

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

*Gabriel Dale-Gau for the STAR Collaboration
University of Illinois at Chicago*



Quark Matter 2025, Frankfurt, Germany

Supported in part by



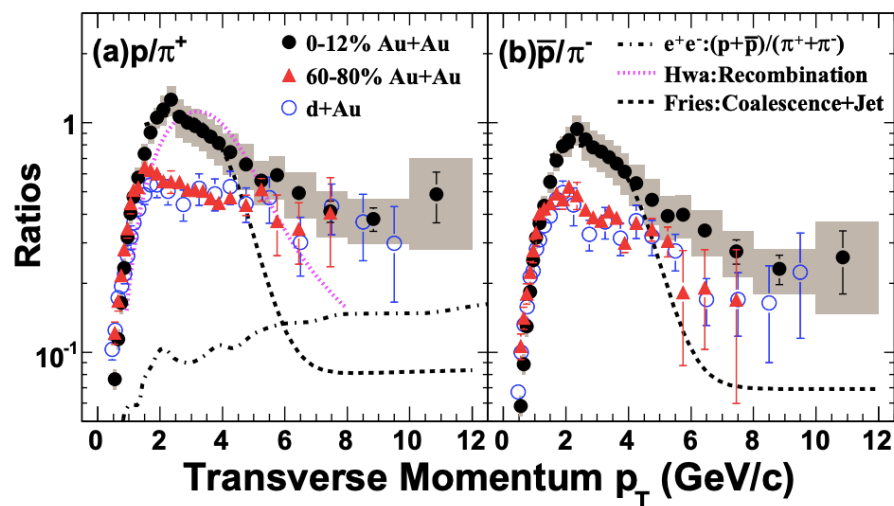
U.S. DEPARTMENT OF
ENERGY

Office of
Science



STAR Collaboration

Motivation



[PRL97(2006)152301]

STAR

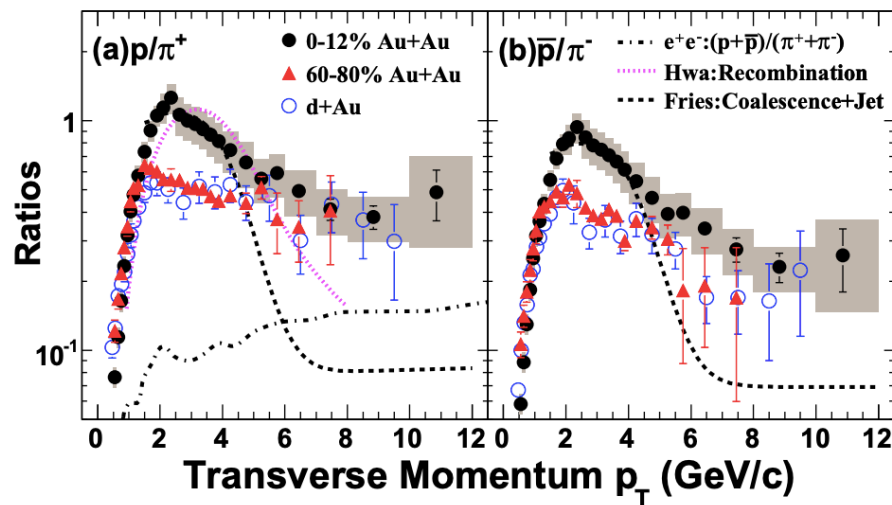
d+Au $\sqrt{s_{NN}} = 200$ GeV

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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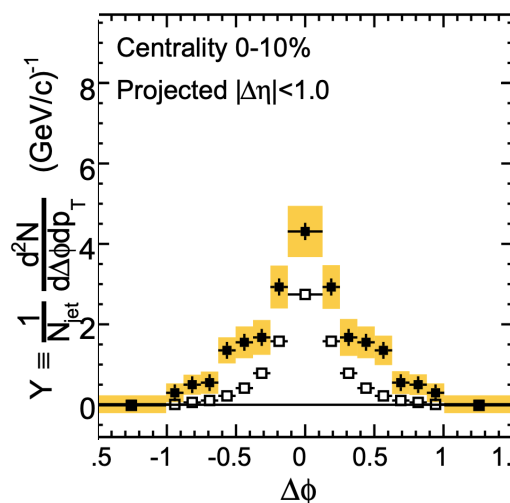


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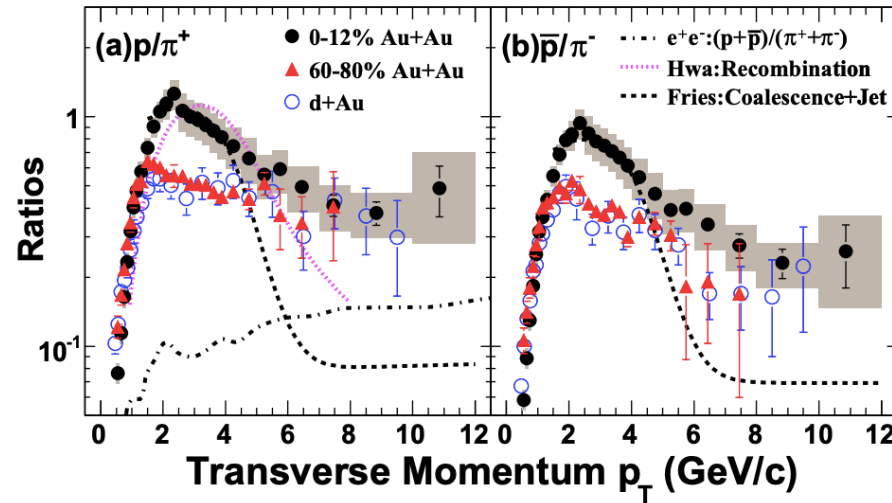
[JHEP 11 (2016) 055]

CMS

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

■ PbPb Leading Jets
 ■ pp Leading Jets

Motivation



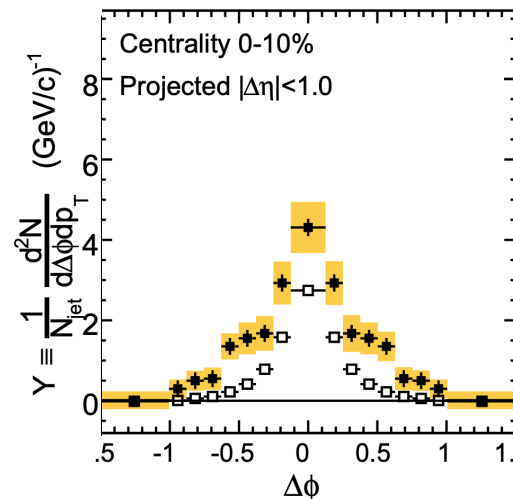
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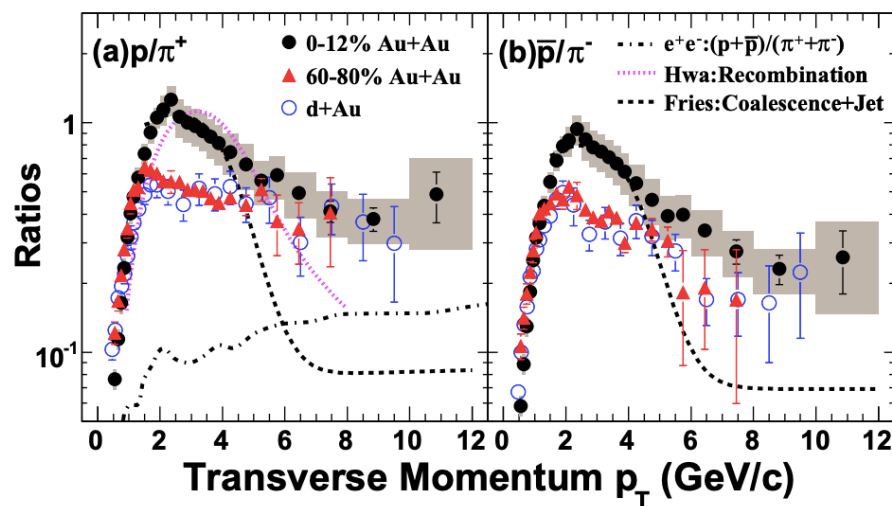
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R.C. Hwa & C. B. Yang [PRC(2004)0312271]

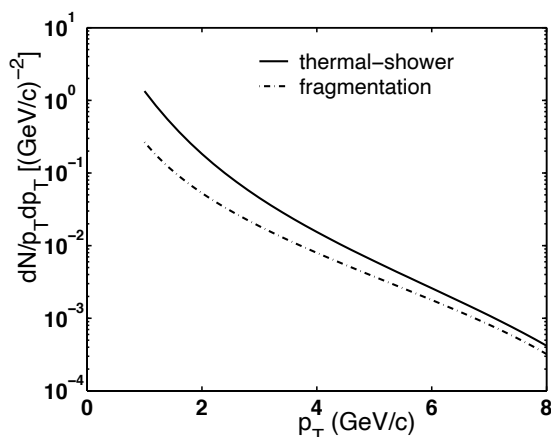
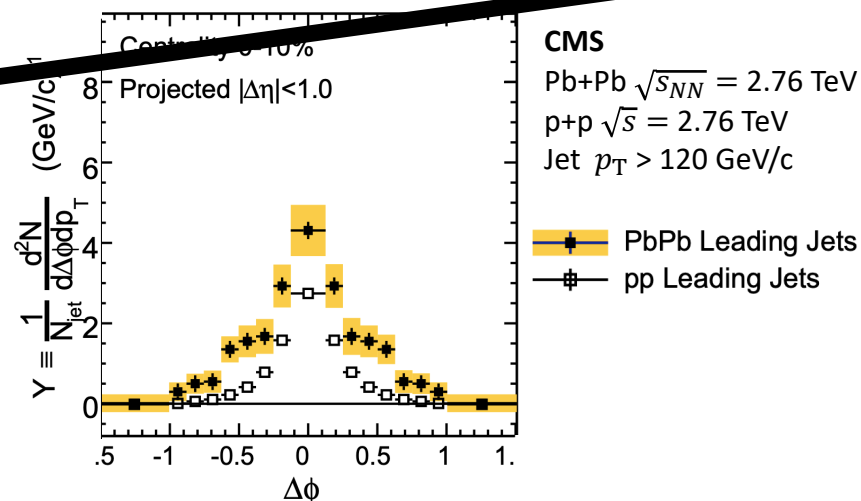


FIG. 4: Distributions of π^+ in p_T arising from thermal-shower recombination (solid line) and shower-shower recombination, i.e. fragmentation (dash-dot line).



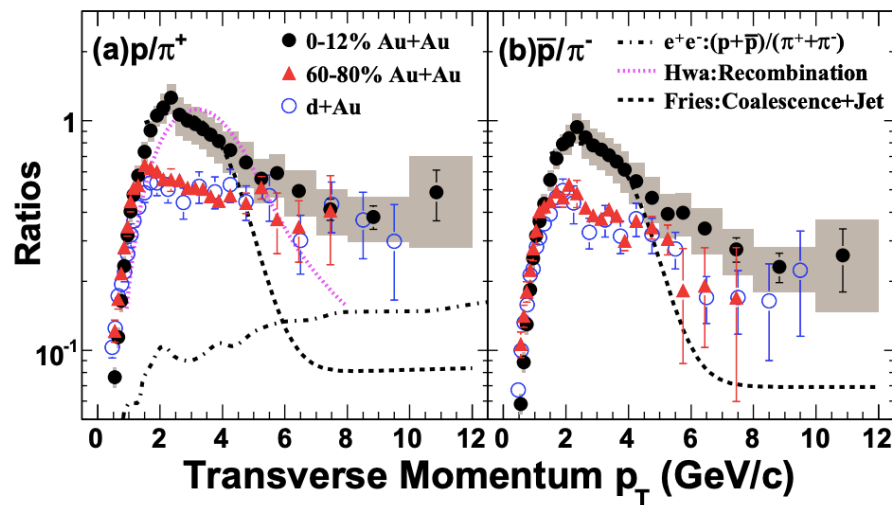
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- **AMPT simulations: p/π is modified for jets in QGP**
A. Luo et al. [PLB(2022)137638]

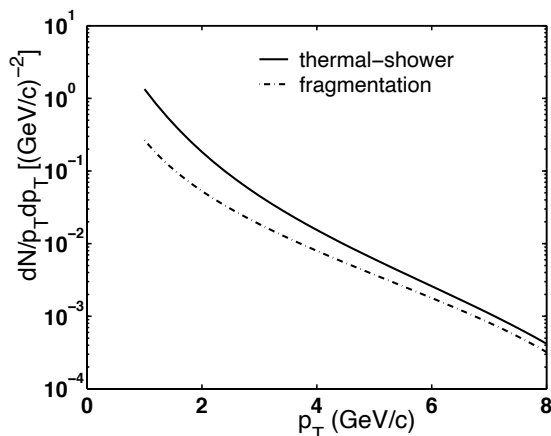
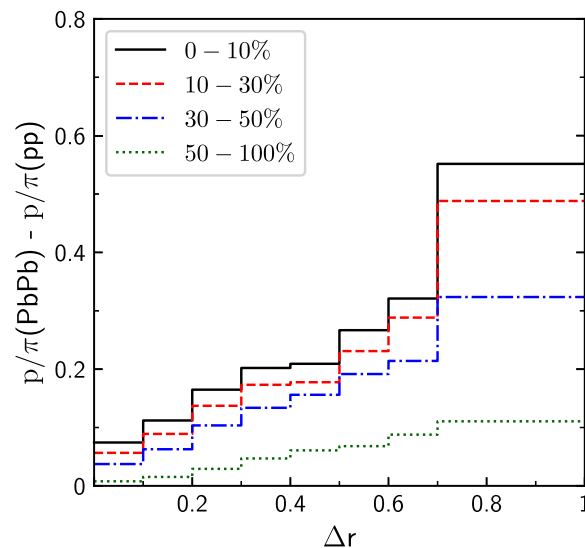
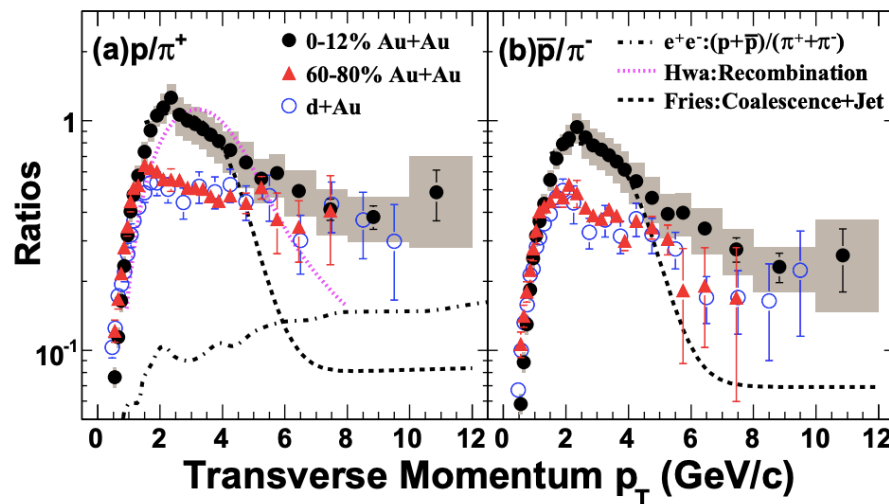


FIG. 4: Distributions of π^+ in p_T arising from thermal-shower recombination (solid line) and shower-shower recombination, i.e. fragmentation (dash-dot line).



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

Motivation



[PRL97(2006)152301]

STAR

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

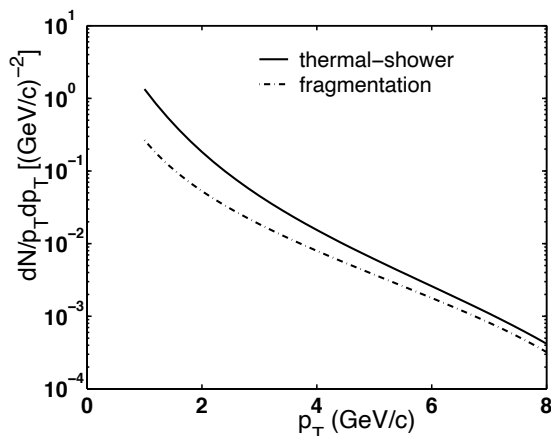
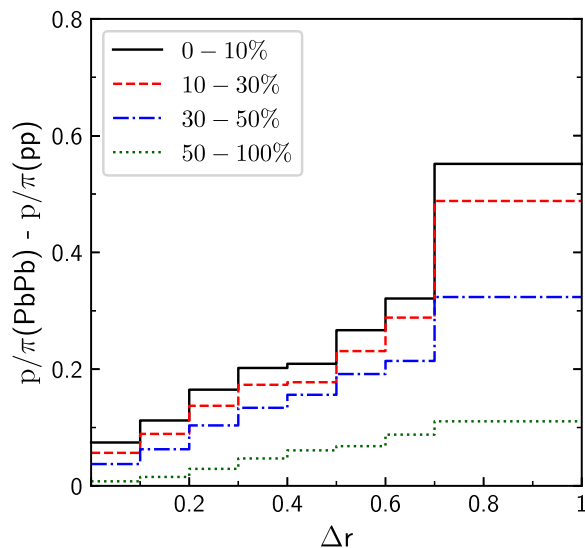


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AMPT

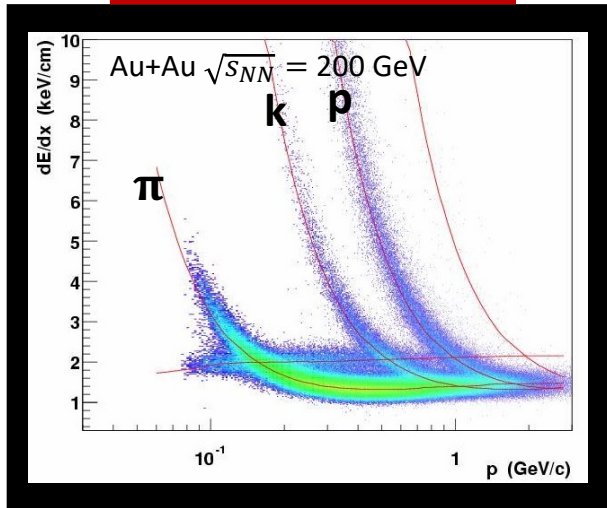
Pb+Pb

p+p

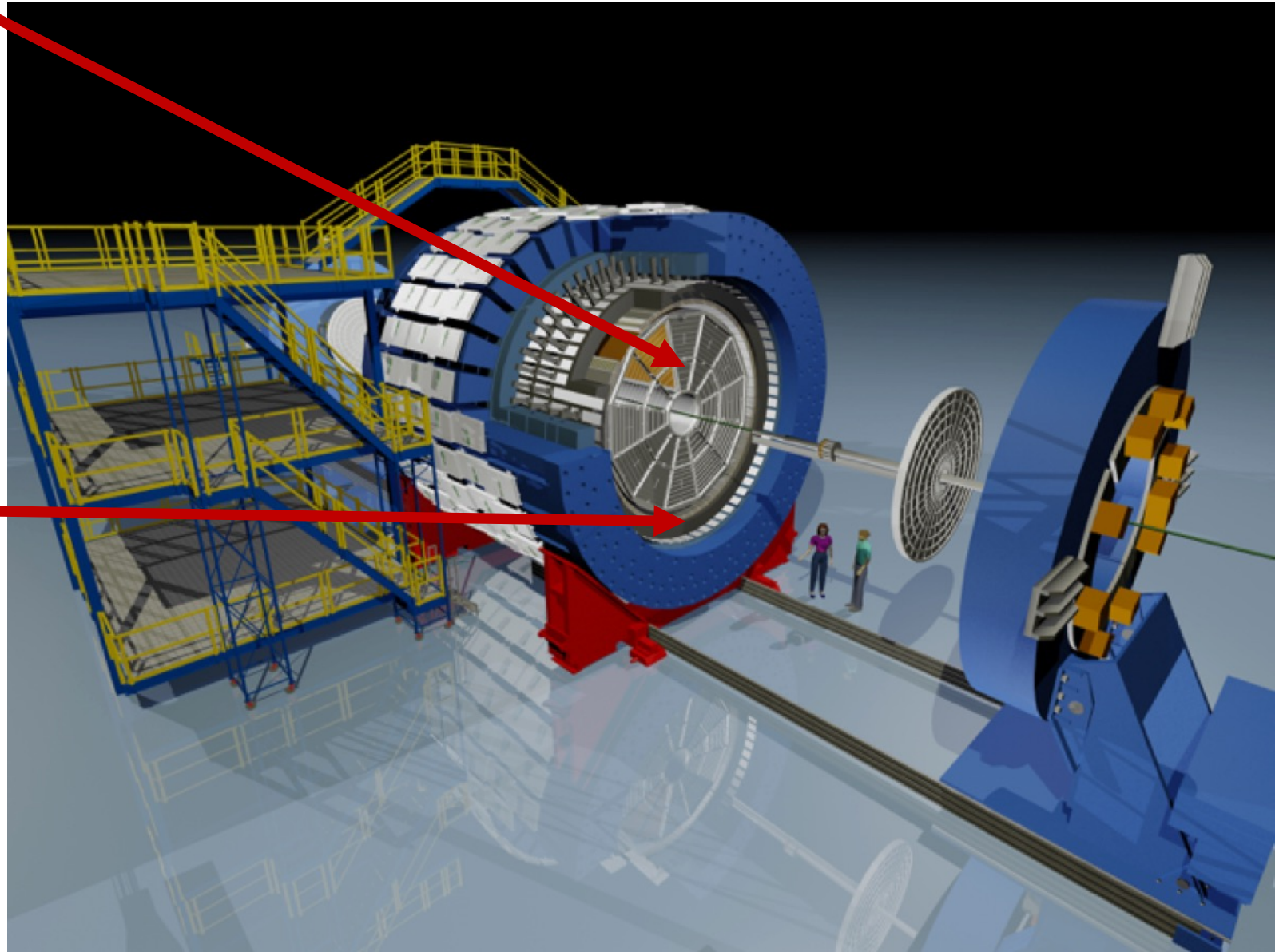
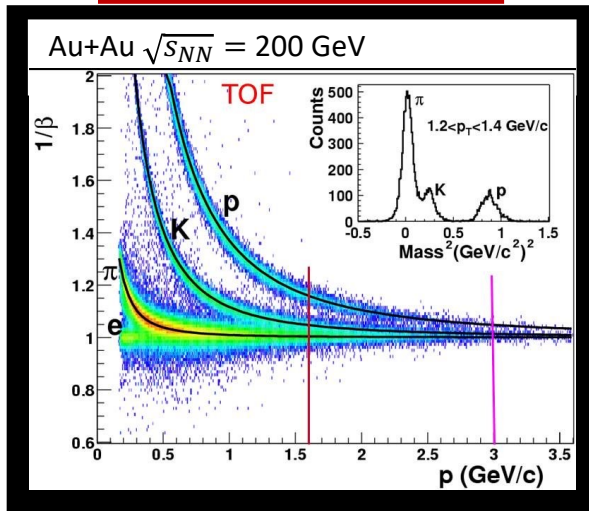
$\sqrt{s_{NN}} = 5.02$ TeV

