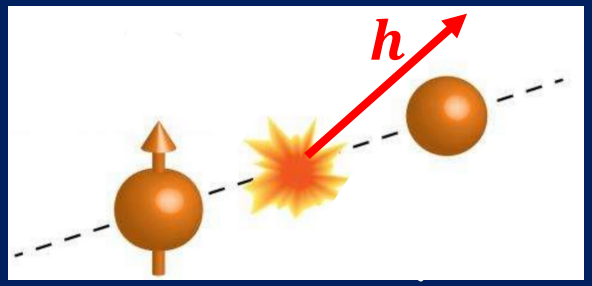


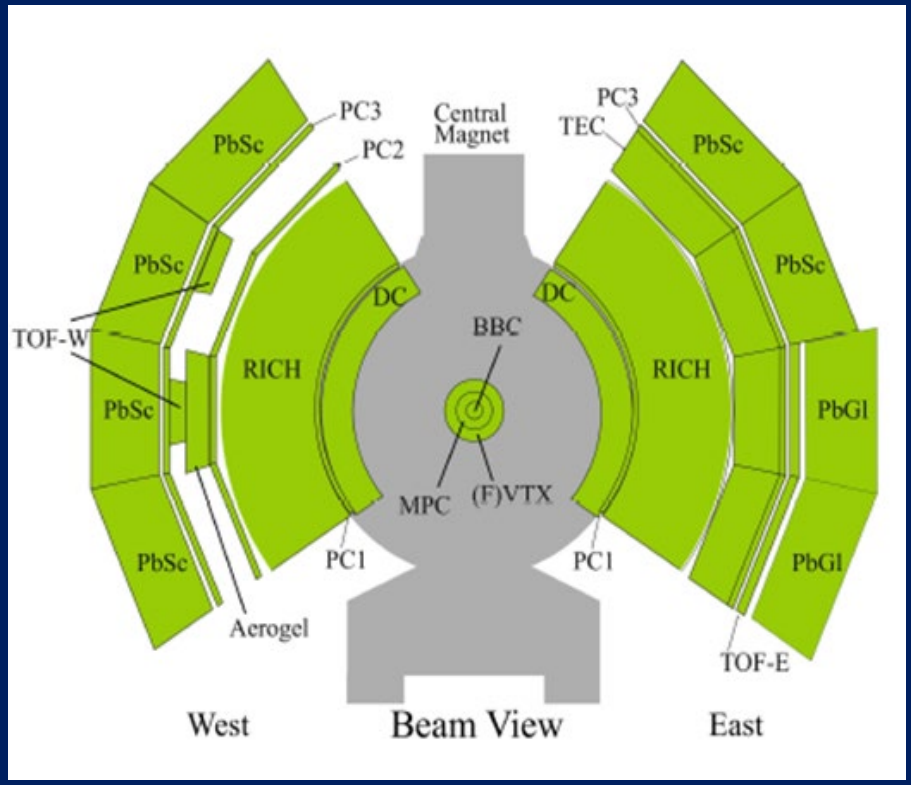
Transverse Single-Spin Asymmetries of Midrapidity Direct Photons and Neutral Mesons at PHENIX

Christine A. Aidala
University of Michigan
on behalf of the PHENIX Collaboration

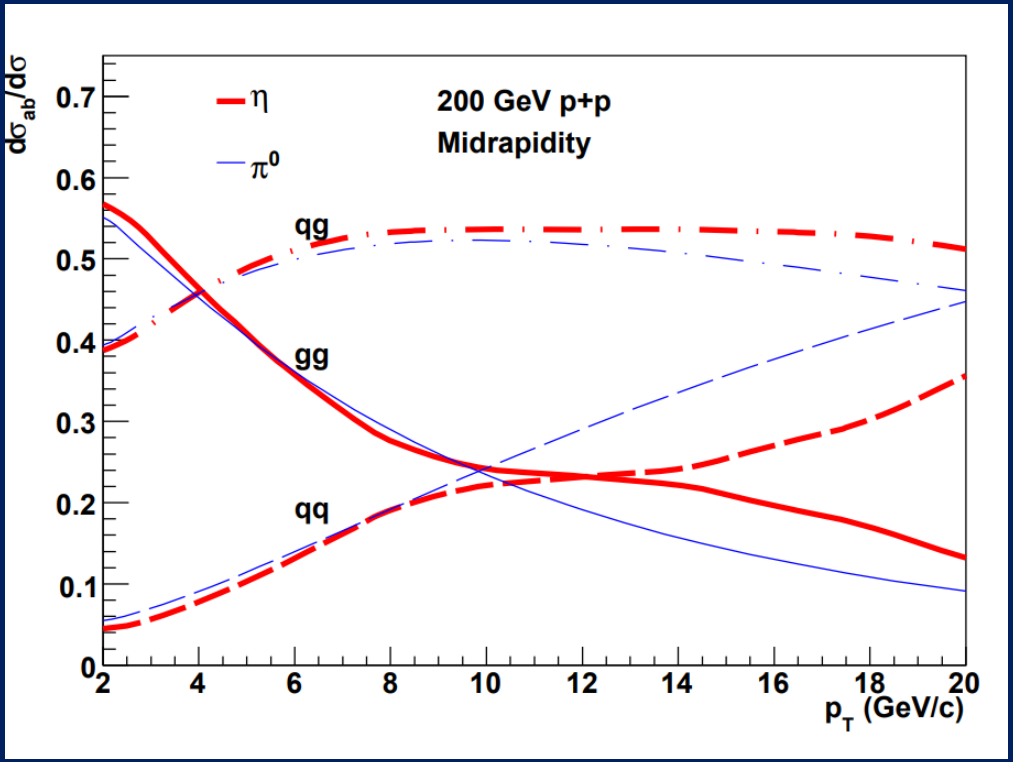
24th International Spin Symposium
Matsue, Japan
October 18-22, 2021

