Z and A reconstruction with MC simulations in GSI2021 setup

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Introduction

- There are several questions to answer before going to GSI:
  - How many primaries do we expect to use for the next physics run?
  - How to divide them over the 2 targets? Should we collect the same amount of statistics for both targets? Not a priori clear, since **targets have different densities and cross sections, and cross section on H is obtained through subtraction**

- In order **to optimize data taking at GSI with 2 targets**, we have to keep in mind:
  - The cross section subtraction technique
  - The limited amount of time available

- Last time: Reco results with ^{12}C beams and preliminary MC truth results with ^{16}O beams

- **TODAY: update of analysis with ^{16}O beams**
  - Issues about needed statistics to be collected (see also todays' presentations by Roberto's and Giuseppe)
  - A-reconstruction by ToF and Calo measurements: some things to consider

- WARNING: results here should be seen as just a first look and not well checked

CNAO2020 setup: MC statistics used for evaluation

MC statistics used for evaluation

- ^{16}O at 200 MeV/u on C
  - Triggered
  - 10^6 primaries
  - 37721 events in file
  - 5 mm C target
  - rho=1.83 g/cm3)

- ^{16}O at 200 MeV/u on C2H4
  - Triggered
  - 27677 events in file
  - 10^6 primaries
  - 5 mm C target
  - rho=0.94 g/cm3

- ^{16}O at 400 MeV/u on C
  - triggered
  - 10^6 primaries
  - 36093 events in file
  - 5 mm C2H4 target
  - rho=1.83 g/cm3)

- ^{16}O at 400 MeV/u on C2H4
  - Triggered
  - 27900 events in file
  - 10^6 primaries
  - 5 mm C2H4 target
  - rho=0.94 g/cm3

All files: triggered events: inelastic interaction in target

Cross section formulas

- Reminder: cross section for production of fragments ***i*** on target (neglecting efficiency factors)

$$\sigma_{i,t} = \frac{Y_{i,t}}{N_p} \frac{A_t}{N_A\, \rho_t\, \delta_t} \quad \textbf{(1)}$$

With:
$\sigma_{i,t}$ = cross section to produce fragment i on target t [cm^2]
$Y_{i,t}$ = Number of fragments of type i [ ]
A_t = molecular mass of target [g mol^{-1}]
N_p = number of primary particles [ ]
N_A = Avogadro's number [mol^{-1}]
ρ_t = density of target [g cm^{-3}]
δ_t = thickness of target [cm^{-1}]

- This CNAO data taking:
    - C beam on C target
    - C beam on C_2H_4 target

$$\sigma_{i,C} = \frac{Y_{i,C}}{N_p} \frac{A_C}{N_A\, \rho_C\, \delta_C} \quad \textbf{(1a)}$$

$$\sigma_{i,C_2H_4} = \frac{Y_{i,C_2H_4}}{N_p} \frac{A_{C_2H_4}}{N_A\, \rho_{C_2H_4}\, \delta_{C_2H_4}} \quad \textbf{(1b)}$$

$$\sigma_{i,H} = \frac{1}{4}\left(\sigma_{i,C_2H_4} - 2\sigma_{i,C}\right) \quad \textbf{(2)}$$

- **What we did: derived formulas for cross section errors and relative errors analytically to have a-priori estimates, and then verified them with MC simulations with $N_p=10^6$ primaries: oxygen**

Fragment production from ^{16}O @200 MeV/u: yields

Z of fragment i	$Y_{i,C}$	Y_{i,C_2H_4}	$\frac{Y_{i,C}}{Y_{i,C_2H_4}}$
1	24802	16789	1.48
2	31189	23290	1.34
3	3692	2624	1.41
4	1742	1276	1.37
5	2074	1783	1.16
6	4104	4197	0.98
7	5054	4340	1.16
8	3042	3403	0.89

Starting with $N_p=10^6$, how many have inelastic interactions?
From MC simulations:
- Carbon: about 3.8%
- Ethylene: about 2.8%

- **These yields from MC are roughly in accordance with what we found for ^{12}C**
- More fragments expected for carbon target than for polyethylene target (remember A and rho!!)
- Ratio between C yield and C_2H_4 yield varies with Z

Fragment production from 12C @200 MeV/u: relative errors

- If N_p for the C_2H_4 target = N_p for the C target, we obtain:

$$\frac{\Delta\sigma_{i,H}}{\sigma_{i,H}} \sim \frac{1.08}{0.33}\frac{\Delta\sigma_{i,C}}{\sigma_{i,C}} \sim 3.3\frac{\Delta\sigma_{i,C}}{\sigma_{i,C}}$$

- The numbers in second and third column are larger than what we derived from ^{12}C. This is just because we ran on 10^6 events instead of 10^7!!
- Fourth column is in accordance with what we derived analytically
- Same conclusion as for ^{12}C: relative error on H target is large

Z of fragment i	$\frac{\Delta\sigma_{i,H}}{\sigma_{i,H}}$	$\frac{\Delta\sigma_{i,C}}{\sigma_{i,C}}$	$\frac{\Delta\sigma_{i,H}}{\sigma_{i,H}} / \frac{\Delta\sigma_{i,C}}{\sigma_{i,C}}$
1	2.50	0.63	3.9
2	1.79	0.57	3.2
3	5.79	1.65	3.5
4	7.89	2.40	3.3
5	5.37	2.19	2.4
6	2.96	1.56	1.9
7	3.45	1.41	2.5
8	3.06	1.81	1.7

- If doubling N_p for the C_2H_4 target w.r.t. C target, we obtain:

$$\frac{\Delta\sigma_{i,H}}{\sigma_{i,H}} \sim 2.5\frac{\Delta\sigma_{i,C}}{\sigma_{i,C}}$$

- If 4 times N_p for the C_2H_4 target we obtain:

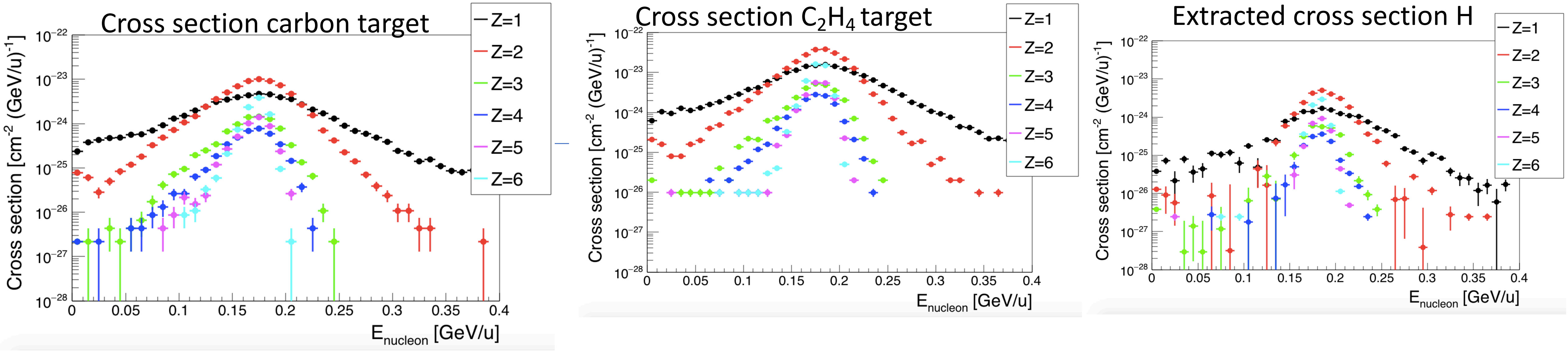
$$\frac{\Delta\sigma_{i,H}}{\sigma_{i,H}} \sim 2.1\frac{\Delta\sigma_{i,C}}{\sigma_{i,C}}$$

probably **doubling N_p for the C_2H_4 target w.r.t. C target is enough**

Fragment production from ^{16}O@200 MeV/u: cross section

So, let's derive the cross sections for the case where we have:

- C target: 10^6 primaries
- C_2H_4 target: 10^6 primaries



- C_2H_4 cross section is largest.
- Errors: heavier fragments have large errors

What numbers do we expect at GSI?

- Assume that we take data at low intensity: about 1000 primaries/s in the spill → given that the duty cycle is 50%, about 500 primaries/s
- Firing 10^7 primaries would take $10^7/500$ s, i.e., 5.5 hours… (shift is about 8 hours)
- As said before , run with C_2H_4 target with double number of primaries

N_p for C target	N_p for C_2H_4 target	Total estimated run time
5×10^6	**10^7**	**2.7+5.5~8.2 $\gtrsim$ 8 hours: ok**

- Summarizing:
  - we need more primaries for the C_2H_4 target than for the C target
  - Given the slow decrease of the error on $\frac{\Delta\sigma_{i,H}}{\sigma_{i,H}}$, probably for a given energy we can point at $n*10^6$ primaries of C and $2n*10^6$ for C_2H_4 , preferably with n not too far away from 5.
  - Or double target thickness (see Giuseppe's presentation)
  - Largest relative errors on cross sections for larger Z (say Z≥3)

Isotope Identification and A reconstruction: overview

See physics meeting May 5

Goal is to do a combined TW+Calorimeter analysis in order to extract

- A reconstructed vs A true: how good are we in detecting a given fragment with true mass A ?
- Z reconstructed vs Z true: how good are we in detecting a given fragment with true charge Z?

