CLINM : Nuclear data for particle therapy

AG du GdR Mi2B – 2023

L.Gesson, C.Reibel, C.Finck, N.Arbor, M.Vanstalle

01. Secondary particles in heavy ion therapy

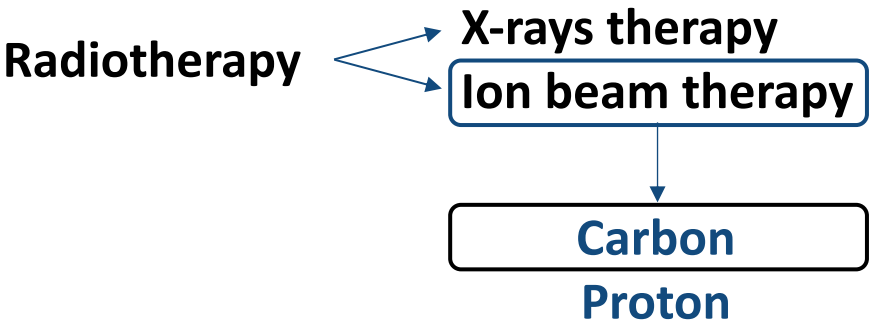
Secondary particles in heavy ion therapy

Secondary particles production

Radiotherapy → **X-rays therapy**
Ion beam therapy

Secondary particles in heavy ion therapy

Secondary particles production

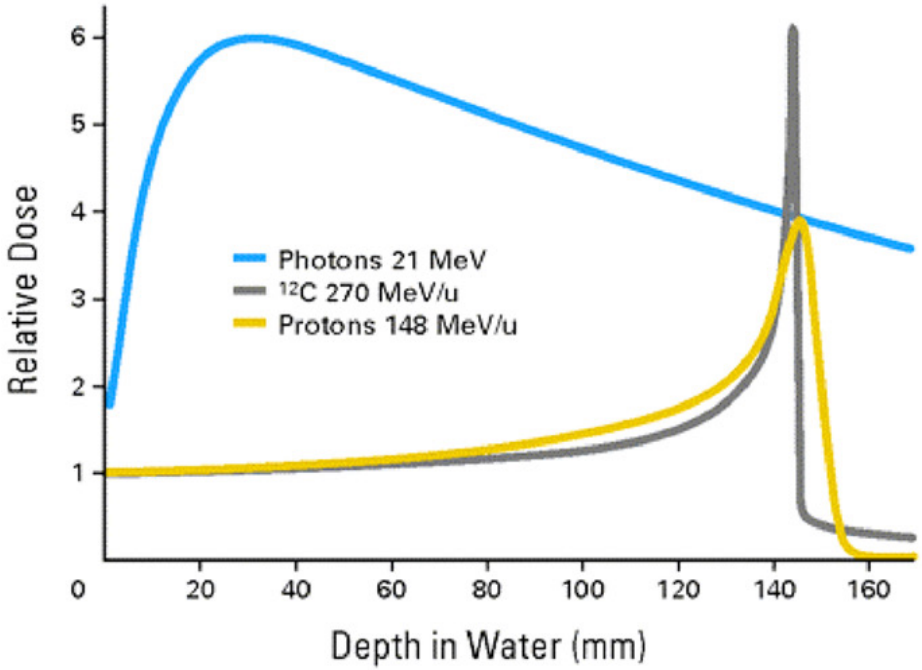


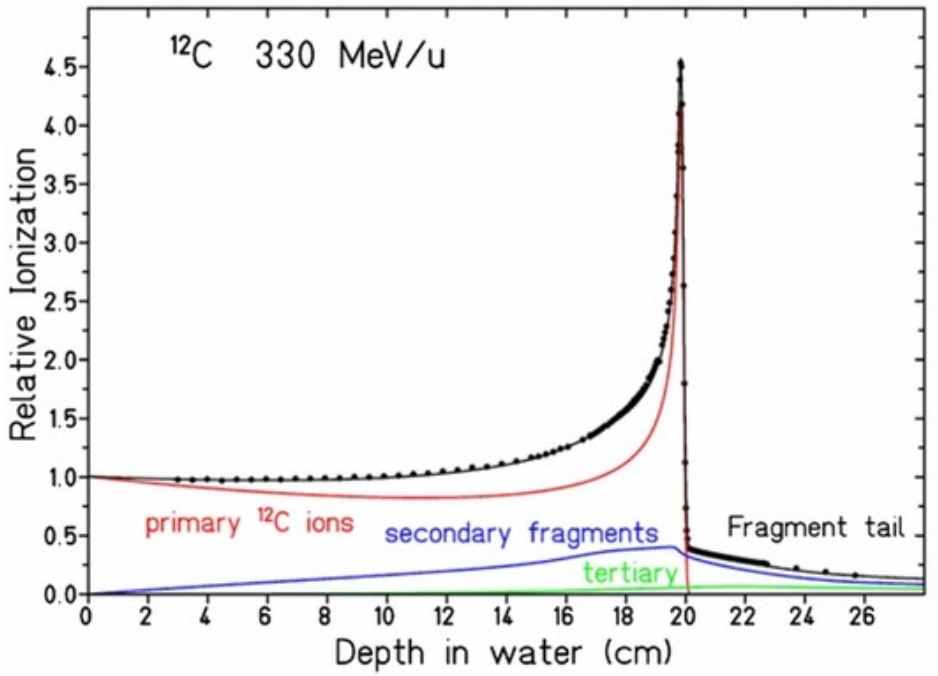
Secondary particles in heavy ion therapy

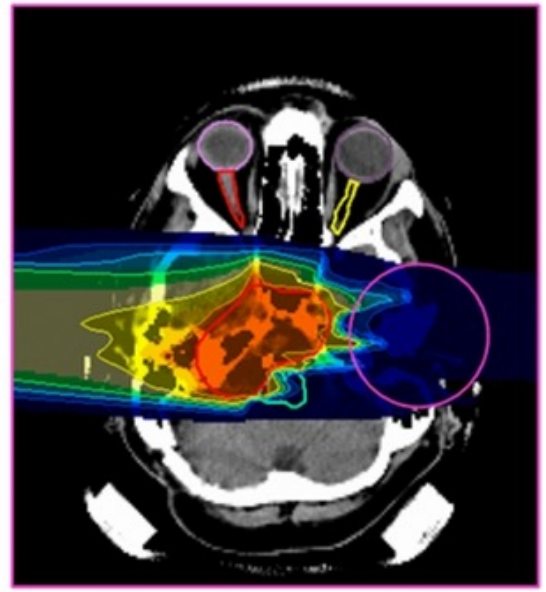
Secondary particles production

Radiotherapy

- **X-rays therapy**
- **Ion beam therapy**
  - **Carbon**
  - **Proton**





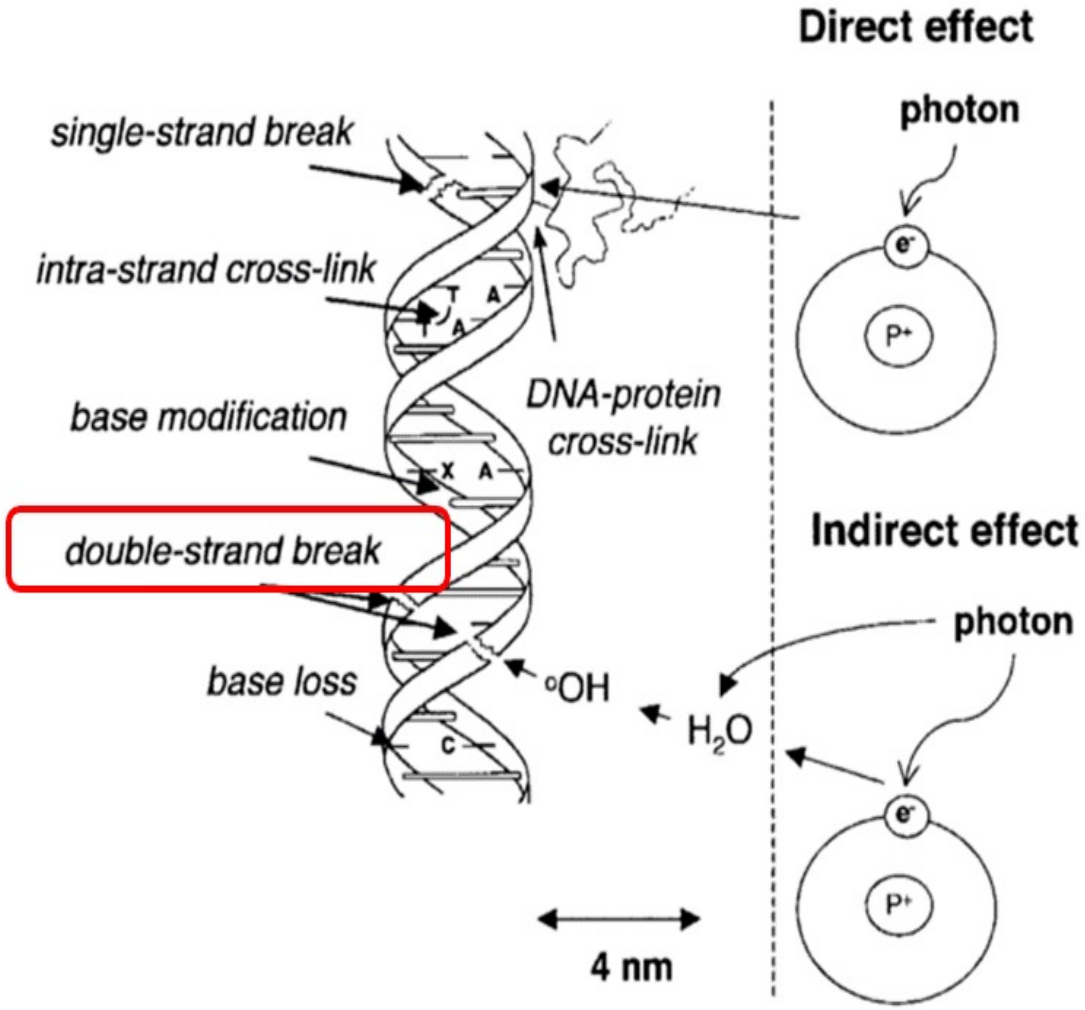


[3]

Figure - Depth-dose characteristics of 330 MeV/u 12C ions stopping in water (described in Sihver et al 1998)[17]

