Calibration and performances of the full scale ΔE-TOF system prototype of the FOOT experiment

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Introduction

FOOT (FragmentatiOn Of Target) → applied nuclear physics experiment relevant in:

Hadron therapy

- Cancer treatment with
  - ✓ Favorable depth-do
  - ✗ Nuclear interactions with
    tissue → **fragments**
- Radiobiology request: more accurate Treatment Planning Systems (TPS)
- p, ^{12}C (^{4}He, ^{16}O) beams
- Energy up to 250 MeV (p) or 400 MeV/u (^{12}C)

TODAY'S FOCUS

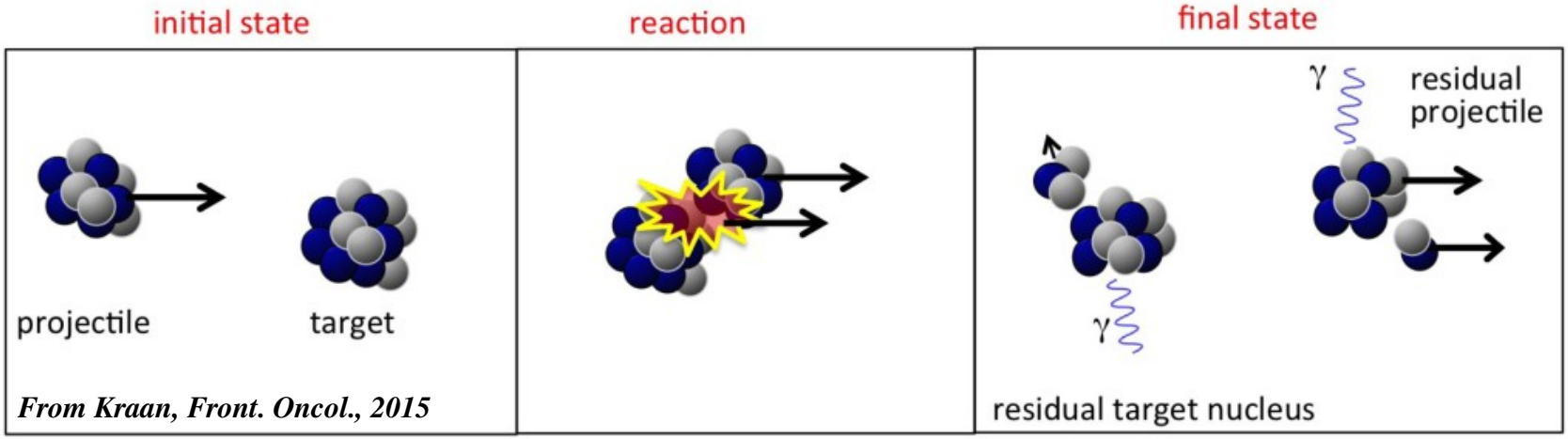
Heidelberg Ion-Beam Therapy Center

Radioprotection in space

- Knowledge of fragmentation processes needed for spacecraft shielding in long term, far from Earth missions
- p, He, Li, C, O beams
- Energies up to 800 MeV/u

Introduction: nuclear fragmentation

Main goal of FOOT → **Identify the nuclear fragments produced inside the body during treatment and measure their production cross section**



Ion species

^{15}O, ^{15}N, ^{14}N, ^{13}C, ^{12}C, ^{11}C, ^{10}B, ^{6}Li, ^{4}He, ^{3}He, ^{3}H, ^{2}H, ^{1}H…

Nuclear fragments contribute to dose mostly outside the tumor

- Many types of fragments
- Energies up to tens of MeV
- Damage to healthy tissue
- RBE variability

→ **New generation of biologically-driven TPS (BioTPS) including nuclear processes**

