Transverse single spin asymmetry in heavy flavor electrons and charged pions production at midrapidity in polarized p + p collisions at 200 GeV

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The Proton Spin Structure

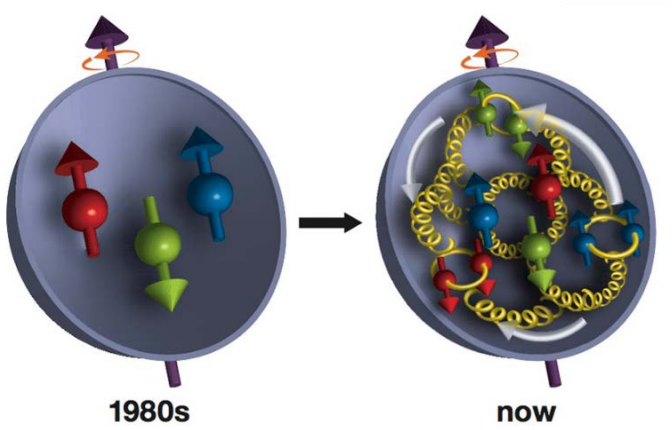


Image courtesy of Brookhaven National Laboratory

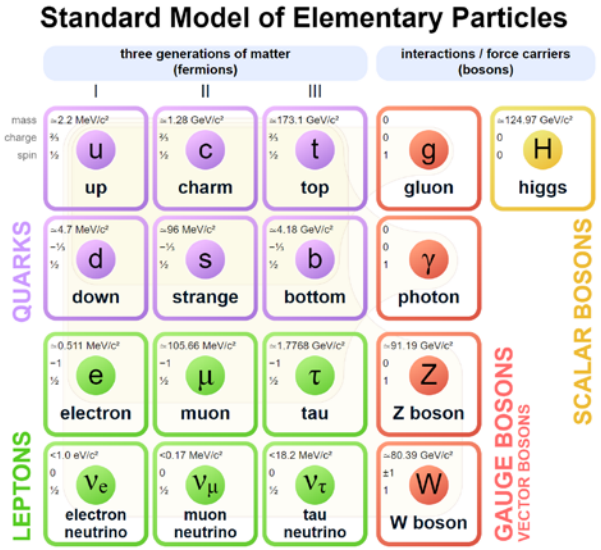
1988 EMC measured:

$\Sigma = 0.123 \pm 0.013 \pm 0.019$ $\Longrightarrow$ Spin Puzzle!

$$S_{proton} = \frac{1}{2} = \frac{1}{2}\Delta q + \Delta G + L_{q,g}$$

$$\frac{1}{2} = \frac{1}{2}(\Delta u_v + \Delta d_v + \underbrace{\Delta q_s}) + \Delta G + L_q + L_g$$

$$\Delta u_v + \Delta d_v + \Delta q_s + \Delta \bar{u}_s + \Delta \bar{d}_s + \Delta \bar{s}_s$$

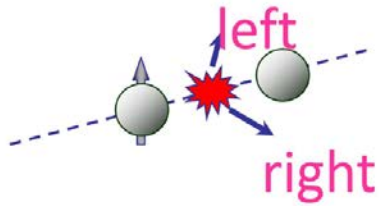


In the 1980s, the EMC experiment discovered that a proton's valance quarks account for only a fraction of the proton's overall spin. New measurements from RHIC experiment reveal that gluons contribute as much as or possibly more than the quarks.

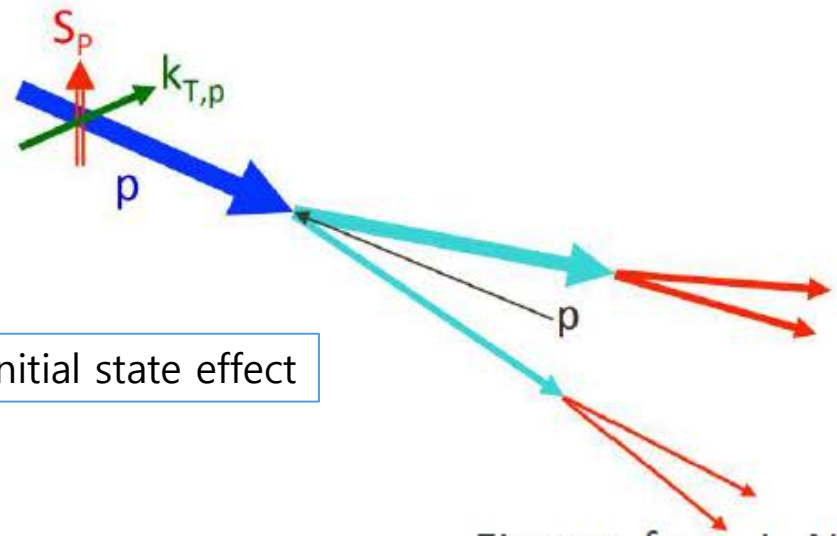
How is proton's spin correlated with the motion of quarks and gluons?
-> Transverse Momentum Dependent (TMD) Functions

Transverse Single Spin Asymmetry

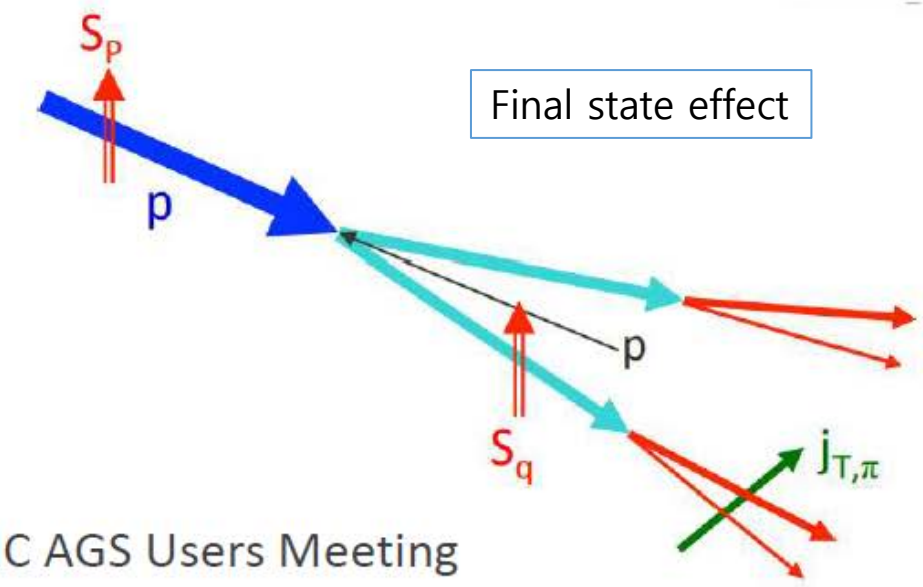
$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$



