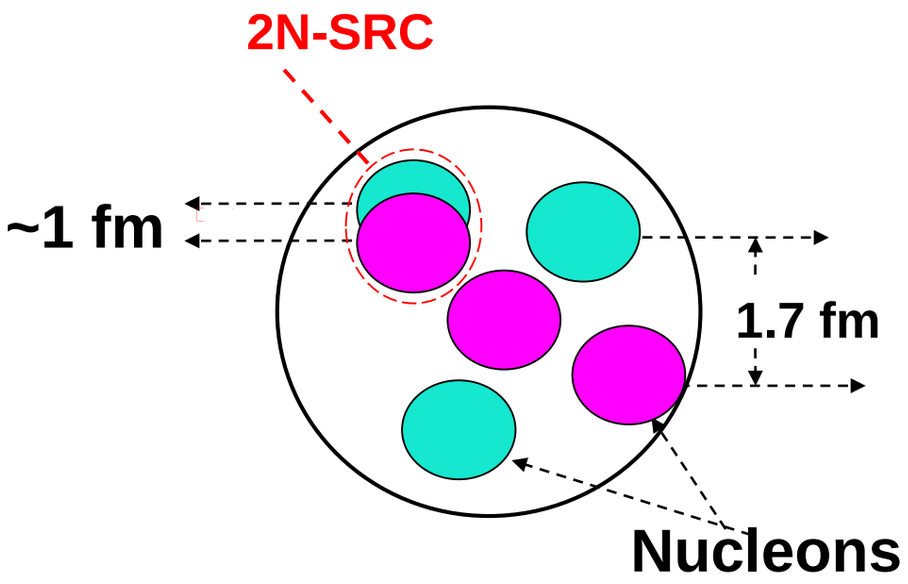
Status of the SRC Analysis

4th Collaboration Meeting of the BM@N Experiment at the NICA Facility

14-15 October 2019

Julian Kahlbow (TAU) for the SRC Collaboration

Short-Range Correlations (SRC) in Nuclei

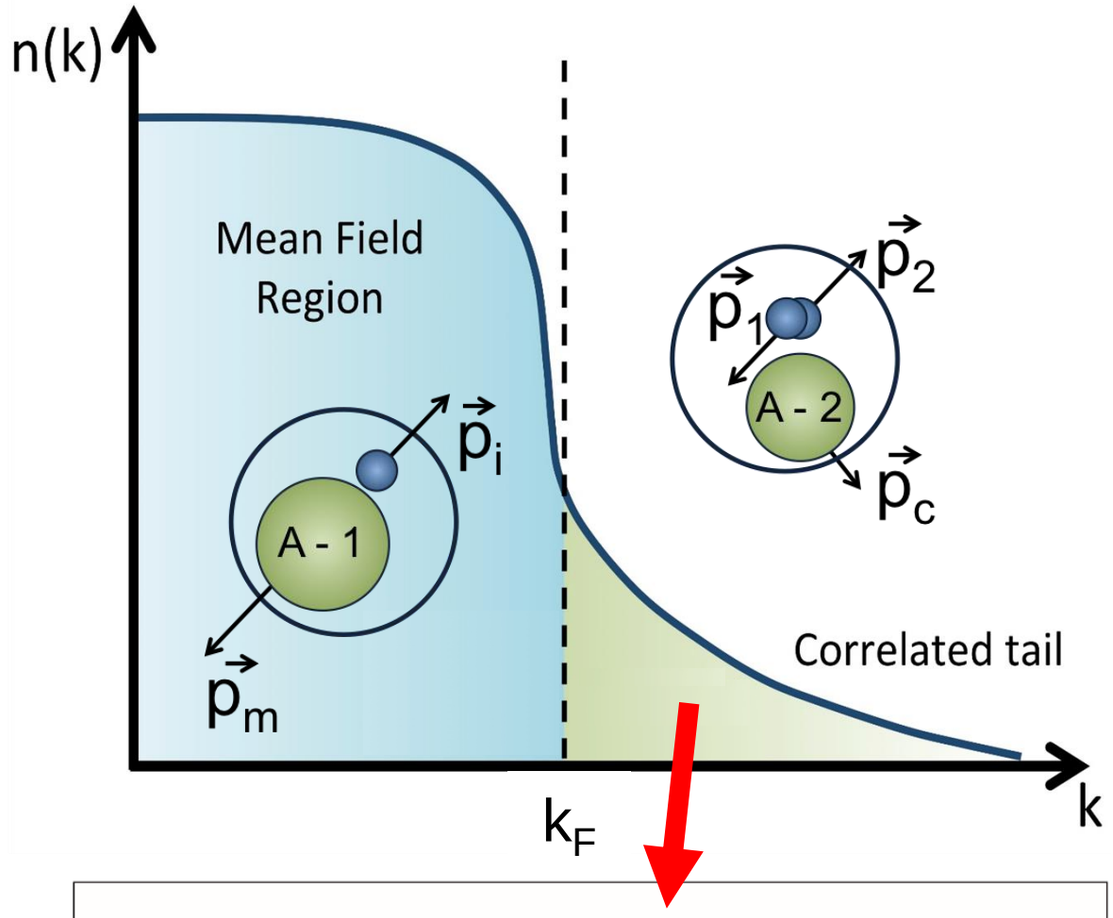


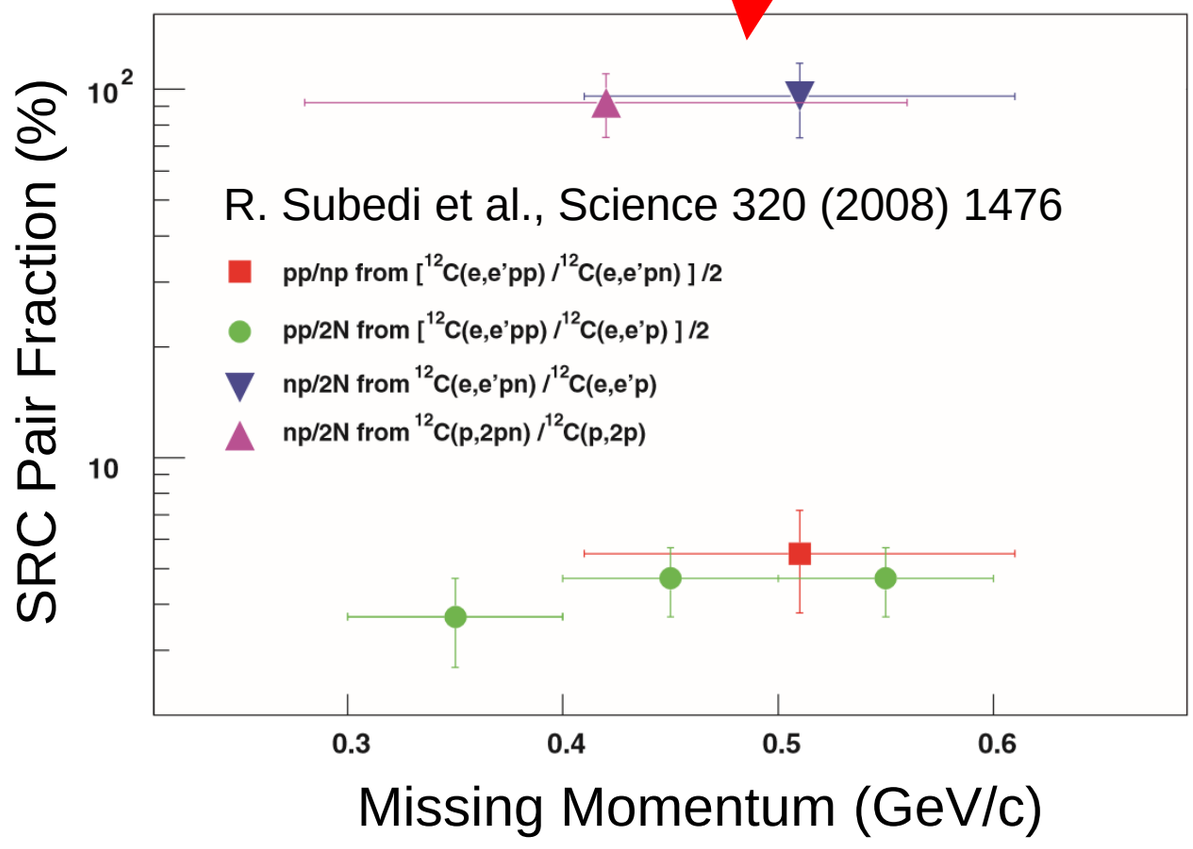
SRC pair: 2N in close proximity

In momentum space:

- *small* center-of-mass motion
- *large* relative momentum

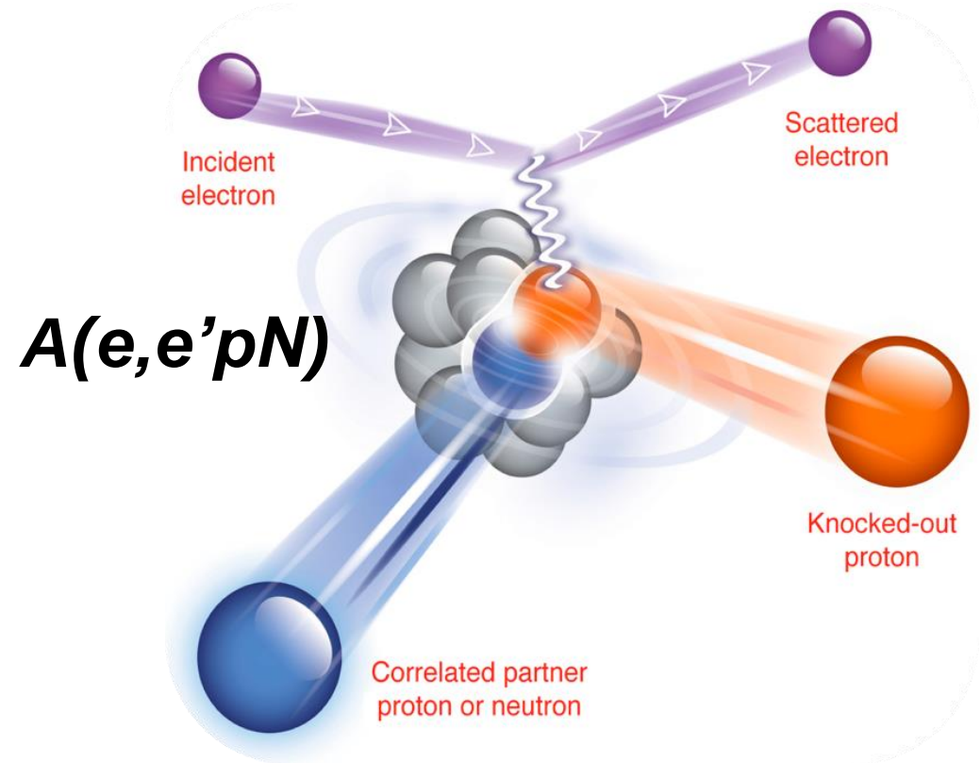
(compared to Fermi momentum k_F)



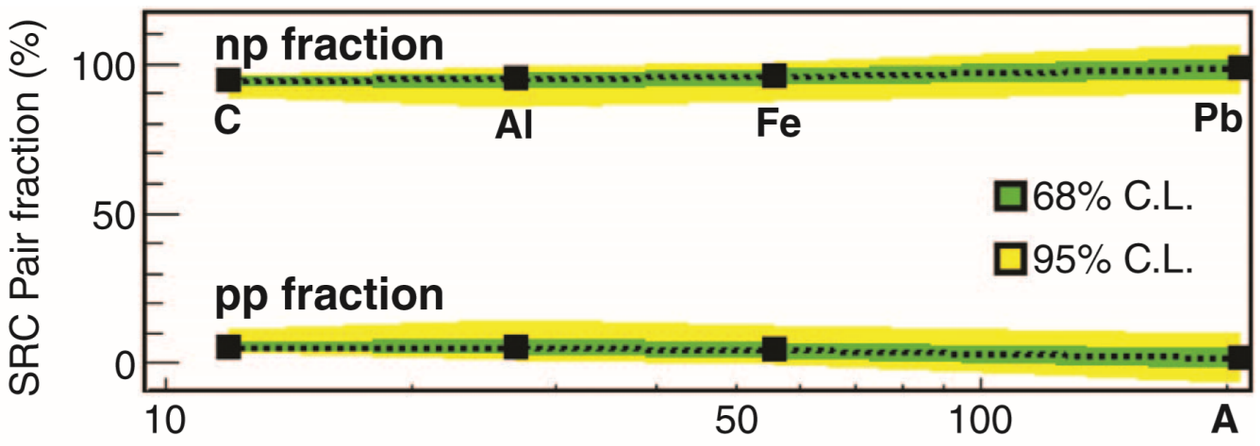


What is known about SRCs?

- (mainly) electron-scattering experiments at Jefferson Lab
- “hard“ break-up reaction and reconstruction of initial state p_{miss} $(Q^2 \gtrsim 2\mathrm{GeV}^2, x_B \gtrsim 1.0)$

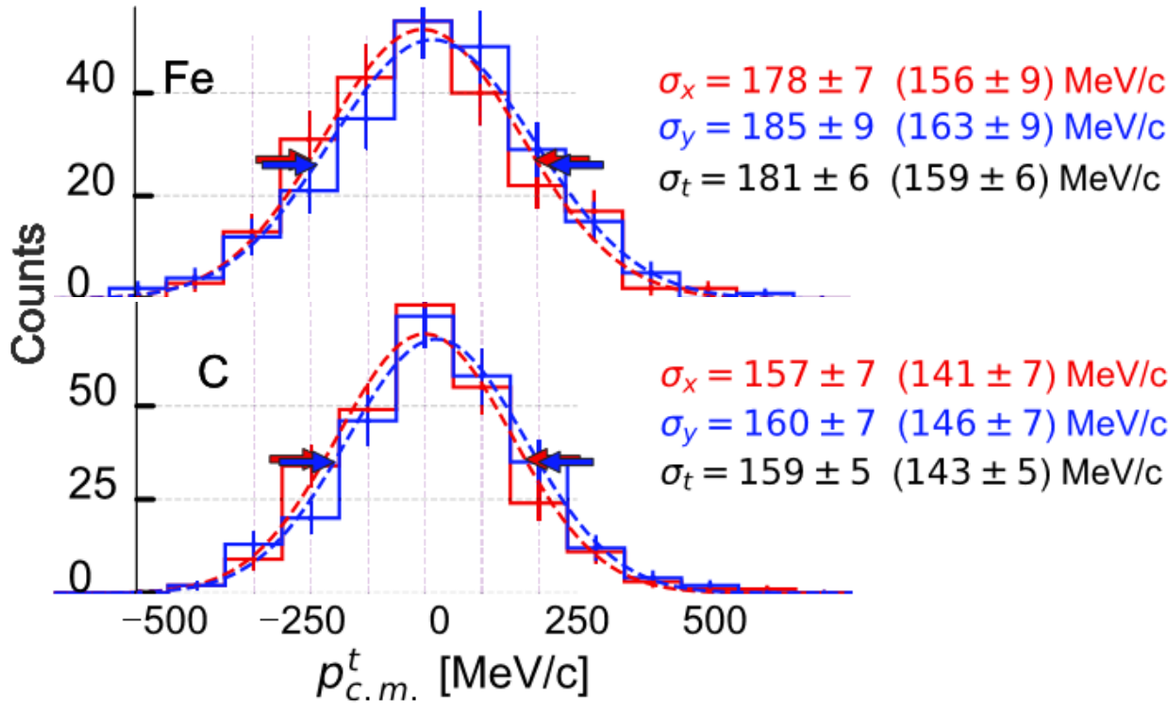


np-pair dominance



O. Hen et al., Science 364 (2014) 614

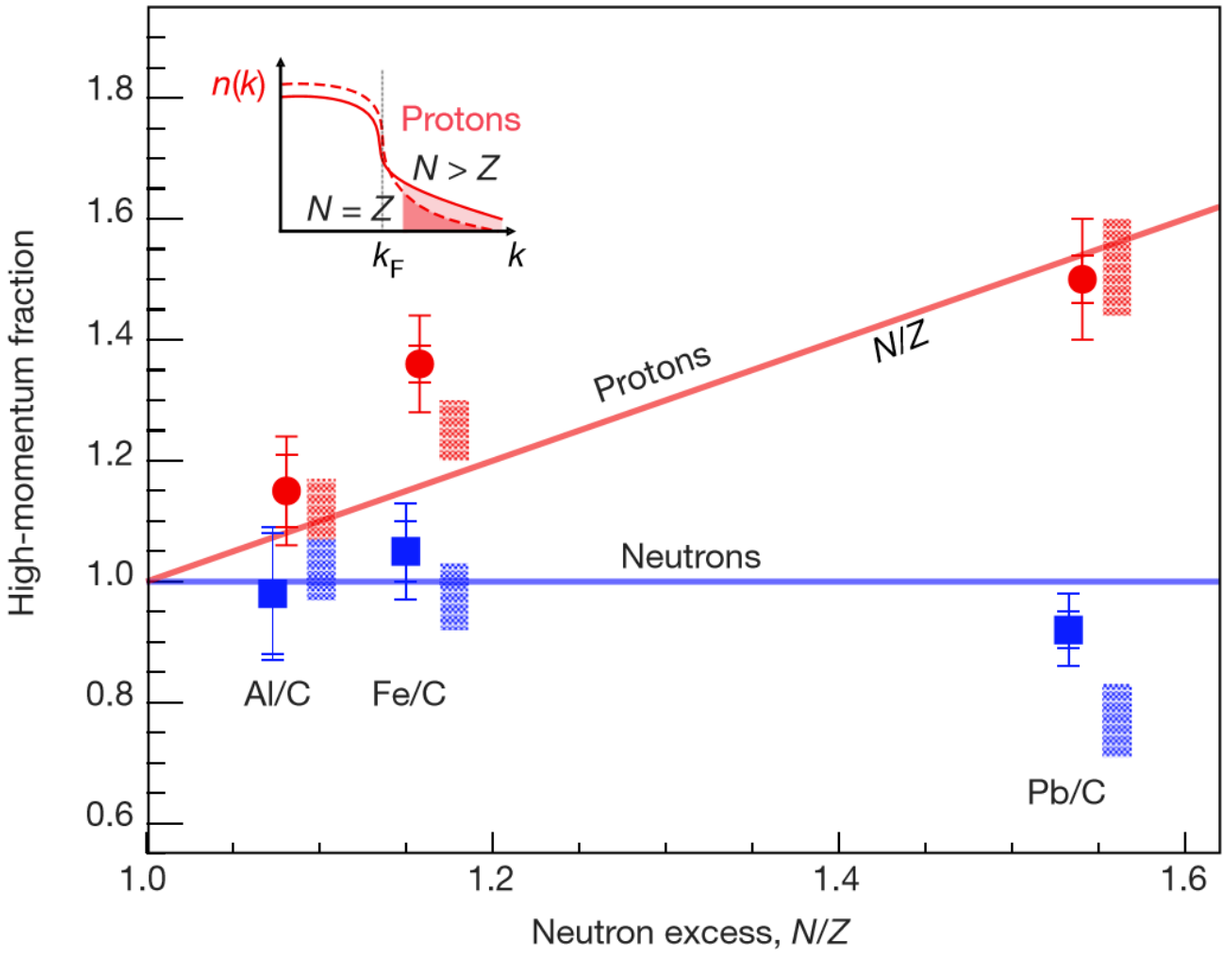
small c.m. motion



E. Cohen et al., PRL 121 (2018) 092501

What is known about SRCs?

M. Duer et al., Nature 560 (2018) 617

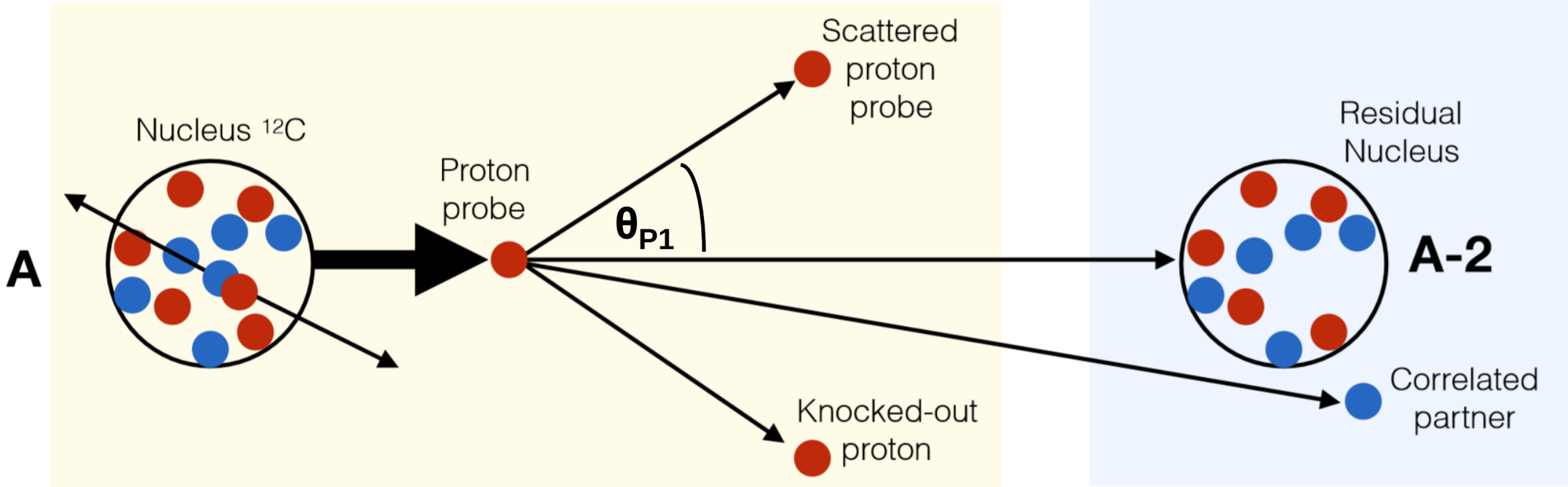


- study neutron-rich nuclei
- measure knocked-out neutron directly *A(e,e'n)*
- *#n = #p* in high-momentum tail
- fraction of minority protons grows
- do deeply-bound protons form pairs?
- excitation of the (A-2)-system?

