In2p3

The CLINM project at CNAO

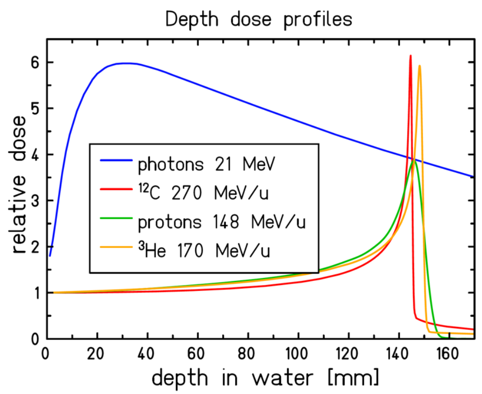
Centro Nazionale di Adroterapia Oncologica

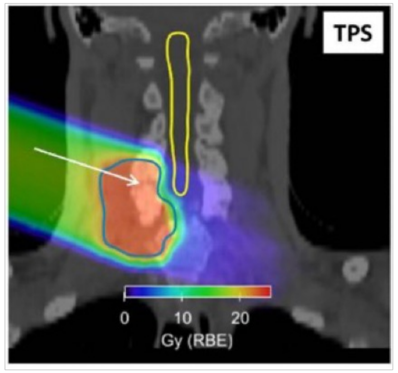
Secondary charged particles measurements

N. Arbor, C. Finck, L. Gesson, S. Higueret, T.D. Lê, C. Reibel, A. Sood, M. Vanstalle

A. Arnone, C. Galindo, C. Hoffmann, P. Peaupardin, Q. Raffy

Why do we need nuclear data for health?

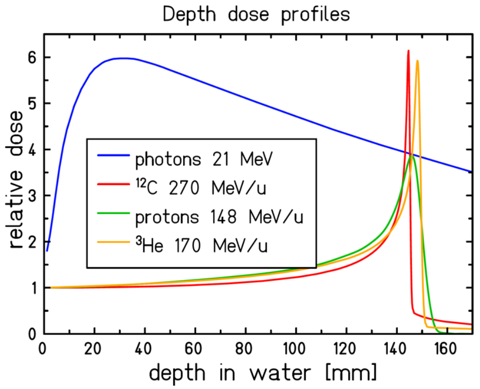


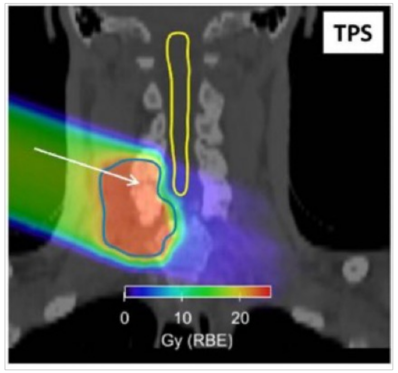


Extrait de **Battistoni et al.**, "*The FLUKA code: an accurate simulation tool for particle therapy*", Frontiers in Oncology (2016).

- Nuclear reactions of the beam with patient ⇒ additionnal dose after the Bragg Peak

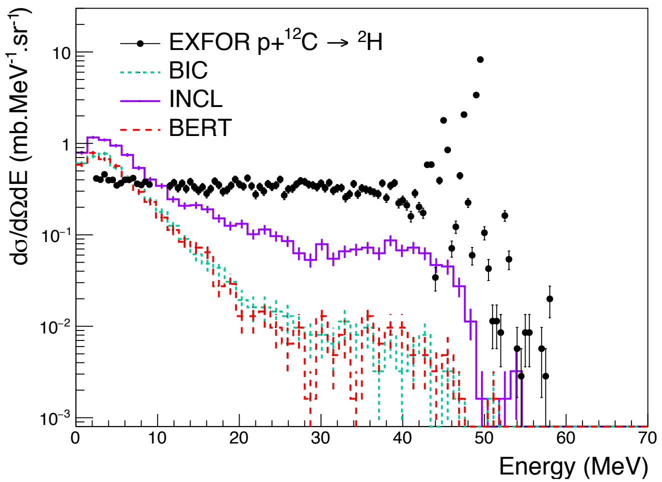
Why do we need nuclear data for health?





Extrait de **Battistoni et al.**, “*The FLUKA code: an accurate simulation tool for particle therapy*”, Frontiers in Oncology (2016).

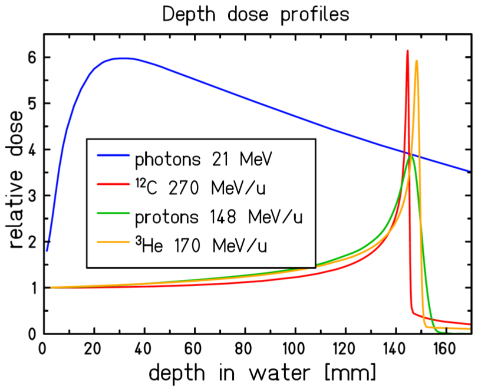
- Nuclear reactions of the beam with patient ⇒ additionnal dose after the Bragg Peak
- MC simulations unable to correctly reproduce these nuclear reactions

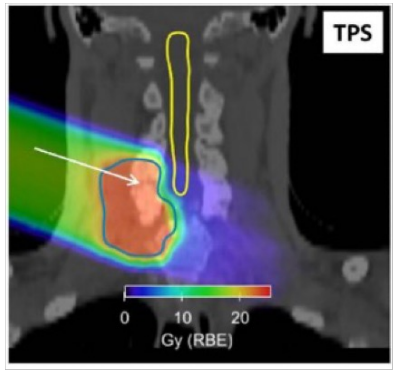


It doesn’t matter how beautiful your theory is, it doesn’t matter how smart you are. If it doesn’t agree with experiment, it’s wrong.

RICHARD FEYNMAN

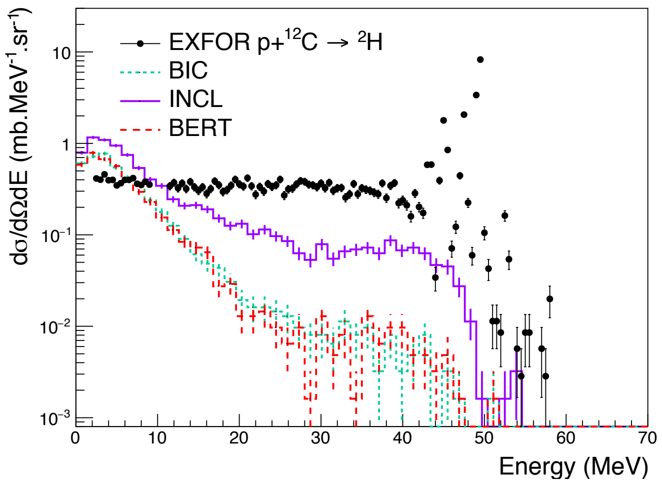
Why do we need nuclear data for health?





Extrait de **Battistoni et al.**, "*The FLUKA code: an accurate simulation tool for particle therapy*", Frontiers in Oncology (2016).

- Nuclear reactions of the beam with patient ⇒ additionnal dose after the Bragg Peak
- MC simulations unable to correctly reproduce these nuclear reactions
- What is the impact of the secondary particles produced by these nuclear reactions? ⇒ not only biology, chemical step needs to be considered

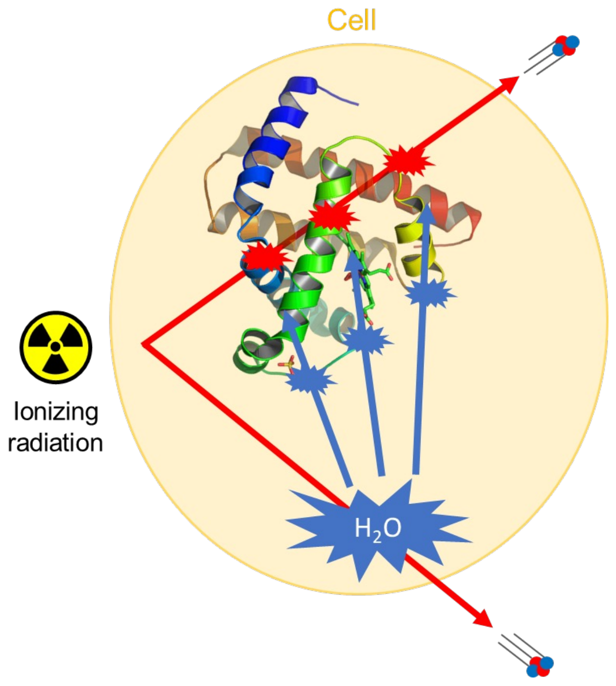


It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong.

