^{4}He-C Cross Sections and first MC Simulation for HIT2022 data taking

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FOOT Collaboration Meeting
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Available Fragmentation Channels

Using ^{4}He projectiles, the only final state channels (excluding target fragmentation) are:

~as many 3He as t are expected

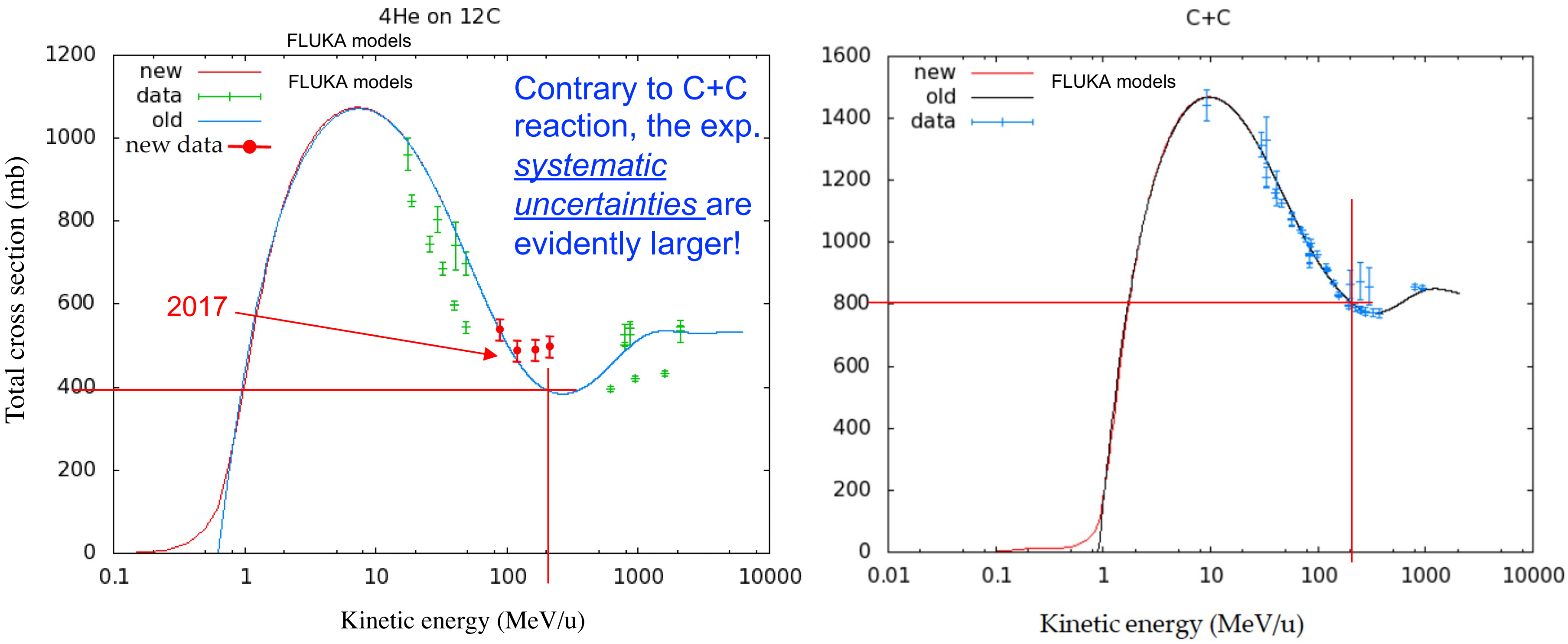
$$^{4}He \rightarrow \begin{cases} n + {}^{3}He \\ p + {}^{3}H \\ {}^{2}H + {}^{2}H \\ n + p + {}^{2}H \\ n + n + p + p \\ \left[\ {}^{4}He + X,\ {}^{4}He + X^{*}\ \right] \end{cases}$$

$$X^{*} \rightarrow X + \gamma$$

It would be fundamental to aim to both Z & A identification using the BGO modules, even in a limited solid angle

$E_{sep}(^{4}He \rightarrow n+{}^{3}He) = E_{bind}(^{4}He) - E_{bind}(^{3}He) = 28.3 - 7.7 = 20.6$ MeV

$E_{sep}(^{4}He \rightarrow {}^{2}H + {}^{2}H\ ) = E_{bind}(^{4}He) - E_{bind}(^{2}H) = 28.3 – 2.23 = 26.07$ MeV



@200 MeV/u we expect a reaction cross section ~1/2 of what we get using ^{12}C projectiles

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Measurement of charge- and mass-changing cross sections for $^{4}He + ^{12}C$ collisions in the energy range 80–220 MeV/u for applications in ion beam therapy