MC **truth** TW analysis:
Evaluate bars fired in each event, dE
TOF, A truth, Z truth

MC **truth** Calo analysis:
Evaluate crystals fired in each event and what energy

MC **local reco** TW analysis:
Evaluate bars fired in each event, dE
TOF, Z reco

MC **local reco** Calo analysis:
Evaluate crystals fired in each event and what energy

A_{true} and Z_{true} in "good" TW positions, i.e., TW positions with a crystal behind it

A_{reco} and Z_{reco} in "good" TW positions, i.e., TW positions with a crystal behind it

COMPARE event per event in a fired (true) position

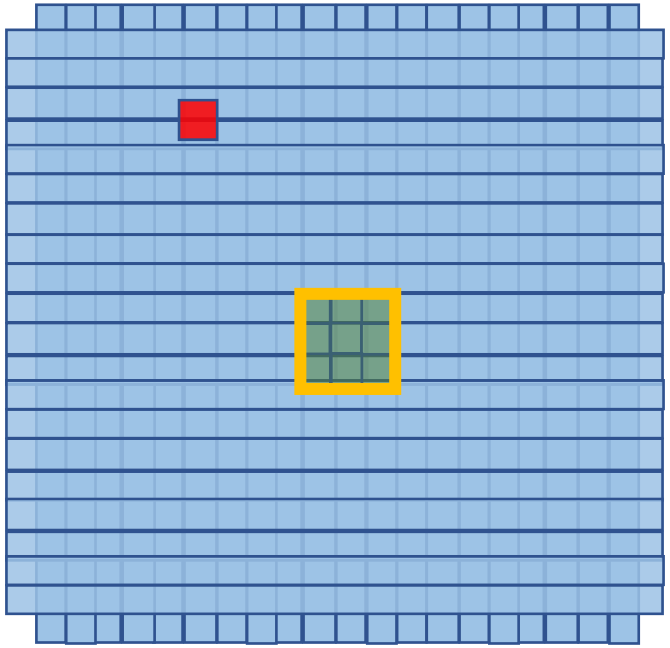
Analysis MC local reco

See physics meeting May 5

- Determine energy and TOF in front and rear bars starting **from TWpoints.**
- Select only positions (a crossing between a front and a rear bar) that are associated with bars with:
  - >=1 MeV in Front bar**: fired bar**
  - >= 1 MeV in rear bar**: fired bar**
- Verify for that position the front-rear consistency:

$$\frac{|E_F - E_R|}{(E_F + E_R)/2} < 0.05$$

- If position passes, call it '**fired position**'
- For 'good' positions (calorimeter behind), evaluate associated calorimeter deposit (see next)
- Store a global event reconstructed value for A and Z for that position
  - Makes only sense when 1 fragment passes per position (see slice 10)



- **Z**: estimate from Bethe-Bloch formula (good cross check for TOF and DeltaE calibration!!)
- **A**: reconstruct it from
  - Strictly speaking, should be Gamma in calorimeter
- Look in more detail at Z and A formulas

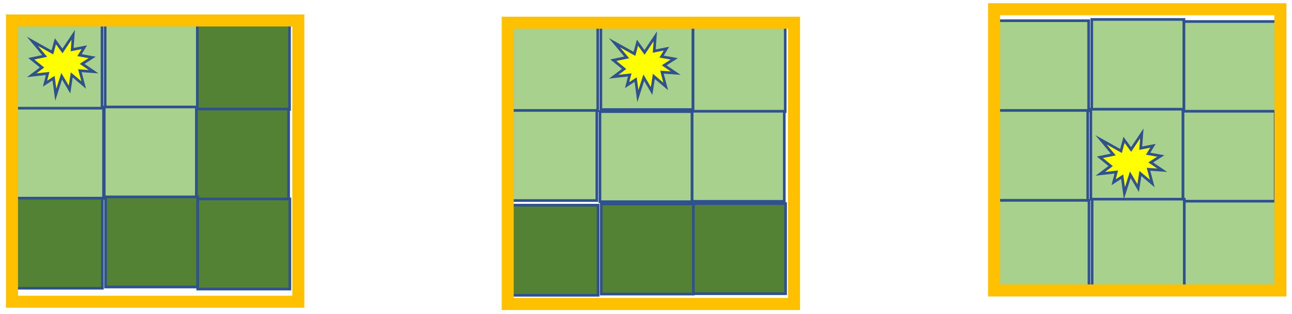
$$A = \frac{E_{calo}}{931.5(\gamma - 1)}$$

Analysis to obtain calorimeter deposits

See physics meeting May 5

- MC reco:
  - Starting from Clusters, in each event fill 9 crystals (threshold 10 MeV)
  - Checked for a fired TW position which crystals can be associated to it (neighbours), examples below
  - Sum the energy of the associated crystals in each event
  - Threshold 10 MeV (tested various thresholds)
  - Then we have for a given ‘good’ TW position the calorimeter energy

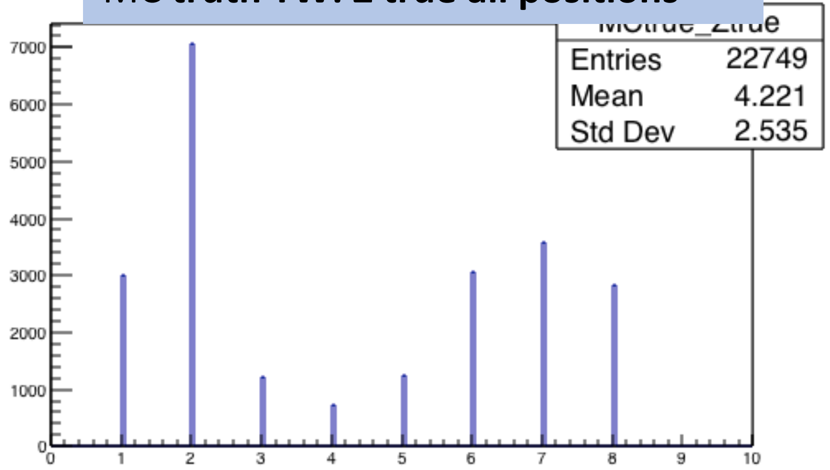
- Same for MC truth but started from TAMCntuhit



MC truth: Z in TW (all positions)

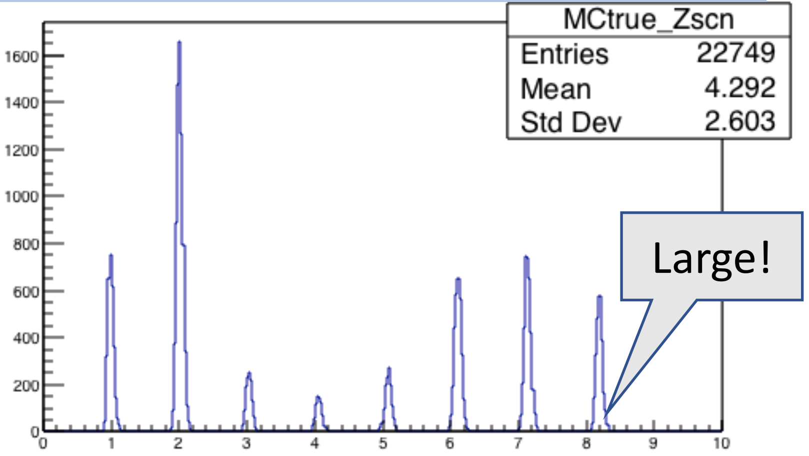
True Z

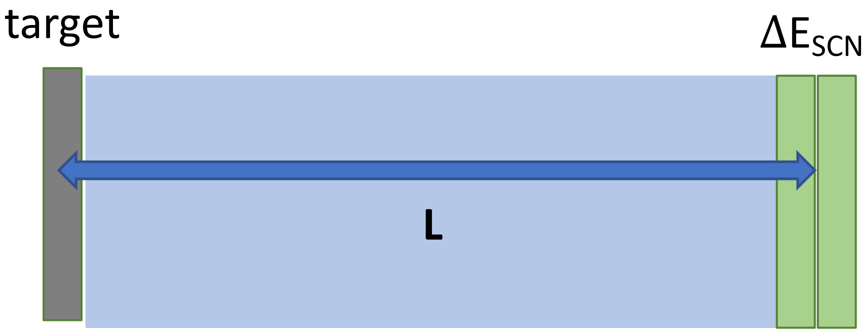
MC **truth TW: Z true all positions**



- Evaluate ΔE_{SCN}
- Evaluate beta from L/TOF
- Z from Bethe Bloch: f(ΔE_{SCN} , beta)
- Only intrinsic physics uncertainties