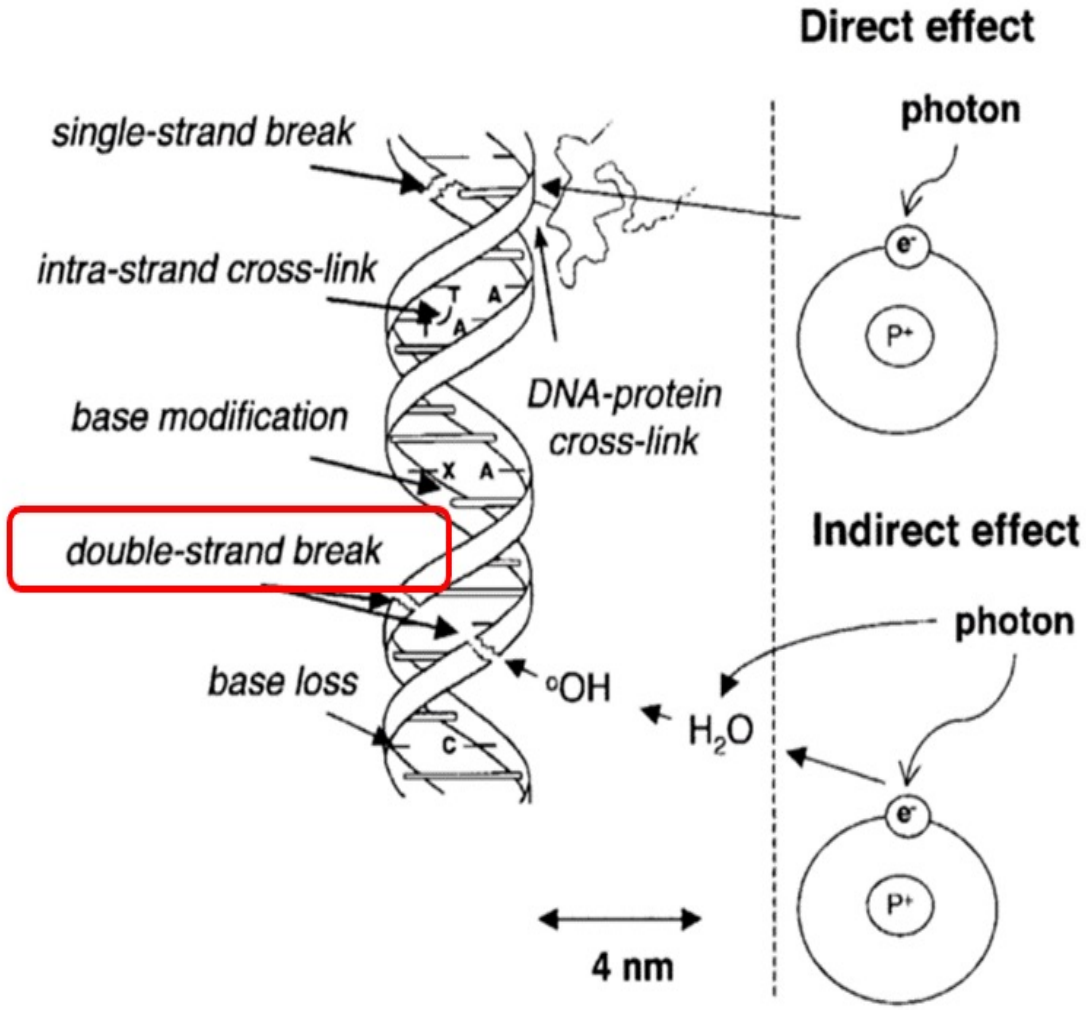
Secondary particles measurement

Radiolytic effects



Secondary particles measurement

Radiolytic effects

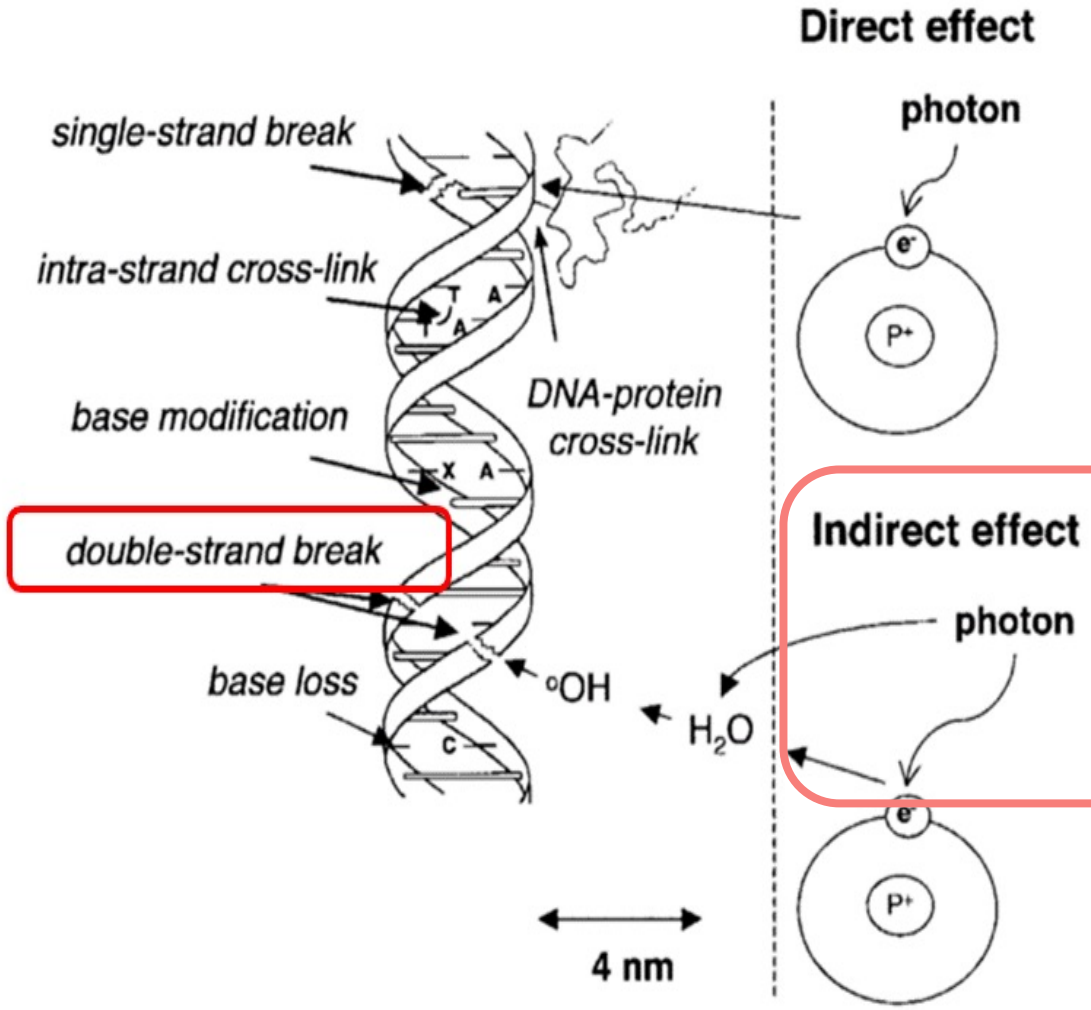


Ionizing radiations

→ Deposite most of its energy in water (~ 65% of cells)

Secondary particles measurement

Radiolytic effects



Ionizing radiations

→ Deposite most of its energy in water (~ 65% of cells)

Indirect effect ← Water Radiolysis

Formation of highly reactive species :

HO• (hydroxyl radical)

e^-_{aq} (hydrated electron)

H_2O_2

~70% of cells damage

Secondary particles in heavy ion therapy

State of art

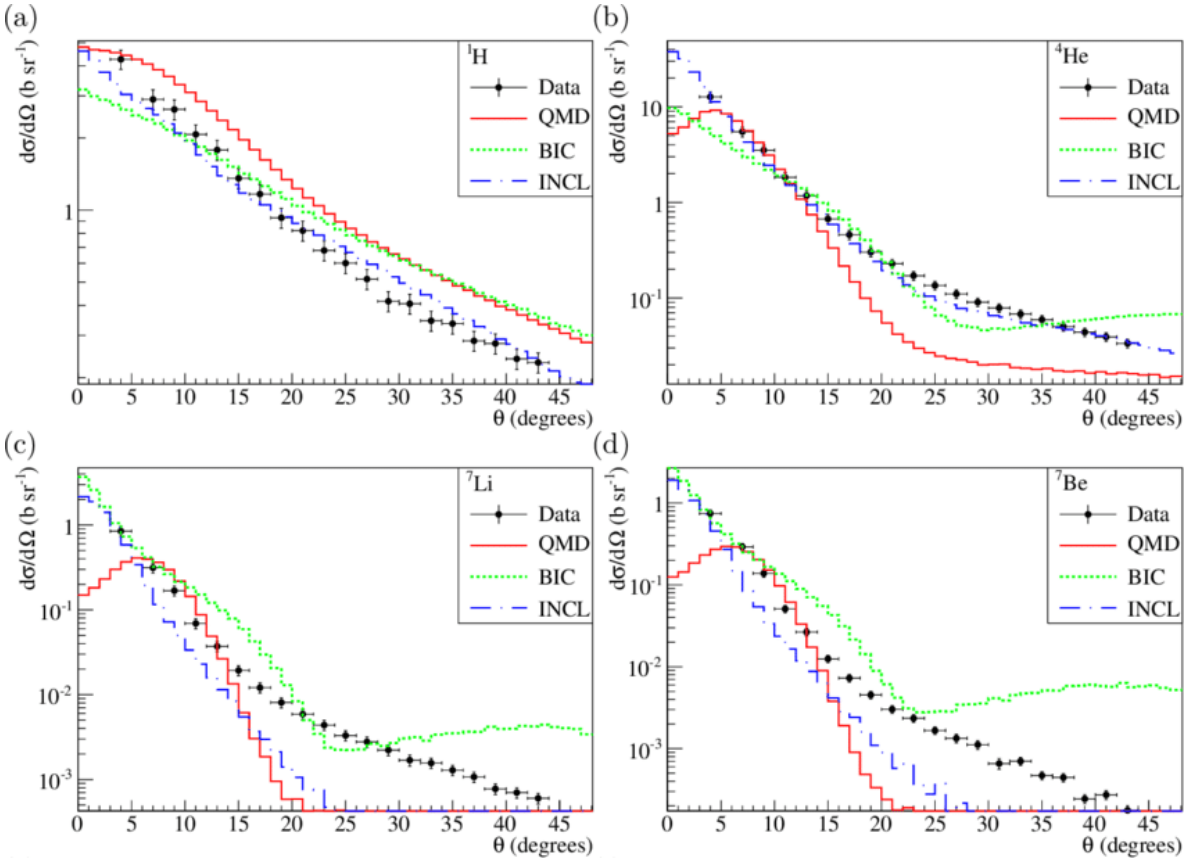
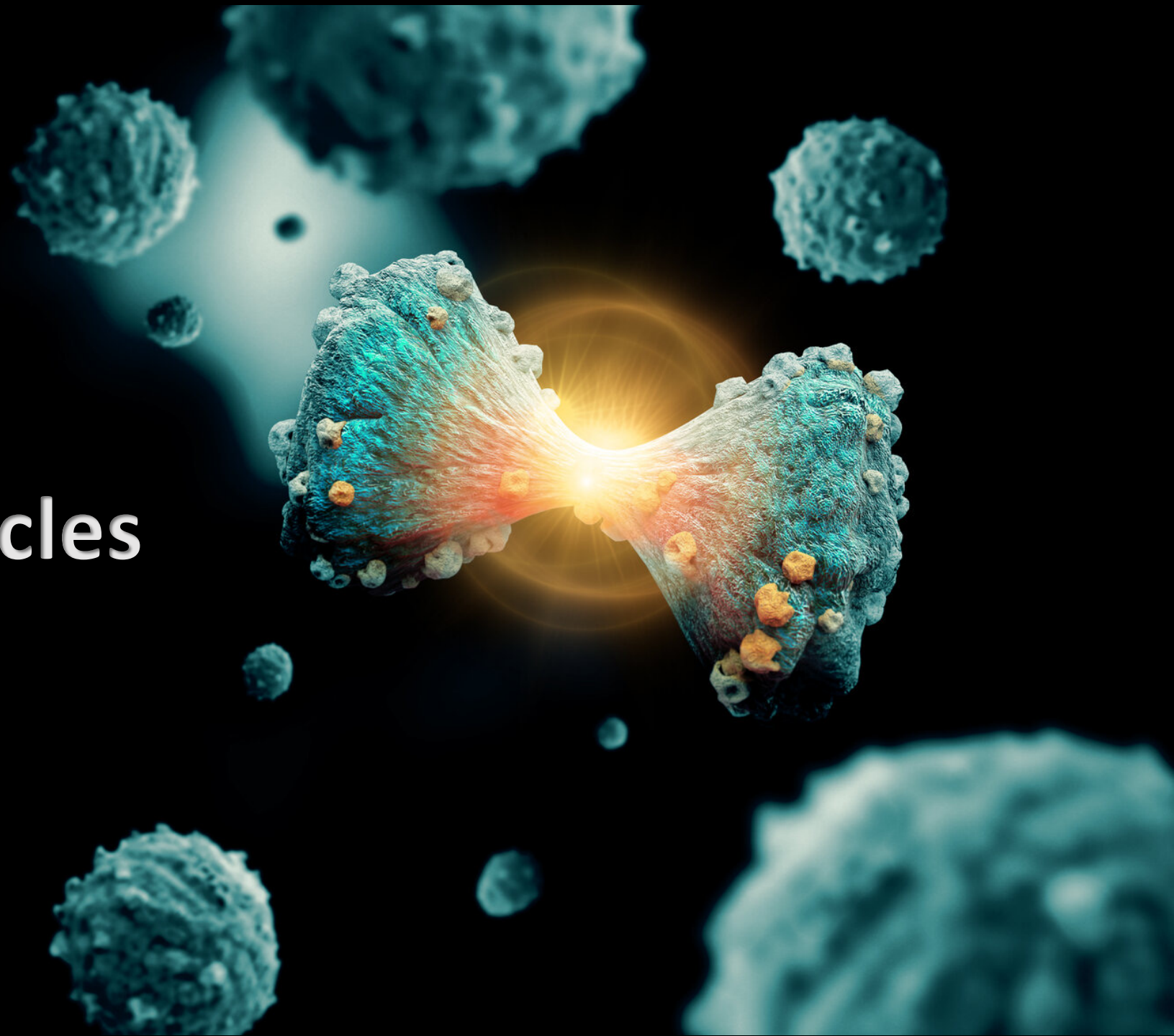


Figure - Absolute differential angular cross-sections of protons, ^{4}He, ^{6}Li, ^{7}Be, obtained for the carbon target. [7]

- Discrepancies between simulation codes / hadronic models
- Discrepancies between simulations code and experimental data

Need to improve nuclear models to understand better the secondary particles production

02. CLINM – Secondary particles measurements



Secondary particles measurement

CLINM project

- CLINM – Cross-Sections of Light Ion and Neutron Measurements
- Combined measurement of secondary particles and radiolysis effectiveness with radiochemistry team (IPHC)
- Secondary charged particle identification + γ + neutrons of high energy measurement

Secondary particles measurement
CLINM project

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ΔE-E telescope

$CeBr_3$ crystal scintillator + plastic scintillator

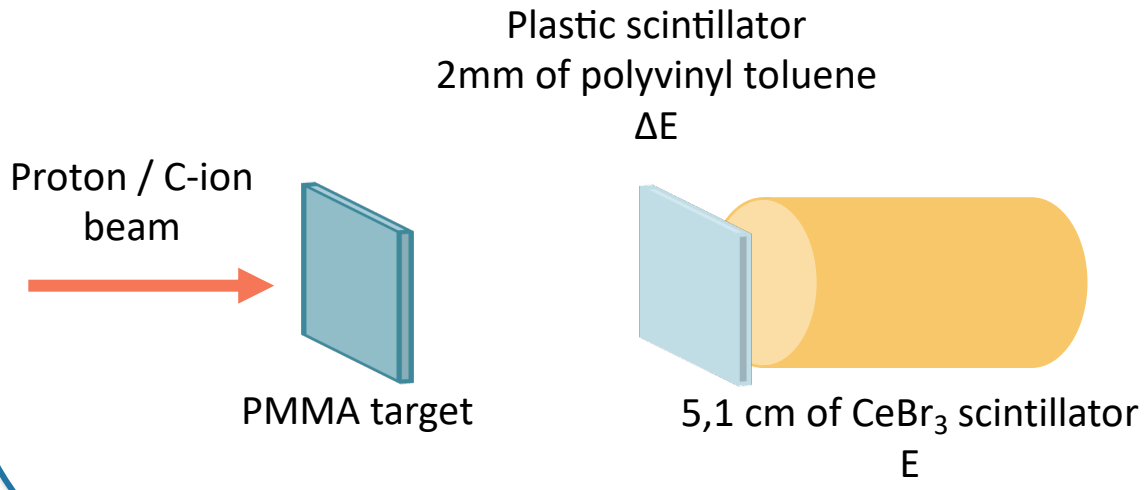
$CeBr_3$ choice

- Not only charged particles but also γ + neutrons
- Time measurement
- No intern radioactivity (unlike $LaBr_3$)
- Energy resolution : 3.8keV
- Short decay time : 19ns

Secondary particles measurement
ΔE-E method

ΔE-E method :

Secondary particles deposit energy in a plastic detector (ΔE), then in a $CeBr_3$ detector where they stop (E).



