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

CNAO Nov 2017 data taking

IlaMi for Roma and Milano, 2024

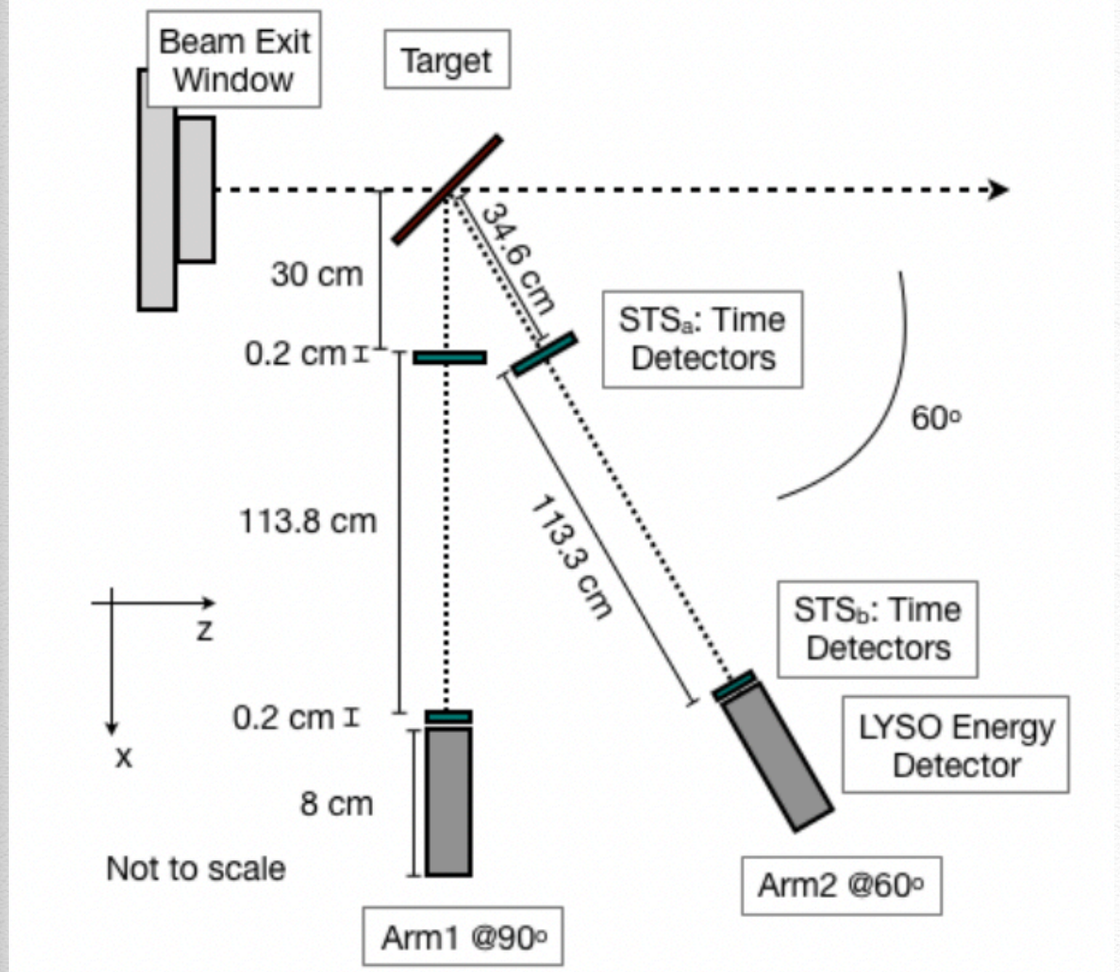
Experimental SETUP

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 inorganic crystals has been used for PID and kinetic energy measurements;

The thin targets (1-2 mm) do not require, as a first approximation, the implementation of a correction for the fragments absorption inside the target.



- 4 STS: thicknesses 2 mm for ToF measurements (Time Resolution ~400-600 ps) and Deposited Energy measurements (dE)
- 2 LYSO: 4x4x8 cm thick for Deposited Energy measurements (E)

Carbon beam energies:
115,150,221,279,351 MeV/u

Angles:
90°/60°;
50°/32° (?)

2020 Publication - 90°/60°

$$\frac{1}{\Delta\Omega}\frac{d\sigma}{dE_k}({}^{A}_{Z}X) = \frac{1}{4\pi}\cdot\frac{1}{N_Y\ \Delta E_k}\cdot\frac{N_{{}^{A}_{Z}X}(E_k)}{N_{^{12}C}}\cdot\frac{1}{\epsilon}$$

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Measurement of ^{12}C Fragmentation Cross Sections on C, O and H in the Energy Range of interest for Particle Therapy Applications.

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***Abstract*—In a carbon ion treatment the nuclear fragmentation of both target and beam projectiles impacts on the dose released on the tumour and on the surrounding healthy tissues. Carbon ion fragmentation occurring inside the patient body has to be studied in order to take into account this contribution. These data are also important for the development of the range monitoring techniques with charged particles. The production of charged fragments generated by carbon ion beams of 115-353 MeV/u kinetic energy impinging on carbon, oxygen and hydrogen targets has been measured at the CNAO particle therapy center (Pavia, Italy). The use of thin targets of graphite (C), PMMA ($C_2O_5H_8$) and polyvinyl-toluene (plastic scintillator, C_bH_a) allowed to measure fragments production cross sections, exploiting a Time of Flight (ToF) technique. Plastic scintillator detectors have been used to perform the ToF measurements, while LYSO crystals have been used for the deposited energy measurement and to perform particle identification. Cross sections have been measured at 90 and 60 degrees with respect to the beam direction. The measured proton, deuteron and triton differential production cross sections on C, O and H, obtained exploiting the target subtraction strategy, are presented here as a function of the fragment kinetic energy.**

***Index Terms*—Scintillators Radiation Detectors for medical applications Radiation Therapy Clinical/preclinical evaluation/application studies Therapy imaging Clinical/preclinical evaluation/application studies**

INTRODUCTION

PARTICLE Therapy (PT) is a well established external radiotherapy technique that exploits light charged hadron beams (as protons and carbon ions) to treat solid tumours. PT is particularly suitable in case of tumours located close to organs at risk, as well as for deep-seated or radio resistant cancers [1]. The maximum dose deposition is concentrated in

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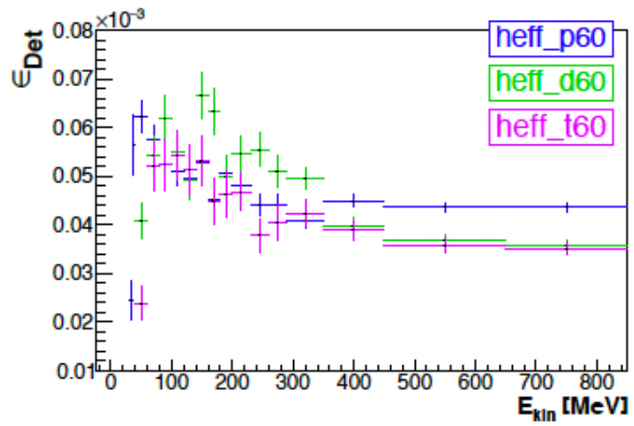
- Zid from STS detectors
- Aid from LYSO detector

- **Detection Efficiency from p,d,t FLAT MC**



- **Ekin@Gen from analytical correction of Ekin@Meas**

- **Selection (mixing) Efficiency from FULL MC**

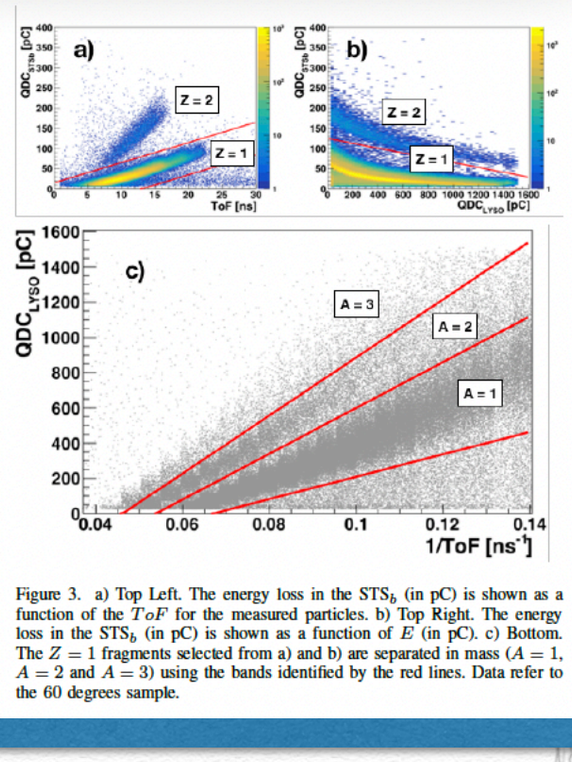


Figure 3. a) Top Left. The energy loss in the STS_b (in pC) is shown as a function of the ToF for the measured particles. b) Top Right. The energy loss in the STS_b (in pC) is shown as a function of E (in pC). c) Bottom. The $Z = 1$ fragments selected from a) and b) are separated in mass ($A = 1$, $A = 2$ and $A = 3$) using the bands identified by the red lines. Data refer to the 60 degrees sample.

$$\epsilon_{mix} = \begin{pmatrix} \epsilon^{pp} & \epsilon^{pd} & \epsilon^{pt} \\ \epsilon^{dp} & \epsilon^{dd} & \epsilon^{dt} \\ \epsilon^{tp} & \epsilon^{td} & \epsilon^{tt} \end{pmatrix}$$

Table III
PARTICLE IDENTIFICATION EFFICIENCY: SELECTION EFFICIENCIES EVALUATED FOR BOTH 90° AND 60° DETECTION CONFIGURATIONS.

E^C_{kin} $[MeV/u]$	ϵ^{pp} [%]	ϵ^{dd} [%]	ϵ^{tt} [%]
90°			
115	95 ± 5	89 ± 9	85 ± 12
153	95 ± 5	85 ± 14	91 ± 6
221	94 ± 5	85 ± 12	86 ± 10
281	94 ± 5	84 ± 12	71 ± 31
353	94 ± 5	84 ± 14	81 ± 15
60°			
115	95 ± 4	78 ± 21	76 ± 32
153	95 ± 5	77 ± 22	83 ± 17
221	95 ± 5	75 ± 23	73 ± 32
281	95 ± 5	75 ± 24	76 ± 26
353	94 ± 5	75 ± 24	69 ± 37

Cross section 2024

- DATA @ 90°/60°/50°/32°
- DATA-MC comparison
- Zid from STS detectors
- Aid from LYSO detector
- **Detection efficiency from FULL MC**
- **Selection Efficiency (mixing) binned in Ekin**
- **UNFOLDING to compute Ekin gen from Ekin meas**

~ same as before

$$\frac{d\sigma}{dE_k}\left({}^{A}_{Z}X\right) = \frac{1}{\Delta\Omega} \cdot \frac{\textbf{Purity}}{N_Y\ \Delta E_k} \cdot \frac{N_{{}^{A}_{Z}X}(E_k)}{N_{^{12}C}} \cdot \frac{1}{\epsilon}$$

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

Full simulation (C on Targets ~1.e^{10} primaries) to calculate the trigger+detection efficiency

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

Full simulation (C on Targets ~1.e^{10} primaries). On the E (and dE) vs ToF distributions, application of the PID selections tuned from data: evaluation of fragments (p, d, t) mis-identification.