STAR Detector

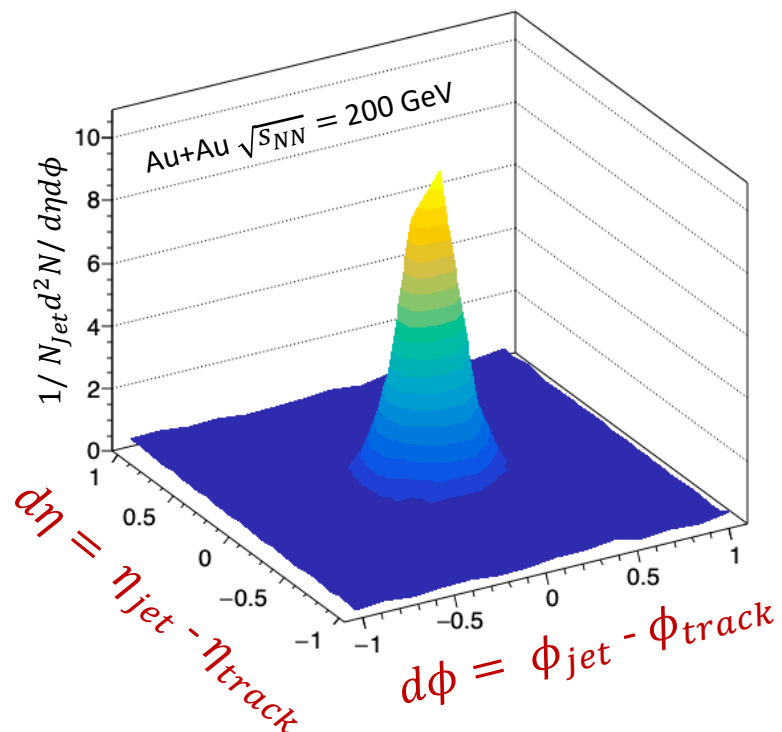
dE/dx from TPC



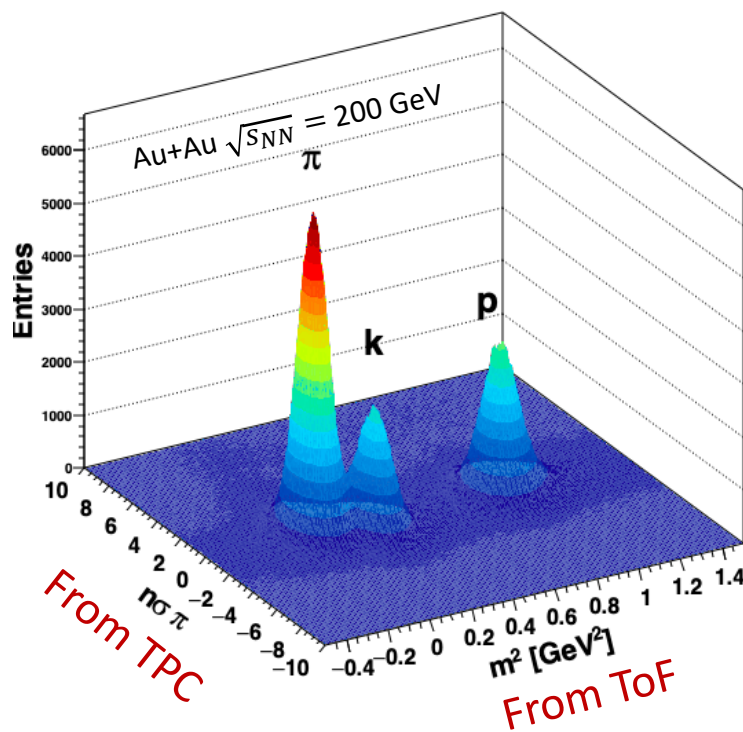
β from ToF



2D jet-track correlation



Particle Identification



Data Samples

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

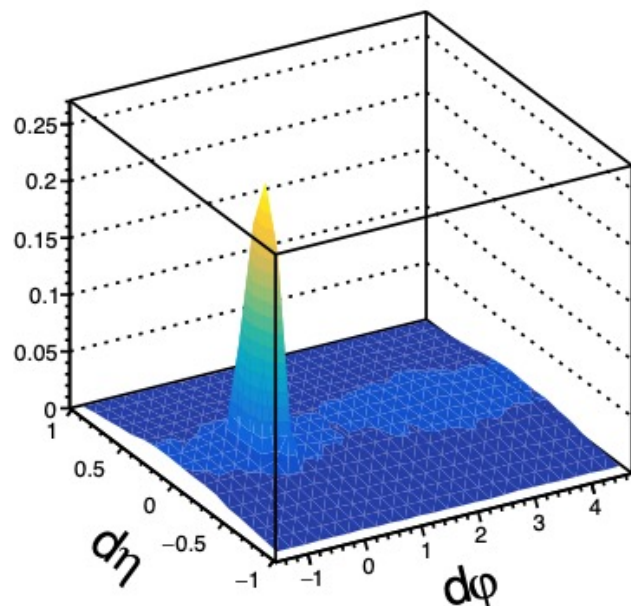
Jet Reconstruction

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

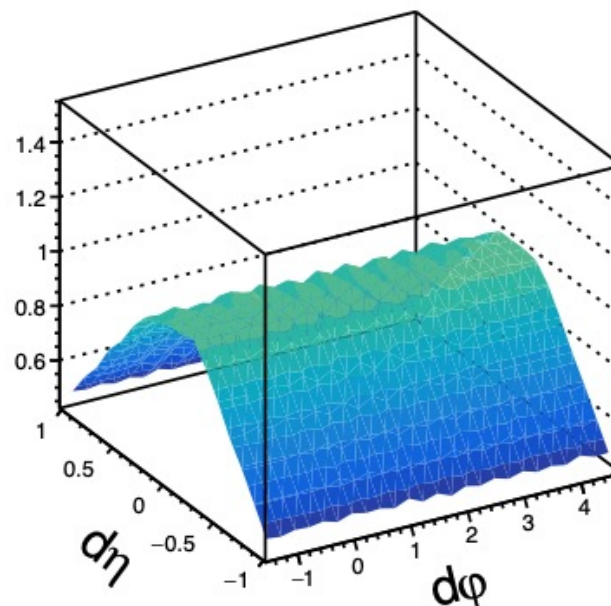
Fully reconstructed jets with tracks identified by Time of Flight (ToF) and Time Projection Chamber (TPC) information
=> Particle Identification in jets

Jet-Track Correlation

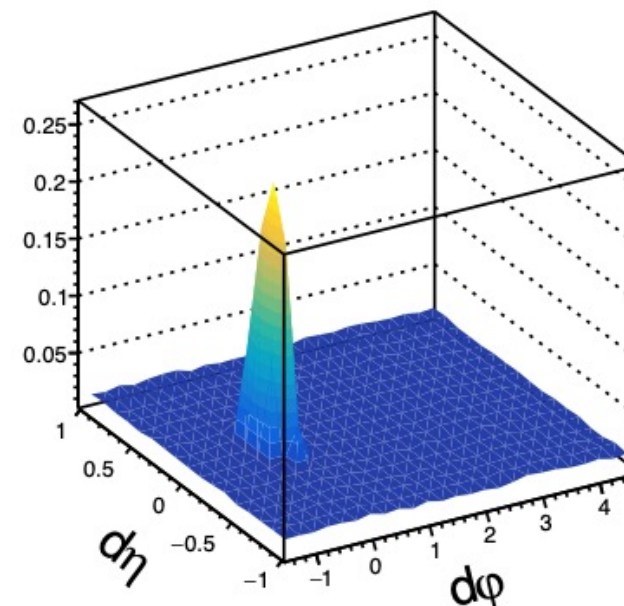
Raw Correlation



Mixed Event



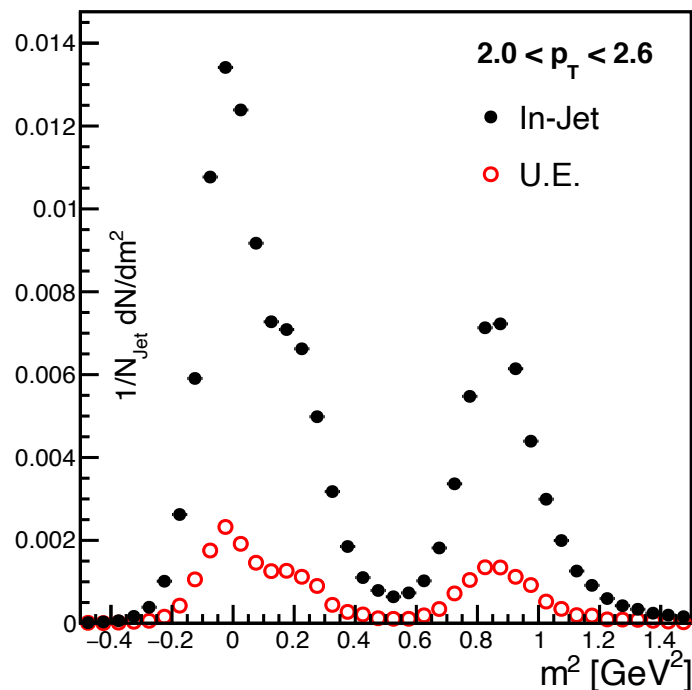
After acceptance correction



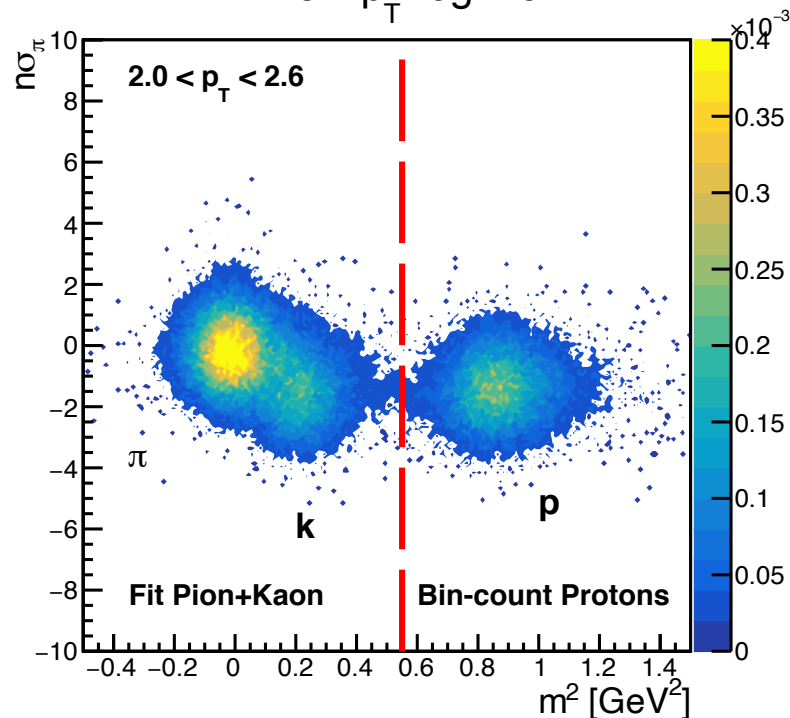
- Run Anti- k_T algorithm to identify Jet Axis
- Perform correlations with all tracks within $|\eta_{\text{track}}| < 0.5$
- Build Mixed event for pair acceptance correction
- Divide signal correlation by mixed event
- Select regions of equal area for jet and underlying event for every p_T bin from 2.0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

Particle Identification

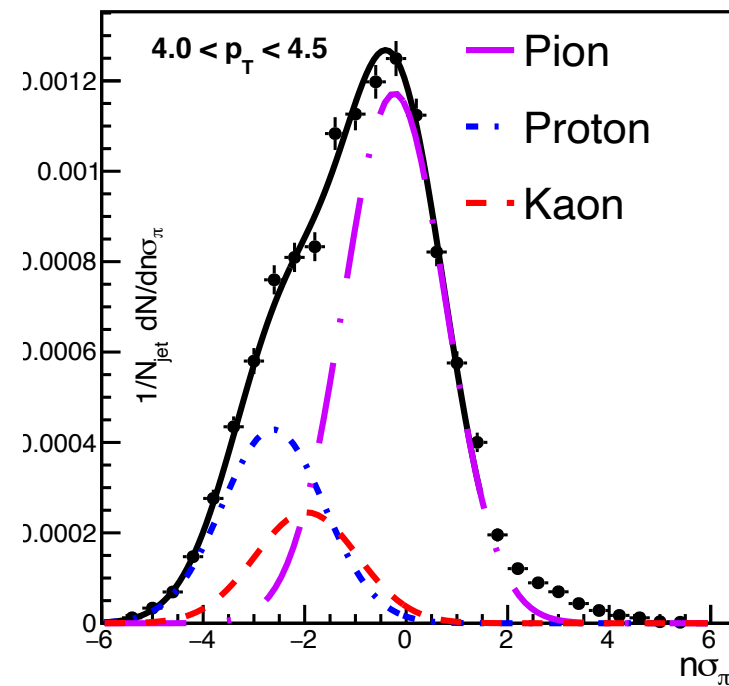
Underlying Event Subtraction



Low p_T regime



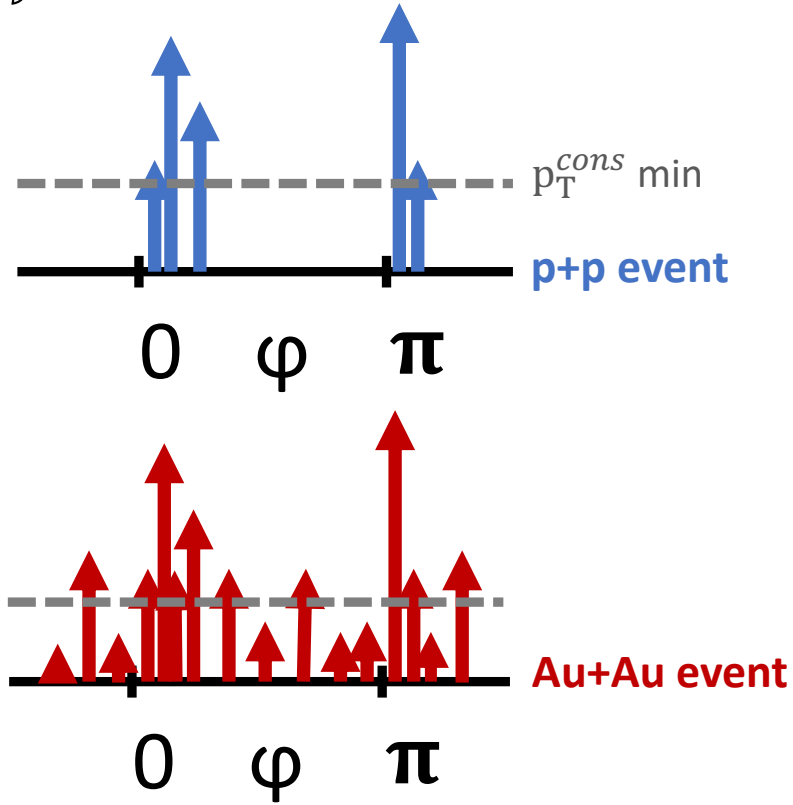
High p_T regime



- Subtract UE from Jet in $d\phi$, $d\eta$, $n\sigma_\pi$, and m^2
- Identify Pion, Proton, Kaon yields from remaining Jet Signal
- Low p_T regime: $p_T < 3.0 \text{ GeV}/c \rightarrow$ bin-count protons
- High p_T regime: $p_T > 3.0 \text{ GeV}/c \rightarrow$ triple Gaussian fit
- Divide proton yield by pion yield to measure ratio

Correlated Background Removal

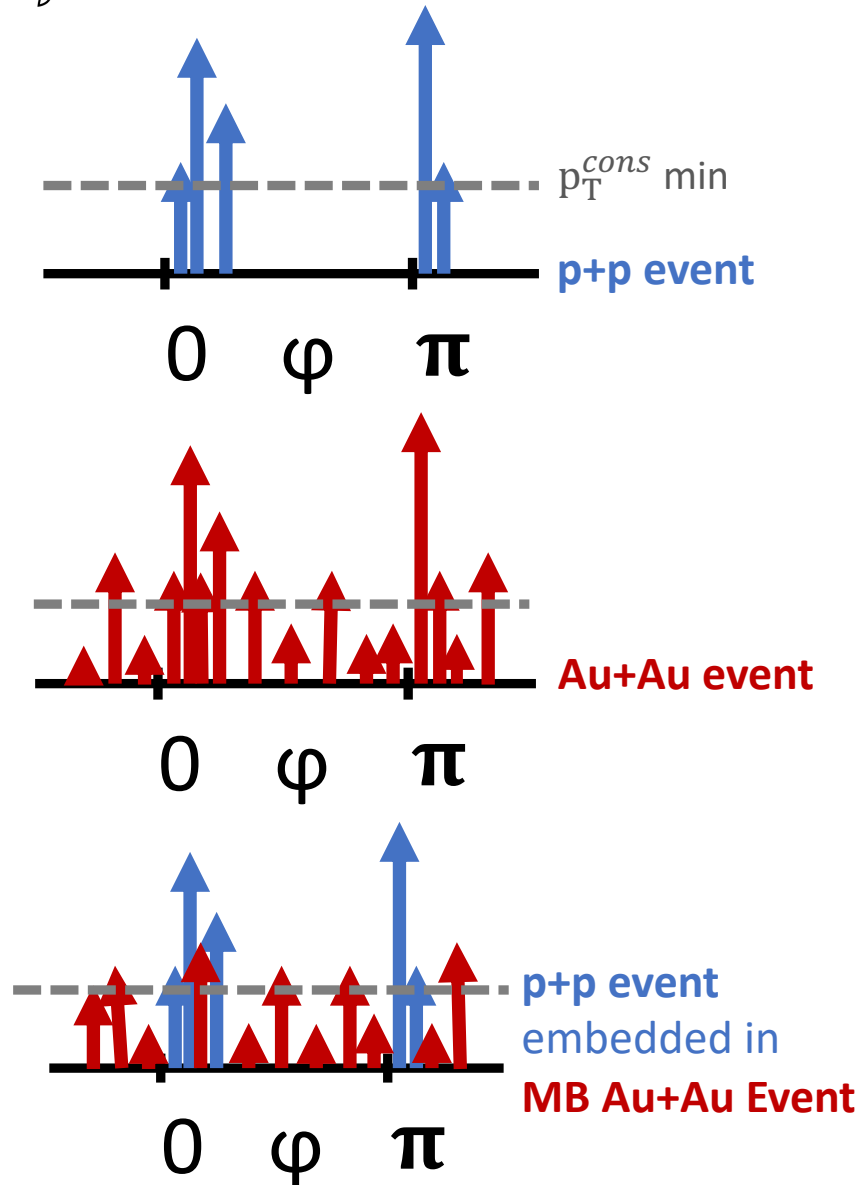
QM 25



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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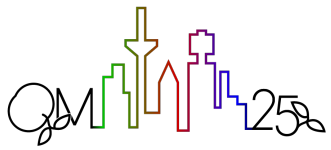


