RG-D: PID and Contamination Studies

CLAS Collaboration Meeting
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Outline

1. Ongoing Particle Identification Refinement
    a. Event Builder PID
    b. Charged Hadrons PID
2. Contamination Studies
3. Summary and Outlook
4. Acknowledgement

Ongoing PID Refinement

S.N.	Detectors	Functions
1	**HTCC**	Separates electrons (positrons) < 4.9 GeV from pions, kaons, protons
2	**LTCC**	Detects charged pions > 3.5 GeV
3	**RICH**	Identifies charged kaons (3–8 GeV)
4	**ECAL**	Used primarily to identify electrons, photons, and neutrons
5	**FT**	Detects electrons and photons at polar angles between 2.5° and 4.5°
6	**FTOF**	Measures time-of-flight of charged particles
7	**CND**	Detects neutrons in the momentum range 0.2–1.0 GeV
8	**CTOF**	Identifies charged particles in the momentum range 0.3–1.25 GeV
9	**BAND**	Detects backward neutrons with momenta between 0.25–0.7 GeV

P.S.: FT and BAND are not used in RG-D

Event Builder PID

PID assignment in Event Builder (From Coatjava):

Step 1: Select the Trigger Particle (Electron)

Electron is identified first, as it serves as the trigger particle (If the particle's status is -ve). The selection is based on:

1. Charge Check → Must be negative
2. HTCC → nphe> 2 ensures the presence of a Cherenkov signal.
3. Energy Deposit in PCAL → E_{PCAL} > 0.06 GeV
4. Sampling Fraction (E/P) vs. E →

   Total energy: E= $E_{PCAL} + E_{ECAL}$

   The SF should be within ±5σ of the expected electron band.

If a particle passes all these conditions, PID= 11 is assigned and set the event start time using it.

Step 2: Assign PID to Other Charged Particles (Hadrons)

Once the trigger electron is selected, the remaining particles are processed:

1. Check Charge
   a. Positive particles: Can be π^+ (211), K^+ (321), p (2212), deuteron (45).
   b. Negative particles: Can be π^- (-211), K^- (-321), etc.
2. Timing-Based Identification
   a. Compare measured vs. expected vertex time for different hadron hypotheses.
   b. Use FTOF (Time-of-Flight Detectors) for timing information.
   c. Compute timing difference (Δt) for each hadron type.
   d. Assign the PID of the hadron with the smallest Δt (best match).
3. Fallback to Signal Checks (HTCC & LTCC):
   a. If timing does not match well, htccSignalCheck: nphe>2 & htccPionThreshold: P> 4.9 GeV → Assign Pion
   b. If the timing matches and is a kaon, but ltccSignalCheck: nphe>2 & ltccPionThreshold: P> 3 GeV → Assign Pion
   c. If the timing matches and is a proton, but ltccSignalCheck: nphe>2 & ltccPionThreshold: P> 3 GeV → Assign Pion

Charged Hadrons PID

- The time difference (Δt) is calculated assuming the pion mass (pion hypothesis)

$$\Delta t = \left[t_{FTOF} - \frac{L}{\beta_h(p) \times c} \right] - t_{startTime} \quad \text{and} \quad \beta_h(p) = \frac{p}{\sqrt{p^2 + m_h{}^2}},$$

where, h: hadron, m: mass, p: momentum, c: speed of light, L: path length, t_{FTOF}: time of flight, and $t_{startTime}$: particle start time, while, L and t_{FTOF} are measured from the beam–target interaction point to the FTOF detector

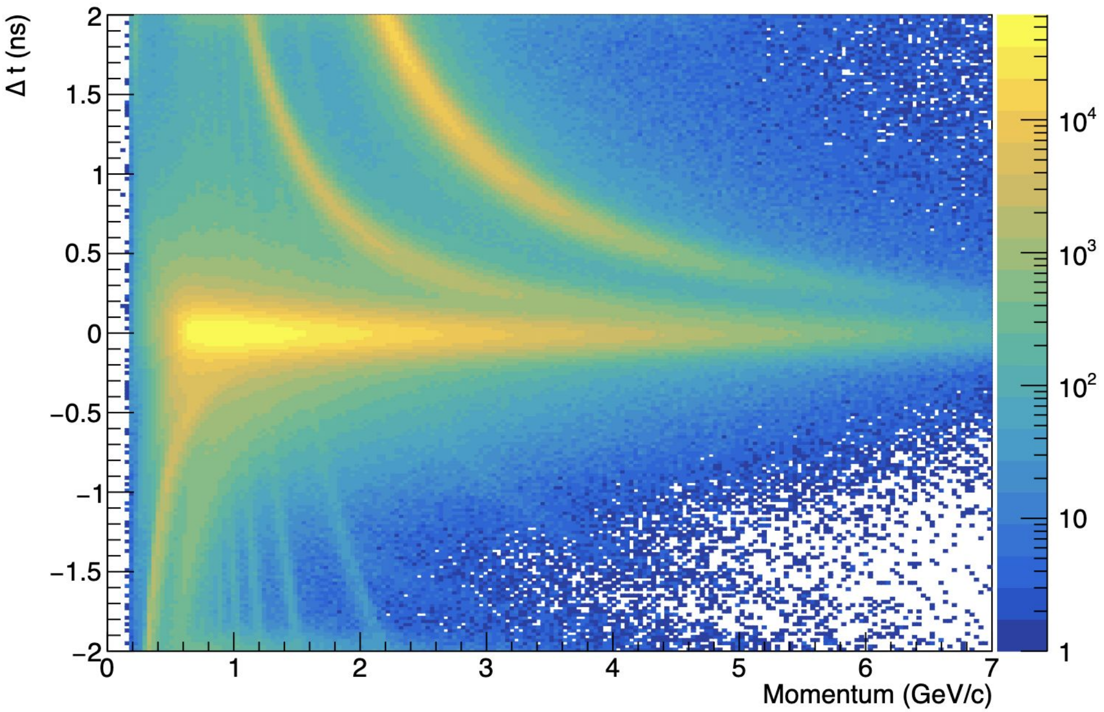
Charged Hadrons PID (Cont'd)

