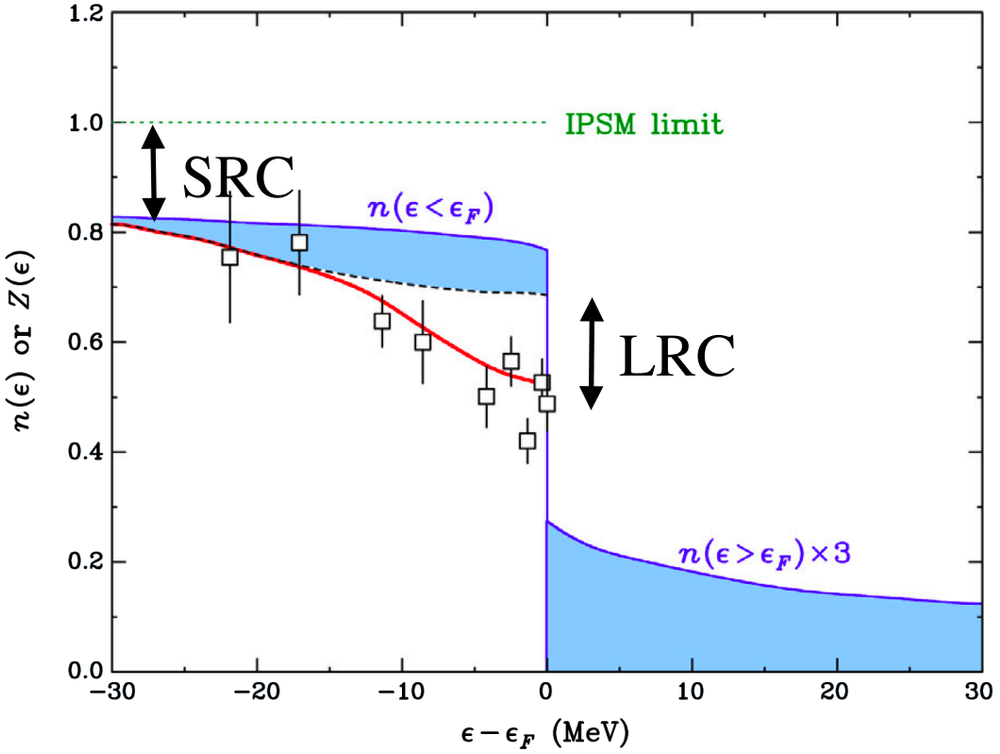
Status of SRC@JINR analysis

Valerii Panin and Efrain Segarra for SRC collaboration

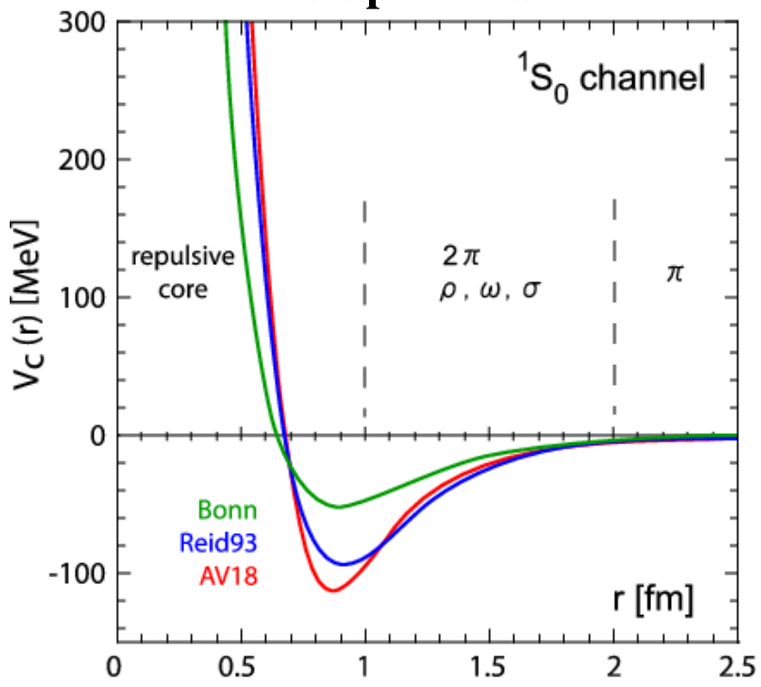
3rd Collaboration meeting of the MPD and BM@N experiments at the NICA Facility
16-17 April 2019

NN correlations and nuclear structure

Progress in Particle and Nuclear Physics 96 (2017) 32–87

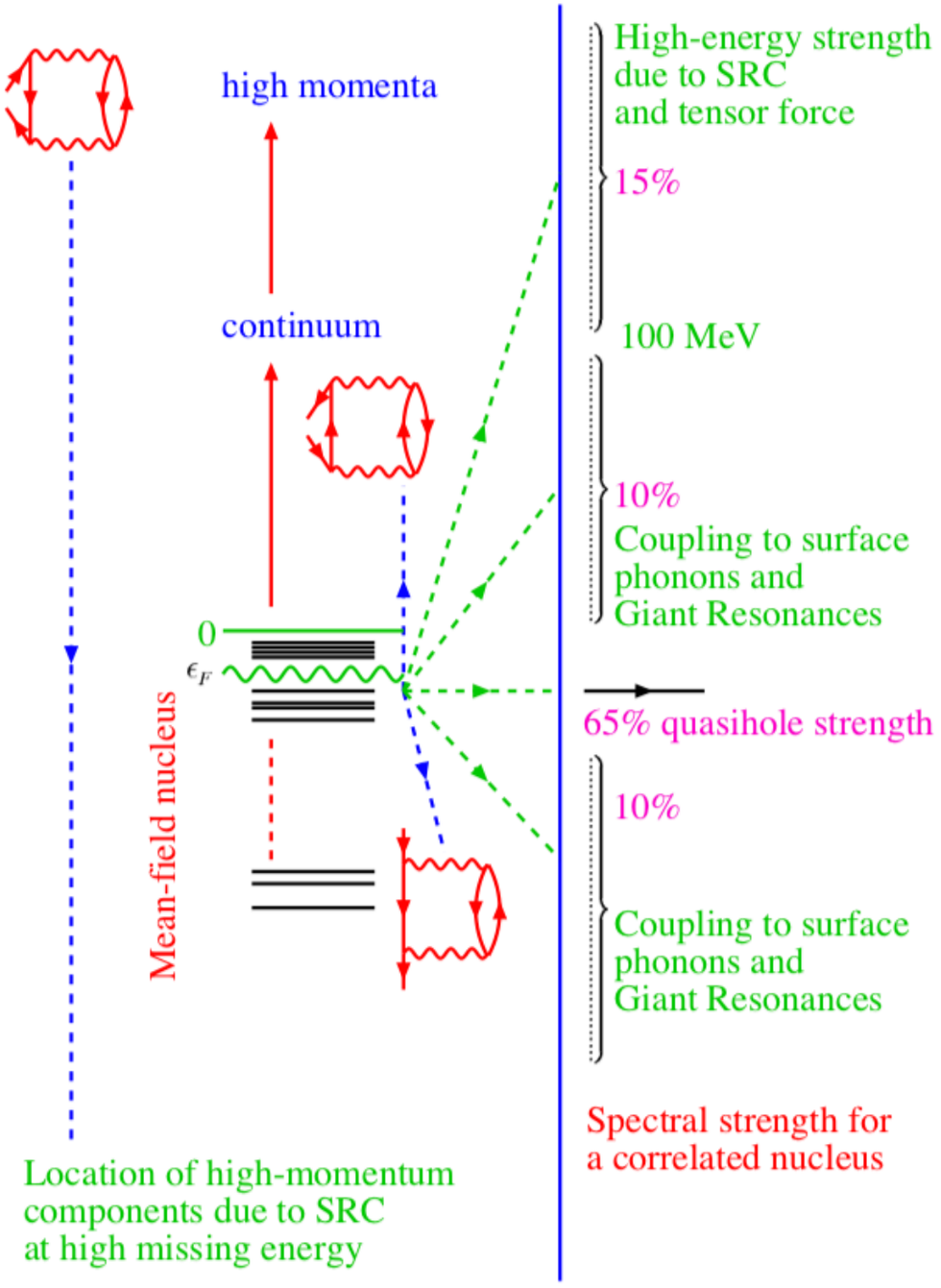


NN potential



N. Ishii, S. Aoki and T. Hatsuda, Phys. Rev. Lett. 99 (200) 022001.

SCGF results

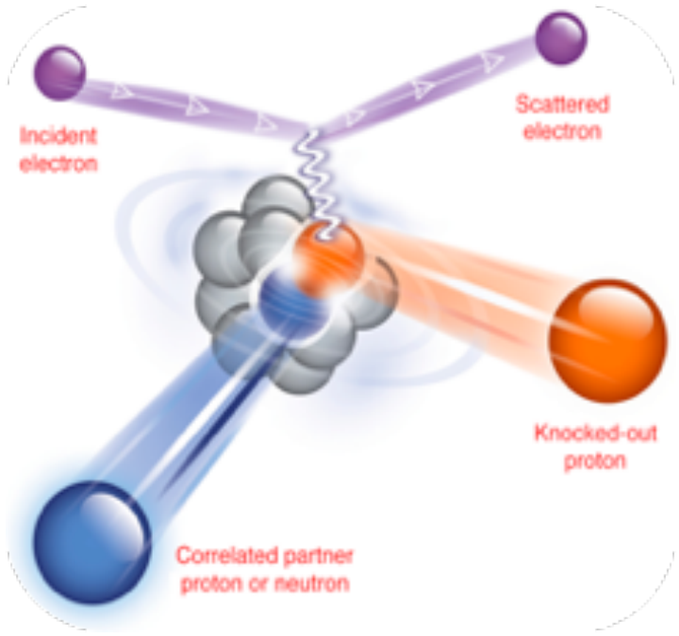


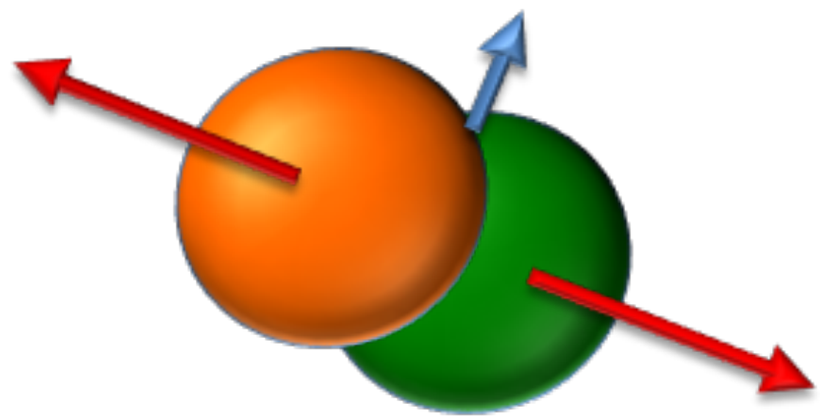
Progress in Particle and Nuclear Physics 52 (2004) 377–496

Short-Range Correlations (SRC)

Nucleon pairs that are close together in the nucleus

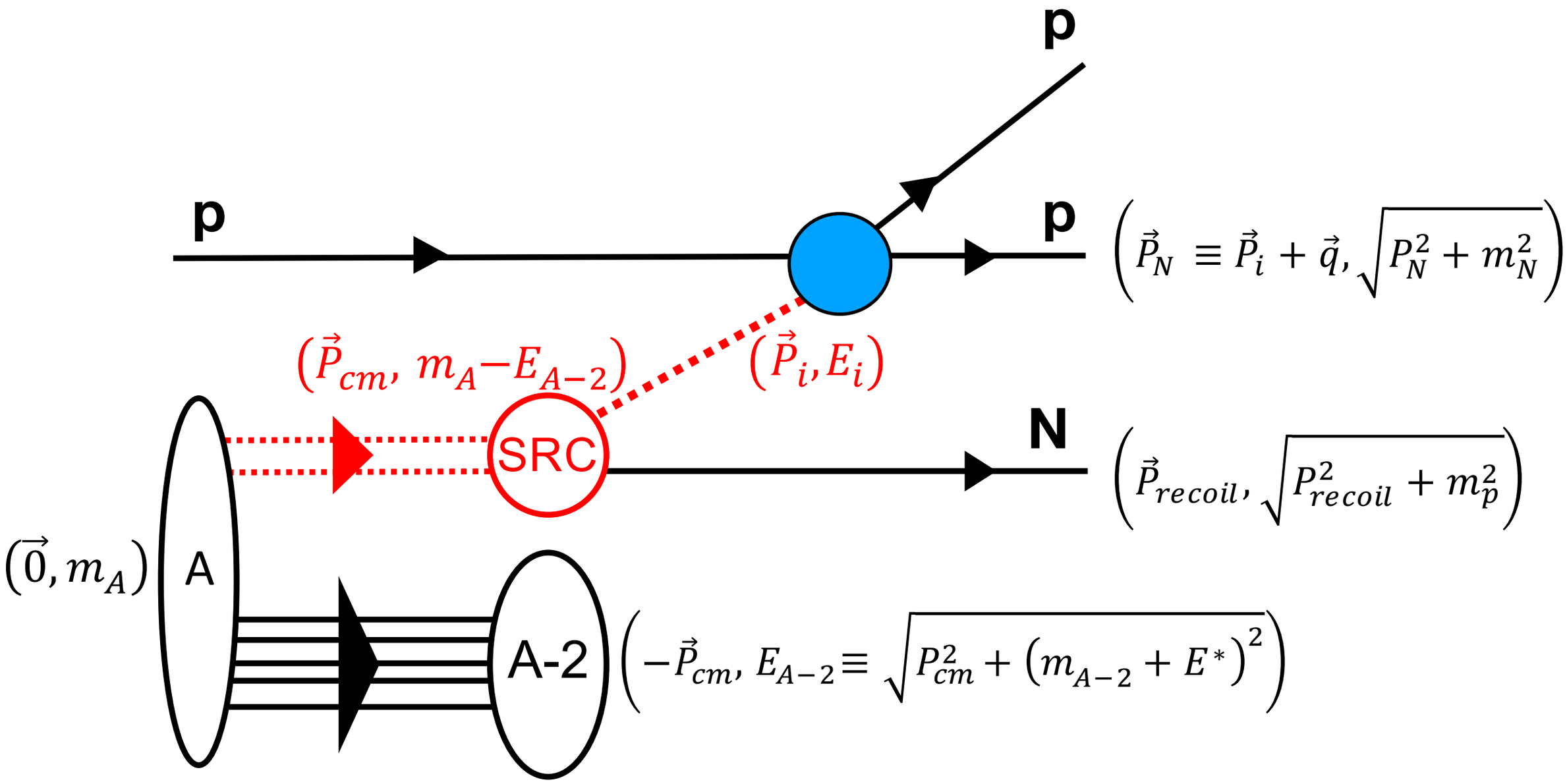
Momentum space: *high relative* and *low c.m. momentum,* compared to the Fermi momentum (k_F)



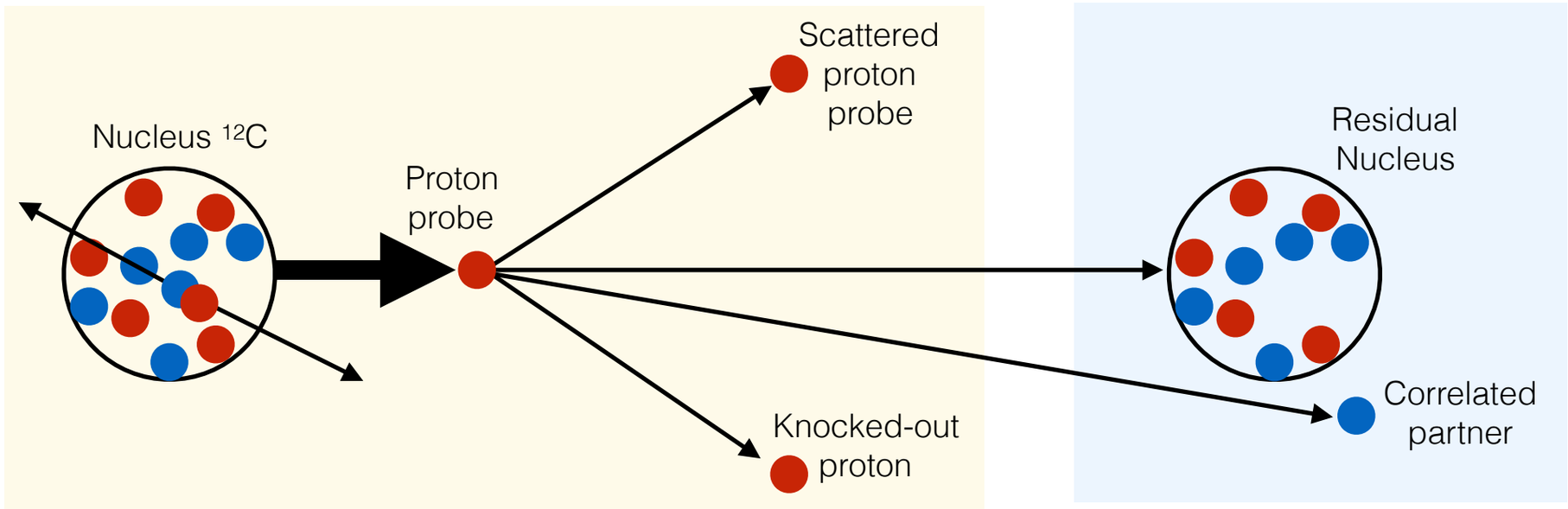


* *Science 320 (5882) 1476-1478 (2008)*
Science 346, 614 (2014)
Nature 560, 617–621 (2018)

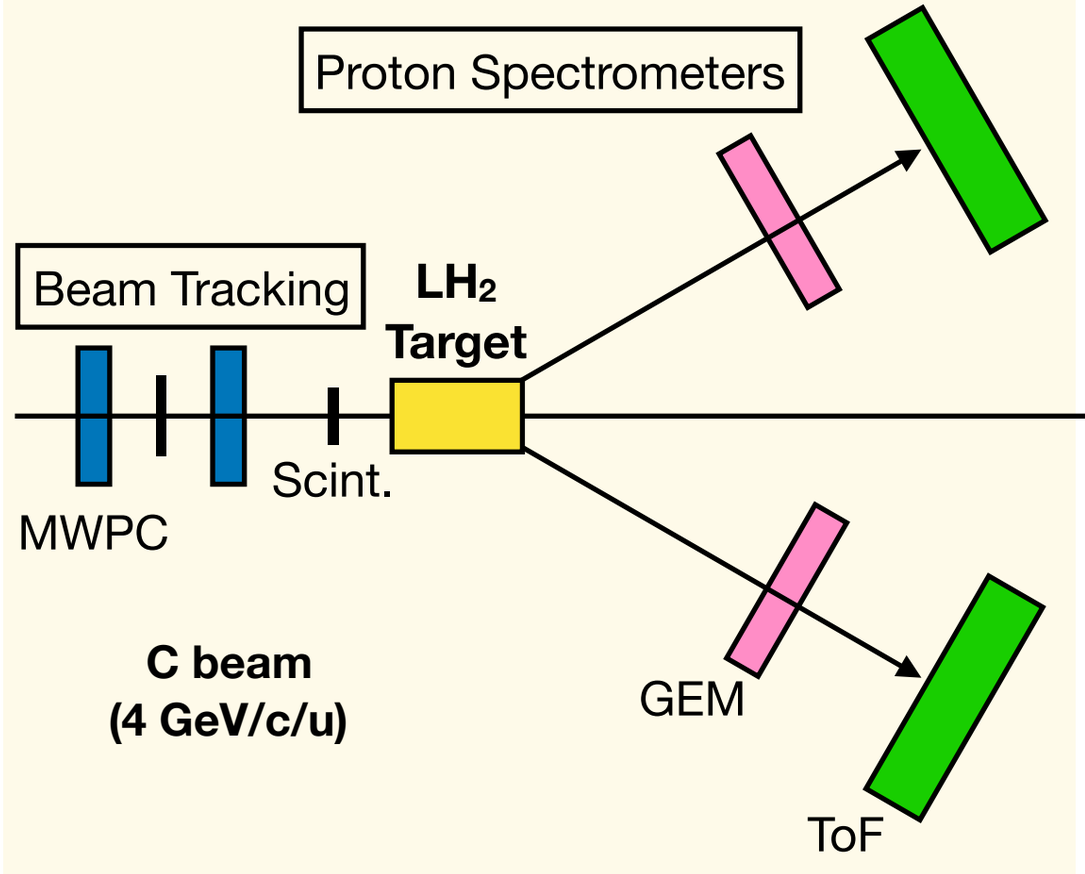
The state of the A-2 residual nucleus impacts SRC kinematics

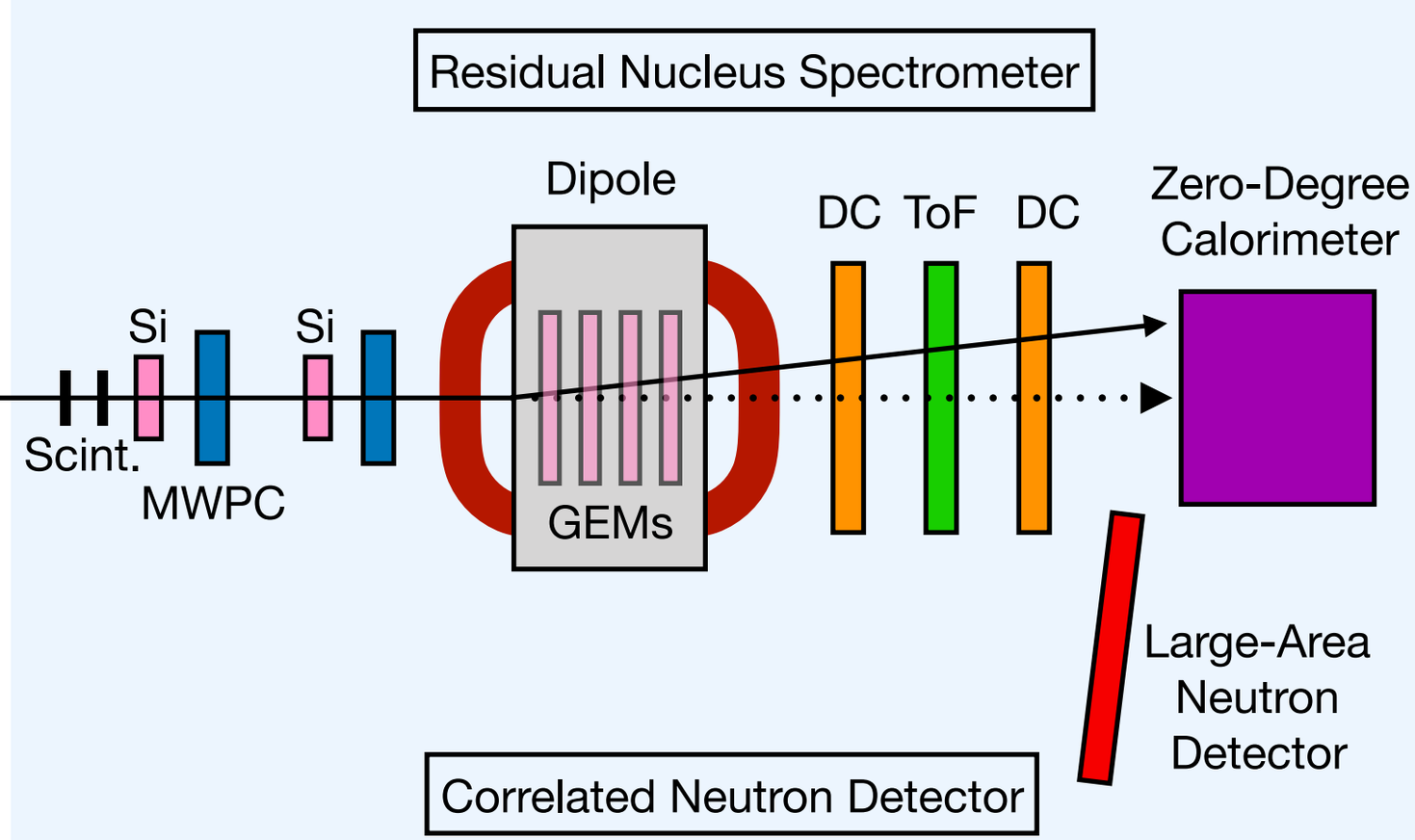


First Fully Exclusive Measurement of Short-Range Correlated Nucleons in Inverse Kinematics at JINR



(Not drawn to scale)





RFBR grant for SRC data analysis by Dr. Maria Patsyuk

Manpower

Name	Area of expertise
Vasilisa + V. Palchik	MWPC + Si
Nikolay Voytishin	DCH
Yuri Petukhov	TOF700
V. Babkin + M. Rumyantsev	TOF400
Yuri Uzikov	Theory
Maria Patsyuk	Coordinator

3 years, evaluation after each year

Plan for 2019:

- Calibration of detector systems
- Correlations between different detectors
- Identification of protons and A-2

Theory plan

- create a theoretical model for NN-SRC breakup p<NN> -> ppN (<NN> - correlated pair) for kinematical conditions of BM@N based on Yu.N. Uzikov, J.Phys. G28 (2002) B13 J.Haidenbauer, Yu.N. Uzikov, Phys. Lett. B 562 (2003) 227.

