Transverse Single Spin Asymmetry for Forward Neutrons at PHENIX

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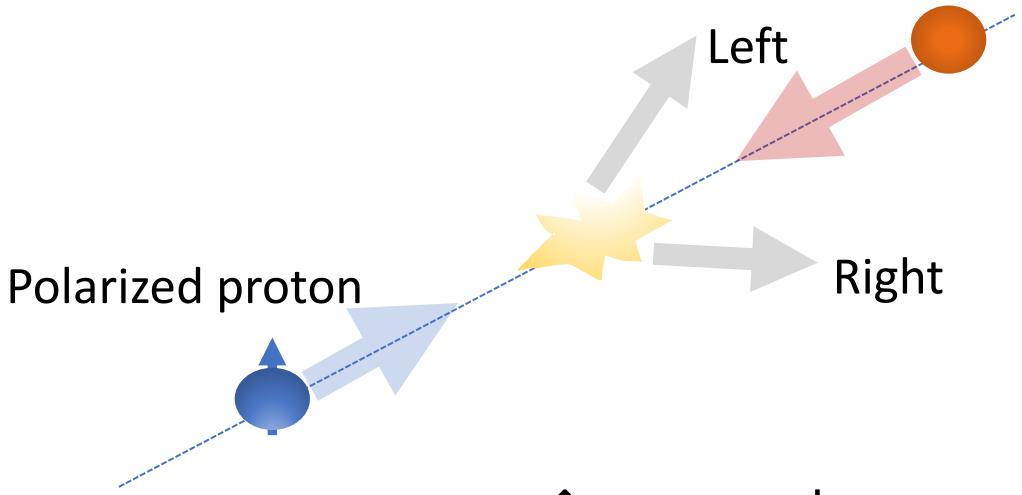
Center for Frontiers in Nuclear Science

Stony Brook University

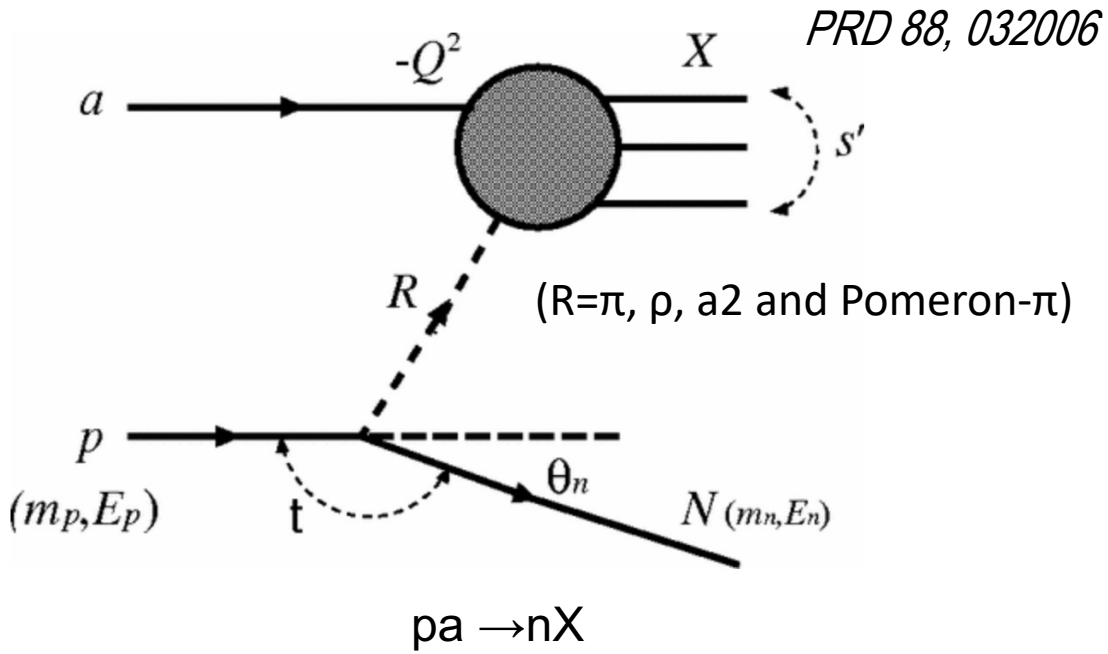
Outline

- Neutron Transverse Single Spin Asymmetry
- Neutron Detection at PHENIX at RHIC
- Measurements from PHENIX
  - Early measurements TSSA for forward neutrons (200 GeV)
    - In $p^{\uparrow}$+p and $p^{\uparrow}$+A systems
    - p_T dependence for $p^{\uparrow}$+p
  - Recent measurement of p_T and x_F dependence of TSSA $p^{\uparrow}$+p, $p^{\uparrow}$+Al and $p^{\uparrow}$+Au
  - Energy dependence (62, 200, 500 GeV)
- Summary

Forward Transverse Single Spin Asymmetry



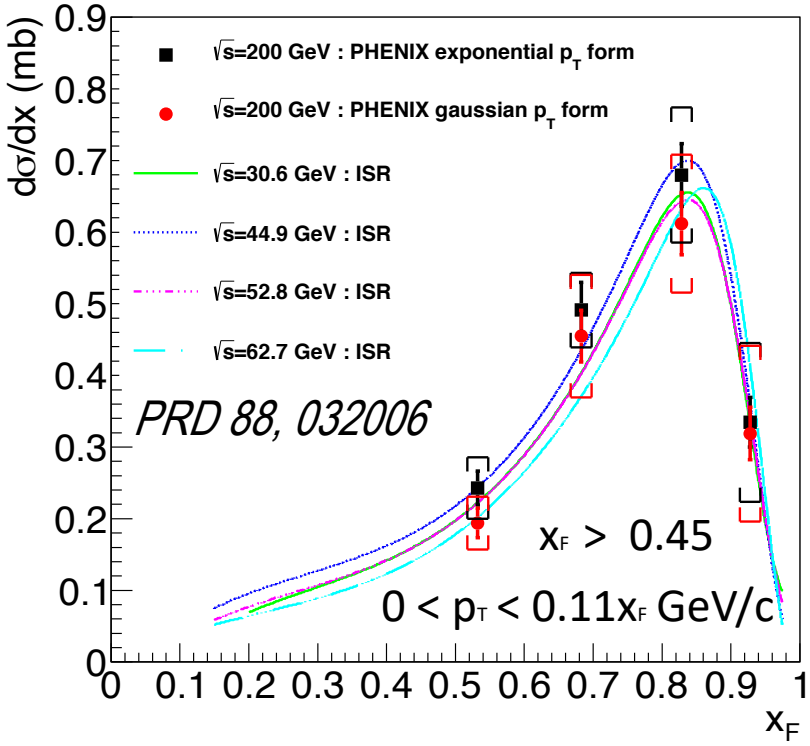
$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$



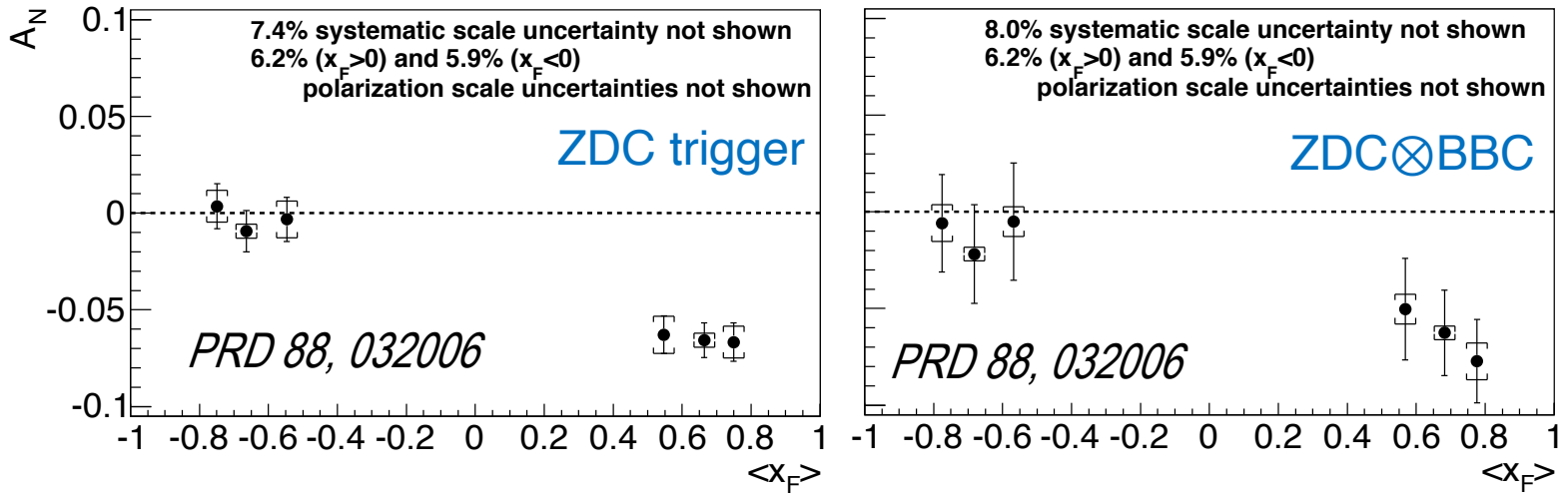
RHIC measurements have shown a large forward neutron A_N

A_N in p↑+p is produced by interference of π^+ and and a_1 amplitude (Regge theory)

