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

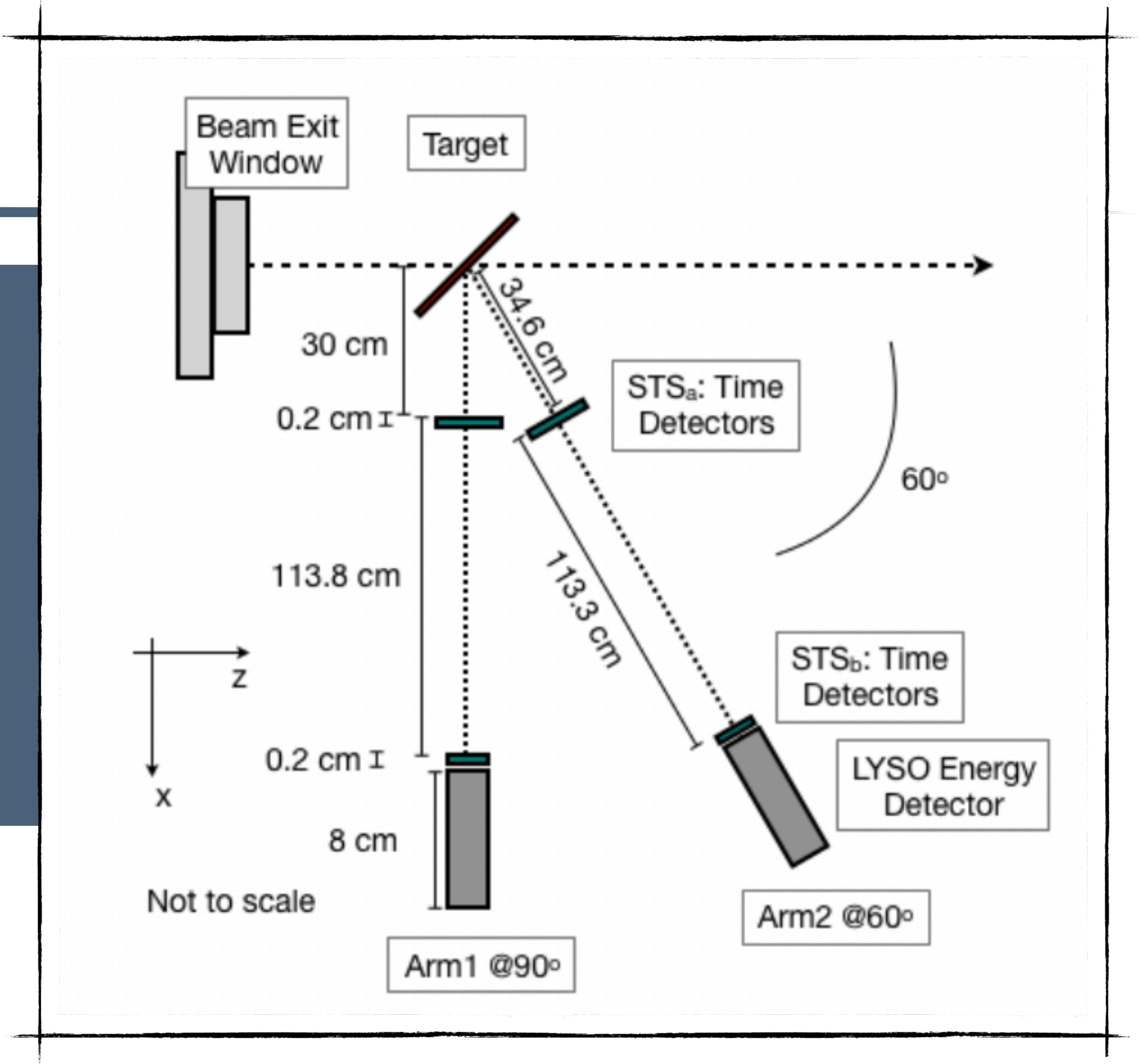
CNAO July 2017 Data Taking

IlaMi from Milano and Roma

FOOT General Meeting, June 2024

Experimental Setup

- 3 thin targets (1-2 mm) based on C, H, O elements
  PMMA, C, CH
- 3 detection angles: **90º, 60º, 32º**
- 5 Carbon Ion beam energies:
  115, 150, 221, 279, 351 MeV/u



- Fragments production (**Z=1, A = 1, 2, 3**) as a function of the production kinetic energy
- Time of Flight in thin plastic scintillators and energy deposit in the inorganic crystals for PID and Ekin measurements
- Experimental Data - Monte Carlo simulation comparison

4 STSs 2mm thick for ToF measurement (time resolution ~ 400-600 ps) and Deposited Energy measurement (dE);
2 LYSOs 4x4x8 cm^3 for Deposited Energy measurement (E);

Cross Section Formula

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

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

Cross Section Formula: Normalization

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

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

From CNAO
Dose Delivery System

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

Information on 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

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

$th_Y = th_Y * sqrt(2)$

Cross Section Formula: Yield

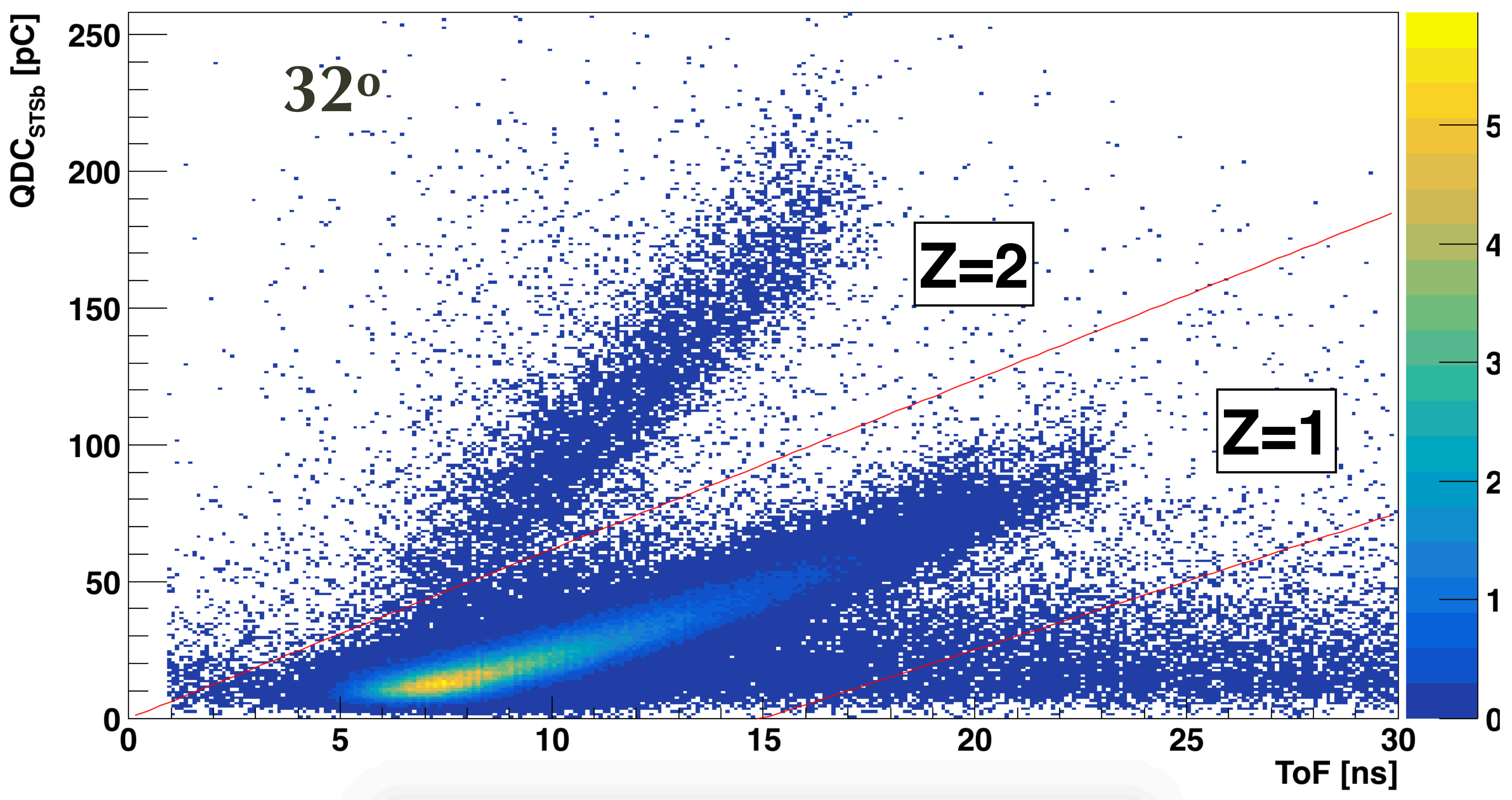
$$\beta_i = L/(ToF_i \cdot c)$$

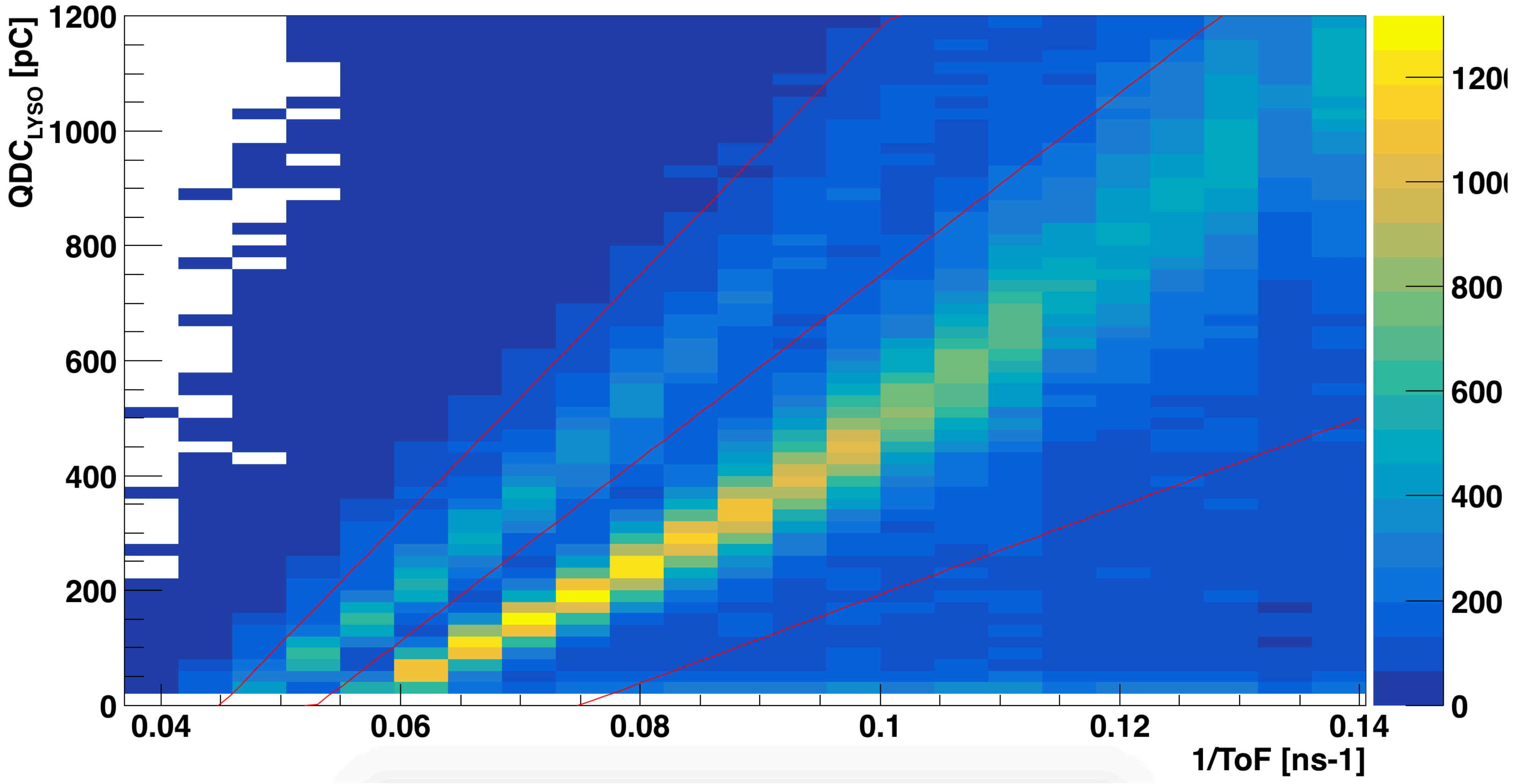
$$E_{kin} = m_i \cdot (\gamma - 1)$$

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

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

- Particle identification (Z,A) from combining the information of QDC LYSO, QDC STSs, ToF STSs





Cross Section Formula: Yield

$$\beta_i = L/(ToF_i \cdot c)$$

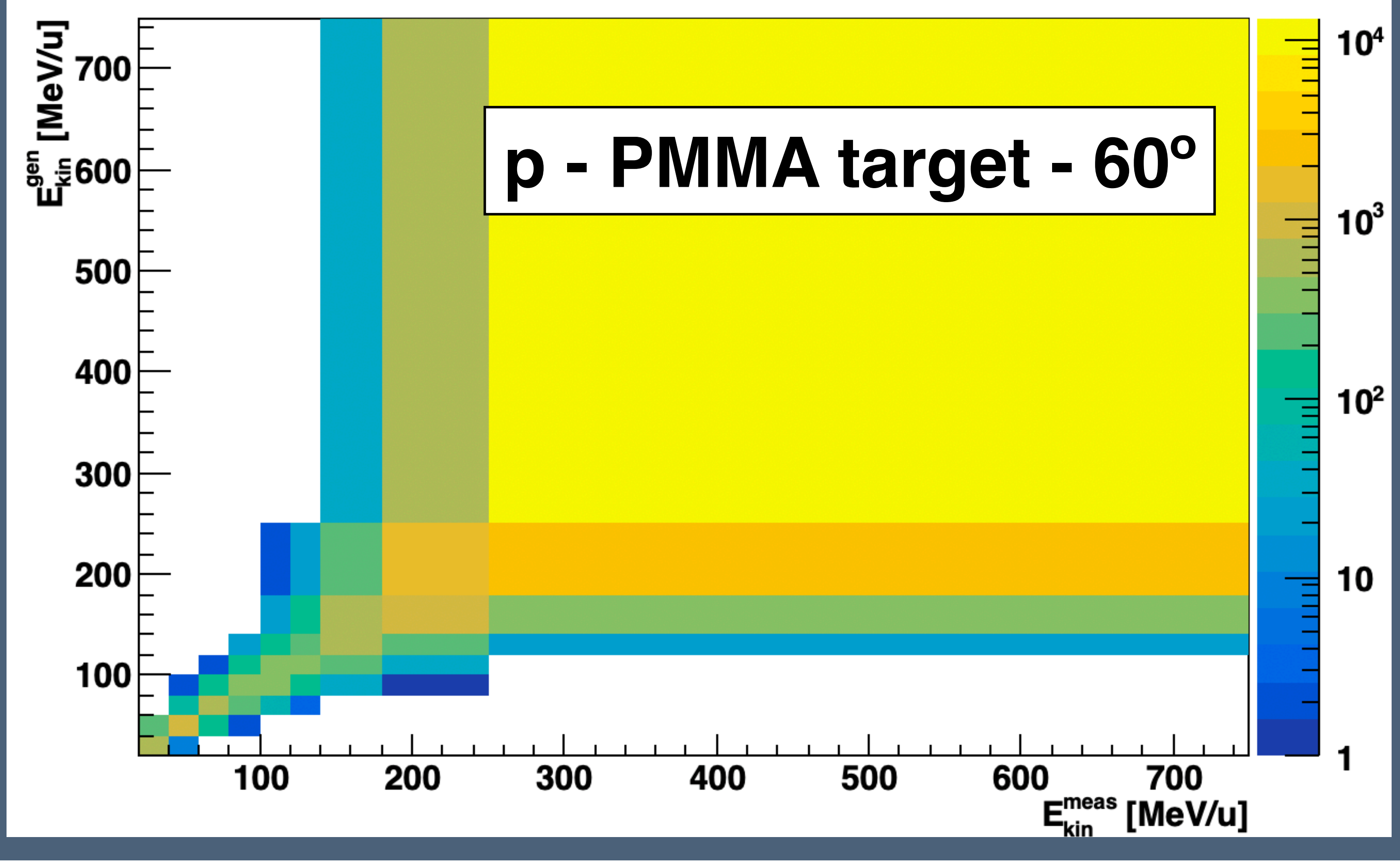
$$E_{kin} = m_i \cdot (\gamma - 1)$$

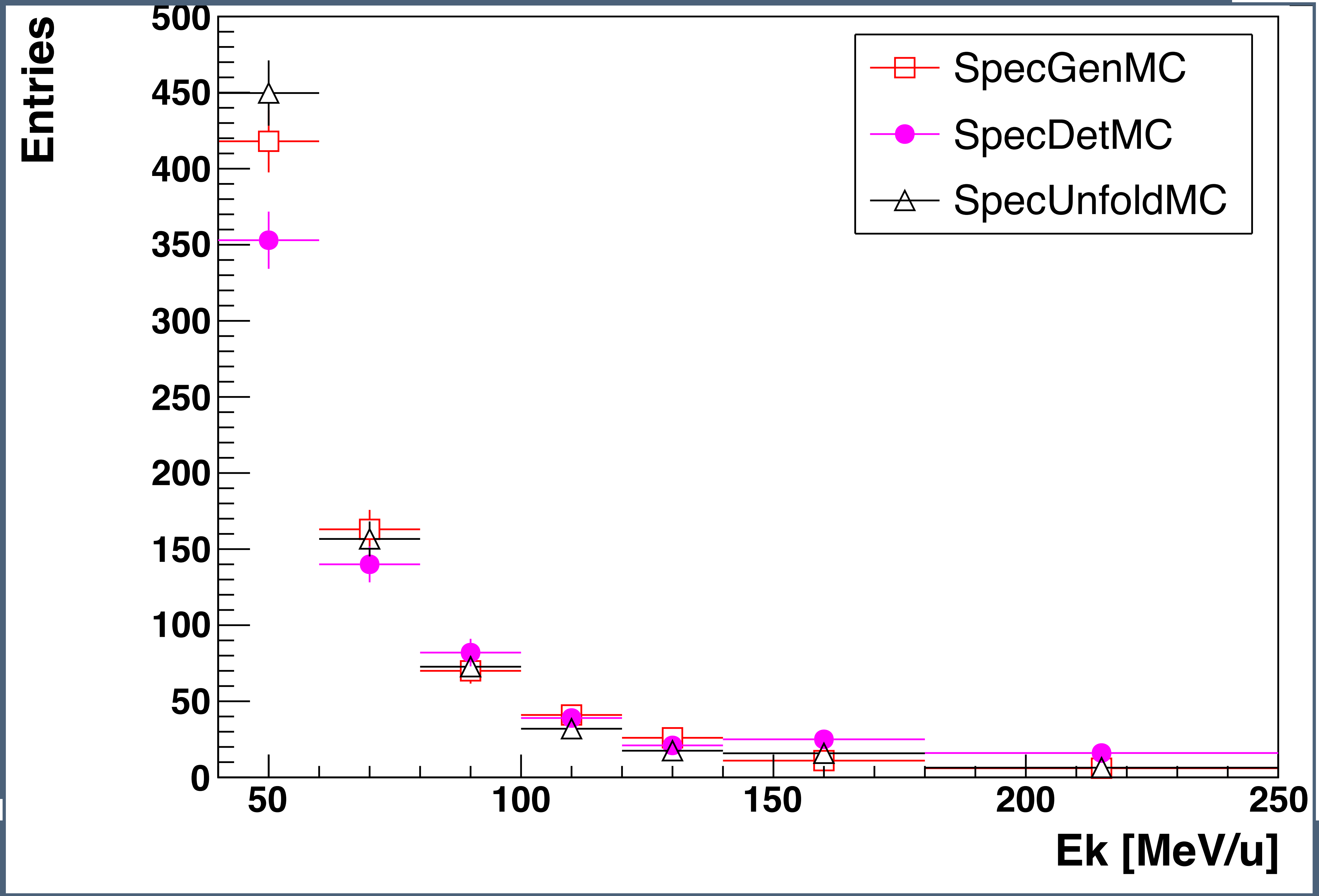
The ^{12}C fragmentation cross section for a $^A_Z X$ fragment are obtained as:

$$\frac{d\sigma}{dE_k}(^A_Z X) = \frac{N_{^A_Z X}(E_k)}{\Delta E_k} \cdot \frac{purity(E_k)}{N_{^{12}C} N_Y} \cdot \frac{1}{\epsilon}$$

