S522 Experiment status update

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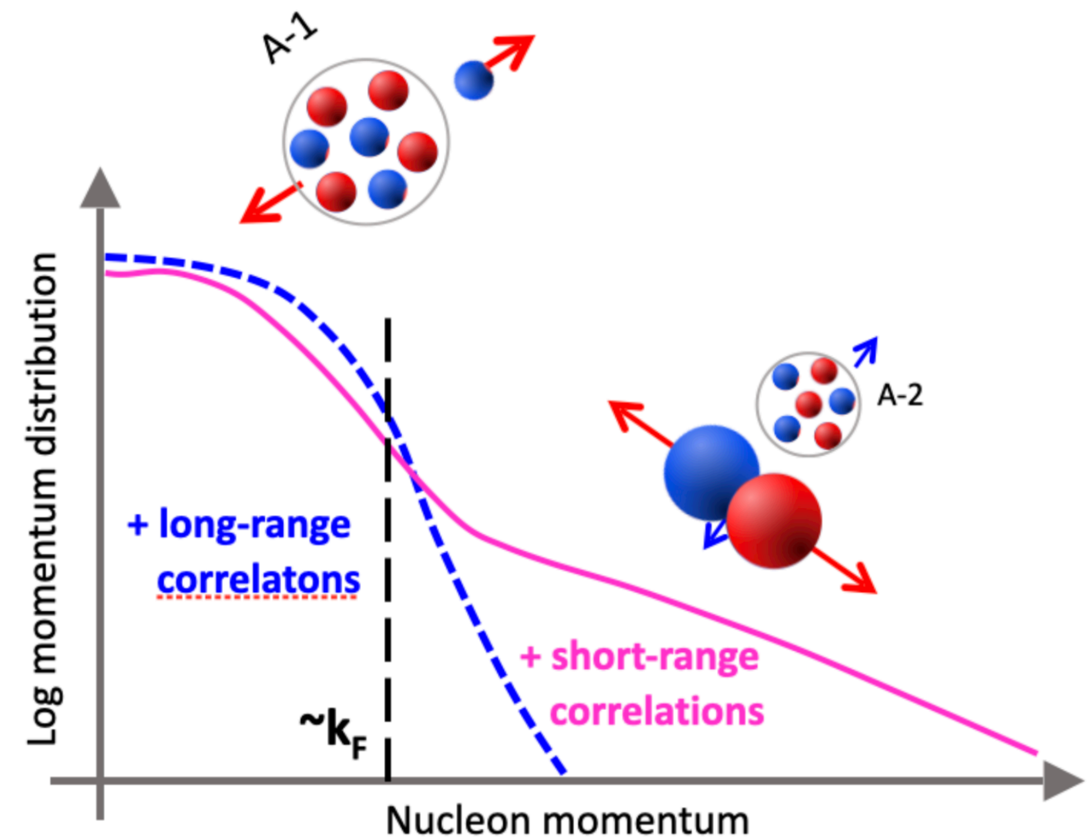
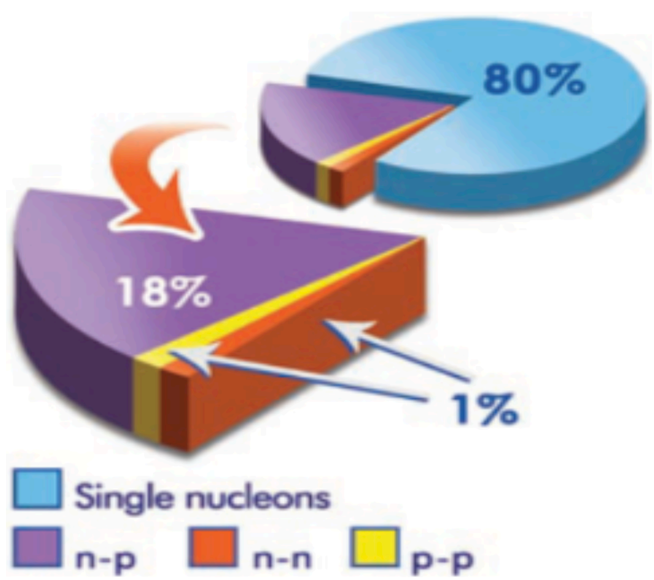
Mainz 9th Nov 2023

What are SRCs?

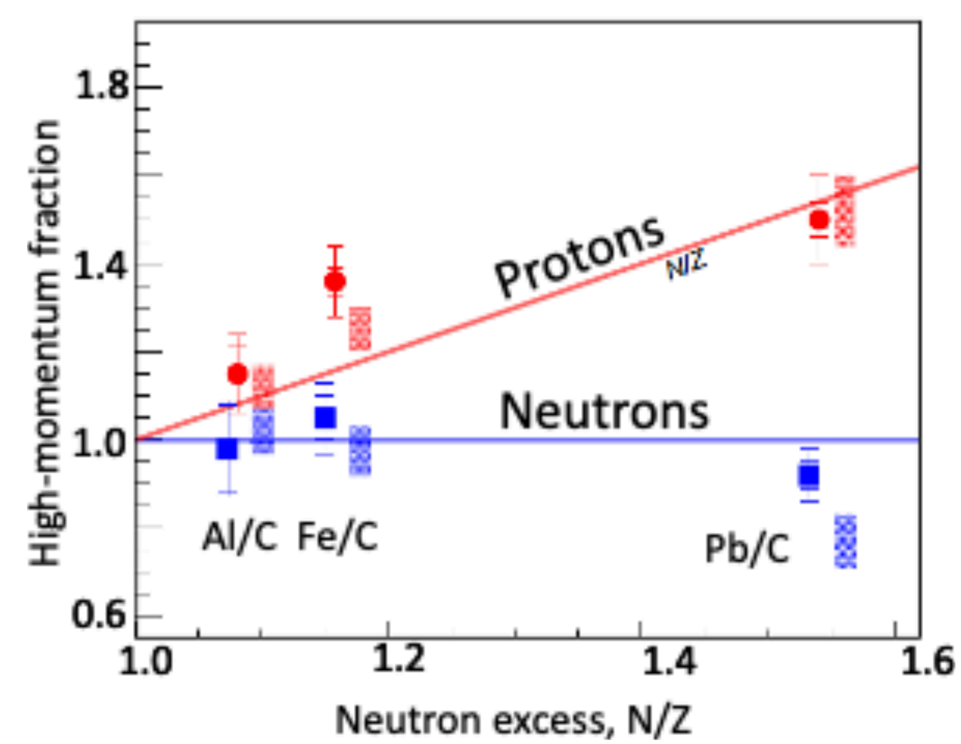
High relative momentum and low centre of mass (c.m.) momentum pairs;

- mainly proton-neutron (pn) pairs;
- pp/pn ratio does not change with A;
- The fraction of high momentum protons increases with N/Z.





R.Saubedi,Science,Vol 320, (2008)



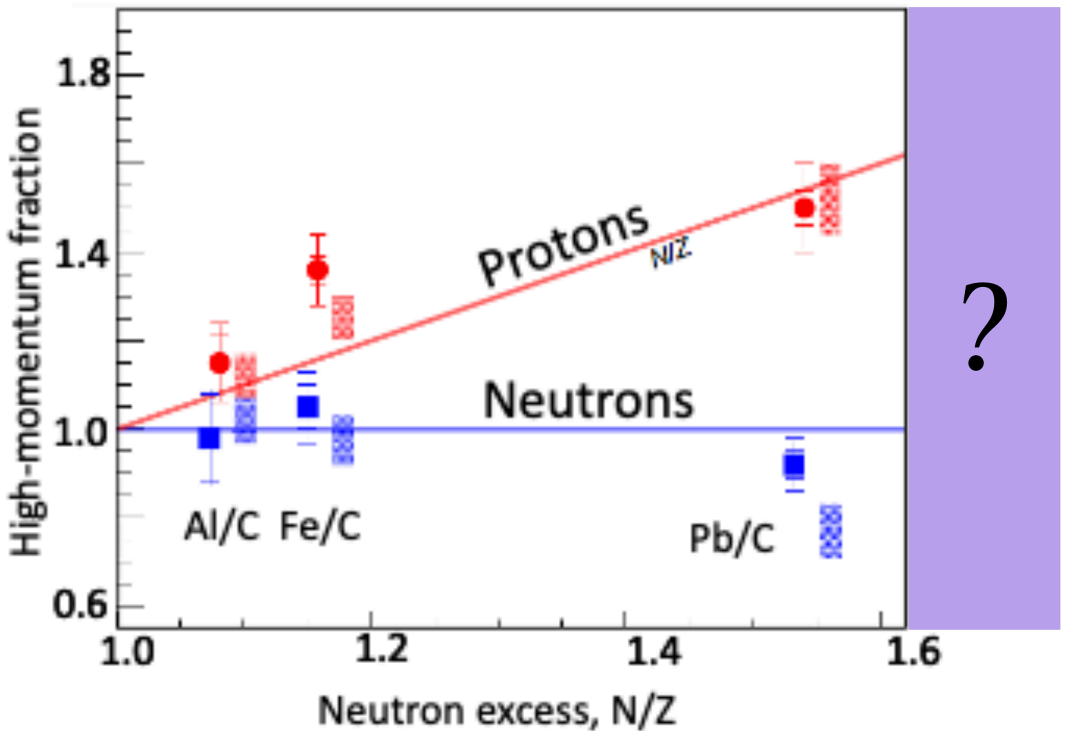
Adapted from M. Duer et al. (CLAS Collaboration), Nature, 560:617, 2018.

Motivation and goals

Motivations R3B Experiment

- Existing trend based on a few points;
- behaviour can depend on shell structure (open/closed shell effects);
- mass and N/Z excess cannot be disentangled with stable nuclei.

- **New measurement at N/Z = 1.67 (^{16}C), above the largest available N/Z and at a much smaller mass.**



Adapted from M. Duer et al. (CLAS Collaboration), Nature, 560:617, 2018.

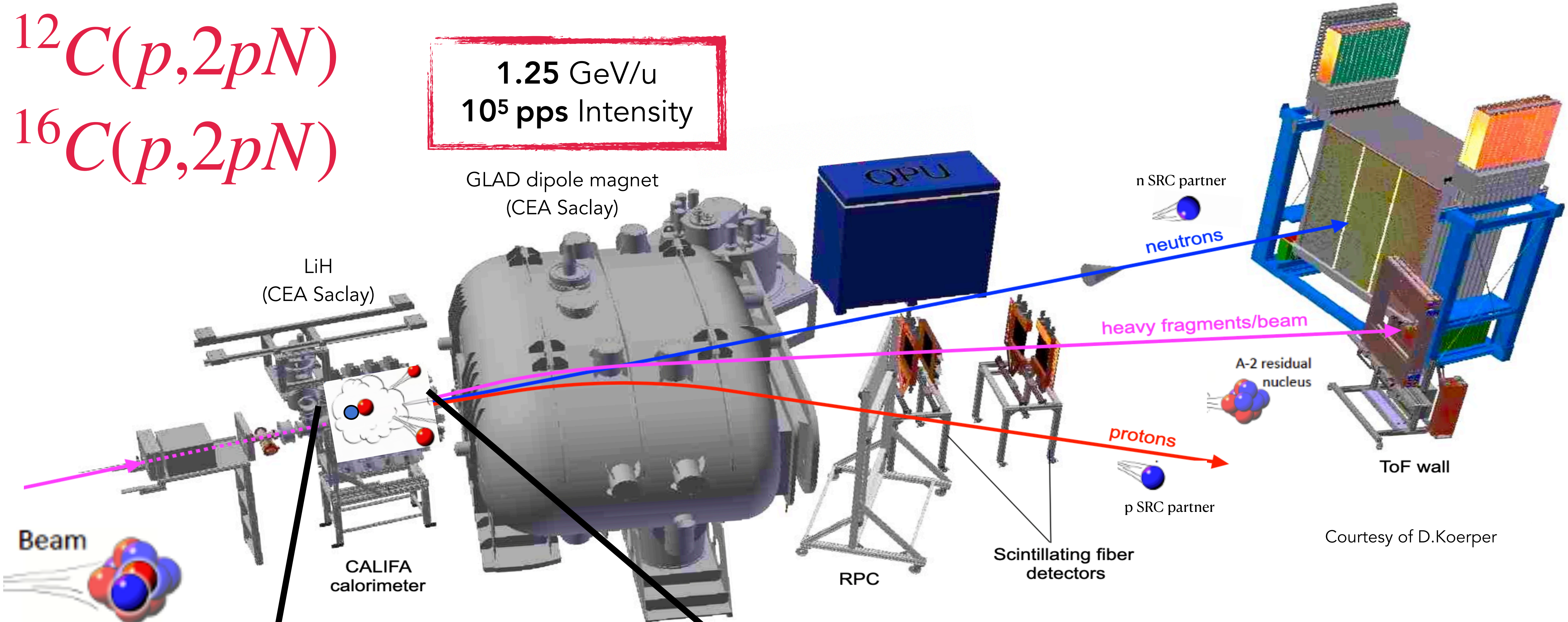
- Experiment run in **May 2022**;
- **Calibration** of the detector completed;
- **Alignment** of the detectors with MDF tracking;
- **(p,2p)** analysis and **QE** events selection.

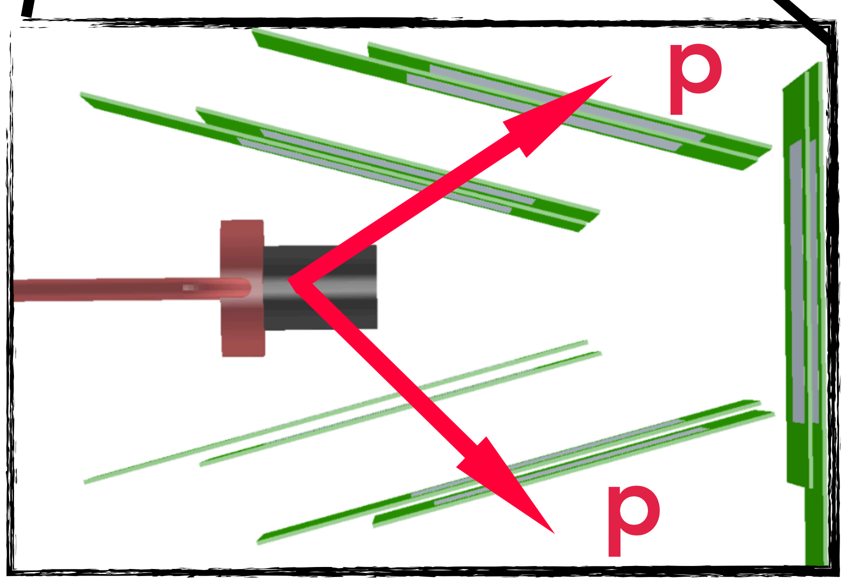
R^3B Experimental Set-up

$^{12}C(p,2pN)$

$^{16}C(p,2pN)$

1.25 GeV/u
10^5 pps Intensity





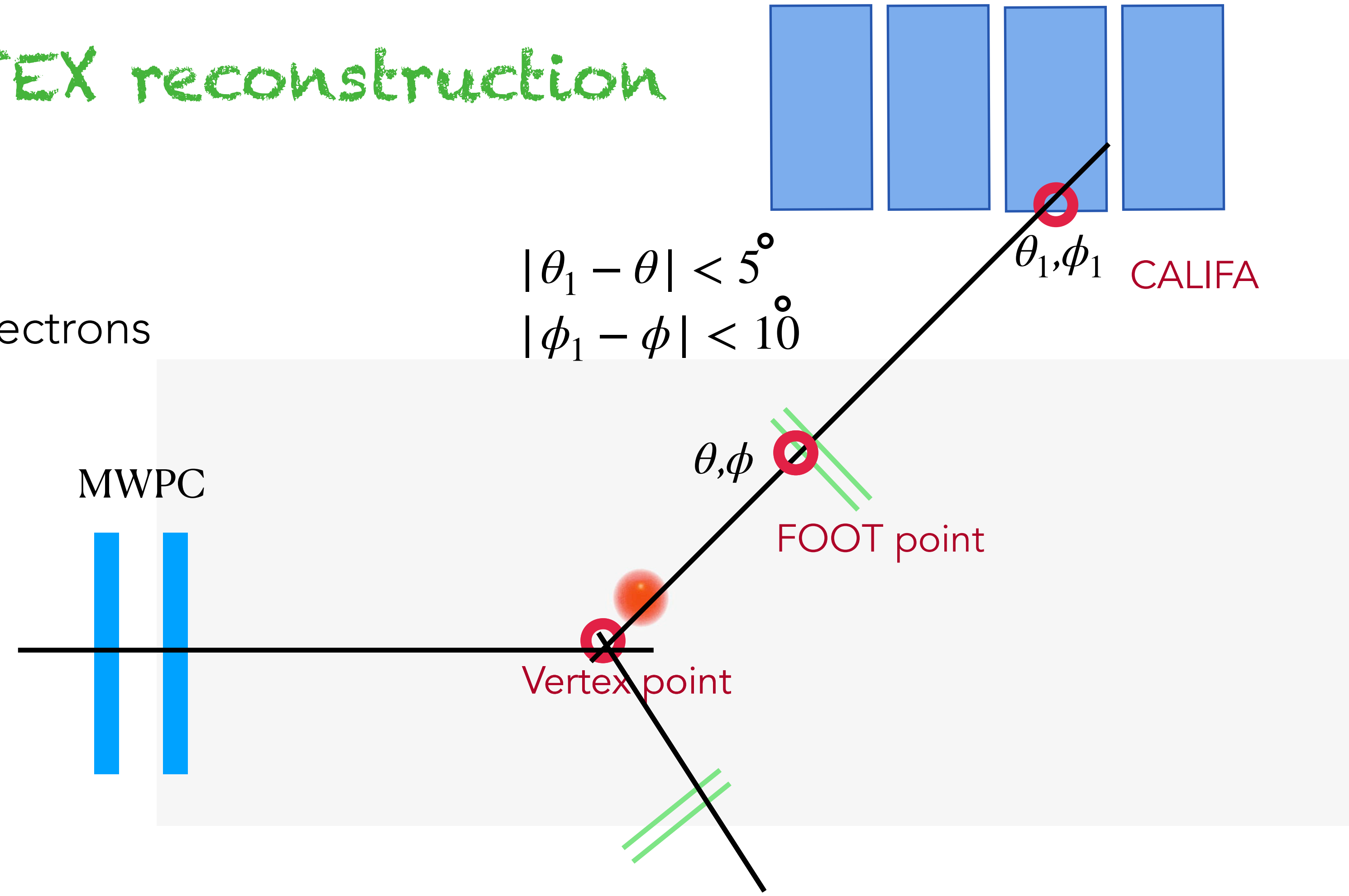
- tracking and momentum of the **two scattered protons** under large laboratory angles (Silicon + Calorimeter);
- **pair-recoil nucleon** (n or p) momentum;
- **A-2 fragment momentum.**

(p,2p): reaction vertex

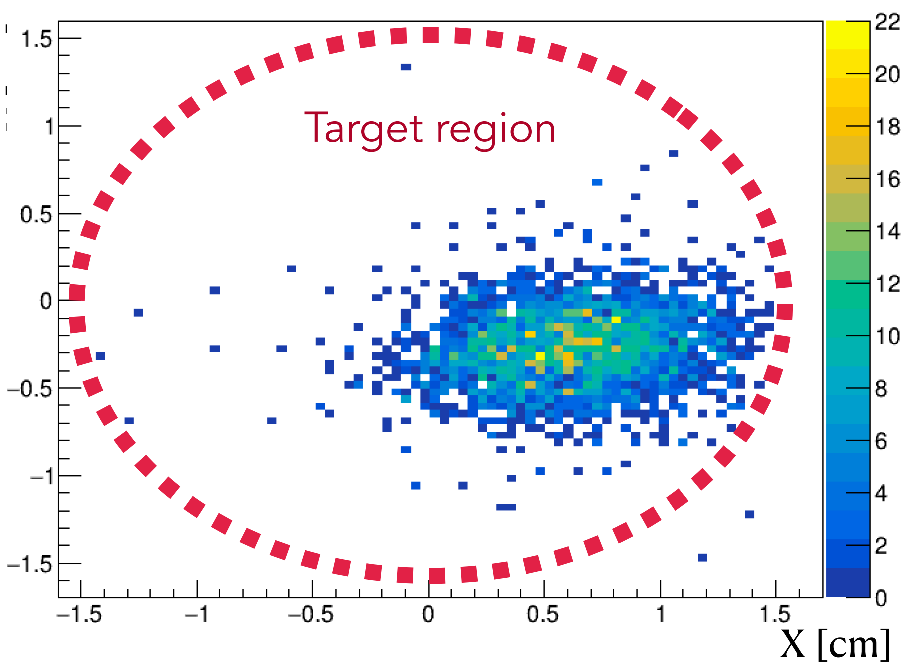
(p,2p) VERTEX reconstruction

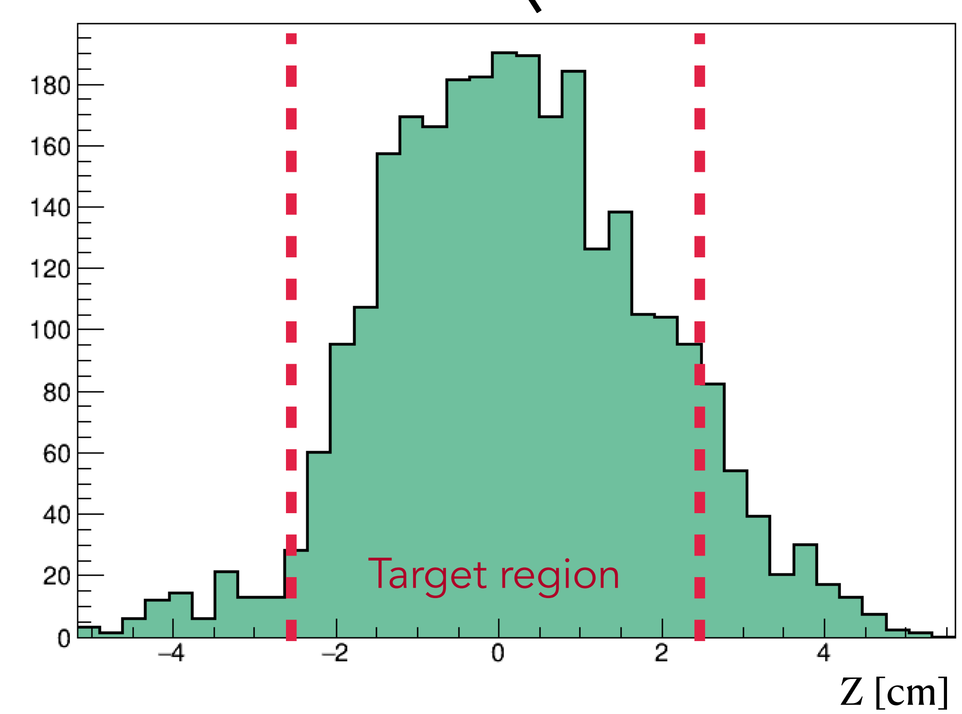
Challenges

- High beam **energy** and **intensity**;
- High **background** and **noise** level (delta electrons and baseline fluctuations);
- Low proton **energy deposited**.



- ✓ **Minimum distance** between all possible combinations of FOOT tracks from the left arm and right arm;
- ✓ Matching with **CALIFA angles**;
- ✓ MWPC tracks projection at the z of the vertex.



