Small systematics in cross section measurements

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Introduction

- While checking the MC numbers for the proposed paper on GSI2019 results, we started to consider in some detail some possible systematics

- The relevant systematic uncertainties are those connected to the determination of efficiency/acceptance, the background subtraction, etc., as already discussed in the talks presented by the analysis team (M. Toppi et al.)

- We realized other few (trivial) things that might be useful to share. These are very small effects of which, in any case, we must be aware, since the FOOT claim is the capability of performing measurements at a few % precision.

FOOT CDR → “The final goal of the experiment would be to measure the heavy fragment (Z>2) cross section with maximum uncertainty of 5%”

“Measuring the Impact of Nuclear Interaction in Particle Therapy and in Radio Protection in Space: the FOOT Experiment” Front. Phys. 2020 8:568242. →

The final goal of the FOOT experiment is to measure differential cross sections with respect to the kinetic energy ($d\sigma/dE_{kin}$) for the target fragmentation process with an accuracy better than 10% and double differential cross sections ($d^2\sigma/d\Omega \cdot dE_{kin}$) for the projectile fragmentation process with an accuracy better than 5% on the determination of the fragment yields in angle and in kinetic energy.

Target Thickness

In June 2021
(https://agenda.infn.it/event/25079/contributions/127084/attachments/82194/107977/FOOT_PhysicsMeeting_GSI2021-2.pdf)
we presented the study about:

1. Energy loss of primary and secondaries

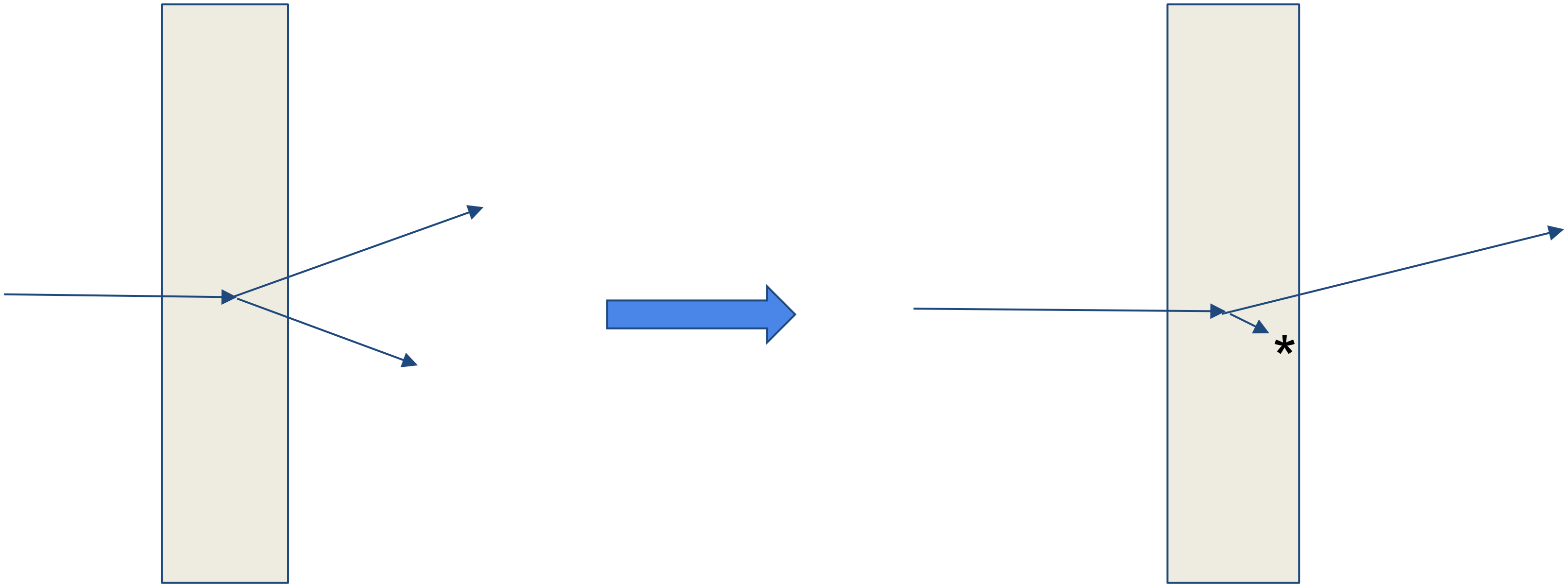
1. Uncertainty in position and time of flight

1. Probability of re-interactions of produced fragments in other parts of the detector

We did not consider the probability of re-interactions of produced fragments in the target itself.

