IDENTIFICATION OF PIONS, KAONS, AND PROTONS IN PHOTONUCLEAR EVENTS AT STAR

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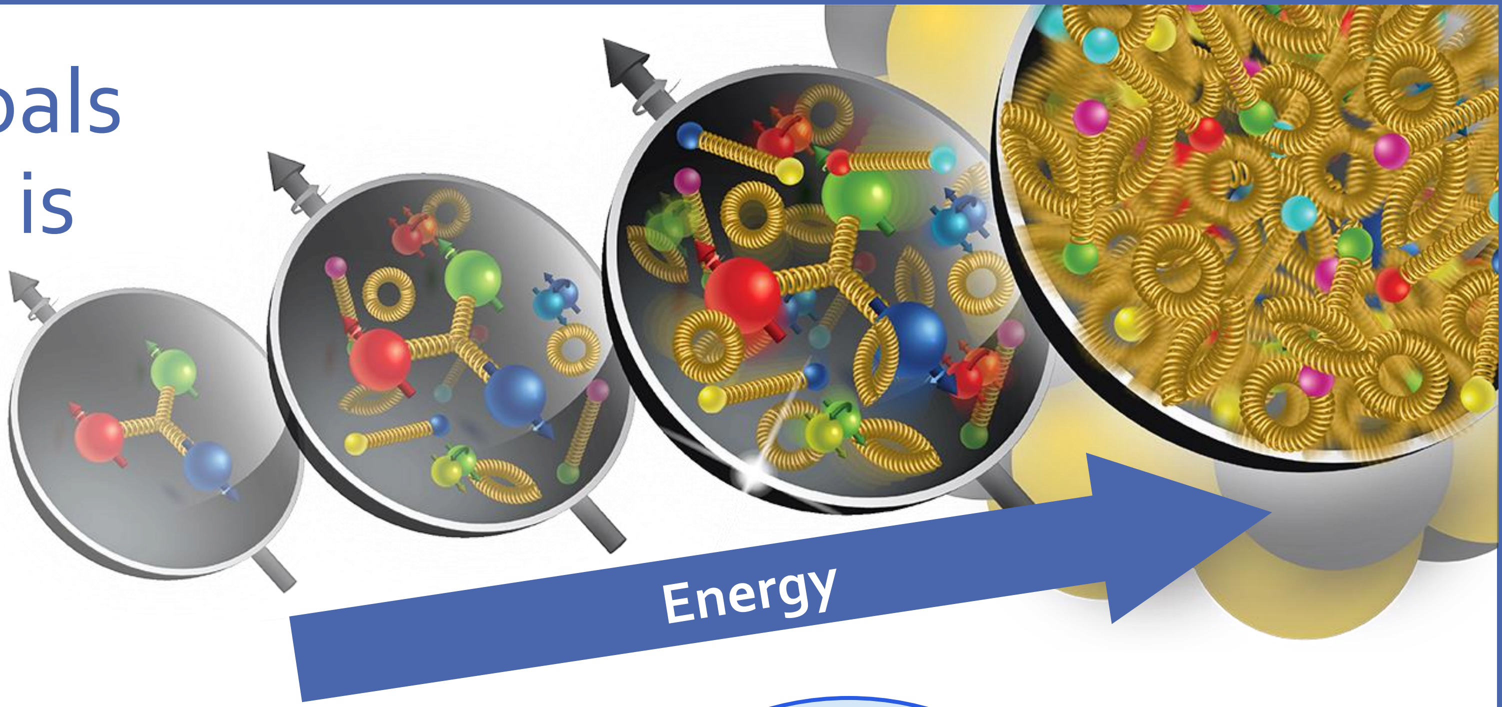
One of the major goals of RHIC and the EIC is to understand the behavior of gluons within the nucleon



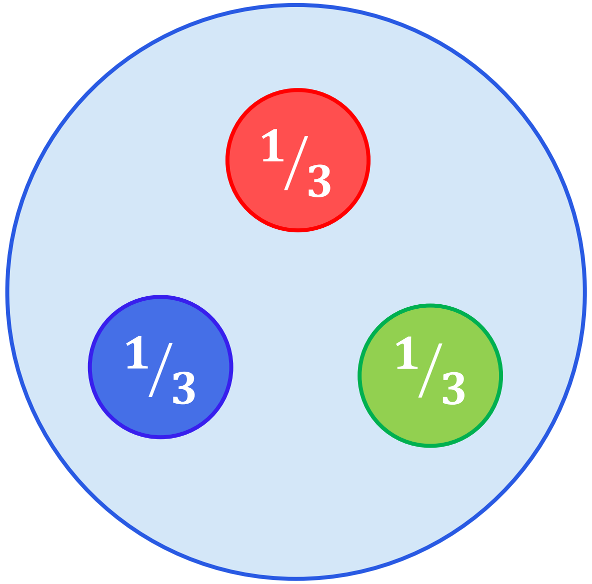
Baryon number – a strictly conserved quantum number

Believed to be carried by the quarks:

$$B = \frac{1}{3}(n_q - n_{\bar{q}})$$

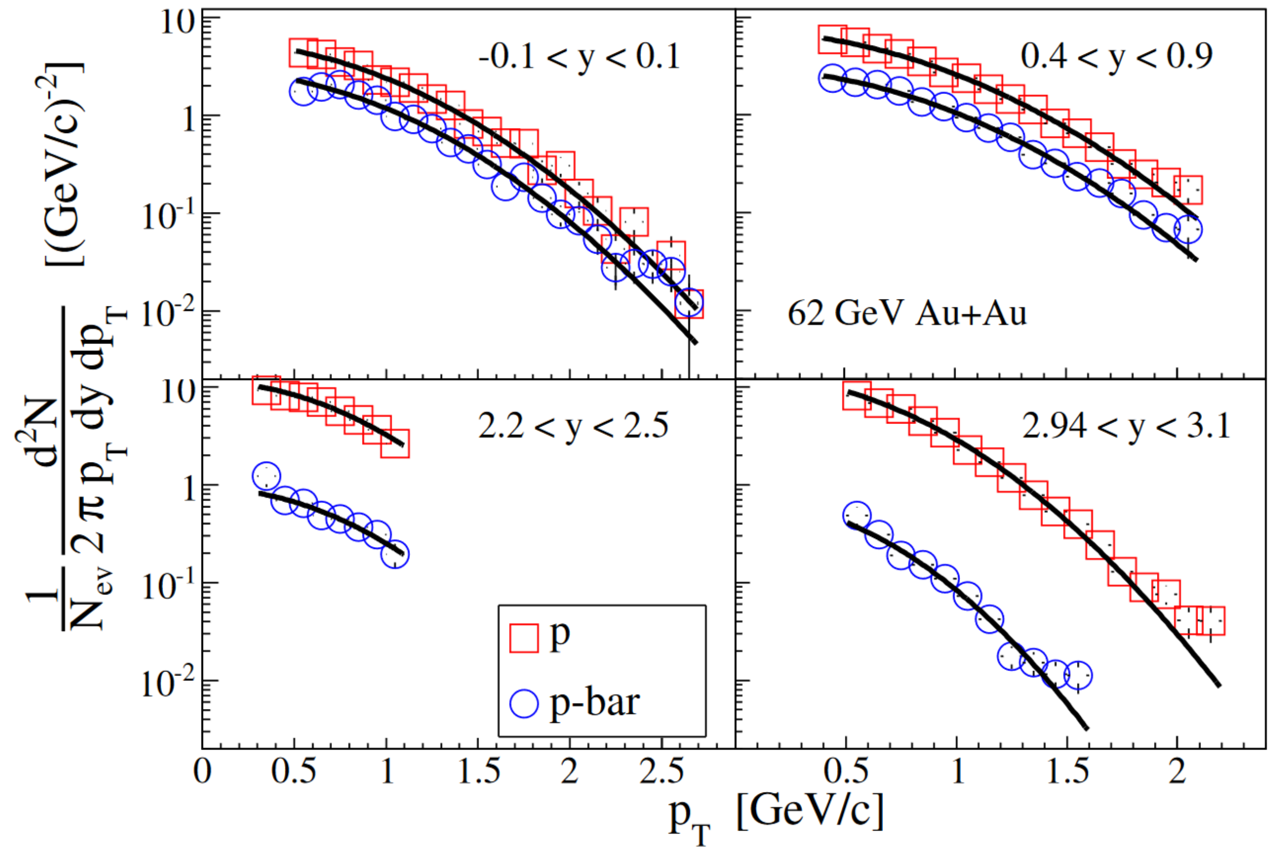
But that is just an assumption

D. Kharzeev, Physics Letters B **378**, 238-246 (1996)



Baryon Stopping

- The energy required for producing the particles in heavy-ion collisions comes from the kinetic energy lost by the baryons in 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



BRAHMS Collaboration, Phys. Lett. B **677,** 267-271 (2009)

Baryon Junction

- Nonperturbative configuration of gluons linked to all three valence quarks
  - Carries the baryon number
  - Theorized to be an effective mechanism of stopping baryons in pp and AA

D. Kharzeev, Physics Letters B **378**, 238-246 (1996)

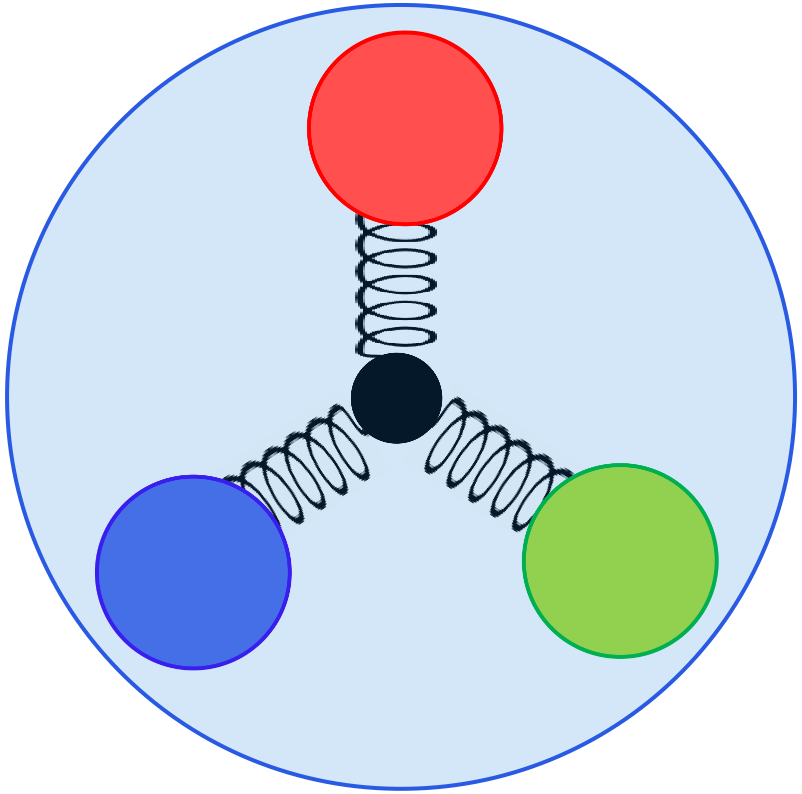
- Many of the models used for heavy-ion collisions at RHIC (HIJING, AMPT, UrQMD) have implemented a nonperturbative baryon stopping mechanism

V. Topor Pop, *et al*, Phys. Rev. C **70**, 064906 (2004)

Zi-Wei Lin, *et al*, Phys. Rev. C **72**, 064901 (2005)

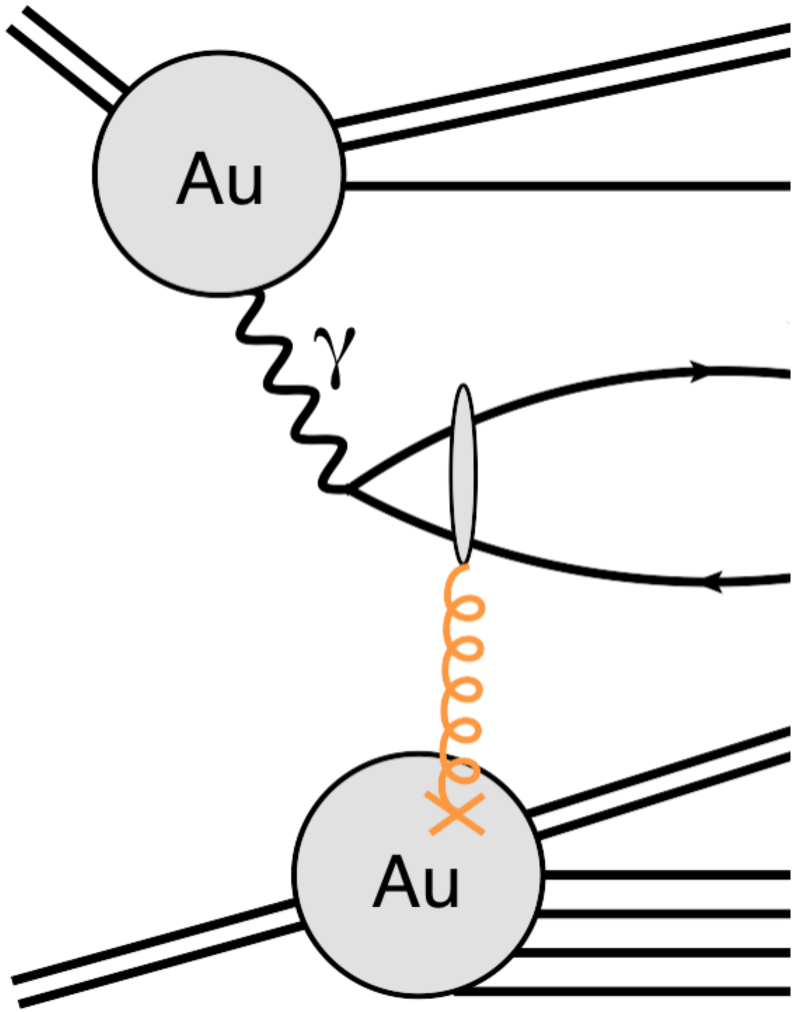
M. Bleicher, *et al*, J.Phys.G **25,** 1859-1896 (1999)

- But no signature of baryon junction has been cleanly identified in the experiment

