Baryon-to-meson Ratios in Jets from Au+Au and p+p Collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV

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University of Illinois at Chicago

Quark Matter 2025, Frankfurt, Germany

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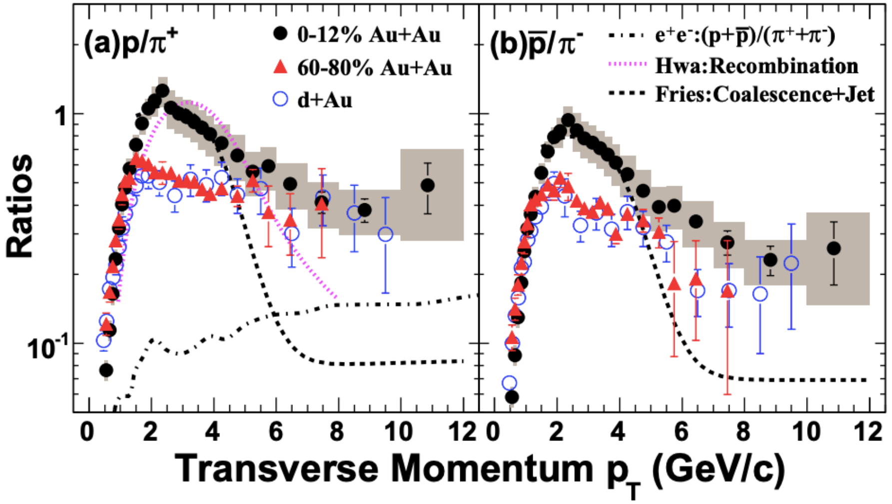
STAR Collaboration

Motivation



[PRL97(2006)152301]

STAR

d+Au $\sqrt{s_{NN}} = 200$ GeV

Au+Au $\sqrt{s_{NN}} = 200$ GeV

$e^{+}+e^{-}$ $\sqrt{s} = 91.2$ GeV

- Two prominent signatures of QGP:
  - **Baryon enhancement**
  - Jet quenching/Jet modification

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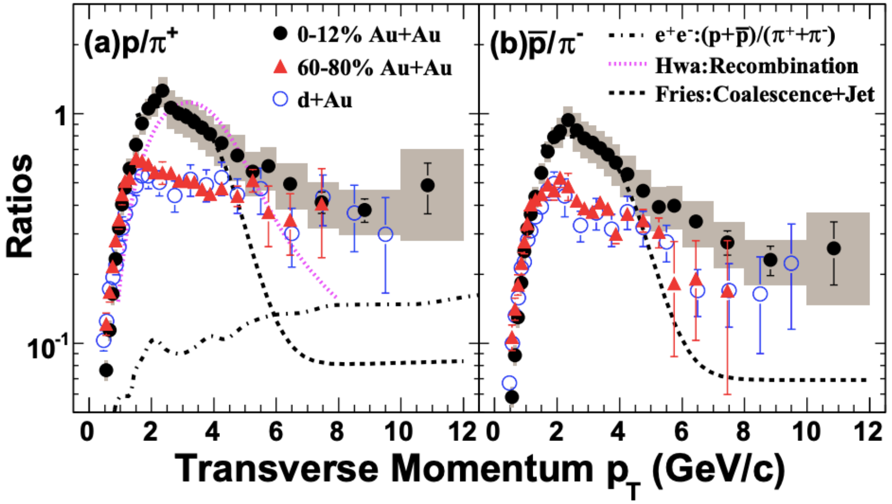

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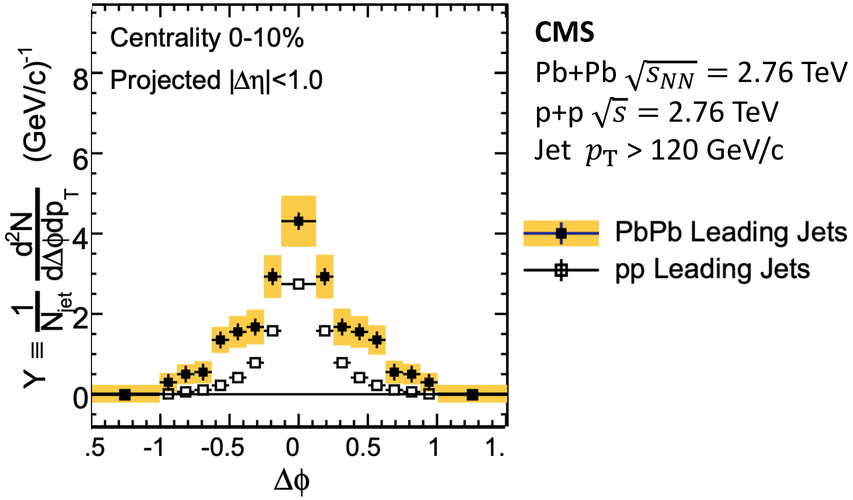

[JHEP 11 (2016) 055]

CMS
Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV
p+p $\sqrt{s} = 2.76$ TeV
Jet $p_T > 120$ GeV/c

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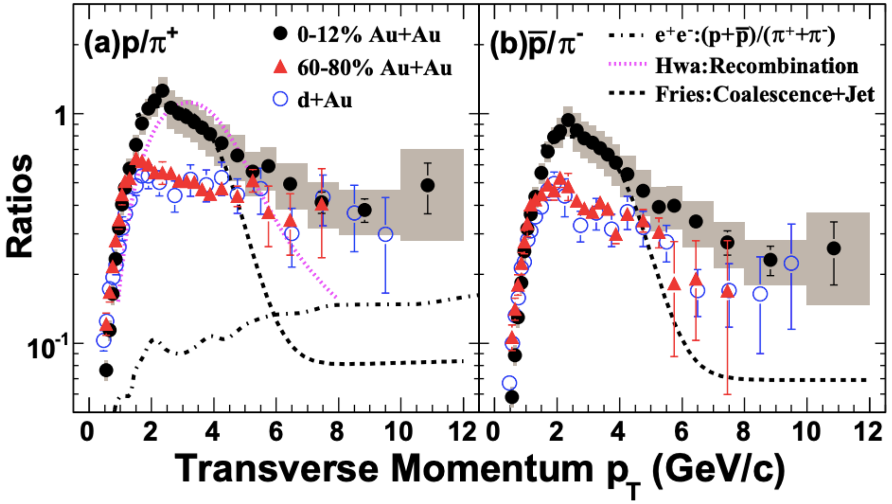

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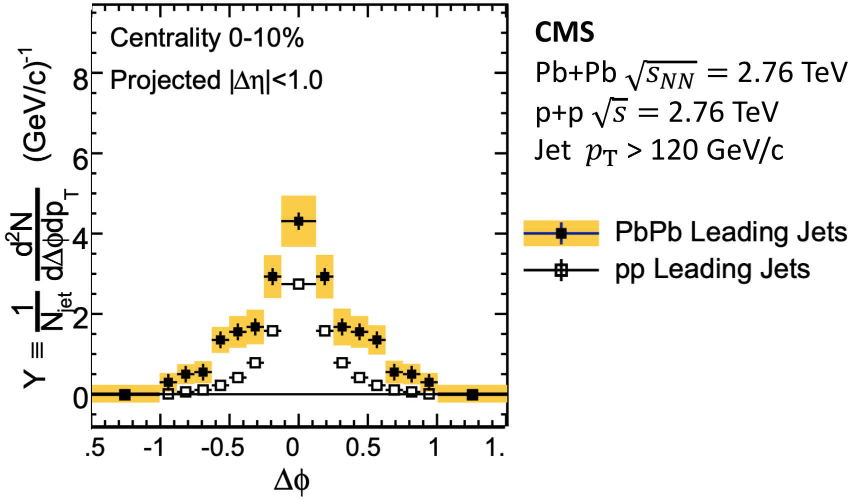

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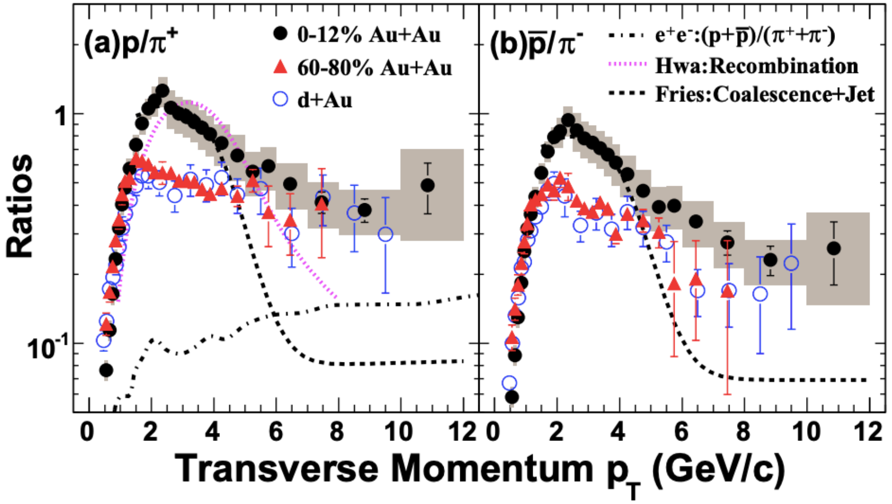

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- **Thermal-Shower Recombination**
  R.C. Hwa & C. B. Yang [PRC(2004)0312271]

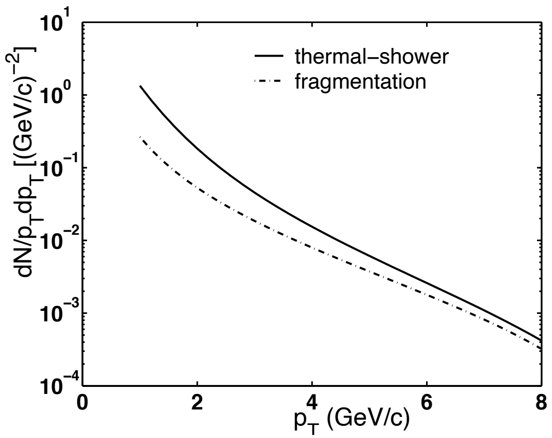
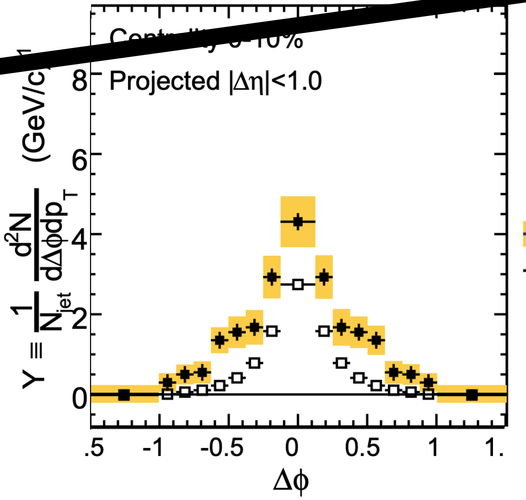


FIG. 4: Distributions of π^{+} in p_T arising from thermal-shower recombination (solid line) and shower-shower recombination, i.e. fragmentation (dash-dot line).



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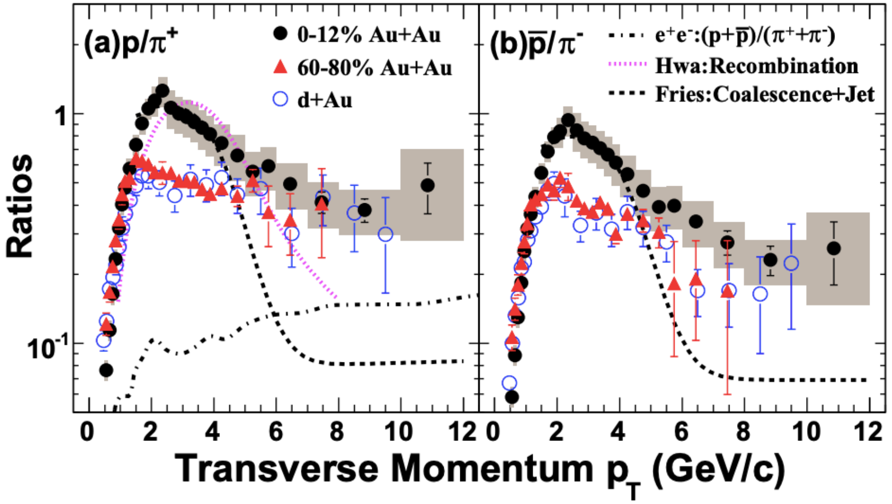
PbPb Leading Jets
pp Leading Jets

Motivation



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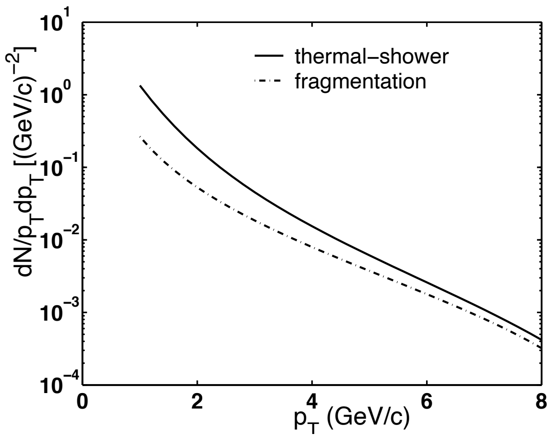
- **AMPT simulations: p/π is modified for jets in QGP**
  A. Luo et al. [PLB(2022)137638]



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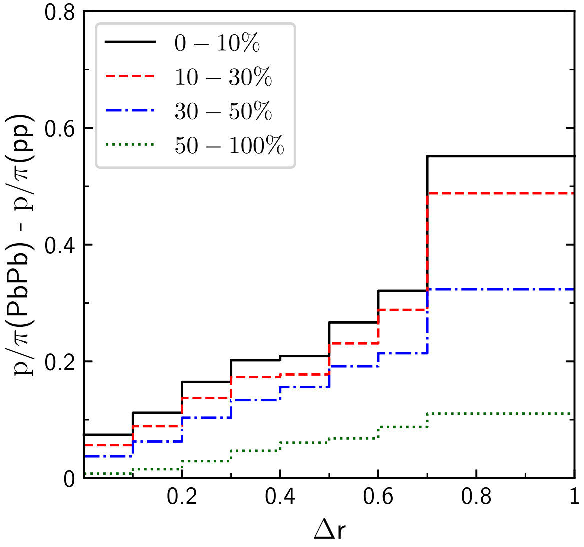
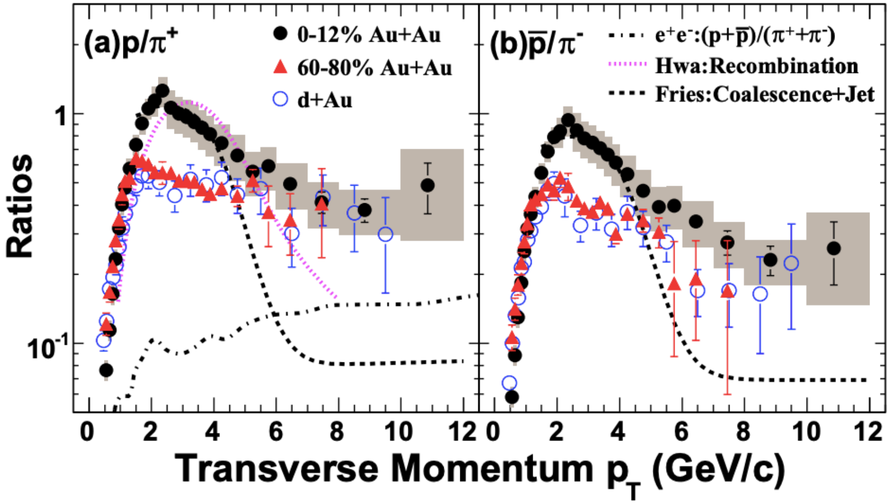


AMPT
Pb+Pb
p+p
$\sqrt{s_{NN}}$ = 5.02 TeV

Motivation



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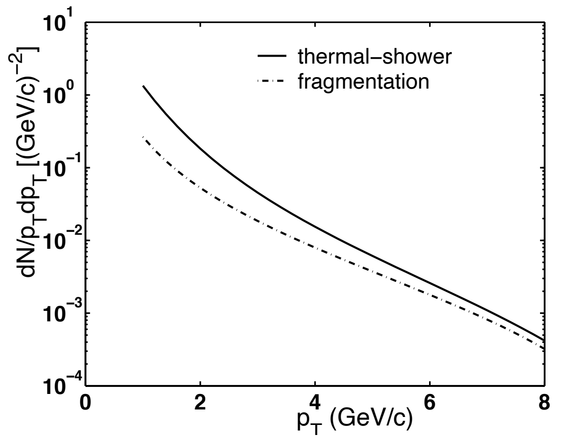

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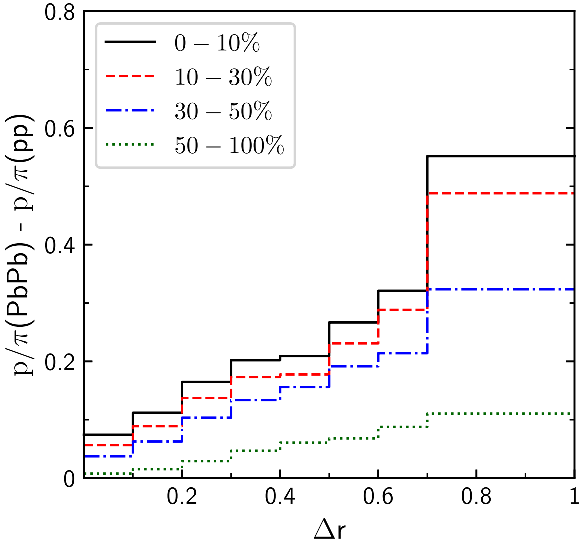

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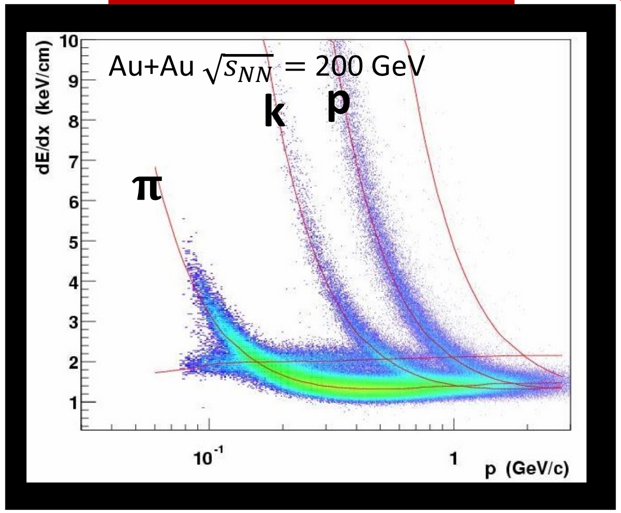
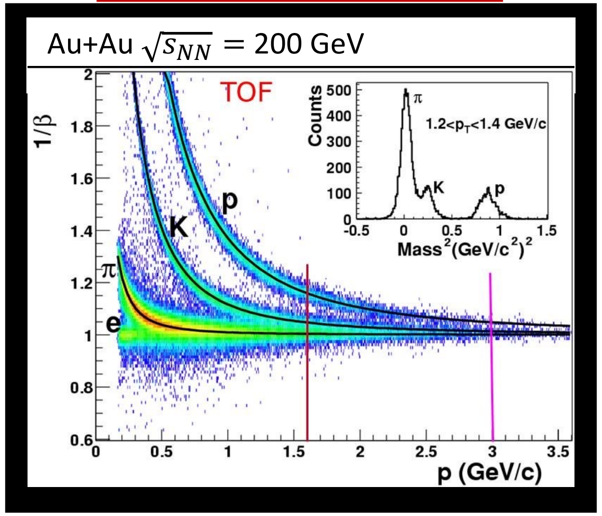
- **We measure p/π in jets using jet-hadron correlations**

