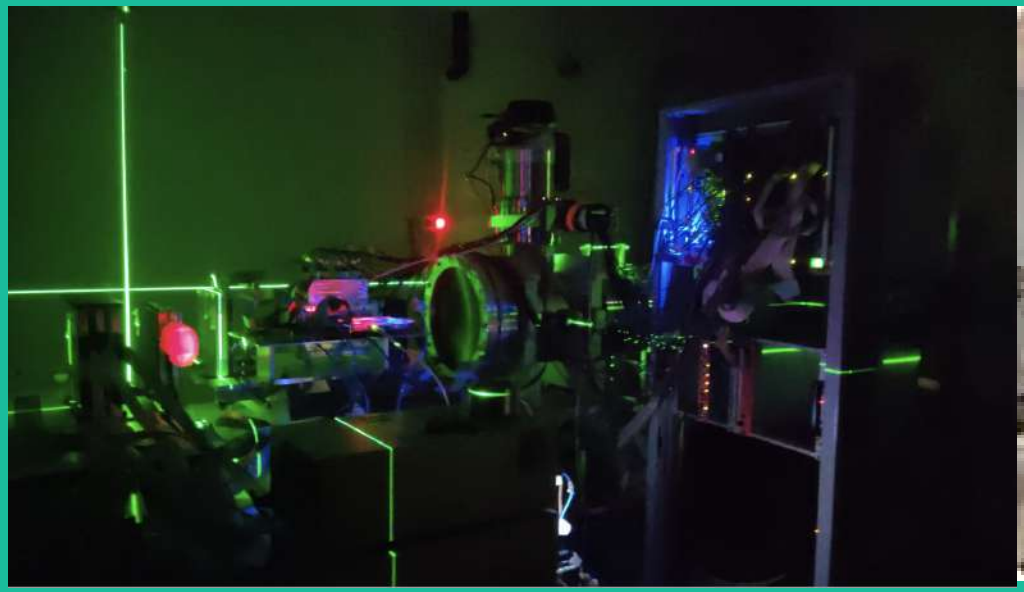

Nuclear physics for hadrontherapy

Yunsheng Dong & Ilaria Mattei *INFN Milano*

Lab2go

26/05/2025

Cross section

Angular differential and elemental fragmentation cross sections of a 400 MeV/u ^{16}O beam on a graphite target with the FOOT experiment

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[31] *Nagoya University, Department of Physics, Nagoya, Japan*
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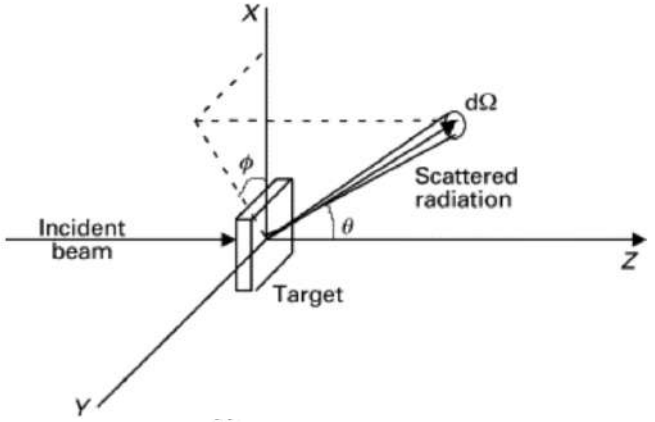
(The FOOT Collaboration)



$$\frac{\mathrm{d}\sigma}{\mathrm{d}\theta}(Z) = \frac{Y(Z,\theta)}{N_{\mathrm{prim}} \cdot N_{\mathrm{TG}} \cdot \Delta\theta \cdot \varepsilon(Z,\theta)}$$

