Measurement of charged fragments production cross sections (dσ/dE) in the interactions of C-ions with C,H,O targets

IlaMi for Roma and Milano, June 2018

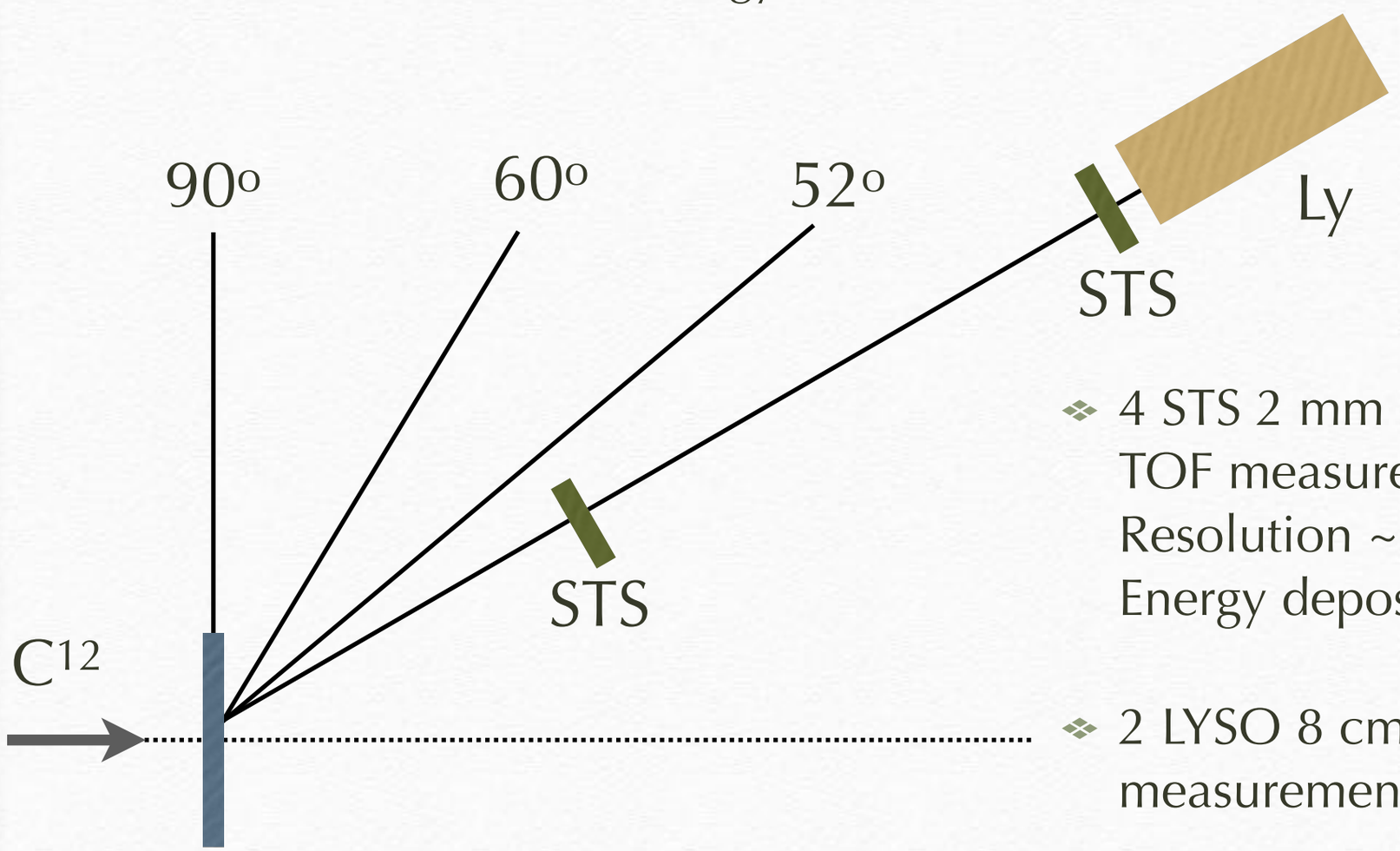
Experimental SETUP

CNAO

Thin Targets based on C,H and O elements: PMMA, Graphite and Plastic Scintillator

- The fragments production (Z=1) has been measured as a function of the kinetic energy for 4 angles;
- The Time of Flight in thin plastic scintillators and the energy deposit in the organic crystals has been used for PID and kinetic energy measurements;

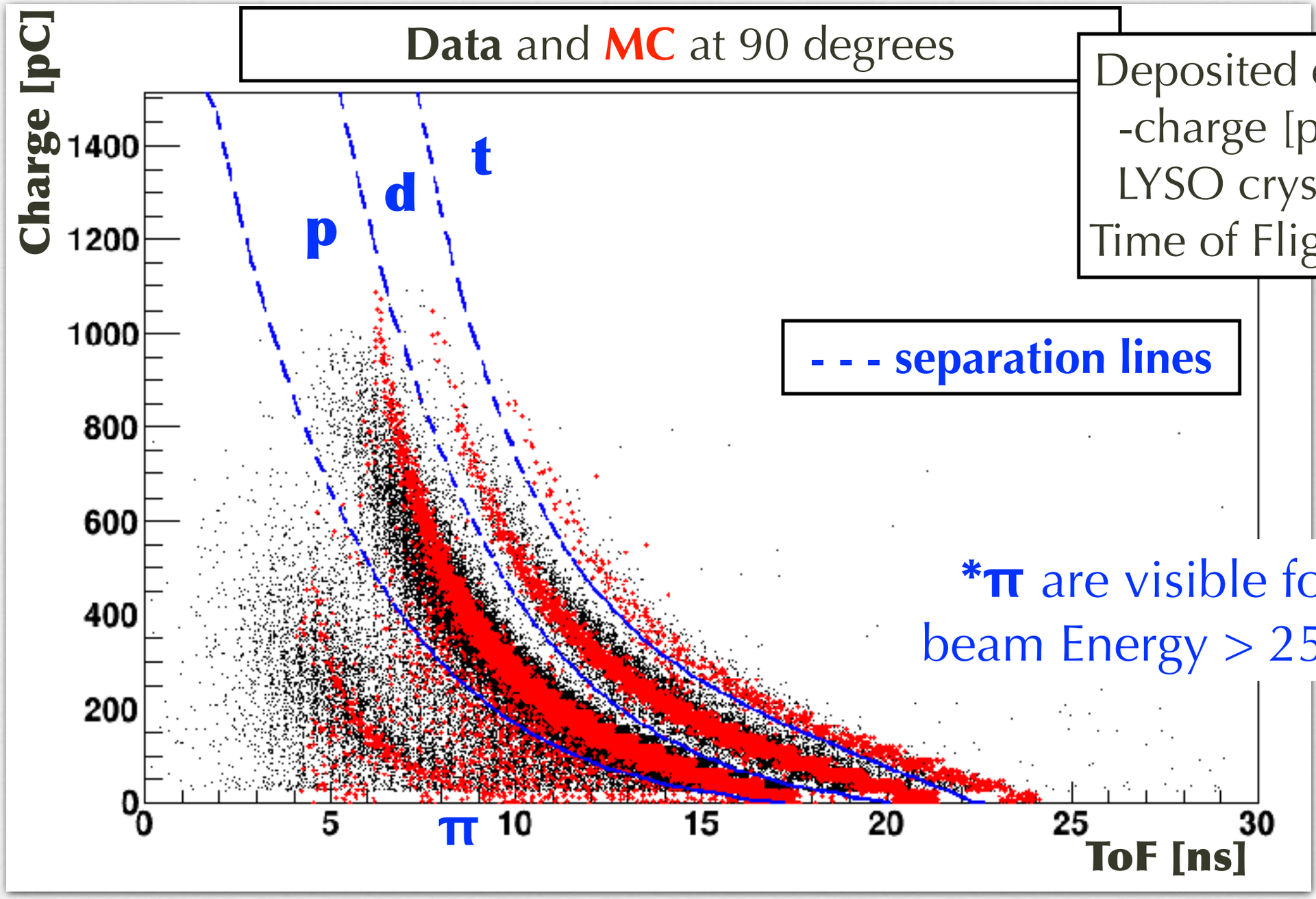
The thin targets do not require, in first approximation, the implementation of a correction for the fragments absorption inside the target.



- 4 STS 2 mm (distance 120 cm) for TOF measurements (Time Resolution ~500-700 ps) and Energy deposit measurements (dE)
- 2 LYSO 8 cm for Energy deposit measurements (E)

Particle ID

Protons and Deutons are selected from all other particles exploiting E vs ToF, dE vs E and dE vs ToF information.



Particle ID

Pro
E vs

Deposited energy -charge [pC] in LYSO crystal vs Time of Flight [ns]

Data and **MC** at 60 degrees

He3,4

p

t

π

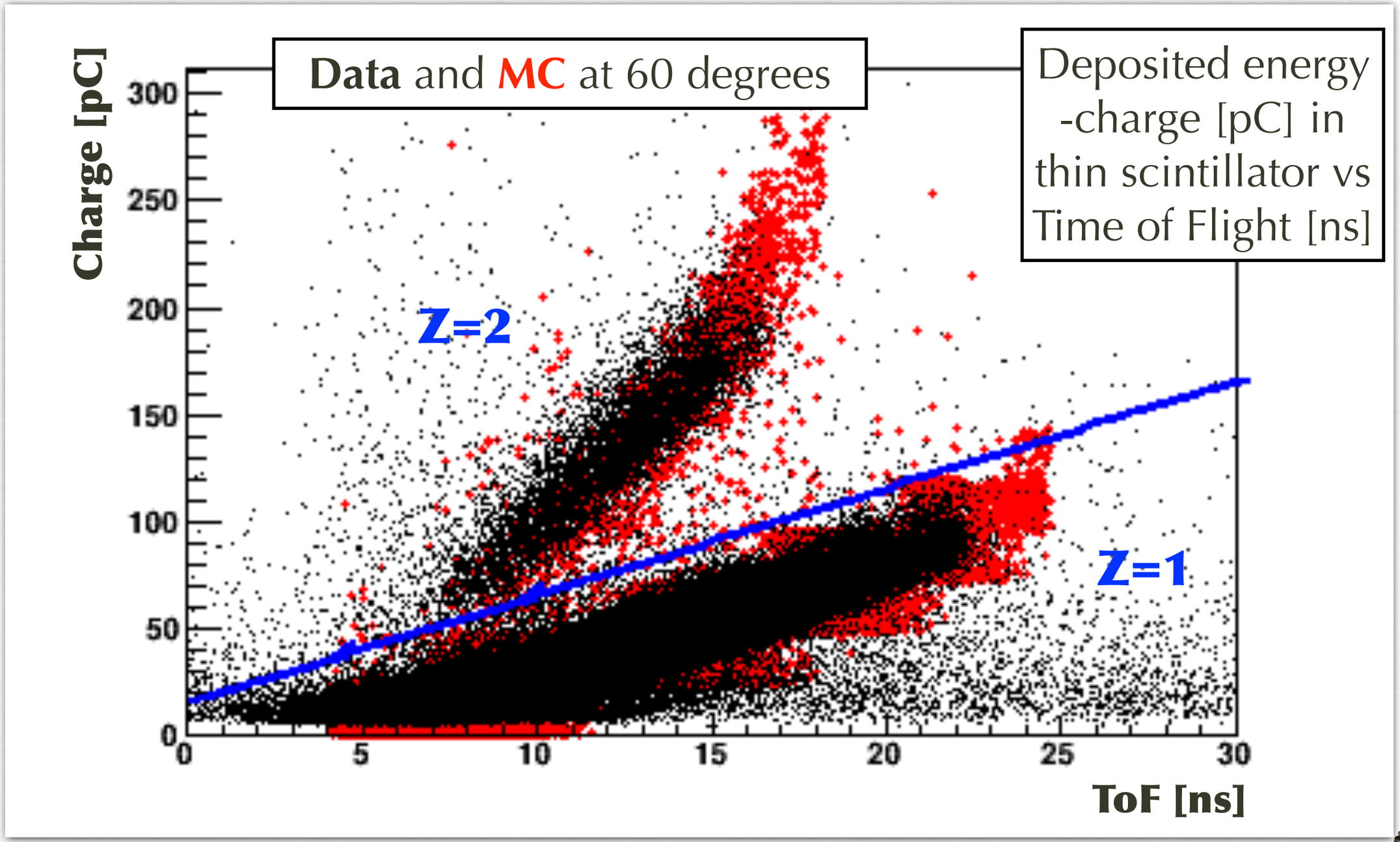
d

Charge [pC]