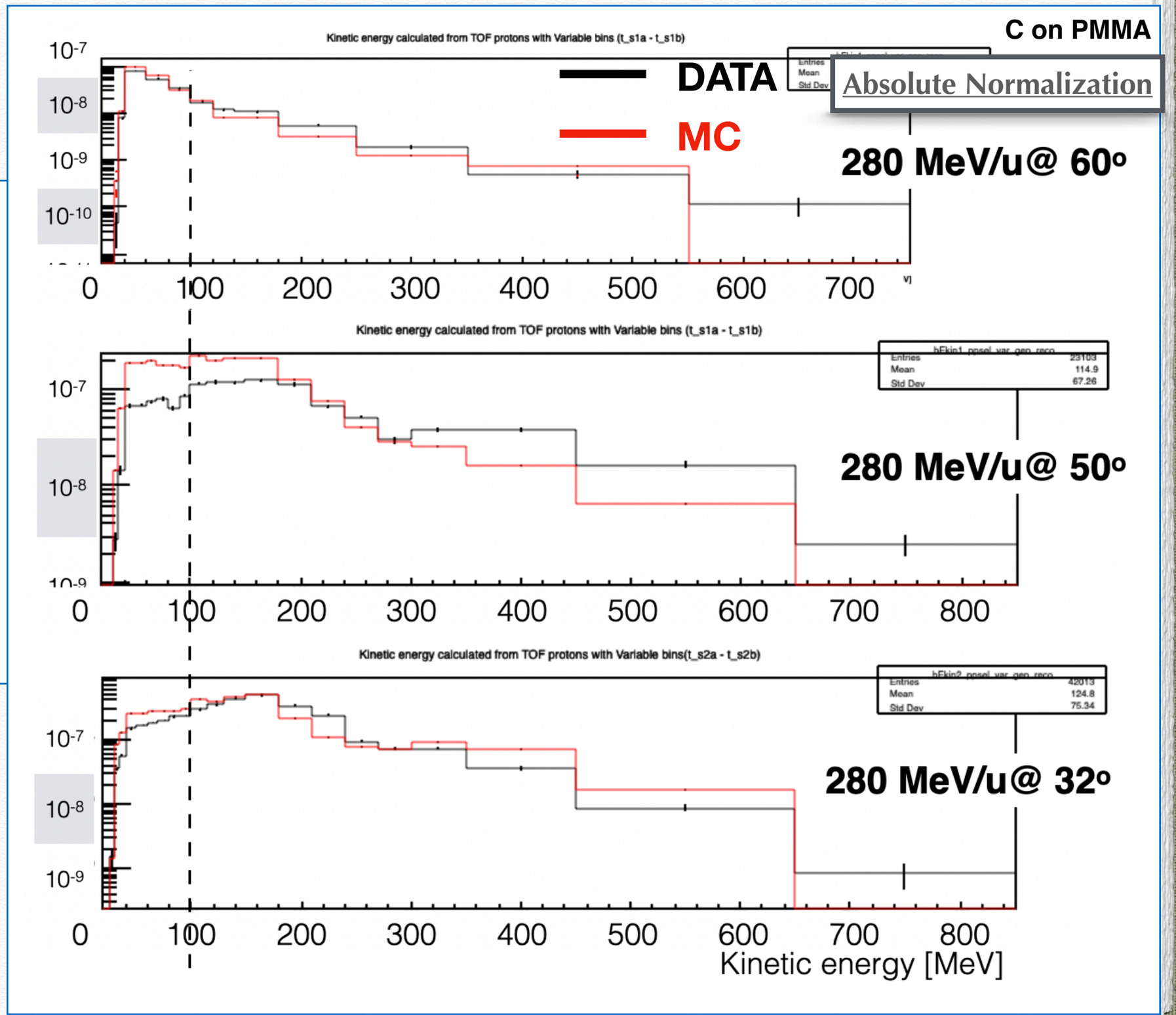
Cross section 2024

DATA @ 90°/60°/50°/32° and DATA-MC comparison

BUT

DATA @ 50°
show some issues:
HW problems (not identified) OR not the right angle (range spanned 30°-38° & 45°-54°) OR both

not publishable

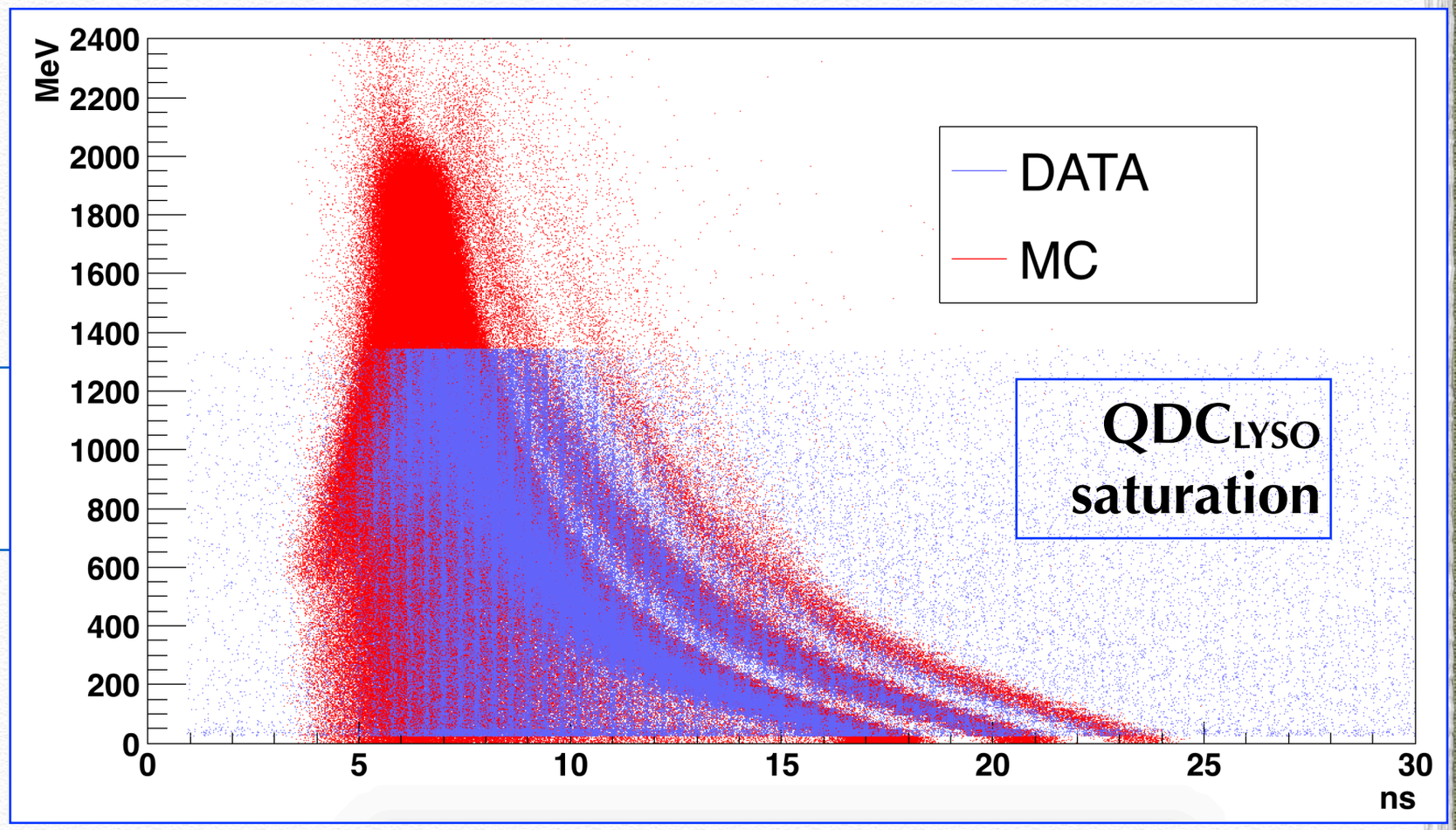


Cross section 2024

DATA @ 90°/60°/50°/32° and DATA-MC comparison

BUT

DATA @ 32°
have a QDC saturation



publication before the related ToF

Cross section 2024 - The FORMULA

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

$$\frac{d\sigma}{dE_k}\left(^{A}_{Z}X\right) = \frac{N_{^{A}_{Z}X}(E_k)}{\Delta E_k} \cdot \frac{\textbf{Purity}}{N_{^{12}C} N_Y} \cdot \frac{1}{\epsilon}$$

Particle identification (Z,A): same as old analysis.

Unfolding to compute Ekin gen from Ekin meas.

Purity correction instead of correcting for the off-diagonal elements of the mixing matrix (same concept, different application)

For fw Angles:
NO DATA for
C 221 MeV/u
CH 150,221 MeV/u

Cross section 2024 - YIELD

From a study on DATA available statistics (raw yield),
it is possible to perform the DATA analysis of:

- 90-60: All Targets, all Beam Energies
- 32: C no 221, CH no 150-221

- **p: 90 - 60 - 32**
- **d: 90 integral - 60 - 32**
- **t: 60 - 32**

Cross section 2024 - Unfolding the Raw YIELD

To obtain the Ekin @ generation of detected particles, we need to UNFOLD the measured Ekin (from TOF).
The UNFOLDING ingredients are:

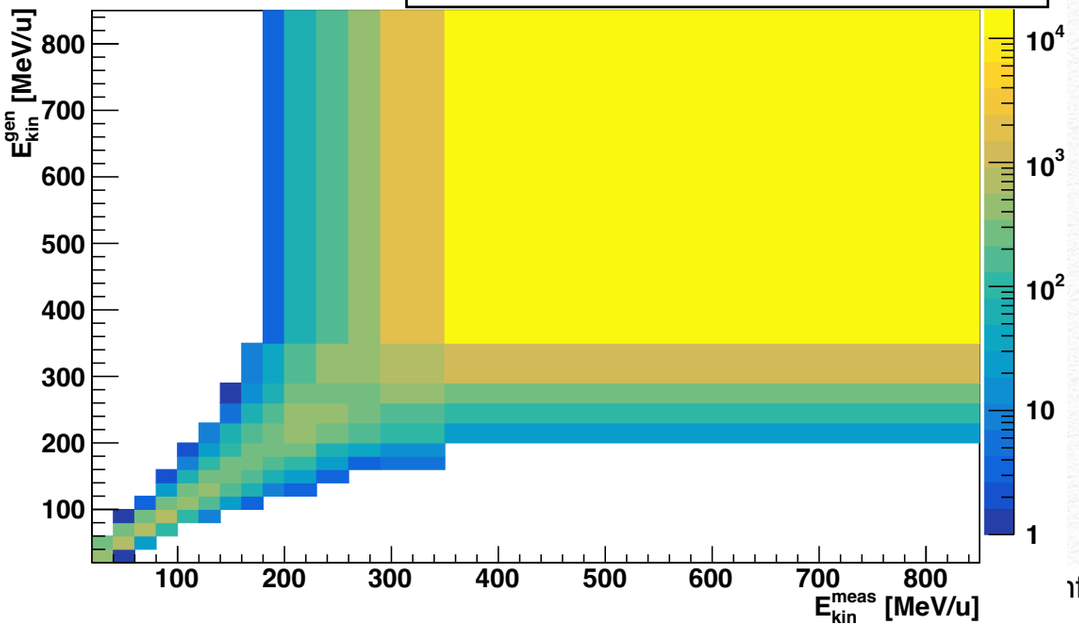
- **unfolding matrix: probability matrix that, given a measured Ekin, tells you the generation Ekin**
- **Measured Ekin distribution: the distribution to be unfolded**
- **Generation Ekin distribution: the distribution to compare with the unfolded one**

UNFOLDING

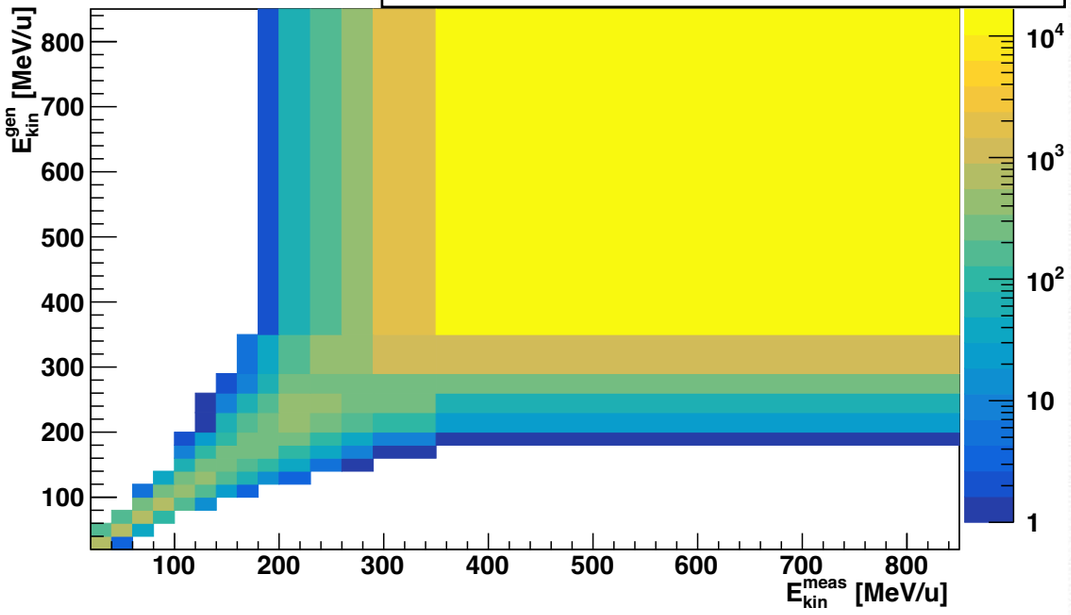
- Same x-y ranges and variable binning of FULL MC/DATA spectra

Unfolding Matrix (Ekin gen vs Ekin meas) from **FLAT** simulations:
p, d, t generated within the PMMA + C + CH targets,
with FLAT Ekin spectrum (5 MeV/u - 1GeV/u)

