Summary of a few physics topics using CNAO2020 and GSI2021 setups

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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

- In December 2020, we introduced the CNAO2020 design (see next).

- **TODAY:**

  - In absence of dedicated GSI samples, summarize the most relevant conclusions we reached with this CNAO2020 setup
    - Issues about needed statistics to be collected (**slides 3-8**)
    - A-reconstruction by ToF and Calo measurements (**slides 10-14**)

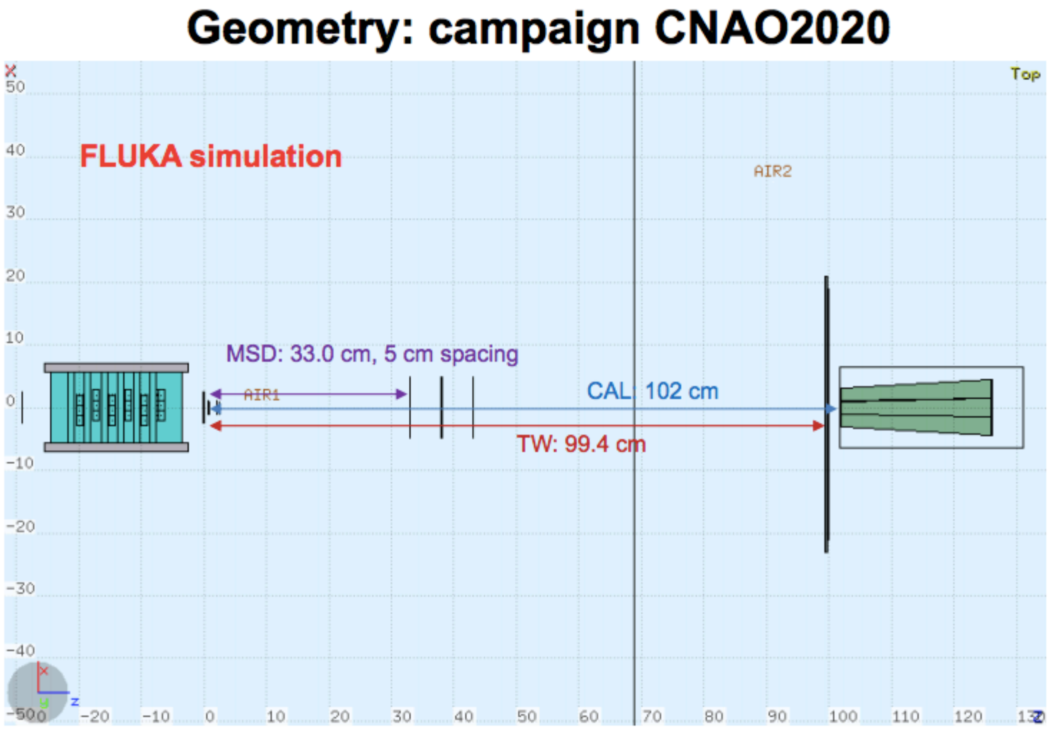
Warning: limited to the case of ^{12}C projectiles at 200 MeV/u, but expect similar conclusions for ^{16}O beam

  - Files just available! A few very preliminary numbers for ^{16}O beam with GSI setup! (**slides 15-21**)

CNAO2020 setup: MC statistics used for evaluation

MC statistics used for evaluation

- 12C at 200 MeV/u on C
  - 10^7 primaries
  - 284246 events on file
  - 5 mm thickness
  - rho=1.83 g/cm3)
- 12C at 200 MeV/u on C2H4
  - 10^7 primaries
  - 5 mm thickness
  - rho=0.94 g/cm3


Geometry: campaign CNAO2020

- First part of presentation: focus on what we can do only with SC and TOF-Wall
- Second part: consider mass reconstruction

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 $N_p = 10^7$ primaries**

Fragment production from 12C @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	334288	207099	1.61
2	274852	197885	1.39
3	28158	22329	1.26
4	15405	13240	1.16
5	32617	26699	1.22
6	26183	26396	0.99

Starting with $N_p=10^7$, how many have inelastic interactions?

From MC simulations:

- Carbon: about 6%
- Ethylene: about 4%

- Not shown, but these yields from MC are roughly in accordance with what we derived analytically
- 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:

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

- Not shown, but these numbers from MC are in accordance with what we derived analytically
- Relative error on H target is large
- It varies with Z

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	0.87	0.17	5.0
2	0.65	0.18	3.4
3	1.68	0.60	2.8
4	1.97	0.81	2.4
5	1.47	0.55	2.7
6	1.19	0.62	1.9

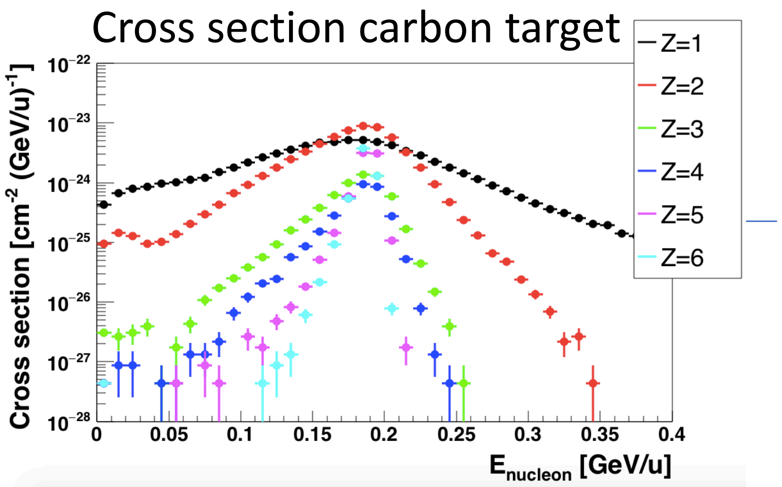
- If doubling N_p for the C_2H_4 target w.r.t. C target, we obtain: $\frac{\Delta\sigma_{i,H}}{\sigma_{i,H}} \sim \mathbf{2.5}\frac{\Delta\sigma_{i,C}}{\sigma_{i,C}}$
- If 4 times N_p for the C_2H_4 target we obtain: $\frac{\Delta\sigma_{i,H}}{\sigma_{i,H}} \sim \mathbf{2.1}\frac{\Delta\sigma_{i,C}}{\sigma_{i,C}}$

Decrease of statistical error is slow… probably **doubling N_p for the C_2H_4 target w.r.t. C target is enough**

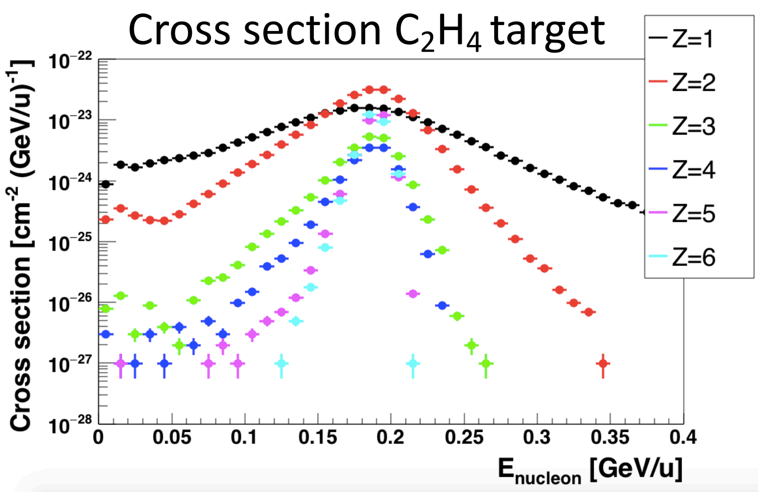
Fragment production from 12C @200 MeV/u: cross section

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

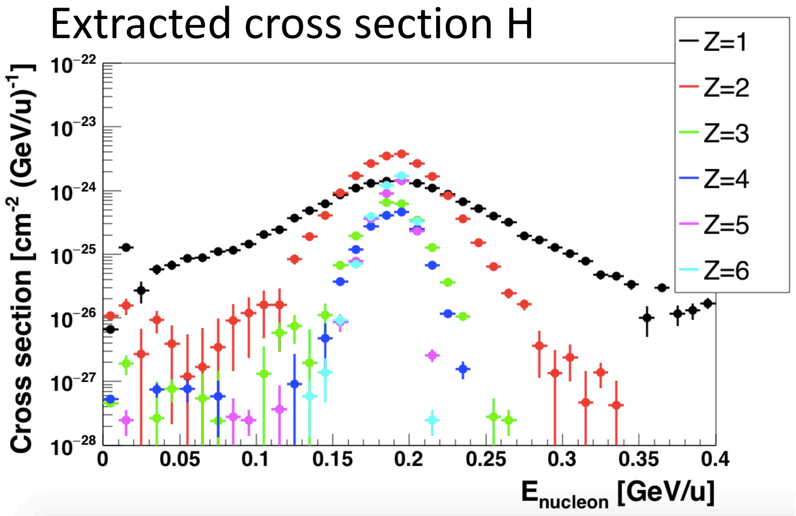
- C target: 5×10^6 primaries
- C_2H_4 target: 10^7 primaries



Cross section carbon target



Cross section C_2H_4 target



Extracted cross section H

- C_2H_4 cross section is largest.
- Still acceptable result with 5×10^6 primaries for C target, and 10^7 primaries for C_2H_4 target
- Errors: heavier fragments have large errors

What numbers do we expect at GSI?

- Numbers were CNAO202 setup. Assume that at GSI, similar numbers apply (see slides 14-21)
- 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
10^7	2 x 10^7	5.5+11=16.5 hours: long
5×10^6	**10^7**	**2.7+5.5~8.2 $\gtrsim$ 8 hours: ok?**
4×10^6	8×10^6	2.2+4.4~6.6 < 8 hours: ok

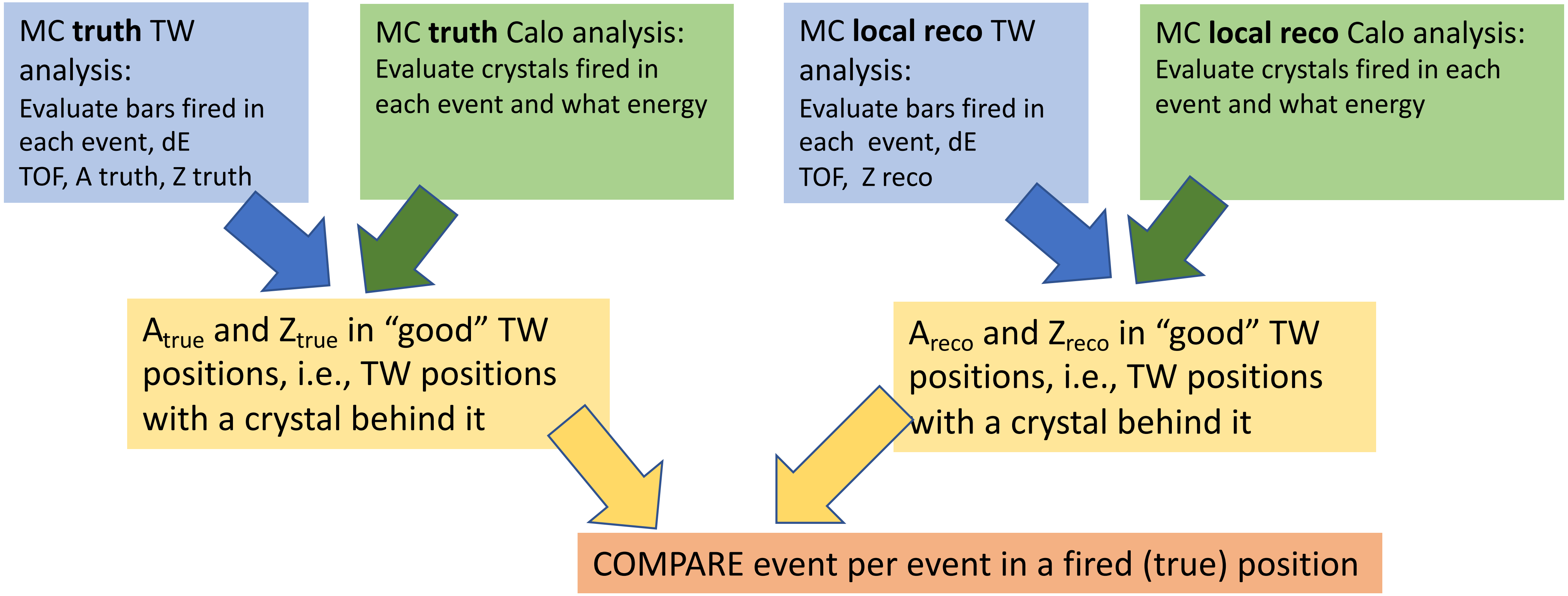
- Summarizing:
  - we need more primaries for the C_2H_4 target than for the C target
  - Given the slow decrease of the error on $\frac{\Delta\sigma_{i,H}}{\sigma_{i,H}}$, probably for a given energy we can point at n*10^6 primaries of C and 2n*10^6 for C_2H_4 , preferably with n not too far away from 5.
  - 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