RICHARD FEYNMAN

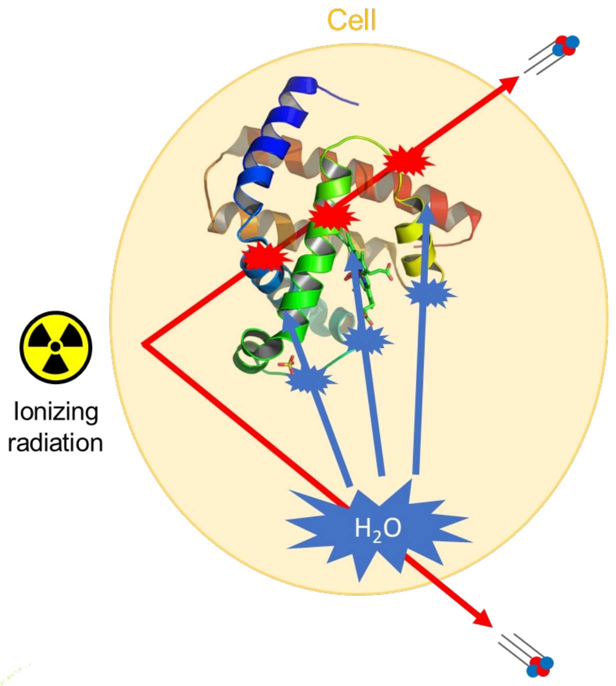
The CLINM project

- CLINM (Cross-sections of Light Ion and Neutron Measurements) : secondary particles impact on radiolysis of biomolecules, produced from ^{4}He, ^{12}C, ^{16}O, … , ^{56}Fe beam fragmentation
  - ❖ ΔE-ToF telescope/ΔE-E for charged particles identification + γ and n measurement ($CeBr_3$) of high energy (> 50 MeV)
  - ❖ Development of a recoil proton telescope (RPT) for low energy neutrons (<50 MeV) + neutron counter (alphaBEAST ⇒ N. Arbor talk)
  - ❖ Water and biomolecules radiolysis of primary & secondary particles (in collaboration with **Radiochemistry team of IPHC** ⇒ A. Arnone talk)



The CLINM project

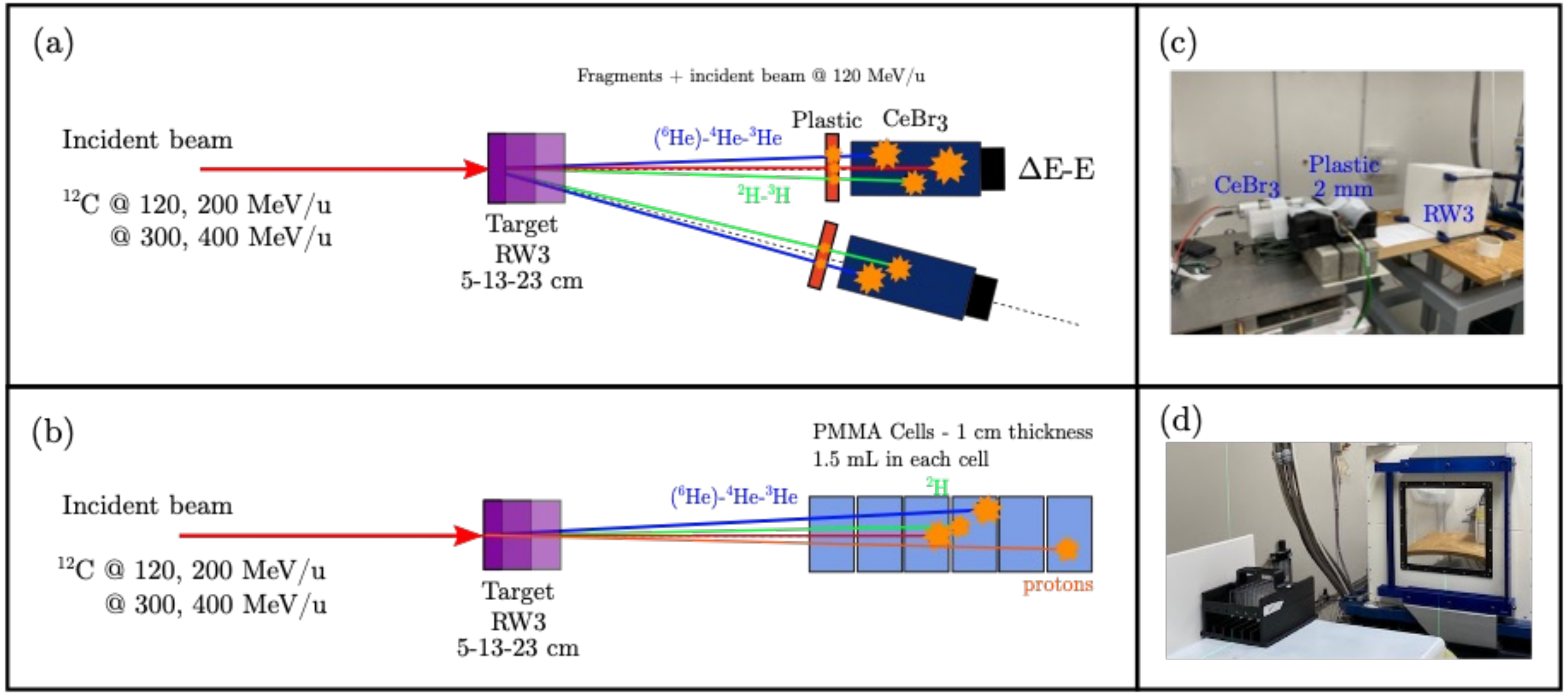
- CLINM (Cross-sections of Light Ion and Neutron Measurements) : secondary particles impact on radiolysis of biomolecules, produced from ^{4}He, ^{12}C, ^{16}O, … , ^{56}Fe beam fragmentation
  - ❖ ΔE-ToF telescope/ΔE-E for charged particles identification + γ and n measurement ($CeBr_3$) of high energy (> 50 MeV)
  - ❖ Development of a recoil proton telescope (RPT) for low energy neutrons (<50 MeV) + neutron counter (alphaBEAST ⇒ N. Arbor talk)
  - ❖ Water and biomolecules radiolysis of primary & secondary particles (in collaboration with **Radiochemistry team of IPHC** ⇒ A. Arnone talk)



Final goal: implementation of physical & chemical data in Geant4-DNA

The CLINM project @CNAO

- Incoming beam of ^{12}C attenuated by different thicknesses of RW3 to achieve 120 MeV/u after attenuation ⇒ same ^{12}C energy in samples, but different fragments composition



- Experiment carried out in 2 parts:
  - ❖ Physical measurements (a) and (c): characterization of fragments field
  - ❖ Radiolysis measurements (b) and (d): impact of fragments on water radiolysis

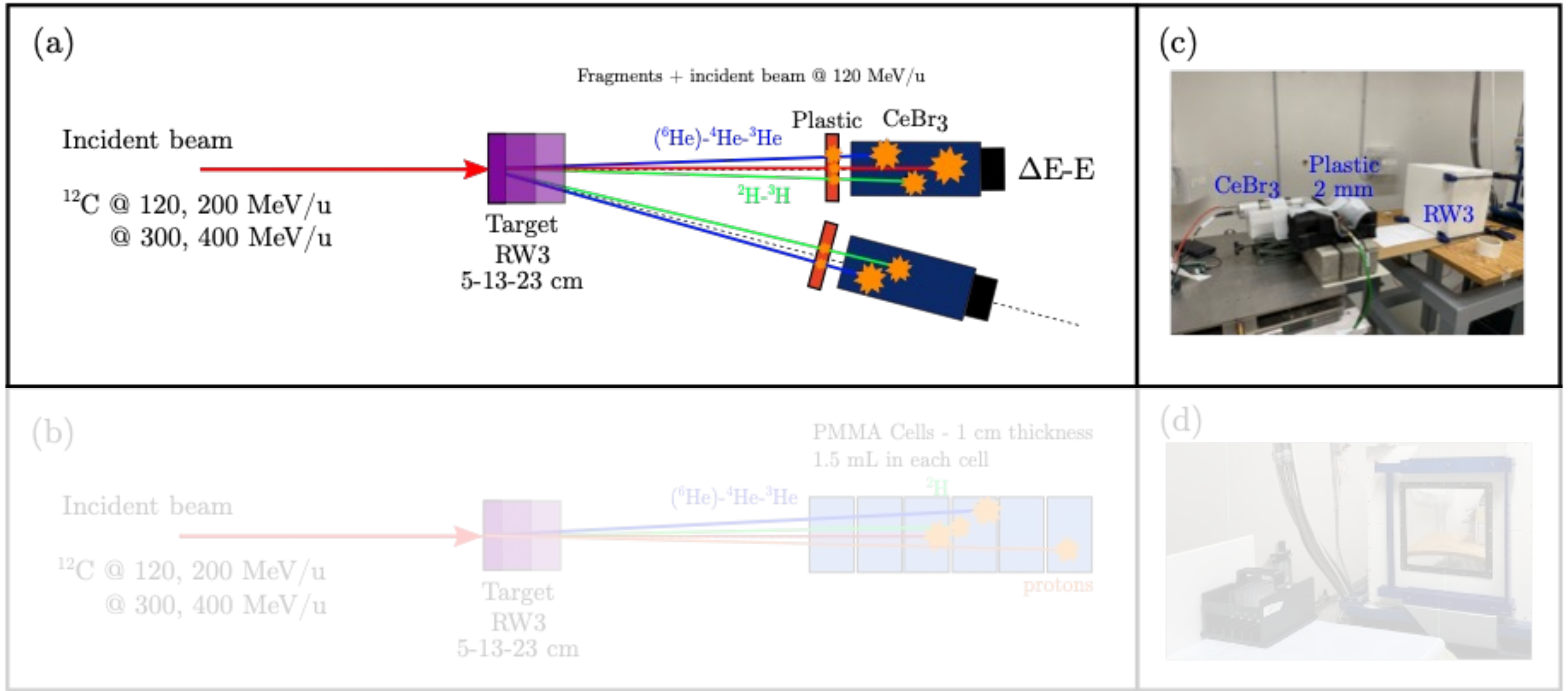
⇒ Talk of A. Arnone

The CLINM project @CNAO

HITRI plus – Heavy Ion Therapy Research Integration

cnrs In2p3

- Incoming beam of ^{12}C attenuated by different thicknesses of RW3 to achieve 120 MeV/u after attenuation ⇒ same ^{12}C energy in samples, but different fragments composition



