UPDATE ON THE ANALYSIS OF GSI ^{16}O@200MEV/N DATA TAKING

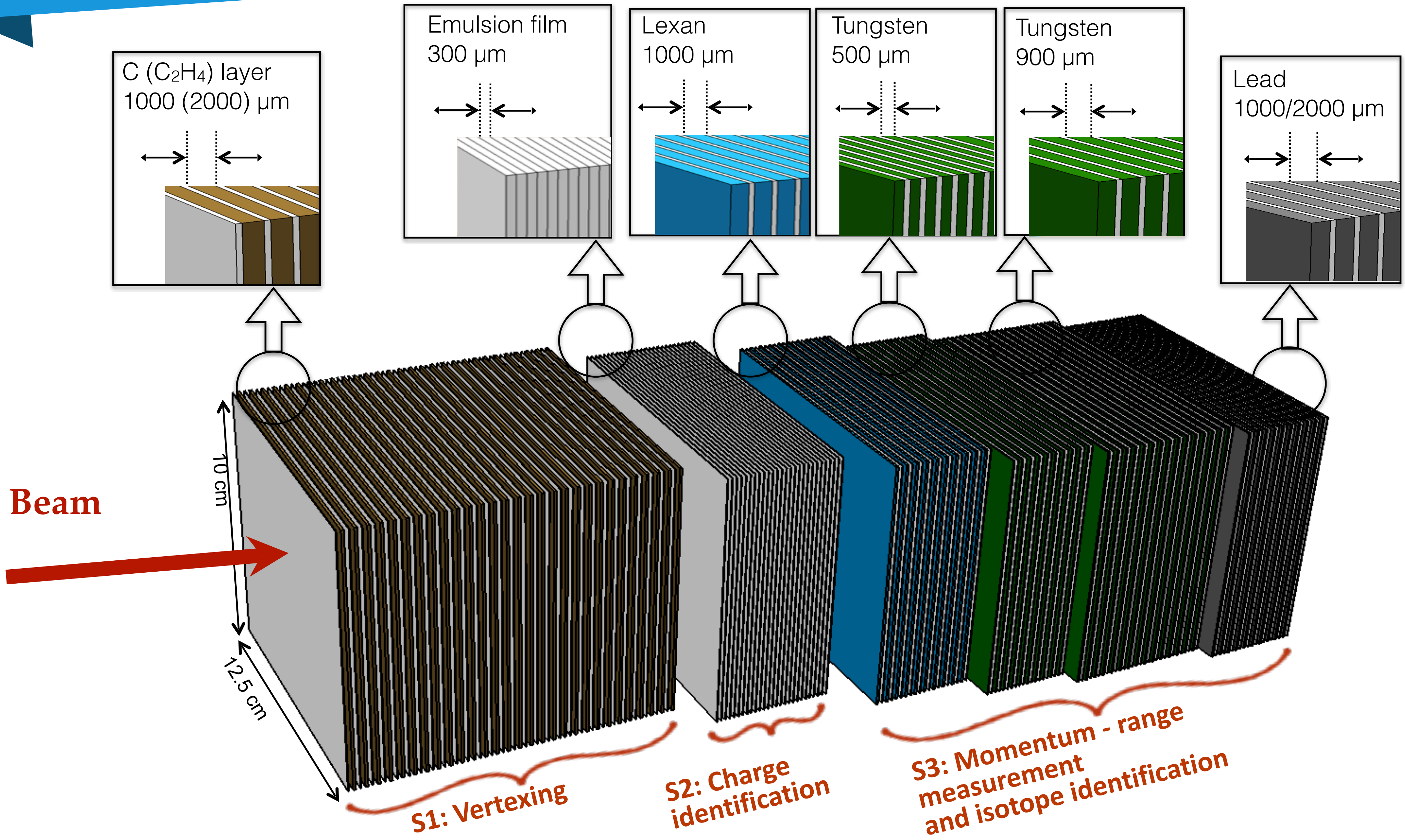
A. Alexandrov, V. Boccia, A. Di Crescenzo, G. De Lellis,
G. Galati, A. Lauria, M. C. Montesi, V. Tioukov

Università di Napoli "Federico II", INFN Napoli

Università di Bari "Aldo Moro", INFN Bari

17/12/2024, XVII General FOOT Meeting
Monastero di Cherasco (TO)

The nuclear emulsion setup



Total Cross Section Measurement

$$\sigma_i|_{C \text{ or } C_2H_4} = \frac{\boxed{Y_i}}{\boxed{N_{B_i}}\boxed{N_{TG_i}}\boxed{\epsilon_{reco_i}}}$$

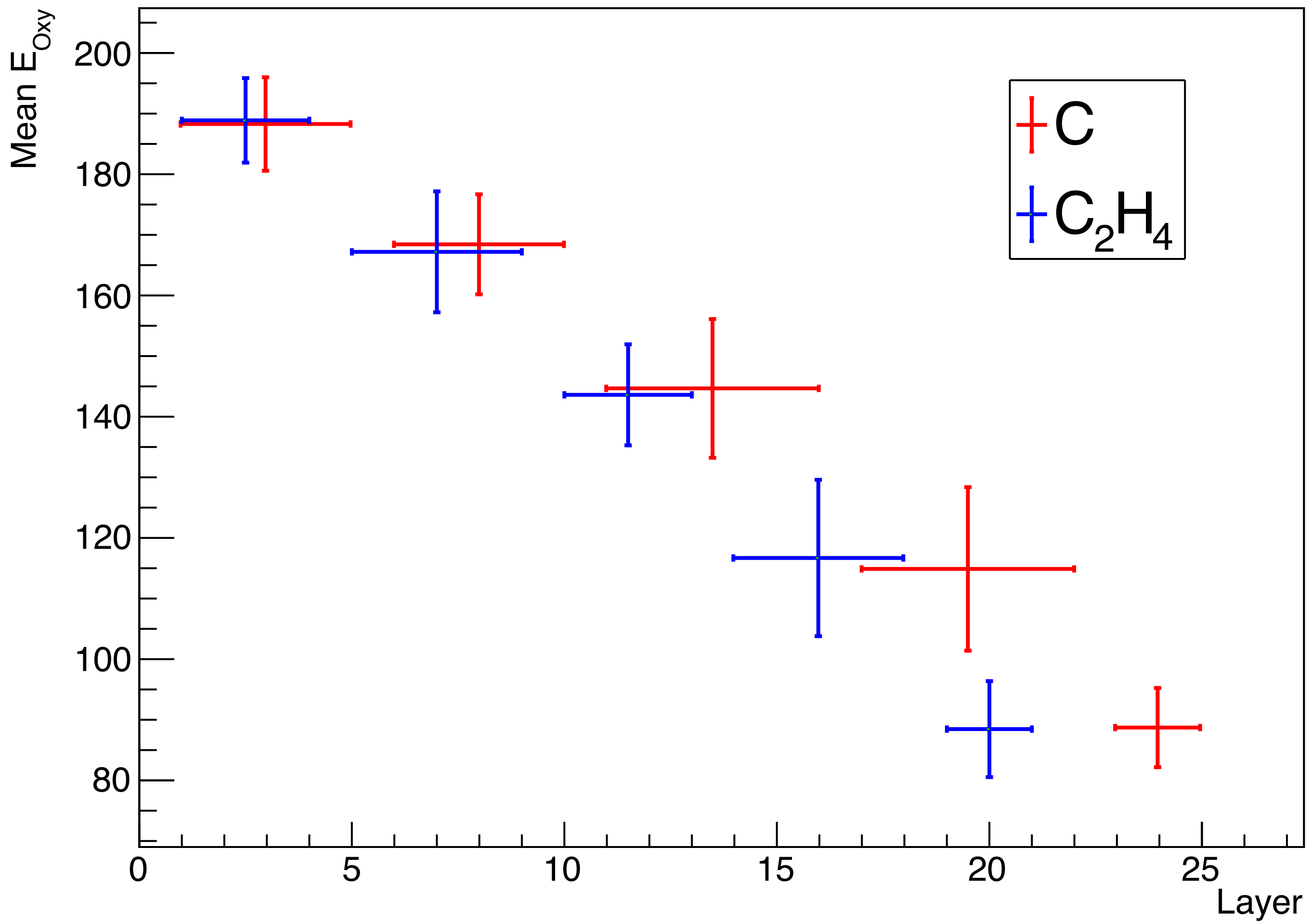
$$\sigma_i|_H = \frac{1}{4}\left(\sigma_i|_{C_2H_4} - 2\sigma_i|_C\right)$$

- Y_i = # of vertices (total xsec) or fragments (production xsec)
- N_B = # of ions colliding on the target
- ϵ_{B_i} = efficiency on beam reconstruction
- N_{TG} = # of particles in the target: $\frac{\rho d N_A}{A}$, with:
  - ρ = target density:
    $\rho_C = 1.73 g/cm^3$
    $\rho_{C_2H_4} = 0.94 g/cm^3$
    $\rho_H = 0.0708 g/cm^3$
  - d = target thickness:
    $d_C = 0.1 cm$ per layer
    $d_{C_2H_4} = 0.2 cm$ per layer
  - $N_A = 6.022 \cdot 10^{23}/mol$
  - A = molar mass:
    $A_C = 12 g/mol$
    $A_{C2H4} = 28 g/mol$
    $A_H = 1 g/mol$
- ϵ^i_{reco} = reconstruction efficiency

One detector… many measurements!

$$\sigma_i|_{C\ or\ C_2H_4} = \frac{Y_i}{N_{B_i}\ N_{TG_i}\ \epsilon_{reco_i}}$$

- The energy loss within S1 is not negligible
- We divide S1 into sub-sections



C:

- (188 ± 8) MeV/n
- (168 ± 8) MeV/n
- (144 ± 11) MeV/n
- (114 ± 13) MeV/
- (88 ± 13) MeV/n

C2H4:

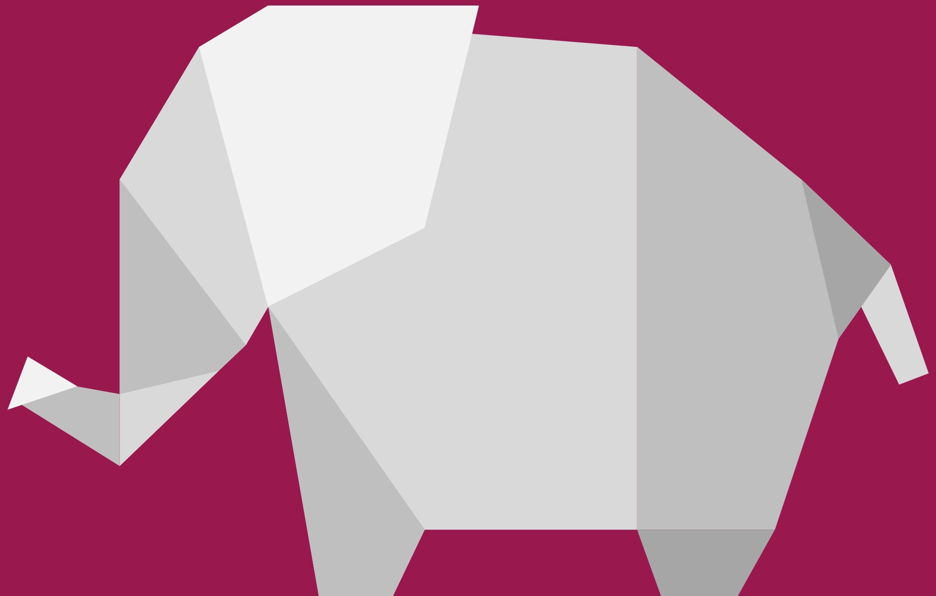
- (188 ± 7) MeV/n
- (167 ± 10) MeV/n
- (143 ± 8) MeV/n
- (116 ± 13) MeV/n
- (88 ± 8) MeV/n

H:

- (188 ± 8) MeV/n
- (168 ± 10) MeV/n
- (144 ± 11) MeV/n
- (115 ± 13) MeV/n
- (88 ± 8) MeV/n

Number of beam particles

$$N_{B_i}$$



N_B evaluation

$$\sigma_i|_{C \ or \ C_2H_4} = \frac{Y_i}{\boxed{N_{B_i}} N_{TG_i} \ \epsilon^i_{reco}}$$

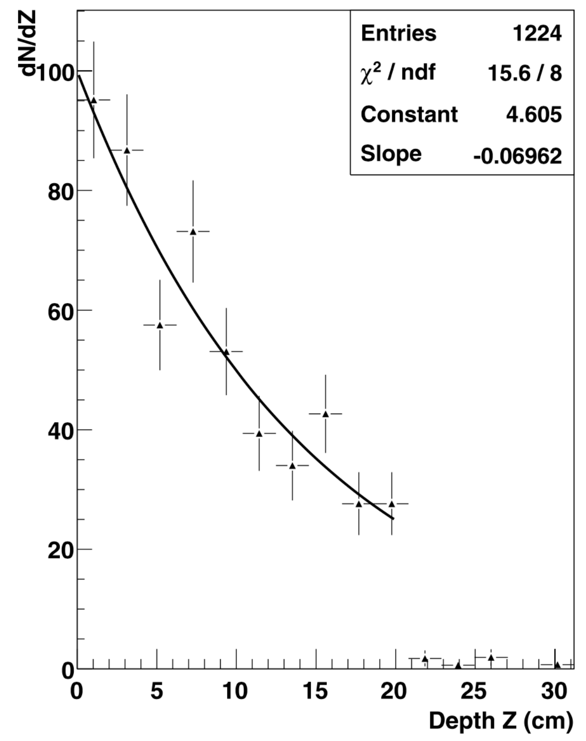
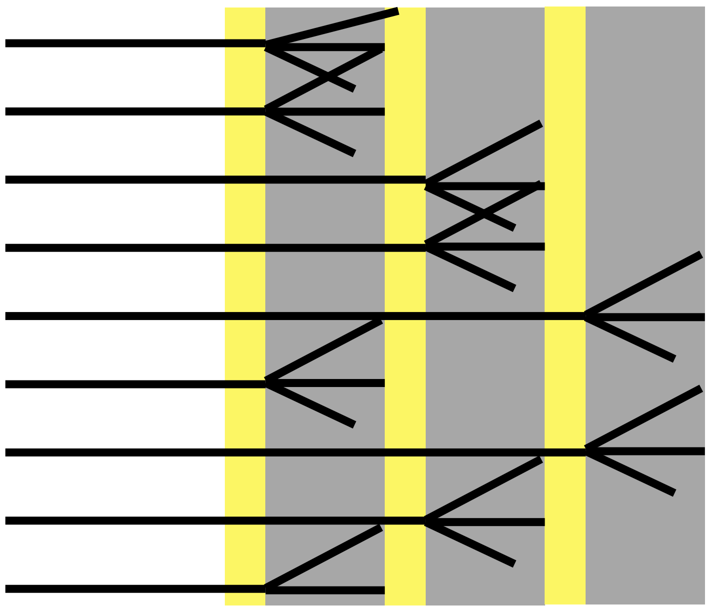


Fig. 2. Fraction of the remnant Carbon beam as a function of the traversed ECC material



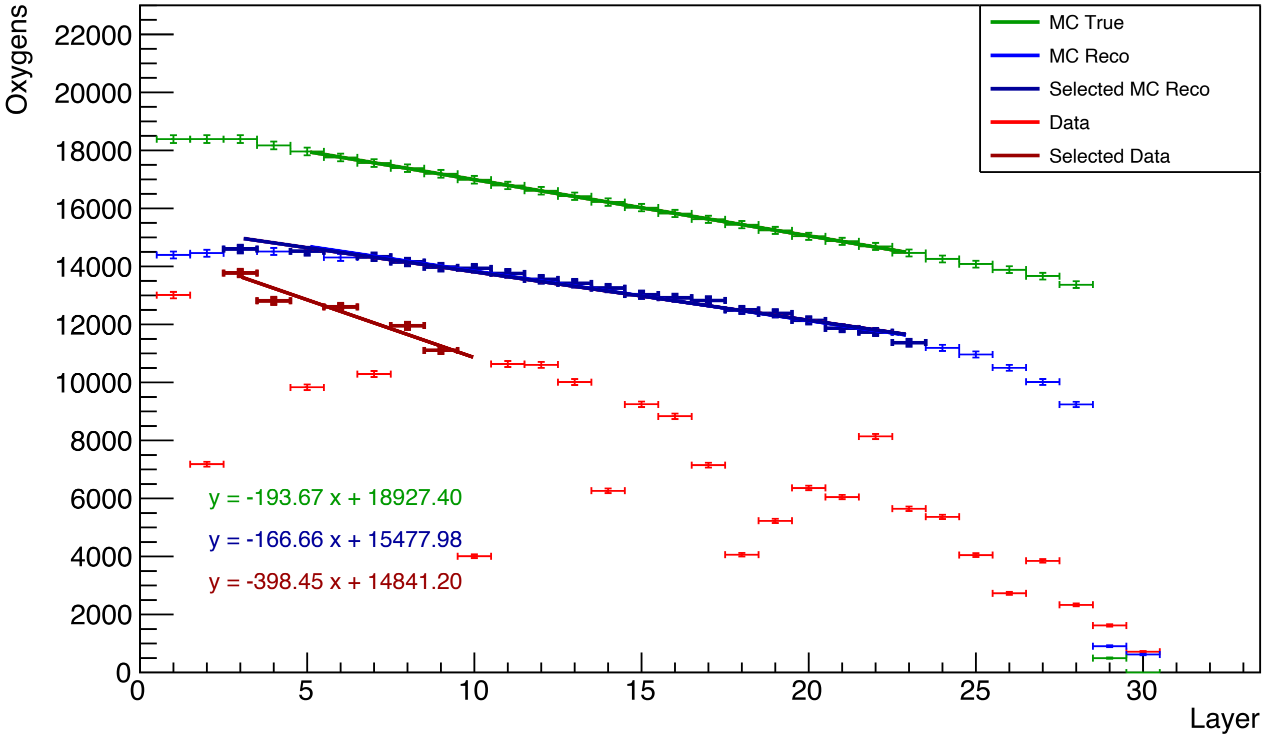
- Each passive material layer can be considered a "new measurement"
- The number of incident beam particle on each layer has to be evaluated and is affected by its efficiency
- New approach: estimation from oxygen tracks

