# Transverse Spin Asymmetry Results from PHENIX

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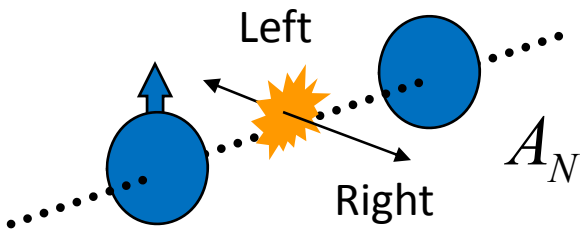
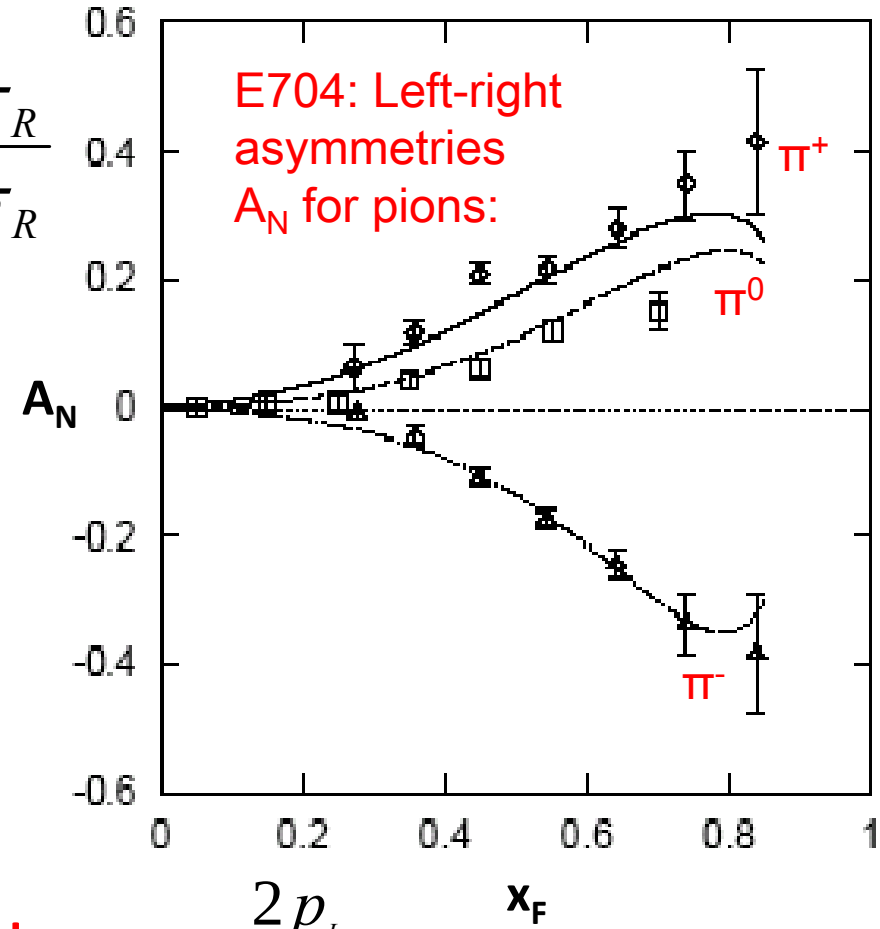
for the PHENIX Collabration

# Single Transverse Spin Asymmetries




$$A_N = \frac{1}{P}\frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$




**Theory Expectation (twist-2):**

Small asymmetries at high energies
(Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978) )

$$A_N \propto \frac{m_q}{\sqrt{s}}$$

**$A_N$ ~O(0.1%) Theory**

**Experiment:**

(E704, Fermi National Laboratory, 1991)

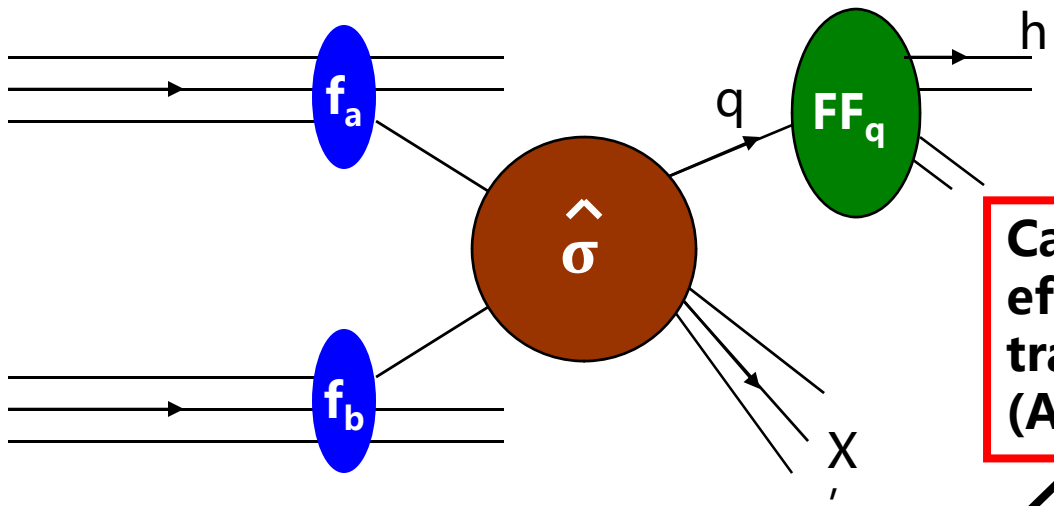
$$pp^{\uparrow} \rightarrow \pi + X$$

$$\sqrt{s} = 20\,\mathrm{GeV}$$

**$A_N$ ~O(10%) Measured**

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

# Possible Origin of Large SSAs




**Can initial and/or final state effects generate large transverse spin asymmetries? ($A_N$ ~$10^{-1}$)**

Proton Structure

pQCD

$$\frac{d^3\sigma^{\uparrow}\left(pp^{\uparrow}\rightarrow\pi^{+}X\right)}{dx_1dx_2dz}\propto q_i^{\uparrow}(x_1,k_{q,T})\cdot G(x_2)\times\frac{d^3\hat{\sigma}^{\uparrow}(q_iq_j\rightarrow q_kq_l)}{dx_1dx_2}\times FF_{q_{k,l}}(z,p_{h,T})$$

small spin dependence

fragmentation function

# Mechanisms in QCD

**TMD mechanism: GPM includes intrinsic transverse momentum**

Possible Expansion:

$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \propto f_{1T}^{\perp} \otimes D_1 + \delta q \otimes H_1^{\perp} + \ldots$$

Sivers Function (angular momentum) → Sivers Effect

Transversity (structure)

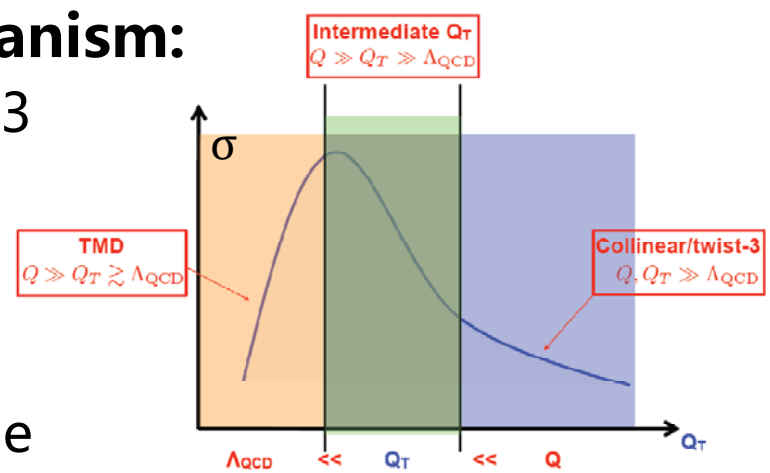
Collins Function (Fragmentation) → Collins Effect