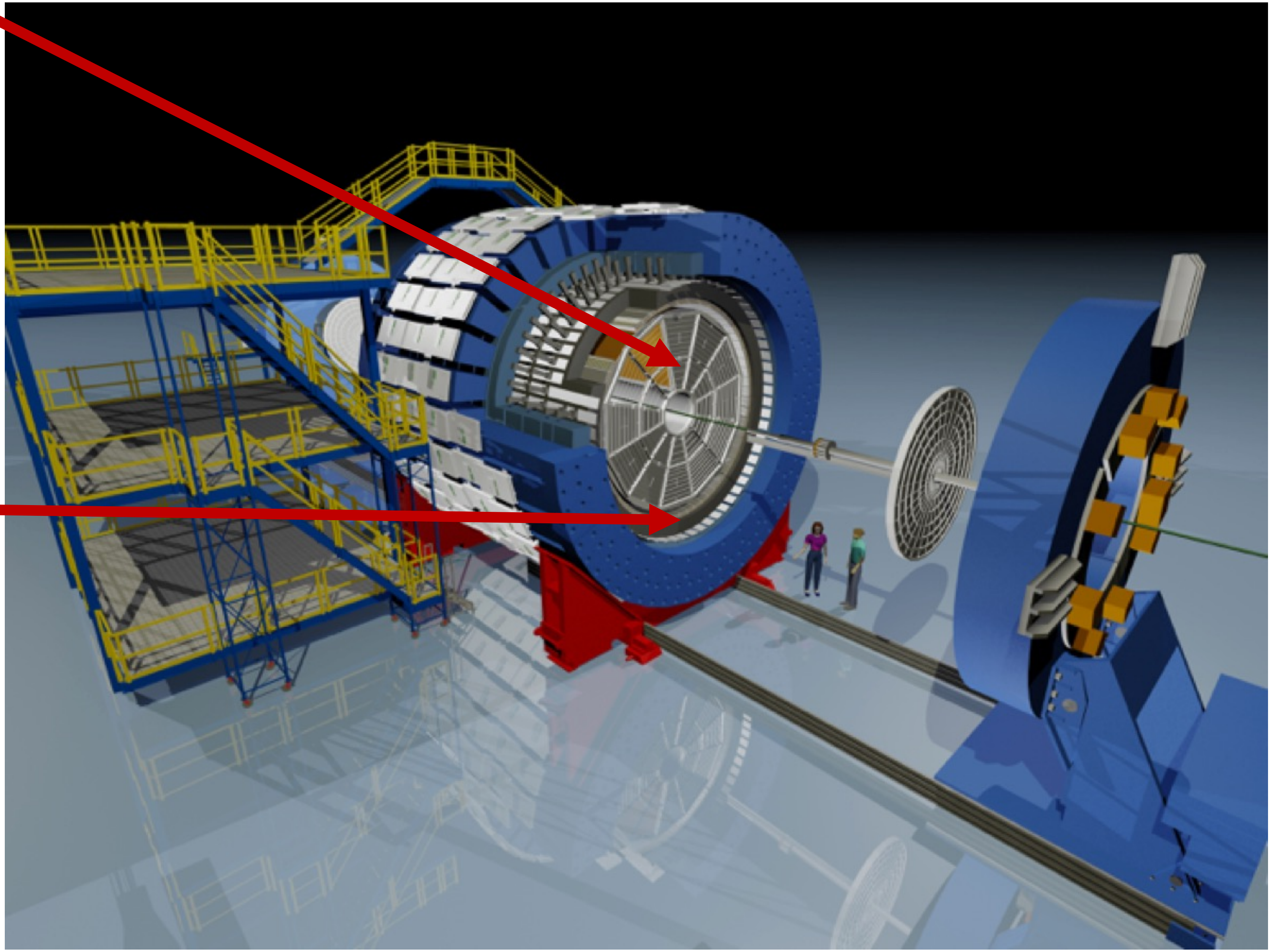
STAR Detector

dE/dx from TPC



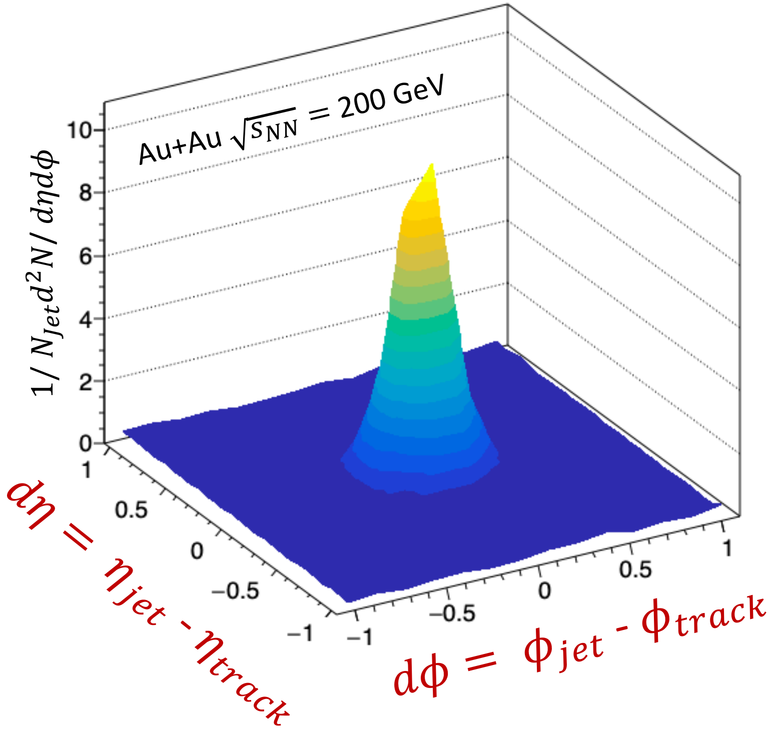
β from ToF



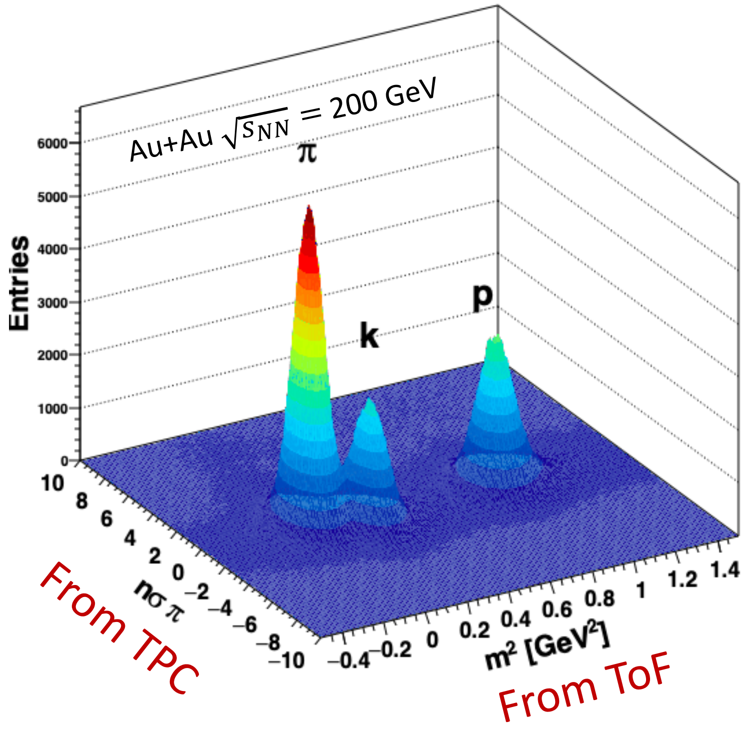


Measurement Technique

2D jet-track correlation



Particle Identification



Fully reconstructed jets with tracks identified by **Time of Flight (ToF)** and **Time Projection Chamber (TPC)** information

=> **Particle Identification in jets**

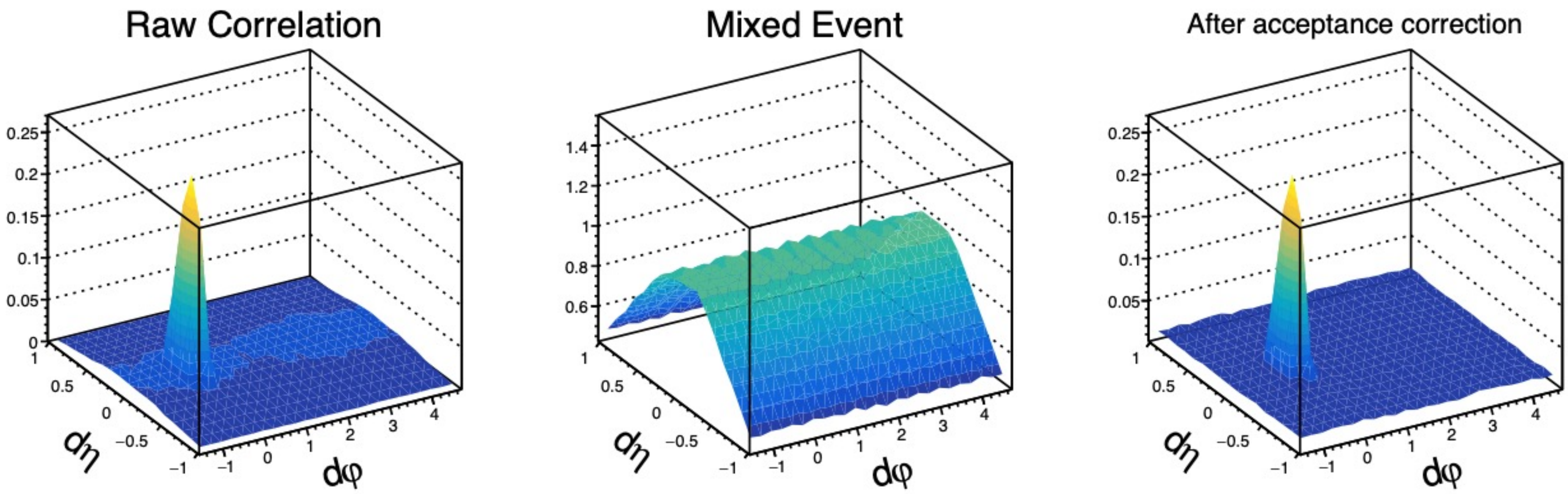
Data Samples

- *p+p* collisions at $\sqrt{s} = 200$ GeV (2015)
- 0-10% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, (2014)

Jet Reconstruction

- **Anti-k_T**
- Jet R = 0.2, 0.3, 0.4
- $p_T^{cons} > 2.0$ GeV/*c*
- Jet $p_T^{raw} > 9$ GeV/*c*
- $|\eta_{jet}| < 1.0 - R$

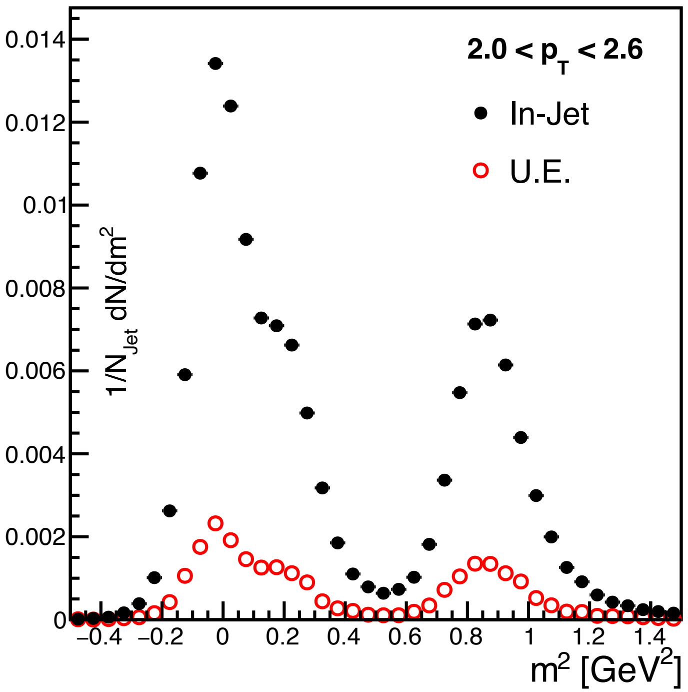
Jet-Track Correlation



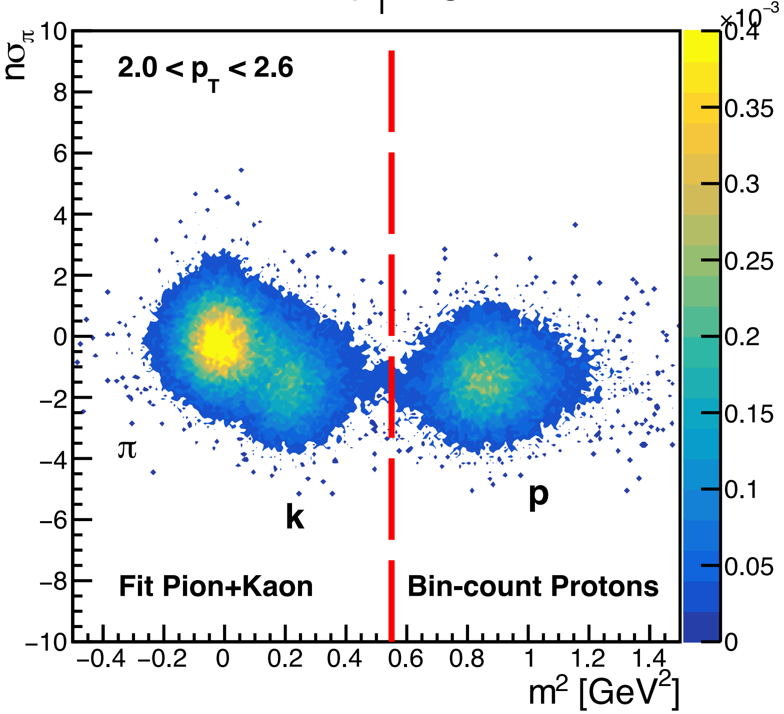
- Run Anti-k_{T} algorithm to identify Jet Axis
- Perform correlations with all tracks within $|\eta_{\mathrm{track}}| < 0.5$
- Build Mixed event for pair acceptance correction
- Divide signal correlation by mixed event
- Select regions of equal area for jet and underlying event for every $\mathrm{p_T}$ bin from 2.0 GeV/c to 5.0 GeV/c

Particle Identification

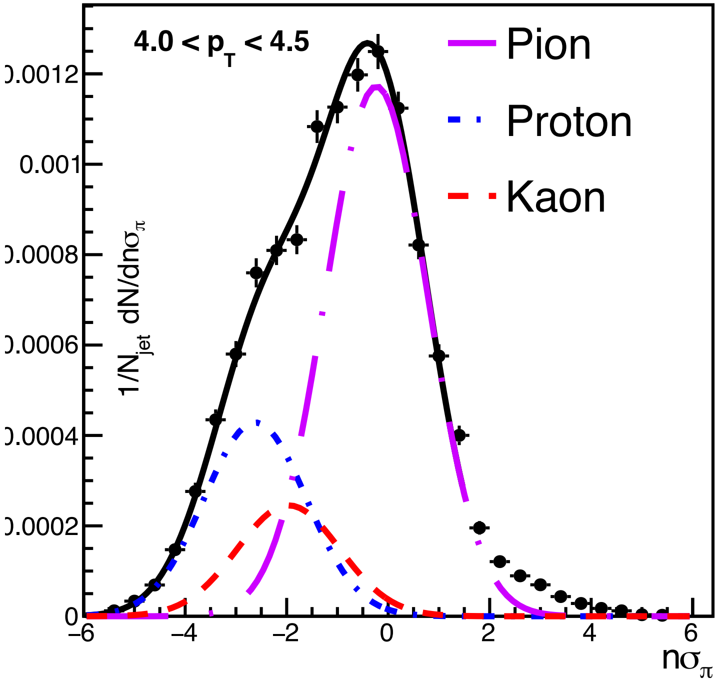
Underlying Event Subtraction



Low p_T regime

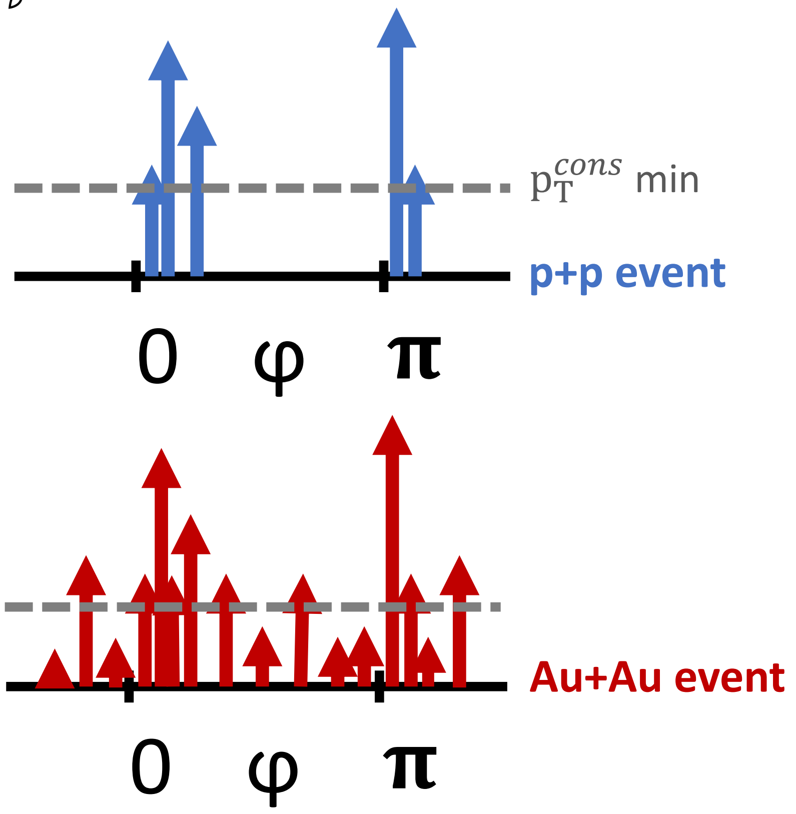


High p_T regime



- Subtract UE from Jet in dφ, dη, $n\boldsymbol{\sigma}_{\boldsymbol{\pi}}$, and m^2
- Identify Pion, Proton, Kaon yields from remaining Jet Signal
- Low $\mathrm{p_T}$ regime: $\mathrm{p_T}$ < 3.0 GeV/c → bin-count protons
- High $\mathrm{p_T}$ regime: $\mathrm{p_T}$ > 3.0 GeV/c → triple Gaussian fit
- Divide proton yield by pion yield to measure ratio

Correlated Background Removal



The Challenge:

Jet selection threshold coupled with upward fluctuation in underlying event causes the jetfinder algorithm to pick up background tracks at a higher rate

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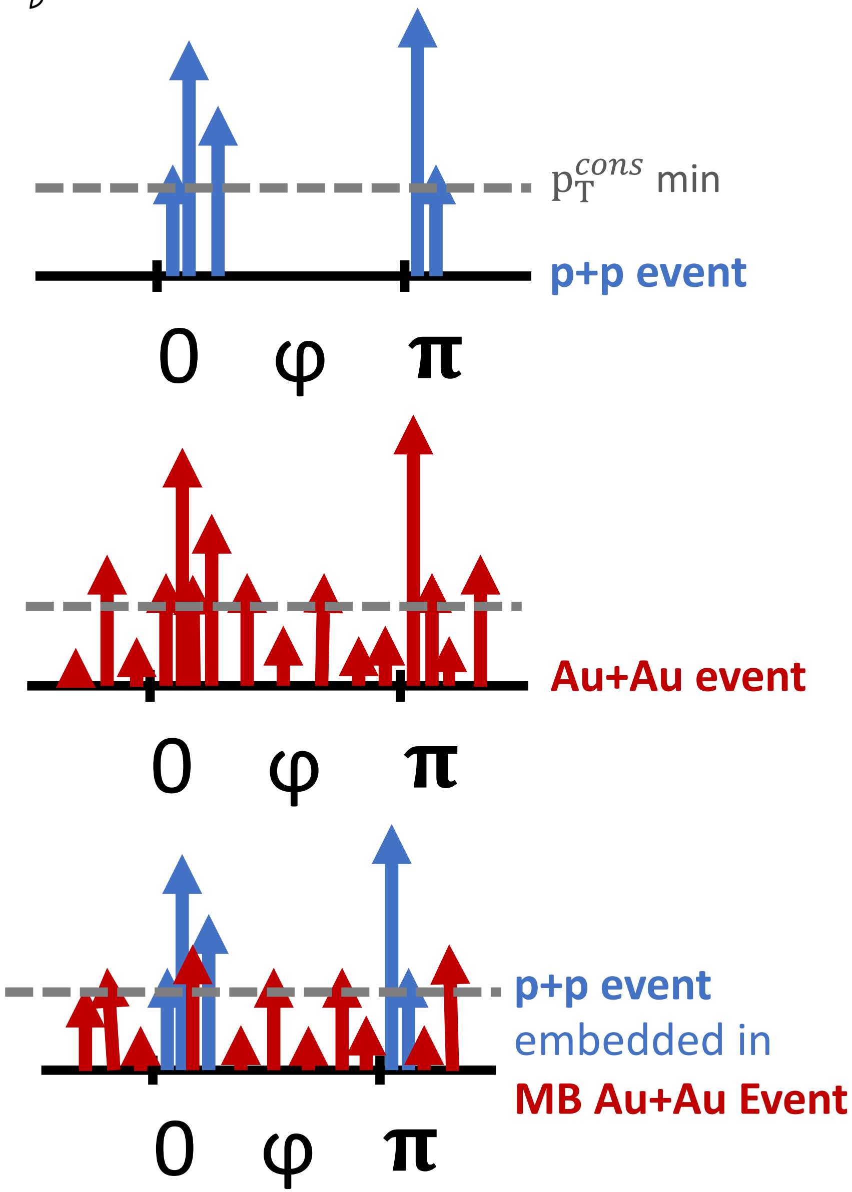

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The Solution:

Pseudo-embedding: take *p+p* jets down to low p_T → overlay with mixed constituent Au+Au event → run jet finder → match to original *p+p* jet → construct jet+track correlations with Au+Au event and perform uncorrelated UE subtraction

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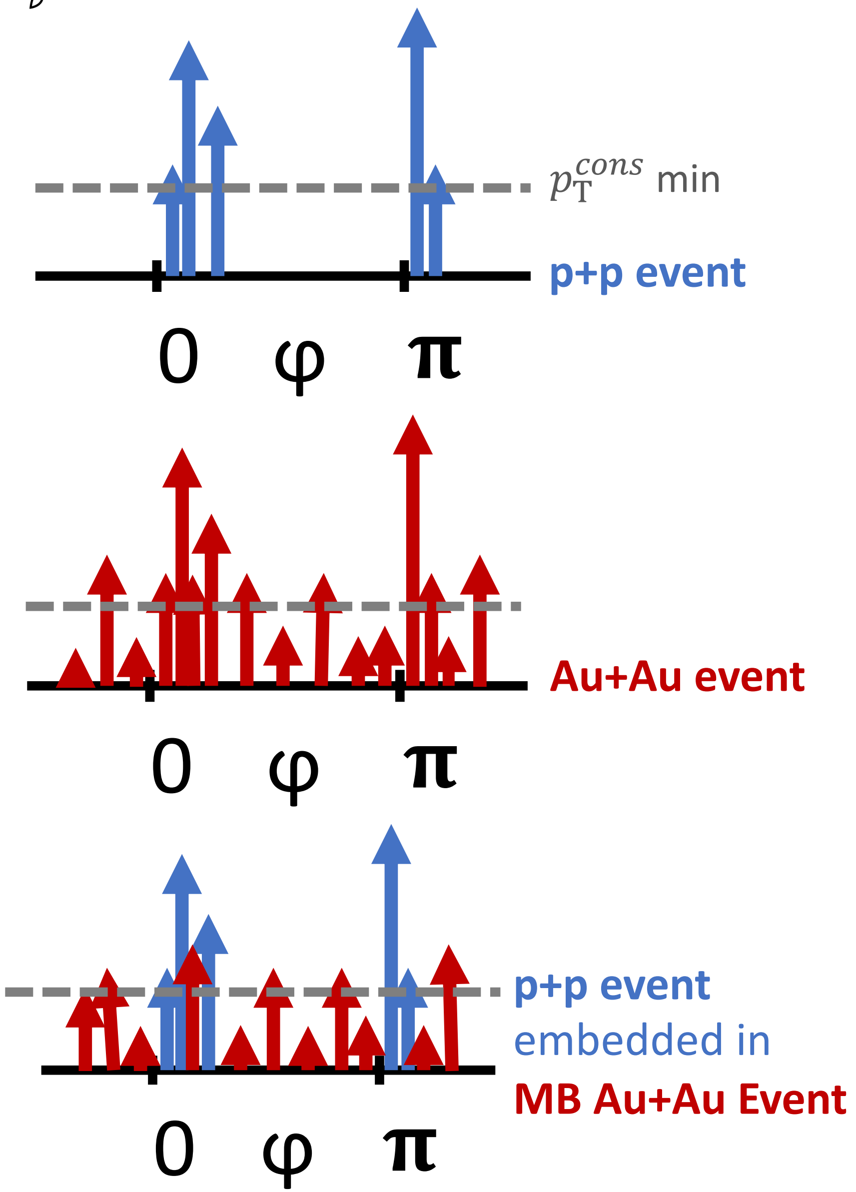

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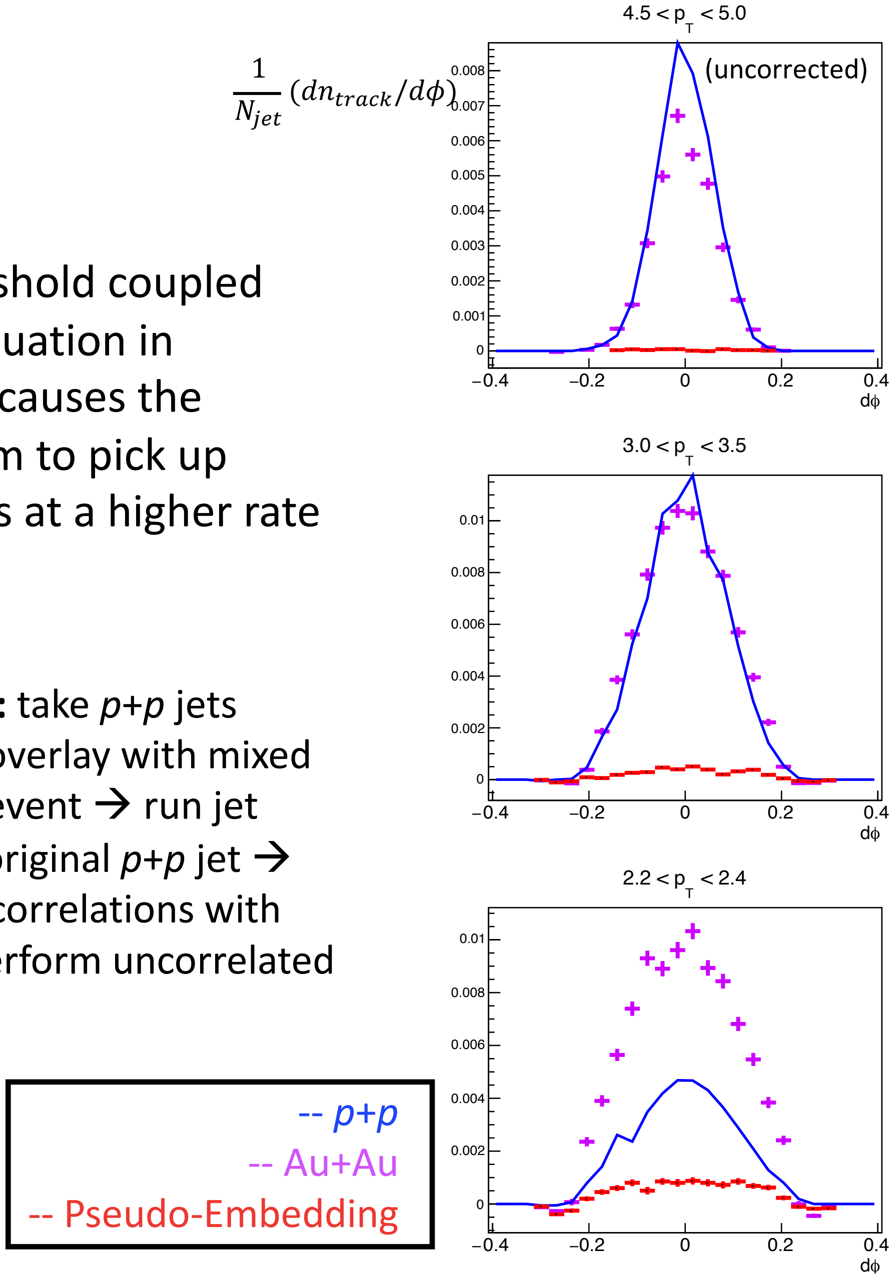
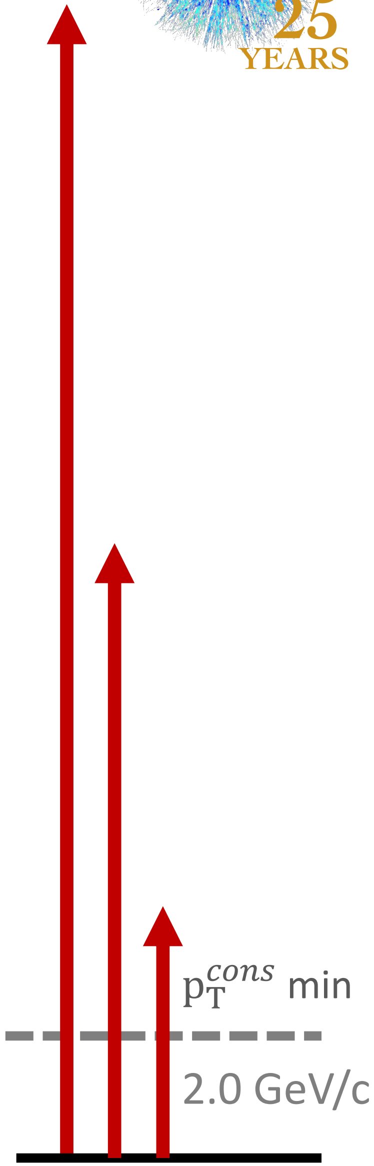
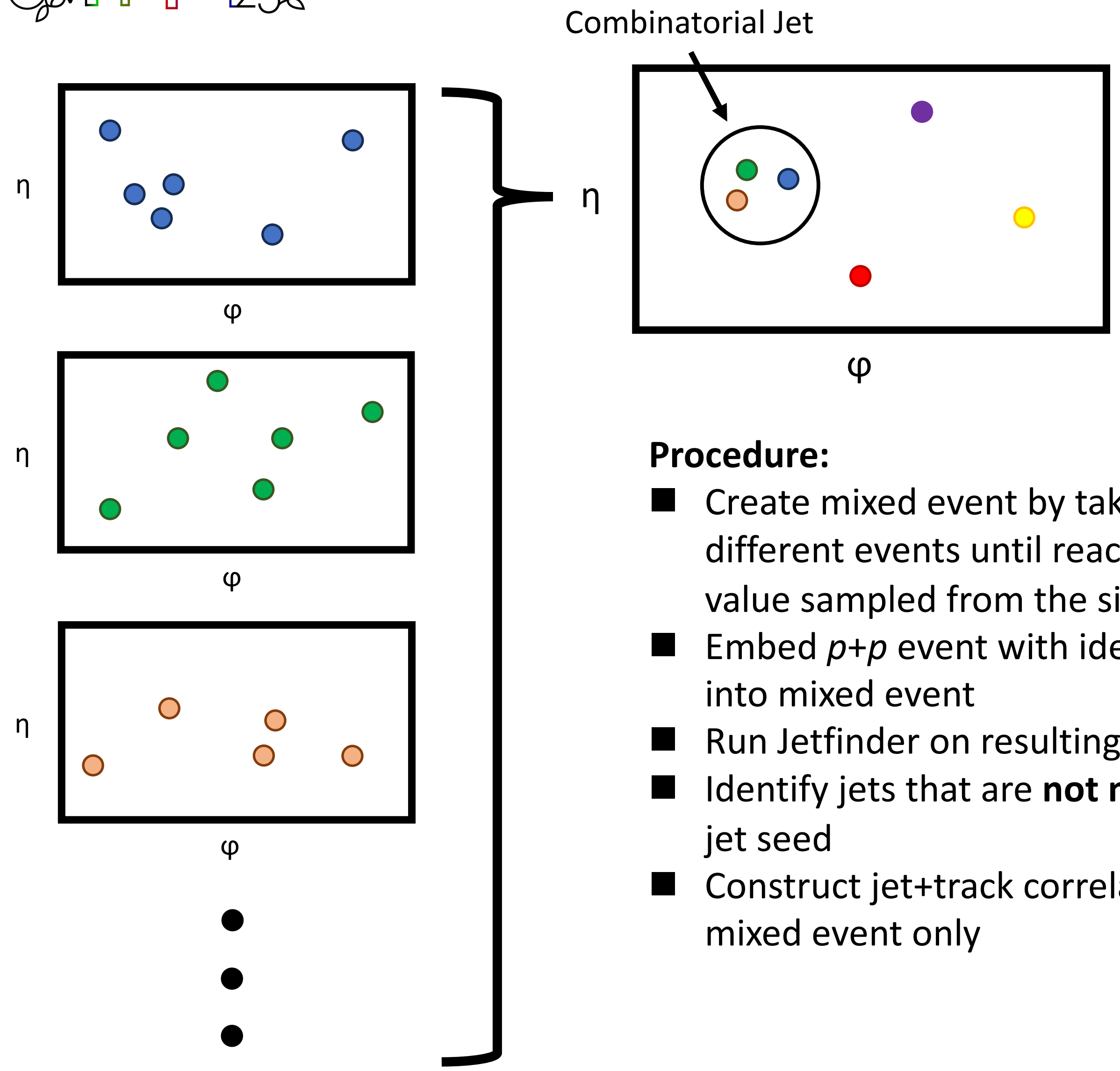




Evaluating Contribution from Combinatorial Jets

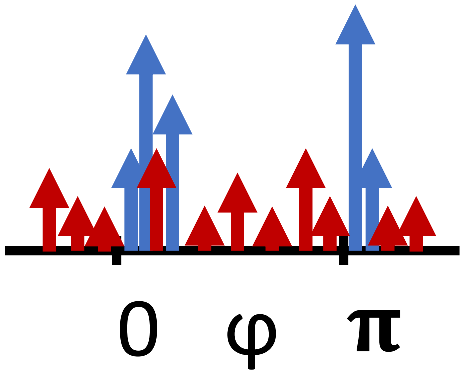


Procedure:

- Create mixed event by taking one track from different events until reaching an n_{track} value sampled from the signal distribution
- Embed *p*+*p* event with identified jet seed into mixed event
- Run Jetfinder on resulting combined event
- Identify jets that are **not matched** to a *p*+*p* jet seed
- Construct jet+track correlations with Au+Au mixed event only

Correlated Background Removal: Embed into Mixed Constituent Event

p+p event
embedded in
Au+Au Mixed Event



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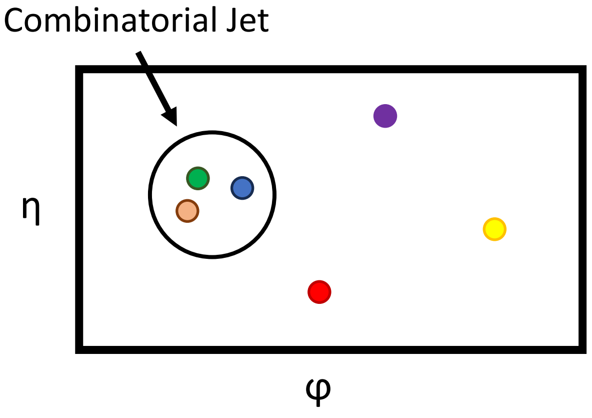


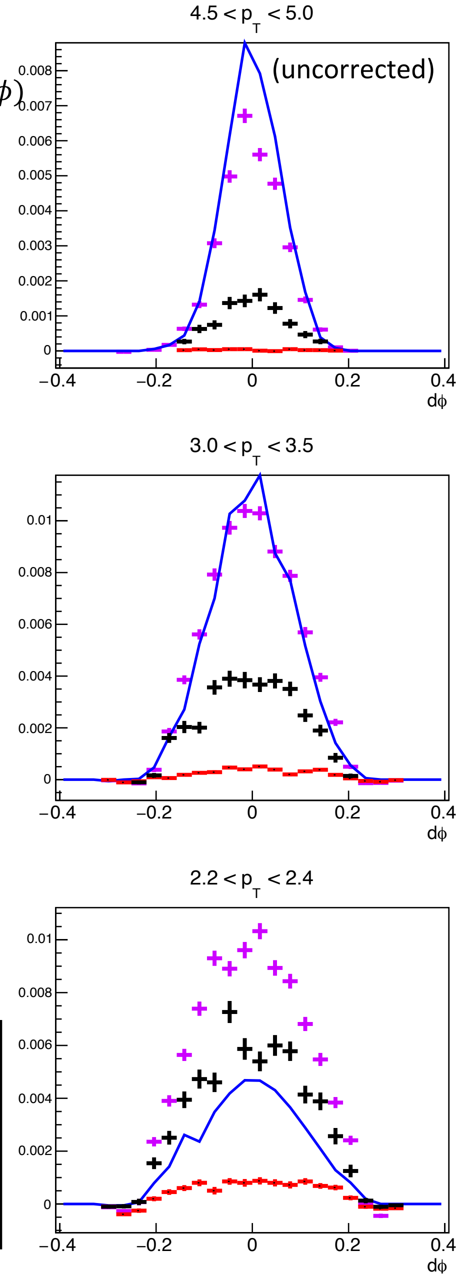
Procedure:

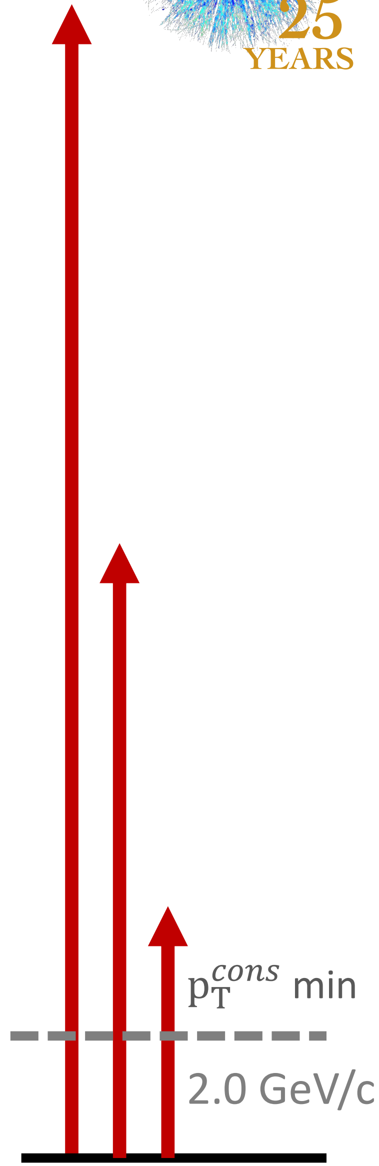
- Run Jetfinder on *p+p* event
- Create Mixed event by taking one track from different events until a reasonable nTrack value is reached
- Combine *p+p* event (with jet) and Mixed Event
- Run Jetfinder on resulting mixed event
- Perform correlations with mixed event

Pseudo-embedding → Matched Jets
Combinatorials → Unmatched jets

Fake Rate Determination:

- Fake Rate = $\frac{n_{\text{jet}}^{\text{combi}}/n_{\text{event}}^{\text{combi}}}{n_{\text{jet}}^{\text{signal}}/n_{\text{event}}^{\text{signal}}}$
- Scale per-jet combinatorial yields by Fake Rate
- Scale per-jet fluctuation yields by (1-Fake Rate)
- Subtract correlated background from jet signal



