Z identification with 2019 data acquired at CNAO and GSI

Roberto Zarrella

Introduction

As you all know, we have written a paper about charge identification with the ΔE-TOF system:

1) Introduction

2) Materials and Methods:

- Detectors: SC and TW + WaveDAQ
- Data samples: CNAO 03/2019 + GSI 04/2019
- MC simulations
- ΔE and TOF calibration procedures → Z id

3) Results

4) Discussion

5) Conclusions

Charge identification of nuclear fragments with the FOOT Time-Of-Flight system

A. C. Kraan[a], R. Zarrella[t,d,*], A. Alexandrov[j,s,ag,ah], B. Alpat[k], G. Ambrosi[k], S. Argirò[ab,q], R. Arteche Diaz[ad], N. Bartosik[q], G. Battistoni[h], N. Belcari[b,a], E. Bellinzona[o], S. Biondi[d,t], G. Bruni[d], P. Carra[b,a], P. Cerello[q], E. Ciarrocchi[b,a], A. Clozza[g], S. Colombi[o,p], G. De Lellis[s,j], A. Del Guerra[b,a], M. De Simoni[l,z], A. Di Crescenzo[s,j], B. Di Ruzza[o], M. Donetti[e], Y. Dong[h,w], M. Durante[f,af], R. Faccini[z,l], V. Ferrero[q], E. Fiandrini[k,x], C. Finck[n], E. Fiorina[q], M. Fischetti[l,v], M. Francesconi[b,a], M. Franchini[d,t], G. Franciosini[l,z], G. Galati[j], L. Galli[a], V. Gentile[j,ag], G. Giraudo[q], R. Hetzel[c], E. Iarocci[g], M. Ionica[k], A. Iuliano[s], K. Kanxheri[k], V. Lante[e], C. La Tessa[o,p], M. Laurenza[g], A. Lauria[s,j], E. Lopez Torres[ad,q], M. Marafini[l,u], C. Massimi[d,t], I. Mattei[h], A. Mengarelli[d], A. Moggi[a], M. C. Montesi[ai,j], M. C. Morone[m,aa], M. Morrocchi[b,a], S. Muraro[h], F. Murtas[z], A. Pastore[ac], N. Pastrone[q], V. Patera[l,v], F. Pennazio[q], P. Placidi[k,y], M. Pullia[e], F. Raffaelli[a], L. Ramello[r,q], R. Ridolfi[d,t], V. Rosso[b,a], C. Sanelli[g], A. Sarti[l,v], G. Sartorelli[d,t], O. Sato[i], S. Savazzi[e], L. Scavarda[ab,q], A. Schiavi[l,v], C. Schuy[f], E. Scifoni[o], A. Sciubba[g,v], A. Sécher[n], M. Selvi[d], L. Servoli[k], G. Silvestre[k,x], M. Sitta[r,q], R. Spighi[d], E. Spiriti[g], G. Sportelli[b,a], A. Stahl[c], S. Tomassini[g], F. Tommasino[o,p], M. Toppi[g,v], G. Traini[l,z], V. Tioukov[j], S. M. Valle[h], M. Vanstalle[n], M. Villa[d,t], U. Weber[f], A. Zoccoli[d,t], M. G. Bisogni[b,a]