Align FOOT detectors and estimate angular acceptance

Extract fragment yields from TW

Calculate MC efficiencies for fragments

Cross section results

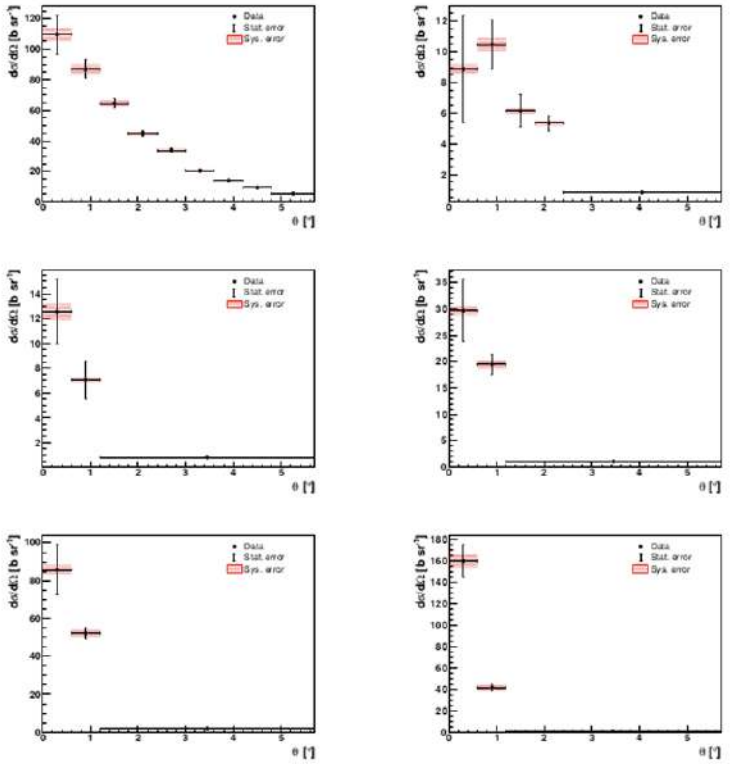


FIG. 6. Angular differential cross sections for fragments $2 \leq Z \leq 7$.

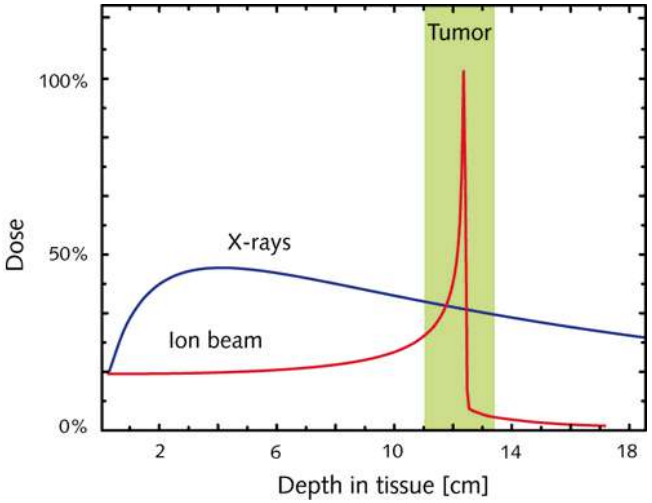
Z	$\theta[^\circ]$	$\sigma \pm \Delta_{stat} \pm \Delta_{sys}$ [b sr^{-1}]	Δ_{stat}/σ	Δ_{sys}/σ
2	$0-0.6$	$110 \pm 13 \pm 5$	11.6%	4.3%
	$0.6-1.2$	$87 \pm 6 \pm 3$	7.2%	4%
	$1.2-1.8$	$65 \pm 3 \pm 2$	5.2%	3.1%
	$1.8-2.4$	$45 \pm 2 \pm 1$	4.7%	3.2%
	$2.4-3$	$34 \pm 1 \pm 2$	3.6%	4.4%
	$3-3.6$	$20 \pm 1 \pm 1$	4.2%	4.5%
	$3.6-4.2$	$14 \pm 1 \pm 0.5$	4.2%	3.5%
	$4.2-4.8$	$9 \pm 0.4 \pm 0.3$	4.3%	3.5%
	$4.8-5.7$	$5 \pm 0.3 \pm 0.7$	5%	14%
3	$0-0.6$	$9 \pm 4 \pm 0.3$	40%	3.7%
	$0.6-1.2$	$11 \pm 2 \pm 0.4$	15%	4.2%
	$1.2-1.8$	$6 \pm 1 \pm 0.2$	17%	3.1%
	$1.8-2.4$	$5 \pm 0.5 \pm 0.2$	9%	3%
	$2.4-5.7$	$1 \pm 0.04 \pm 0.04$	5%	4.2%
4	$0-0.6$	$13 \pm 3 \pm 0.7$	20%	5.3%
	$0.6-1.2$	$7 \pm 1.5 \pm 0.2$	21%	3.2%
	$1.2-5.7$	$1 \pm 0.1 \pm 0.03$	9%	3.5%
5	$0-0.6$	$30 \pm 6 \pm 1$	20%	3.1%
	$0.6-1.2$	$19 \pm 2 \pm 1$	10%	4.7%
	$1.2-5.7$	$1 \pm 0.1 \pm 0.05$	7%	4.3%
6	$0-0.6$	$86 \pm 13 \pm 3$	15%	3%
	$0.6-1.2$	$52 \pm 3 \pm 2$	5.5%	4.3%
	$1.2-5.7$	$2 \pm 0.1 \pm 0.08$	5.6%	4.6%
7	$0-0.6$	$160 \pm 15 \pm 6$	9%	3.9%
	$0.6-1.2$	$42 \pm 3 \pm 3$	6.8%	7.5%
	$1.2-5.7$	$1 \pm 0.1 \pm 0.03$	13%	4.4%