- Development of this model for the light front dynamics.

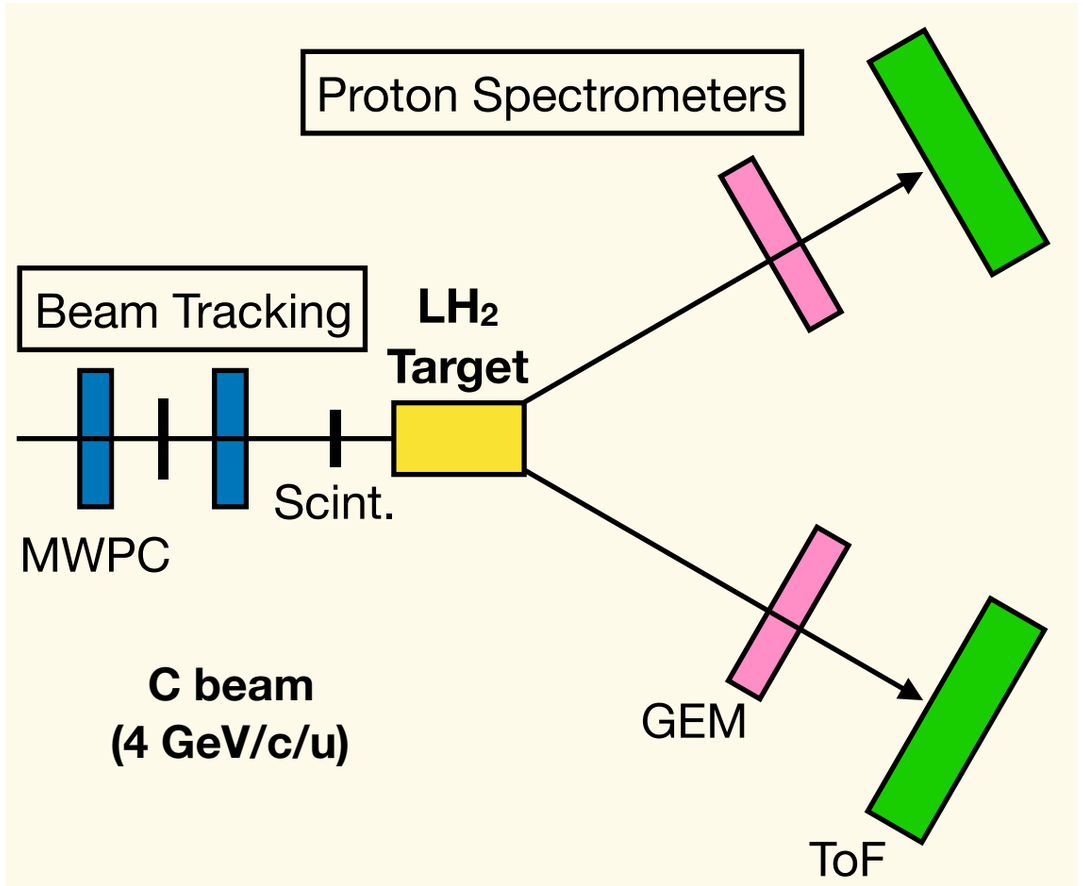
- Main mechanism: pole diagram in momentum approximation including rescattering in the initial and final states using eikonal approximation and the effect of amplitude of pN-scattering off mass shell.

- Estimation of Delta-isobar contribution in the intermediate state and a triangular diagram with single pion exchange.

Goals of the analysis

- Identification of quasi-elastic (p,2p) events with ^{12}C beam
  - **QFS tagging and cleaner event sample**
  - optics calibration
  - GEM + TOF calibration
  - reconstruction of Pmiss and beam vector
- Study of A-2 residual system after SRC knockout
  - **N of tracks - DCH / Si / GEM / TOF700**
  - clean SRC event sample using TOF 400 + GEM + beam tracking
  - momentum reconstruction for fragments
  - **PID using TOF700**
  - efficiency corrections
  - yields for different fragmentation channels

QFS tagging

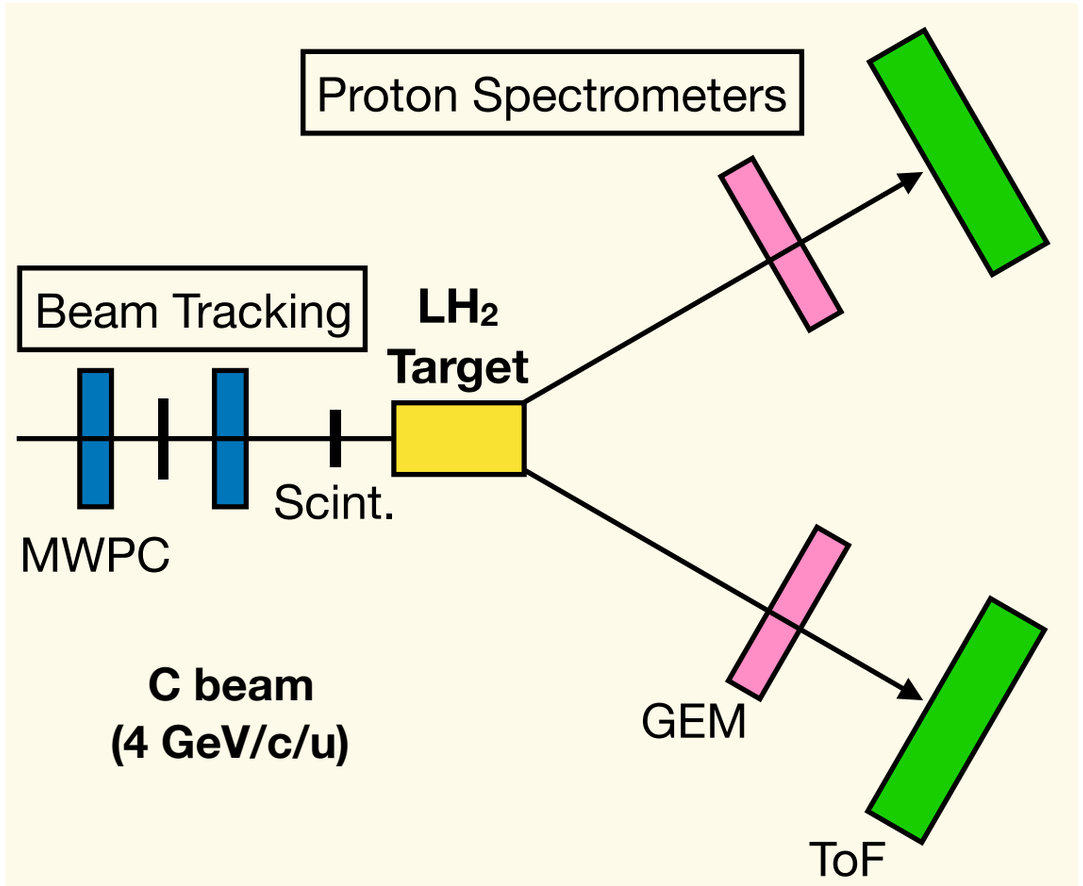


$$\beta = \frac{x}{c_{\text{air}} \cdot \text{ToF}}$$

$$|\vec{p}_1| = \frac{m_p}{\sqrt{1/\beta^2 - 1}}$$

$$\vec{p}_{\text{miss}} = \vec{p}_1 + \vec{p}_2 - \vec{p}_{\text{beam}}$$

QFS tagging



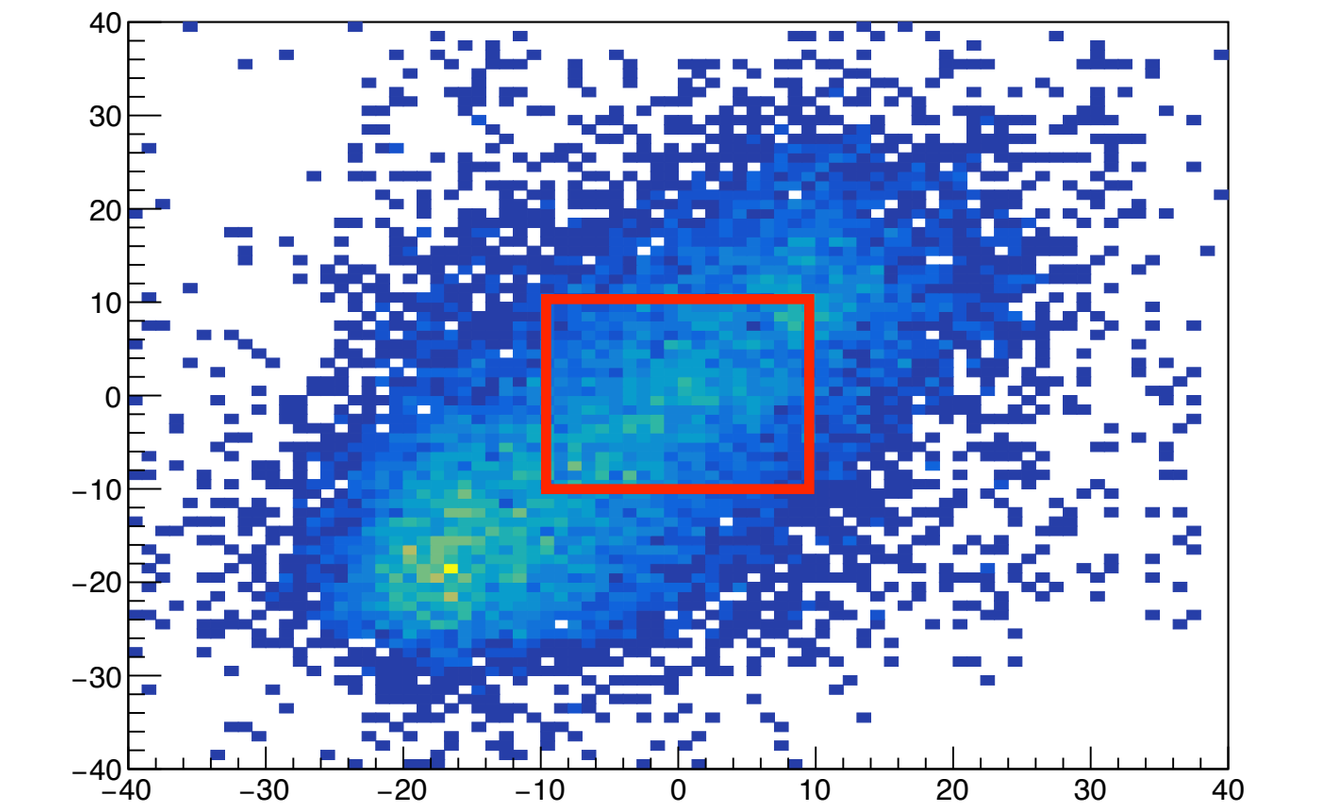
$$\beta = \frac{x}{c_{\text{air}} \cdot \text{ToF}}$$

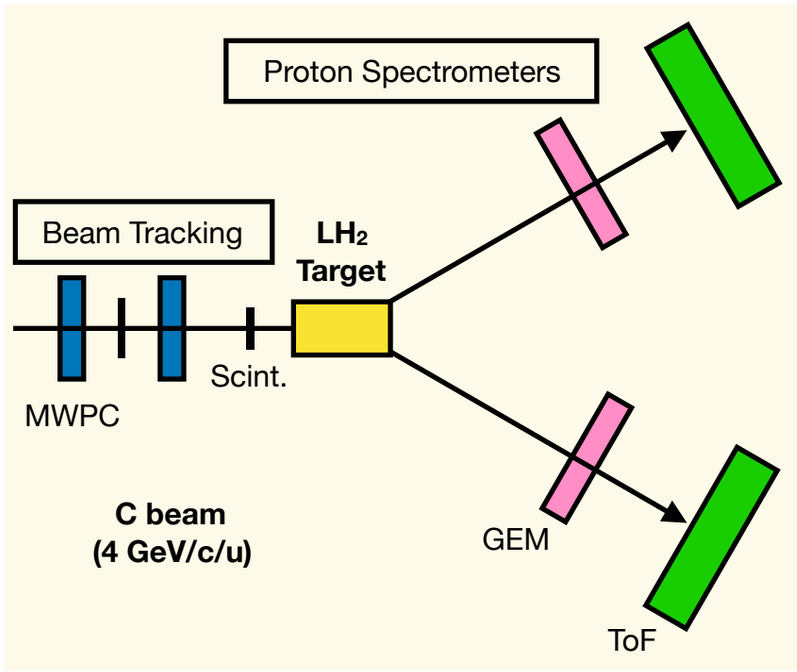
$$|\vec{p}_1| = \frac{m_p}{\sqrt{1/\beta^2 - 1}}$$

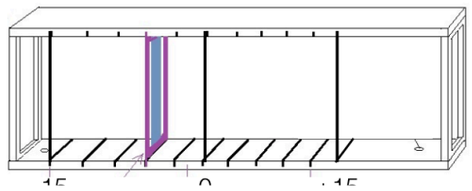
$$\vec{p}_{\text{miss}} = \vec{p}_1 + \vec{p}_2 - \vec{p}_{\text{beam}}$$

- Cannot discriminate pion from proton event-by-event in arms
- Need to have precise optics (for position measurement) & timing
- Need beam vector

Target Reconstruction on Production Data (GEMs)



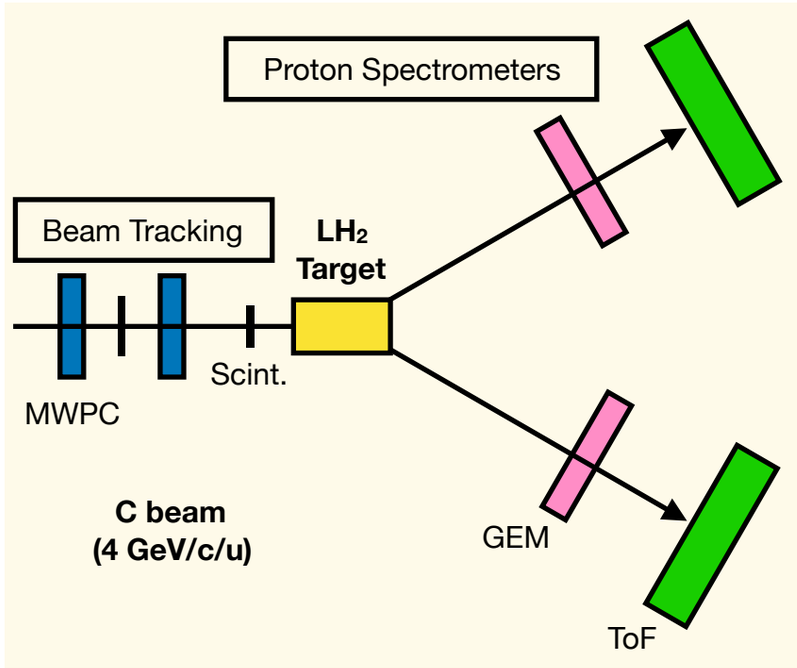




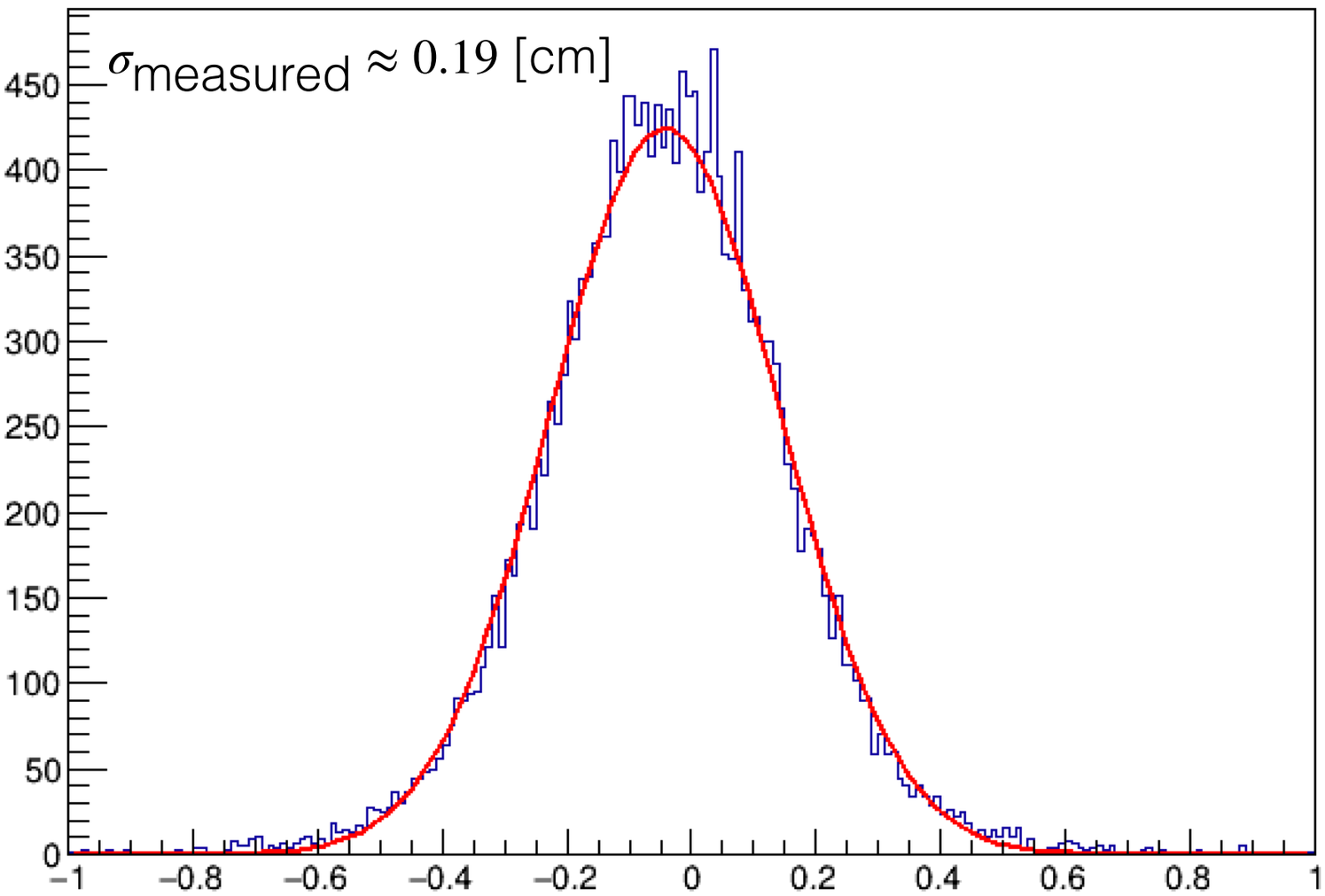
by E. Segarra

z_{target} [cm]

Extracting Beam Vector (all 4 MWPCs)



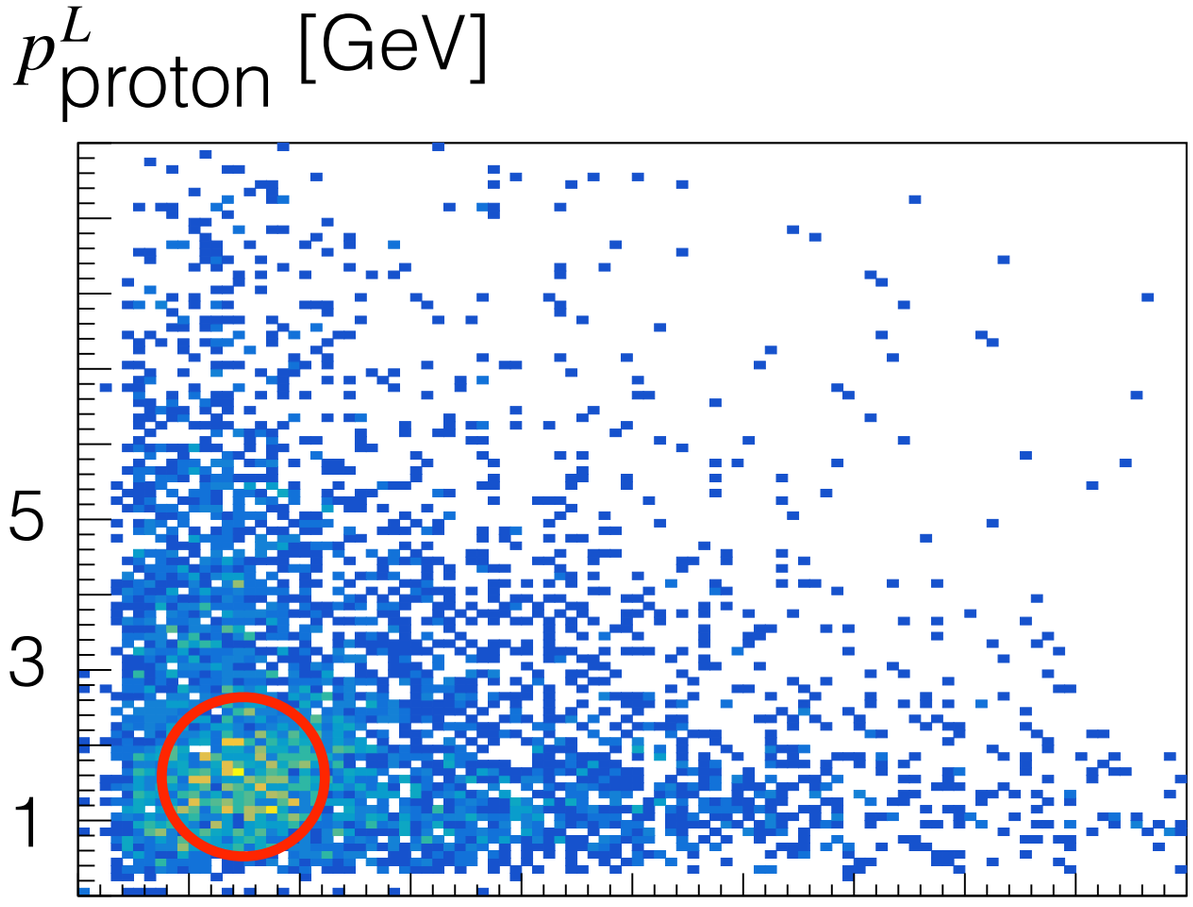
(Track Projection - Measured Hit)