MC **truth TW: Z from BB without correcting**



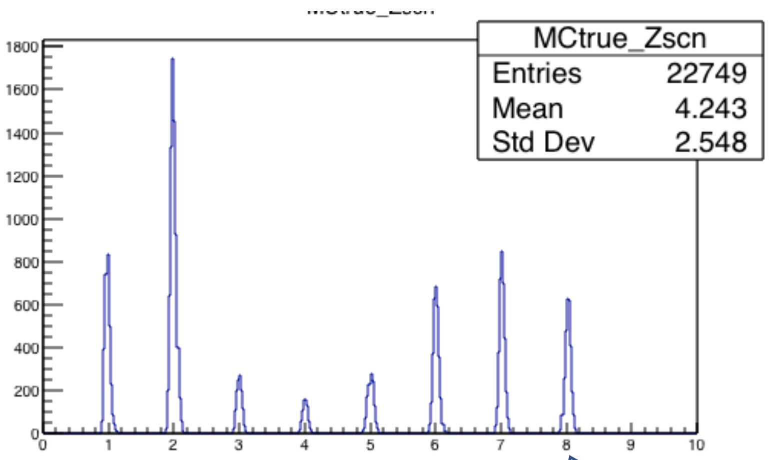


beta=L/TOF gives average velicity somewhere in air between target and TW, but in reality beta is smaller at TW entrance in front plane, and even smaller at entrance in rear plane!! → overestimation (especially at high Z)

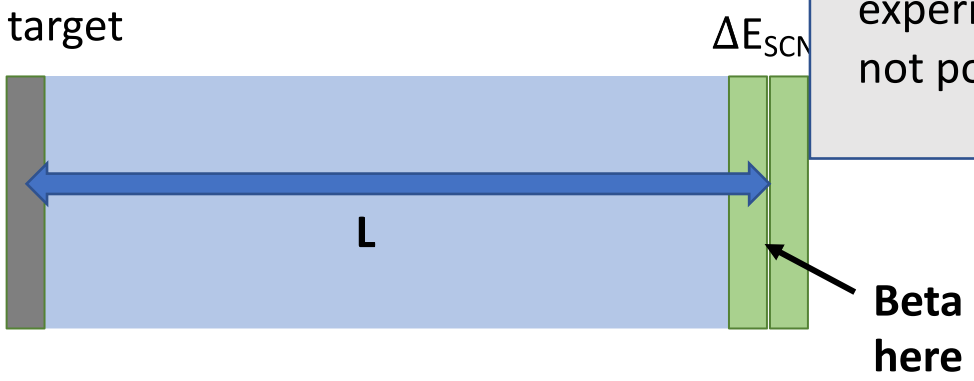
MC truth: Z in TW (all positions)

- Evaluate ΔE_{SCN}
- Evaluate true beta in **at exit of first TW plane**
- Z from Bethe Bloch
- Only intrinsic physics uncertainties

MC **truth TW: Z with beta at the front exit: perfect situation**

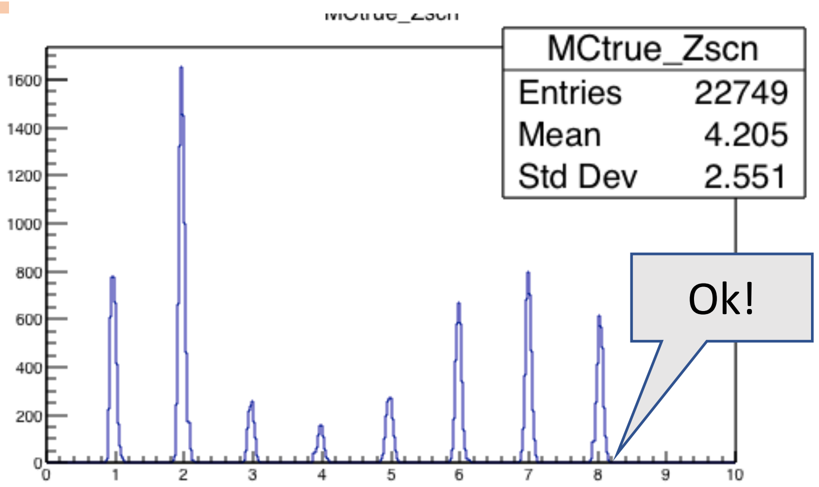


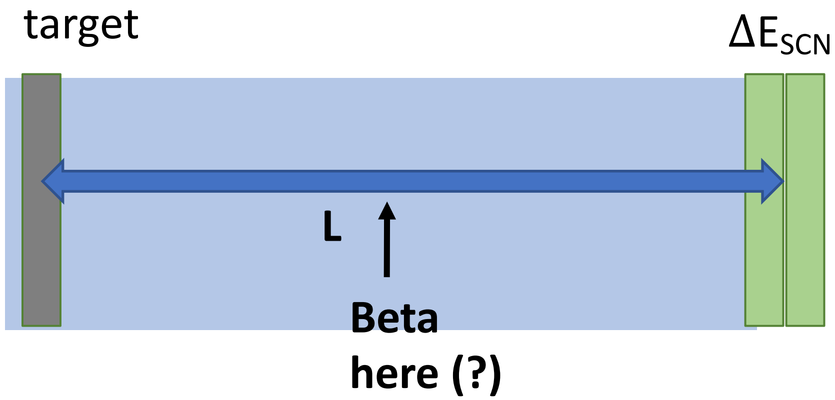
Now ok… But experimentally not possible!



MC **truth TW: Z with beta from L and TOF, but energy loss corrected**

- Evaluate ΔE_{SCN}
- Evaluate beta from L/TOF
- **Add correction for energy lost in air**
- Z from Bethe Bloch
- Only intrinsic physics uncertainties



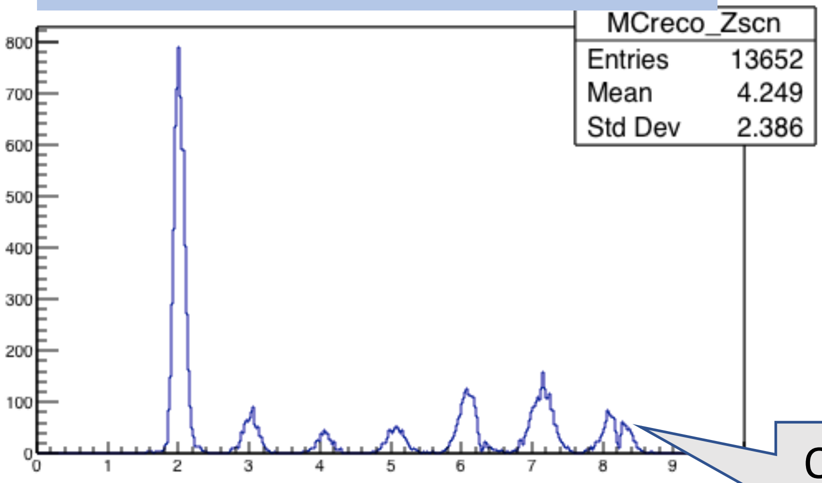


Should add energy lost in air

MC reco: Z (all positions)

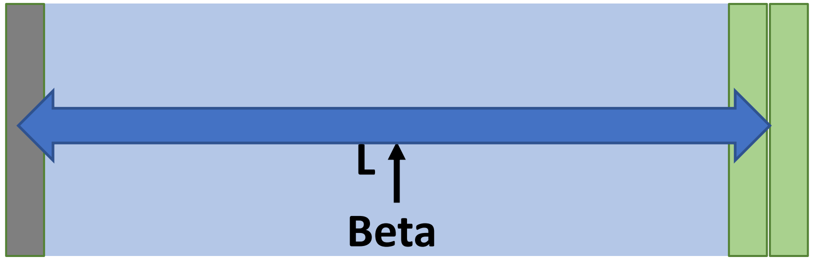
MC **reco TW: Uncorrected Z**

- Evaluate ΔE_{SCN}
- Evaluate beta from L/TOF
- Z from Bethe Bloch



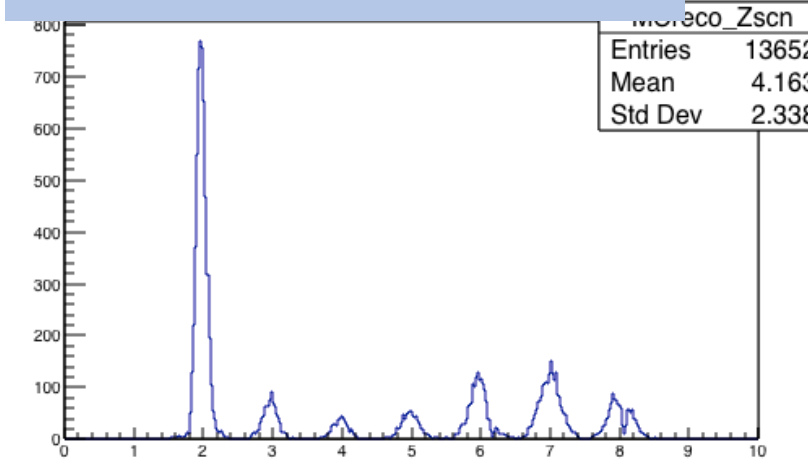
Too large

Ok central value! (what happens with O?)

