Towards isotopic cross sections: mass reconstruction and first cross section results for GSI26PS_MC at 700 MeV/n

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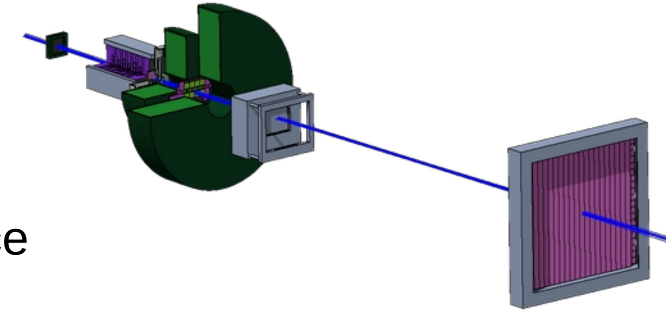
FOOT analysis meeting

Context

20 million simulated events for GSI26PS_MC campaign

- 700 MeV/n ^{16}O beam on a 5 mm graphite target
- Full detector setup without CALO
- Beam energy of interest for Radiation Protection in Space



The final goal is the implementation of **isotopes separation** and computation of **isotopic single differential and double differential cross sections** for the most abundant isotopes

Mass reconstruction technique

No CALO → Mass reconstruction only accessible through momenta and speed (from TOF)

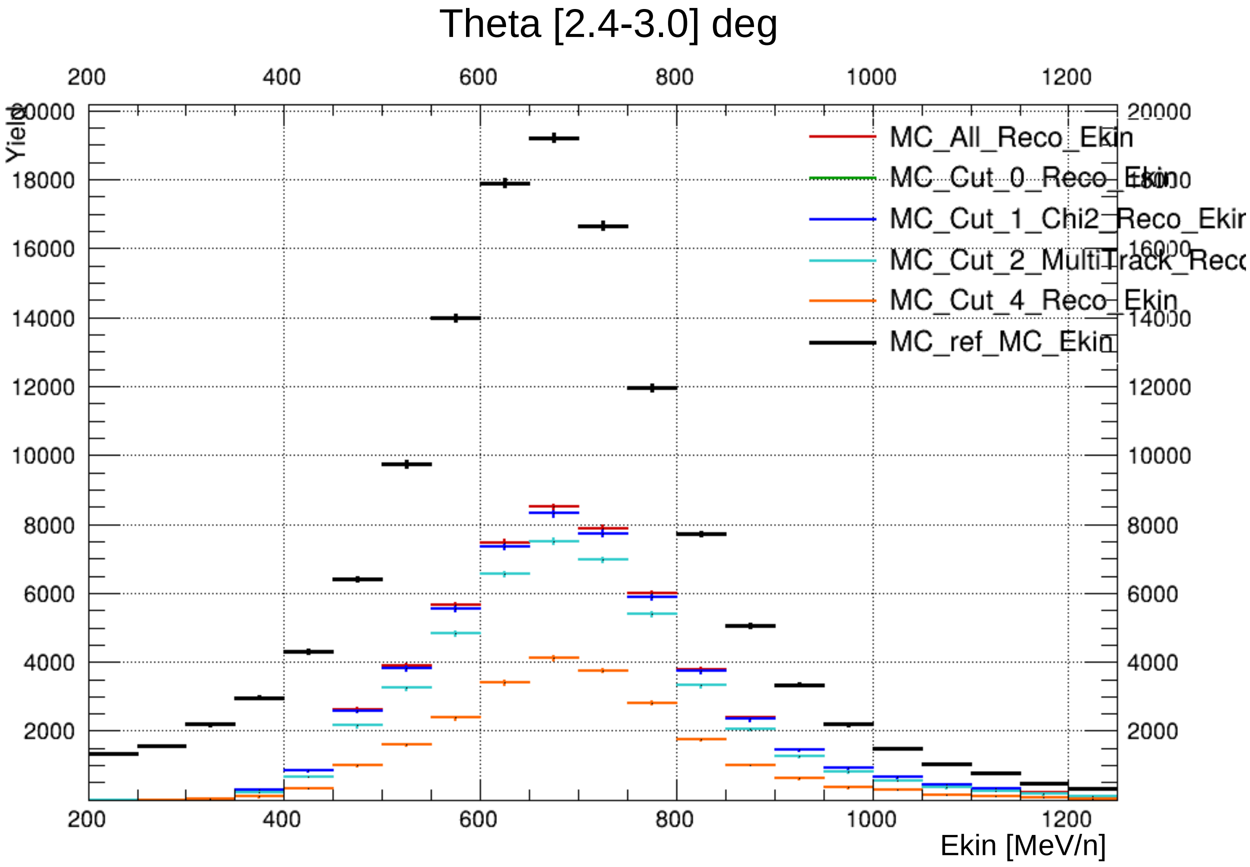
$$\boxed{m = \frac{p}{\gamma v} = \frac{p}{c}\sqrt{\frac{1}{\beta^2} - 1}} \qquad \beta = \frac{L}{c \cdot TOF}$$

Global tracks are selected according to four selection cuts already implemented in past works:

Cut 1	Cut 2	Cut 3	Cut 4
• 1 BM track • At least 9 clusters • Has TW point	• P-value>0.01 • Worst cluster residue < 0.01cm	At least 2 tracks in the event (rejection of non-interacting primaries and non-detectable processes)	• Tracks selected with different TW points • # of tracks = # TW points

