Transverse Single Spin Asymmetries of charged hadron from p+p and p+A collisions in PHENIX

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for the PHENIX Collaboration

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Outline

- Introduction
- Analysis of Transverse Single Spin Asymmetry at forward, backward rapidity in PHENIX
  - Heavy flavor A_N
- Transverse Single Spin Asymmetry of inclusive charged hadron production at forward and backward rapidity from p+p(A) collisions in the PHENIX experiment
- Nuclear dependence of A_N of positively charged hadron at $0.1<x_F<0.2$

Transverse Single Spin Asymmetry A_N

Transverse Single Spin Asymmetries A_N

$$A_N = \frac{\sigma_L^\uparrow - \sigma_R^\uparrow}{\sigma_L^\uparrow + \sigma_R^\uparrow}$$

Left

Right
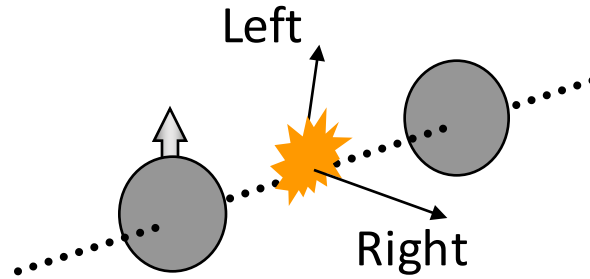
Theory Expectation:

Small asymmetries at high energies

(*Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978)*)

$$A_N \propto \frac{m_q}{\sqrt{s}}$$
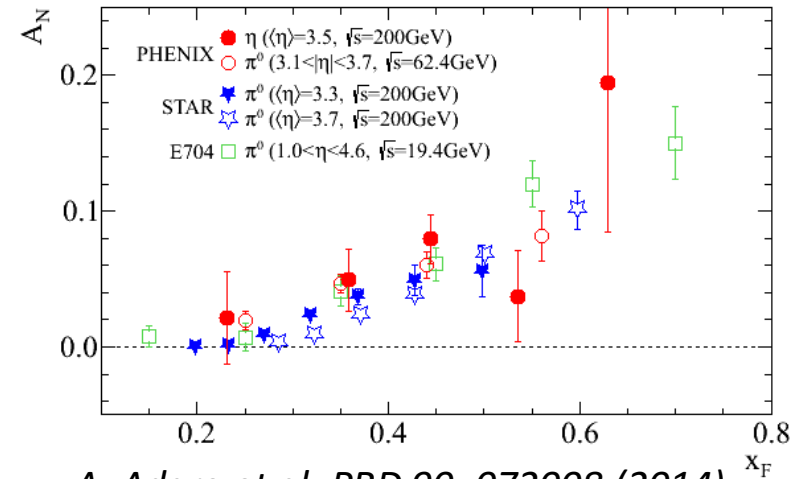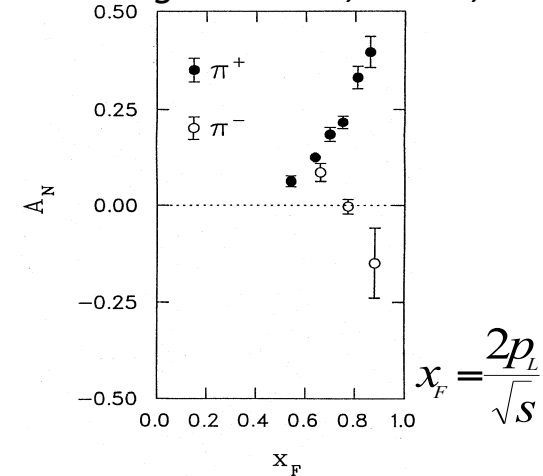
$A_N \sim O(10^{-4})$ theory

Experiments:

ZGS, AGS, FERMILAB to RHIC

$A_N \sim O(10^{-1})$ observed at forward rapidity

$$\sqrt{s} = 5 \sim 500 \text{ GeV}$$

Argonne ZGS, p_{beam} = 12 GeV/c

W.H. Dragoset et al., PRL36, 929 (1976)

$$x_F = \frac{2p_L}{\sqrt{s}}$$

A. Adare et al. PRD 90, 072008 (2014)

# Mechanisms for A_N of hadrons in p+p

- Twist-3 collinear factorization approach is appropriate for A_N in inclusive high p_T hadron procution in p+p collision
  - works at $Q, Q_T \gg \lambda_{QCD}$, need only 1 scale
  - (1) Twist-3 transverse-spin-dependent multi-parton correlation functions
 - (2) Twist-3 multi-parton fragmentation functions

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A_N in p+A

- ## Help us to understand
  - underlying mechanisms of A_N
  - small-x saturation of gluon distribution

