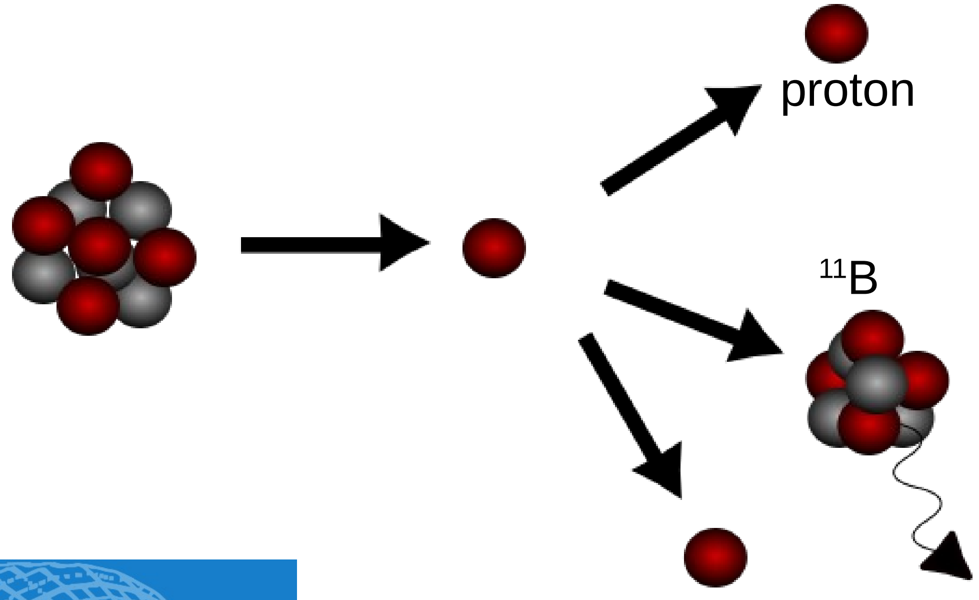
12C(p,2p)11B reaction:

- ^{12}C beam
- proton like target

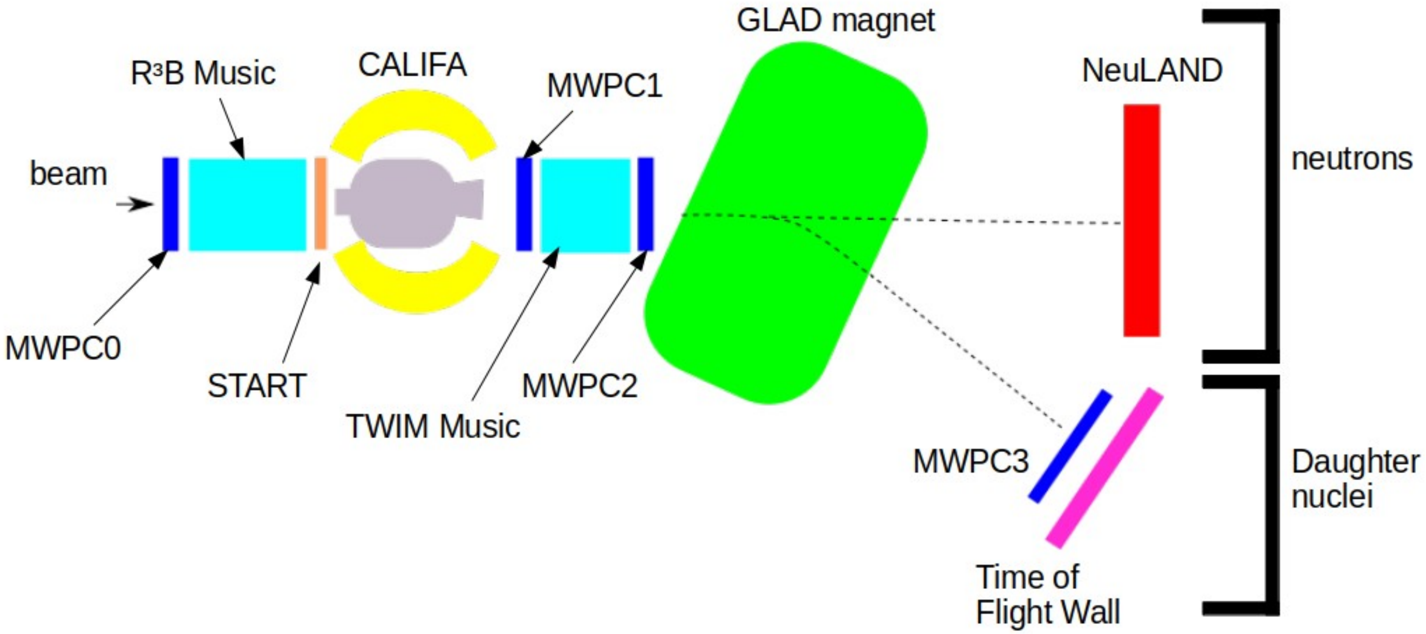
→

- 2 protons
- ^{11}B fragment (spectator)



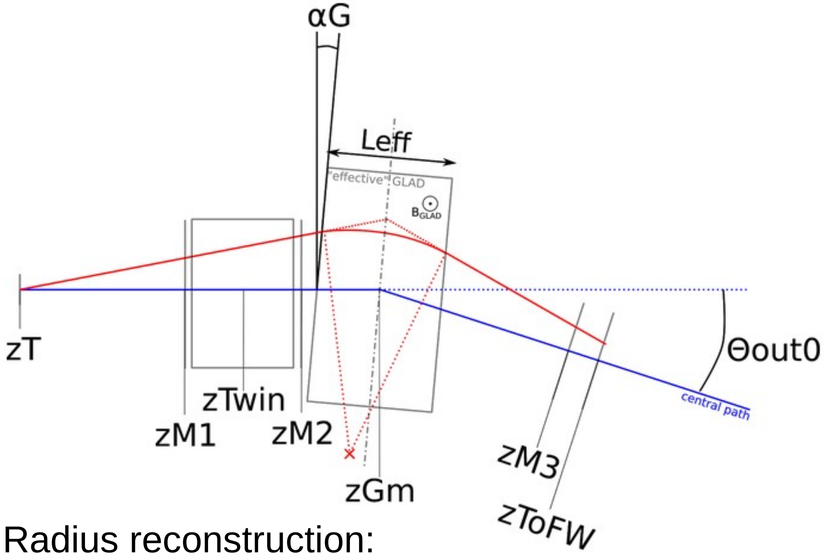
SETUP:

Beam energy: 400 AMeV
Beamtype: ^{12}C
Target: CH_2



Fragment Particle Identification

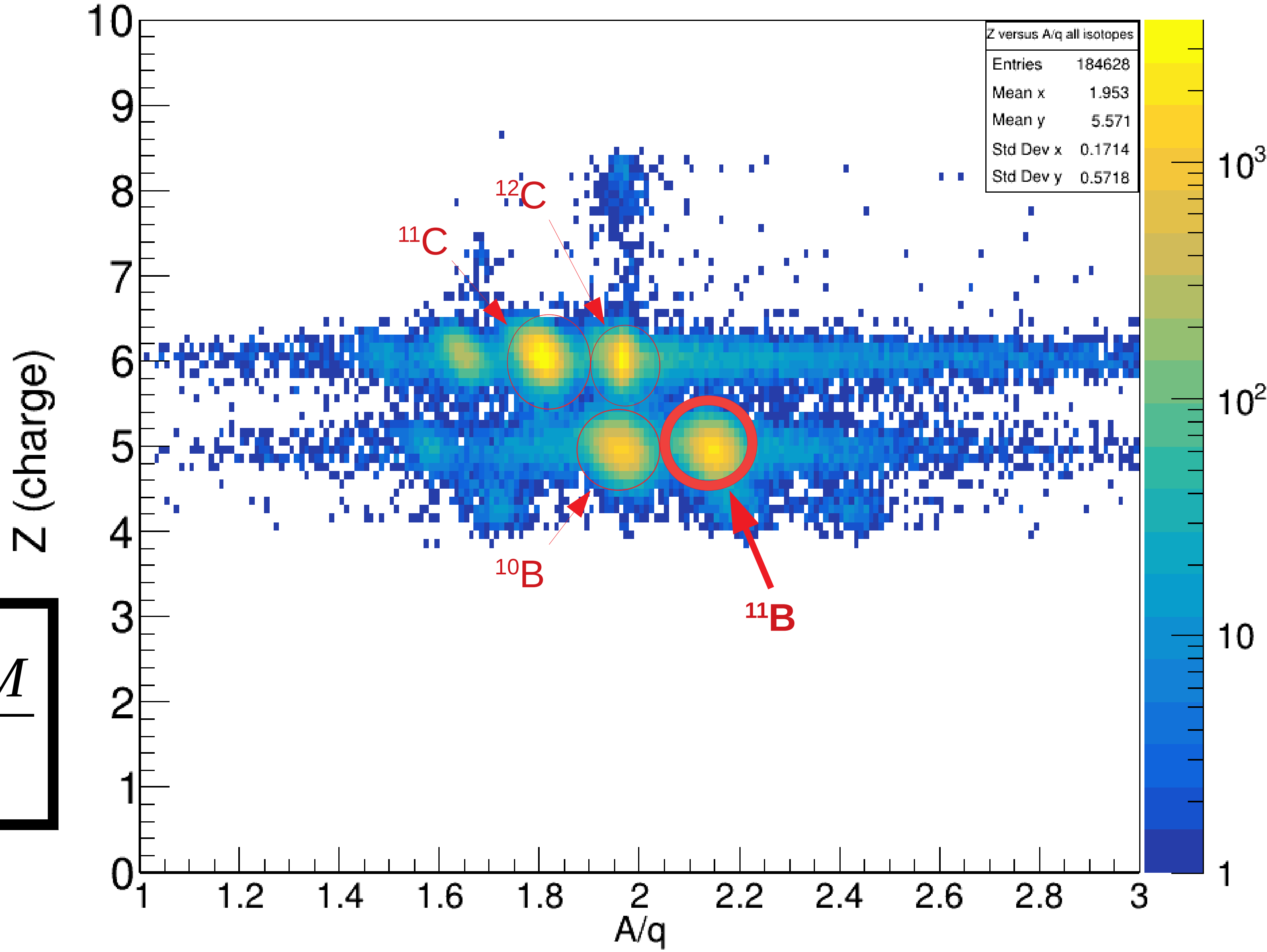
Flightpath reconstruction:



Radius reconstruction:

$$R = \frac{L_{eff}}{2\sin\left(\frac{\theta_{in}+\theta_{out}}{2}\right)}$$

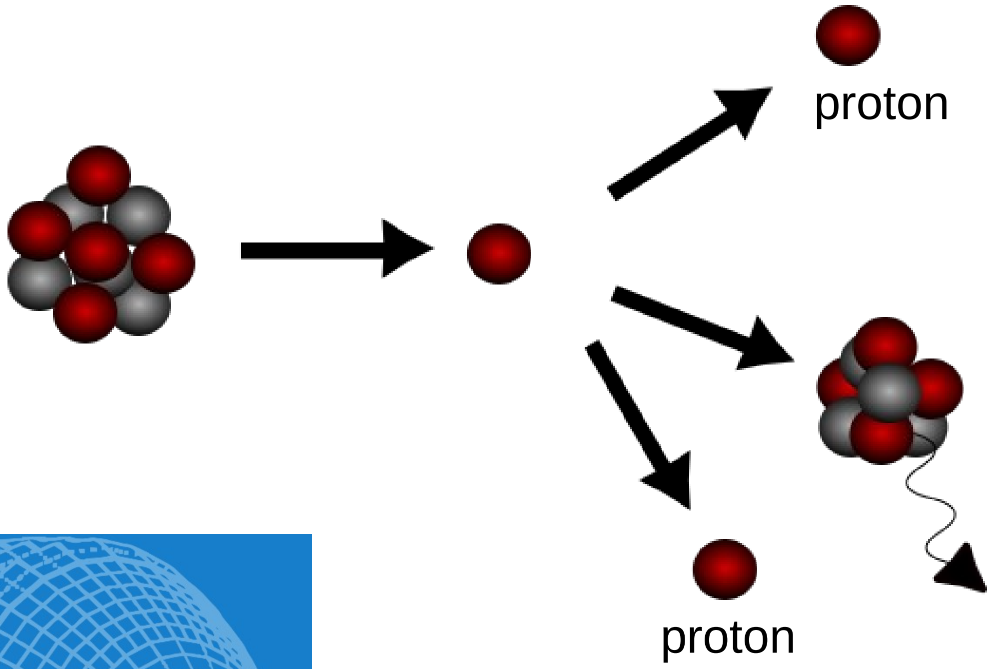
$$\boxed{B * \rho = \frac{\beta * \gamma * M}{q}}$$

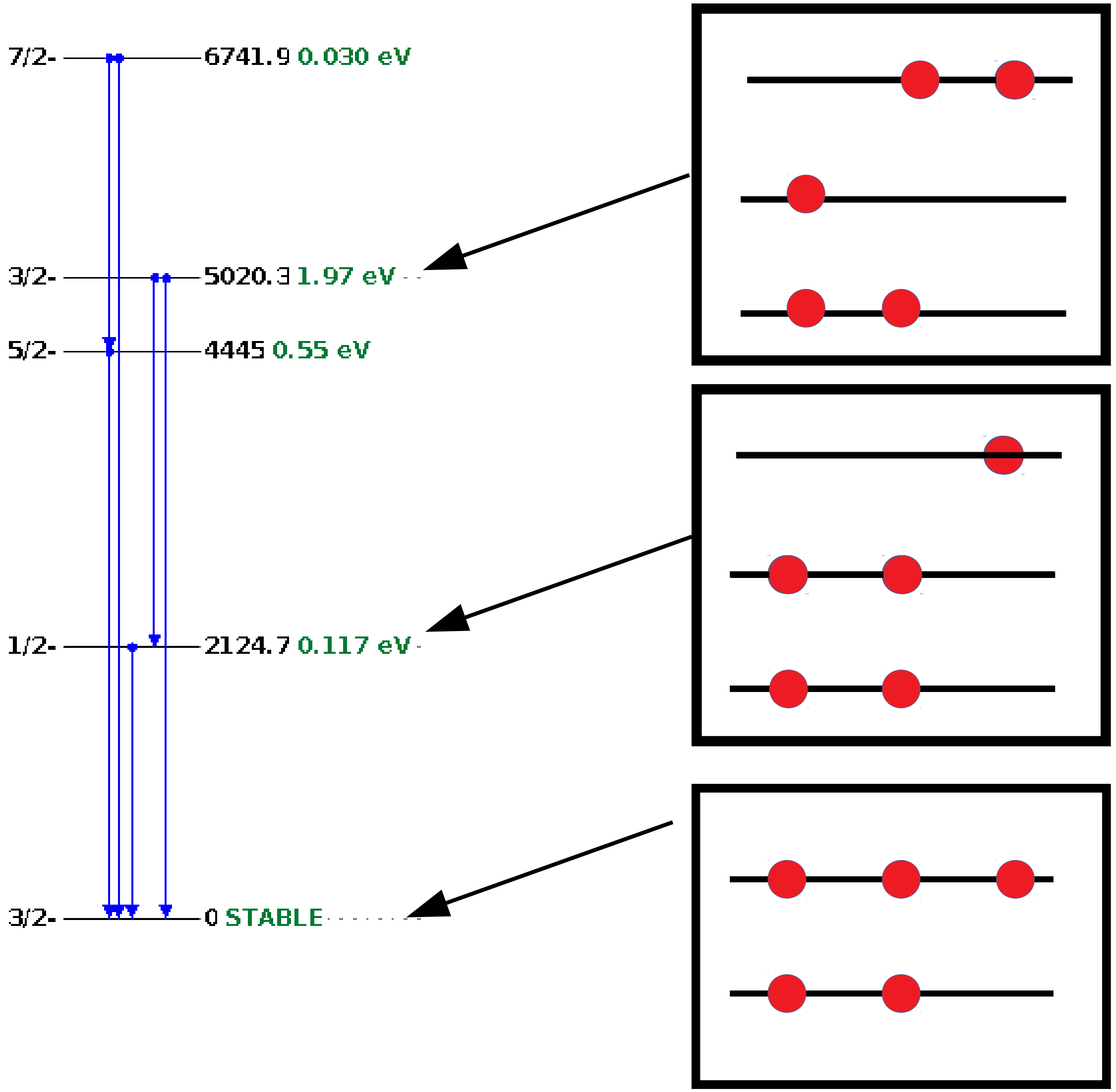


12C(p,2p)11B reaction

Two Proton Identification:

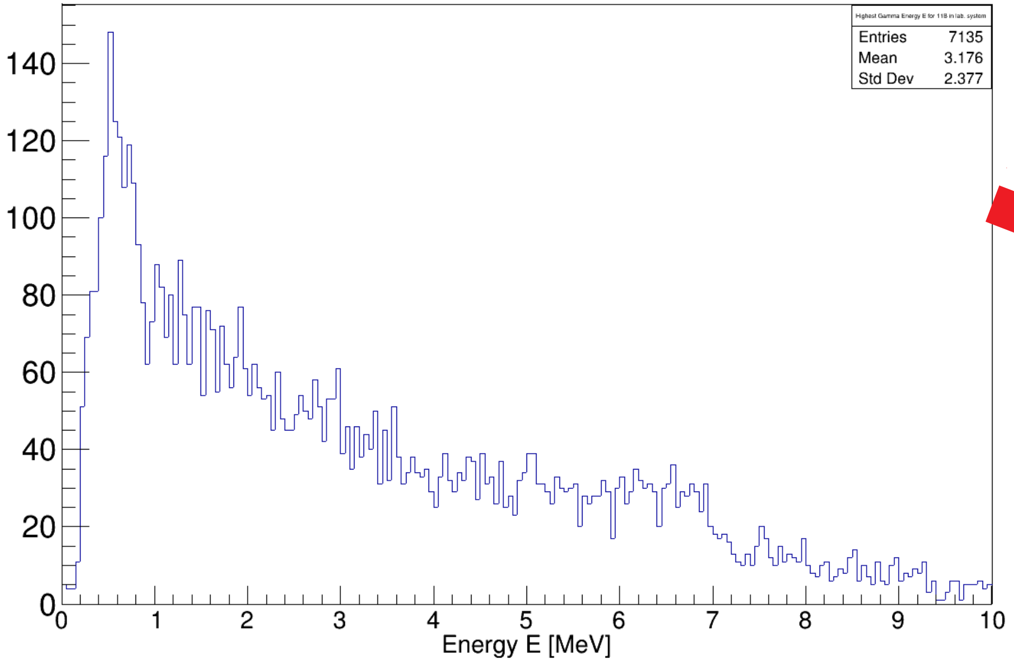
→ two hits with E_{hit} > 30 MeV





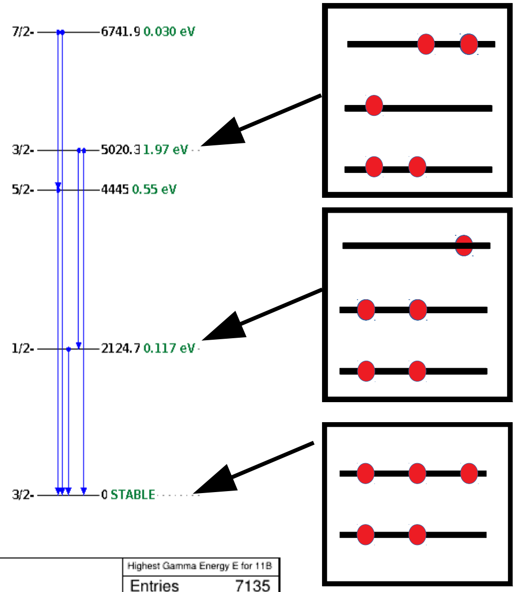
Gamma Spectrum of 11B

laboratory system

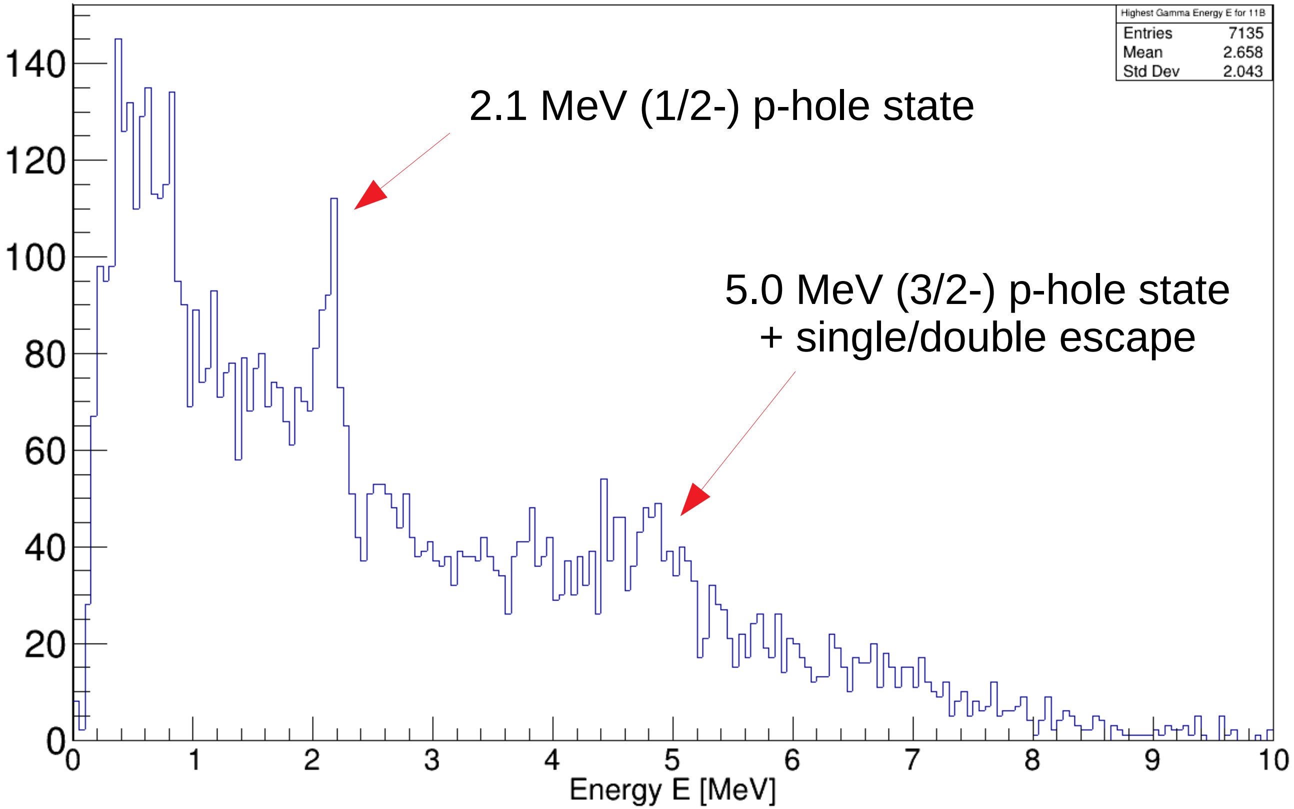


Doppler Correction:

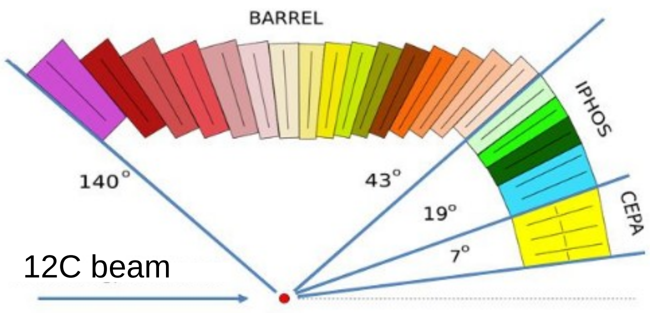
$$E_{\gamma} = \gamma E_{lab} \left(1 - \beta \cos(\theta)\right)$$

