PHENIX

very forward neutron A_N

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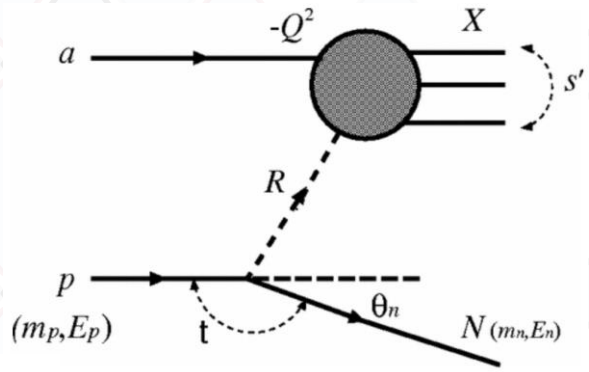
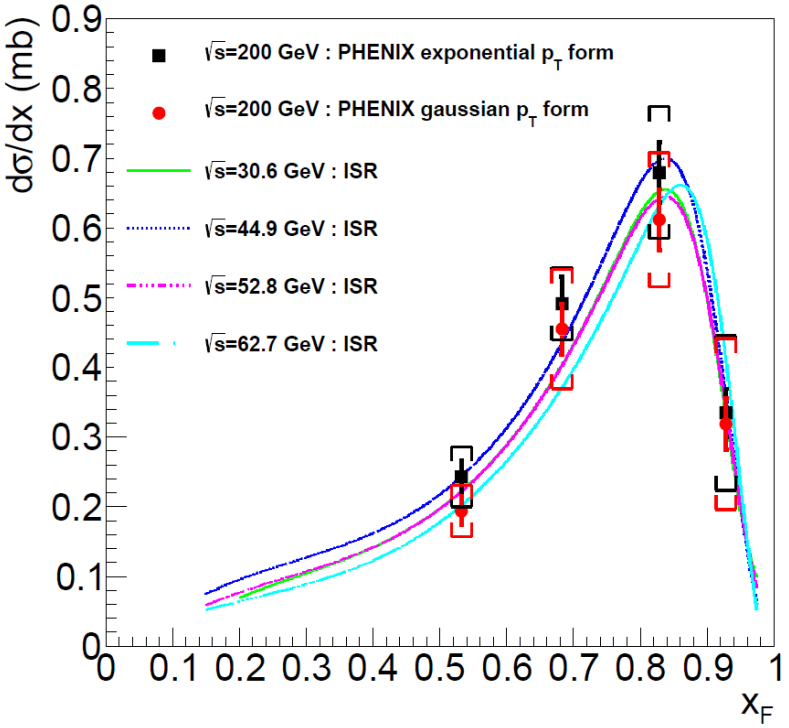
Very Forward neutron production in p+p collisions

- Forward neutron production at ISR qualitatively described by one-pion exchange (OPE) model (Regge)
- Also at RHIC in unpolarized cross sections; reasonable consistency with model

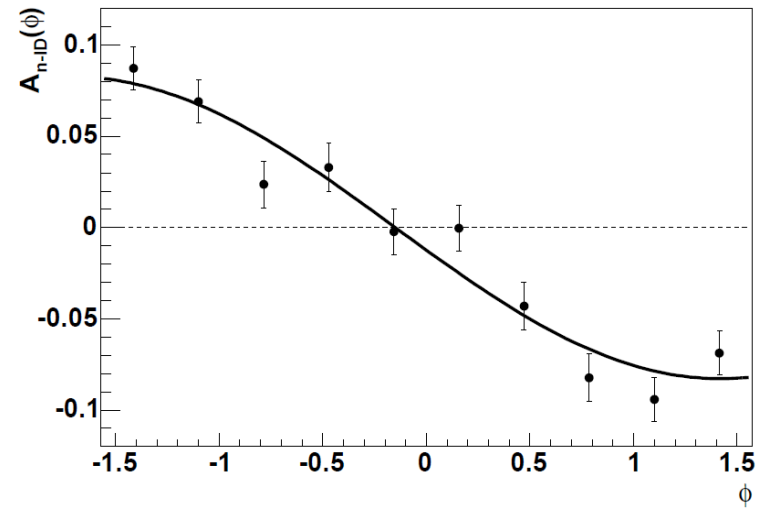


PRD 88 (2013) 032006

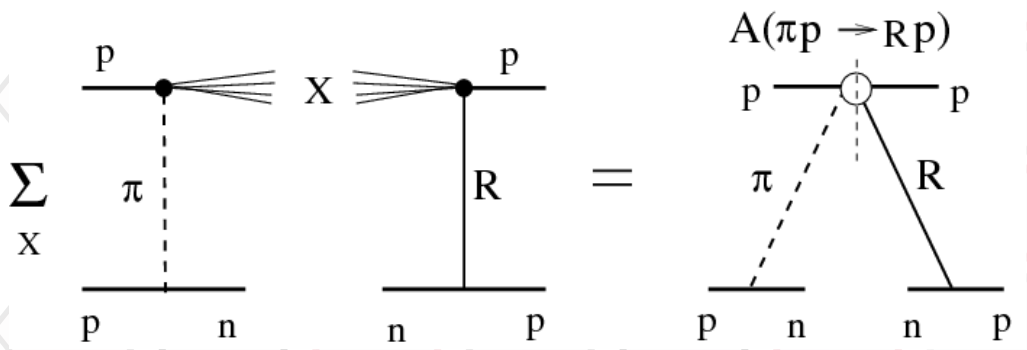


Transverse Single spin asymmetries (TSSAs)

