DNP2022

Fall Meeting of the Division of Nuclear Physics
of the American Physical Society
Oct. 27 – 30, 2022
Hyatt Regency Hotel, New Orleans, LA

APS physics

IDENTIFIED HADRON SPECTRA AND BARYON STOPPING IN $\gamma + \mathbf{Au}$ COLLISIONS AT STAR

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Supported by:

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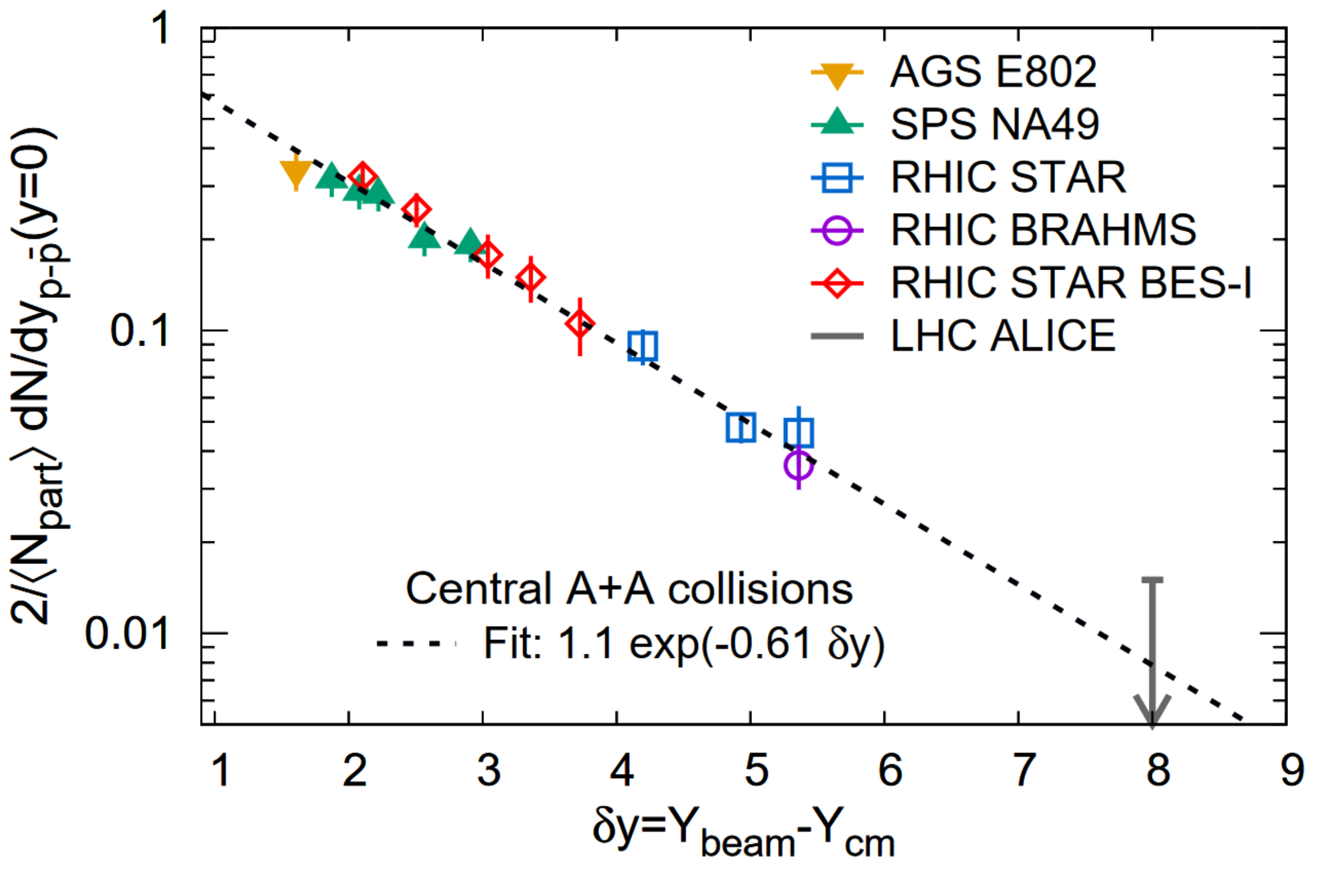
Baryon Stopping

- Energy required to produce large number of particles in heavy-ion collisions comes from the kinetic energy lost by the baryons of the colliding nuclei
  - Larger effect in collisions with higher multiplicity (small impact parameter)
- Net-baryon yield can be estimated from the net-proton yield: difference in number of protons and anti-protons
- Cannot be fully explained by pure string fragmentations



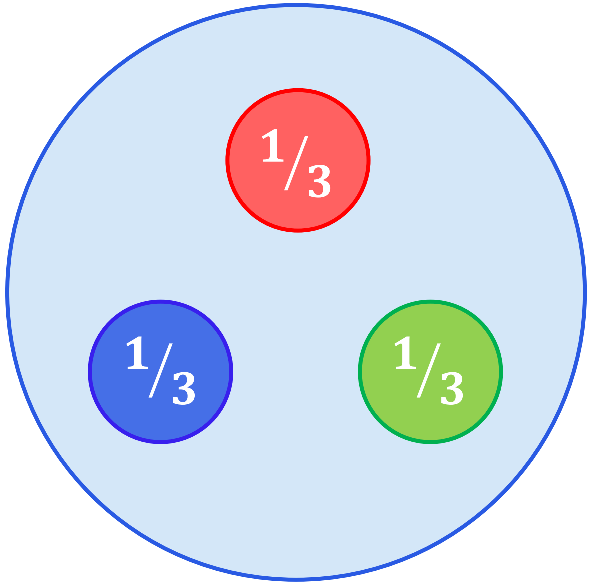
J. D. Brandenburg *et al*, arXiv:2205.05685

Baryon Junction

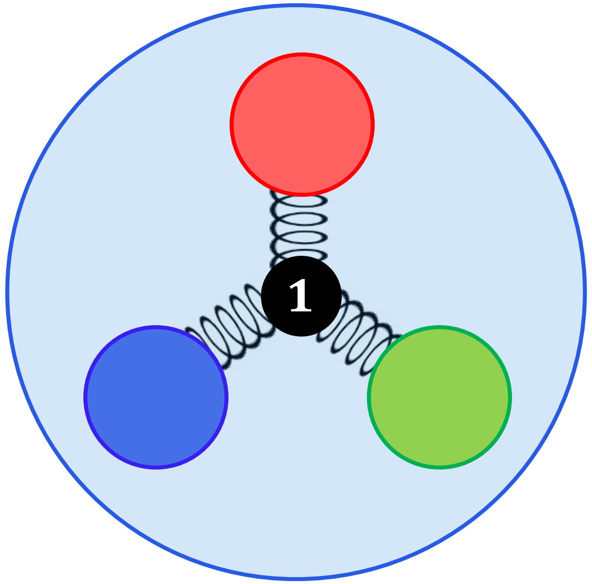
- Nonperturbative configuration of gluons linked to all three valence quarks
  - First proposed as a way to construct a gauge-invariant baryon made of quarks and gluons

  G.C. Rossi and G. Veneziano, Physics Reports **63**, 153 (1980)
  - Carries the baryon number
  - Theorized to be an effective mechanism of stopping baryons in pp and AA
  - Unlike valence quarks, junctions in target have sufficient time to interact and be stopped by the projectile, even at high energy collisions

  D. Kharzeev, Physics Letters B **378**, 238-246 (1996)
- No signature of baryon junction has been cleanly identified in the experiment

