Spin Physics Results from PHENIX

Diffraction 2014 Primošten, Croatia
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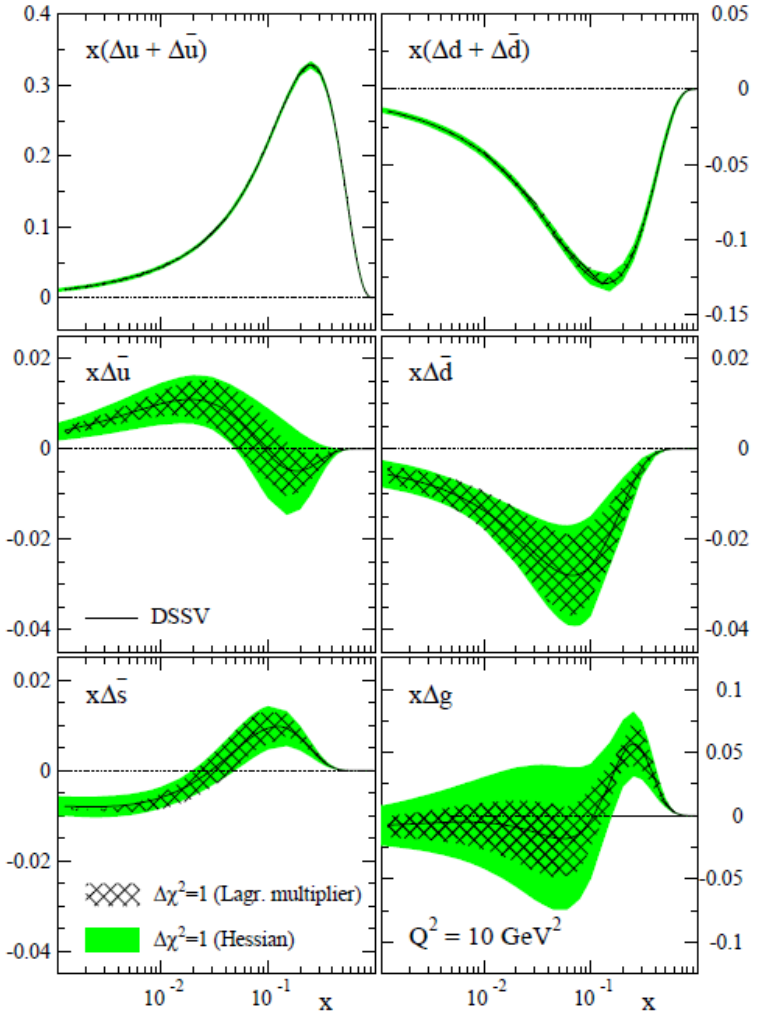
Paul Kline (for the PHENIX collaboration)

