XIV Workshop on High Energy Spin Physics

September 20-24, 2011

Dubna, Russia

Transverse Spin Physics in PHENIX

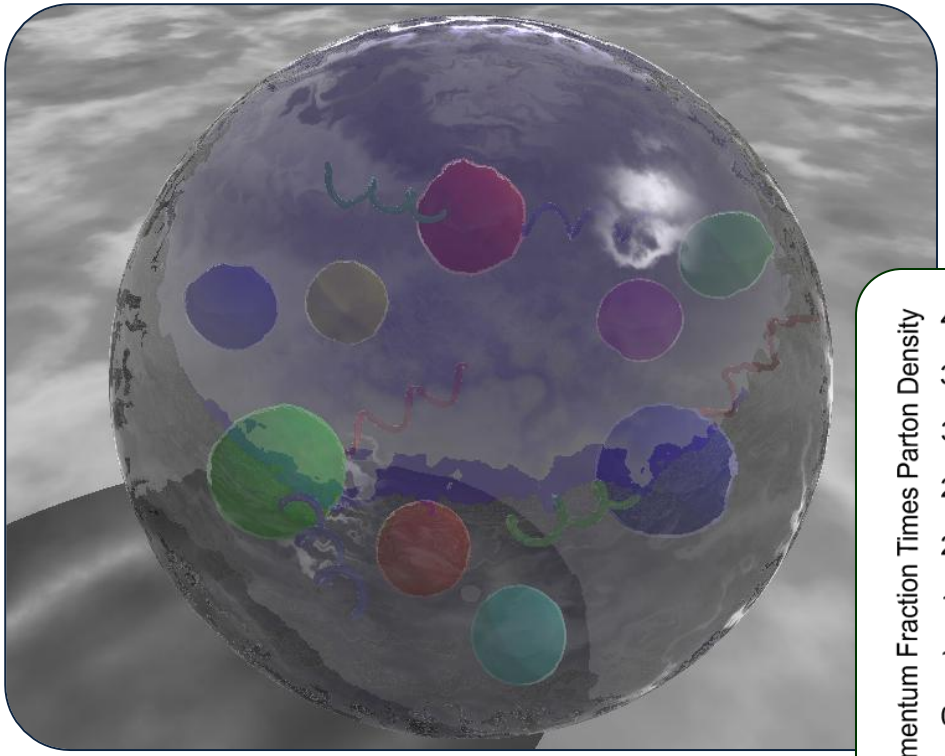
K. Oleg Eyser

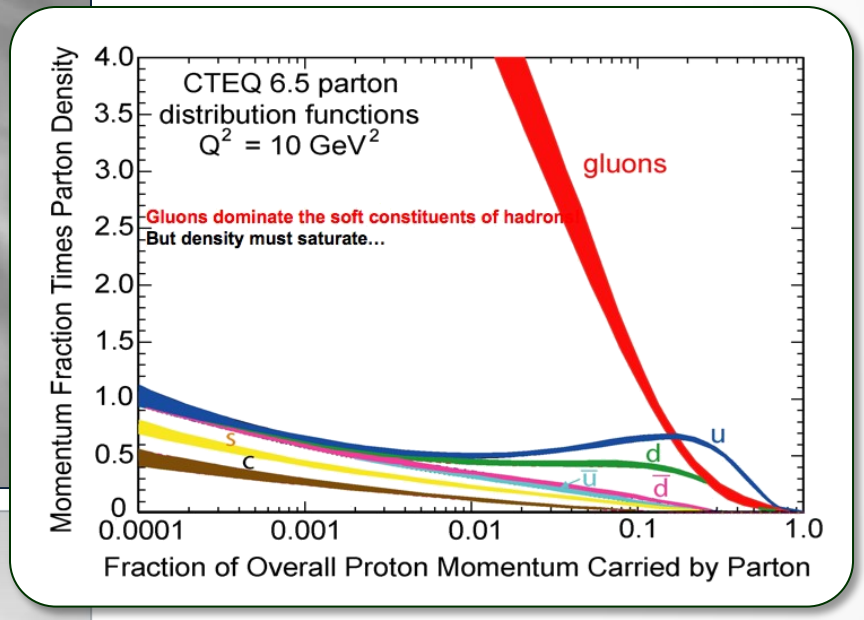
for the

PHENIX collaboration

UNIVERSITY OF CALIFORNIA UC RIVERSIDE

The Proton Structure



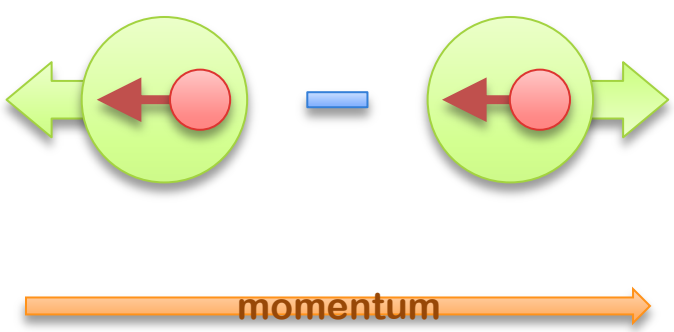


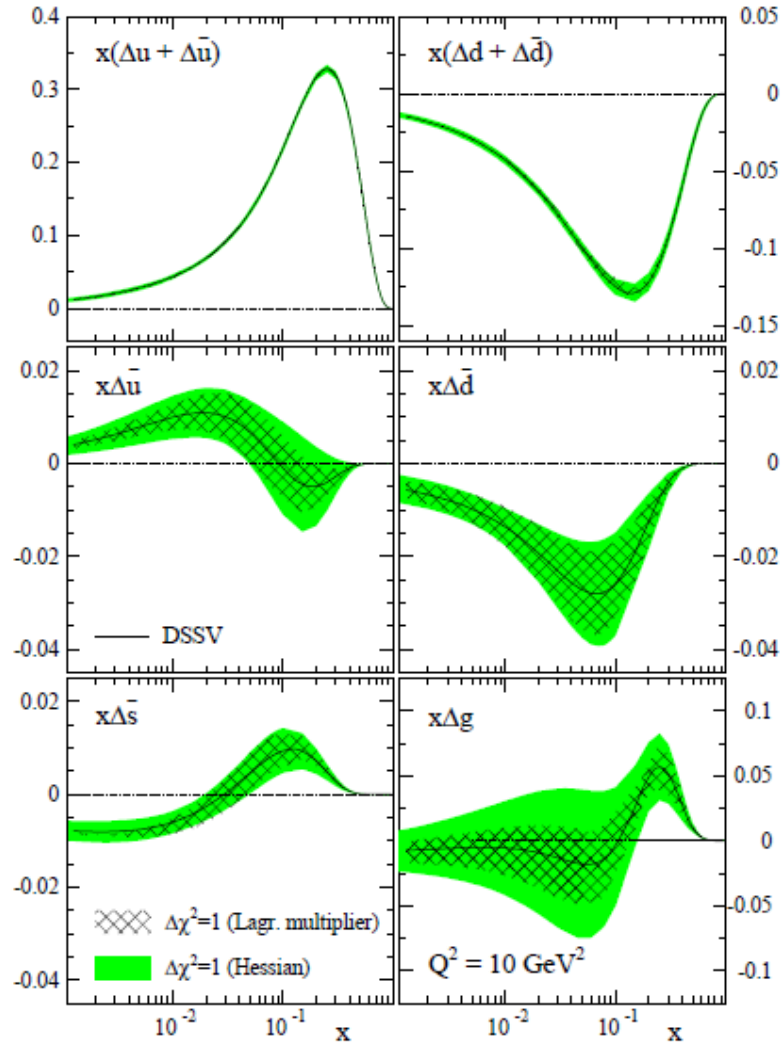
$$\frac{1}{2}\hbar = \frac{1}{2}(\Delta u + \Delta d)\hbar$$

$$\Sigma = \Delta u + \Delta d = 0.33 \pm 0.03_{stat} \pm 0.05_{syst}$$

The Proton Spin Structure

- **Polarization experiments**
  - **Helicity**
    - Valence quarks
    - Sea quarks
    - Gluons

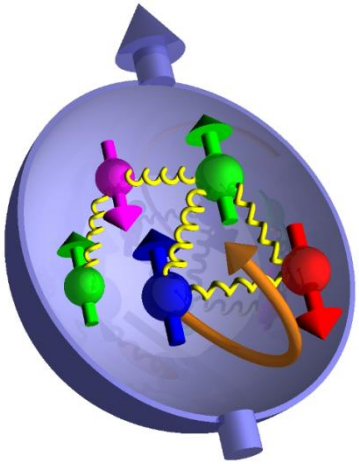


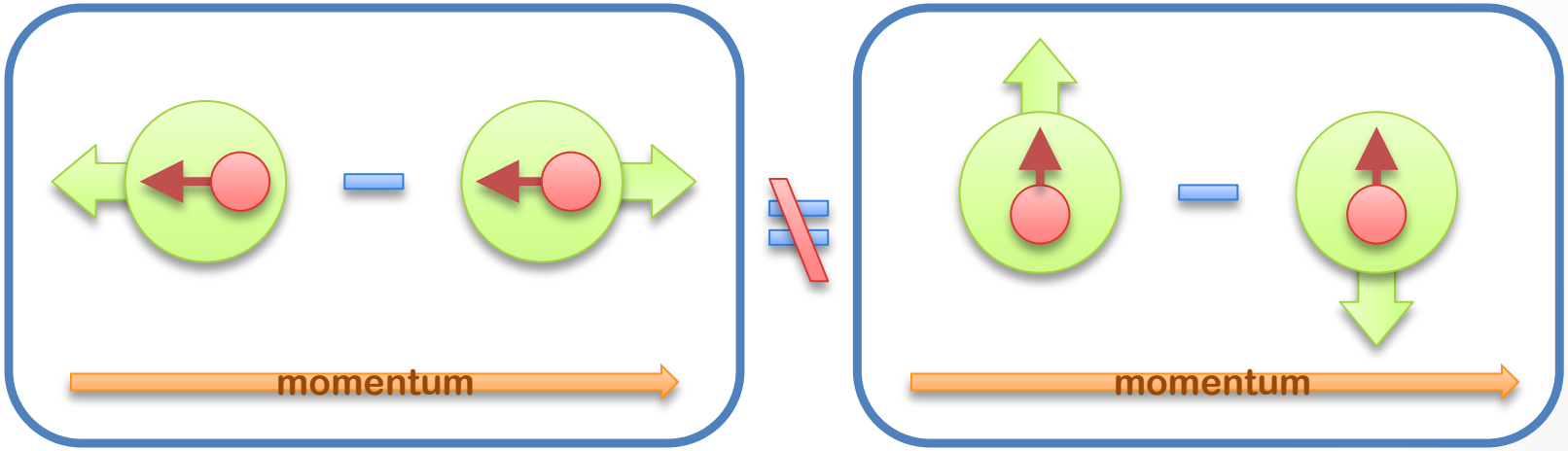


DSSV arXiv:0904.3821

The Proton Spin Structure

- Polarization experiments
  - Helicity
    - Valence quarks
    - Sea quarks
    - Gluons
  - Transversity