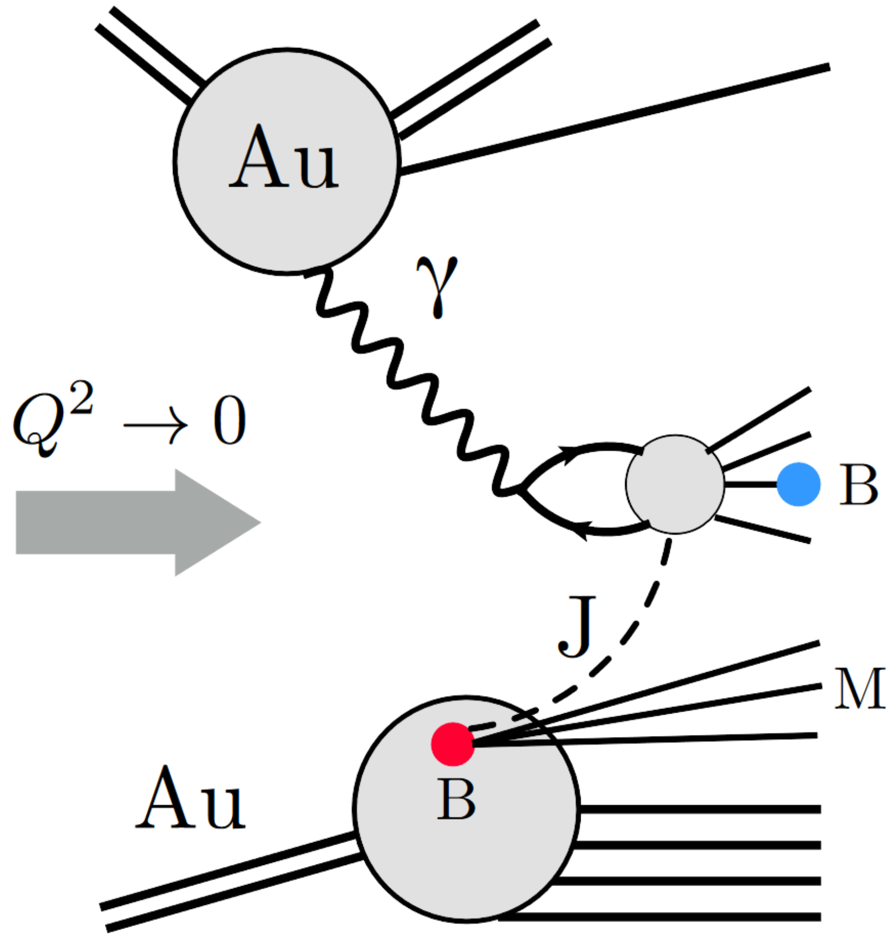


VS



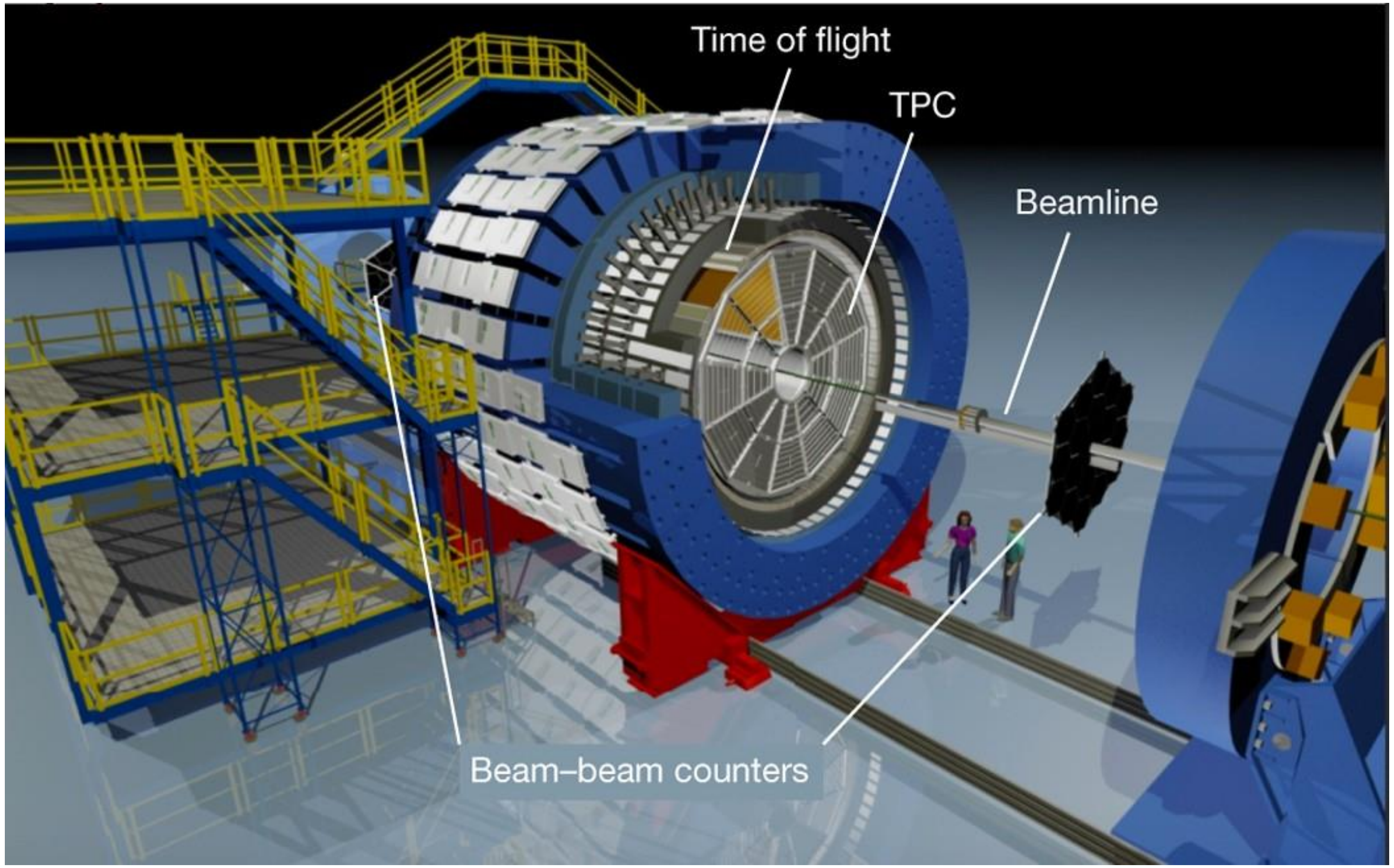
Photonuclear Collisions

- Inclusive particle production in photonuclear collisions
  - Large flux of quasi-real photons produced by ultra-relativistic large-Z nuclei
  - Similar to eA collisions except that the photon has much smaller virtuality
- Can be used to study bulk properties such as collectivity from initial-state effects (i.e. radial flow, rapidity correlation) and hadron chemistry
- Can be used to study baryon stopping with the cleanest possible process
  - $q\bar{q}$ + Baryon Junction producing a midrapidity proton
  - Rapidity distribution of $dN/dy \propto \exp(-y/2)$



J. D. Brandenburg *et al*, arXiv:2205.05685

Particle Identification With STAR



Time Projection Chamber (TPC) identifies particles at lower p_T using ionization energy loss, dE/dx

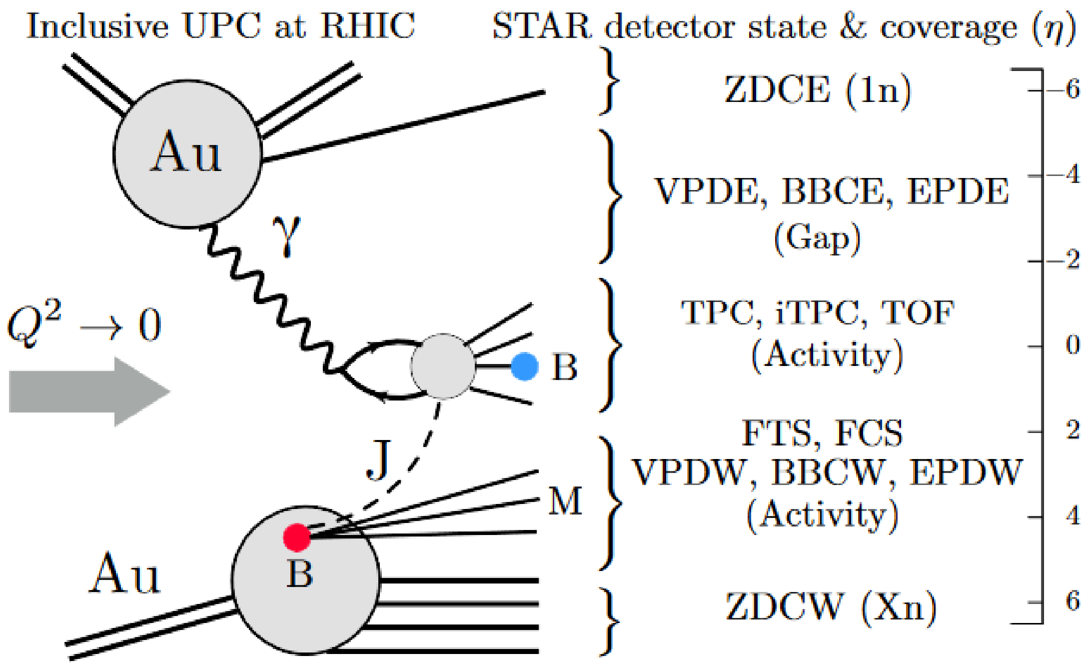
Time of Flight (TOF) identifies particles at higher p_T

