Charge measurement with nuclear emulsions spectrometers for hadron therapy fragmentation cross section measurements with the FOOT experiment

FragmentatiOn Of Target

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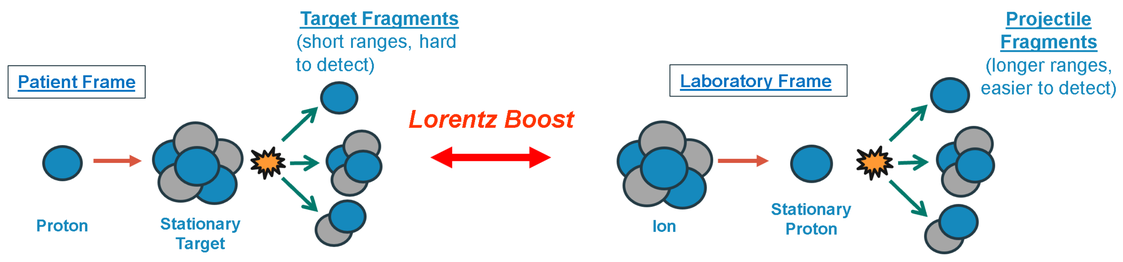
Measuring Nuclear Fragmentation for Particle Therapy

- Accurate models of nuclear fragments produced by particle beams are needed to reduce the uncertainty on the **Relative Biological Effectiveness (RBE)**
- **FOOT** (***FragmentatiOn Of Target***) experiment aim: measure nuclear fragmentation cross sections at energies ranging from 200 MeV/n to 800 MeV/n with 5% accuracy
- **Inverse kinematic approach** to overcome the challenge of detecting target fragments with ranges of a few µm



- **Linear combination method** for H cross section:

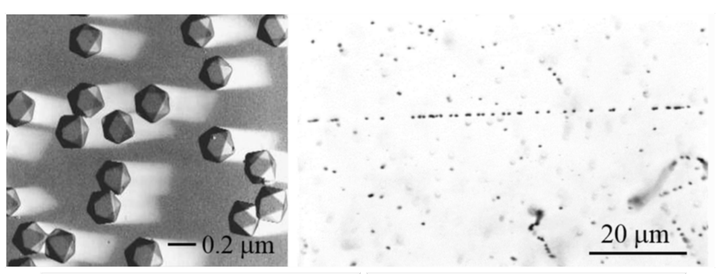
$$\frac{d\sigma}{dE_{kin}(H)} = \frac{1}{4}\left(\frac{d\sigma}{dE_{kin}(C_2H_4)} - 2\frac{d\sigma}{dE_{kin}(C)}\right)$$

Two *complementary* setups:

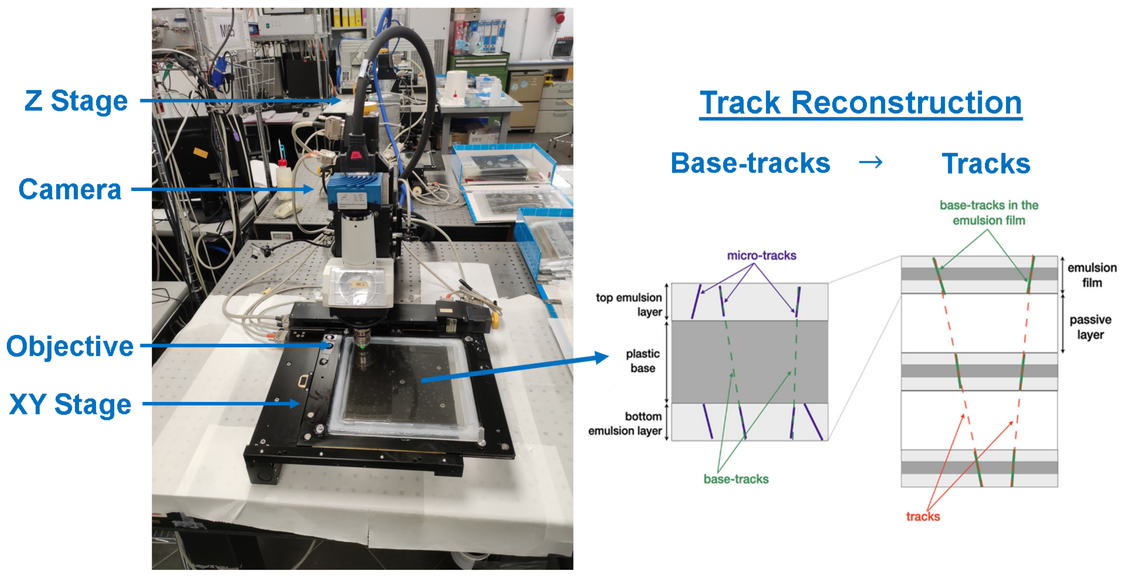
- **Electronic Setup**: magnetic spectrometer coupled with electronic detectors, optimized for heavier fragments ($Z \geq 3$)
- **Nuclear Emulsion Setup**, optimized for the lighter fragments ($Z \leq 3$)