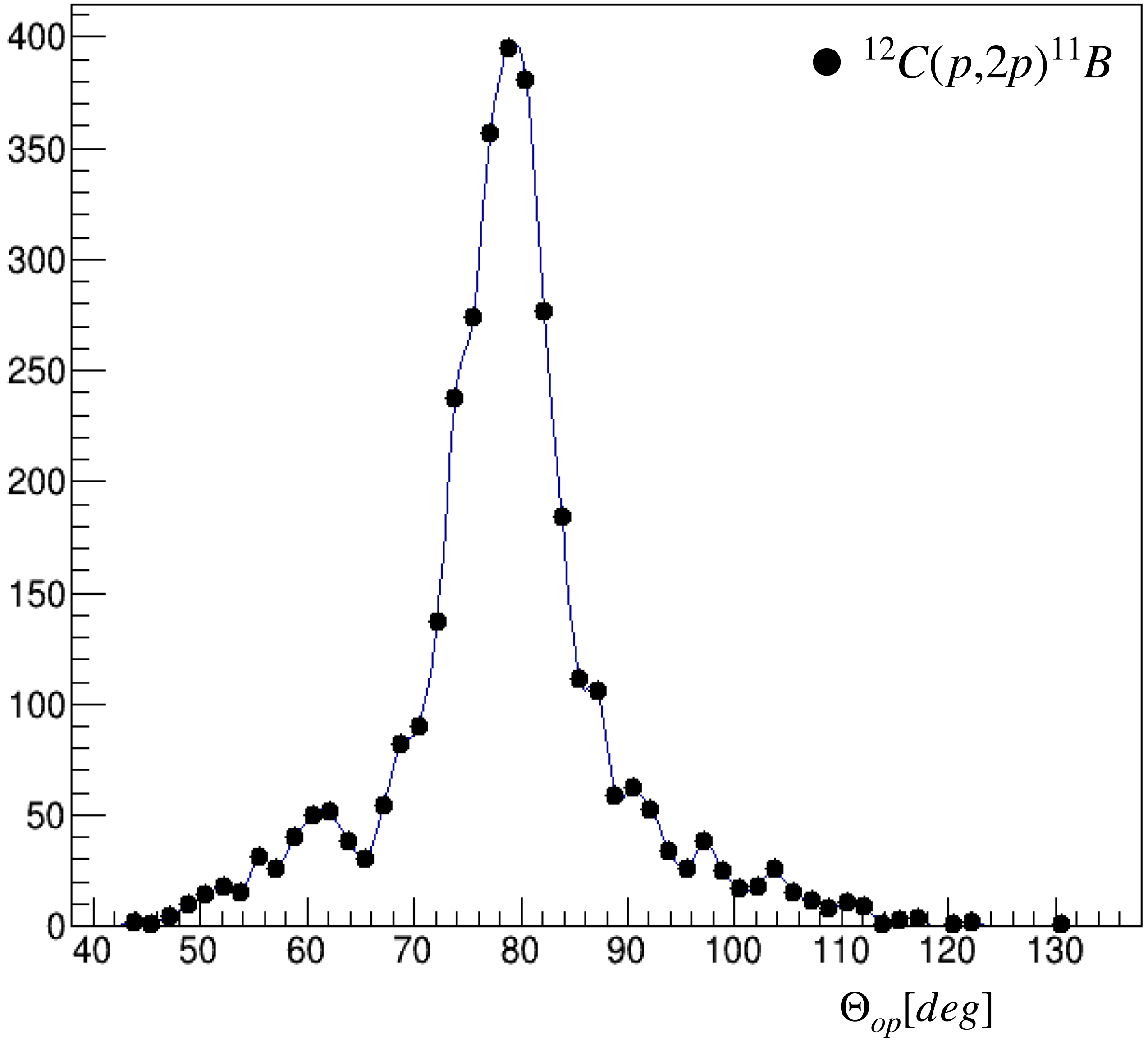


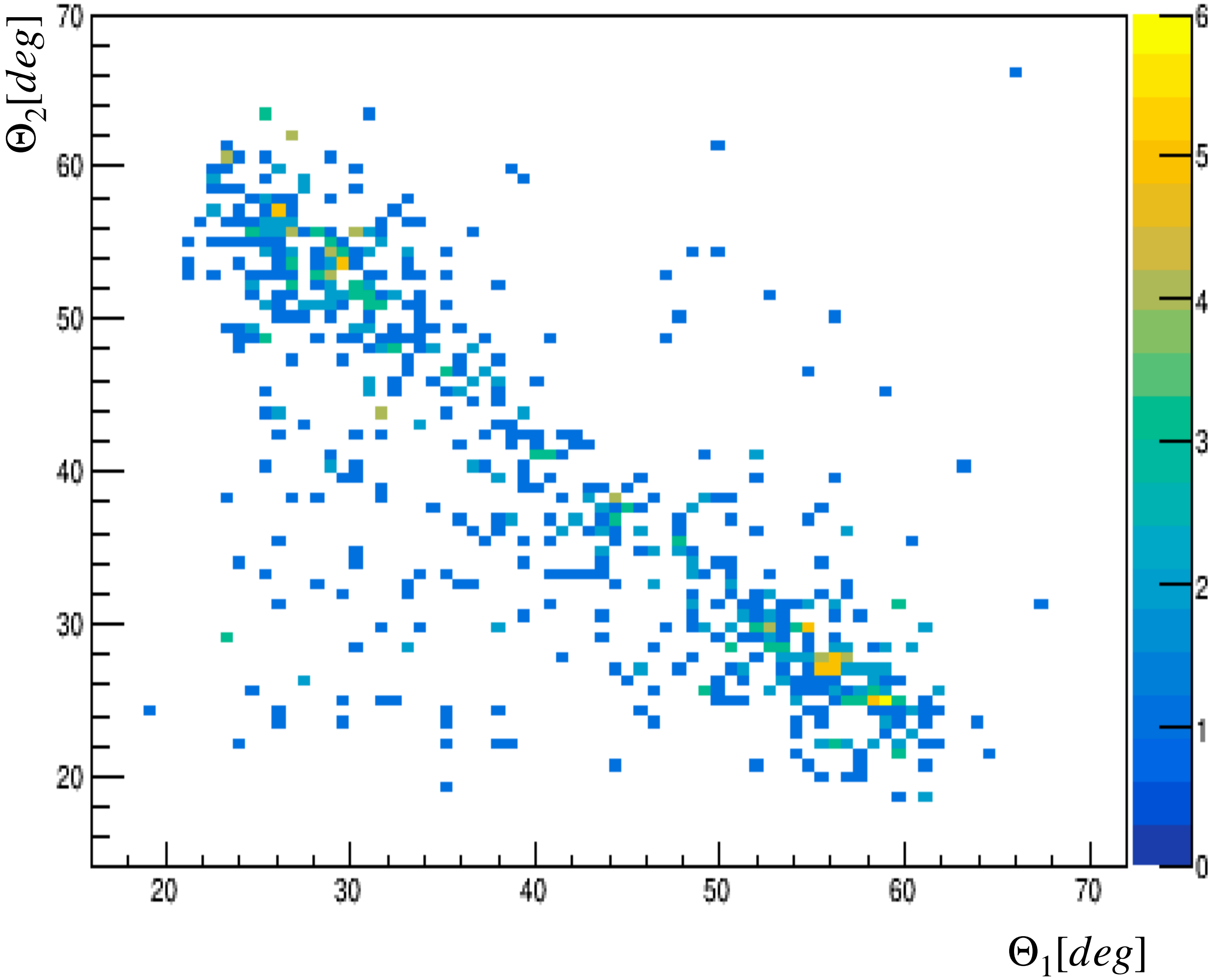
pp Opening angle Vertex

Opening Angle

- In-plane Opening Angle between the two scattered protons;
- Selection of ^{11}B fragment;

pp angle correlations





Fragment analysis: MDF Tracking

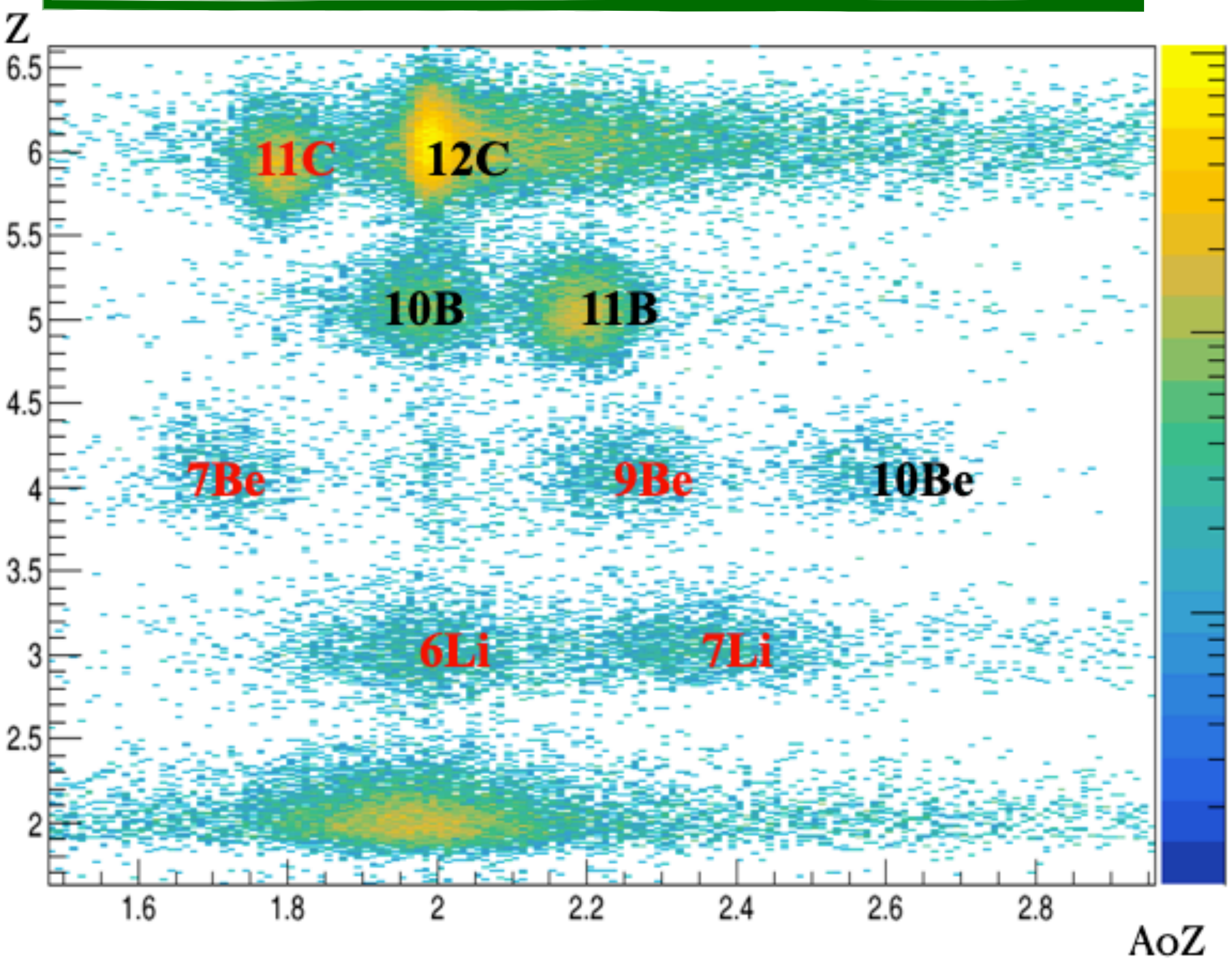
12C Fragments PID

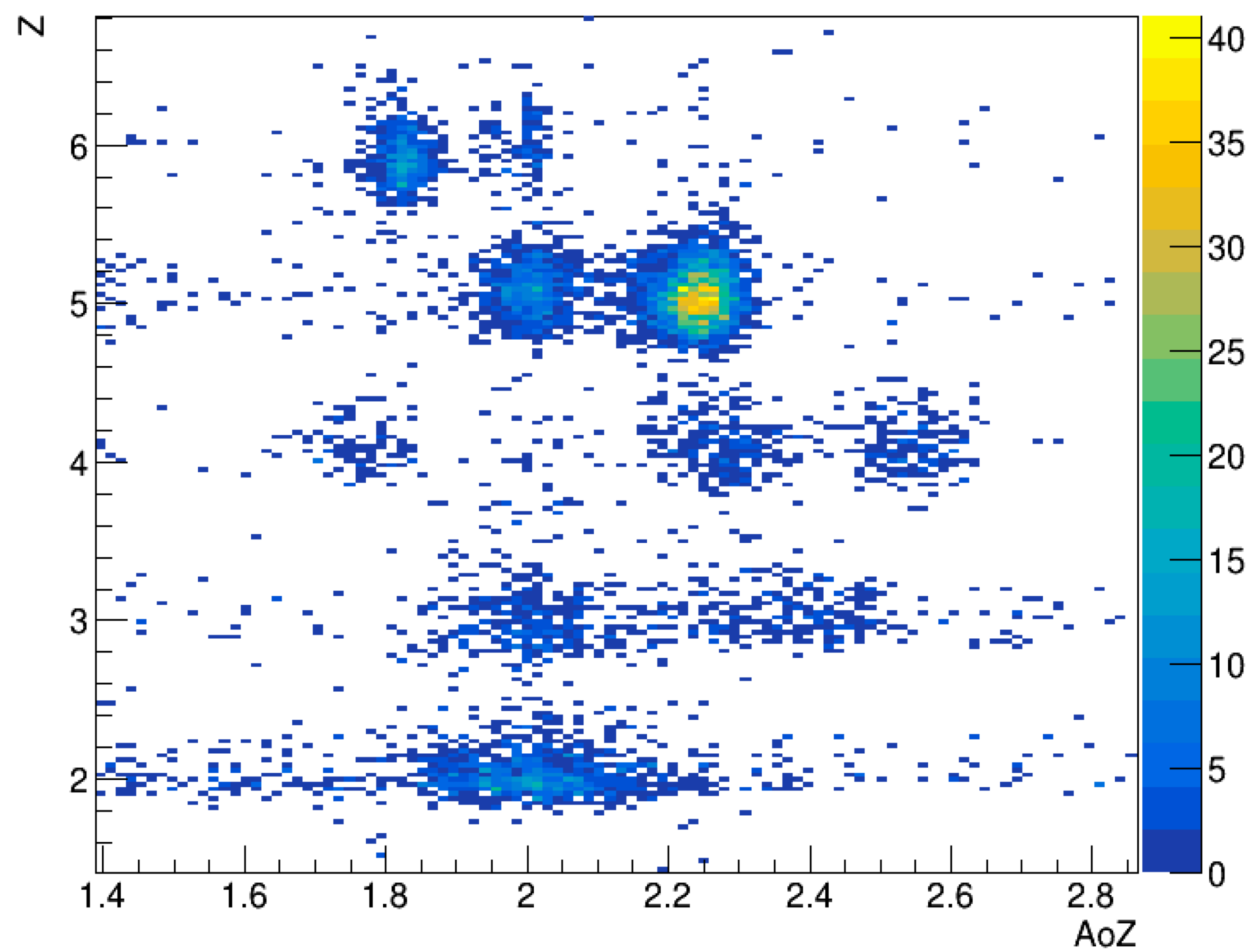
Multi-Dimensional Fit (MDF) with In-beam FOOT

- Input (x,y,z) of the in-beam foot positions (inside vacuum chamber);
- MDF Functions relative to the in-beam FOOT position;
- Track selection problem due to high multiplicity;
- Match of MWPC tracks with in-beam FOOT ones;
- Alignment derived with in-beam FOOT MDF tracking.

Multi-Dimensional Fit (MDF) with FOOT Vertex

- Input (x,y,z) of the vertex point;
- MDF Functions relative to the vertex position;
- No conditions for in-beam FOOT, detectors not considered for MDF tracking;
- Same alignment derived with in-beam FOOT MDF tracking.



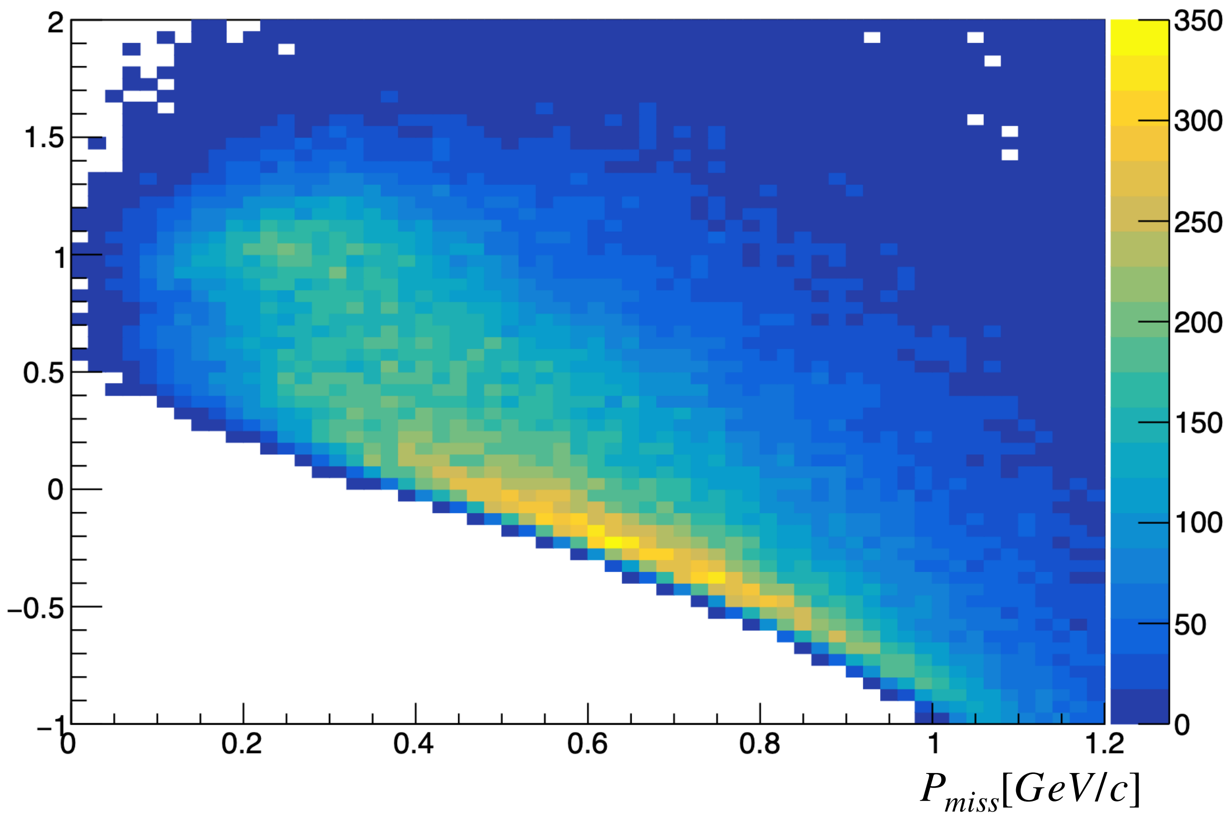


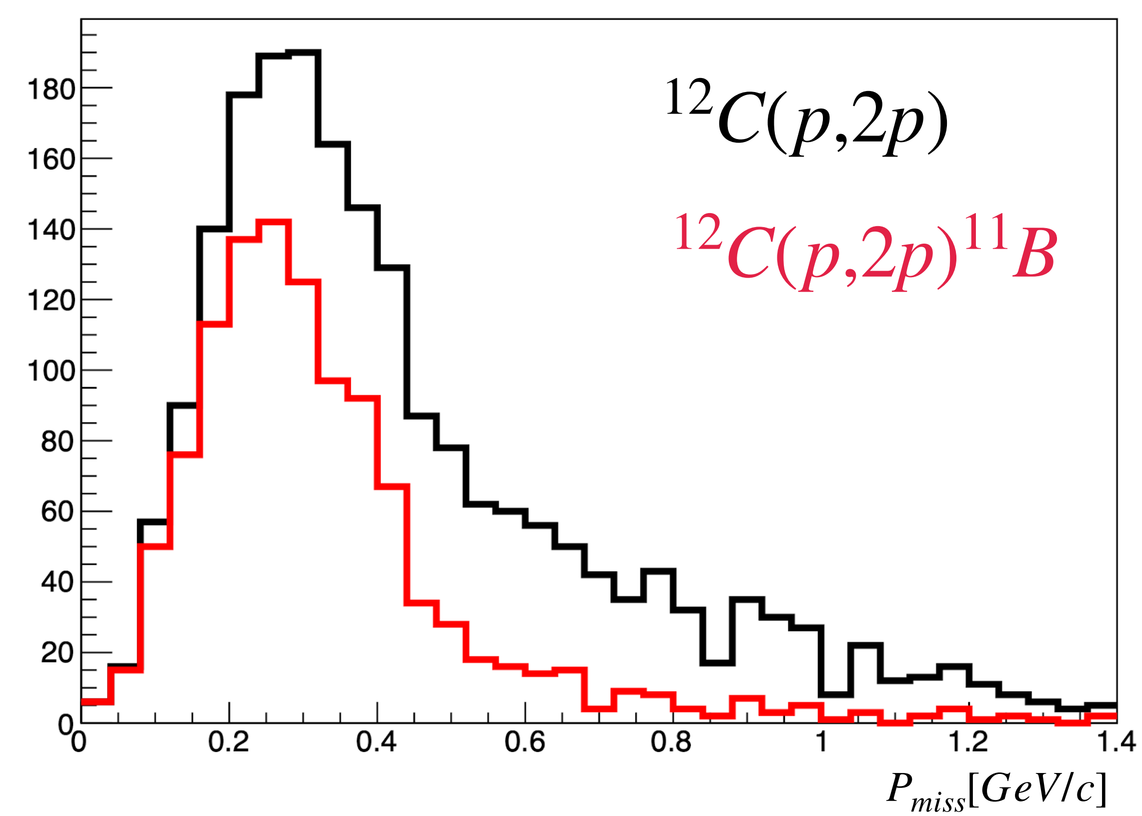
Quasi-Elastic event identification CALIFA

PRELIMINARY

Missing mass vs Missing momentum

$^{12}C(p,2p)$





- (p,2p) selection;
- 2 hits in califa;
- Selection with $|u| > 0.65\ GeV^2$ && $|t| > 0.65\ GeV^2$.

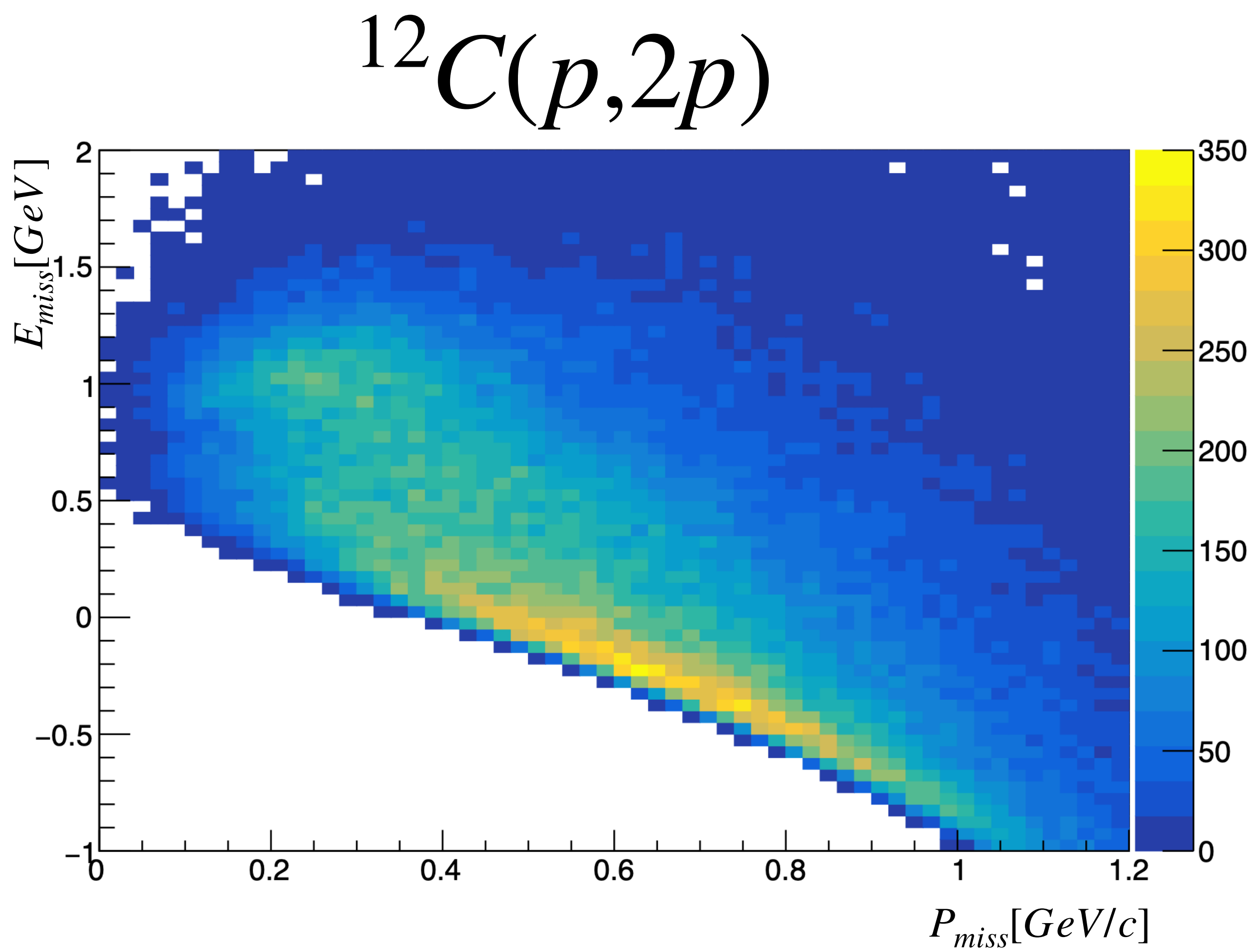
Califa open issues:

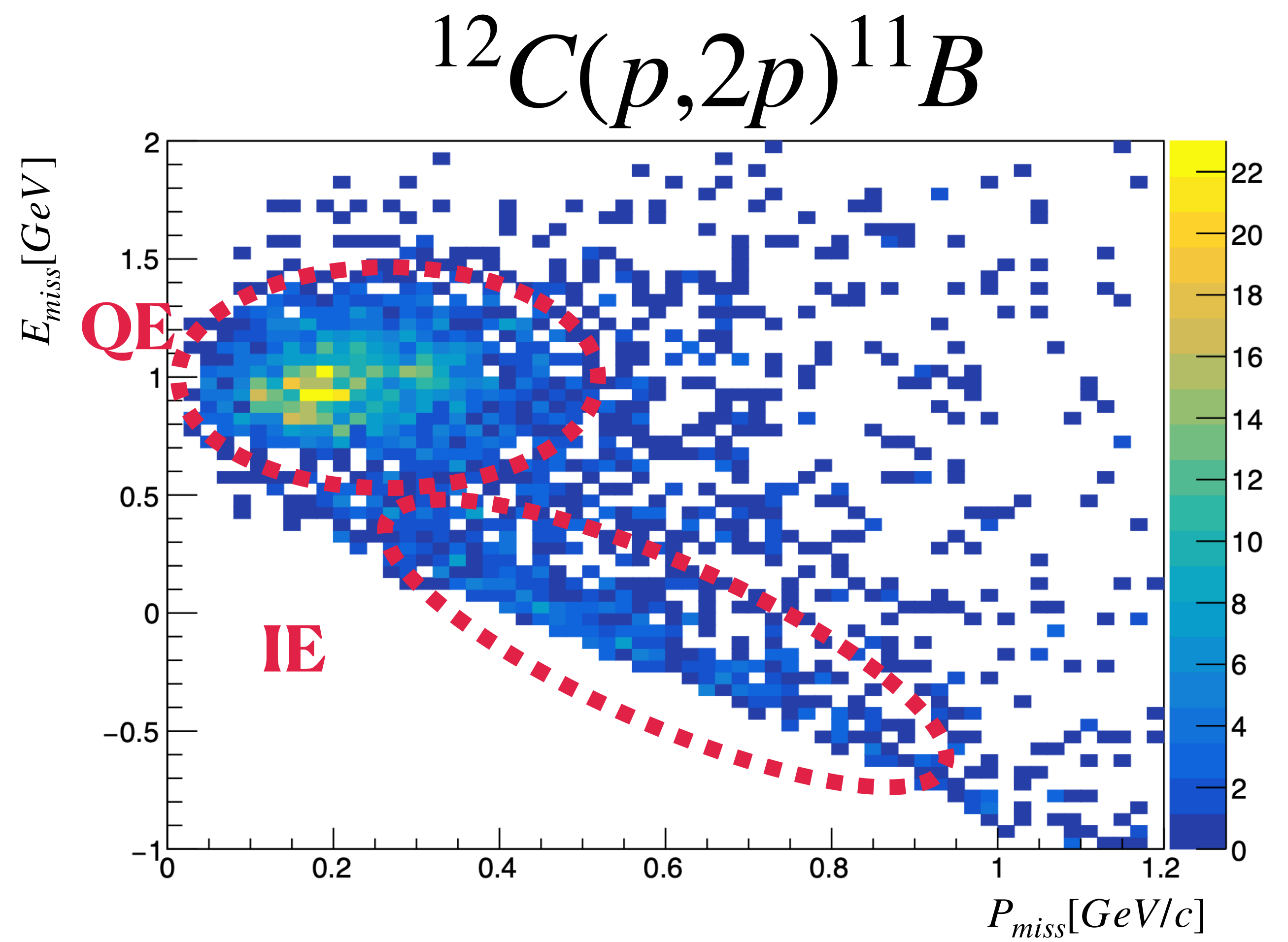
- punch through vs stopped protons ID
- resolution total energy.