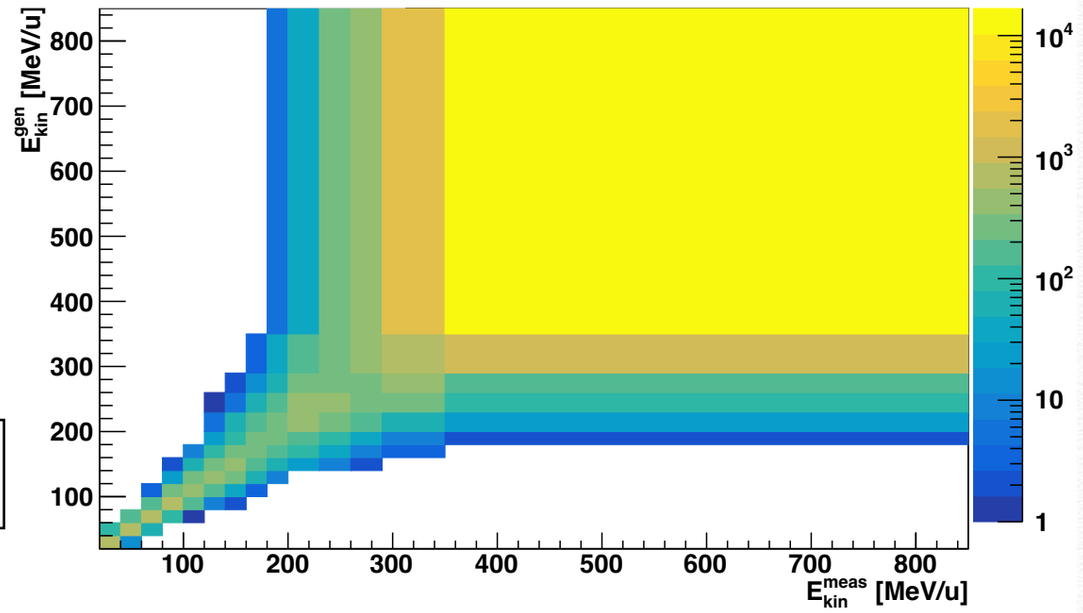
p - C - 60°



d - C - 60°



t - C - 60°



UNFOLDING

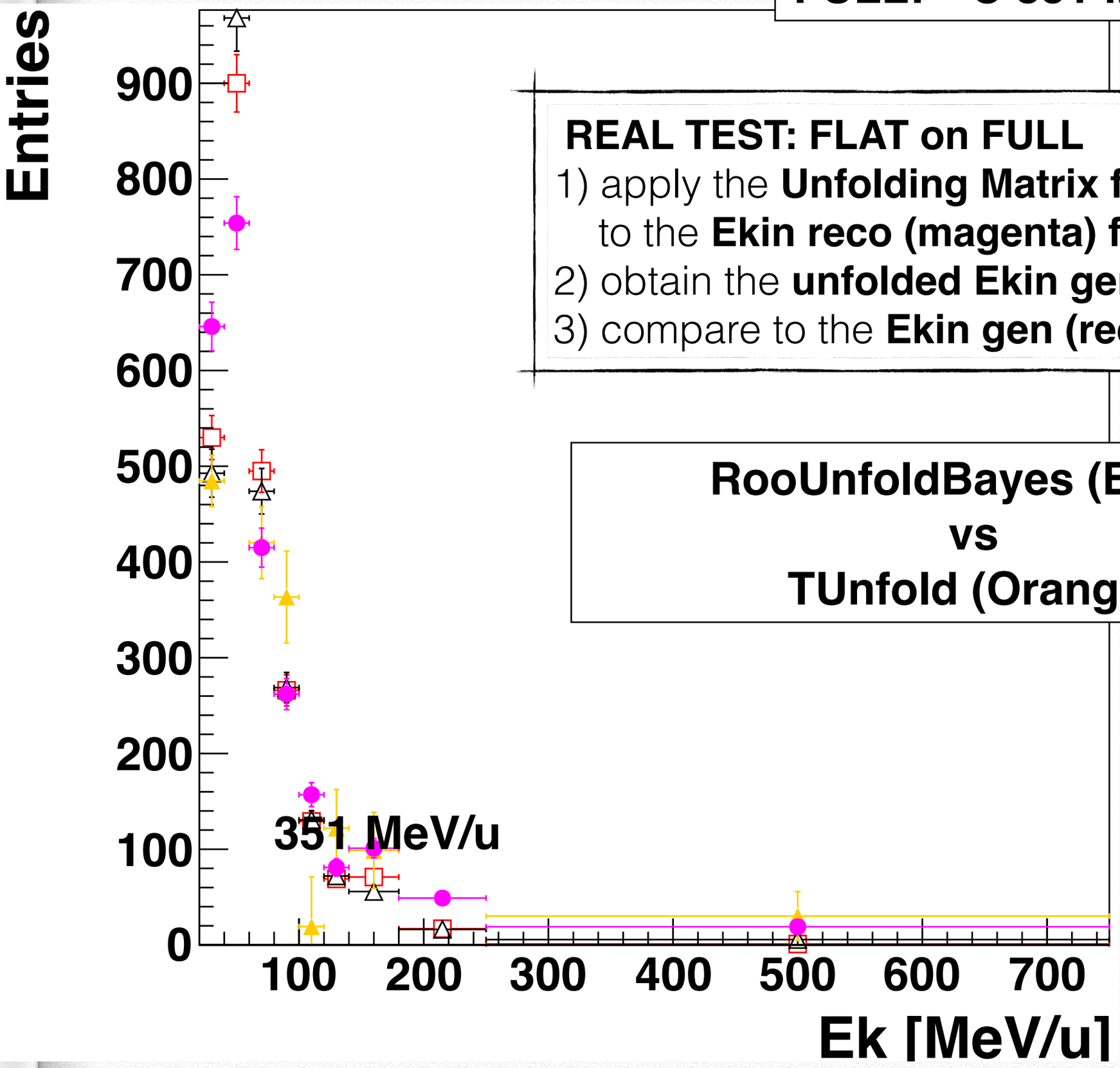
FLAT: p - PMMA - 90°

FULL: ^{12}C 351 MeV/u - PMMA - 90°

REAL TEST: FLAT on FULL

1) apply the **Unfolding Matrix from FLAT MC** to the **Ekin reco (magenta) from FULL MC**
2) obtain the **unfolded Ekin gen (black)**
3) compare to the **Ekin gen (red) of FULL MC**

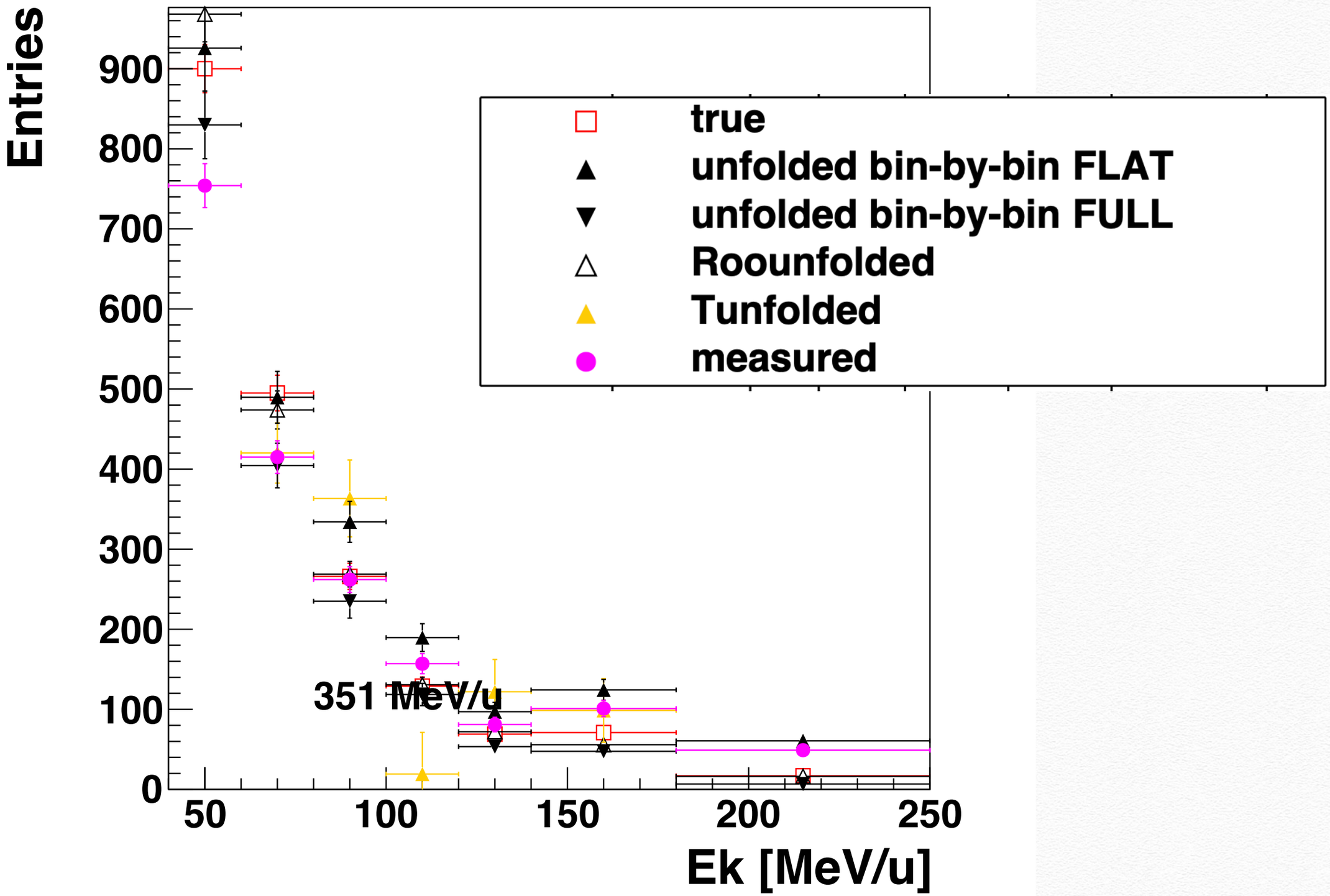
RooUnfoldBayes (Black)
vs
TUnfold (Orange)