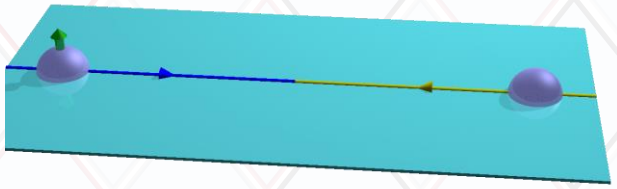
Fukao et al: PLB 650 (2007) 325



Kopeliovich et al: PRD 84 (2011) 114012

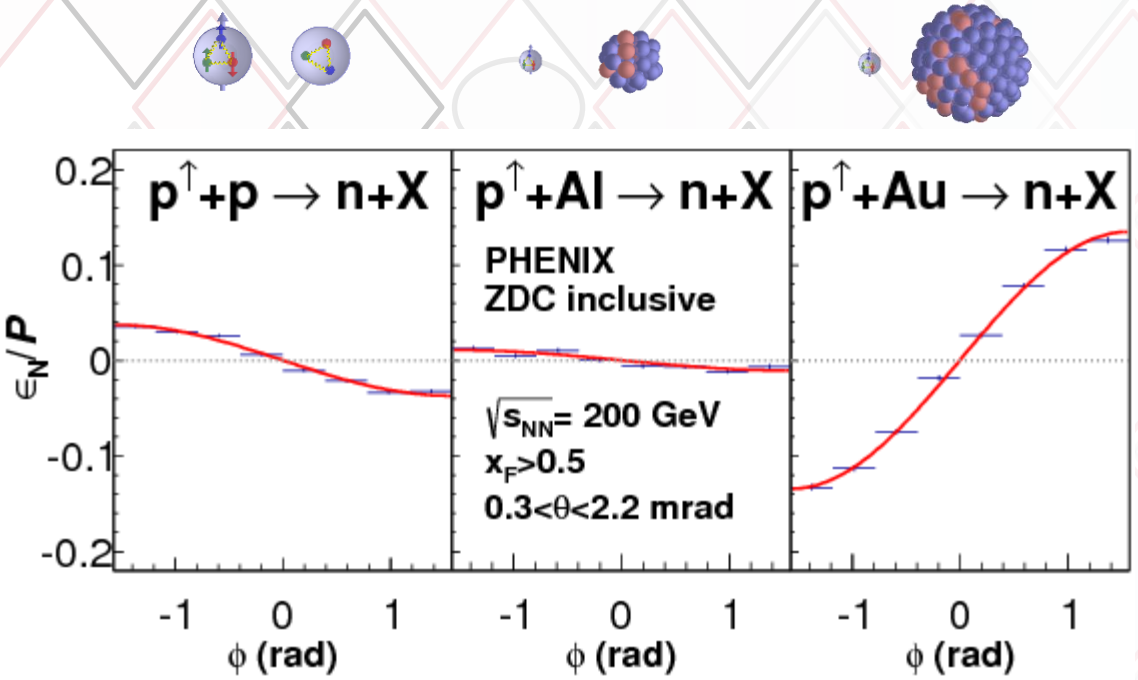


$$A_N = \frac{1}{P}\frac{N^L - N^R}{N^L + N^R}$$



- First forward neutron asymmetries seen at RHIC
- Existence of nonzero asymmetries requires an extension to OPE model: interference of pion and a_1 Regge amplitudes can qualitatively describe A_Ns

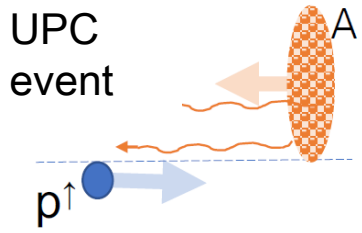
From p+p to p+A neutron asymmetries



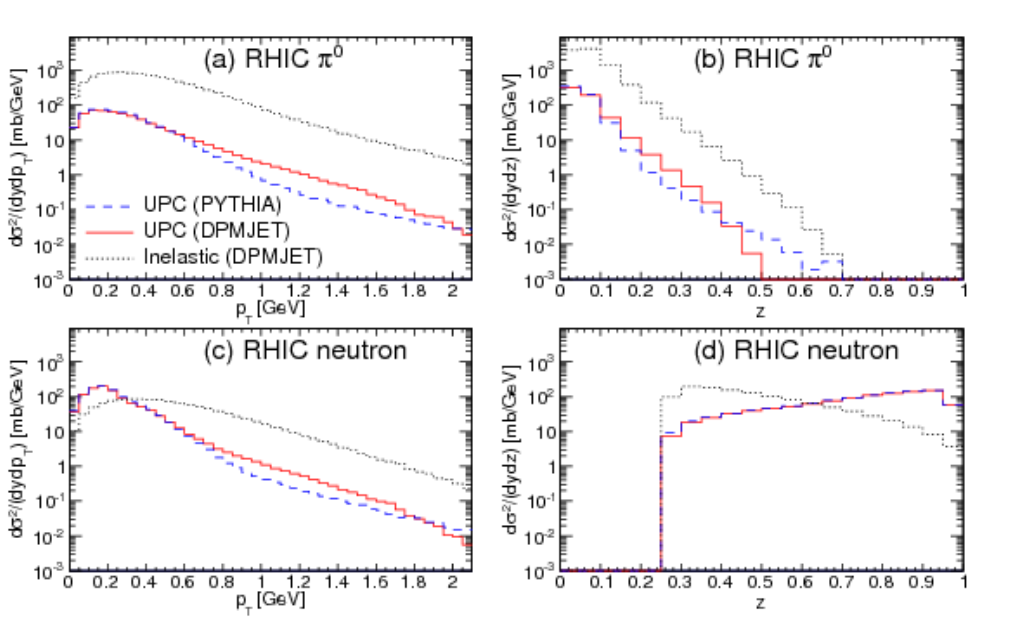
PRL 120 (2018), 022001

- Unexpectedly large A dependence in neutron asymmetries
- Even a sign change seen
- OPE model does not predict such a change in asymmetries
- Are there other sources to the asymmetries?