- **Unfolding technique (RooBayesUnfold) to obtain the fragments Ekin gen from Ekin meas**

Unfolding Matrix from FLAT simulation





Cross Section Formula: Purity

$$\beta_i = L/(ToF_i \cdot c)$$

$$E_{kin} = m_i \cdot (\gamma - 1)$$

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

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

Purity = $\dfrac{\textbf{number of particles selected as p (d,t)}}{\textbf{number of true p (d,t) in p (d,t) selection}}$

Cross Section Formula: Efficiency

$$\beta_i = L/(ToF_i \cdot c)$$
$$E_{kin} = m_i \cdot (\gamma - 1)$$

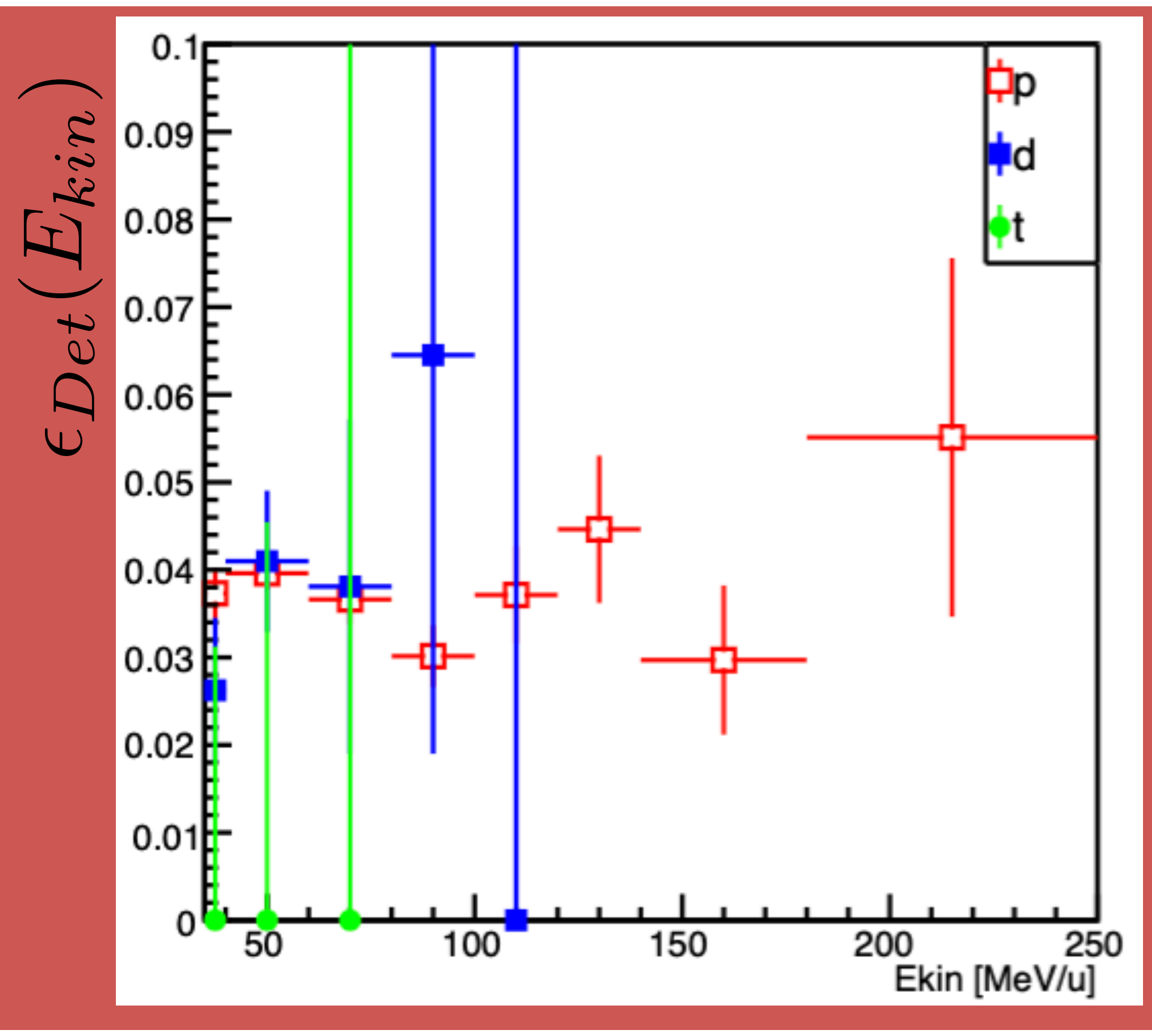
The ^{12}C fragmentation cross section for a $^{A}_{Z}X$ fragment are obtained as:

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

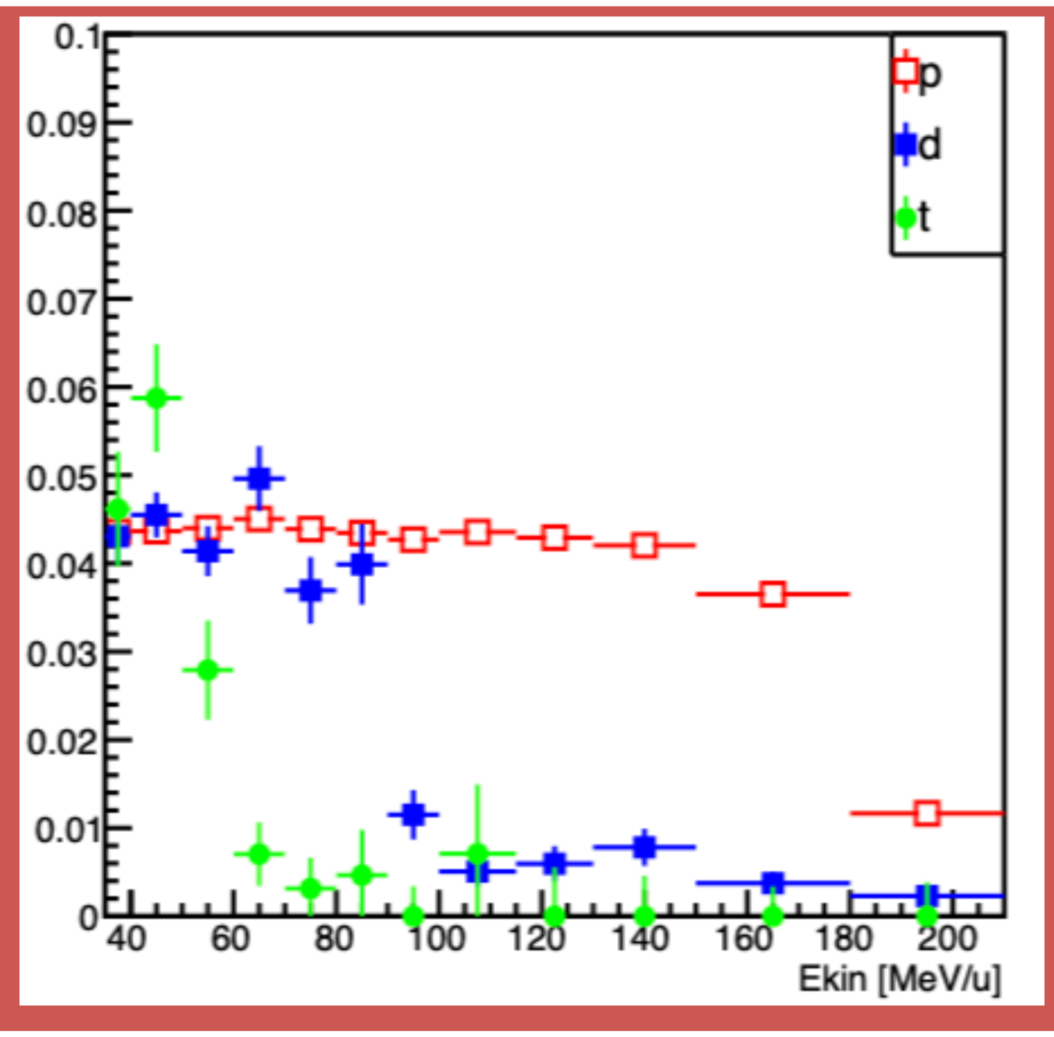
$$\epsilon = \epsilon_{Det} \cdot \epsilon_{Sel} \cdot \epsilon_{DT}$$

Full simulation (FLUKA)
(C on Targets ~1.e10 primaries)
to calculate the
trigger+detection+geometrical efficiency
as a function of fragment production Ekin

PMMA target - 90° - ^{12}C 115 MeV/u



PMMA target - 32° - ^{12}C 351 MeV/u



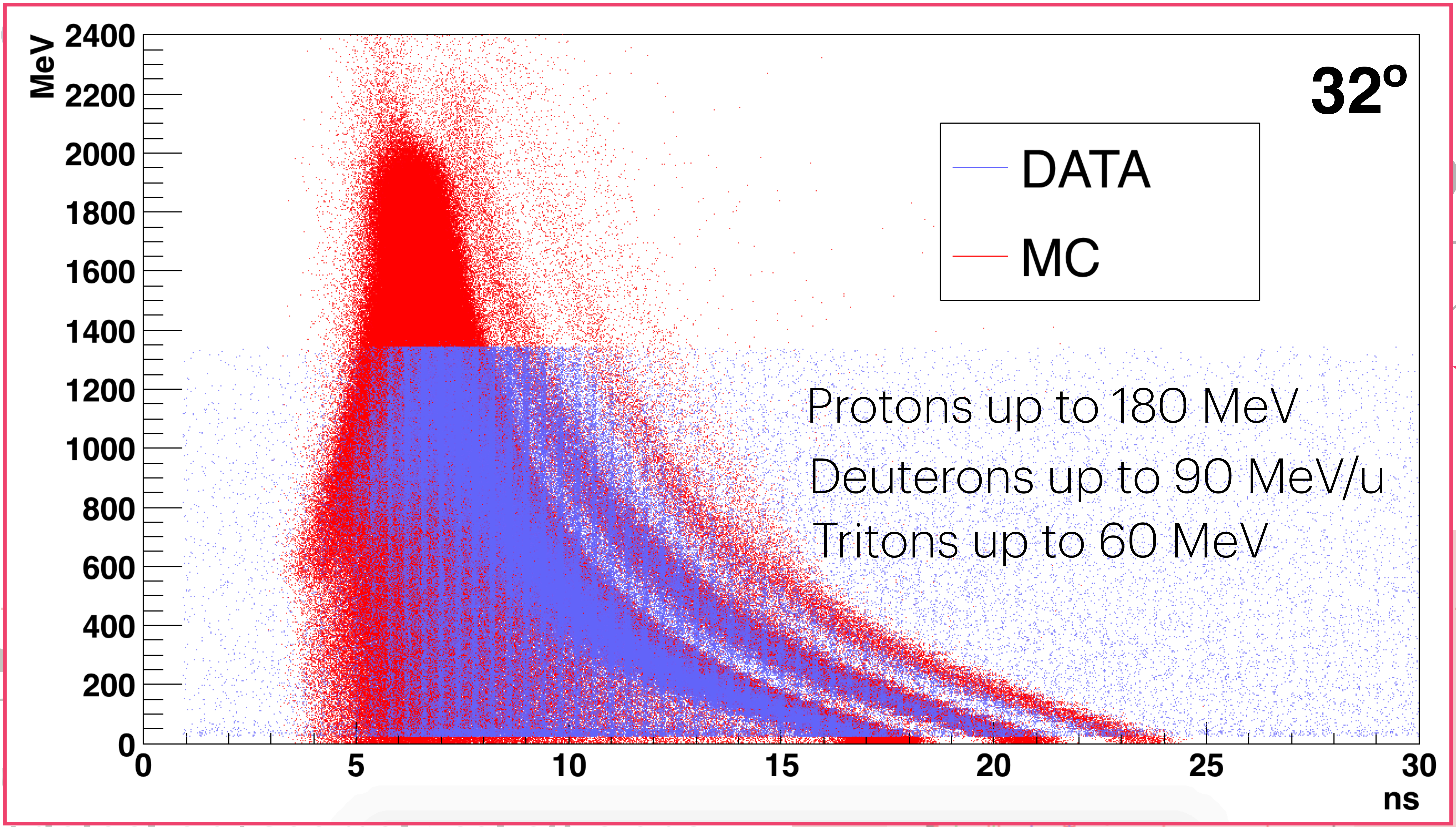
Cross Section Formula: Efficiency

$$\beta_i = L/(ToF_i \cdot c)$$

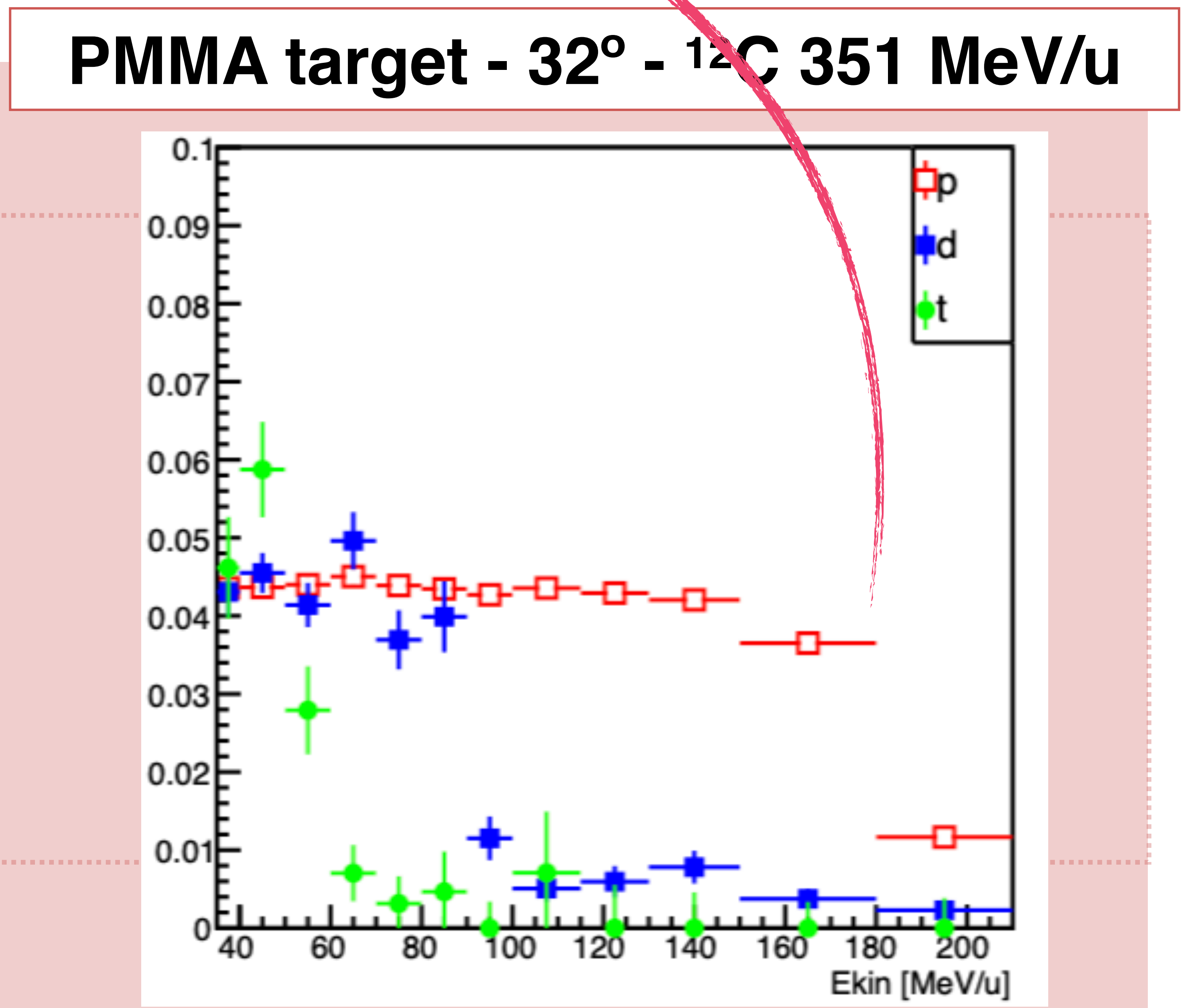
$$E_{kin} = m_i \cdot (\gamma - 1)$$

The 12 ... as:

$$\cdot \frac{1}{\epsilon}$$



Full si... (C on T... to calc...
trigger+detection+geometrical efficiency
as a function of fragment production Ekin



Cross Section Formula: Efficiency

$$\beta_i = L/(ToF_i \cdot c)$$

$$E_{kin} = m_i \cdot (\gamma - 1)$$

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

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

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

Full simulation (FLUKA)
(C on Targets ~1.e^{10} primaries)
to compute the **PID efficiency**
of PID selection on E (dE) vs ToF
distributions, tuned from data