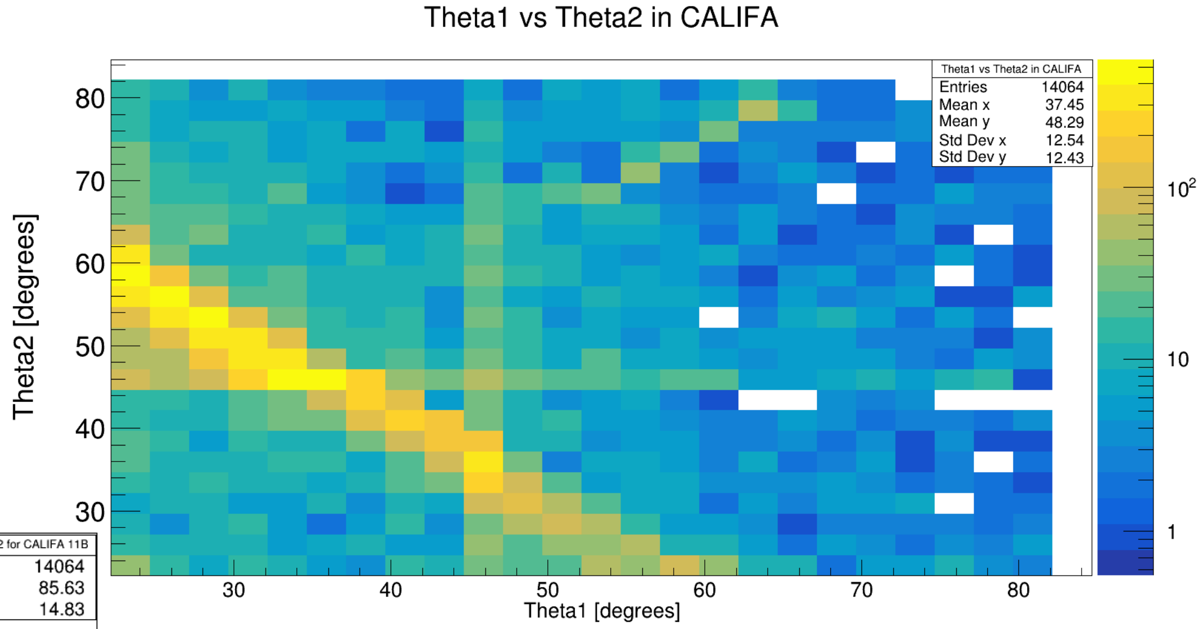


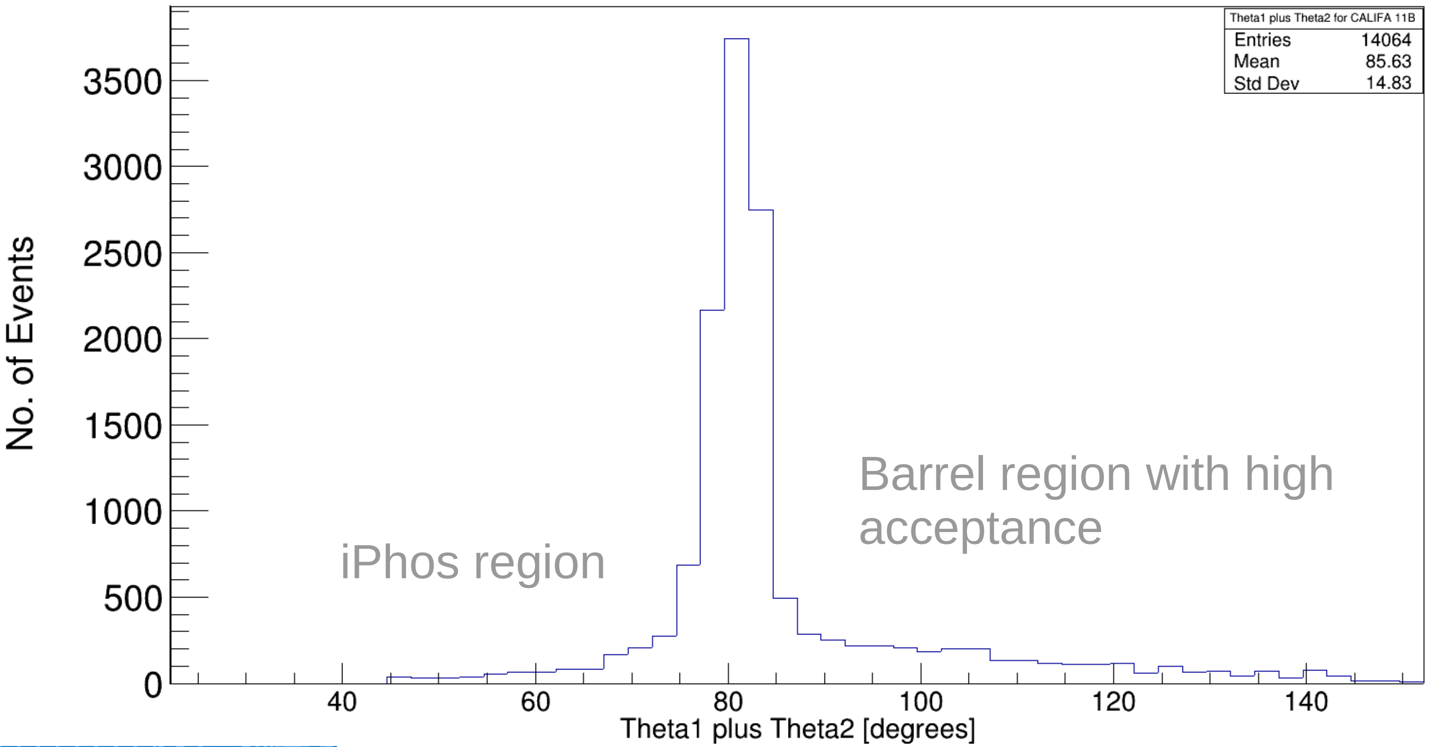
^{11}B rest frame

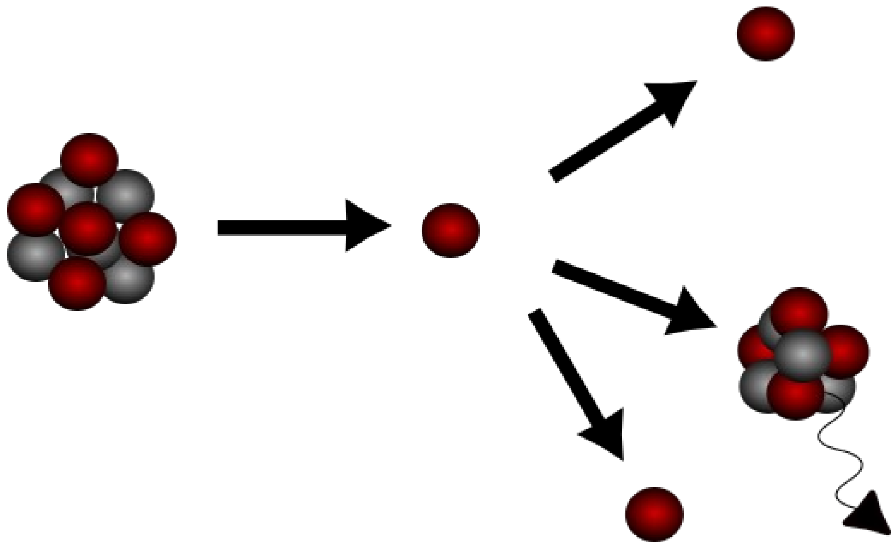


Polar Angular Distribution of protons for 12C(p,2p)11B

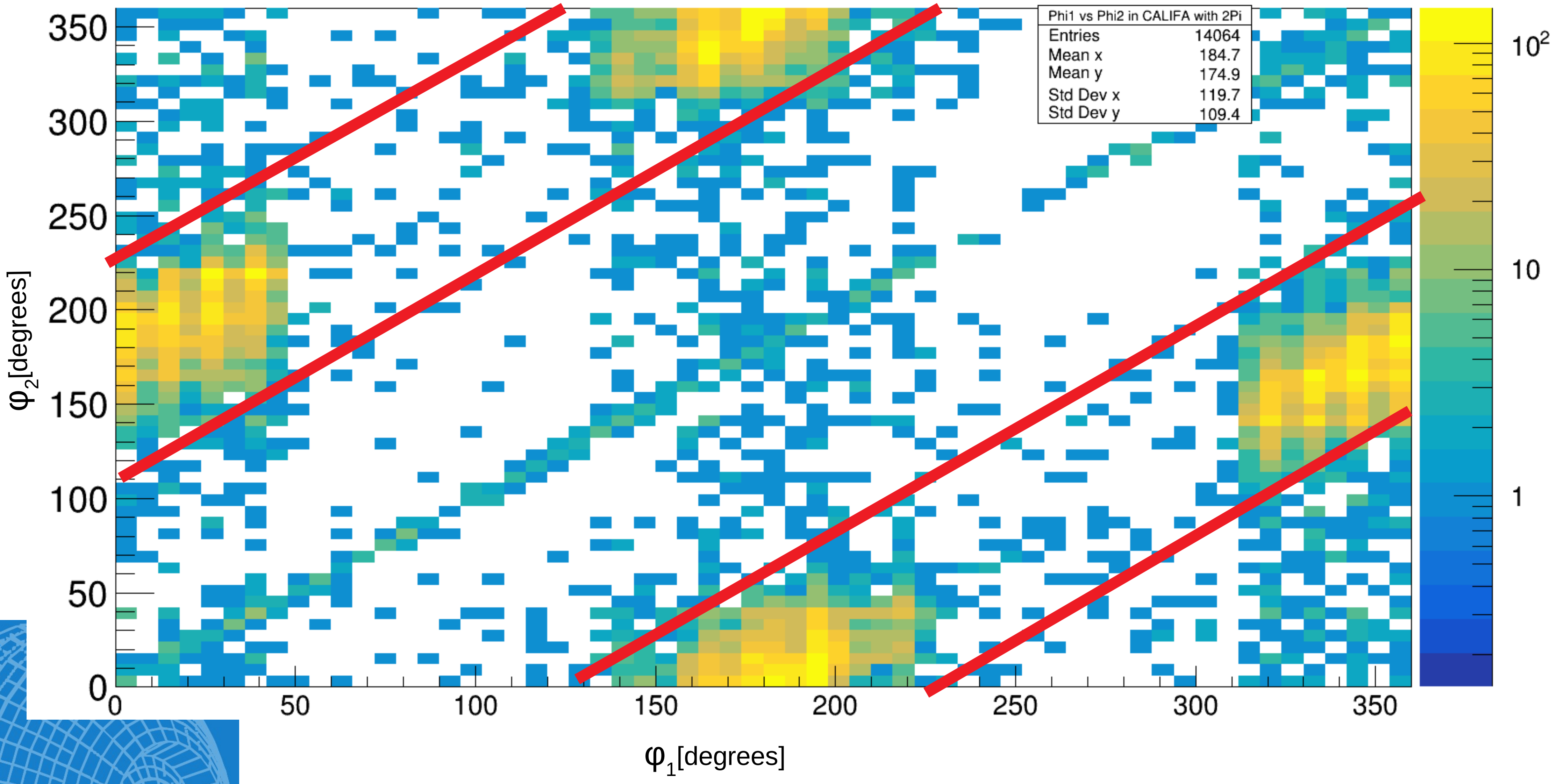


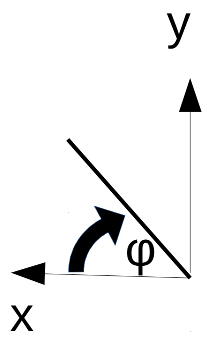






Arzimuthal Distribution of protons for 12C(p,2p)11B





Gamma Spectrum with Angular Cuts

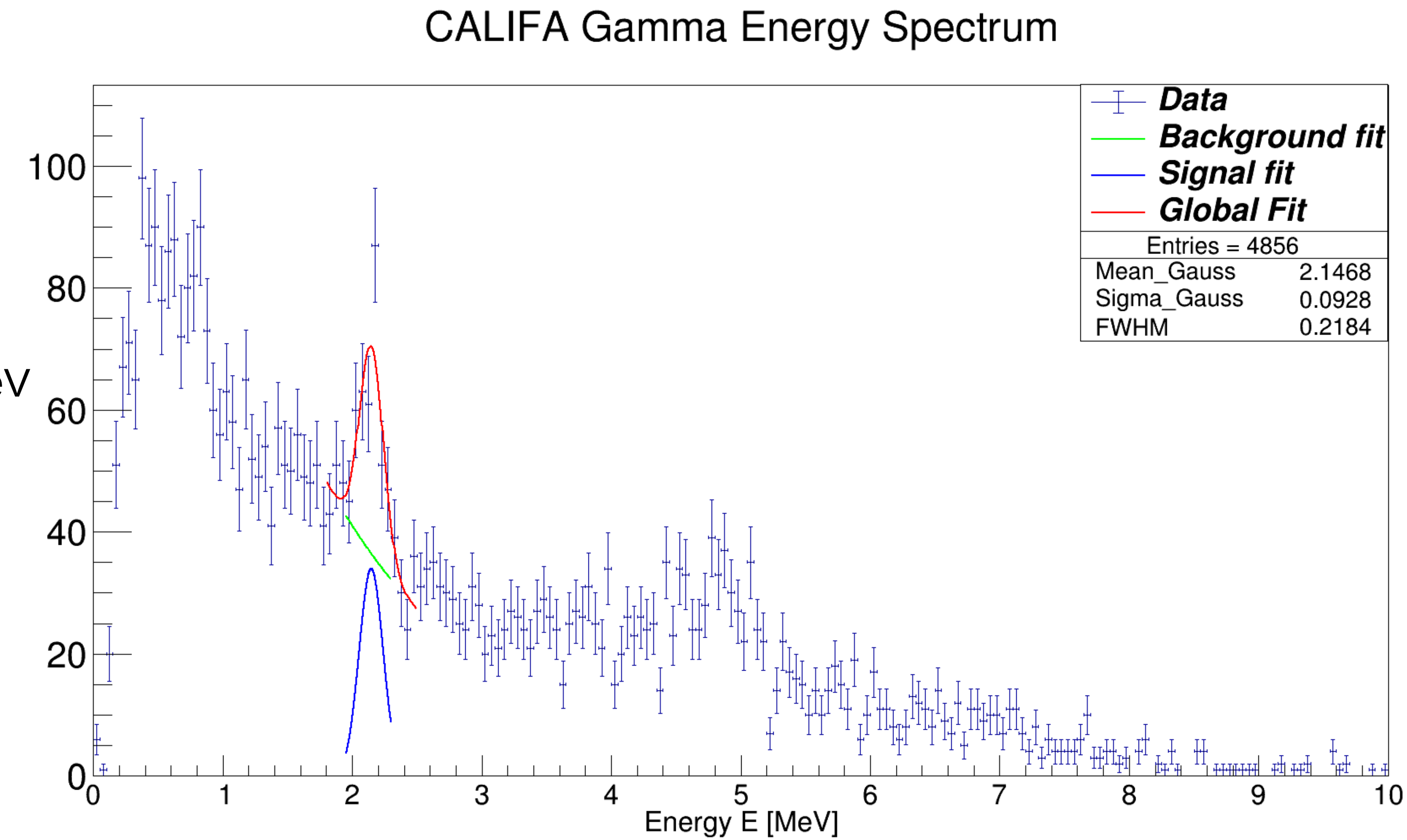
Event selection criteria for CALIFA:

→ 11B fragment identification

→ two hits (protons) with E_{hit} > 30 MeV

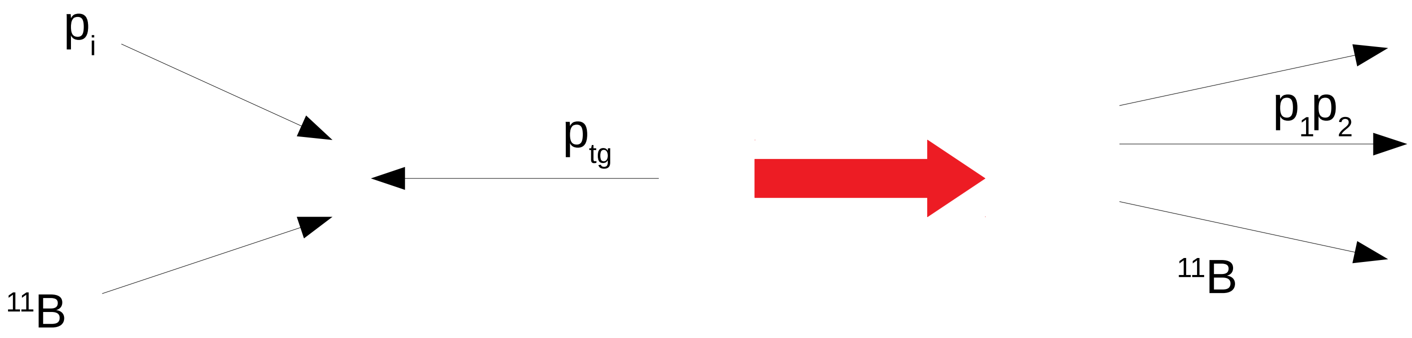
→ θ1 + θ2 < 90°

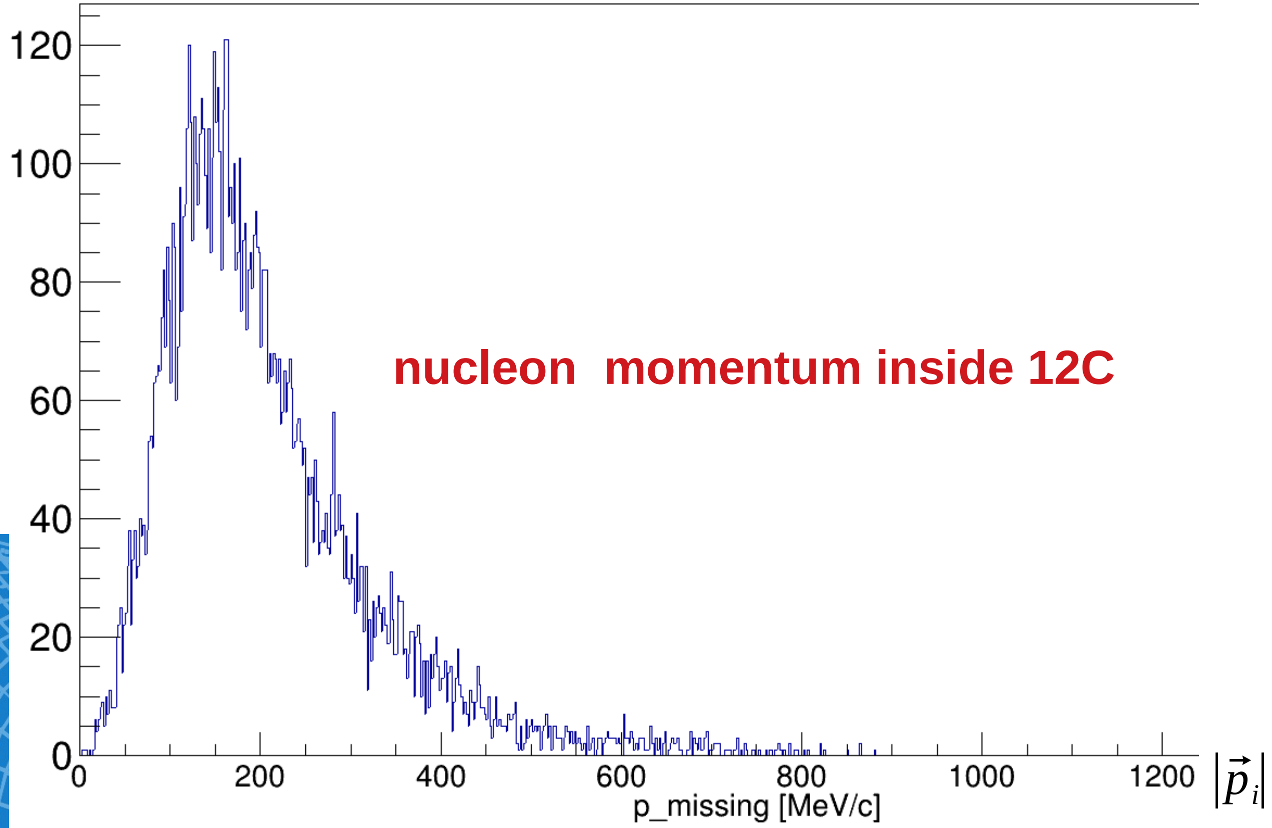
→ Δφ = 180° +- 40°



TODO: make bkg from 1 to 3 and add also plots with hit-multiplicities...

Reconstruction of Inner Momenta





Momentum conservation relation:

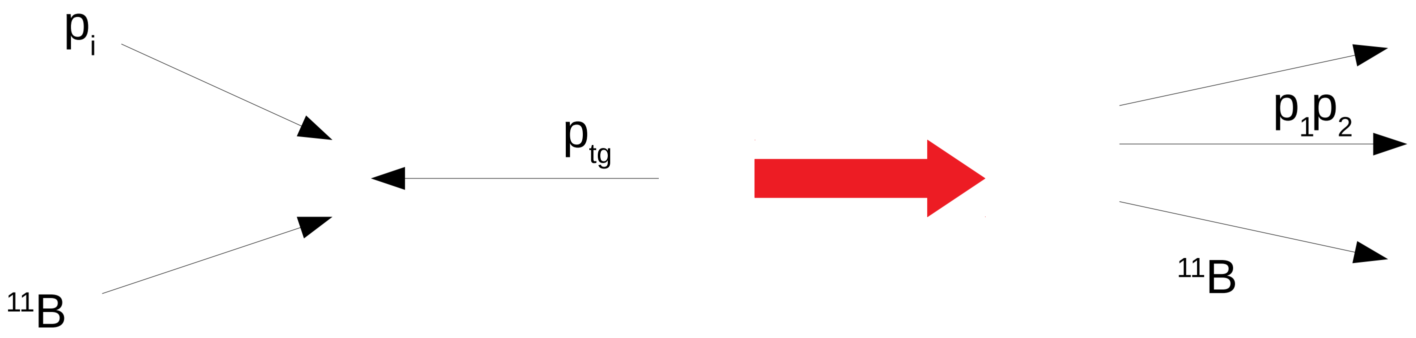
$$p_{12C} + p_{tg} = p_1 + p_2 + p_{11B}$$

assuming QE scattering in mean field potential:

$$p_{12C} = p_i + p_{11B}$$

$$p_i \approx p_{missing} = p_1 + p_2 - p_{tg} \,(no\; ISI/FSI)$$

Momentum components of p_i



Momentum conservation relation:

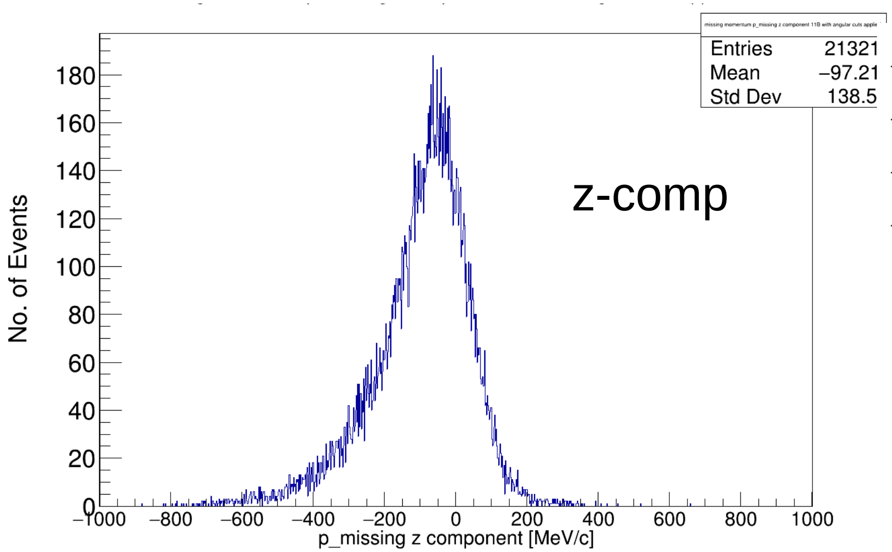
$$\boldsymbol{p}_{12\,C} + \boldsymbol{p}_{tg} \;=\; \boldsymbol{p}_1 + \boldsymbol{p}_2 + \boldsymbol{p}_{11\,B}$$

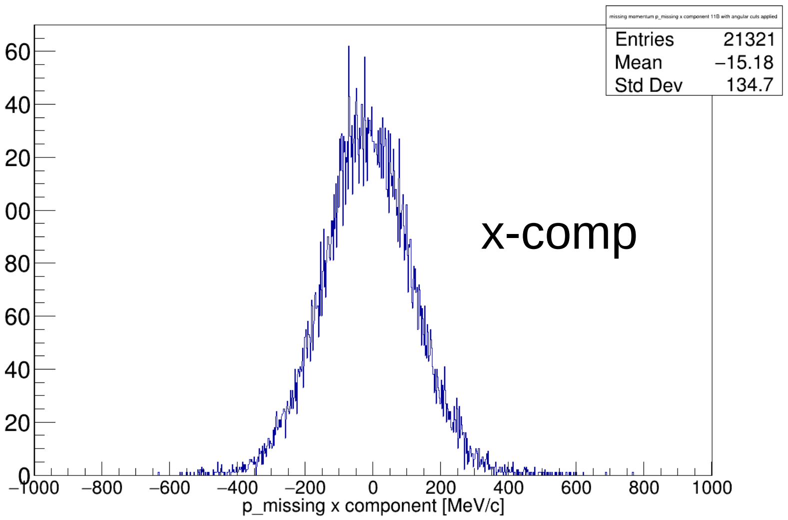
assuming QE scattering in mean field potential:

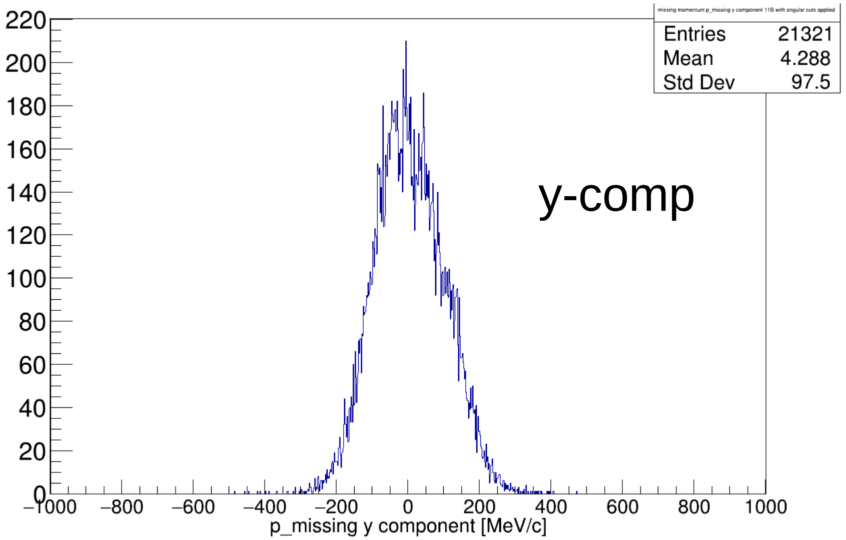
$$\boldsymbol{p}_{12\,C} \;=\; \boldsymbol{p}_i + \boldsymbol{p}_{11\,B}$$

$$\boldsymbol{p}_i \approx \boldsymbol{p}_{missing} \;=\; \boldsymbol{p}_1 + \boldsymbol{p}_2 - \boldsymbol{p}_{tg} \left(no\; ISI\,/\,FSI \right)$$

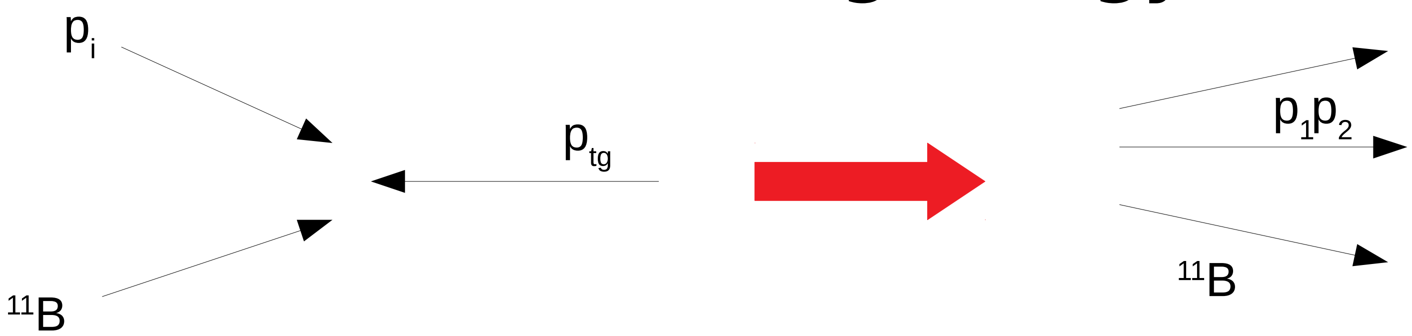
momentum-components (with angular cuts applied)







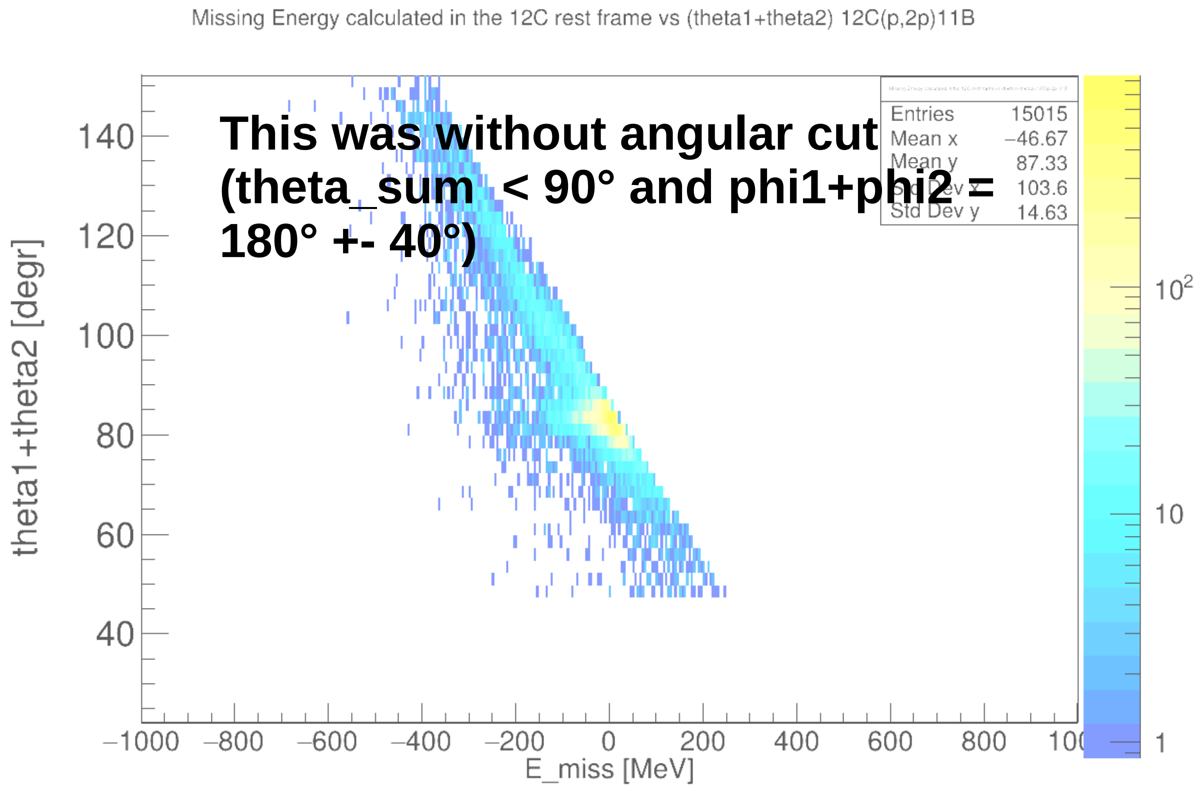
Missing Energy Distribution



$$\boldsymbol{p}_i \approx \boldsymbol{p}_{missing} = \boldsymbol{p}_1 + \boldsymbol{p}_2 - \boldsymbol{p}_{tg}\,(no\ ISI/FSI)$$

$$E_{miss} = m_p - e_{miss}$$

(where e_miss is the energy component of $\mathbf{p}_{\mathbf{missing}}$)



This was without angular cut (theta_sum < 90° and phi1+phi2 = 180° +- 40°)

Emiss can be interpreted as E_sep + E_mean_exc:

$E_{miss} = E_{final} - E_{initial}$

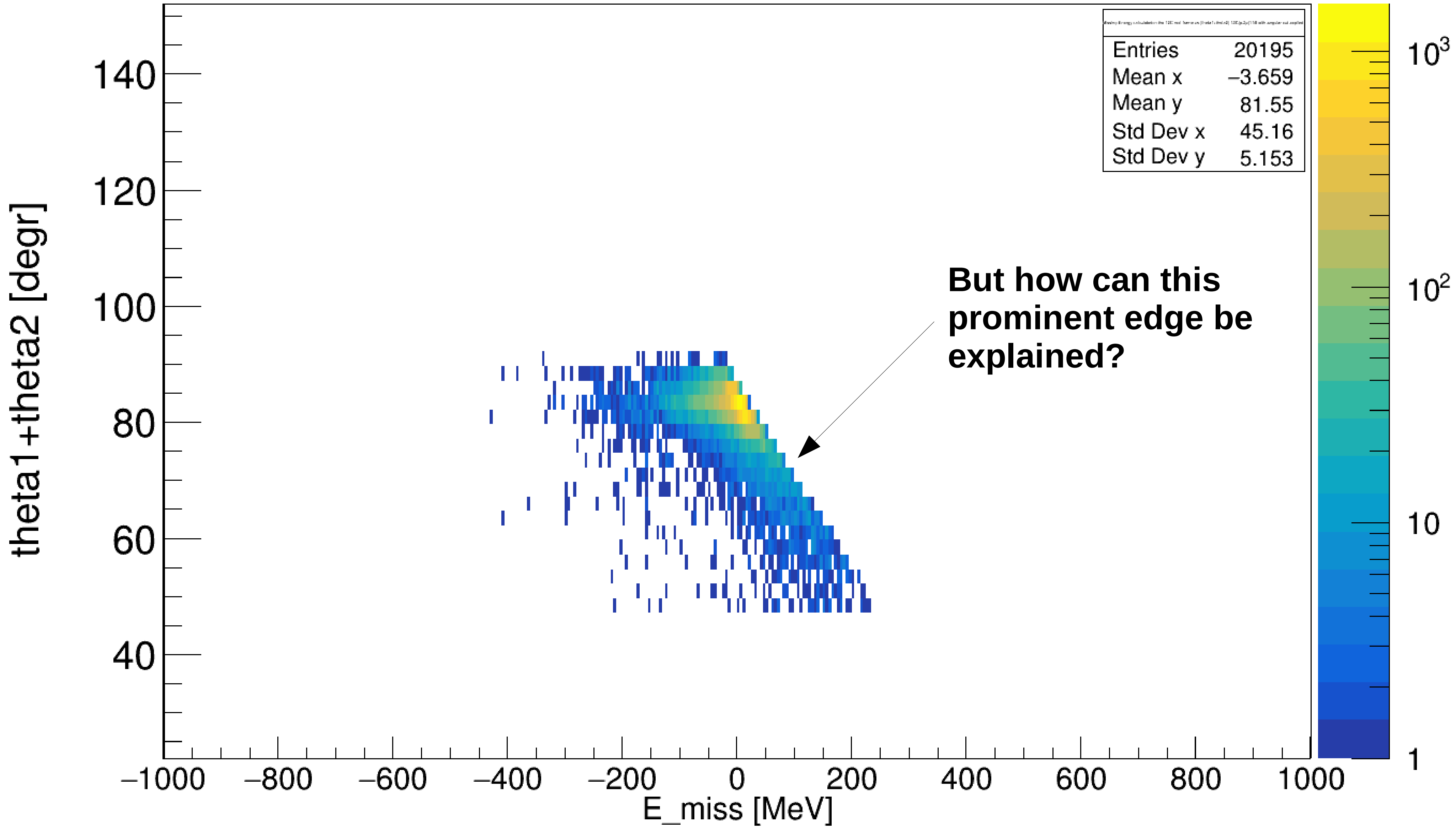
$E_{miss} = E_{tgkin} + m_{tg} + m_p - m_{p1} - E_{p1kin} - m_{p2} - E_{p2kin}$

(where $m_p = m_{tg} = m_{p1} = m_{p2}$ as they are all protons)

$E_{miss} = E_{tgkin} - E_{p1kin} - E_{p2kin}$ (in 12C cms)

Missing Energy Distribution

Now with cut on angles: theta_sum < 90° and phi_diff = 180° +- 40°



Analysis Missing Energy Distribution

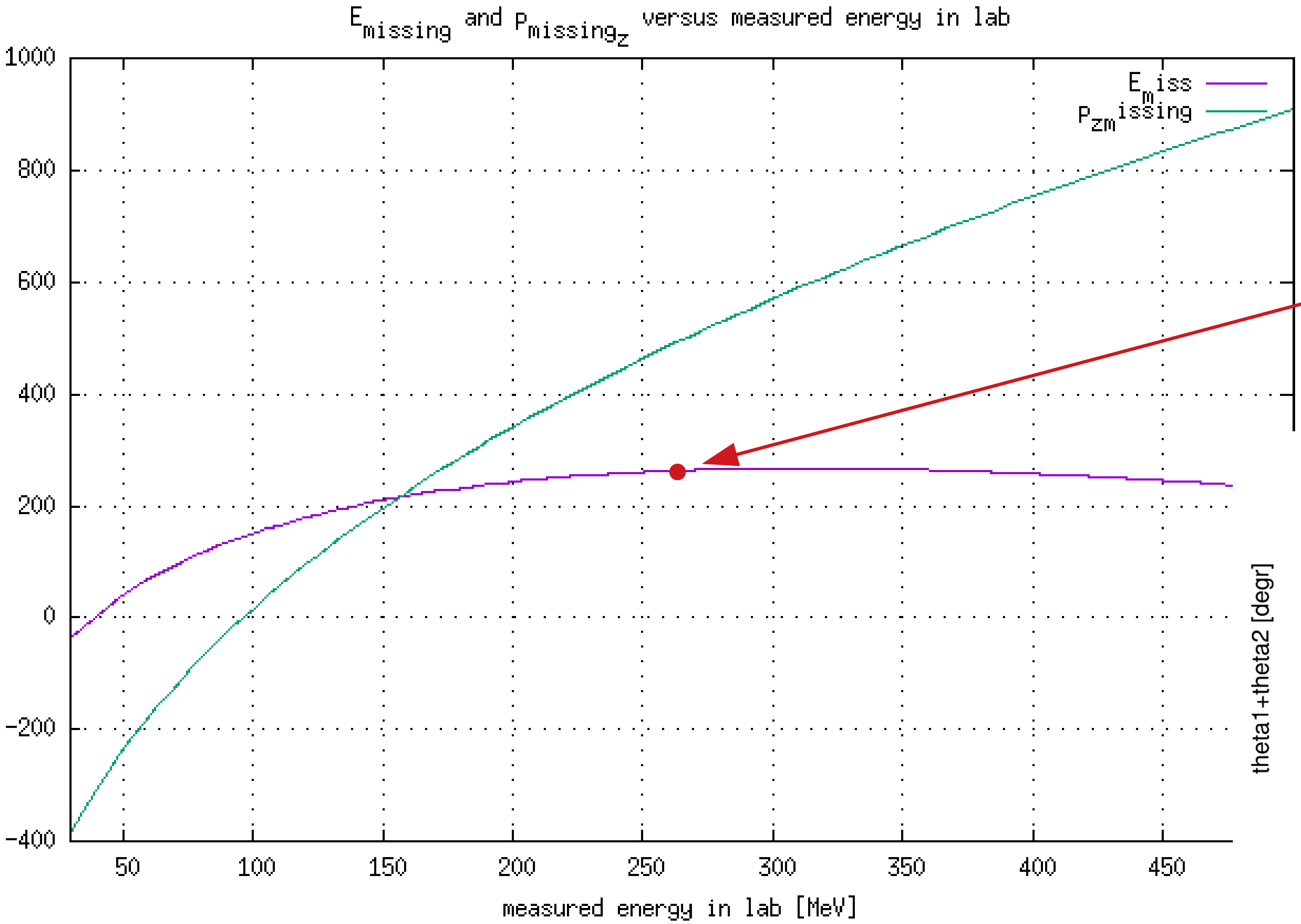
Explicit calculation of the Missing Energy (in the 12C frame):