The impact of every selection cut can be checked by plotting the yield

50 MeV/n Ekin bins and 0.6 deg angular bins have been used



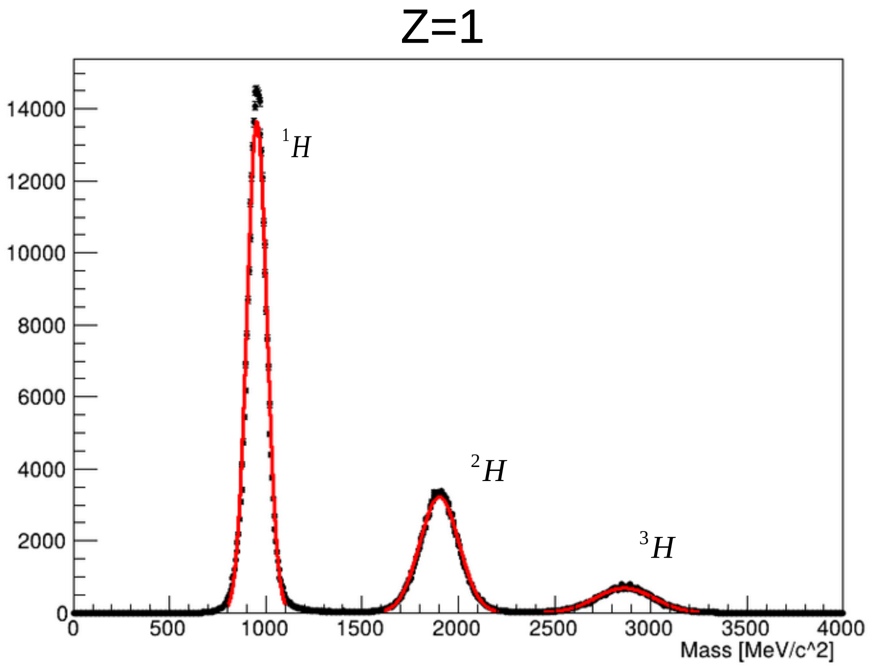
To produce mass distributions for each element, fragments are selected according to their **reconstructed** Z

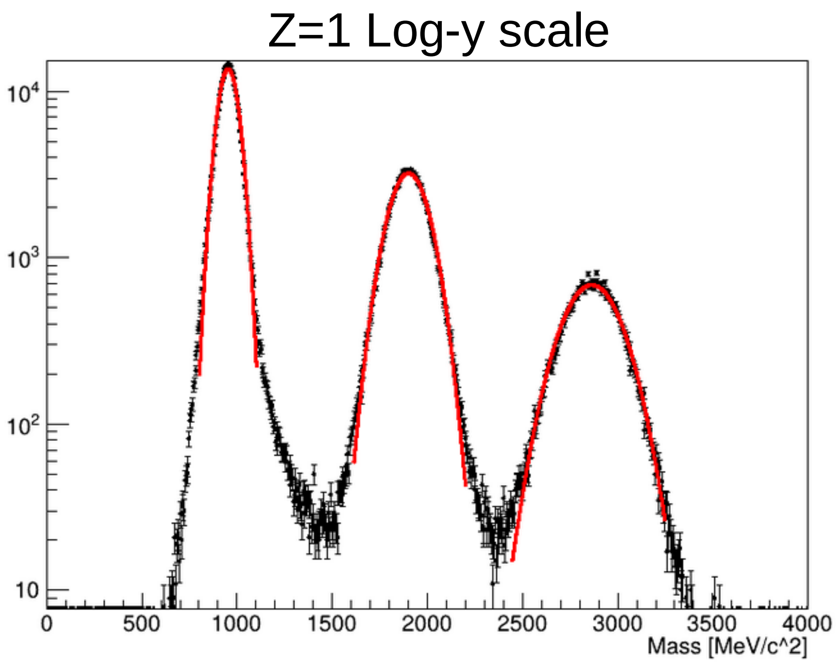
Masses have been fitted using *TSpectrum* and *RooFit* classes with 2 different techniques:

- **Light fragments (Z=1,2):** fitted using **independent Gaussians** for each isotope because peaks are well separated → No contamination
- **Heavier fragments (Z>2):** fitted using a unique PDF defined as a **sum of N Gaussians** (one for each peak) weighted by their yields. Yields are a parameter of the fit.

$$f(m) = \frac{1}{Y}\sum_{i=1}^{N} Y_i G(m; \mu_i, \sigma_i) \qquad Y = \sum_{i=1}^{N} Y_i$$

