Status of paper on FIRST results

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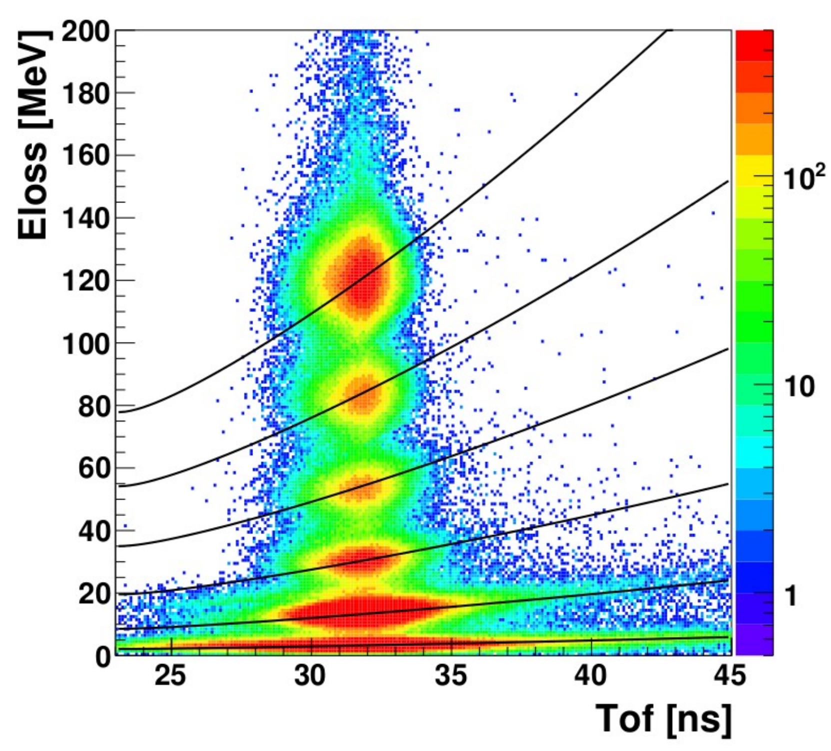
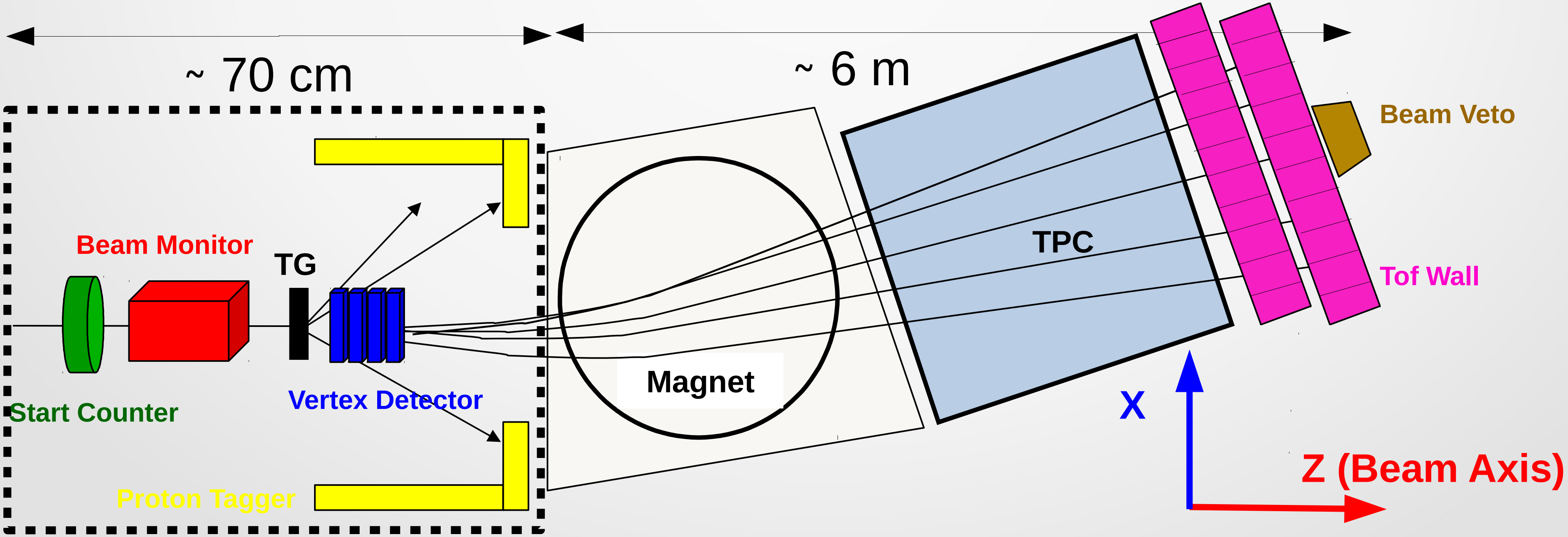
The FIRST apparatus

- **Vertex detector (VTX): tracking resolution < 10 μm (x,y) and < 50 μm (z)**
- **Tof Wall (TW). ToF resolution: σ_{ToF} ~ 800 ps, X & Y hit position resolution: σ_X ~ 0.7 cm , σ_Y ~ 2 – 9 cm, Eloss resolution: σ_E ~ 2 – 12 MeV**
- **VTX and TW are fundamental to reconstruct fragment tracks in the magnet acceptance (θ < 5°)**





Cross Section Measurements

FIRST measures the fragmentation of a C beam @ 400 MeV/u on a thin C target (8 mm)

Double differential cross section for the i-th isotope ^Z_AX with charge Z and mass number A:

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

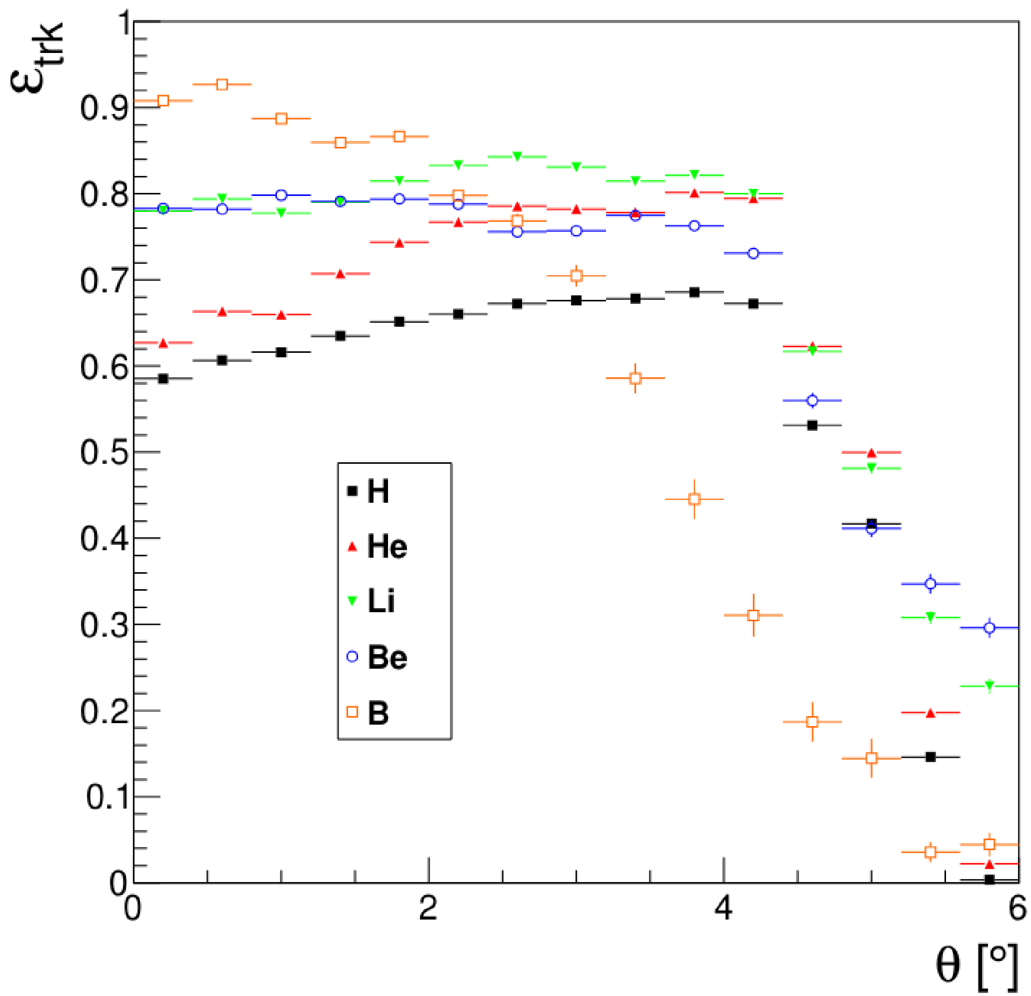
- **Y_i(θ,E)**: fragment yields for a given isotope ^Z_AX in an angular / energy bin ΔΩ / ΔE, **measured from mass fits**
- **ε_{trk}(θ,E)**: tracking reconstruction efficiency per angular/energy bin
- **N $_{TG}$**: number of atoms in the target per unit surface
- **N $_C$**: number of total carbon impinging on the target from Start Counter

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
- In order to cross check the efficiencies and to assess a systematic uncertainty we are producing a biased MC in which we shoot fragments from the target itself [full theta, E_{kin} phase space coverage]



Fragment yields measurements

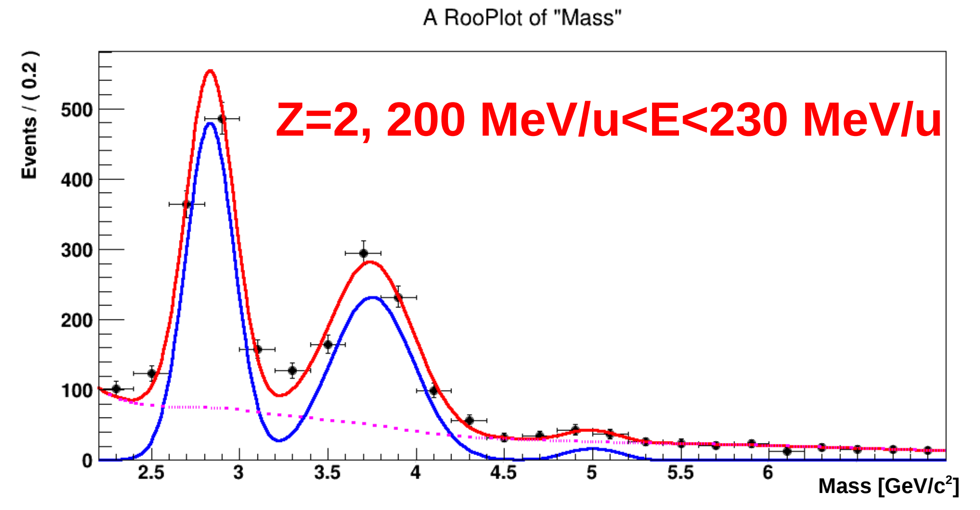
The reconstructed mass spectra are fitted, for each charge and angular (energy) bin ΔΩ (ΔE) to measure the fragment yield Y_i for each isotope $^{Z}_{A}X$