Emiss = E_{tgkin} -E_{p1kin} – E_{p2kin}

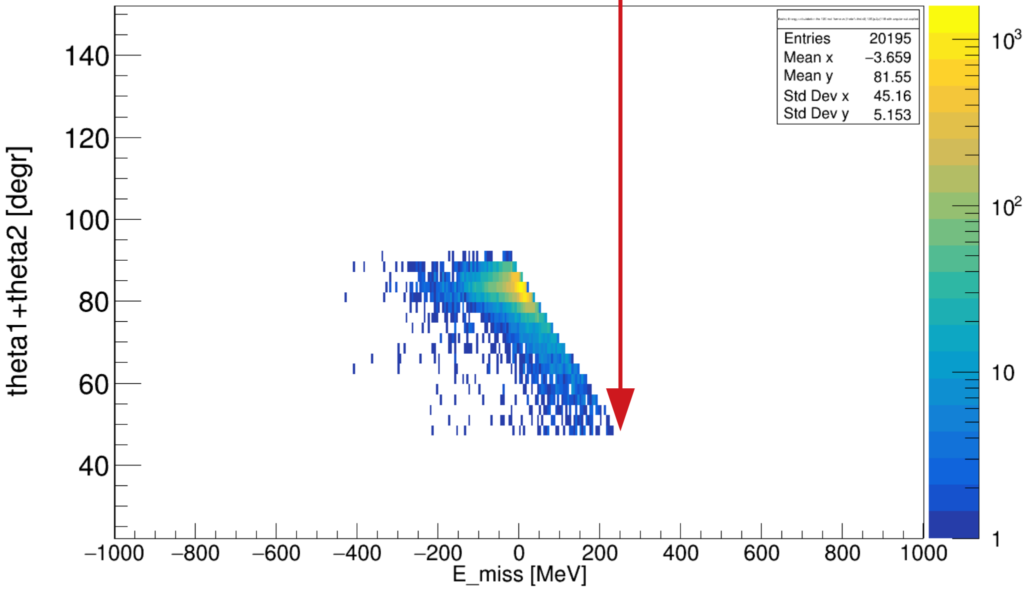
$$E_{miss}=\underbrace{400}_{E_{tgkin}}\underbrace{-\left(\underbrace{\gamma*(E_{kin1}+938)-\gamma*\beta*\sqrt{(E_{kin1}+938)^2-938^2}*\cos(\theta_1)}_{E'_{p1}}\underbrace{-938}_{E\_pot_{p1}}\right)}_{E_{kin1}}\underbrace{-\left(\underbrace{\gamma*(E_{kin2}+938)-\gamma*\beta*\sqrt{(E_{kin2}+938)^2-938^2}*\cos(\theta_2)}_{E'_{p2}}\underbrace{-938}_{E\_pot_{p2}}\right)}_{E_{kin2}}$$

E_missing and p_z_missing for different opening angles

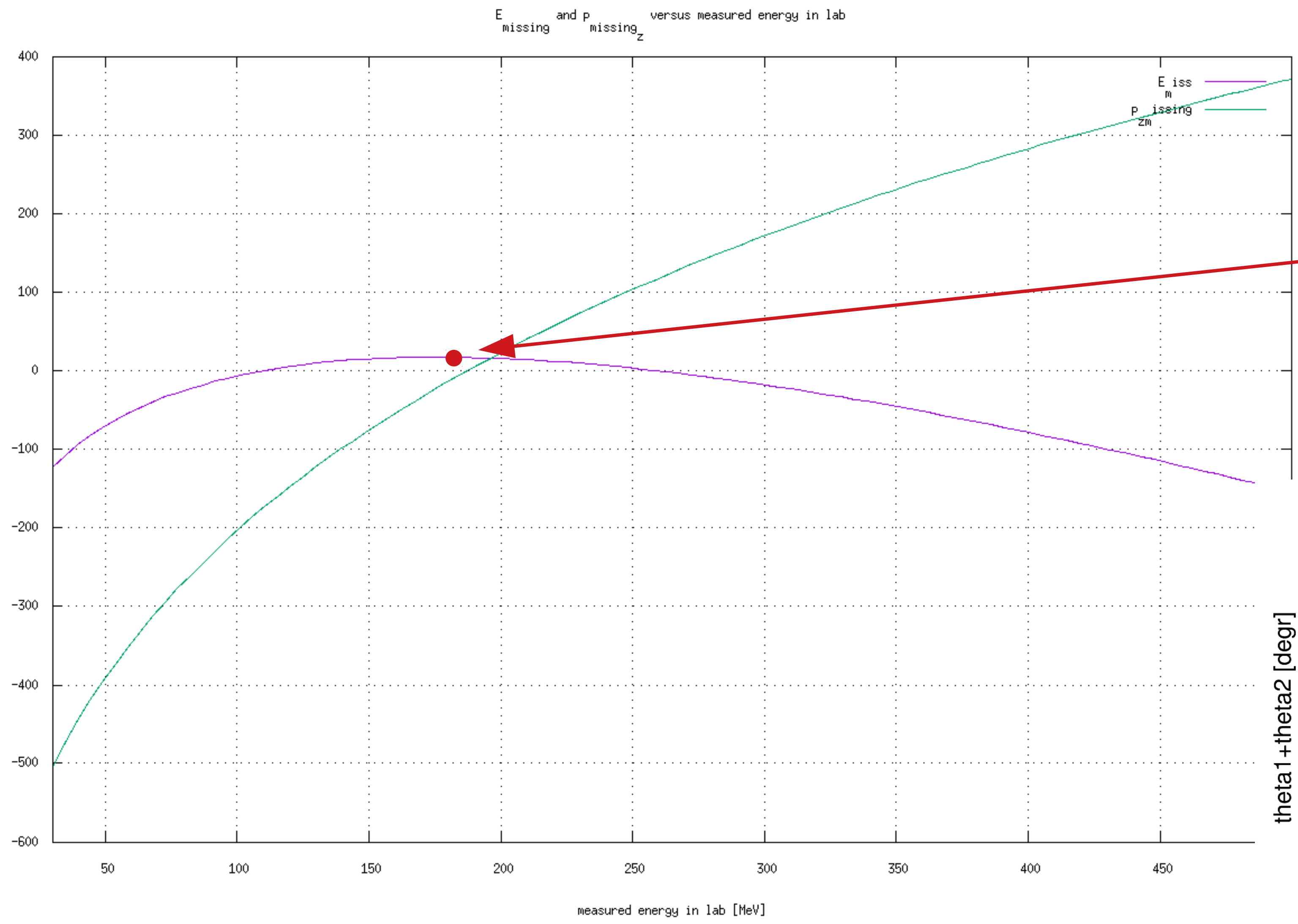
For simplicity let's say $\theta_1 = \theta_2$. That means for theta_sum = 44 ° → $\theta_1 = \theta_2 = 22°$



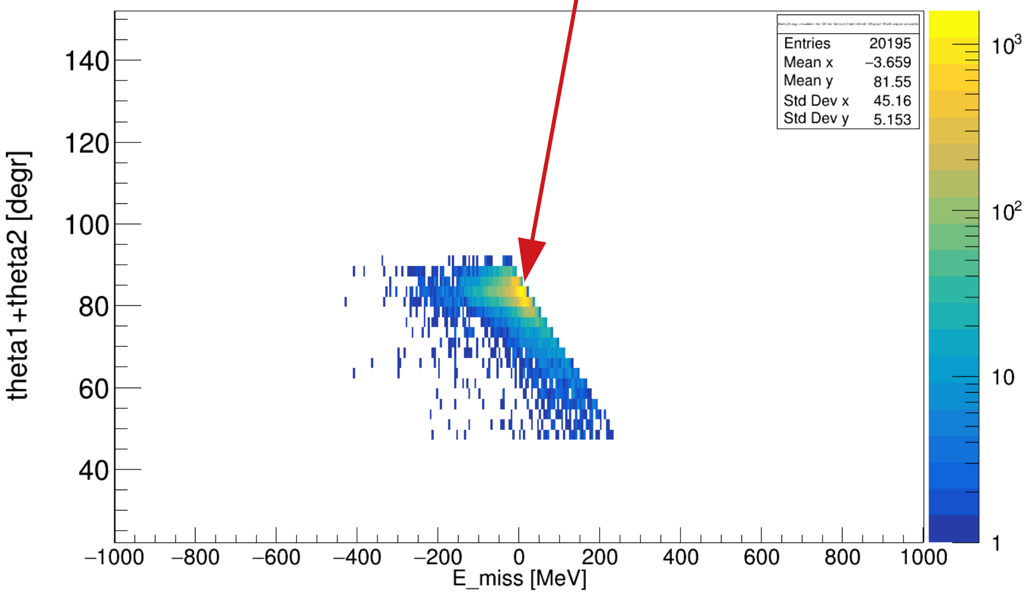
Maximum ≈ 270 MeV



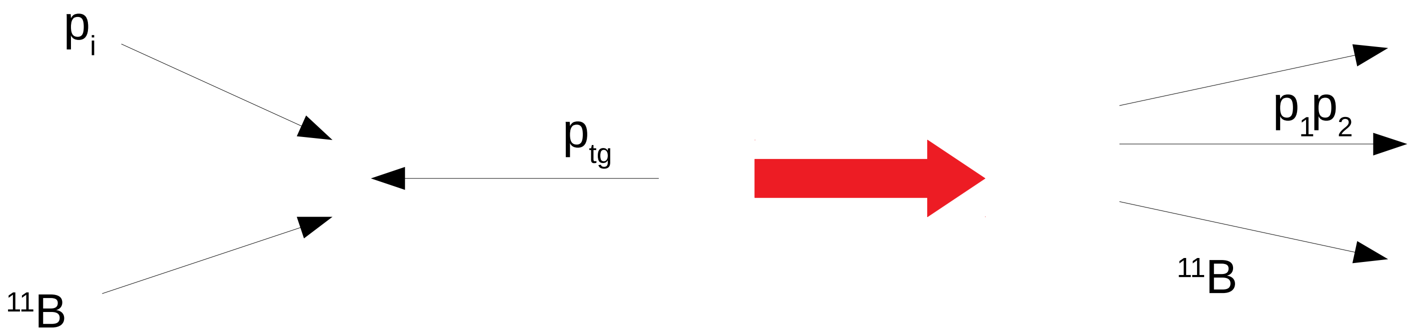
E_missing and p_z_missing for $\theta_1 = \theta_2 = 41°$



Maximum ≈ 20 MeV

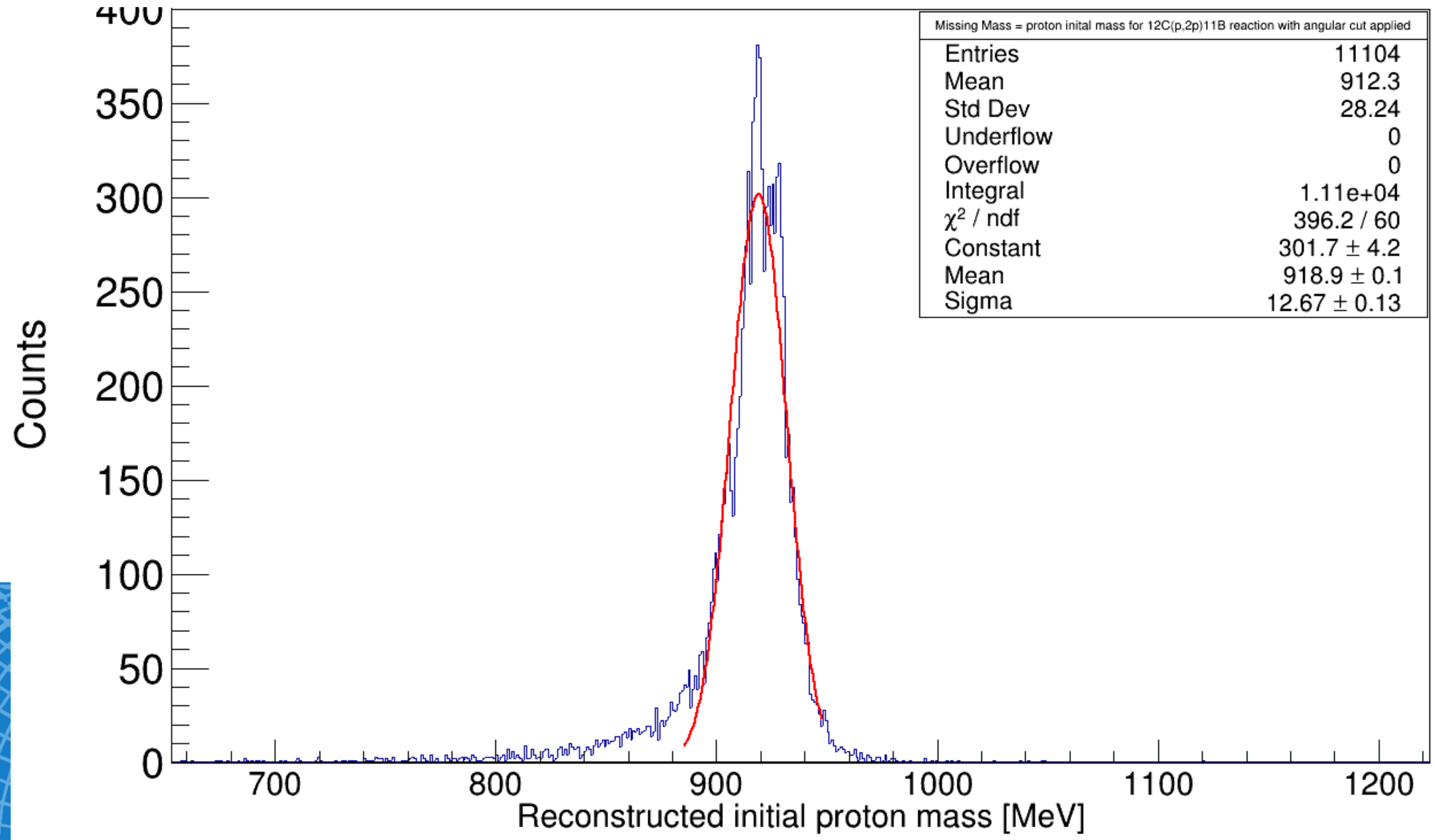


Mass reconstuction of p_i



$$p_i \approx p_{missing} = p_1 + p_2 - p_{tg} \left(no\ ISI / FSI \right)$$

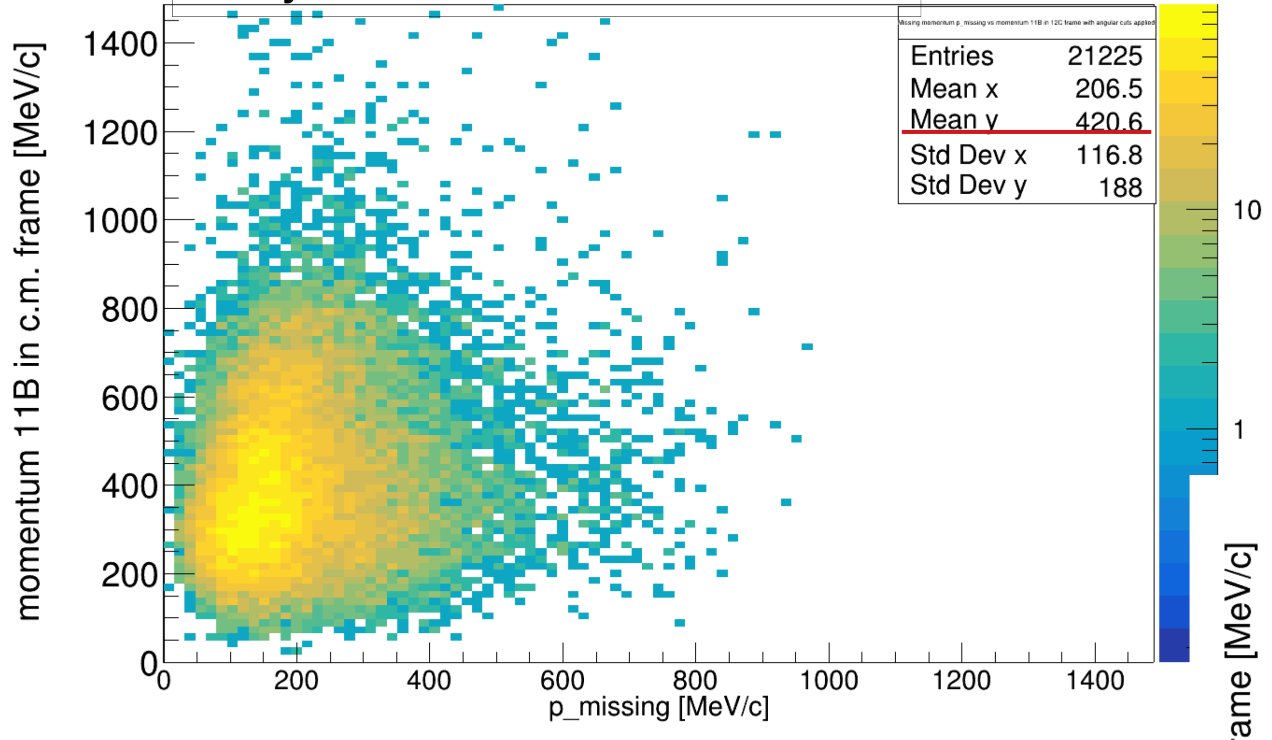
$$M_i = \sqrt{\left(p_1 + p_2 - p_{tg} \right)^2}$$