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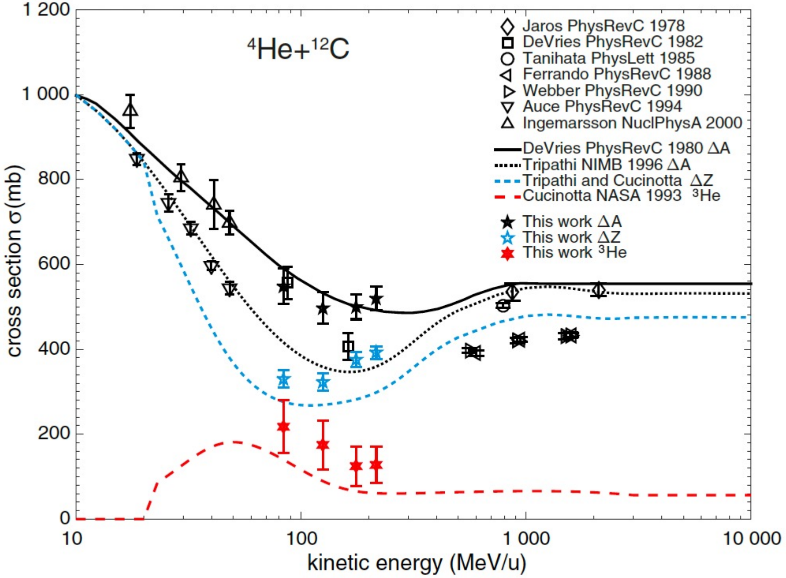
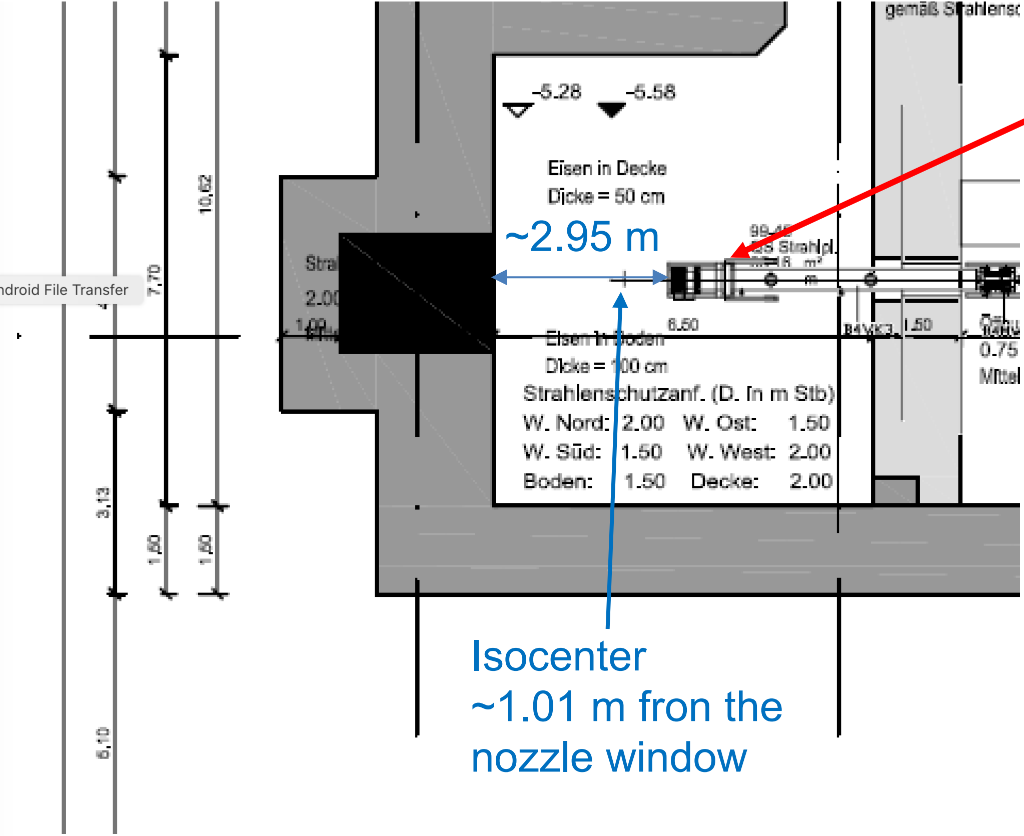
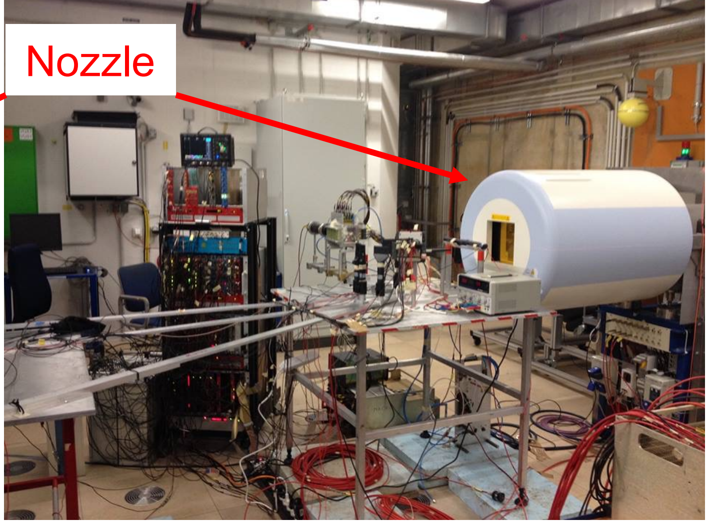
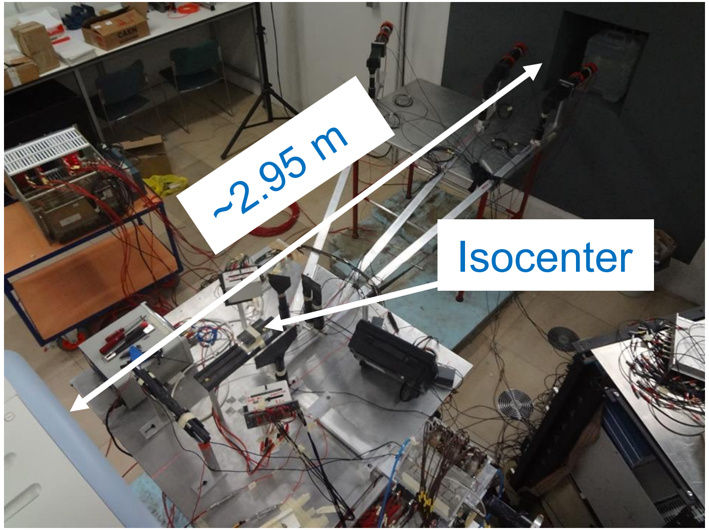


TABLE I. Cross sections for mass-changing, charge-changing and ^3He producing reactions by ^4He ions on ^{12}C targets at four different kinetic energies.

Kinetic Energy (MeV/u)	Mass-changing cross section $\sigma_{\Delta A}$ (mb)	Charge-changing cross section $\sigma_{\Delta Z}$ (mb)	^3He production cross section $\sigma_{^3He}$ (mb)
83.5 ± 6.5	548 ± 47	330 ± 25	218 ± 72
125 ± 5	497 ± 40	323 ± 23	174 ± 63
176 ± 4	500 ± 35	376 ± 23	124 ± 58
216 ± 4	520 ± 32	392 ± 19	128 ± 51







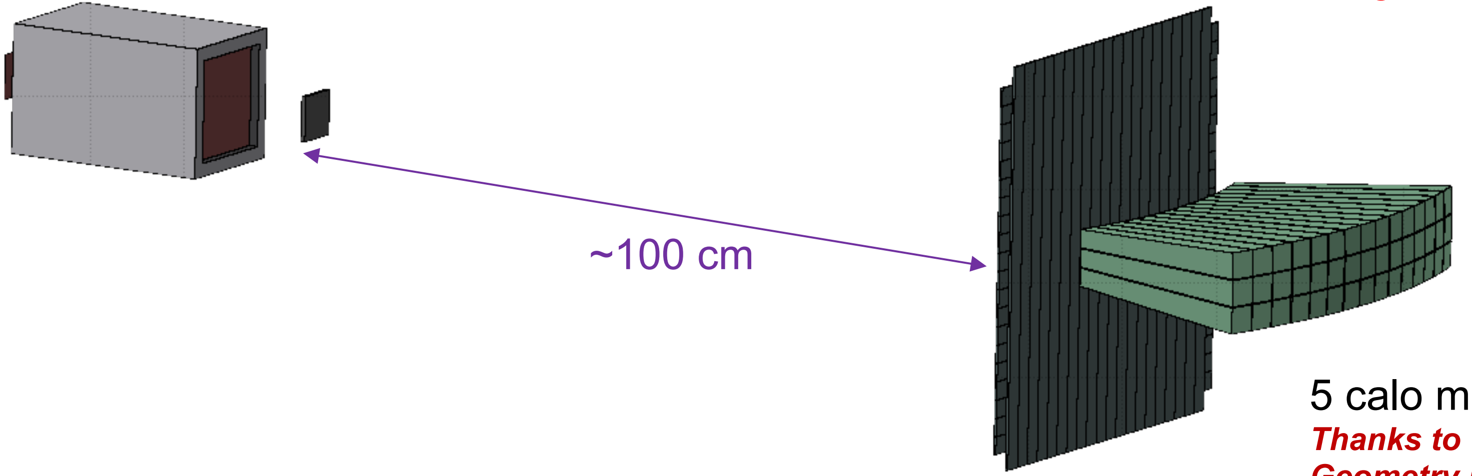
Let us assume the standard FOOT baseline of 100 cm distance between target and TW

Notice: although there are advantages, it’s not strictly mandatory for us to place the target exactly in the isocenter

