Measurements of ^{12}C ions fragmentation cross sections on thin Carbon target with the FIRST apparatus

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on behalf of the FIRST collaboration

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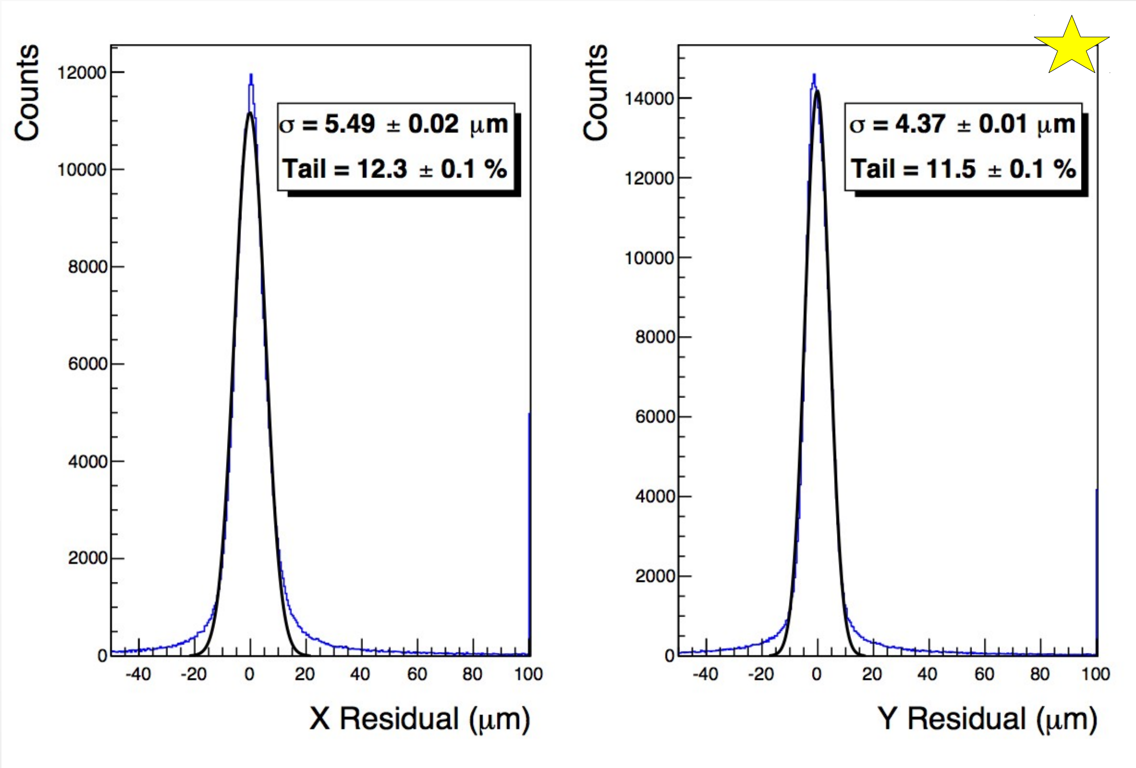
Aim of the presentation

- **Present the paper content and the results to be "blessed" before publication:**
  - The plots and the results we want to publish will be marked explicitly in the presentation with a star ☆
  - The material is taken from the draft currently under svn (to be considered as "draft 2")
- The idea is to have a wide collaboration review before the draft is submitted
- **It is crucial to have feedback on all the material presented:** quality of plots, document structure, key results presented, analysis strategy, etc etc
- After the presentation a list of final checks/issues to be dealt with will be made, in order to make the last steps before the final submission

- A warm thank you to Abdul, Alessio, Christian and Vincenzo for providing the material and feedback necessary to prepare this presentation
- Another big thanks goes to all the readers that helped improving draft 0 and draft 1 of the paper (Adalberto, Alessandro, Christian, Christoph, Eleuterio, Francesca, Marzio, Riccardo, Vincenzo)

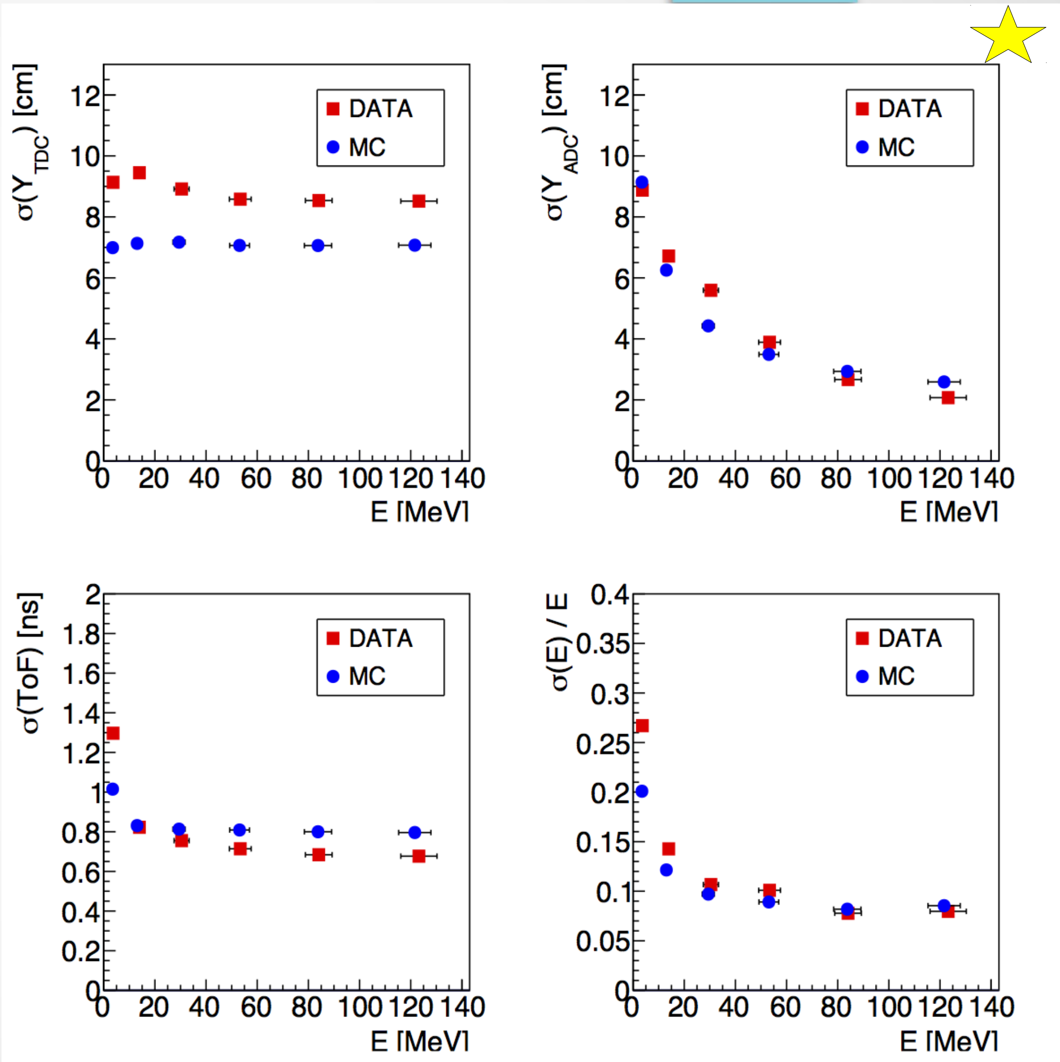
Vertex detector performances

- High fragments tracking efficiency and vertex reconstruction efficiency as documented in the published VTX paper
- Excellent tracking resolution < 10 µm (x,y) and < 50 µm (z): fundamental when extrapolating the fragment tracks along ~6 m to the ToF Wall
- **Tracking and vertexing algorithms have been changed to assign a systematic uncertainty**
- The VTX can provide also information on the fragment charge looking at the number of fired pixels per cluster (see global reconstruction)
- The VTX slow integration time (115 µs) causes some Pile-up that was taken into account: see MC simulation + systematics



Tof Wall detector performances - 1

- TW detector measures the ToF, the Eloss and the X and Y position of the tracks
- The resolutions have been estimated by comparing the values measured for hits in the two planes that are compatible with the same particle
- **ToF resolution: $\sigma_{ToF} \sim 800$ ps**
- **X & Y hit position resolution: $\sigma_X \sim 0.7$ cm, $\sigma_Y \sim 2 – 9$ cm**
- **Eloss resolution: $\sigma_E \sim 2 – 12$ MeV**
- **Nice Data/MC agreement is obtained !!**

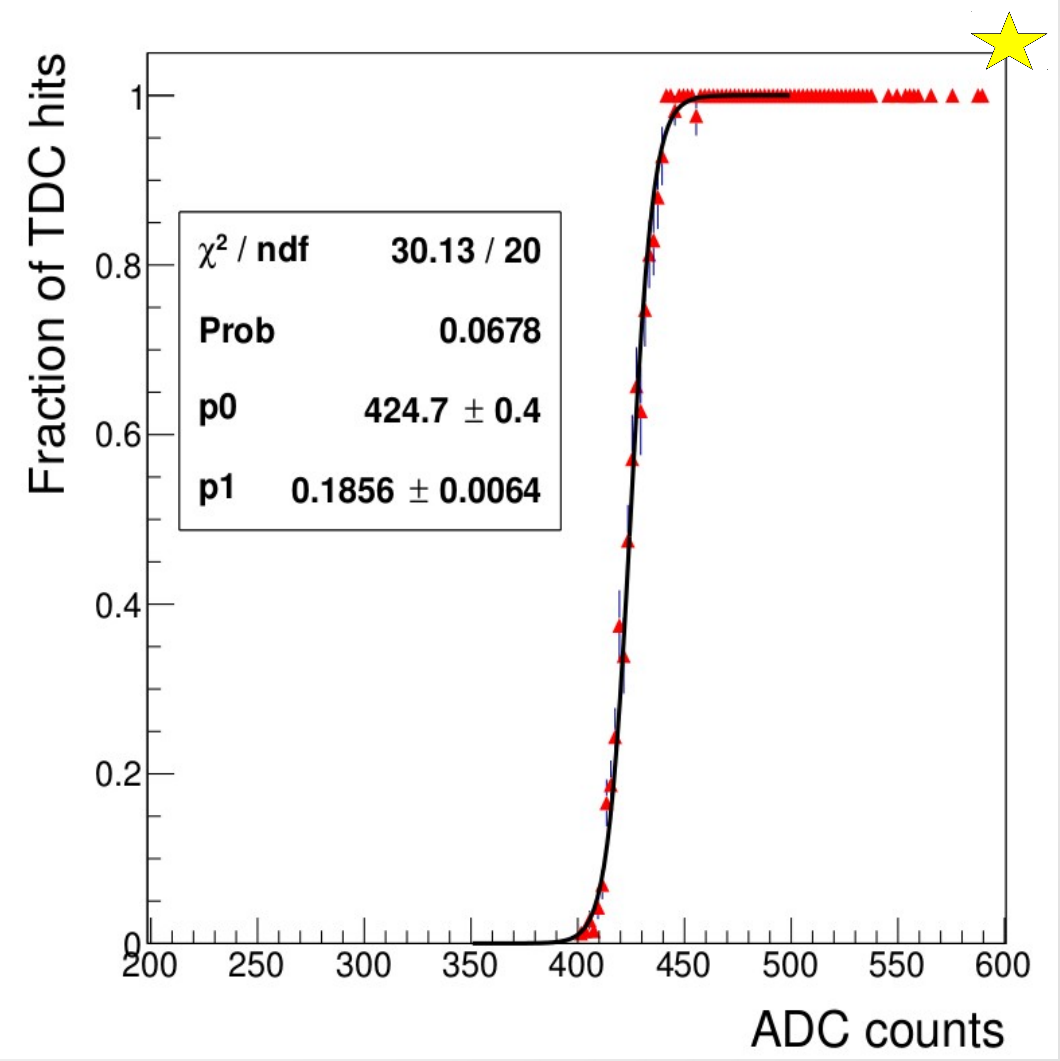


Tof Wall detector performances - 2

- TW efficiency has been computed from raw data using a threshold function defined as:

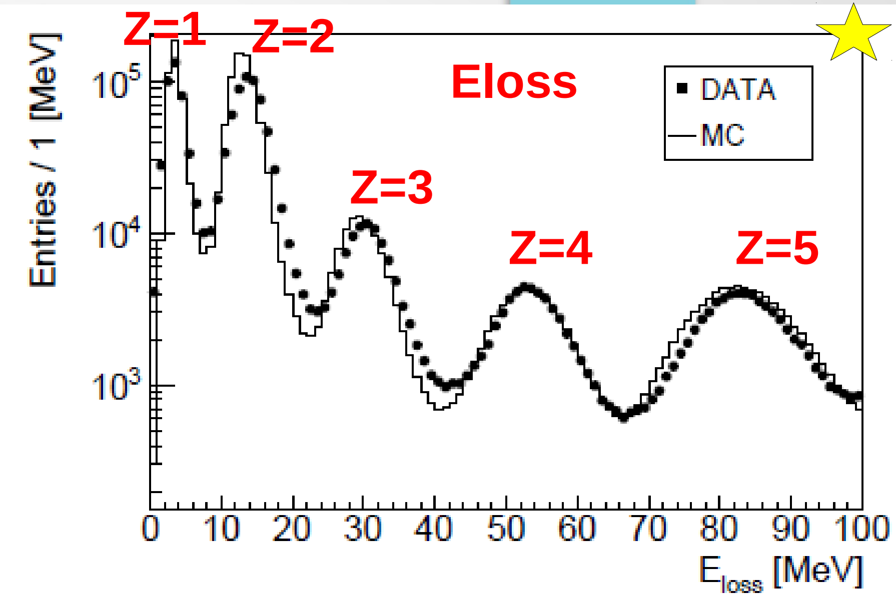
$$[1+\exp(-p_1*(x-p_0))]^{-1}$$

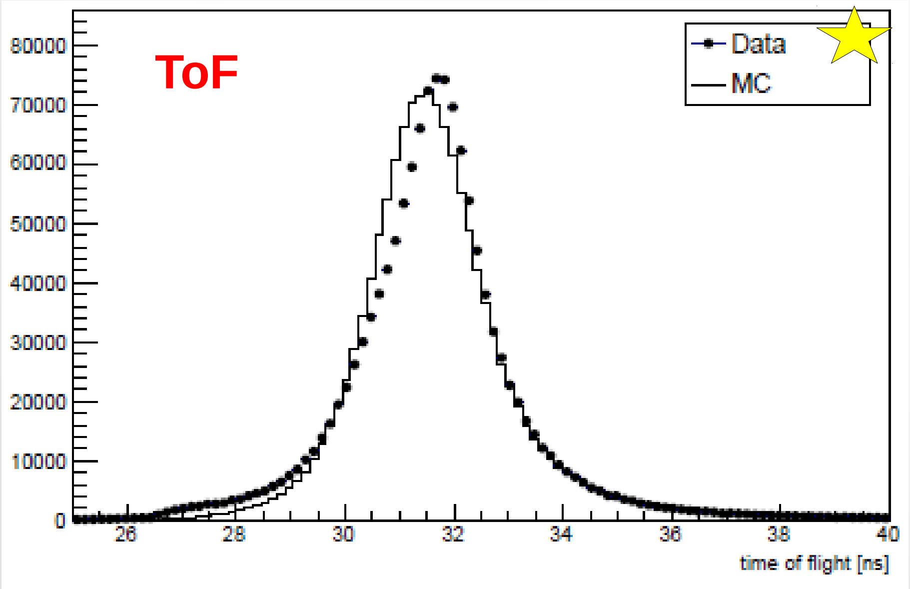
- The thresholds are computed for each slat
- **The systematics due to the limited knowledge on the threshold values, as well as the reliability of the MC in measuring the efficiency will be discussed later**
- The TW provides also the fragment charge ID (see global reconstruction)

