Analysis II

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BVR Subcommittee Meeting for MUSE

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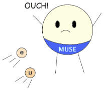


Overview

- Blinding
- Carbon scattering and vertex reconstruction
- LH_2 background subtraction
- Systematics uncertainties
- Conclusion

Blinding

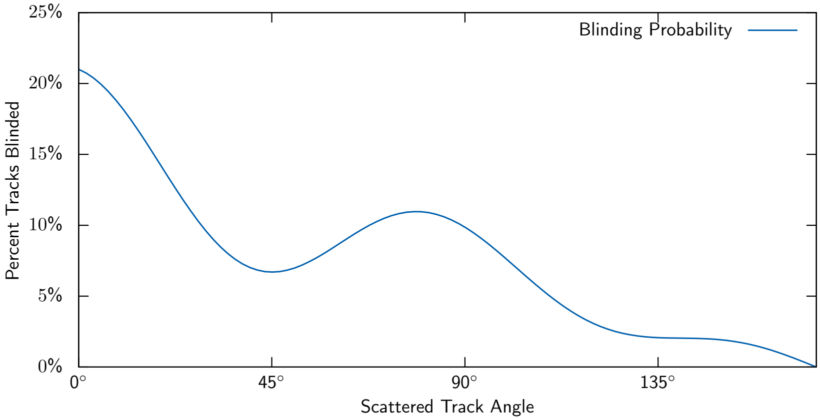
- Blind at track level using blinding scheme presented by J. C. Bernauer in BVR 52
- Encrypt tracks with angular dependence
- A, B are generated from fixed seed and are unique for charge, species, momentum, simulation
- $A = 0.25..1, \; B = 3..10$

$$s = 0.2(A + 0.3\cos(B \times \theta)) \tag{1}$$

$$P = s \times \frac{3 - \theta}{3} \tag{2}$$

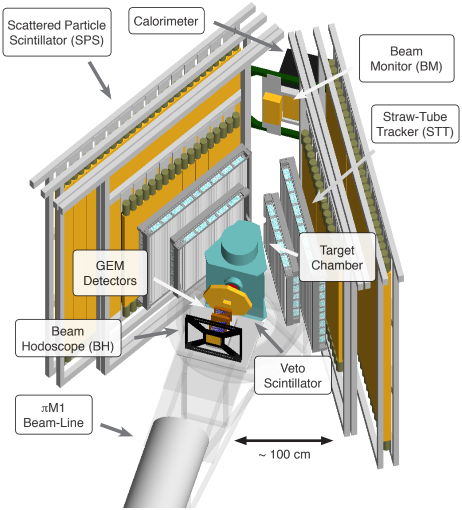
- if $P \leq R$, where R is a uniformly distributed random number between 0 and 1, encrypt the track
- Can blind up to 25 % of tracks at any given angle
- **All data shown in this talk are blinded**
- Scheme may be implemented in G_{Mn} collaboration at JLab

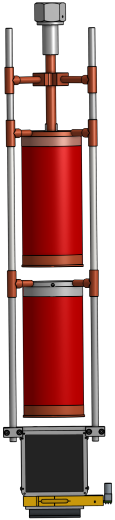
Example Blinding Curve



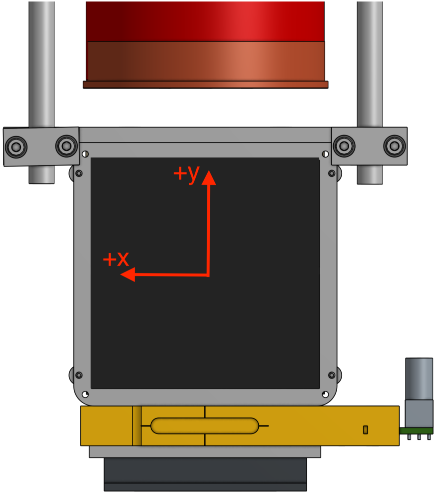
Chance of blinding a track for A = 0.75 and B = 4.2 as a function of STT angle.

MUSE Sketch


Scattered Particle Scintillator (SPS)
Calorimeter
Beam Monitor (BM)
Straw-Tube Tracker (STT)
Target Chamber
GEM Detectors
Beam Hodoscope (BH)
Veto Scintillator
πM1 Beam-Line
~ 100 cm