Preliminary MC layout

No MSD version

HIT2022_MC
campaign in the
newgeom branch

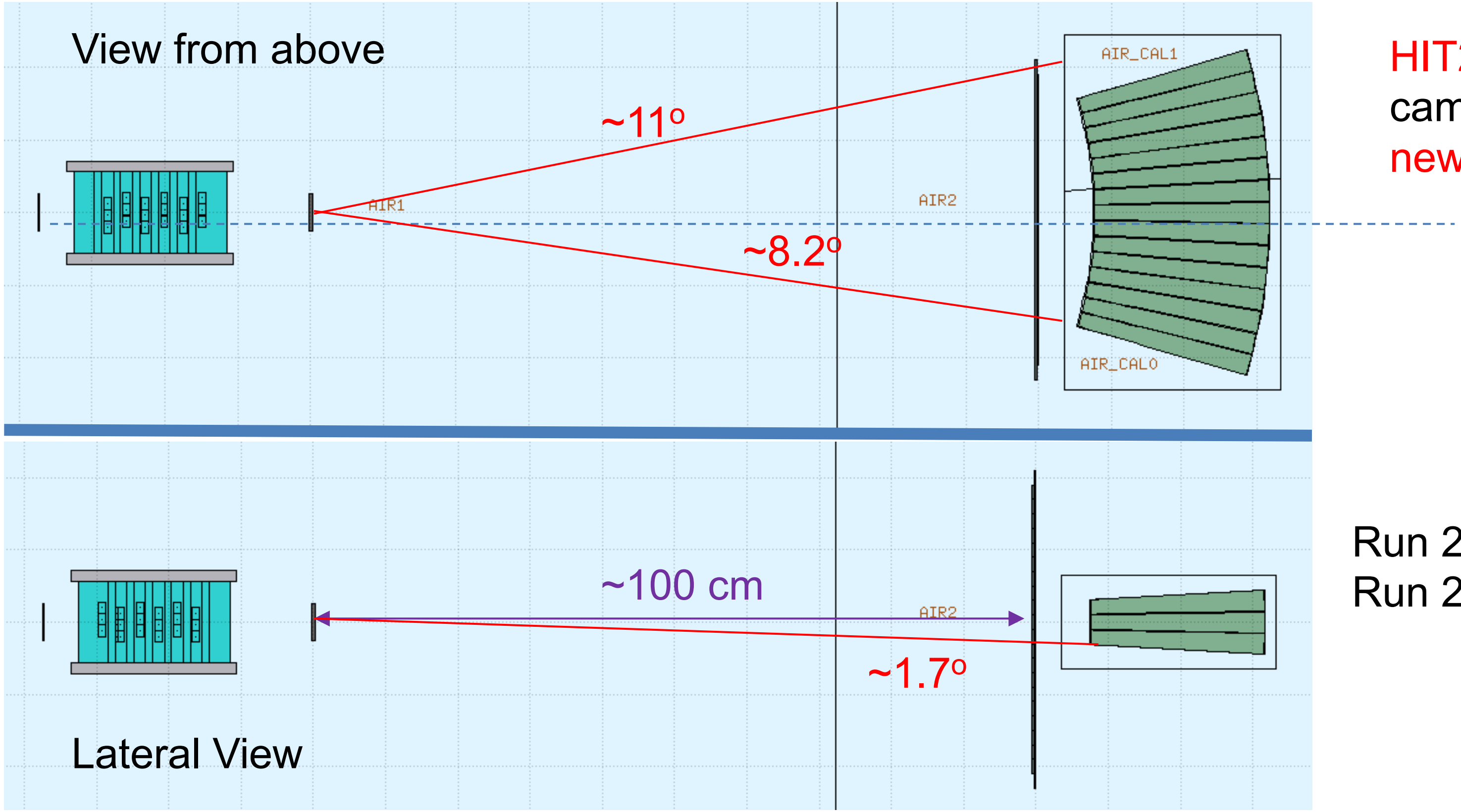


5 calo modules

Thanks to the new calo Geometry implemented by L. Scavarda

As for GSI2021: at present positioning is just a guess, and a definitive geometry can be established only after detector mounting

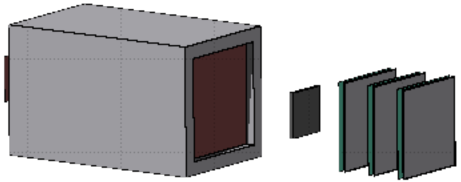
Preliminary MC layout

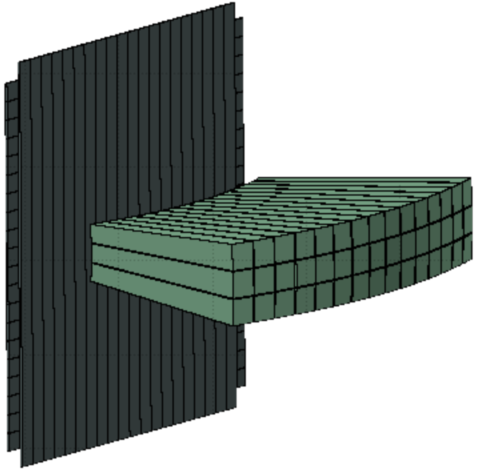


HIT2022_MC campaign in the newgeom branch

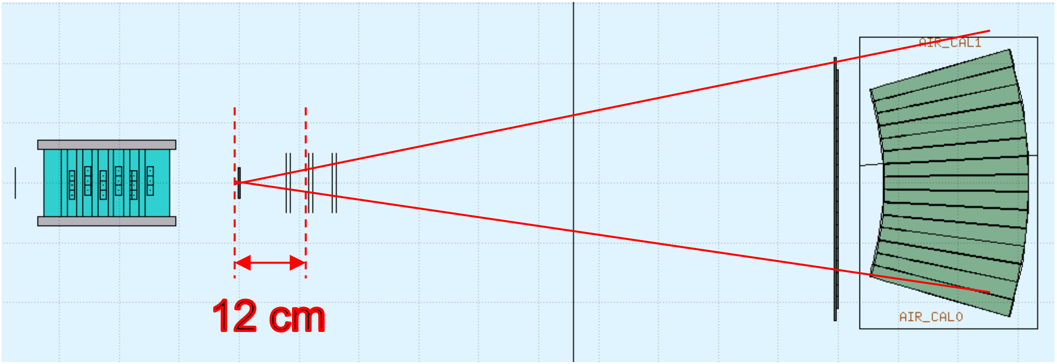
Run 200: C target (0.5 cm)
Run 201: C_2H_4 target (1 cm)

Setup version with MSD





At this time positioning is just a guess!



In this case our suggestion is to have MSD close to target, so to obtain a full angular coverage matched to the TW

One technical detail to remember in SHOE

in config/HIT2022_MC a parameter had to be reduced in TABMdetector.cfg:

//Energy Threshold in GeV on the particle energy release
EnThresh: **0.00001**

In previous campaigns with ^{12}C or ^{16}O was set to 0.0001, but since 4He ionization is lower, that prevented tracking in BM.

A part from simulation issues → This reminds us that it will be important to check actual readout thresholds in the case of real data. Maybe at GSI2019 and 2021 they were too high. The same settings used for protons (see test beams in Trento) must be used.

200 MeV/u + C target (no MSD, no CALO)

Total no. of Processed Events: 5000000
No. of interactions in Air: 134232
No. of interactions in STC: 4015
No. of interactions in BMN: 3767
No. of interactions in TGT: 114296
No. of interactions in VTX: 0
No. of interactions in MSD: 0
No. of interactions in TWL: 84970
No. of primaries interacting before target is 20769

With MSD: ~ 16k/5M ~ 3.2/1000 primary interactions

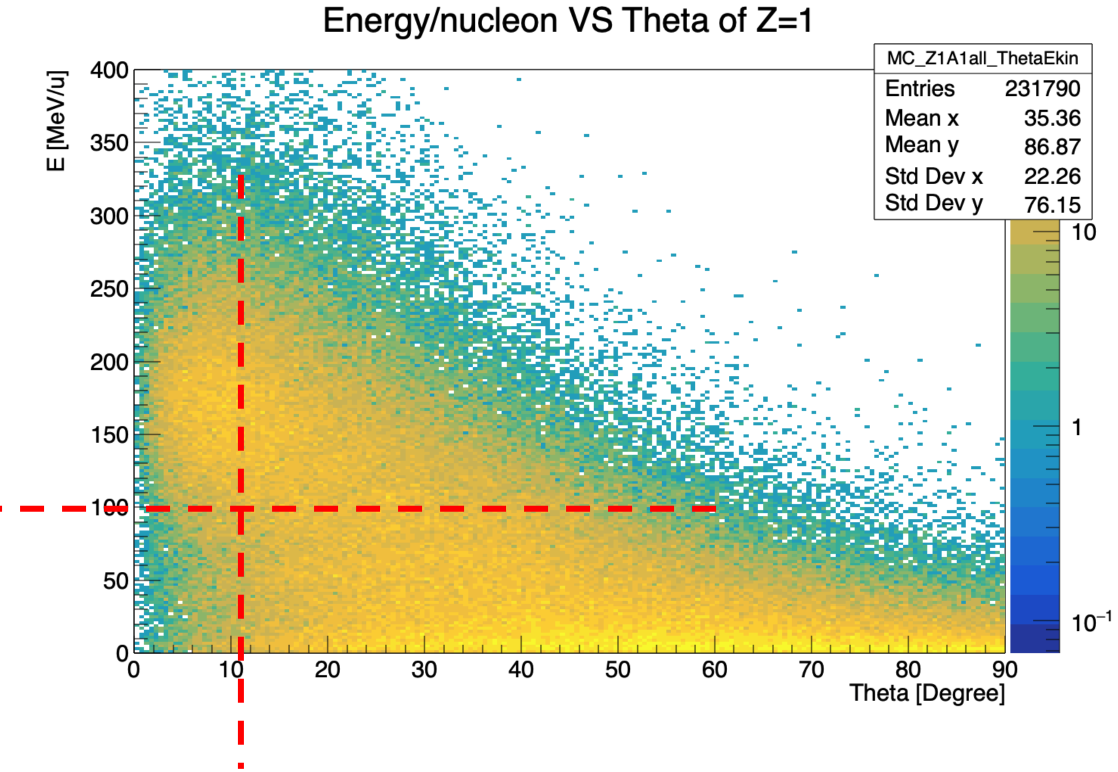
Target Material = C
A_target = 1.201070e+01 rho_target = 1.830000e+00 thickness = 5.000000e-01
N_prim = 4.979231e+06 Ntg = 4.587792e-05