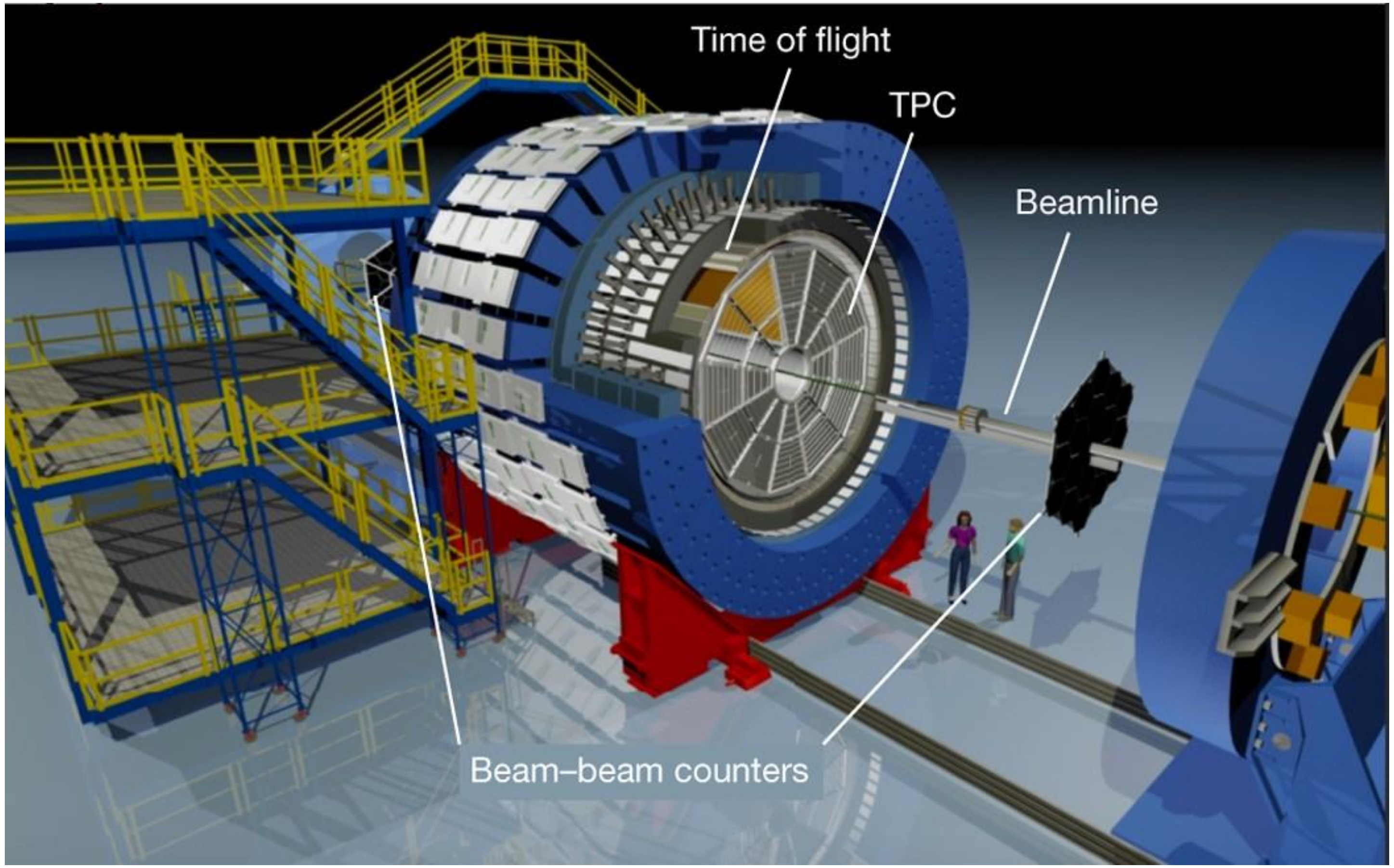


Photonuclear Events

- Inclusive particle production in photonuclear collisions
  - Large flux of quasi-real photons produced by ultra-relativistic large-Z nuclei
  - Similar to $e + A$ collisions except that the photon tends to have a 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)
  - Low p_T rapidity distribution of $dN/dy \propto \exp(-y/2)$



Particle Identification With STAR



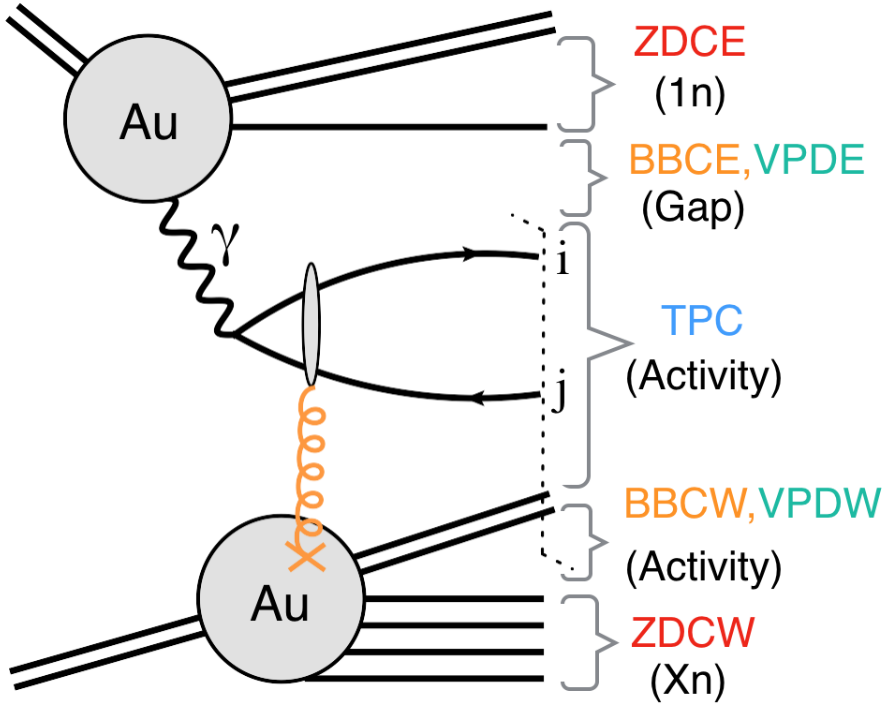
Time Projection Chamber (TPC) identifies particles at lower p_T using ionization energy loss, dE/dx