Large asymmetry for a single spin in p↑+p scattering



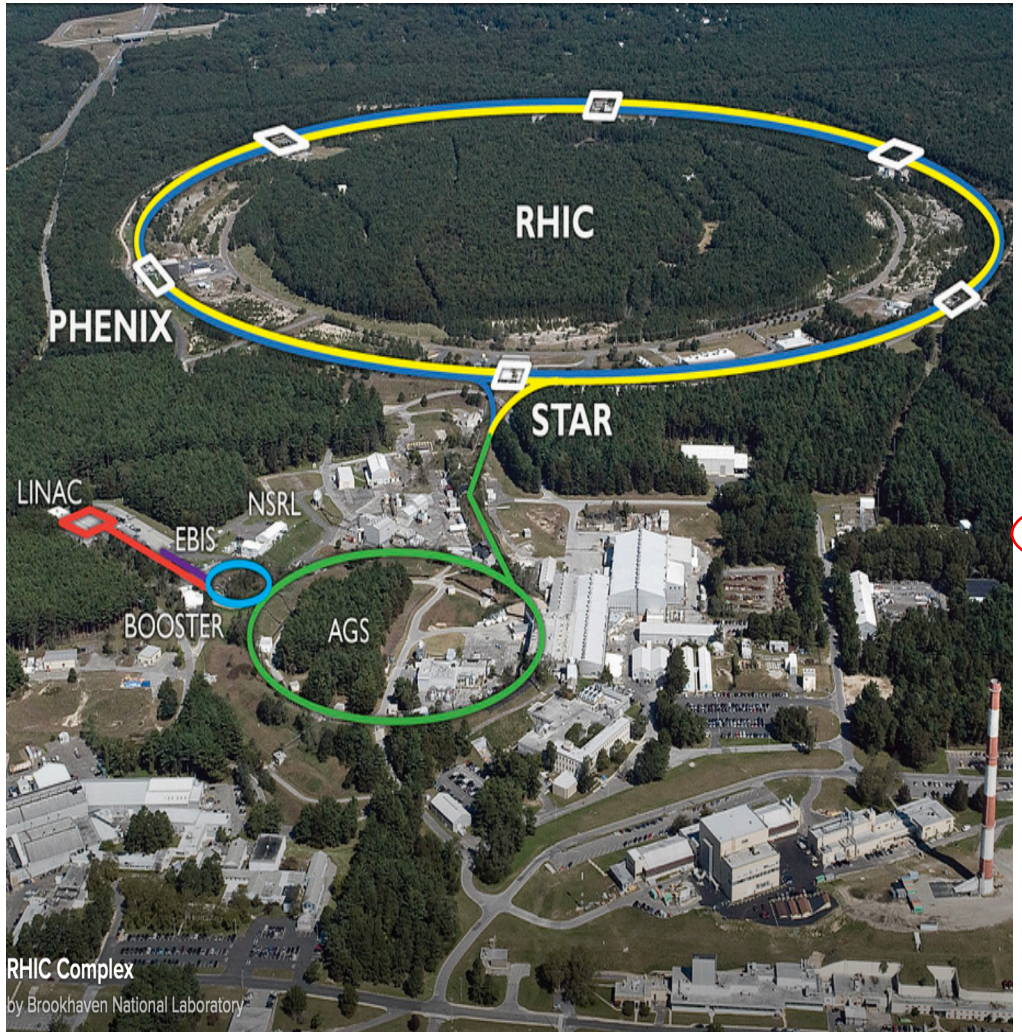
The cross sections for large x_F neutron production for p↑+p collisions are described by a pion exchange mechanism.



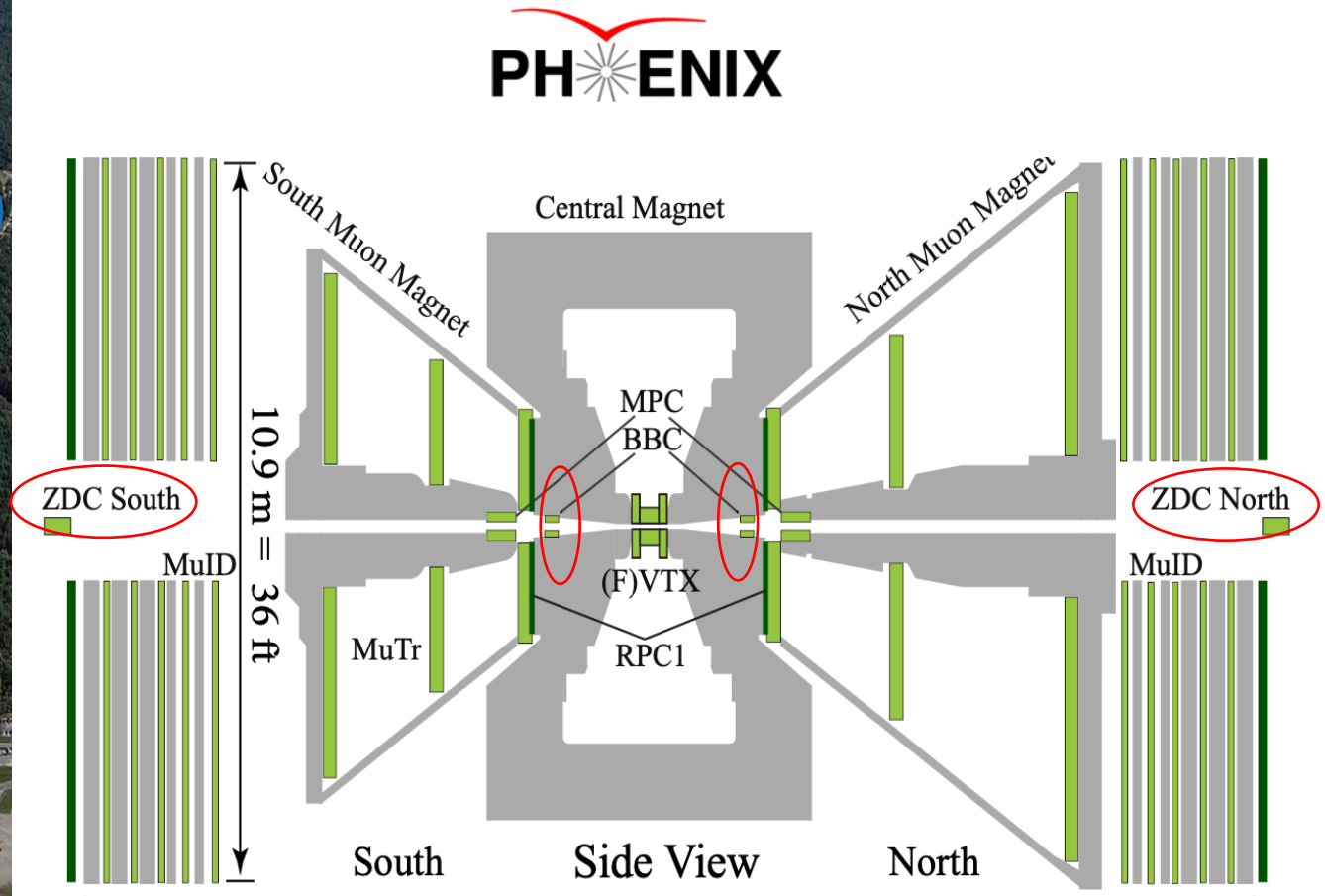
The observed asymmetry expected to appear due interference between the spin-flip amplitude due to the pion exchange and nonflip amplitudes from all Reggeon exchanges

- ✓ need to be understood
- ✓ need to explicitly measure the p_T dependence

Polarized RHIC collider and the PHENIX detector

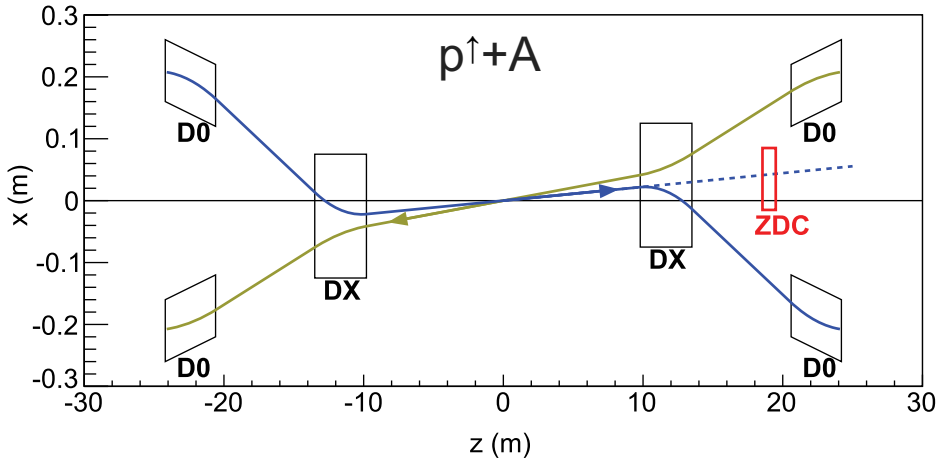


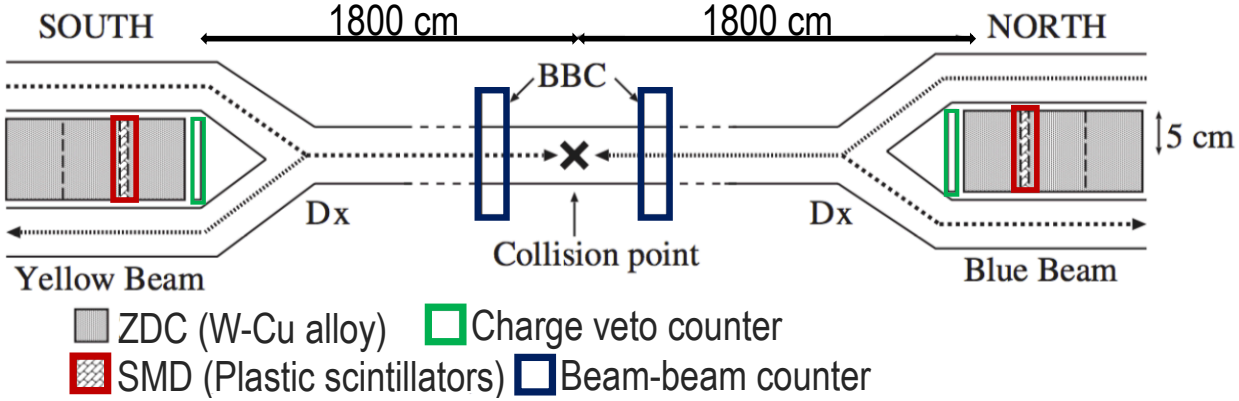
Relativistic Heavy Ion Collider (RHIC) - BNL



Side view of the PHENIX detector system at RHIC

Zero Degree Calorimeter (ZDC) : neutron detection





For p↑+A collisions where due to the different rigidities there is a beam angle and in p+p it is straight.

