Recent Highlights from Spin Structure Study of proton in PHENIX Experiment at RHIC

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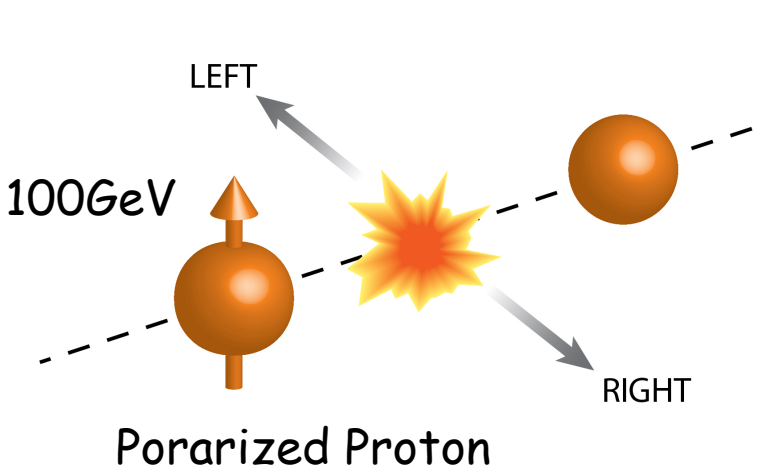
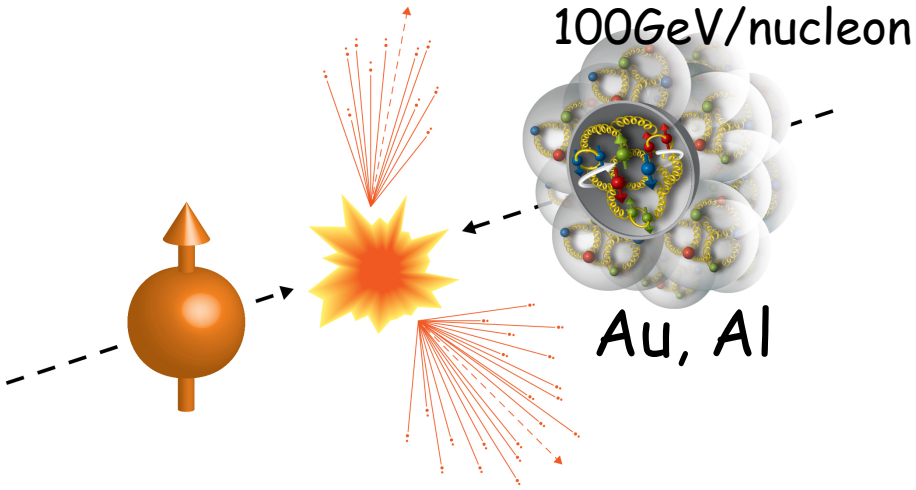
On behalf of PHENIX Spin Collaboration



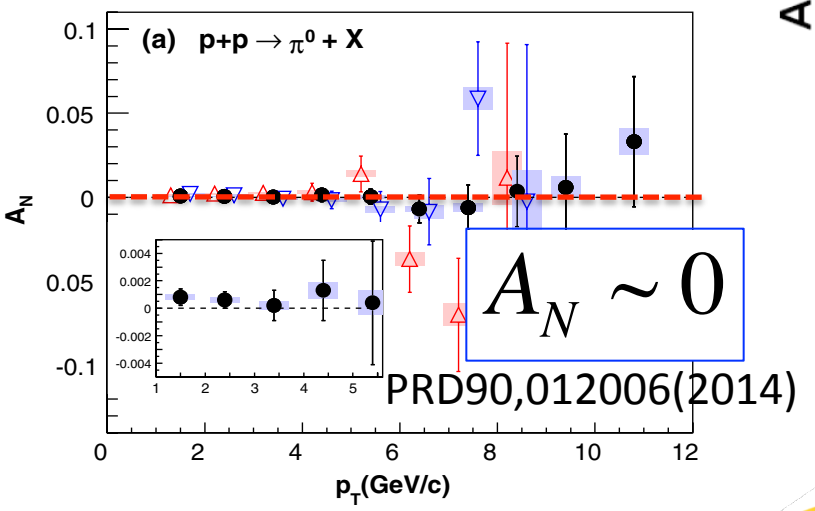


Central p0, two particle correlation

TRANSVERSE SINGLE SPIN ASYMMETRY

Rapidity Dependent Asymmmetries in p+p

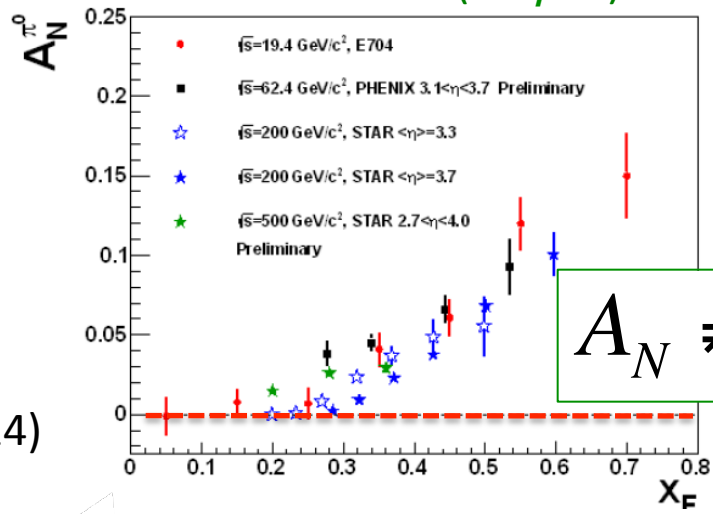
π^0 central ($0.35>|\eta|$)



$A_N \sim 0$

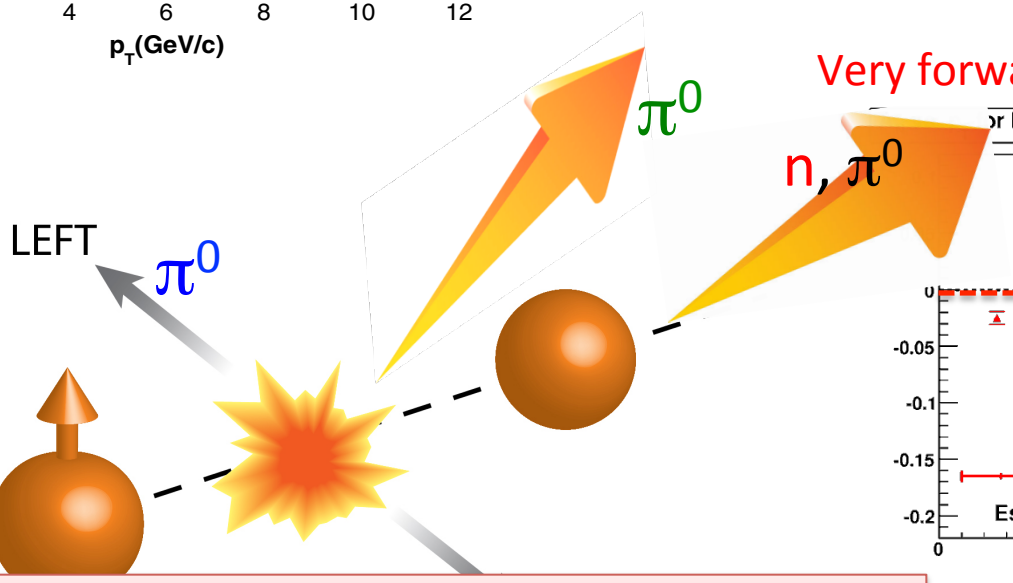
PRD90,012006(2014)