Sources of Transverse SSA's



Initial state effect



Final state effect

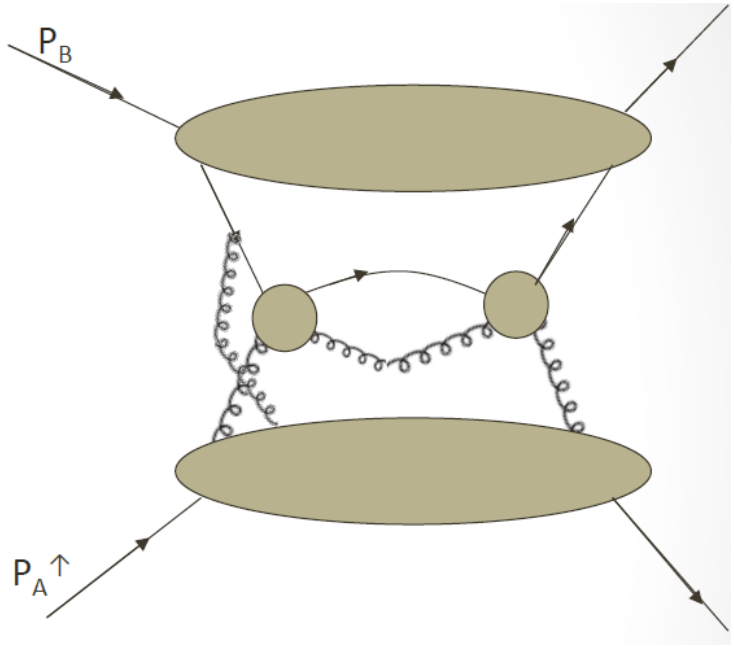
Figures from L. Nogach 2006 RHIC AGS Users Meeting

Sivers Function
- correlation between proton spin and parton k_T.

Collins Function
- Spin momentum correlation in a Fragmentation Function.

Transverse momentum dependent (TMD) framework
- two observed scales: . $\Lambda_{QCD} \ll Q_T^2\ (P_{h\perp}) \ll Q^2$
- applicable in SIDIS and Drell Yan

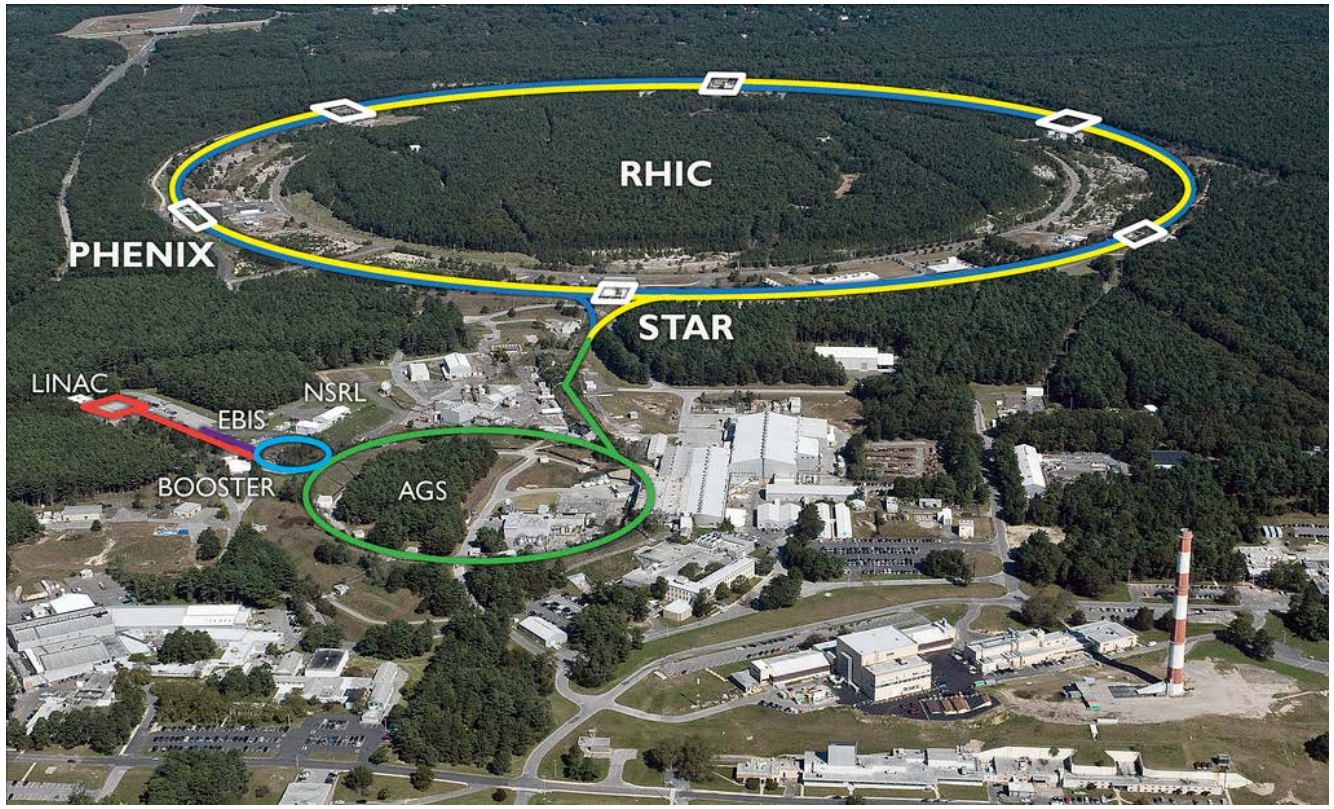
Higher Twist Effects



Twist-3 Function
- Multiparton correlations
- Power suppressed terms in factorization expansion by $\sim 1/Q$
- applicable when only single hard scale observed, such as in ANs in hadronic collisions. ($A_N \sim 1/p_T$)

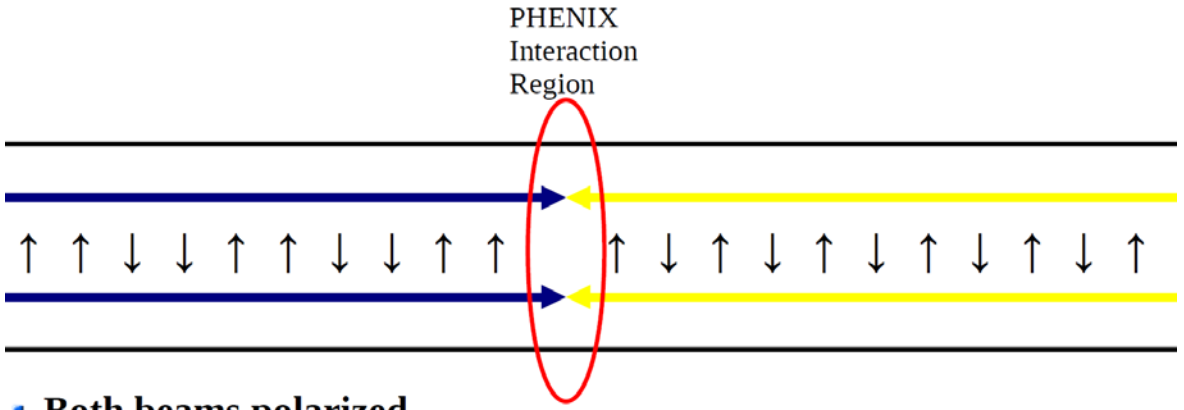
- **They also contain initial state (correlations in the nucleon) and final state (correlations in the fragmentation) effects**
- **Several of the higher twist effects can be related to moments over intrinsic transverse momenta of TMDs, such as Sivers moment --> Efremov-Teryaev-Qiu-Sterman function.**

