Pion Transparency Analysis Updates

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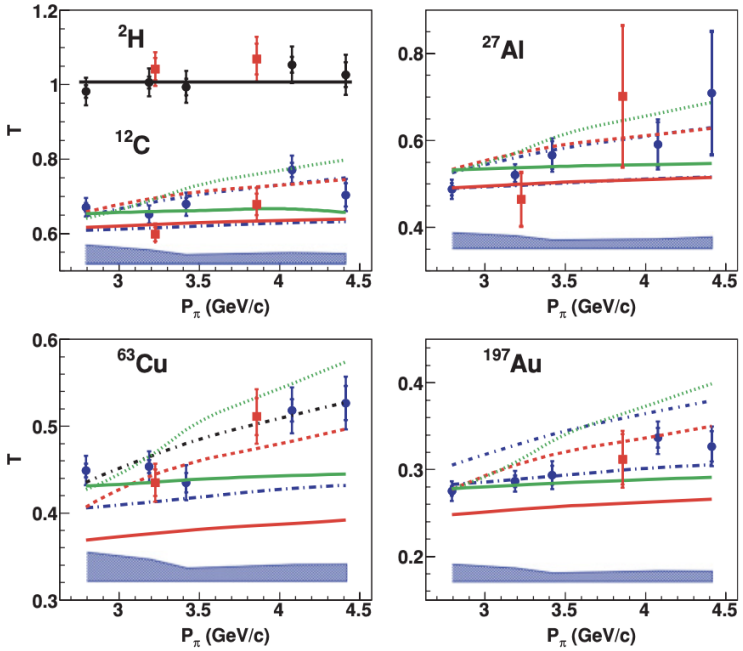
Goals

Measure pion transparency with CLAS6

$$\text{Pion Transparency} = \frac{\#\text{ of events with pion exiting nucleus without significant FSI}}{\#\text{ of events with pion produced in initial interaction}}$$

Technique:

- Use a W selection to identify a Δ-rich sample corresponding to events with initial-state charged pions
- Require a proton in the final state, then use proton and electron measurements to predict the initial state pion energy



X. Qian et al, Phys. Rev. C81, 055209 (2010). The only existing measurement of pion transparency, relied on a MC prediction for the denominator

Sample Dataset

Generator: GENIE 3.04.02

Tune: G18_10a_00_000

– Default local Fermi gas model
– hA final state interactions
– Default EM Scattering Models

– No Q^2 cut
– 40 million events
– 2.261GeV electron beam
– Target: 12-Carbon

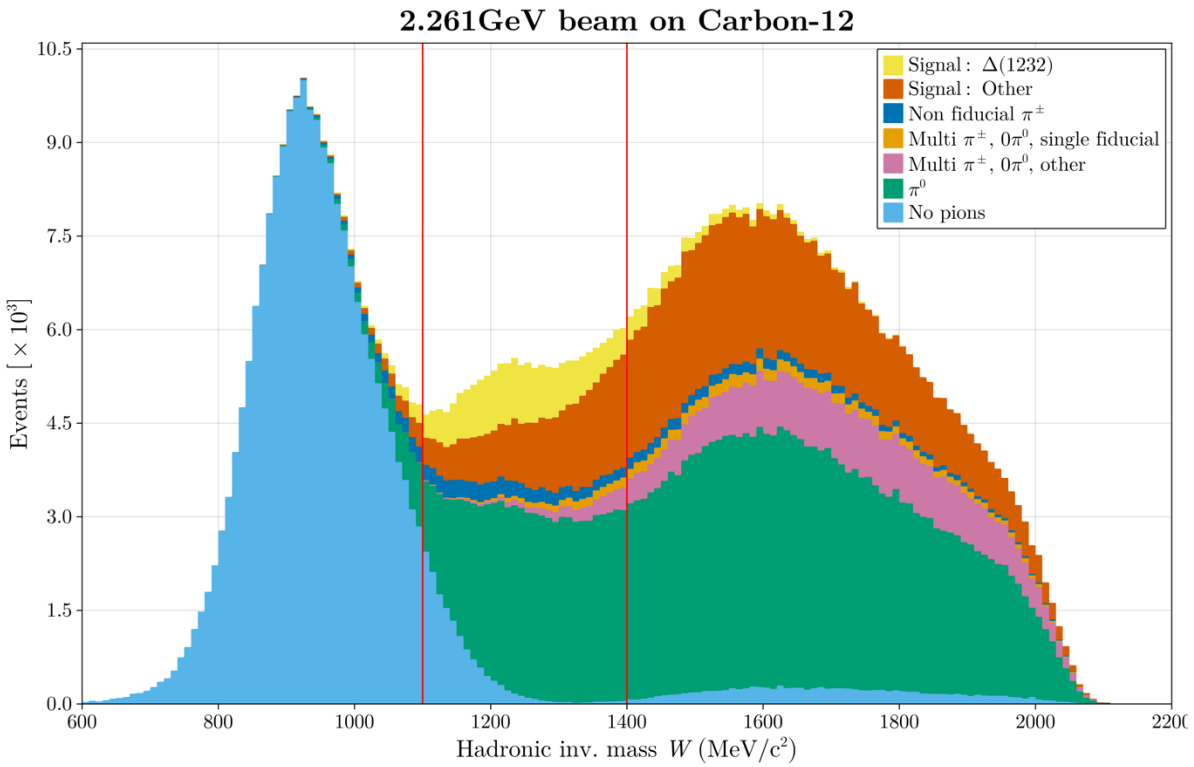
Previous Work (Summer 2024)

Weight events by electron acceptance $(\phi, \cos\theta, p)$ and smear electron energy and momentum by 0.5%

W computed assuming struck nucleon at rest with a binding energy of −31.5 MeV and average nucleon mass of 938.9 MeV.
Require: 1100 MeV < W < 1400 MeV

Signal: Δ(1232) only
- purity = 13.5%
- efficiency = 76.9%

Signal: Δ(1232) + other single charged pion
- purity = 33.3%
- efficiency = 32.5%