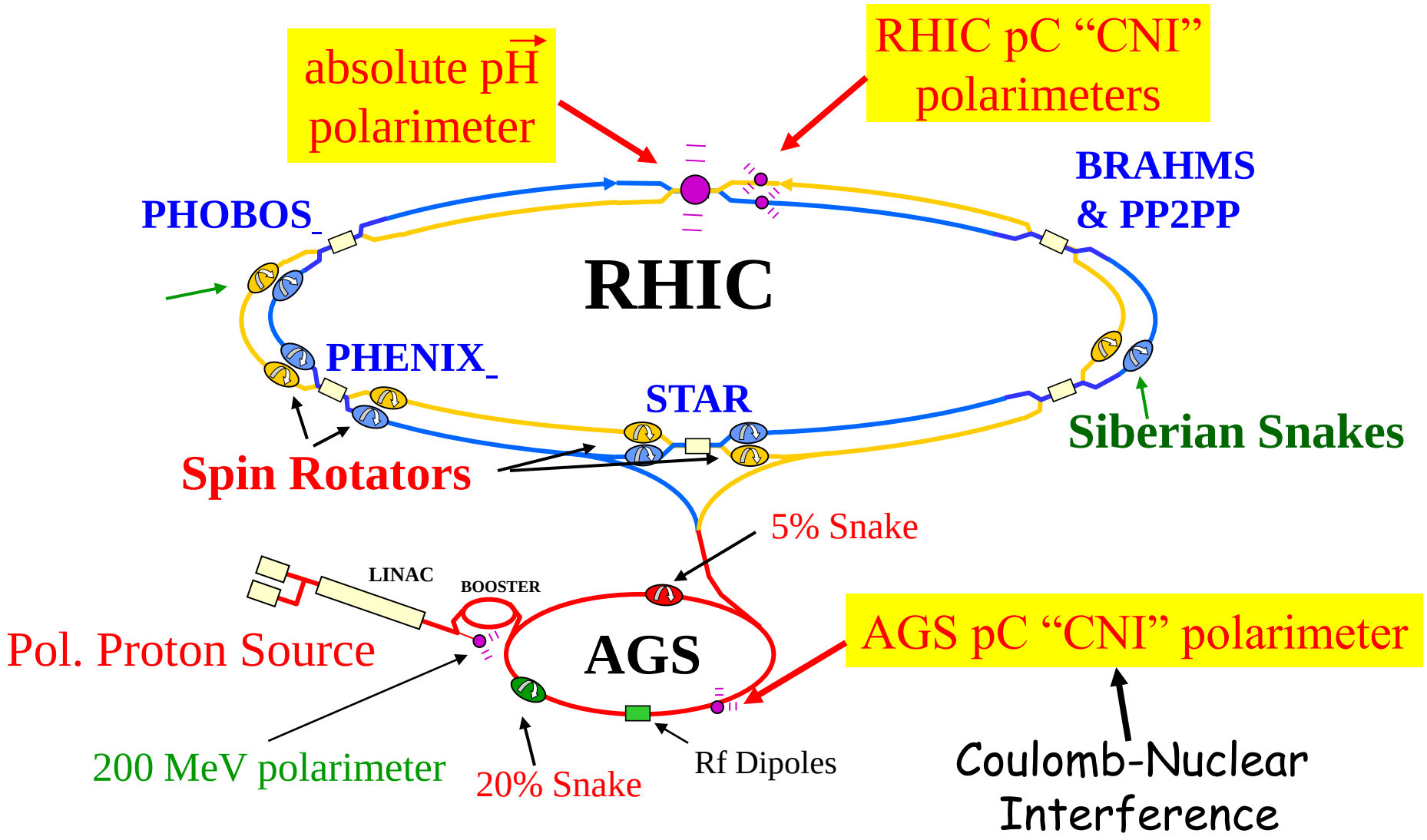
Motivation

- What is the spin structure of the proton?
  - DIS (quarks) only accounts for 25-30%
  - Longitudinally polarized proton collisions directly probe gluon structure
  - W production separates quark flavors
- Surprising asymmetries in transversely polarized fixed target experiments persist to RHIC energies
  - Study and disentangle effects
  - Sivers, Collins, higher twist . . .