UNFOLDING

FLAT: p - PMMA - 90°

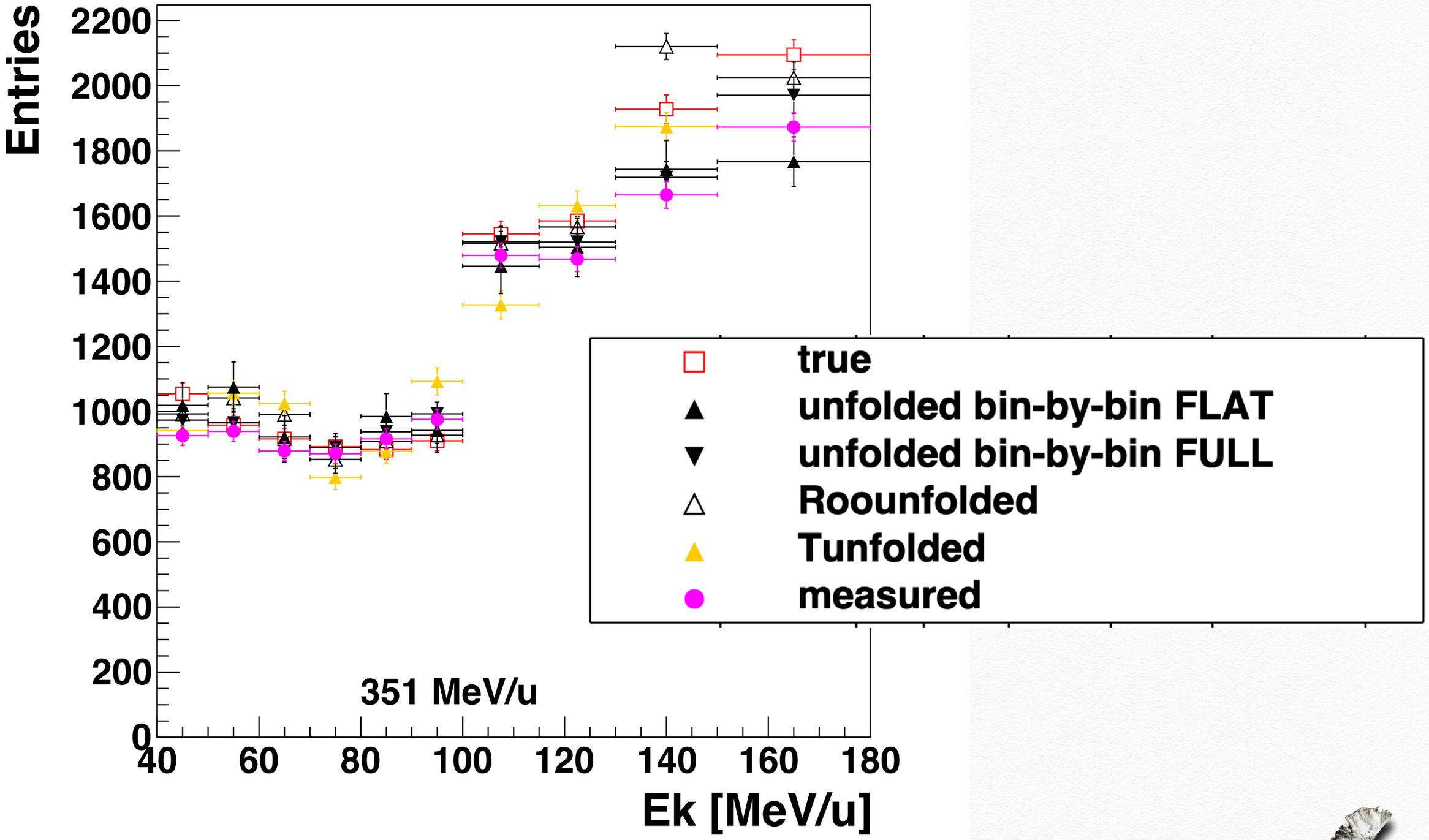
- **REAL TEST: FLAT on FULL**



UNFOLDING

FLAT: p - C - 32°

- REAL TEST: FLAT on FULL



Cross section 2024 - PURITY

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

$$\frac{d\sigma}{dE_k}\left(^{A}_{Z}X\right) = \frac{N_{^{A}_{Z}X}(E_k)}{\Delta E_k} \cdot \frac{\textbf{Purity}}{N_{^{12}C} N_Y} \cdot \frac{1}{\epsilon}$$

$$\text{Purity} = \frac{\text{number of particles selected in p (d,t) band}}{\text{number of true p (d,t) in p (d,t) band}}$$

Purity values range [96 - 100] %

Normalization

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

$$\frac{d\sigma}{dE_k}\left(^{A}_{Z}X\right) = \frac{N_{^{A}_{Z}X}(E_k)}{\Delta E_k} \cdot \frac{\textbf{Purity}}{N_{^{12}C} N_Y} \cdot \frac{1}{\epsilon}$$

From CNAO Dose Delivery

Information of the target composition:

Target	Composition	Thickness $[mm]$	Density $[g/cm^3]$
PMMA	$C_5O_2H_8$	2	1.19
Graphite	C	1	0.94
Plas.Scint.	C_bH_a	2	1.024

dose-current conversion systematic uncertainty. The relative uncertainty on $N_{^{12}C}$ (4%) is hence the convolution of the uncertainty on the stopping power determination [20] and on the dose measurements [21]. A possible additional contribution to the systematic uncertainty, coming from the monitoring system measurement stability [22], was found to be negligible

$N_{^{12}C}$	$\cdot 10^6$	$\cdot 10^6$	$\cdot 10^6$	$\cdot 10^6$	$\cdot 10^6$
Target	115 [MeV/u]	153 [MeV/u]	222 [MeV/u]	281 [MeV/u]	353 [MeV/u]
PMMA	49866	46512	49395	49601	42000
Graphyte	49454	46583	47484	47288	49328
Plast. Scint.	49728	50600	49347	49787	49653

$$N_Y = \frac{\rho_Y \cdot th_Y \cdot N_A}{A_Y}$$

$th_y = th_y * \mathrm{sqrt}(2)$

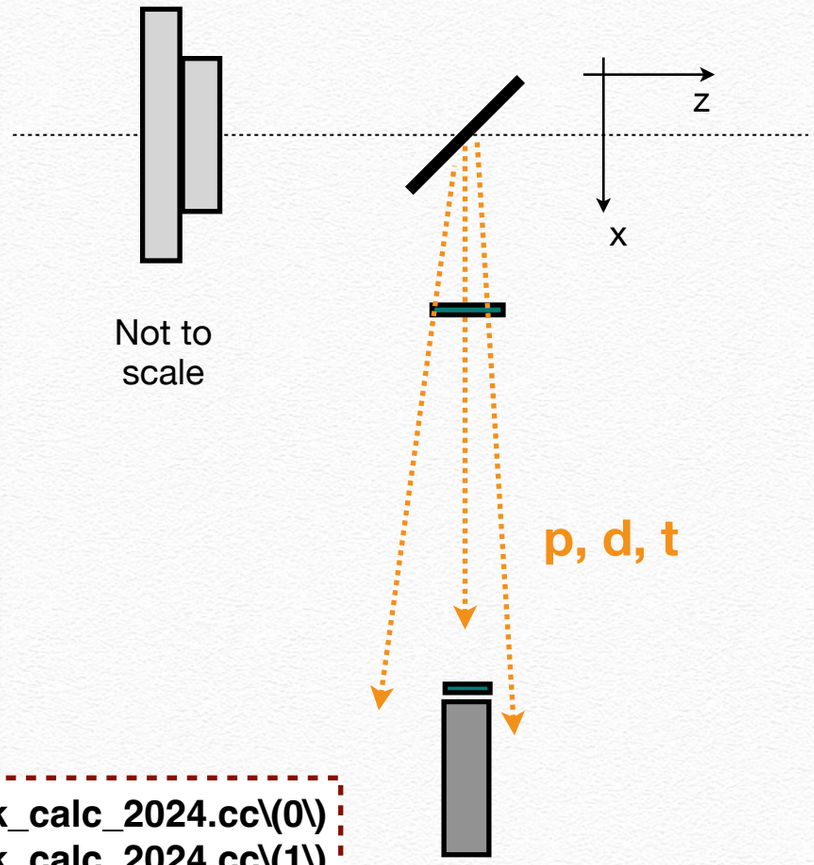
Efficiency evaluation:

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

The efficiency $\epsilon_{Det}(E_{kin})$ and $\epsilon_{Sel}(E_{kin})$ have been evaluated using dedicated Monte Carlo simulations developed with the FLUKA code
=> MC FULL triggered: at least 1 fragment (idpa = 1 or -3 or -4) born in tgt

- To evaluate $\epsilon_{Det}(E_{kin})$: trigger and detector efficiency + geometry

$$\epsilon_{Det}(E_{kin}) = \frac{\epsilon_{Det}^{NUME}}{\epsilon_{Det}^{DENO}}$$



Eps_det_NUME

- Triggered (time coinc btw STSa and STSb < 150 ns && Edep in STSa,b > 100keV)
- Cross STSa, STSb, LYSO
- above detectors (STSa, STSb, LYSO) energy thresholds cuts as data
  (90/60°: Ely_cut = 24 MeV, Estsa,b_cut = 5 MeV)
  (50/32°: Ely_cut = 24 MeV, Estsa,b_cut = 2,3 MeV)
- Eps_det_DENO selections