Beam-Beam Counter (BBC) used for rapidity gap cuts

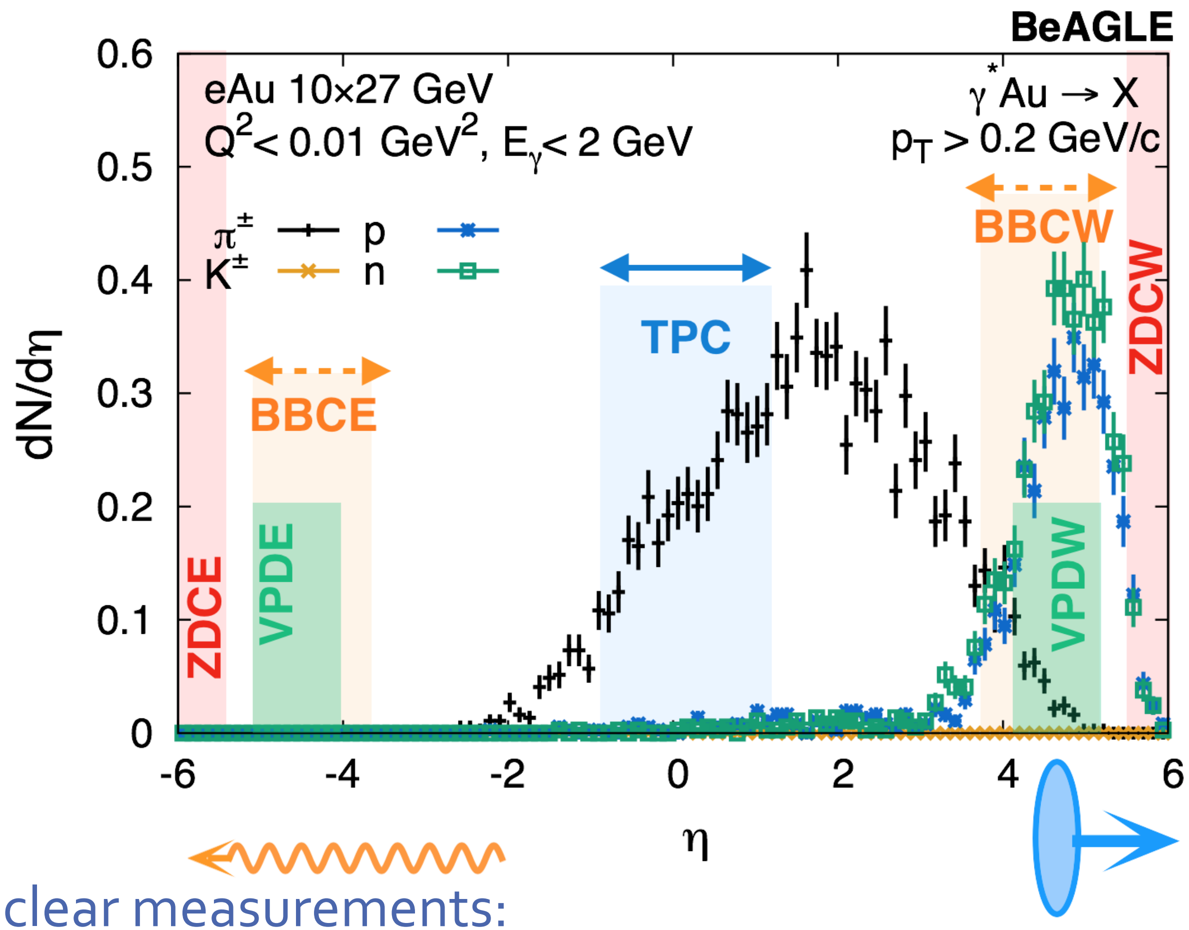
Data collected in 2017,

$\mathrm{Au} + \mathrm{Au}$ collisions with $\sqrt{s_{NN}} = 54.4\ \mathrm{GeV}$, trigger did not require coincidence in both sides of the detector ~700 million events

Photonuclear Events Are Selected With Rapidity Gaps



J. D. Brandenburg *et al*, arXiv:2205.05685

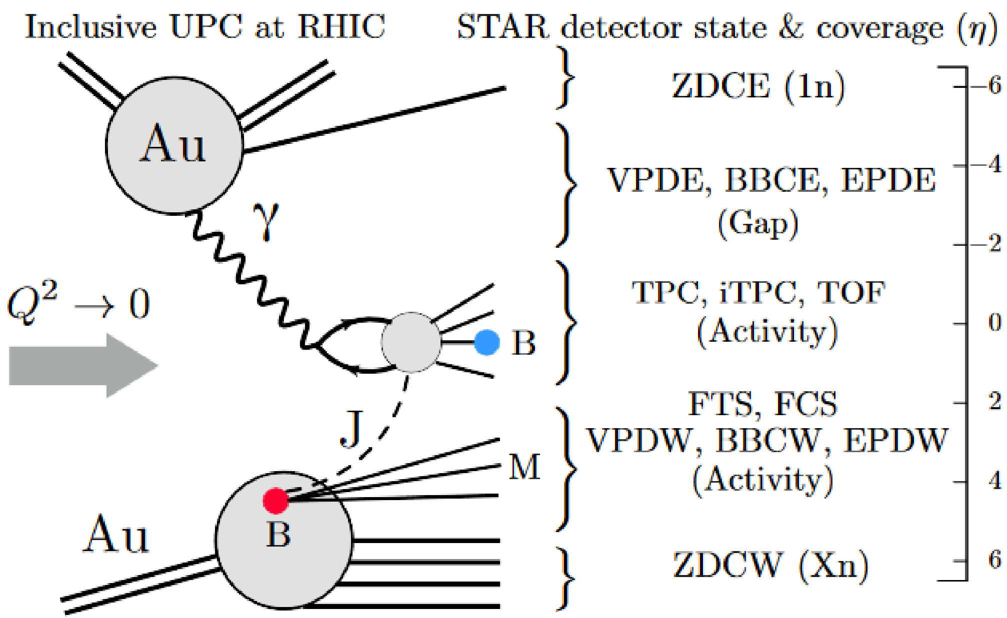


Similar technique used by LHC photonuclear measurements:

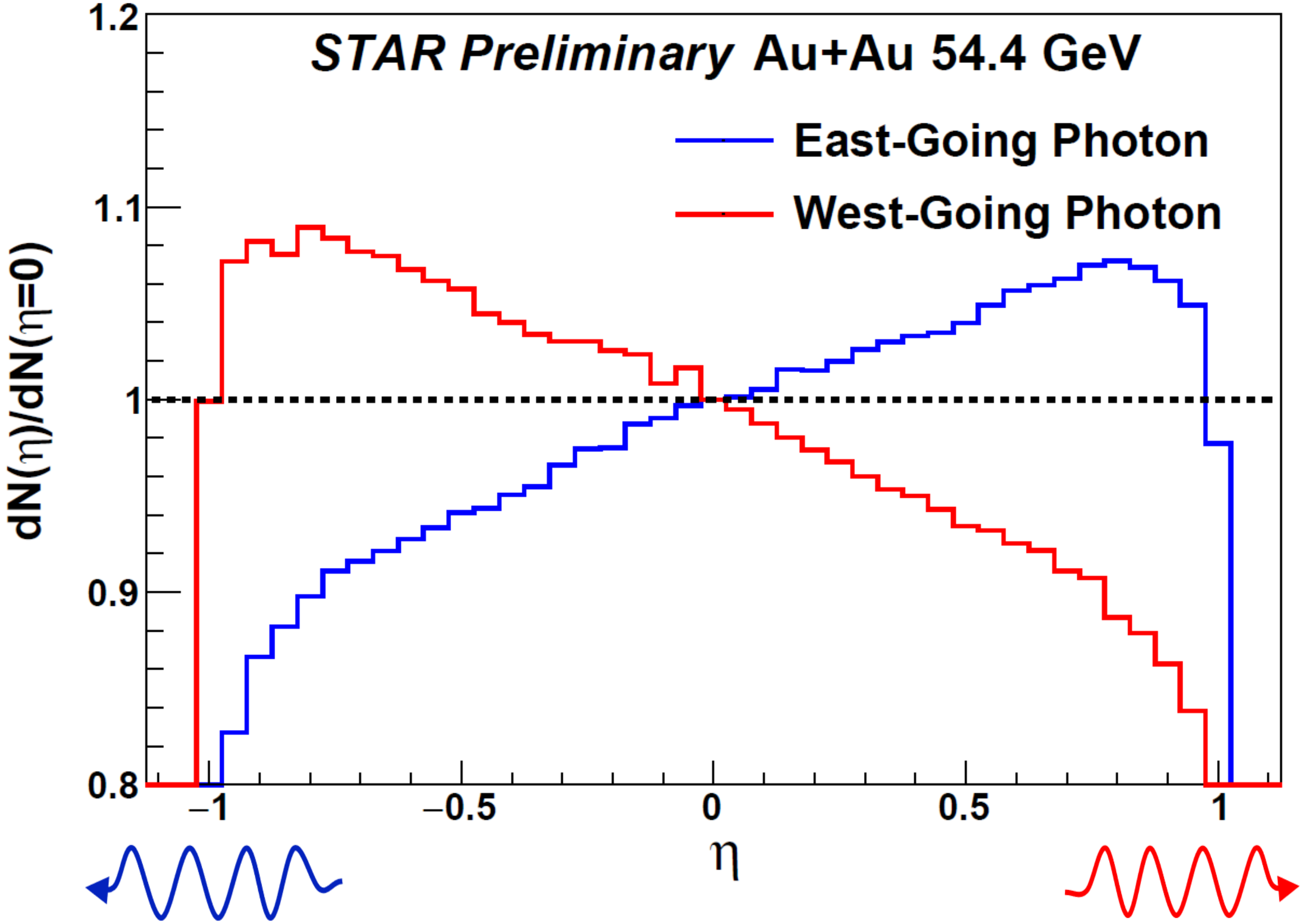
ATLAS Collaboration, Phys. Rev. C **104**, 014903 (2021)