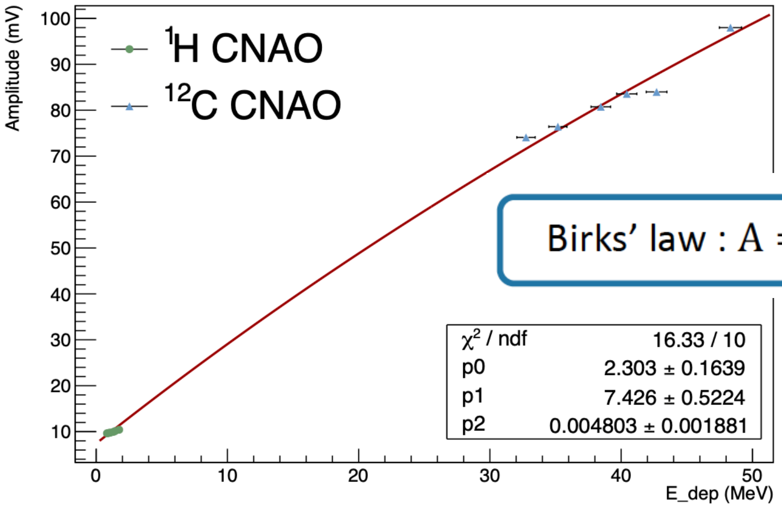
- Experiment carried out in 2 parts:
  - ❖ Physical measurements (a) and (c): characterization of fragments field
  - ❖ Radiolysis measurements (b) and (d): impact of fragments on water radiolysis

⇒ Talk of A. Arnone

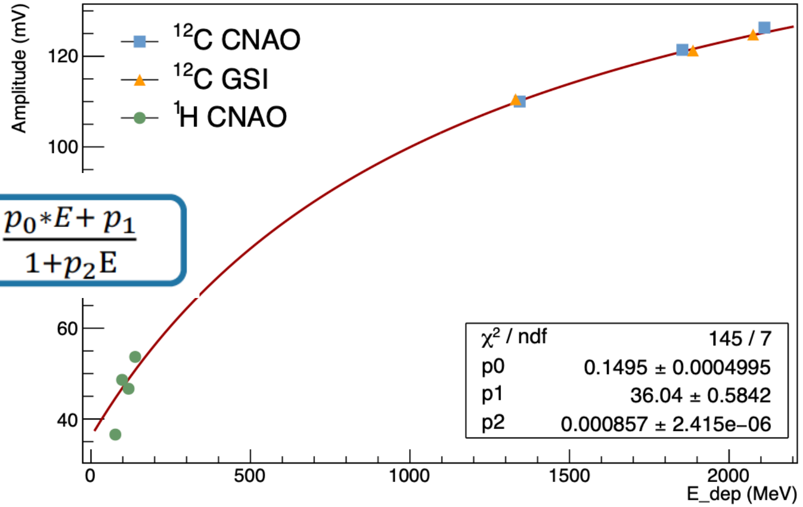
ΔE-E calibration @CNAO

From **Lévana Gesson** PhD
& **Claire Reibel** Master internship
+ **Julie Gross** & **Carlotta Mozzi** work

Plastic scintillator

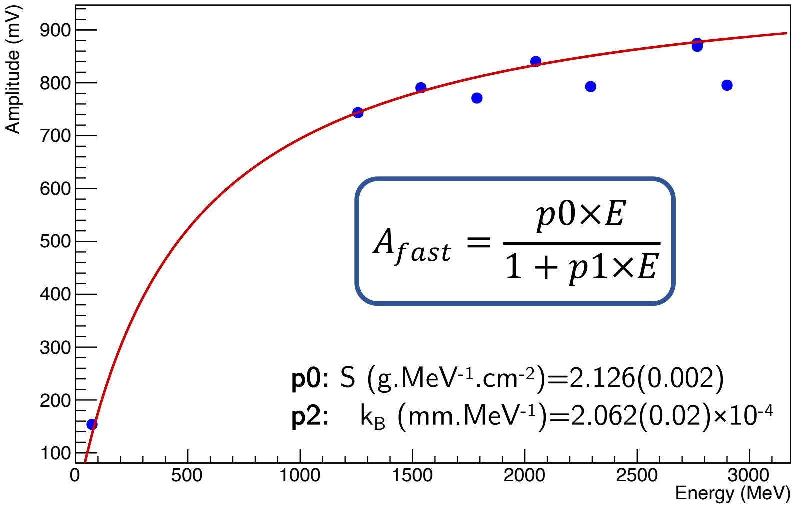


$^{}$$CeBr_3$

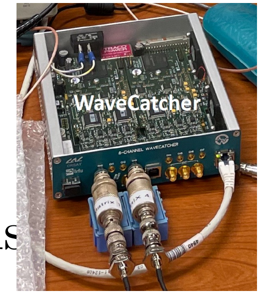


Birks' law : $A = \frac{p_0 * E + p_1}{1 + p_2 E}$

Phoswich



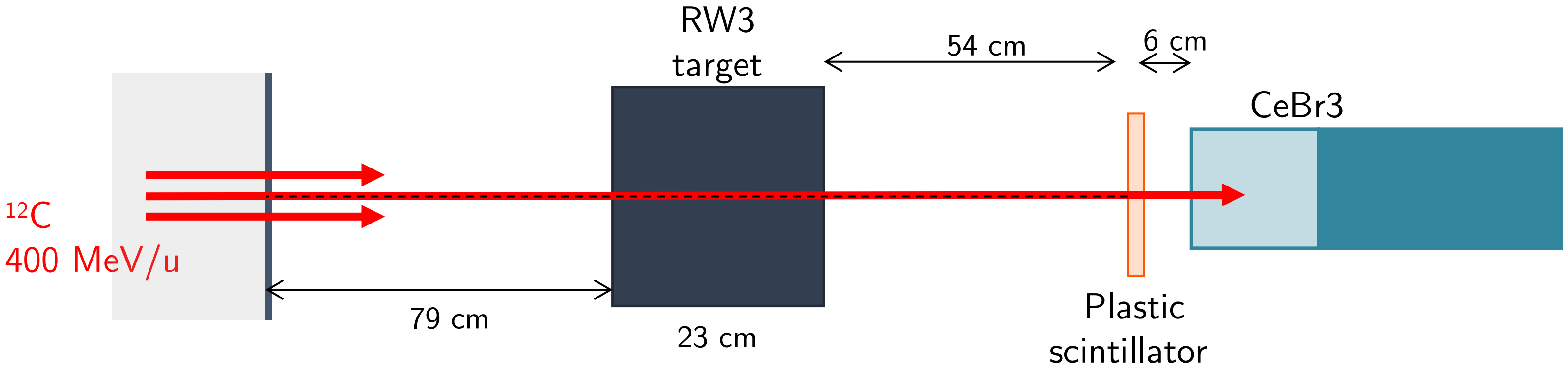
- Acquisition made with WaveCatcher digitizer
- Two detectors were tested for E: $CeBr_3$ and phoswich ($LaBr_3$+CsI)
- Response of three detectors from ΔE-E follow Birks law
- Cerium bromide and phoswich are able to respond to several MeV up to GeV ions