**Twist-3 Collinear factorization mechanism:**

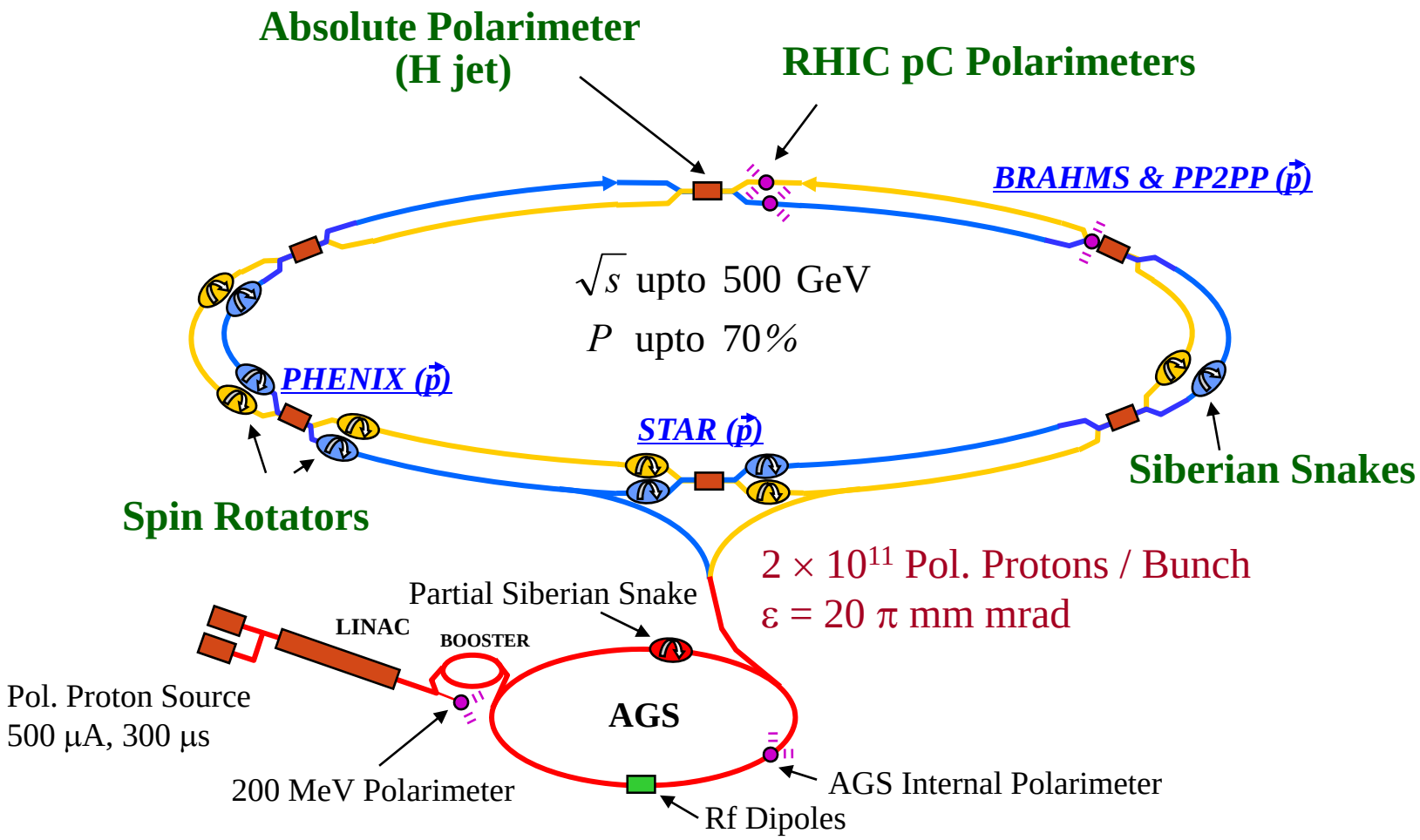
At high transverse momenta : two twist-3 correlation functions

1. Quark-gluon correlation function $T_{q,f}$
2. Two independent trigluon correlation functions $T_G^{(f)}, T_G^{(d)}$

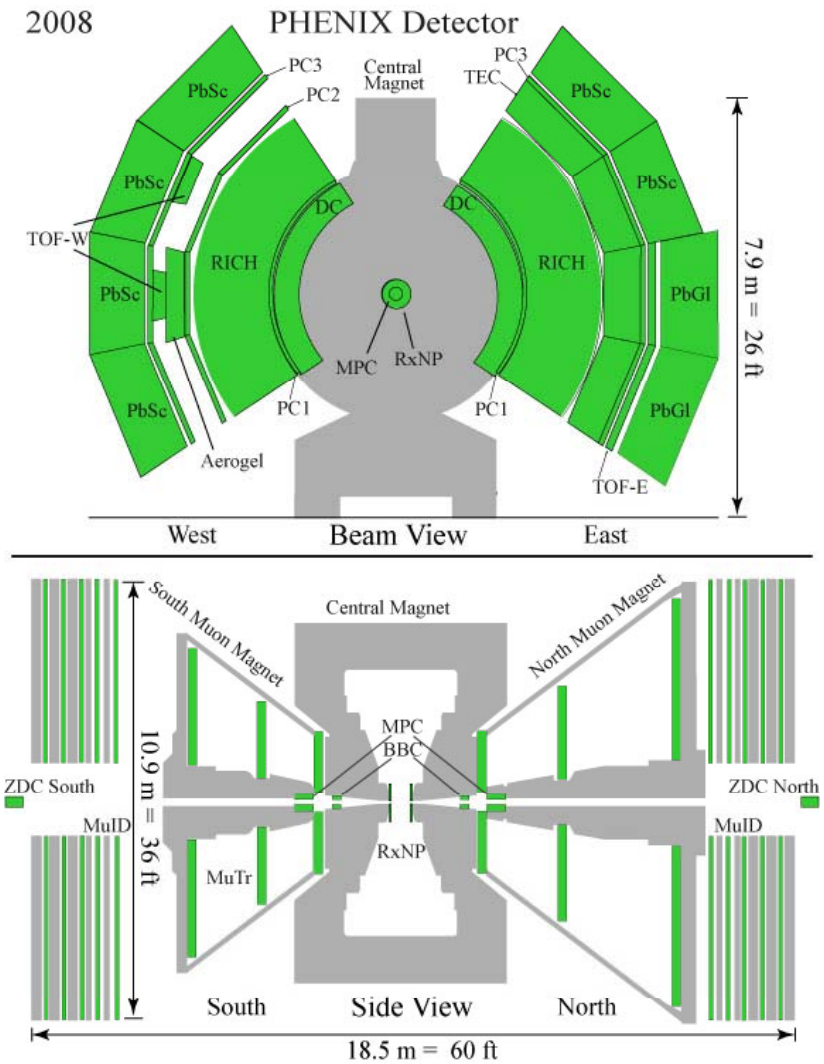
$T_{q,f}, T_G^{(d)}$ related to a moment in $k^{\perp}$ of the corresponding quark/gluon Sivers function