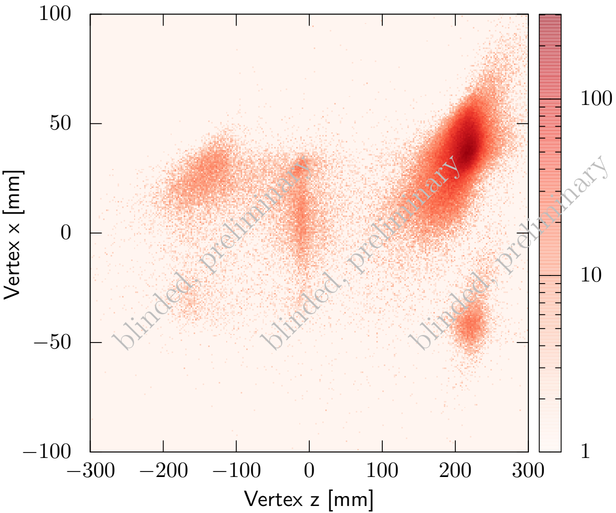
MUSE Solid Target



Vertex Reconstruction

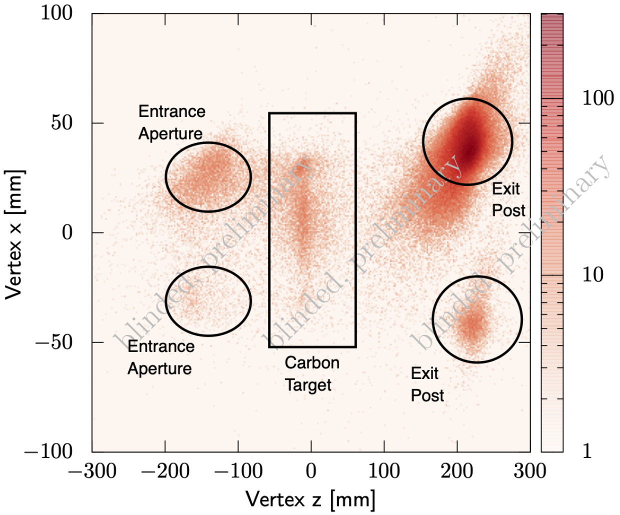
- Here we show reconstructed vertices from STT and GEM tracks
- We project GEM tracks to the target and apply a 50 mm fiducial cut in x and y
- Analysis done for left and right STT
- e^-C and e^+C scattering at 115 MeV/c
- Cut on distance of closest approach < 10 mm, effective "Track quality" selection
- Analysis ongoing; some additional plots shown that were not present in draft
- Develop analysis techniques on carbon scattering
- 7 runs, 14 M events, of each polarity combined in analysis

Top-Down Target Distribution



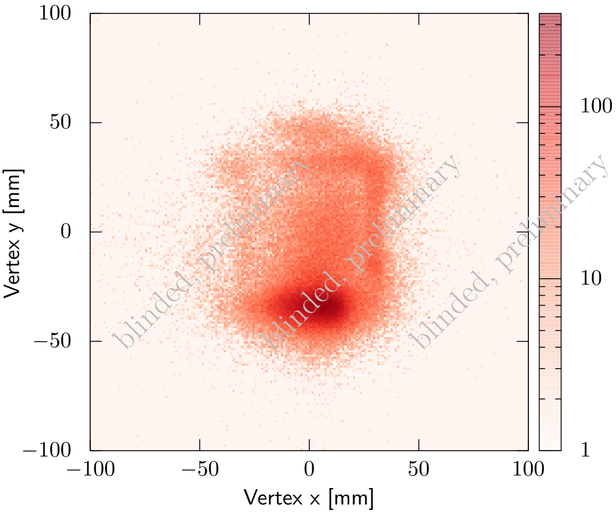
Cut on $|y| < 25$ mm. Carbon target x v z vertex reconstruction.

Top-Down Target Distribution



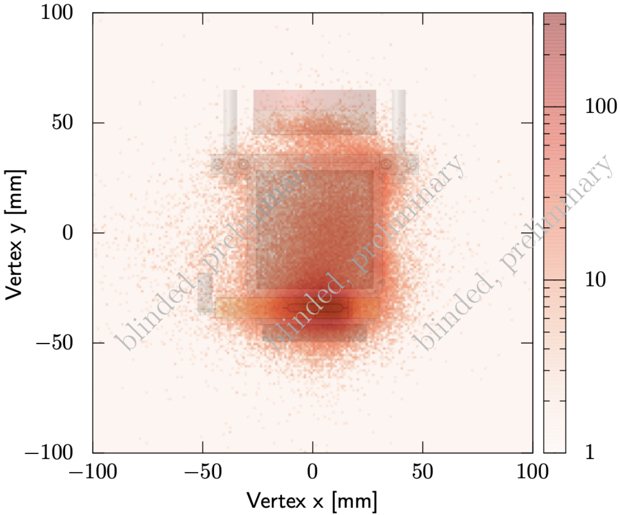
Cut on $|y| < 25$ mm. Carbon target x v z vertex reconstruction.