PMMA 115

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	-

Cross Section Formula: Efficiency

$$\beta_i = L/(ToF_i \cdot c)$$
$$E_{kin} = m_i \cdot (\gamma - 1)$$

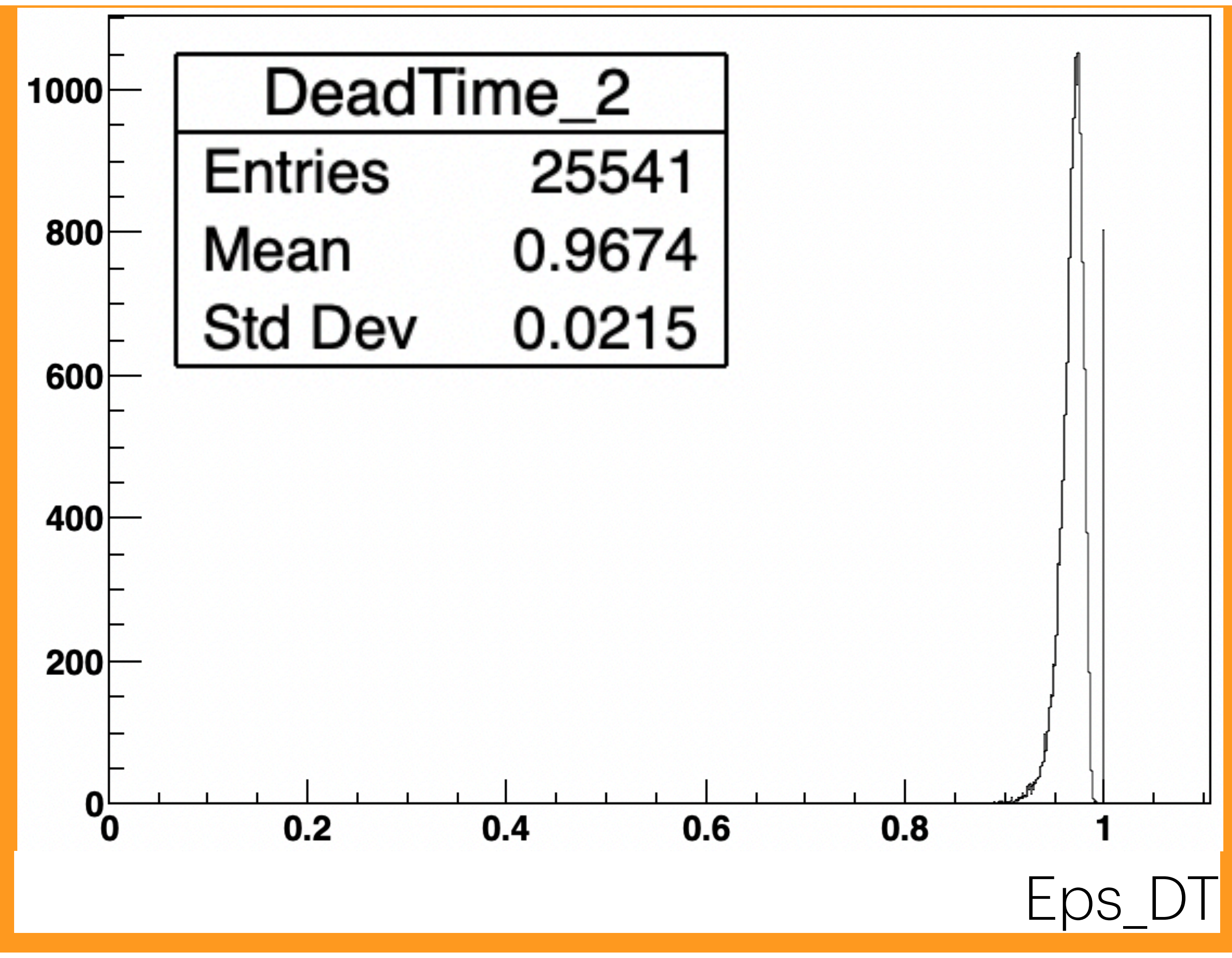
The ^{12}C fragmentation cross section for a $^{A}_{Z}X$ fragment are obtained as:

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

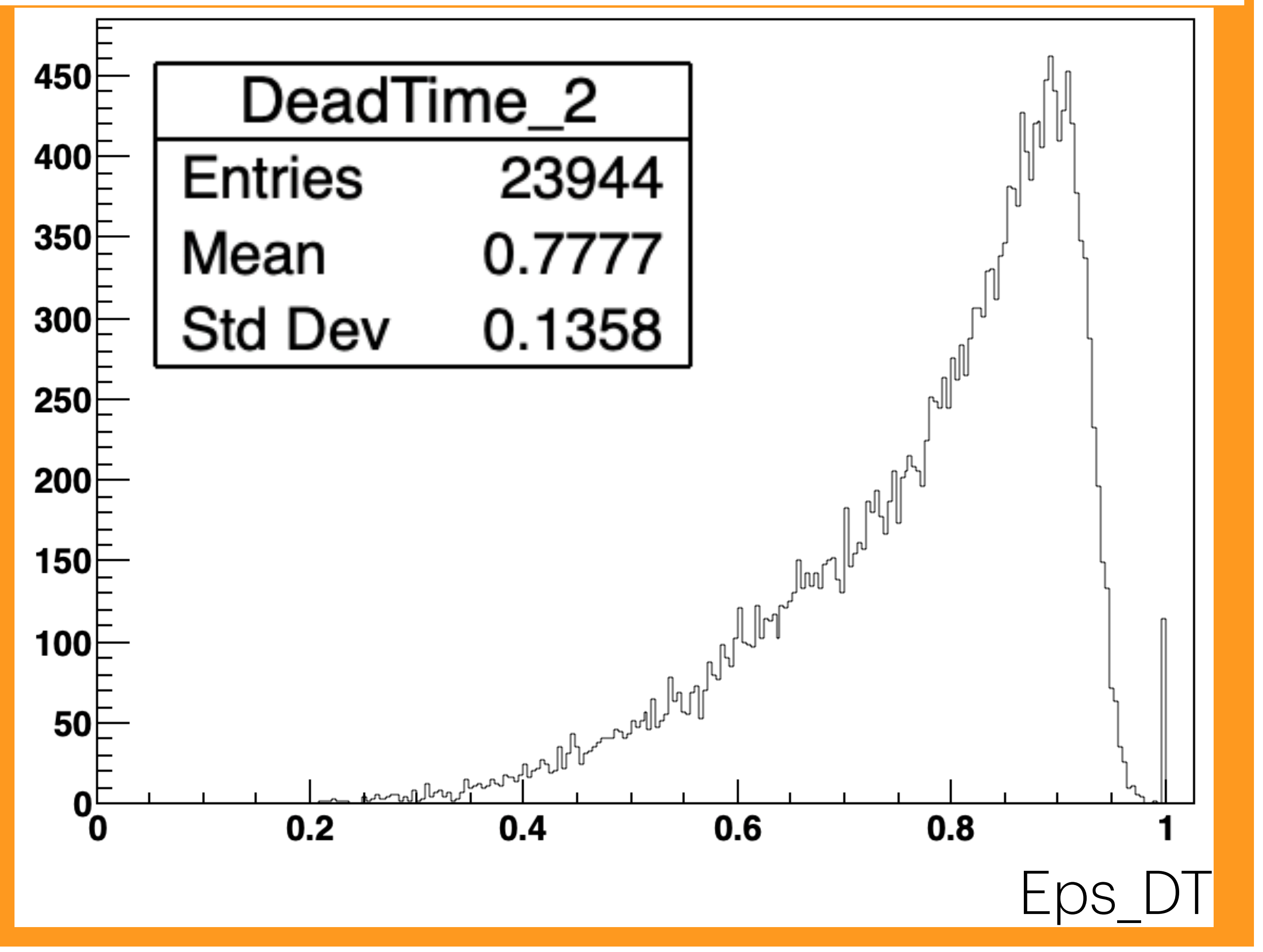
$$\epsilon = \epsilon_{Det} \cdot \epsilon_{Sel} \cdot \epsilon_{DT}$$

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

PMMA target - 90° - ^{12}C 115 MeV/u



PMMA target - 32° - ^{12}C 351 MeV/u



Systematics to the measurement

1) Monte Carlo Closure Test:

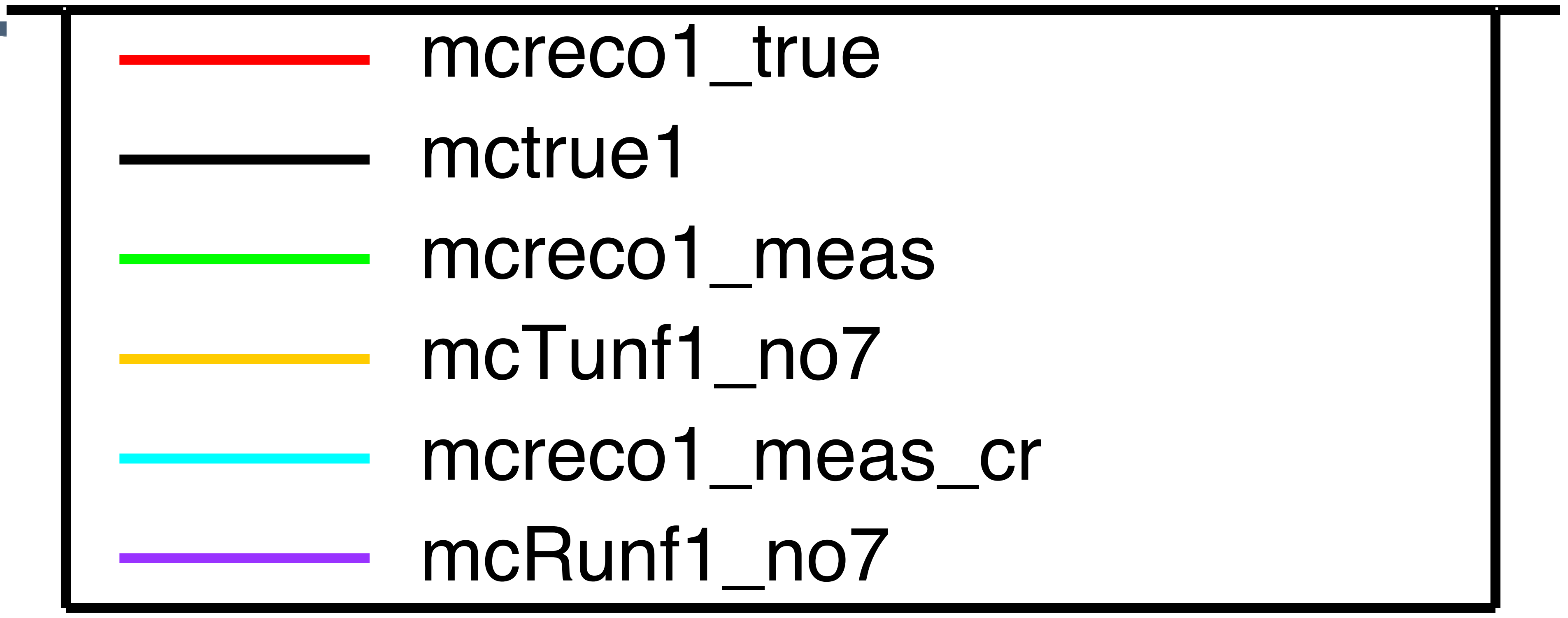
study of the Monte Carlo reliability in assessing the efficiencies to be applied to experimental data:

- define the **MCtruth** (EpsDet_DENO) = p (d, t), born in tgt, son of a primary particle, exiting the target, produced in (**ϴ** ± △**ϴ**(4º); *φ*± △*φ*(4º/6º@32deg)) [angular bin due to Multiple Scattering*]
- reconstruction of the MC with efficiencies applied (**MCreco**)
- comparison of MCreco with MC truth

$$\mathbf{sys_{MC}} = \frac{|\,\mathrm{MCreco} - \mathrm{MCtruth}\,|}{\mathrm{MCtruth}}$$

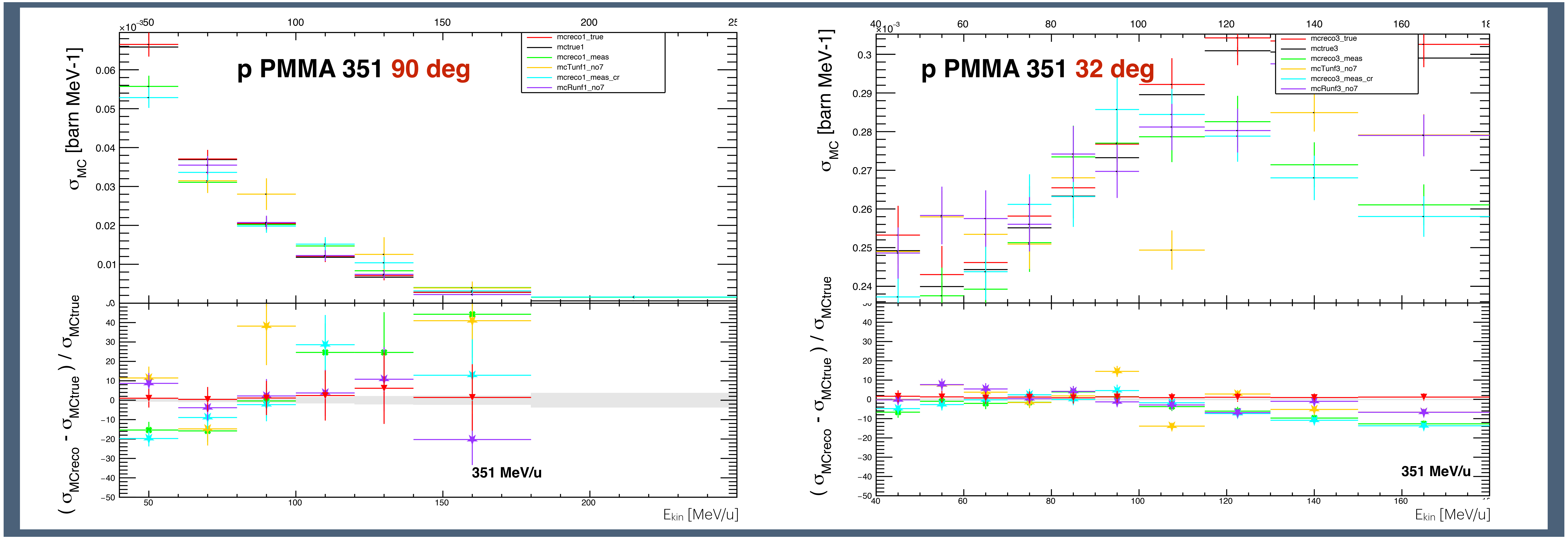
[*the LYSO theoretical solid angle is **ϴ**,*φ* ± 0.8º]

Systematics to the measurement



1) Monte Carlo 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)**



Systematics to the measurement

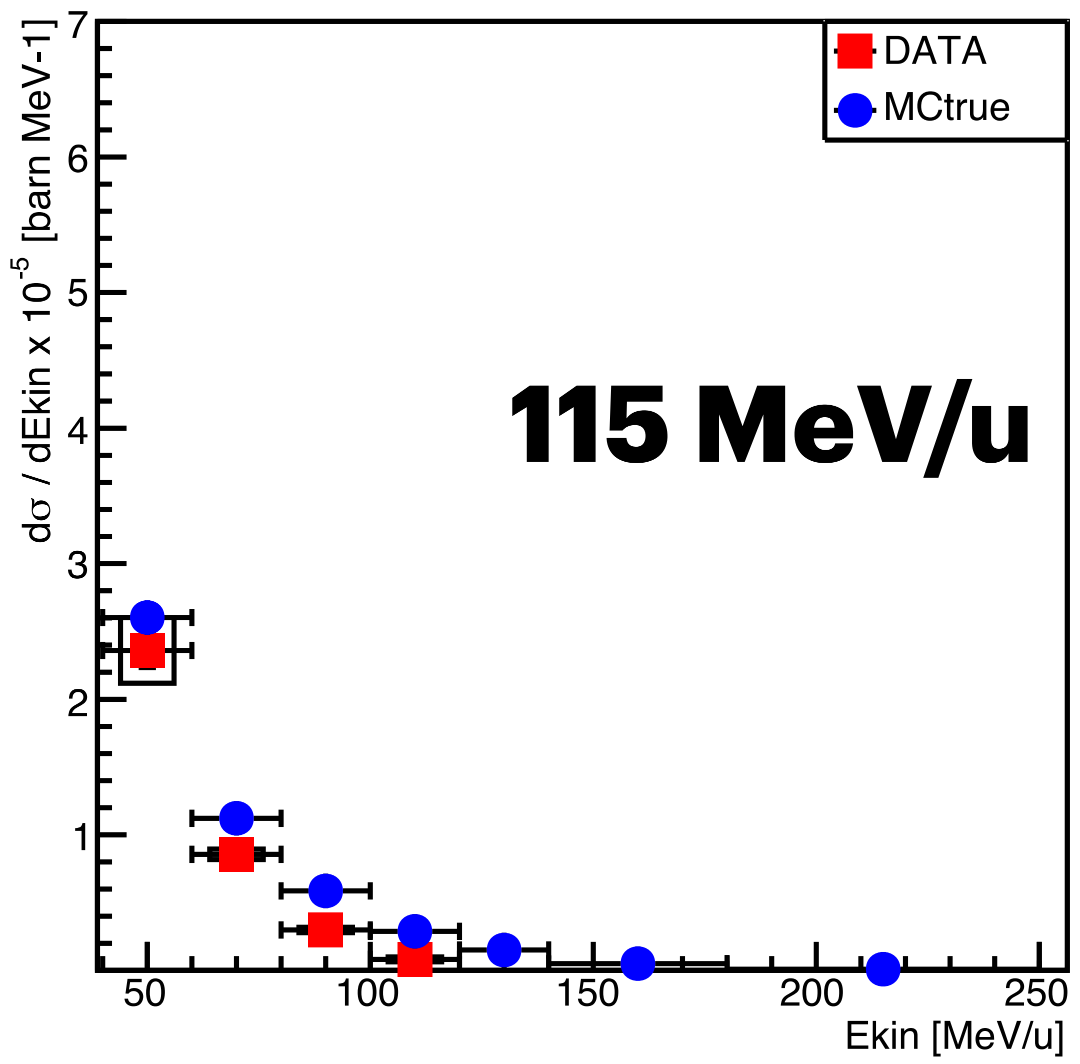
2) PID systematic: moving the p, d, t selection bands (hard and soft selection) and computing the average difference of XSec wrt the nominal selection ($\mathbf{sys_{PID}}$)