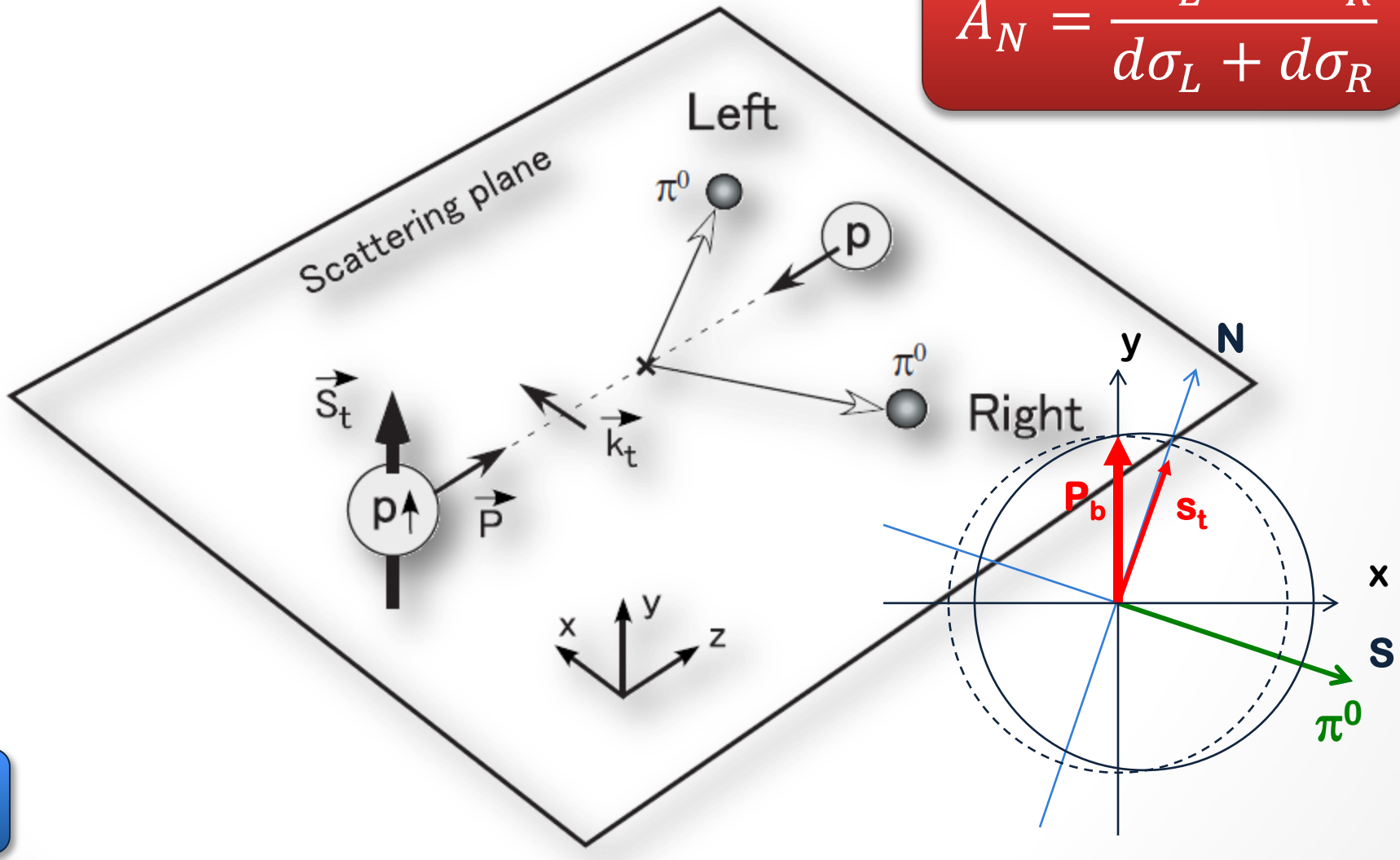




What is the connection to orbital angular momentum?

Transverse Spin Asymmetries

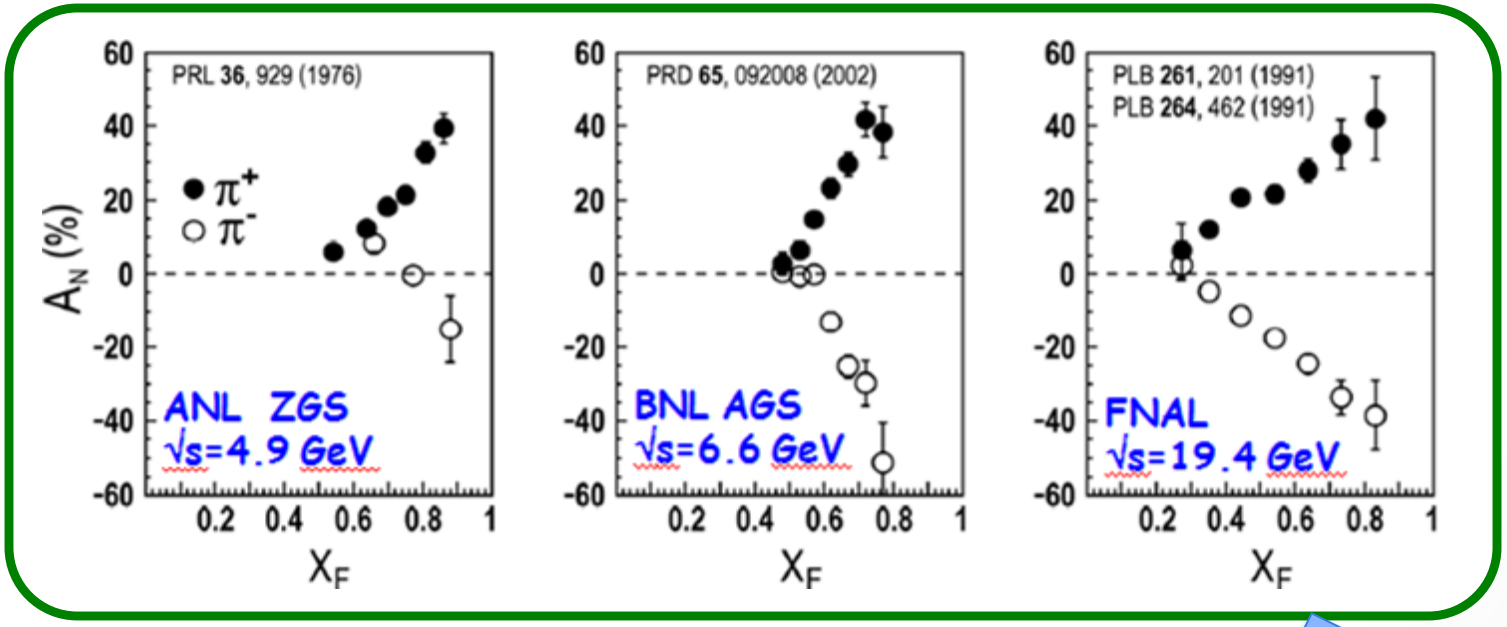
$$A_N = \frac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R}$$



Transverse Spin Asymmetries

- In (collinear) pQCD A_N suppressed by $m_q \alpha_s / p_\perp$

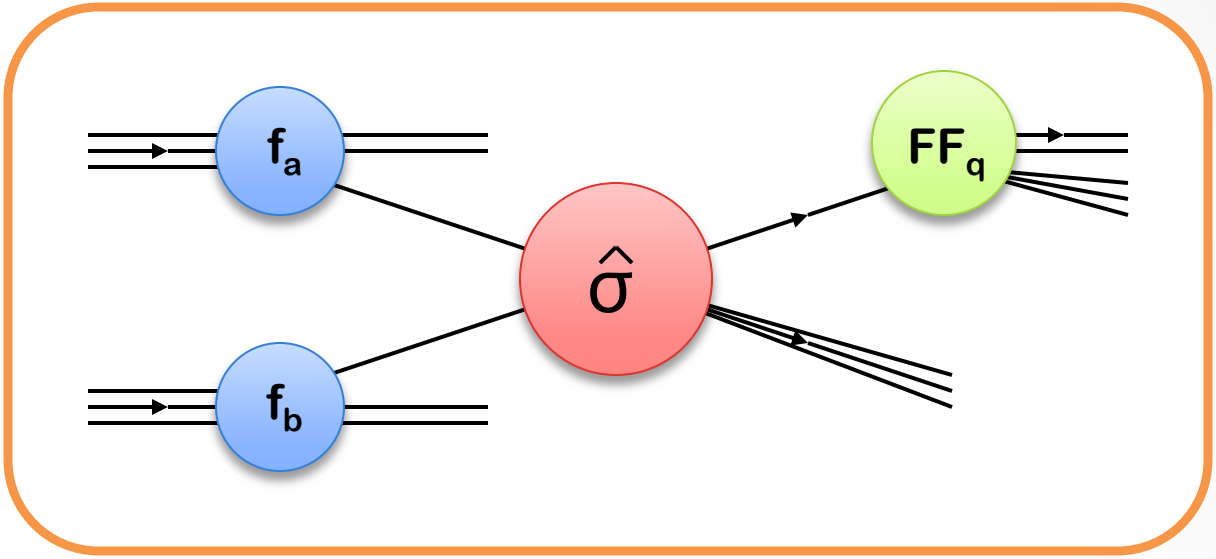
Asymmetries are expected to be zero?



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

Proton-Proton Collisions

- Initial State
- pQCD
- Final State



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

How valid is factorization for hadronic collisions?

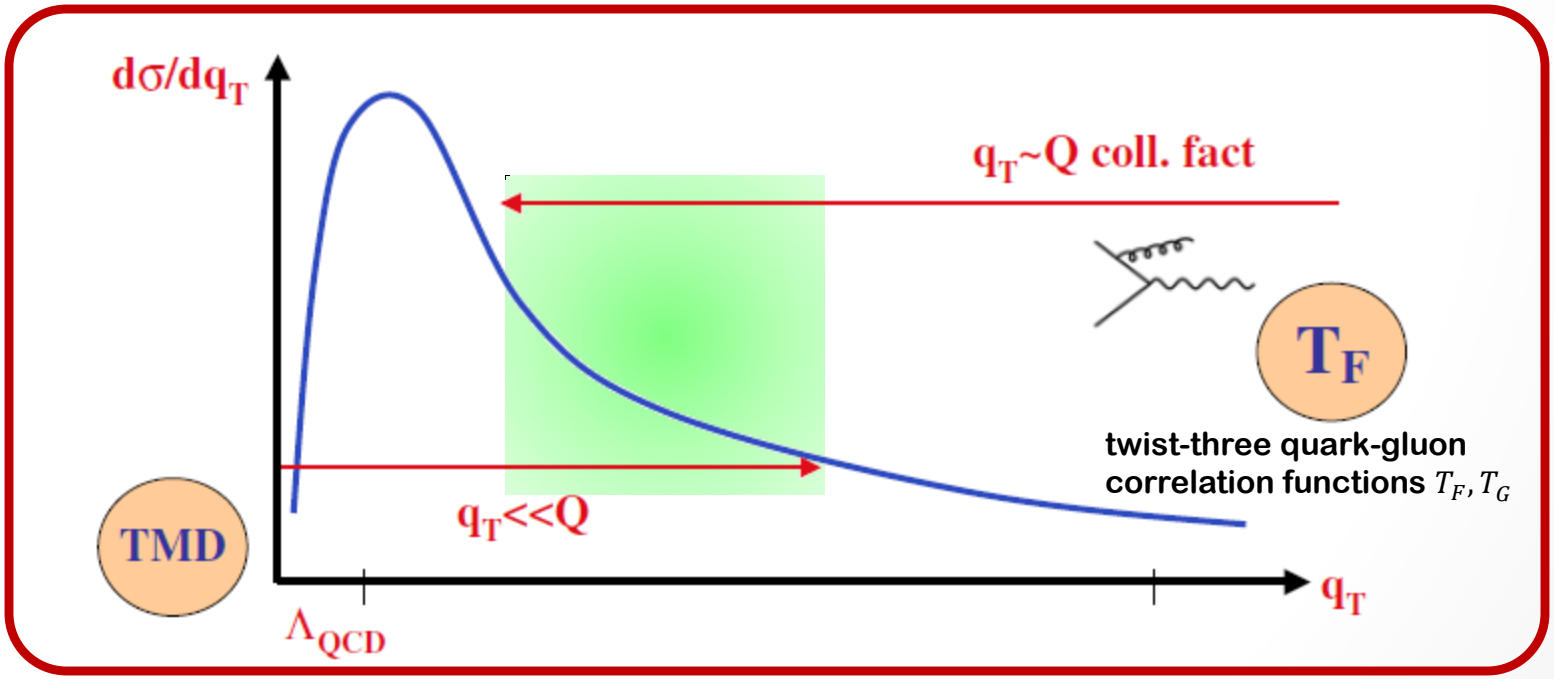
Are the separate contributions universal?