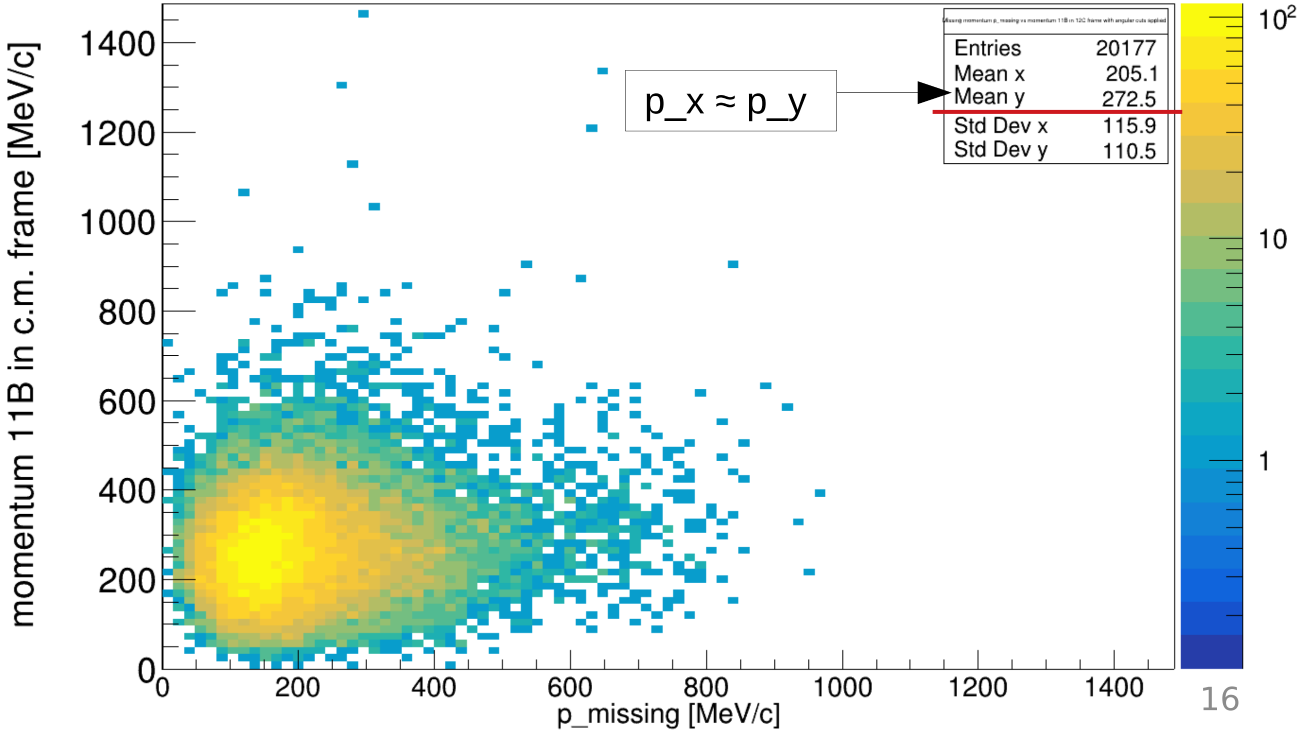
Looks ok, mean of 918 MeV is lower than expected….

Momentum p_i vs p_11B in 12C

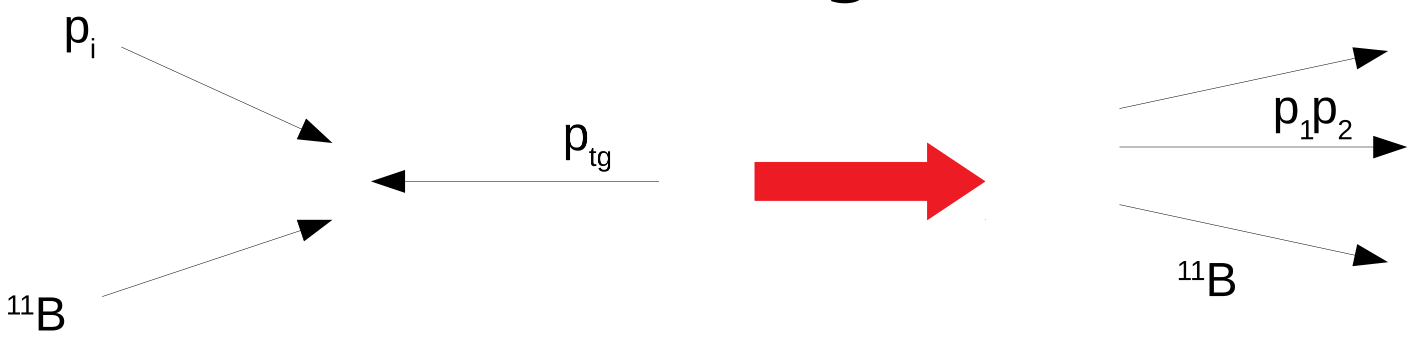
With y-information from MW1 and MW2



Now with y-info from MW1 and MW3



Missing mass reconstruction

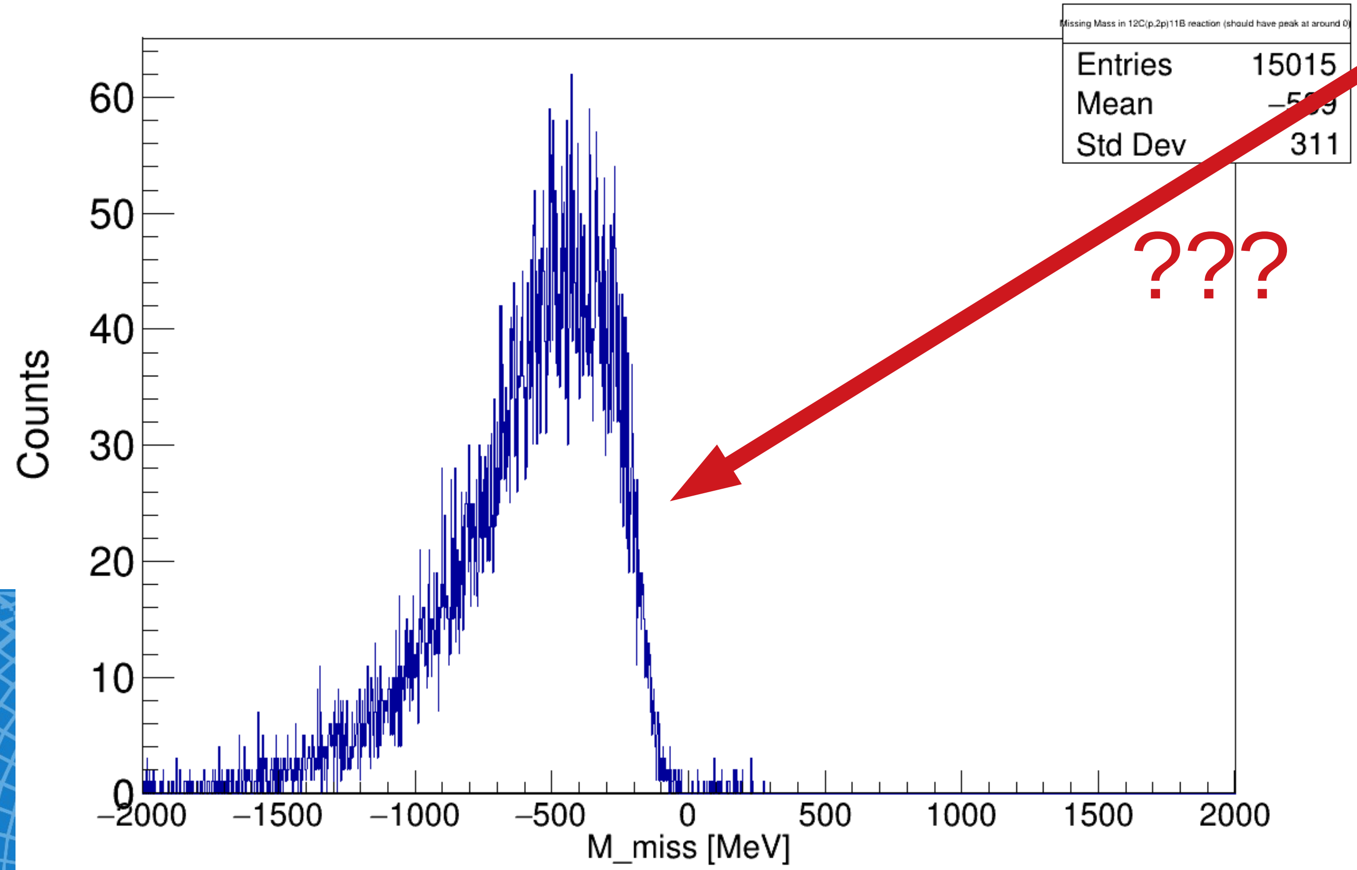


$$M_{miss} = \sqrt{\left(p_{12C} - p_i - p_{11B}\right)^2}$$

should be ≈ 0

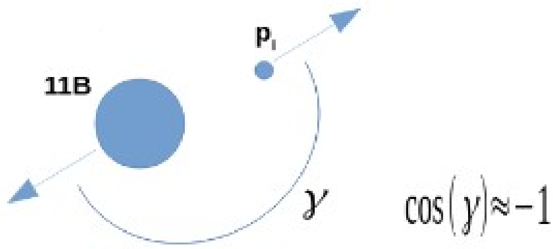
→ give better look at the 3-momentum distribution
(+- permutation at MW position??)

→ as the reconstruction of p_i works well it can be deduced that 11B reconstruction faulty….

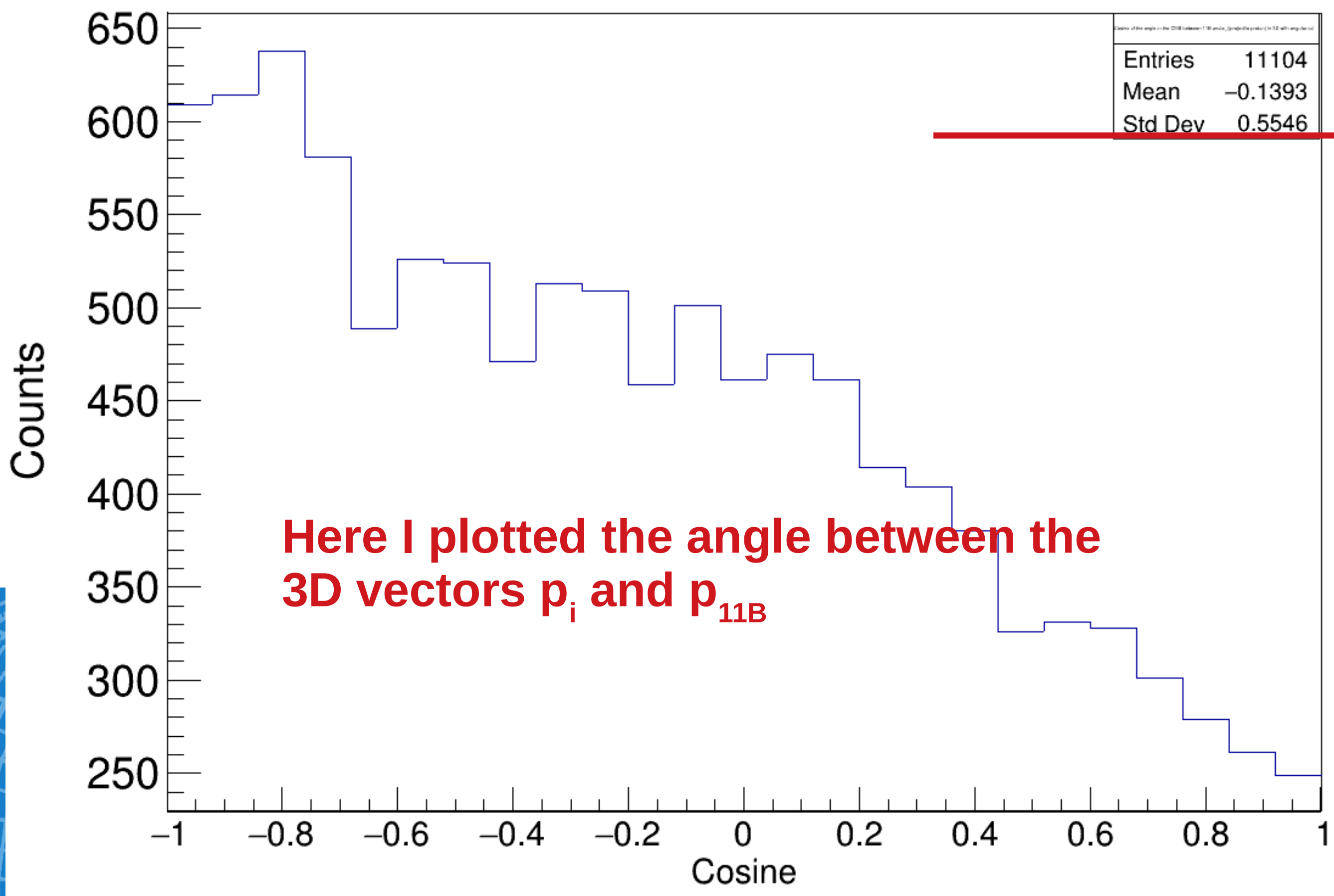


Inner angular distributions

$$p_{12C} = p_i + p_{11B}$$

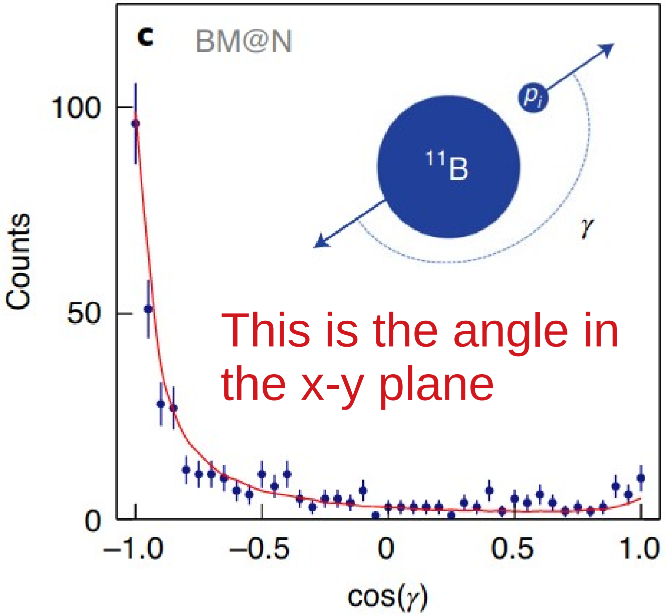


In 12C cms frame (using MW1 and MW2) :



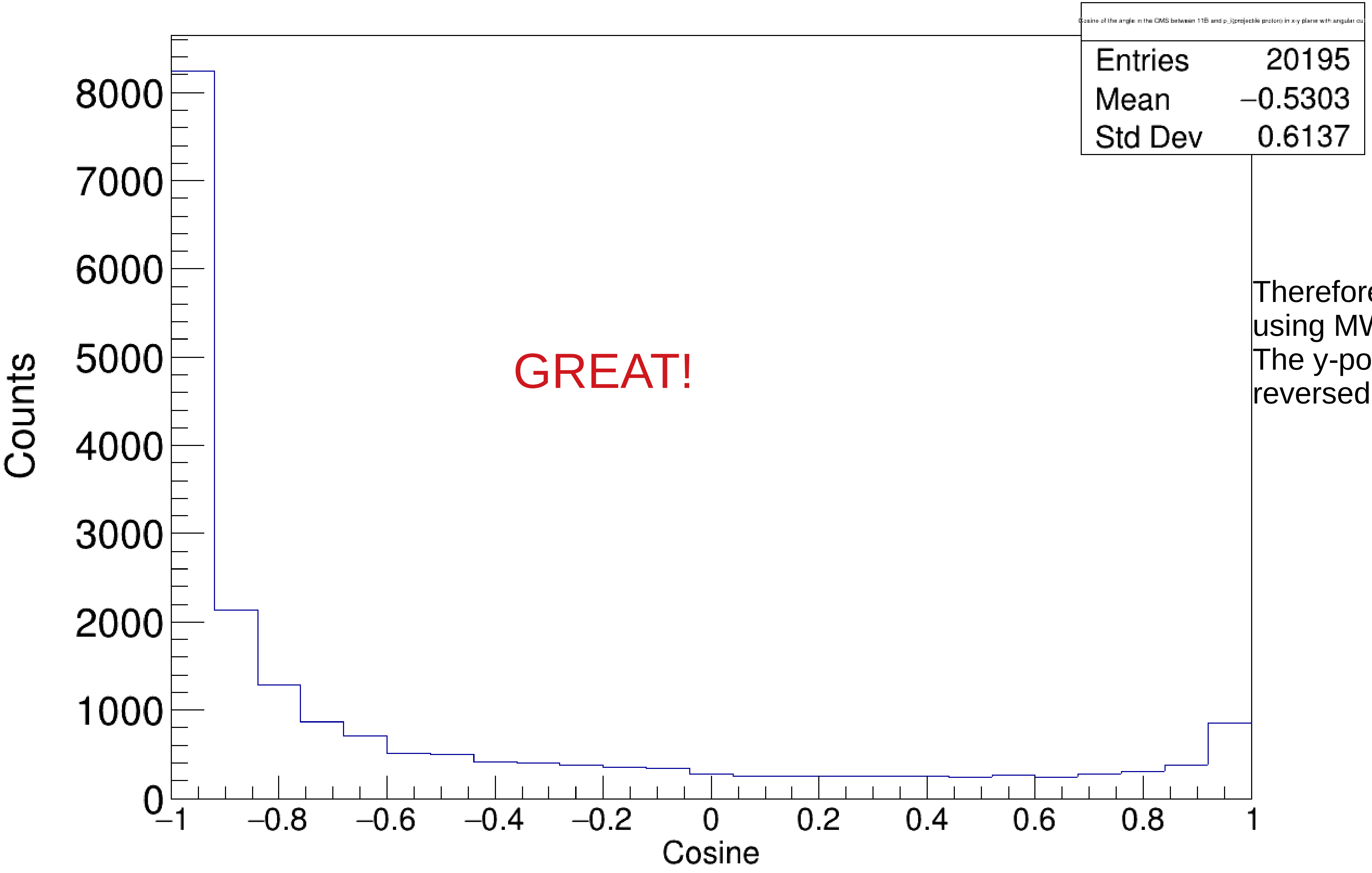
Here I plotted the angle between the 3D vectors p_i and p_{11B}