- ## Suppression of A_N in $p^\uparrow$+A is sensitive to Qs

- ## ~$A^{1/3}$ suppression by gluon saturation is expected
  - PRD.84.034019 (2011), Odderon exchange : PRD.86.034028 (2012)
  - Hybrid approach of Twist-3 and color glass condensate
    - PRD90. 034026 (2014), PRD95, 014008 (2017)
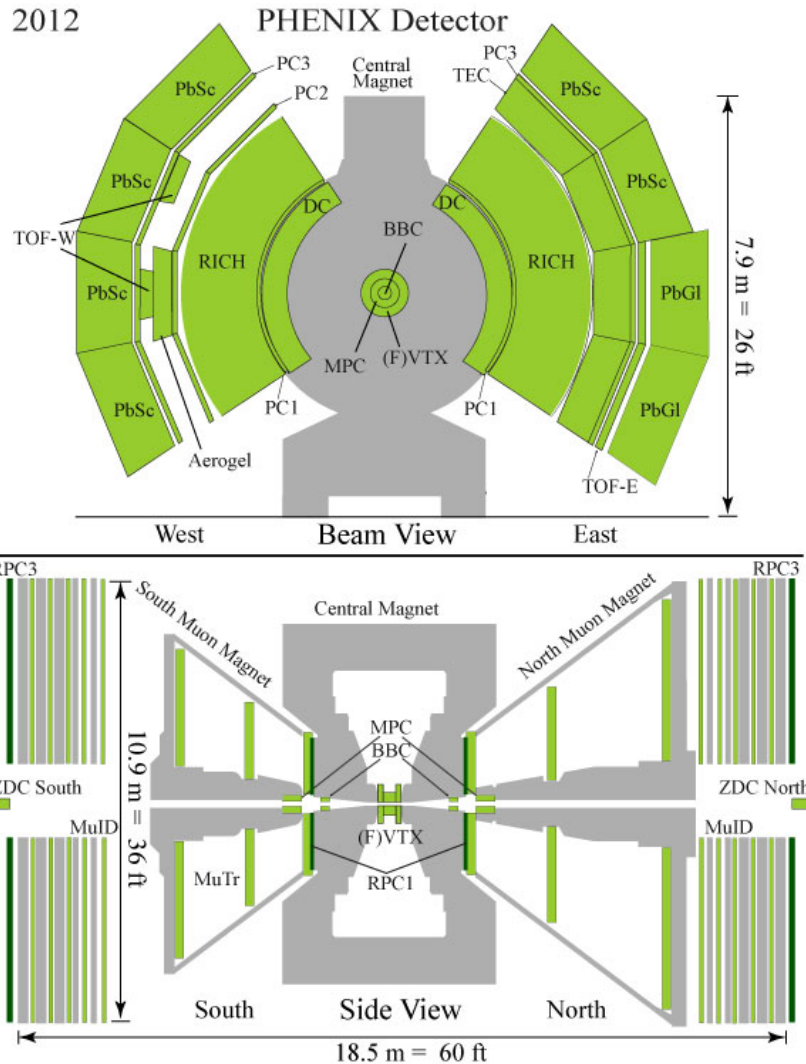   - fragmentation term contributes to A_N while other contributions are small or NO A-dependence

Polarized *p*+*p*(A) collision at RHIC
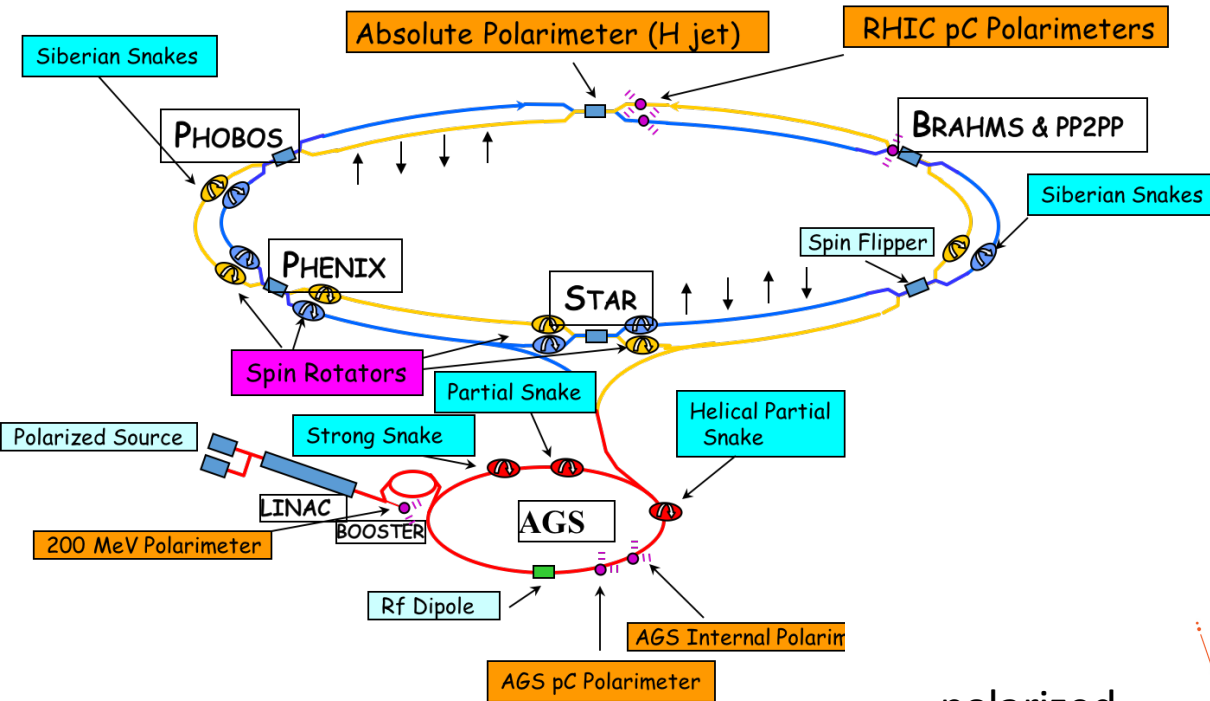
ion (Al, Au…)
$\sqrt{s_{NN}}$ = 200 GeV
RHIC 2015 run