The FOOT experiment

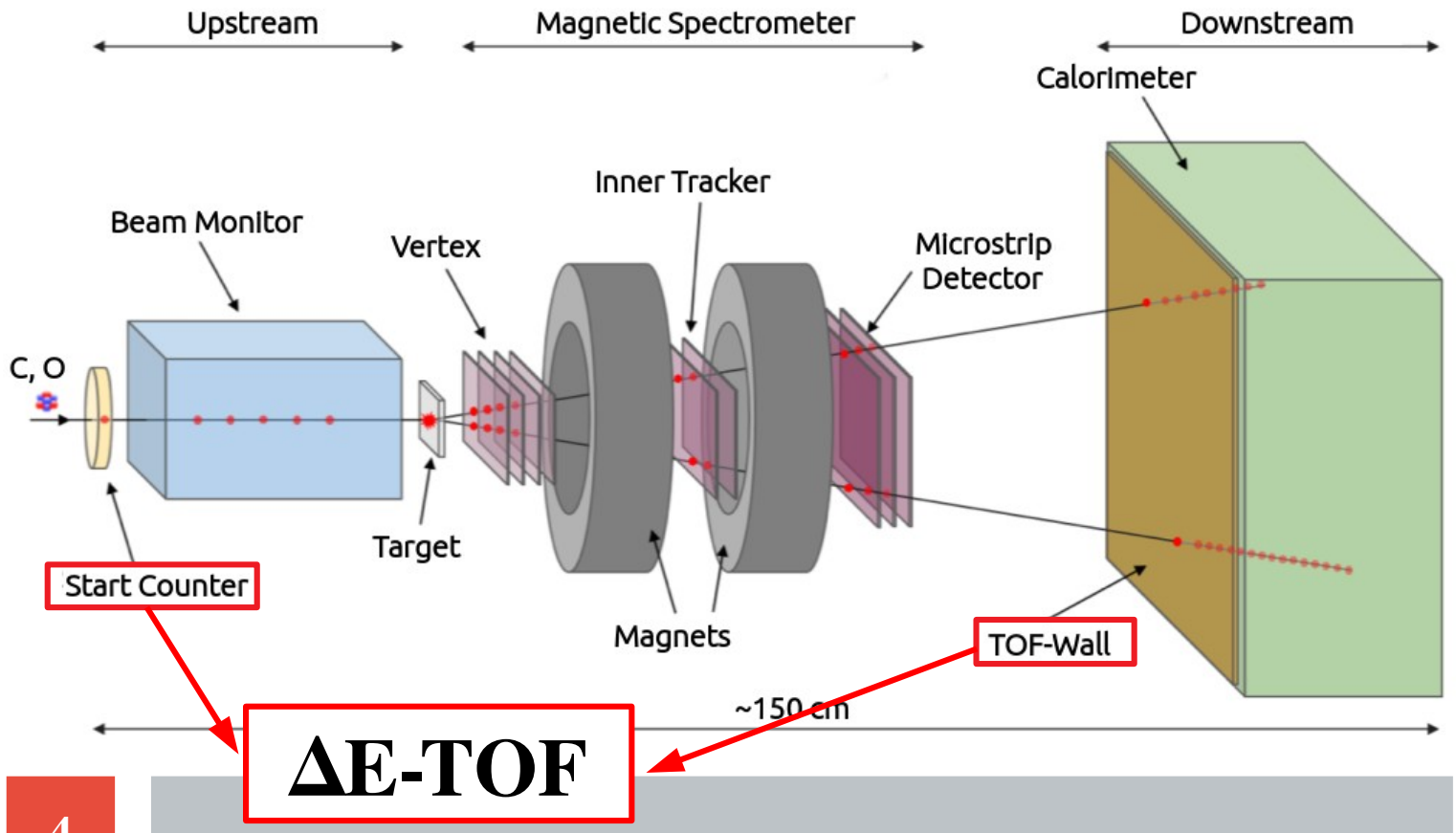
C/O beams on tissue-like target → study nuclear fragments:

- Mass identification (3-6%)
- **Charge identification** (2-6%)

→ Cross section (<5%)

International Collaboration

- >100 members
- 11 INFN sections
- 10 Italian and 3 foreign universities
- 3 research institutions