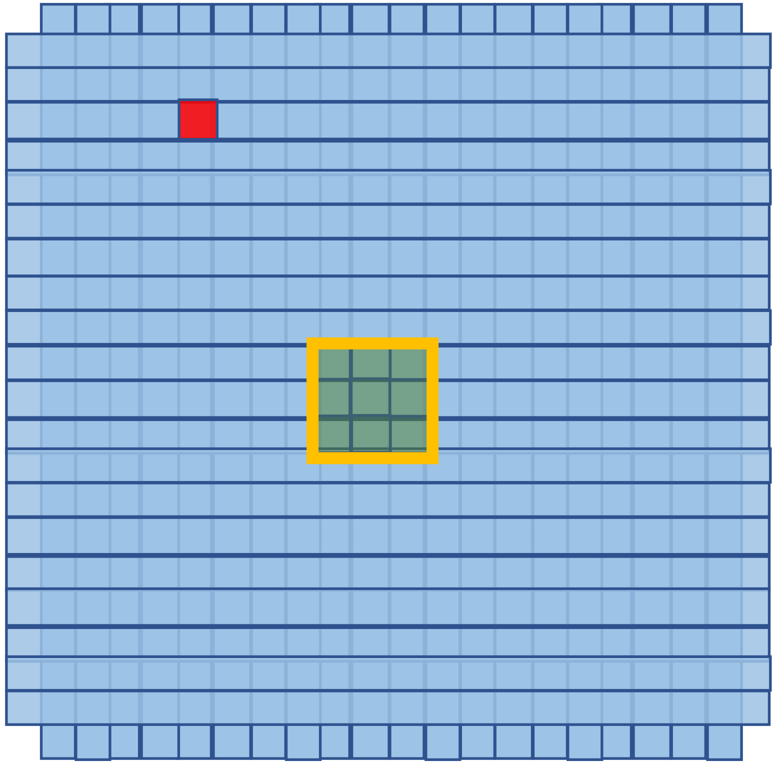
Analysis MC local reco

See physics meeting May 5

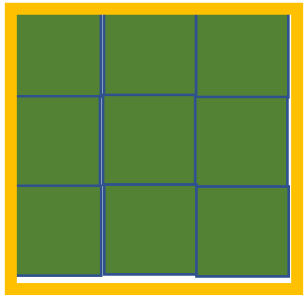
- Determine energy and TOF in front and rear bars starting **from TWpoints.**
- Select only positions (a crossing between a front and a rear bar) that are associated with bars with:
  - >=1 MeV in Front bar**: fired bar**
  - >= 1 MeV in rear bar**: fired bar**
- Verify for that position the front-rear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



Enable TWZmc	n
Enable TWnoPU	n
Enable TWZmatch	y



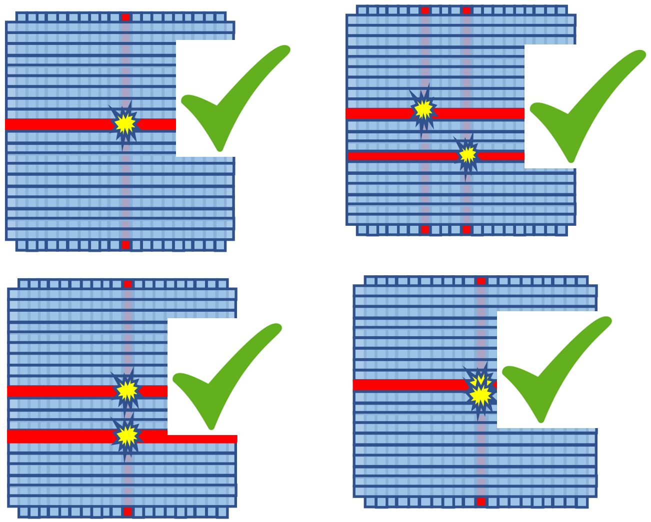
- Z: use Z from TWPoint (a true Z associated to the point)
- A: reconstruct it from:

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

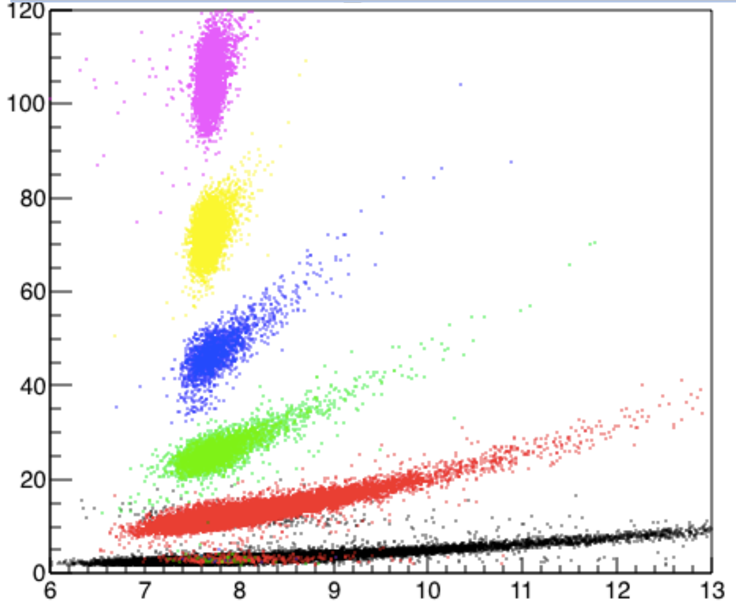
MC reco: Delta E vs TOF for selected positions

See physics meeting May 5

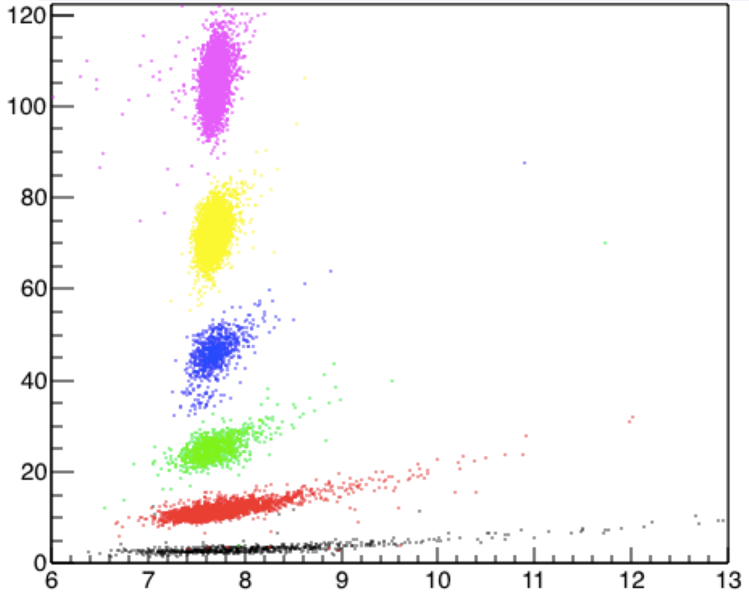
For each position in each event, evaluate for the fired positions ΔE_{SCN} vs TOF



MC reco: ΔE_{SCN} vs TOF in whole TW



MC reco: ΔE_{SCN} vs TOF in centre TW



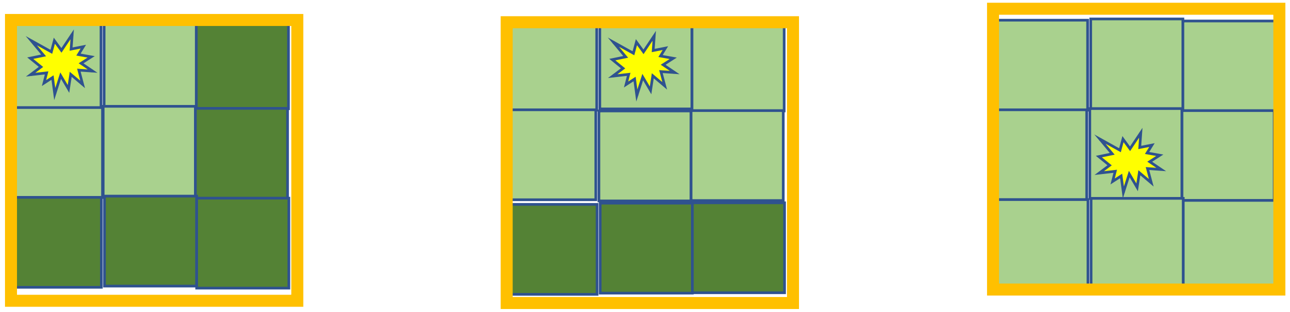
To be investigated and redone with more recent TOFpoints code

Analysis MC local reco: calorimeter deposits

See physics meeting May 5

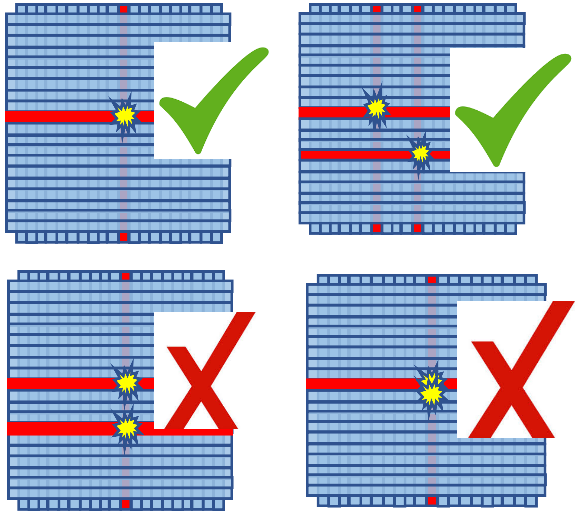
- Starting from Clusters, in each event fill 9 crystals (threshold 10 MeV)
- Checked for a fired TW position which crystals can be associated to it (neighbours)
- Examples below
- Sum the energy of the associated crystals in each event
- Threshold 10 MeV (tested various thresholds)
- Then we have for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

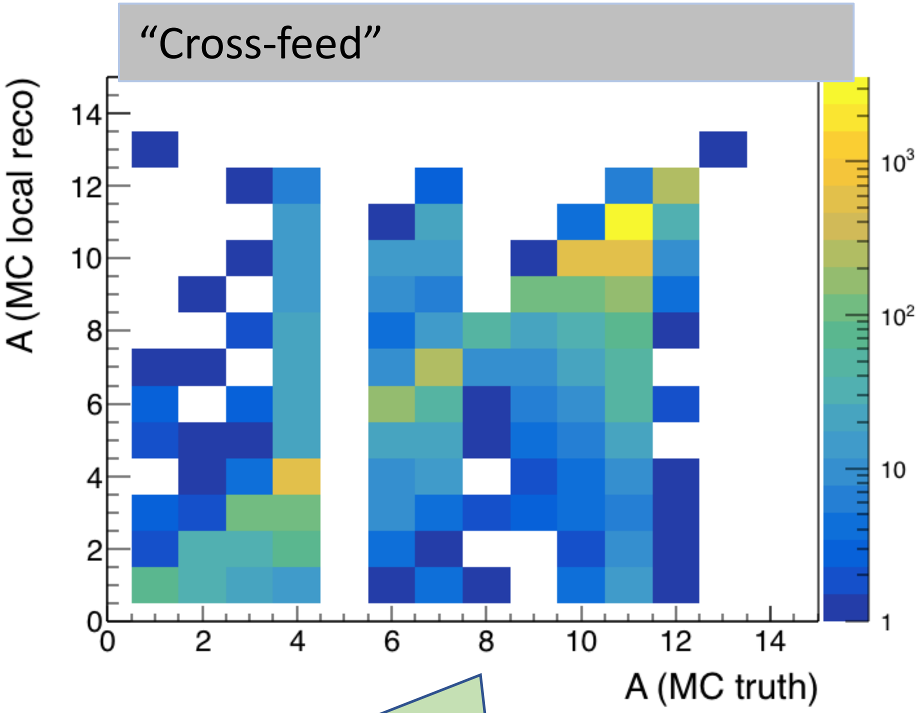
$$A = \frac{E_{calo}}{931.5(\gamma - 1)}$$



Local Reco: TW+Calorimeter

See physics meeting May 5




“Cross-feed”

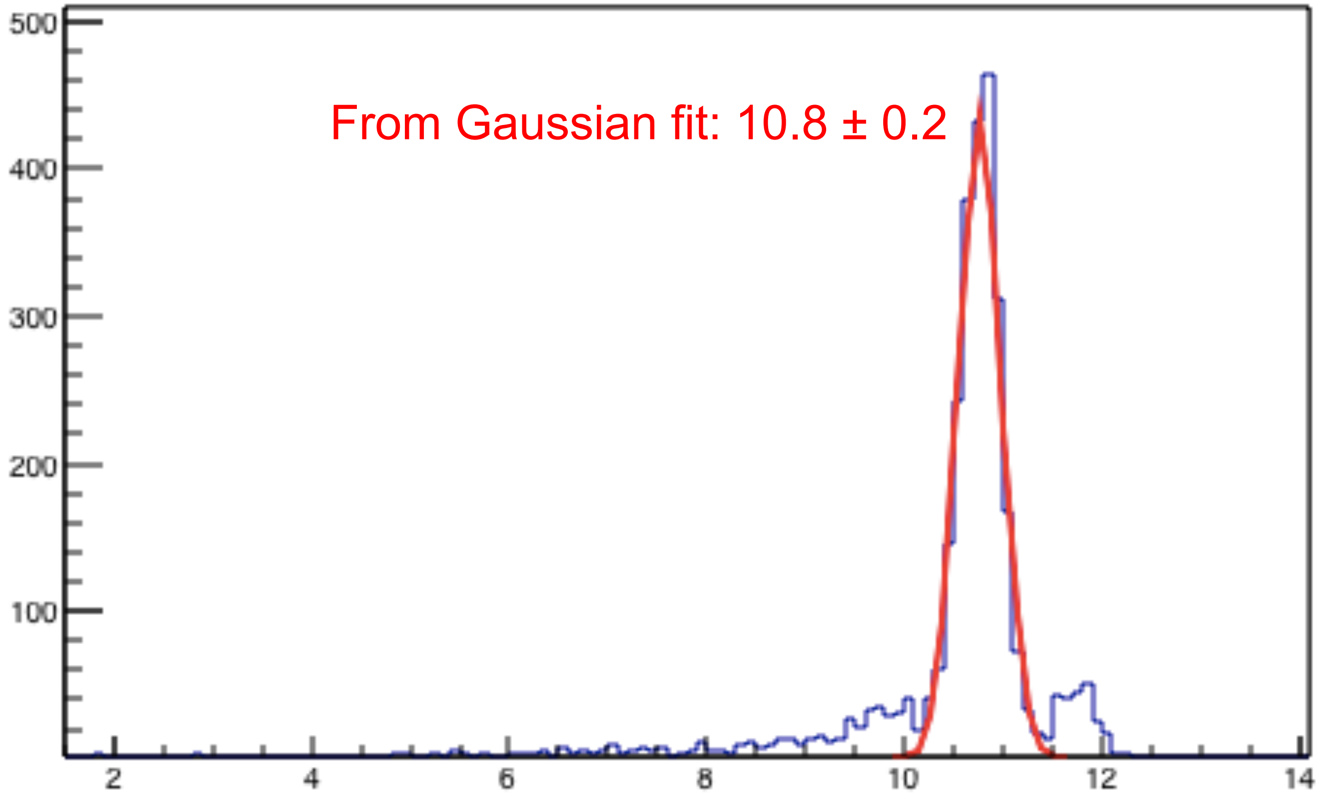
For the moment, positions that are associated with double hits in a bar are excluded