Eps_det_DENO

- p (d, t)
- born in tgt
- son of a primary particle
- out of tgt
- out of tgt in (Theta±DTheta(4°); Phi± DPhi(4°/6°@32deg))

```
root -l effEk_calc_2024.cc\(0\)
root -l effEk_calc_2024.cc\(1\)
  root -l histos_effdet.cc\(0\)
  root -l histos_effdet.cc\(1\)
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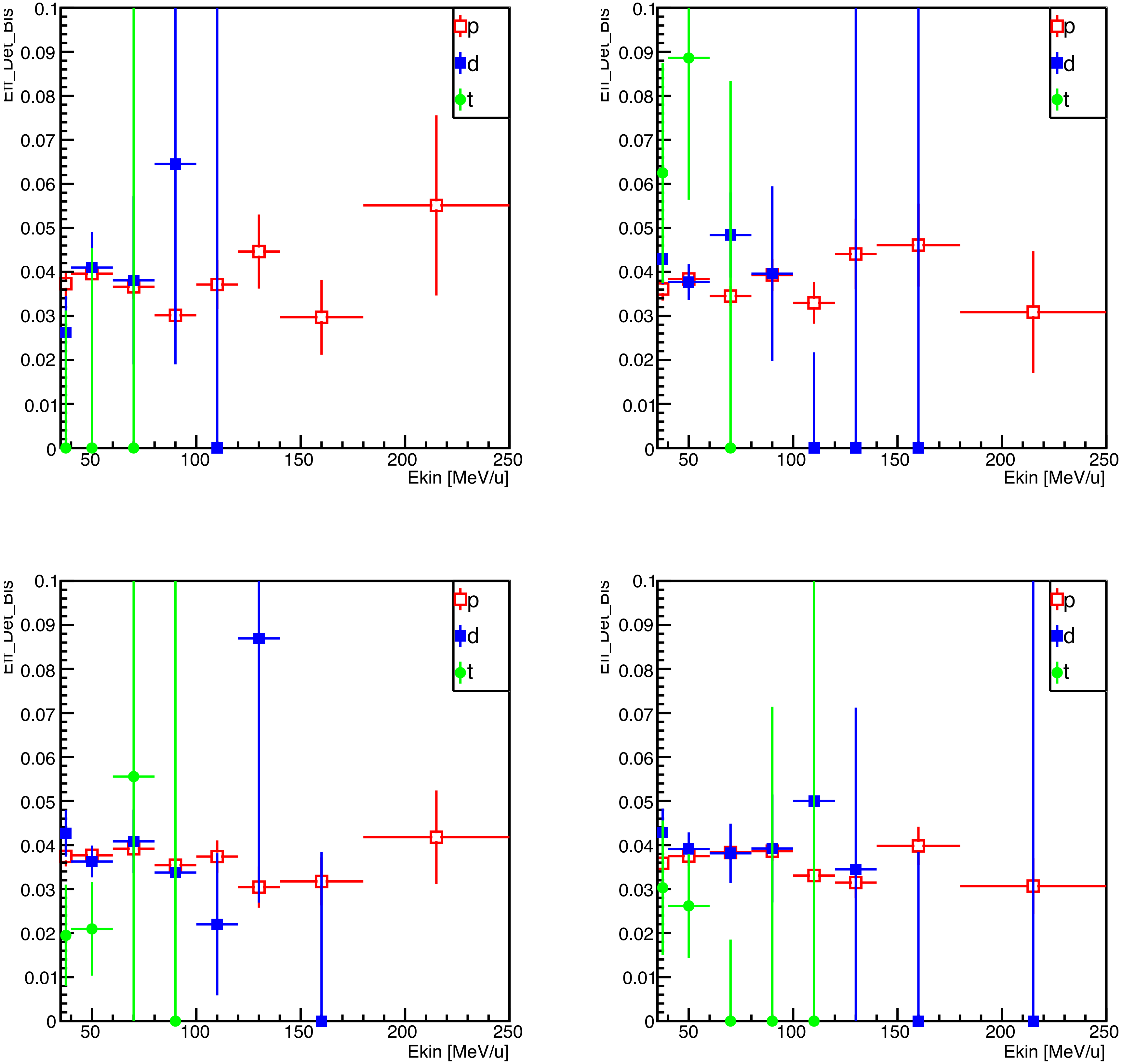
Efficiency evaluation:

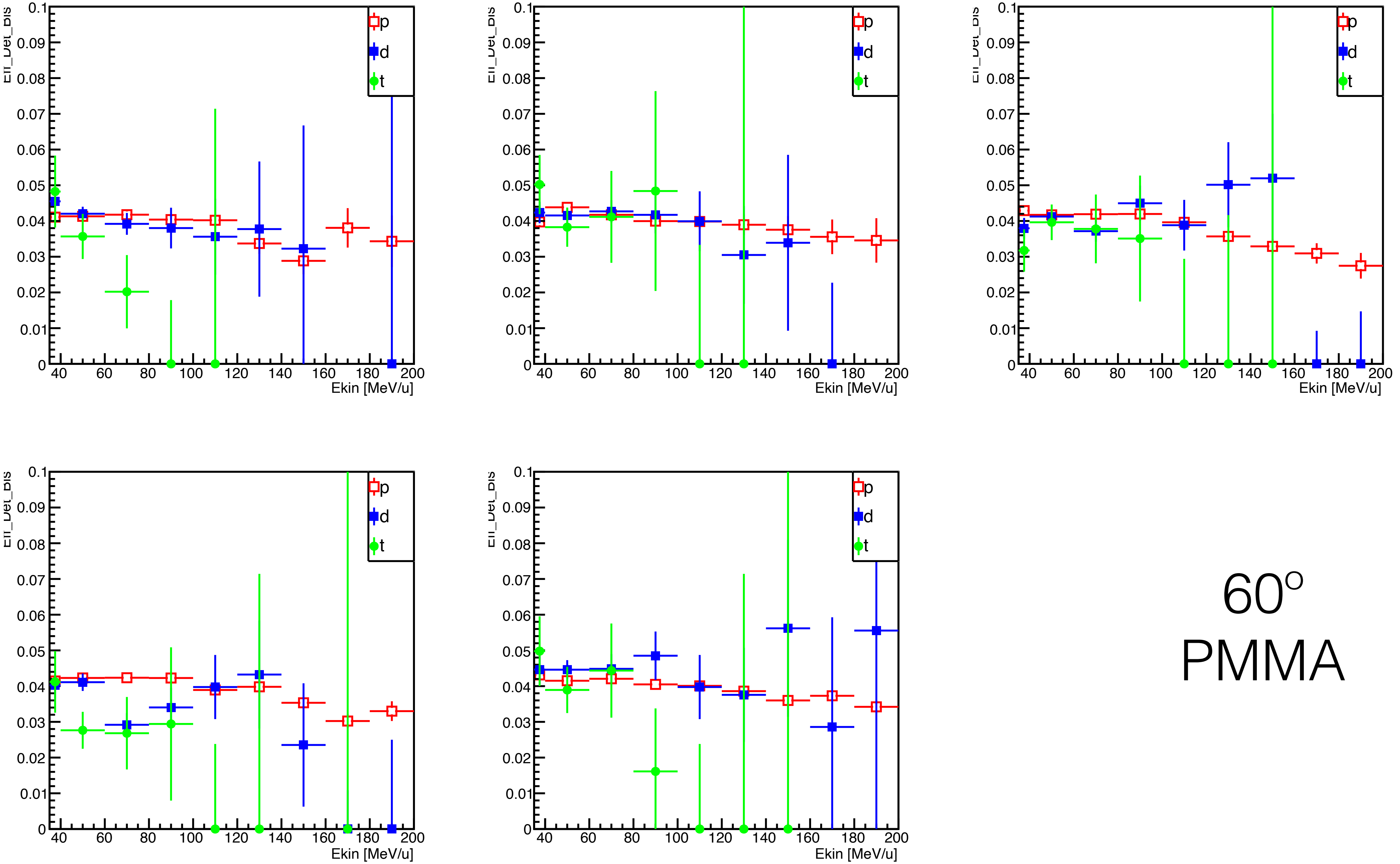
$$\epsilon = \epsilon_{Det} \cdot \epsilon_{Sel} \cdot \epsilon_{DT}$$



90^{O}
PMMA

Efficiency evaluation:

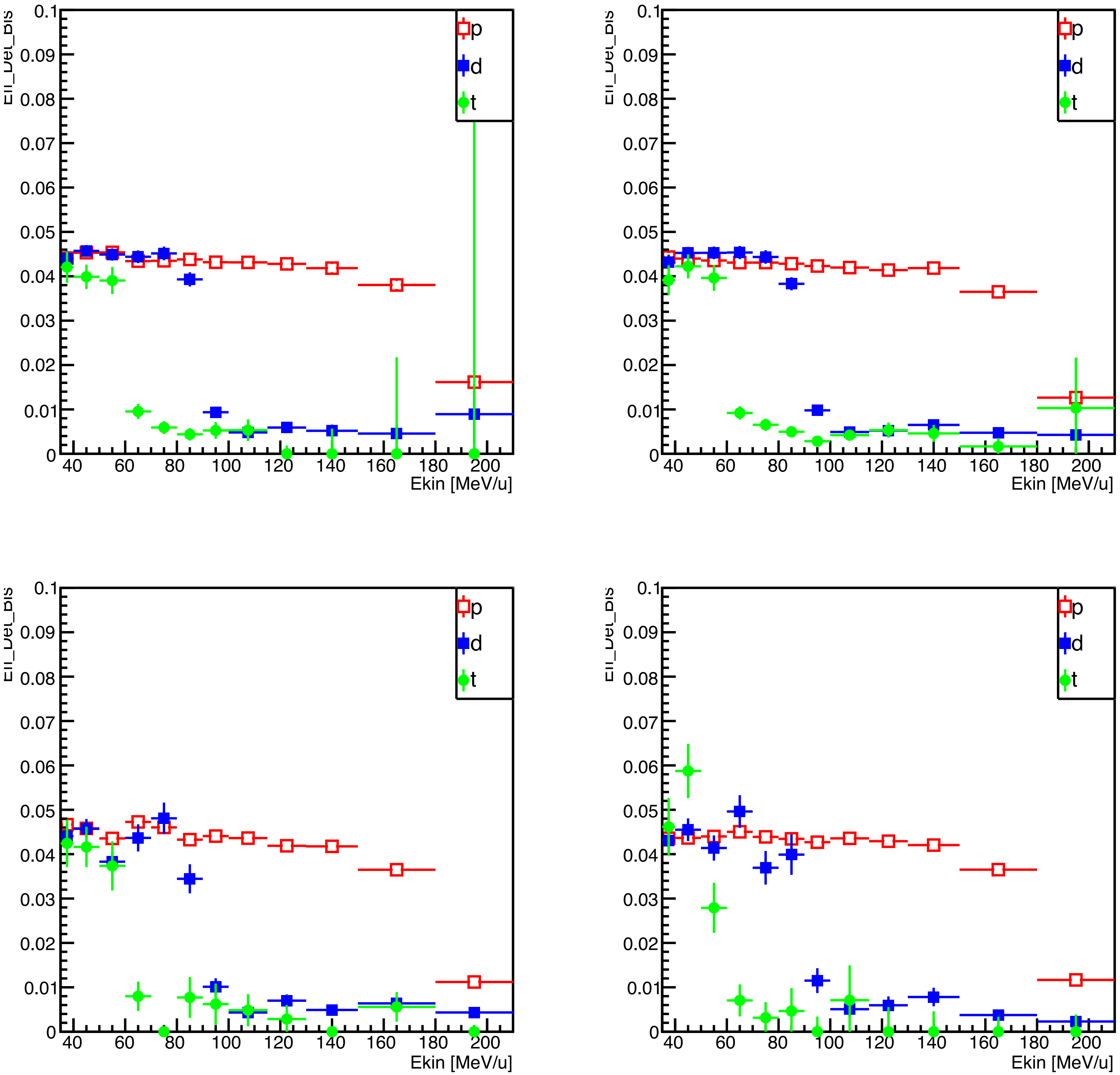
$$\epsilon = \epsilon_{Det} \cdot \epsilon_{Sel} \cdot \epsilon_{DT}$$



60°
PMMA

Efficiency evaluation:

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



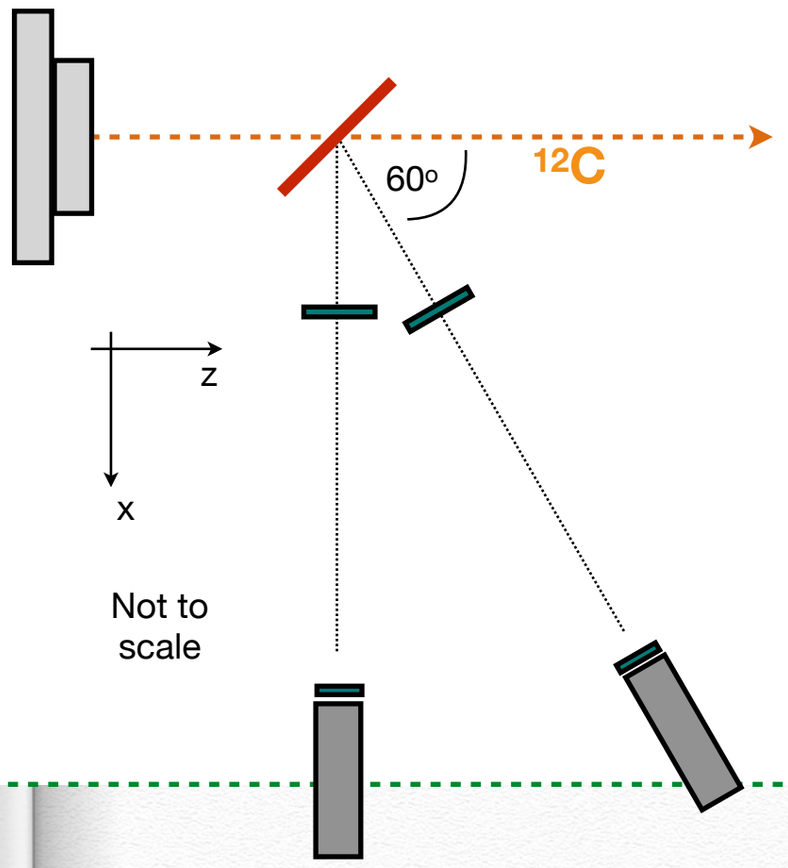
32°
PMMA

Efficiency evaluation:

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

The efficiency $\epsilon_{Det}(E_{kin})$ and $\epsilon_{Sel}(E_{kin})$ have been evaluated using dedicated Monte Carlo simulations developed with the FLUKA code
=> MC FULL triggered: at least 1 fragment (idpa = 1 or -3 or -4) born in tgt

- To evaluate ϵ_{Sel} : p, d, t identification efficiency using the Zid + PID bands



root -l effMix_Ekin_2024_E.cc

Probability that a fragment of type *u* is measured in the region *v* (*u, v = p, d, t*)

$$\epsilon_{mix}^{uv} = \frac{N^{uv}}{N^{u}}$$

Eps_sel_NUME

- in p (d, t) selection, z1 selection, z2 selection
- Eps_sel_DENO selections

Eps_sel_DENO = Eps_det_NUME

- Triggered (time coinc btw STSa and STSb < 150 ns && Edep in STSa,b > 100keV)
- Cross STSa, STSb, LYSO
- above detectors (STSa, STSb, LYSO) energy thresholds cuts as data
  (90/60°: Ely_cut = 24 MeV, Estsa,b_cut = 5 MeV)
  (50/32°: Ely_cut = 24 MeV, Estsa,b_cut = 2,3 MeV)
- p (d, t)
- born in tgt
- son of a primary particle
- out of tgt