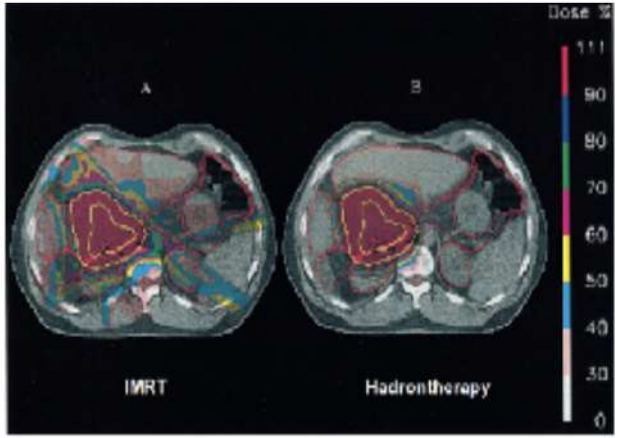
TABLE II. Angular differential cross section measured in this work. The contribution of the statistical and systematic uncertainties is reported separately. The contribution of the statistical and systematic uncertainties to the final result is visible through the reported relative errors.

Cross section results

Hadrontherapy

Hadrontherapy: a form of radiotherapy that uses hadrons for the treatment of solid tumours





Pancreatic tumor treatment planning
A: Intensity modulated coplanar photon beam (9 beams)
B: Coplanar proton beam (4 beams)

Main properties:

- Better dose conformation over the tumour volume, minimizing the damage in the healthy tissues
- Enhanced biological effectiveness for heavy ion therapy (Z>1)
- Mainly proton and carbon ion treatment centres

Particle therapy brief timeline

1954 – Berkeley treats the first patient and begins extensive studies with various ions
1957 – first patient treated with protons in Europe at Uppsala
1961 – collaboration between Harvard Cyclotron Lab. and Massachusetts General Hospital
1993 – patients treated at the first hospital-based facility at Loma Linda
1994 – first facility dedicated to carbon ions operational at HIMAC, Japan
2009 – first European proton-carbon ion facility starts treatment in Heidelberg
2017 – hadrontherapy treatments included in the Italian SSN

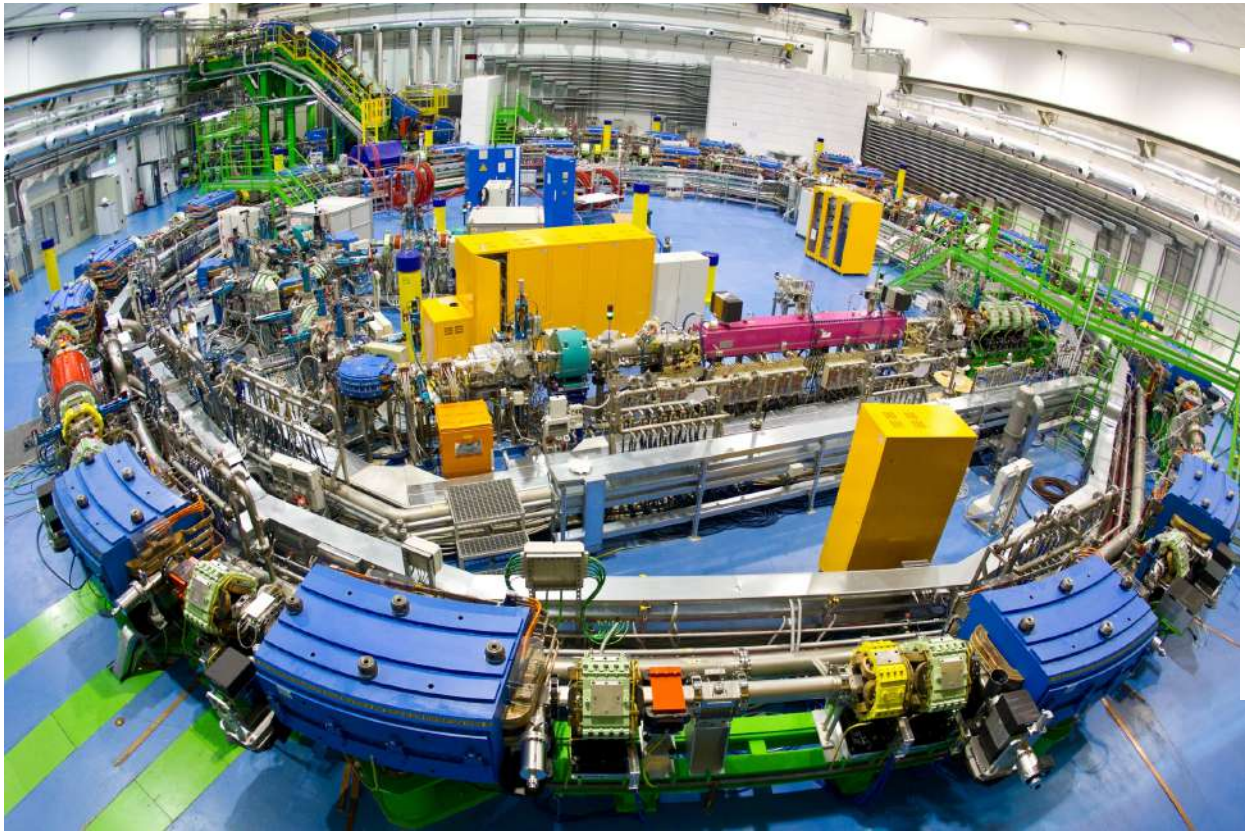
1st TAKE HOME MESSAGE: Science needs time!!!