- To be investigated: the reconstructed A. is somewhat low (see next)
- Example A_{MCtrue} =11: relative efficiency to be riconstructed correctly is 80%

Local Reco: TW+Calorimeter

- Mass resolution for heavy fragments about 2-3%
- Mass resolution for lighter fragments worse (5-8%)
- Underestimation of mass: seems related to value of the TOF of the TWPoints, to be redone in New Geom branch…

Example (preliminary!) of MC reconstructed A for Z=6

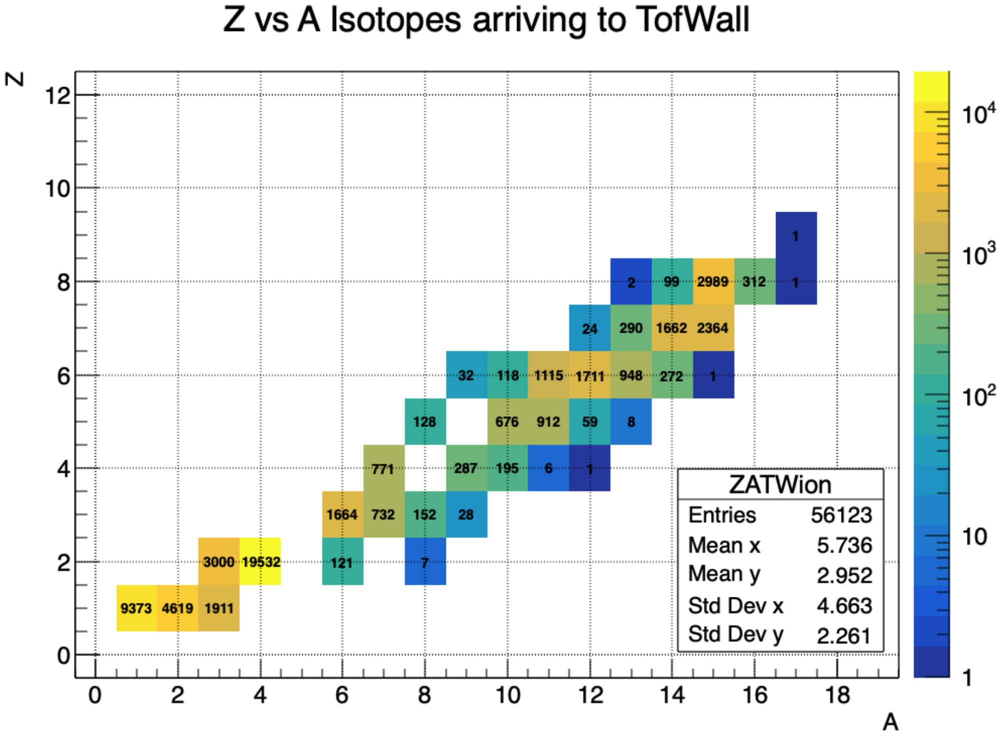


GSI 2021: influence of target: C vs C_2H_4

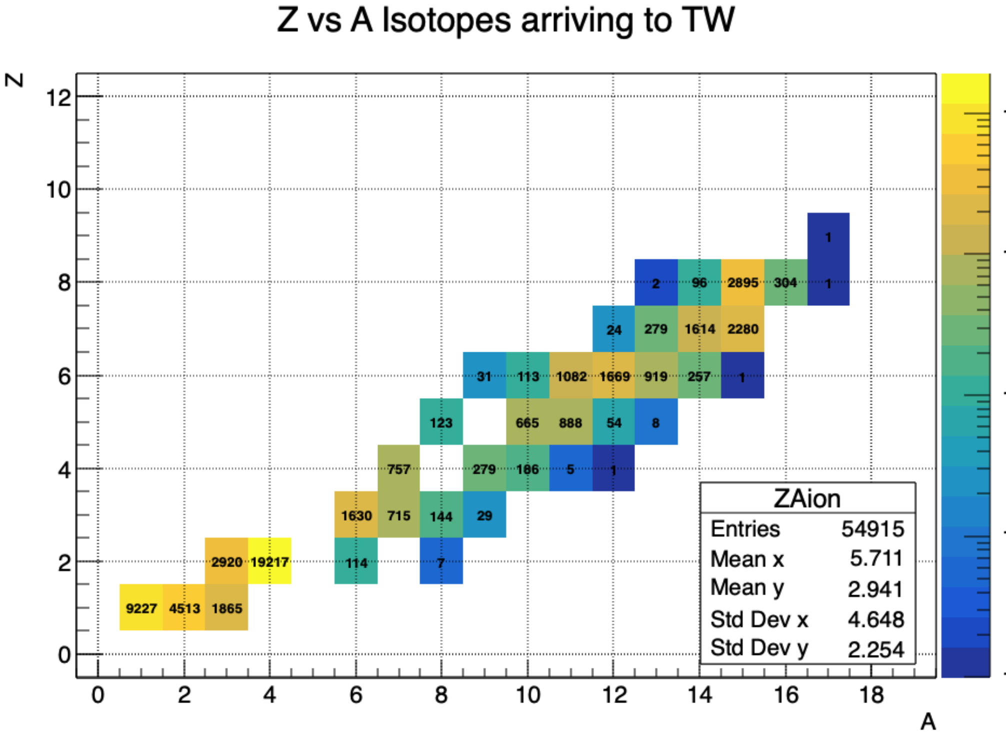
Charged secondaries produced in target arriving at TW

Consider 1 cm thickness target for C_2H_4?

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



^{16}O @200 MeV/u – C_2H_4 target – 10^6 primaries



$\frac{Y_{i,C}}{Y_{i,C_2H_4}}$ about 1.4: similar as at CNAO!

Remember: C_2H_4 has larger σ, but lower ρ and larger A

$$Y_{i,C} = \frac{N_p N_A\, \rho_C\, \delta_C \sigma_{i,C,}}{A_C}$$

$$Y_{i,C_2H_4} = \frac{N_p N_A\, \rho_{C_2H_4}\, \delta_{C_2H_4} \sigma_{i,C_2H_4}}{A_{C_2H_4}}$$

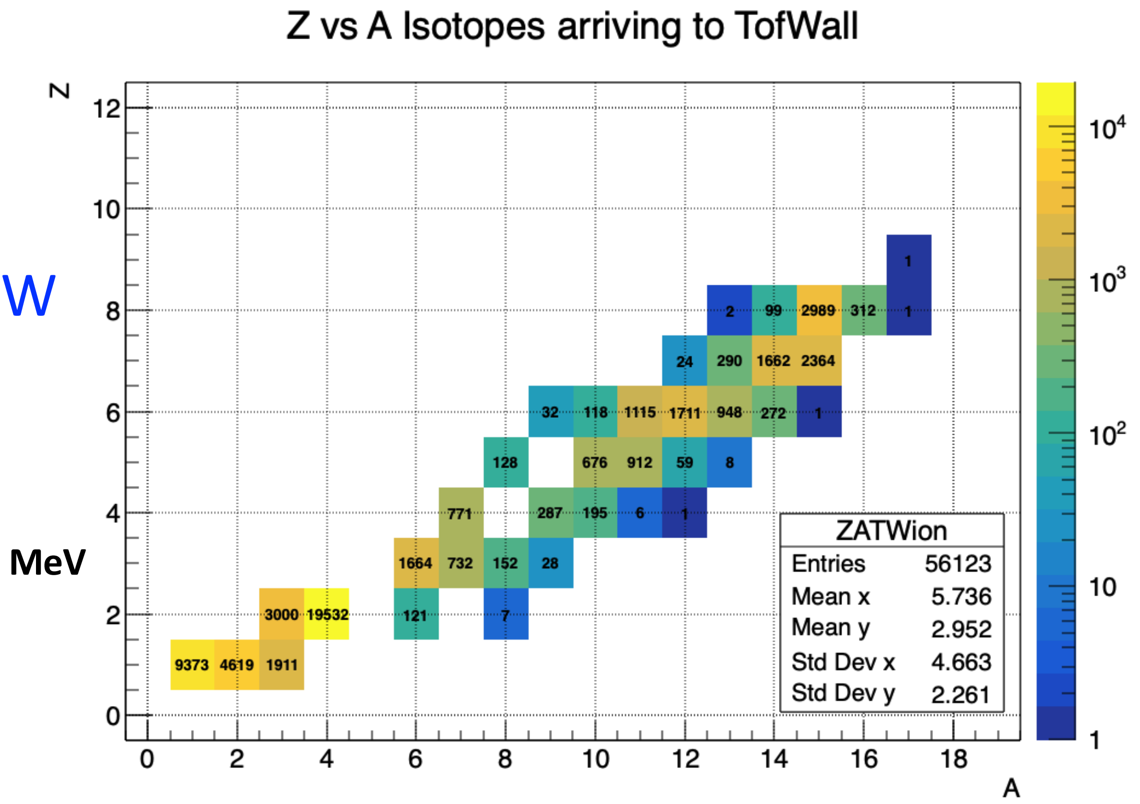
GSI 2021: influence of beam energy: 200 vs 400 MeV/u oxygen

Charged secondaries produced in **C target** arriving at TW

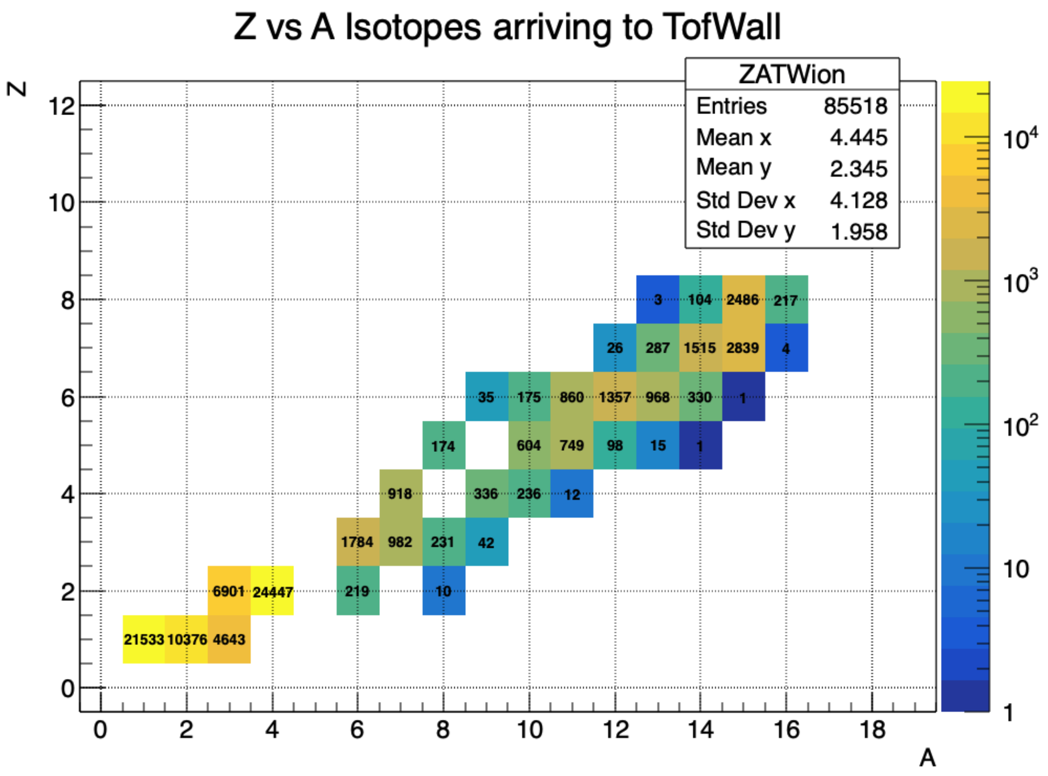
Note that:

$\sigma_{400\ \mathrm{MeV}} < \sigma_{200\ \mathrm{MeV}}$

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



^{16}O @400 MeV/u - C target – 10^6 primaries



- Light fragments: Nfrag$_{TW}$@400 MeV > Nfrag$_{TW}$@200 MeV (larger boost at 400 MeV)
- Heavy fragments: Nfrag$_{TW}$@400 MeV < Nfrag$_{TW}$@200 MeV (were already produced in center)

