Improved Particle Identification from Time of Flight Data in Polarized Proton-Proton Collisions

Minjun Baik of Abilene Christian University for STAR Collaboration

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Introduction

- Relativistic Heavy Ion Collider (RHIC)
- Capable of colliding spin-polarized protons
  - Data at $\sqrt{s}$ up to 510GeV
  - $\sqrt{s} \equiv$ center-of-mass energy
- Resulting jets = key for proton spin structure
  - Jets probe colliding partons
  - Because such jets probe proton structure
  - Identifying particles in jets probes parton flavors
- Particle Identification (PID)
  - Mainly pion, kaon, proton, and electron

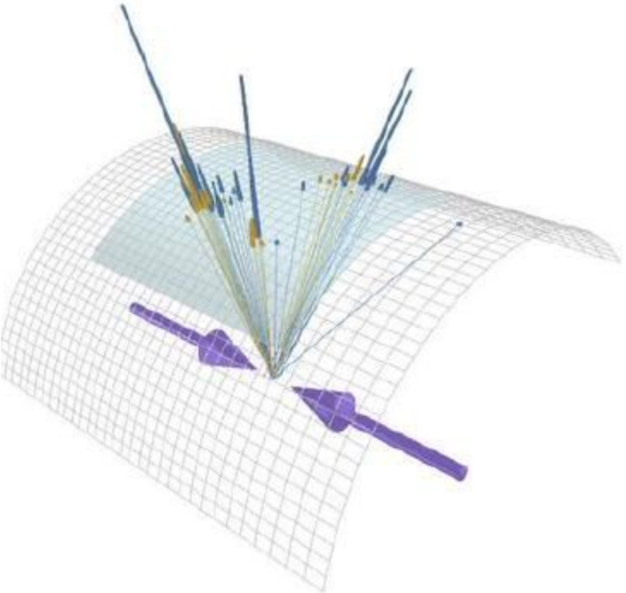
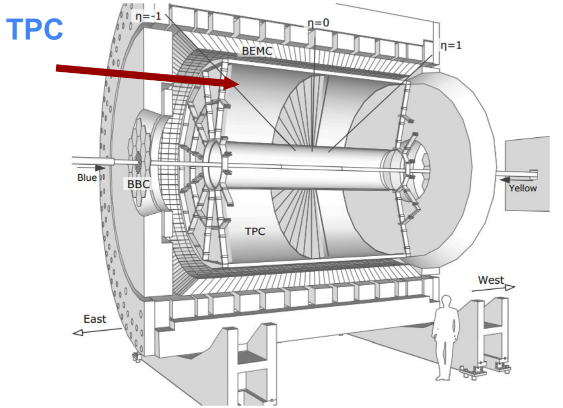
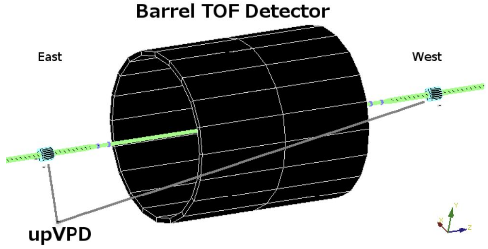


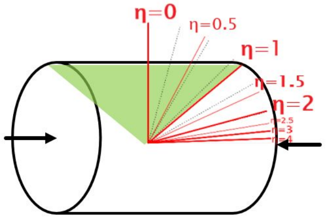
Image of Jet

Solenoidal Tracker at RHIC (STAR)

- STAR measures traces of particles from the collision
- Two detectors used in PID:
  - Energy loss (dE/dx) in Time Projection Chamber (TPC)
  - Particle time-of-flight (Δt) in the TOF detector.
- TOF geometry
  - There are total 120 trays (unit of TOF system)
  - TOF covers approximately |η| <1, where $\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$
  - We selected data from |η| <0.33
- Using data from the 2017 RHIC run
  - Polarized proton-proton data with √s = 510GeV