PHENIX detector

- PHENIX Central Arms
  - $\Delta\phi \sim \pi/2$ per arm
  - $|\eta| < 0.35$
- Electromagnetic Calorimeter used for $\gamma, \pi^0 \rightarrow \gamma\gamma$, and $\eta \rightarrow \gamma\gamma$ detection
  - Lead scintillator (PbSc) sectors: $\Delta\phi \times \Delta\eta \approx 0.011 \times 0.011$
  - Lead glass (PbGl) sectors: $\Delta\phi \times \Delta\eta \approx 0.008 \times 0.008$



Partonic contributions for midrapidity π^0 and η meson production



PRD 83, 032001 (2011)

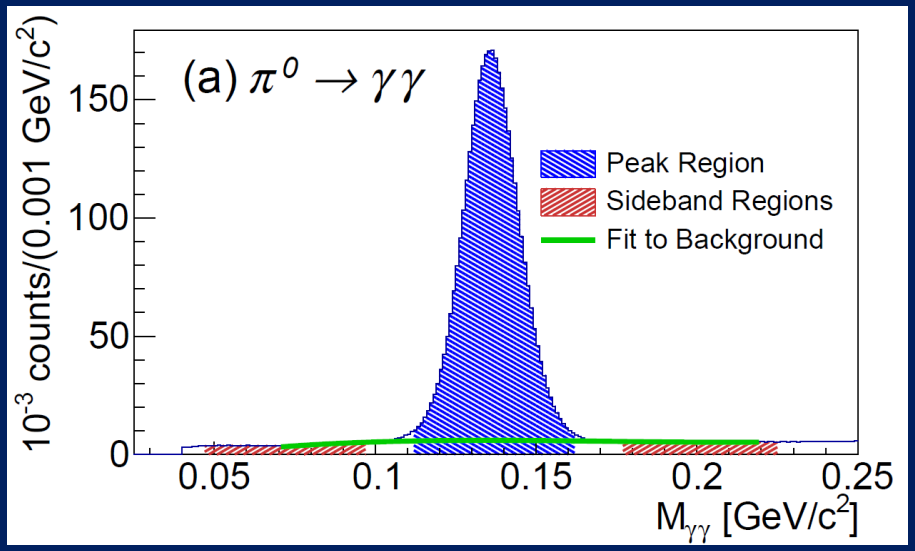
- Midrapidity: Combination of quarks and gluons coming from the polarized proton
- (Forward rapidity: Primarily quarks coming from the polarized proton)

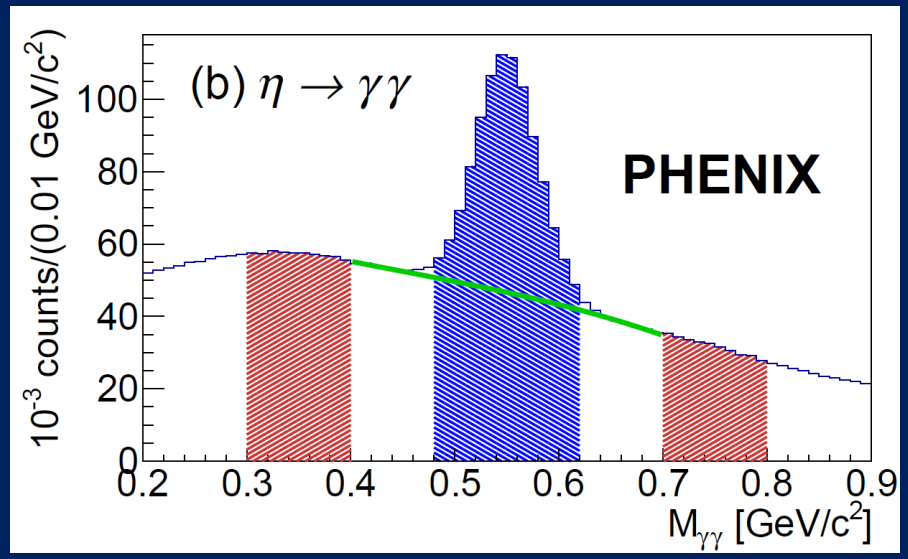
Asymmetry background subtraction

$$A_N = \frac{A_N^{peak} - r A_N^{bg}}{1 - r}$$

Where $r = \frac{N_{bg}}{N_{sig}+N_{bg}}$ is measured from a fit in the invariant mass peak region

