PHENIX Preliminary Results of Forward Neutron Transverse Single Spin Asymmetry in $p^{\uparrow} + p$ Collisions at $\sqrt{s}$ = 200 GeV

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Outline

Intoduction

- ❑ Forward neutron cross sections
- ❑ Transverse single spin asymmetries

Relativitic Heavy Ion Collider (RHIC)

- ❑ PHENIX detector at RHIC
- ❑ Neutron detection system

Asymmetry Extraction

- ❑ Unfolding procedure
- ❑ Re-weighting procedure

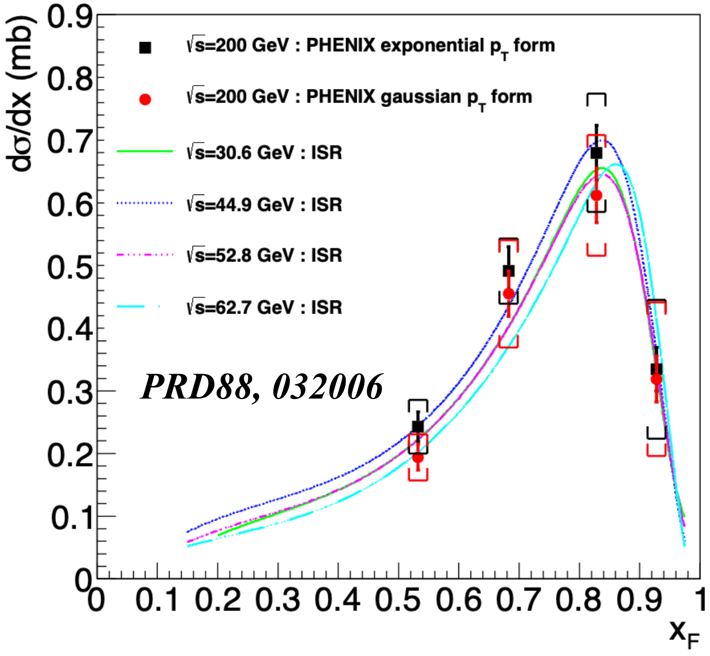
Pleriminary Results

- ❑ Unfolded asymmetry results based on polynomial
- ❑ Unfolded asymmetry results based on power law
- ❑ Unfolded asymmetry results based on exponential
- ❑ Combined result with systematic uncertainties

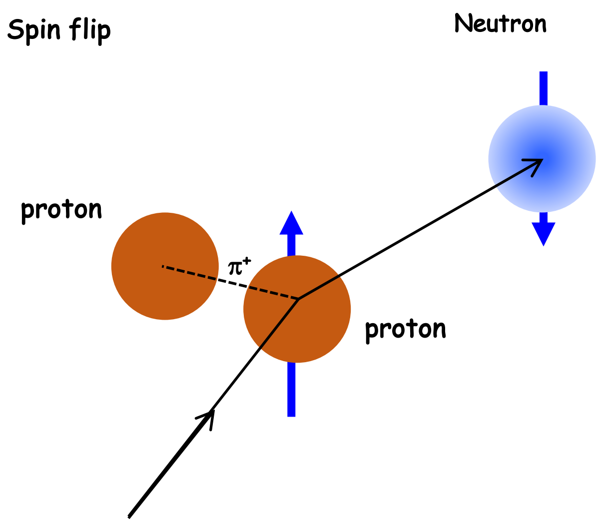
Summary

Introduction – Forward Neutron Cross sections

Forward neutron cross sections in p+p collisions studied at CERN (ISR) and PHENIX (RHIC)



One Pion Exchange (OPE)

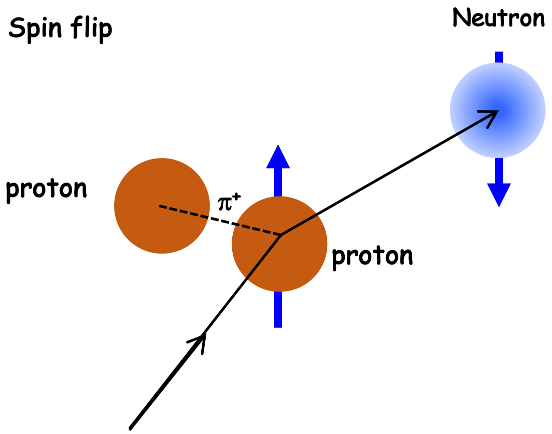


Forward neutron
carries a large fraction of proton energy

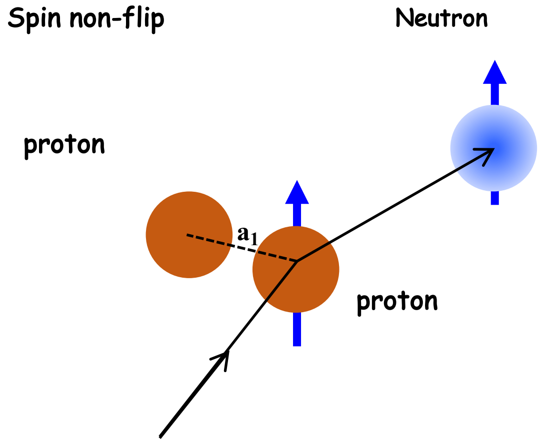
Forward neutron cross section
is well explained by OPE model

Motivation – Forward Neutron Transverse Single Spin Asymmetry (A_N)

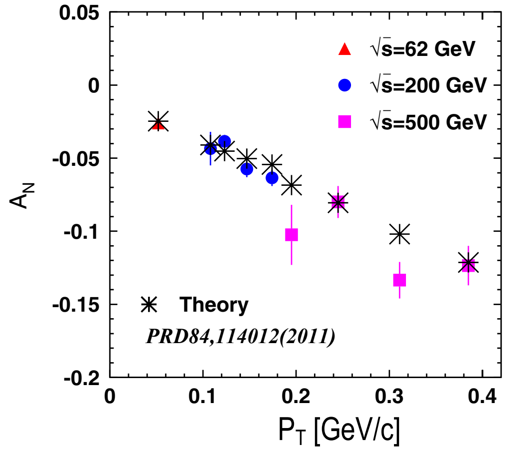
One Pion Exchange (OPE)