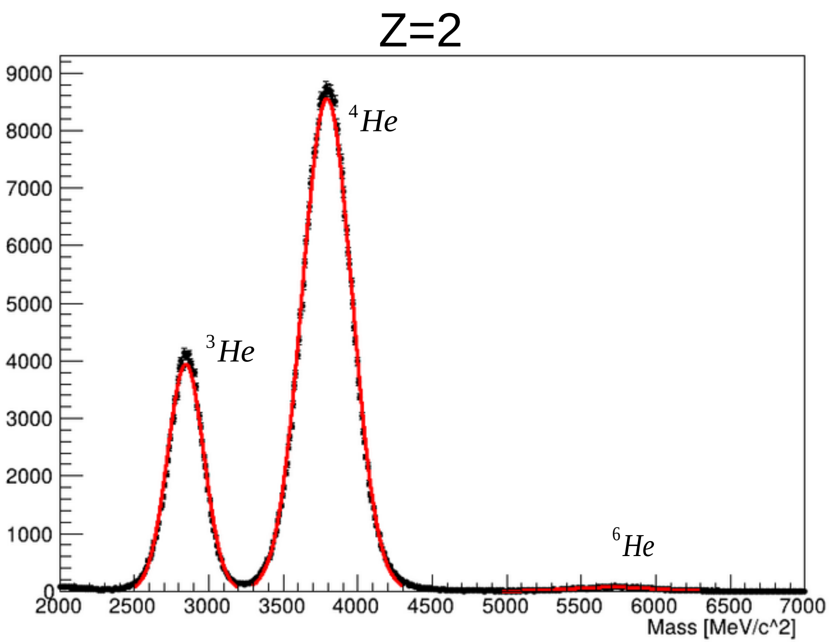
Fit results for Z=1

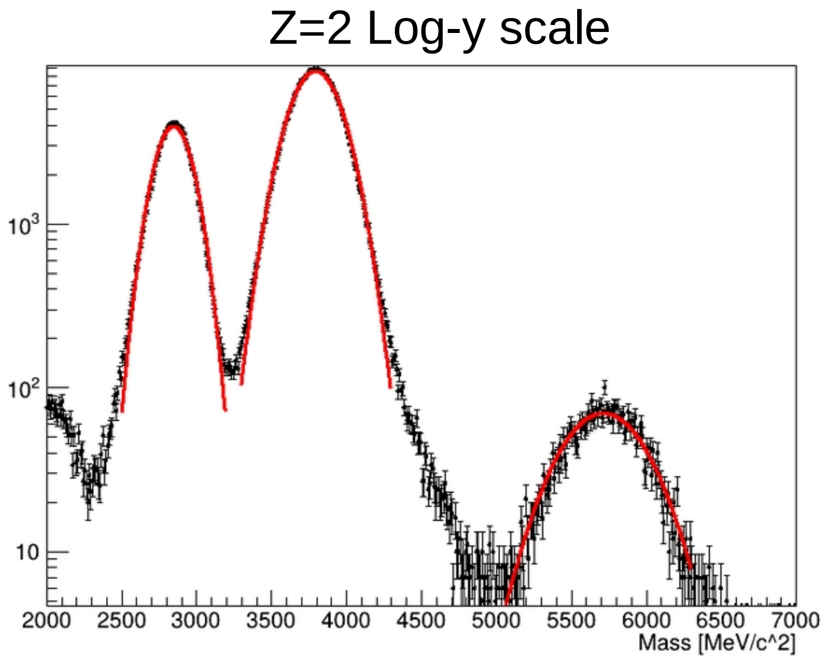




Isotope	Fitted mass [MeV/c^2]	Real mass [MeV/c^2]
1-H	953.5 ± 51.8	938.3
2-H	1901.7 ± 101.5	1875.6
3-H	2863.7 ± 150.8	2808.9

Fit results for Z=2

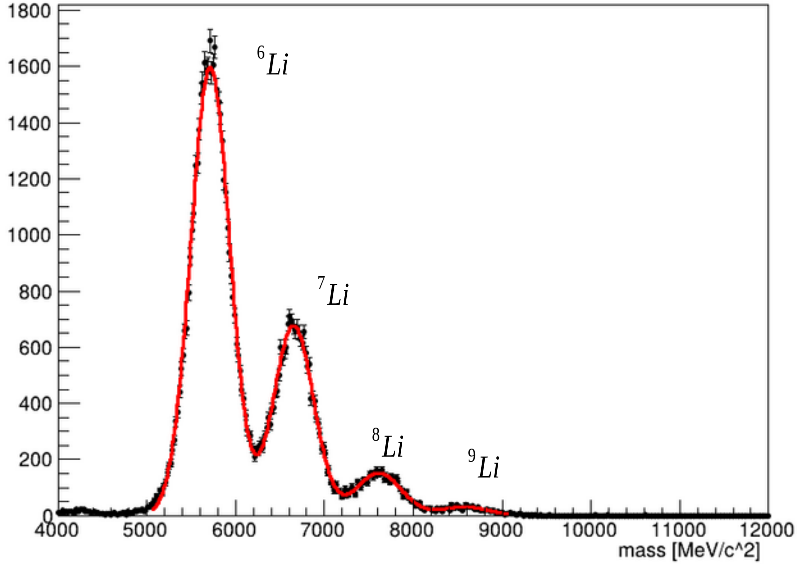




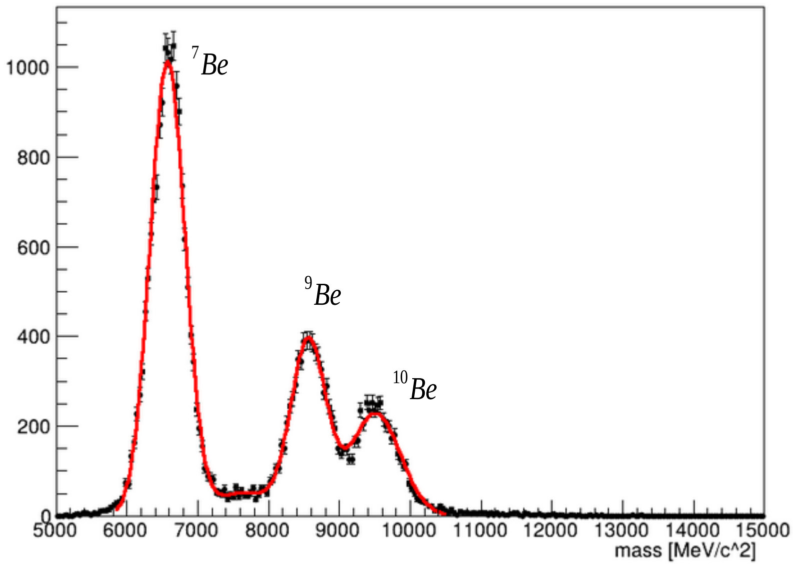
Isotope	Fitted mass [MeV/c^2]	Real mass [MeV/c^2]
3-He	2845.2 ± 121.5	2808.4
4-He	3793.4 ± 167.2	3727.4
6-He	5712.8 ± 279.9	5605.5