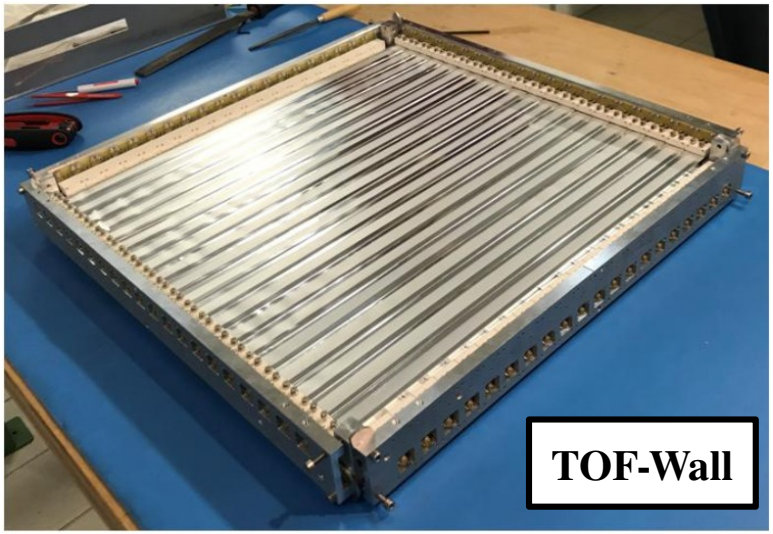
- Upstream region: primary beam
- Magnetic spectrometer: particle tracking
- Downstream region: energy and TOF
- First data taking scheduled for 2021

The ΔE-TOF system

- Characterization of nuclear fragments → measures:
  - **Energy loss ΔE**
  - **Time-Of-Flight → β**

  → **Charge $Z = Z(\Delta E, \beta)$**
- Two plastic scintillator detectors:
  - Start Counter → 250 μm thick foil
    → provides start time
  - TOF-Wall → 2 orthogonal layers of 20 bars (44x2x0.3 cm³)
    → provides stop time and energy loss
  - Readout with SiPMs and fast digitizers


Start Counter


TOF-Wall

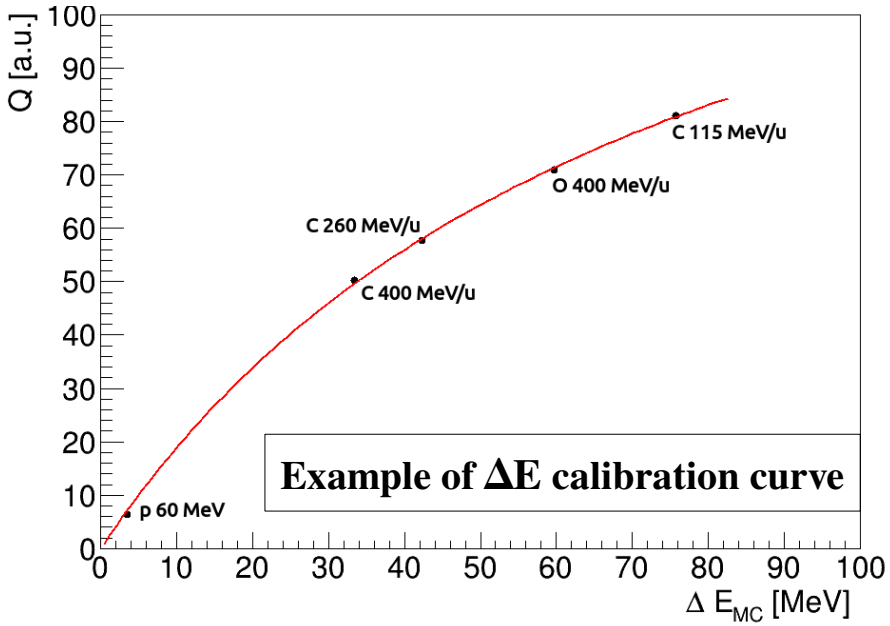
FOOT requirements:
- **σ(ΔE)/ΔE ~ 4-5%**
- **σ(TOF) < 100 ps**