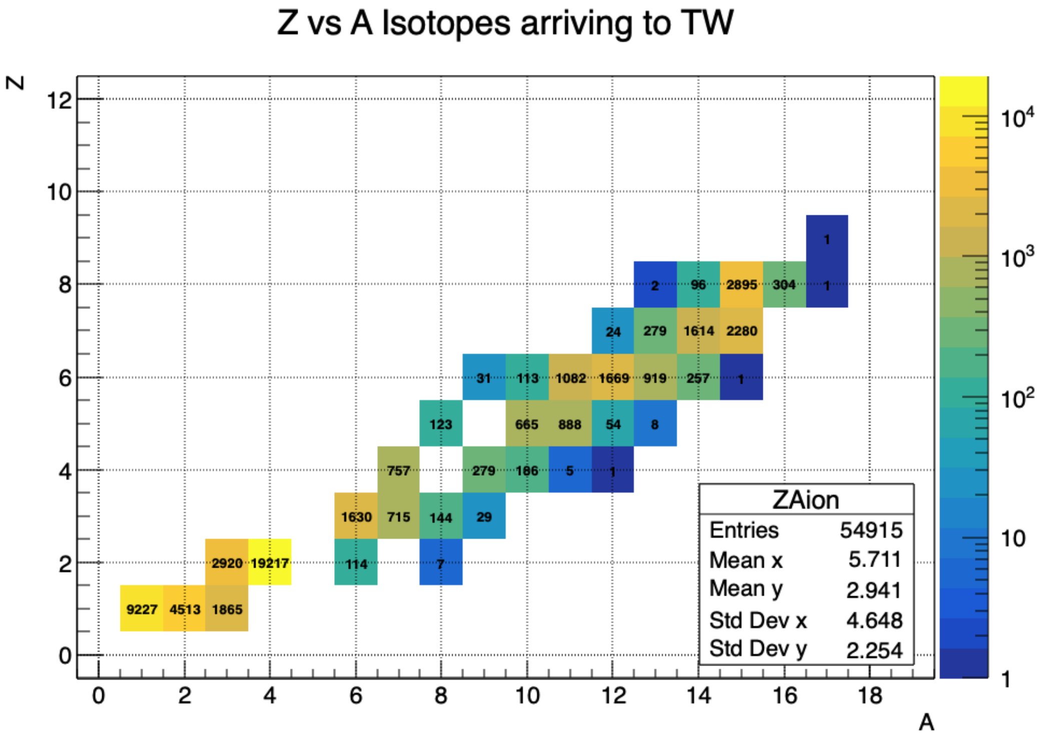
GSI 2021: influence of beam energy: 200 vs 400 MeV/u oxygen

Charged secondaries produced in **C_2H_4 target** arriving at TW

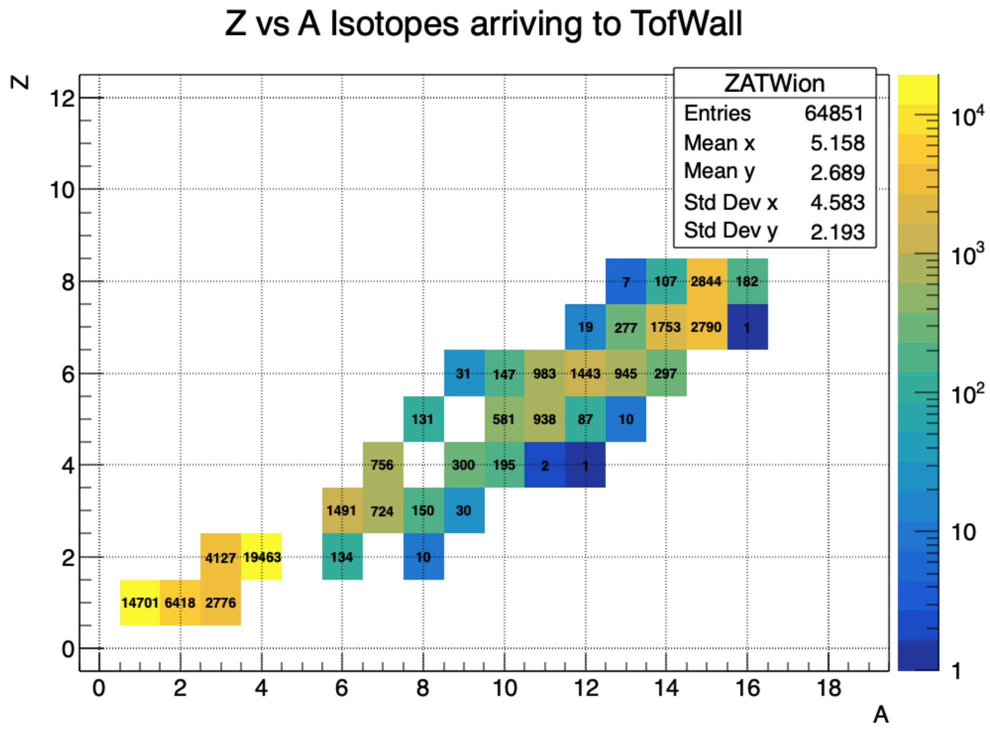
Note that:

$\sigma_{400\ \mathrm{MeV}} < \sigma_{200\ \mathrm{MeV}}$

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


Z vs A Isotopes arriving to TW

^{16}O @400 MeV/u – C2H4 target – 10^6 primaries

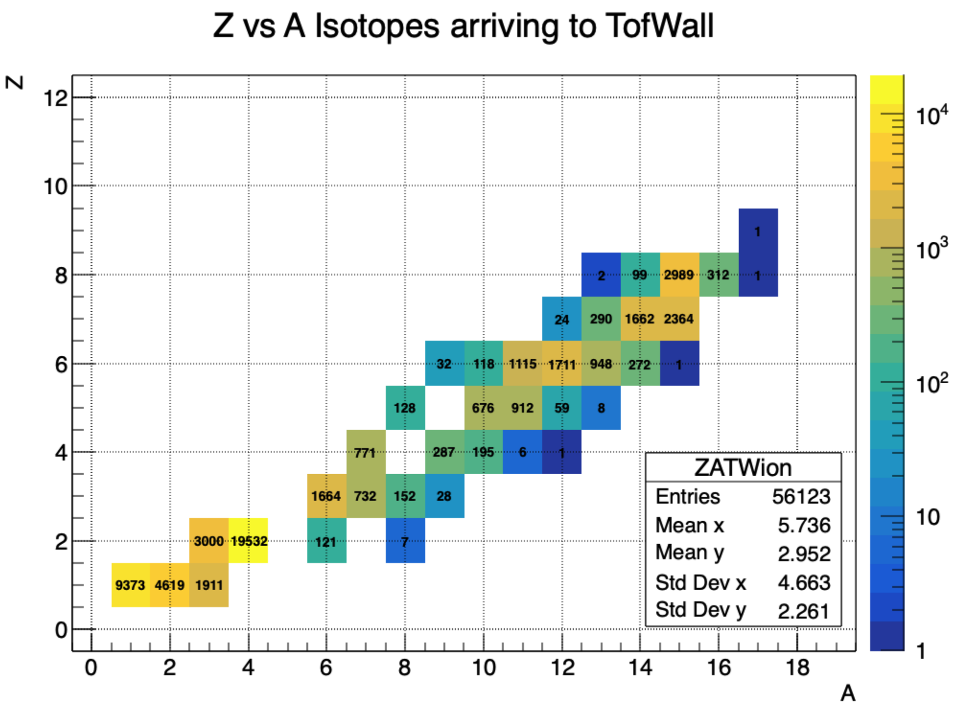

Z vs A Isotopes arriving to TofWall

- Light fragments: $\mathrm{Nfrag}_{\mathrm{TW}}$@400 MeV > $\mathrm{Nfrag}_{\mathrm{TW}}$@200 MeV
- Heavy fragments: $\mathrm{Nfrag}_{\mathrm{TW}}$@400 MeV ~> $\mathrm{Nfrag}_{\mathrm{TW}}$@200 MeV
- Why different from C target? Presence of H atoms…

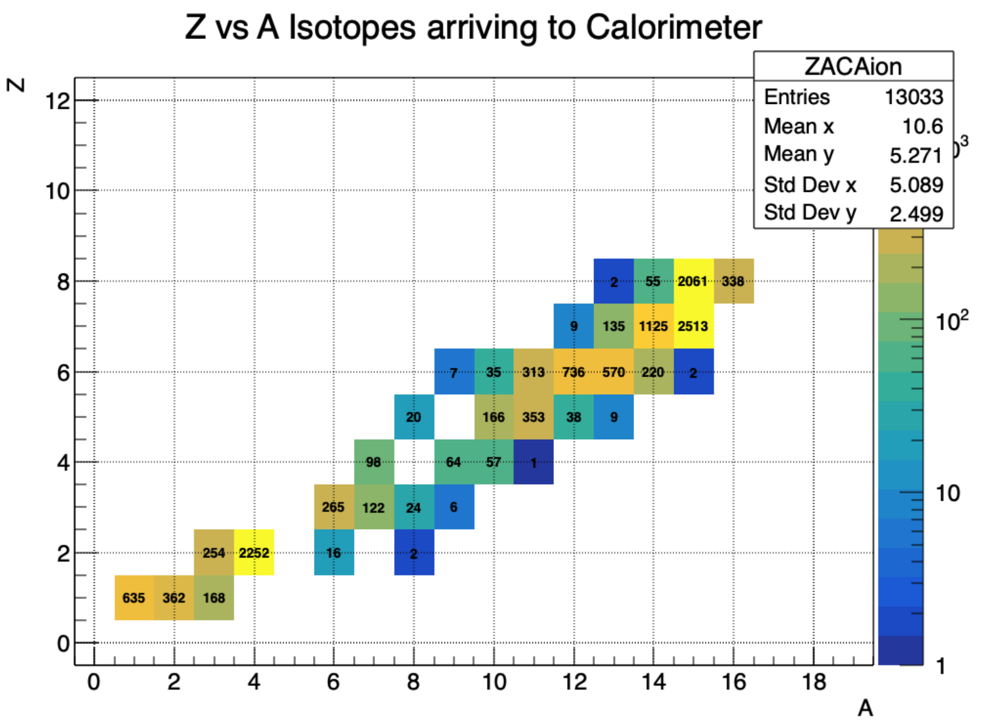
GSI 2021: TW vs calorimeter (central module)

Charged secondaries produced in target arriving at TW vs CALO

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



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

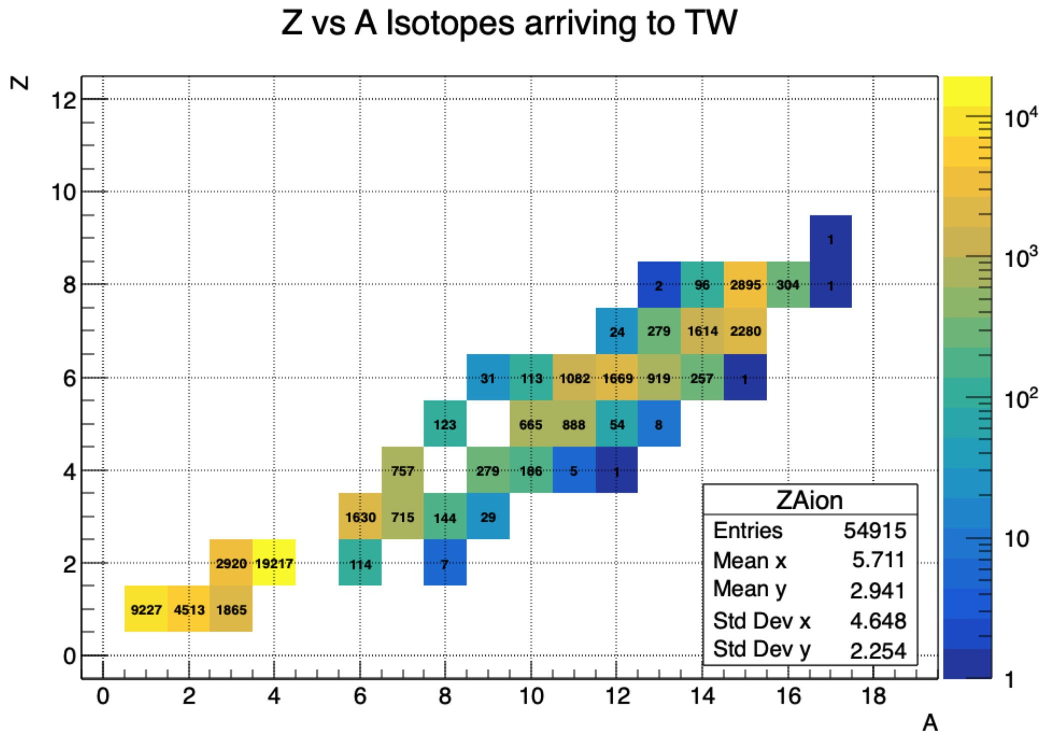


- Light fragments: we mostly loose them
- Heavy fragments: we mostly see them

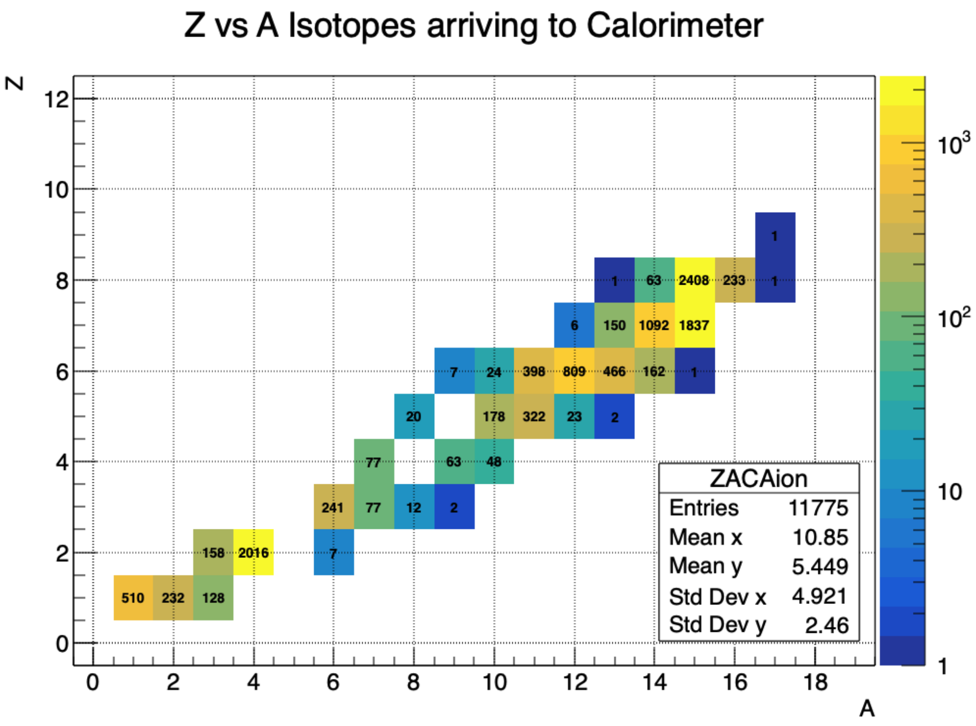
GSI 2021: TW vs calorimeter (central module)