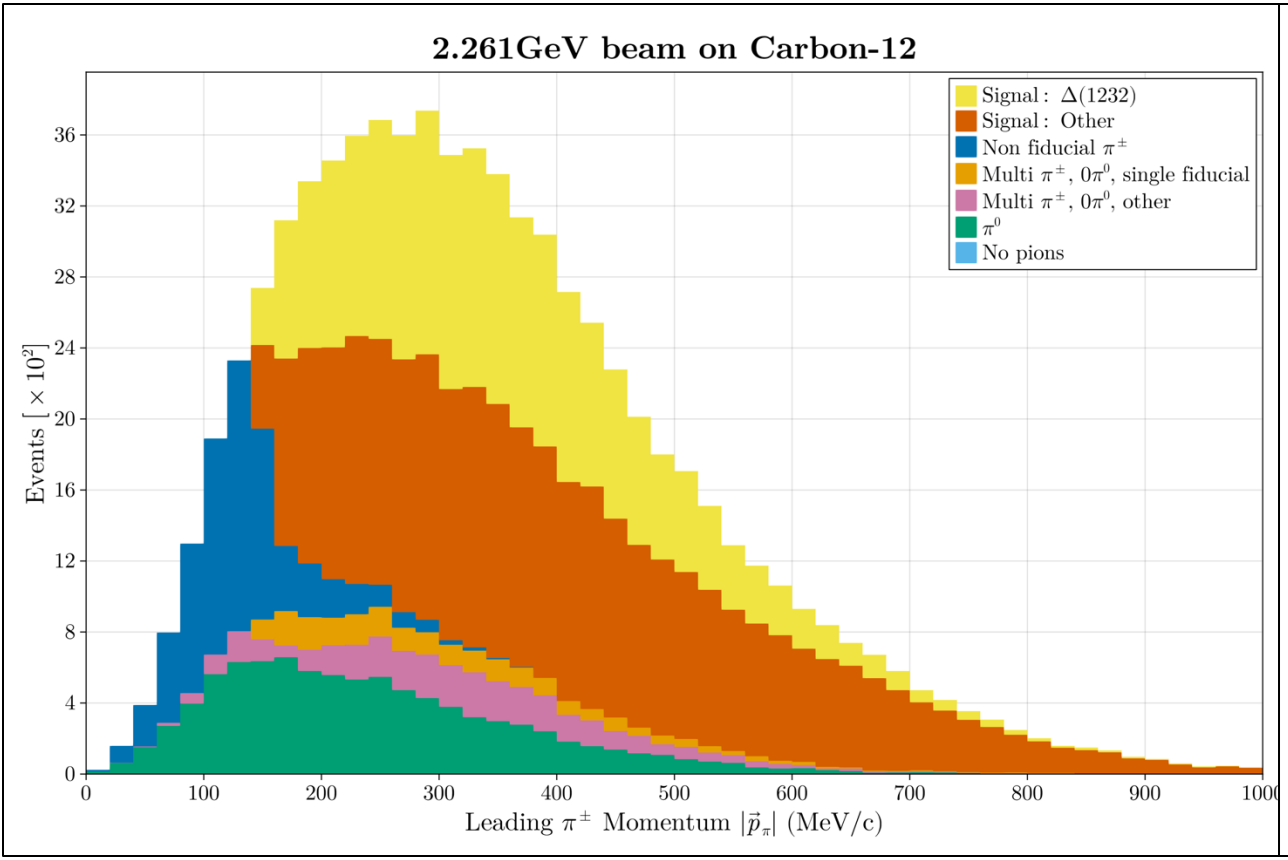
$$Q^2 = -q^2 = -|p_e - p_{e'}|^2$$

$$\omega = E_e - E_{e'}$$

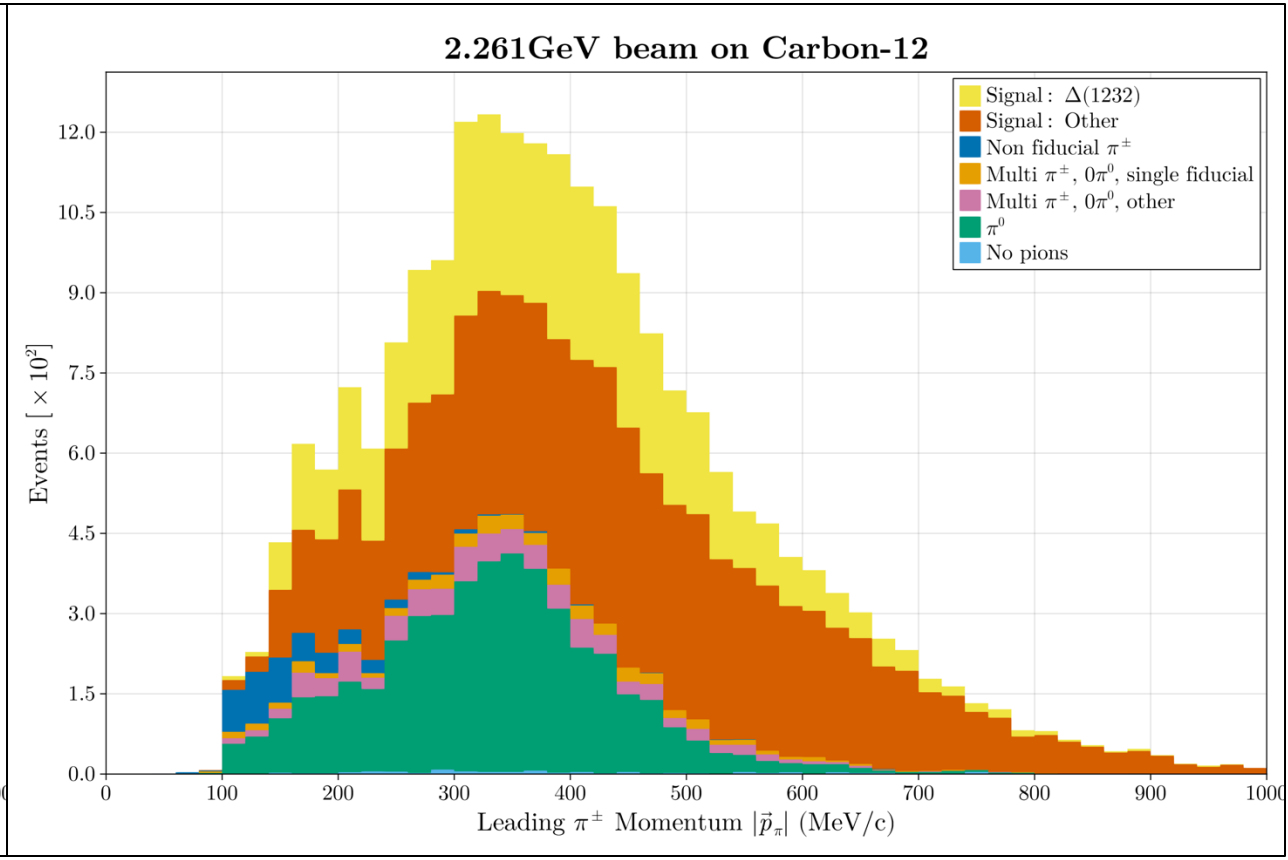
$$W^2 = (M + E_B)^2 - Q^2 + 2(M + E_B)\omega$$

Previous Work (Summer 2024) – Leading Pion

Determined whether each final-state charged pion or proton is reconstructed by comparing a random number to the particle's acceptance weight



Pre-FSI



Post-FSI: reconstructed pion is required

New Selections

W and electron acceptance selections

- Efficiency 32.5% and purity 33.3%

Three new selections investigated for transparency denominator:

1) Require at least one reconstructed proton

- Relative efficiency 46.1% and purity 32.8% (all signal categories)

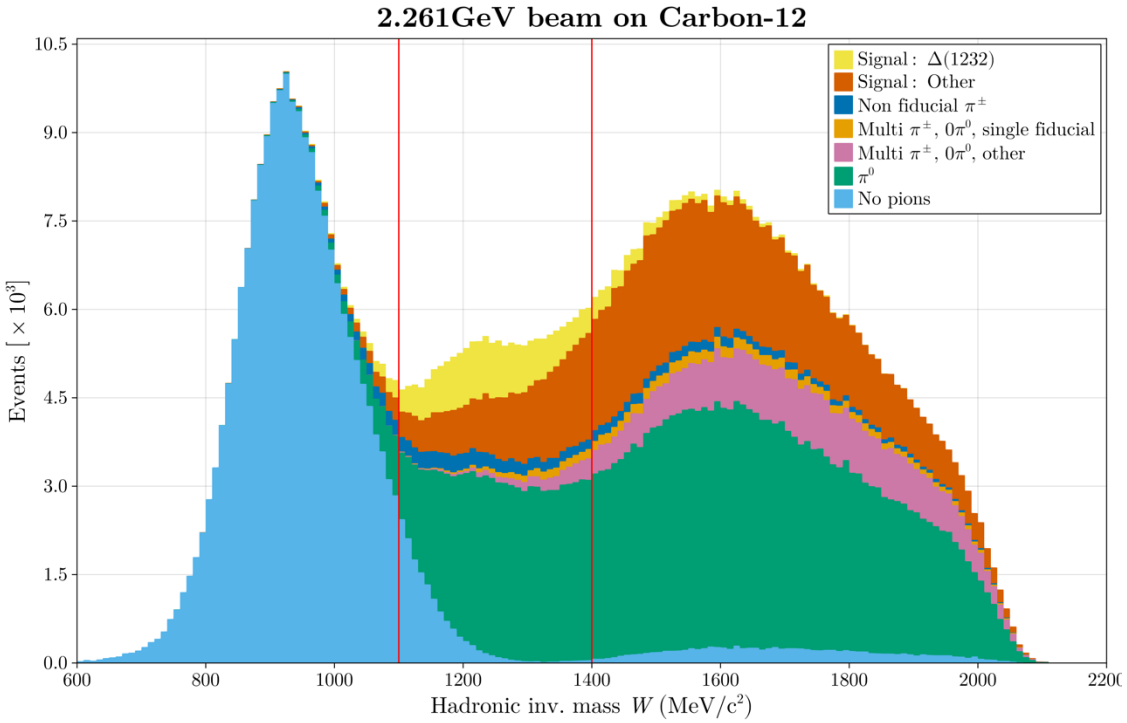
2) Reject events with more than one reconstructed charged pion

- Relative efficiency 98.9% and purity 33.2% (all signal categories)

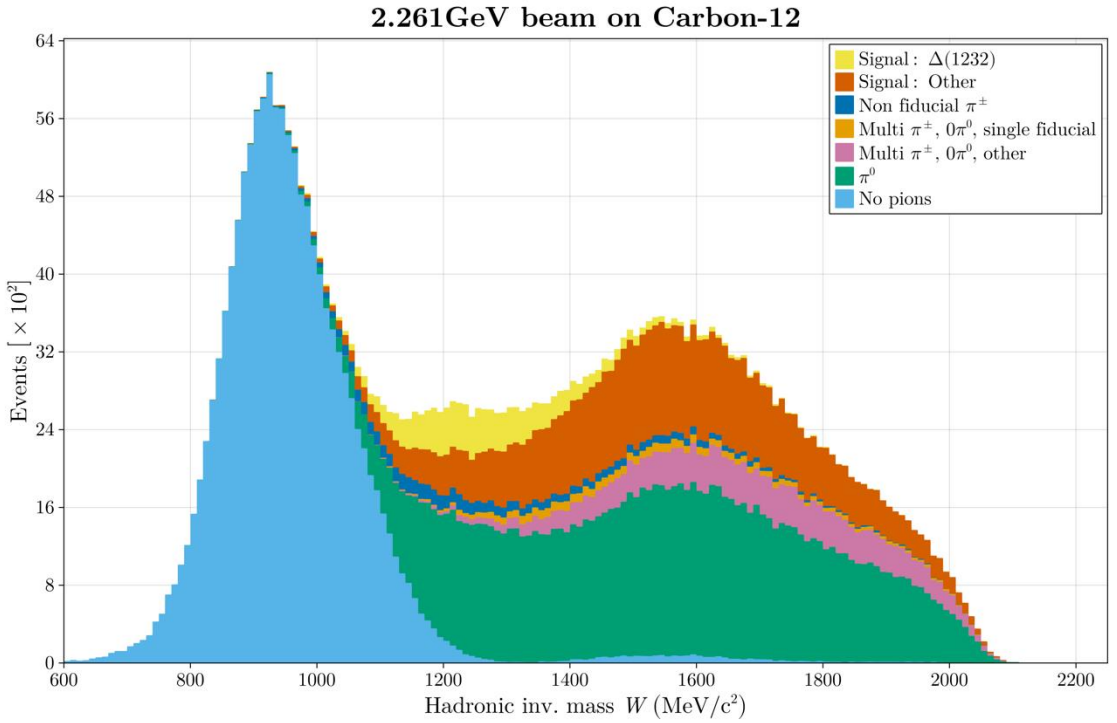
3) Reject events with a final-state photon above 300 MeV or final-state π^0 above 600 MeV