A Unified Approach

- Collinear QCD factorization vs. TMD parton distribution functions
- Phenomenological approach in overlap region

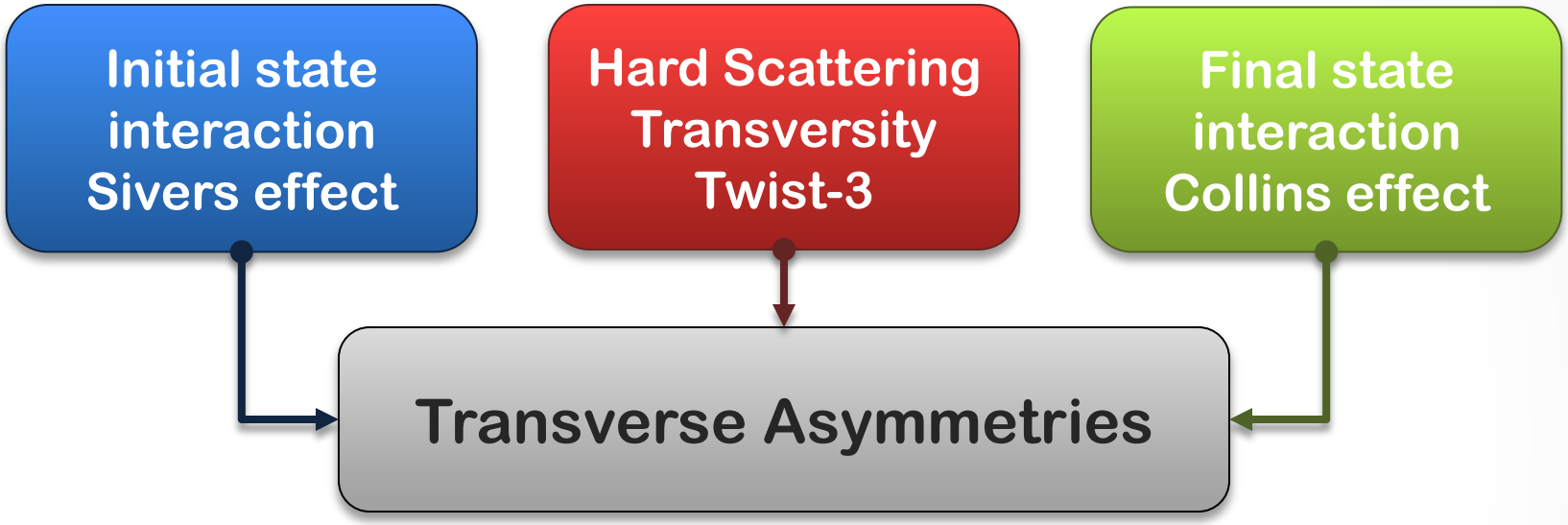
soft p_T breaks factorization

1 / p_T shape not yet observed



X. Ji, J.-W. Qiu, W. Vogelsang, F. Yan, PRL 97, 082002 (2006)

Measurements



- Inclusive A_N (central/forward)
- Hadron Correlations (back-to-back)
- Interference Fragmentation Functions
- Jet correlations/structure
- Drell-Yan

Upgrades

Upgrade plans

Polarized Proton Collider

Absolute Polarimeter (H jet)

