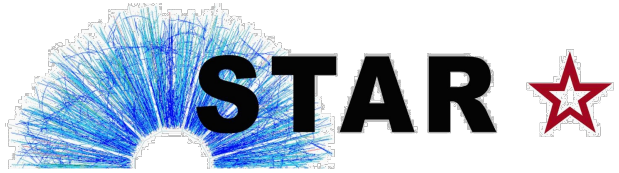
Baryon to Meson Ratios in Jets from Au+Au and p+p collisions at $\sqrt{s_{NN}} = 200$ GeV

Gabriel Dale-Gau, on behalf of the STAR Collaboration

University of Illinois at Chicago



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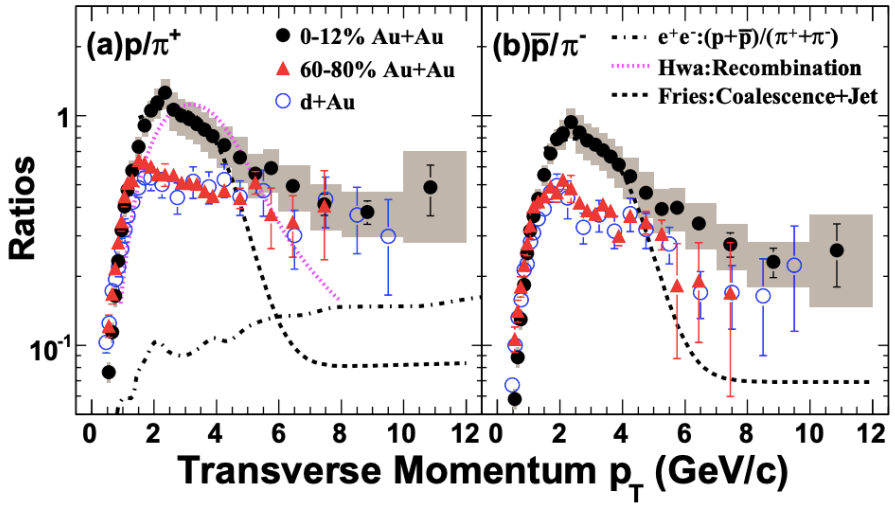
Motivation



[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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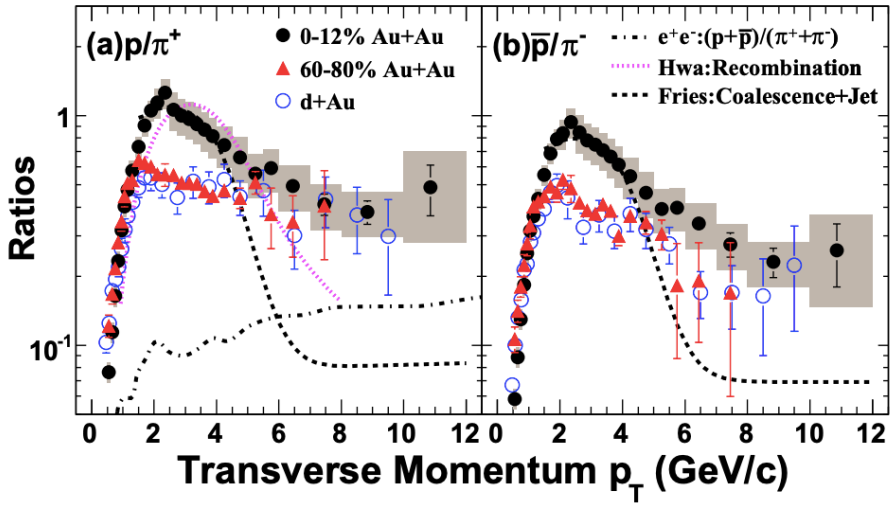

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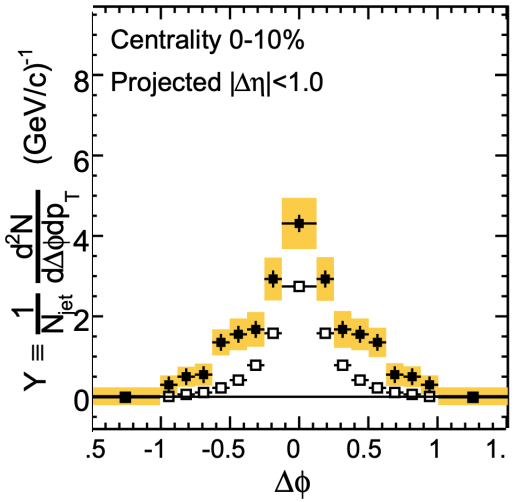


CMS

Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV

p+p $\sqrt{s} = 2.76$ TeV

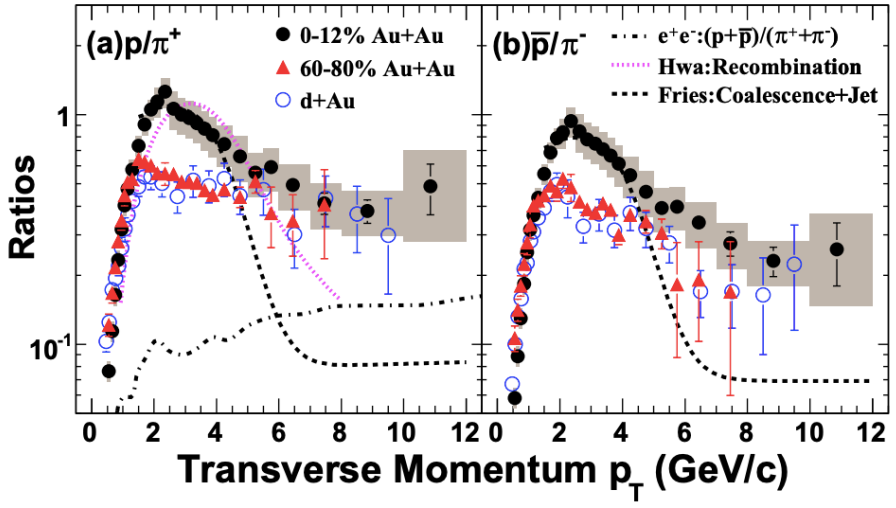
Jet p_T > 120 GeV/c

PbPb Leading Jets

pp Leading Jets

[JHEP 11 (2016) 055]

Motivation



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- **Shower Parton Recombination** [PR(2004)0312271]

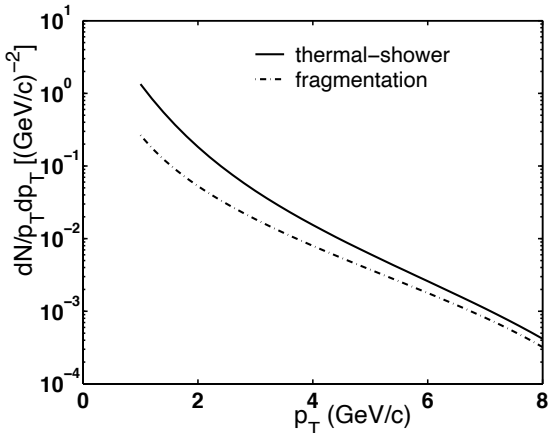
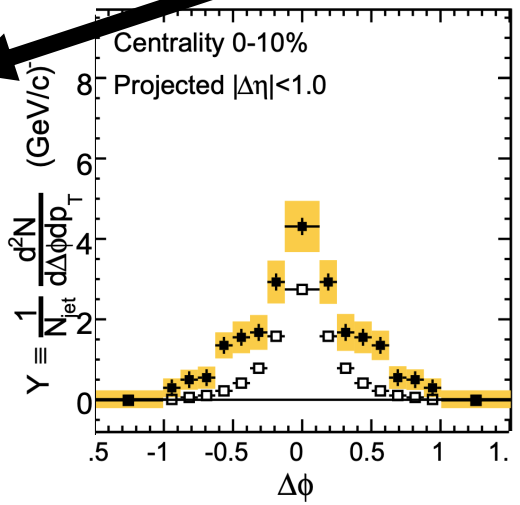


FIG. 4: Distributions of π^+ in p_T arising from thermal-shower recombination (solid line) and shower-shower recombination, i.e. fragmentation (dash-dot line).



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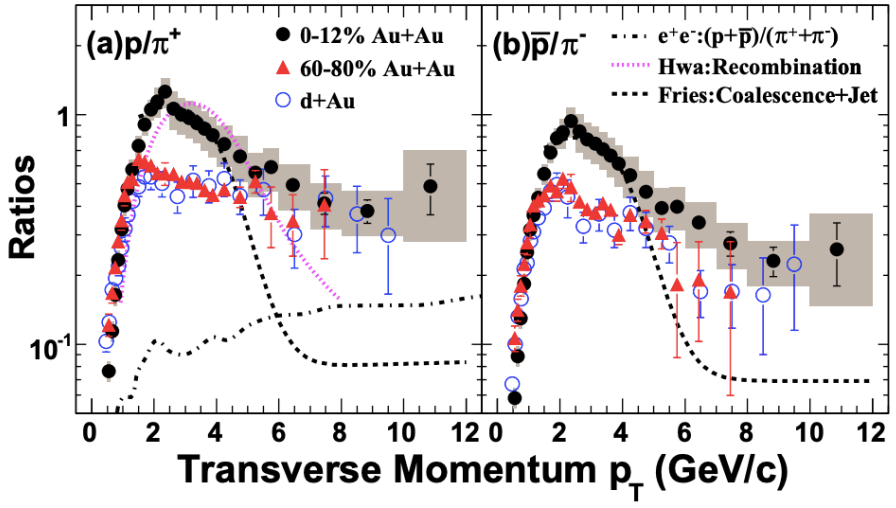

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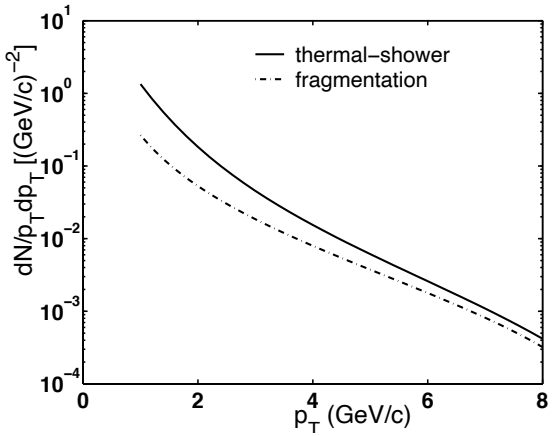

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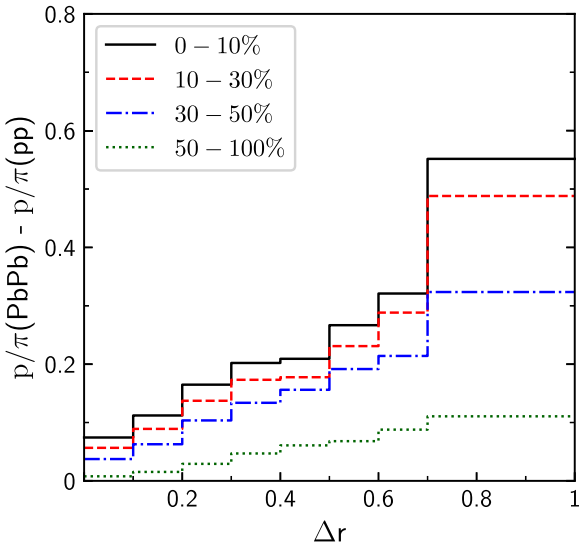

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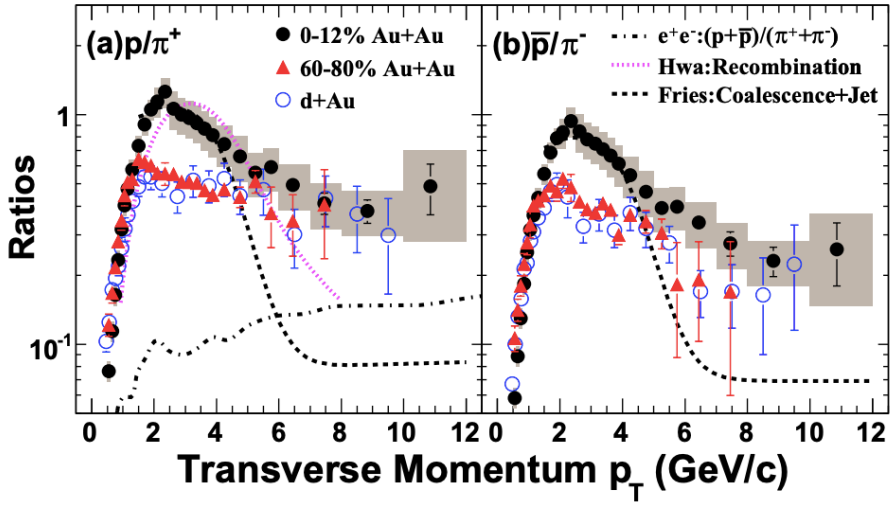

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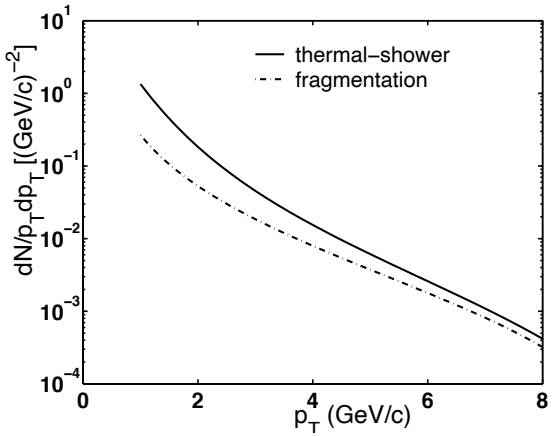

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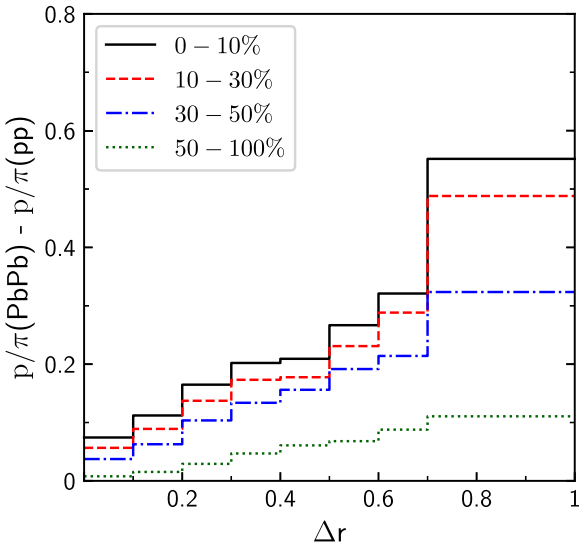

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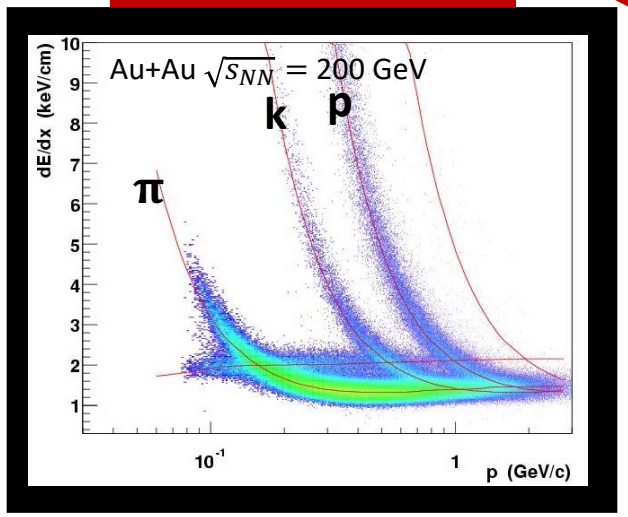
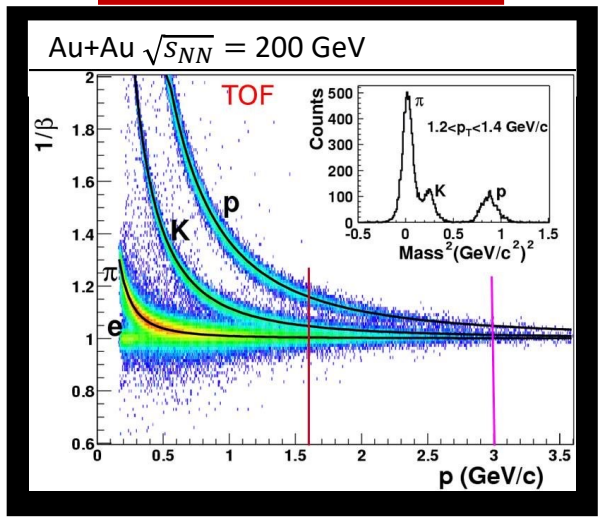
- Shower Parton Recombination [PR(2004)0312271]
- **AMPT simulations: baryon/meson is modified for jets in QGP** [PLB(2022)137638]
- **Is jet fragmentation modified by QGP?**
- We measure **p/π in jets** using **jet-hadron correlations**