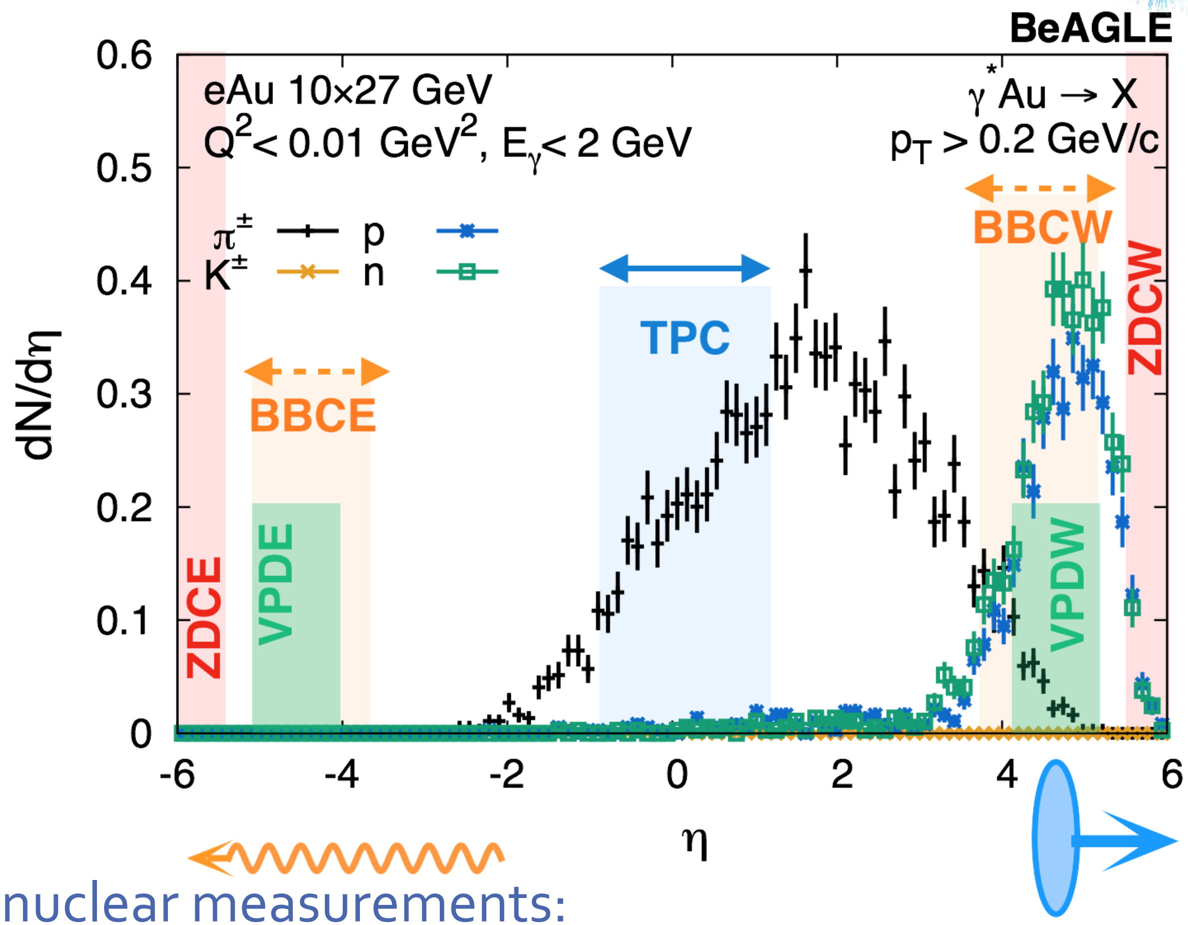
Time of Flight (TOF) identifies particles at higher p_T

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

Data collected in 2017, $\mathrm{Au}+\mathrm{Au}$ collisions with $\sqrt{s_{NN}} = 54\ \mathrm{GeV}$, trigger did not require coincidence in both sides of the detector ~700 million events

Photonuclear Events Are Selected With Rapidity Gaps



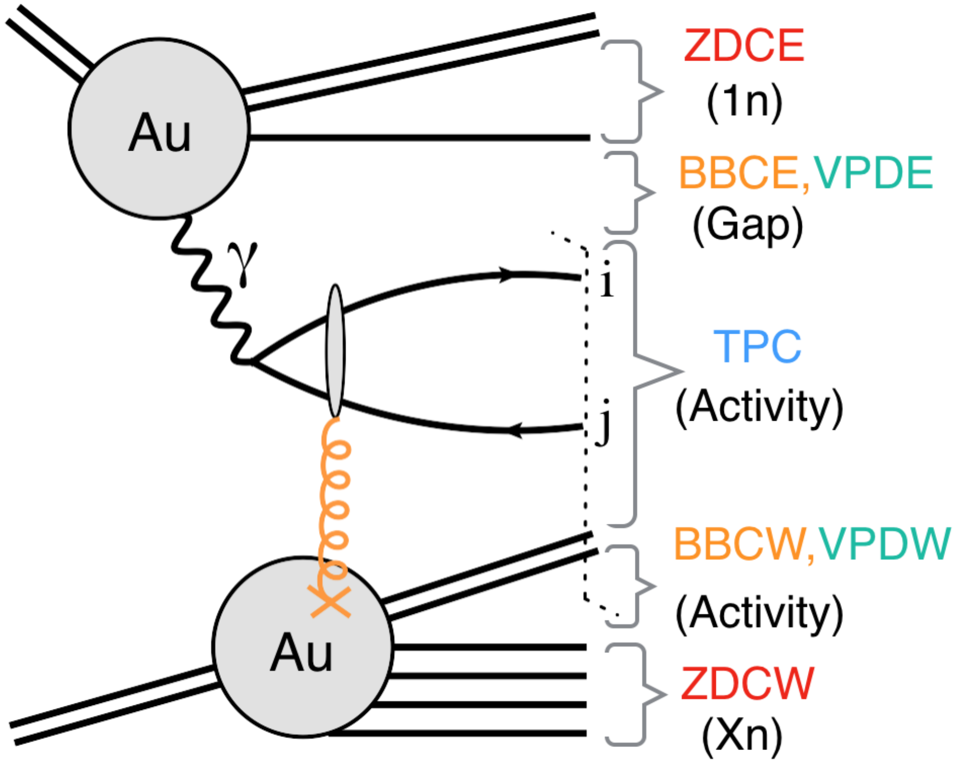


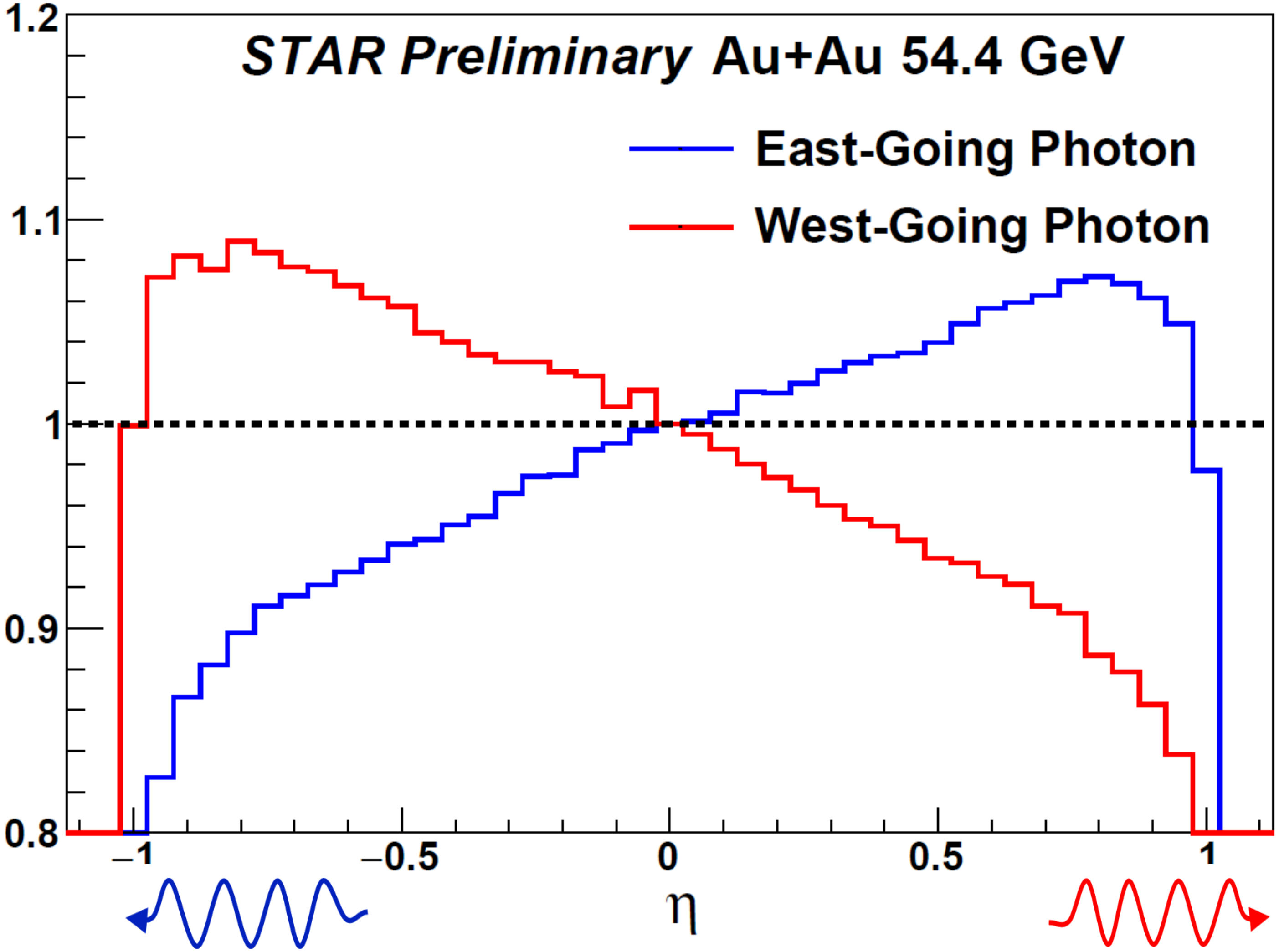
Similar technique used by ATLAS photonuclear measurements:

ATLAS Collaboration, Nuclear Physics A **967**, 277 (2017)

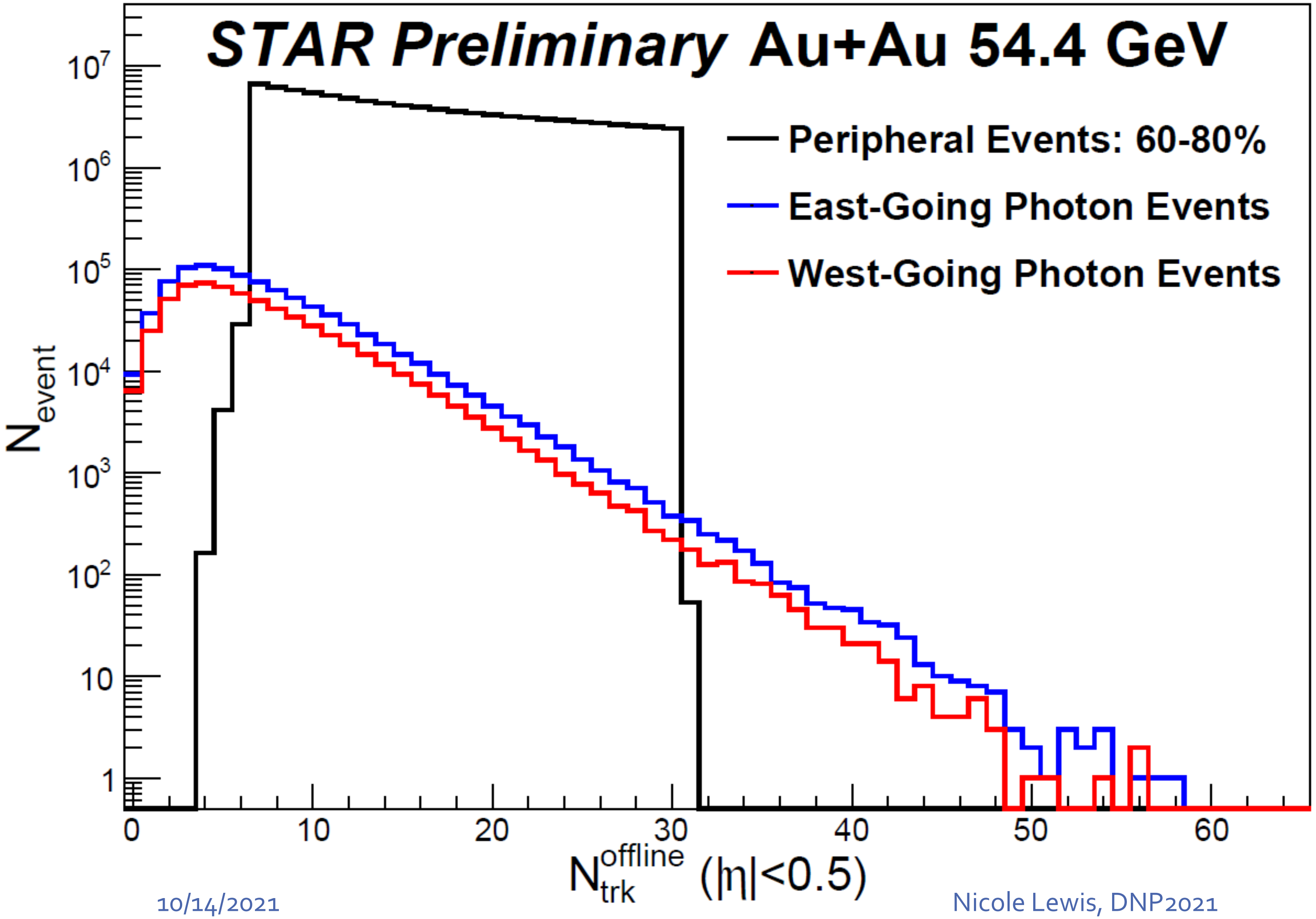
ATLAS Collaboration, Phys. Rev. C **104**, 014903 (2021)

Rapidity Asymmetry in $\gamma + A$-Rich Events





Defining $\gamma + A$ and $A + A$ Event Classes



Most photonuclear events have low multiplicity, concentrated at equivalent $\mathrm{Au} + \mathrm{Au}$ centrality of roughly 80%

Using peripheral events as a baseline comparison, multiplicity consistent with $60 - 80\%\ \mathrm{Au} + \mathrm{Au}$