Charged secondaries produced in target arriving at TW vs CALO

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



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



- Light fragments: we mostly loose them: hardly any light fragments in TW pass by central calo module
- Heavy fragments: we mostly see them!
- Example: Z=8 in Calo, we get 80% of what's in TW, Z=7 we get 70%, … Z=2 we get 10%, Z=1 we get 5%

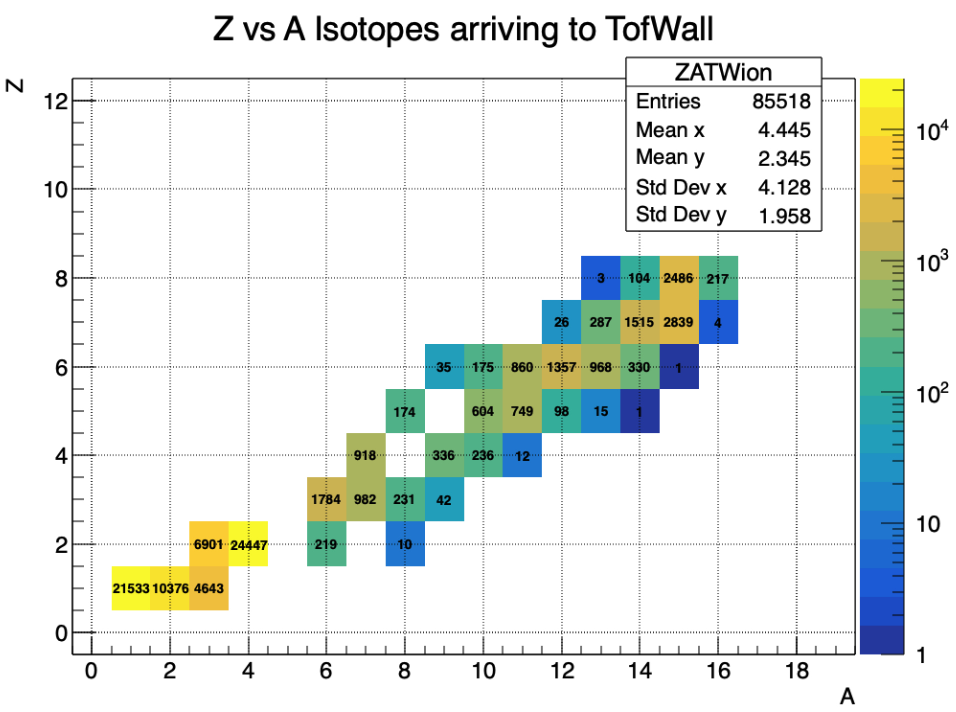
GSI 2021: TW vs calorimeter (central module)

Charged secondaries produced in target arriving at TW vs CALO

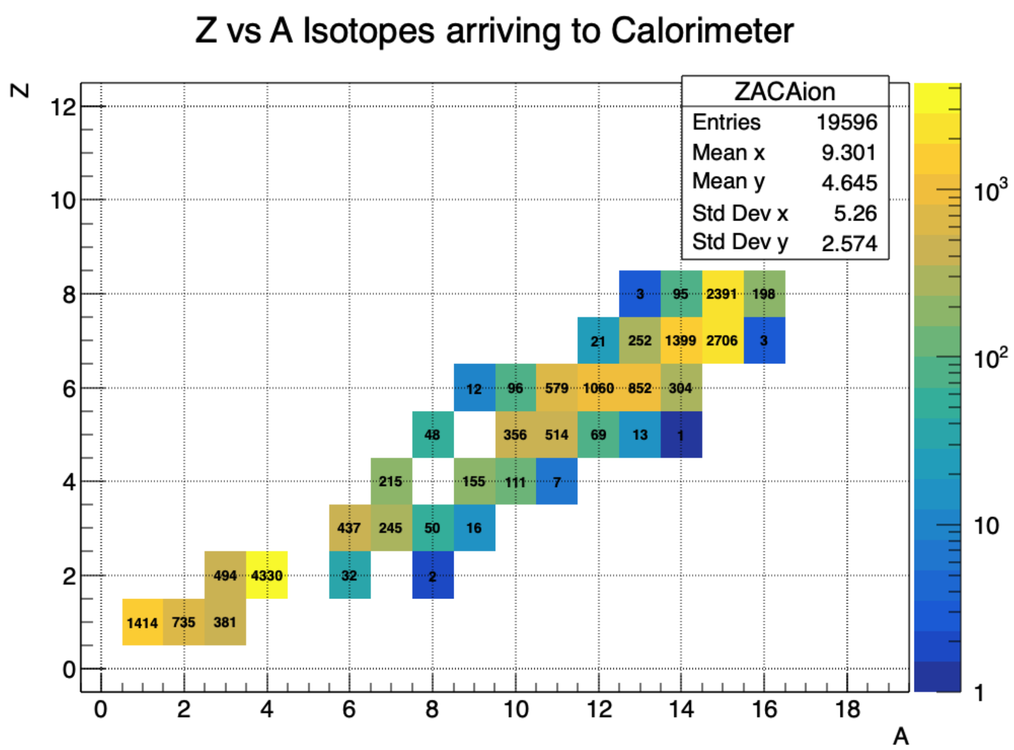
Note that:

$\sigma_{400\ \mathrm{MeV}} < \sigma_{200\ \mathrm{MeV}}$

^{16}O @400 MeV/u – C target – 10^6 primaries



^{16}O @400 MeV/u – C target – 10^6 primaries

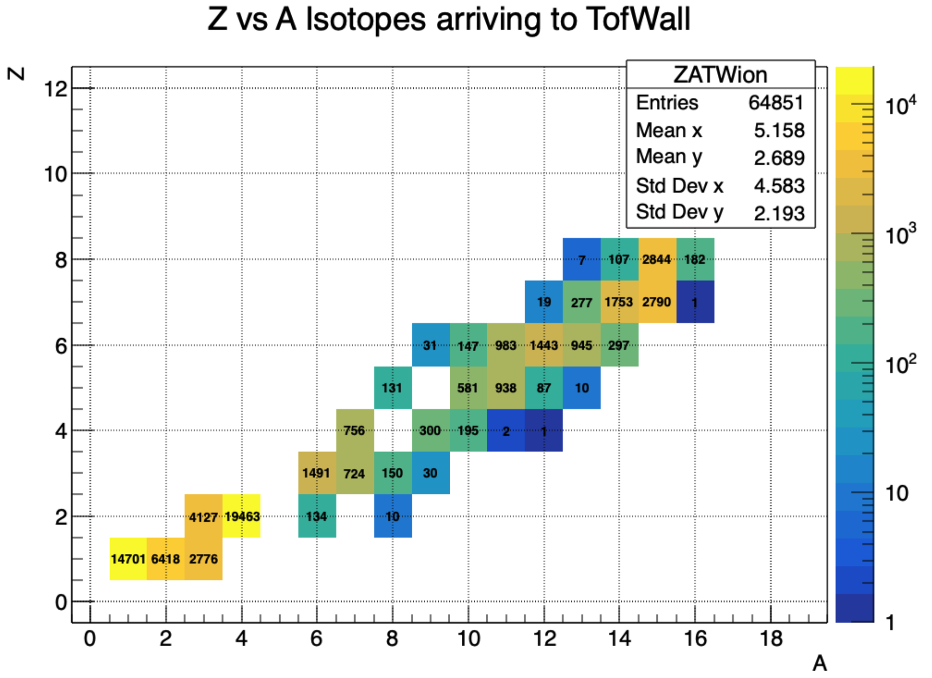


- Light fragments: we mostly loose them
- Heavy fragments: we mostly see them
- Example: Z=8 we get about 100% in Calo of what we get in TW!!!!

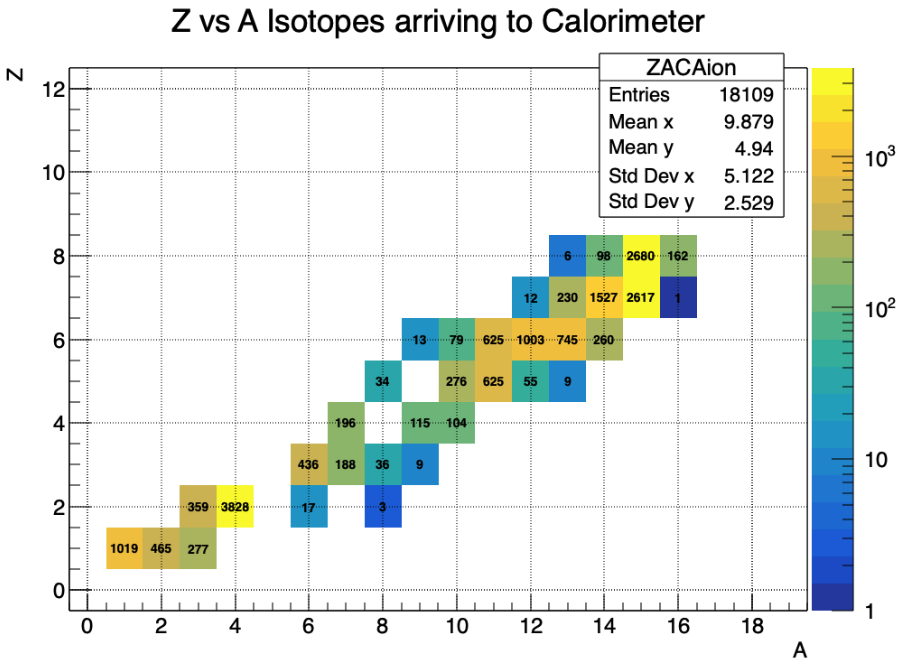
GSI 2021: TW vs calorimeter (central module)

Charged secondaries produced in target arriving at TW vs CALO

^{16}O @400 MeV/u – C2H4 target – 10^6 primaries



^{16}O @400 MeV/u – C2H4 target – 10^6 primaries



- Light fragments: we mostly loose them
- Heavy fragments: we mostly see them
- Example: Z=8 we get 93% in Calo with respect to TW

Conclusions

1. Conclusion from CNAO2020 studies: For measurements, 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.
2. Consider possibility to use target of 1 cm for C_2H_4
3. We had a first look at A reconstruction with 9 calorimeter crystals
   - CNAO2020 setup, 200 MeV/u ^{12}C on C target
4. GSI preliminary numbers: we believe that ”CNAO2020” numbers in 1) still hold
5. More detailed discussion in next physics meeting
6. In central calo model can study A reconstruction of heavy fragmenst: Z=8, 7, 6 …
7. To be done:
   - Analyze GSI samples available since a few days
   - Upgrade to newgeom branch
   - Decide strategy on how to determine A and Z cross feed and efficiency in more detail

See also

https://agenda.infn.it/event/25078/contributions/127067/attachments/81143/106200/2021_April_FOOTExpectedMassResolution_v1.pdf

https://agenda.infn.it/event/24595/contributions/126307/attachments/77646/100112/20201210_FOOTCollaborationMeeting_v1.pdf

THANKS

Backup Slides

Software used

- Ran DecodeMC on CNAO2020 production: ^{12}C on C target 10^7 primaries
- Master branch (March 30 2021)
- Macro developed starting from Giuseppe’s/Yun’s ReadShoe.C and Lorenzo’s PrintCalClusMcInfo.C (and shoe tutorial studied)
  - MC truth
    - TAMCntuhits (using shoe-tree branches of TW, Calo, STC)
    - mcNtuEve
  - MC local reco
    - TATWntuPoint for TW
    - TACAntuCluster for calorimeter

Reminder: cross section formulas

- Goal of FOOT: measure (single and double differential) cross sections of heavy ion beams (C, O) on tissue like targets (H, C, O)
- Reminder: cross section for production of fragments ***i*** on target (neglecting efficiency factors)

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

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

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

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

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

- For the targets inherited from GSI:
  - $\delta_C = \delta_{C_2H_4}$= 5 mm, ρ_C = 1.83 g/cm^3, $\rho_{C_2H_4}$= 0.94 g/cm^3, A_C ~12 g mol^{-1}, $A_{C_2H_4}$~28 g mol^{-1}

Reminder: cross section formulas

- Reminder: **statistical errors** on cross section for production of fragment ***i*** on target (neglecting efficiency factors). Essentially they are only determined by the yield of the detected fragments

$$\Delta\sigma_{i,t} = \frac{\sqrt{Y_{i,t}}}{N_p}\,\frac{A_t}{N_A\,\rho_t\,\delta_t}$$ **(3)**

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 = Avogado’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

$$\Delta\sigma_{i,C} = \frac{\sqrt{Y_{i,C}}}{N_p}\,\frac{A_C}{N_A\,\rho_C\,\delta_C}$$ **(3a)**

$$\Delta\sigma_{i,C_2H_4} = \frac{\sqrt{Y_{i,C_2H_4}}}{N_p}\,\frac{A_{C_2H_4}}{N_A\,\rho_{C_2H_4}\,\delta_{C_2H_4}}$$ **(3b)**

$$\Delta\sigma_{i,H} = \frac{1}{4}\sqrt{(\Delta\sigma_{i,C_2H_4})^2 + 4(\Delta\sigma_{i,C})^2}$$ **(4)**

- For the targets inherited from GSI:
  - $\delta_C = \delta_{C_2H_4}$ = 5 mm, ρ_C = 1.83 g/cm^3, . $\rho_{C_2H_4}$ = 0.94 g/cm^3, A_C ~12 g mol^{-1}, $A_{C_2H_4}$ ~28 g mol^{-1}

$$\Delta\sigma_{i,t} = \frac{\sqrt{Y_{i,t}}}{N_p}\,\frac{A_t}{N_A\rho_t\delta_t}$$

Note that targets have the same thickness → for the same nr. of primaries, the measurement with the C_2H_4 target, having a density smaller by a factor of ~2 w.r.t. the carbon target, will have a larger relative statistical error

What errors do we expect?