- out of tgt in LYSO acceptance (in cartesian coordinates)

Efficiency evaluation:

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

PMMA 115

90^o — Ekin [MeV]	ϵ_{pp} [%]	ϵ_{dd} [%]	ϵ_{tt} [%]
37.5 ± 2.5	99.4 ± 0.7	80.0 ± 12.4	-
50.0 ± 10.0	99.0 ± 0.5	92.0 ± 5.6	-
70.0 ± 10.0	97.0 ± 1.4	100.0 ± 10.0	-
90.0 ± 10.0	97.2 ± 2.1	50.0 ± 28.9	-
110.0 ± 10.0	95.3 ± 3.3	-	-
130.0 ± 10.0	96.3 ± 3.9	-	-
160.0 ± 20.0	83.3 ± 10.6	-	-
215.0 ± 35.0	71.4 ± 16.2	-	-
60^o — Ekin [MeV]	ϵ_{pp} [%]	ϵ_{dd} [%]	ϵ_{tt} [%]
37.5 ± 2.5	99.6 ± 0.2	99.4 ± 0.6	81.8 ± 8.2
50.0 ± 10.0	98.6 ± 0.2	96.4 ± 0.9	96.8 ± 3.4
70.0 ± 10.0	96.7 ± 0.5	89.2 ± 2.5	75.0 ± 20.0
90.0 ± 10.0	95.3 ± 0.8	60.5 ± 7.4	-
110.0 ± 10.0	93.5 ± 1.4	27.3 ± 13.0	-
130.0 ± 10.0	90.8 ± 2.5	25.0 ± 20.0	-
150.0 ± 10.0	86.2 ± 4.5	0.0 ± 25.0	-
170.0 ± 10.0	76.1 ± 6.2	0.0 ± 25.0	-
190.0 ± 10.0	54.5 ± 10.4	-	-
215.0 ± 15.0	61.1 ± 11.2	-	-
245.0 ± 15.0	100.0 ± 16.7	-	-
32^o — Ekin [MeV]	ϵ_{pp} [%]	ϵ_{dd} [%]	ϵ_{tt} [%]
37.5 ± 2.5	97.9 ± 0.3	96.2 ± 0.8	87.4 ± 2.9
45.0 ± 5.0	98.2 ± 0.2	94.1 ± 0.7	85.7 ± 2.5
55.0 ± 5.0	98.1 ± 0.2	94.8 ± 0.7	88.0 ± 2.6
65.0 ± 5.0	96.8 ± 0.3	93.7 ± 0.8	51.6 ± 8.8
75.0 ± 5.0	96.0 ± 0.4	92.4 ± 0.9	0.0 ± 2.8
85.0 ± 5.0	95.8 ± 0.4	88.3 ± 1.3	0.0 ± 4.5
95.0 ± 5.0	95.4 ± 0.4	59.4 ± 4.7	0.0 ± 5.6
107.5 ± 7.5	94.9 ± 0.4	19.2 ± 5.4	0.0 ± 8.3
122.5 ± 7.5	93.0 ± 0.6	3.2 ± 3.4	-
140.0 ± 10.0	90.0 ± 0.7	0.0 ± 3.3	-
165.0 ± 15.0	80.0 ± 1.2	0.0 ± 8.3	-

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90^o — Ekin [MeV]	ϵ_{dp} [%]	ϵ_{tp} [%]	ϵ_{pd} [%]	ϵ_{td} [%]	ϵ_{pt} [%]	ϵ_{dt} [%]
37.5 ± 2.5	0.6 ± 0.7	0.0 ± 0.3	0.0 ± 4.5	0.0 ± 4.5	-	-
50.0 ± 10.0	0.2 ± 0.3	0.0 ± 0.1	0.0 ± 1.9	0.0 ± 1.9	-	-
70.0 ± 10.0	0.0 ± 0.3	0.0 ± 0.3	0.0 ± 10.0	0.0 ± 10.0	-	-
90.0 ± 10.0	0.0 ± 0.7	0.0 ± 0.7	0.0 ± 16.7	0.0 ± 16.7	-	-
110.0 ± 10.0	0.0 ± 1.1	0.0 ± 1.1	-	-	-	-
130.0 ± 10.0	0.0 ± 1.8	0.0 ± 1.8	-	-	-	-