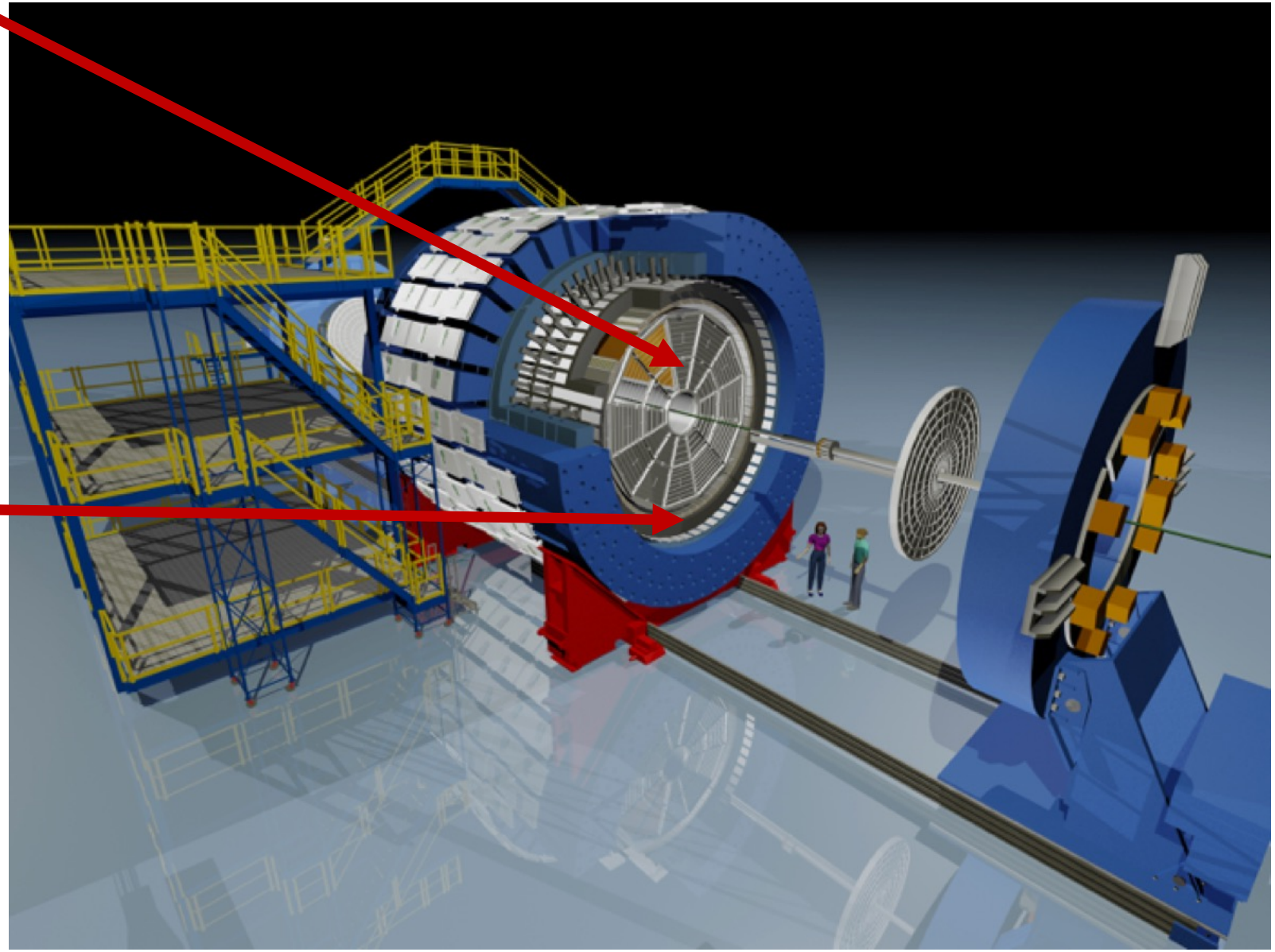
STAR Detector

dE/dx from TPC



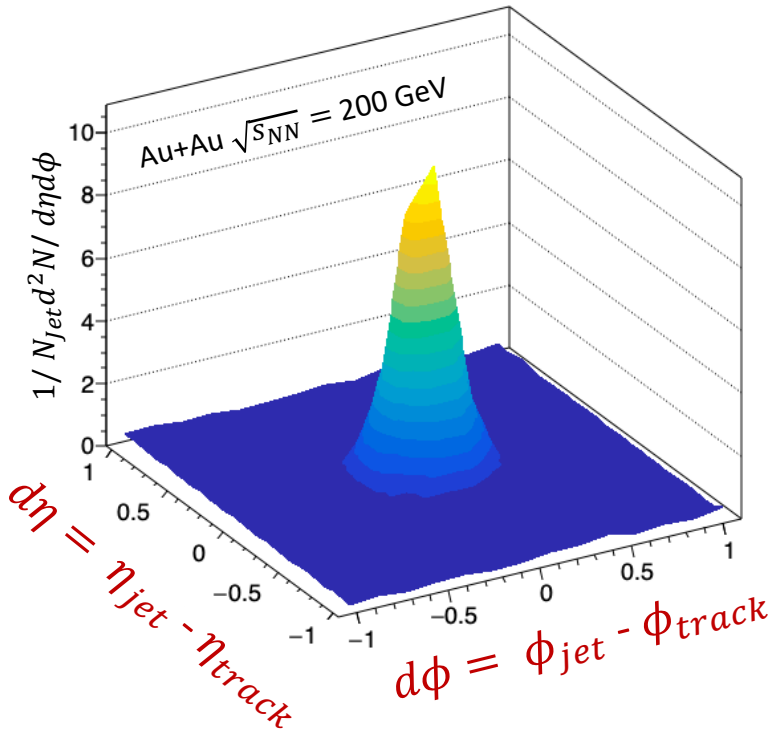
β from ToF



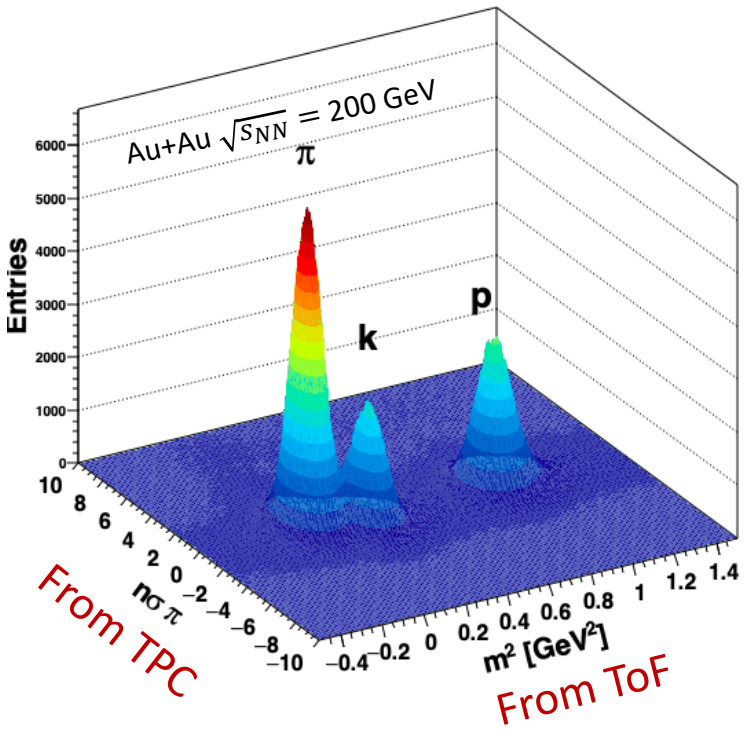


Measurement Technique

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**

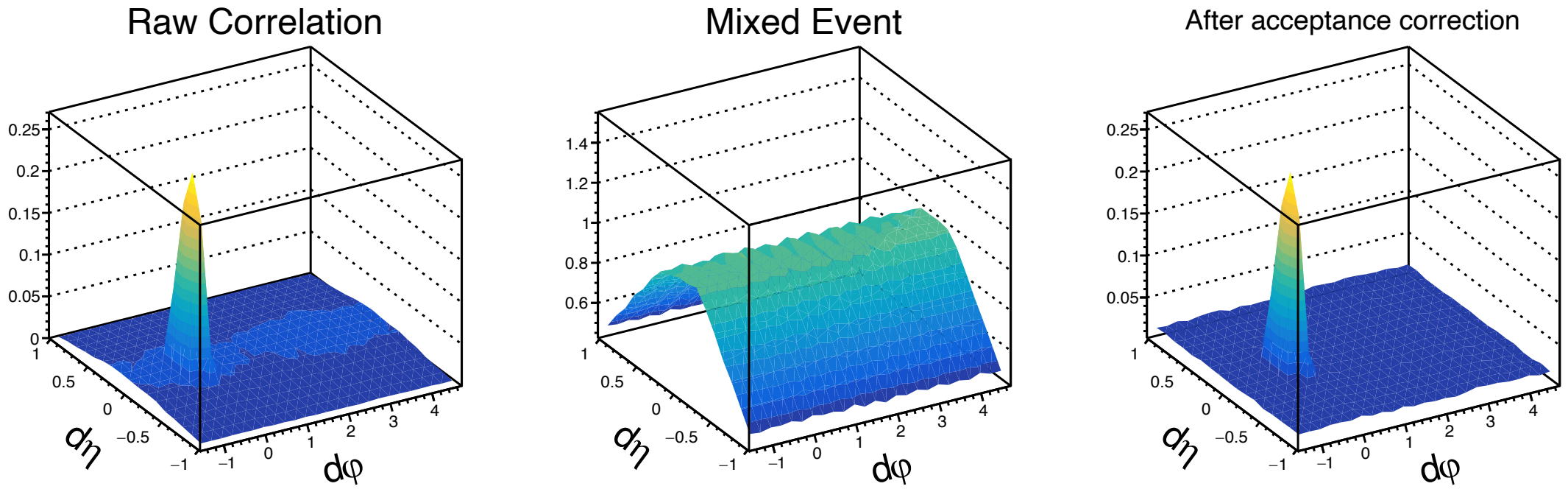
Data Samples

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

Jet Reconstruction

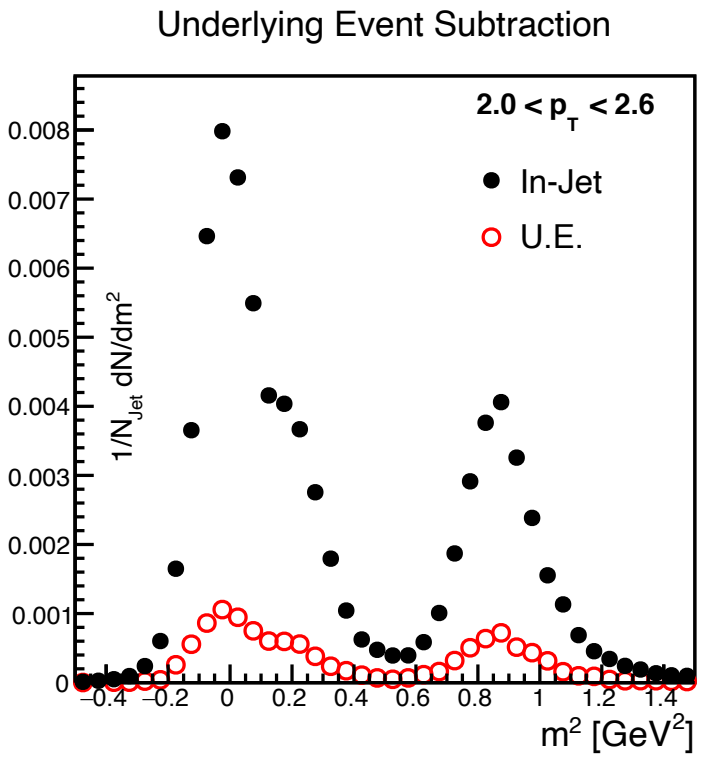
- Anti- k_T
- Jet R = 0.2, 0.3, 0.4
- $p_T^{const} > 2.0$ GeV/c
- Jet $p_T^{raw} > 9$ GeV/c
- $|\eta_{Jet}| < 1.0 - R$
- Inclusive Jets

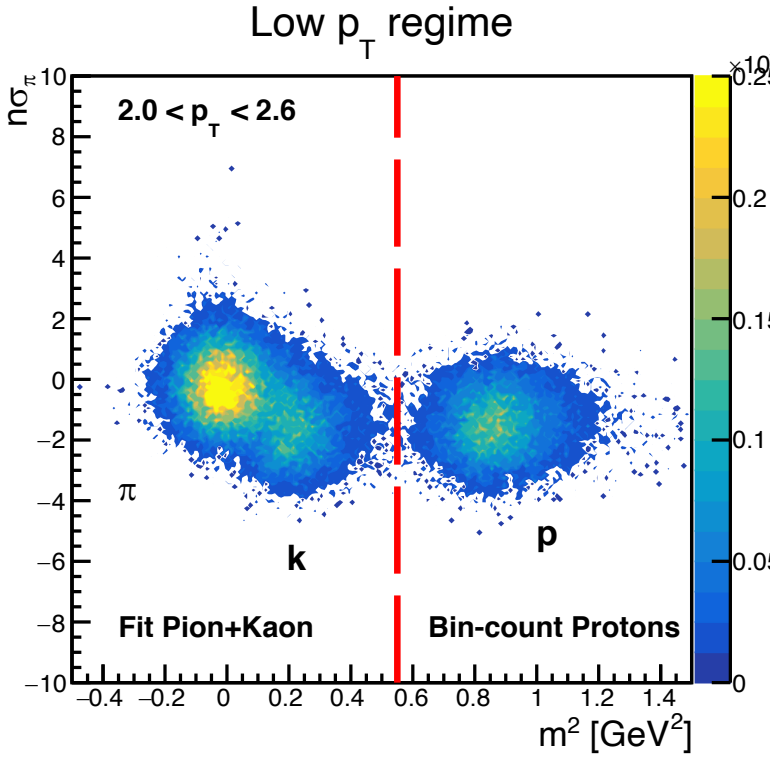
Jet-Track Correlation

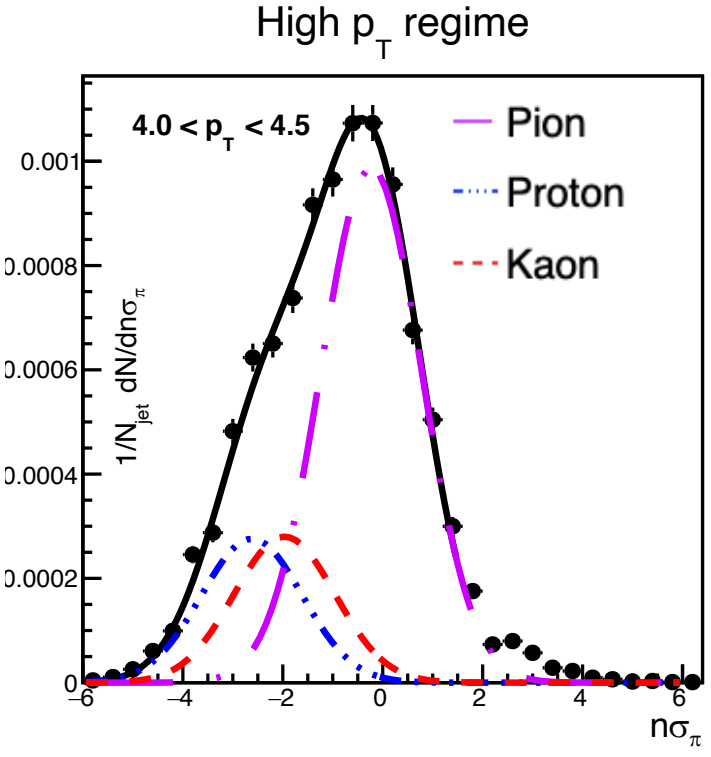


- Run Anti-k_{T} algorithm to identify Jet Axis
- Perform correlations with all tracks within $|\eta_{\mathrm{track}}| < 0.5$
- Build Mixed event for pair acceptance correction
- Divide signal correlation by mixed event
- Select regions of equal area for jet and underlying event for every p_{T} bin from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