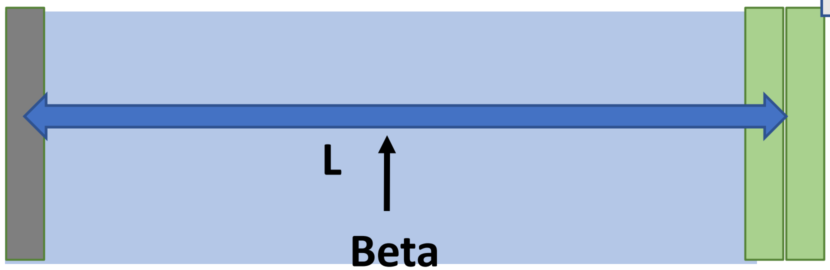


MC **reco TW: corrected Z**

- Evaluate ΔE_{SCN}
- Evaluate beta from L/TOF
- Add correction for energy lost in air
- Z from Bethe Bloch



Ok central value! (what happens with O?)

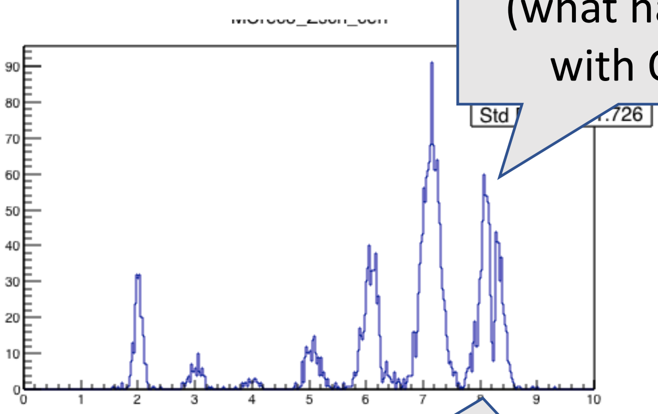


Add estimate for energy lost in air

MC reco: Z in good TW positions

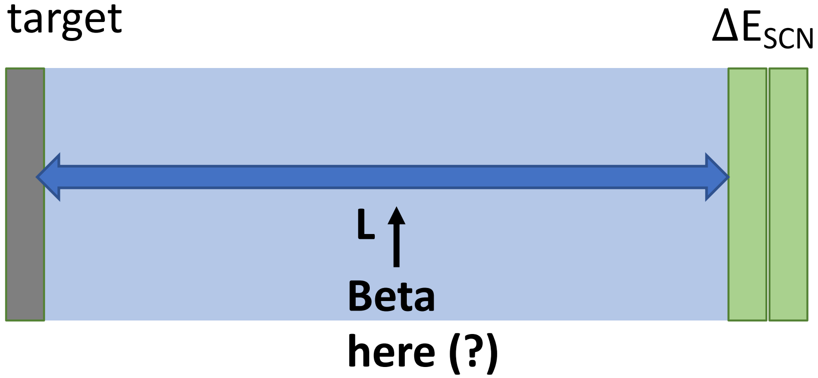
MC **reco TW: Uncorrected Z**

- Evaluate ΔE_{SCN}
- Evaluate beta from L/TOF
- Z from Bethe Bloch



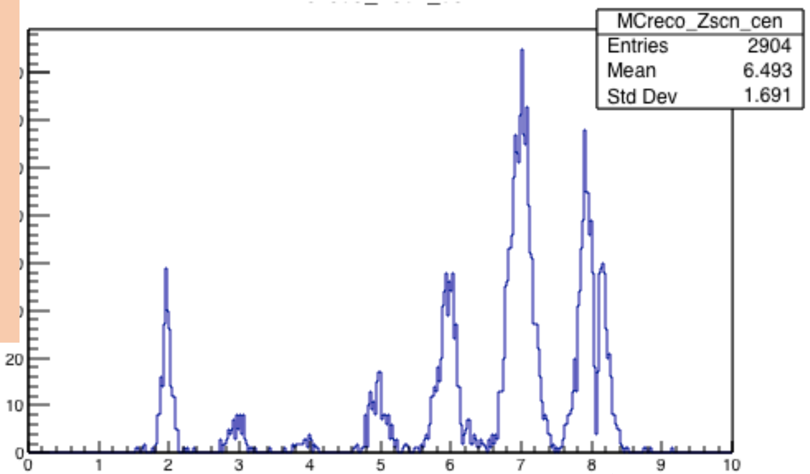
Ok central value! (what happens with O?...)

beta is higher in TW → too high Z

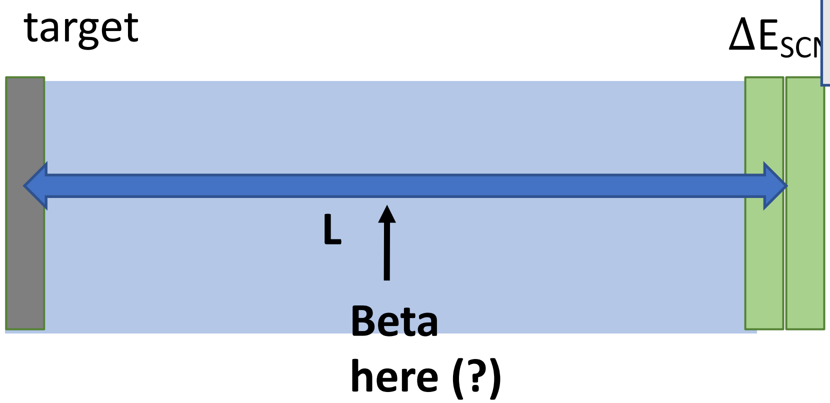


MC **reco TW: corrected Z**

- Evaluate ΔE_{SCN}
- Evaluate beta from L/TOF
- Add correction for energy lost in air
- Z from Bethe Bloch



Ok central value! (what happens with O?