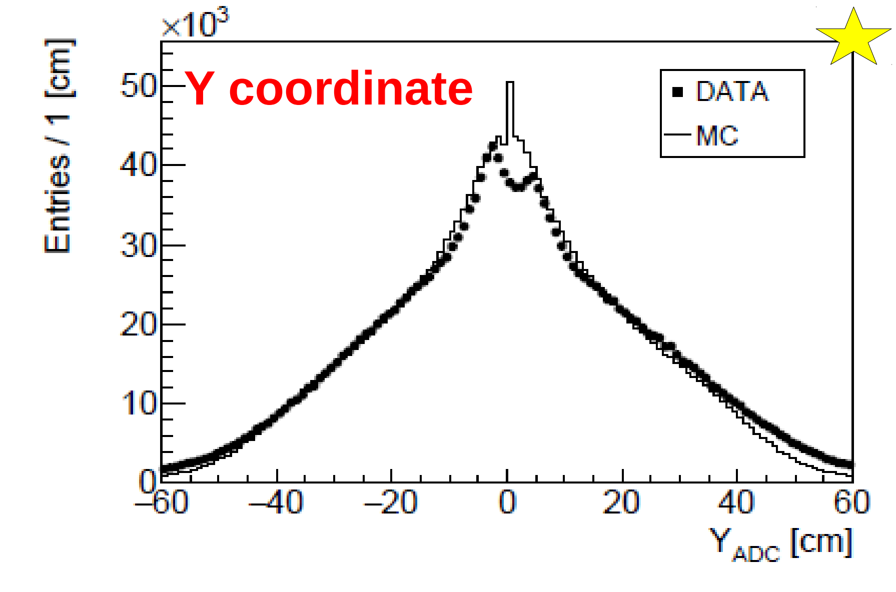


MC simulation

- **Needed for the evaluation of efficiencies, resolutions and background PDF modeling / cross feed subtraction**
- A MC sample of 105 M events has been used for this purpose
- The comparisons of Eloss, ToF and Y coordinate measured from the TW detector for DATA and MC events have been obtained for fragmented events (tracks associated to a reconstructed vertex > 1)

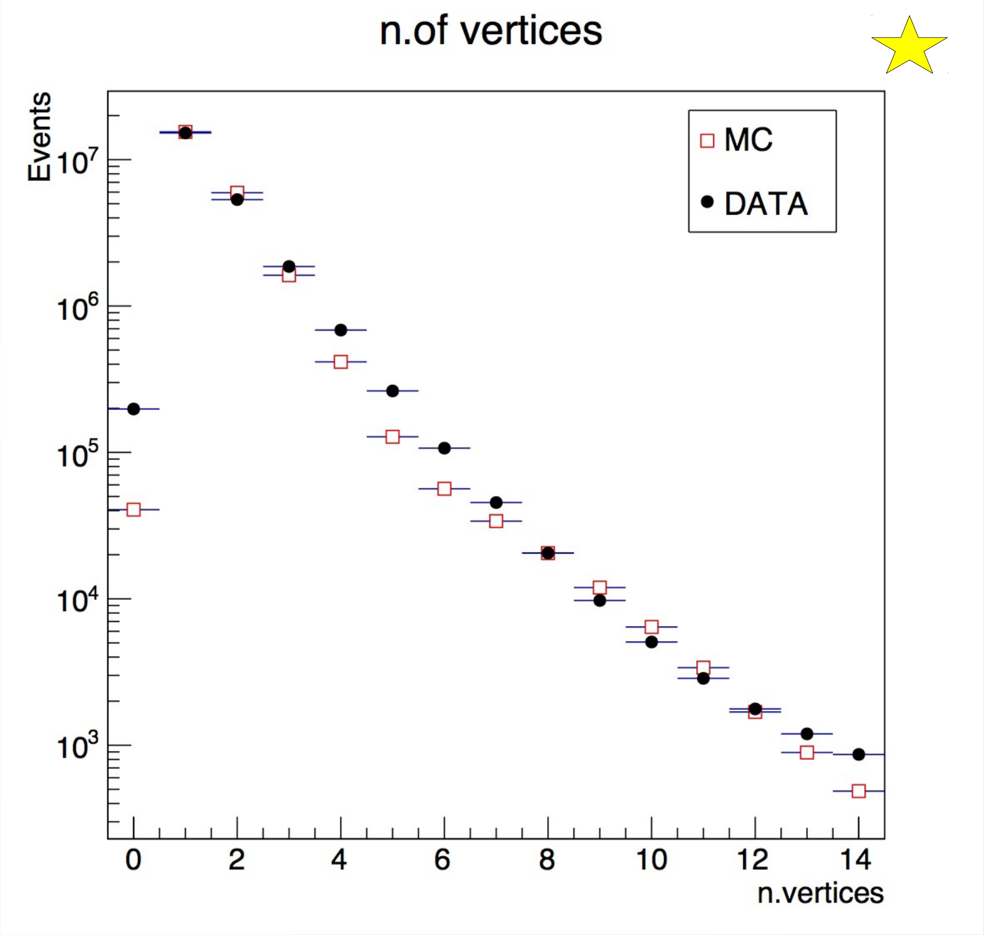






Pile-up in the VTX

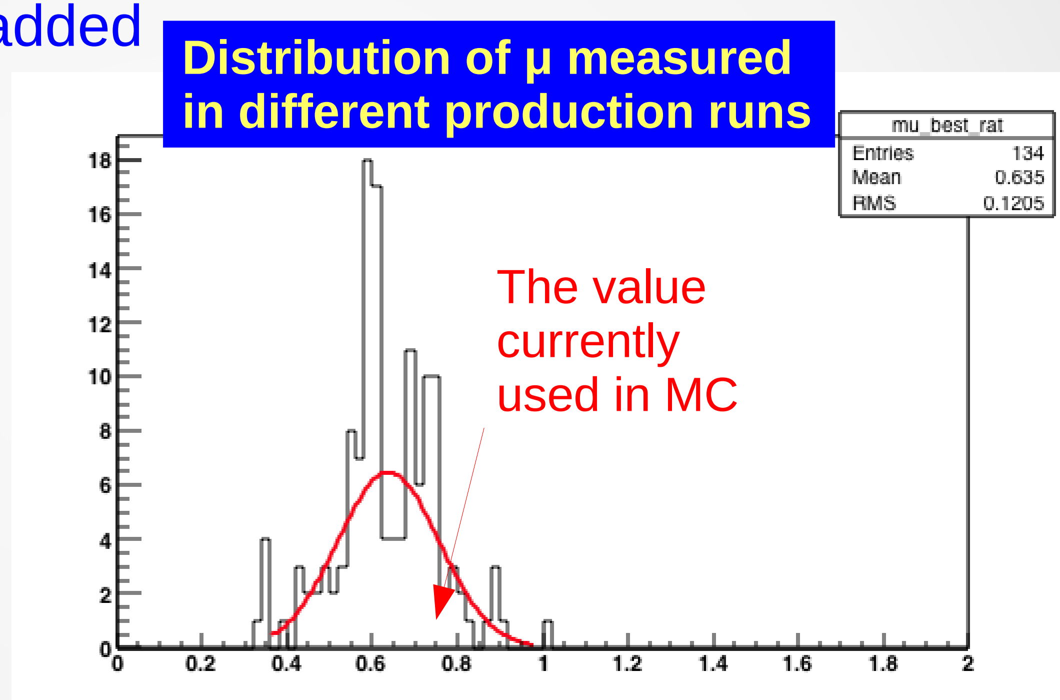
- Currently the mean value used (μ = 0.758) has been obtained from a poissonian fit to the data distribution from a single run. The nice agreement that is shown in the paper is for the "test" run + MC that has been tuned on it
- The value quoted in the VTX paper is slightly different (μ=0.74)
- **In order to justify the number written on the paper and assign an uncertainty to it, a study on the full data sample for different runs has been done**



Pile-up in the VTX [for us]

- We tried to study the pile-up over the full production: the number of vertexes distribution CANNOT be described by Poisson only. An exponential tail has to be added

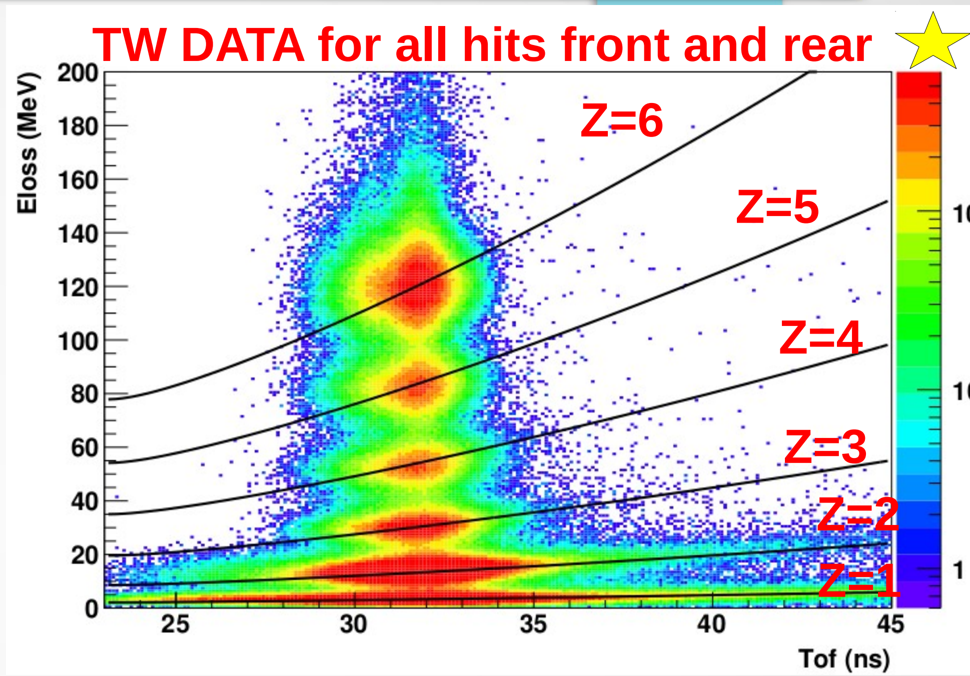
- For the runs in which a Poisson dominance wrt the exponential tail is obtained and a good fit was achieved a distribution yielding **μ=(0.63+/-0.12)** has been obtained

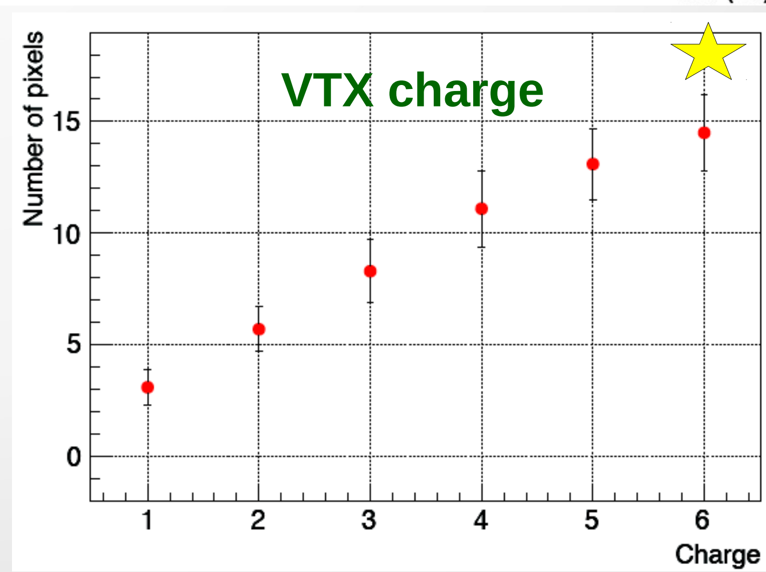


- **In the paper we are going to quote the μ=(0.63+/-0.12) value in the VTX section (compatible with what already published) and we will state that the MC simulation uses μ=0.76 to account for the larger pile-up condition that is found in some runs**

Global Reconstruction: charge ID

- Fragments are reconstructed using an iterative procedure that matches VTX tracks and TW hits
- A scoring function based on both Y_{ADC} and global charge (VTX + TW) is used to rate the combinations of VTX/TW tracks,
- The fragment charge ID is performed using a 2D algorithm based on detected dE/dX in the TW vs ToF
- The VTX can also provide some information on the fragment charge based on the number of fired pixels per cluster