Ultraperipheral collisions in p+A



Mitsuka: EPJC 75 (2015) 614

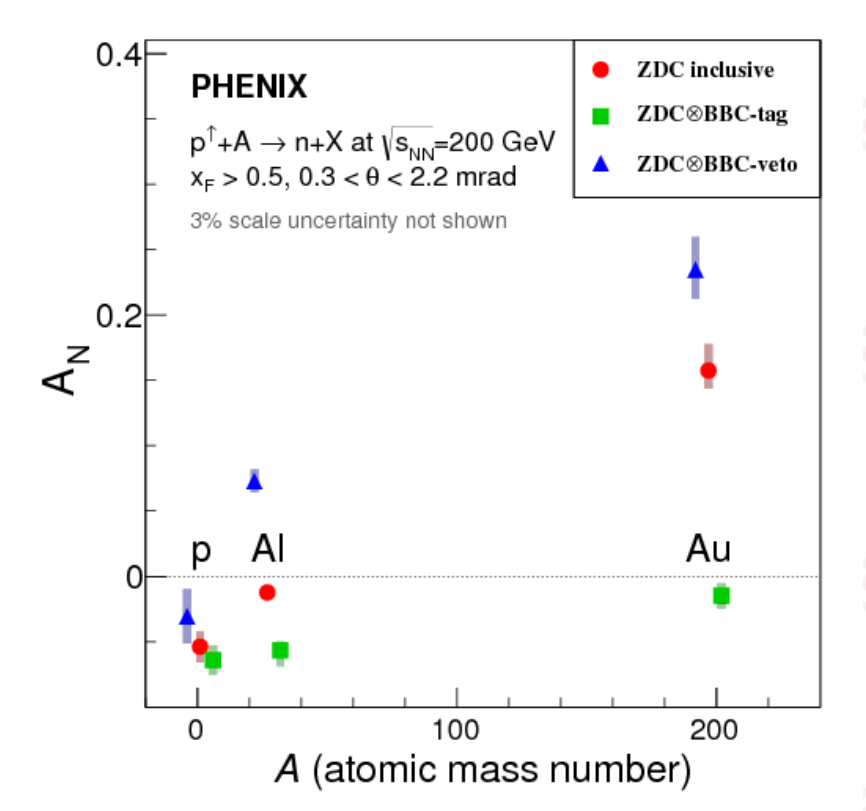


STARLIGHT+SOPHIA+DPMJET/PYTHIA simulations

- When impact parameter too large for nuclear interactions, ultra-peripheral collisions still possible with photon field from nucleus
- Especially for forward neutrons at low transverse momenta and high momentum fractions x_F substantial contribution
- Z^2 dependence increases relative contribution from Al to Au

Enhance or suppress UPC and hadronic contributions via correlations

PRL 120 (2018), 022001



- Coincidence with charged particle activity in forward and backward region (BBC) enhances hard interactions → asymmetries stay negative
- Veto enhances UPC contribution → p+Al asymmetries already positive

→study also the actual x_F and P_T dependence for actual interplay

Enhance or suppress UPC and hadronic contributions via correlations

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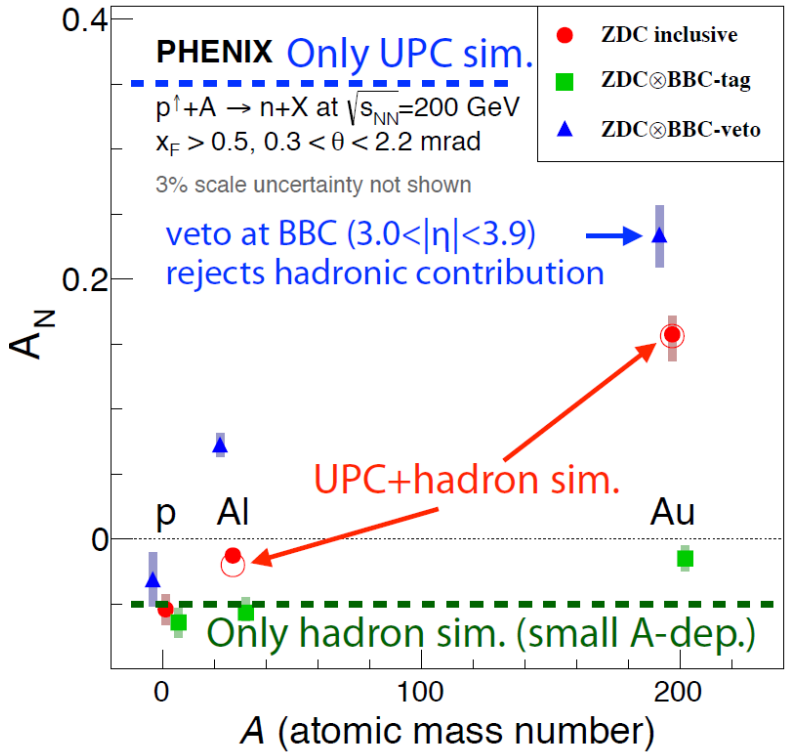

Mitsuka PRC95 (2017) 044908 - qualitative agreement in polarized UPC model (MAID)