→ study the fragments in inverse kinematics at JINR

First Fully Exclusive SRC Measurement in Inverse Kinematics at JINR

- ^{12}C beam at 4GeV/c/u on LH_2 target (hadronic probe)
- measure incoming beam and all reaction fragments at BM@N setup
- reactions of interest e.g.: $^{12}\mathrm{C}(p,2pn)^{10}\mathrm{B}$, $^{12}\mathrm{C}(p,2px)X$, $^{12}\mathrm{C}(p,2p)^{11}\mathrm{B}$



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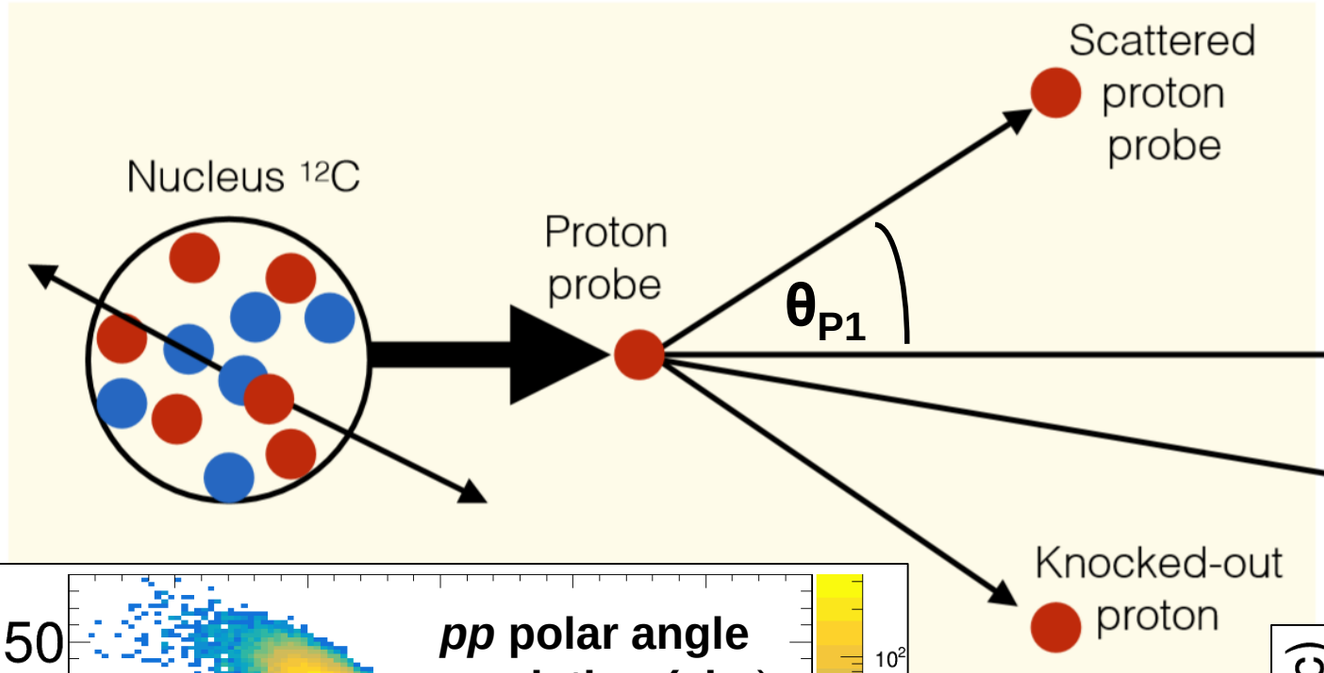
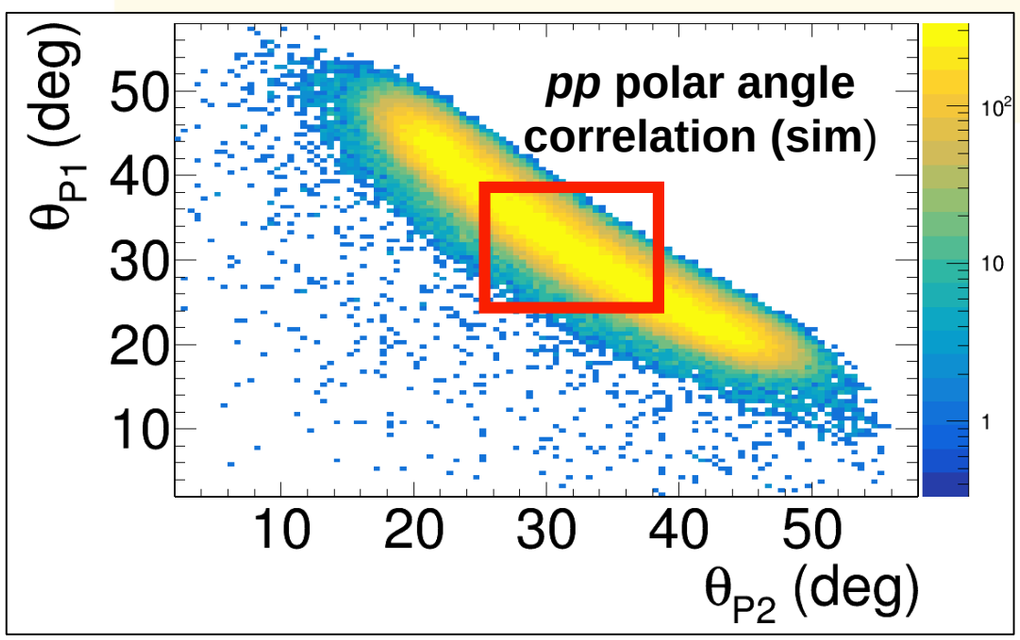
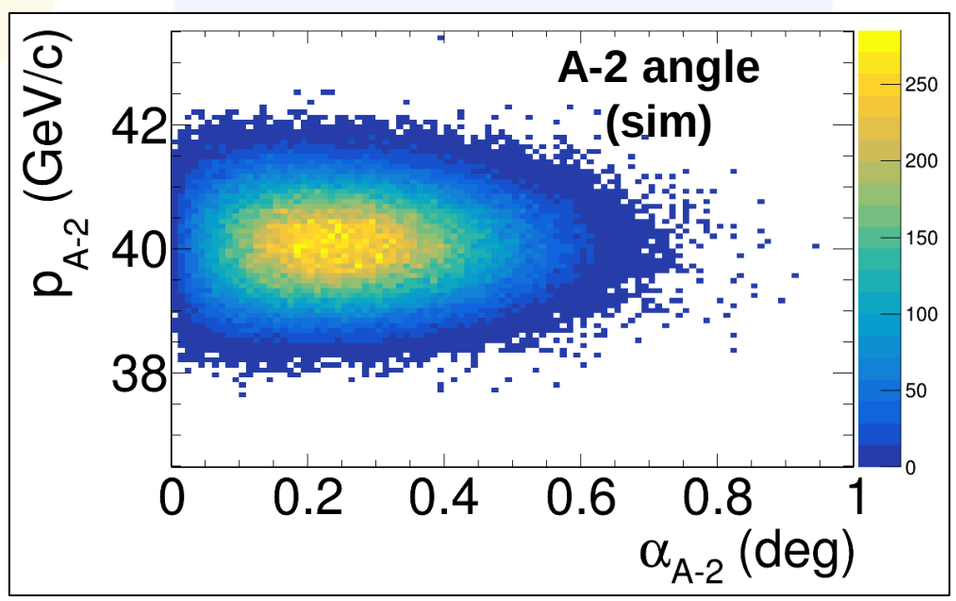
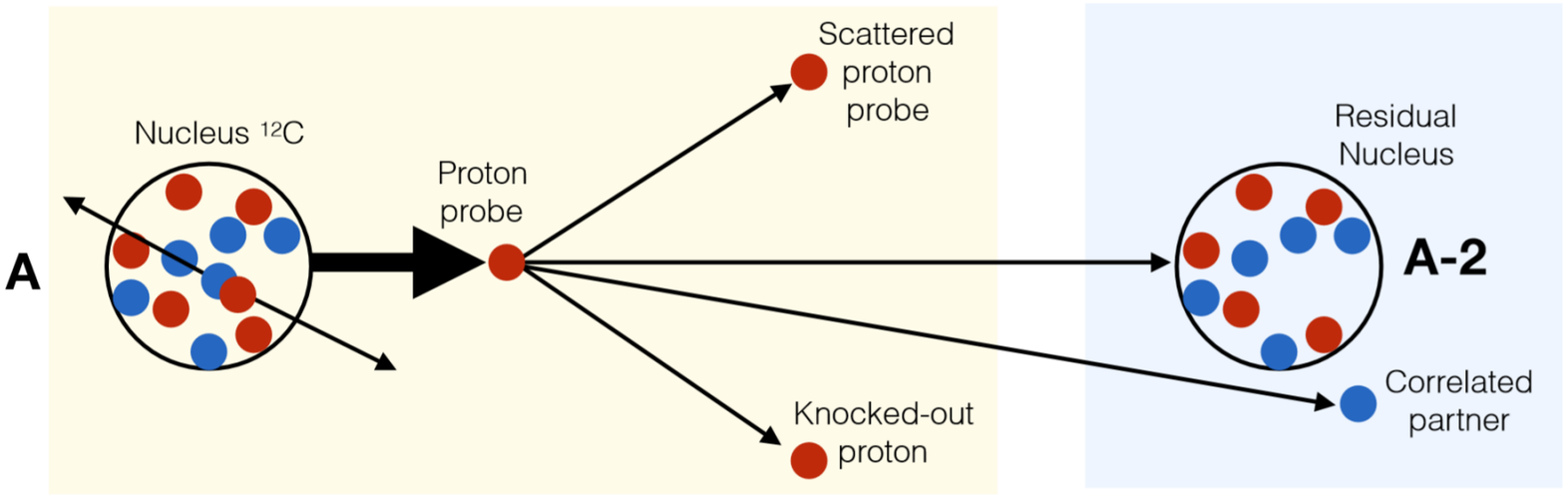
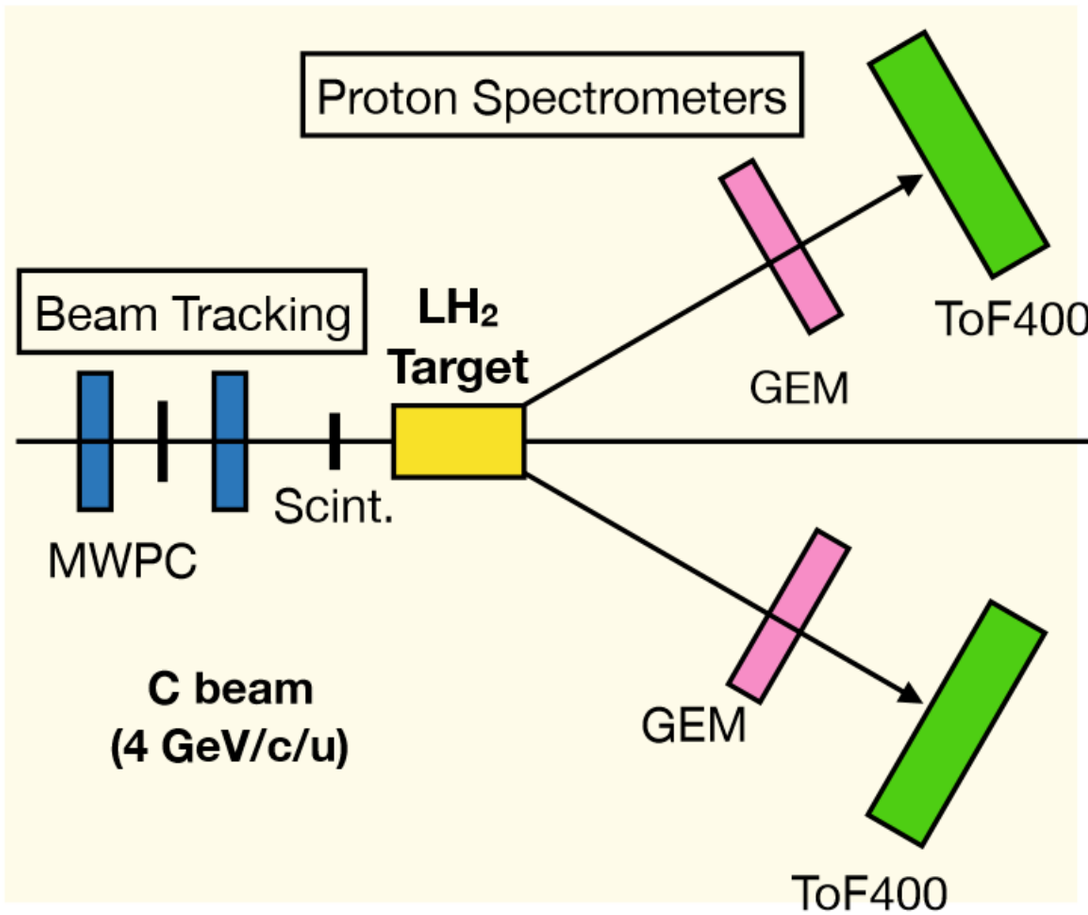


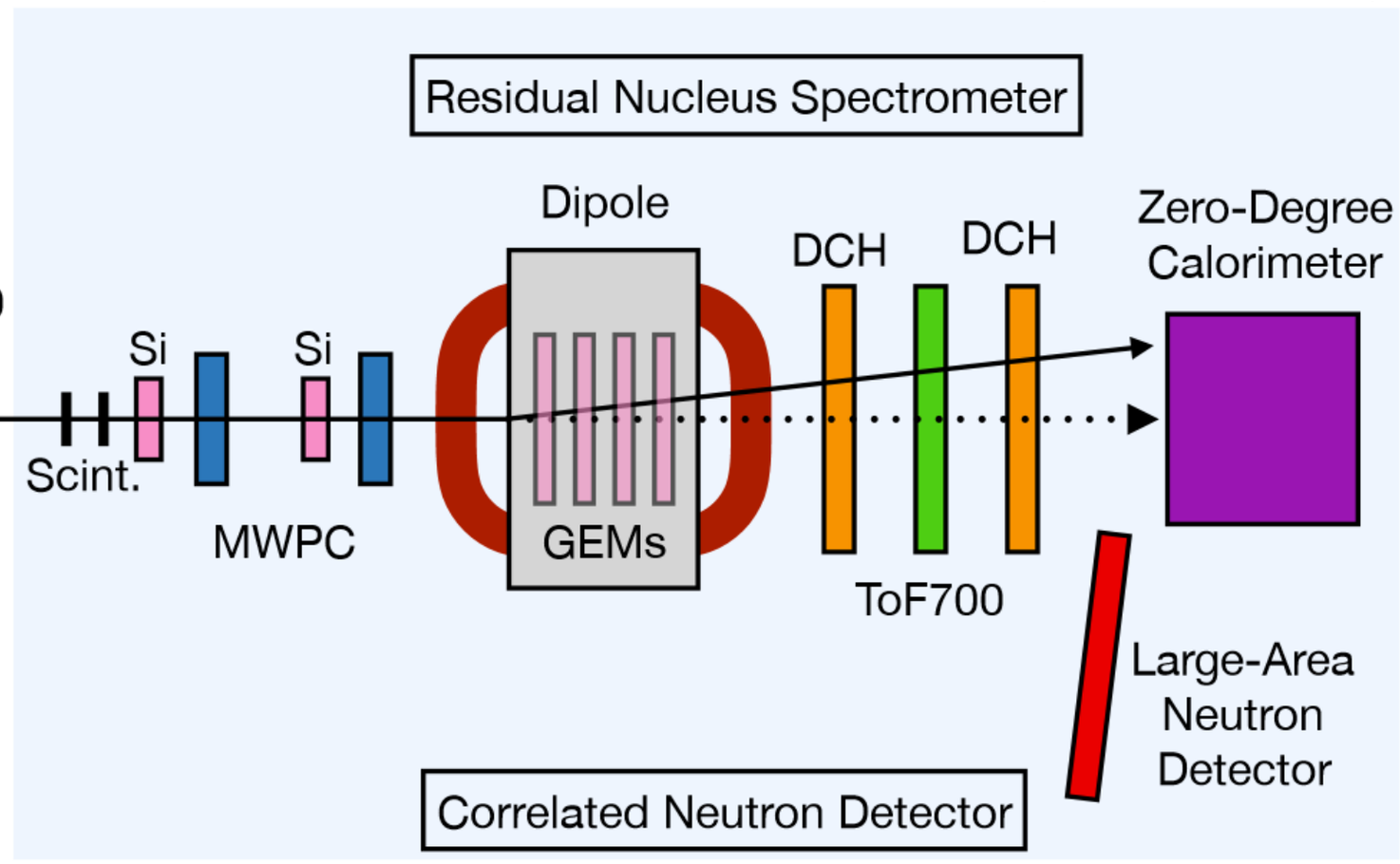




Experimental Setup

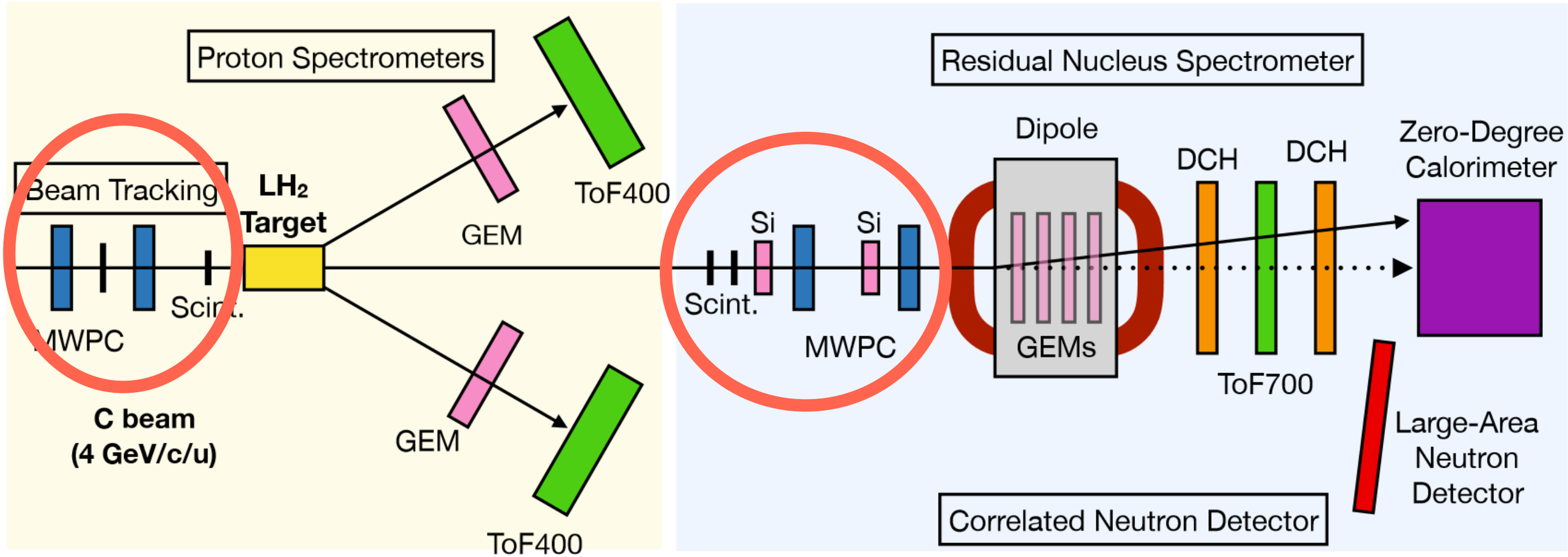






Courtesy of Efrain Segarra

Analysis Groups

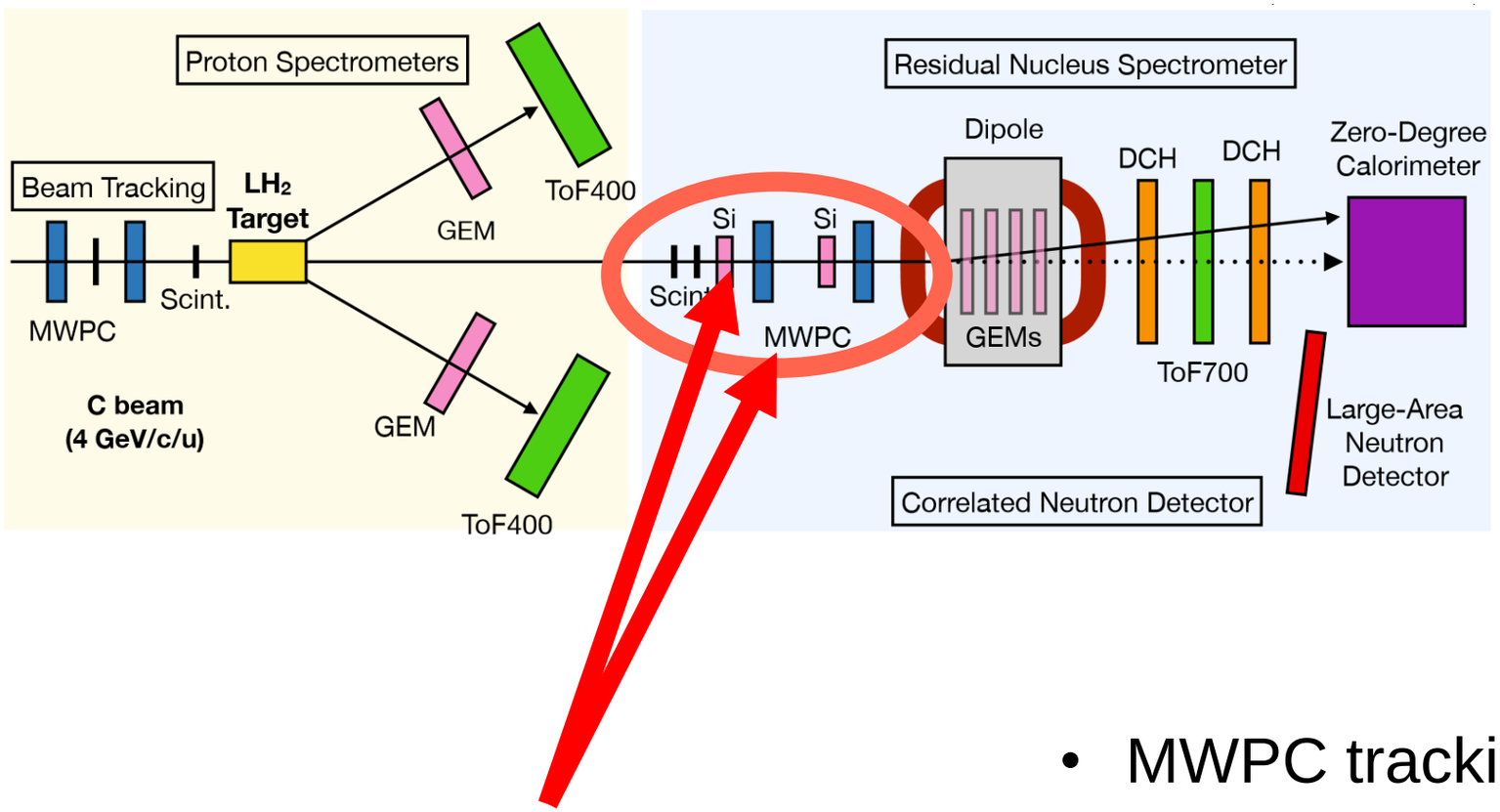


In-Beam Tracking

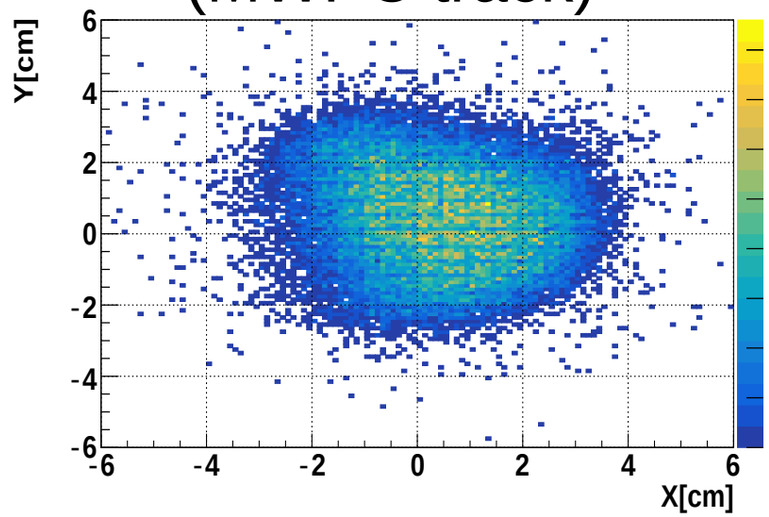
Maria Patsyuk
Vasilisa Lenivenko
Vladimir Palichik
(JINR)