# RHIC as Polarized Proton Collider



# PHENIX Detectors




**Central Arms** $|\eta| < 0.35$

- charged hadrons
- $\pi^0$, $\eta$
- direct photon
- $J/\Psi$
- heavy flavor

**Muon Arms** $1.2 < |\eta| < 2.4$

- $J/\Psi$
- charged hadrons
- heavy flavor

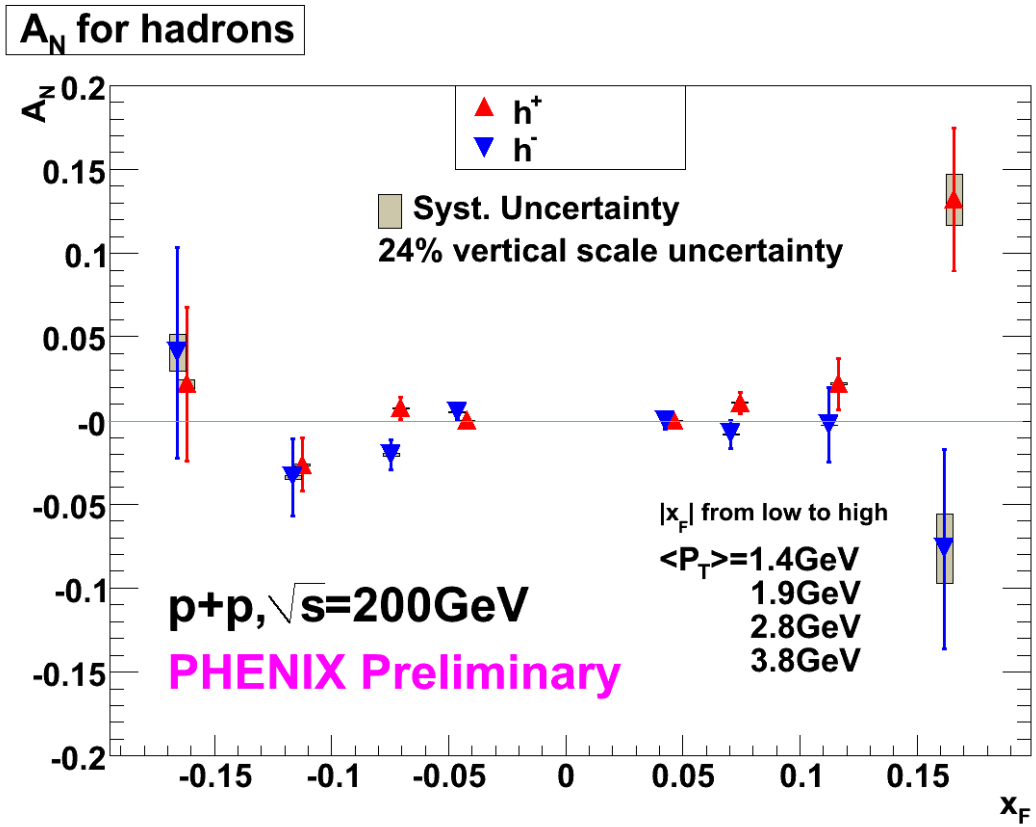
**MPC** $3.1 < |\eta| < 3.9$

- $\pi^0$, $\eta$

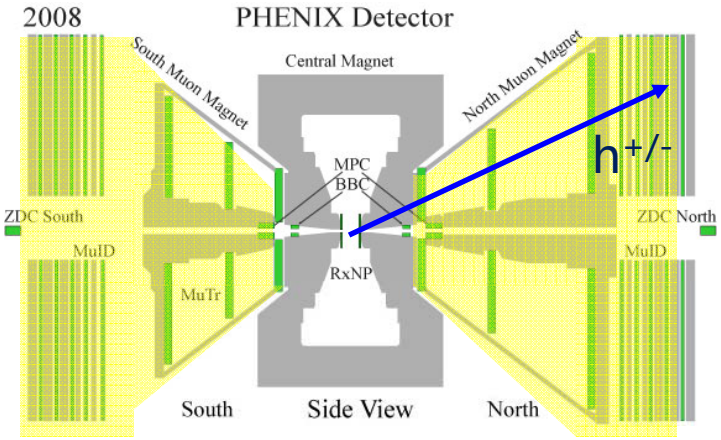
# Integrated Luminosity and Polarization

| Year of RHIC Run | Energy [GeV] | Polarization [%] | L [$pb^{-1}$] | $LP^2$ [$pb^{-1}$] |
|---|---|---|---|---|
| 2002 | 200 | 15 | 0.15 | $3.4 \times 10^{-3}$ |
| 2005 | 200 | 47 | 0.16 | $3.5 \times 10^{-2}$ |
| 2006 | 62.4 | 48 | 0.02 | $4.6 \times 10^{-3}$ |
| 2006 | 200 | 51 | 2.7 | $7.0 \times 10^{-1}$ |
| 2008 | 200 | 46 | 5.2 | $1.1 \times 10^{0}$ |