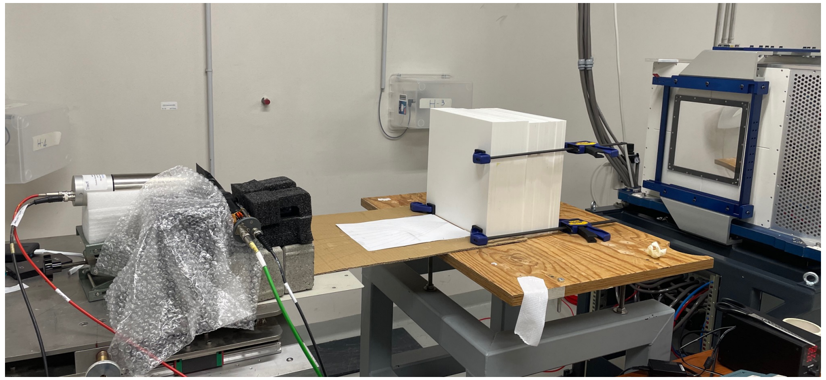


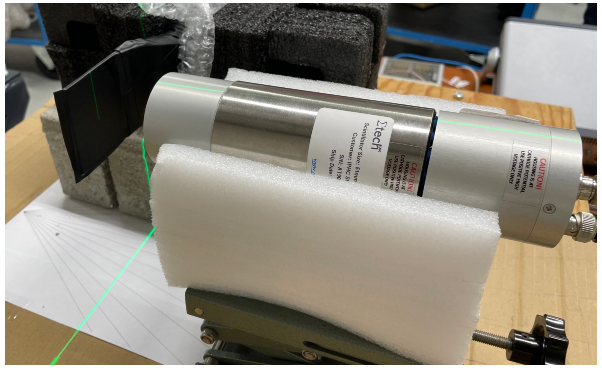
Measurements @CNAO

From **Lévana Gesson** PhD
& **Claire Reibel** Master internship

- Run @ 0º, 400 MeV/u ^{12}C



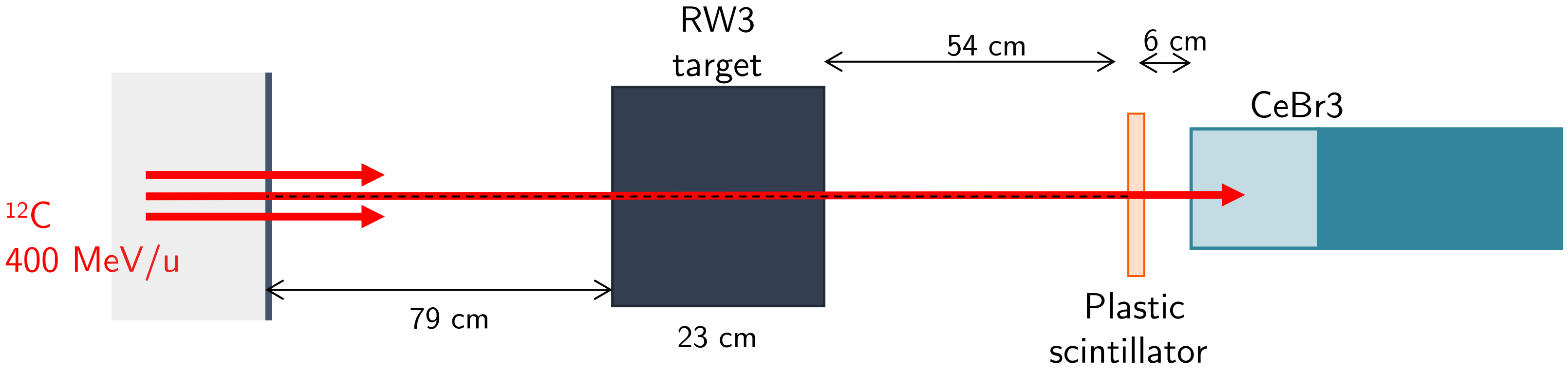


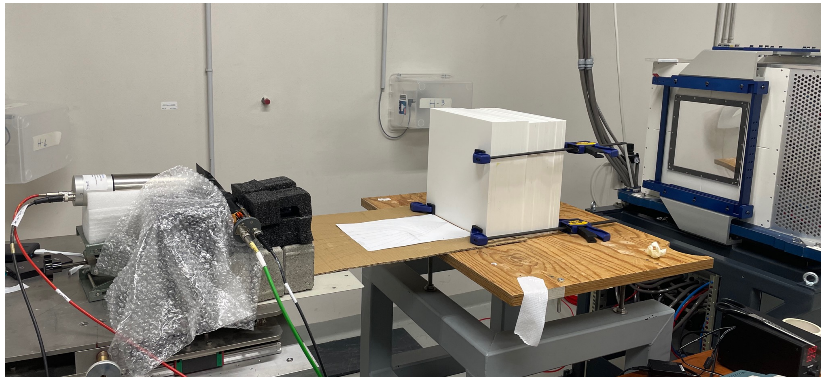


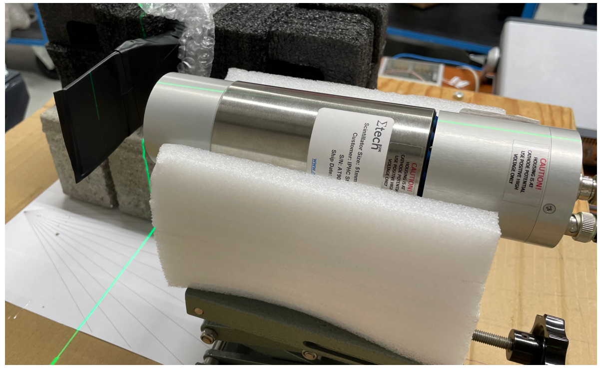
Measurements @CNAO

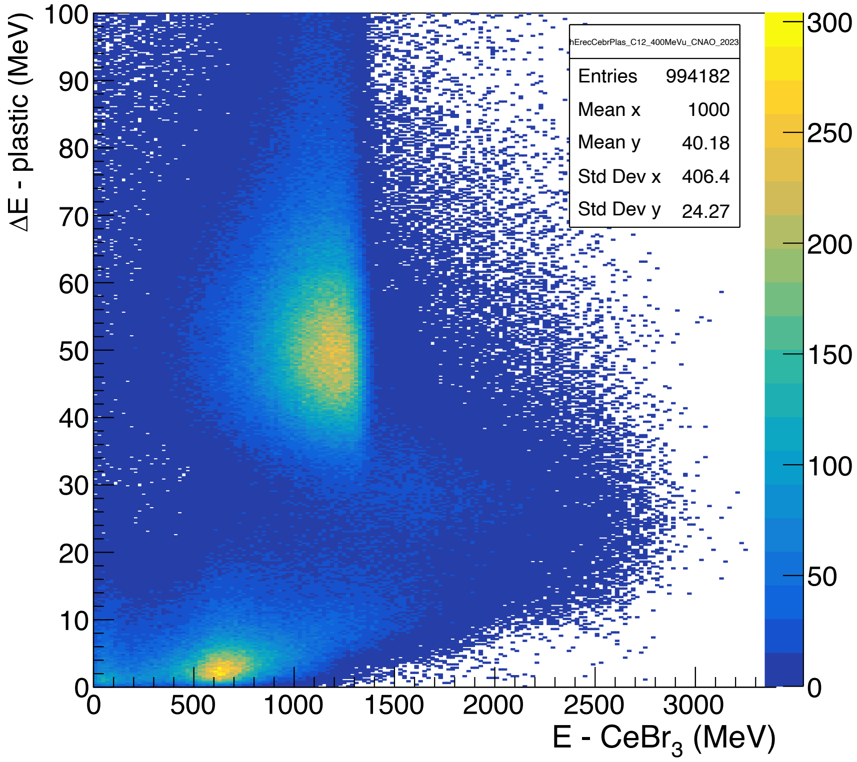
From **Lévana Gesson** PhD
& **Claire Reibel** Master internship