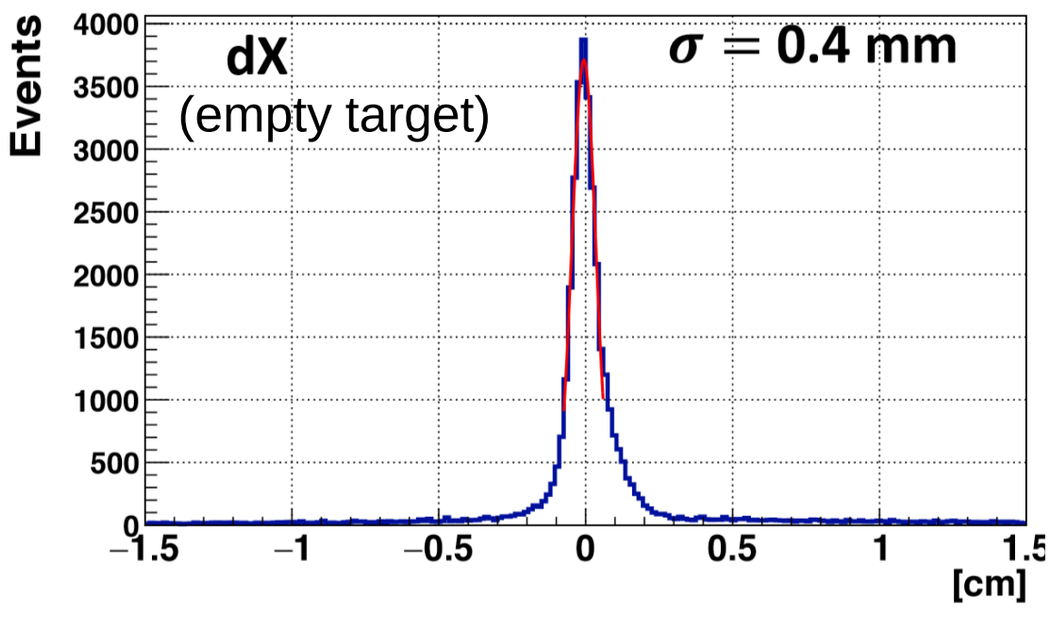
Efrain Segarra (MIT)

Calibration Status – In-Beam Tracking



Beam spot downstream of target (MWPC track)

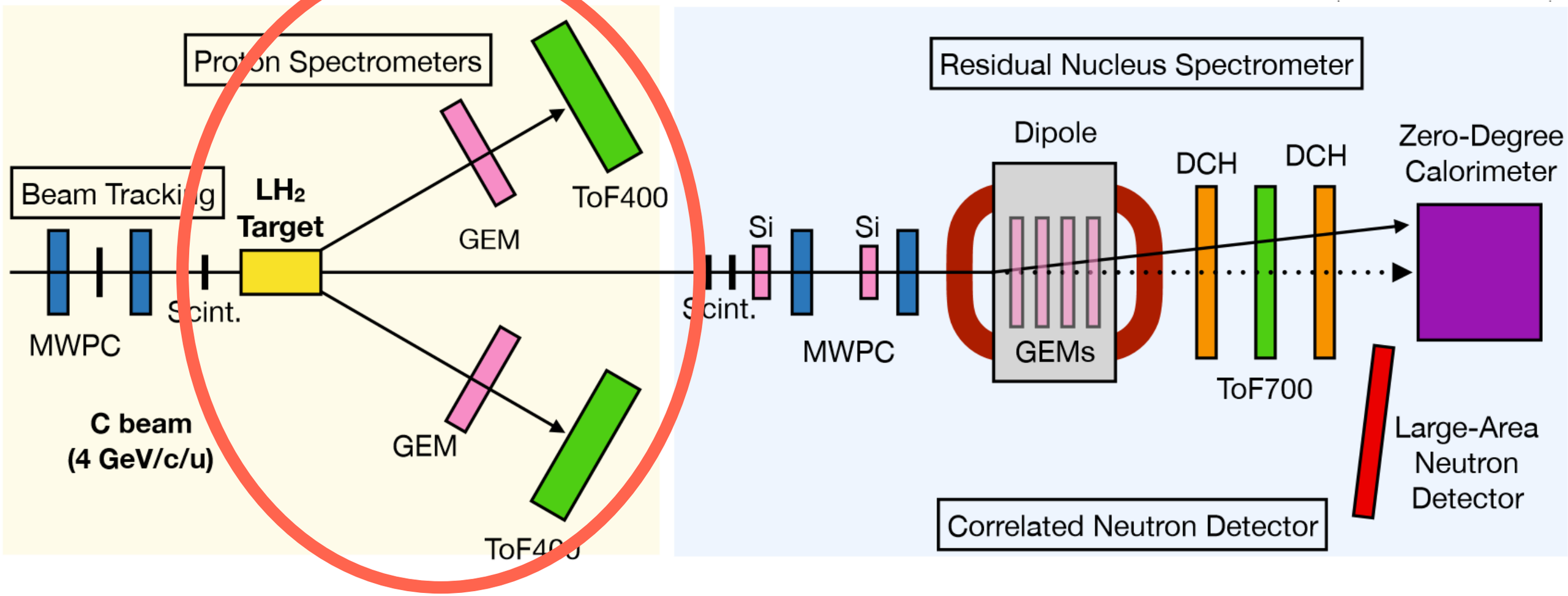




- MWPC tracking improved
- silicon strip detectors have better resolution but problem in *y* coordinate (Si2)
- combined MWPC+Si tracking in progress
- tracking efficiency (#track==1):
  - **95% for MWPC**
  - 65.2% for combined MWPC+Si tracks (to be improved)

Courtesy of Vasilisa Lenivenko

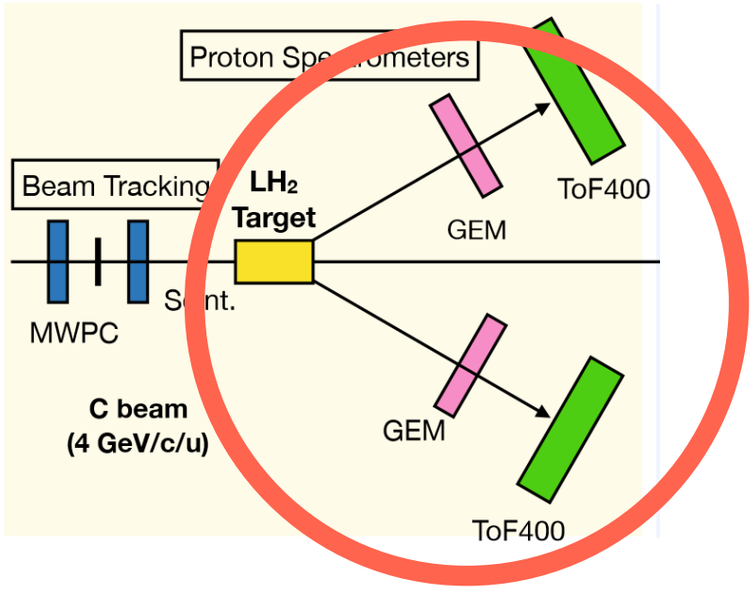
Analysis Groups



Proton-Arm Analysis

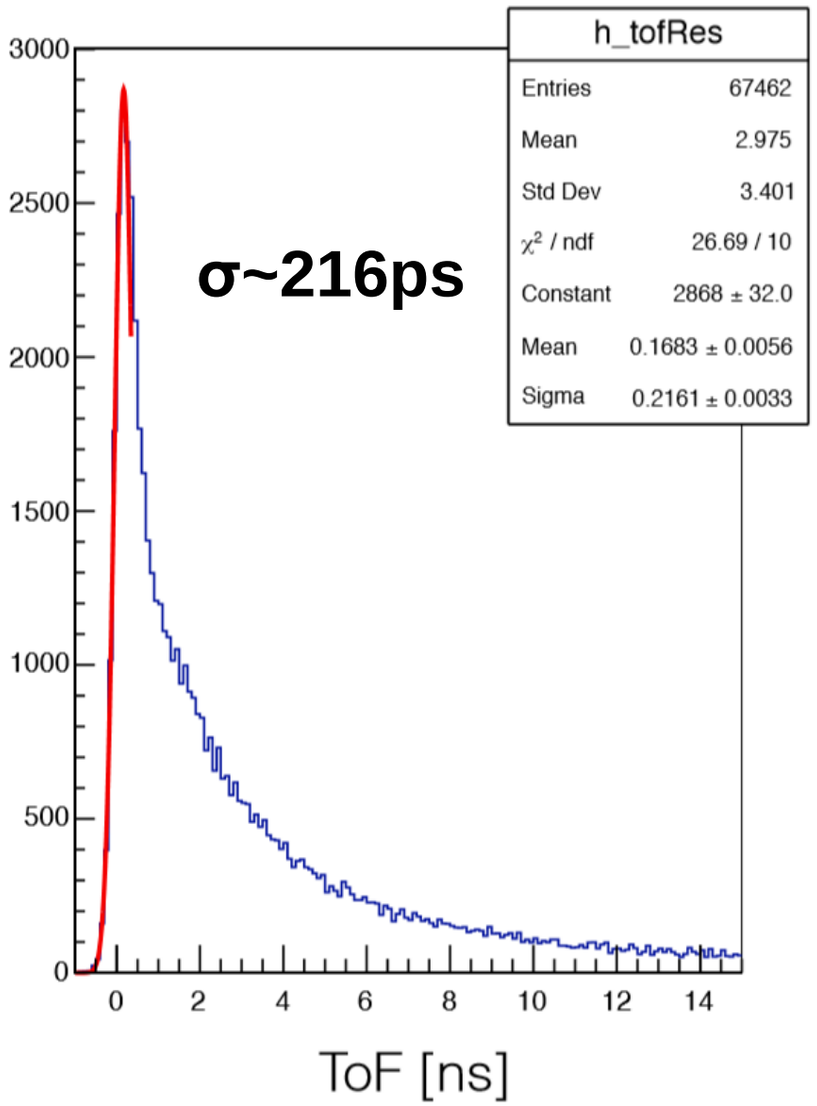
Efrain Segarra (MIT) Mikhail Rumyantsev (JINR)

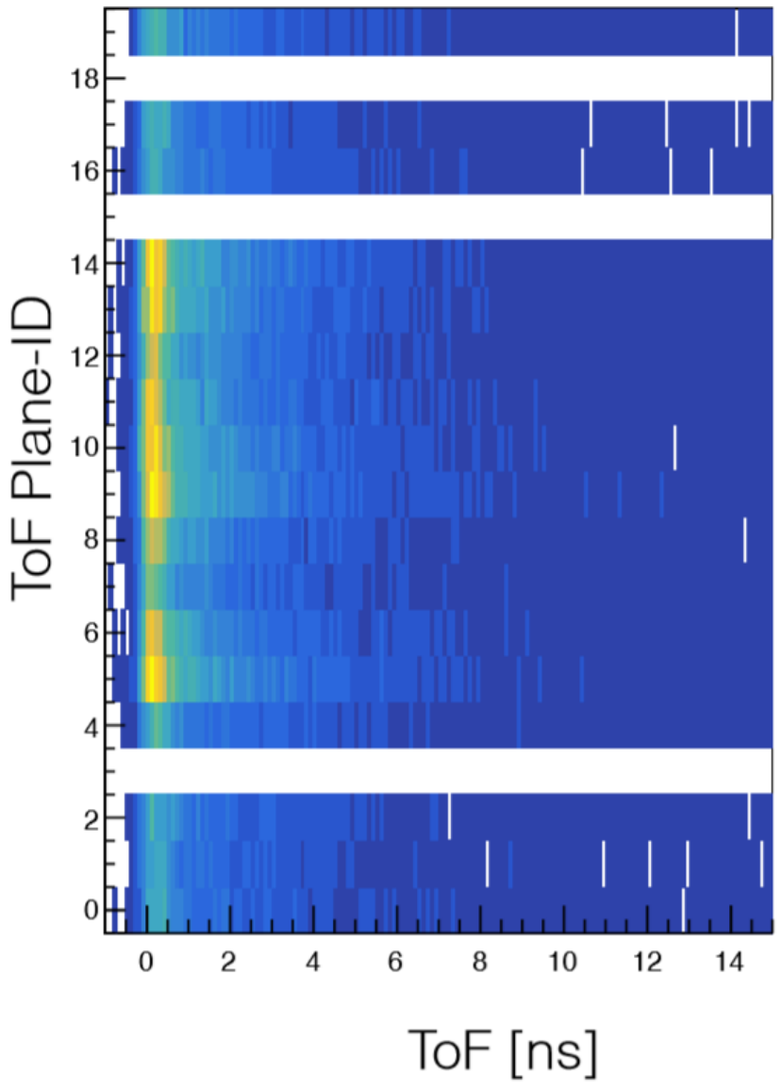
Calibration Status – Proton Arms



ToF Alignment for (*p*,2*p*)

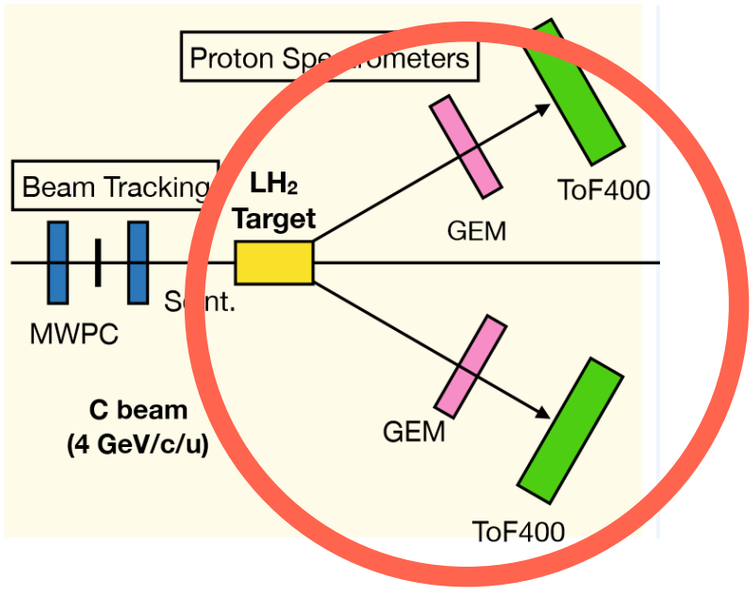
- internal alignment with gammas from Pb target
- results from iterated time and position calibration:



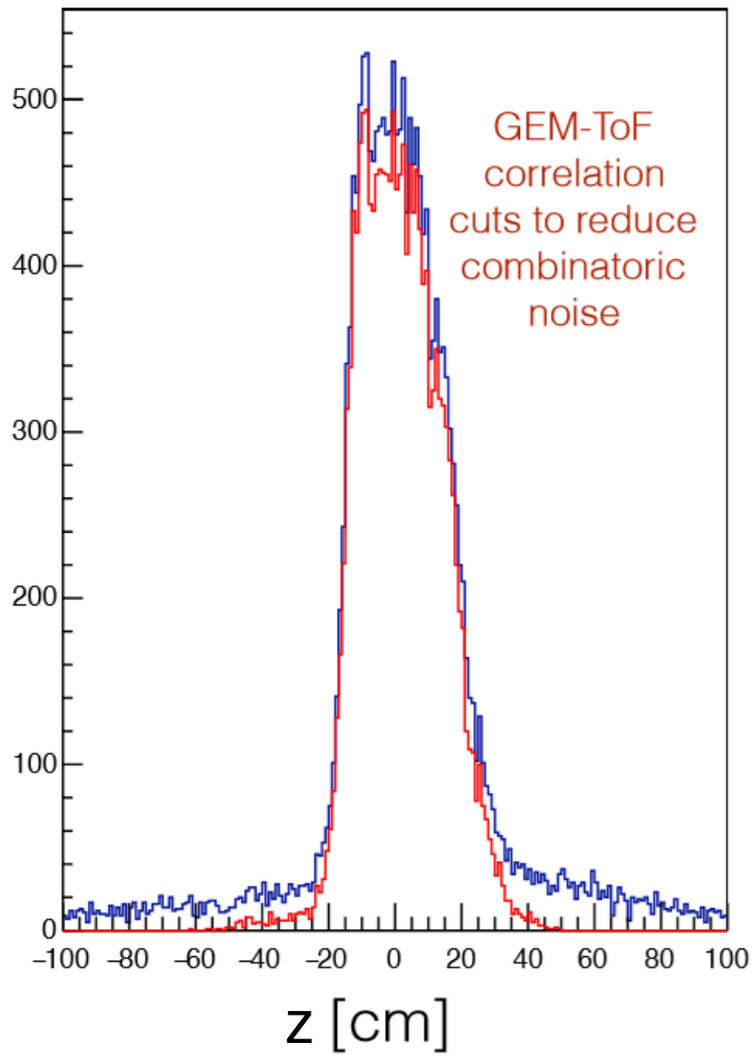


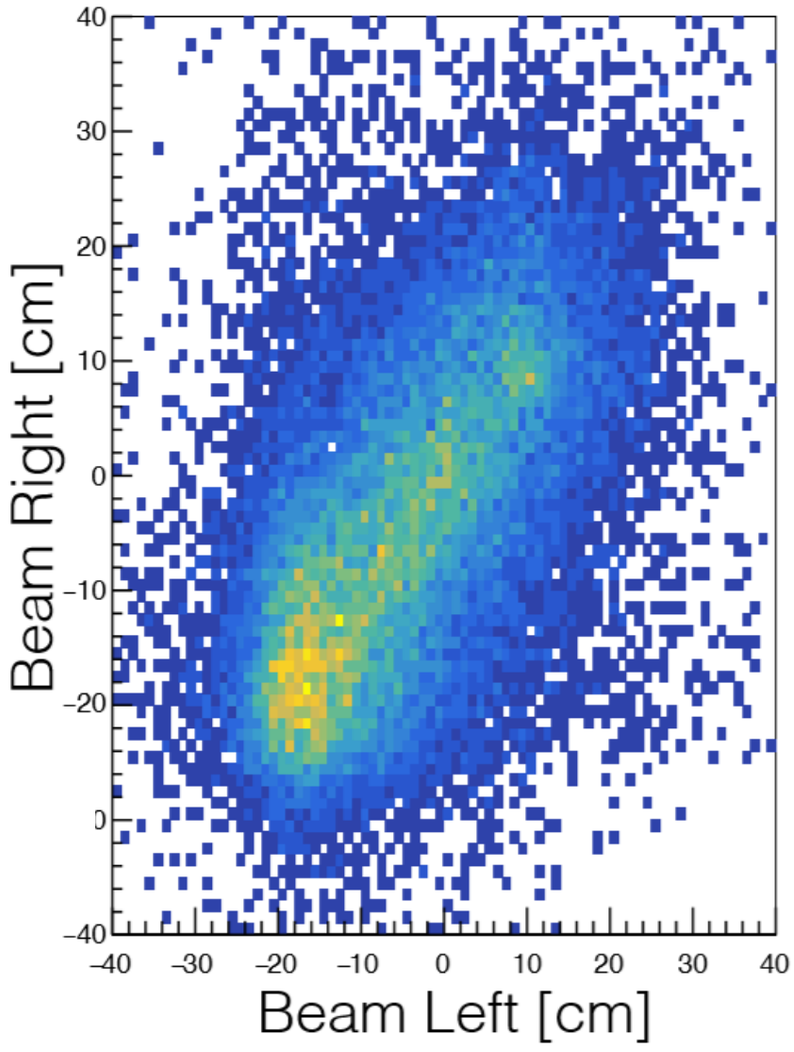
Courtesy of Efrain Segarra

Calibration Status – Proton Arms



2*p* tracking and vertex reconstruction using GEM+ToF400



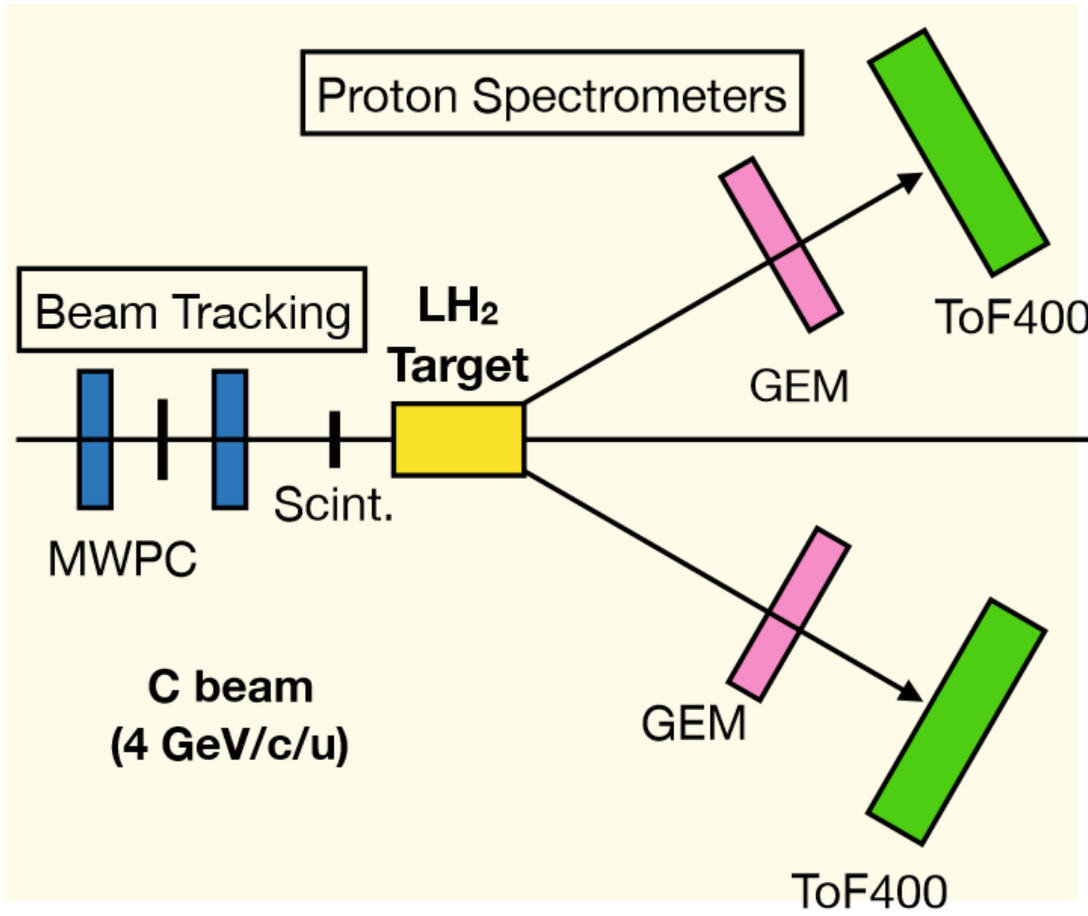


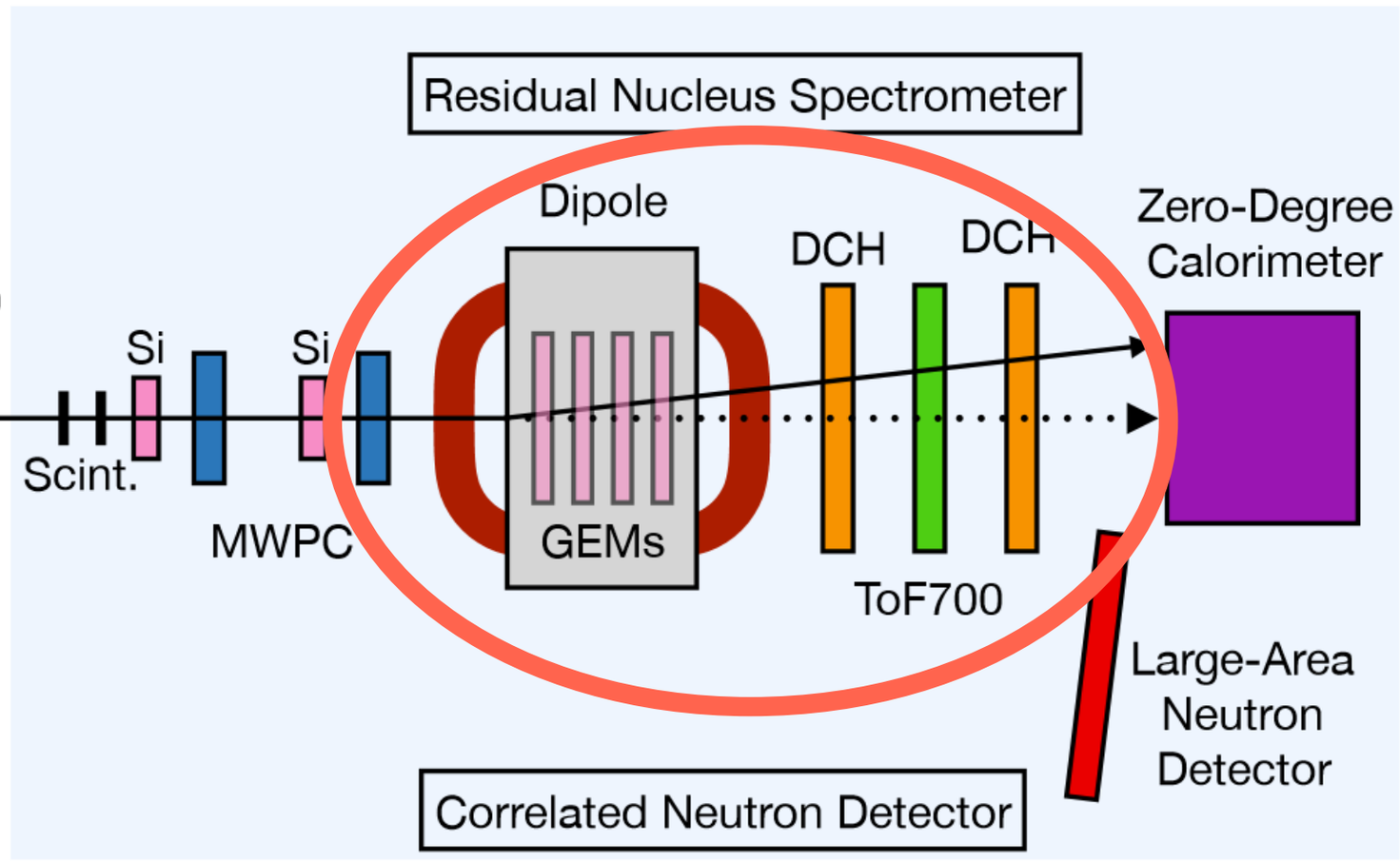
Ongoing:

- include up- and downstream tracking
- sensitivity to abs. alignment
- proton correlation and p_{miss}

Courtesy of Efrain Segarra

Analysis Groups



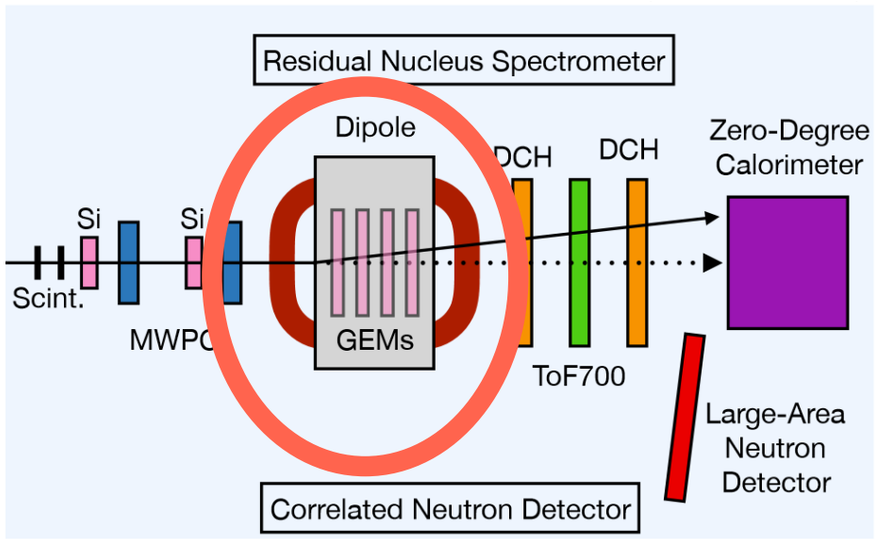


Fragment Analysis

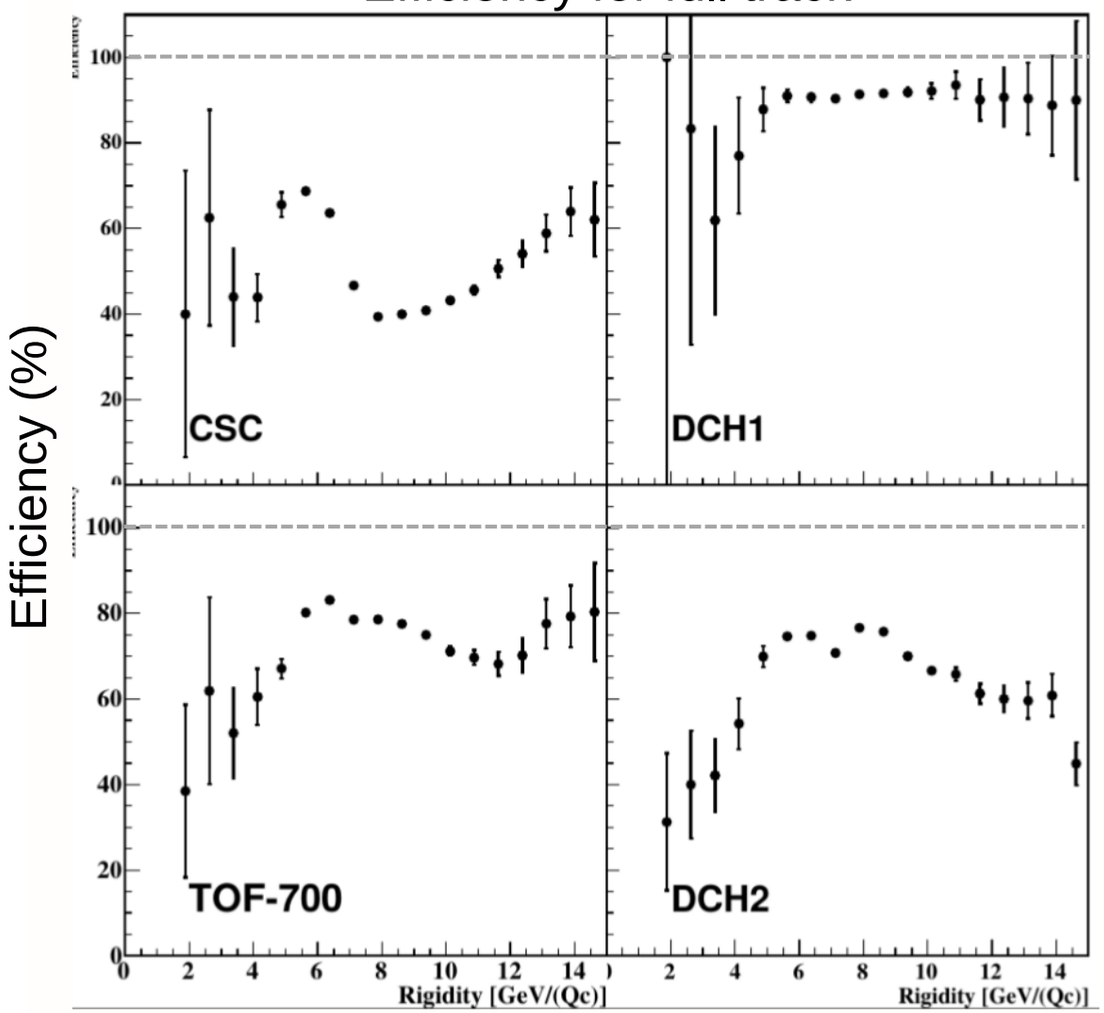
Sergei Merts
Nikolay Voytishin
Timur Atovullaev
(JINR)

Valerii Panin (CEA Saclay)
Göran Johansson (TAU)
Yuri Pethukov
Vladimir Palichik

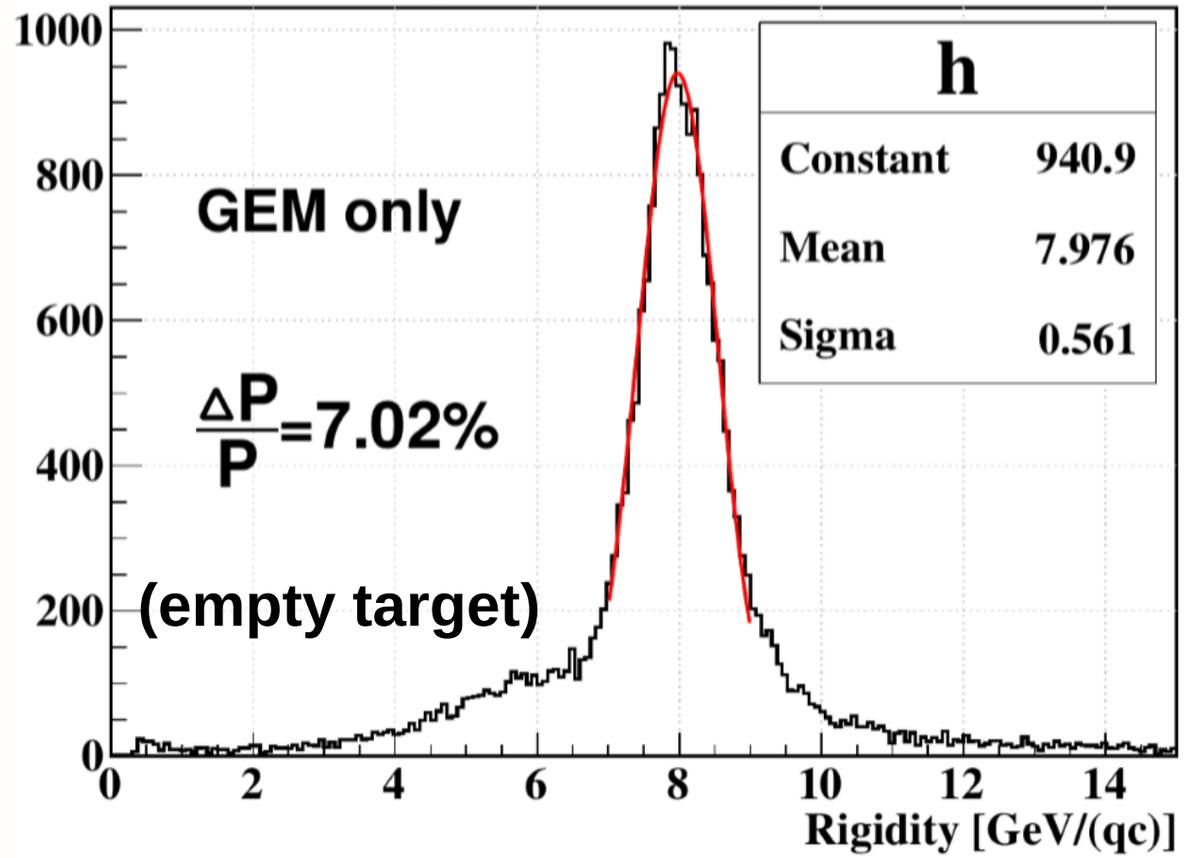
Calibration Status – Fragment Tracking



Efficiency for full track



Tracking in the magnetic field

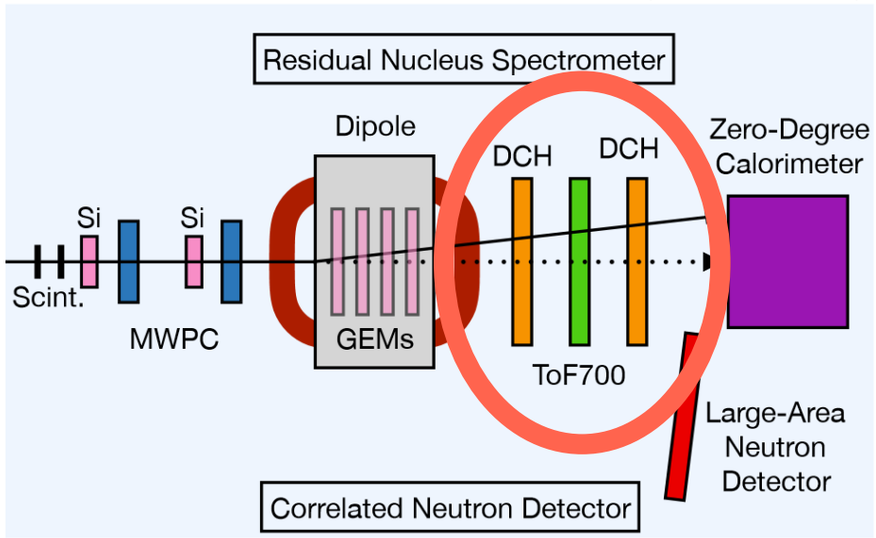


- Kalman filter applied for fitting
- attempts towards global tracking:
  - include CSC, DCHs, ToF700 in downstream tracking
  - updated path length, ToF for momentum and ID

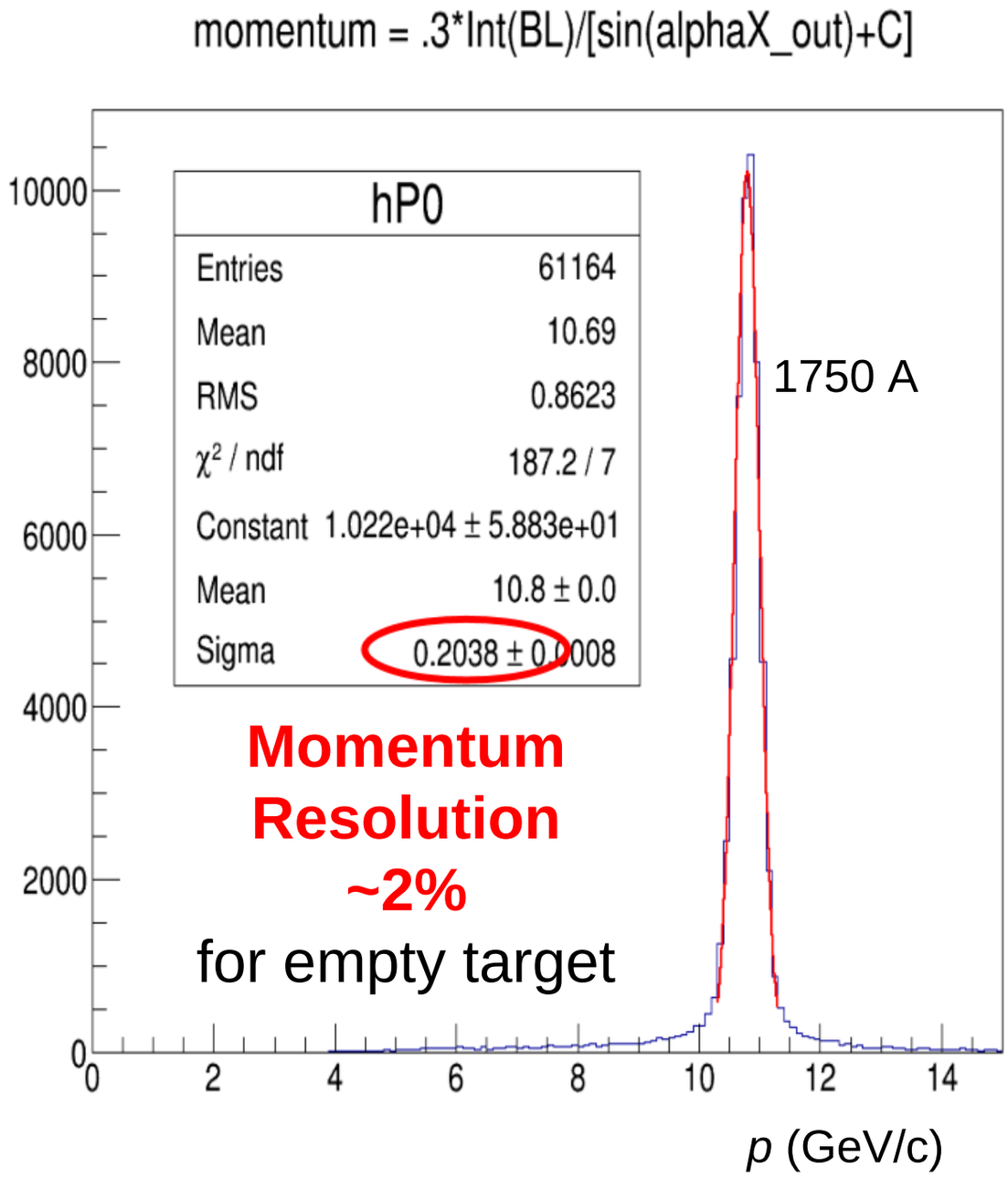
→ **resolution improves to 6.2%**

Courtesy of Sergei Merts

Calibration Status – Fragment Tracking



- alignment of DCH and ToF700 done
- improved tracking efficiency
- $\varepsilon_{DCH1} \approx 98\%$, $\varepsilon_{DCH2} \approx 95\%$ (rel. to GEM & DCH#)



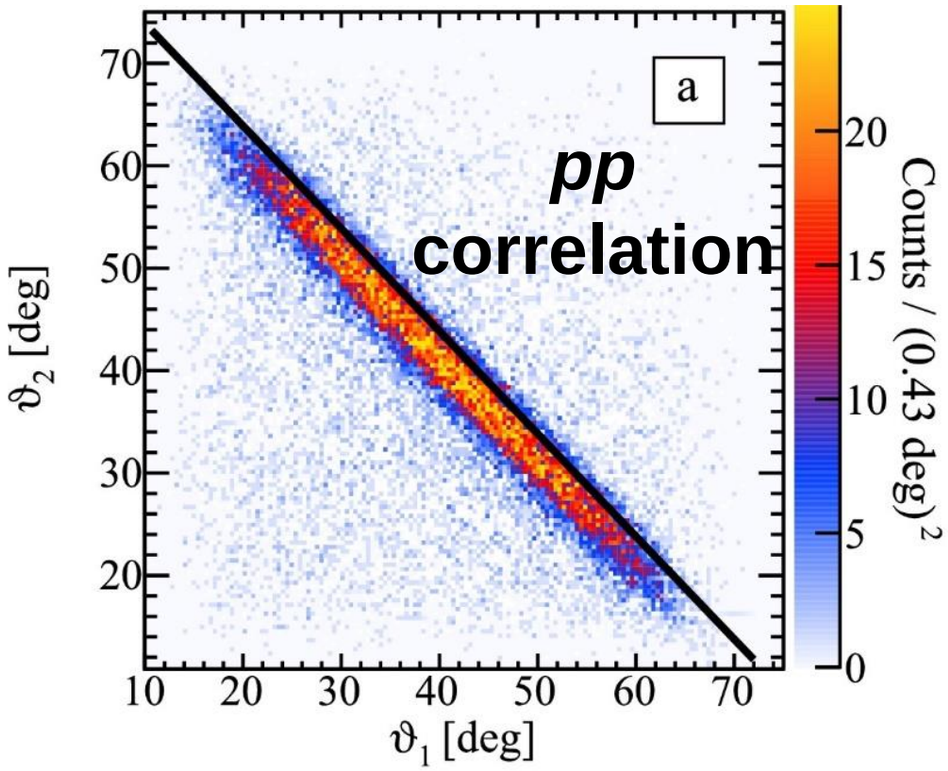
Courtesy of Vladimir Palichik & Nikolay Voytishin

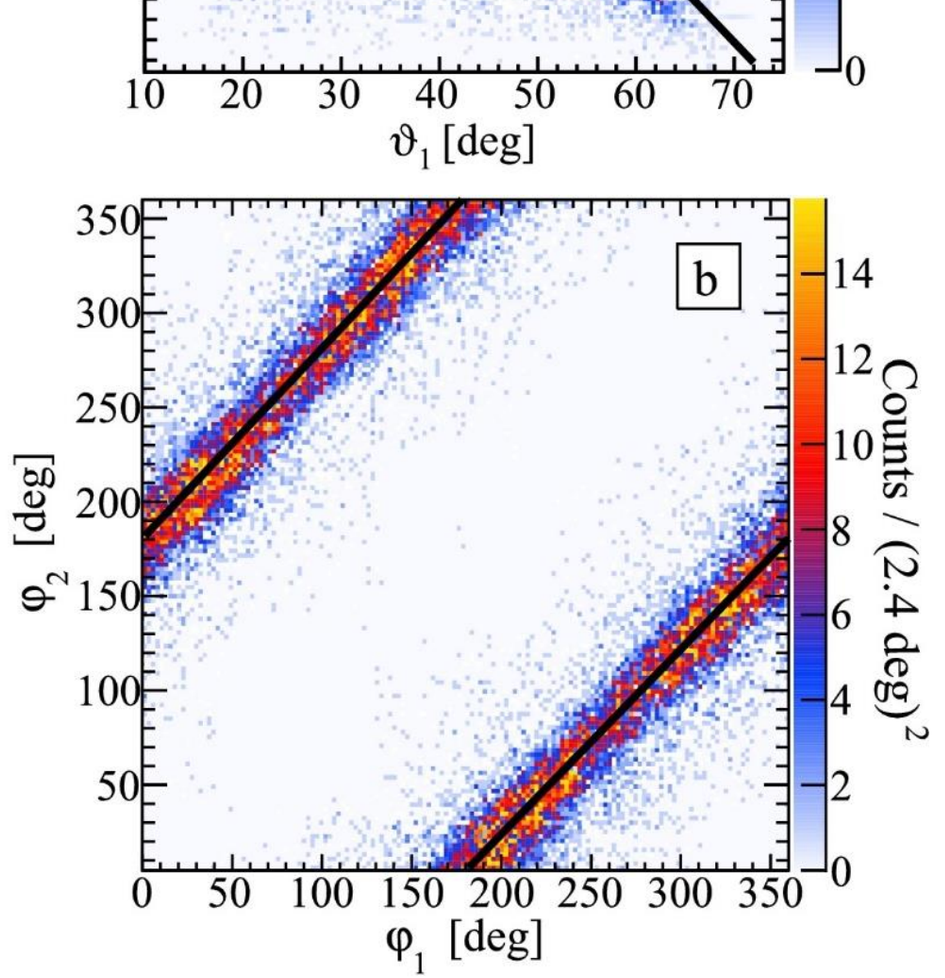
Primary Analysis Goals

Quasi-elastic scattering
^{12}C(p,2p)^{11}B at 4GeV/c/u

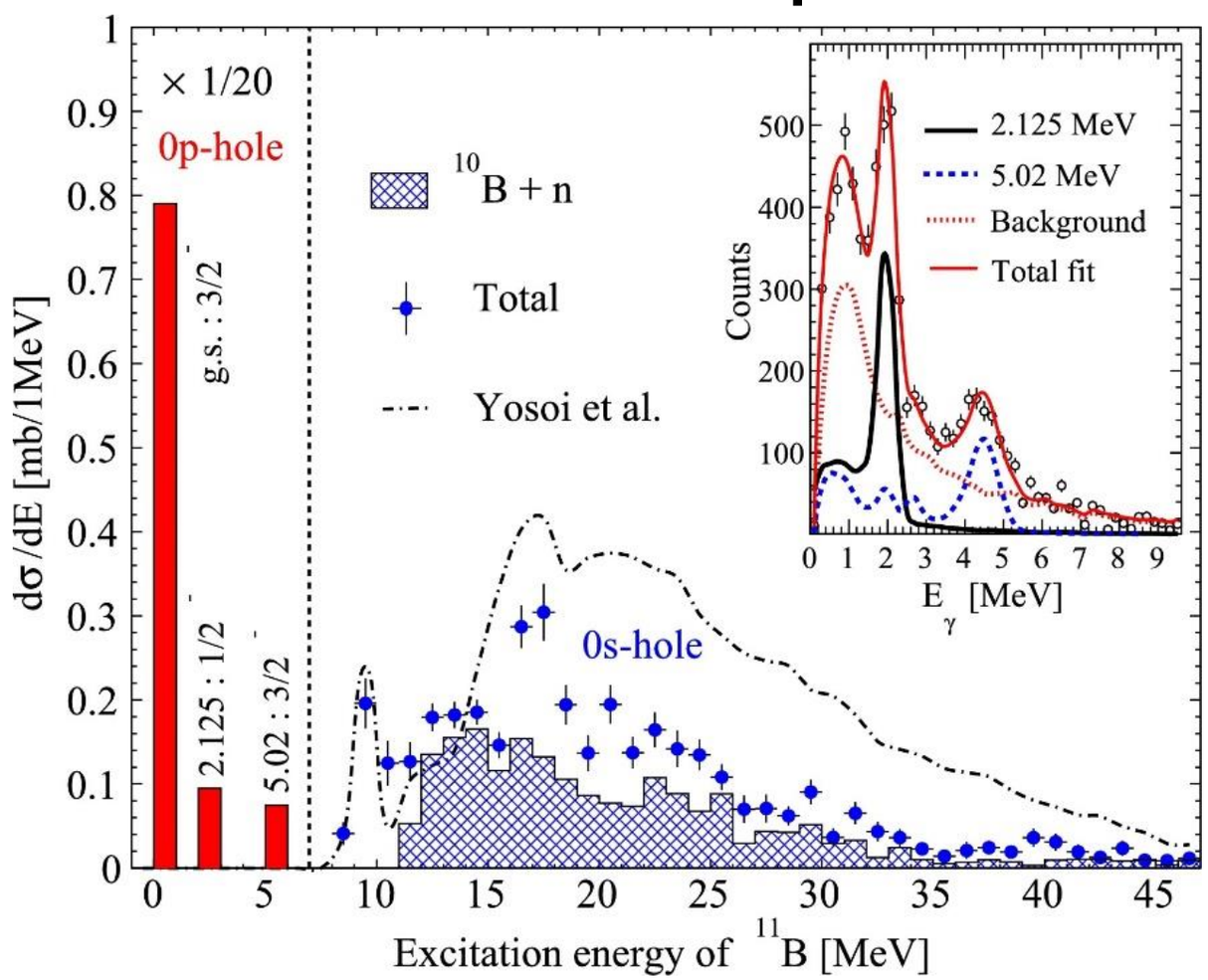
Previous measurement at R^{3}B/LAND Setup at GSI **at 0.95GeV/c/u in inverse kinematics**
(V. Panin et al., Phys. Lett. B 752 (2016) 204)