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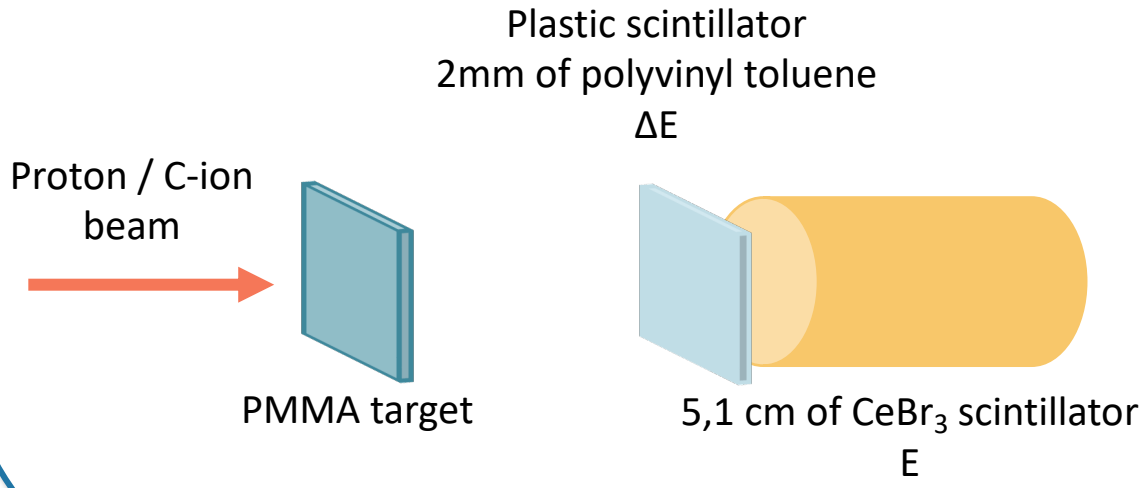

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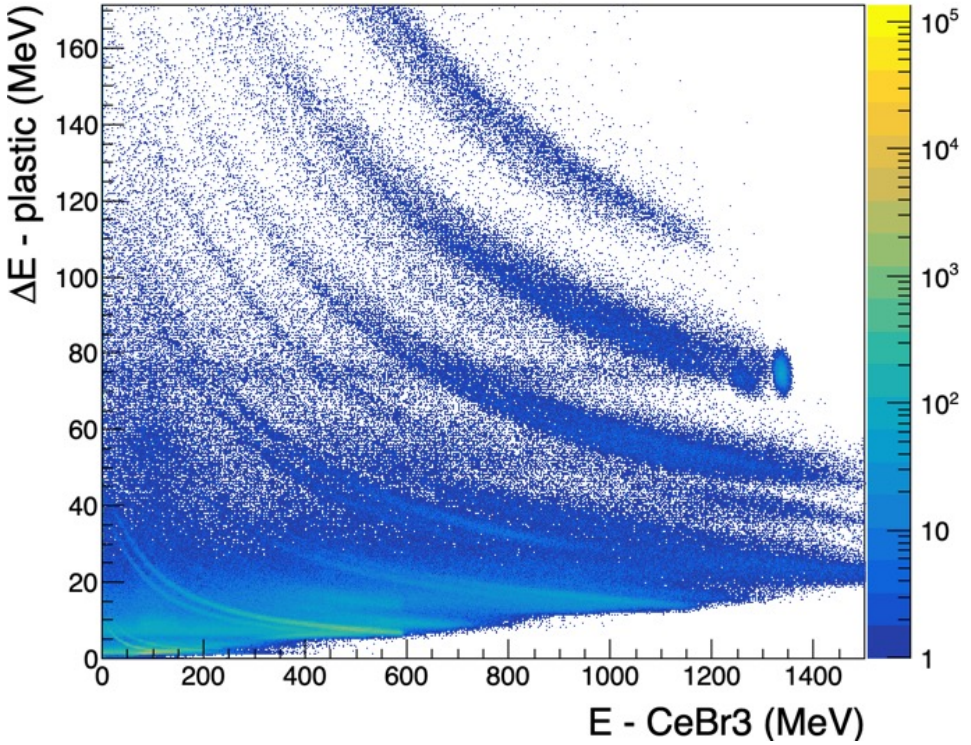

ΔE-E results from simulation with a carbon-ion beam of 200MeV, the detectors at 5° from the beam axis, and a PMMA target of 4 cm

Work done by M. Vanstalle

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ΔE-E method

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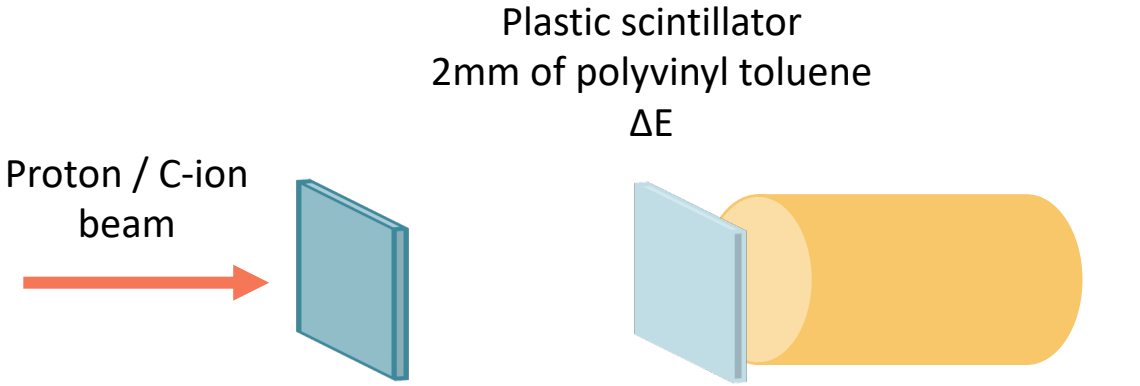
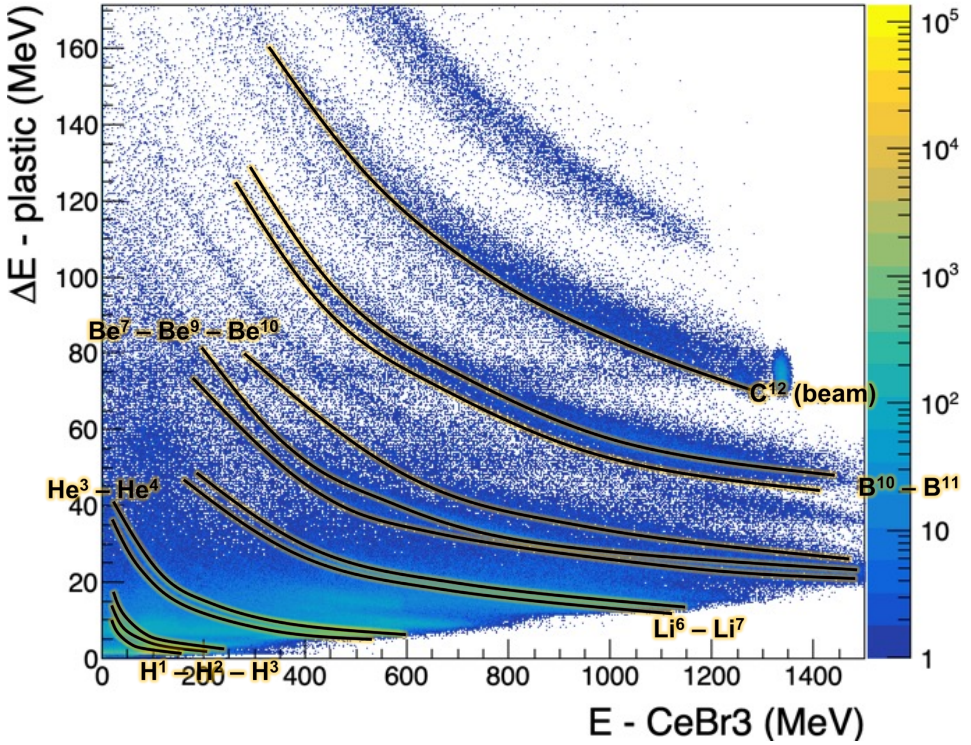


ΔE-E method :



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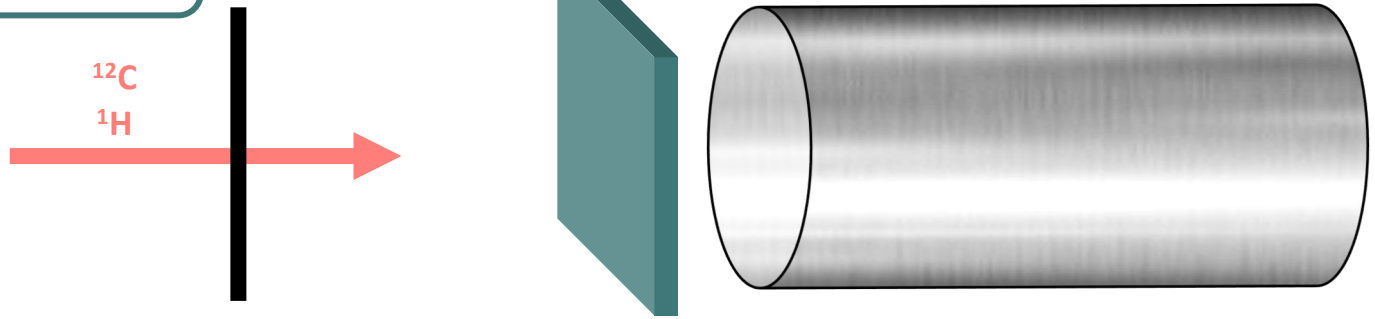
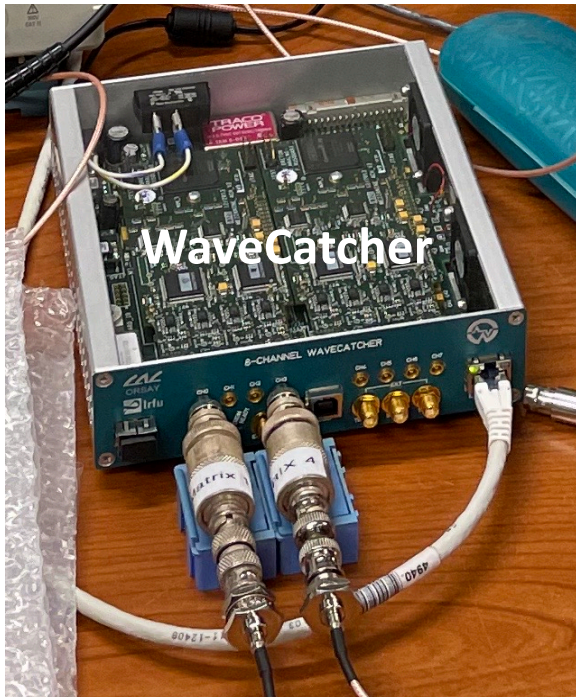
Secondary particles measurement

Calibration measurements

Plastic : - 1200V
CeBr : + 350V





Facility	Ion type	Energy
Cyrcé - Strasbourg	^{1}H	16 - 25 MeV
CAL - Nice	^{1}H	60 MeV
GSI - Darmstadt	^{12}C	110 - 180 MeV/u
CNAO - Pavia	^{12}C	120 - 200 MeV/u