Spin parity = 1^+
a_1 (1260) Reggeon



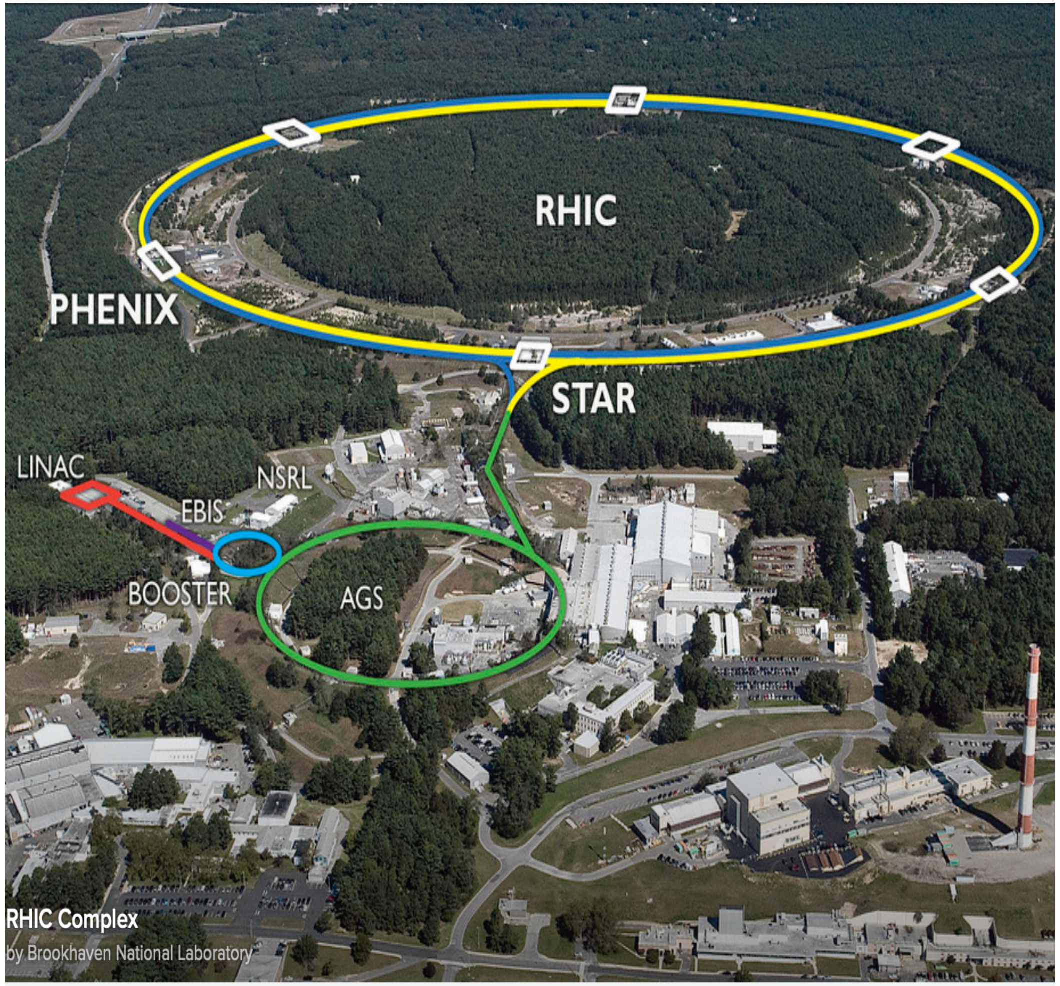
<u>Unpublished</u>, <u>non-unfolded</u>
asymmetry (A_N) data