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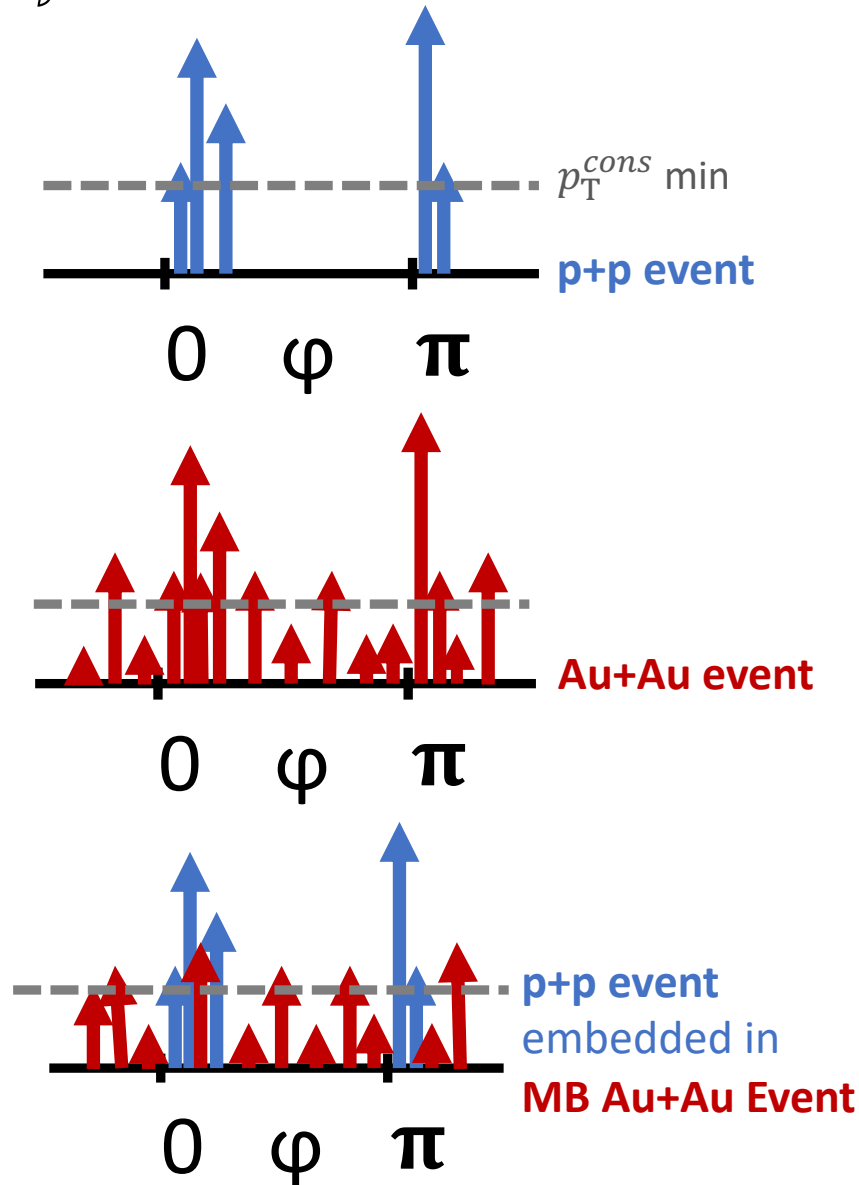
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The Solution:

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



Correlated Background Removal

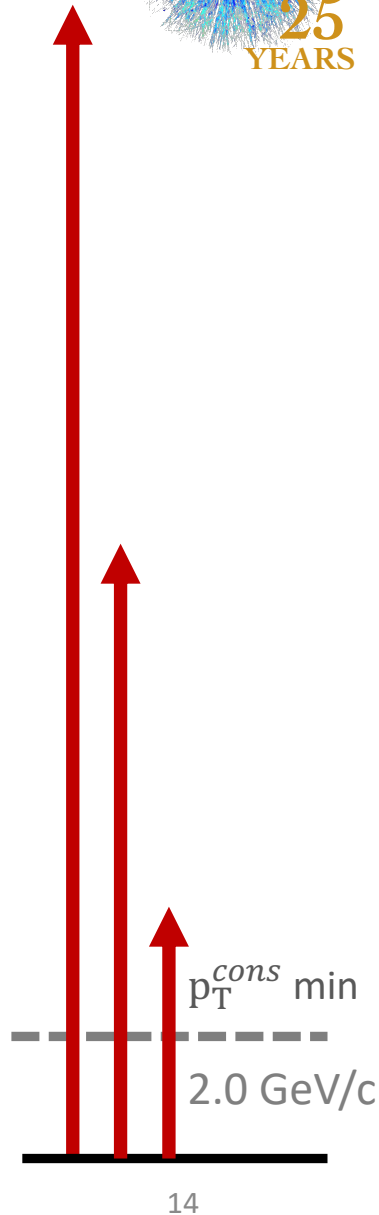
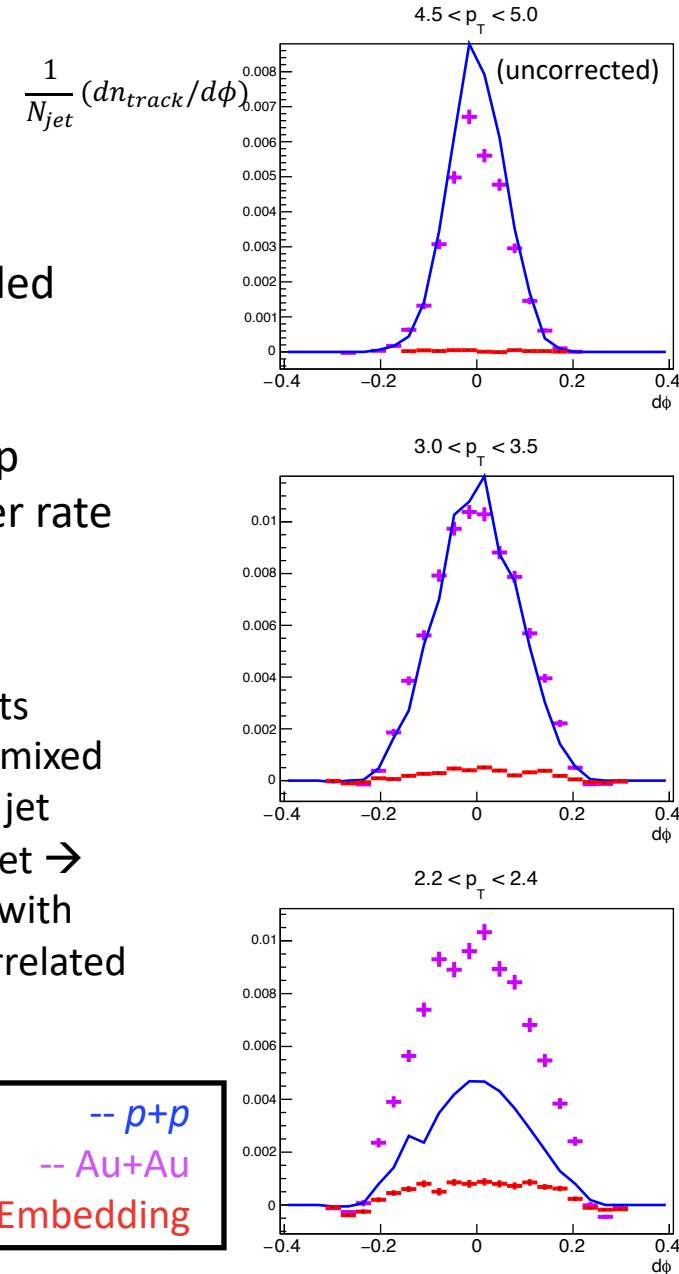
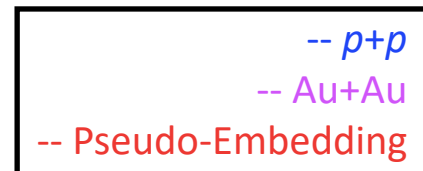


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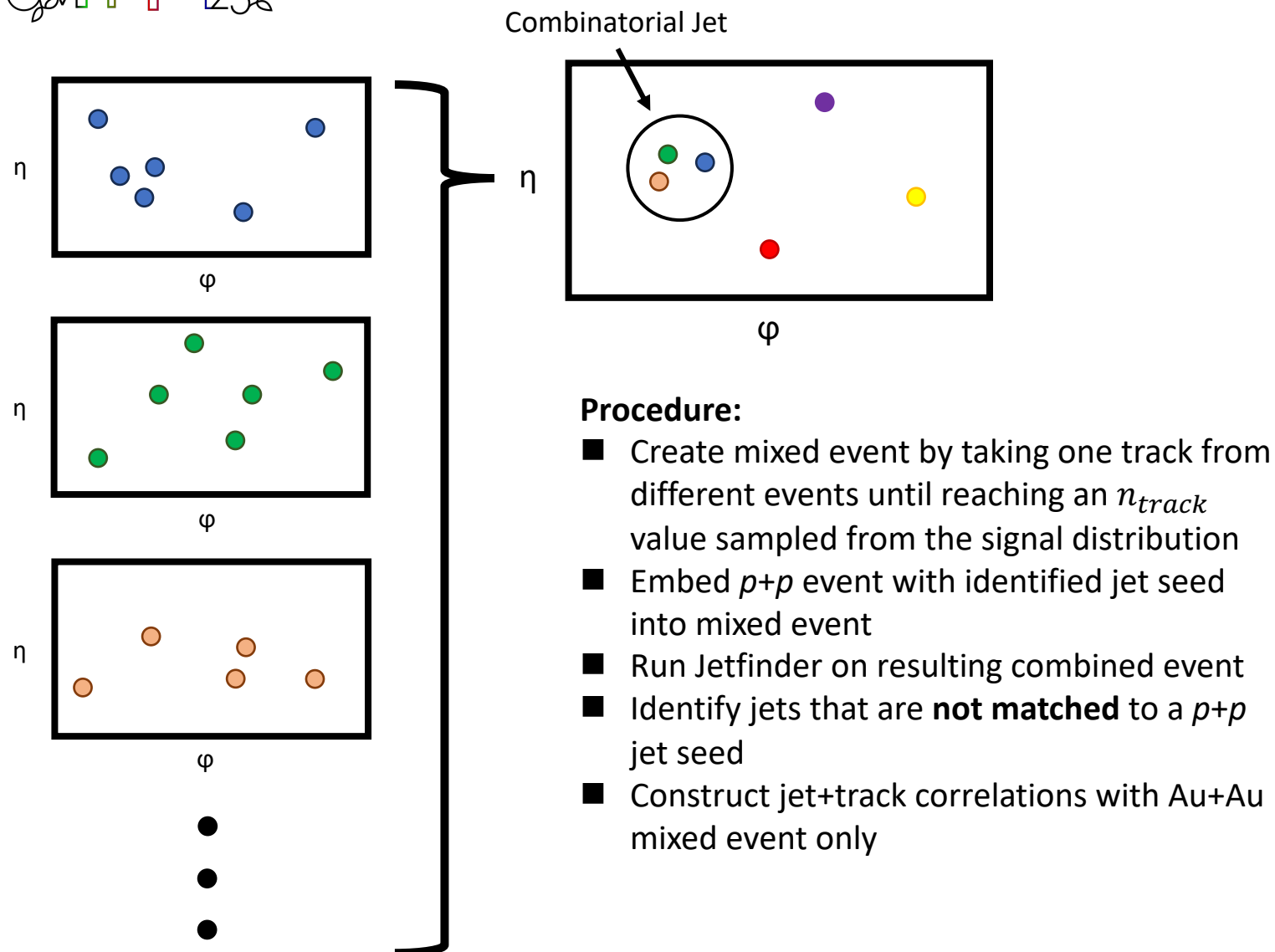
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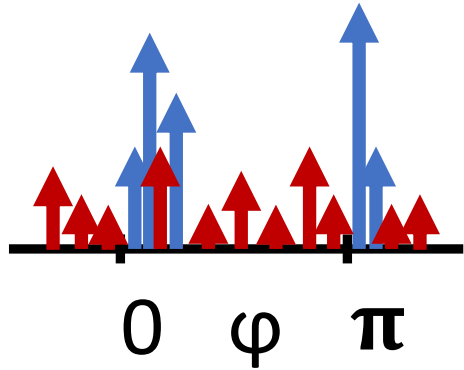


Evaluating Contribution from Combinatorial Jets



Correlated Background Removal: Embed into Mixed Constituent Event

p+p event
embedded in
Au+Au Mixed Event



+

Procedure:

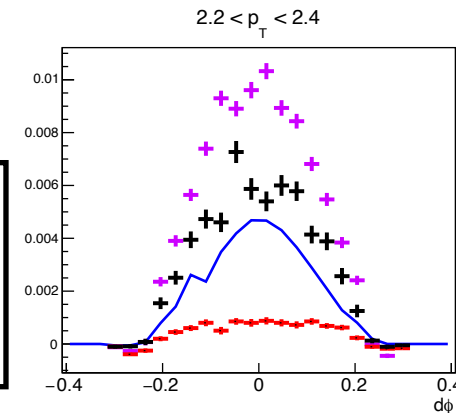
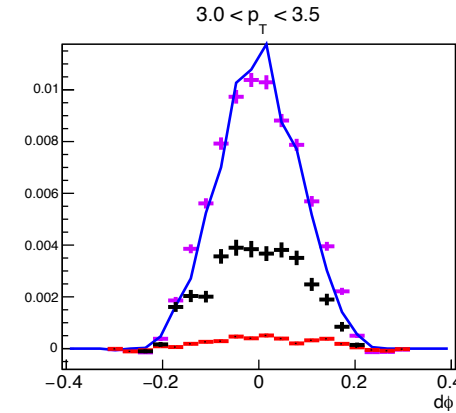
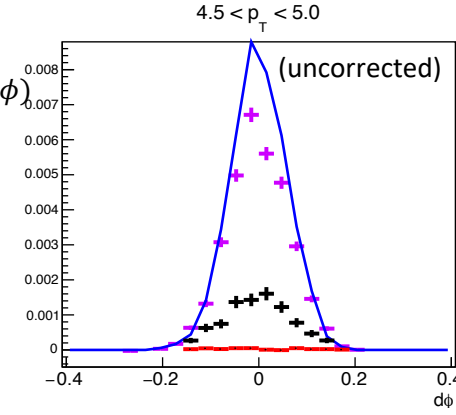
- Run Jetfinder on $p+p$ event
- Create Mixed event by taking one track from different events until a reasonable nTrack value is reached
- Combine $p+p$ event (with jet) and Mixed Event
- Run Jetfinder on resulting mixed event
- Perform correlations with mixed event

Pseudo-embedding → Matched Jets
Combinatorials → Unmatched jets

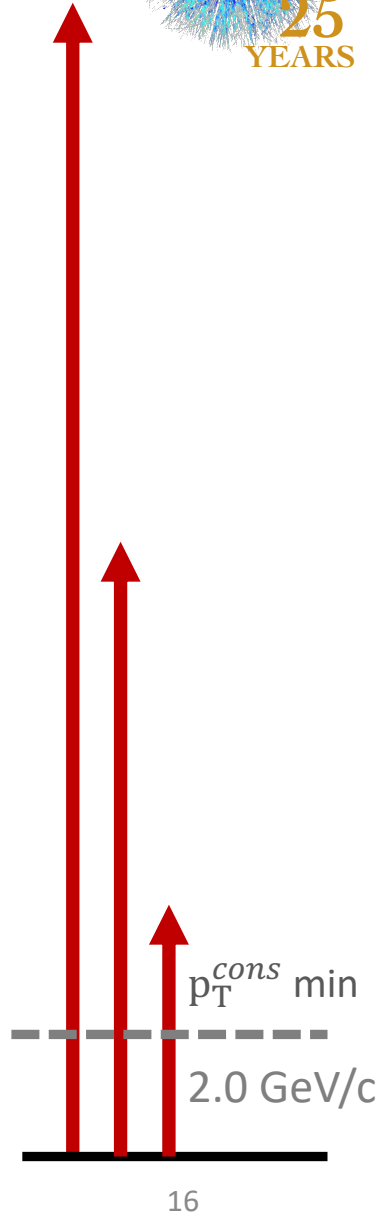
Fake Rate Determination:

- 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

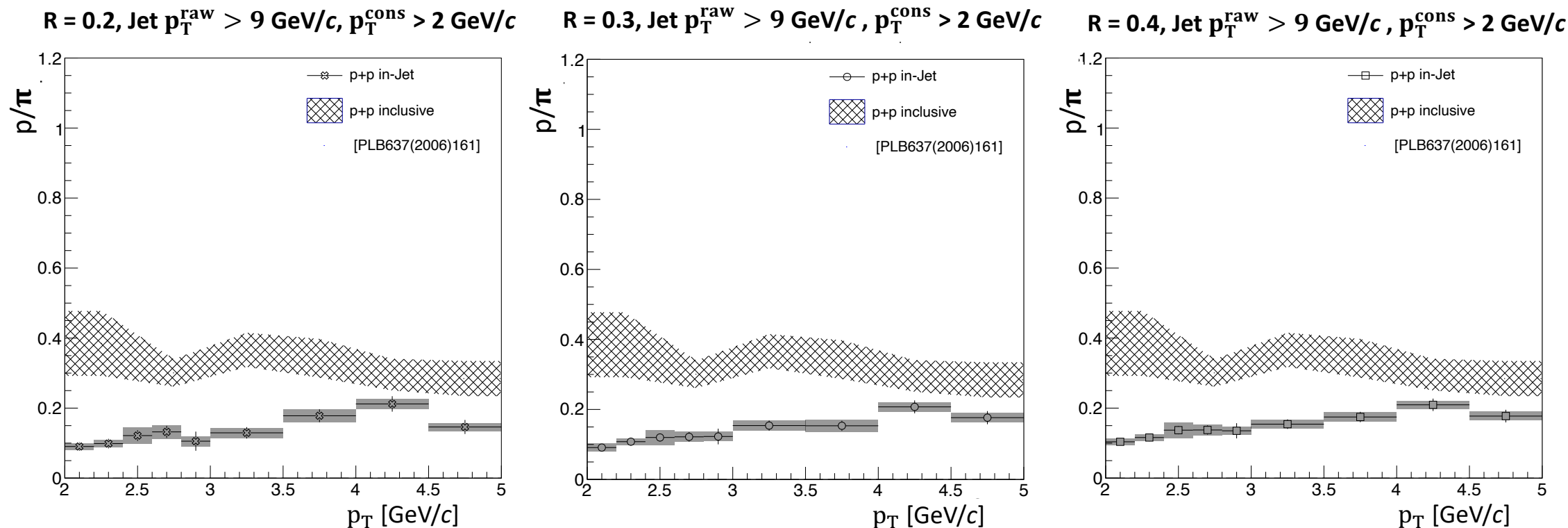
$$\frac{1}{N_{\text{jet}}} (dn_{\text{track}}/d\phi)$$



-- $p+p$
-- Au+Au
-- BG fluctuation
-- Combinatorial

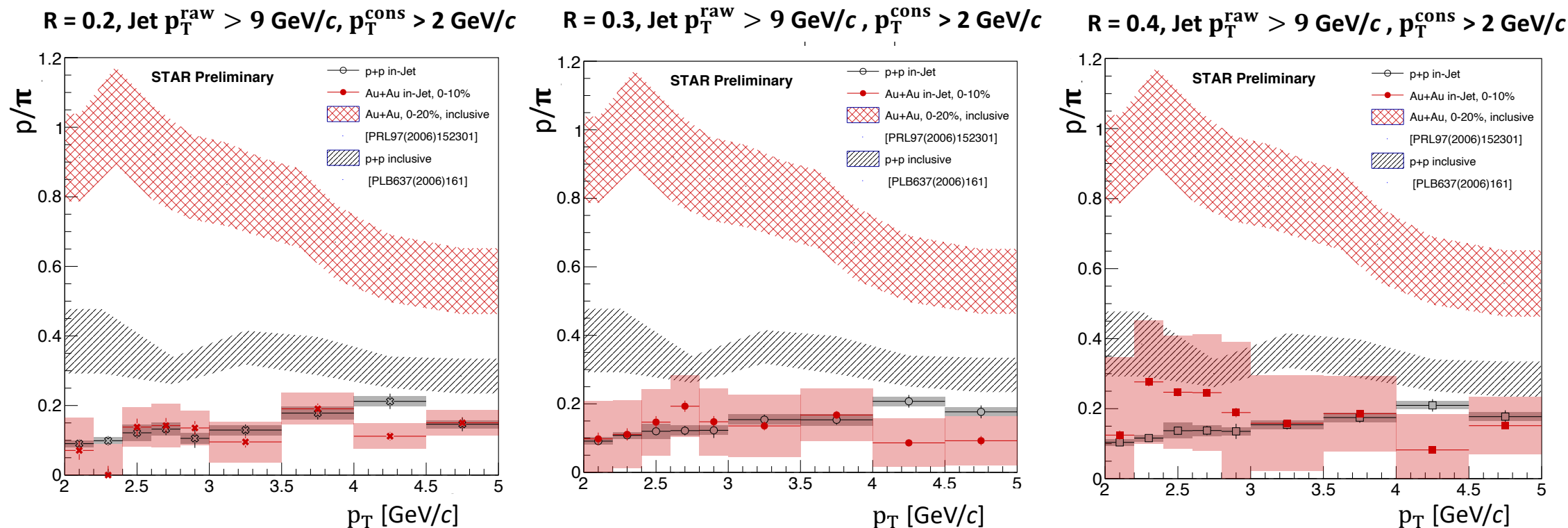


p/π Ratios In-Jet vs Inclusive Hadron



- In $p+p$ collisions, the in-jet p/π sits below p/π from inclusive hadrons, with no dependence on jet R