Particle Identification

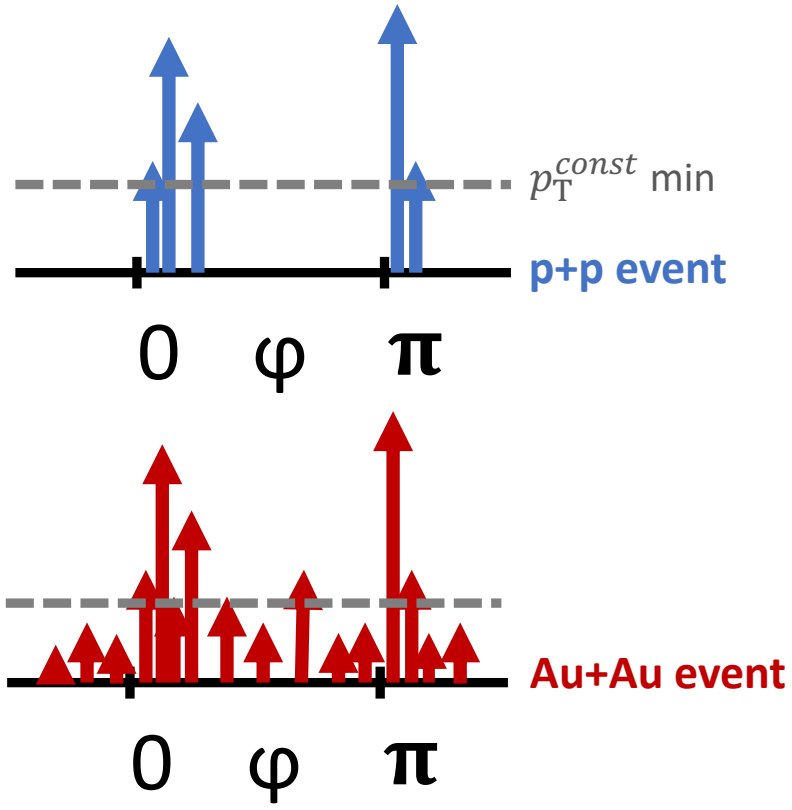






- Subtract UE from Jet in dφ, dη, $n\boldsymbol{\sigma_{\pi}}$, and m^2
- Identify Pion, Proton, Kaon yields from remaining Jet Signal
- Low p_{T} regime: p_{T} < 3.0 GeV/c → bin-count protons
- High p_{T} regime: p_{T} > 3.0 GeV/c → triple Gaussian fit
- Divide proton yield by pion yield to measure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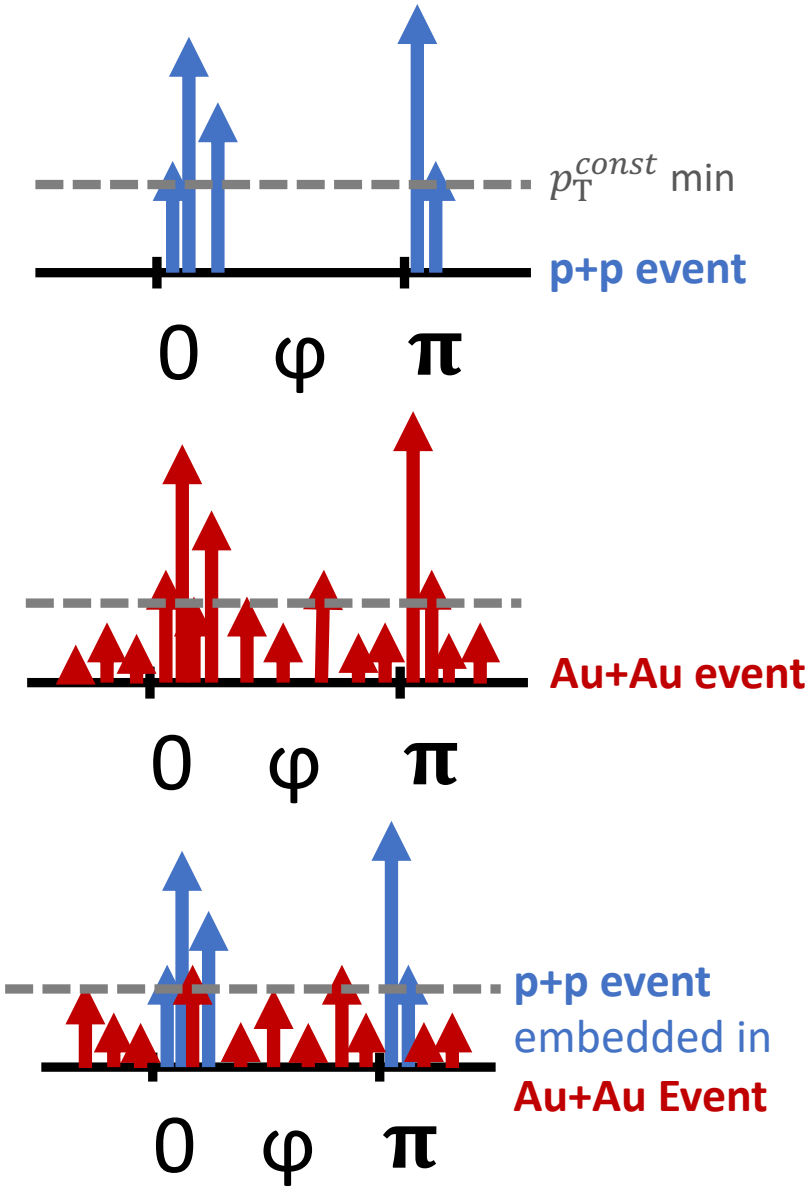

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The Solution:

Pseudo-embedding: take *p+p* jets down to low p_{T} → overlay with central 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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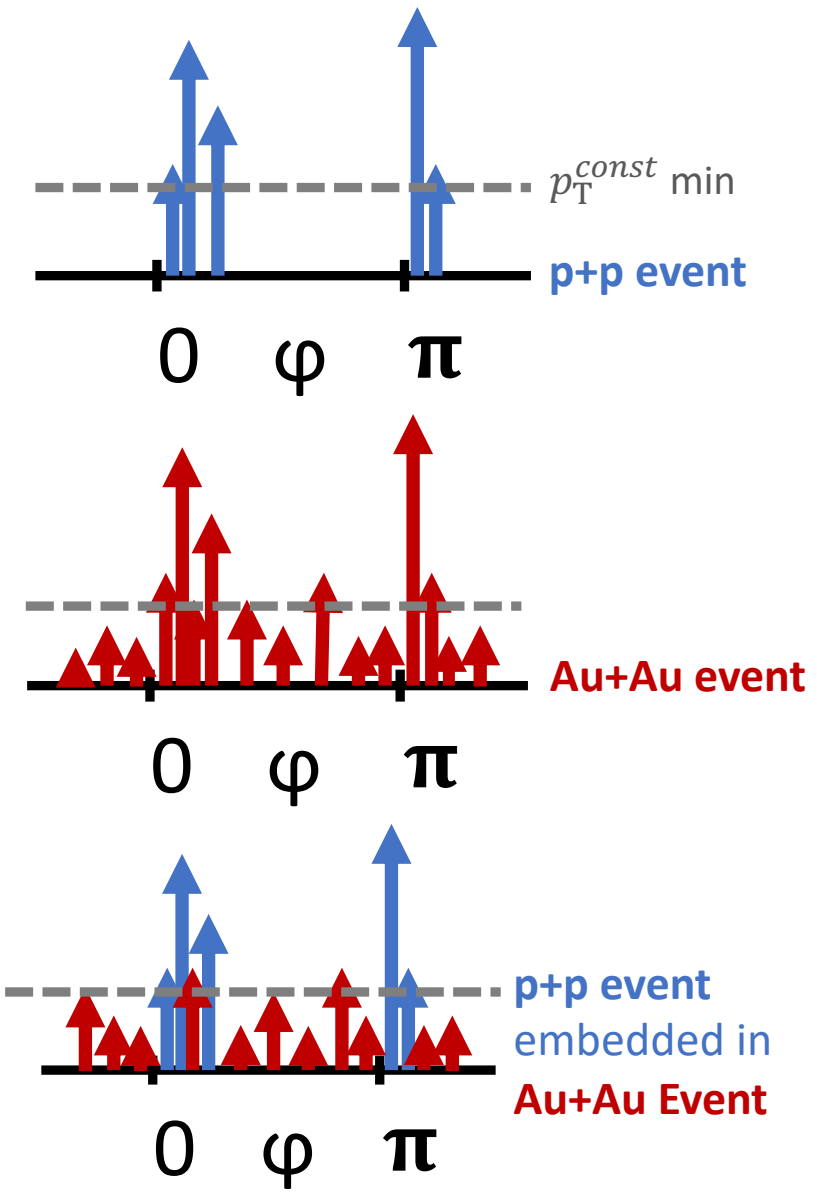

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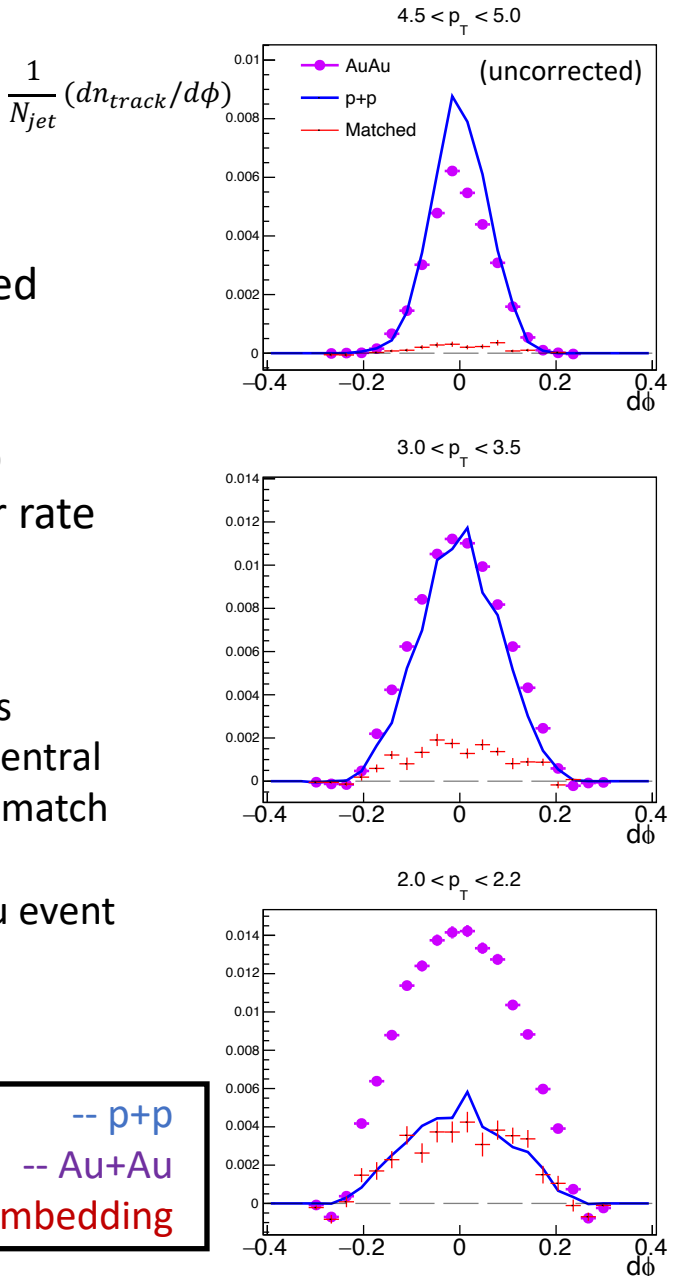
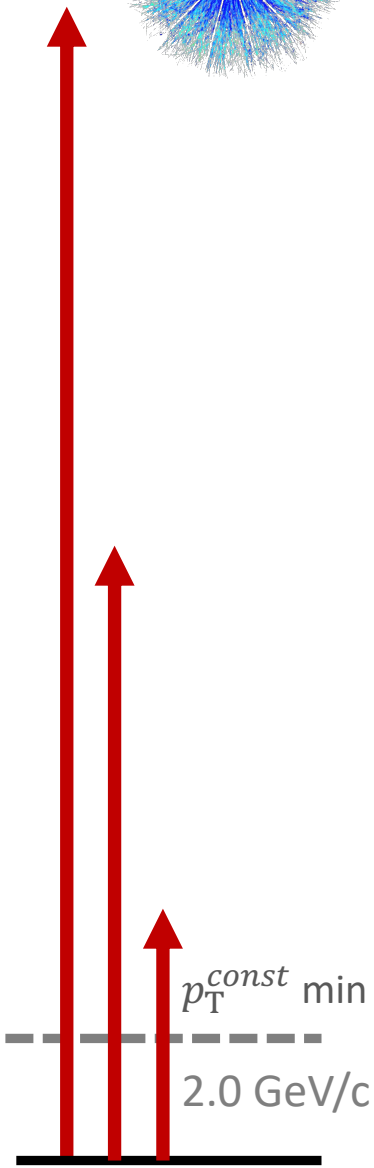
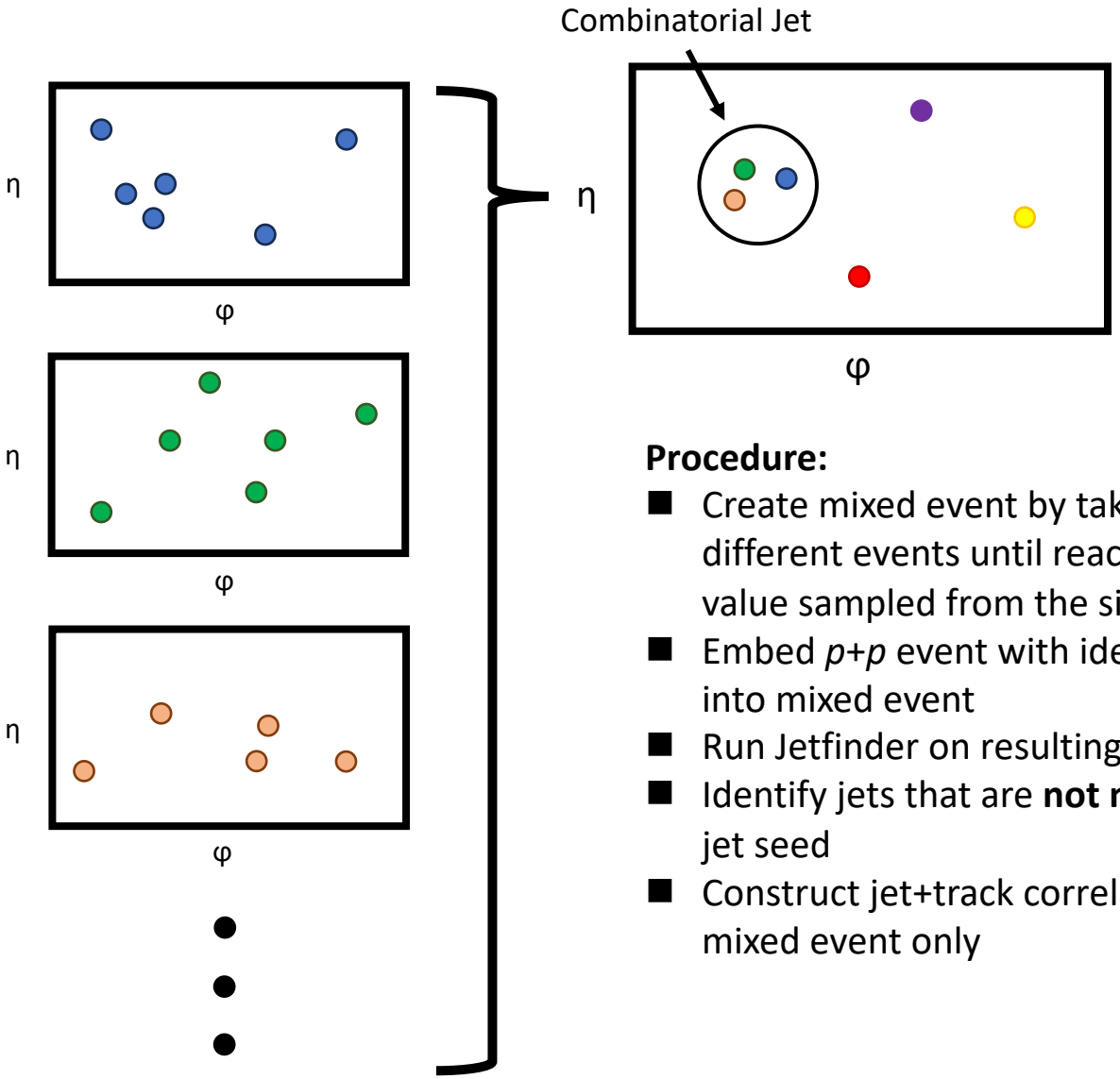
-- p+p
-- Au+Au
-- Pseudo-Embedding



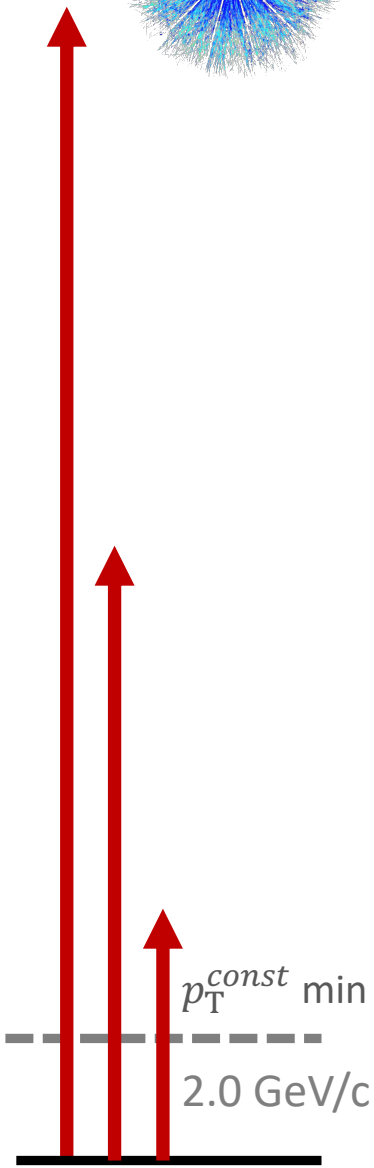


Evaluating Contribution from Combinatorial Jets



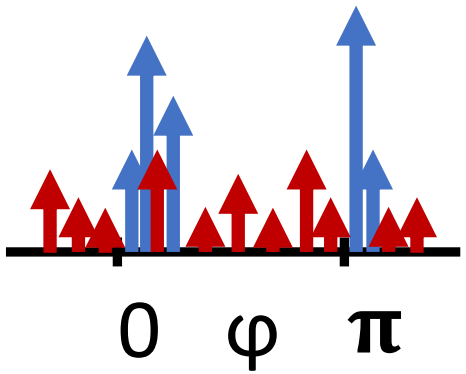
Procedure:

- 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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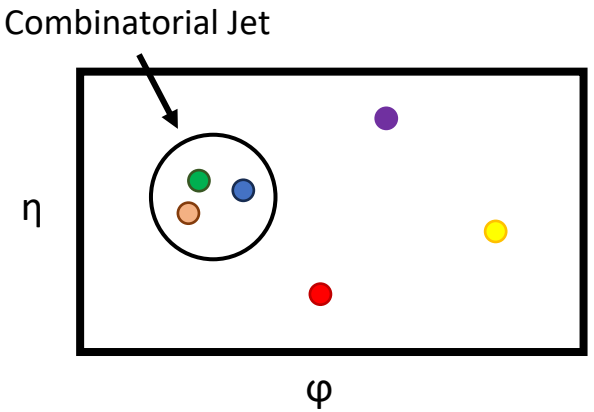


Procedure:

- 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

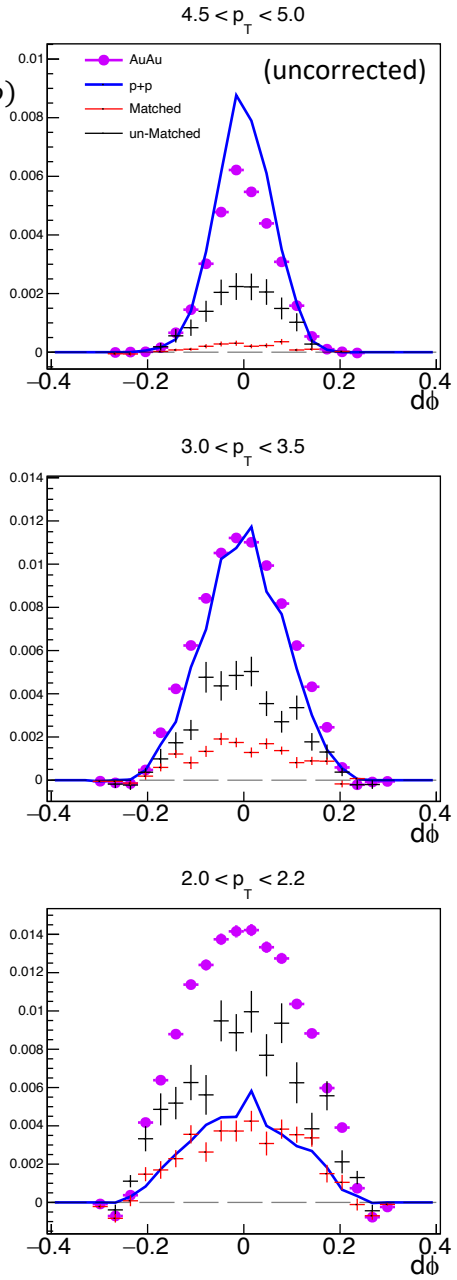
Pseudo-embedding → Matched Jets
Combinatorials → Unmatched jets

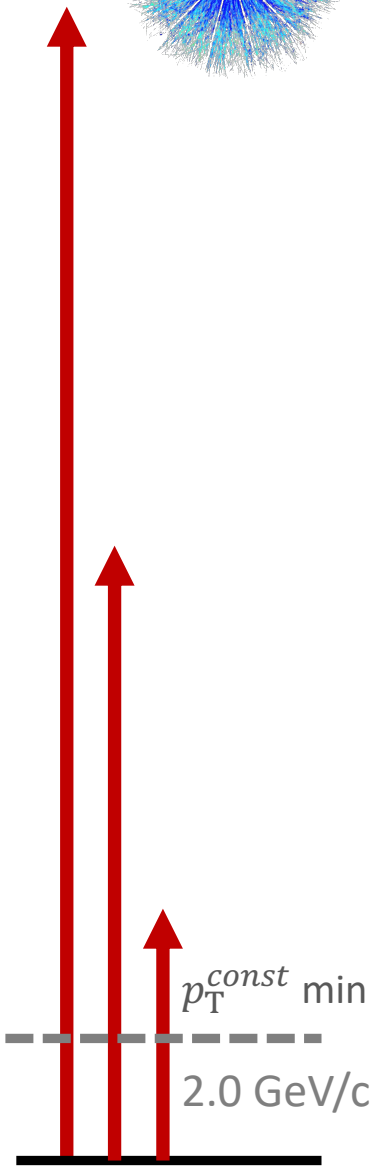
Fake Rate Determination:

- Build Template fit using *p+p* and combinatorial jet spectra
- Fit to Au+Au Jet spectra
- Scale *p+p* and combinatorial n_{jet} values by fit parameters to determine fake rate
- Subtract correlated background from jet signal

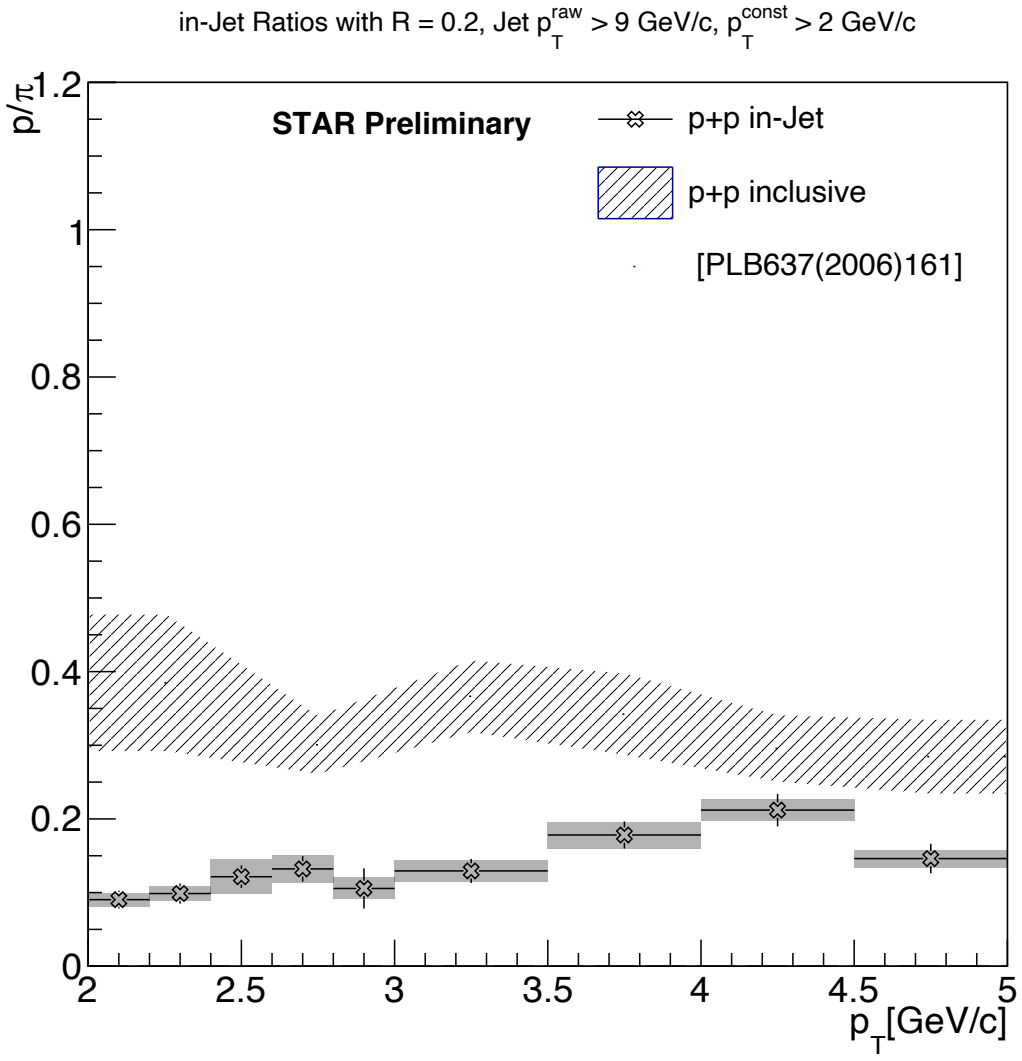
-- p+p
-- Au+Au
-- BG fluctuation
-- Combinatorial

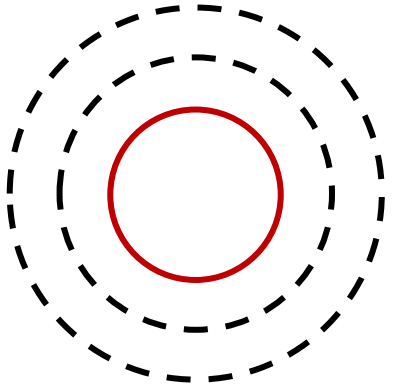
$\frac{1}{N_{jet}}(dn_{track}/d\phi)$





Results: R = 0.2, p_{T}^{const} > 2.0 GeV/c

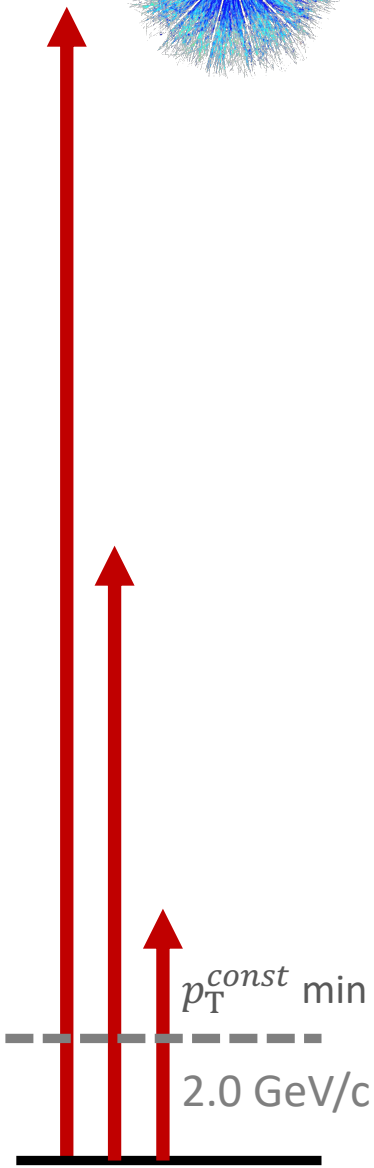




Jets in *p+p*

- Strong preference for **π** over p

NOTE: p/**π** is used as shorthand for $(p^+ + p^-)/(\pi^+ + \pi^-)$ throughout this presentation



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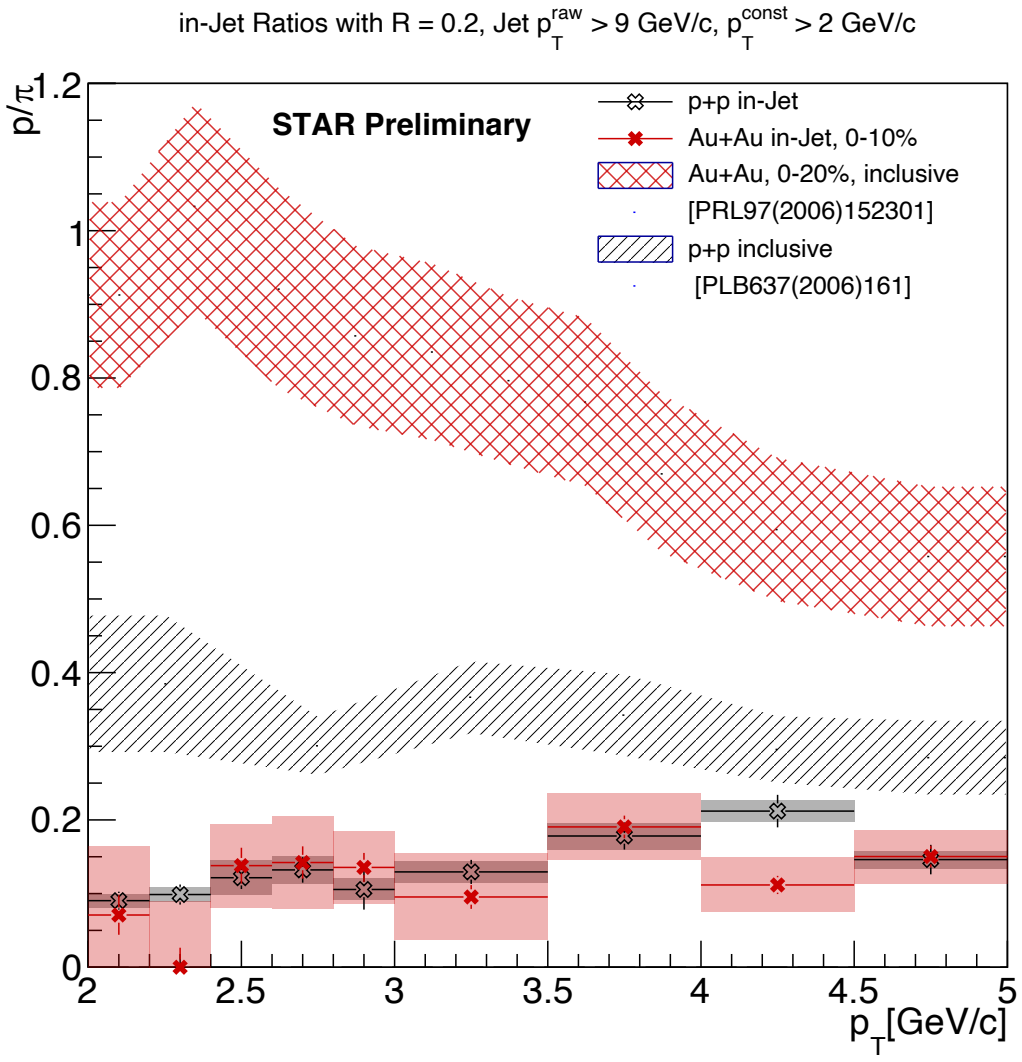
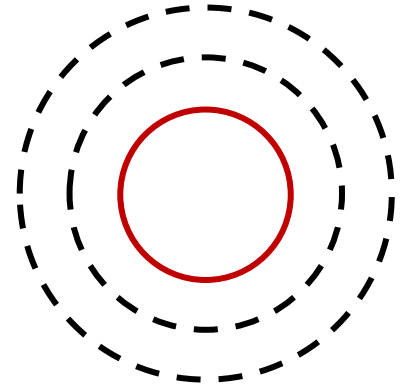


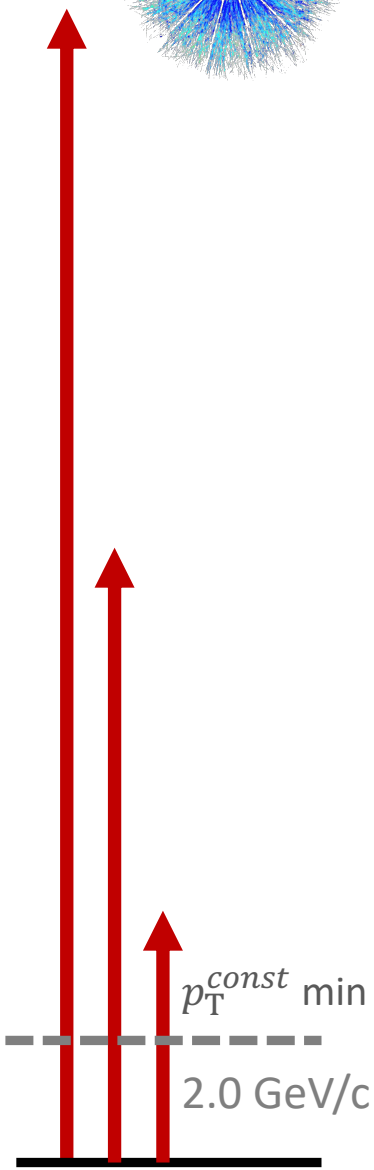


Jets in *p+p*

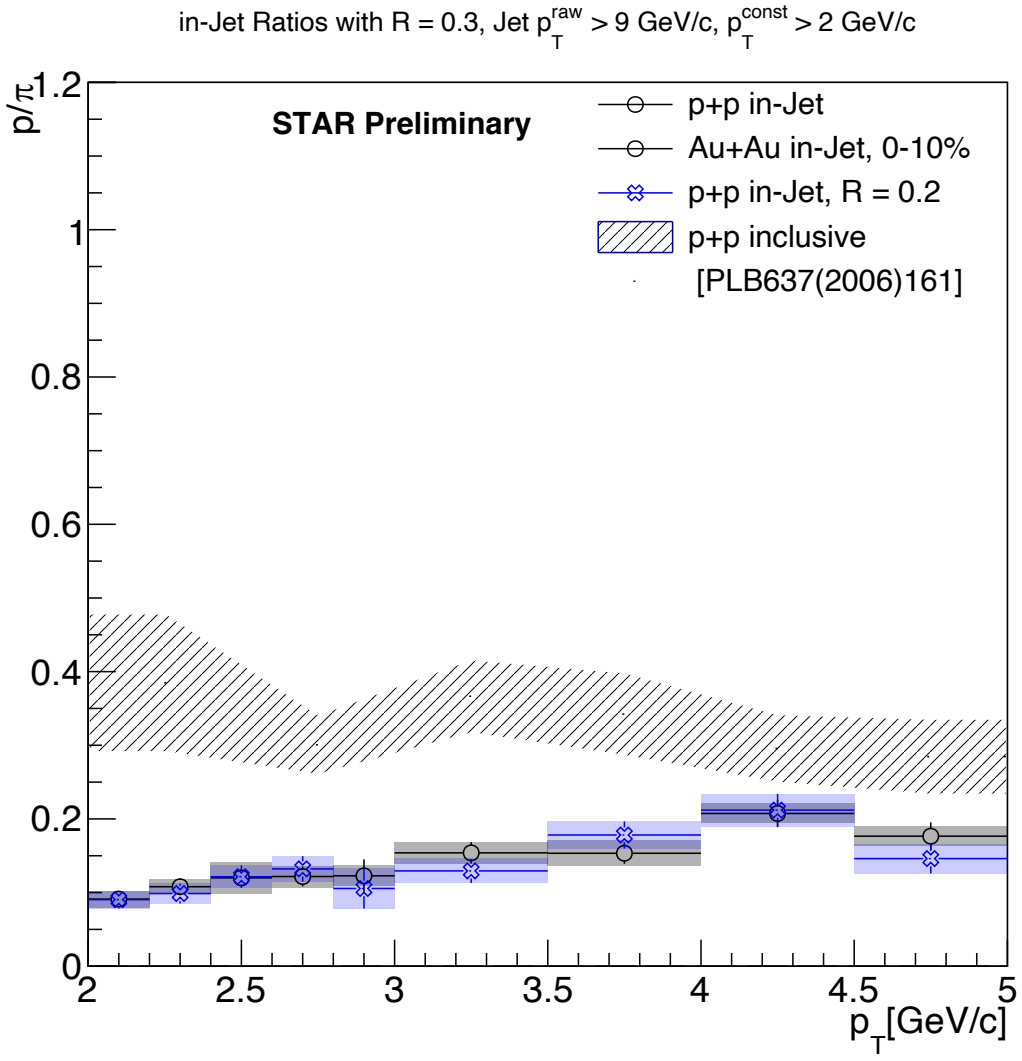
- Strong preference for **π** over p

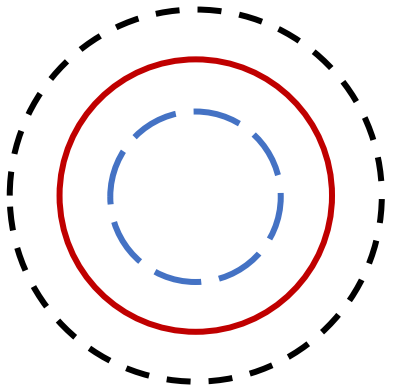
Jets in Au+Au

- Strong preference for **π** over p
- Similar in-jet p/**π** ratio between Au+Au and *p+p*
- Fake jet rate: 13%