Beam View Target Distribution



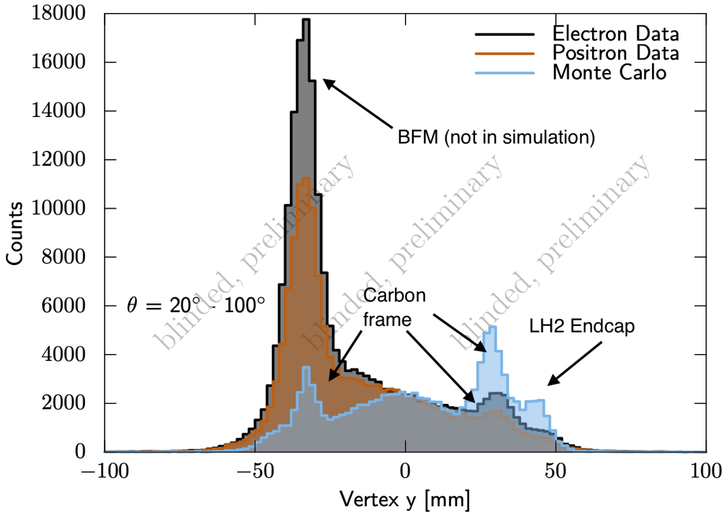
Cut on $|z| < 80$ mm. Carbon target y vs. x vertex reconstruction. Note that $+x$ points toward left STT.

Beam View Target Distribution



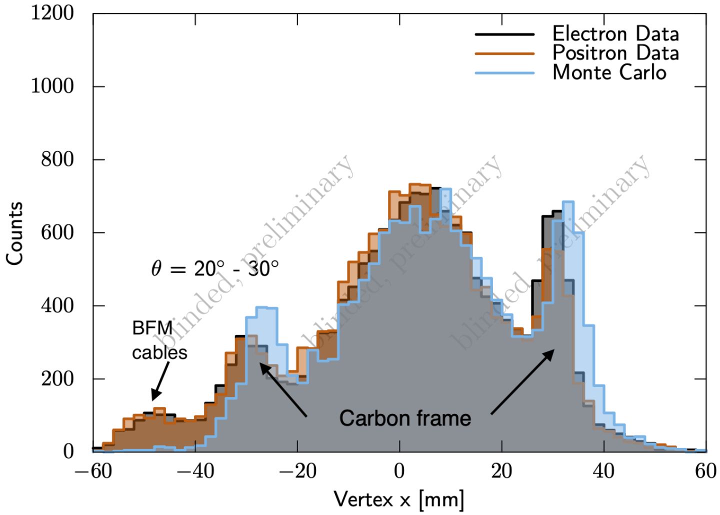
Cut on $|z| < 80$ mm. Carbon target y vs. x vertex reconstruction. Can apply fiducial cut $|y| < 25$ mm and $|x| < 25$ mm on GEM tracks to prevent contamination from BFM. Note that $+x$ points toward left STT.

y Vertex



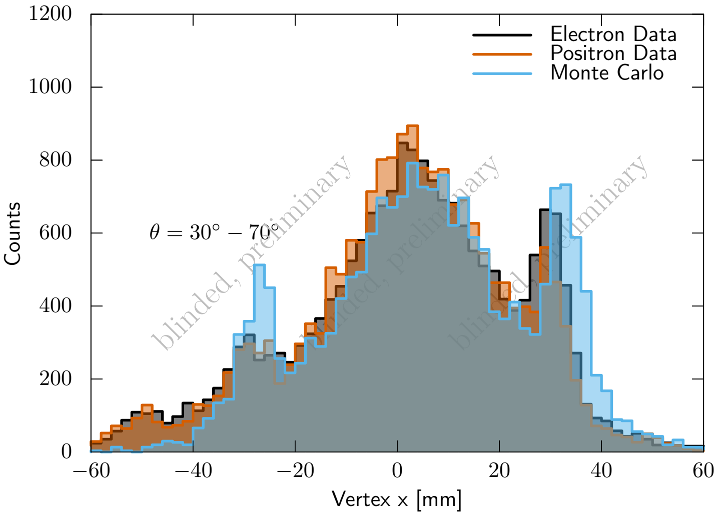
Cut on $|z| < 80$ mm and $|x| < 25$ mm.

x Vertex



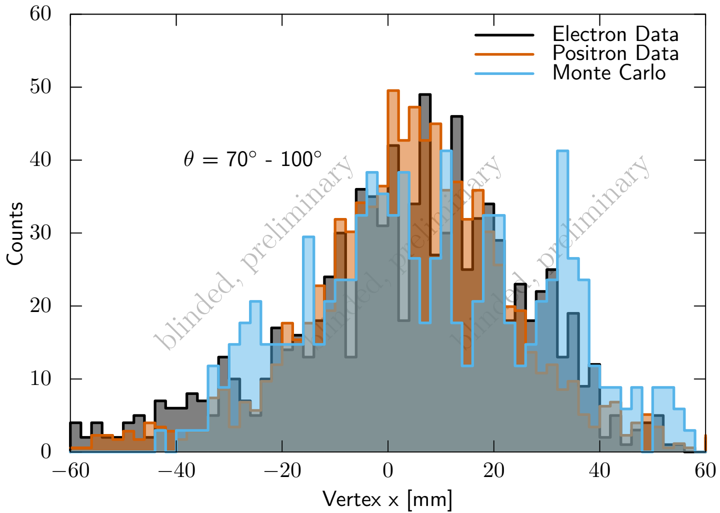
Cut on $|y| < 25$ mm, $|z| < 80$ mm, and $20 < \theta < 30$