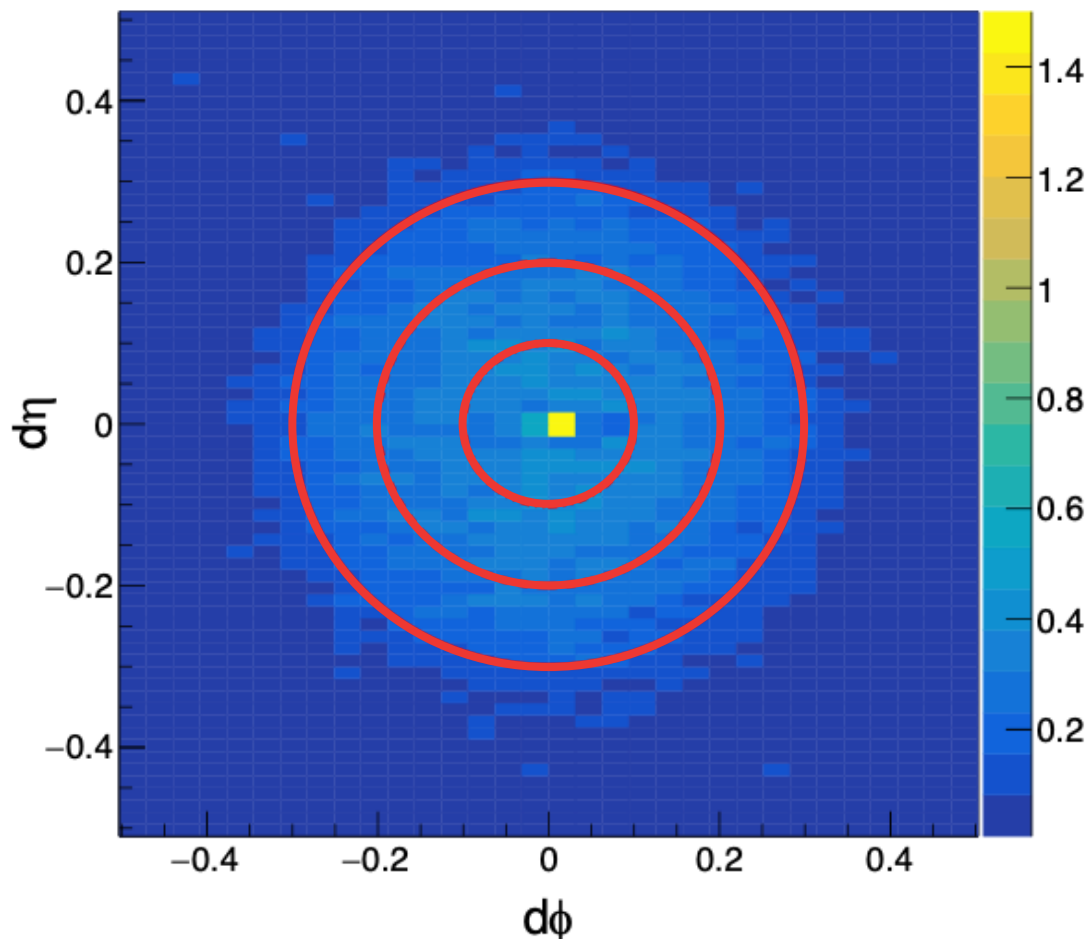
p/π Ratios In-Jet vs Inclusive Hadron



- 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

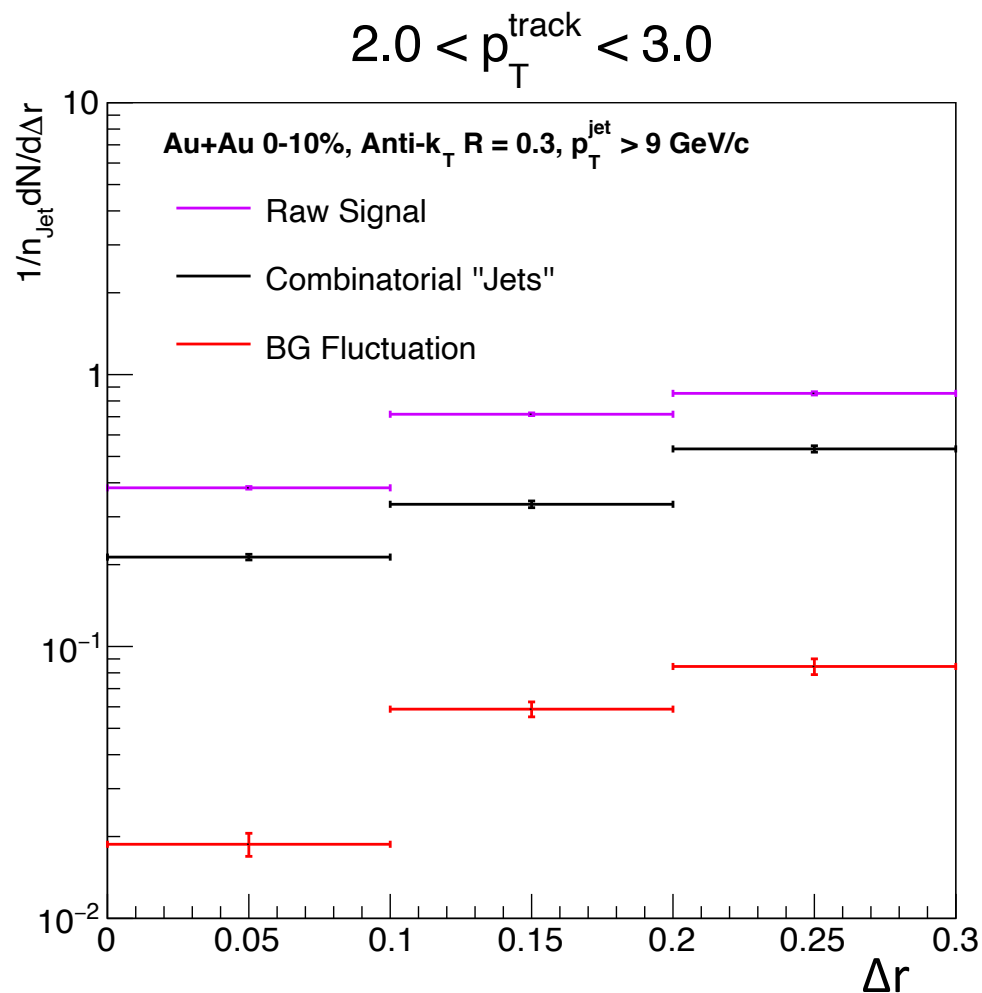
$$2.0 < p_T^{\text{track}} < 3.0 \text{ GeV}/c$$



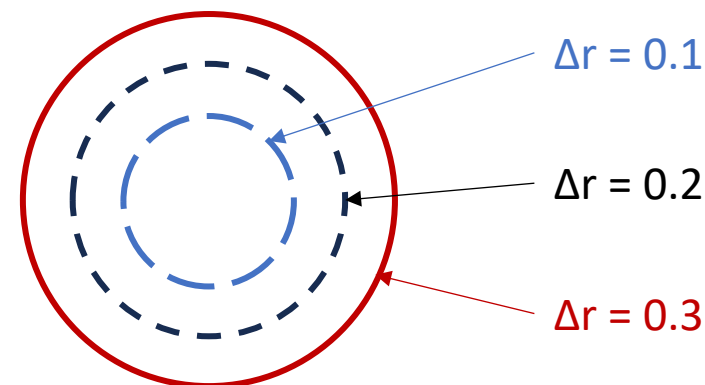
$$\Delta r = \sqrt{(\eta_{\text{jet}} - \eta_{\text{track}})^2 + (\phi_{\text{jet}} - \phi_{\text{track}})^2}$$

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

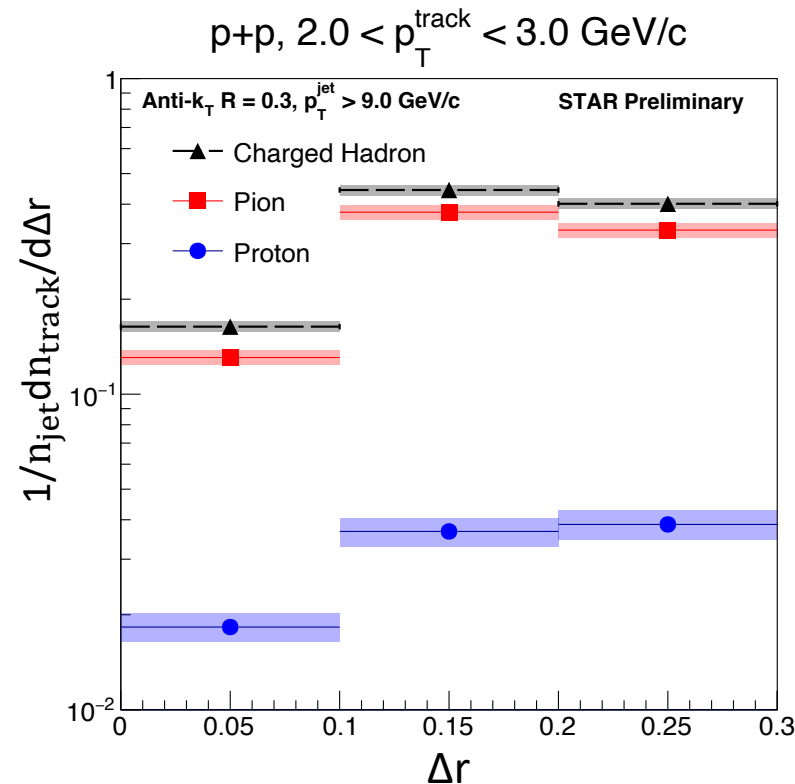
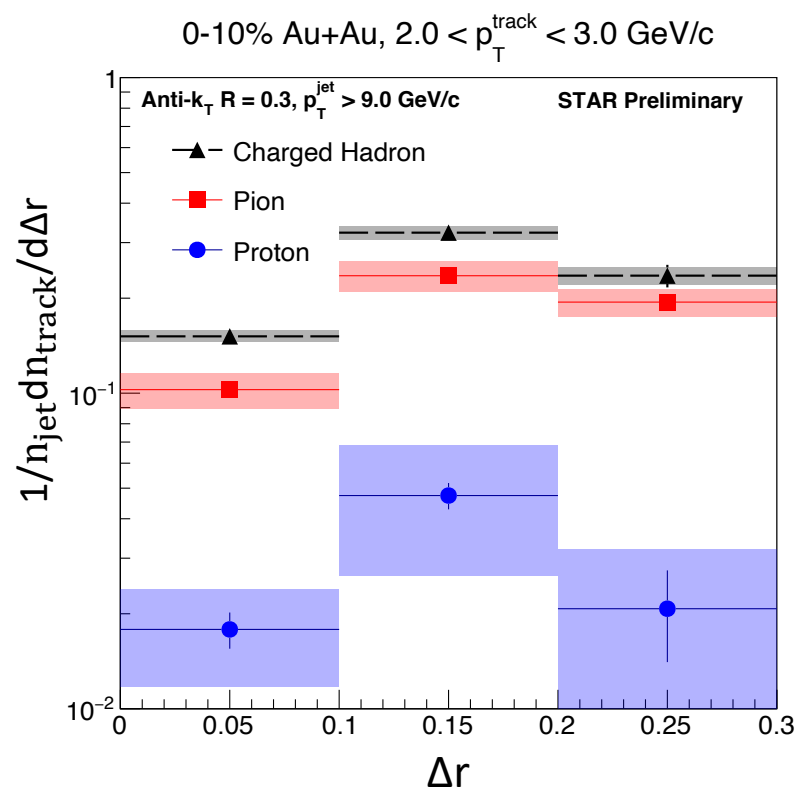
Correlated Background Correction in Δr



- 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

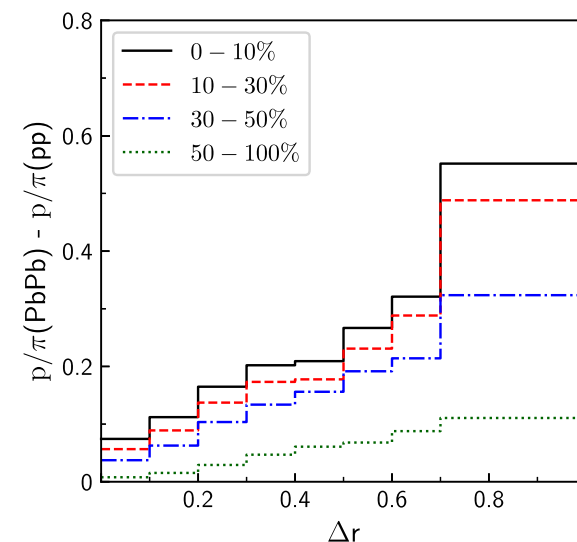
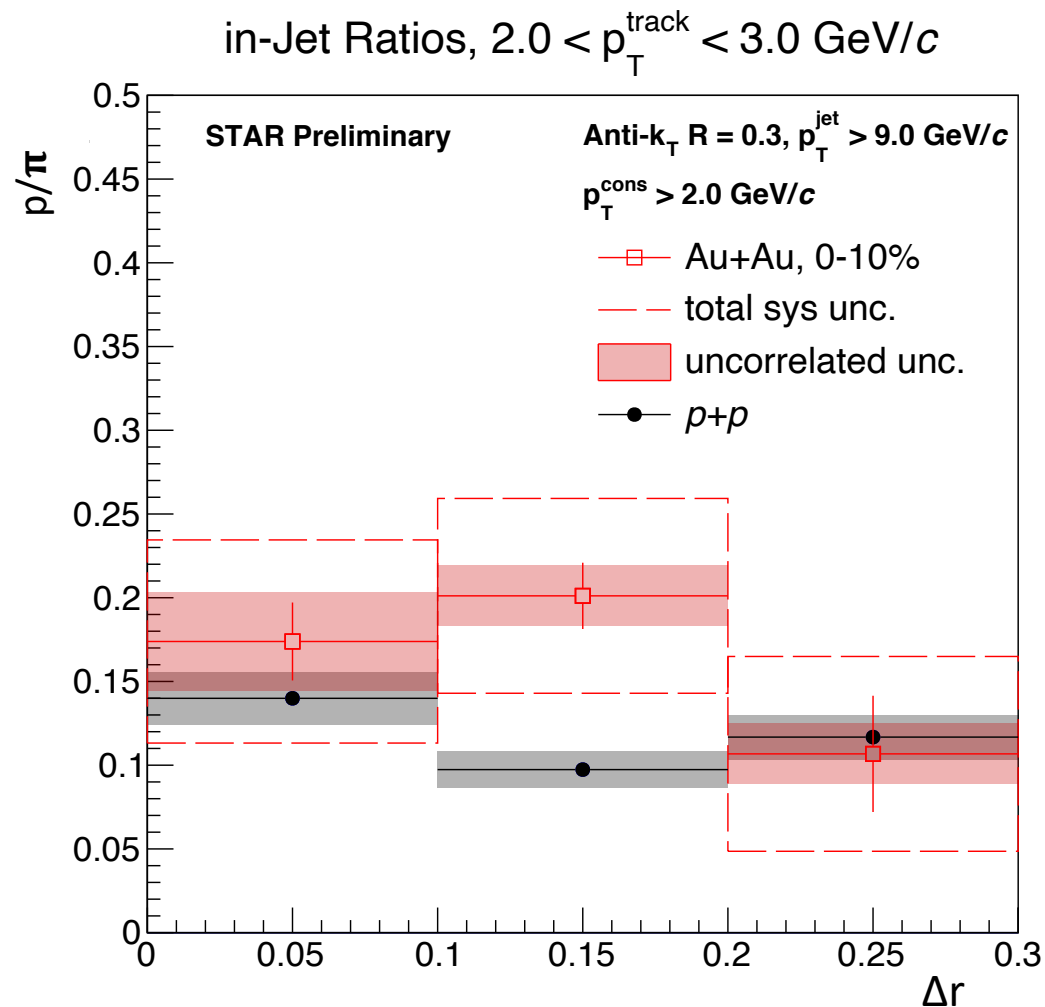


Identified Yields as a Function of Δr



- 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

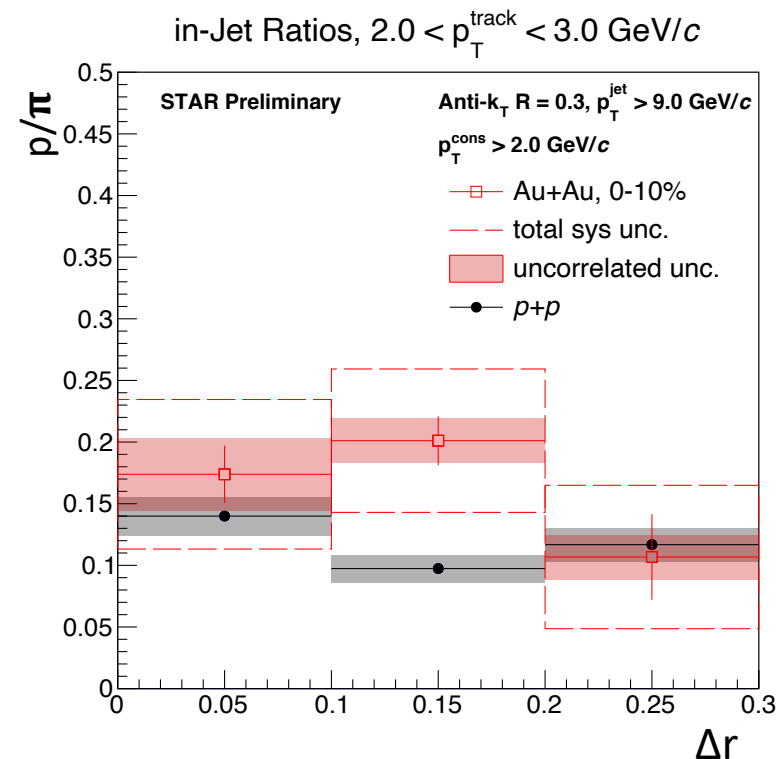
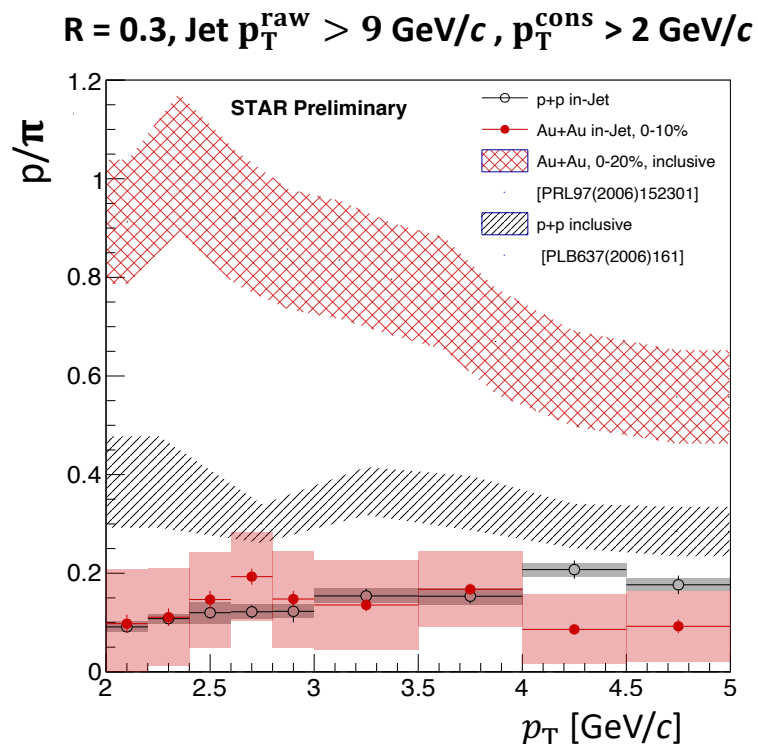
p/π Δr Dependence



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



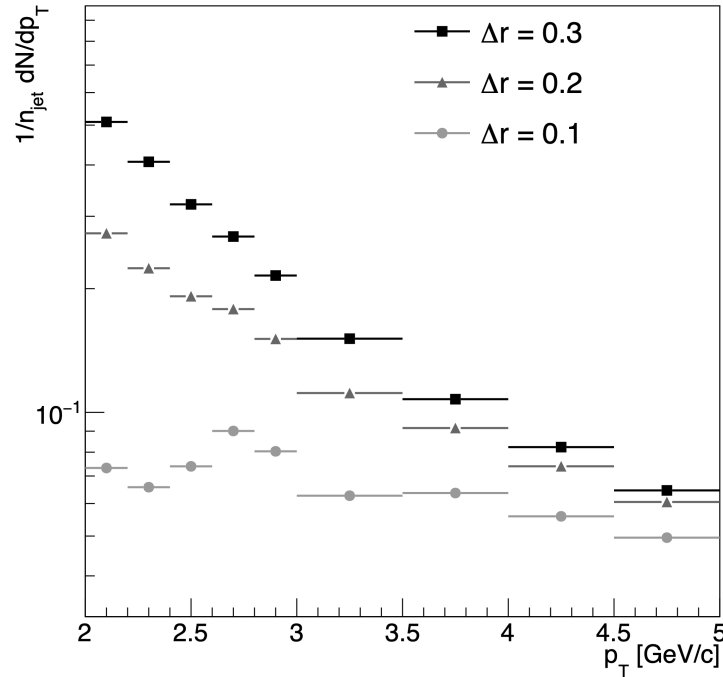
- We present the **first ever in-jet baryon-to-meson ratio measurement from STAR**, with both Anti- k_T Jet R and Δr dependence
- For every jet R studied, with $p_T^{\text{cons}} > 2.0 \text{ GeV}/c$ and jet $p_T^{\text{raw}} > 9.0 \text{ GeV}/c$, in-jet p/π measured in central Au+Au are consistent with those from $p+p$, with **no evidence for enhancement** between the two systems
- Selecting tracks with $2.0 < p_T < 3.0 \text{ GeV}/c$ in jets with $R = 0.3$, $p_T^{\text{cons}} > 2.0 \text{ GeV}/c$ and jet $p_T^{\text{raw}} > 9.0 \text{ GeV}/c$, **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 $\Delta r = 0.15$**