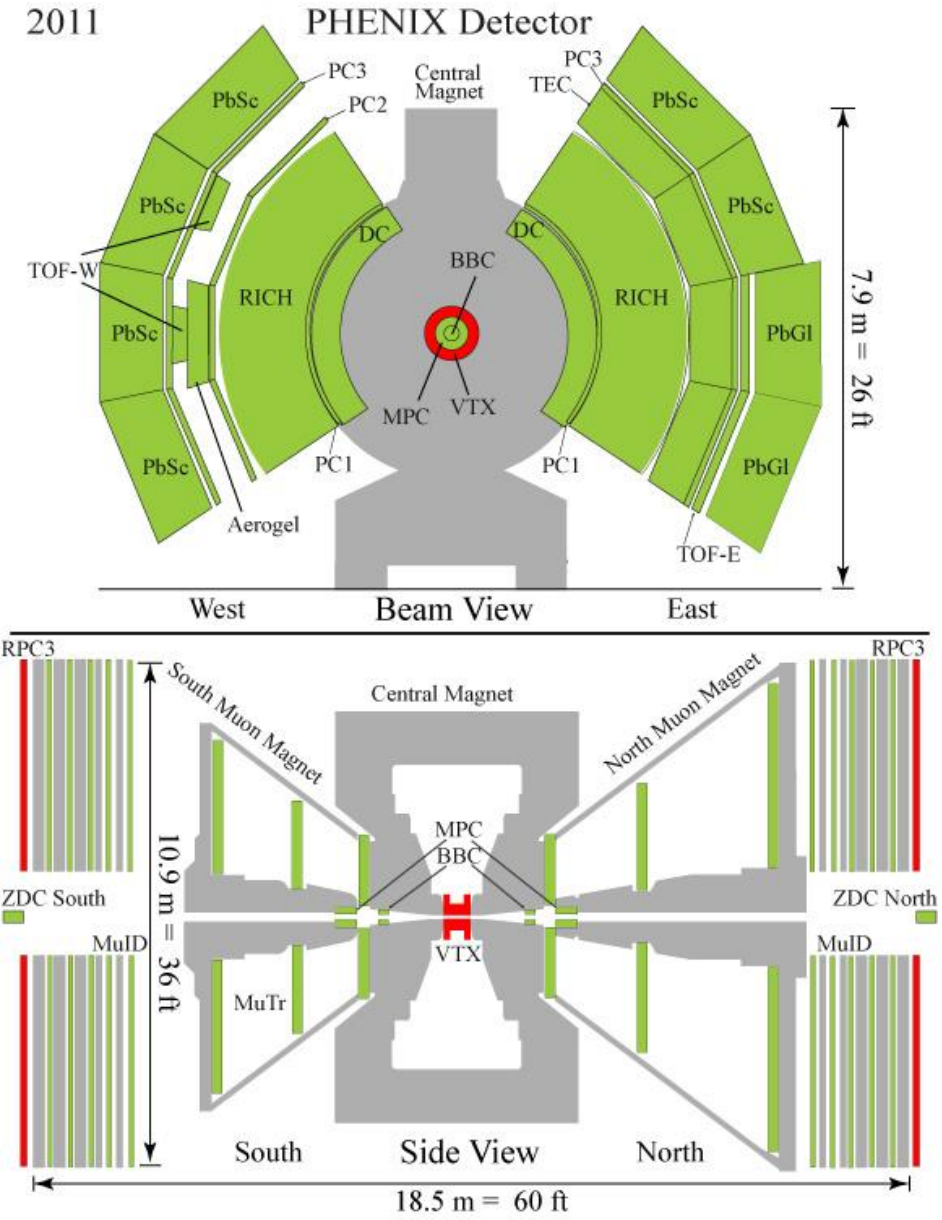


DSSV08
Phys.Rev. D80 (2009) 034030

Relativistic Heavy Ion Collider



PHENIX



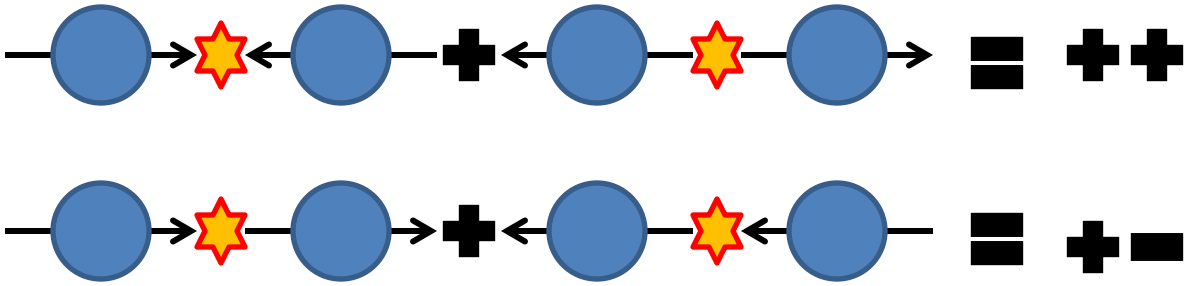
- **Central Arms**
  - $|\eta| < 0.35$, $\Delta\phi = 2 \times (\pi/2)$
  - Tracking
    - Drift Chamber
    - Pad Chambers
  - Electromagnetic Calorimeter
    - PbSc and PbGl technologies
    - $\Delta\phi \sim 0.01$ and $\Delta\eta \sim 0.01$

- **Forward Arms**
  - Muon System
    - ID, tracking
  - Forward vertex detector
  - Muon Piston Calorimeter
  - Zero Degree Calorimeter
    - Local polarimetry
  - Beam Beam Counter
    - Luminosity, vertexing

Parton Helicity Structure

What do we measure?

Helicity Class:



Theory:

PDFs

Partonic Crossection

$$A_{LL} = \frac{\sum_{a,b,c} \boxed{\Delta f_a} \otimes \Delta f_b \otimes \boxed{\Delta \sigma^{a+b\to c+X}} \otimes D_c^h}{\sum_{a,b,c} f_a \otimes f_b \otimes \sigma^{a+b\to c+X} \otimes \boxed{D_c^h}}$$

Fragmentation Function

Experiment:

Yields

$$A_{LL} = \frac{1}{\boxed{P^2}} \frac{\boxed{N^{++}} - R_L N^{+-}}{N^{++} + \boxed{R_L} N^{+-}}$$

Polarization

Luminosity Normalization

Neutral Mesons

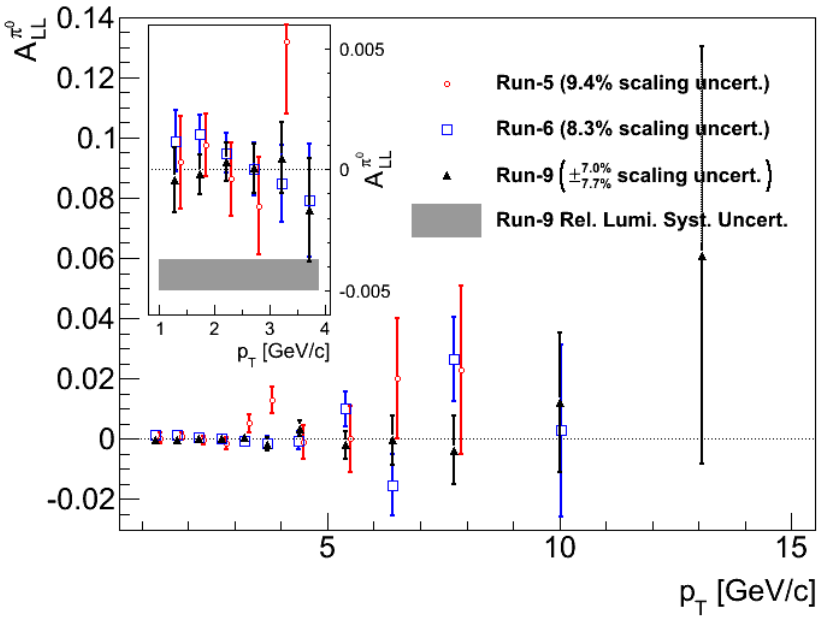
- π^0, η two photon peak reconstruction
  - EMCal triggers
  - Fine granularity in detectors
  - Fit peak over background