ZDC : 3 modules, 10x10 cm^2, 1.7 interaction length/module, 51 radiation length

SMD : 7strips for x-position, 7strips for y-position. $\boldsymbol{\sigma}_{pos}$ = 1cm

(ZDC's energy resolution is about 20% for 100 GeV neutrons)

Neutron Selection

- Required E_{ZDC2}/E_{Tot} > 3%(photon elimination)

  $E_{Tot} = E_{ZDC1} + E_{ZDC2} + E_{ZDC3}$

  ZDC total energy cut: 40 GeV to 120 GeV

- Acceptance cut: 0.5 cm < *r* < 4.0 cm

  0.5 cm to counteract left-right ambiguity

  σ_{pos} of SMD ~ 1.0 cm.

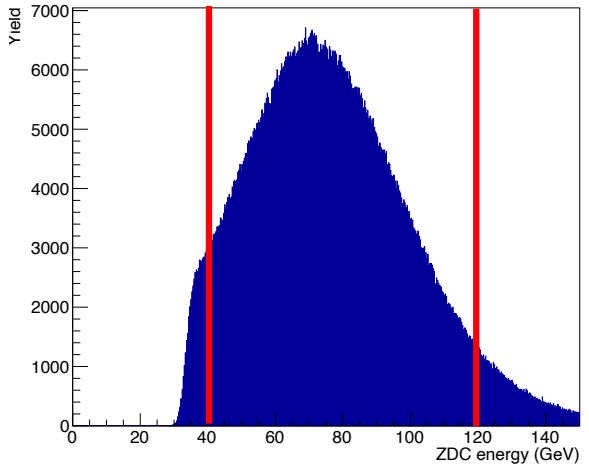
  4.0 cm used to reduce detector edge effect

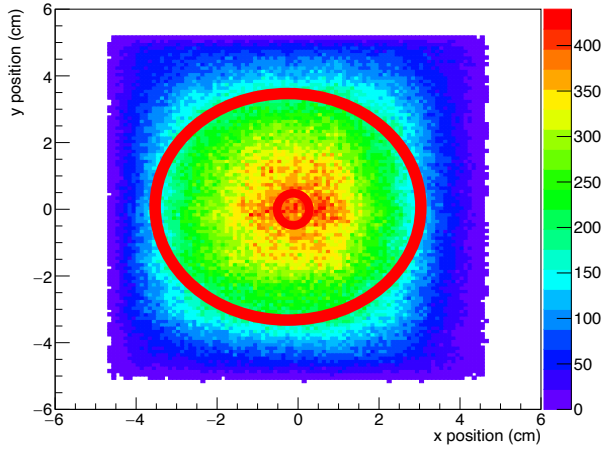
- SMD threshold cut

  Photon rejection

  Required *Nx* and *Ny* > 1 (above 0.003 GeV)

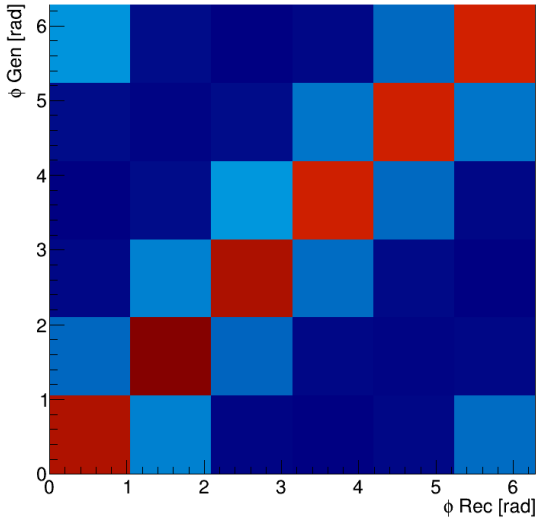
Benard : Workshop on forward physics and QCD wit LHC, EIC and cosmic rays (2021)

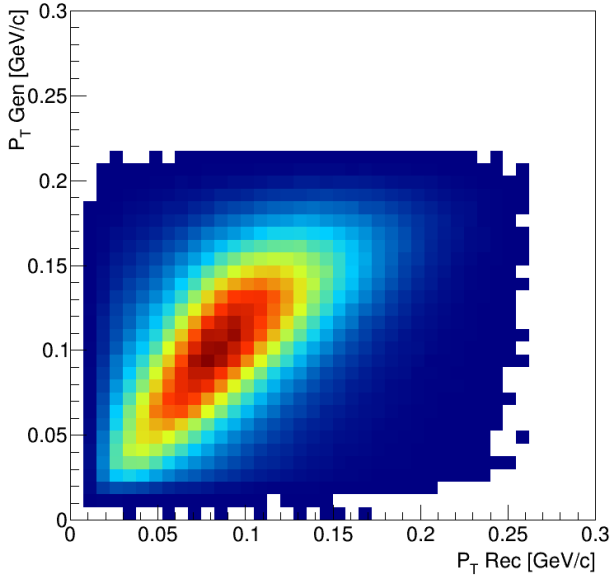


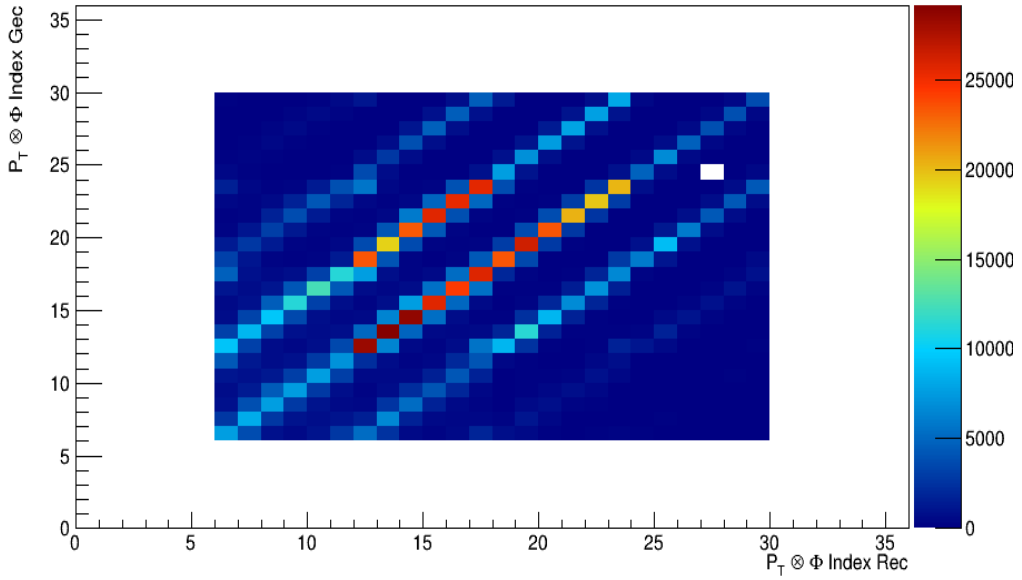


Unfolding : Actual A_N from measured

Benard : Workshop on forward physics and QCD wit LHC, EIC and cosmic rays (2021)