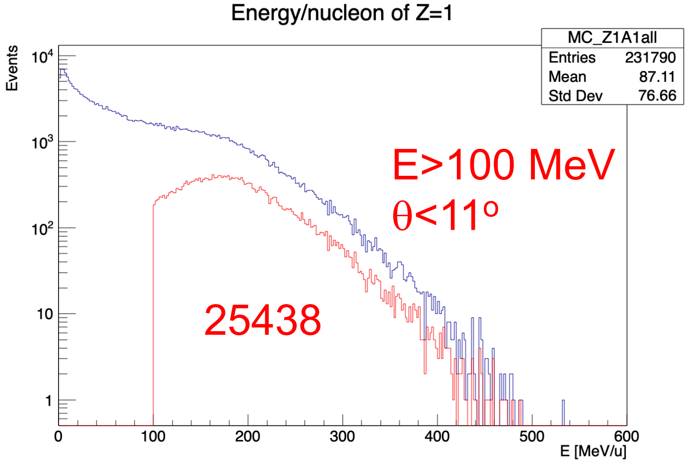
Selection cuts: E_cut = 0.10 Theta_cut = 11.00

N(Z1) with cuts = 64920.00 sigma(Z1) with cuts = 284.19 +/- 1.12 mb
N(Z2) with cuts = 21160.00 sigma(Z2) with cuts = 92.63 +/- 0.64 mb