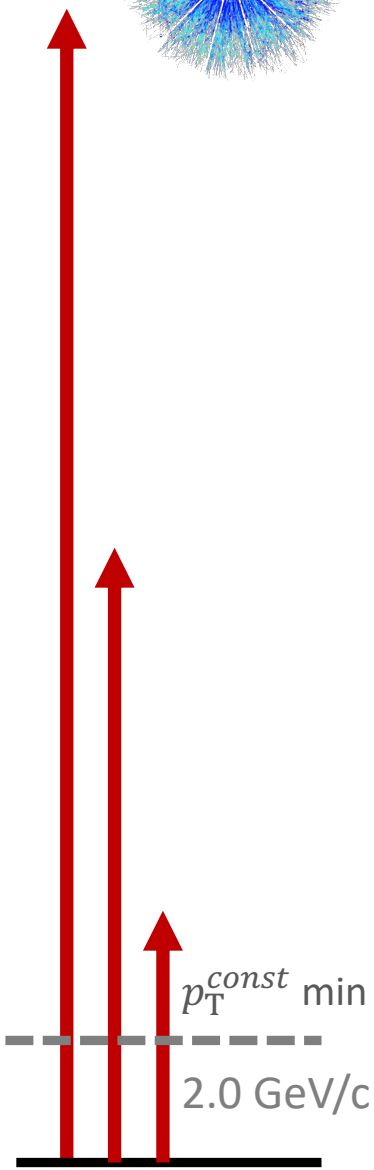
Results: R = 0.3, p_{T}^{const} > 2.0 GeV/c





Jets in *p+p*

- Strong preference for **π** over p
- No modification observed with increase in Jet R



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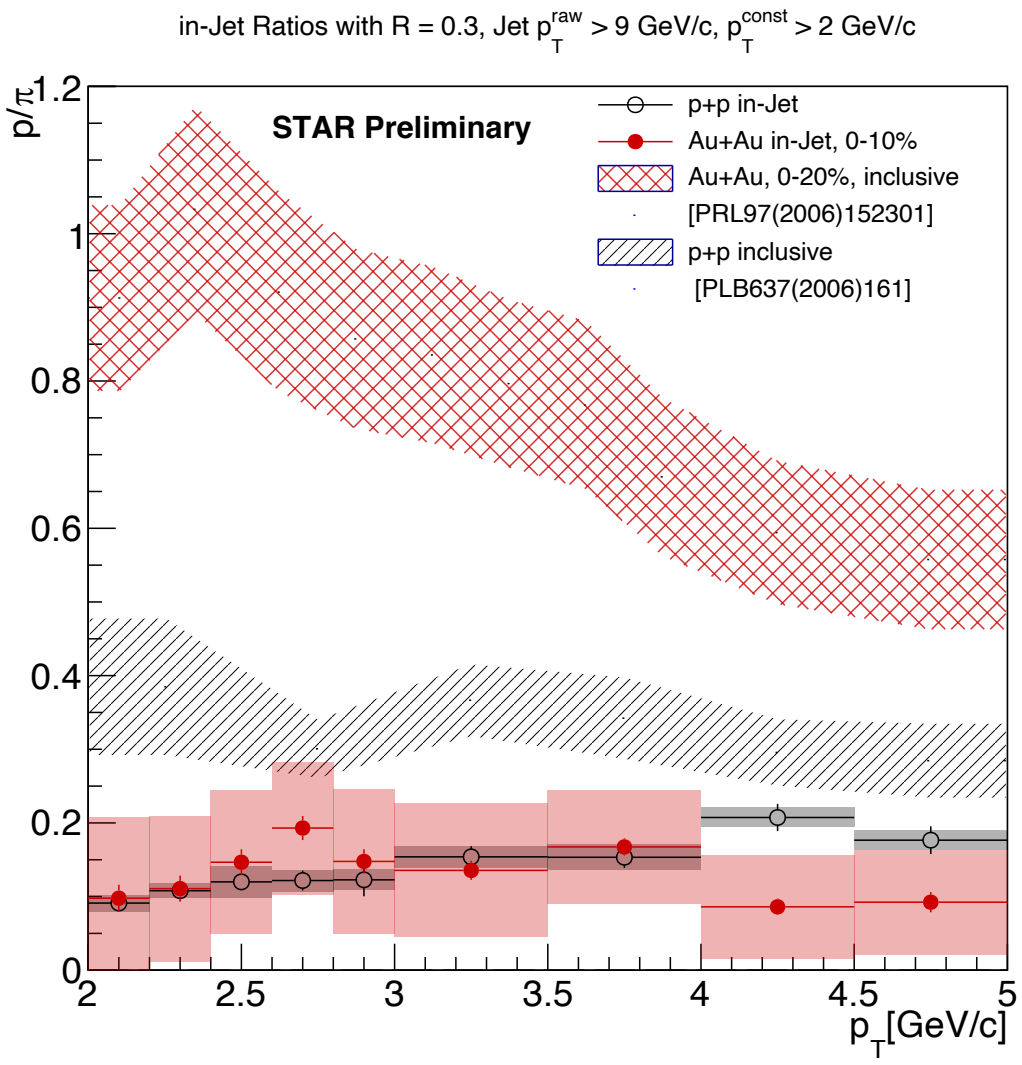
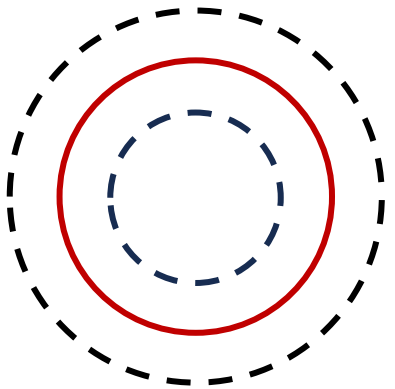


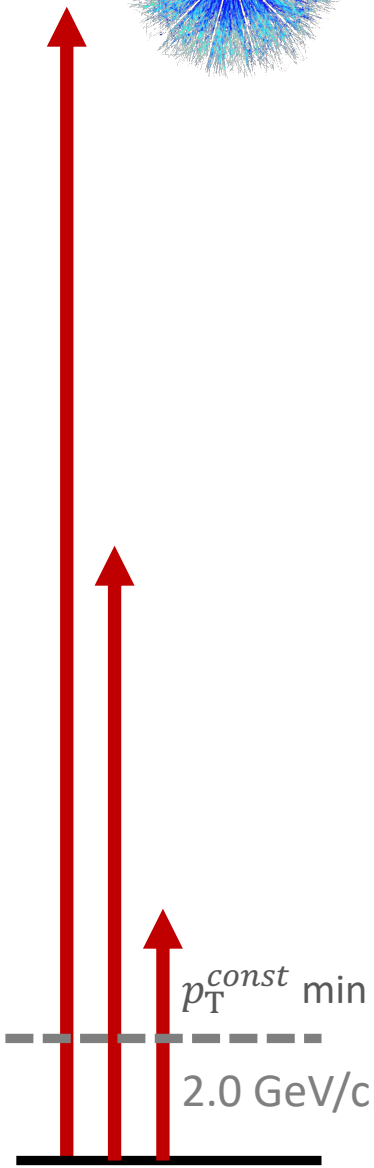


Jets in *p+p*

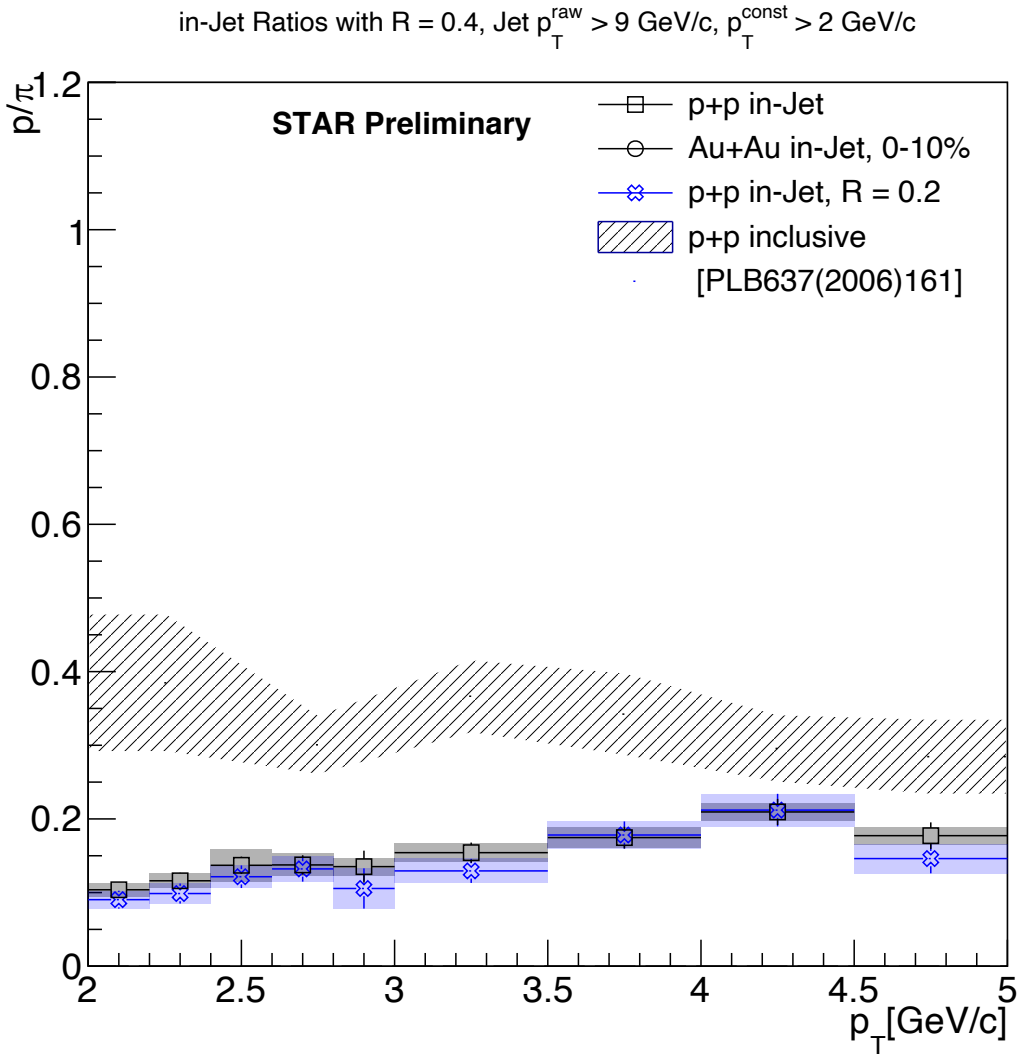
- Strong preference for π over p
- No modification observed with increase in Jet R

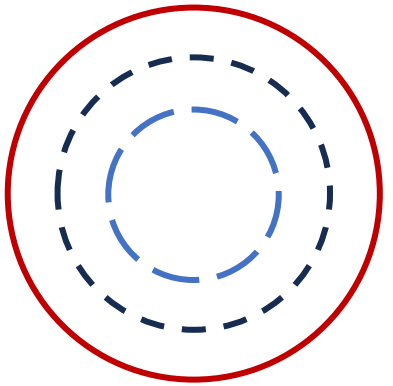
Jets in Au+Au

- Strong preference for π over p
- Similar in-jet p/π ratio between Au+Au and *p+p*
- No modification observed with increase in Jet R
- Fake jet rate: 39%



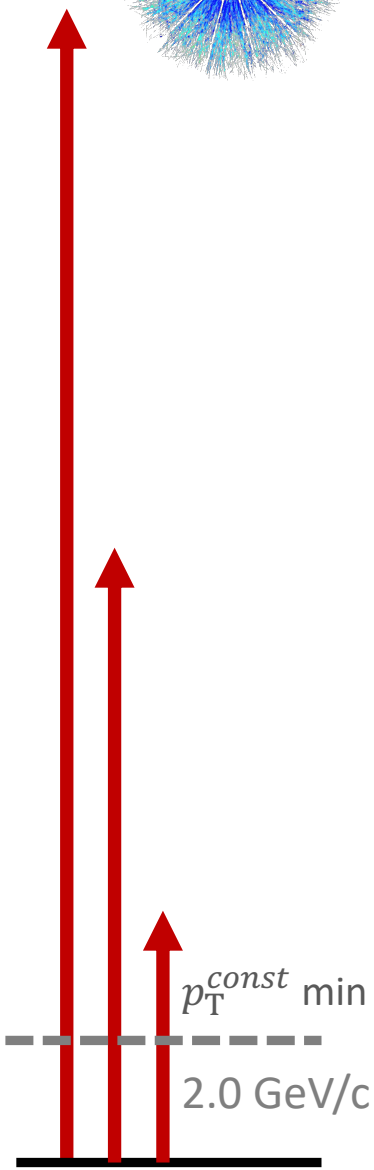
Results: R = 0.4, p_{T}^{const} > 2.0 GeV/c



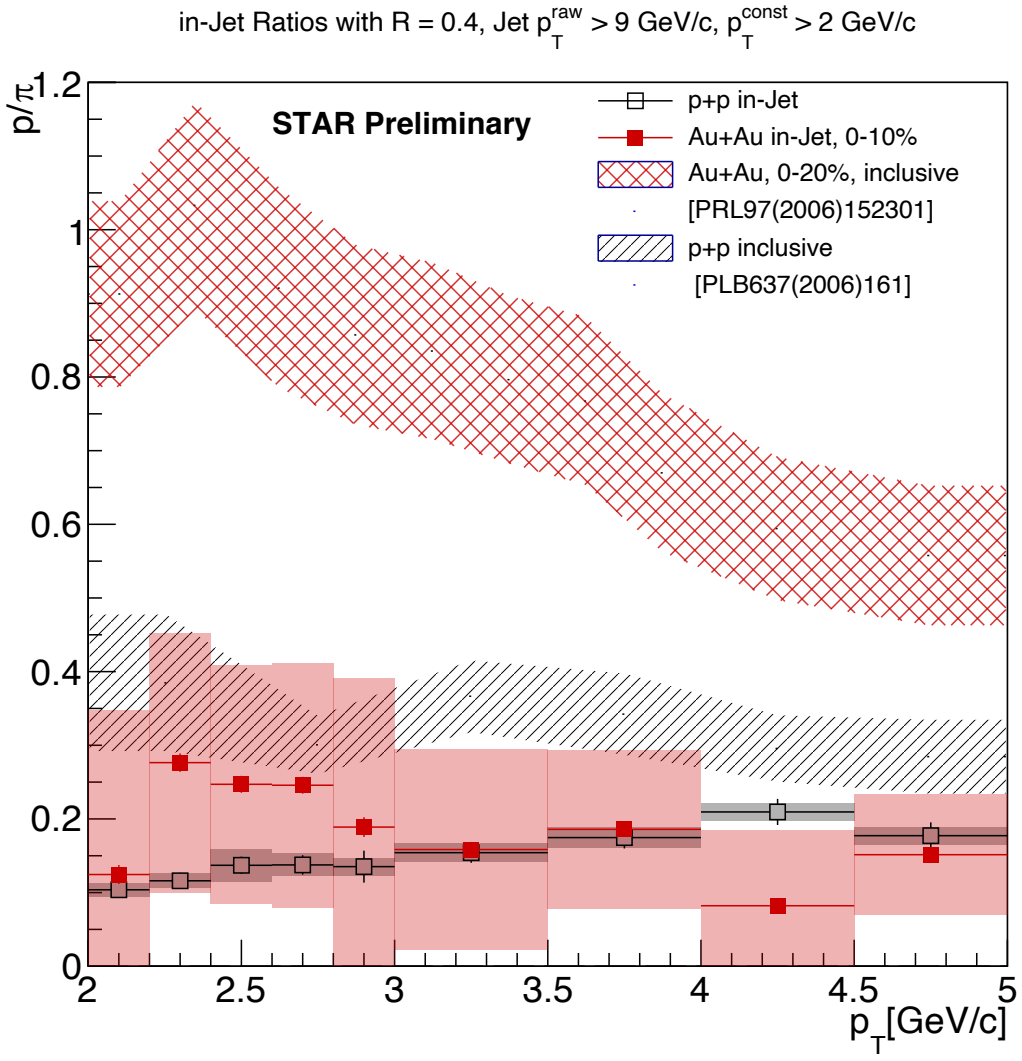


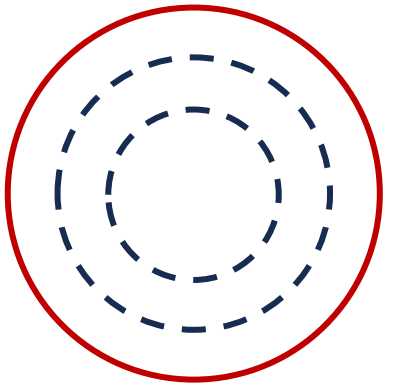
Jets in *p+p*

- Strong preference for **π** over p
- No modification observed with increase in Jet R