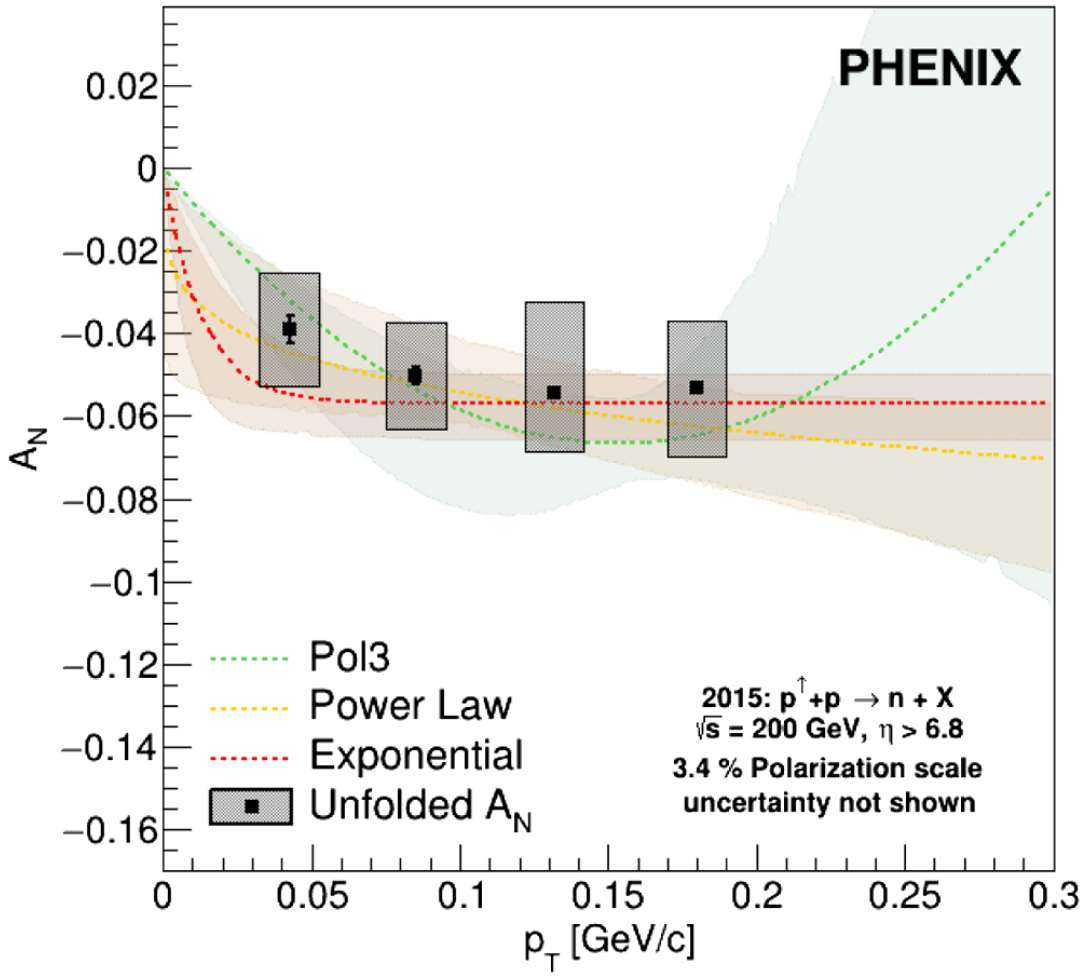




- ZDC smearing response matrix was obtained as generated (Gen) p_T–ϕ index versus reconstructed (Rec) p_T-ϕ index ($I=p_T(i) * \phi_{nbin} + \phi_i$)
- Executed unfolding via TSVD in CERN's ROOT using weighted smearing matrices : Reweighting done using : Polynomial function(Pol3), Power law, Exponential
- Composition, energy, momentum, etc. for forward region not well understood. Sampled 5 MCs to gauge impact on the unfolded asymmetries DPMJet, PYTHIA6(8), OPE, UPC

A_N as a function of the true transverse momentum

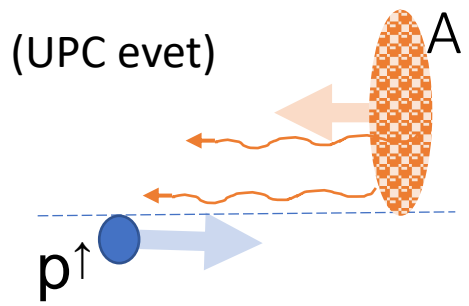
PHYSICAL REVIEW D 103, 032007 (2021)



- Data points are **unfolded A_N obtained** from average over all parameterizations
- Boxes are total uncertainties arising from the unfolding, MC generators and parameterizations

- The absolute values of the asymmetries are negative with leveling of higher transverse momenta
- MC reweighting exercise no substantial differences between the different MC generators have been seen.

A_N in $p^{\uparrow}$+p, $p^{\uparrow}$+Al and $p^{\uparrow}$+Au collisions at $\sqrt{s}$= 200 GeV



Phys. Rev. C **95**, 044908

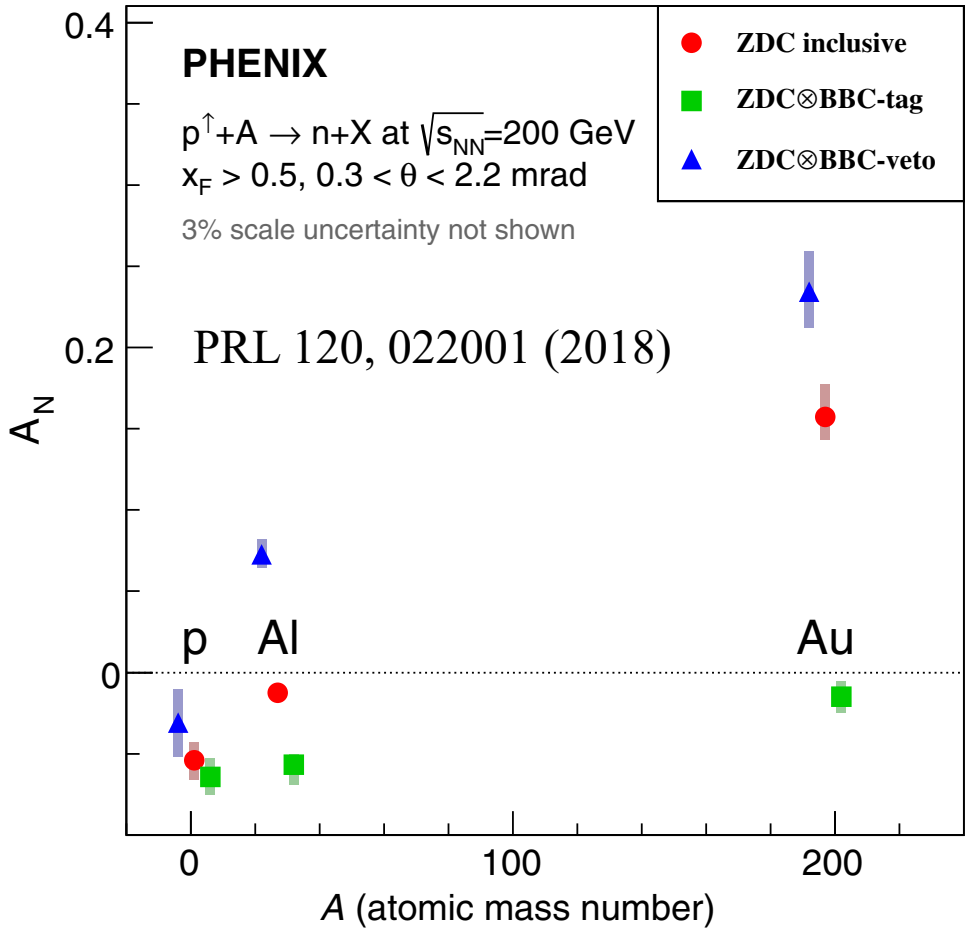
- ✓ $\gamma^*p^{\uparrow}$ **interaction** depends on the azimuthal angle of the scattered neutrons relative to the proton polarization
- ✓ Large A_N for forward neutrons
- ✓ UPCs : comparable cross section with the hadronic interactions at forward rapidity and **strongly depends on the charge of nuclei**.

- Neutrons were detected either **inclusively** or in **(anti-)correlation with detector activity (BBC)** related to hard collisions

- A_N observed with **transverse momentum (p_T)** of the neutron as well as its **longitudinal momentum fraction (x_F)**

(Understanding interplay of different mechanisms : hadronic interactions or ultra-peripheral collisions, UPC)

Forward neutrons for p↑+A systems



Unexpectedly strong A dependence in A_N with +ve value (Au)

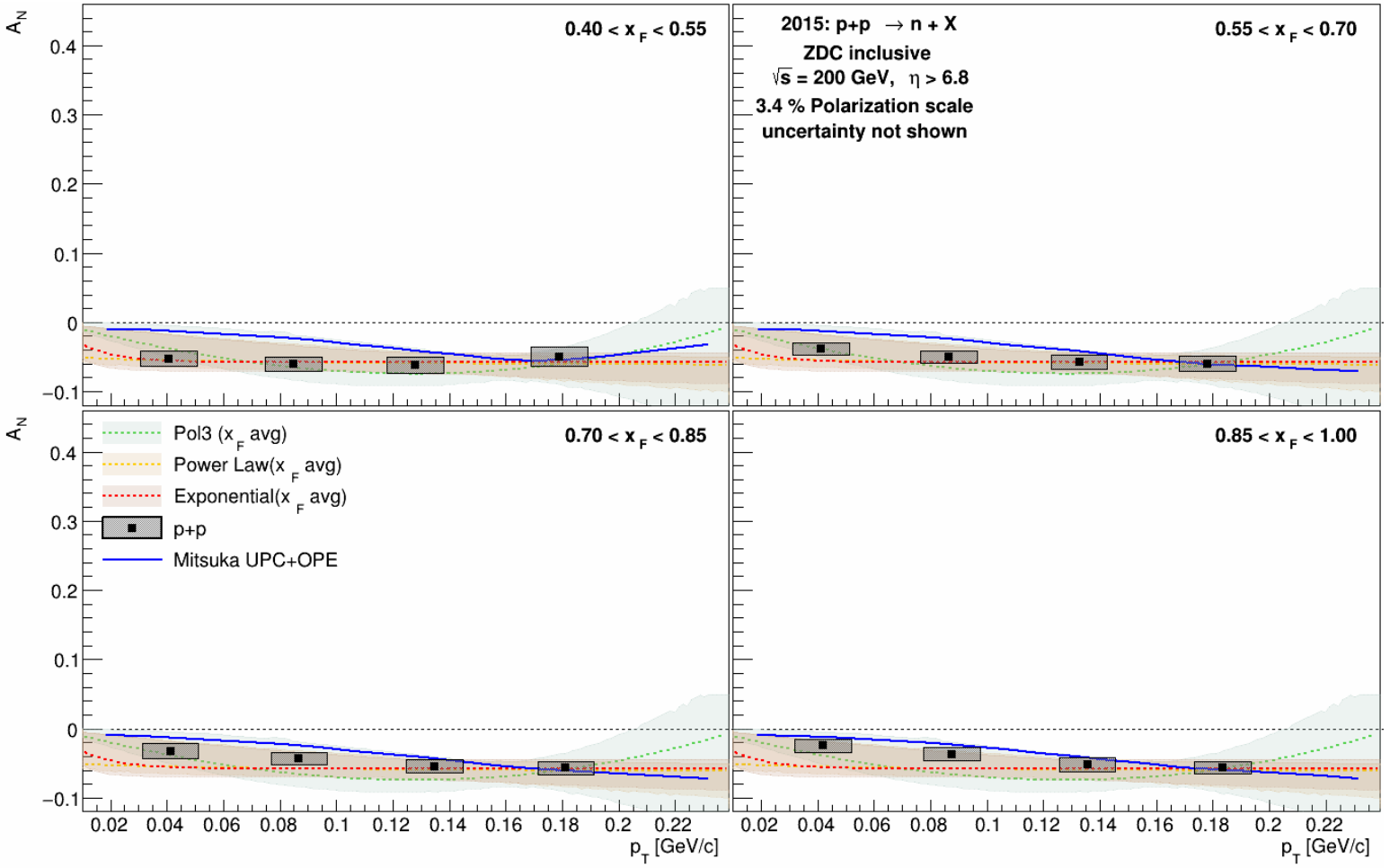
- ✓ ZDC ⊗ BBC-tag sample may be explained by the conventional pion and a1 -Reggeon interference mechanism
- ✓ the ZDC ⊗ BBC- veto triggered sample could be explained by contributions from interference with EM amplitudes