RHIC



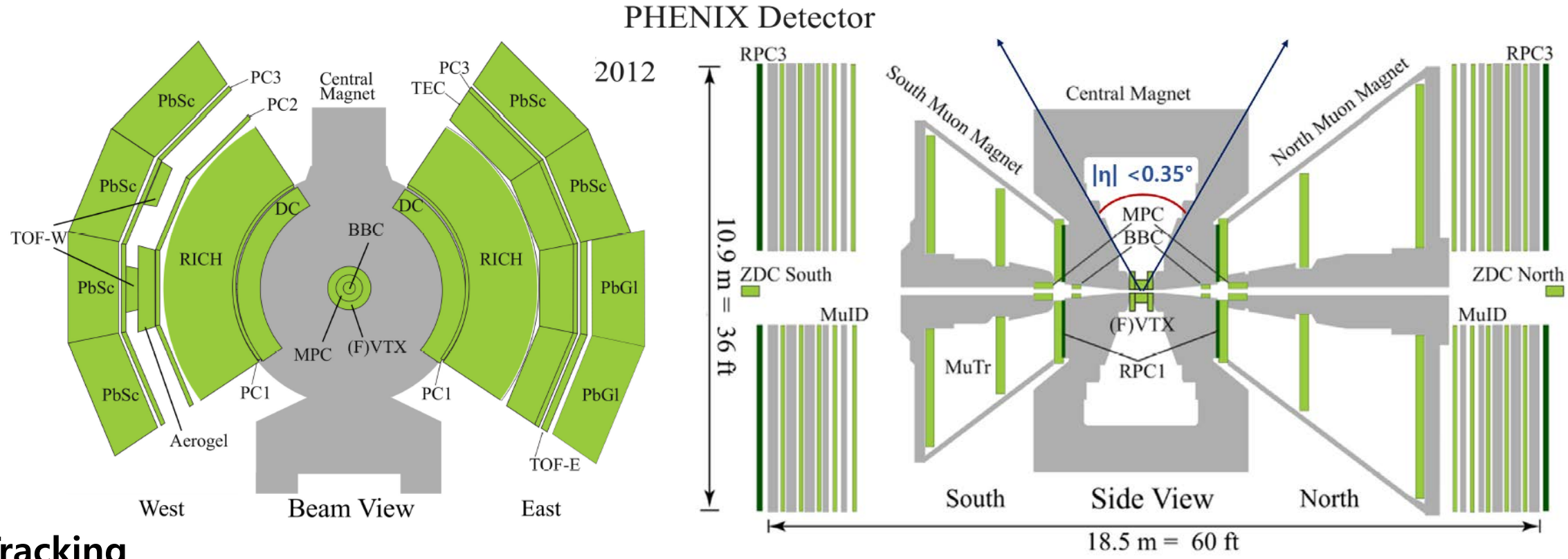
View of the Brookhaven National Laboratory, NY, USA

Polarized Beams



- **Both beams polarized**
- Variation of bunch polarization direction minimizes systematic uncertainties in measurement
- For transversely polarized beams, allows for two independent A_N measurements

PHENIX Detector System



Tracking

- Drift Chamber (DC) - Pad Chamber (PC1/PC3)

Charged particle Identification

- Ring Imaging Cherenkov Detector (RICH)
- Electromagnetic Calorimeter (PbSc/PbGl)

Relative Luminosity

- Beam Beam Counter (BBC)
- Zero Degree Calorimeter (ZDC)

Acceptance

- $|\eta|<0.35$ - $\Delta\varphi = 2 \times \pi/2$

Particle ID for $\pi^{\pm}$ and $e^{\pm}$

$\pi^{\pm}$ identification

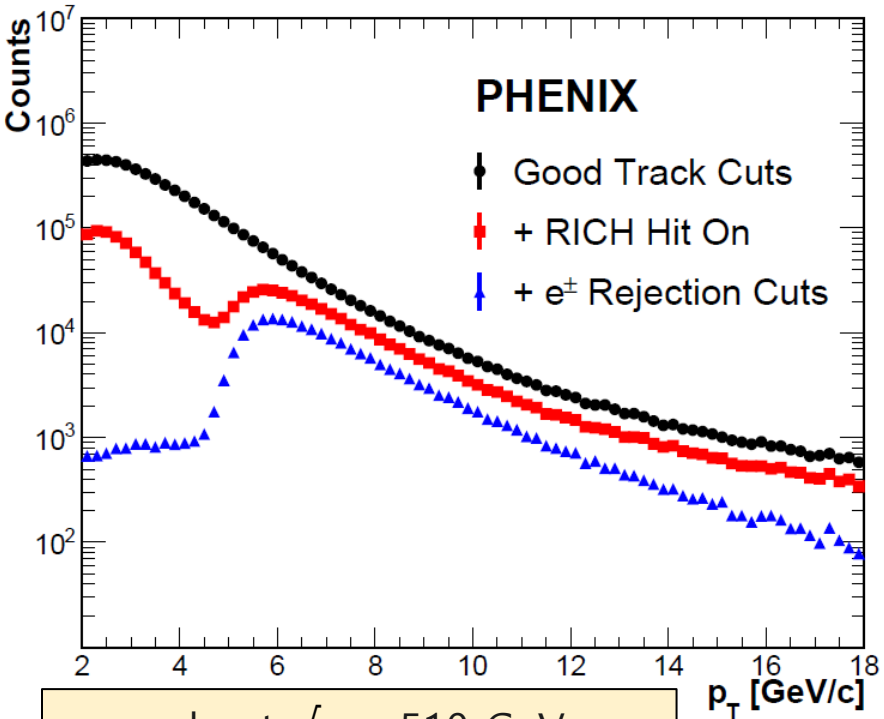
- Trigger $\pi^{\pm}$ with a BBC and EMCal.
- Track can be divided into two categories according to RICH response at pT 5~16GeV/c.
  - RICH Hit: $e^{\pm}$ and $\pi^{\pm}$.
  - No RICH Hit: $K^{\pm}$ and p.
- $0.2 < E/p < 0.8$
- EM shower shape probability < 0.1

$e^{\pm}$ identification

- Trigger $e^{\pm}$ with a BBC and EMCal.
- $|E\backslash\mathrm{p} - \langle E/p\rangle| < 2\sigma_{E/p}$ at $(\langle E/p\rangle \sim 1)$
- RICH Hit: $e^{\pm}$ $(20\ MeV/c < p)$
- EM shower shape probability > 0.01
- Hit requirement in inner 2 layers of VTX
- Conversion veto cut on opening angle of nearby $e^{\pm}$ candidates