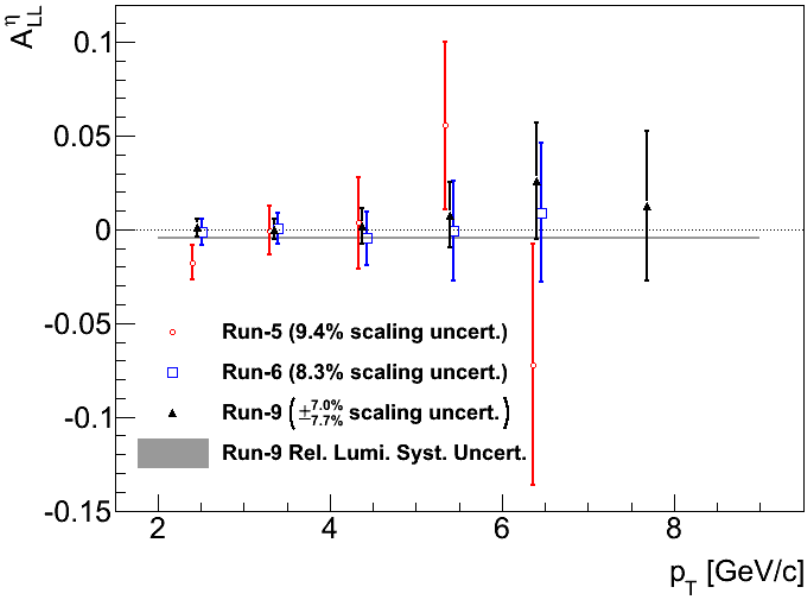
$$A_{LL}^{Sig} = \frac{A_{LL}^{Sig+BG} - w_{BG} A_{LL}^{BG}}{1 - w_{BG}}$$

  - q-g and g-g processes contribute

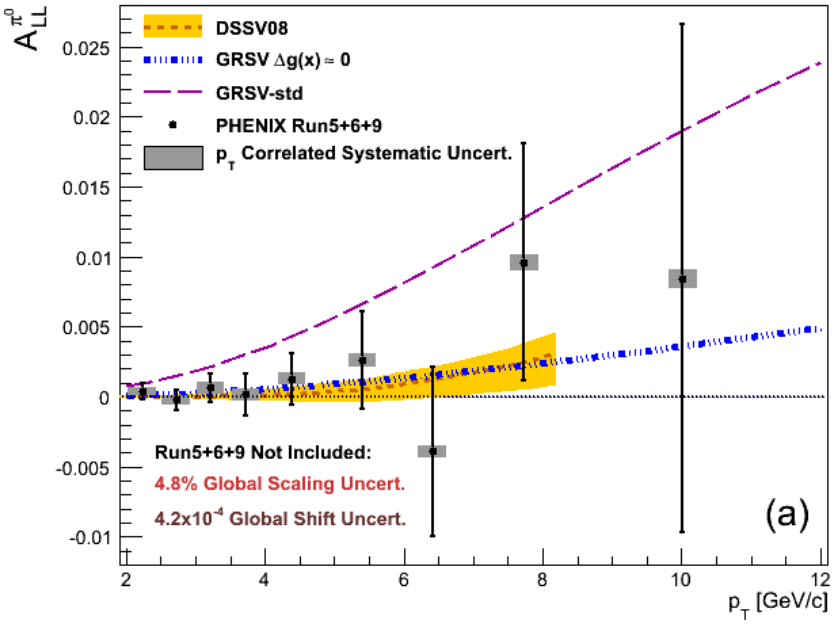
- π^0 a high statistics probe
  - $\sqrt{s}$ = 62.4 & 200 GeV in global analysis
  - 500 GeV analysis ongoing
  - Rel. Lumi limited at low p_T

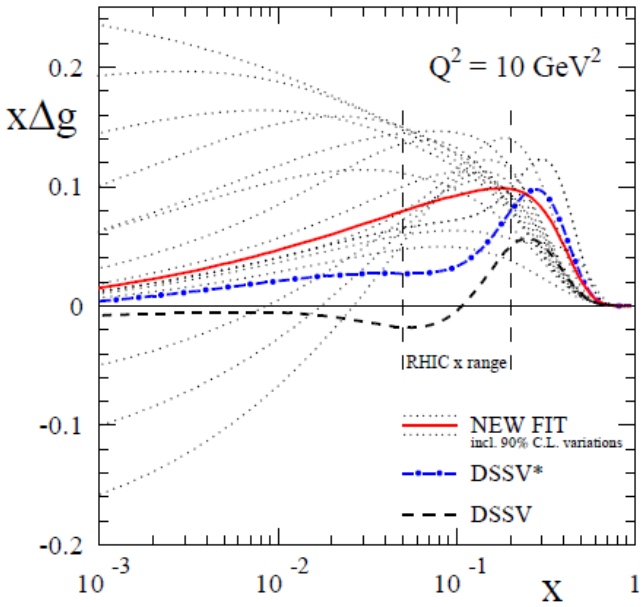
- η has different flavor structure, subprocess mix
  - Get to p_T due to later merge of photons
  - Global analysis requires better determination of fragmentation function