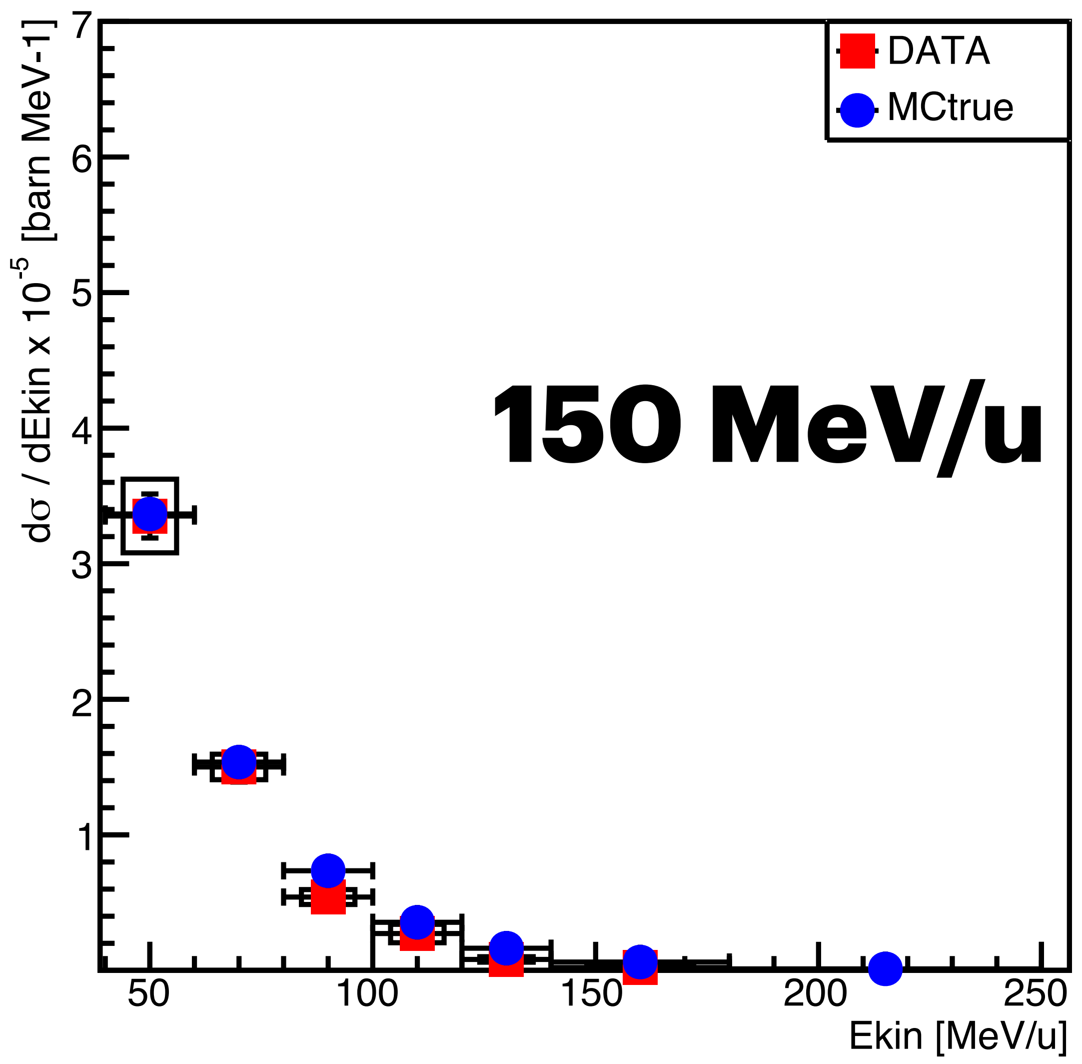
3) EpsDet from a different simulation: instead of the FULL simulation use of the FLAT simulation, i.e. p,d,t produced within the target with a FLAT Ekin spectrum in the range [5 MeV/u - 1 GeV/u] ($\mathbf{sys_{EpsDet}}$)

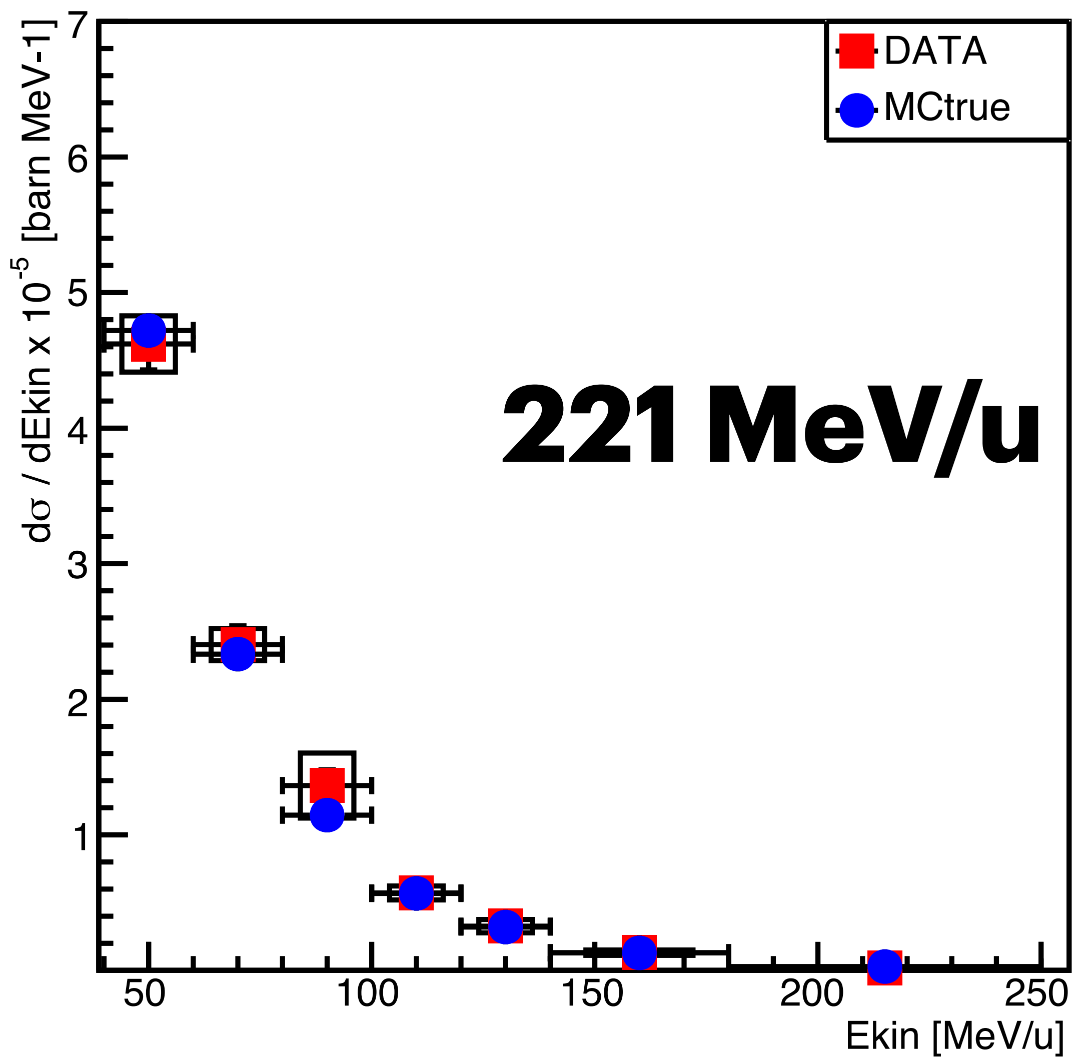
4) Unfolding procedure: changing unfolding technique (RooUnfoldIDS) wrt the nominal one (RooUnfoldBayes) and compute the XSec difference ($\mathbf{sys_{unf}}$)

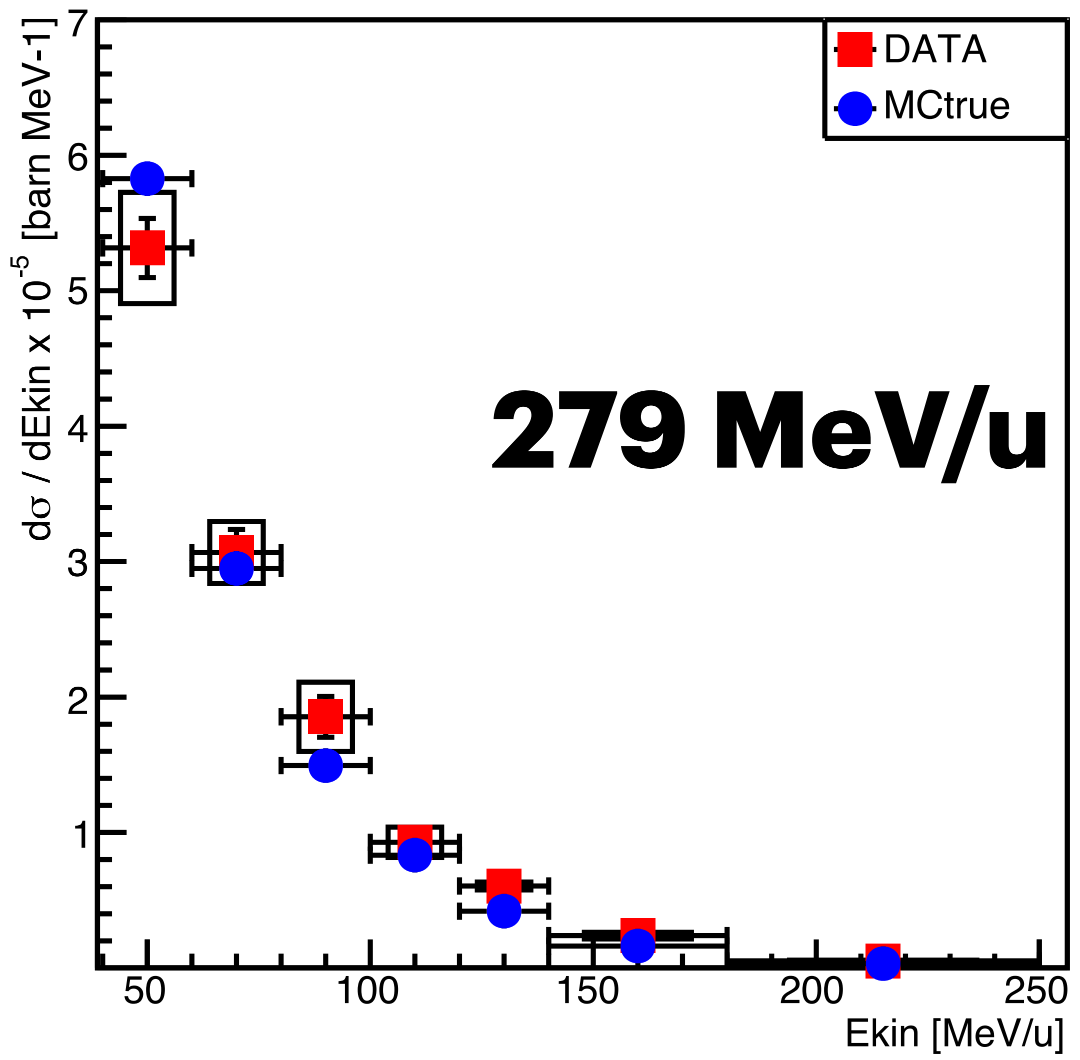
5) $N^{12}C$ from CNAO DDS: 4% relative error from dose-current conversion uncertainty ($\mathbf{sys_{N12C}}$)