- Run @ 0º, 400 MeV/u ^{12}C





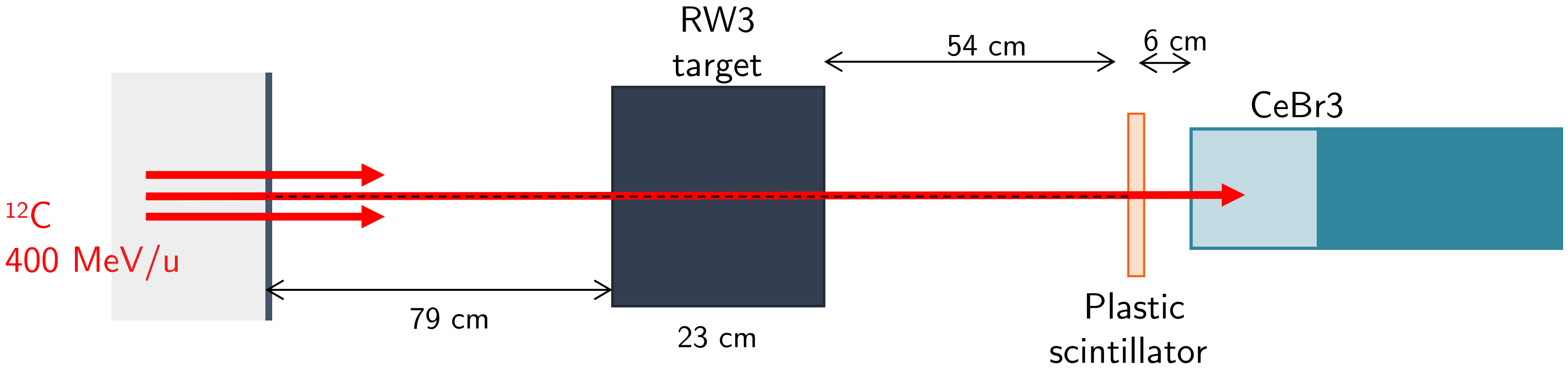


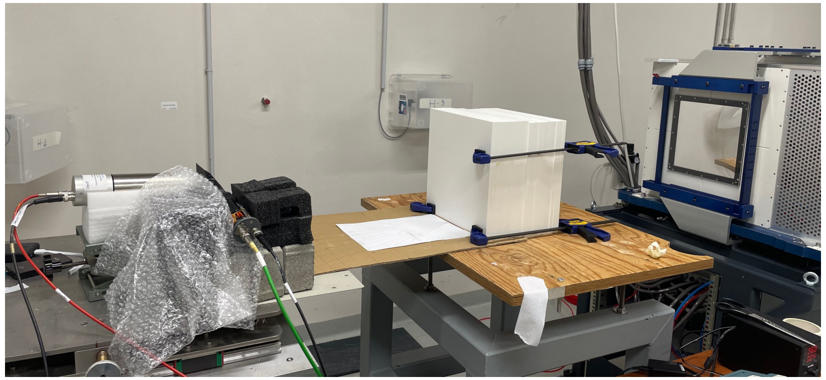


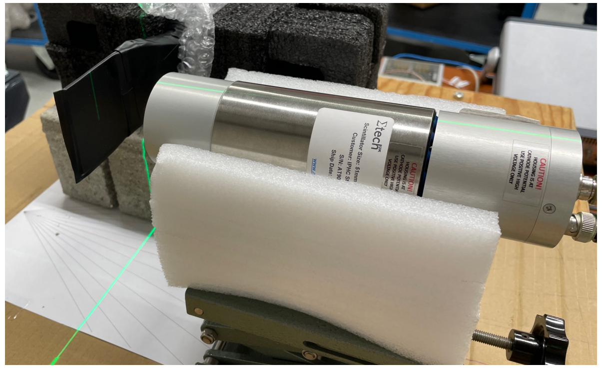
Measurements @CNAO

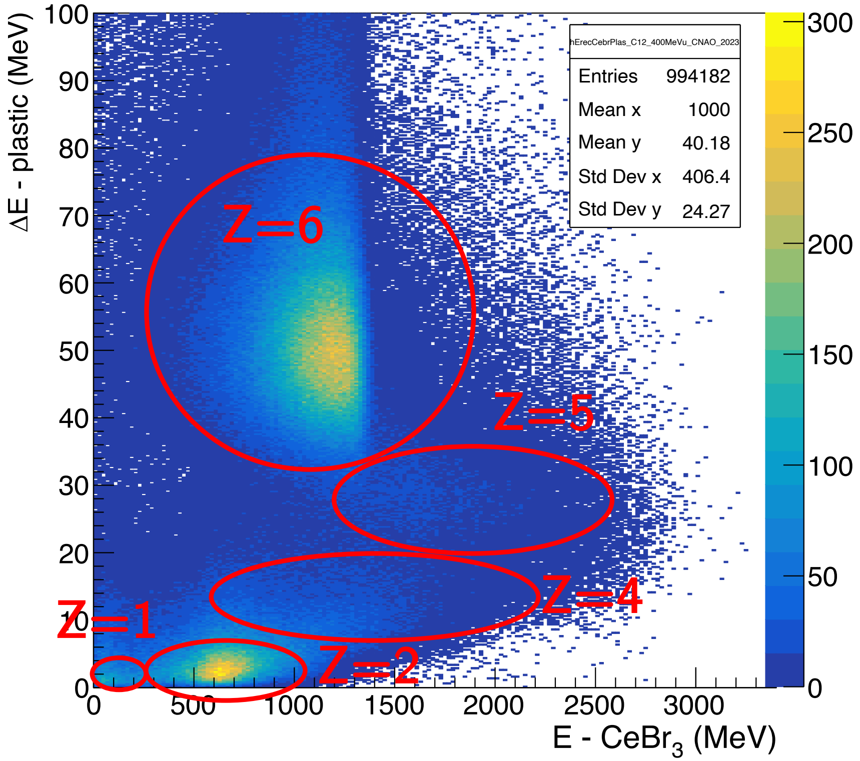
From **Lévana Gesson** PhD
& **Claire Reibel** Master internship

- Run @ 0º, 400 MeV/u ^{12}C







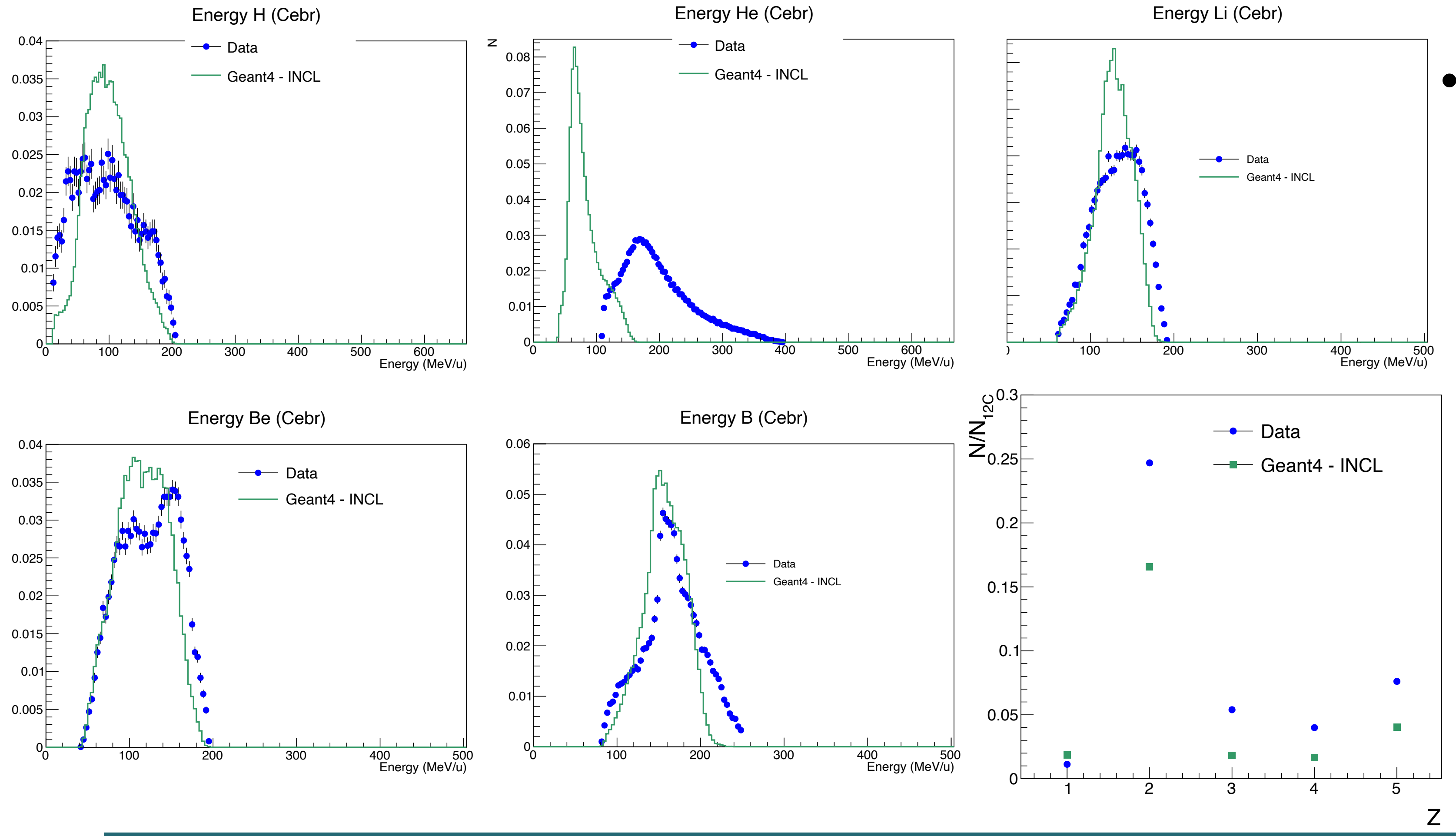


Preliminary!

Measurements @CNAO

From **Lévana Gesson** PhD
& **Claire Reibel** Master internship

Reconstructed energy spectra (E+ΔE): comparison between data and GEANT4



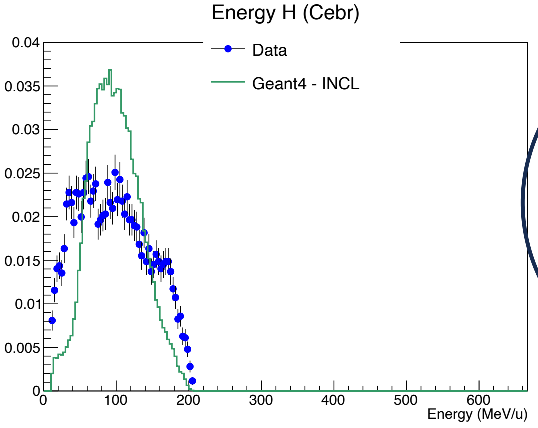
- Run @ 0º, 400 MeV/u ^{12}C
  - ❖ Good agreement between experimental and simulated energy distributions, except for Z=2 ⇒ carbon break-up badly reproduced
  - ❖ Particle yields are underestimated by Geant4 except for Z=1

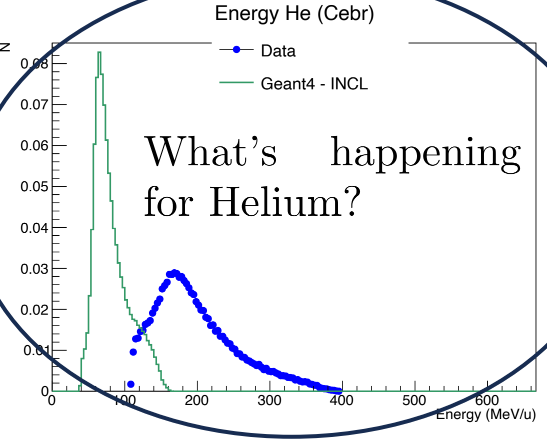
Preliminary!

Measurements @CNAO

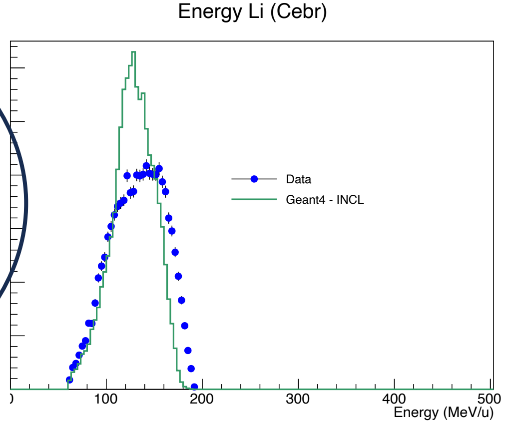
From Lévana Gesson PhD
& Claire Reibel Master internship

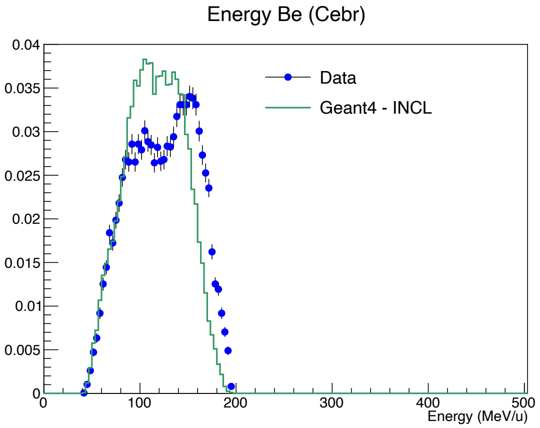
Reconstructed energy spectra (E+ΔE): comparison between data and GEANT4