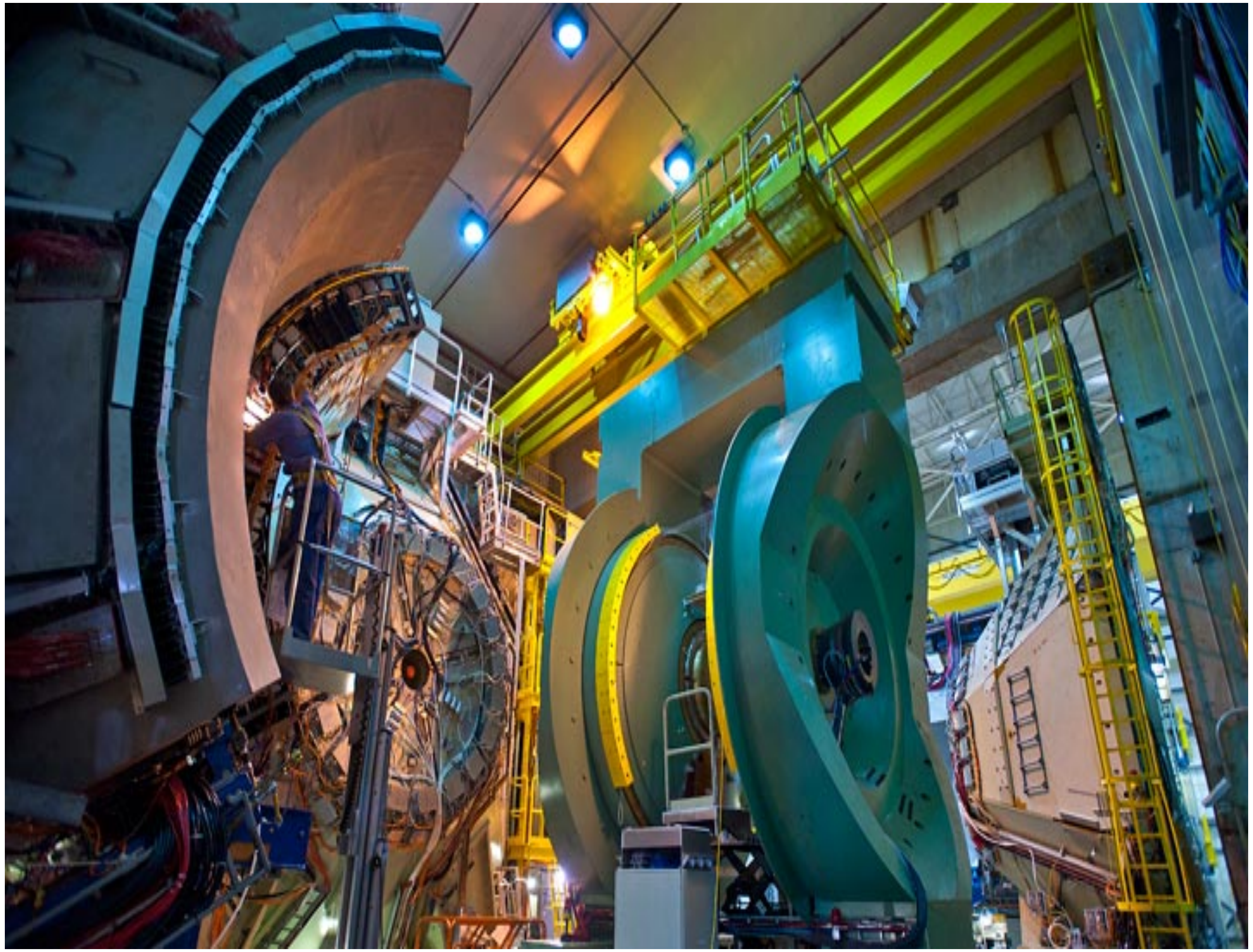
Theory points (*) published

A_N's in p+p are produced by interference of the spin flip and spin non-flip amplitudes (Regge model)

Relativistic Heavy Ion Collider and PHENIX



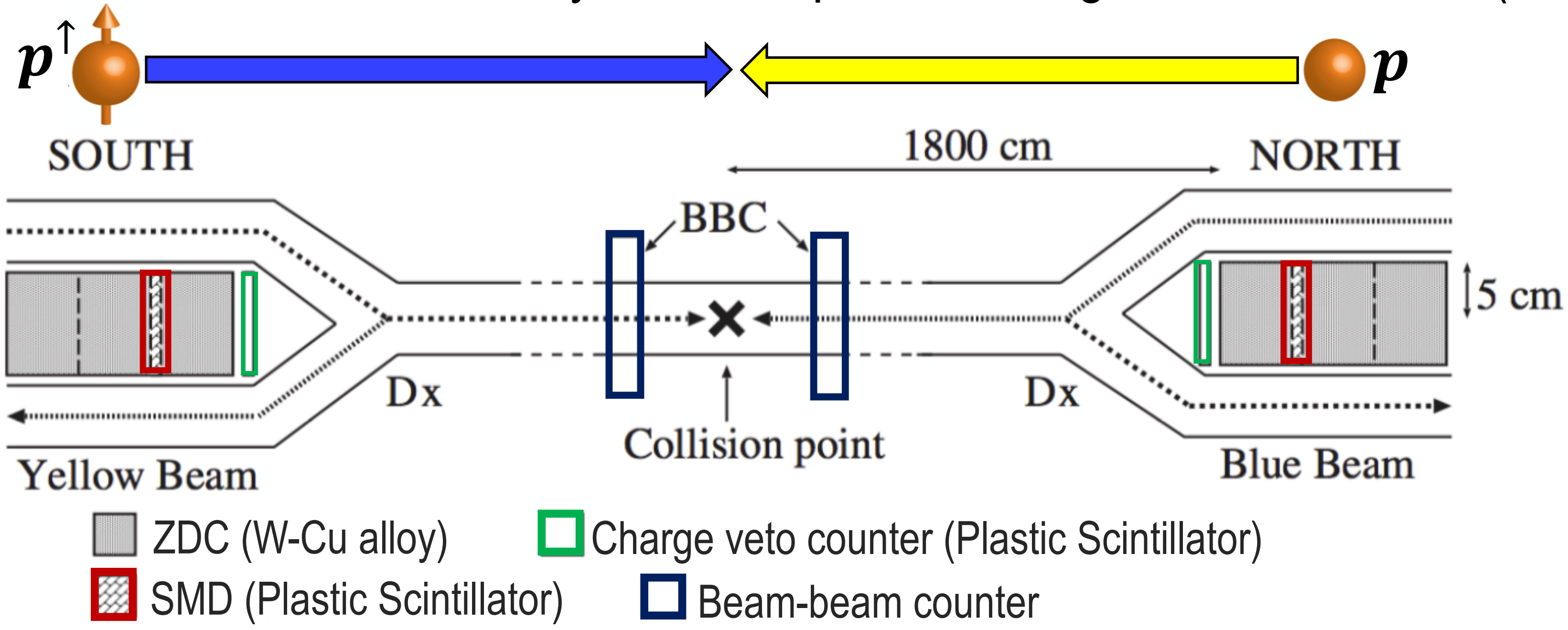
Relativistic Heavy Ion Collider (RHIC) - BNL



PHENIX Central detector at RHIC, Upton, New York

Zero Degree Calorimeter (ZDC) at PHENIX

Forward neutron detection system setup – Zero Degree Calorimeters (ZDCs)



Shower maximum detector (SMD, σ ~ 1 cm): neutron position measurement.
ZDC' E resolution is ~ 20% for 100 GeV neutrons and acceptance of 5 cm in transverse plane.

Measured variables by ZDCs are smeared due to the limited acceptance and resolution.
Thus unfolded asymmetries as a function of p_T to correct the smearing effect induced by ZDCs.

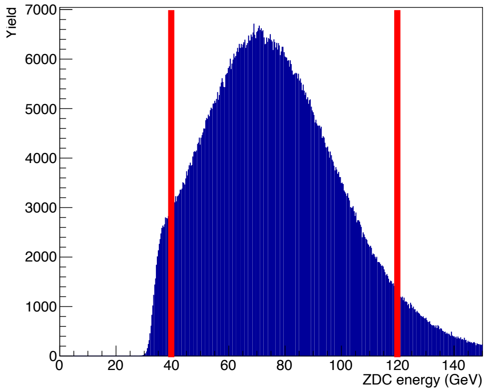
Forward Neutron Transverse Single Spin Asymmetries – Fundamental Cuts