ToF [ns]

Particle ID

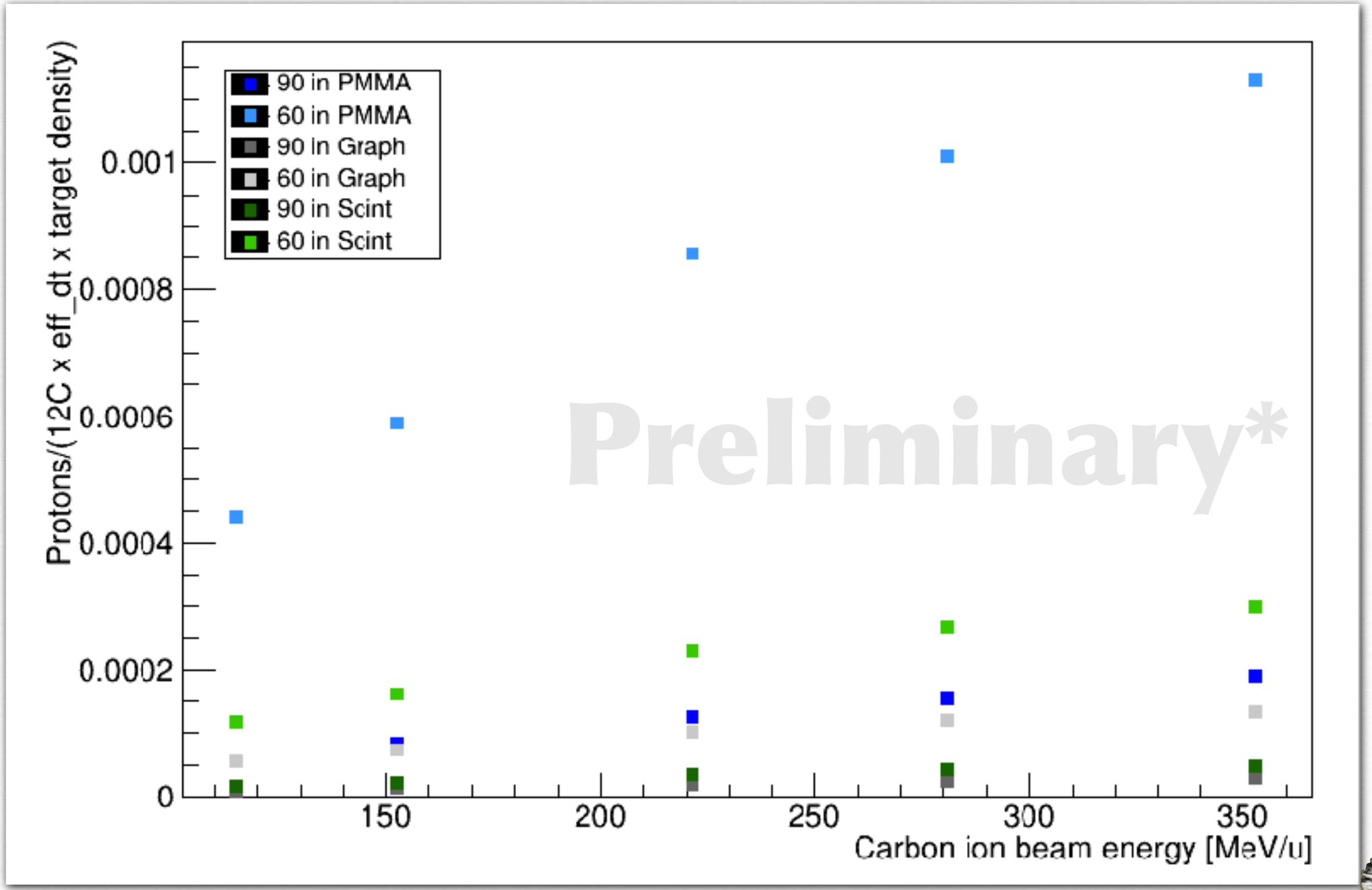
Protons and Deutons are selected from all other particles exploiting E vs ToF, dE vs E and dE vs ToF information.



Protons

*Only statistical uncertainties

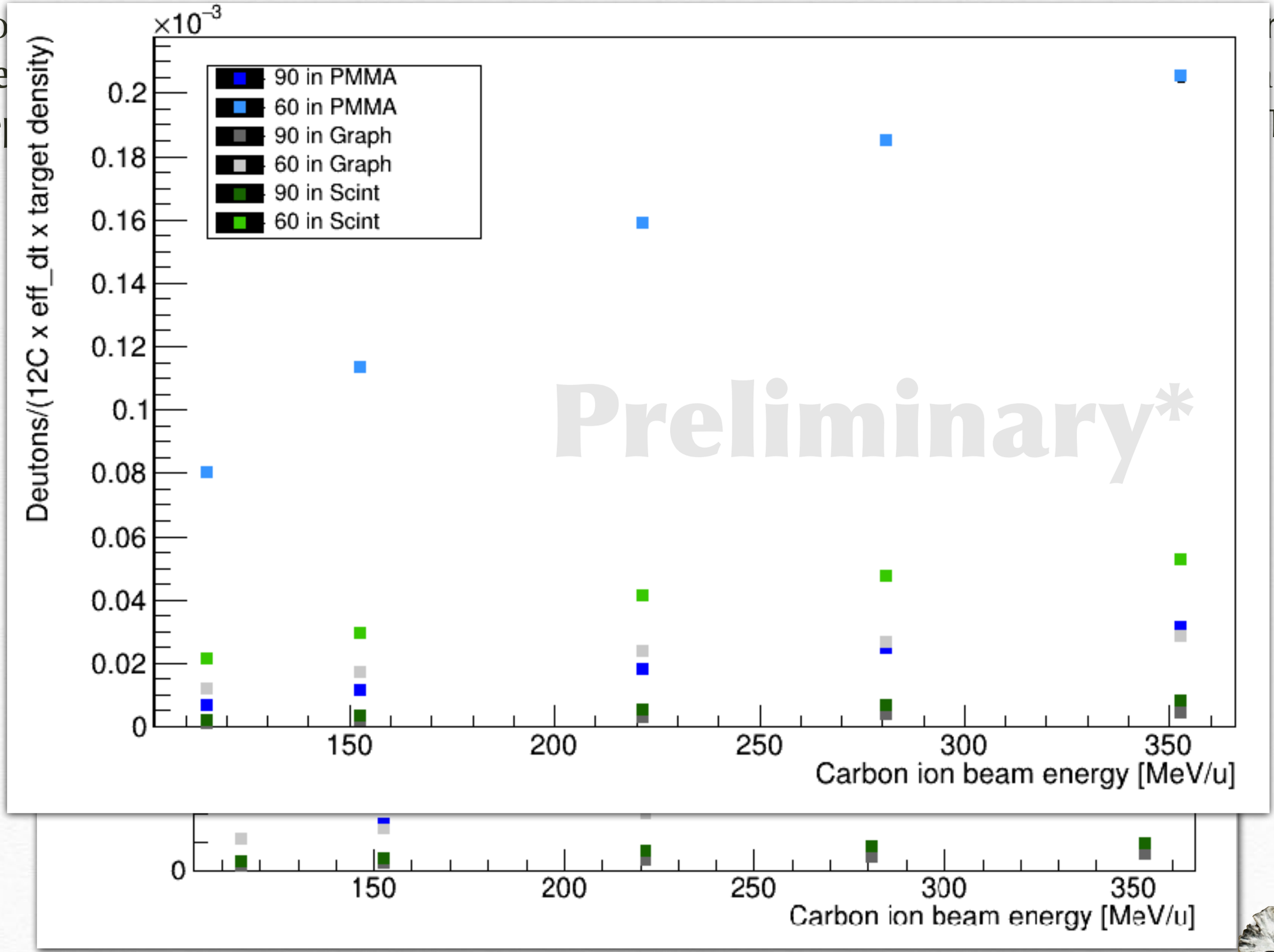
For the different beam energies we evaluated the number of **protons and deutons** in PMMA, Graphite and Scintillator. The data at 90° and 60° are reported here normalised to the number of Carbon ions and corrected by the DT.



Deutons

*Only statistical uncertainties

Fo **nd** **de** re re T.



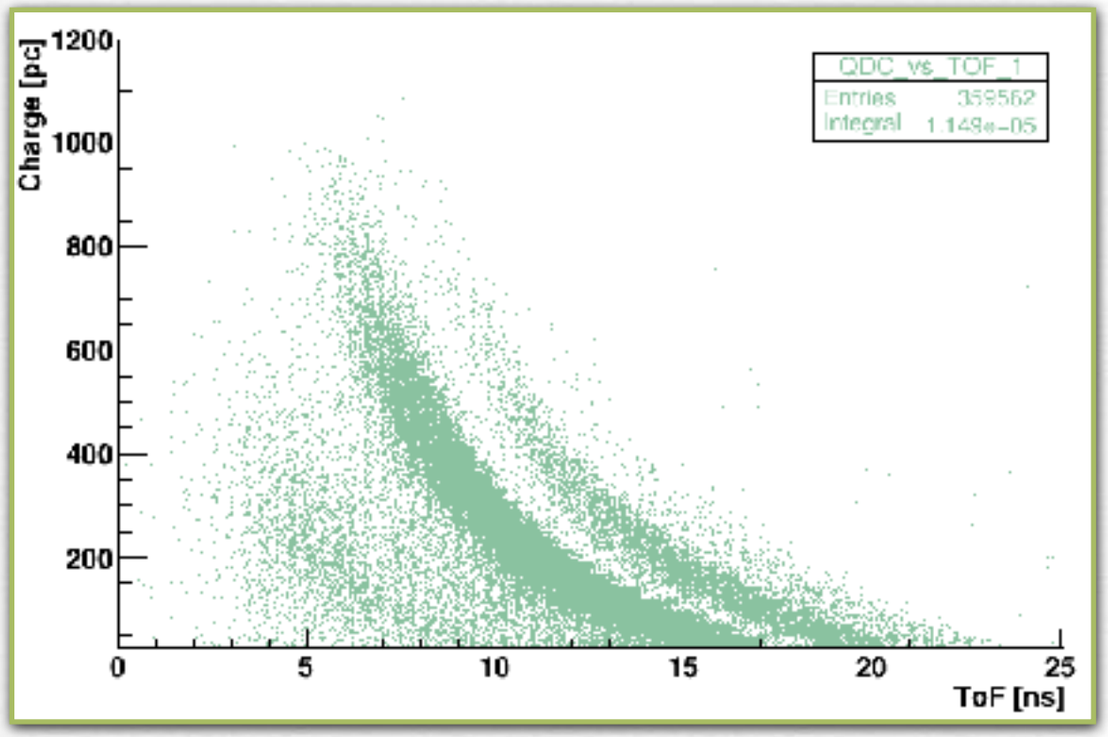
Cross section

The ^{12}C fragmentation cross sections for a $^{A}_{Z}$X fragment are obtained as:

$$\frac{d\sigma}{dE}\left({}^{A}_{Z}X\right) = \frac{N_{{}^{A}_{Z}X}}{N_{^{12}C}} \cdot \frac{(u.m.a.)}{\rho \cdot th \cdot N_A} \cdot \frac{1}{\epsilon} \cdot \frac{1}{bin_{size}}$$