Energy threshold for the emission of Cherenkov radiation in RICH

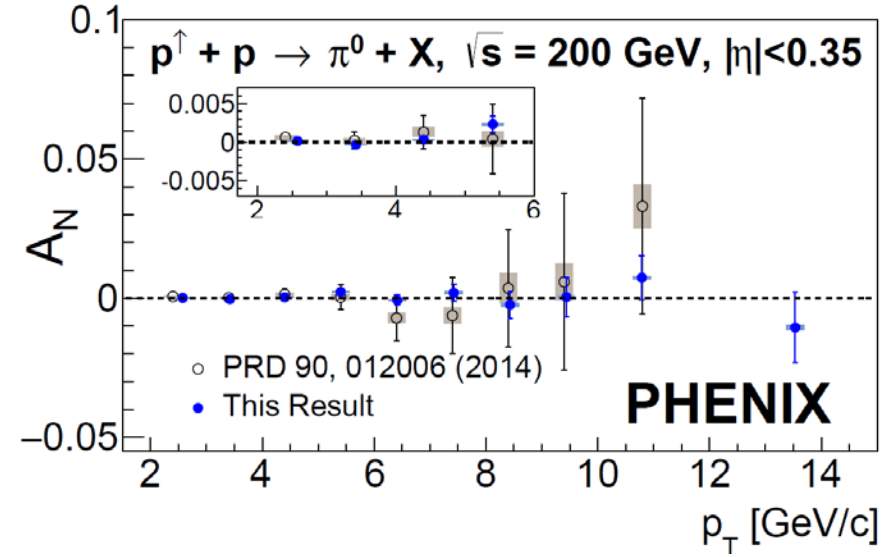
Particle	*Electron*	*Pion*	Kaon	*Proton*
Threshold	*20MeV/c*	*4.9GeV/c*	*17.3GeV/c*	*33GeV/c*

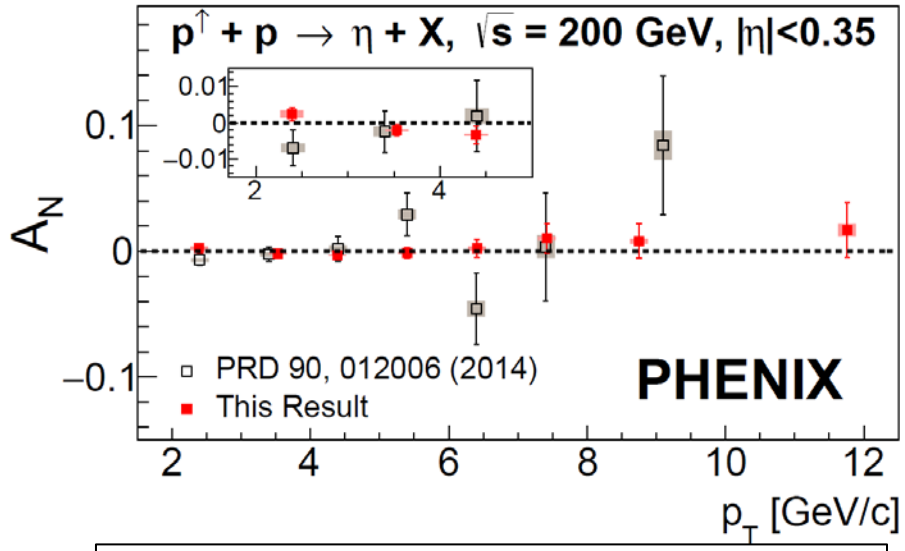


example at $\sqrt{s}$ = 510 GeV

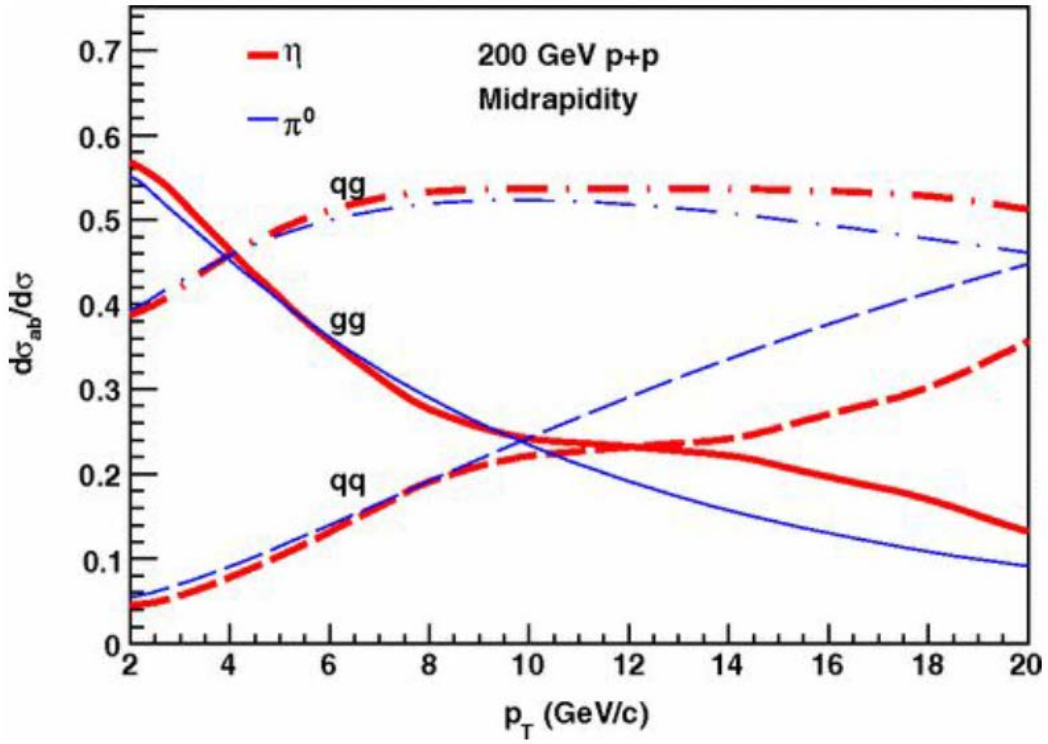
(PHENIX Collaboration) PRD 102, 032001

Recent π^0 and η A_N results at 200 GeV with Run-15 data





(PHENIX Collaboration) Phys. Rev. D 103, 052009 (2021)