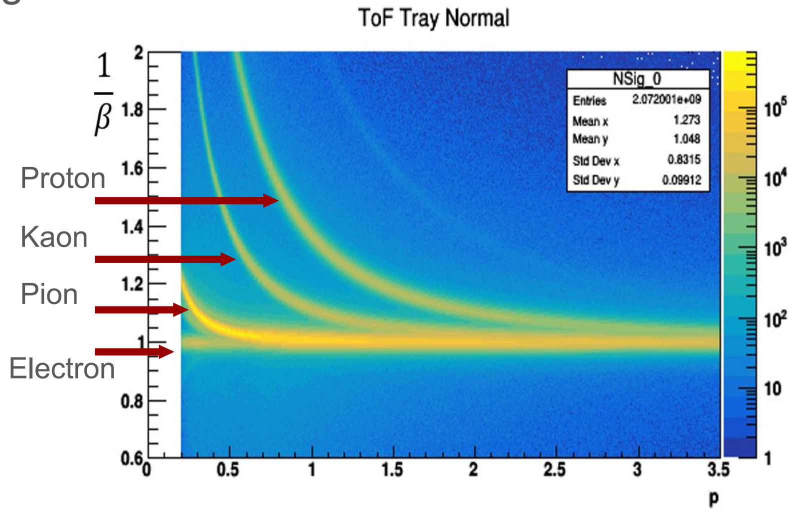


Theory of Particle Identification

$$n_\sigma(\mathrm{TOF}) = \frac{(Fit\ Center) - \frac{1}{\beta^{calc}}}{\mathrm{Fit}\ \sigma}$$

$$n_\sigma(\mathrm{TPC}) = \frac{1}{\sigma_{exp}} \ln\left(\frac{dE/dx_{obs}}{dE/dx_{\pi calc}}\right)$$

- Different physical traits result in distinct behaviors in 1/β vs momentum plots
- dE/dx and TOF ⇒ n_σ(TPc) and n_σ(TOF)
  - How do particles compare to predicted values
  - n_σ helps extract high purity samples
  - We develop n_σ(TOF) for this data set
- Fit the 1/β and n_σ(TPC) distributions
  - Extract the center and std of the pion's 1/β distribution
  - n_σ(Tpc) helps distinguish particles where 1/β curves overlap.
- Fitting TOF distribution gives centers and σs



Methodology

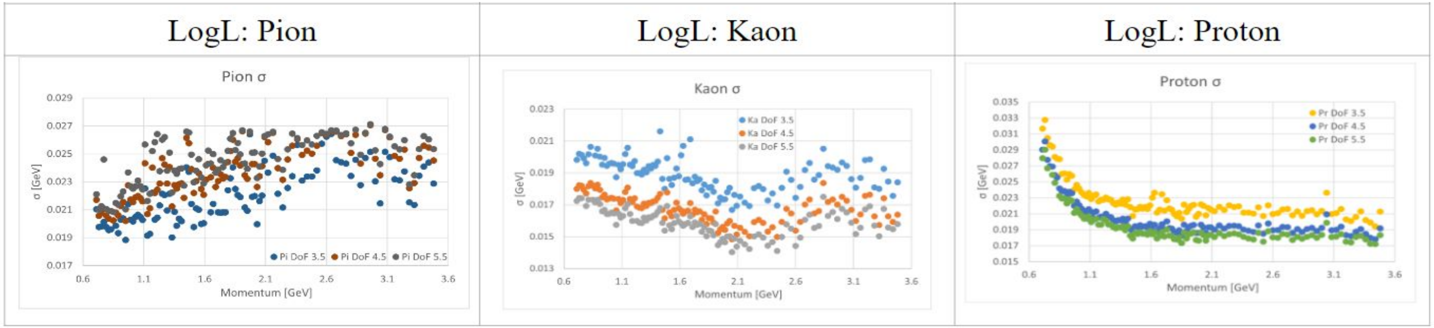
- Fitting function for TOF: Student's T distribution

$$f(p) = \frac{A}{B(\frac{1}{2},\frac{\nu}{2})}\sqrt{\frac{1}{\sigma^2(\nu-2)}}\left(1 + \frac{(p-\mu)^2}{\sigma^2(\nu-2)}\right)^{\frac{-(\nu+1)}{2}}$$