polarized proton
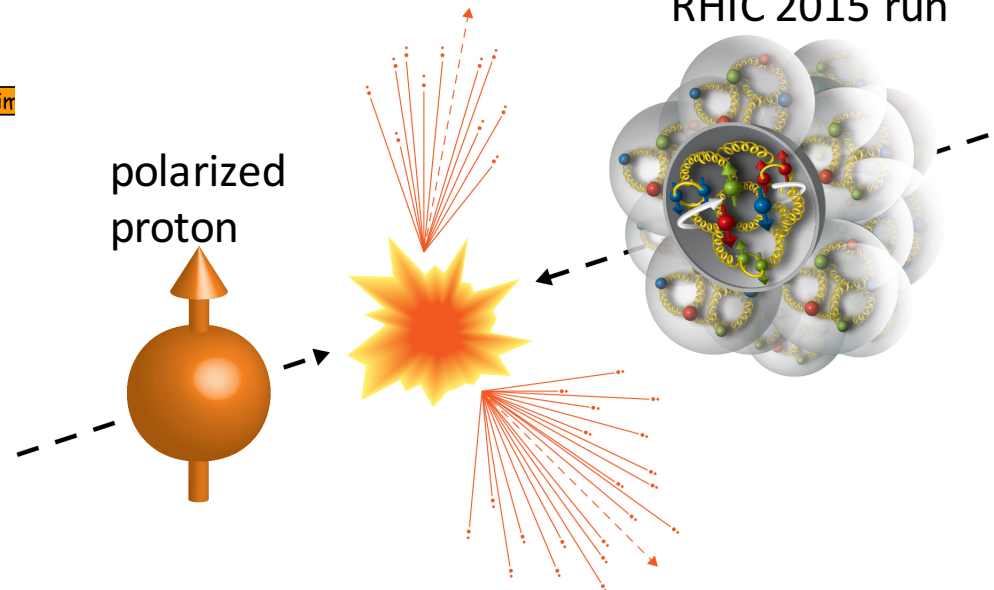
PHENIX Detectors

- Philosophy
  - high resolution & high-rate
  - trigger for rare events
- Central Arms
  - $|\eta| < 0.35$, $\Delta\varphi \sim \pi$
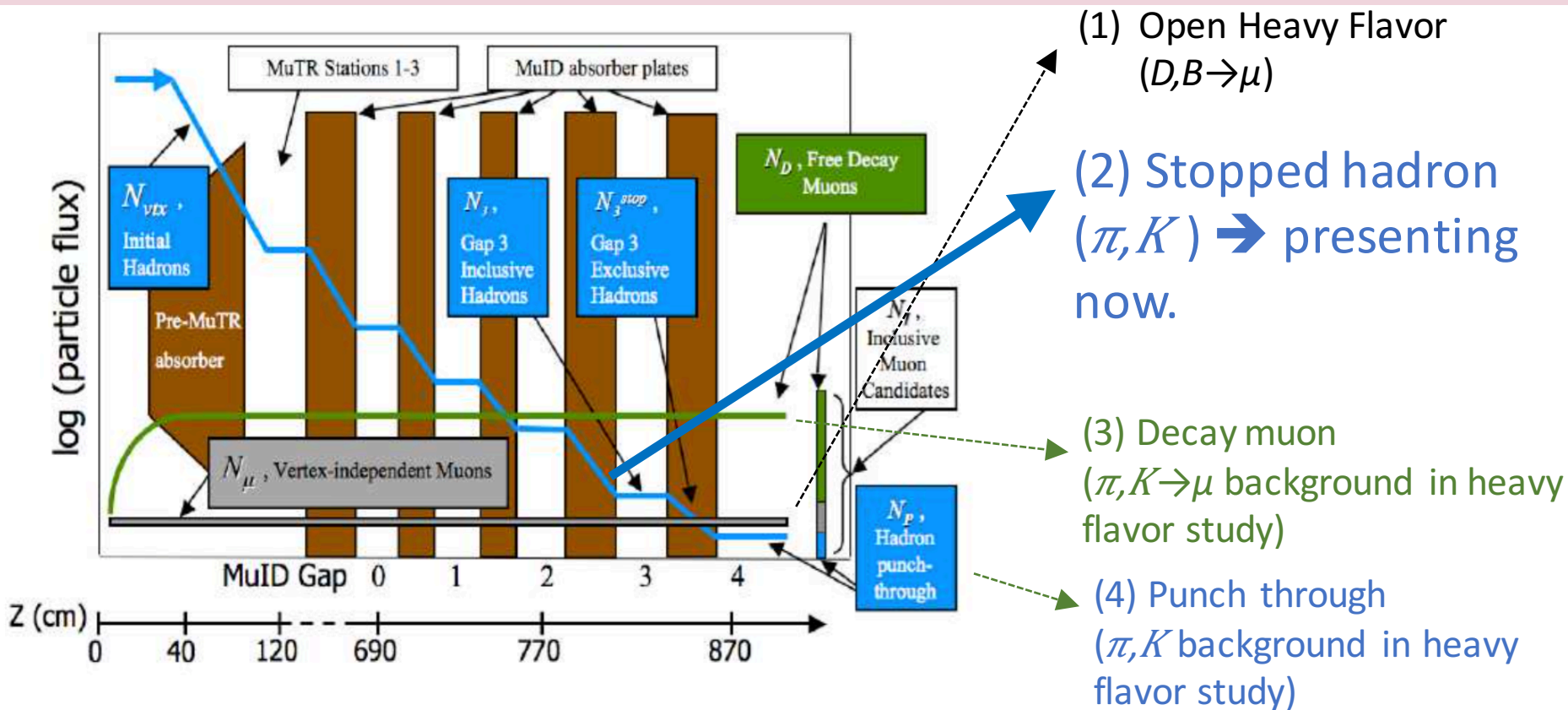 - Momentum, EM Energy
- Muon Arms
  - $1.2 < |\eta| < 2.4$
  - Momentum
  - High p_T muons
- Muon piston calorimeter
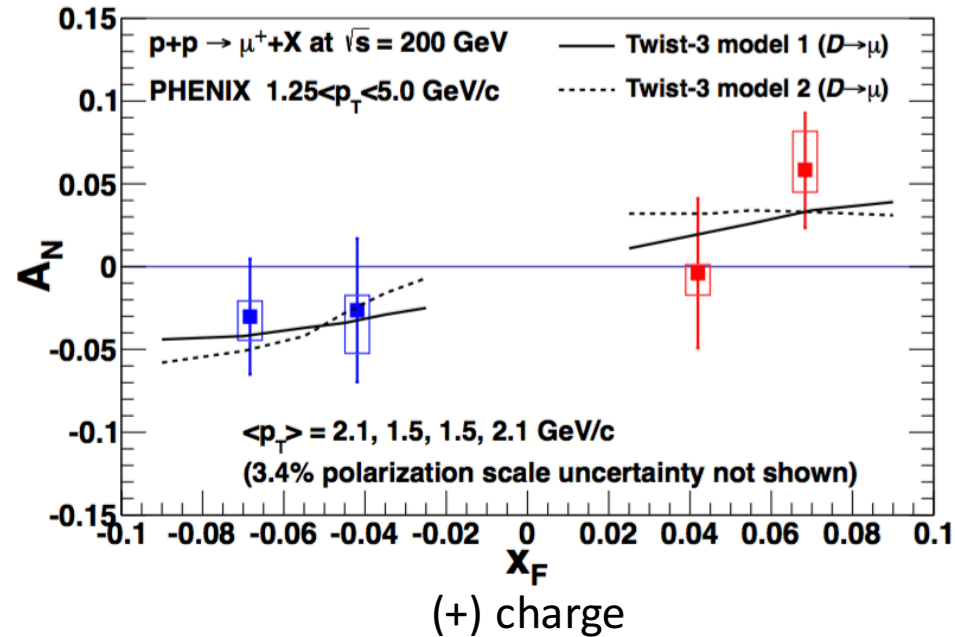 - $3.1 < |\eta| < 3.9$
  - EM Energy
  - π^0 and η