CMS Collaboration, arXiv:2204.13486 (2022)

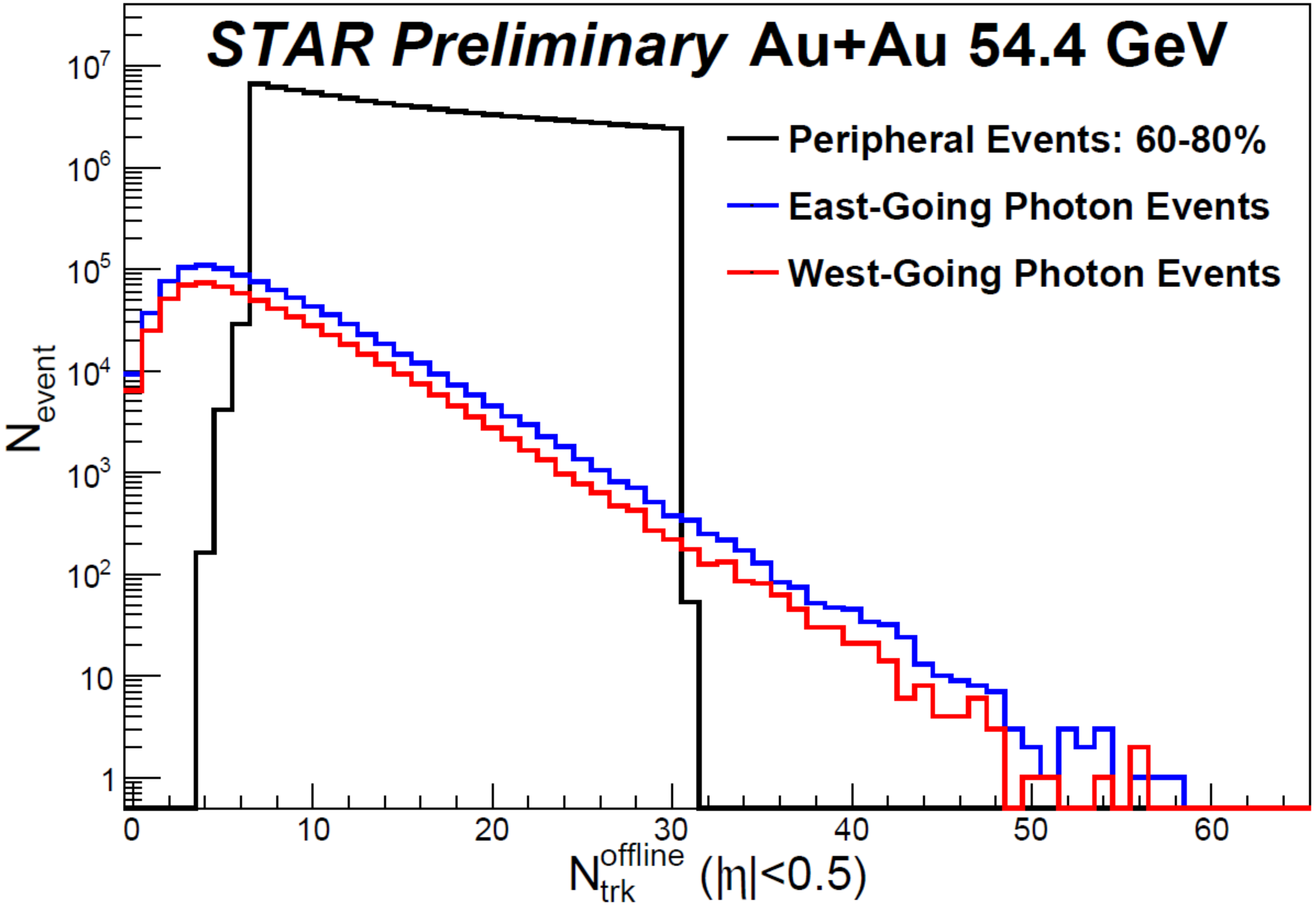
Rapidity Asymmetry in γA-Rich Events



J. D. Brandenburg *et al*, arXiv:2205.05685



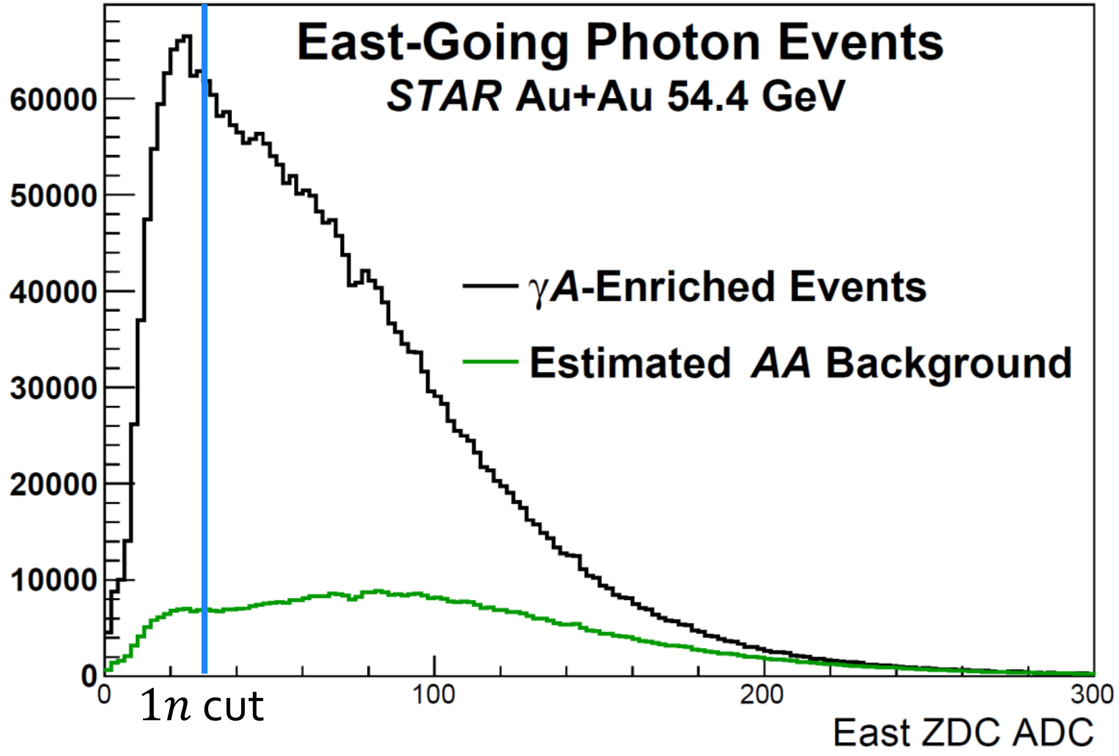
Defining γA and AA Event Classes

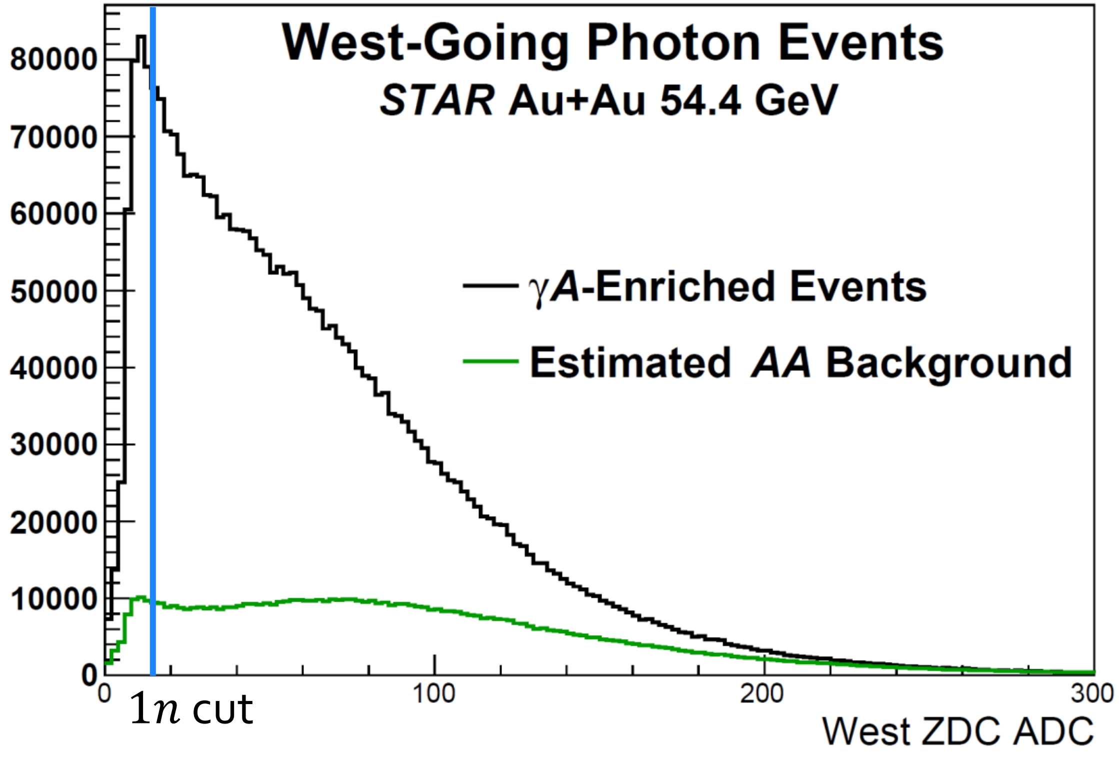


Most photonuclear events have low multiplicity, consistent with very peripheral $\mathrm{Au} + \mathrm{Au}$ collisions

Using $60 - 80\%$ peripheral events as a baseline comparison

Estimating Background Contamination from Peripheral Collisions



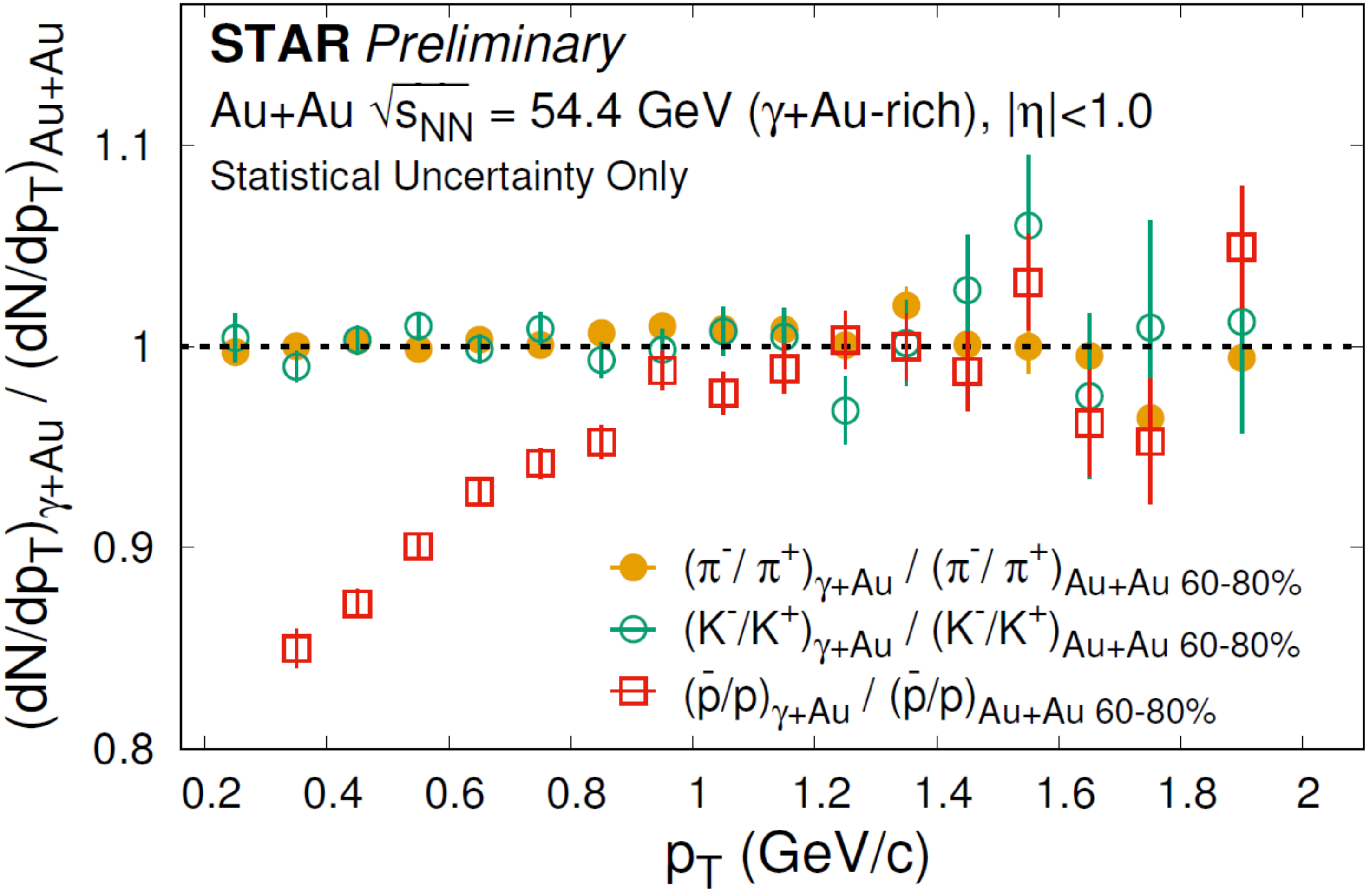