x Vertex



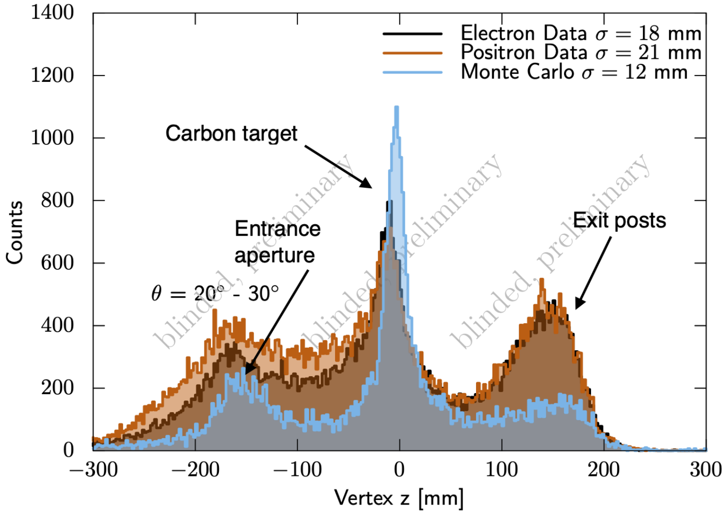
Cut on $|y| < 25$ mm, $|z| < 80$ mm, and $30 < \theta < 70$

x Vertex



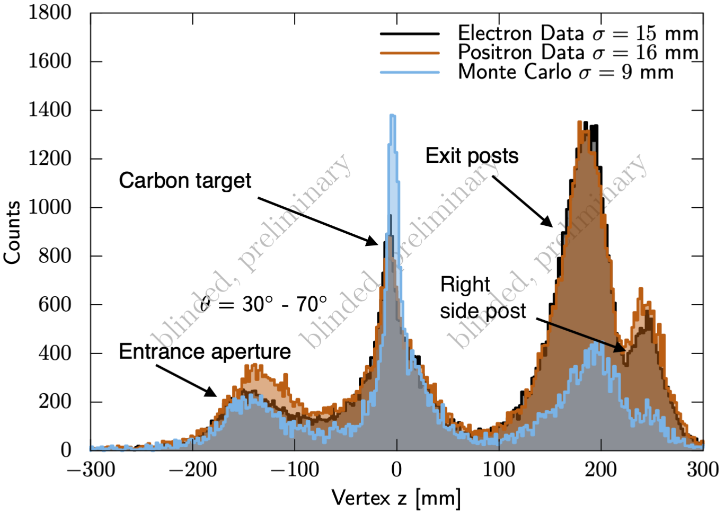
Cut on $|y| < 25$ mm, $|z| < 80$ mm, and $70 < \theta < 100$

z Vertex



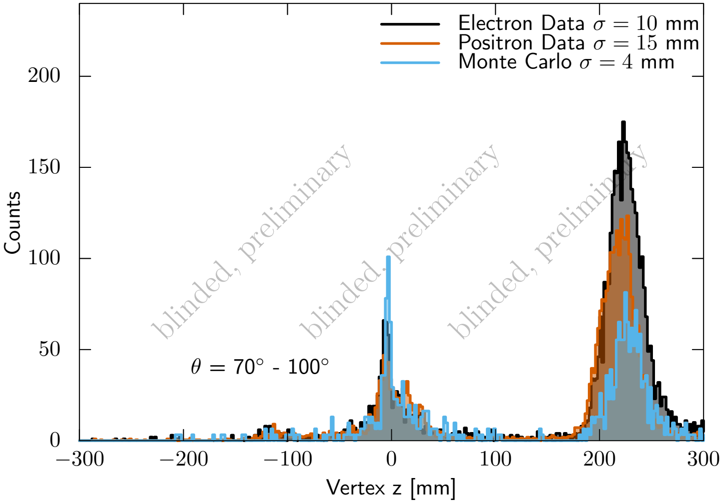
Cut on $|x| < 25$ mm, $|y| < 25$ mm, $20 < \theta < 30$. Note that while the agreement between electron and positron is reasonable at the target position, there is some background due to changes in the beam distribution.