Fit results for heavier fragments

Z=3

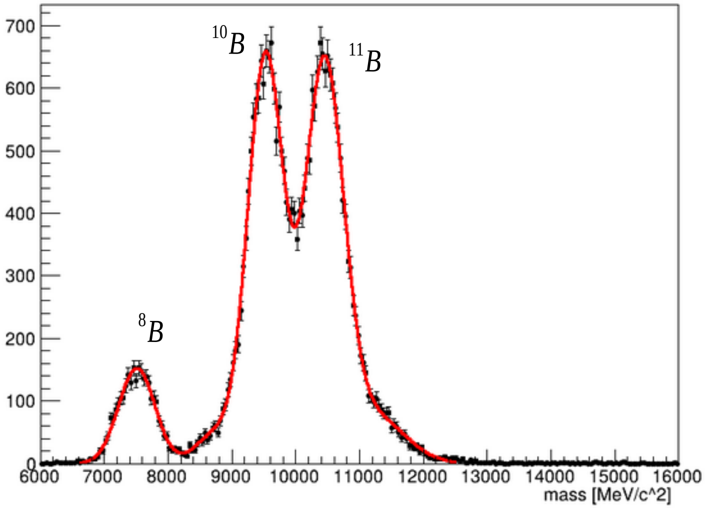


Z=4



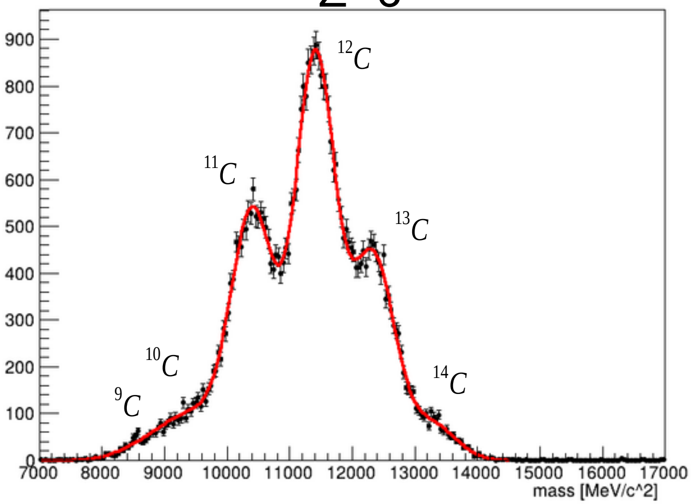
Isotope	Fitted Mass [MeV/c^2]	Real Mass [MeV/c^2]
6-Li	5714.4 ± 219.6	5601.5
7-Be	6574.1 ± 246.7	6534.2

Z=5



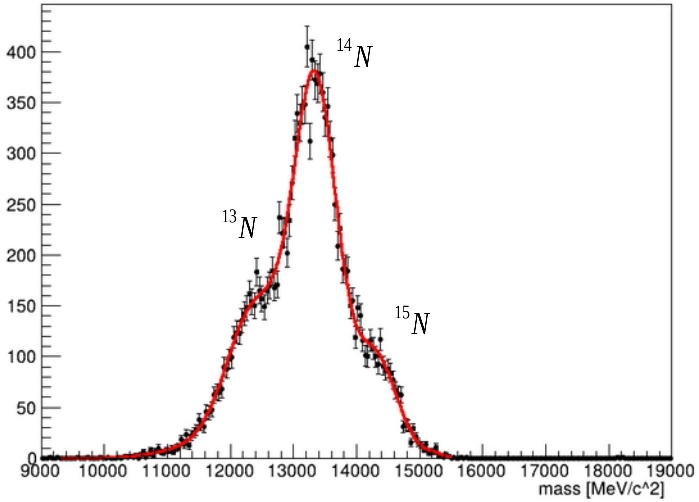
^{10}B
^{11}B
^{8}B
mass [MeV/c^2]

Z=6



^{12}C
^{11}C
^{13}C
^{10}C
^{9}C
^{14}C
mass [MeV/c^2]

Z=7



^{14}N
^{13}N
^{15}N
mass [MeV/c^2]

Considerations

- General effect of **mass overestimation**, different for each isotope
  e.g: Protons: 15 MeV shift
  6-Li: 113 MeV shift
  7-Be: 40 MeV shift

→ In fact, this is a direct consequence of **momenta overestimation** from GENFIT
→ No CALO means no redundancy in mass reconstruction

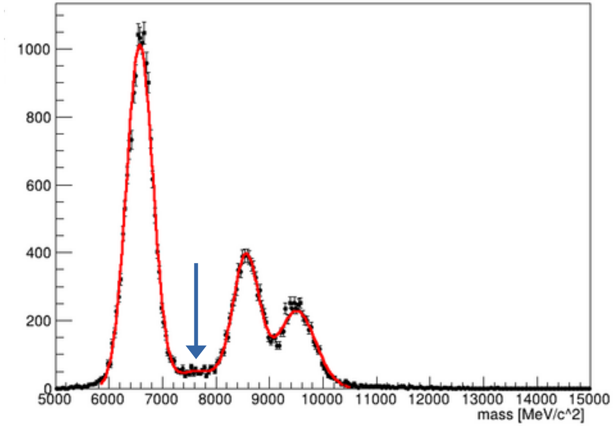
- For Z>2 isotopes, **peaks tend to overlap** due to scarce detector resolution. Overlapping Gaussians are handled automatically by *RooFit*, which returns **corrected yields** for each isotope

- Heavier fragments cannot be properly resolved. For my thesis isotopic cross sections will be calculated for the most abundant isotopes of H, He, Li and Be.