Hadron measurements in the PHENIX Muon Arm

(1) Open Heavy Flavor ($D,B{\rightarrow}\mu$)

(2) Stopped hadron (π,K) ➜ presenting now.

(3) Decay muon ($\pi,K{\rightarrow}\mu$ background in heavy flavor study)

(4) Punch through (π,K background in heavy flavor study)

- π,K are background in open heavy flavor study($D,B{\rightarrow}\mu$)
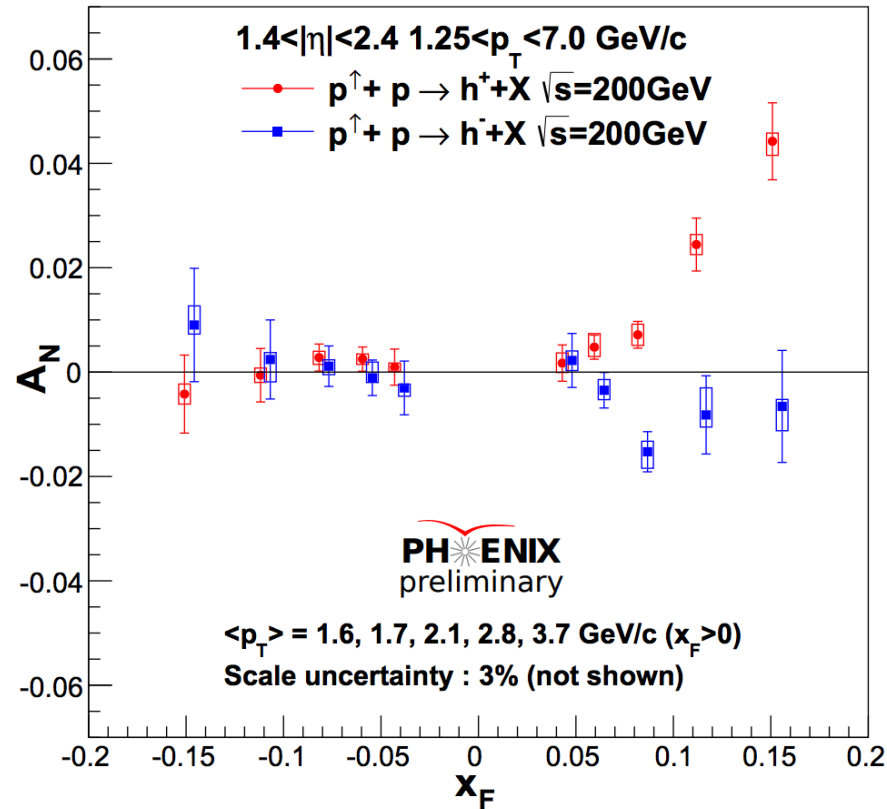- π,K are signal in charged hadron study.

