

Beam, PID, and the Upstream tracking

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for the SRC Collaboration

5th BM@N Collaboration Meeting

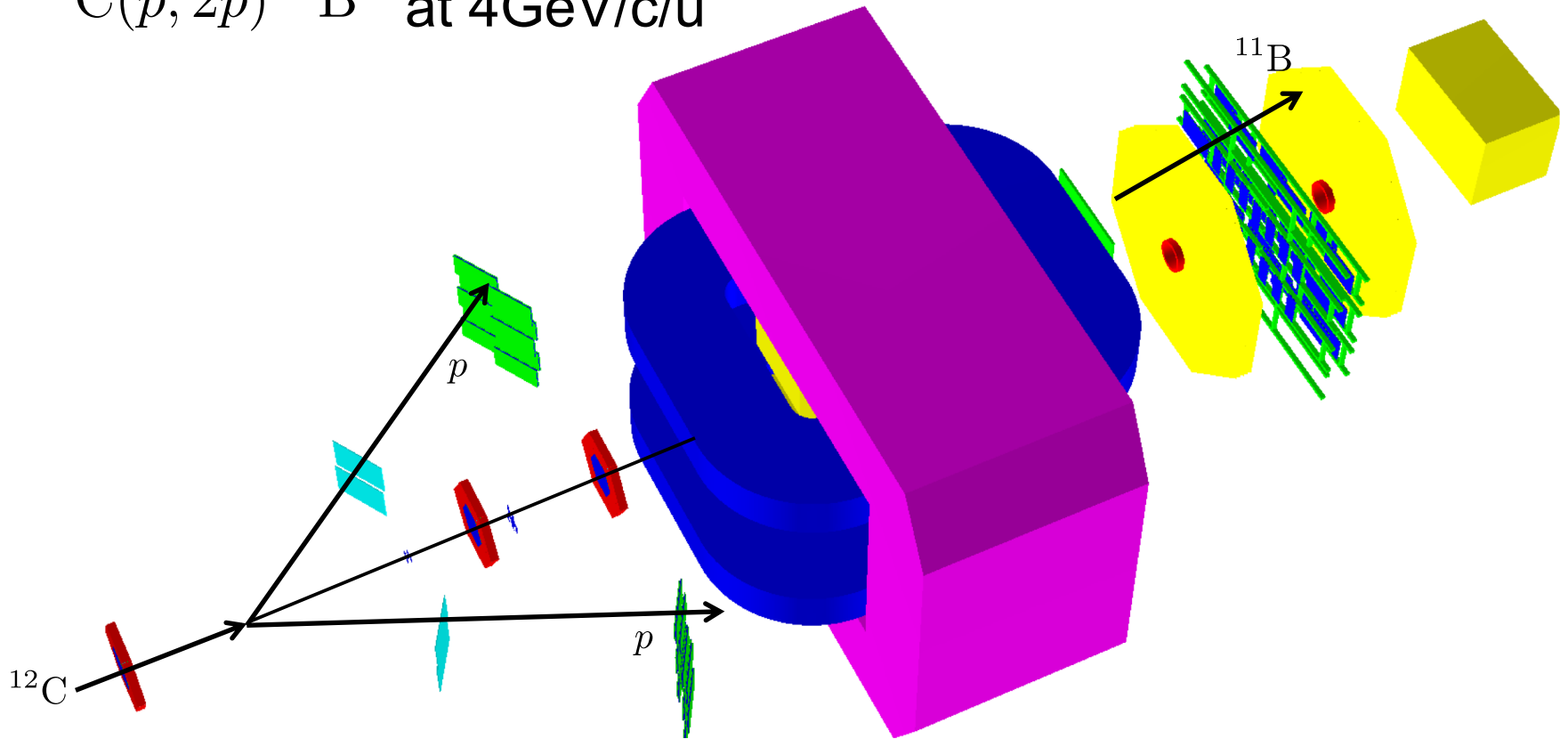
April 20th, 2020



Focus of the first analysis - Quasi-Elastic Scattering in Inverse Kinematics

*See the plenary talk
of Julian Kahlbow
tomorrow*

$^{12}\text{C}(p, 2p)^{11}\text{B}$ at 4 GeV/c/u



Data collected in 2018

Crucial technical aspects of the analysis $^{12}\text{C}(p,2p)^{11}\text{B}$

1. Precise determination of the beam energy at the target and downstream:
 - momentum of the struck nucleon before interaction $\rightarrow$ QE identification
 - [momentum of the residual ion](#)
2. PID of the residual ion $\rightarrow$ identification of the QE reaction
3. Upstream tracking
4. [Reconstruction of the proton arms](#)
5. [Momentum of the residual ion](#)

See today's talk of Julian Kahlbow
"Reconstruction of the proton arms"

See talk of Valerii Panin "Analysis of
fragments" later today

Crucial technical aspects of the analysis $^{12}\text{C}(p,2p)^{11}\text{B}$

1. Precise determination of the beam energy at the target and downstream:

- momentum of the struck nucleon before interaction $\rightarrow$ QE identification
- momentum of the residual ion

2. PID of the residual ion $\rightarrow$ identification of the QE reaction

3. Upstream tracking

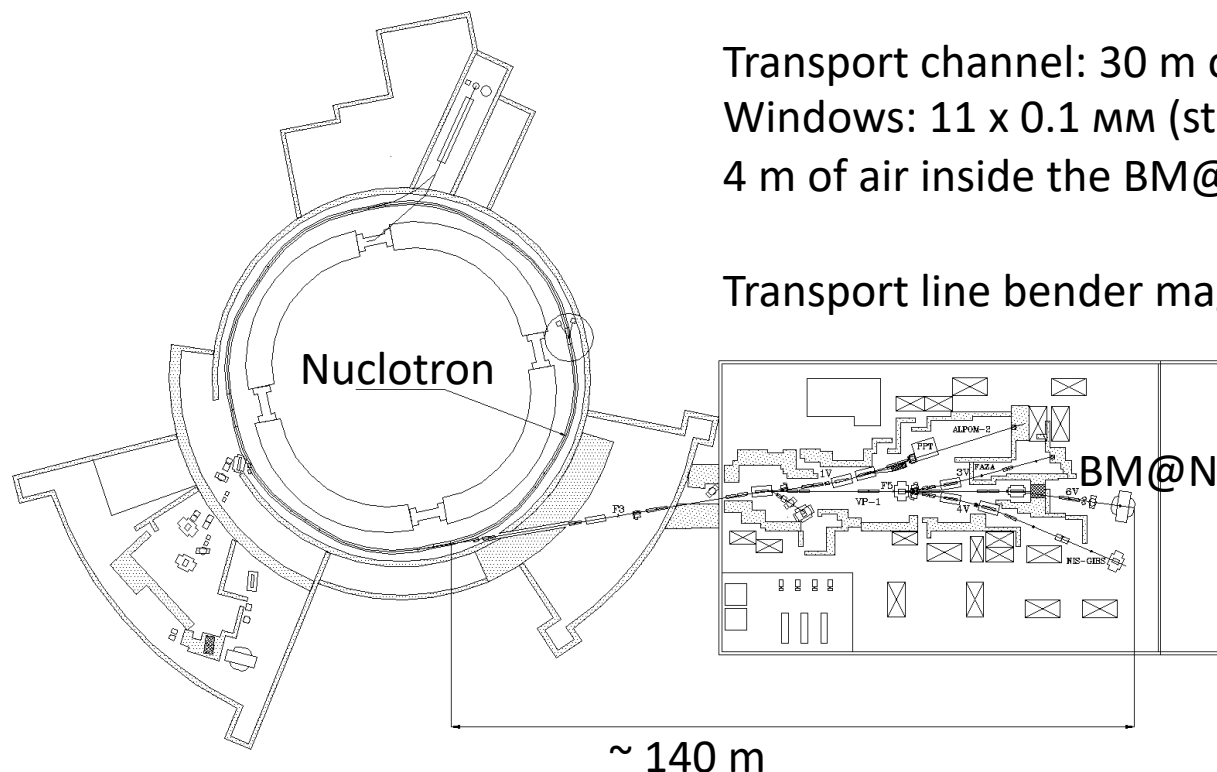
Focus of my talk

4. Reconstruction of the proton arms

5. Momentum of the residual ion

Beam momentum determination

The ^{12}C beam momentum is measured inside the Nuclotron ring: 4 GeV/c/nucleon with 0.5% precision



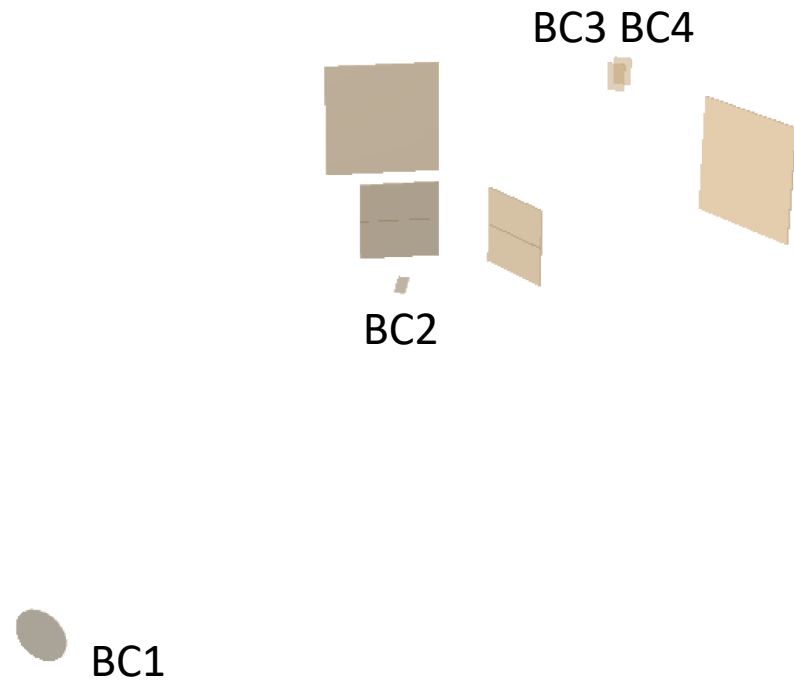
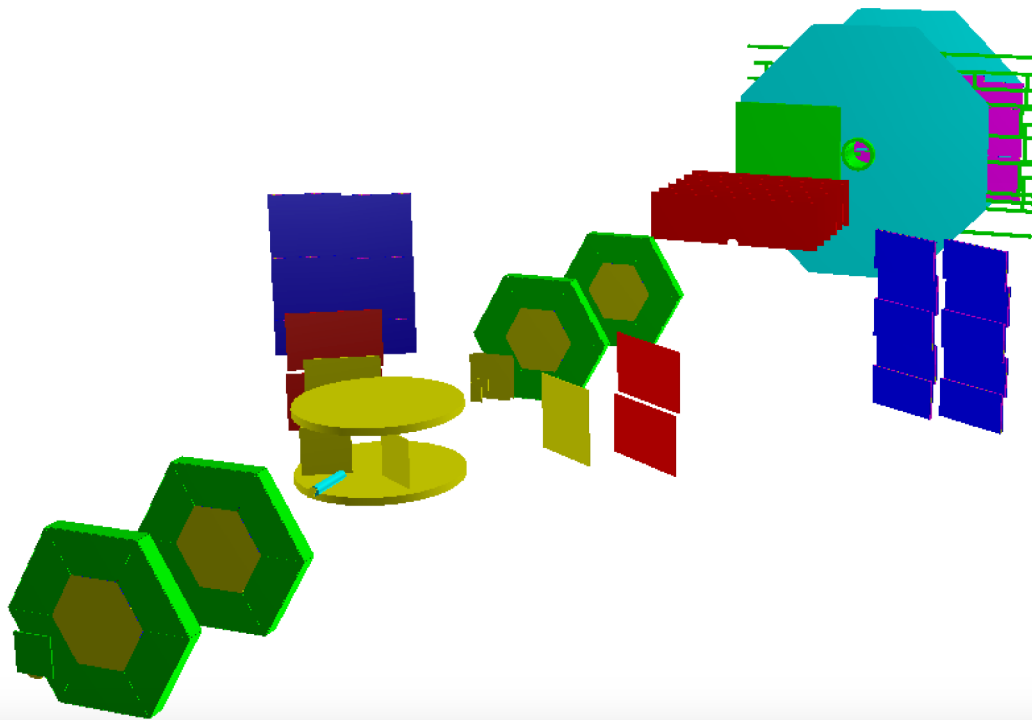
Transport channel: 30 m of air + 110 m of vacuum
Windows: 11 x 0.1 mm (steel) + 1 x 0.05 mm (titanium)
4 m of air inside the BM@N hall up to the target

Transport line bender magnets with 4+-1% tuning

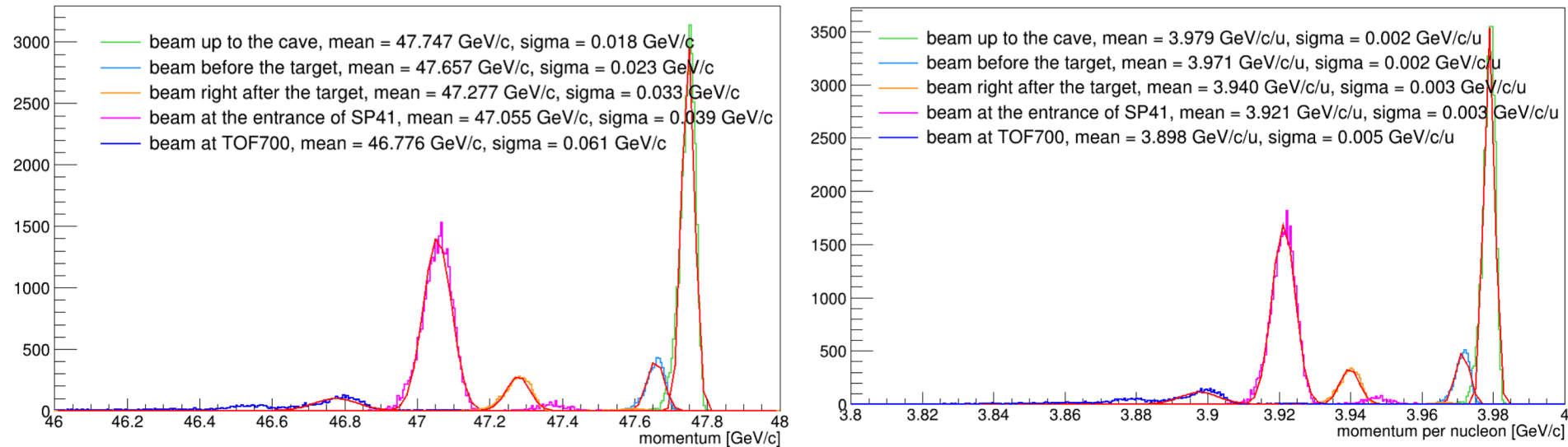
Energy loss was defined
using Geant3 and
double checked in
LISE++, ATIMA,
calculations

Several geometrical elements were added for more precise simulation of energy loss in BmnRoot

- Windows of magnetic elements
- LH target
- BC counters
- Windows for the Si detectors



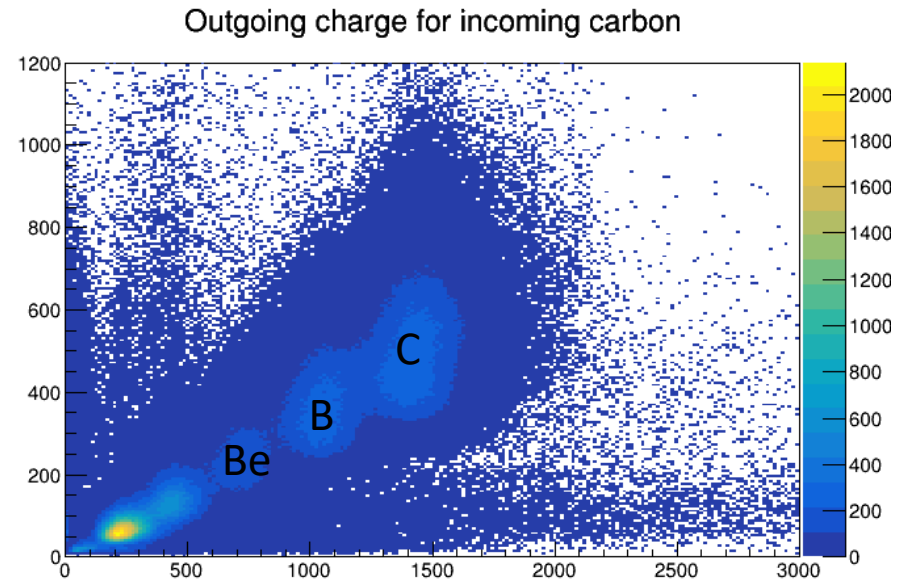
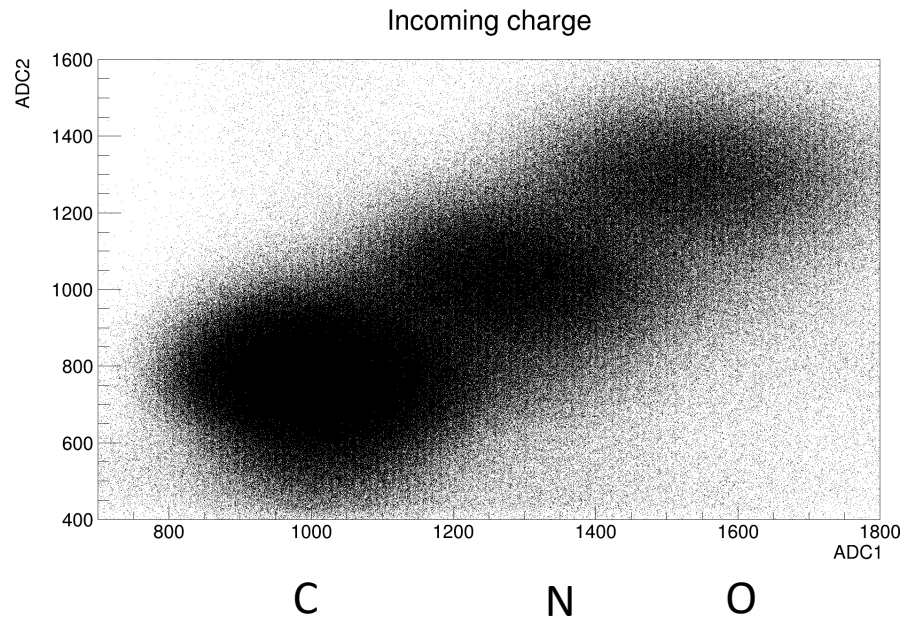
Beam energy defined by BmnRoot simulation