A **distinctly different behavior of A_N in two oppositely trigger-enhanced data sets** : a contribution of EM interactions and diffractive scattering need to be well understood**.**

Inclusive

Inclusive p↑+p collisions

arXiv:2110.07504

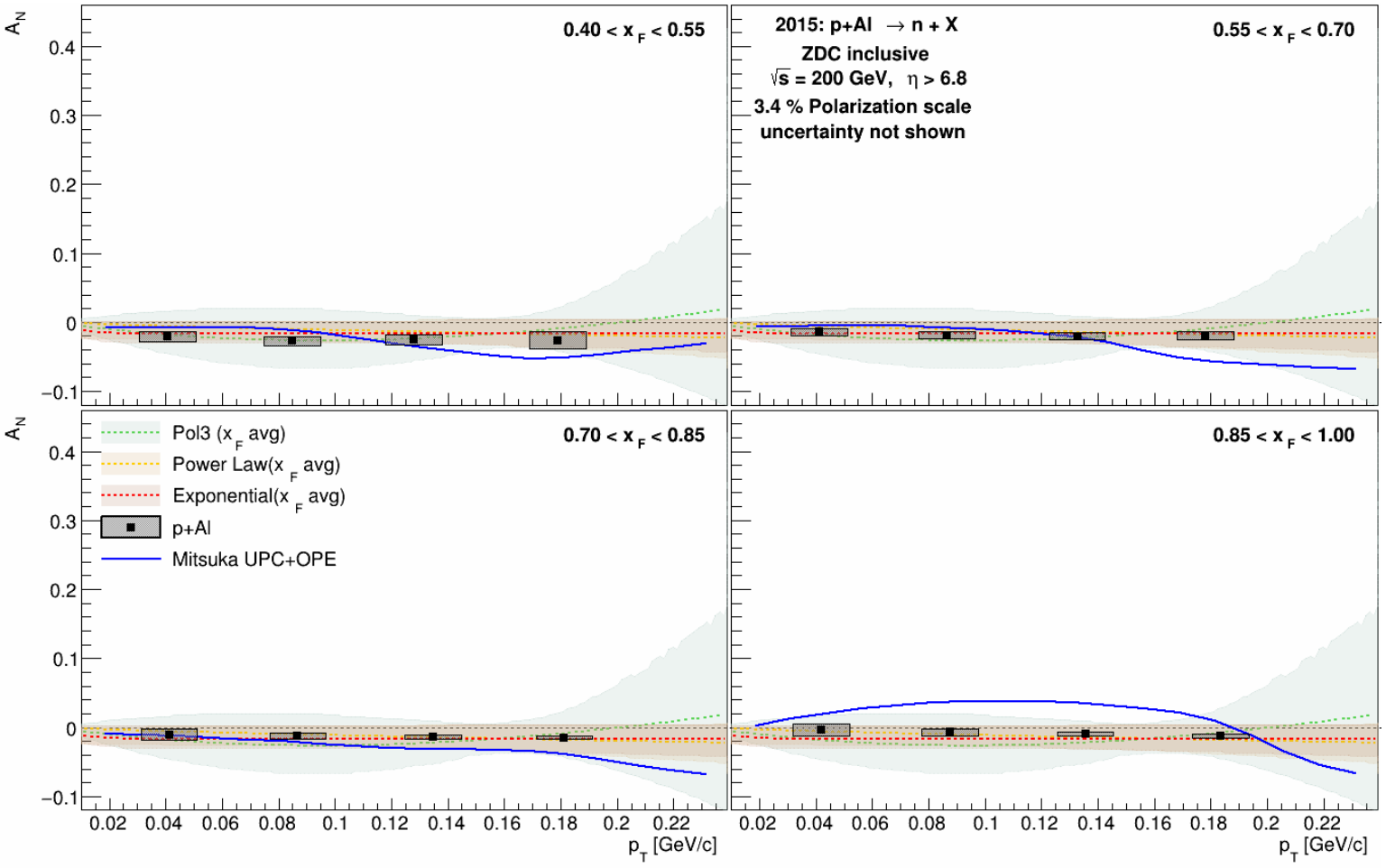


- ✓ Negative A_N with slightly increasing magnitude with increasing p_T (except for the lowest x_F).
- ✓ In p+p the interactions dominated by the hadronic processes and hence the theory calculations are mostly negative and increasing in magnitude.

Gaku Mitsuka - theory calculations
Phys. Rev. C **95**, 044908

Inclusive p↑+Al collisions

arXiv:2110.07504



- ✓ A_N are slightly negative and are often consistent with zero
- ✓ UPC (+ve) and hadron (-ve) contributions cancel out to a large part
- ✓ The theory calculations are again describing the data mostly well

Gaku Mitsuka - theory calculations
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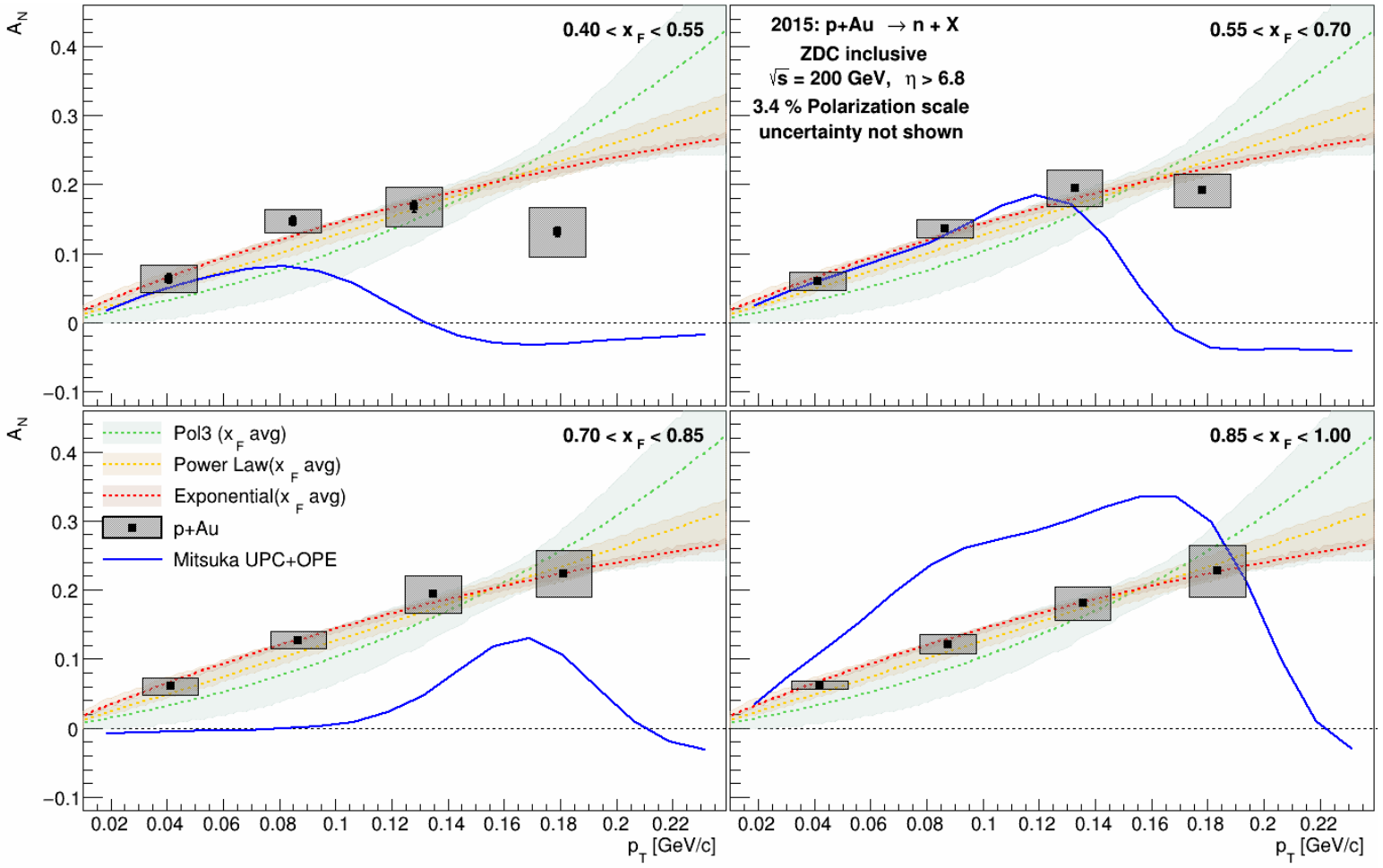
Inclusive p↑+Au collisions

arXiv:2110.07504



- ✓ A_N become positive
- ✓ A_N rising with increasing p_T in all x_F and reach more than 20%
- ✓ Lower x_F there is an indication of the asymmetries saturating or even falling again
- ✓ The Drop qualitatively also seen in the theory predictions (A_N drop : moving away from the Δ resonance)

Gaku Mitsuka - theory calculations
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BBC Tag

Generally, **a large fraction of hadronic events fire the BBCs** as *there is activity in a wide range of rapidities.*