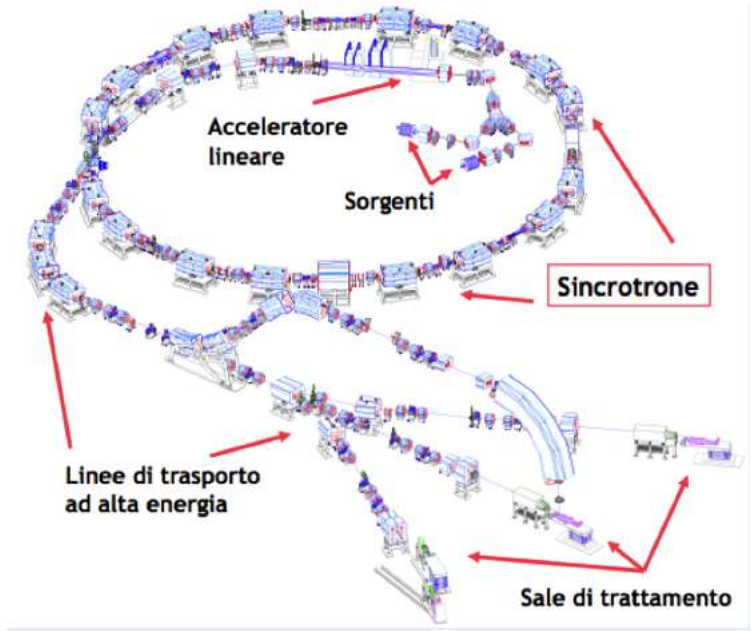
Particle therapy facilities at present

Particle therapy facilities in Italy

- Operating centers
- Centers under construction

CNAO

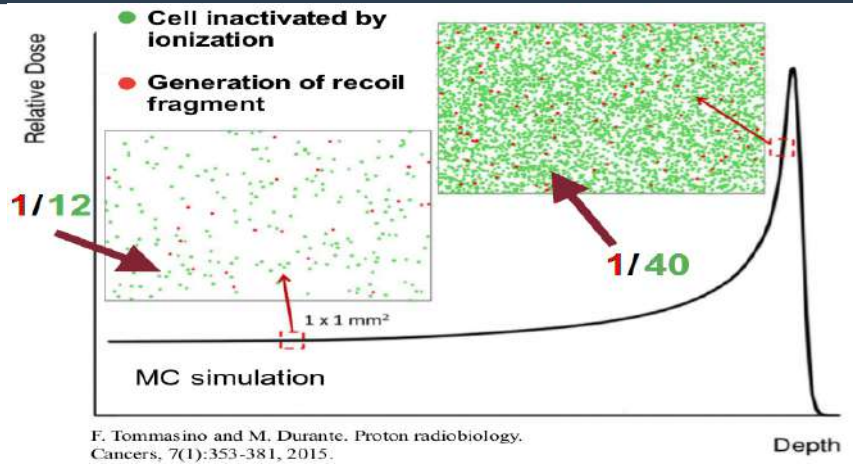



Acceleratore
lineare
Sorgenti
Sincrotrone
Linee di trasporto
ad alta energia
Sale di trattamento