A$_N$ result in PHENIX Muon Arm : Open Heavy Flavor A$_N$
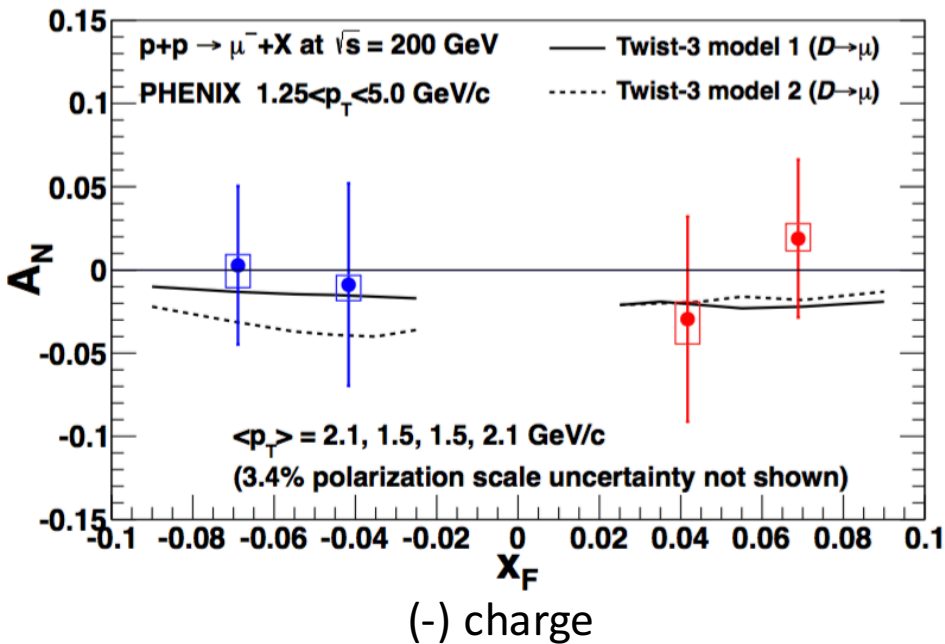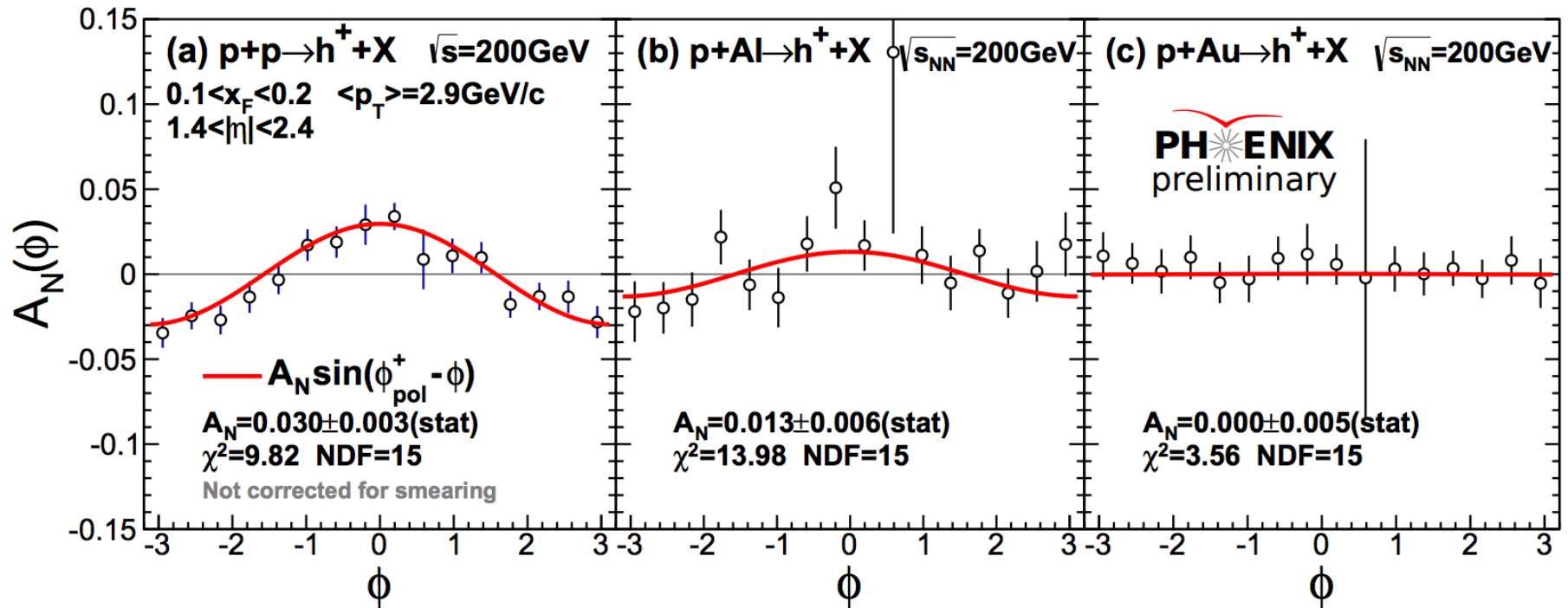

(-) charge

(+) charge

- *A$_N$* of μ from open heavy flavor as a function of x$_F$
- published *PRD95, 112001 (2017)*
- charged hadron is the main source of background in the open heavy flavor *A$_N$* measurements.
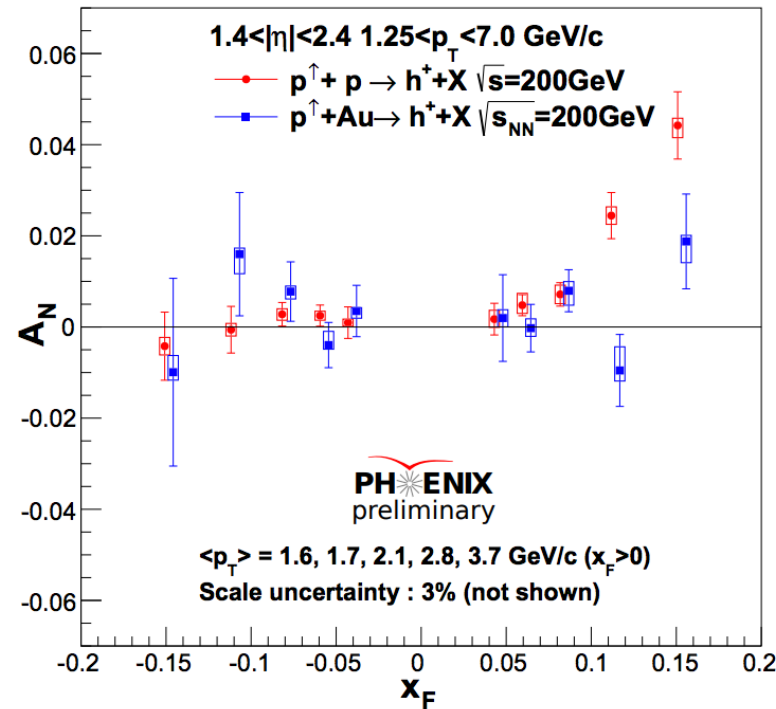
Charged hadron A_N in p+p

- A_N of (survived) $\pi^{\pm}, K^{\pm}$ mixture
- p+p$\rightarrow$h$^{(+)}$+X at x_F>0 shows positive A_N while h$^{(-)}$ shows negative A_N
- A_N increases as x_F increases for positively charged hadron at x_F>0
- consistent with zero for x_F<0
- comparable with BRAHMS results, but not same kinematics.