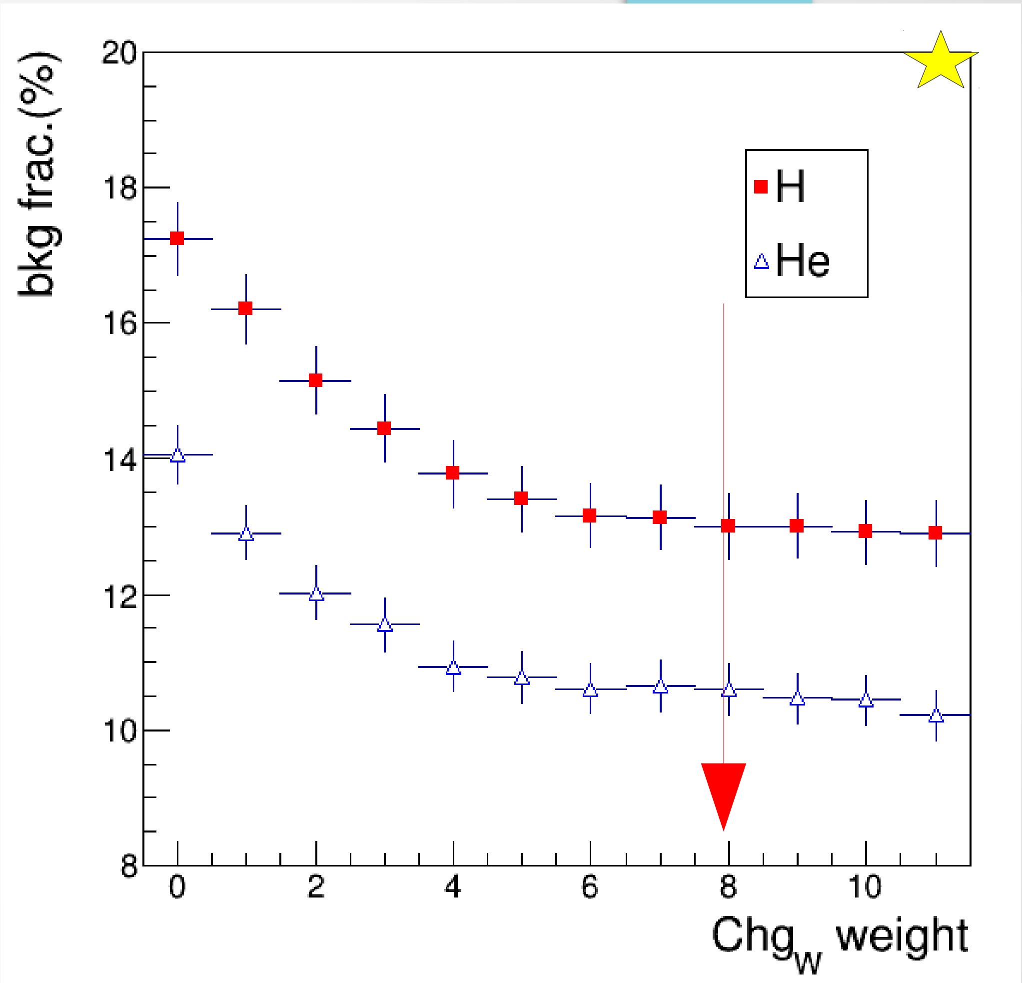


Global Reconstruction: Scoring function

- A scoring algorithm combines the information from the VTX and TW detectors to select the best track candidate

$$\sqrt{\Delta^2_{Chg} \cdot Chg^2_W + \Delta^2_Y \cdot Y^2_W}$$

- $\Delta_{Chg} = (Chg)_{TW} - (Chg)_{VTX}$
- $\Delta_Y = (Y)_{TW} - (Y)_{VTX}$
- $(Chg)_W$ and $(Y)_W$ are two weight factors tuned using the MC simulation by minimizing the fraction of wrong (background) tracks reconstructed



- H and He are the two fragment families for which the VTX charge can significantly improve the background rejection to the particle ID

FIRST performances: efficiencies

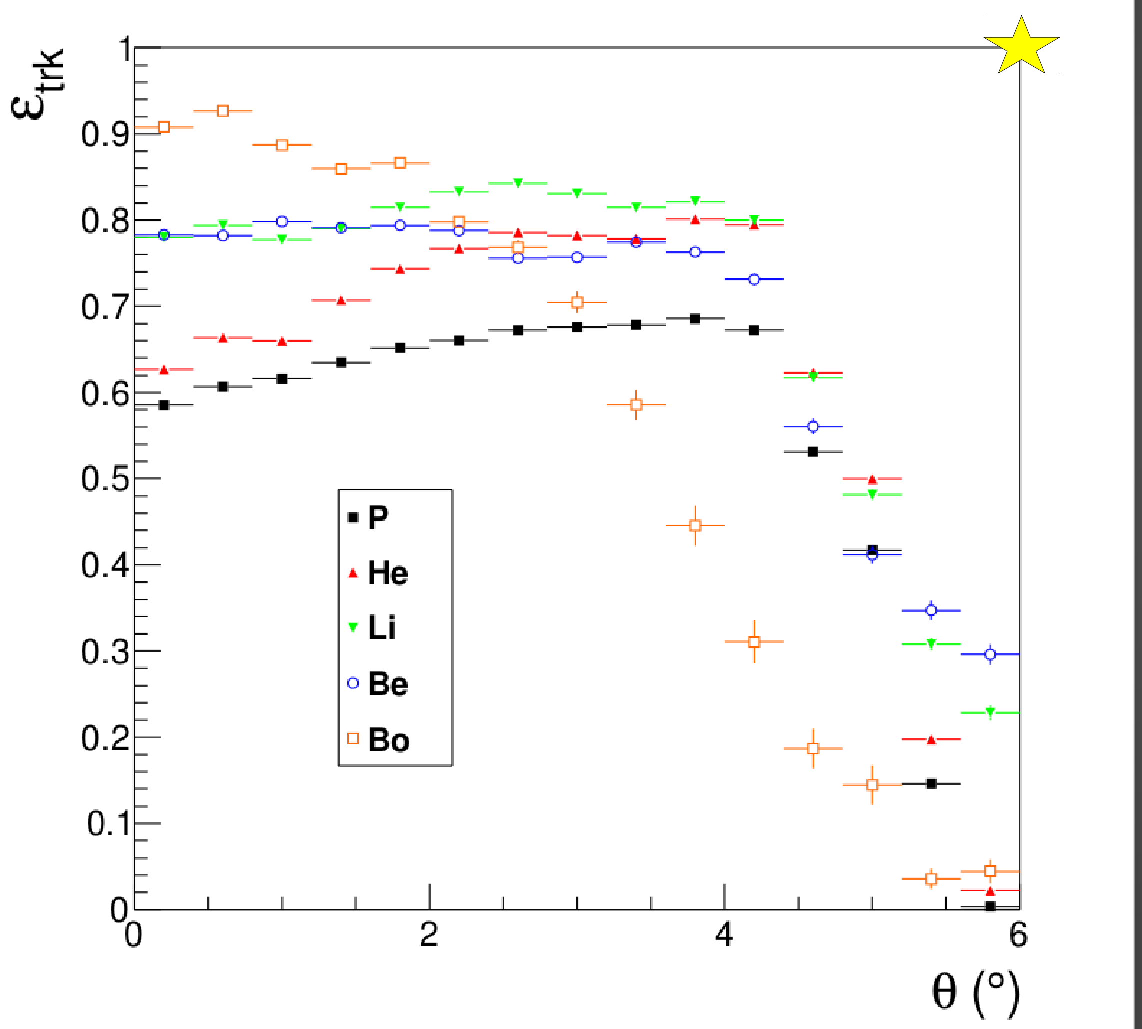
- **Tracking efficiency evaluated using the full MC simulation:**

  $\varepsilon_{trk} = n_{REC} / n_{PROD}$

- n_{PROD}: fragments emerging from the TG in the geometrical acceptance of the magnet

- n_{REC}: reconstructed tracks built using the true VTX and TW hits belonging to the true MC tracks under study

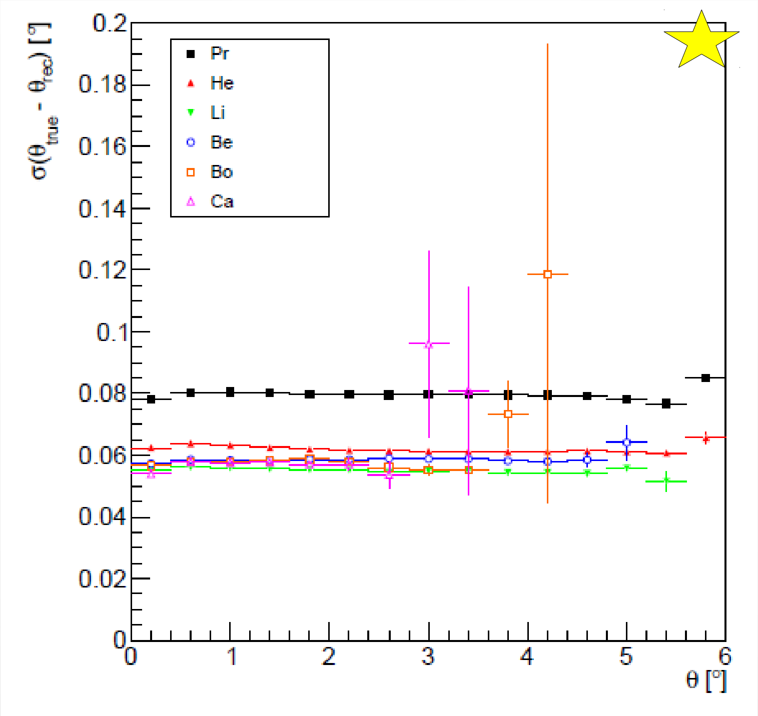
- These efficiencies are applied to the raw unfolded energies: still waiting the unfolding to do the right thing

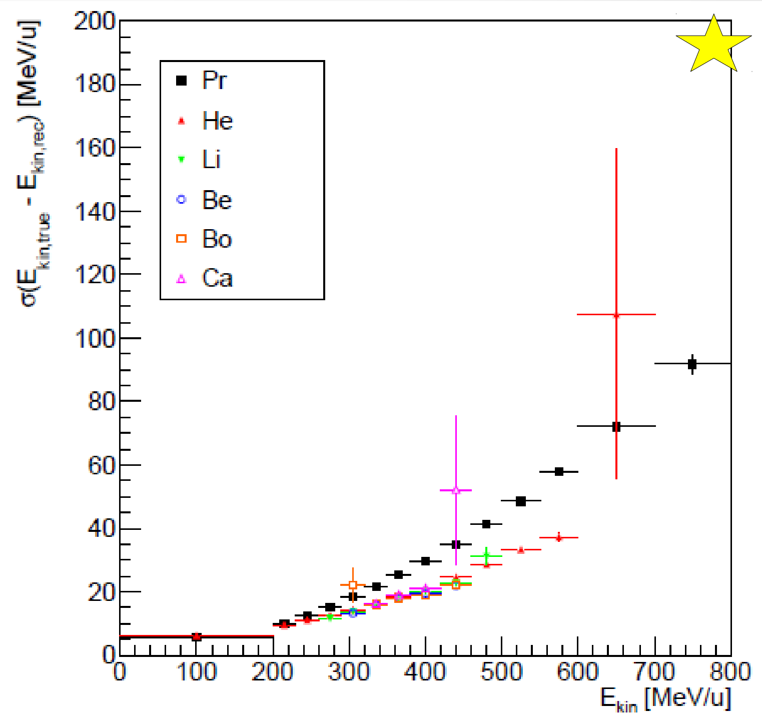


FIRST performances: resolutions

- **The global reconstruction algorithm has been benchmarked against the full MC simulation**. Angular and kinetic energy resolutions have been measured to:
  - ➔ evaluate any possible bias introduced by the reconstruction algorithm
  - ➔ optimize the binning adopted for the cross section measurement

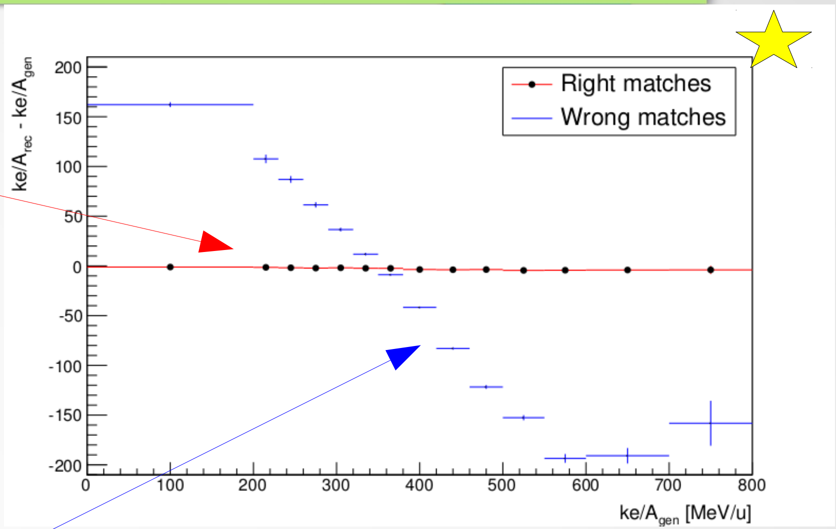
The resolutions have been obtained comparing the true generated fragment angle (energy) with the one reconstructed by the FIRST algorithm

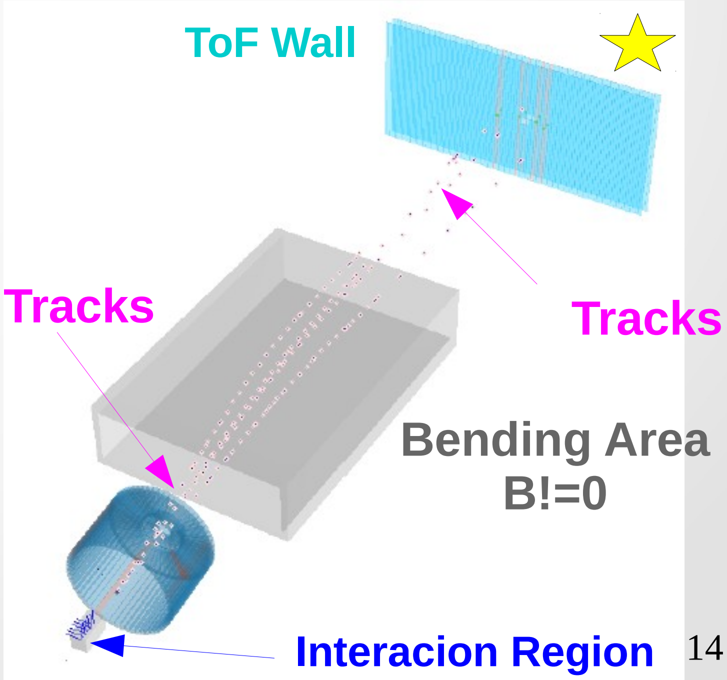




Global Reconstruction strategy

- "right" combinations of VTX tracks and TW hits, requiring to match only particles with the same ID
- Matching particles with different ID and so taking a "wrong" combination of VTX tracks and TW hits the reconstruction is biased
  - ➔ **We will have more combinatorial events in the central [250-450 MeV/u] energy bins**