z Vertex



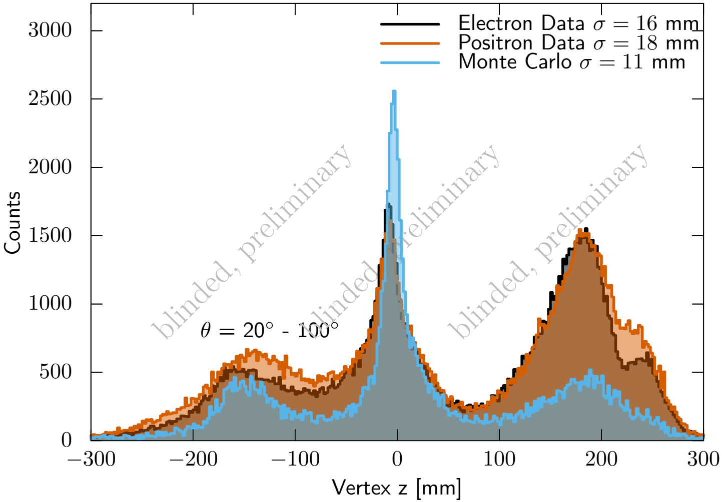
Cut on $|x| < 25$ mm, $|y| < 25$ mm, $30 < \theta < 70$. Note that while the agreement between electron and positron is reasonable at the target position, there is some background due to changes in the beam distribution.

z Vertex



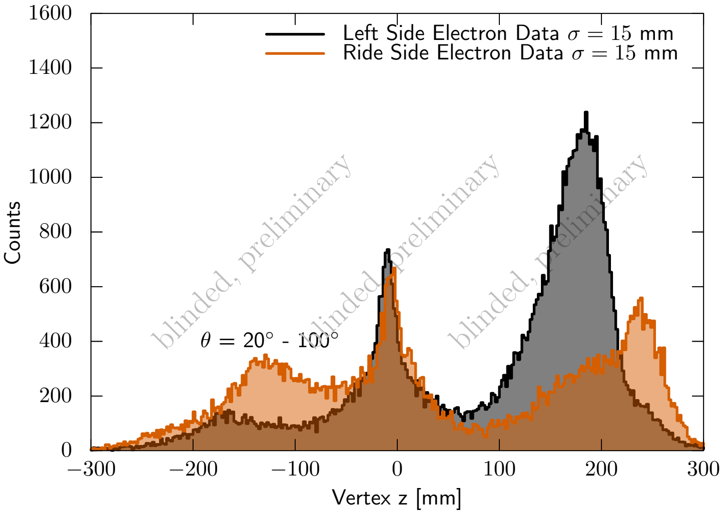
Cut on $|x| < 25$ mm, $|y| < 25$ mm, $70 < \theta < 100$. Note that while the agreement between electron and positron is reasonable at the target position, there is some background due to changes in the beam distribution.

z Vertex



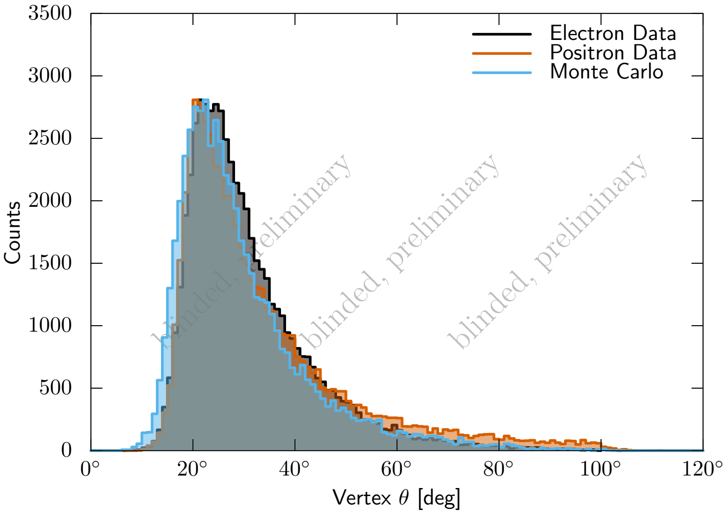
Cut on $|x| < 25$ mm, $|y| < 25$ mm, $20 < \theta < 100$. Note that while the agreement between electron and positron is reasonable at the target position, there is some background due to changes in the beam distribution.

z Vertex



Cut on $|x| < 25$ mm, $|y| < 25$ mm, $20 < \theta < 100$. Reconstructed z vertex from the left and right side STT chambers. Note the target width is about the same, but the backgrounds differ. The beam contains $< x'|x >$ correlations, so we expect slightly different beam tails.

Scattering Angle



Cut on $|x| < 25$ mm, $|y| < 25$ mm, and $|z| < 80$ mm.Reconstructed scattering angle from $e^{-}C$ and $e^{+}C$ data and $e^{-}C$ simulation. Note that radiative corrections are not applied, which can introduce shapes in the scattering angles