Quasi-Elastic event identification CALIFA

PRELIMINARY

Missing mass vs Missing momentum





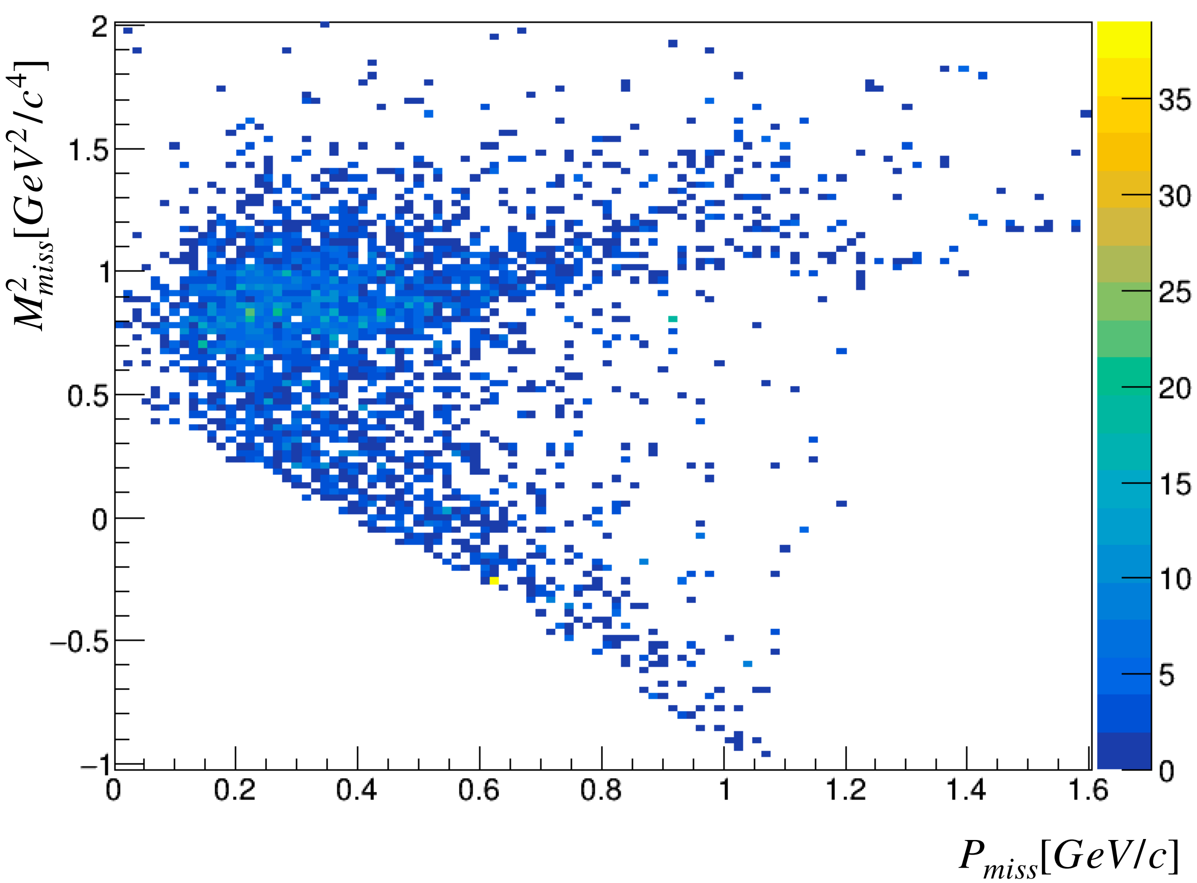
Quasi-Elastic event identification Vertex

PRELIMINARY

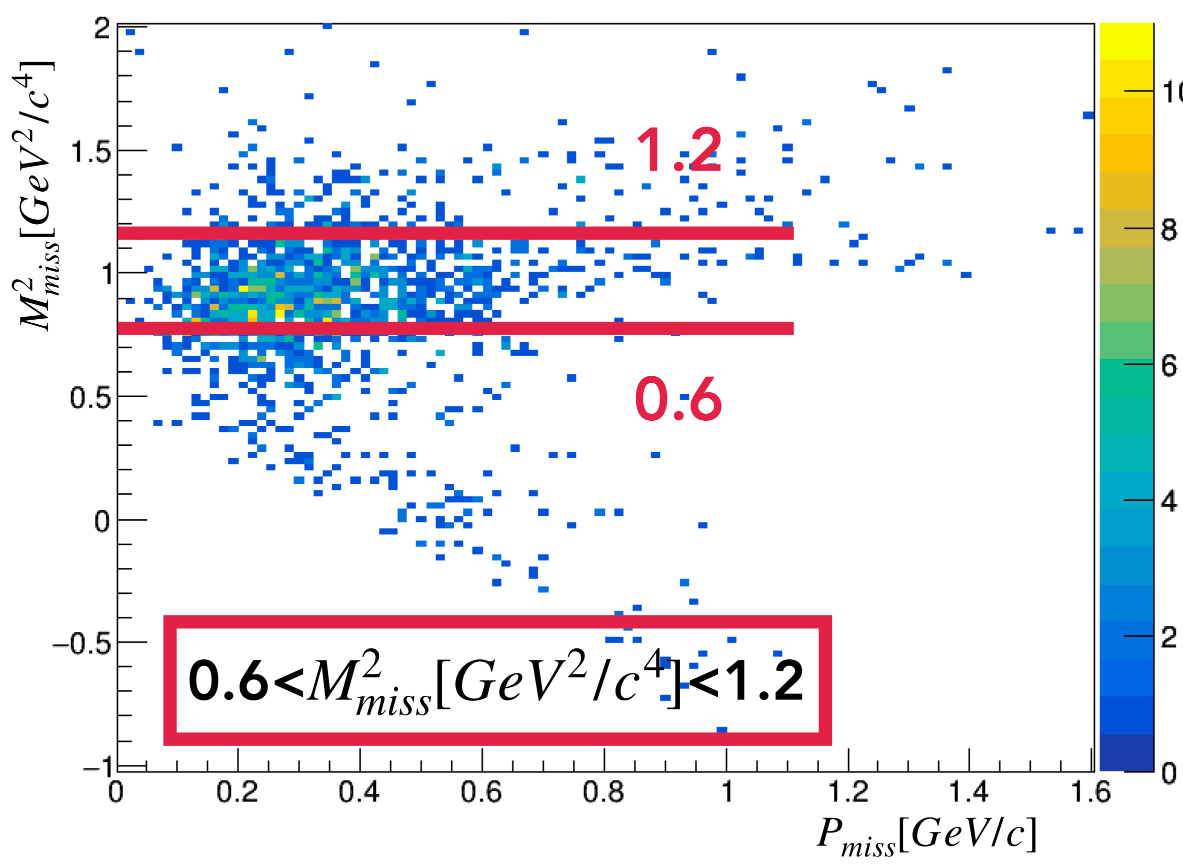
Missing mass vs Missing momentum

- The ^{11}B detection is shown to select the **QE part of the reaction**;
- Similar to BM@N (JINR) experiment.

* No selection of ^{11}B fragment;
* (p,2p) reconstructed with FOOT detectors;



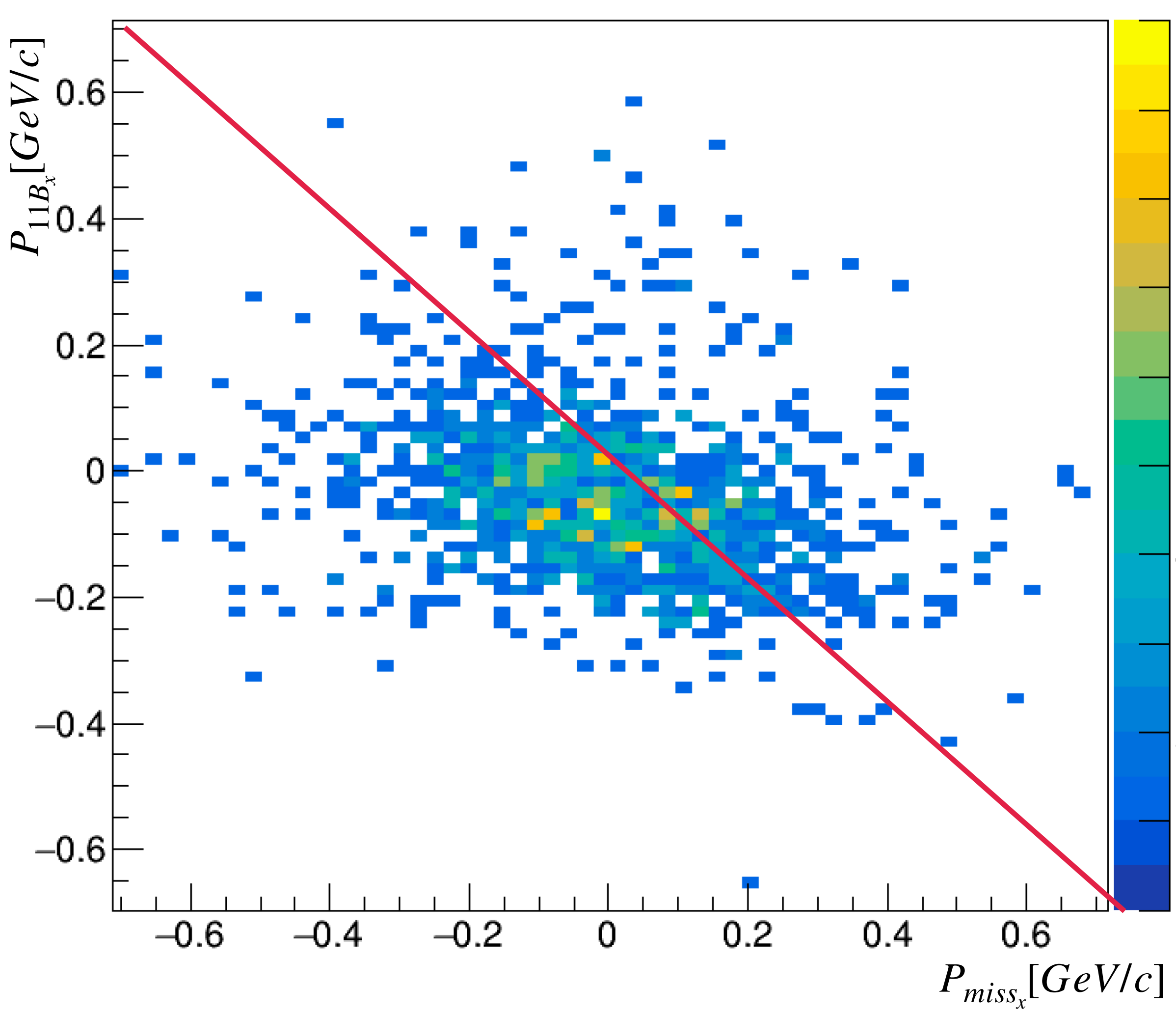
* Selection of ^{11}B fragment;
* (p,2p) reconstructed with FOOT detectors;

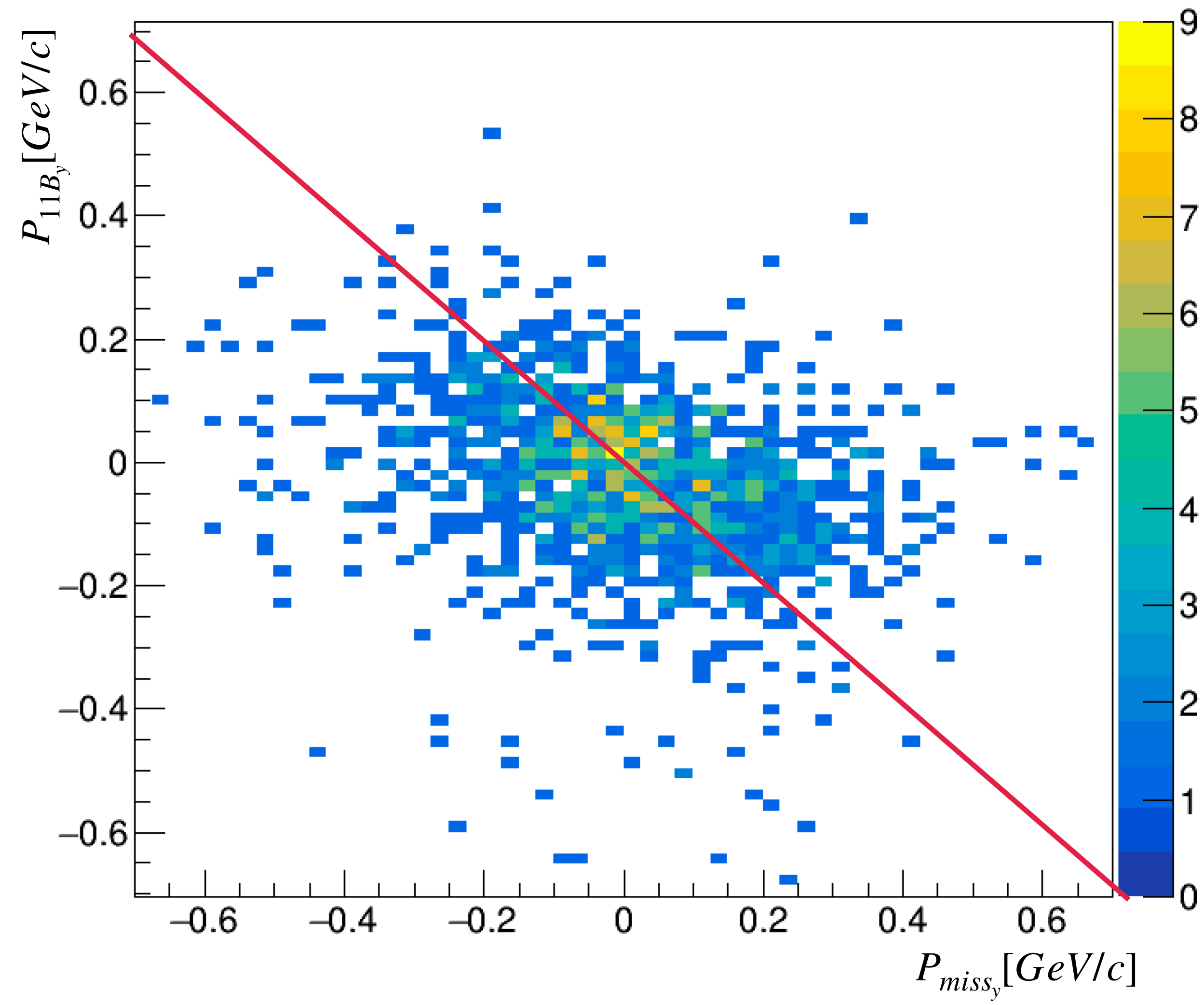


Missing momentum Vertex

- Missing momentum derived from 2 scattered protons (arm FOOT):
  $P_{miss} = p_1 + p_2 - p_{target}$
- Selection of ^{11}B fragment;
- Selection with 0.7<$M^2_{miss}[GeV^2/c^4]$ <1.2.

- Missing momentum derived from MDF tracking using vertex position:
  $P_{miss} = p_{11B} - p_{beam}$
- Selection of ^{11}B fragment;
- Selection with 0.7<$M^2_{miss}[GeV^2/c^4]$ <1.2.

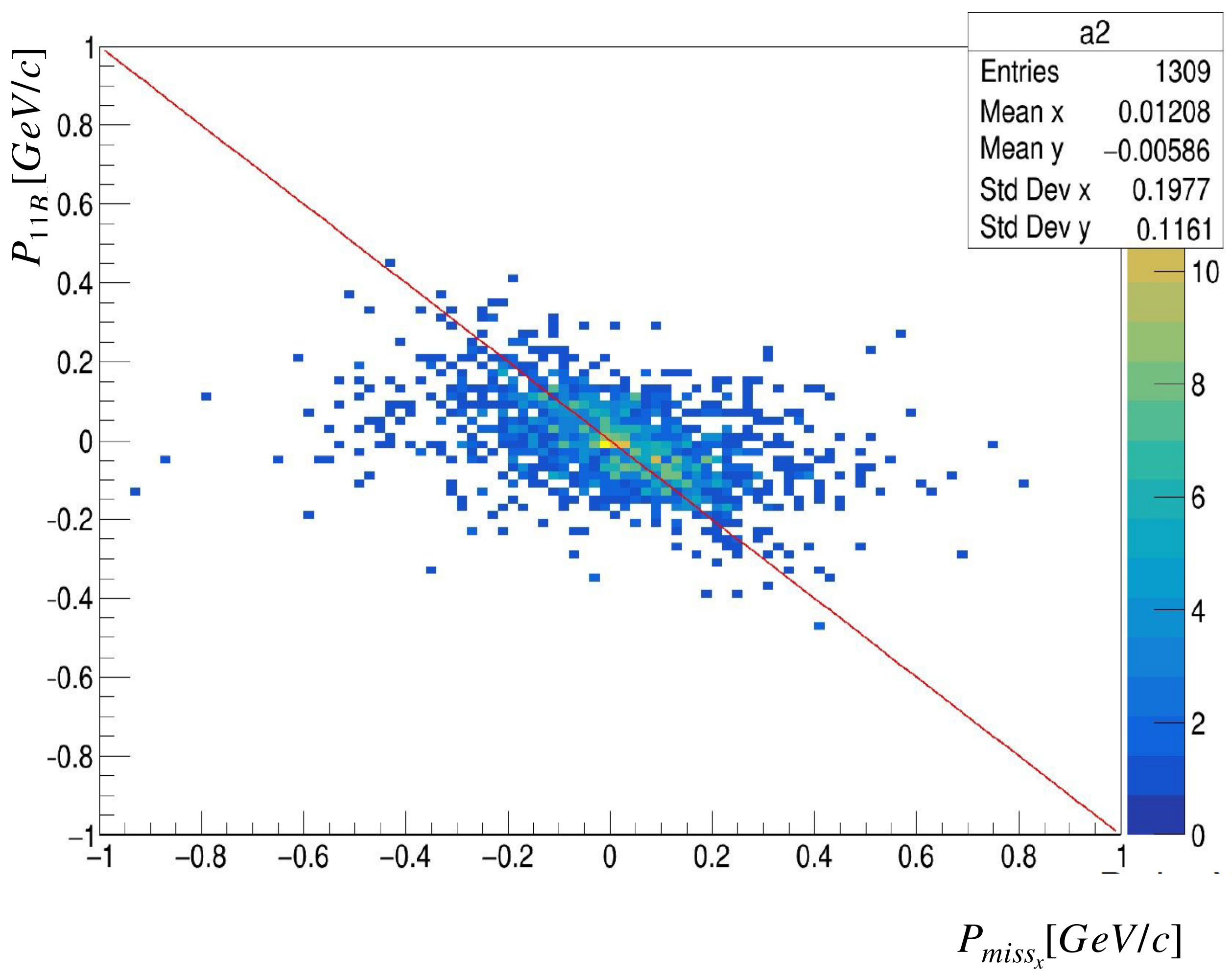


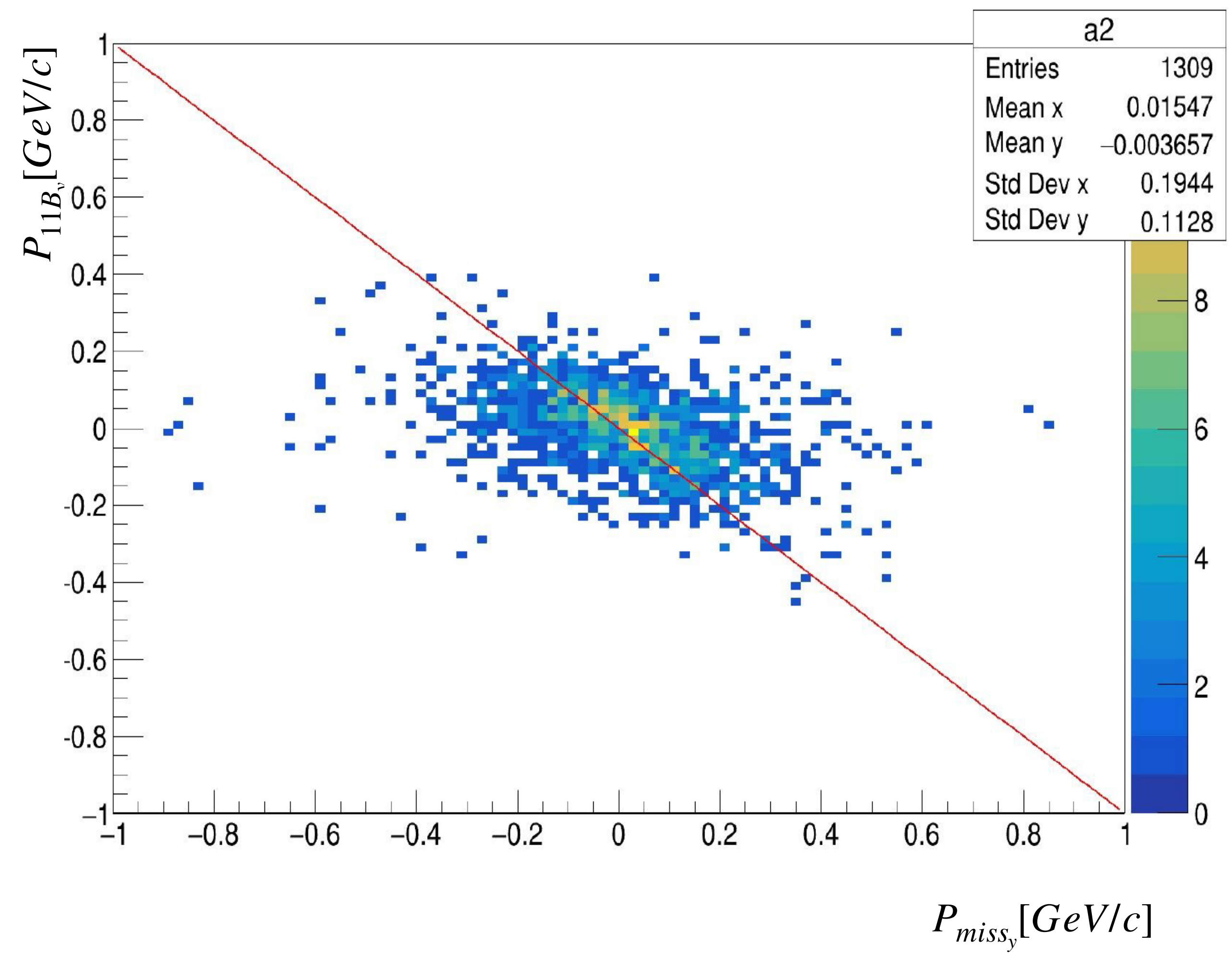


Missing momentum In beam FOOT

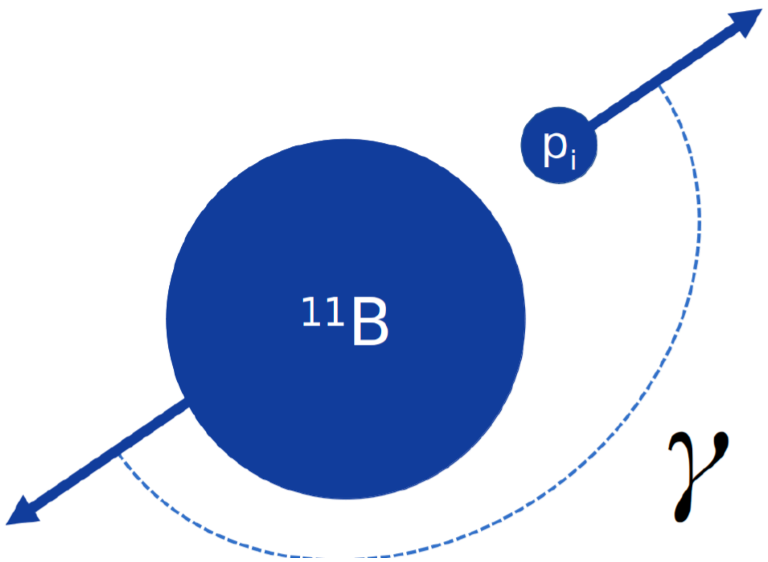
- Missing momentum derived from 2 scattered protons (CALIFA):
  $P_{miss} = p_1 + p_2 - p_{target}$
- Selection of ^{11}B fragment;
- Selection with $|u| > 0.65\ GeV^2$ && $|t| > 0.65\ GeV^2$;
- Selection with $0.7 < M^2_{miss}[GeV^2/c^4] < 1.2$

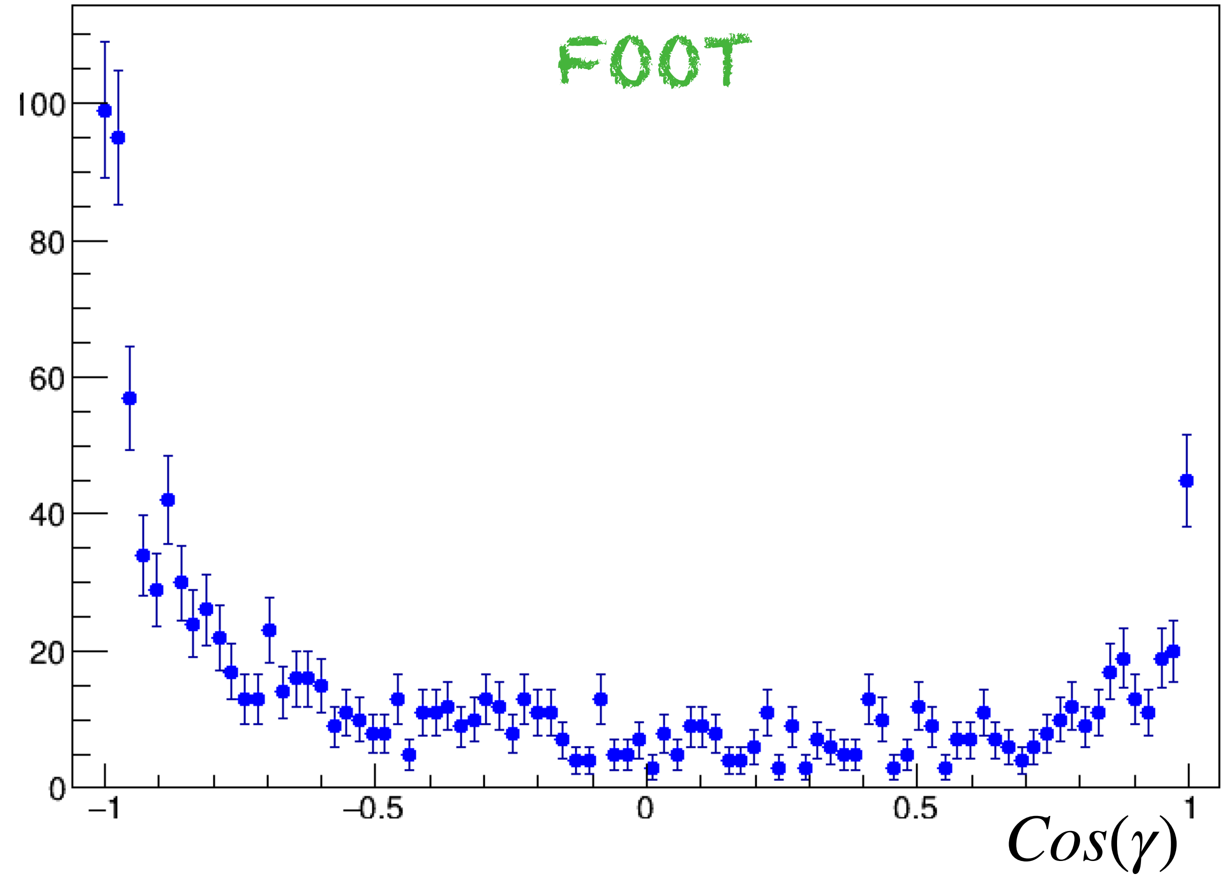
- Missing momentum derived from MDF tracking usingIn-beam FOOT:
  P_{11B} from MDF.
- Selection of ^{11}B fragment;
- Selection with $|u| > 0.65\ GeV^2$ && $|t| > 0.65\ GeV^2$.
- Selection with $0.7 < M^2_{miss}[GeV^2/c^4] < 1.2$



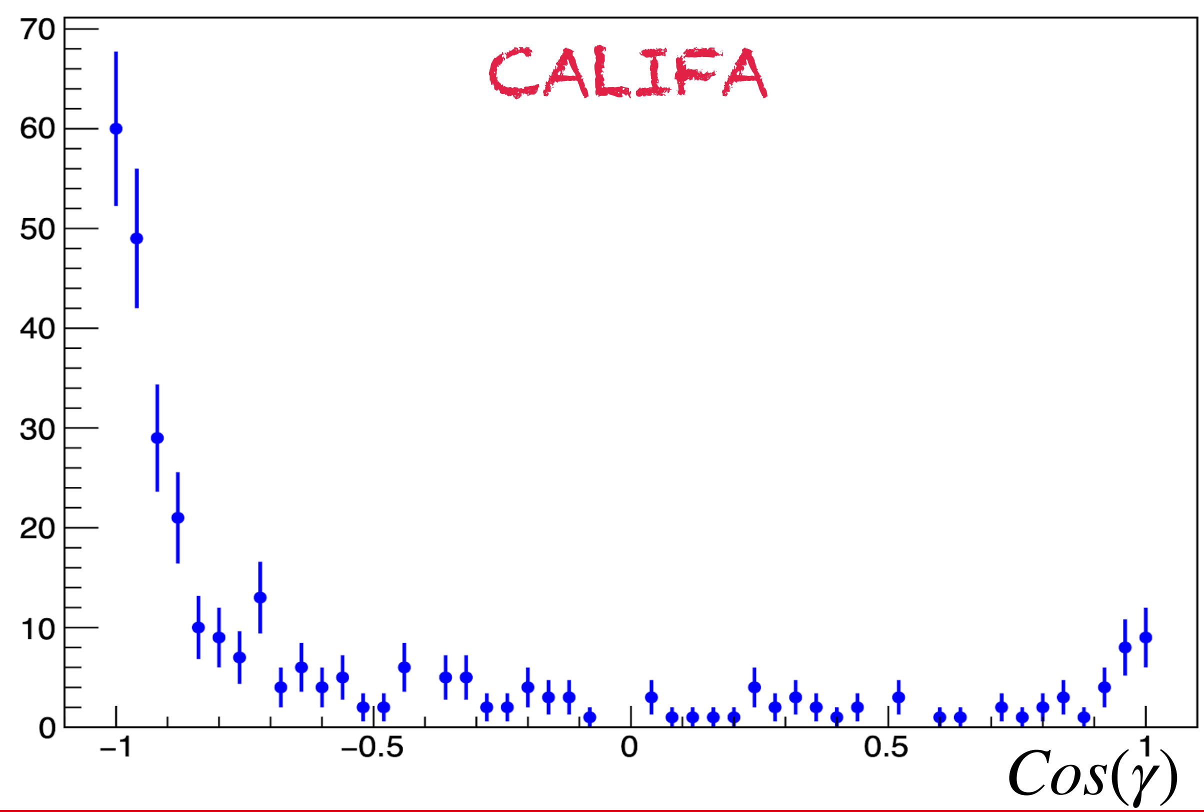


Distribution of the cosine of the opening angle between the missing and fragment momentum in the plane transverse to the beam





- Selection of ^{11}B fragment;
- (p,2p) reconstructed with FOOT detectors;
- Selection with 0.7<$M^2_{miss}[GeV^2/c^4]$<1.2.