From CNAO Dose Delivery

Solid angle and efficiencies

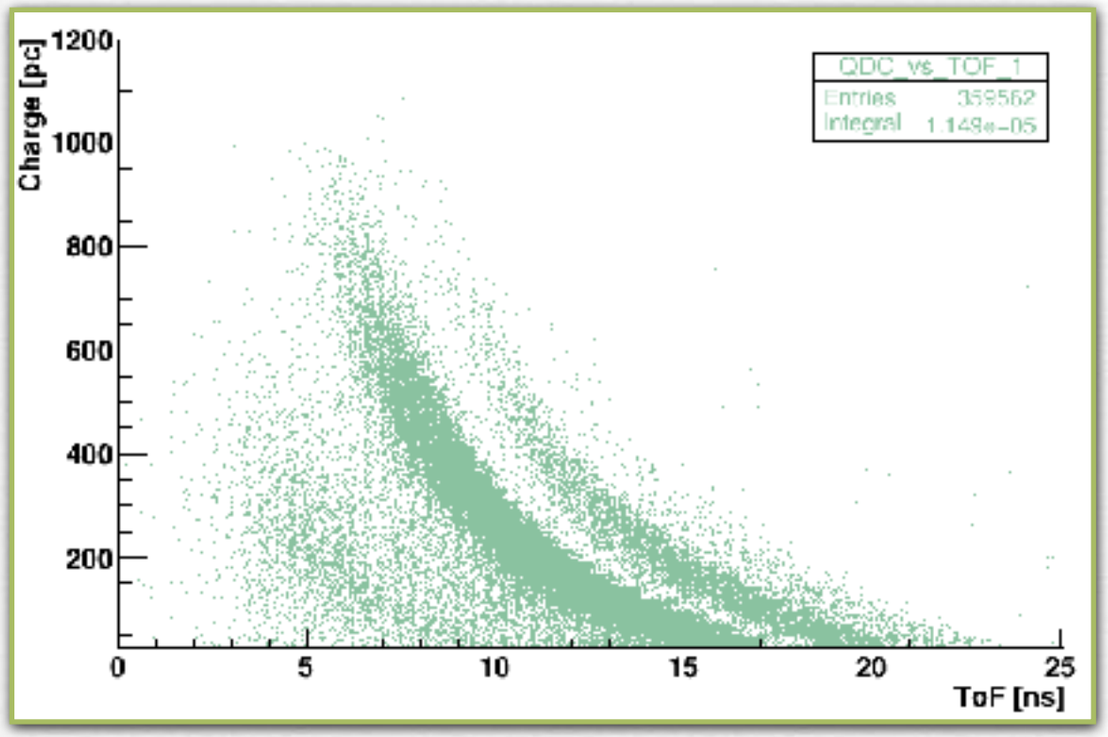


Cross section

The ^{12}C fragmentation cross sections for a $^{A}_{Z}X$ fragment are obtained as:

$$\frac{d\sigma}{dE}\left({}^{A}_{Z}X\right) = \frac{N_{{}^{A}_{Z}X}}{N_{^{12}C}} \cdot \frac{(u.m.a.)}{\rho \cdot th \cdot N_A} \cdot \frac{1}{\epsilon} \cdot \frac{1}{bin_{size}}$$

From CNAO Dose Delivery



Information of the target composition:

- PMMA C5O2H8 - 2mm - density 1.19 g/cm^3
- Graphite C - 1mm -density 0.94 g/cm^3
- Plastic Scintillator C2H4 - 2mm - density 1.024 g/cm^3

Cross section

The ^{12}C fragmentation cross sections for a $^{A}_{Z}$X fragment are obtained as:

$$\frac{d\sigma}{dE}\left({}^{A}_{Z}X\right) = \frac{N_{{}^{A}_{Z}X}}{N_{^{12}C}} \cdot \frac{(u.m.a.)}{\rho \cdot th \cdot N_A} \cdot \frac{1}{\epsilon} \cdot \frac{1}{bin_{size}}$$

From CNAO Dose Delivery

$$\epsilon = \epsilon_{MC} \cdot \epsilon_{Sel} \cdot \epsilon_{DT}$$

Protons and deutons impinged on the experimental setup to calculate the geometrical acceptance and the trigger+detection efficiency

Measurements of the DAQ dead time for each run (rate dependent)

Full simulation (C on Targets and fragments production). On the E (and dE) vs ToF distributions application of the PID selections tuned from data: evaluation of fragments (p, d) mis-identification.

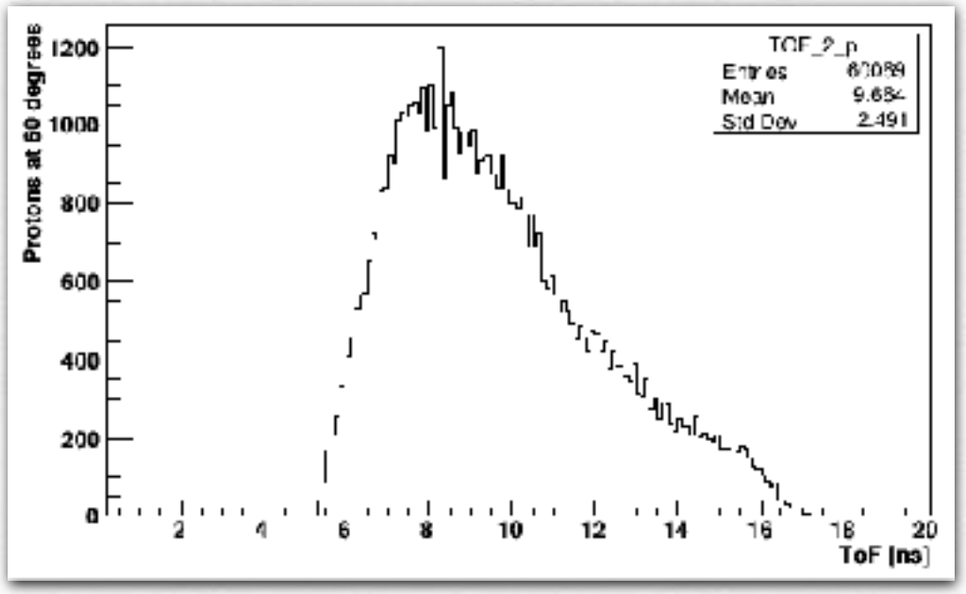
Information of the target compositions:

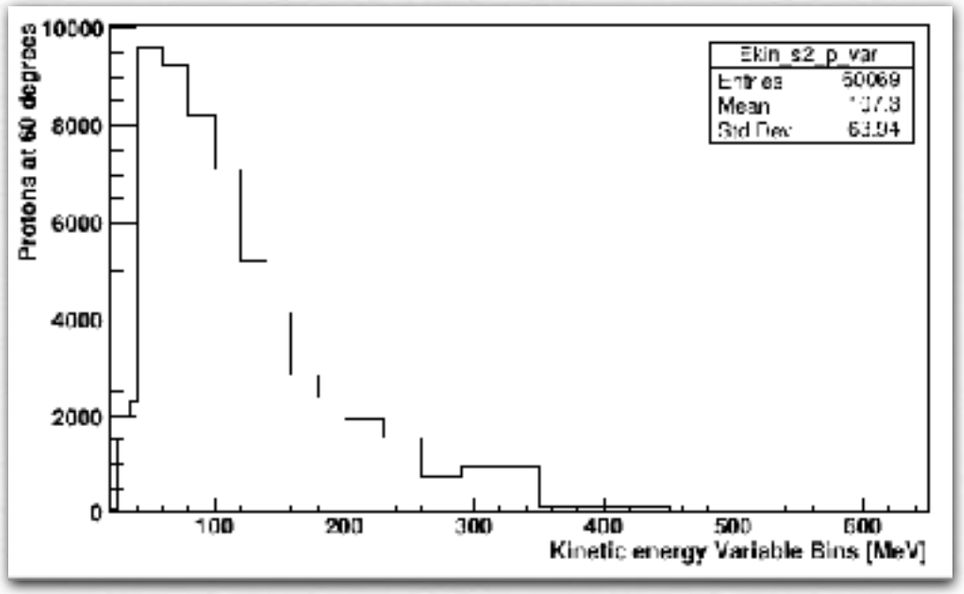
- PMMA C5O2H8 - 2mm - density 1.19 g/cm^3
- Graphite C - 1mm -density 0.94 g/cm^3
- Plastic Scintillator C2H4 - 2mm - density 1.024 g/cm^3

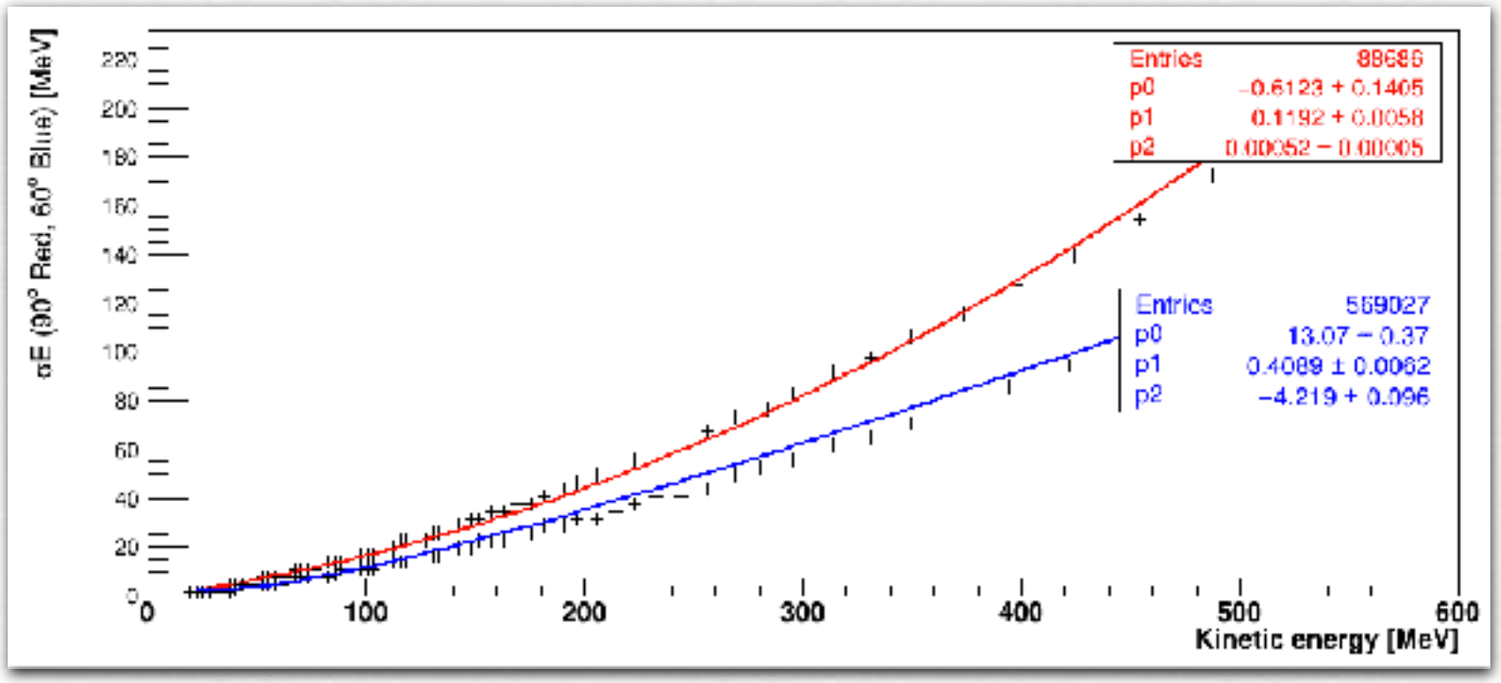
Energy spectra

*Only statistical uncertainties

Es. data at 60 degrees. After the PID analysis, from the ToF of the particle we calculate the kinetic energy. The energy bin has been defined in order to match the measured energy resolution.