- Data Selection for this Analysis:

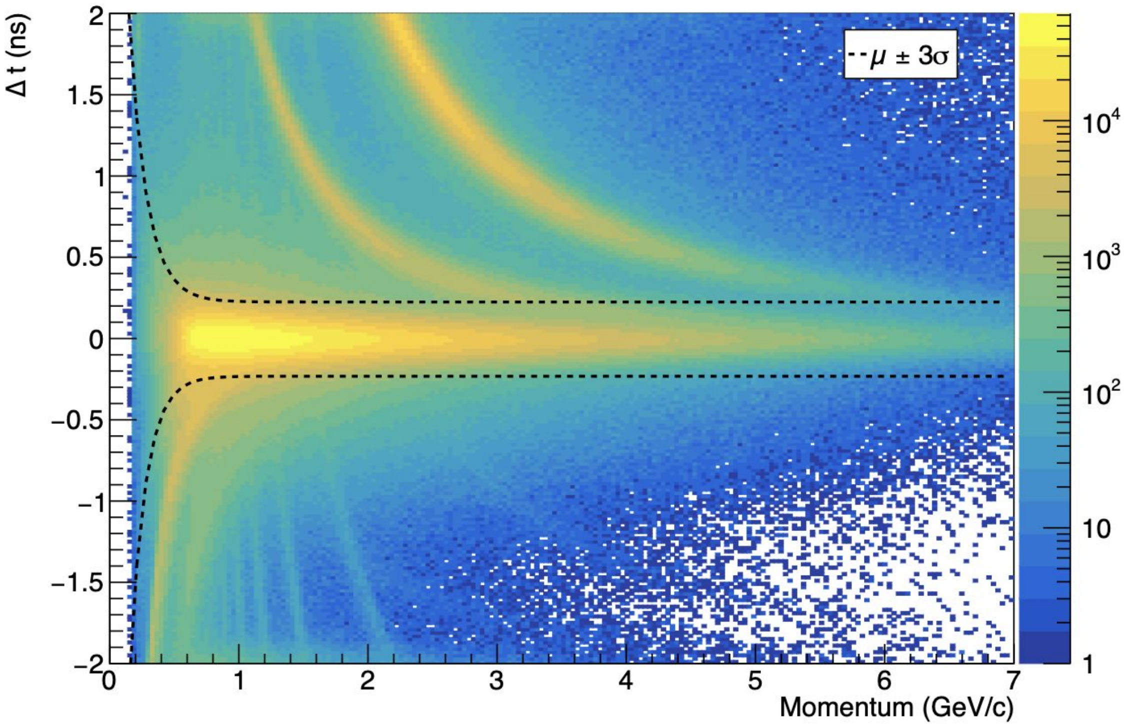
1. RG-D Data
2. Target: Dual carbon foils (CxC)
3. Even selection :
   a. Trigger electron Cut
      i. EB PID: 11
      ii. status < 0
      iii. Forward Detector
      iv. |chi2pid| < 5, vz: [-10.56, 5] cm
4. $\boldsymbol{\pi}^{+}$ sample selection
   a. charge > 0
   b. Forward Detector
   c. 3$\boldsymbol{\sigma}$ cut for ‘Δt’

See Mathieu Ouillon talk for ongoing RG-D Vz study and cuts

Charged Hadrons PID (Cont'd)