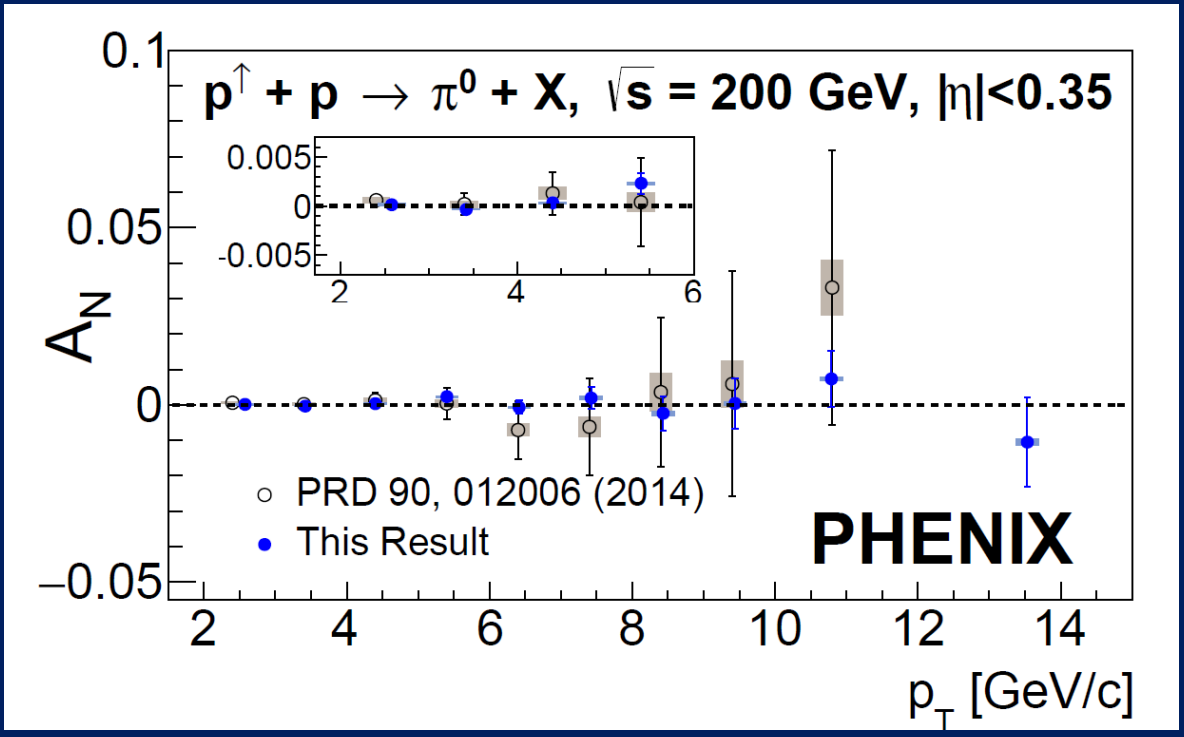
Example invariant mass spectra for photon pairs in the West Arm with $4 < p_T < 5$ GeV/c





PRD103, 052009 (2021)

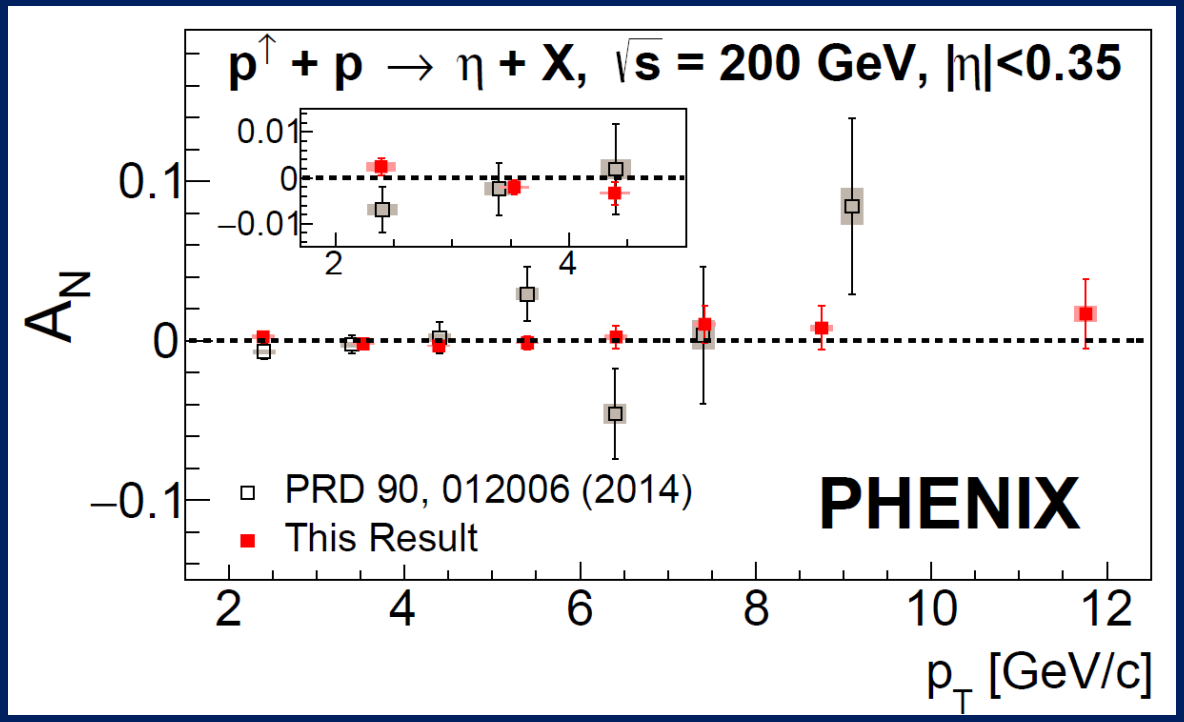
Midrapidity neutral pion A_N



PRD103, 052009 (2021)

- Consistent with zero to within 10^{-4} at low p_T
- Definitive results from PHENIX, from final $p^{\uparrow} + p$ data taken in 2015
- Factor of 3 improvement in statistical uncertainty with respect to previous result, and higher reach in p_T