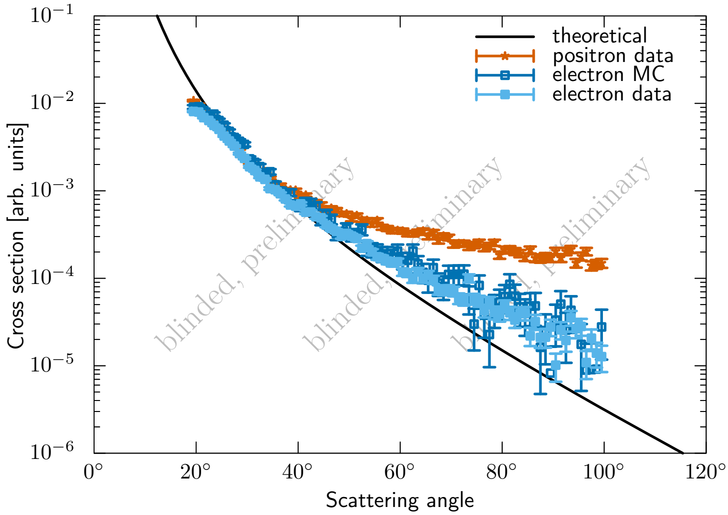
Cross Section Extraction

- Measured cross section for $e^{\pm}, \mu^{\pm}, \pi^{\pm}$-^{12}C/H
- Presenting results for $e^{\pm}C$ scattering

$$\frac{d\sigma}{d\Omega}_i = \frac{\mathrm{counts_i}}{N_{beam} n_t \Delta\Omega_i \epsilon_{DAQ} \epsilon_{fiducial} \epsilon_{rad}}, \quad (3)$$

- counts_i given from reconstructed vertices binned in angle
- N_{beam} calculated from BH trigger rates
- n_t carbon areal density
- $\Delta\Omega_i$ estimate of current acceptance. Requires full simulation
- ϵ_{DAQ} (reconstruction efficiency, detector efficiency, live time, etc.) known from analysis
- $\epsilon_{fiducial}$ imposed in analysis
- ϵ_{rad} radiative corrections, taken to be 1 for this analysis

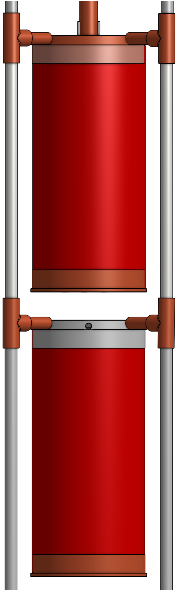
Electron/Positron-Carbon Scattering



$e^- C$ and $e^+ C$ data with common arbitrary normalization. $e^- C$ simulation scaled to lie on top of data. All points shown are at 115 MeV/c. Figure shows statistical uncertainties only.

MUSE LH2/Empty Target

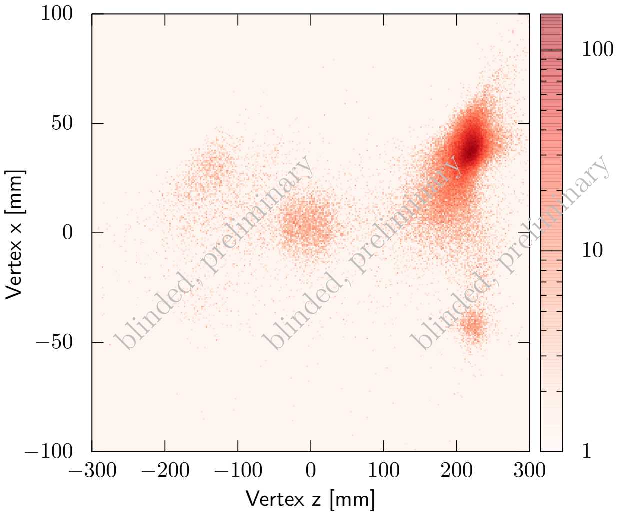
- Top cylinder filled with LH_2, bottom empty
- 6 cm diameter
- 13.7 cm tall
- Copper end caps
- $4 \times 25\ \mu$m wrapping around cell (not shown)



Vertex Reconstruction

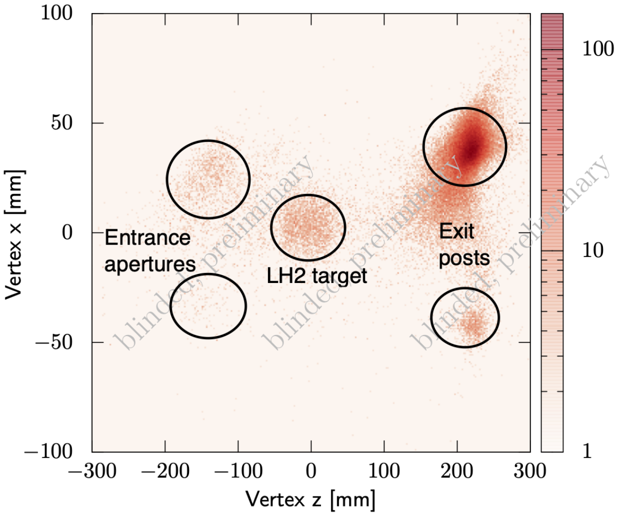
- Here we show reconstructed vertices from the left and right STTs and GEMs
- Full and empty cell measurements
- Apply fiducial cuts on target, discussed on next slide
- Cut on distance of closest approach < 10 mm, effective "Track quality" selection
- Data taken at $+160$ MeV$/c$