Δt for all positively charged particles under the pion hypothesis

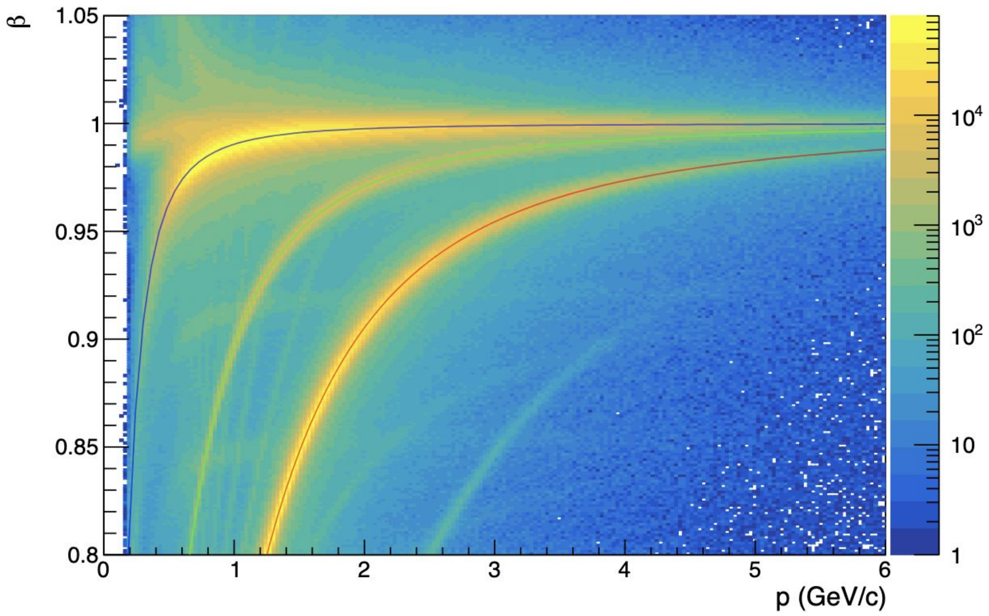


Selection of the +ve pions candidates

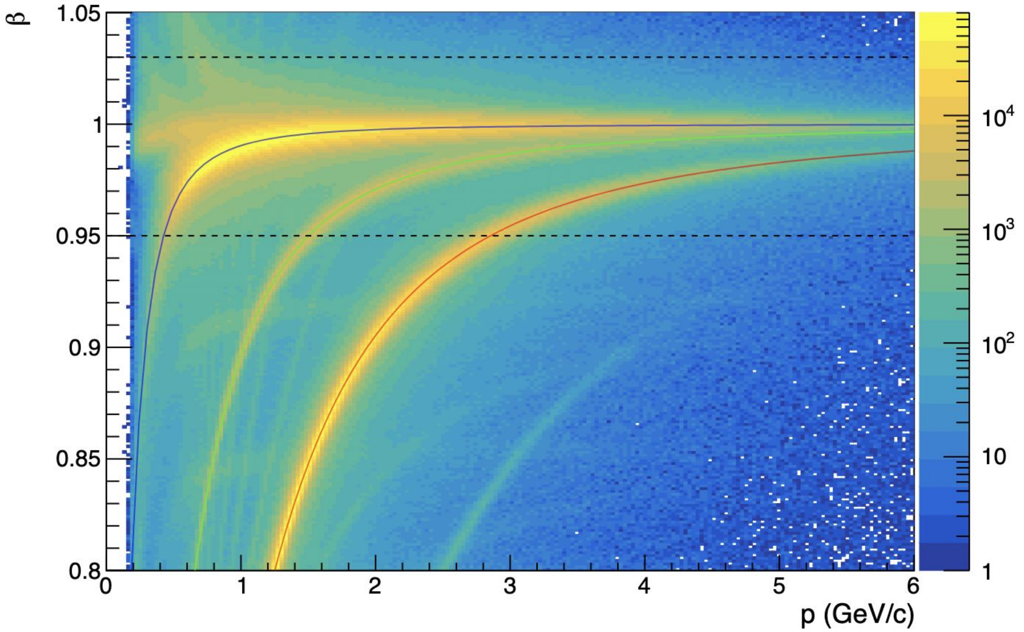
Contamination Studies

- Two methods have been used to study K^+ and proton contamination in the π^+ sample:
  1. Data-driven (experimental)
  2. Simulation-based

Data-driven (experimental)



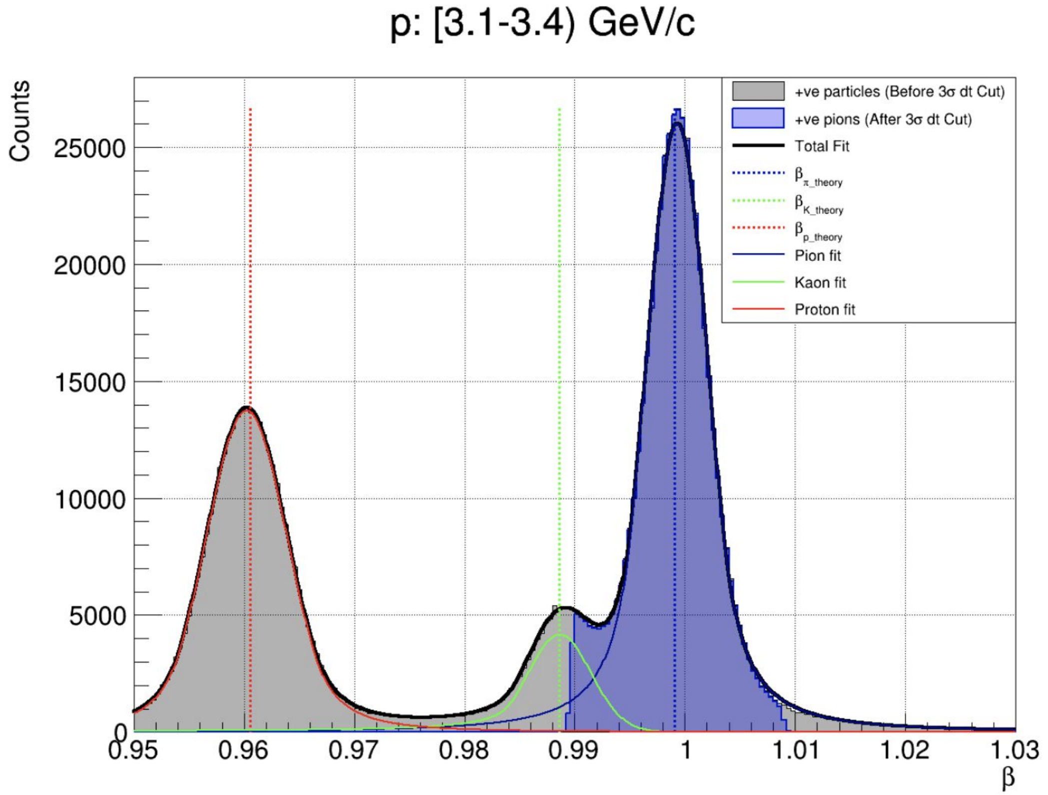
Beta vs. momentum for all positively charged particles



Beta region to investigate the contamination: [0.95, 1.03]