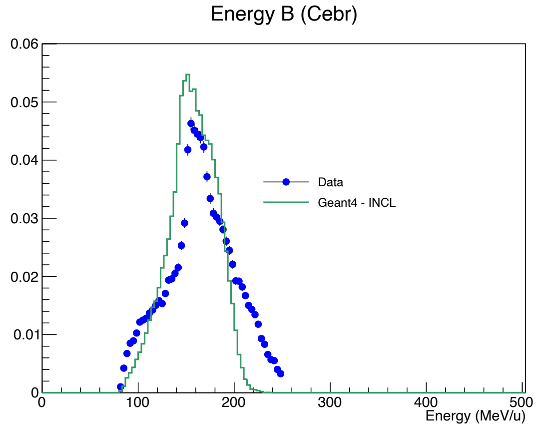


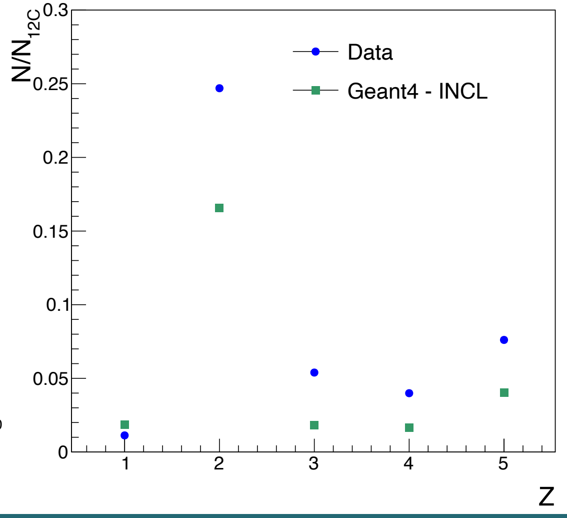


What's happening for Helium?









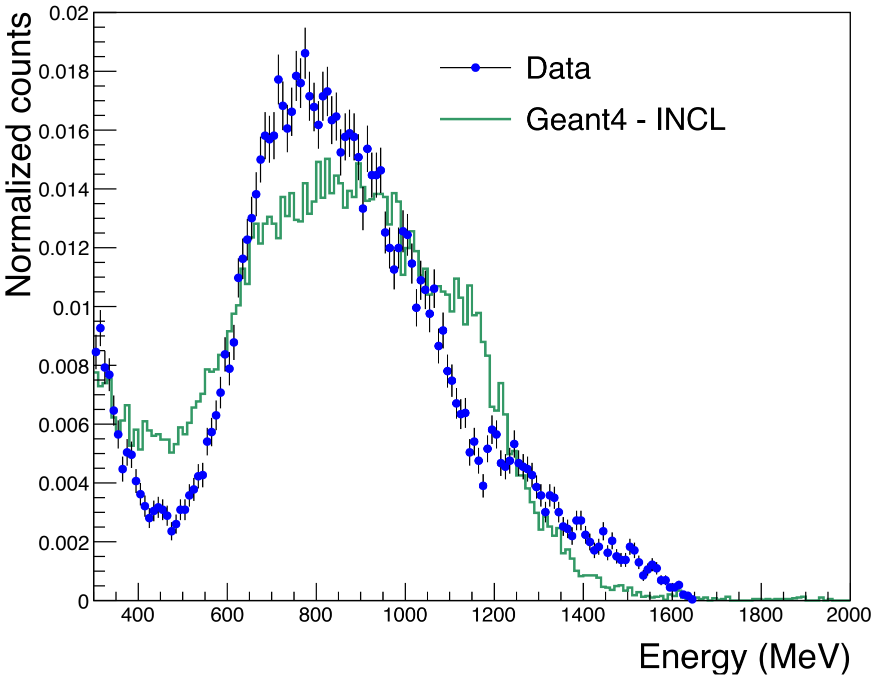
- Run @ 0º, 400 MeV/u ^{12}C
  - ❖ Good agreement between experimental and simulated energy distributions, except for Z=2 ⇒ carbon break-up badly reproduced
  - ❖ Particle yields are underestimated by Geant4 except for Z=1

Preliminary!

Measurements @CNAO

From Lévana Gesson PhD
& Claire Reibel Master internship

- Comparison between experimental spectra and simulated energy **arriving on the detector**

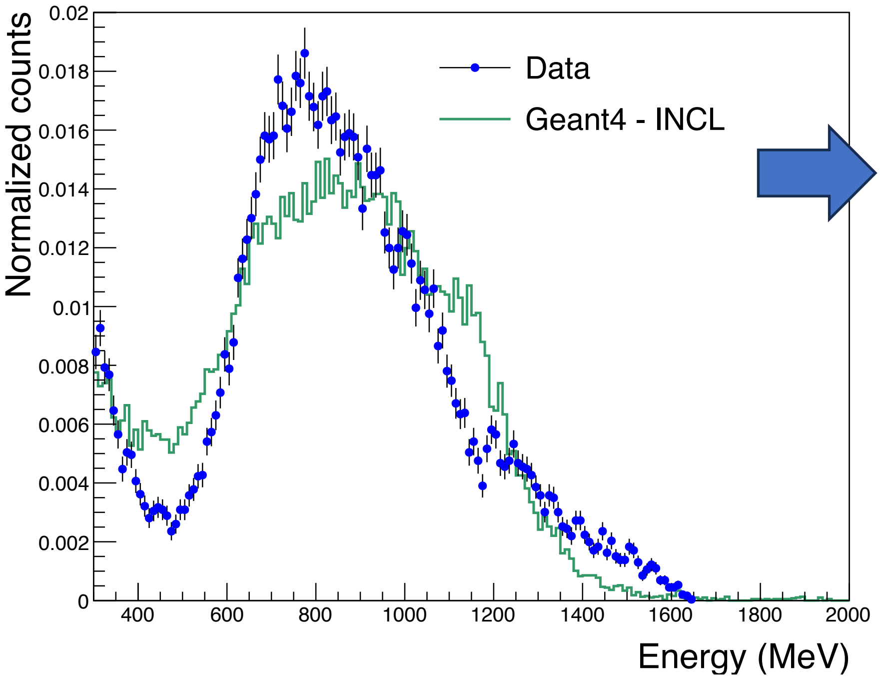


Preliminary!

Measurements @CNAO

From **Lévana Gesson** PhD
& **Claire Reibel** Master internship

- Comparison between experimental spectra and simulated energy **arriving on the detector**



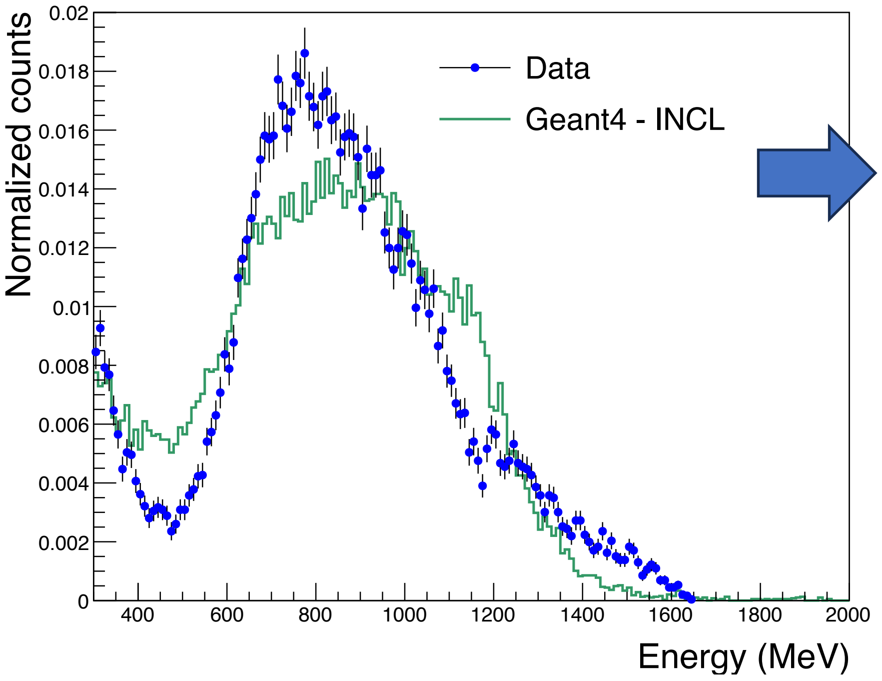
Helium of 800 MeV (200 MeV/u) are not stopped in the $CeBr_3$
⇒ how does it come that we detect alphas of 200 MeV/u in $CeBr_3$?

Preliminary!

Measurements @CNAO

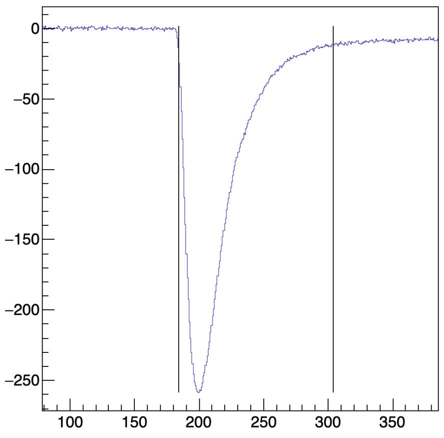
From **Lévana Gesson** PhD
& **Claire Reibel** Master internship

- Comparison between experimental spectra and simulated energy **<u>arriving on the detector</u>**

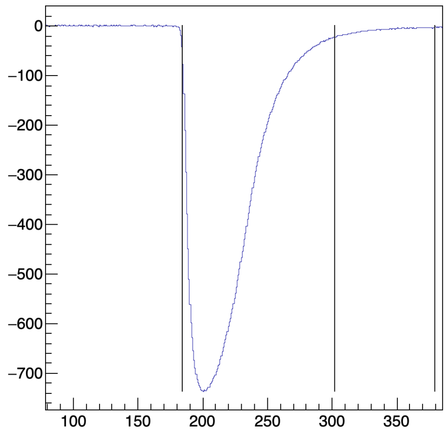


Helium of 800 MeV (200 MeV/u) are not stopped in the $CeBr_3$
⇒ how does it come that we detect alphas of 200 MeV/u in $CeBr_3$?