Some results: Energy and Angle of Protons

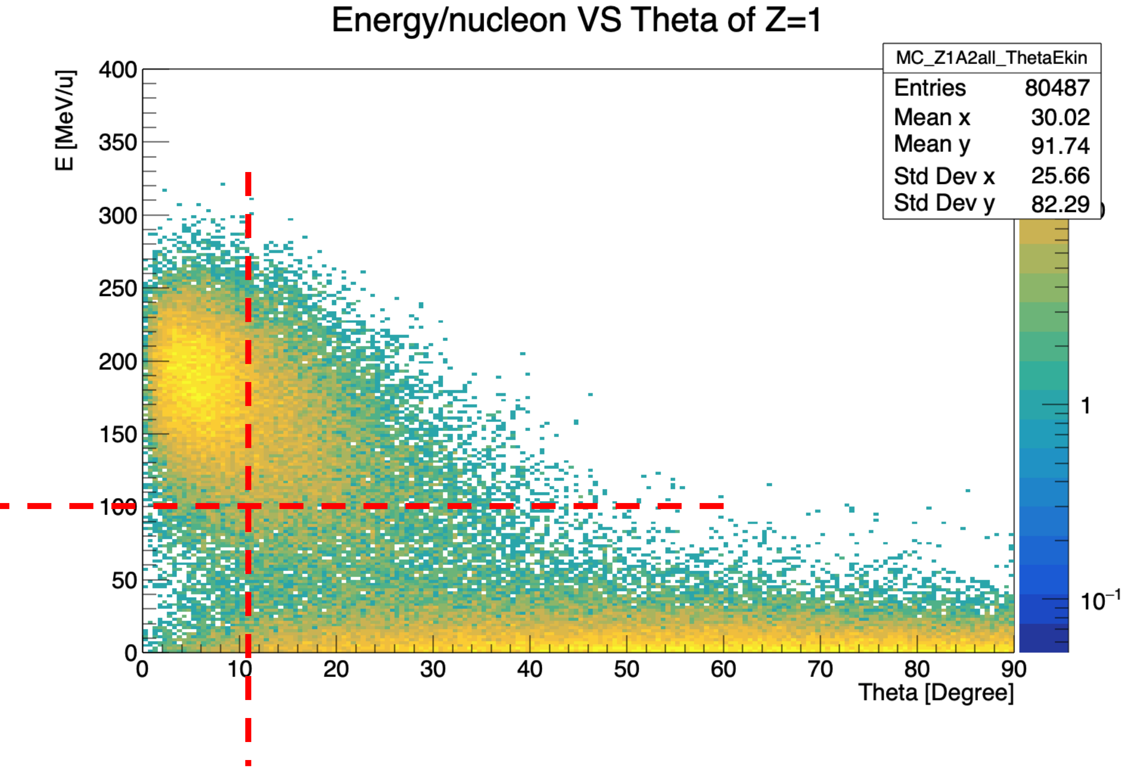
At production in target

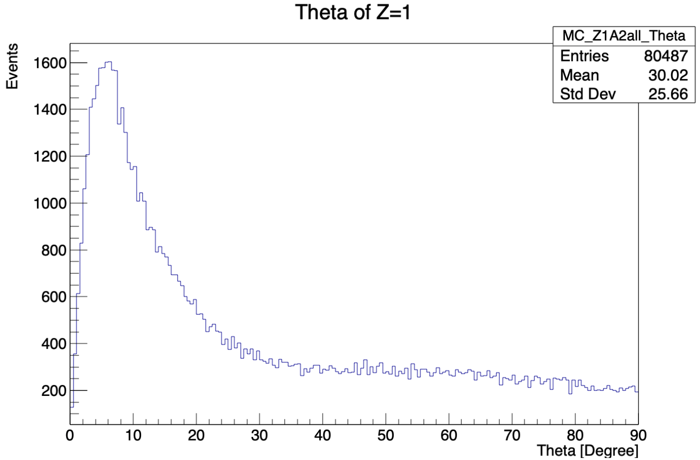


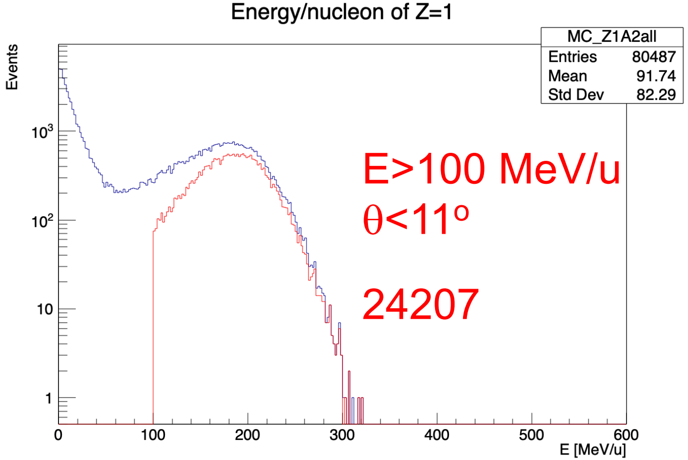


Some results: Energy and Angle of Deuterons

At production in target

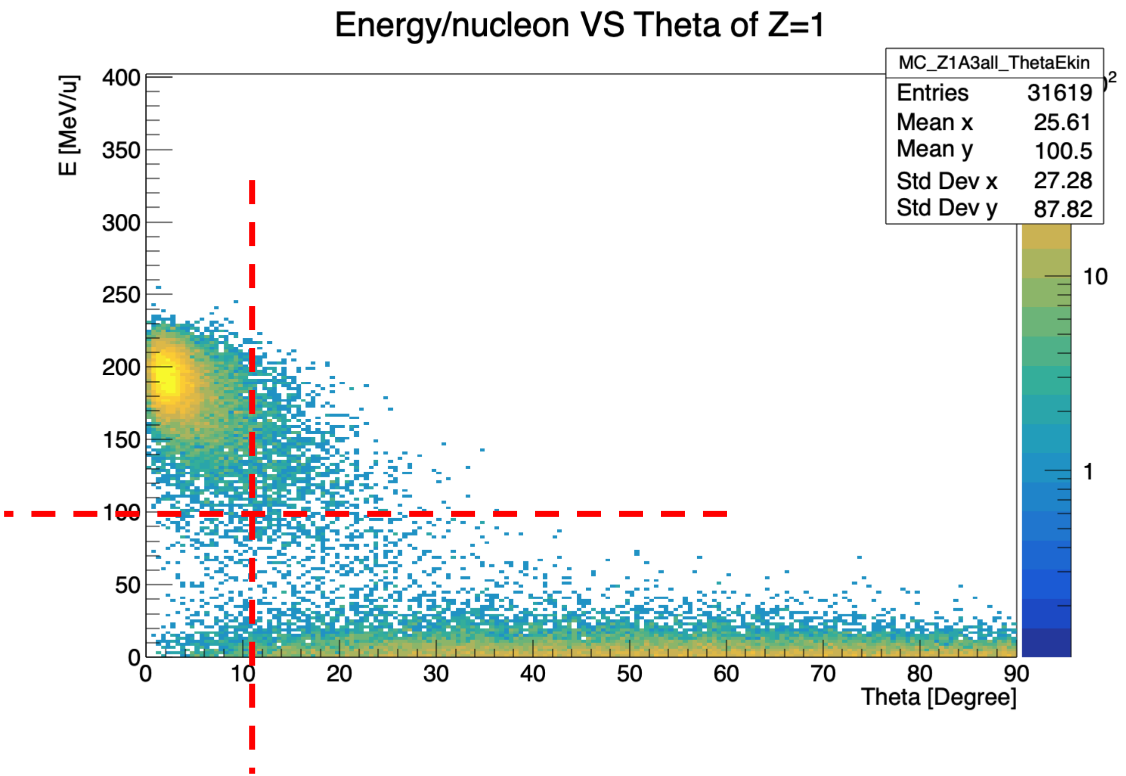


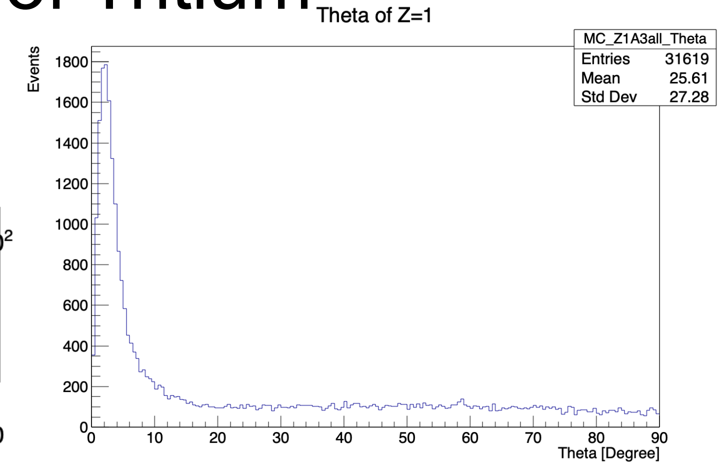


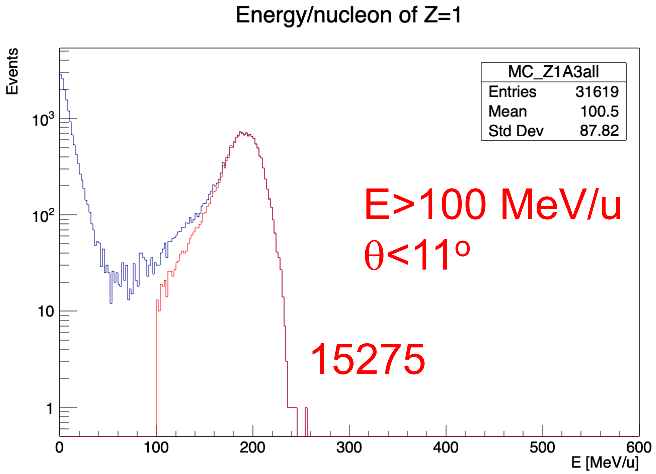


Some results: Energy and Angle of Tritium

At production in target

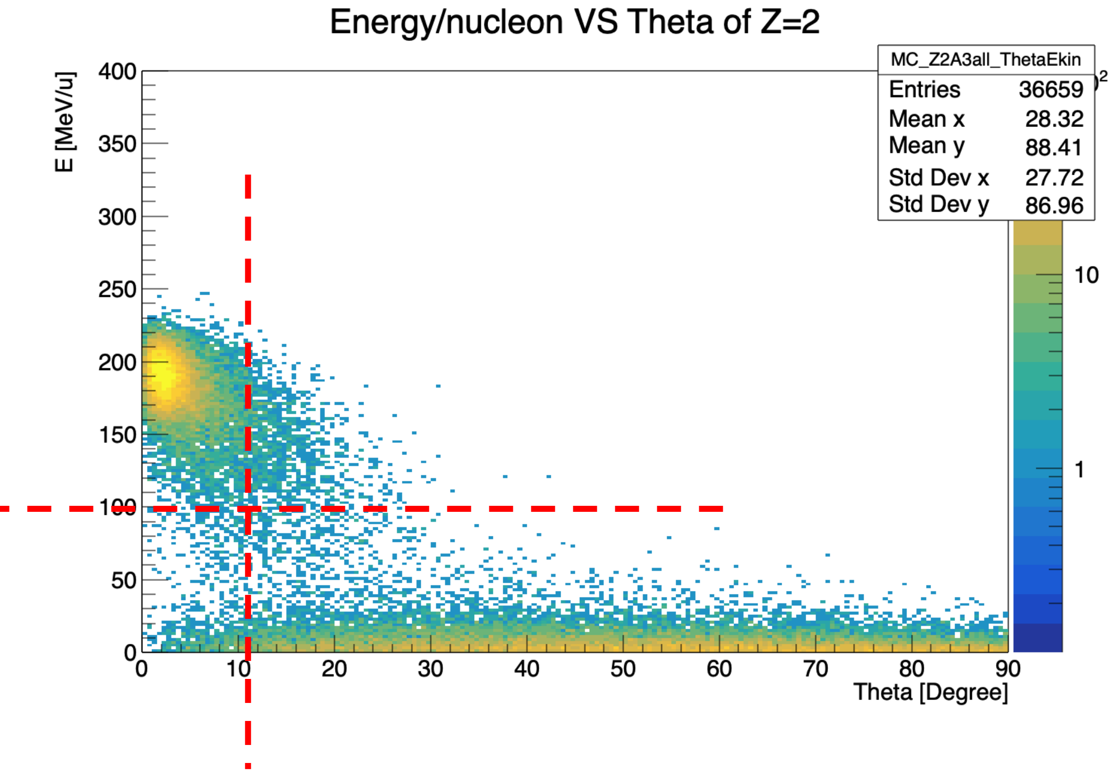


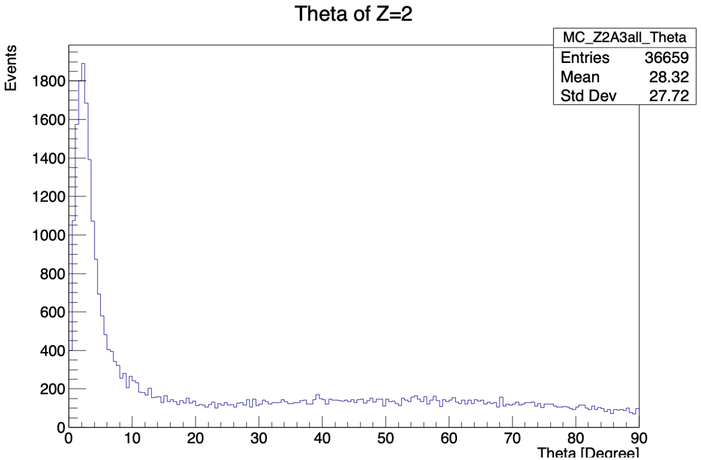


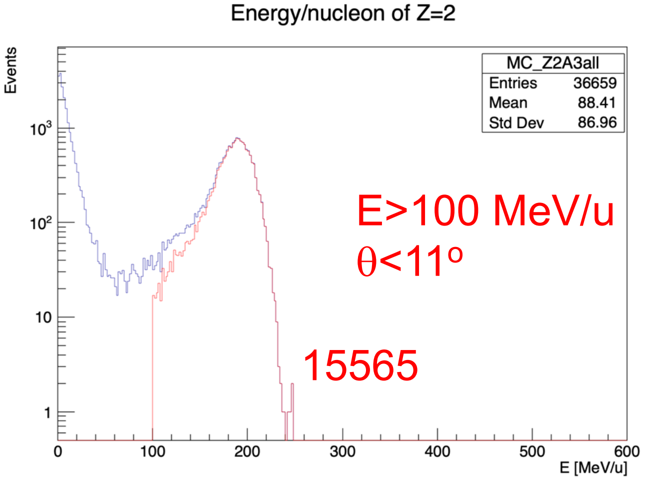


Some results: Energy and Angle of ^{3}He

At production in target







200 MeV/u + C_2H_4 target (no MSD no CALO)

Total no. of Processed Events: 5000000
No. of interactions in Air: 133833
No. of interactions in STC: 3884