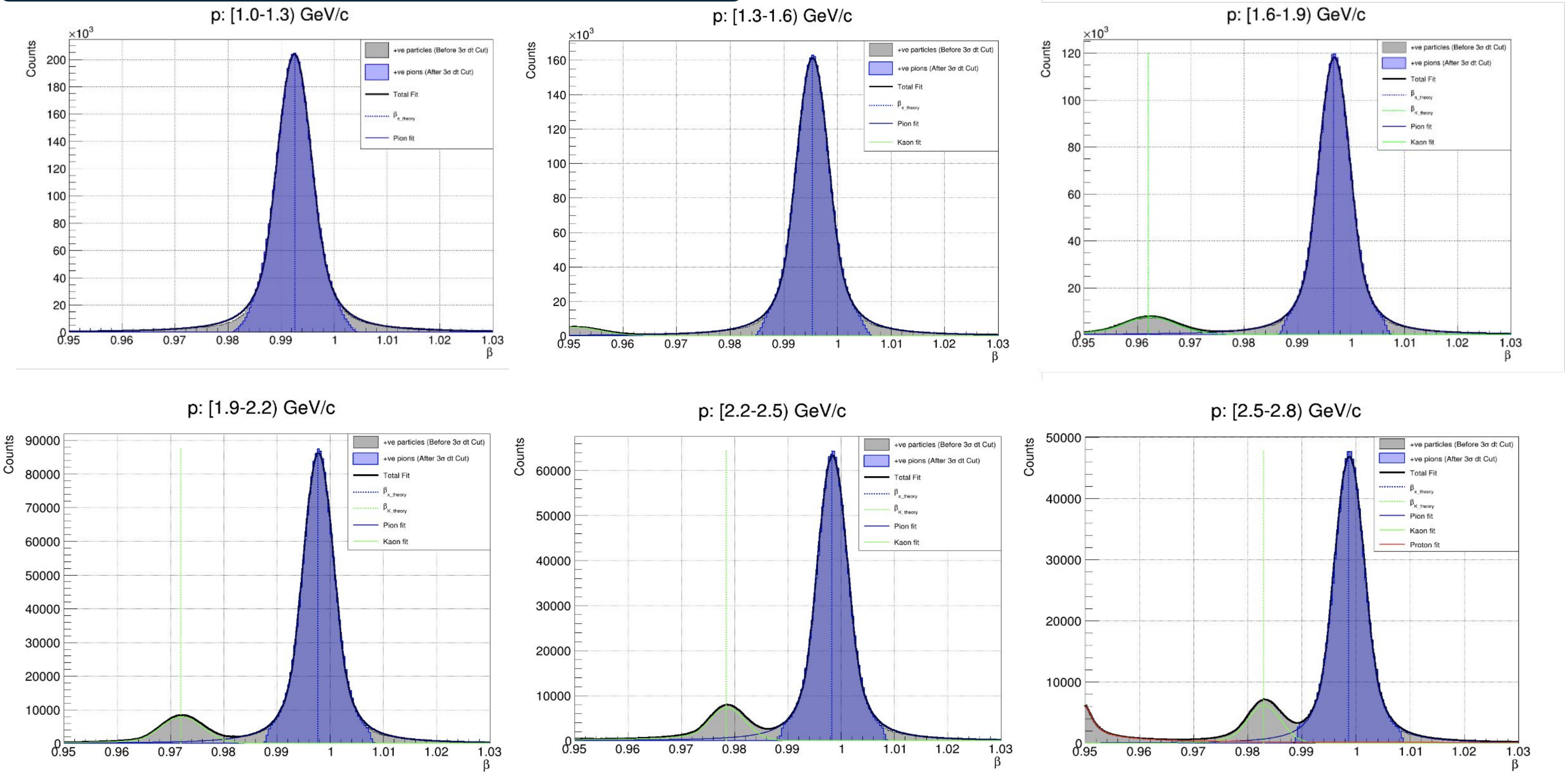
Data-Driven Contamination

1. All positively charged particles β is plotted for each momentum bin.
2. After applying a 3σ Δt cut based on the pion hypothesis, β is re-plotted for the surviving positive candidates.
3. All positive particles are fitted with a total fit function composed of:
   a. A double Crystal Ball function describing the pion and proton peak regions
   b. A single Crystal Ball function describing the kaon peak region
4. Therefore, the contamination is evaluated as