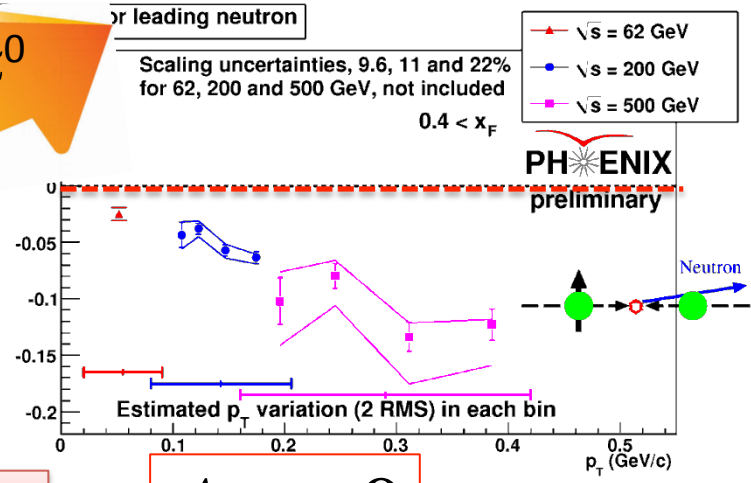
π^0 Forward ($2<\eta<4$)



$A_N \neq 0$

Very forward ($6<\eta<8$)

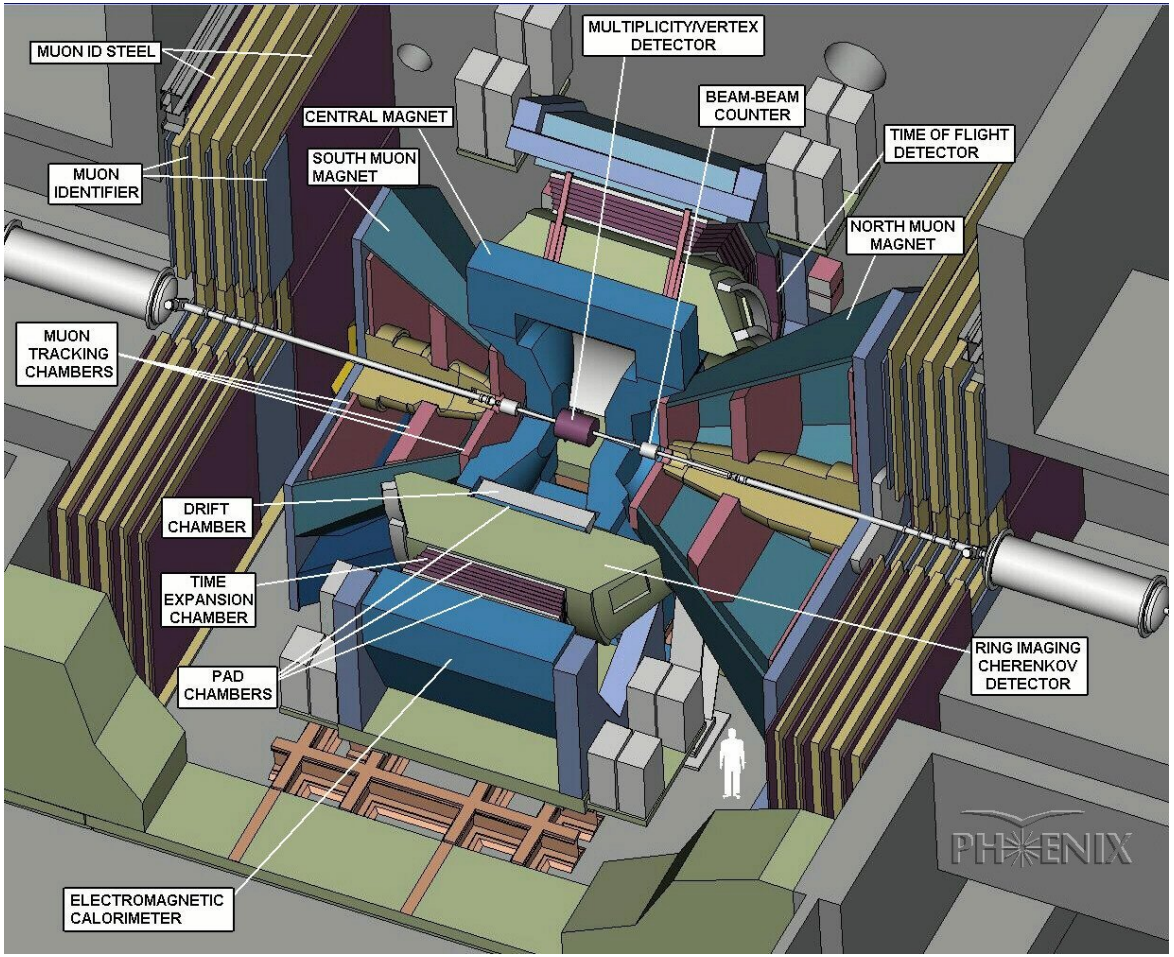




$A_N \neq 0$

Observed asymmetry only in forward

PHENIX Detector



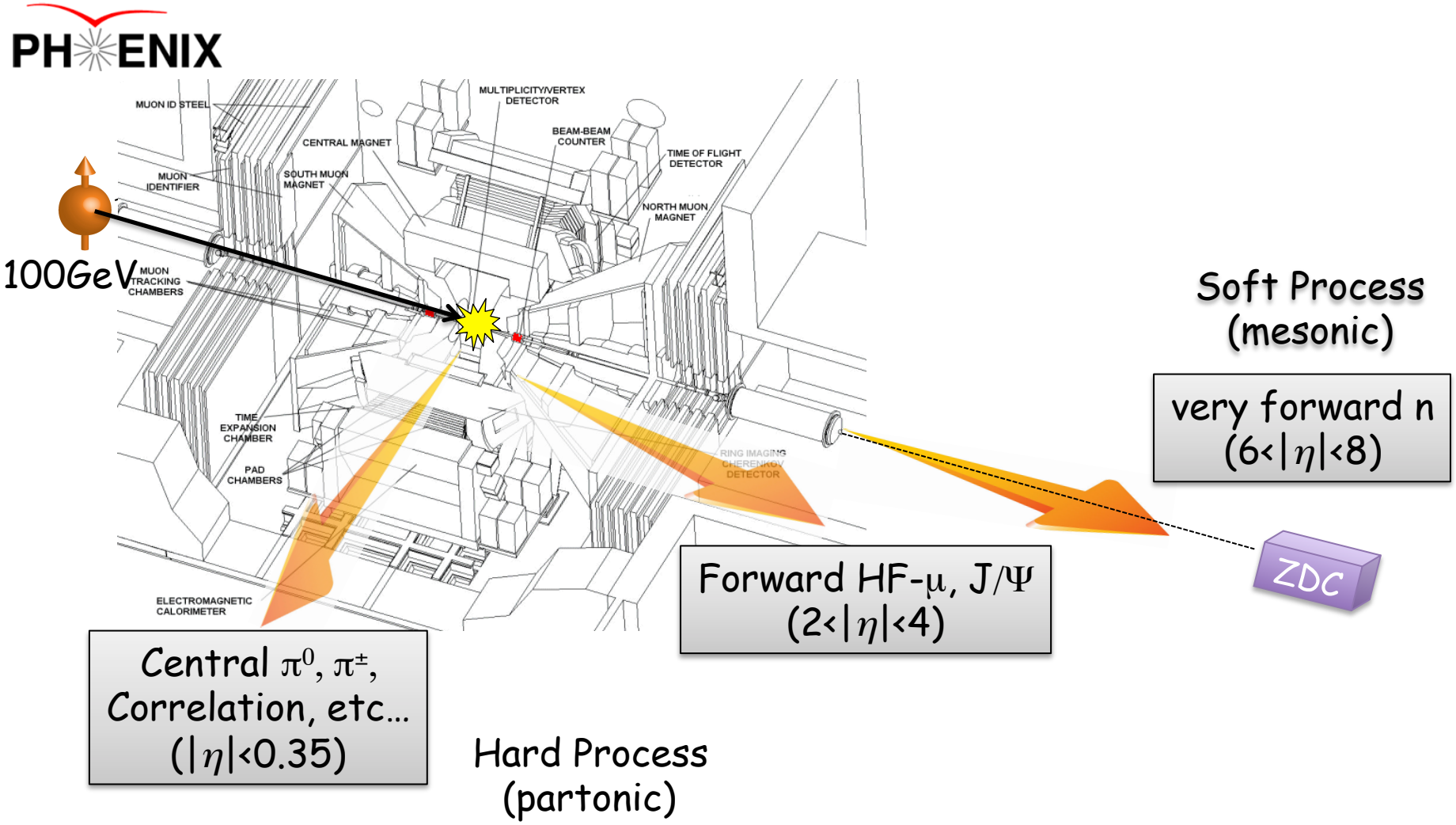
Central arms $|\eta|<0.35$
- Neutral pions
- Direct photons
- Identified charged hadrons
- Jets
- $W \rightarrow e$
- J/ψ and heavy flavor electrons