- In particular, double differential cross sections will be calculated for 1-H, 2-H, 3-He and 4-He, which are the most relevant for Space Radiation Protection

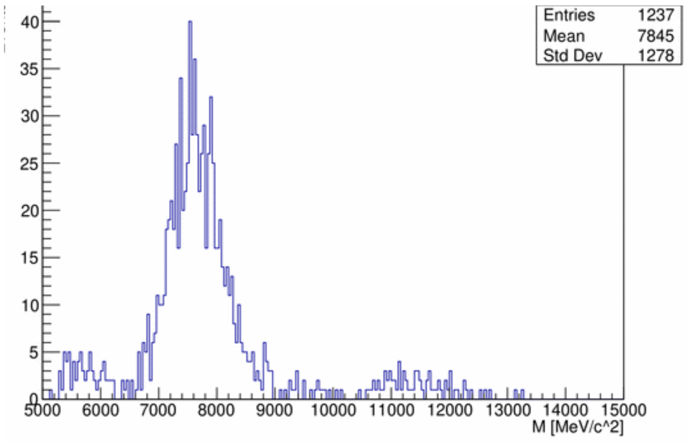
Z mis-id contamination

Z=4



Since the fragments are selected according to their **reconstructed Z**, there is a source of contamination due to TW mis-id of Z

Z_reco=4 Z_MC= 1,2,3,5



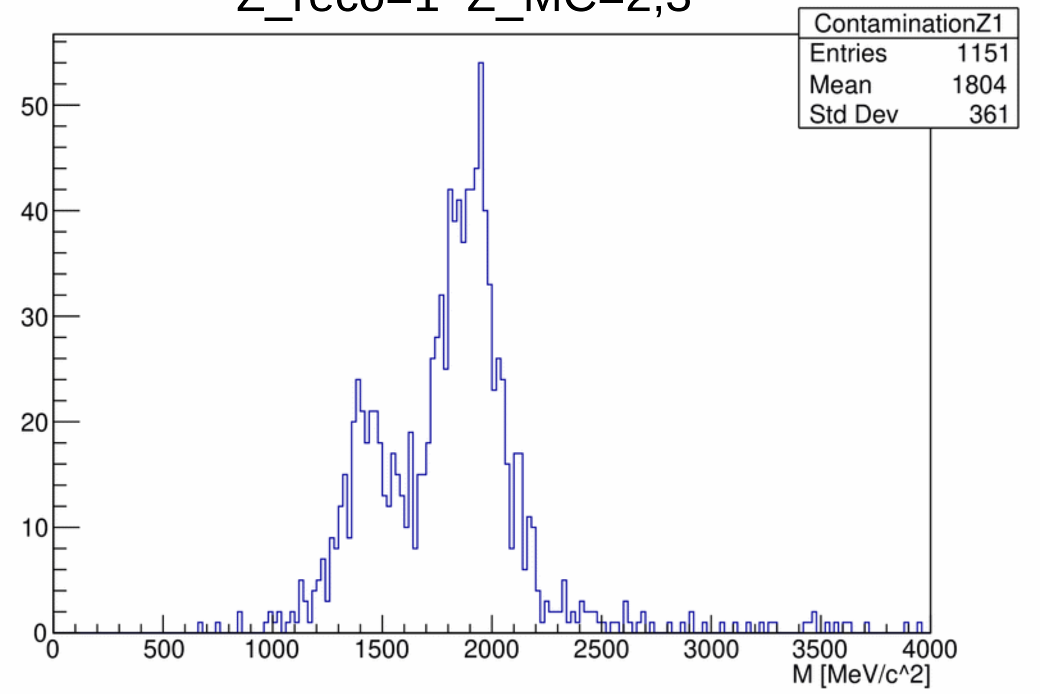
These contaminations can be quantified, for each Z_reco, by inspecting the **true charge Z_MC** of the MC particle associated to that track.

E.g: in the case of Z_reco=4 I select Z_MC=1,2,3,5 and fill the mass distribution.
The peak could be a contamination both from **8-Li** (M=7471.3 MeV/c^2) and **8-B** (7472.3 MeV/c^2)

→ **Treated as a Gaussian in the model**

In fact there is a **third source of contamination:**

Z_reco=1 Z_MC=2,3



In this case tracks with Z_reco=1 and Z_MC=2,3 have been selected

The distribution is peaked in a mass range not compatible with Z=2 isotopes masses...rather around the mass of Deuterium (1875.6 MeV/c^2)

→ Z_reco is identified in the TW and used as a seed for the momentum reconstruction by GENFIT.
If the initial guess for Z_reco is underestimated, than the momentum (**and the mass!**) will be underestimated.

$$p = q B r$$

q=charge
B=magnetic field
r=curvature radius

Cross section analysis

- Cross section analysis was performed by adapting the *GlobalAna* class (G. Ubaldi) for the computation of isotopic double differential cross sections in energy and angle

- For light fragments (1-H, 2-H, 3-He, 4-He) yields were calculated **within a 2σ interval** around each mass peak

- Heavier fragments cross section computation requires the fitted yields as direct input because of peak overlaps, which is still not manageable inside of GlobalAna. The analysis was performed just for 6-Li and 7-Be using an asymmetric mass interval and computing **single differential cross sections in Ekin** to balance the reduced statistics

- A manual subtraction in the reconstructed momenta was implemented to correct the systematic shift

$$\frac{d^2\sigma(A,Z,\theta,E)}{d\Omega\,dE} = \frac{Y(A,Z,\theta,E)}{N_{\mathrm{beam}}\,N_t\,\epsilon(A,Z,\theta,E)\,\Delta E\,\Delta\Omega(\theta)}$$

Efficiencies

Given a MC dataset:

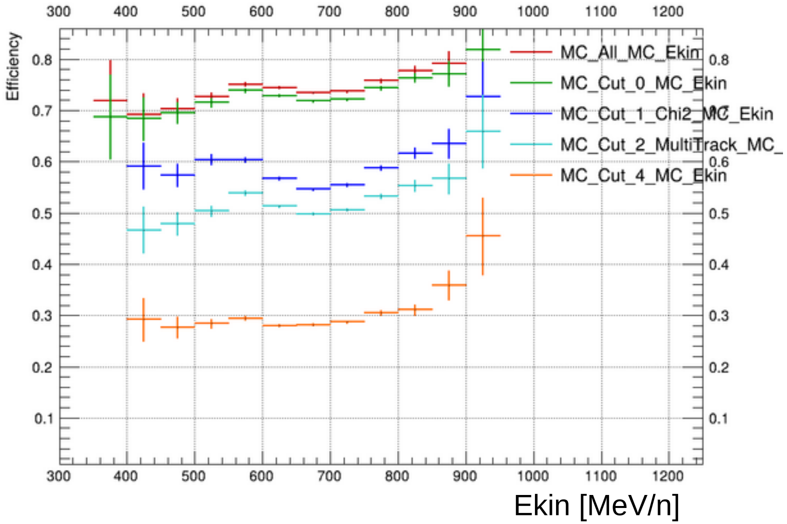
- **Reference (MC):** all the TAMCParticles from FLUKA MC (primary beams, fragments produced in the TG that reach the TW)