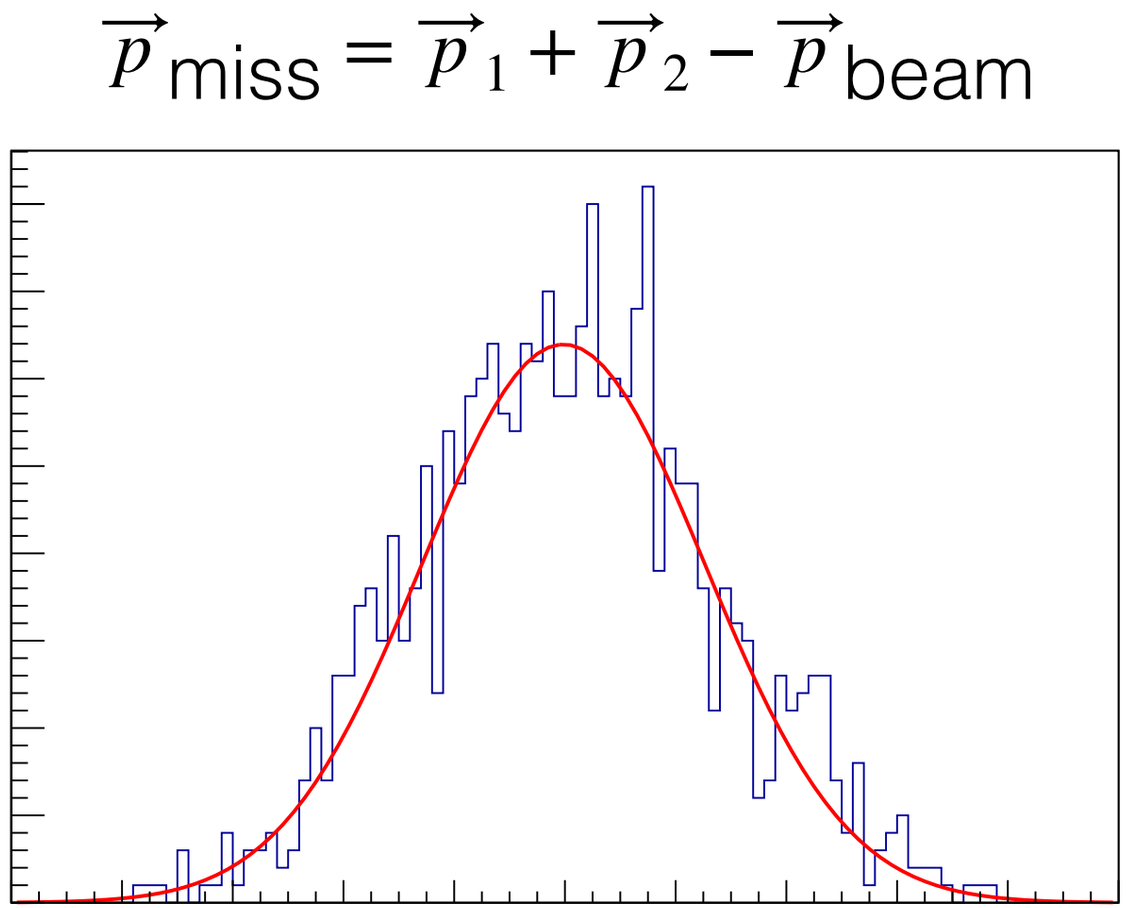


$\left(x_{\text{projected}} - x_{\text{measured}}\right)$ [cm]

by E. Segarra

Looking at the (p,2p) reaction

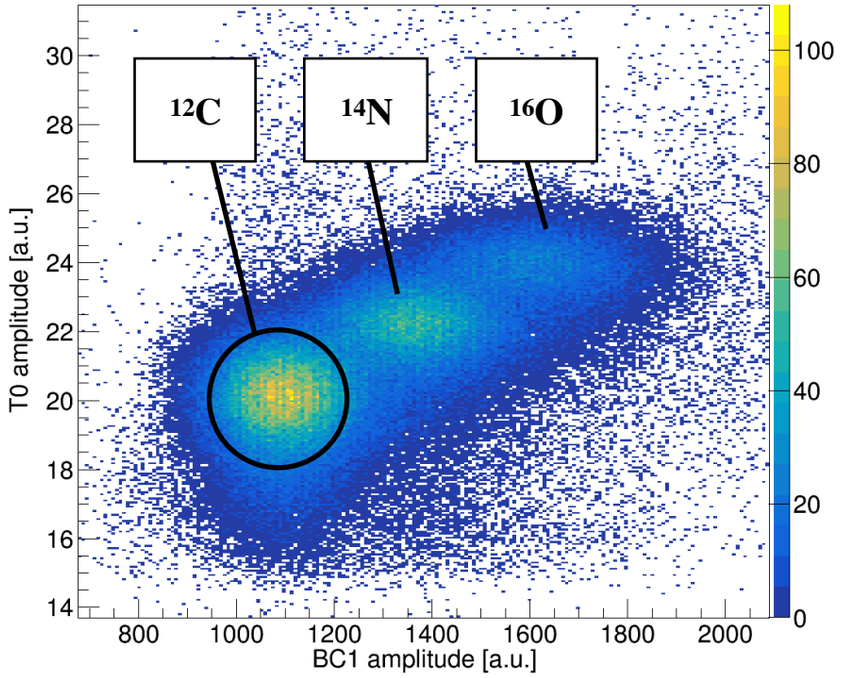




by E. Segarra

Identification of the residual system

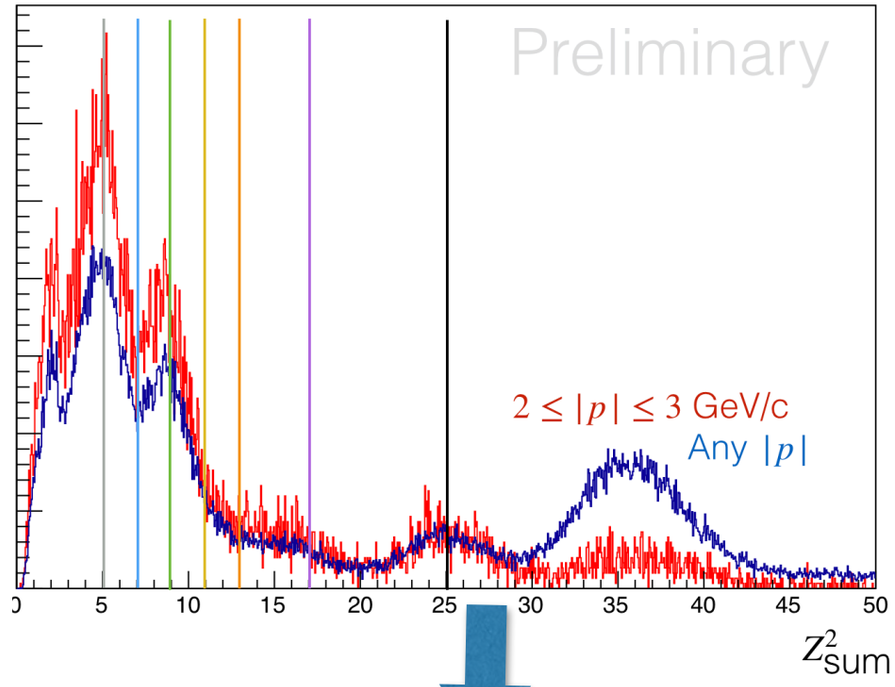
Incident beam



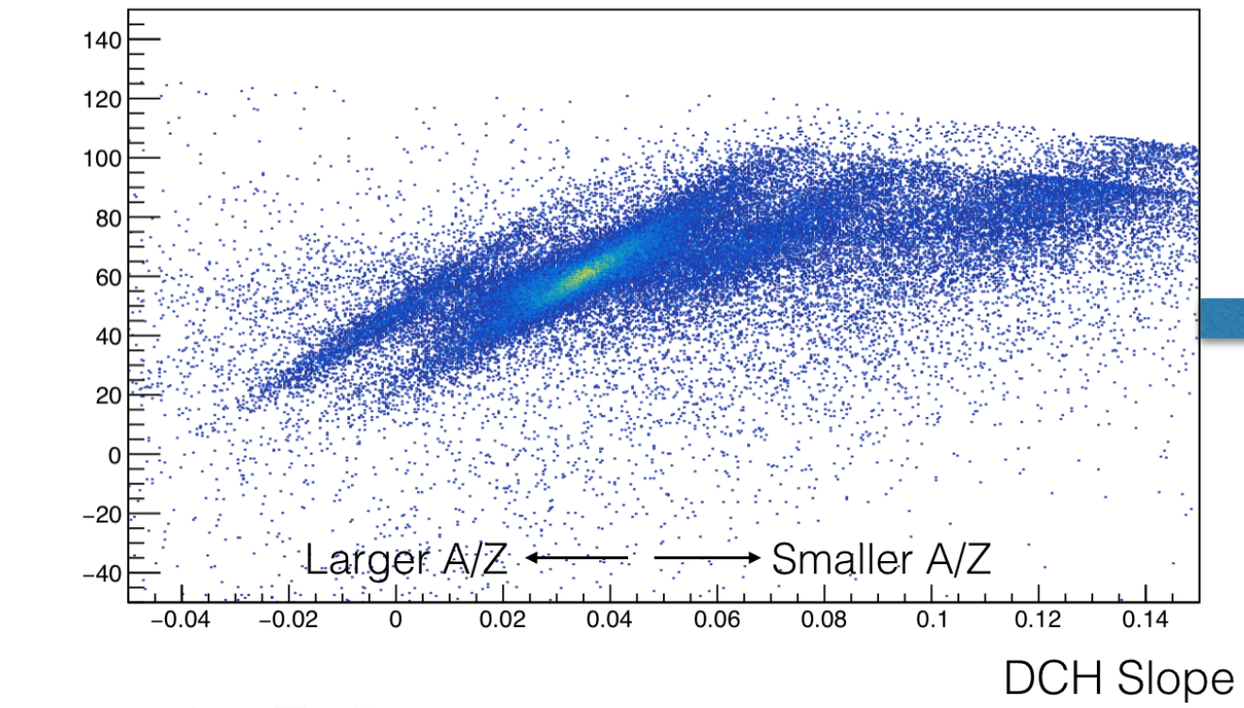
Z after the target (BC3 & BC4)

$^{12}C(p,2p)^{11}_{5}X$

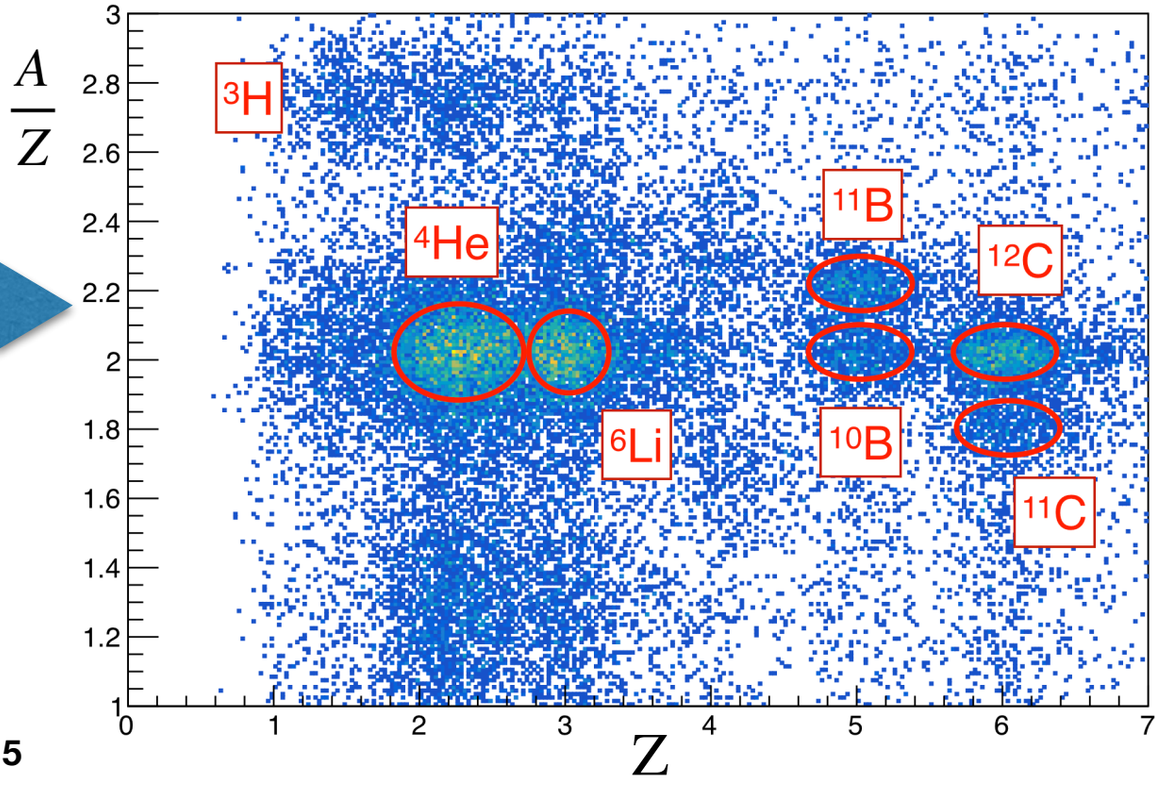
Possible Z^2_{sum} of X
25
17
13
11
9
7
5



Bρ in DCH



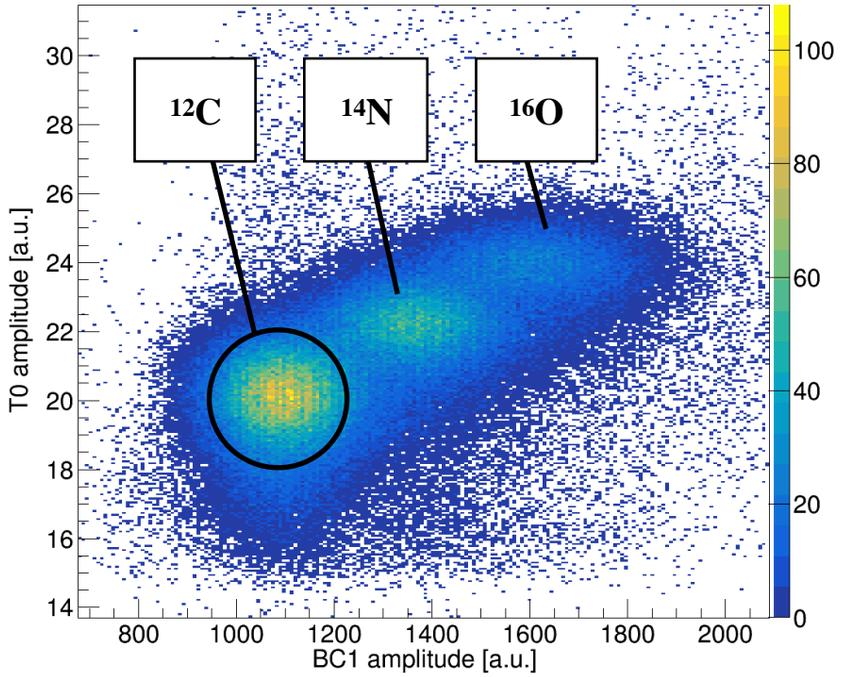
Combined PID of the fragments



by E. Segarra

Identification of the residual system

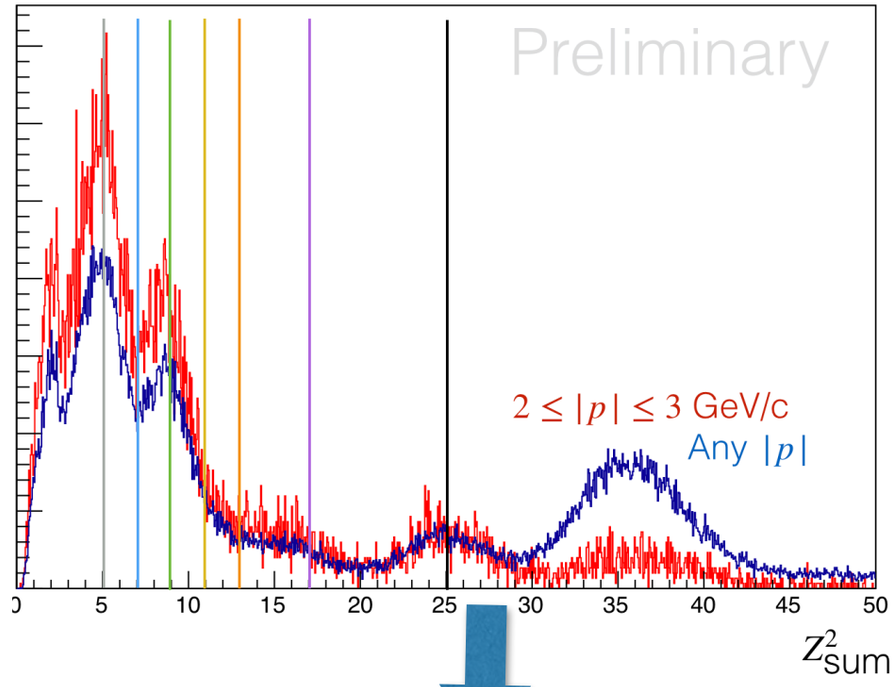
Incident beam



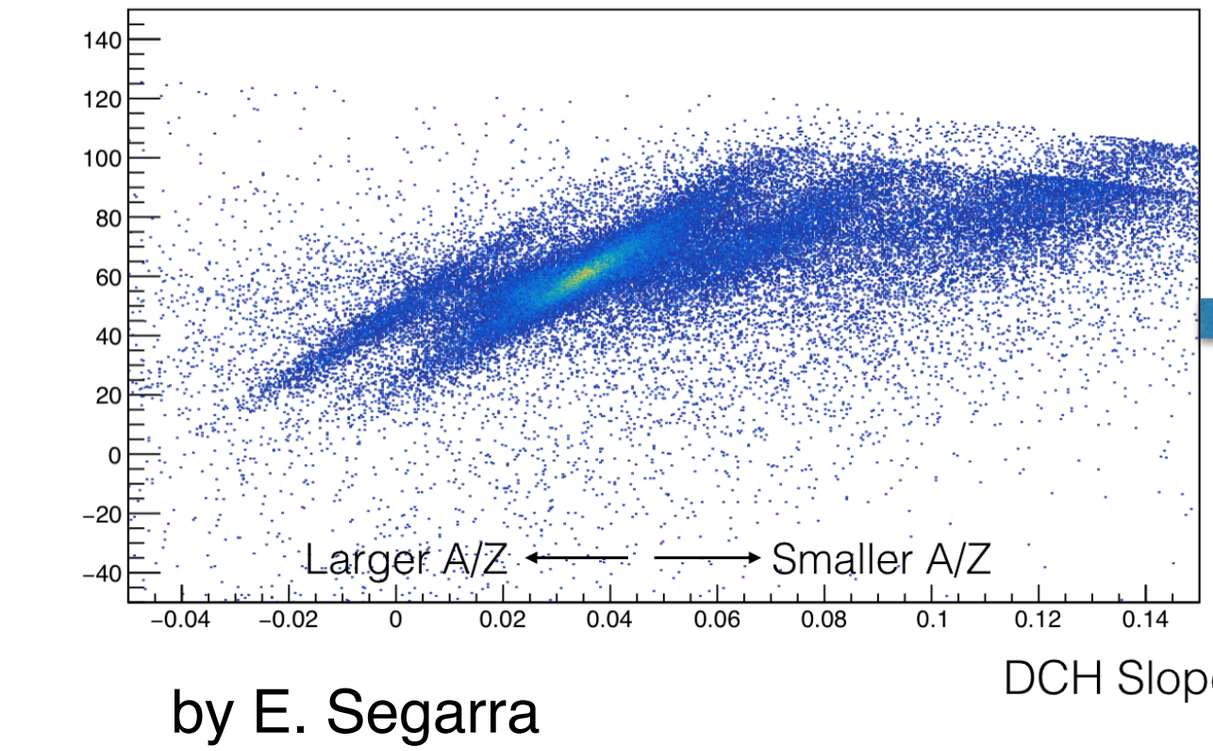
Z after the target (BC3 & BC4)

$^{12}C(p,2p)^{11}_{5}X$

Possible Z^2_{sum} of X
25
17
13
11
9
7
5

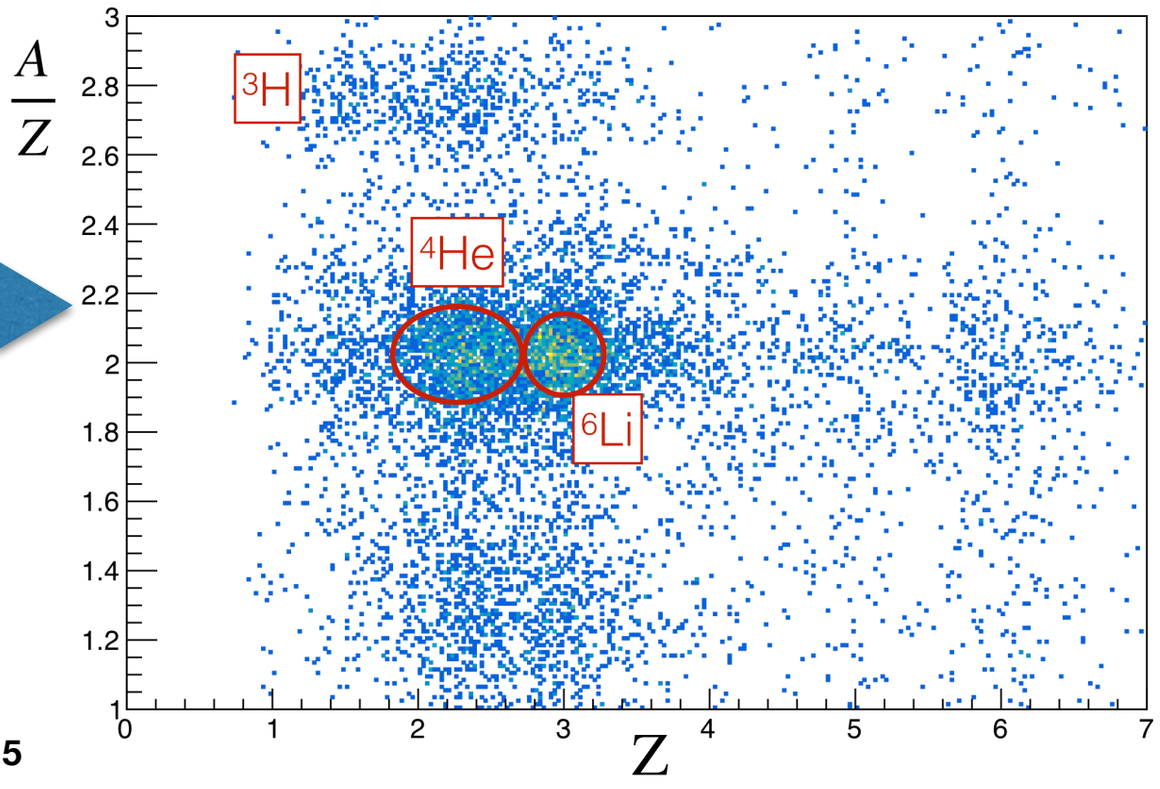


Bρ in DCH

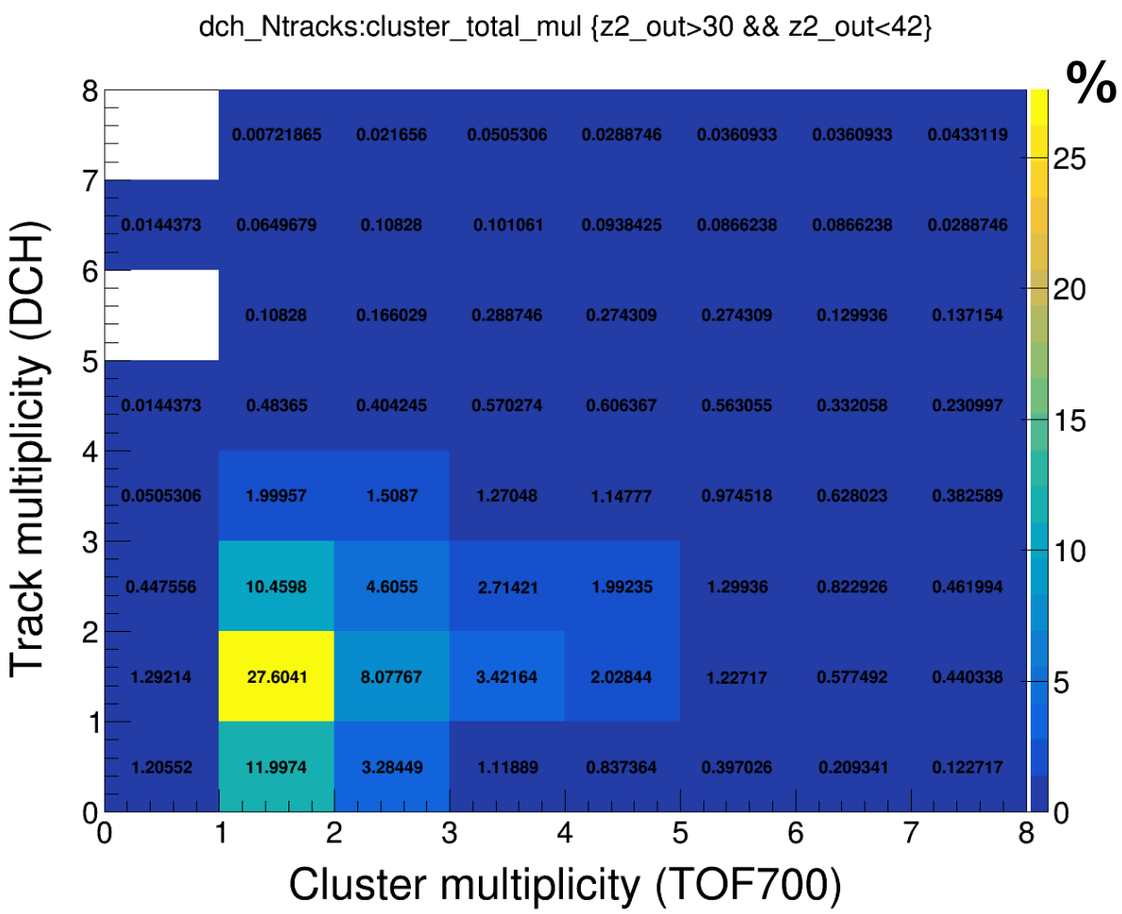


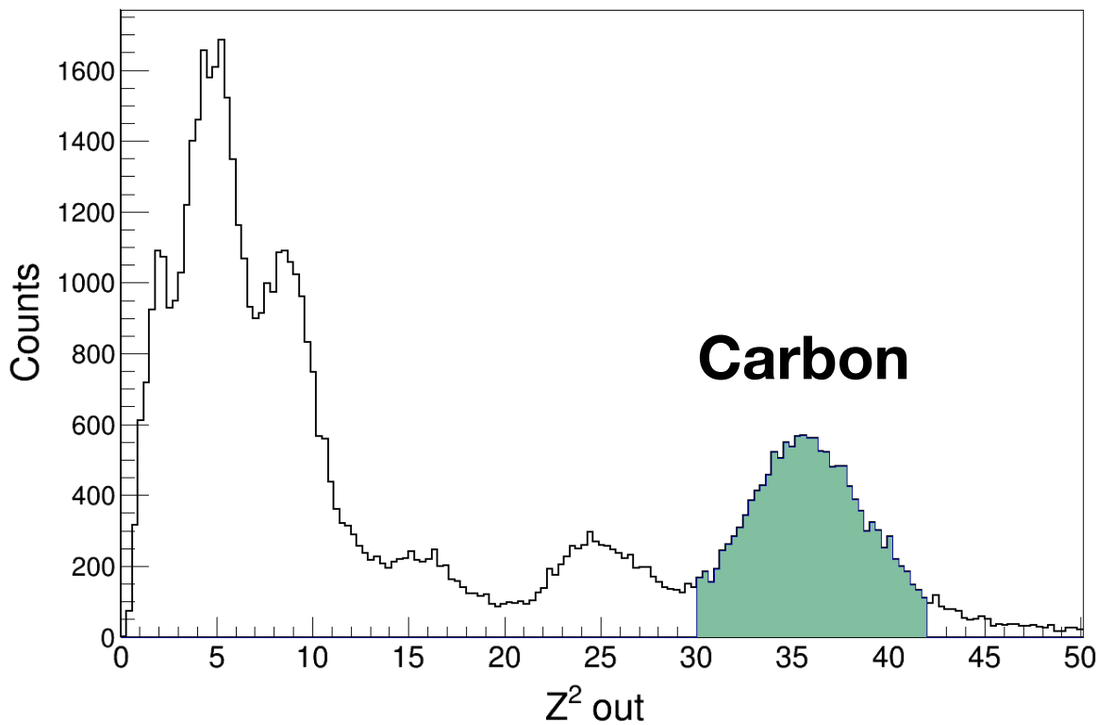
by E. Segarra

Combined PID of the fragments (2 tracks)