Nuclear dependence of A_N

(a) $p+p \rightarrow h^+ +X$ $\sqrt{s}=200\text{GeV}$
$0.1<x_F<0.2$ $<p_T>=2.9\text{GeV/c}$
$1.4<|\eta|<2.4$

$A_N \sin(\phi^+_{pol} - \phi)$

$A_N=0.030\pm0.003\text{(stat)}$
$\chi^2=9.82$ NDF=15
Not corrected for smearing

(b) $p+Al \rightarrow h^+ +X$ $\sqrt{s_{NN}}=200\text{GeV}$

$A_N=0.013\pm0.006\text{(stat)}$
$\chi^2=13.98$ NDF=15

(c) $p+Au \rightarrow h^+ +X$ $\sqrt{s_{NN}}=200\text{GeV}$

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preliminary
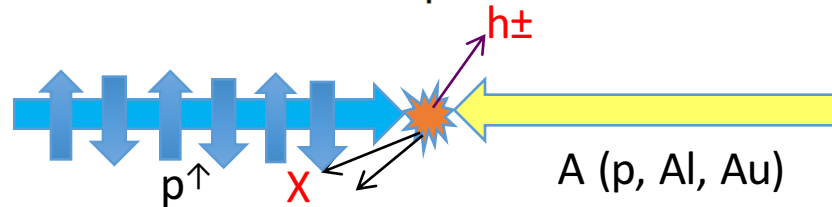
$A_N=0.000\pm0.005\text{(stat)}$
$\chi^2=3.56$ NDF=15

- cosine modulations of A_N for positively charged hadron at $0.1<x_F<0.2$
- clear modulation in p+p, weaker one in p+Al, disappears in p+Au
- low statistics in one bin is caused by detector inefficiency.
- momentum smearing is not corrected in this plot.

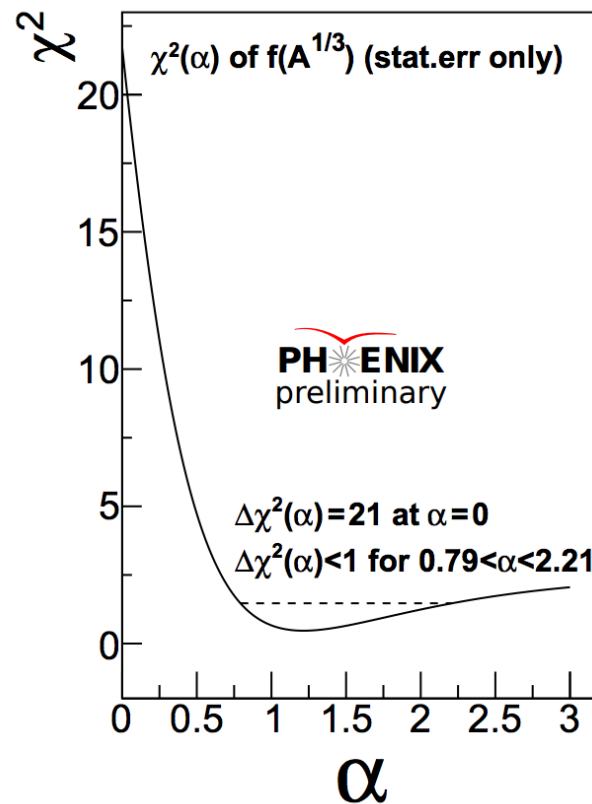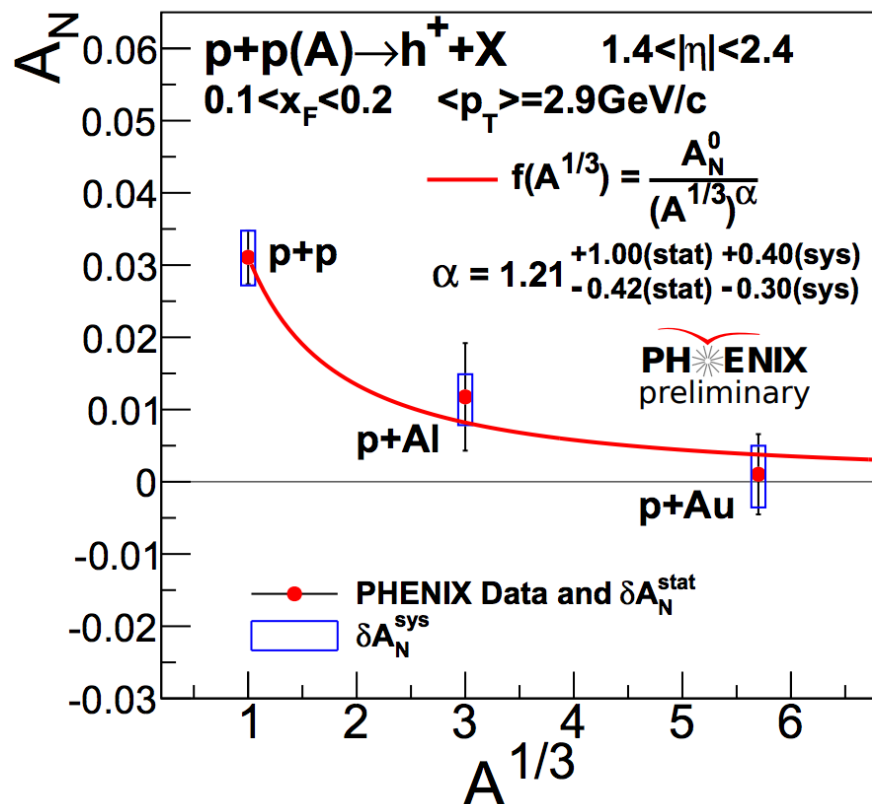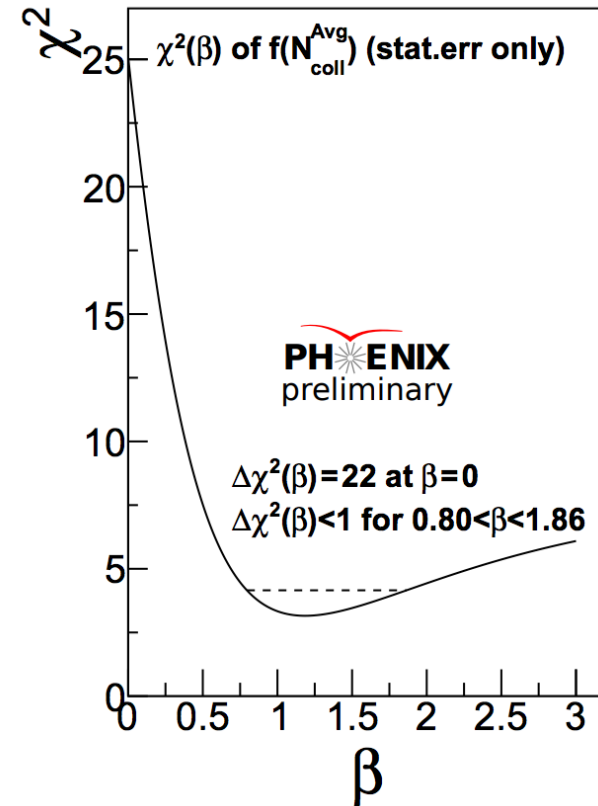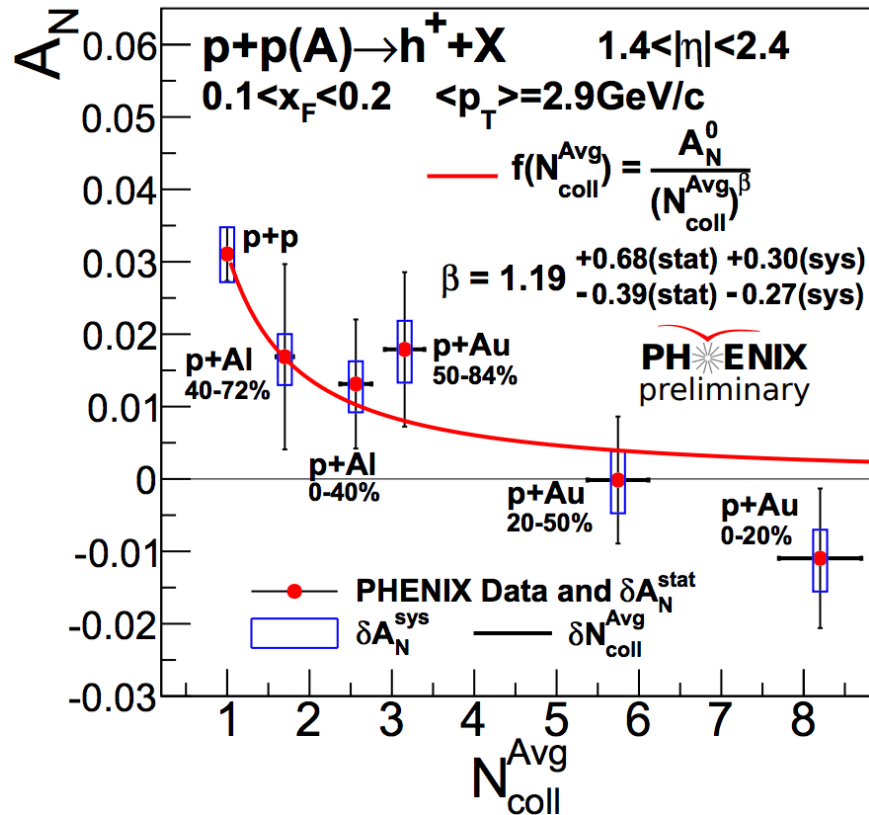# positively charged hadron A_N in p+p, p+Au