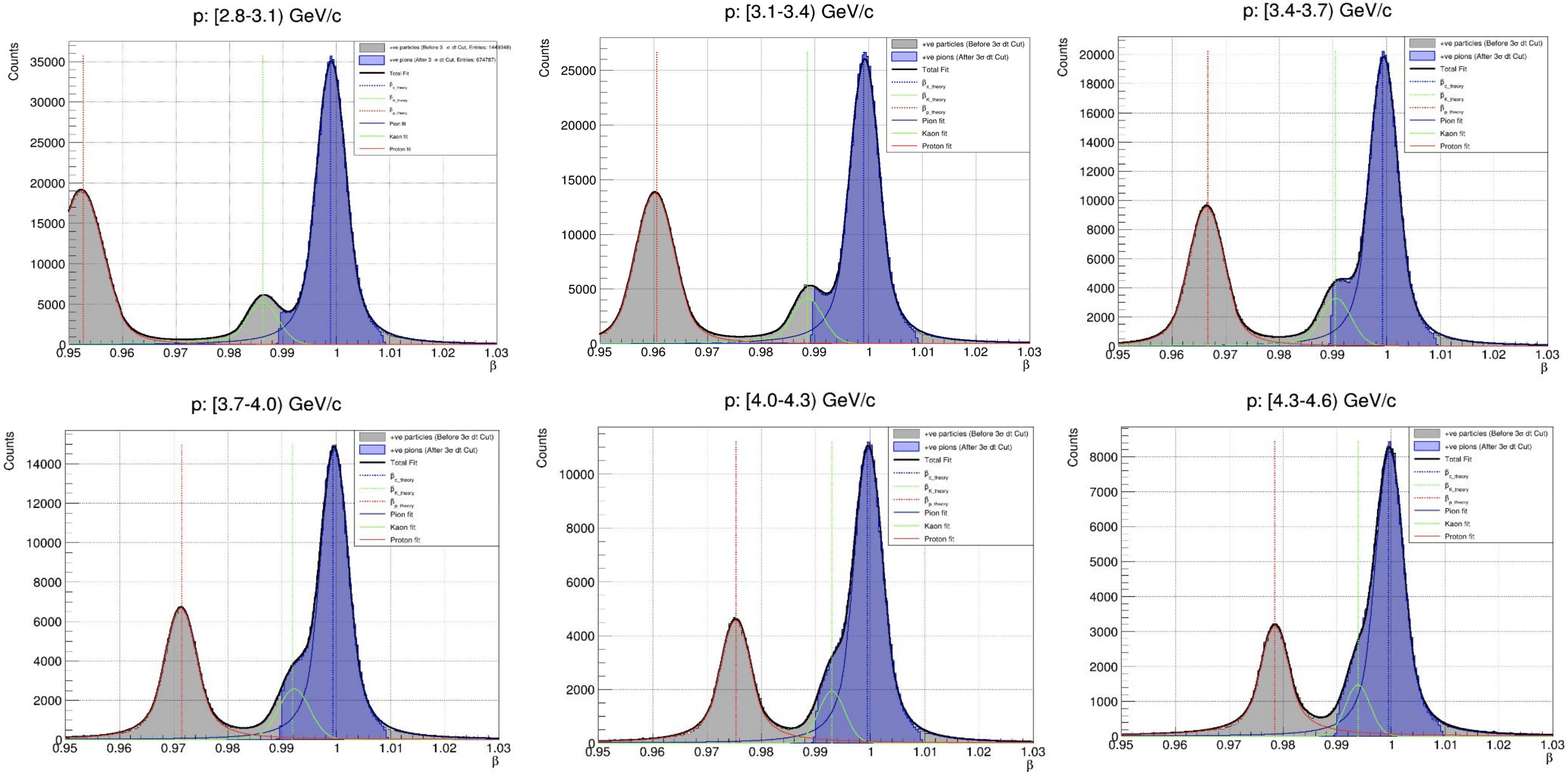


$$K^{+}\ (\text{or proton contamination}) = \frac{\text{The integral of } K^{+}\ (\text{or protons}) \text{under the } \pi^{+\prime}\text{s area}}{\text{The integral of } \pi^{+\prime}\text{s area}}$$

Data-Driven Contamination (Cont'd)



Data-Driven Contamination (Cont’d)



Contamination based on Simulation

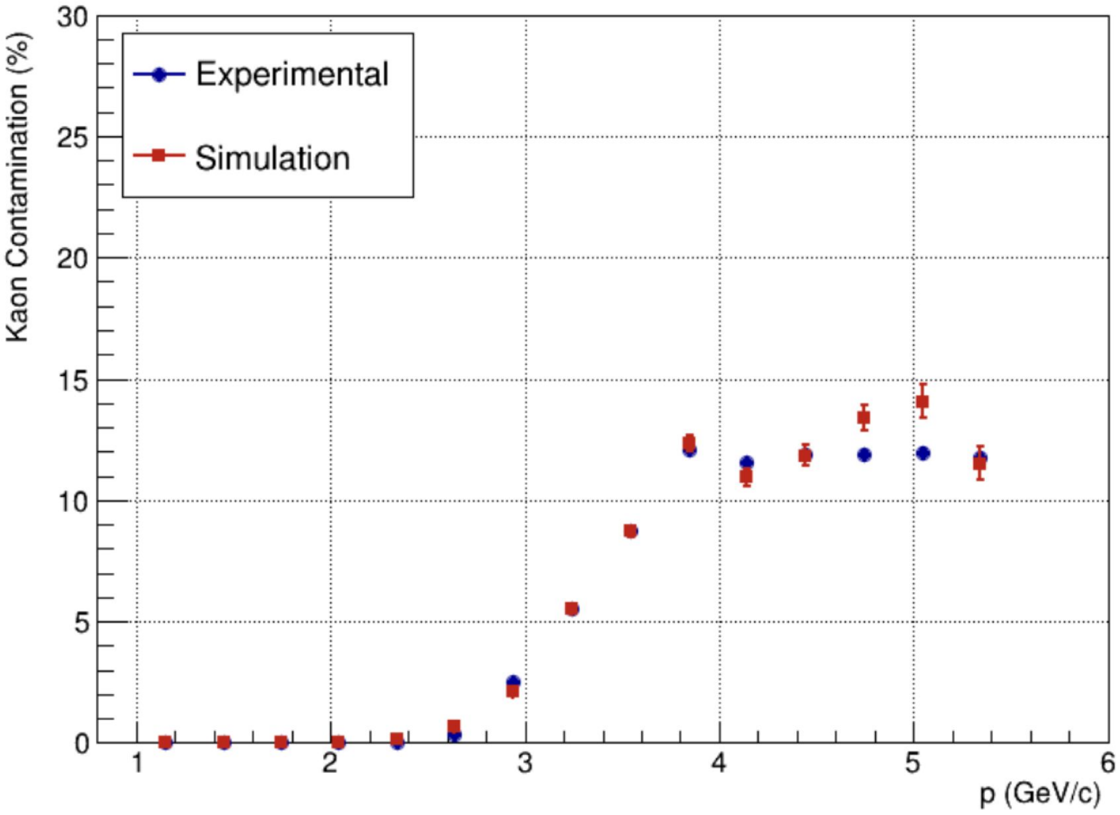
- Two Monte Carlo (MC) banks have been used:
    1. MC::Particle - Generated (or True) Particles
    2. REC::Particle - Reconstructed Particles