The problem of N_B evaluation

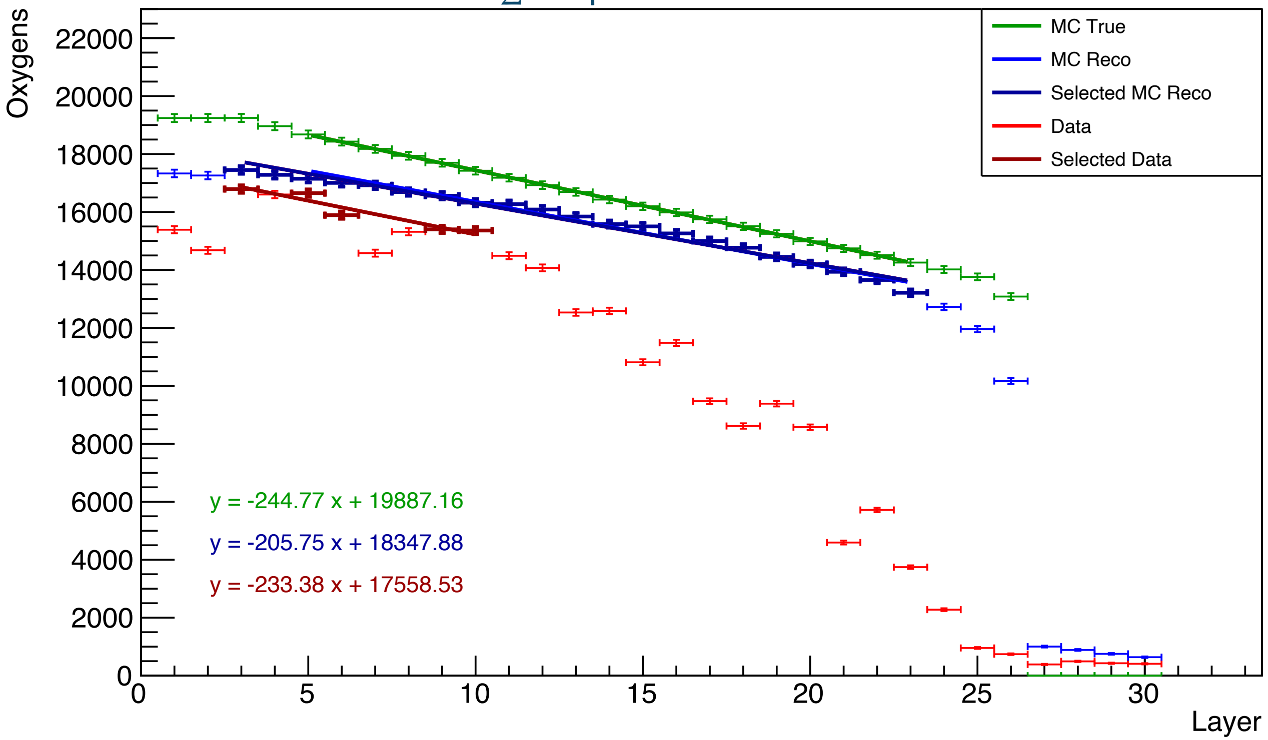
from XVI FOOT Collaboration Meeting

- Cross section measurement sensitive to N_B
- Oxygen: tracks with $\tan\theta \leq 0.02$ rad
- New attempts on-going for improving (only) oxygen reconstruction
- If successful, it will be a double check for cross section evaluation!

C TARGET



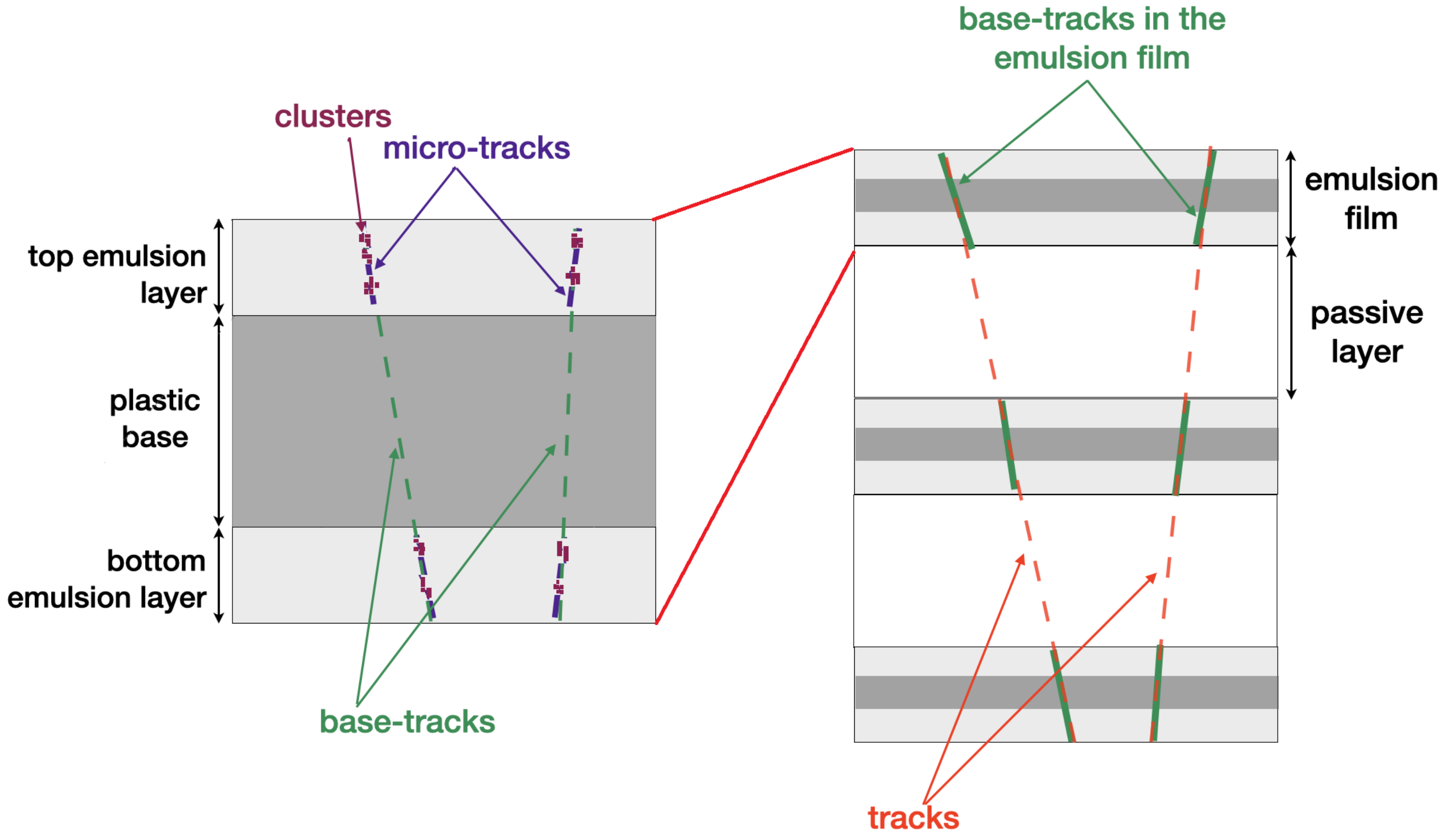
C_2H_4 TARGET




797 µm
590 µm

Emulsion Reconstruction Workflow (1)

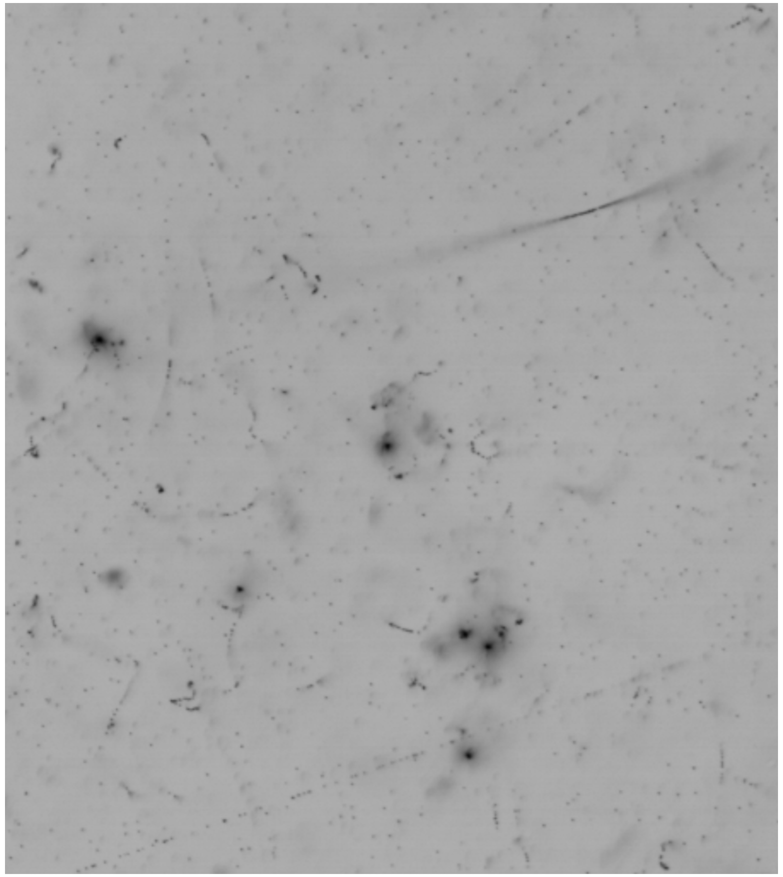
During scanning, the emulsion surface is divided into views ($800 \times 600\ \mu m^3$) and several images («frames») are collected with a step along the Z axis equal to 1.75 μm



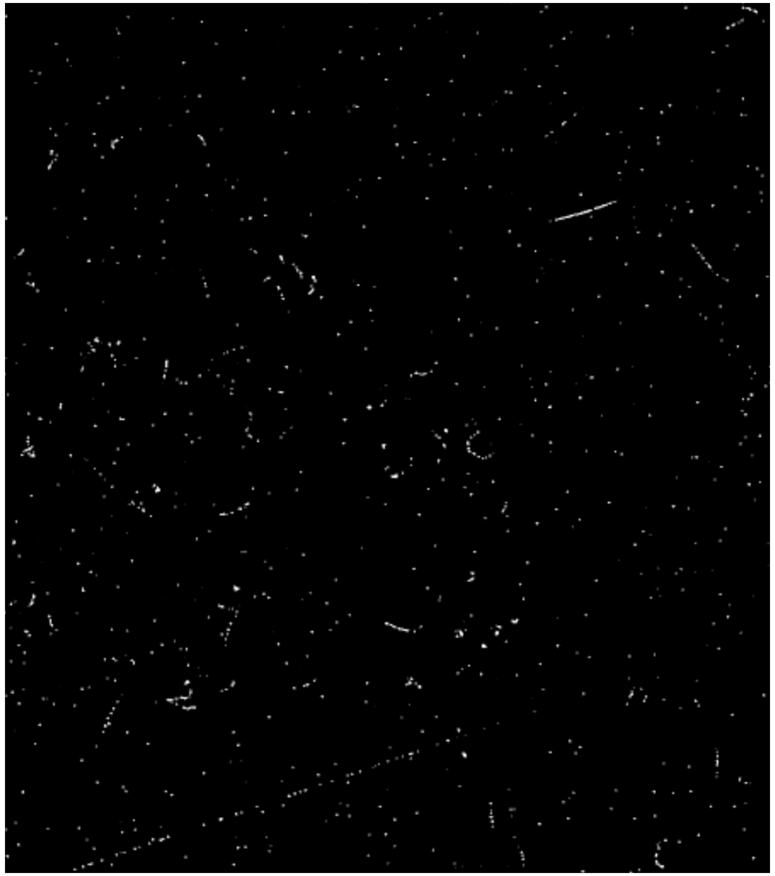
Emulsion Reconstruction Workflow (2)

- Convolution with a high pass filter is performed to reduce background
- The size of the «standard» filter is 5x5 pixels and it was optimized for MIP reconstruction
- All pixels with values greater than a given threshold are used for cluster reconstruction

Original Image

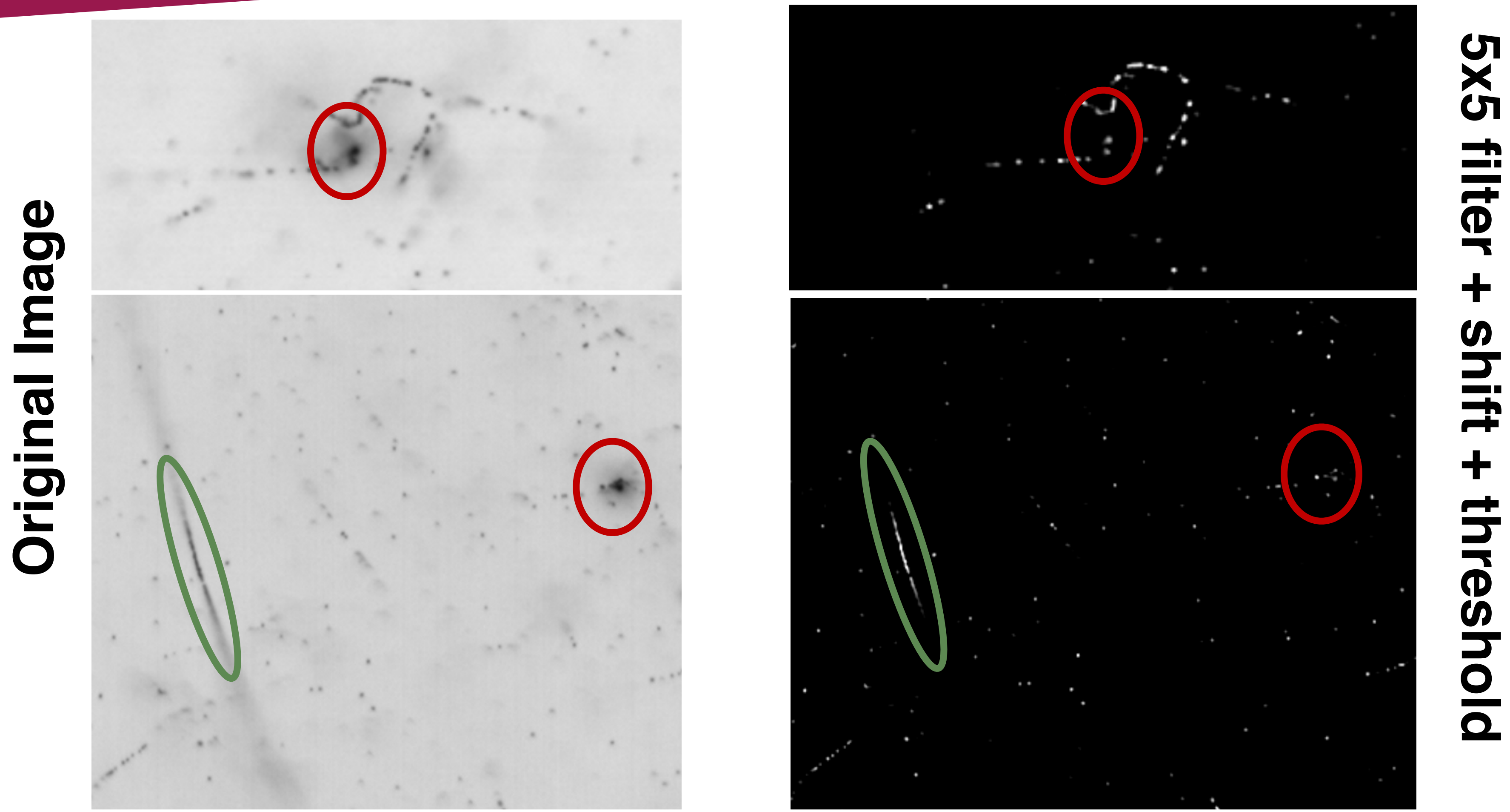


5x5 filter + shift + threshold



→ Cluster reconstruction

Effect of 5x5 Filter on Oxygen Clusters (2)



- Smaller objects are highlighted while larger objects (such as oxygens) are split into smaller clusters
- The 5x5 filter leads to additional position and angular smearing and an overall loss of efficiency in oxygen reconstruction

Possible Strategies

- The 5x5 kernel breaks oxygen clusters into smaller structures, which are later identified as separate clusters and in many cases this prevents the reconstruction of the track
- New strategy needed!