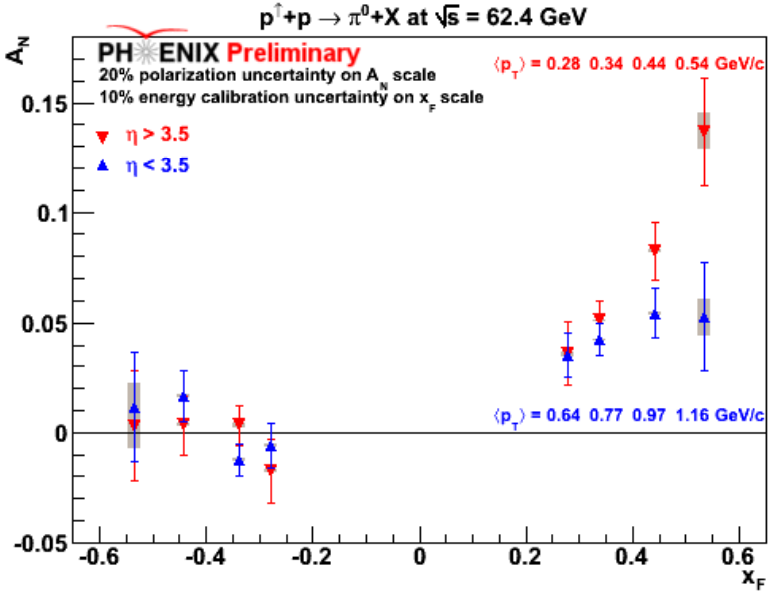
# Forward $A_N$ for Charged Hadrons



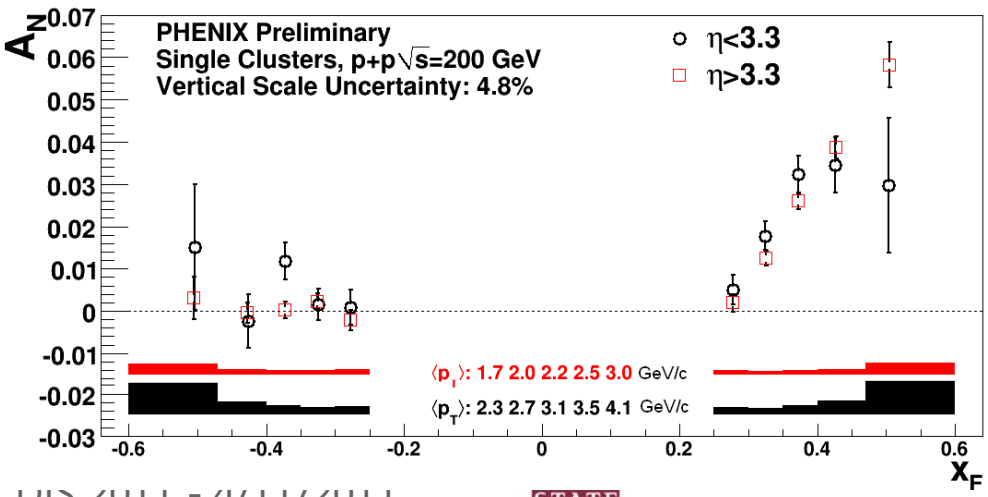

- Measured at Muon Arms $1.2<|\eta|<2.2$
- No PID – Unidentified charge hadrons

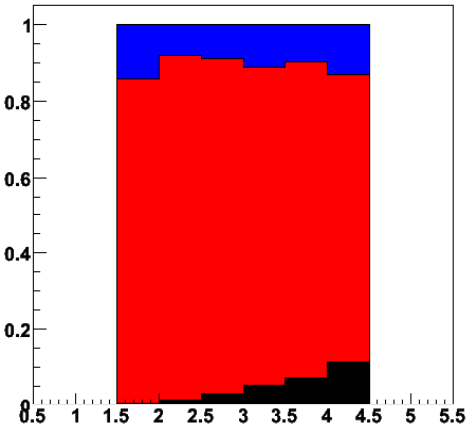


# Forward $A_N$ for Clusters (I)




- Measurements from MPC $3.1<|\eta|<3.7$
- Cluster contribution
  - Decay photon
  - $\pi^0$
  - Direct photon





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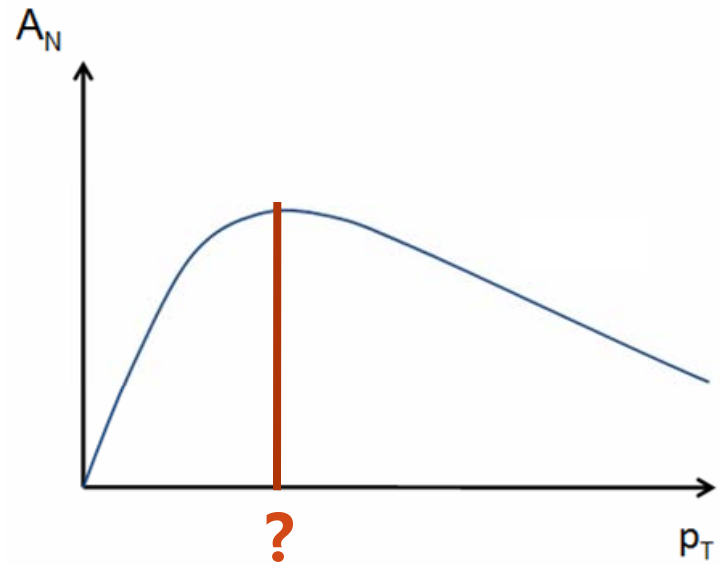
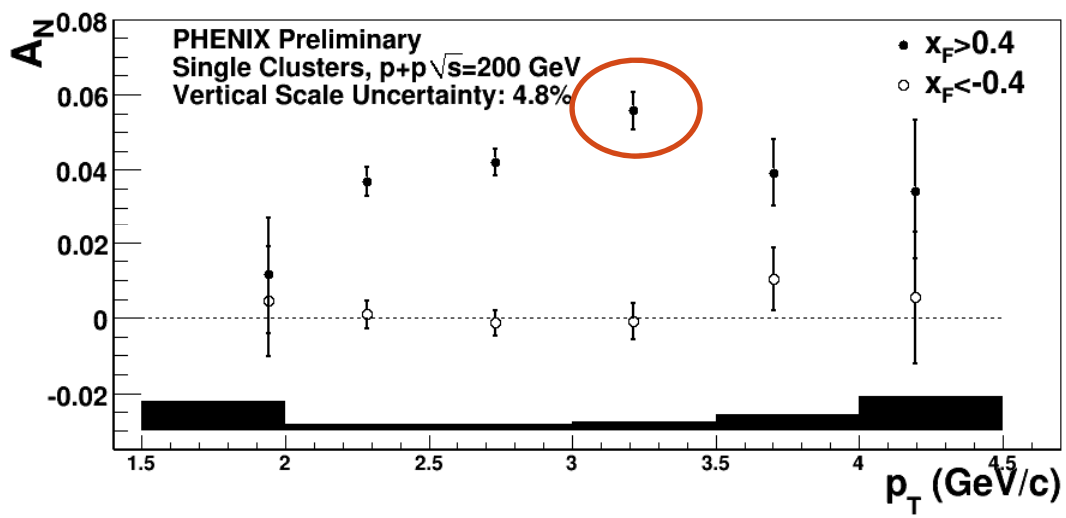
# Forward $A_N$ for Clusters (II)

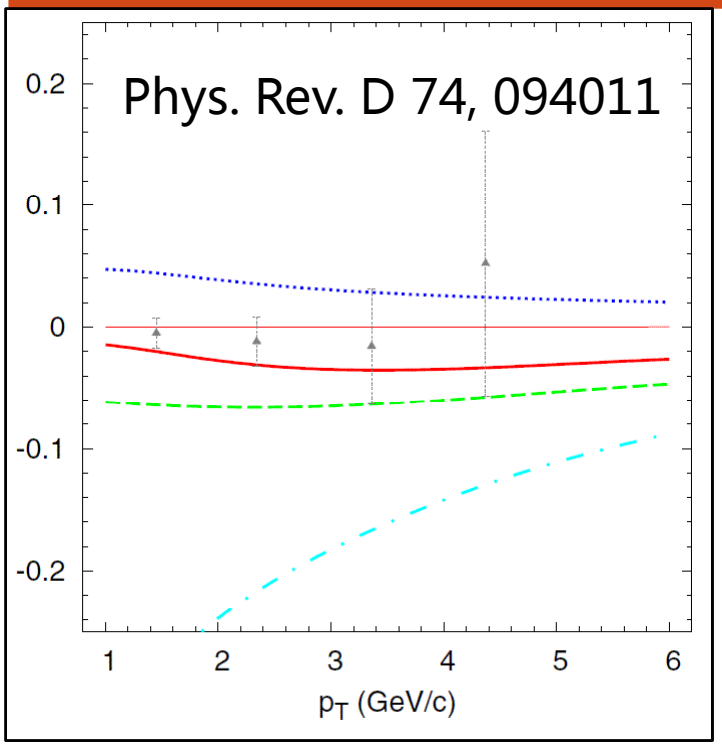
Twist-3 mechanism predicts that $A_N$ should drop when $p_T$ is large enough.



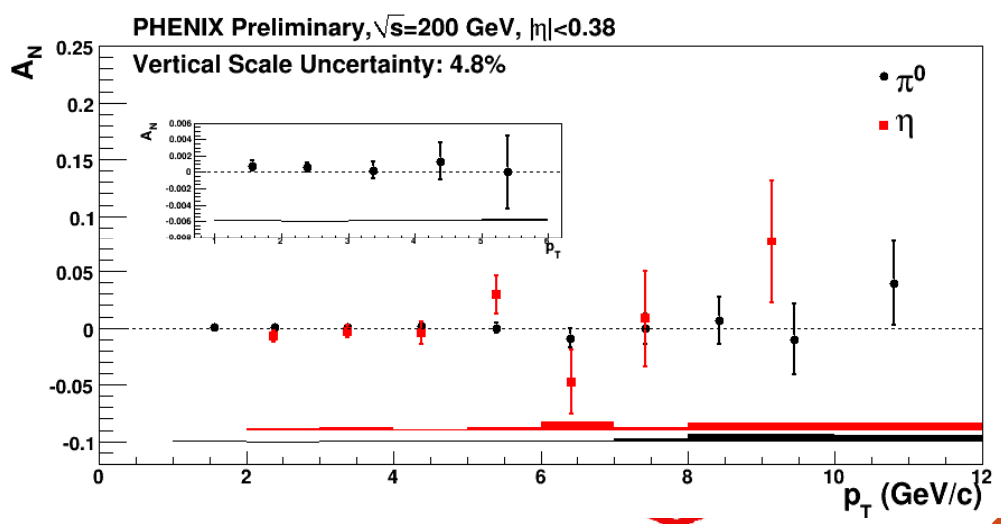

Forward cluster pT dependent $A_N$ shows the turning point.