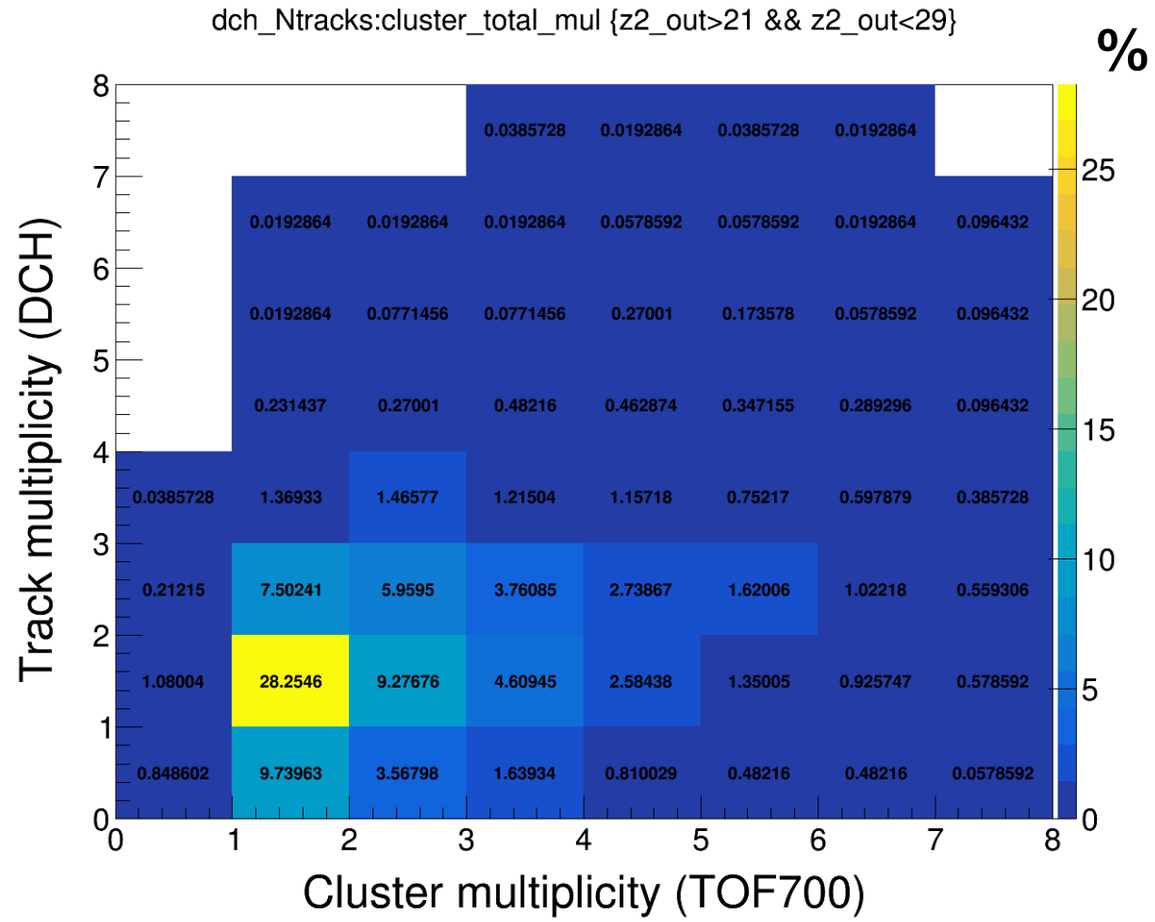


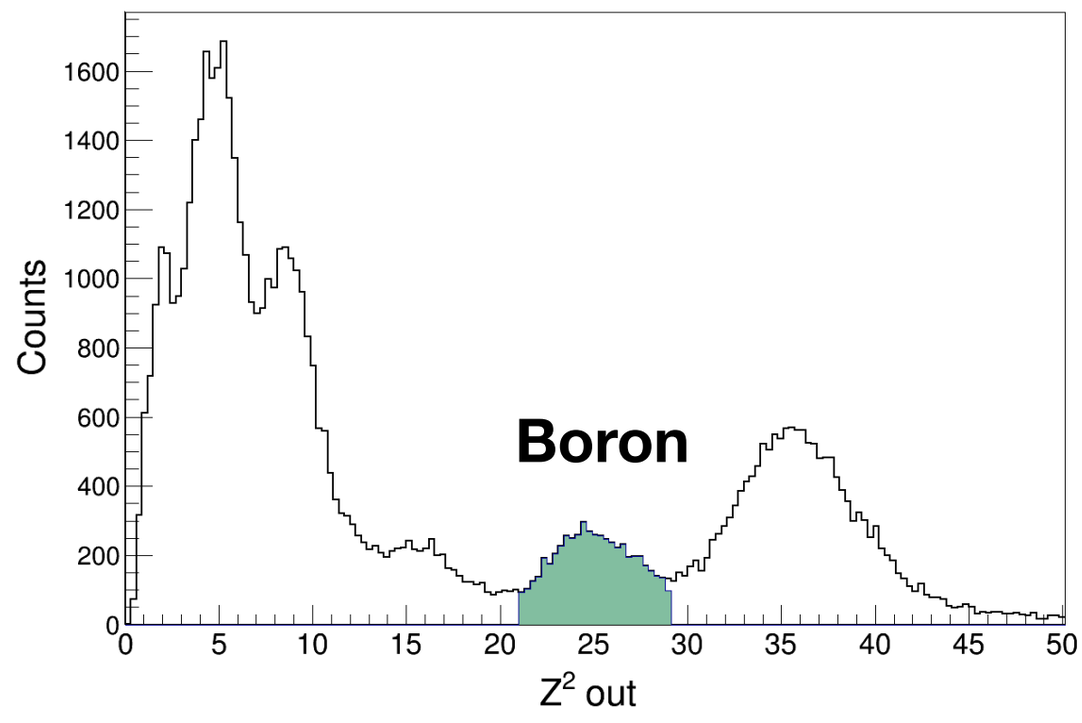
Z=6 out


dch_Ntracks:cluster_total_mul {z2_out>30 && z2_out<42}
Track multiplicity (DCH)
Cluster multiplicity (TOF700)
%
0.00721865 0.021656 0.0505306 0.0288746 0.0360933 0.0360933 0.0433119
0.0144373 0.0649679 0.10828 0.101061 0.0938425 0.0866238 0.0866238 0.0288746
0.10828 0.166029 0.288746 0.274309 0.274309 0.129936 0.137154
0.0144373 0.48365 0.404245 0.570274 0.606367 0.563055 0.332058 0.230997
0.0505306 1.99957 1.5087 1.27048 1.14777 0.974518 0.628023 0.382589
0.447556 10.4598 4.6055 2.71421 1.99235 1.29936 0.822926 0.461994
1.29214 27.6041 8.07767 3.42164 2.02844 1.22717 0.577492 0.440338
1.20552 11.9974 3.28449 1.11889 0.837364 0.397026 0.209341 0.122717

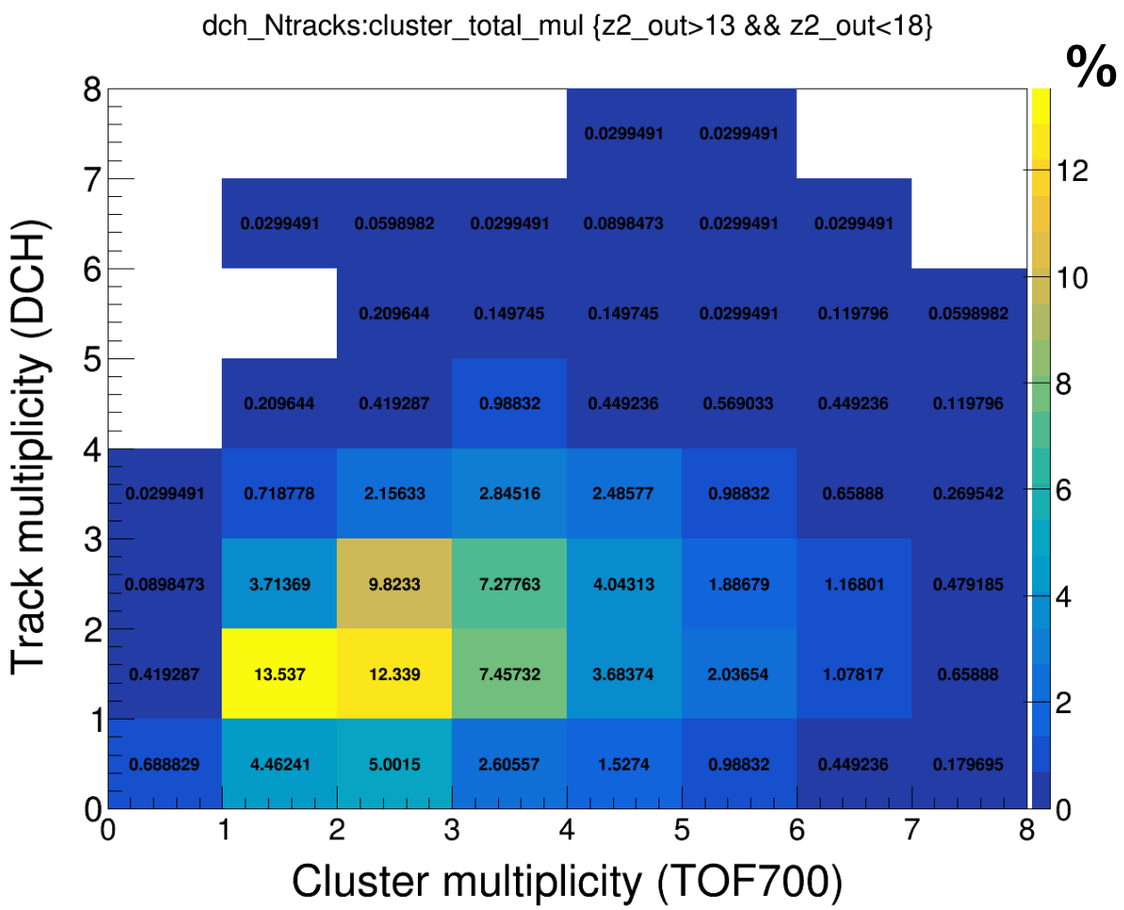

Counts
Carbon
Z² out

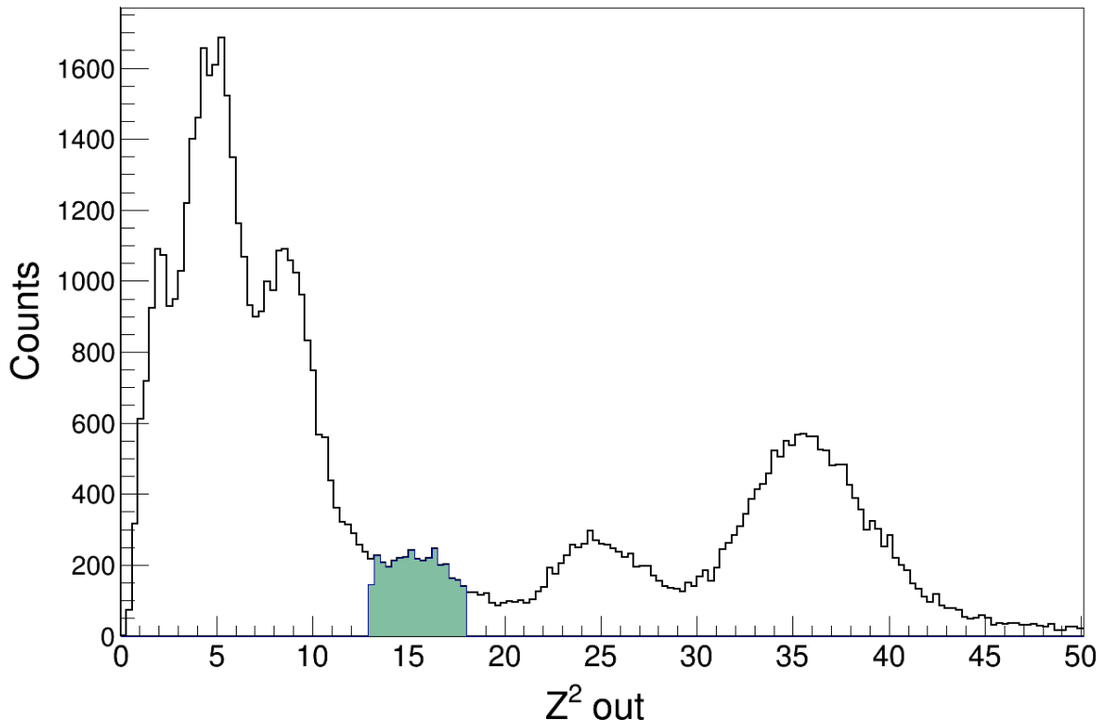
Z=5 out


dch_Ntracks:cluster_total_mul {z2_out>21 && z2_out<29}
Track multiplicity (DCH)
Cluster multiplicity (TOF700)
%
0.0385728 0.0192864 0.0385728 0.0192864
0.0192864 0.0192864 0.0192864 0.0578592 0.0578592 0.0192864 0.096432
0.0192864 0.0771456 0.0771456 0.27001 0.173578 0.0578592 0.096432
0.231437 0.27001 0.48216 0.462874 0.347155 0.289296 0.096432
0.0385728 1.36933 1.46577 1.21504 1.15718 0.75217 0.597879 0.385728
0.21215 7.50241 5.9595 3.76085 2.73867 1.62006 1.02218 0.559306
1.08004 28.2546 9.27676 4.60945 2.58438 1.35005 0.925747 0.578592
0.848602 9.73963 3.56798 1.63934 0.810029 0.48216 0.48216 0.0578592

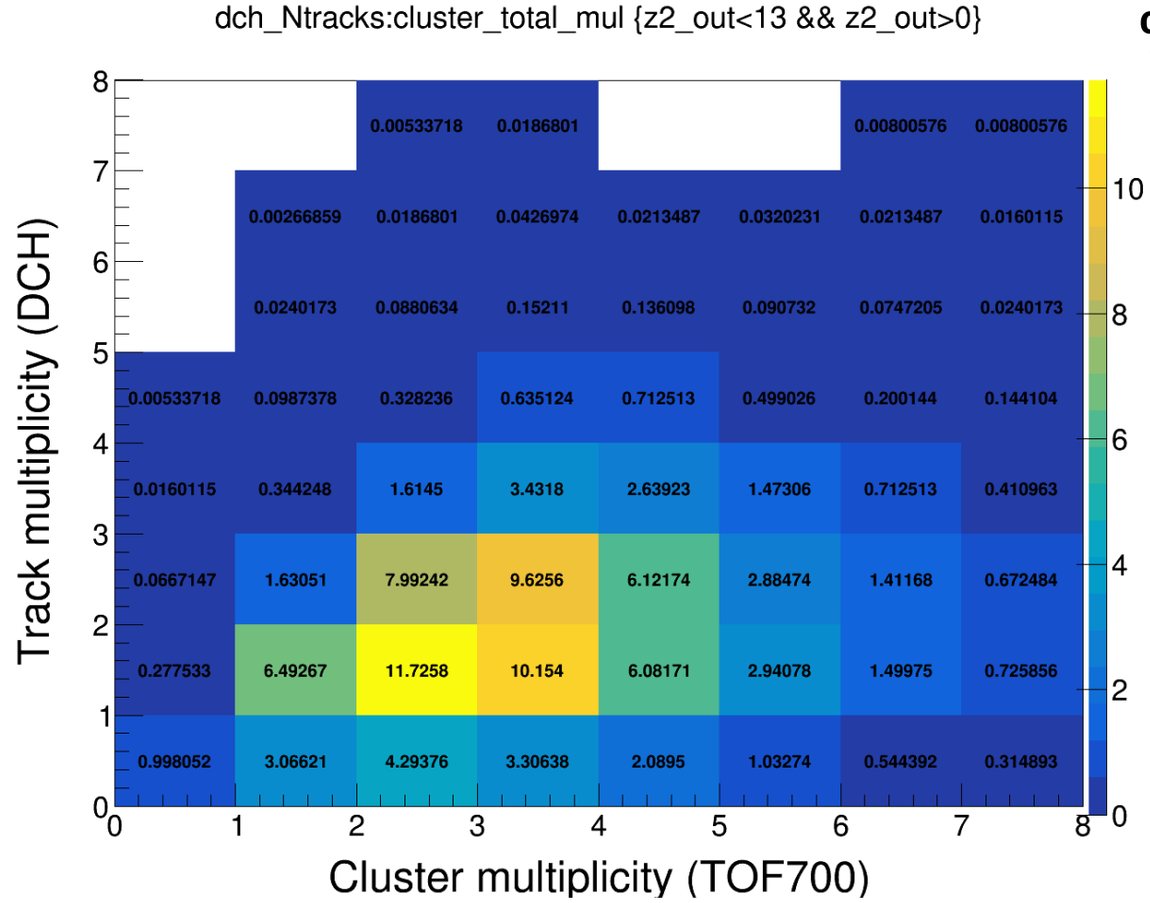

Counts
Boron
Z² out

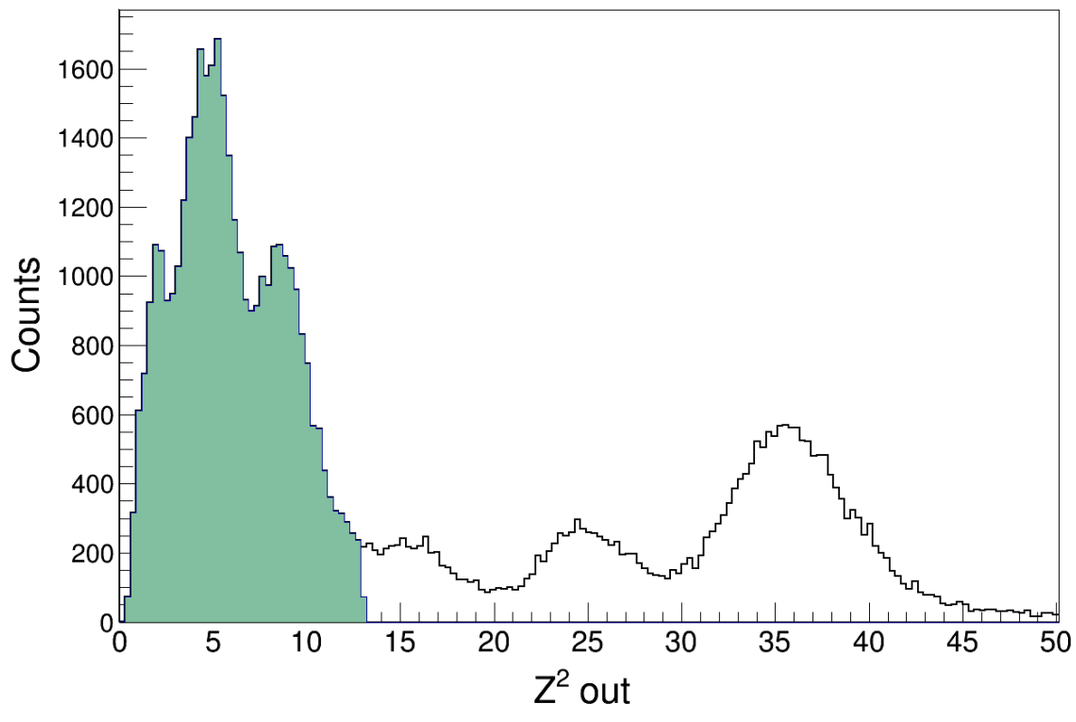
Z=4 out


dch_Ntracks:cluster_total_mul {z2_out>13 && z2_out<18}
%
Track multiplicity (DCH)
Cluster multiplicity (TOF700)
0.0299491 0.0299491
0.0299491 0.0598982 0.0299491 0.0898473 0.0299491 0.0299491
0.209644 0.149745 0.149745 0.0299491 0.119796 0.0598982
0.209644 0.419287 0.98832 0.449236 0.569033 0.449236 0.119796
0.0299491 0.718778 2.15633 2.84516 2.48577 0.98832 0.65888 0.269542
0.0898473 3.71369 9.8233 7.27763 4.04313 1.88679 1.16801 0.479185
0.419287 13.537 12.339 7.45732 3.68374 2.03654 1.07817 0.65888
0.688829 4.46241 5.0015 2.60557 1.5274 0.98832 0.449236 0.179695