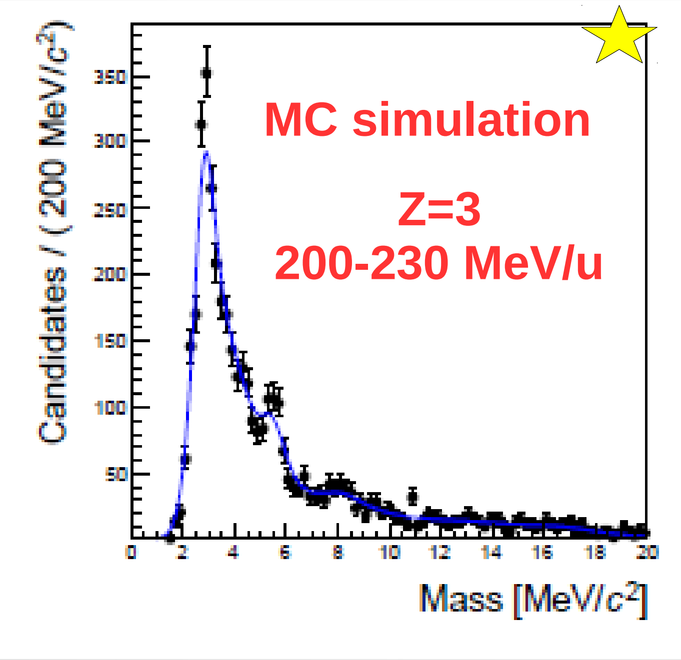


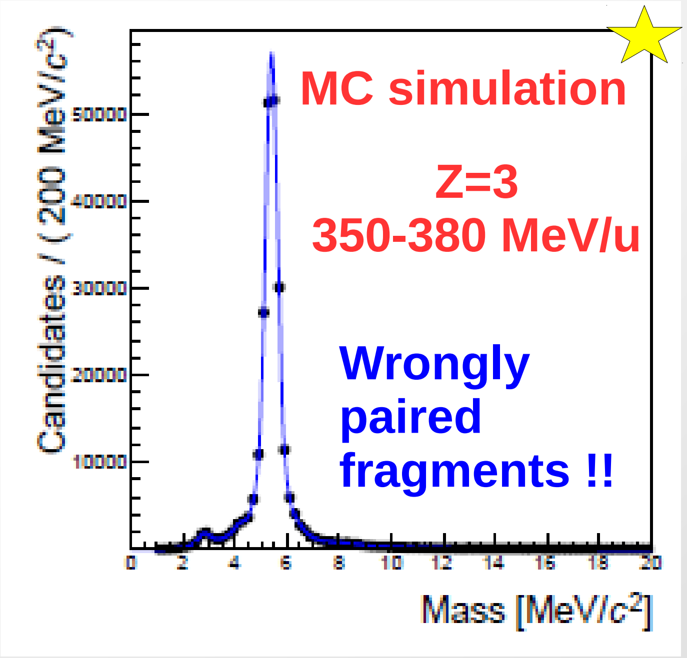
Combinatorial background

- **A fragment is marked as combinatorial background candidate whenever a track from VTX is paired with an hit from TW that does not belong to the SAME fragment.**
- The combinatorial background has to be taken into account and subracted from the fully reconstructed track sample
- How do we handle the combinatorial background in our analysis?
  - Take the shape from MC,
  - **Fit the normalization of combinatorial background directly on data, using the mass distribution**

Combinatorial background PDFs

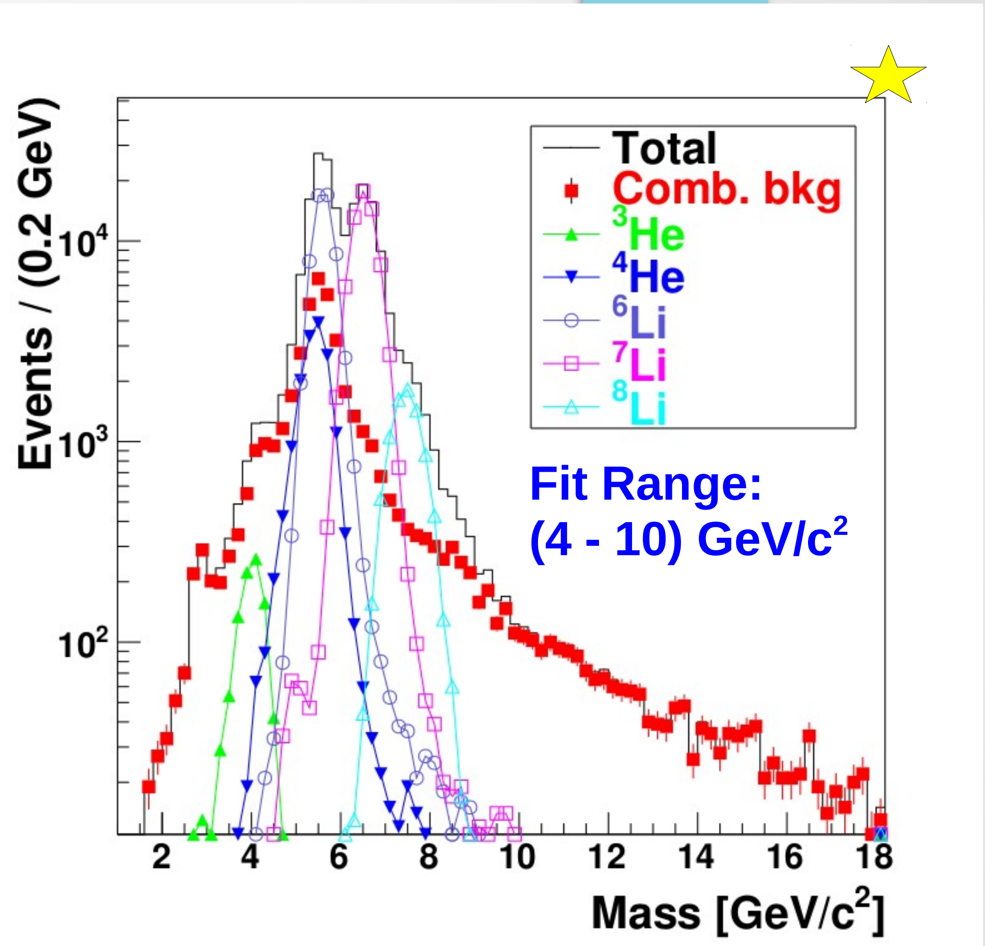
- The combinatorial background PDFs to be used in the mass fits are obtained, for each angular/energy bin, from a MC sample in which all the WRONG combinations are selected at MC truth level.
- The background PDF component has been modeled using a kernel estimation algorithm *(Cranmer KS. Computer Physics Communications 136:198-207,2001)*





Cross feed background - 1

- **Crossfeed: global tracks, properly matched, that have a wrong charge ID**
- Has to be considered only if in the fit range since the yields are computed only in a given range of the data distribution
- Not all the isotopes are contributing (in fact we have max 2 isotopes in a given fit that have to be considered, and usually we have JUST 1 isotope under a given mass peak)
- In the plot the reconstructed mass for Lithium in an energy bin is shown:



1. In red is the combinatorial background
2. The signal are 6Li, 7Li and 8Li
3. The contamination to be taken into account with crossfeed correction is the isotope 4He under the 6Li

Cross feed background - 2

- **In order to make the crossfeed correction we do rely on the MC simulation**
- We use the MC to evaluate the RATIO of yields: so we are not depending on the ABSOLUTE cross sections embedded in the MC BUT on the relative contributions....
- We're going to check the impact of a cross feed change rescaling the fractions accordingly to what we measure on data.
- **Anyway we are talking about a few percent impact on most of the bins... large effect is seen on the tails but there we have anyway a large uncertainty from the fit**

Cross Section Measurements

Double differential cross section for the i-th isotope $^{Z}_{A}X$ with charge Z and mass number A:

$$\frac{d^2\sigma_i}{d\Omega dE}(\theta, E) = \frac{Y_i(\theta, E)}{N_C \times N_{TG} \times \Delta\Omega \times \Delta E \times \epsilon_{trk}(\theta, E)}$$

- **$Y_i(\theta,E)$**: fragment yields for a given isotope $^{Z}_{A}X$ in an angular / energy bin ΔΩ / ΔE, measured from mass fits.
- **$\varepsilon_{trk}(\theta,E)$**: tracking reconstruction efficiency per angular/energy bin
- **N_{TG}**: number of atoms in the target per unit surface
- **N_{C}**: number of total carbon impinging on the target from SC

➔ **Unfolding of the spectra has to be done before applying the efficiency correction**

Fragment yields measurements

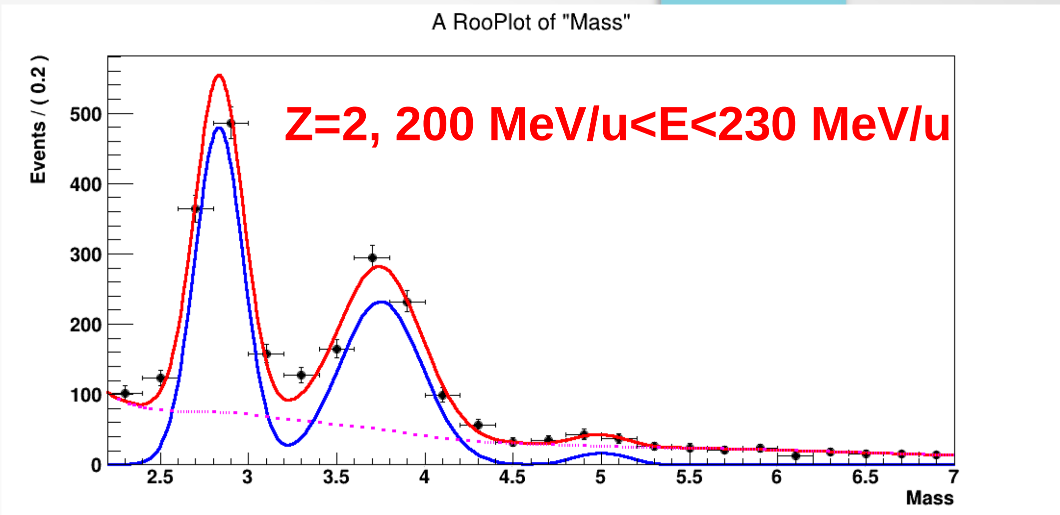
The reconstructed mass spectra are fitted, for each charge and angular (energy) bin ΔΩ (ΔE) to measure the fragment yield Y_i for each isotope $^{Z}_{A}X$

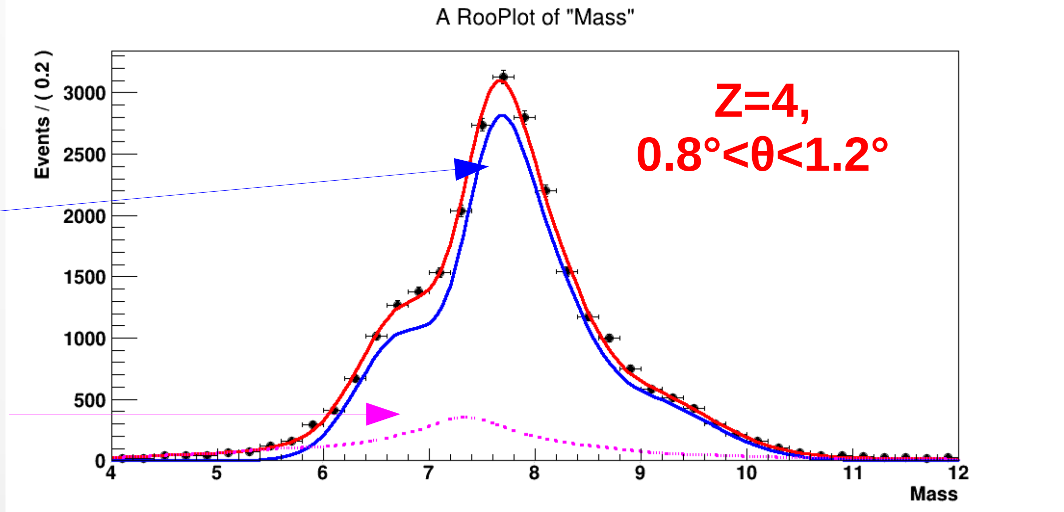
The Y_i yield are measured using an unbinned extended maximum likelihood fit: we get the yields of signal and background with uncertainties

Signal (for each isotope) is modeled with **Gaussian signal PDF**

Background PDFs are taking into account the combinatorial background

The crossfeed background is subtracted from the signal yield only if contamination is in the fit range