Not satisfactory….
See:
https://www.nature.com/articles/s41567-021-01193-4.pdf



This is the angle in the x-y plane

Angular Distribution in x-y plane

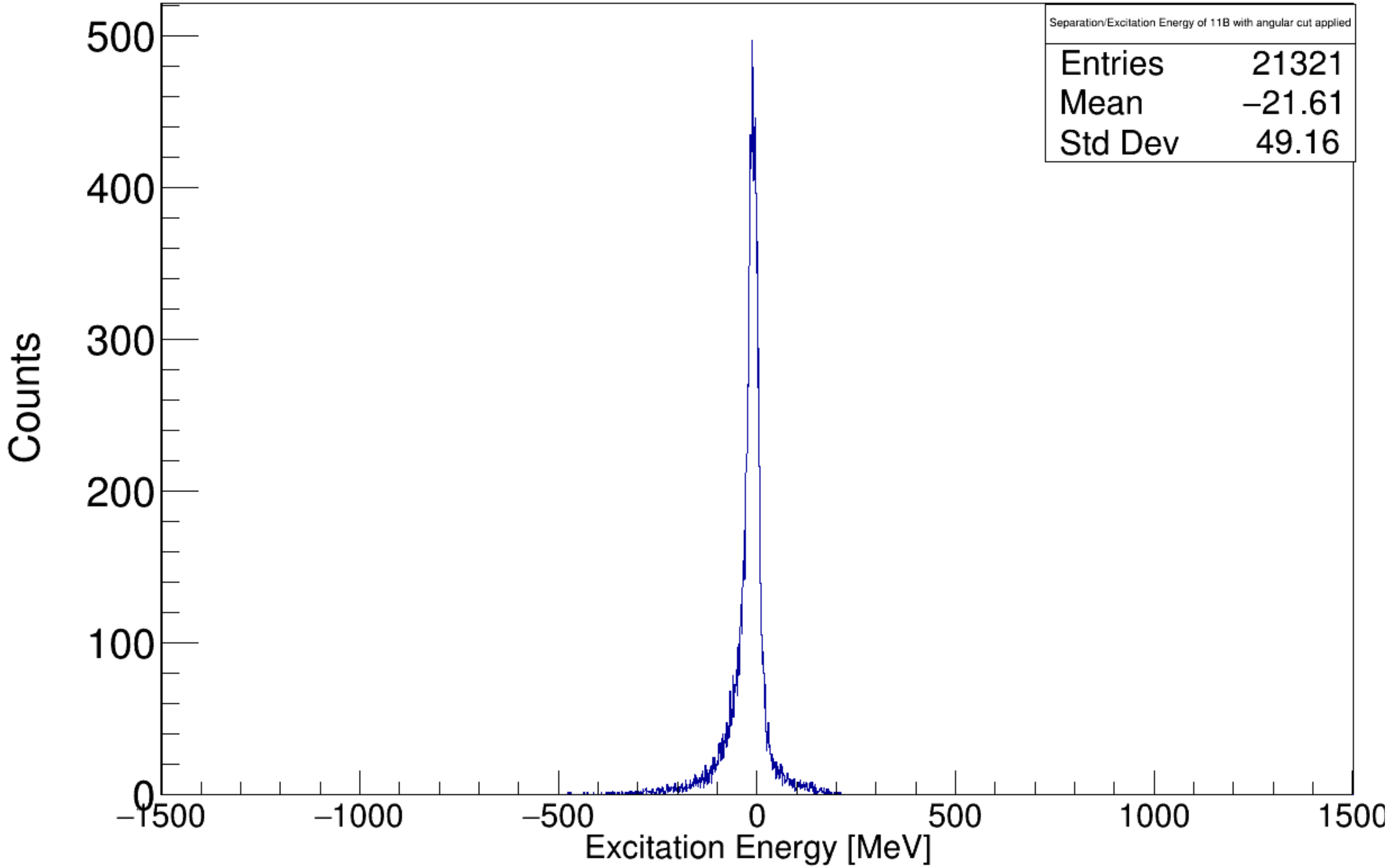


Therefore the y position was determined using MWPC3

The y-position of MWPC3 has been reversed (meaning +y→-y and -y→+y)

Excitation Energy of 11B

$$E_{exc} = \left(\boldsymbol{P}_{12C} + \underbrace{\boldsymbol{p}_{tg} - \boldsymbol{p}_1 - \boldsymbol{p}_2}_{-\mathbf{p}_i}\right).M - M_{11B}$$

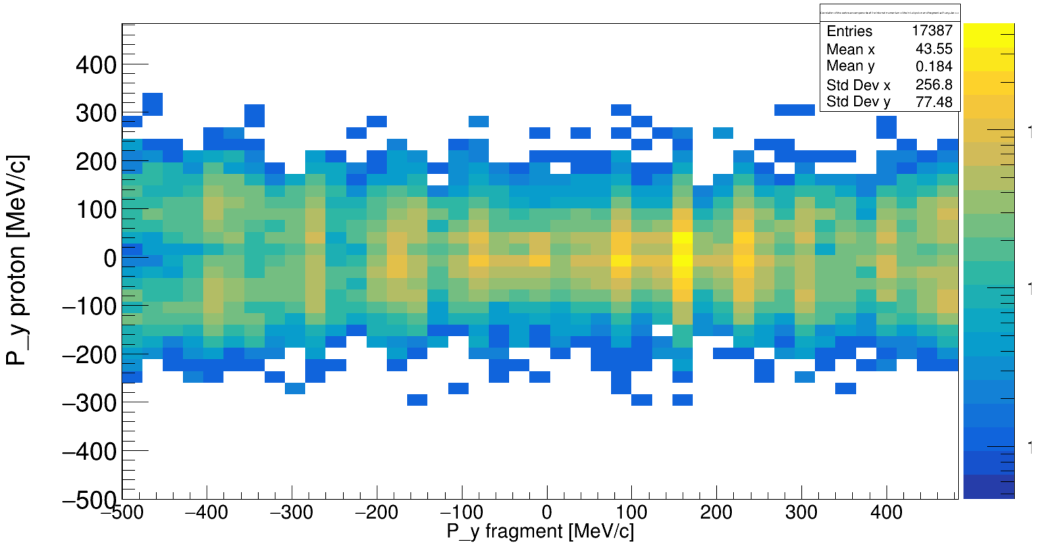


Is this formula valid?

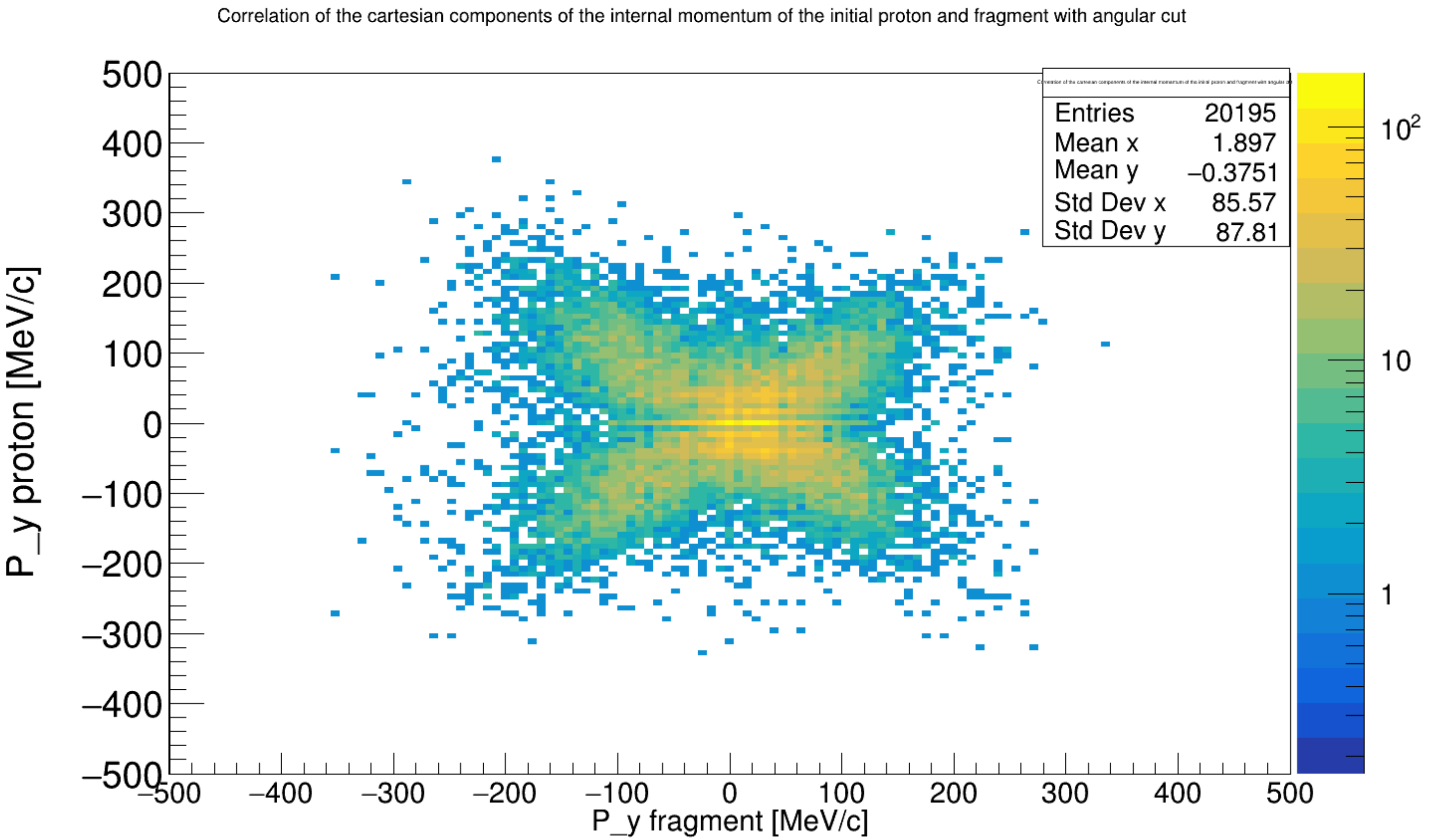
Correlation between knocked out proton and 11B

With given formula: $P_y = Q_k \times sin\theta_k sin(\varphi_k - \varphi_i),$

This plot was with Py_fragment reconstruction from MW1 and MW2



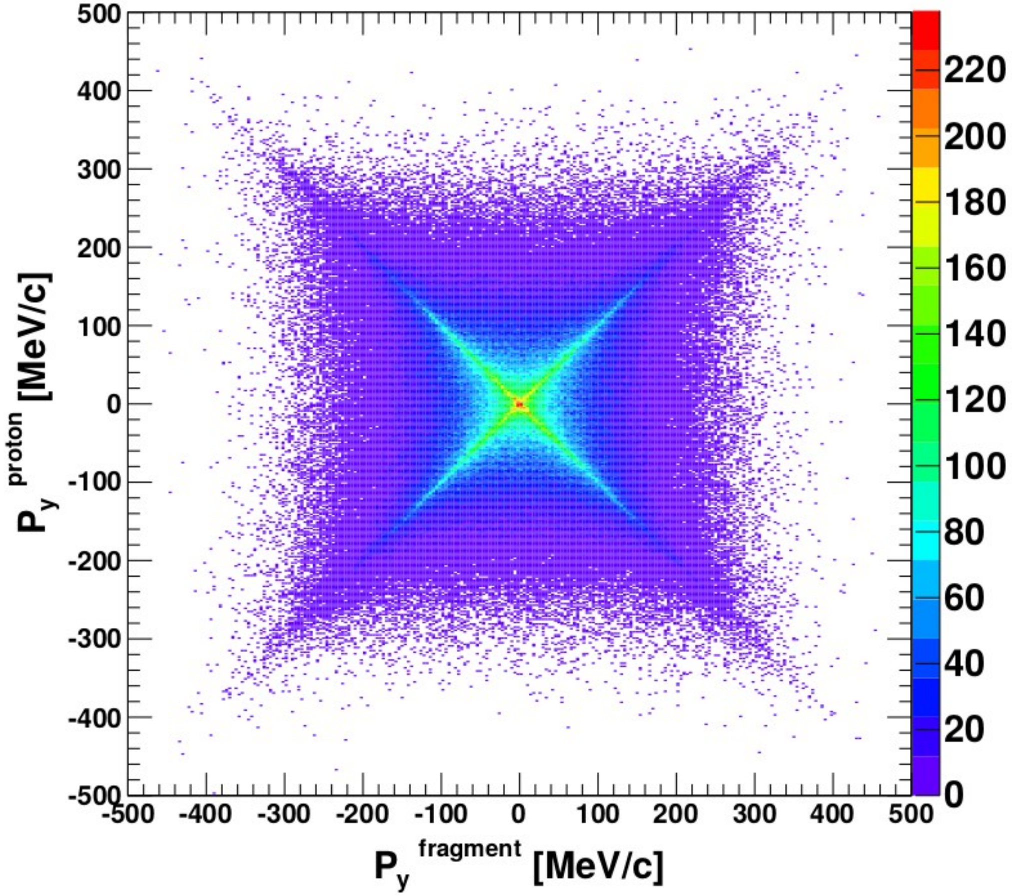
This is with Py_fragment reconstruction from MW1 and MW3



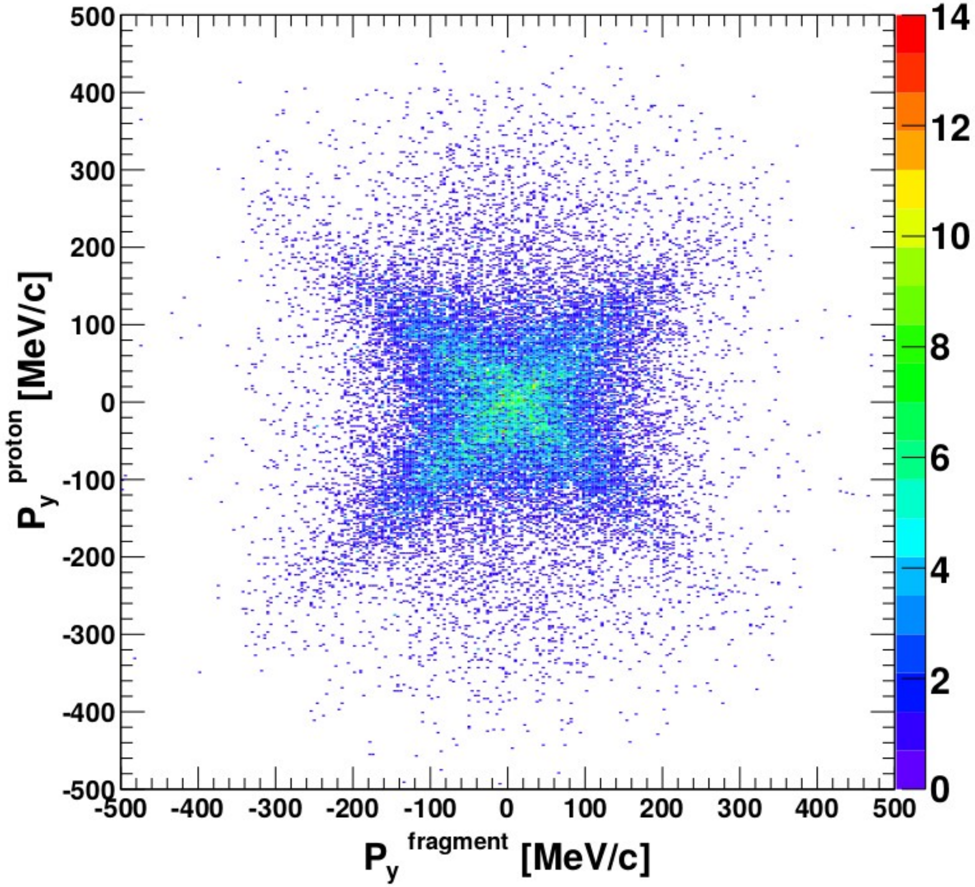
Correlation between knocked out proton and 11B