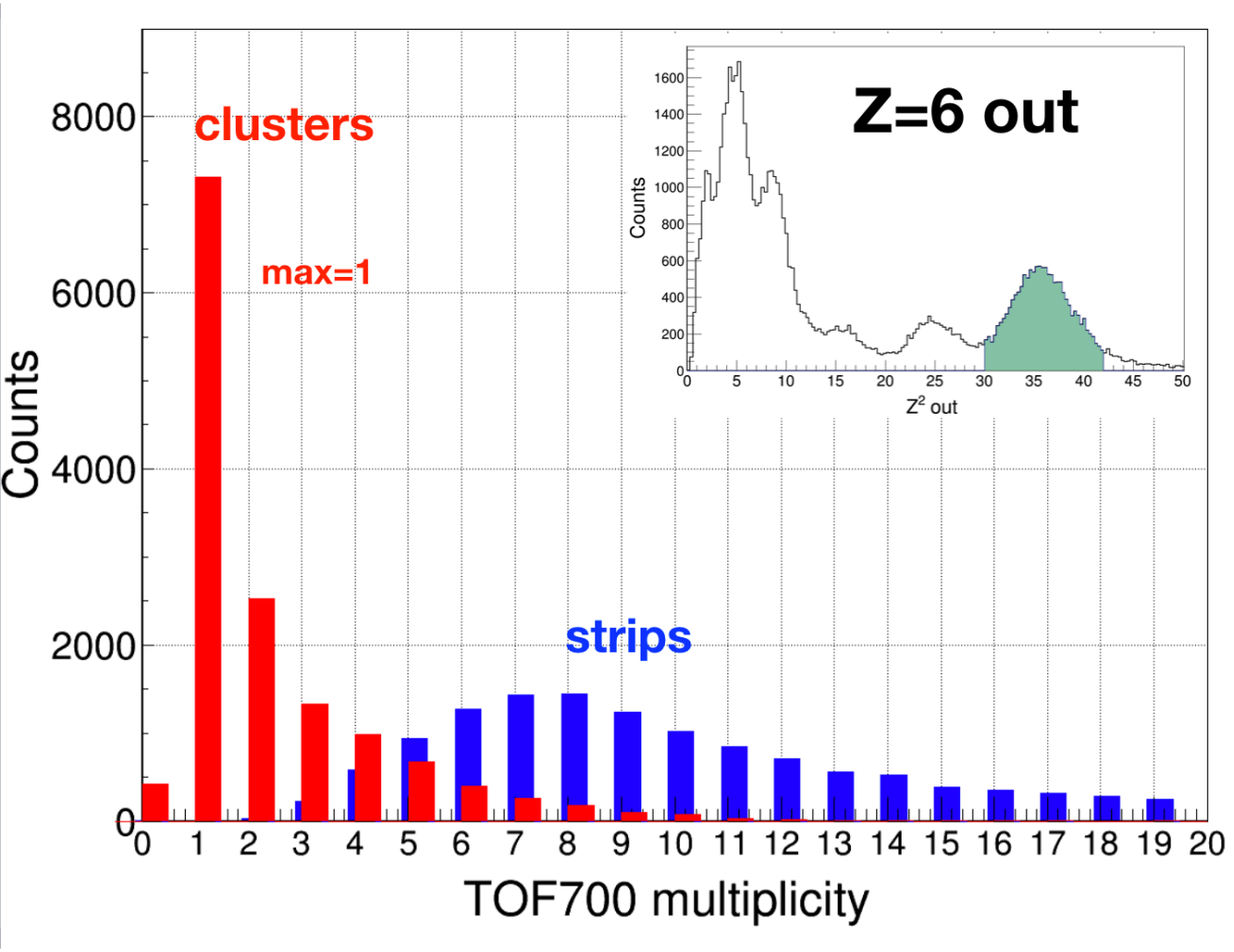

Counts
Z^2 out

Z<4 out


dch_Ntracks:cluster_total_mul {z2_out<13 && z2_out>0}
%
Track multiplicity (DCH)
Cluster multiplicity (TOF700)
0.00533718 0.0186801 0.00800576 0.00800576
0.00266859 0.0186801 0.0426974 0.0213487 0.0320231 0.0213487 0.0160115
0.0240173 0.0880634 0.15211 0.136098 0.090732 0.0747205 0.0240173
0.00533718 0.0987378 0.328236 0.635124 0.712513 0.499026 0.200144 0.144104
0.0160115 0.344248 1.6145 3.4318 2.63923 1.47306 0.712513 0.410963
0.0667147 1.63051 7.99242 9.6256 6.12174 2.88474 1.41168 0.672484
0.277533 6.49267 11.7258 10.154 6.08171 2.94078 1.49975 0.725856
0.998052 3.06621 4.29376 3.30638 2.0895 1.03274 0.544392 0.314893

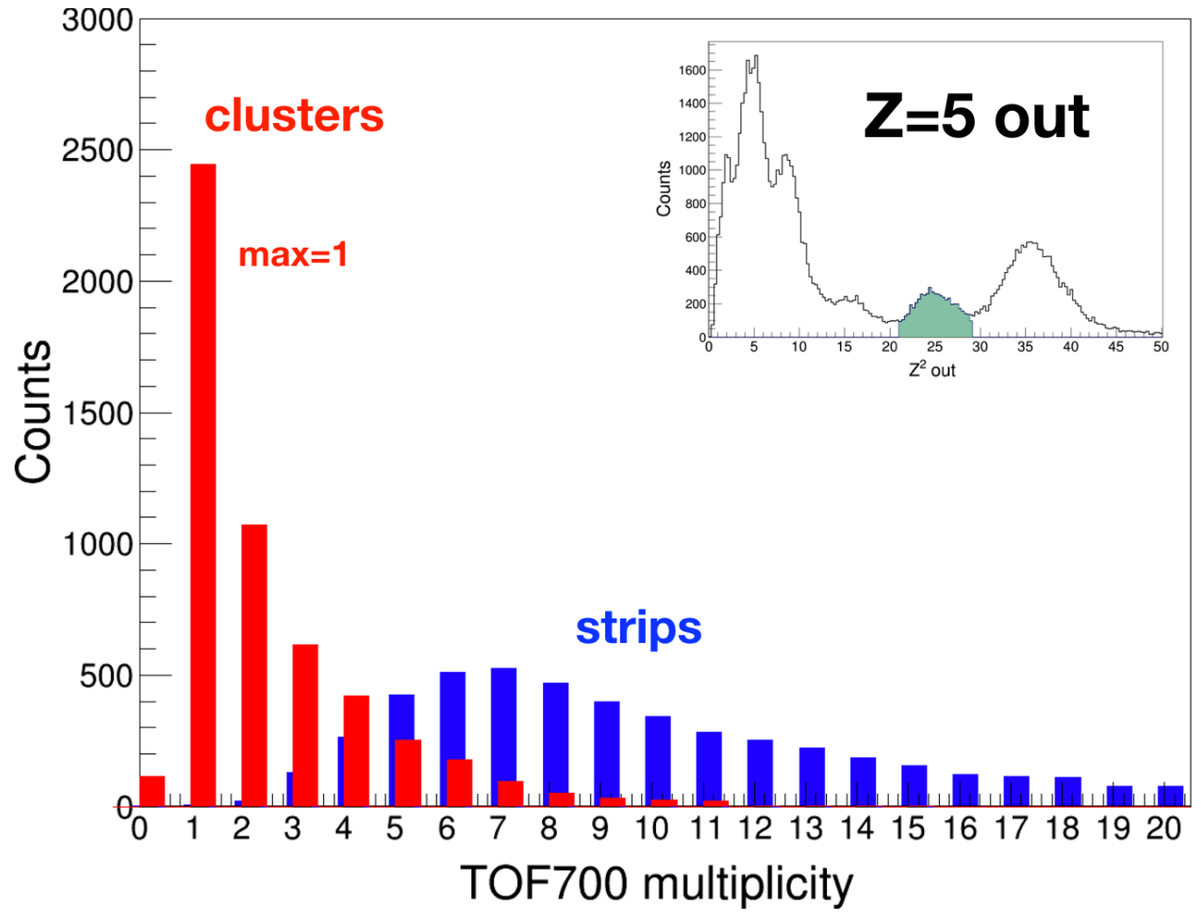

Counts
Z^2 out

Counting particle hits in TOF700



Example channel:

^{12}C (p,pn) → ^{11}C

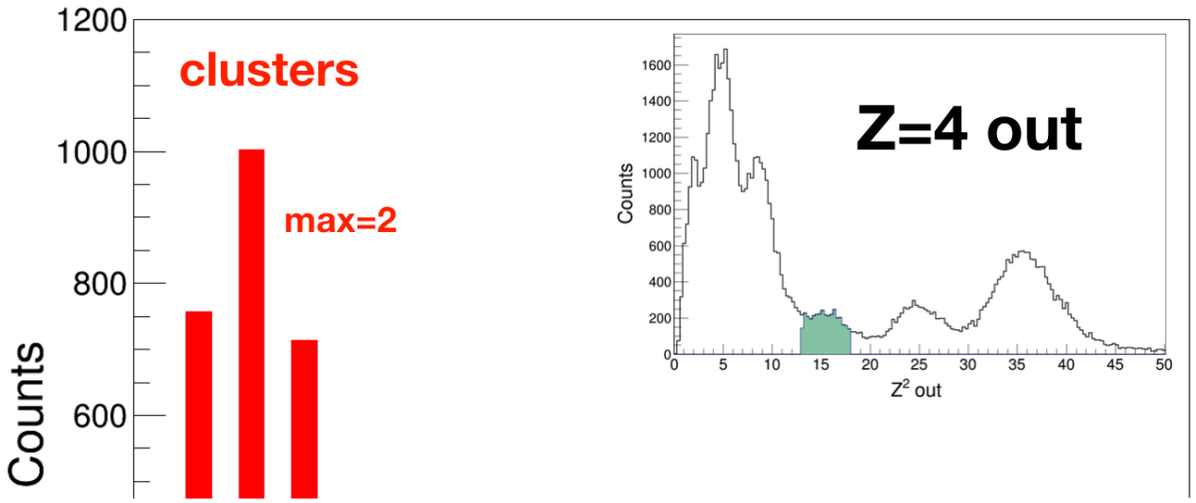


Example channel:

^{12}C (p,2p) → ^{11}B

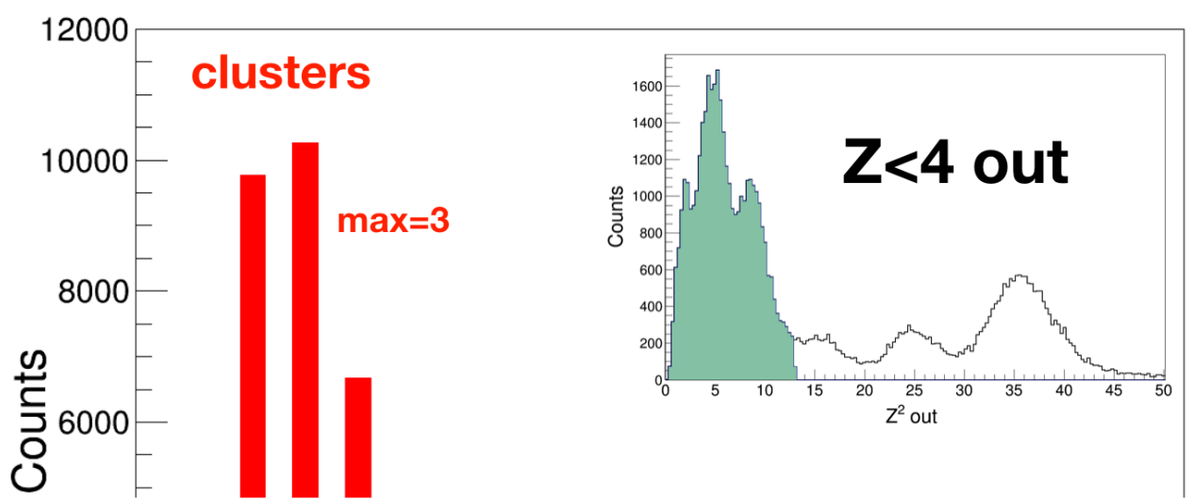
→ ^{11}B* → ^{10}B + n

Counting particle hits in TOF700



Example channel:

$^{12}C\ (p,2p) \rightarrow {}^{11}B^{*} \rightarrow {}^{9}Be + d$



Example channel:

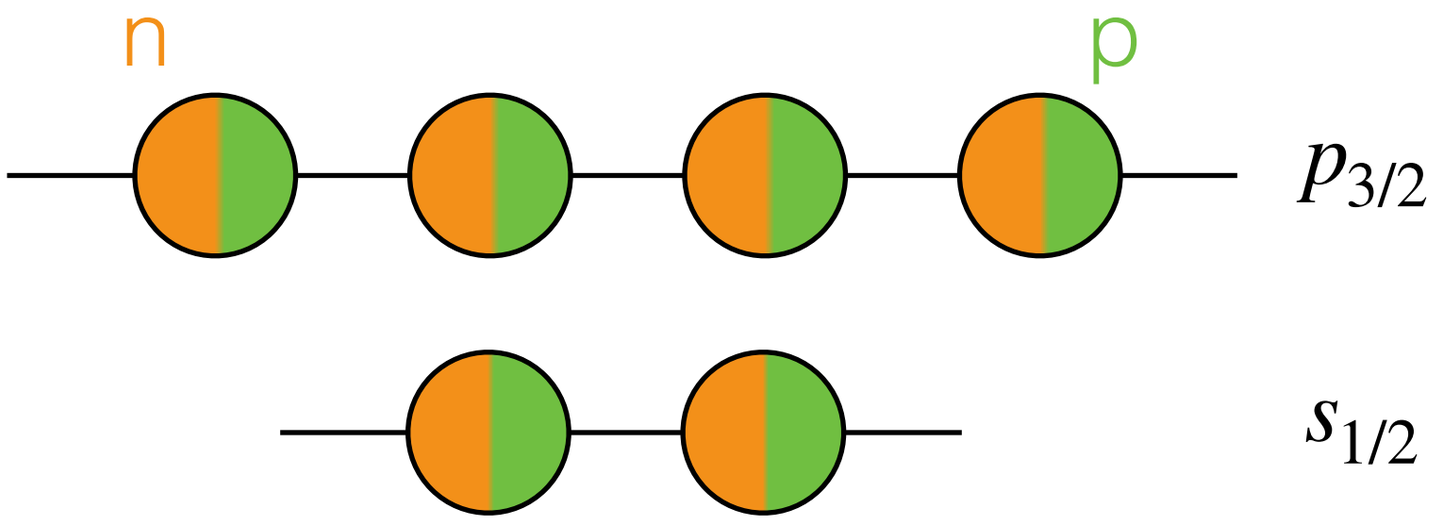
$^{12}C\ (p,2p) \rightarrow {}^{11}B^{*} \rightarrow {}^{7}Li + {}^{4}He$

$\rightarrow {}^{4}He + {}^{4}He + {}^{3}H$

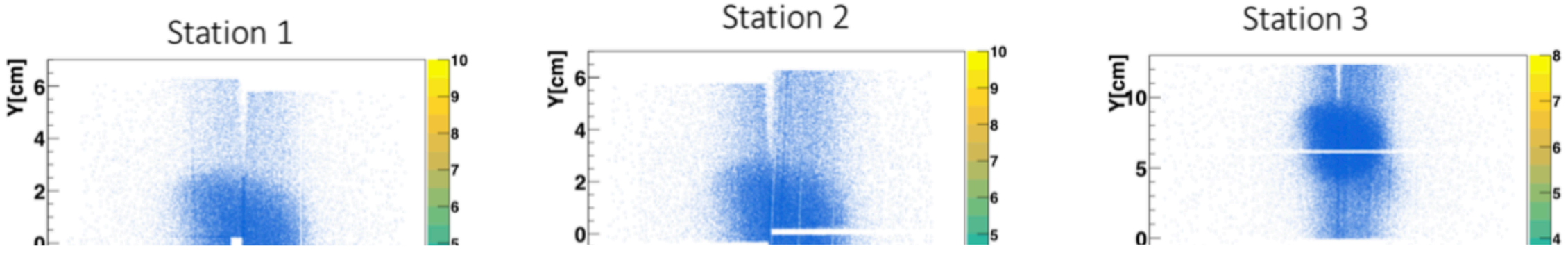
What we are moving towards next

- Integrating all of these components to identify QE and SRC knock-out events
- Continue calibrations
- Unpacking other detector systems

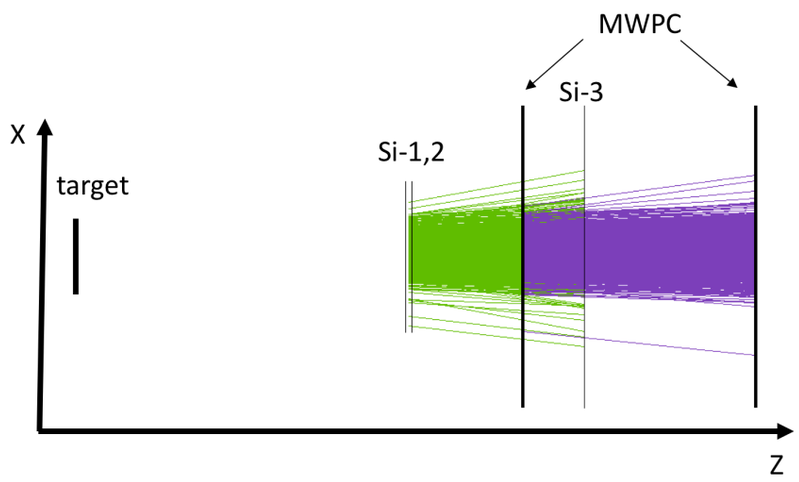
Residual system and SRC pair formation

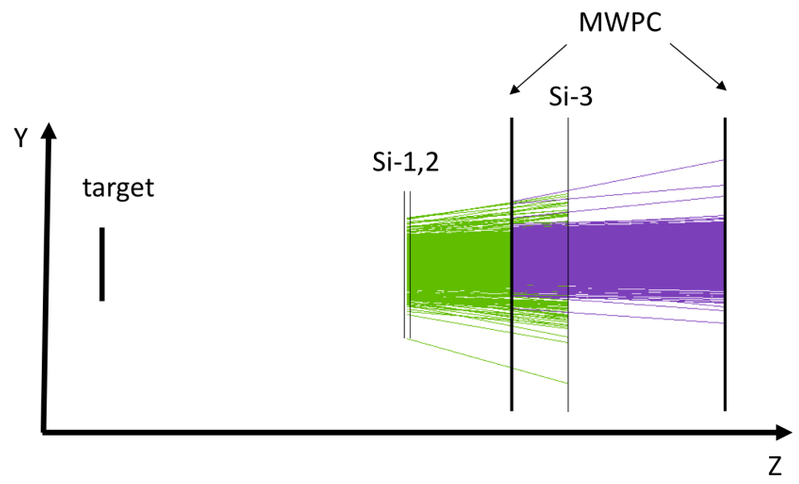


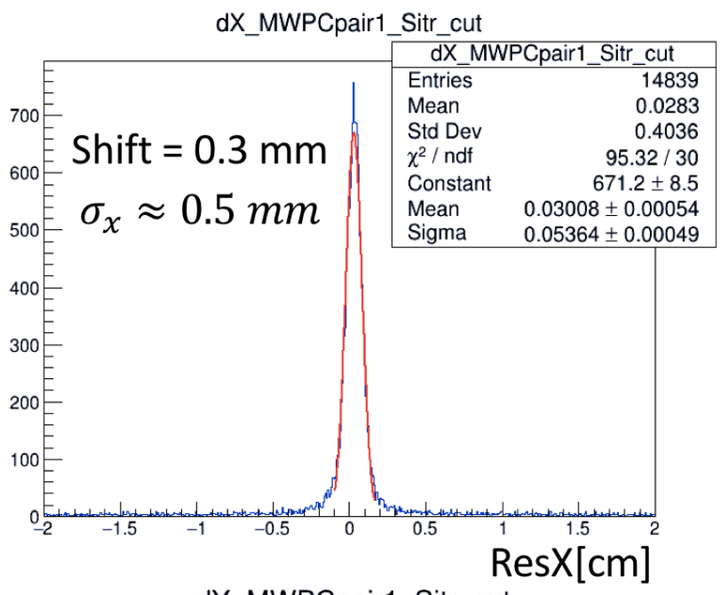
Tracking in Silicons (V. Lenivenko)

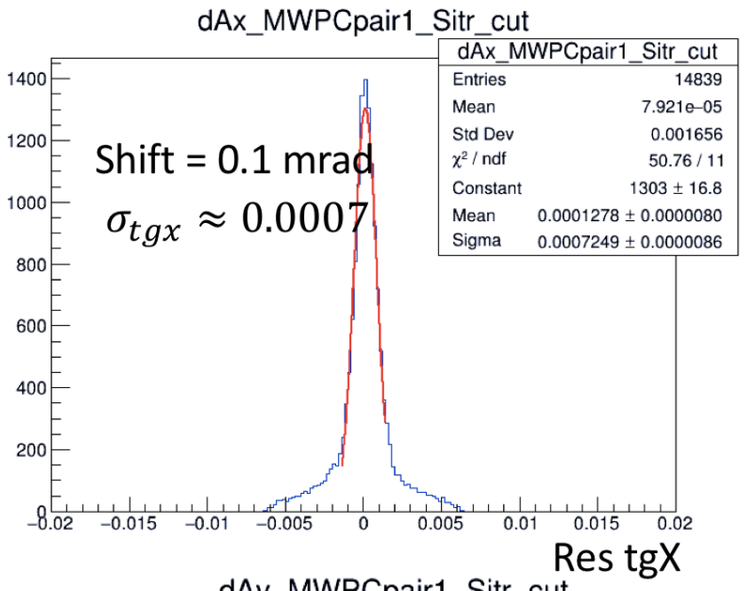


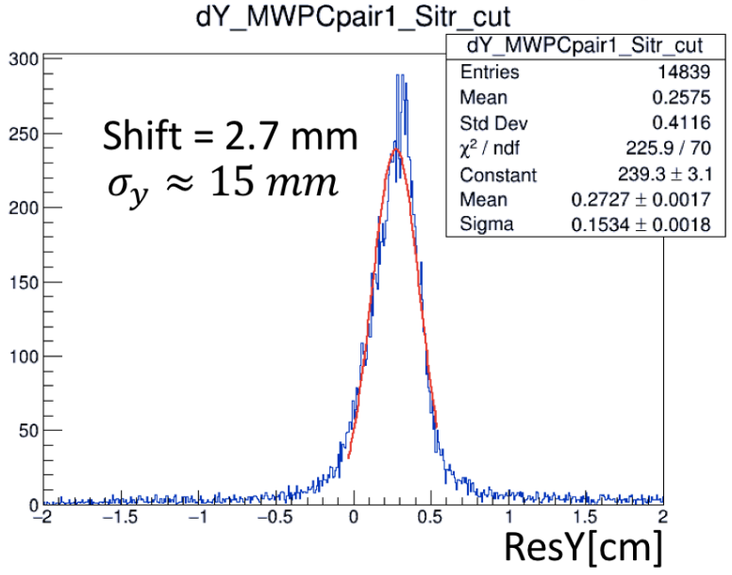
Tracking in Silicons + MWPCs (V. Lenivenko)