Backup

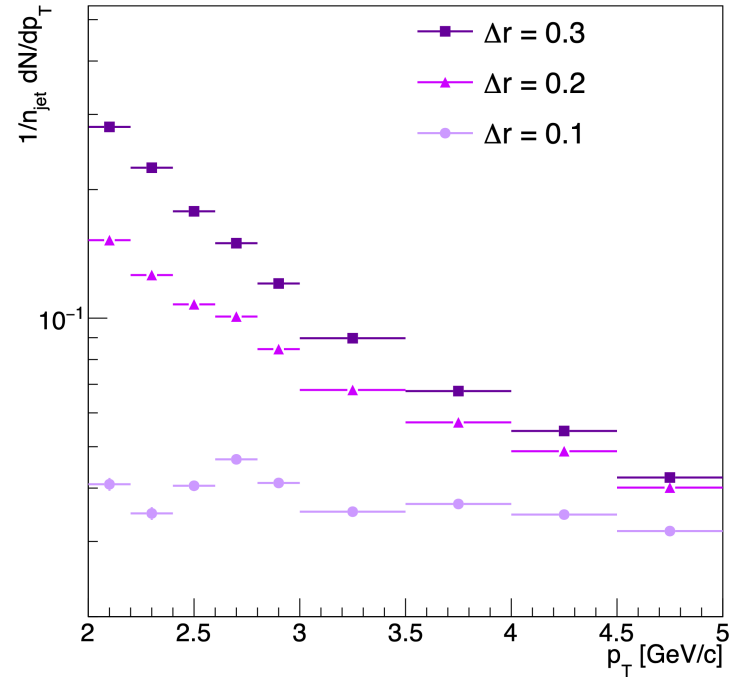
Yields as a function of ΔR



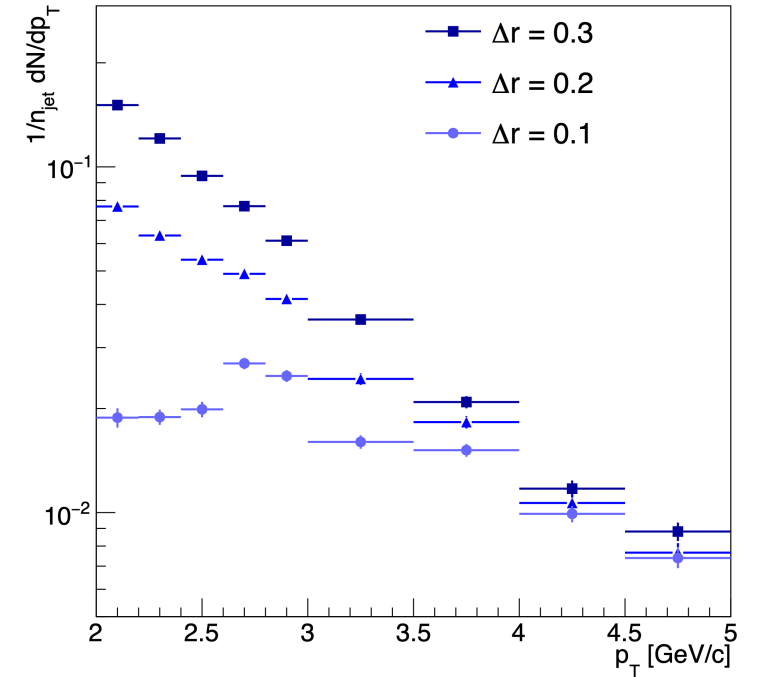
Raw Charged Hadron Yield



Raw Pion Yield

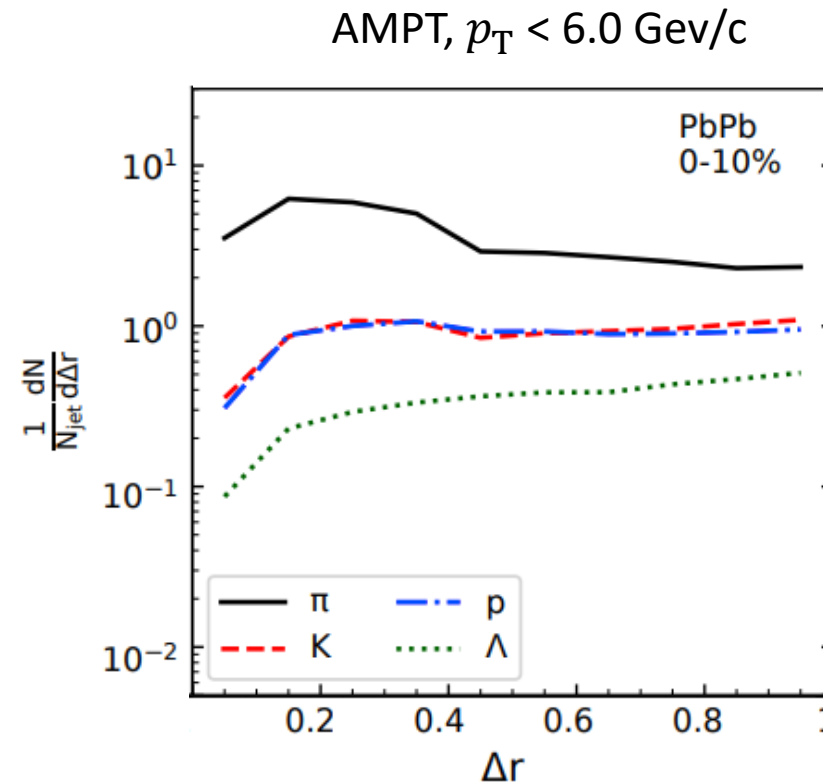
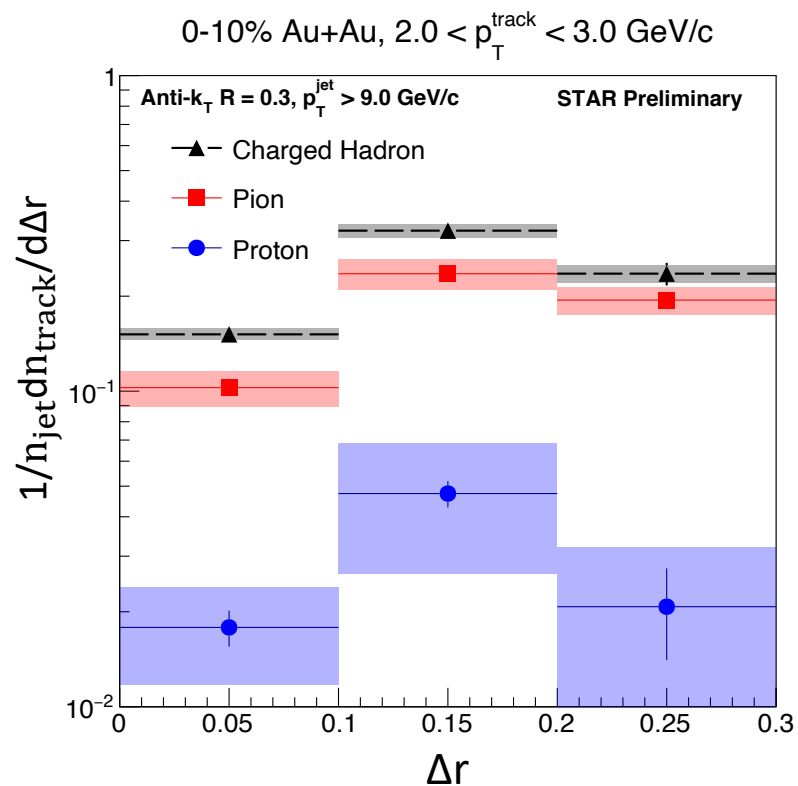


Raw Proton Yield



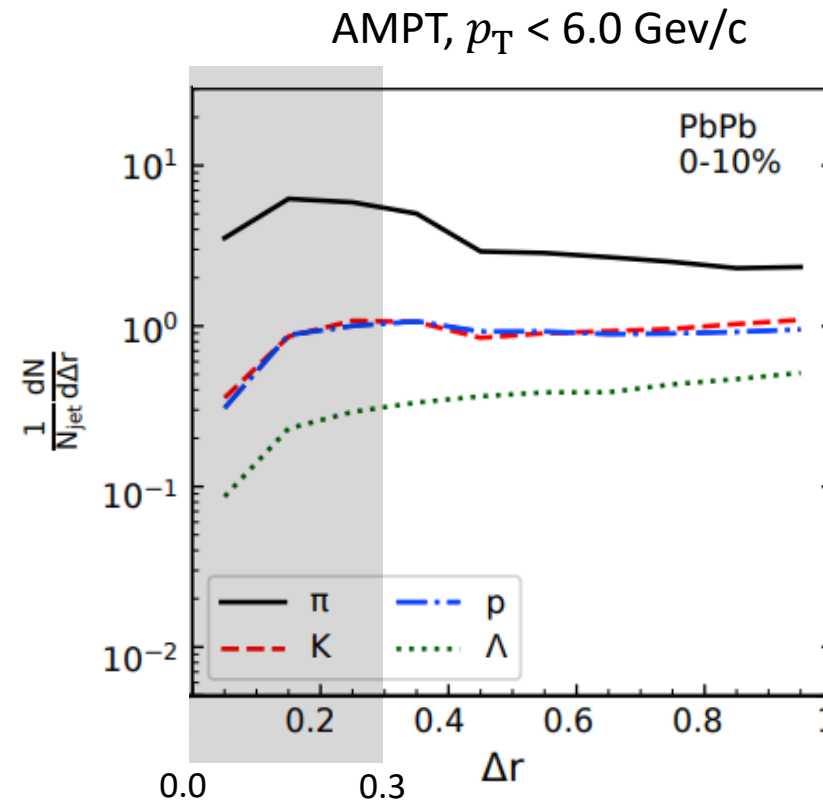
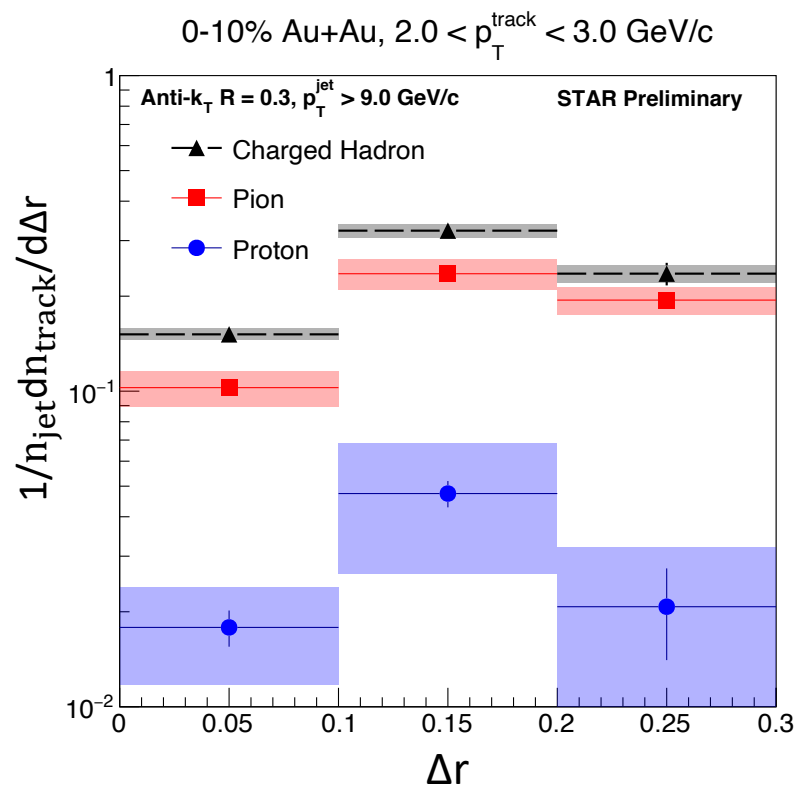
- Raw (before correlated background correction) yields for charged hadrons, identified protons and pions from jets with $R = 0.3$ at $\Delta r = 0.1, 0.2, 0.3$
- To isolate yield for each ring in Δr , we subtract smaller Δr yields from larger Δr yields

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

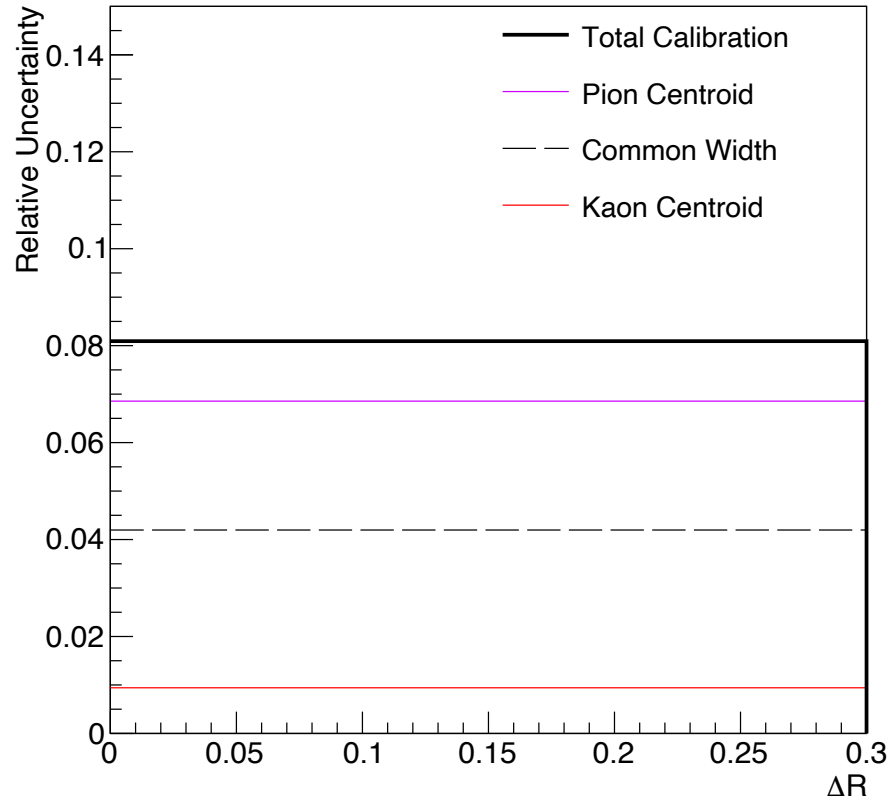
Identified Yields as a function of Δr



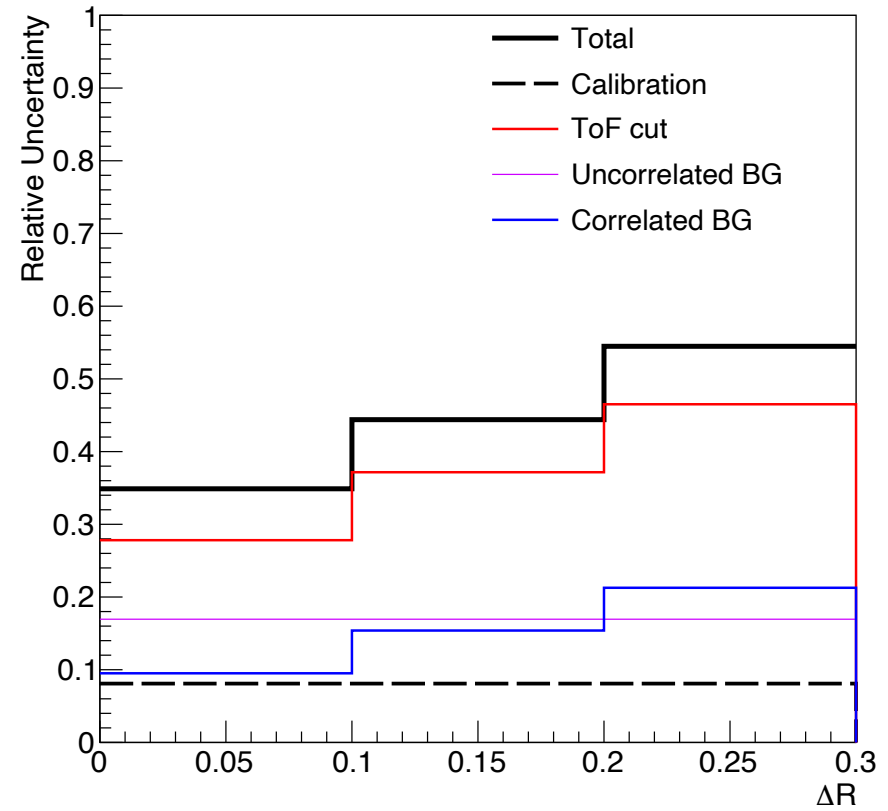
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- Highlighted region shows our radial coverage

Au+Au p/ π ΔR Systematics

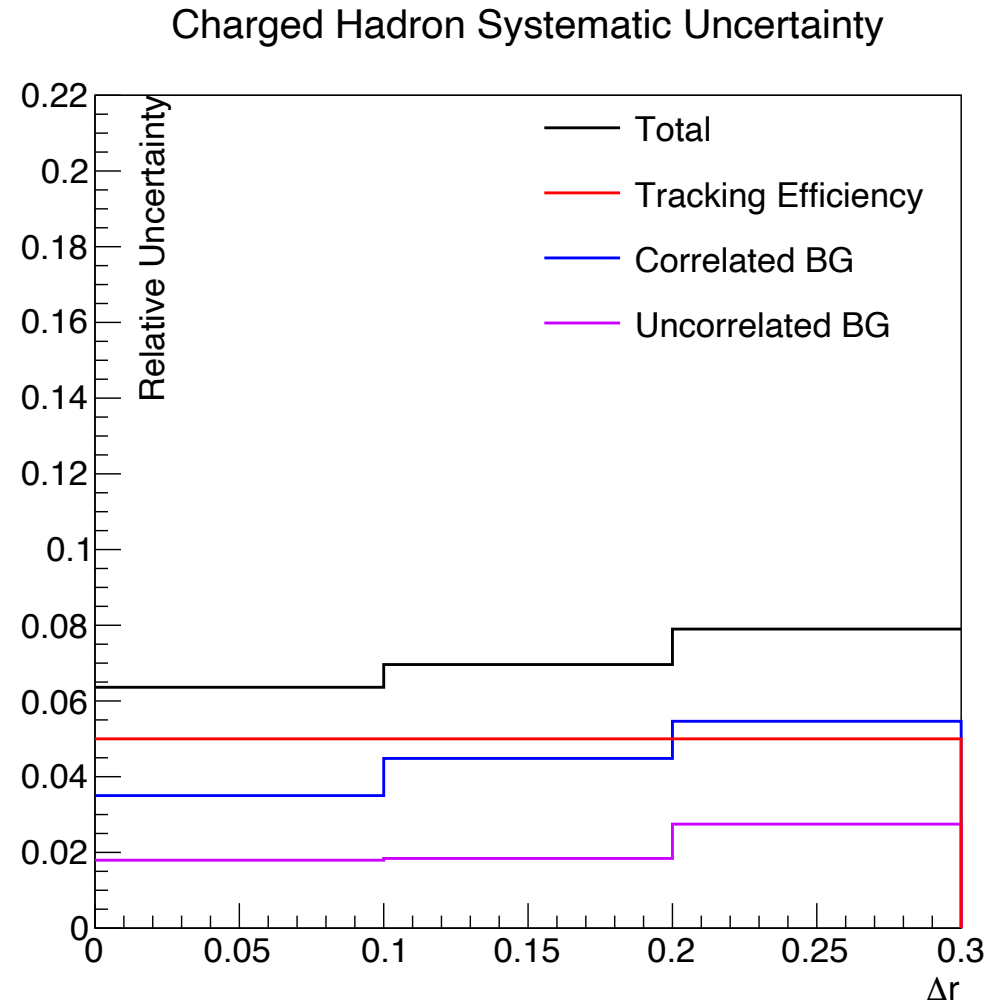
p/ π Systematic Uncertainty from Calibration, R = 0.3