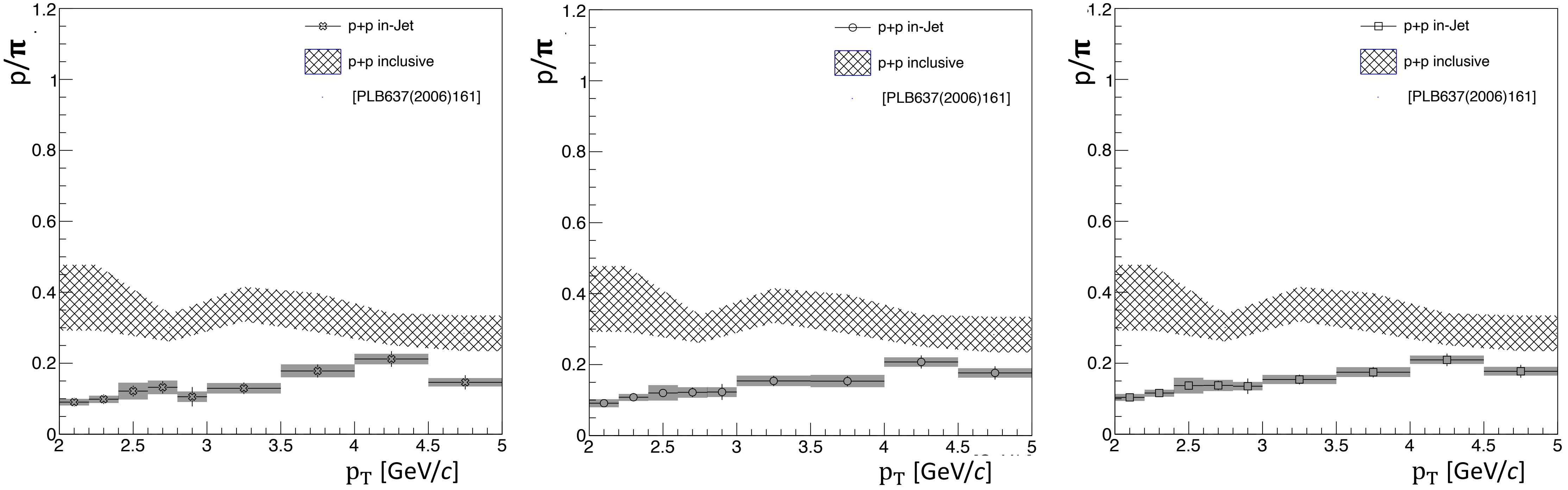


p/π Ratios In-Jet vs Inclusive Hadron

R = 0.2, Jet p_T^{raw} > 9 GeV/c, p_T^{cons} > 2 GeV/c

R = 0.3, Jet p_T^{raw} > 9 GeV/c , p_T^{cons} > 2 GeV/c

R = 0.4, Jet p_T^{raw} > 9 GeV/c , p_T^{cons} > 2 GeV/c



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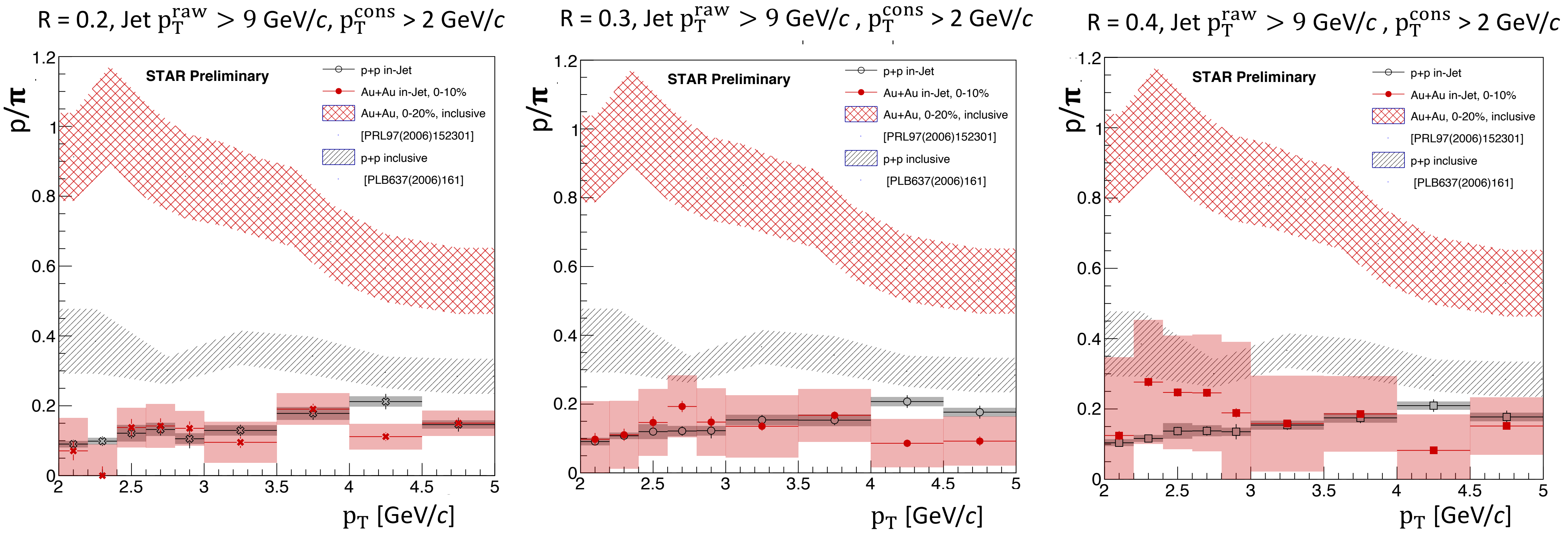
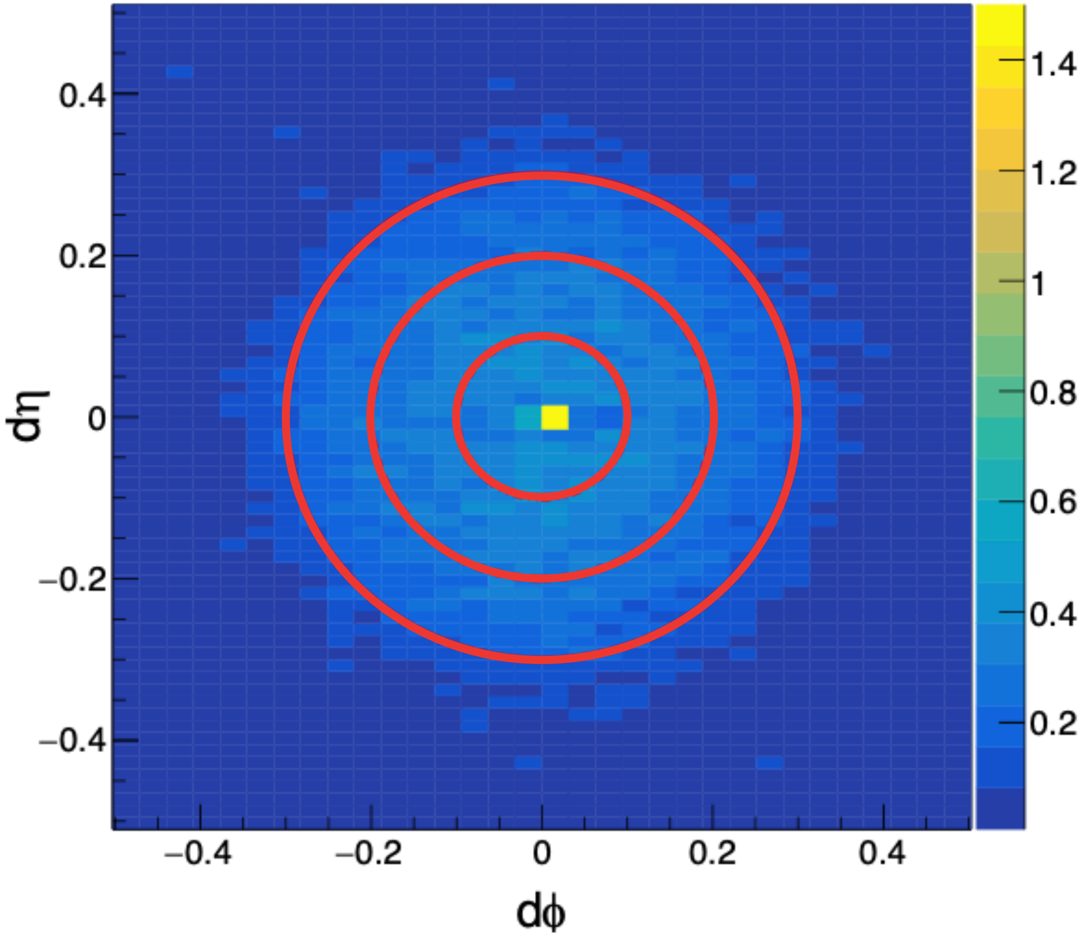


- In *p+p* collisions, the in-jet p/**π** sits below p/**π** from inclusive hadrons, with no dependence on jet R
- For every jet R studied, in-jet p/**π** measured in central **Au+Au** are consistent with those from *p+p*, with no evidence for enhancement between the two systems

Yields as a Function of Δr

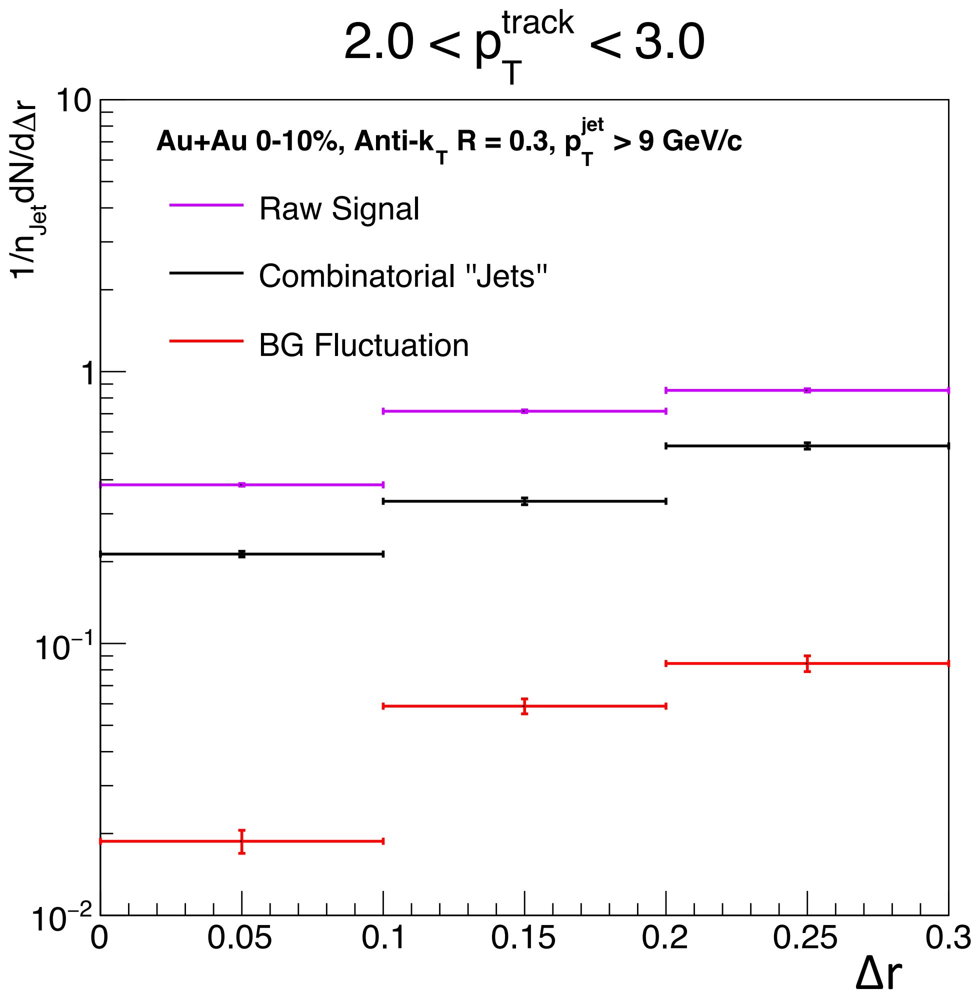
$2.0 < p_T^{track} < 3.0$ GeV/c



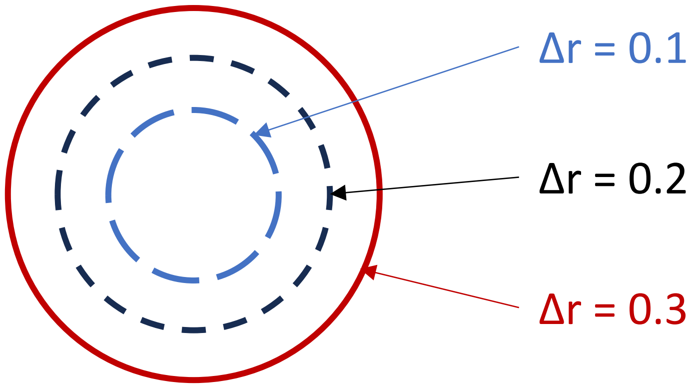
$$\Delta r = \sqrt{(\eta_{jet} - \eta_{track})^2 + (\varphi_{jet} - \varphi_{track})^2}$$

- All previous results are integrated using Δr = R
- Fixed Anti-k_T R = 0.3, integrate yields for Δr = 0.1, 0.2, 0.3
- $2.0 < p_T^{track} < 3.0$ Gev/c is chosen for clean PID

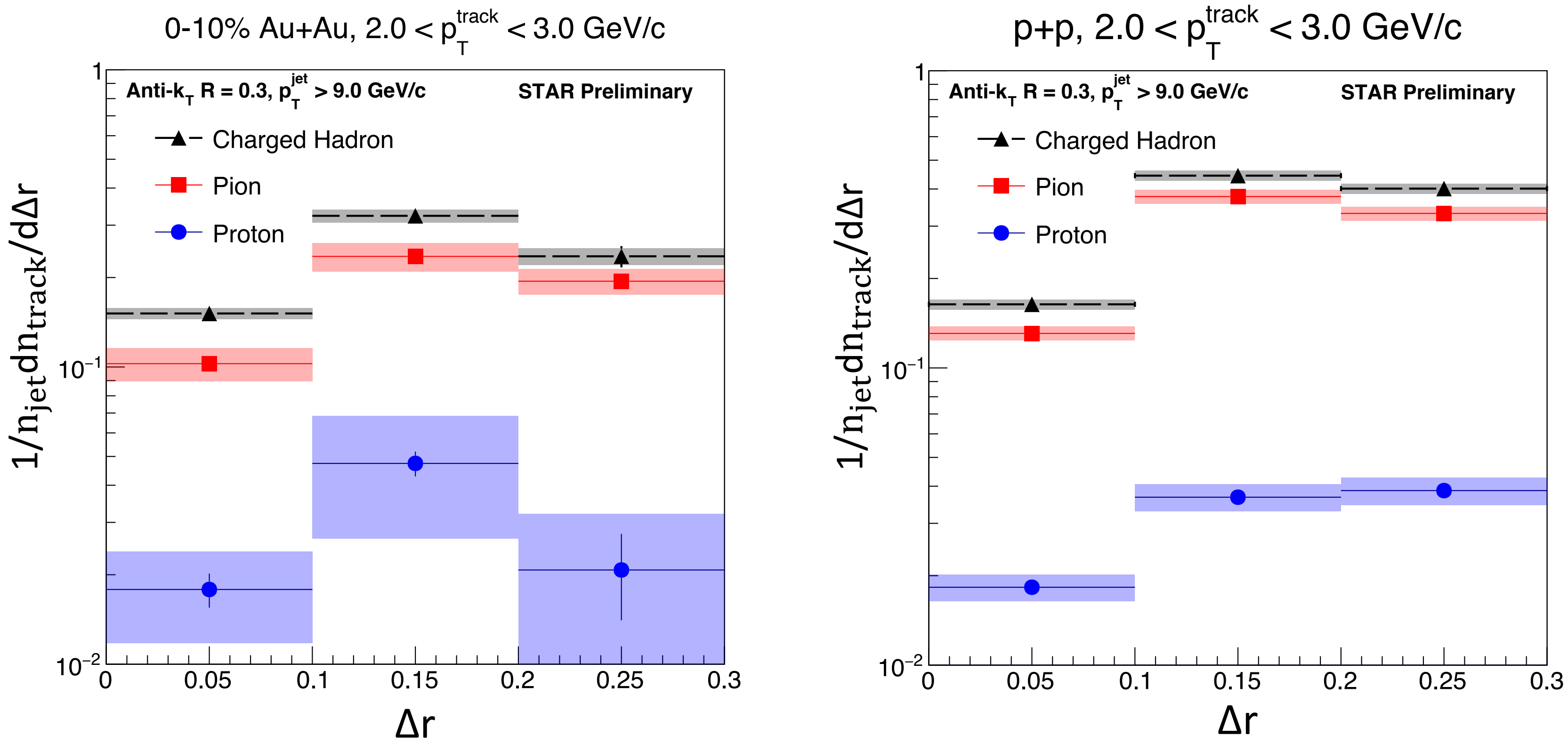
Correlated Background Correction in Δr



- Subtract inner from outer radii to measure yield as a function of Δr
- The same procedure is followed for combinatorial "jets" and BG fluctuation contamination

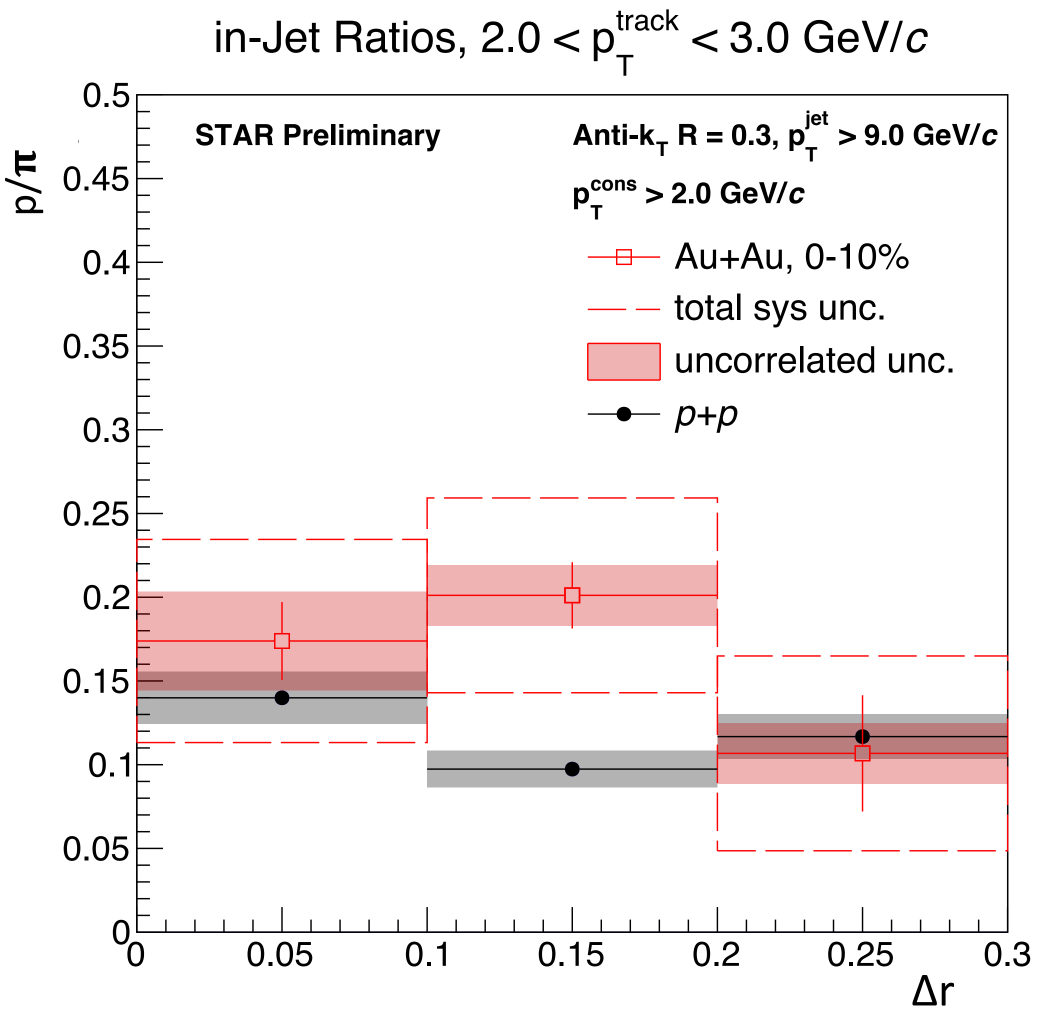


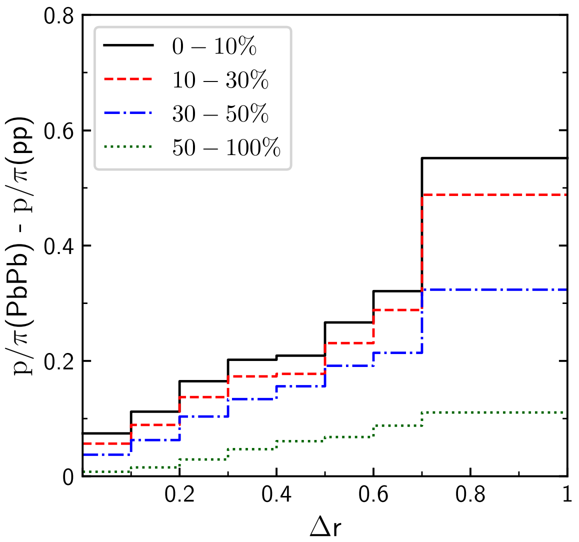
Identified Yields as a Function of Δr



- Per-Jet Identified hadron yields are shown as function of Δr for jets with R = 0.3 in *p+p* and 0-10% central Au+Au collisions at 200 GeV

p/π Δr Dependence

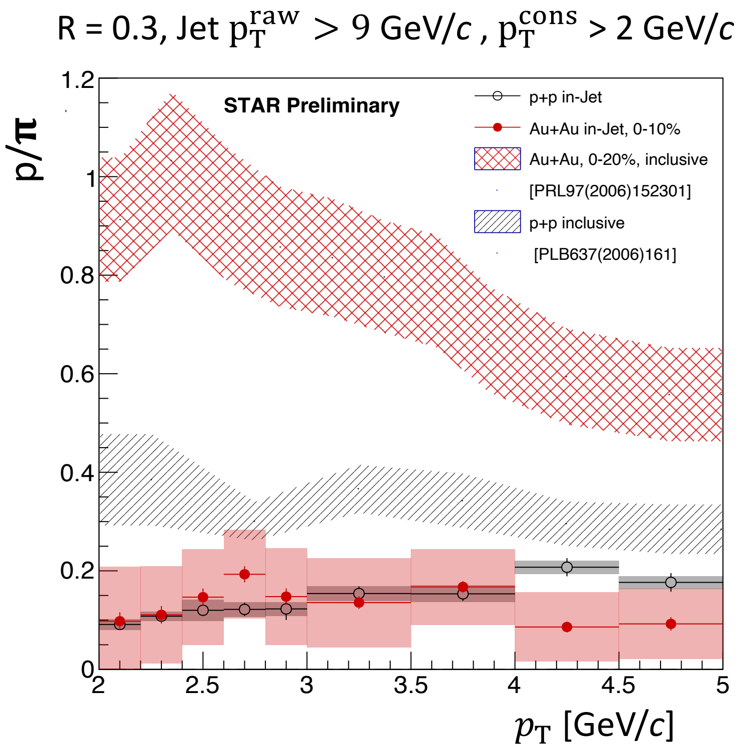


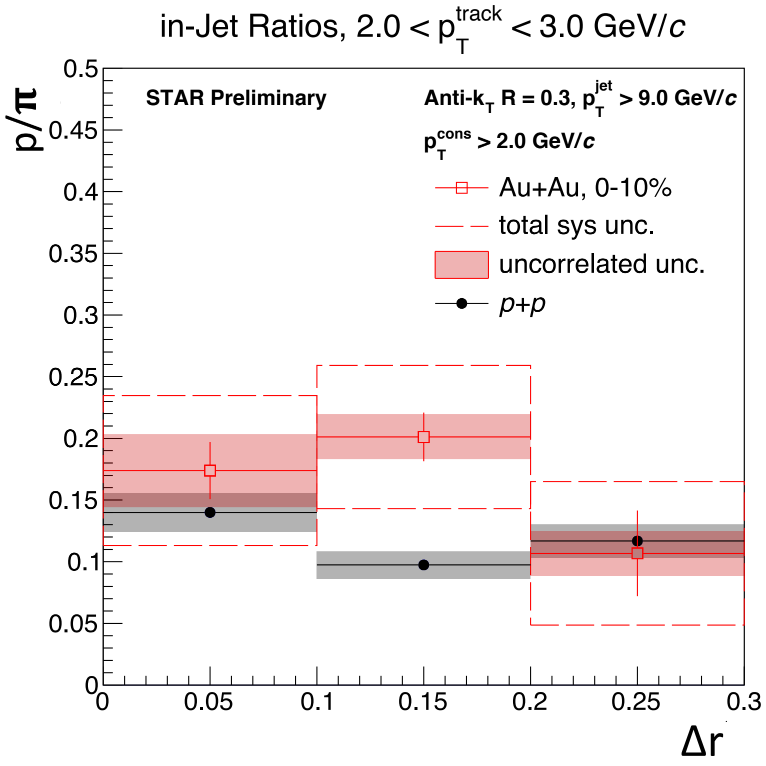


AMPT, Pb+Pb
$\sqrt{s_{NN}}$ = 5.02 TeV
p_T^{track}< 6.0 GeV/c

- In our selected kinematic regime, **we do not observe the predicted linear trend** in the difference of the in-cone radial evolution of p/**π** between 0-10% Au+Au and *p+p* collisions at 200 GeV
- Different collision energies between our measurement and AMPT prediction