Muon arms $1.2<|\eta|<2.4$
- J/ψ
- Heavy flavor muons
- $W \rightarrow \mu$

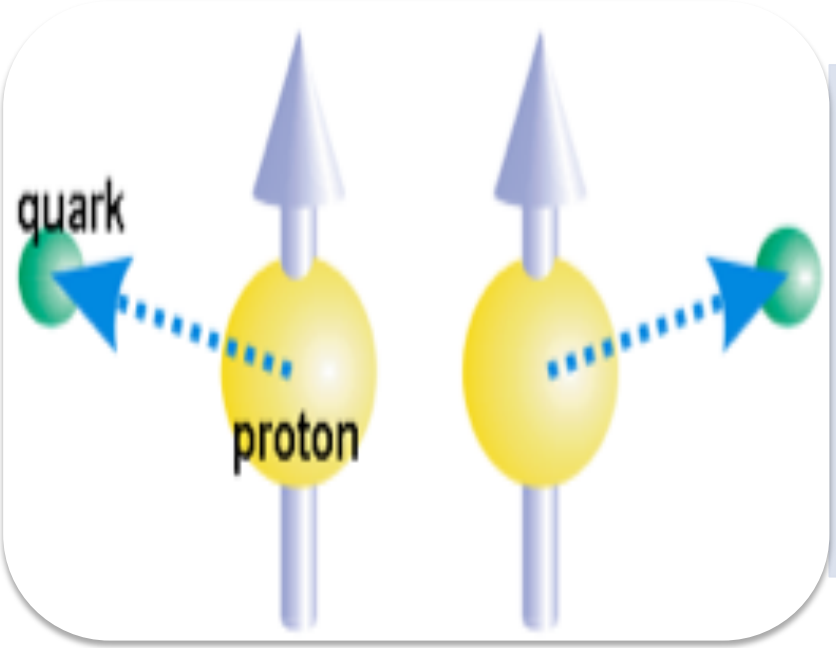
MPC $3.1<|\eta|<3.9$
- Neutral pion/eta
- EM cluster

ZDC $|\eta|>5.9$
- Zero-degree neutrons

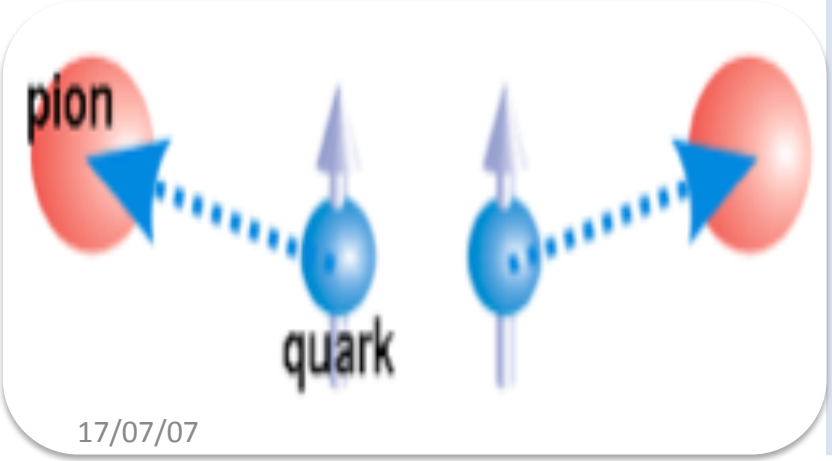
Transverse Asymmetry Observables



What Could be the Cause?

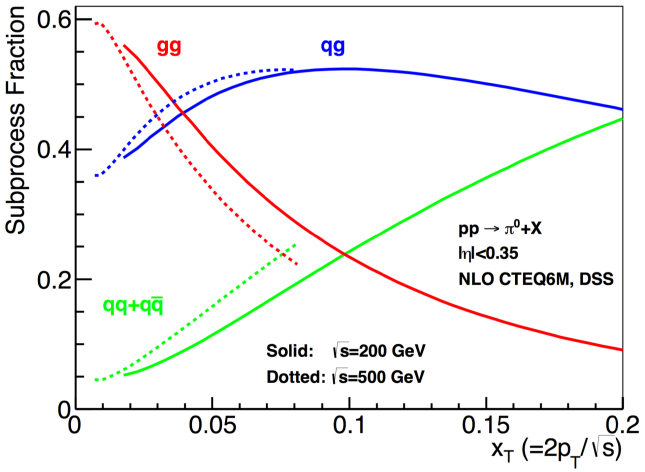


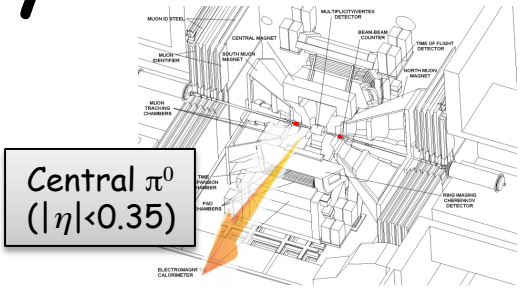
- **Sivers Effect +higher twist**
  - transverse-momentum dependence of partons inside the transversely-polarized nucleon



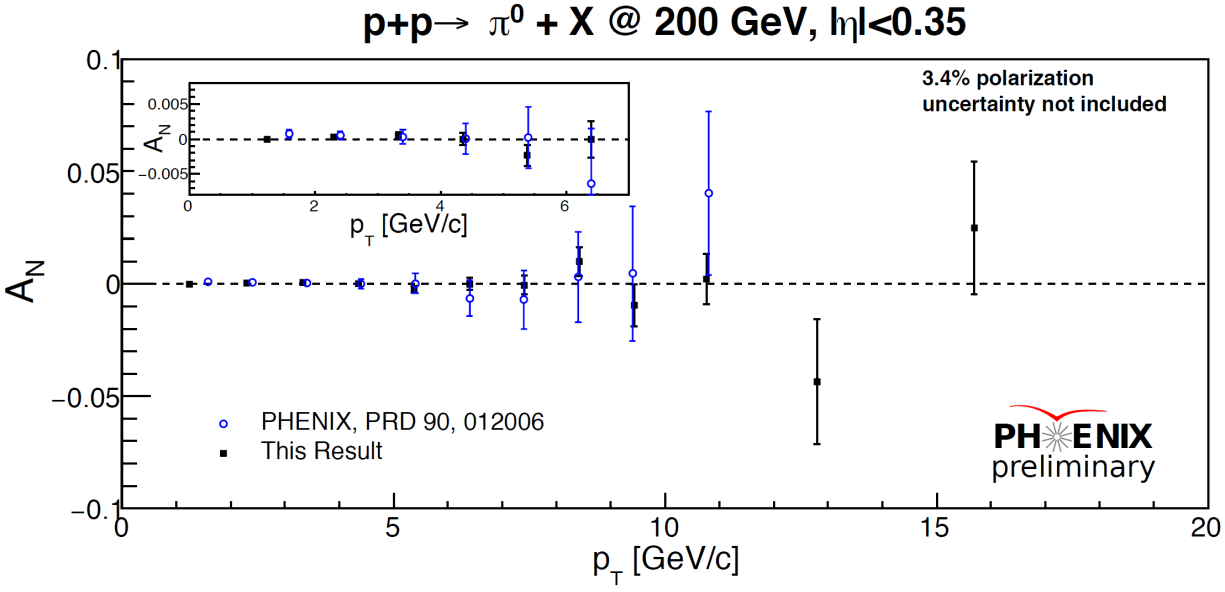
- **Collins Effect +higher twist**
  - correlation between transversely-polarized nucleon and transversely polarized partons inside
  - Collins fragmentation function