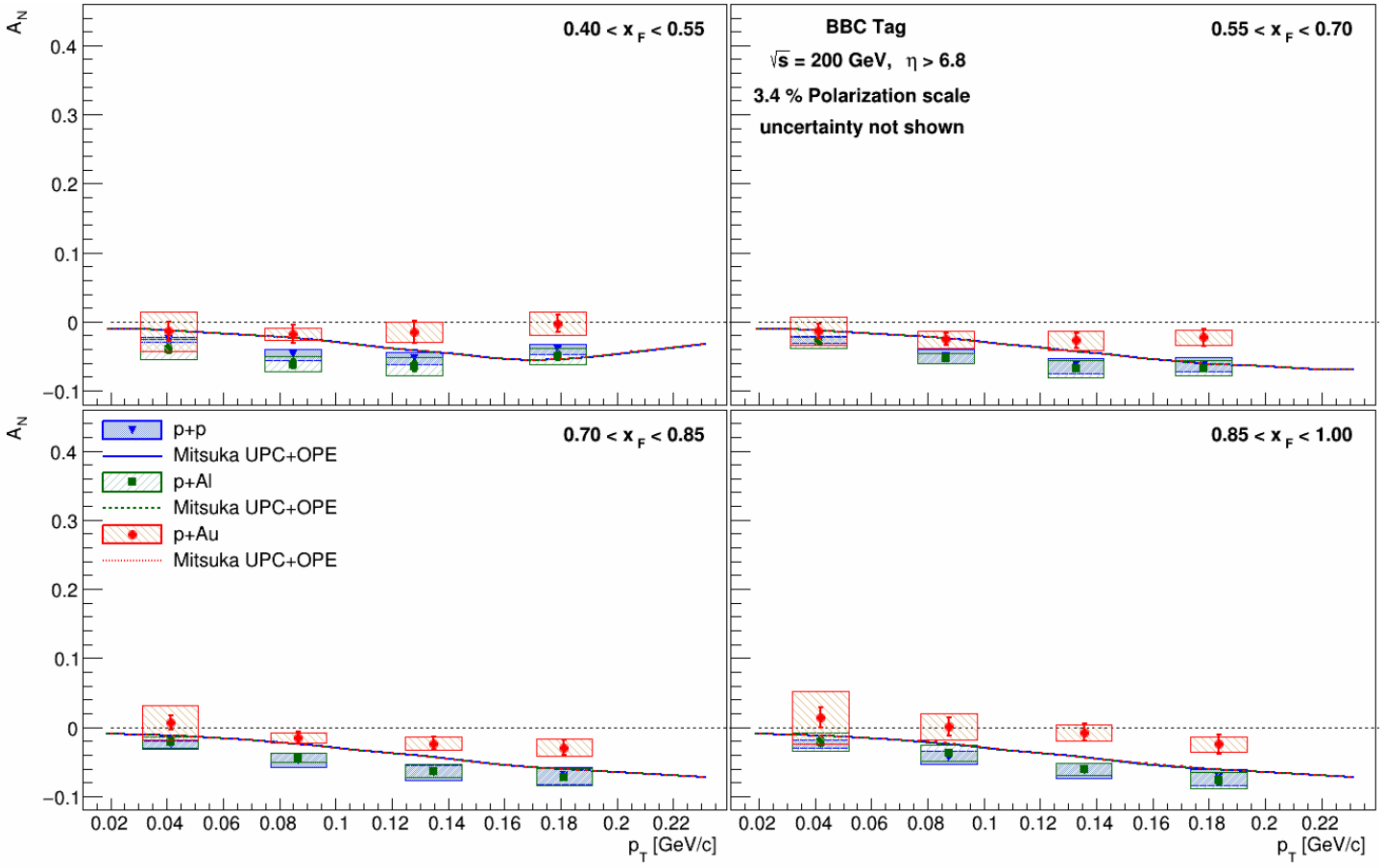
BBC Veto

UPC interactions, where *photons at relatively small scales only excite the proton to a Δ resonance or another nucleon states very little activity other than the decay products of these states is expected* : **UPC events do not show any activity in the BBCs.**

(Would be talking about two contributions **- hadronic** and **UPC**)

BBC-tagged for p↑+p, p↑+Au and p↑+Al collisions

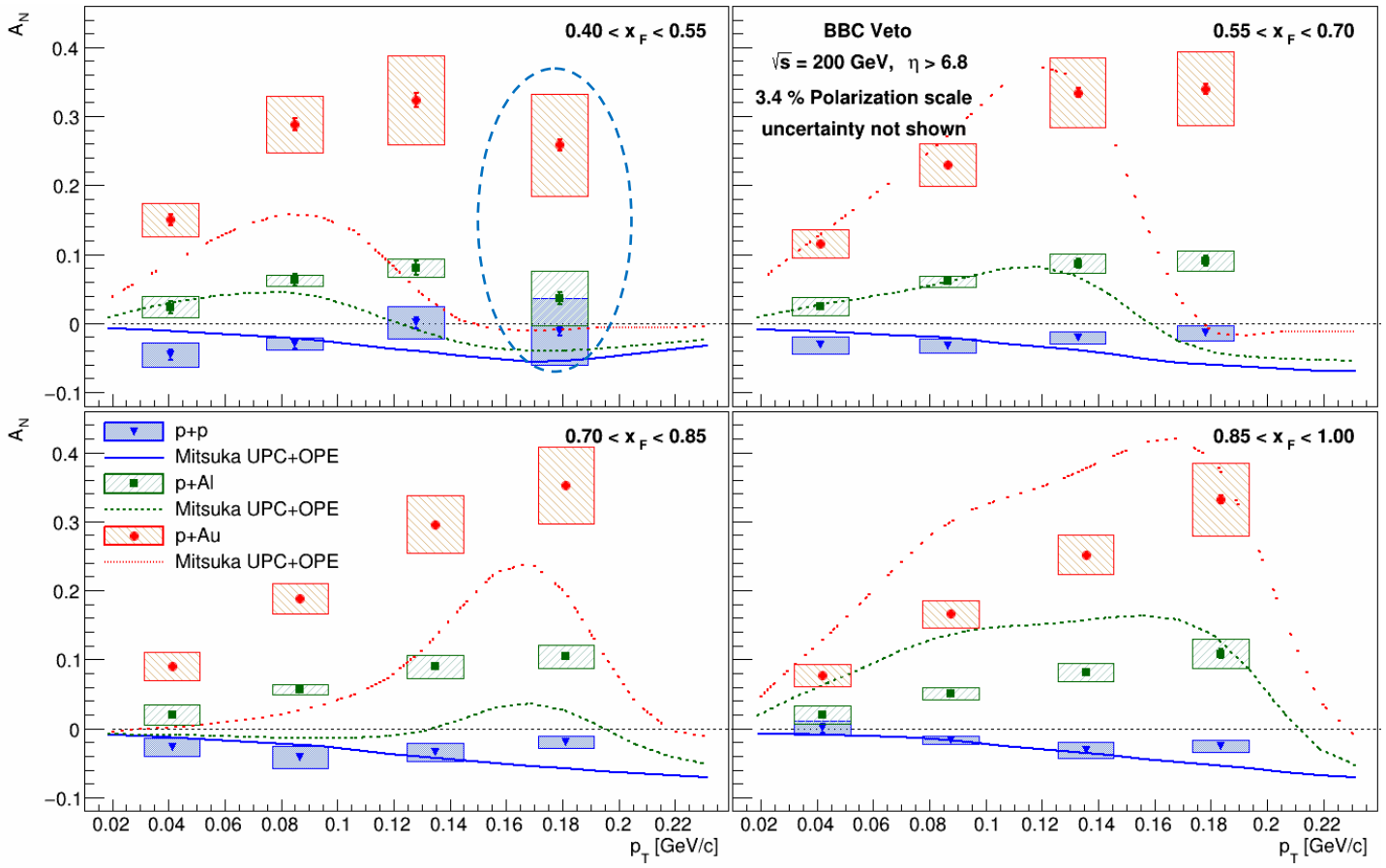
arXiv:2110.07504



- ✓ A_N for **p↑+p** and the **p↑+Al** are negative : increasing in magnitude more than the inclusive neutron asymmetries (reach to -10%)
- ✓ In **p↑+Au** collisions the asymmetries are generally smaller and only are slightly negative at intermediate x_F

BBC-vetoed for p↑+p, p↑+Au and p↑+Al collisions

arXiv:2110.07504



- ✓ **p↑+p** : the two contributions mostly cancel each other ($A_N \simeq 0$)
- ✓ **p↑+Al** : the larger UPC contribution now switches the sign of the A_N (to +ve) with rising in transverse momentum (reaching up to +10%)
- ✓ **p↑+Au** : the UPC contributions strongest (A_N > +30%)