RHIC pC Polarimeters

Siberian Snakes

BRAHMS & PP2PP

Spin Flipper

STAR

PHENIX

Siberian Snakes

Spin Rotators

Partial Snake

Polarized Source

Strong Snake

Helical Partial Snake

LINAC

BOOSTER

AGS

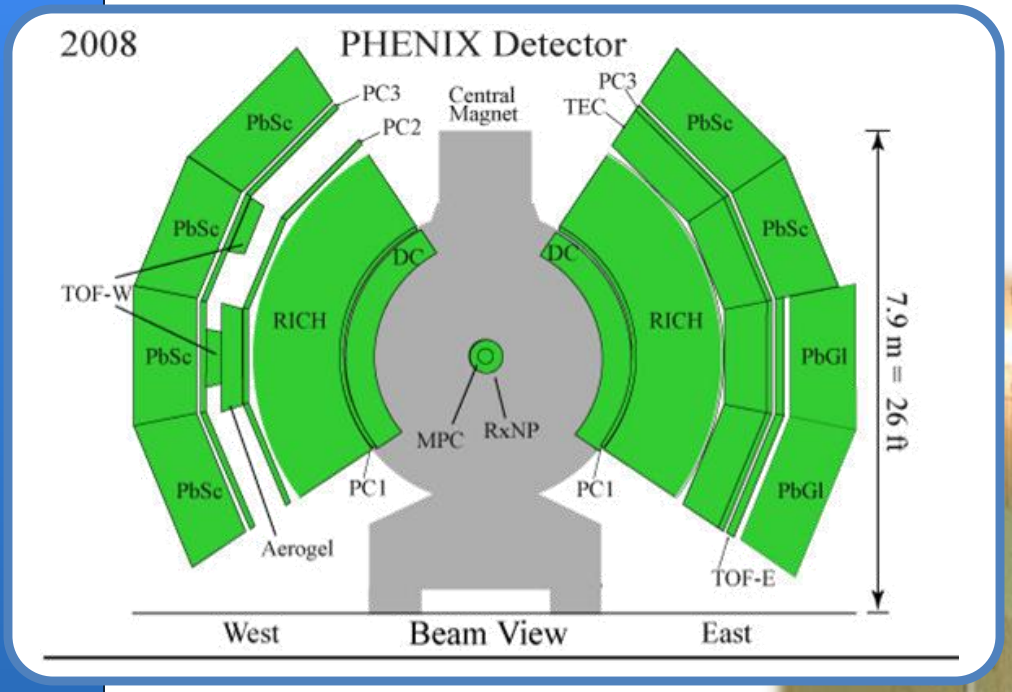
200 MeV Polarimeter

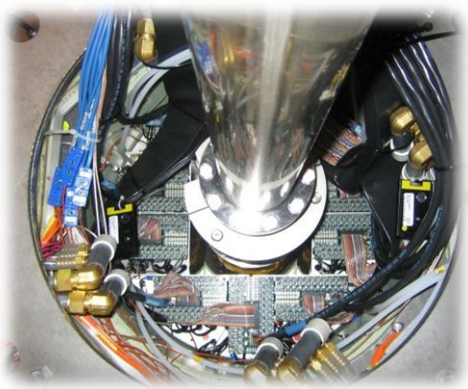
Rf Dipole

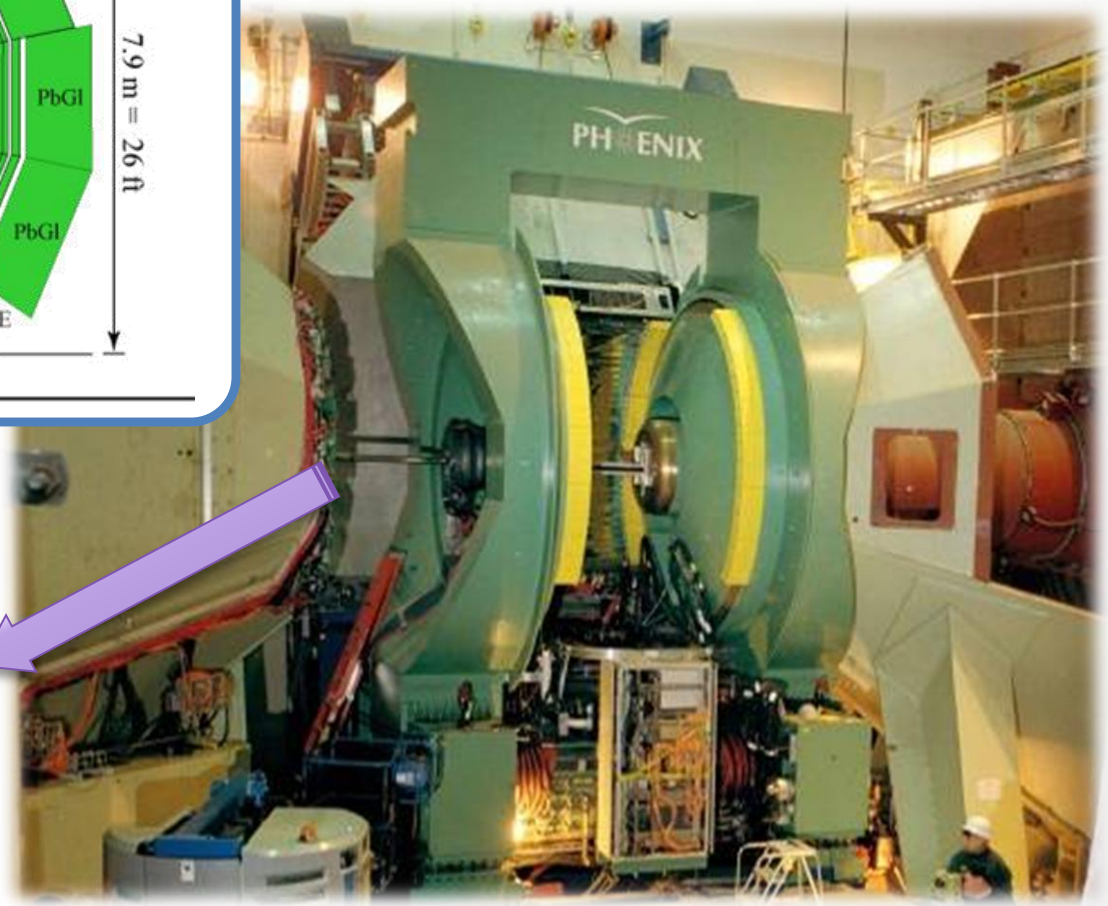
AGS Internal Polarimeter

AGS pC Polarimeter

The PHENIX Detector





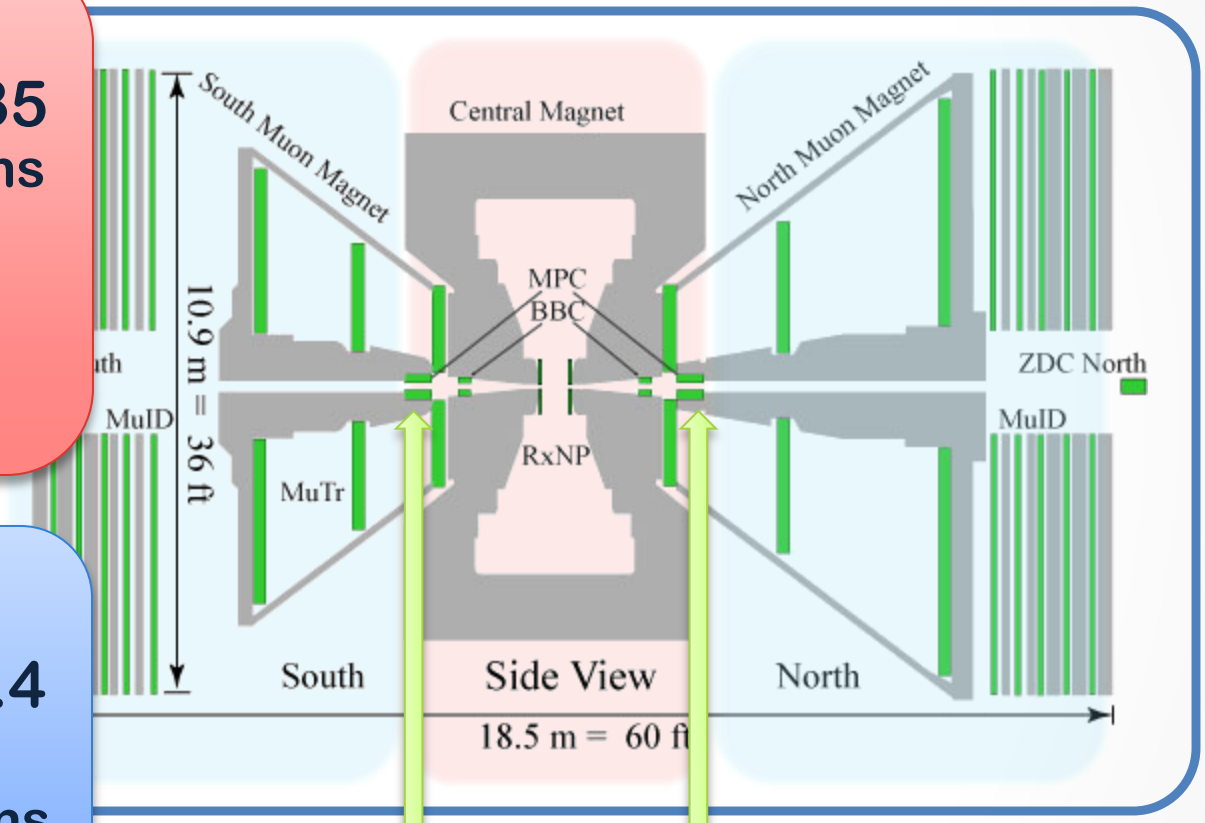


The PHENIX Detector

Central Arms

$|\eta| < 0.35$

- charged hadrons
- π^0, η
- direct photon
- J/Ψ