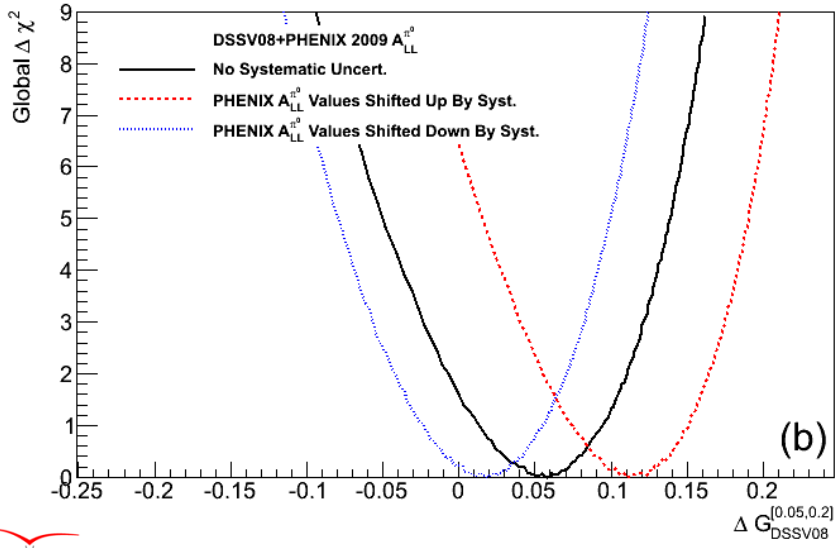


π^0 Impact on Global Fits





DSSV
Phys.Rev.Lett.
113 (2014)
012001

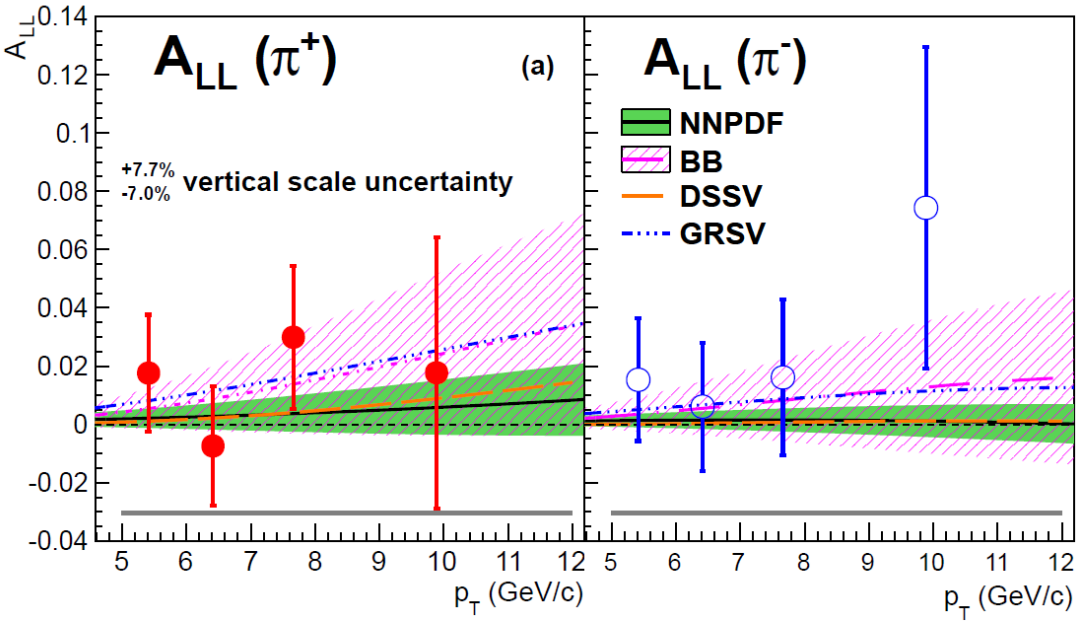


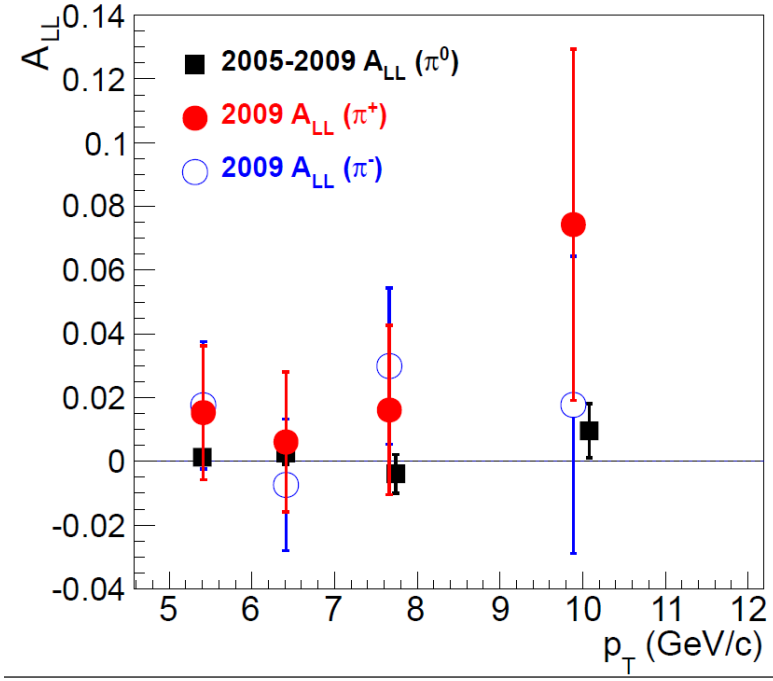
- RHIC probes in $0.05 < x < 0.2$

$$\Delta G_{DSSV08}^{[0.05,0.2]} = 0.005^{+0.129}_{-0.164}$$

- π^0 recently included in new DSSV fits
- Systematic errors are important to full understanding on uncertainties
  - DSSV08 + Run 9 π^0 gives $\Delta G = 0.06$
  - Plus rel. lumi gives $\Delta G = 0.12$
  - Minus rel. lumi gives $\Delta G = 0.02$