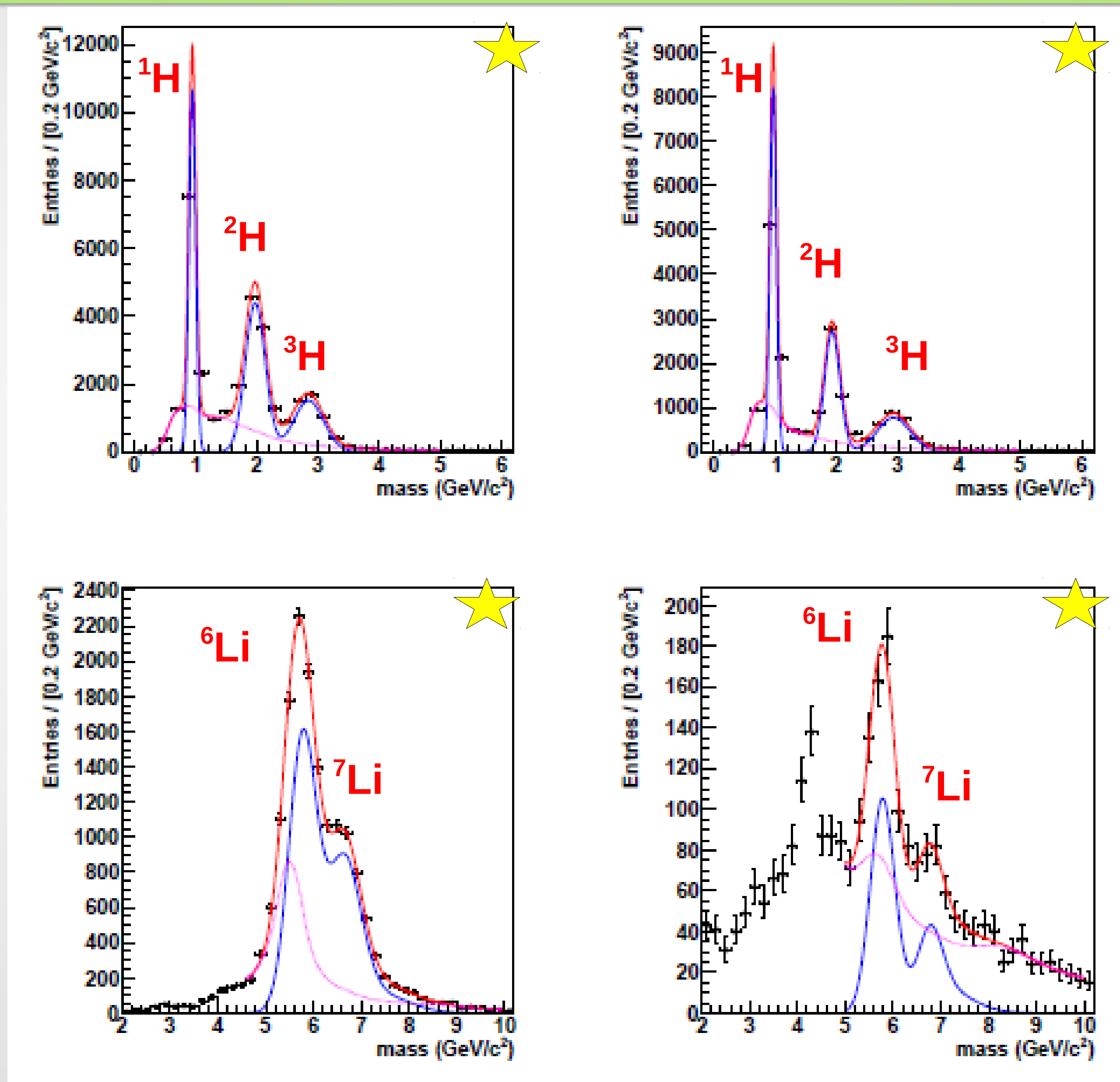




Z = 1, 3 mass fit results

Z=1
0.4°< θ <0.8°

Z=1
(200 < E < 230) MeV/u



Z=3
1.2°< θ <1.6°

Z=3
(260 < E < 290) MeV/u

Now that all the ingredients are available we need to decide what to publish

What do we want to publish?

A PROPOSAL to be discussed

- **Single differential cross section. Why?**
  - Because going 2D (DDCS) is technically complex and will imply a further delay in the paper submission: we need a few more months in order to have the full machinery under control for a big grid of fits/corrections to be applied
- **Only fragments (Z = 1 → Z = 5). Why?**
  - Because $^{\{10,11,12\}}$C measurements are not under control: we need a lot of work in order to tune the selection cuts to disentangle the non interacting ^{12}C from the elastically scattered carbon + we need to handle a HUGE ^{12}C contamination in $^{\{10,11\}}$C measurements and the mass distribution/fit is not helping/reliable.
  - That is why material concerning the C “fragments” data analysis has been removed from the paper [efficiencies, comparisons data/MC...]

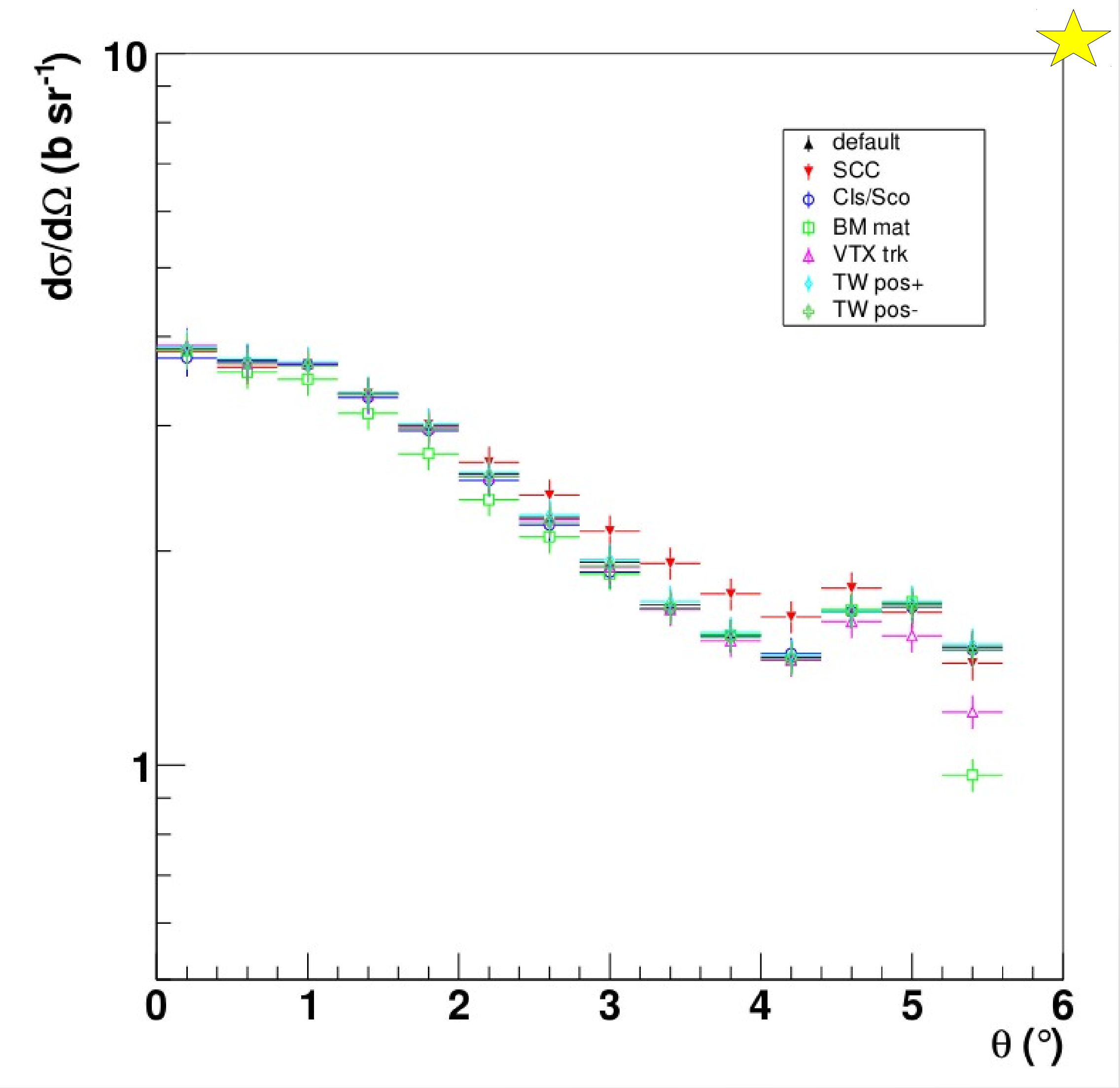
The next slides will be thus focused on SDCS results of fragments with Z from 1 to 5

Systematics (I)

- **Our measurement is dominated by systematics uncertainties:** even the tails of the distributions in which the “statistics” starts to play a role, the contribution of the systematic uncertainties is significant since we rely on the MC to compute the corrections to be applied, the efficiencies and the unfolding procedure necessary inputs
- How do we compute systematics?
- Systematic checks:
  - Tracking algorithms: checked the L0 algorithms [VTX tracking, TW hit efficiency] and the global algorithms [scoring, clustering]. Those changes are sensitive to pile-up/secondary fragmentation...
  - Detector description and alignment: global positioning of detectors has been varied within the precision achieved by the survey
  - PDF modeling: the description of the BKG has to be varied.

Systematics (II)

- The principle to evaluate the systematic uncertainty:
  - We redo the analysis several times, changing the strategy, the algorithms, the corrections, **and we take the spread (RMS) of the distributions as systematic uncertainty** to be added in quadrature to the stat uncertainty coming from the Default result (used also to quote the central value)



Systematics (III)

- A little bit more in detail:
  - The limited knowledge of the TW thresholds (obtained from data whenever possible) is taken into account by the **SCC** study: we are removing the TW hits in which only one TDC has fired and we recompute the efficiencies from our MC simulation. As expected the impact is significant only for the Z = 1 distributions
  - The impact of our global reconstruction algorithm strategy (matching of TW and VTX L0 candidates and rating of the tracks) is tested in the **Cls/Sco** study. We have changed the way we weight the Δ_Y and Δ_{Chg} to account for sub-optimal optimization of such weights, and we have also removed the clustering of TW hits, to account for sub-optimal optimization of the clustering algorithm. **This study is sensitive to tracking algorithm sub-optimal tuning AND to different combinatorial background conditions.**

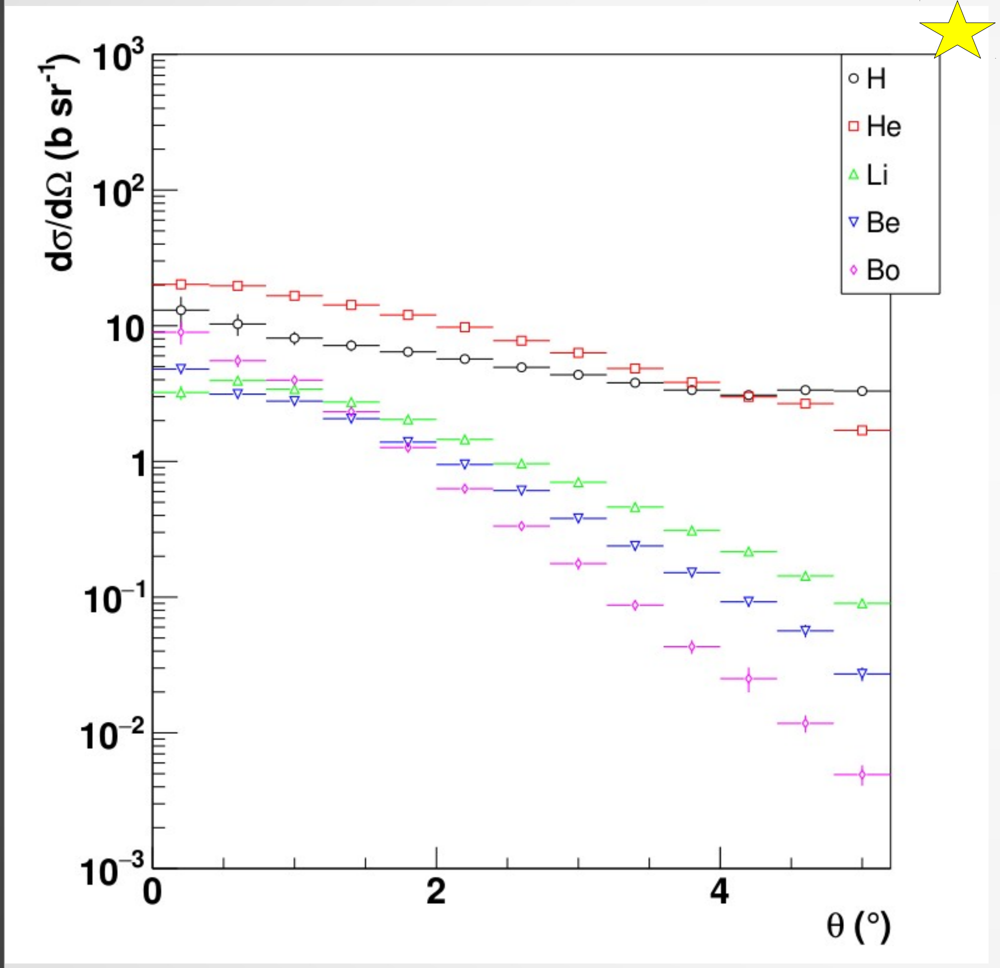
Systematics (IV)

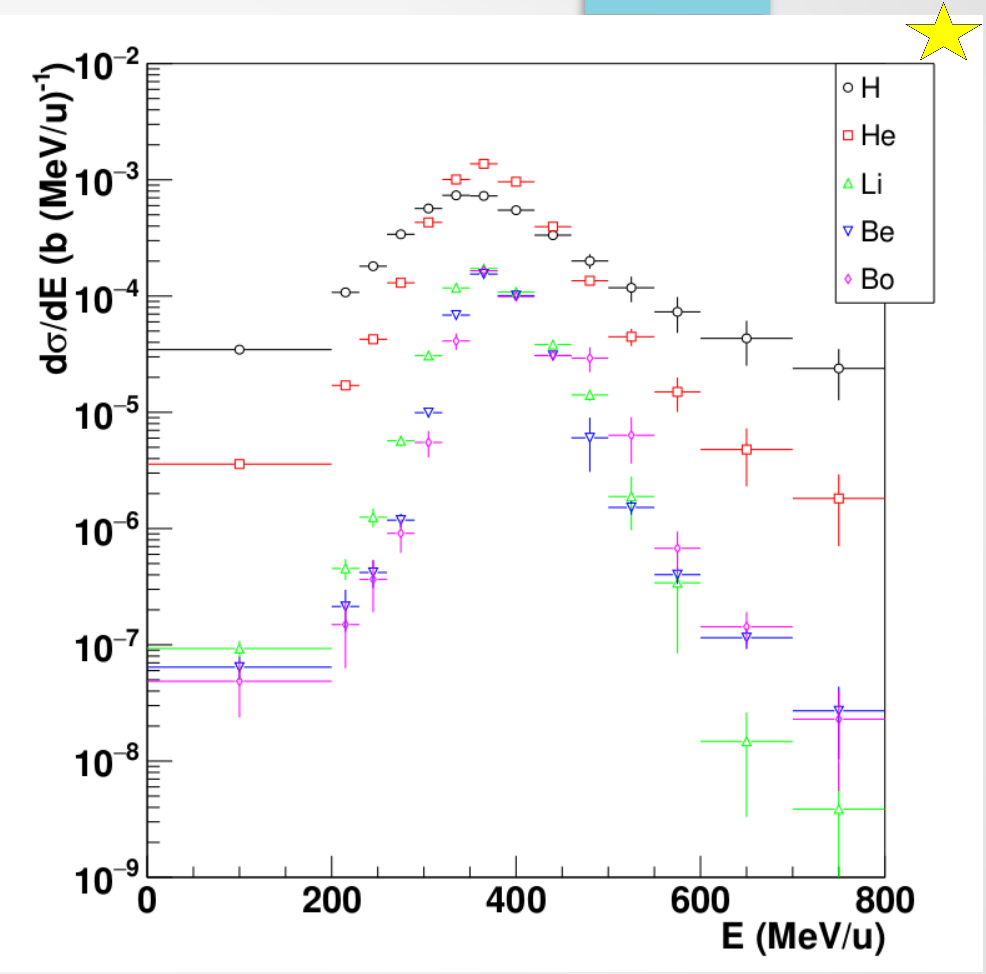
- A little bit more in detail:
  - The impact of the BM used in predicting the carbon impinging point on the TGT, when performing the VTX tracking (BM point is used as seed for VTX track reconstruction) is tested in the **VTX trk** study. The L0 candidate reconstruction in the VTX has been redone using a fully standalone procedure (documented in the VTX paper) that is not relying on the BM.
  - The requirement that the vtx reconstructed from the VTX in the event is a BM matched vtx has been tested in the **BM mat** study. However, it has to be noted that currently we are using really LOOSE requirements on the BM tracking: **we're going to test the impact of a real quality cut on the BM tracking**.
  - The study related to the detector positioning has started for the TW, and is tested in the **TW pos+,-** study. We're going to test also the ALADIN positioning and the magnetic field scale [we expect a minor effect]