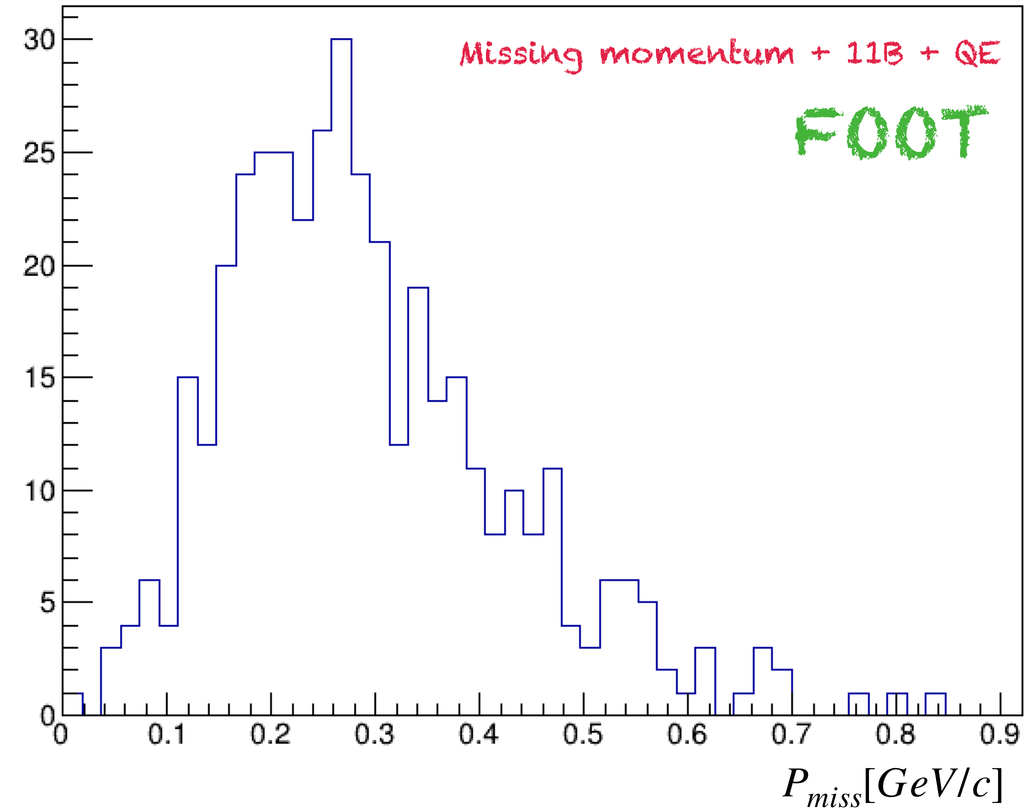


- Selection of ^{11}B fragment;
- (p,2p) reconstructed with CALIFA detectors;
- Selection with 0.7<$M^2_{miss}[GeV^2/c^4]$<1.2.

Quasi-Elastic event identification

Missing momentum with QE selection

- Selection of ^{11}B fragment;
- (p,2p) reconstructed with FOOT detectors;
- Selection with $0.7 < M^2_{miss}[GeV^2/c^4] < 1.2$ and Selection with $|u| > 0.65\ GeV^2$ && $|t| > 0.65\ GeV^2$.



- Selection of ^{11}B fragment;
- (p,2p) reconstructed with CALIFA detectors;
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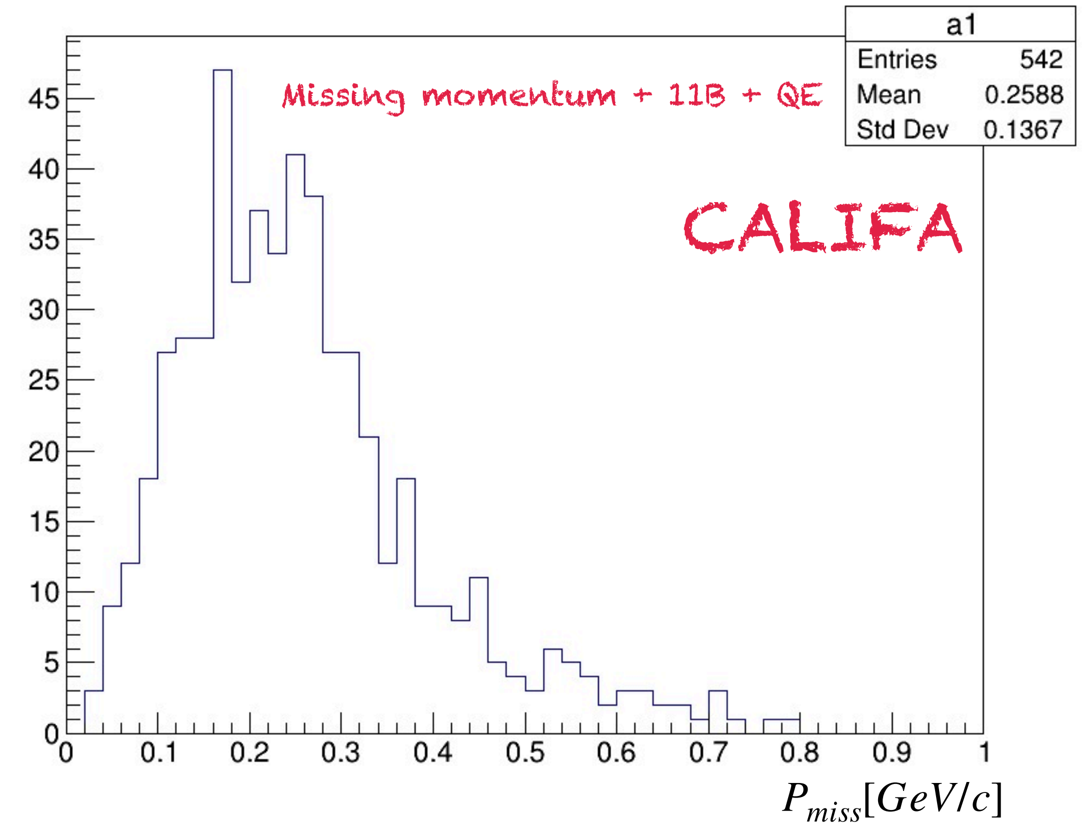
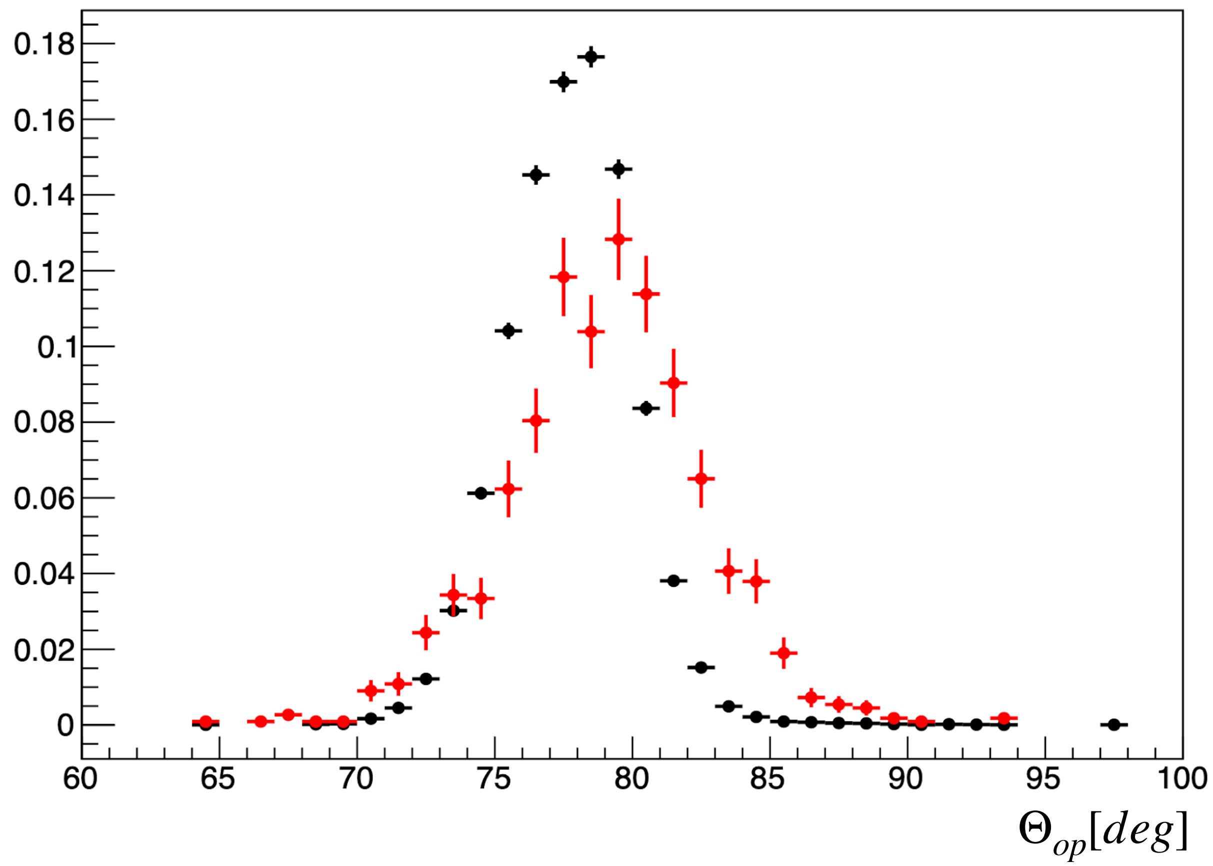


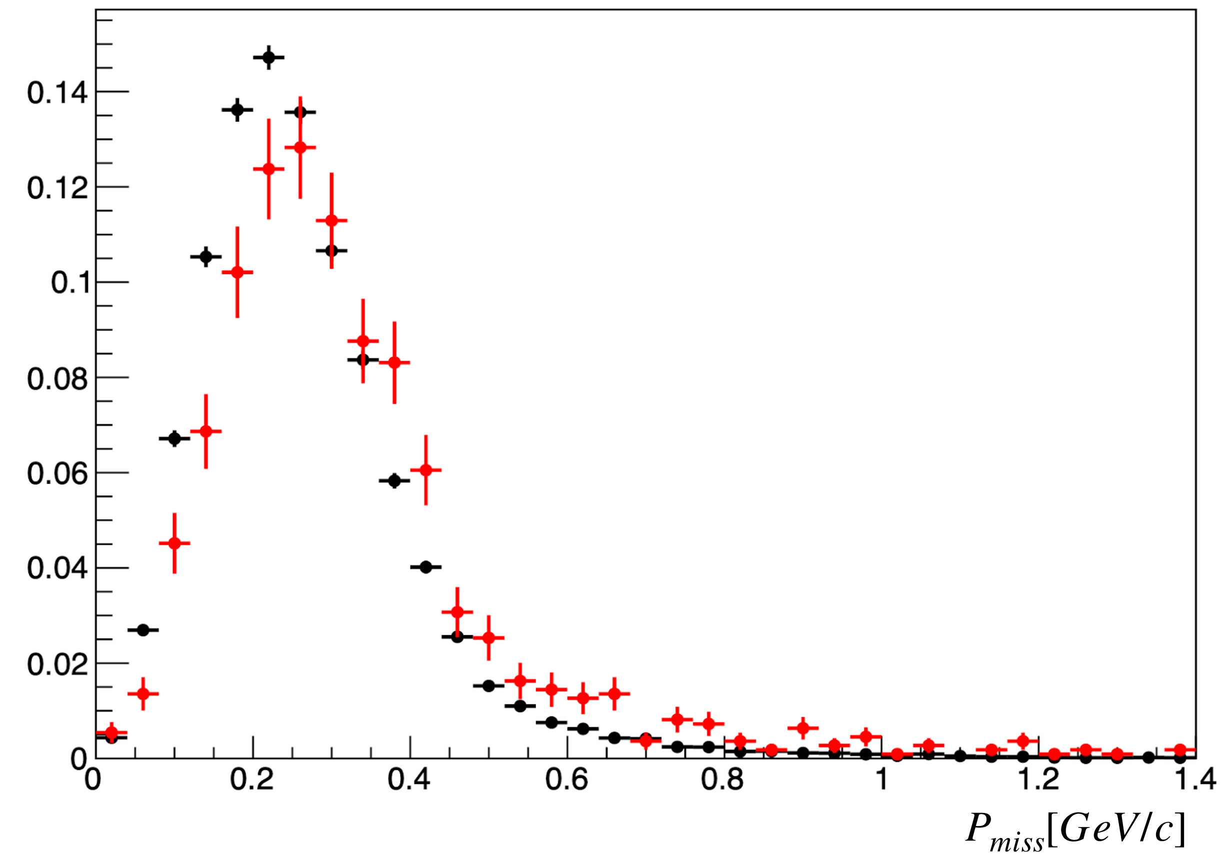
Quasi-Elastic event identification

Missing momentum with QE selection CALIFA

simulation
Data, p,2p with QE



Quasi-elastic p,2p simulation
Data, p,2p with ^{11}B tagging and QE



(p,2p) FOOT reconstruction efficiency

Estimate of the (p,2p) vertex reconstruction efficiency using arm FOOT:

1- Compute the number of (p,2p) in CALIFA considering the angular range covered by FOOT:

—> **1058 (p,2p)** events;

2- Compute the number of (p,2p) of arm FOOT with CALIFA conditions;

—> **61 (p,2p)** events without the requirement to have a track in the in-beam FOOT;

—> **27 (p,2p)** events with the requirement to have a track in the in-beam FOOT;

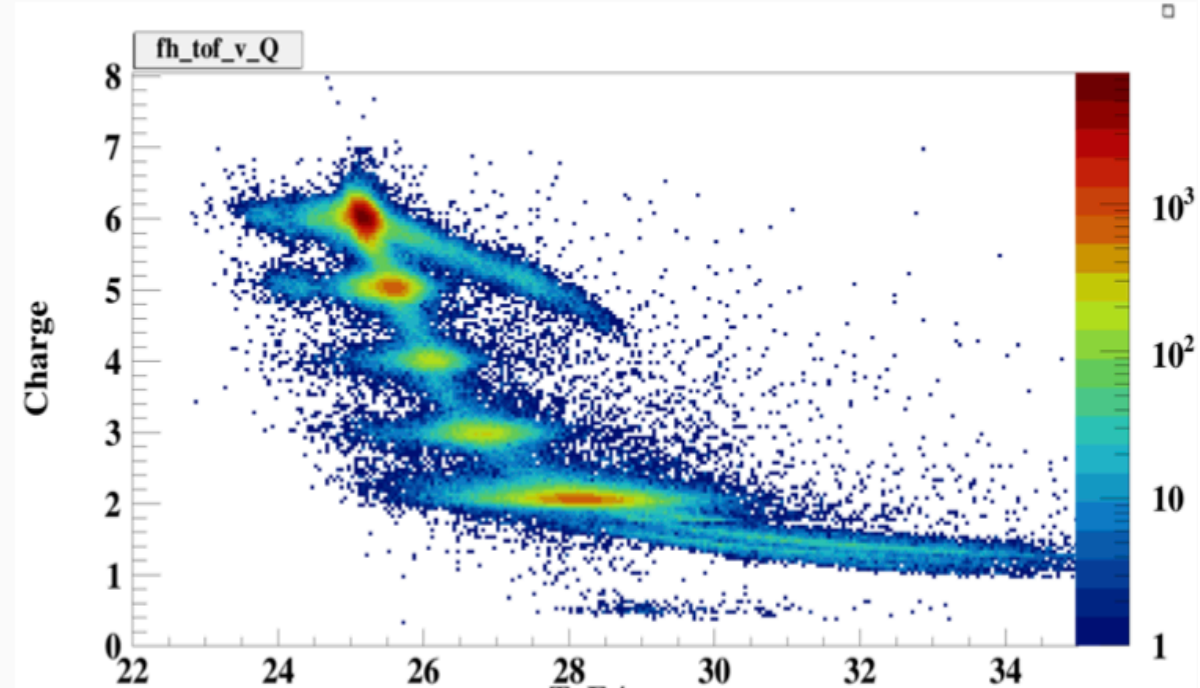
Reconstruction efficiency of FOOT wrt CALIFA —> **5.76 %** without in-beam FOOT;

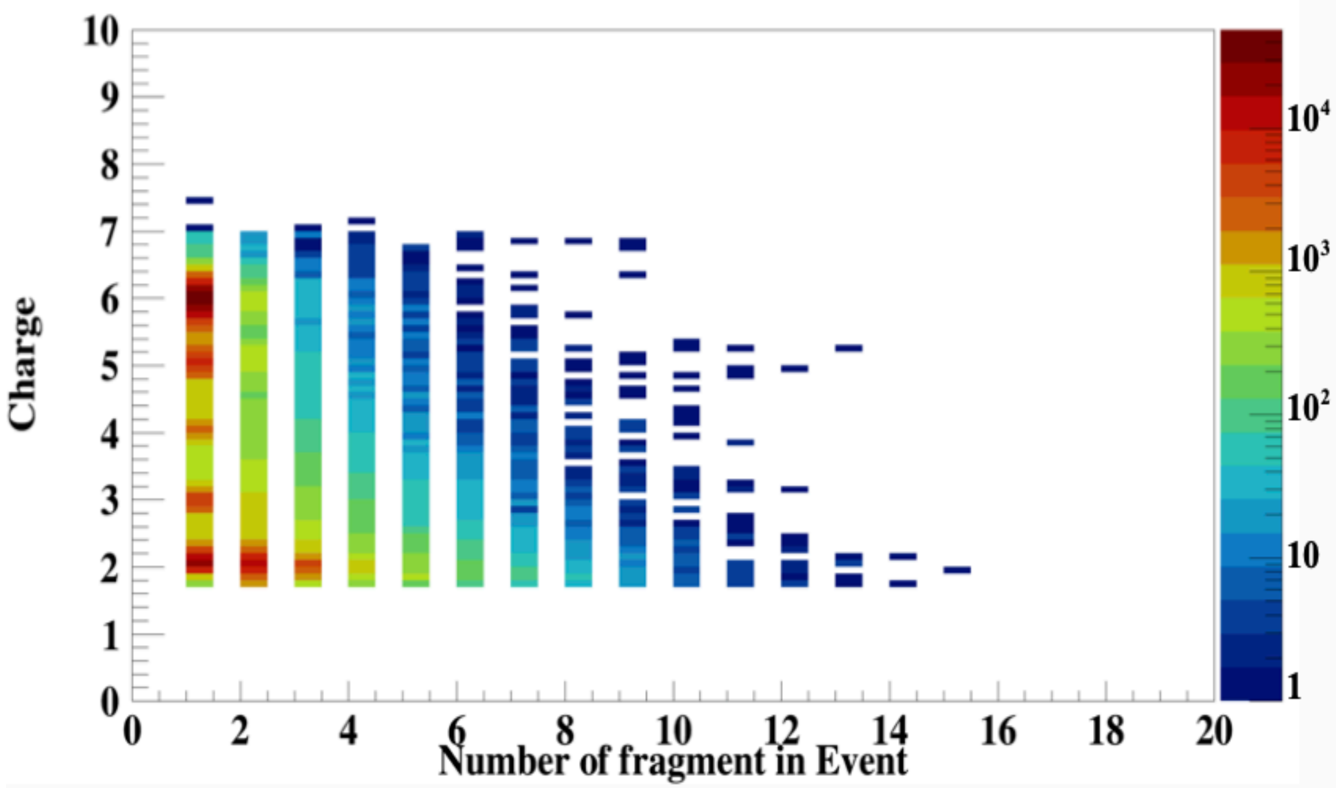
Reconstruction efficiency of FOOT wrt CALIFA —> **2.55 %** with in-beam FOOT;

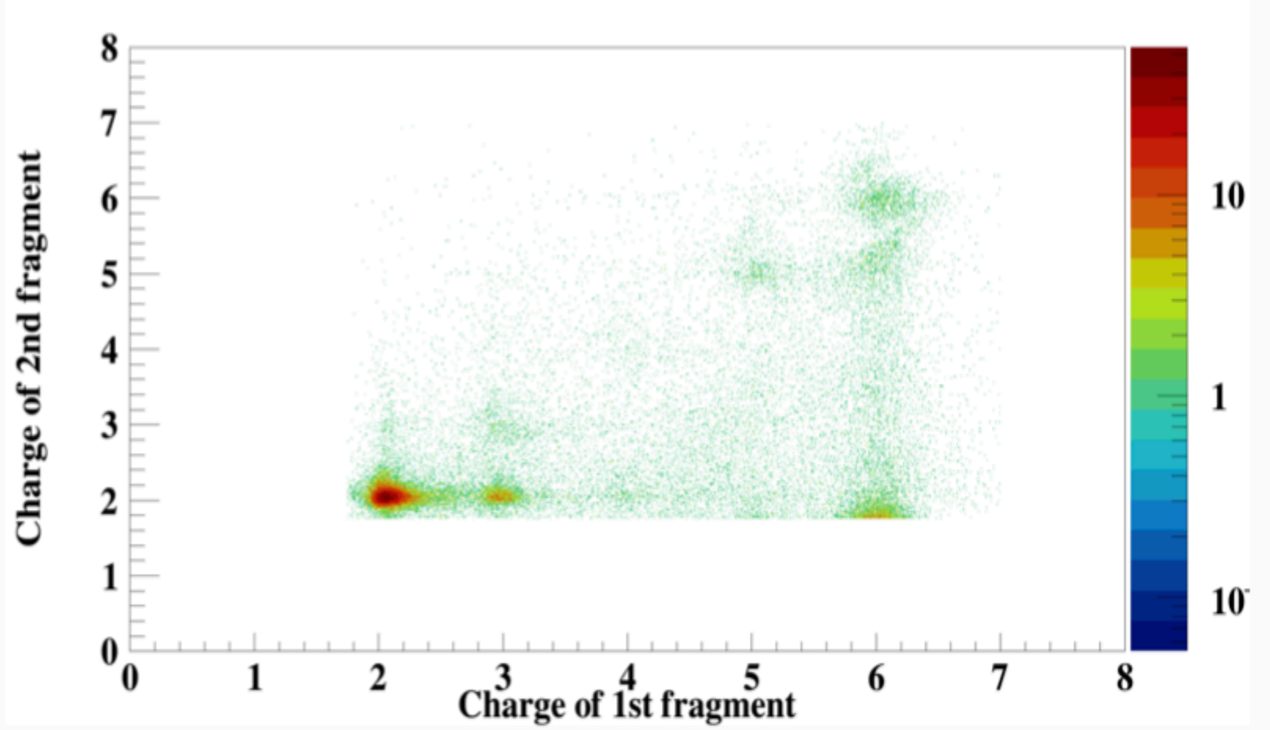
140_0001.lmd unpacked with **2 sigma** cut on the FOOT ADC Energy

How many fragments at ToFD?