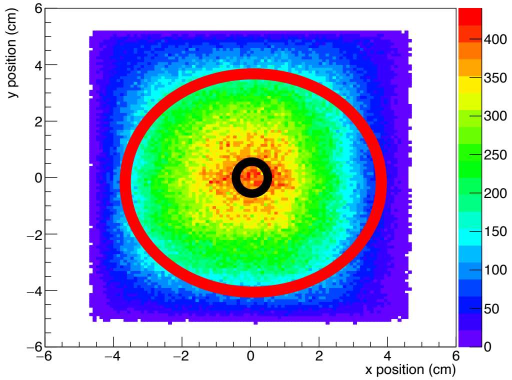
High neutron purity basic selection criteria:

- ZDC total energy cut: 40 GeV to 120 GeV
  ZDC is composed of 3 modules: ZDC1, ZDC2 and ZDC3
  $E_T = E_{ZDC1} + E_{ZDC2} + E_{ZDC3}$
  Required $E_{ZDC2}/E_T > 3\%$ (photon elimination)

- Acceptance cut: 0.5 cm < r < 4.0 cm
  Position resolution of SMD ~ 1.0 cm.
  0.5 cm to counteract left-right dilution at center (1.0 cm SMD)
  4.0 cm used to reduce neutron edge dilution

- SMD threshold cut
  Photon rejection
  Required Nx and Ny > 1 fired above 0.003 GeV



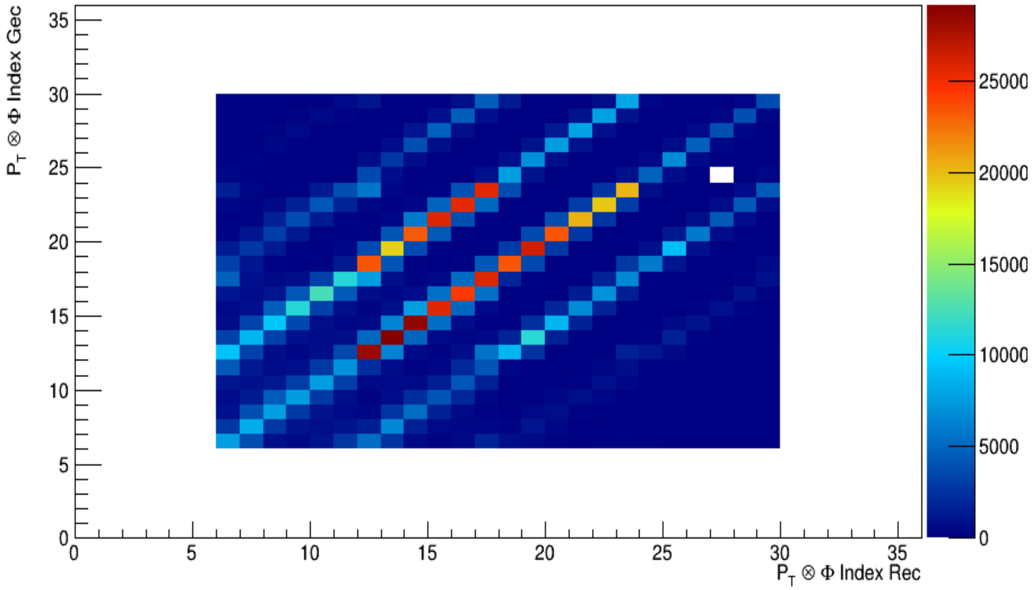


Zero Degree Calorimeter (ZDC) Smearing Response Matrix

The one-dimensional p_T-ϕ index ***(I)*** was first obtained by mapping from two-dimensional p_T and ϕ smeared variables using the relation:

$$I = p_{T(i)} * \phi_{nbin} + \phi_i$$

ZDC smearing response matrix was then obtained as generated (Gen) p_T–ϕ index versus reconstructed (Rec) p_T-ϕ index.



Transverse momentum (p_T) binned as:
[0.01-0.06],[0.06-0.11],
[0.11-0.16],[0.16-0.21].

Azimuth (ϕ) binned into 6 bins spanning a full range, i.e. ($0 – 2\pi$).

SVD of response matrix was finally executed to correct off-diagonal smearing in p_T and azimuth (ϕ)

Unfolding and Asymmetry Extraction Method

Asymmetry extraction and unfolding technique:

$$A_{N(\varphi)} \frac{1}{\langle P\rangle}\frac{Y^{+}(\varphi) - RY^{-}(\varphi)}{Y^{+}(\varphi) + RY^{-}(\varphi)}$$

- $\langle P\rangle$ = average beam polarization
- $Y^{\pm}(\varphi)$ = neutron yields
- R = luminosities ~ 1
- A_N = calculated asymmetries

1. Obtained spin dependent two-dimensional data yields in transverse momentum and azimuthal angle.

2. Executed the unfolding via TSVD in CERN's ROOT using the re-weighted smearing matrices (previous slide).

3. Asymmetries were finally calculated using the relative luminosity formula.

Sampling MC	Interactions
OPE	Hadronic (HAD)
PYTHIA6(8)	Hadronic (HAD)
DPMJET	Hadronic (HAD)
UPC	Electromagnetic (EM)

Used 5 MCs for systematic uncertainty studies [result slides.....]

Re-weighting Procedure – Functional Forms

Three different parameterizations ultilized:

- Polynomial function (Pol3)

$$w = \left(a \cdot P_{T,g} + b \cdot P_{T,g} + c \cdot P_{T,g}\right)\sin\left(\varphi_g + \lambda\pi\right)$$

- Power law

$$w = \left(a \cdot P_{T,g}^{b}\right)\sin\left(\varphi_g + \lambda\pi\right)$$

- Exponential

$$w = a\left(1 - \exp^{P_{T,g} \cdot b}\right)\sin\left(\varphi_g + \lambda\pi\right)$$