Midrapidity η meson A_N



PRD103, 052009 (2021)

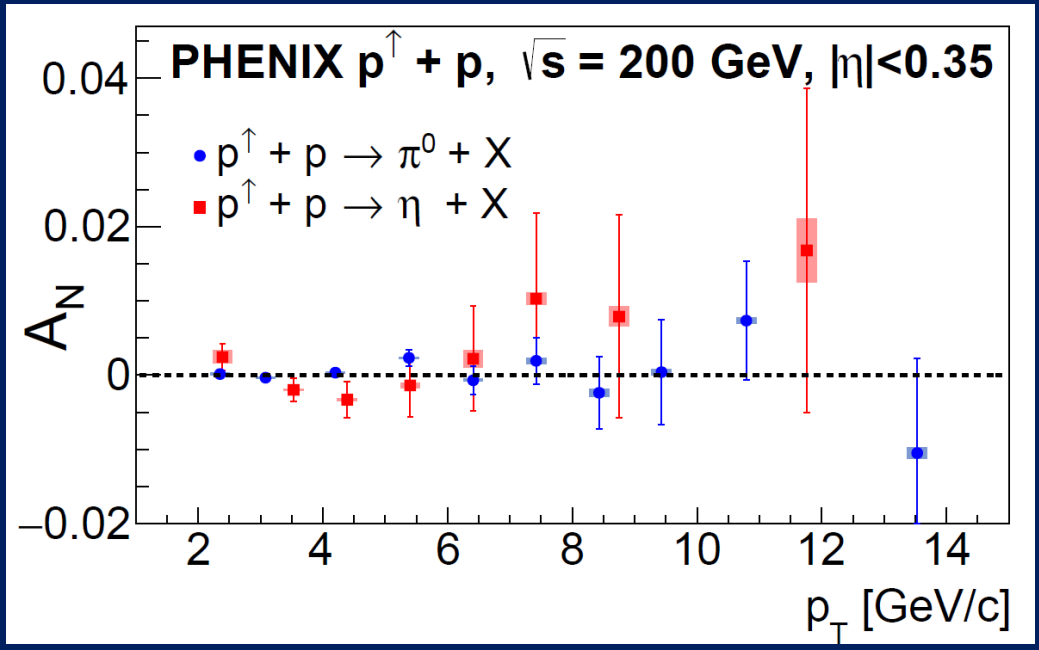
- Consistent with zero to within 5×10^{-3} at low p_T
- Also a factor of 3 improvement in statistical uncertainty with respect to previous result, and higher reach in p_T

Comparing midrapidity π^0 and η results

- Any differences in π^0 and η A_N could be due to effects of strangeness or isospin in hadronization:

$$\pi^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$$

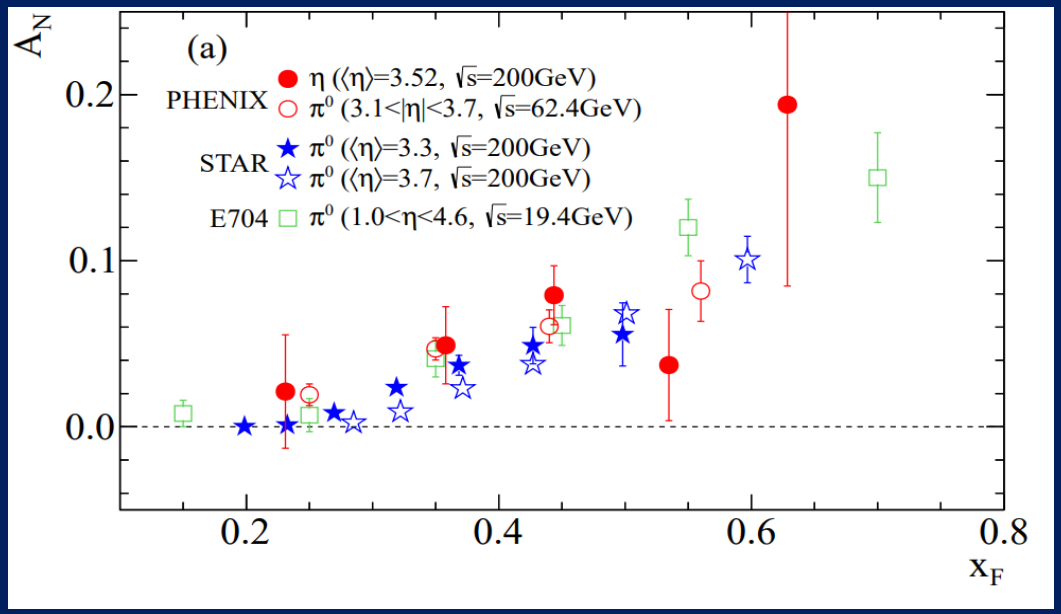
$$\eta = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s})$$