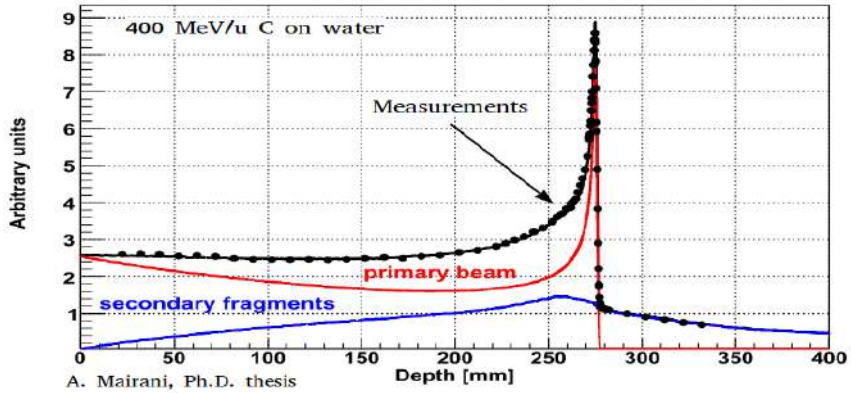
CNAO

What does hadrontherapy have to do with cross sections?

Nuclear physics (for hadrontherapy)



F. Tommasino and M. Durante. Proton radiobiology. Cancers, 7(1):353-381, 2015.



A. Mairani, Ph.D. thesis

Nuclear interactions not always included with sufficient details in the treatment planning systems (TPS), especially in proton therapy

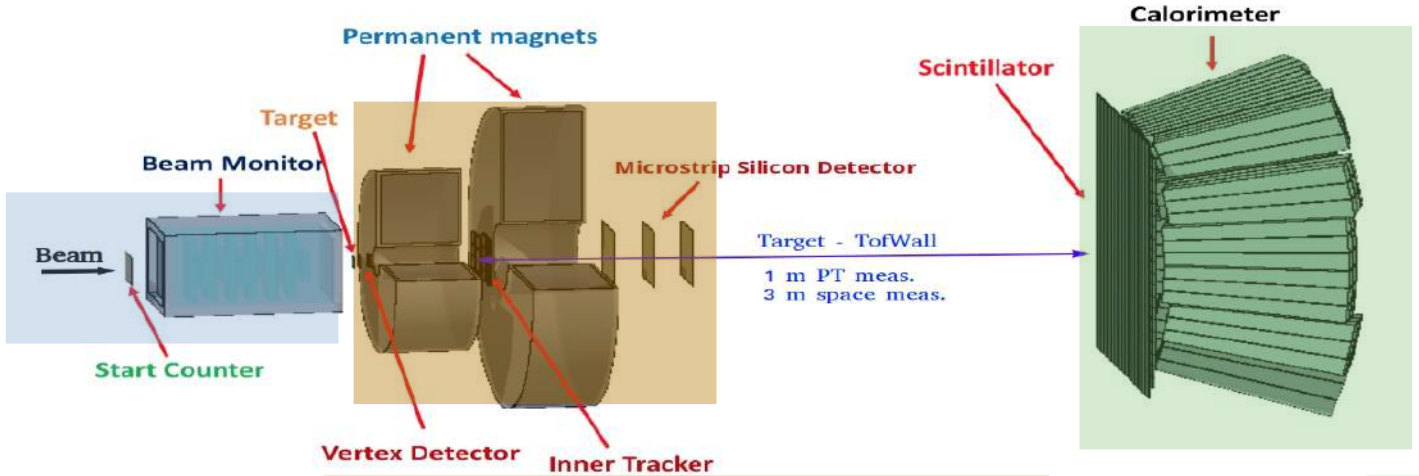
- Target fragmentation in proton therapy (Z=1; 50-250 MeV)
- Projectile fragmentation in heavy ion therapy (Z>1; 50-400 MeV/u)
- Data available with integrated cross sections
- Differential cross sections data only from Ganil (^{12}C @ 50 and 95 MeV/u, 2011)

Need of differential cross section data to improve the TPS and explore the possibility to exploit new particles such as ^{16}O and ^{4}He

(lack of data especially for ^{4}He)

The FOOT experiment

Electronic spectrometer to detect the fragments with Z≥3 and θ<10°



Pre target region:

- Plastic scintillator for TOF and trigger measurements
- Drift chamber for the beam direction and position meas.