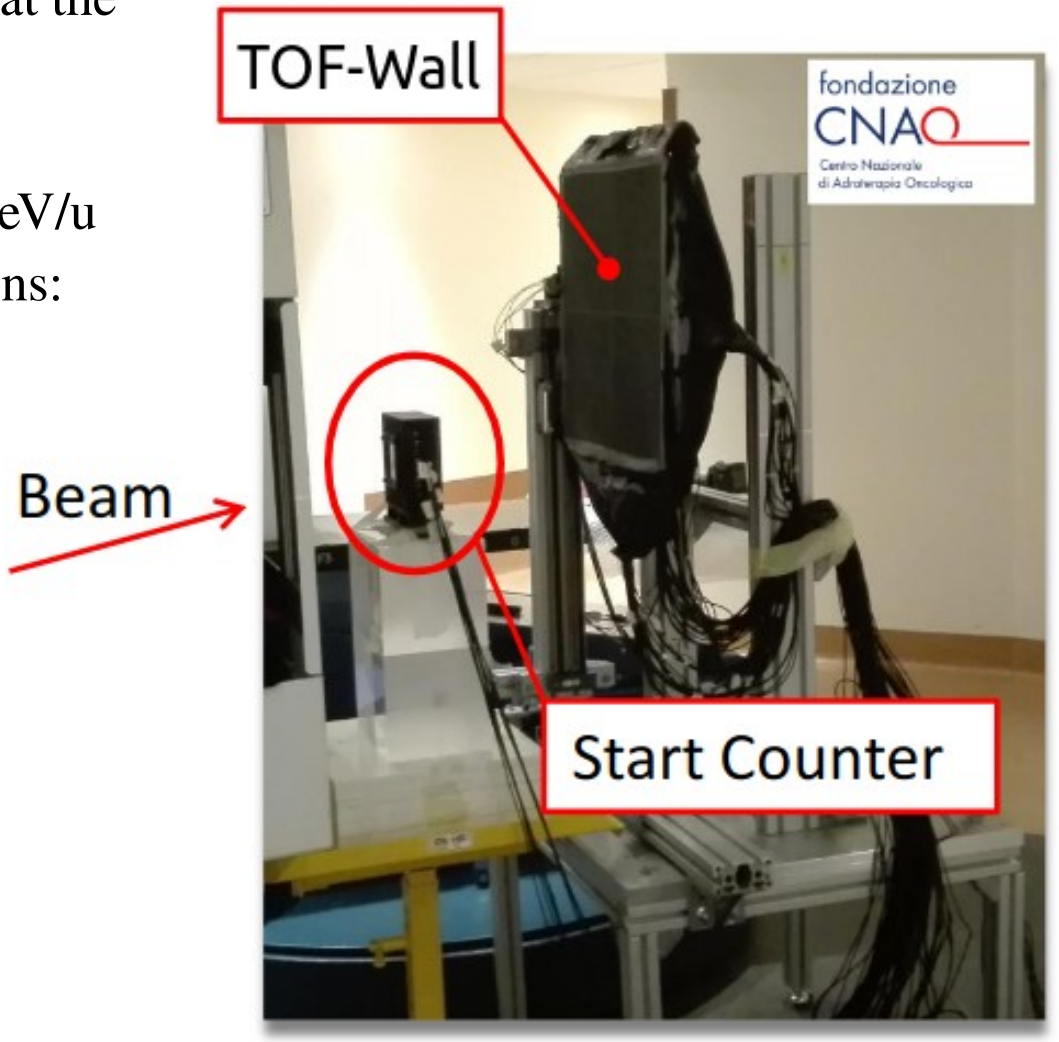
→ **σ(Z)/Z ~ 2-6%**

Beam test at CNAO

First test of the full-scale ΔE-TOF prototype at the CNAO facility (Pavia, March 2019):

- Beams: → Protons at 60 MeV
  → ^{12}C ions at 115, 260 and 400 MeV/u
- Calibration through Monte Carlo simulations:
  - ΔE → Birks' model
  - TOF → matching with MC values