Estimate background contribution utilizing ZDC ADC distributions of peripheral events

- Scale down so the tail matches γA-enriched events, for ADC between 250 and 800
- Background fraction $\sim 15\%$

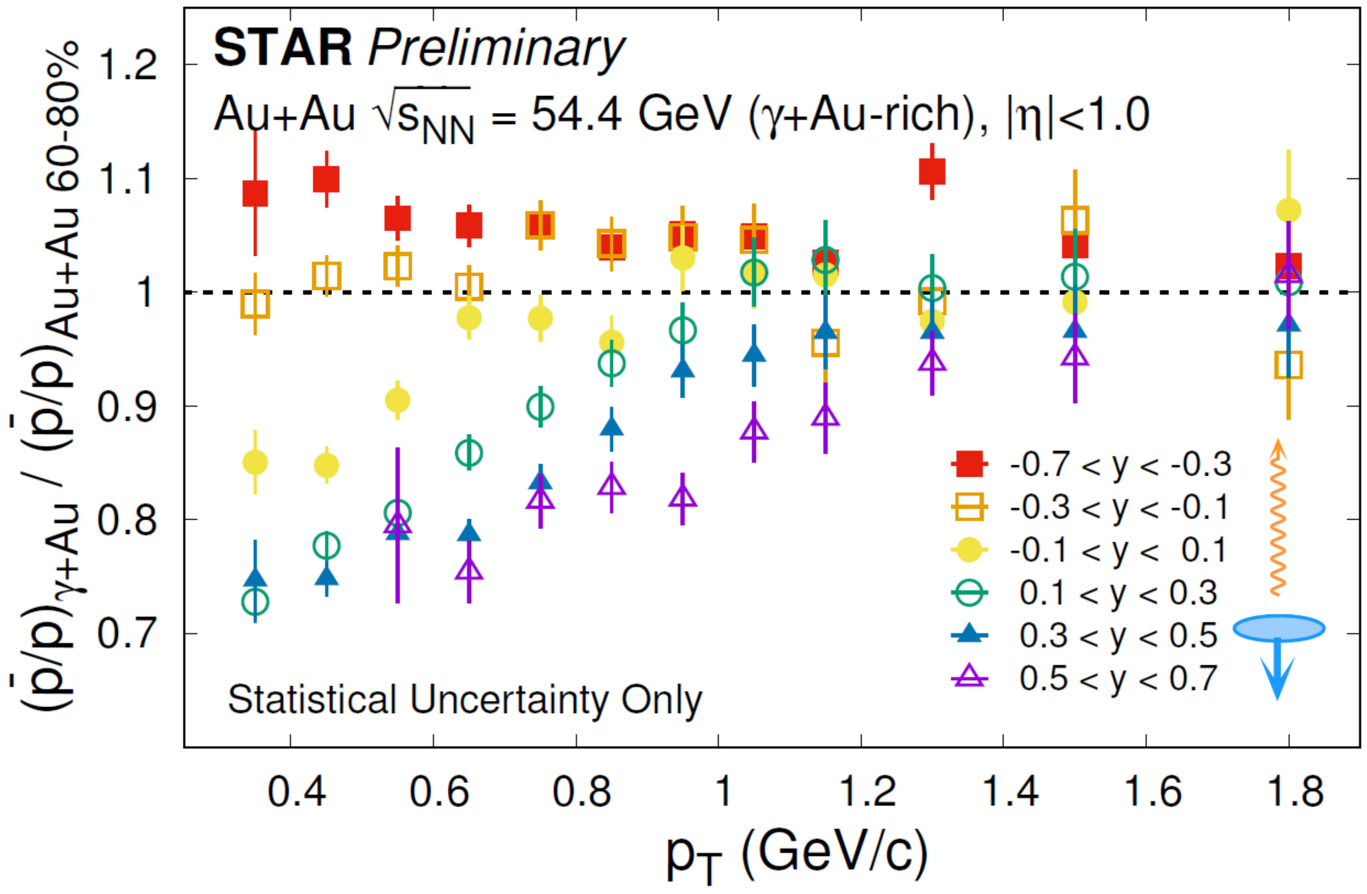
Low p_T Baryon Enhancement in γA

- Double ratio: antiparticle/particle in $(\gamma A)/(AA)$
- $\bar{p}/p < 1$ for $p_T \lesssim 1$ GeV/c → soft baryon stopping that is **stronger** in γA compared to peripheral AA
- Not seen in PYTHIA simulations, which do not include a baryon junction
- Not corrected for efficiency, but largely cancels in the ratio