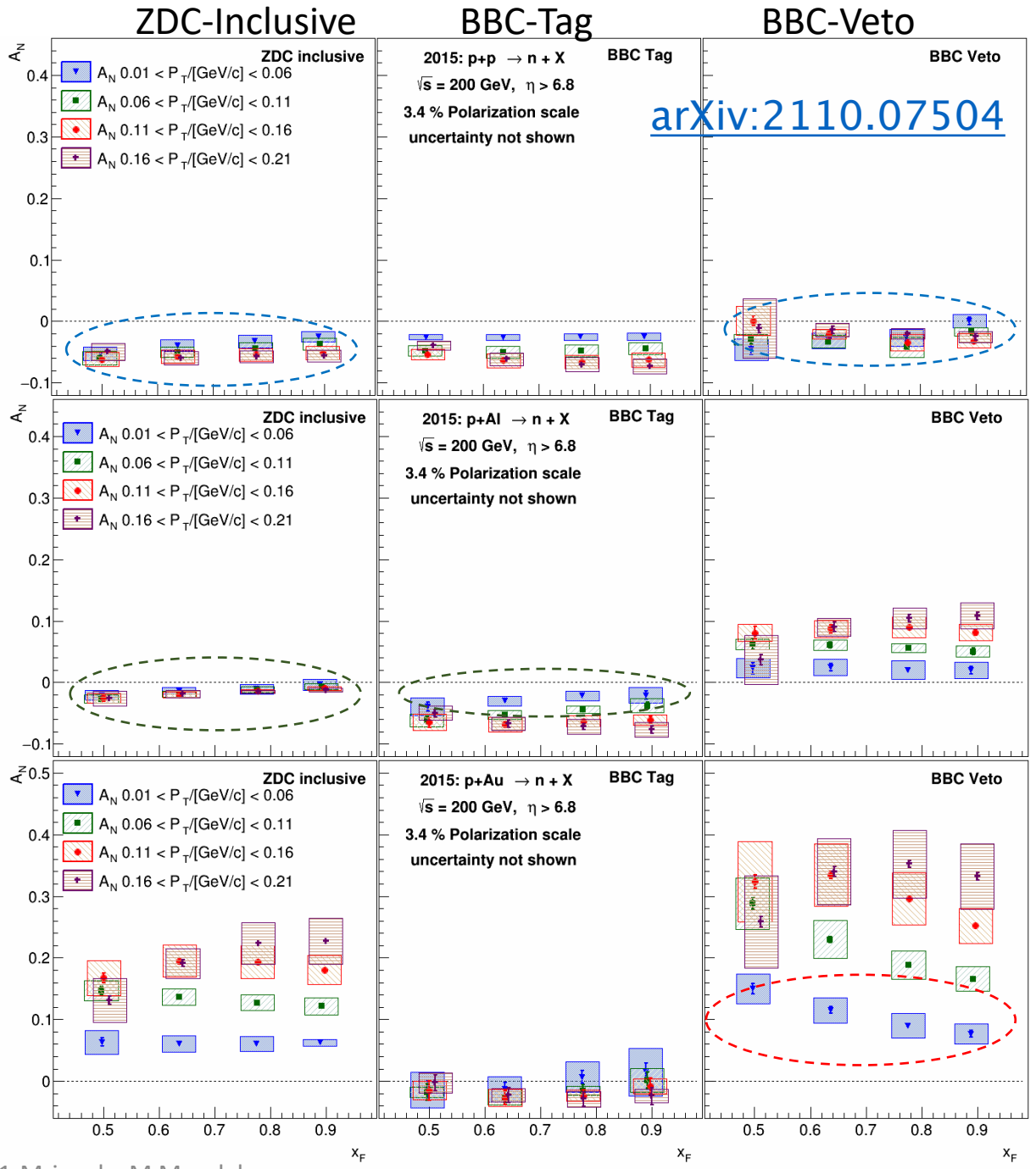
drop of the asymmetries at high p_T at lower x_F p↑+Al and p↑+Au

A_N with x_F

(very little dependence in general)

Few exceptions where A_N becomes smaller with increasing x_F

- ✓ **$p^{\uparrow}$+p** : inclusive and for BBC vetoed
- ✓ **$p^{\uparrow}$+Al** : inclusive and BBC tagged small p_T bin (UPC events become stronger with x_F)
- ✓ **$p^{\uparrow}$+Au** :BBC-vetoed at low p_T



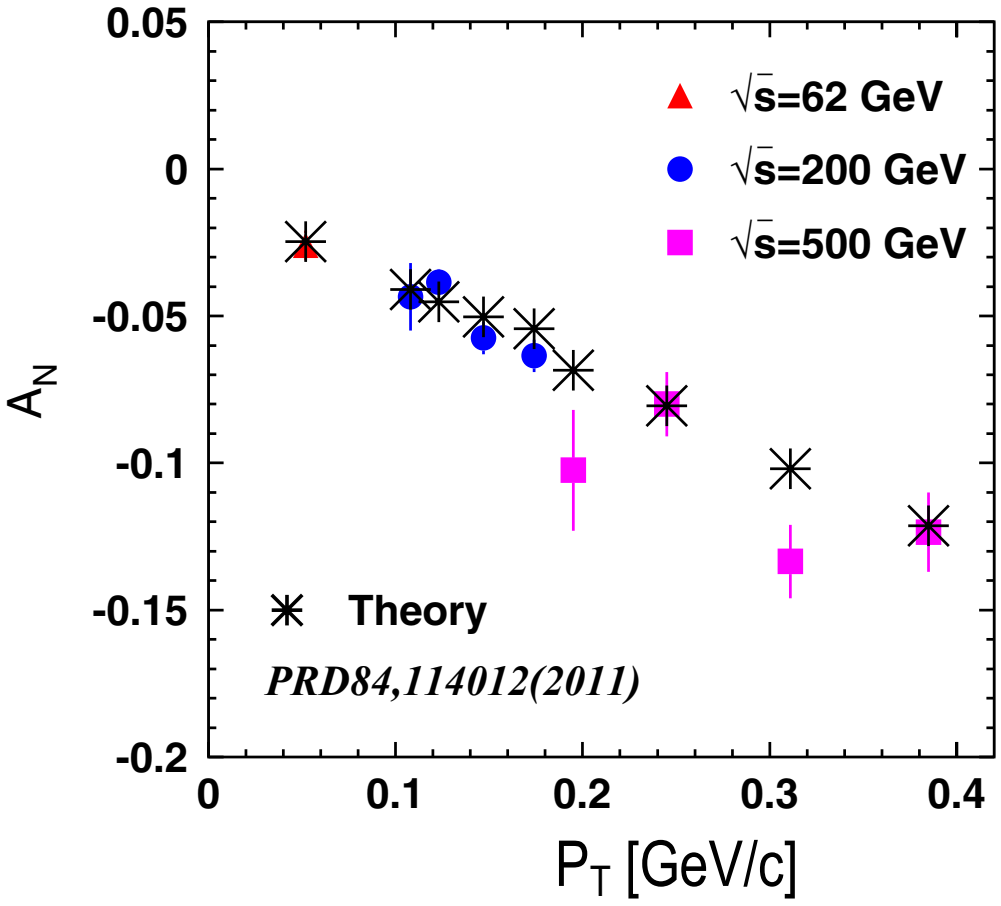
arXiv:2110.07504

$p^{\uparrow}$+p

$p^{\uparrow}$+Al

$p^{\uparrow}$+Au

A_N for various collision energies $p^{\uparrow}$+p



- ✓ Preliminary data points for 62GeV 500GeV A_N exists
- ✓ In the process to complete the analysis : intergraded over p_T
- ✓ 500 GeV may extend relatively larger p_T region compared to 500 GeV

Summary

- The origin of Large Forward Transverse Single Spin Asymmetry measured at PHNIX is needed to be well understood.
  - Different sign asymmetry in $p^{\uparrow}$+A collisions appears to be from UPC contribution.
  - Unfolded A_N for $p^{\uparrow}$+p @200GeV are consistent with an increase with transverse momentum but show an indication of leveling off at higher transverse momenta (UPC contribution is limited in this p_T region)
- A_N is shown for $p^{\uparrow}$+p, $p^{\uparrow}$+Al and $p^{\uparrow}$+Au at 200GeV in correlations BBC to separate out hadronic and UPC contributions:
  - Hadronic processes : A_N is –ve and increase with p_T to up to 10% with hardly any x_F dependence
  - UPC: A_N is +ve and reach more than 30% of magnitude with p_T. For low x_F a subsequent decrease at high p_T is consistent with the model calculations which originate from the different nucleon resonances contributing.
- To further understand asymmetries beyond current results, study of A_N at different energies will also be performed.

Results from p+p 200GeV

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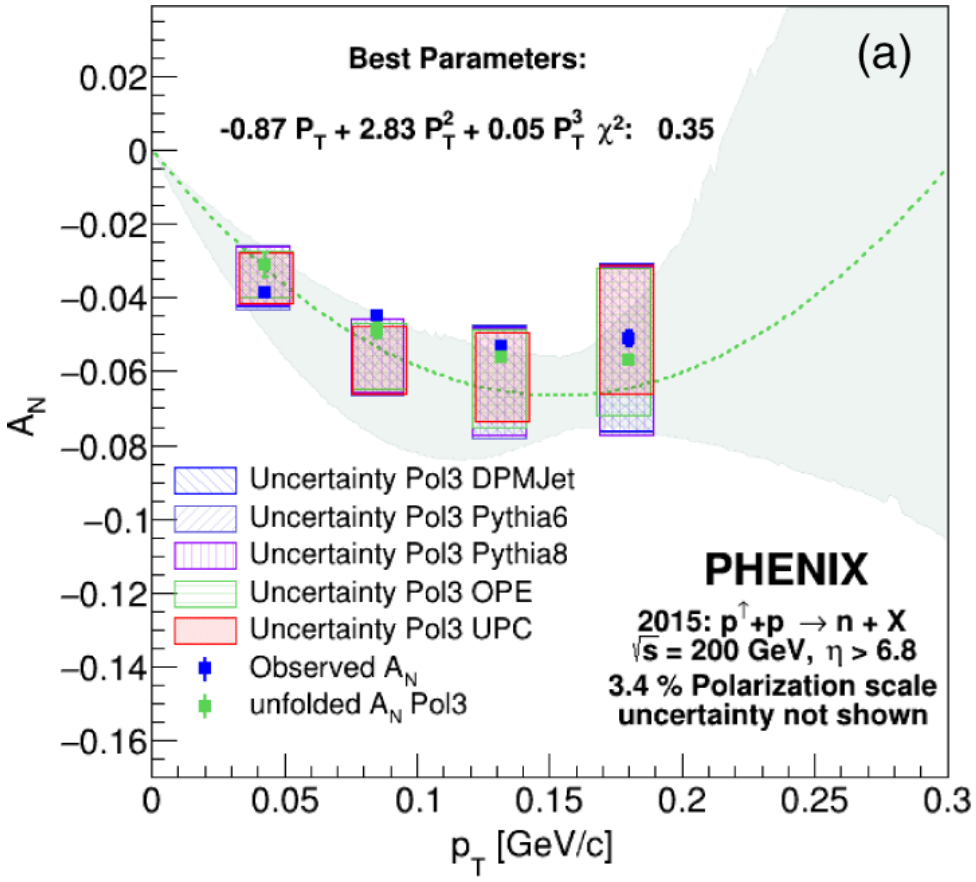
Unfolded A_N based on Pol3