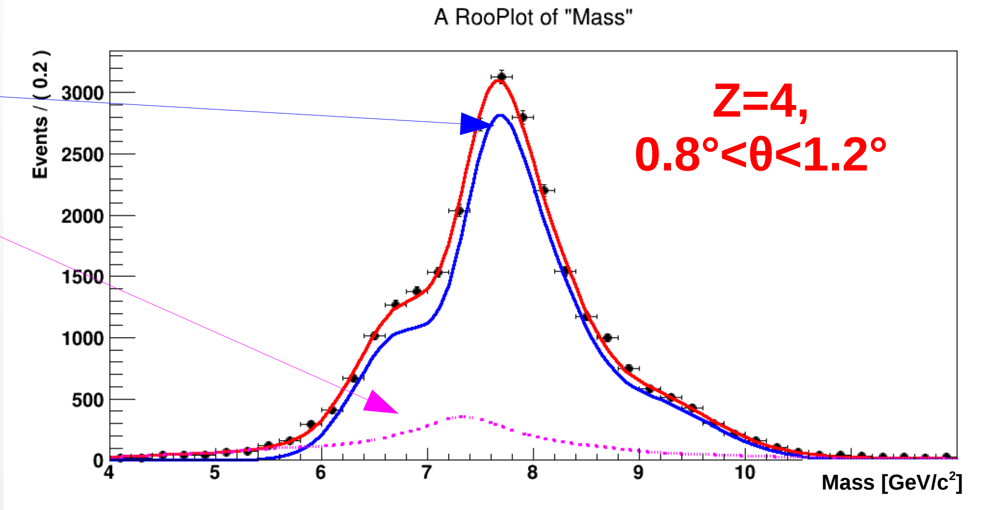
The Y_i yield are measured using an unbinned extended maximum likelihood fit: we get the yields of signal and background with uncertainties

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

Background PDFs are taking into account the combinatorial background (see next slides)

The crossfeed background is subtracted from the signal yield to take into account the contamination from isotopes with a wrong charge ID in the fit range (see next slides)