Not accounted for 0.5 % of momentum resolution inside the Nuclotron ring

Resulting beam momentum is consistent with the expected 1% uncertainty

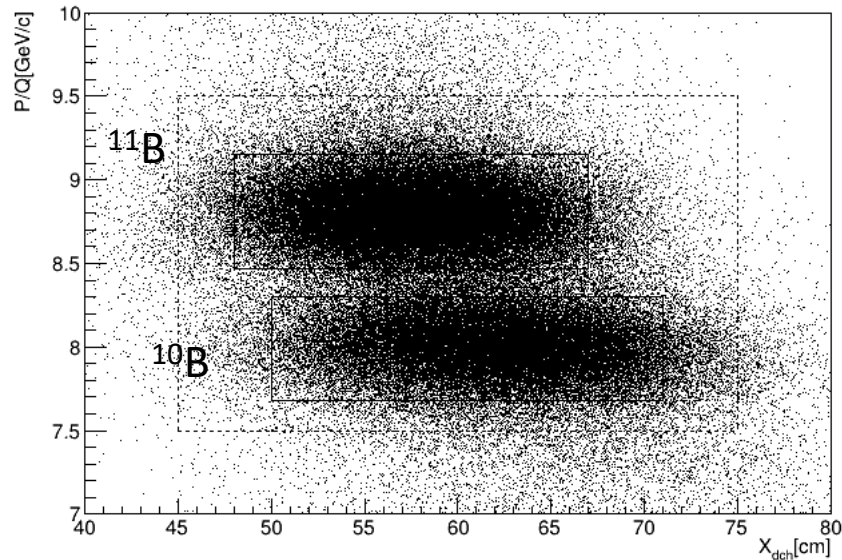
PID of the residual ion based on BC counters amplitudes



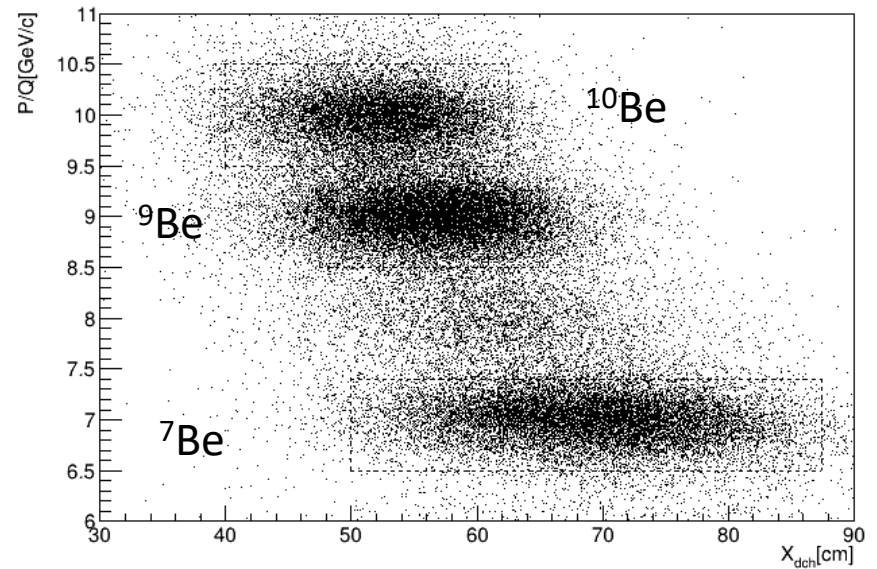
A set of runs selected for the analysis: two arms trigger

Isotopes of Boron and Beryllium can be identified

Boron Isotopes



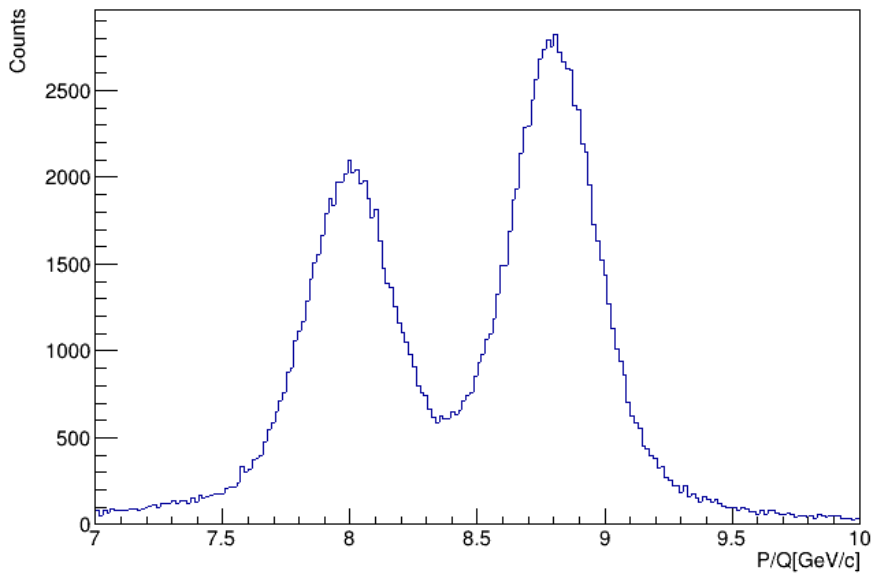
Beryllium Isotopes



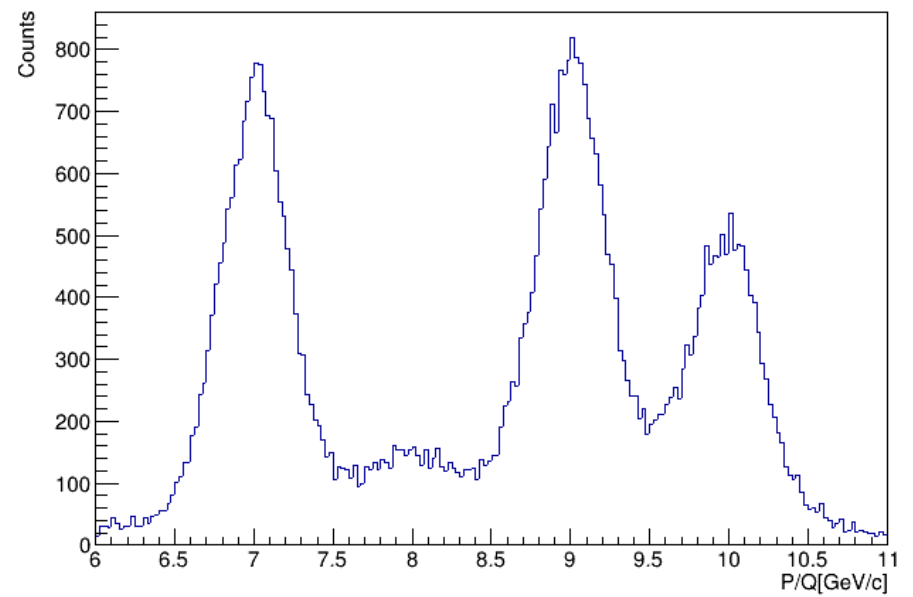
$$P/Q = 0.3 * \text{Int}(\text{Bdl}) / (\alpha_{\text{out}} - \alpha_{\text{in}})$$

Separation of Boron and Beryllium isotopes

Boron isotope separation

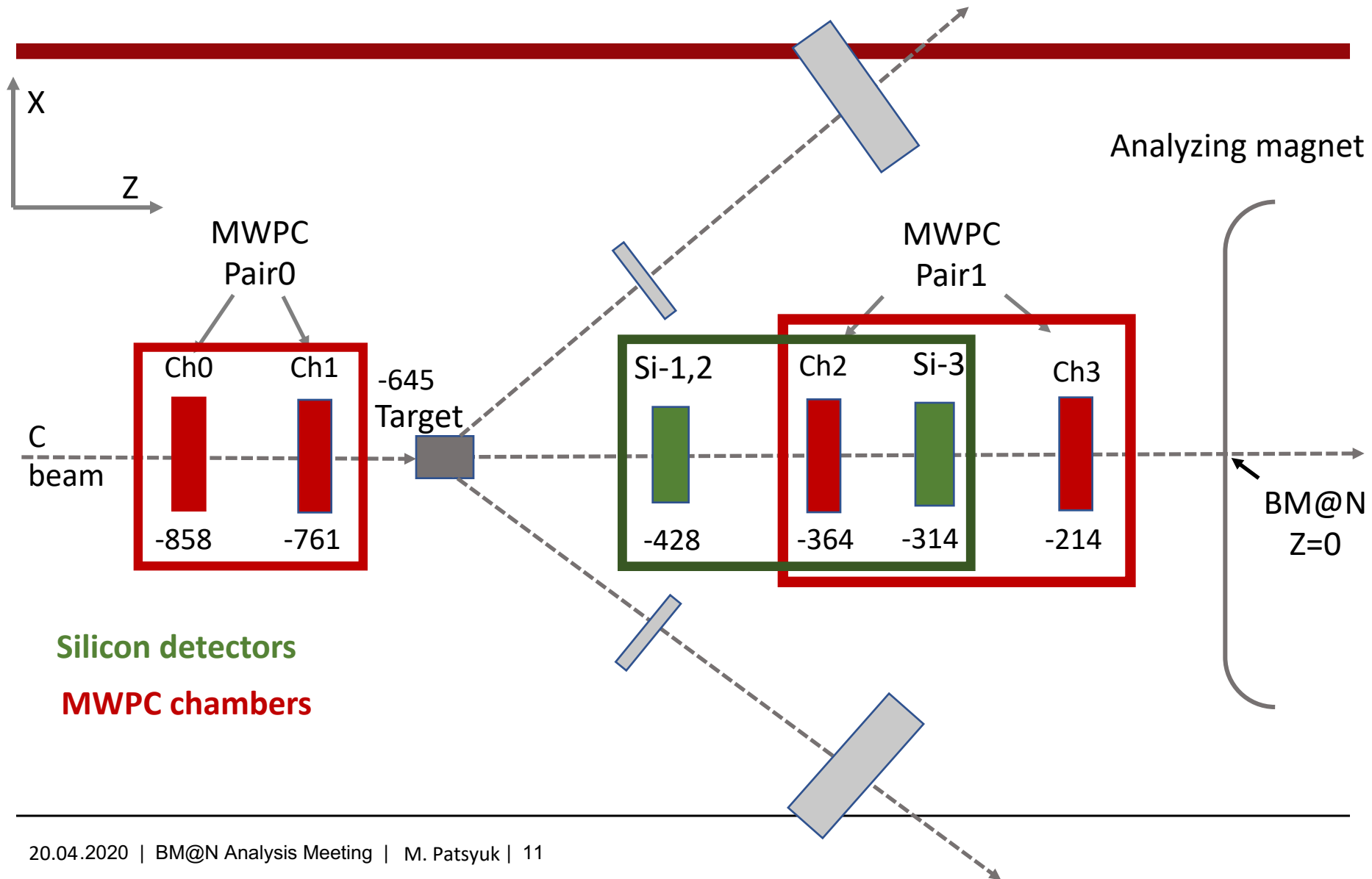


Beryllium isotope separation

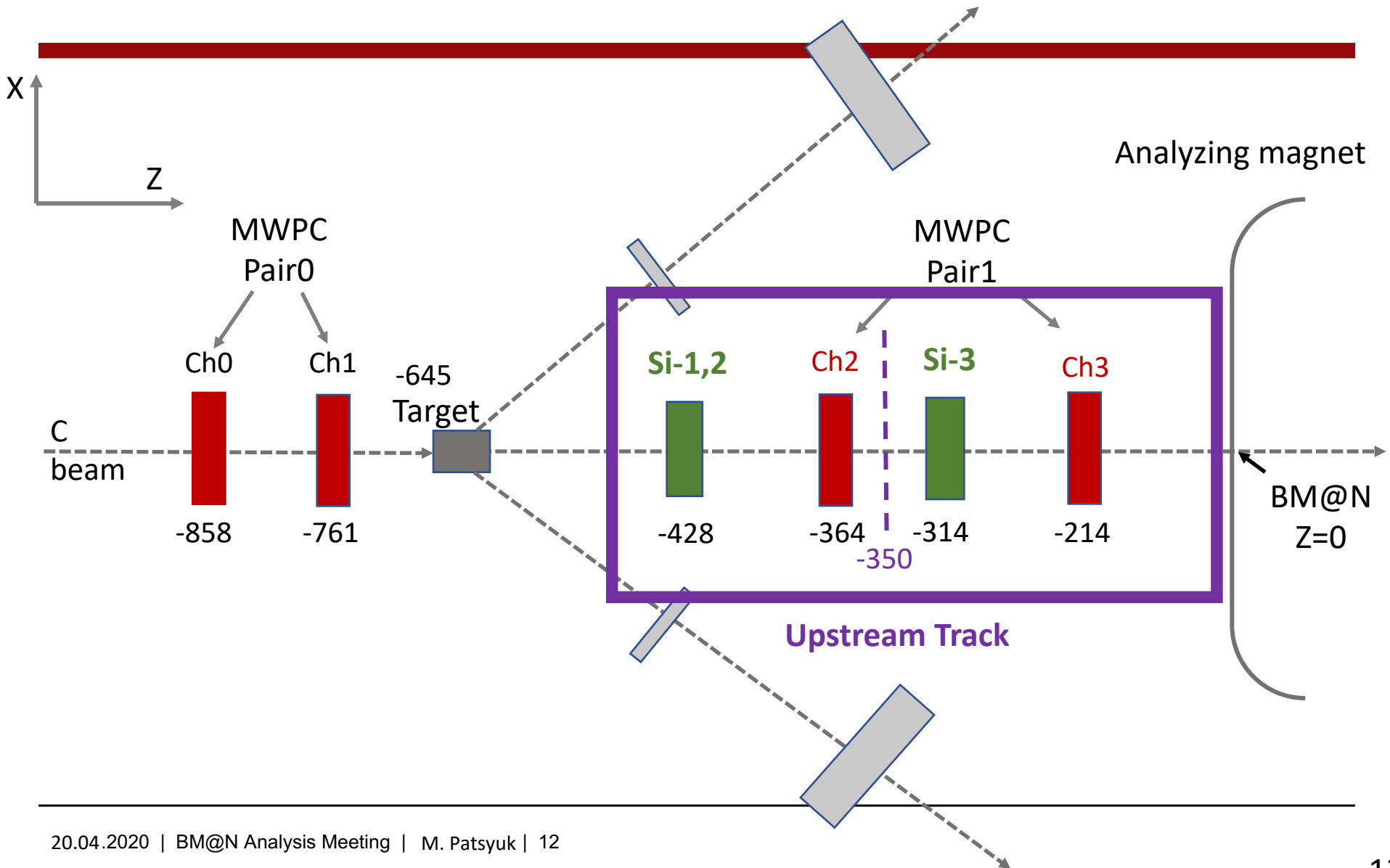


Isotopes are well separated, so that we can calculate ratios between them for the analysis

Tracking Upstream the analyzing magnet



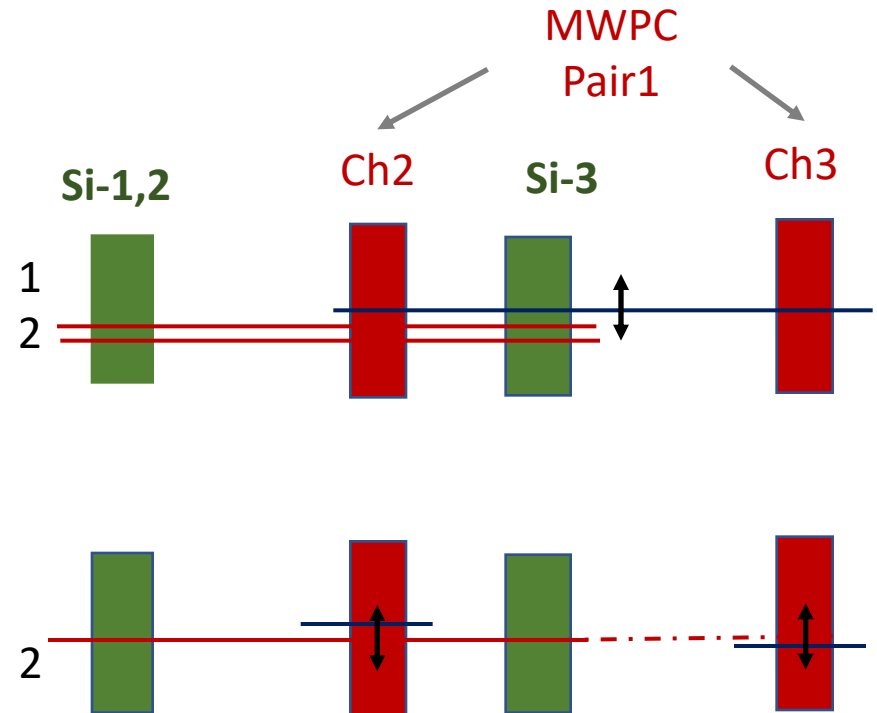
Upstream track is constructed using **Si** and **MWPC**