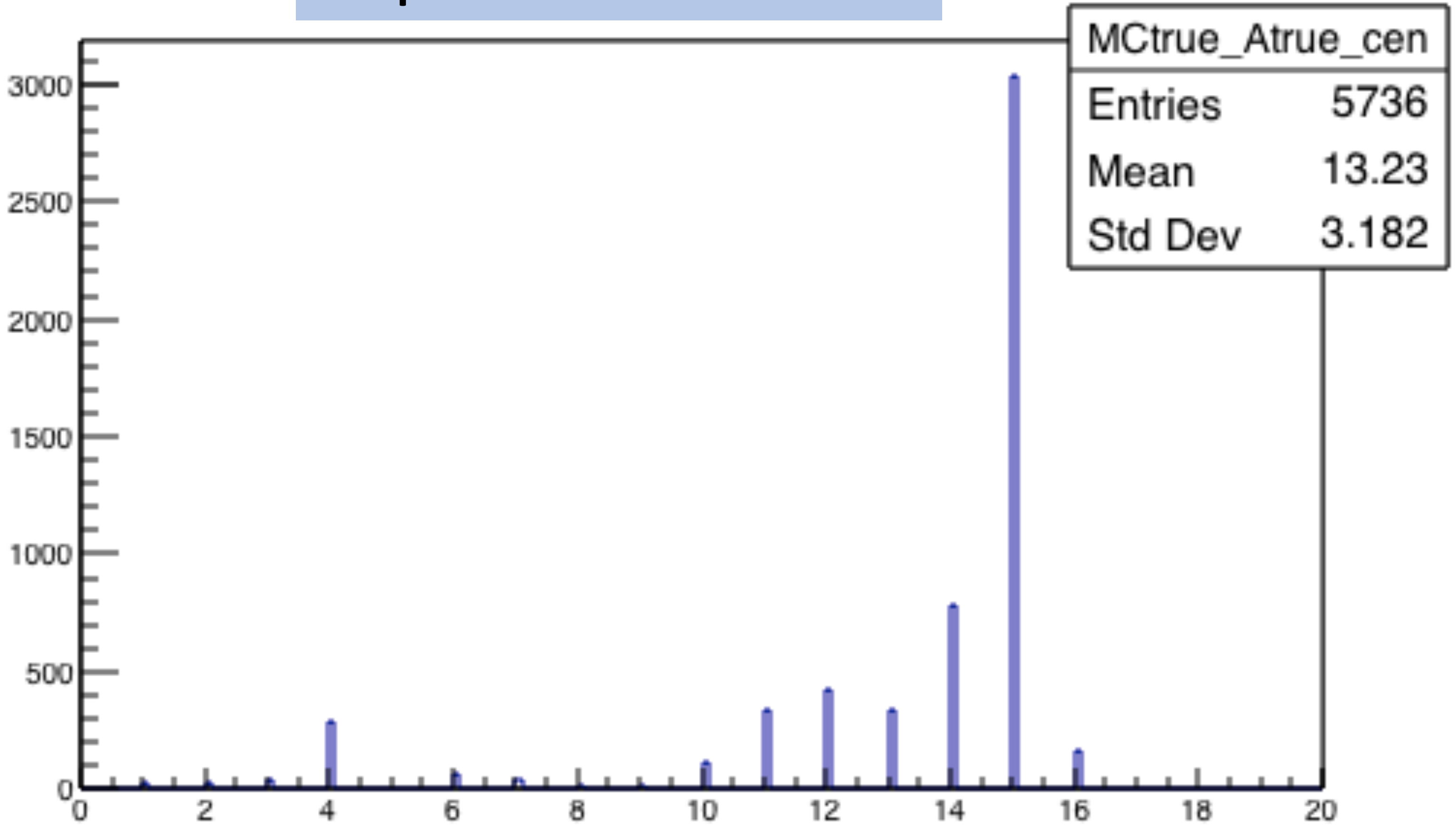


Add estimate for energy lost in air

MC truth: A in good TW positions

MC **truth TW: A true in good TW positions**

True A



MC truth: A in good TW positions

PRELIMINARY

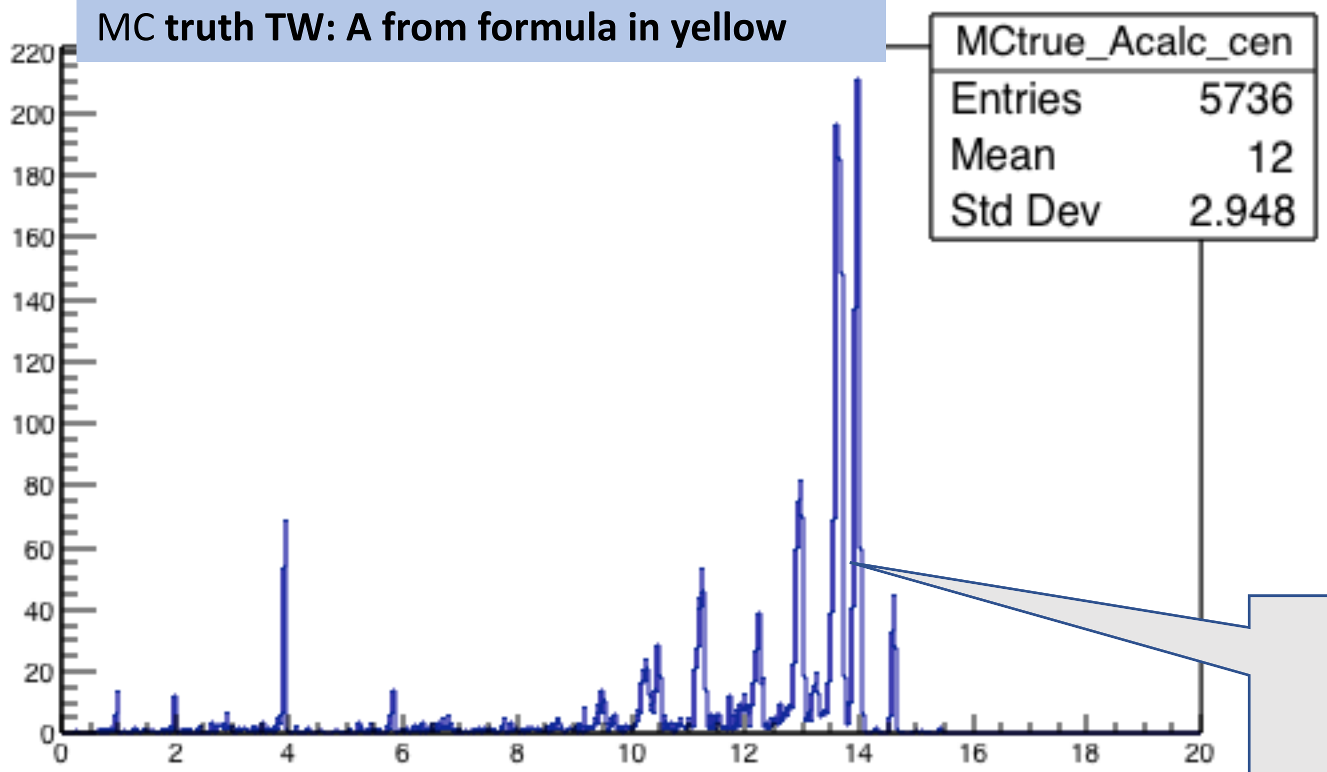
True A

- Evaluate ΔE_{SCN}
- Evaluate beta from L/TOF
- Evaluate Ecal as before (from crystals)
- A from

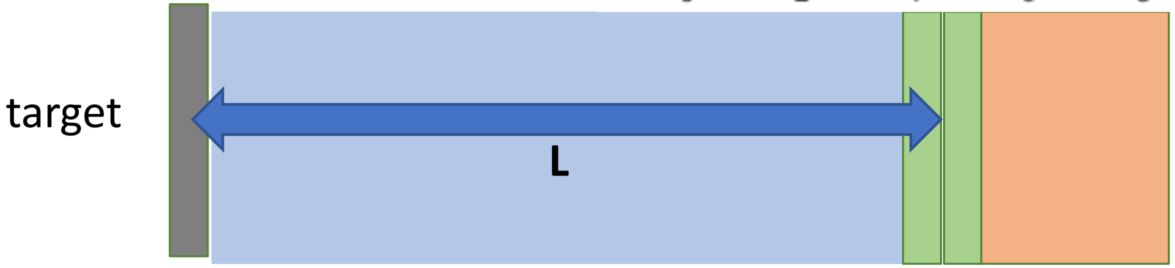
$$A = \frac{E_{calo}}{931.5(\gamma - 1)}$$

- with gamma from beta

MC **truth TW: A from formula in yellow**



?



