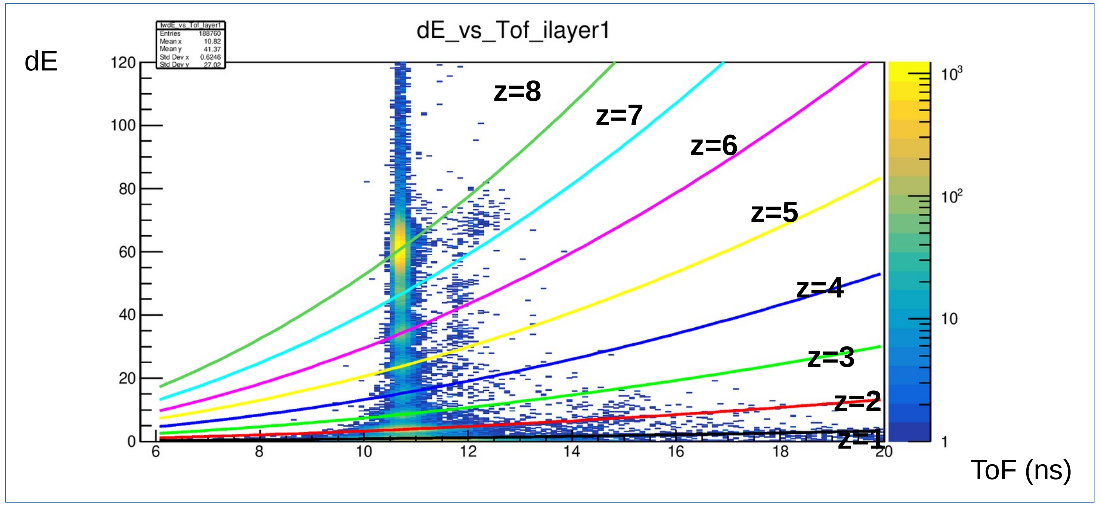
$$\frac{d\sigma}{d\theta} = \frac{(Y_f - B_f)^u}{N_{beam} \cdot N_{target} \cdot \Delta\theta \cdot \epsilon}$$

Fragment identification

$$\frac{d\sigma}{d\theta} = \frac{(Y_f - B_f)^u}{N_{beam} \cdot N_{target} \cdot \Delta\theta \cdot \epsilon}$$

- MC data

*TW **charge reconstruction** algorithm*

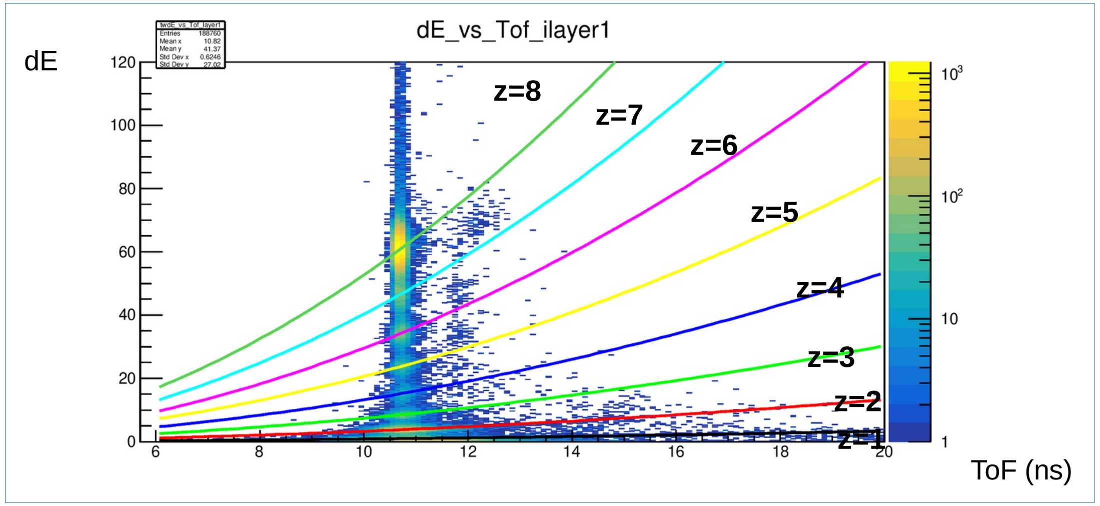


Fragment identification

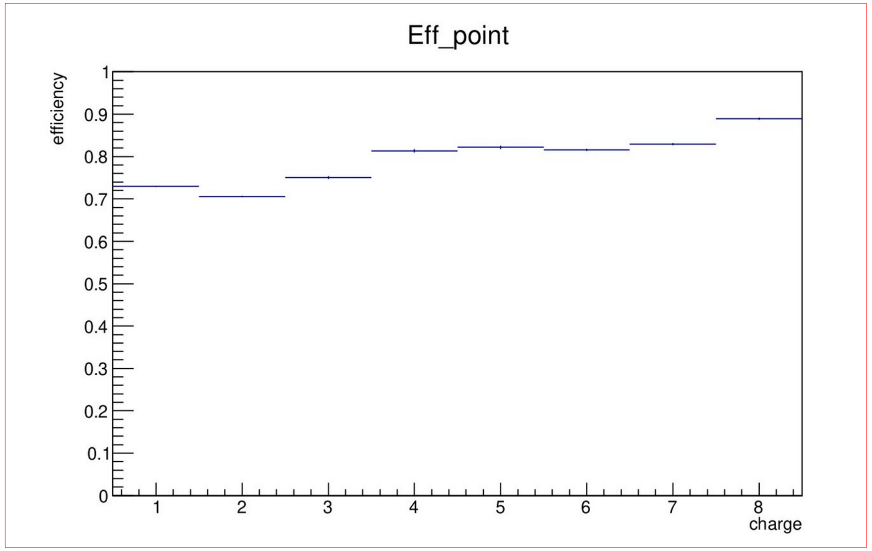
$$\frac{d\sigma}{d\theta} = \frac{(Y_f - B_f)^u}{N_{beam} \cdot N_{target} \cdot \Delta\theta \cdot \epsilon}$$