What we expect:

simulation



experiment



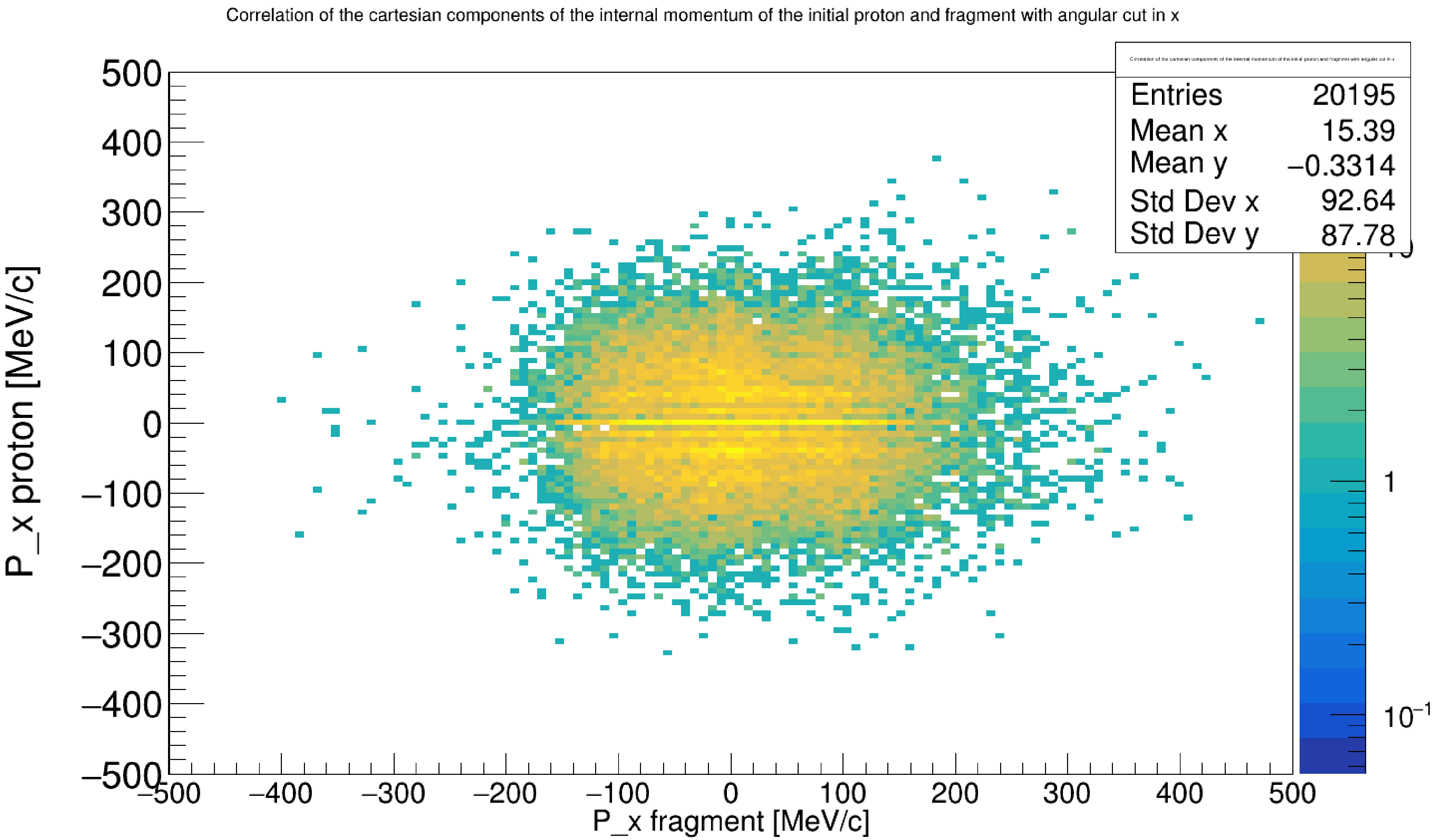
Explanation of $P_y = Q_k \times sin\theta_k sin(\varphi_k - \varphi_i),$

$Q_k \times sin\theta_k sin(\varphi_k - \varphi_i)$ Is a Cartesian component of the internal momentum of the internal momentum of the knocked out proton from 12C perpendicular to the reaction plane.
The reaction plane is given by the 12C momentum vector and the scattered target proton.

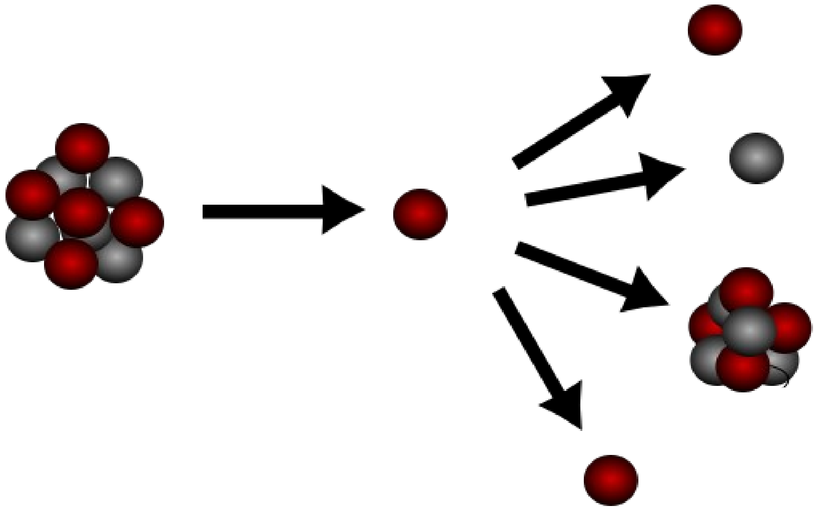
Can be plotted also against Px_fragment (see next slide). This is a blurred centered spot. This can be explained by:

→ acceptance of CALIFA: no crystals in the phi +-90° region , therefore the y component is dominant
→ low precision for y position (can be partly solved using MW1.Y vs MW3.Y, but then straggling..)

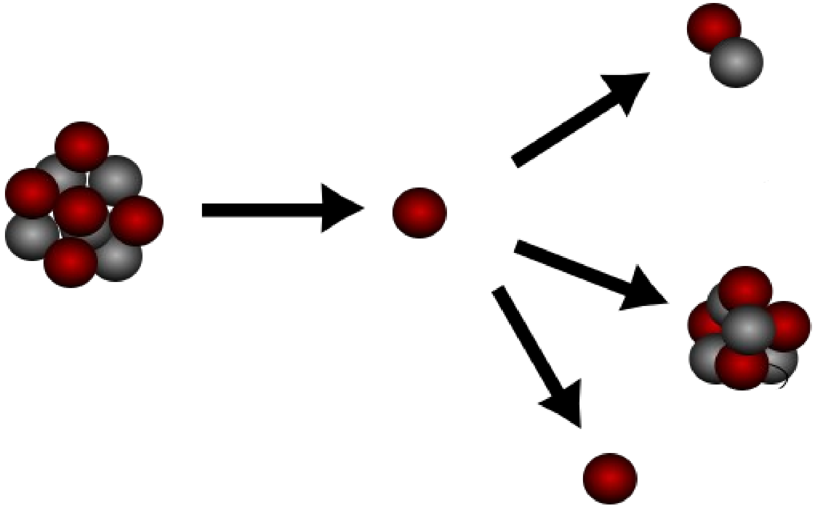
For more details and derivation see:
https://www.sciencedirect.com/science/article/abs/pii/S0375947405008523


Correlation of the cartesian components of the internal momentum of the initial proton and fragment with angular cut in x
Entries 20195
Mean x 15.39
Mean y −0.3314
Std Dev x 92.64
Std Dev y 87.78
P_x proton [MeV/c]
P_x fragment [MeV/c]
500
400
300
200
100
0
−100
−200
−300
−400
−500
1
10^{-1}

12C(p,ppn/pd)10B Reaction

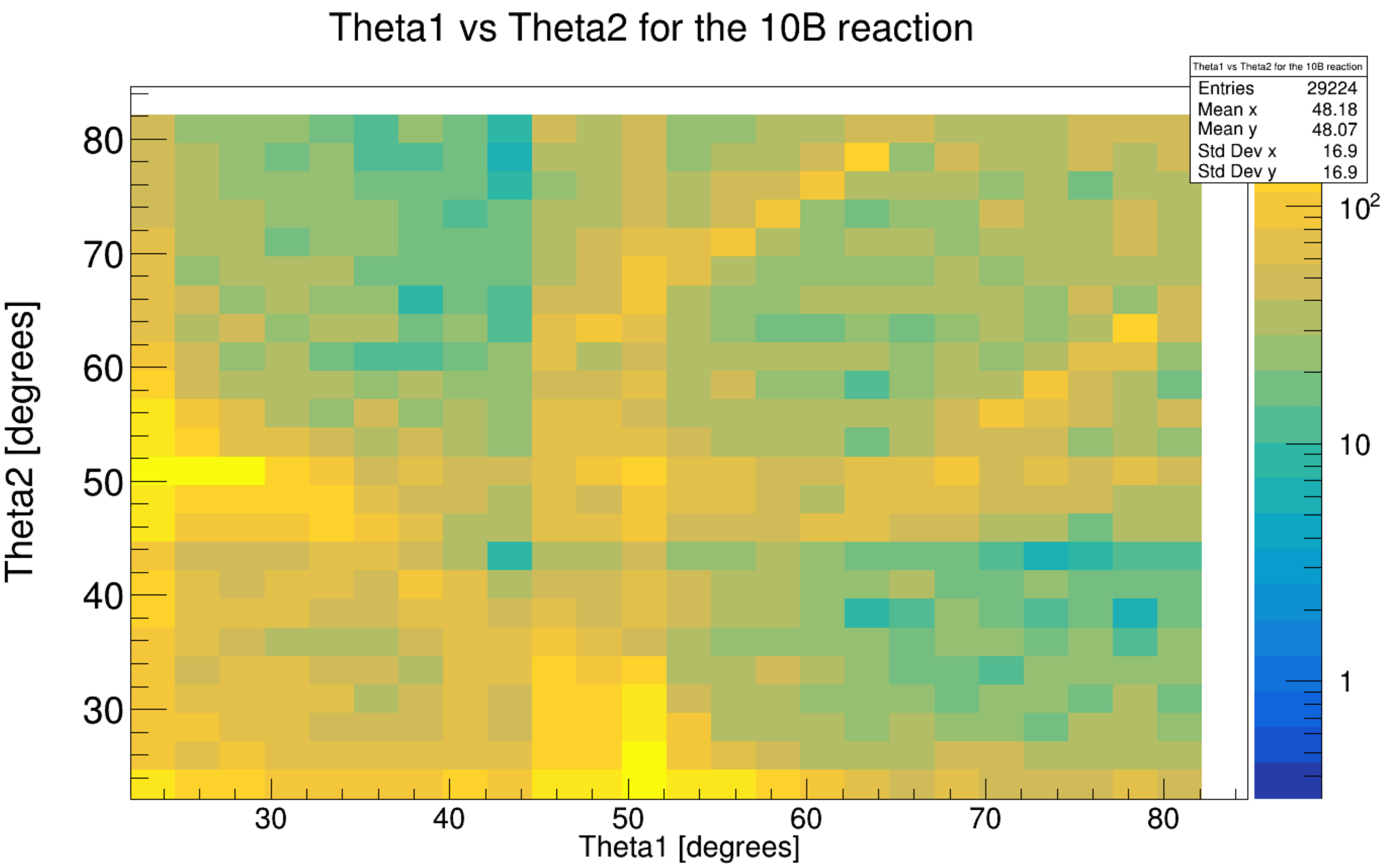


or



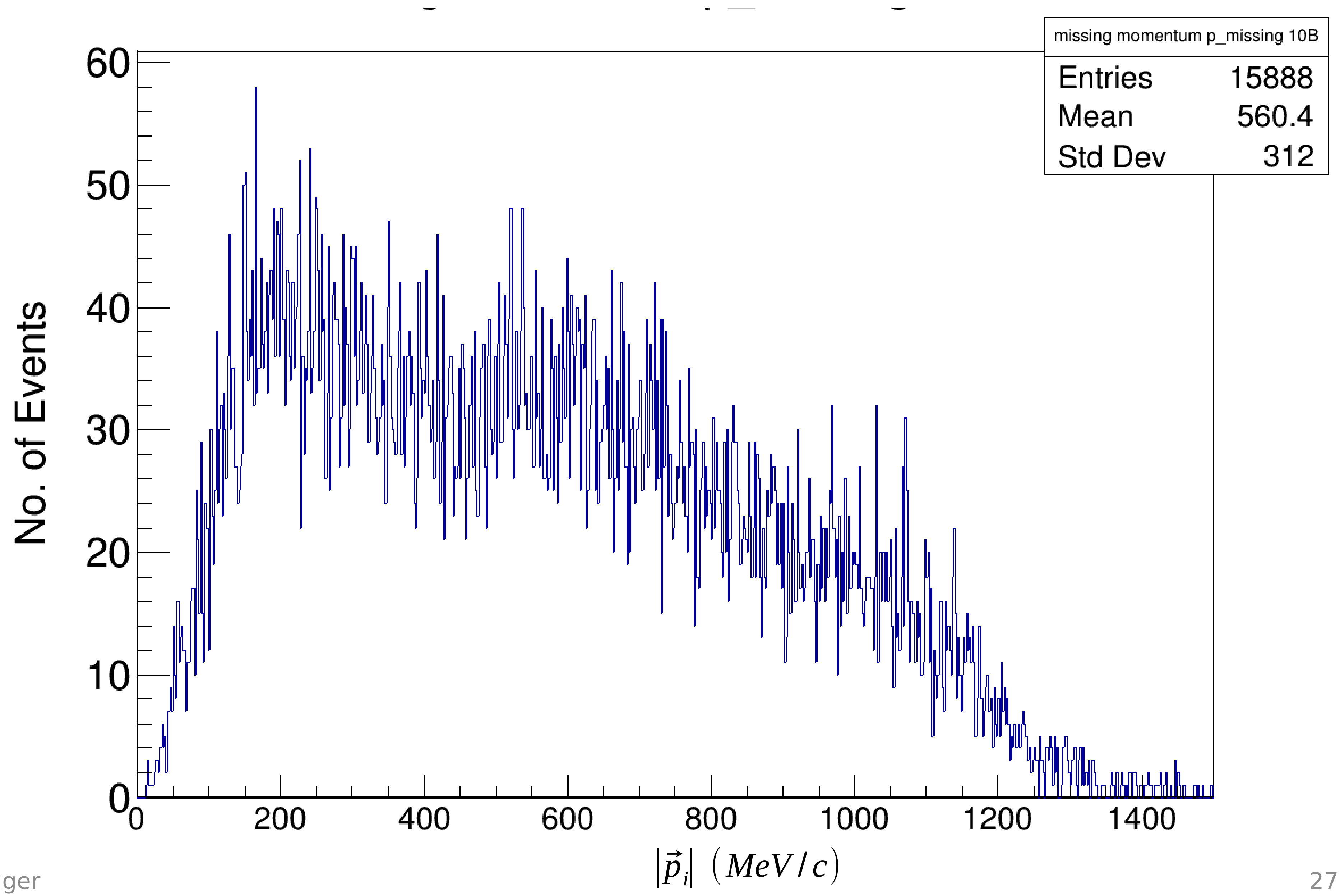
First Angular and Momentum Plots …

Without cut:



Reconstruction of inner momentum p_i

$$p_i = (p_1 + p_1 - p_{tg})$$



Neutron Mass Reconstruction

$$M^2_{missing} = (\underbrace{p_{12C} + p_{tg}}_{\text{before reaction}} \underbrace{- p_1 - p_2 - p_{10B}}_{\text{after reaction}})^2$$