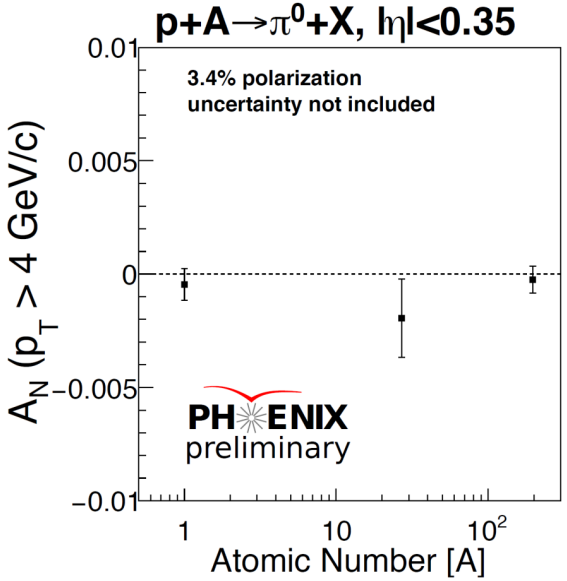
A-dependent Central π^0 Asymmetries



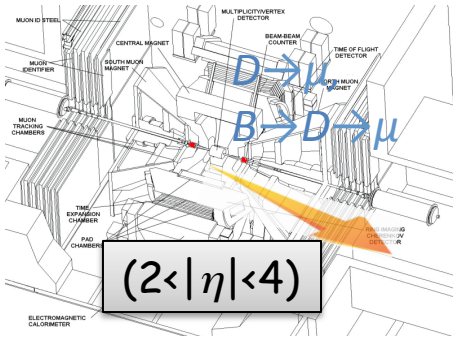


- gg/gq dominates
- New PHENIX data show A_N~0 in p+p even with improved statistical precision.
- First nuclear dependence attempt show no A-dependence and consistent with A_N~0.

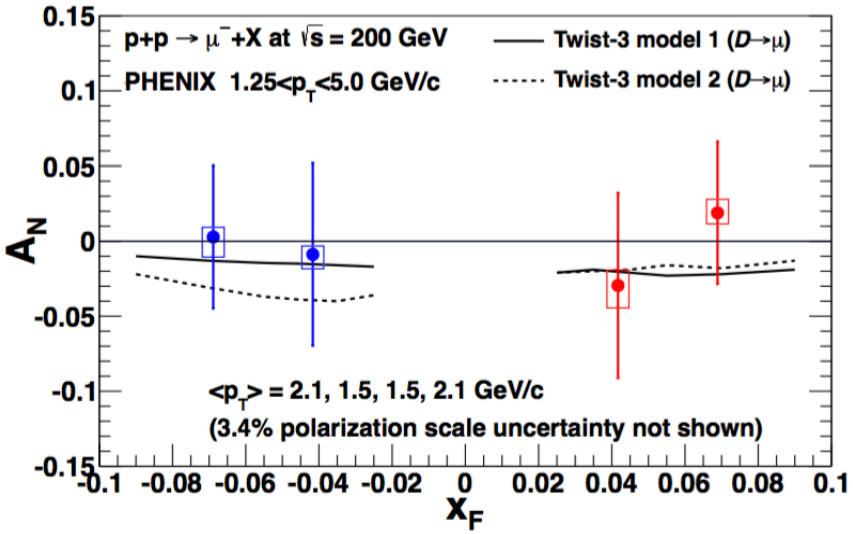




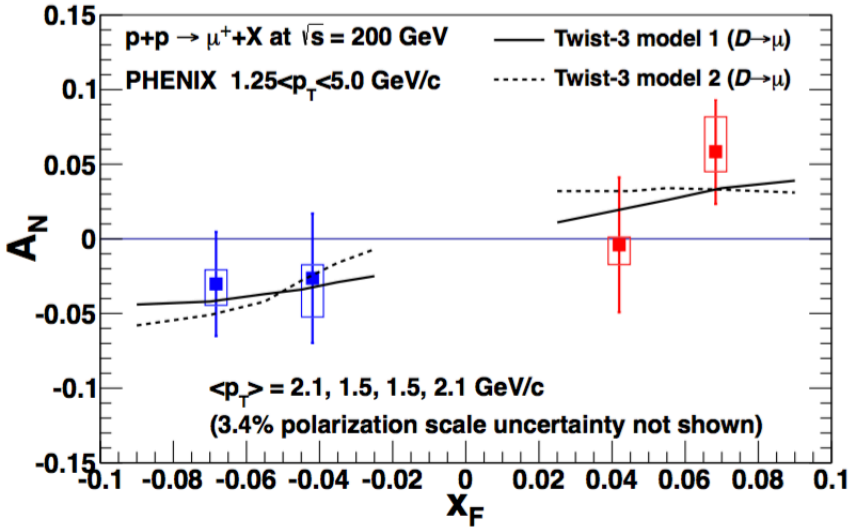
Forward Open Heavy Flavor



Data: PRD95, 112001(2017)
Theory: Y. Koike, S. Yoshida PRD84:014026



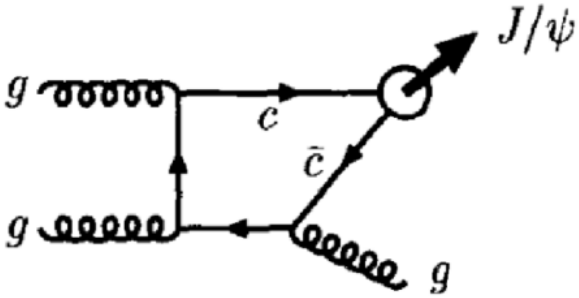
(-) charge



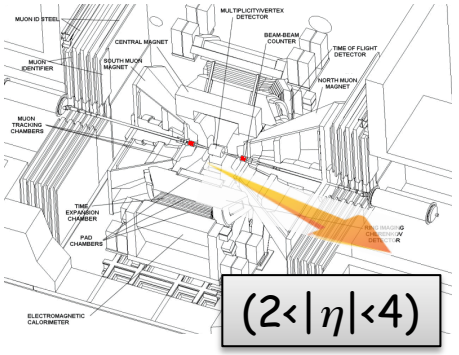
(+) charge

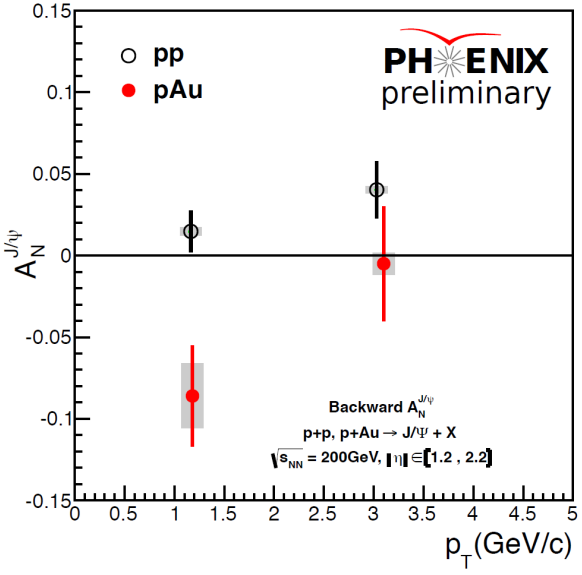
- Data are consistent with zero and Sivers-type Twist-3 three-gluon correlation functions within statistical error
- A-dependence study is underway.