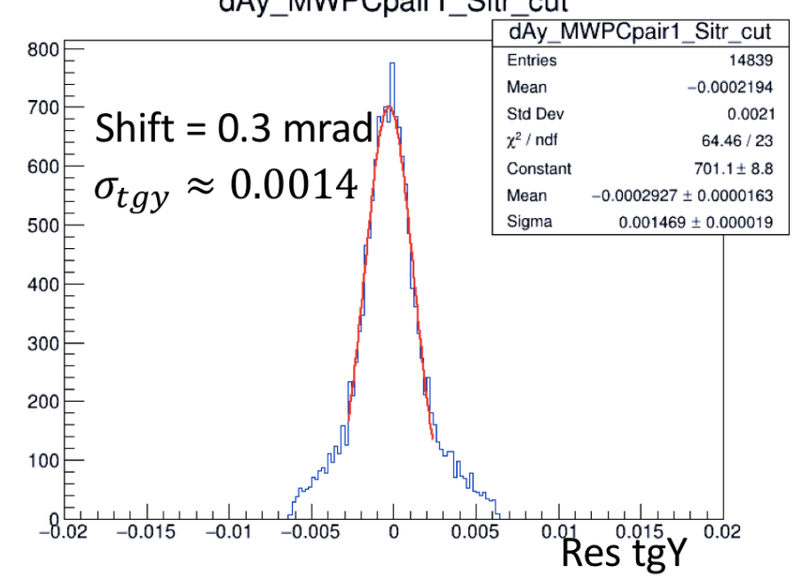




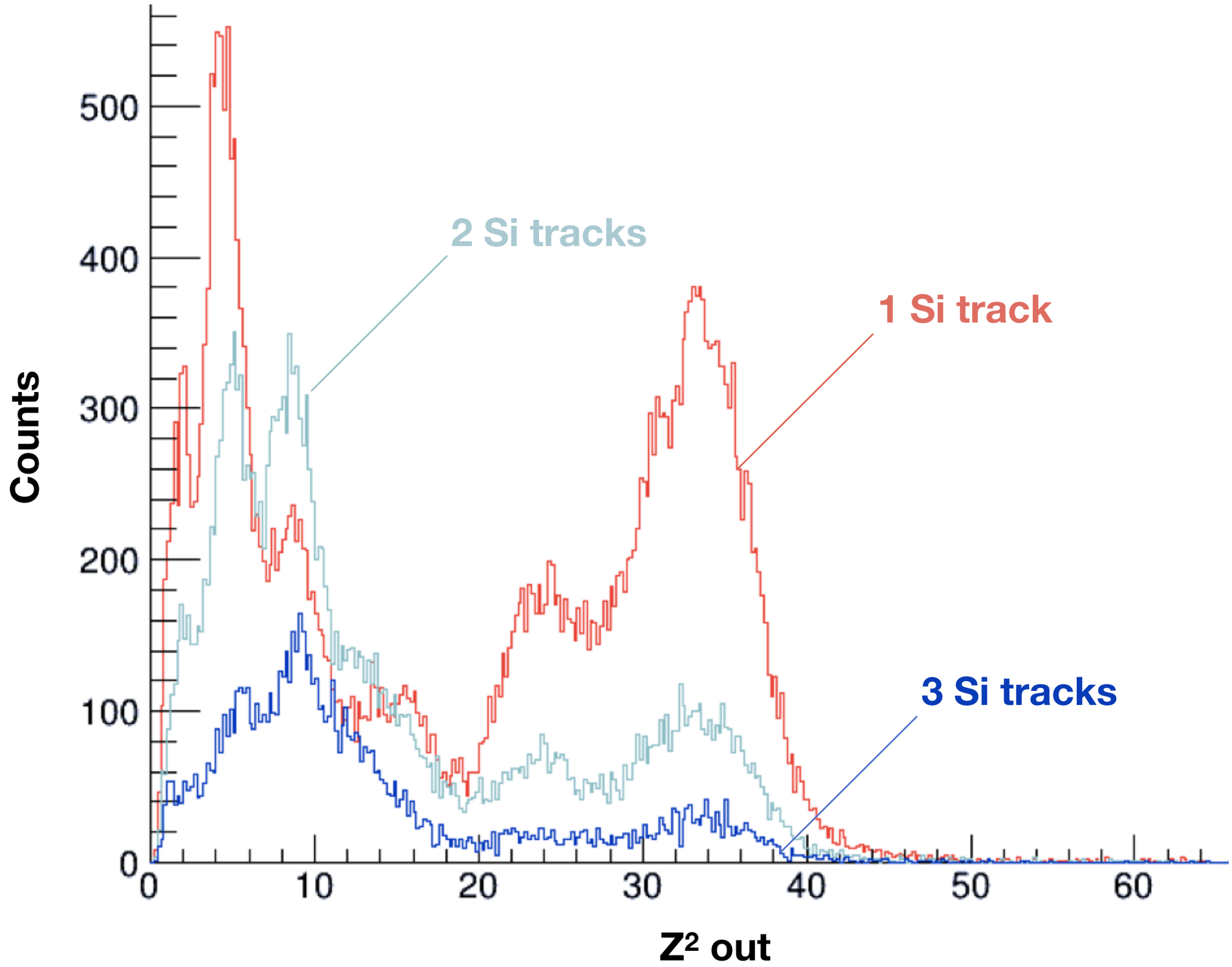








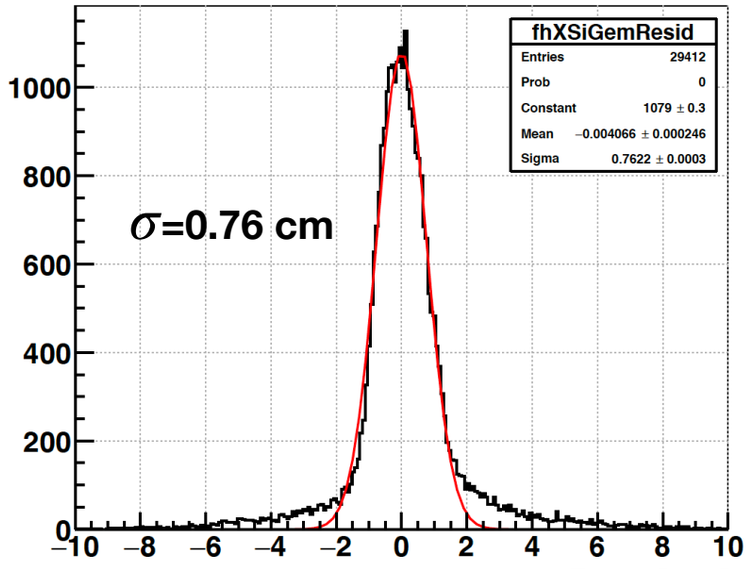
Tracking in Silicons (V. Lenivenko)

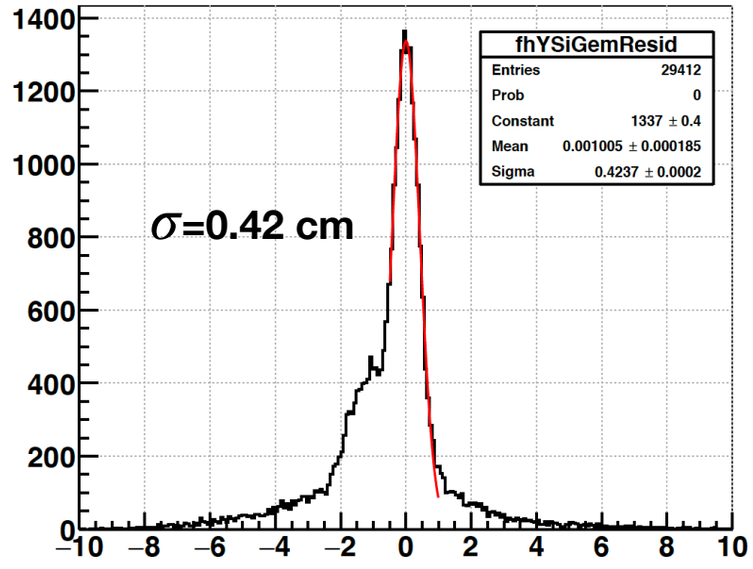


Merging tracks in different subsystems (S. Merts)

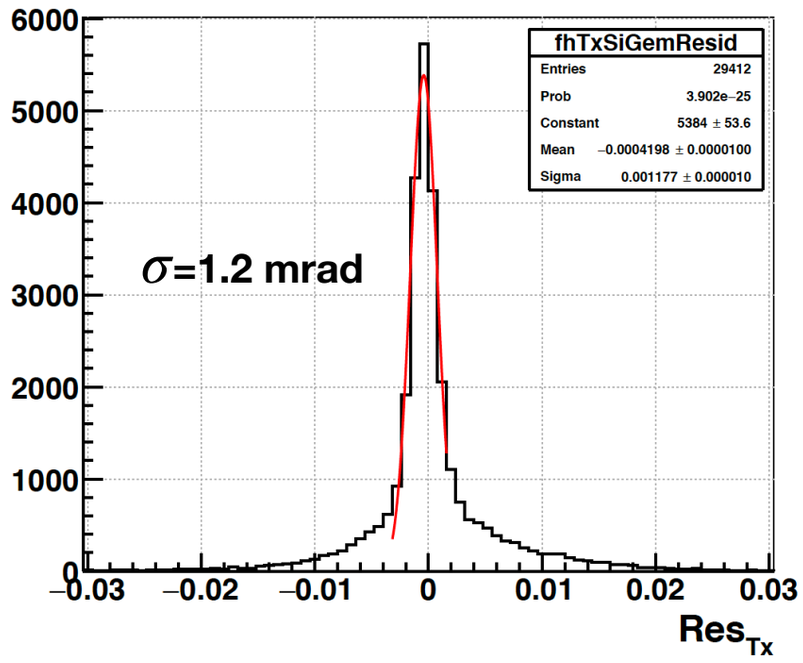
(no target, no field)

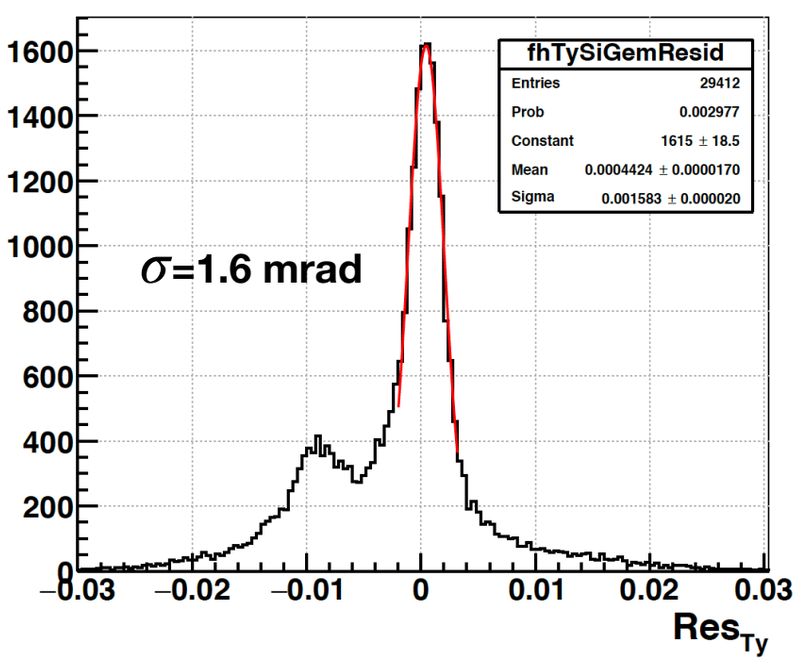
SIL+GEM coordinate residuals after alignment





SIL+GEM angle residuals after alignment

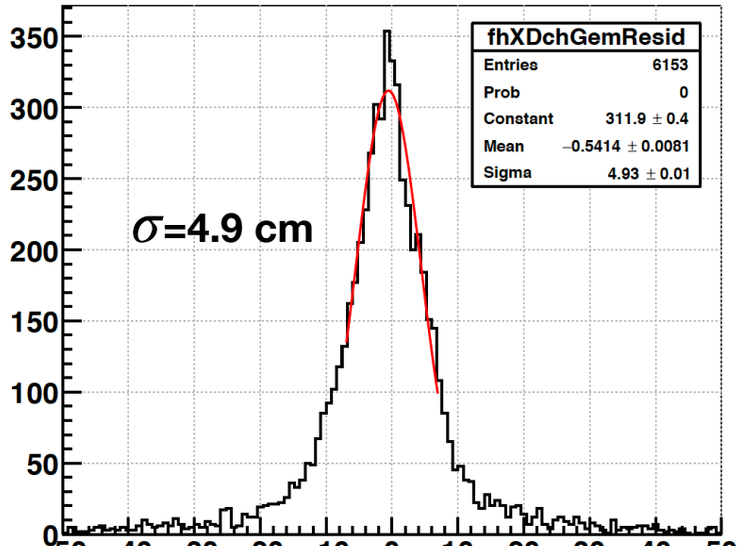


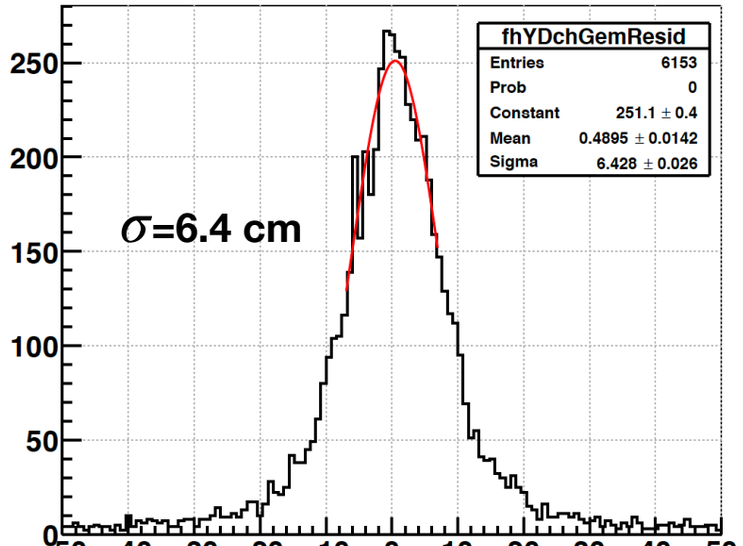


Merging tracks in different subsystems (S. Merts)

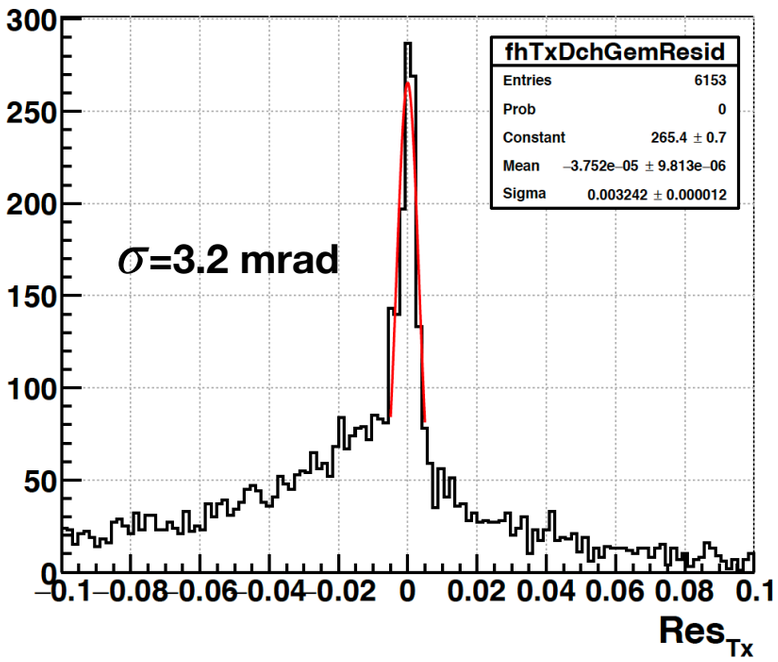
(no target, no field)

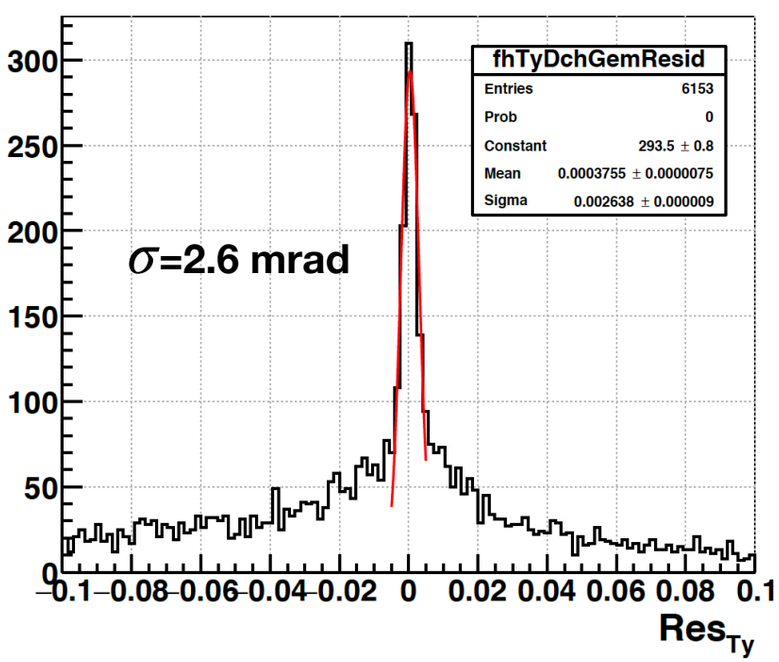
GEM+DCH coordinate residuals after alignment





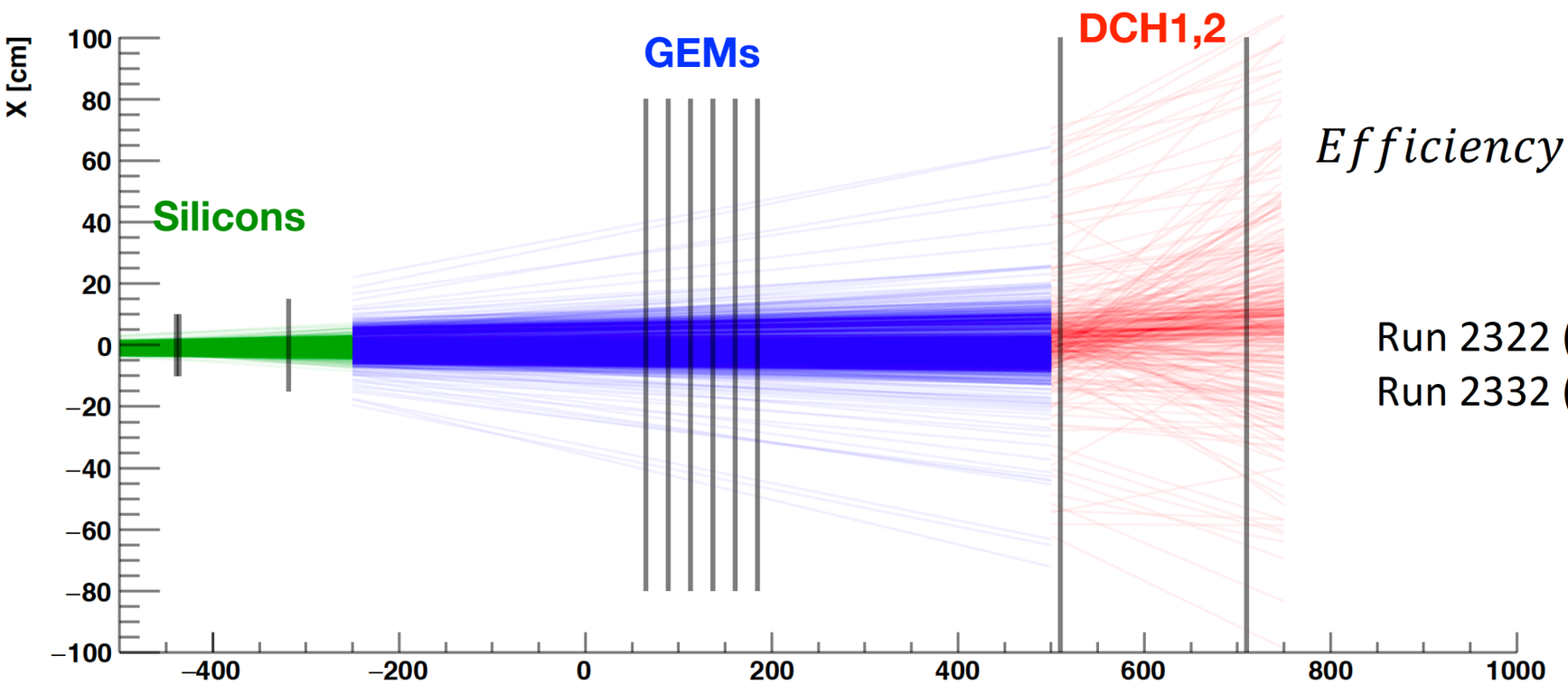
GEM+DCH angle residuals after alignment





Merging tracks in different subsystems (S. Merts, N. Voitishin, V. Lenivenko)

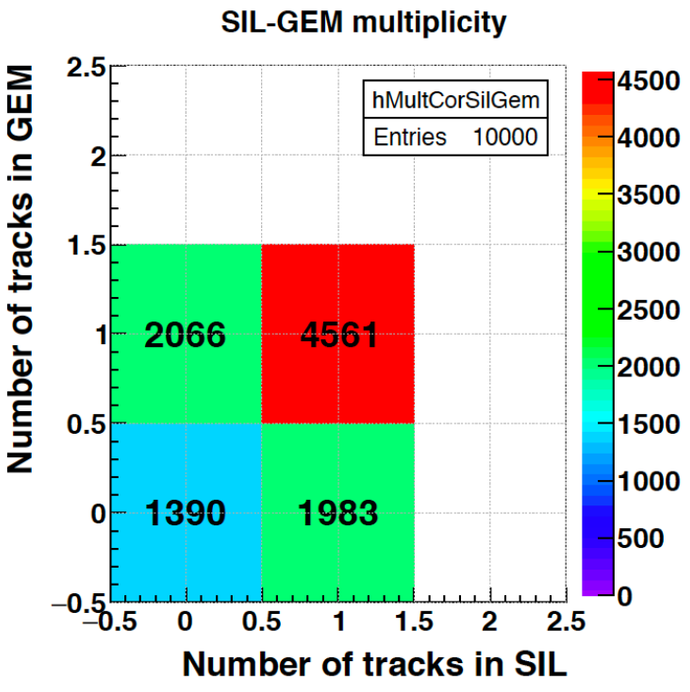
Relative alignment/matching of tracks - no target, no field



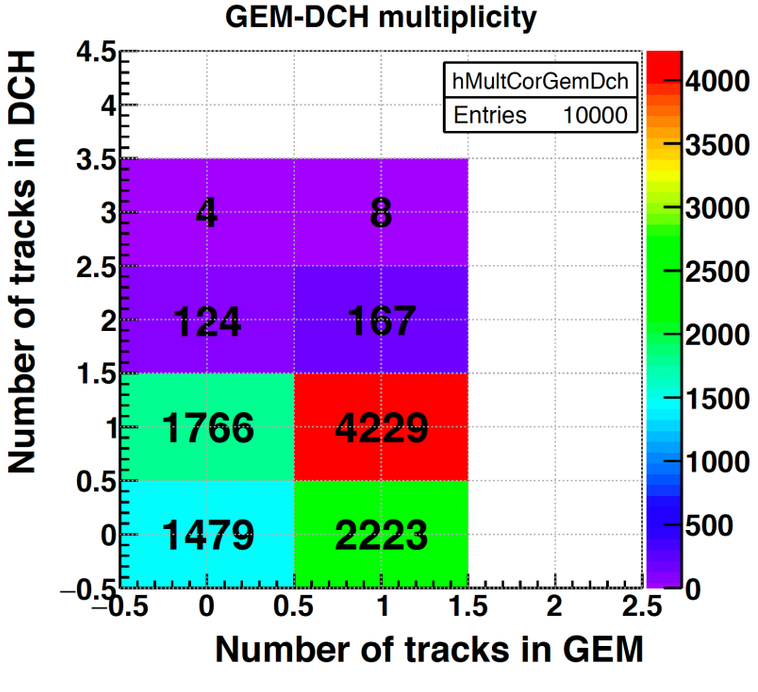
$$Efficiency = \frac{(DC1+DC2)_{matched\ track}}{GEM_{track}+DC1_{segment}} * 100\%$$

Run 2322 (900A, empty target) Eff = 66.1%
Run 2332 (1800A, empty target) Eff = 75.3%