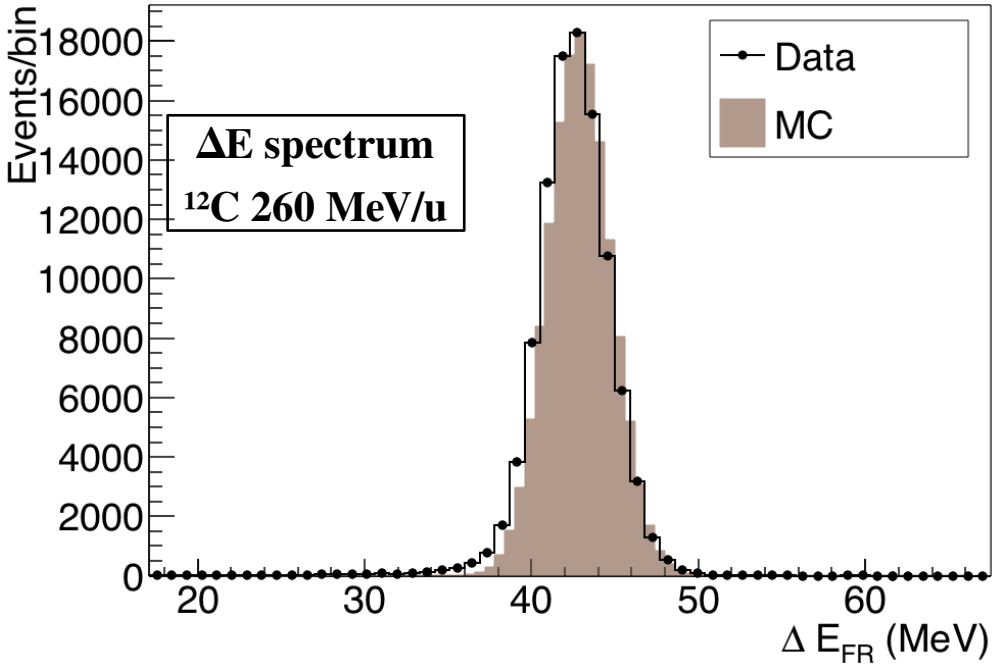


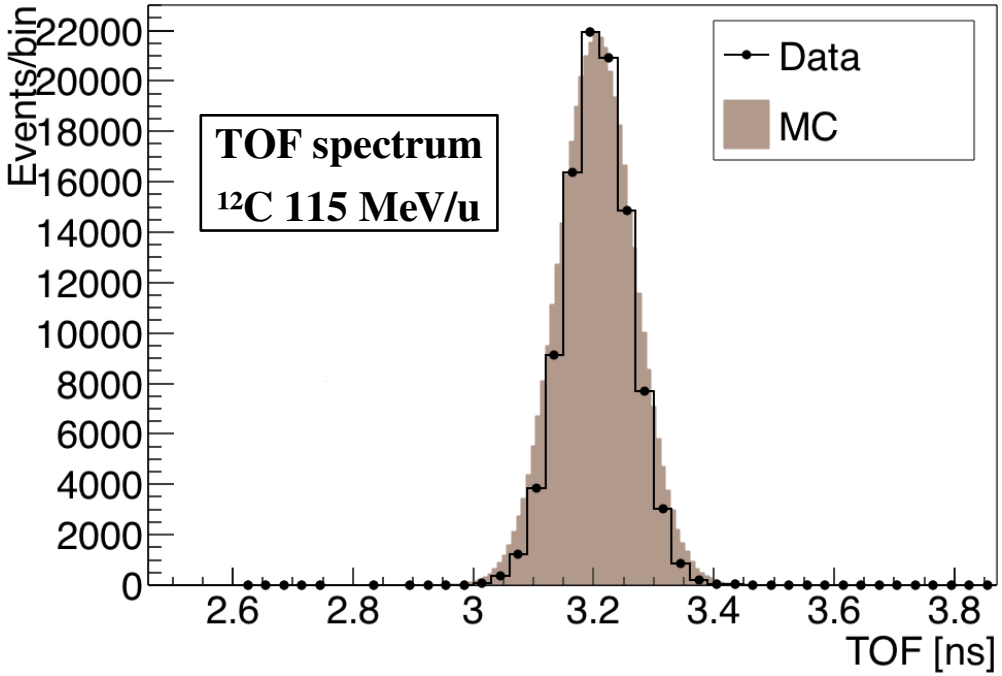
Beam test at CNAO

σ(ΔE)/ΔE → 4 - 4.7% for ^{12}C
→ 5.3% for protons
σ(TOF) → 54 - 72 ps for ^{12}C
→ 260 ps for protons