Summary

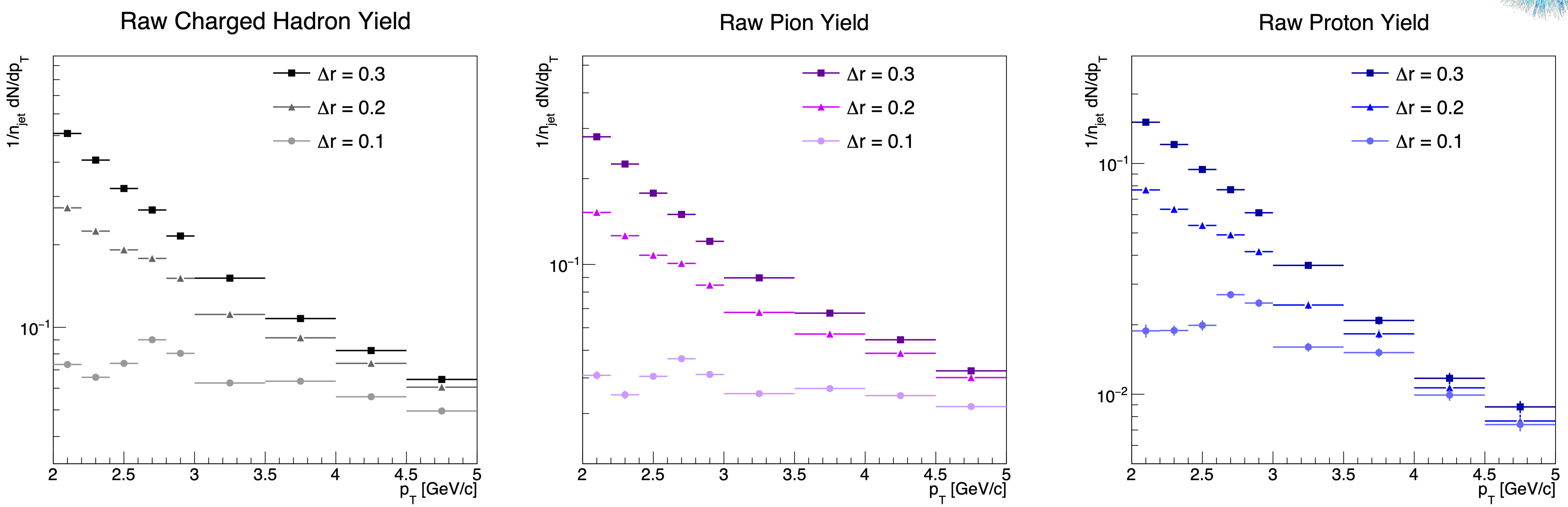




- We present the **first in-jet baryon-to-meson ratio measurement from STAR**, with both Jet R and Δr dependence
- For every jet R studied, with p_T^{cons} > 2.0 GeV/c and jet p_T^{raw}> 9.0 GeV/c, in-jet p/**π** measured in central Au+Au are consistent with those from *p+p*, with **no evidence for enhancement** between the two systems
- Selecting tracks with 2.0 < p_T < 3.0 GeV/c in jets with R = 0.3, **we do not observe the predicted linear trend** in the difference of the in-cone radial evolution of p/**π** between 0-10% Au+Au and *p+p* collisions at 200 GeV
- **We observe no evidence for enhancement of the in-jet p/π between central Au+Au and *p+p* collisions for our kinematic selections,** aside from a hint of deviation at Δr = 0.15

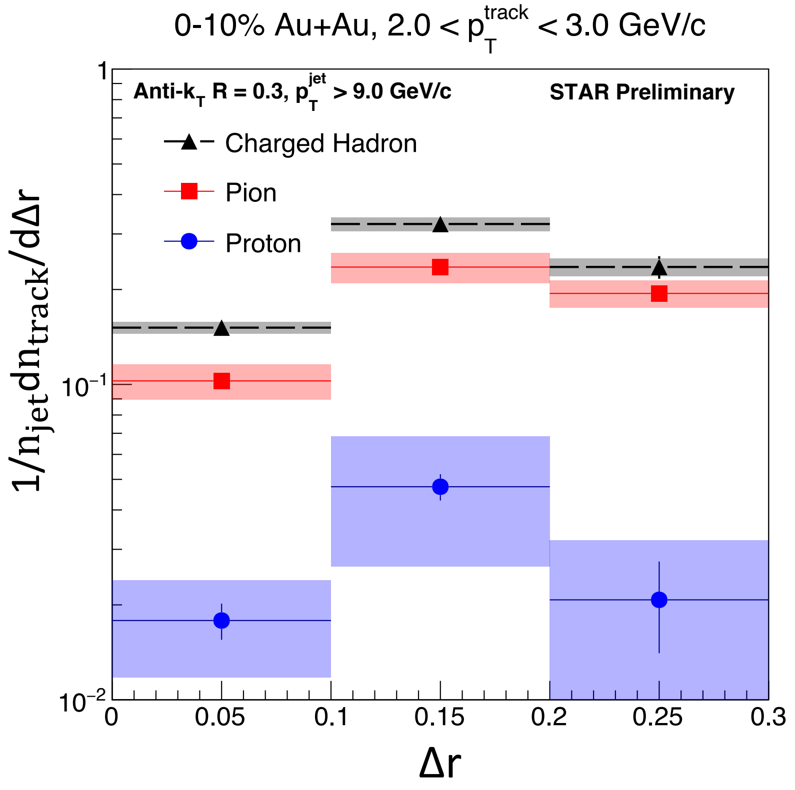
Backup

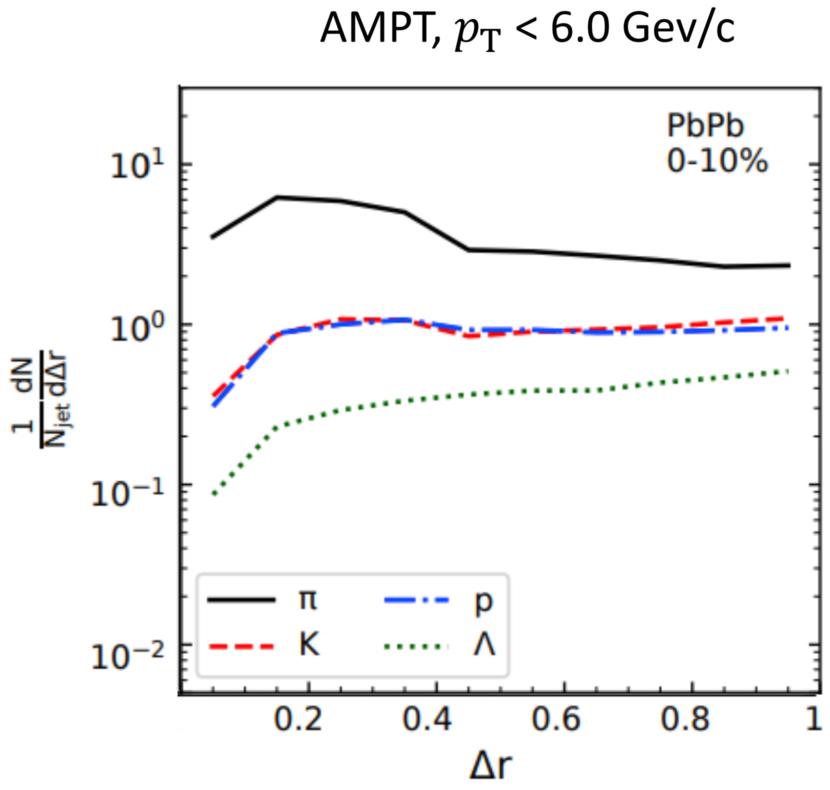
Yields as a function of ΔR



- Raw (before correlated background correction) yields for charged hadrons, identified protons and pions from jets with R = 0.3 at Δr = 0.1, 0.2, 0.3
- To isolate yield for each ring in Δr, we subtract smaller Δr yields from larger Δr yields

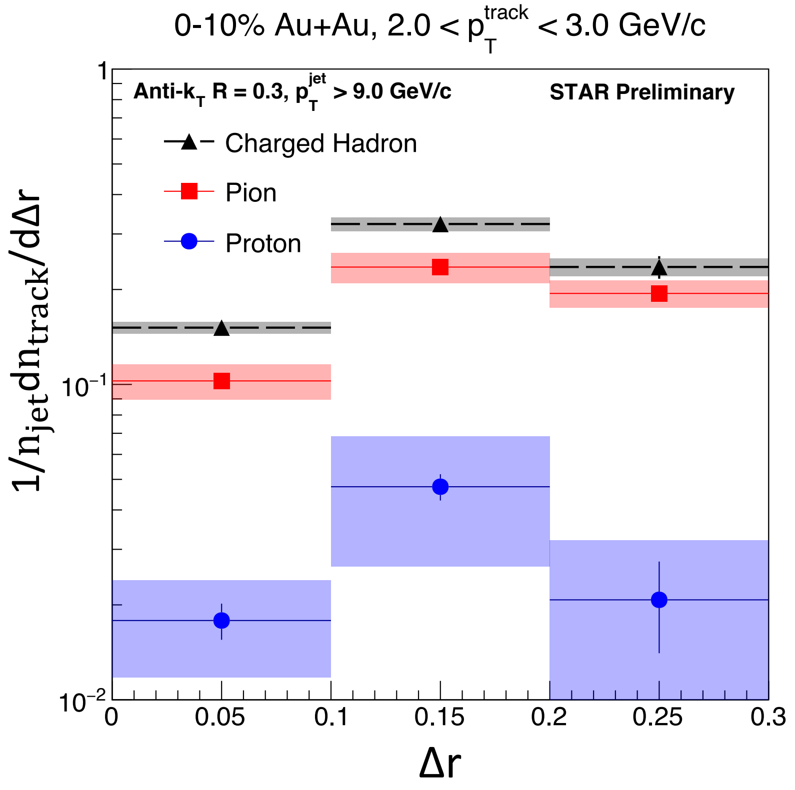
Identified Yields as a function of Δr

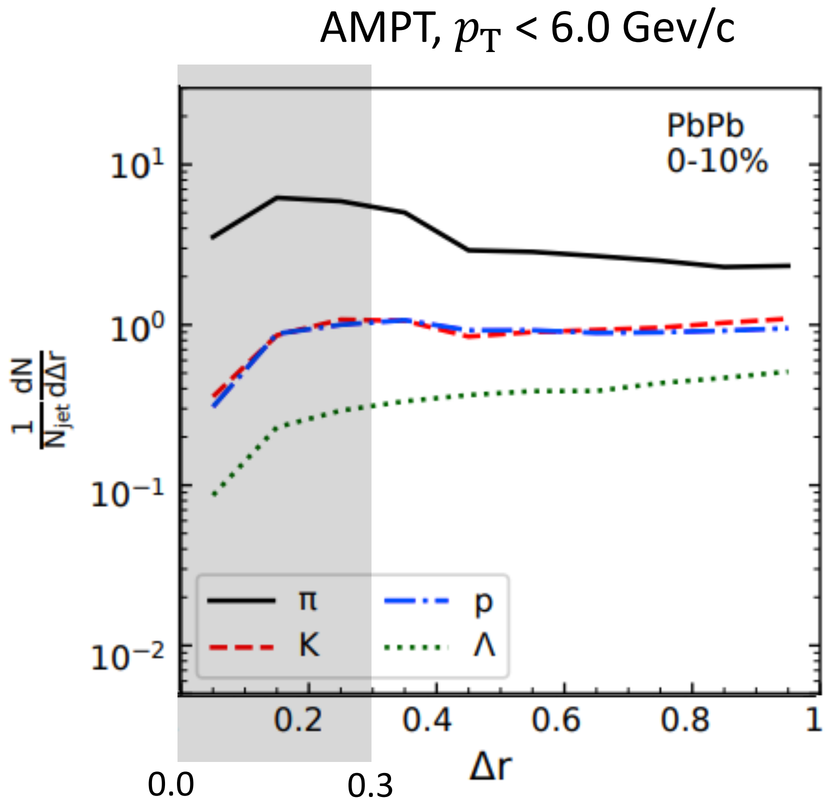




- Per-Jet Identified hadron yields are shown as function of Δr for jets with R = 0.3 in 0-10% central Au+Au collisions at 200 GeV
- Total charged hadron yield is shown to provide reference for the overall radial distribution

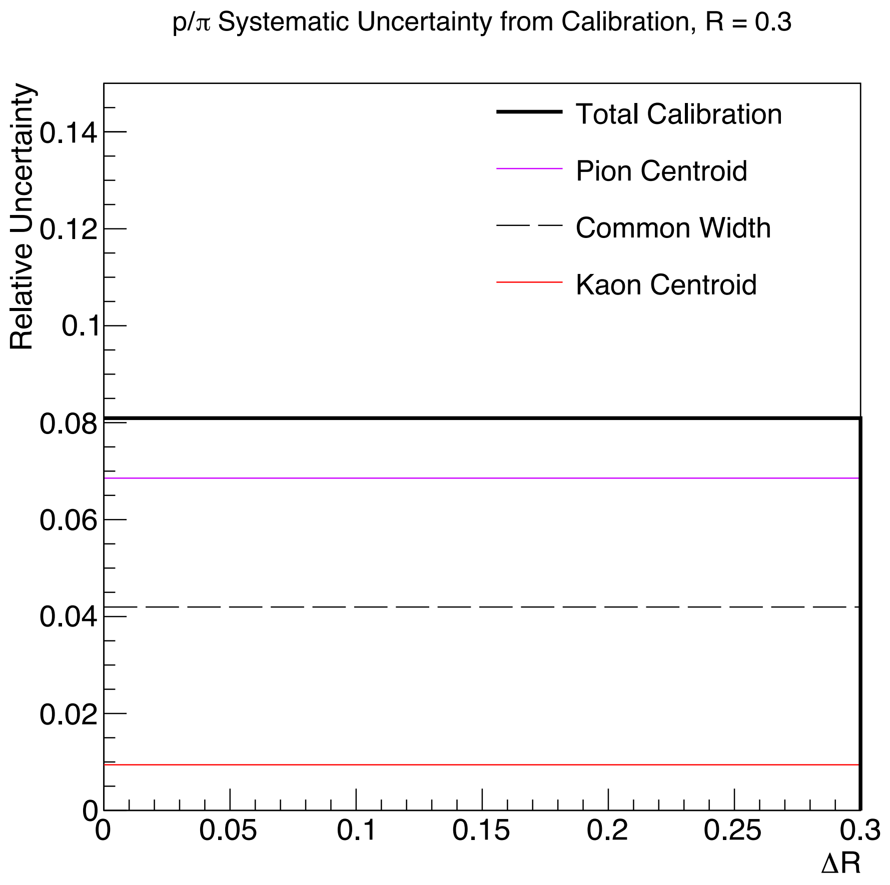
Identified Yields as a function of Δr

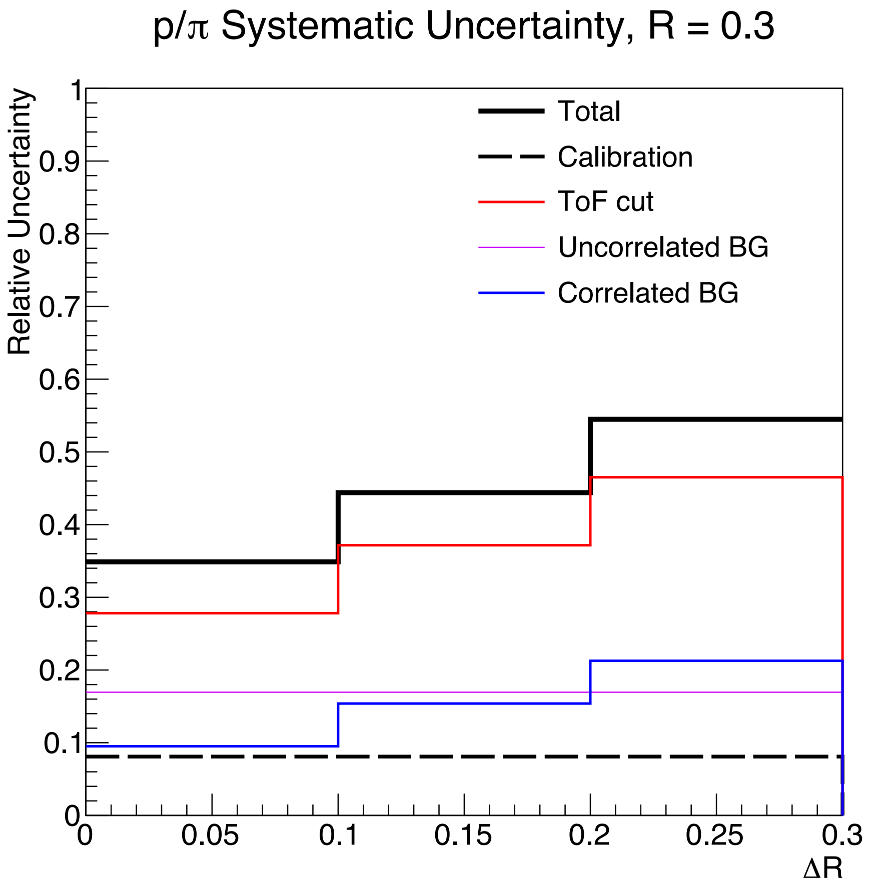




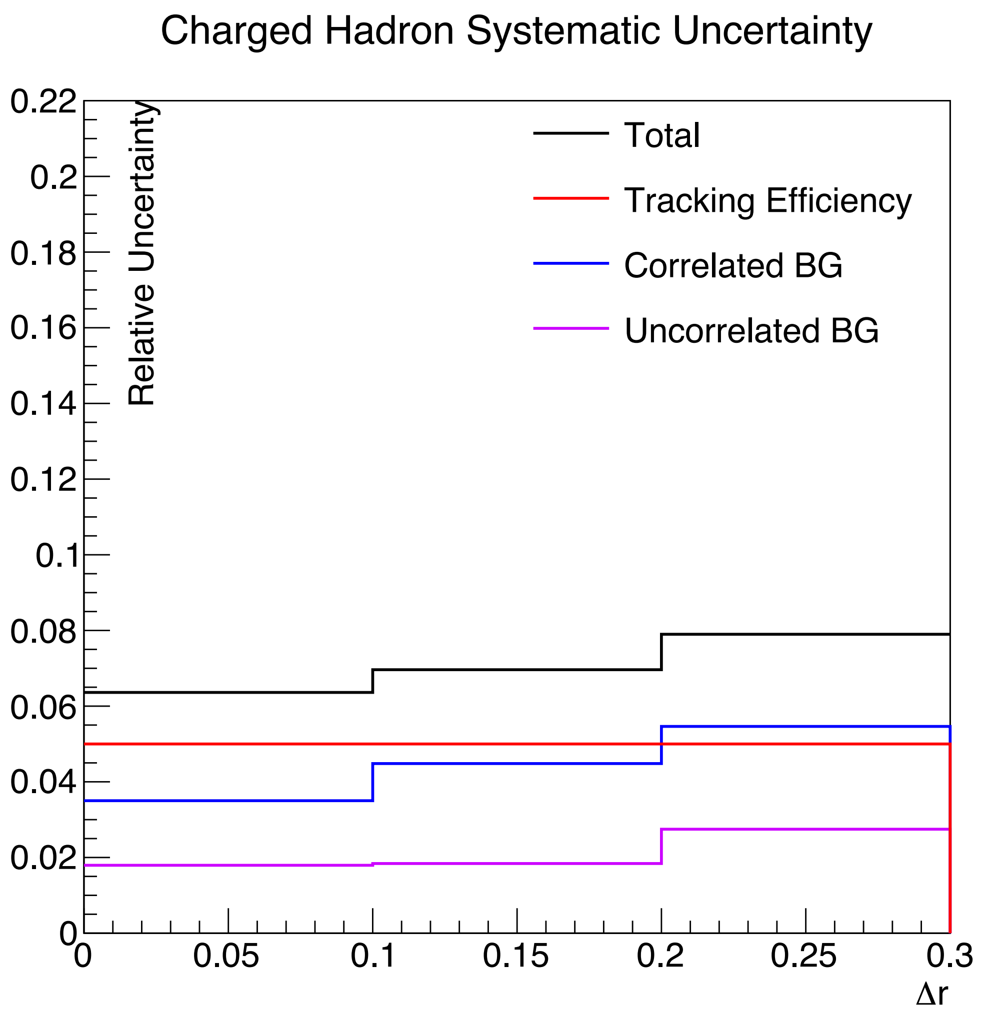
- Per-Jet Identified hadron yields are shown as function of Δr for jets with R = 0.3 in 0-10% central Au+Au collisions at 200 GeV
- Highlighted region shows our radial coverage