- **Problem:** Too many combinations of all hits in fragment arm detectors
  - Connecting incoming and outgoing **only** by combinatorics
  - Reduce multiplicity by building fragment tracks
- Combine information of all planes
  - Use only hits correlated with trigger (~13 ns window)
  - Grouping hits that belong to same particle
    - by Time, Charge, bar
    - Not always all planes active
    - Dependent on conditions (over counting)

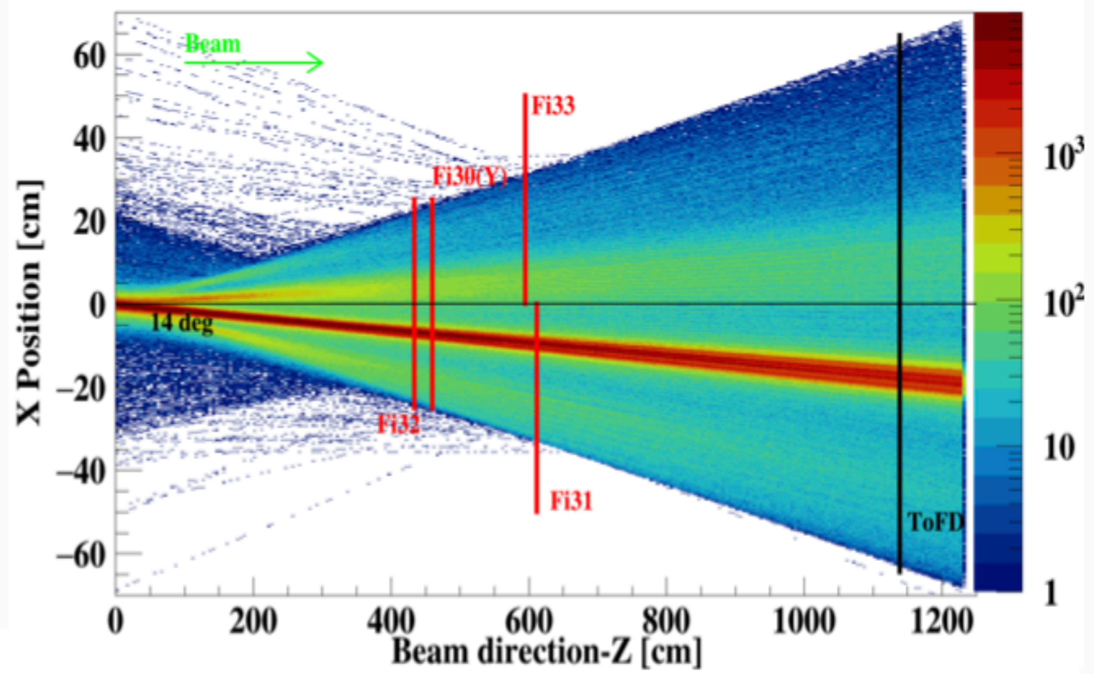


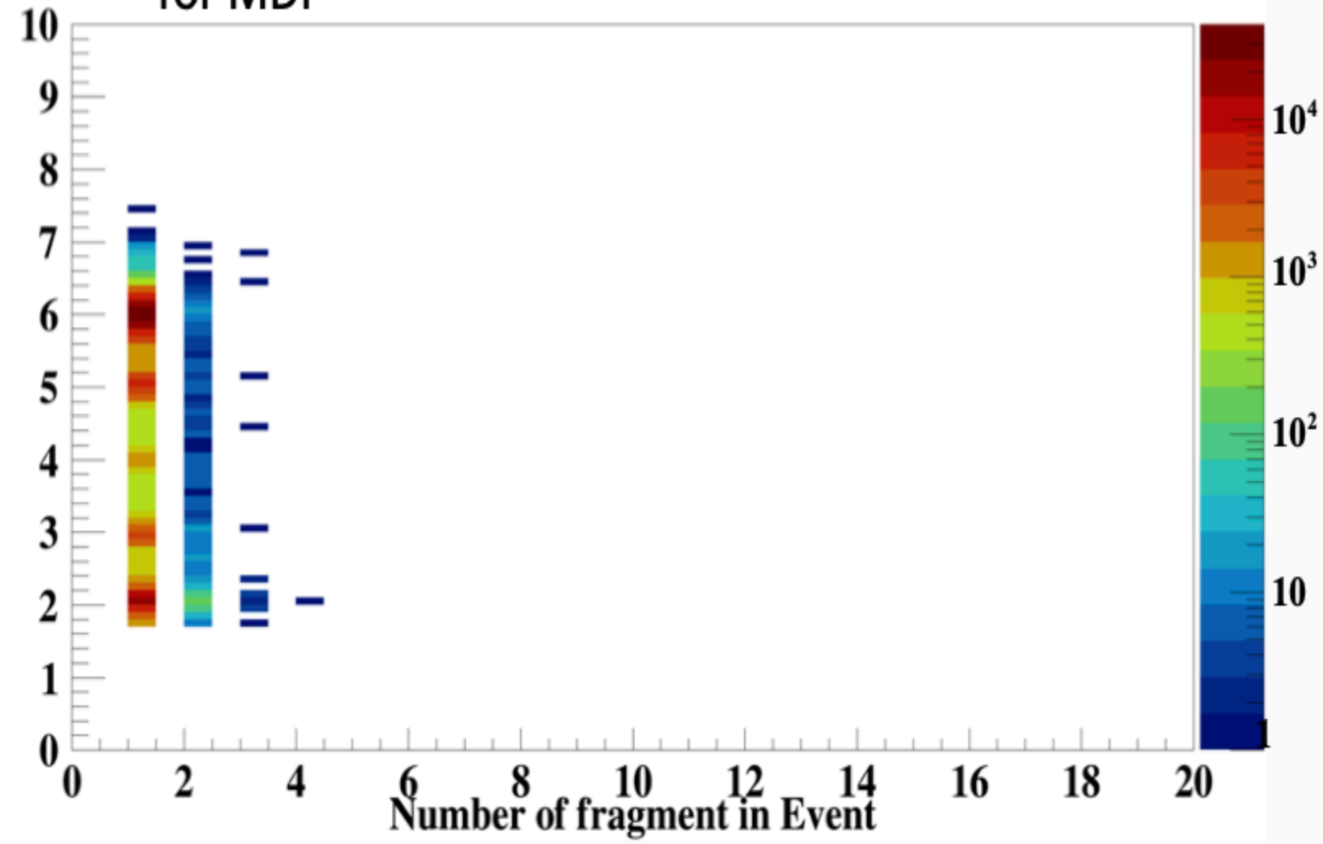


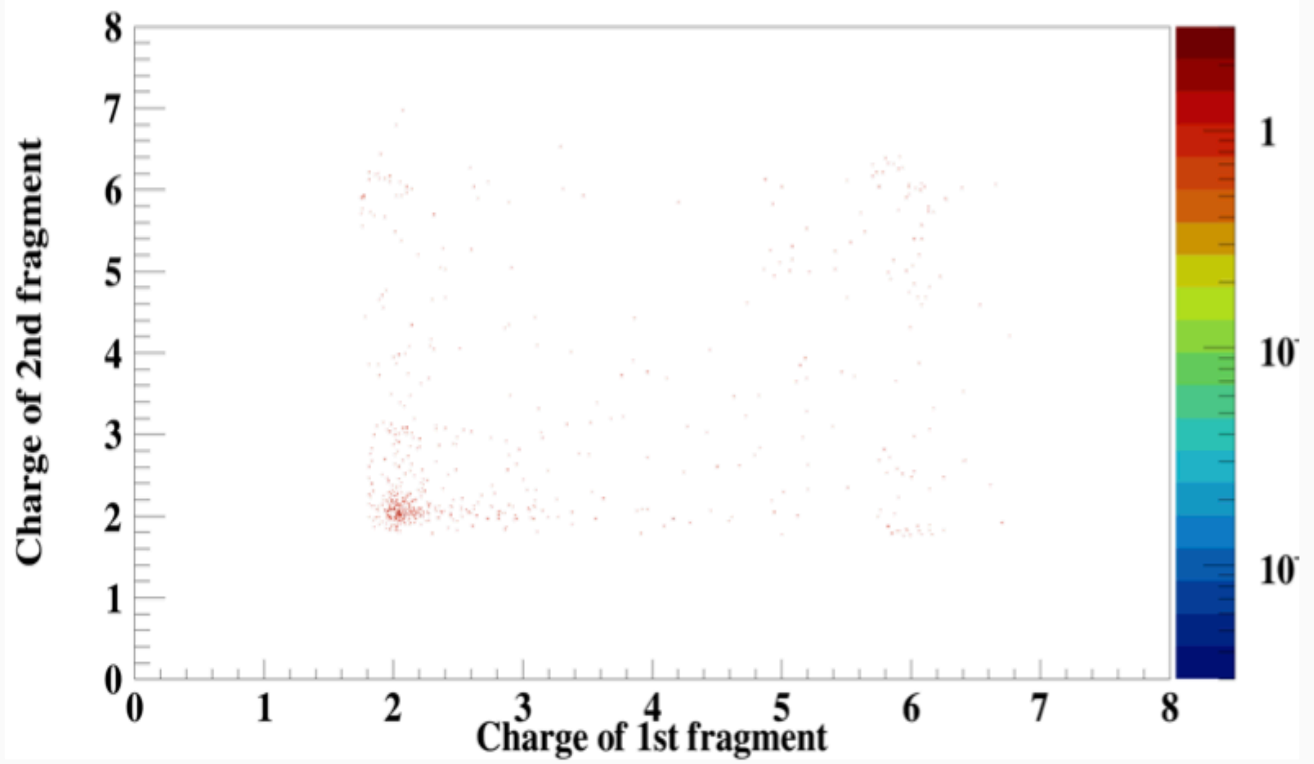


Use Fibers to build complete tracks

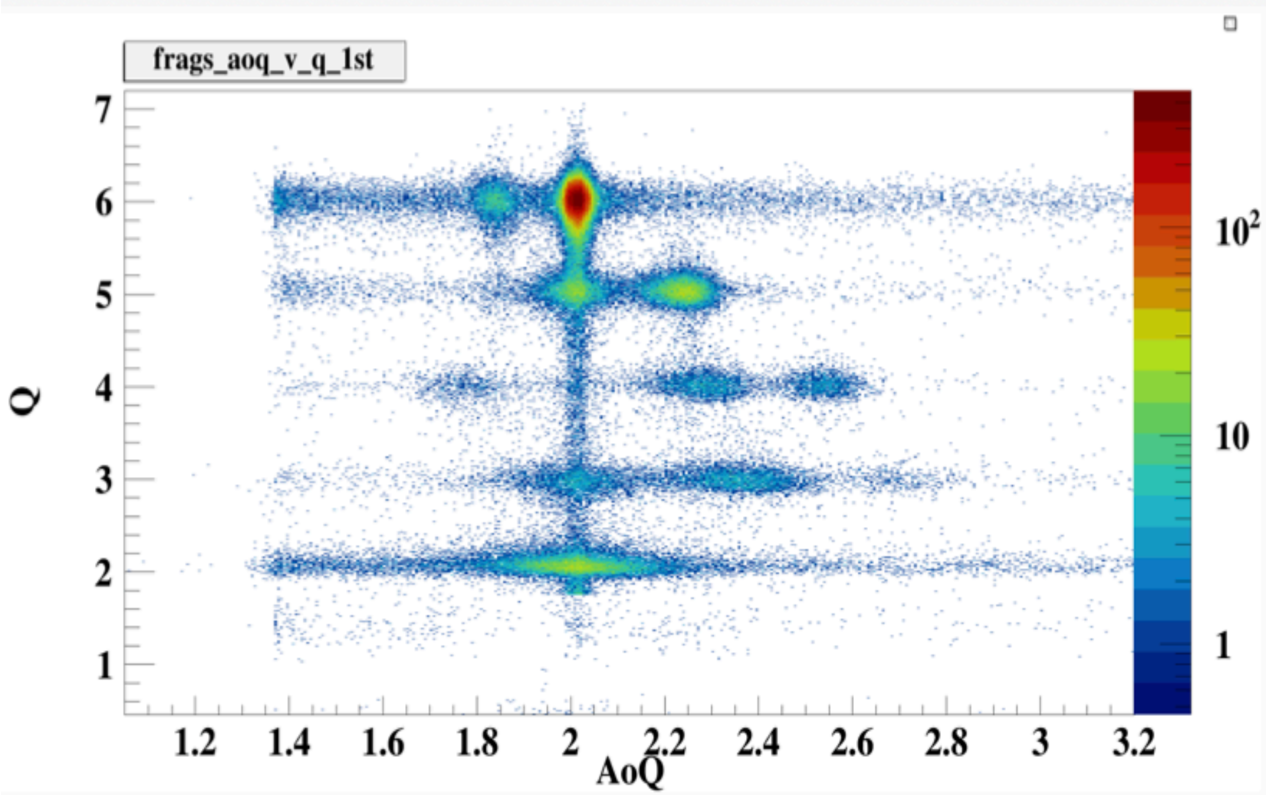
- List all hits in Fib32 and Fib31/33 correlated with trigger (13 ns window) (= “good” hits)
- Perform linear regression through Fib32, Fib31/33 and ToFD with R^2 test
- Consider combinations with highest R^2
  - Take into account not to double count hits
  - Highest number of possible tracks given by detector layer with lowest number of “good” hits.
- Save all detector informations (Q, ToF, X, Y, TX, TY) and use for MDF

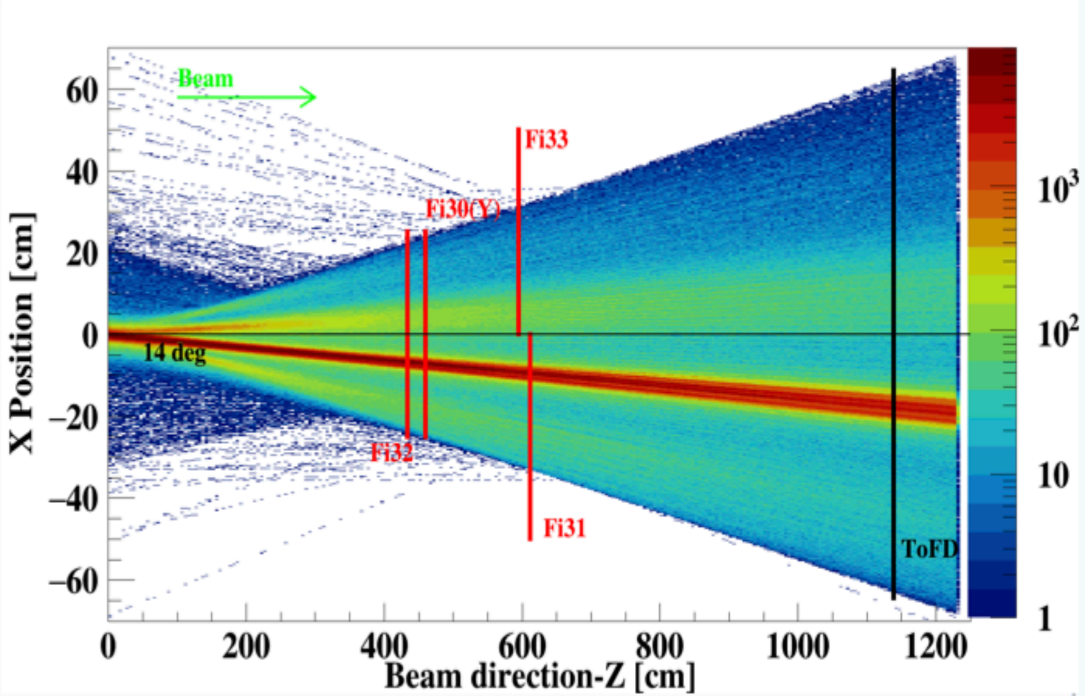


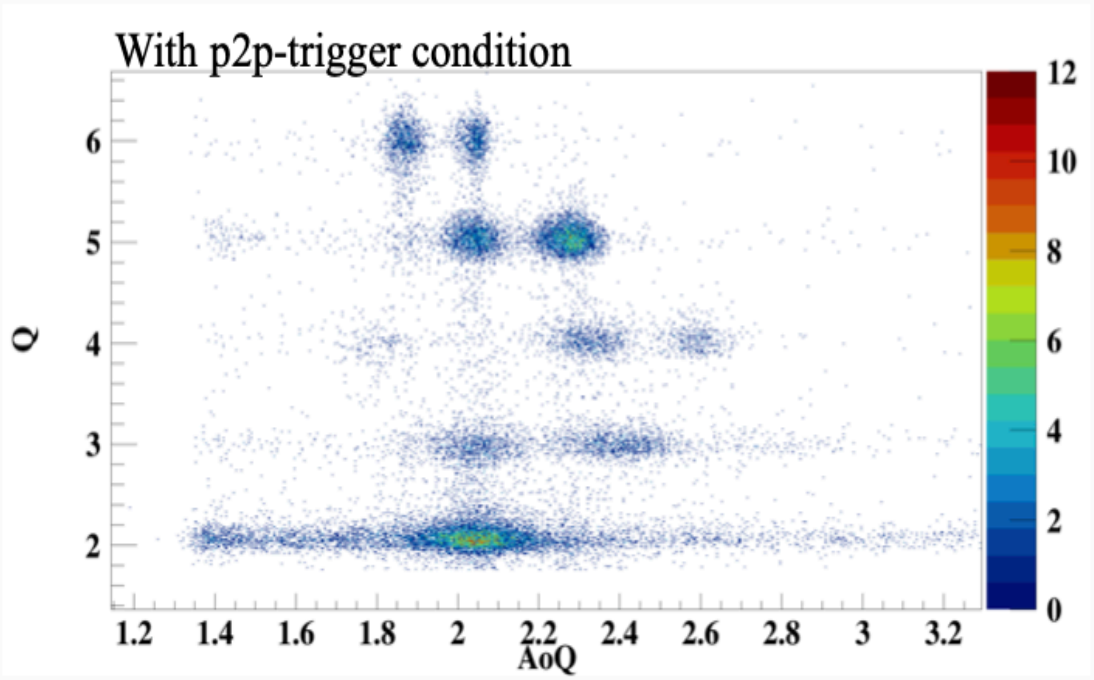


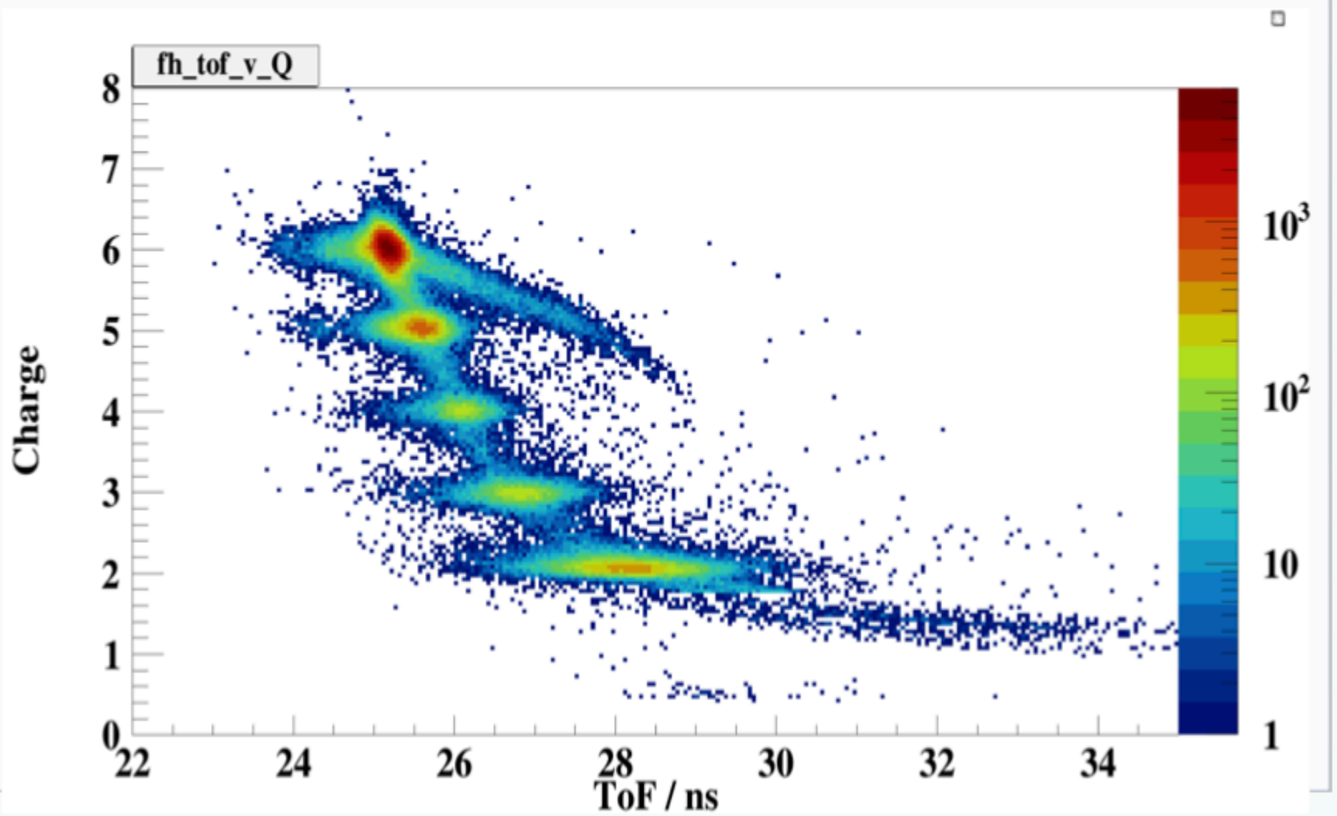


Use Fibers to build complete tracks







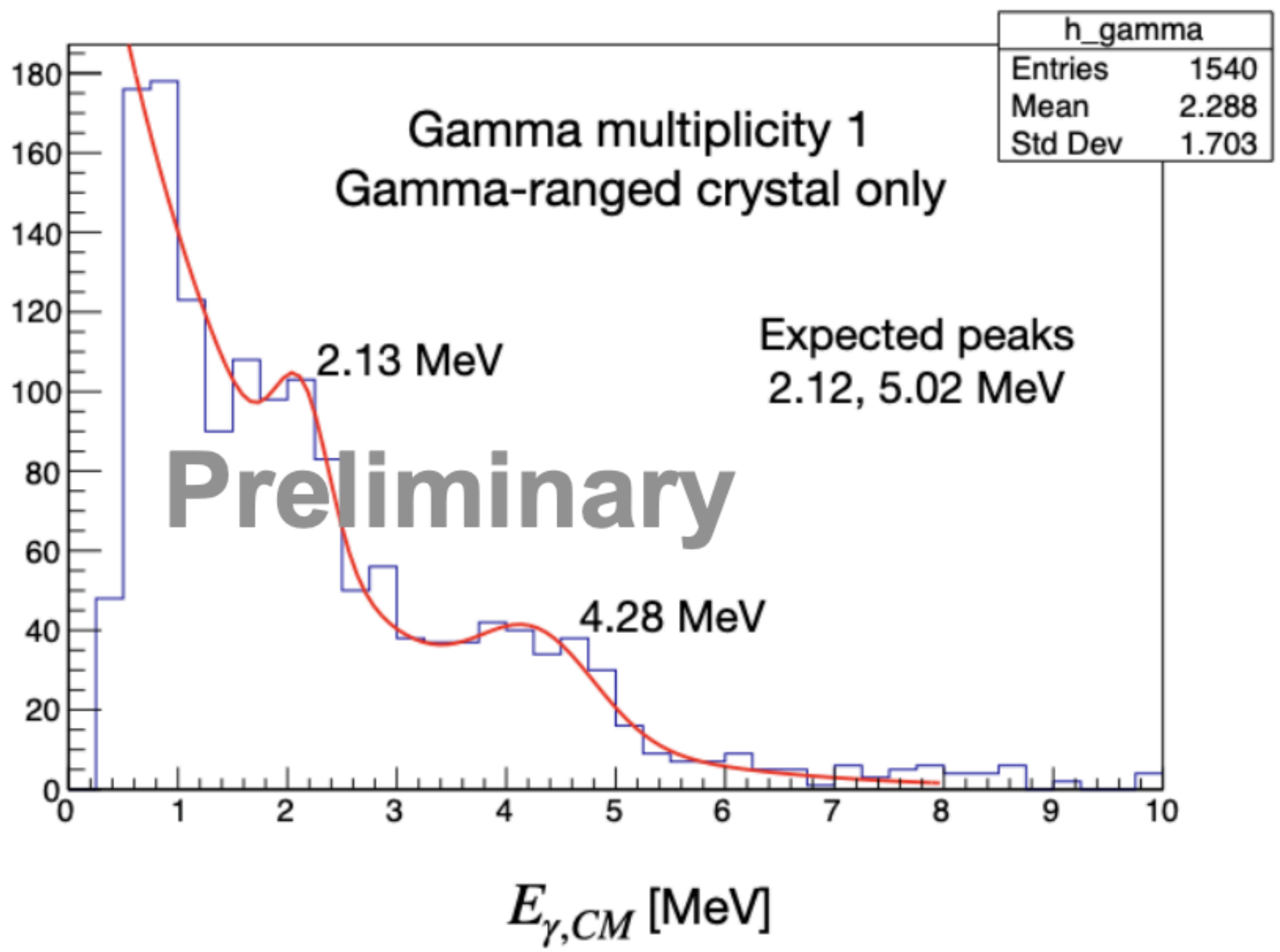


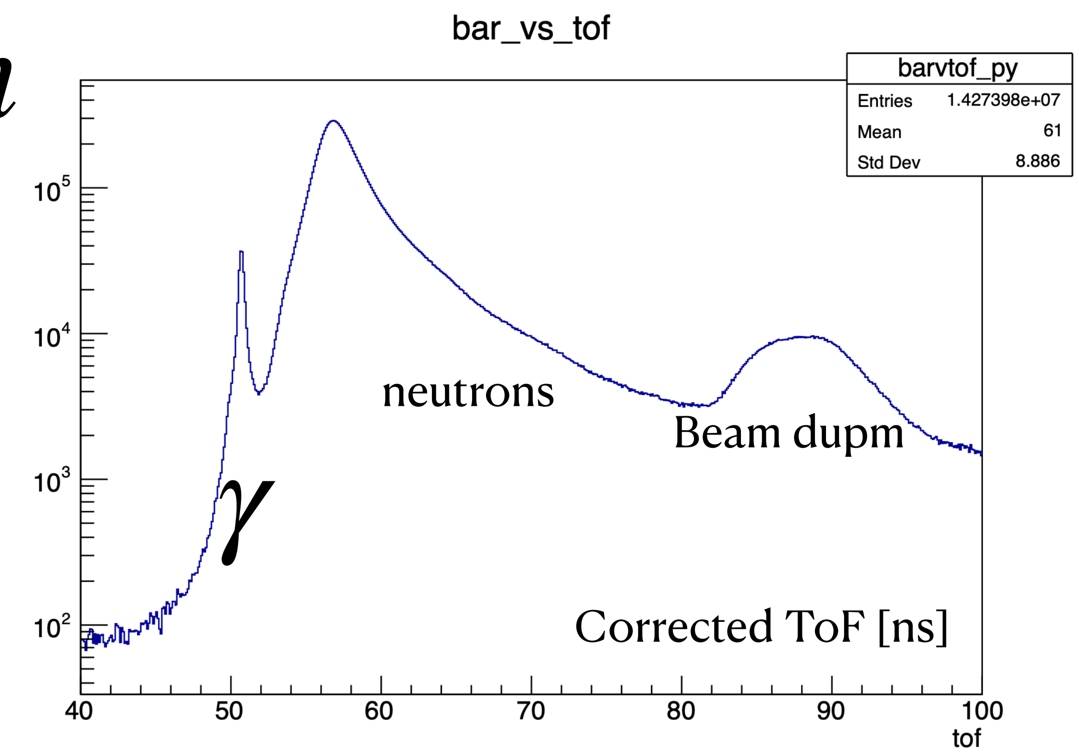
Pending gamma and neutron analysis

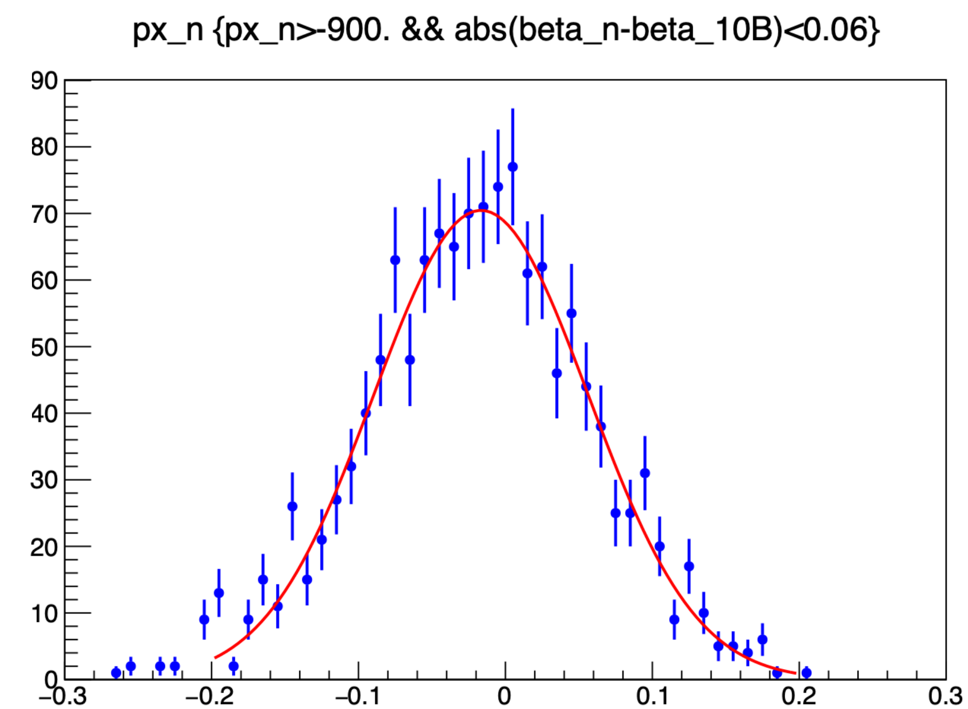
Gamma peak time resolution ~ 180 ps

$$^{10}B + n$$

$$E_{CM} = E_{lab}\gamma \times (1 - \beta cos\theta)$$







Summary and perspectives

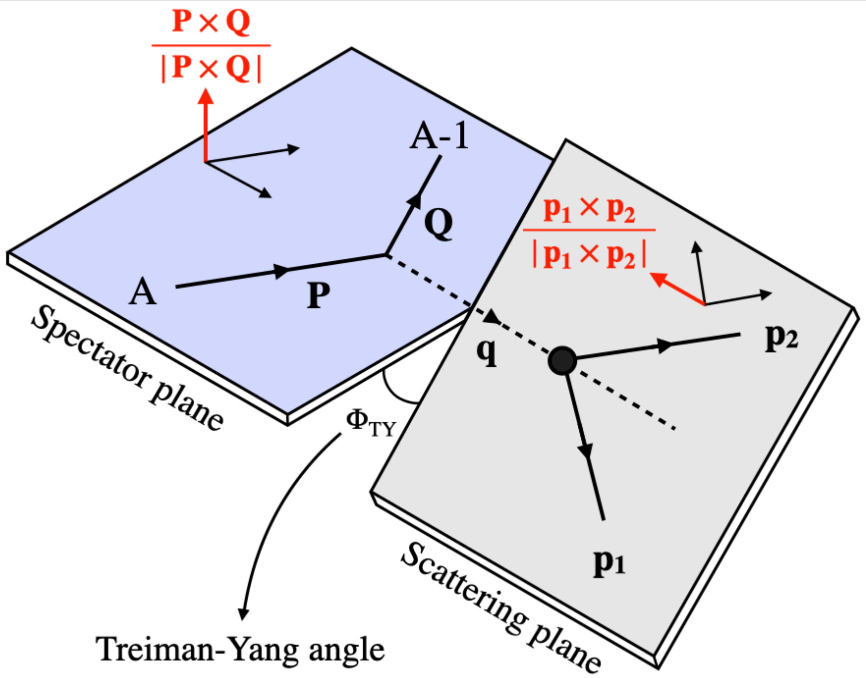
- QE reaction identified in 12C(p,2p)11B at 1.25 GeV/u