160.0 ± 20.0	0.0 ± 3.8	0.0 ± 3.8	-	-	-	-
215.0 ± 35.0	0.0 ± 6.2	0.0 ± 6.2	-	-	-	-
60^o — Ekin [MeV]	ϵ_{dp} [%]	ϵ_{tp} [%]	ϵ_{pd} [%]	ϵ_{td} [%]	ϵ_{pt} [%]	ϵ_{dt} [%]
37.5 ± 2.5	0.0 ± 0.1	0.1 ± 0.1	0.0 ± 0.3	1.1 ± 0.8	0.0 ± 2.2	4.5 ± 4.8
50.0 ± 10.0	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.2 ± 0.3	0.0 ± 1.6	9.7 ± 5.4
70.0 ± 10.0	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.3	0.0 ± 0.3	0.0 ± 10.0	225.0 ± 10.0
90.0 ± 10.0	0.3 ± 0.2	0.0 ± 0.1	0.0 ± 1.1	0.0 ± 1.1	-	-
110.0 ± 10.0	0.0 ± 0.2	0.0 ± 0.2	0.0 ± 4.2	0.0 ± 4.2	-	-
130.0 ± 10.0	0.0 ± 0.4	0.0 ± 0.4	0.0 ± 10.0	0.0 ± 10.0	-	-
150.0 ± 10.0	0.0 ± 0.8	0.0 ± 0.8	0.0 ± 25.0	0.0 ± 25.0	-	-
170.0 ± 10.0	0.0 ± 1.1	0.0 ± 1.1	300.0 ± 25.0	0.0 ± 25.0	-	-
190.0 ± 10.0	0.0 ± 2.2	0.0 ± 2.2	-	-	-	-
215.0 ± 15.0	0.0 ± 2.6	0.0 ± 2.6	-	-	-	-
245.0 ± 15.0	0.0 ± 16.7	0.0 ± 16.7	-	-	-	-
32^o — Ekin [MeV]	ϵ_{dp} [%]	ϵ_{tp} [%]	ϵ_{pd} [%]	ϵ_{td} [%]	ϵ_{pt} [%]	ϵ_{dt} [%]
37.5 ± 2.5	0.5 ± 0.2	0.2 ± 0.1	0.2 ± 0.2	1.6 ± 0.5	0.0 ± 0.4	0.0 ± 0.4
45.0 ± 5.0	0.7 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	1.2 ± 0.3	0.0 ± 0.2	0.0 ± 0.2
55.0 ± 5.0	0.8 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.6 ± 0.2	0.0 ± 0.3	0.0 ± 0.3
65.0 ± 5.0	1.0 ± 0.2	0.3 ± 0.1	0.2 ± 0.2	0.5 ± 0.2	3.2 ± 3.4	9.7 ± 5.4
75.0 ± 5.0	0.9 ± 0.2	0.2 ± 0.1	0.1 ± 0.1	1.1 ± 0.4	0.0 ± 2.8	29.4 ± 10.8
85.0 ± 5.0	0.9 ± 0.2	0.0 ± 0.0	0.0 ± 0.1	1.4 ± 0.5	0.0 ± 4.5	100.0 ± 4.5
95.0 ± 5.0	1.2 ± 0.2	0.1 ± 0.1	1.9 ± 1.4	3.8 ± 1.9	0.0 ± 5.6	12.5 ± 11.8
107.5 ± 7.5	1.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.9	0.0 ± 0.9	0.0 ± 8.3	0.0 ± 8.3
122.5 ± 7.5	0.8 ± 0.2	0.0 ± 0.0	0.0 ± 1.6	0.0 ± 1.6	-	-
140.0 ± 10.0	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 3.3	0.0 ± 3.3	-	-
165.0 ± 15.0	0.2 ± 0.1	0.0 ± 0.0	100.0 ± 8.3	0.0 ± 8.3	-	-

Closure TEST

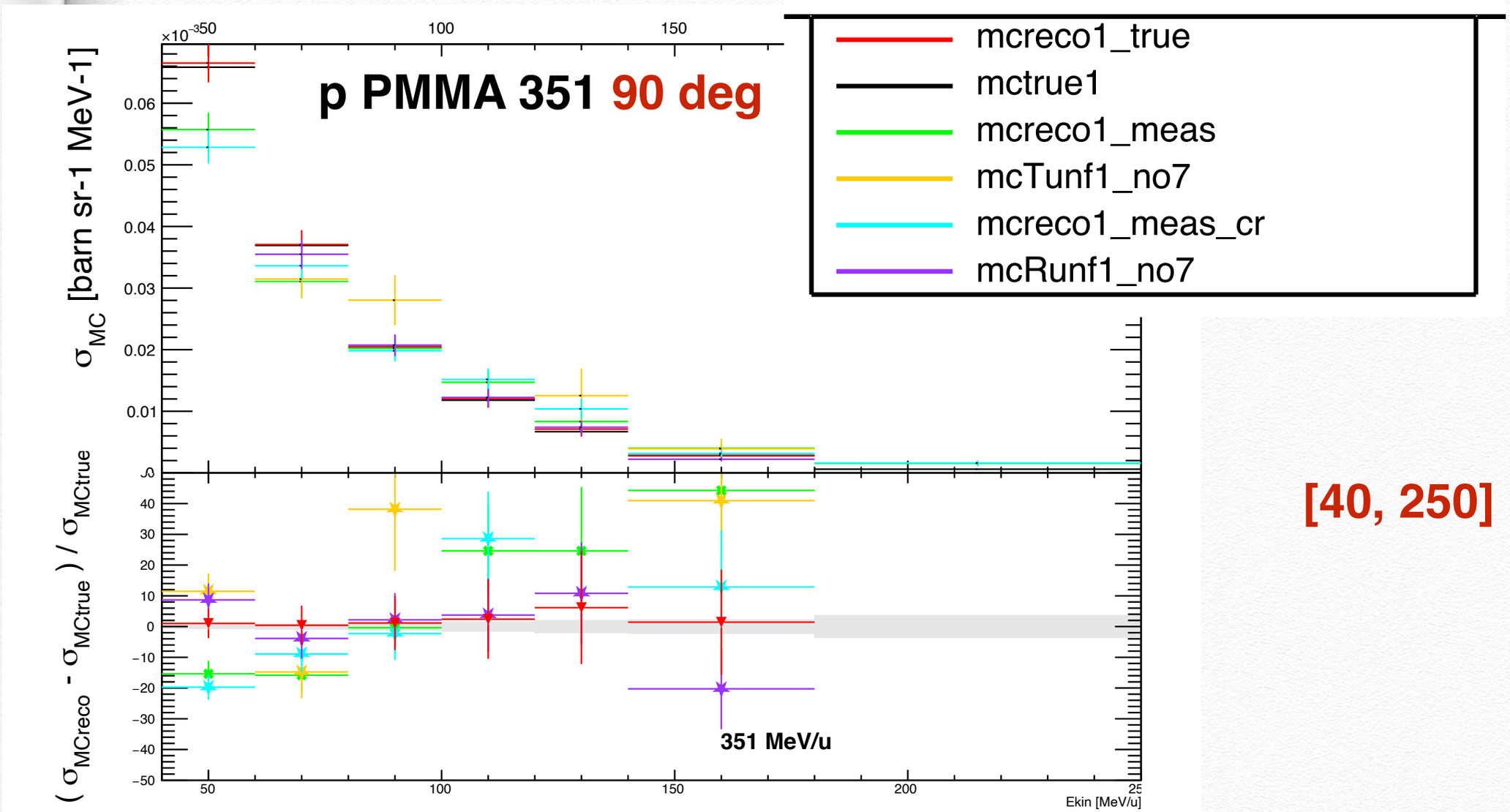