Single event waveform



Double event waveform



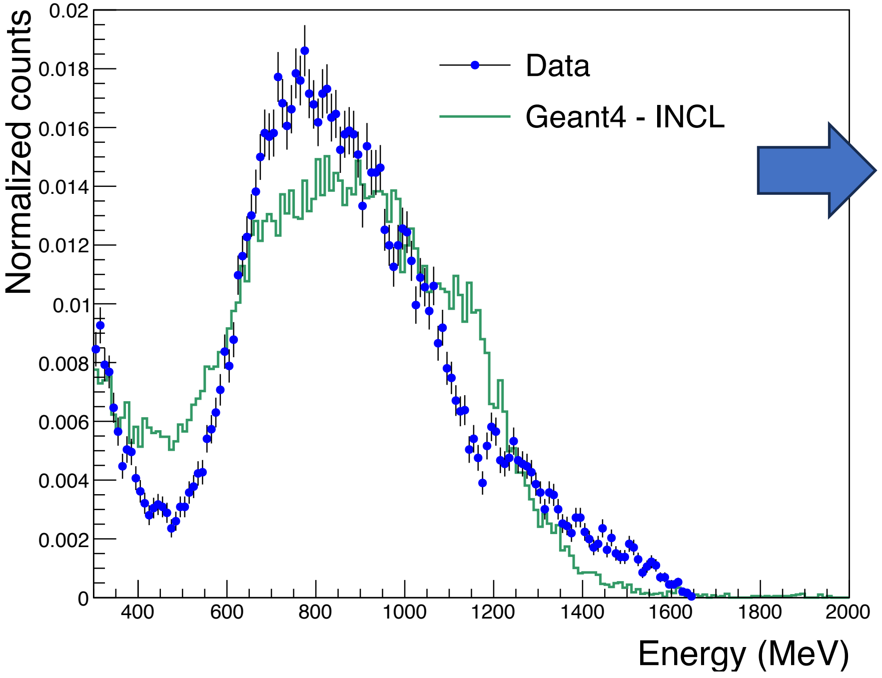
❖ Two alpha-particles detected at the same time (carbon break-up)

Preliminary!

Measurements @CNAO

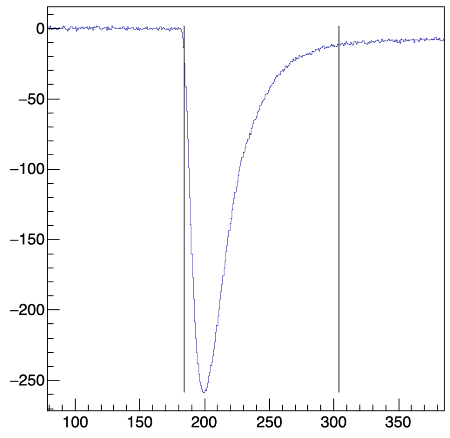
From **Lévana Gesson** PhD
& **Claire Reibel** Master internship

- Comparison between experimental spectra and simulated energy **arriving on the detector**

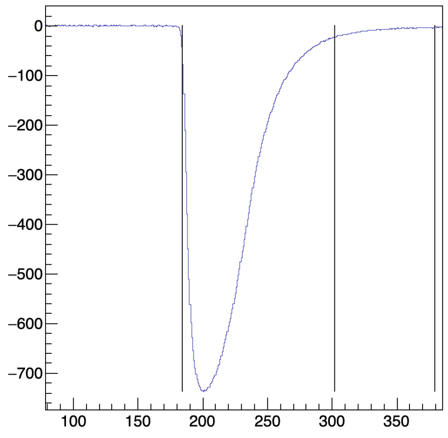


Helium of 800 MeV (200 MeV/u) are not stopped in the $CeBr_3$
⇒ how does it come that we detect alphas of 200 MeV/u in $CeBr_3$?

Single event waveform



Double event waveform



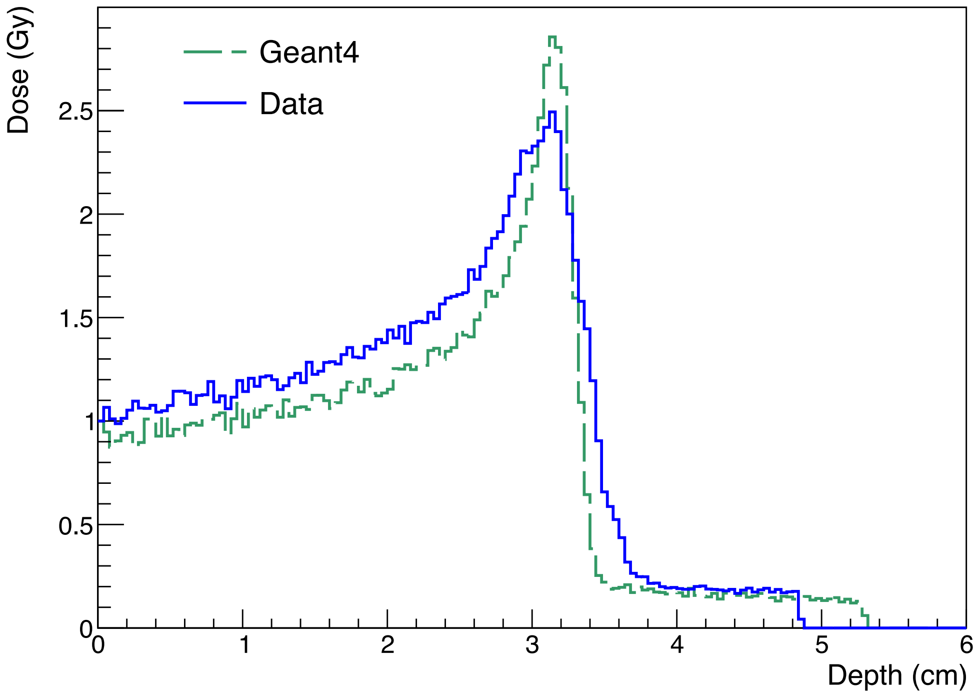
❖ Two alpha-particles detected at the same time (carbon break-up)
❖ Geant4 is reproducing the incident energy spectrum, but associates it to only ONE alpha ⇒ wrong deposited energy in water!

Preliminary!

Measurements @CNAO

From **Lévana Gesson** PhD
& **Claire Reibel** Master internship

- Comparison between Geant4 and data-corrected dose profiles in water of 400 MeV/u ^{12}C after 23 cm RW3 target



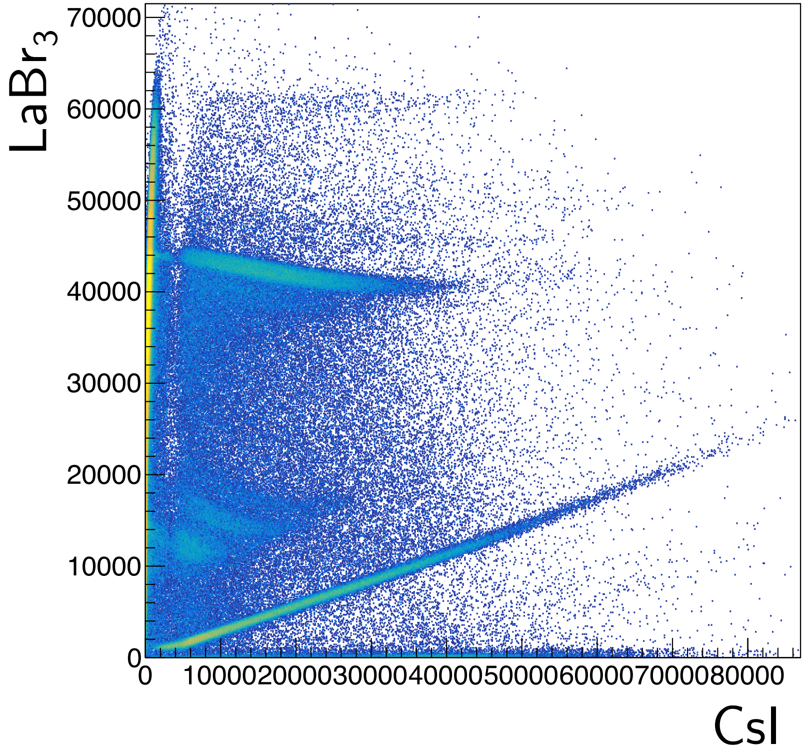
- Change of secondary particles field change the dose profiles (higher dose before the BP, lower in the BP)
- Energy distributions of ^{12}C exiting the target are the same, but not same proportions (more secondaries in the data than predicted)

Prospects

- Implementation of the corrected dose in the radiolysis measurements to evaluate impact

- Calibration of CsI part of the phoswich detector for higher energy particles + isotopes identification

- Time-of-Flight measurements to evaluate high energy neutrons field



- New experiments to complete existing measurements @ CNAO, GANIL
  - ❖ ΔE with silicon detectors in order to improve energy resolution and identify isotopes
  - ❖ Other ions? (^{4}He, ^{7}Li)

Acknowledgements

This work was possible thanks to the support of the HITRI+ project and the funding of the European Union's Horizon 2020 Research and innovation (Grant Agreement №101008548)

From CNAO

Marco Pullia, Michele Ferrarini, Angelica Facoetti, Chiara Marazzi

From

Joel Herault, Petter Hofverberg

From

Cédric Mathieu, Michel Pellicioli, Jacky Schuler, Nathalie Dick-Schuler, Thomas Adam
Julie Gross, Carlotta Mozzi
Antoine Danvin, Séverine Chefson, and all the DeSIS & the Ramses team!