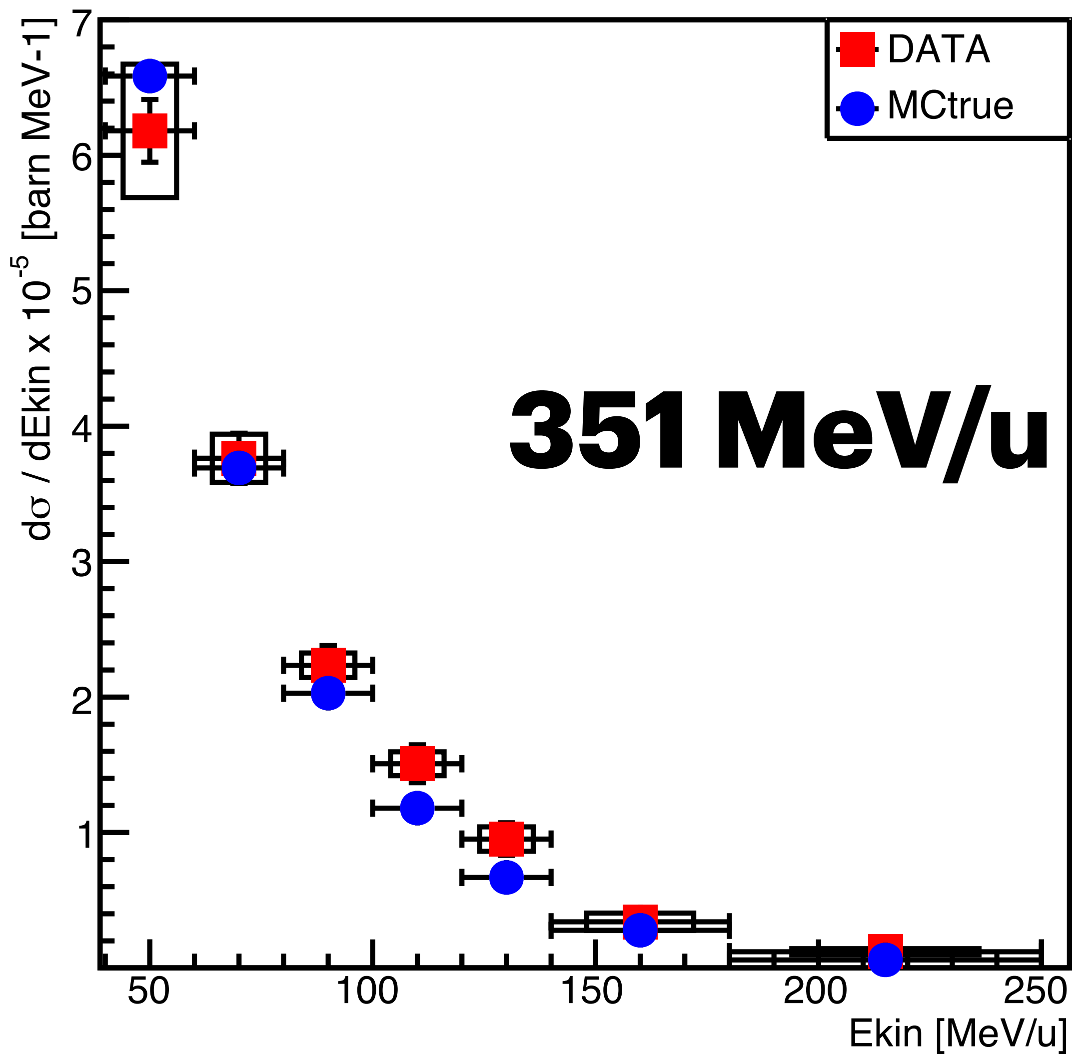
Final Results and MC comparison





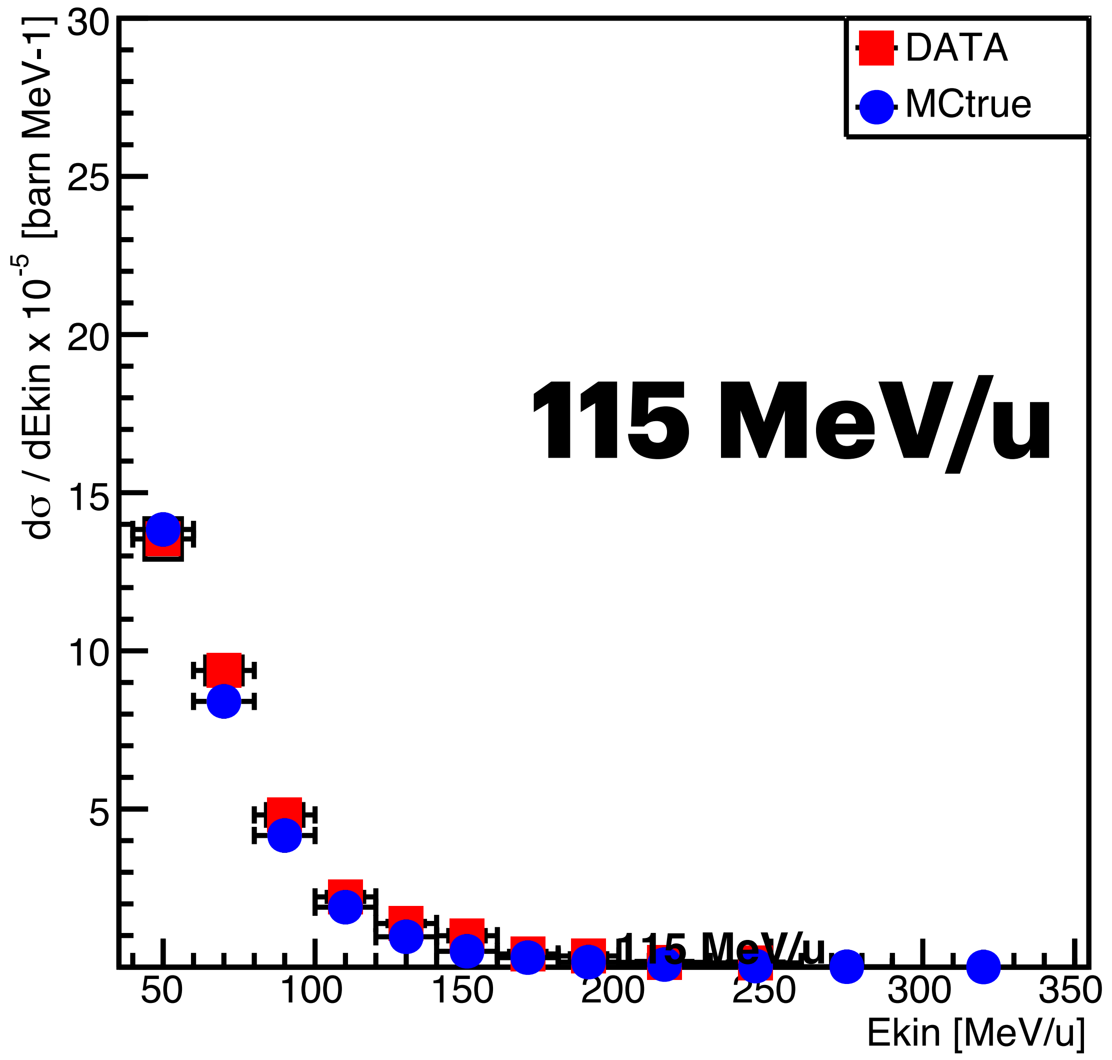


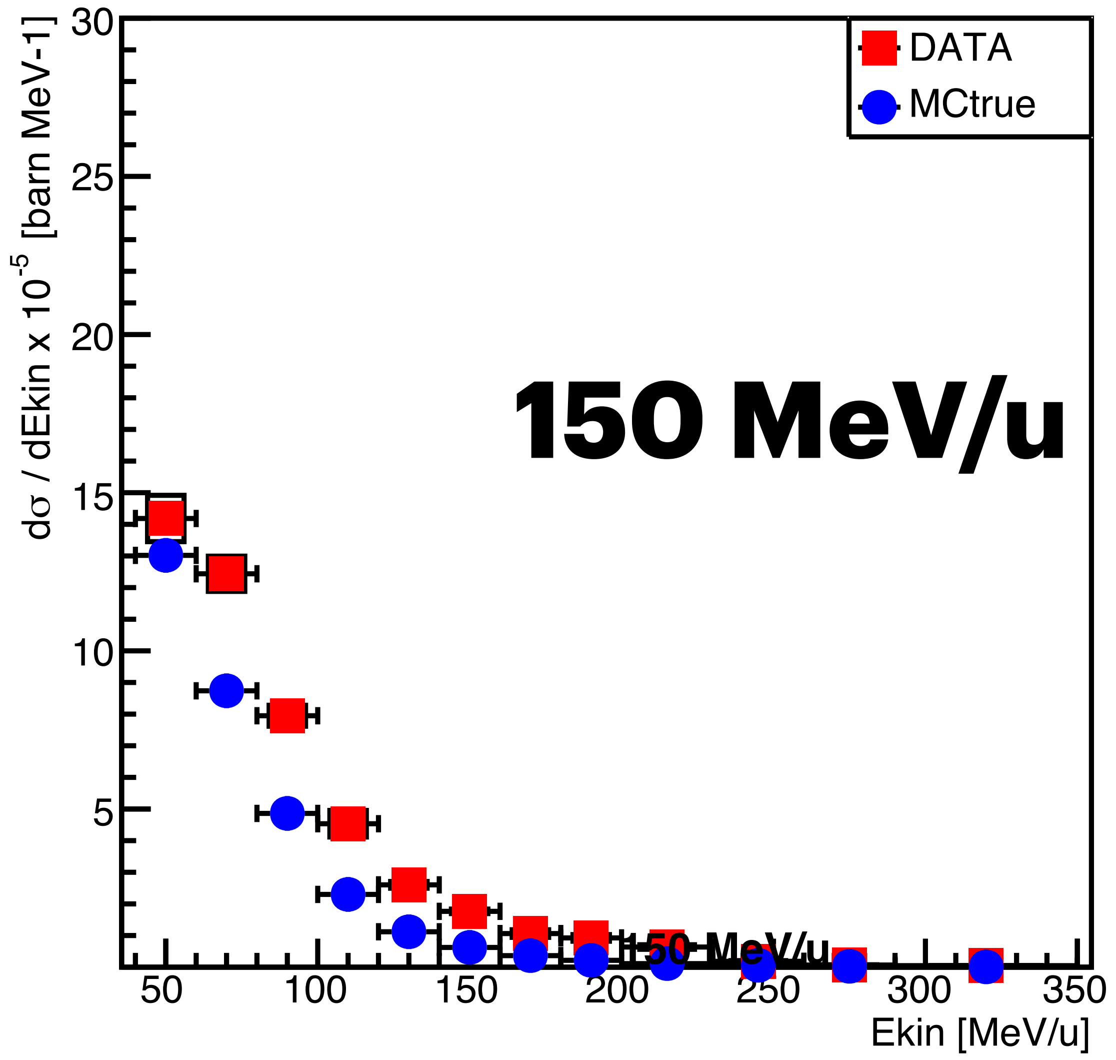


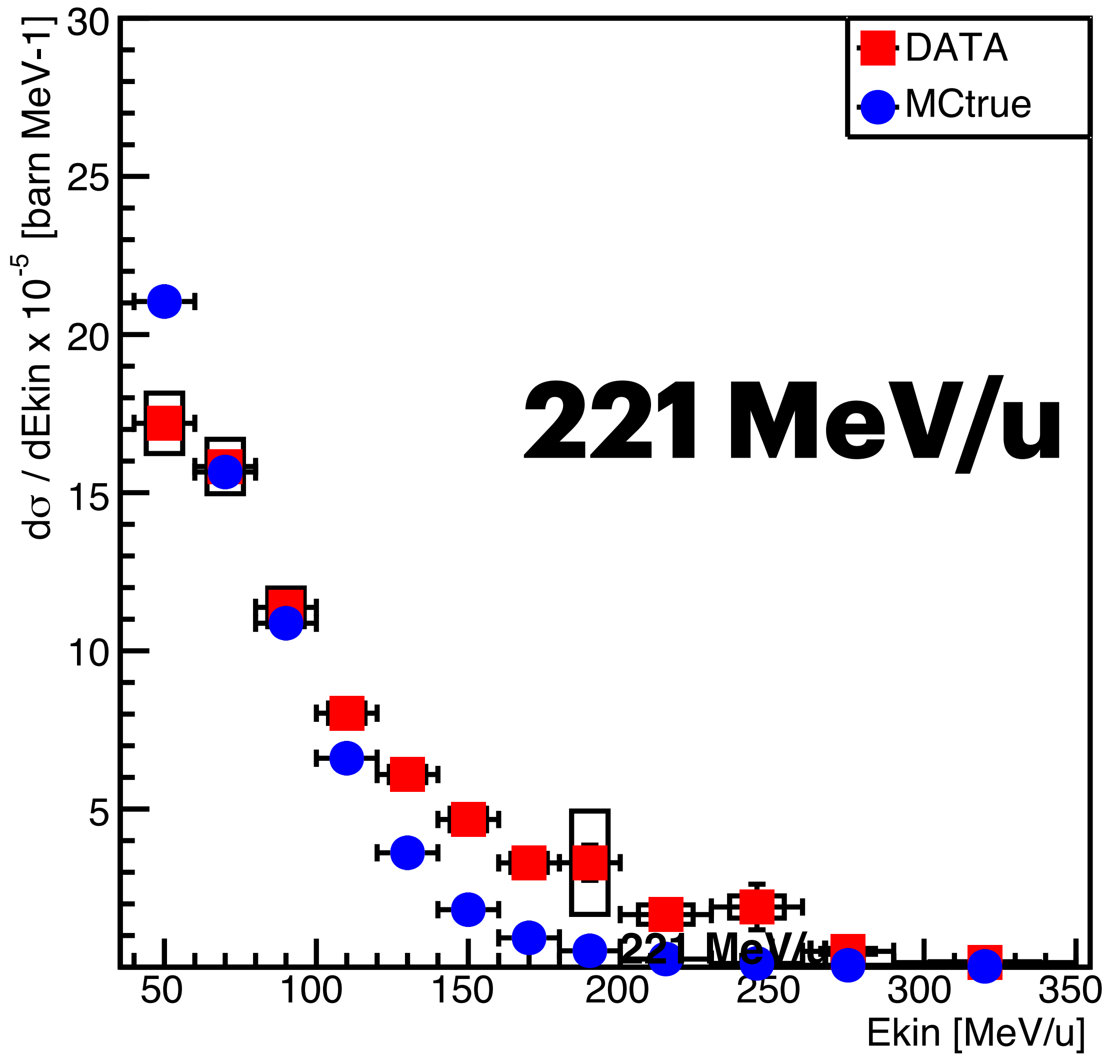


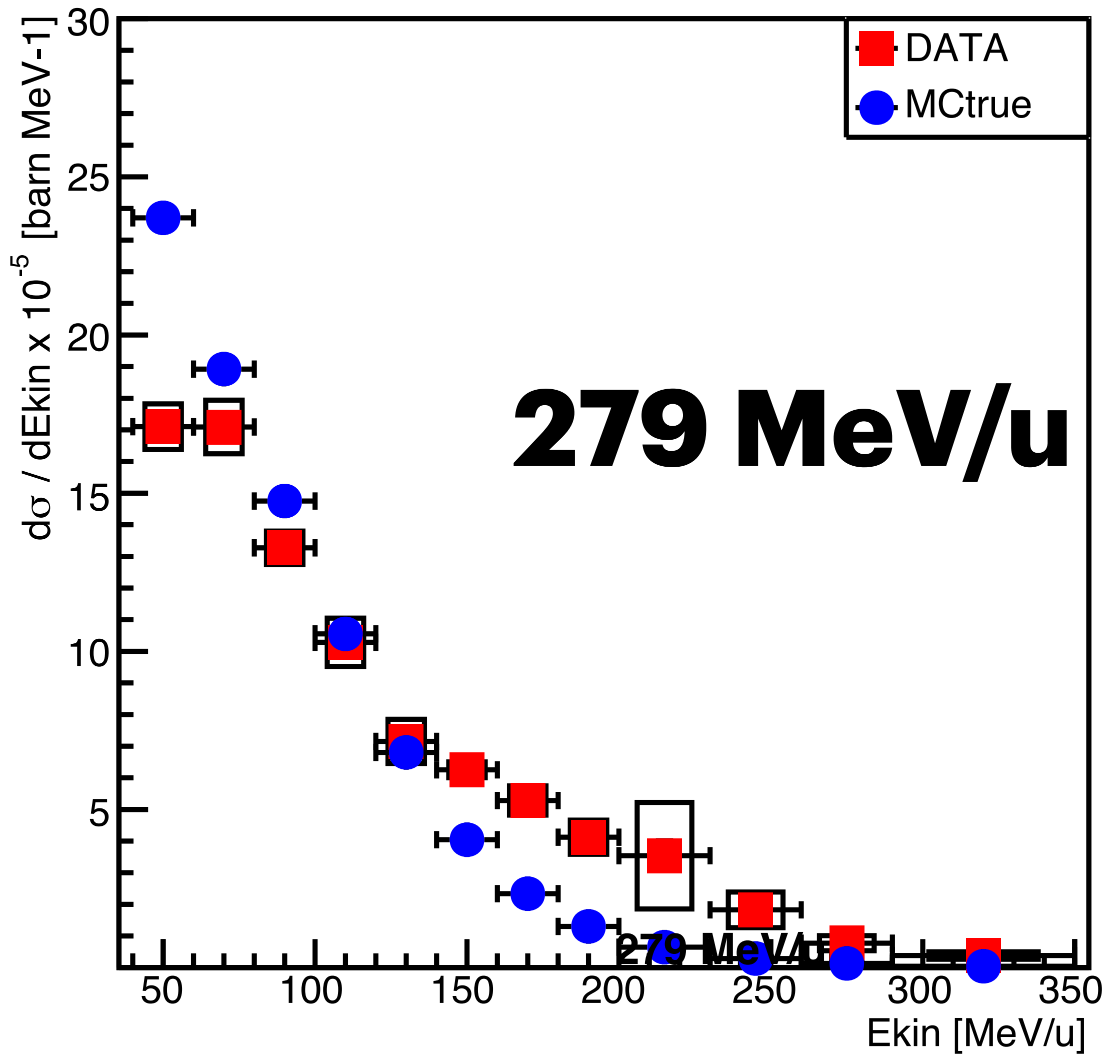
Protons detected at 90°
Production XSection from
12C on PMMA target