Results: R = 0.4, p_{T}^{const} > 2.0 GeV/c



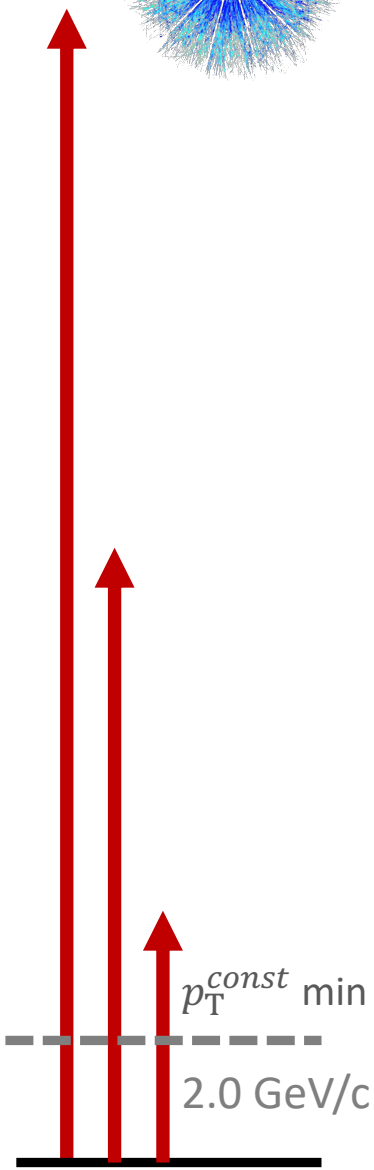


Jets in *p+p*

- Strong preference for **π** over p
- No modification observed with increase in Jet R

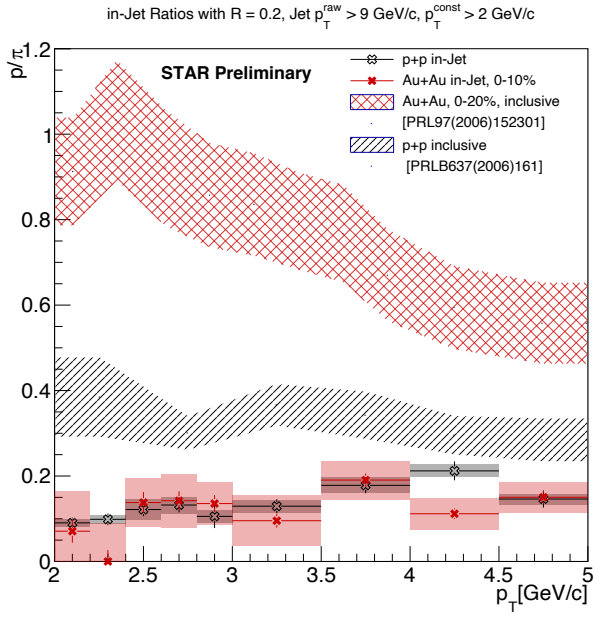
Jets in Au+Au

- Strong preference for **π** over p
- Similar in-jet p/**π** ratio between Au+Au and *p+p*
- No modification observed with increase in Jet R
- Fake jet rate: 63%

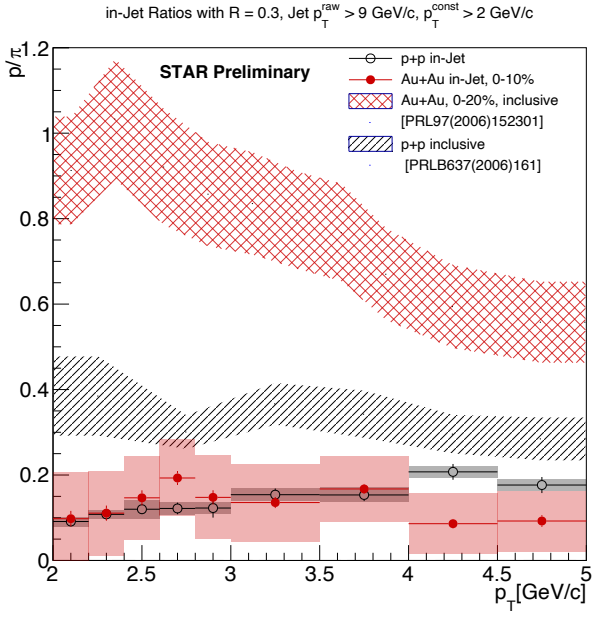


Summary

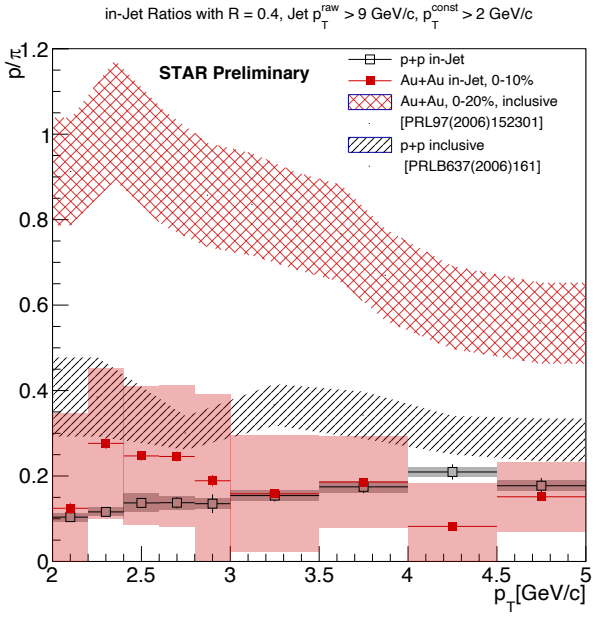
R = 0.2



R = 0.3



R = 0.4

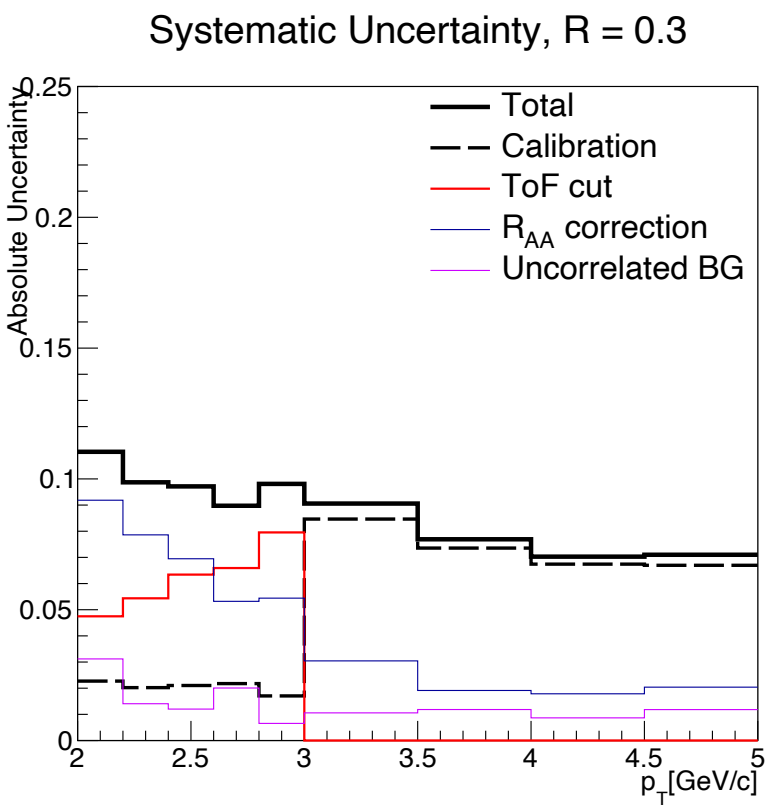


- We present the first ever in-Jet p/**π** study with jet R dependence from STAR
- Study shows jets with p_{T}^{const} > 2.0 GeV/c and jet $p_{\mathrm{T}}^{\mathrm{raw}}$> 9.0 GeV/*c*
- In p+p collisions, the in-jet p/**π** ratio sits below the p/**π** ratio from inclusive hadrons, with no dependence on jet R
- For every jet R studied, in-jet p/**π** ratios measured in central Au+Au are consistent with those from p+p, with no evidence for enhancement between the two systems

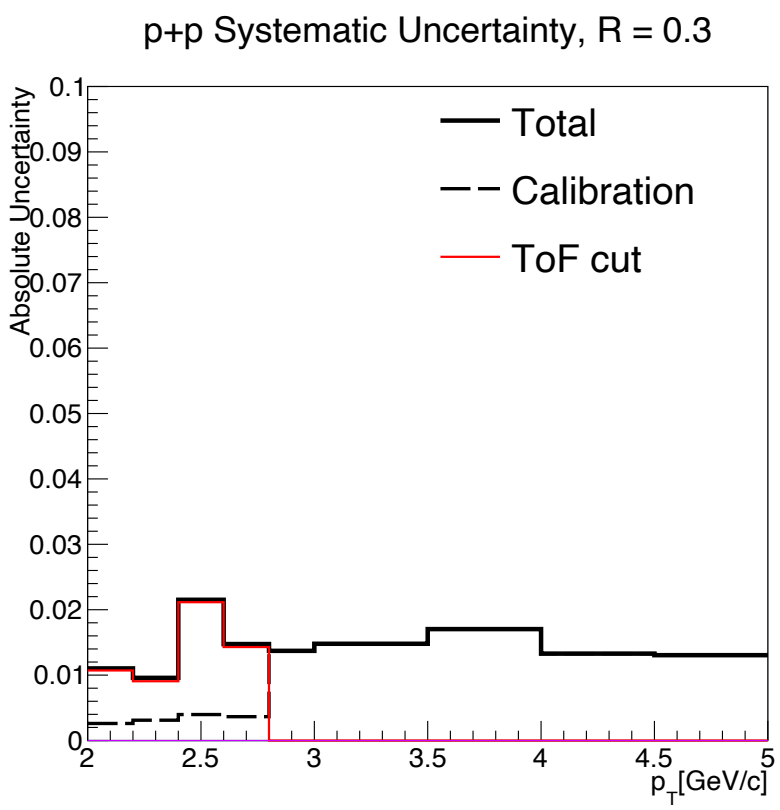
Backup

Systematic Uncertainty

Au+Au



p+p



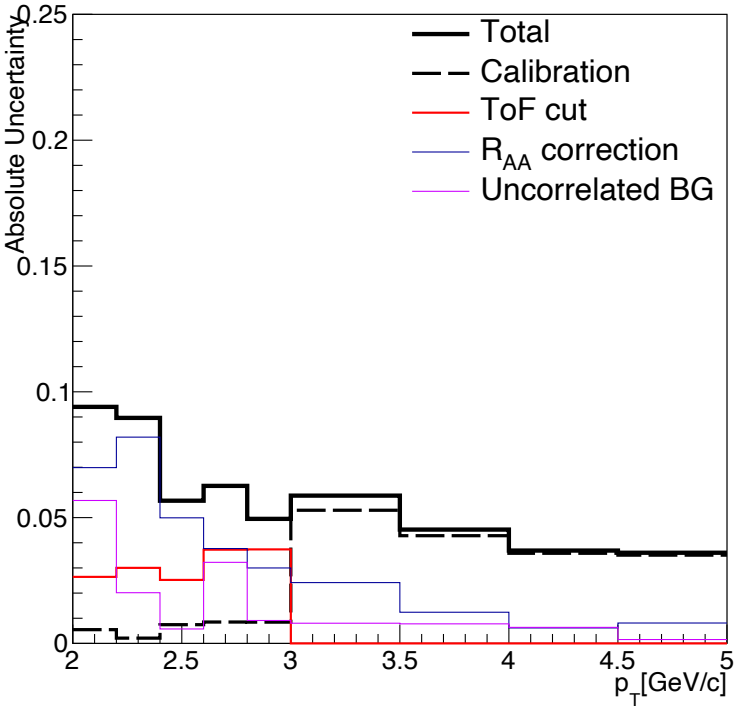
- One representative Jet R is shown here, all Systematics included in backup

Systematic Sources:

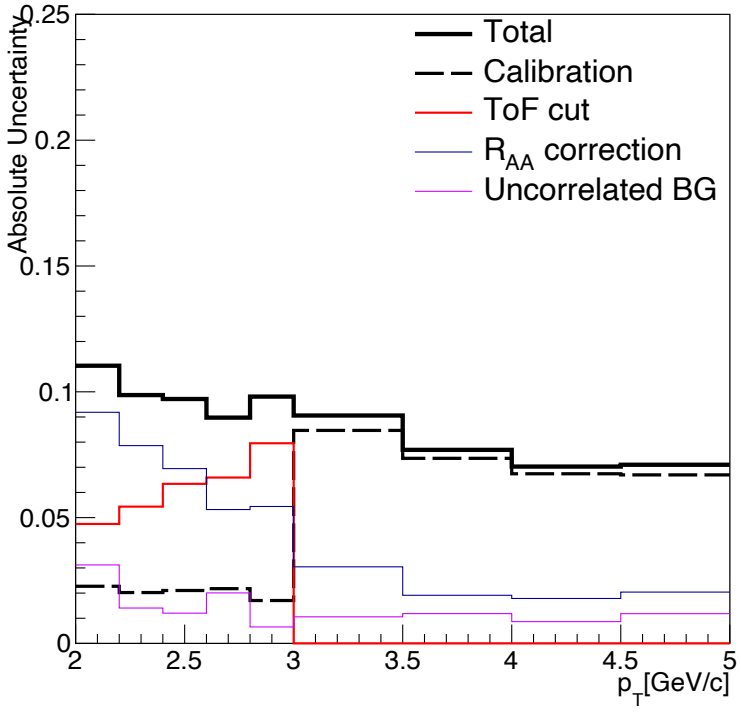
- dE/dx calibration, determined by varying each input parameter for gaussian fits
- ToF cut placement for proton identification below 3.0 GeV/*c*
- Uncorrelated background subtraction, determined by varying UE definition
- R_{AA} correction is included in nominal, for systematic uncertainty on fake rate,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