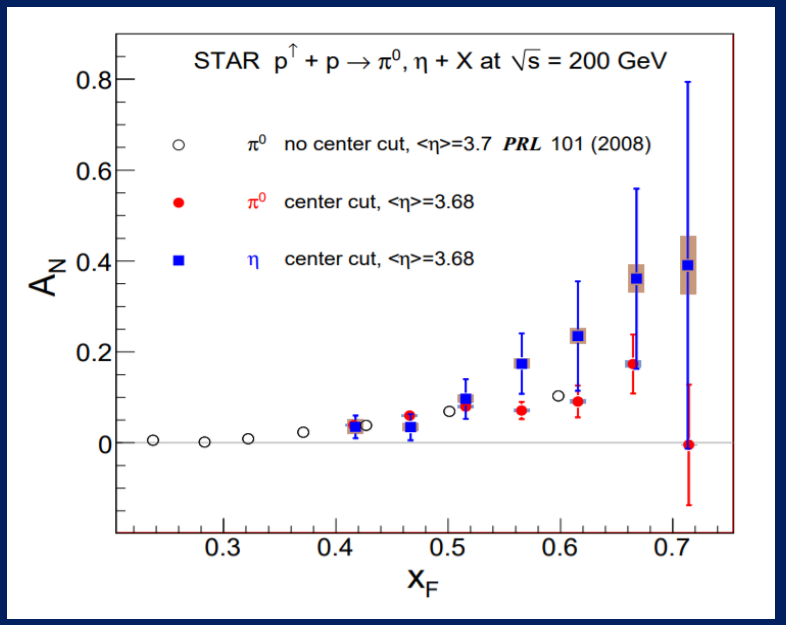
PRD103, 052009 (2021)

- Or to mass effects in hadronization:
  $m_{\pi^0} \approx 135$ MeV/c^2 $m_\eta \approx 548$ MeV/c^2

Comparing forward π^0 and η results



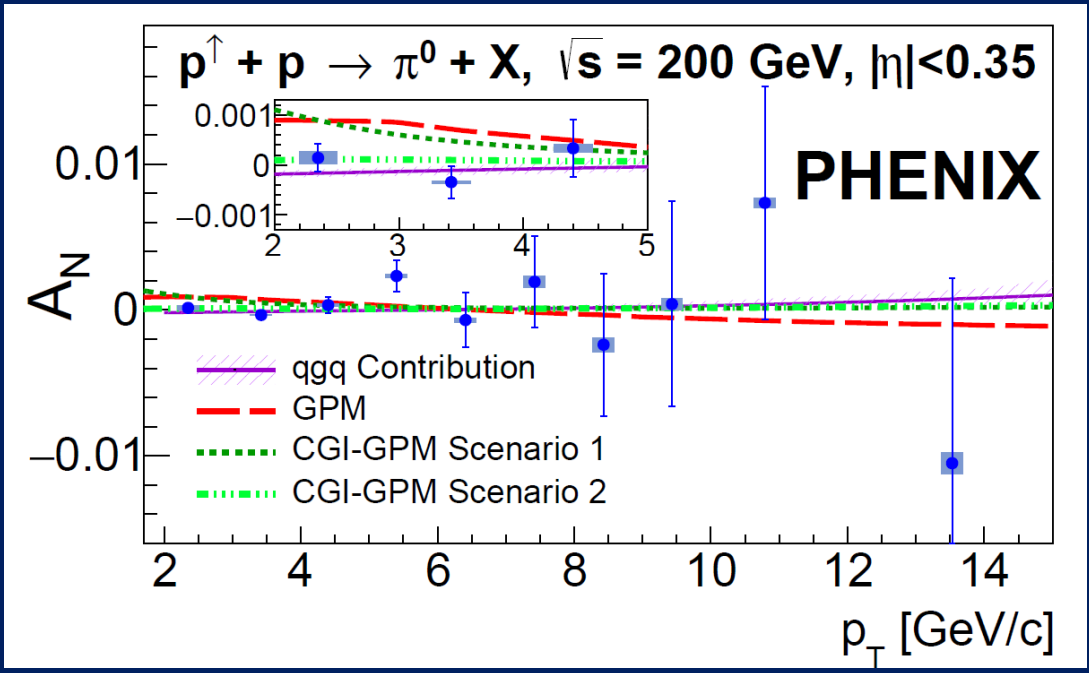
PHENIX, PRD 90, 072008 (2014)



STAR, PRD 86, 051101(R) (2012)

- Forward rapidity: Large contribution of quarks coming from the polarized proton
- Results hint that A_N^{η} may be larger than $A_N^{\pi^0}$ at forward rapidity. Further studies required.

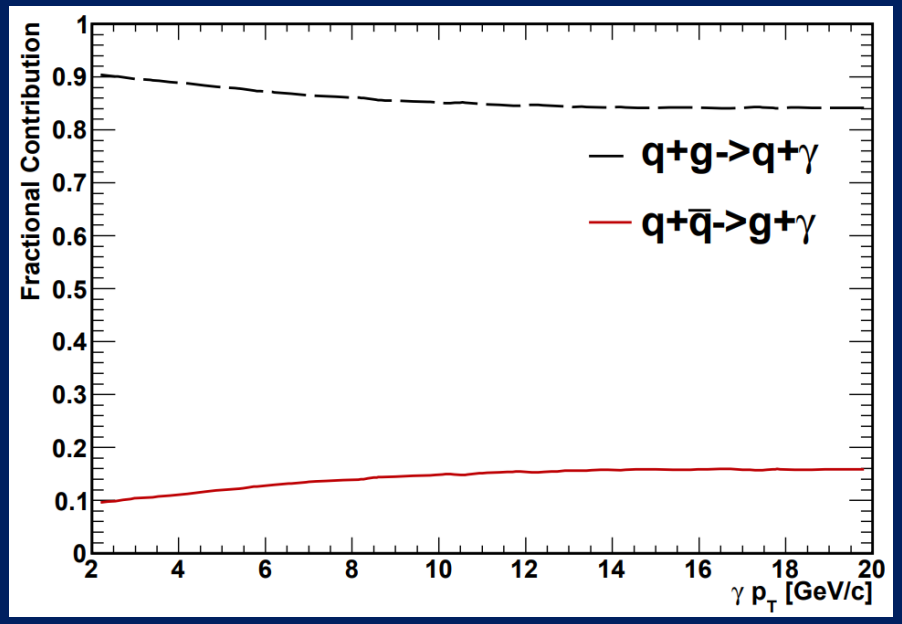
Midrapidity $A_N^{\pi^0}$: Theoretical predictions