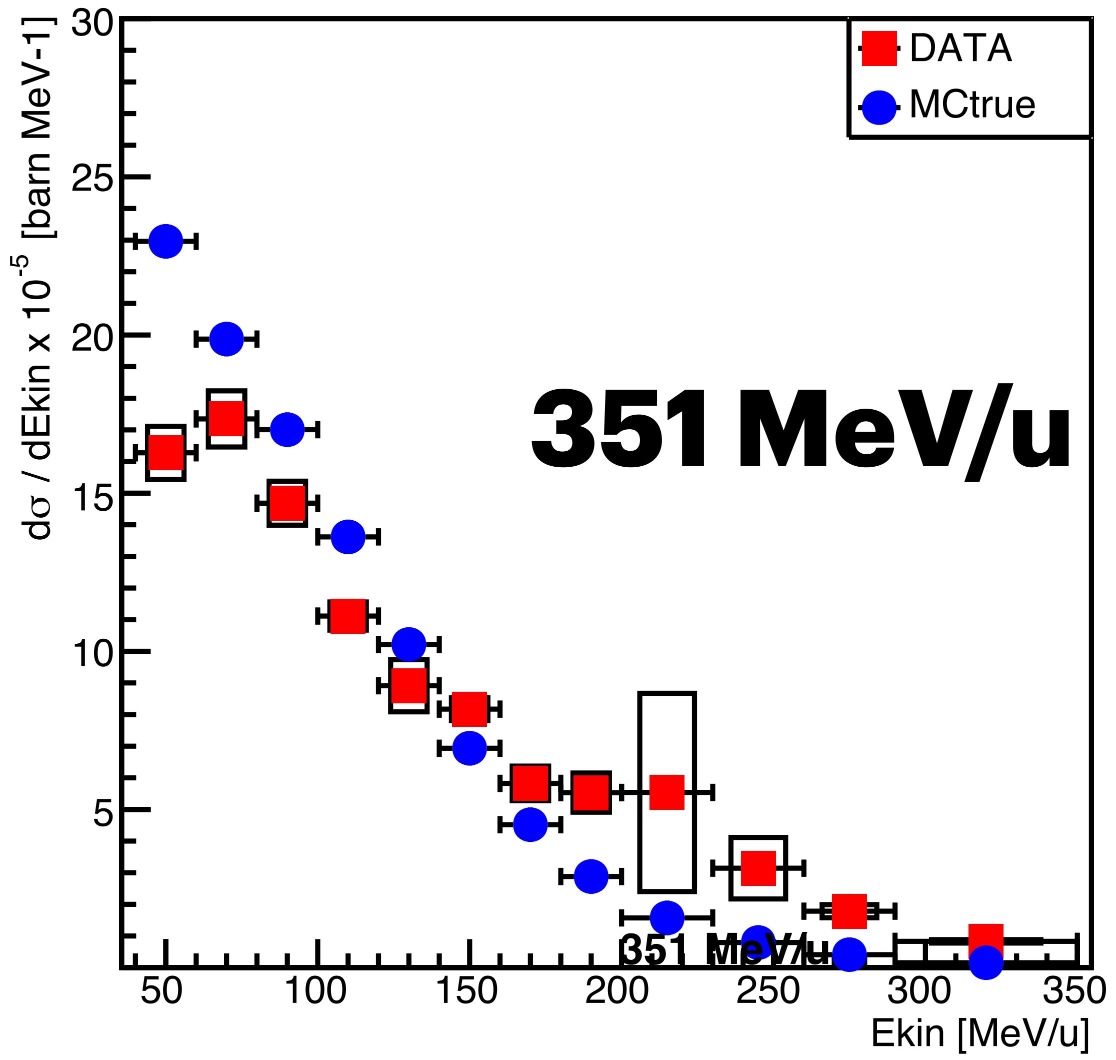
Final Results and MC comparison





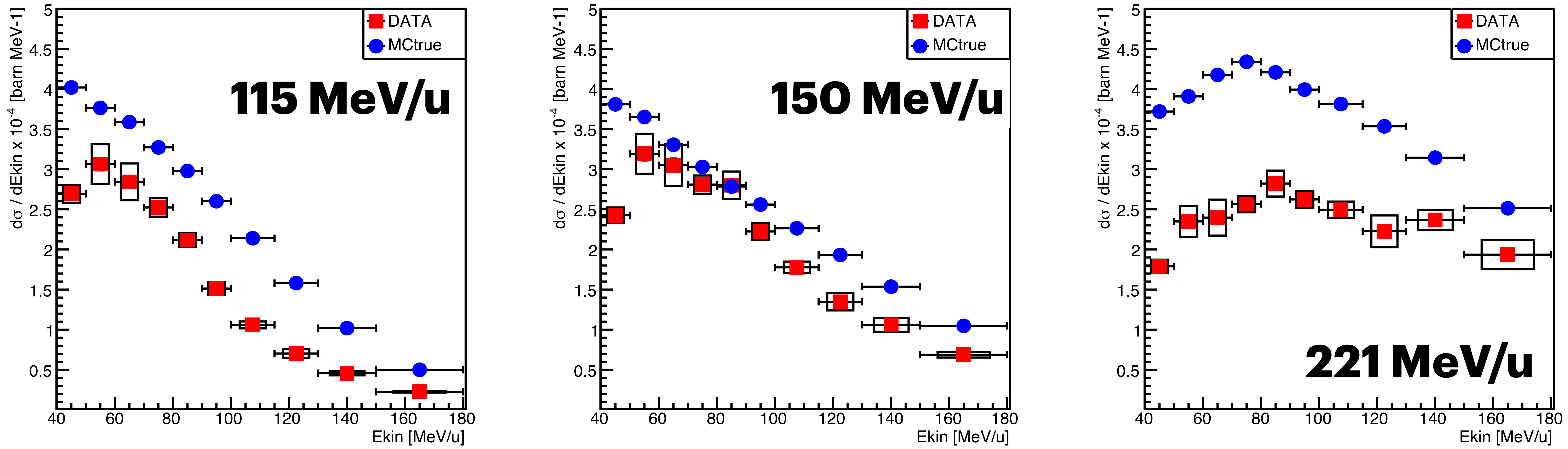


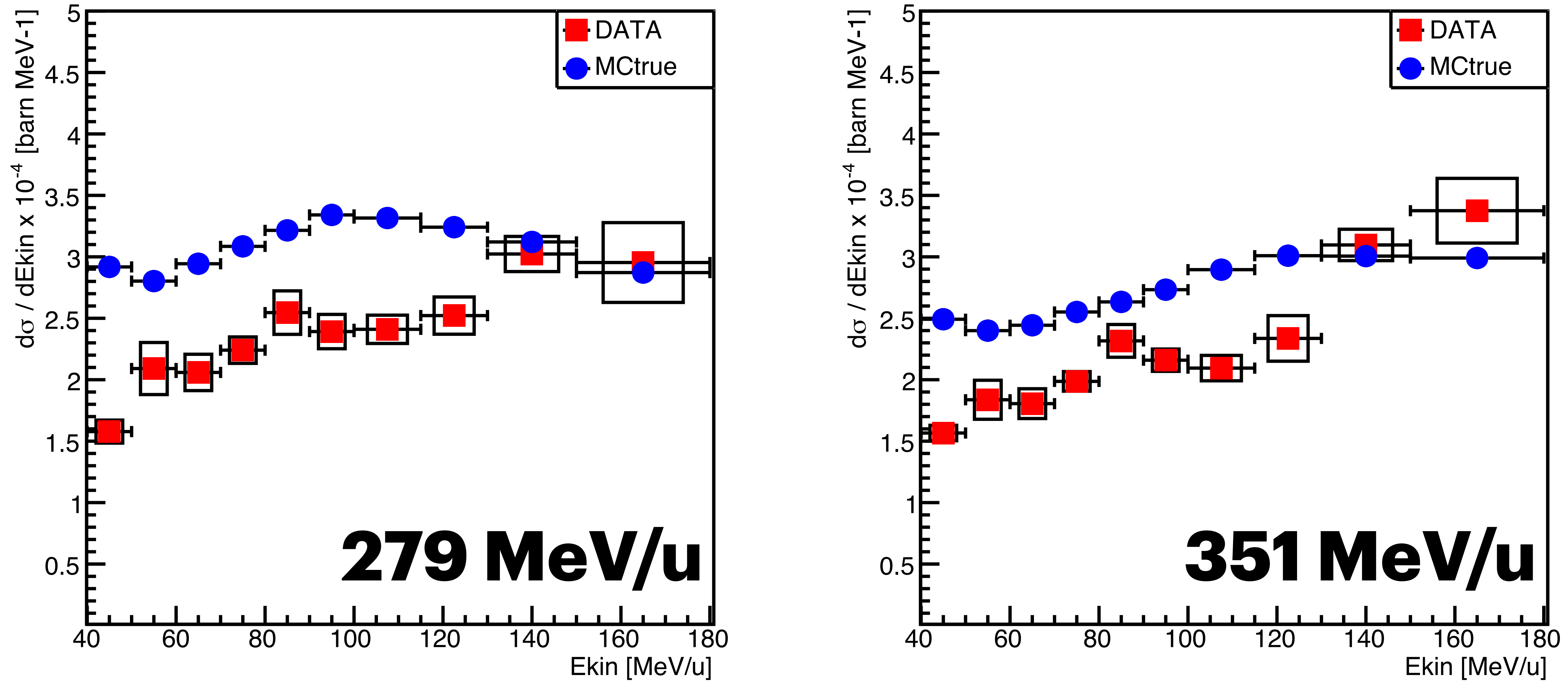




Protons detected at 60º
Production XSection from
12C on PMMA target

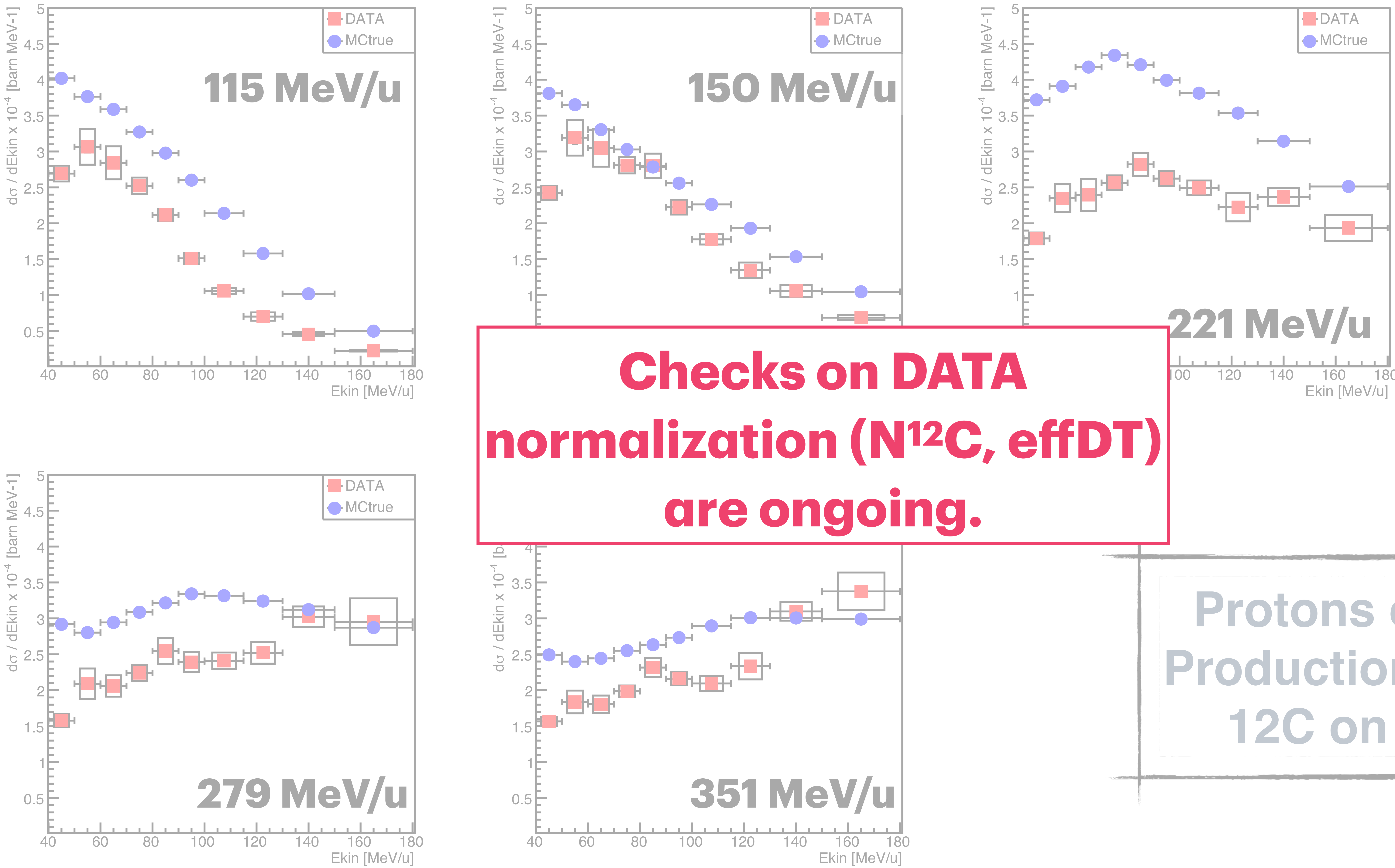
Final Results and MC comparison





Protons detected at 32º
Production XSection from
12C on PMMA target

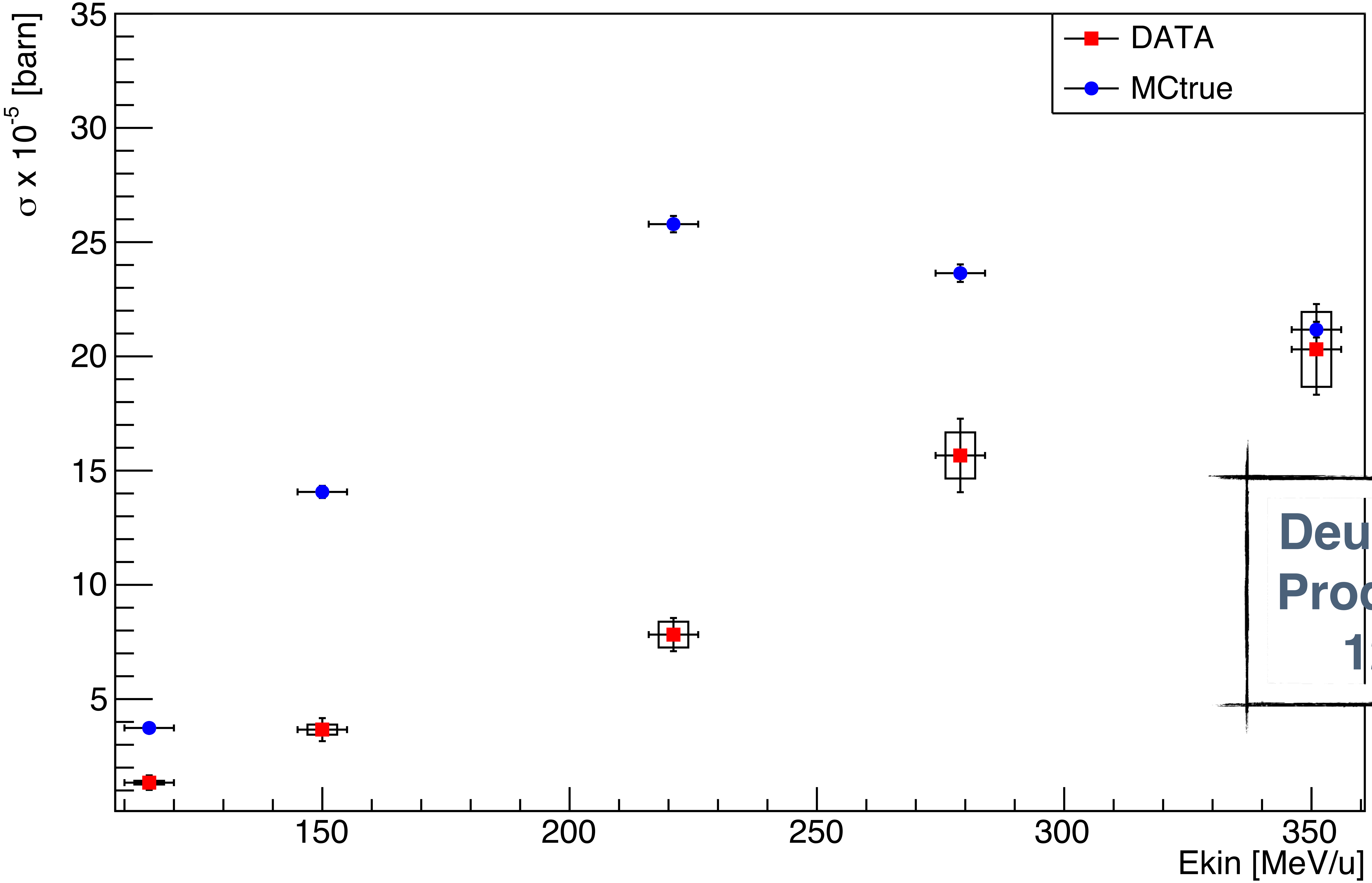
Final Results and MC comparison



Checks on DATA normalization ($N^{12}C$, effDT) are ongoing.

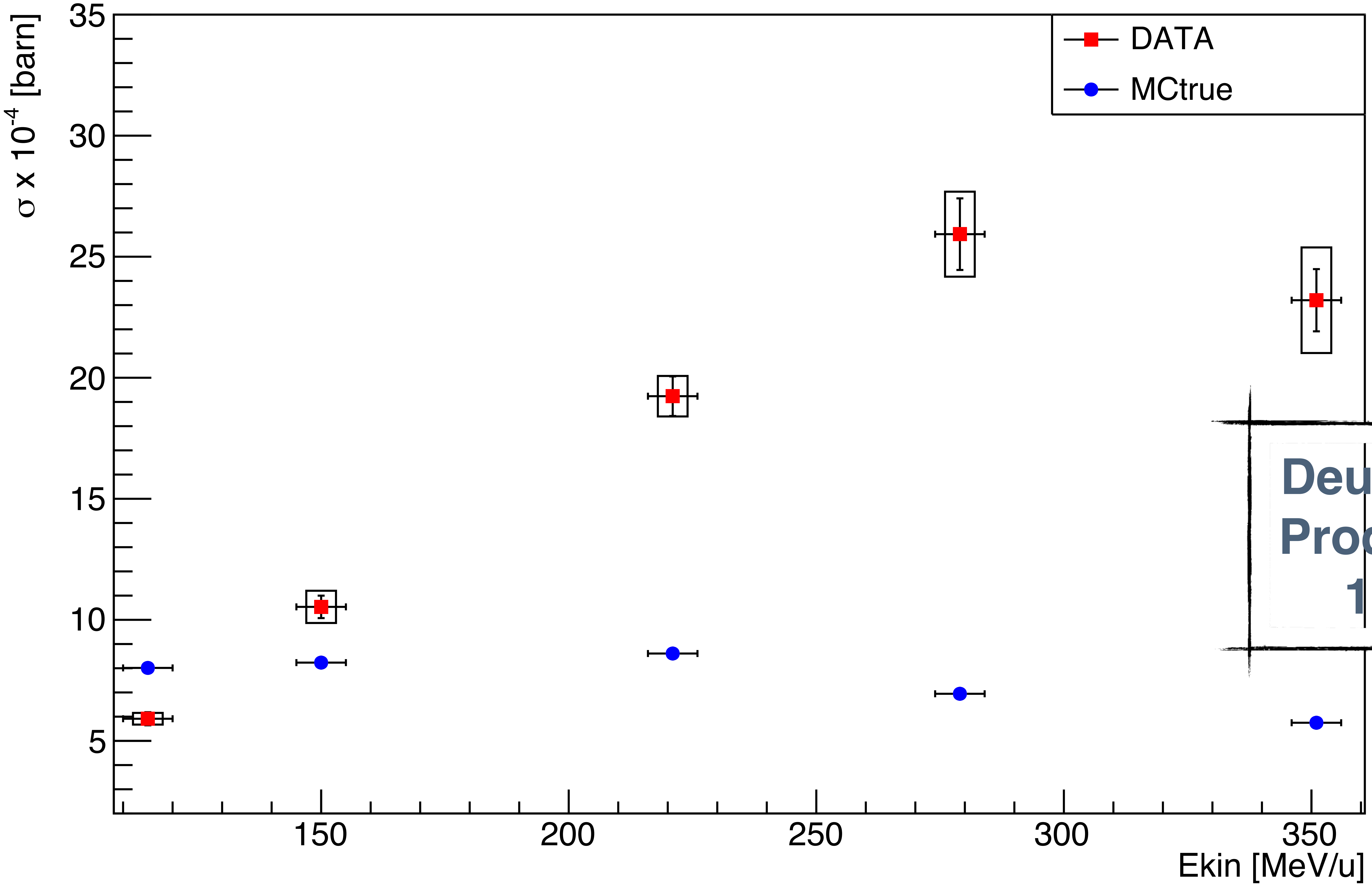
Protons detected at 32° Production XSection from 12C on PMMA target

Final Results and MC comparison



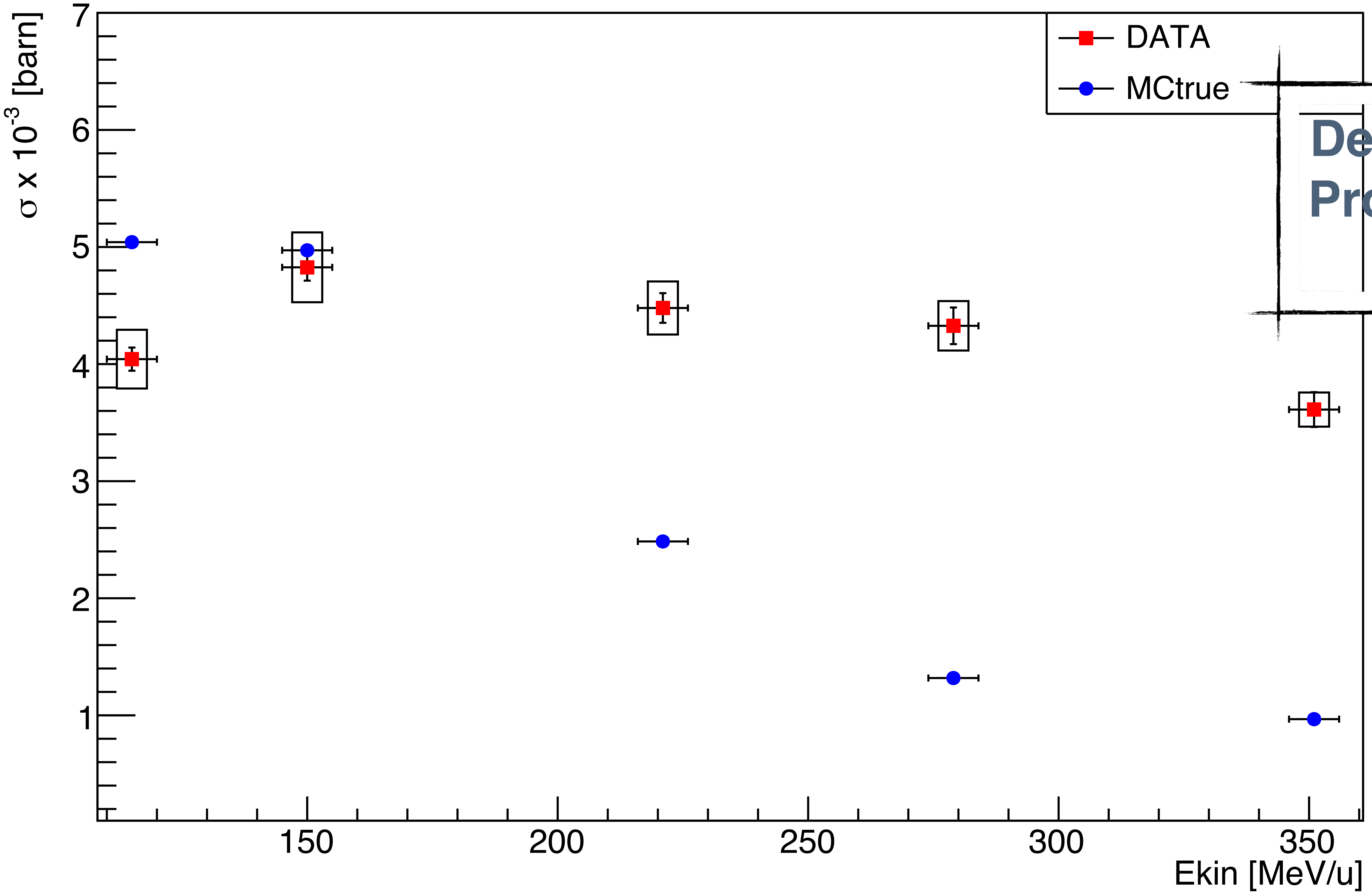
Deuterons detected at 90º Production XSection from 12C on PMMA target

Final Results and MC comparison



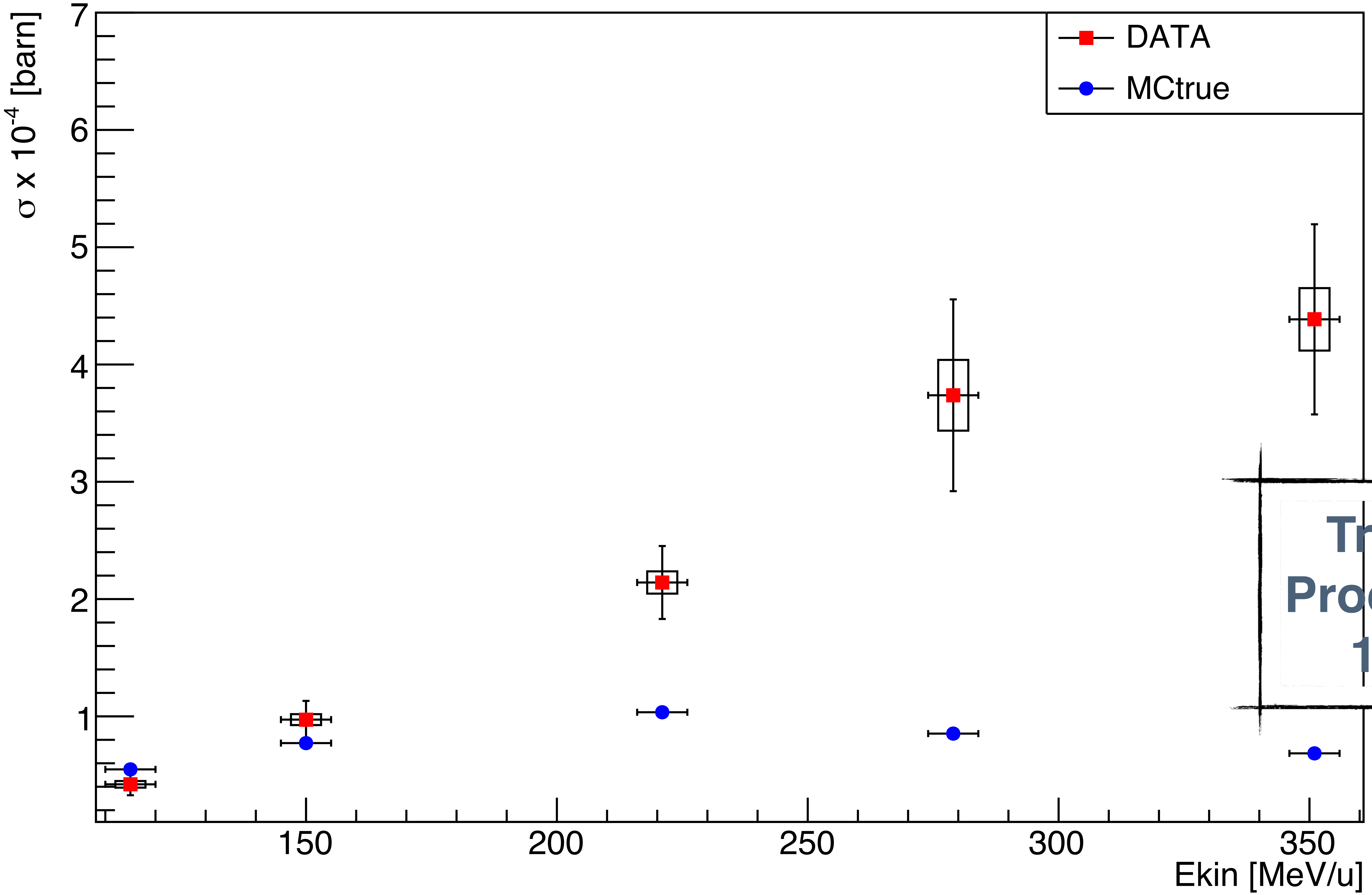
Deuterons detected at 60º Production XSection from 12C on PMMA target