V. Panin et al., Phys. Lett. B 752 (2016) 204





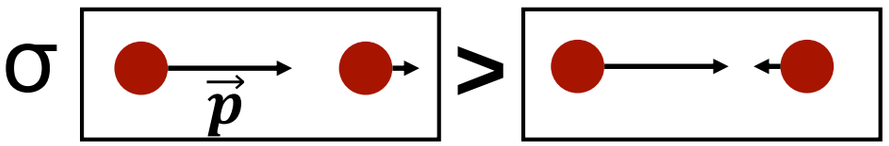
^{11}B excitation spectrum



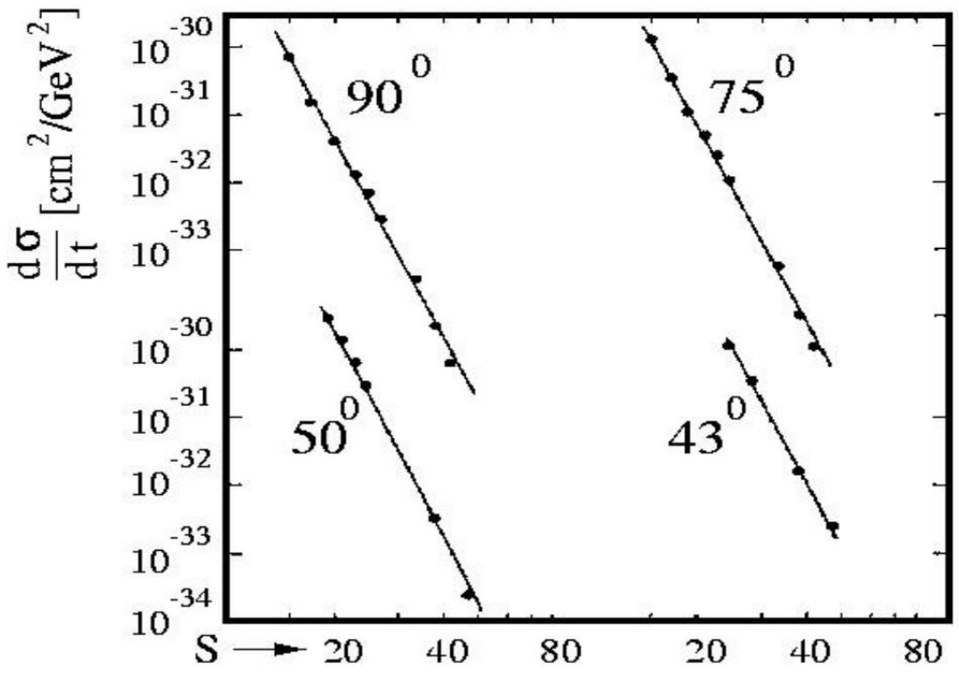
Primary Analysis Goals

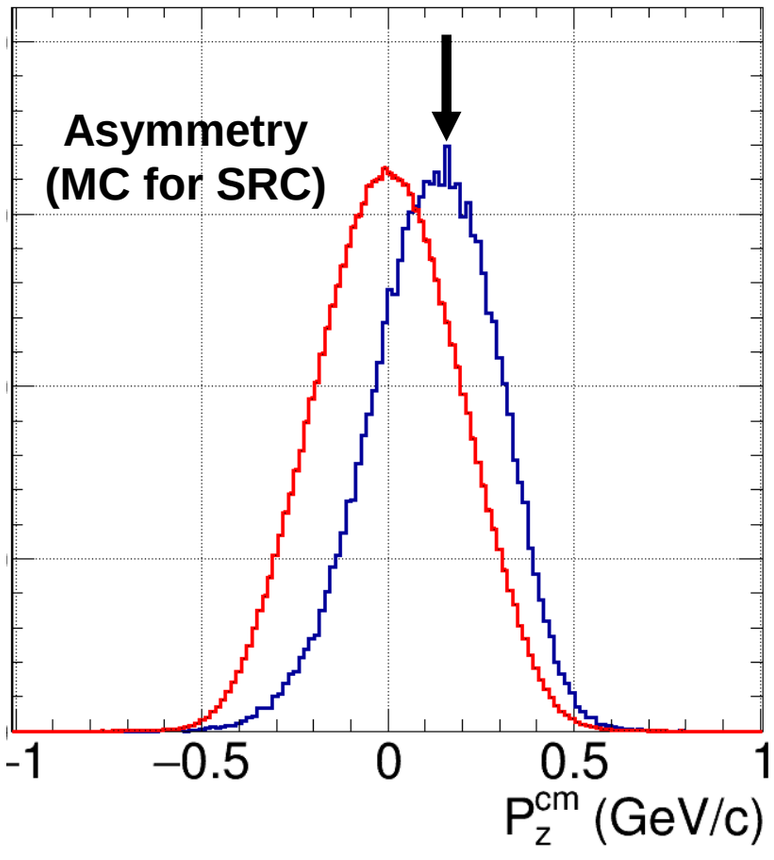
Quasi-elastic scattering $^{12}C(p,2p)^{11}B$ at 4GeV/c/u

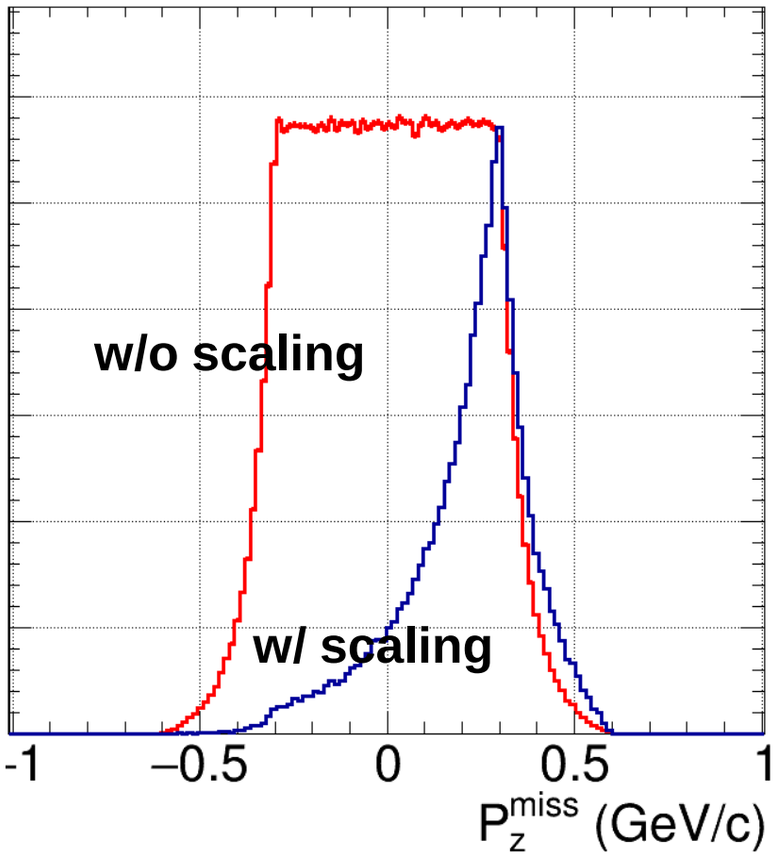
- hard scattering with large momentum transfer
- *pp* cross section scales ~S^{-10}
- nucleon momenta in same direction (small c.m. energies) are strongly favored



- signature in asymmetry of momentum distributions



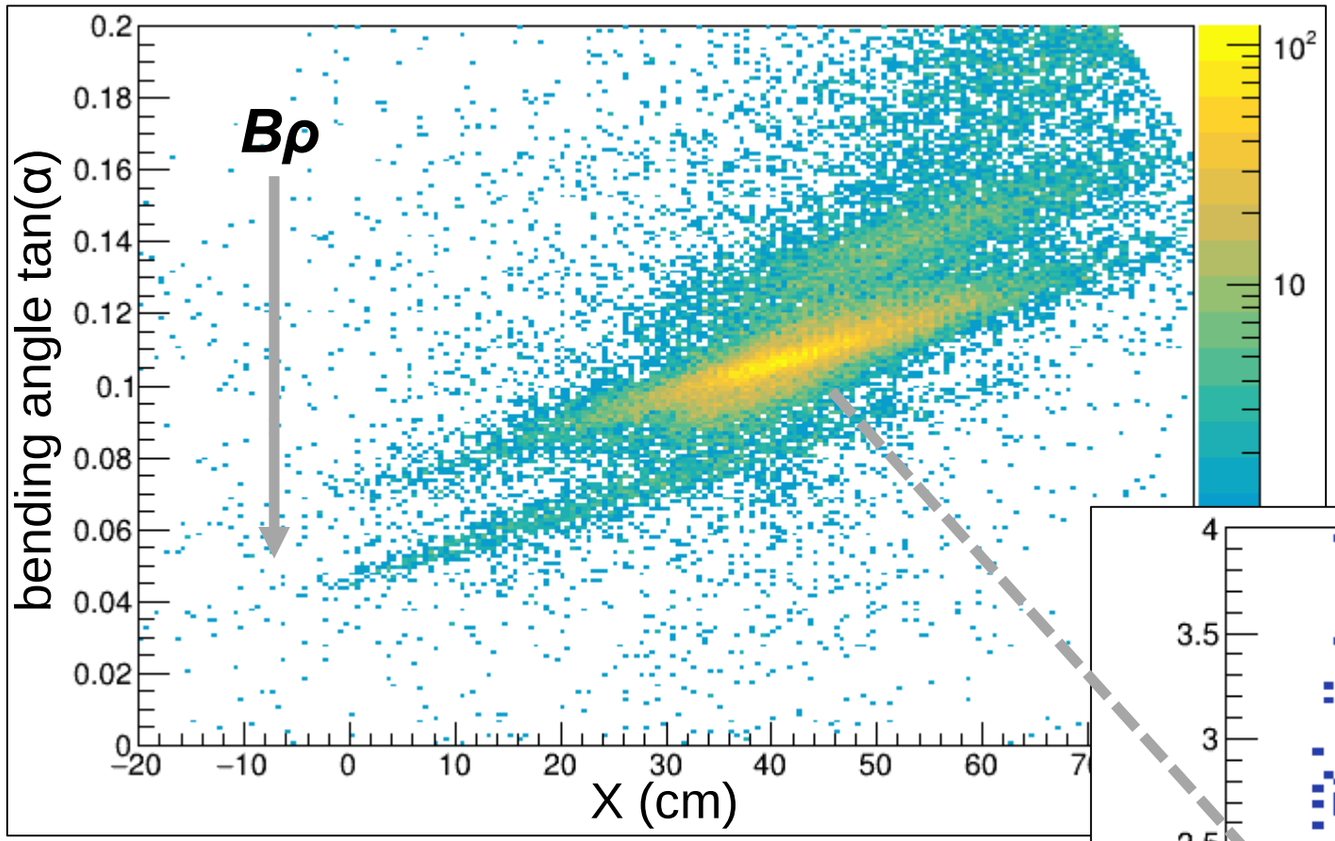




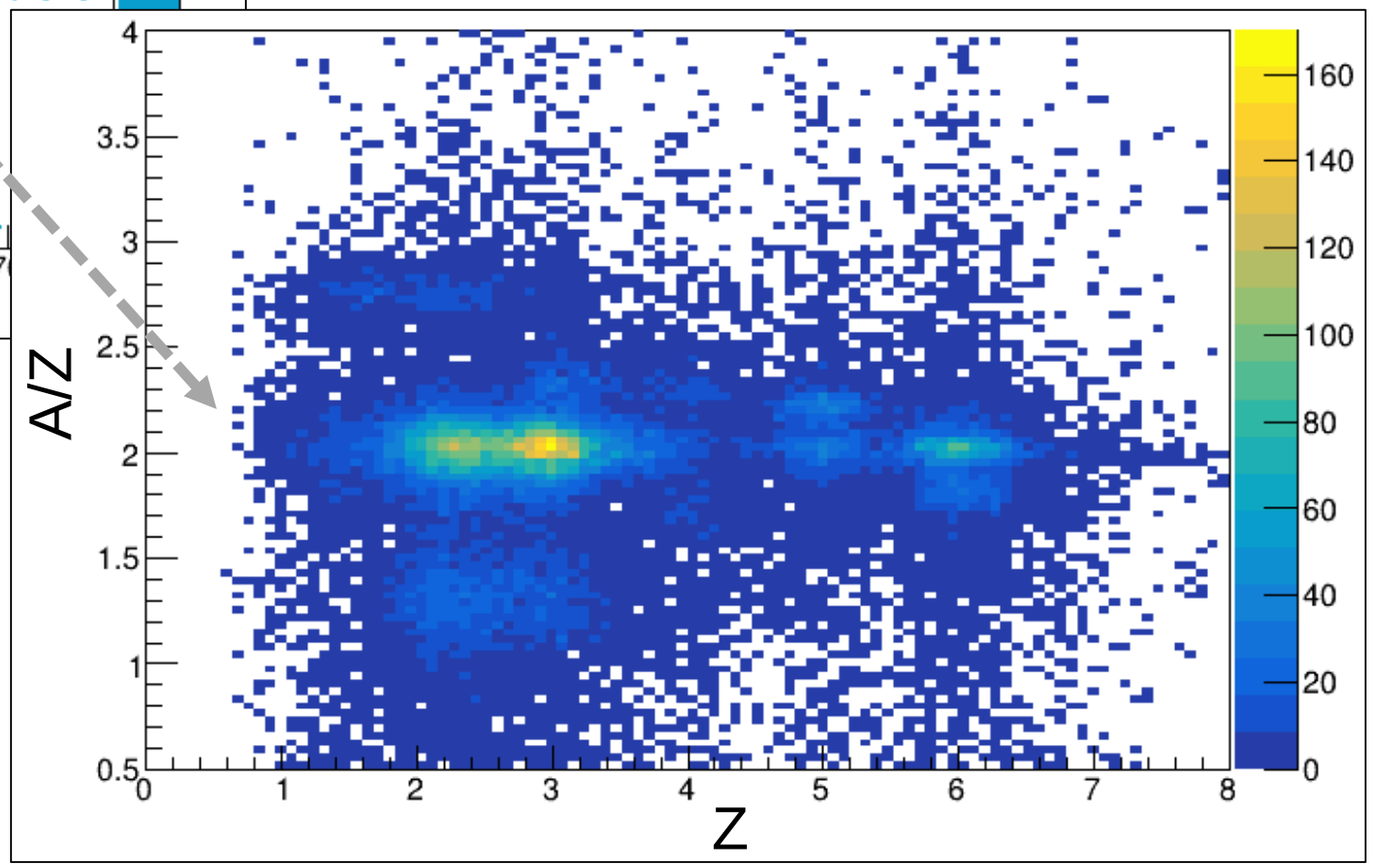
Primary Analysis Goals II

Study of break-up reactions of the heavy charged residual nucleus

- identify the abundance of produced fragments, $^{12}C + p \rightarrow X$



- A/Z separation after analyzer magnet, $B\rho \propto \frac{A}{Z}\beta\gamma$
- here: DCH tracking and proton-arm trigger

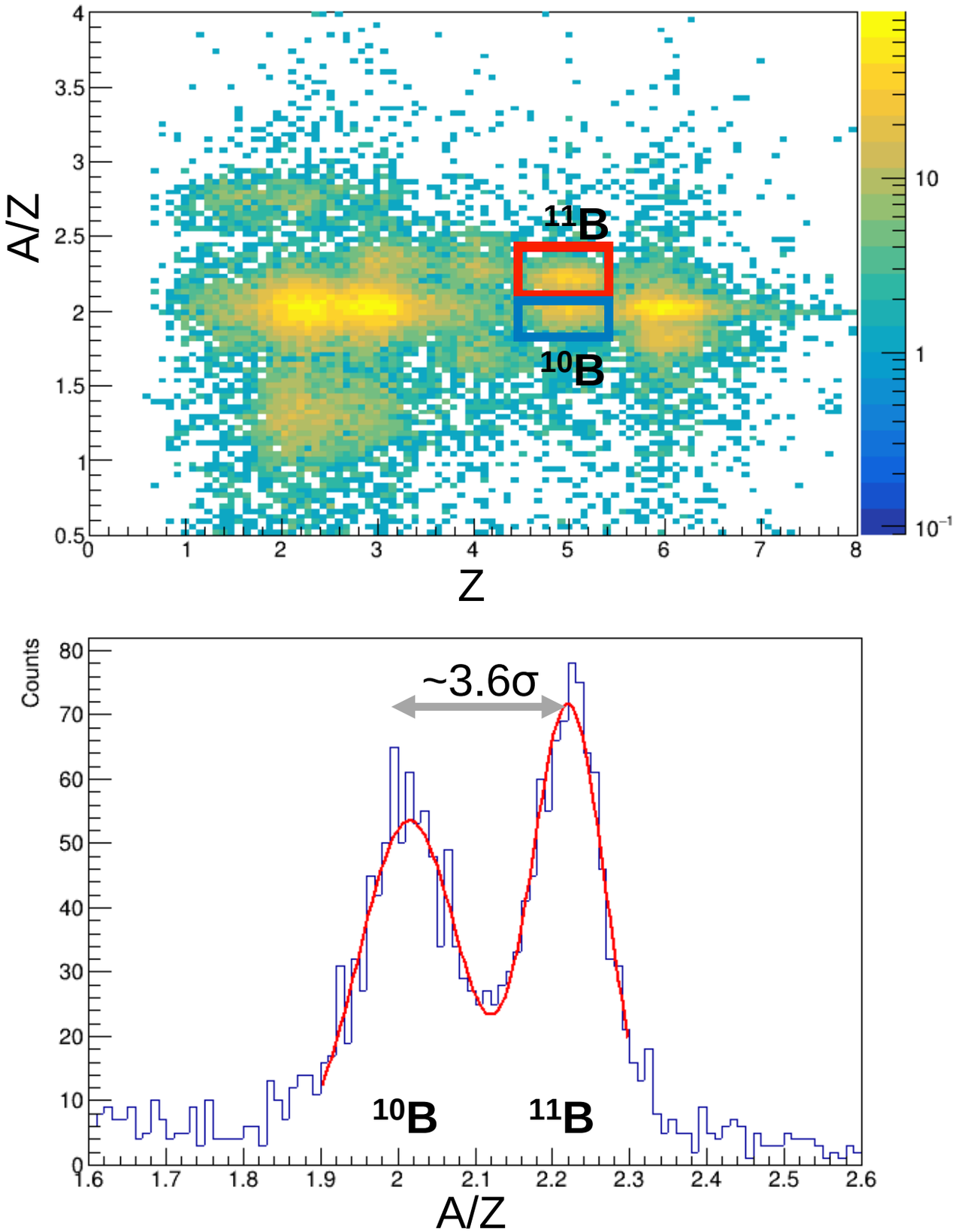


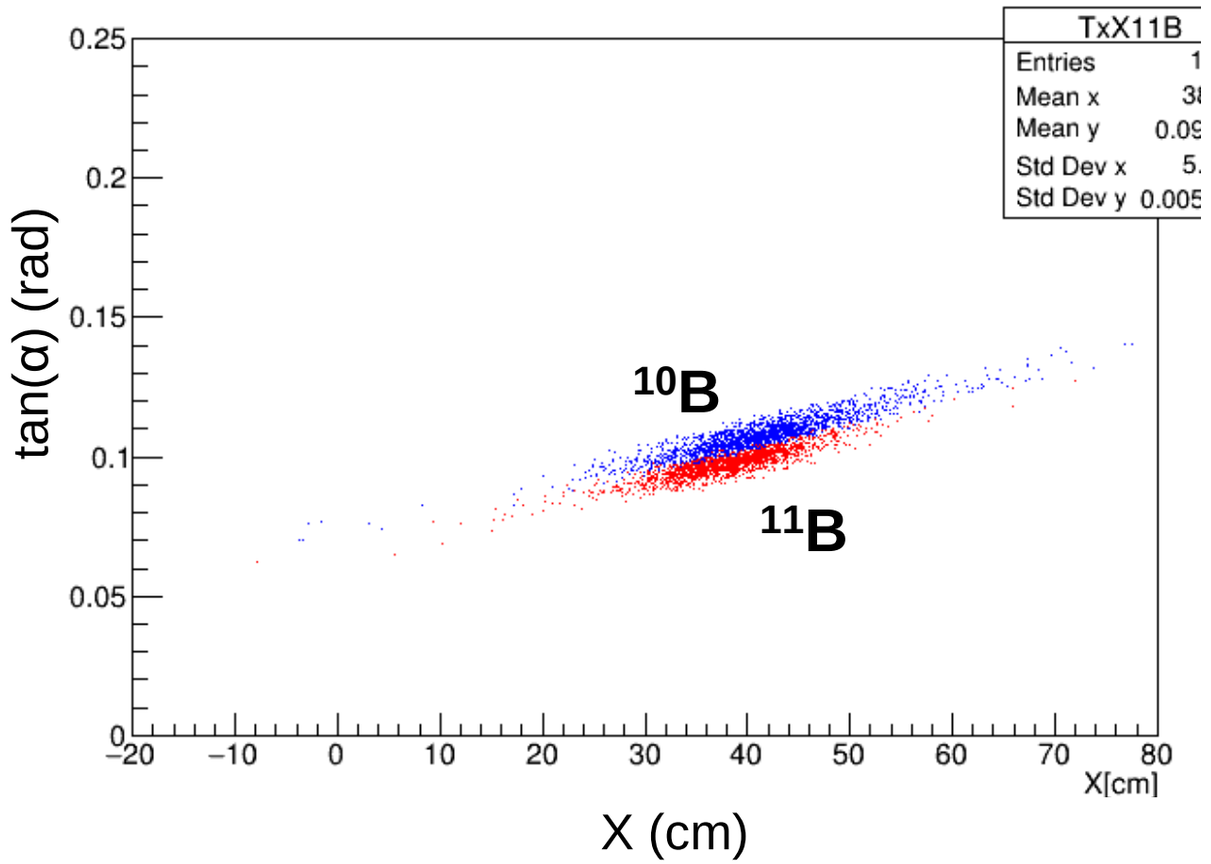
- break-up also into multiple light fragments
- analysis in terms of excitation enery planned (+ theory guidance)