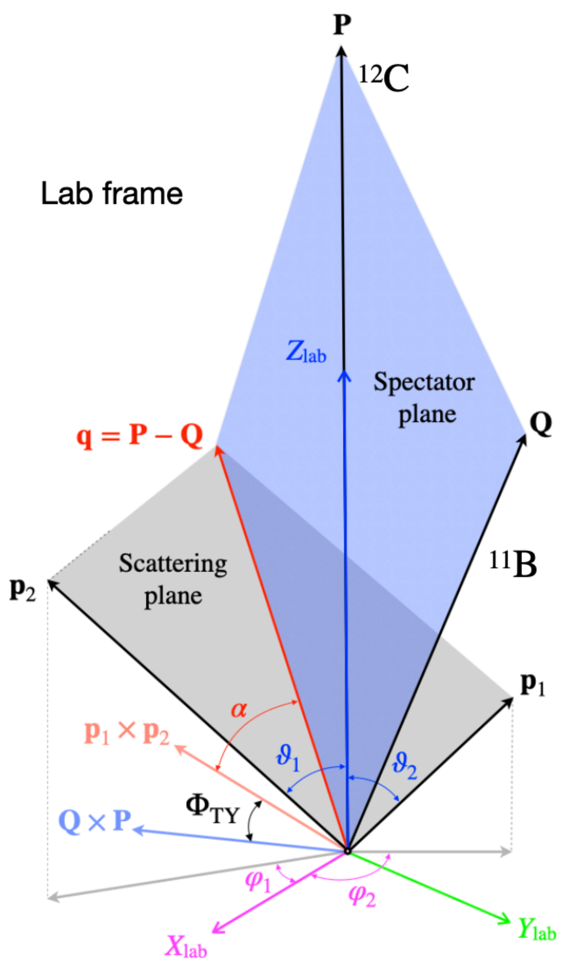
- Open technical issues:
    - vertex efficiency;
    - FOOT multiplicity;
    - CALIFA punch-through ID and energy reconstruction.

- Next:
    - QE in 16C setting;
    - SRC ID (-> challenges due to high off-shellness) .

Backup

Simple reaction mechanism test (Vertex)

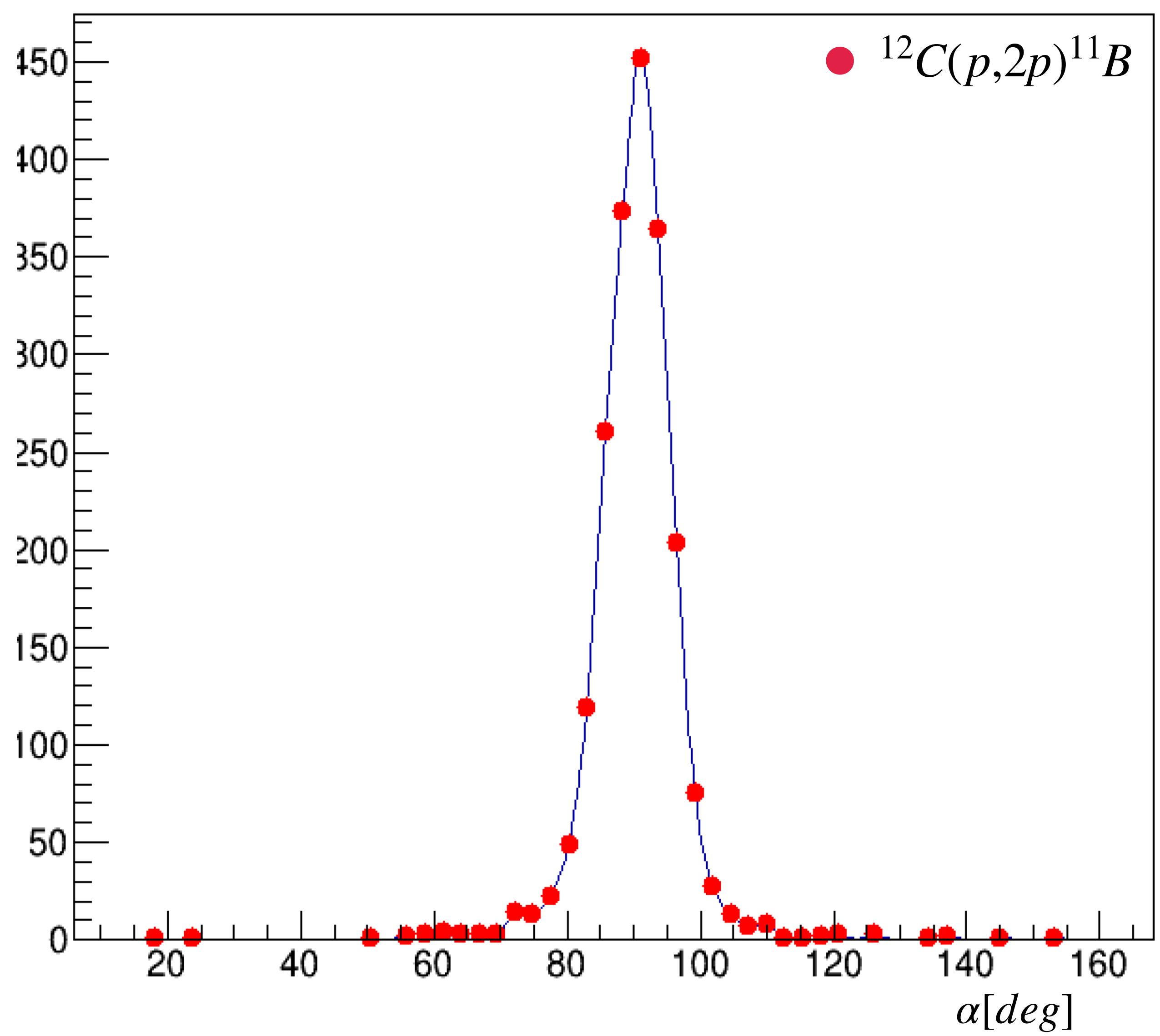




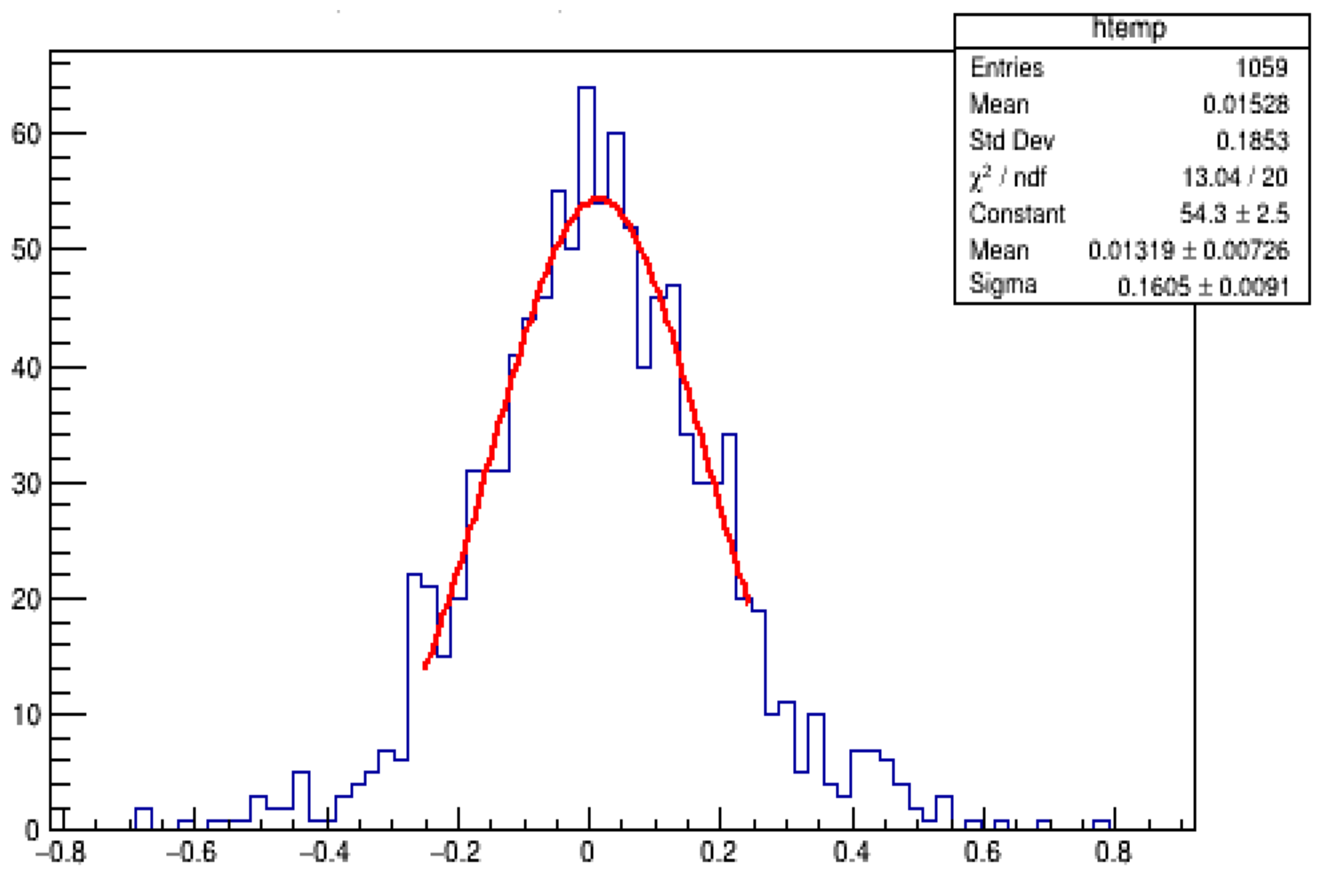
Alpha Angle

$$\cos\alpha = \frac{\mathbf{p_1}\times\mathbf{p_2}}{|p_1\times p_2|}\cdot\frac{\mathbf{P}-\mathbf{Q}}{|P-Q|}\approx 0$$

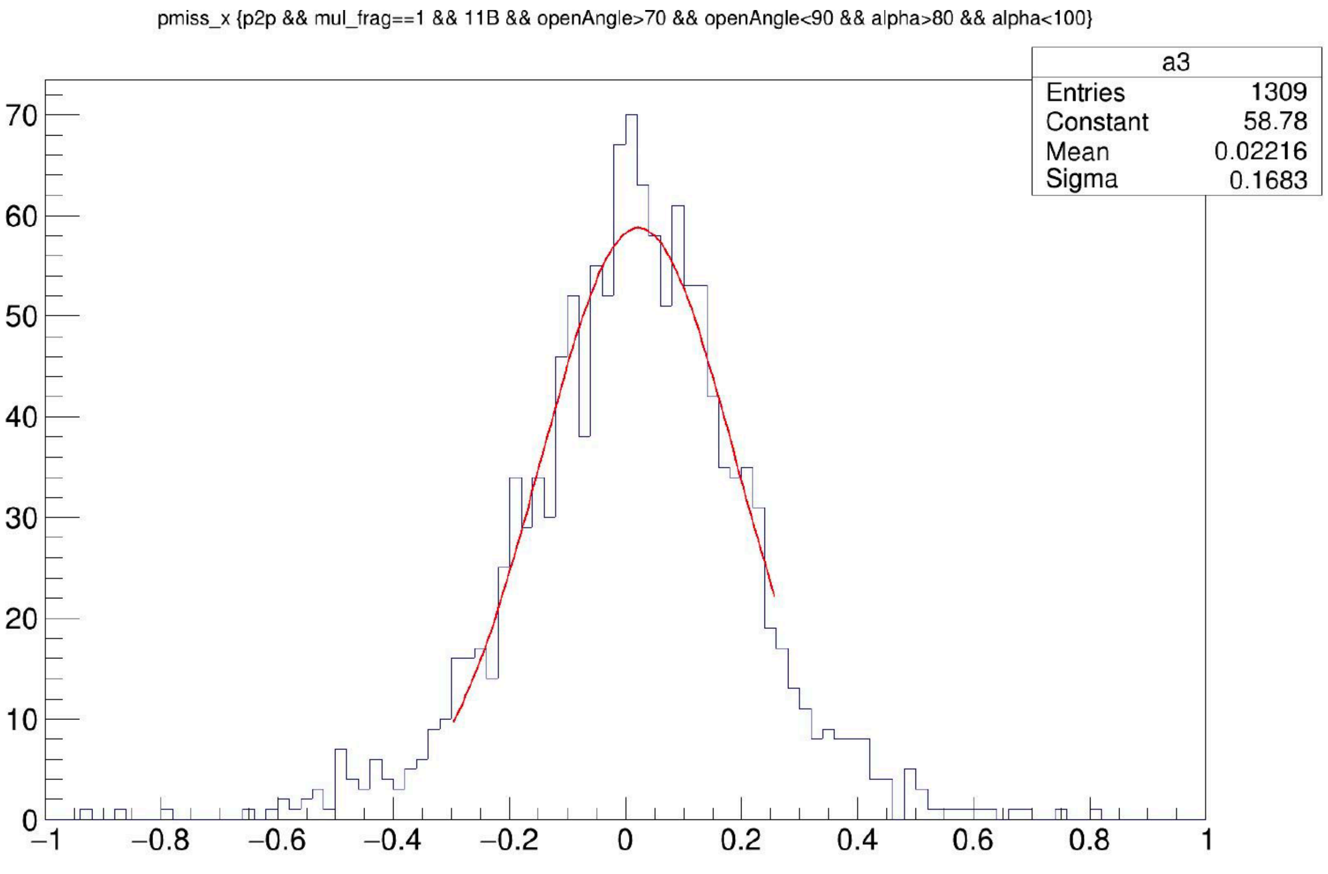
- Angle between the normal vector to the (p,2p) reaction plane and ^{12}C-^{11}B plane;



P_{miss_x}

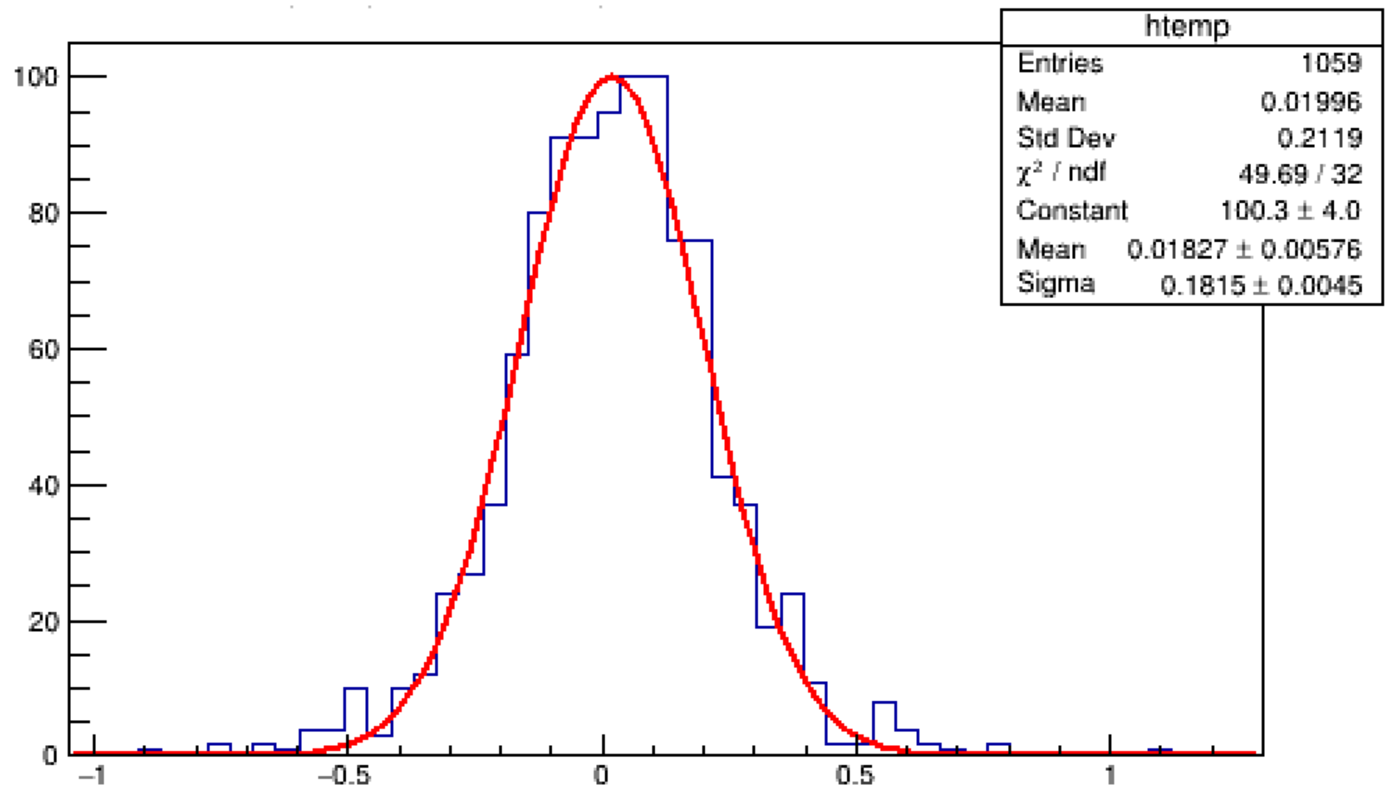


htemp
Entries 1059
Mean 0.01528
Std Dev 0.1853
χ² / ndf 13.04 / 20
Constant 54.3 ± 2.5
Mean 0.01319 ± 0.00726
Sigma 0.1605 ± 0.0091

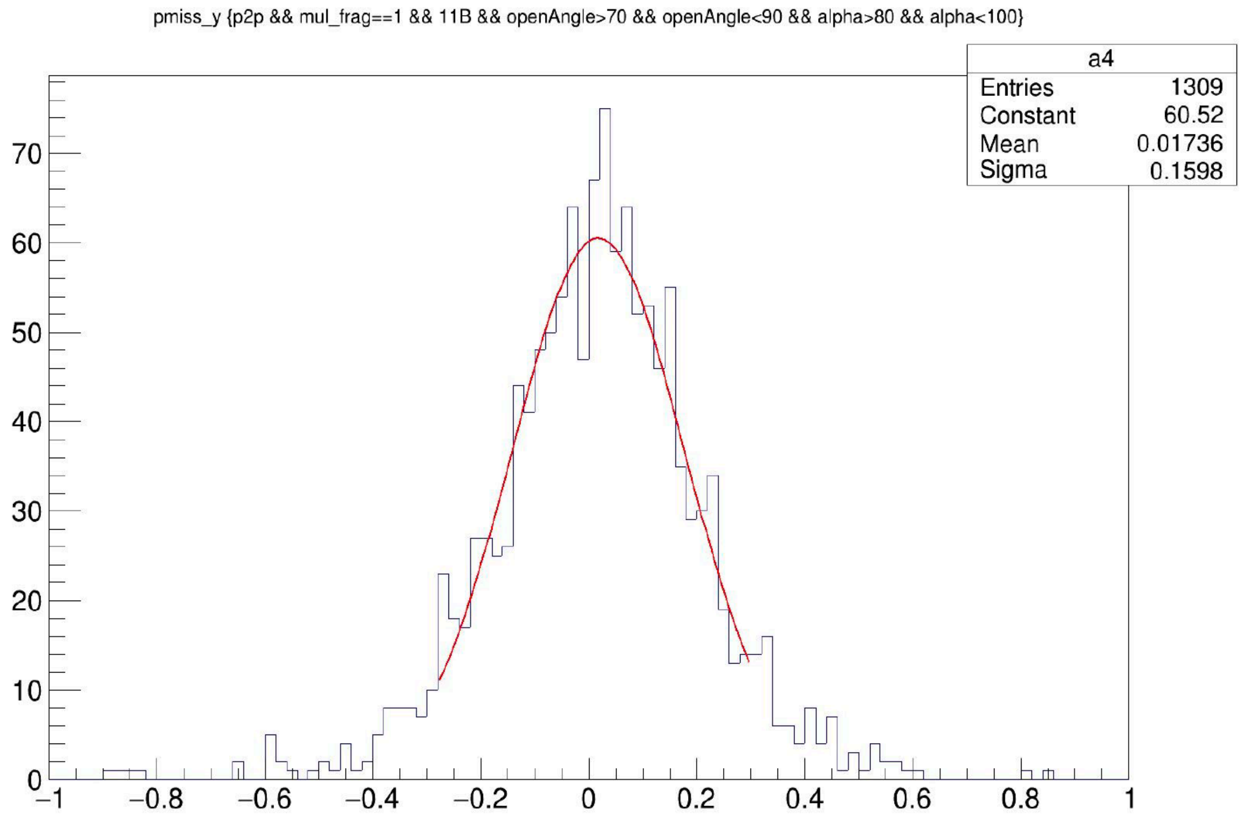


pmiss_x {p2p && mul_frag==1 && 11B && openAngle>70 && openAngle<90 && alpha>80 && alpha<100}
a3
Entries 1309
Constant 58.78
Mean 0.02216
Sigma 0.1683