- Relative efficiency 99.6% and purity 34.3% (all signal categories)

New Selections – W Distribution

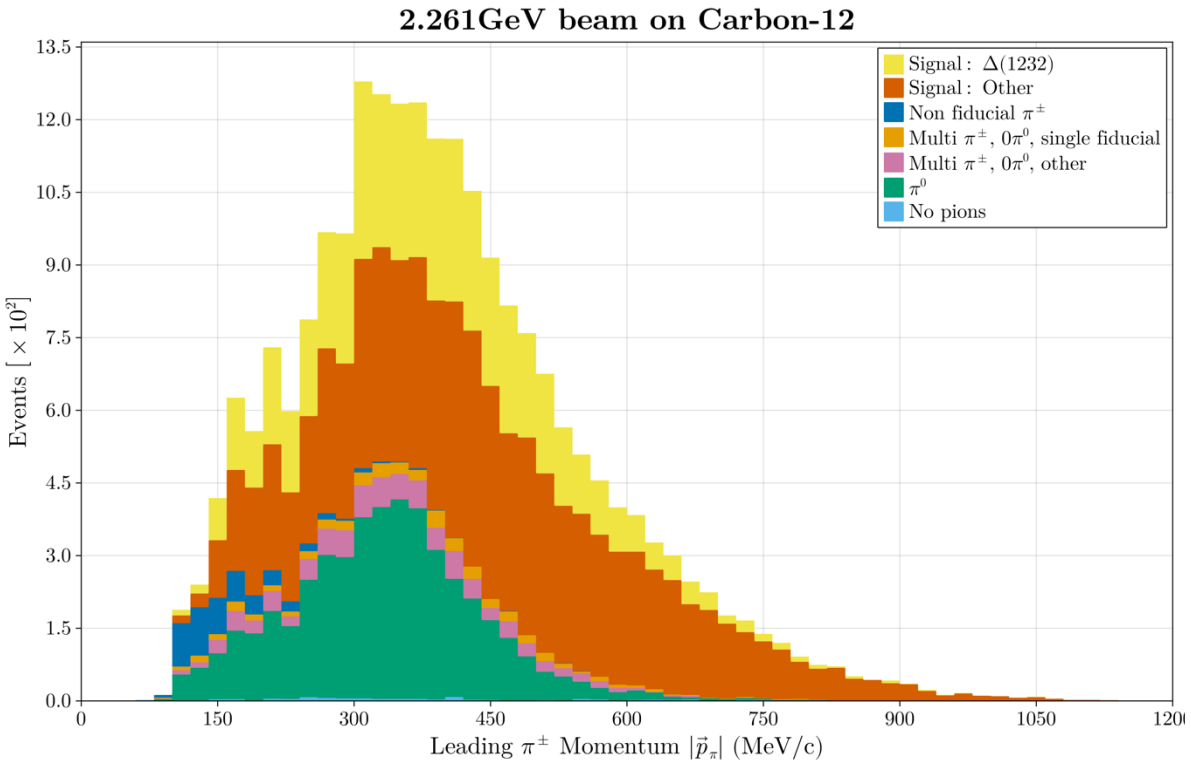


electron acceptance only

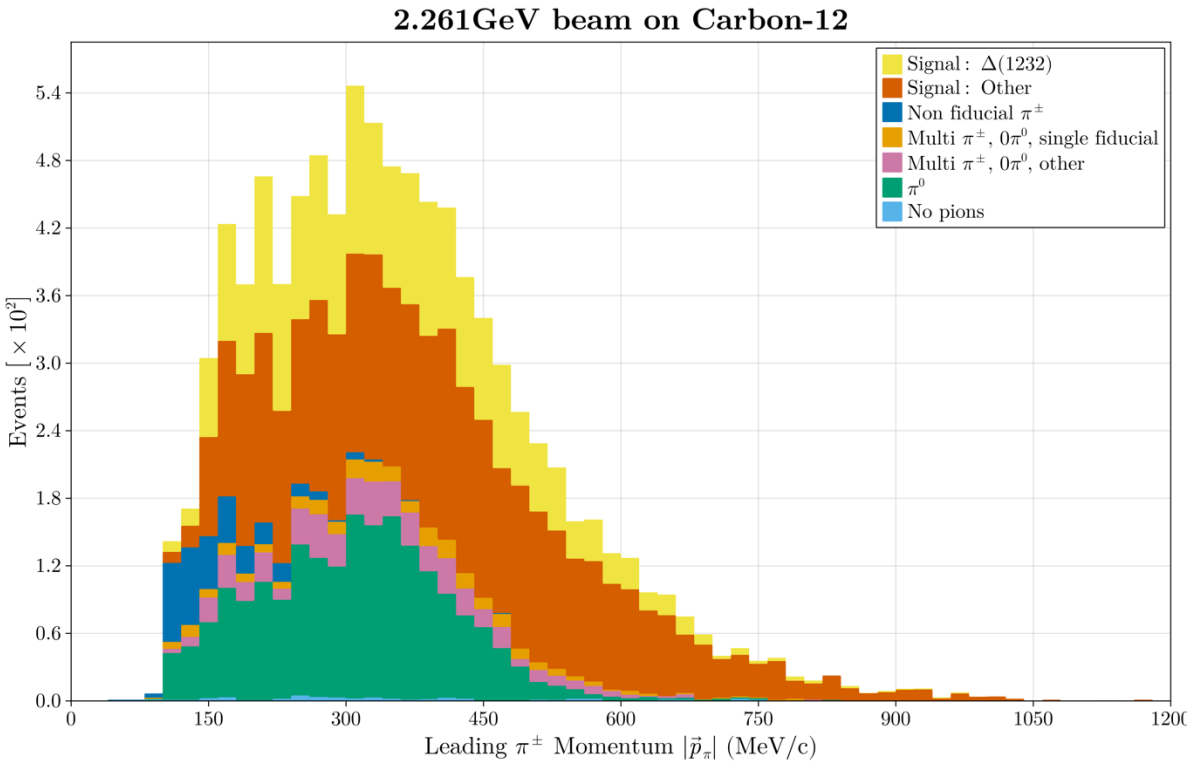


Added reconstructed proton requirement

New Selections – Post FSI Pion Momentum

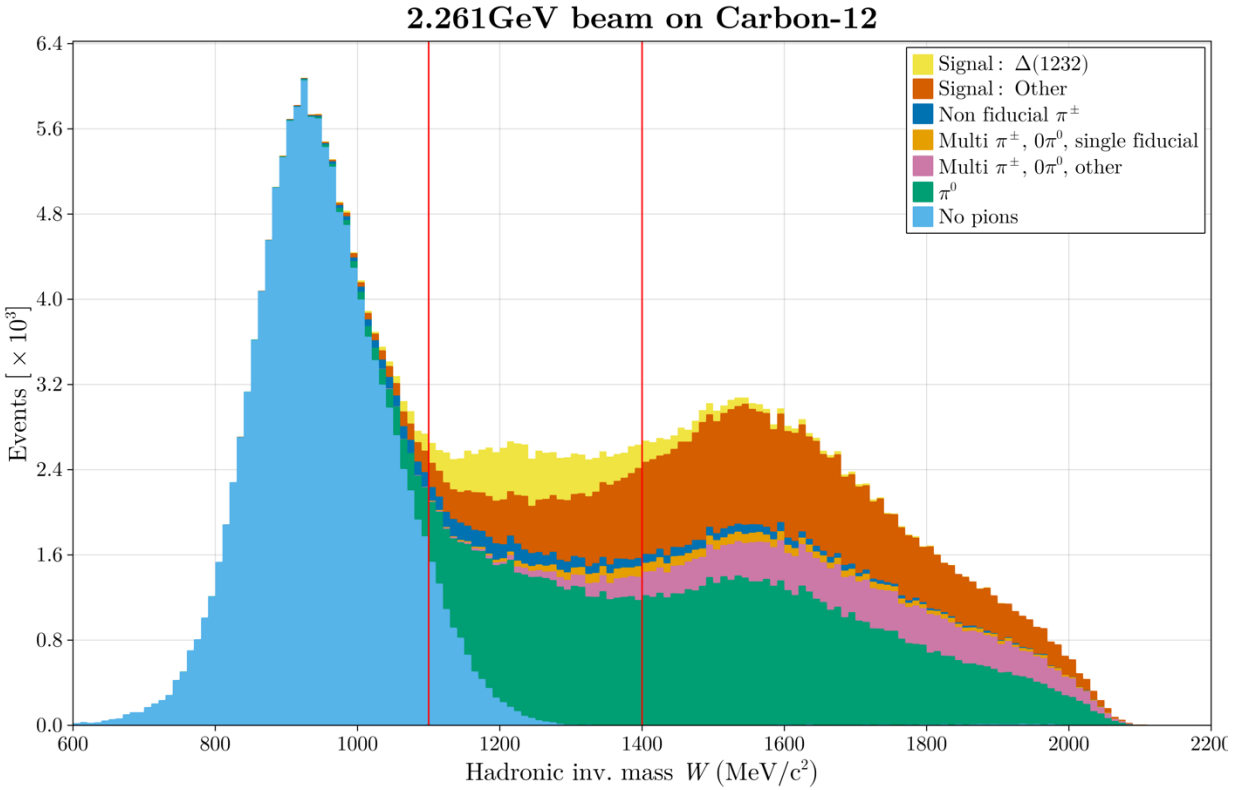


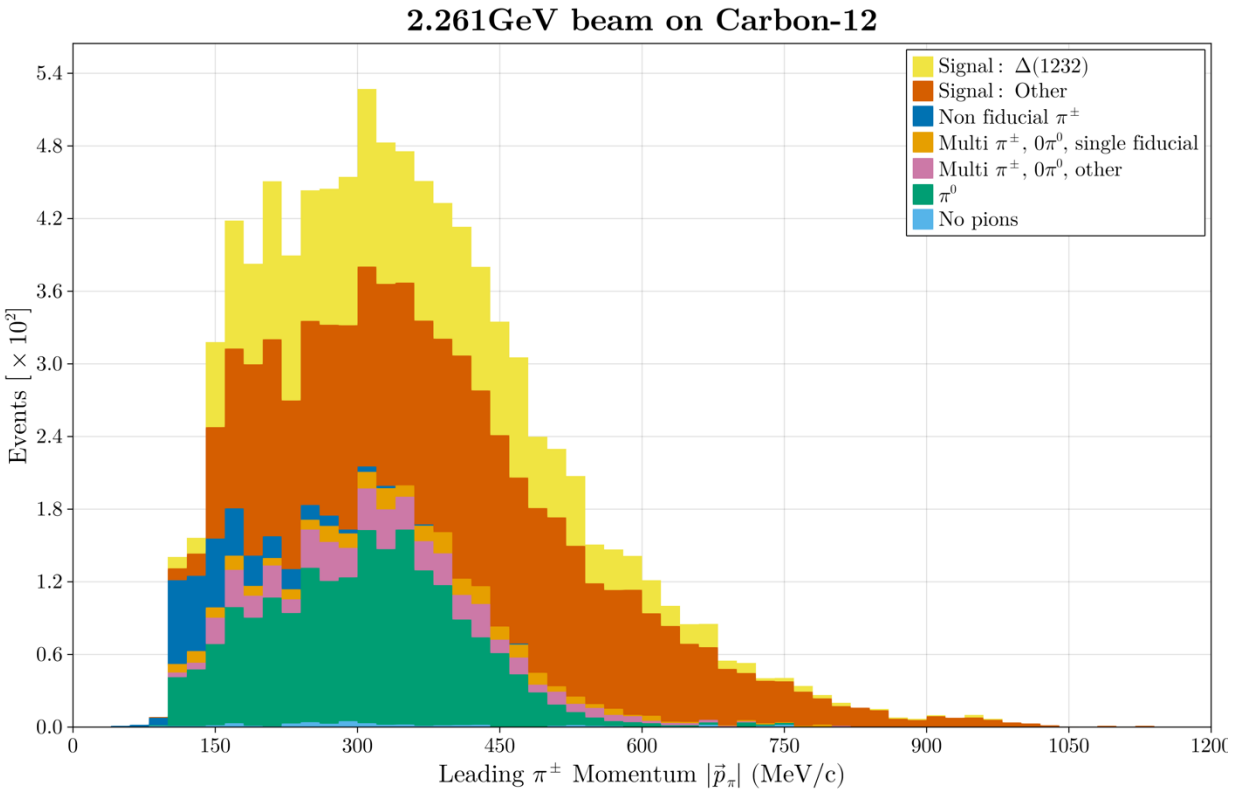
W cut, electron acceptance, and at least one reconstructed pion



Added reconstructed proton requirement

New Selections – All cuts applied