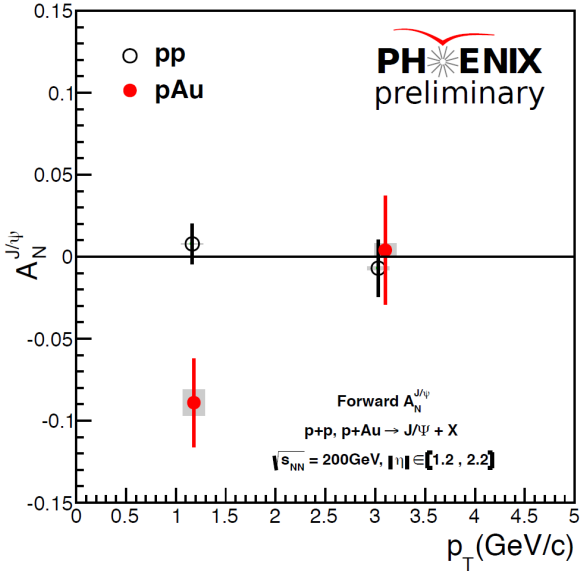
A-dependent Forward J/Ψ Asymmetry



Heavy flavor probes sensitive to gluon Sivers-type effect via gluon fusion production

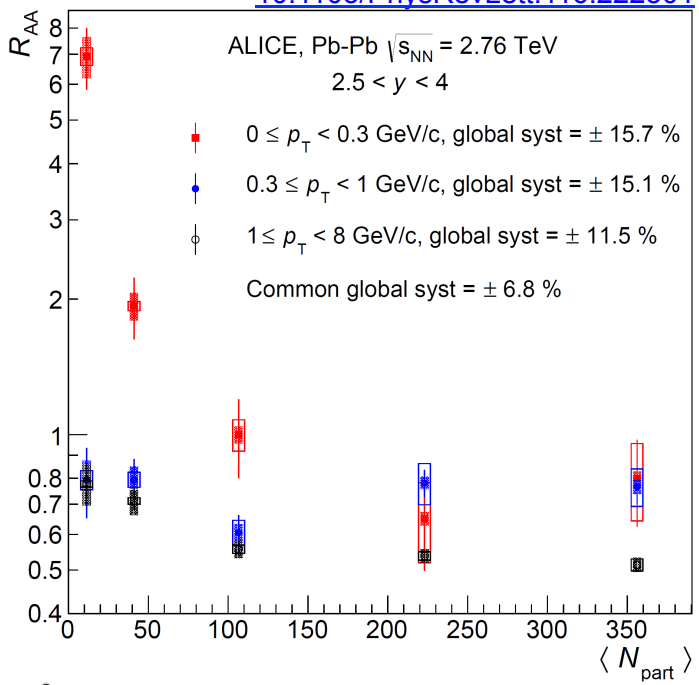


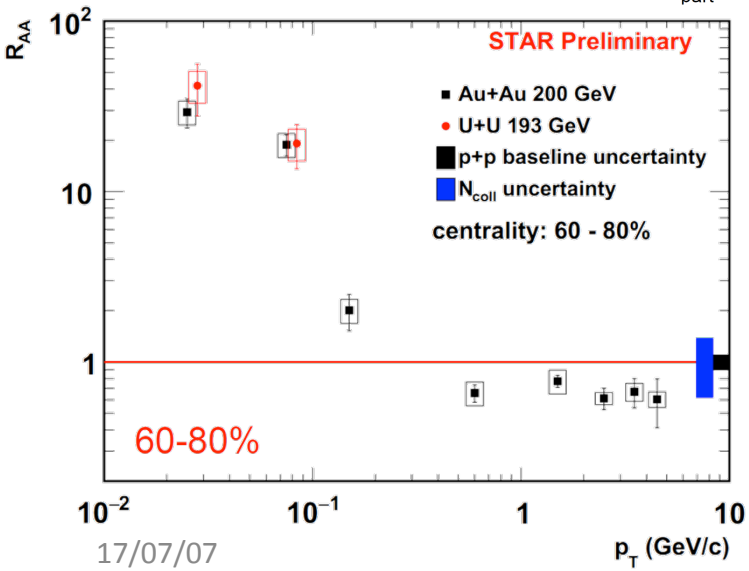




- Contradict to central π^0 result, observed unexpected large A-dependence in low-p_T
- Different behavior from forward π^0 A_N in p+p.

10.1103/PhysRevLett.116.222301

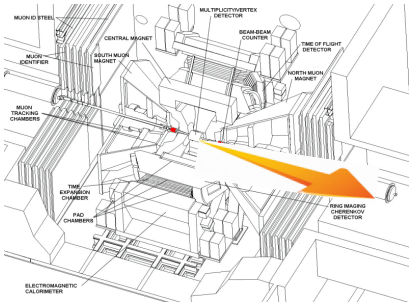


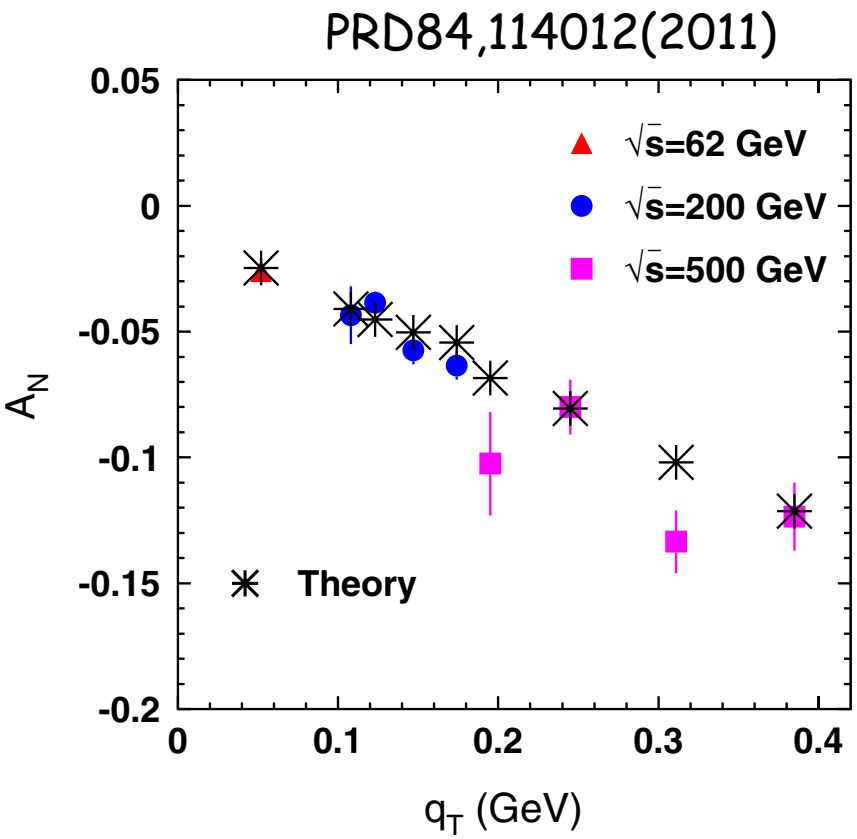


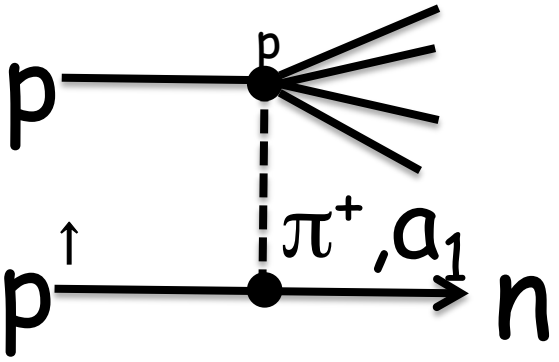
Hypothesis?