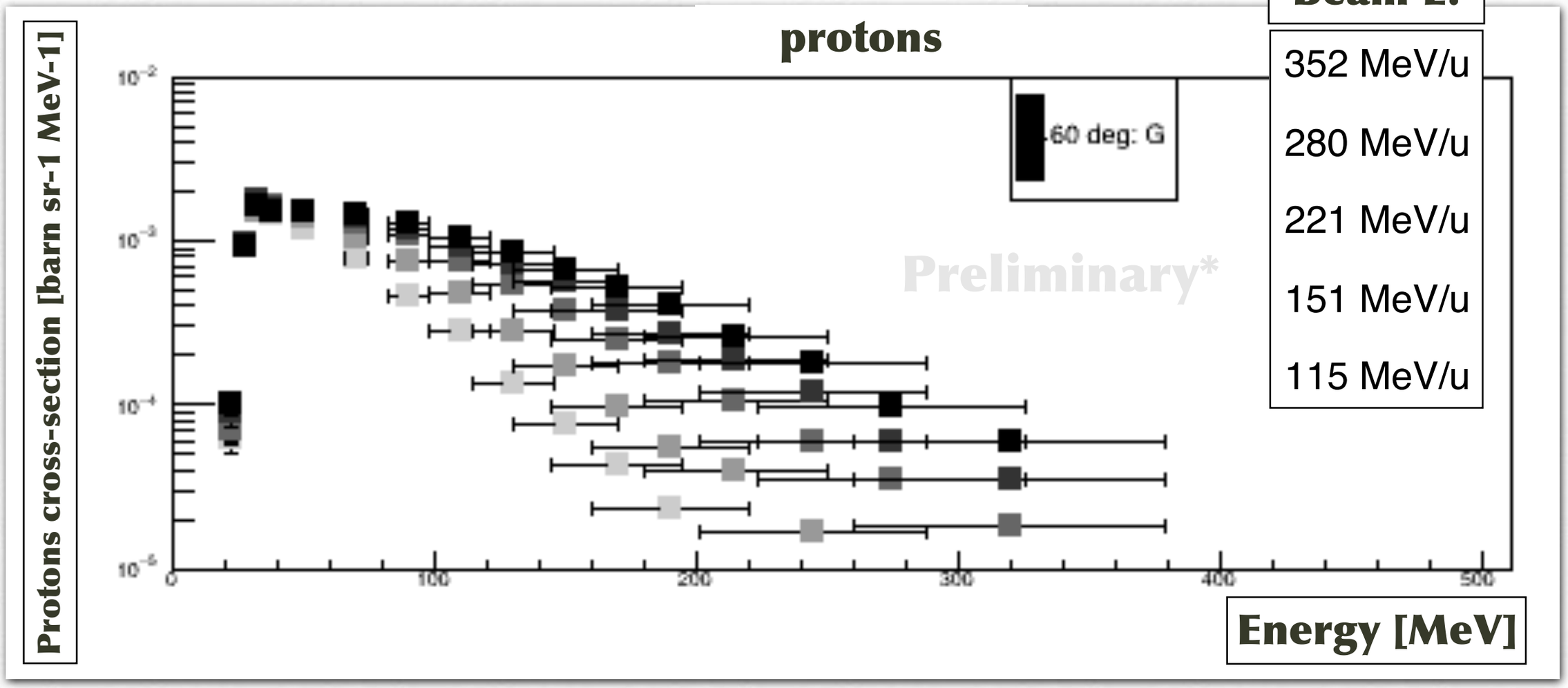
[0]+[1]*x+[2]*pow(x,2)
time res ~0.7 ns

[0]+[1]*x+[2]*pow(x,0.5)
time res ~0.5 ns

Cross section

*Only statistical uncertainties

Es. Graphite data at 60 degrees. All efficiencies included.



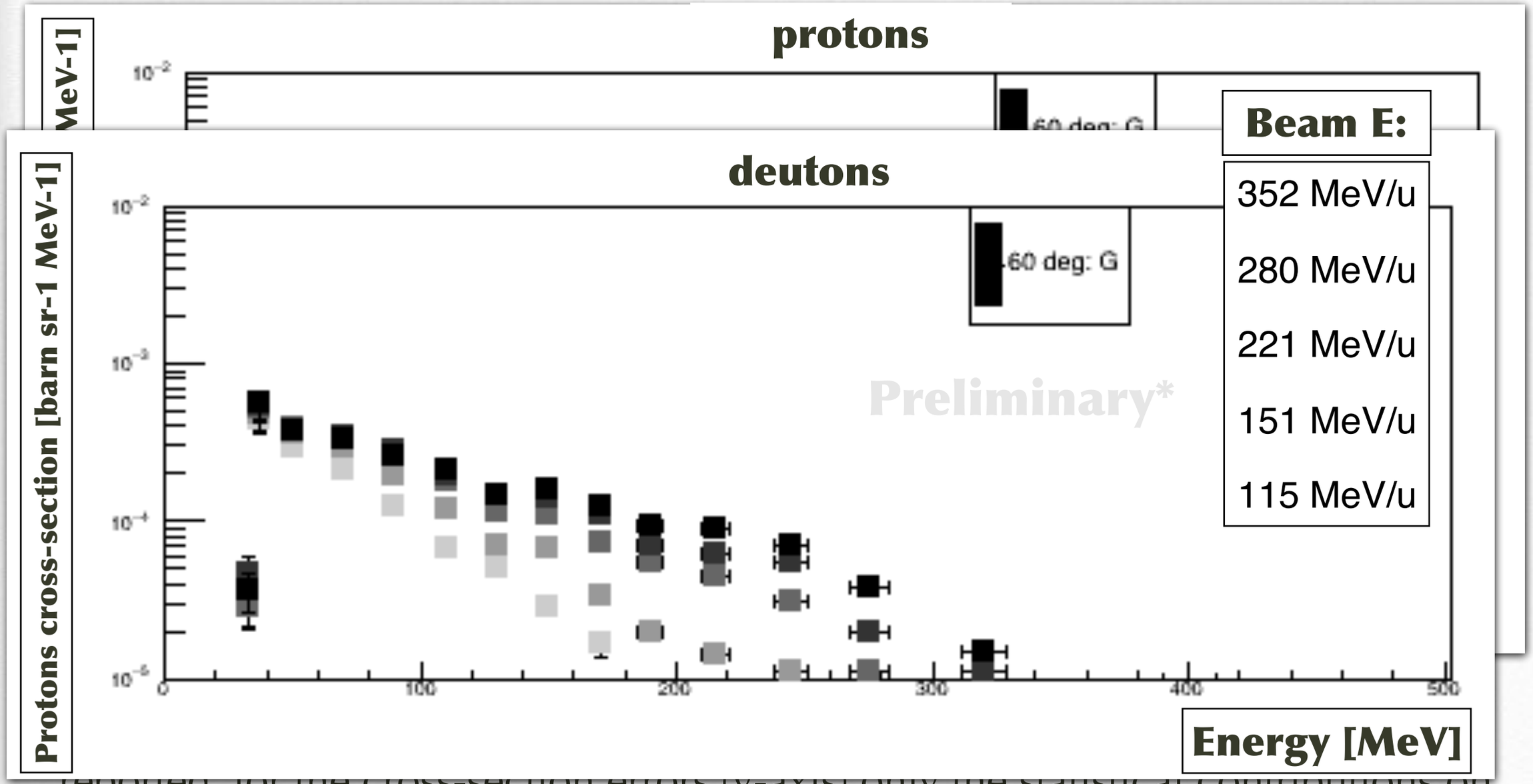
For the energy (x-axis) the energy resolution at the mean energy of the bin is reported, for the cross-section errors (y-axis) only the statistical contributions on N_frag, eps_DT, eps_Sel, eps_MC are included.

Analysis performed for all targets, protons and deutons, at 90° and 60°.

Cross section

*Only statistical uncertainties

Es. Graphite data at 60 degrees. All efficiencies included.



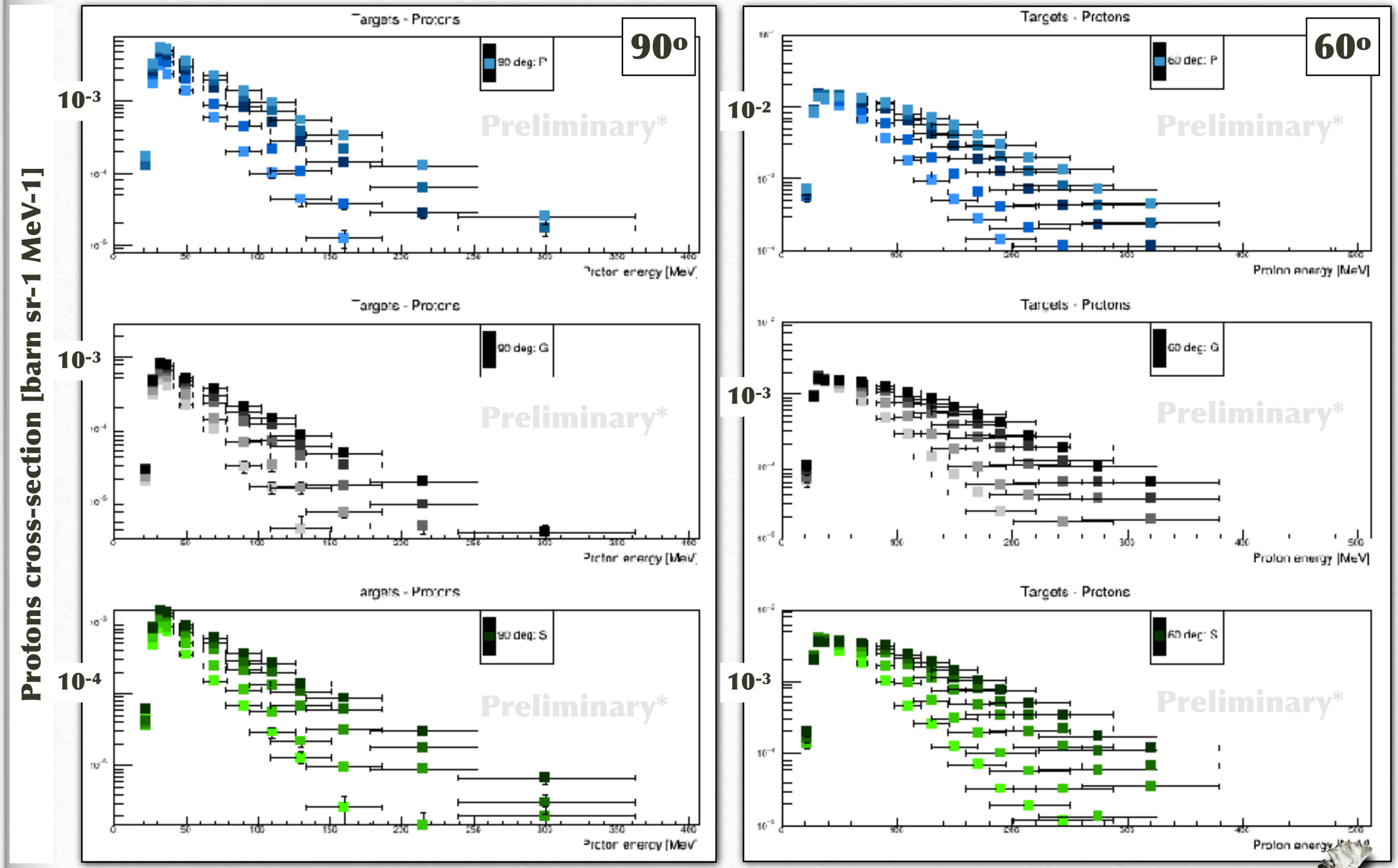
reported, for the cross-section errors (y-axis) only the statistical contributions on N_frag, eps_DT, eps_Sel, eps_MC are included.

Analysis performed for all targets, protons and deutons, at 90º and 60º.