# Mid-rapidity $A_N$ for $\pi^0$ and $\eta$




- gluon Sivers at positivity bound no sea quark Sivers
- gluon Sivers parameterized to be 1 sigma from PHENIX $\pi^0$ $A_N$
- sea quark maximized plus valence quarks
- gluon contribution




- LO model-dependent constraints on gluon Sivers function from PHENIX data at SMALL x



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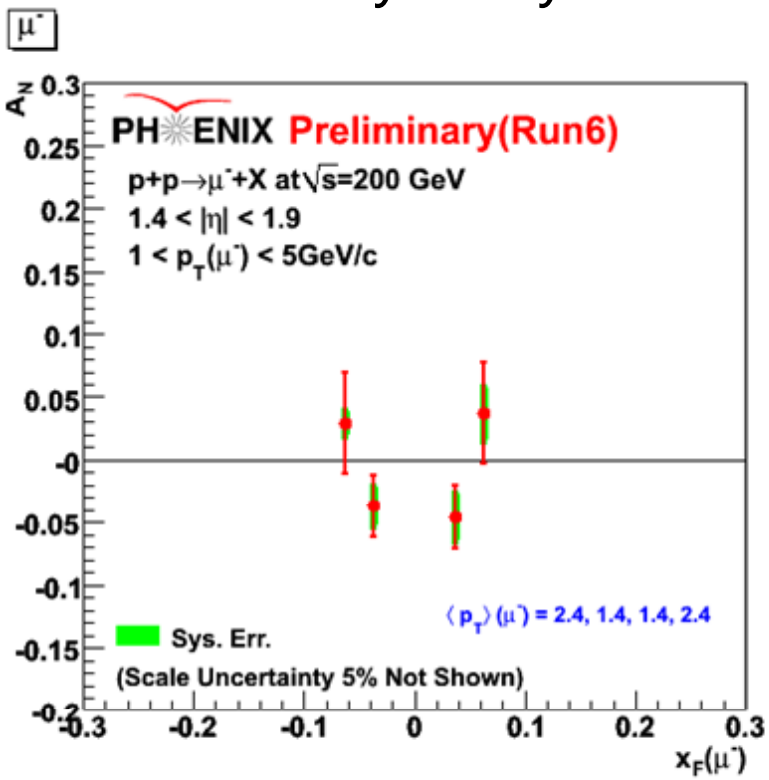
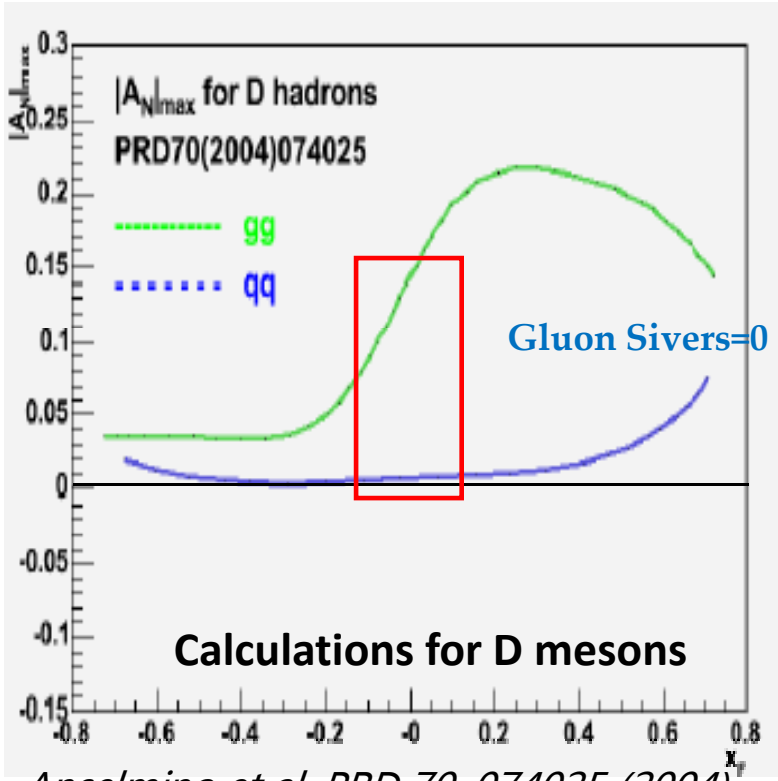
# $A_N$ for Heavy Flavor (I)

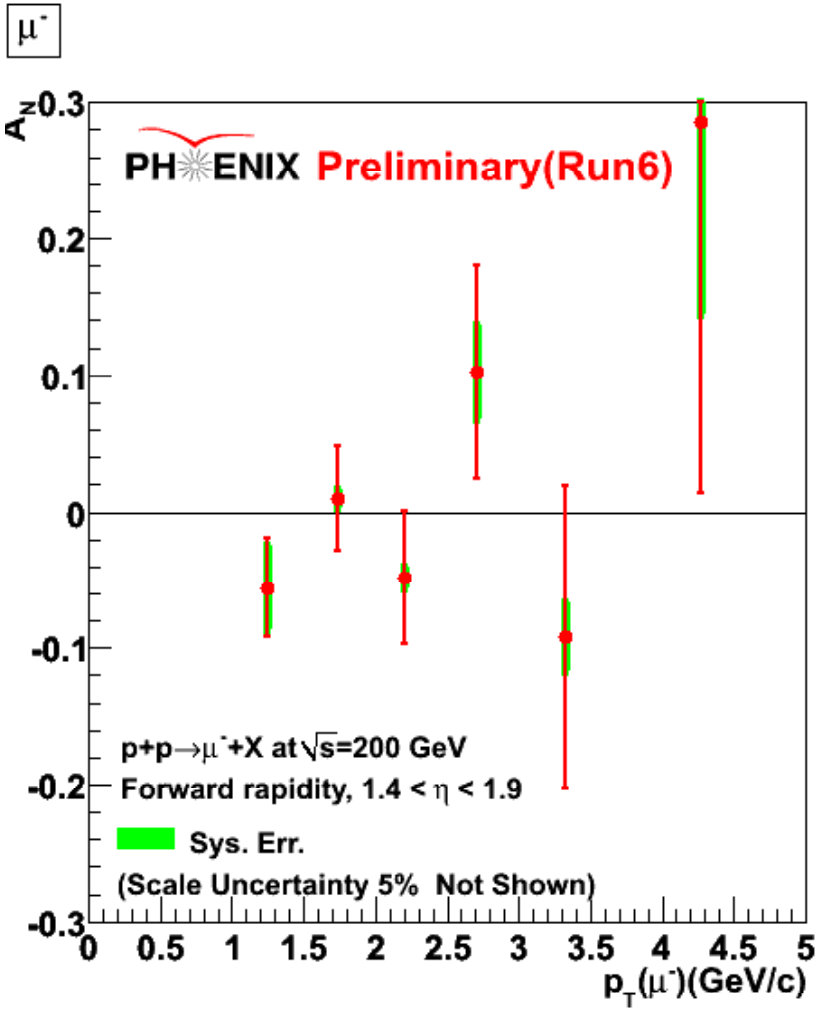
- D meson production dominated by gluon-gluon fusion at RHIC energy
- $A_N$ measured for muons from D decay
  - Smear by decay kinematics