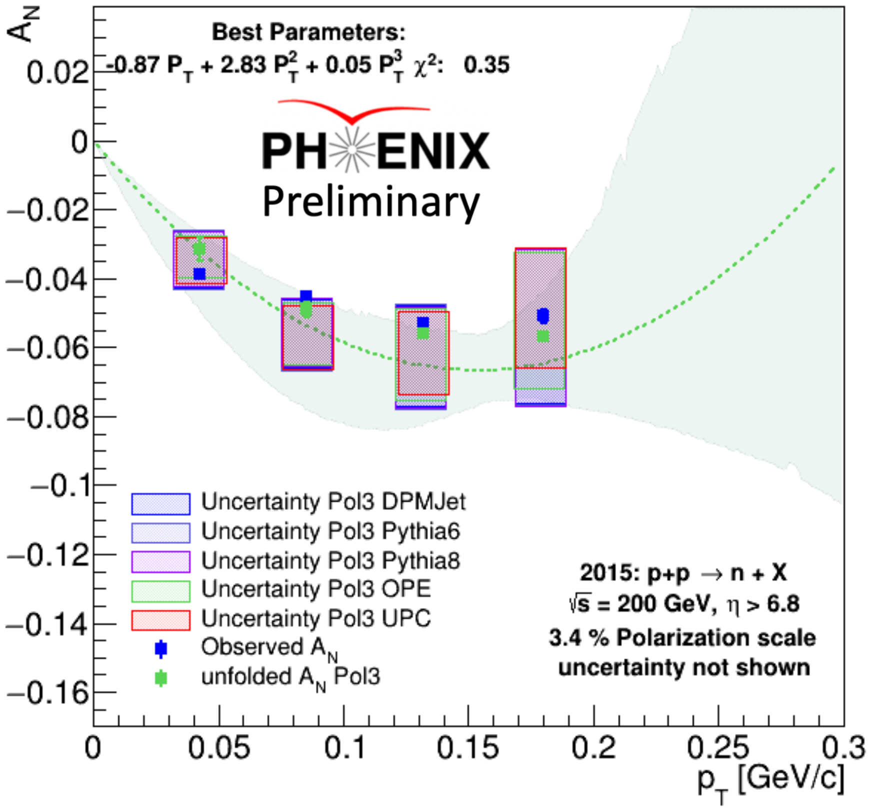
- where a, b, c and d are free parameters valid.

Chi-square between data asy and reco asymmetries from MC:

$$\chi^2 = \frac{\left(Y^{Expt} - Y^{Reco}\right)^2}{\Delta(Y^{Expt})^2 + \Delta(Y^{Reco})^2}$$

Y^{Expt} is experimental neutron data yields.
Y^{Reco} is the reconstructed neutron data yields
χ^2 is minimum Chi-square between data and the reconstructed yields.

Preliminary Results – Pol3 Based



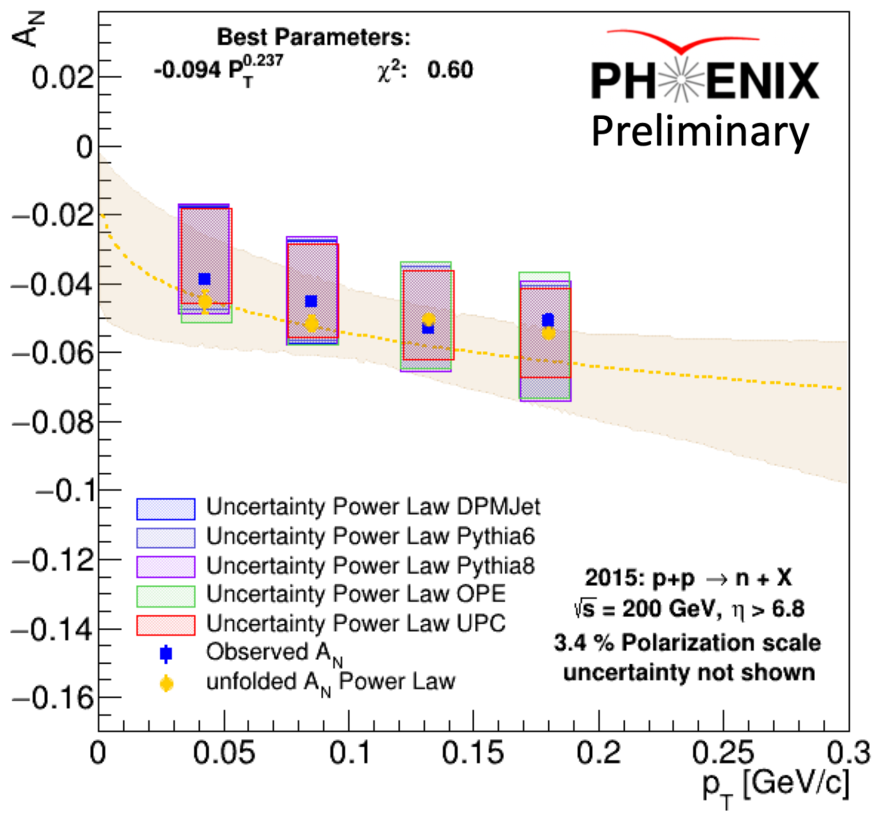
The light green shaded region shows χ^2 below 10. Chi-square is small below 0.2 GeV/c and large above 0.2 GeV/c.

Dashed line represents best matching parameterizations.

RMS ranges of unfolded asymmetries are visualized as shaded boxes for various Monte Carlo generators.

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

Preliminary Results – Power Law Based



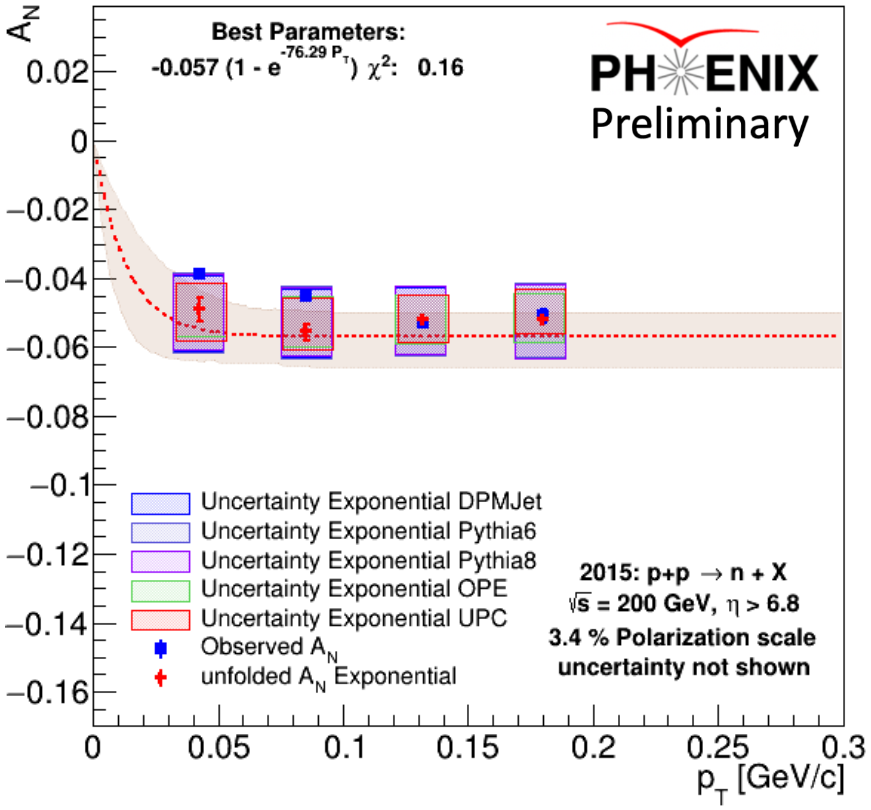
The light yellow shaded region shows Chi-square below 10 units.