Systematics (V)

- Still missing: more refined checks on the BKG handling
  - Test of the combinatorial PDF modeling: we are currently using the MC (trough a kernel estimation method) to compute the PDF for the comb bkg modeling. We will change the PDF creation parameters in order to verify what happens if we tune the kernel estimation promoting the detail preservation over the PDF smoothness. **This check is crucial since it is sensitive to the comb bkg subtraction that plays a major role in most of our Y_raw measurements.**
  - Reweighing of the data/MC difference when computing the Xfeed correction weights. When applying the corrections we are sensitive to the difference btw the ratio of production cross sections in data and MC. Anyway **we expect a minor impact: the Xfeed is relevant only for ^{4}He ↔ ^{6}Li and ^{7}Be ↔ ^{8}B contaminations (where 10%-20% corrections max are applied now)...**

Final result to be published





- **The measured distributions have not yet been unfolded to take into account the detector resolution**

What do we want to compare with?

A PROPOSAL to be discussed

- The work presented in the following slides is done “just for ourselves”:
  - We are **NOT** going to explicitly quote any comparison with other published data: **IF** we find a robust agreement with some other published result, we can add a sentence in the paper (in the conclusions) like “The obtained results are in agreement with what already published in [ref]”.
- We just want to convince ourselves that our result is **robust enough to be published!**

Not an easy task (see next slides)...

Comparison (I)

- **The toughest job: decide who we can compare with!**
- Articles that have been "selected" so far [if you know about other possibilities, please let us know!!!!]:
  - Zeitlin et al., Phys. Rev. C vol. 76 (2007)
  - Webber et al, Phys.Rev C, vol. 41, N. 2 (1990)
  - Alpat et al., IEEE TRANS. ON NUCL. SCIENCE, vol. 60, N. 6, (2013)

  } **C + C @ 400-450 MeV/u**

  - Toshito et al., Phys Rev C 75, 054606 (2007) — **C + water @ 400 MeV/u**
  - J.Dudouet et al Phys. Rev. C 88, (2013)
  - J.Dudouet et al Phys. Rev. C 89, (2014)

  } **C + C @ 95 MeV/u**
- These experiments have measured TCC cross section and integral and differential fragmentation cross sections (the ones underlined in red)
- Whenever comparing the TCC cross sections, we need to carefully review HOW they were obtained! [if we want to make a "fair" comparison] and take into account the ΔΩ used for the measurement.
- **For the moment we compare only with differential cross section measurements**

Comparison (II)

- **Some FIRST parameters we need to keep in mind: ρ·d = 3.43 g/cm², Energy = 400 MeV/u, Angular coverage: 0º -> 5º (max)**
- **Zeitlin** et al.**,** Phys. Rev. C 76, 014911, (2007).
  - Fixed position telescope with ΔΩ = 14 msr. Energy: 400 MeV/u. 5º measurement on carbon target [ρ·d = 2 gm/cm²], angular acceptance is 3.9º
  - The comparison with the 0º measurement poses several problems, since no easy "Z" definition can be found: an effective charge is defined but is difficult to be compared with since takes into account the multiple fragment simultaneous detection….
- **Dudouet** et al., Phys. Rev. C 88, 024606, (2013) and Phys. Rev. C 89, 064615, (2014)
  - telescope @ 0º (ΔΩ = 0.51 msr) and 4° (ΔΩ =0.43 msr). Energy: 95 MeV/u, measurements on carbon TG respectively with ρ·d = 0.176 g/cm² and 0.041 g/cm²
  - Big difference of beam energy and ρ·d wrt FIRST
  - The comparison @ 0° is somehow difficult, as it relies on the ability to subtract the 0º background from non interacting beam

Zeitlin @ 5º. ^{12}C on C @ 400 MeV/u

- The FIRST result is obtained as an average of our results between 1º and 5º (consider that the angular coverage of Zeitlin is 5º+/-3.9º
- Consider here that the angular configuration is quite different and thus is not easy to make direct comparisons

Fragment charge	dσ/dΩ ($b \cdot sr^{-1}$) (FIRST)	dσ/dΩ ($b \cdot sr^{-1}$) (Zeitlin)
	ρ x d = 3.43 g/cm² *1° < θ < 5°*	*ρ x d = 2 g/cm²* *θ = 5° +/- 3.9°*
Z = 1	4.89 ± 0.08	7.63 ± 0.23
Z = 2	6.42 ± 0.12	4.22 ± 0.13
Z = 3	0.771± 0.017	0.20 ± 0.01
Z = 4	0.580 ± 0.014	0.054 ± 0.005

Ganil @ 0º. ^{12}C on C @ 95 MeV/u

- The comparison is somehow difficult, as it relies on the ability of Ganil to subtract the 0º background from non interacting beam

- **We take average between 0° & 0.8°**

dσ/dΩ(b sr-1)	Ganil (95 MeV/u)	FIRST (400 MeV/u)
4He	28.5+/-4.4	18.70+/0.82
6Li	2.03+/-0.32	1.48+/-0.18
7Li	1.96+/-0.31	1.52+/-0.34
7Be	1.87+/-0.29	1.54+/-0.14
Z =2	30.8+/-2.9	18.85+/0.96
Z =3	3.99 +/- 0.38	3.08+/-0.28
Z =4	4.65+/- 0.44	4.28+/-0.28
Z =5	18.7+/-1.7	7.92+/-0.69

Ganil @ 4º. ^{12}C on C @ 95 MeV/u

- The only other point available for comparison is the **4º [3.3° - 4.7°]** one (the other points are outside the FIRST geometrical acceptance for now). Comparison performed for different Z!
- **We take average between 3.2° & 4.8°**

dσ/dΩ (b sr-1)	Ganil (95 MeV/u)	FIRST (400 MeV/u)
1H	4.26+/-0.39	1.59+/-0.05
2H	2.42+/- 0.26	1.17+/-0.04
3H	1.17+/-0.13	0.73+/-0.04
3He	1.73+/-0.4	0.93+/-0.03
4He	12.7+/-1.6	2.82+/-0.08
6He	0.43 +/- 0.26	0.011+/-0.002
6Li	0.89+/-0.12	0.10+/-0.02
7Li	0.85+/-0.11	0.17+/-0.02
7Be	0.74+/-0.07	0.110+/-0.004
9Be	0.32+/-0.034	0.022+/-0.003
10Be	0.17+/-0.02	0.009+/-0.004
8B	0.10+/-0.03	0.0066+/-0.0012
10B	0.99+/-0.13	0.024+/-0.006
11B	1.34+/-0.18	0.011+/-0.005

Comparison: not used at the moment

- **Webber** et al, Phys.Rev C, vol. 41, N. 2 (1990)
  - 0º telescope, angular aperture 7.7º ($\Delta\Omega$ = 56.7 msr), Energy: 435/450 MeV/u, measurements on carbon TG with ρ·d : 10 and 7 g/cm^2.
  - TCC and PCC measurements. Various corrections and selection criteria to take into account the secondary fragmentation inside the telescope. Difficulty of employing consistent selection criteria
- **Alpat,** et al.: Total and Partial Fragmentation Cross-Section of 500 MeV/nucleon Carbon Ions on Different Target Materials, IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 60, NO. 6 (2013)
  - Fixed position telescope @ 0°. Two carbon target with ρ d = 3.4 g/cm^2 and 1.7 g/cm^2, energy 400 MeV/u
  - The comparison is problematic since the TCC cross section is defined in a completely different way (using the max charge in a given event). Results quoted in terms of integrated TCC and Z ! =6 results are quoted as % wrt to the Total. Total: 713 mb and 672 mb. <u>We could not easily figure out what is the solid angle and hence we cannot make a comparison</u>.
- **Toshito** et al,. Phys Rev C 75, 054606 (2007):
  - performs TCC and PCC cross section in water.
  - Hard to compare: <u>not considered for now</u>!

Ongoing work

- **To be finalized by the end of this month:**
  - Finalize efficiency check.
  - Finalize unfolding strategy
  - [both issues NOT affecting the order of magnitude of the result hence the comparison with other exp]
- **Finalize the systematic studies [2 weeks of time max allowed]:**
  - Change the BM tracking
  - Play with positions + field scale

Angular and energy isotopic Cross Sections: tables

θ (deg)	^{1}H $d\sigma/d\Omega(b\ sr^{-1})$	^{2}H $d\sigma/d\Omega(b\ sr^{-1})$	^{3}H $d\sigma/d\Omega(b\ sr^{-1})$	^{3}He $d\sigma/d\Omega(b\ sr^{-1})$	^{4}He $d\sigma/d\Omega(b\ sr^{-1})$	^{6}He $d\sigma/d\Omega(b\ sr^{-1})$
0.2(0.2)	3.8 (0.23)	7.3 (2.3)	2.8 (0.5)	1.7 (0.38)	18 (1.2)	0.051 (0.076)
0.6(0.2)	3.7 (0.2)	4.5 (1.3)	2.6 (0.33)	1.8 (0.18)	19 (1.2)	0.28 (0.088)
1(0.2)	3.7 (0.2)	2.7 (0.41)	2.1 (0.28)	1.9 (0.19)	16 (1)	0.13 (0.066)
1.4(0.2)	3.3 (0.19)	2.3 (0.22)	1.9 (0.28)	1.9 (0.19)	13 (0.75)	0.17 (0.06)
1.8(0.2)	3 (0.18)	2.2 (0.16)	1.6 (0.17)	1.8 (0.16)	11 (0.57)	0.21 (0.033)
2.2(0.2)	2.6 (0.16)	2 (0.13)	1.5 (0.088)	1.6 (0.14)	8.7 (0.46)	0.12 (0.019)
2.6(0.2)	2.2 (0.14)	1.8 (0.11)	1.2 (0.074)	1.4 (0.095)	6.7 (0.35)	0.087 (0.0087)
3(0.2)	1.9 (0.13)	1.5 (0.085)	1 (0.079)	1.3 (0.081)	5.3 (0.28)	0.045 (0.0085)
3.4(0.2)	1.7 (0.12)	1.4 (0.084)	0.82 (0.075)	1.2 (0.068)	3.9 (0.21)	0.0087 (0.0072)
3.8(0.2)	1.5 (0.11)	1.1 (0.081)	0.72 (0.073)	0.99 (0.058)	3 (0.16)	3.4e-08 (0.0027)
4.2(0.2)	1.4 (0.1)	1 (0.076)	0.64 (0.078)	0.82 (0.046)	2.3 (0.12)	0.012 (0.0048)
4.6(0.2)	1.6 (0.1)	1.1 (0.064)	0.69 (0.069)	0.77 (0.044)	2.1 (0.12)	0.023 (0.0034)
5(0.2)	1.7 (0.1)	1.1 (0.068)	0.7 (0.06)	0.46 (0.03)	1.3 (0.078)	0.017 (0.0033)
5.4(0.2)	1.5 (0.2)	0.89 (0.13)	0.61 (0.099)	0.13 (0.01)	0.34 (0.022)	0.006 (0.0019)
5.8(0.2)	0.0091 (0.0037)	0.006 (0.0026)	0.003 (0.0015)	0.0014 (0.00055)	0.0018 (0.00069)	0.00046 (0.00025)

θ (deg)	^{6}Li $d\sigma/d\Omega(b\ sr^{-1})$	^{7}Li $d\sigma/d\Omega(b\ sr^{-1})$	^{8}Li $d\sigma/d\Omega(b\ sr^{-1})$	^{7}Be $d\sigma/d\Omega(b\ sr^{-1})$	^{9}Be $d\sigma/d\Omega(b\ sr^{-1})$	^{10}Be $d\sigma/d\Omega(b\ sr^{-1})$
0.2(0.2)	1.4 (0.31)	0.99 (0.46)	0.51 (0.17)	1.8 (0.25)	0.94 (0.37)	2 (0.56)
0.6(0.2)	1.5 (0.16)	1.6 (0.49)	0.18 (0.032)	1.4 (0.14)	1.2 (0.3)	1.2 (0.37)
1(0.2)	1.5 (0.22)	1.4 (0.41)	0.17 (0.036)	1.3 (0.087)	0.93 (0.16)	0.82 (0.19)
1.4(0.2)	1.3 (0.21)	0.96 (0.32)	0.18 (0.033)	1.1 (0.075)	0.69 (0.11)	0.46 (0.11)
1.8(0.2)	1 (0.16)	0.61 (0.23)	0.19 (0.046)	0.82 (0.049)	0.39 (0.063)	0.29 (0.053)
2.2(0.2)	0.8 (0.17)	0.42 (0.22)	0.15 (0.041)	0.61 (0.038)	0.33 (0.031)	0.049 (0.03)
2.6(0.2)	0.49 (0.13)	0.39 (0.13)	0.017 (0.014)	0.43 (0.026)	0.13 (0.031)	0.085 (0.018)
3(0.2)	0.36 (0.11)	0.31 (0.1)	0.01 (0.025)	0.28 (0.017)	0.072 (0.014)	0.048 (0.02)
3.4(0.2)	0.14 (0.077)	0.33 (0.078)	0.0017 (0.014)	0.18 (0.011)	0.044 (0.012)	0.029 (0.016)
3.8(0.2)	0.09 (0.039)	0.22 (0.033)	0.0017 (0.014)	0.13 (0.009)	0.014 (0.005)	0.017 (0.0055)
4.2(0.2)	0.065 (0.024)	0.15 (0.024)	0.0082 (0.004)	0.079 (0.0055)	0.017 (0.0039)	0.002 (0.0046)
4.6(0.2)	0.047 (0.017)	0.09 (0.019)	0.0013 (0.0019)	0.049 (0.0042)	0.012 (0.0028)	0.0024 (0.00074)
5(0.2)	0.036 (0.0079)	0.038 (0.0059)	0.0071 (0.0016)	0.021 (0.0022)	0.0077 (0.0017)	0.00056 (0.00024)
5.4(0.2)	0.008 (0.002)	0.0066 (0.0019)	0.00049 (0.001)	0.0046 (0.00069)	0.00058 (0.00062)	4.4e-11 (8.3e-05)
5.8(0.2)	0.0002 (0.00014)	0.0001 (9.4e-05)	5.1e-05 (6.4e-05)	6e-05 (7e-05)	3e-05 (4.8e-05)	3e-05 (4.8e-05)