[a] *Istituto Nazionale di Fisica Nucleare (INFN), Section of Pisa, Pisa, Italy*
[b] *University of Pisa, Department of Physics, Pisa, Italy*
[c] *RWTH Aachen University, Physics Institute III B, Aachen, Germany*
[d] *Istituto Nazionale di Fisica Nucleare (INFN), Section of Bologna, Bologna, Italy*
[e] *Centro Nazionale di Adroterapia Oncologica (CNAO), Pavia, Italy*
[f] *Biophysics Department, GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany*
[g] *Istituto Nazionale di Fisica Nucleare (INFN), Laboratori Nazionali di Frascati, Frascati, Italy*
[h] *Istituto Nazionale di Fisica Nucleare (INFN), Section of Milano, Milano, Italy*
[i] *Nagoya University, Department of Physics, Nagoya, Japan*
[j] *Istituto Nazionale di Fisica Nucleare (INFN), Section of Napoli, Napoli, Italy*
[k] *Istituto Nazionale di Fisica Nucleare (INFN), Section of Perugia, Perugia, Italy*
[l] *Istituto Nazionale di Fisica Nucleare (INFN), Section of Roma 1, Rome, Italy*
[m] *University of Rome Tor Vergata, Department of Physics, Rome, Italy*
[n] *Université de Strasbourg, CNRS, IPHC UMR 7871, F-67000 Strasbourg, France*
[o] *Trento Institute for Fundamental Physics and Applications, Istituto Nazionale di Fisica Nucleare (TIFPA-INFN), Trento, Italy*
[p] *University of Trento, Department of Physics, Trento, Italy*
[q] *Istituto Nazionale di Fisica Nucleare (INFN), Section of Torino, Torino, Italy*
[r] *University of Piemonte Orientale, Department of Science and Technological Innovation, Alessandria, Italy*