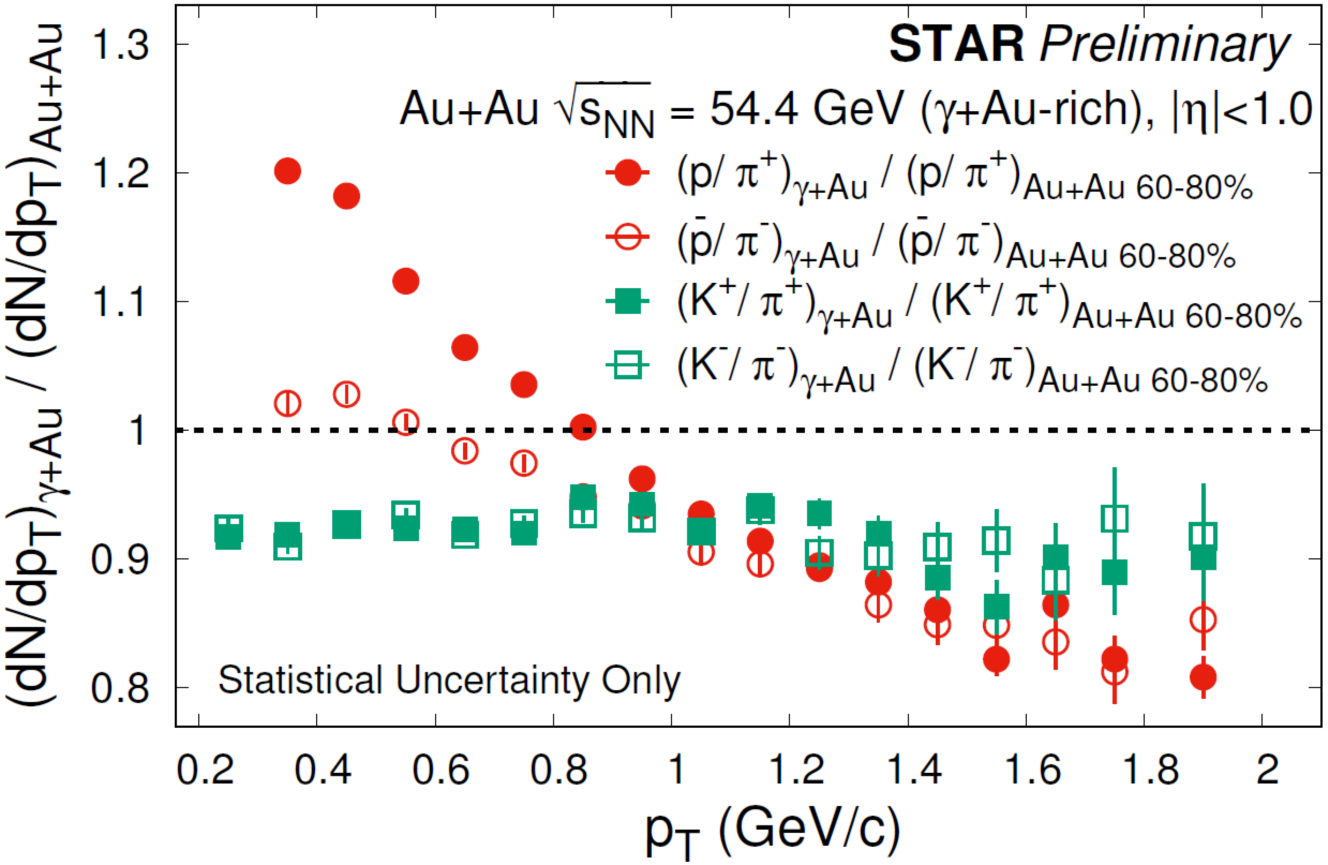
p_T Dependence of Particle Ratios in $\gamma + A/A + A$

$k/\pi < 1$ and flat with p_T
→ less access to strangeness in
$\gamma + A$ 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

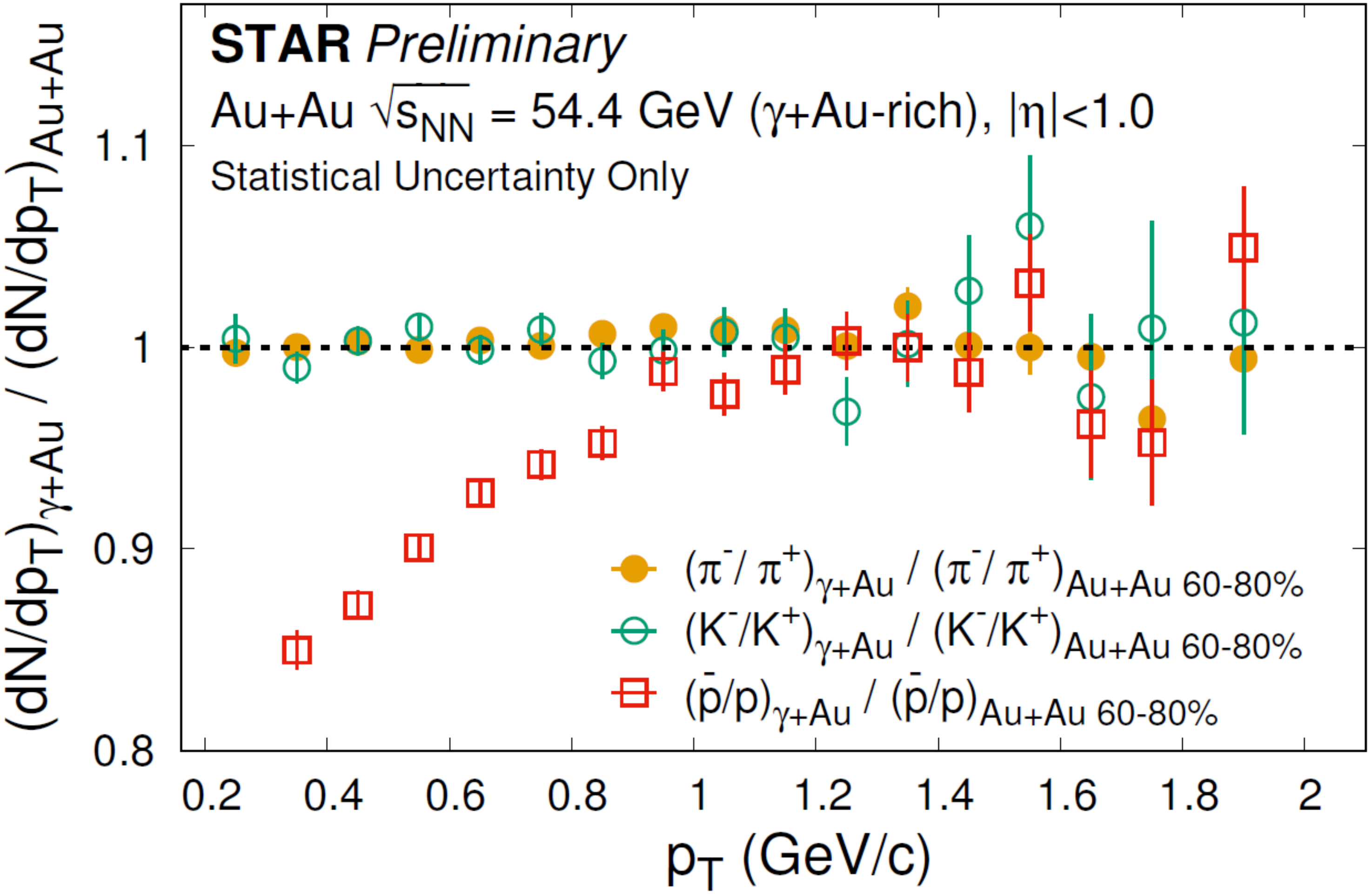
Not corrected for efficiency, but largely canceled in the ratio



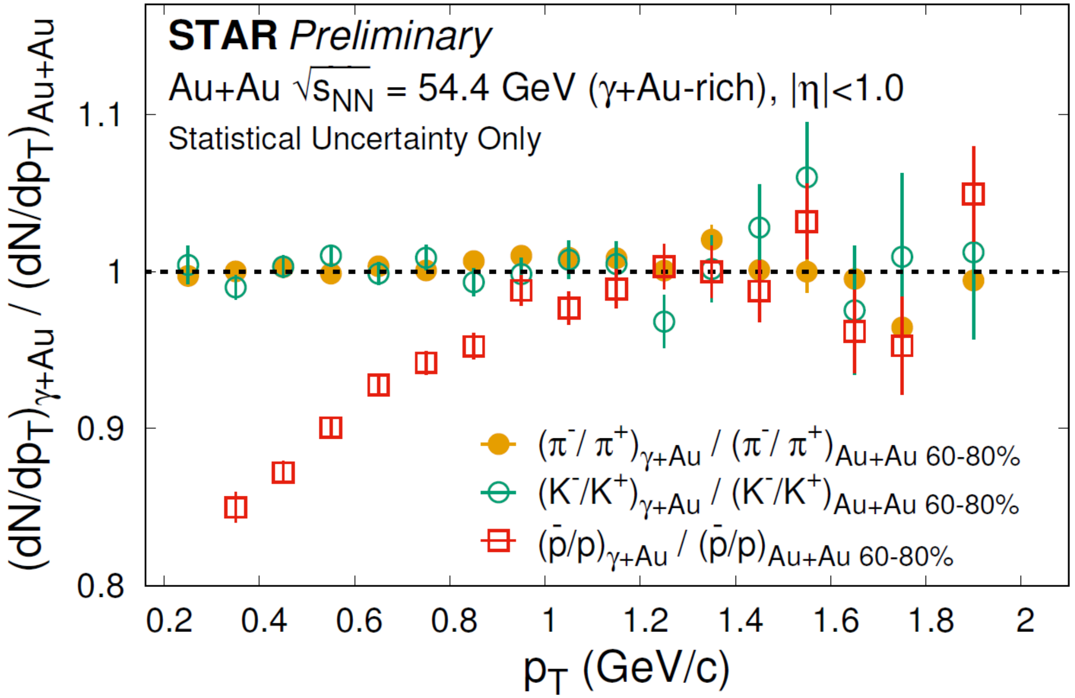
Low p_T Baryon Enhancement in $\gamma + A$