- MC data

TW ***charge reconstruction*** *algorithm*



charge reconstruction *efficiency*

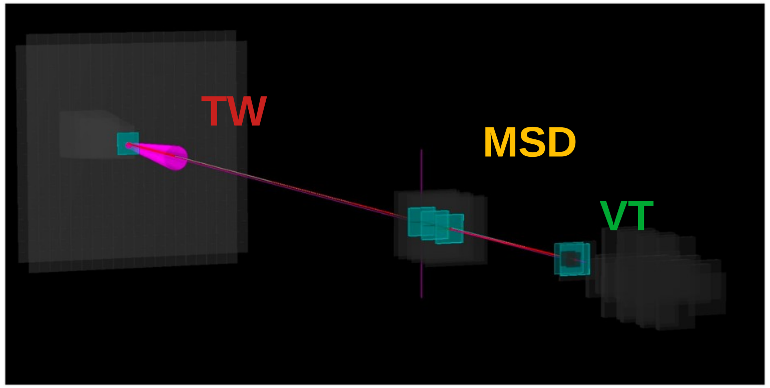


Track reconstruction

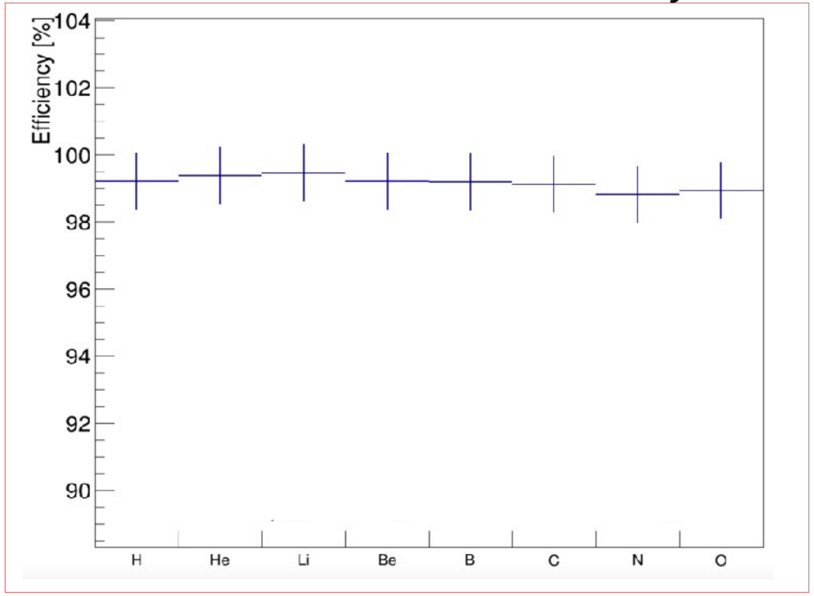
$$\frac{d\sigma}{d\theta} = \frac{(Y_f - B_f)^u}{N_{beam} \cdot N_{target} \cdot \Delta\theta \cdot \epsilon}$$

- MC data

***Kalman Filter reconstruction** of a track*



***Track reconstruction** efficiency*



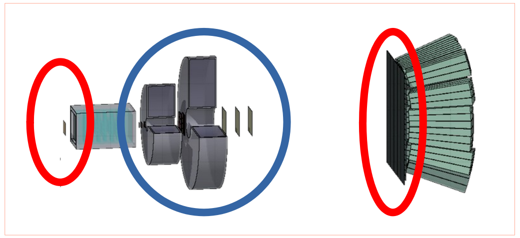
Isotope identification

$$\frac{d\sigma}{d\theta} = \frac{(Y_f - B_f)^u}{N_{beam} \cdot N_{target} \cdot \Delta\theta \cdot \epsilon}$$

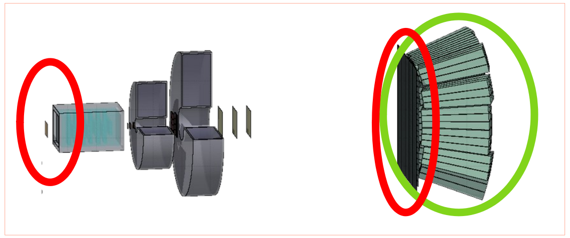
- MC data

Mass reconstruction *using all FOOT subdetectors:*

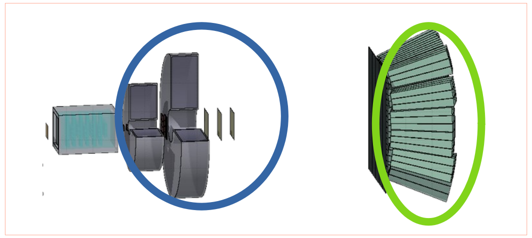
$$A_1 = \frac{p}{U\beta c\gamma}$$



$$A_2 = \frac{E_k}{Uc^2(\gamma - 1)}$$



$$A_3 = \frac{p^2c^2 - E_k^2}{2Uc^2E_k}$$



Isotope identification

$$\frac{d\sigma}{d\theta} = \frac{(Y_f - B_f)^u}{N_{beam} \cdot N_{target} \cdot \Delta\theta \cdot \epsilon}$$

- MC data

Augmented Lagrangian Method

- *Minimization of*

$$L(\vec{x}, \lambda, \mu) \equiv f(\vec{x}) - \sum_a \lambda_a c_a(\vec{x}) + \frac{1}{2\mu} \sum_a c_a^2(\vec{x})$$

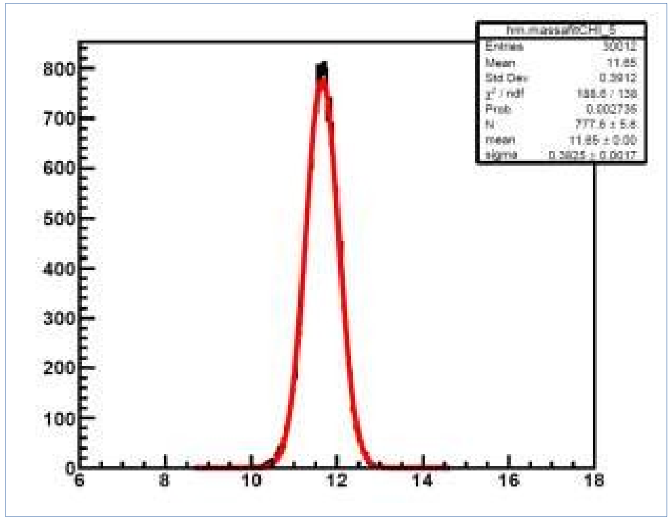
where

$$f(\vec{x}) = \left(\frac{TOF - T}{\sigma_{TOF}}\right)^2 + \left(\frac{p - P}{\sigma_p}\right)^2 + \left(\frac{E_k - K}{\sigma_{E_k}}\right)^2$$

$$c_a(\vec{x}) = A - A_a$$

Es. **A = 12**

A_{ALM} = 11.66 ± 0.38
A/σ_A = 3.2 %
χ 2 < 5

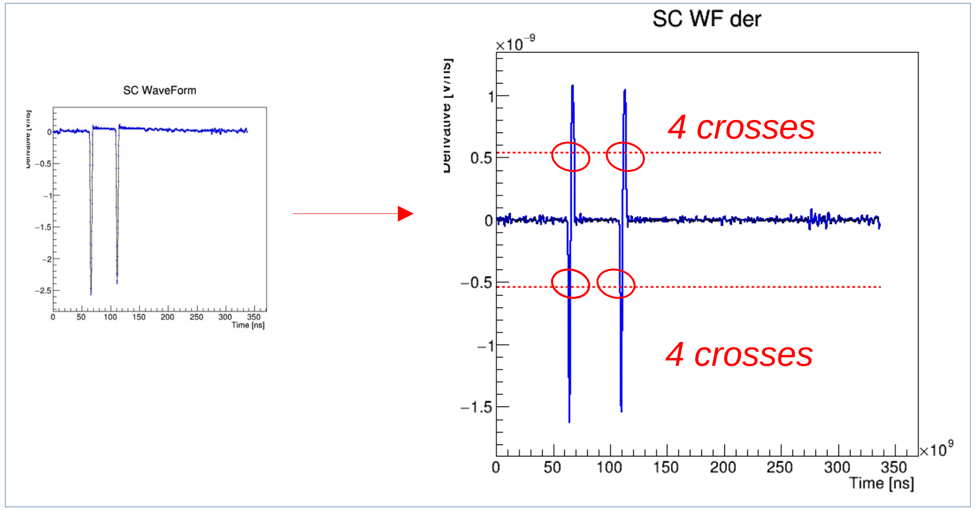


Pile-up removal

$$\frac{d\sigma}{d\theta} = \frac{(Y_f - B_f)^u}{N_{beam} \cdot N_{target} \cdot \Delta\theta \cdot \epsilon}$$