- **Reco:** all reconstructed global tracks by GENFIT (+ cuts)

Good Reco: tracks with MC particle Id that satisfies MC generation requests

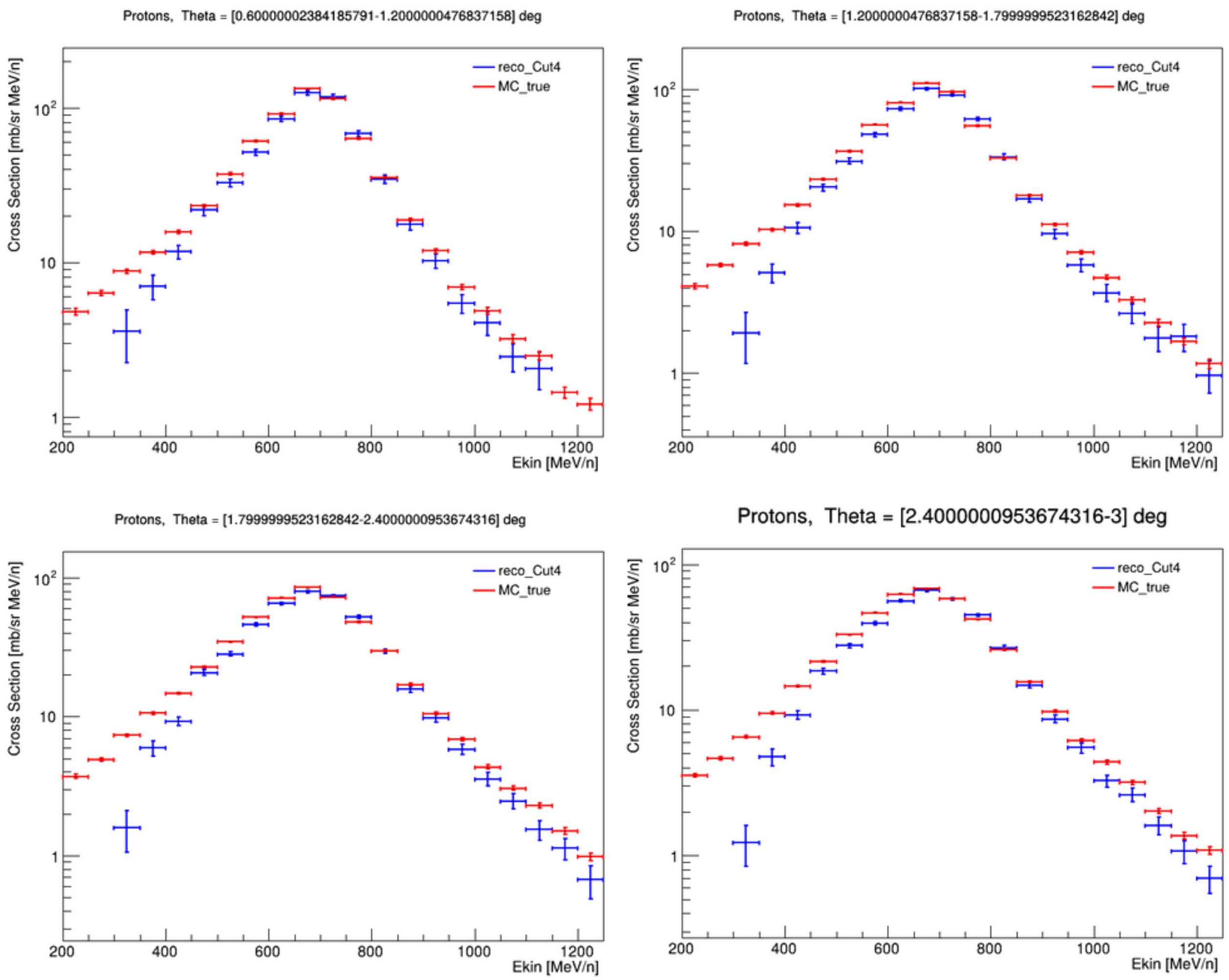
$$\boxed{\epsilon(Z, A, \theta, E) = \frac{Good\ Reco\ tracks}{Reference\ MC\ tracks}}$$

4-He [1.8-2.4] deg



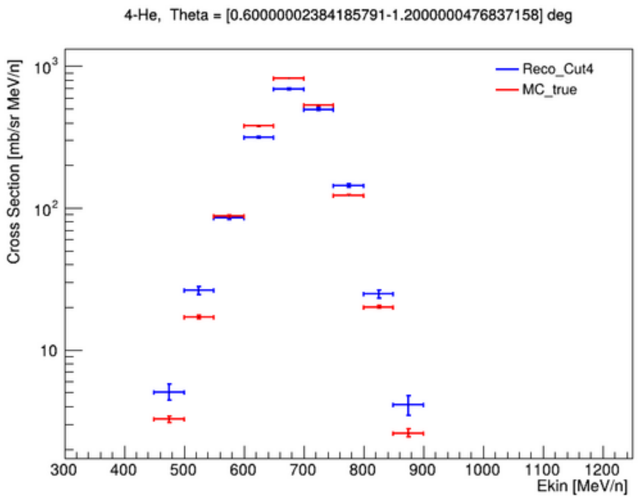
Method already implemented in *GlobalAna* by G. Ubaldi