- heavy flavor



Muon Arms

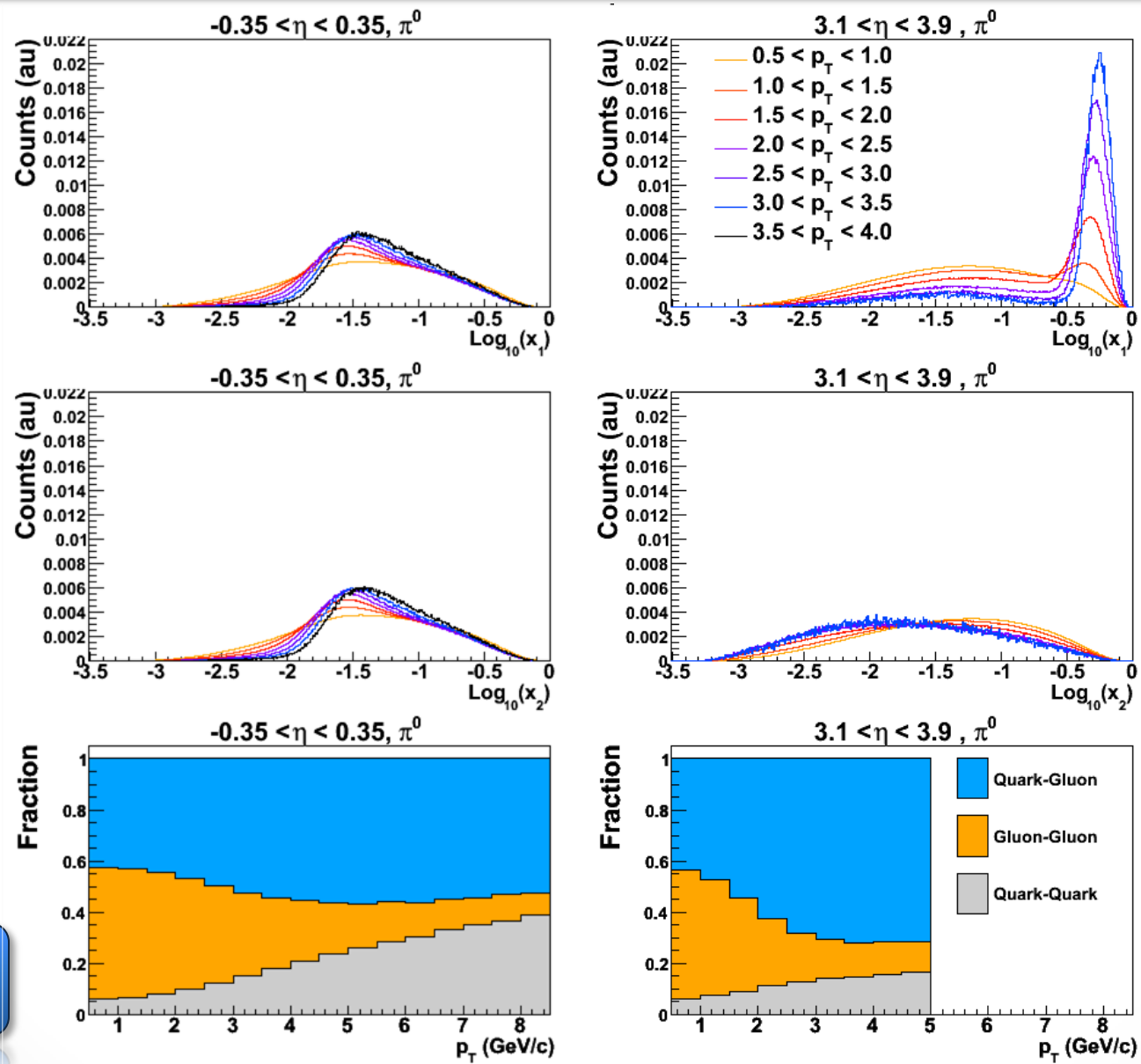
$1.2 < |\eta| < 2.4$

- J/Ψ
- charged hadrons
- heavy flavor

MPC $3.1 < |\eta| < 3.9$

- π^0, η

Kinematics§ @ √s = 200 GeV

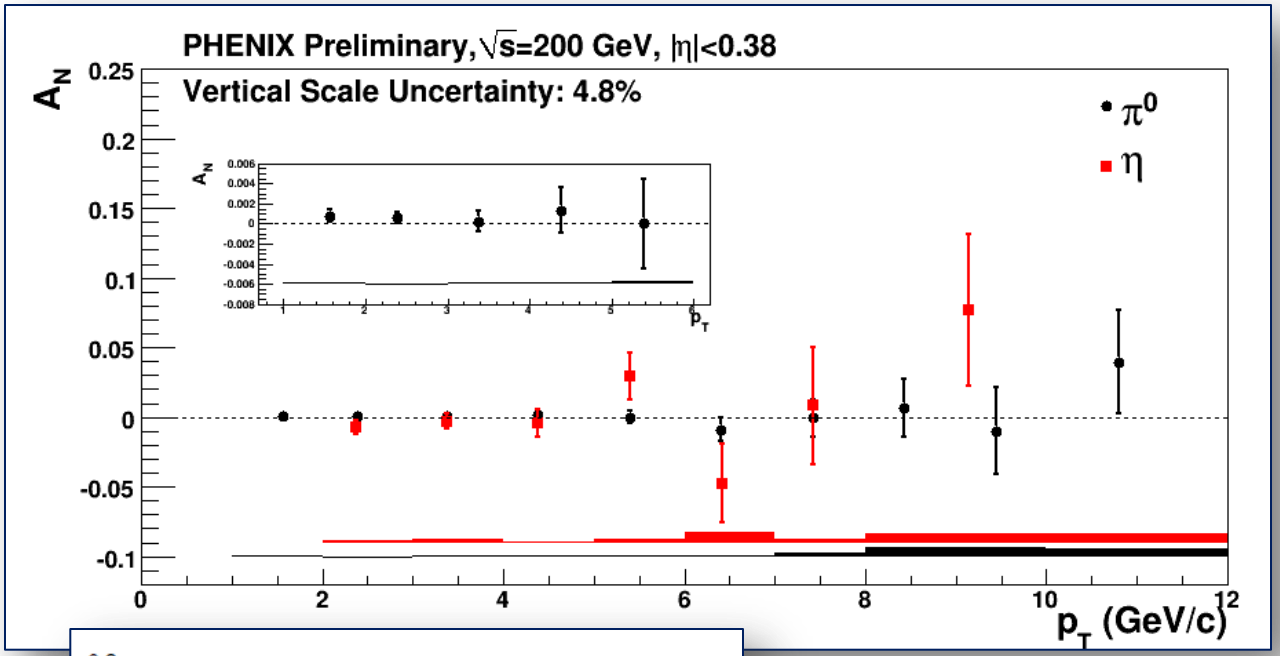


[§] from PYTHIA

x_1 projectile

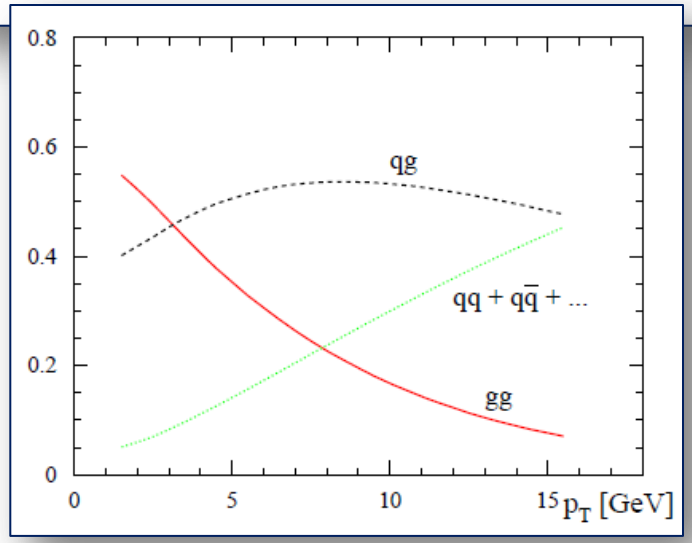
x_2 target

A_N: mid-rapidity π^0 and η



π^0 and η
$\sqrt{s}$=200 GeV

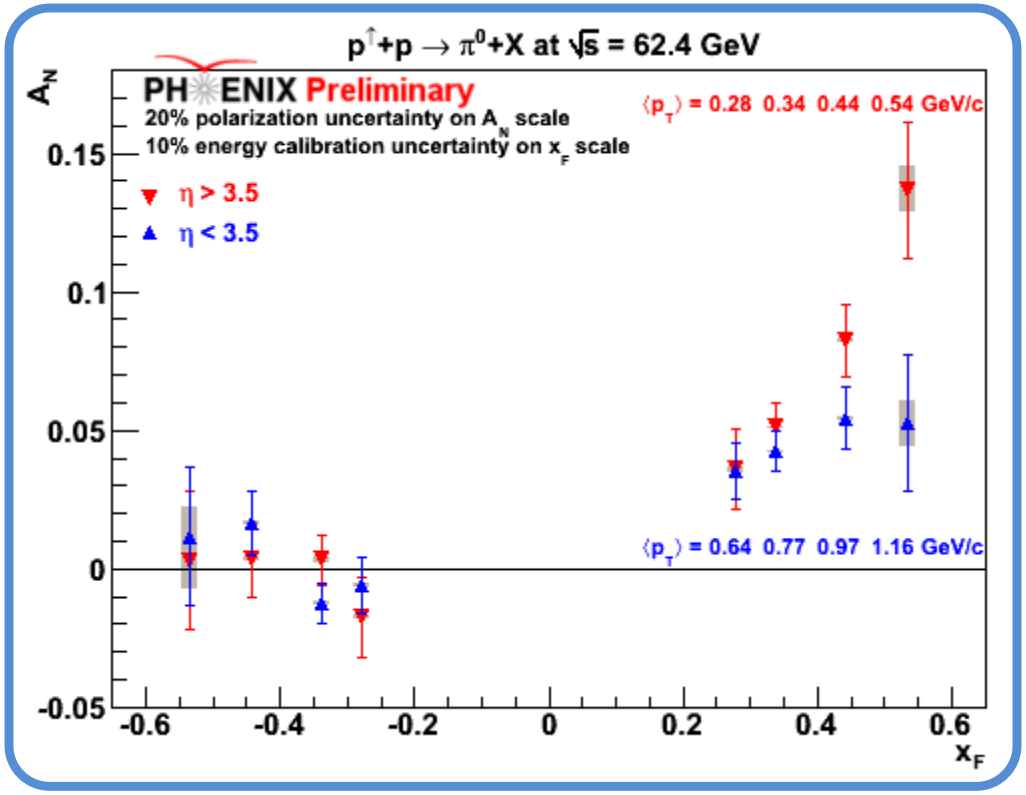
Phys. Rev. D 74, 094011



Partonic Cross Sections

- quark-gluon dominated
- gluon-gluon at low p_T (Sivers)
- quark-quark at large p_T (Sivers+Collins)