θ (deg)	^{8}Bo $d\sigma/d\Omega(b\ sr^{-1})$	^{10}Bo $d\sigma/d\Omega(b\ sr^{-1})$	^{11}Bo $d\sigma/d\Omega(b\ sr^{-1})$
0.2(0.2)	0.16 (0.073)	4.9 (2)	4.2 (1.3)
0.6(0.2)	0.023 (0.018)	0.35 (1.5)	6.1 (1.5)
1(0.2)	0.063 (0.012)	1.8 (0.69)	2.4 (0.74)
1.4(0.2)	0.052 (0.025)	0.2 (0.32)	2.2 (0.36)
1.8(0.2)	0.06 (0.014)	0.81 (0.31)	0.45 (0.29)
2.2(0.2)	0.033 (0.013)	0.11 (0.072)	0.52 (0.093)
2.6(0.2)	0.037 (0.0057)	0.083 (0.089)	0.23 (0.095)
3(0.2)	0.016 (0.0032)	0.16 (0.055)	0.0063 (0.054)
3.4(0.2)	0.014 (0.0037)	0.052 (0.024)	0.018 (0.021)
3.8(0.2)	0.0041 (0.0023)	0.035 (0.0056)	0.0042 (0.0025)
4.2(0.2)	0.0041 (0.0014)	0.018 (0.008)	0.0047 (0.0044)
4.6(0.2)	0.0058 (0.0013)	0.0053 (0.0019)	0.0017 (0.0015)
5(0.2)	0.0011 (0.00076)	0.0037 (0.00089)	0.00036 (0.00055)

Energy (MeV/u)	^{1}H $d\sigma/dE(b\ MeV/u^{-1})$	^{2}H $d\sigma/E(b\ MeV/u^{-1})$	^{3}H $d\sigma/E(b\ MeV/u^{-1})$	^{3}He $d\sigma/E(b\ MeV/u^{-1})$	^{4}He $d\sigma/E(b\ MeV/u^{-1})$	^{6}He $d\sigma/E(b\ MeV/u^{-1})$
100(100)	1.28e-05 (9.01e-07)	1.73e-05 (1.03e-06)	5.43e-06 (3.14e-07)	2.10e-06 (8.90e-08)	1.58e-06 (5.94e-08)	1.94e-07 (4.14e-08)
215(15)	5.33e-05 (2.60e-06)	3.88e-05 (1.46e-06)	1.71e-05 (9.07e-07)	1.01e-05 (4.26e-07)	7.84e-06 (4.23e-07)	9.26e-07 (2.05e-07)
245(15)	8.45e-05 (2.72e-06)	6.37e-05 (2.99e-06)	3.88e-05 (3.15e-06)	2.21e-05 (7.29e-07)	2.33e-05 (1.06e-06)	1.67e-06 (3.70e-07)
275(15)	1.52e-04 (3.57e-06)	1.21e-04 (6.54e-06)	8.25e-05 (6.26e-06)	4.79e-05 (1.71e-06)	8.56e-05 (4.01e-06)	2.51e-06 (8.11e-07)
305(15)	2.40e-04 (5.12e-06)	1.98e-04 (9.93e-06)	1.54e-04 (8.01e-06)	1.01e-04 (3.45e-06)	3.37e-04 (1.78e-05)	4.33e-06 (1.30e-06)
335(15)	3.11e-04 (6.42e-06)	2.52e-04 (8.74e-06)	2.02e-04 (5.36e-06)	1.62e-04 (5.46e-06)	9.27e-04 (3.59e-05)	1.52e-05 (3.75e-06)
365(15)	3.26e-04 (6.29e-06)	2.41e-04 (7.71e-06)	1.95e-04 (3.39e-06)	1.99e-04 (4.55e-06)	1.31e-03 (2.39e-05)	1.78e-05 (5.38e-06)
400(20)	2.68e-04 (4.51e-06)	1.78e-04 (6.94e-06)	1.34e-04 (3.28e-06)	1.62e-04 (3.80e-06)	9.03e-04 (1.80e-05)	8.02e-06 (1.18e-06)
440(20)	1.79e-04 (5.71e-06)	1.07e-04 (8.13e-06)	7.35e-05 (4.58e-06)	8.04e-05 (1.64e-06)	3.52e-04 (6.35e-06)	1.61e-06 (5.01e-07)
480(20)	1.15e-04 (9.36e-06)	6.62e-05 (9.51e-06)	3.96e-05 (5.80e-06)	3.29e-05 (9.43e-07)	1.17e-04 (8.67e-06)	4.79e-07 (2.77e-07)
525(25)	7.30e-05 (1.10e-05)	3.84e-05 (8.72e-06)	2.45e-05 (6.12e-06)	1.19e-05 (8.12e-07)	3.81e-05 (6.63e-06)	5.82e-07 (2.31e-07)
575(25)	4.56e-05 (9.69e-06)	2.43e-05 (6.89e-06)	1.73e-05 (5.58e-06)	1.14e-05 (4.53e-06)	6.26e-06 (3.48e-06)	3.27e-07 (1.43e-07)
650(50)	2.69e-05 (7.16e-06)	1.67e-05 (5.46e-06)	1.02e-05 (3.54e-06)	4.55e-06 (2.22e-06)	1.16e-06 (4.39e-07)	1.15e-07 (5.37e-08)
750(50)	1.45e-05 (4.42e-06)	9.45e-06 (3.39e-06)	6.03e-06 (2.13e-06)	1.73e-06 (9.14e-07)	5.65e-07 (2.01e-07)	4.40e-08 (1.81e-08)

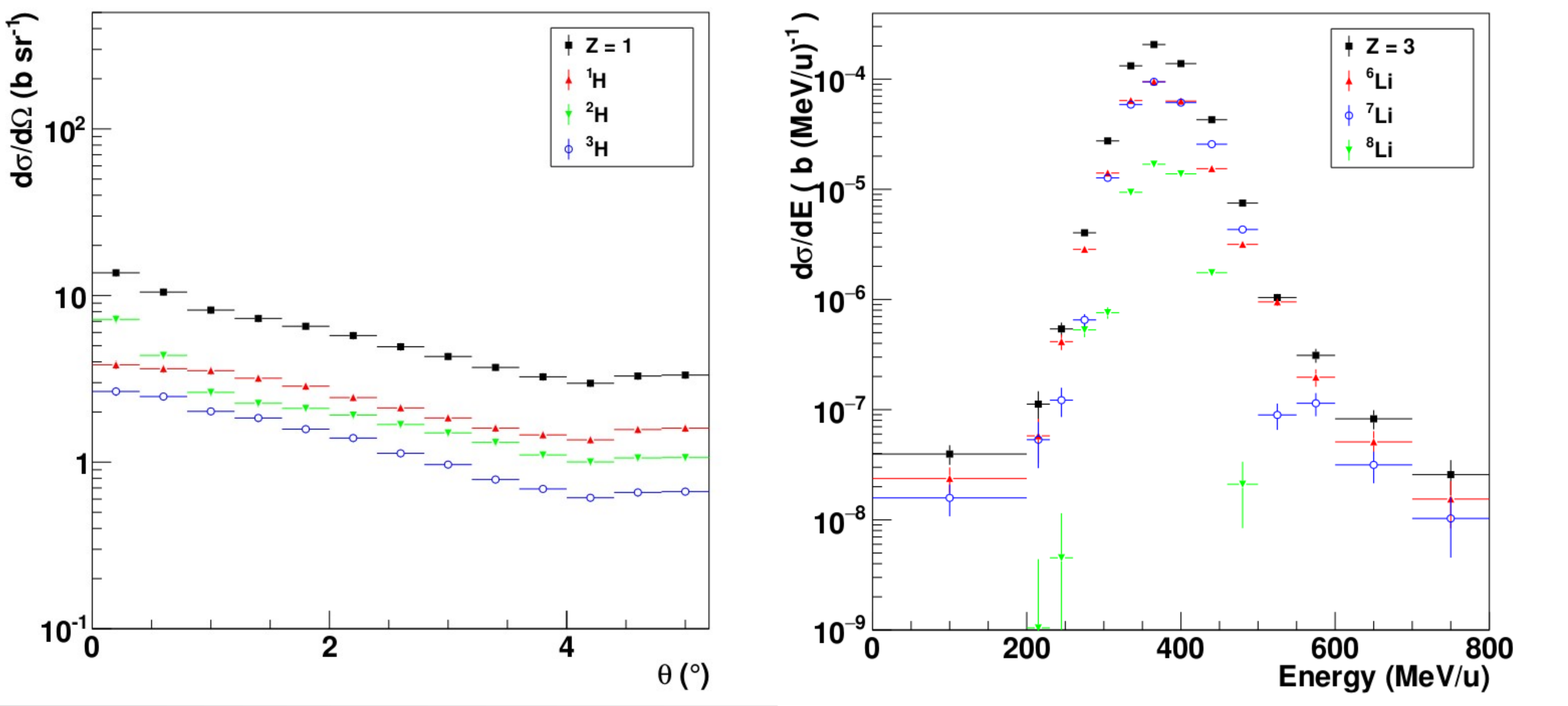
Energy (MeV/u)	^{6}Li $d\sigma/E(b\ MeV/u^{-1})$	^{7}Li $d\sigma/E(b\ MeV/u^{-1})$	^{8}Li $d\sigma/E(b\ MeV/u^{-1})$	^{7}Be $d\sigma/E(b\ MeV/u^{-1})$	^{9}Be $d\sigma/E(b\ MeV/u^{-1})$	^{10}Be $d\sigma/E(b\ MeV/u^{-1})$
100(100)	2.37e-08 (6.73e-09)	1.58e-08 (5.45e-09)	2.04e-11 (1.81e-10)	5.17e-09 (2.98e-09)	1.74e-09 (1.71e-09)	6.66e-10 (1.04e-09)
215(15)	5.78e-08 (2.69e-08)	5.34e-08 (2.65e-08)	1.05e-09 (3.36e-09)	4.63e-08 (2.53e-08)	8.98e-09 (1.01e-08)	5.25e-09 (7.64e-09)
245(15)	4.14e-07 (9.19e-08)	1.22e-07 (4.08e-08)	4.52e-09 (7.12e-09)	1.13e-07 (4.01e-08)	3.78e-08 (2.14e-08)	2.10e-08 (1.55e-08)
275(15)	2.85e-06 (3.30e-07)	6.53e-07 (3.84e-07)	5.30e-07 (1.89e-07)	9.17e-07 (1.39e-07)	1.77e-07 (5.23e-08)	4.97e-09 (9.08e-09)
305(15)	1.40e-05 (1.02e-06)	1.27e-05 (1.30e-06)	7.59e-07 (4.14e-07)	6.69e-06 (8.07e-07)	2.49e-06 (5.02e-07)	3.40e-07 (7.54e-07)
335(15)	6.39e-05 (2.83e-06)	5.88e-05 (6.05e-06)	9.40e-06 (1.26e-06)	3.83e-05 (2.81e-06)	1.10e-05 (5.78e-06)	2.33e-05 (6.32e-06)
365(15)	9.46e-05 (4.73e-06)	9.45e-05 (8.58e-06)	1.69e-05 (2.16e-06)	7.92e-05 (2.72e-06)	6.94e-05 (1.36e-05)	1.31e-05 (1.64e-05)
400(20)	6.32e-05 (6.30e-06)	6.12e-05 (7.68e-06)	1.38e-05 (2.30e-06)	5.94e-05 (2.03e-06)	3.13e-05 (2.65e-06)	8.63e-06 (1.14e-06)
440(20)	1.54e-05 (2.87e-06)	2.57e-05 (5.07e-06)	1.75e-06 (8.06e-07)	2.09e-05 (6.42e-07)	5.49e-06 (7.75e-07)	4.69e-06 (1.73e-06)
480(20)	3.16e-06 (4.87e-07)	4.32e-06 (1.40e-06)	2.10e-08 (1.43e-08)	7.72e-06 (9.36e-07)	1.59e-07 (5.87e-08)	6.62e-07 (1.58e-07)
525(25)	9.51e-07 (1.47e-07)	8.96e-08 (8.24e-08)	9.48e-10 (2.50e-09)	1.21e-06 (2.24e-07)	3.09e-08 (1.69e-08)	3.34e-18 (7.98e-10)
575(25)	1.97e-07 (4.57e-08)	1.14e-07 (4.61e-08)	3.47e-11 (4.73e-10)	7.59e-08 (3.16e-08)	5.29e-08 (2.44e-08)	0.00e+00 (0.00e+00)
650(50)	5.10e-08 (1.42e-08)	3.15e-08 (1.05e-08)	6.57e-11 (4.60e-10)	1.95e-08 (8.28e-09)	1.68e-08 (7.68e-09)	0.00e+00 (0.00e+00)
750(50)	1.54e-08 (8.42e-09)	1.03e-08 (6.52e-09)	0.00e+00 (0.00e+00)	2.59e-09 (2.94e-09)	2.59e-09 (2.94e-09)	2.96e-09 (3.22e-09)