Cross section

*Only statistical uncertainties

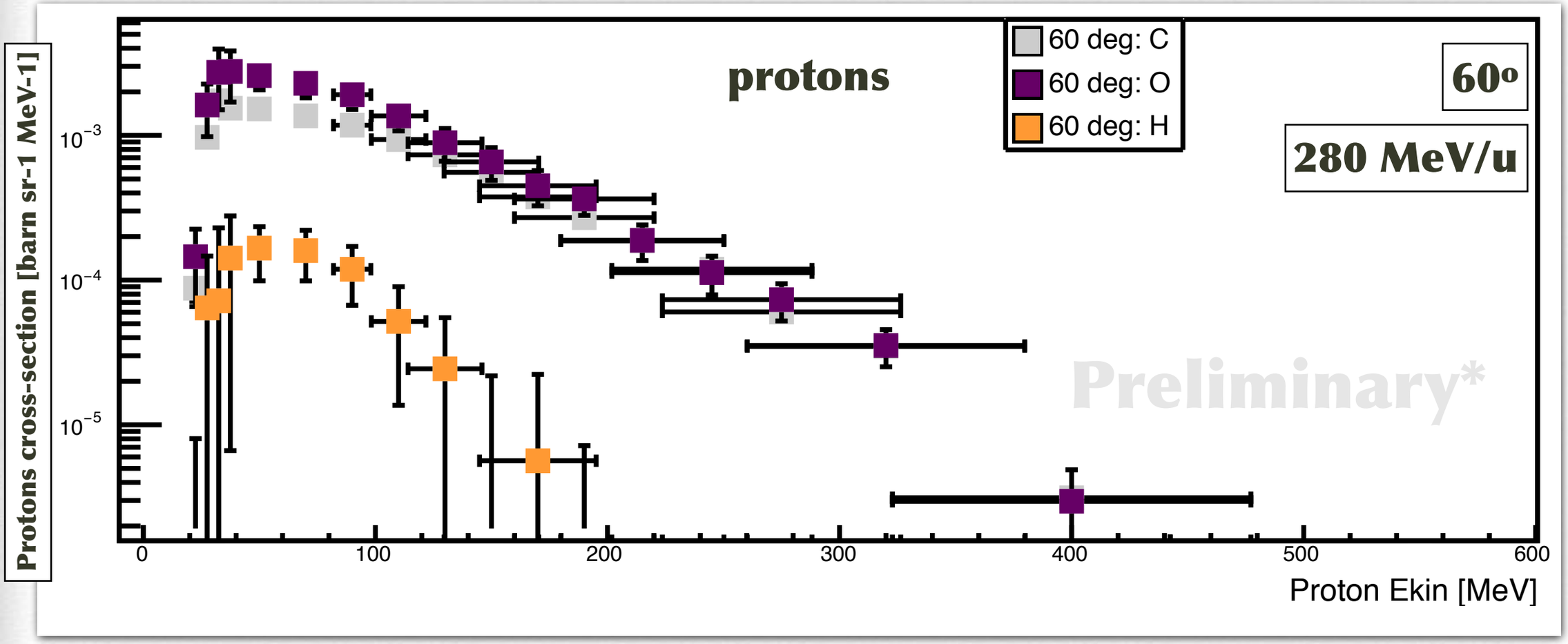
Per PMMA, Graphite and Plastic scintillator. All efficiencies included.



Cross section

*Only statistical uncertainties

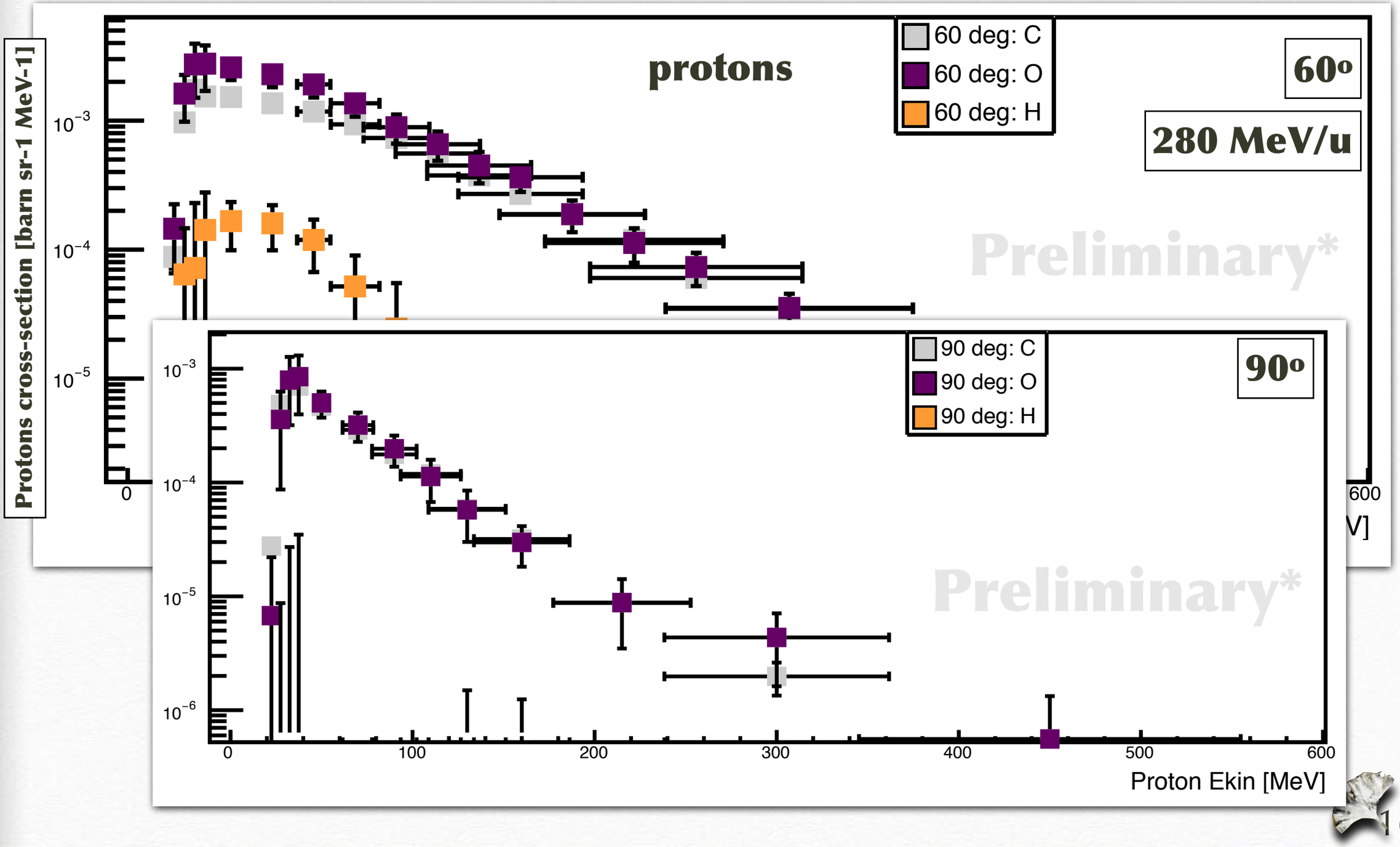
From the combination of the different targets (subtraction of C from C2H4 and of C and H from C5O2H8) we obtain the C, O, H proton production cross-sections as a function of the kinetic energy, at 90º and 60º.



Cross section

*Only statistical uncertainties

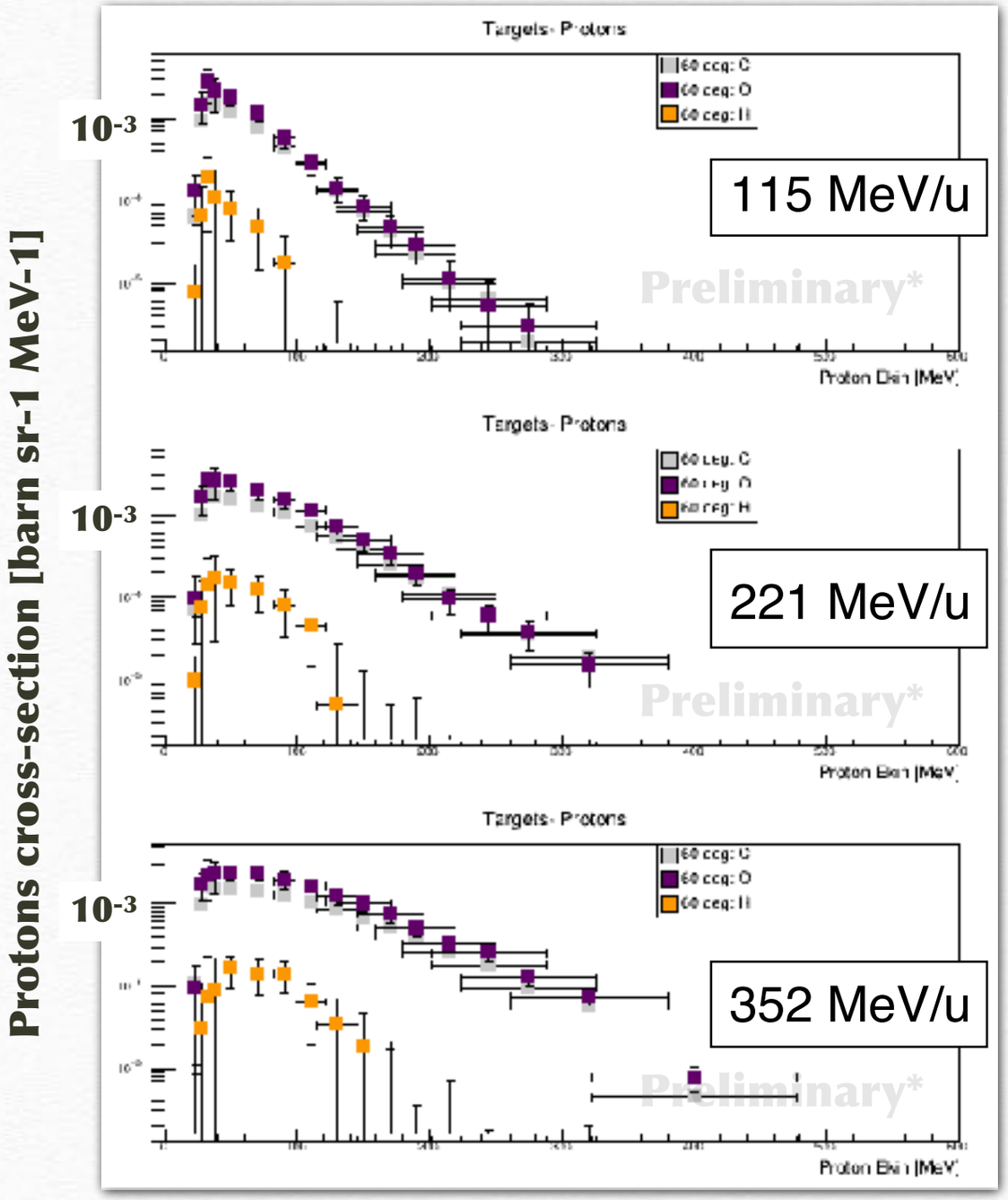
From the combination of the different targets (subtraction of C from C2H4 and of C and H from C5O2H8) we obtain the C, O, H proton production cross-sections as a function of the kinetic energy, at 90º and 60º.