Proton Double Ratio as a Function of Rapidity

$y > 0$ is in the A-going direction



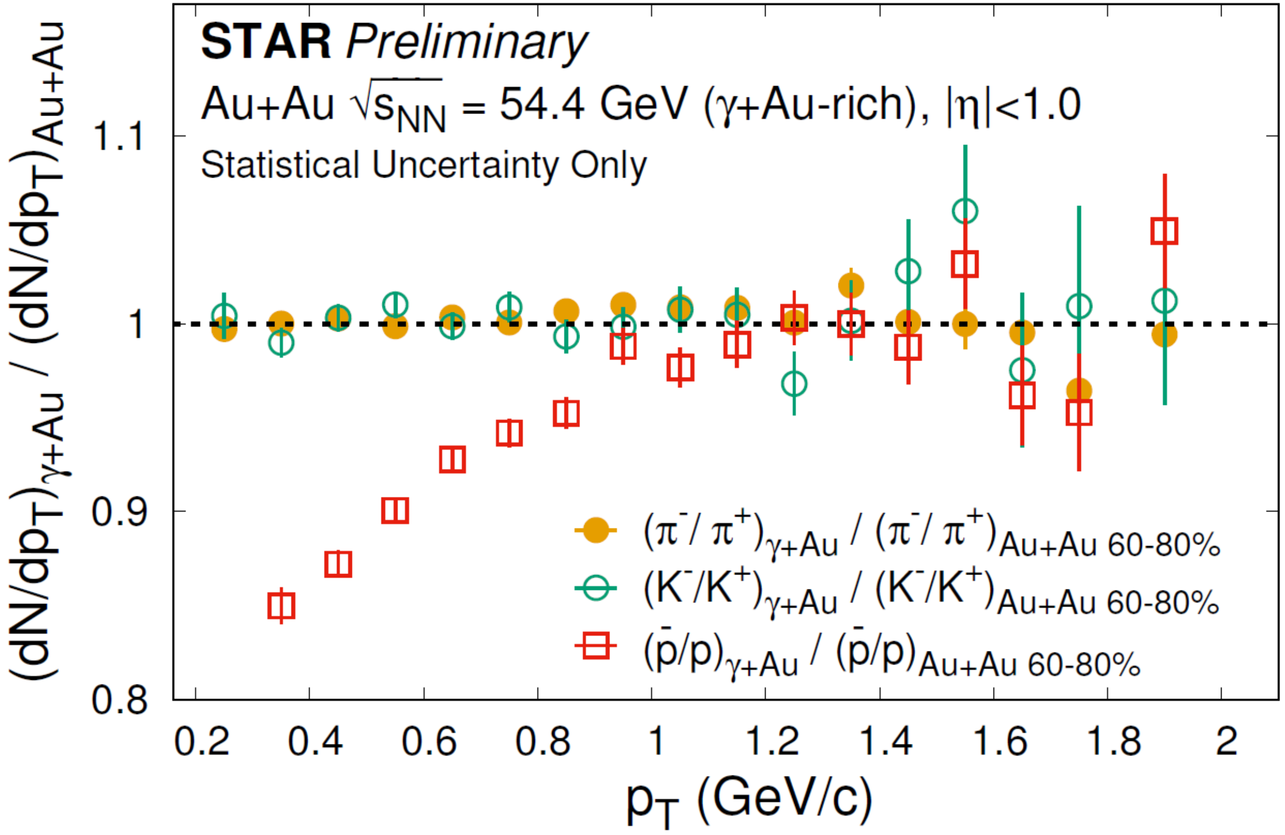
- **High p_T:** double ratio consistent with 1
  - Same baryon stopping in γA compared to peripheral AA
- **$y < 0$ (γ-going side):** double ratio is slightly greater than 1
  - Slightly less baryon stopping in γA compared to peripheral AA
- **Low p_T, $y > 0$ (A–going side):** double ratio gets smaller with increasing rapidity
  - More baryon stopping in γA than peripheral AA
  - Consistent with baryon junction prediction

Summary

- Studied identified particle spectra in photonuclear events from $\sqrt{s_{NN}} = 54.4$ GeV Au + Au ultraperipheral collisions
- Baryon stopping observed at low p_T
  - Possible evidence of a baryon junction existing inside nucleon

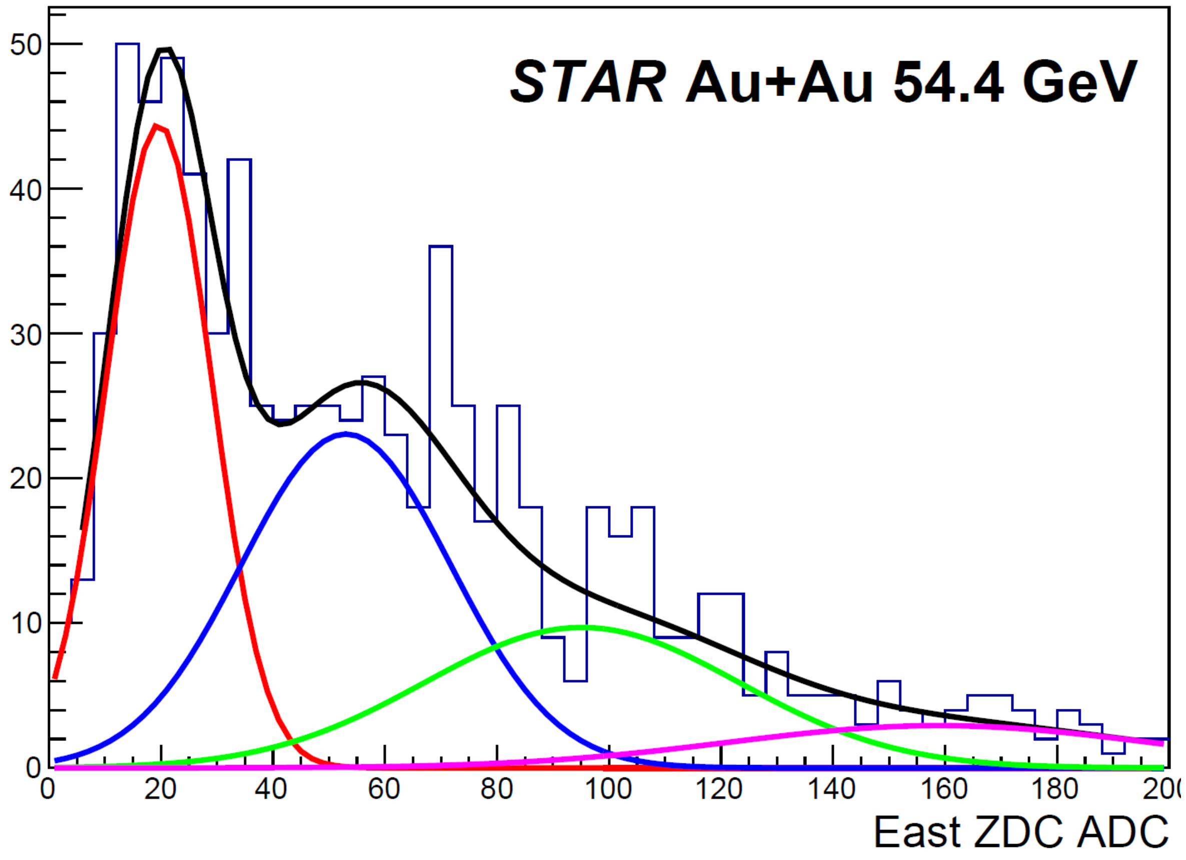
J. D. Brandenburg *et al*, arXiv:2205.05685