P_{miss_y}

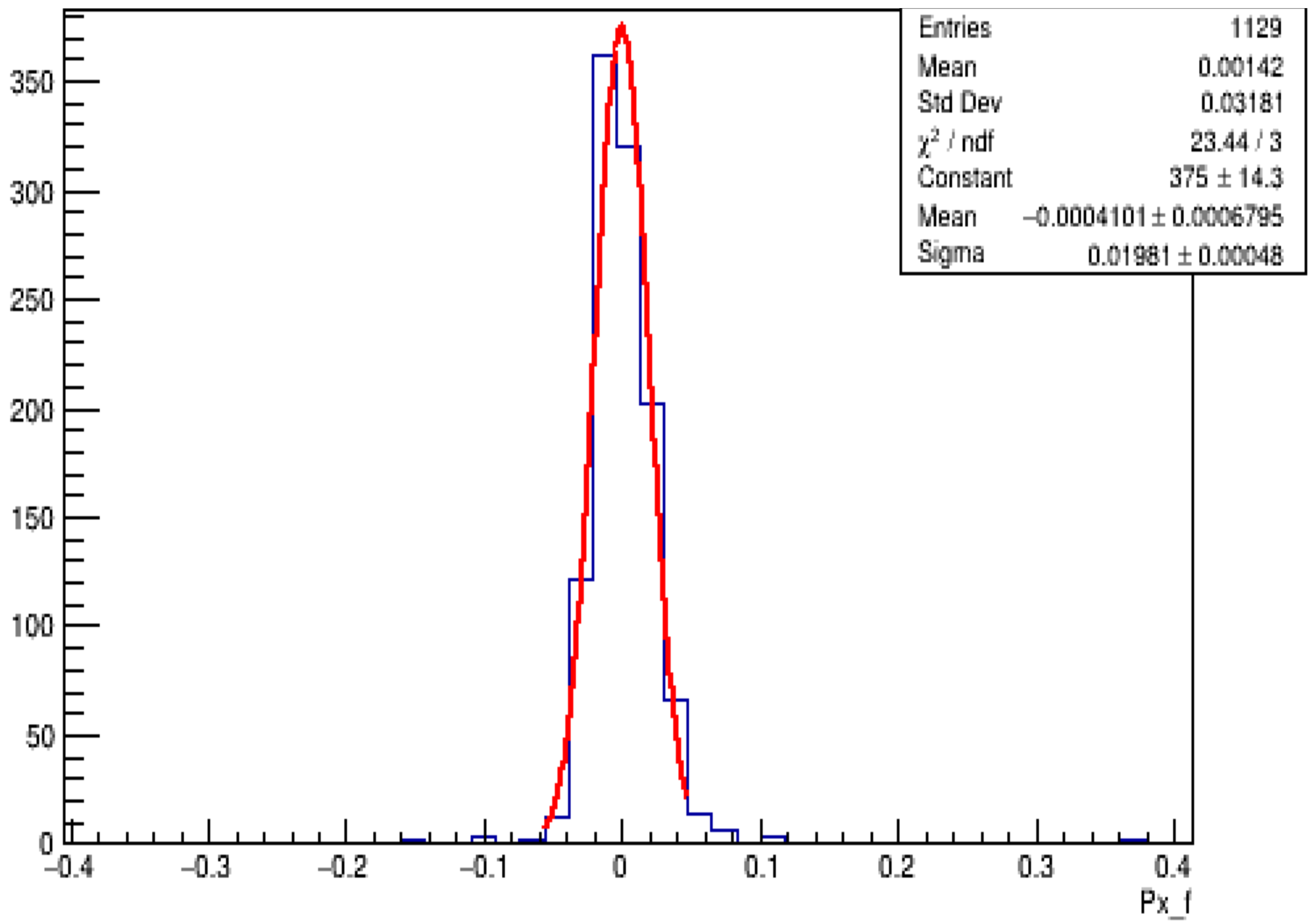


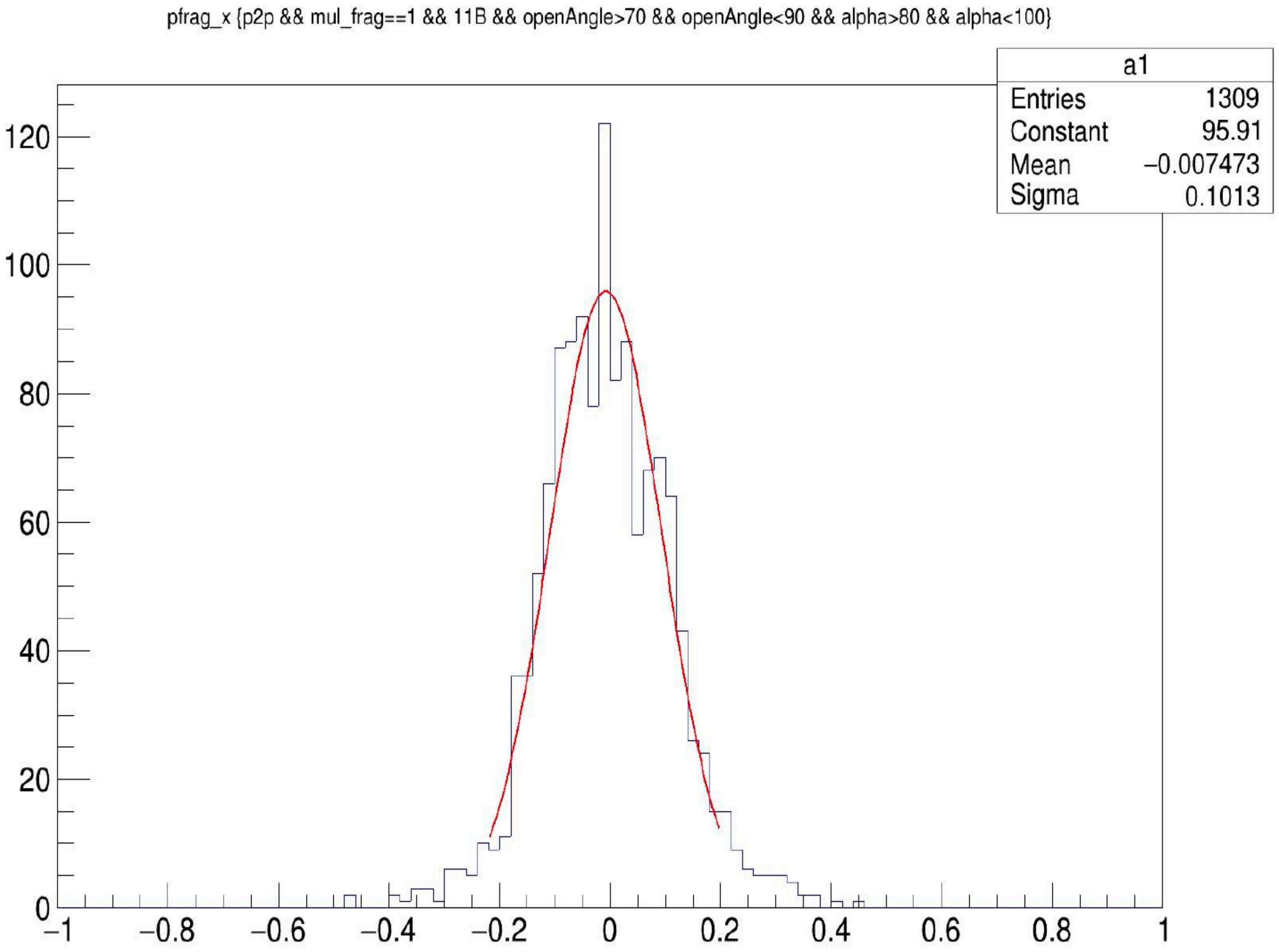
htemp
Entries 1059
Mean 0.01996
Std Dev 0.2119
χ² / ndf 49.69 / 32
Constant 100.3 ± 4.0
Mean 0.01827 ± 0.00576
Sigma 0.1815 ± 0.0045



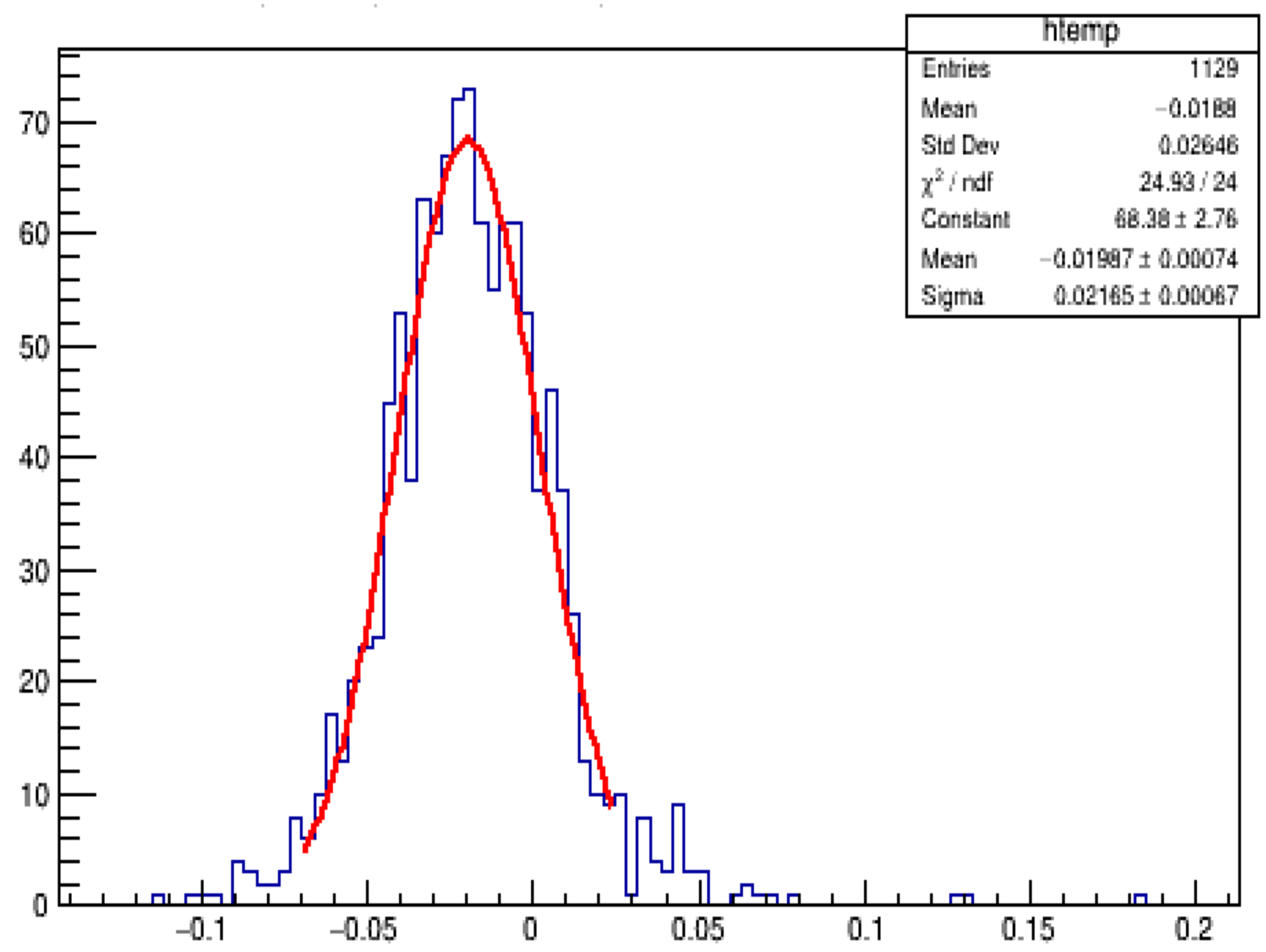
pmiss_y {p2p && mul_frag==1 && 11B && openAngle>70 && openAngle<90 && alpha>80 && alpha<100}
a4
Entries 1309
Constant 60.52
Mean 0.01736
Sigma 0.1598

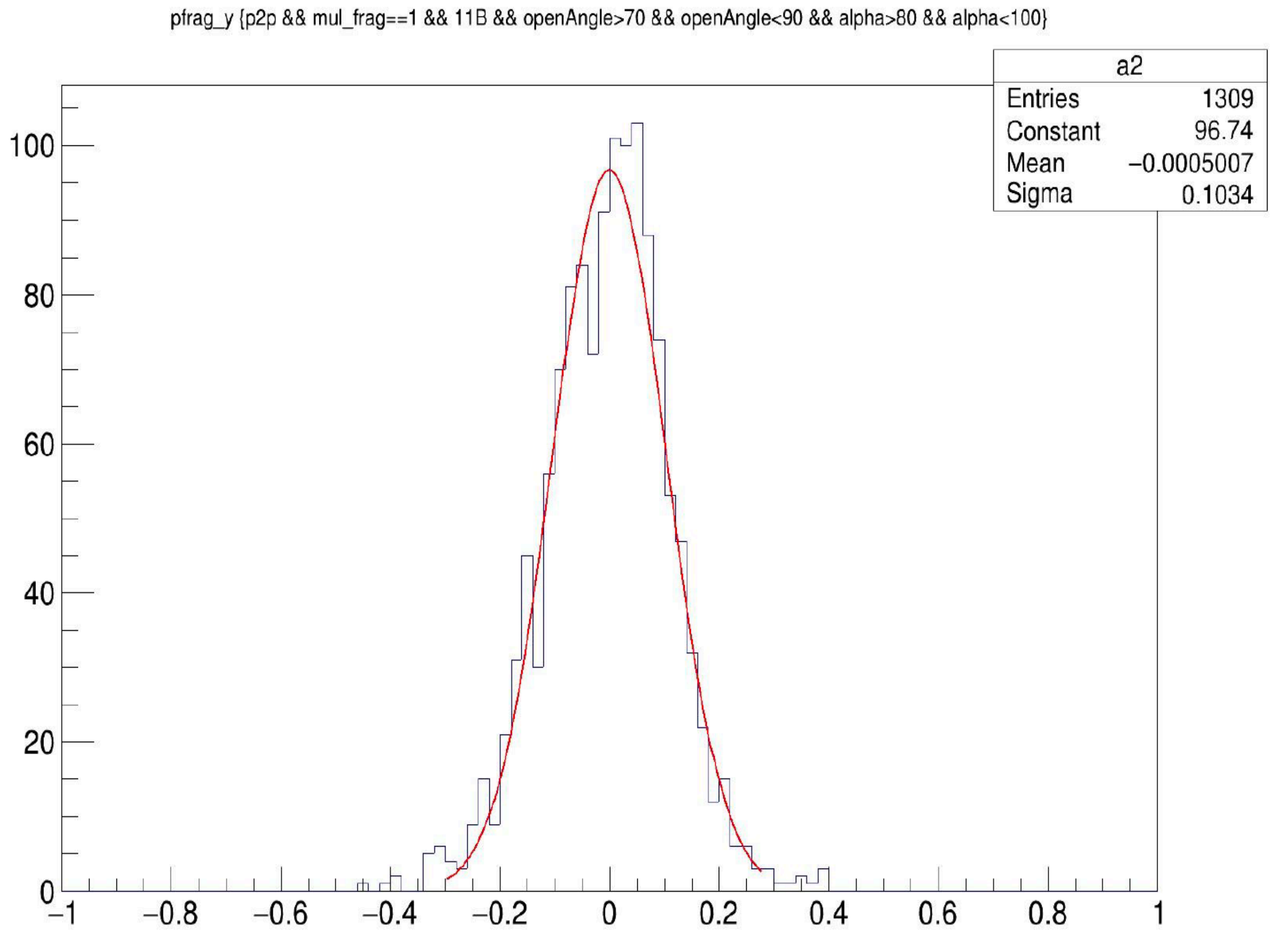
P_{frag_x}


Entries 1129
Mean 0.00142
Std Dev 0.03181
χ² / ndf 23.44 / 3
Constant 375 ± 14.3
Mean −0.0004101 ± 0.0006795
Sigma 0.01981 ± 0.00048
Px_f


pfrag_x {p2p && mul_frag==1 && 11B && openAngle>70 && openAngle<90 && alpha>80 && alpha<100}
a1
Entries 1309
Constant 95.91
Mean −0.007473
Sigma 0.1013

P_{frag_y}


htemp
Entries 1129
Mean −0.0188
Std Dev 0.02646
χ² / ndf 24.93 / 24
Constant 68.38 ± 2.76
Mean −0.01987 ± 0.00074
Sigma 0.02165 ± 0.00067
70
60
50
40
30
20
10
0
−0.1
−0.05
0
0.05
0.1
0.15
0.2


pfrag_y {p2p && mul_frag==1 && 11B && openAngle>70 && openAngle<90 && alpha>80 && alpha<100}
a2
Entries 1309
Constant 96.74
Mean −0.0005007
Sigma 0.1034
100
80
60
40
20
0
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1

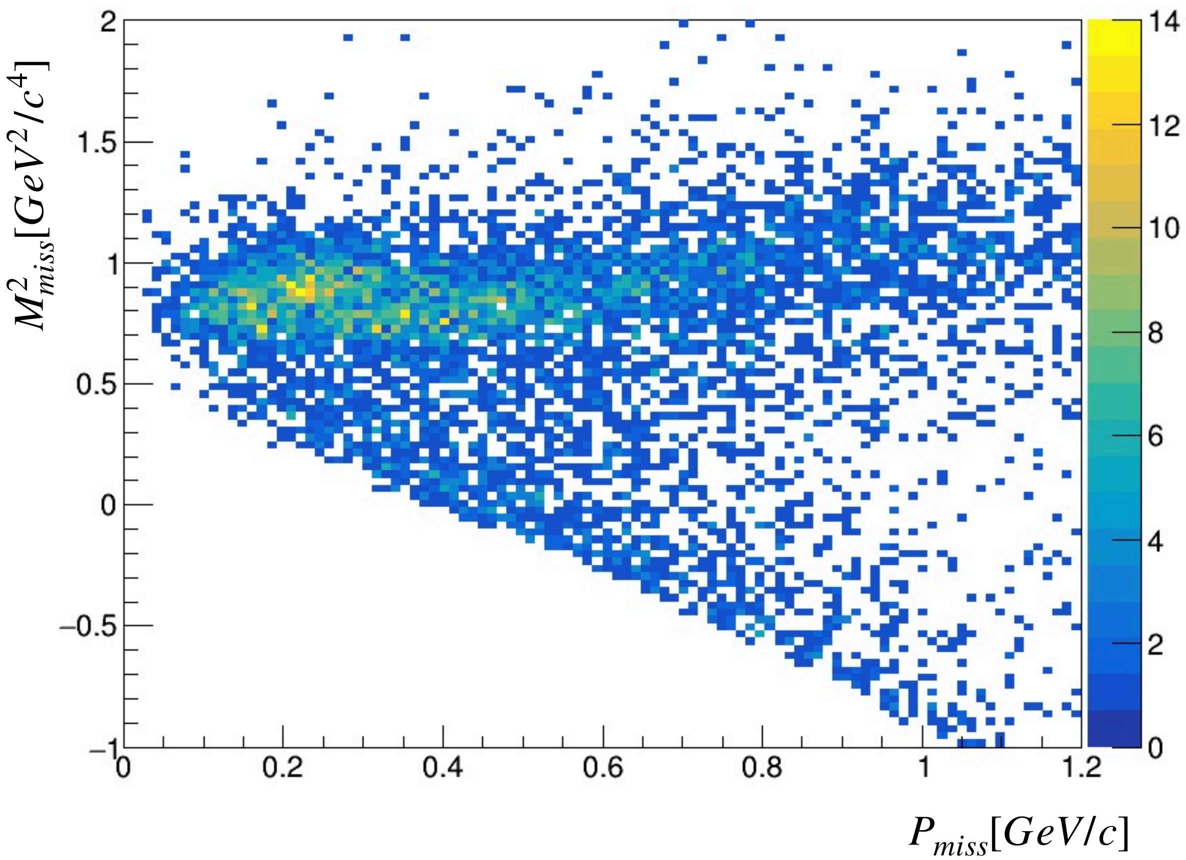
Quasi-Elastic event identification CALIFA

PRELIMINARY

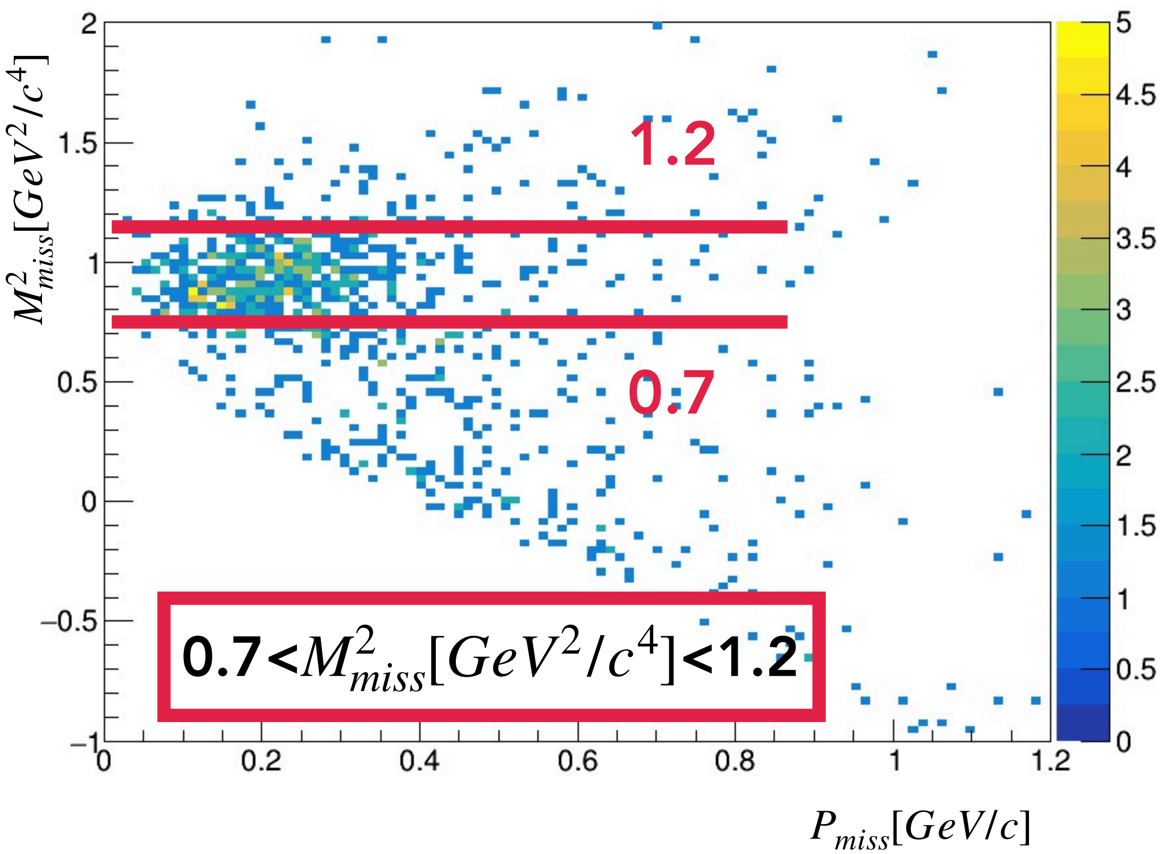
Missing mass vs Missing momentum

- The ^{11}B detection is shown to select the **QE part of the reaction**;
- Similar to BM@N (JINR) experiment.

* No selection of ^{11}B fragment;
* (p,2p) reconstructed with CALIFA;

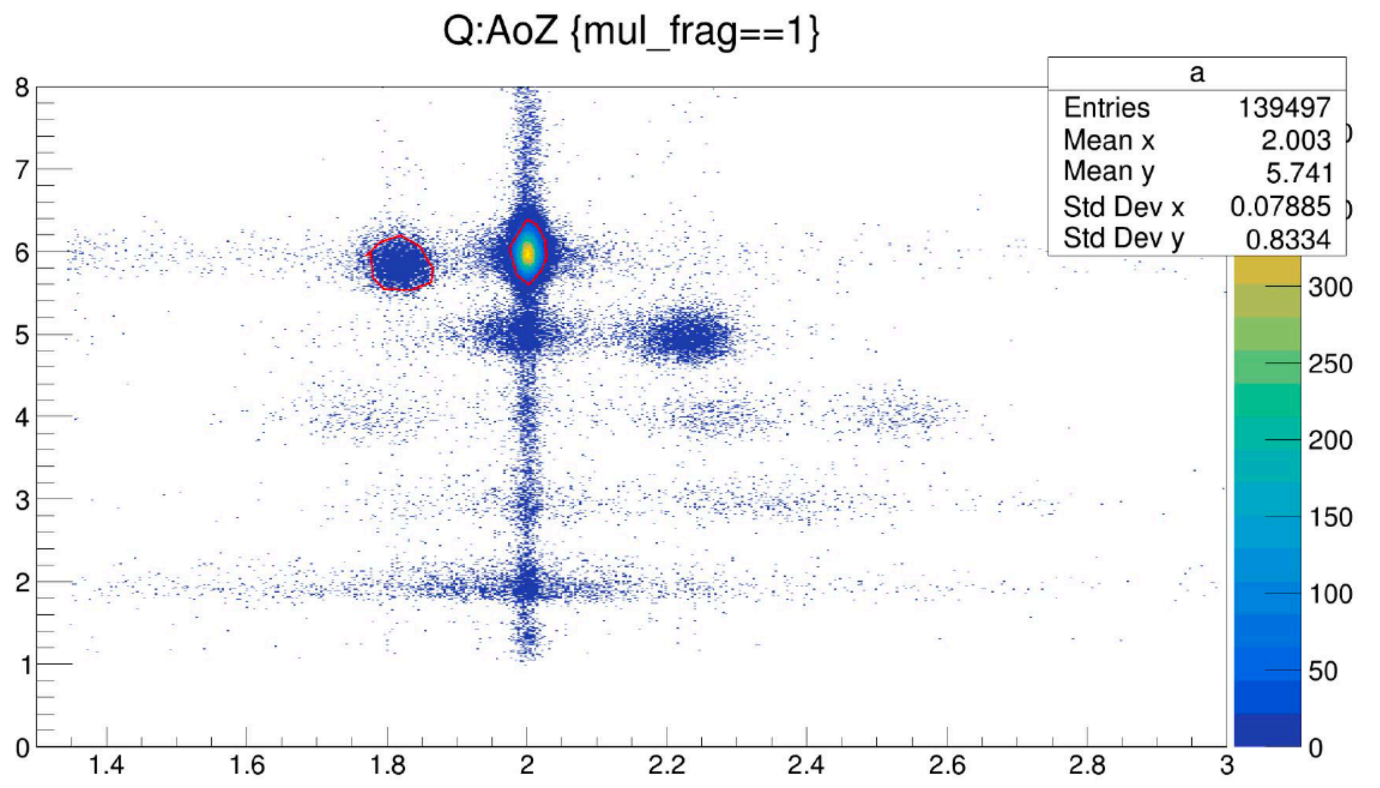


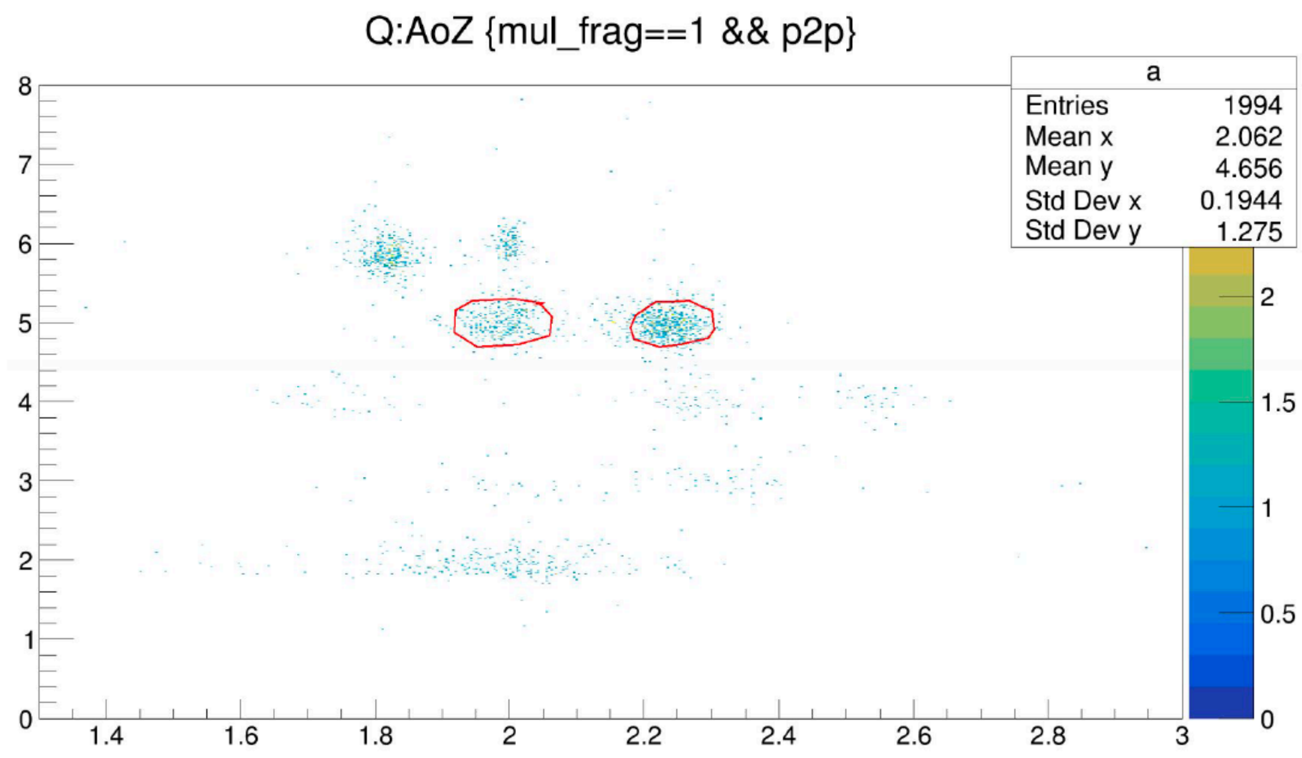
* Selection of ^{11}B fragment;
* (p,2p) reconstructed with CALIFA;
* Selection with $|u| > 0.65\ GeV^2$ && $|t| > 0.65\ GeV^2$.