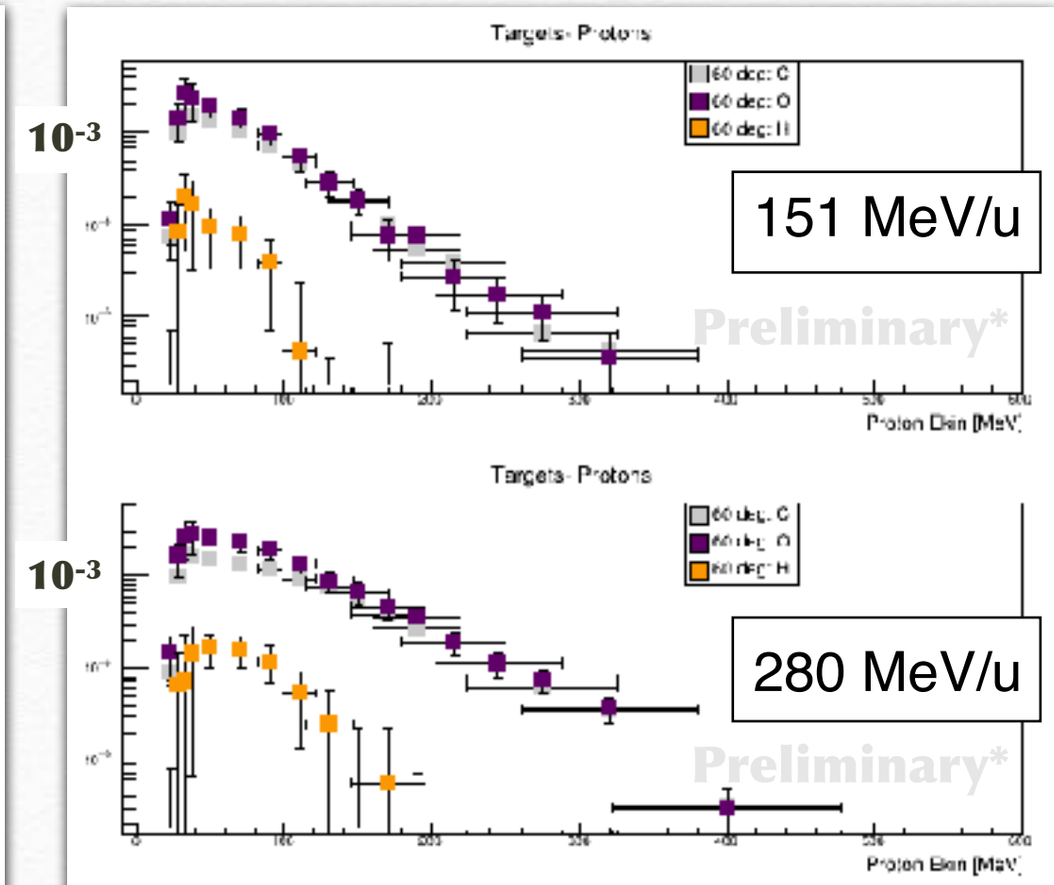


Cross section

*Only statistical uncertainties

The C, O, H proton production cross-sections as a function of their kinetic energy.

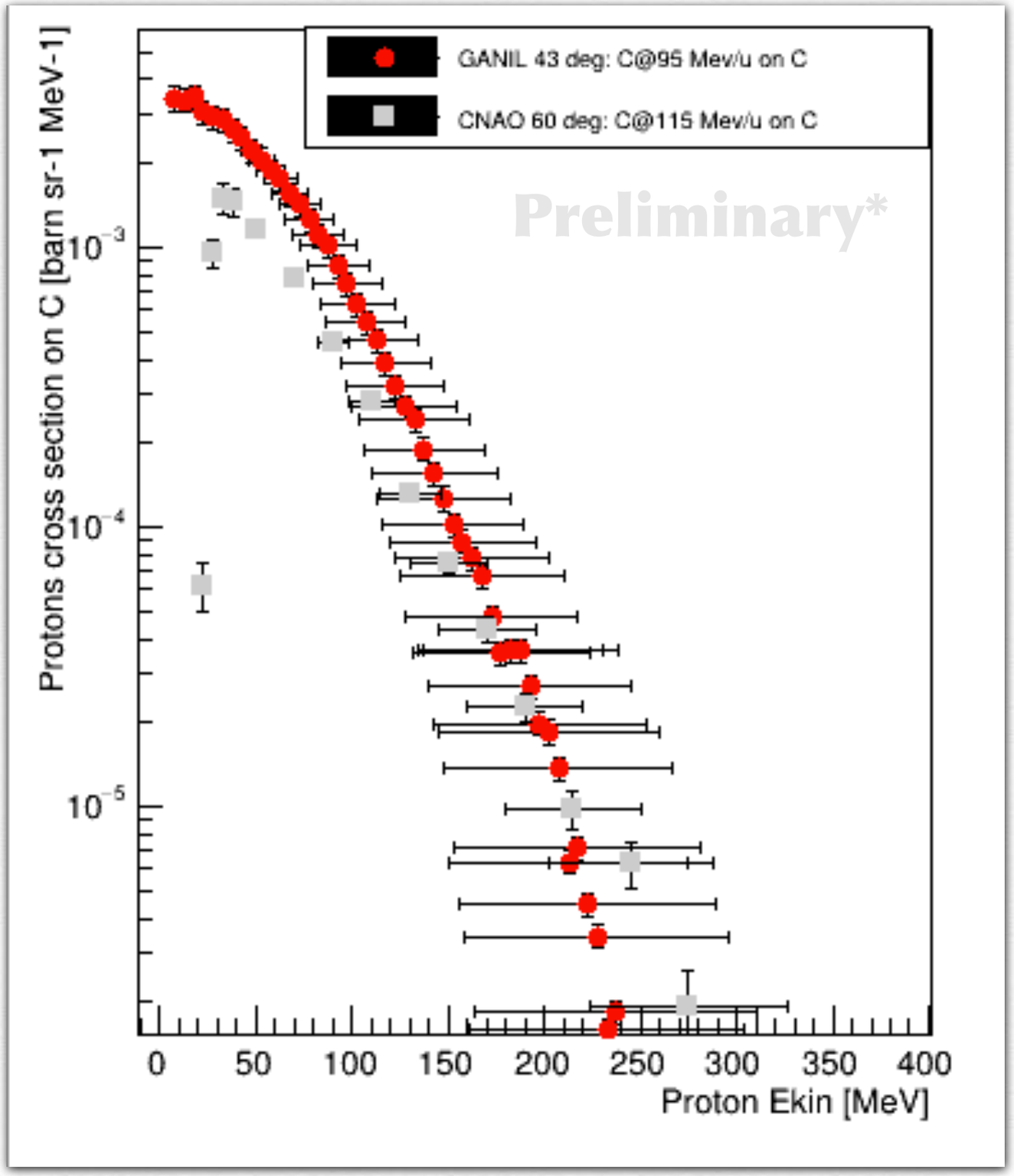




Proton per Carbon production cross section for C,O,H at 60° for 5 beam energies

Analysis performed for all targets, protons and deutons, at 90º and 60º.

Proton cross-section comparison with Ganil data:

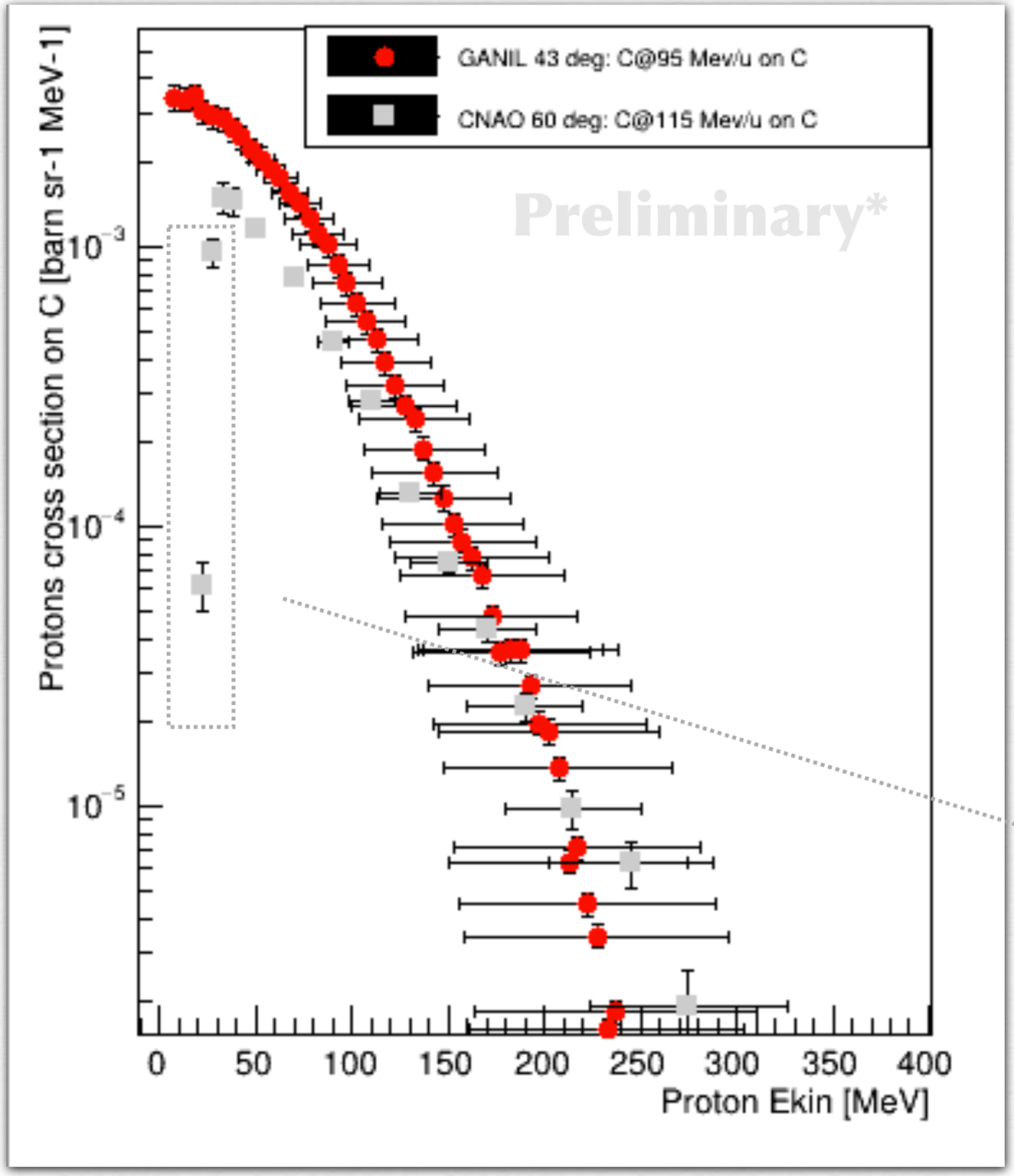


THE BEAM ENERGY AND THE ANGLES ARE NOT EXACTLY THE SAME.. HOWEVER WE CAN START TRUSTING OUR ANALYSIS: THE ORDER OF MAGNITUDE IS DEFINITELY COMPARABLE.

C exists as target .. most easy results to compare!

Ganil [http://hadrontherapy-data.in2p3.fr/index.php]

Proton cross-section comparison with Ganil data:

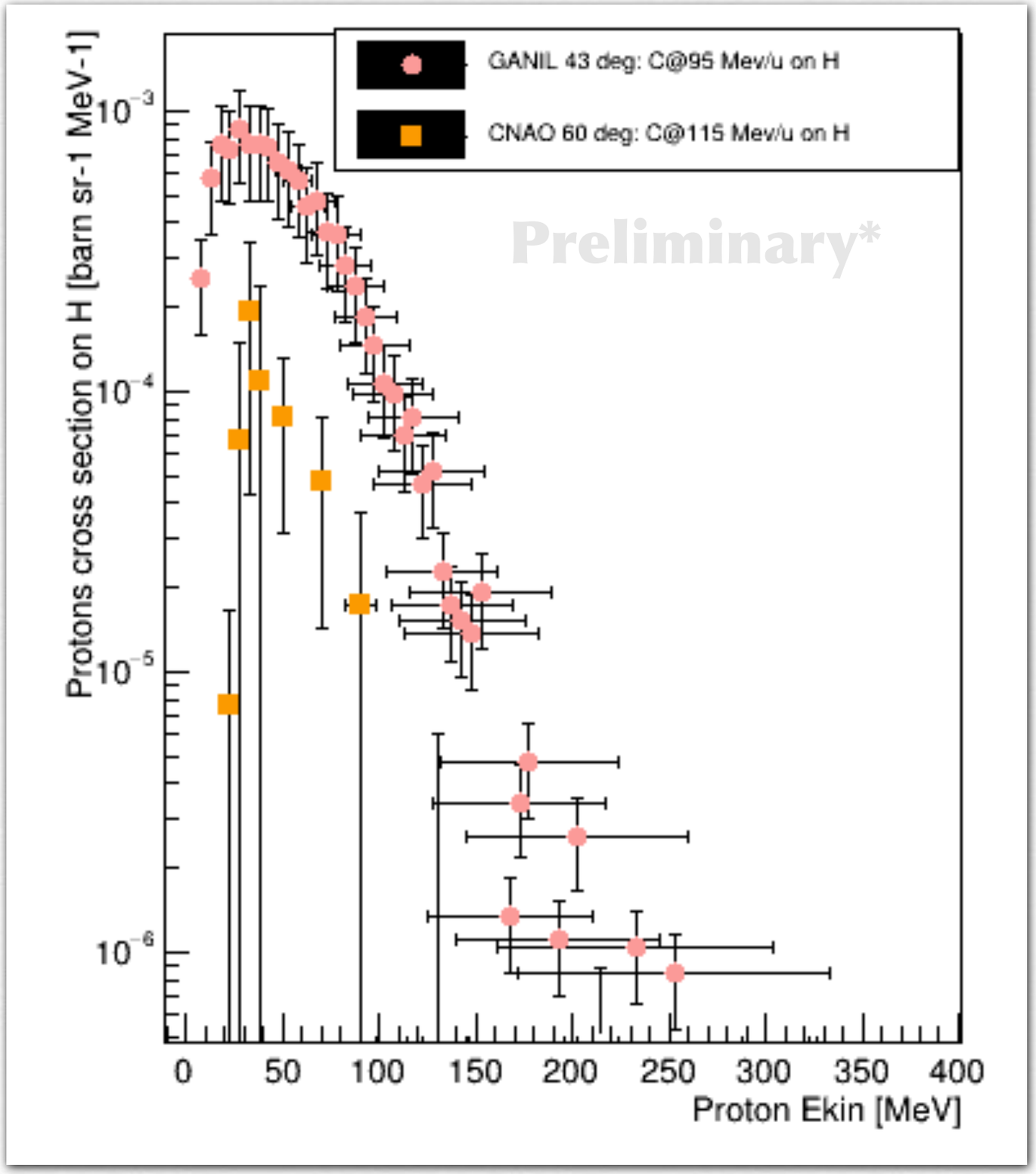


THE BEAM ENERGY AND THE ANGLES ARE NOT EXACTLY THE SAME.. HOWEVER WE CAN START TRUSTING OUR ANALYSIS: THE ORDER OF MAGNITUDE IS DEFINITELY COMPARABLE.

NB: our threshold in energy is ~20 MeV and we are probably not taking into account properly our detection efficiency below 40 MeV

Ganil [http://hadrontherapy-data.in2p3.fr/index.php]

Proton cross-section comparison with Ganil data:



NB with targets!

the H cross-section data are obtained form:

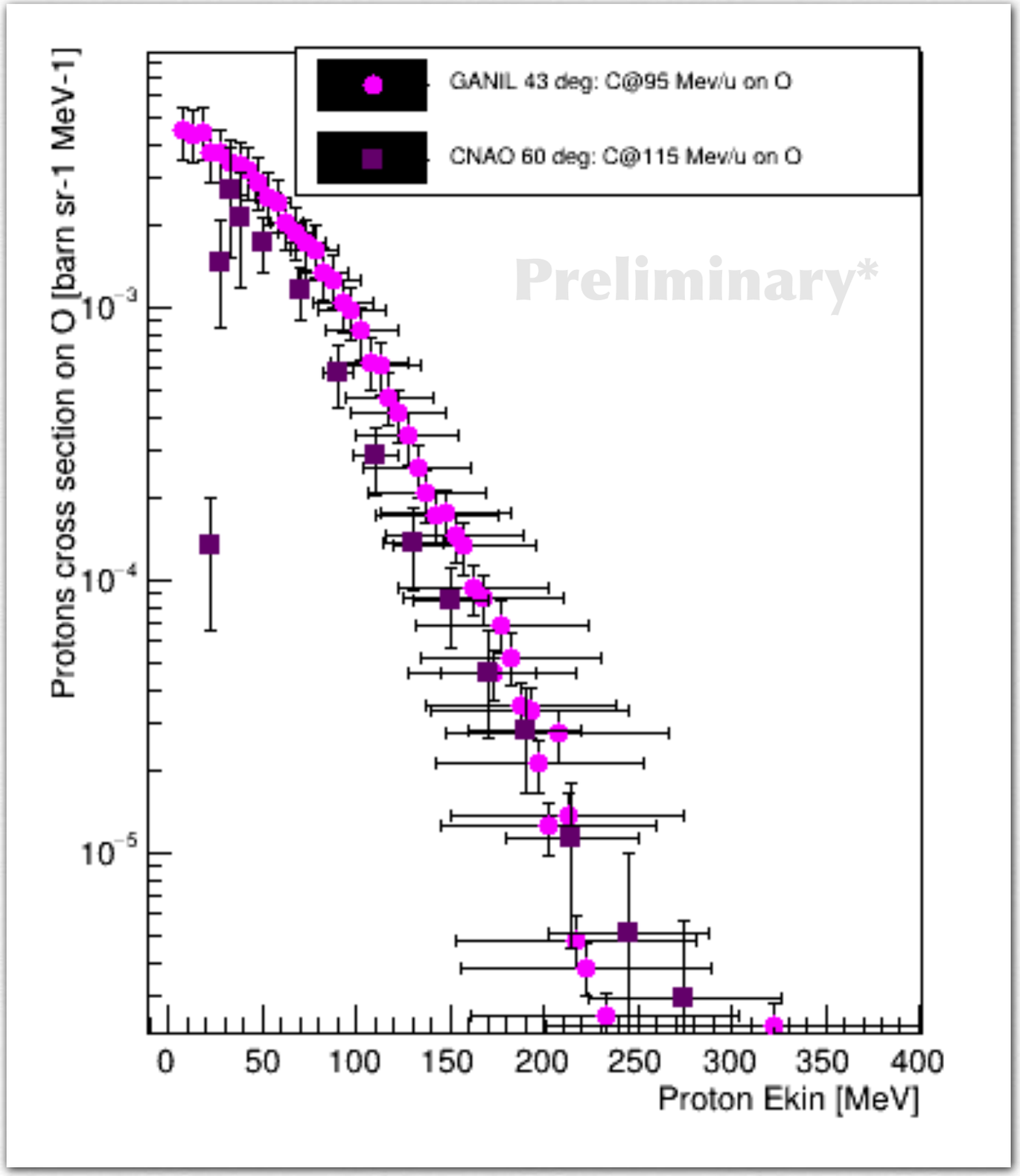
- CH2 GANIL
- C2H4 CNAO

in combination with C information from Graphite Target

NB: our threshold in energy is ~20 MeV and we are probably not taking into account properly our detection efficiency below 40 MeV

Ganil [http://hadrontherapy-data.in2p3.fr/index.php]

Proton cross-section comparison with Ganil data:



NB with targets!

the O cross-section data are obtained form:

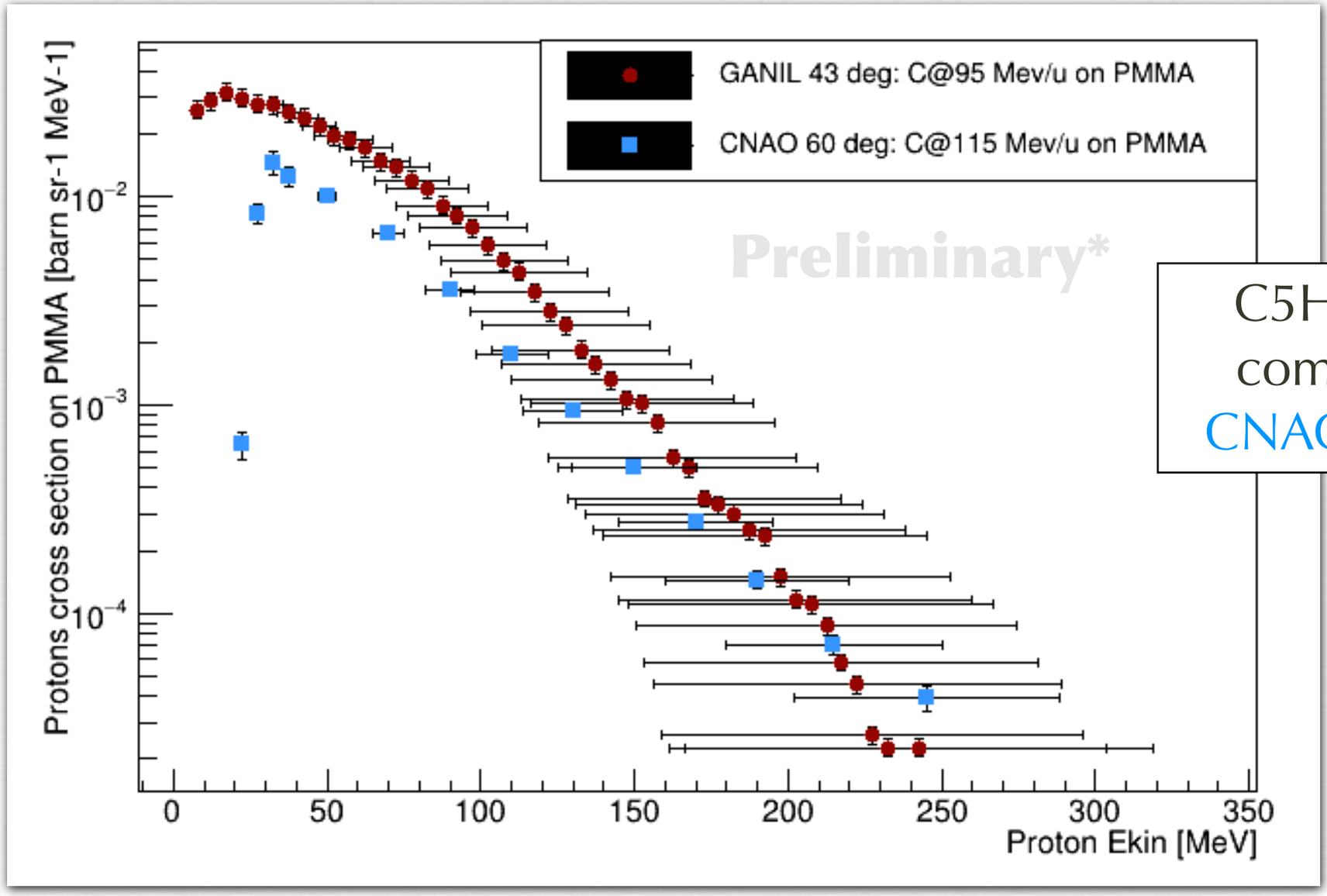
- Al2O3 GANIL
  in combination with Al
  information from Al Target
- C5H8O2 CNAO
  in combination with H
  information from C2H4 Target
  and with C information from Graphite Target

NB: our threshold in energy is ~20 MeV and we are probably not taking into account properly our detection efficiency below 40 MeV

Ganil [http://hadrontherapy-data.in2p3.fr/index.php]

Proton cross-section comparison with Ganil data:

The GANIL measurements has also data on PMMA targets that can be used as cross-check for our analysis.