Average beta between target and TW is not the one in calorimeter

MC truth: A in good TW positions

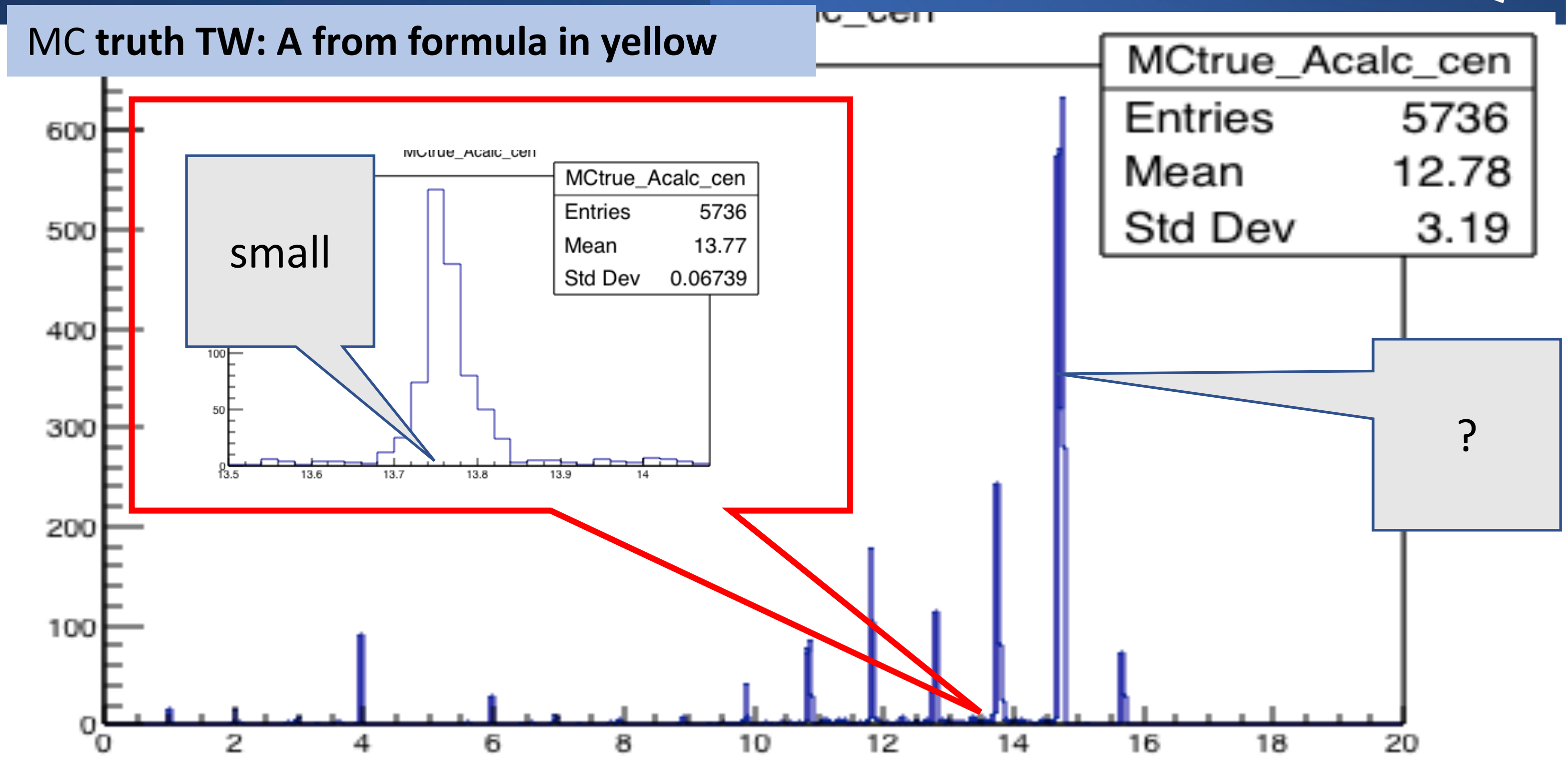
PRELIMINARY

True A

- Evaluate ΔE_{SCN}
- Evaluate beta from L/TOF
- A from

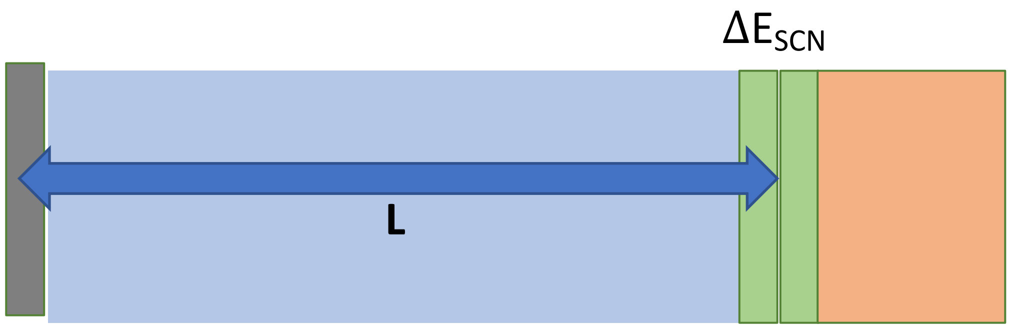
$$A = \frac{E_{calo} + E_{TW}}{931.5(\gamma - 1)}$$

- with gamma from beta



Add TW energy brings us closer to the real kinetic energy lost by fragment.
But still not perfect, energy lost also in air

target



MC truth: A in good TW positions

PRELIMINARY

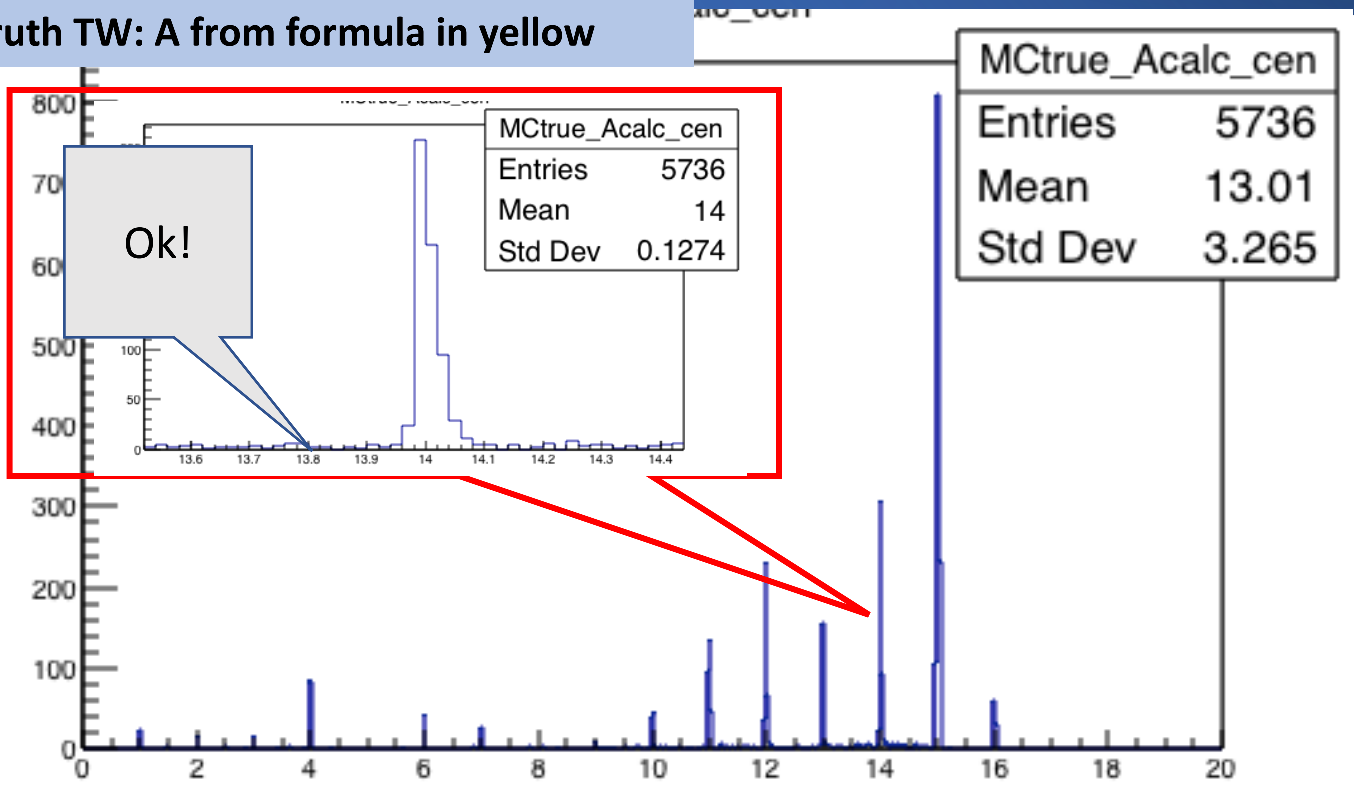
True A

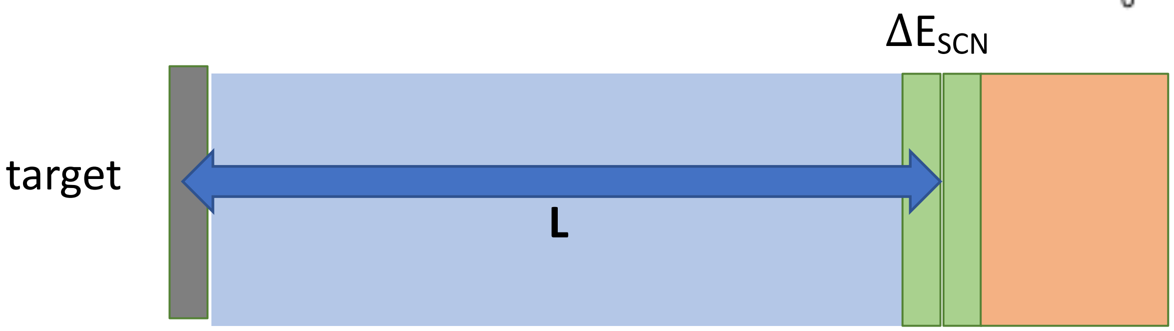
- Evaluate ΔE_{SCN}
- Evaluate beta from L/TOF
- A from

$$A = \frac{E_{calo} + E_{TW} + E_{corr}}{931.5(\gamma - 1)}$$

- with gamma from beta
- E corr correlated to TW energy (no details)