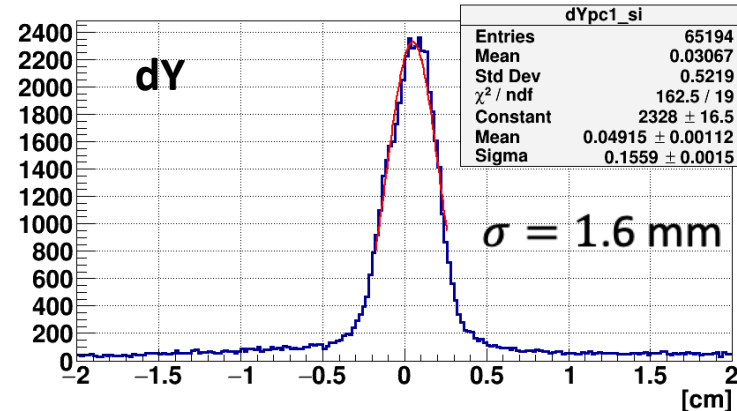
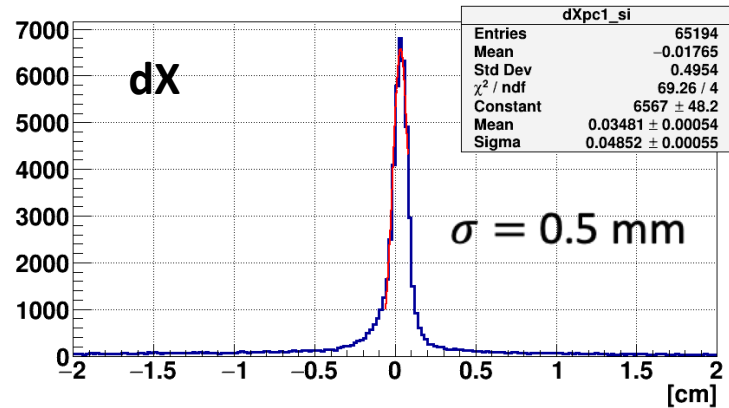
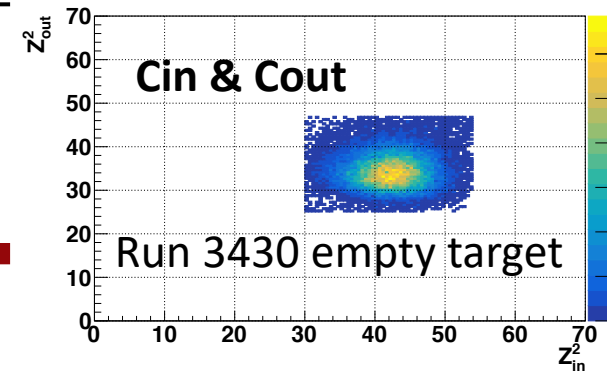
Two stages of Si-MWPC matching

More tracks in Si than in MWPCs:

1. Match Si tracks + MWPC (Pair 1) tracks (min distance criterion)
2. Match remaining Si tracks + segments in MWPC2,3



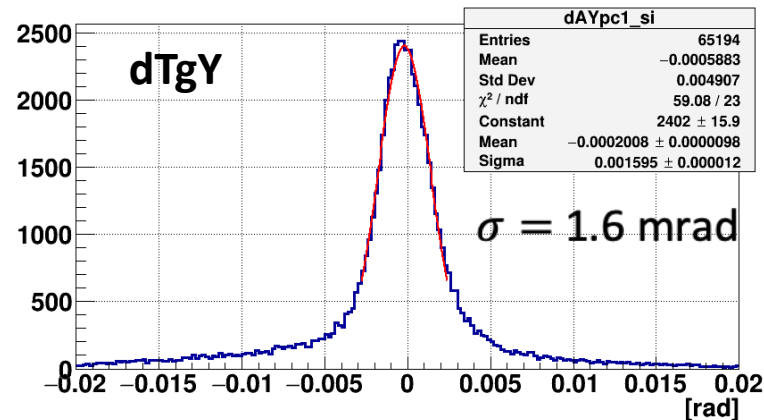
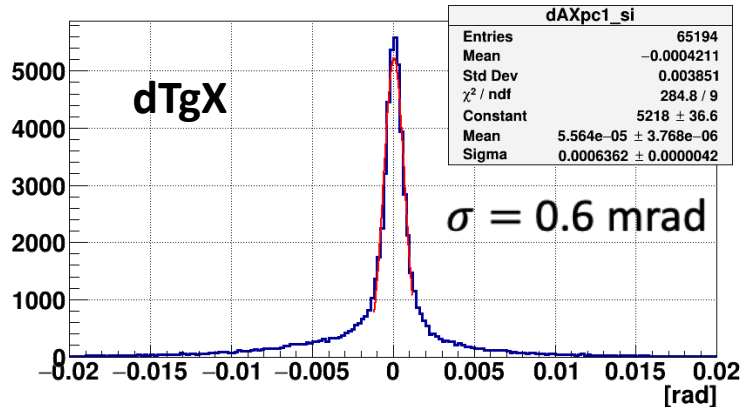
Si-MWPC matching quality at Z = -290 cm



Design
detector
resolutions:

$$\sigma X_{\text{Si}} \sim 50 \text{ } \mu\text{m}$$

$$\sigma Y_{\text{Si}} \sim 1 \text{ mm}$$



$$\sigma X_{\text{MWPC}} = 0.72 \text{ mm}$$

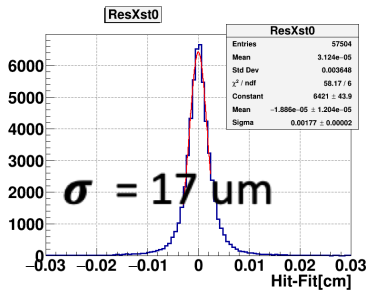
$$\sigma Y_{\text{MWPC}} =$$

$$\sigma X_{\text{MWPC}} * \sqrt{2}$$

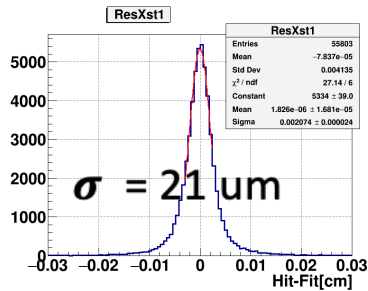
Residuals for Upstream tracks (Hit - Fit)

Residuals X

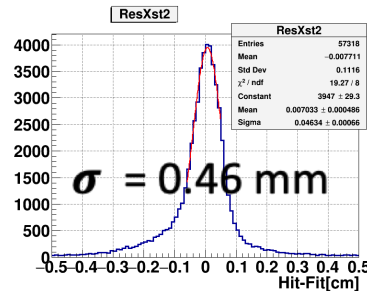
Silicon1



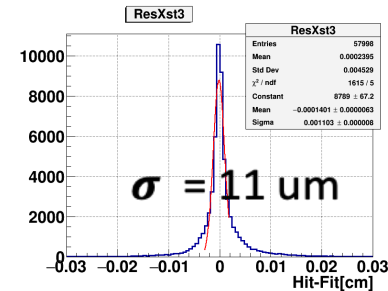
Silicon2



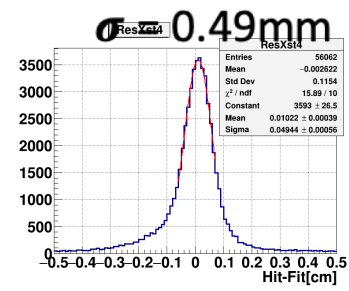
MWPC2



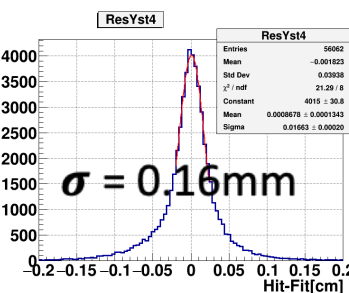
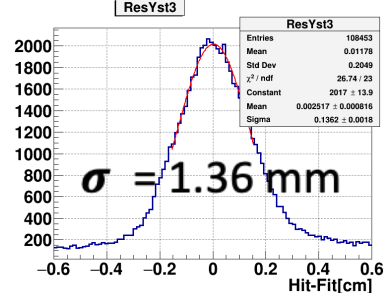
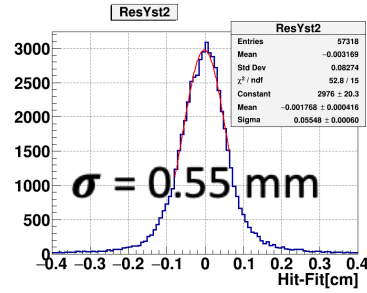
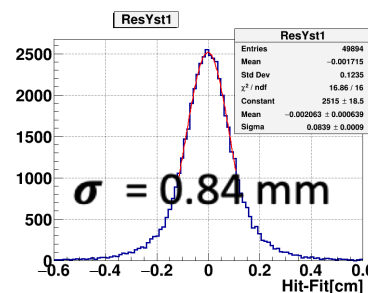
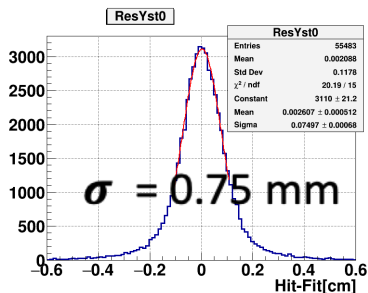
Silicon3



MWPC3



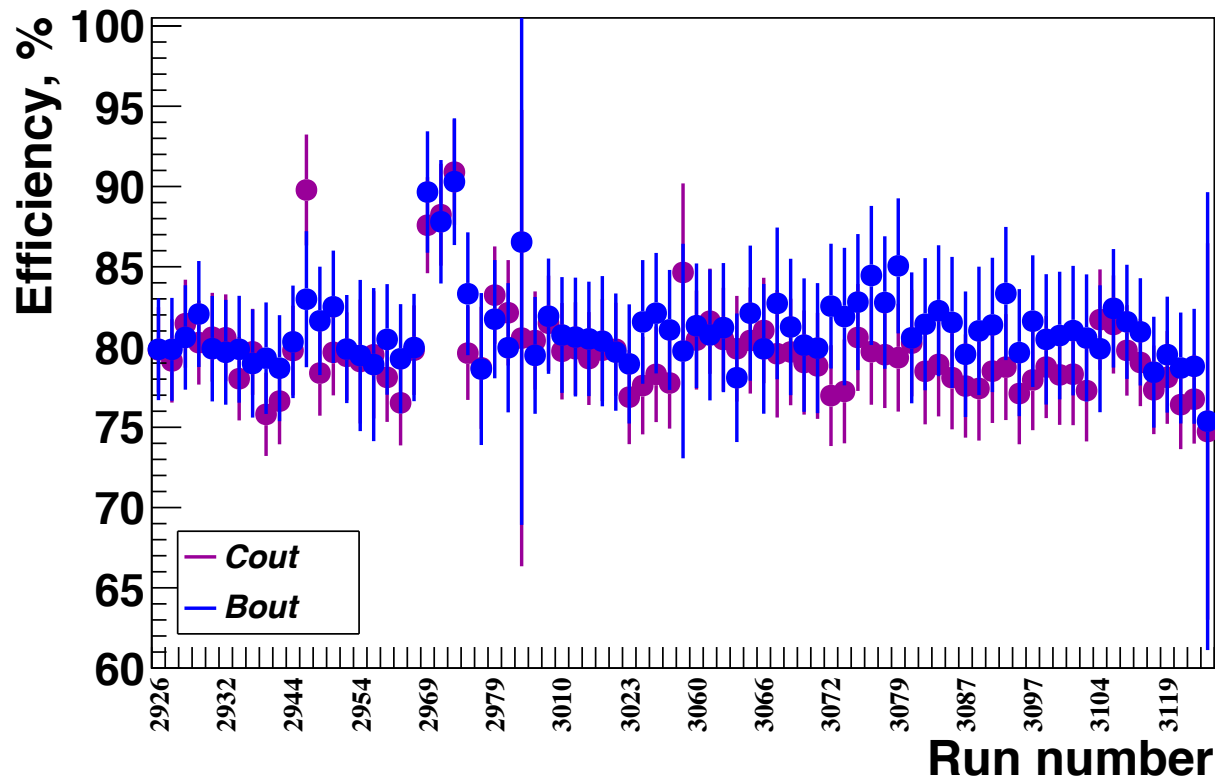
Residuals Y



Efficiency

Pics to be changed by Vasilisa
(they are correct, but X axis is not
labeled properly)

Courtesy of V. Lenivenko



MWPCp0 & (Upstream or Si)
MWPCp0

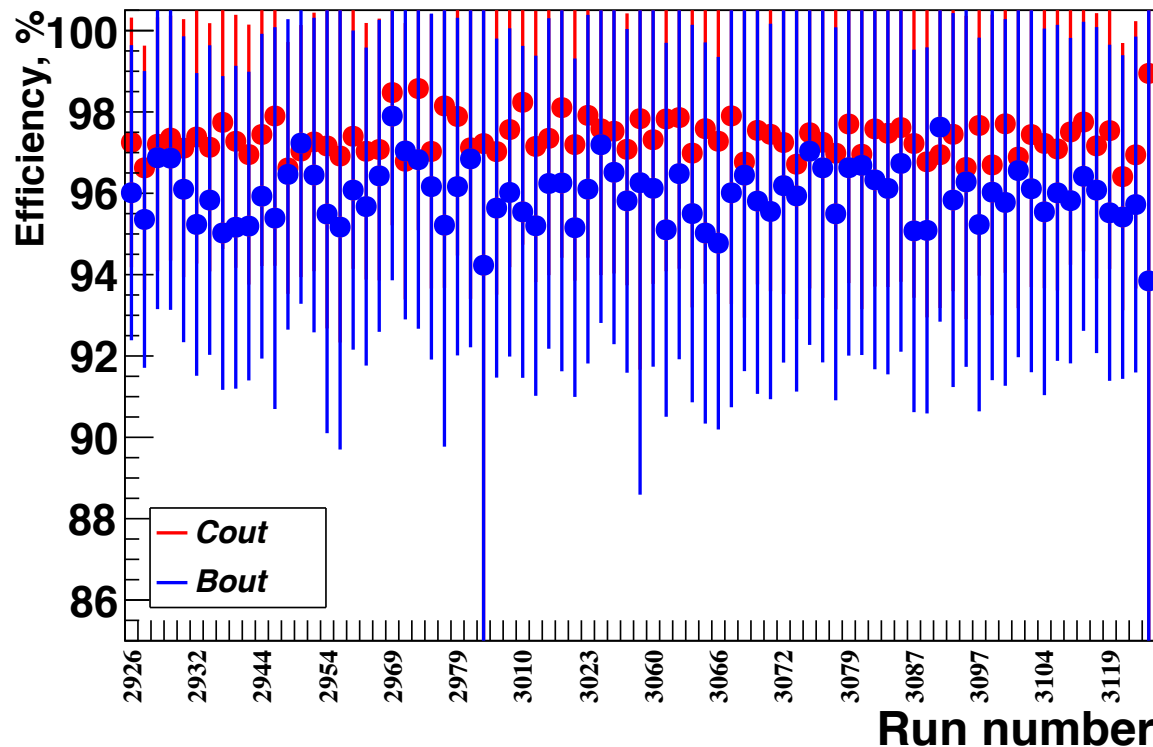
How often the track
after the target
(Upstream or Si) is
found relative to the
incoming track

Runs from the list of good runs chosen for the analysis

Efficiency

Pics to be changed by Vasilisa
(they are correct, but X axis is not
labeled properly)

Courtesy of V. Lenivenko



MWPCp0 & (MWPCp1 or Si)
MWPCp0

How often the track
after the target
(MWPCp1 or Si) is
found relative to the
incoming track

Runs from the list of good runs chosen for the analysis

Conclusions

Beam momentum loss around 21 MeV/c/nucleon, which is 253 MeV/c for C ion was obtained by BmnRoot and is consistent with other estimations

Realistic beam momentum before and after the target as well as before and after the analyzing magnet was obtained as well

PID: good separation of B and Be isotopes using the amplitudes of BC counters

Tracking before the analyzing magnet was done in Si, MWPC, and using combination of these detector systems. The fraction of events with a track in Si or MWPC is around 97%, and the fraction of events with a combined track or Si is around 80%