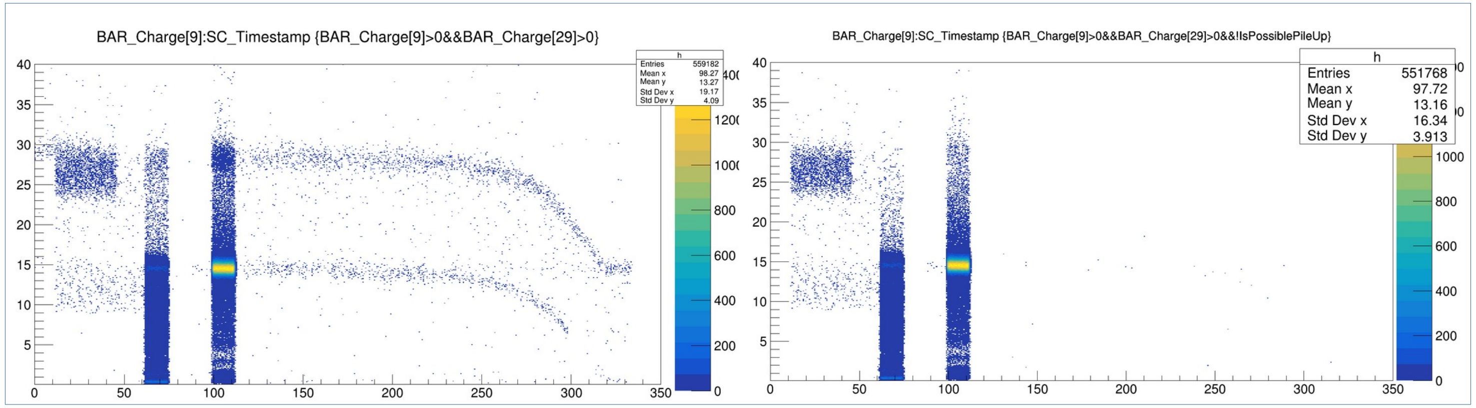
- Real data

constant threshold ***discrimination method***



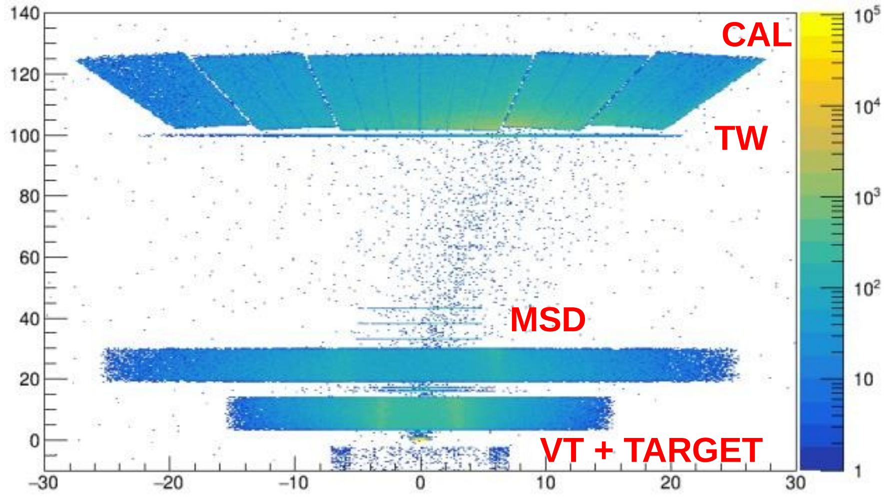
pileup projectile: >4 crosses

Pile-up rejection ~ 1%

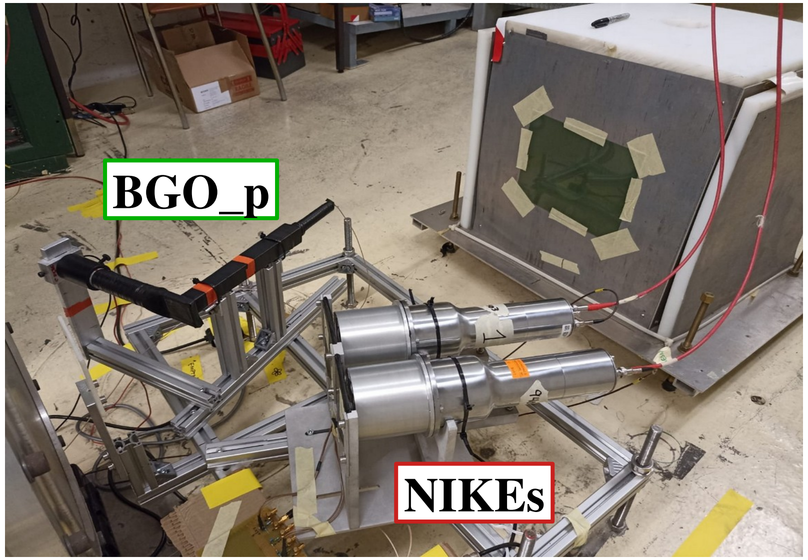


Fast neutrons detectors

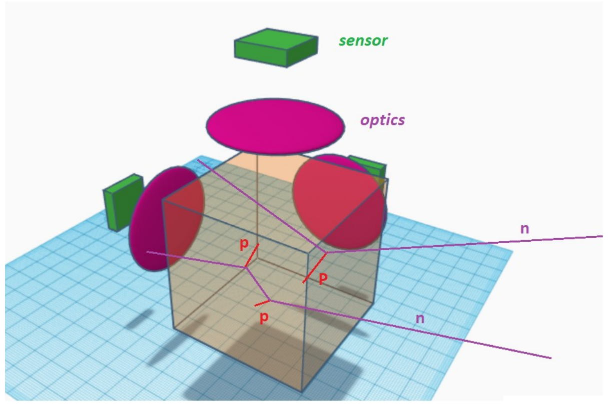
High **neutron production** as a consequence of fragmentation with detectors



Purpose to Add neutron detectors:



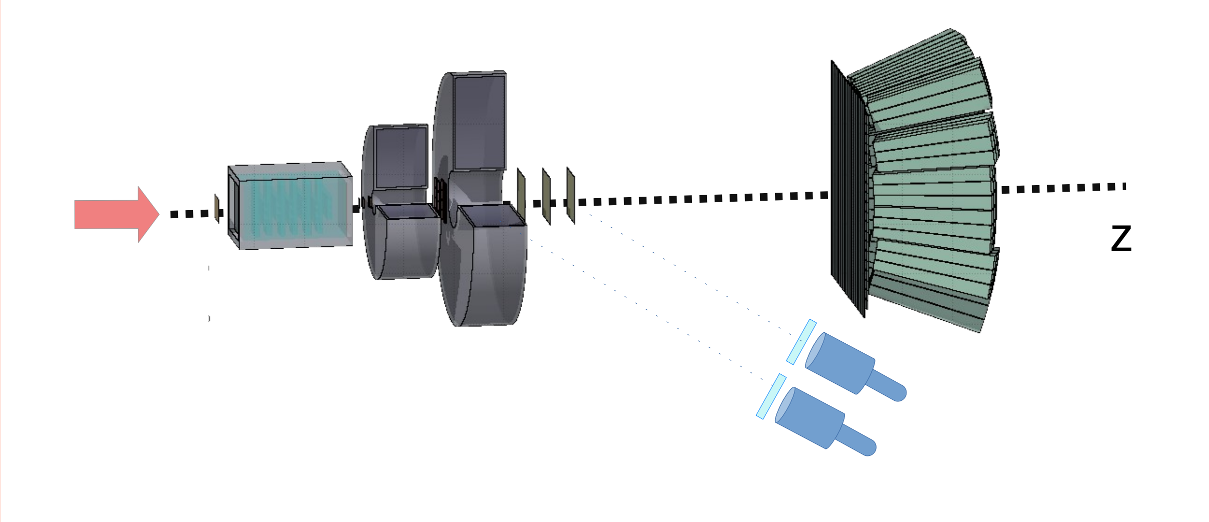
- BC-501A **liquid scintillator**
- **BGO Phoswich**



- recoil-proton track **imaging detector**

Future data taking

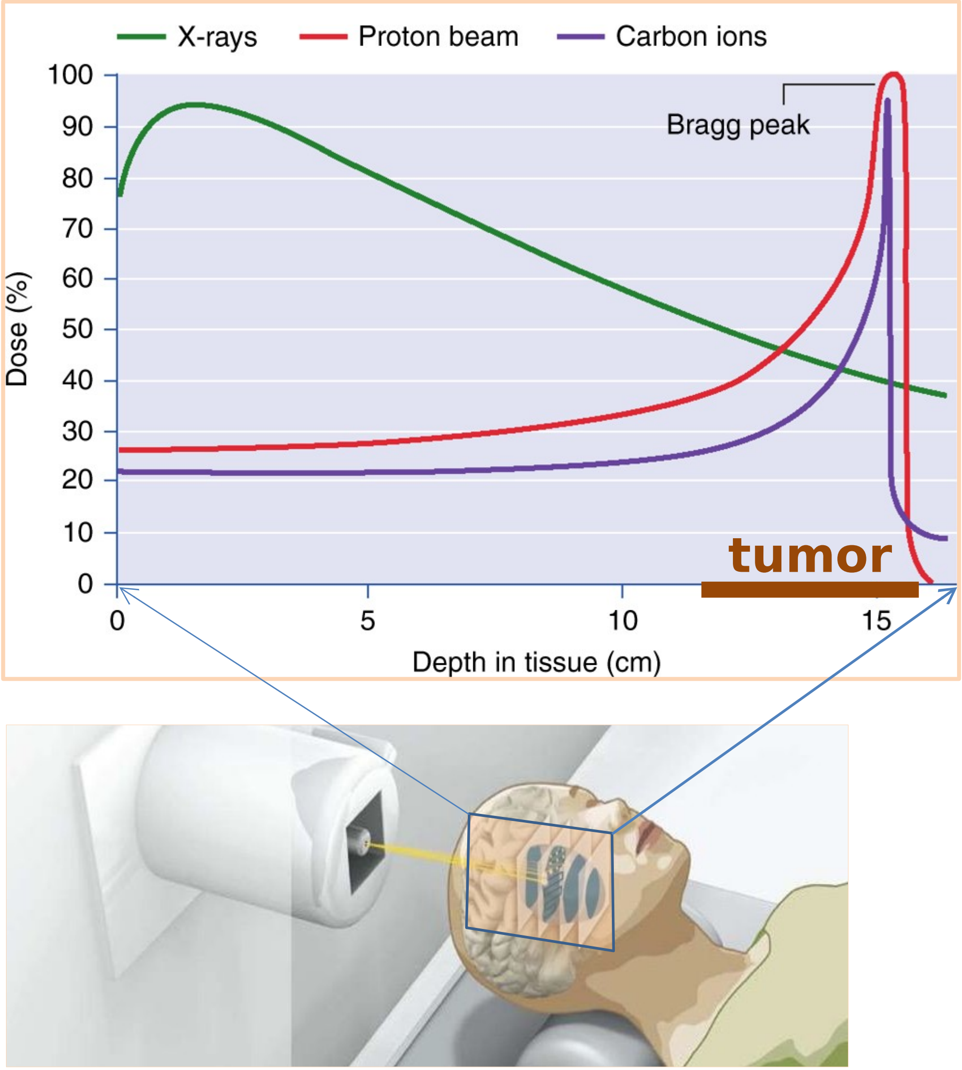
Foreseen within 2023 – 2024
- All detectors will be present



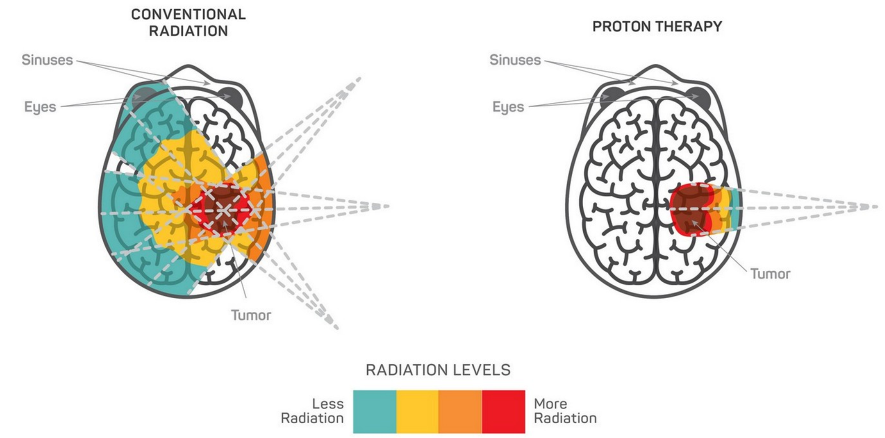
- Beam tests for calibration of all detectors togheter
- Compact analysis strategy needed
- Implementation of neutron detectors in analysis software
- Inverse kinematic application