p/ π Systematic Uncertainty, R = 0.3

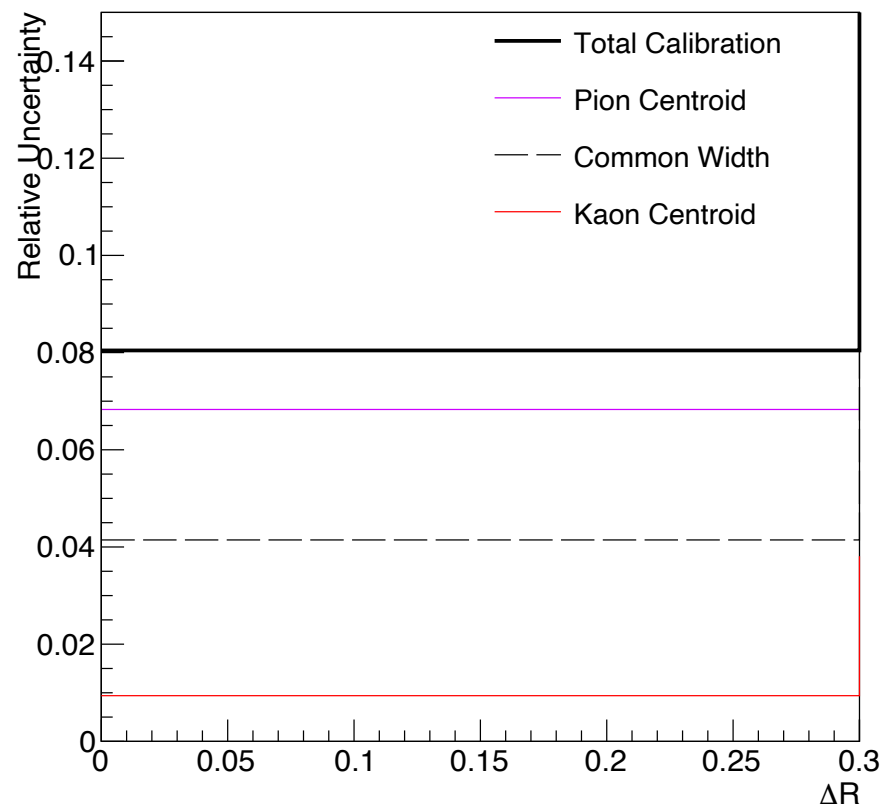


Au+Au Charged Hadron Yield Δr Systematics

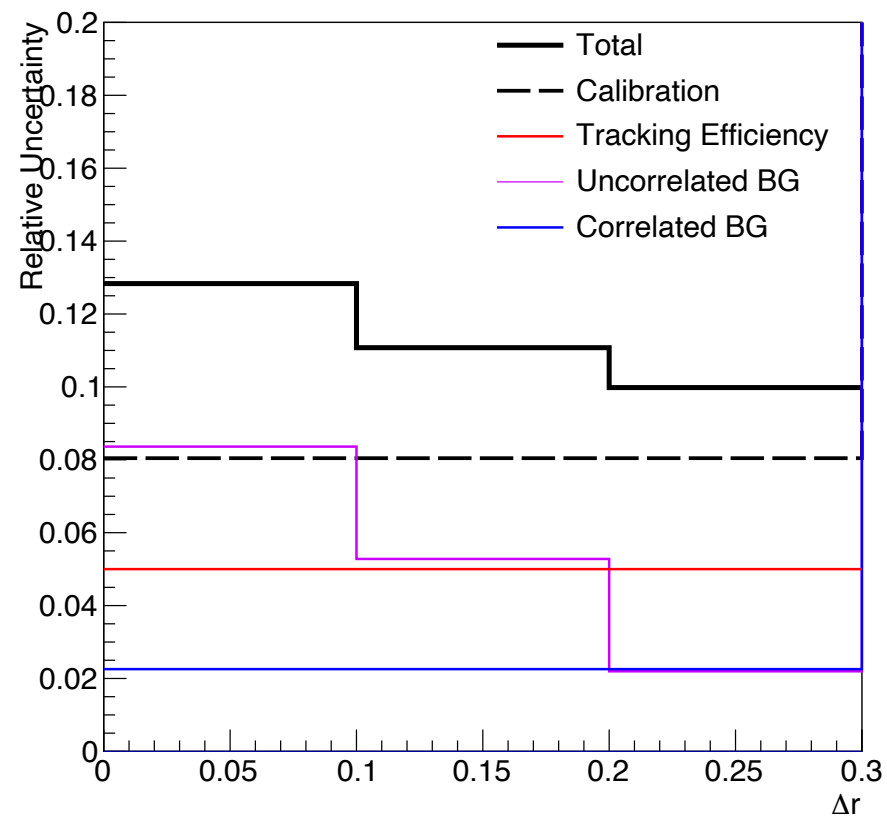


Au+Au Pion Yield Δr Systematics

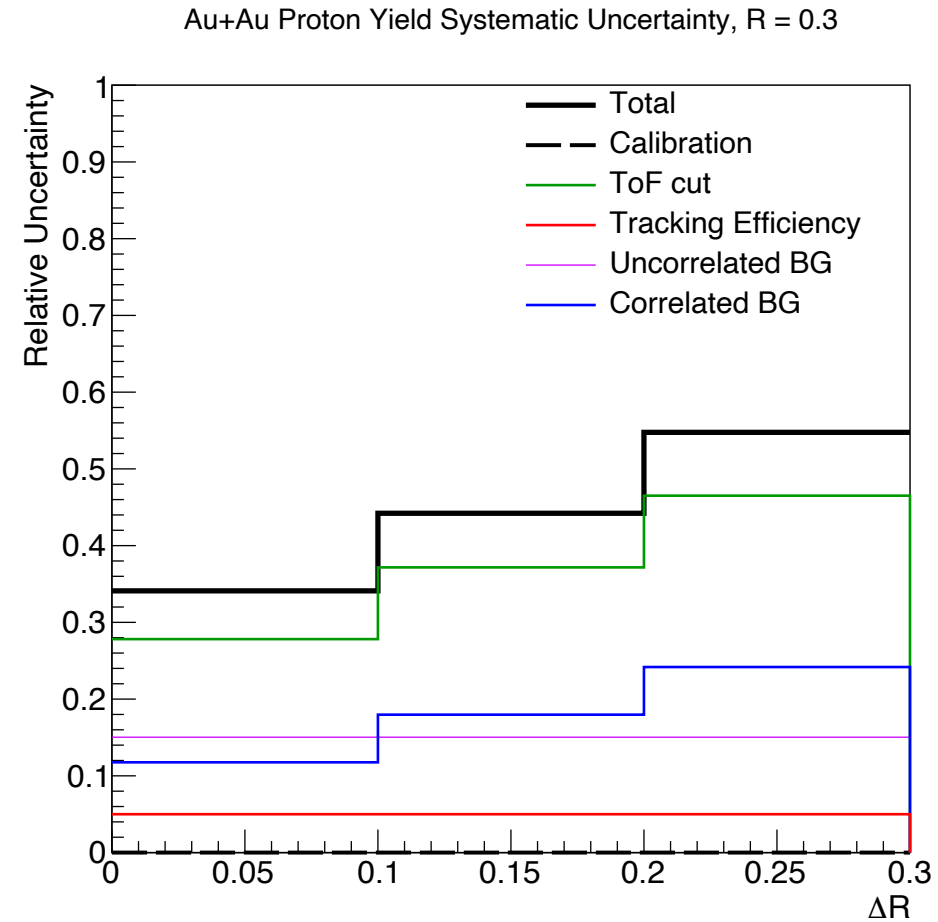
Systematic Uncertainty from Calibration, $R = 0.3$



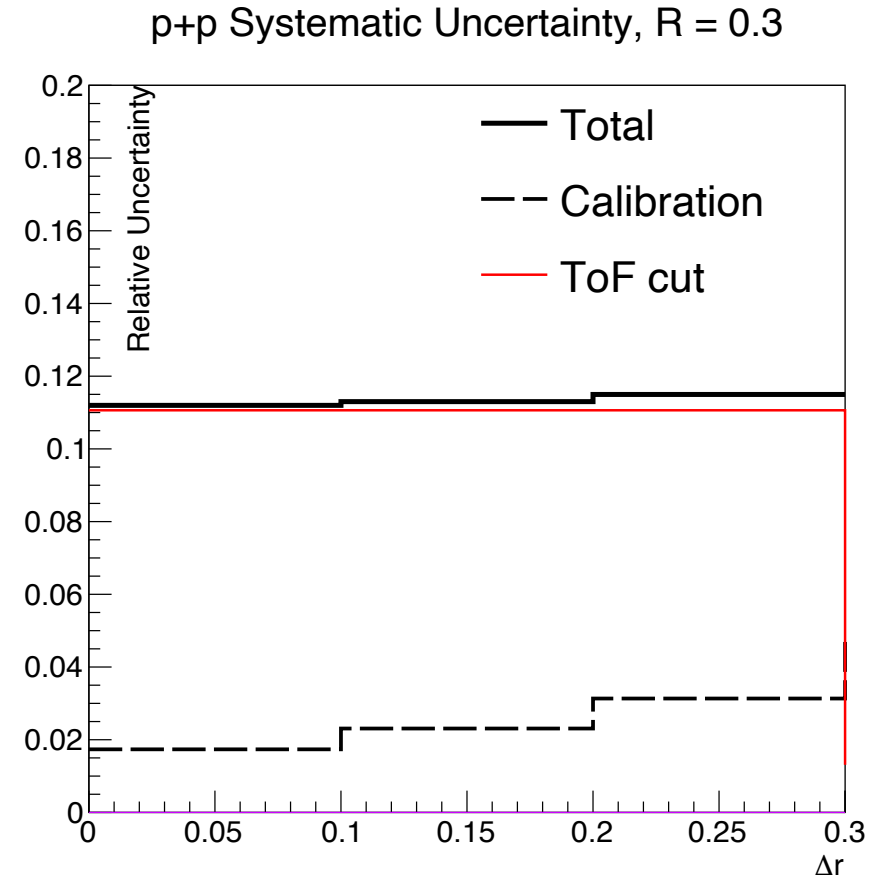
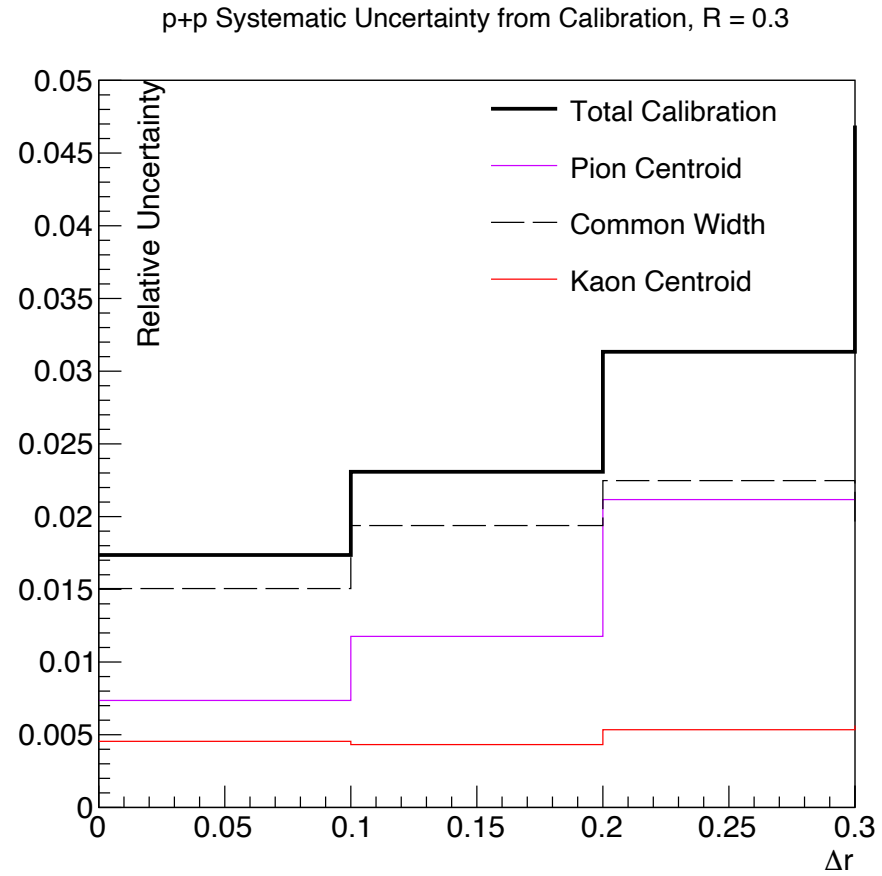
Au+Au Pion Yield Systematic Uncertainty, $R = 0.3$



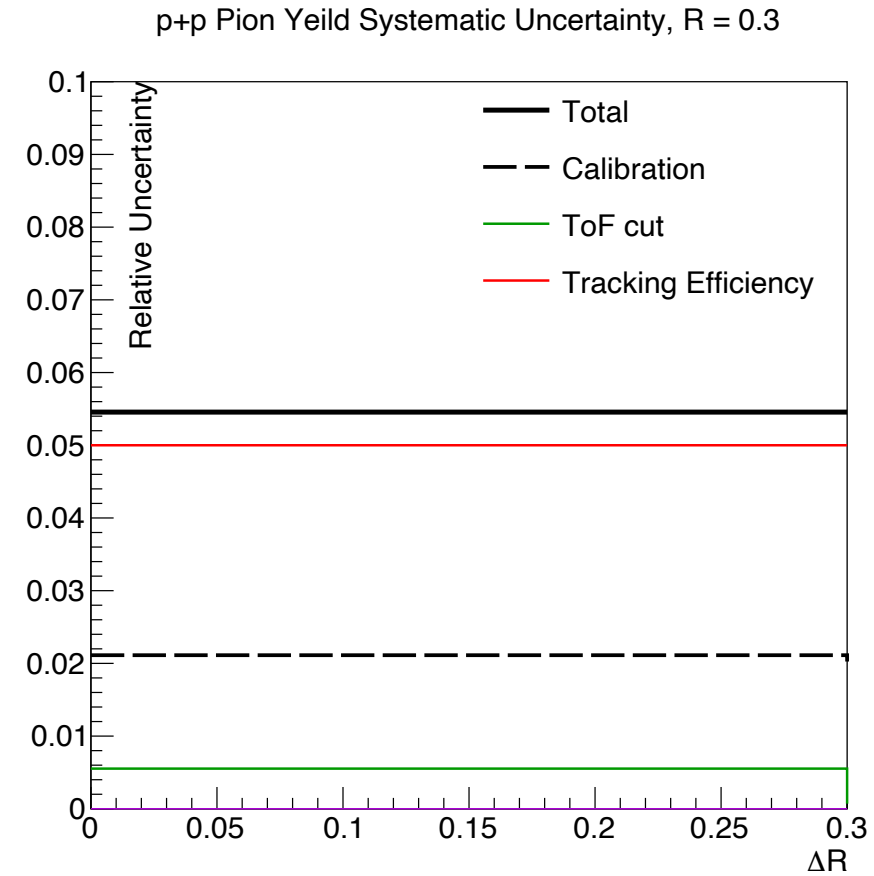
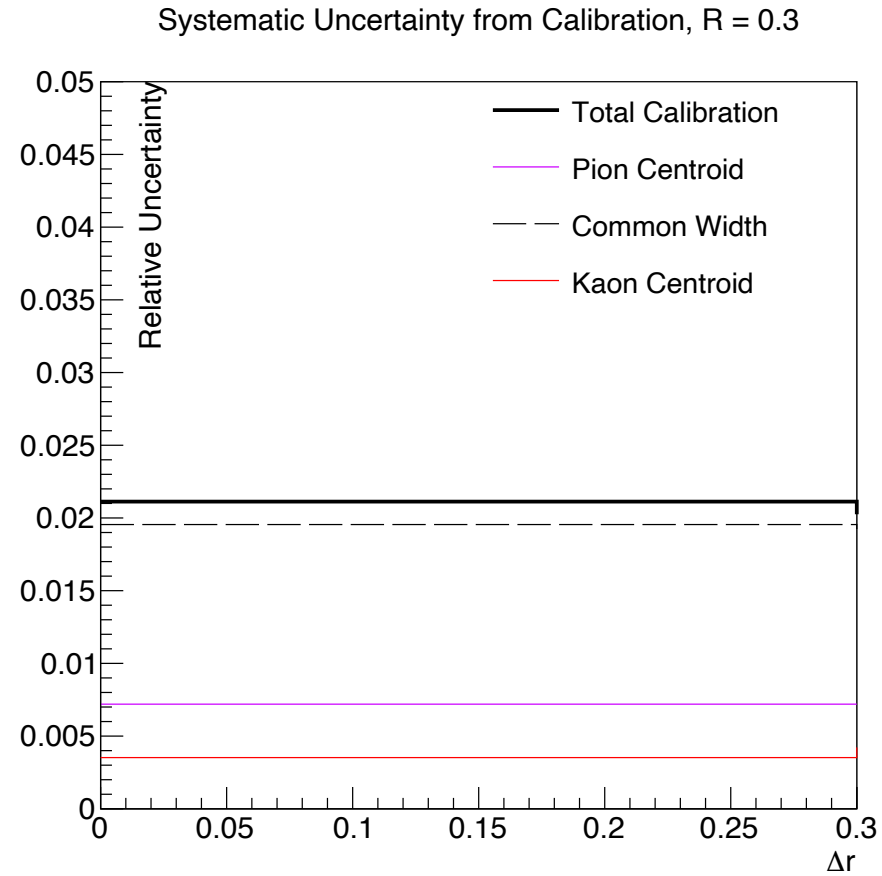
Au+Au Proton Yield Δr Systematics



p+p p/ π Δr Systematics

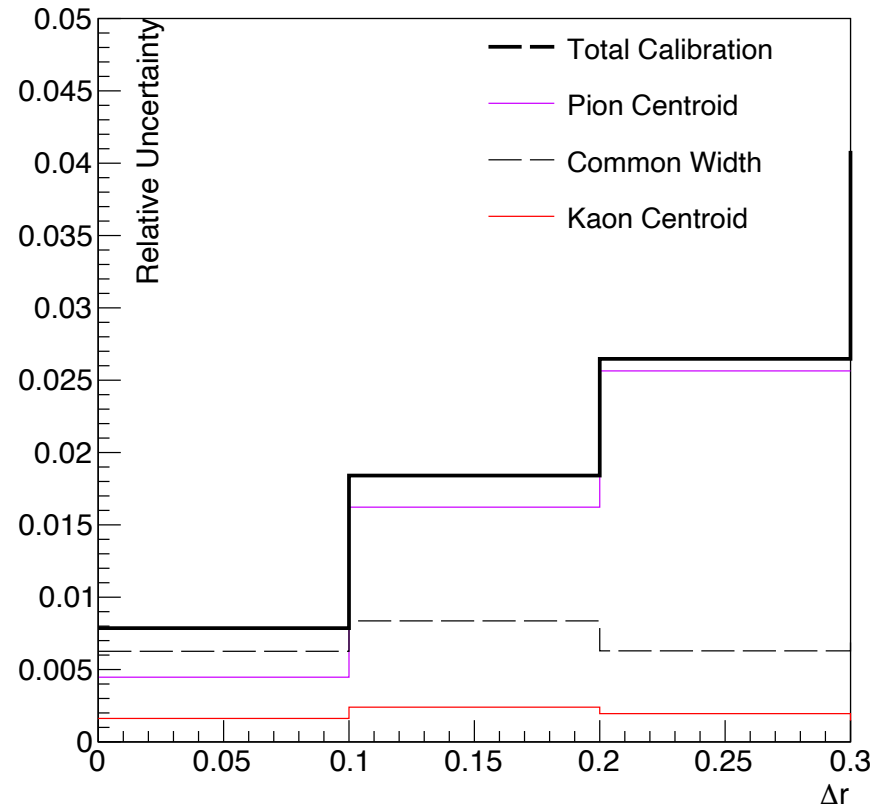


p+p Pion Yield Δr Systematics

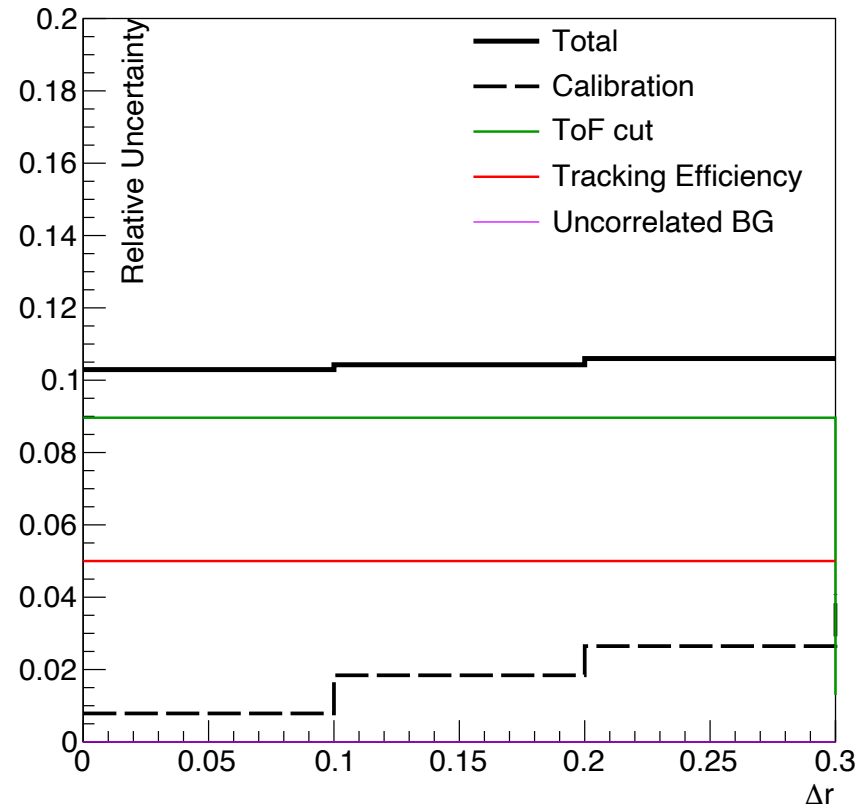


p+p Proton Yield Δr Systematics

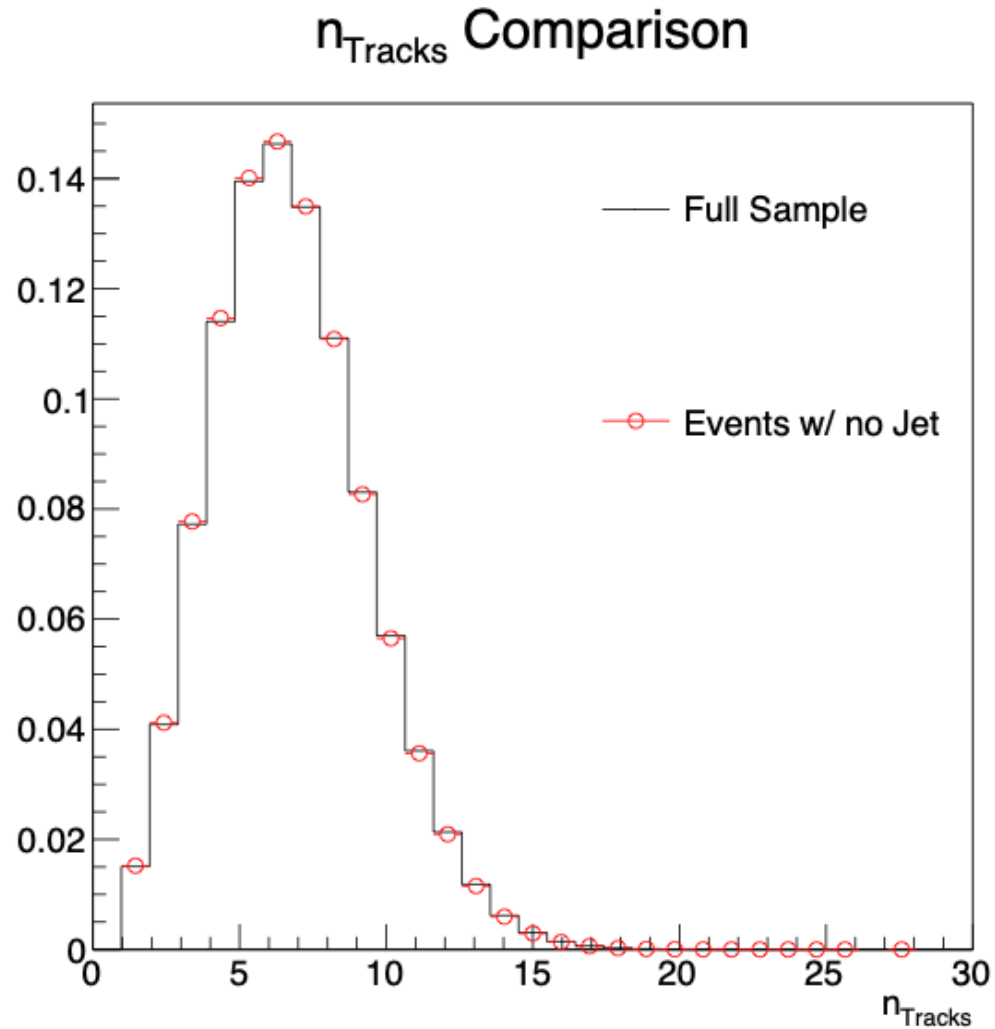
Systematic Uncertainty from Calibration, $R = 0.3$