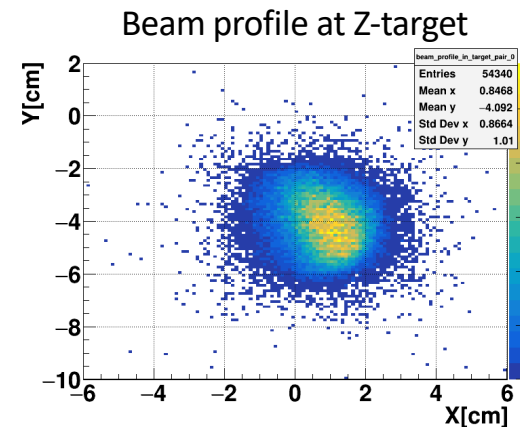
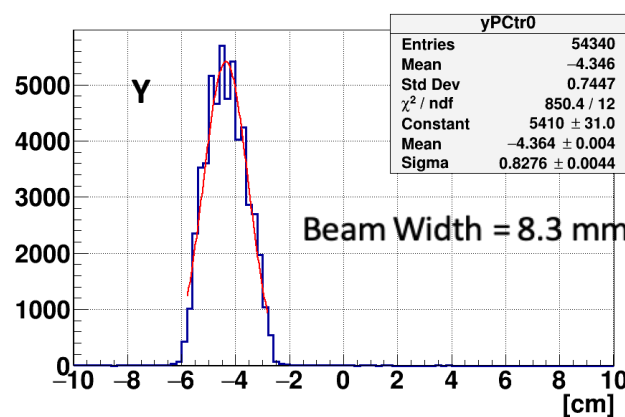
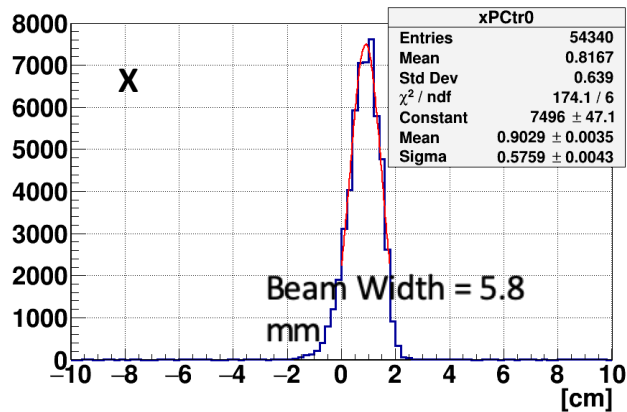
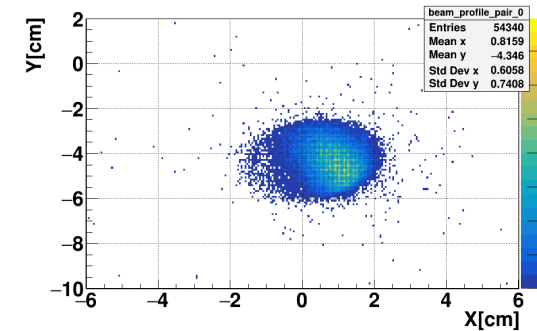
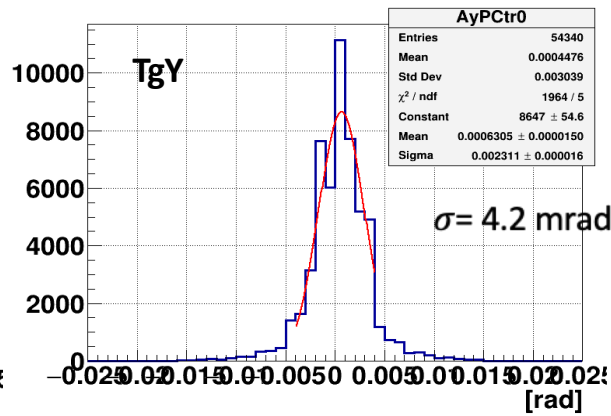
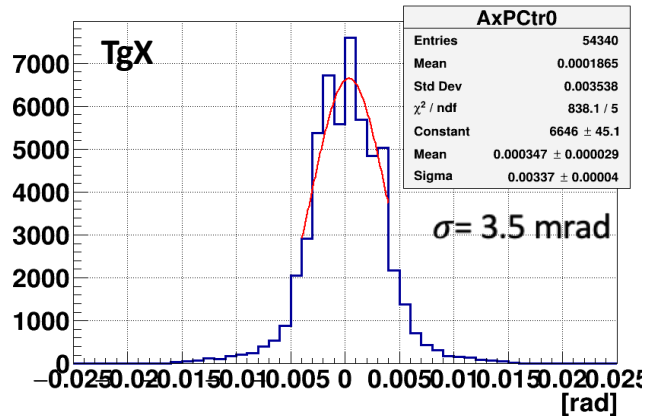
Backups



MWPC-Track (Pair0) Parameters upstream the target

Run 3430, empty target | Cin

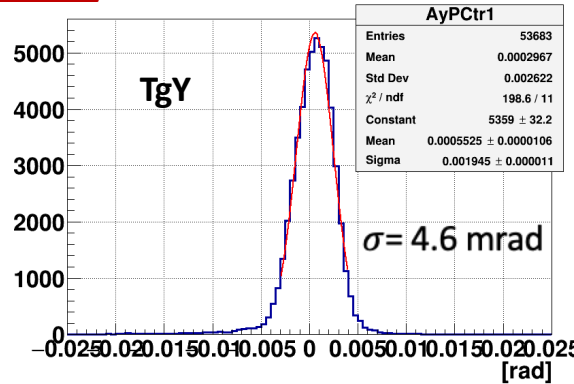
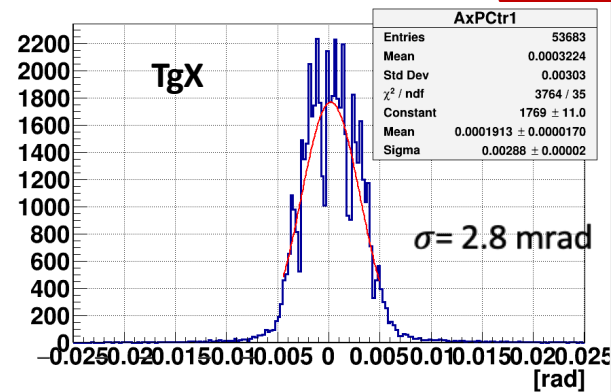
Beam profile at Z middle =
(PC0+PC1)/2



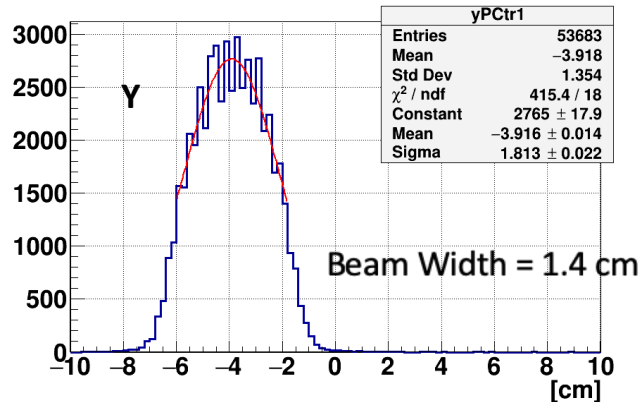
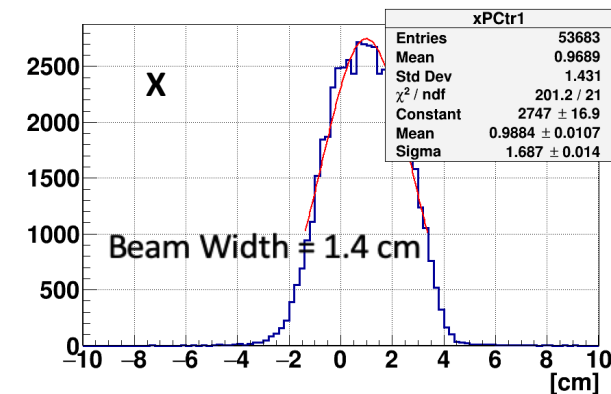
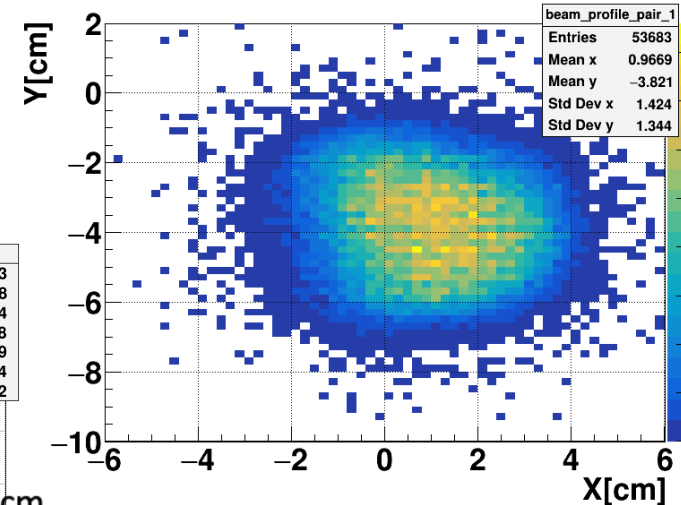
at Z middle = (PC0+PC1)/2

MWPC-Track (Pair1) Parameters downstream the target

Run 3430, empty target CinCout cut

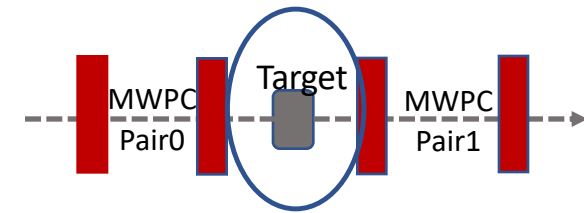
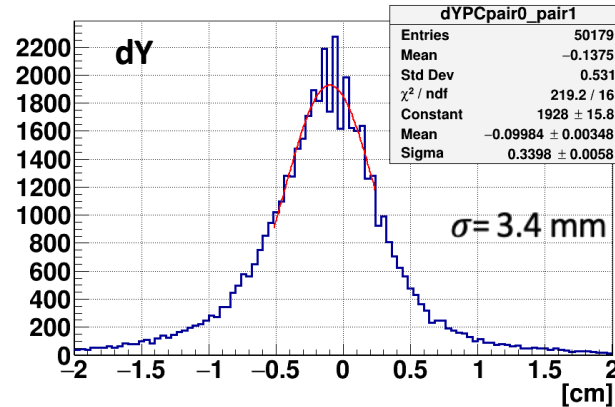
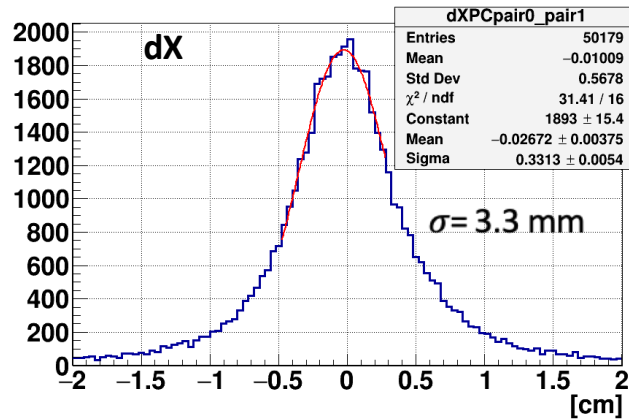


Beam profile at Z middle =
(PC2+PC3)/2

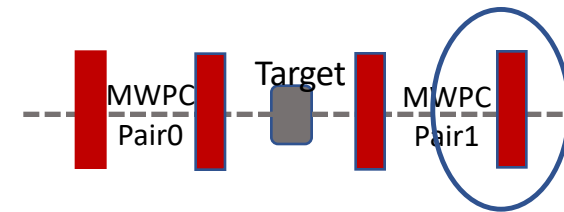
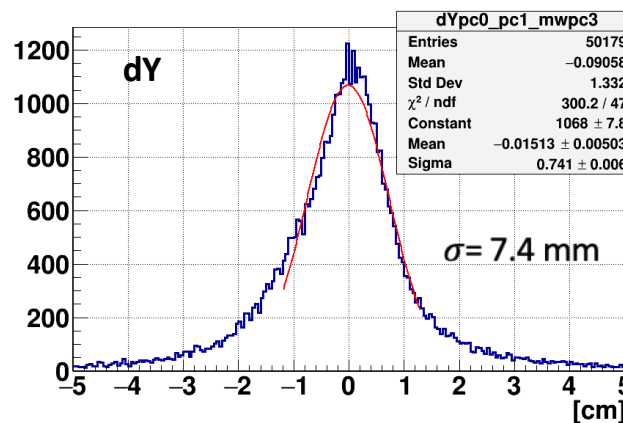
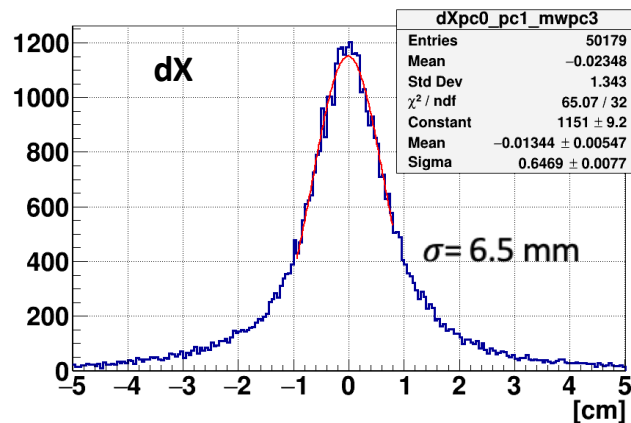


at Z middle = (PC0+PC1)/2

Pair0 – Pair1 matching; Run 3430 (empty target); CinCoutcut



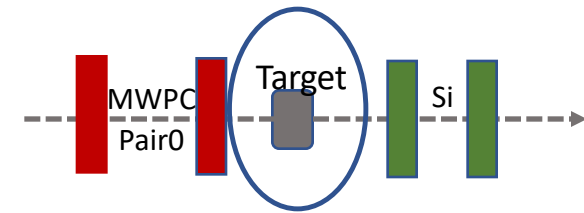
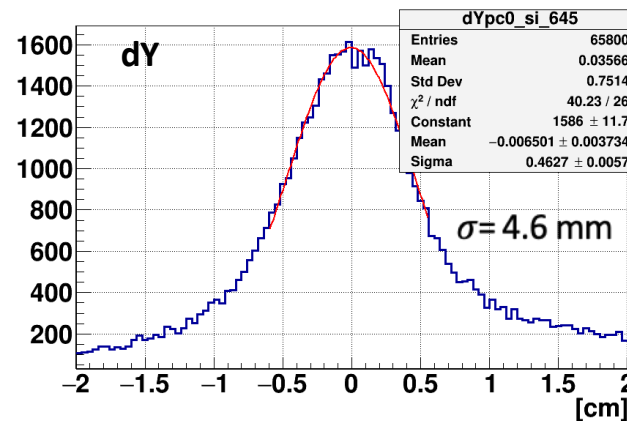
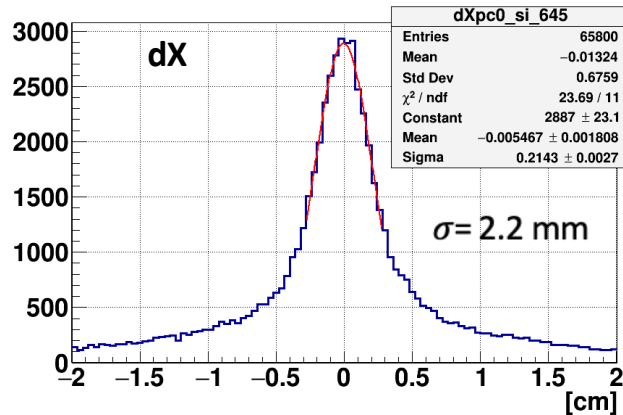
At Z-target:
Widths are minimal



Extrapolation to Z-mwpc3

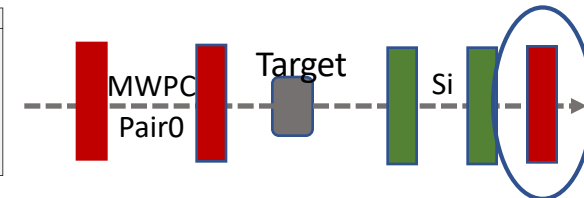
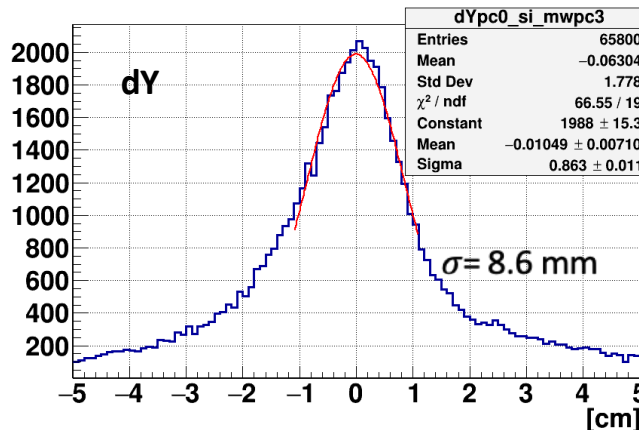
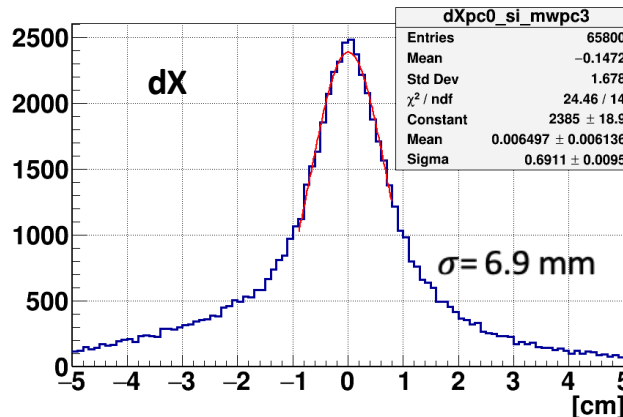
Pair0 – Si matching; Run 3430 (empty target); CinCoutcut

Highest statistics : 66 Key



At Z-target: Widths are minimal

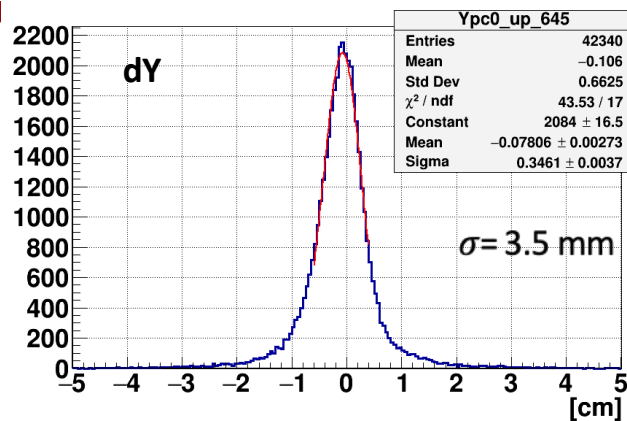
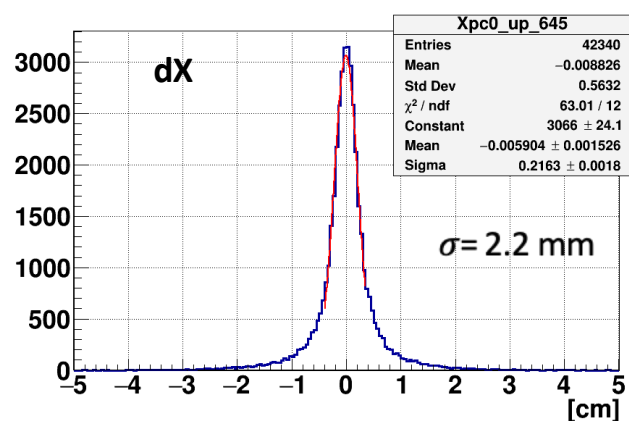
SigmaX is better & SigmaY is worse due to SiDet accuracy