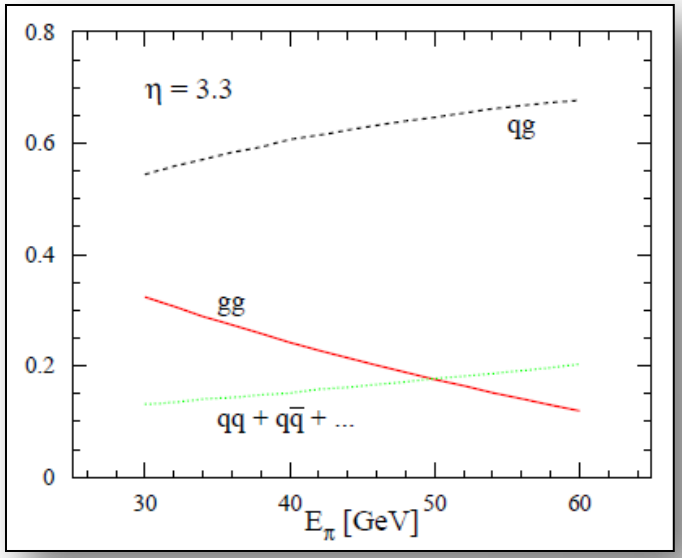
Forward A_N @ 62.4 GeV



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

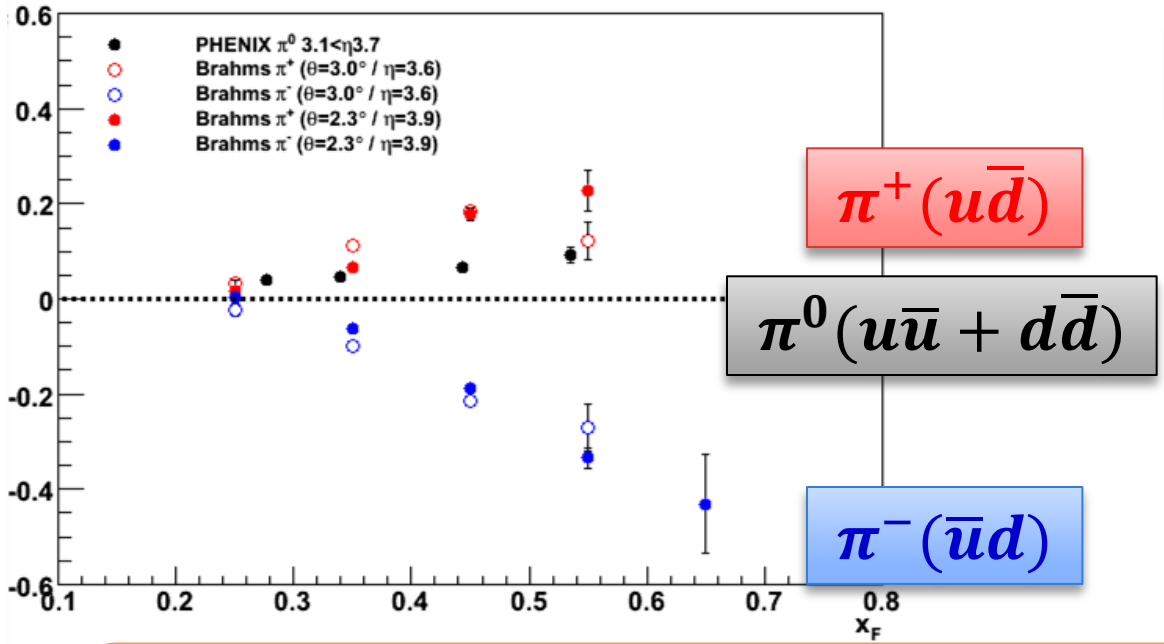
π^0 processs contribution
η=3.3, $\sqrt{s}$=200 GeV

Guzey et al, PLB **603**,173 (2004)



- significant asymmetry
- quark-gluon dominated…

Isospin Dependence



$\pi^+(u\bar{d})$

$\pi^0(u\bar{u} + d\bar{d})$

$\pi^-(\bar{u}d)$

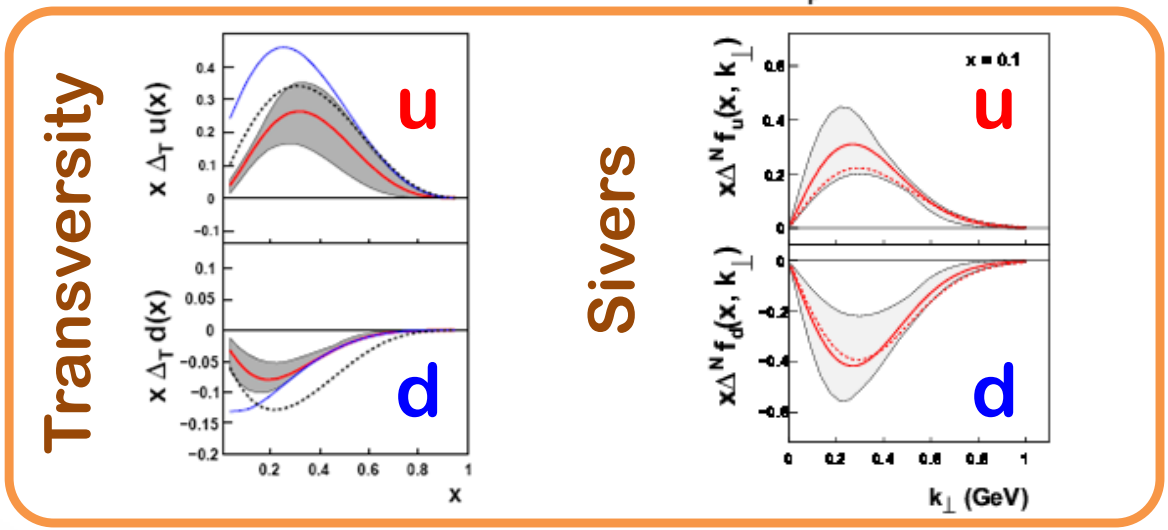
$\sqrt{s}$ = 62.4 GeV

fragmentation u/d

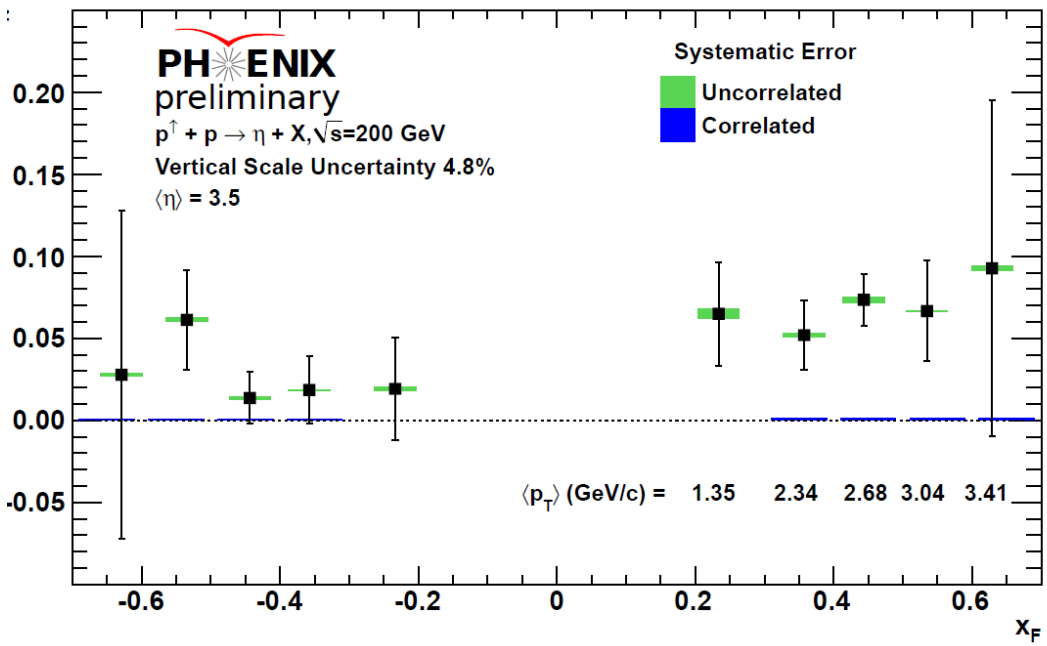
1:0

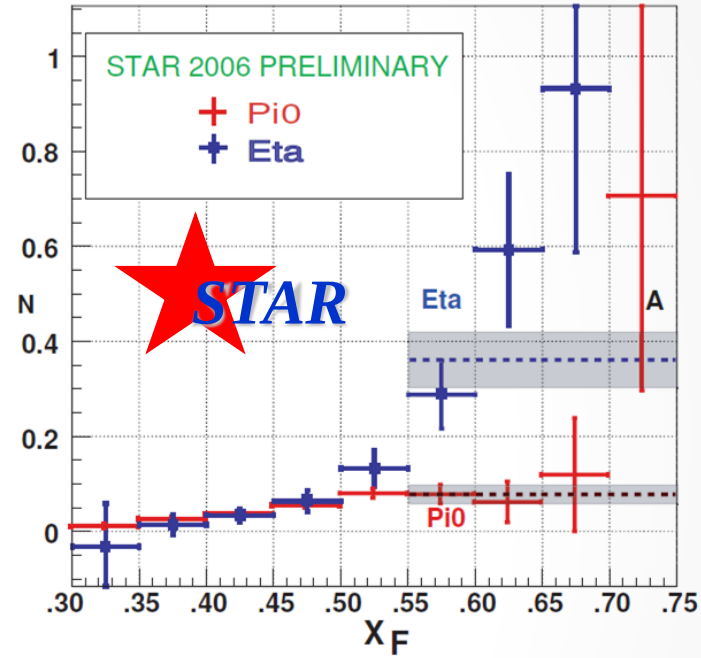
2:1

1:1



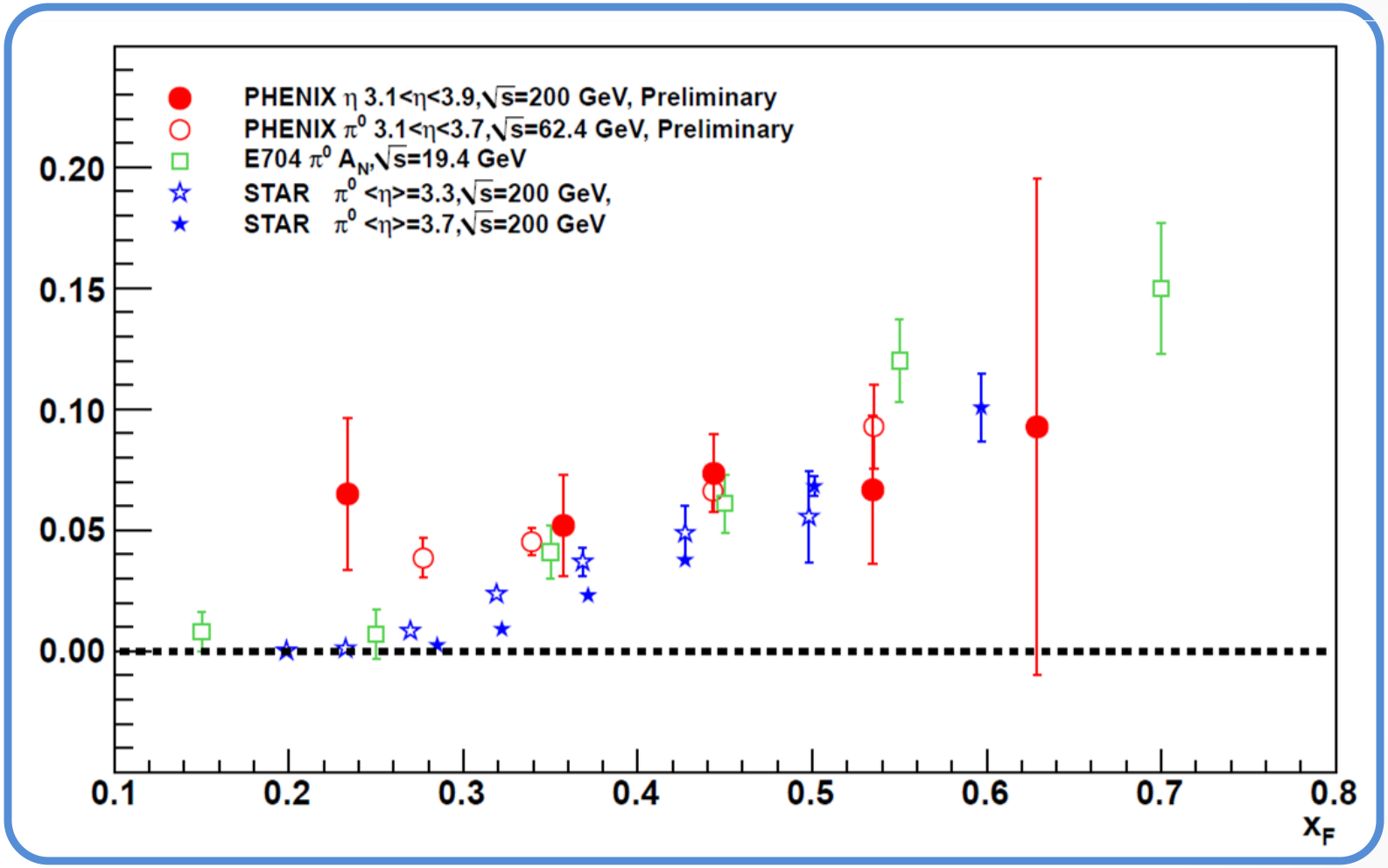
Forward $A_N(\eta)$





- Cross check with two polarized beams
- Background contribution
- Difference in fragmentation
  - mass, strangeness, isospin