Nuclear Emulsions

- A nuclear emulsion film is composed of a large number of AgBr crystals (about 200 nm) dispersed in an organic gelatine binder
- Passage of radiation activates the crystals forming the **latent image**: $Ag^+ + e^- \rightarrow Ag$
- Amplification of the process with a reduction agent (**development**)



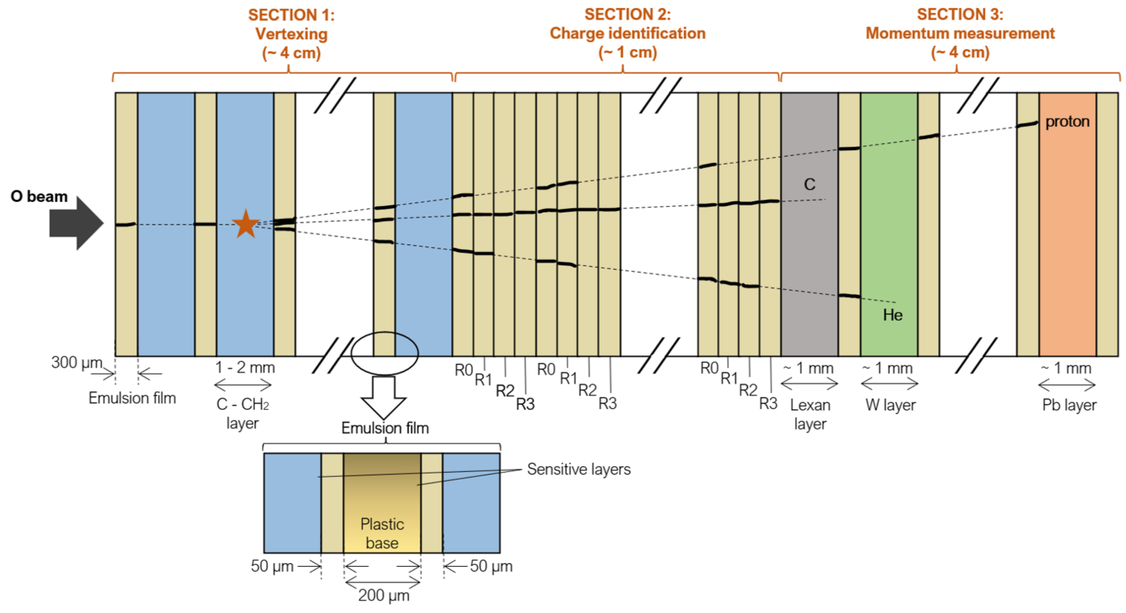
- Fast automated scanning with optical microscopes ($\sim 20\,cm^2/h$)
- Dedicated track reconstruction algorithm (Large Angle Scanning System, LASSO)



- Emulsion Cloud Chamber setup → micrometric spatial resolution
- Compact detector → compatible with limited space in the experimental rooms of therapeutic centres