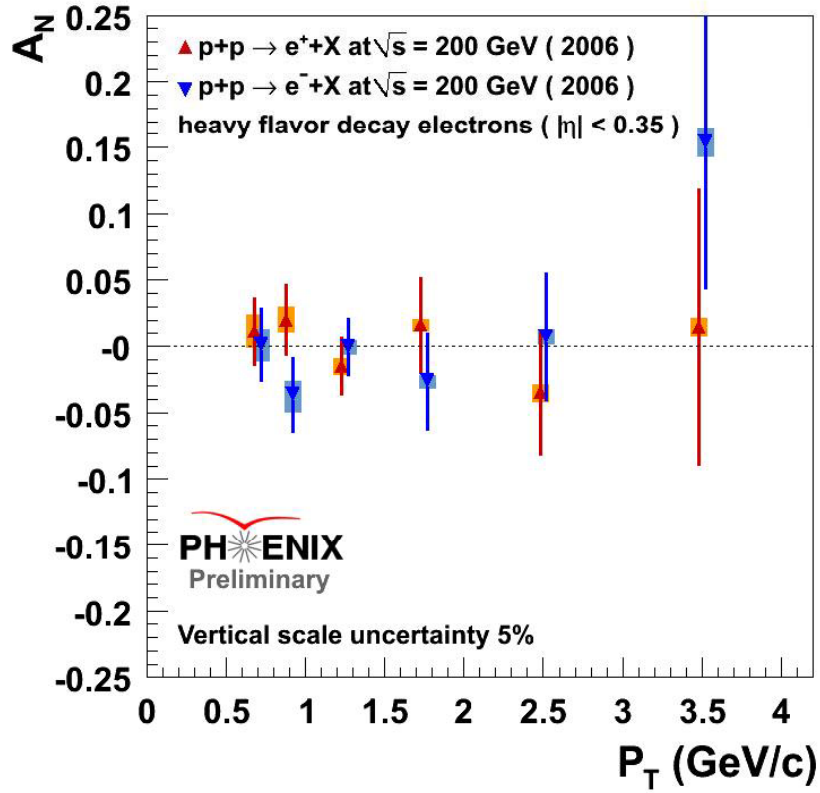




*Anselmino et al, PRD 70, 074025 (2004)*

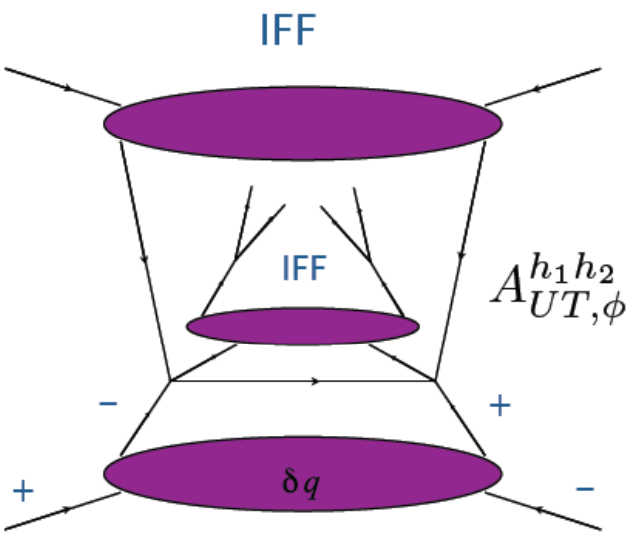
# $A_N$ for Heavy Flavor (II)



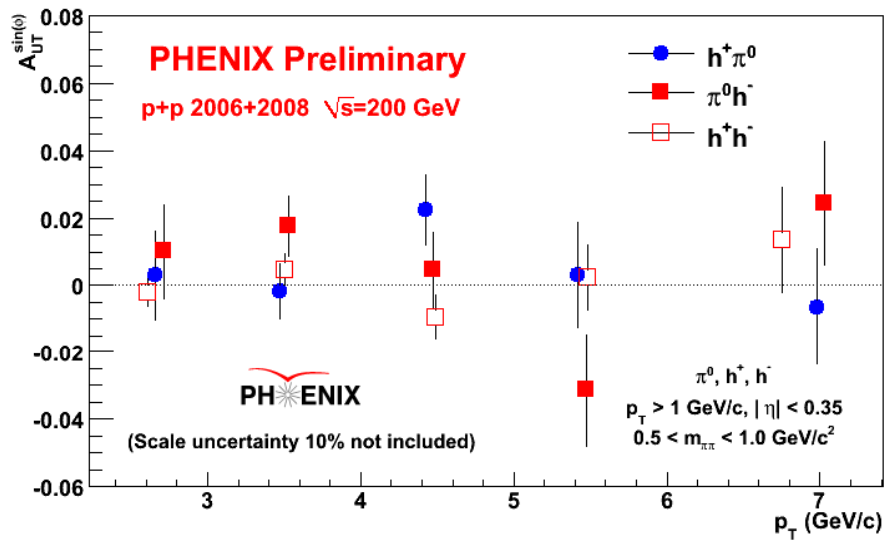

The result for electrons is consistent with that for muons

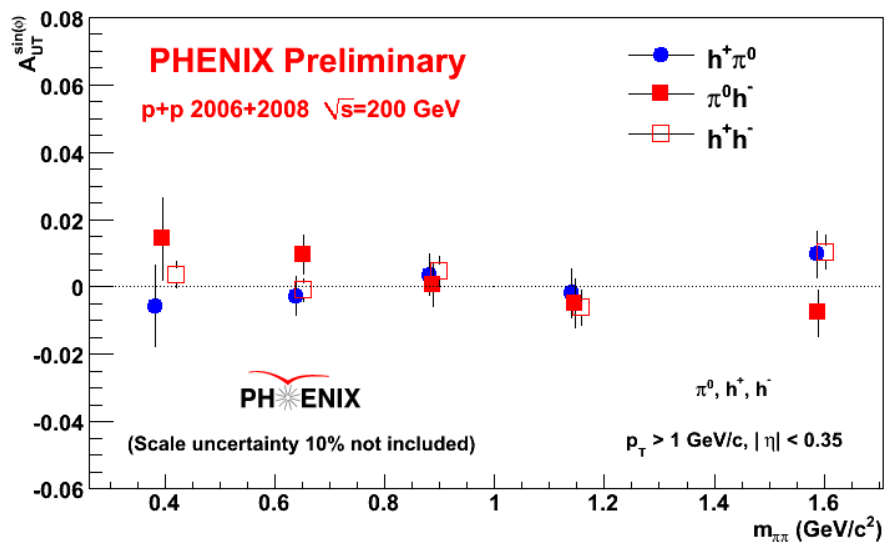


# Collins Function -- IFF Measurement




$$A_{UT,\phi}^{h_1 h_2} = \frac{\sigma_\phi^\uparrow - \sigma_\phi^\downarrow}{\sigma_\phi^\uparrow + \sigma_\phi^\downarrow}$$