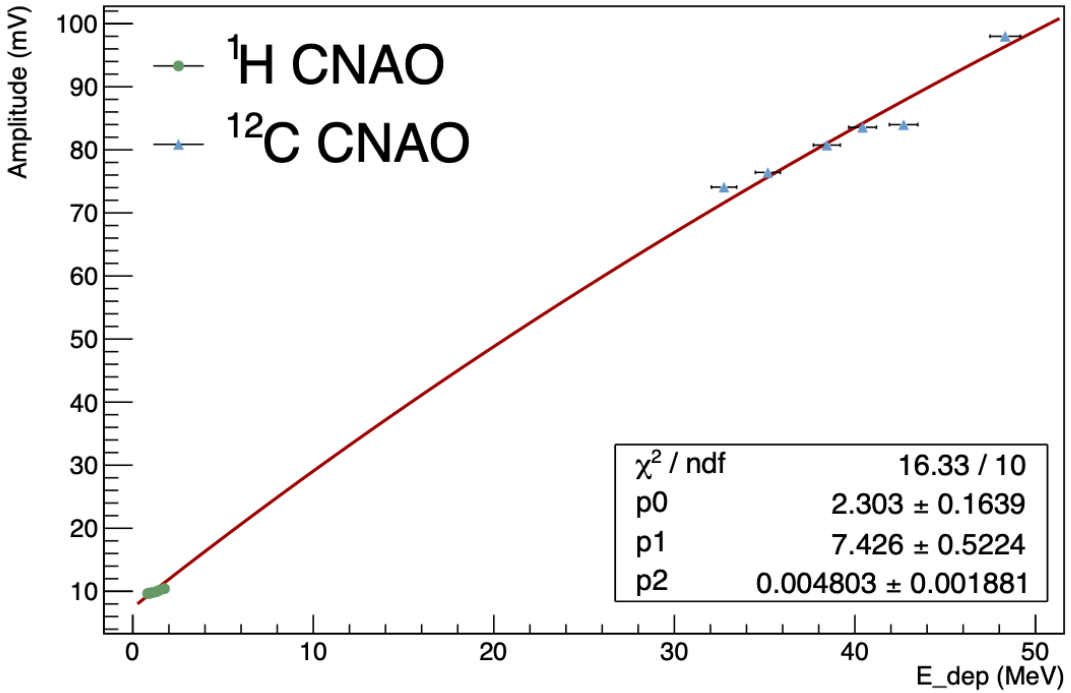
Secondary particles measurement

Plastic scintillator

Work done with C.Mozzi, J.Gross and C.Reibel

Calibration in amplitude

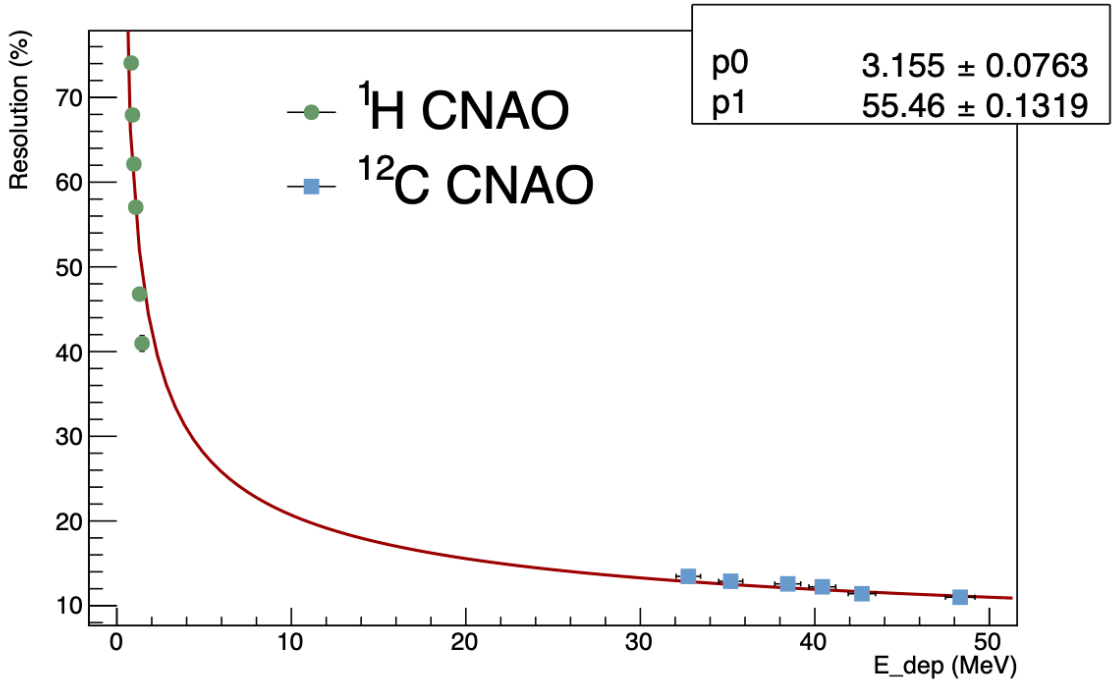
Voltage applied : -1200V



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

Energy resolution

Voltage applied : -1200V



Resolution : Res[%] = $p_0 + \frac{p_1}{\sqrt{E}}$

- **Birk's law respected up to 50 MeV**
- **Energy resolution : from 70% to 10%**

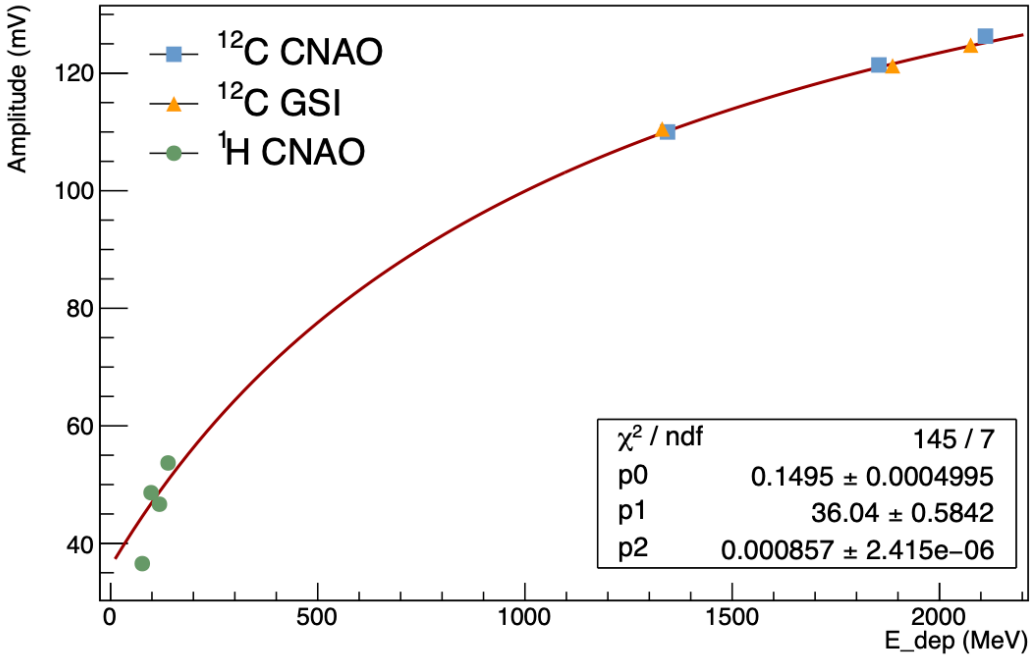
Secondary particles measurement

$CeBr_3$ scintillator

Work done with C.Mozzi, J.Gross and C.Reibel

Calibration in amplitude

Voltage applied : +350V



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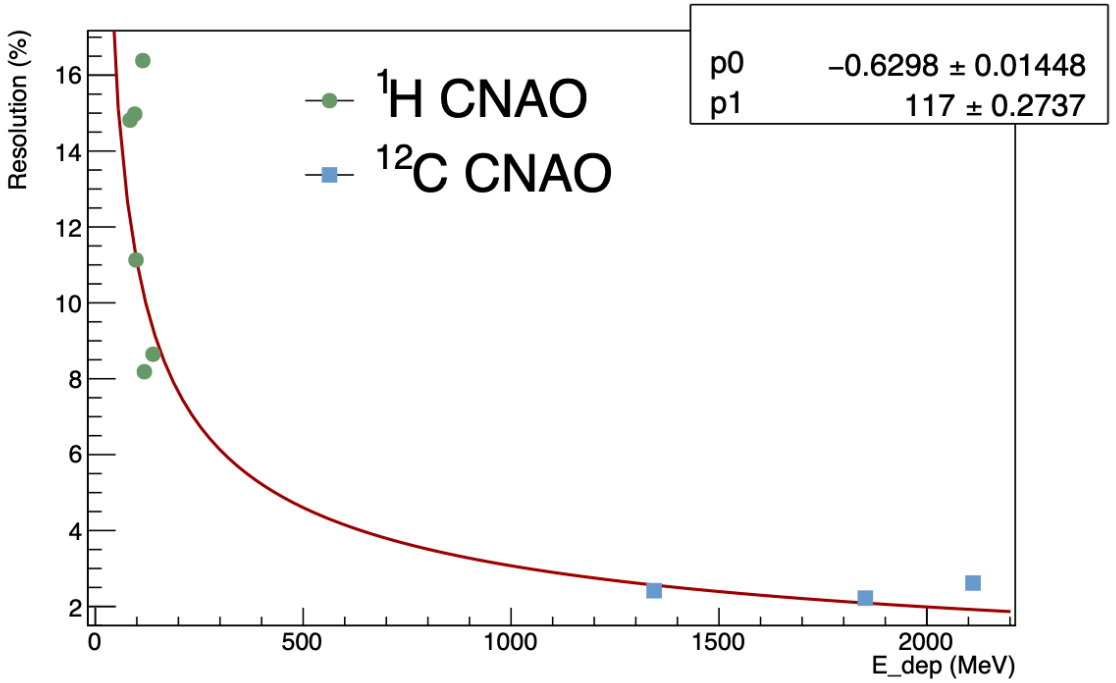


Resolution : $Res[\%] = p_0 + \frac{p_1}{\sqrt{E}}$

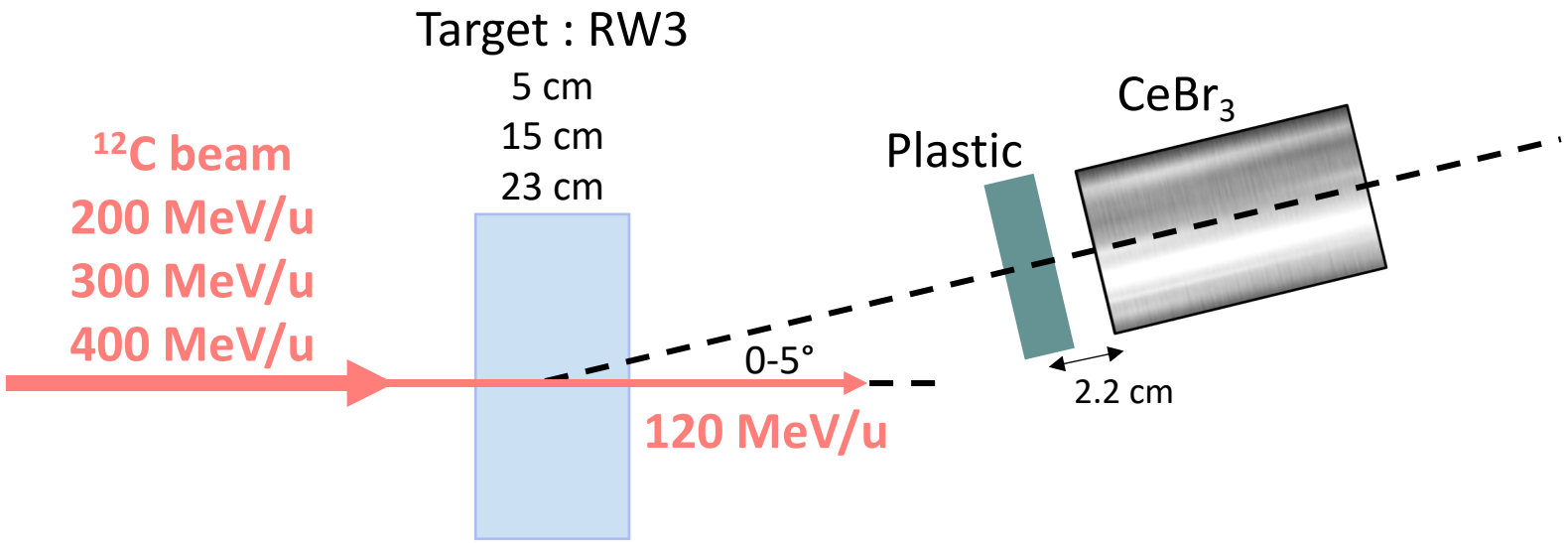
- **$CeBr_3$ response from few MeV to 2 GeV for both protons and carbons**
- **Energy resolution : between 2% and 16%**