Tracking region:

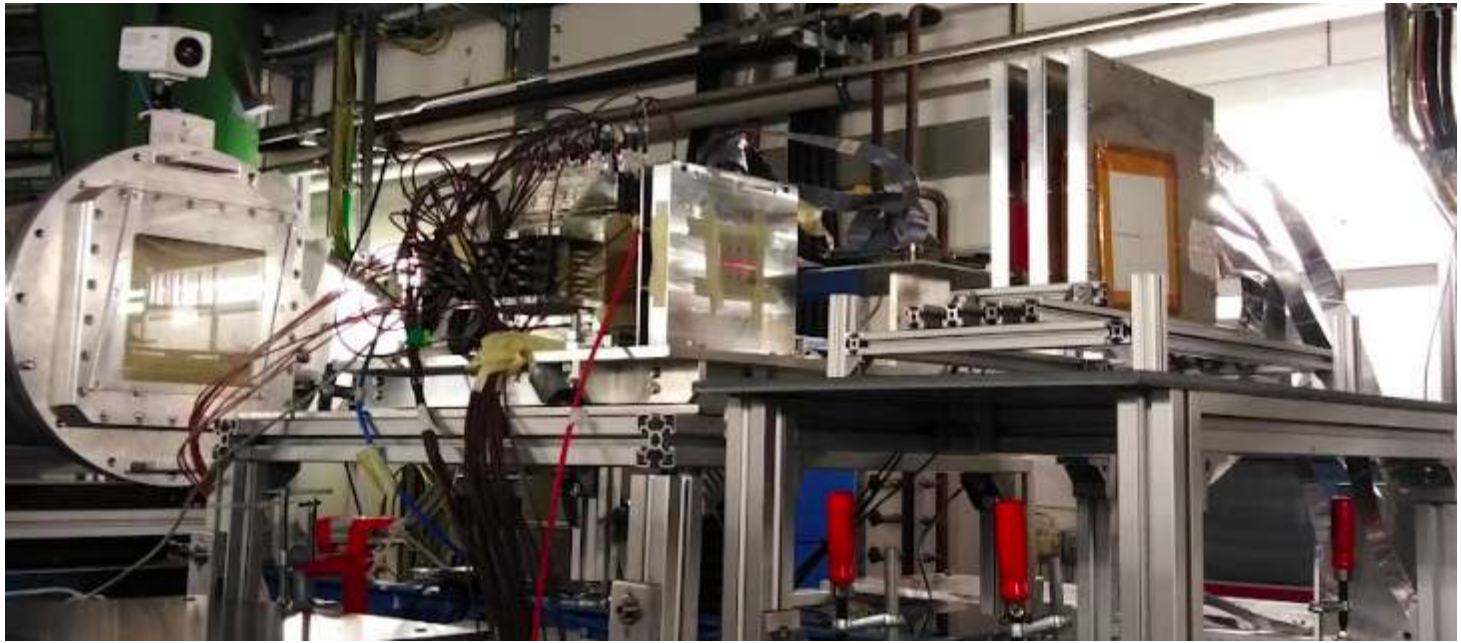
- Silicon pixel and strip detectors for track and momentum reco
- Permanent magnet in Halbach conf. ~ 1.4 T ⊥ the beam axys

Downstream region:

- Plastic scintillator bars for the TOF and dE/dx measurements
- Calorimeter for the kinetic energy measurement

The FOOT experiment

Electronic spectrometer data takings



Angular differential and elemental fragmentation cross sections of a 400 MeV/u ^{16}O beam on a graphite target with the FOOT experiment