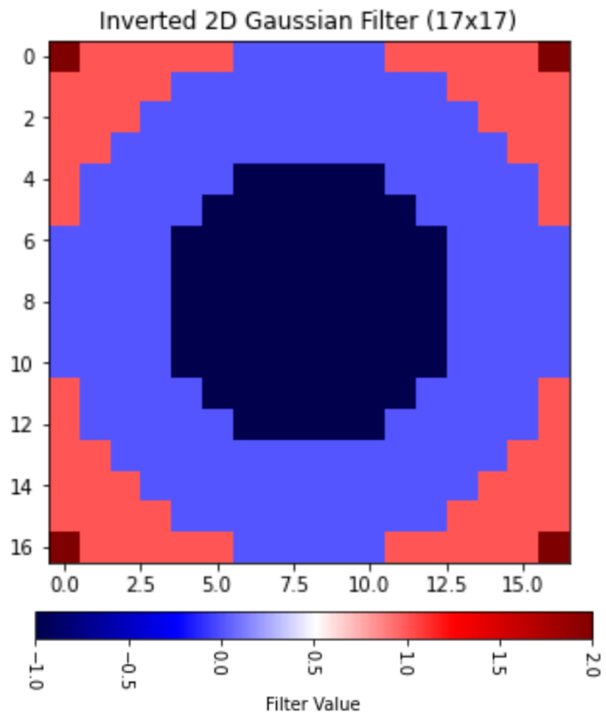
- Two main approaches possible, each with pros and cons

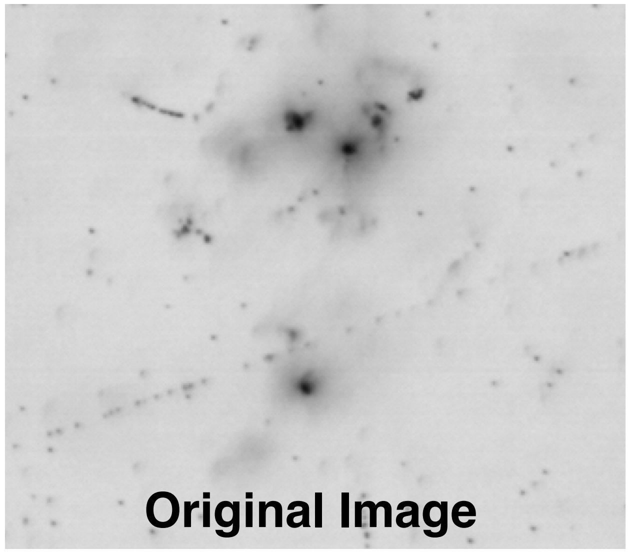
  - Keep using the same filtering kernel to preserve the reconstruction of secondaries and identify oxygens from large number of clusters close to each other
  - Design new filtering kernel optimized for the identification of oxygens (low efficiency for secondary tracks)

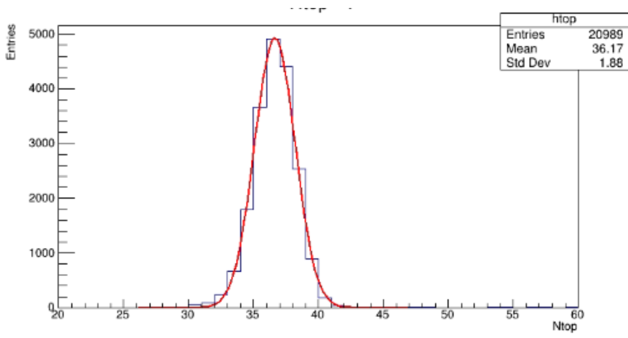
For more details: V. Boccia FOOT Physics Meeting 4 December 2024:
https://agenda.infn.it/event/44578/contributions/250785/attachments/129107/191445/VB_PhysMeet_Dec24.pdf

Second Approach: New High Pass Filter

- Gaussian filter of 17x17 pixels and $\sigma = 11$ pixels, purely dedicated to oxygen reconstruction
- The number of oxygens in each plate is evaluated by a cut on the number of clusters in the top and bottom layers of each emulsion
- Robust measurement of the number of oxygens (each plate is independent from the others, no tracks reconstruction)



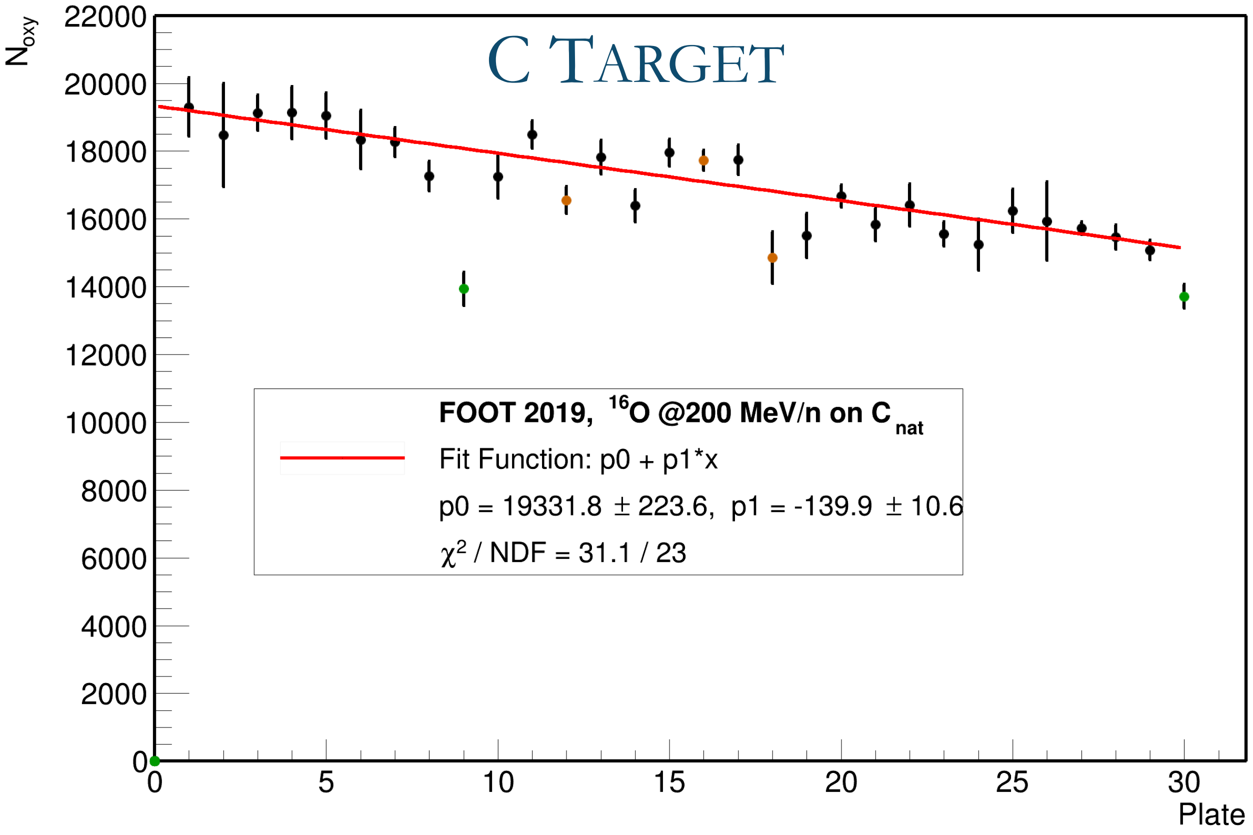


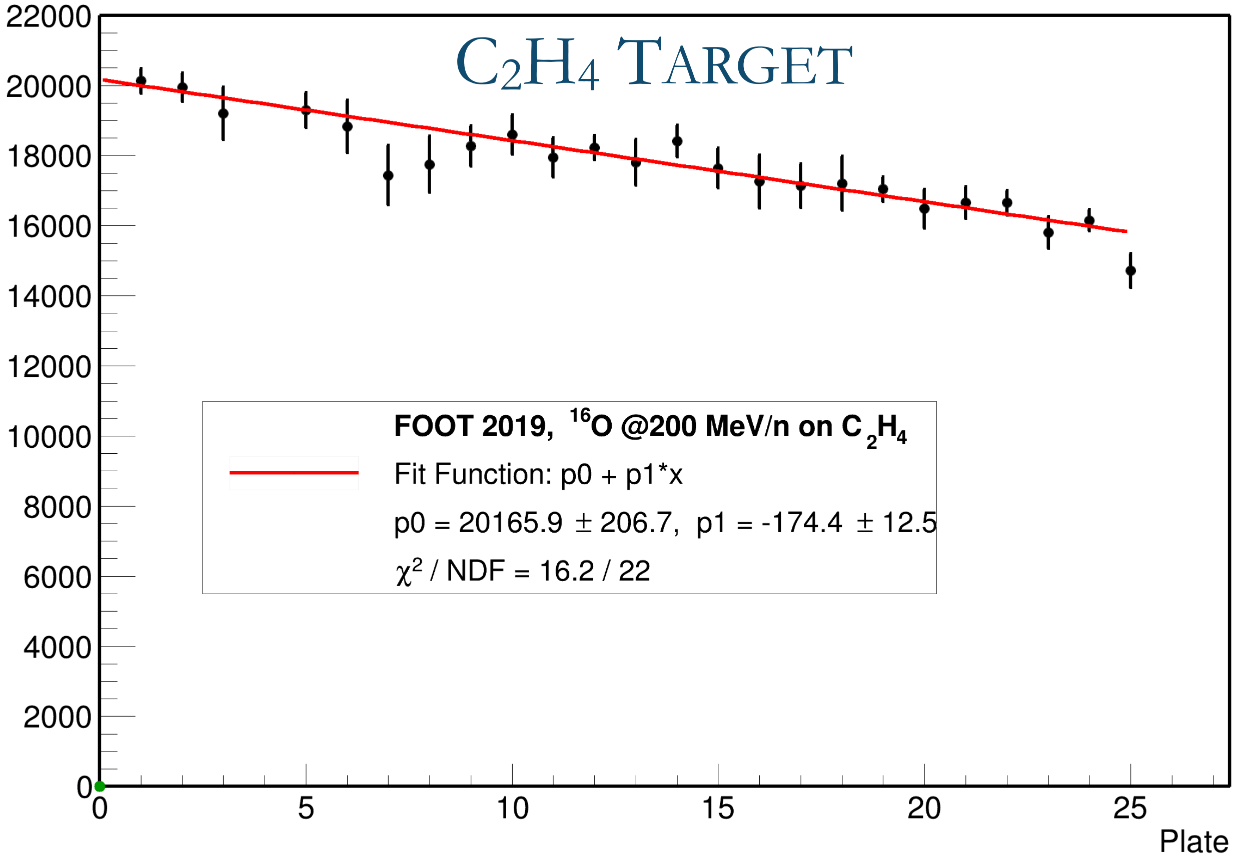


Number of top clusters (example)

First results

- Plates outside 2σ from the fit have been removed and the fit performed again
- The slope obtained must be corrected to take into account contamination coming from the heaviest secondary fragments: to estimate it, we assume that all tracks that are left after the Bragg Peak were uniformly produced up to Bragg Peak plate

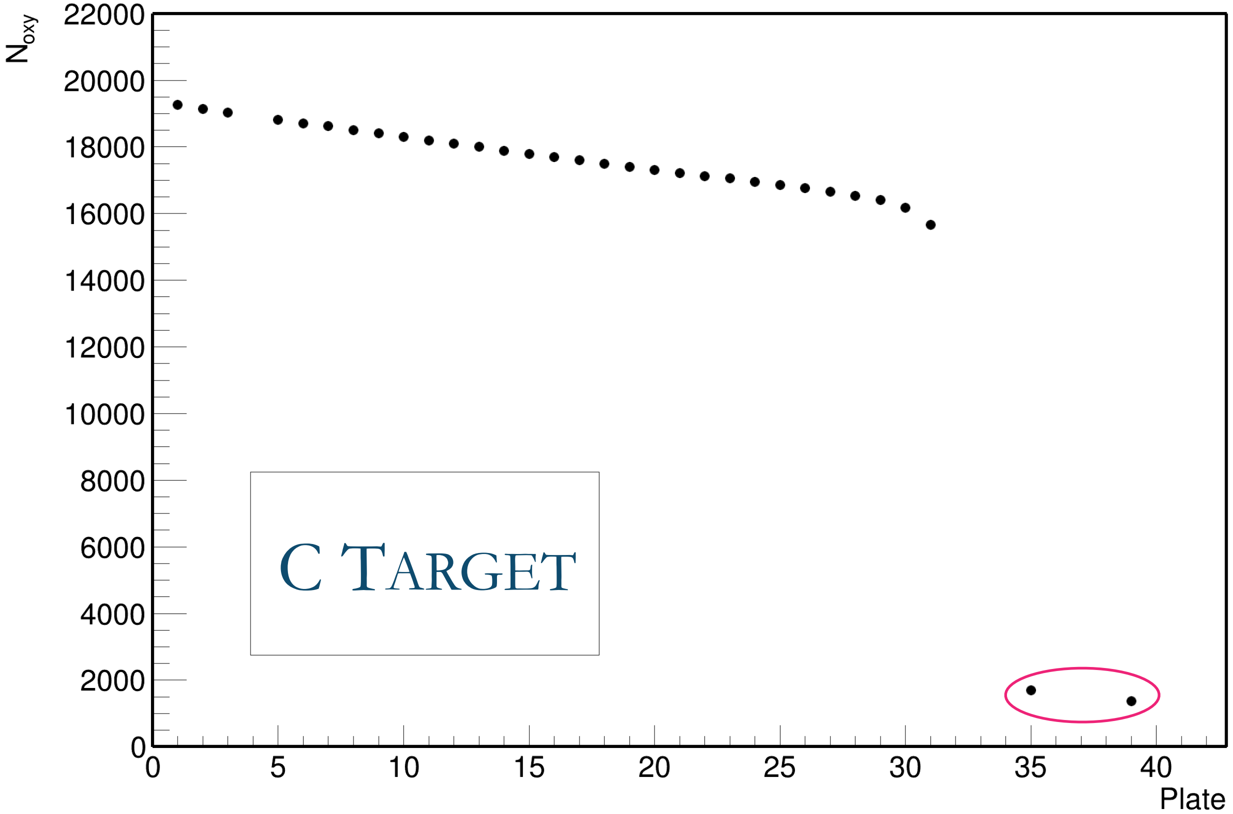


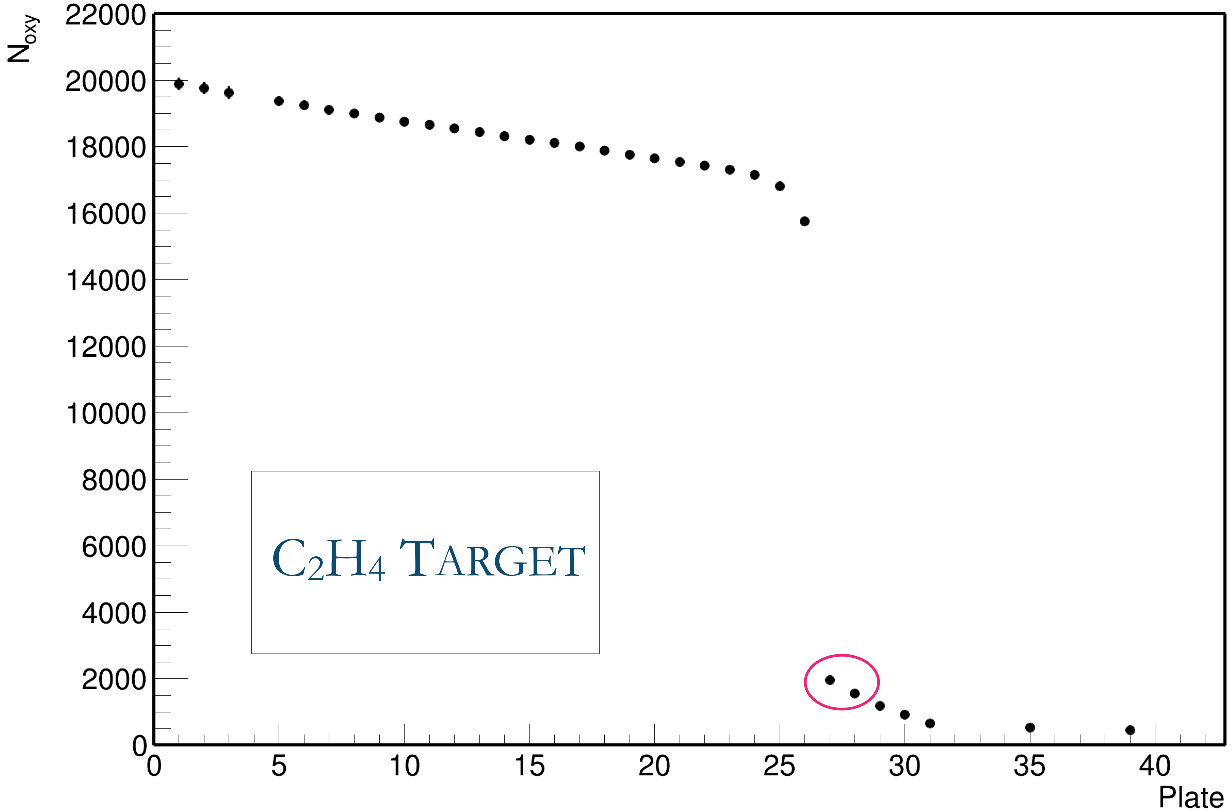


MC Simulation results

Goal: estimate the systematic error introduced by the new procedure

- We assume 100% efficiency on all tracks with Z>=4 (after comparison with 5x5 filter results)
- Fit by using the average of 2 plate after the Bragg Peak to estimate the fragmentation background
- Charge MC True information to evaluate the slope correction also for DATA



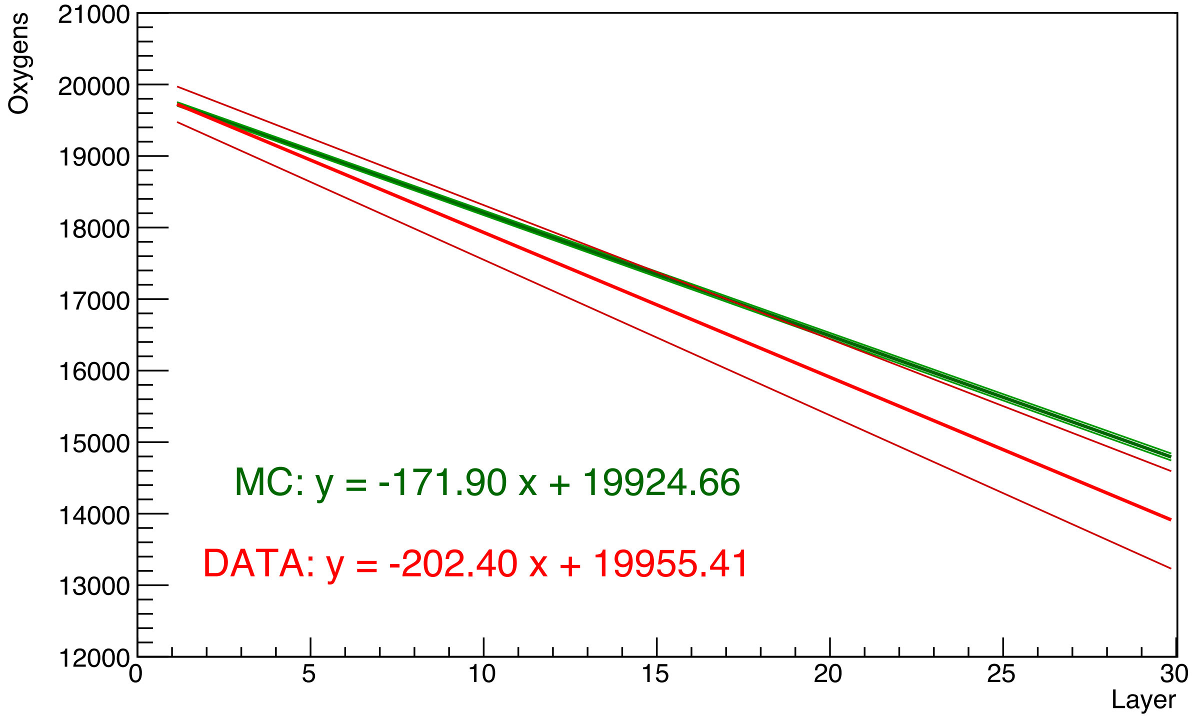


More details will be given at the next physics meeting when analysis will be completed