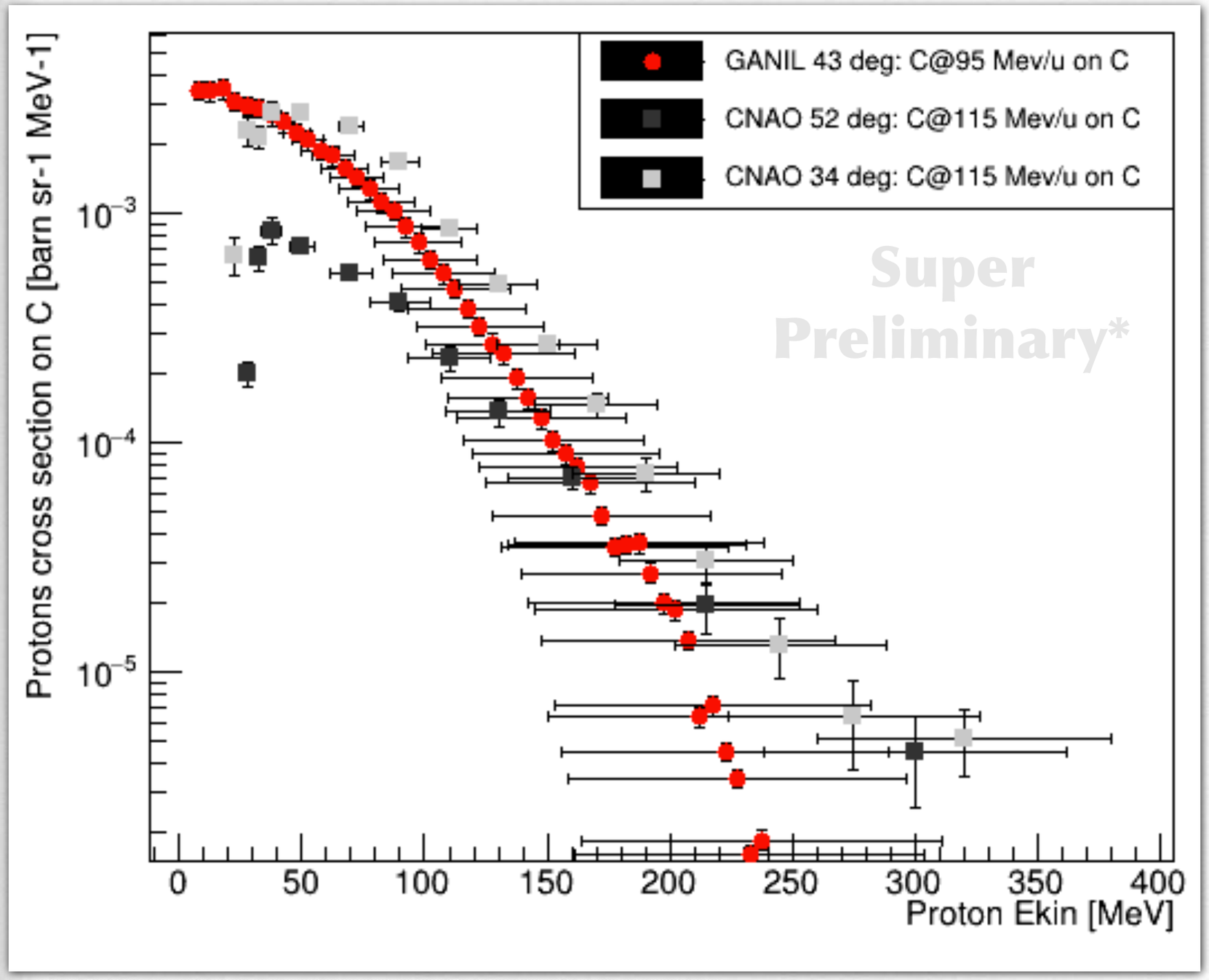


C5H8O2 targets comparisons for CNAO and GANIL

NB: our threshold in energy is ~20 MeV and we are probably not taking into account properly our detection efficiency below 40 MeV

Ganil [http://hadrontherapy-data.in2p3.fr/index.php]

Proton cross-section comparison with Ganil data:

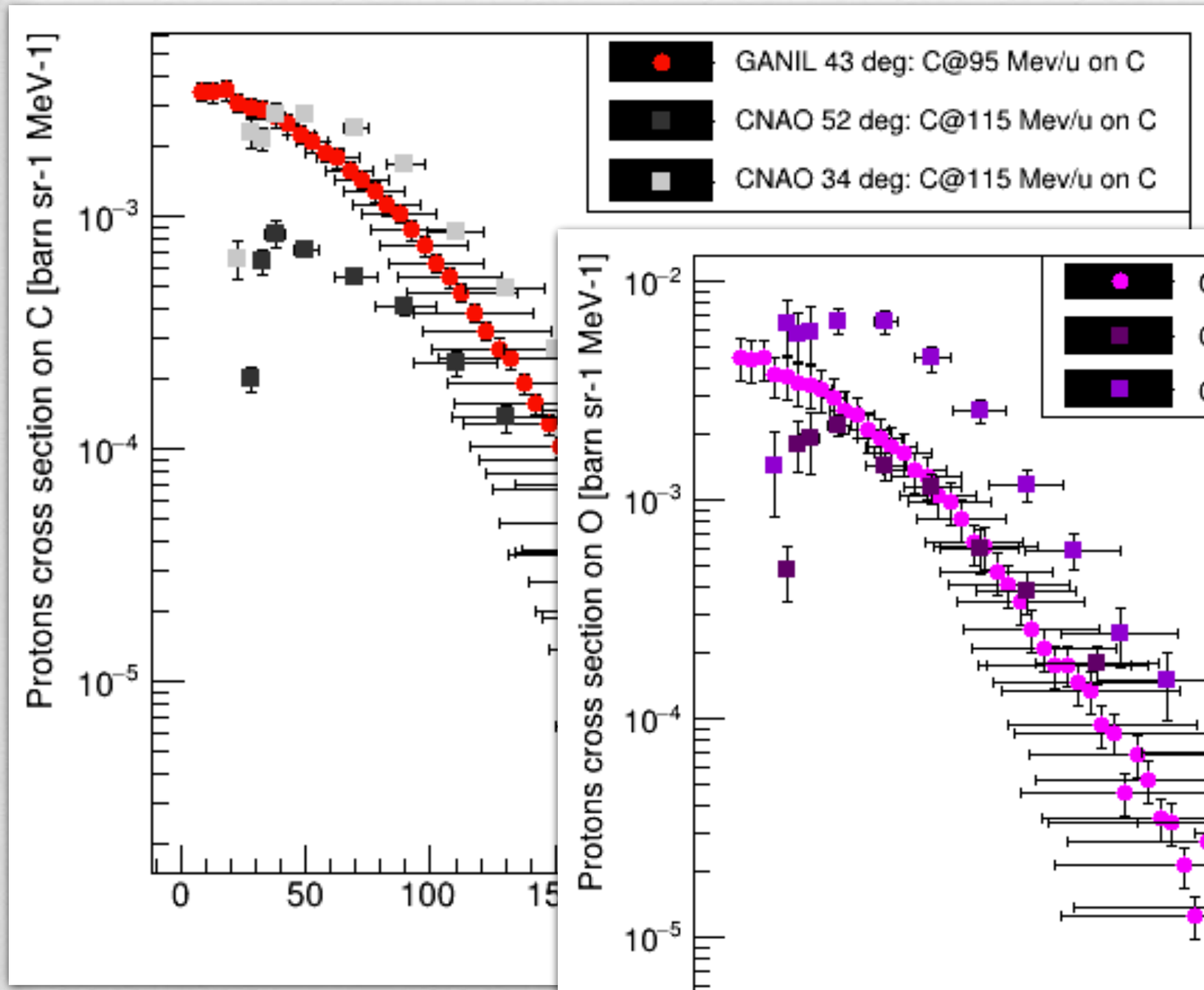


Our 52° and 34° data analysis has not been cross-checked in details but the first results are promising.

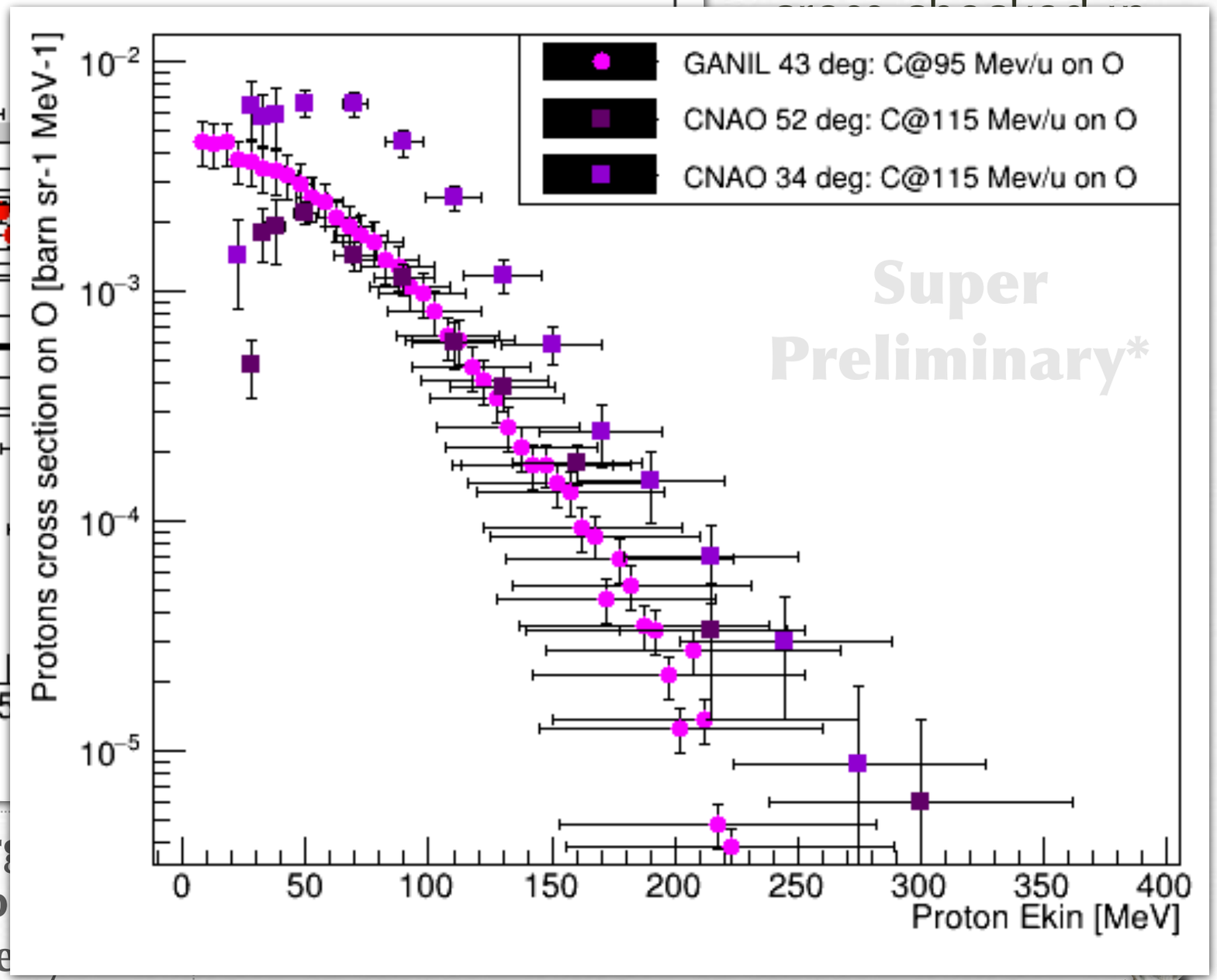
NB: our threshold in energy is ~20 MeV and we are probably not taking into account properly our detection efficiency below 40 MeV

Ganil [http://hadrontherapy-data.in2p3.fr/index.php]

Proton cross-section comparison with Ganil data:



Our 52° and 34° data analysis has not been



NB: our threshold in energ
MeV and we are probab
taking into account prope
detection efficiency below 40 MeV

Summarising

- The analysis is still ongoing for C, H, O:

- The H cross-section for protons are compatible with zero;
- The detection inefficiency for low energy is underestimated;
- We need to finalise the 90° and 60° data analysis;
- Some information on tritons at 60° is available (as well as Z=2, He3 and He4) we need more time to perform the analysis;
- At 52° and 34°:
  - fragments are not all totally contained => more accurate analysis and estimation of detection efficiency (kinetic energy miss-evaluation) is needed;
  - we have also tritons data.. but we need time to analyse them (as well as Z=2, He3 and He4);
  - the time (thus energy) resolution in this forward setup is better.. need to optimise some parameters (ex. energy binning).
  - NB: unfortunately not all energies data exist (only 115, 280, 352 MeV/u);
- Comparison with literature data is still ongoing;

- We plan to have a paper draft ready before the summer break

BACKUP