Secondary particles measurement

ΔE-E measurement

At CNAO – Centro Nazionale di Adroterapia Oncologica , Pavia, Italy

Plastic : - 1200V
$CeBr_3$: + 350V



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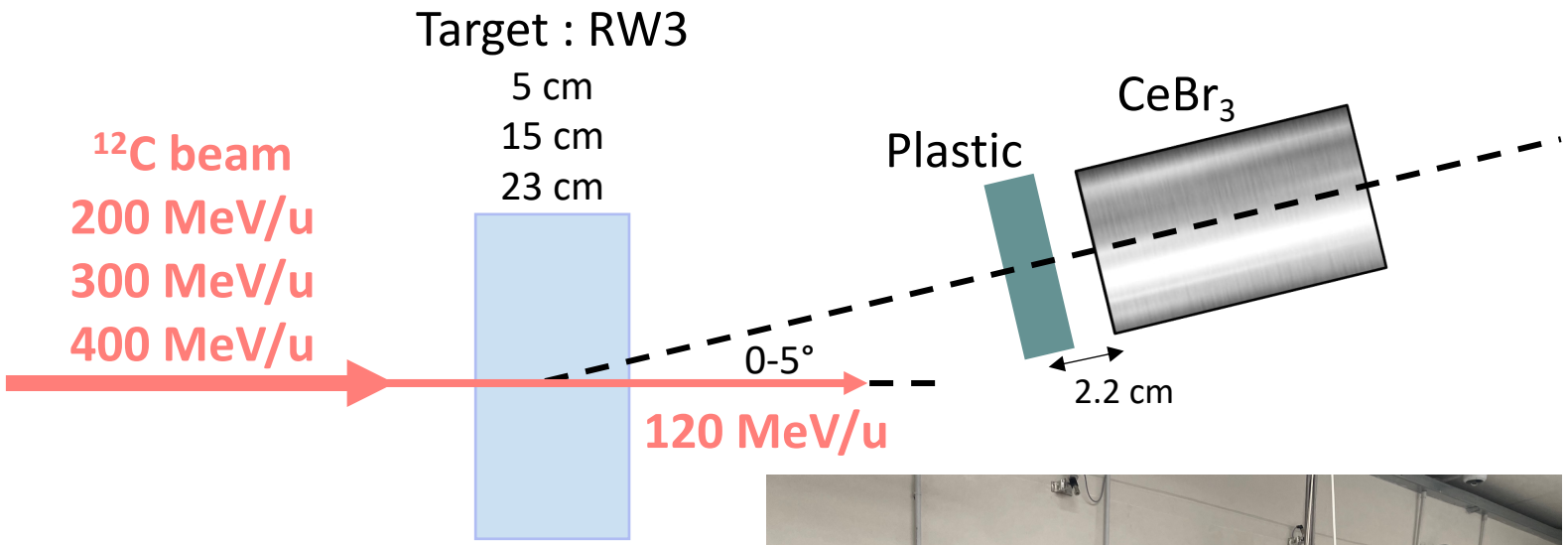
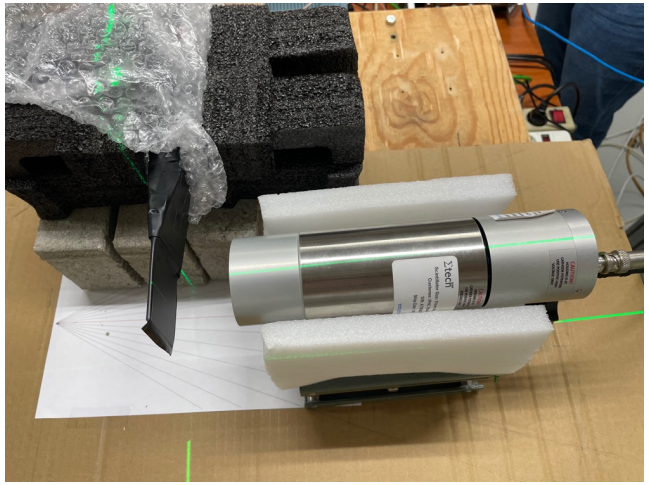
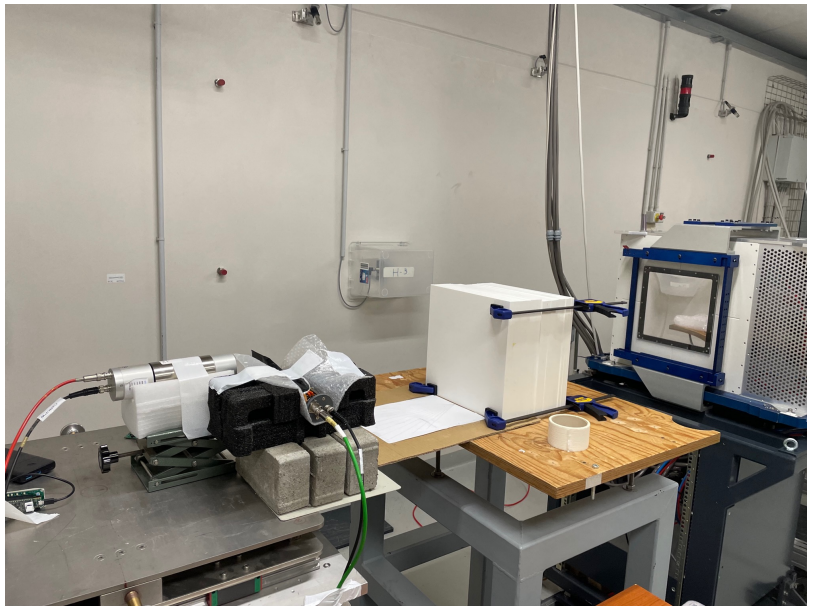
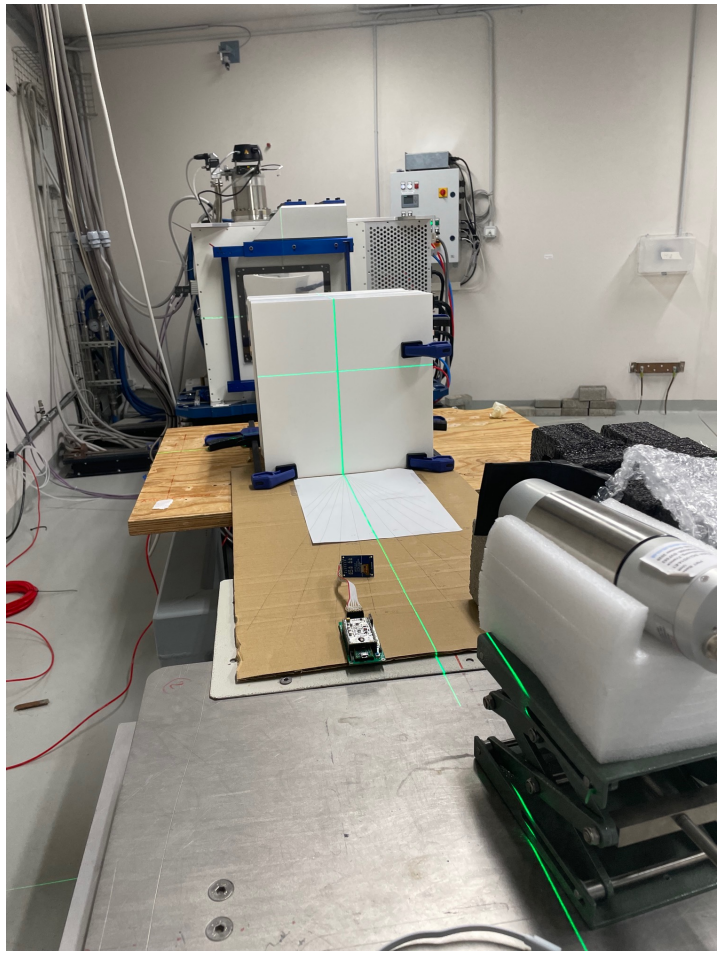






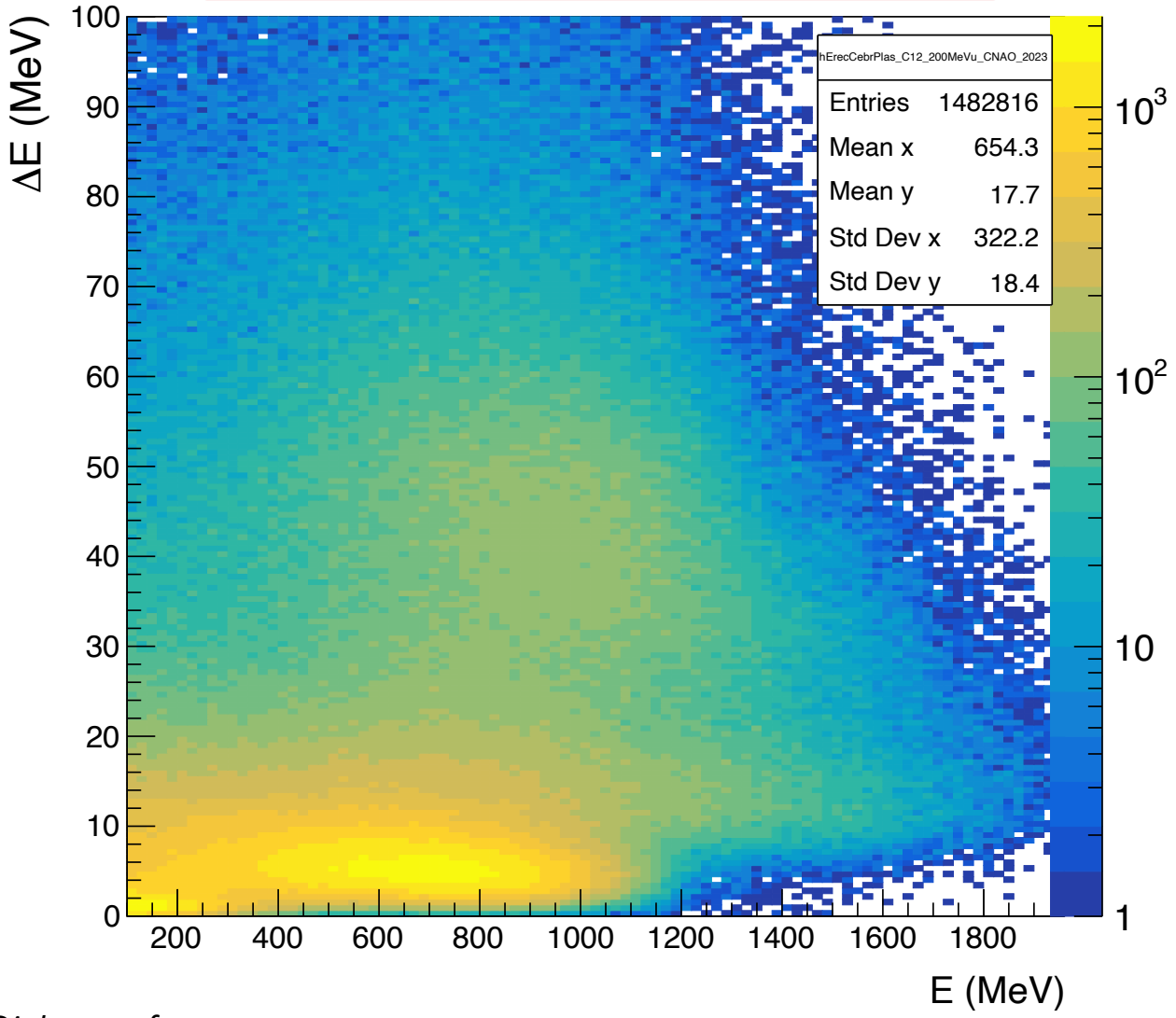


Secondary particles measurement

ΔE-E measurement CNAO

5cm target - 200MeV/u - 5 °

Preliminary



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Secondary particles measurement

ΔE-E measurement CNAO

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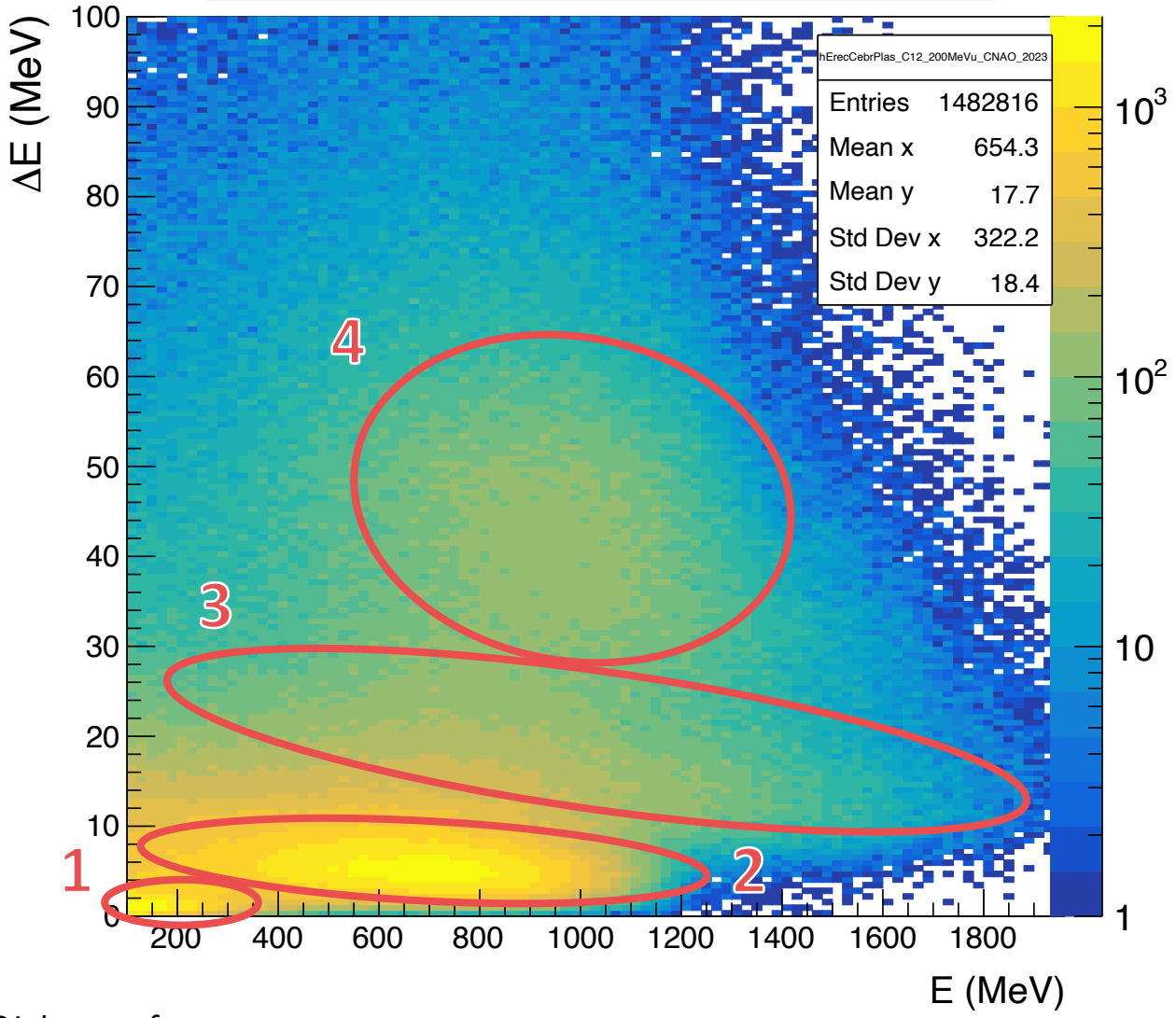