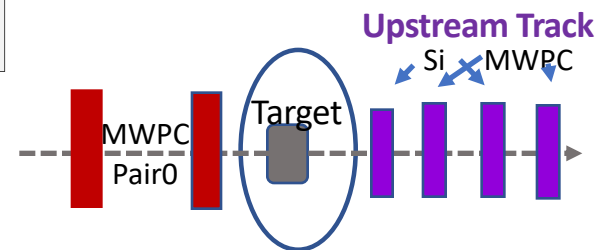
Extrapolation to Z-mwpc3

All MWPC & SiDet are aligned correspondently the magnet: all means = 0

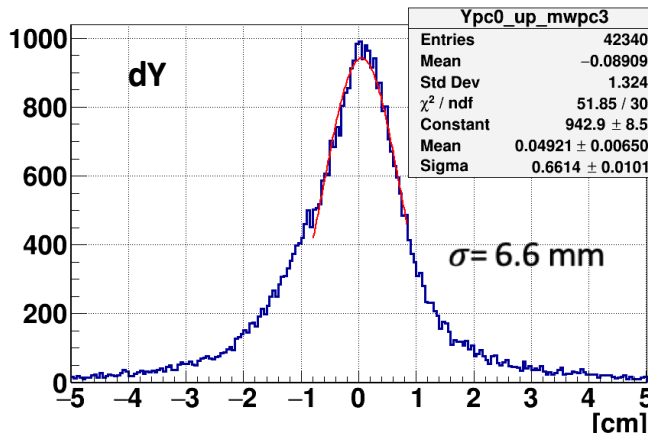
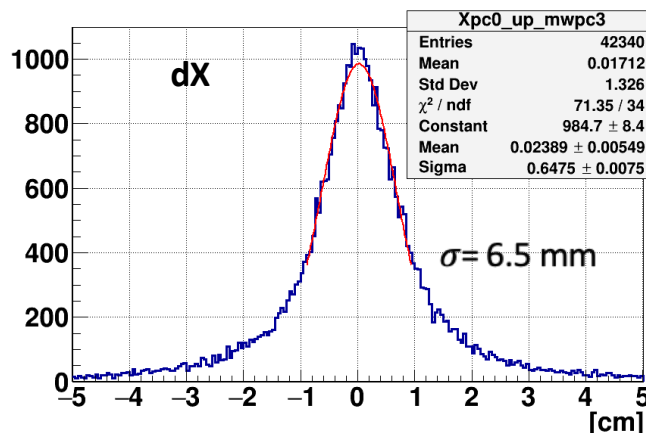
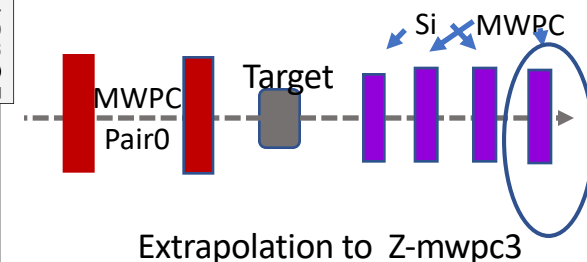
Pair0 – Upstream matching; Run 3430 (empty target); CinCoutcut



Statistics is 1.5 times lower: 42 Kev



At Z-target: Widths are minimal
SigmaX is similar to Pair0-Si matching
But SigmaY is better



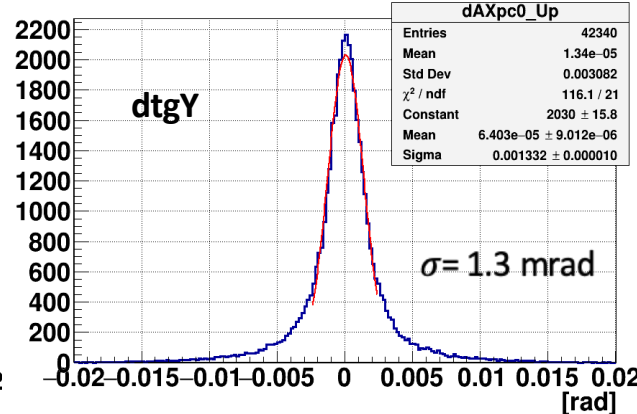
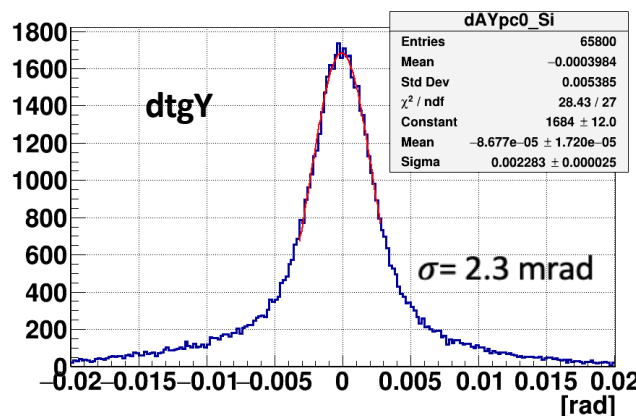
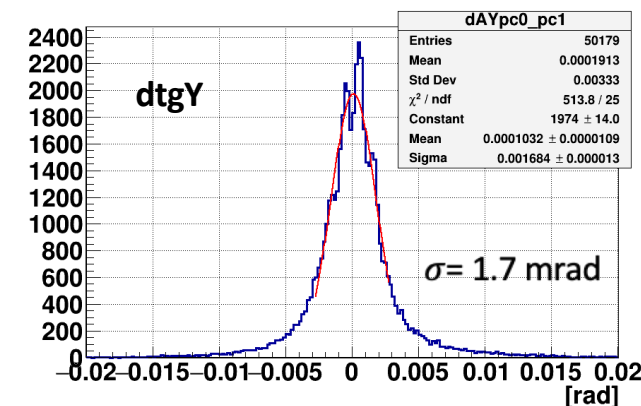
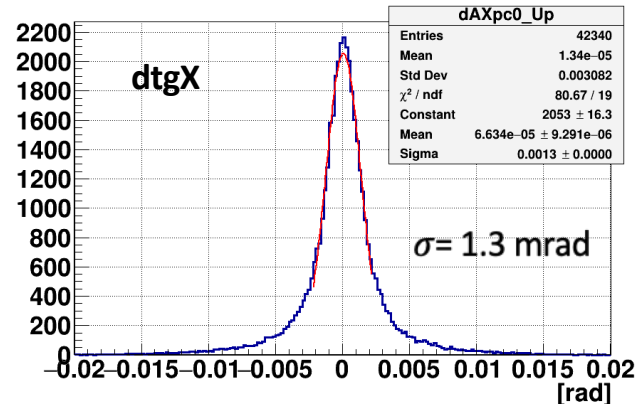
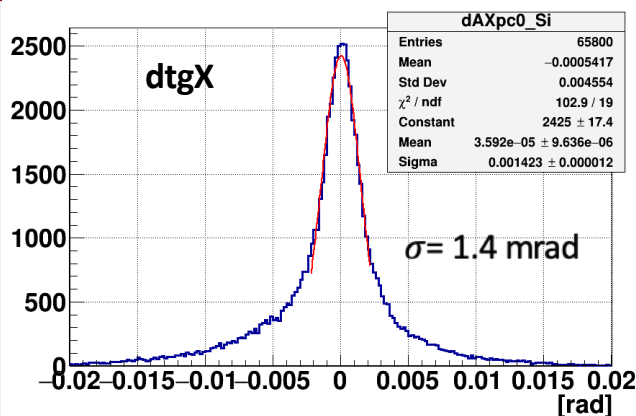
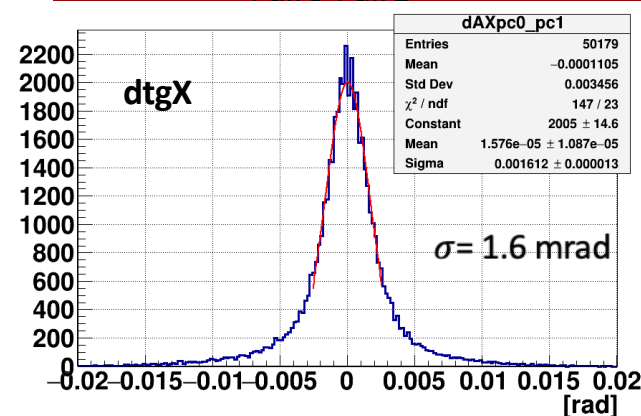
All MWPC & SiDet are aligned correspondently the magnet: all means = 0

Angles matching; Run 3430 (empty target); CinCoutcut

Pair0-Pair1

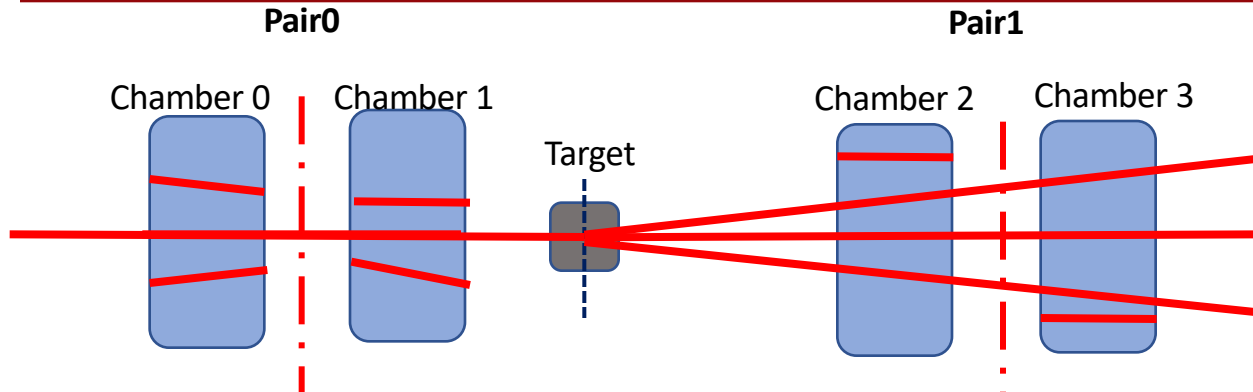
Pair0-Si

Pair0-Upstream



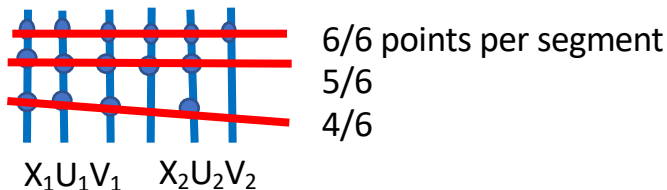
All MWPC & SiDet are aligned correspondently the magnet: all means = 0
 Pair0-Upstream Difference is the best but statistics is lower

Improved Track Reconstruction in MWPCs



1. Track-segment = reconstructed straight track in one chamber

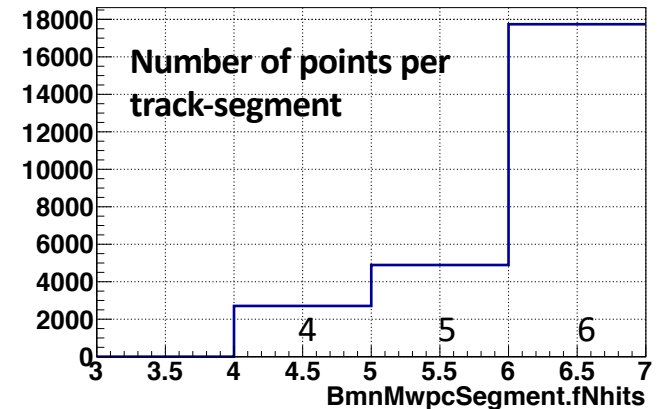
2. Track-segment formed using



3. Reconstruct & fit track-segment in each chamber

4. Extrapolate segments to $Z_{0,1} = (Z_1 + Z_2)/2$ & select best pairs by χ^2 criteria, **angles are not taken into account**

5. MWPC track in Pair0 and Pair1

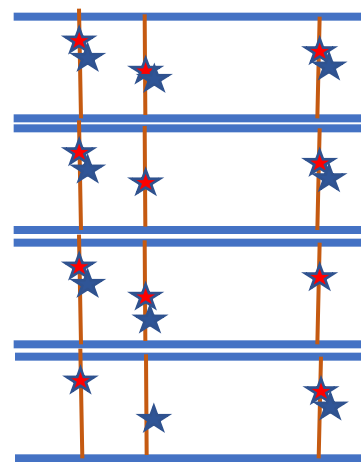


Track Reconstruction in Silicon Detector

1. **X and X' (2.5°)** neighboring fired strips – cluster center $CoG = \frac{\sum^N A_i * i}{\sum^N A_i}$, A_i – charge amplitude on i-th strip

2. Track Reconstruction using various cases

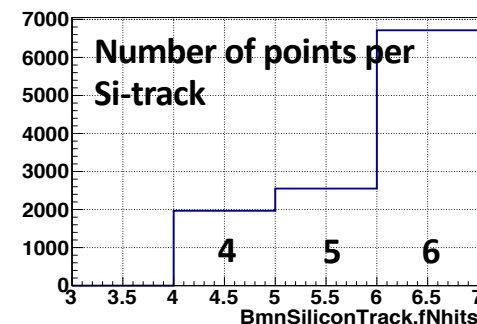
- Case 1: 6 hits (3 spatial points) per track
- Case 2: 1 spatial point in st. 1 and 3 + X / X' in st.2
- Case 3: 1 spatial point in st. 1 and 2 + X / X' in st. 3
- Case 4: (X + X') in (st. 1 + st. 2) + spatial point in st. 3



★ - X hit
★ - X' hit

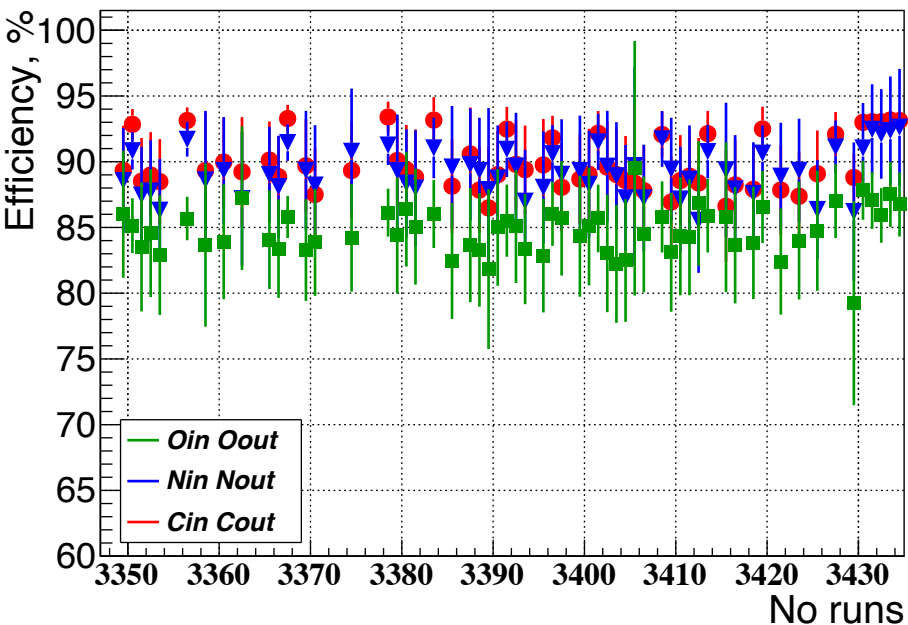
3. **Straight line fit on X & X'** – coordinates, rough Y – coordinate: $Y = \frac{X' - X}{tg 2.5^\circ}$

Accepted track goes out from the target area



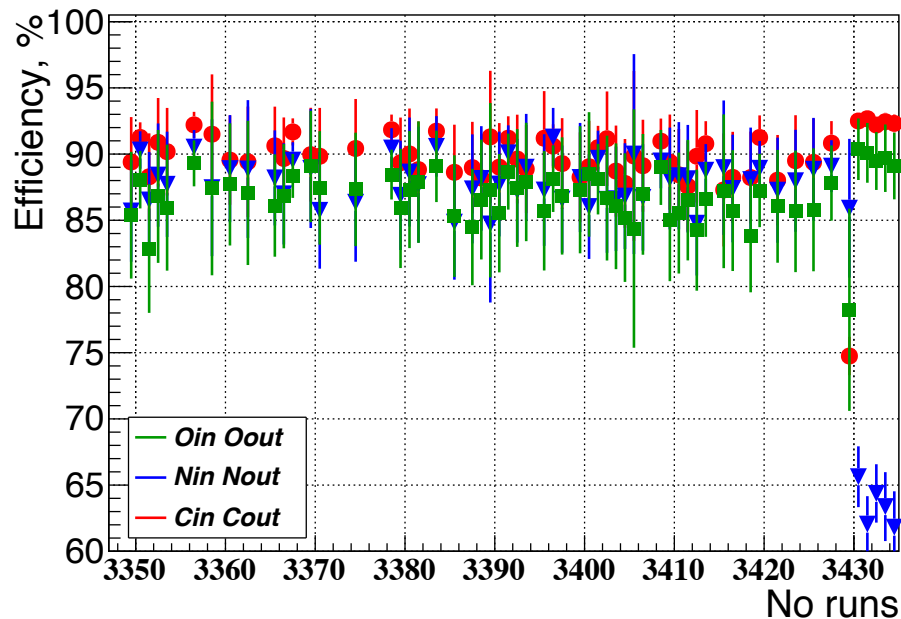
MWPC Track Efficiency with Ion cuts

Efficiency per Run $N_{\text{tracks}}(\text{pair0}) / N_{\text{tracks}}(\text{pair1})$