Pre-FSI Pion Energy Prediction

Need a prediction of the pion energy before FSI, E_π^{pred}, to select the numerator sample of the transparency

Use conservation of energy assuming single-pion production with a single proton and the struck nucleon at rest:

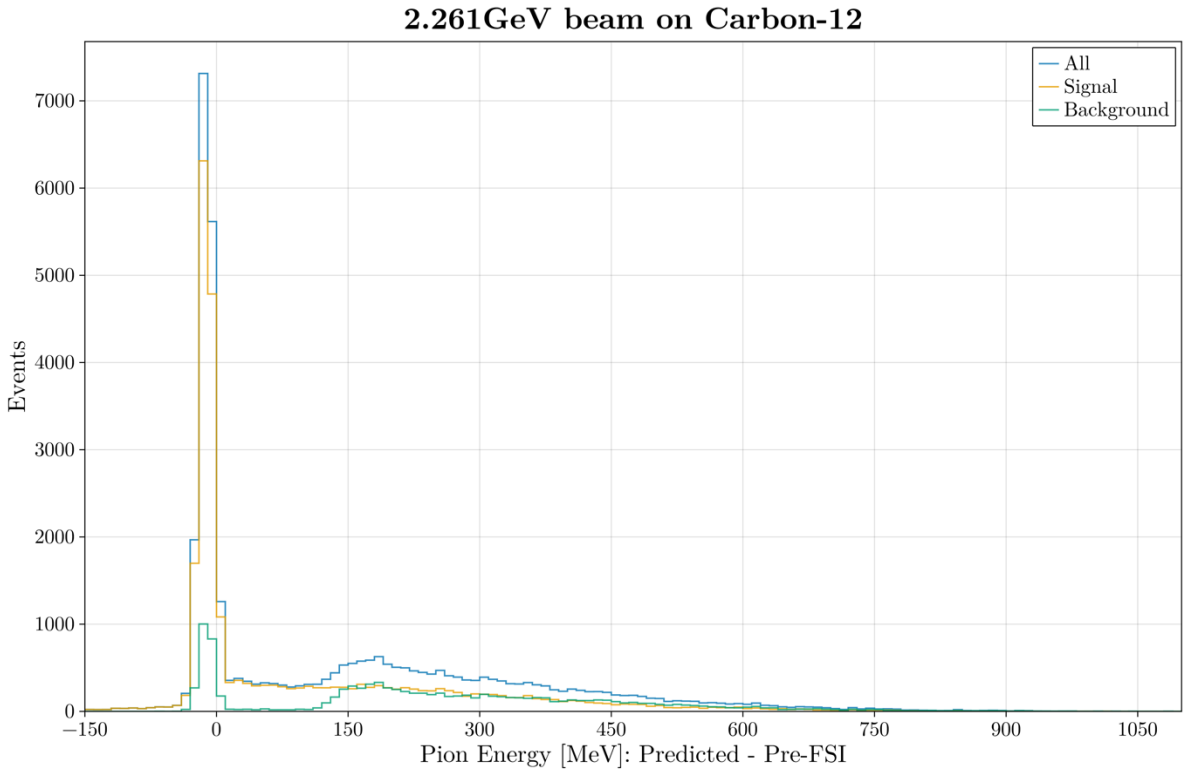
$$E_\pi^{\mathrm{pred}} = E_e - E_{e'} + M + E_B - E_p$$

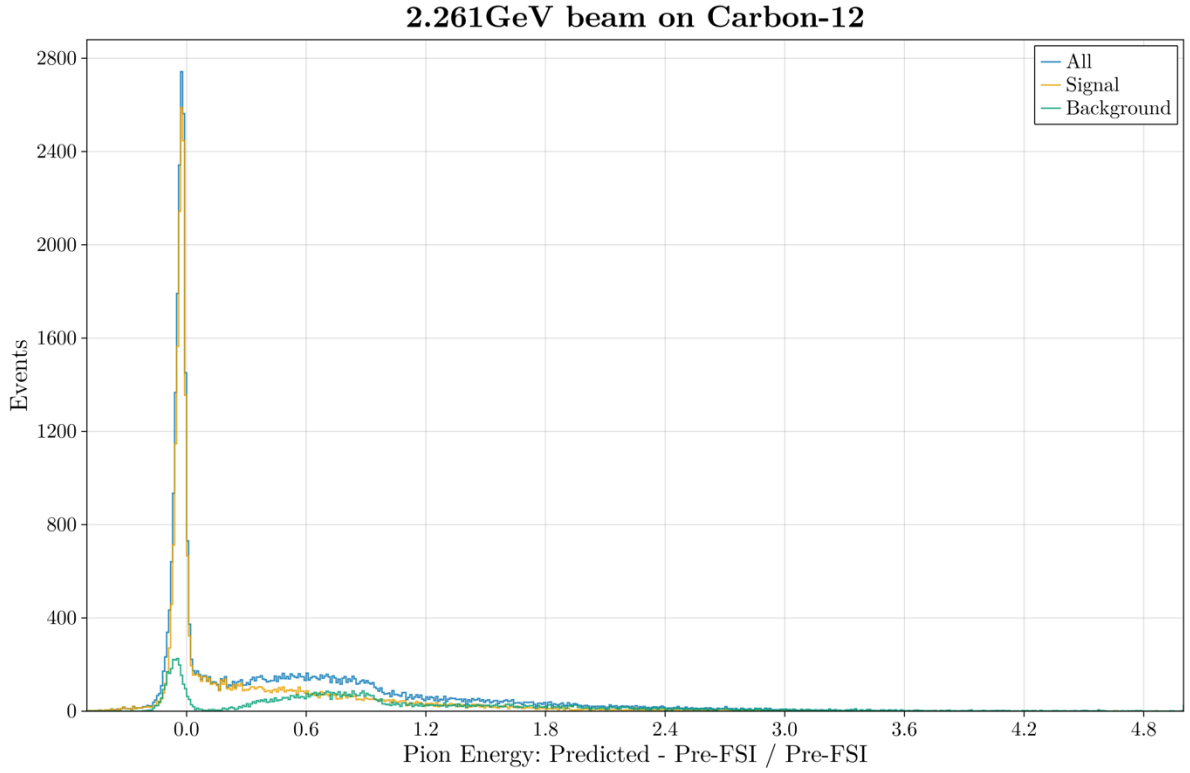
E_p is the energy of the leading reconstructed proton, $E_B = -31.5$ MeV is the mean binding energy, and M is the mean nucleon mass