No. of interactions in BMN: 3858
No. of interactions in TGT: 144465
No. of interactions in VTX: 0
No. of interactions in MSD: 0
No. of interactions in TWL: 84701
No. of primaries interacting before target is 21029

Target Material = Polyethy
A_target = 2.805340e+01 rho_target = 9.400000e-01 thickness = 1.000000e+00
N_prim = 4.978971e+06 Ntg = 2.017870e-05

Selection cuts: E_cut = 0.10 Theta_cut = 11.00

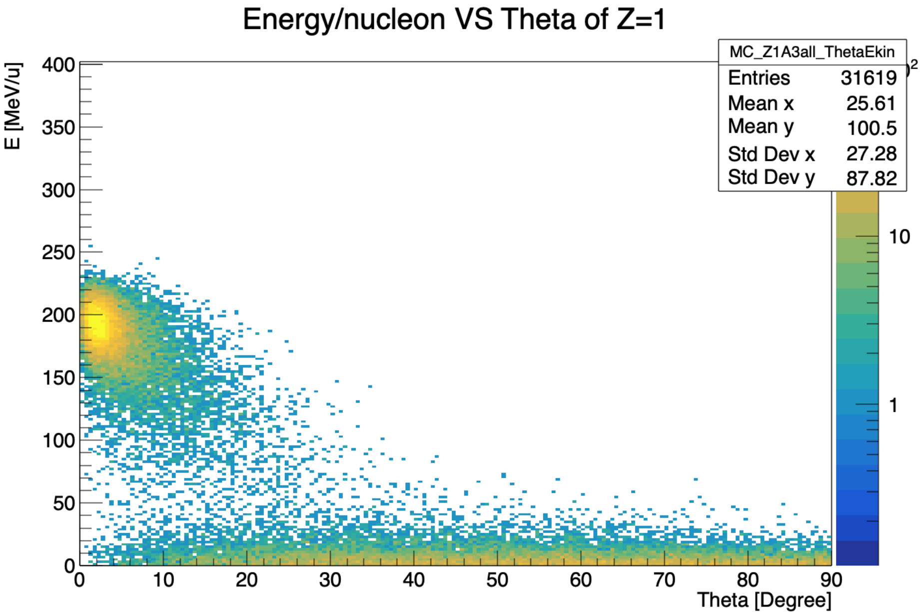
N(Z1) with cuts = 64920.00 sigma(Z1) with cuts = 768.78 +/- 2.77 mb ⇨ **σ_H(Z1) ~ 50.1 +/- 0.9 mb**
N(Z2) with cuts = 21160.00 sigma(Z2) with cuts = 335.84 +/- 1.83 mb ⇨ **σ_H(Z2) ~ 37.7 +/- 0.6 mb**

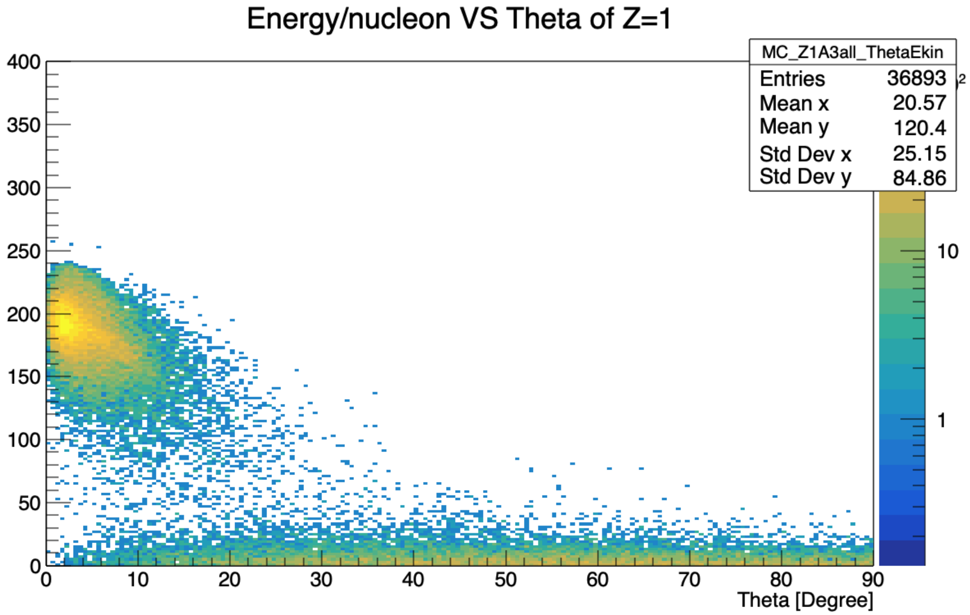
$$\sigma(H) = \frac{1}{4}\left(\sigma(C_2H_4) - 2\sigma(C)\right) \qquad \Delta\sigma(H) = \frac{1}{4}\sqrt{\Delta\sigma(C_2H_4)^2 + 4\,\Delta\sigma(C)^2}$$