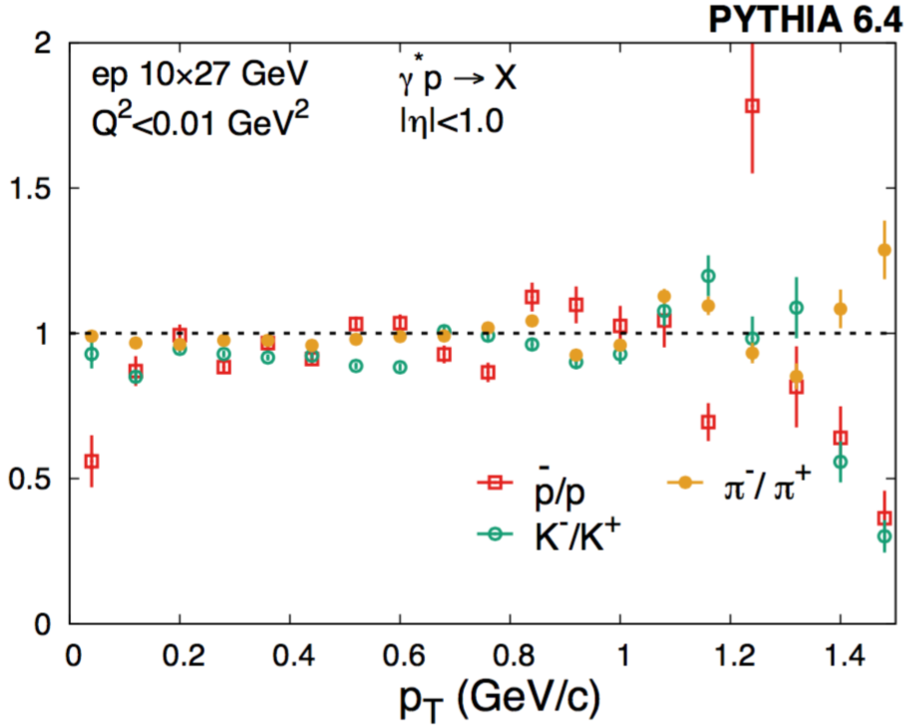
Double ratio: antiparticle/particle in $(\gamma + A)/(A + A)$

$\bar{p}/p < 1$ for $p_T \lesssim 1\ \mathrm{GeV}/c$ → soft baryon stopping that is **stronger** in $\gamma + A$ compared to peripheral $A + A$



Comparison with PYTHIA

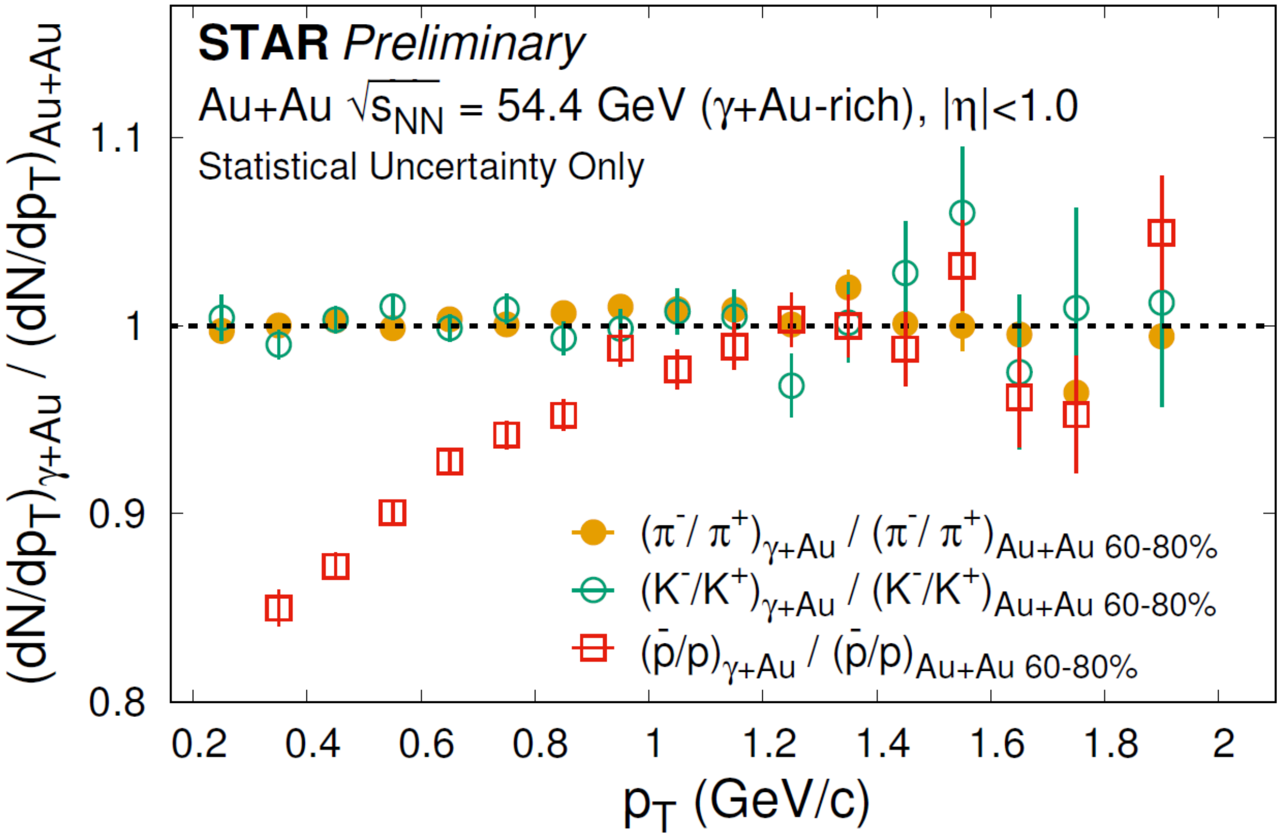




- PYTHIA6 $\gamma^* p \rightarrow X$ simulation does not include a baryon junction → pion, kaon, and proton ratios are all consistent with 1 within uncertainty
- Possible explanation: photon fluctuates into a $q\bar{q}$ pair which is not able to stop all three valence quarks of the target baryon in the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

Summary

- Studied identified particle spectra in photonuclear events via $\sqrt{s_{NN}} = 54$ GeV Au + Au ultraperipheral collisions
- Baryon stopping observed at low p_T
  - Possible evidence of a baryon junction existing inside nucleon