Final Results and MC comparison



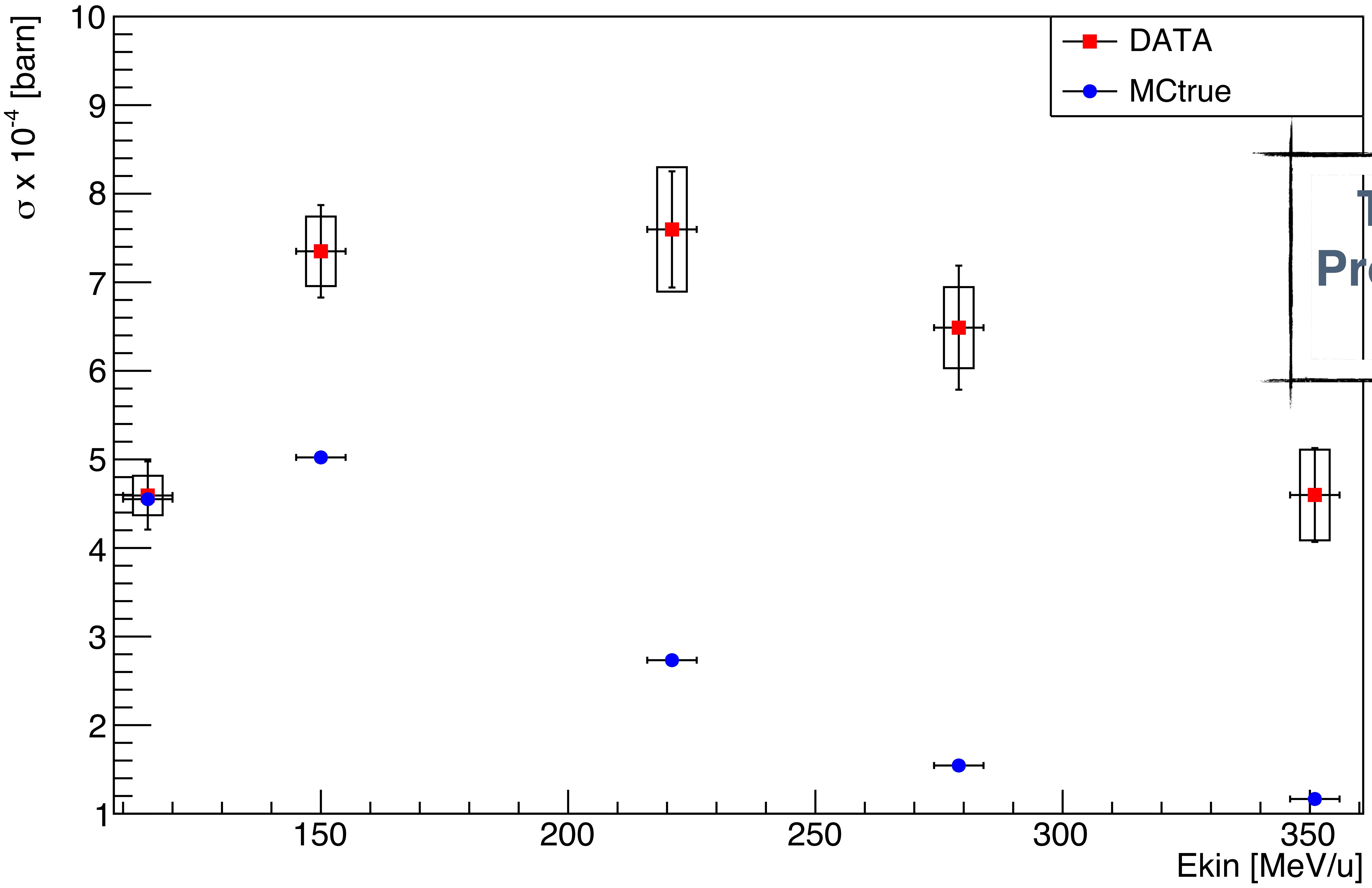
Deuterons detected at 32º Production XSection from 12C on PMMA target

Final Results and MC comparison



Tritons detected at 60º
Production XSection from 12C on PMMA target

Final Results and MC comparison



Tritons detected at 32°
Production XSection from 12C on PMMA target

Comparison with 2020 published results

To compare with old data published in 2020, the XSections have to be normalized to the LYSO ΔΩ (ϴ±4º, φ±4º(6º@32º))*:

$$\frac{d\sigma}{dE_k}^{\text{NEW}}({}^A_Z X) = \frac{N_{^A_Z X}(E_k)}{\Delta E_k} \cdot \frac{purity(E_k)}{N_{^{12}C} N_Y} \cdot \frac{1}{\epsilon} \cdot \frac{1}{\Delta\Omega}$$

$$\frac{d\sigma}{dE_k}^{\text{OLD}}({}^A_Z X) = \frac{N_{^A_Z X}(E_k)}{\Delta E_k} \cdot \frac{1}{N_{^{12}C} N_Y} \cdot \frac{1}{\epsilon} \cdot \frac{1}{4\pi}$$

[*the LYSO theoretical solid angle is ϴ,φ ± 0.8º]

Comparison with 2020 published results

PROTON PRODUCTION DIFFERENTIAL CROSS SECTION IN THE DIFFERENT ELEMENTS FROM CARBON ION BEAM ENERGY OF 221 MeV/u.

E^p_{bin} [MeV]	δ_E [MeV]	$d\sigma^p_C/dE_k$ [b/sr/MeV]
90^o		$\cdot 10^{-4}$
30-35	0	8.6 ± 1.3
35-40	2	5.2 ± 0.6
40-60	2	3.5 ± 0.2
60-80	4	1.6 ± 0.1
80-100	6	0.9 ± 0.1
100-120	10	0.4 ± 0.1
120-140	14	0.2 ± 0.1
140-180	18	0.1 ± 0.1
60^o		$\cdot 10^{-4}$
30-35	2	24.4 ± 3.4
35-40	2	18.4 ± 2.0
40-60	2	14.4 ± 0.8
60-80	3	10.0 ± 0.6
80-100	5	6.3 ± 0.4
100-120	8	3.9 ± 0.2
120-140	10	2.2 ± 0.1
140-160	13	1.2 ± 0.1
160-180	16	0.7 ± 0.1
180-200	20	0.4 ± 0.1
200-230	23	0.2 ± 0.1
230-260	27	0.1 ± 0.1
260-290	33	0.1 ± 0.1
290-350	40	-

p C 221

E^p_{kin} [MeV/u]	$\frac{d\sigma^{MC}_{true}}{dE_k}$	$stat^{MC}_{reco}$	sys_{PID}	sys^{MC}_{reco}	sys^{MC}_{unf}	$\frac{d\sigma^{data}}{dE_k}$	$stat^{data}$	sys^{data}
90^o	$\cdot 10^{-5}$ [b/sr]	[%]	[%]	[%]	[%]	$\cdot 10^{-5}$ [b/sr]	[%]	[%]
40 - 60	32.7 ± 0.4	8.4	0.4	18.4	4.7	$36.3 \pm 2.2 \pm 2.2$	6.2	6.2
60 - 80	16.5 ± 0.3	12.4	0.4	17.4	7.2	$21.2 \pm 1.9 \pm 1.8$	8.9	8.3
80 - 100	8.1 ± 0.2	17.7	0.4	19.7	10.0	$11.9 \pm 1.6 \pm 1.3$	13.6	10.8
100 - 120	4.0 ± 0.1	24.1	0.4	0.0	12.0	$4.6 \pm 0.8 \pm 0.6$	17.8	12.6
120 - 140	2.2 ± 0.1	-0	0.4	-	-	$2.1 \pm 0.5 \pm 0.3$	23.8	12.6
140 - 180	0.8 ± 0.0	-0	0.4	-	-	$1.0 \pm 0.3 \pm 0.1$	32.6	12.6
180 - 250	0.2 ± 0.0	-0	0.4	-	-	-	-0	-
250 - 350	-	-0	0.4	-	-	-	-0	-
350 - 550	-	-0	0.4	-	-	-	-0	-
550 - 750	-	-0	0.4	-	-	-	-0	-
60^o	$\cdot 10^{-5}$ [b/sr]	[%]	[%]	[%]	[%]	$\cdot 10^{-5}$ [b/sr]	[%]	[%]
40 - 60	129.3 ± 0.8	4.1	1.1	9.1	5.6	$110.6 \pm 3.5 \pm 7.6$	3.2	6.9
60 - 80	95.4 ± 0.7	4.9	1.1	8.2	3.1	$108.8 \pm 4.0 \pm 5.5$	3.7	5.0
80 - 100	67.2 ± 0.5	6.0	1.1	12.2	3.6	$81.1 \pm 3.5 \pm 4.4$	4.3	5.4
100 - 120	42.7 ± 0.4	7.8	1.1	8.1	1.4	$59.4 \pm 3.3 \pm 2.5$	5.6	4.2
120 - 140	24.1 ± 0.3	11.3	1.1	22.2	8.3	$44.8 \pm 3.4 \pm 4.1$	7.7	9.2
140 - 160	13.2 ± 0.2	14.5	1.1	7.1	0.3	$34.9 \pm 3.7 \pm 1.4$	10.5	4.0
160 - 180	7.0 ± 0.2	21.0	1.1	14.3	11.1	$25.2 \pm 3.9 \pm 3.0$	15.4	11.8
180 - 200	4.1 ± 0.1	30.5	1.1	41.0	-	$23.3 \pm 5.5 \pm 2.8$	23.5	11.8
200 - 230	1.9 ± 0.1	-0	1.1	-	-	$18.0 \pm 5.4 \pm 2.1$	30.0	11.8
230 - 260	0.9 ± 0.1	-0	1.1	-	-	$9.7 \pm 4.3 \pm 1.2$	43.9	11.8
260 - 290	0.5 ± 0.0	-0	1.1	-	-	$2.7 \pm 1.1 \pm 0.3$	41.2	11.8
290 - 350	0.2 ± 0.0	-0	1.1	-	-	$1.8 \pm 1.1 \pm 0.2$	60.6	11.8
350 - 450	0.0 ± 0.0	-0	1.1	-	-	-	-0	-
450 - 650	-	-0	1.1	-	-	-	-0	-
650 - 850	-	-0	1.1	-	-	-	-0	-

90°	RATIO NEW/OLD
40-60	1.04
60-80	1.33
80-100	1.32
100-120	1.15
120-140	1.05
140-180	1.00
180-250	-

60°	RATIO NEW/OLD
40-60	0.77
60-80	1.09
80-100	1.29
100-120	1.52
120-140	2.04
140-160	2.91
160-180	3.60
180-200	5.83
200-230	9.00
230-260	9.70
260-290	2.70
290-350	-

Comparison with 2020 published results

E^C_{kin} $[MeV/u]$	σ^p_C [barn $/sr$]	σ^p_O [barn $/sr$]	σ^p_H [barn $/sr$]
90^o	$\cdot 10^{-3}$	$\cdot 10^{-3}$	$\cdot 10^{-5}$
115	8.97 ± 0.63	12.77 ± 2.48	11.44 ± 7.88
153	12.45 ± 0.89	19.52 ± 3.29	6.25 ± 9.43
221	18.87 ± 1.22	27.43 ± 4.48	16.28 ± 19.08
281	23.58 ± 1.50	33.17 ± 5.24	6.78 ± 19.62
353	28.23 ± 1.76	44.35 ± 6.08	25.05 ± 29.16
60^o	$\cdot 10^{-2}$	$\cdot 10^{-2}$	$\cdot 10^{-2}$
115	5.84 ± 0.52	7.68 ± 1.06	0.50 ± 0.23
153	7.90 ± 0.74	9.90 ± 1.36	0.69 ± 0.29
221	10.99 ± 1.02	15.12 ± 1.90	1.10 ± 0.37
281	12.92 ± 1.19	18.10 ± 2.19	1.38 ± 0.40
353	14.75 ± 1.36	21.36 ± 2.48	1.38 ± 0.44

90°	RATIO NEW/OLD bin sum	RATIO NEW/OLD 1 bin
115	0.62	0.67
153	0.77	0.78
221	0.83	0.83
281	0.84	0.79
353	0.85	0.83

60°	RATIO NEW/OLD bin sum	RATIO NEW/OLD 1 bin
115	0.89	0.86
153	0.86	0.82
221	0.98	0.90
281	0.99	0.90
353	1.08	0.95

p C

1 bin - eff ave

E^C_{kin} [MeV/u]	σ^{MC}_{true}	$stat^{MC}_{reco}$	sys_{PID}	sys^{MC}_{reco}	sys^{MC}_{unf}	σ^{data}	$stat^{data}$	sys^{data}
90^o	$\cdot 10^{-3}$ [b/sr]	[%]	[%]	[%]	[%]	$\cdot 10^{-3}$ [b/sr]	[%]	[%]
115	6.3 ± 0.1	8.3	0.3	7.1	3.4	6.0 ± 0.4± 0.3	6.3	5.3
150	9.0 ± 0.1	7.2	0.4	6.4	3.1	9.7 ± 0.5± 0.5	5.4	5.1
221	13.1 ± 0.1	6.0	0.4	8.3	1.3	15.6 ± 0.7± 0.7	4.5	4.2
279	16.3 ± 0.1	5.1	0.5	5.8	3.5	18.7 ± 0.7± 1.0	3.9	5.3
351	20.1 ± 0.1	4.7	0.6	6.4	2.0	23.5 ± 0.8± 1.1	3.5	4.5
60^o	$\cdot 10^{-2}$ [b/sr]	[%]	[%]	[%]	[%]	$\cdot 10^{-2}$ [b/sr]	[%]	[%]
115	4.2 ± 0.0	3.4	0.6	13.2	0.5	5.0 ± 0.1± 0.2	2.5	4.0
150	4.0 ± 0.0	3.4	0.8	10.3	1.2	6.5 ± 0.2± 0.3	2.4	4.2
221	7.8 ± 0.0	2.5	1.1	8.5	2.5	9.9 ± 0.2± 0.5	1.8	4.7
279	10.6 ± 0.0	2.1	1.3	7.6	1.7	11.6 ± 0.2± 0.5	1.6	4.4
351	12.9 ± 0.0	2.0	1.5	5.3	2.0	14.0 ± 0.2± 0.6	1.5	4.5

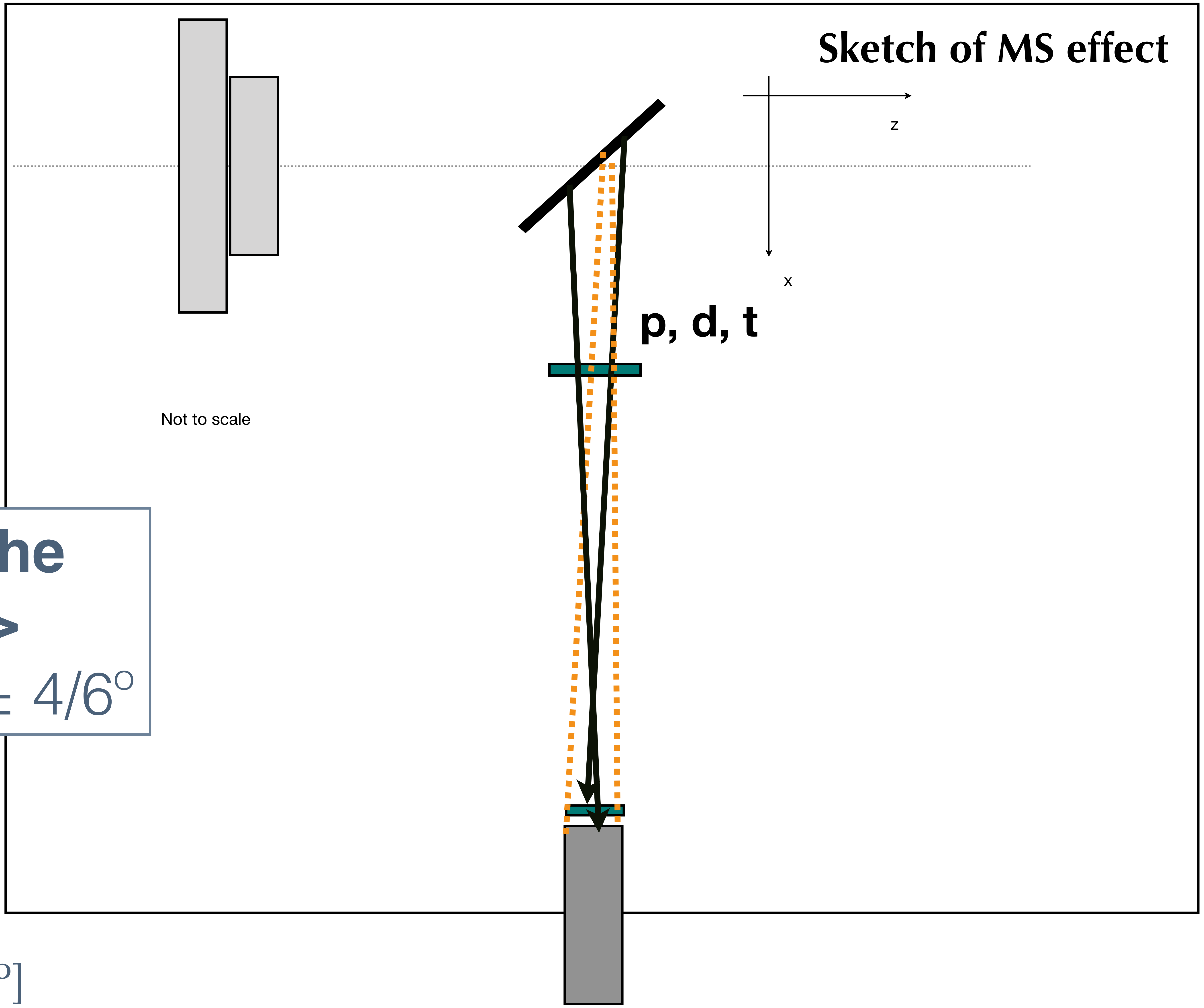
Bin sum

σ^{data}	$stat^{data}$	sys^{data}
$\cdot 10^{-3}$ [b/sr]	[%]	[%]
5.6 ± 0.4± 0.3	6.5	5.3
9.6 ± 0.5± 0.5	5.6	5.1
15.6 ± 0.7± 0.7	4.5	4.2
19.9 ± 1.0± 1.1	5.0	5.3
24.0 ± 0.9± 1.1	3.7	4.5
$\cdot 10^{-2}$ [b/sr]	[%]	[%]
5.2 ± 0.2± 0.2	4.2	4.0
6.8 ± 0.3± 0.3	3.9	4.2
10.8 ± 0.3± 0.5	2.9	4.7
12.8 ± 0.4± 0.6	2.8	4.4
15.9 ± 0.4± 0.7	2.3	4.5

Comparison with 2020 published results

The **remaining difference** between the **old published analysis and the new analysis** is due to the **Multiple Scattering** that has been taken into account in the detection efficiency of new analysis and has NOT in the old analysis