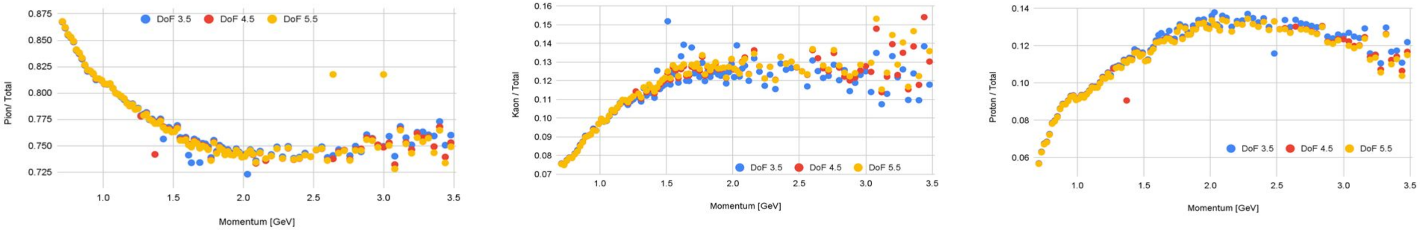
  - B =Beta function, p = momentum, ν = DoF, μ = mean, σ = standard deviation
- To find optimal fitting…
  - Varied parameters like degrees of freedom(DoF)
  - Fitting methods: the log likelihood (LogL)

Varying DoF: σ and Yield

- Consistent σ and (raw) yields as DoF changes from 3.5 to 5.5
  - Kaon and Proton σ changes approximately 10%
  - Pion σ is very consistent and stable



Uncorrected yields

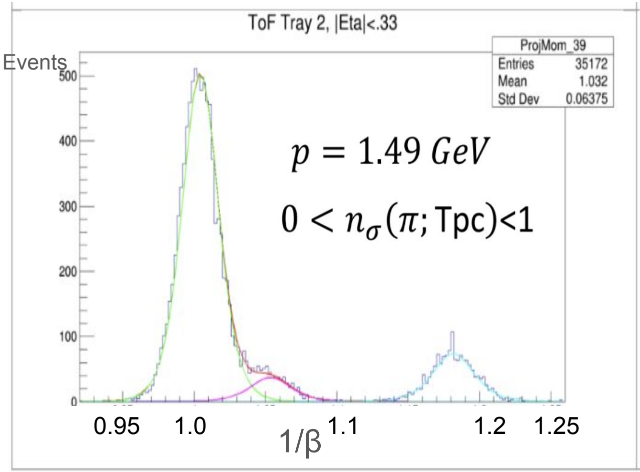


Fit Graphs

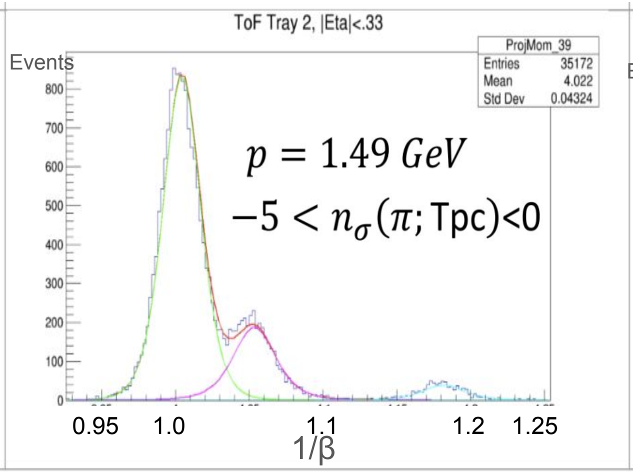
- Momentum of 1.49 GeV, with same DoF, center, and standard deviation
  - From 1.49 GeV, peaks starts to merge (total range is [0,3.6] GeV)
- Three different regions of n_σ(Tpc)
  - Enhanced each particle yields
- Fits are able to describe data well