Au+Au p/π Δr Systematics

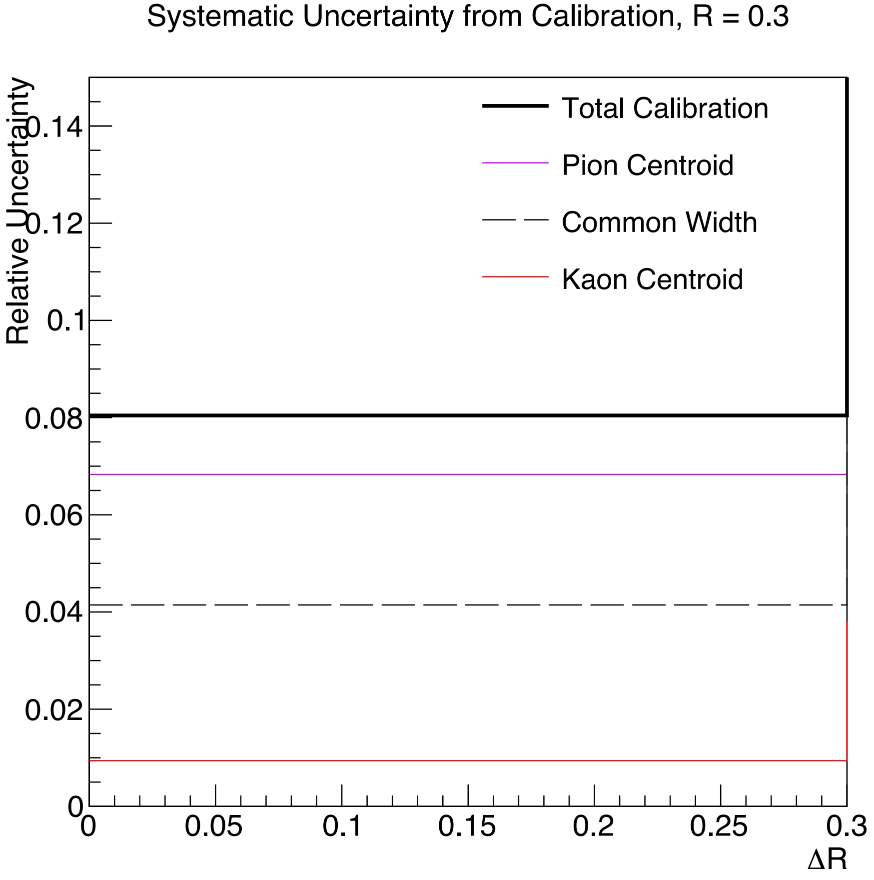


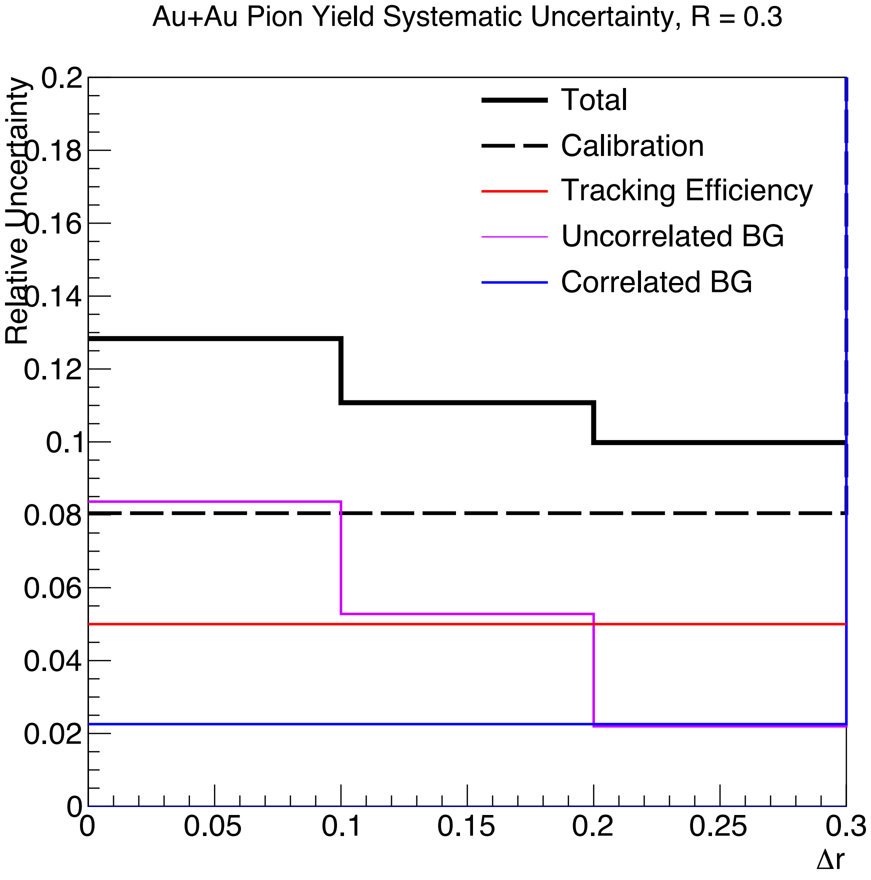


Au+Au Charged Hadron Yield Δr Systematics

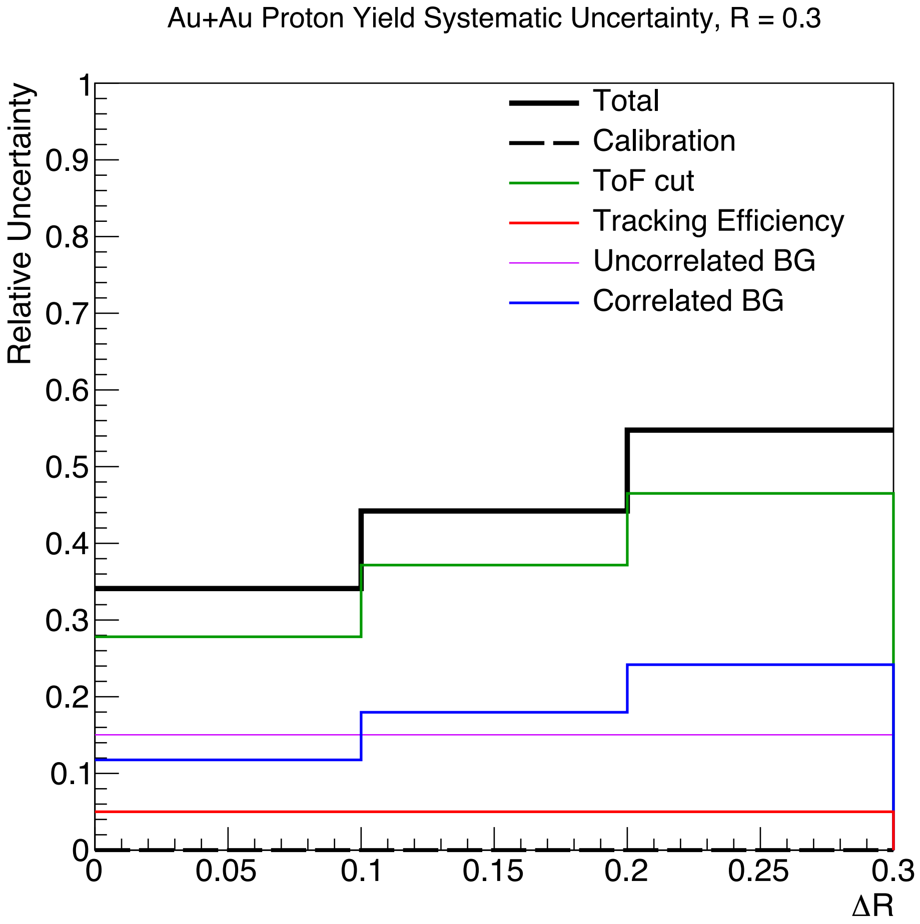


Au+Au Pion Yield Δr Systematics

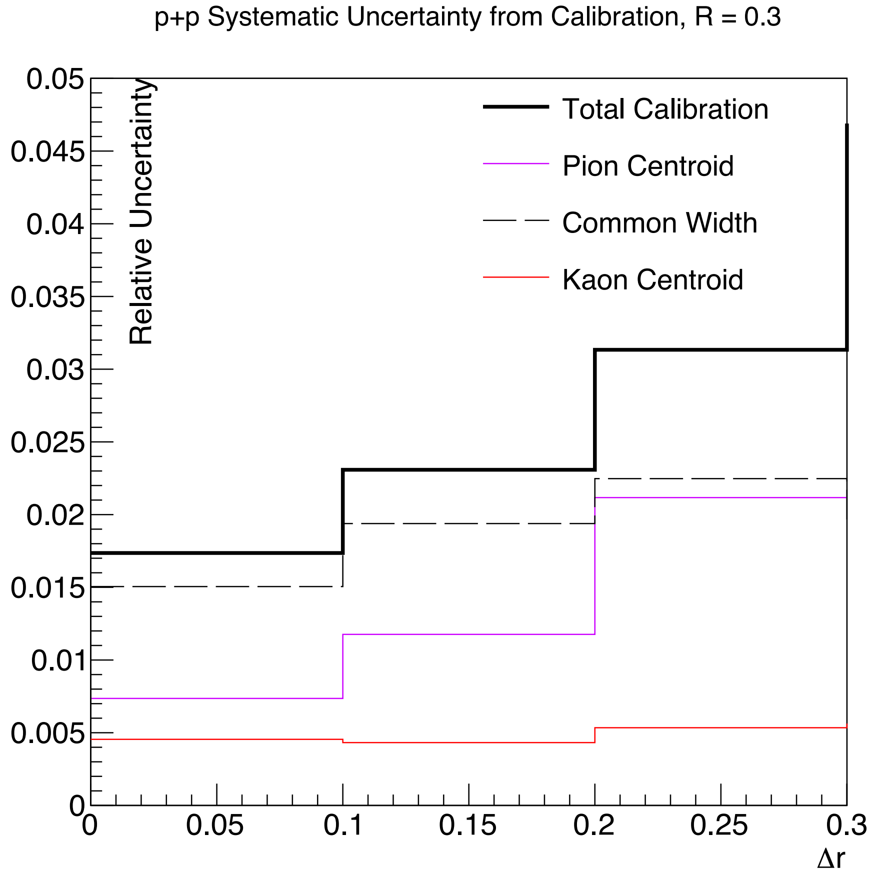


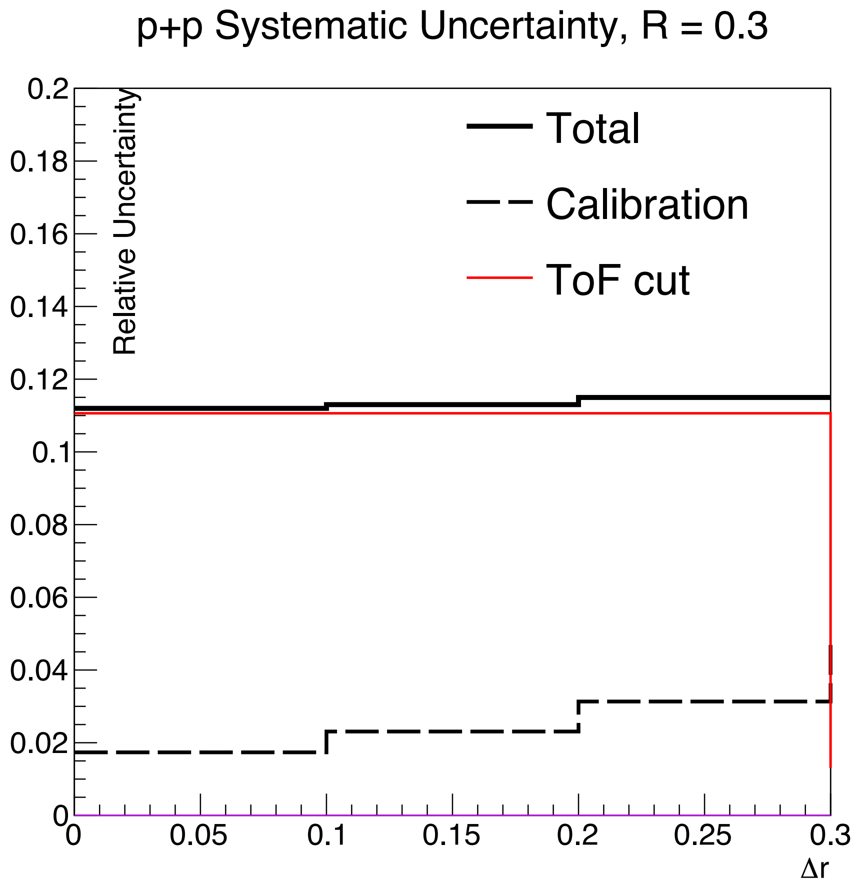


Au+Au Proton Yield Δr Systematics

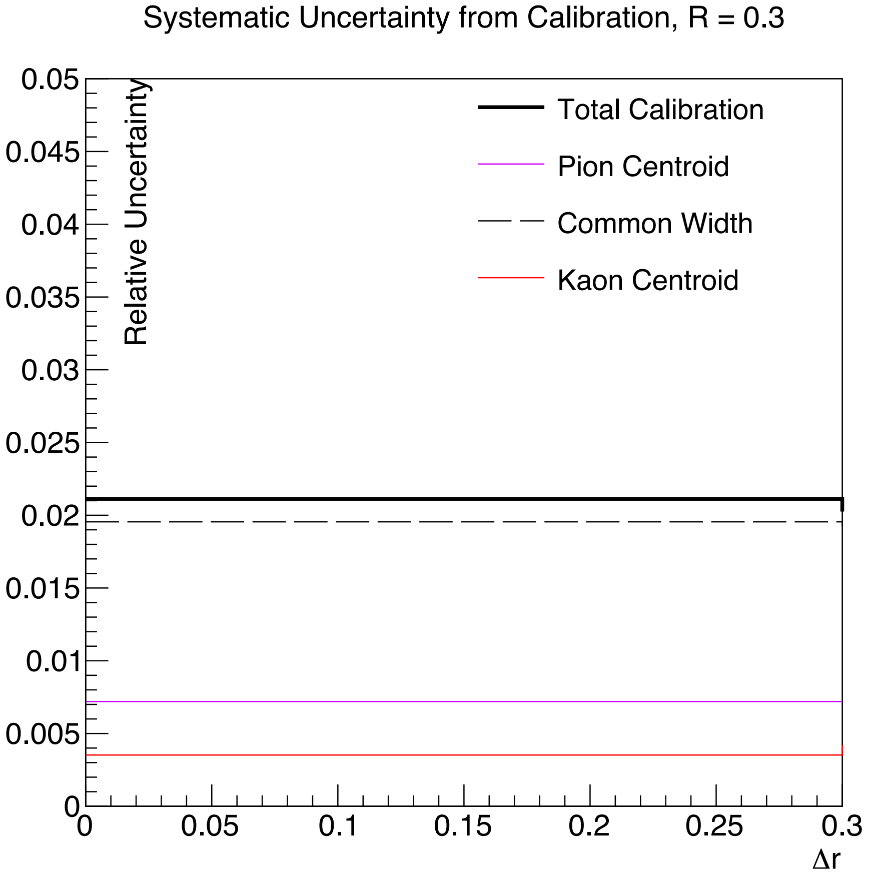


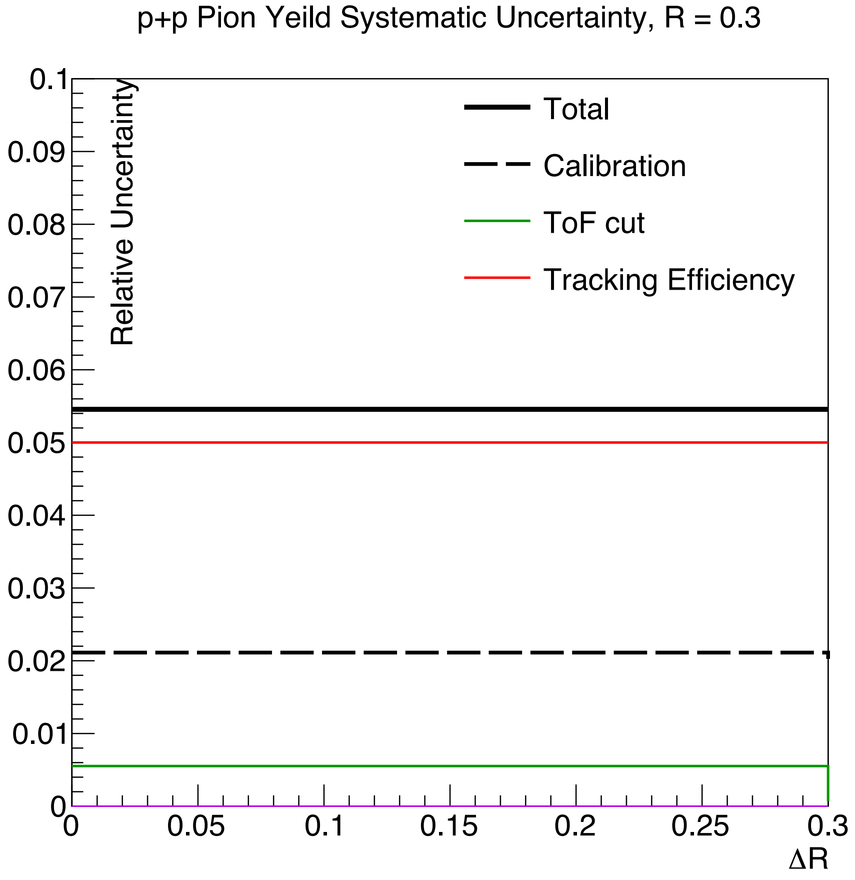
p+p p/π Δr Systematics



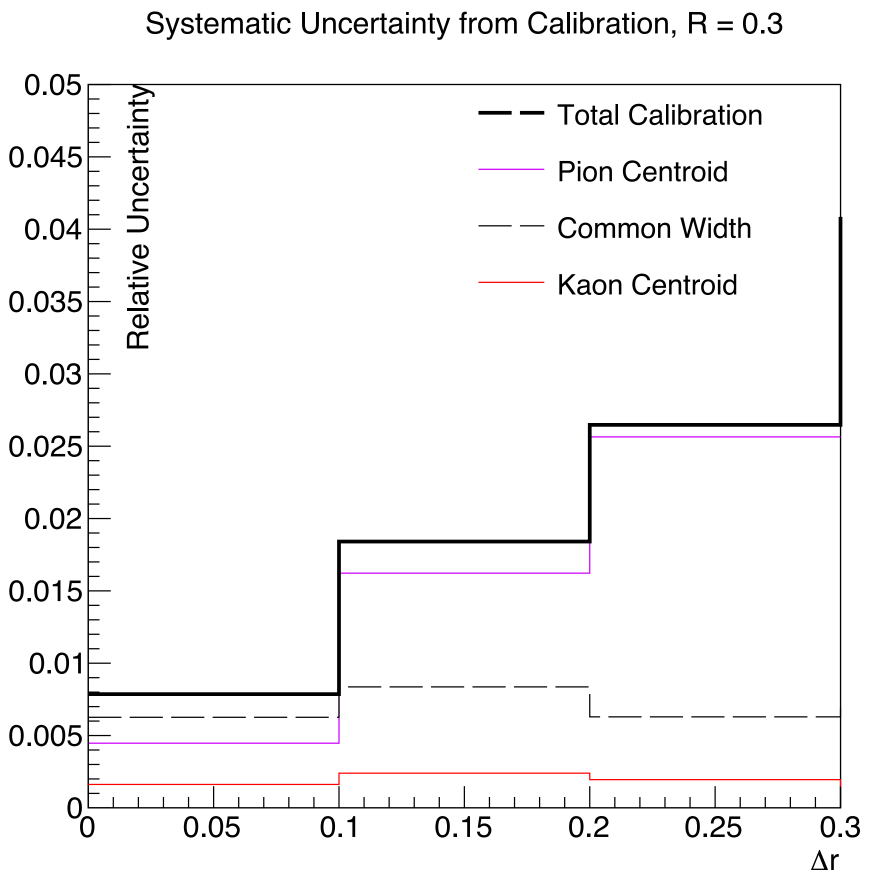


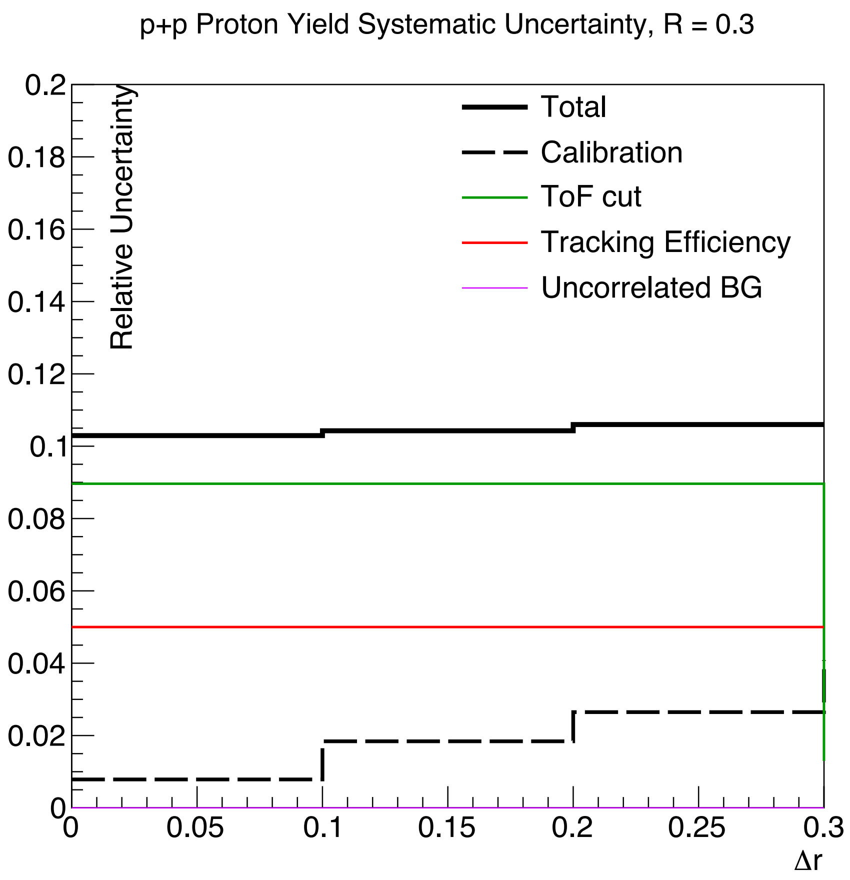
p+p Pion Yield Δr Systematics



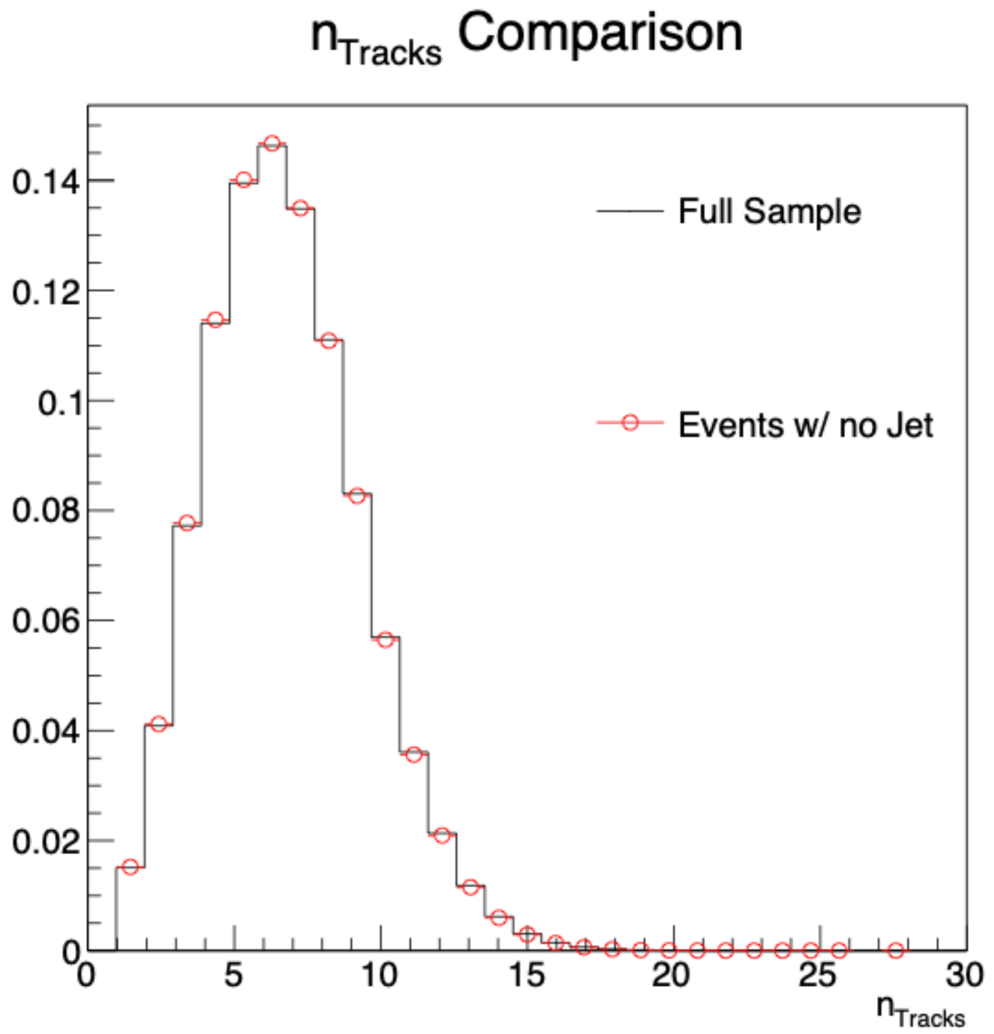


p+p Proton Yield Δr Systematics





Combinatorial Evaluation Uncertainty



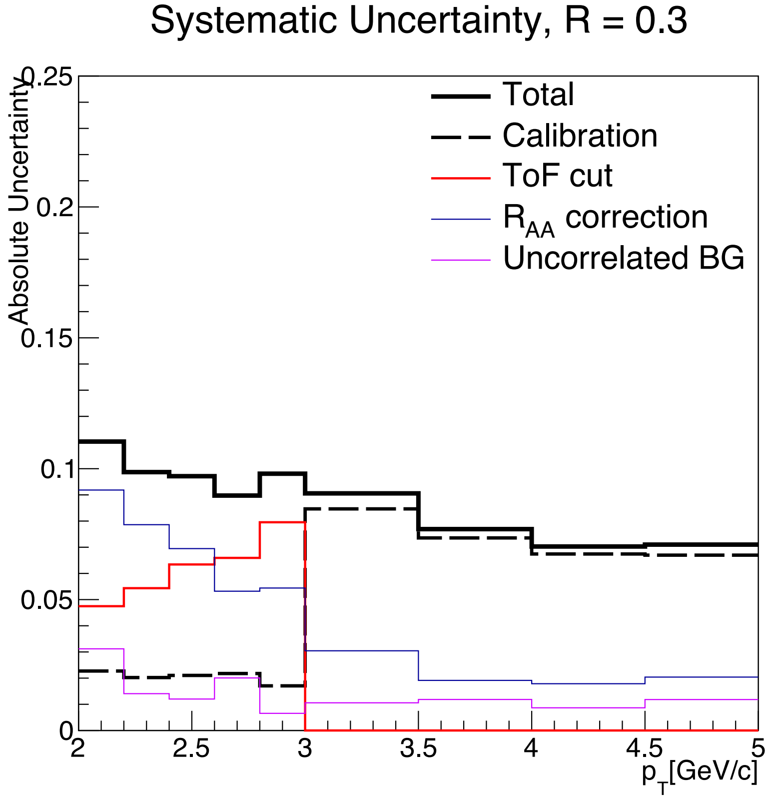
Sample	nEvents	Mean nTracks
Full	20,058,323	6.691
Events w/o Jet	19,898,309	6.471