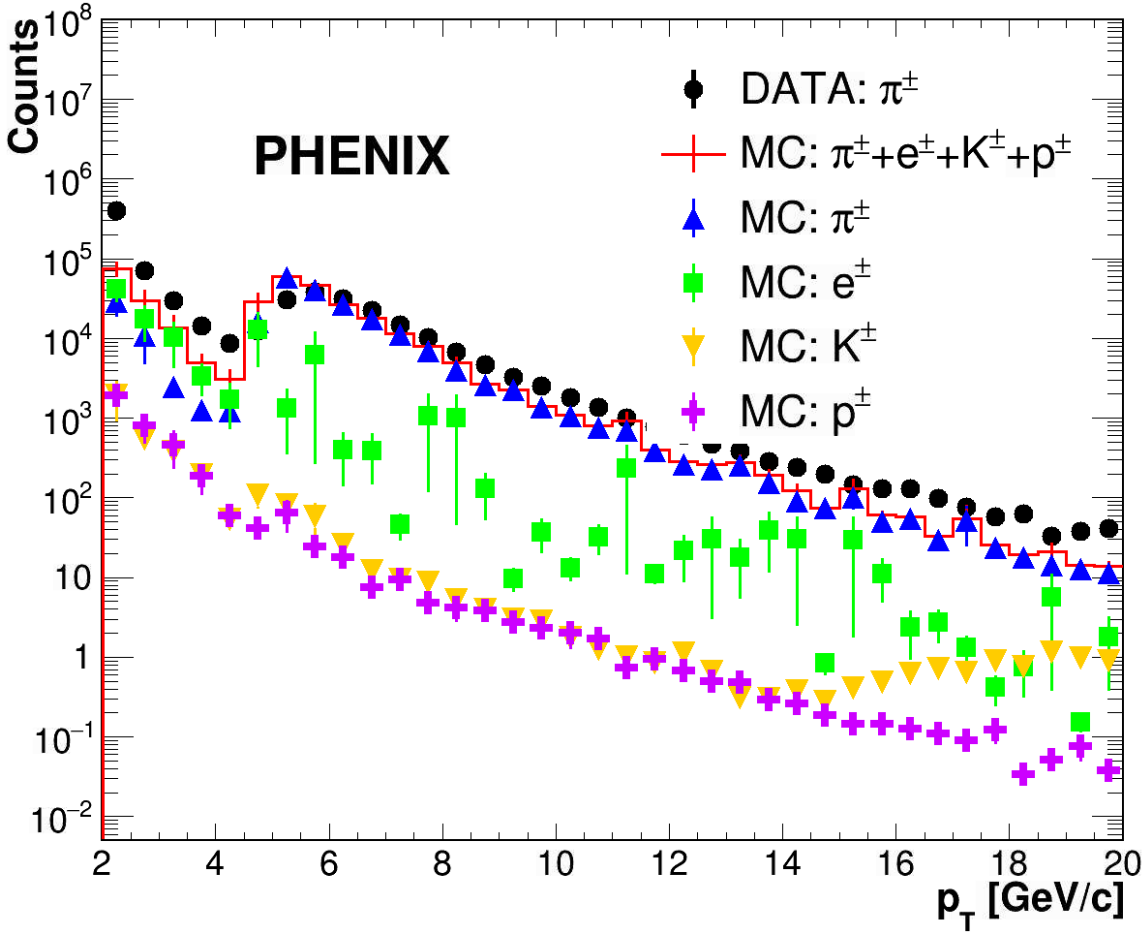


(PHENIX Collaboration) Phys. Rev. D 83, 032001 (2011)

- π^0 and η production
  - quark-gluon scattering is dominant process
  - A_N consistent with zero.
- These results are sensitive to initial and final state effects

Charged pion A_N can provide flavor sensitivity (u and d quarks)

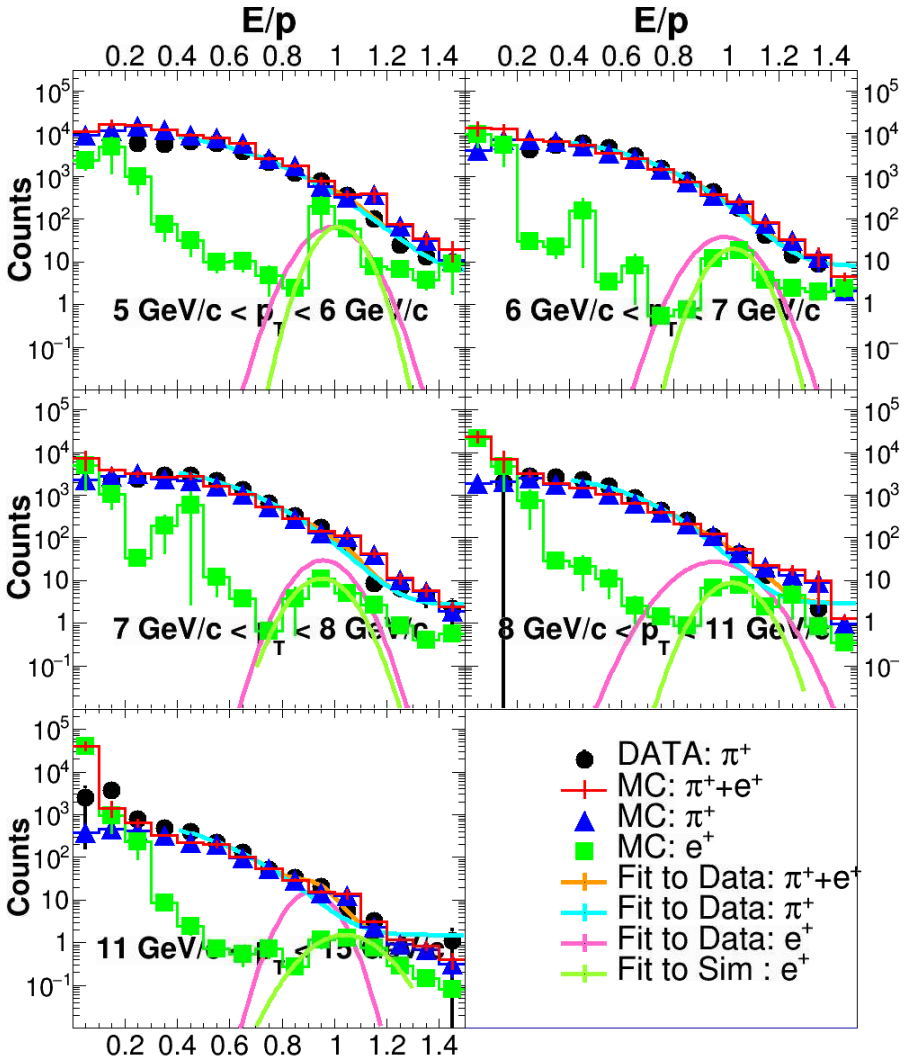
Charged pion background



Comparison of reconstructed particle momentum distributions as a function of the transverse momentum in the data and MC simulations.

- At low p_T below 5 GeV/c the distribution is dominated by electrons (kaons and protons is insignificant)
- At higher p_T, electrons are the dominant background.