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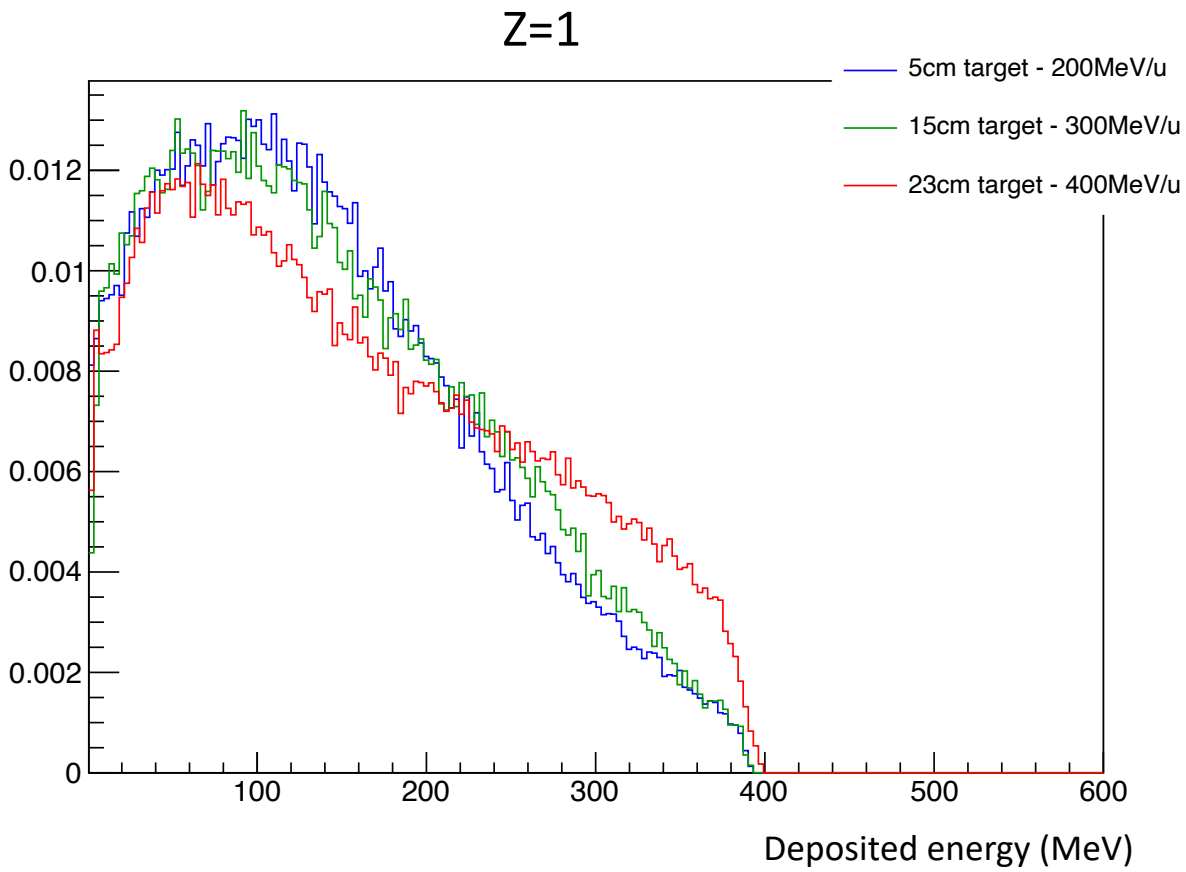
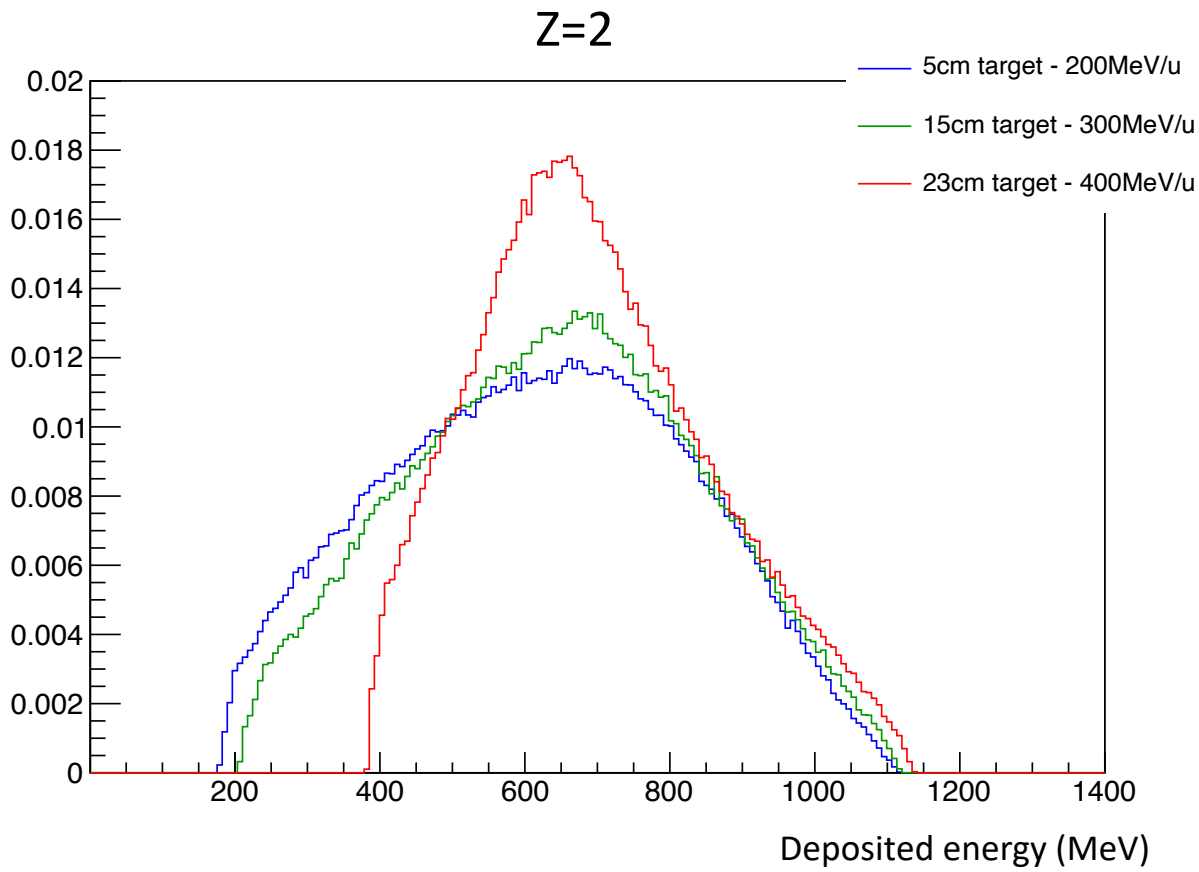
Secondary particles measurement

ΔE-E measurement CNAO

Comparison between different target thicknesses at 5°

Preliminary

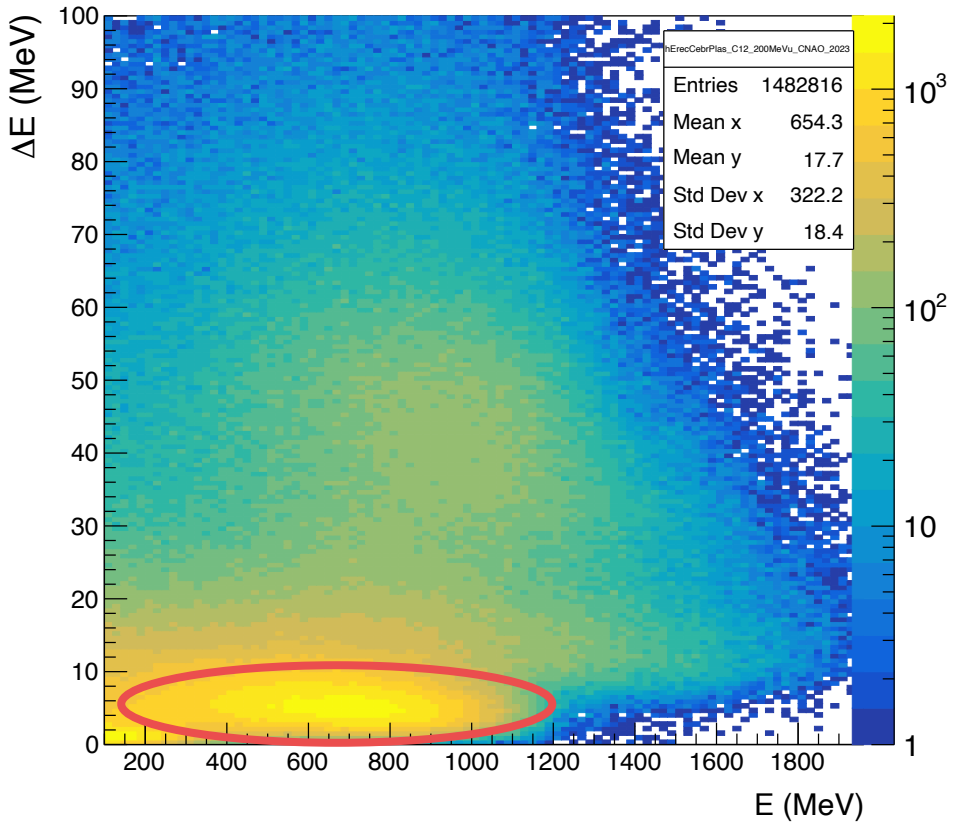




Secondary particles measurement

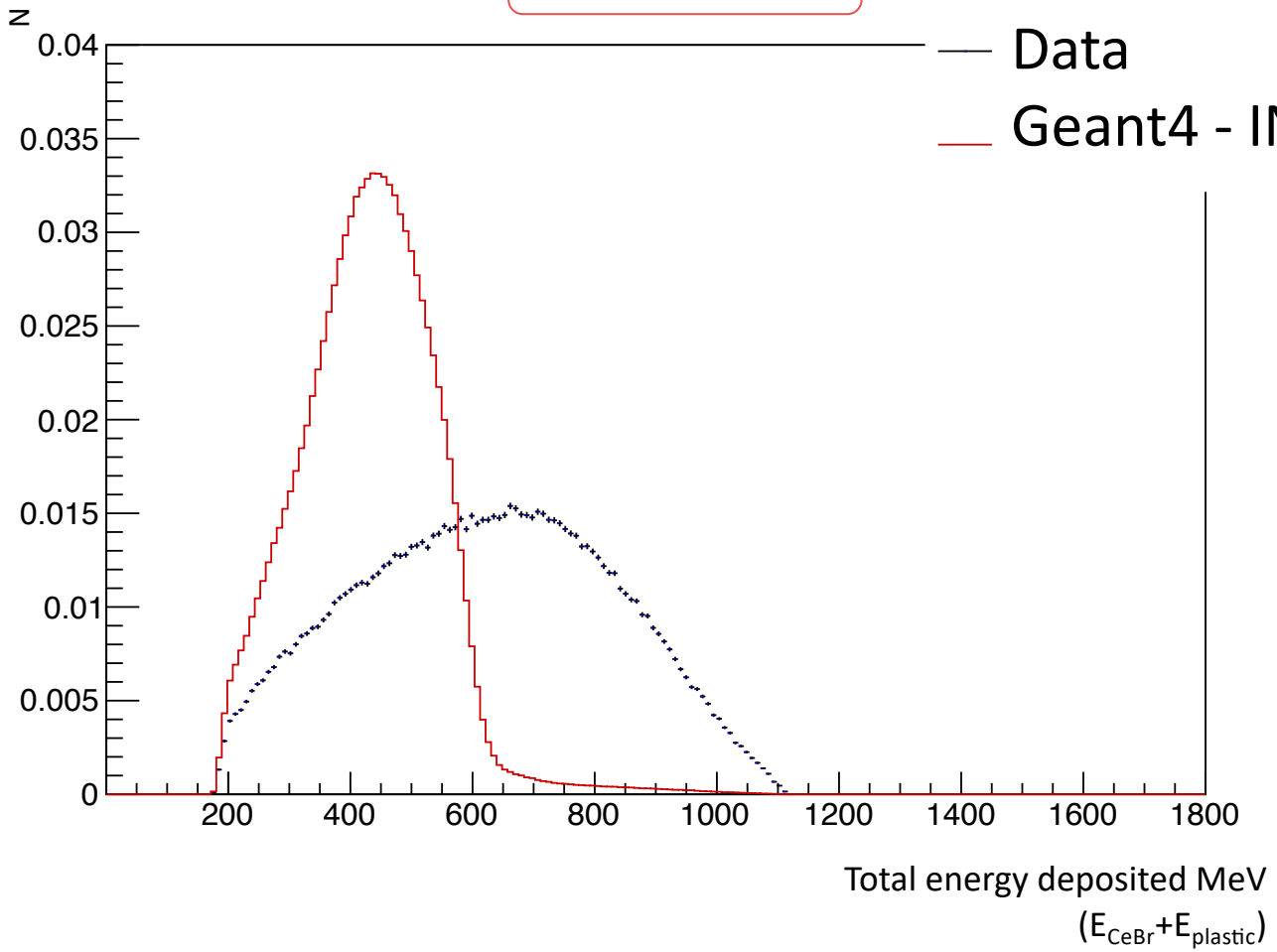
ΔE-E measurement CNAO

Comparison between G4 simulation and experimental data
5cm target and 200MeV/u beam, at 5°