Kaon
Proton
Pion

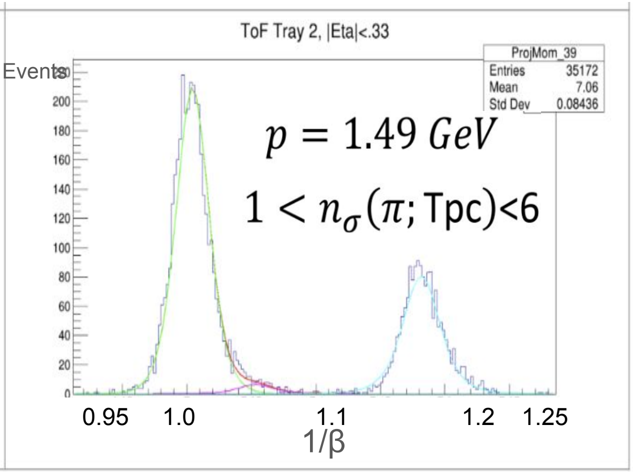
Pion Rich



Kaon Rich

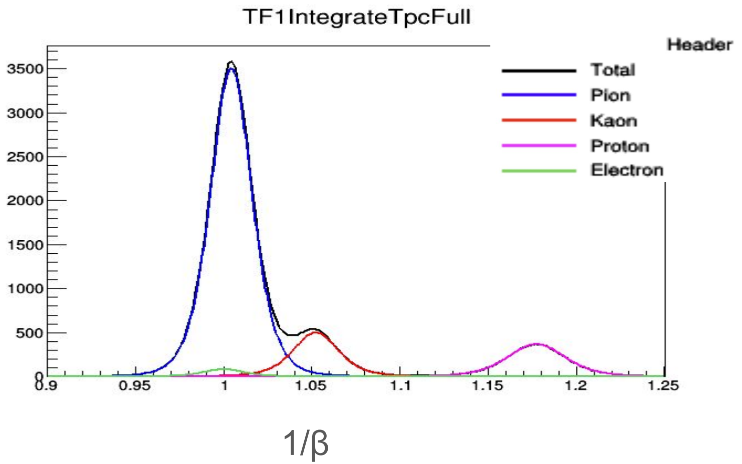


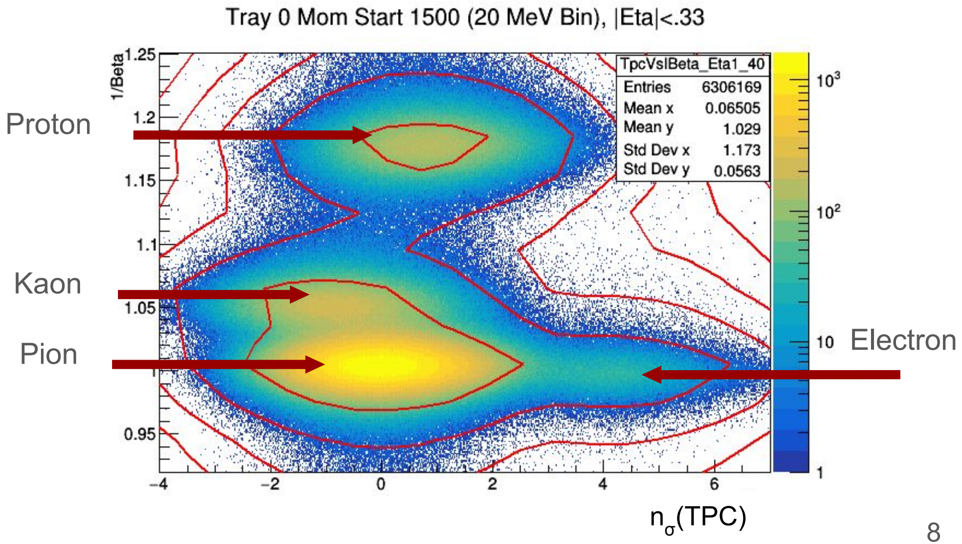
Proton Rich



2D fits

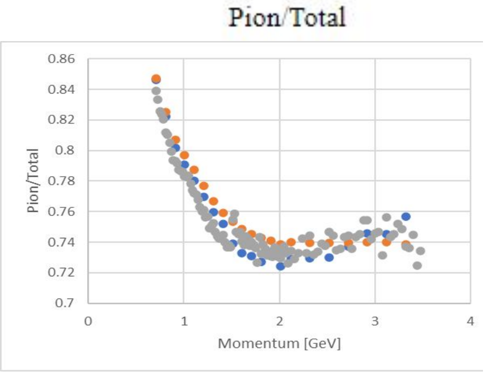
- Using full n_σ(TPC) distribution gives better fit than 1D
  - Better determines σ, optimal DoFs, and the small yield of electrons
- But, numerically expensive
  - Takes 5-6 times longer than 1D fit.