- A_N of (survived) $\pi^{\pm}, K^{\pm}$ mixture.
- p+Au→h$^{(+)}$+X shows clear suppression of A_N at $x_F > 0.1$

Nuclear dependence of A_N

- Nuclear dependence of A_N for positively charged hadron at $0.1 < x_F < 0.2$
  - Fit function is to quantify the A-dependence, x-axis is $A^{(1/3)}$
  - power parameter $\alpha = 1$ corresponds to $1/A^{(1/3)}$ dependence
  - Right panel is χ^2 for wide range of power parameter α
  - $\Delta\chi^2 = 21$ at $\alpha = 0$ (NO A-dep), out of 4sigma

Avg.N$_{coll}$ dependence of A$_N$

- Avg.N$_{coll}$ dependence of A$_N$ for positively charged hadron at $0.1<x_F<0.2$
  - x-axis is averaged-N$_{coll}$, related to the path length in a nucleus in p+A collisions
  - x-axis indicates how much material proton go through
  - Right panel is χ^2 for wide range of power parameter β
  - $\Delta\chi^2=22$ at $\beta=0$

Summary and Outlook

- Transverse Single Spin Asymmetry of charged hadron at forward and backward rapidity is studied in PHENIX experiment.

- For positively charged hadron, nonzero A_N is observed in p+p, but smaller A_N in p+Al & clear suppression in p+Au are observed.