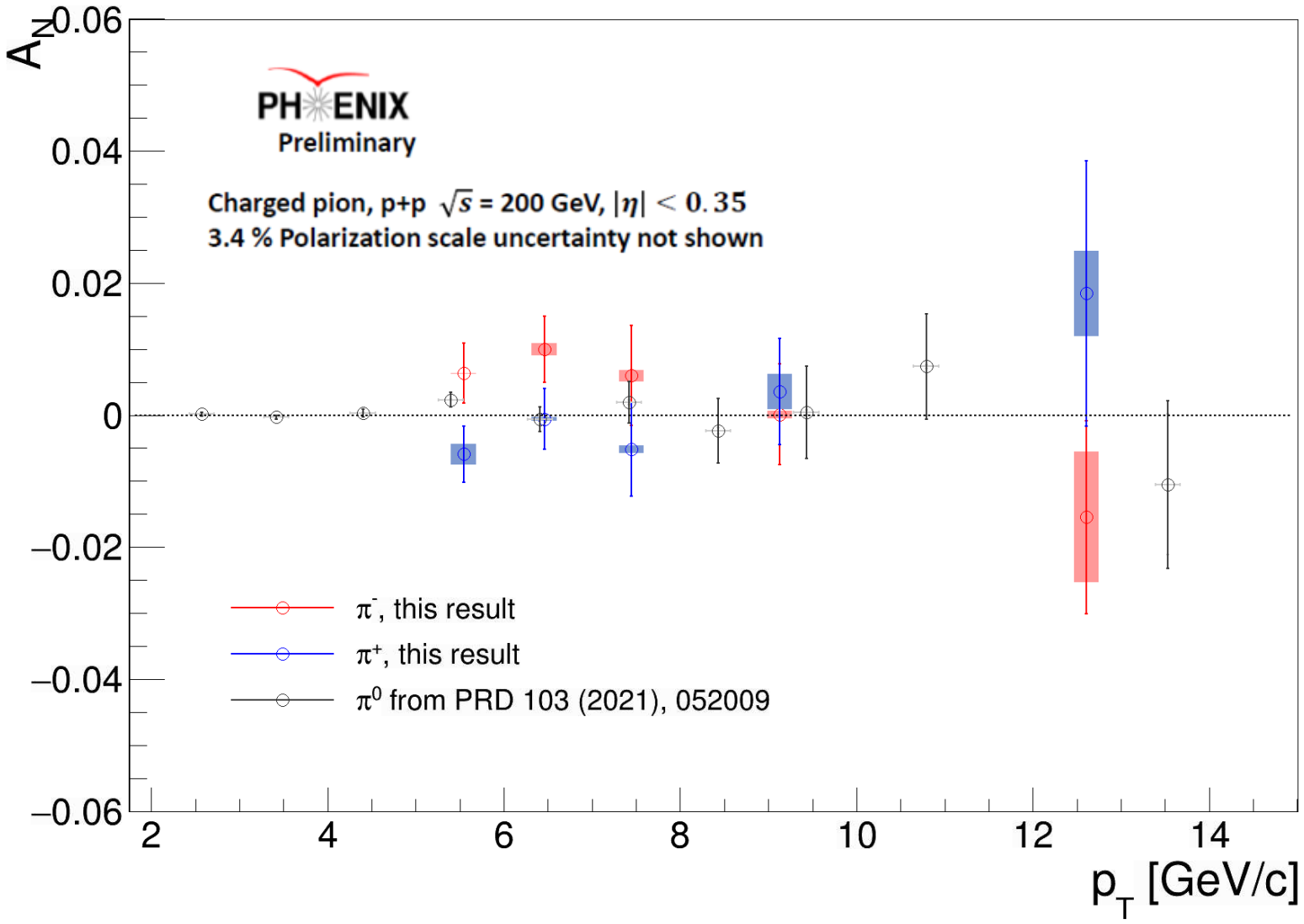
Charged pion background



Energy over momentum ratio for pion candidates in bins of transverse momentum.

- e/p < 0.2 , electrons from photon conversion decay-in-flight are reconstructed with higher p_T
- e/p > 0.8 , considering that most pions do not deposit all their energy in the electromagnetic calorimeter in contrast to electrons.
- Calibrate electron background fraction from simulation by fitting E/p peak to data
- Correct for electron background using asymmetries from electron enhanced data sample

Charged Pion A_N

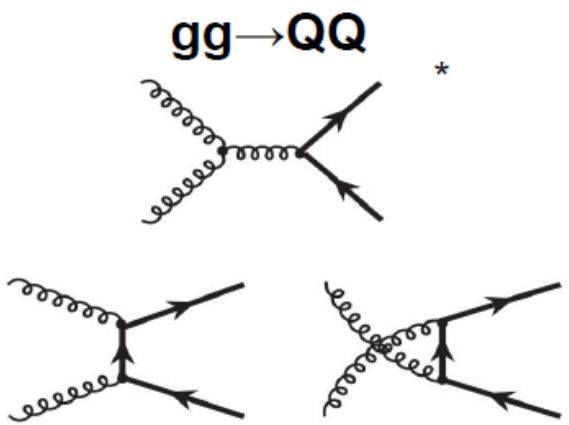


- First central charged pion AN measurement at PHENIX
- A_N of each charge consistent with zero
- But slight indication of differences with each other. (particularly low P_T region)

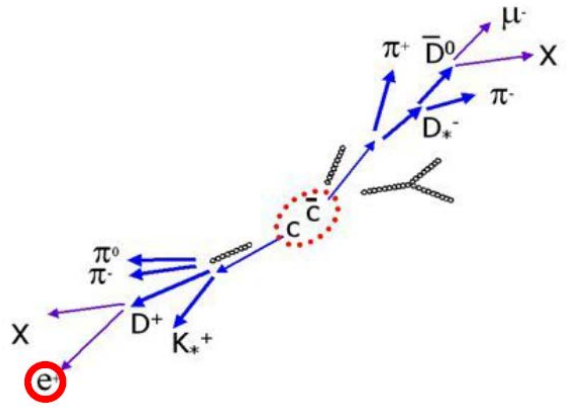
Hint of different asymmetries from up and down quarks

Open Heavy Flavor $e^{\pm}$ Production

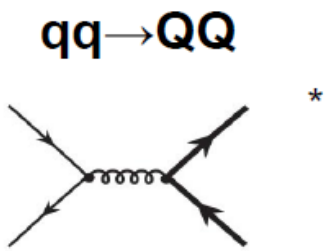
- **Open charm production is dominant contribution**



Dominant contribution @ 200 GeV midrapidity
- ggg correlator **not** well constrained from previous measurements