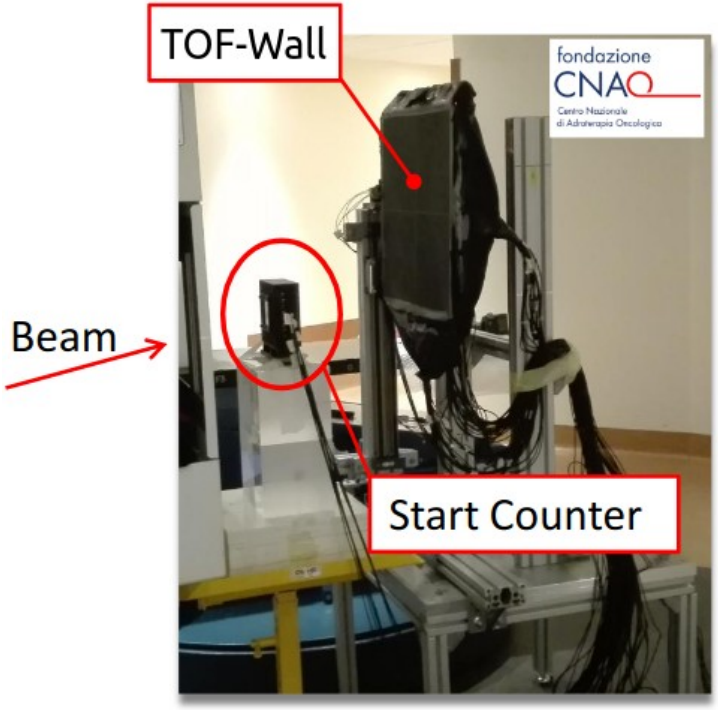
Data samples

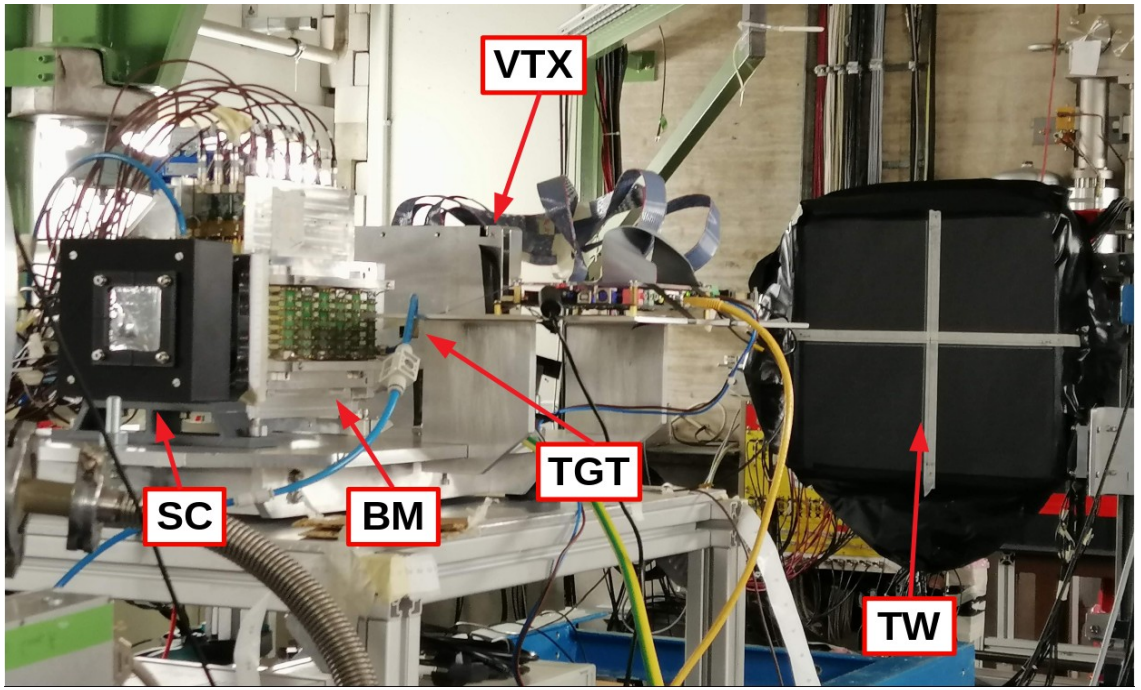
CNAO

- 4 calibration runs
- p @ 60 MeV
- ^{12}C @ 115, 260, 400 MeV/u

GSI

- ^{16}O @ 400 MeV/u
- 1 calibration run
- 1 fragmentation run → 5mm graphite



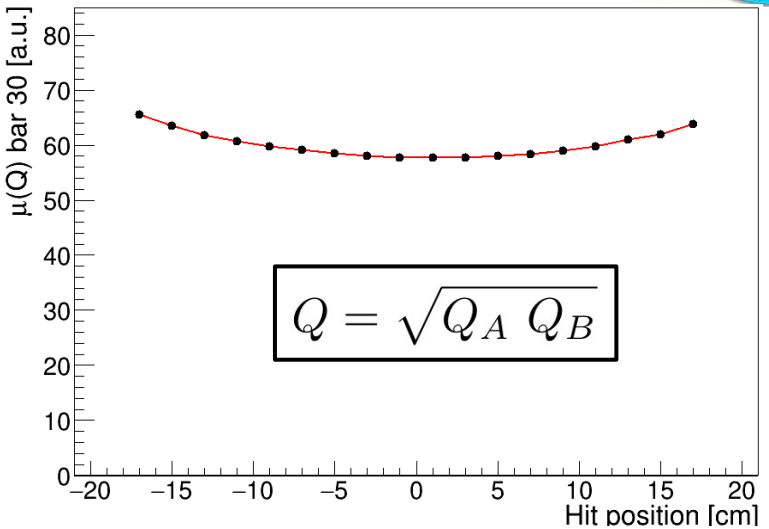