Is this a relevant number?

Re-interactions of secondaries



Even for the higher energy fragments directed within the acceptance cone, there is a non null probability to interact before exiting the target

Here we take as test case the simulation of GSI 2019 data:
^{16}O @ 400 MeV/u on the 5 mm thick C target

Example:
MC results for the first batch of 2.5 10^6 simulated primaries - 1

Selections:

- E_{cut} = 200 MeV/u, Theta_Max = 5.7°
- **Particle exiting from the target**

N_prim = 2.5e+06

N(Z1) = 71259.00	sigma(Z1) = 621.29 +/- 2.33 mb
N(Z2) = 79323.00	sigma(Z2) = 691.60 +/- 2.46 mb
N(Z3) = 8421.00	sigma(Z3) = 73.42 +/- 0.80 mb
N(Z4) = 4234.00	sigma(Z4) = 36.92 +/- 0.57 mb
N(Z5) = 4702.00	sigma(Z5) = 41.00 +/- 0.60 mb
N(Z6) = 9805.00	sigma(Z6) = 85.49 +/- 0.86 mb
N(Z7) = 12371.00	sigma(Z7) = 107.86 +/- 0.97 mb
N(Z8*) = 7627.00	sigma(Z8) = 66.50 +/- 0.76 mb

Z8*: A<16

Target C:

A=12.0107

δx = 0.5 cm

ρ = 1.83 g/cm^3

N_{Av} = 6.022140857 10^{-4} (to express results in mb)

$\sigma(Z) = N(Z)/ (N_{prim} * N_{tg} * \varepsilon(Z))$

$N_{tg} = N_{Av} * \delta x * \rho/A = 4.587792e-05$

$\varepsilon(Z) = 1$

Example:
MC results for the first batch of 2.5 10^6 simulated primaries - 2

Selections:

- E_{cut} = 200 MeV/u, Theta_Max = 5.7°)
- **Particle created in the target. No request to exit the target**

N_prim = 2.5e+06

N(Z1) = 71761.00	sigma(Z1) = 625.67 +/- 2.34 mb	
N(Z2) = 80178.00	sigma(Z2) = 699.06 +/- 2.47 mb	← + 8.4 mb
N(Z3) = 8548.00	sigma(Z3) = 74.53 +/- 0.81 mb	
N(Z4) = 4304.00	sigma(Z4) = 37.53 +/- 0.57 mb	
N(Z5) = 4792.00	sigma(Z5) = 41.78 +/- 0.60 mb	
N(Z6) = 9983.00	sigma(Z6) = 87.04 +/- 0.87 mb	← + 1.6 mb
N(Z7) = 12623.00	sigma(Z7) = 110.06 +/- 0.98 mb	← + 2.2 mb
N(Z8*) = 7773.00	sigma(Z8) = 67.77 +/- 0.77 mb	

⇒ With this target thickness, measured cross sections in this energy and angle range are systematically lower by ~1% - 2% with respect to the actual values

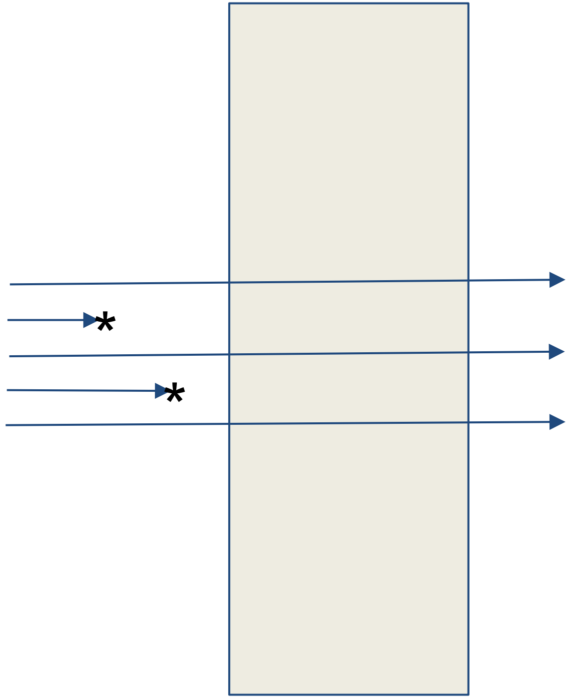
Other minor systematics

1. Pre-target interaction of primaries

2. Actual primary energy at interaction point

Number of primaries

Due to primary loss by interaction in the path from Start Counter to target, there is a small correction in the no. of primaries to be considered.