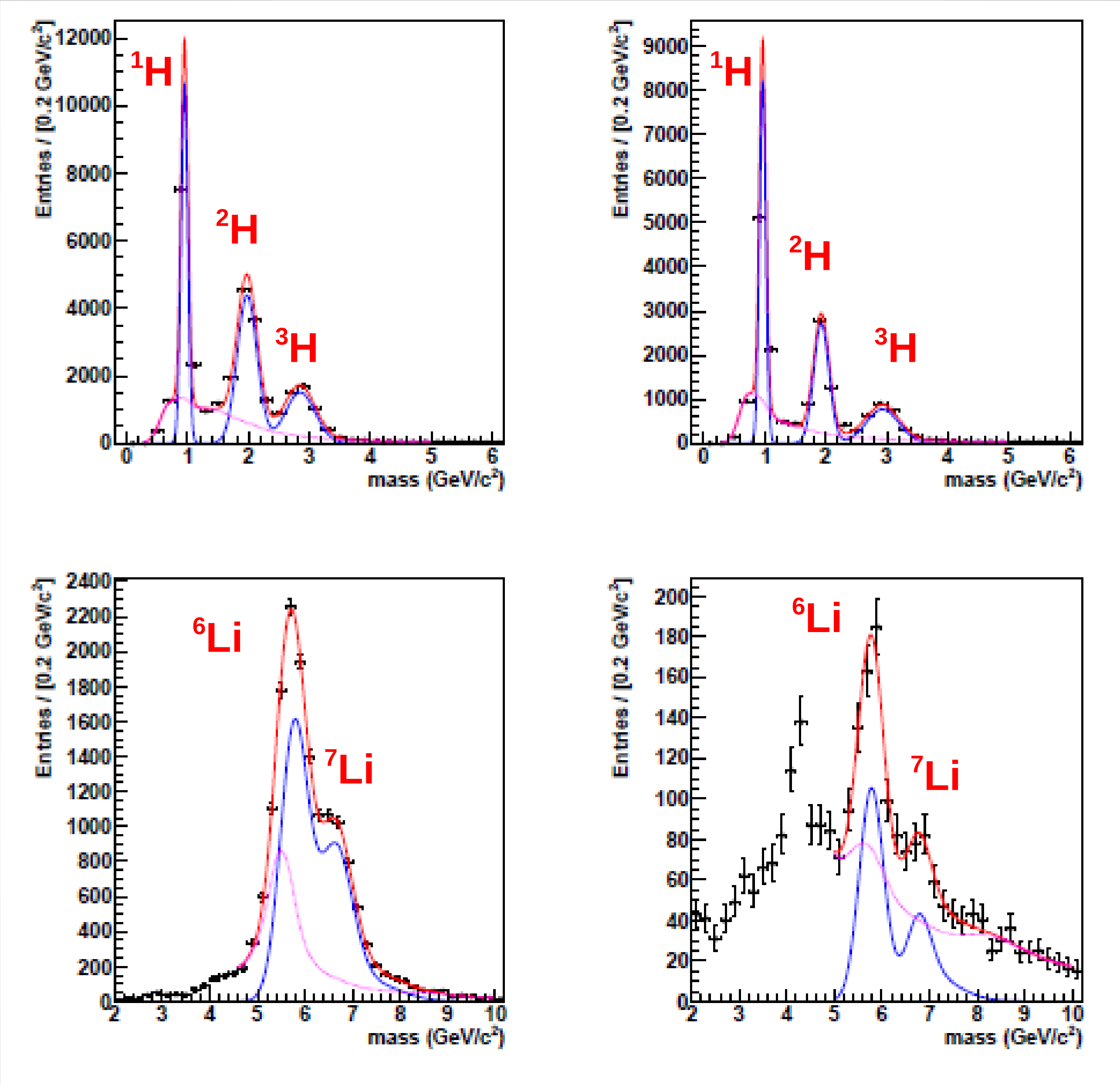




Z = 1, 3 mass fit results

Z=1
0.4°< θ <0.8°

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



Z=3
1.2°< θ <1.6°

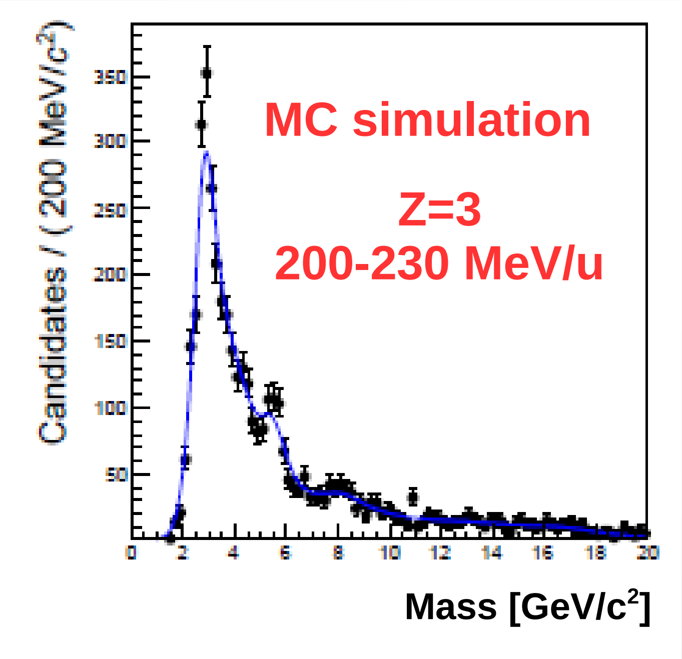
Z=3
(260 < E < 290)
MeV/u

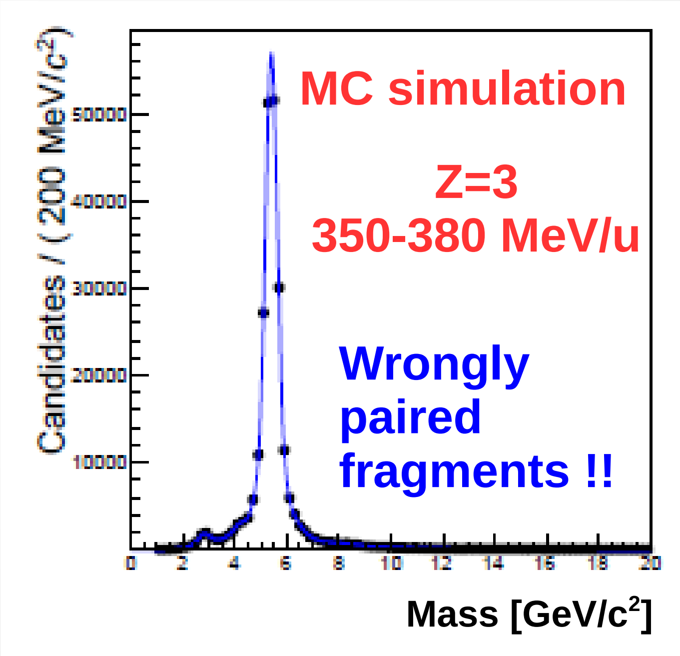
Combinatorial background

- **In the MC study, a fragment is marked as combinatorial background candidate whenever a track from VTX is paired with a hit from TW that does not belong to the SAME fragment.**
- The combinatorial background has to be taken into account and subtracted 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

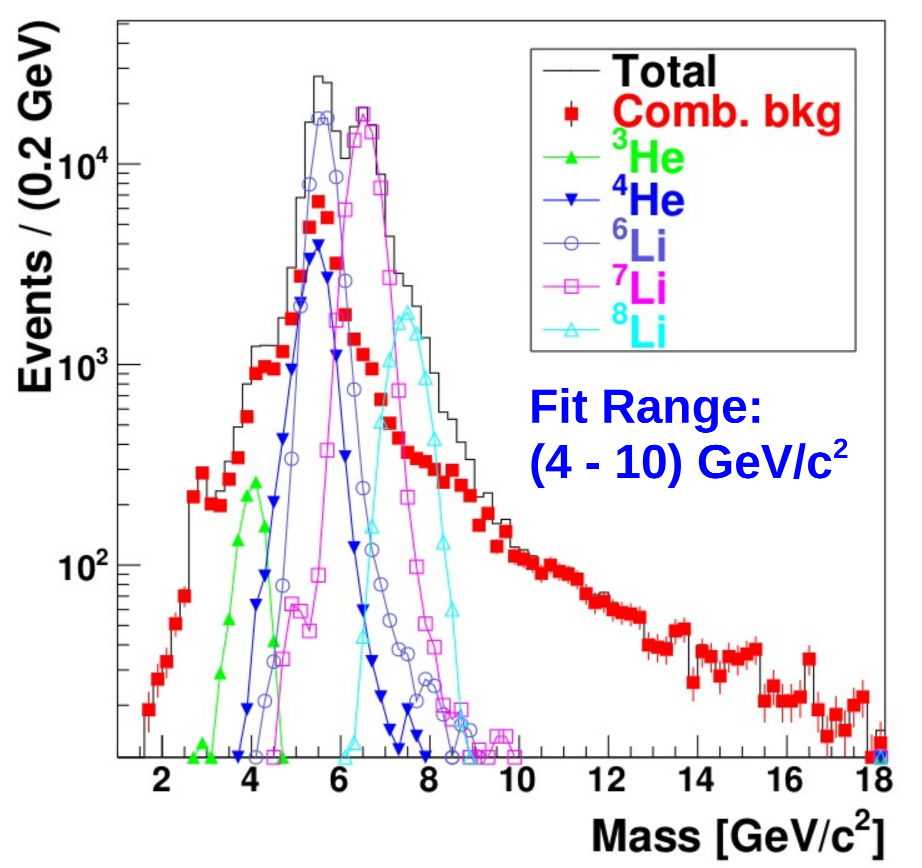
- The combinatorial background PDFs to be used in the mass fits are obtained, for each angular/energy bin, from a MC sample in which all the WRONG combinations are selected at MC truth level.
- The background PDF component has been modeled using a kernel estimation algorithm *(Cranmer KS. Computer Physics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