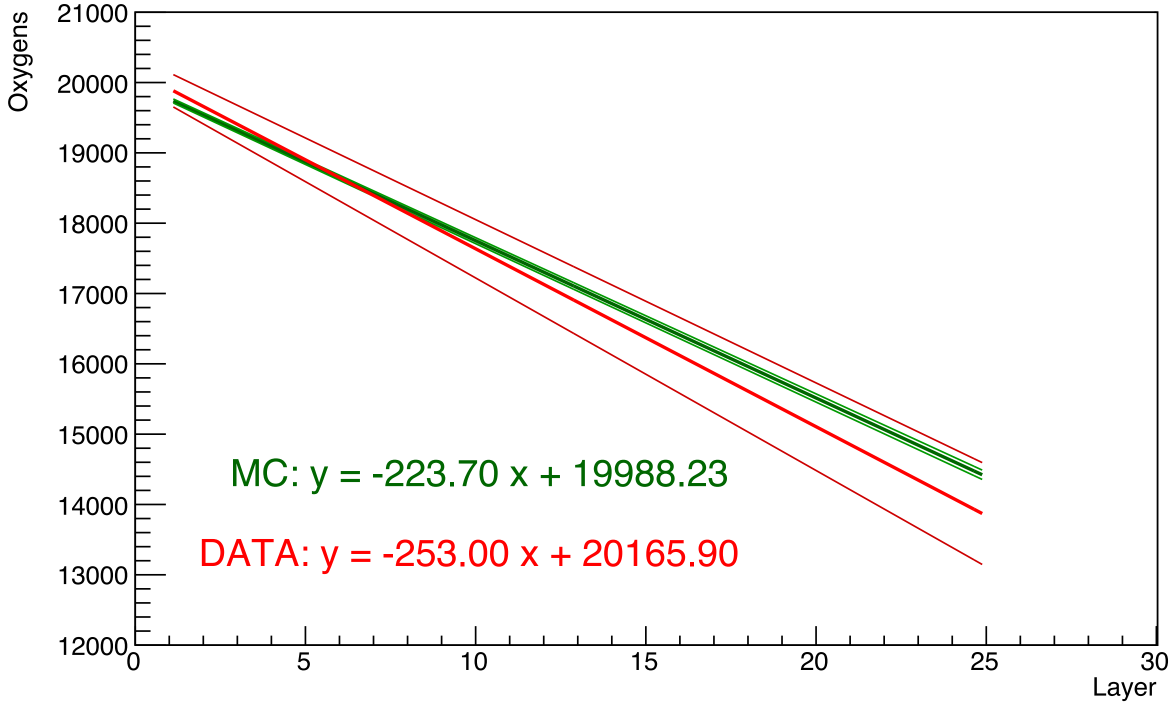
Preliminary results

Some checks on MC corrections still to be performed

C Target



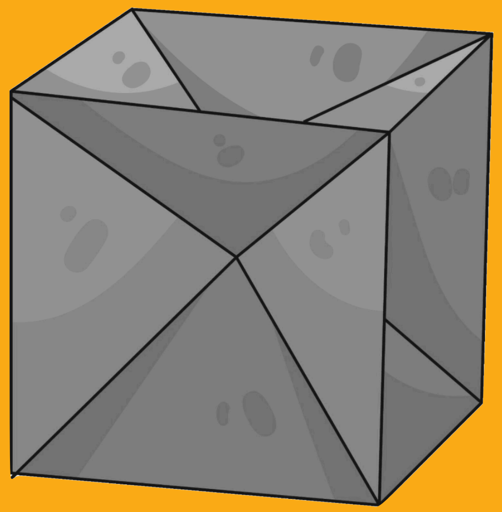
C_2H_4 Target



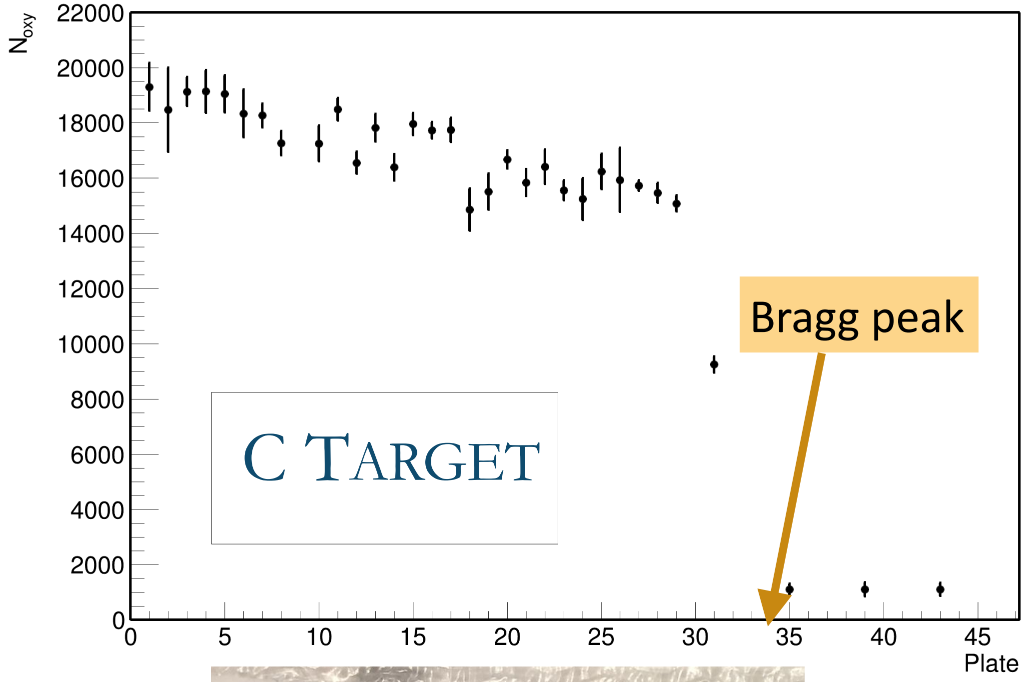
Thinner lines: fit plus/minus errors

$$N_{TG} = \frac{\rho d N_A}{A}$$

Number of target atoms



S



- With 17x17 filter we noticed that in C target there were Oxygens beyond the film in which we expected the Bragg Peak from MC simulation 😱

Cross check of C density:

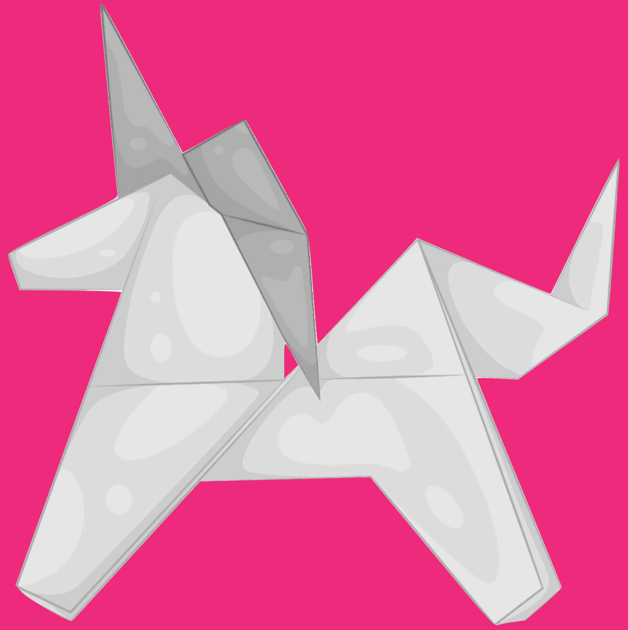
- Nominal value from seller:1.842 g/cm^3
- Measurement with a scale accurate to one hundredth of a gram: $(1.73 \pm 0.03)\ g/cm^3$ (using nominal dimensions)

New MC simulation* (100k events): density value confirmed the data Bragg Peak observations

*** Many thanks to Giuseppe Battistoni that solved several problems!**

$$Y_i/\epsilon_i^{reco}$$

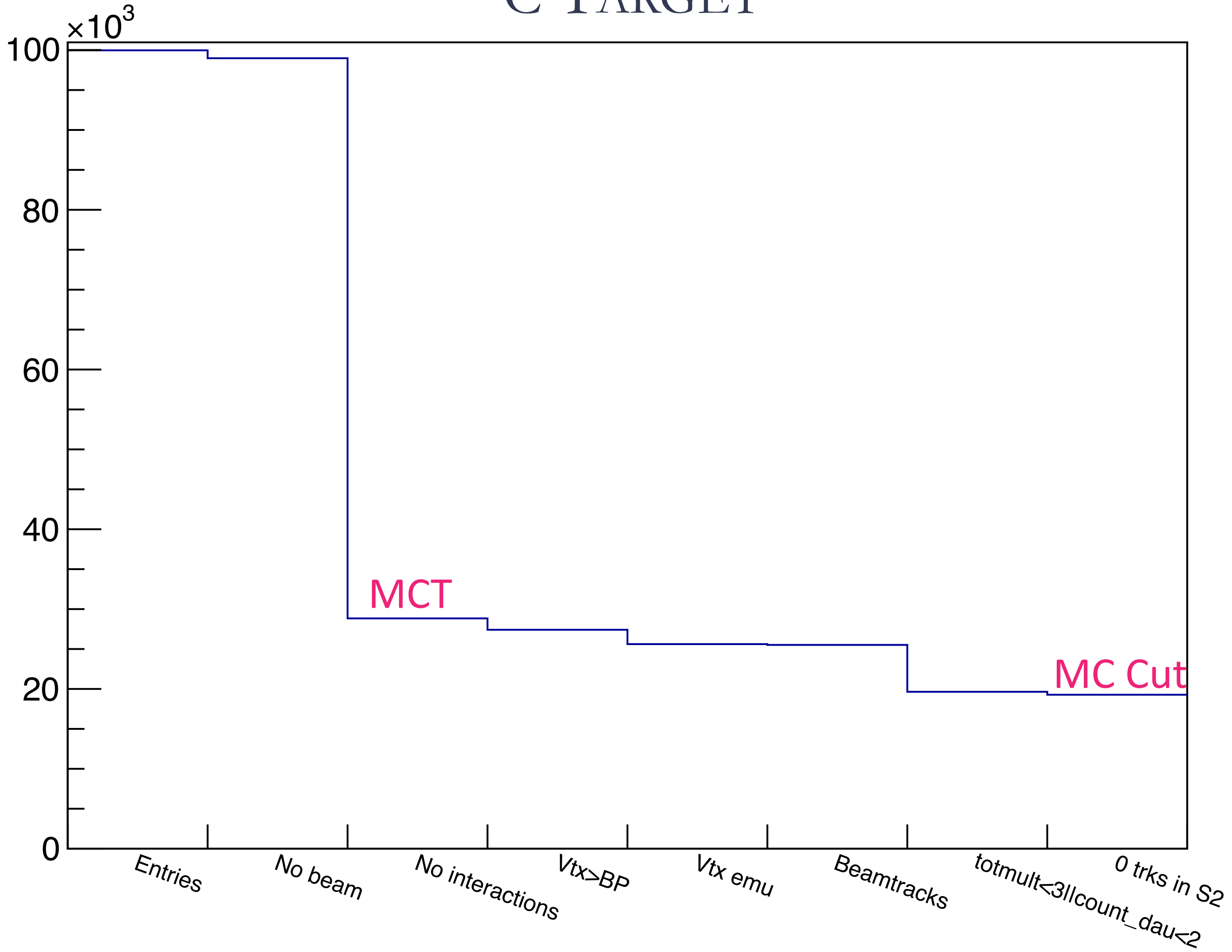
Number of vertices and number of produced fragments



Cuts for vertices selection and bkg rejection

NEW MC PRODUCTION 100k events

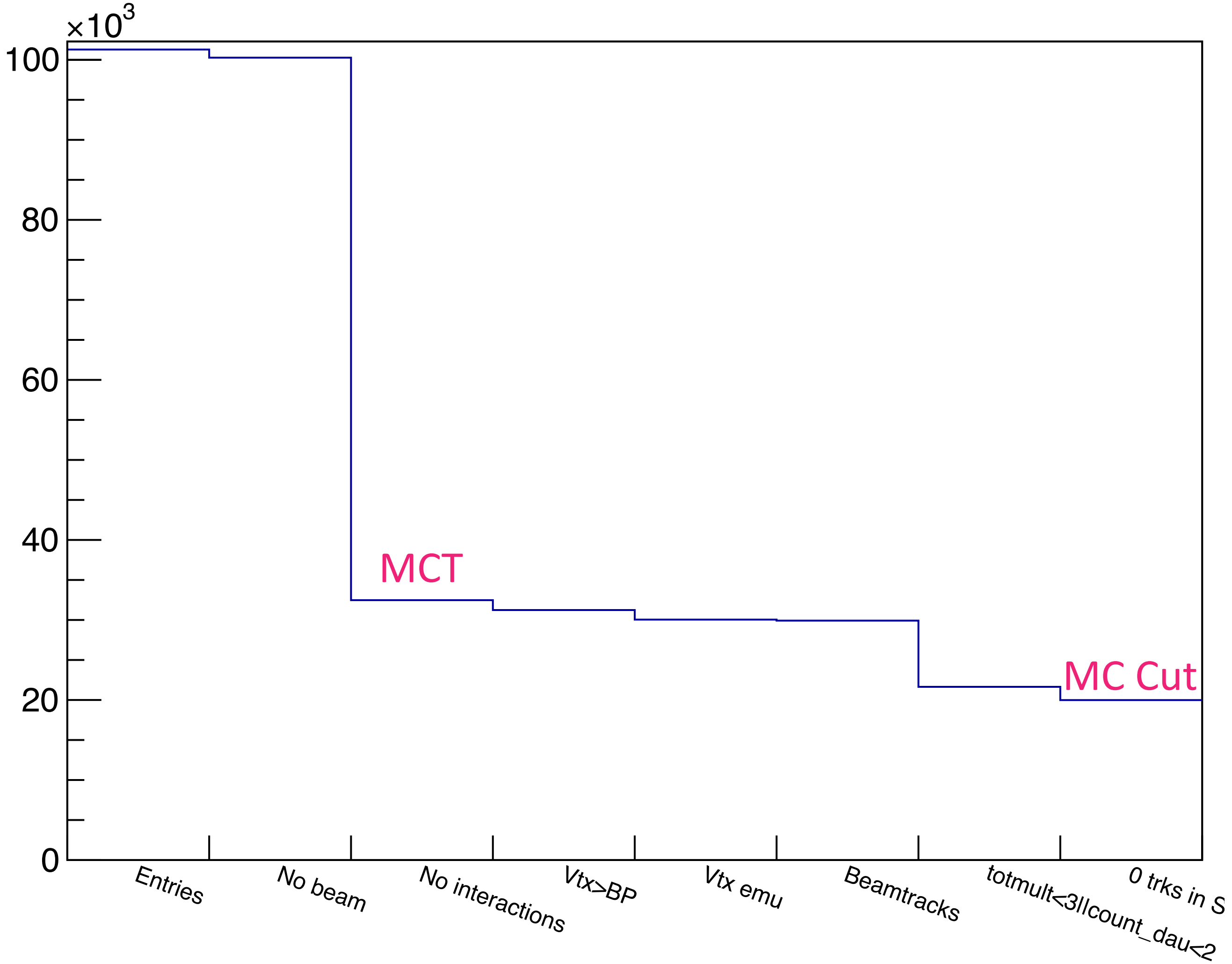
C TARGET



- Events: 99970
- Events without beam Oxygen: 989
- Events with no interactions: 70144
- Interactions after plate BP: 1426
- **Interactions in emulsion film: 1797** **(NEW)**
- The number of tracks with $\theta \leq 0.03$ mrad is ≥ 2 if the remaining number of tracks is ≤ 2: 98
- Less than 3 tracks and less than 2 daughters with at least 3 base tracks: 5872
- No tracks arriving in S2: 368

Cuts for vertices selection and bkg rejection

C_2H_4 TARGET



- Events: 101287
- Events without beam Oxygen: 1016
- Events with no interactions: 67795
- Interactions after plate BP: 1235
- **Interactions in emulsion film: 1196** **(NEW)**
- The number of tracks with $\theta \leq 0.03$ mrad is ≥ 2 if the remaining number of tracks is ≤ 2: 127
- Less than 3 tracks and less than 2 daughters with at least 3 base tracks: 8273
- No tracks arriving in S2: 1658

Closure test?