p+p Proton Yield Systematic Uncertainty, $R = 0.3$



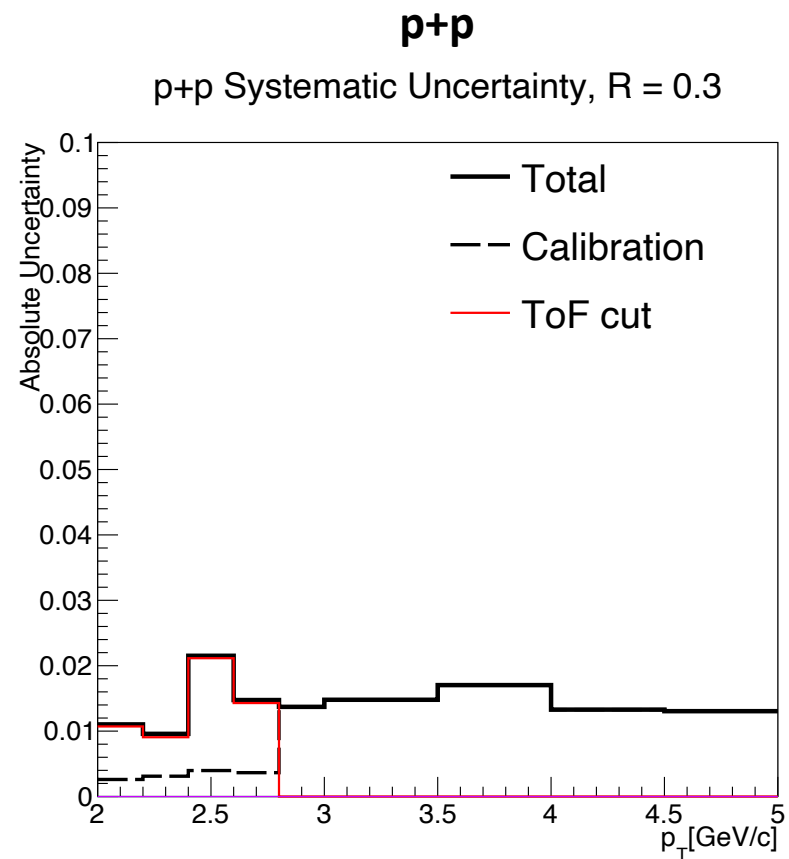
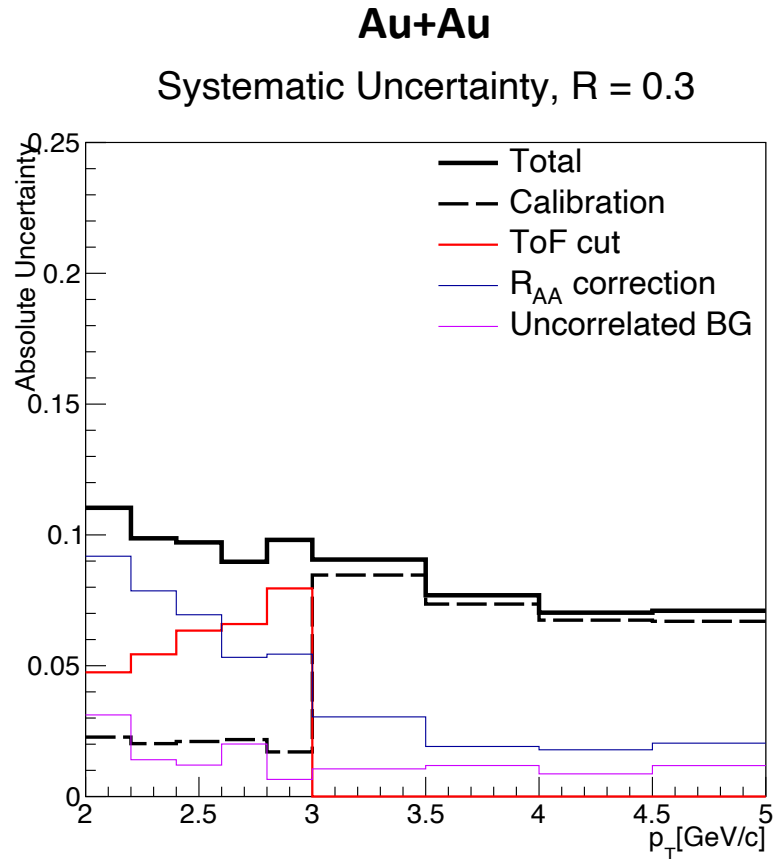
Combinatorial Evaluation Uncertainty



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 n_{Track} per event distribution from signal.
- Constructing Mixed Events with non-jetty n_{track} distribution yields a 0.2% variation in resulting Fake rate

Systematic Uncertainty



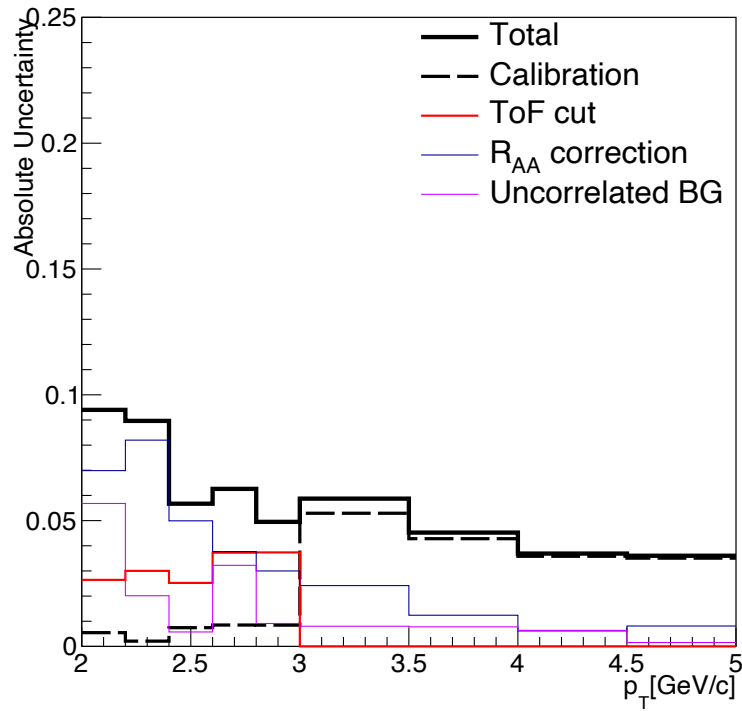
- One representative Jet R is shown here, all Systematics included in backup

Systematic Sources:

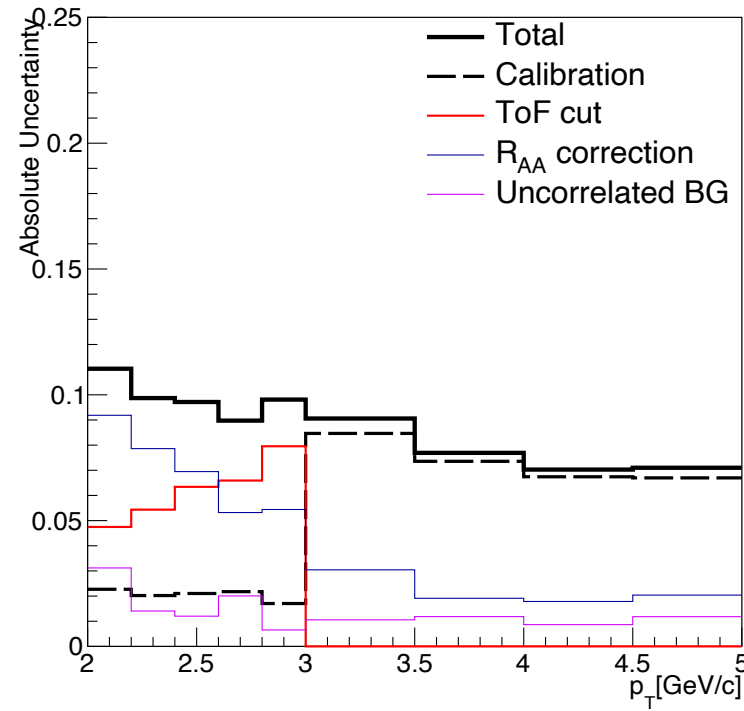
- dE/dx calibration, determined by varying each input parameter for gaussian fits
- ToF cut placement for proton identification below 3.0 GeV/c
- Uncorrelated background subtraction, determined by varying UE definition
- R_{AA} correction is included in nominal, for systematic uncertainty on fake rate,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

Au+Au Systematics

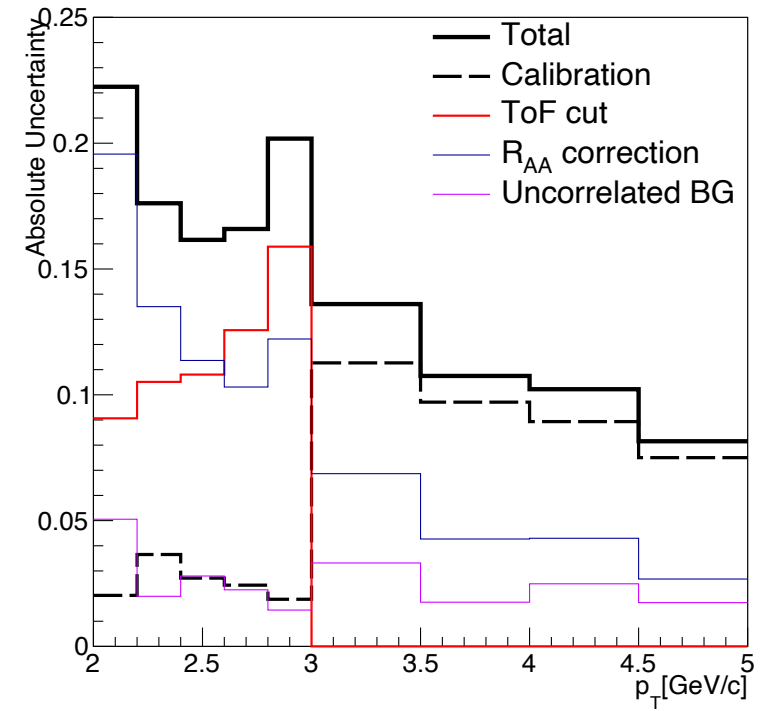
Systematic Uncertainty, $R = 0.2$



Systematic Uncertainty, $R = 0.3$

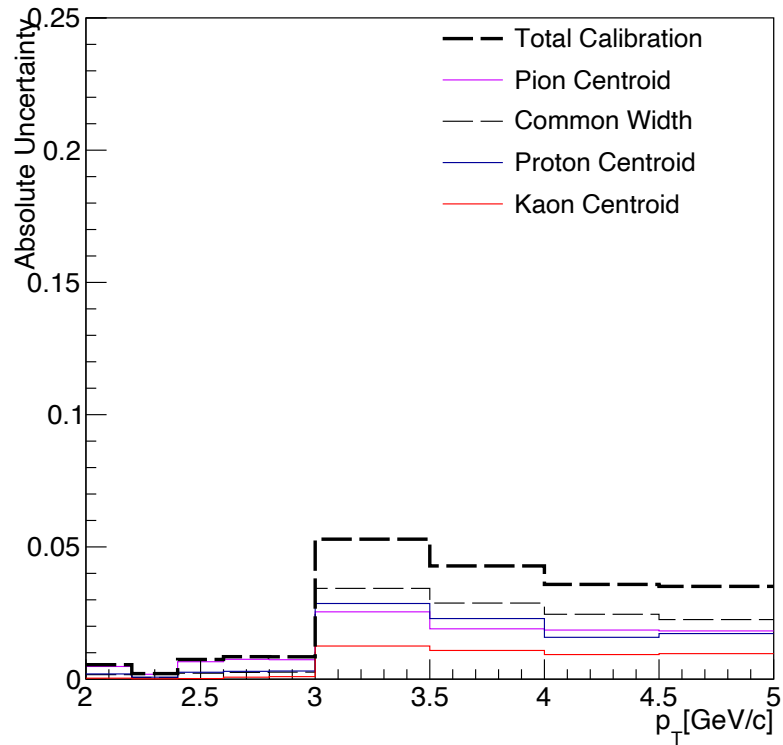


Systematic Uncertainty, $R = 0.4$

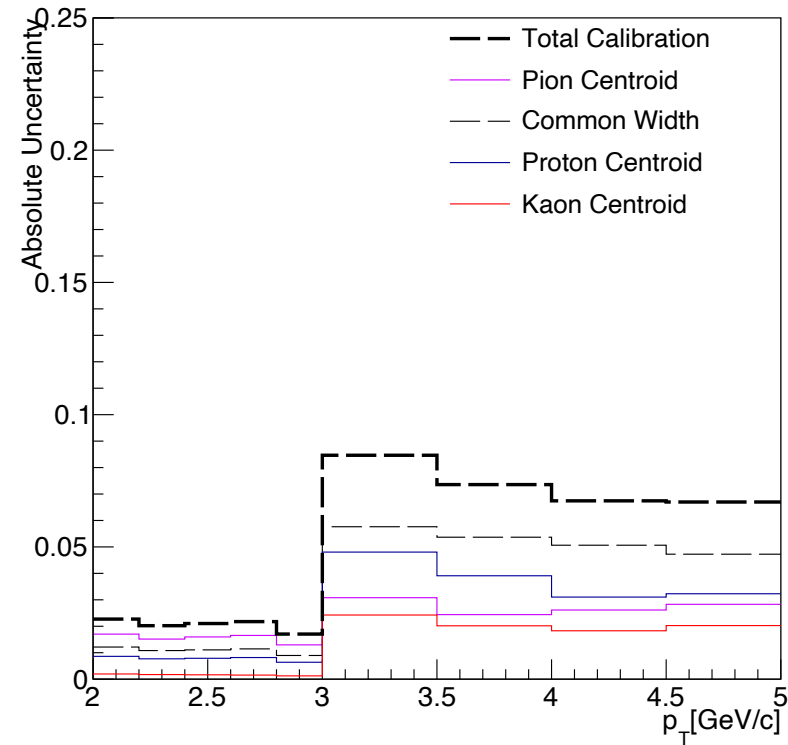


Au+Au, dE/dx Calibration Breakdown

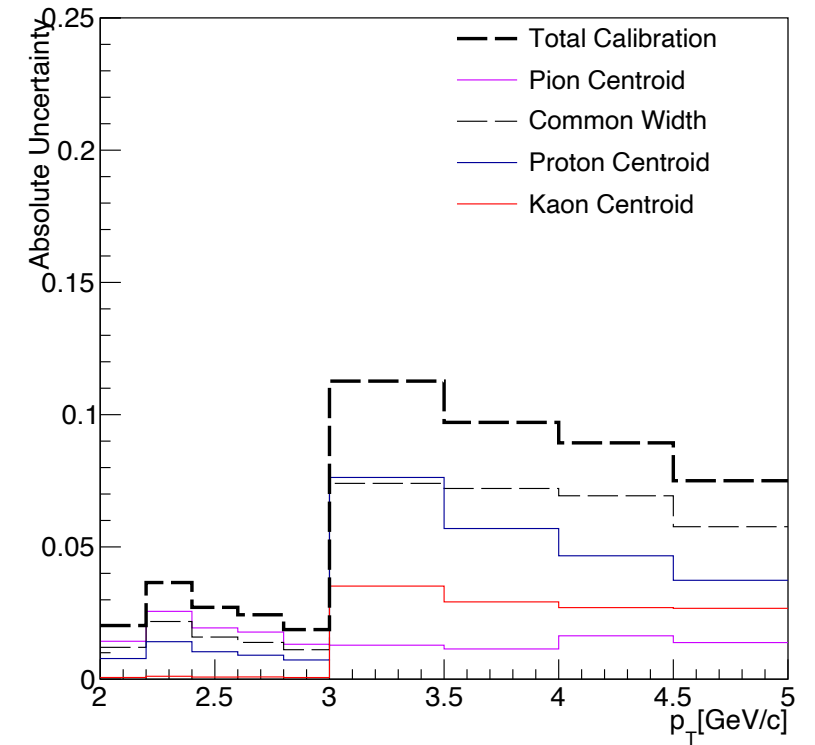
Systematic Uncertainty from Calibration, $R = 0.2$