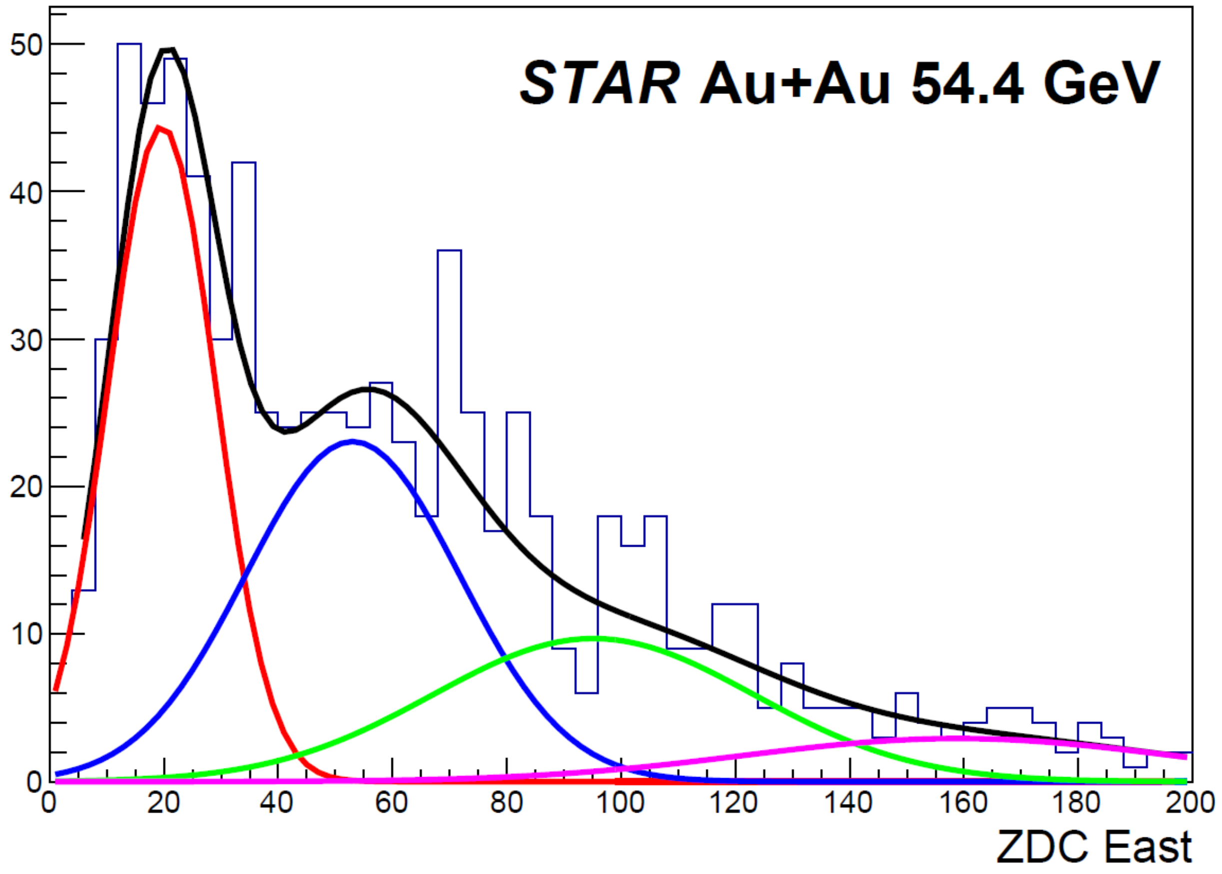


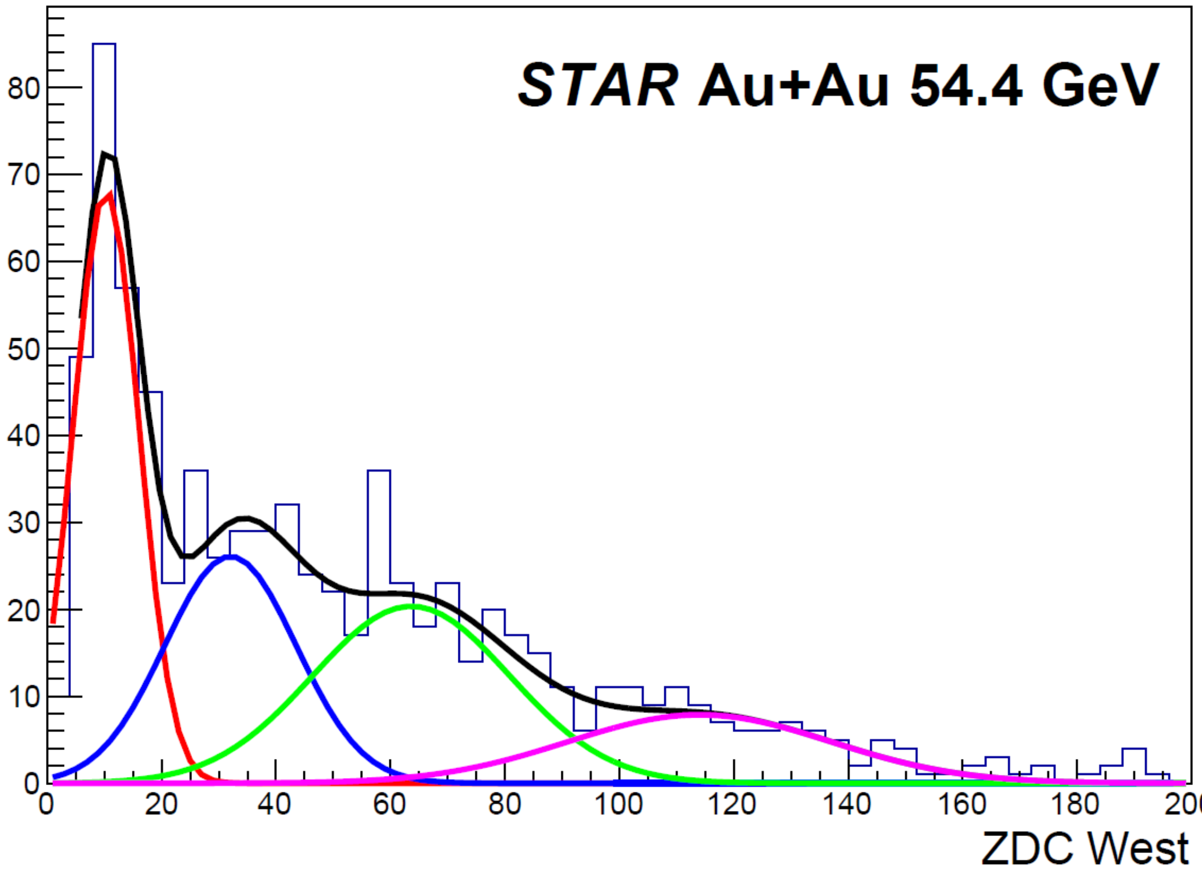
Next Steps

- Measure these particle ratios as a function of rapidity and multiplicity
- Measure the spectra and yields vs rapidity to compare with baryon junction prediction ($dN/dy \propto \exp(-y/2)$)
- Measure of azimuthal and rapidity correlations in photonuclear events
- Unbiased Au + Au collisions from 2019 data set with $\sqrt{s_{NN}} = 200$ GeV

Back Up

ZDC Spectra





Low multiplicity events collected with ZDC triggers
Cutting on single neutron peak, dominated by $\gamma + A$ 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