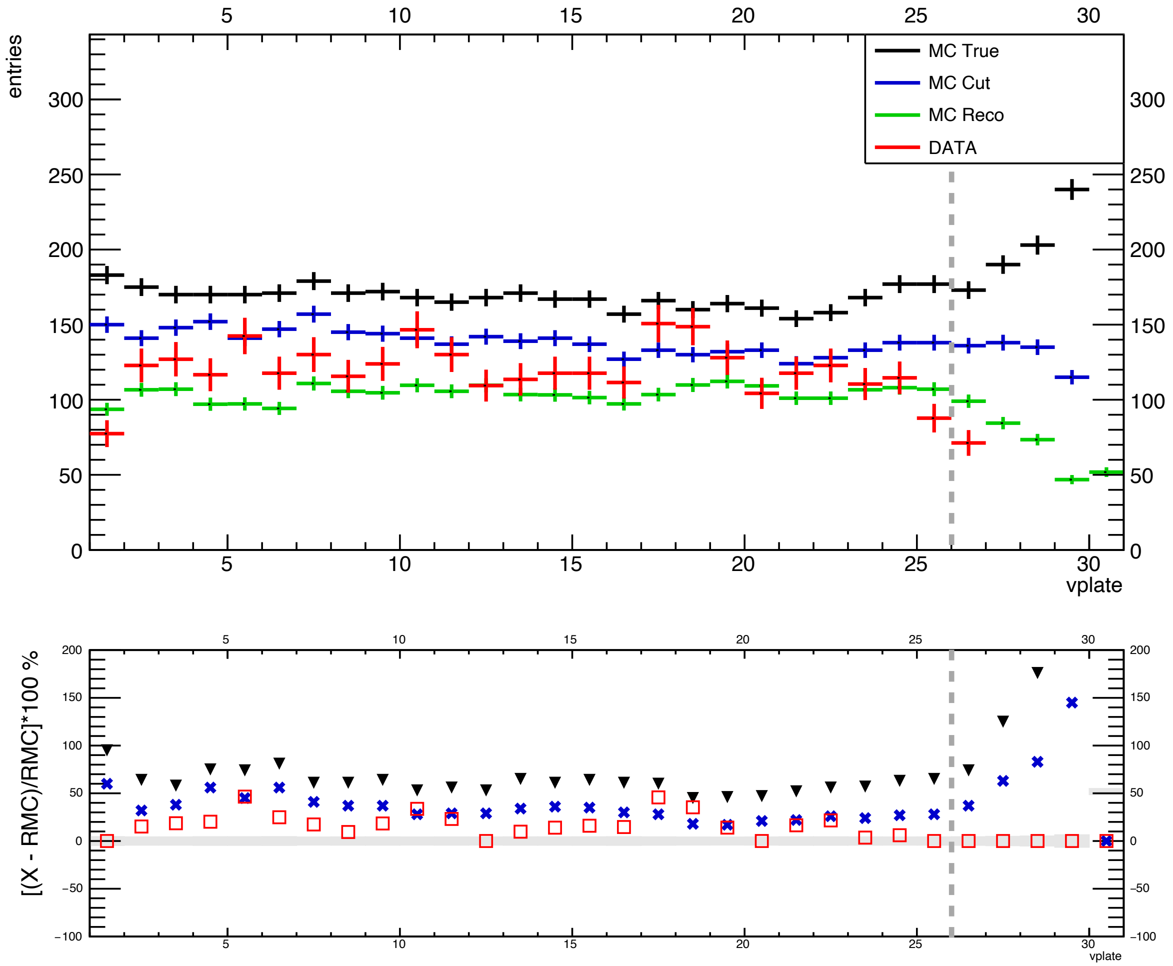
$$\sigma_i|_{C\ or\ C_2H_4} = \frac{Y_i}{N_{B_i}\ N_{TG_i} \boxed{\epsilon_{reco_i}}}$$

- How to evaluate efficiencies? At the moment: $\epsilon = \dfrac{Y_{i_{MCReco}}}{Y_{i_{MCTrue}}}$
- We cannot evaluate efficiency from MC event by event (no trigger, no time stamp for emulsions…)

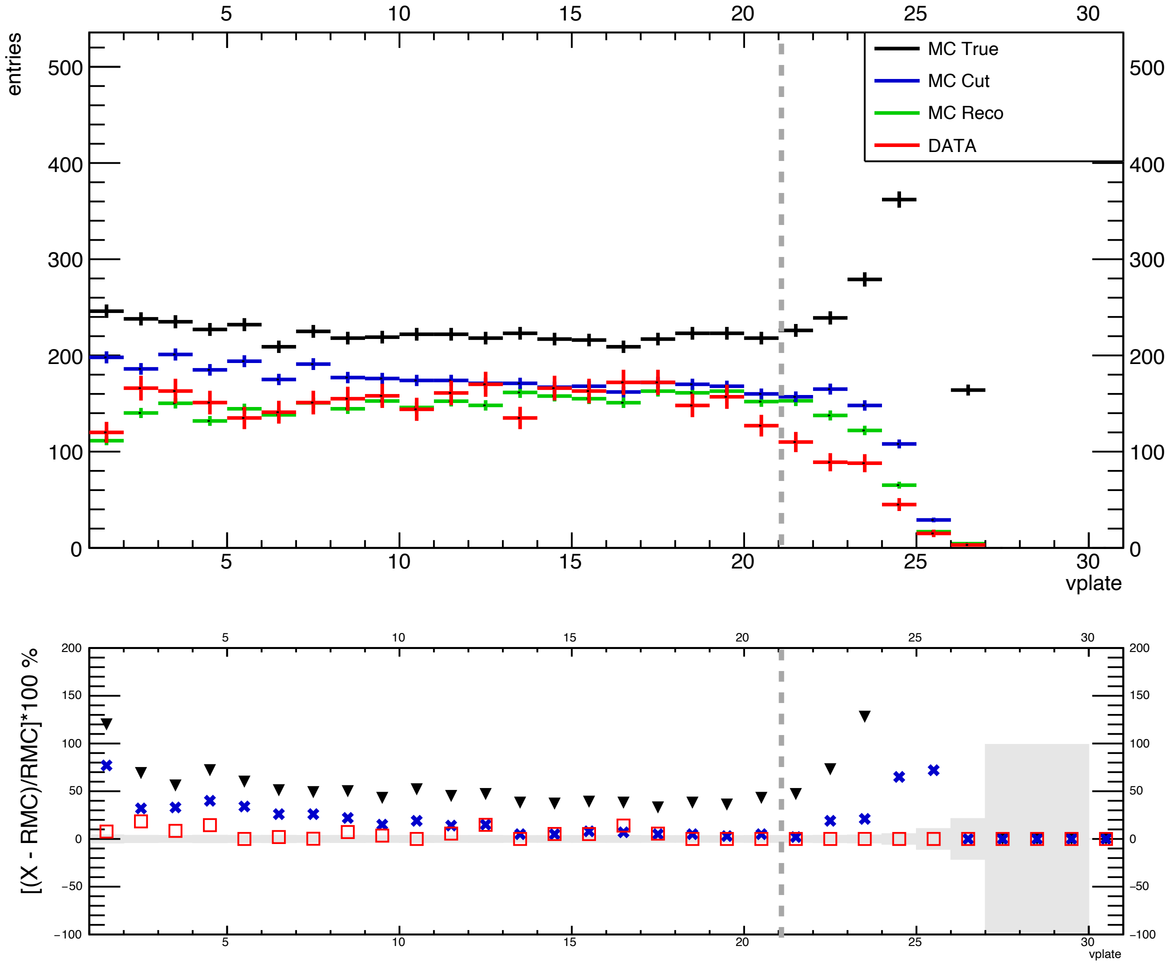
- Comparison of integrated cross section at Z=3 and $\theta < 10°$ with electronic detector setup
- Comparison with literature
- **Cross check with oxygens disappearance**