- What can we expect for $\Delta\boldsymbol{\sigma}_{i,H}$, $\Delta\boldsymbol{\sigma}_{i,C}$ and $\Delta\boldsymbol{\sigma}_{i,C_2H_4}$ if the same number of primaries is used on both targets? (efficiencies same)
- Using 200 MeV/u carbon ions, assuming similar cross sections , we estimate for fragment type ***i*** for our targets:

$$\frac{Y_{i,C}}{Y_{i,C_2H_4}} = \frac{\boldsymbol{\sigma}_{i,C}}{\boldsymbol{\sigma}_{i,C_2H_4}} \frac{\rho_C}{\rho_{C_2H_4}} \frac{A_{C_2H_4}}{A_C} \qquad \textbf{(5)}$$

$$\frac{Y_{i,C}}{Y_{i,C_2H_4}} \approx 4.54 \frac{\boldsymbol{\sigma}_{i,C}}{\boldsymbol{\sigma}_{i,C_2H_4}} \approx \mathbf{1.4} \qquad \textbf{(7)}$$

From previous publications and simulations:

$$\frac{\boldsymbol{\sigma}_{tot,C}}{\boldsymbol{\sigma}_{tot,C_2H_4}} \approx 0.3 \qquad \textbf{(6)}$$

This is for $\boldsymbol{\sigma}_{tot,C}$ but may depend on fragment type i

$$\begin{aligned}\Delta\sigma_{i,H} &= \frac{1}{4}\sqrt{(\Delta\sigma_{i,C_2H_4})^2+4(\Delta\sigma_{i,C})^2} \\ &= \frac{1}{4}\sqrt{(3.8\Delta\sigma_{i,C})^2+4\Delta\sigma_{i,C}^2} \\ &\approx \frac{1}{4}\sqrt{18.8}\Delta\sigma_{i,C}\,\Delta\sigma_{i,C} \approx \mathbf{1.08\,\Delta\boldsymbol{\sigma}_{i,C}}\end{aligned} \qquad \textbf{(9)}$$

$$\frac{\Delta\boldsymbol{\sigma}_{i,C_2H_4}}{\Delta\boldsymbol{\sigma}_{i,C}} = \sqrt{\frac{Y_{i,C_2H_4}}{Y_{i,C}} \frac{\rho_C\,A_{C_2H_4}}{\rho_{C_2H_4}A_C}} \approx \sqrt{\frac{1}{1.4}}\,4.54 \approx \mathbf{3.84} \qquad \textbf{(8)}$$

What errors do we expect?

- But actually, what matters are the relative errors… $\frac{\boldsymbol{\Delta\sigma_{i,H}}}{\boldsymbol{\sigma_{i,H}}}$ $\frac{\boldsymbol{\Delta\sigma_{i,C}}}{\boldsymbol{\sigma_{i,C}}}$

$$\sigma_{i,H} = \frac{1}{4}\left(\sigma_{i,C_2H_4} - 2\sigma_{i,C}\right) = \frac{1}{4}\sigma_{i,C}\left(\frac{\sigma_{i,C_2H_4}}{\sigma_{i,C}} - 2\right) \sim \frac{1}{4}\sigma_{i,C}\left(\frac{1}{0.3} - 2\right) \sim \mathbf{0.33}\ \boldsymbol{\sigma_{i,C}}$$

$$\Delta\sigma_{i,H} \approx \mathbf{1.08}\ \boldsymbol{\Delta\sigma_{i,C}} \qquad \textbf{(9)}$$

$$\frac{\boldsymbol{\Delta\sigma_{i,H}}}{\boldsymbol{\sigma_{i,H}}} \sim \frac{1.08}{0.33}\frac{\boldsymbol{\Delta\sigma_{i,C}}}{\boldsymbol{\sigma_{i,C}}} \sim 3.3\ \frac{\boldsymbol{\Delta\sigma_{i,C}}}{\boldsymbol{\sigma_{i,C}}} \qquad \textbf{(10)}$$

For the same nr of primaries in both target runs, relative cross section error on H is > 3 times larger than that on C (the most accurate case)…

- Does it depend on i? (type of fragment?) → see slide 9 and further (MC)

What if we double the statistics of the C_2H_4 run?

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

$$\frac{\Delta\sigma_{i,H}}{\sigma_{i,H}} \sim 2.5\,\frac{\Delta\sigma_{i,C}}{\sigma_{i,C}} \qquad (12)$$

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

$$\frac{\Delta\sigma_{i,H}}{\sigma_{i,H}} \sim 2.1\,\frac{\Delta\sigma_{i,C}}{\sigma_{i,C}} \qquad (13)$$

Decrease of statistical error is slow…

- In the case of $d\sigma/dE$ and $d\sigma/d\Omega$, the correct numerical factor of course depends on the actual value of $\frac{\sigma_{i,C_2H_4}}{\sigma_{i,C}}$ (or equivalently $\frac{Y_{i,C_2H_4}}{Y_{i,C}}$) in each ΔE, $\Delta\Omega$ bin for each secondary fragment type of interest, ***i***

Note

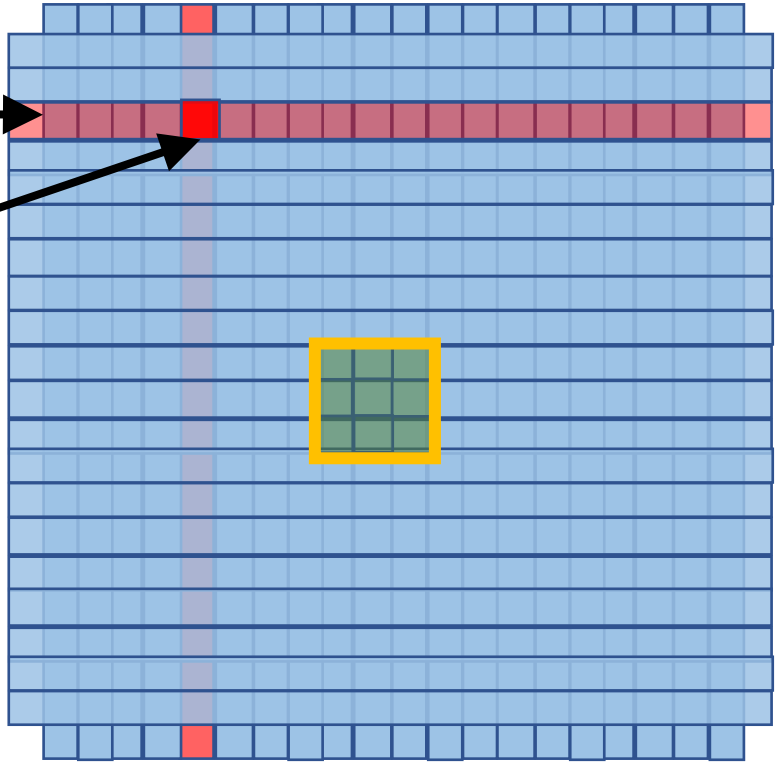
A factor 2 more for the C_2H_4 target than for C target the is the 'minimum' we should do (assuming same target thicknesses of 5 mm for now. We can also increase them if needed…)

Let's now try to confirm some of these considerations with MC and check behaviour of different fragments

- Determine energy and TOF in front and rear bars (TAMCntuHit *twMChits)
- 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:

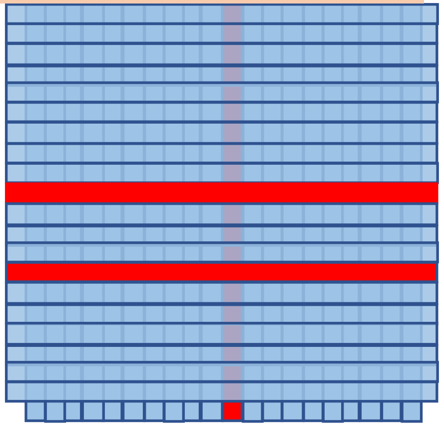
$$\frac{|E_F - E_R|}{(E_F + E_R)/2} < 0.05$$

- If position passes, call it '**fired position**'
- For a selected position, find the corresponding hit and evaluate true Z and A
  - Makes only sense when 1 fragment passes per position
- If a fired position is one of the **9** central positions, call it '**good**' 🟩

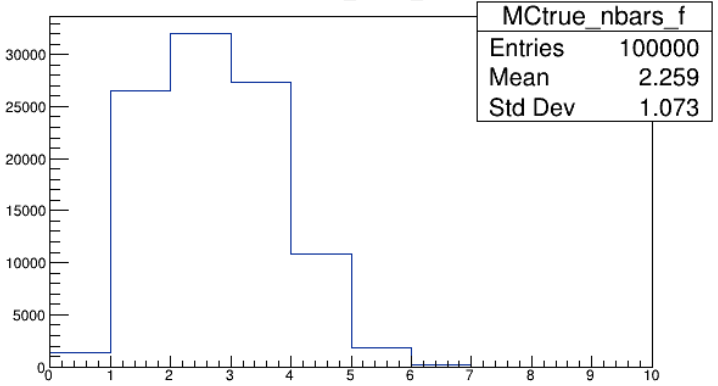


For each event, count N_{bars}, i.e., number of bars that are fired (=DeltaE>1)

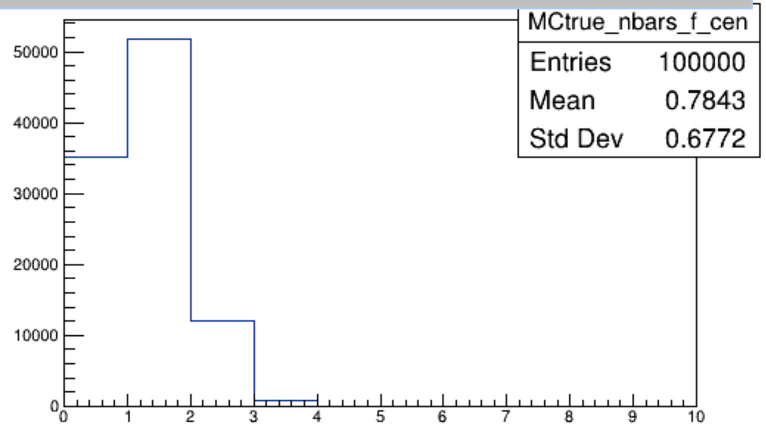
Example:
$N_{bars,F}$=2
$N_{bars, R}$=1



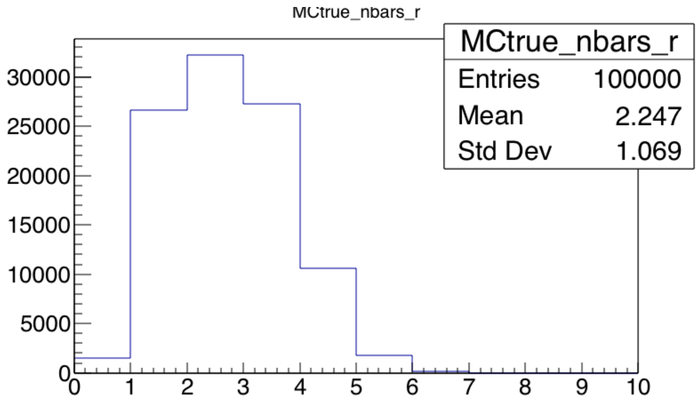
Whole TW: MC truth N_{bars} in front



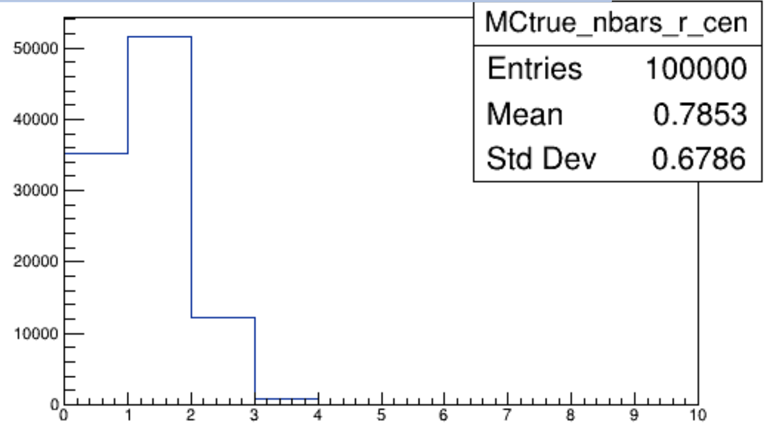
Central bars (8,9,10): MC truth: N_{bars} in front



Whole TW: MC truth N_{bars} in rear

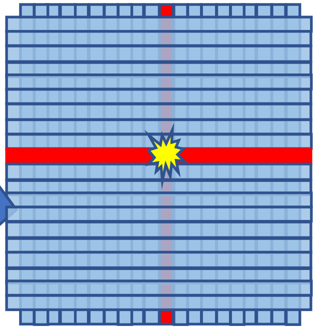


Central (8, 9, 10):MC truth: N_{bars} in rear

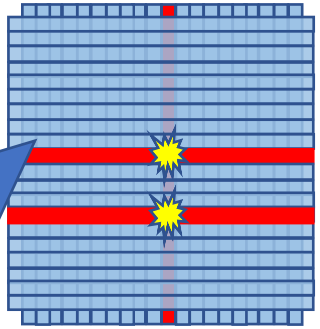


- In whole TW, average nr of hit bars per layer ~2.2
- Even when considering only central bars, still often multiple bars fired