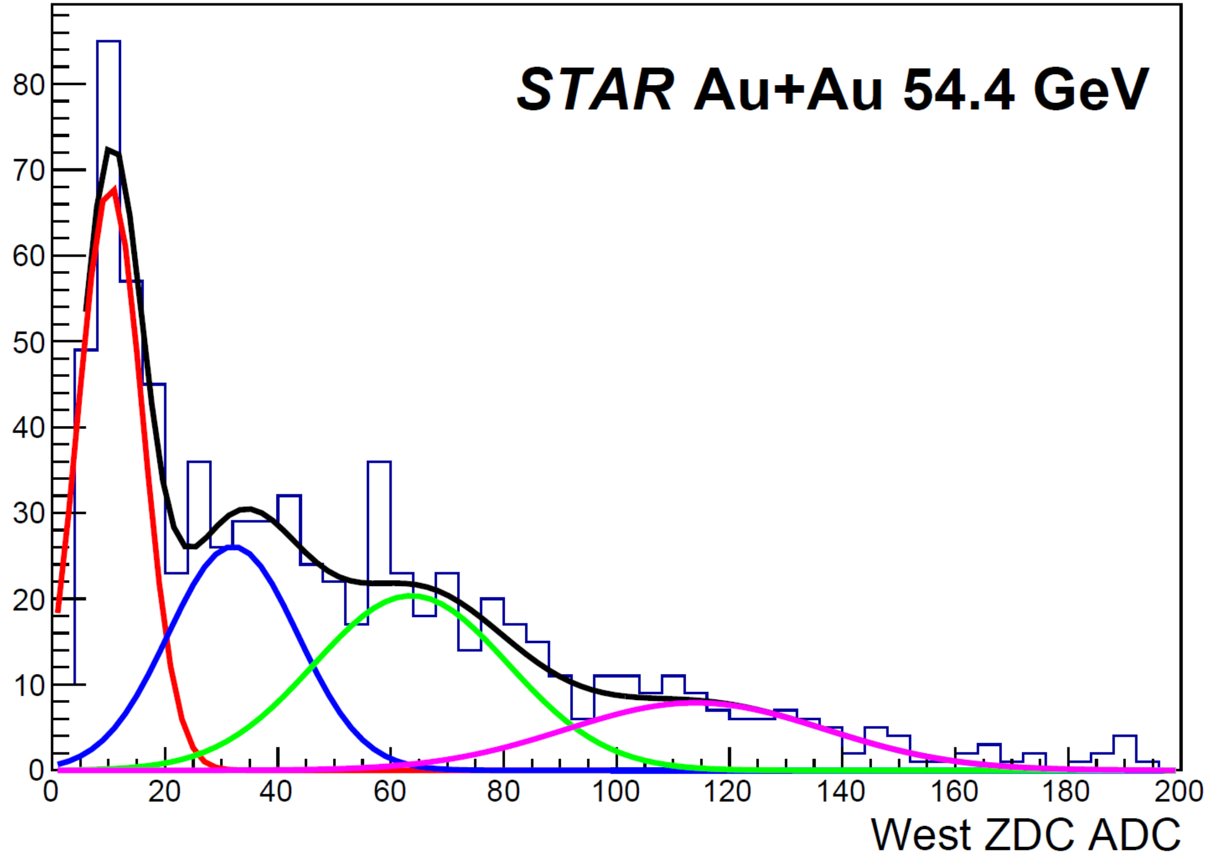
- Next Step: Measure net-proton dN/dy vs rapidity
- Will inform future measurements of identified particles at the EIC



Back Up

γA-Rich Events:
Cutting on ZDC Spectra



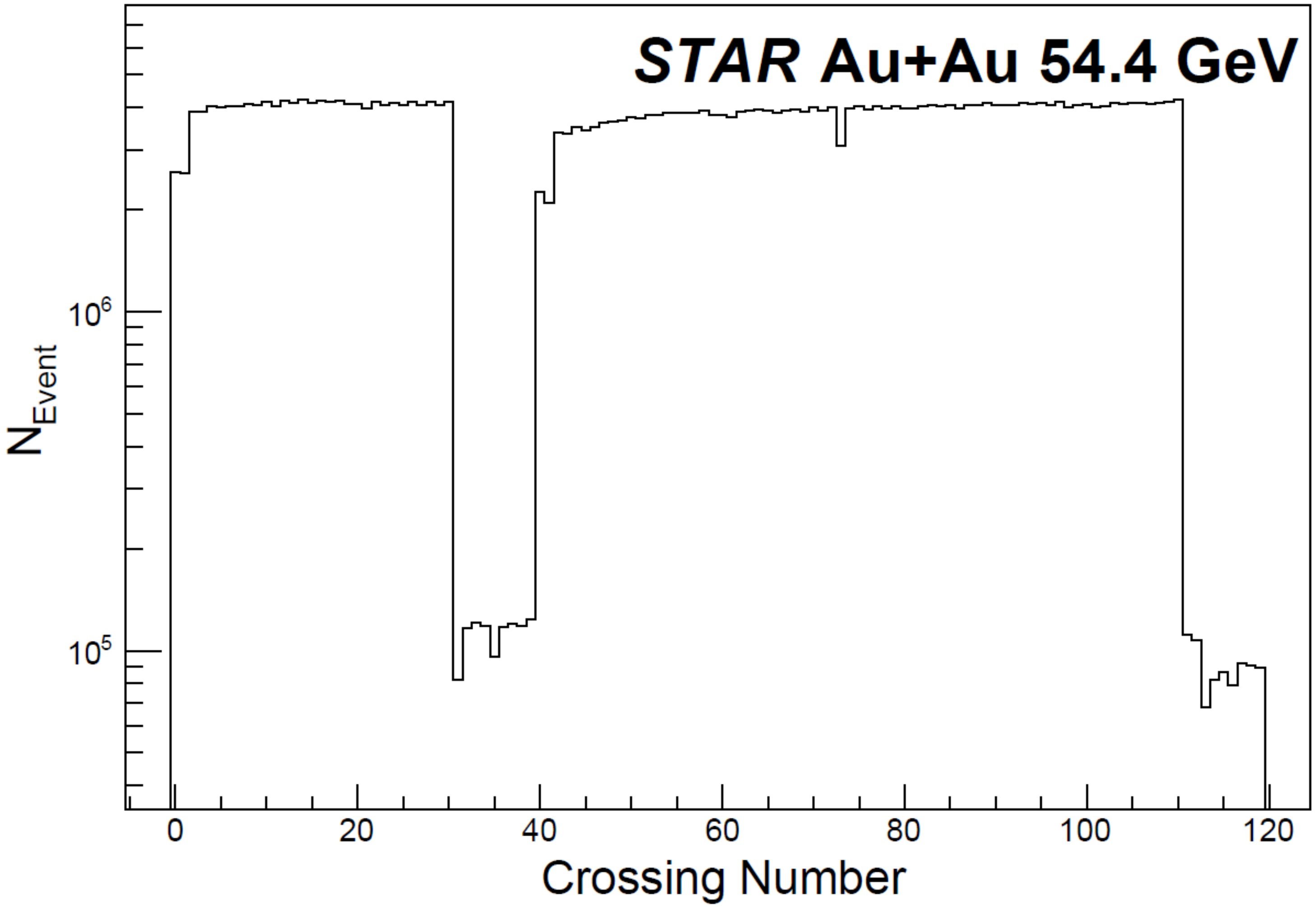


Low multiplicity events collected with ZDC triggers

Cutting on single neutron peak: $1nXn$ $(X > 1)$, dominated by γA events.

Study Beam Gas Background with Abort Gap Events

- At STAR, 18 out of 120 crossings (31 to 39 and 111 to 119) have only one of the beams filled due to the abort gaps
- Most abort gap events occur because of beam gas and beam material interactions
  - Only a small portion of these abort gap events pass our event cuts
- Background contribution estimated to be about 3%
- $(\bar{p}/p)_{\gamma+\mathrm{Au}}/(\bar{p}/p)_{\mathrm{Au+Au\ 60-80\%}}$ ratio is flat with p_T and consistent with 1 ratio for abort gap events which pass these cuts