Au+Au Systematics

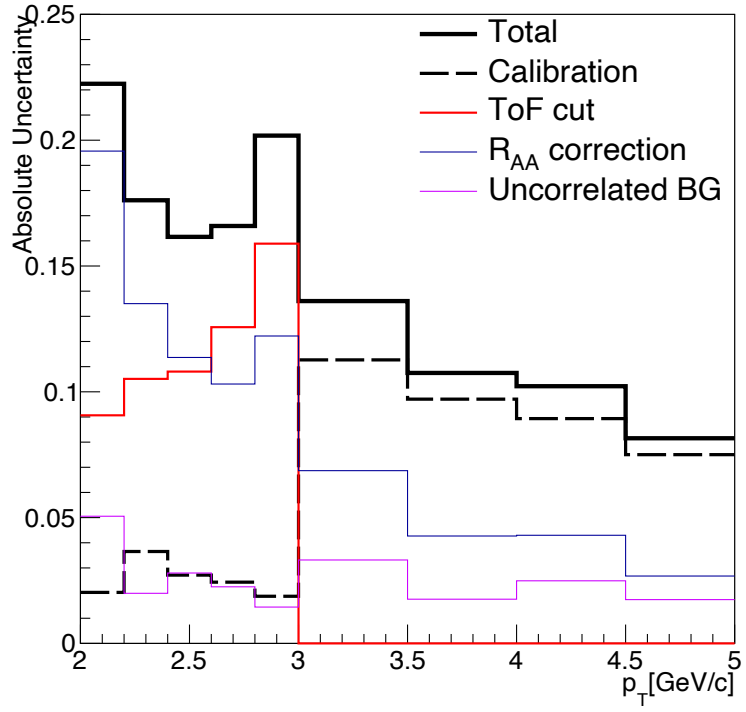
Systematic Uncertainty, R = 0.2



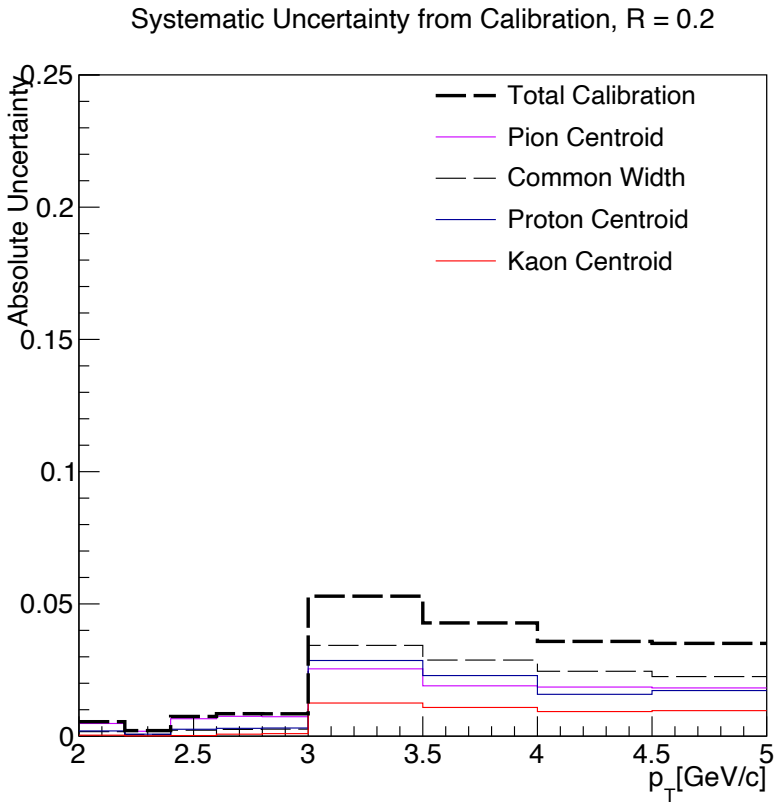
Systematic Uncertainty, R = 0.3

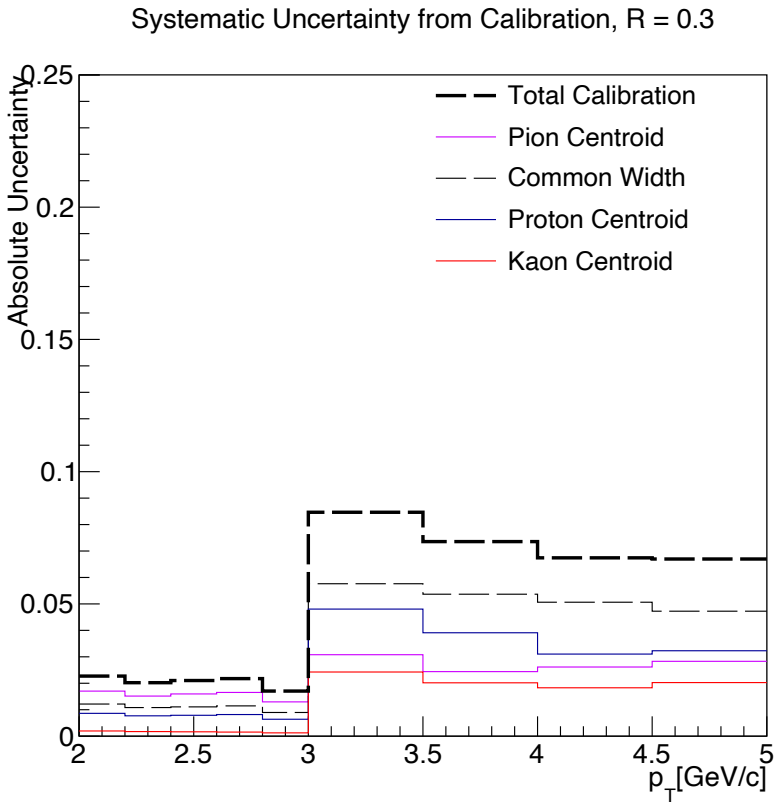


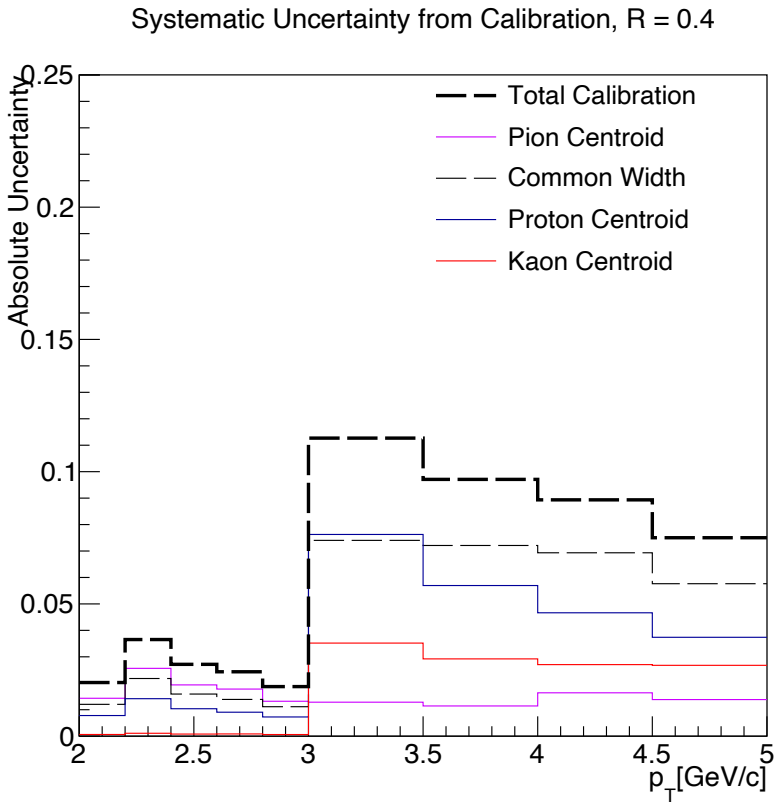
Systematic Uncertainty, R = 0.4



Au+Au, dE/dx Calibration Breakdown

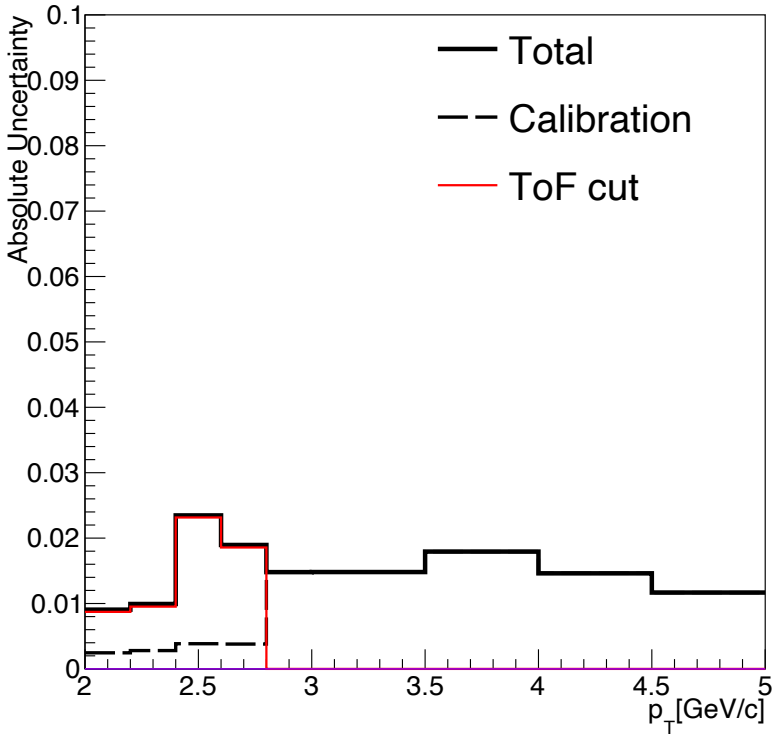




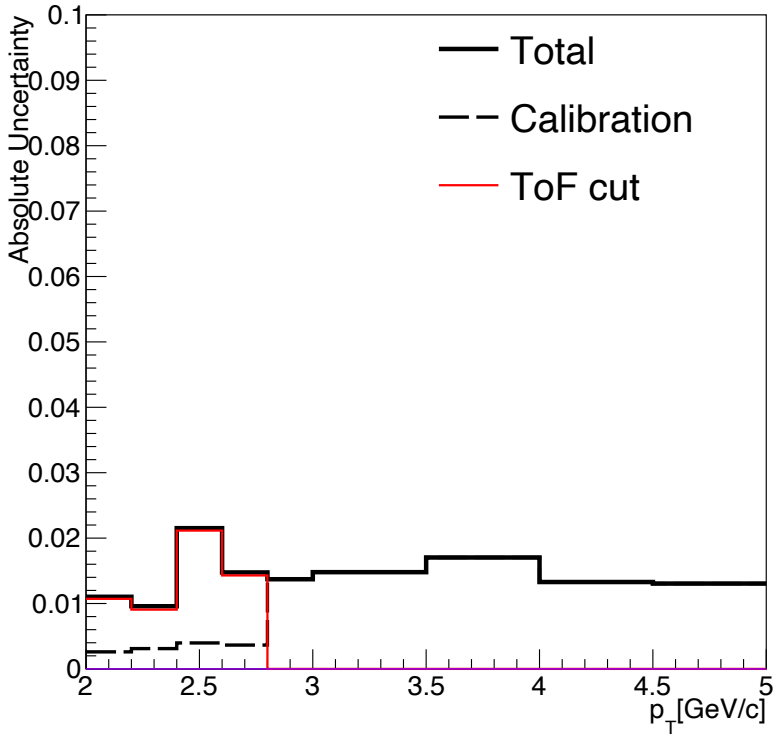


p+p Systematics

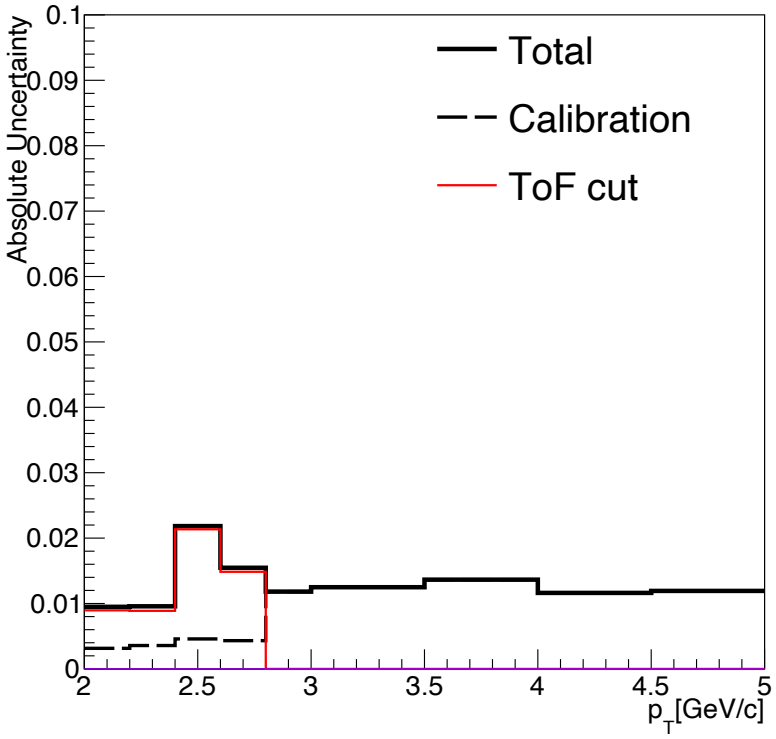
p+p Systematic Uncertainty, R = 0.2



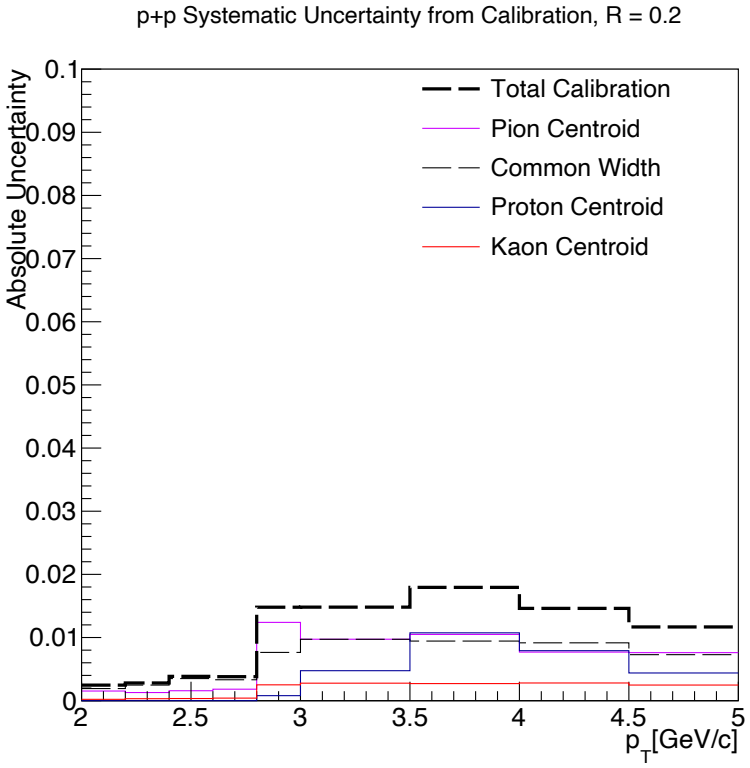
p+p Systematic Uncertainty, R = 0.3

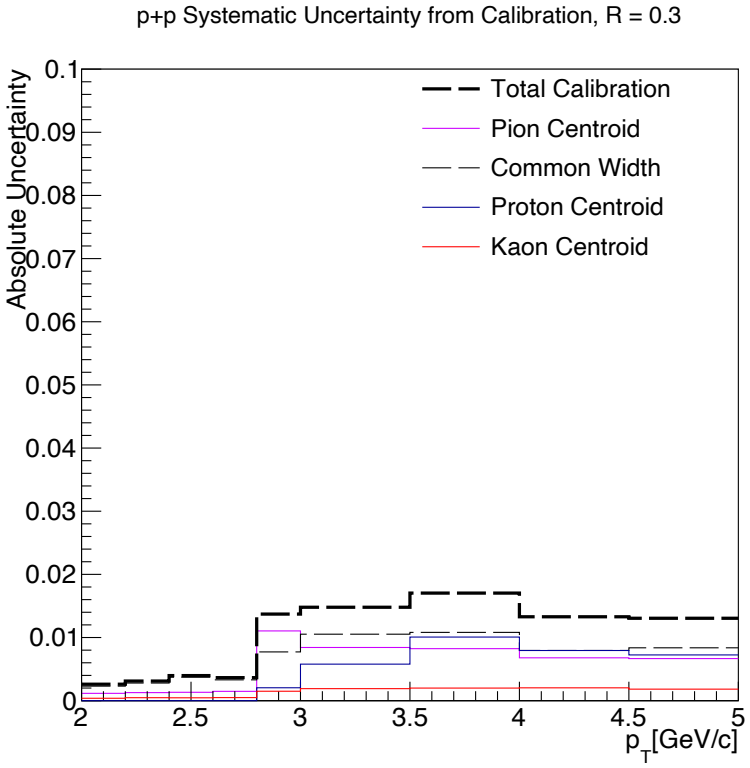


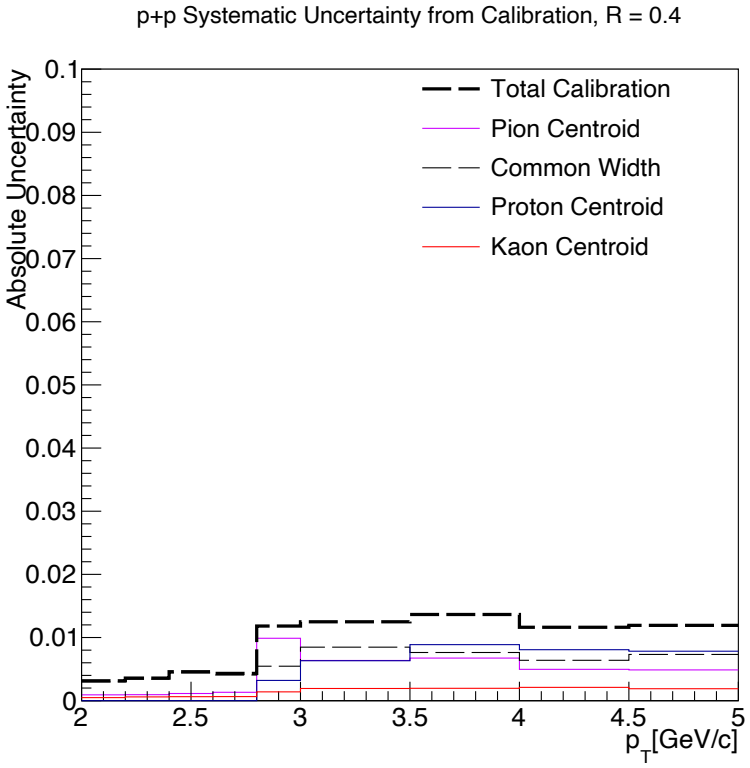
p+p Systematic Uncertainty, R = 0.4



p+p, dE/dx Calibration Breakdown



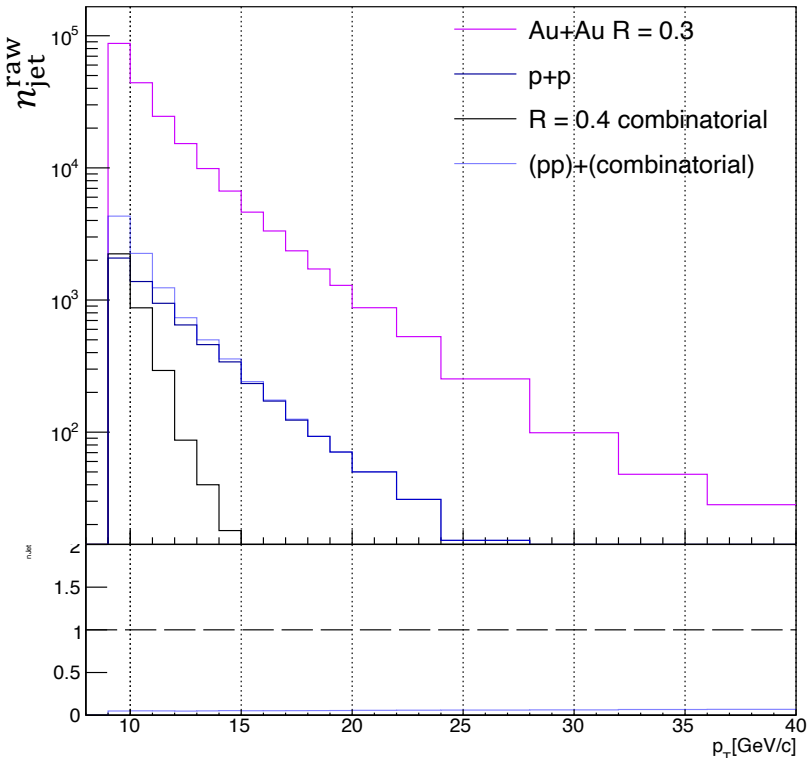




Determining Fake Rate: Spectra Template Fit

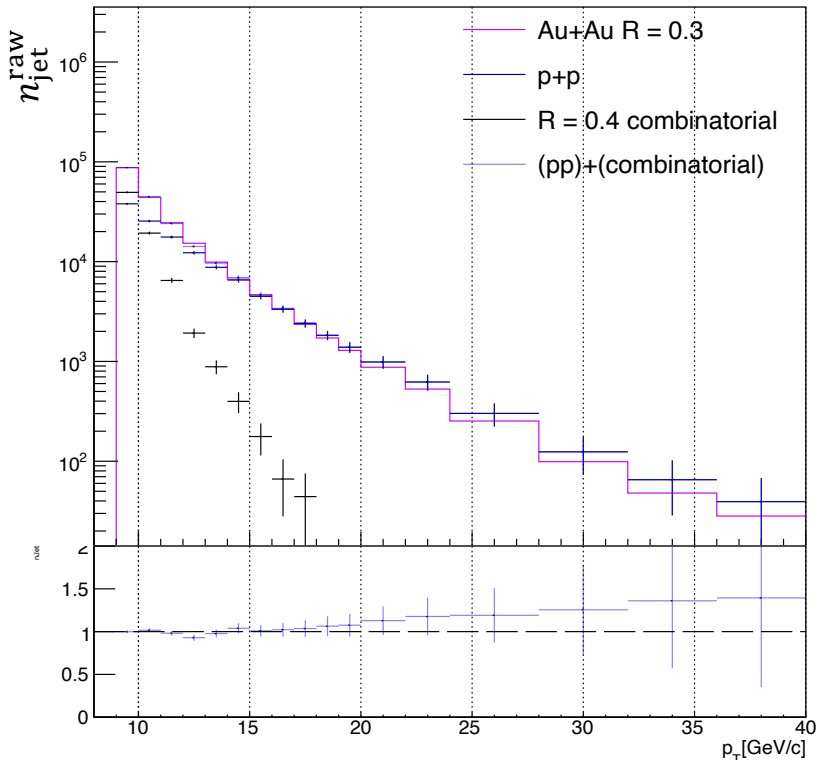
Raw Spectra → **Template Fit**

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

Rebuilding R = 0.3 Spectra

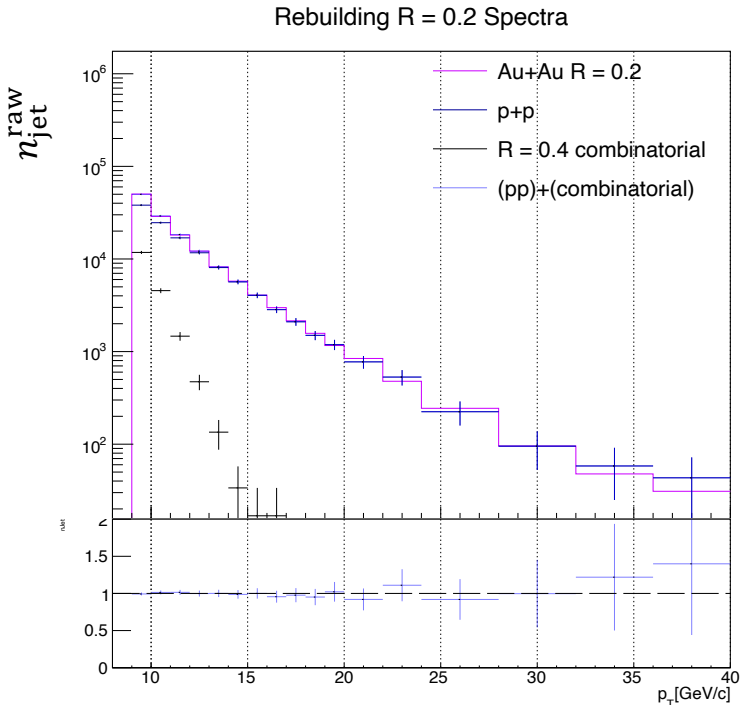


p+p	->	6,984 jets	*	20.5	=	143,715		
Combinatorial	->	4,143 jets	*	22.1	=	91,597	->	**39% Fake Rate**