Predicted Energy Compared to Pre-FSI Energy

Residuals of the pre-FSI pion energy prediction compared to the true pre-FSI pion energy

- Includes W, electron acceptance, and reconstructed proton requirements
- Requires a pre-FSI charged pion





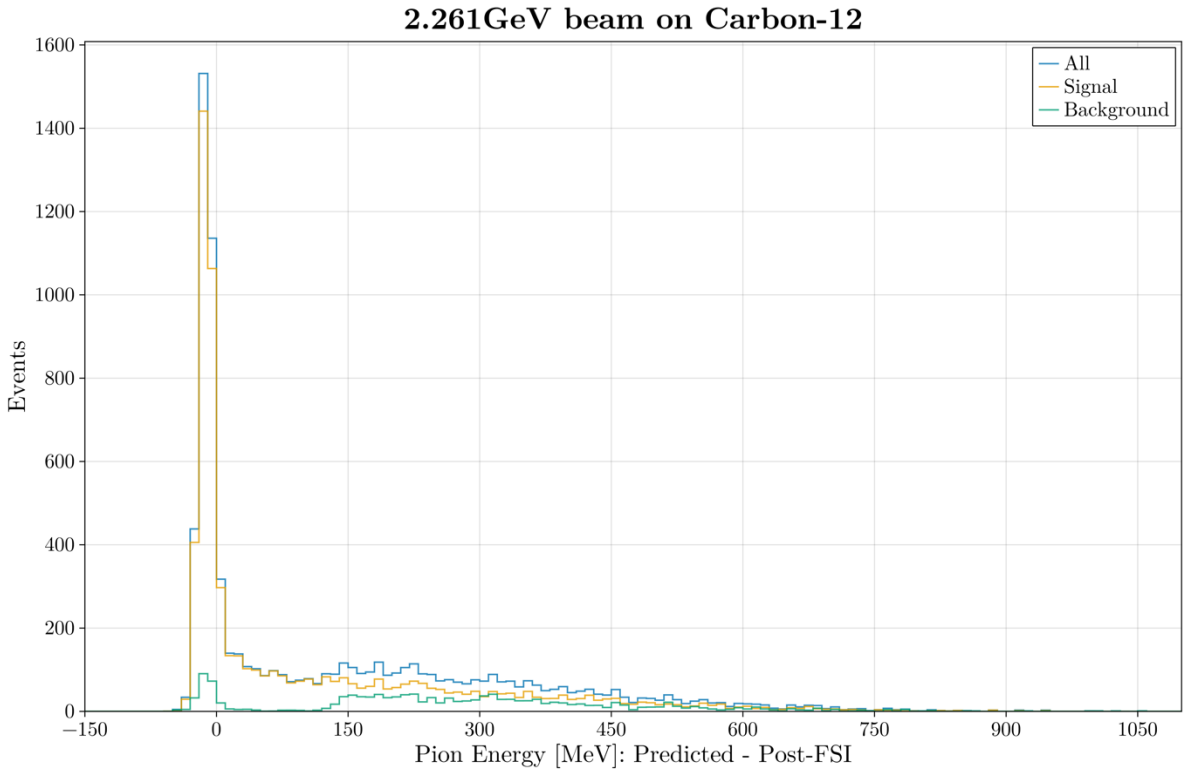
width of peak: struck-nucleon-at-rest assumption

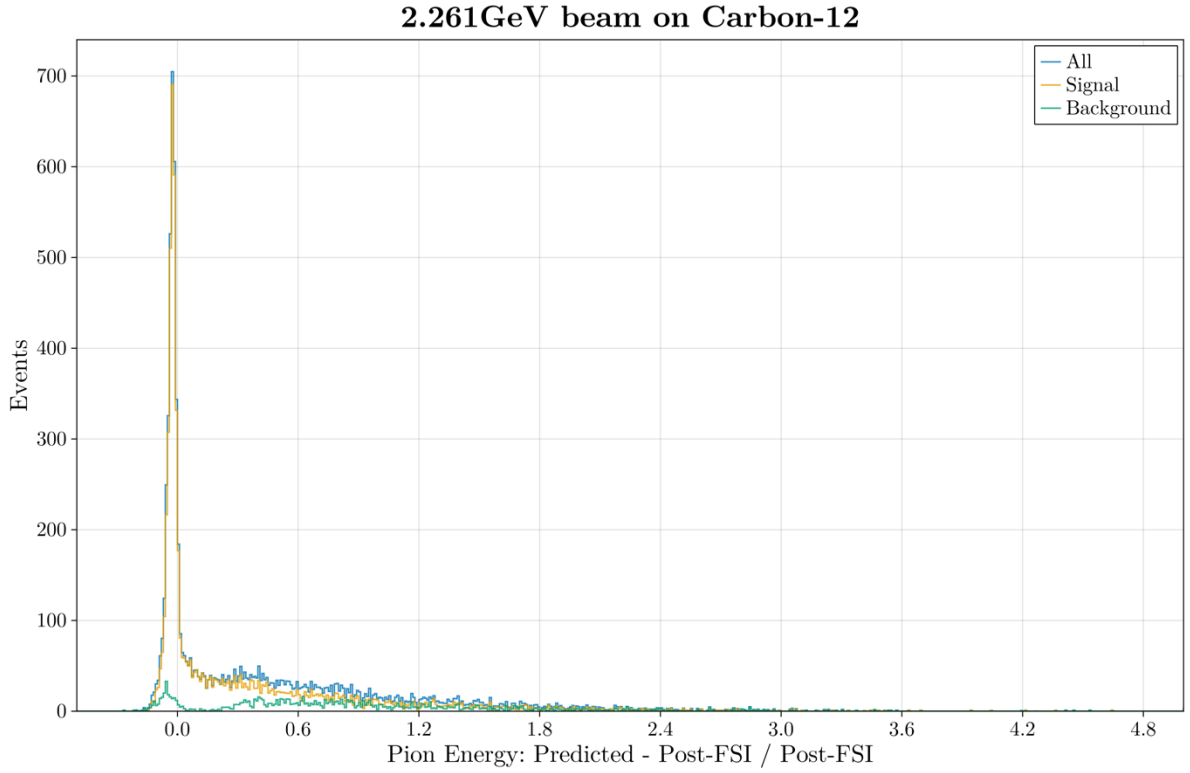
tail of signal: proton FSI

Predicted Energy Compared to Post-FSI Energy

Residuals of the pre-FSI pion energy prediction compared to the post-FSI pion energy

- Includes W, electron acceptance, and reconstructed proton requirements
- Requires a post-FSI charged pion





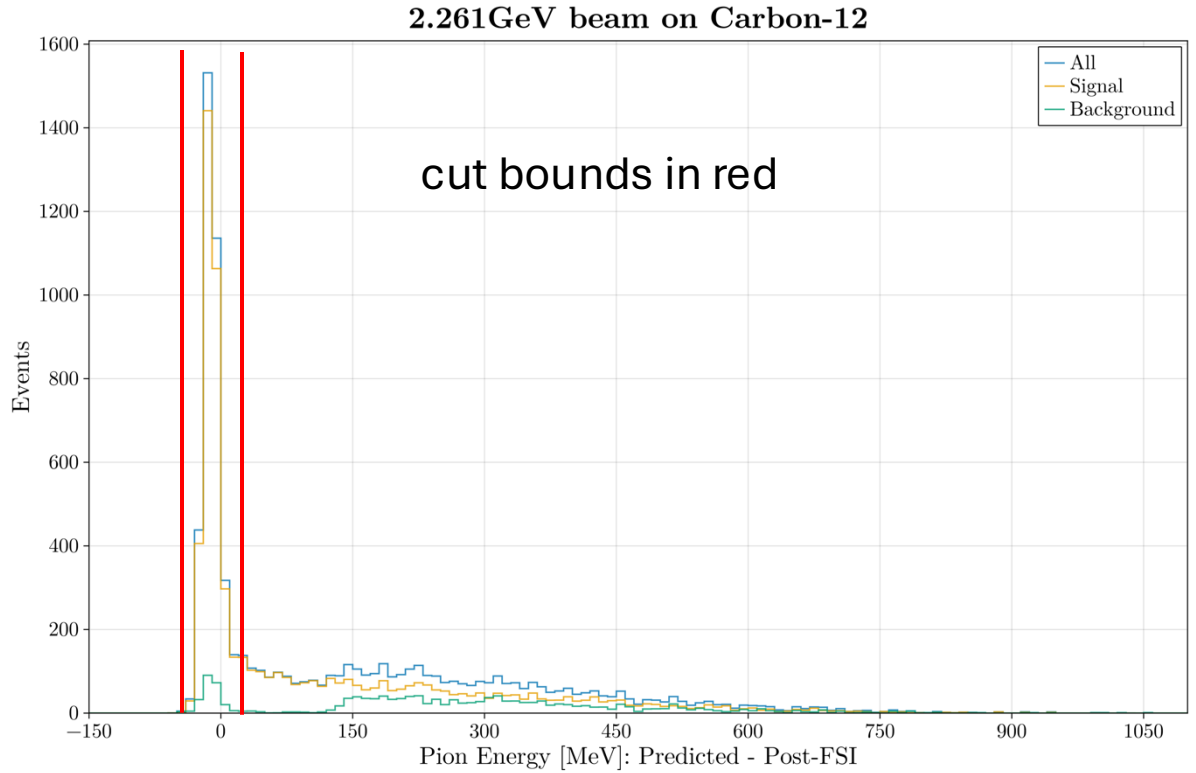
width of peak: struck-nucleon-at-rest assumption