Fit Range: (4 - 10) GeV/c^2

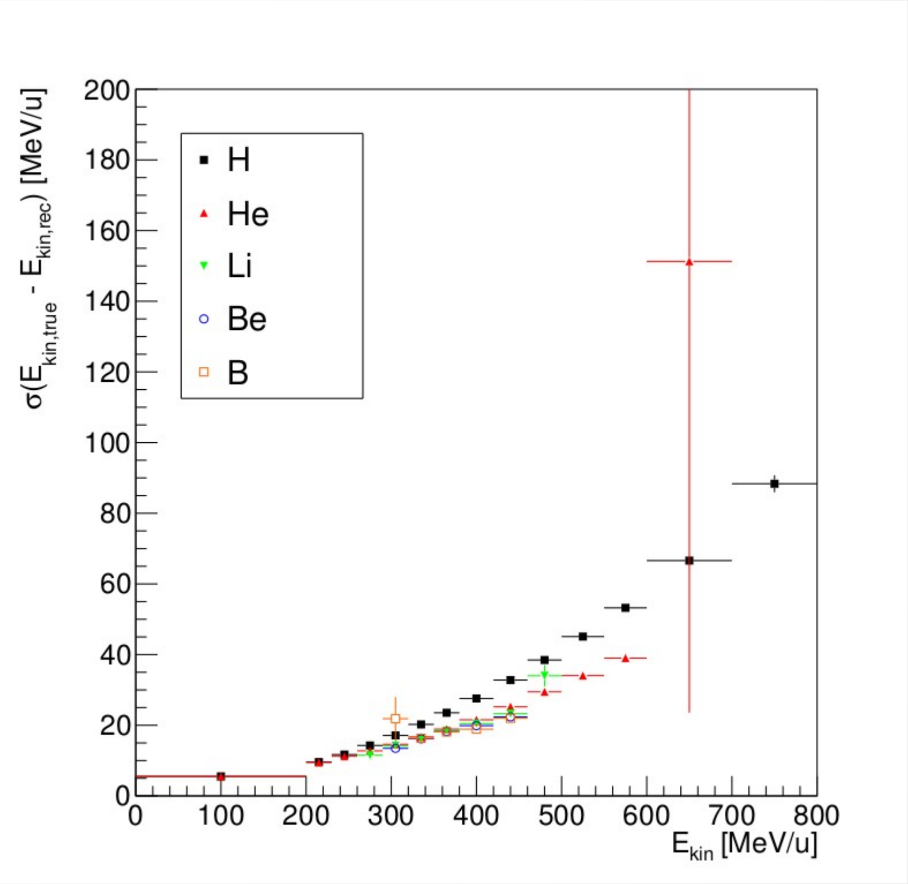
1. In red is the combinatorial background
2. The signal are 6Li, 7Li and 8Li
3. The contamination to be taken into account with crossfeed correction is the isotope 4He under the 6Li

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....
- **When applying the corrections we are sensitive to the difference btw the ratio of production cross sections in data and MC.**
- So we have rescaled the fractions of yields accordingly to what we have measured on data respect to MC
- **The Xfeed is relevant only for ^{4}He ↔ ^{6}Li and ^{7}Be ↔ ^{8}B contaminations (where 10%-20% corrections max are applied now)...**

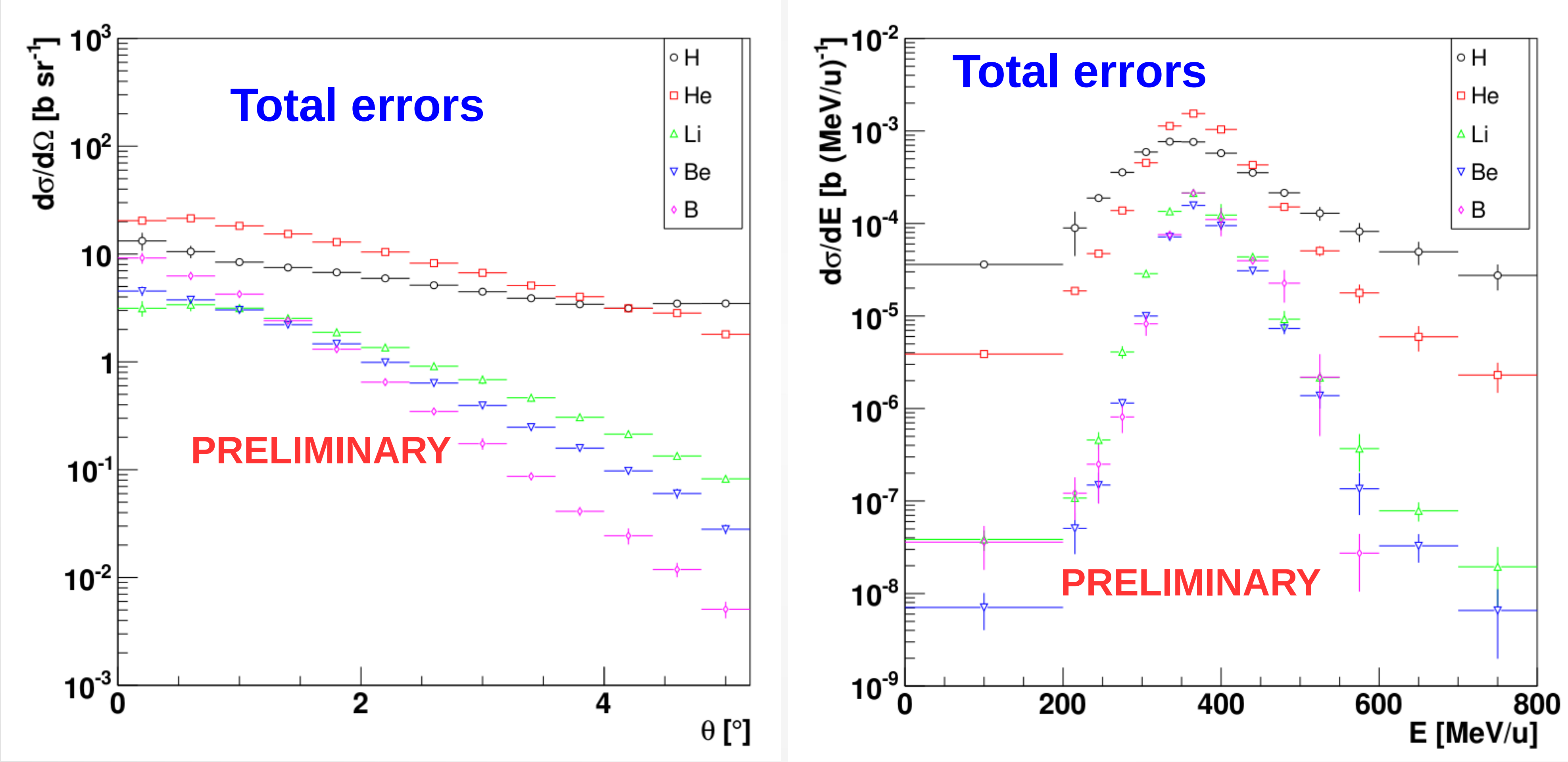
E_{kin} distribution unfolding (to be finalized)