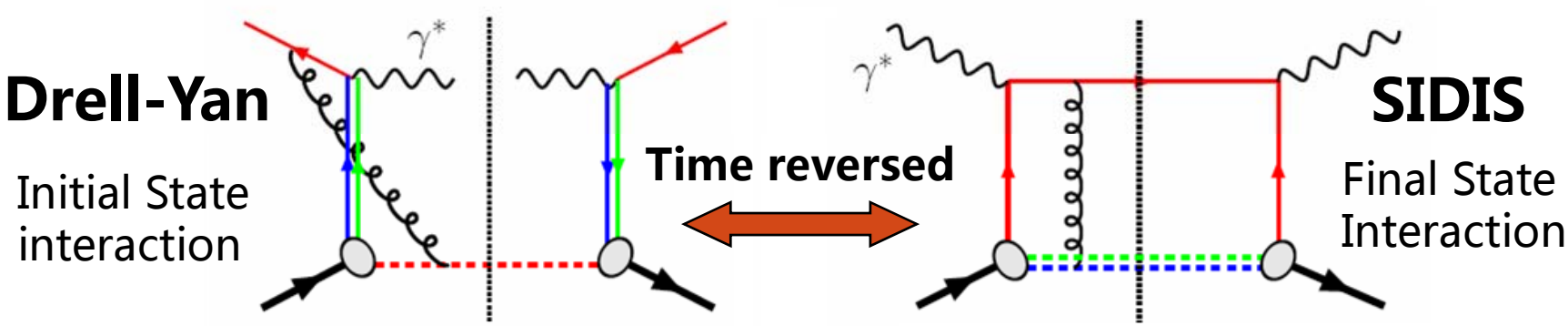



- Measure transversity ⊗ IFF
- No significant asymmetry seen at mid-rapidity
- Moving to more forward rapidities

# Drell-Yan Process

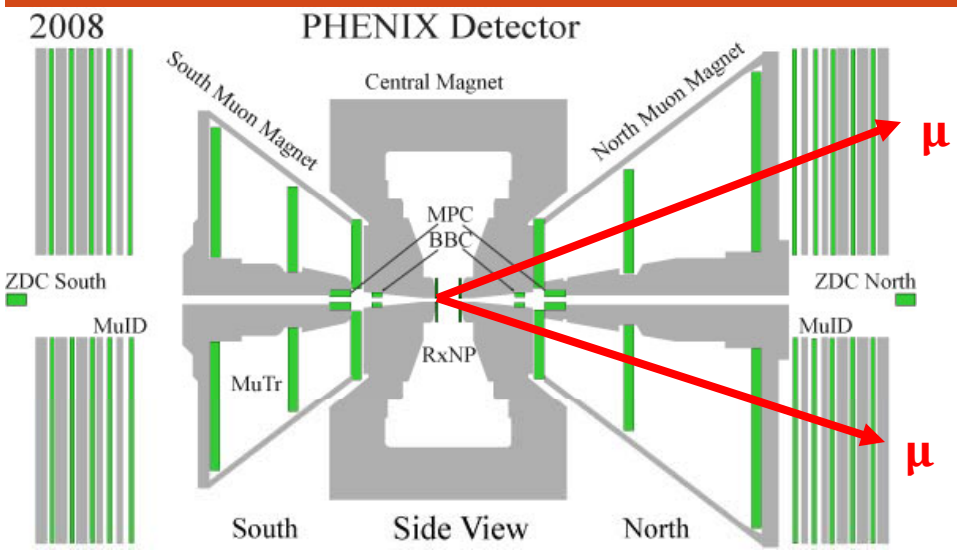
- No fragmentation (no Collins effect folded)
- TMD factorization is valid
- The Sivers function in DY is opposite to that in DIS which can test current SSA QCD mechanisms (TMD & Twist-3)
- $A_{TT}$ in Drell-Yan is sensitive to transversity!



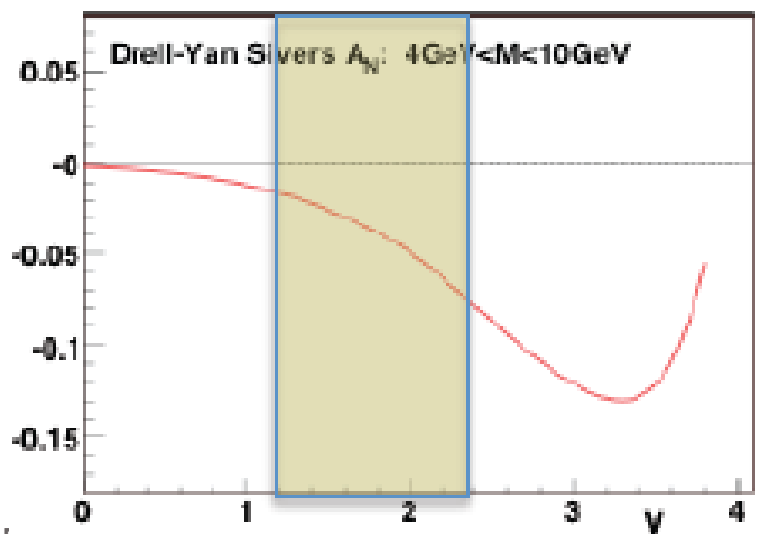

$$p + p \rightarrow l^+ + l^- + X \qquad\qquad l + p \rightarrow l + \pi + X$$

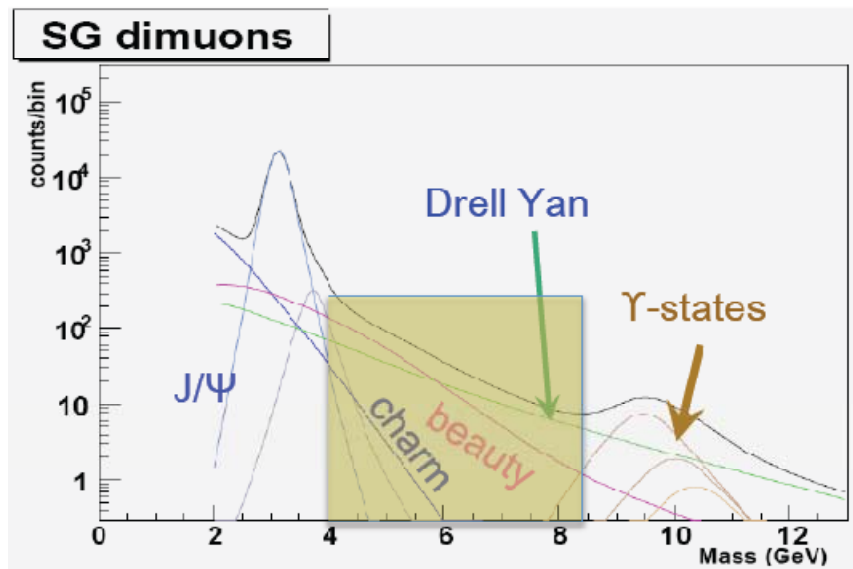
$$\Delta f_{1T}^{\perp}(x, \vec{k}_T^2)\,|_{\text{Drell-Yan}} = -\Delta f_{1T}^{\perp}(x, \vec{k}_T^2)\,|_{\text{SIDIS}}$$