Back up slides

Hadrontherapy



depth- dose profile for X-rays and charged particles as a beam

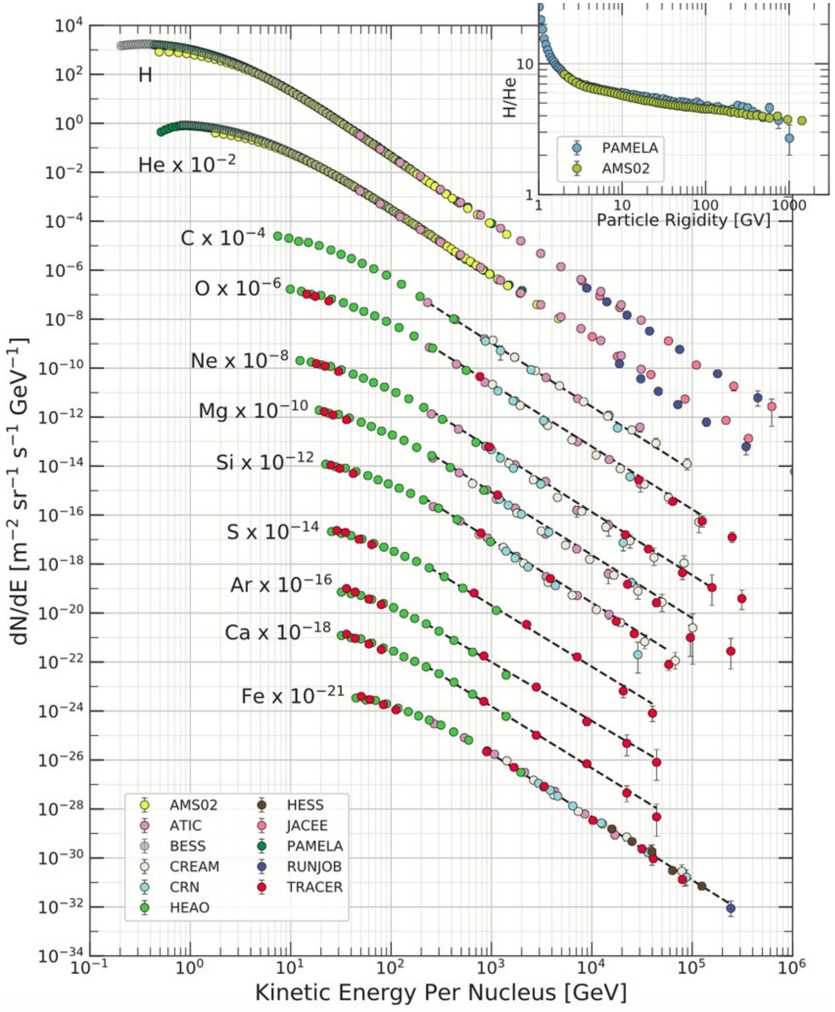


Sketch of a treatment planning system on brain-located tumor

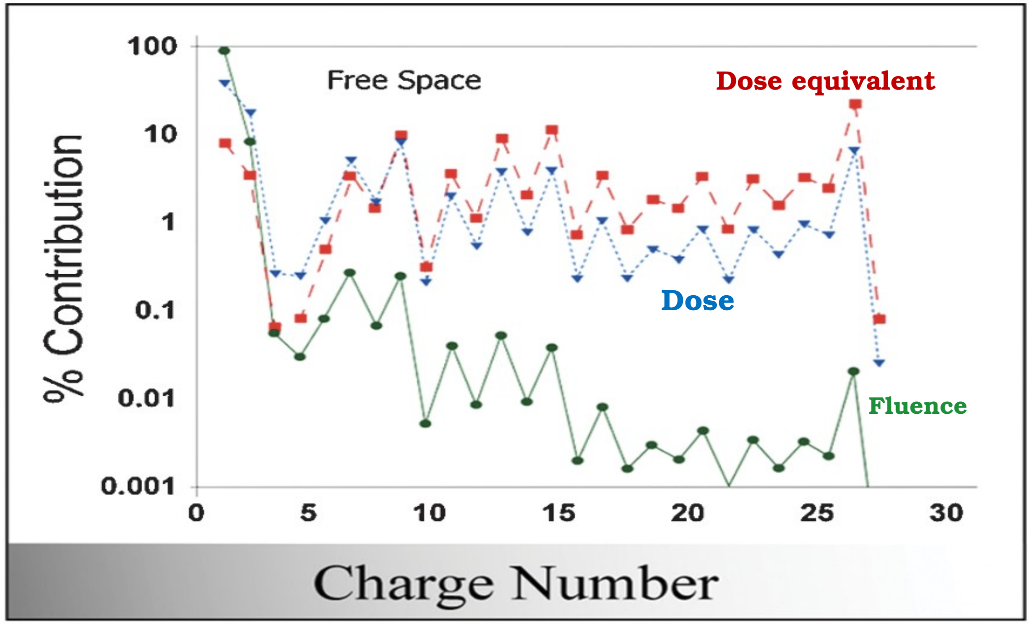
Hadrontherapy vs radiotherapy:

- **Finite range**
- **Localized dose profile**
- **Nuclear fragmentation**

Space radioprotection



GCR fluence



Particles contribution in
Fluence, dose and equivalent dose

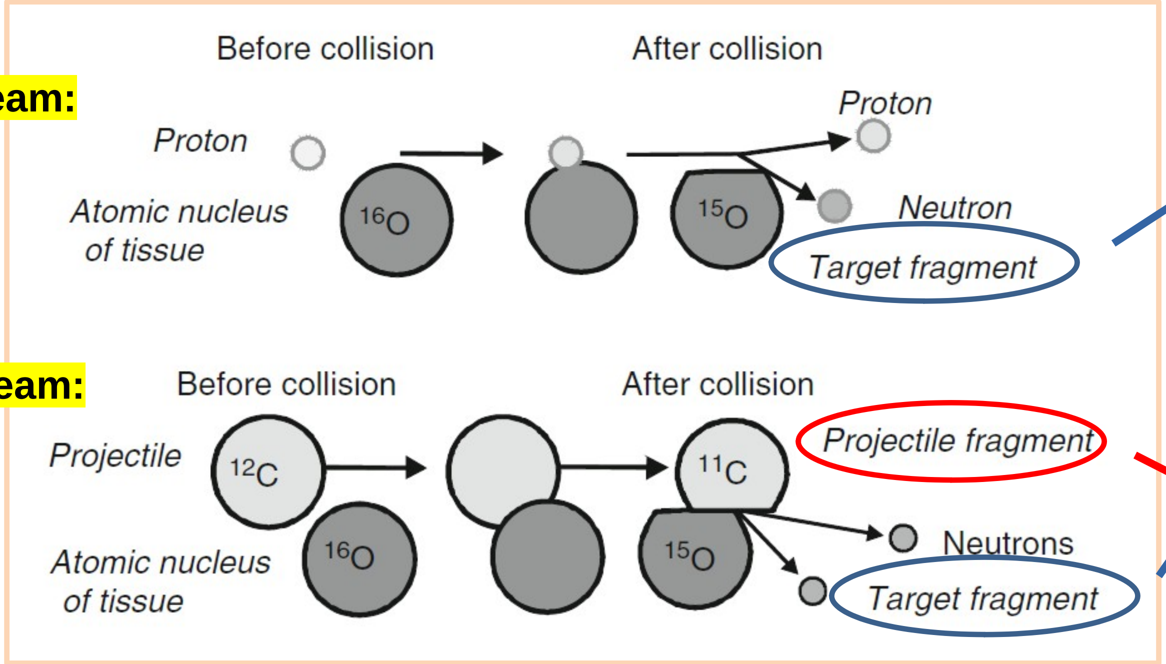
Nuclear Fragmentation

Proton beam:

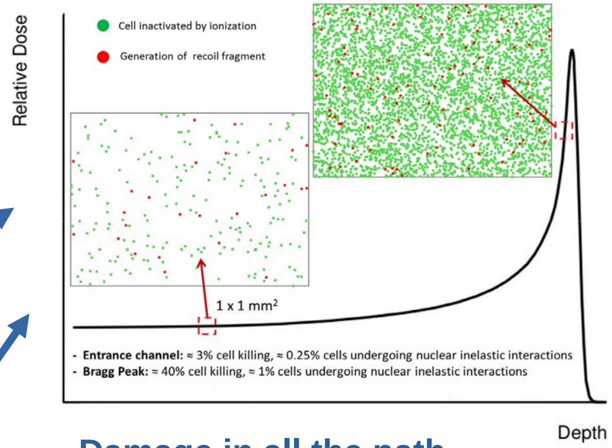
~ 200 MeV

Carbon beam:

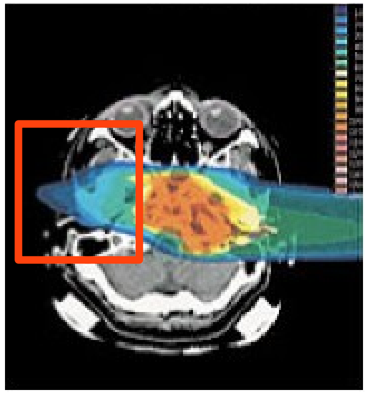
~ 400 MeV/u



Sketch of Nuclear fragmentation



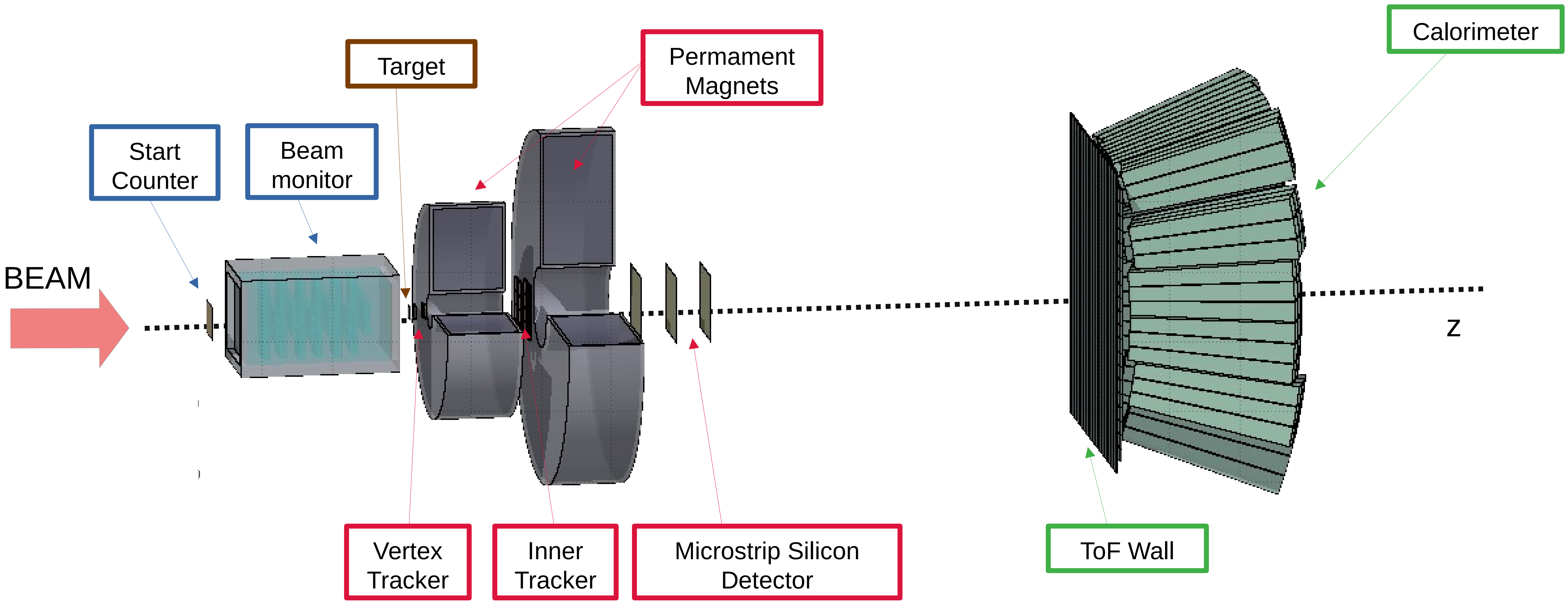
Damage in all the path



BEAM

Damage after the BP

The FOOT detector



Pre-target region

Tracking region

Downstream region

Differential Cross section

Yield of all fragments

Background

unfolding

$$\frac{d\sigma}{d\theta} = \frac{(Y_f - B_f)^u}{N_{beam} \cdot N_{target} \cdot \Delta\theta \cdot \epsilon}$$