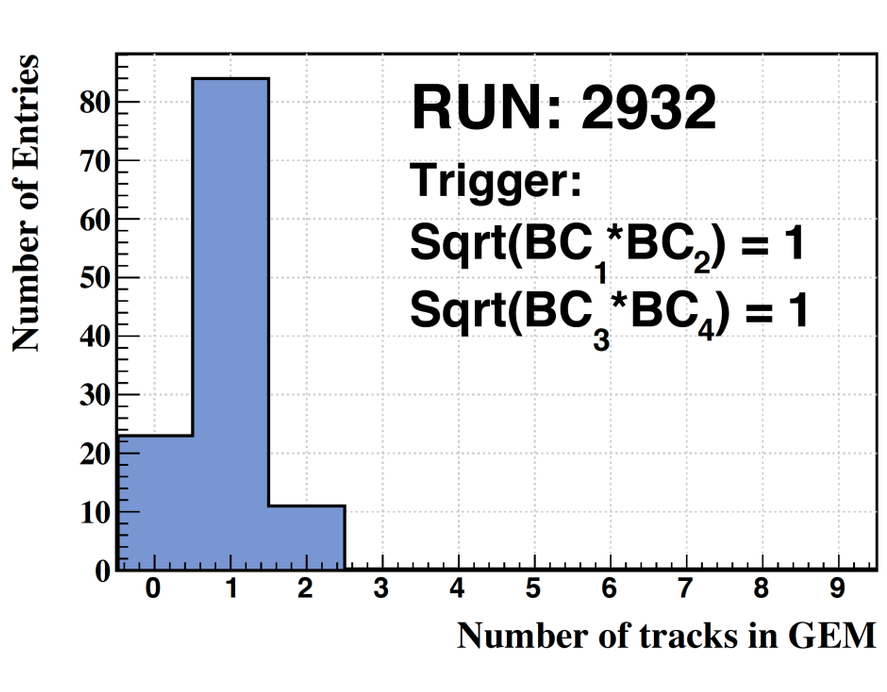
Empty target



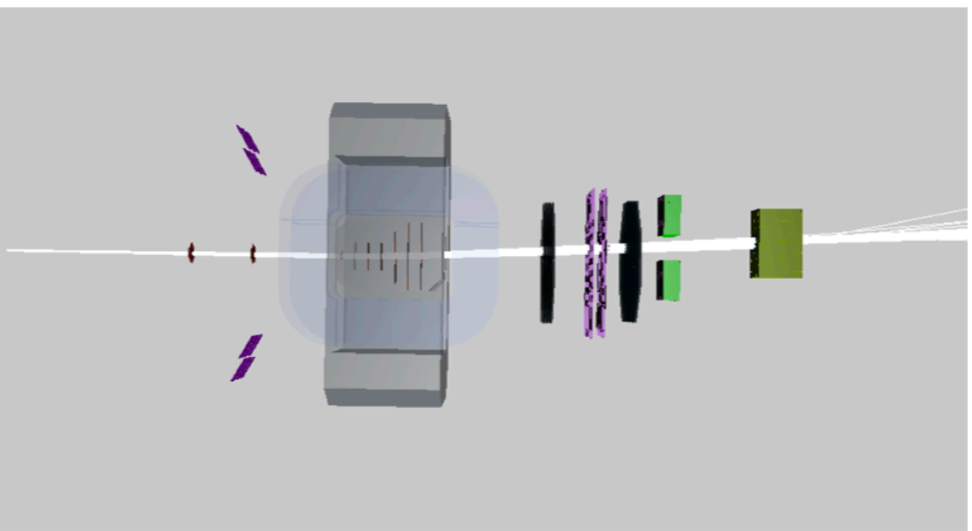
Empty target



Production run

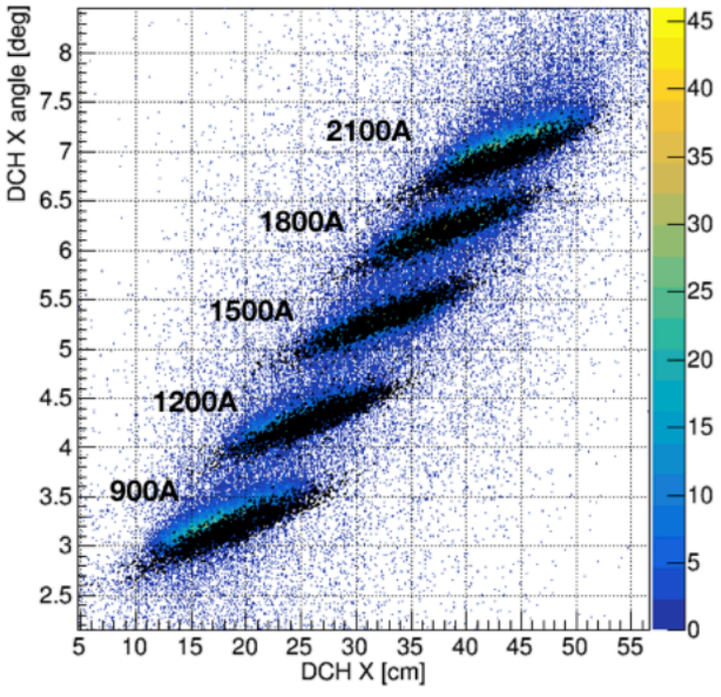


BMNRoot simulations



Unreacted 12C beam profile

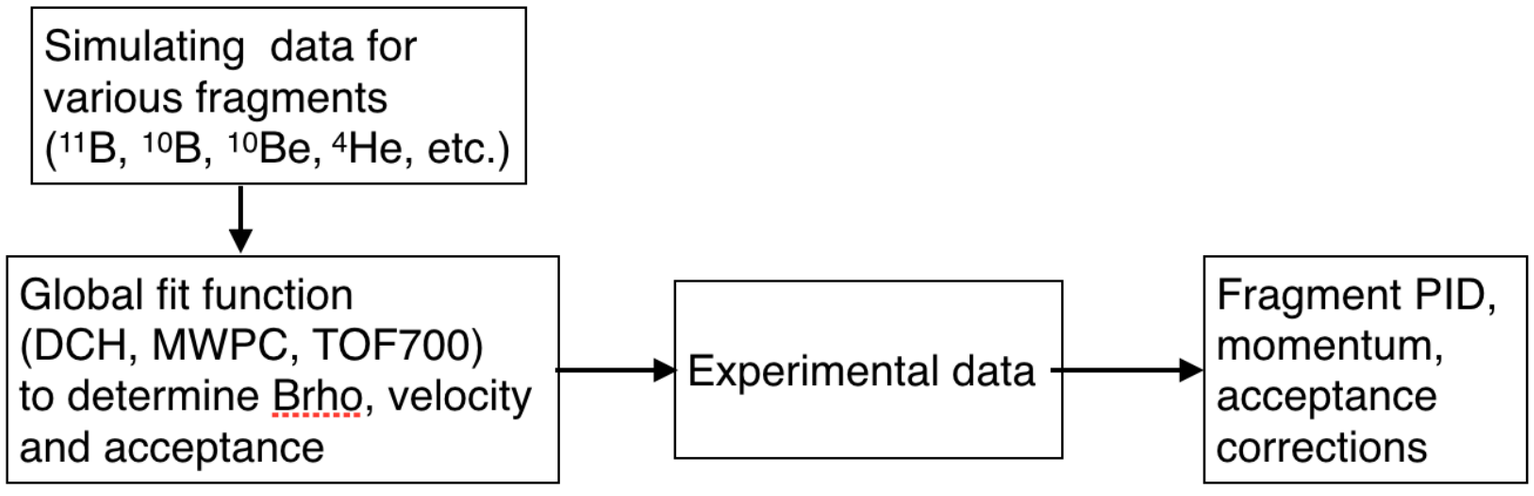
- New event generator introduced in BMNRoot
  - ➡ Realistic beam profile (angle, position and momentum spread)
- Fine adjustment of DCH hit positions and angles to match simulations for run 2332 (Empty target, B-field @ 1800A)



Blue: Experiment

Black: BMNRoot

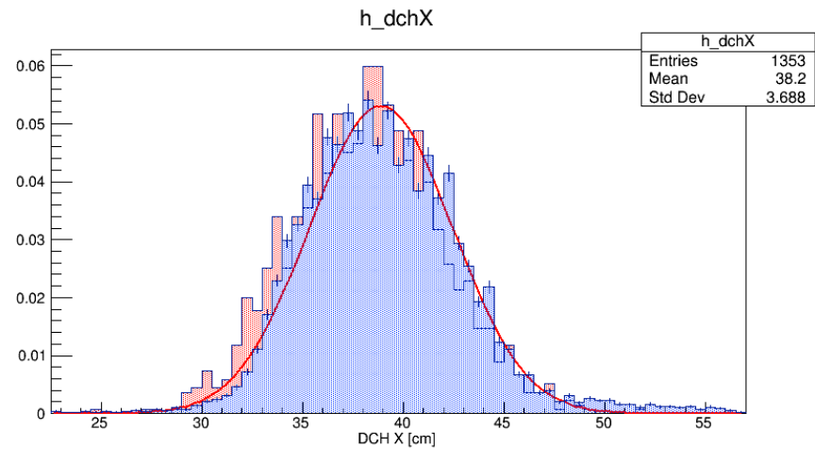
- Mismatch between simulations and experiment for different B-field settings
- Trying to extract tracking function for fragments using global fit of the simulated data



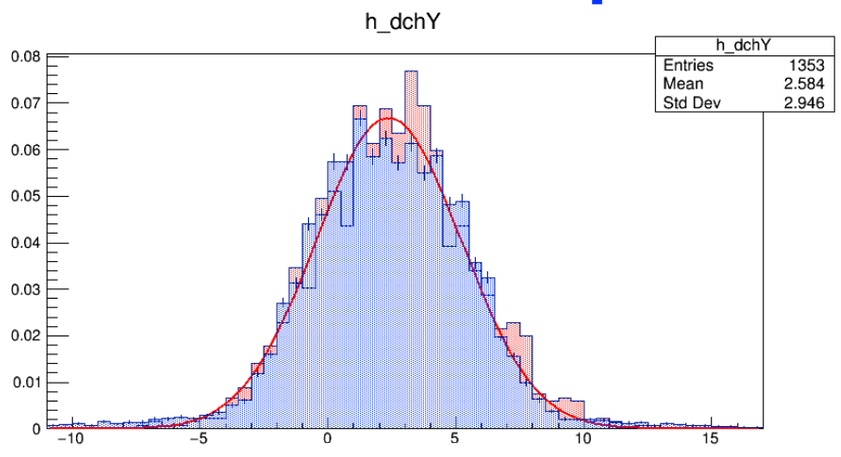
BMNRoot simulations

- DCH and TOF700 with nominal geometry.
- Realistic beam profile from MWPCs.
- B-field scaling 1.932 (1800A run 2332) from Hall probe.

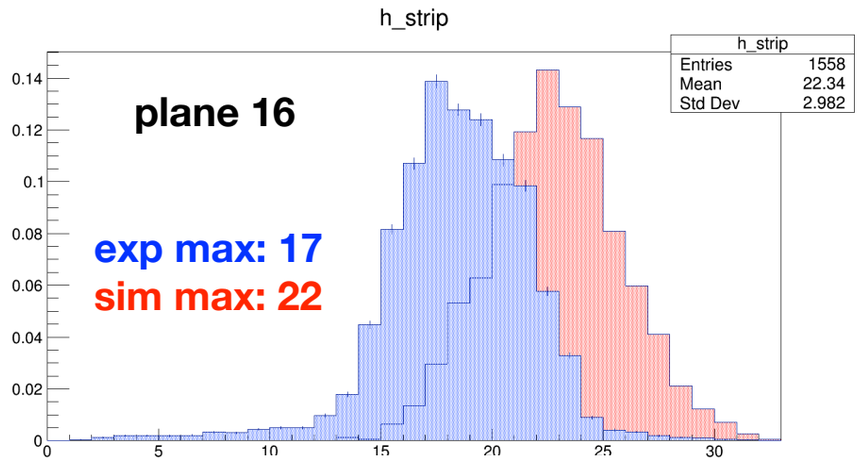
simulation / experiment



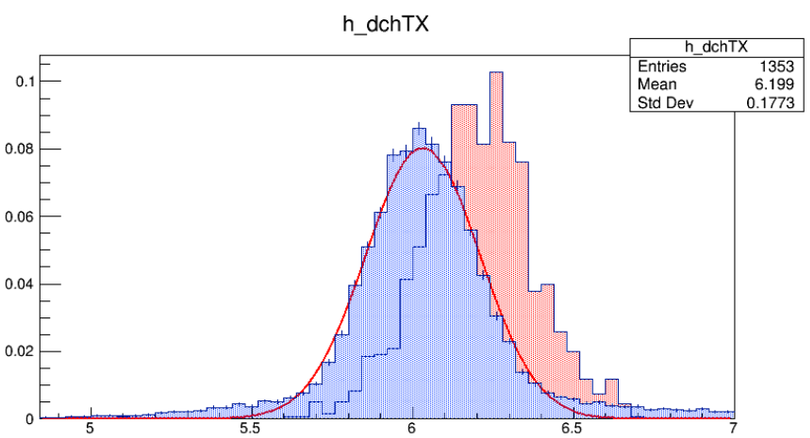
DCH X [cm]



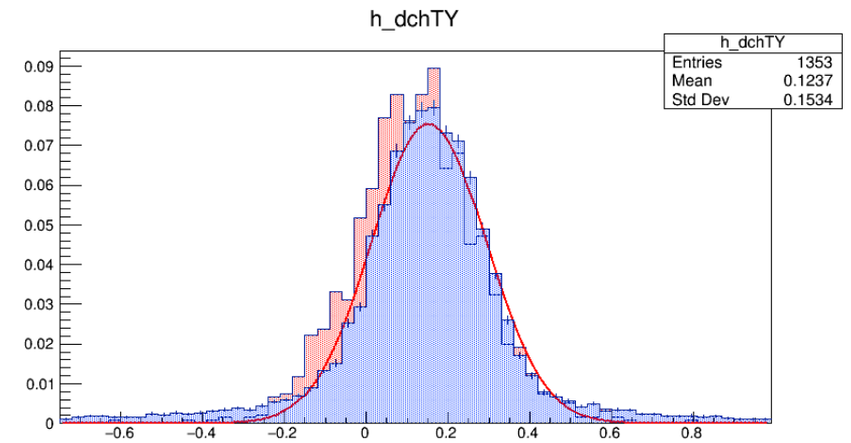
DCH Y [cm]



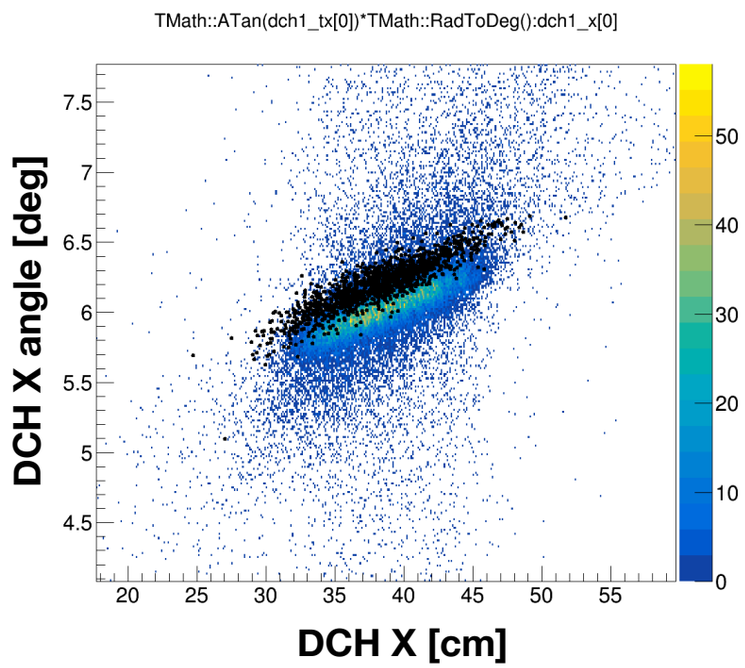
TOF700 strip



DCH X angle [deg]



DCH Y angle [deg]



Summary

- **Identification of p2p events**
  - Preliminary reconstruction of the reaction vertex and proton momenta
    - Still lacking accurate optics calibration for GEM+TOF400
  - Preliminary reconstruction of the beam vector from MWPCs, and P_{miss}

- **Identification of the residual system**
  - Possible with DCH tracks and Z information from plastic
  - Preliminary results on track multiplicities in DCH/TOF700
    - ➡ Information on the fragmentation of the residual system
  - First results of merging track information from different subsystems
    - DCH + GEM + Silicons

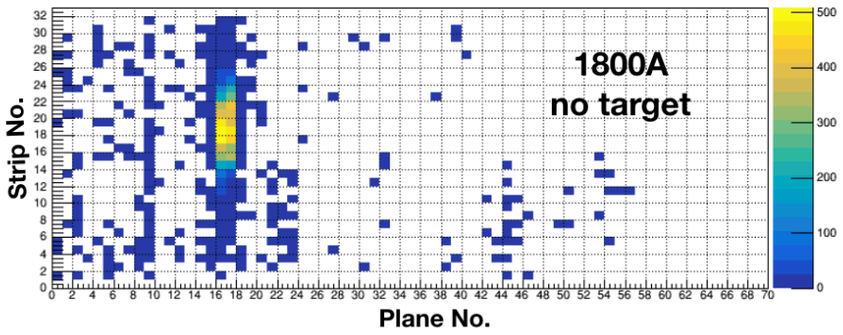
- Ongoing work on global track reconstruction and tracking efficiency
- BmnRoot simulations are needed but not working properly at the moment

Outlook

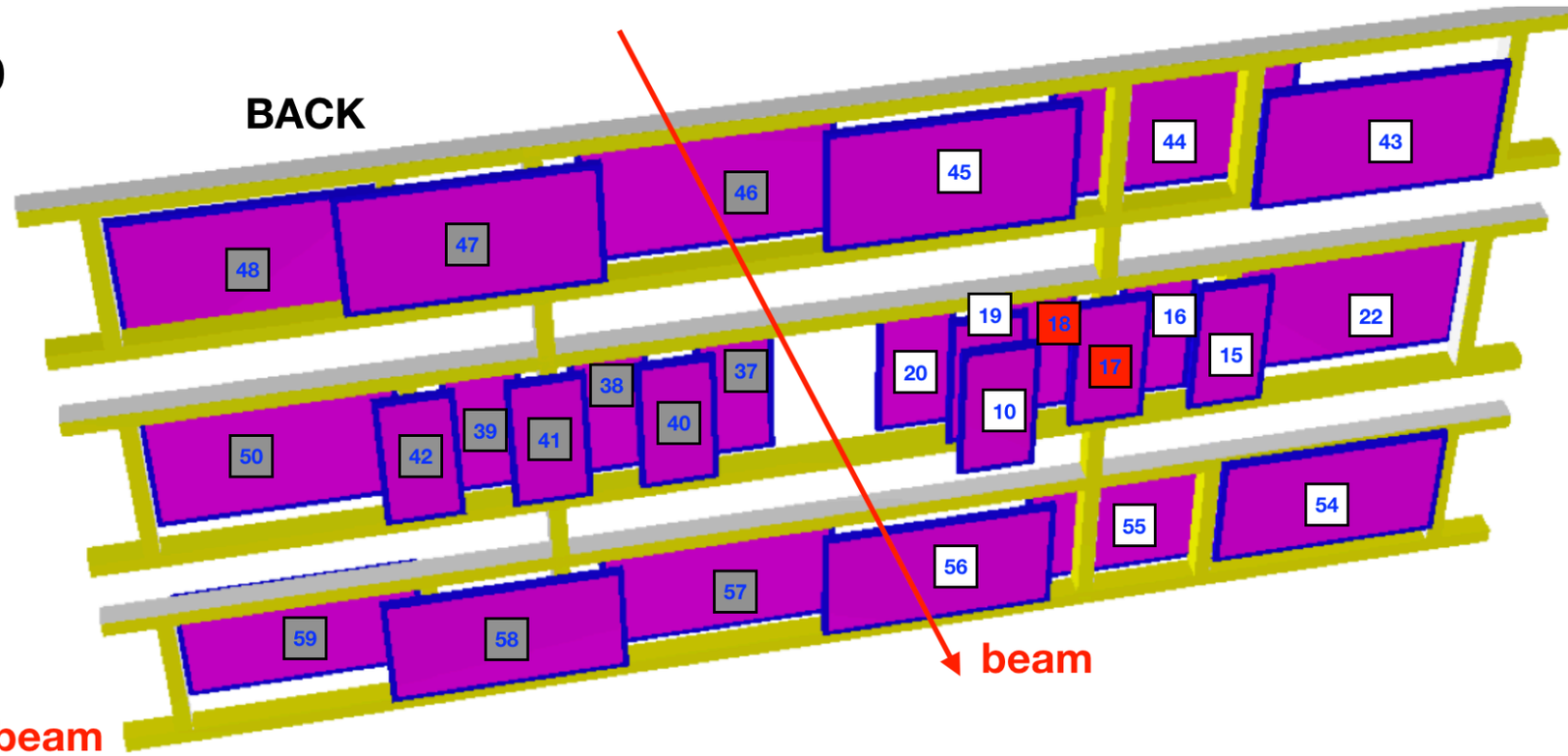
- Looking at SRC neutrons in LAND
- Merging information from all detectors to tag the final state
- Improving BmnRoot simulations
- 3 years RFBR grant from Maria Patsyuk for SRC data analysis
- New PhD student in Tel Aviv (Göran Johansson)

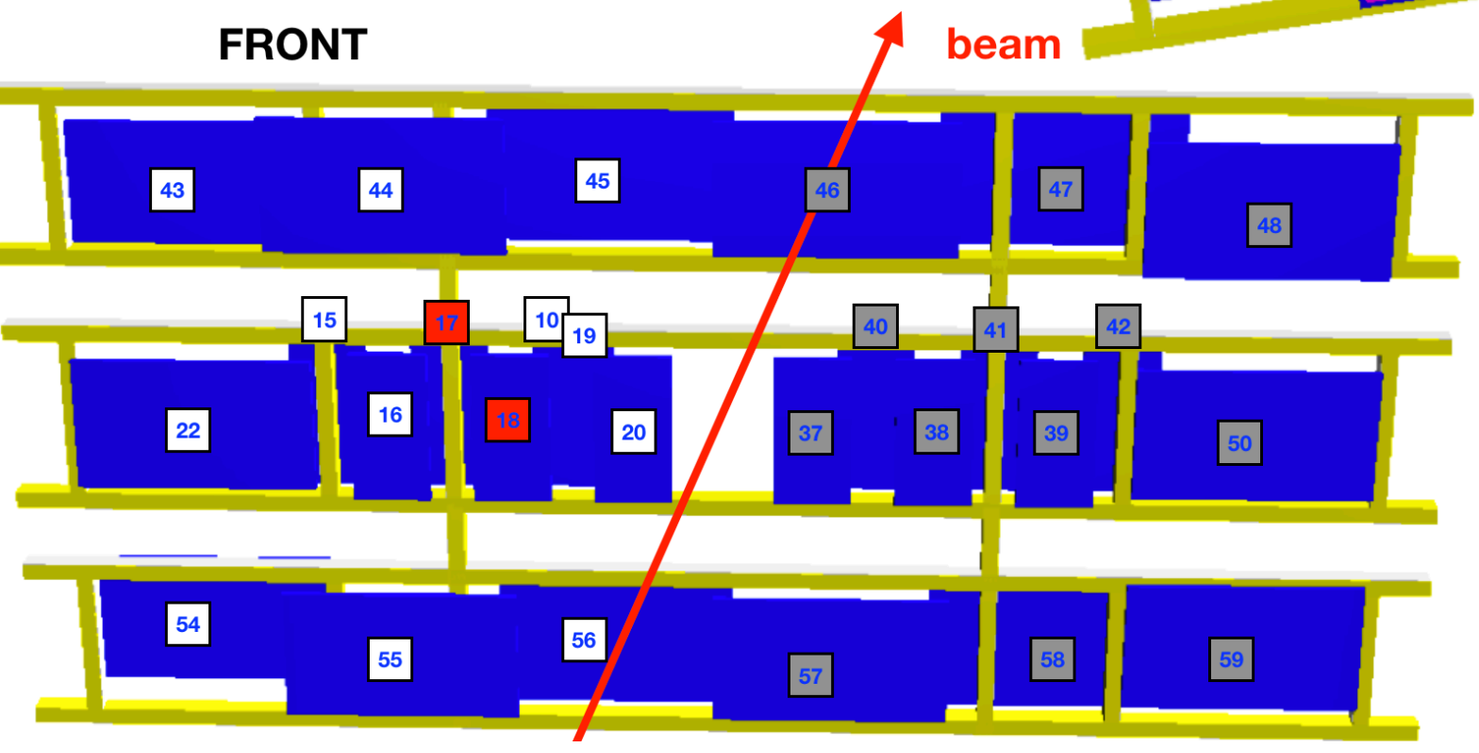
BCKP

Second (downstream) wall of ToF700



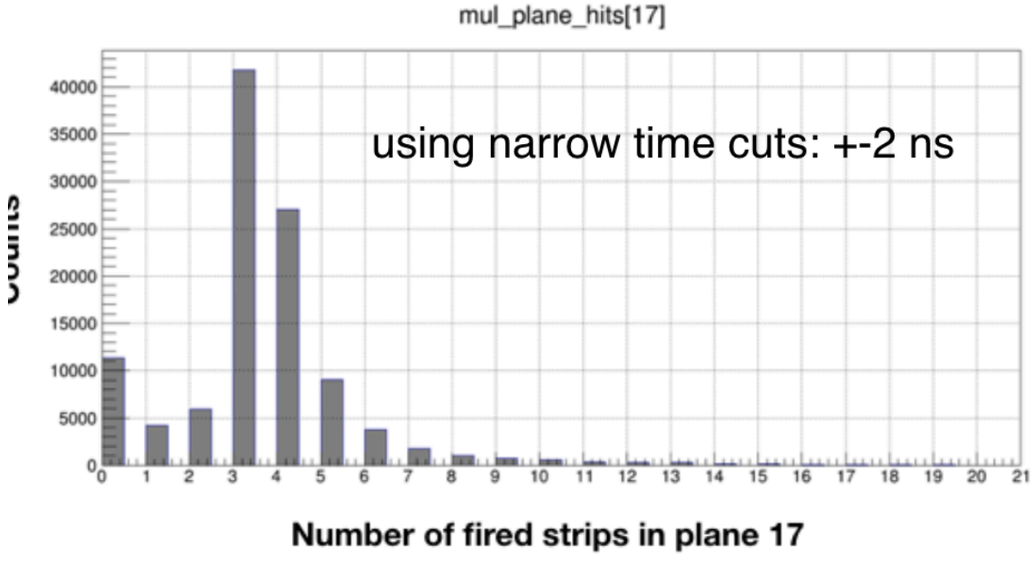
^{12}C is centered on plane 17 and 18
for B-field@1800A (physics run)