Charged Pion



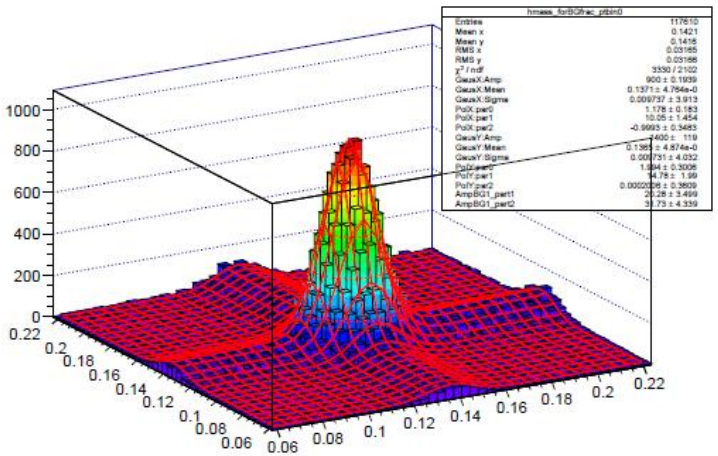


- Complimentary to π^0 probe
  - Favored fragmentation from flavor structure of $\pi^{\pm}$
  - Well determined quark polarizations lead to hierarchy

$$\Delta G > 0 \Rightarrow A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-}$$
$$\Delta G < 0 \Rightarrow A_{LL}^{\pi^+} < A_{LL}^{\pi^0} < A_{LL}^{\pi^-}$$

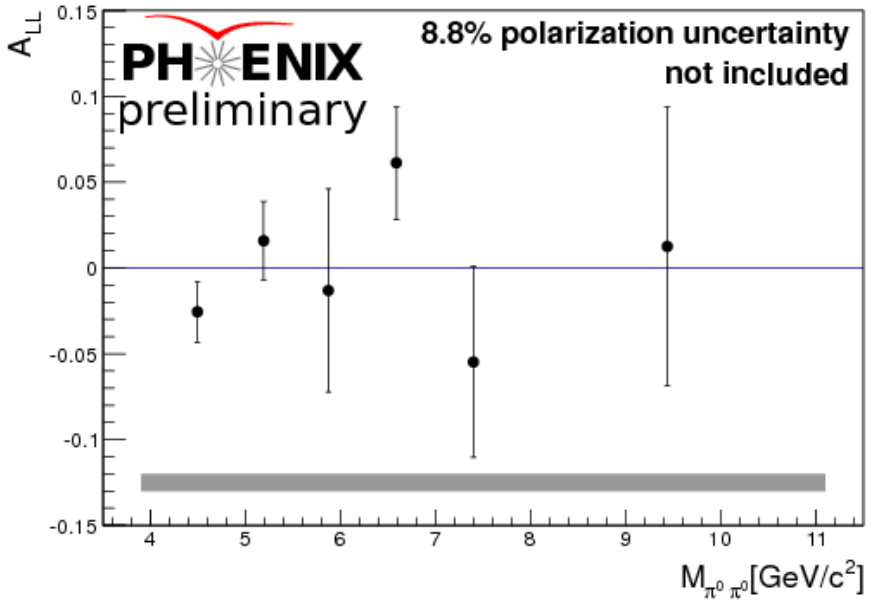
- Fragmentation functions need refinement for global analysis inclusion

π^0 Correlations

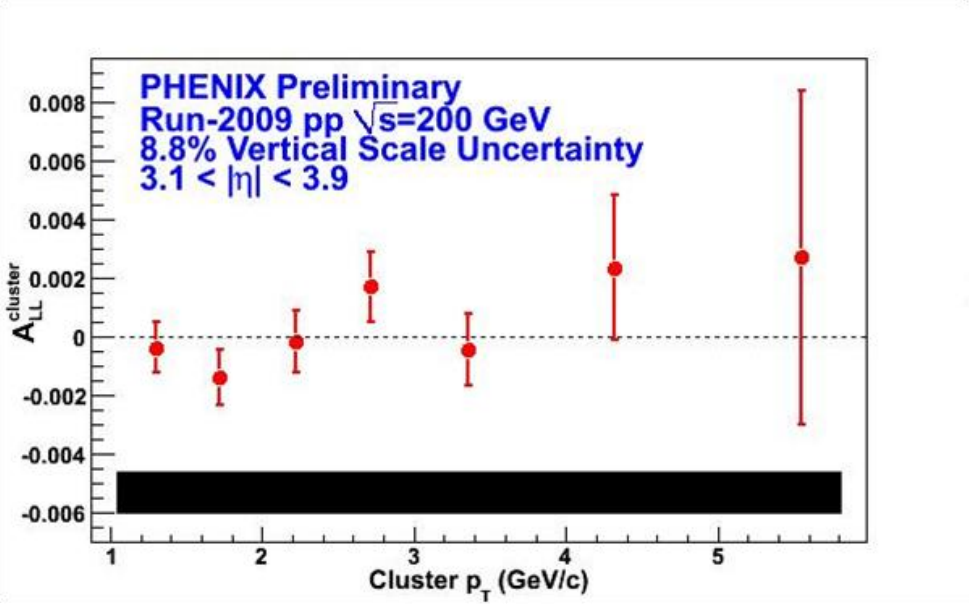


- First pair correlation A_{LL} in PHENIX
- Brings in strong kinematic constraint due to correlation
- Similar to single π^0 analysis with new backgrounds