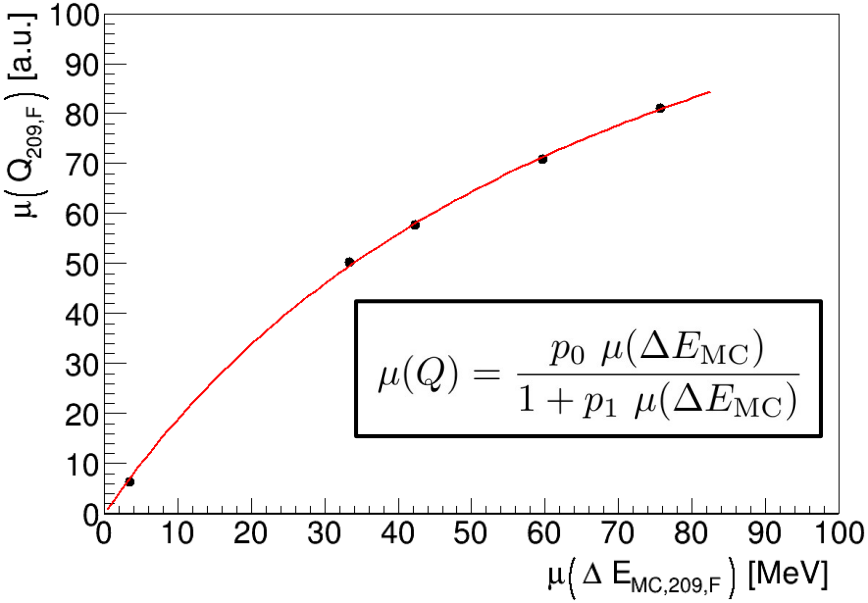
Energy calibration

- Raw energy is not constant along bars
- Position-per-position calibration
- Birks model with MC as reference for ΔE
- Reliable if >100 events for all CNAO beams
- Calibrated ΔE calculation

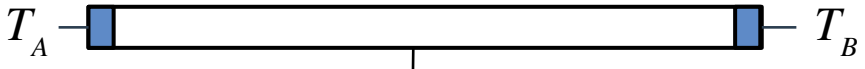