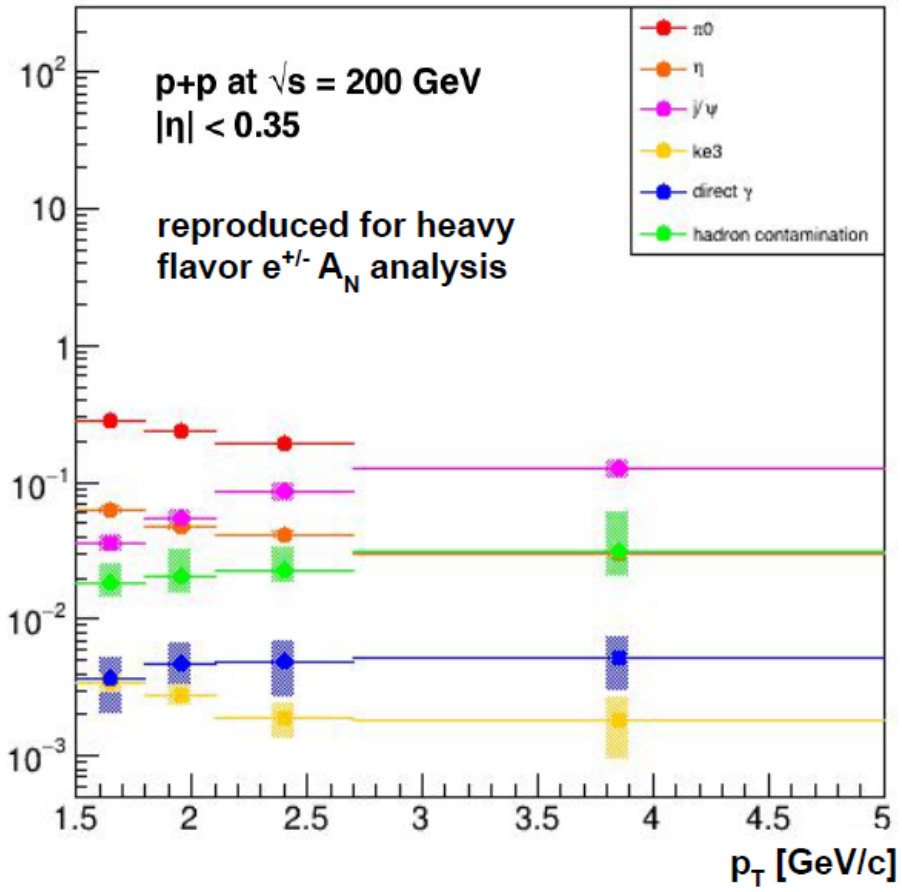
gluon transversity distributions = 0
→ access to trigluon correlator



Small contribution @ 200 GeV Midrapidity
- qgq correlator somewhat constrained from previous measurements

Open Heavy Flavor $e^{\pm}$(background)

Heavy flavor electron background fraction

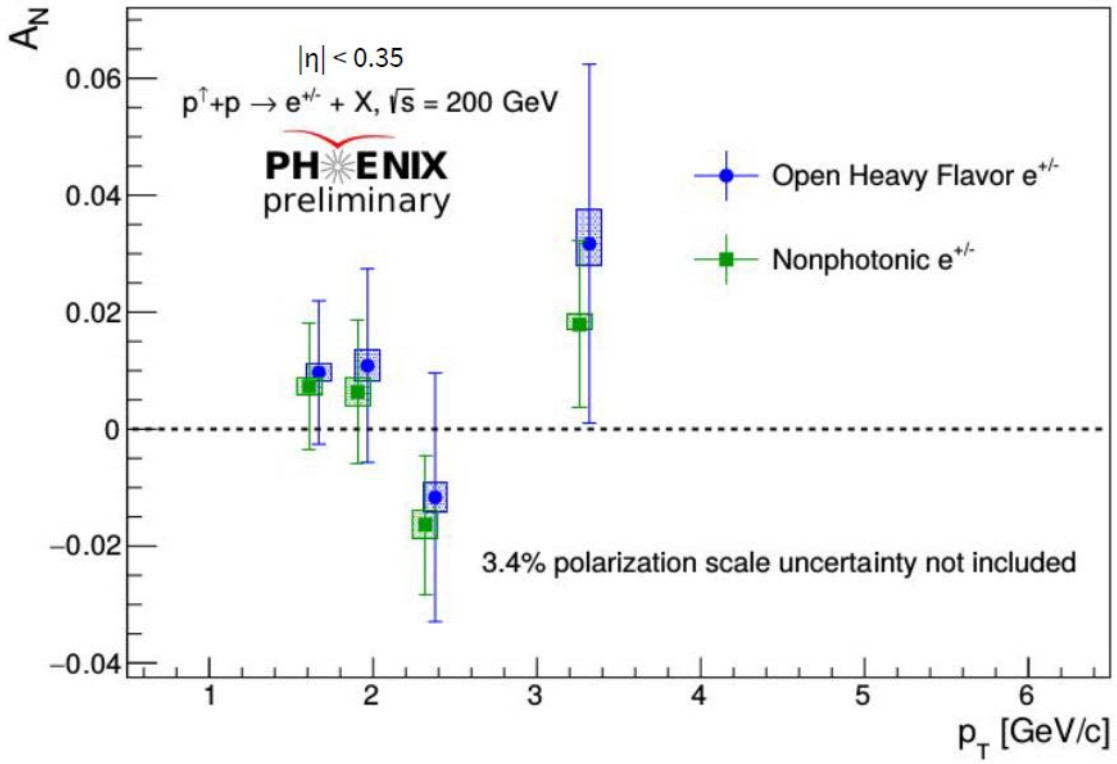


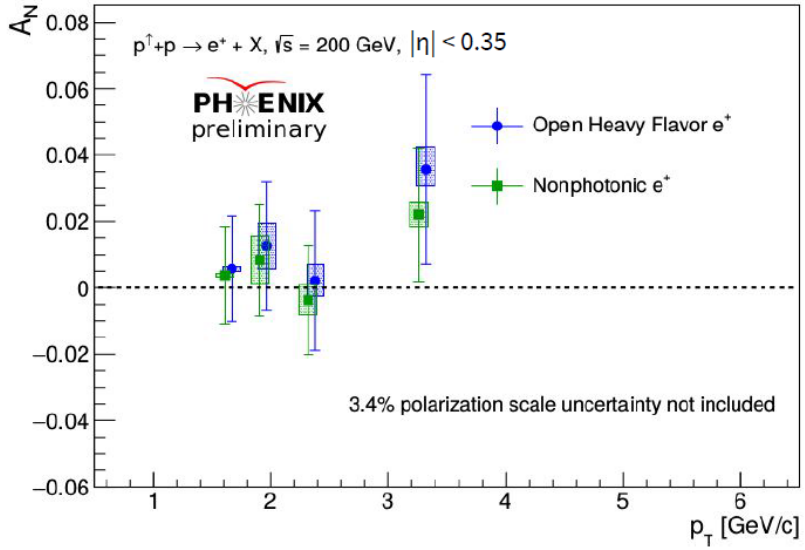
- Largest contribution from photonic electron background sources (π0+ η + γ) at pT < 3 GeV/c
  - Asymmetries for these sources well constrained to be zero at 200 GeV midrapidity

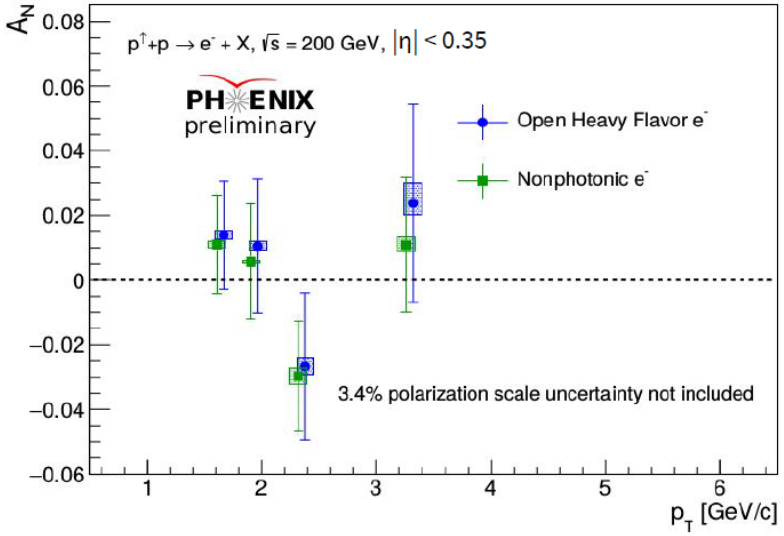
- Largest contribution from J/ψ at pT > 3 GeV/c
  - σ_{AN} affected significantly in this region due to $A_N^{J/\psi}$ suffering from large statistical uncertainty