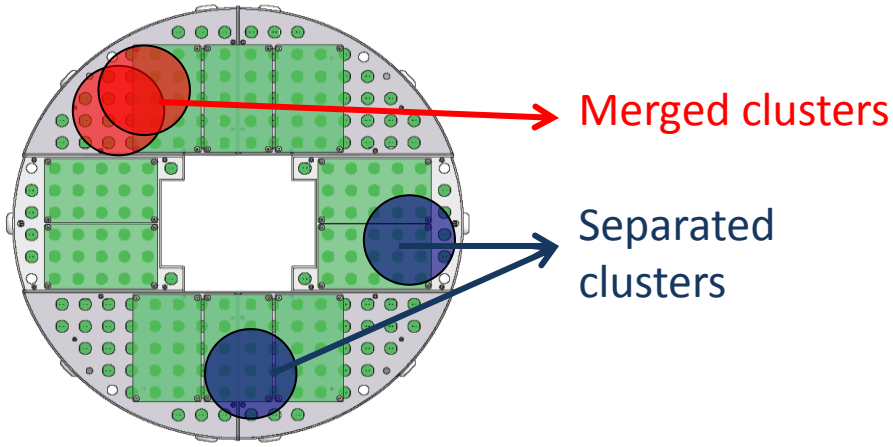
- Requires large integrated luminosity
- Can be extended to other channels
  - π^0 + hadron
  - π^0 + forward cluster

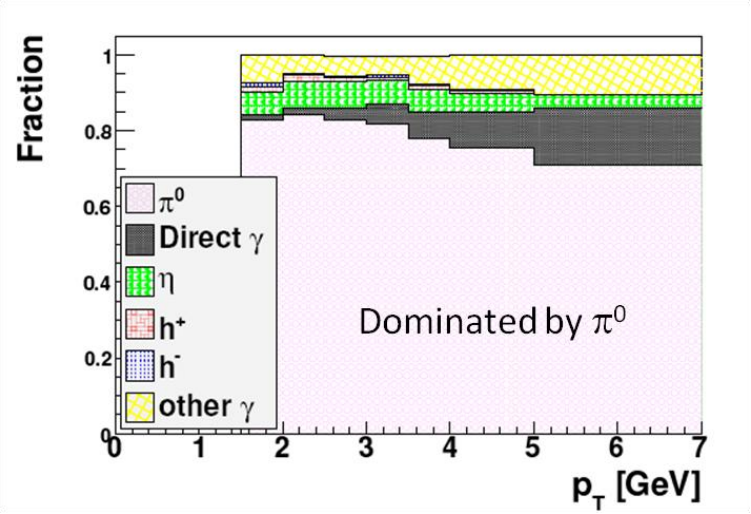


Forward Cluster Analysis



- Forward clusters dominated by π^0
  - Low x reach
  - Systematic limited
- 500 GeV analysis underway
  - Trigger upgrade increased purity of sample by a factor of 4
  - Expected uncertainty ~ $1e^{-4}$





Weak Bosons as a Probe

- W couplings are parity violating
  - Exploit kinematics for (almost) direct sea quark determination

$$A_L^{W^+} = -\frac{\Delta u\bar{d}(1-cos\theta)^2 + \Delta\bar{d}u(1+cos\theta)^2}{u\bar{d}(1-cos\theta)^2 + \bar{d}u(1+cos\theta)^2}$$

$$A_L^{W^-} = -\frac{\Delta d\bar{u}(1+cos\theta)^2 + \Delta\bar{u}d(1-cos\theta)^2}{d\bar{u}(1+cos\theta)^2 + \bar{u}d(1-cos\theta)^2}$$