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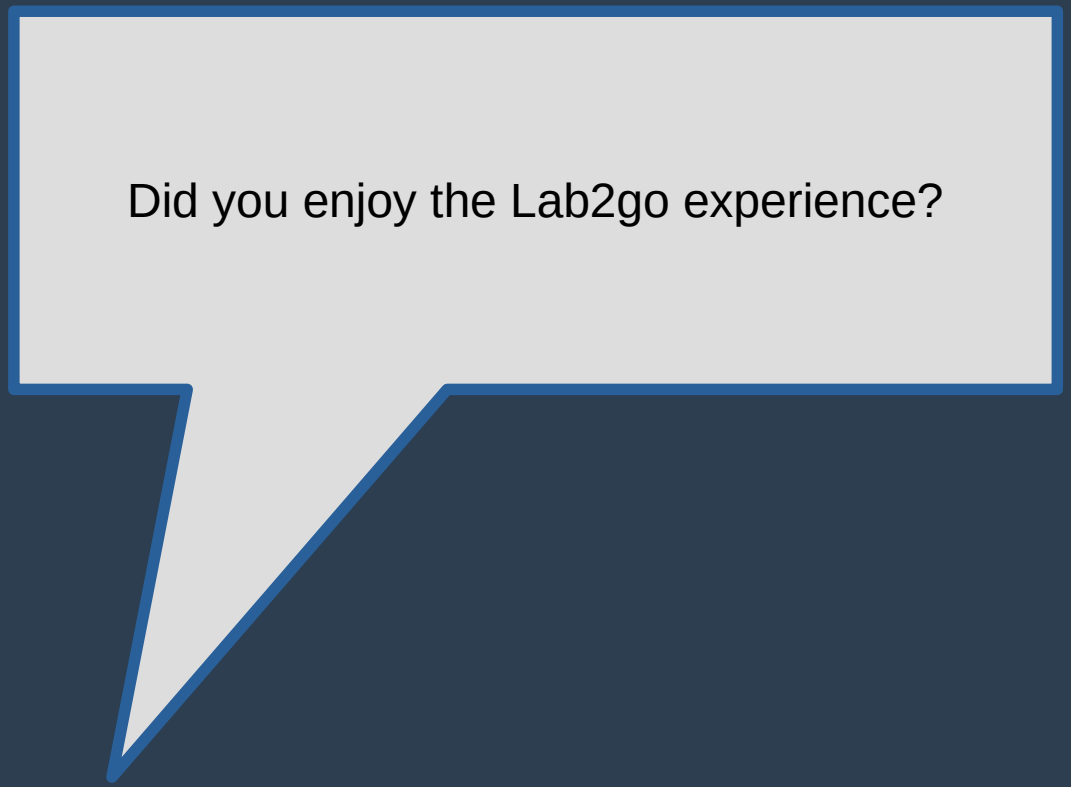
(The FOOT Collaboration)

2nd take home message:

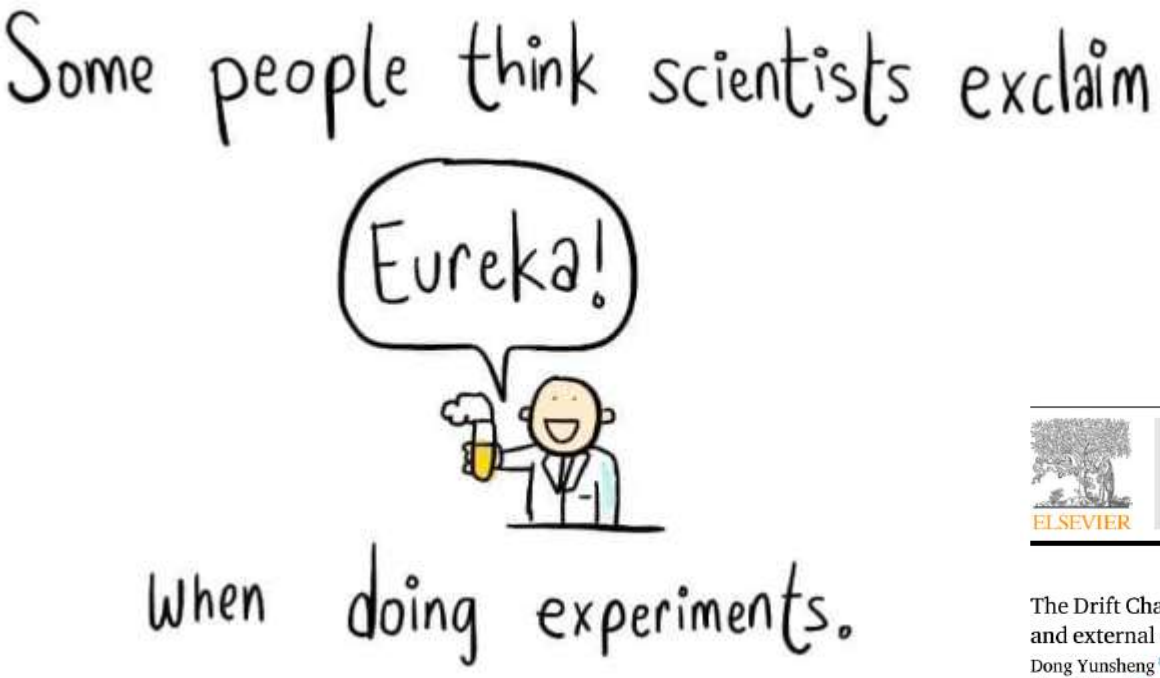
"Physics is like sex: sure, it may give some practical results, but that's not why we do it."