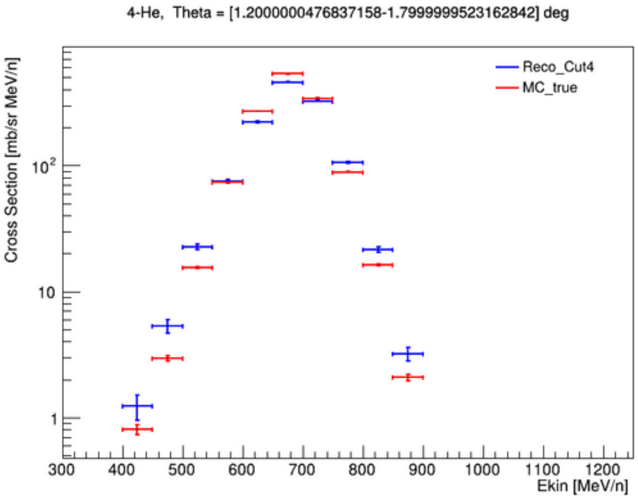
Double differential cross sections for protons

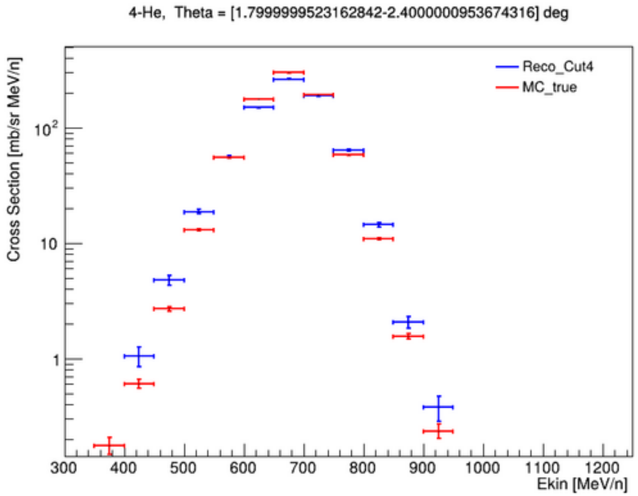


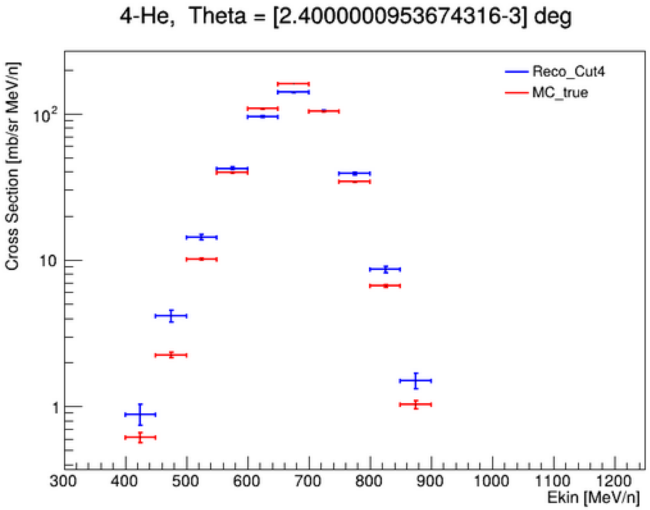
- 0.6 deg angular bins and 50 MeV/n Ekin bins
- Results are shown for 4 angular bins ranging from 0.6 to 3 deg
- Error bars calculated from statistical error of yields and error propagation from the efficiency (binomial)
- The compatibility with target production cross sections from FLUKA MC was verified

Double differential cross sections for 4-He









Results show a slight **overestimation of XS in the tails** for reconstructed data compared to MC, in contrast to protons where cross sections were slightly underestimated

Systematic error of the cross sections can be estimated comparing the total integral of the double differential cross sections:

Protons

$$\sigma_{tot}^{reco} = 1231.6\, mb$$

$$\sigma_{tot}^{MC} = 1187.6\, mb$$

4-He

$$\sigma_{tot}^{reco} = 778.05\, mb$$

$$\sigma_{tot}^{MC} = 754.05\, mb$$

$$Sys\, error = \frac{\sigma_{tot}^{reco} - \sigma_{tot}^{MC}}{\sigma_{tot}^{MC}}$$

Sys error=3.7%

Sys error=3.3%

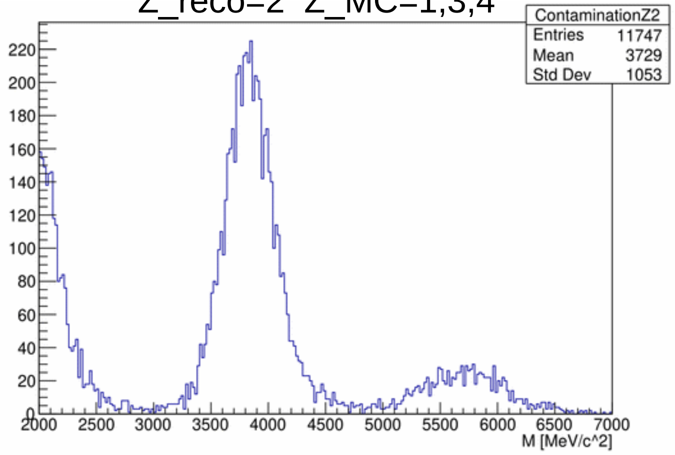
- One possible cause of 4-He cross section overestimation might be Z mis-Id contaminations, which are quite relevant in the case of 4-He

- Another possible cause could be fragmentation of nuclei between TG and TW

- Z mis-id in the TW is currently limiting the performance. A better Z-id capability may be achieved using also the MSD

- Future work, after my thesis, will concern the determination of cross sections using the yields obtained from the fit to reconstructed masses