MC truth TW: A from formula in yellow





MC reco: A in good TW positions

PRELIMINARY

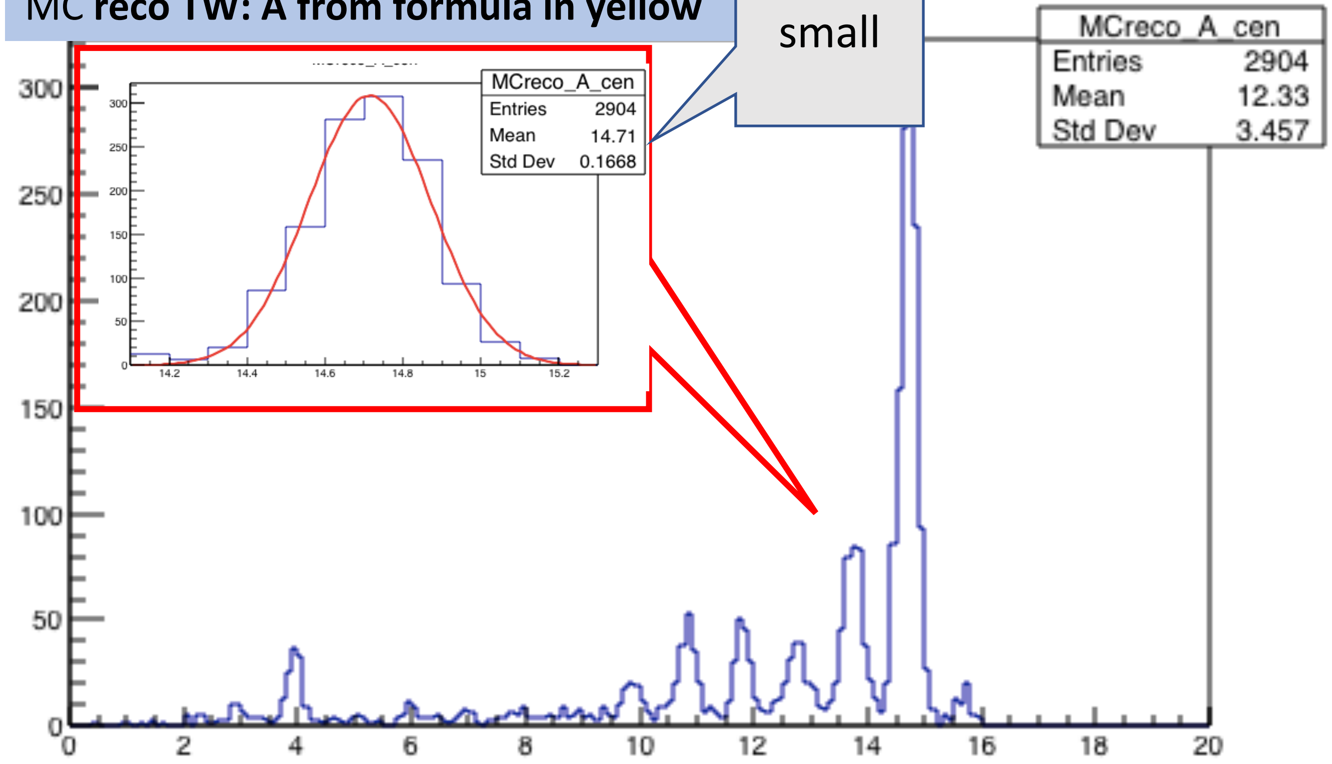
True A

- Evaluate ΔE_{SCN}
- Evaluate beta from L/TOF
- A from

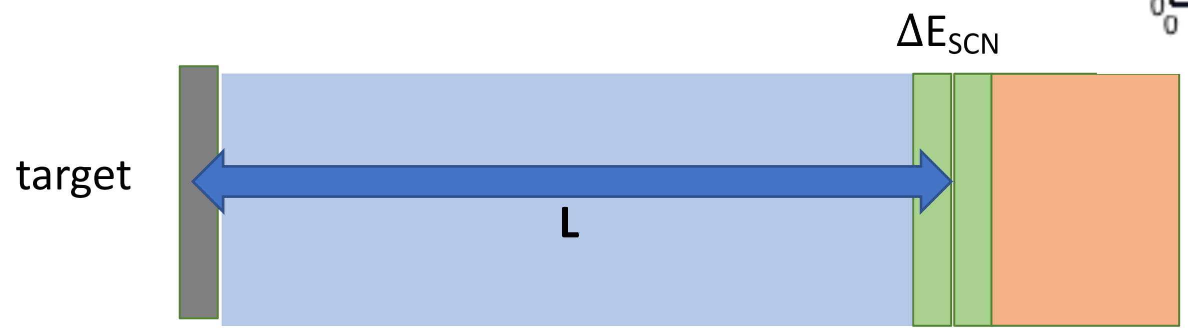
$$A = \frac{E_{calo} + E_{TW}}{931.5(\gamma - 1)}$$

- with gamma from beta

MC **reco TW: A from formula in yellow**



Uncorrected for loss in air



MC truth: A in good TW positions

PRELIMINARY

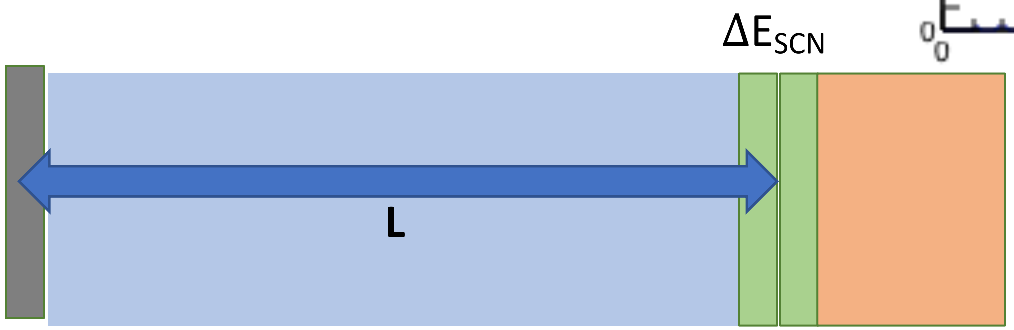
True A

- Evaluate ΔE_{SCN}
- Evaluate beta from L/TOF
- A from

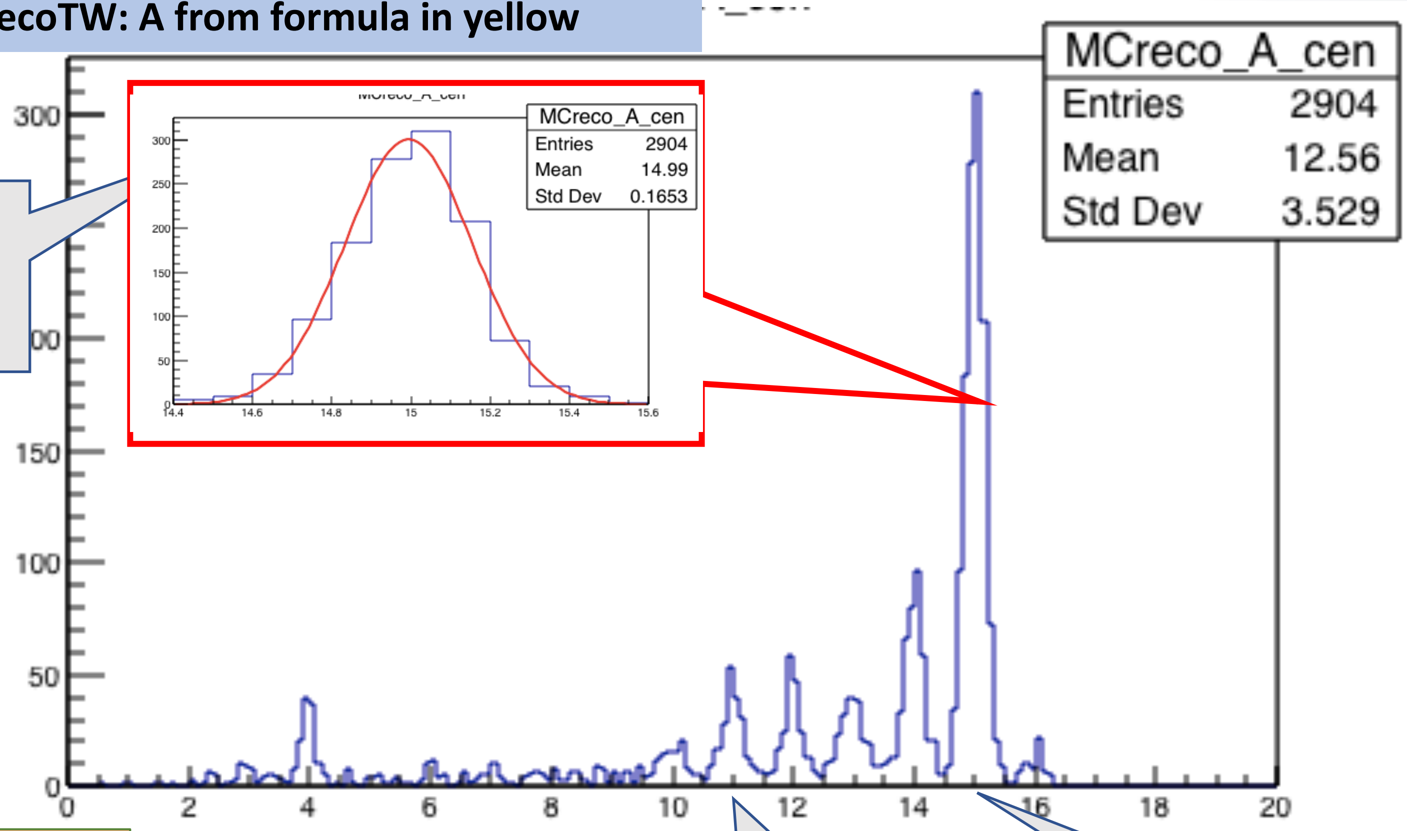
$$A = \frac{E_{calo} + E_{TW} + E_{corr}}{931.5(\gamma - 1)}$$

- with gamma from beta
- E corr correlated to TW energy (no details)

target



MC **recoTW: A from formula in yellow**



Ok!!