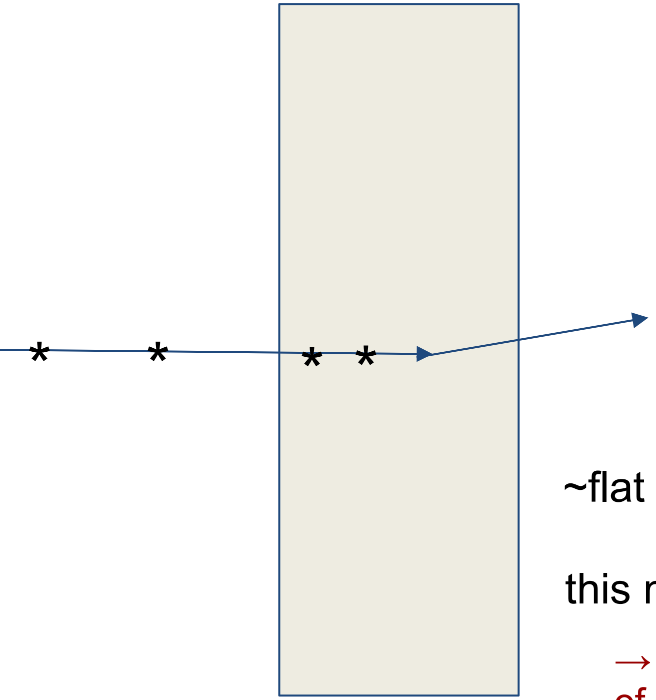
Counting as good primaries only those which actually arrive to target

(N_prim = 2.485e+06 instead of 2.5e+06):

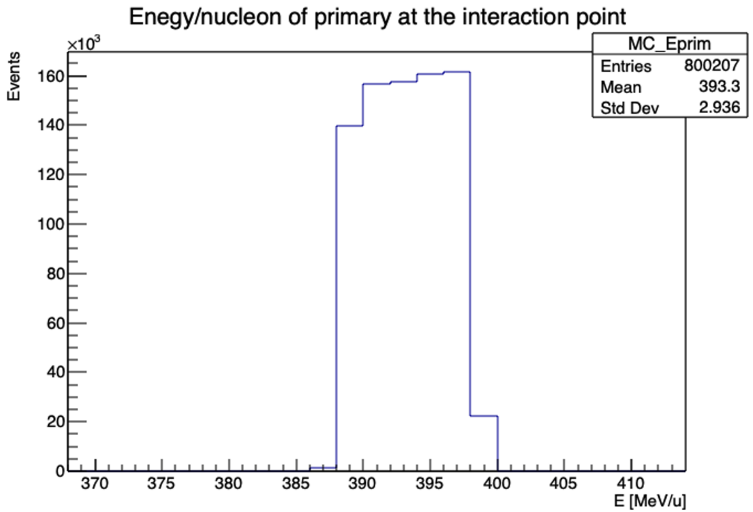
cross sections increase by +0.6%

Primary energy

Due to energy loss in pre-target materials and in the target itself, the primary energy is slightly different from the nominal one, with a fluctuation uncertainty



Actual primary energy at interaction point:



~flat distribution with <E> = 393 MeV/u and a FWHM of ~ 11 MeV/u

For instance, from the FLUKA model point of view, this makes a difference of -0.4% (for example -3 mb over 700 for Z=2)

→ Hopefully a good VTX backtracing can help in improving the determination of coordinate of the interaction point in the target

Conclusions

- From the point of view of possible biological effects, it is important to evaluate cross sections in production (for MC benchmarking: which can be directly compared to a calculation model), avoiding biases introduced by selection, geometry etc.

- Because of target thickness, in order to obtain cross sections at production stage (directly comparable to a model prediction) within 2% accuracy, we need to consider:
  1. loss due re-interactions in target
  2. number of primaries corrected for pre-target interactions
  3. actual primary energy (and energy loss of secondary fragments in the target)

- All the discussed effects have indeed a small impact. However the FOOT community has to be aware of all these physics details.

- Not 100% sure if the impact on Inverse Kinematics approach is really small (to be studied)

- The reduction of target thickness is probably not a viable solution because of the problems deriving from the need to collect a sufficient total statistics in presence of beam time and data acquisition rate limitations.