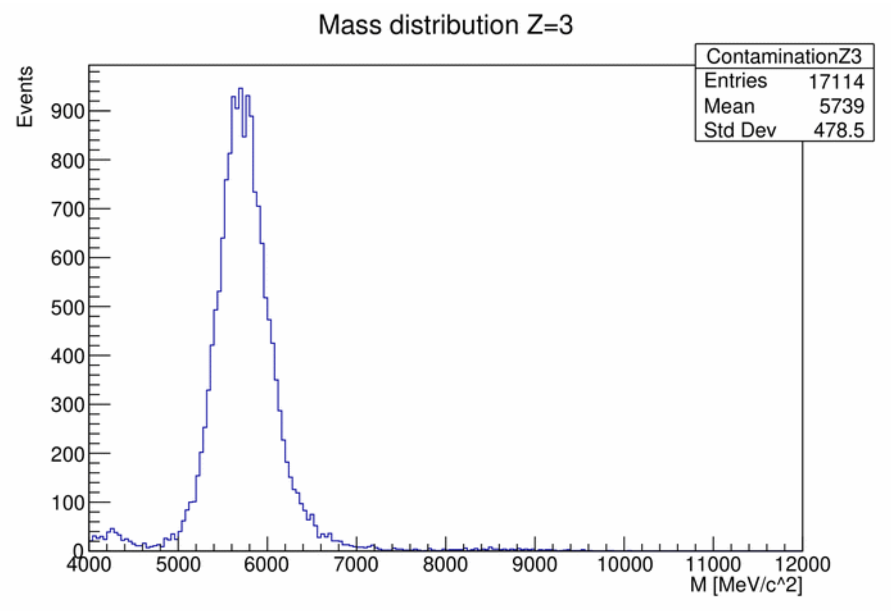
Z_reco=2 Z_MC=1,3,4

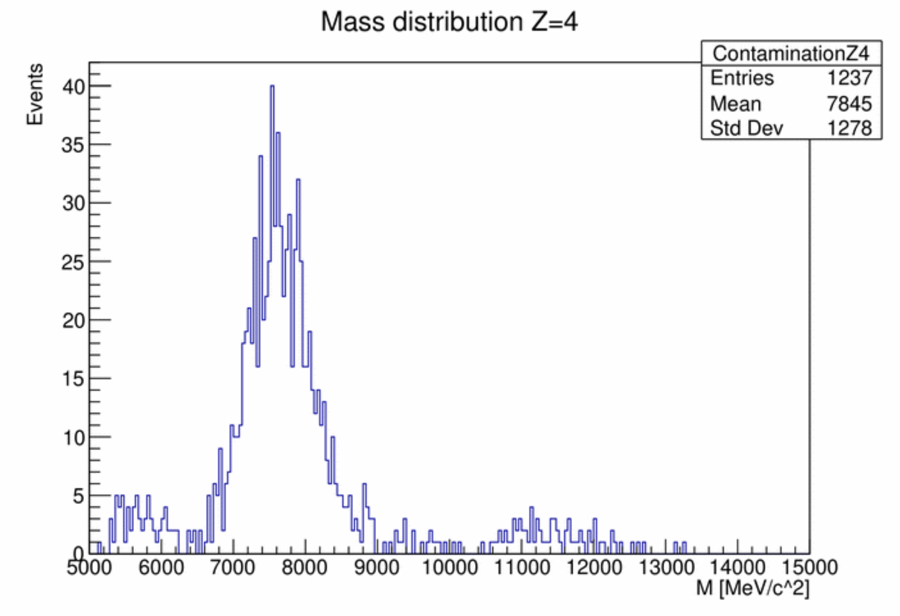


Thank you for the attention!

Backup slides

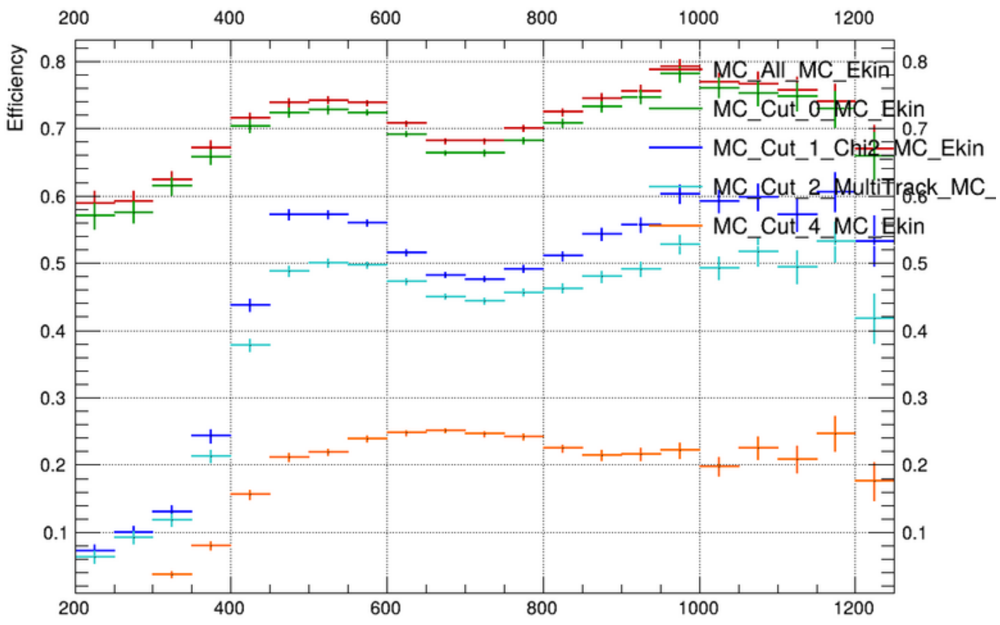
Contaminations to other fragments





Efficiencies for protons and 4-He in [1.8-2.4]deg bin

Protons



4-He