- A_N of positively charged hadron at $0.1 < x_F < 0.2$ shows nuclear dependence
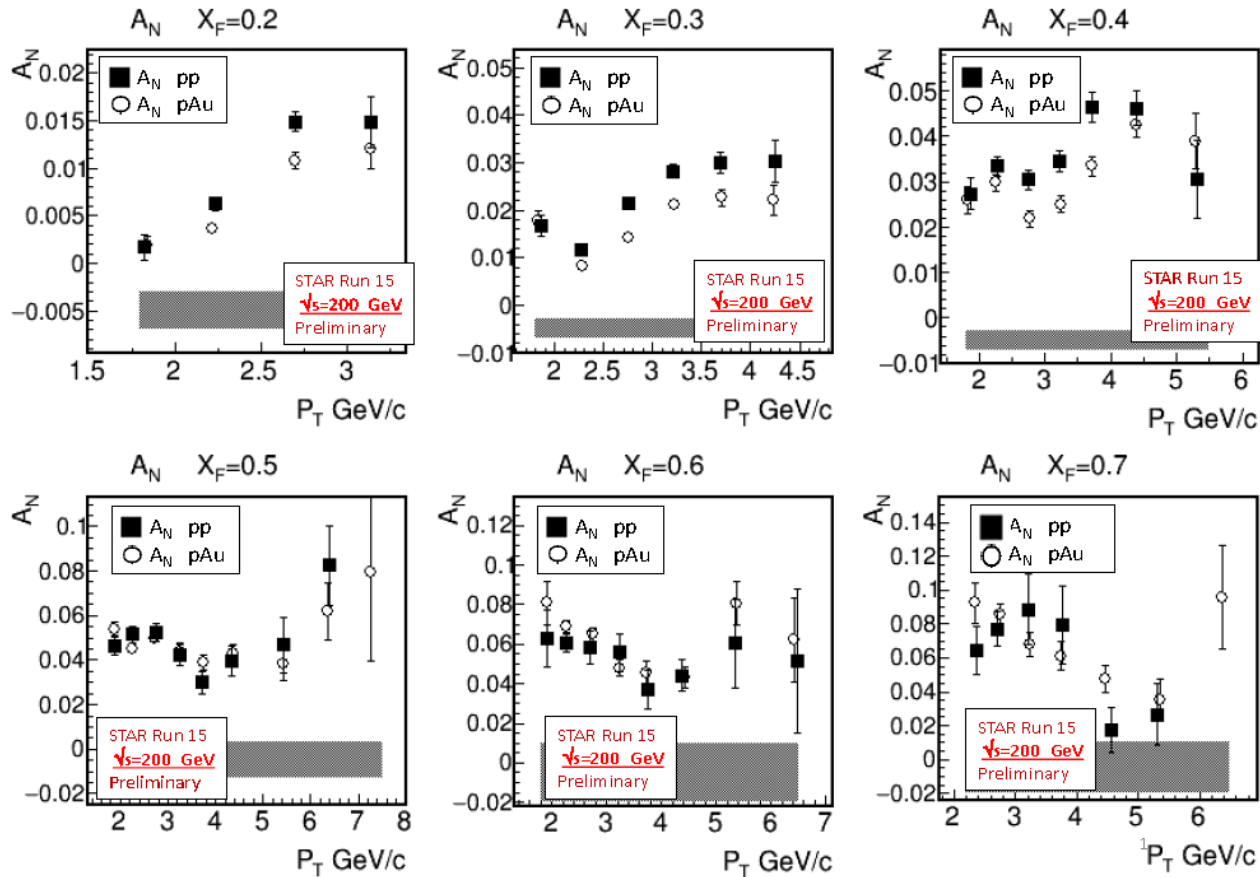
backup : charged hadron A_N in BRAHMS
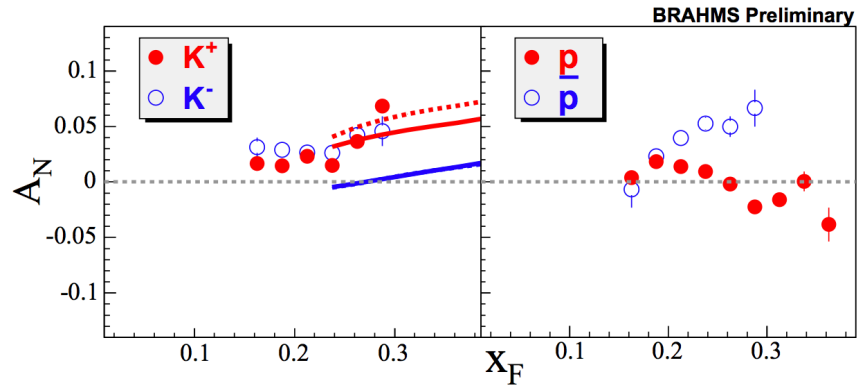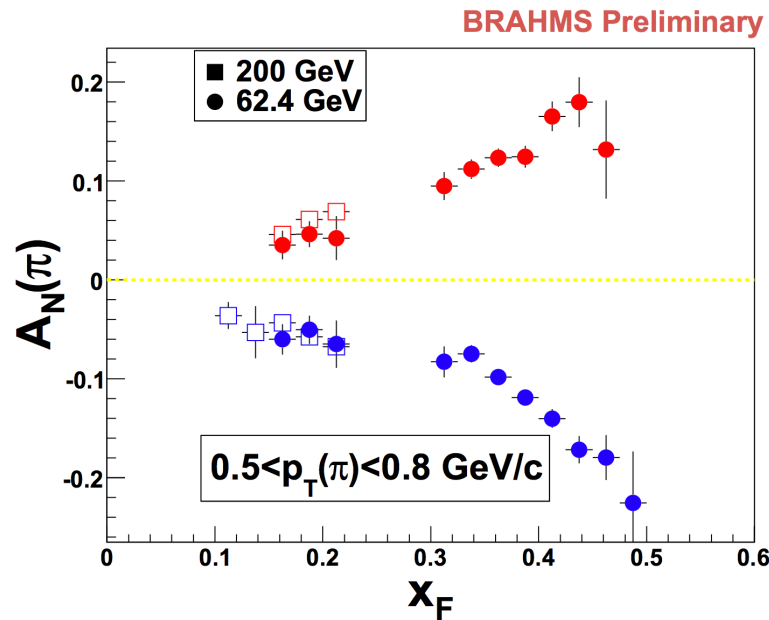
- PRL101 042001(2008) at 62.4GeV
- BRAHMS preliminary for 200GeV from DIS09 (arXiv:0908.4551)
- increasing trend of A_N as x_F increases
- opposite sign of A_N in charged pions, same sign of A_N in charged Kaons
- different kinematics

backup : recent STAR pi0 in p+A

- taken from QM 2017, SPIN 2016
- small to no suppression within systematic uncertainty
- different kinematic region