Full Target distribution



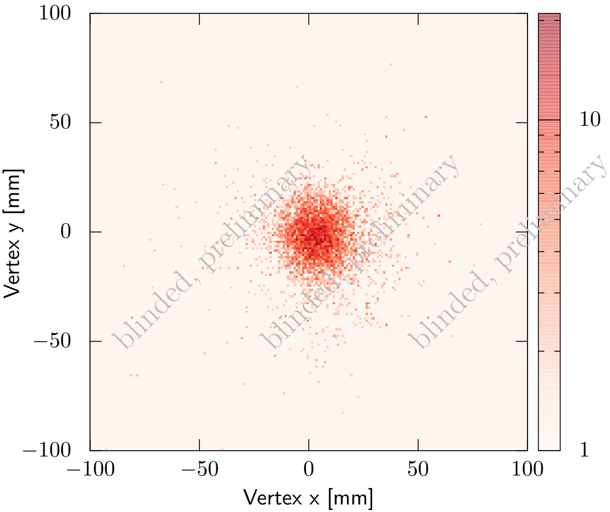
Cut on $|y| < 50$ mm.

Full Target Distribution



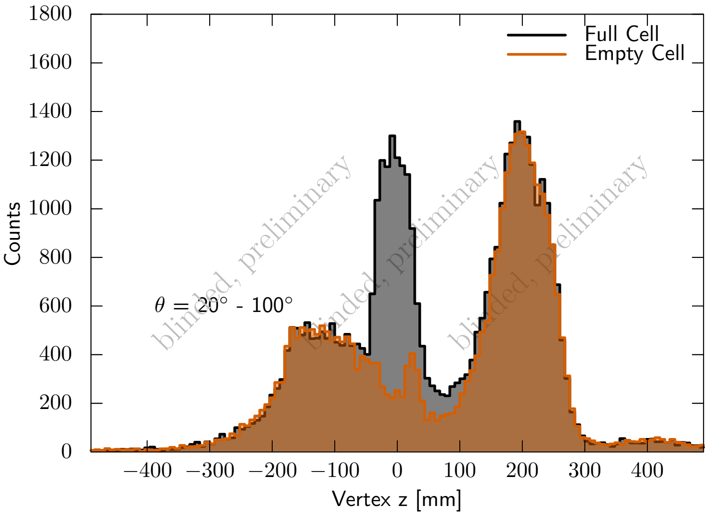
Cut on $|y| < 50$ mm.

Full Target Distribution



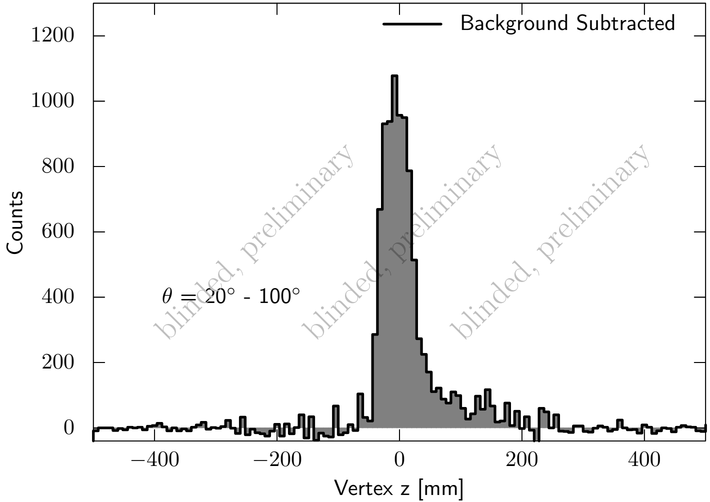
Cut on $|z| < 80$ mm. Full target y vs. x vertex reconstruction. In contrast to the carbon target, here we only see the beam spot on the LH_2 target.

LH2 Scattering

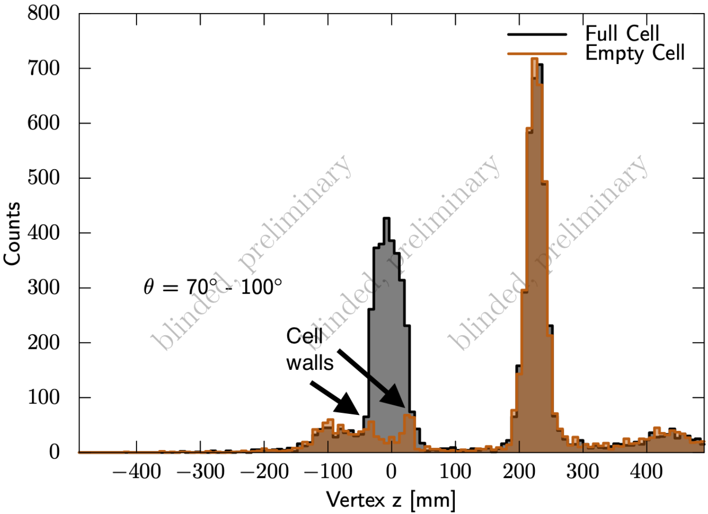


Cut on $|x| < 25$ mm, $|y| < 25$ mm, $20 < \theta < 100$.