See also D. Fitzgerald at DIS2021

Open Heavy Flavor Electron AN

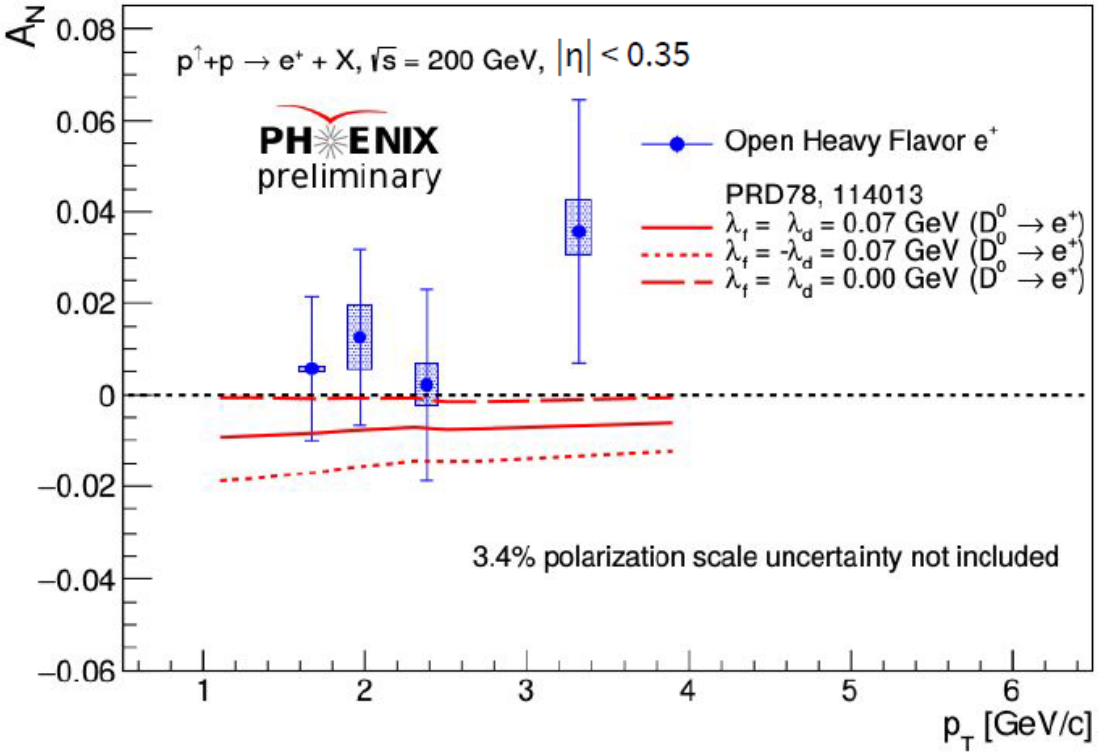


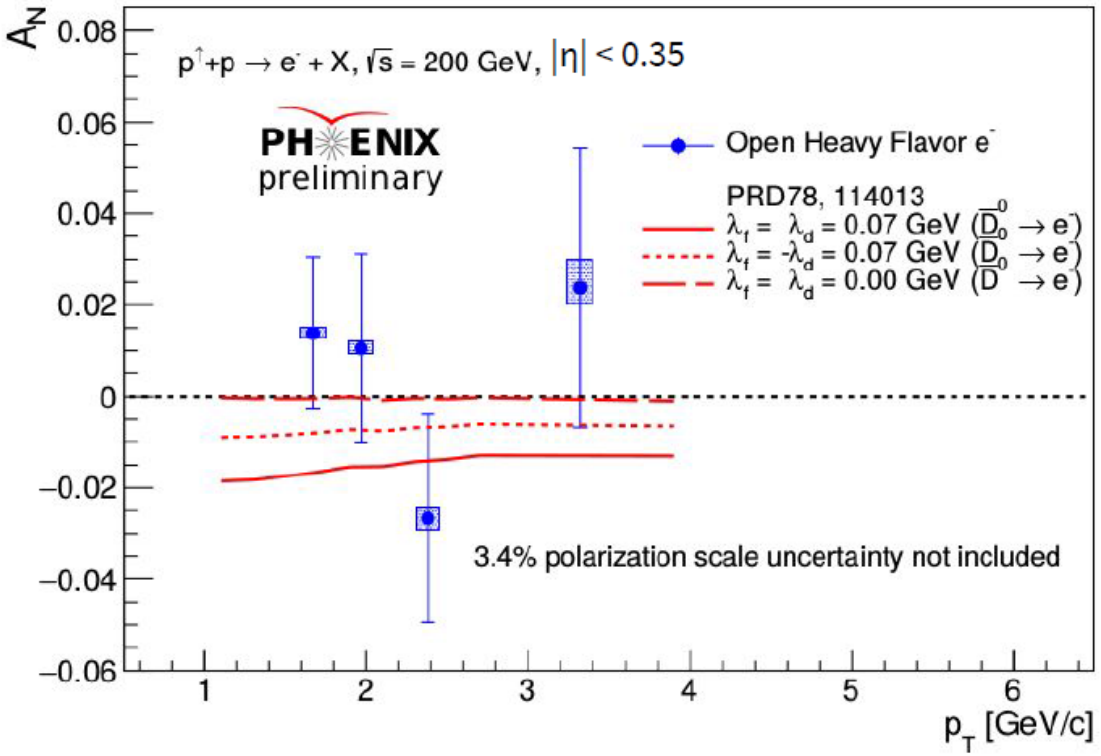




- First result of open heavy flavor and nonphotonic electron TSSA at midrapidity
- Consistent with zero in measured range

Open Heavy Flavor Electron A_N





- Red line: $D^0 \rightarrow e^{\pm}$ A_N calculations
- sensitivity to different parameters from charge separated asymmetries

Summary

- **First A_N measurements of $\pi^{\pm}$ at midrapidity**

- A_N in $\pi^{\pm}$ production are sensitive to quark flavors.

- With a complementary probe with improved statistics, might help to check the up and down quarks make a different asymmetries.

- It expands π^{+} and π^{-} for each quarks flavor.

- **First open heavy flavor $e^{\pm}$ A_N result to be published**

- p ↑ + p, $\sqrt{s}$ = 200 GeV, $|\eta| < 0.35$

- Consistent with zero in measured range

- Charge separated results sensitive to different parameterizations

Thank you.