To study the **Monte Carlo reliability** in assessing the efficiencies to be applied to experimental data, we perform the MC Closure Test:

- define the **MC truth** (EpsDet_DENO) = p (d, t),
  born in tgt, son of a primary particle,
  out of tgt in (**Θ** ± △**Θ**(4°); Φ± △Φ(4°/6°@32deg))
  [no angular bin due to Multiple Scattering]
- **reconstruction of the MC** with efficiencies applied

=> CLOSURE TEST: $\frac{|\ \text{MCreco} - \text{MCtruth}\ |}{\text{MCtruth}}$

Closure TEST

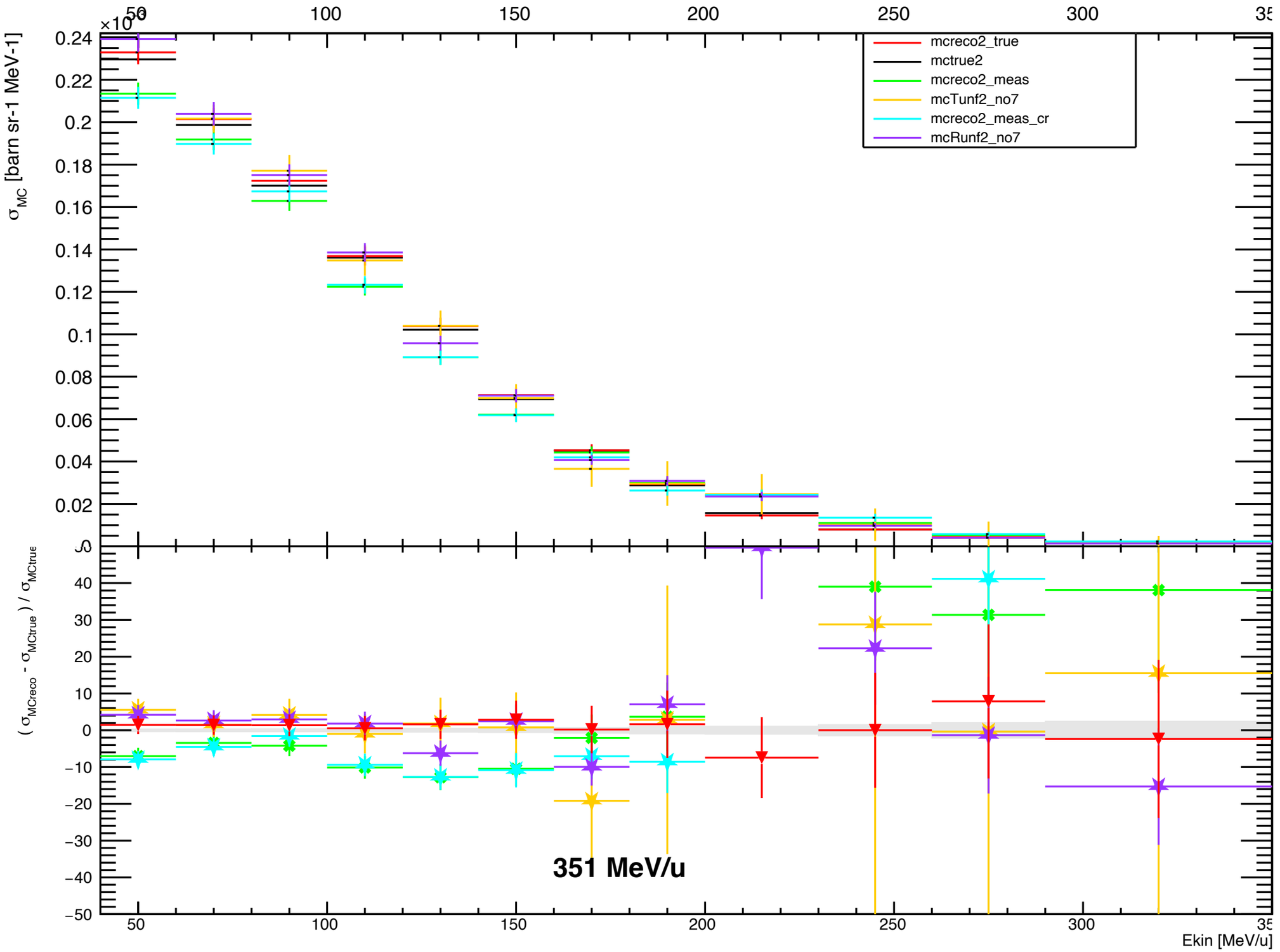
- mctrue = mc @ generation
- mcreco_meas = mc reco (no IDmatch) (Ekin MEAS)
- mcreco_true = mc reco IDmatch (Ekin GEN)
- mcreco_meas_cr = mc reco IDmatch (Ekin MEAS)
- mcTunf = mcreco_meas UNFOLDED with TUnfold (Ekin@gen)
- mcRoounf = mcreco_meas UNFOLDED with RooUnfold (Ekin@gen)



[40, 250] MeV/u

Closure MC

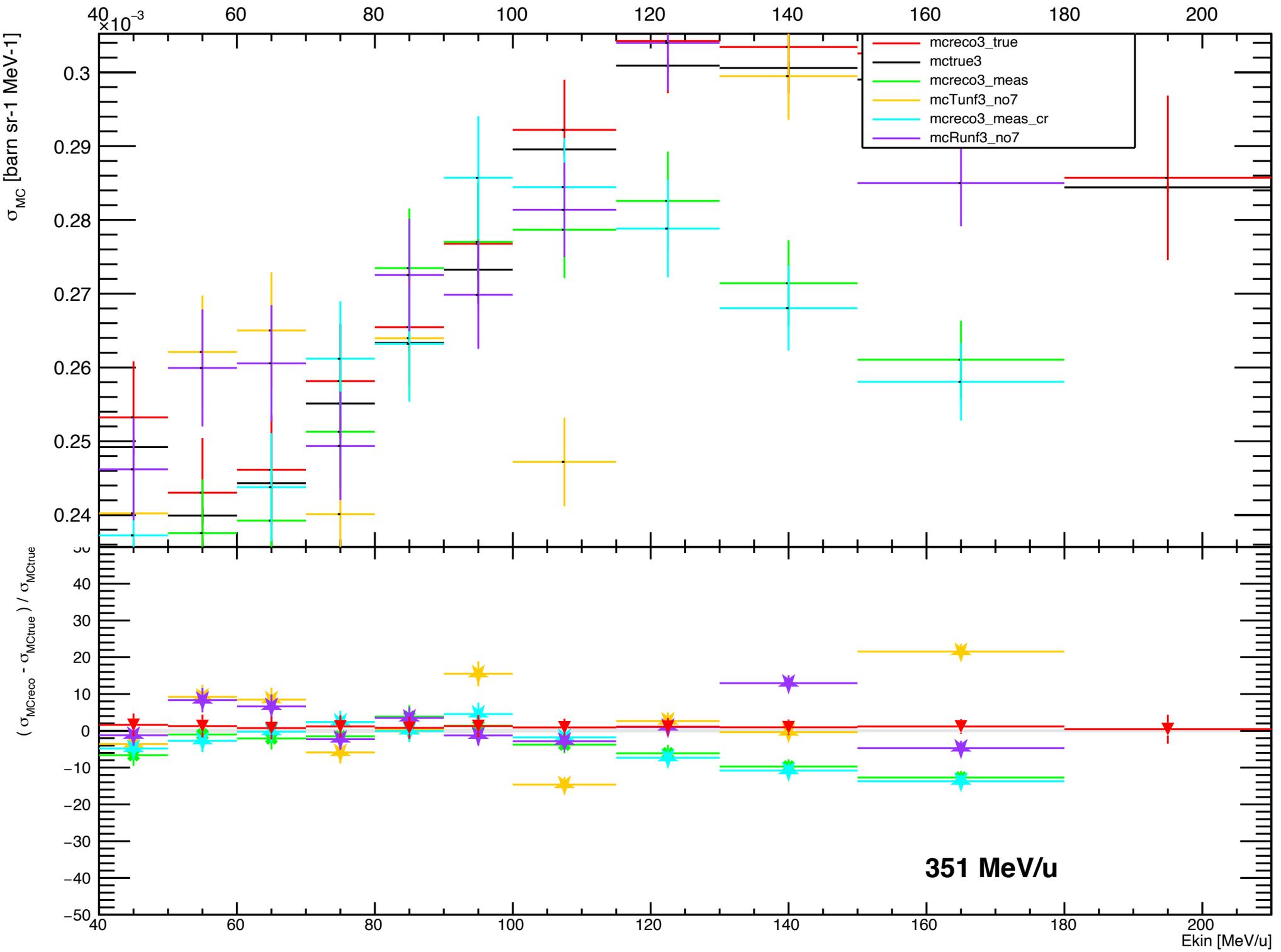
p PMMA 351 60 deg



[40, 350] MeV/u

Closure MC

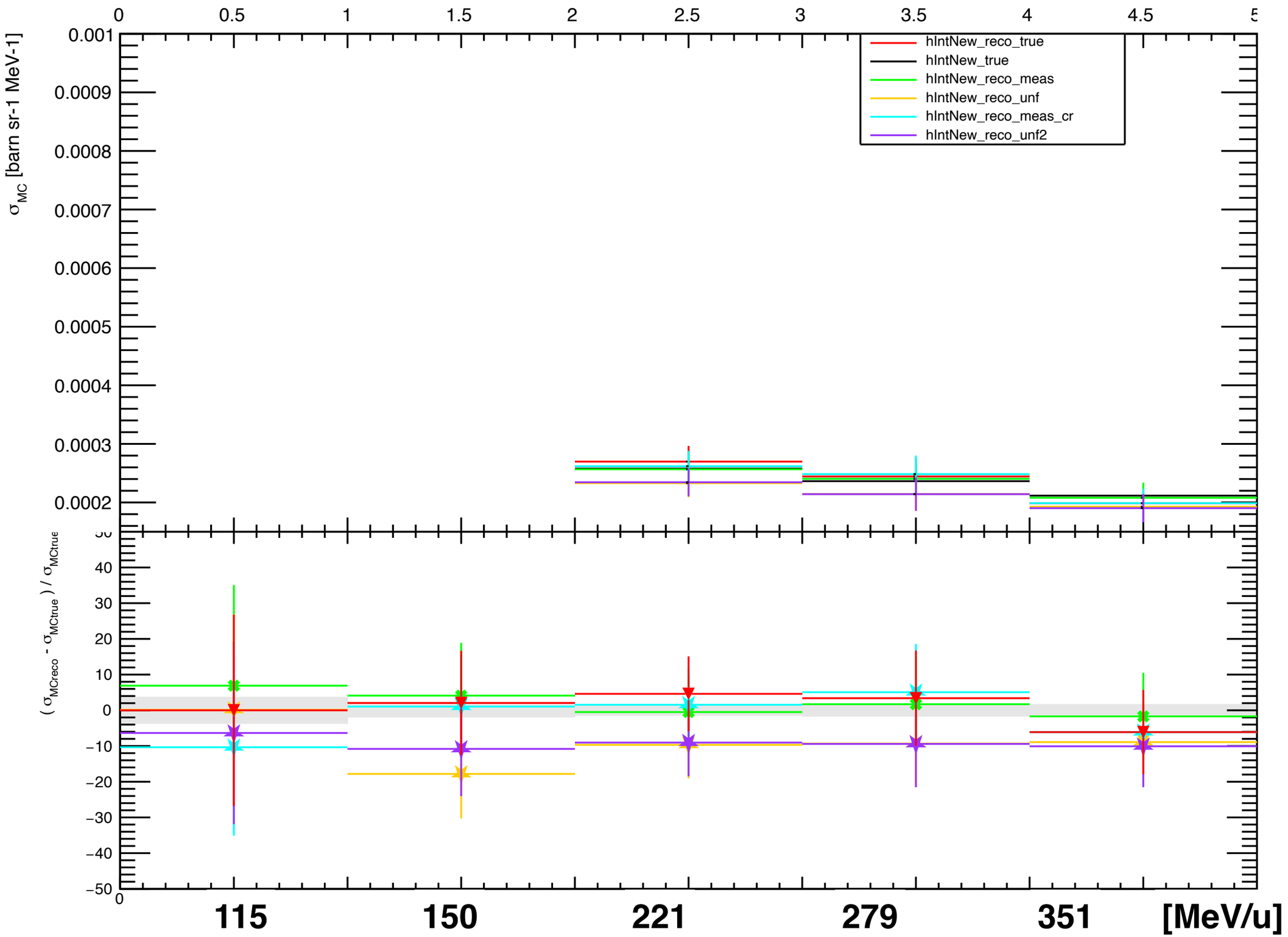
p PMMA 351 32 deg



[40, 180] MeV/u

Closure MC

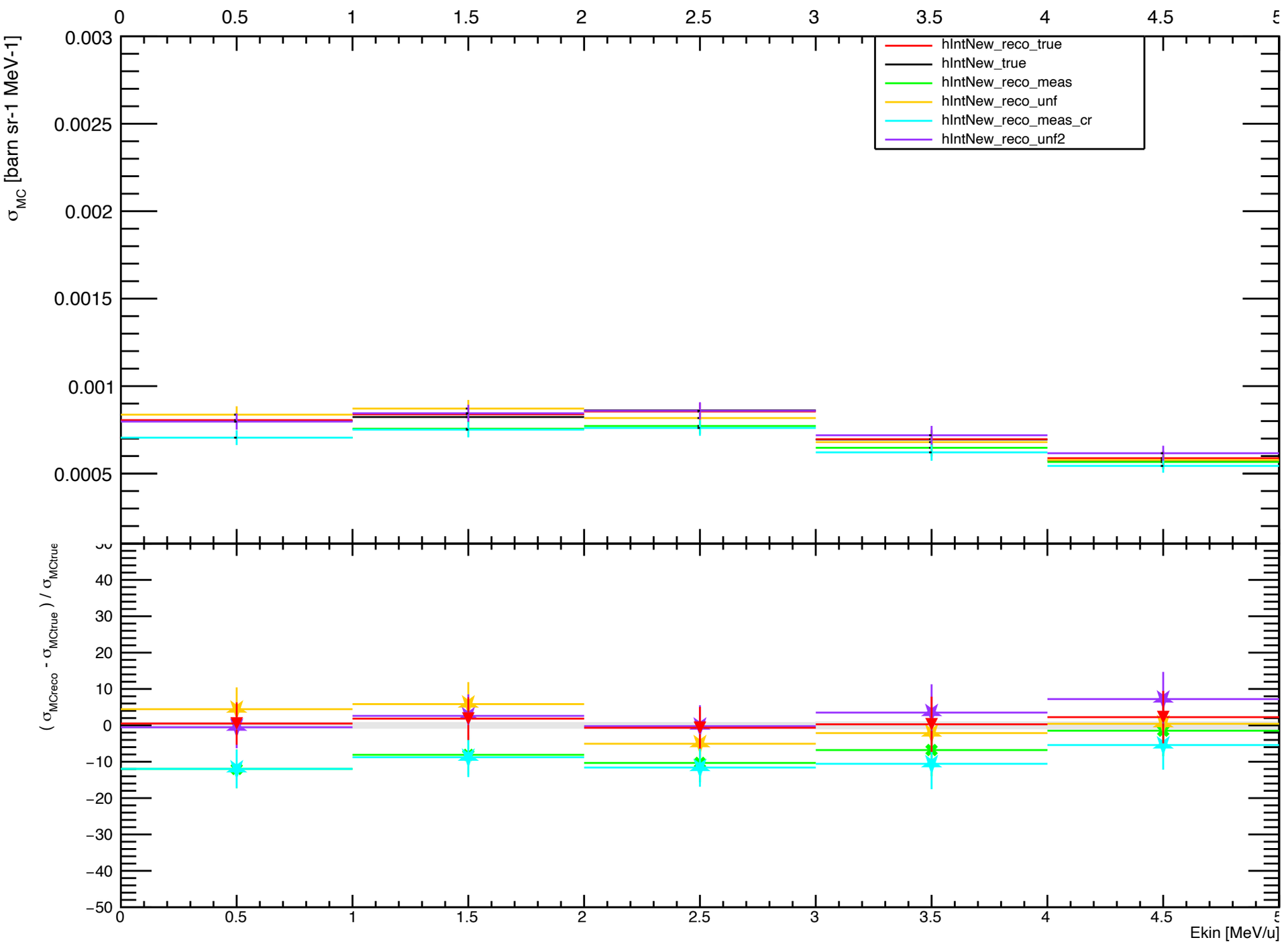
d PMMA Integral 90 deg



[40., 250.] MeV/u

Closure MC

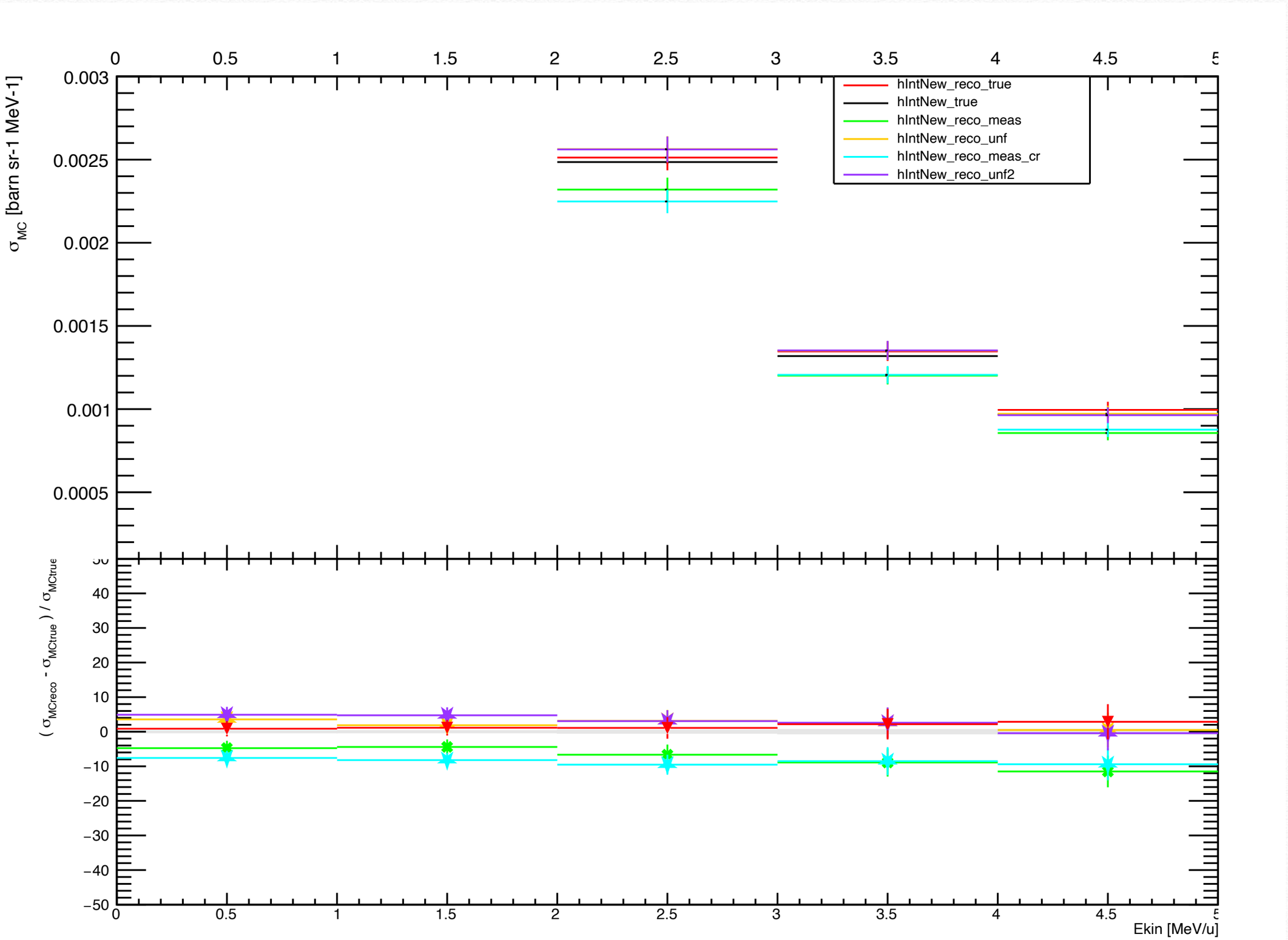
d PMMA Int 60 deg



[40., 350.] MeV/u

Closure MC

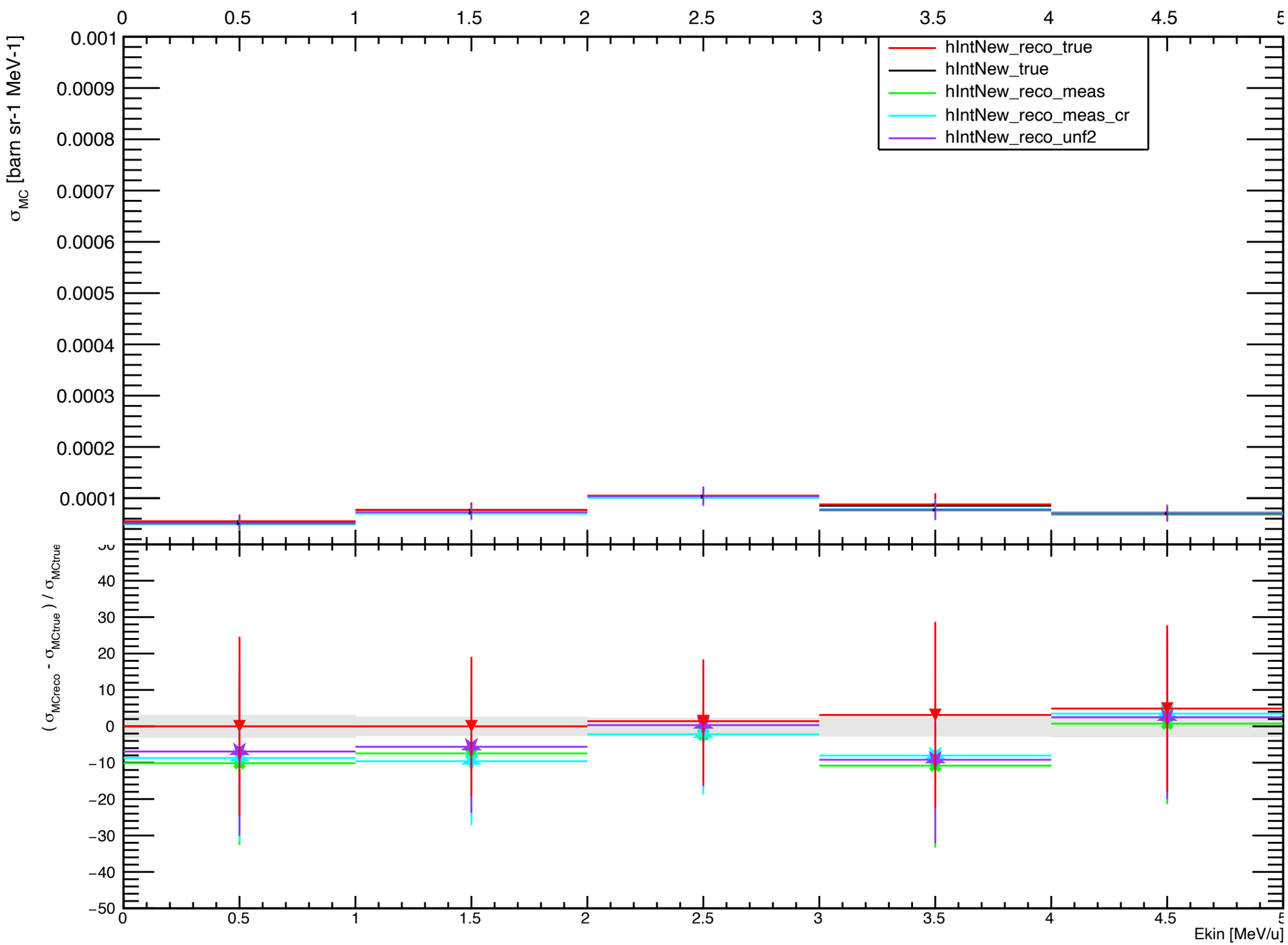
d PMMA Int 32 deg



[40., 90.] MeV/u

Closure MC

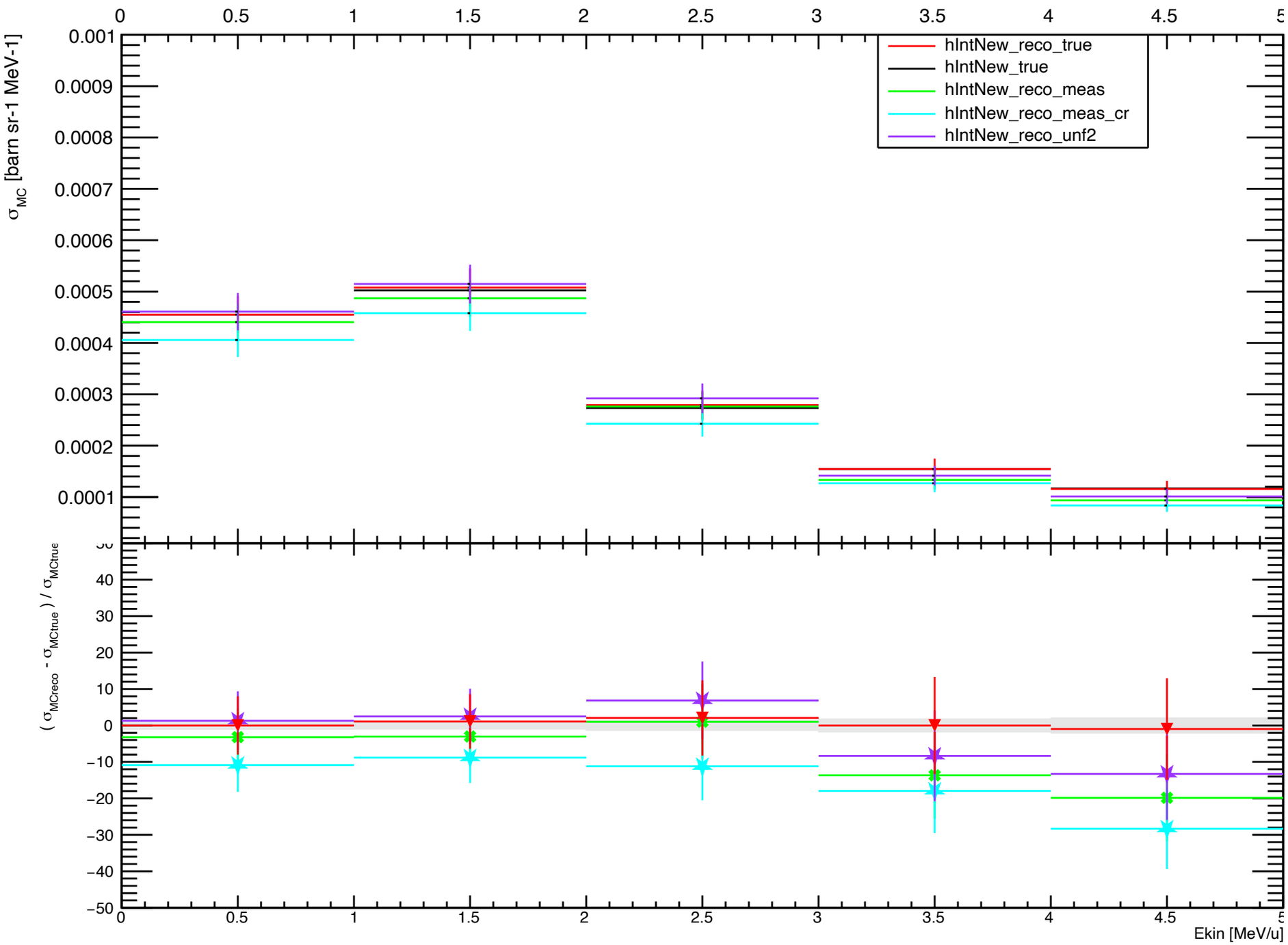
t PMMA Int 60 deg



[40., 350.] MeV/u

Closure MC

t PMMA Int 32 deg



[40., 60.] MeV/u

Conclusions

- **We are performing a study on RooUnfoldBayes to assess the best n iteration parameter which made the unfolding stable also at 32 degrees** (by now we used niter = 3)
- Once the unfolding procedure is stable we will:
  1) assess the MCsys error from the closure test
  2) apply the unfolding to experimental data
  3) add the sys errors to experimental data (machinery ready):
     N12C (4%), Closure MC, PID sys, Unfolding sys (?)