tail of signal: proton and pion FSI

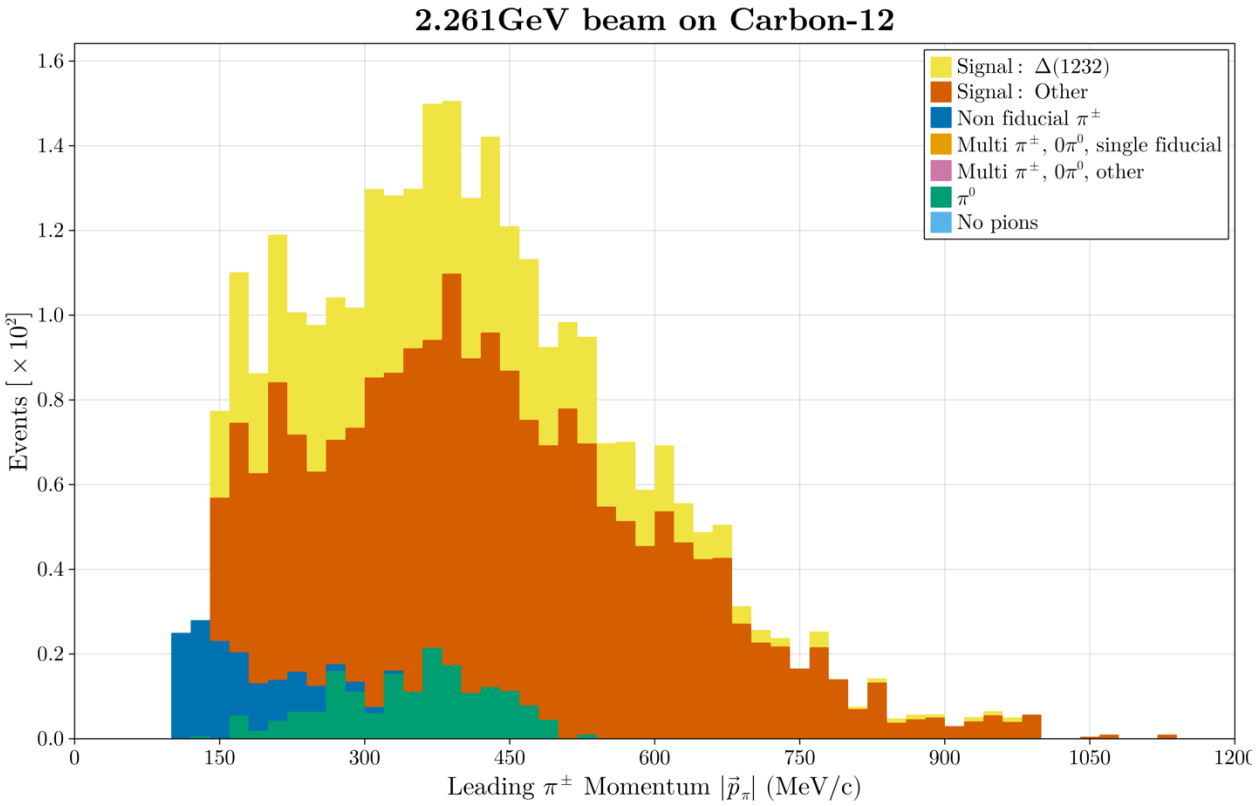
Numerator Selection

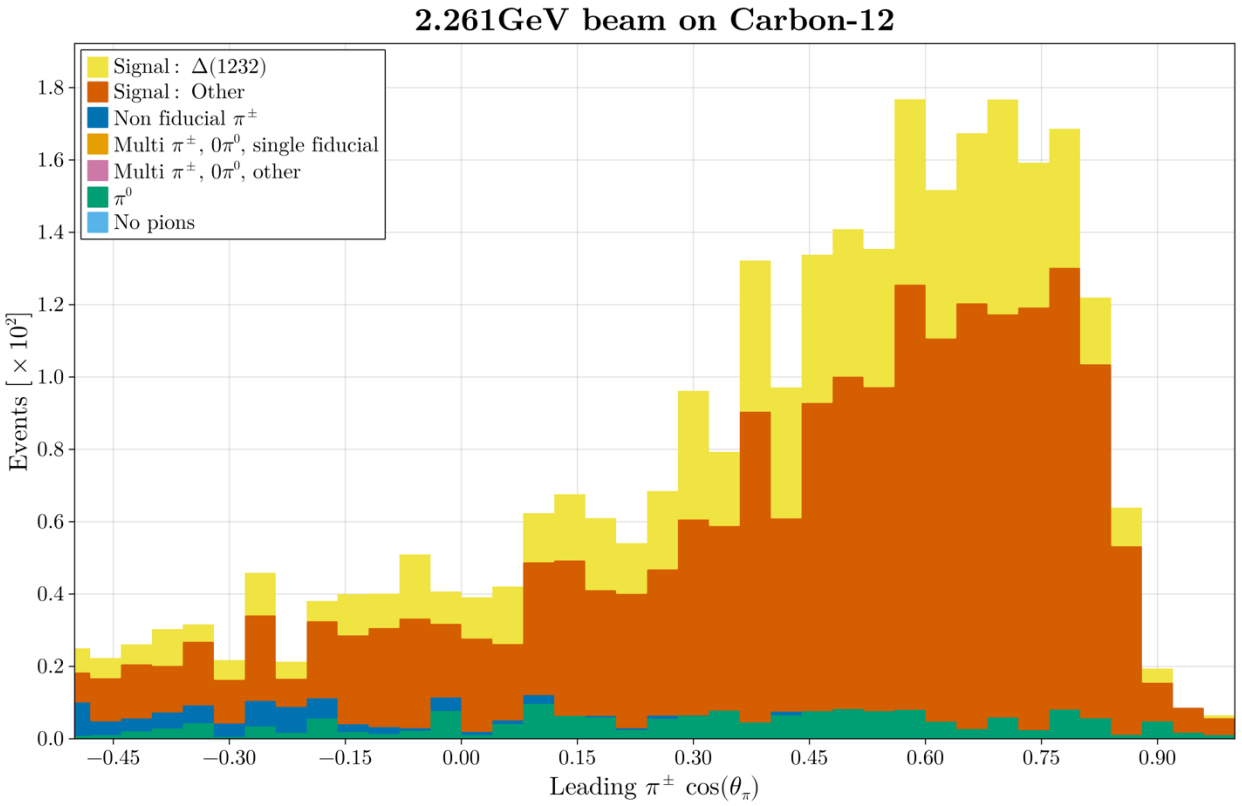
Require numerator sample to pass the same cuts as the denominator sample, and add two more selections:

- Event must contain one reconstructed charged pion
- Require that $-40\ \text{MeV} \leq E_{\pi}^{\text{pred}} - E_{\pi}^{\text{reco}} \leq 20\ \text{MeV}$