Systematically Efficiency C out > N out > O out
“Or” Trigger Efficiency is higher, than “&” Trigger Efficiency

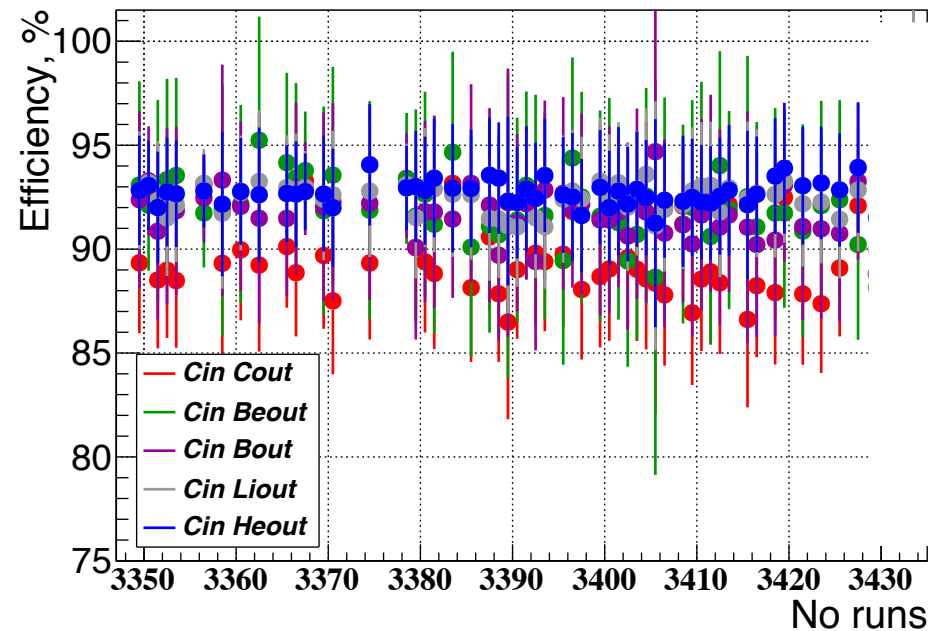
Efficiency per Run $N_{\text{tracks}}(\text{pair1}) / N_{\text{tracks}}(\text{pair0})$



Difference is not so far

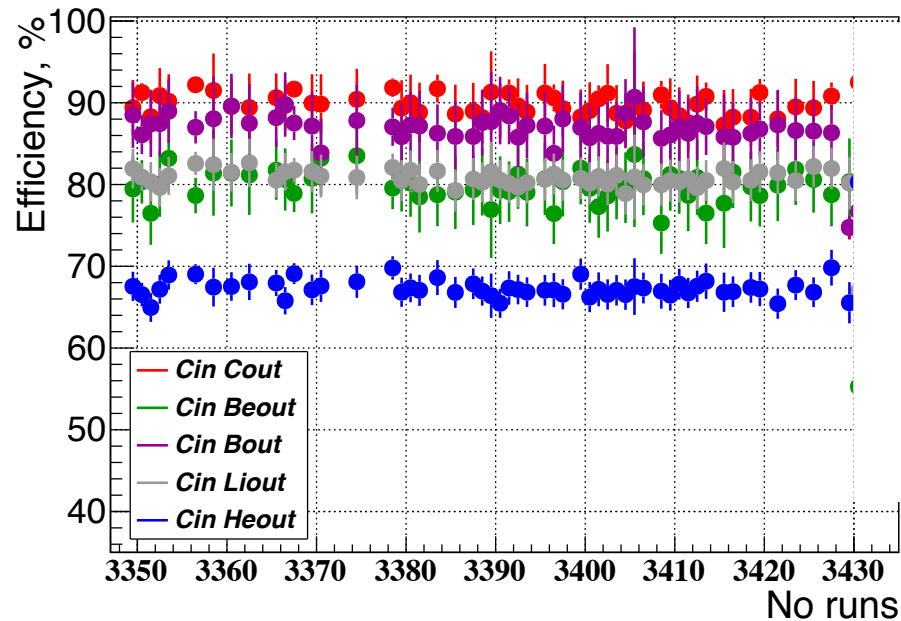
MWPC Track Efficiency with Ion cuts

Efficiency per Run $N_{\text{tracks}}(\text{pair0}) / N_{\text{tracks}}(\text{pair1})$



Difference is not so far

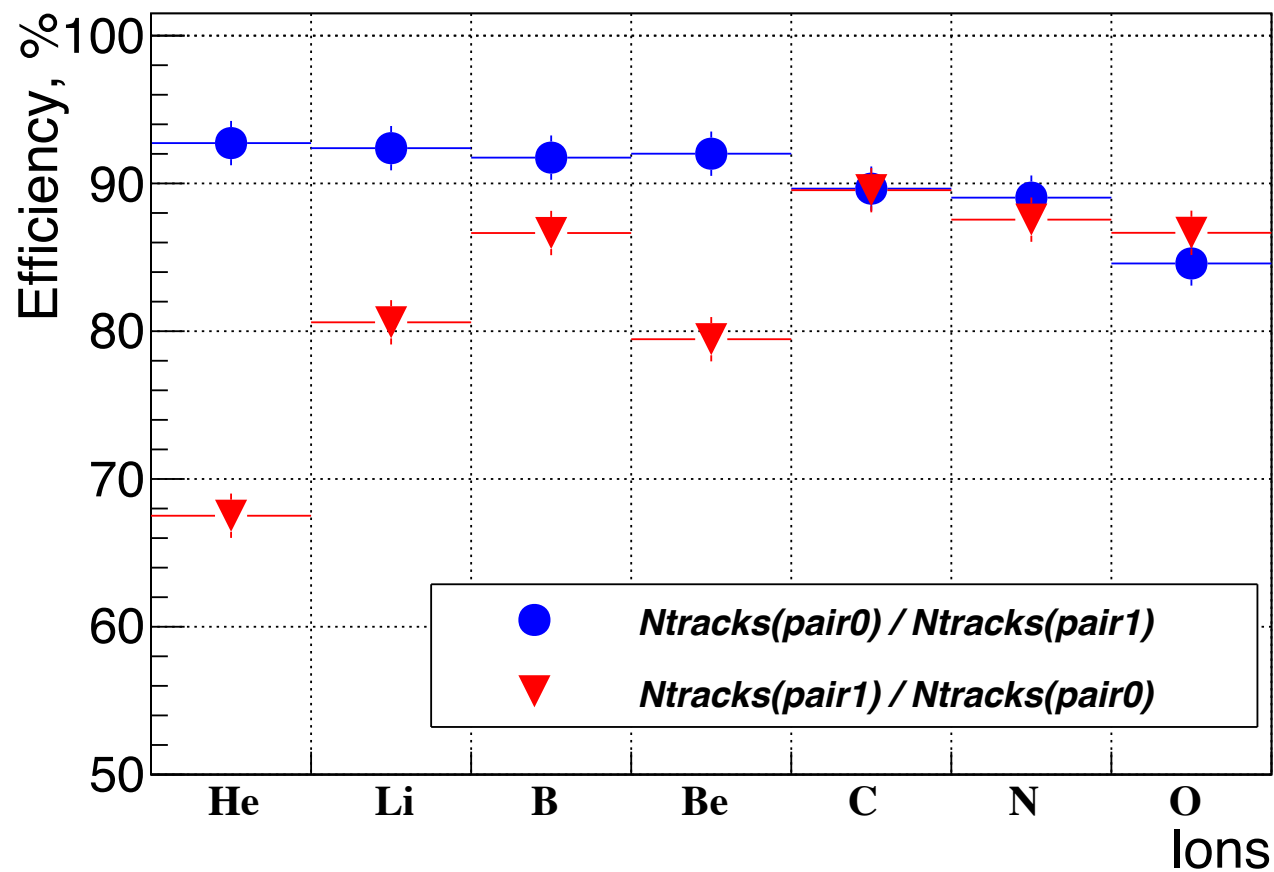
Efficiency per Run $N_{\text{tracks}}(\text{pair1}) / N_{\text{tracks}}(\text{pair0})$



Efficiency increases from He to C

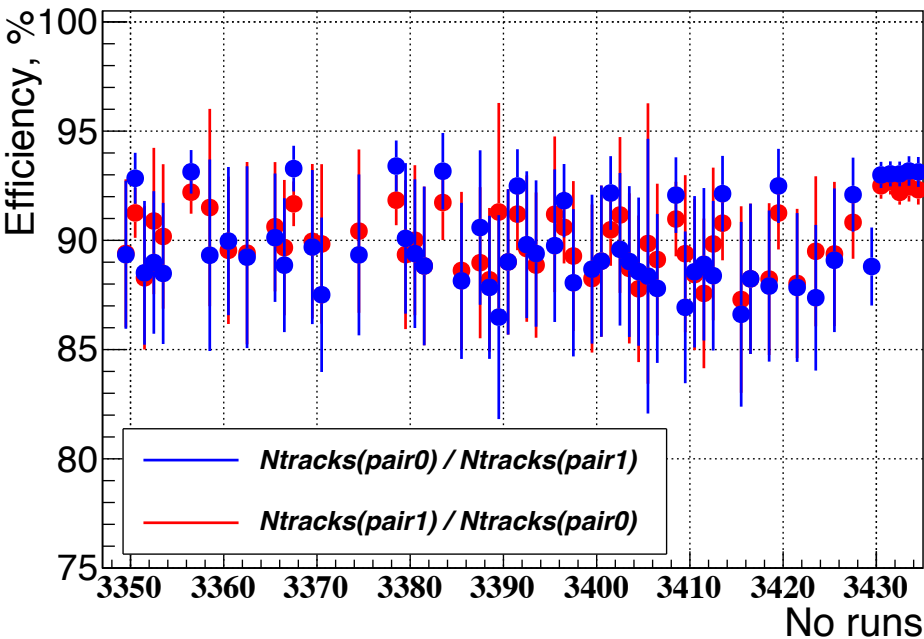
Some particularity for Be (trigger conditions),
see below

MWPC average Efficiency for Ions



Track Efficiency

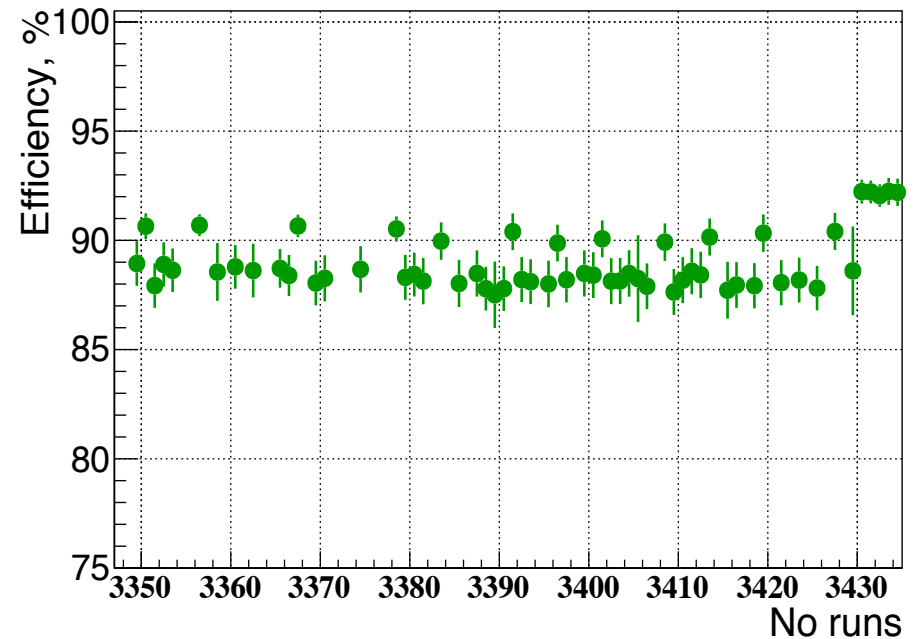
Efficiency per Run: Cin Cout



Efficiency pair1/pair0 > pair0/pair1
“Or” Trigger Efficiency is higher, than “&” Trigger Efficiency

Upstream track

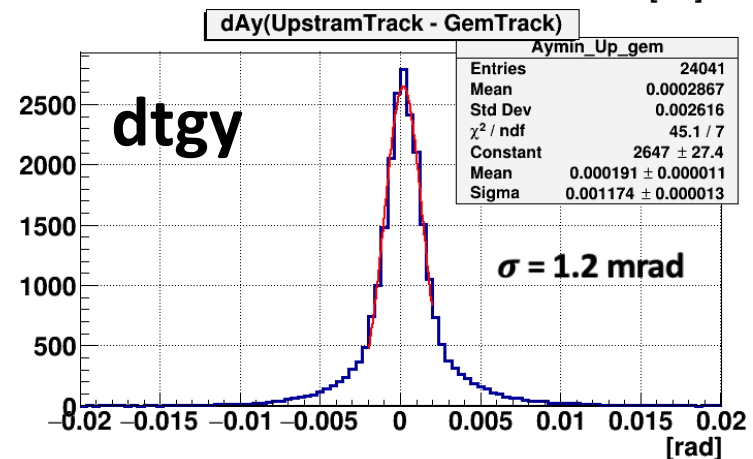
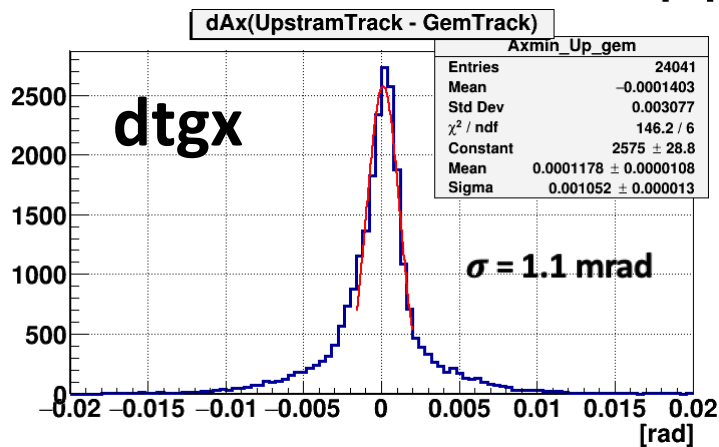
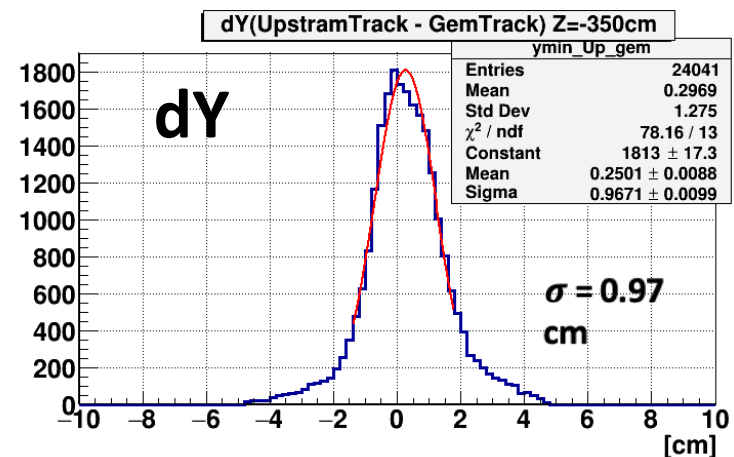
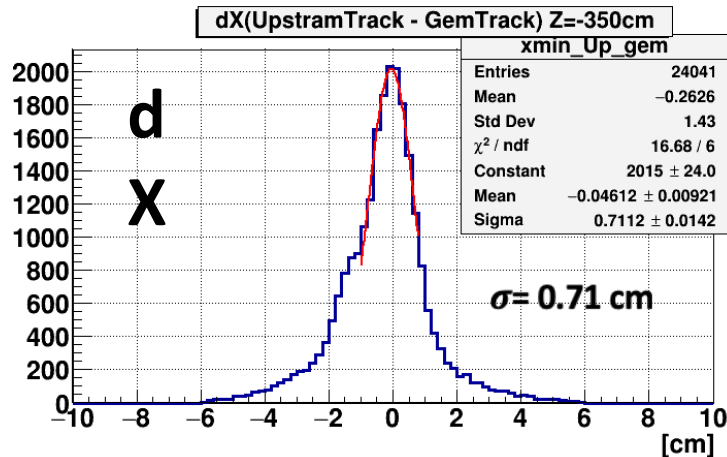
Efficiency per Run $Ntracks(pair0) / Ntracks(pair1)$ & $N(Si + PC)tracks$