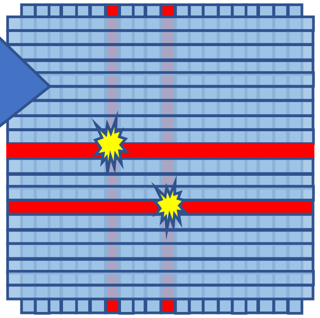
Example:
Event has N_{pos}=1, since energy deposit in F and R is typically similar



Such events are mostly (but not fully, see next slide) excluded, since F and R deposits typically don't match

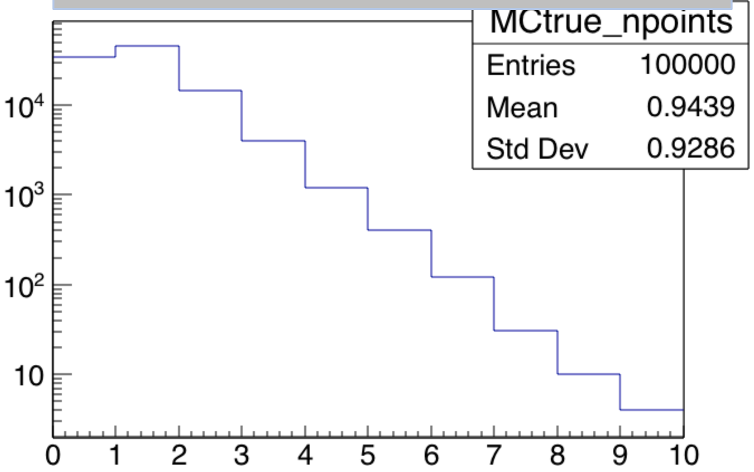


Events like this would typically result in N_{pos}=2, given that two different fragments leave different energy deposit

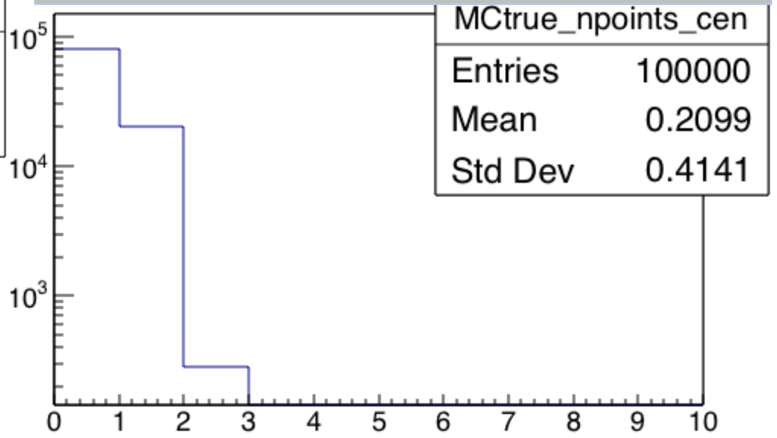


- For each event, evaluate how many of the positions are 'fired positions' (strongly correlated with nr of fragments passing)

Nr of positions N_{pos} fired per event (entire TW)

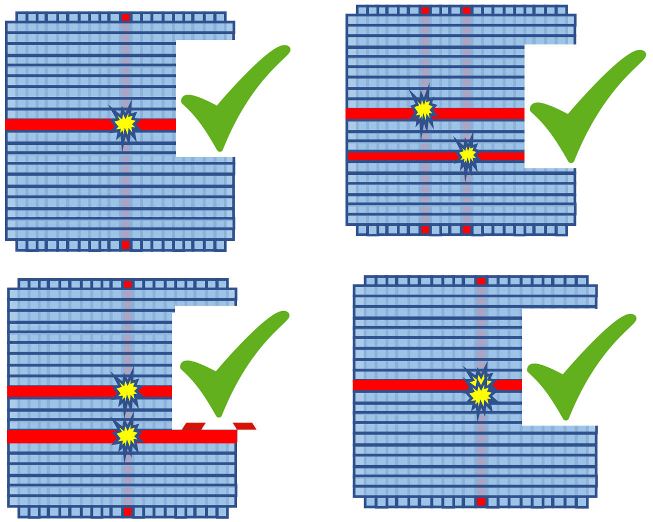


Nr of good positions N_{pos} fired per event (central positions)

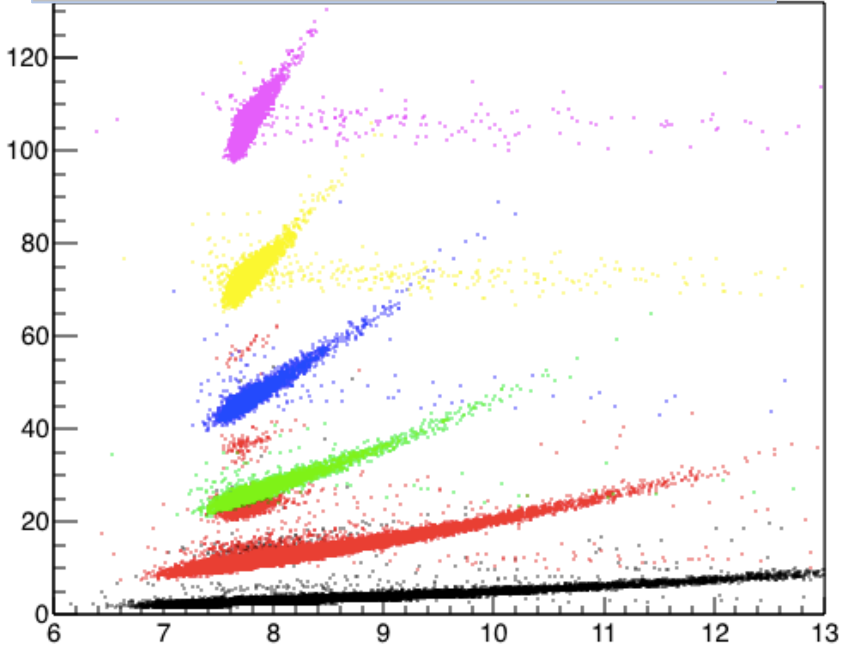


- About 65% of all events fire at least 1 position in the TW
- About 15% of all events fire at least 2 positions in the TW
- About 20% of all events fire at least 1 good position (with calorimeter crystal behind)

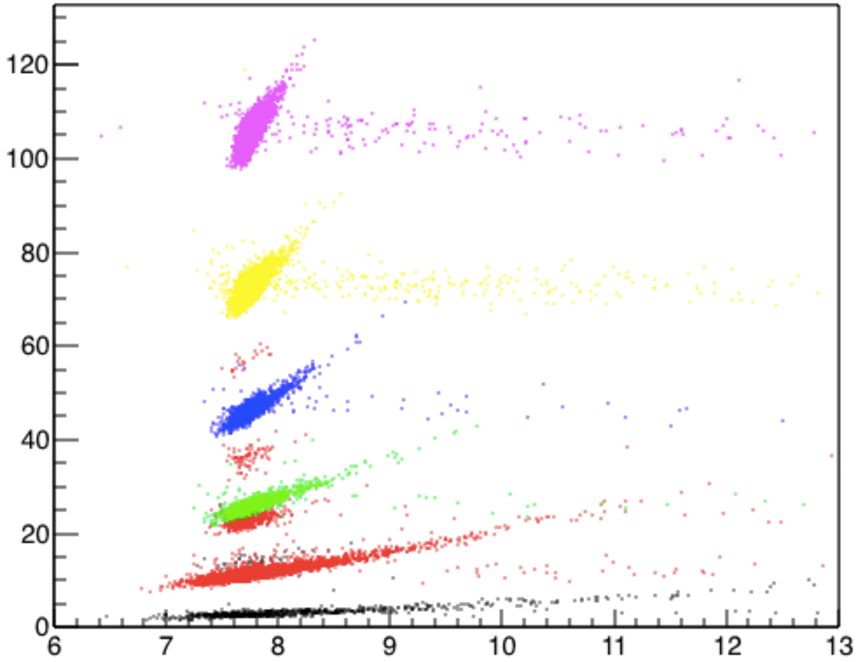
For each event, evaluate for the fired positions ΔE_{SCN} vs TOF



MC truth: ΔE_{SCN} vs TOF in whole TW

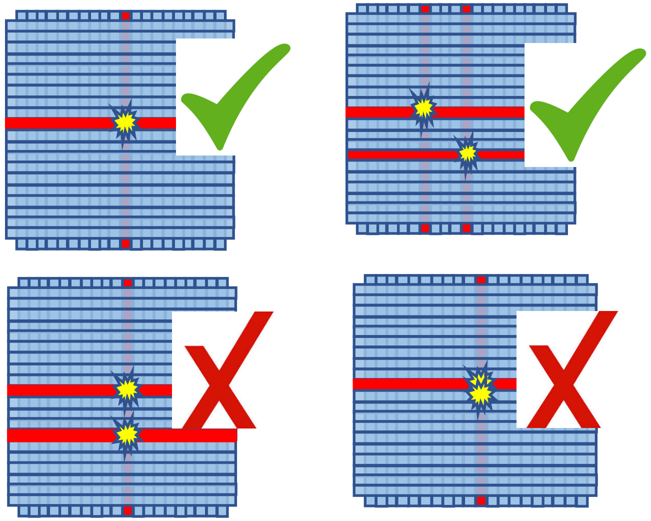


MC truth: ΔE_{SCN} vs TOF in centre TW

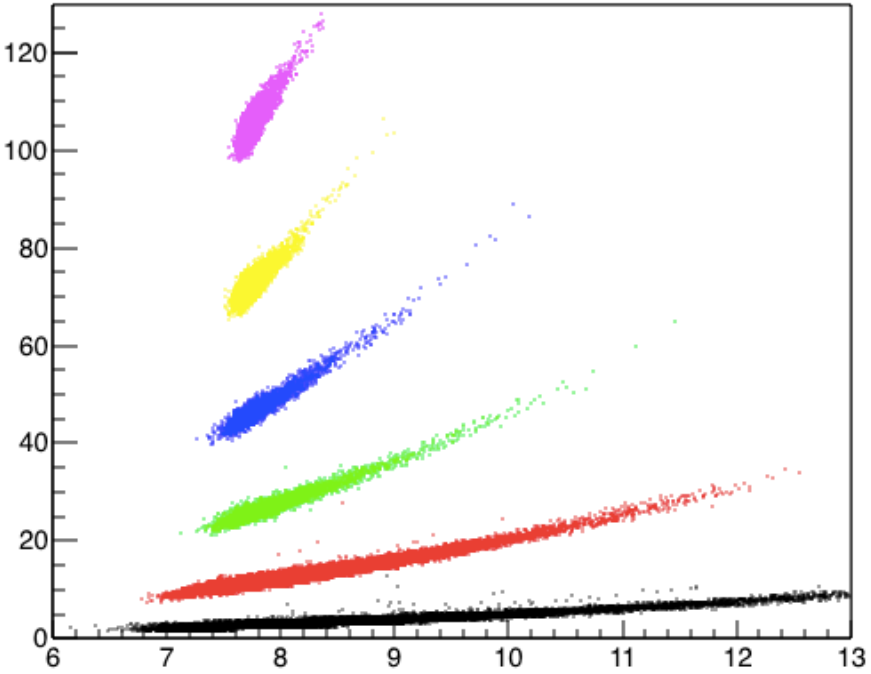


- In centre positions, dominated by heavy fragments (no surprise)
- Positions associated to bars with more than 1 hit can disturb Z identification. But only at most 6%.