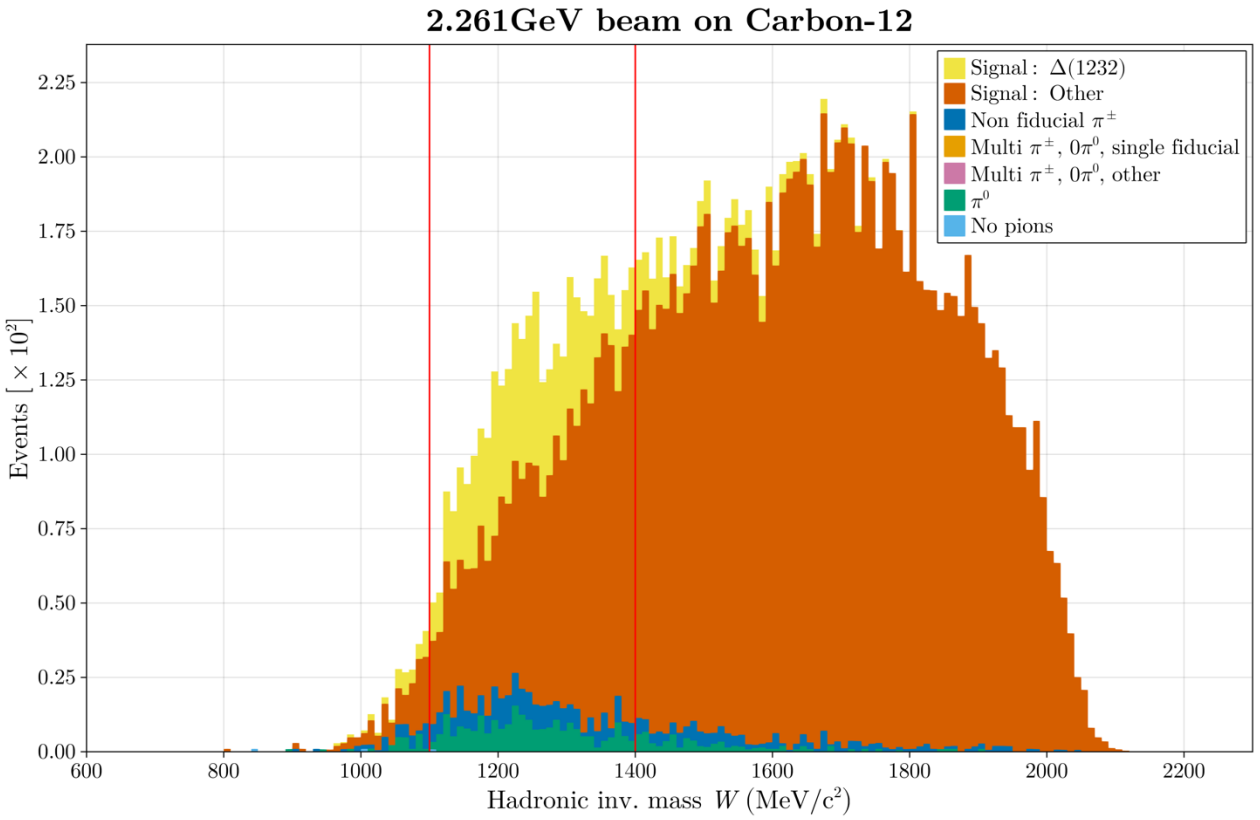


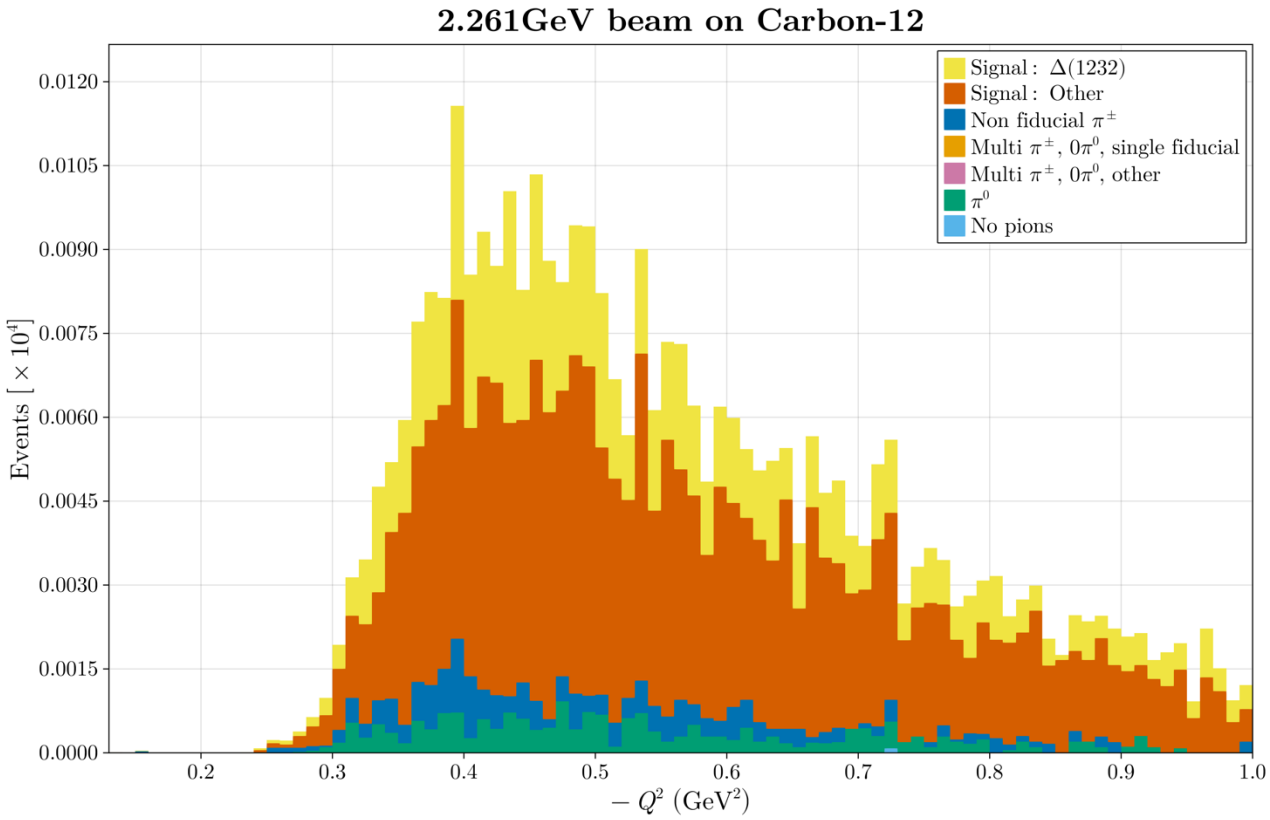
Numerator Distributions – Leading Charged Pion





Numerator Distributions





Next Steps

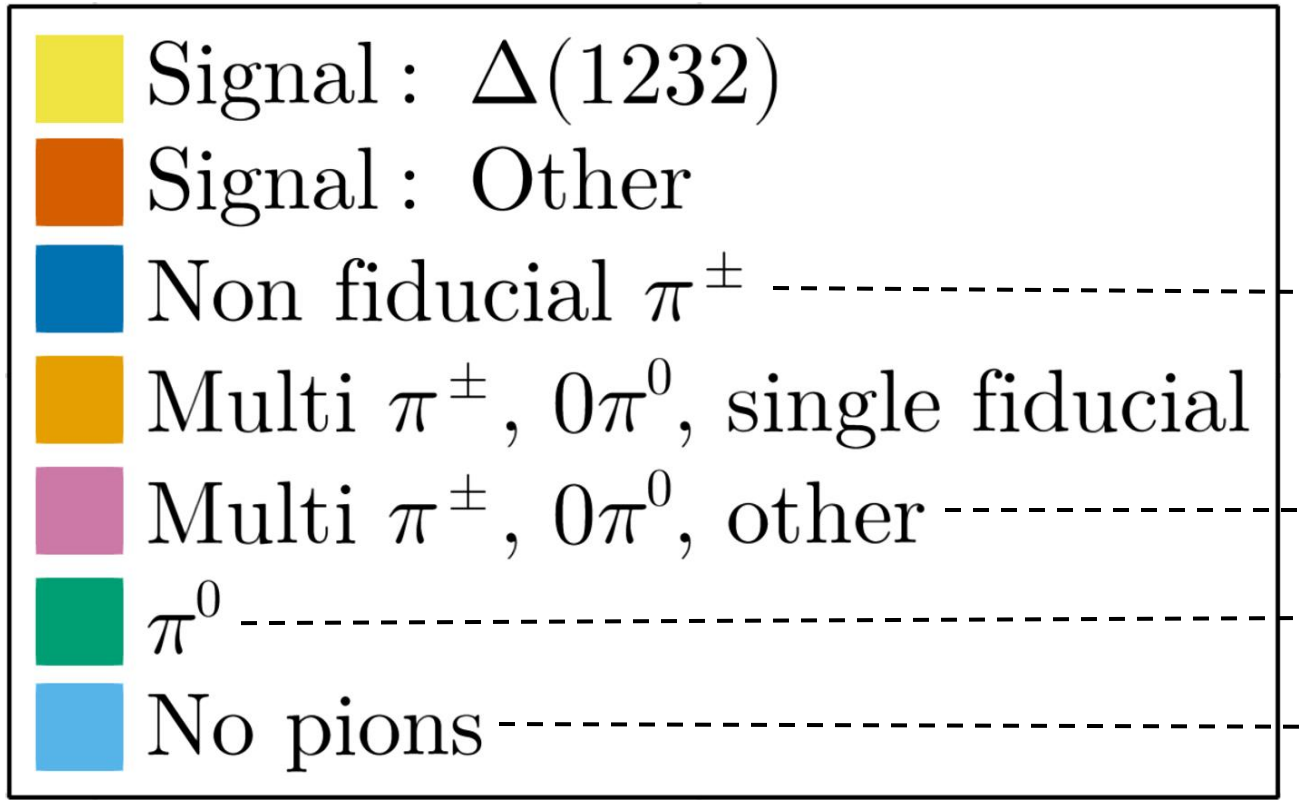
- Explore other beam energy and targets
- Study methods to handle the large π^0 background in the denominator sample
- Smear reconstructed proton and pion energies and momenta
- Calculate the transparency vs. pion momentum and compare to the GENIE prediction
- Compare to an alternate analysis that uses the method of Qian *et al*

Back-ups

Event Categories (Signal vs Background)

*All particle counts are **pre-FSI (primary state)***

Pion Fiducial Check
$|\vec{p}_\pi| > 150$ MeV
$\cos\theta_\pi > -0.5$



Signals:
- Exactly 1 $\pi^\pm$ before FSI
- Exactly 0 π^0 before FSI
- $\pi^\pm$ before FSI passes Pion Fiducial Check