Dashed line represents best matching parameterizations.

RMS ranges of unfolded asymmetries are visualized as shaded boxes for various Monte Carlo generators.

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

Preliminary Results – Exponential Based



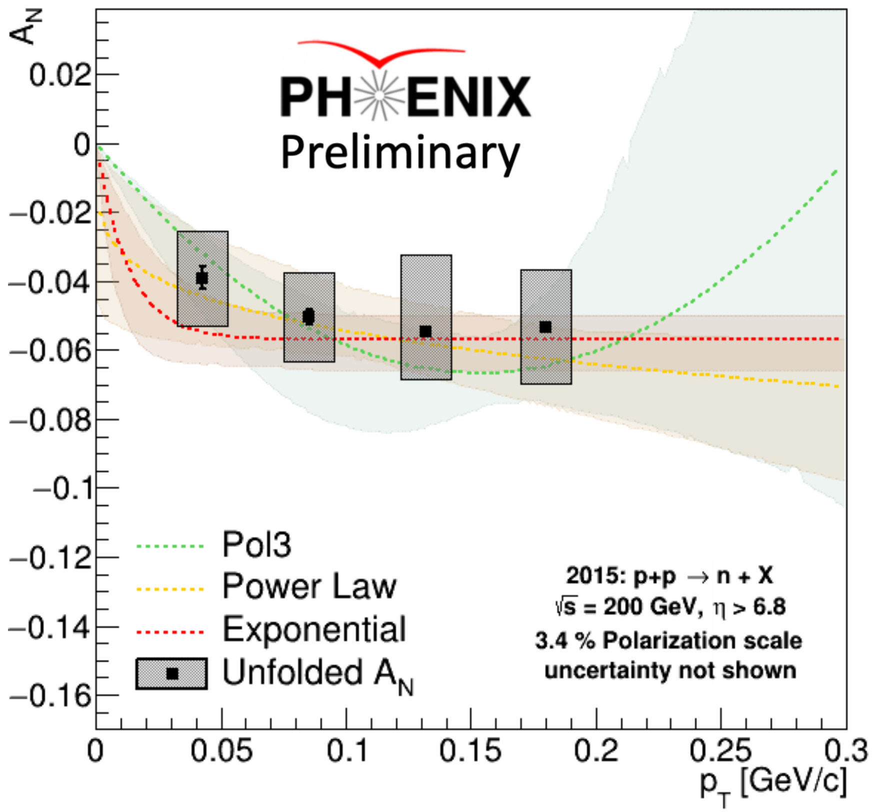
The light brown shaded region shows Chi-square below 10 units.

Dashed line represents best matching parameterizations.

RMS ranges of unfolded asymmetries are visualized as shaded boxes for various Monte Carlo generators.

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

Combined Results with Systematic Uncertainties



The overall unfolded A_N's versus transverse momentum (p_T).

Data points display unfolded A_N's obtained from the average over all parameterizations.

Boxes represent systematic uncertainties arising from the unfolding, MC generators and parameterizations.

Unfolded asymmetries tend to slowly increase at low p_T and almost leveling off at high p_T, even a turnround is observed.

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Summary

- The PHENIX experiment has measured the first explicit unfolded p_T dependent A_N of forward neutrons in inclusive $p^{\uparrow} + p$ collisions at $\sqrt{s}$ = 200 GeV.

- With this measurement, first reliable tests of mechanisms that produce these asymmetries can be performed.

- Unfolded asymmetries appear to show a tendency to slowly increase at low transverse momentum (p_T).

- At high p_T, unfolded A_N's almost level off. This trend seems not to follow a simple linear p_T dependence theoretical prediction in Phys. Rev. D84, 114012 (2011 (slide 4).

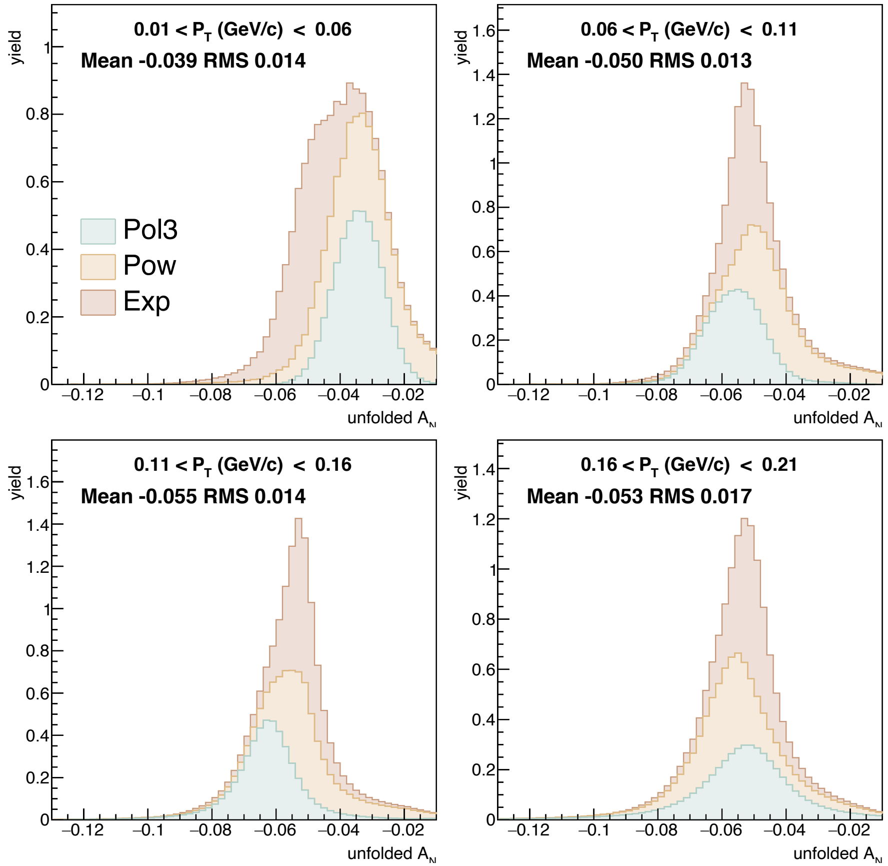
- The preliminary results are currently being finalized and paper being prepared for the publication.