$$\Delta E_{i,l} = \frac{Q_{i,l}}{p_{0,i,l} - p_{1,i,l}\ Q_{i,l}}$$

i = TW position *l* = TW layer





TOF calibration

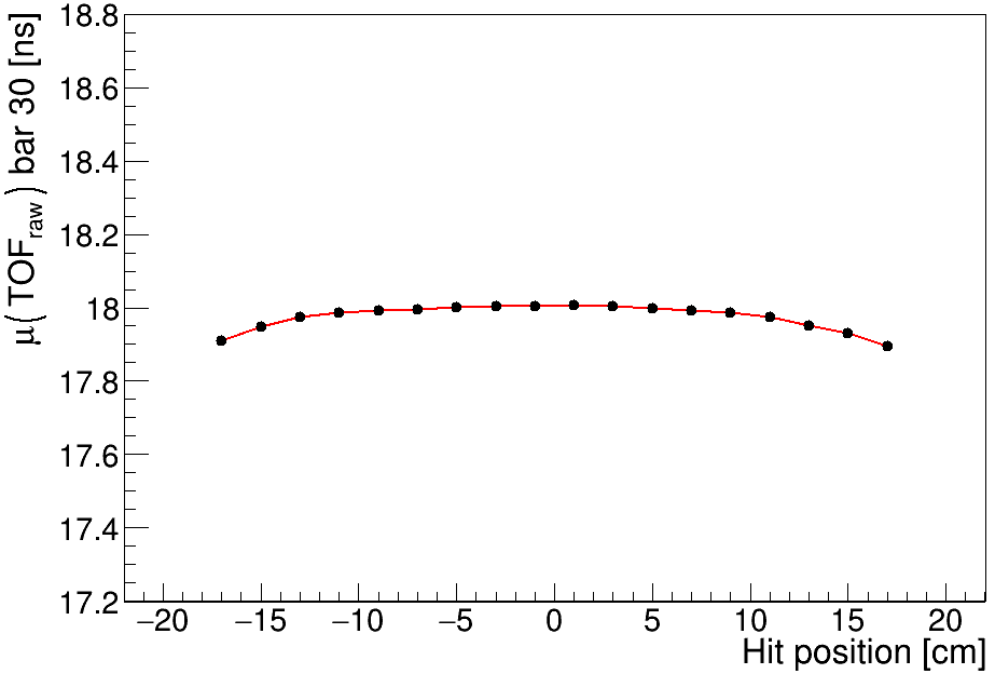


$$T_{bar} = \frac{T_A - \Delta_{CLK,A} + T_B - \Delta_{CLK,B}}{2} \rightarrow \mathrm{TOF}_{\mathrm{raw}} = T_{bar} - T_{SC}$$