# Drell-Yan Projection

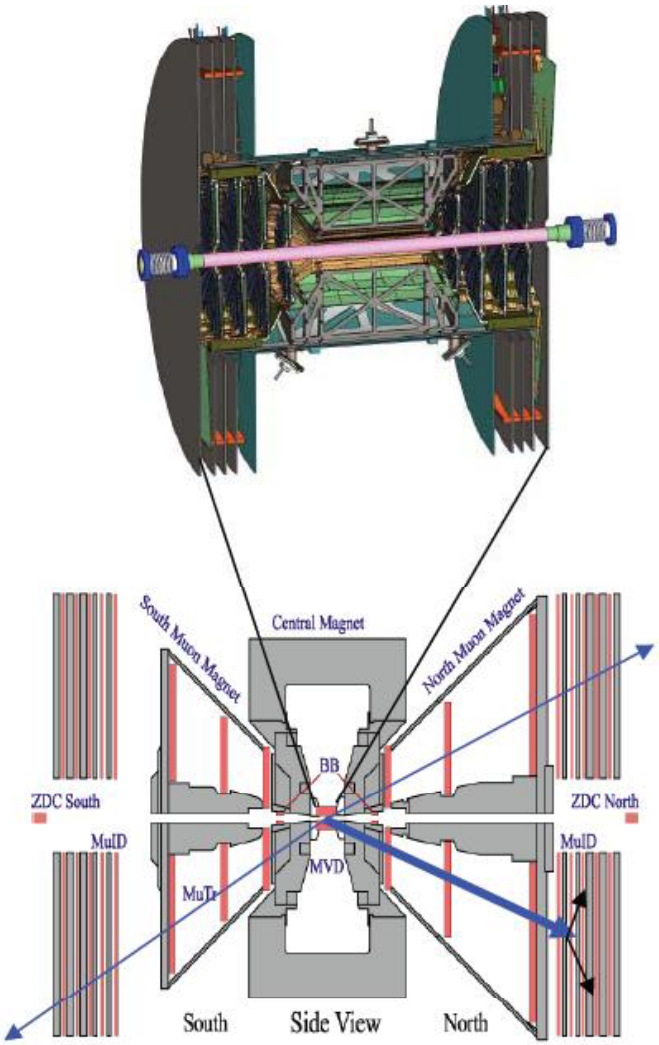



- Di-muon ($\mu^+\mu^-$) from Drell-Yan can be measured by muon arms.
- Average ~5% asymmetry
- 4< Mass < 8 GeV has relative smaller background, and major background comes from beauty decays muons.

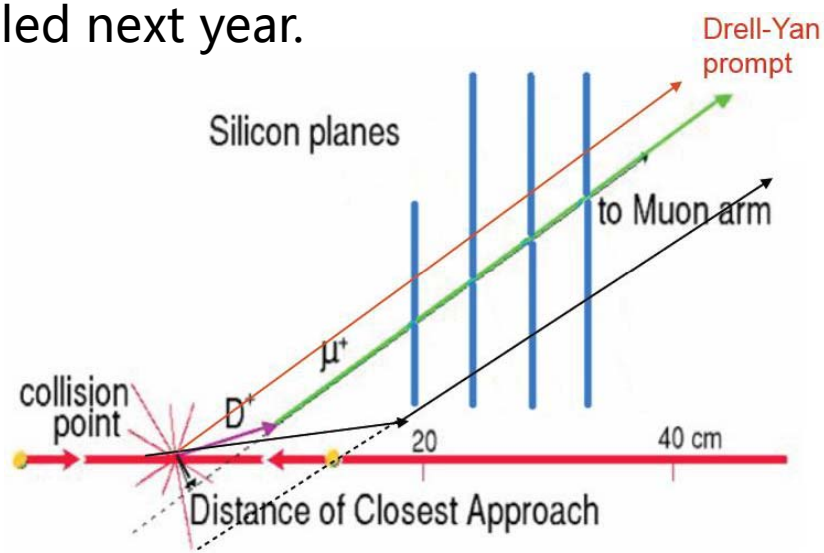


# PHENIX VTX & FVTX upgrade



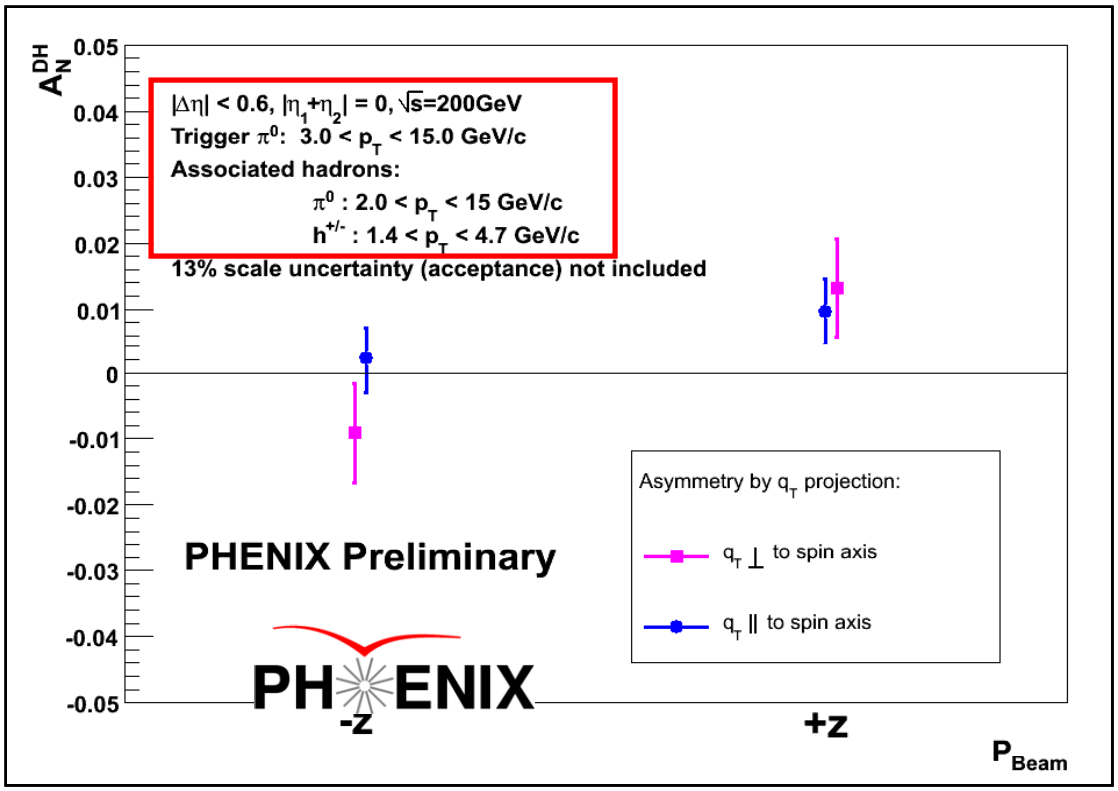

- 4 layers barrels (VTX) and endcaps (FVTX), cover $|\eta|<3$, resolution ~100um.
- Separating Drell-Yan from D, B mesons and $\pi$, K by DCA.
  - D, B travel ~1mm before decay
  - $\pi$, K have longer live decay.
- VTX has been installed this year, FVTX will be installed next year.



# Summary and Outlook

- Non-zero single transverse spin asymmetry at forward direction
- LO model-dependent constraints on gluon Sivers function from PHENIX mid-rapidity results
- To verify the relation between initial-state and final-state effects
  - Drell-Yan is the key
- Open questions concerning
  - TMD factorization
  - Universality (universality breakdown)
  - Process dependence (color forces)
  - Orbital angular momentum

# $A_N$ for Di-hadron




- Sivers asymmetry ($q_T\perp$)
- No asymmetry expected for $q_T\parallel$
- Improved statistics for 2008 data set!

TMD is not valid for back to back di-hadron process in p+p collision

Similar analysis possible in different combinations of rapidity

| | | | | | |
|---|---|---|---|---|---|
| $\eta_{min}$ | -3.7 | -2.4 | -0.35 | 1.2 | 3.1 |
| $\eta_{max}$ | -3.1 | -1.2 | +0.35 | 2.4 | 3.9 |