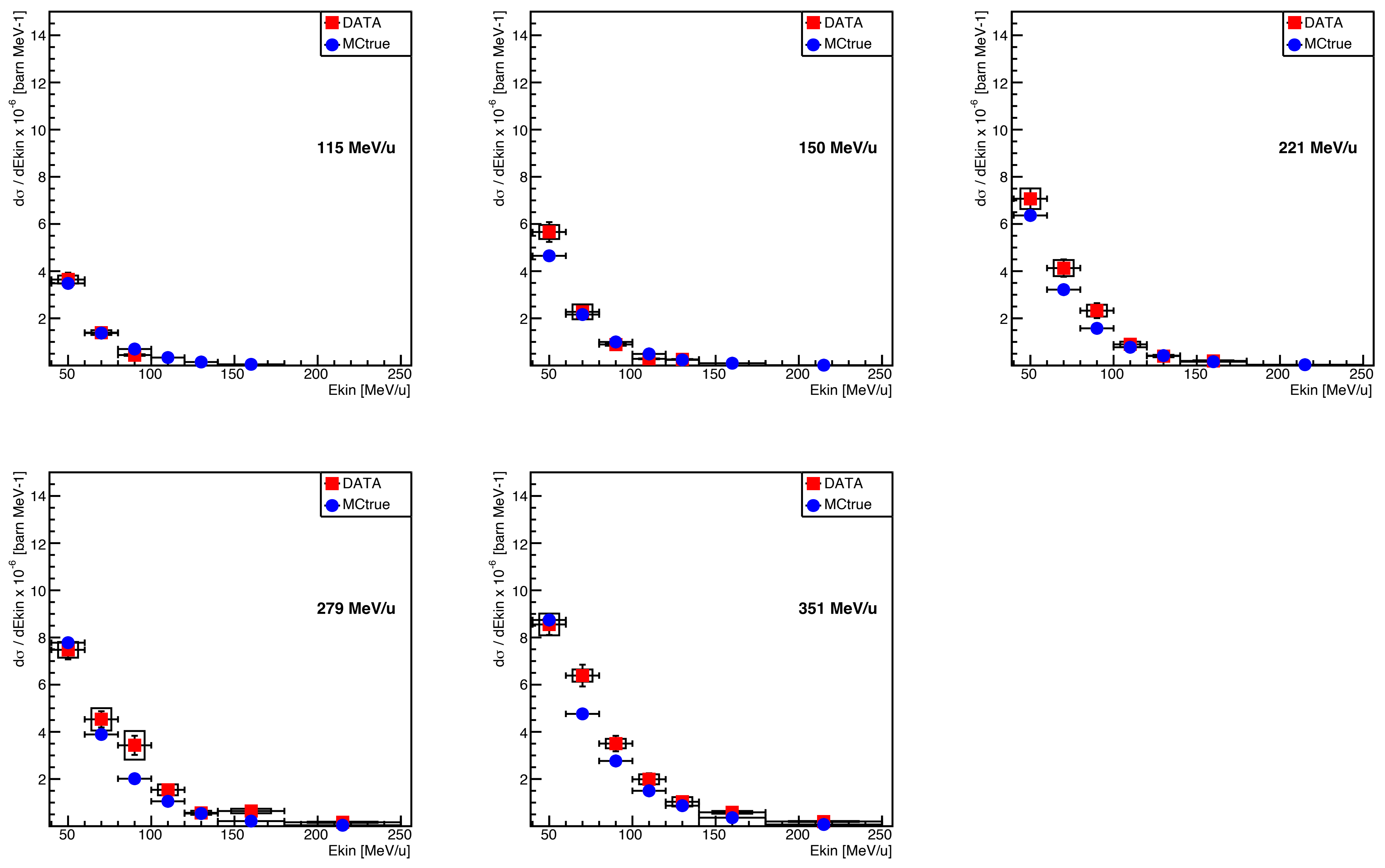
No tracking system in the experimental setup => LYSO solid angle* is θ,φ ± 4/6°



[*the LYSO theoretical solid angle is **θ**,φ ± 0.8°]

Conclusions

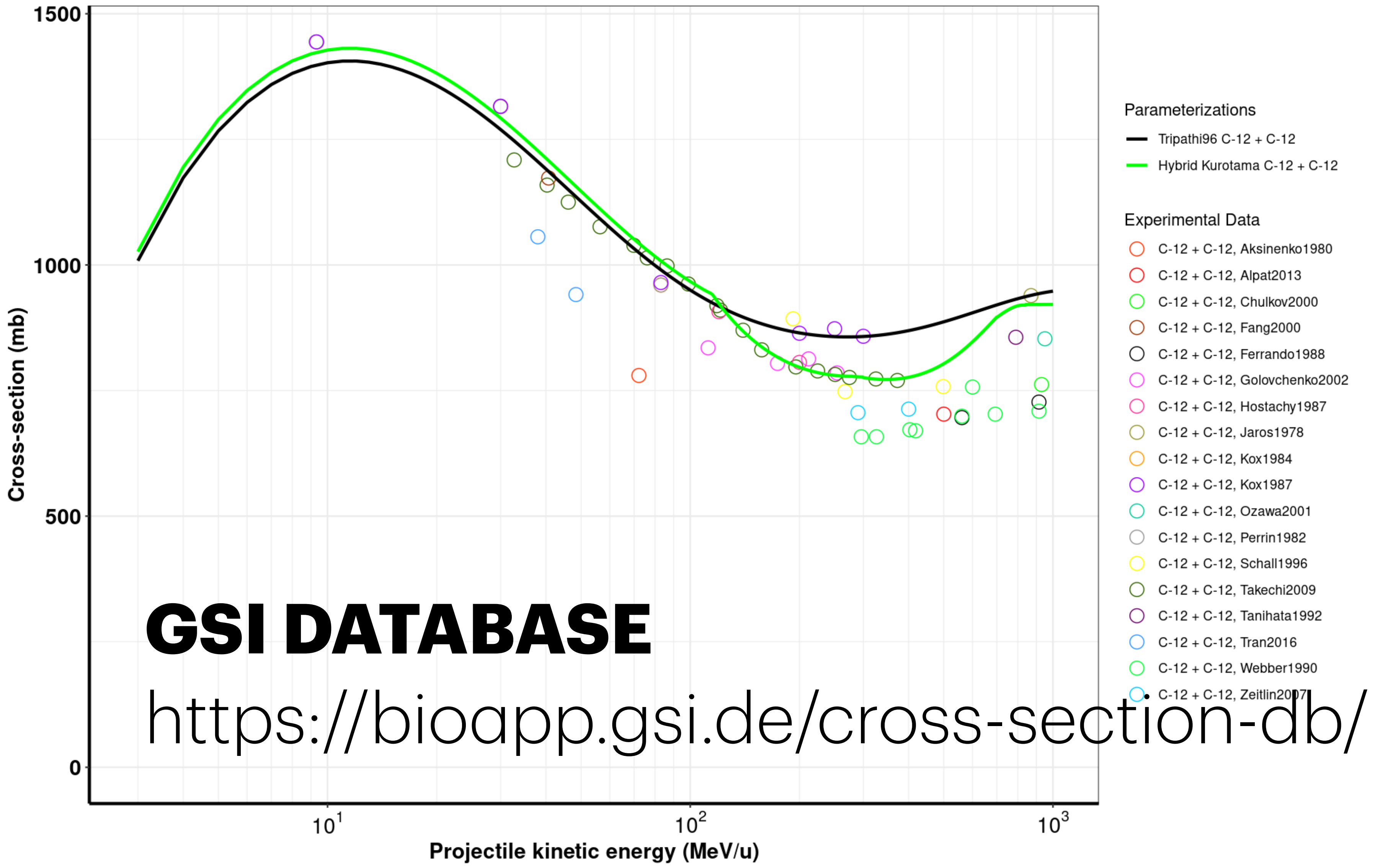
- **Small effort more to assess the 32deg analysis normalization**
- **The systematic errors from detection efficiency and PID selection have to be added to the total systematic error**

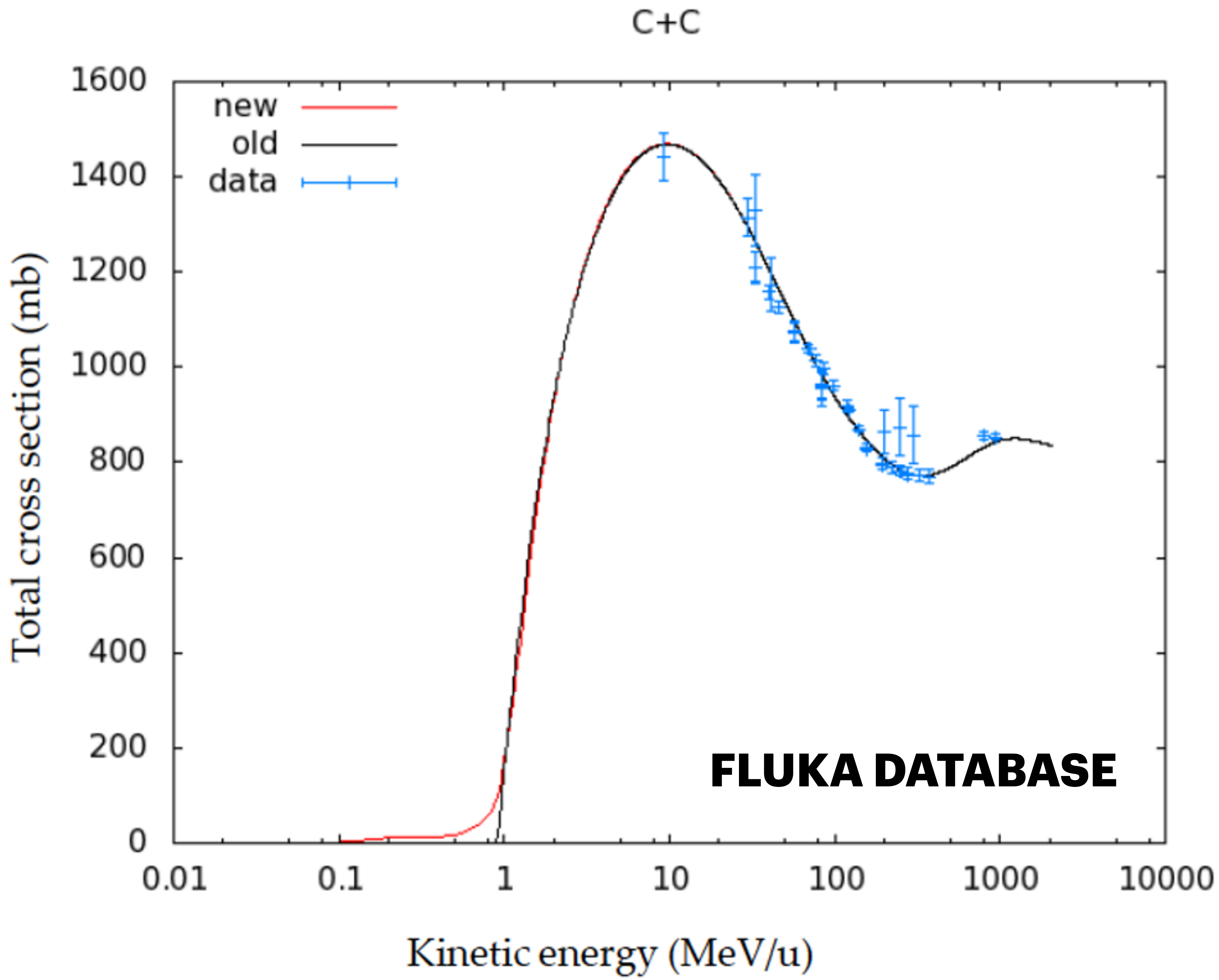


p C 115								
E^p_{kin} [MeV/u]	$\frac{d\sigma^{MC}_{true}}{dE_k}$	stat^{MC}_{reco}	sys_{PID}	sys^{MC}_{reco}	sys^{MC}_{unf}	$\frac{d\sigma^{data}}{dE_k}$	stat^{data}	sys^{data}
90^o	$\cdot 10^{-6}$ [b]	[%]	[%]	[%]	[%]	$\cdot 10^{-6}$ [b]	[%]	[%]
40 - 60	3.5 ± 0.1	11.1	0.5	20.9	2.4	3.6 ± 0.3± 0.2	8.0	4.6
60 - 80	1.4 ± 0.0	17.1	0.5	0.0	6.0	1.4 ± 0.2± 0.1	13.1	7.3
80 - 100	0.7 ± 0.0	26.1	0.5	7.1	6.4	0.4 ± 0.1± 0.0	20.4	7.6
100 - 120	0.3 ± 0.0	-	0.5	-	-	-	-	-
120 - 140	0.1 ± 0.0	-	0.5	-	-	-	-	-
140 - 180	0.0 ± 0.0	-	0.5	-	-	-	-	-
180 - 250	-	-	0.5	-	-	-	-	-
250 - 350	-	-	0.5	-	-	-	-	-
350 - 550	-	-	0.5	-	-	-	-	-
550 - 750	-	-	0.5	-	-	-	-	-
60^o	$\cdot 10^{-6}$ [b]	[%]	[%]	[%]	[%]	$\cdot 10^{-6}$ [b]	[%]	[%]
40 - 60	15.1 ± 0.1	5.1	0.7	16.7	0.8	15.7 ± 0.6± 0.6	3.8	4.1
60 - 80	10.0 ± 0.1	6.6	0.7	16.5	4.3	12.0 ± 0.6± 0.7	4.7	5.9
80 - 100	5.3 ± 0.1	9.1	0.7	1.5	8.7	7.0 ± 0.5± 0.7	6.7	9.6
100 - 120	2.4 ± 0.0	13.3	0.7	11.0	4.2	3.5 ± 0.3± 0.2	9.5	5.8
120 - 140	1.2 ± 0.0	18.9	0.7	15.0	13.9	1.7 ± 0.2± 0.2	13.1	14.4
140 - 160	0.6 ± 0.0	28.9	0.7	28.6	29.8	1.4 ± 0.3± 0.4	21.9	30.1
160 - 180	0.3 ± 0.0	-	0.7	-	-	0.5 ± 0.1± 0.2	25.3	30.1
180 - 200	0.2 ± 0.0	-	0.7	-	-	0.3 ± 0.1± 0.1	33.6	30.1
200 - 230	0.1 ± 0.0	-	0.7	-	-	1.0 ± 1.0± 0.3	97.0	30.1
230 - 260	0.0 ± 0.0	-	0.7	-	-	-	-	-
260 - 290	0.0 ± 0.0	-	0.7	-	-	-	-	-
290 - 350	-	-	0.7	-	-	-	-	-
350 - 450	-	-	0.7	-	-	-	-	-
450 - 650	-	-	0.7	-	-	-	-	-
650 - 850	-	-	0.7	-	-	-	-	-
32^o	$\cdot 10^{-6}$ [b]	[%]	[%]	[%]	[%]	$\cdot 10^{-6}$ [b]	[%]	[%]
40 - 50	4.2 ± 0.0	4.1	1.3	10.8	0.5	3.1 ± 0.1± 0.1	3.8	4.0
50 - 60	3.9 ± 0.0	4.2	1.3	2.0	7.4	3.7 ± 0.2± 0.3	4.1	8.4
60 - 70	3.7 ± 0.0	4.2	1.3	6.7	4.7	2.9 ± 0.1± 0.2	4.2	6.2
70 - 80	3.4 ± 0.0	4.6	1.3	4.8	5.8	2.7 ± 0.1± 0.2	4.5	7.0
80 - 90	3.1 ± 0.0	4.9	1.3	5.4	0.9	2.3 ± 0.1± 0.1	4.6	4.1
90 - 100	2.7 ± 0.0	5.2	1.3	10.9	7.4	1.6 ± 0.1± 0.1	4.9	8.4
100 - 115	2.3 ± 0.0	4.9	1.3	8.0	0.9	1.2 ± 0.1± 0.0	5.1	4.1
115 - 130	1.7 ± 0.0	5.8	1.3	12.1	8.0	0.8 ± 0.0± 0.1	5.7	8.9
130 - 150	1.1 ± 0.0	6.2	1.3	7.1	3.4	0.6 ± 0.0± 0.0	6.3	5.2
150 - 180	0.5 ± 0.0	7.7	1.3	3.0	2.6	0.3 ± 0.0± 0.0	8.8	4.8

Conclusions

- **Small effort more to assess the 32deg analysis normalization**
- **The systematic errors from detection efficiency and PID selection have to be added to the total systematic error**
- **Comparison with FLUKA model and other published data can be shown…**

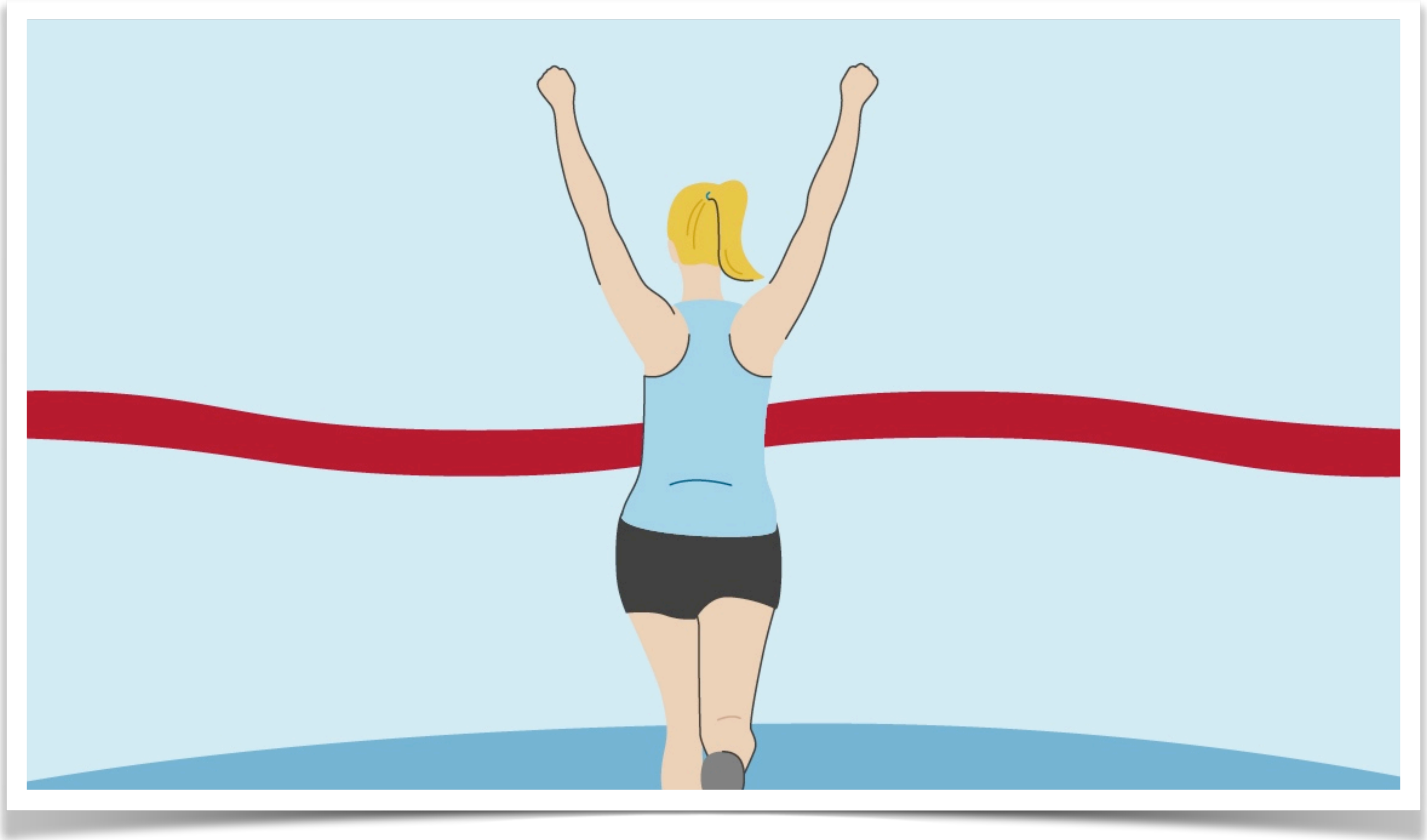




Conclusions

- **Small effort more to assess the 32deg analysis normalization**
- **The systematic errors from detection efficiency and PID selection have to be added to the total systematic error**
- **Comparison with FLUKA model and other published data can be shown…**

…But the analysis is done :)



Thank you for the Attention

(…and the patience…)