→

σ(Z) → 2.5 - 4% for ^{12}C
→ 6.2% for protons

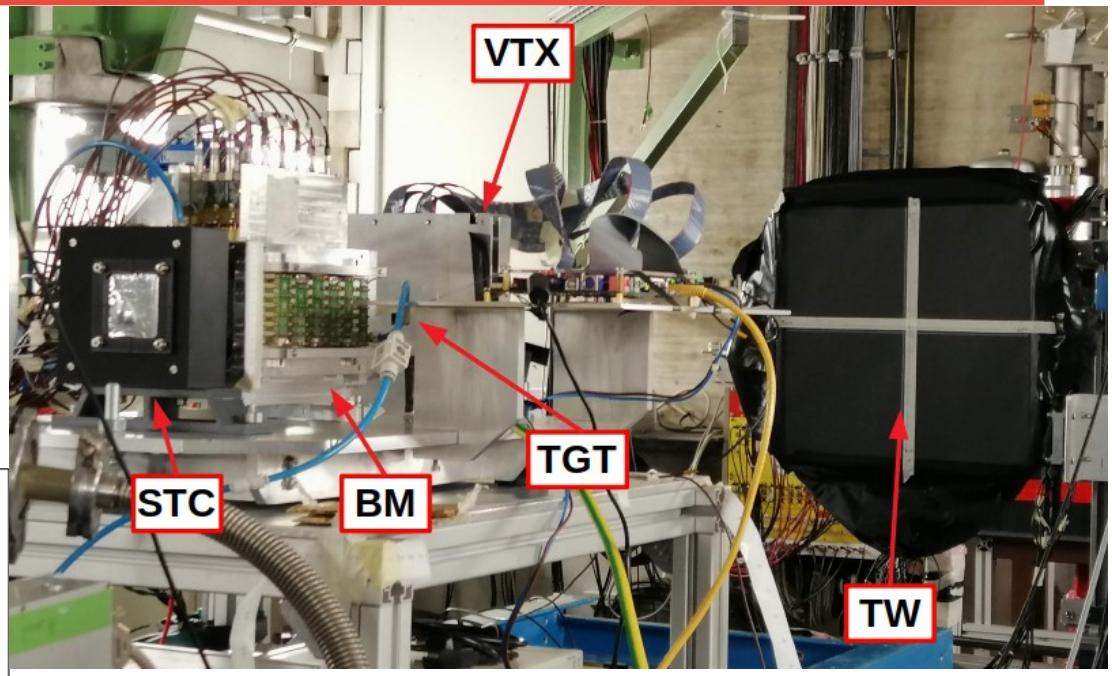


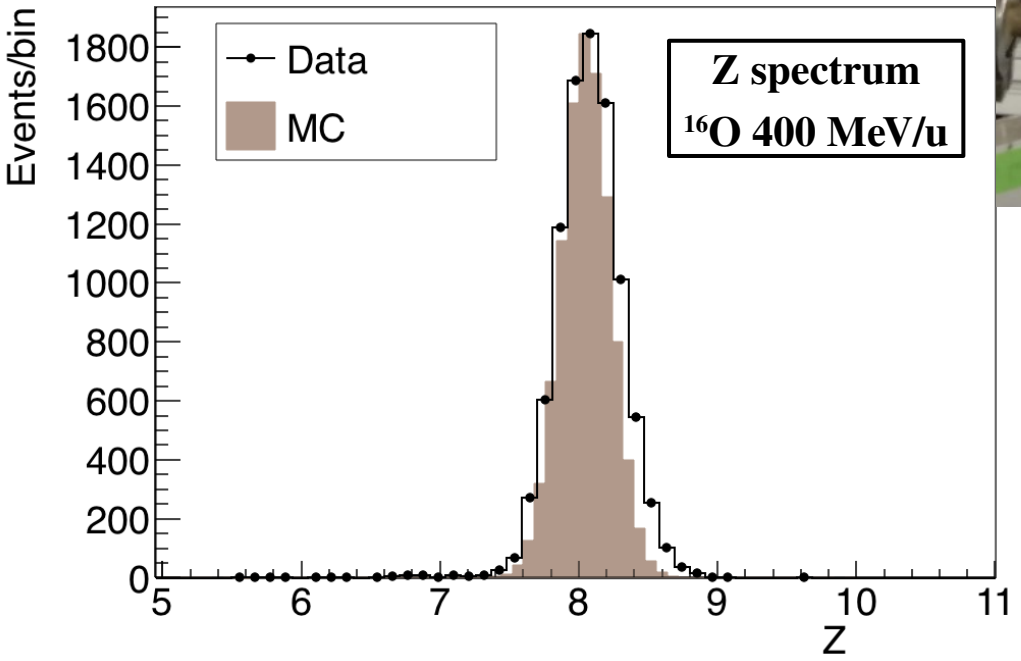


Beam test at GSI

First test of the global DAQ at the GSI facility (Darmstadt, April 2019):