From

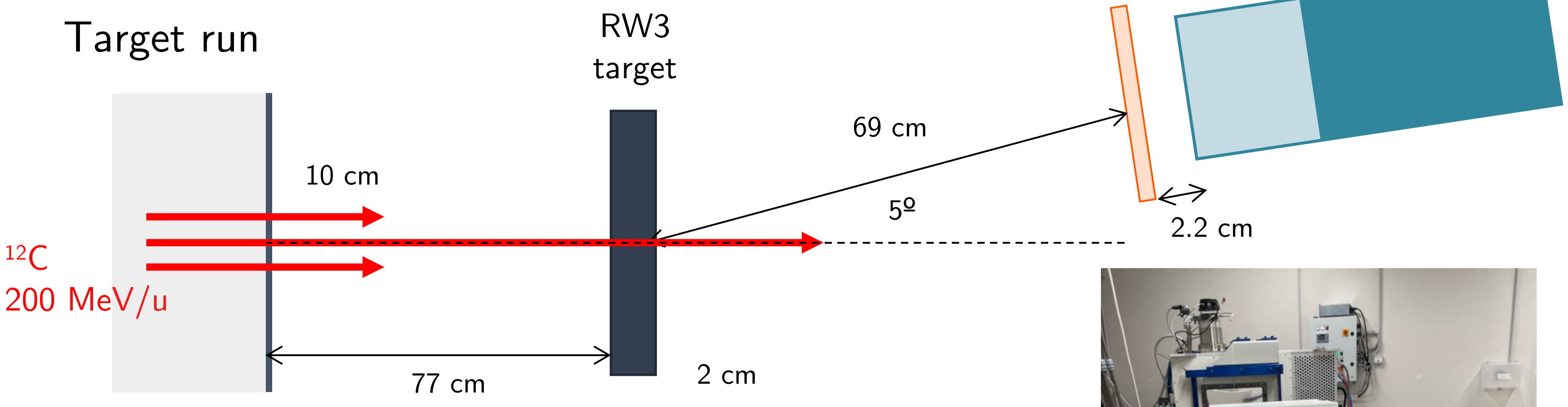
Claire-Anne Reidel, Christoph Schuy, Uli Weber

Backup

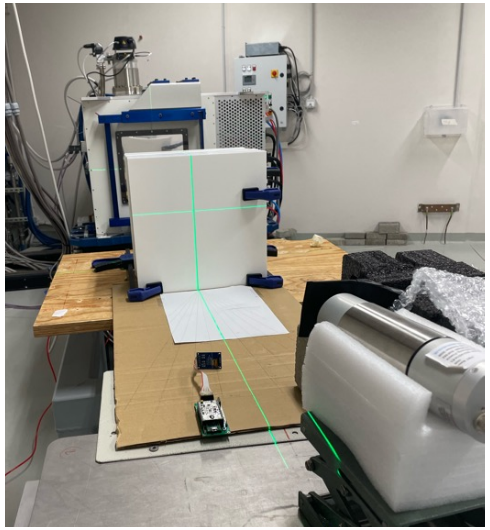
Measurements @CNAO

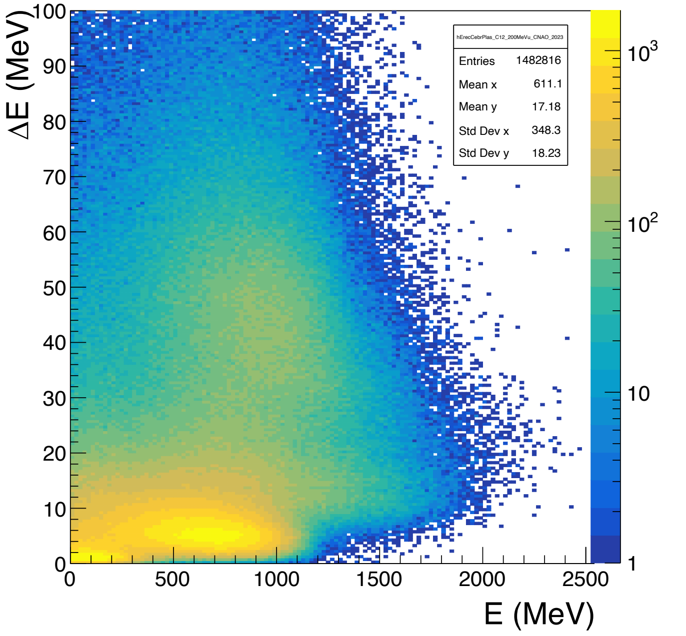
From **Lévana Gesson** PhD
& **Claire Reibel** Master internship

- Run @ 5º, 200 MeV/u ^{12}C



Phoswich = 5 cm long LaBr3 + 15 cm long CsI

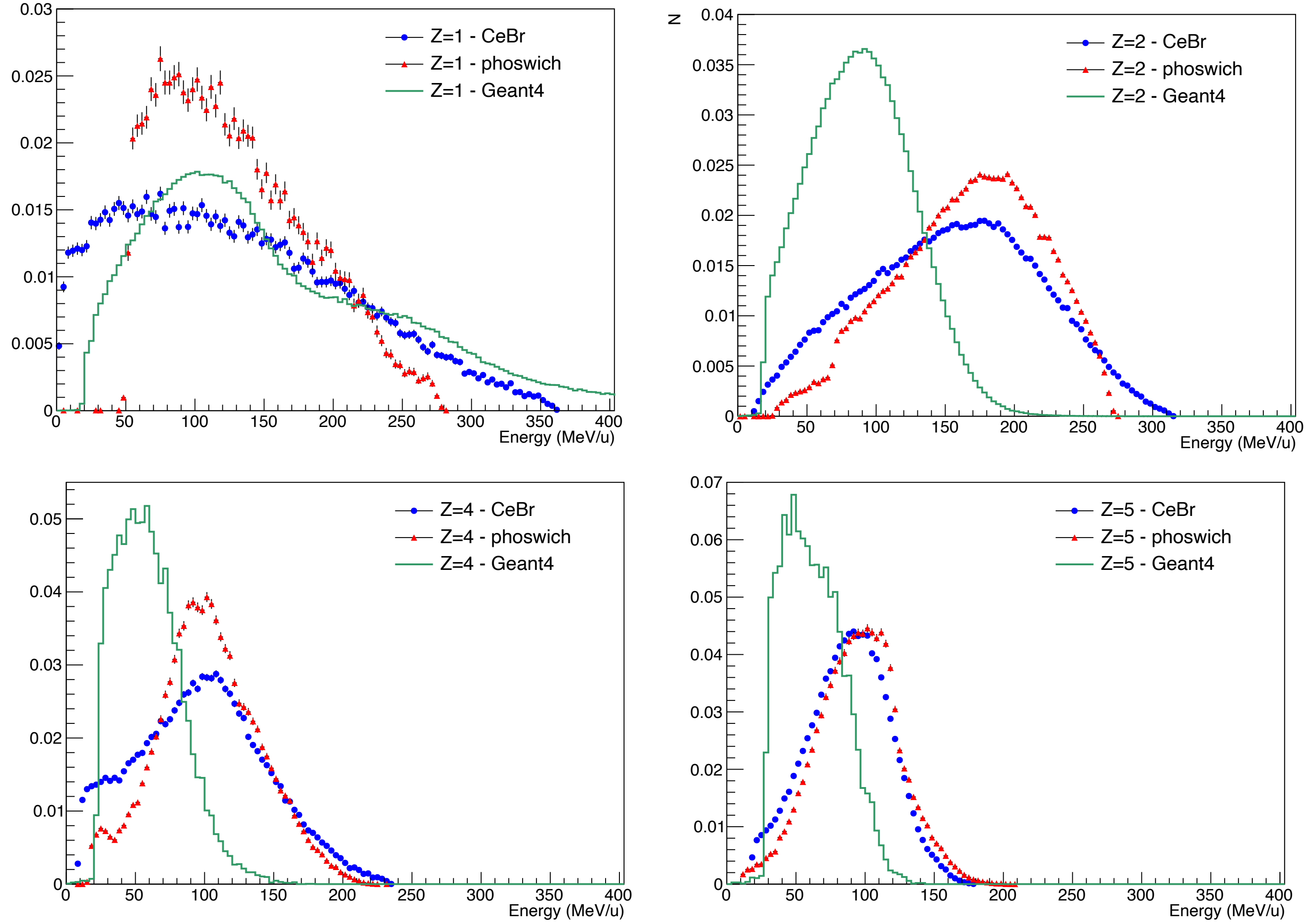




Preliminary!

Measurements @CNAO

From **Lévana Gesson** PhD
& **Claire Reibel** Master internship



- Run @ 5º, 200 MeV/u ^{12}C
  - ❖ Good agreement between both detectors ($CeBr_3$ & phoswich)
  - ❖ Phoswich ($LaBr_3$ part) has better energy resolution
  - ❖ Bigger discrepancies between experimental and simulated energy distributions @ 5º