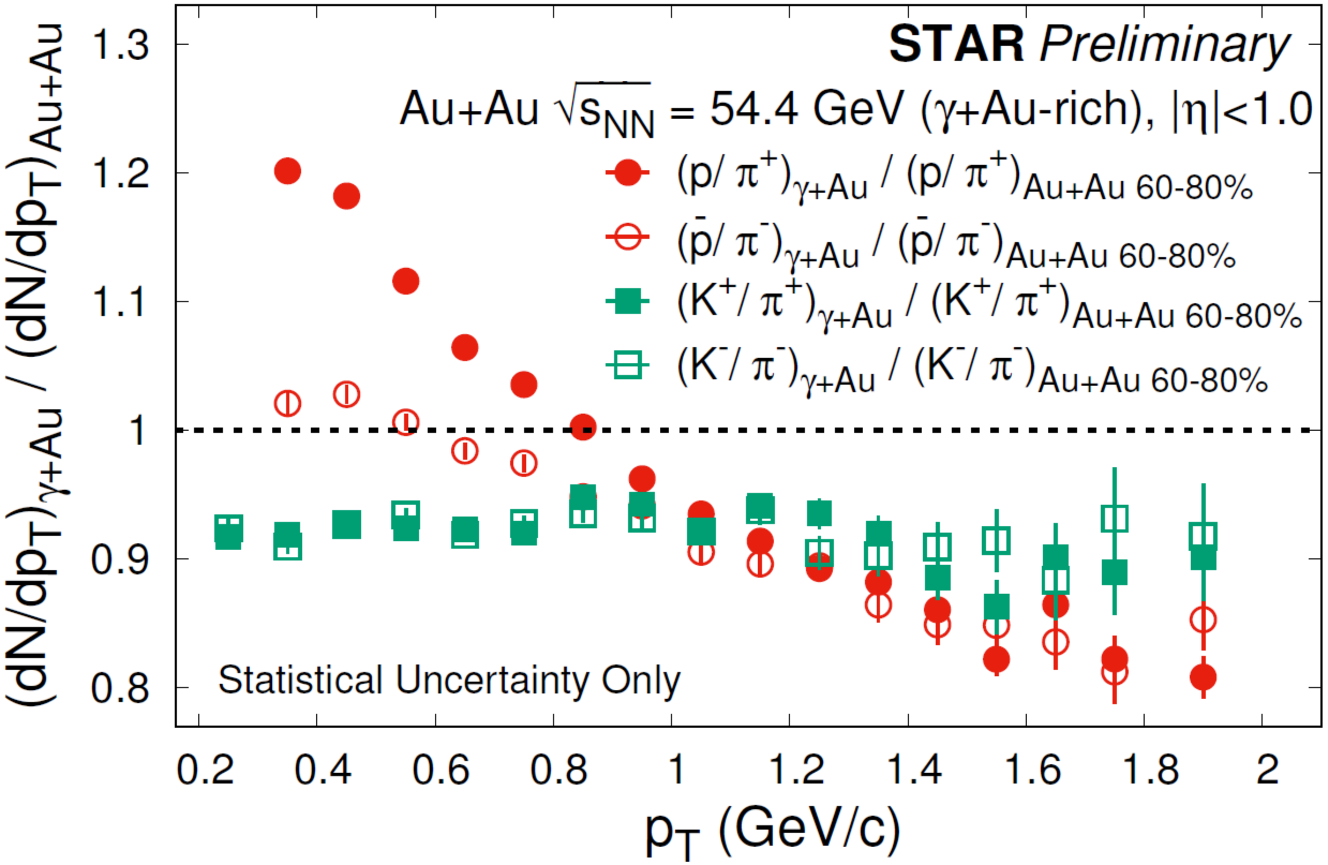
p_T Dependence of Particle Ratios in $\gamma A/AA$

$K/\pi < 1$ and flat with p_T
→ less access to strangeness in γA events

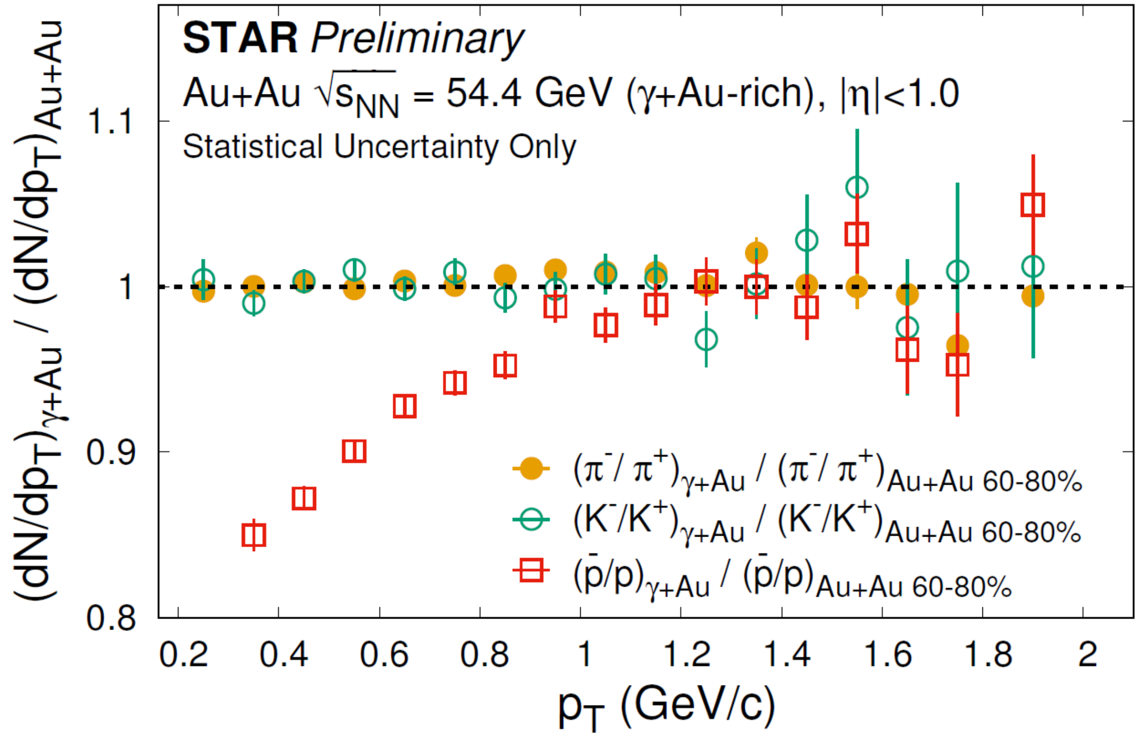
$\bar{p}/\pi$ and p/π steeper than K/π
→ larger radial flow in $60-80\%$ Au + Au

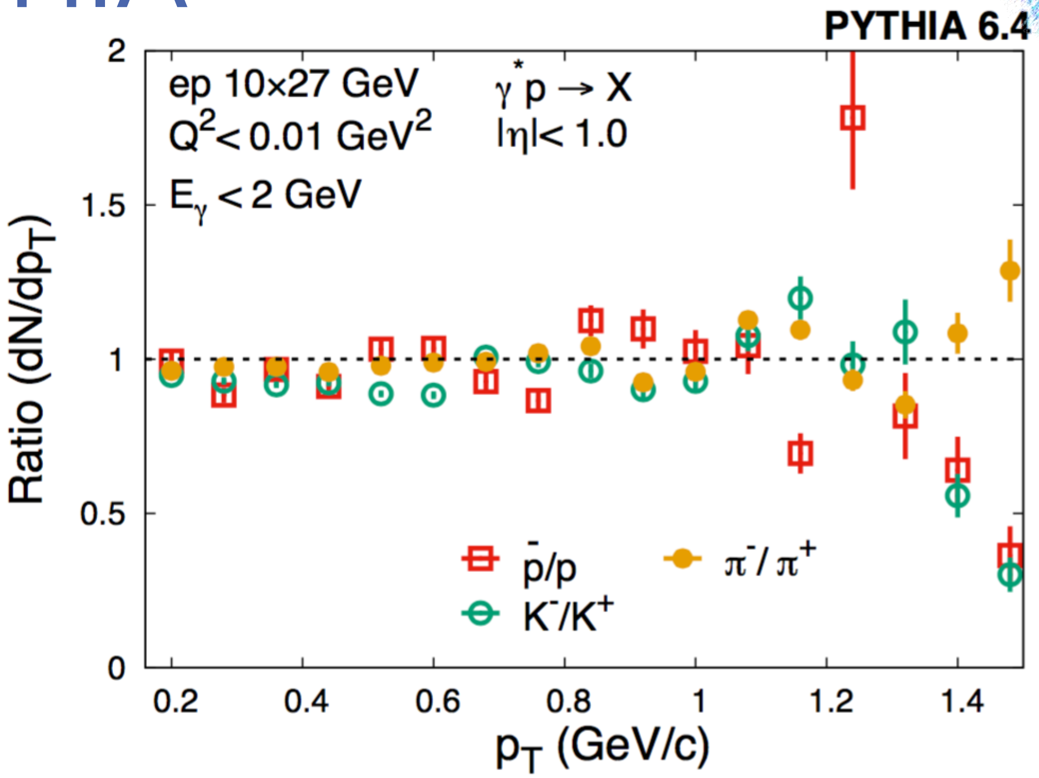
$\bar{p}/\pi^- < p/\pi^+$ for $p_T \lesssim 1$ GeV/c
→ soft baryon stopping

Not corrected for efficiency, but largely canceled in the ratio



Comparison with PYTHIA





- PYTHIA6 $\gamma^* p \rightarrow X$ simulation does not include a baryon junction → pion, kaon, and proton ratios are all consistent with 1 within uncertainty
- Possible explanation: photon fluctuates into a $q\bar{q}$ pair which is not able to stop all three valence quarks of the target baryon in the colliding ion
  - Baryon stopping can occur because the $q\bar{q}$ pair interacts directly with the baryon junction