- When building Mixed events we match the nTrack per event distribution from signal.

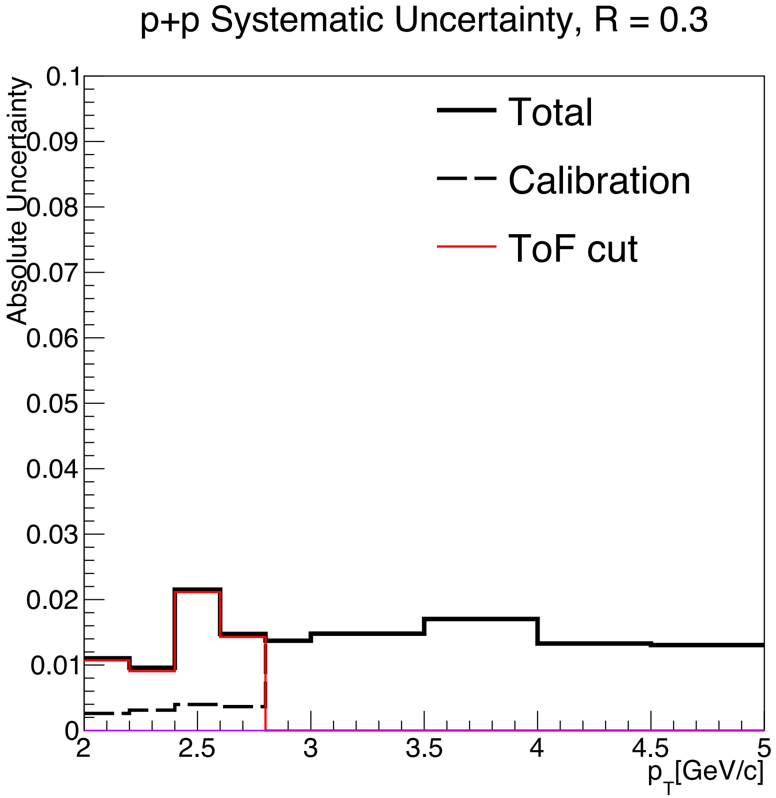
- Constructing Mixed Events with non-jetty ntrack distribution yields a 0.2% variation in resulting Fake rate

Systematic Uncertainty

Au+Au



p+p

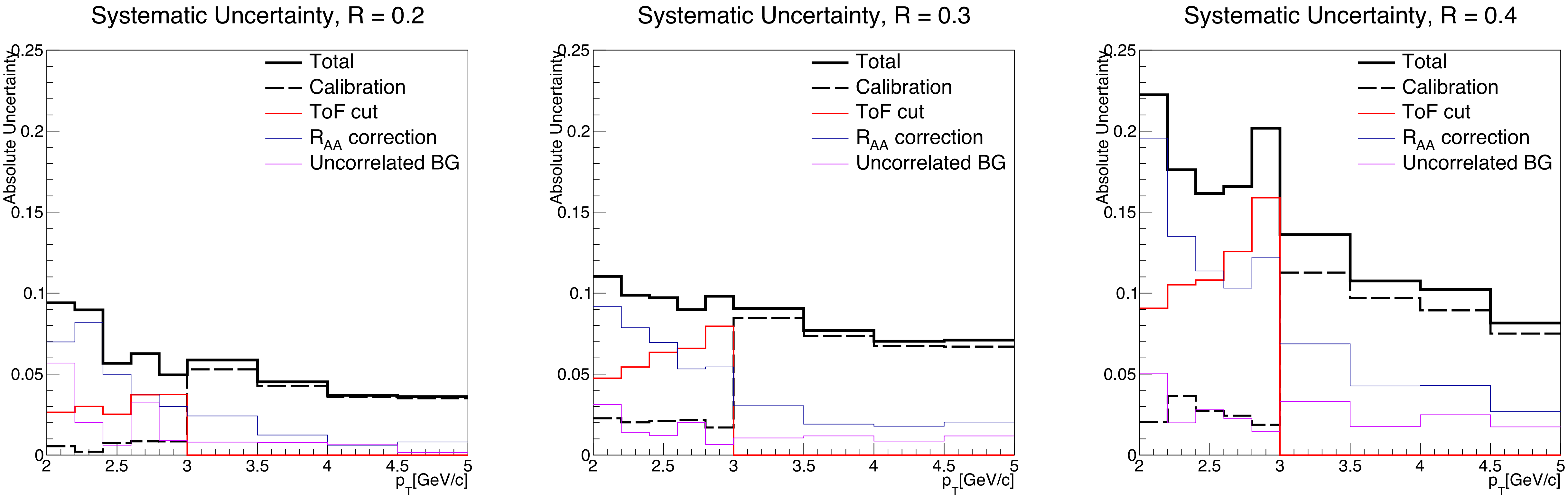


- One representative Jet R is shown here, all Systematics included in backup

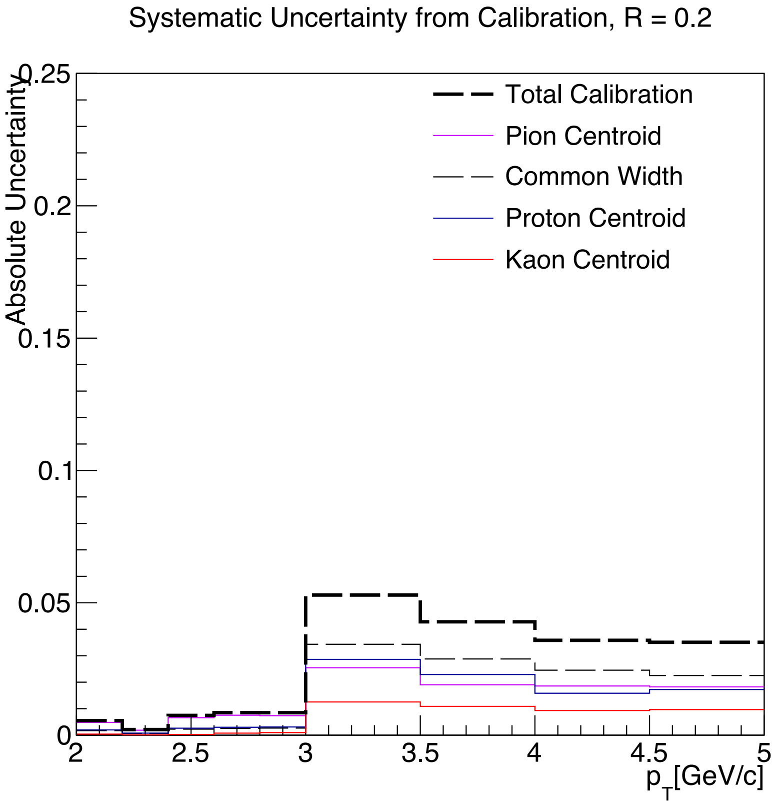
Systematic Sources:

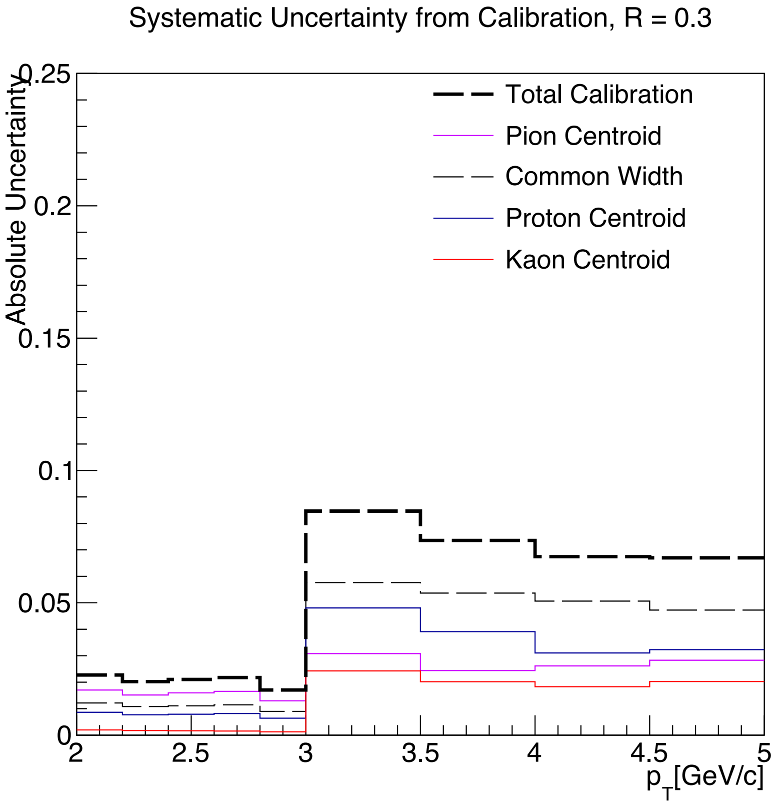
- dE/dx calibration, determined by varying each input parameter for gaussian fits
- ToF cut placement for proton identification below 3.0 GeV/*c*
- Uncorrelated background subtraction, determined by varying UE definition
- R_{AA} correction is included in nominal, for systematic uncertainty on fake rate, the template fits are run without R_{AA} correction, and the resulting fake rate is used