- Numbering as in digi file but 1 based (N_{digi} = N -1)
- Different from plane ID in the standard geometry file
- Can differ from the numbering used in the simulation

ToF700



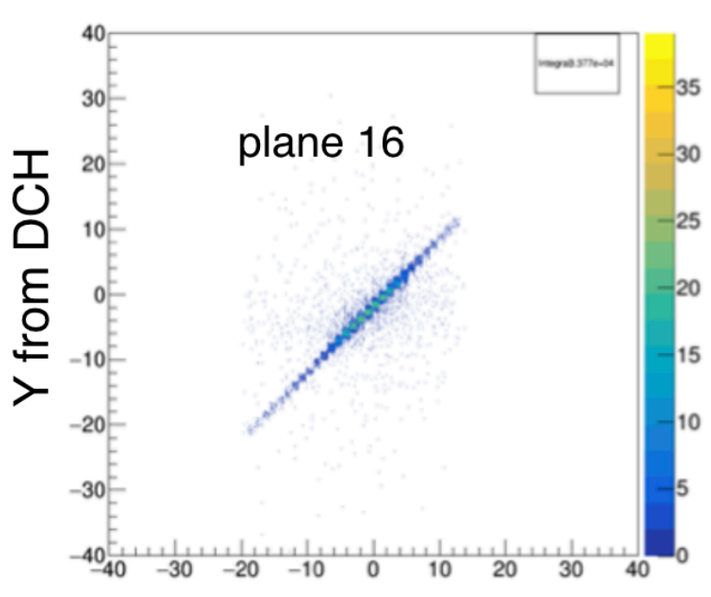
- Large hit multiplicity in TOF700
  - ➡ Improved by clustering algorithm

- Position calibration of TOF700 using DCH tracks
  - ➡ Unreacted 12C
  - ➡ Depends on DCH alignment
  - ➡ Resolution: 5 mm sigma in X and Y

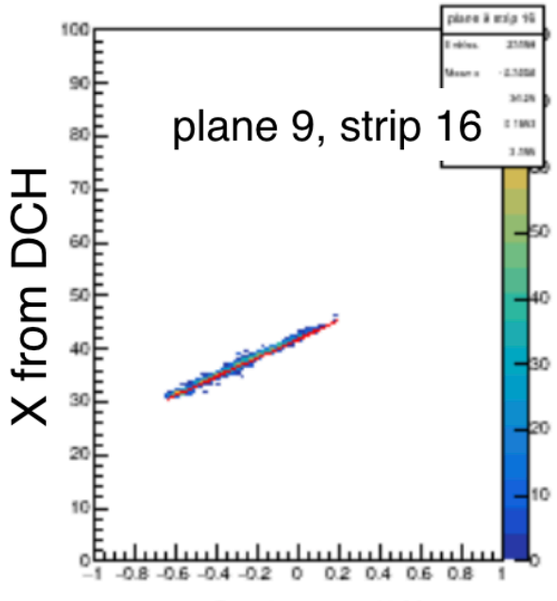
- Estimated time resolution: 116 ps (sigma)

- Absolute time-offset calibration for individual strips is based on BMNRoot simulation of unreacted 12C
  - ➡ in progress

Example of position calibration

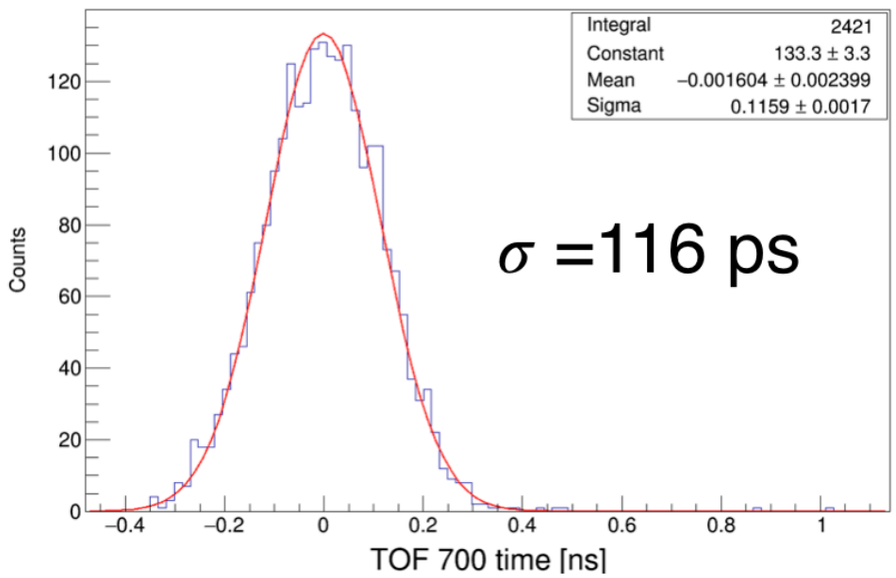


Y from strip No.

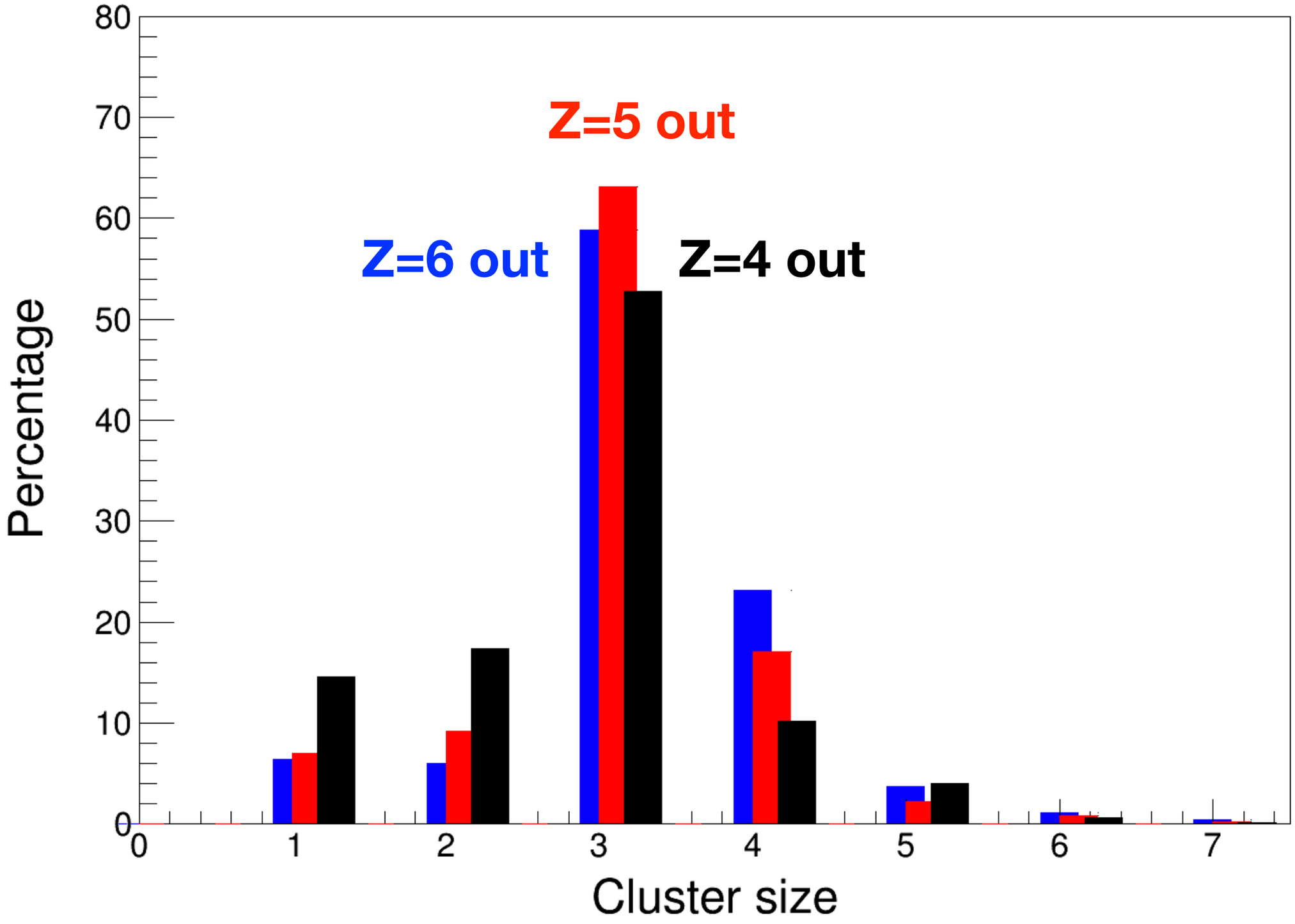


Strip t_diff

Time resolution in a single strip

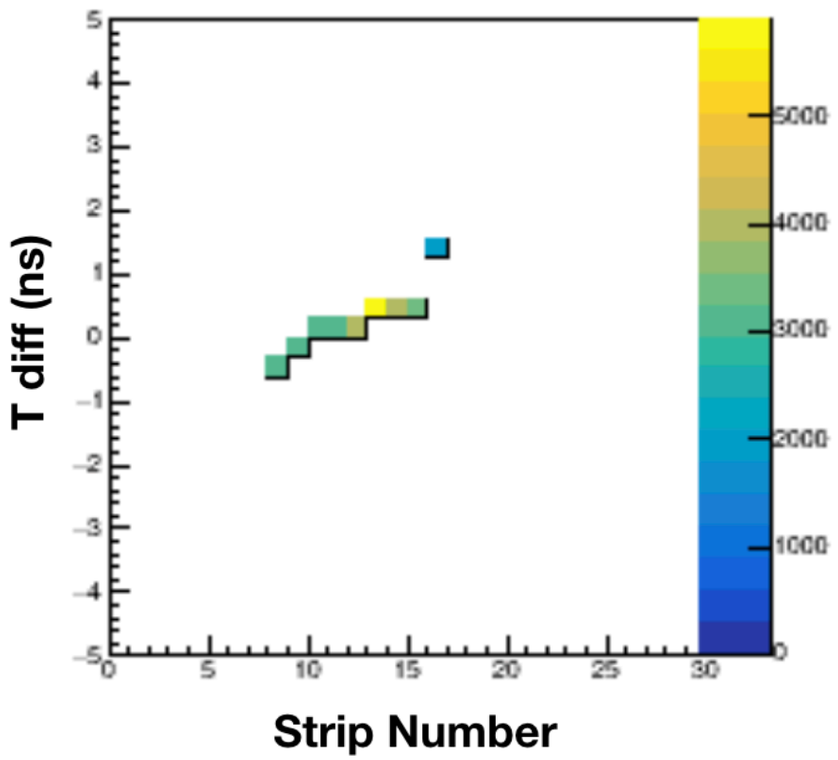


TOF700 cluster size

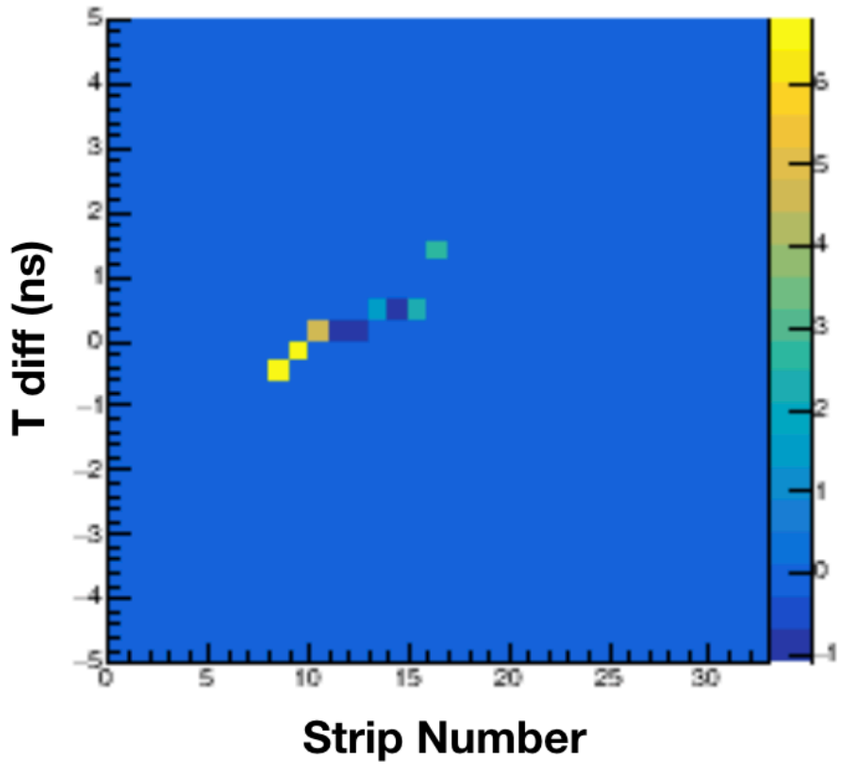


Single “cluster” events in plane 17 (no time cuts)

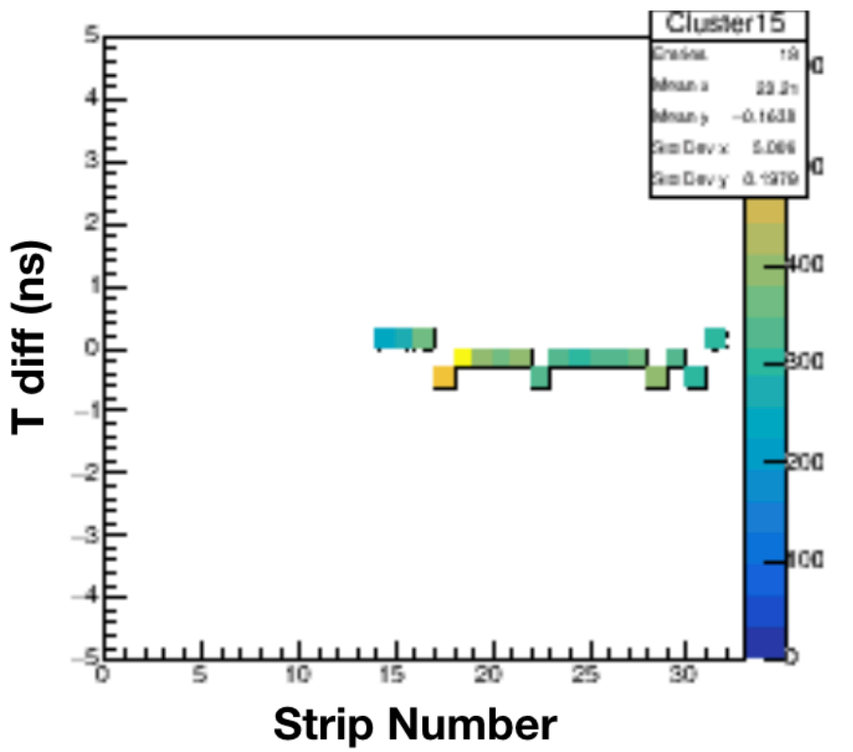
amplitude



ToF(ns)



amplitude



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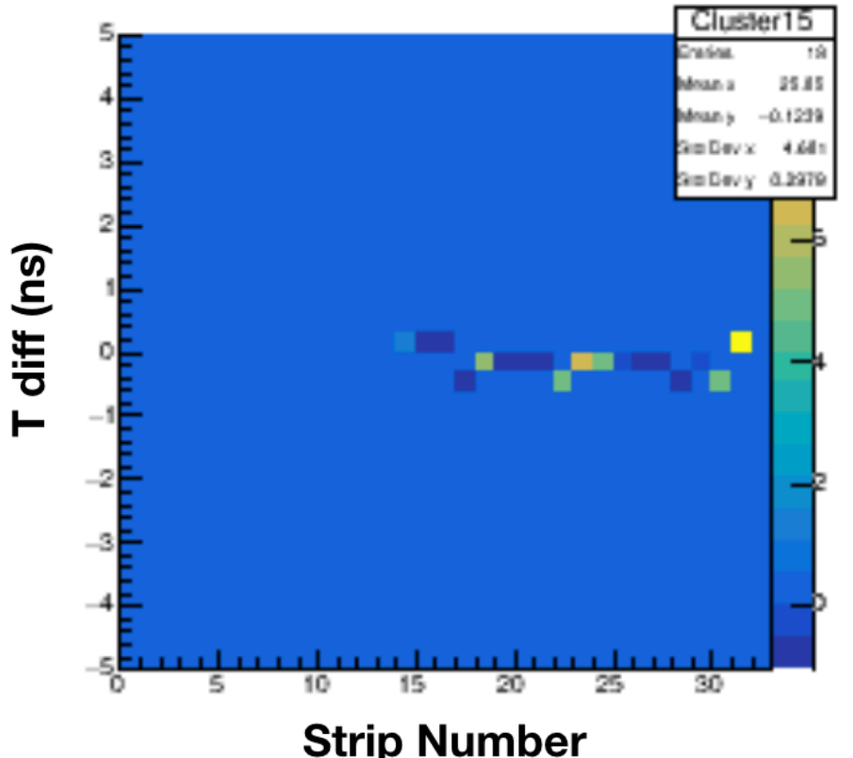
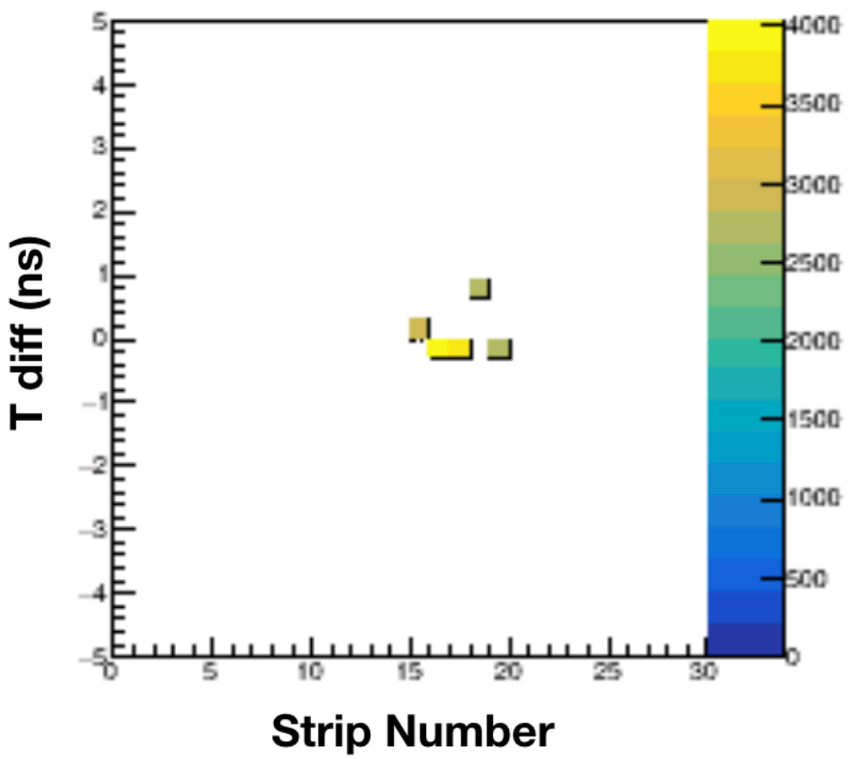
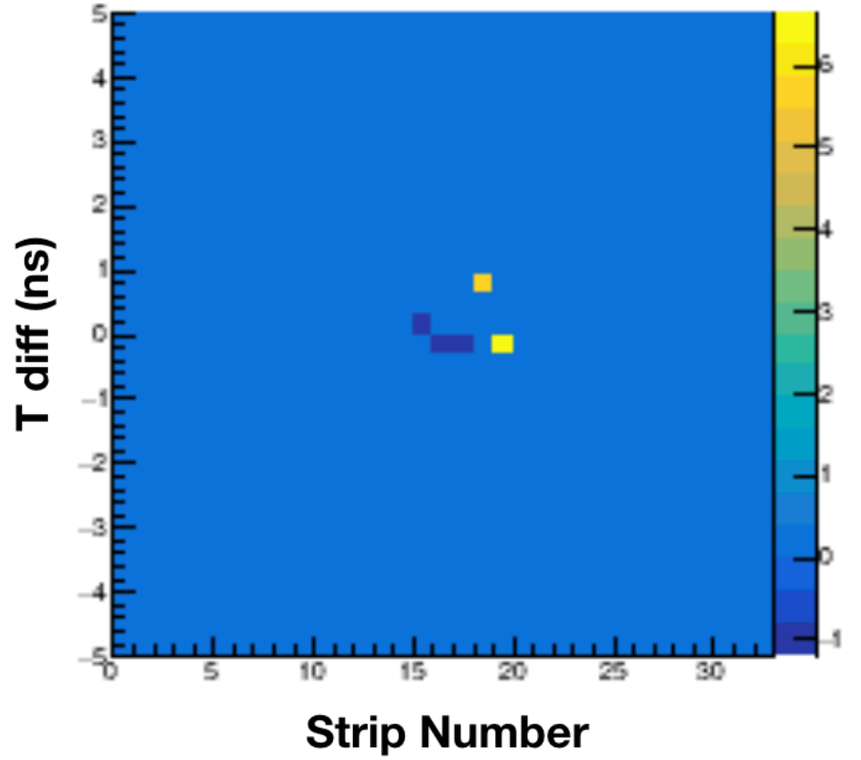


Single “cluster” events in plane 17 (no time cuts)

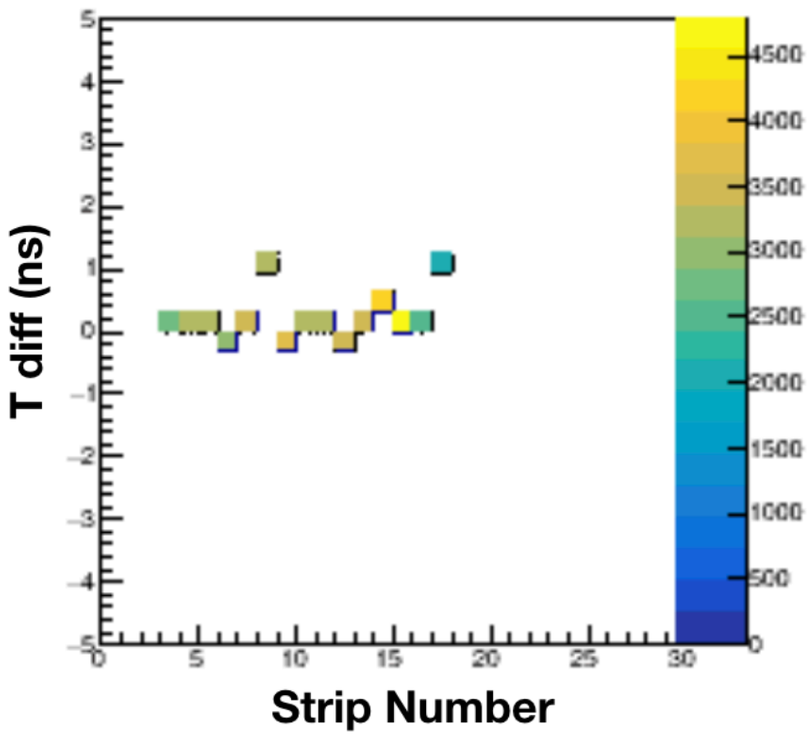
amplitude



ToF(ns)



amplitude



ToF(ns)