Number of vertices per plate

C Target

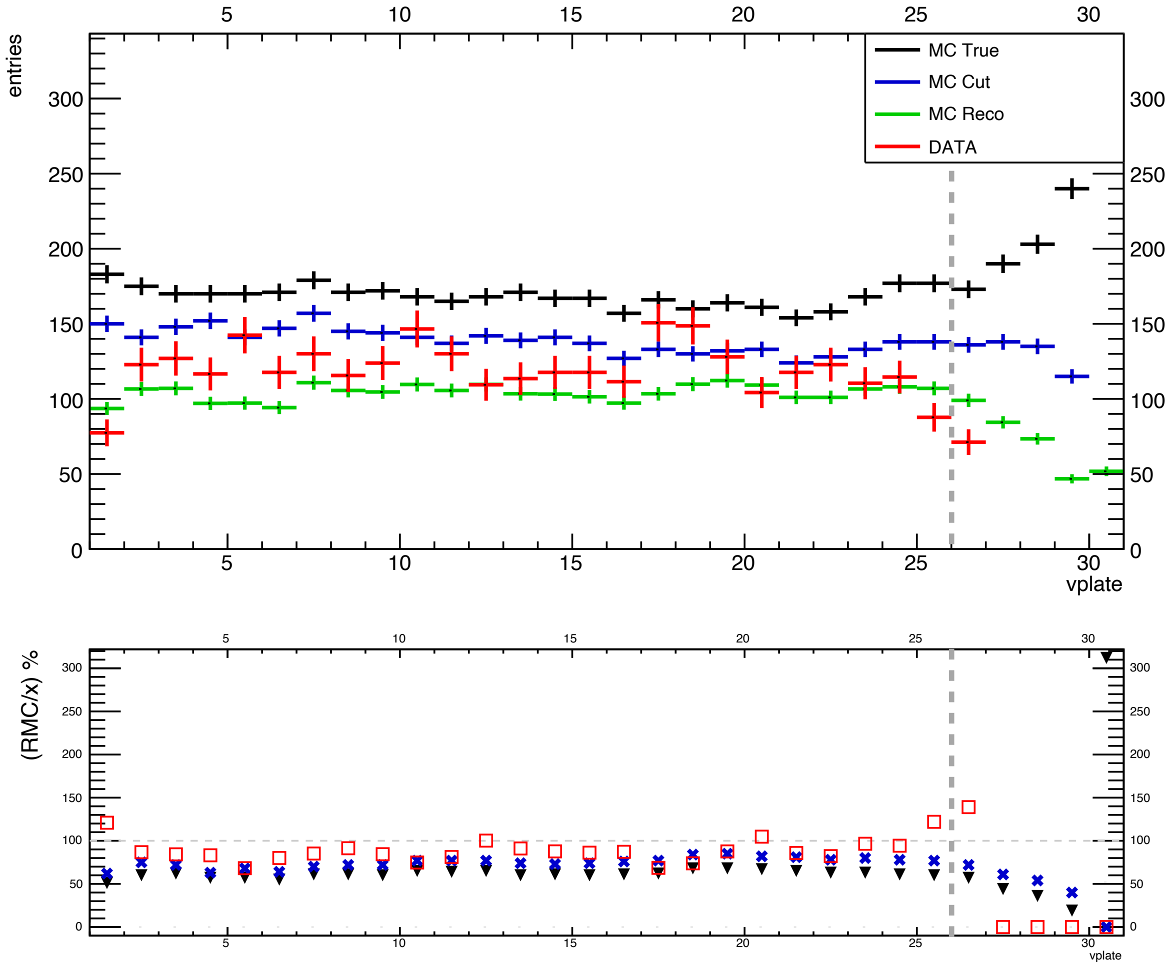


C_2H_4 Target

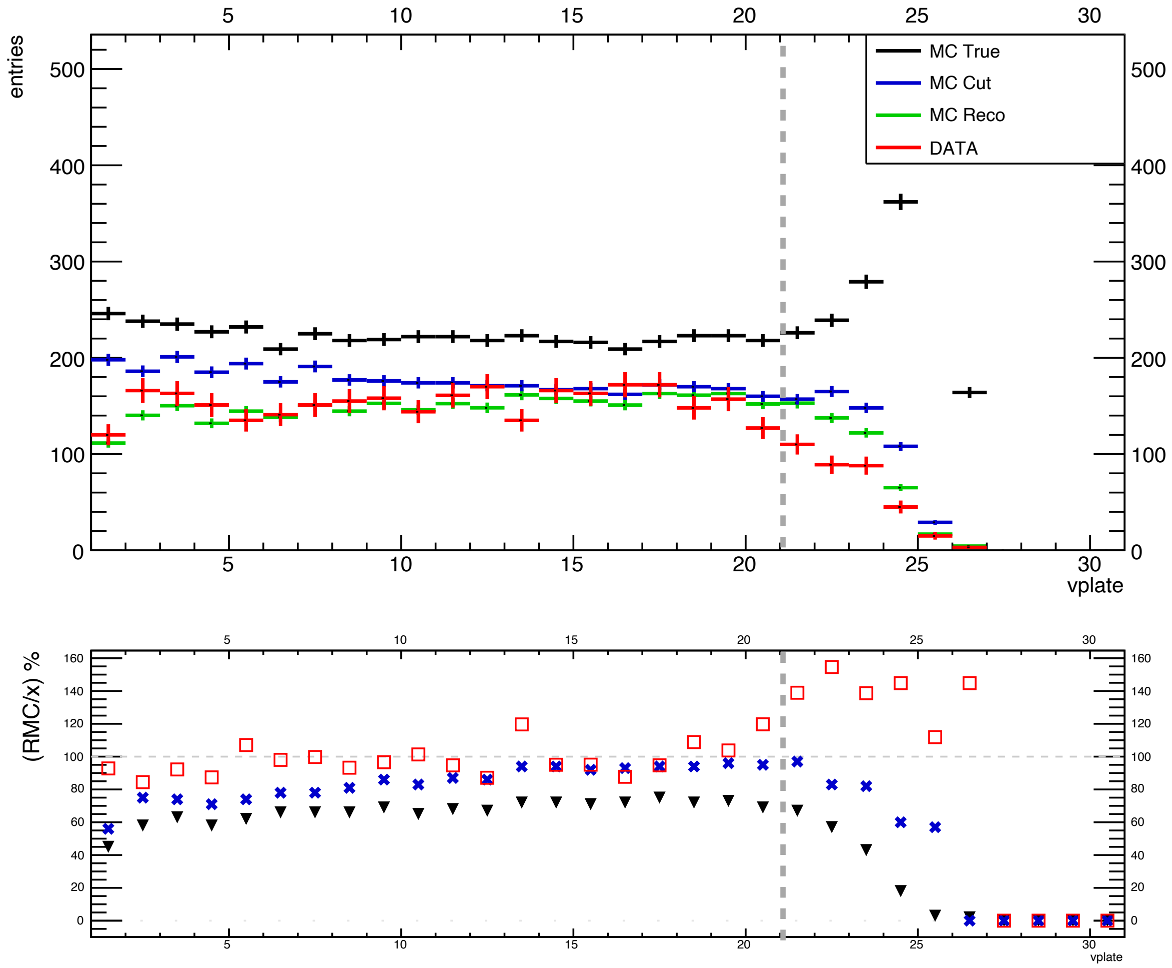


Number of vertices per plate

C Target



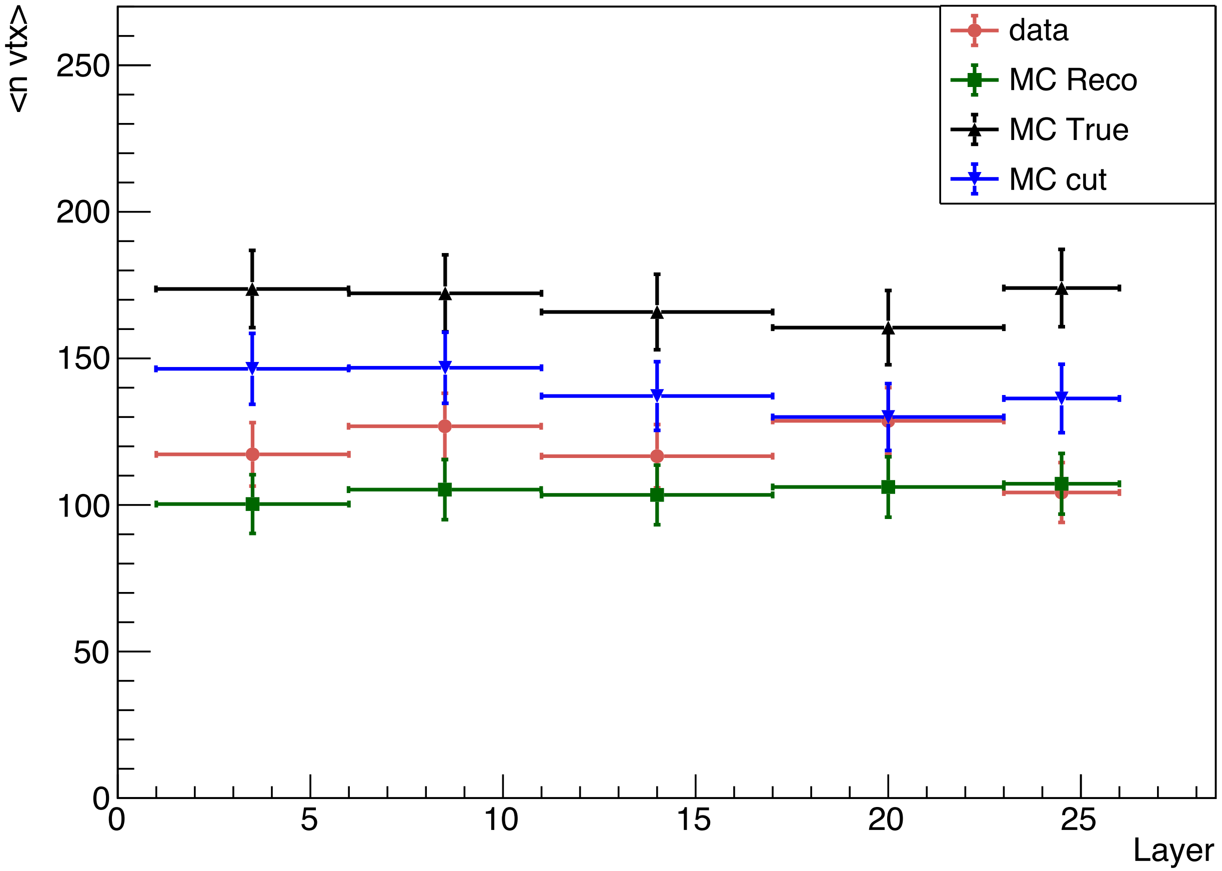
C_2H_4 Target



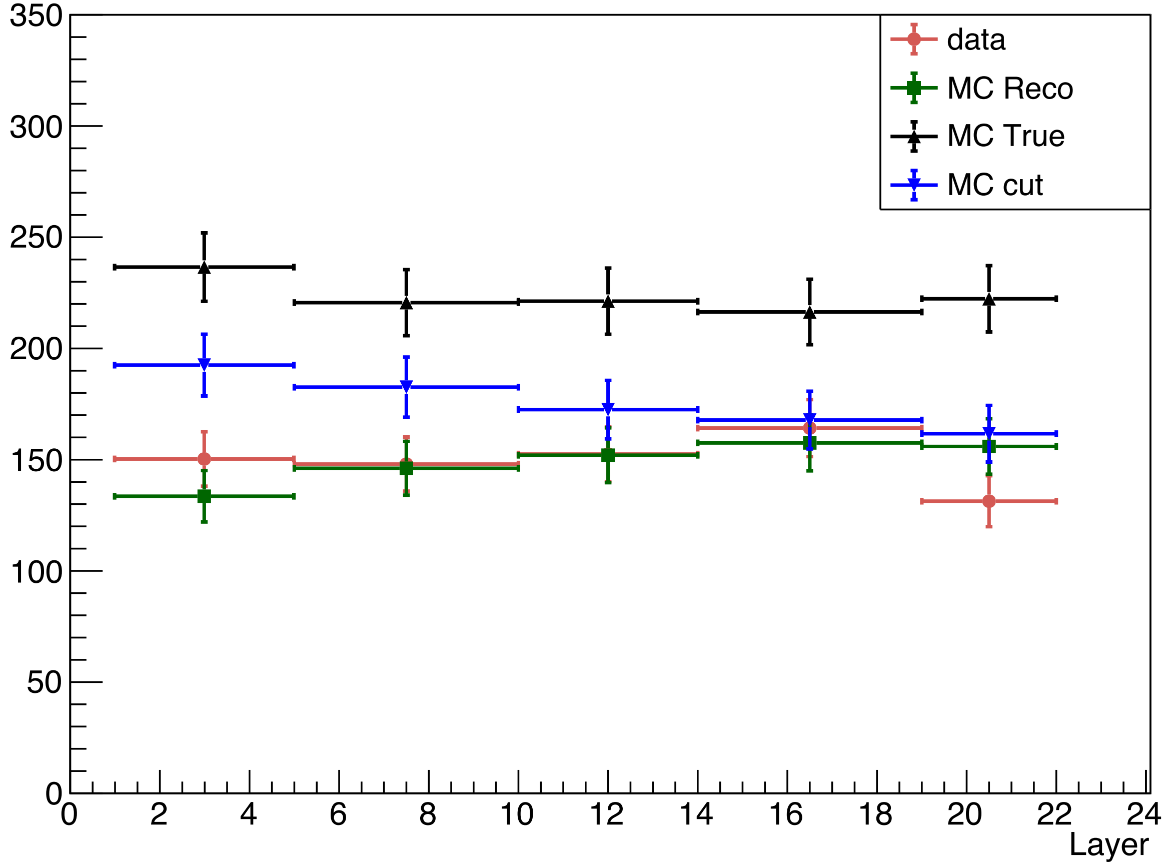
$$\blacktriangledown = \; = \frac{RMC}{MC_{True}} = \epsilon_{reco_i}$$