- Raw TOF also depends on hit position
- Calibration performed by matching mean raw values with MC reference

$$\mu(\mathrm{TOF}_{\mathrm{raw},i,l}) = \mu(\mathrm{TOF}_{\mathrm{MC},i,l}) + a_{i,l}$$

$$\mathrm{TOF}_{i,l} = \mathrm{TOF}_{\mathrm{raw},i,l} - a_{i,l}$$

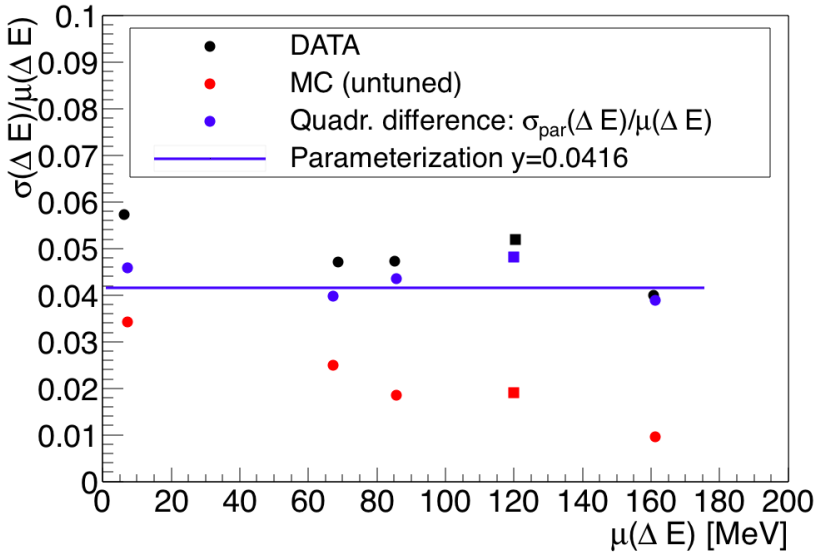


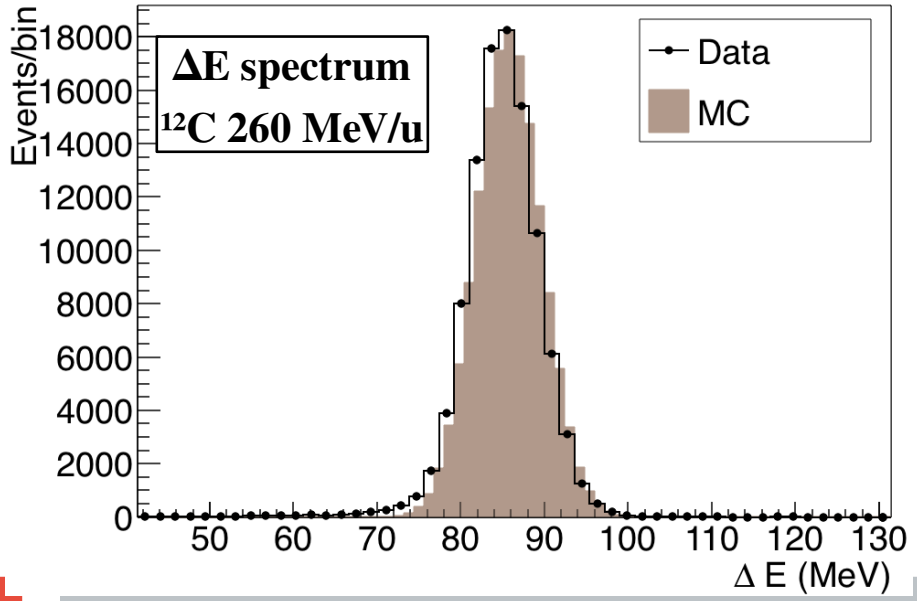
- Each beam calibrated separately

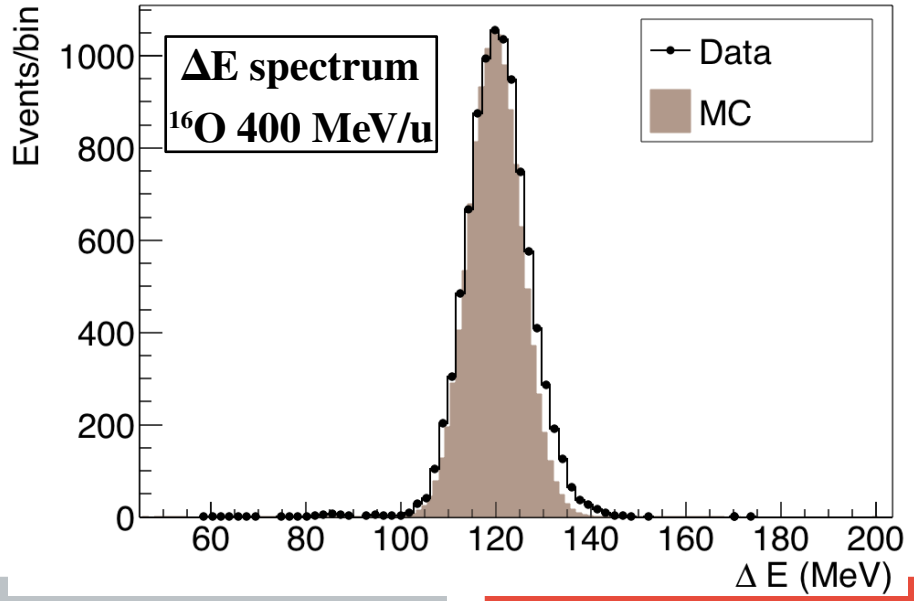
Results: Energy calibration

σ(ΔE)/ΔE → 4 - 4.7% for ^{12}C
→ 5.3% for p
→ 5.2% for ^{16}O

- "Intrinsic" contribution subtracted
- Energy resolution parameterized with a constant for tuned MC simulations