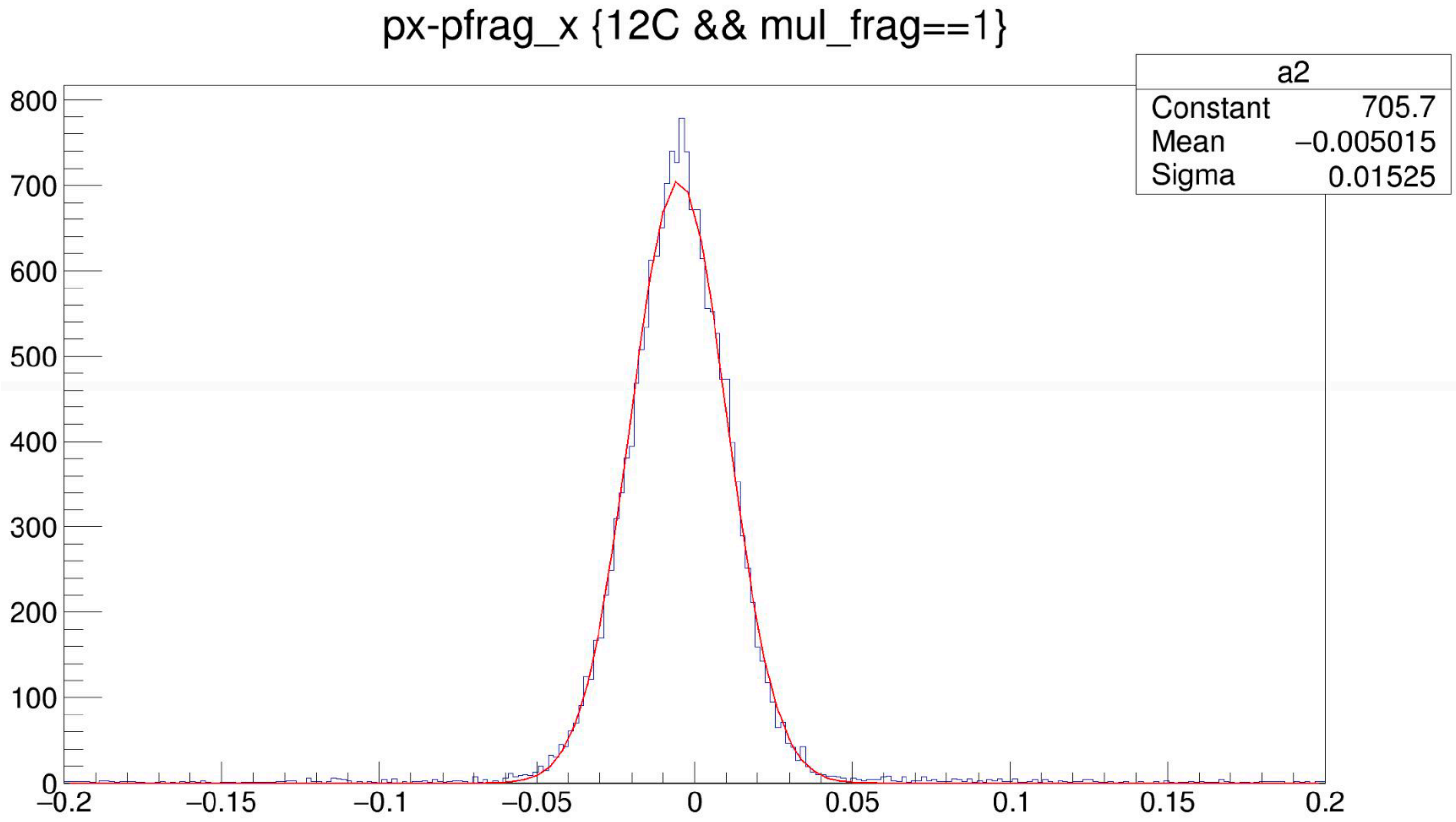
Maybe

Checking calibration Maybe

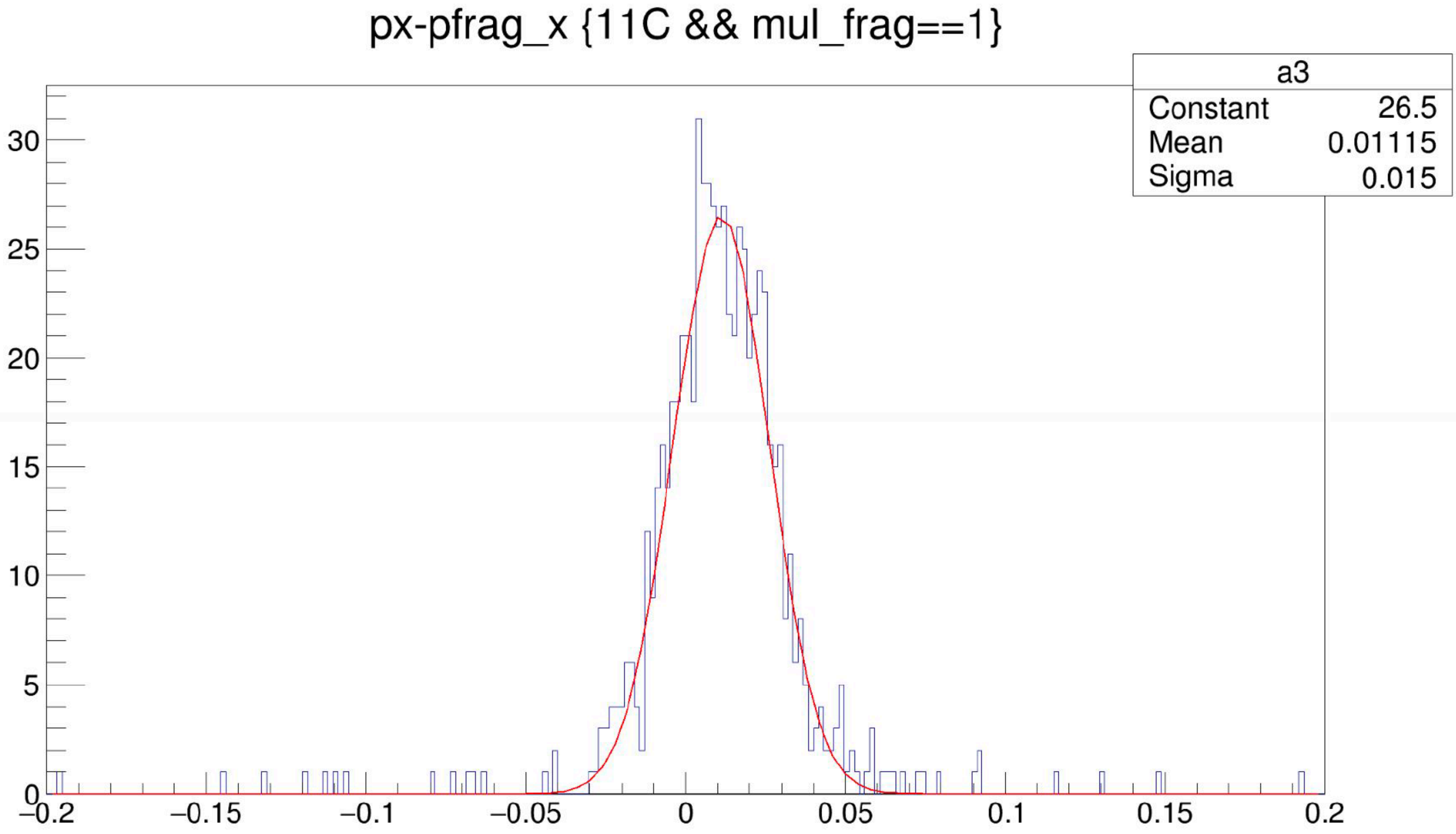




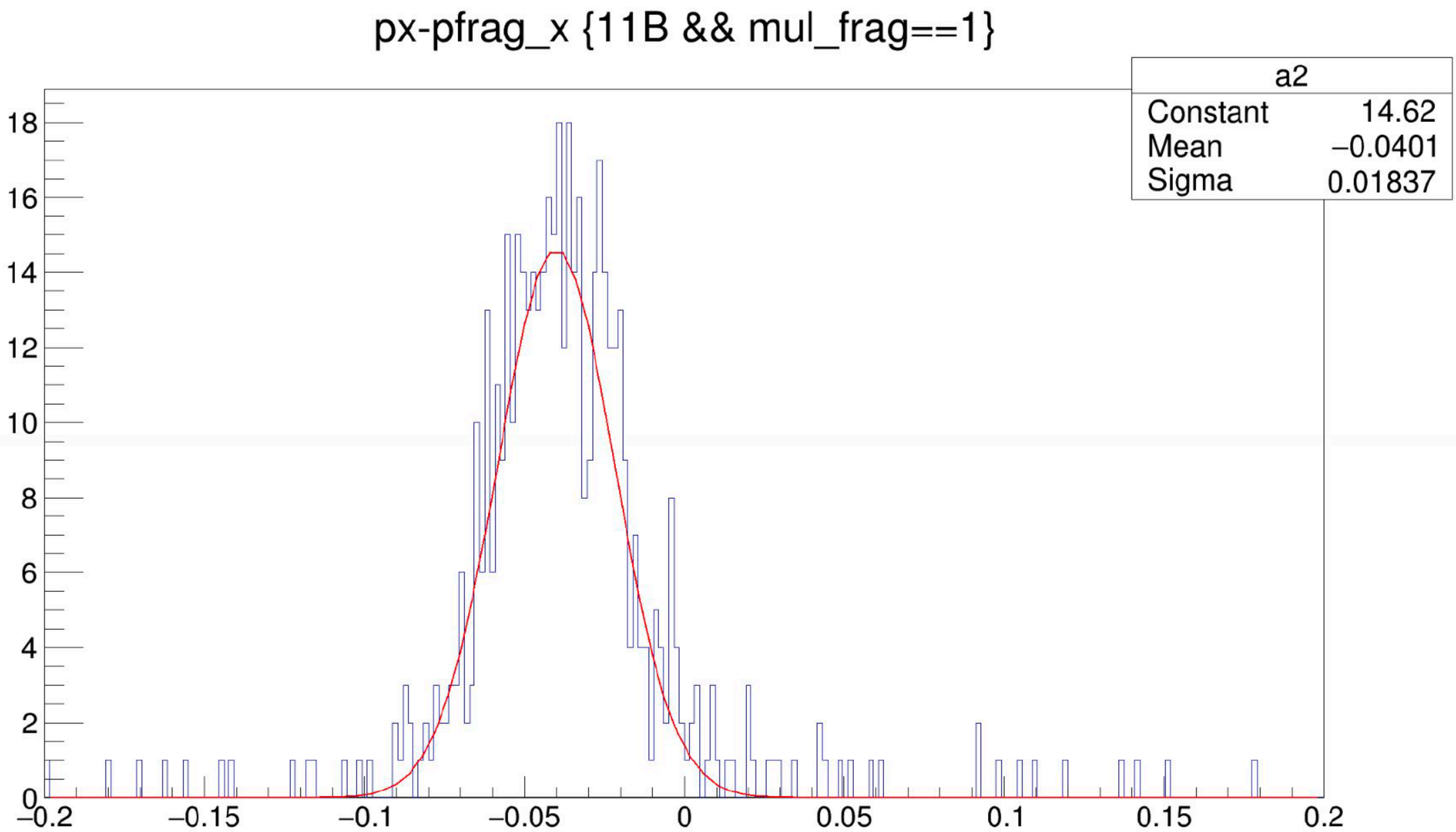
Delta TX0 for 12C



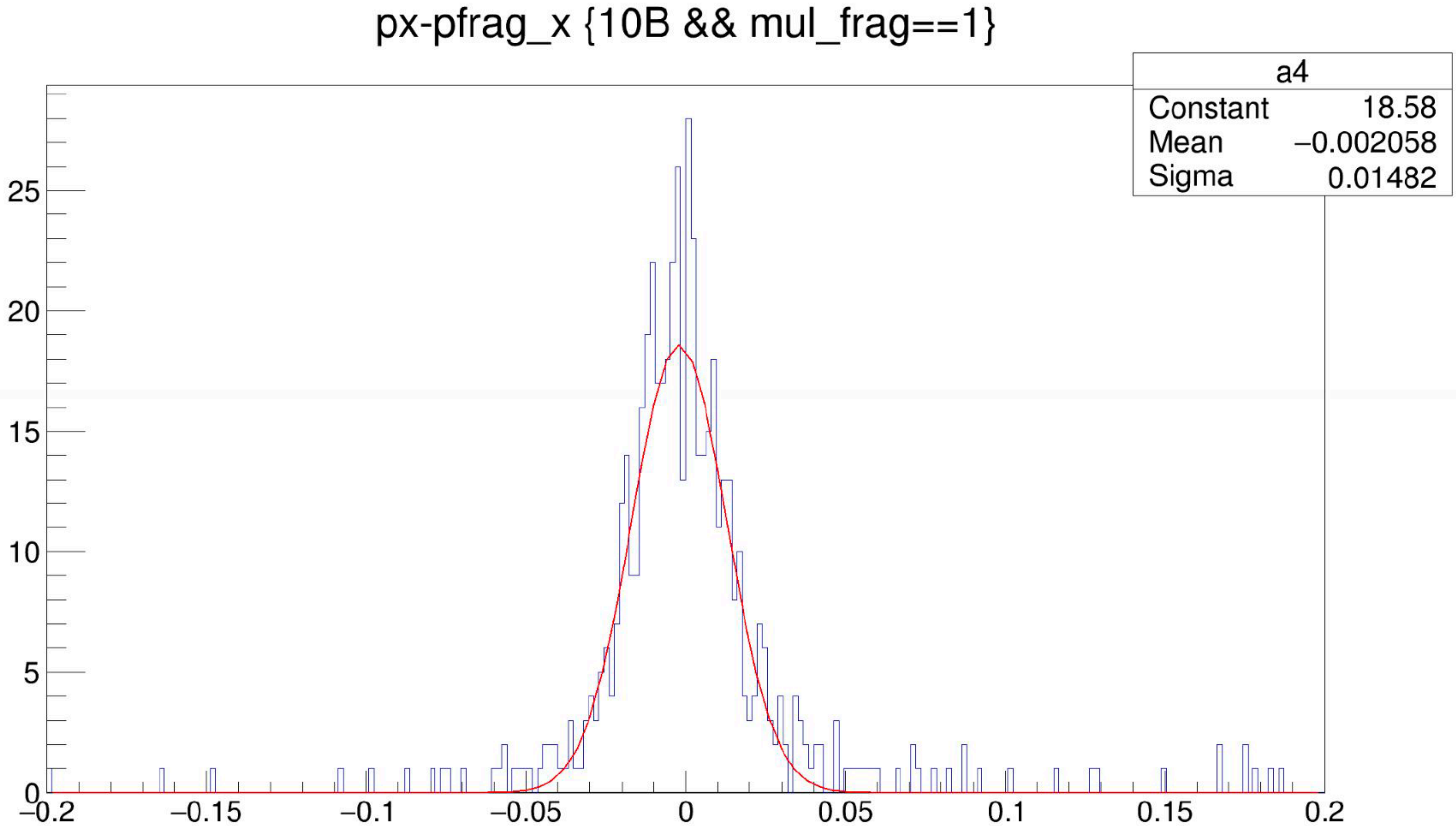
Delta TX0 for 11C



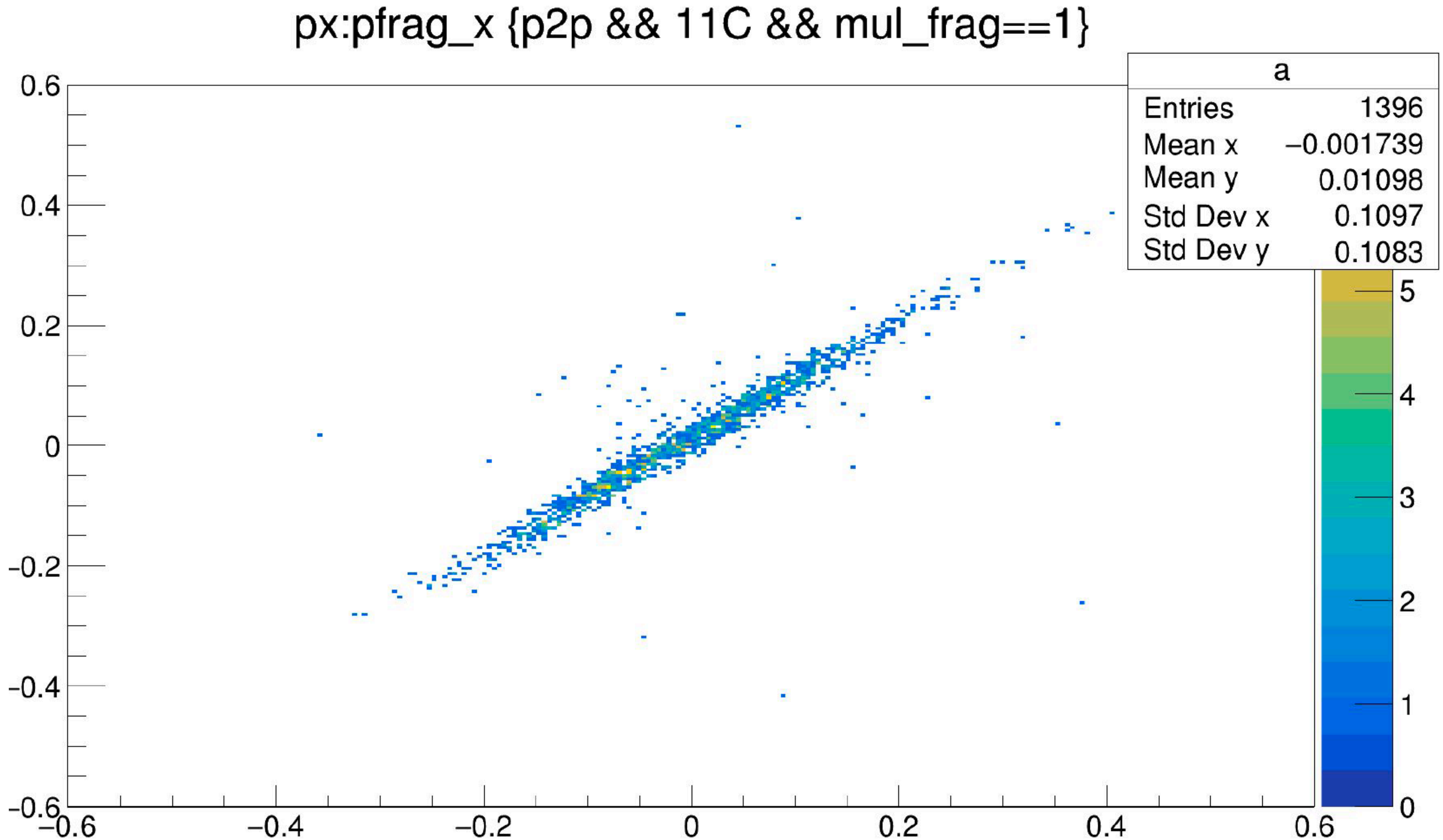
Delta TX0 for 11B



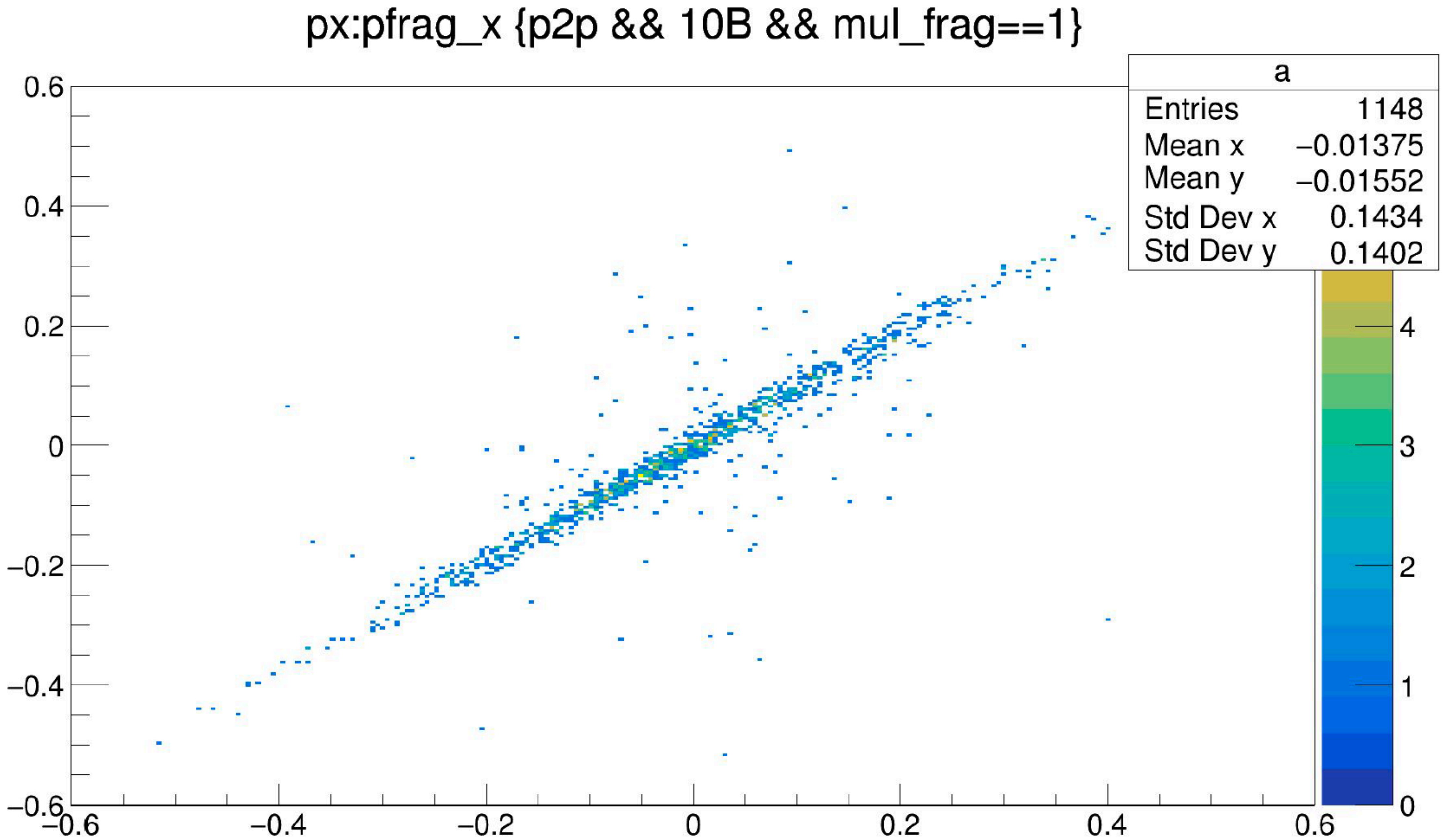
Delta TX0 for 10B



TX0 for 11C

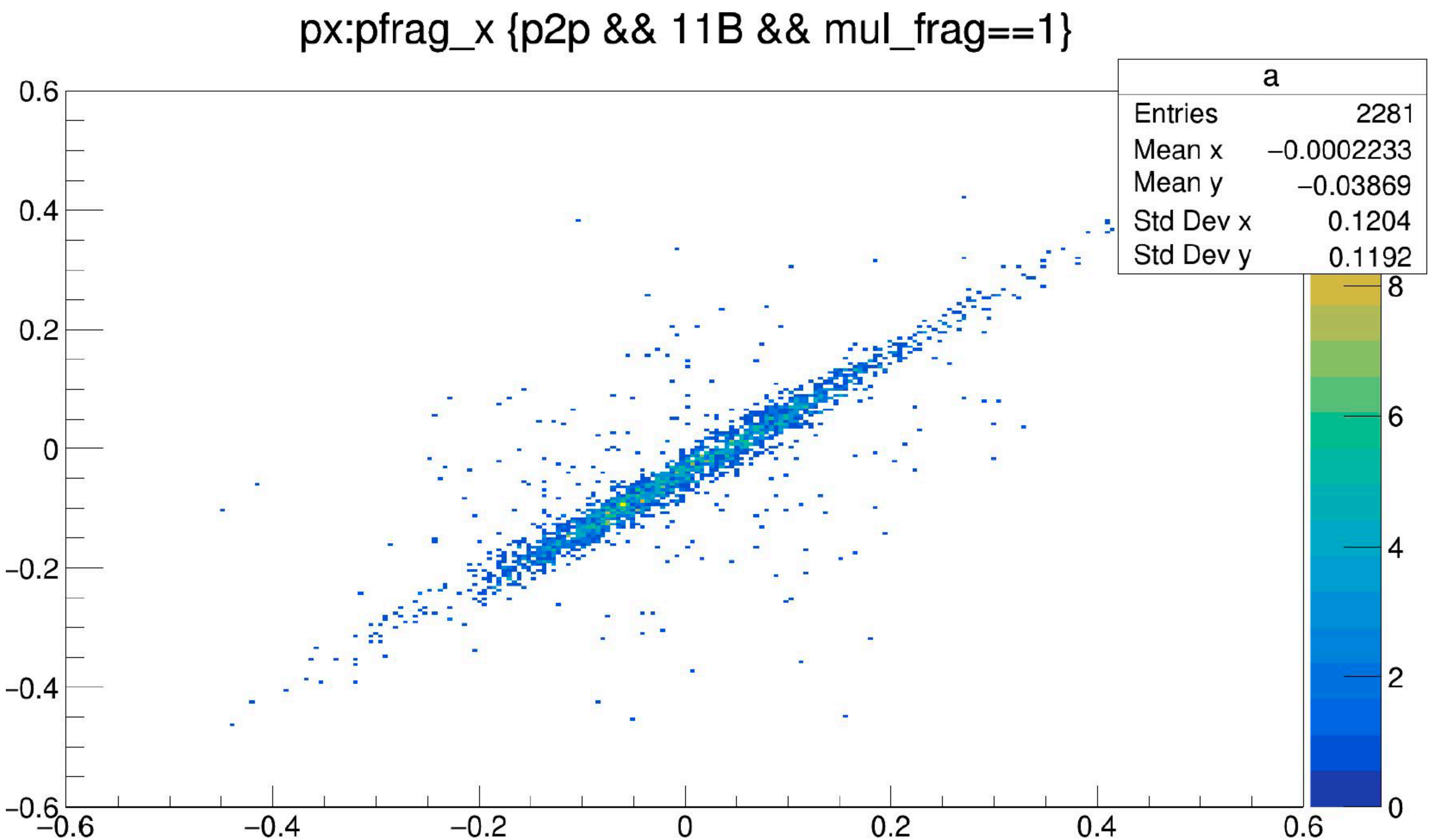

px:pfrag_x {p2p && 11C && mul_frag==1}
a
Entries 1396
Mean x −0.001739
Mean y 0.01098
Std Dev x 0.1097
Std Dev y 0.1083
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
5
4
3
2
1
0

TX0 for 10B



px:pfrag_x {p2p && 10B && mul_frag==1}
a
Entries 1148
Mean x −0.01375
Mean y −0.01552
Std Dev x 0.1434
Std Dev y 0.1402
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
4
3
2
1
0

TX0 for 11B



px:pfrag_x {p2p && 11B && mul_frag==1}
a
Entries 2281
Mean x −0.0002233
Mean y −0.03869
Std Dev x 0.1204
Std Dev y 0.1192
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.6 −0.4 −0.2 0 0.2 0.4 0.6
0 2 4 6 8