Non fiducial $\pi^\pm$: $1\pi^\pm$ (0 pass fiducial check), $0\pi^0$

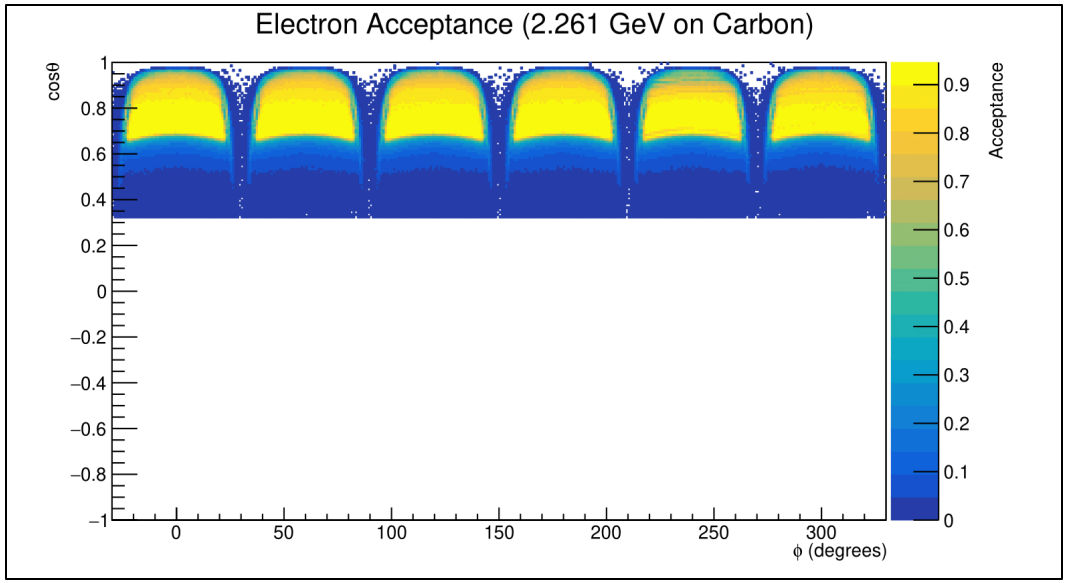
Multi $\pi^\pm$, $0\pi^0$, single fiducial: $\geq 2\pi^\pm$(1 pass fiducial check), $0\pi^0$

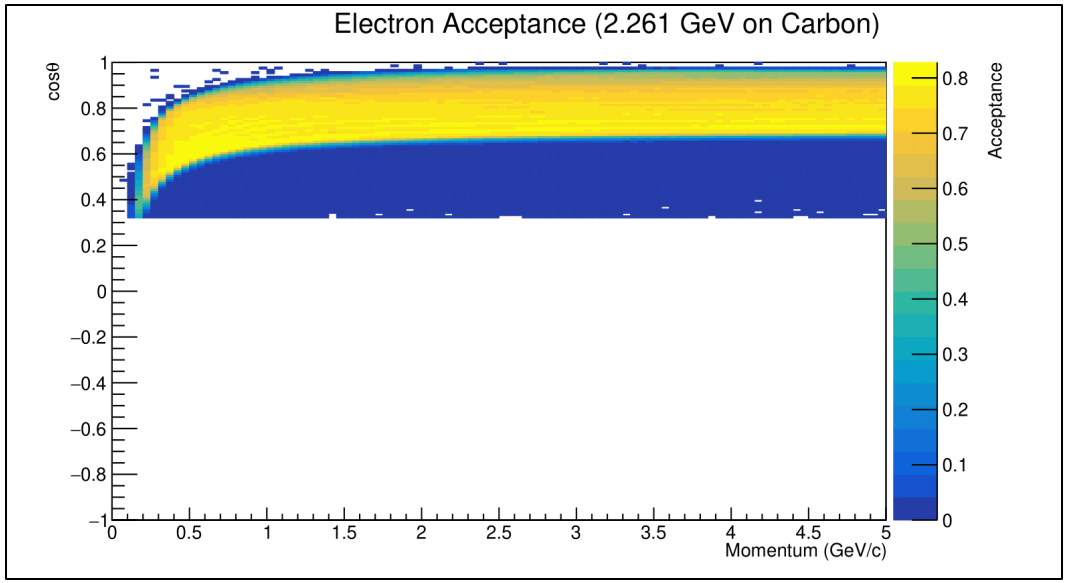
Multi $\pi^\pm$, $0\pi^0$, other: $\geq 2\pi^\pm$($\neq 1$ pass fiducial check), $0\pi^0$

π^0: $\geq 1\pi^0$

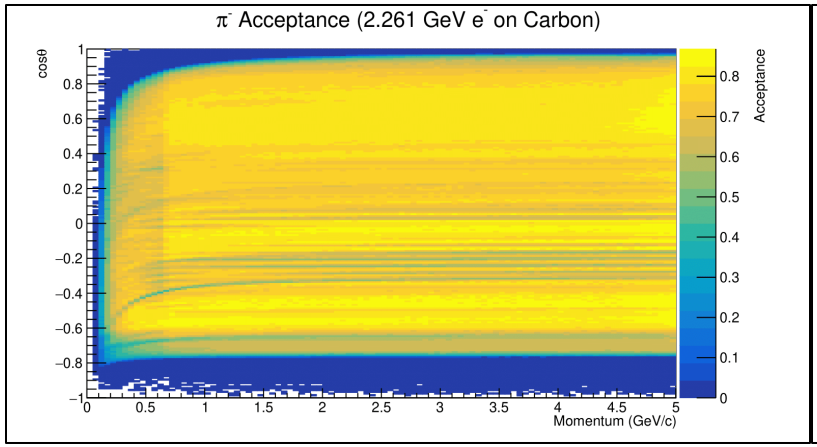
No pions: $0\pi^\pm$, $0\pi^0$

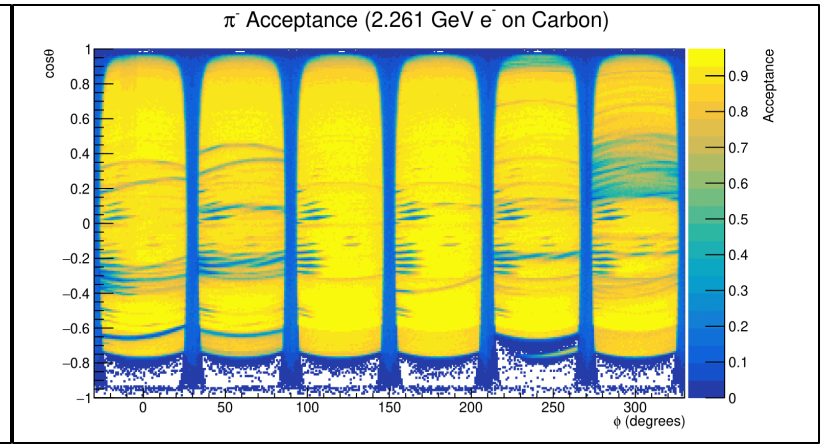
Electron Acceptance

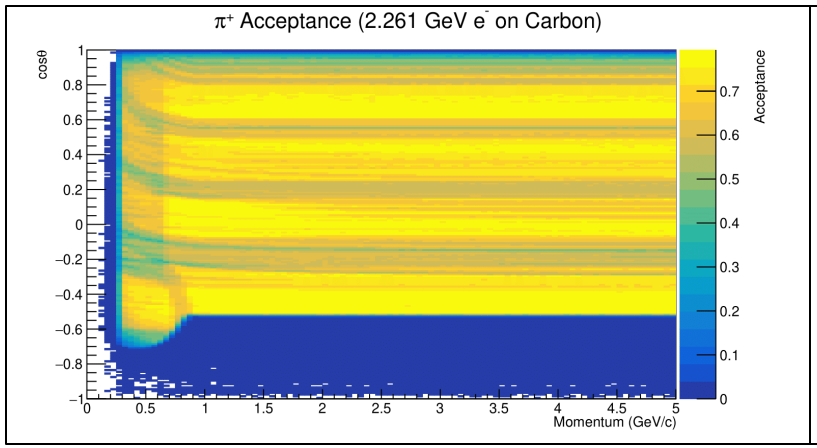


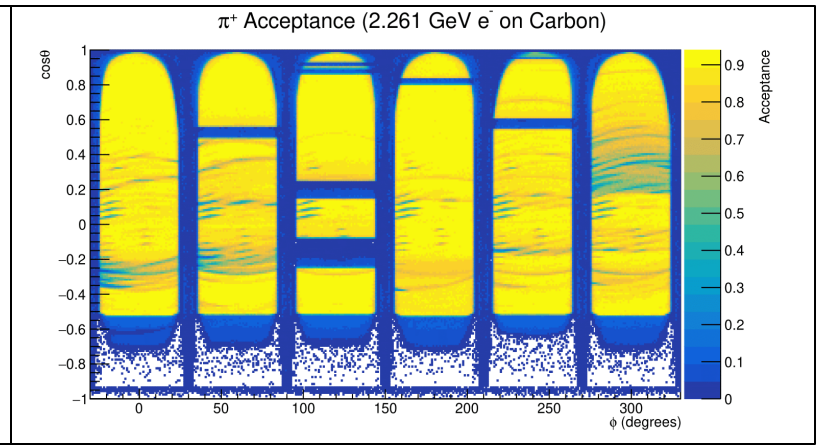


Charged Pion Acceptance









Smearing The Outgoing Electron

- Smeared electron momentum with a width of 0.5%, preserving direction.