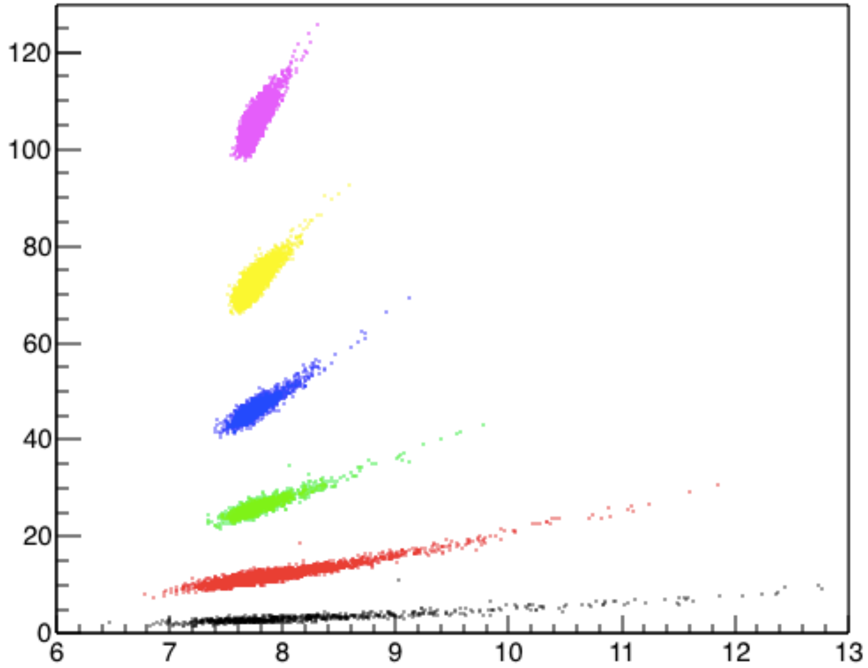
For each event, select the fired positions (see slide 4) that are associated with bars that have N_{hits}=1
Evaluate ΔE_{SCN} vs TOF



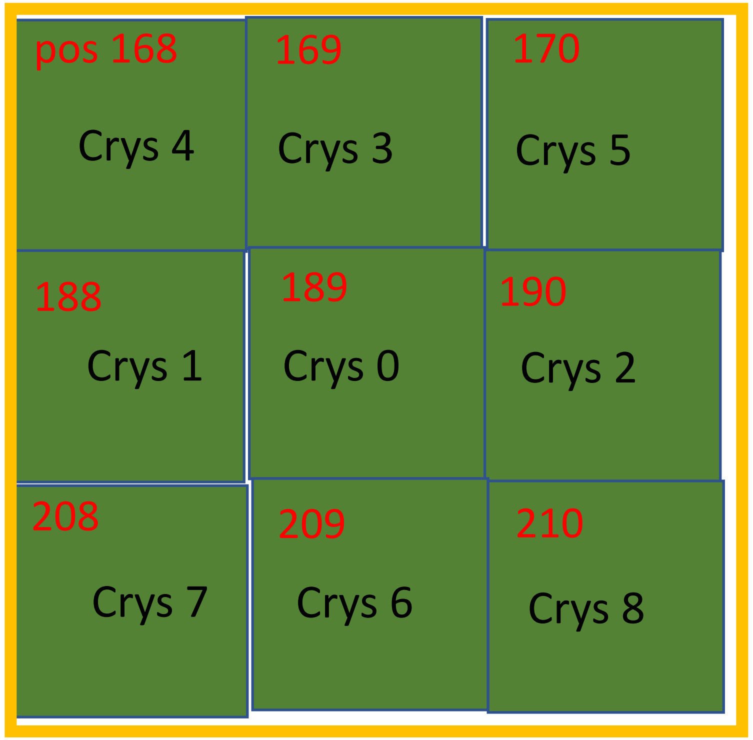
ALL MC truth: ΔE_{SCN} vs TOF in whole TW



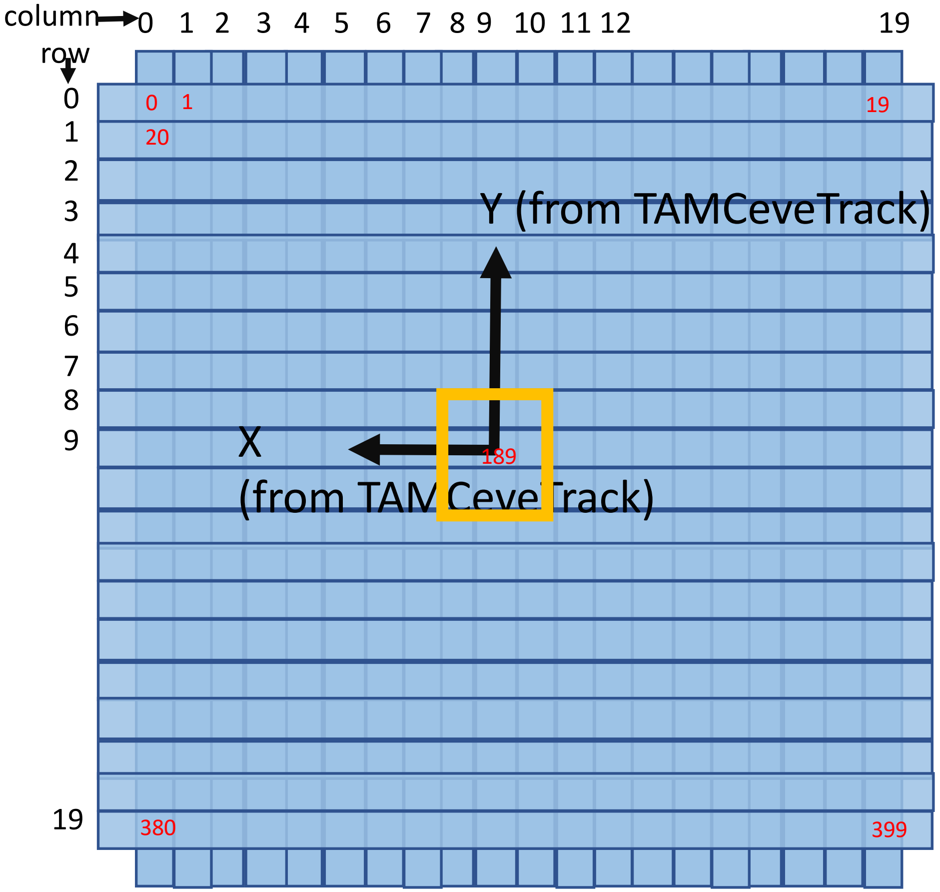
CENTRE MC truth: ΔE_{SCN} vs TOF in centre T



Excluding such events with bars with double-hits, distribution is clean

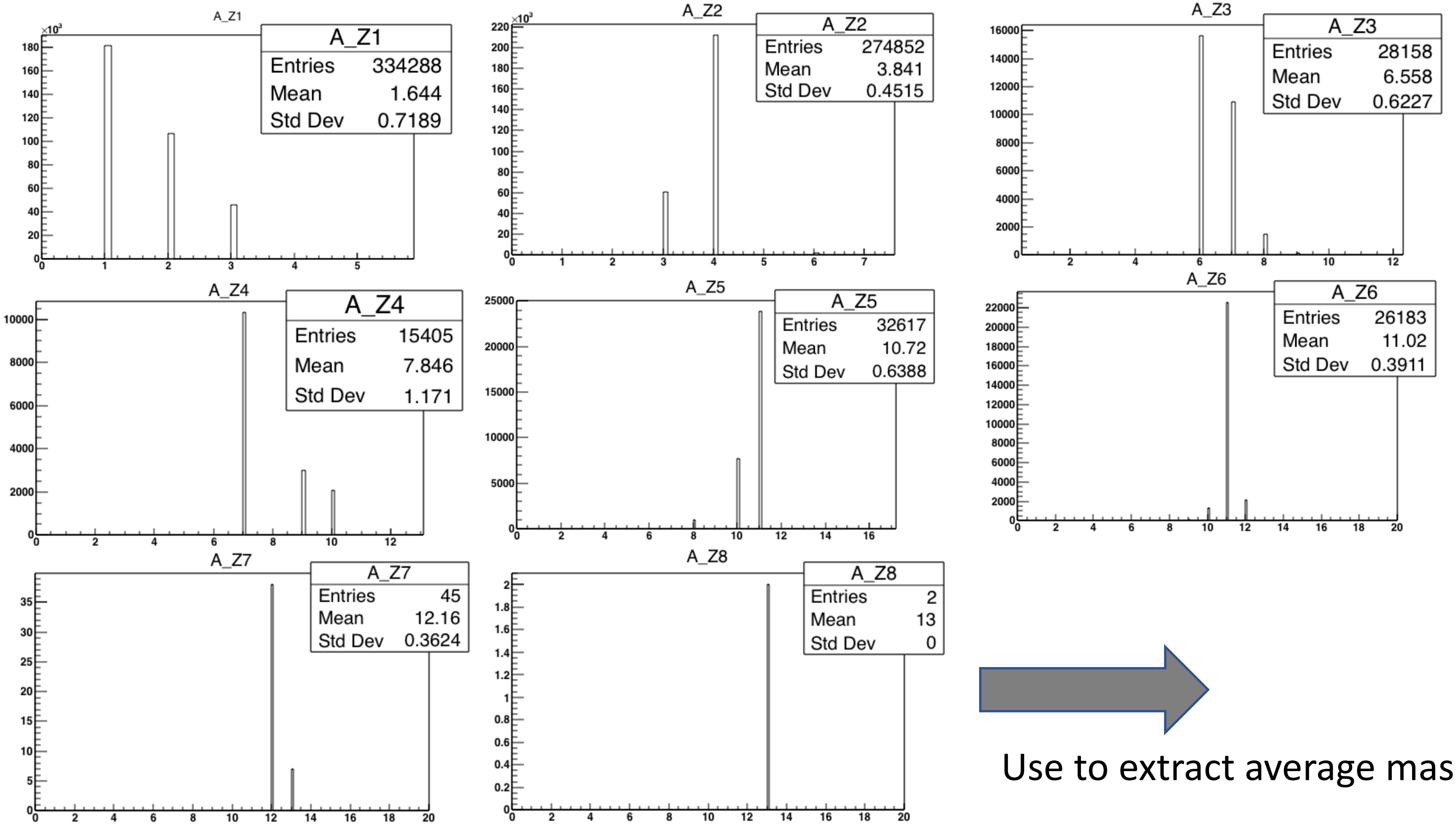


pos 168 Crys 4	169 Crys 3	170 Crys 5
188 Crys 1	189 Crys 0	190 Crys 2
208 Crys 7	209 Crys 6	210 Crys 8



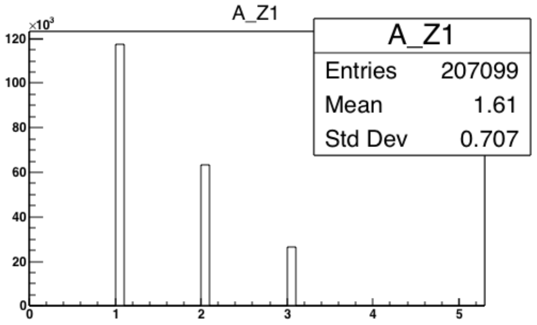
(0,0) in front bar 9 and rear bar 9

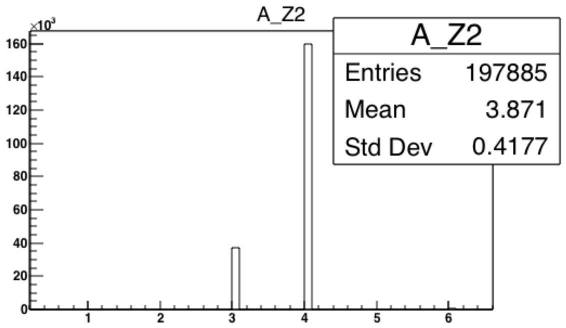
Mass isotopes for carbon target

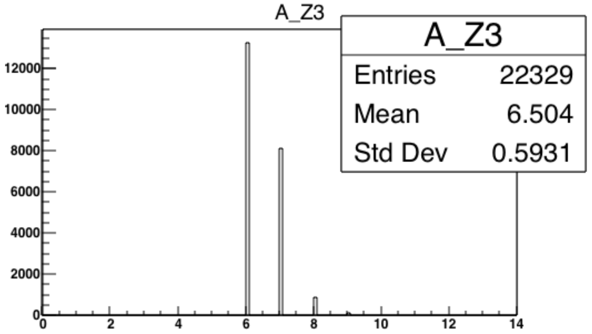


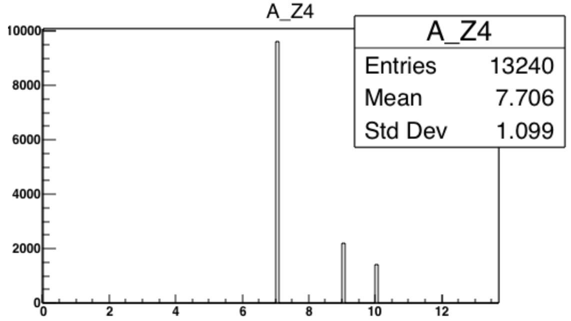
Use to extract average mass for carbon target

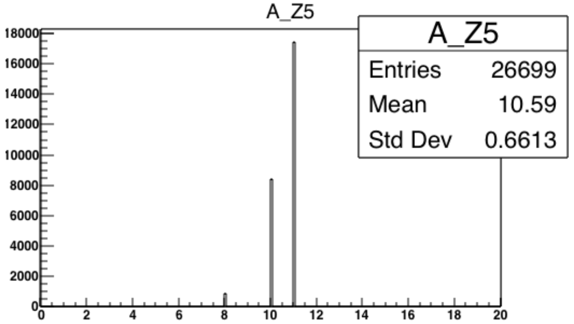
Mass isotopes for C_2H_4 target

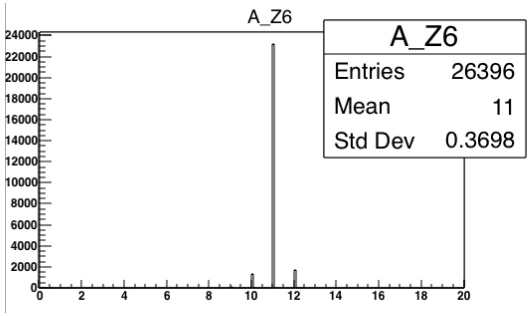


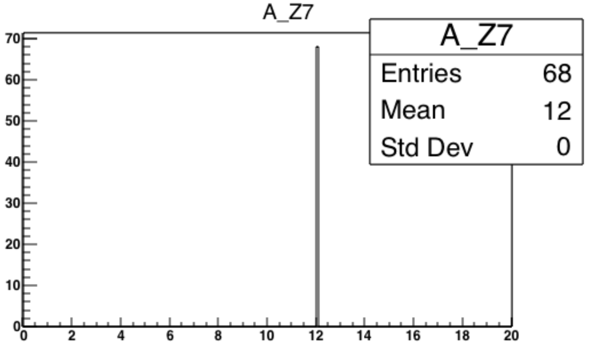


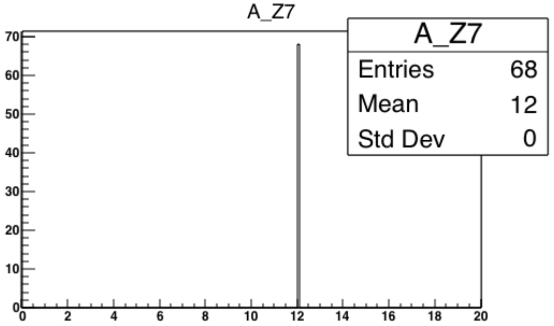












Use to extract average mass for C2H4 target

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