Forward Asymmetries



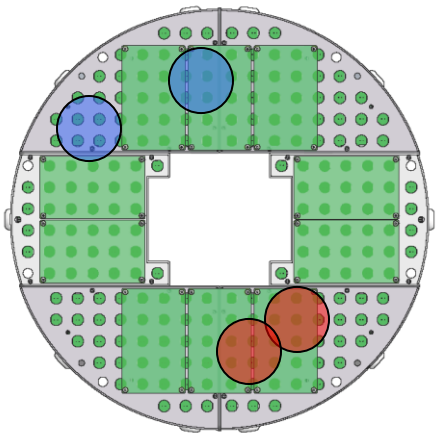
No strong dependence on √s from 19.4 ~ 200 GeV

Slight differences in pseudo-rapidity and/or p_T

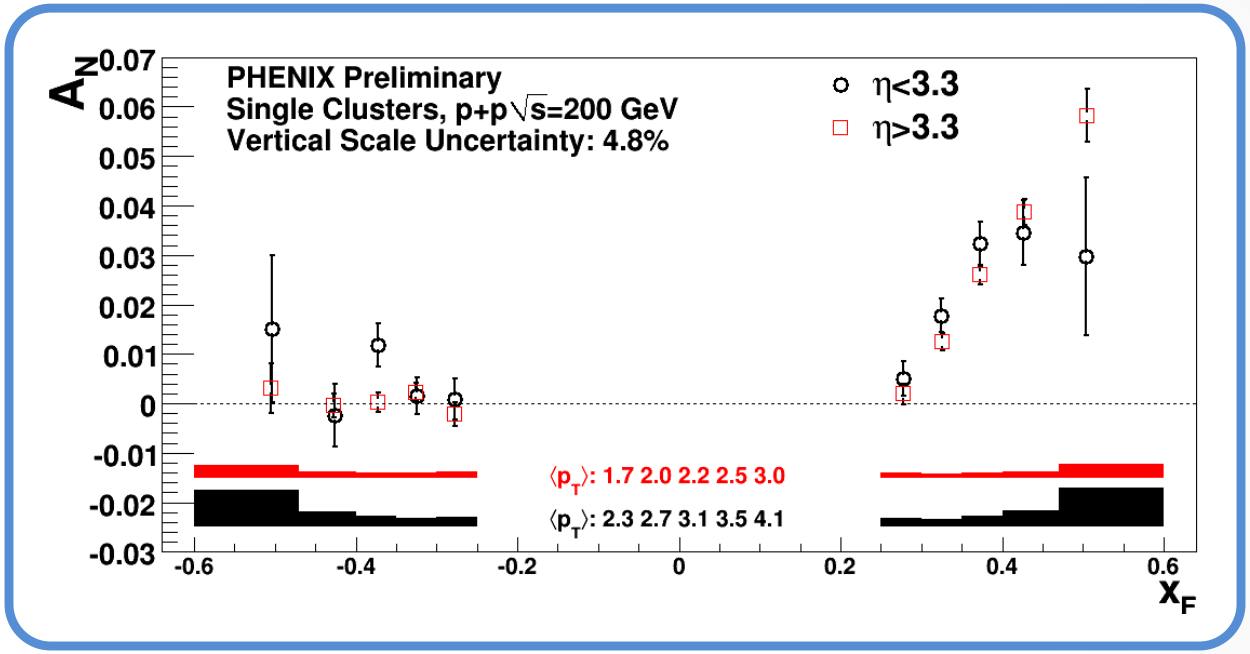
Forward A_N for Clusters

MPC

tower size 2.25^2 cm^2
220 cm from vertex

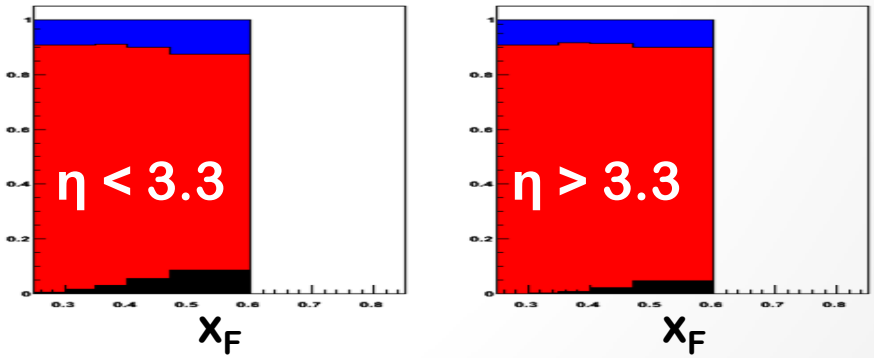


$\sqrt{s}$ = 200 GeV

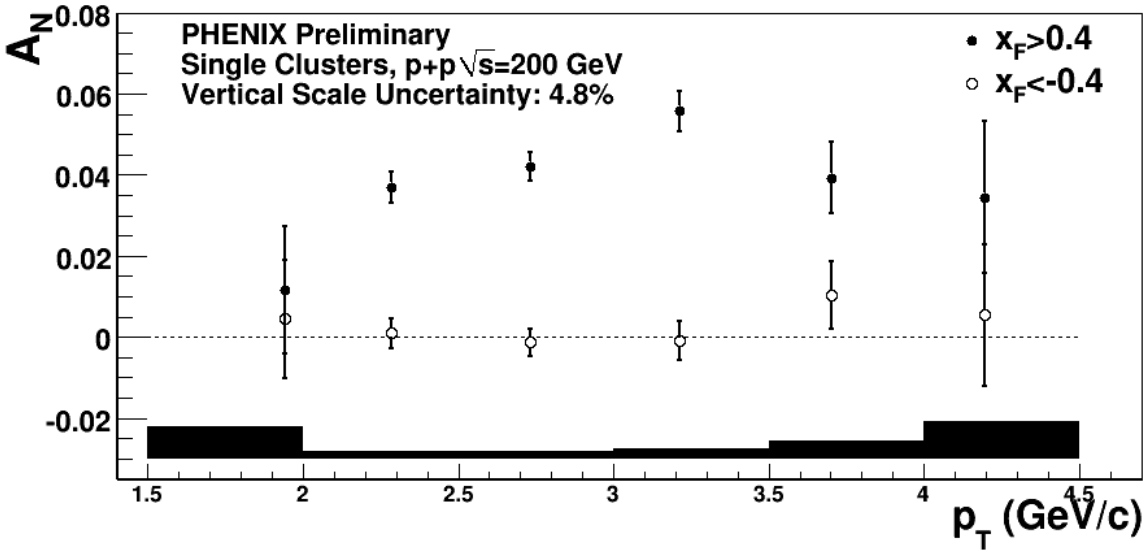


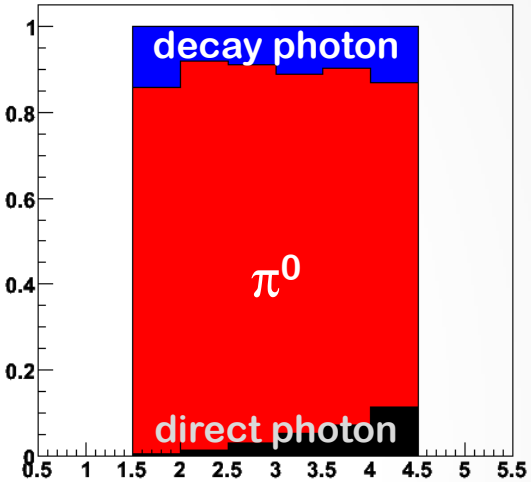
Cluster contribution

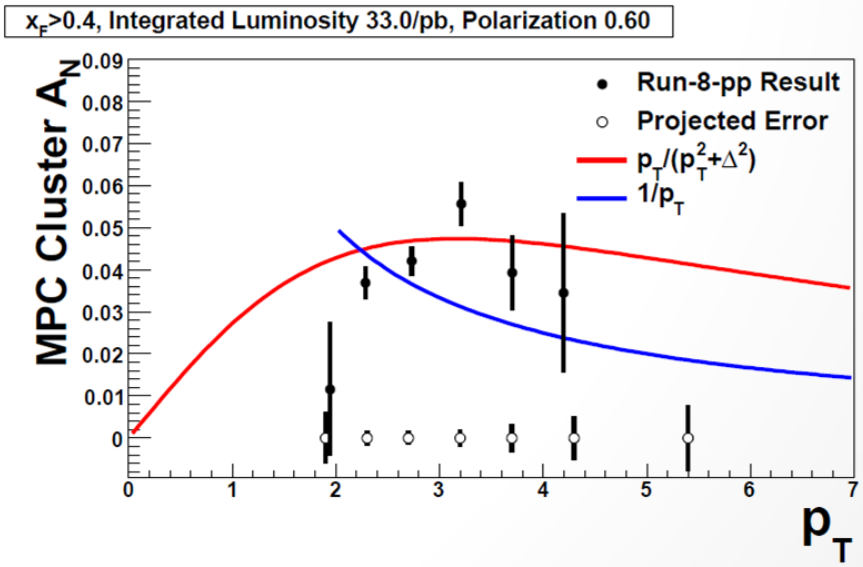
- decay photon
- π^0
- direct photon



p_T Behavior

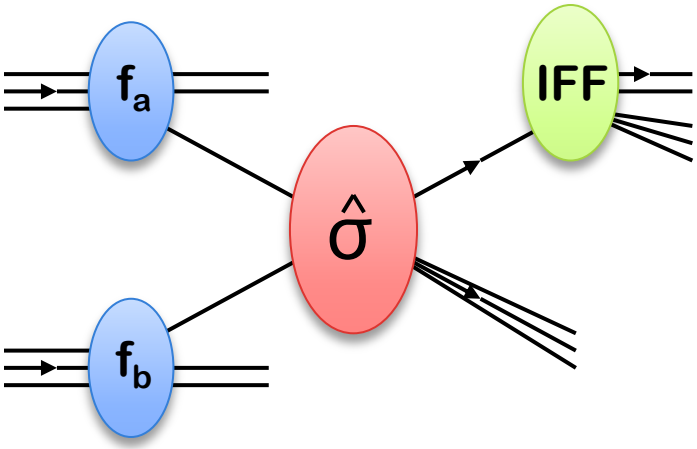




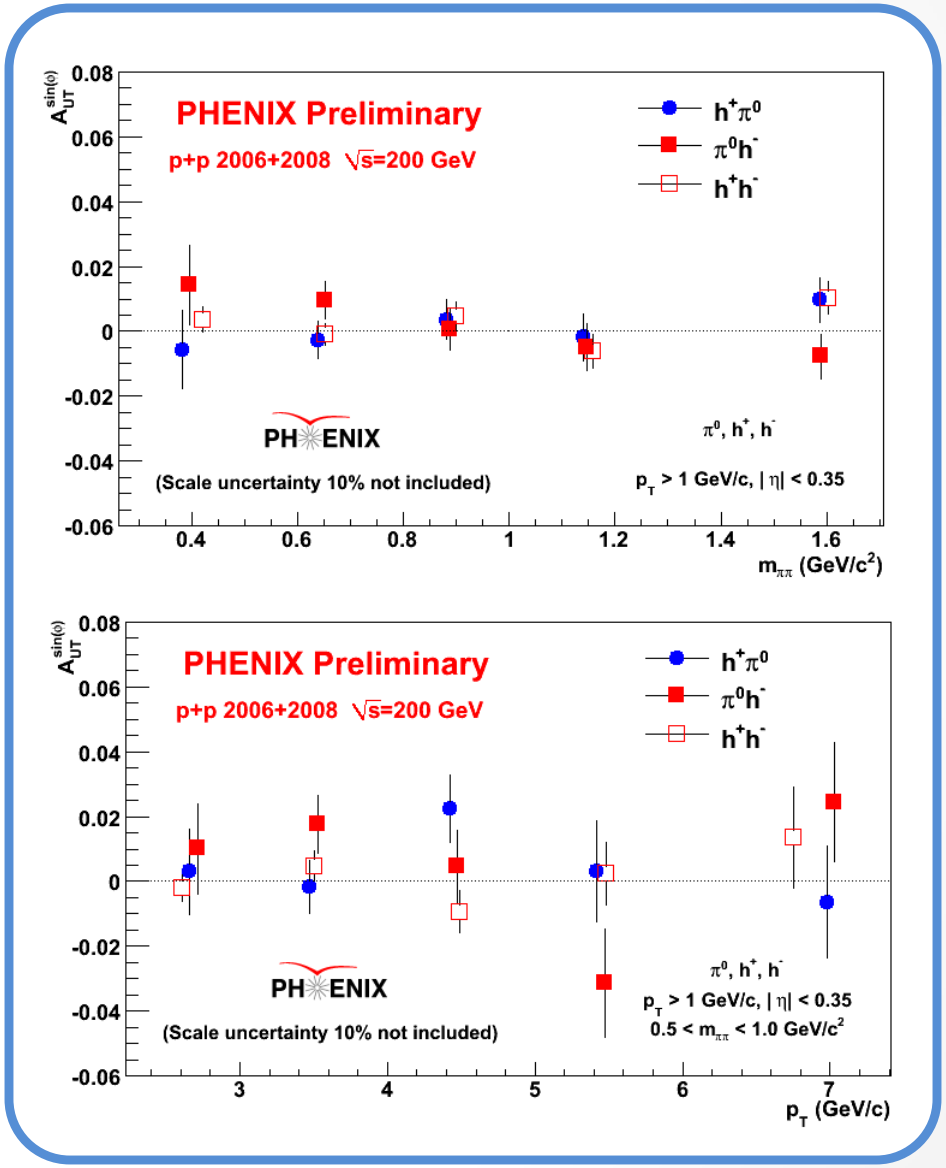


❖ Projection for 2012/13

Interference Fragmentation

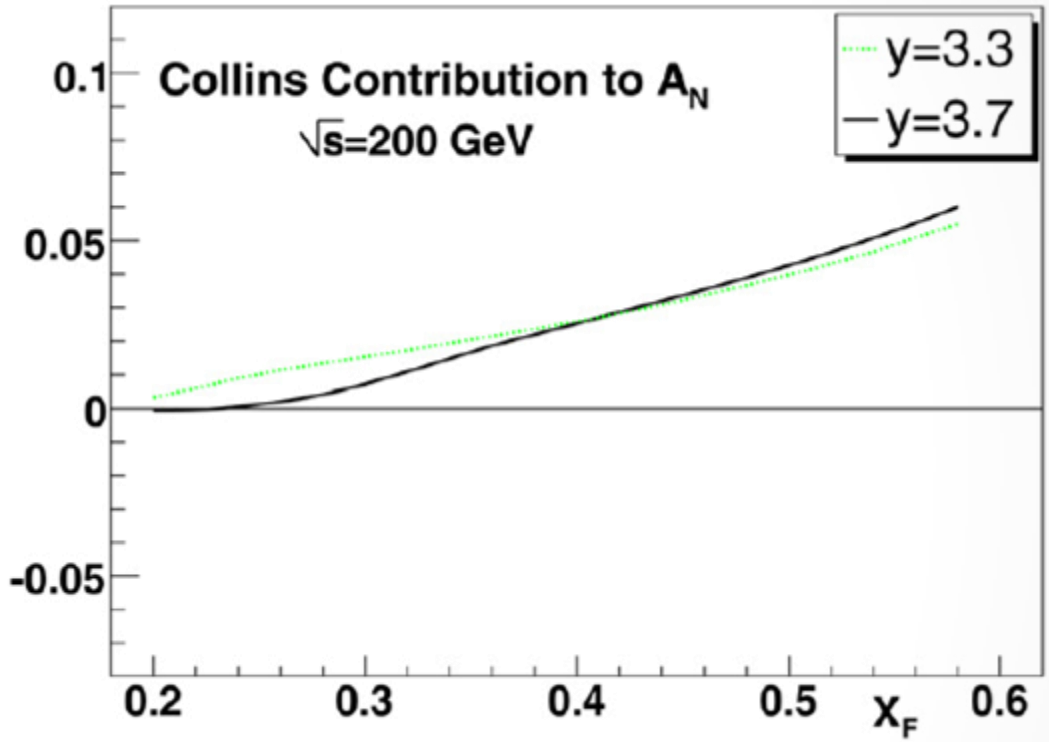


- IFF x transversity
- input e^+e^- annihilation few percent @ Belle
- Forward direction



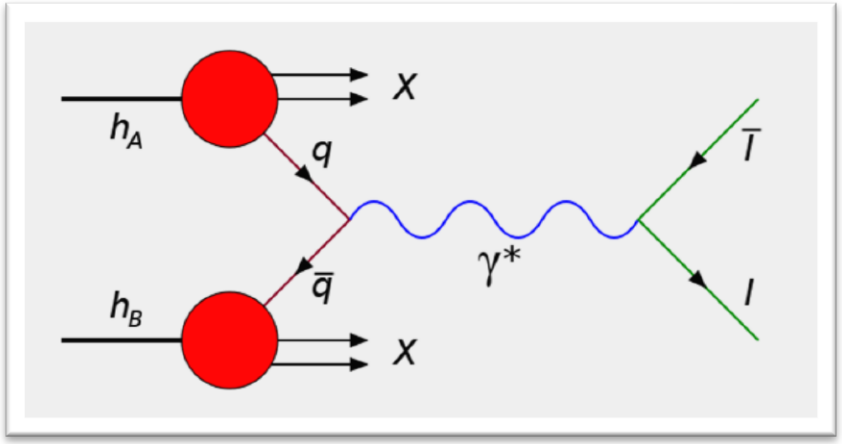
Hadrons in Jets

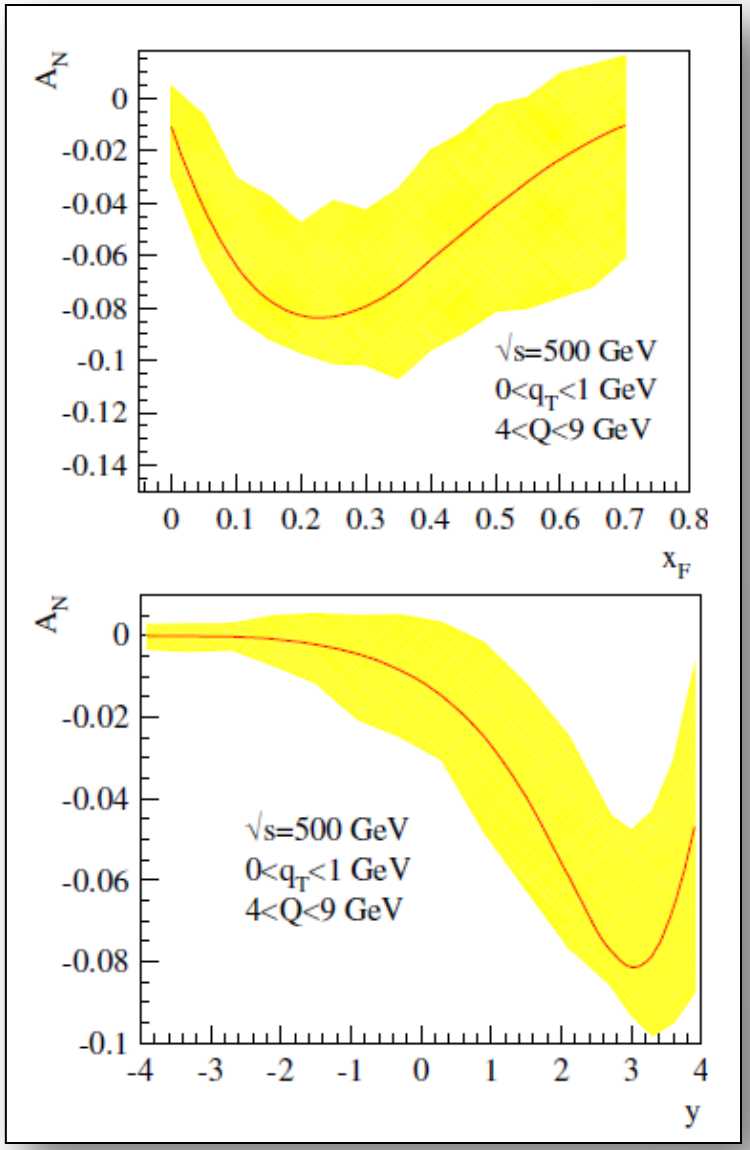
$jet \rightarrow h + X$



- F. Yuan
  PLB 666 (2008) 44-47
- Direct Collins measurement of fragmentation
- Expect large asymmetries in forward direction