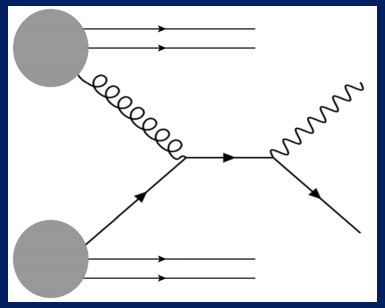
PRD103, 052009 (2021)

- Very small qgq correlator contribution predicted
  - JAM Collaboration, PRD 102, 054002 (2020)
- Results can help constrain gluon spin-momentum correlations
  - Twist-3 trigluon correlators (Beppu, Kanazawa, Koike, Yoshida, PRD 89, 034029 (2014))
  - Gluon Sivers function – in the Generalized Parton Model (GPM) (D'Alesio Flore, Murgia, Pisano, Taels, PRD 99, 036013 (2019))

Midrapidity direct photons



Fractional contribution of parton scattering to midrapidity inclusive direct photon production at leading order for p+p collisions at $\sqrt{s} = 200$ GeV. PHENIX PRD82, 072001 (2010)



- Only sensitive to initial-state proton structure
  - With isolation cut, NLO fragmentation photon contribution < 15% (PHENIX PRD 82, 072001 (2010))
- Strong sensitivity to gluons in the proton

Direct photon selection

- Tagging cut - subtract out photons that are tagged as coming from $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$ decays
- Isolation cut – eliminate decay photons and next-to-leading-order fragmentation photons

$$E_\gamma * 10\% > E_{cone}$$

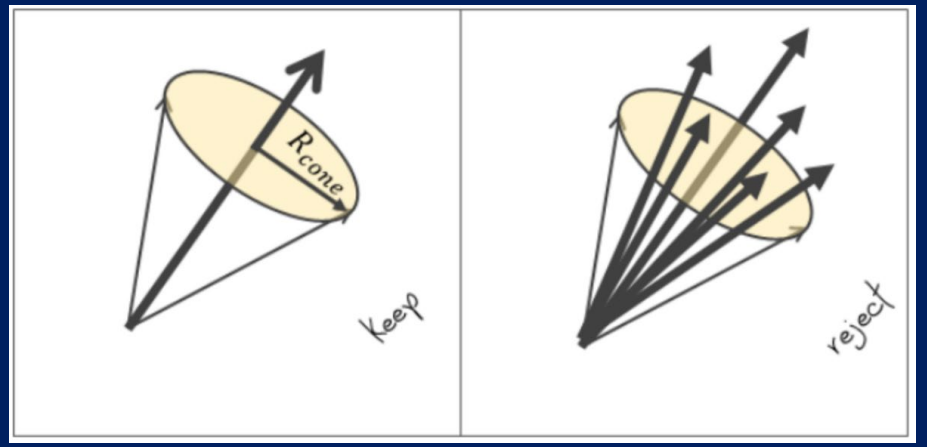


Figure from J.D. Osborn

Direct photon background:
Hadron decay photons with missing partner

Sometimes only one of the photons from a $h \to \gamma\gamma$ decay is measured and the second photon is missed

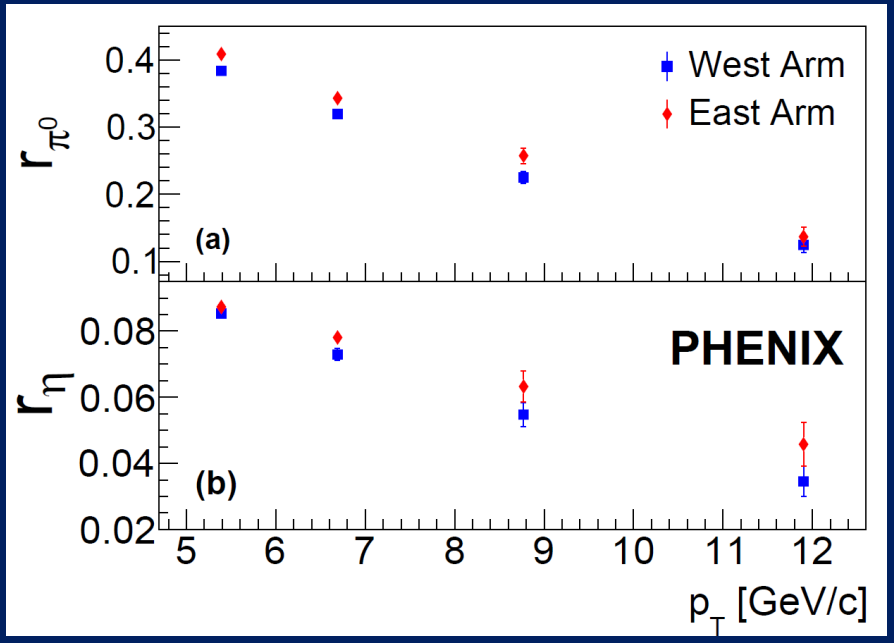
- η decays tend to be more asymmetric because they are ~4 times heavier than π^0s