- **The kinetic energy resolution degrades, as expected, linearly with the fragments kinetic energy**



- **In order to correct the measured energy for this resolution effect an unfolding procedure has been setup using the TUnfold package of ROOT**
- A biased MC simulation has to be used for this purpose: a sample of 10 M events for each isotope has been generated with FLUKA shooting directly from the TG itself a fragment with a flat production E_{kin} /u spectrum in the range 0-0.8 GeV/u
- Using this MC simulation it is possible to build the 2-dim unfolding matrix that holds the information needed to translate the measured energy in a production energy measurement

Single differential cross sections vs θ, E_{kin}

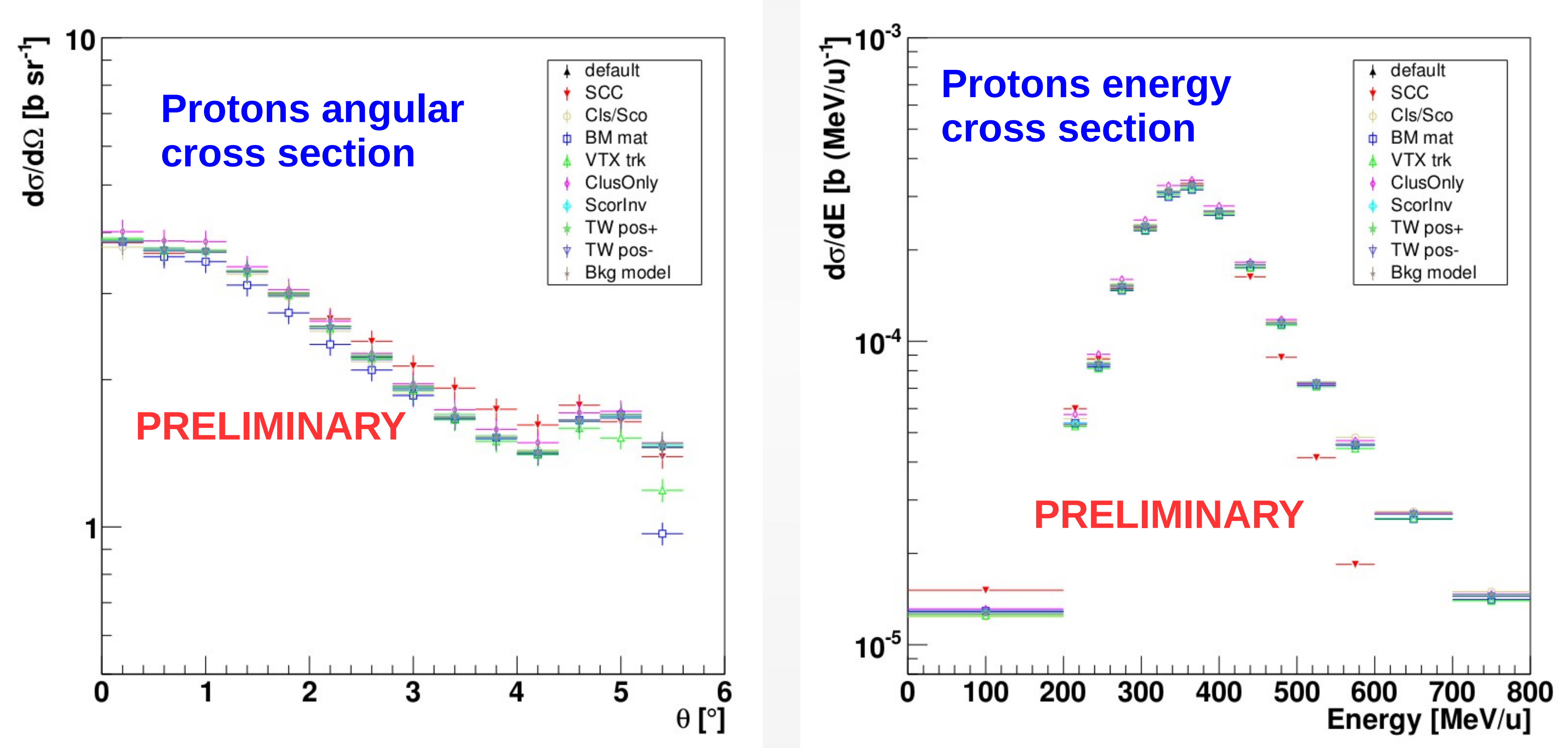


- **In these plots the measured distributions have not yet been unfolded to take into account the detector resolution**

Systematics (I)

- **Our measurement is dominated by systematics uncertainties**
- How do we compute systematics?
  - **We redo the analysis several times**, changing the strategy, the algorithms, the corrections, **and we assign a systematic uncertainty to be added in quadrature to the stat uncertainty coming from the Default result** (used also to quote the central value)
- 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 been varied.