- ALICE and STAR observed enhancement in J/ψ at peripheral $A+A$ collisions and at very low p_T (~0.1 GeV/c). Interpretation could be photonuclear/two photon process that produce J/ψ in $A+A$ collisions
- Does this effect contribute to $p+A \rightarrow J/\psi + X$ and manifested as very different A_N than p+p? Other ideas?
- Caveat: PHENIX J/ψ A_N cut on p_T >0.42 GeV/c (region with good azimuthal resolution for A_N) and coincided with a valid BBC vertex

Very Forward Neutron A_N in p+p







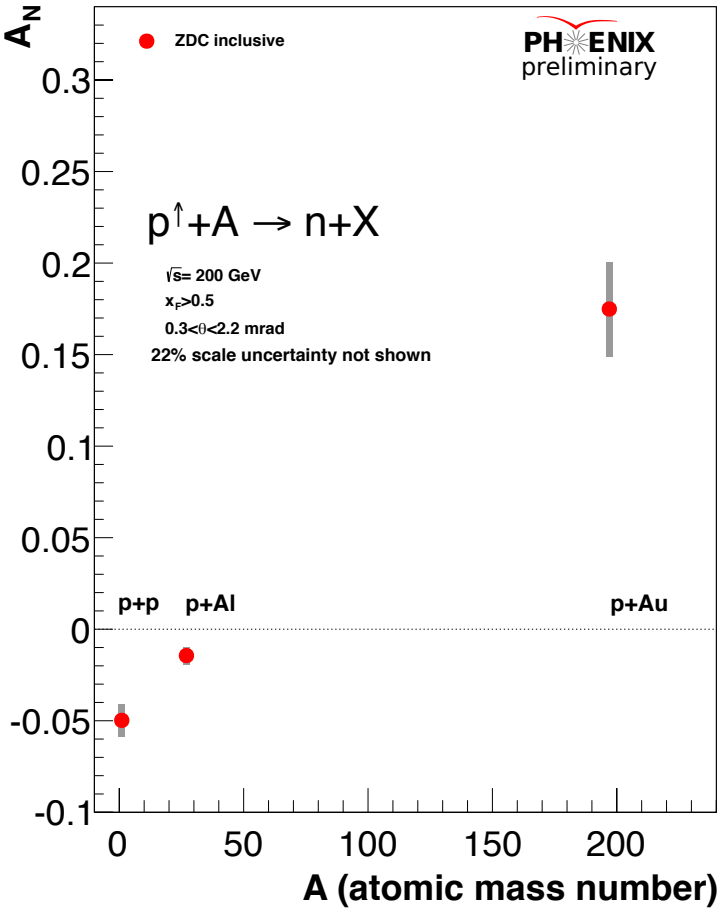
Data are well reproduced by the interference between π and a_1 Reggeon

$$A_N \approx \frac{\left(\phi^*_{non-flip}\phi_{flip}\sin\delta\right)}{\left|\phi_{non-flip}\right|^2 + \left|\phi_{flip}\right|^2}$$

δ : phase shift

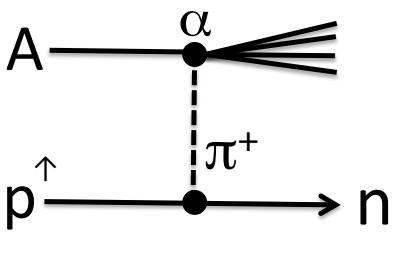
A-Dependence of Very Forward Neutron A_N

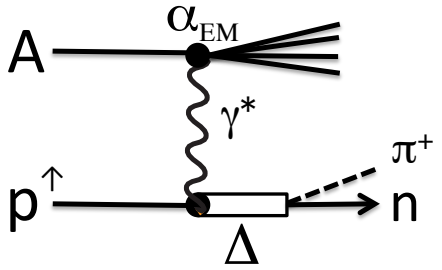
arXiv:1703.10941



- Observed strikingly strong A-dependence.
- Opposite sign of A_N in p+Au compared to p+p
- Possible UPC effect in addition to conventional strong interaction