Estimate number missed using ones that were tagged:

From data: Ratio of number isolated decay photons to direct photon candidate sample

$$r_{miss} = \frac{N_{bg}}{N_{sig} + N_{bg}} = R\frac{N_{tag}^{iso,h}}{N^{iso}}$$

From simulation: Converts between tagged decay photons to missed decay photons



PRL 127, 162001 (2021)

Direct photon background:
Merging of π^0 decay photons

Photon merging - sometimes the two photons from a $\pi^0 \rightarrow \gamma\gamma$ decay are so close together that the EMCal cannot resolve them as separate photons

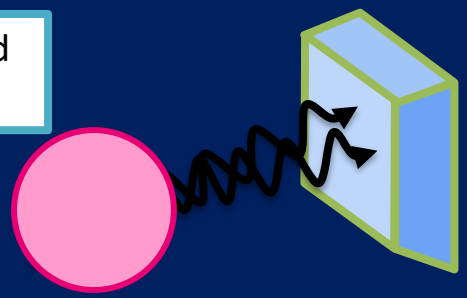
Similar to the background fraction due to missing one of the decay photons

Found to be negligible after a cluster shower shape cut

From Data: Ratio of number isolated decay photons to direct photon sample

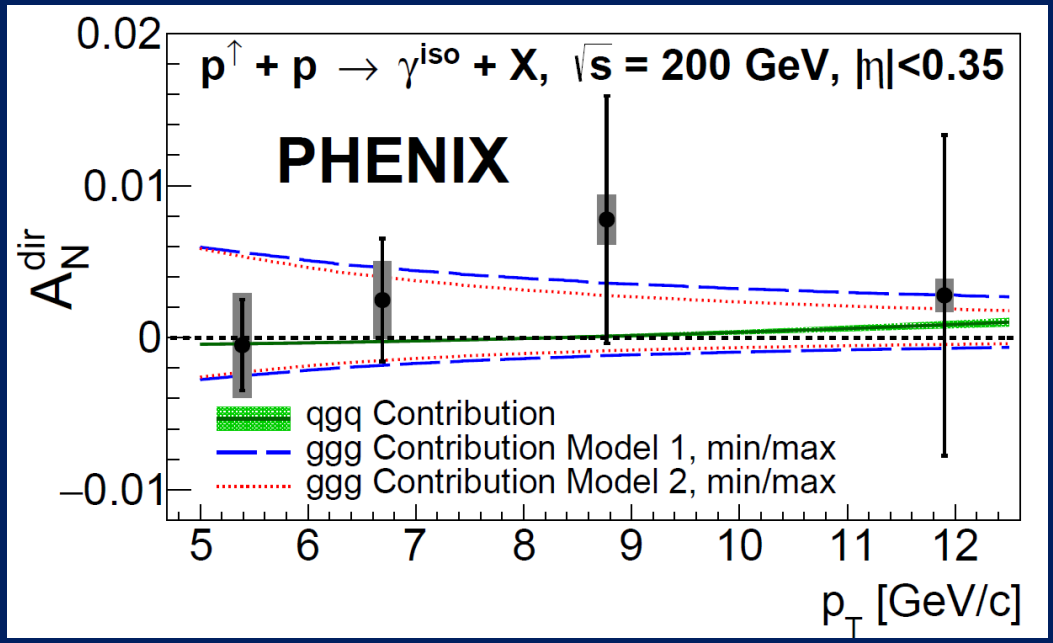
$$r_{merge} = \frac{N_{bg}}{N_{sig} + N_{bg}} = \frac{N_{merge}}{N_{tag}} \frac{N_{tag}^{iso,h}}{N^{iso}}$$

From Simulation: Converts between tagged decay photons and merged π^0 photons



Midrapidity direct photon A_N

- Measured for the first time at RHIC
- Consistent with zero to within $\sim 2 \times 10^{-2}$
- Will help constrain the trigluon correlators
  - In particular in conjunction with new PHENIX midrapidity open heavy flavor electron results (see previous talk by D. Fitzgerald)
- *qgq* contribution – Kanazawa, Koike, Metz, Pitonyak, PRD 91, 014013 (2015)
  - Already constrained by other measurements to be very small
- *ggg* contribution – Koike and Yoshida, PRD 85, 034030 (2012)



PRL 127, 162001 (2021)

Probing Gluon Spin-Momentum Correlations in Transversely Polarized Protons through Midrapidity Isolated Direct Photons in $p^{\uparrow} + p$ Collisions at $\sqrt{s} = 200$ GeV