MEAN vertices per plate

C TARGET

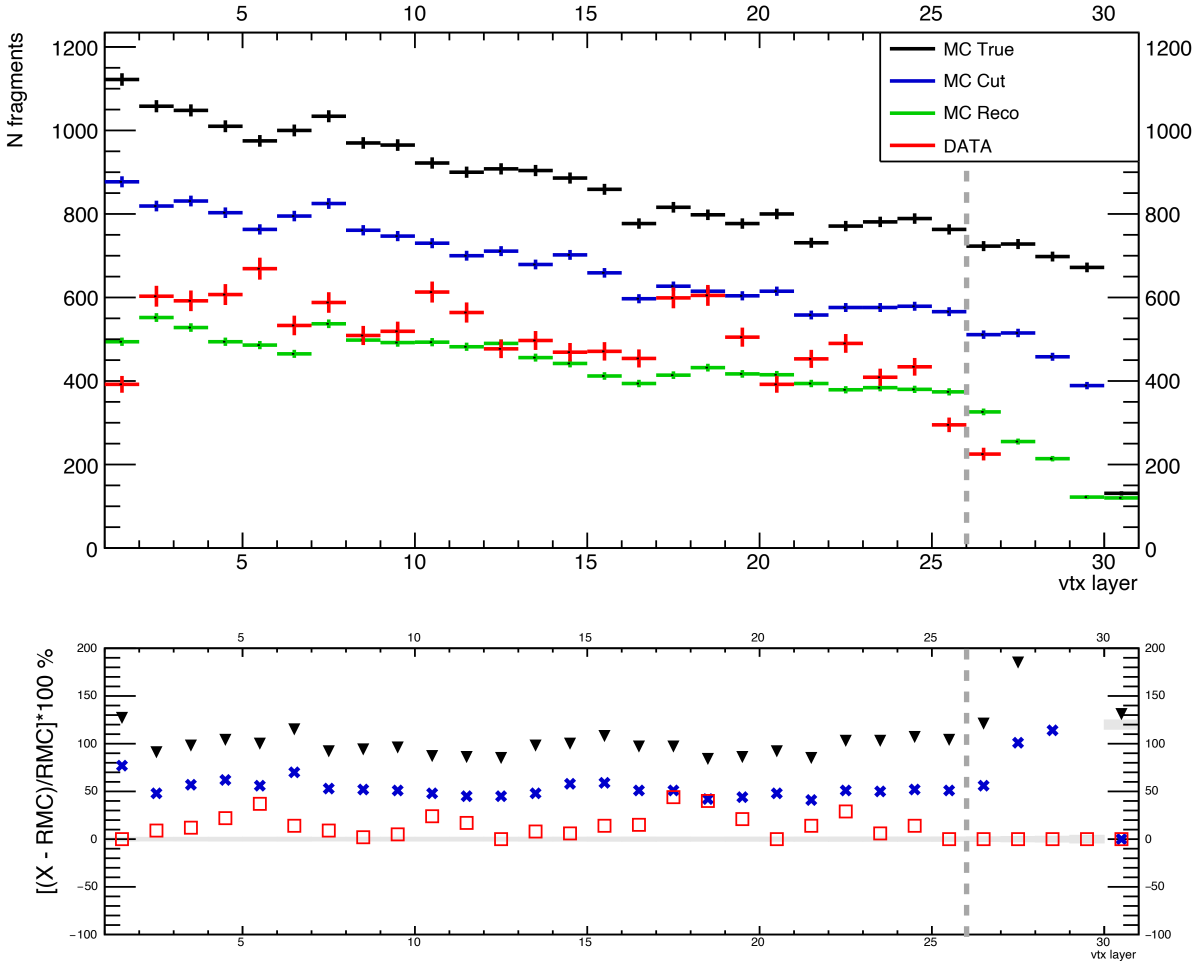


C_2H_4 TARGET

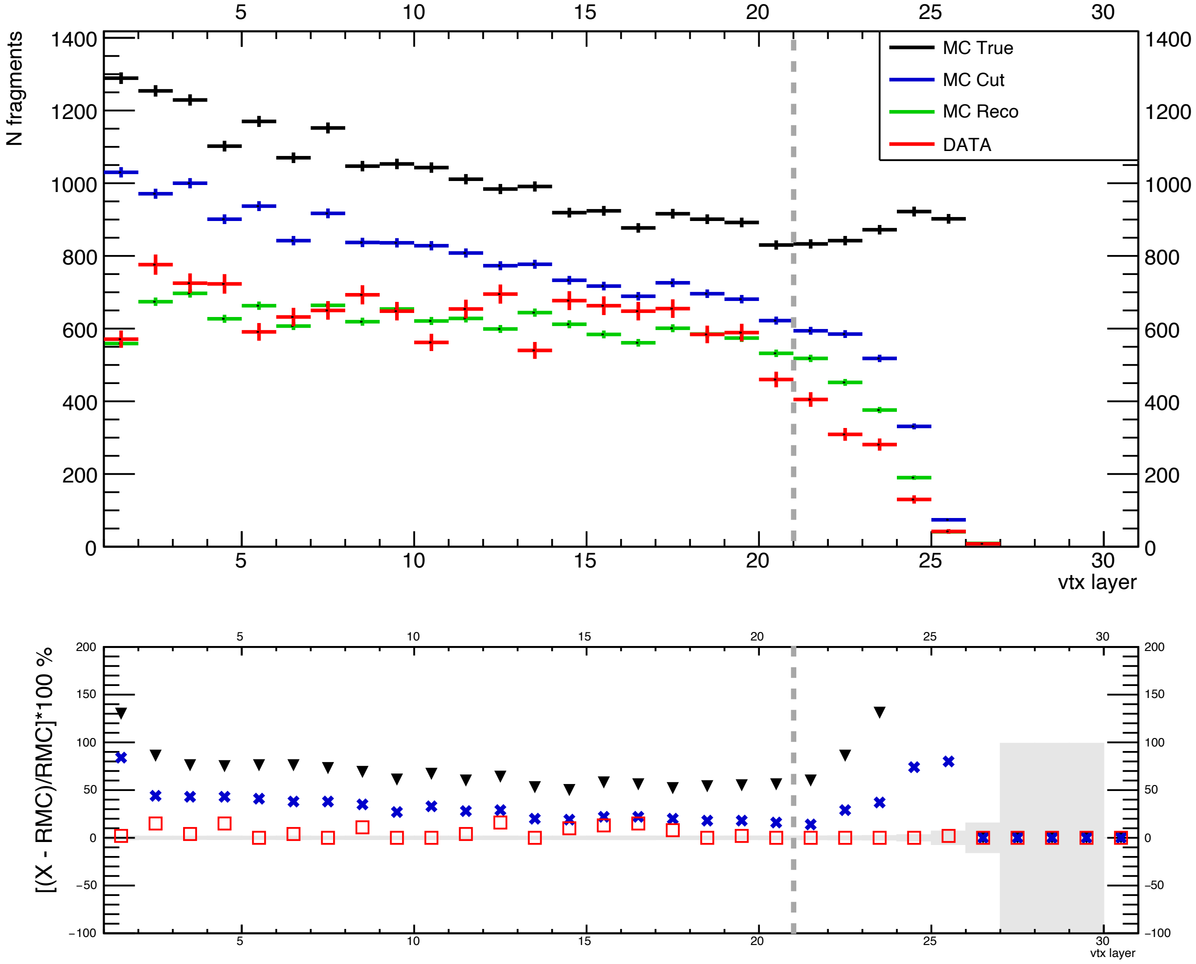


Number of produced fragments per plate

C TARGET

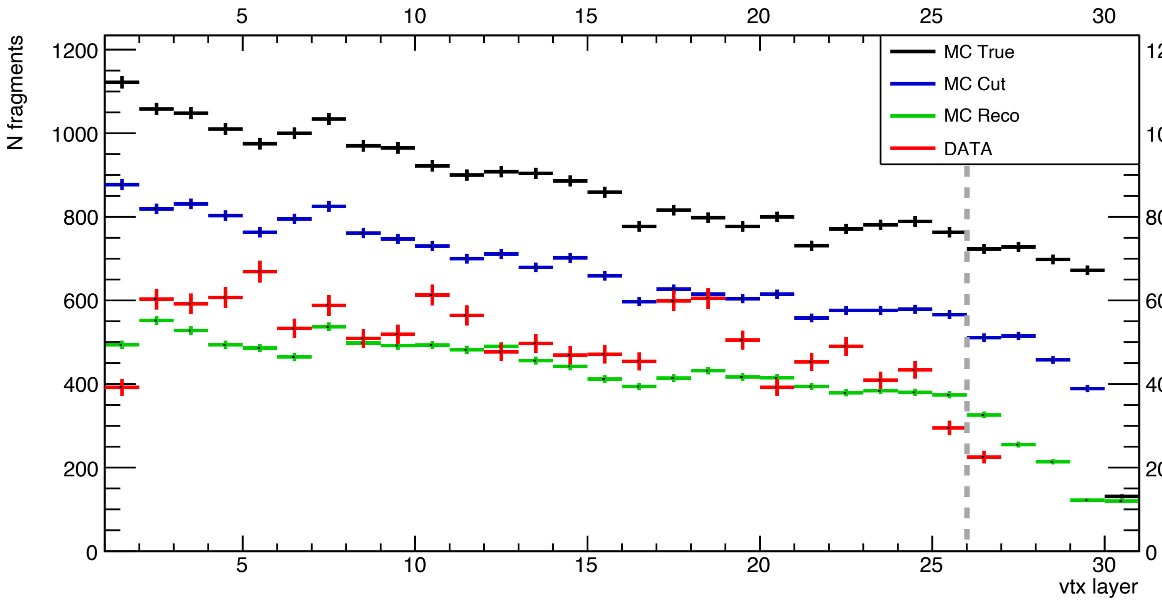


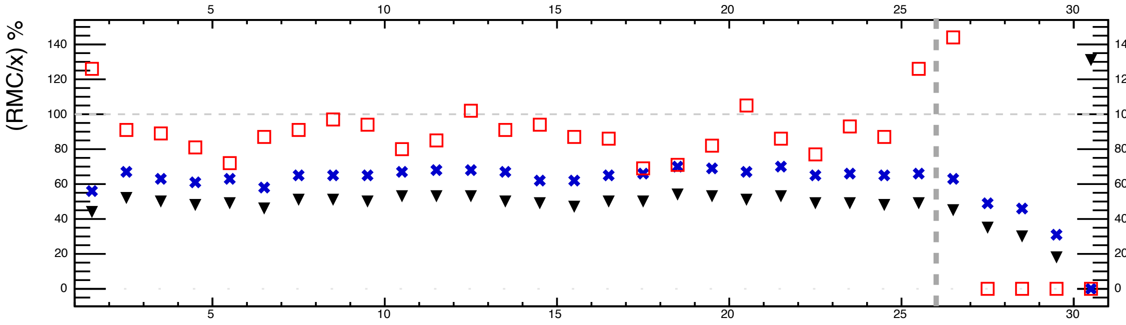
C_2H_4 TARGET



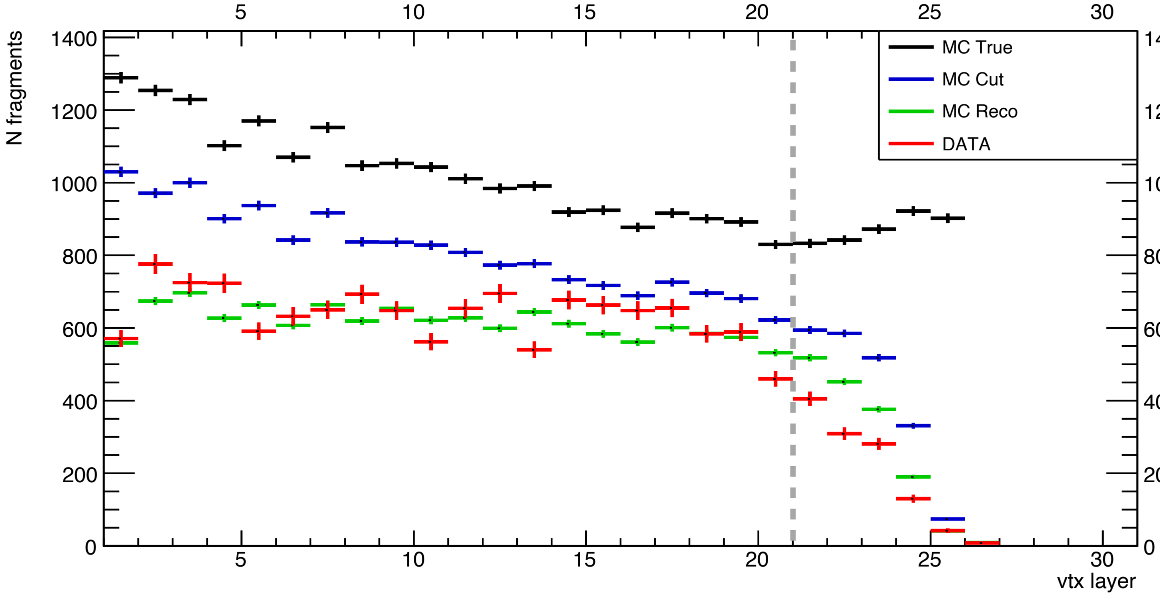
Number of produced fragments per plate

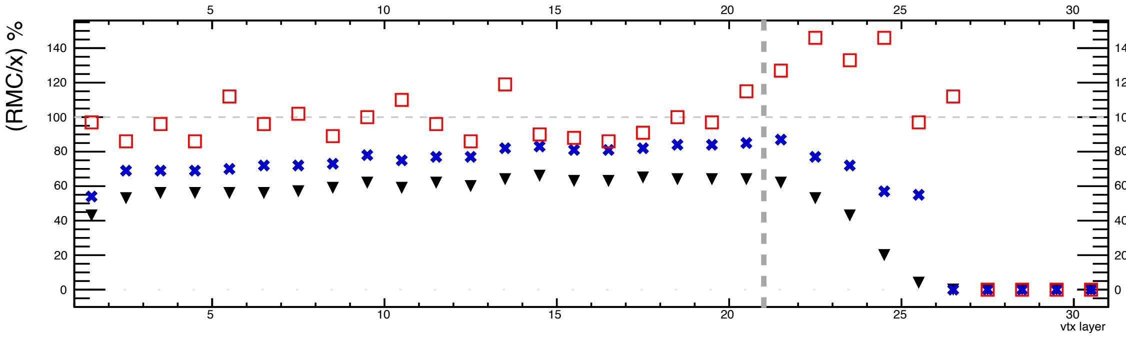
C Target





C_2H_4 Target

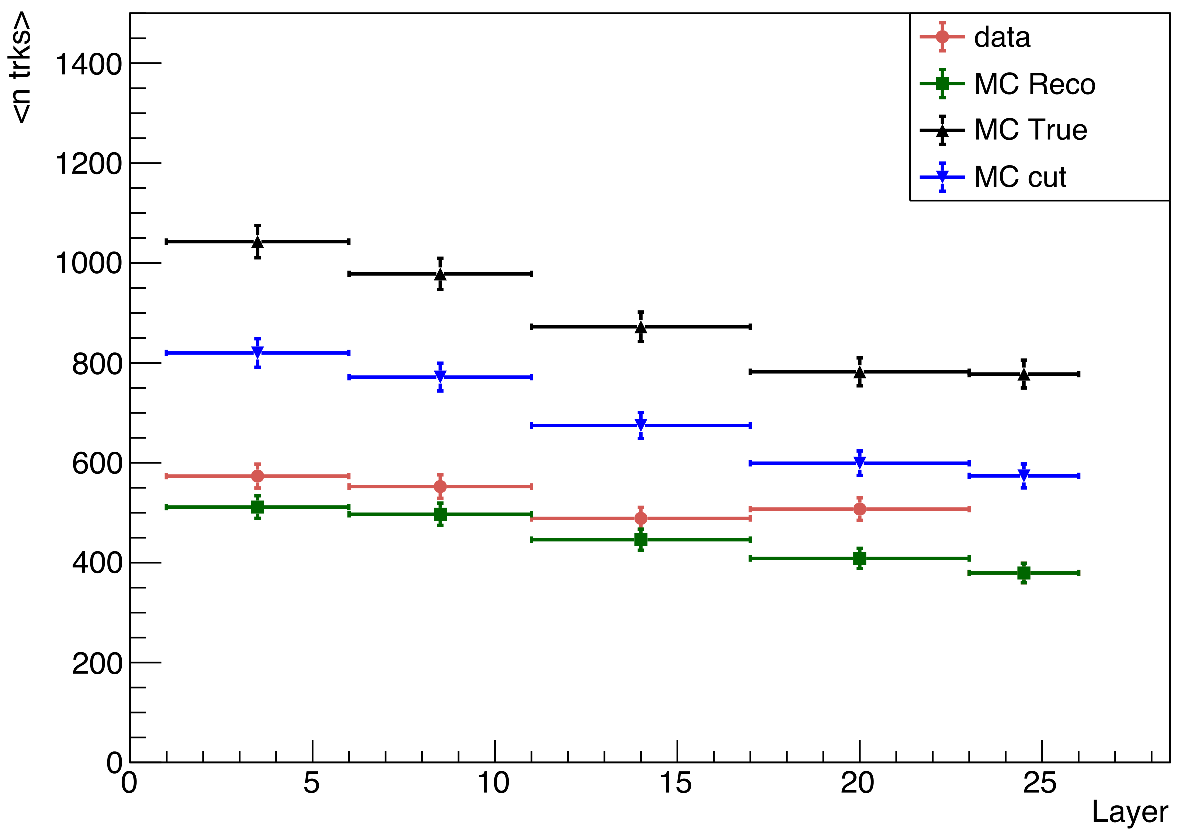




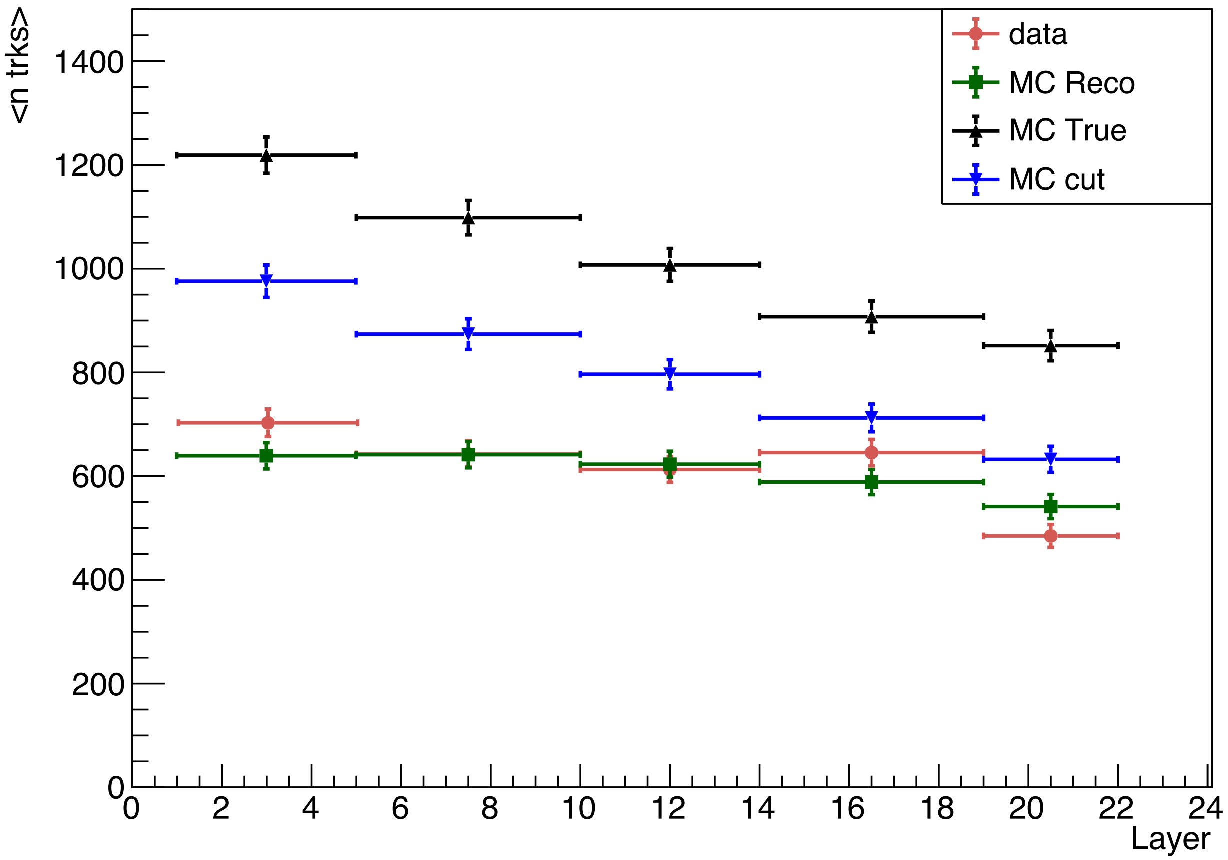
$$\blacktriangledown = \frac{RMC}{MC_{True}} = \epsilon_{reco_i}$$

MEAN produced fragments per plate

C Target

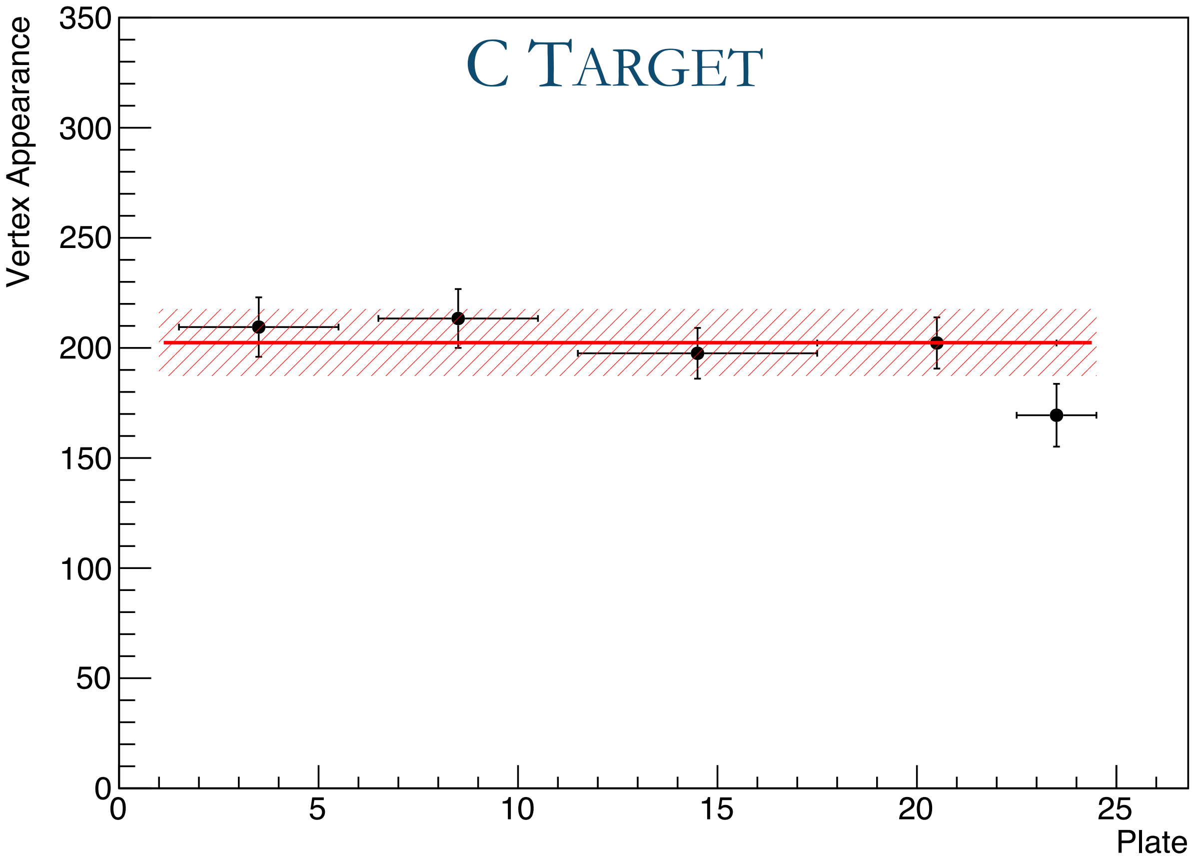


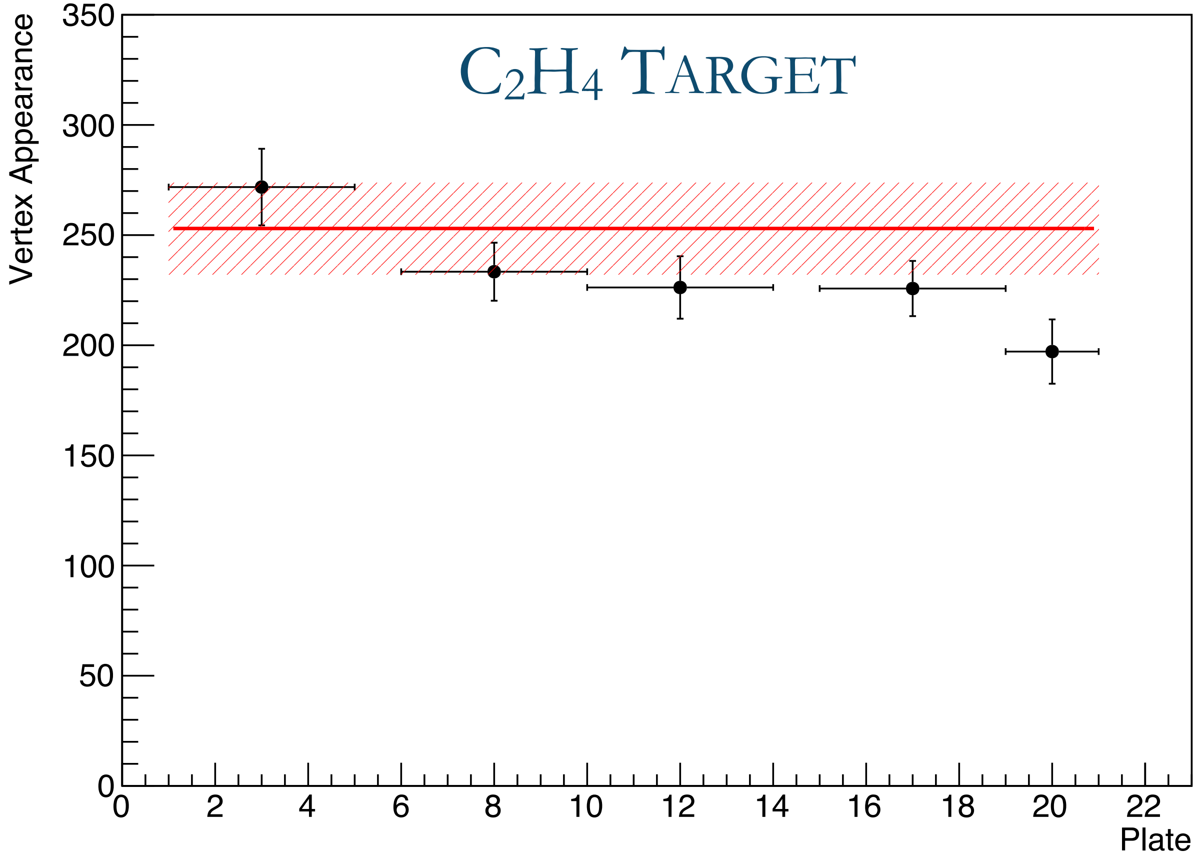
C_2H_4 Target



Beam disappearance vs reconstructed vertices

- Comparison of the number of disappearing beam oxygens and the number of reconstructed vertices(*)
- Double check for cross section with **completely independent methods** (different scan, different reconstruction…)
- errors in the plot = 1σ
- Maybe a systematic error can be derived from this comparison?





* vertices in the nuclear emulsion film considered in this sample

Cross section evaluation

Error evaluation

Y = counting

$N_b = p_0 + p_1 x$

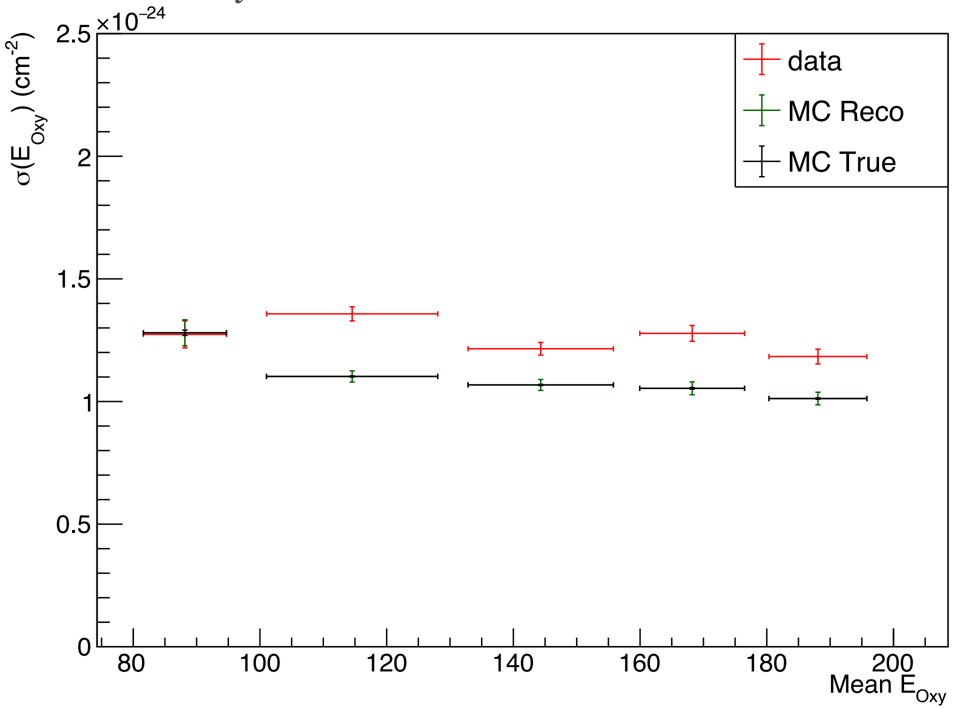
$\epsilon = \dfrac{RMC}{MC}$ (counting)

$$\sigma_i|_{C\ or\ C_2H_4} = \frac{Y_i}{N_{B_i} N_{TG_i} \epsilon^i_{reco}}$$

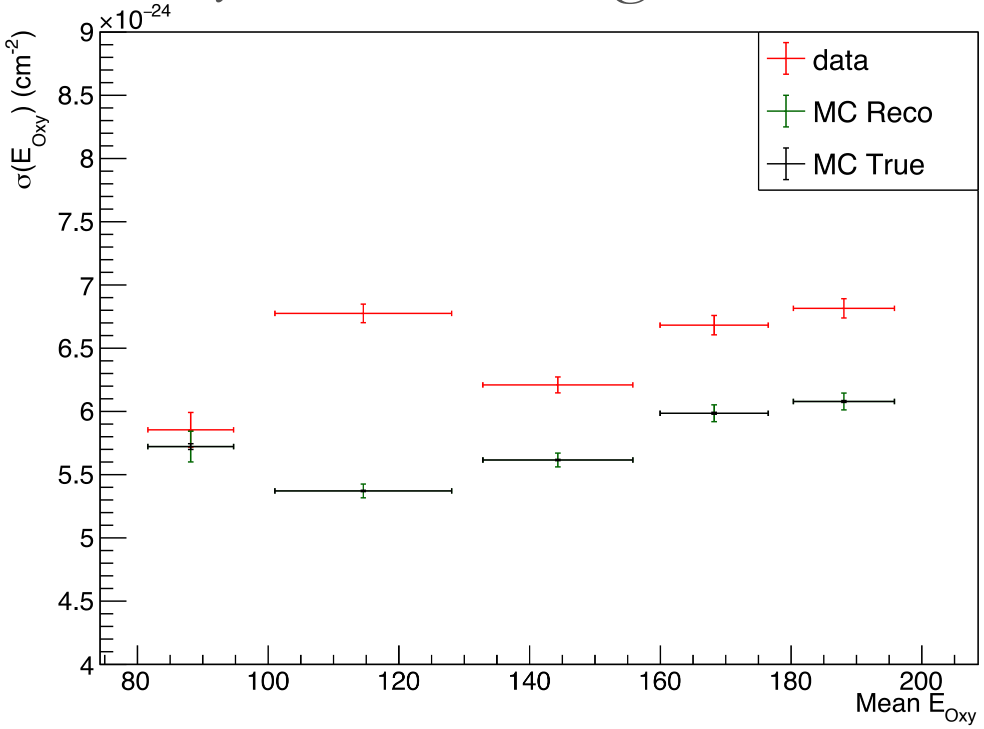
$$\text{sigma}_\sigma = \sqrt{\left(\frac{1}{N_B N_{TG}\epsilon}\right)^2 Y + \left(\frac{Y}{N_B^2 N_{TG}\epsilon}\right)^2 (\sigma_{p0}^2 + x^2\sigma_{p1}^2) + \left(\frac{Y}{N_B N_{TG}\epsilon^2}\right)^2 \left(\frac{1}{MC^2} RMC + \left(\frac{RMC}{MC^2}\right)^2 MC\right)}$$