$A = 4$ Resolution roughly 0.14 MeV

$A = 11$ Resolution roughly 0.22 MeV

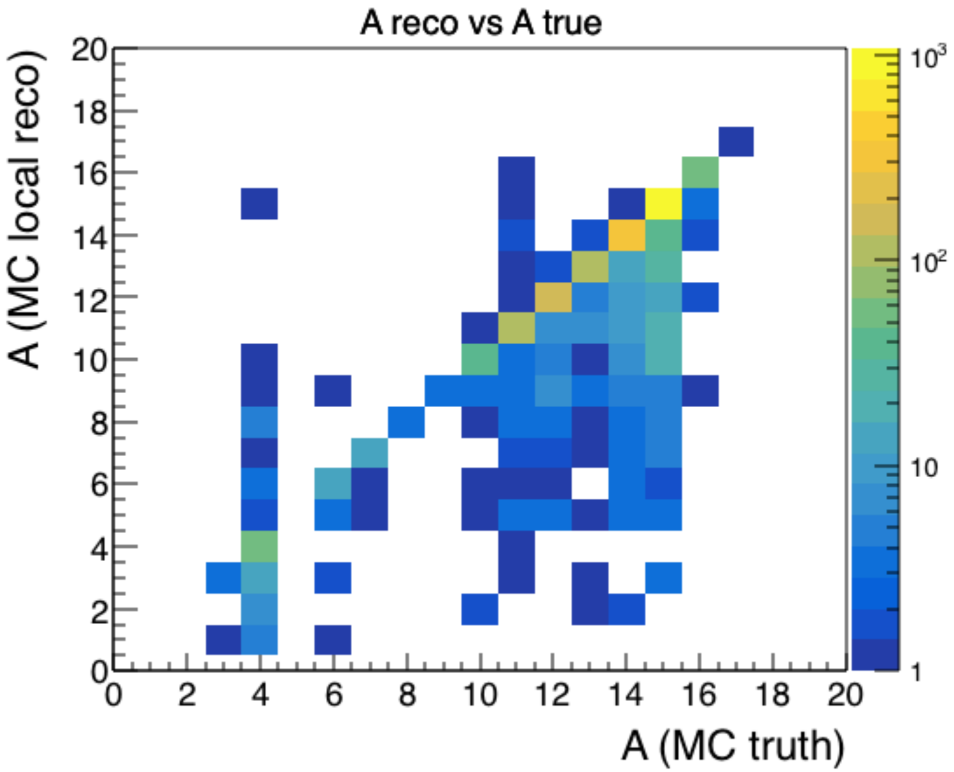
$A = 15$ Resolution roughly 0.16 MeV

MC truth: Z and A cross feed (with correction)

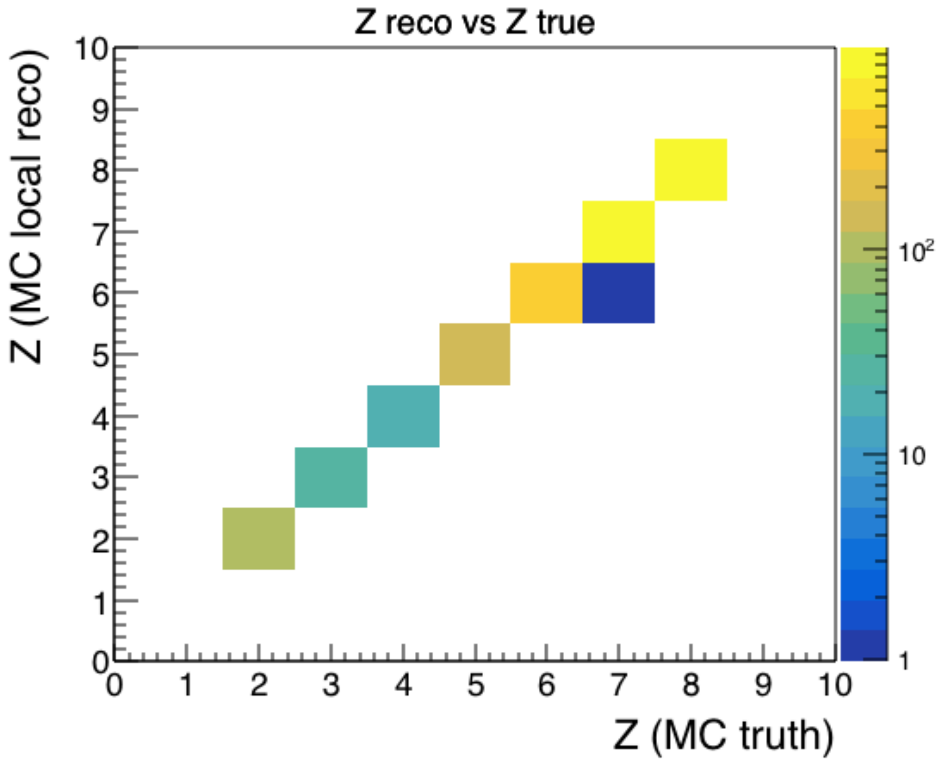
PRELIMINARY

In good TW positions

MC RECO: Reconstructed **A vs true A**



MC RECO: Reconstructed **Z vs true Z**



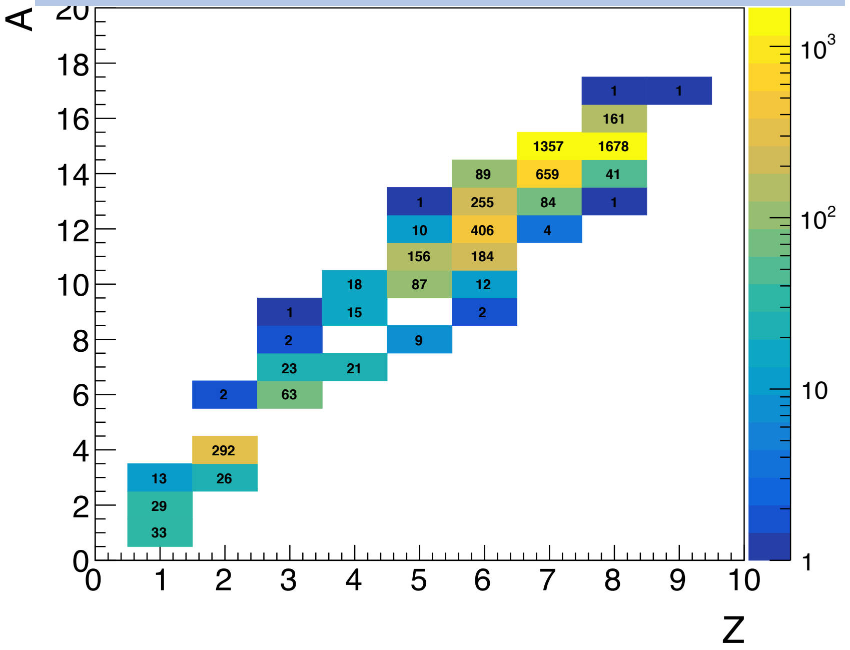
GSI 2021: in good TW positions

PRELIMINARY

Charged secondaries produced in target arriving at TW vs CALO

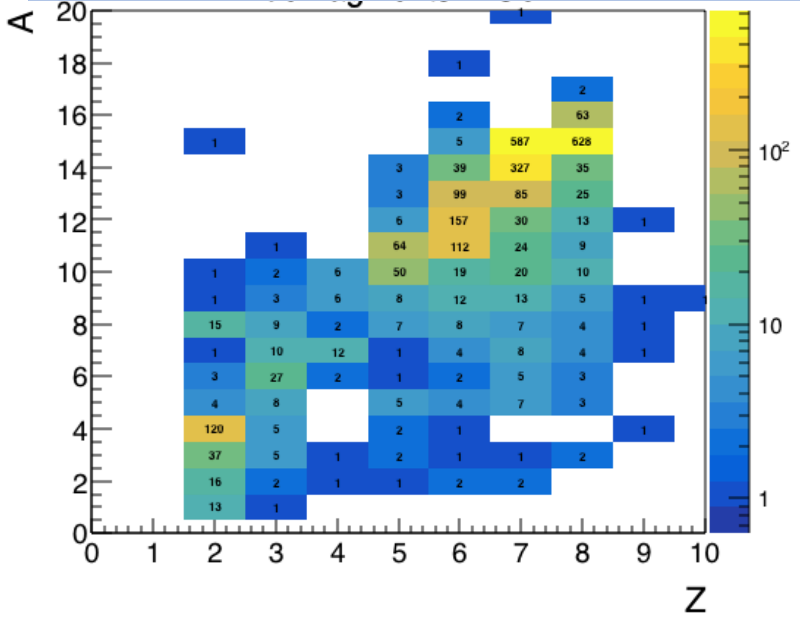
^{16}O @200 MeV/u – C2H4 target – 10^6 primaries

MC RECO: true A vs true Z



^{16}O @200 MeV/u – C2H4 target – 10^6 primaries

MC RECO: Reconstructed A vs reconstructed Z



- Seems we loose too much, check…

Conclusions

1. Updated CNAO2020 analysis to GSI2021 analysis (new_geom)
2. Physics considerations still valid: we can point at $n*10^6$ primaries of C and $2n*10^6$ for C_2H_4 , preferably with n not too far away from 5.
3. Consider possibility to use target of 1 cm for C_2H_4
4. We had a first look at A reconstruction with 9 calorimeter crystals, GSI2021 setup, 200 MeV/u ^{16}O on C target
5. Run on other files, improve and clean analysis, understand reconstructed hits and TW points, ………