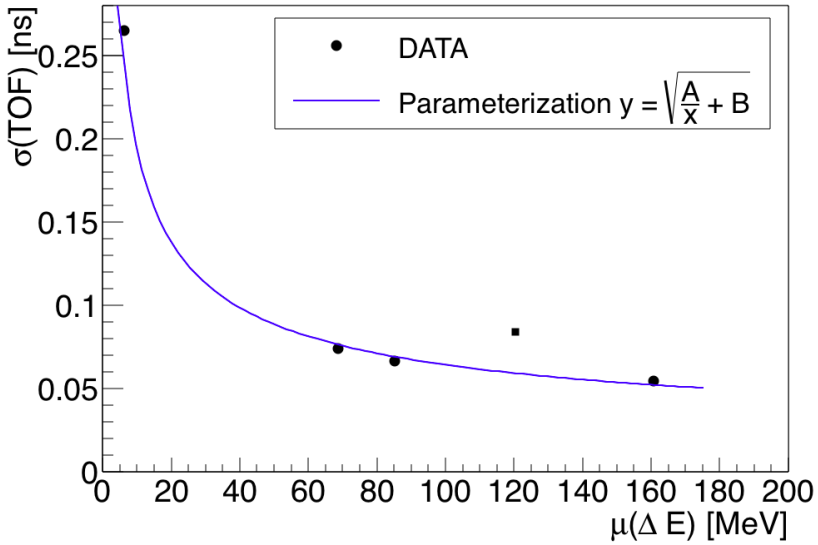


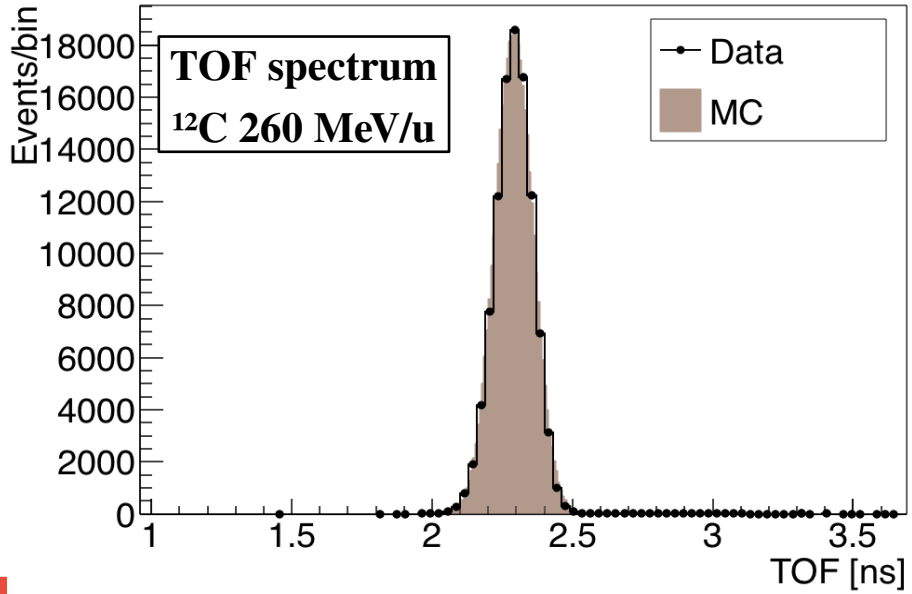


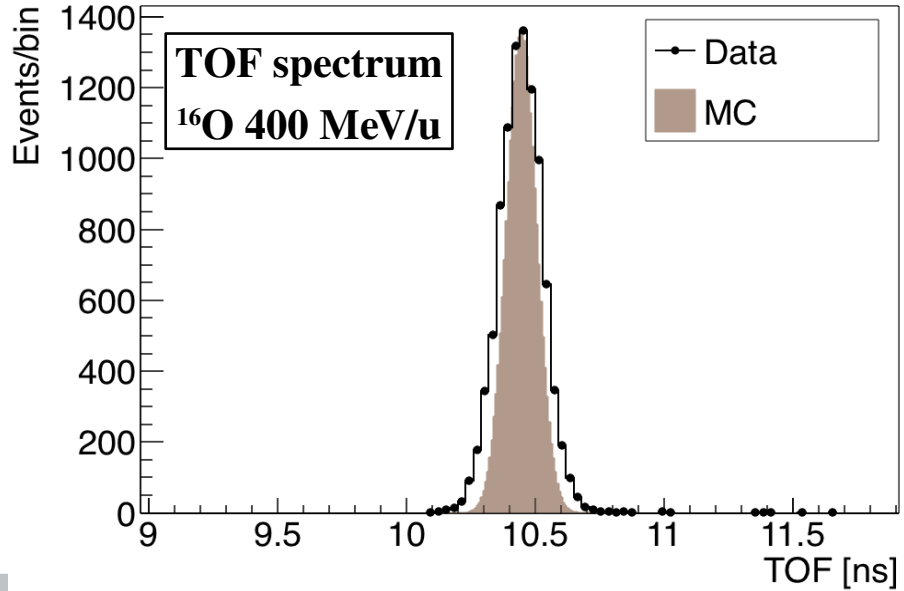
Results: TOF calibration

σ(TOF) → 54 - 74 ps for ^{12}C
→ 265 ps for p
→ 84 ps for ^{16}O

- Intrinsic contribution always negligible
- Resolution for tuned MC parameterized as a function of ΔE