- ΔE-TOF with other detectors
- ^{16}O beam at 400 MeV/u





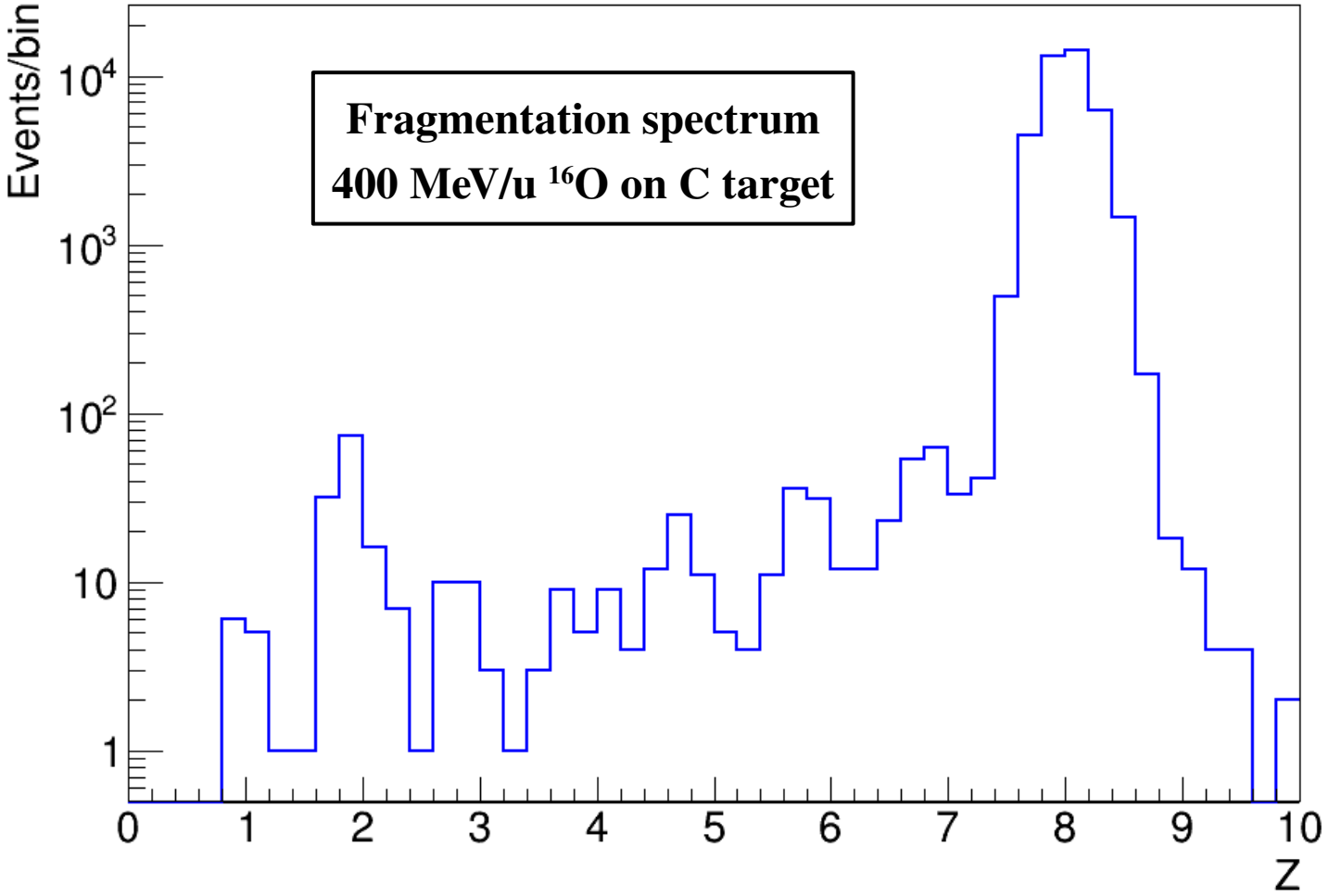
σ(ΔE)/ΔE = 5.0%

σ(TOF) = 84 ps

σ(Z) = 2.8%

Beam test at GSI: fragmentation

First fragmentation acquisition → **400 MeV/u ^{16}O ions on a 5mm graphite target**



First application of the Z identification procedure to fragmentation data

Conclusions

We studied the capabilities of the current ΔE-TOF system of FOOT

- ΔE and TOF calibration procedures developed and validated with MC simulations
- Good ΔE (4-5.5%) and TOF (50-75 ps) resolution
- Good overall Z resolution (2.5-6.2%)
- Z identification procedure applied to fragmentation data
- Still much work can be done to optimize the performances
- Important data takings scheduled for the near future:
  - CNAO → December 2020
  - HIT (Heidelberg, Germany) → early 2021

THANK YOU FOR YOUR ATTENTION