Systematics (II)



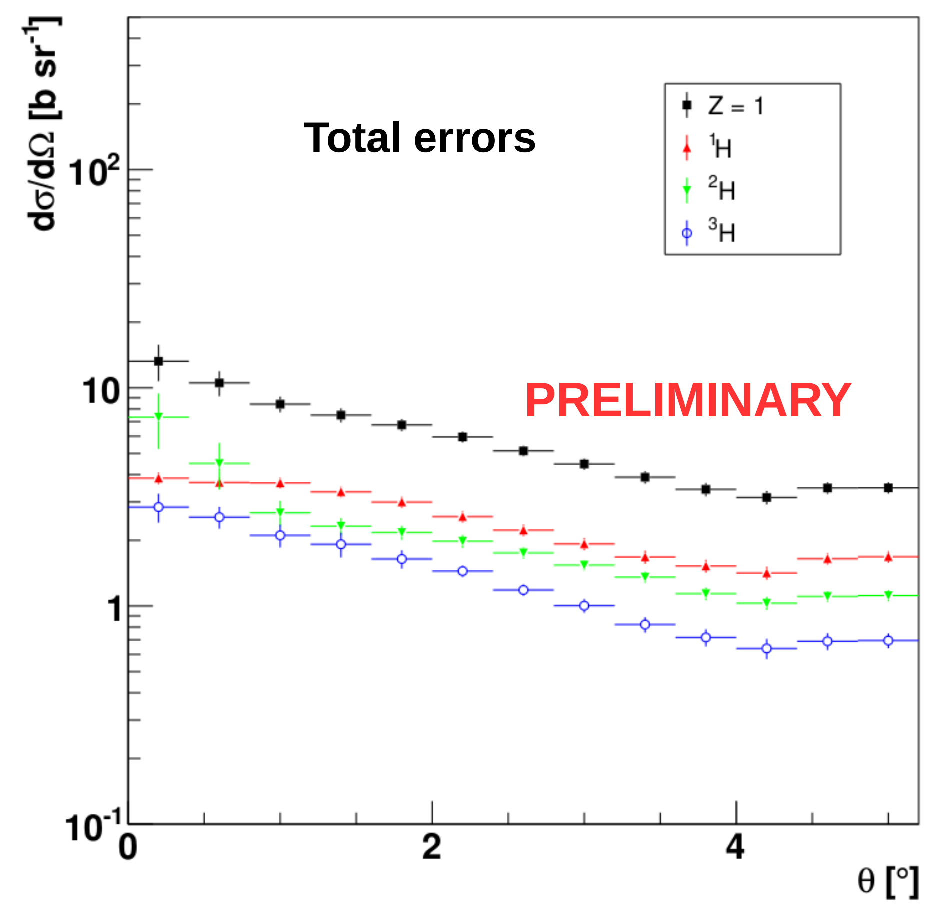
Effects of systematic checks on the production cross section of protons.
The production cross section obtained changing the analysis strategy, algorithm and cuts is shown.

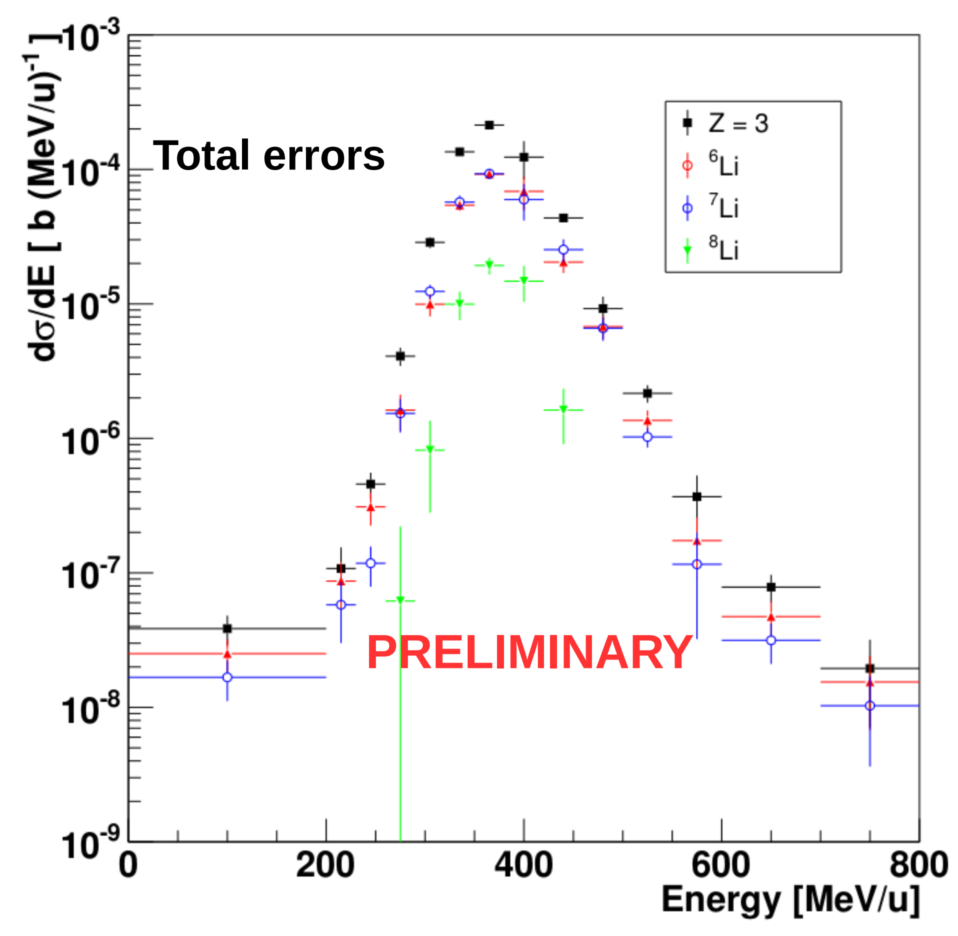
Isotopic cross sections

Left : Proton, deuterium and tritium angular differential cross sections

Right : Lithium isotopes energy differential cross sections

Full set of results will be tabulated/ plotted for each isotope in the paper appendix