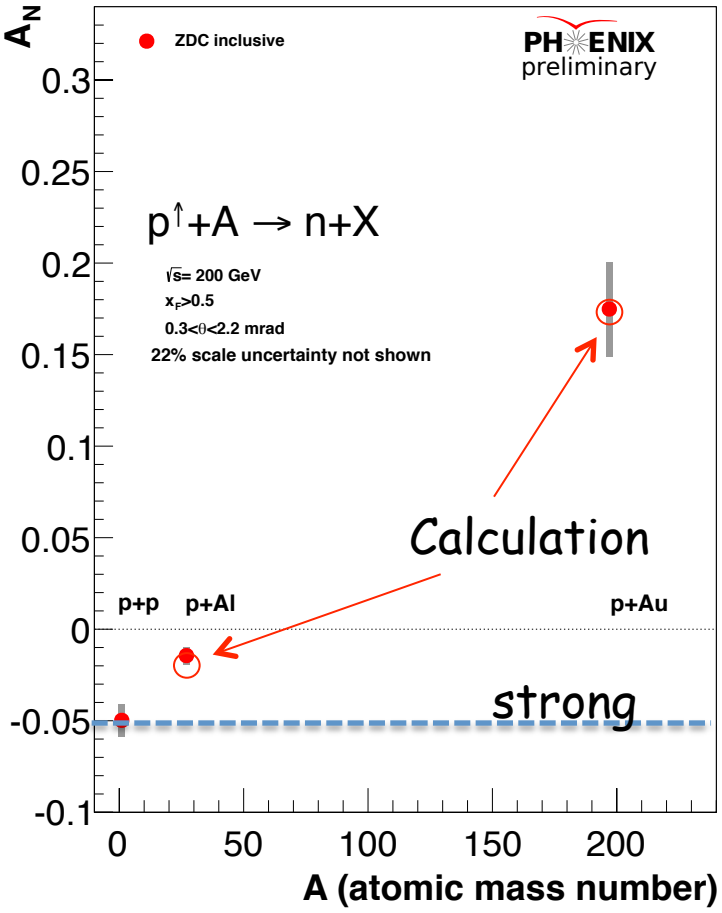
$$Z \cdot \alpha_{EM} \sim 79/137$$





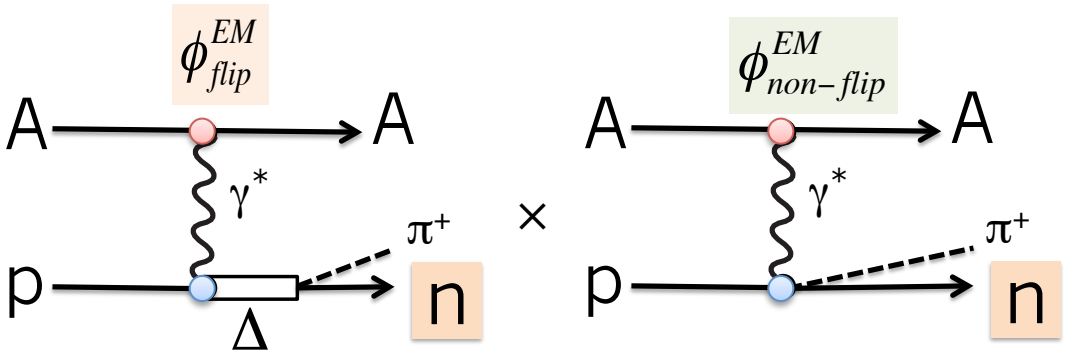
Strong + UPC Calculation

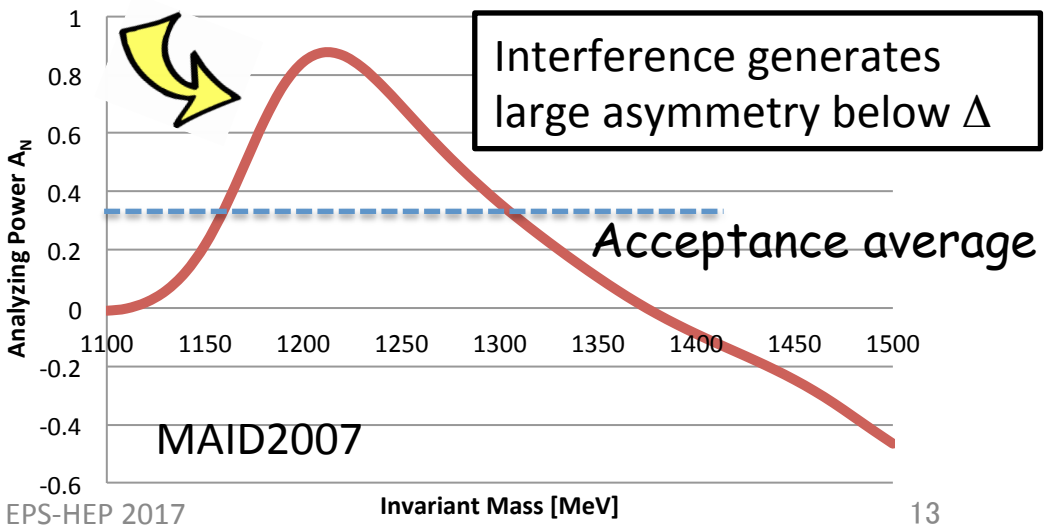
G. Mitsuka PRC95,044908(2017)



$$A_N^{\mathrm{UPC+HAD}} = \frac{\sigma_{\mathrm{UPC}} A_N^{\mathrm{UPC}} + \sigma_{\mathrm{HAD}} A_N^{\mathrm{HAD}}}{\sigma_{\mathrm{UPC}} + \sigma_{\mathrm{HAD}}}$$

$$\frac{d\sigma^4_{\mathrm{UPC}(pA\to\pi^+n)}}{dW\,db^2\,d\Omega_n} = \underbrace{\frac{d^3N_{\gamma^*}}{dW\,db^2}}_{\text{photon flux}} \frac{d\sigma_{\gamma^* p\to\pi^+n}(W)}{d\Omega_n} \overline{P_{\mathrm{had}}}(b),$$



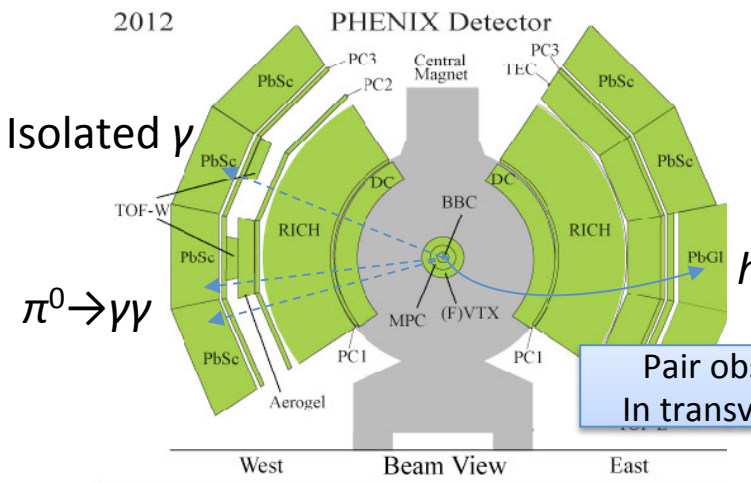


Summary

- Explored A-dependence of transverse single spin asymmetries in wide rapidity region.
- No asymmetry observed in central region neither $p^{\uparrow}$+p nor $p^{\uparrow}$+Au.
- Observed unexpectedly strong A-dependence in forward J/ψ and very forward neutron asymmetries.
- Important role of UPC effect is demonstrated at least for very forward neutron asymmetries.
- To be investigated further:
  - Heavy flavor D/B decay m Asymmetry in $p^{\uparrow}$+A
  - p_T dependence for further test of UPC effect

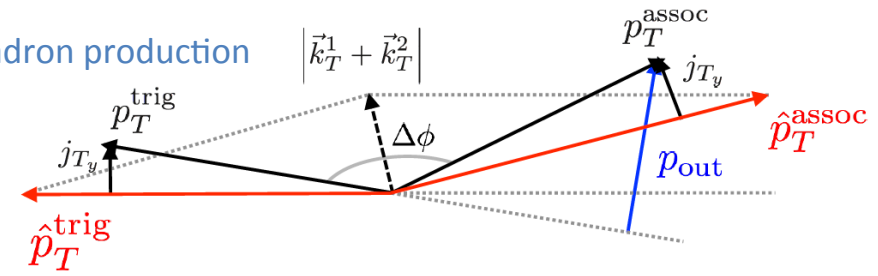
BACKUP SLIDES

Study initiated investigating the non-TMD-factorized process

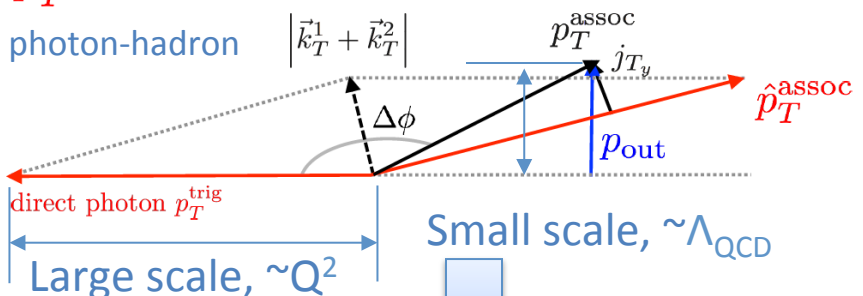


Pair observables
In transverse plane

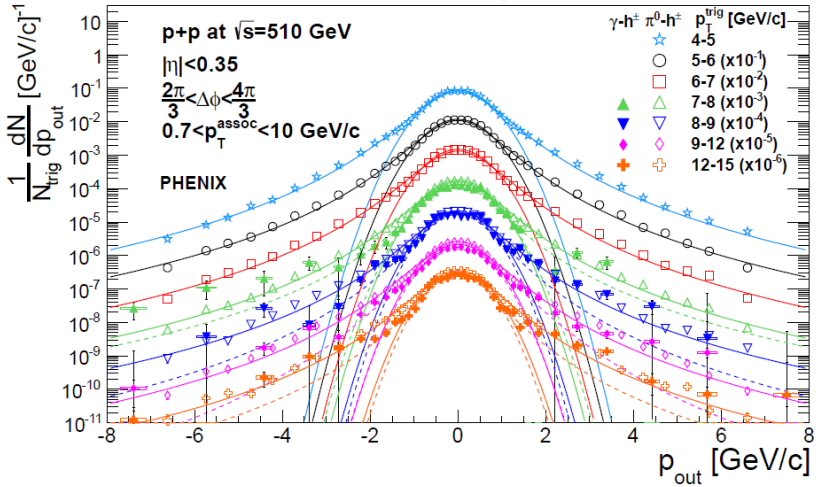
Di-hadron production



Direct photon-hadron

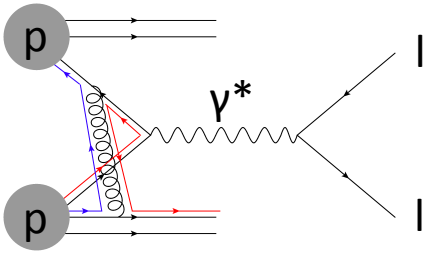


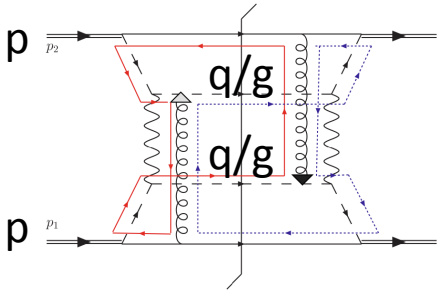
Histogram p_{out}



- High p_T two-particle correlation has been a valuable tool to study interaction between hard probe in QGP
- It can also be used to construct two scale observables in *p*+*p* and *p*+A collisions
- Not factorizable in TMD framework
- But how their behavior difference from the factorizable observables (like DY)?