Total reaction and production cross section on C

$Y_i = <\#\ \text{of vertices}>$



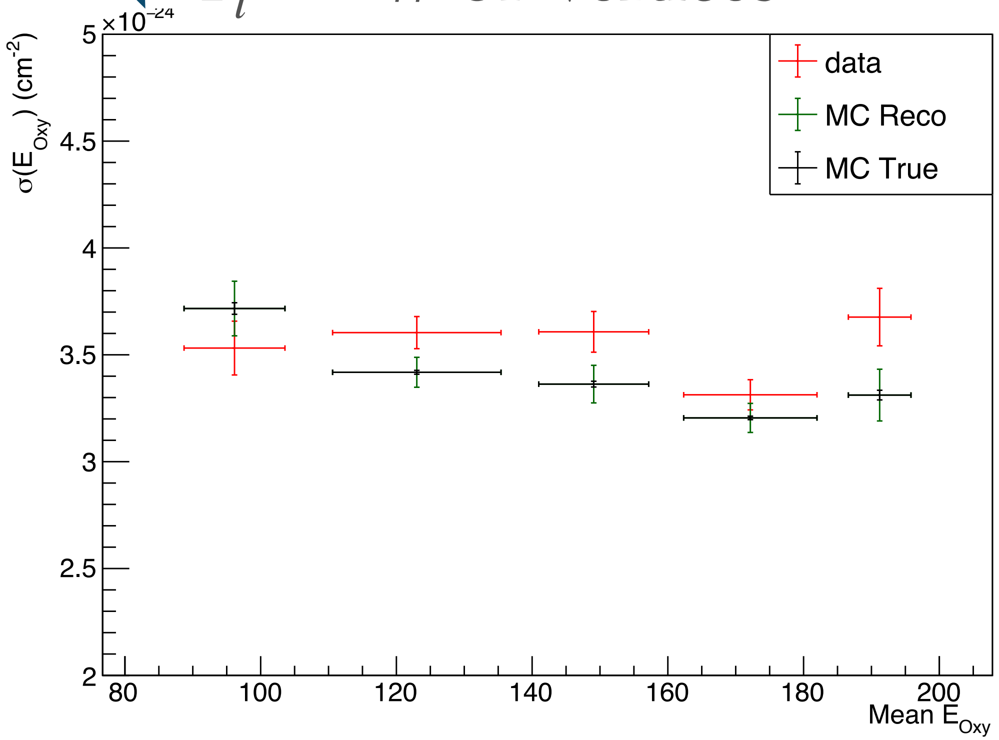
$Y_i = <\#\ \text{of fragments}>$



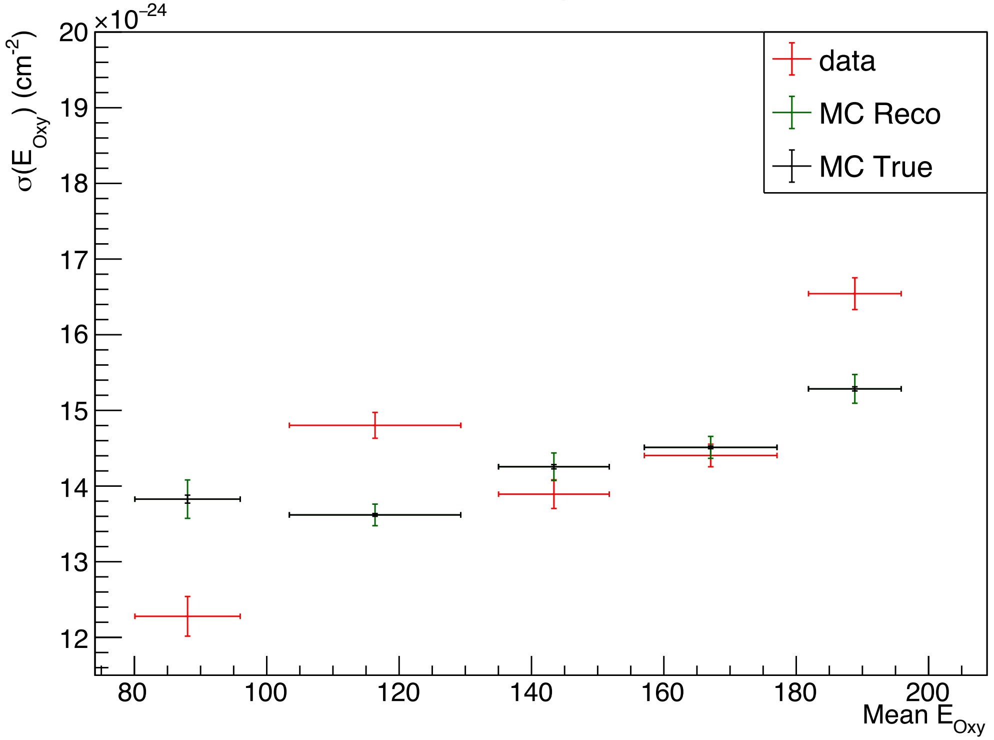
	Projectile Ekin (MeV/n)	Cross section
Yamaguchi 2011	288	852 ±17
Zeitlin 2011	290	863 ±20
Zeitlin 2011	400	842 ±22

Total reaction and production cross section on C_2H_4

$Y_i = \langle \#\ \text{of vertices} \rangle$



$Y_i = \langle \#\ \text{of fragments} \rangle$

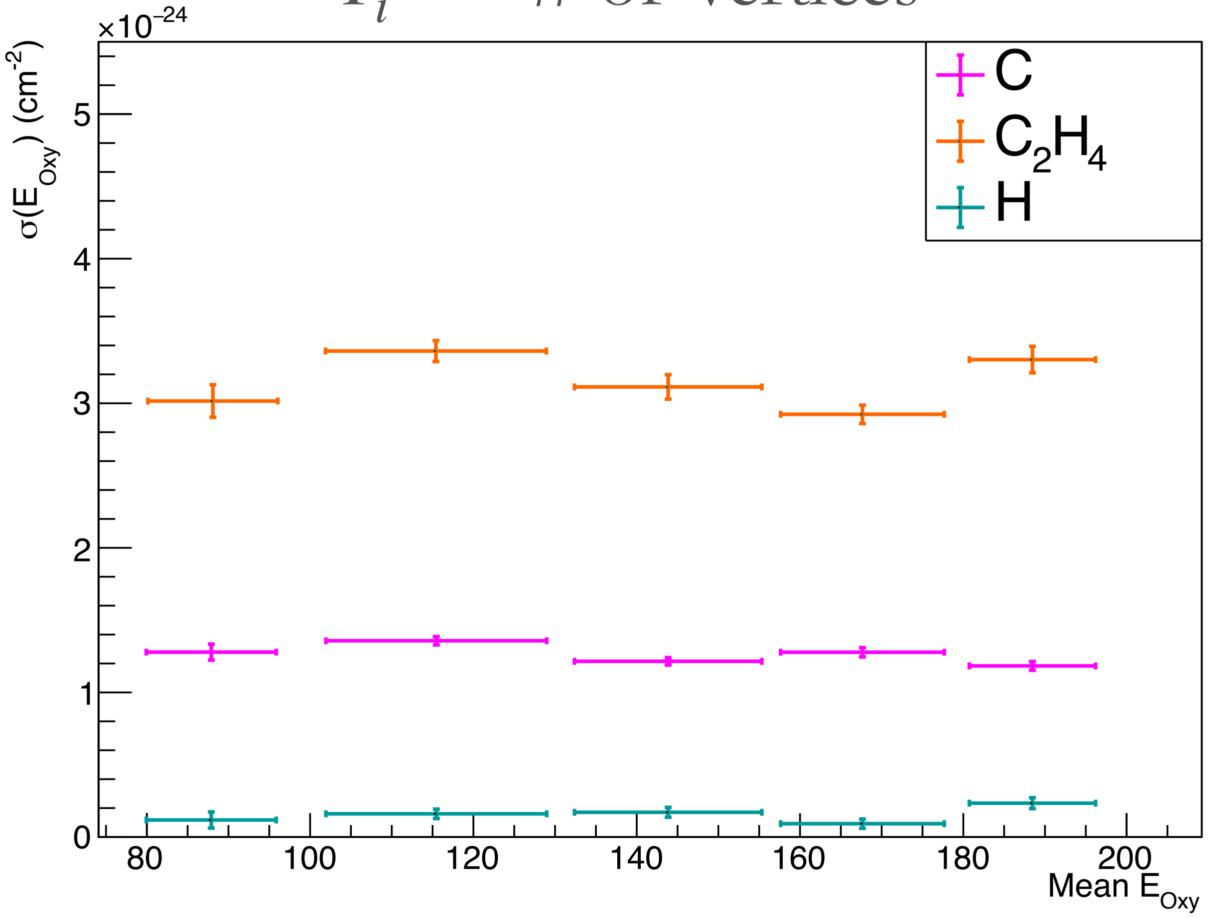


	Projectile Ekin (MeV/n)	Cross section on CH_2
Webber 1990	441	1260 ±13
Webber 1990	591	1316 ±13
Webber 1990	669	1328 ±13

Integrated cross section H

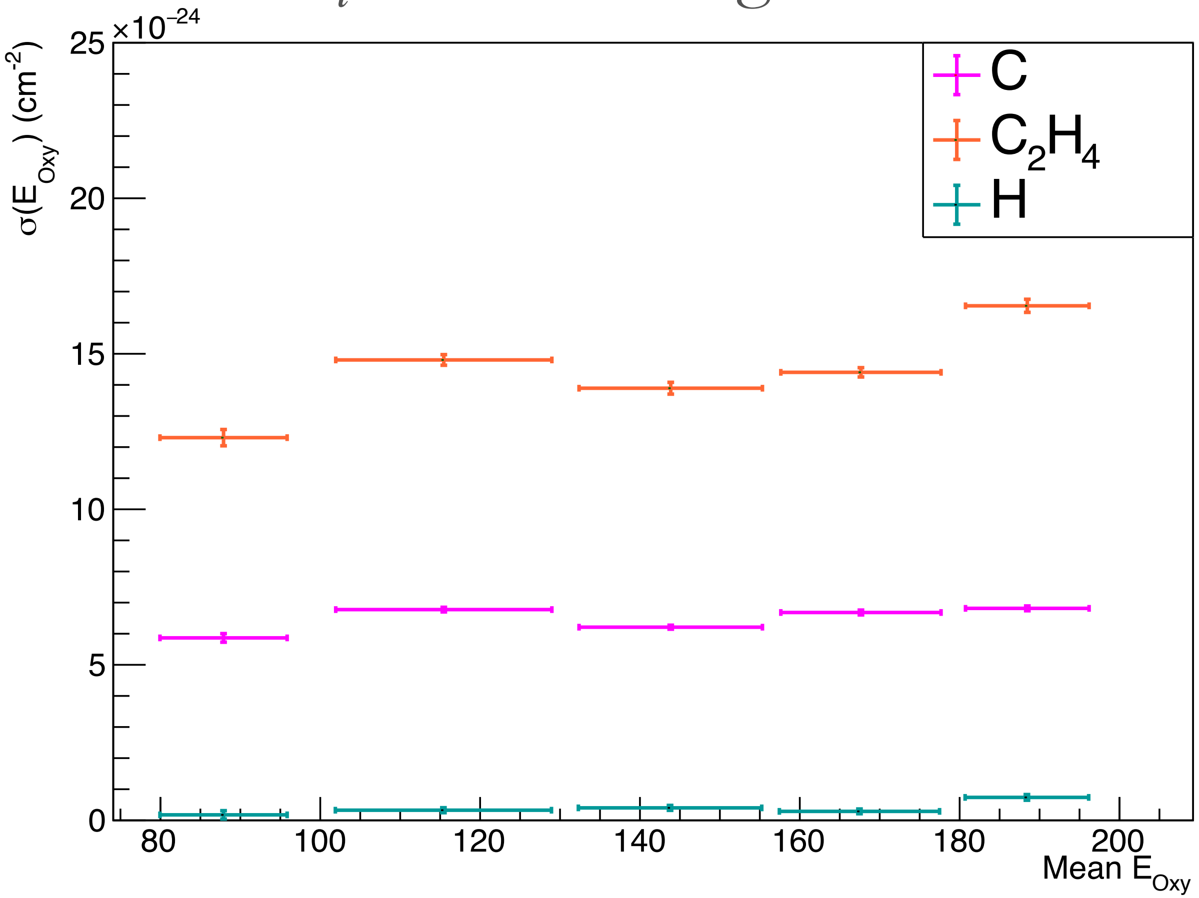
Total reaction cross section

$Y_i = <\# \text{ of vertices}>$

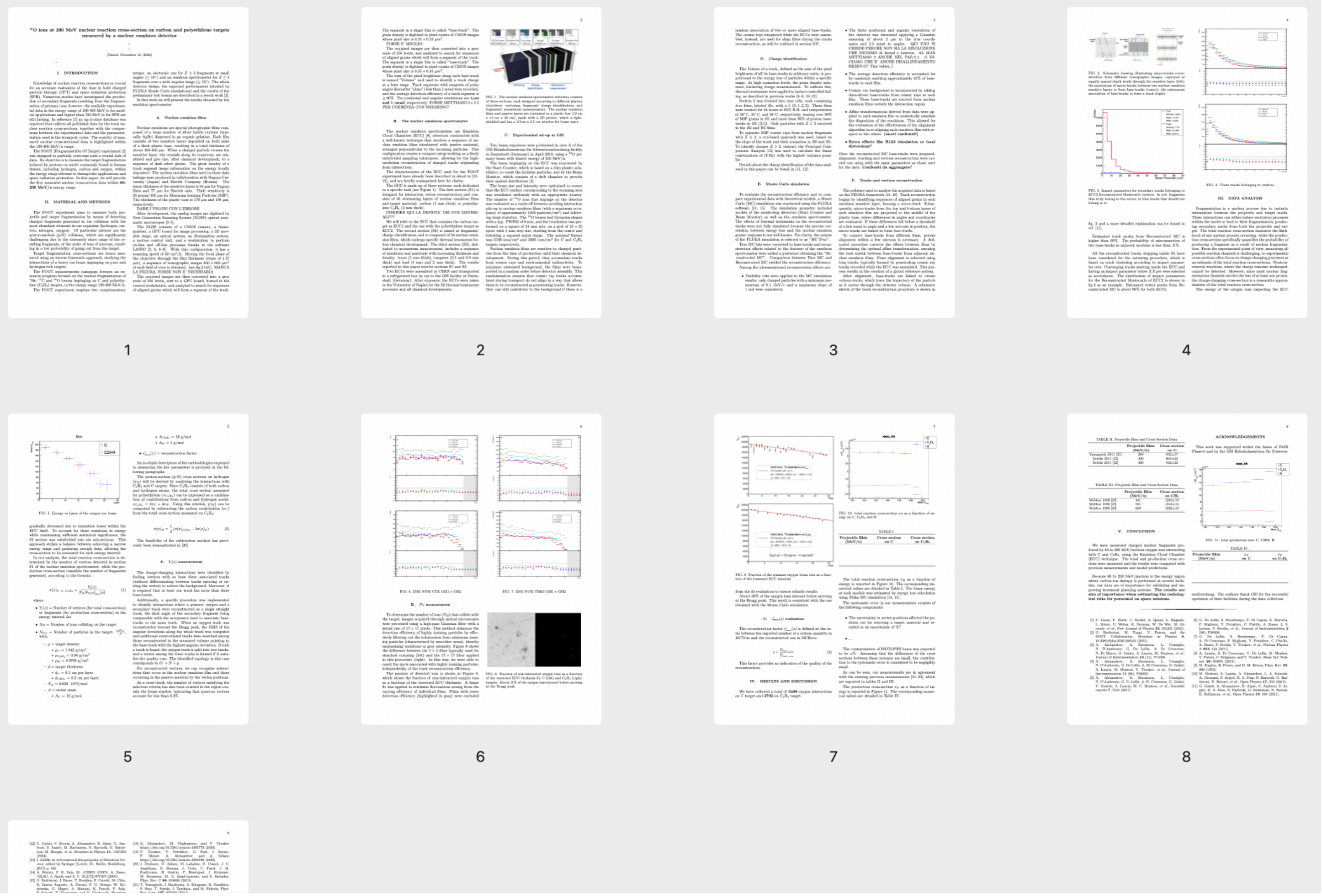


Total production cross section

$Y_i = <\# \text{ of fragments}>$



New article almost completed!



To be submitted on **Physical Review C** (2023 IF: 3.2)

I. Introduction

II. Material and methods

- A. Nuclear emulsion films
- B. The nuclear emulsions spectrometer
- C. Experimental set-up at GSI
- D. Charge identification
- E. Monte Carlo simulation
- F. Tracks and vertices reconstruction

III. Data analysis

- A. Y_i measurement
- B. N_{B_i} measurement
- C. ϵ_{reco_i} evaluation

IV. Results and discussion

V. Conclusion

Conclusions

Improvements:

- New strategy to count the number of beam ions
- C density measurement
- New MC production for C target (100k)
- Errors evaluation

Oxygen @ 200 MeV/n on C and C_2H_4 Cross Section Measurement

To do:

- Systematics evaluation
- **Final checks and new publication soon**

THANK YOU!