Courtesy of Göran Johansson

Primary Analysis Goals II

QE tagging: $^{12}C(p,2p)^{11}B$ selection





- **^{11}B and ^{10}B (A-2 system) can be separated**
- resolution to be improved with full tracking (MWPC – GEM – DCH + ToF700)

Courtesy of Göran Johansson

Analysis Plans

Next Analysis Steps – combine the work from sub-groups:

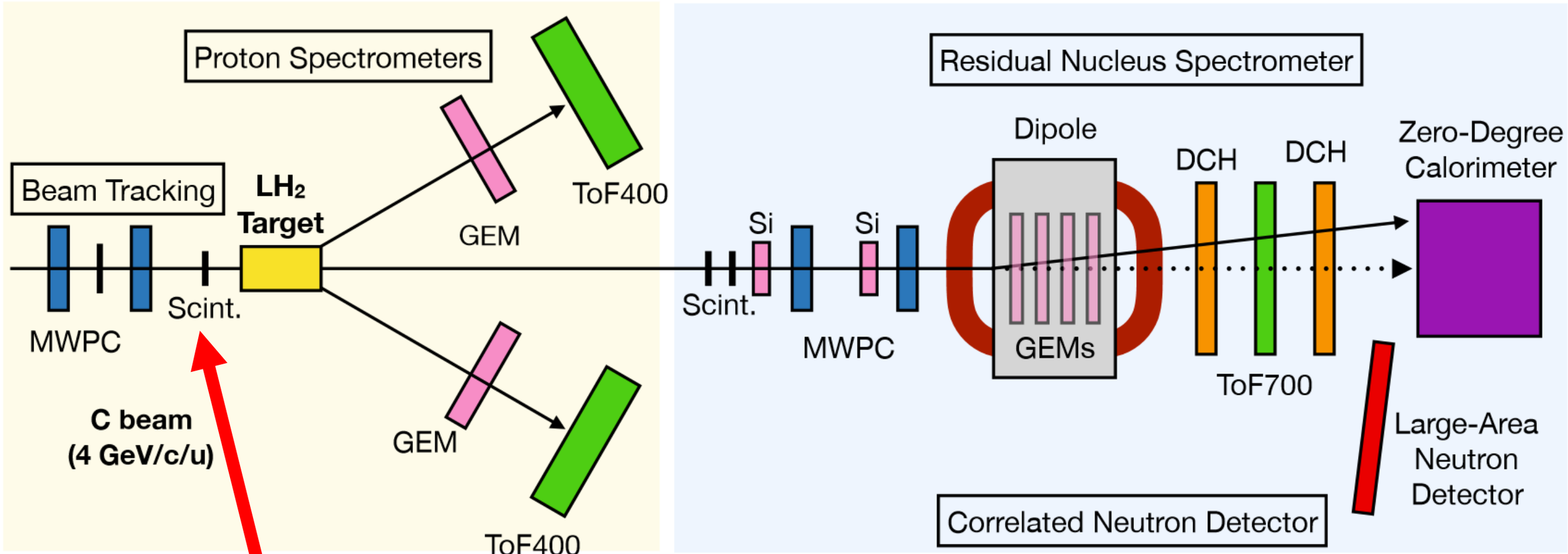
- global tracking (track eff.)
- reaction-channel identification:
  compare different approaches to improve resolution and efficiency
- proton-arm vertex reconstruction and identification

  → **momentum analysis: incoming beam, protons, fragments**
- include in BMNRoot repository

- regular analysis meetings at JINR (~2months), coordination Maria Patsyuk
- **5 PhD students**
  - Efrain (MIT)
  - Göran (TAU)
  - Vasilisa, Ksenia, Timur (JINR)
- 1st publication and thesis expected on QE scattering
- preliminary results to be presented at next Nuclotron User's Meeting

Preparations for the Next Run

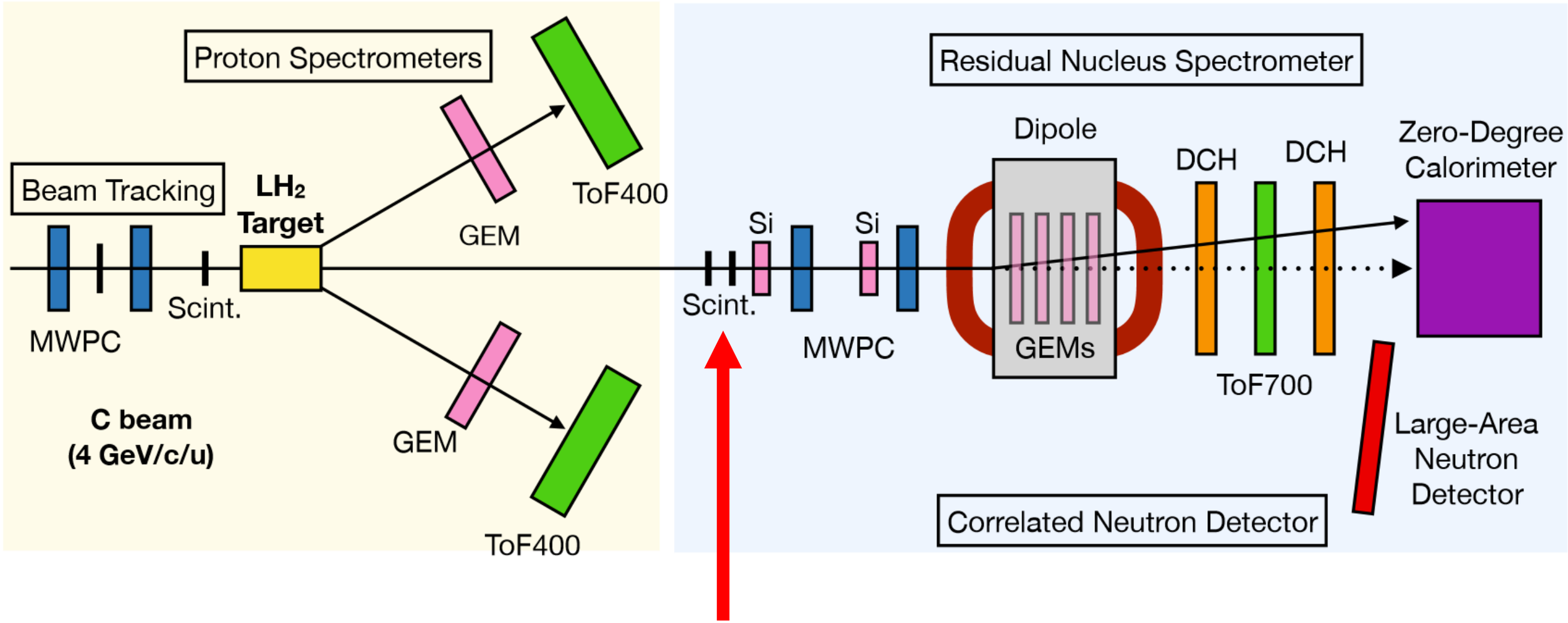
Preparations + Improvements for SRC run early 2021: ^{12}C (4GeV/c/u) + LH_2



New and additional T0 counter (improve time resolution)

Preparations for the Next Run

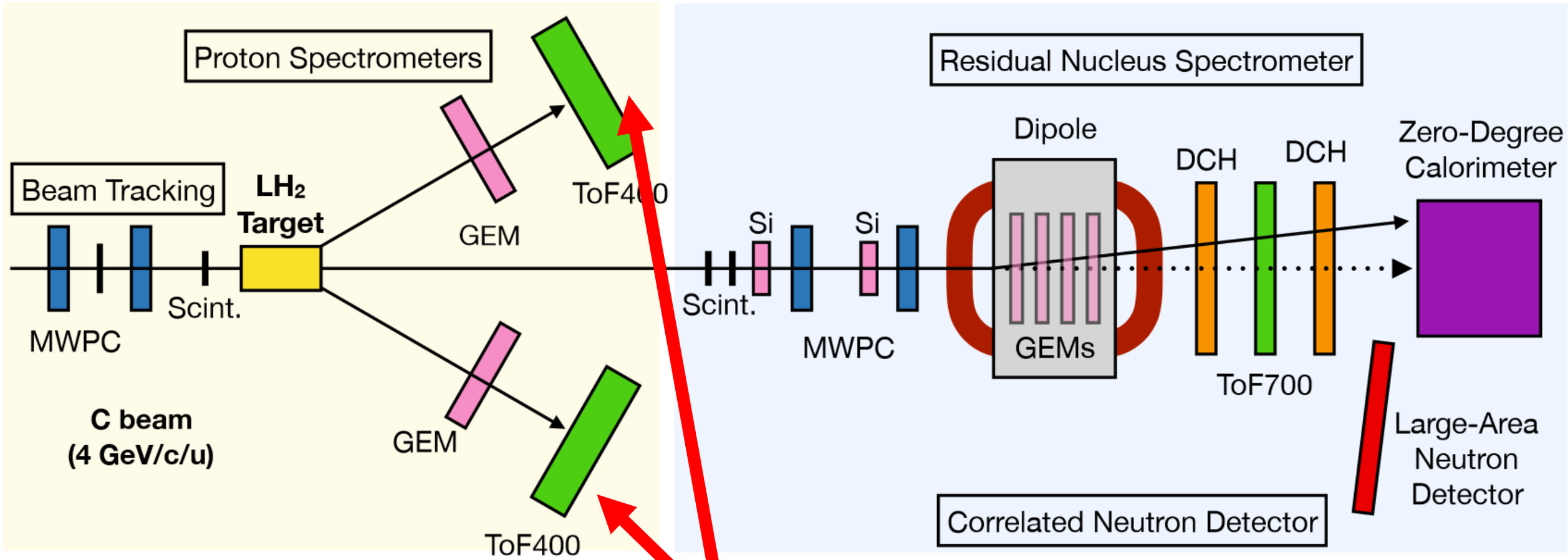
Preparations + Improvements for SRC run early 2021: ^{12}C (4GeV/c/u) + LH_2



New Beam Counters
(charge identification)

Preparations for the Next Run

Preparations + Improvements for SRC run early 2021: ^{12}C (4GeV/c/u) + LH_2

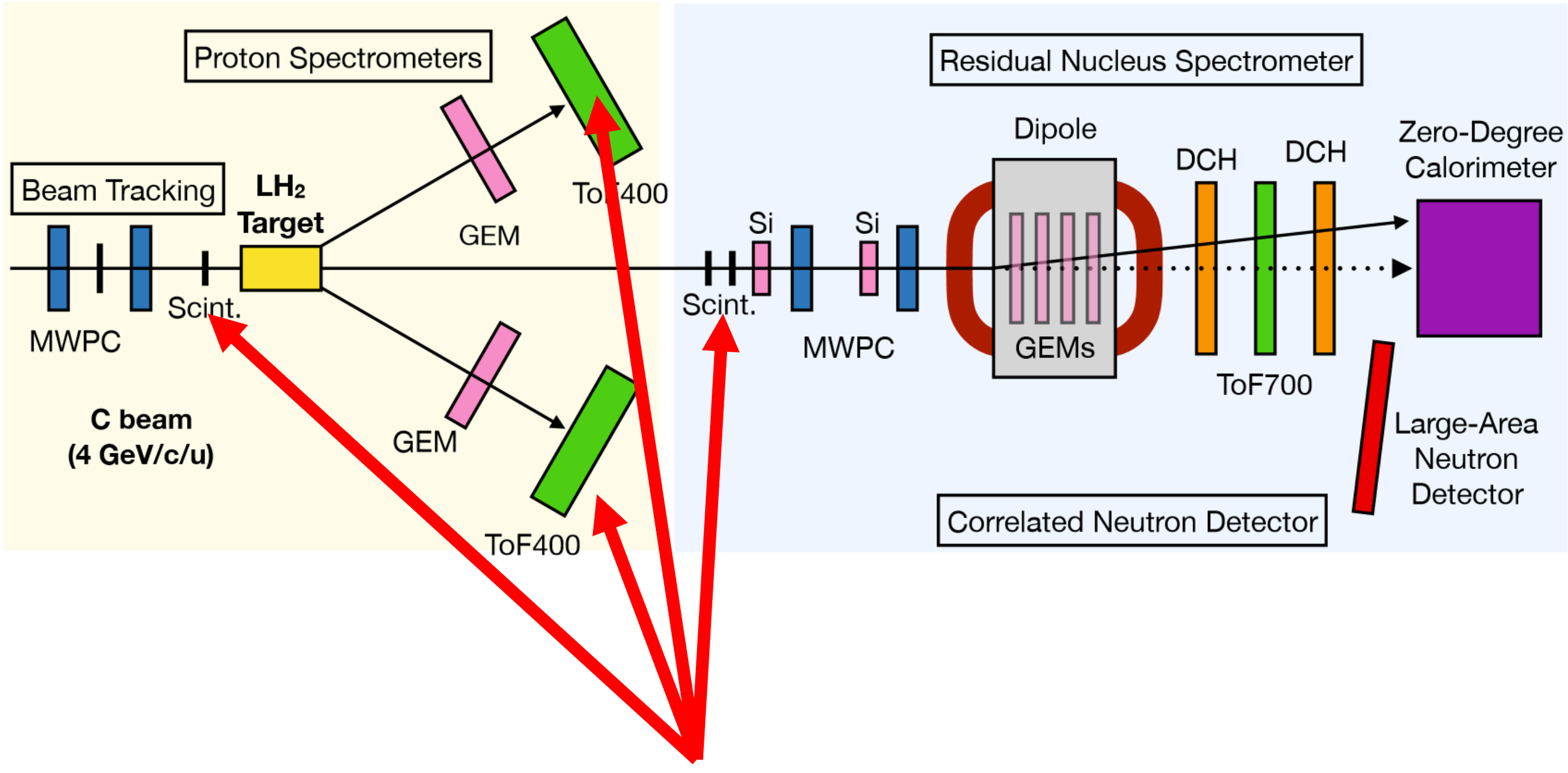


Additional ToF RPCs (increase angular coverage)

Additional plastic-scintillator hodoscope
(improved ToF and pion discrimination)

Preparations for the Next Run

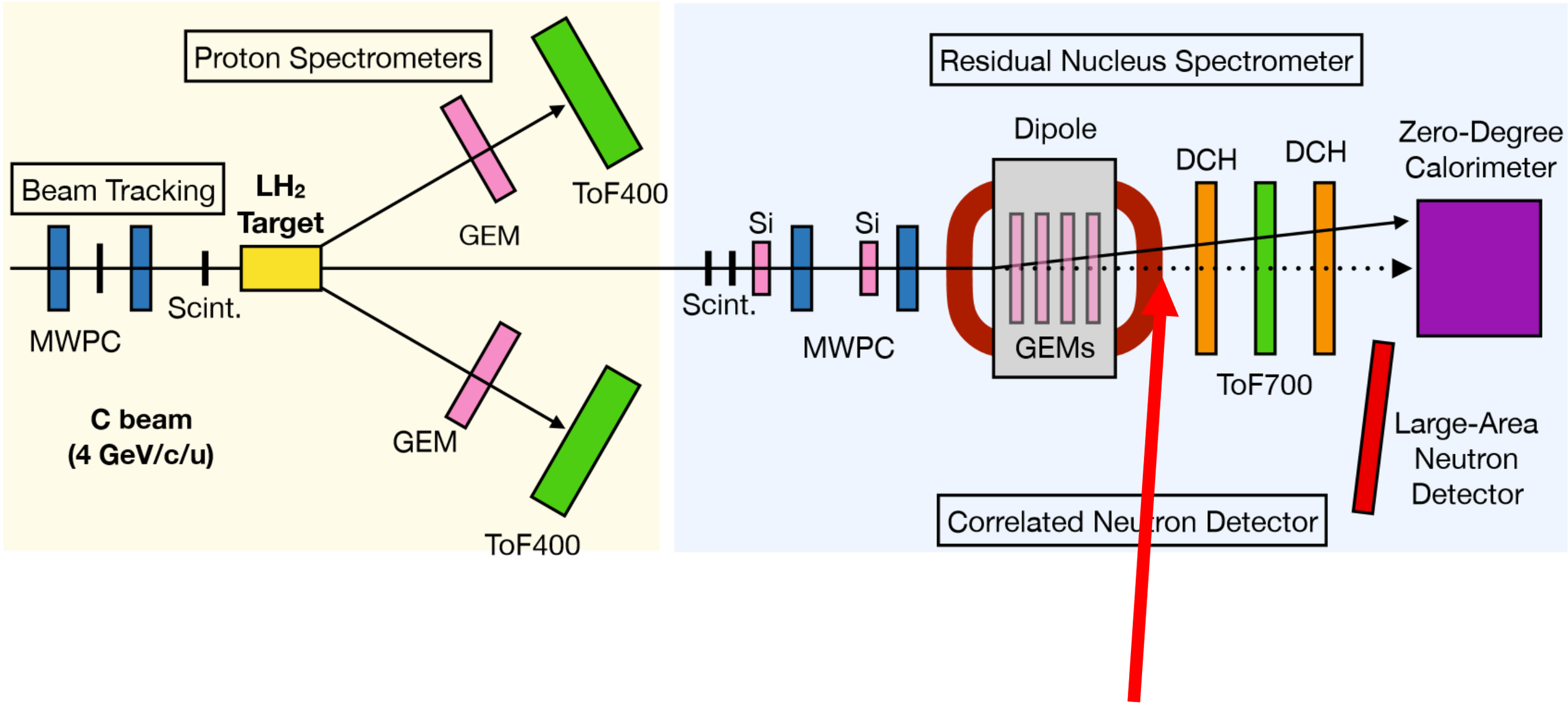
Preparations + Improvements for SRC run early 2021: ^{12}C (4GeV/c/u) + LH_2



Connect scintillators to **laser-based calibration system**
(MIT development)

Preparations for the Next Run

Preparations + Improvements for SRC run early 2021: ^{12}C (4GeV/c/u) + LH_2



New **beam-pipe** intended to be used only within magnetic field and downstram

Thank You for Your Attention.

Many Thanks to the Collaborators

BM@N
Baryonic Matter at Nuclotron

JINR

DE LA RECHERCHE À L'INDUSTRIE
cea

TEL AVIV UNIVERSITY
אוניברסיטת תל אביב

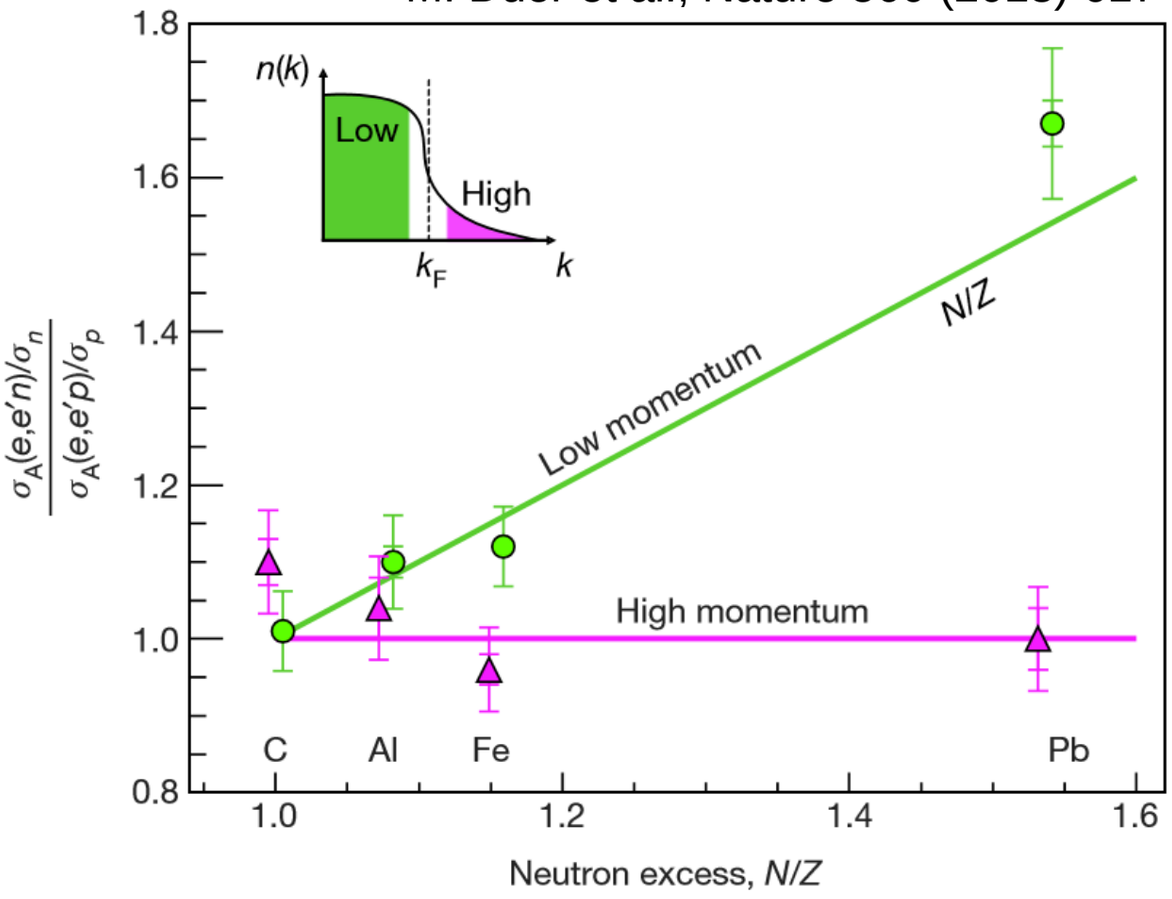
TECHNISCHE UNIVERSITÄT DARMSTADT

GSI

Appendix

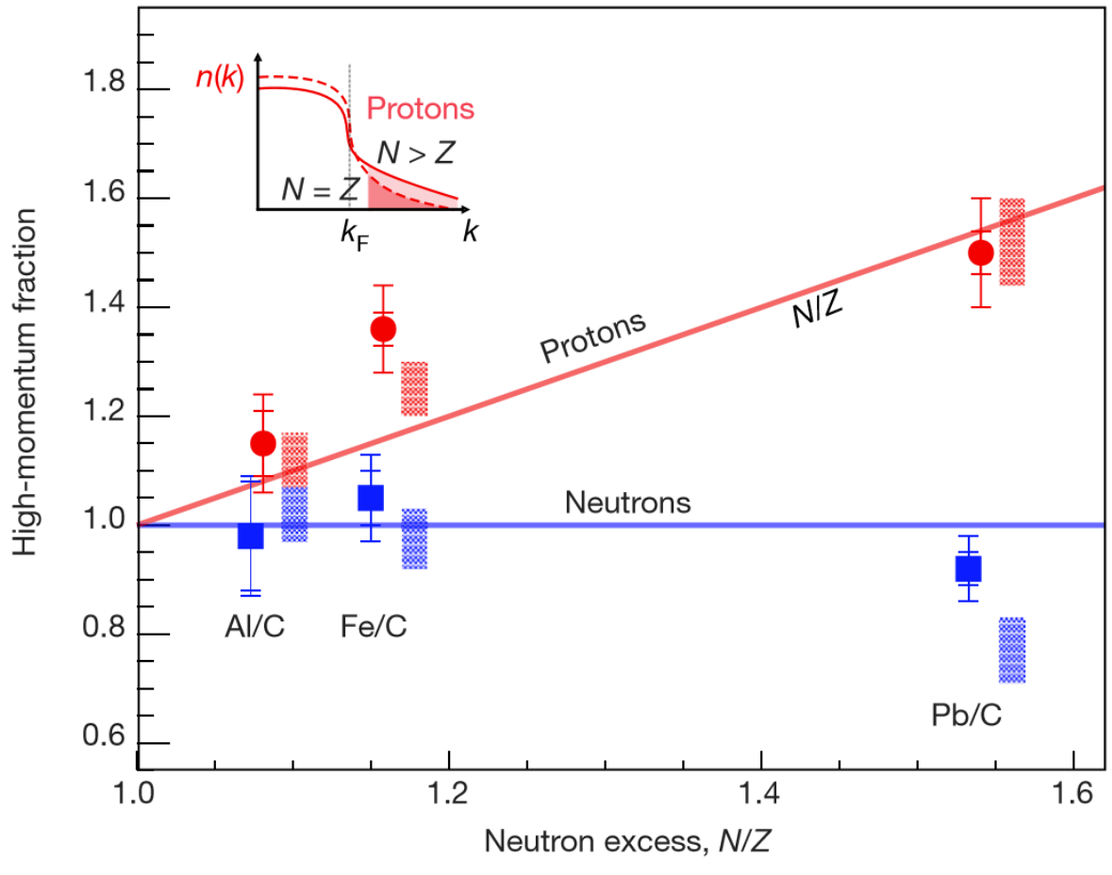
What is known about SRCs?