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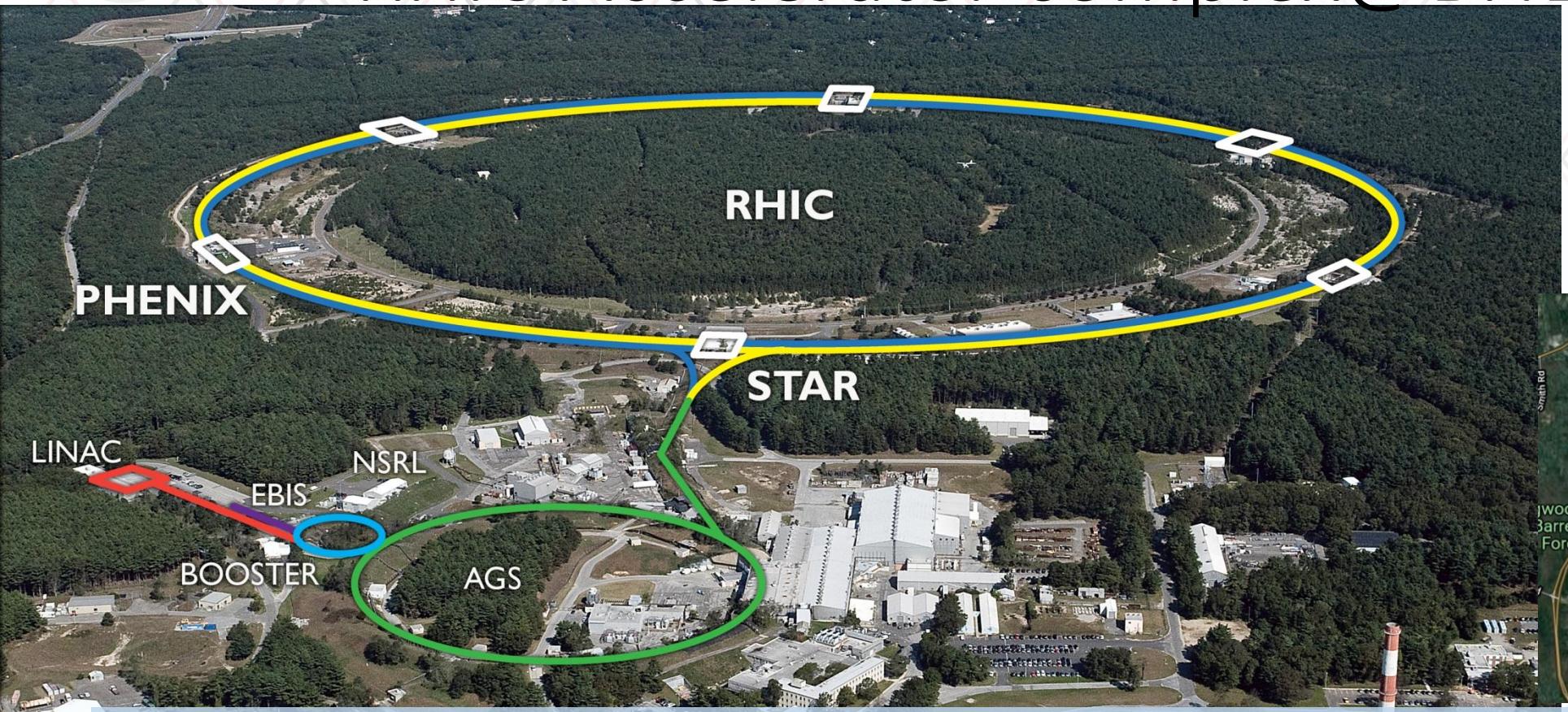
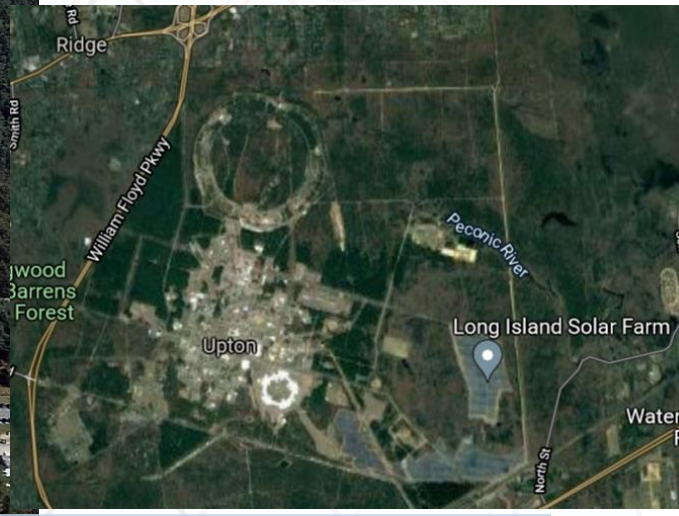
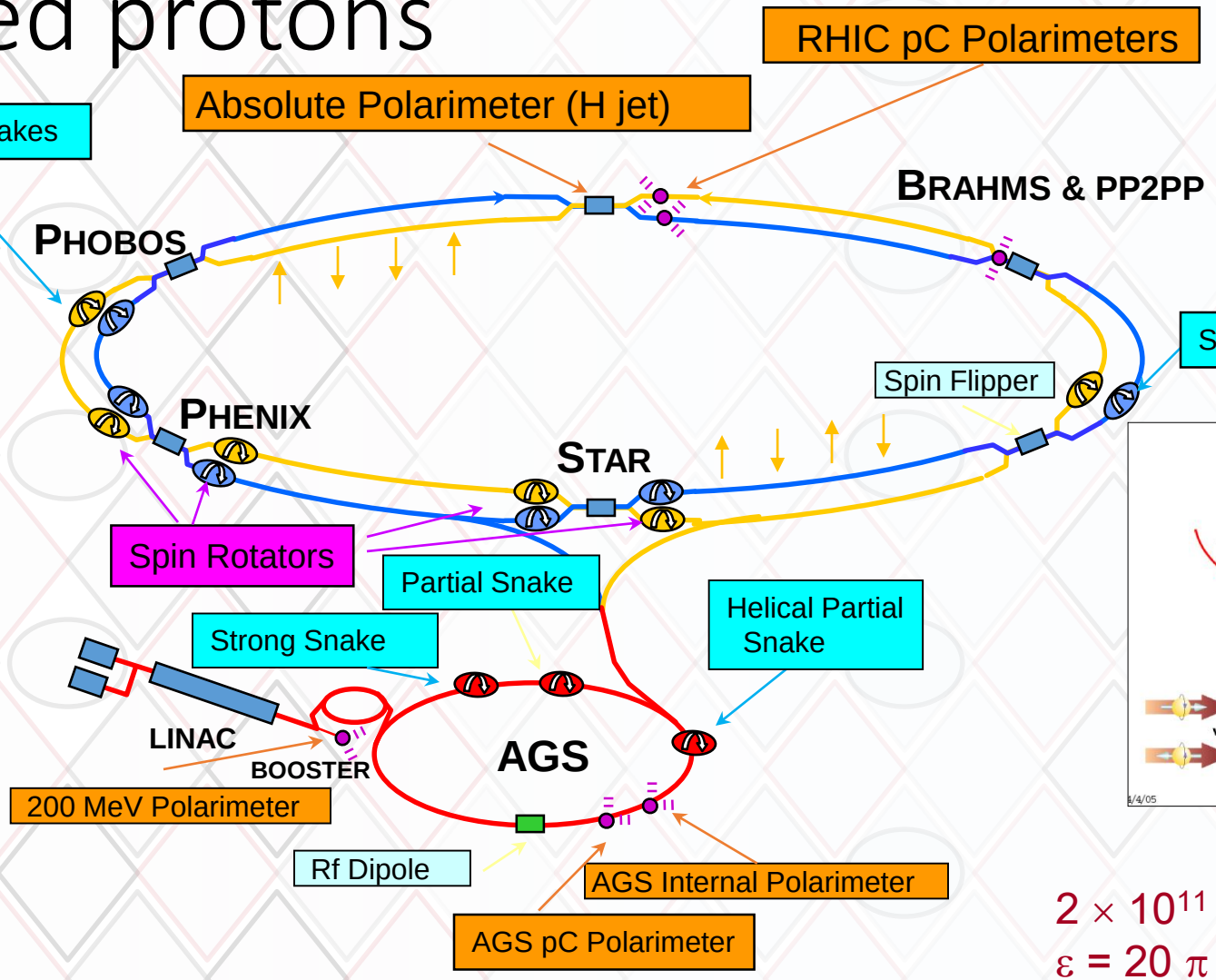
RHIC Accelerator complex@BNL