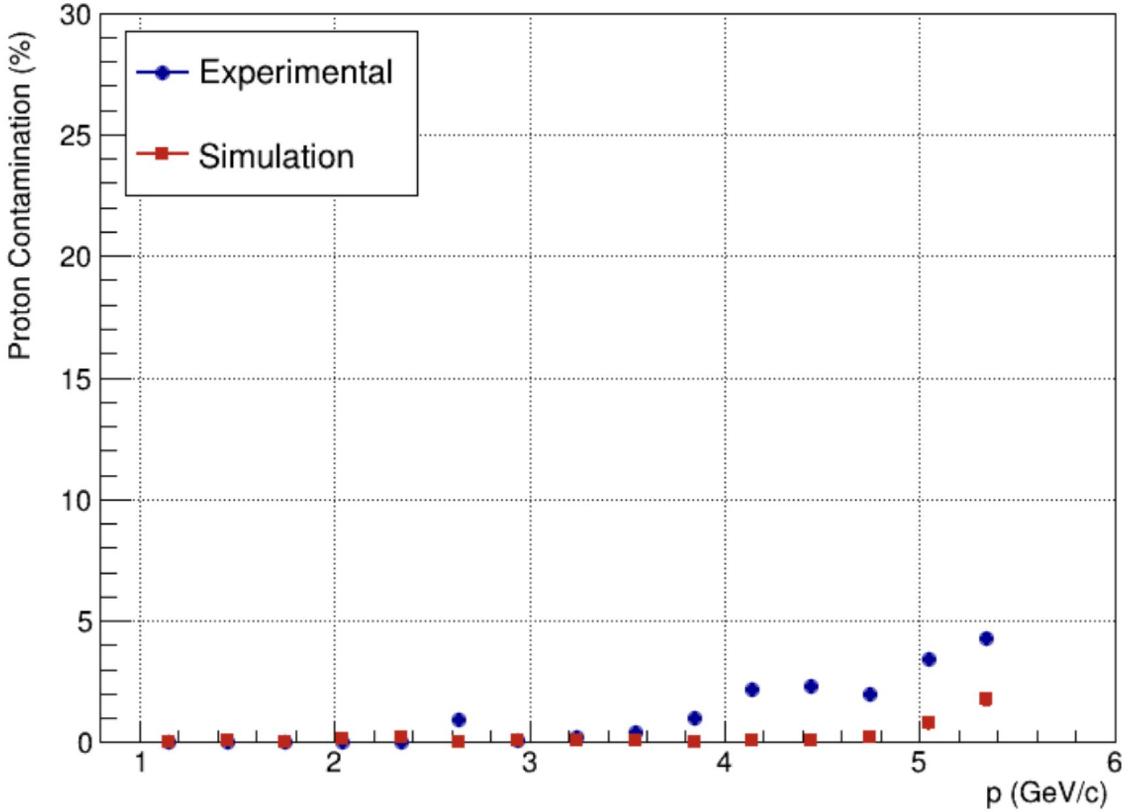
- The reconstructed particles have been matched to the generated particles by requiring
    a. matching charge, and
    b. $\Delta\theta < 1°$ and $\Delta\varphi < 3°$

- The contamination is evaluated as

$$K^+ \left(\text{or proton contamination}\right) = \frac{\text{MC matched } K^+ \left(\text{ or protons }\right) \text{ reconstructed as } \pi^+}{\text{All reconstructed } \pi^+}$$

Preliminary Contamination Results





Summary and Outlook

- ✓ K^+ and proton contamination in the π^+ sample has been studied using timing cuts from the FTOF detector with both experimental and simulated data
- ✓ Next steps**:** Cherenkov information from the LTCC detector will be explored for particle PIDs and further contamination studies to finalize them