Some difference expected between the two targets

At production in target

Example: the ^{2}H case

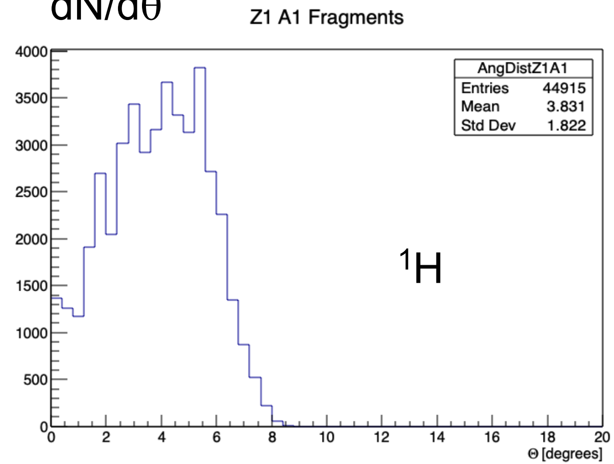


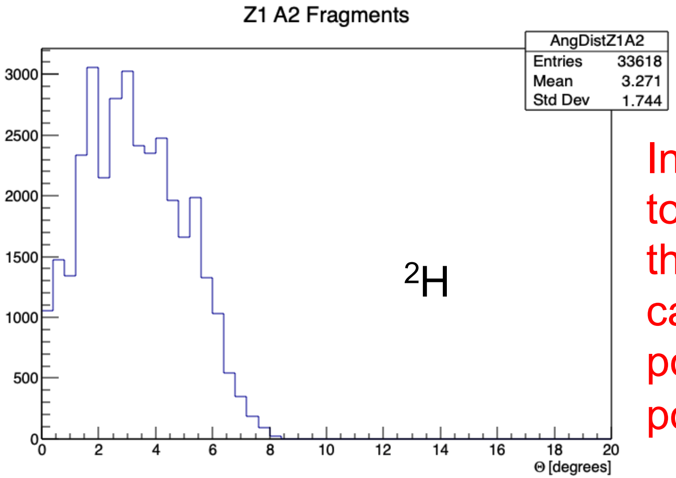


Using the TW points + A-id from Calo (ToF+E_{kin})

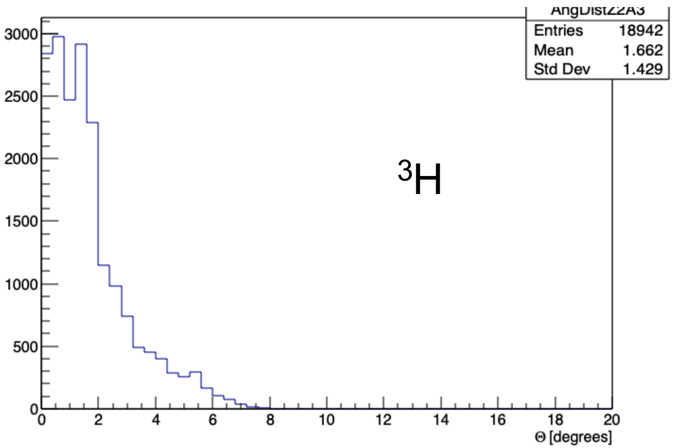
Only tracks produced in target

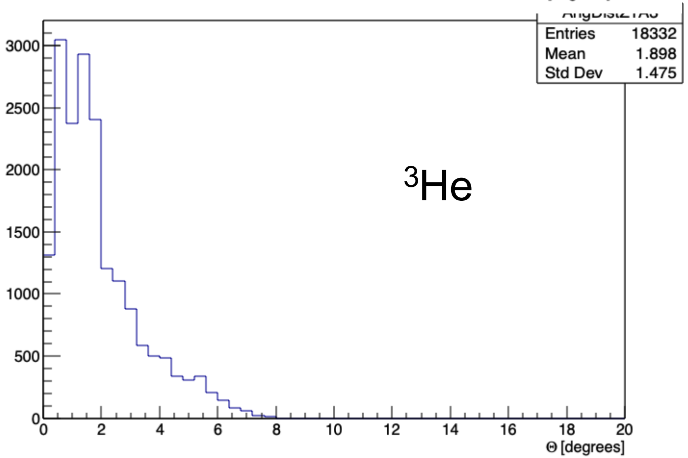
dN/dθ





In principle we could aim to have dσ(Z,A)/dΩ in the acceptance of calorimeter, and just the position resolution of TW point