Fit Parameters

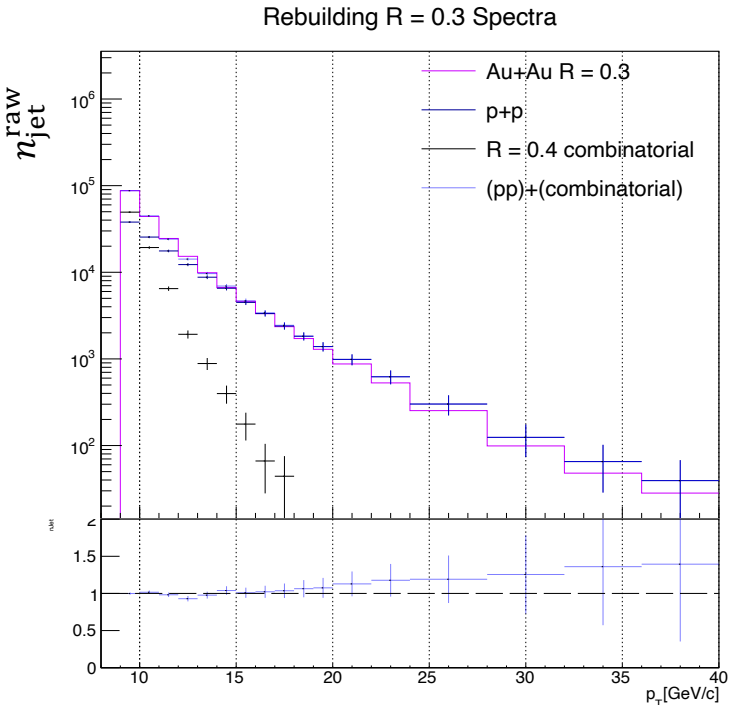
Determining Fake Rate: Spectra Template Fit

R = 0.2



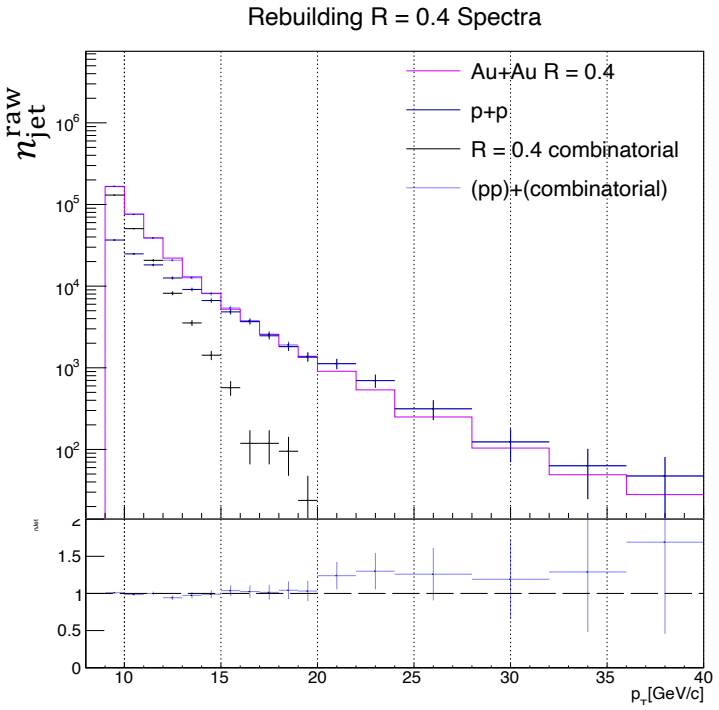
Fake Rate: 13%

R = 0.3



Fake Rate: 39%

R = 0.4



Fake Rate: 63%

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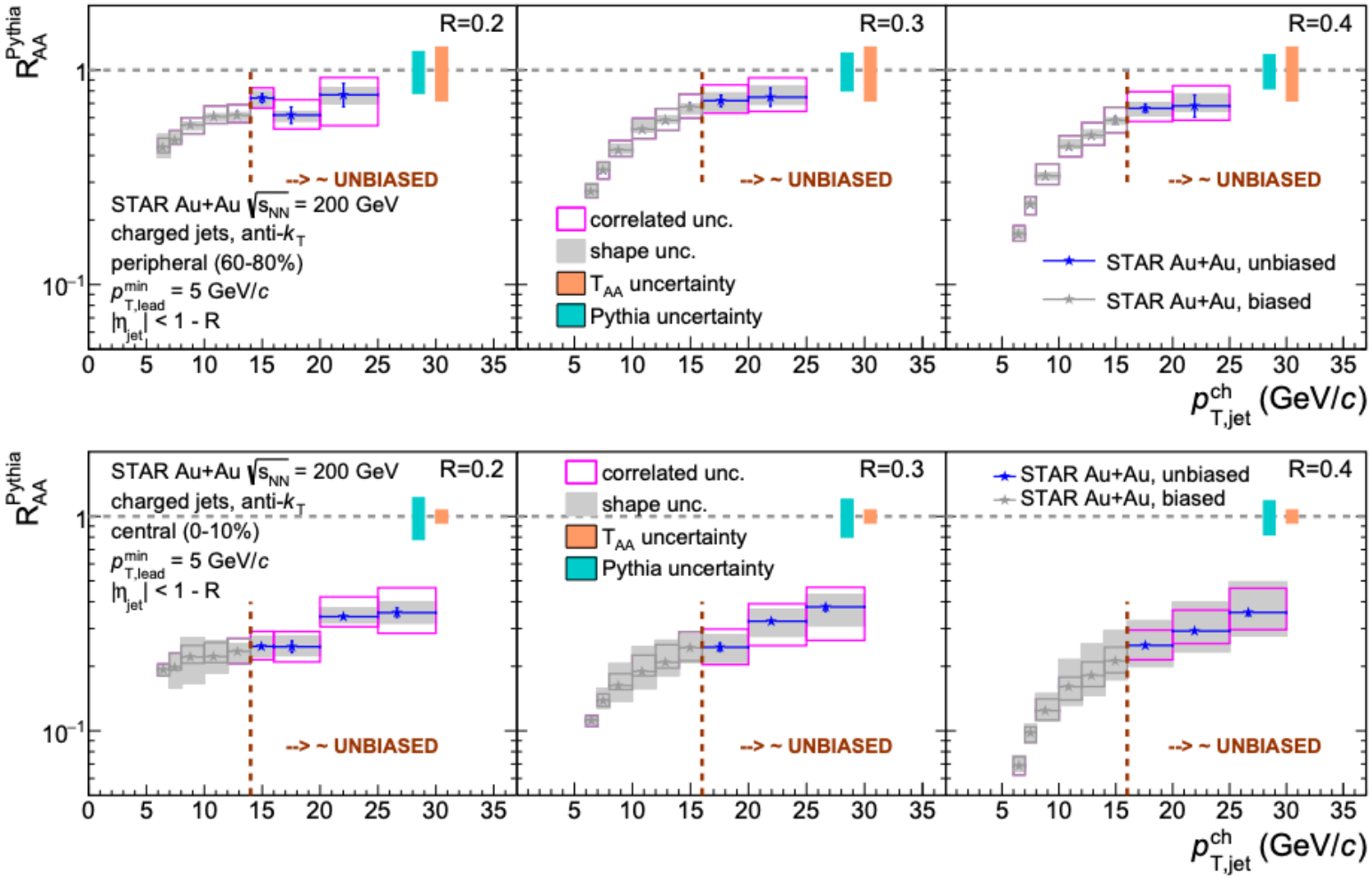
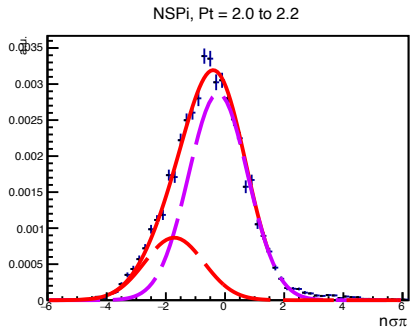
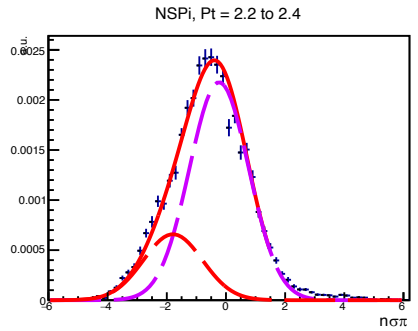
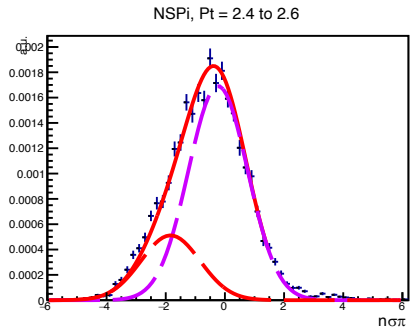


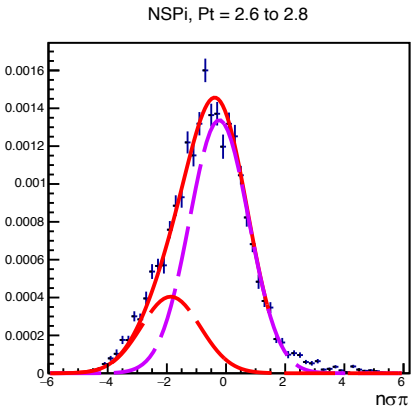
FIG. 17. (Color online) R_{AA}^{Pythia} for quasi-inclusive charged jets in peripheral (upper) and central (lower) Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, for $R = 0.2$, 0.3, and 0.4. The reference spectrum for pp collisions at $\sqrt{s} = 200$ GeV is generated by PYTHIA; see text for details. The region where the bias due to the $p_{T,\mathrm{lead}}^{\mathrm{min}}$ cut is small is indicated by the vertical dashed line.

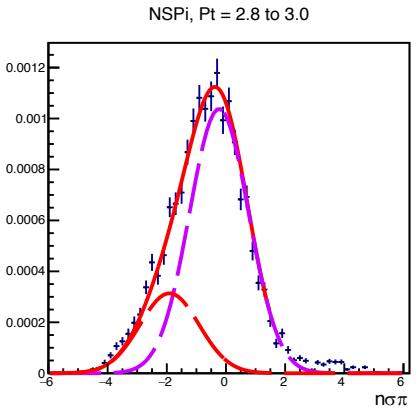
Double Fits for m^{2} < 0.5

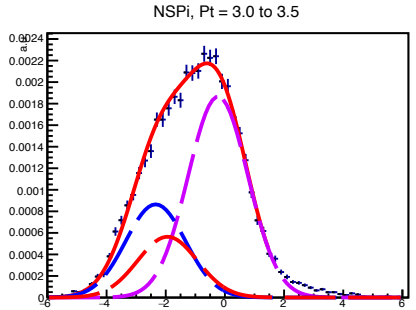




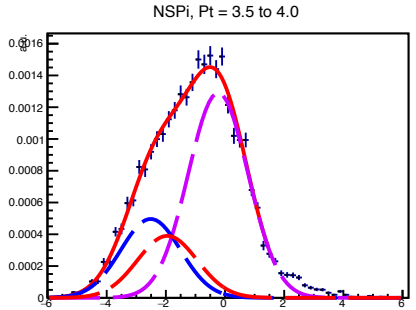


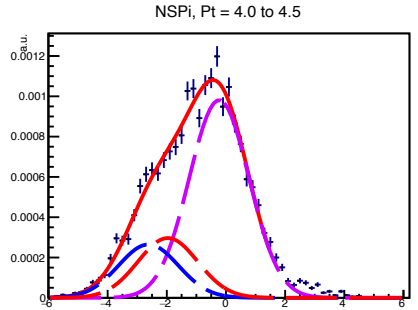


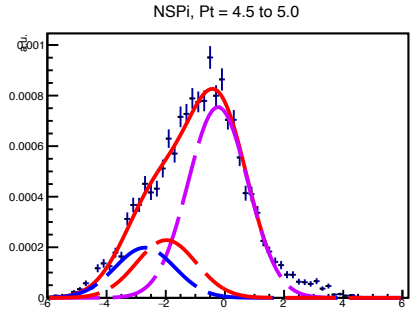




Triple Fits for full m^{2} Range



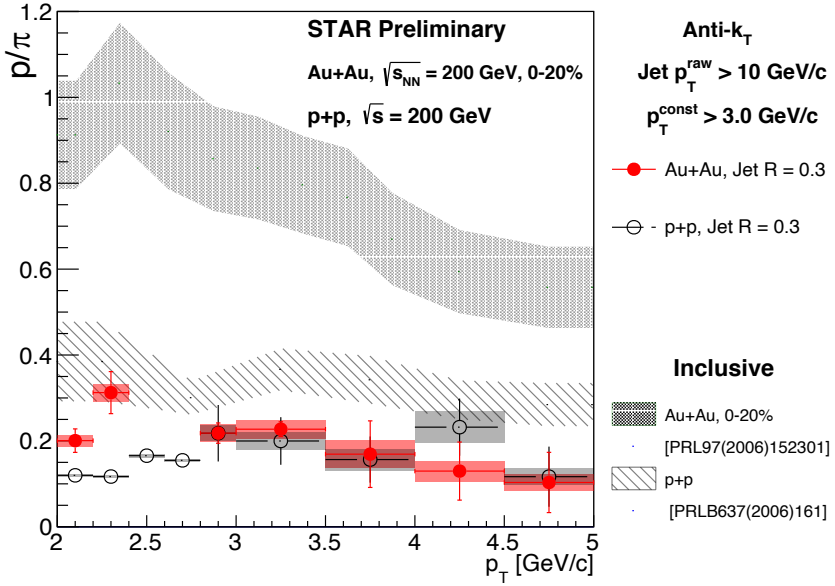




Gaussian Fits for R = 0.3

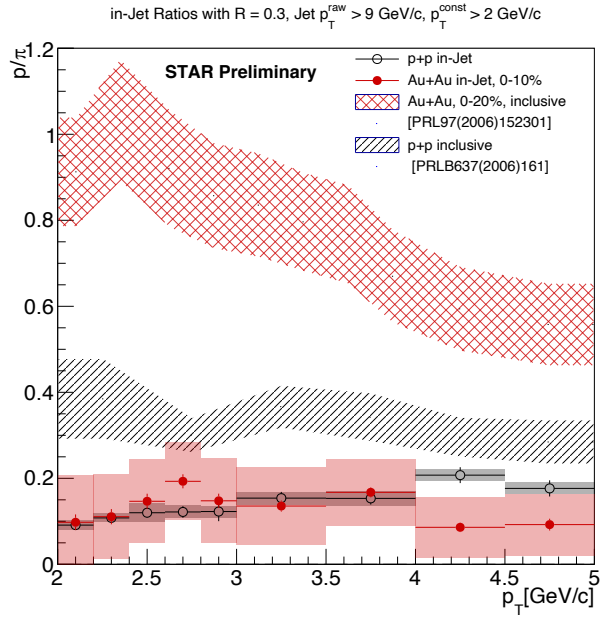
Developments Since Hard Probes 2023

Results Presented at HP23



- In Jet p/π ratios presented for jets with p_{T}^{const} > 3.0 GeV/c
- Leading jets only
- No correlated background evaluation

Results Presented at HP24



- In Jet p/π ratios presented for jets with p_{T}^{const} > 2.0 GeV/c
- Larger Data set (mid + low lumi)
- Inclusive jets
- Novel approach to correlated background evaluation