Comparison with other measurements

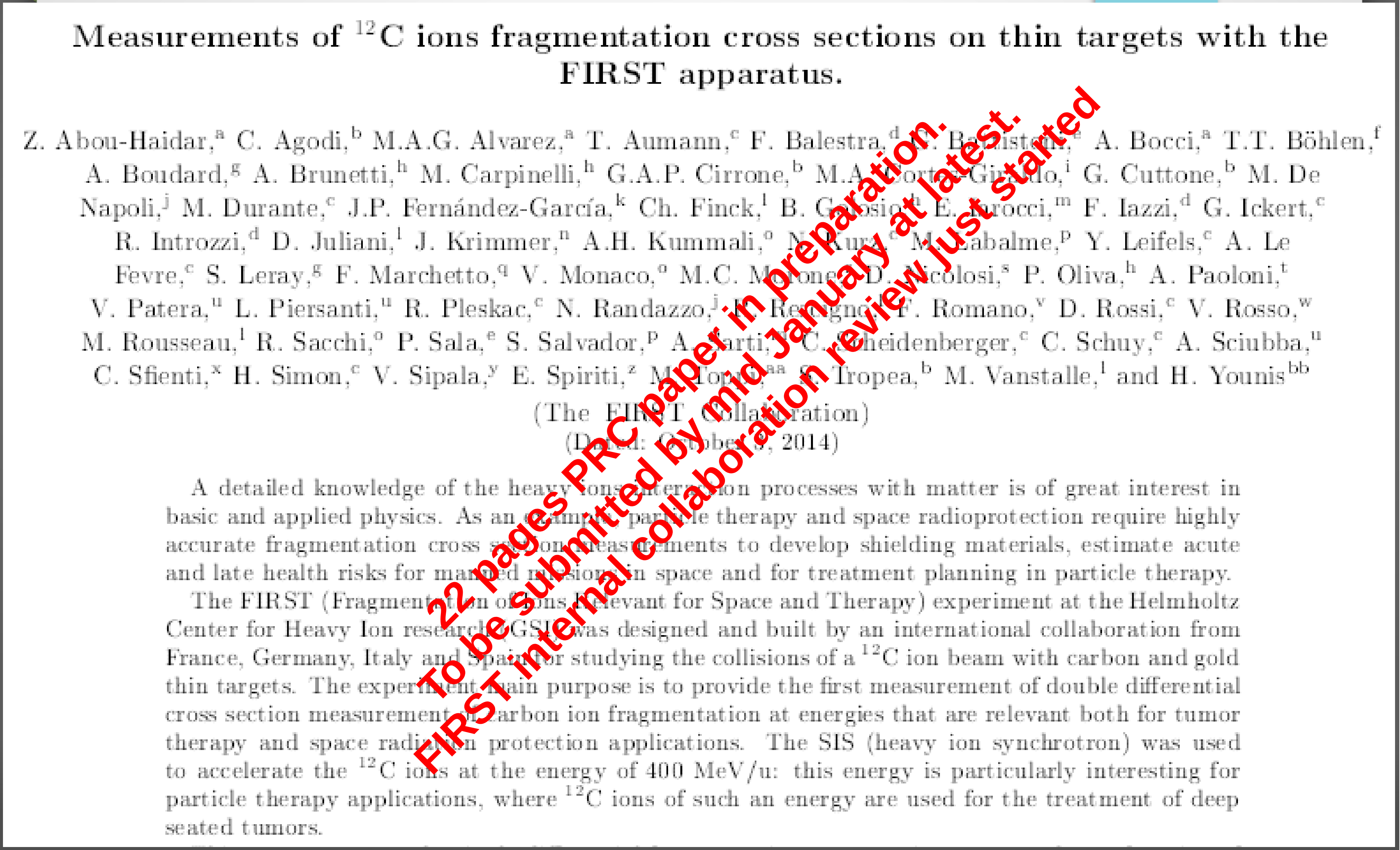
- Comparison with three experiments that have studied total and partial charge-changing (TCC, PCC) fragmentation cross section for C+C reaction in the energy range 400-450 MeV/u:
  - Webber et al, Phys.Rev C, vol. 41, N. 2 (1990) → TCC
  - Zeitlin et al., Phys. Rev. C vol. 76 (2007) → TCC, PCC, differential in angle for θ = 5°
  - Alpat et al., IEEE TRANS. ON NUCL. SCIENCE, vol. 60, N. 6, (2013) → TCC

E_{BEAM} (MeV/u)	*ρ x d (g/cm^2)*	σ_{TCC} (mb)	Experiment
400	**1.734**	**672 ± 7**	Alpat et al.
400	**3.434**	**713 ± 11**	Alpat et al.
435	**7.03**	**672 ± 7**	Webber et al.
450	**7.03**	**670 ± 7**	Webber et al.
400	**2.0**	**713 ± 11**	Zeitlin et al.

Fragment charge	$d\sigma_{PCC}/d\Omega$ (b·sr^{-1})(FIRST) θ = 5°	$d\sigma_{PCC}/d\Omega$ (b·sr^{-1})(Zeitlin) θ = 5°
	1° < θ < 5°	*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**

Preliminary checks using full reco / only TW gave respectively 779 ± 3 mb and 650 ± 2 mb ← **ONLY STAT ERRORS**

The paper...



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

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(The FIRST Collaboration)

(Dated: October [illegible], 2014)

A detailed knowledge of the heavy ions interaction processes with matter is of great interest in basic and applied physics. As an example, particle therapy and space radioprotection require highly accurate fragmentation cross section measurements to develop shielding materials, estimate acute and late health risks for manned missions in space and for treatment planning in particle therapy.

The FIRST (Fragmentation of Ions Relevant for Space and Therapy) experiment at the Helmholtz Center for Heavy Ion research (GSI) was designed and built by an international collaboration from France, Germany, Italy and Spain for studying the collisions of a ^{12}C ion beam with carbon and gold thin targets. The experiment main purpose is to provide the first measurement of double differential cross section measurement of carbon ion fragmentation at energies that are relevant both for tumor therapy and space radiation protection applications. The SIS (heavy ion synchrotron) was used to accelerate the ^{12}C ions at the energy of 400 MeV/u: this energy is particularly interesting for particle therapy applications, where ^{12}C ions of such an energy are used for the treatment of deep seated tumors.

22 pages PRC paper in preparation.

To be submitted by mid January at latest.

FIRST internal collaboration review just started