Results: Charge identification

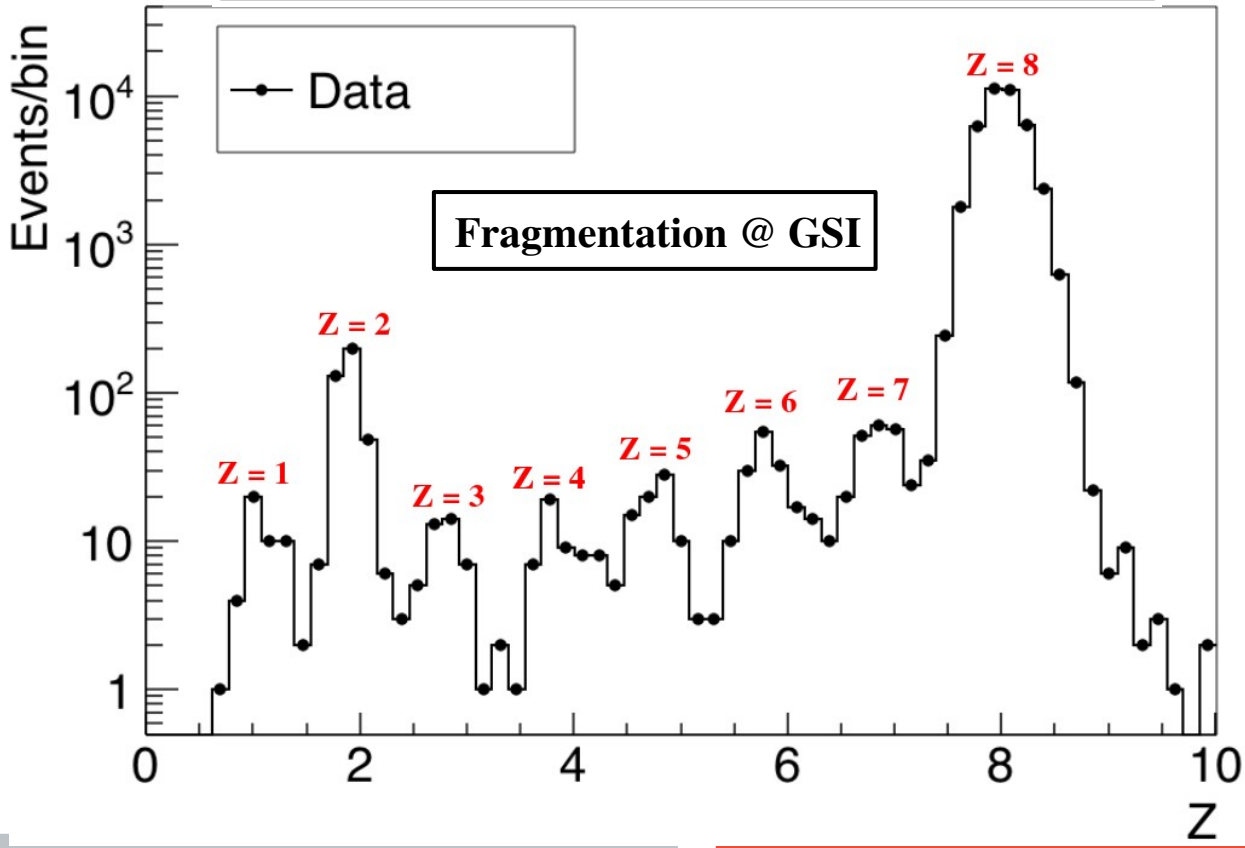
Calibration runs:

- **Z reconstructed accurately**
- **Resolution compatible with requirements (2.5-6%)**

Fragmentation run:

- **First application of the full procedure**
- **Fragments charge determined with good accuracy**

Particle	E_{beam} [MeV/u]	$\mu(Z)$	$\sigma(Z)$	$\sigma(Z)/\mu(Z)$ [%]
p	60	0.96	0.06	6.10 ± 0.02
^{12}C	115	6.17	0.15	2.51 ± 0.01
^{12}C	260	6.01	0.21	3.52 ± 0.01
^{12}C	400	6.07	0.24	3.85 ± 0.01
^{16}O	400	8.07	0.22	2.67 ± 0.02



Discussion and conclusions

Discussion:

- Full irradiation of the TW needed → beam time
- Differences in the experimental setups
- Fluctuations (up to 3%) of SiPM gain between acquisitions
- Scintillator light output model can be improved
- Mechanical stability → new frame

Conclusions:

- Despite the above issues, **detector response was modeled accurately**
- Good overall ΔE, TOF and Z resolution → **requirements met**
- **First application of Z identification to fragmentation data**

Paper submitted to NIM-A on November 23rd

THANK YOU FOR YOUR ATTENTION