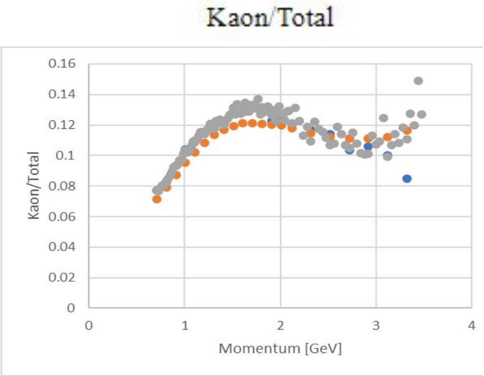


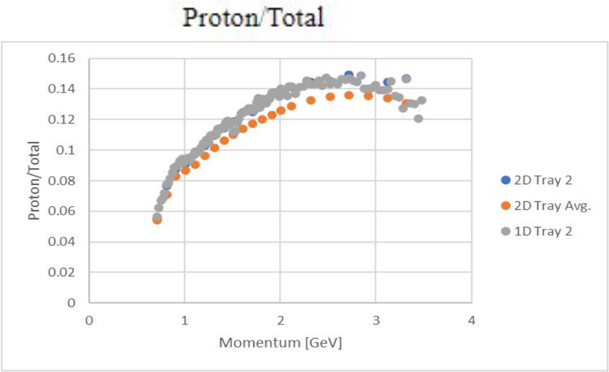


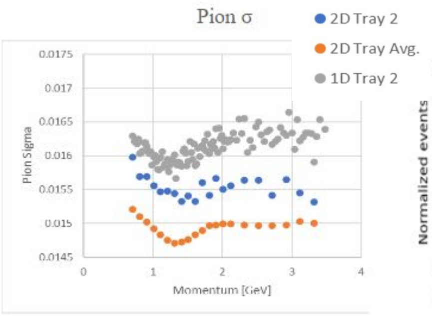
Guided 1D Fit Comparison

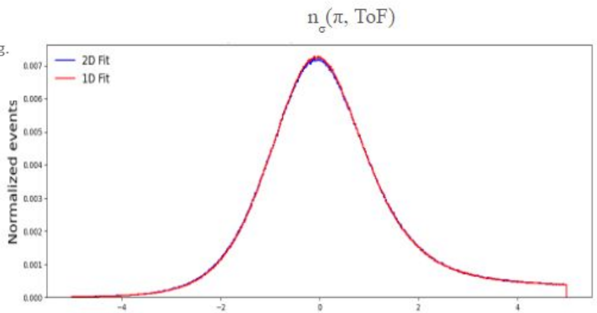
- Consistent result from particle yields of the guided 1D fits
  - Obtained from integrating the yield of the fittings
- Rescaled n_σ(TOF) to have width of 1











$$n_\sigma(\mathrm{TOF}) = \frac{(Fit\ Center) - \frac{1}{\beta'}}{Fit\ std}$$

Summary

- Identifying particles in jets are a valuable tool for probing nucleon spin structure.
- Identifying kaons, pions, and protons using 1/β and dE/dx
- Fit the 1/β and n_σ(TPC) distributions
  - 1/β from TOF: Data can be fit well with Student's T function
  - 2D fit of 1/β and n_σ(TPC) provide better fit, but numerically expensive
  - 1D guided fit of 1/β is consistent with 2D, and numerically cheap

Future work:

- Improve computation efficiency of 2D fits

Any questions?

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Back up slide

Guided 1D Fits

- Devised for faster method of analysing individual trays
- We combine all ToF trays and fit them
  - to extract an average DoF, kaon σ, and electron yields
- Electron yields ⇒ improvement on fit of the low momentum pion peak