BACKUP SLIDES

BACKUP

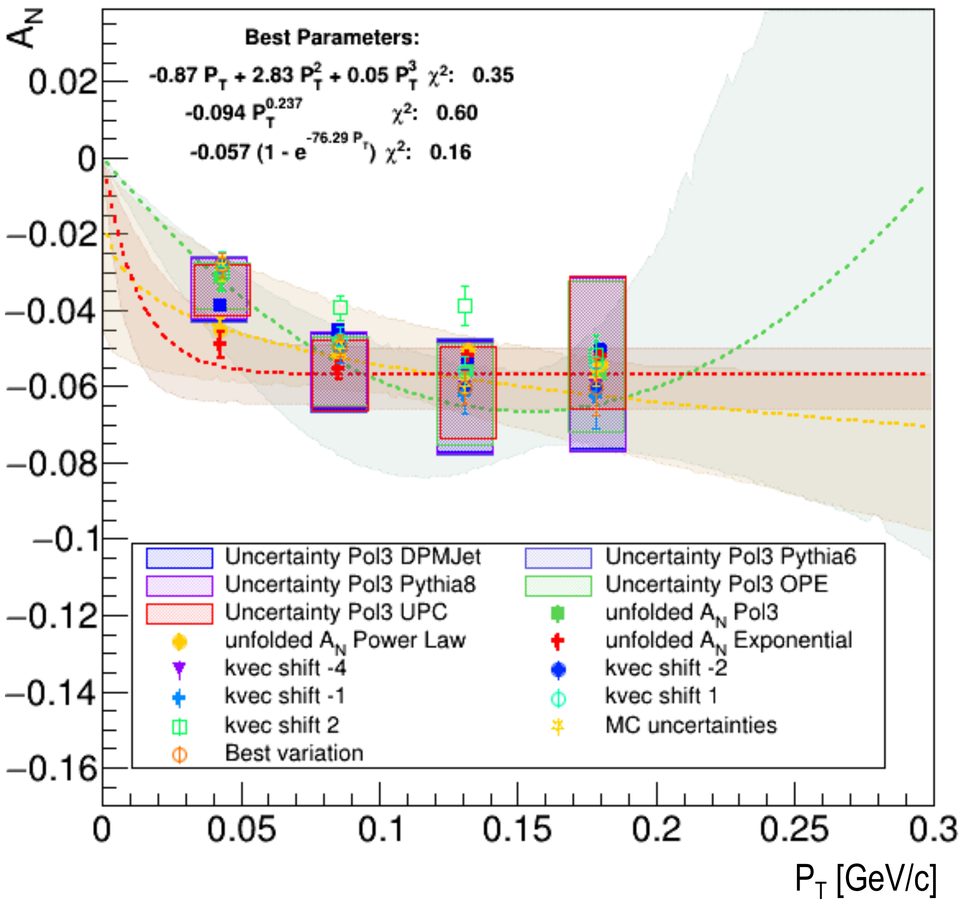
Results – Systematic Uncertainties Sources

- ❑ Monte Carlo sampling using DPMJET, PYTHIA6, PYTHIA8, UPC, OPE. OPE best described data asymmetries.
- ❑ Functional form to describe asymmetries: Pol3, power law, exponential.
- ❑ Choice of regularization parameter for the unfolding.
- ❑ Limited statistics in the response matrix.



Results – Systematic Uncertainties Sources

- Monte Carlo sampling using DPMJET, PYTHIA6, PYTHIA8, UPC, OPE. Plot not yet fully updated.
- Functional form to describe asymmetries: Pol3, power law, exponential.
- Choice of regularization parameter for the unfolding.
- Limited statistics in the response matrix.



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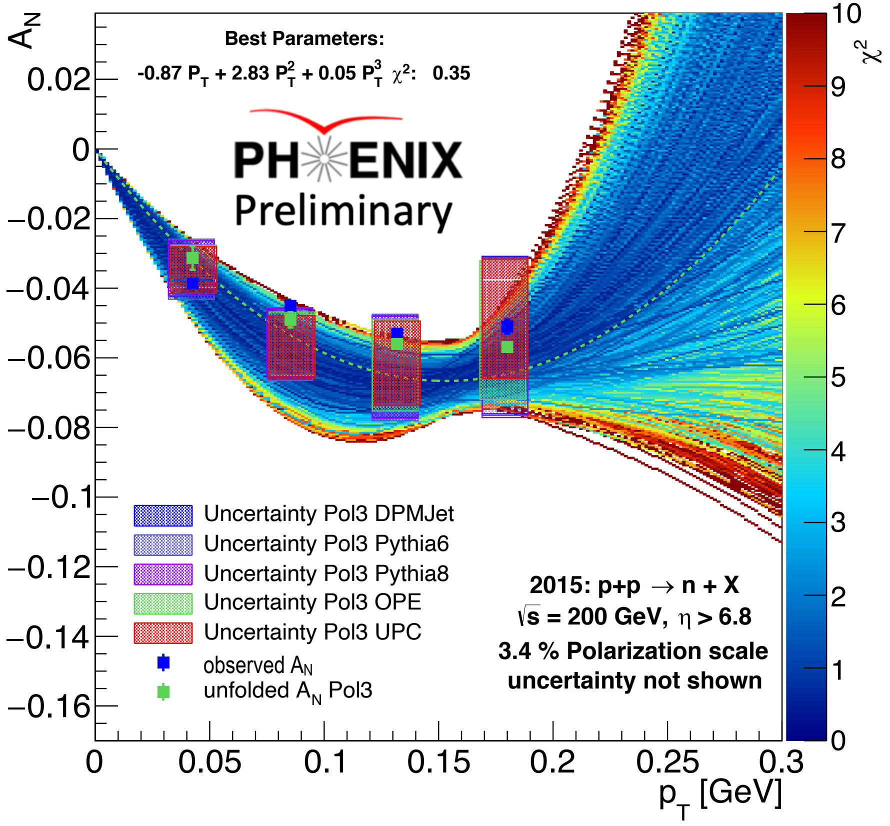
Unfolded Results – Pol3 Based