Energy (MeV/u)	^{8}Bo $d\sigma/E(b\ MeV/u^{-1})$	^{10}Bo $d\sigma/E(b\ MeV/u^{-1})$	^{11}Bo $d\sigma/E(b\ MeV/u^{-1})$
100(100)	1.53e-08 (1.09e-08)	9.38e-09 (8.04e-09)	1.33e-08 (9.98e-09)
215(15)	5.11e-08 (4.57e-08)	3.29e-08 (3.59e-08)	4.63e-08 (4.32e-08)
245(15)	1.17e-07 (7.72e-08)	7.56e-08 (5.89e-08)	1.03e-07 (7.13e-08)
275(15)	3.58e-07 (1.33e-07)	2.97e-07 (1.18e-07)	3.17e-07 (1.24e-07)
305(15)	1.27e-06 (3.86e-07)	2.58e-07 (1.47e-07)	6.58e-06 (1.59e-06)
335(15)	3.13e-06 (2.59e-07)	5.68e-06 (2.05e-06)	6.66e-05 (7.78e-06)
365(15)	4.17e-06 (3.83e-07)	6.95e-05 (1.69e-05)	1.41e-04 (2.77e-05)
400(20)	1.74e-06 (1.80e-07)	4.87e-05 (5.64e-06)	7.68e-05 (6.39e-06)
440(20)	2.93e-07 (7.61e-08)	3.99e-05 (4.04e-06)	3.47e-07 (4.45e-06)
480(20)	7.79e-08 (5.11e-08)	2.22e-05 (4.90e-06)	2.38e-07 (1.12e-07)
525(25)	5.27e-08 (3.83e-08)	1.86e-06 (1.40e-06)	6.97e-09 (1.26e-08)
575(25)	0.00e+00 (0.00e+00)	0.00e+00 (0.00e+00)	2.82e-08 (2.71e-08)
650(50)	0.00e+00 (0.00e+00)	0.00e+00 (0.00e+00)	0.00e+00 (0.00e+00)
750(50)	0.00e+00 (0.00e+00)	0.00e+00 (0.00e+00)	0.00e+00 (0.00e+00)

Final result to be published: isotopic CS

- Proton deuterium and tritium angular differential cross sections
- Lithium energy differential cross sections
- Isotope distributions (coloured) as well as total cross sections (in black) are shown

Only statistical errors reported here

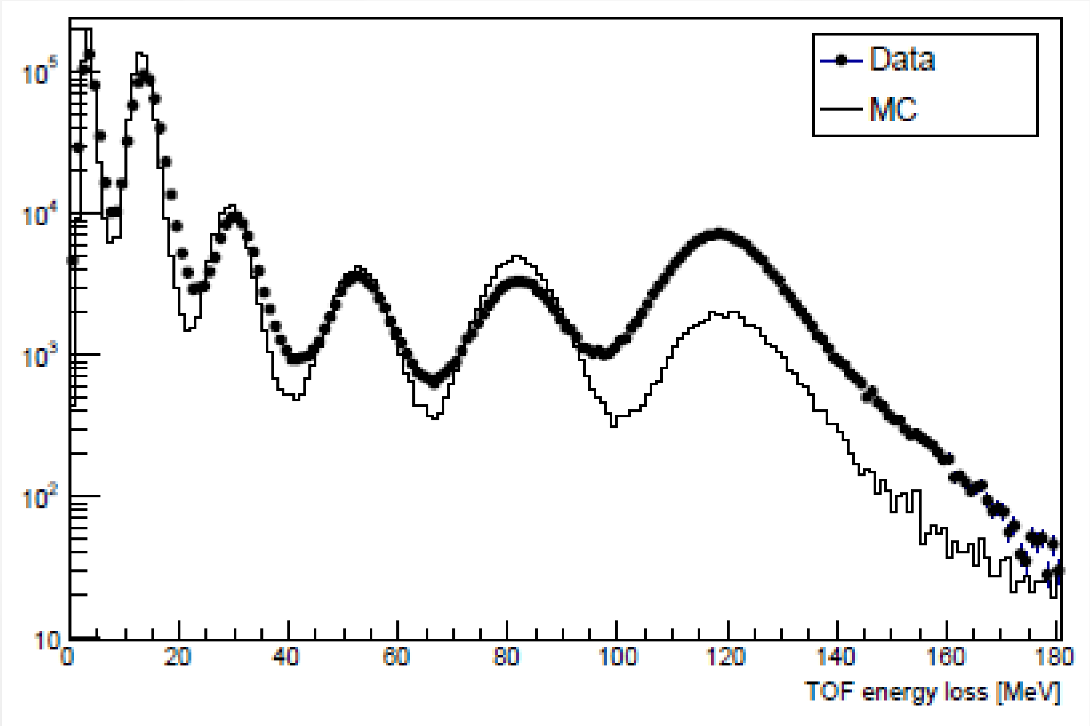


Spares

6Li cross section and errors

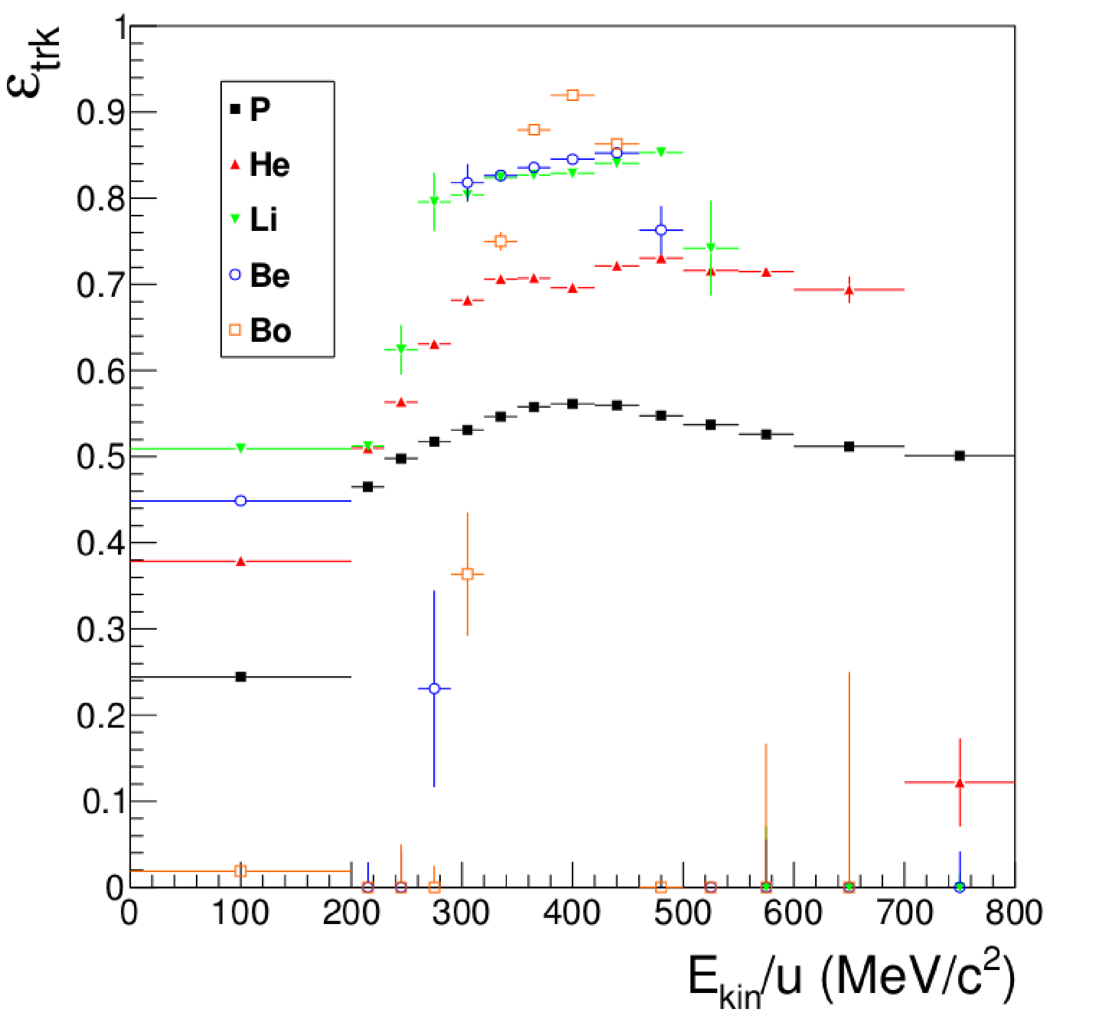
XS	err stat	total err
1.38139	(0.0888688)	(0.312815)
1.51467	(0.0839612)	(0.160131)
1.45442	(0.0782966)	(0.224024)
1.31614	(0.070099)	(0.20693)
1.04426	(0.0555479)	(0.164698)
0.799785	(0.042621)	(0.169955)
0.488607	(0.0264287)	(0.128335)
0.362457	(0.019806)	(0.112709)
0.137794	(0.008153)	(0.0768184)
0.0902991	(0.00557967)	(0.0385802)
0.0652363	(0.00421244)	(0.0241954)
0.0467943	(0.00316514)	(0.0166364)
0.0361728	(0.00254492)	(0.00788141)
0.00799945	(0.00089142)	(0.00195703)
0.000204637	(0.000122739)	(0.000143663)

Eloss DT-MC comparison with carbon

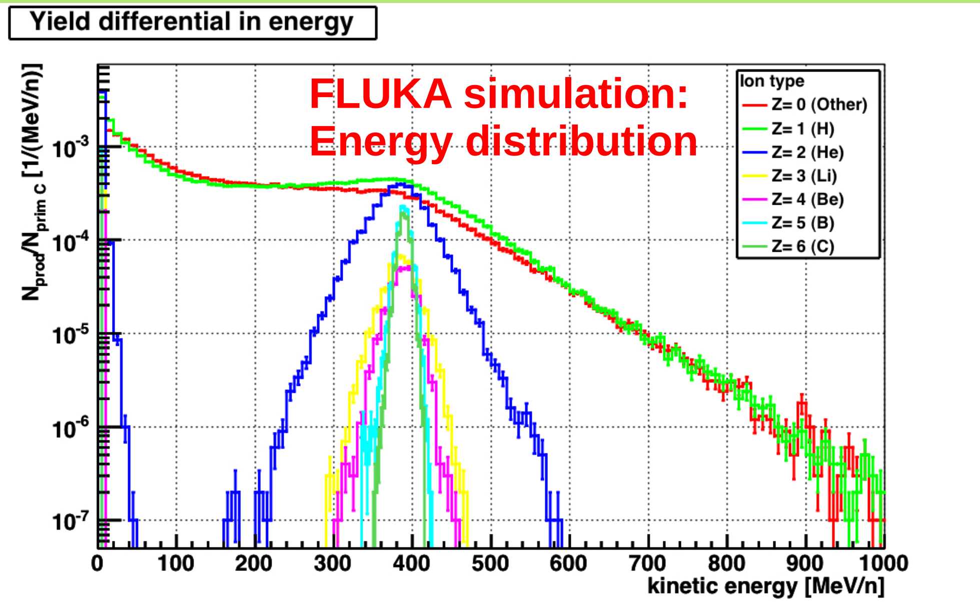


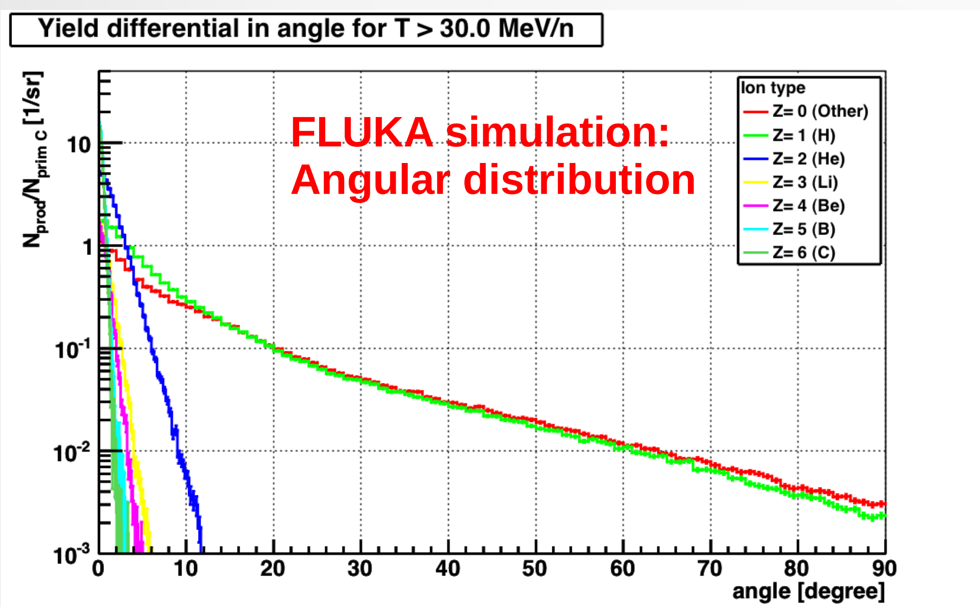
Efficiencies: issues

- Still need to decide:
  - how to handle the “low statistics” bins for Ekin.
  - how to quote a dedicated systematic uncertainty



FIRST Detector optimization





(What do we expect from MC?)

Performed a simulation of a 400 MeV/u ^{12}C beam on a 0.5 cm carbon target using the FLUKA MC software

Z>2 fragments ~ same velocity of the ^{12}C ions. Emitted in forward direction

Protons & neutrons are the most abundant fragments: wide β spectrum 0<β<0.6 and wide angular distribution

The dE/dX released by the fragments spans about from 2 to 100 m.i.p.

The FIRST apparatus

Start Counter (SC): thin scintillator. N_C, start of ToF and trigger

Beam Monitor (BM): drift chamber for beam direction and impact point measurements

Target (TG): carbon target with $\rho \times d = 3.62\ g/cm^2$

Vertex Detctor (VD): pixel silicon detector. Tracks direction θ (±40°), φ (2π)

Proton Tagger (PT): plastic scint. and scint. fibers. Position, ToF, dE/dX for θ>5° H & He

ToF Wall (TW): two layers of plastic scint. Position, Z_ID, ToF for trks θ < 5°

Beam Veto (BV): non interacting beam veto