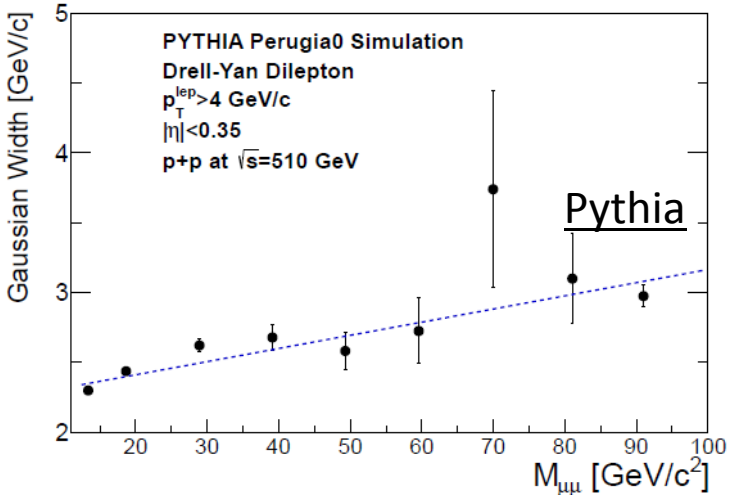
Study initiated investigating the non-factorized process - First Results

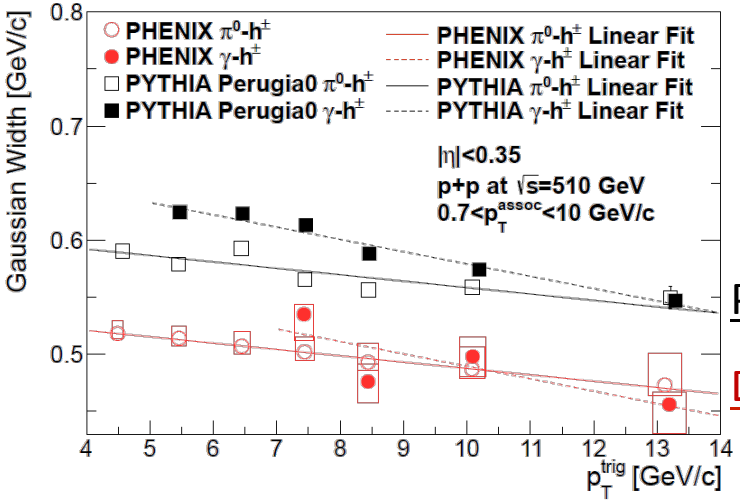




Example of TMD-factorized process:
DY in Pythia simulation
Positive width against scale (M)
As expected in CSS evolution

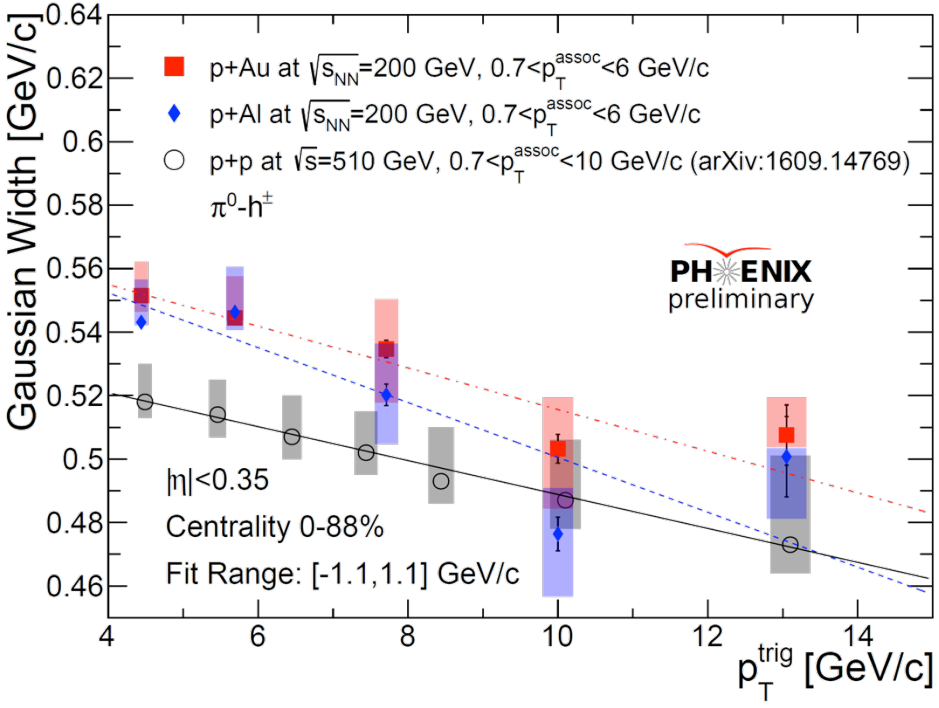
Non-TMD-factorized process: π^0+h, γ+h
Data and Pythia simulation:
Both show negative width slope against scale (p_T^{trig})
Very different from CSS indicate impact from color flow

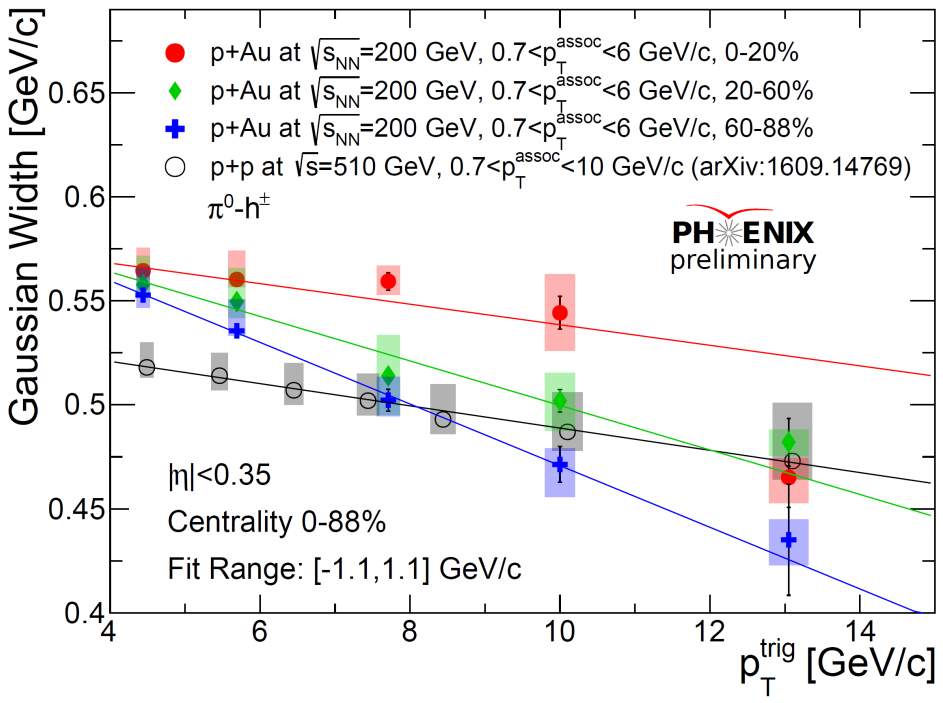




Study initiated investigating the non-factorized process: first p+A result

- First preliminary release of *p*+A π^0+*h* result
- Wider Gauss core for p_{out} in *p*+A collisions: multiple scattering in A?
- Stronger p_T^{trig} dependence in peripheral *p*+Au: Interpretation in discussion





See the whole story: QM17 talk, Joe Osborn