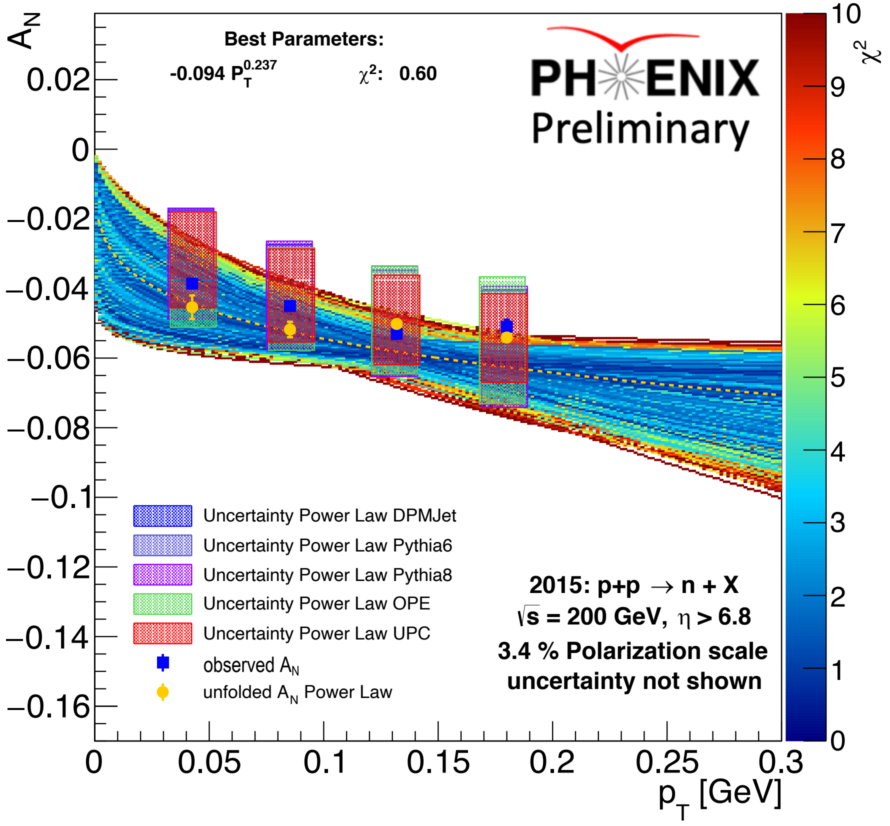
Chi-square, χ^2, between smeared and data A_N's scanned was under 10 units.

Dashed lines represent best matching parameterizations.

RMS ranges of unfolded asymmetries are visualized as shaded boxes for various MCs.

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

Unfolded Results – Power Law Based



Chi-square, χ^2, between smeared and data A_N's scanned was under 10 units.

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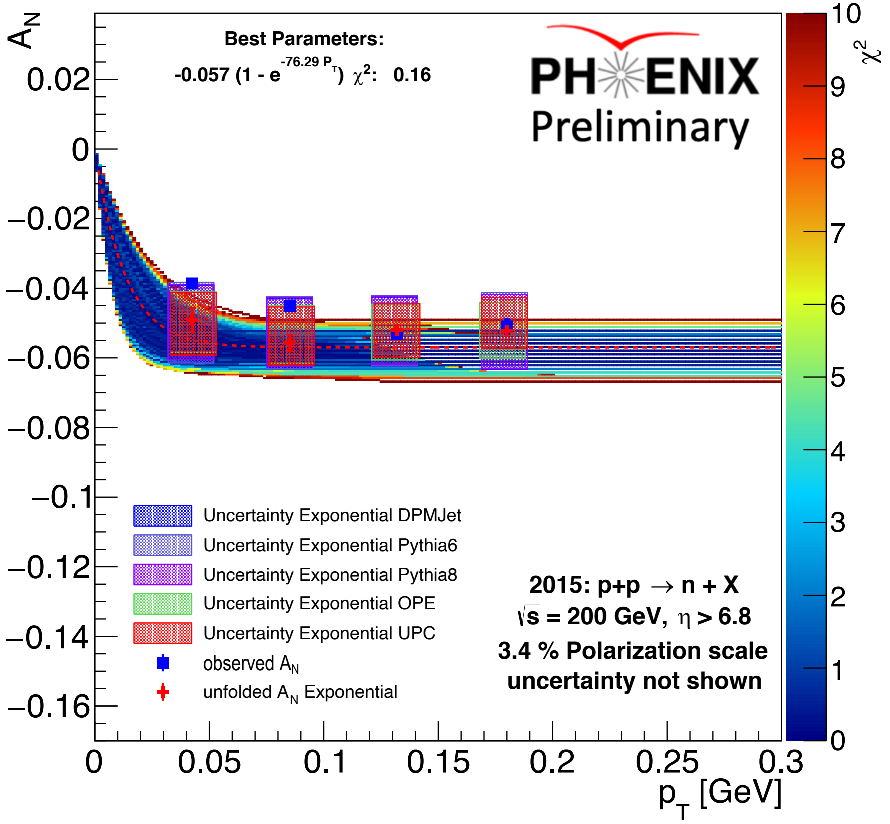
Unfolded Results – Exponential Based



Chi-square, χ^2, between smeared and data A_N's scanned was under 10 units.

Dashed lines represent best matching parameterizations.

RMS ranges of unfolded asymmetries are visualized as shaded boxes for various MCs.

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