Efficiency with Si conditions is consistent

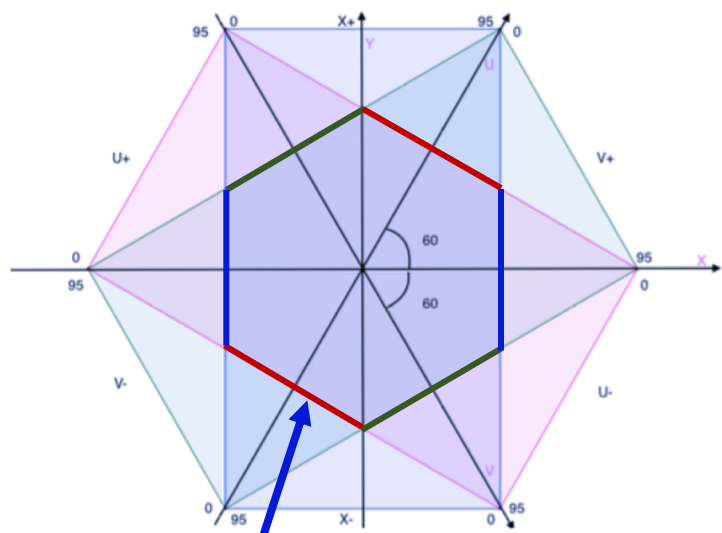
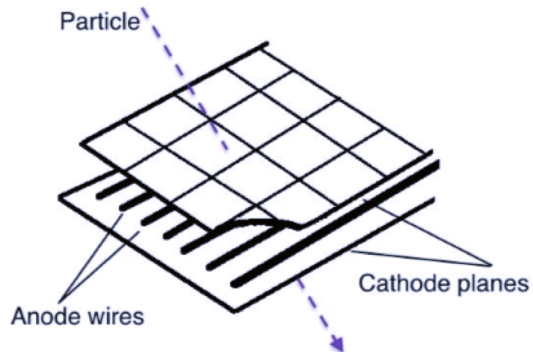
GemTracks extrapolated to Z = -350 (run 3430; empty target)

Difference between UpstreamTracks & GemTracks





Multi Wire Proportional Chambers



Each MWPC has 6:
 two **X**, two **U** and two **V**-planes
 with wire angles $0^\circ, \pm 60^\circ$.
 Wire pitch is $d = 2.5 \text{ mm}$.
 Coordinate resolution is $d/\sqrt{12} = 0.72 \text{ mm}$.

$$U = \frac{x + \sqrt{3}y}{2},$$

$$V = \frac{x - \sqrt{3}y}{2},$$

This point should satisfy the following condition:

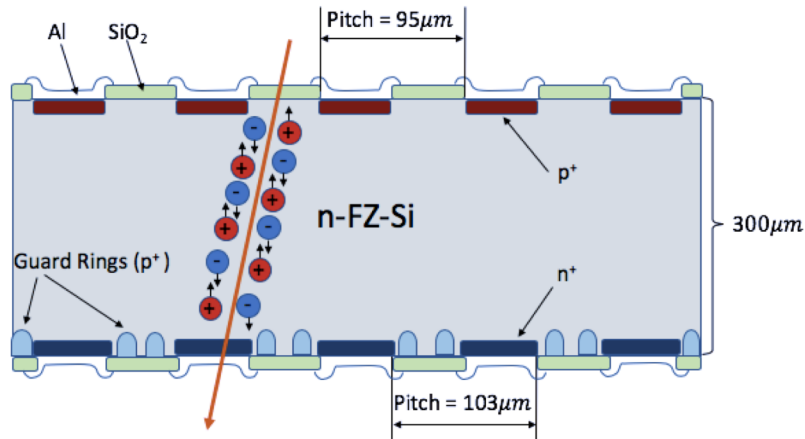
$$V + U - X = 0$$



The intersection of these planes is a working area.



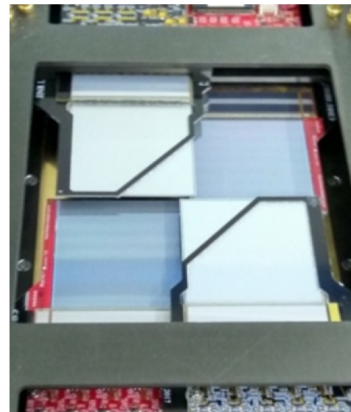
Silicon Tracking detector



Double-Sided Silicon Detectors
(DSSD)
2-coordinate Si strip detector

Capability of stable operation in conditions of high loadings
up to 10^6 Hz/cm²
Response time is 10-15 ns
Coordinate resolution ~ 50 μm

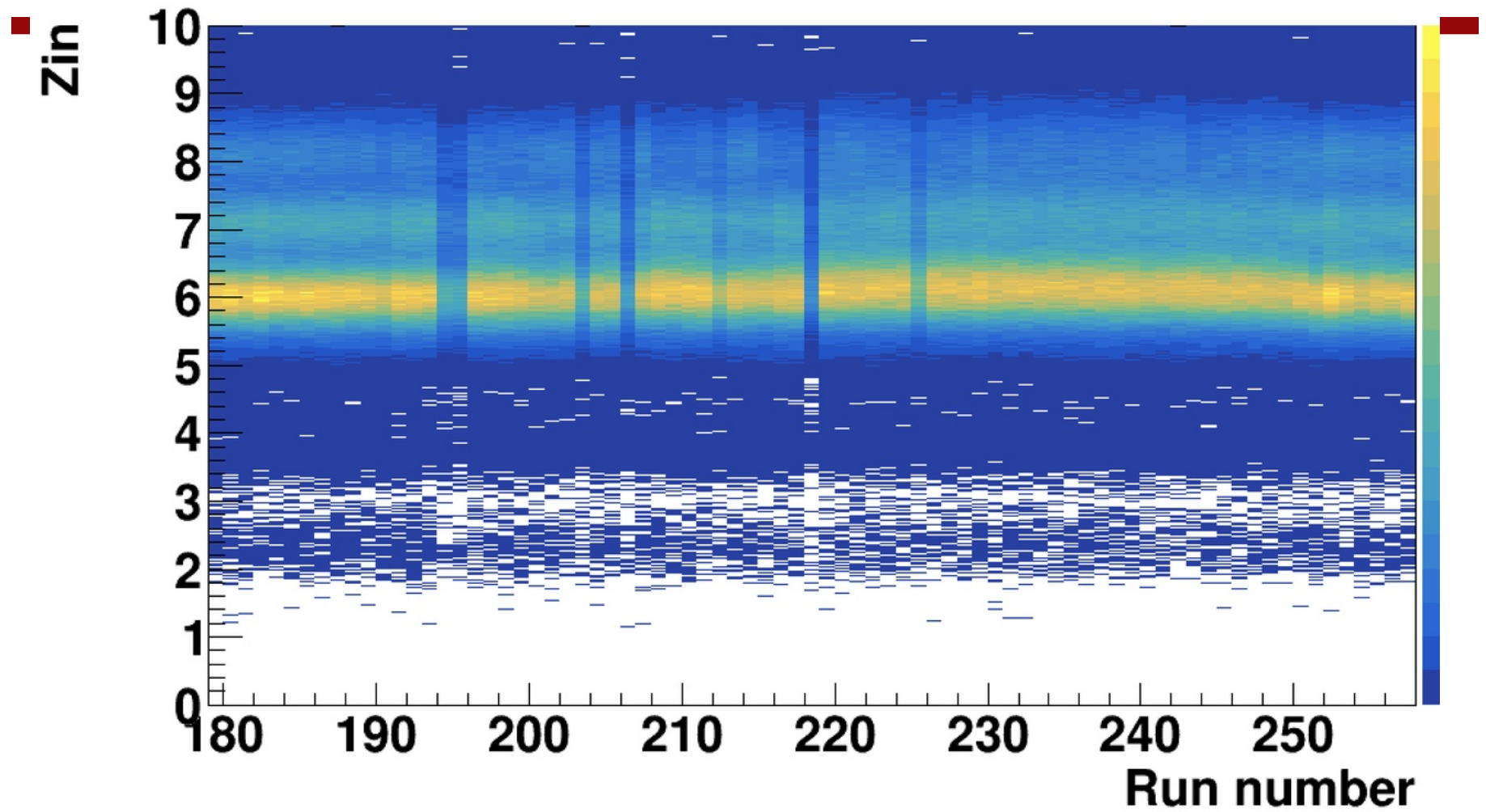
640 X strips with 0°
640 X' strips with 2.5°
The pitch of X strips : 95 μm
The pitch of X' strips : 103 μm.
Thickness of detectors is 300 μm

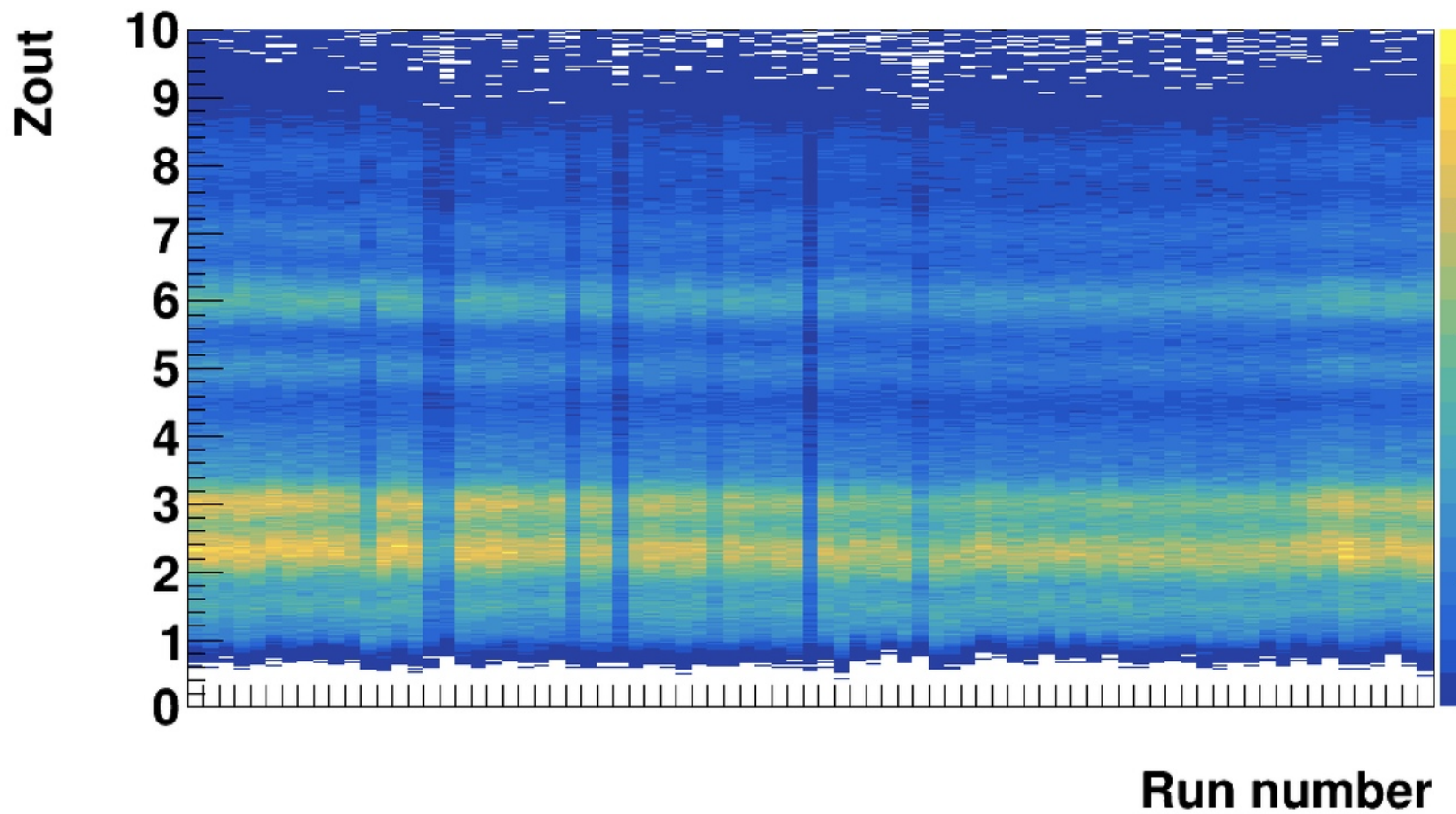


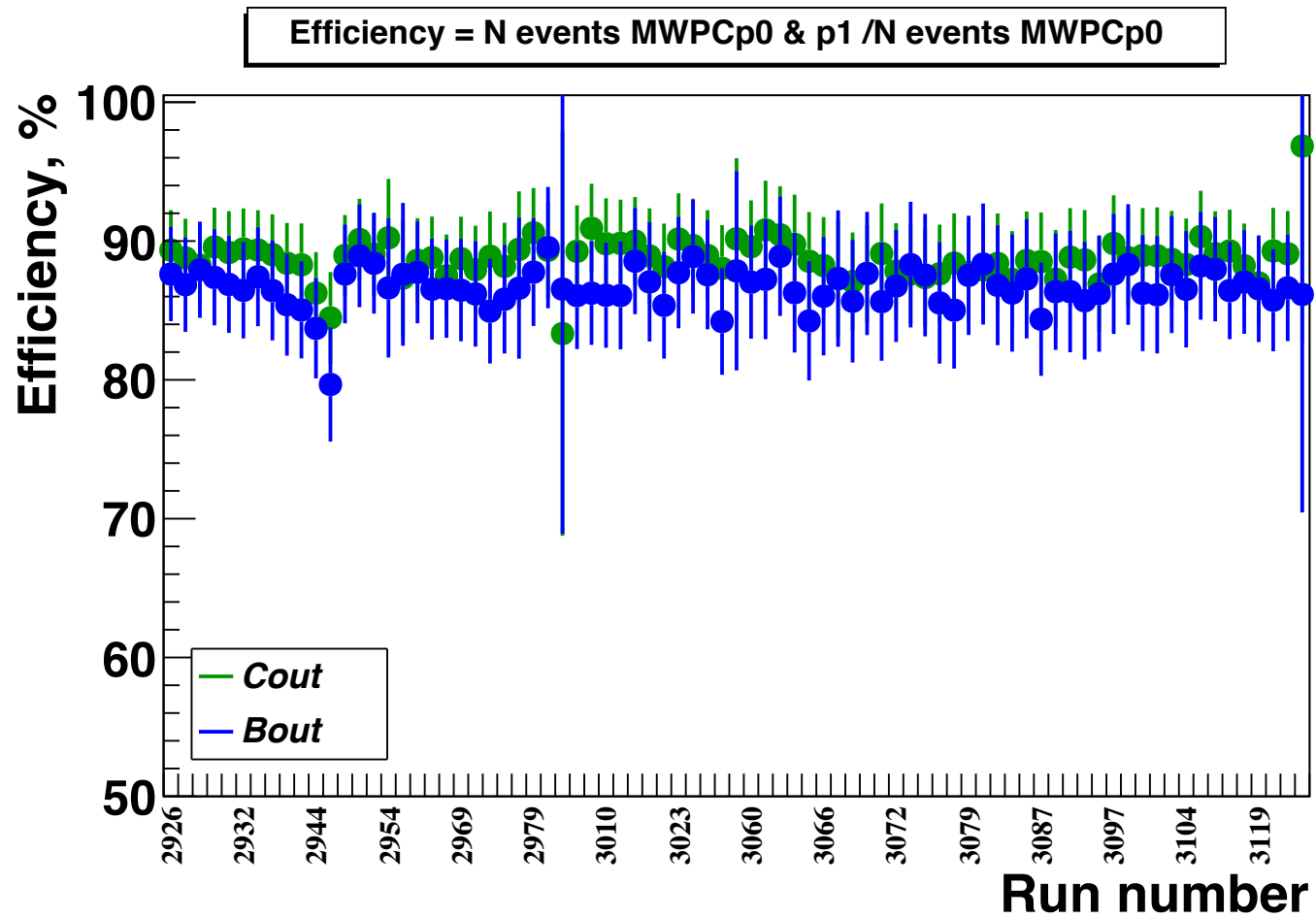
The contribution to the collected charge value is given by both electron and hole flow.

Full sensitive size of 12 x 12 cm²

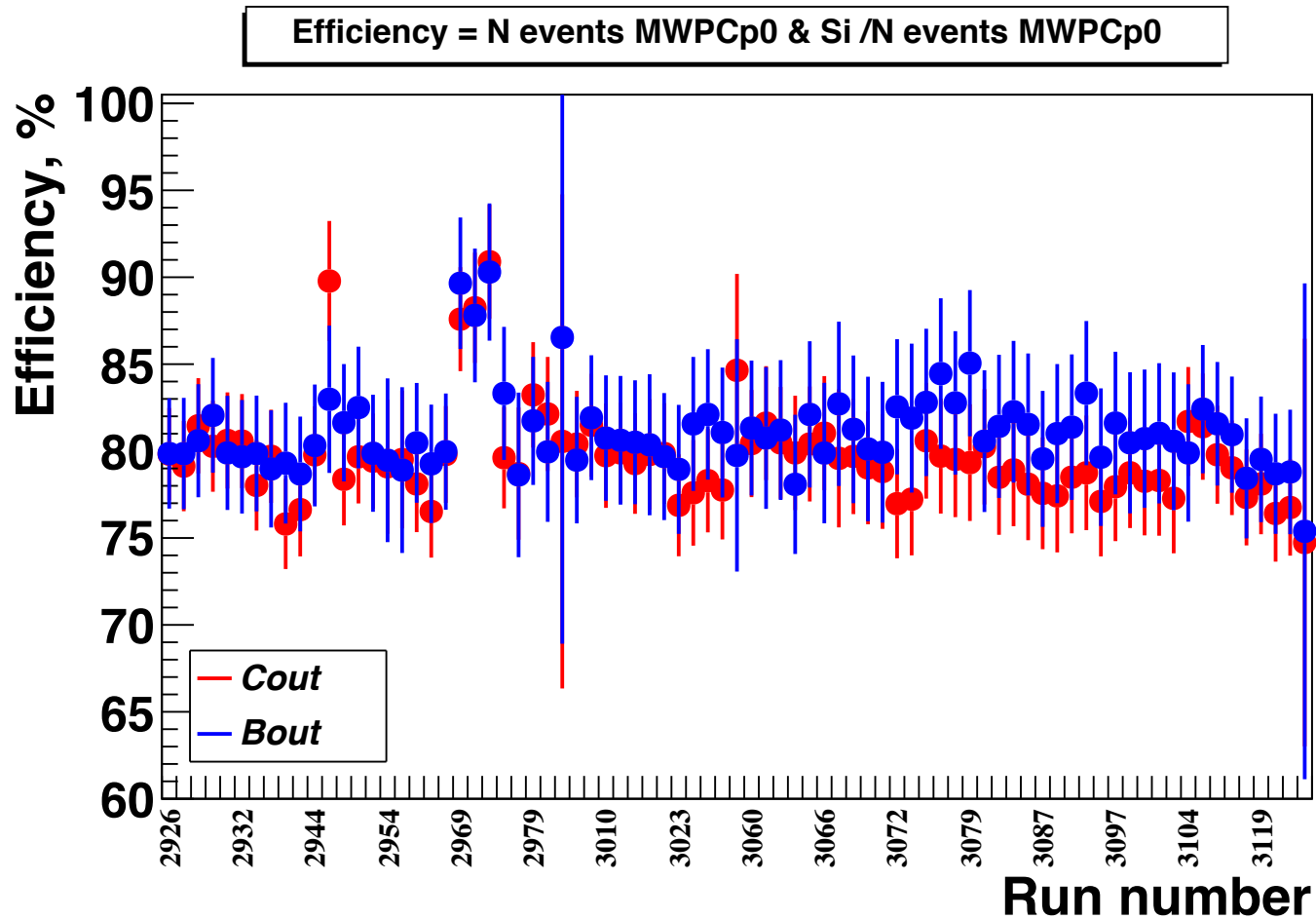
Full sensitive size of 25 x 25 cm²







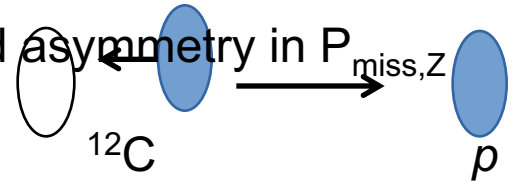
Compare MonteCarlo to Exp. Data for different S^{-N}



Physics Question:

Holds Constituent Counting Rule in low-Energy ``QCD``?