M. Duer et al., Nature 560 (2018) 617



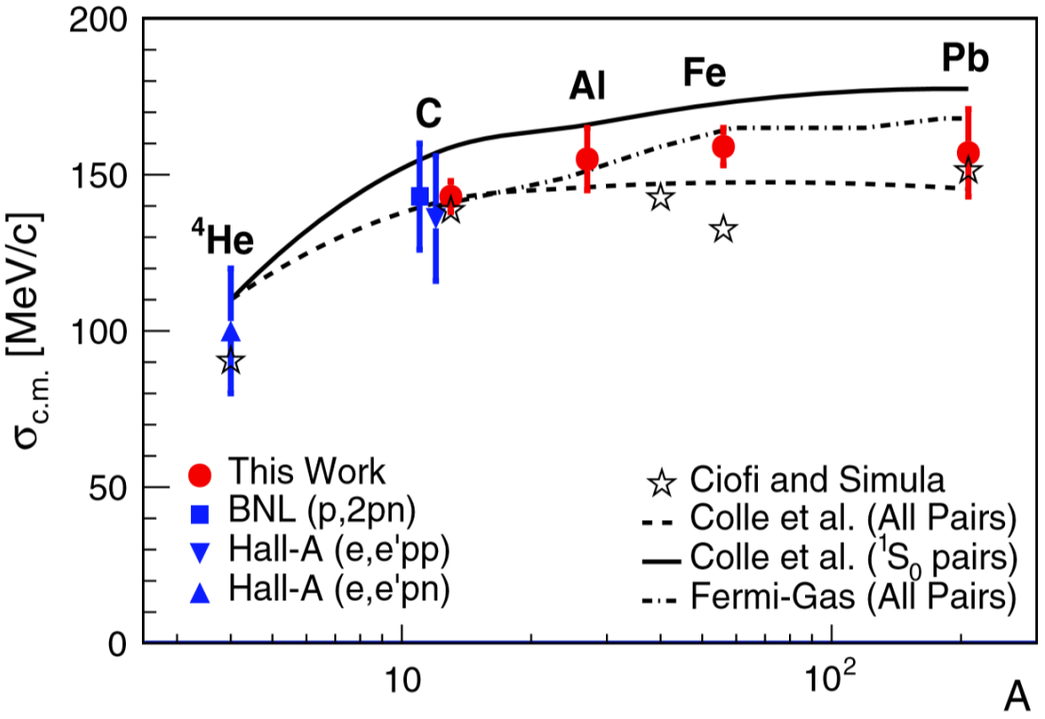
- study neutron-rich nuclei
- measure knocked-out neutron directly *A(e,e'n)*
- *#n = #p* in high-momentum tail

M. Duer et al., Nature 560 (2018) 617



- fraction of minority protons grows
- do deeply-bound protons form pairs?
- excitation of the (A-2)-system?

→ study the fragments in inverse kinematics at JINR



$$\vec{p}_{\text{c.m.}} = \vec{p}_{\text{miss}} + \vec{p}_{\text{recoil}} = \vec{p}_p - \vec{q} + \vec{p}_{\text{recoil}},$$

$$\vec{p}_{\text{rel}} = \frac{1}{2}(\vec{p}_{\text{miss}} - \vec{p}_{\text{recoil}}).$$

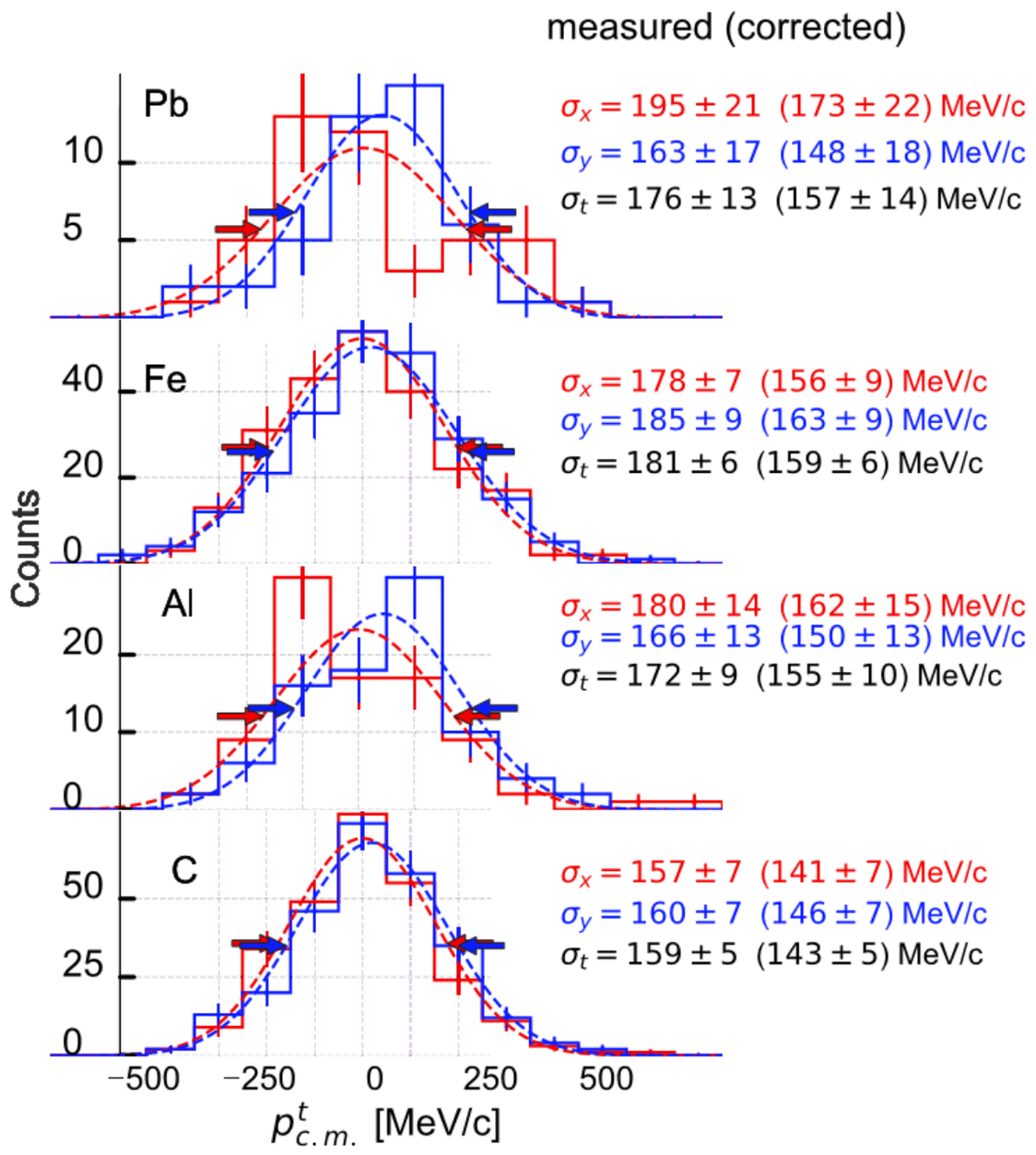
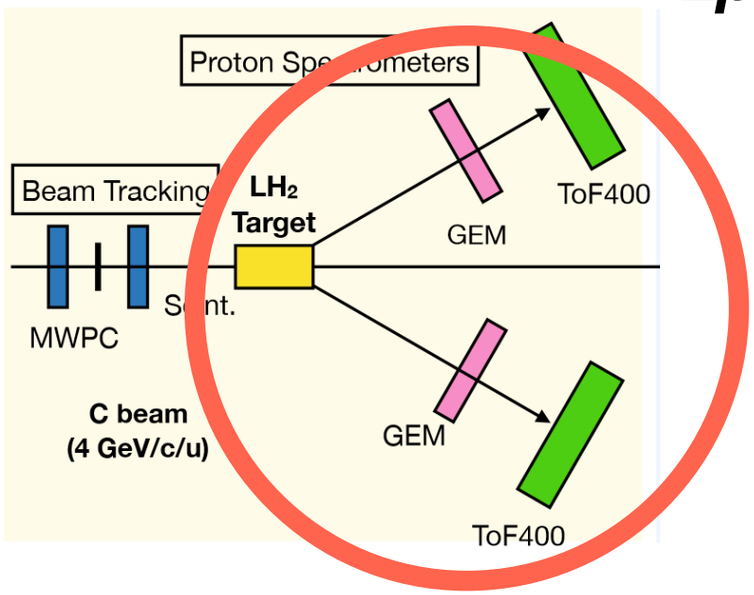
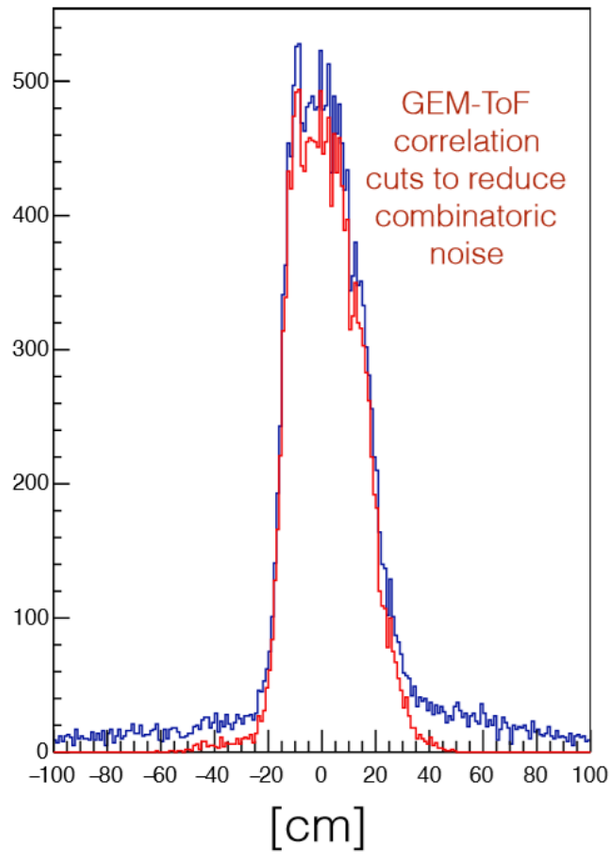


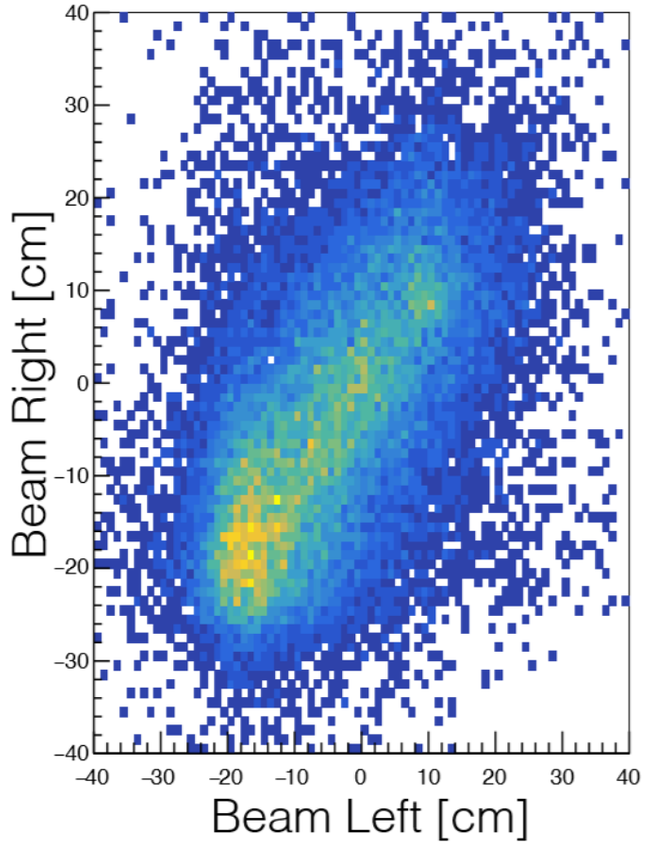
FIG. 2. The number of $A(e, e'pp)$ events plotted versus the components of $\vec{p}_{\text{c.m.}}$ perpendicular to $\vec{p}_{\text{miss}}$. The red and blue histograms show the $\hat{x}$ and $\hat{y}$ directions, respectively. The data are shown before corrections for the CLAS detector acceptance. The dashed lines show the results of Gaussian fits to the data. The widths in parentheses with uncertainties are corrected for the CLAS acceptance as discussed in the text.

Calibration Status – Proton Arms

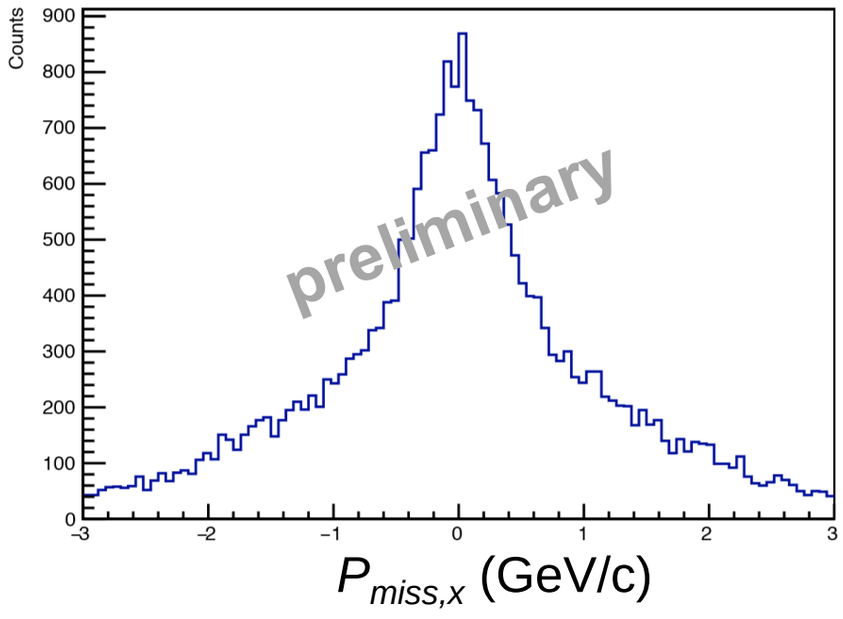
2*p* tracking and vertex reconstruction using GEM+ToF400

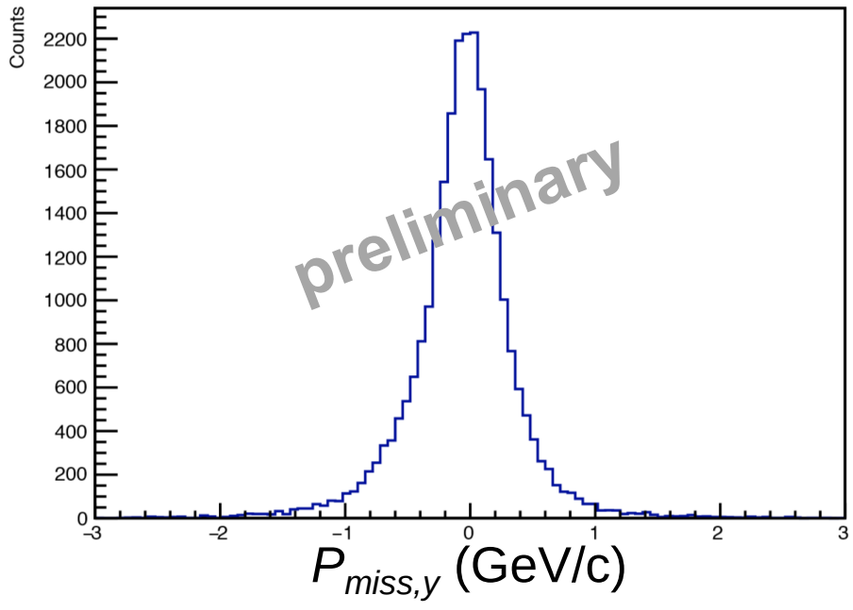






$$\vec{p}_{miss} = \vec{p}_{p1} + \vec{p}_{p2} - \vec{p}_{beam}$$



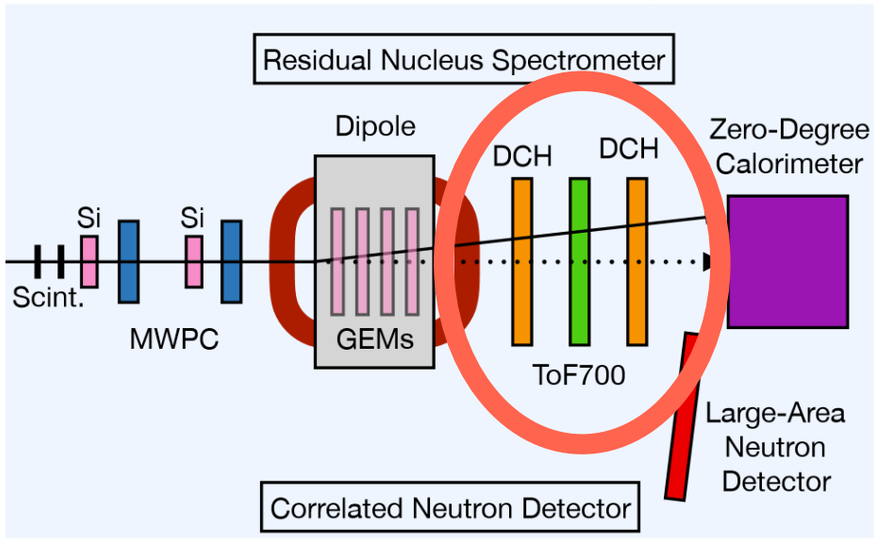


Ongoing:

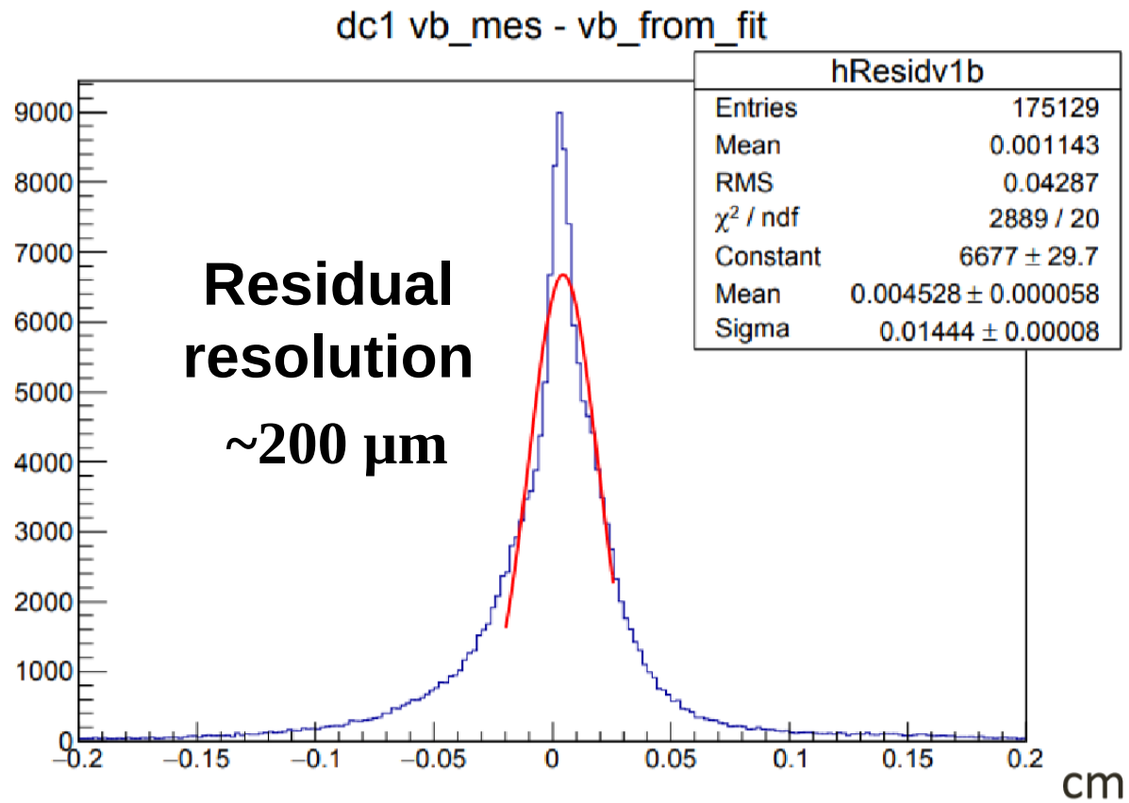
- include up- and downstream tracking
- sensitivity to abs. alignment
- proton identification