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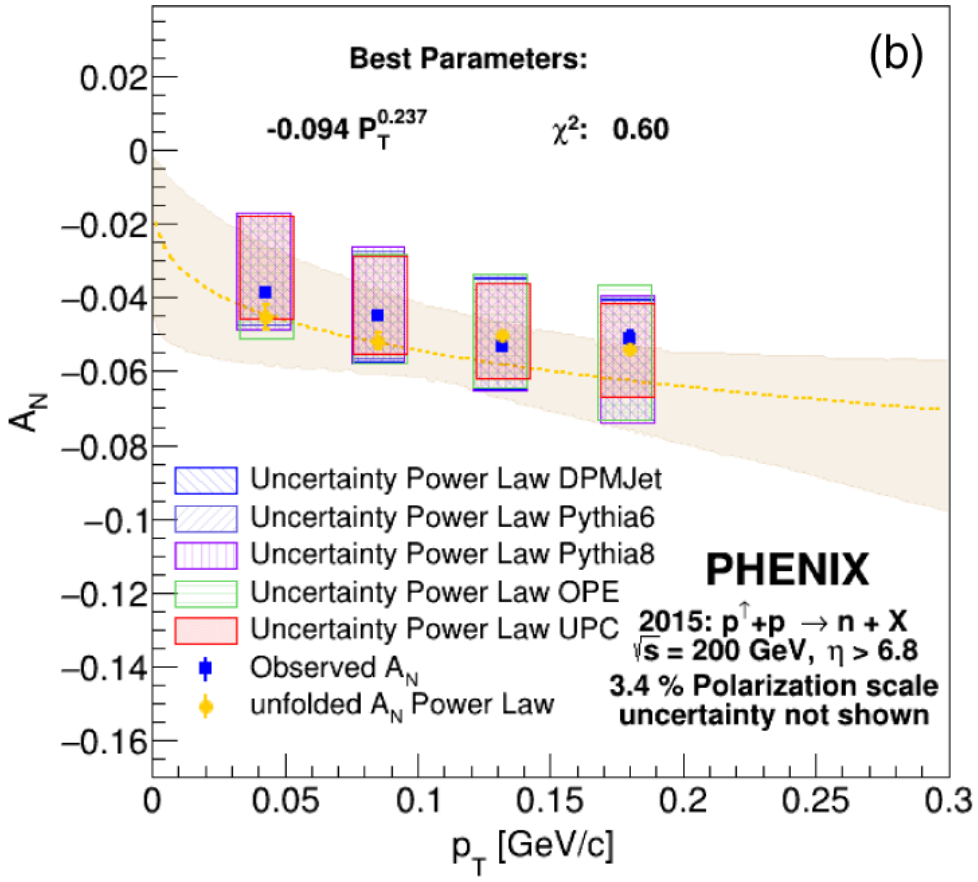
The shaded regions represent the regions where the χ^2 is below 10

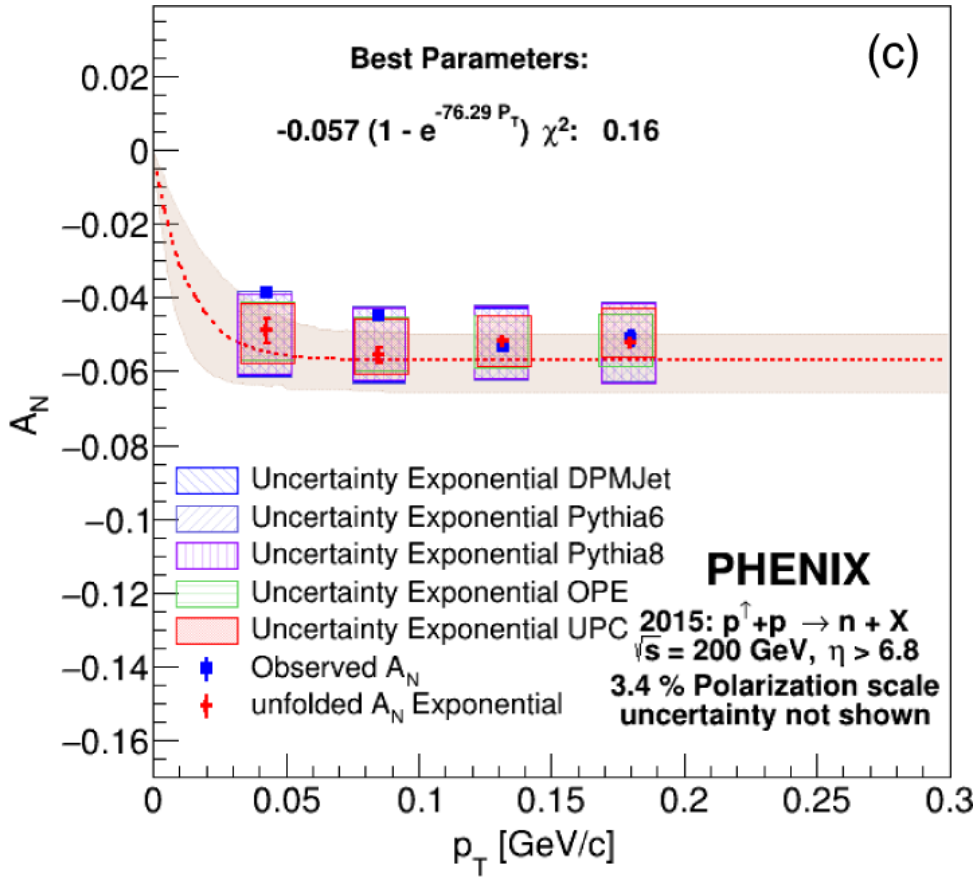
The dashed lines represent the best matching parametrizations

The rms ranges of unfolded asymmetries are visualized as shaded boxes for the various MC generators

UPC used to sample EM process
(Minimal in p+p & its errors fall within errors from HAD process for PYTHIA6(8), DPMJET and OPE).

Unfolded A_N based-on Power Law and Exponential





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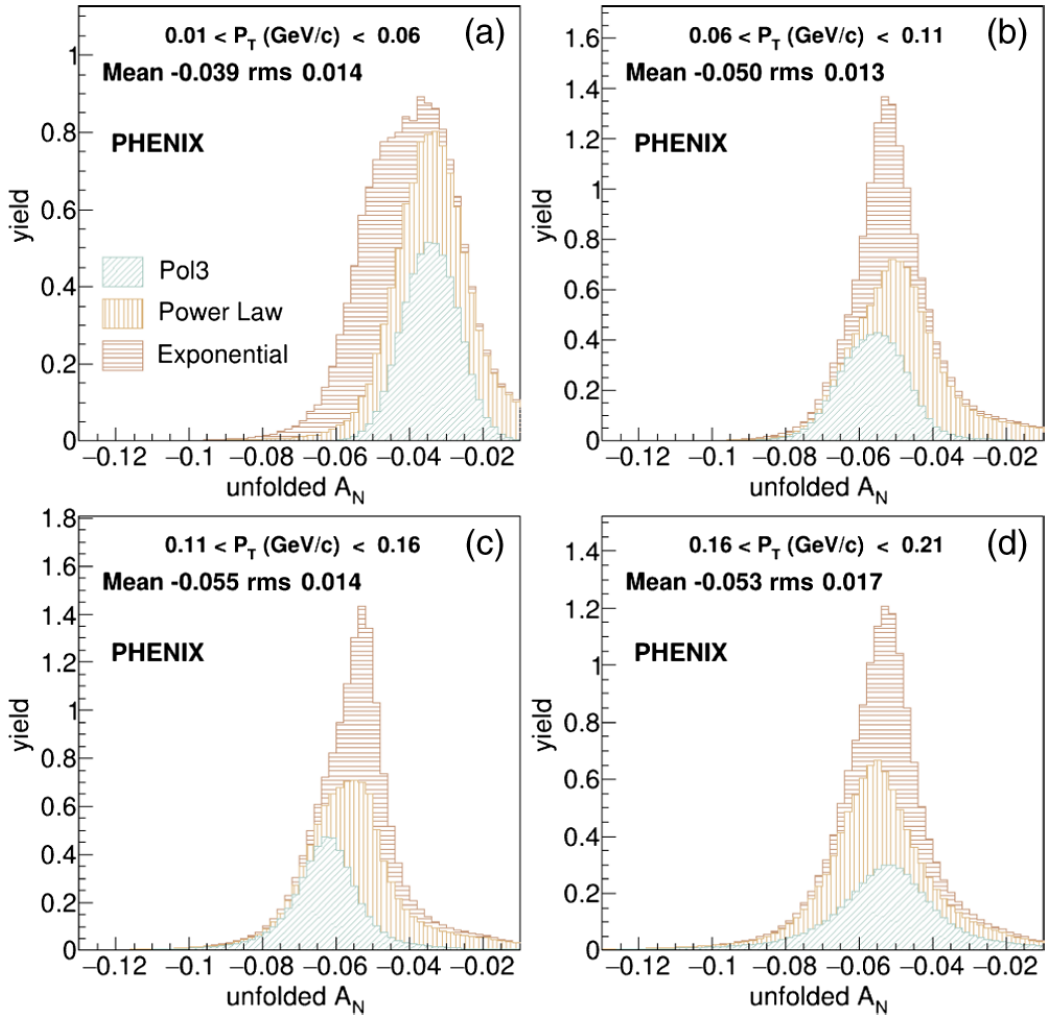
Relative spread of unfolded asymmetries



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All different MC generators distributions have been combined in these panels

"Pol3" power law behavior and exponential have been shown in these figures : the spread of A_N in each p_T bin

The overall central and rms values are also displayed