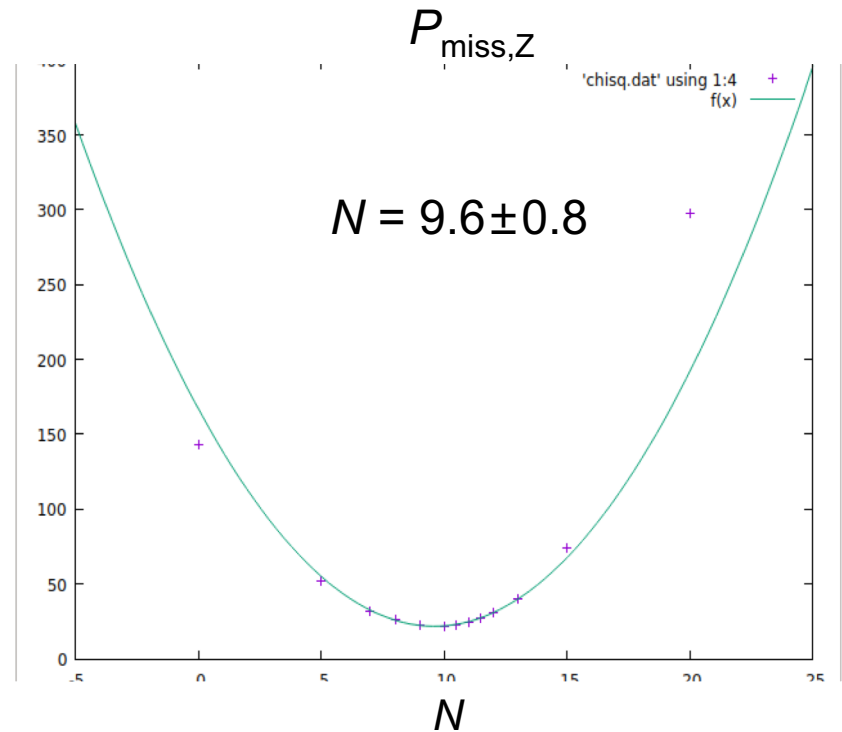
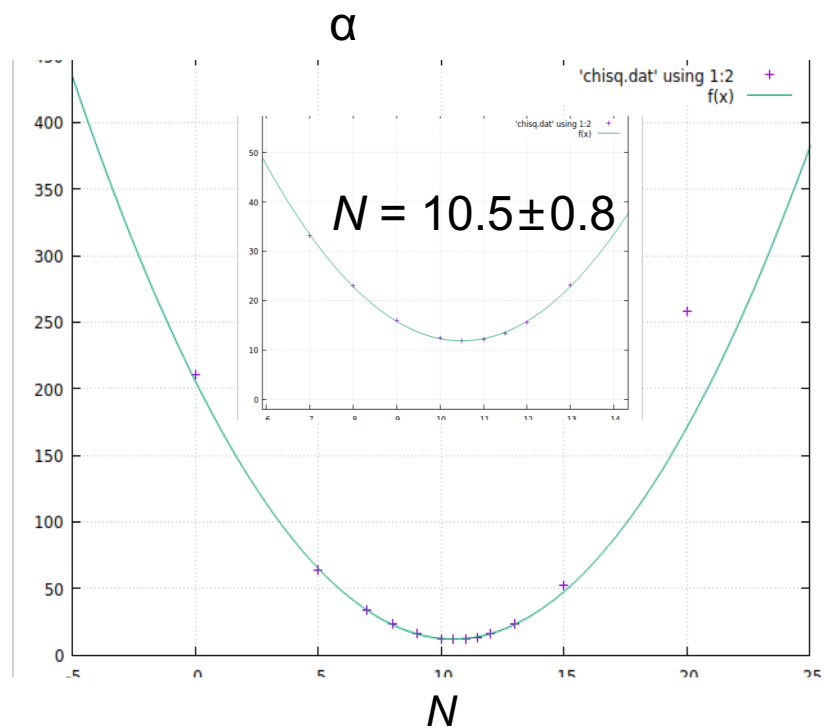
- scaling $d\sigma/dt \sim S^{-N} f(t/s)$ for 90° pp elastic scattering, with $N=10$
- Does it hold in nuclei (for non-QCD degrees of freedom) at “small” momenta?
- anti-parallel momenta result in small S , lead to shift and asymmetry in $P_{\text{miss},Z}$
- compare to $p, 2p$ MonteCarlo with scaling like



- for different N
- $\left(\frac{d\sigma}{dt}\right) \sim S^{-N} \cdot (1 - \cos^2(\theta_{cm}))^{-4\gamma_i}$

S Scaling: MC vs. Experiment

Finding minimum N



Quadratic fit in limited range $N[6,14]$

Summary: $^{12}\text{C}(p,2p)^{11}\text{B}$

We are able to:

- .Select incoming beam and outgoing fragment in inverse kinematics
- .Reconstruct reaction vertex with arm detectors
- .Select protons (reject pions) under large scattering angle
- .Determine missing momentum in QE scattering process
- .Show S scaling in ^{12}C

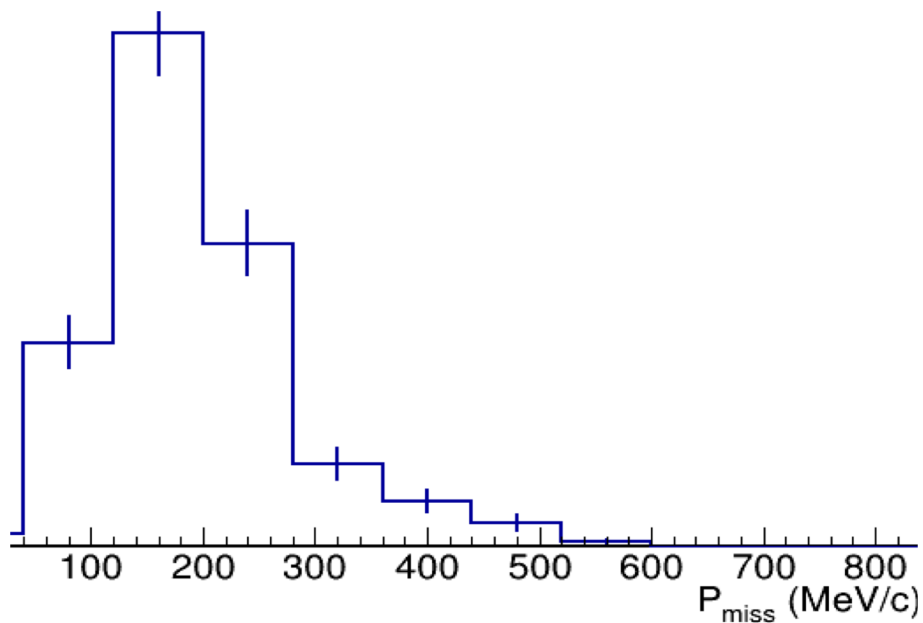
Next Steps

Initiated a task force to eventually combine all sub-systems into one analysis:

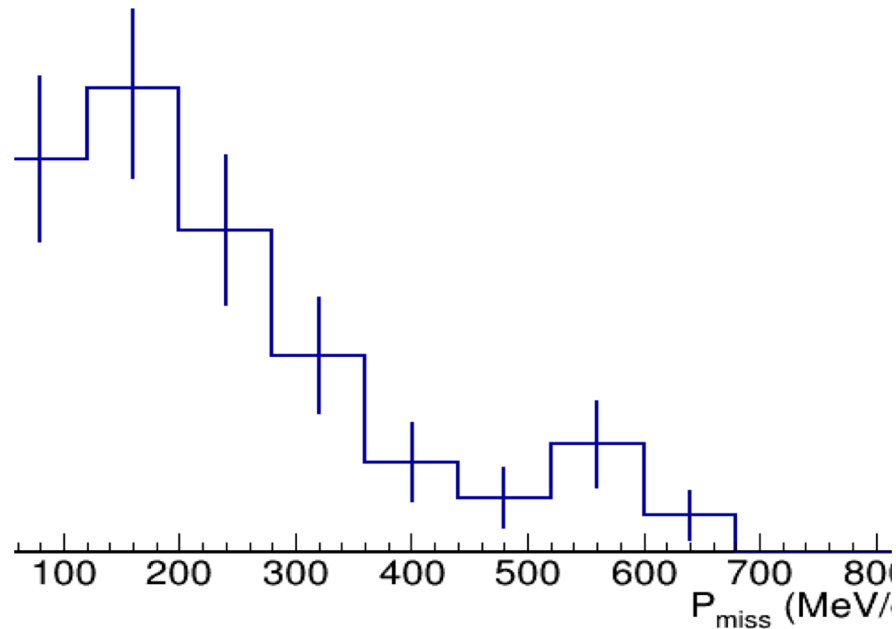
- .Proton arm analysis and fragment momentum
- .S scaling
- .QE on N and O
- .SRC channels
- .Fragment production and simulations

Missing Momentum ^{11}B vs. ^{10}B

$^{12}\text{C}(p,2p)^{11}\text{B}$

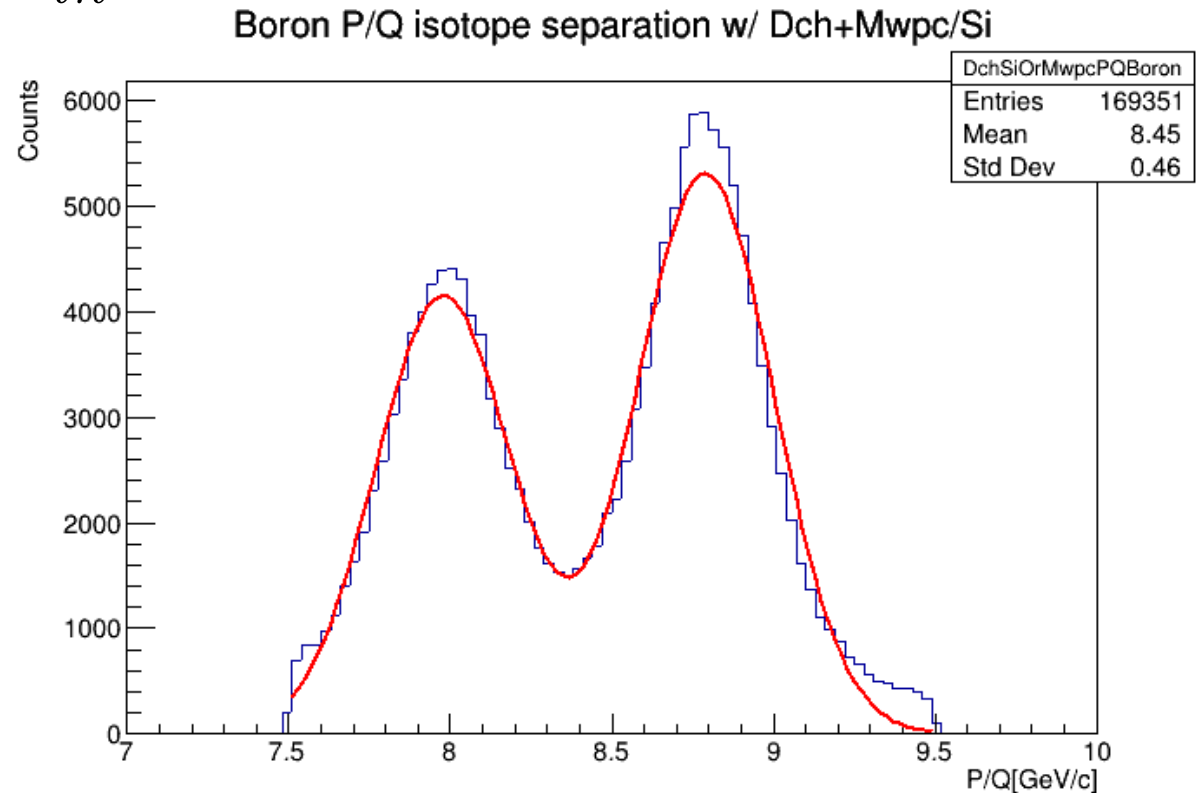


$^{12}\text{C}(p,2pX)^{10}\text{B}$

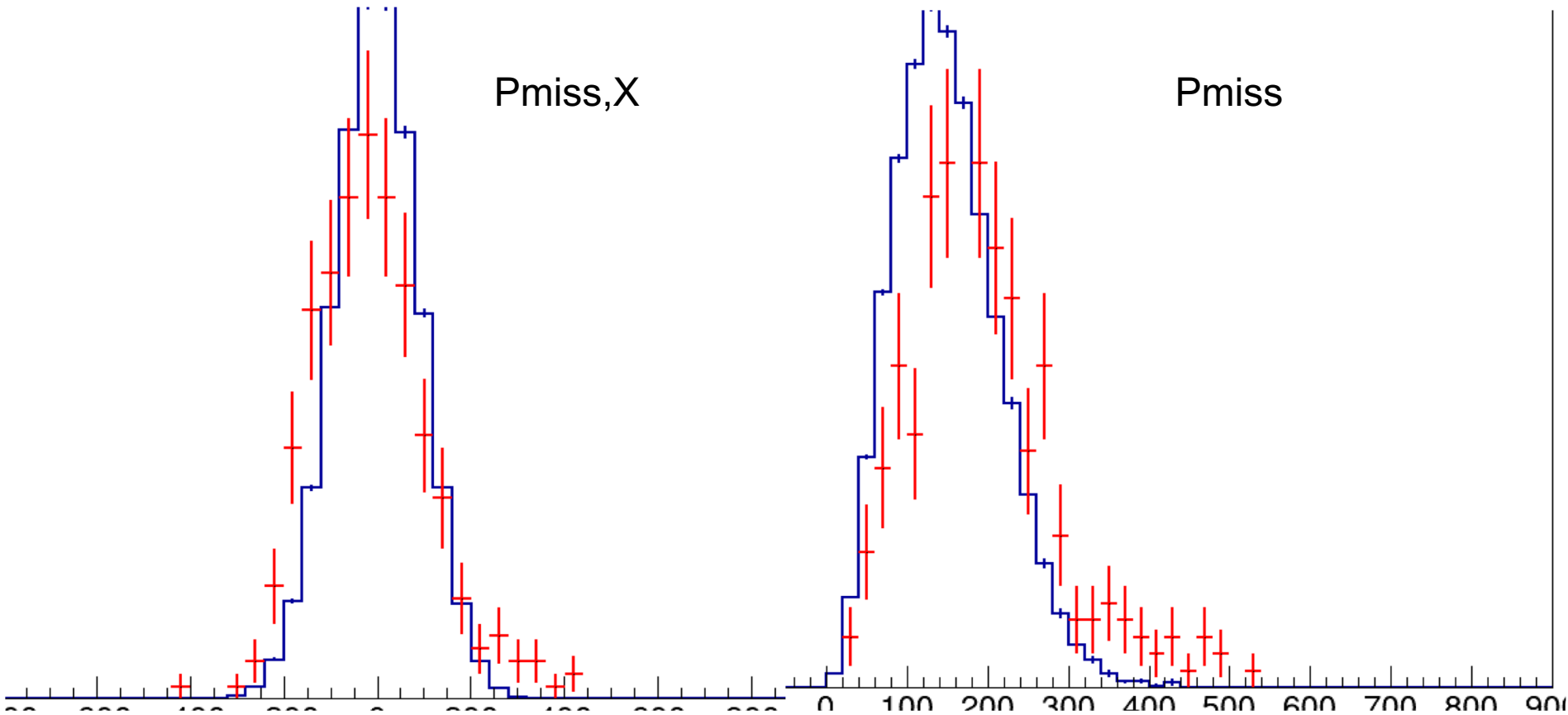


Boron Separation

$$\frac{p}{q} = \frac{0.3 \int B dl}{\sin \alpha_{out} - \sin \alpha_{in}}$$



Scaling



Scaling