Preliminary

Population 2

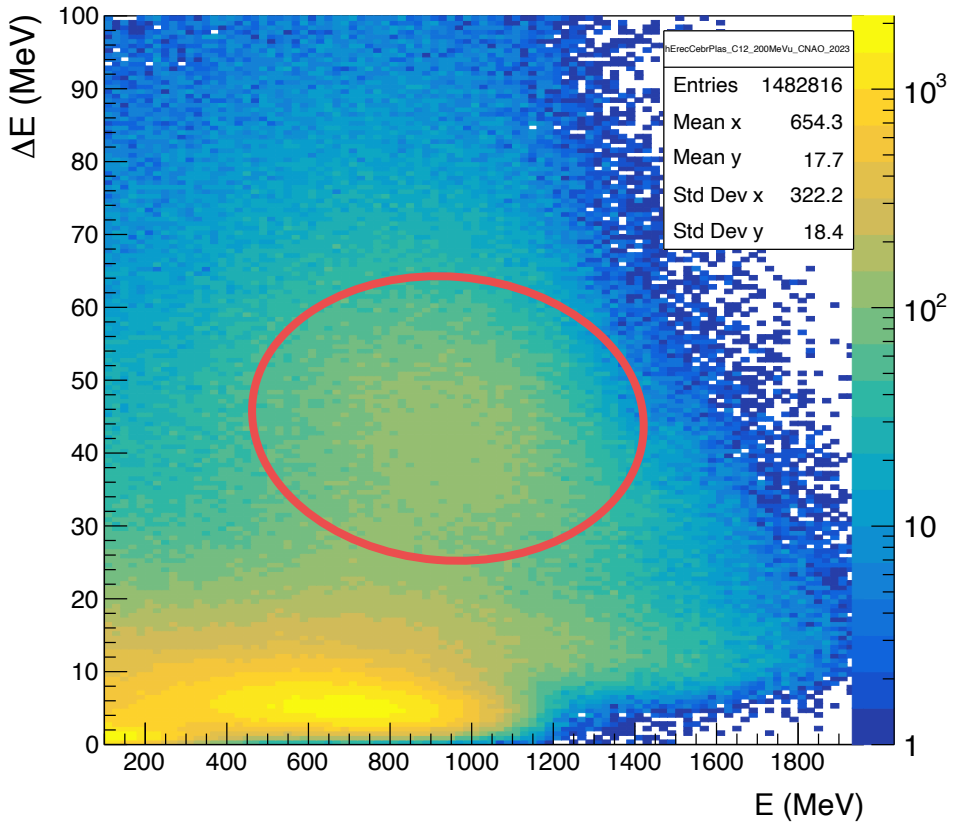


Secondary particles measurement

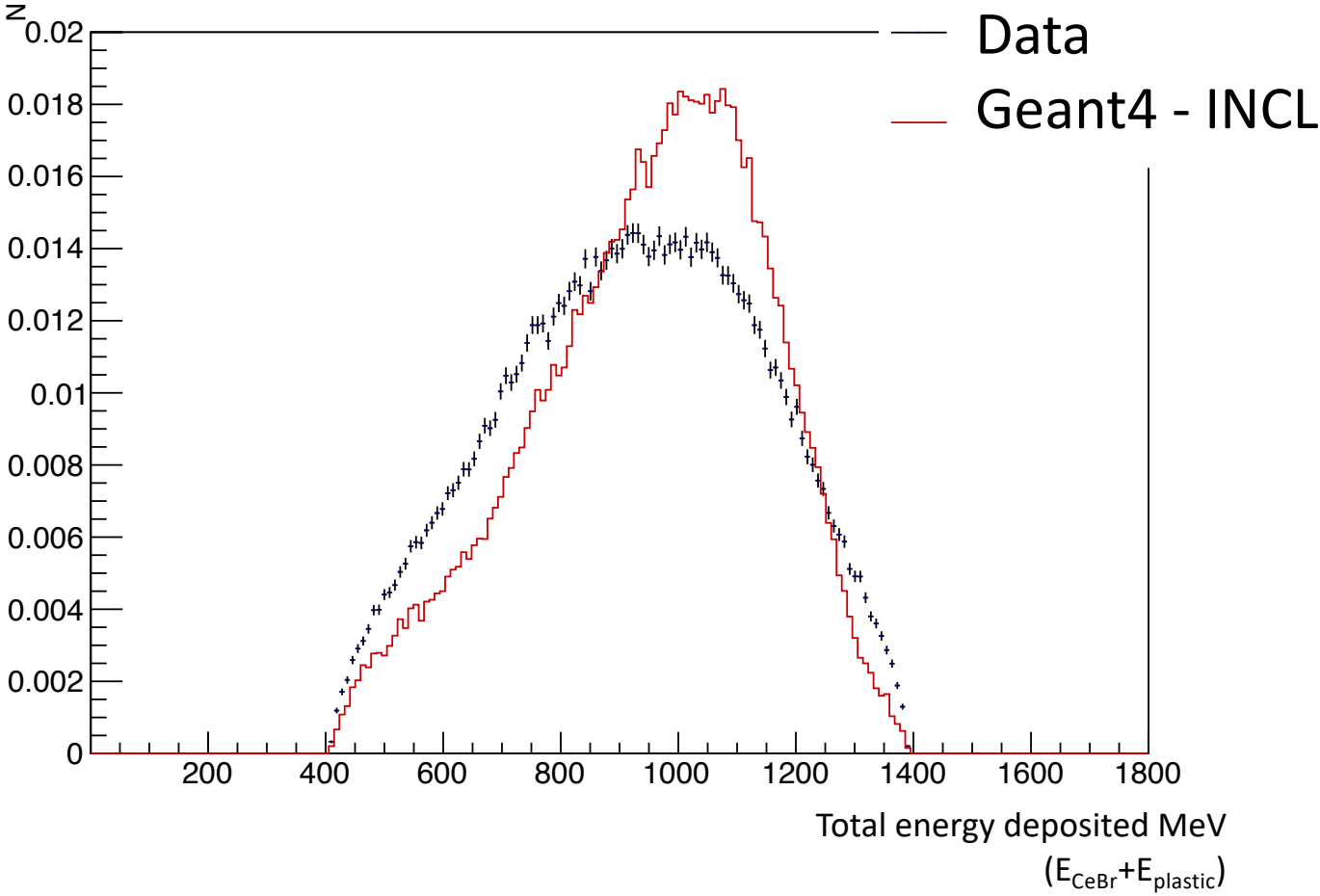
ΔE-E measurement CNAO

Comparison between G4 simulation and experimental data
5cm target and 200MeV/u beam, at 5°

Preliminary



Population 4

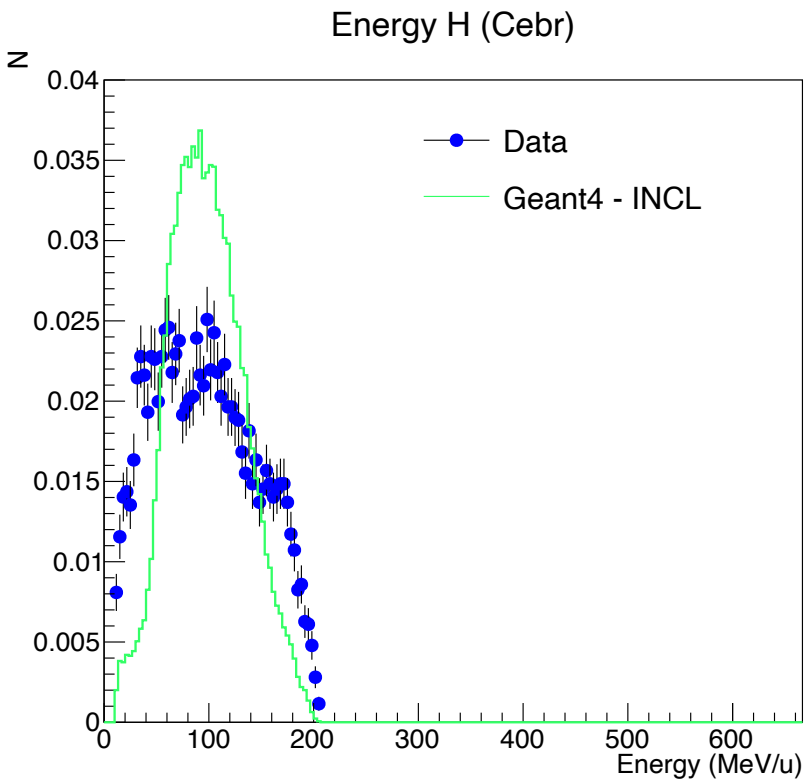


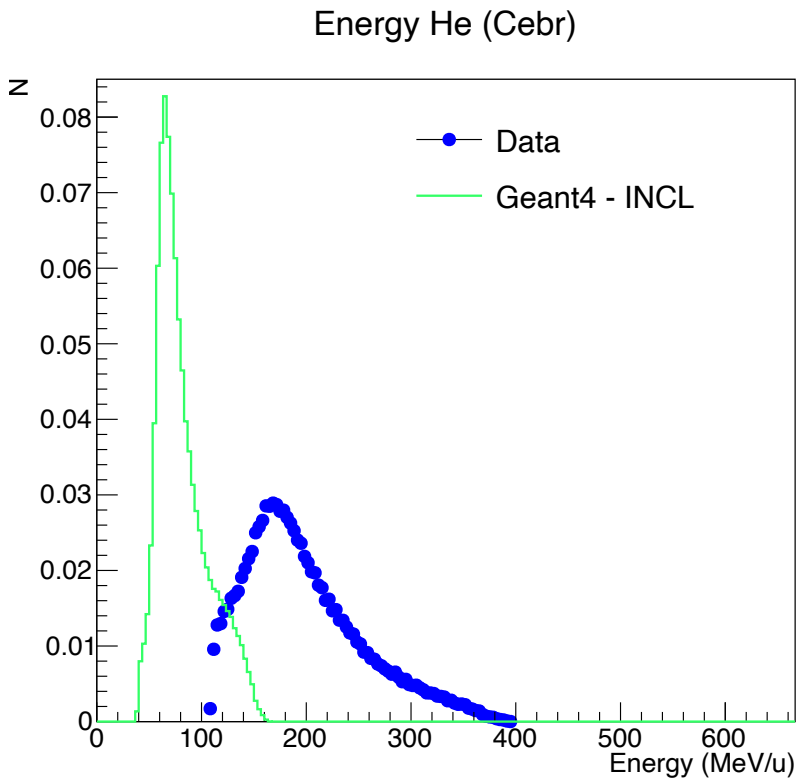
Secondary particles measurement

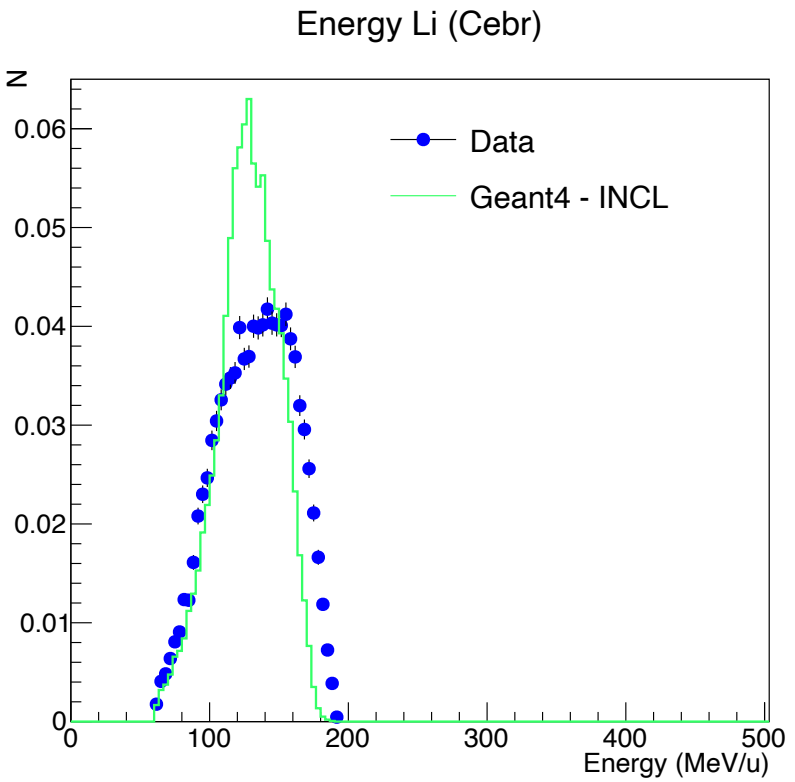
ΔE-E measurement CNAO

Comparison between G4 simulation and experimental data
23cm target and 400MeV/u beam, at 0°

Preliminary







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ΔE-E measurement CNAO

Comparison between G4 simulation and experimental data
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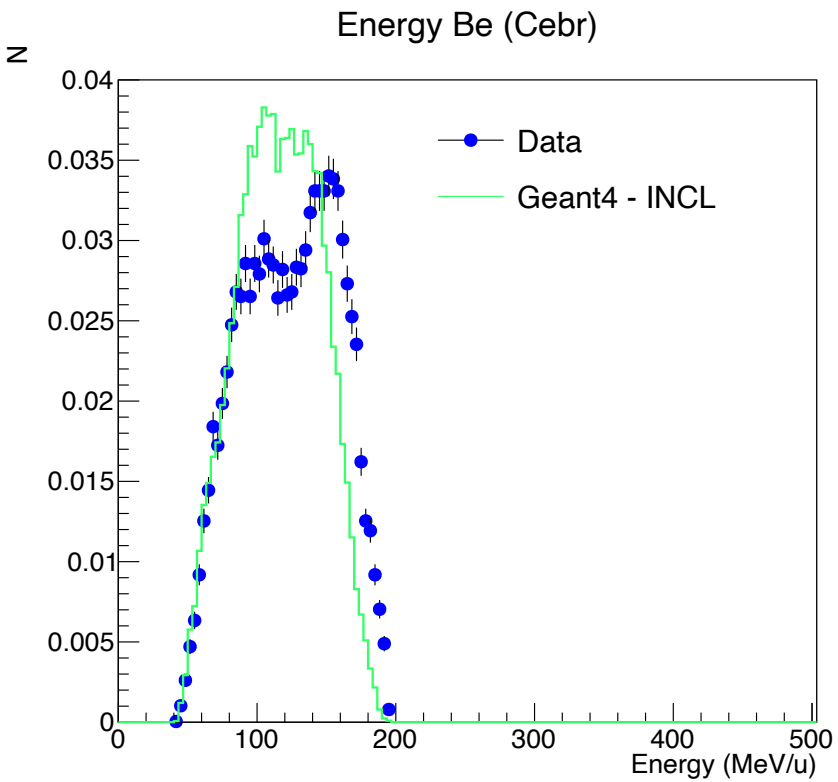