U. A. Acharya *et al.* (PHENIX Collaboration)
Phys. Rev. Lett. **127**, 162001 – Published 12 October 2021

Conclusions

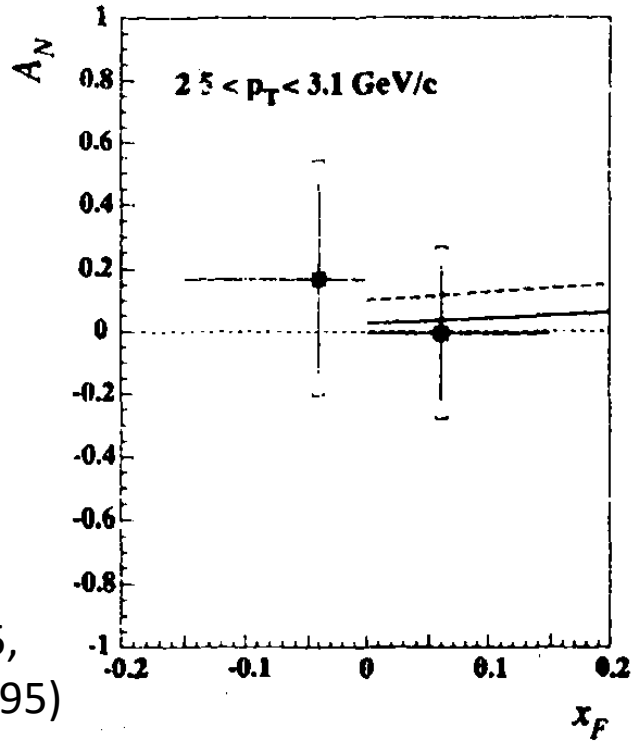
- Transverse single-spin asymmetries probe spin-momentum correlations in the proton as well as the process of hadronization
  - Twist-3 formalism only requires a single hard energy scale to be measured directly
- Final PHENIX results for midrapidity π^0 and η A_N in $\sqrt{s} =$ 200 GeV p+p collisions shown
  - Consistent with zero, factor of 3 higher precision than the previous PHENIX results
  - Sensitive to proton transverse spin structure as well as hadronization effects for both gluons and quarks
  - A_N^η sensitive to strangeness in twist-3 functions
- Direct photon A_N measured for the first time at RHIC
  - Also consistent with zero
  - Will improve constraints on twist-3 trigluon correlation functions, in particular in conjunction with open heavy flavor results

Backup

Inclusive direct photon A_N from Fermilab E704

- $\sqrt{s} = 19.4$ GeV

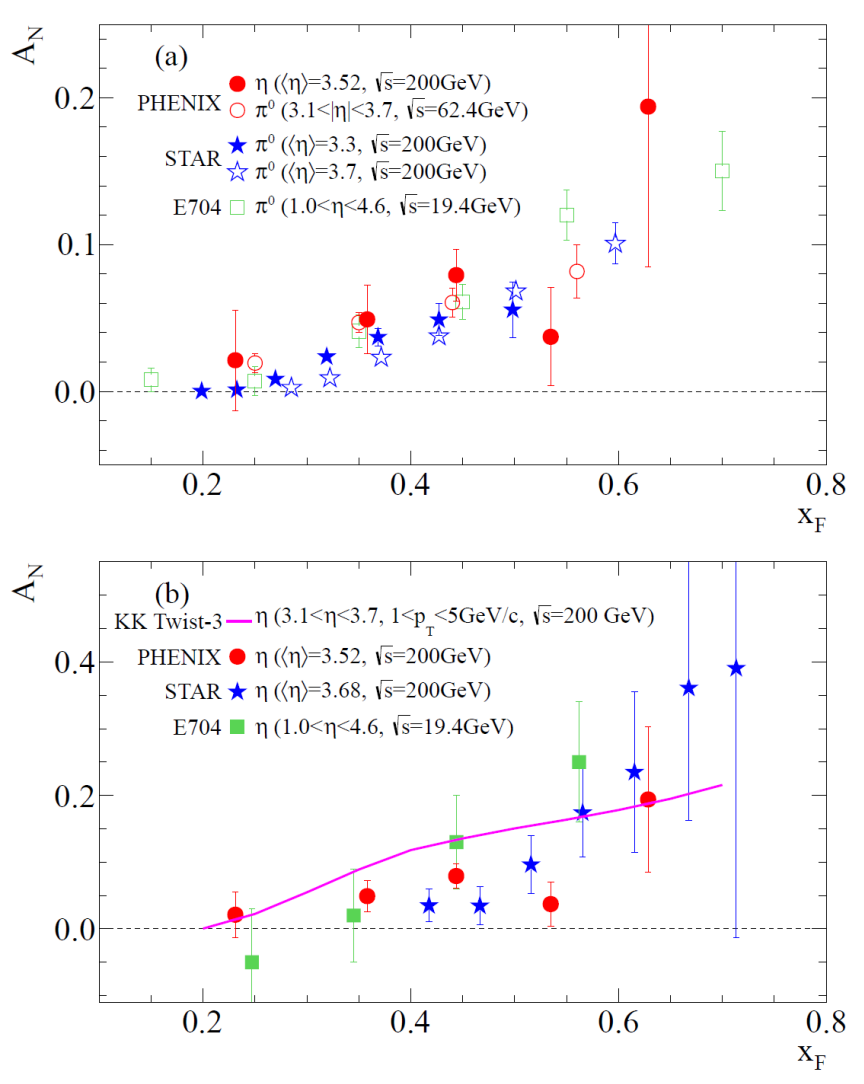
x_F	x_F^{avg}	A_N (%)
−0.15–0.00	−0.04	16.7±30.0±7.4
0.00–0.15	0.06	−0.6±21.6±5.7



E704, PLB 345, 569 (1995)

Fig. 5. Single transverse spin asymmetry, A_N, for direct photon production in pp collisions at 200 GeV/c as a function of x_F. Statistical errors are indicated as error bars and systematic errors are indicated as squared brackets. Solid and dashed curves show theoretical predictions at $\sqrt{s}$ = 30 GeV and p_T = 4.0 GeV/c assuming two types of the quark-gluon correlation strength [5].

Comparing forward π^0 and η results (E704)



- For $x_F > 0.4$, E704 measurements also hint that η A_N may be larger than π^0 A_N (compare green open squares in top panel to green closed squares in bottom)