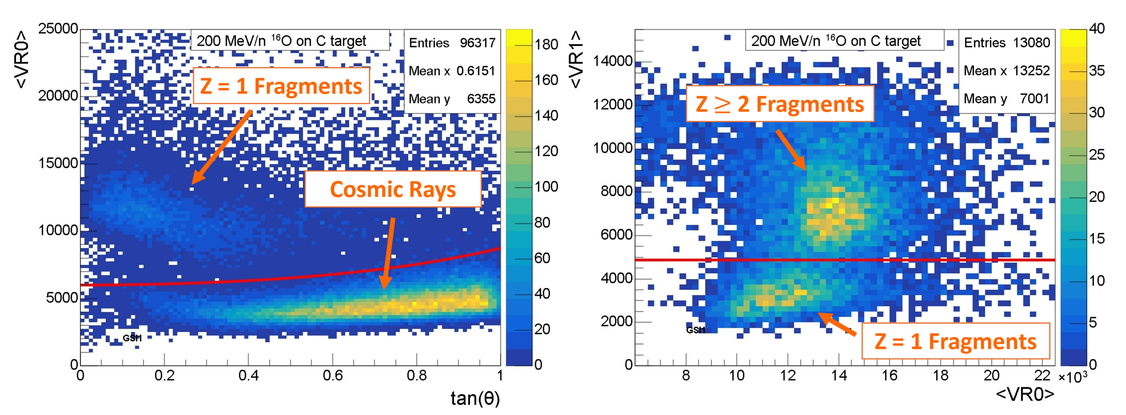
The Emulsion Cloud Chamber of the FOOT Experiment

- Controlled fading technique → **charge identification**
- Correlation between range and kinetic energy + Multiple Coulomb Scattering (MCS) method → momentum measurement and **isotopic identification**

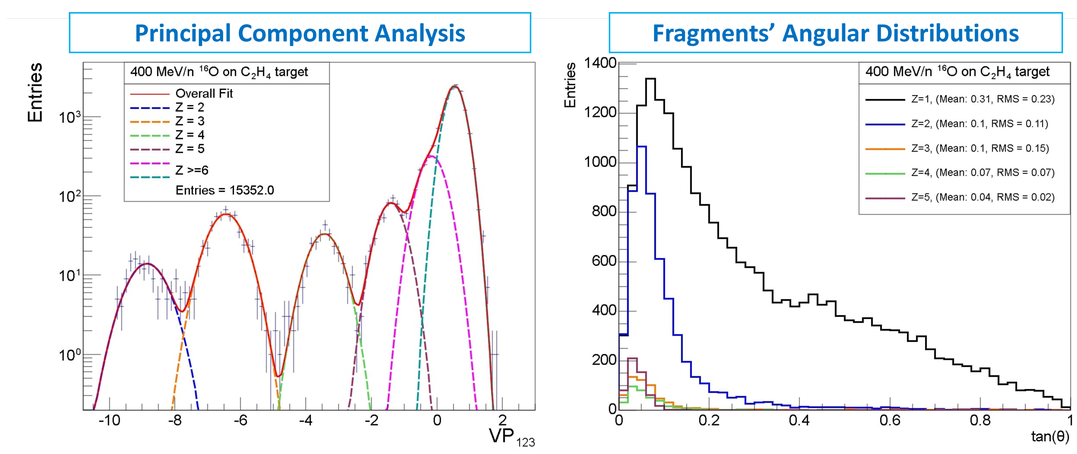


Charge Identification of Oxygen Fragments

- ECCs with carbon and polyethylene targets exposed to 200 MeV/n and 400 MeV/n O^{16} beams (GSI 2019)
- Section 2 composed of 36 nuclear emulsion films divided into 9 quadruplets with 4 different thermal treatments (R0, R1, R2, R3)
- **Cut-Based** analysis → identification of $Z \leq 2$ fragments



- **Principal Component Analysis (PCA)** to identify fragments with $Z >= 2$



- Measurement of charges up to $Z = 3$ at 200 MeV/n and up to $Z = 5$ at 400 MeV/n

Conclusions

The FOOT experiment measures nuclear fragmentation cross sections relevant to particle therapy and space radiation protection.
The nuclear emulsion spectrometer has been optimized for the detection and identification of $Z \leq 3$ fragments. The application of thermal treatments has enabled to achieve charge classification up to $Z = 3$ of fragments produced by 200 MeV/n O^{16} beams impinging on carbon and polyethylene, and up to $Z = 5$ for interactions at 400 MeV/n.

References

[1] G. Galati, V. Boccia et al., Charge identification of fragments produced in ^{16}O beam interactions at 200 MeV/n and 400 MeV/n on C and C_2H_4 targets, *Frontiers in Physics*

[2] G. Galati et al., Charge identification of fragments with the emulsion spectrometer of the FOOT experiment, *De Gruyter*

[3] G. Battistoni et al., Measuring the impact of nuclear interaction in particle therapy and in radio protection in space: the FOOT experiment, *Frontiers in Physics*