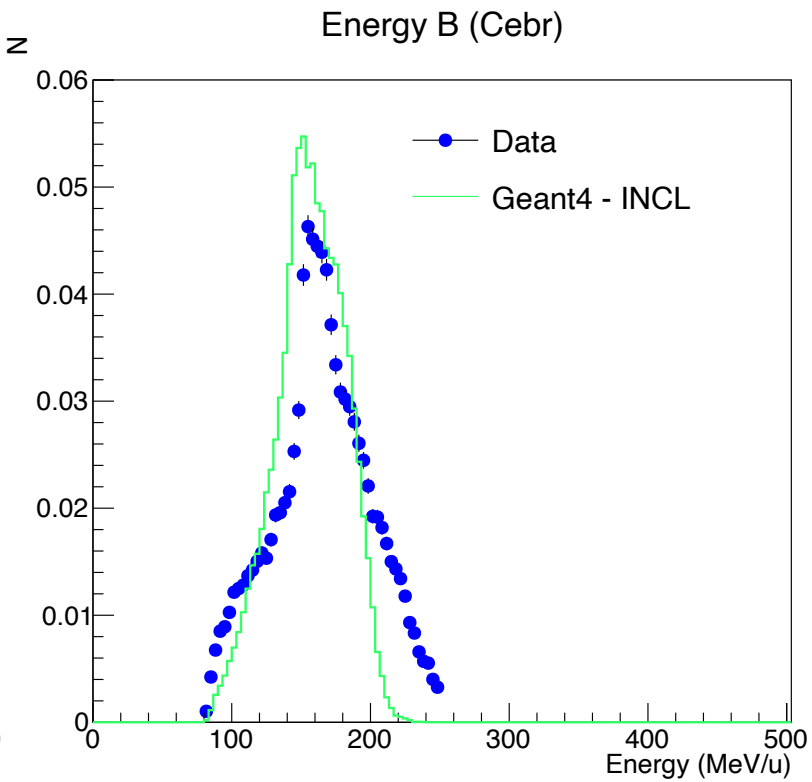

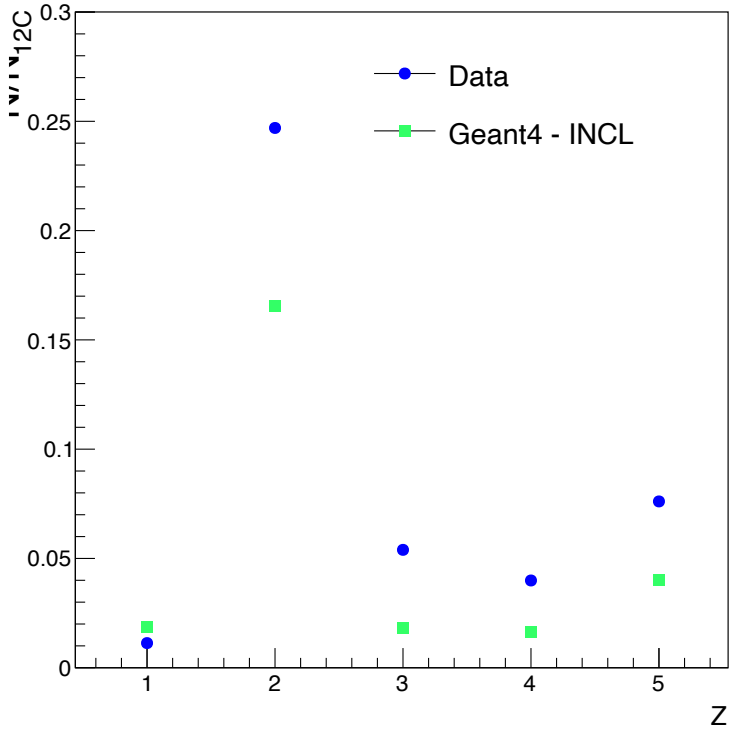

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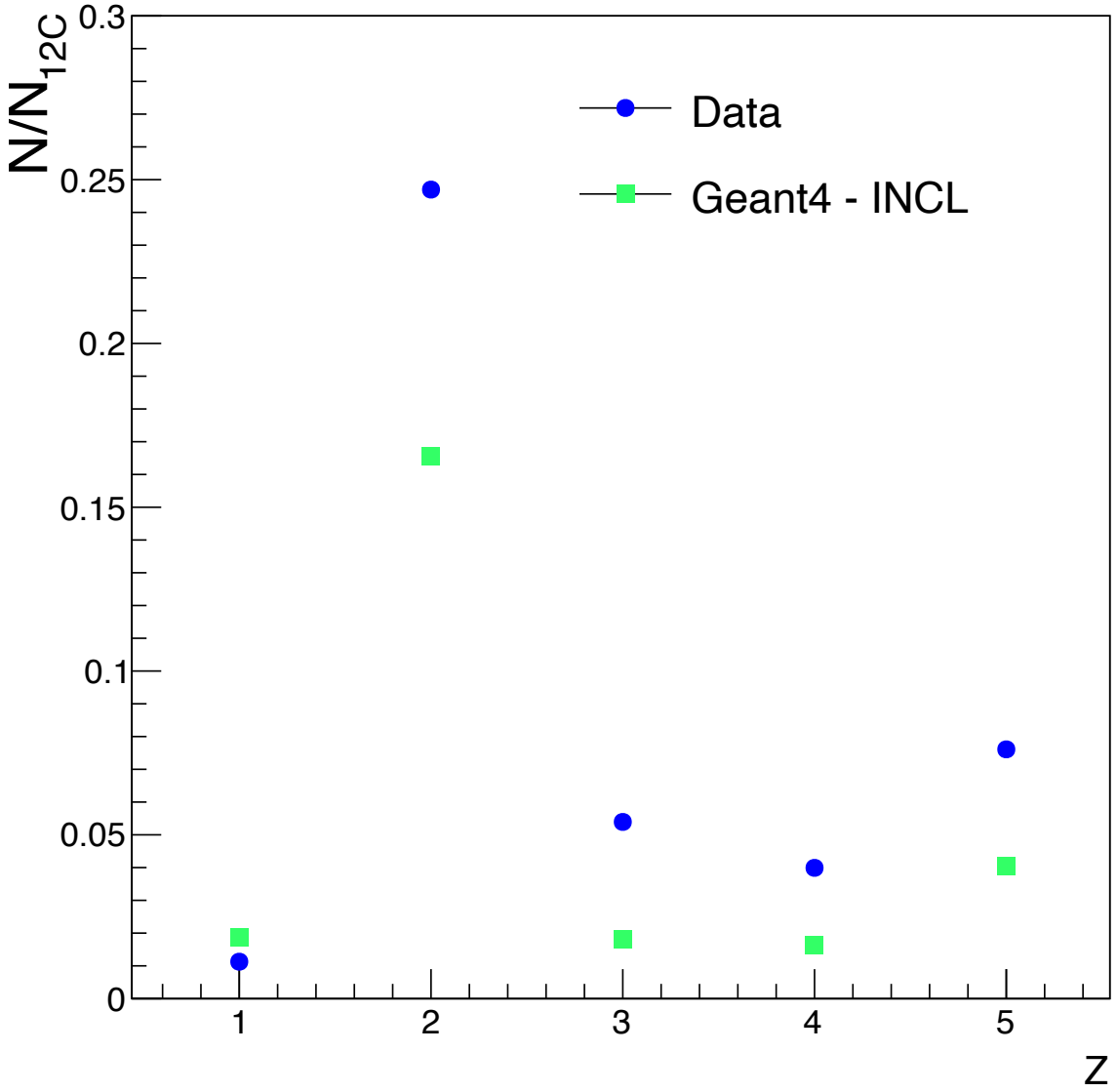


Underestimation of all secondary particles except Z=1 by Geant4

Comparison between G4 simulation and experimental data
23cm target and 400MeV/u beam, at 0°

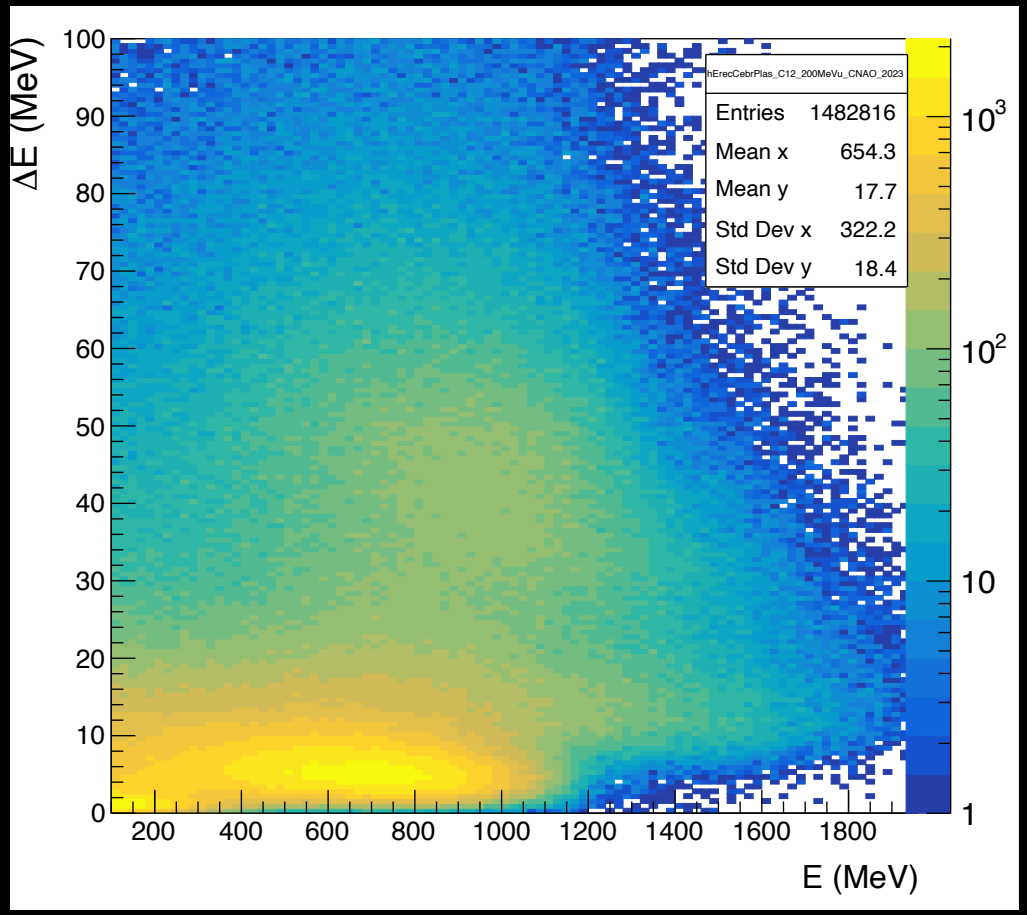
Conclusion

CLINM project

- Secondary charged particle identification
- Calibration of the ΔE-E telescope detectors with protons and carbons
- First ΔE-E measurements at CNAO
- Z identifications and comparison with G4 simulations

Perspectives

- Implementation of data in simulation
- Comparison with radiolysis results
- Next beam time in spring 2024



Merci pour votre attention

Remerciements

HITRI plus
Heavy Ion Therapy Research Integration

cnrs

CNAO
The National Center for Oncological Hadrontherapy

IPHC
Institut Pluridisciplinaire Hubert CURIEN
STRASBOURG

CAL Nice
Centre Antoine-Lacassagne
Centre Régional de Lutte contre le Cancer

CYRCÉ

FAIR
GSI

References

[1] Nymus 3D animations – part of the Demcon group
[2] Oliver Jäkel, Physical advantages of particles: protons and light ions, Published Online:26 Sep 2019 - https://doi.org/10.1259/bjr.20190428
[3] https://news.emory.edu/features/2018/11/proton-therapy-center/index.html
[4] Cucinotta and Durante, Lancet Oncol. 2006
[5] Jakob et al., Proc. Natl. Acad. Sci. USA 2009; Nucl. Acids Res. 2011
[6] https://bmccancer.biomedcentral.com/articles/10.1186/1471-2407-11-242
[7] Dudouet, J. & Cussol, Daniel & Durand, D. & Labalme, M.. (2013). Benchmarking GEANT4 nuclear models for carbon-therapy at 95 MeV/A. Physical Review C. 89. 10.1103/PhysRevC.89.054616.
[8] M. E. Wolf. Robust optimization in 4D treatment planning for carbon ion therapy of lung tumors. PhD thesis, Technische Universita¨t, Darmstadt, November 2018. URL http://tuprints.ulb.tu-darmstadt.de/8354/
[9] University of Iowa health care - https://www.youtube.com/watch?v=nZ044EicYO4
[10] International Agency for Research on Cancer – World Health Organization
[11] D. Schardt, T. Elsasser, and D. Schulz-Ertner. Heavy-ion tumor therapy; Physical and radiobological benefits. Rev, Mod. Phys., 82(1):383, 2010.
[12] Seco, Joao, Daniel Robertson, Alexei Trofimov, et Harald Paganetti. « Breathing Interplay Effects during Proton Beam Scanning: Simulation and Statistical Analysis ». Physics in Medicine and Biology 54, no 14 (21 juillet 2009): N283-94.
[13] Reidel, C.-A., C. Schuy, Ch. Finck, F. Horst, D. Boscolo, J. Baudot, E. Spiriti, et al. « Response of the Mimosa-28 Pixel Sensor to a Wide Range of Ion Species and Energies ». Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 1017 (novembre 2021): 165807.
[14] Sarikaya, Ismet. « Biology of Cancer and PET Imaging: Pictorial Review ». Journal of Nuclear Medicine Technology 50, no 2 (juin 2022): 81-89.
[15] Sarrut D, Bardiès M, Boussion N, et al. A review of the use and potential of the GATE Monte Carlo simulation code for radiation therapy and dosimetry applications. Med Phys. 2014;41(6):064301.
[16] Mein S, Tessonnier T, Kopp B, Harrabi S, Abdollahi A, Debus J, Haberer T, Mairani A. Spot-Scanning Hadron Arc (SHArc) Therapy: A Study With Light and Heavy Ions. Adv Radiat Oncol. 2021 Feb 4;6(3):100661. doi: 10.1016/j.adro.2021.100661. PMID: 33817410; PMCID: PMC8010580.
[17] Haettner, Emma & Iwase, Hiroshi & Krämer, M & Kraft, G & Schardt, Dieter. (2013). Experimental study of nuclear fragmentation of 200 and 400 MeV/u C-12 ions in water for applications in particle therapy. Physics in medicine and biology. 58. 8265-8279. 10.1088/0031-9155/58/23/8265.