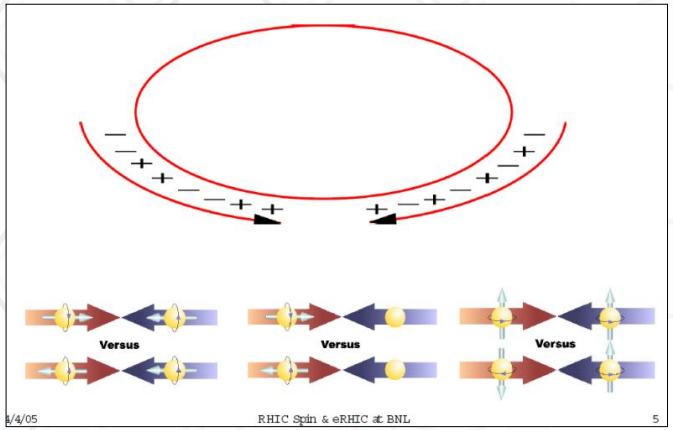




- Polarized proton beams from $\sqrt{s}$ of 62-510 GeV
- up to 120 filled bunches, spin orientations alternating bunch-by-bunch in several predefined spin pattern
- pA, AA collisions up to 200 GeV
- Spin rotators around PHENIX and STAR to select long. or transversely polarized beams
- Global (polarized H-jet, C targets) and local (ZDC) polarimetry

The RHIC ring(s) with polarized protons





$L_{max} = 2 \times 10^{32} s^{-1} cm^{-2}$

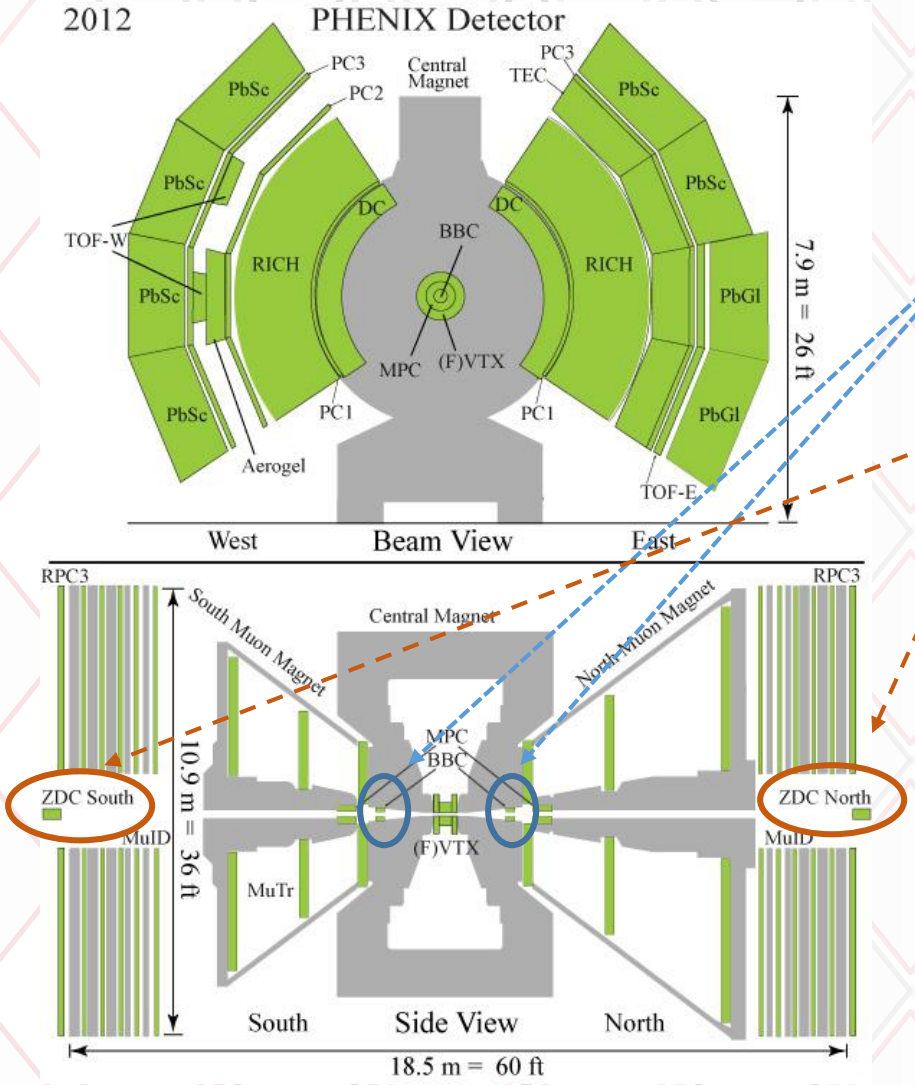
$50 < \sqrt{s} < 500\ GeV$

~ 70% Polarization

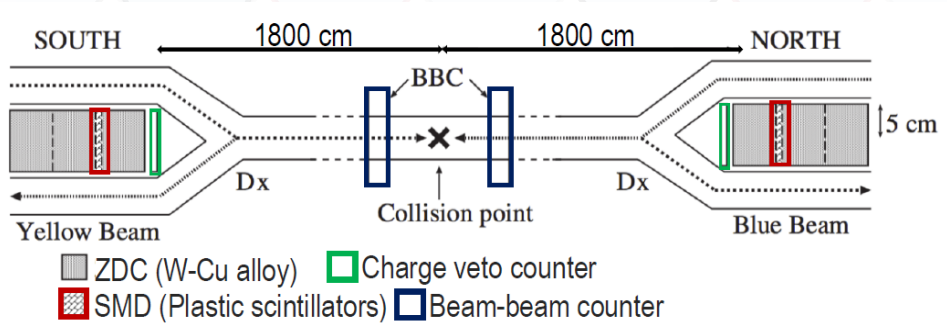
2×10^{11} Pol. Protons / Bunch

$\varepsilon = 20\ \pi$ mm mrad

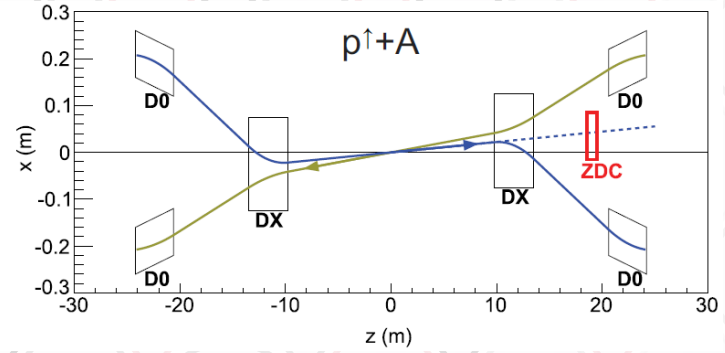
PHENIX



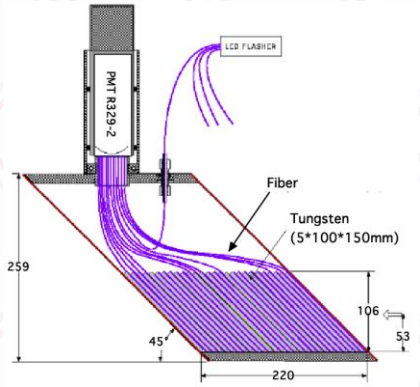
- main detector:
  - 2 Central arms ($|\eta|<0.35$, 90 degrees each):
  - 2 Muon arms ($1.2<|\eta|<2.4$)
- BeamBeamCounter (BBC, $3.1<|\eta|<3.9$, hard collision/luminosity detectors)
- ZeroDegreeCalorimeter ($|\eta|>6.1$) :
  - 3 10x10 cm^2 modules of 1.7 nuclear interaction lengths each, 20% energy resolution for 100 GeV neutrons
  - ShowerMaxDetector 7 strips horizontally and vertically, 1cm resolution