Polarized Drell-Yan Production





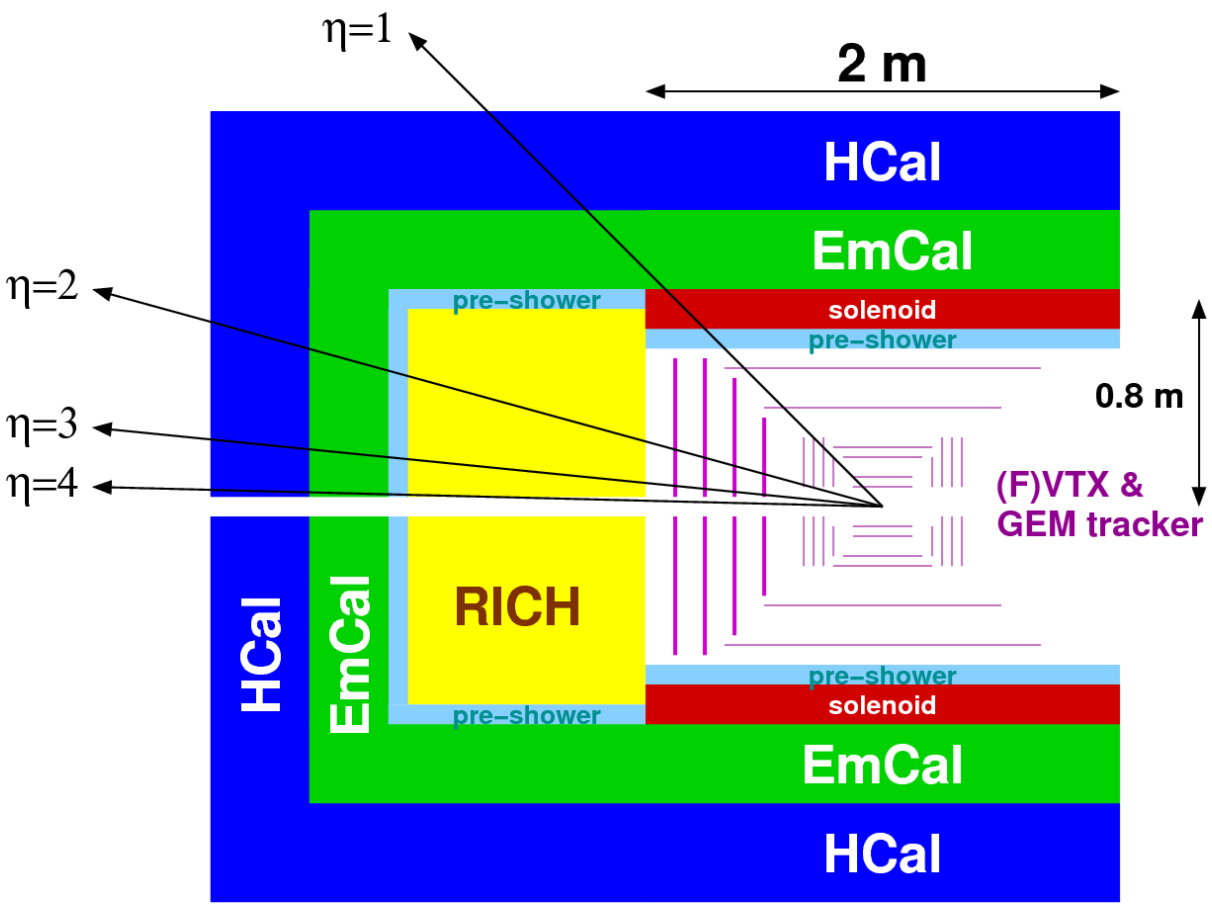
No fragmentation

Direct correlation of intrinsic transverse quark properties and proton spin

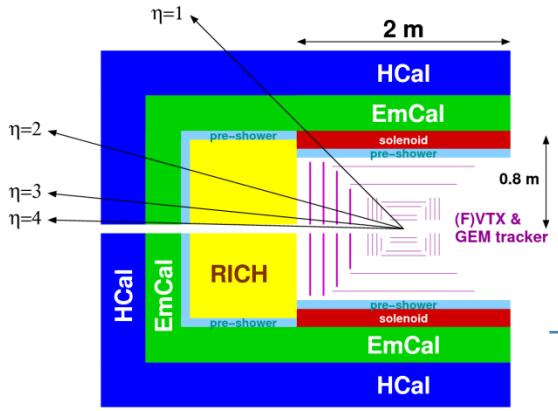
Solid factorization

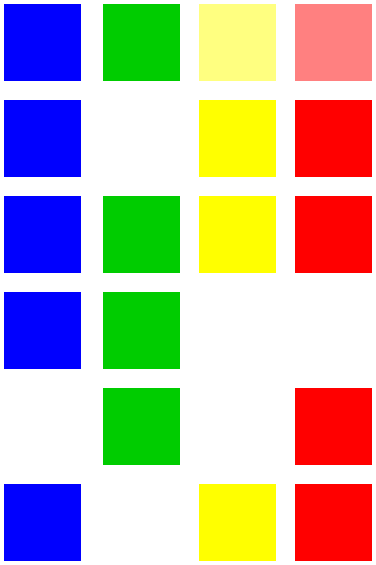
Fundamental QCD test

PHENIX Decadal Plan Upgrade



Proposed sPHENIX Design

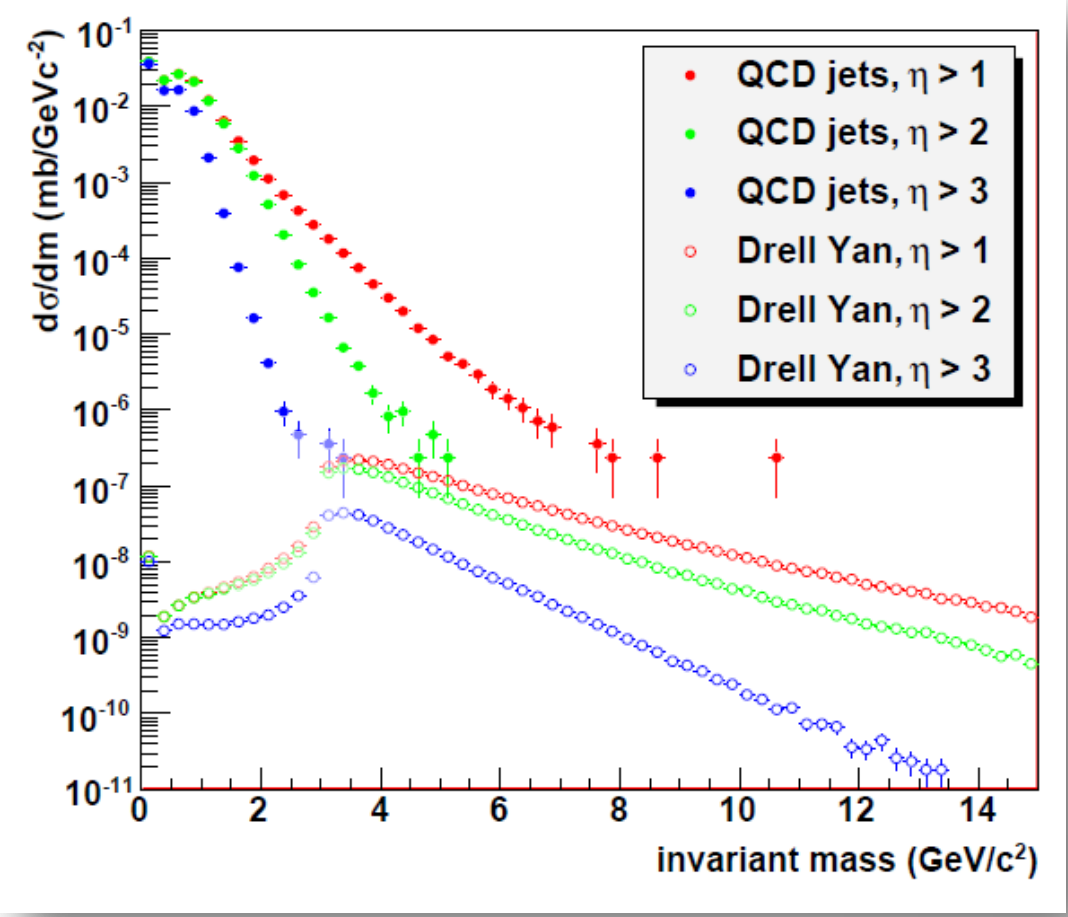




Measurement	Physics
Drell-Yan	Sivers function Transversity distribution Boer-Mulders function
Identified $h^{0/+/-}$ IFF	Transversity distribution
Hadron in jet	Collins effect
Jet A_N	Sivers function
Direct photon A_N	Sivers function
Identified $h^{+/-}$ A_N	Sivers function Collins effect

Drell-Yan Feasibility

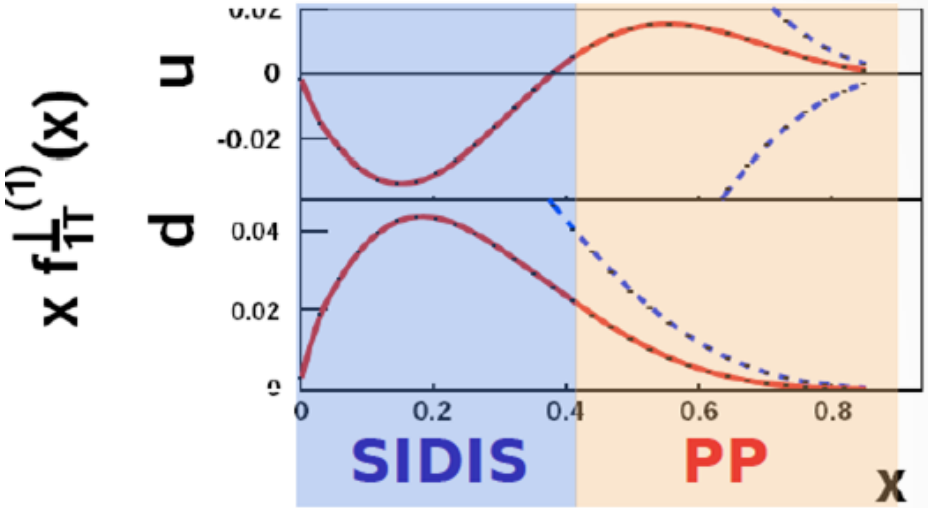
- Fast Monte-Carlo studies with effective detector smearing
- QCD background decreases with increasing rapidity
- Drell-Yan reduced signal

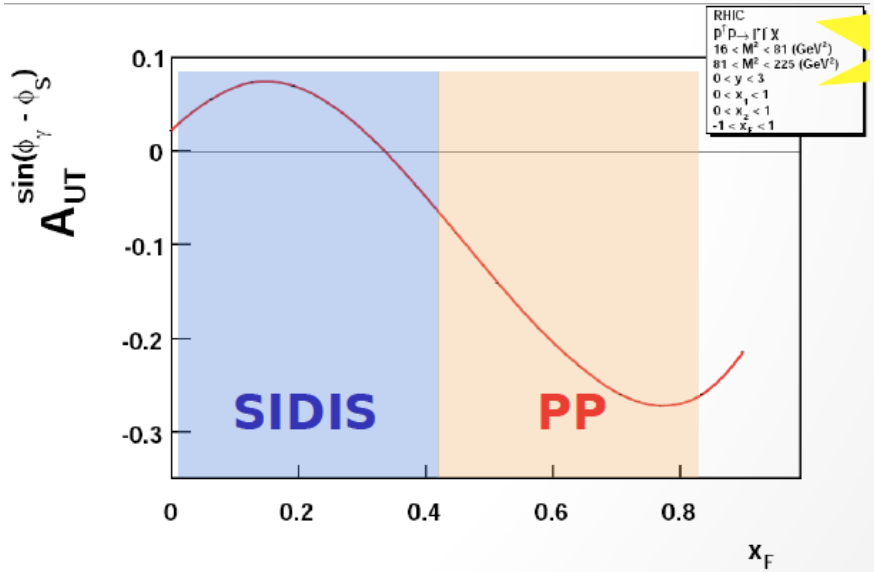


Global Analysis

- A. Prokudin, Z.-B. Kang
- Input
  - HERMES
  - COMPASS
  - STAR π^0
- Functional form similar to DSSV

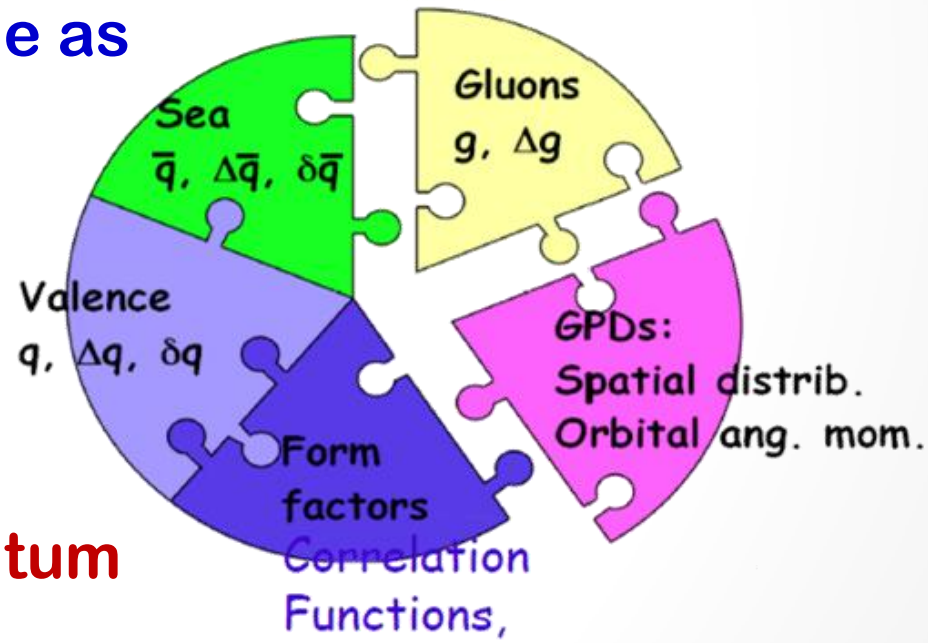
$$f_{1T}^{\perp q} \sim x^{\alpha_q}(1-x)^{\beta_q}(1-\eta_q x)$$





Summary

- Mechanism for transverse asymmetries is diverse
- PHENIX measured non-vanishing asymmetries in forward direction
- Clean channels needed to disentangle effects
- Ambitious upgrade scheme as outlined in the PHENIX decadal plan
- Still open many questions
  - TMD factorization
  - Universality
  - Orbital angular momentum



BACKUP

Luminosity & Polarization

Year	Energy	Polarization	Longitudinal		Transverse	
	[GeV]	[%]	L [pb^{-1}]	LP^4 [pb^{-1}]	L [pb^{-1}]	LP^2 [pb^{-1}]
2002	200	15	-	-	0.15	3.4×10^{-3}
2003	200	27	0.35	1.9×10^{-3}	-	-
2004	200	40	0.12	9×10^{-3}	-	-
2005	200	49 (47)	3.4	2×10^{-1}	0.16	3.5×10^{-2}
2006	200	57 (51)	7.5	7.9×10^{-1}	2.7	7.0×10^{-1}
2006	62	48	0.08	4.2×10^{-3}	0.02	4.6×10^{-3}
2008	200	46	-	-	5.2	1.1×10^{0}
2009	500	35	14	2.1×10^{-1}	-	-
2009	200	55	16	1.5×10^{0}	-	-