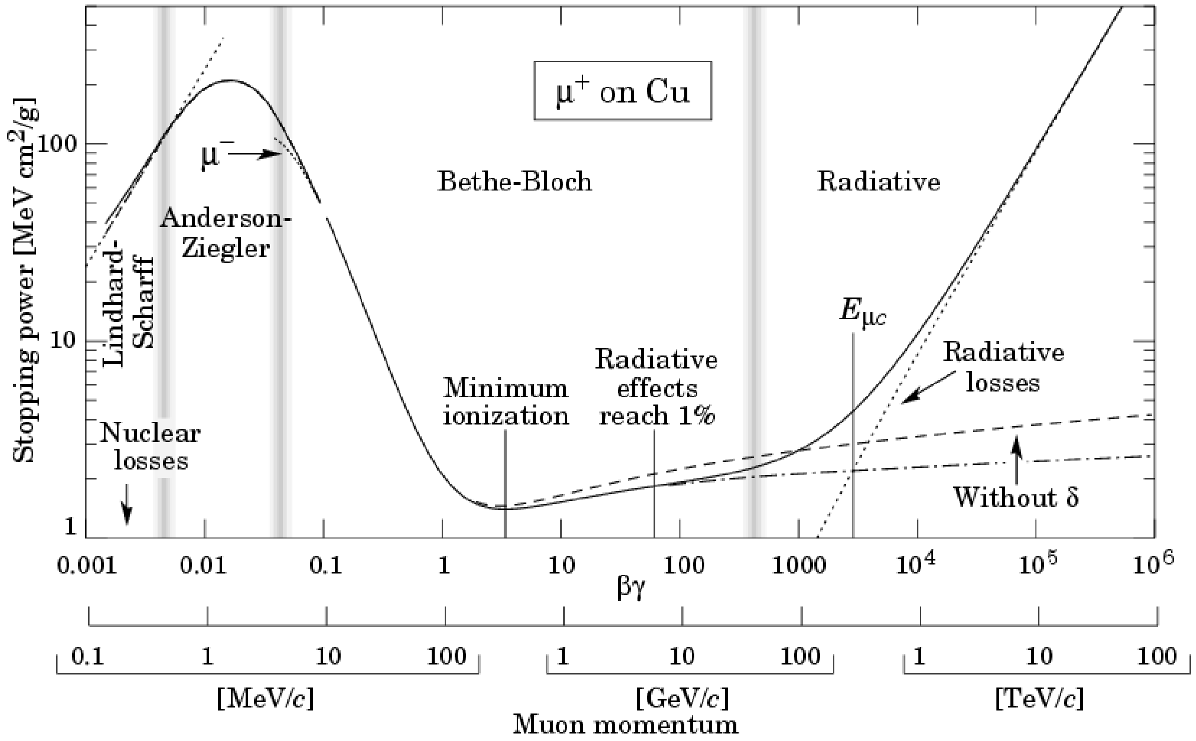
efficiency

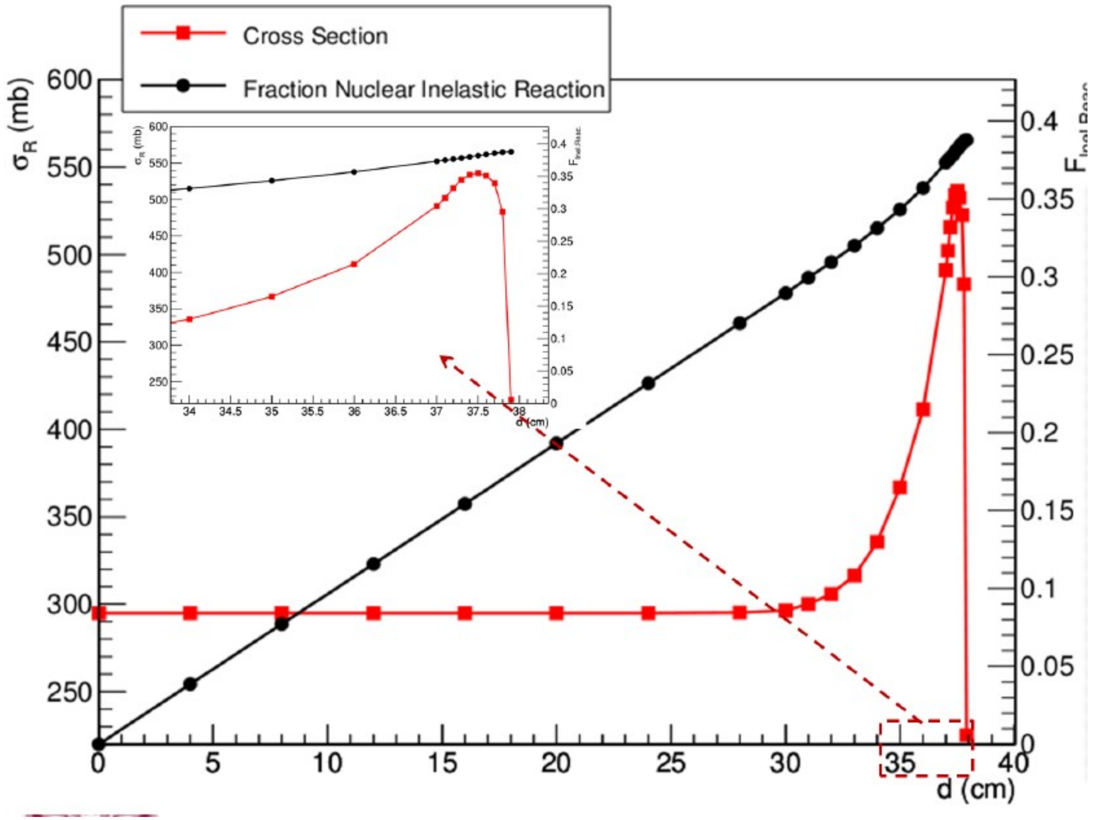
N° of primary events

N° of scattered centers

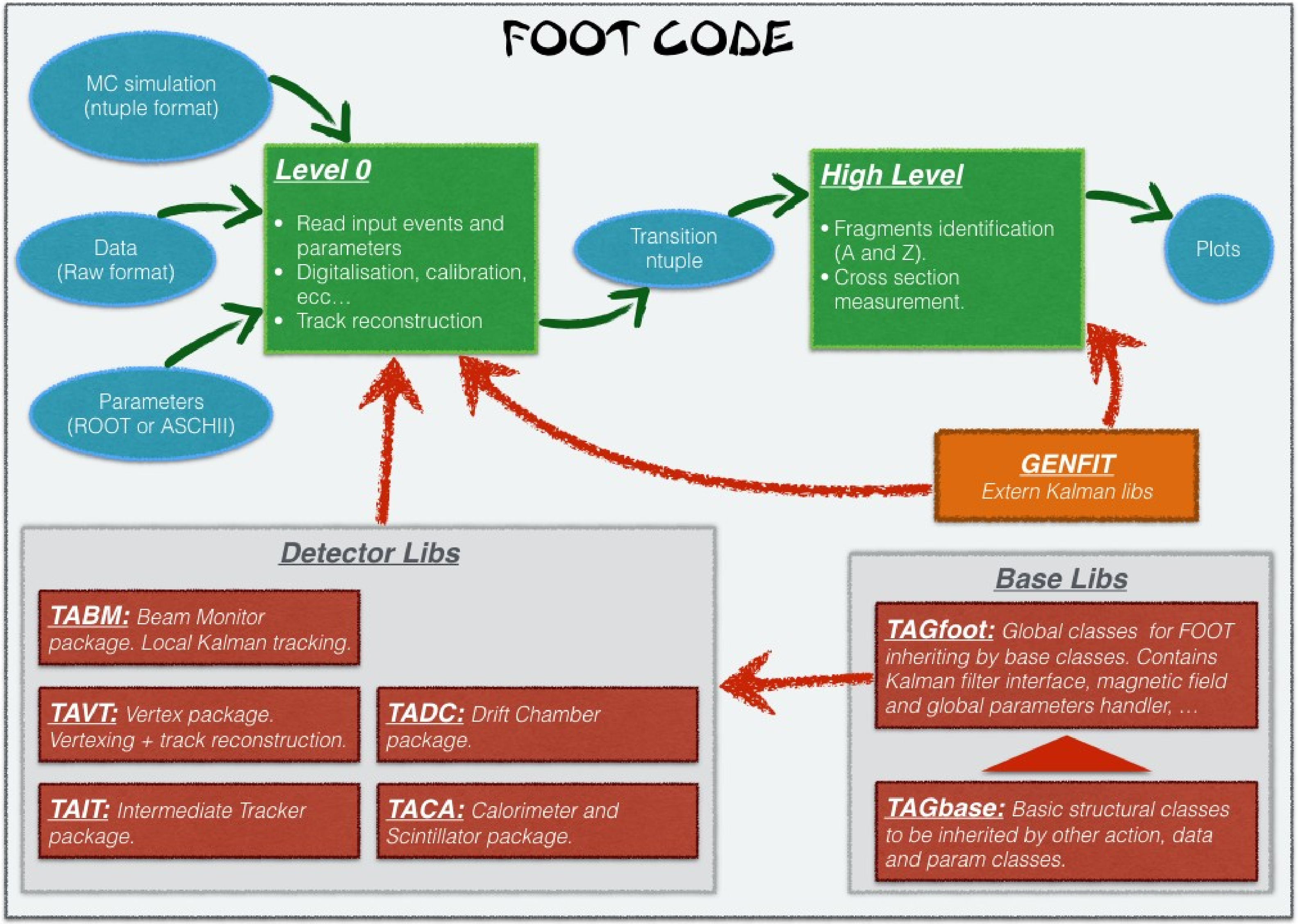
Phase space

Bethe Bloch vs nuclear cross section





SHOE organization



Kalman filter in pills

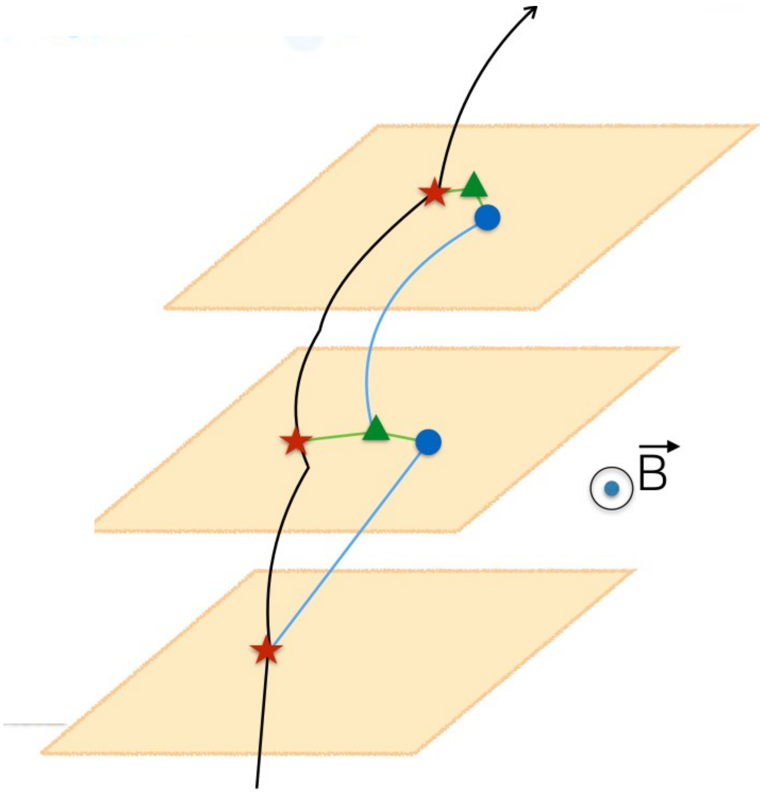
1. Take an ideal particle in vacuum. If we add air + detector layers, trajectory changes due to M.S. and energy loss.

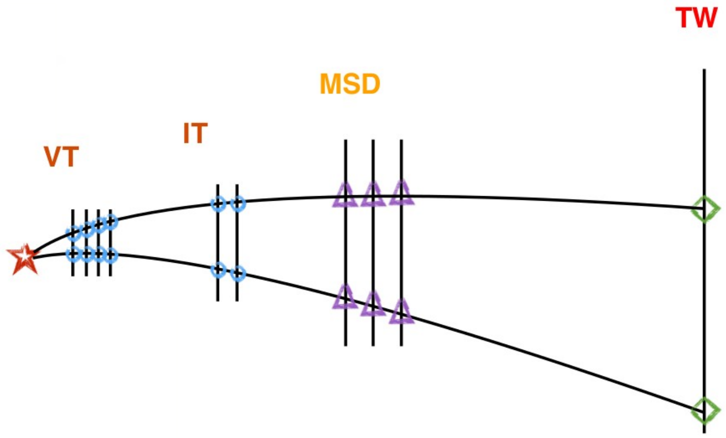
2. We'll see some measurement hits on the detector layers (considering finite detector uncertainty).
Filtering

3. Propagate the first hit to the next layer. Propagator Matrix F.