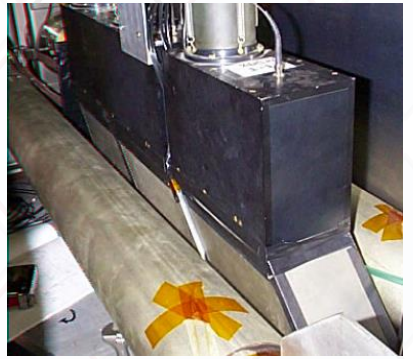


ZDC running in 2015 p+p and p+A, neutron reconstruction



- In 2015 p+p, p+Al and p+Au collisions at 200 GeV
- For p+A running tilted beam direction compensated by shifting ZDC to nominal beam center



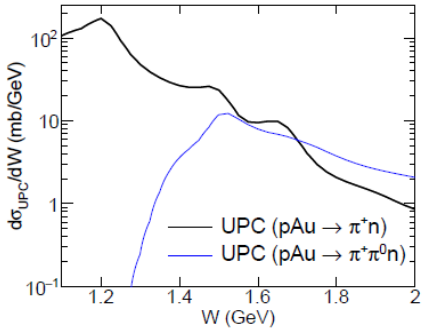


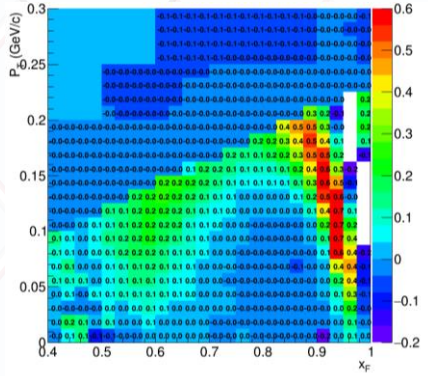
- Total energy in ZDC1+2+3: 40 – 120 GeV
- EM veto: $E_{ZDC2}/E_{tot} > 3\%$
- 0.5 cm < r < 4.0 cm for neutron hits
- >0 SMD Strips horizontal and vertical strips hit
- 4(+2) P_T bins [0,0.01, 0.06,0.11, 0.16, 0.21,0.4] GeV/c
- 4(+2) x_F bins [0,0.4,0.55,0.7,0.85,1.,1.2]

Unfolding procedure, Systematics, Predictions

- RooUnfold (Bayes) unfolding (iterative unfolding – variation of iterations as one source of systematics) on spin dependent 3D yields → Asymmetry calculation
- Several MC generators + GEANT3 simulations as basis for unfolding: Pythia6/8, DPMJET, OPE motivated (π+p Pythia 8, using measured n spectra), UPC (STARlight+Sophia+DPMJET) → variation as systematics
- Variation of beam center at ZDC and asymmetry reconstruction method → systematics

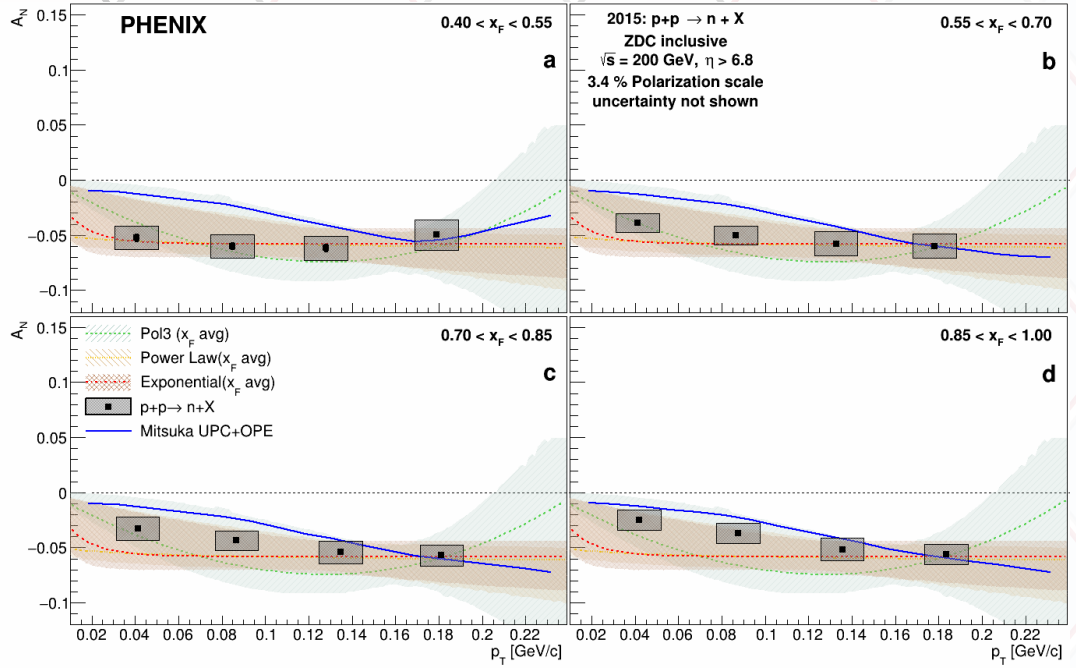
- Model calculations from Mitsuka, combining UPC and hadronic (*Kopeliovich et al: PRD* 84 (2011) 114012) calculations
- For p+p and p+Al scaled UPC xsecs by simple Z^2 dependence and OPE xsecs by $A^{0.42}$ dependence
- UPC model takes into account only n+π^+ resonances → sharp P_T/x_F behavior