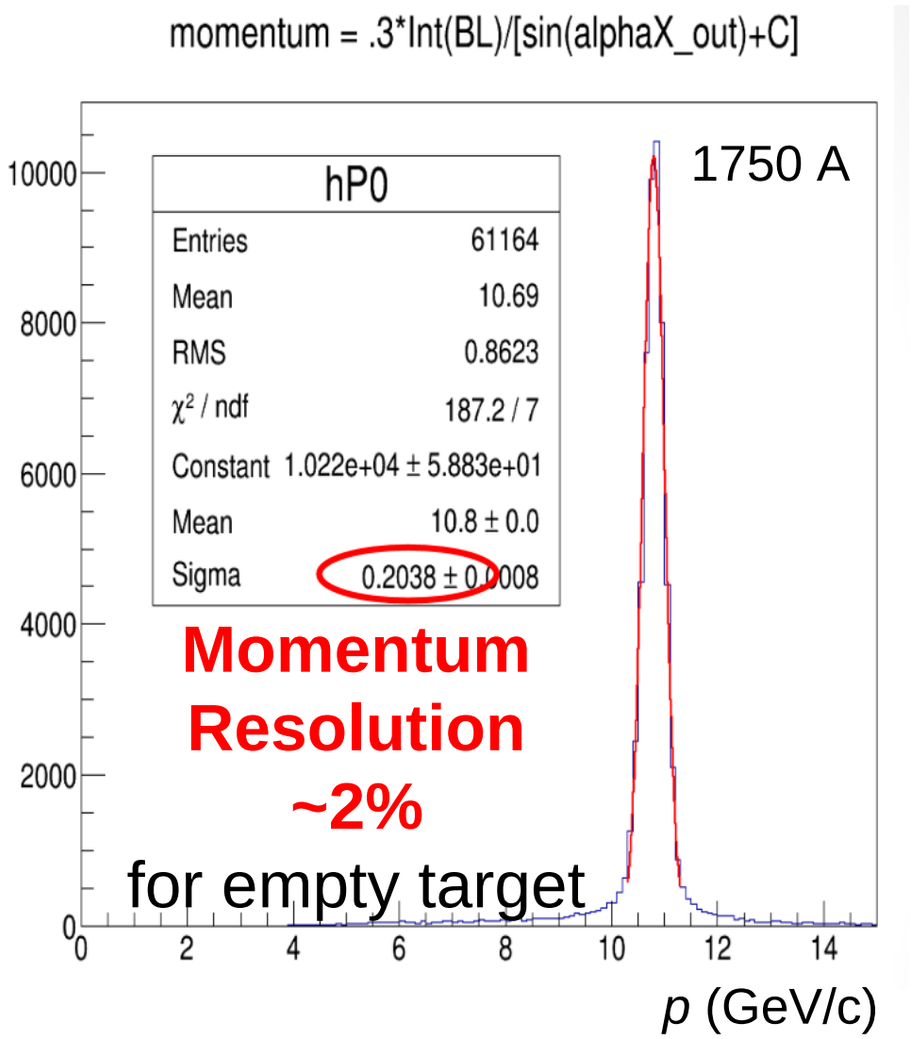
Courtesy of Efrain Segarra

Calibration Status – Fragment Tracking



- alignment of DCH and ToF700 done
- improved tracking efficiency
- $\varepsilon_{DCH1} \approx 98\%$, $\varepsilon_{DCH2} \approx 95\%$ (rel. to GEM & DCH#)





Courtesy of Vladimir Palichik & Nikolay Voytishin

Quantities	Cuts
$\theta_{1,2}$ of P_1,P_2	$25° \leq \theta_{1,2} \leq 38°$
φ_1	$\lvert\varphi_1\rvert < 7.5^o$
φ_2	$\lvert\varphi_2 - 180.0^o\rvert < 7.5^o$
|s,t,u|	≥ 2 (GeV/c)^2

Quantities	Cuts	Counts
$\theta_{1,2}$ φ_1 φ_2	$25° \leq \theta_{1,2} \leq 38°$ $\lvert\varphi_1\rvert < 7.5^o$ $\lvert\lvert\varphi_2\rvert - 180.0^o\rvert < 7.5^o$	8976
$TOF_{1,2}$	17.4 nsec <$TOF_{1,2}$<18.7 nsec	517
|s,t,u| P_{miss}	≥ 2 (GeV/c)^2 0.25 (GeV/c)≤ P_{miss} ≤1.0(GeV/c)	401
$\theta_{1,2}$	2D-cut at (θ_2,θ_1)	216
$\theta_{1,2}$ vs $P_{1,2}$	2D-cut at ($P_{1,2}$,$\theta_{1,2}$)	96
P_1+P_2	5.4 GeV/c < p_1 + p_2 < 5.65 GeV/c	20

Table 8: A summary of the cuts (columns 1,2) and the background events, per 10^8 proton-Carbon interactions, to the p(^{12}C,2p)X reaction that survive after each cut (column 3).

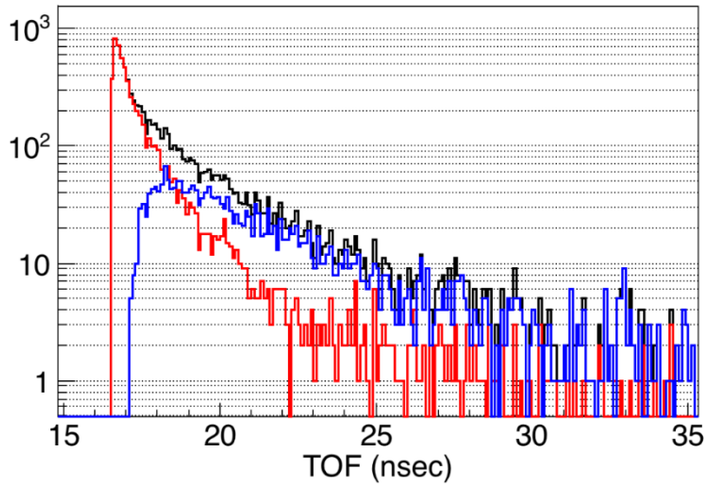


Figure 27 Time of flight spectra of $\pi^{\pm}$ and protons (black), $\pi^{\pm}$ alone (red), and protons alone (blue).

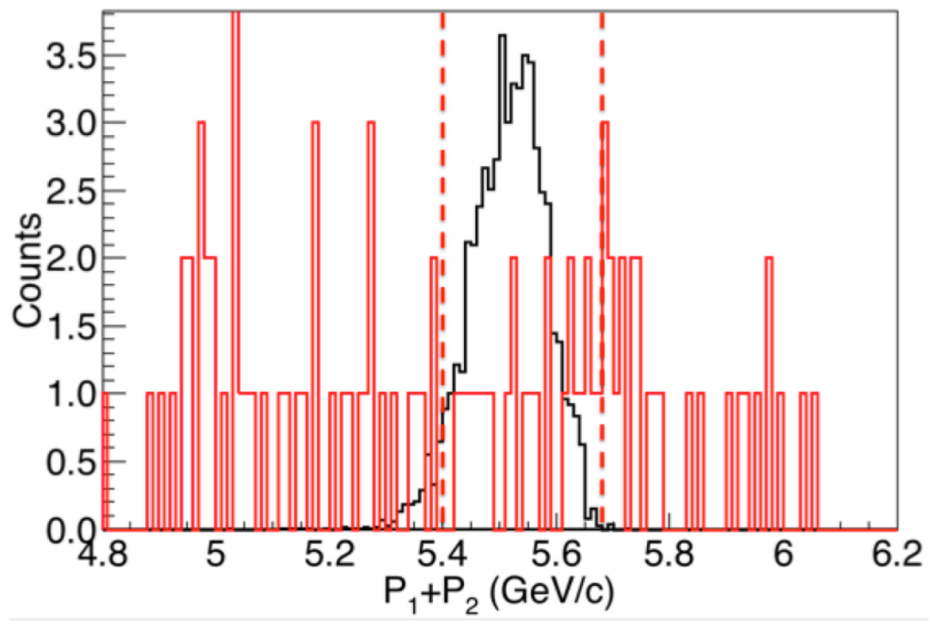


Figure 31 The sum of the momenta p_1+p_2 of the two leading protons for SRC events in the ^{12}C nucleus rest frame (black distribution). The background events are shown in red.

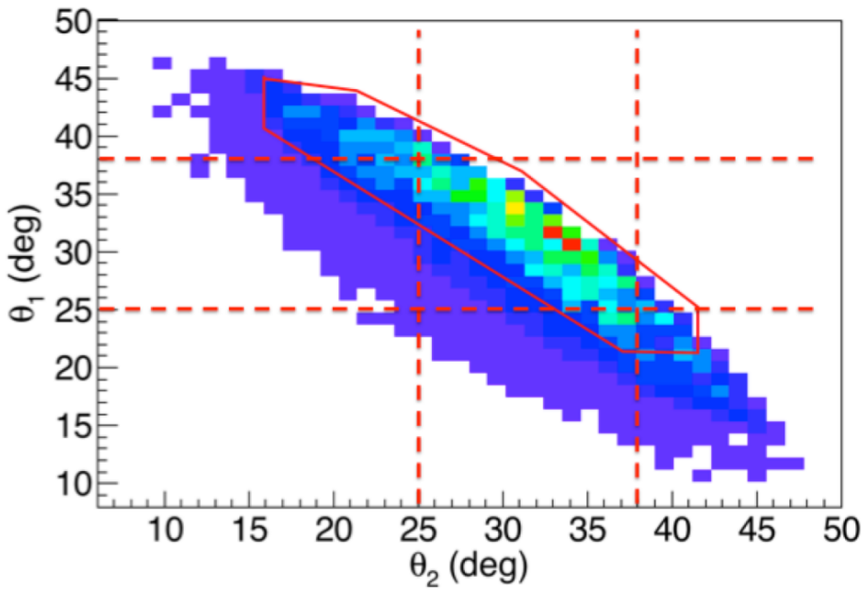


Figure 29 The correlation of the polar angles of the leading protons in the laboratory frame for the SRC signal events. Also shown is the graphical cut (red line) that accepts the majority of the SRC events.

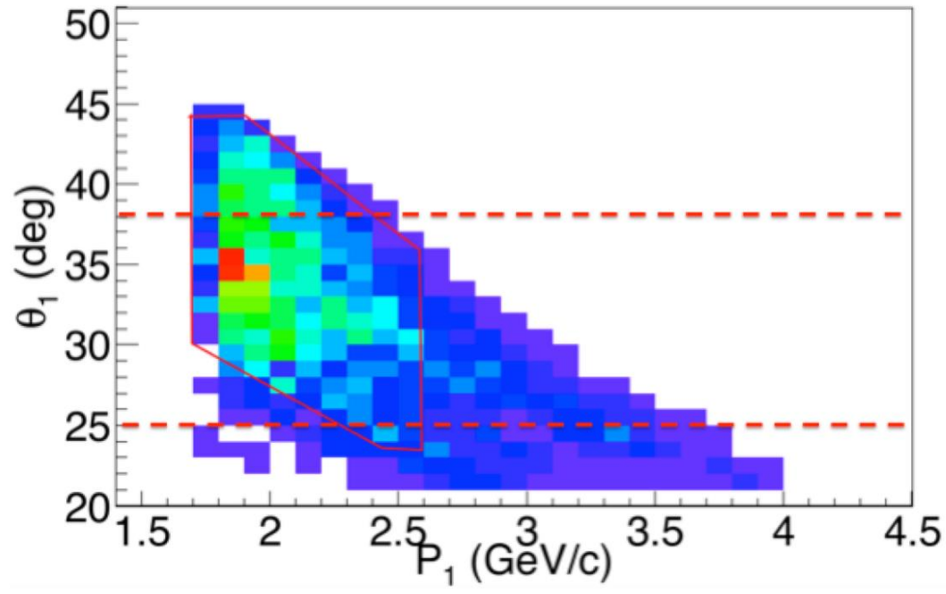
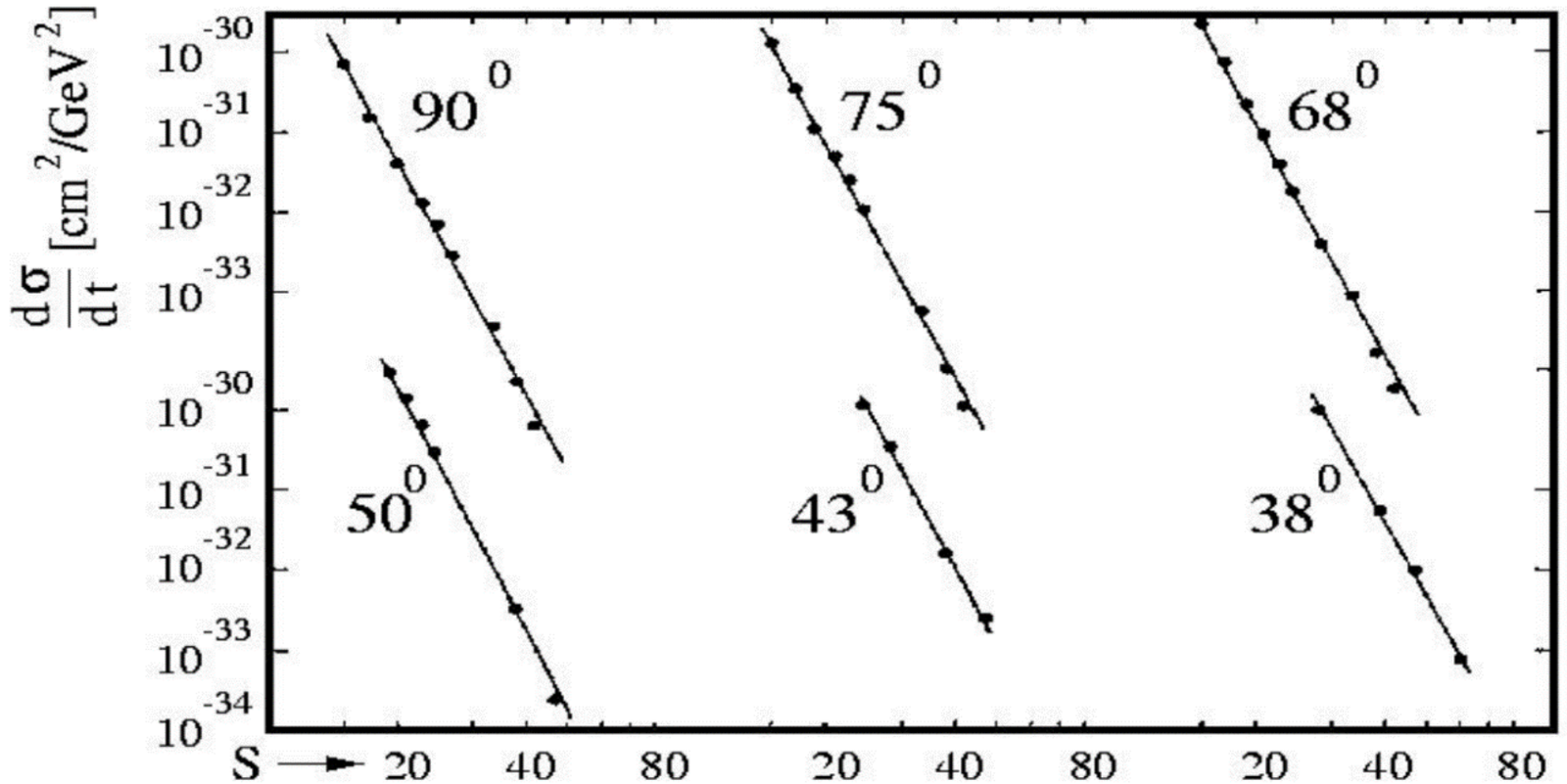
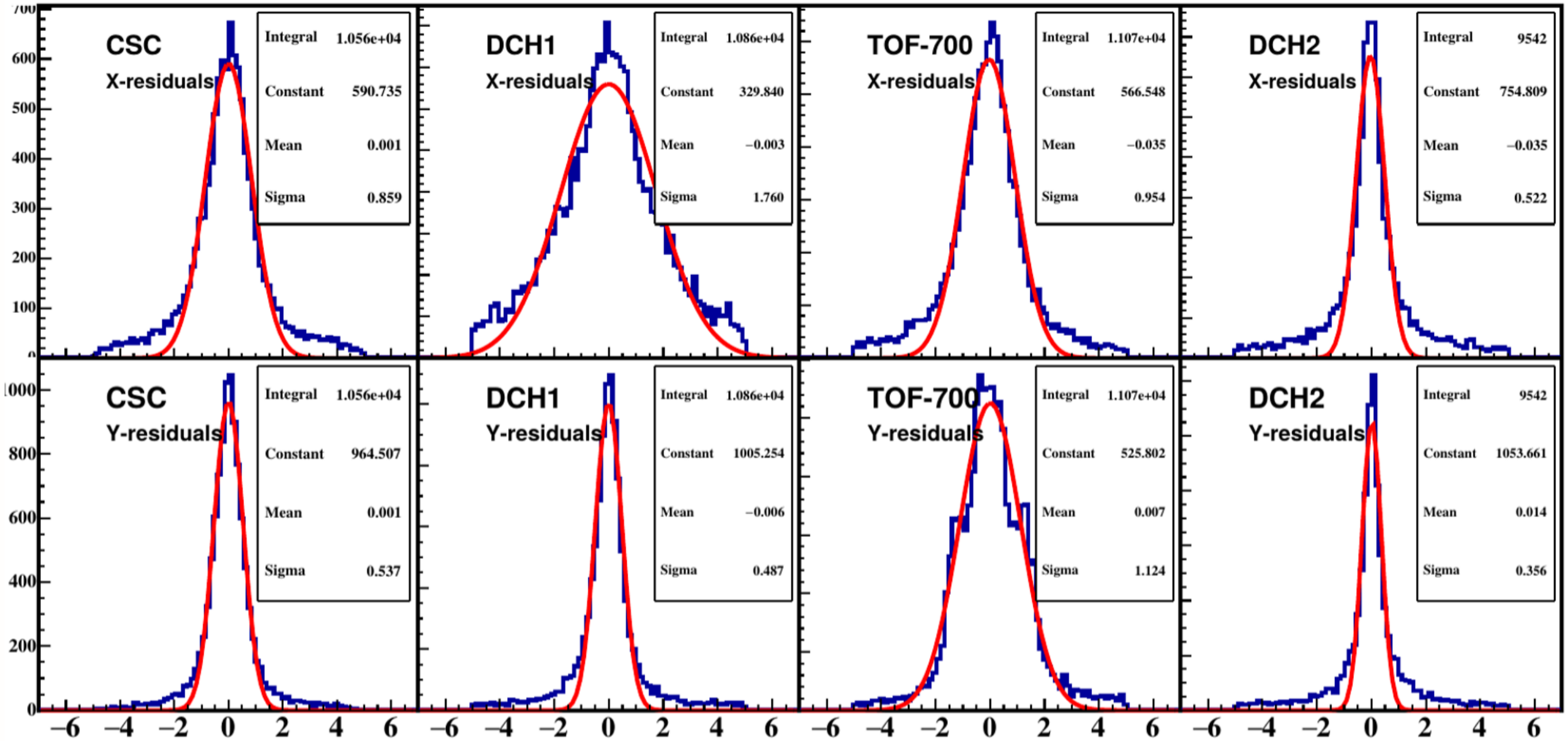
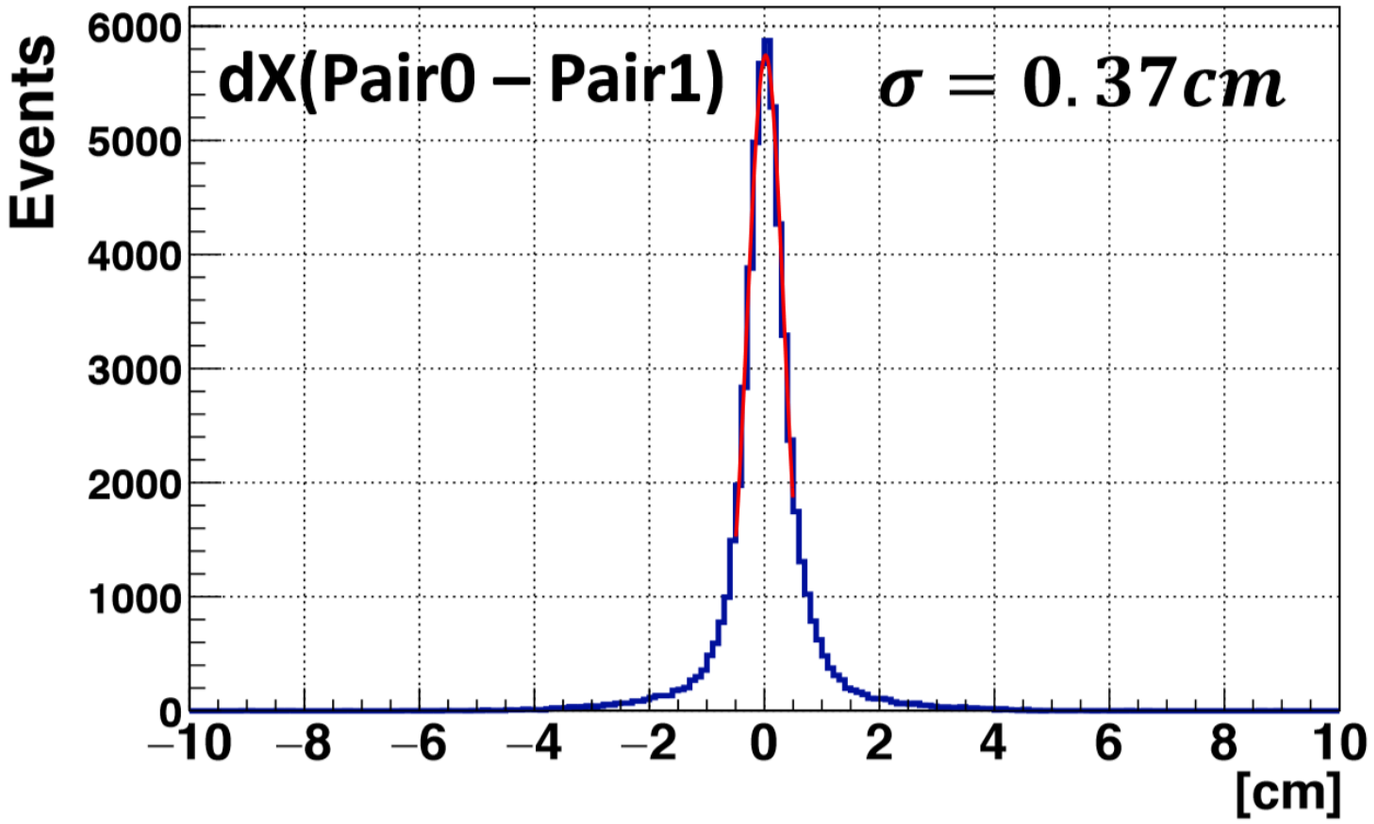


Figure 30 The correlation of the polar angle with momentum for one of the leading protons for the SRC signal together with a graphical cut (red line) that accepts the majority of the SRC events.


$\frac{d\sigma}{dt}$ [cm^2/GeV^2]
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
90^0
75^0
68^0
50^0
43^0
38^0
S →
20
40
80
20
40
80
20
40
80


CSC
X-residuals
Integral 1.056e+04
Constant 590.735
Mean 0.001
Sigma 0.859
DCH1
X-residuals
Integral 1.086e+04
Constant 329.840
Mean −0.003
Sigma 1.760
TOF-700
X-residuals
Integral 1.107e+04
Constant 566.548
Mean −0.035
Sigma 0.954
DCH2
X-residuals
Integral 9542
Constant 754.809
Mean −0.035
Sigma 0.522
CSC
Y-residuals
Integral 1.056e+04
Constant 964.507
Mean 0.001
Sigma 0.537
DCH1
Y-residuals
Integral 1.086e+04
Constant 1005.254
Mean −0.006
Sigma 0.487
TOF-700
Y-residuals
Integral 1.107e+04
Constant 525.802
Mean 0.007
Sigma 1.124
DCH2
Y-residuals
Integral 9542
Constant 1053.661
Mean 0.014
Sigma 0.356


dX(Pair0 – Pair1)
$\sigma = 0.37cm$
Events
6000
5000
4000
3000
2000
1000
0
−10
−8
−6
−4
−2
0
2
4
6
8
10
[cm]