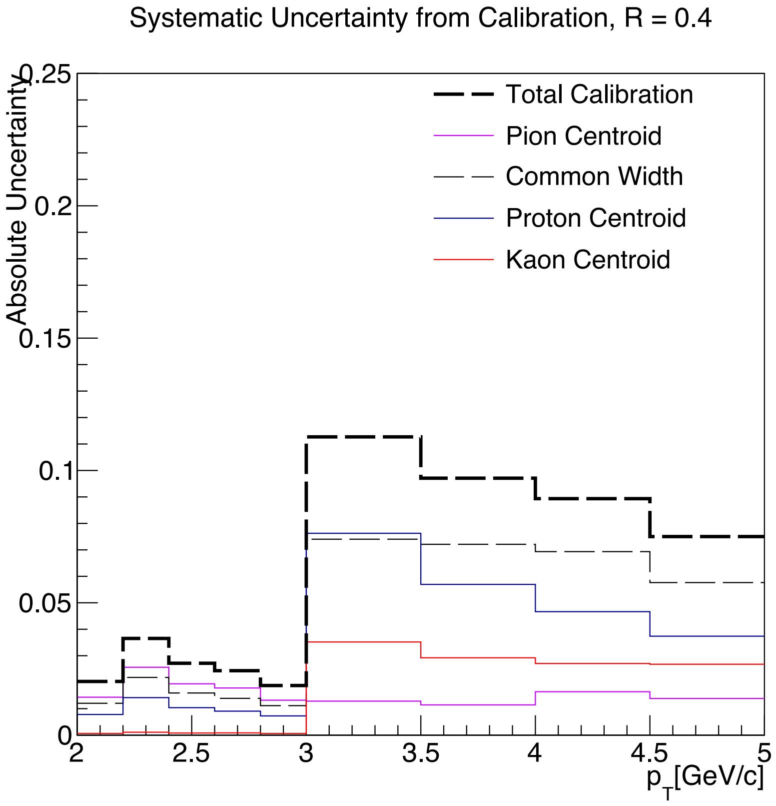
Au+Au Systematics



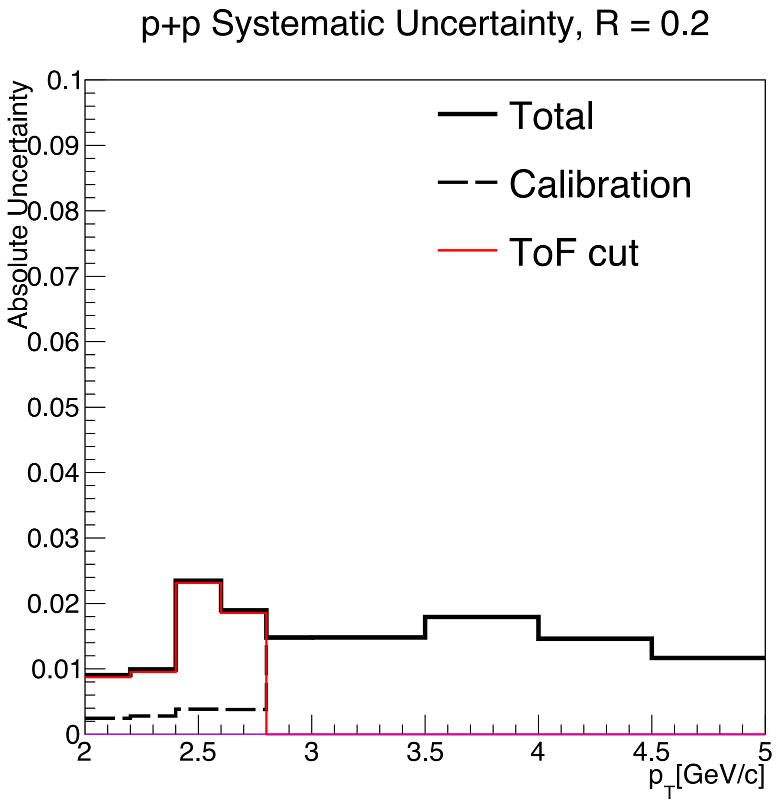
Au+Au, dE/dx Calibration Breakdown

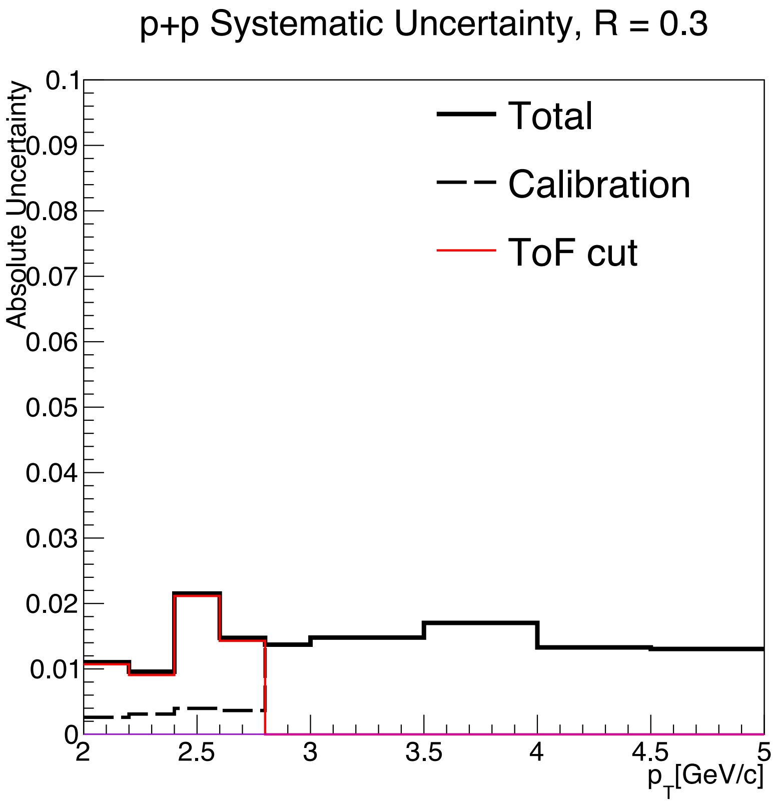


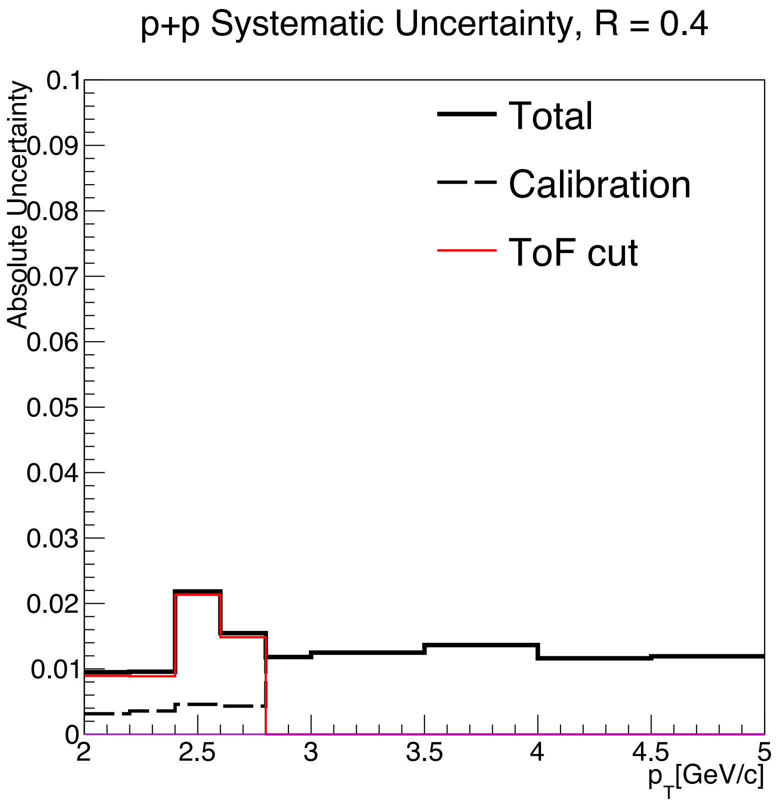




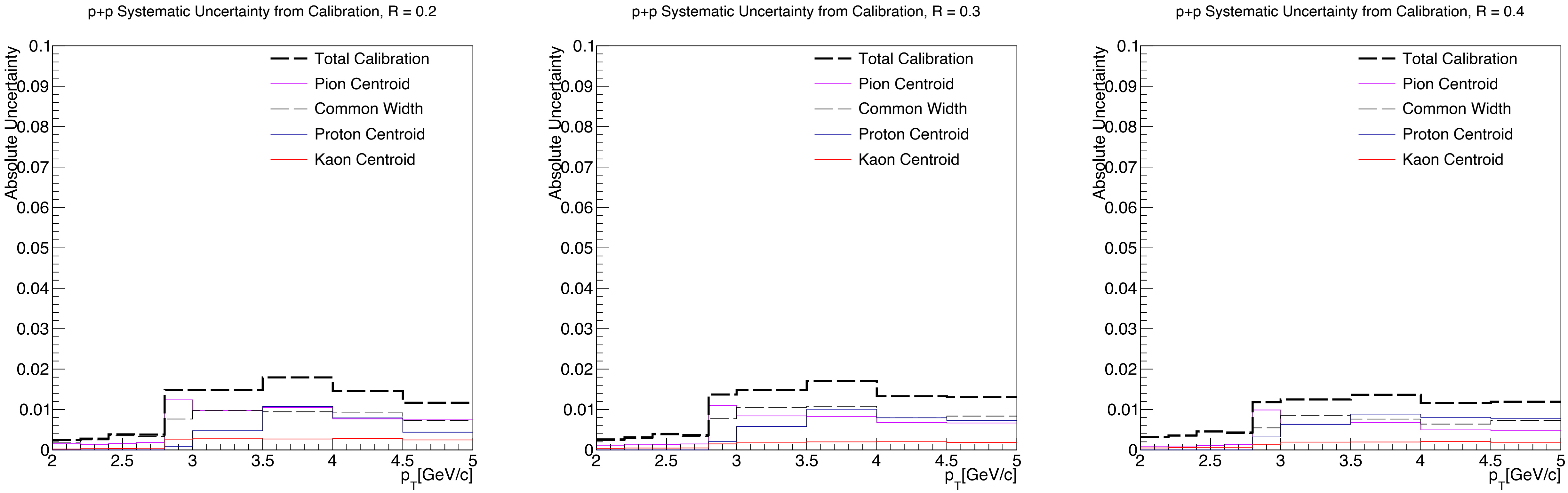
p+p Systematics







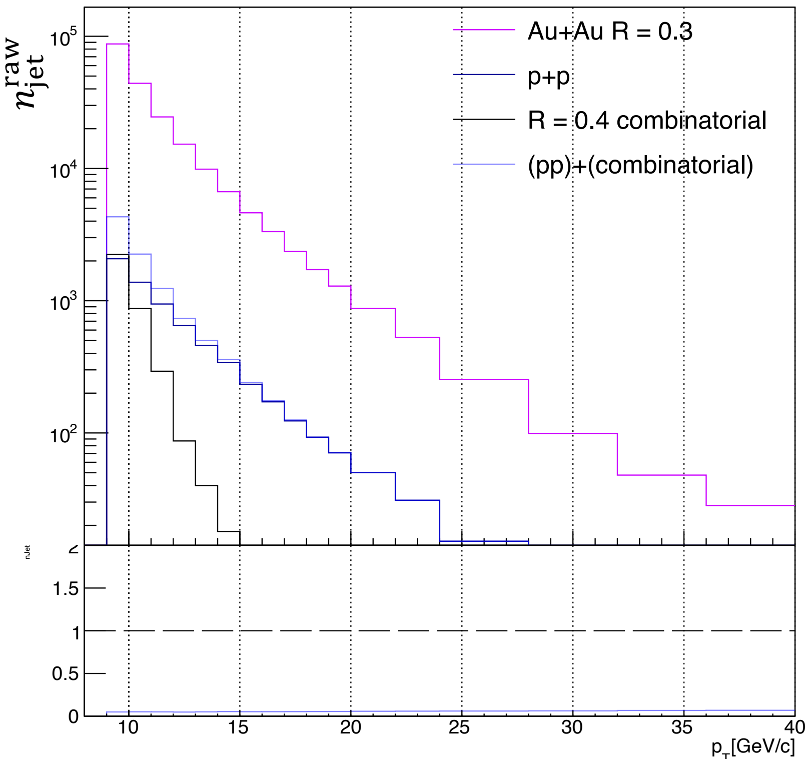
p+p, dE/dx Calibration Breakdown



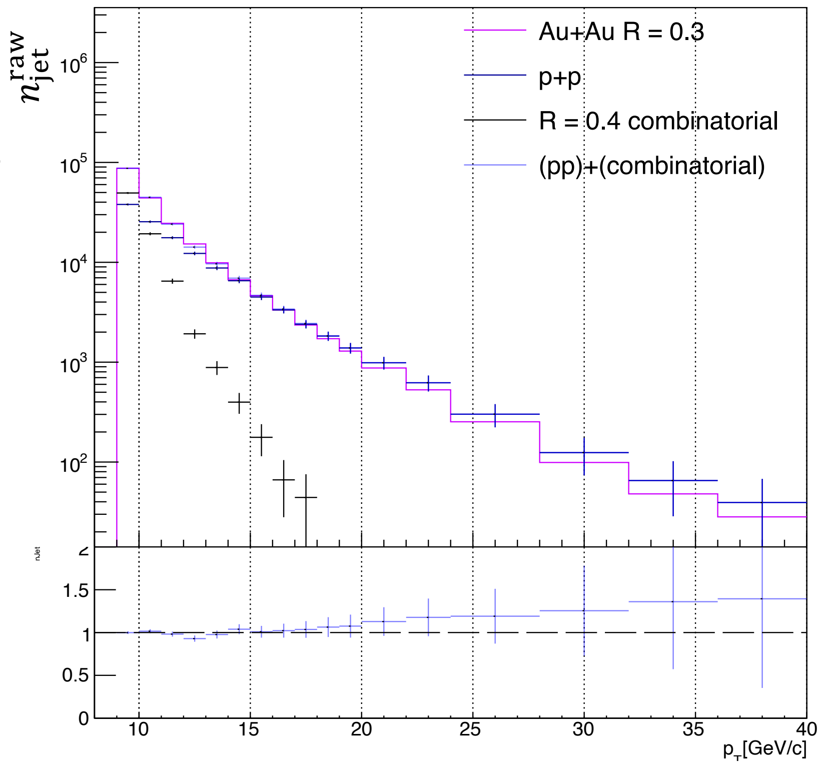
Determining Fake Rate: Spectra Template Fit

Raw Spectra → **Template Fit**

Rebuilding R = 0.3 Spectra



Rebuilding R = 0.3 Spectra



- Create a two-parameter template fit using the raw jet spectra from p+p and combinatorial jets
- Fit the raw Au+Au spectra
- Scale p+p and combinatorial Njet values by the resulting parameters to calculate fake rate

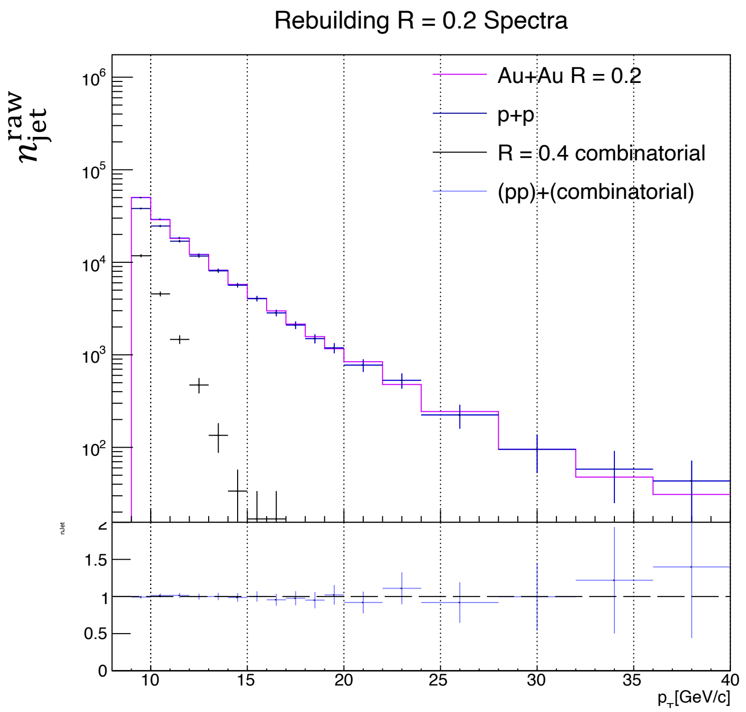
p+p -> 6,984 jets * $\boxed{20.5}$ = 143,715

Combinatorial -> 4,143 jets * $\boxed{22.1}$ = 91,597 -> **39% Fake Rate**

Fit Parameters

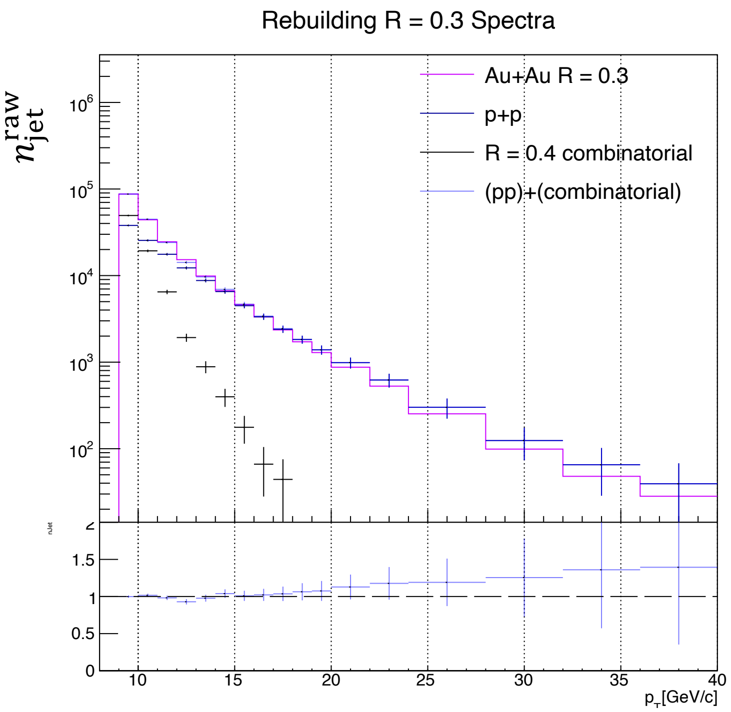
Determining Fake Rate: Spectra Template Fit

R = 0.2



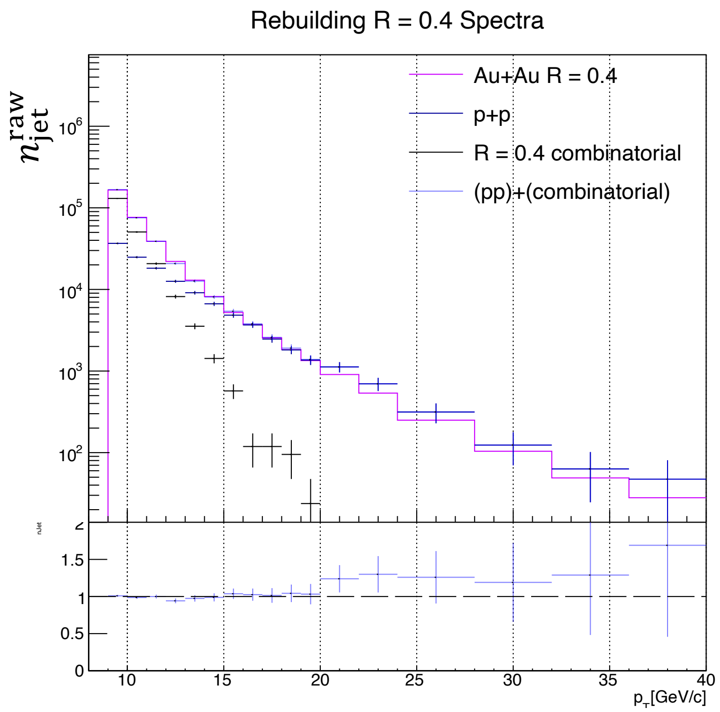
Fake Rate: 13%

R = 0.3



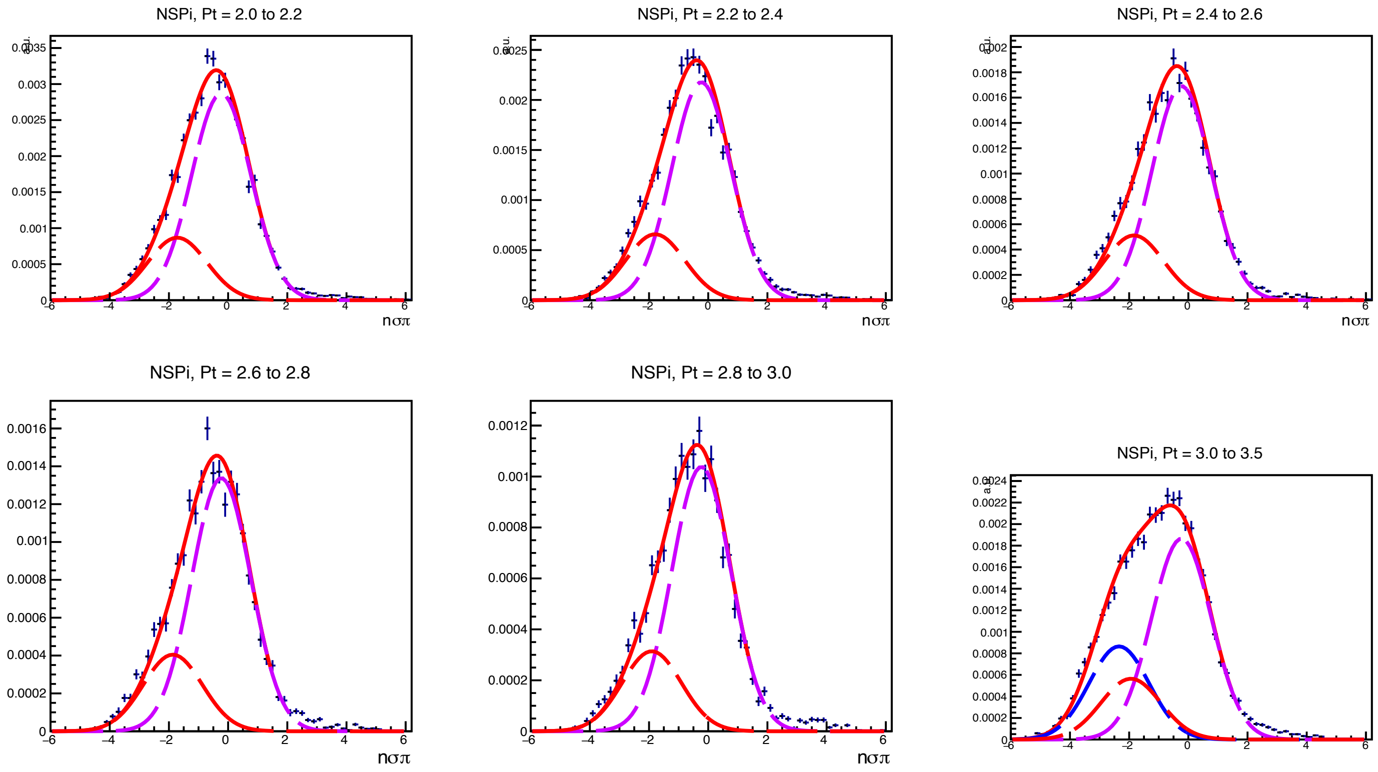
Fake Rate: 39%

R = 0.4



Fake Rate: 63%

Double Fits for m^{2} < 0.5



Gaussian Fits for R = 0.3

Triple Fits for full m^{2} Range