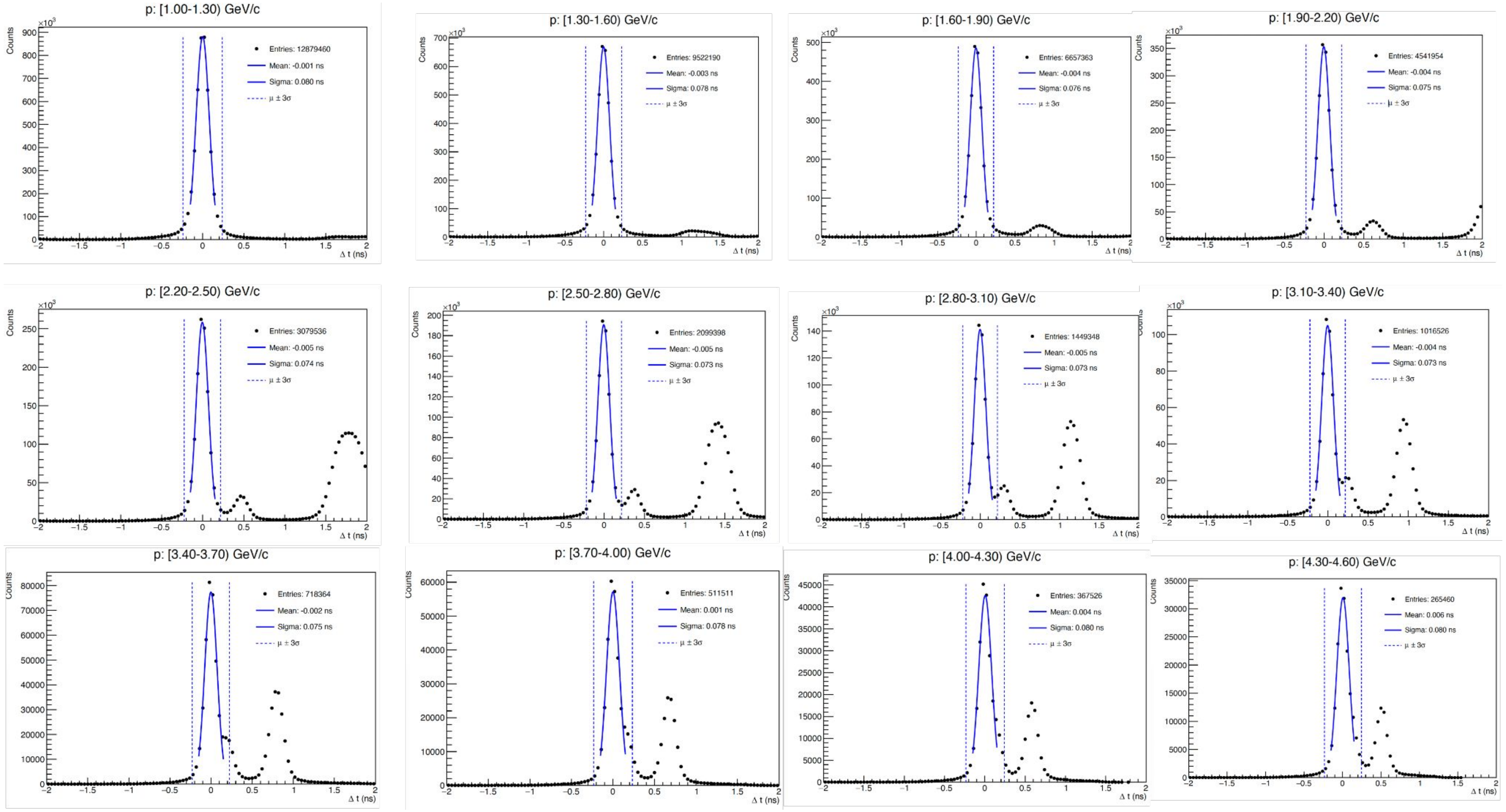
Acknowledgement

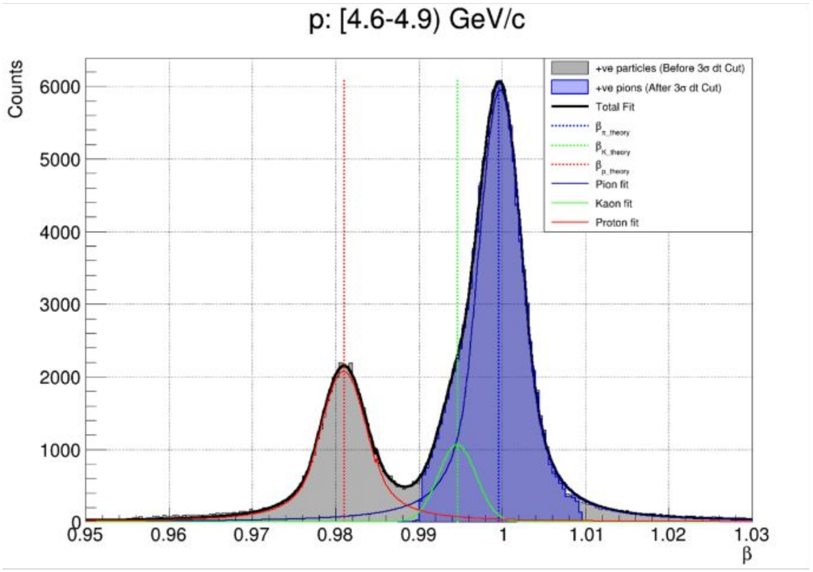
This work is supported by the US DOE award #: DE-SC0016577