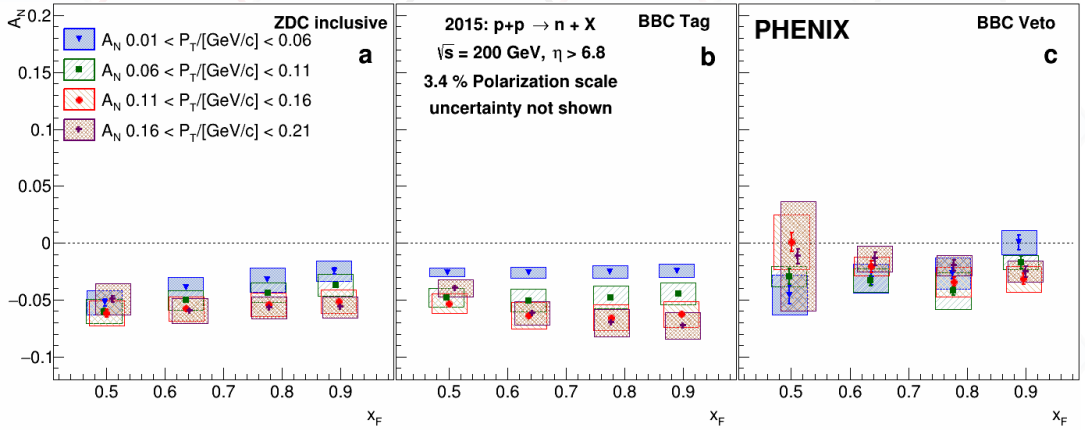




Inclusive neutron asymmetries in p+p

PRD 105 (2022) 032004



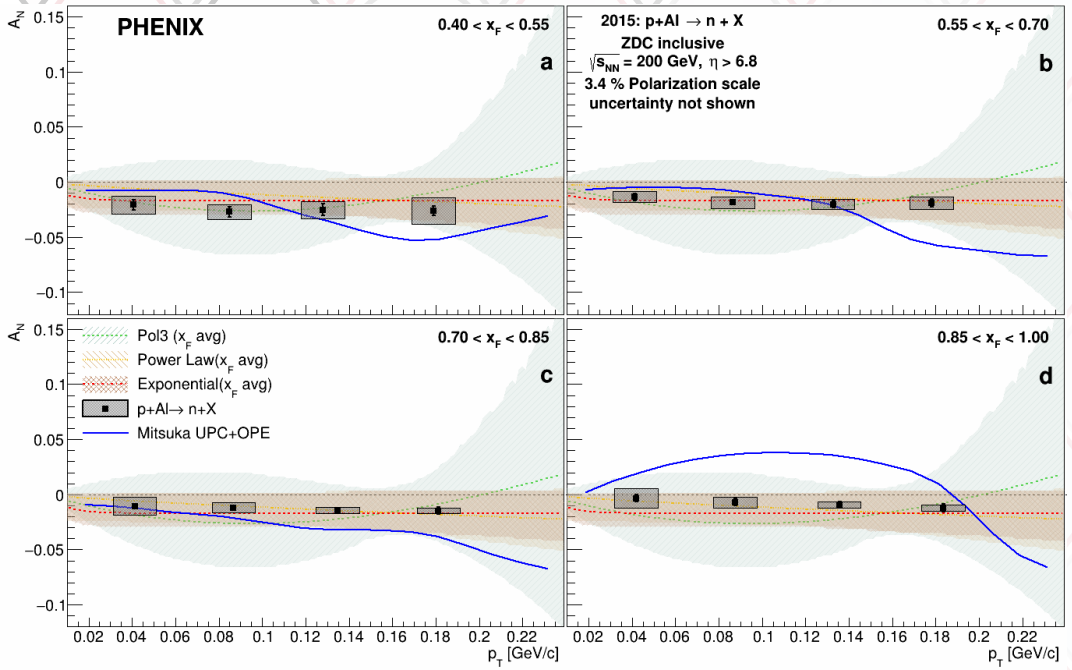


Dashed areas: best parameterizations of x_F integrated asymmetries using Pol3, Power law or Exponential

- Magnitude increasing with P_T except for low x_F
- Only weak x_F dependence in hadronic events, slightly larger in BBC vetoed events
- Comparable to (OPE dominated) model curves

Inclusive neutron asymmetries in p+Al

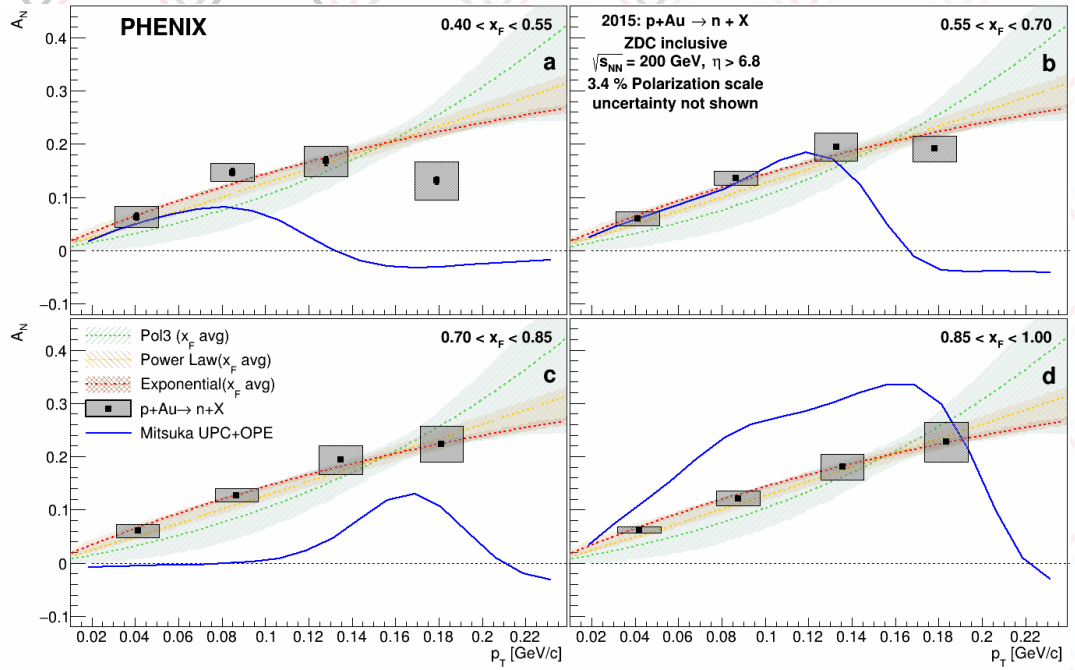
PRD 105 (2022) 032004



- Cancellation between hadronic and UPC contributions results in very small asymmetries in data and model
- Qualitative agreement of model except at high x_F