4. Find the best compromise between the propagated point and the closest hit on the 2 nd layer. Use a Chi2 and a Projection Matrix H.

5. Iterate 3 and 4 for the next layers.

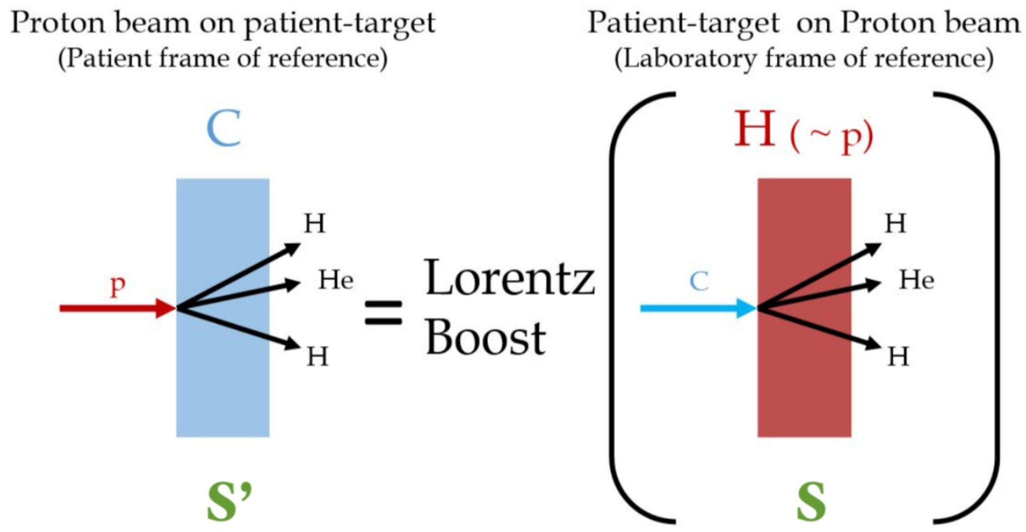




Kalman Filter reconstruction of a track

- Start from VT tracklets
- Projection to possible planes of IT
- KF extrapolation to MSD
- KF extrapolation to TW
- Fit the track candidates and extract reconstructed quantities: **Z**, **momentum** ...

Inverse kinematics



$$
\begin{aligned}
ct' &= \gamma(ct - \beta z) \\
x' &= x \\
y' &= y \\
z' &= \gamma(z - \beta ct)
\end{aligned}
$$

$$
\begin{aligned}
E'/c &= \gamma(E/c - \beta p_z) \\
p'_x &= p_x \\
p'_y &= p_y \\
p'_z &= \gamma(p_z - \beta E/c)
\end{aligned}
$$