LH2 Scattering

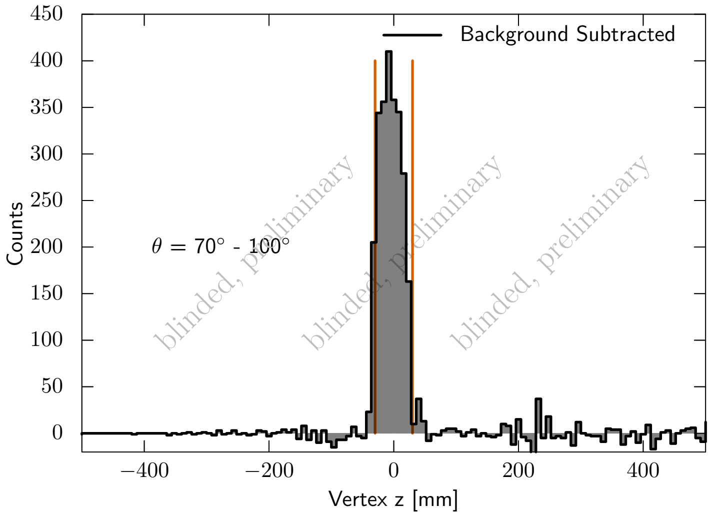


Cut on $|x| < 25$ mm, $|y| < 25$ mm, $20 < \theta < 100$.



Cut on $|x| < 25$ mm, $|y| < 25$ mm, $70 < \theta < 100$.

LH2 Scattering



Cut on $|x| < 25$ mm, $|y| < 25$ mm, $70 < \theta < 100$. The orange lines denote the nominal target position.

Expected Systematic Uncertainties on Cross Section

Uncertainty	angular distribution (%)	μ/e (%)	$+/-$ (%)
Detector efficiencies	0.1	0.1	0.1
Solid angle	0.1	small	small
Scattering angle offset	0.2	small	small
Multiple scattering	0.15	small	small
Beam momentum offset	0.1	0.1	0.1
Radiative correction	0.1 (μ), 0.5 (e)	0.5	1γ small
Magnetic contribution	0.15	small	small
Subtraction of μ decay	0.1	0.1	small
Target Subtraction	0.3	small	small
Beam PID	0.1	0.1	0.1
TOTAL	0.5 (μ), 0.7 (e)	0.5	0.2

from MUSE TDR https://arxiv.org/pdf/1709.09753.pdf.
Systematic uncertainties dominate statistical uncertainties for e and forward angle μ.

Measured Systematic Uncertainties on Cross Section

Uncertainty	angular distribution (%)	Measured (%)
Detector efficiencies	0.1	**0.1, cf. previous low level analysis talks** ✓
Solid angle	0.1	0.1, Requires full MC implementation *
Scattering angle offset	0.2	0.2, Survey implementation *
Multiple scattering	0.15	0.25, Vertex reconstruction cf. next slide *
Beam momentum offset	0.1	**0.05, cf. beam properties paper** ✓
Radiative correction	0.1 (μ), 0.5(e)	**0.1 (μ), 0.3 (e), cf. SS talk** ✓
Magnetic contribution	0.15	0.15, magnetic contribution in MUSE Q^2 ✓
Subtraction of μ decay	0.1	**0.1, Resolutions on track** *
Target Subtraction	0.3	0.3, Target downstream study *
Beam PID	0.1	**0.1, from RF studies after vertexing** *
TOTAL	0.5 (μ), 0.7 (e)	0.52(μ), 0.59(e)

* Have yet to confirm in detail, but clear plan to study and affirm.

✓On track to meet or exceed TDR estimates for uncertainty on radius.

Bold indicates uncertainties that do not cancel in cross section ratios, see previous slide.

Angular Resolution

- *If* poorer vertex resolution suggests worse angle resolution then systematic uncertainties increased
- **Worst case scenario:** acts like multiple scattering systematic, increases this systematic from 0.15 % to 0.25 %
- Arises from $\approx$ 25 mr contribution to angle determination
- Results will improve with full survey implementation

Summary

- Have reconstructed tracks from $e^{-}C$,$e^{+}C$,and $e^{+}H$ scattering
- In scattering off of hydrogen, background subtraction suppresses exit posts in data
  - Exact background subtraction requires MC
- See offsets in geometry between data and simulation
  - Vertex resolution worse in data than in simulation
- Blinded cross sections from $e^{-}C$,$e^{+}C$ scattering extracted and compared to simulation and theory
- Analysis work and development ongoing