Systematic Uncertainty from Calibration, $R = 0.3$

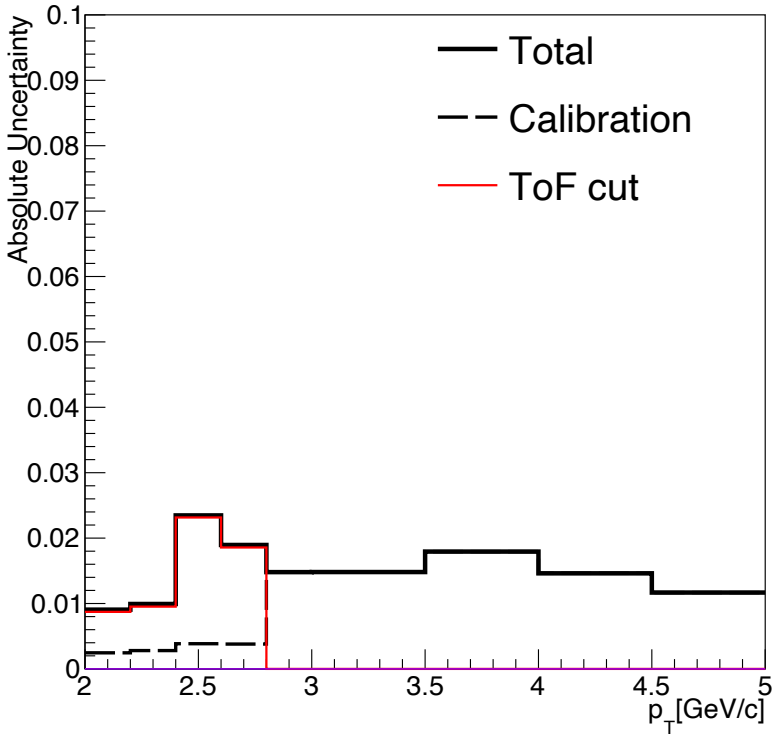


Systematic Uncertainty from Calibration, $R = 0.4$

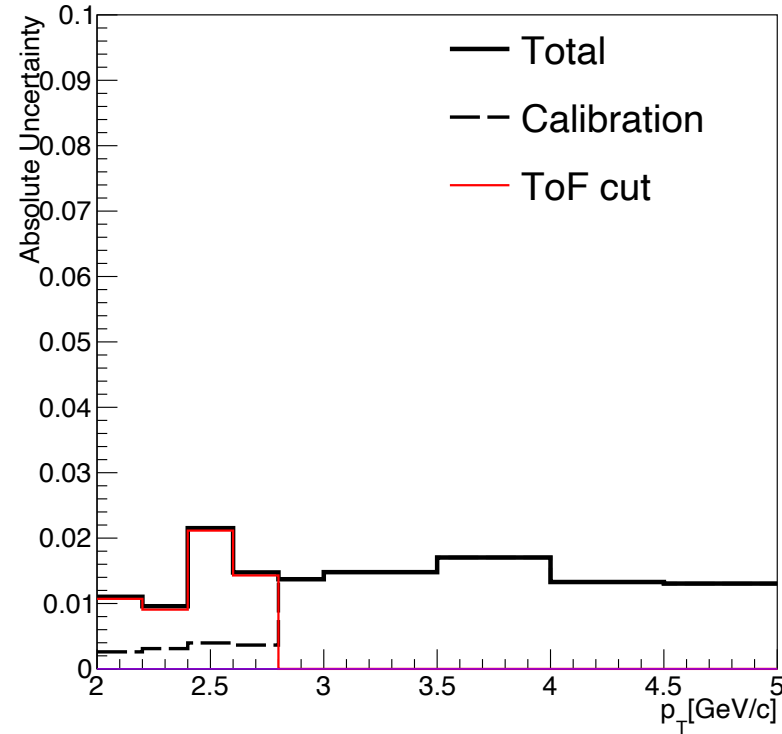


p+p Systematics

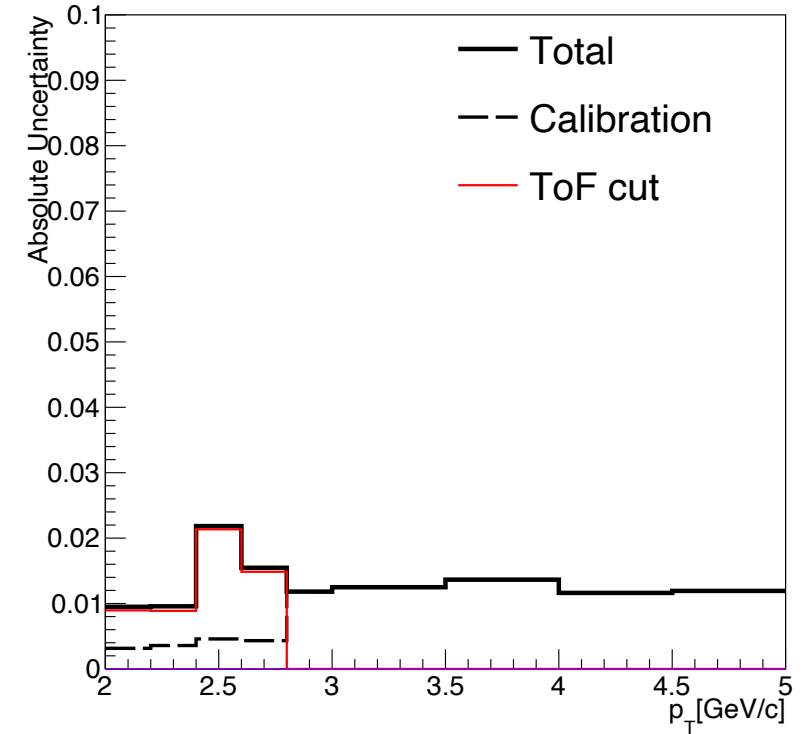
p+p Systematic Uncertainty, $R = 0.2$



p+p Systematic Uncertainty, $R = 0.3$



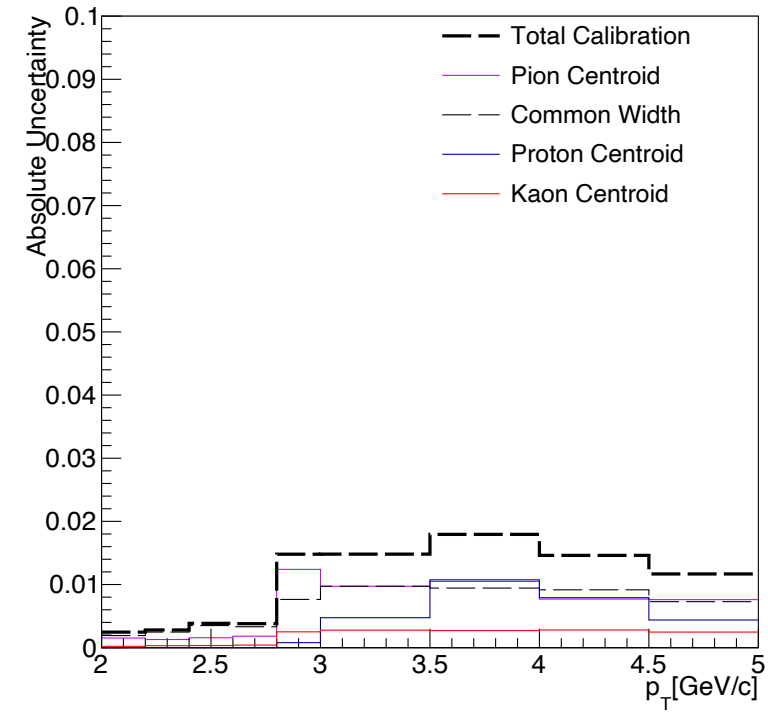
p+p Systematic Uncertainty, $R = 0.4$



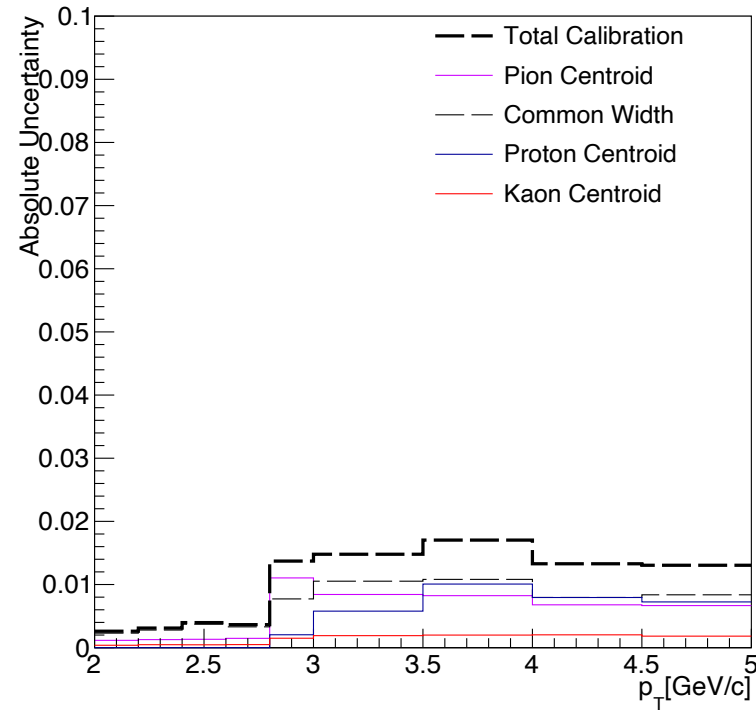


p+p, dE/dx Calibration Breakdown

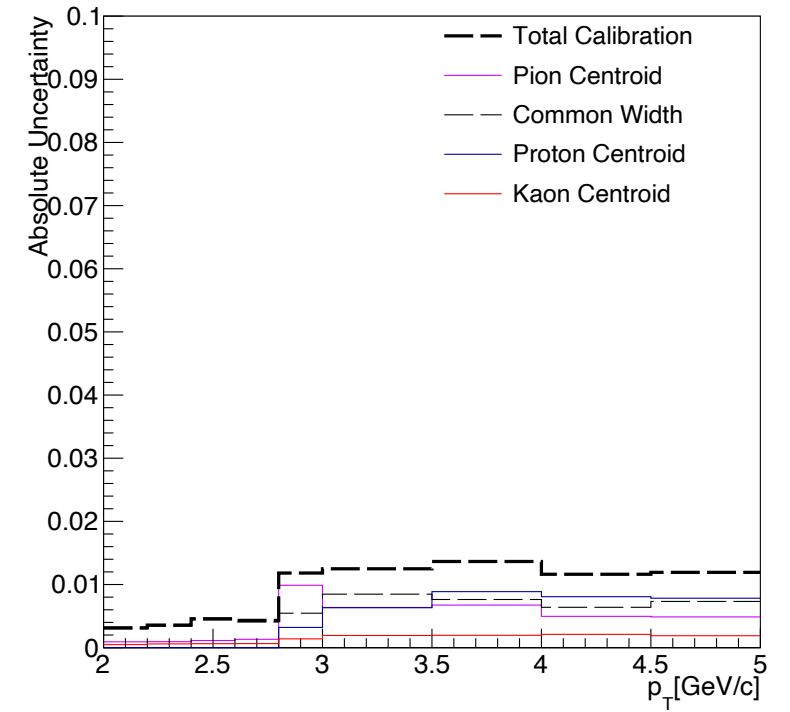
p+p Systematic Uncertainty from Calibration, $R = 0.2$



p+p Systematic Uncertainty from Calibration, $R = 0.3$



p+p Systematic Uncertainty from Calibration, $R = 0.4$

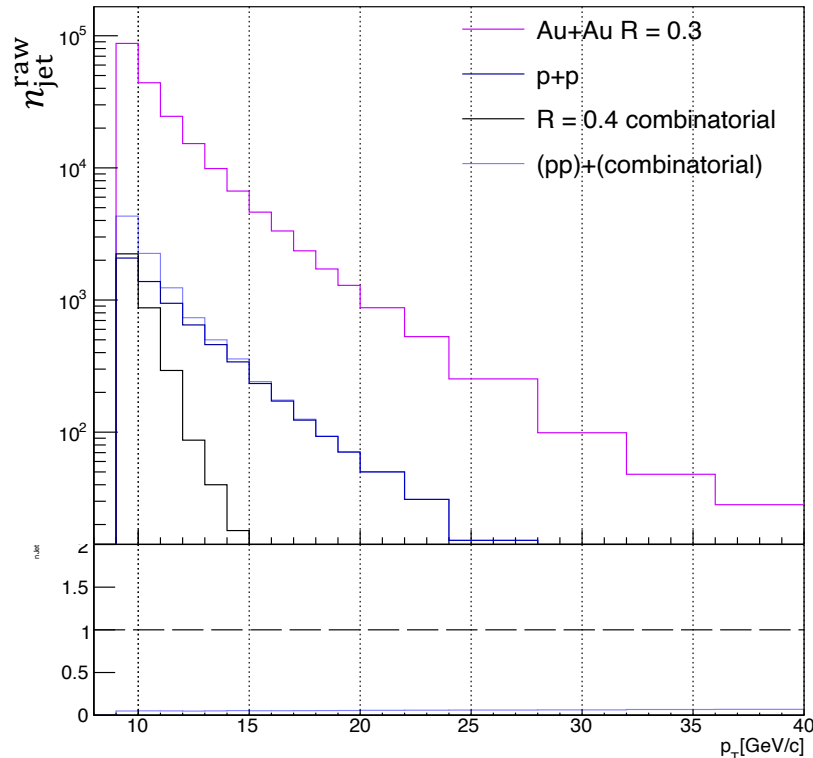


Determining Fake Rate: Spectra Template Fit



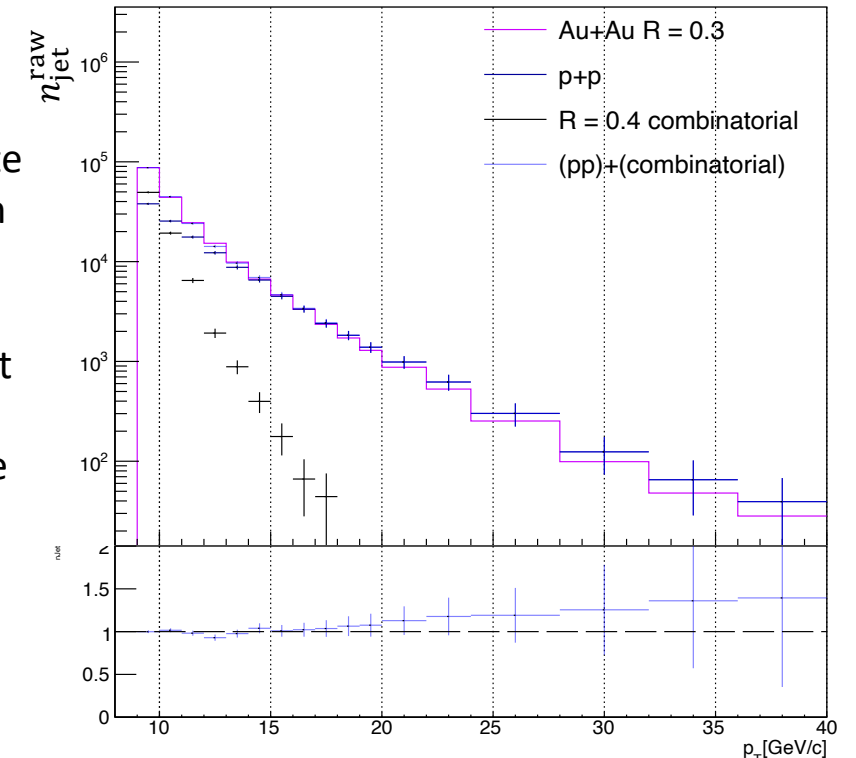
Raw Spectra

Rebuilding R = 0.3 Spectra



Template Fit

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	*	20.5	=	143,715	
Combinatorial	->	4,143 jets	*	22.1	=	91,597	-> 39% Fake Rate

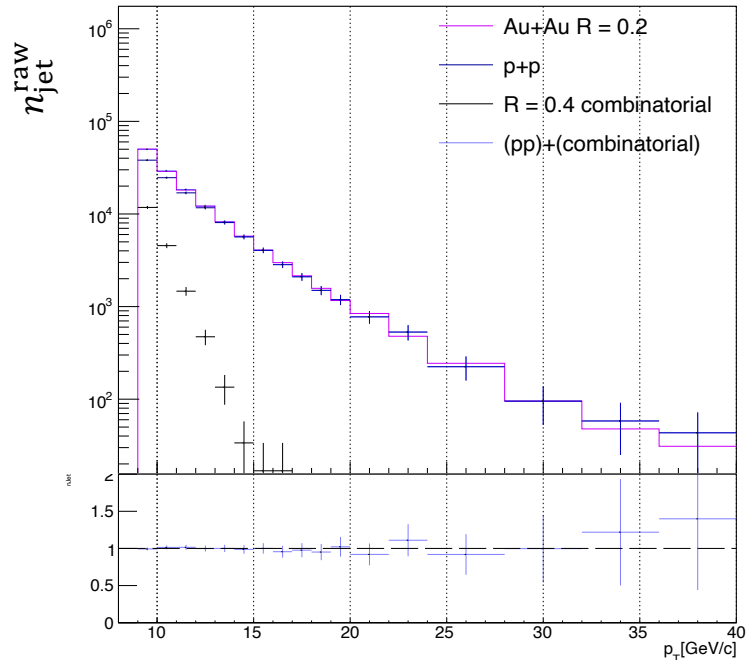
Fit Parameters



Determining Fake Rate: Spectra Template Fit

R = 0.2

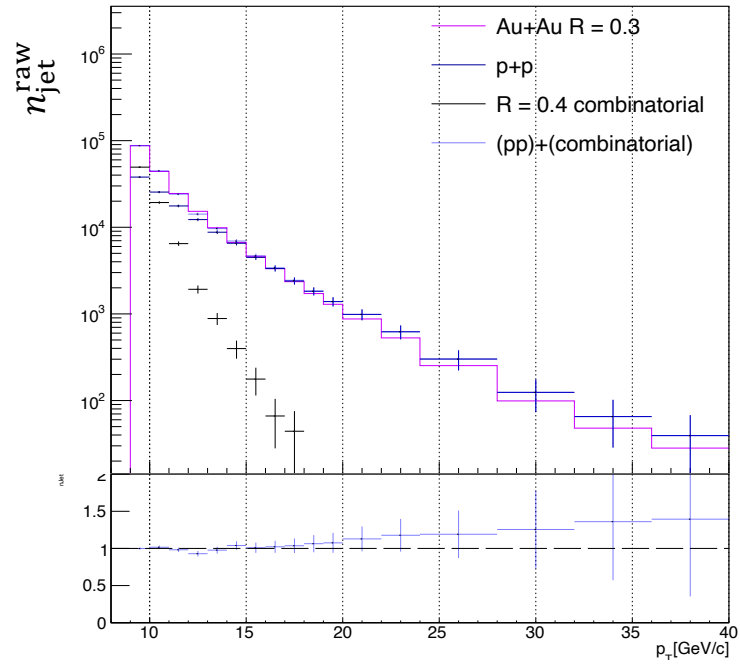
Rebuilding R = 0.2 Spectra



Fake Rate: 13%

R = 0.3

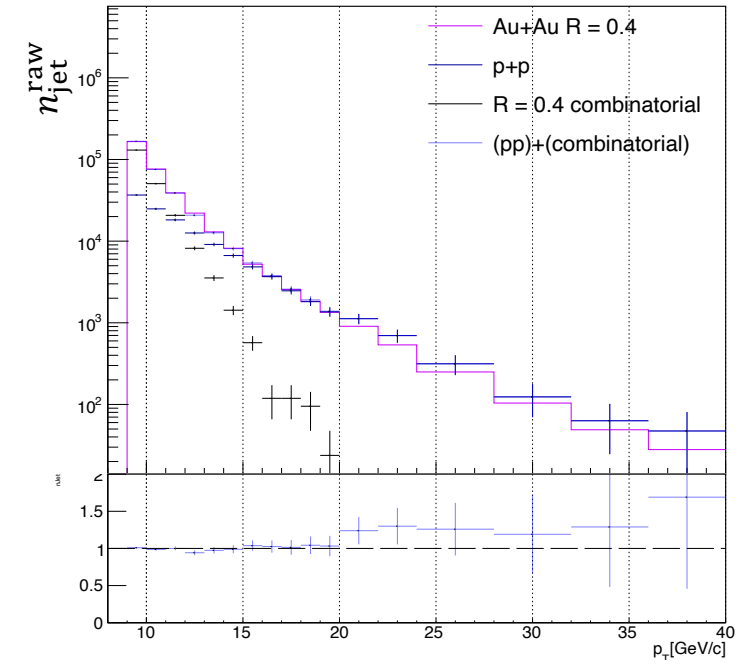
Rebuilding R = 0.3 Spectra



Fake Rate: 39%

R = 0.4

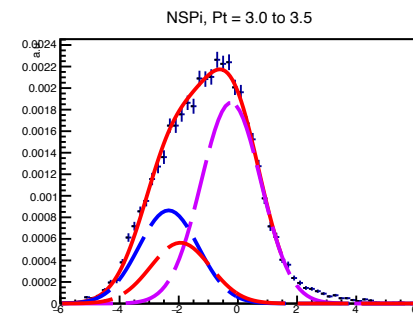
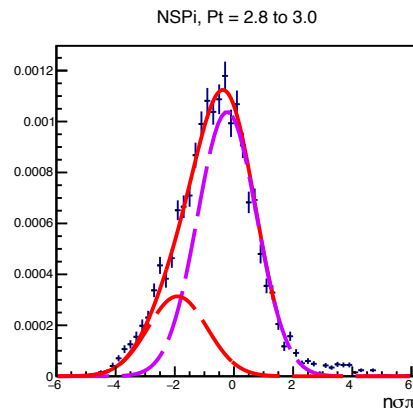
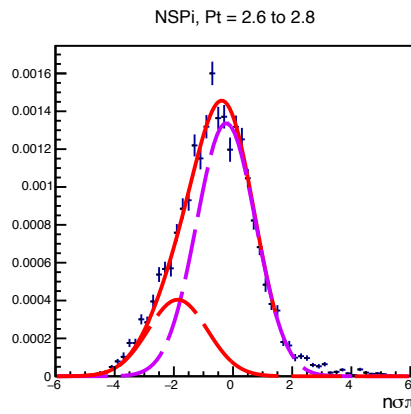
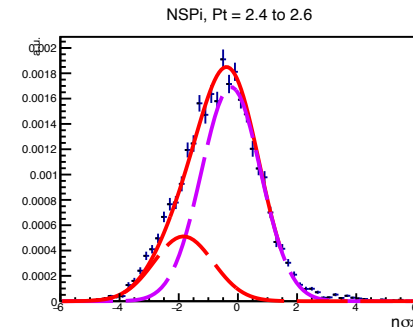
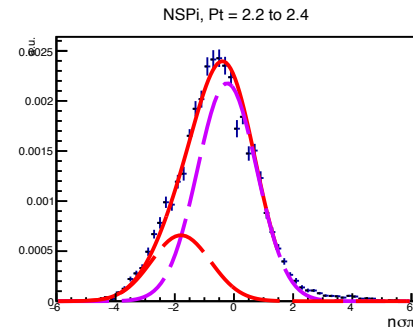
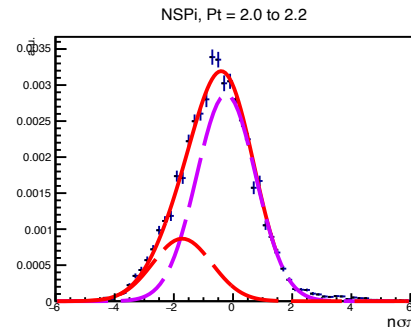
Rebuilding R = 0.4 Spectra



Fake Rate: 63%



Double Fits for $m^{\{2\}} < 0.5$



Gaussian Fits for $R = 0.3$

Triple Fits for full $m^{\{2\}}$ Range