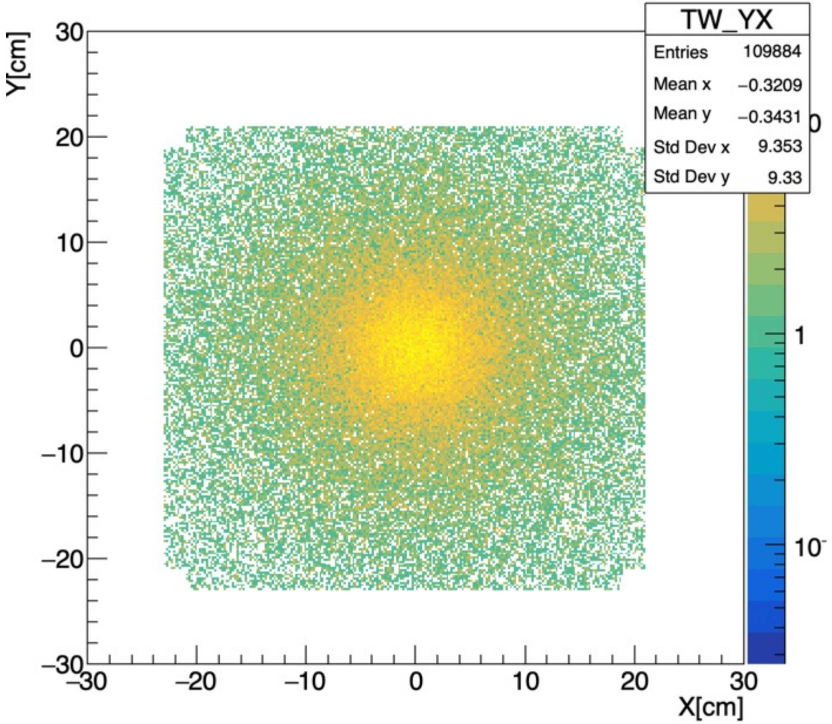




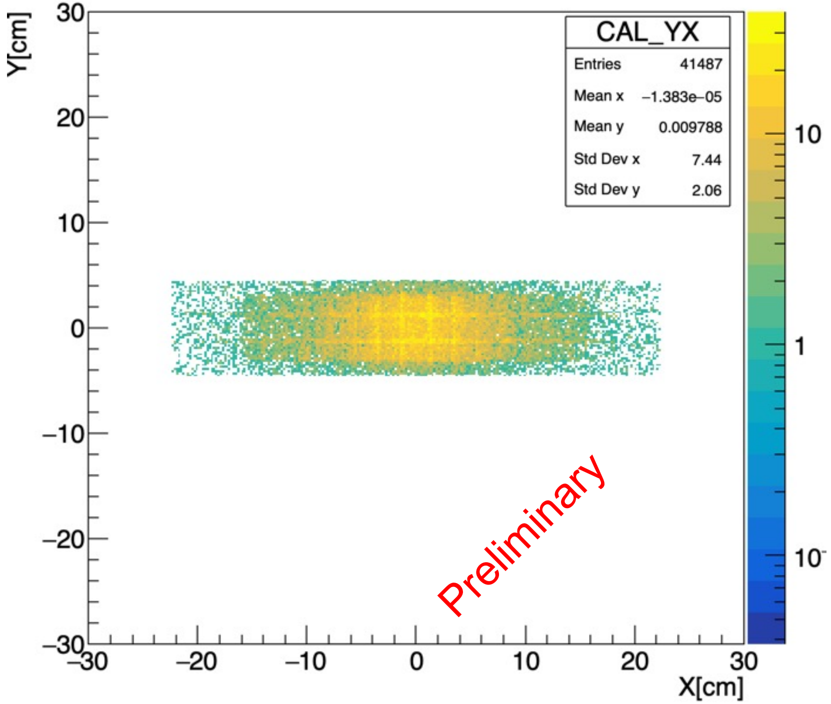
Acceptance of the Calorimeter

Only tracks produced in target

XY impact point in TW



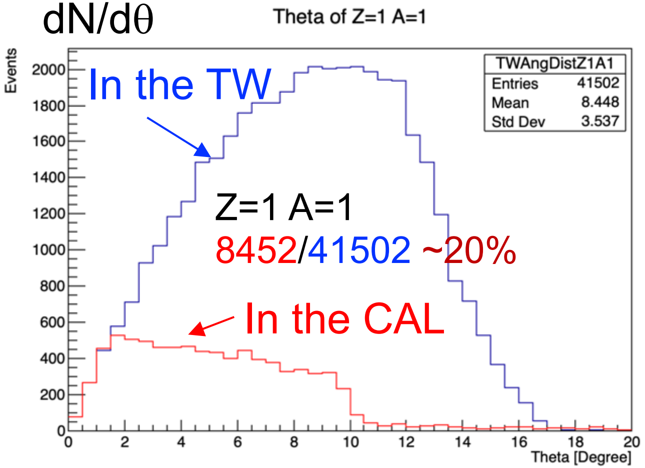
XY impact point in CAL

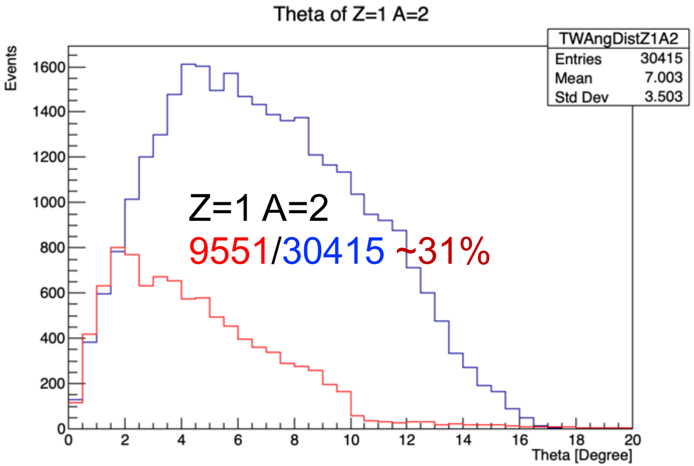


Acceptance of the Calorimeter

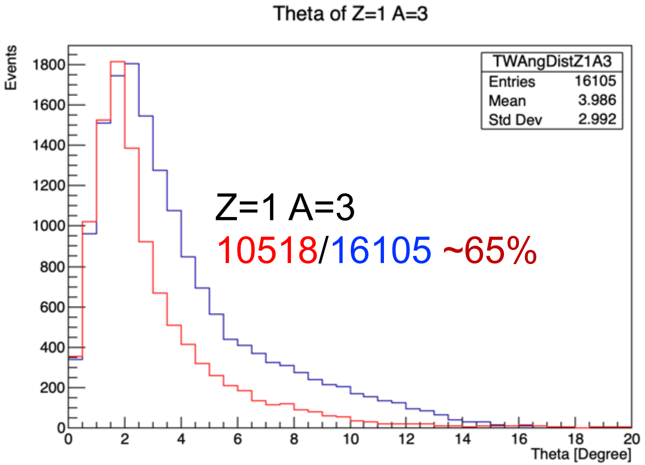
Only tracks produced in target

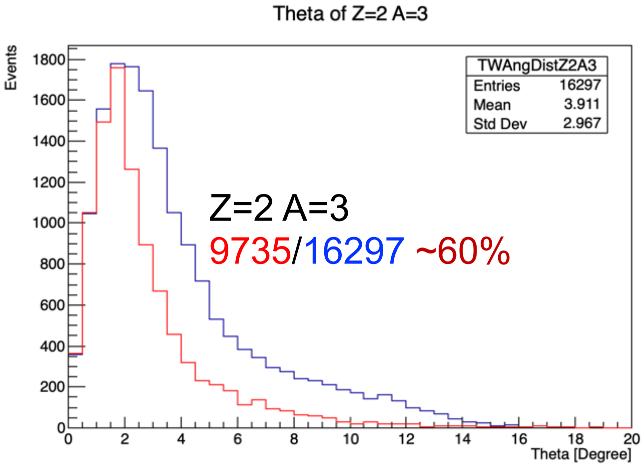
dN/dθ





Preliminary

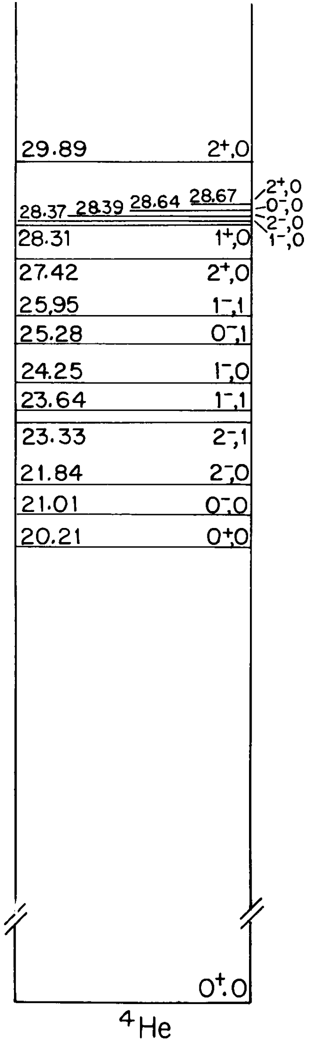




Conclusions

- Measurements with He beam in the range 100-200 MeV/u are useful and interesting, because there are still systematic uncertainties in the existing data
- The reaction cross section is ~1/2 of that for C+C at the same energy/nucleon: for the same statistical significance this means that we need a no. of primaries at least a factor of 2 larger
- It would be nice to go beyond the charge-changing cross sections: $\sigma(Z,A)$ and $d\sigma(Z,A)/d\Omega$
- The use of calorimeter to get A-id would be a fundamental step *(further reduction of statistics)*
- A new MC campaign (HIT2022_MC) has been prepared and ready to be used. Please: let us agree on an initial layout and positioning before the installation
- In the best possible world (= all the time you want) it would be nice to explore more than 1 energy and 1 target *(10 days ago it seemed better to have energy change instead of target change… Now not so sure)*
- Not sure about using MSD for the physics run… *(in case: extreme care in alignement and positioning is necessary)*
- ***Question: which configuration has to be chosen to produce simulated data now?***

Appendix: The ^{4}He nucleus



E_x (MeV)	J^π	T	Γ_p (MeV)	Γ_n (MeV)	Γ_d (MeV)	Γ (MeV)	Decay
g.s.	0+	0					
20.21	0+	0	0.50	0.00	0.00	0.50	p
21.01	0−	0	0.64	0.20	0.00	0.84	p, n
21.84	2−	0	1.26	0.75	0.00	2.01	p, n
23.33	2−	1	2.64	2.37	0.00	5.01	p, n
23.64	1−	1	3.44 [a]	2.76 [a]	0.00	6.20	p, n, (γ)
24.25	1−	0	3.08 [a]	2.87 [a]	0.15	6.10	p, n, d
25.28	0−	1	4.12	3.85	0.00	7.97	p, n
25.95	1−	1	6.52 [b]	6.14 [b]	0.00	12.66	p, n, γ
27.42	2+	0	0.25	0.23	8.21 [c]	8.69	p, n, d
28.31	1+	0	4.72	4.66	0.51	9.89	p, n, d
28.37	1−	0	0.07	0.08	3.77	3.92	(p, n), d
28.39	2−	0	0.02	0.02	8.71	8.75	(p, n), d
28.64	0−	0	0.00	0.00	4.89	4.89	d
28.67	2+	0	0.00	0.00	3.78 [d]	3.78	d, γ
29.89	2+	0	0.04	0.04	9.64 [e]	9.72	(p, n), d

$E_{bind}(^4He) = 28.3$ MeV

The excited levels are very high. All of them above the separation energy to take away 1 proton and get tritium: $^4He \rightarrow p + ^3H$

$E_{sep}(^4He \rightarrow p+^3H) = E_{bind}(^4He) - E_{bind}(^3H) = 28.3 - 8.5 = 19.8$ MeV

No states close to the 0^+ ground state with different J^π assignment: no γ de-exctitation

Appendix: Some kinematics

T_{proj} (MeV/u)	β	$T_{c.m.}$ (MeV) in $^{4}He+^{12}C$ collisions	$T_{c.m.}$ (MeV) in $^{4}He+H$ collisions	ToF in 1 m for T= T_{proj} (ns)
100	0.4295	277	80	7.77
150	0.5080	423	119	6.57
200	0.5676	568	158	5.88