– Richard P. Feynman


Did you enjoy the Lab2go experience?

Lab2go

Scientists (what people think)



Elemental fragmentation cross sections for a ^{16}O beam of 400 MeV/u kinetic energy interacting with a graphite target using the FOOT ΔE-TOF detectors

M. Toppi[1,2], A. Sarti[1,3], A. Alexandrov[4,5], B. Alpat[6], G. Ambrosi[6], S. Argirò[7,8], R. A Diaz[9], M. Barbanera[6], N. Bartosik[8],

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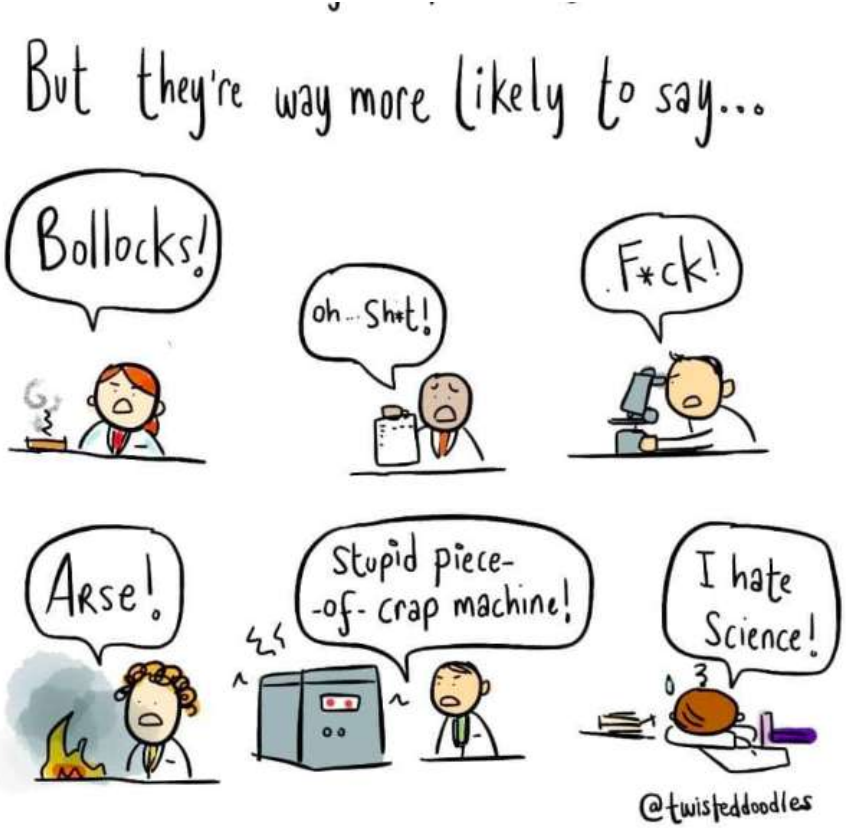
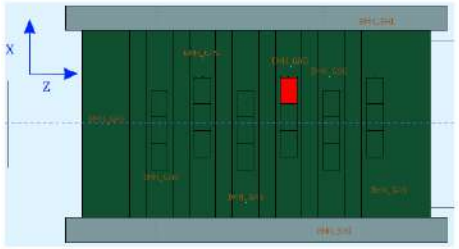
The Drift Chamber detector of the FOOT experiment: Performance analysis and external calibration

Dong Yunsheng[8,23,*], Silvestre Gianluigi[11,24], Colombi Sofia[15,16], Alexandrov Andrey[10,19,33,34], Alpat Behcet[11], Ambrosi Giovanni[11], Argirò Stefano[28,17], Arteche Diaz Raul[30], Barbanera Mattia[2,35], Bartosik Nazar[17], Belcari Nicola[3,2], Bellinzona Elettra[15], Biondi Silvia[5,20], Bisogni Maria Giuseppina[3,2], Bruni Graziano[5], Carra Pietro[3,2], Cerello Piergiorgio[17], Ciarrocchi Esther[3,2], Clozza Alberto[7], De Lellis Giovanni[10,19], Del Guerra Alberto[3,2]

Scientists (reality)



Channel lost



- The capacitors used in the voltage stabilizer circuit have been damaged.
- During the substitution of the capacitors, one sense wire of a cell has been broken and it has been extracted.

3rd take home message: physics (actually, not just physics) is trial and error. The important thing is to have fun

Scientists (reality)


That's all Folks!