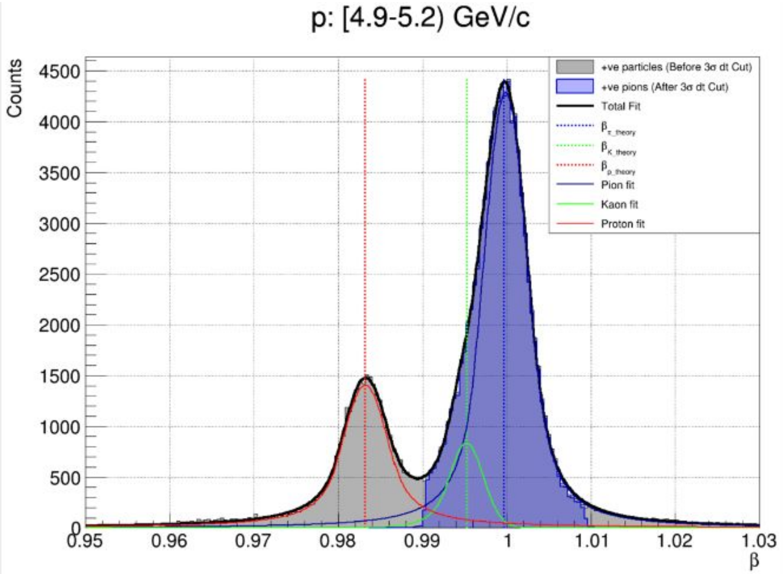
Thank You

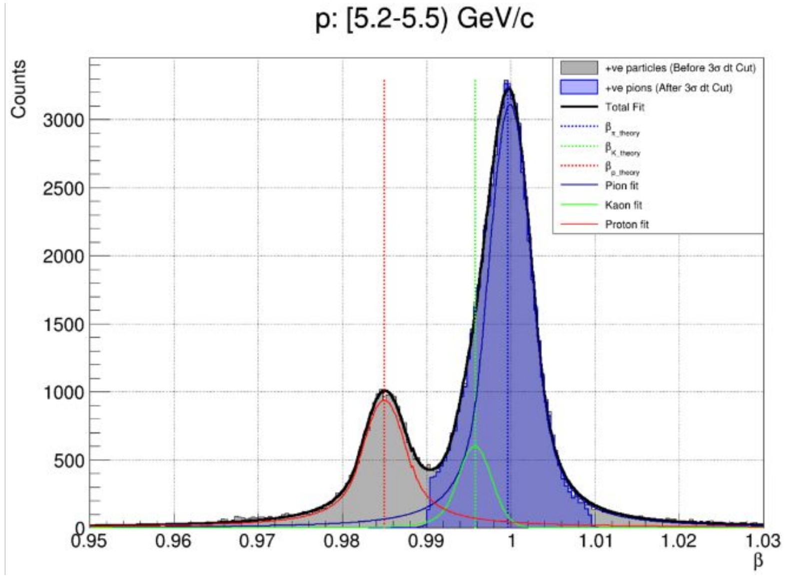
Thank You

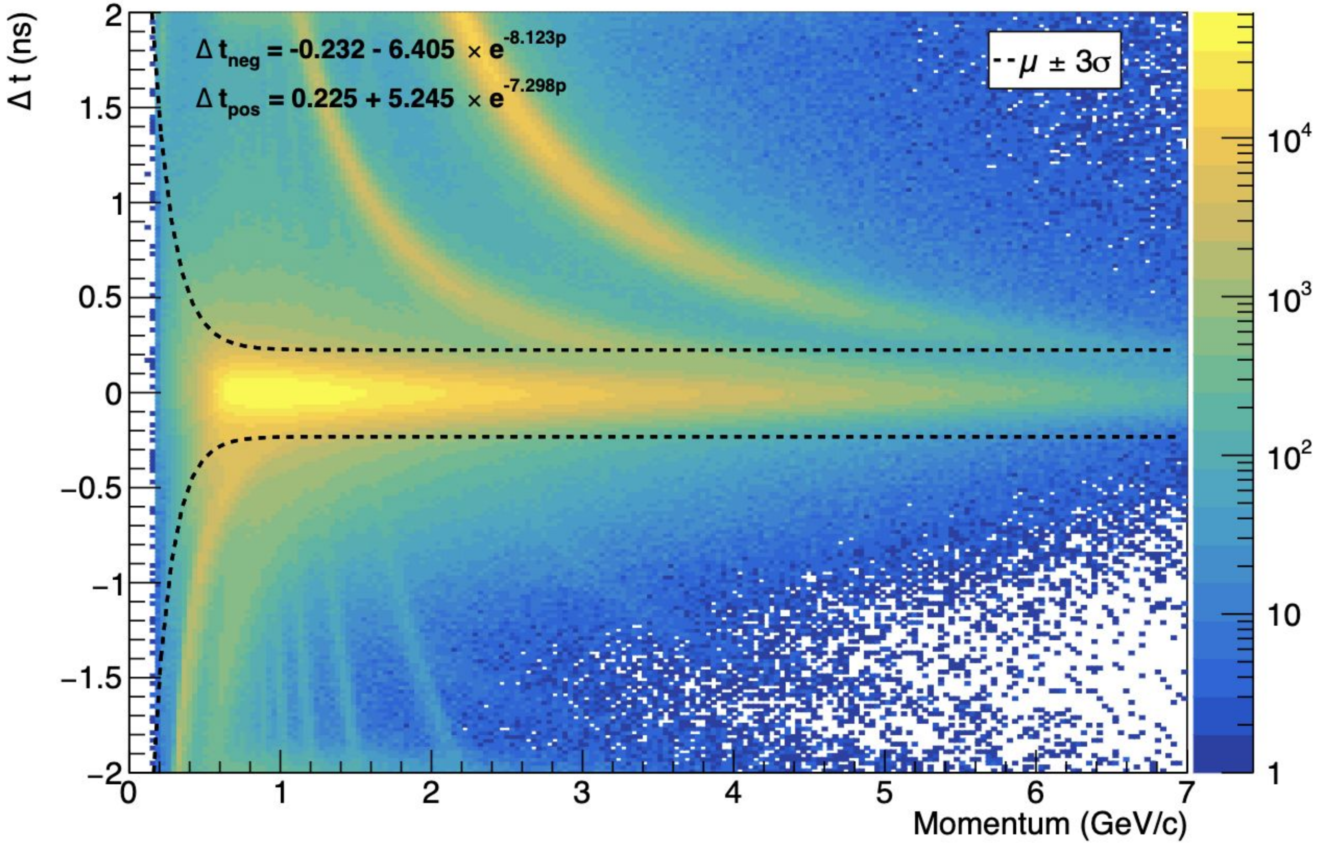
Backup Slides


p: [1.00-1.30) GeV/c
Entries: 12879460
Mean: -0.001 ns
Sigma: 0.080 ns
μ ± 3σ
p: [1.30-1.60) GeV/c
Entries: 9522190
Mean: -0.003 ns
Sigma: 0.078 ns
μ ± 3σ
p: [1.60-1.90) GeV/c
Entries: 6657363
Mean: -0.004 ns
Sigma: 0.076 ns
μ ± 3σ
p: [1.90-2.20) GeV/c
Entries: 4541954
Mean: -0.004 ns
Sigma: 0.075 ns
μ ± 3σ
p: [2.20-2.50) GeV/c
Entries: 3079536
Mean: -0.005 ns
Sigma: 0.074 ns
μ ± 3σ
p: [2.50-2.80) GeV/c
Entries: 2099398
Mean: -0.005 ns
Sigma: 0.073 ns
μ ± 3σ
p: [2.80-3.10) GeV/c
Entries: 1449348
Mean: -0.005 ns
Sigma: 0.073 ns
μ ± 3σ
p: [3.10-3.40) GeV/c
Entries: 1016526
Mean: -0.004 ns
Sigma: 0.073 ns
μ ± 3σ
p: [3.40-3.70) GeV/c
Entries: 718364
Mean: -0.002 ns
Sigma: 0.075 ns
μ ± 3σ
p: [3.70-4.00) GeV/c
Entries: 511511
Mean: 0.001 ns
Sigma: 0.078 ns
μ ± 3σ
p: [4.00-4.30) GeV/c
Entries: 367526
Mean: 0.004 ns
Sigma: 0.080 ns
μ ± 3σ
p: [4.30-4.60) GeV/c
Entries: 265460
Mean: 0.006 ns
Sigma: 0.080 ns
μ ± 3σ
Counts
Δ t (ns)


p: [4.6-4.9) GeV/c
Counts
β
+ve particles (Before 3σ dt Cut)
+ve pions (After 3σ dt Cut)
Total Fit
Pion fit
Kaon fit
Proton fit


p: [4.9-5.2) GeV/c
Counts
β
+ve particles (Before 3σ dt Cut)
+ve pions (After 3σ dt Cut)
Total Fit
Pion fit
Kaon fit
Proton fit


p: [5.2-5.5) GeV/c
Counts
β
+ve particles (Before 3σ dt Cut)
+ve pions (After 3σ dt Cut)
Total Fit
Pion fit
Kaon fit
Proton fit


Δt_{neg} = -0.232 - 6.405 × $e^{-8.123p}$
Δt_{pos} = 0.225 + 5.245 × $e^{-7.298p}$
μ ± 3σ
Δ t (ns)
Momentum (GeV/c)