Inclusive neutron asymmetries in p+Au

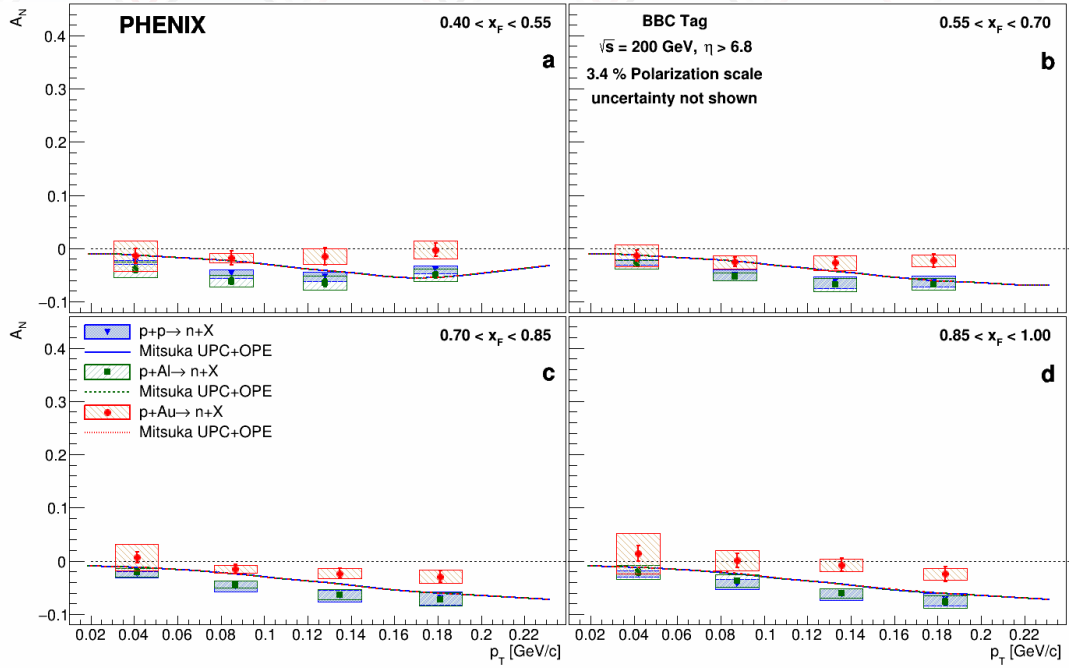
PRD 105 (2022) 032004



- Large, increasing asymmetries seen with likely a hint of decrease at high P_T for lower x_F
- Roughly similar behavior in model seen but details shifted – possibly due to inclusion of single pion resonances only

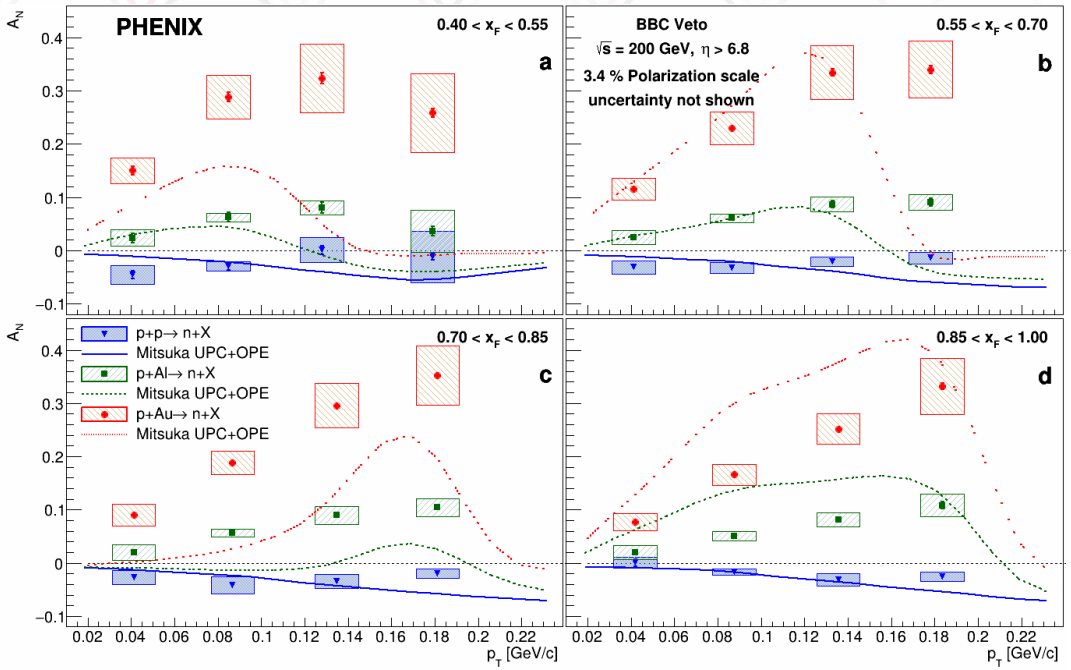
BBC correlated (hits in both BBCs required)

- BBC correlation enhances hadronic interactions → p+p and p+Al asymmetries nearly identical, p+Au slightly smaller (some UPC contribution still present)
- Qualitatively consistent with the nearly linear behavior predicted from OPE model



BBC Veto (no hits in either BBC)

- BBC Veto enhances UPC contributions:
  - p+p asymmetries much smaller (but still barely negative)
  - p+Al and p+Au asymmetries larger, reaching up to 40%
- UPC related asymmetries increasing with P_T, again suggestion of a reduction at higher P_T at low x_F
- Similar rough agreement of model calculations



Summary

- Explicit x_F and P_T dependence of very forward neutron asymmetries studied in p+p, p+Al and p+Au collisions
- Generally weak x_F dependence of asymmetries while magnitude increasing with P_T
- Interplay between hadronic and UPC interactions studied using correlation studies:
  - BBC tagged asymmetries enhance hadronic interaction and show negative, nearly linear x_F dependence predicted by OPE model
  - BBC vetoed asymmetries enhance UPC interaction and show even larger positive p+A asymmetries, rough model agreement likely limited by included resonances
- Studies of p+p asymmetries at other collisions energies (→different reach in P_T) ongoing

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