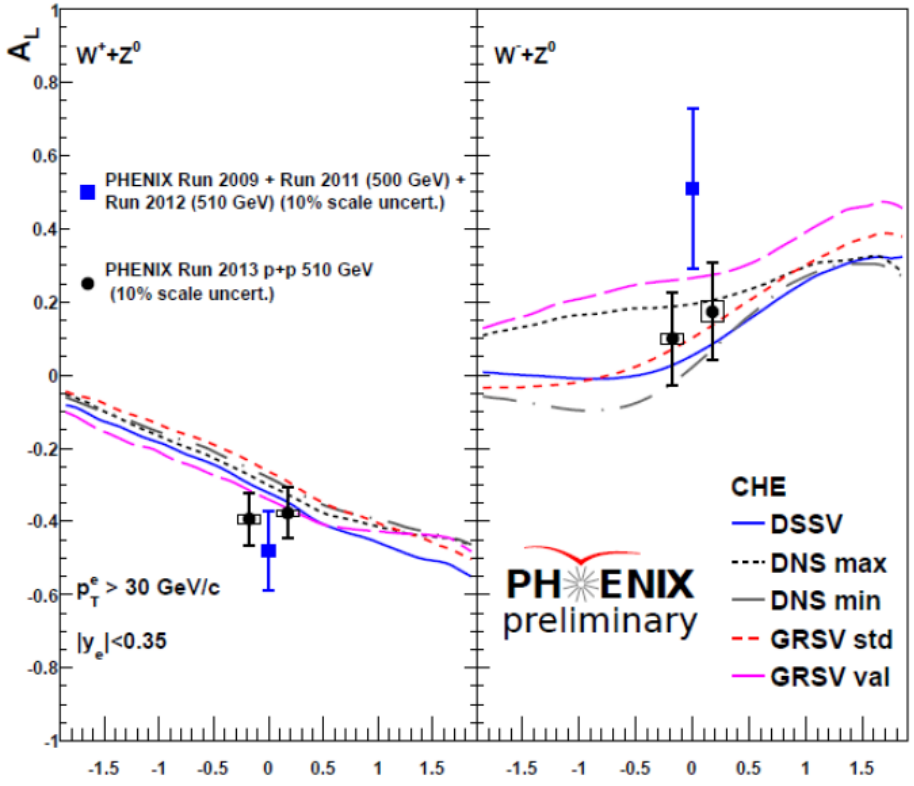
- Single spin asymmetry (same determination as double)
  - Detect outgoing leptons
  - No fragmentation function
  - “Unpolarized” beam is averaged over, leading to two measurements

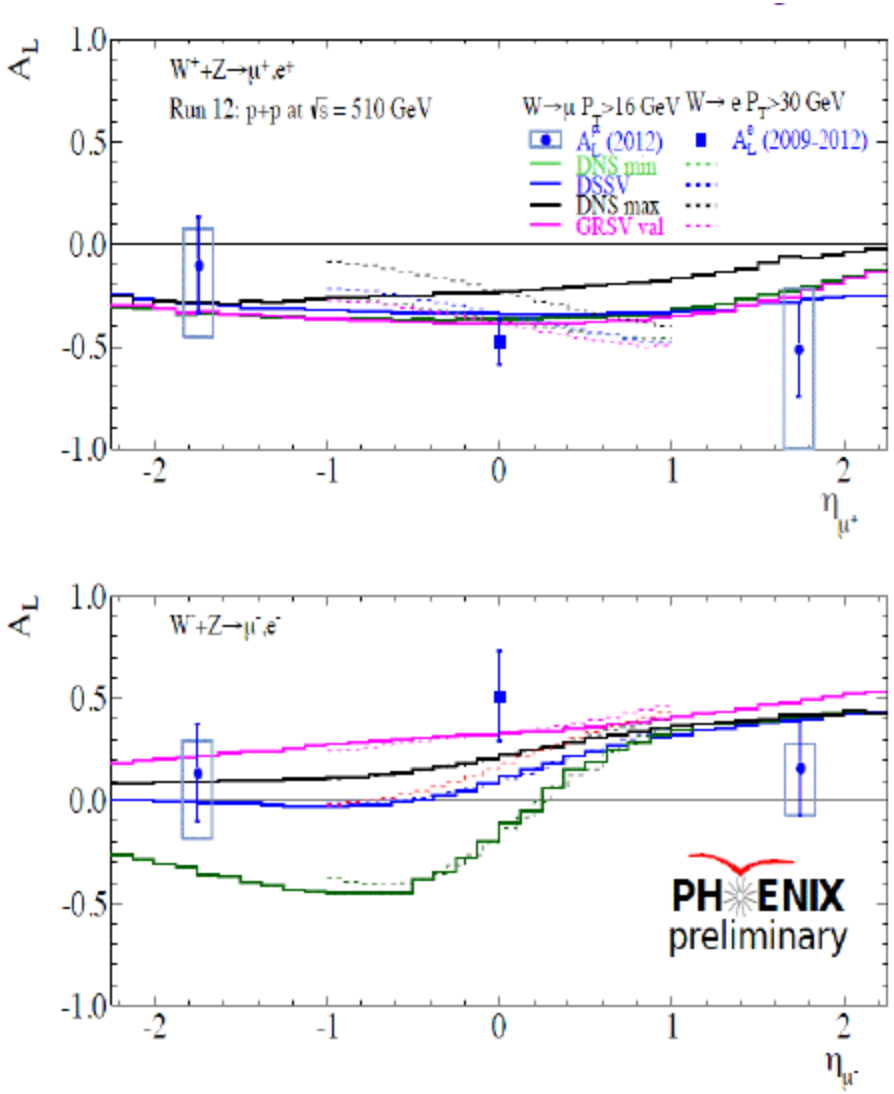
- Electron channel detected in Jacobian peak
  - Isolation cut reduces background, not signal

- Muon channel measured via multivariate analysis and unbinned max likelihood fit
  - Extract signal-to-background in W rich region

$W^{\pm} \rightarrow e^{\pm}$ & $\mu^{\pm}$

- Electron data close to publication
- 2011, 2012 muons being finalized
  - 2013 data benefits from FVTX tracking





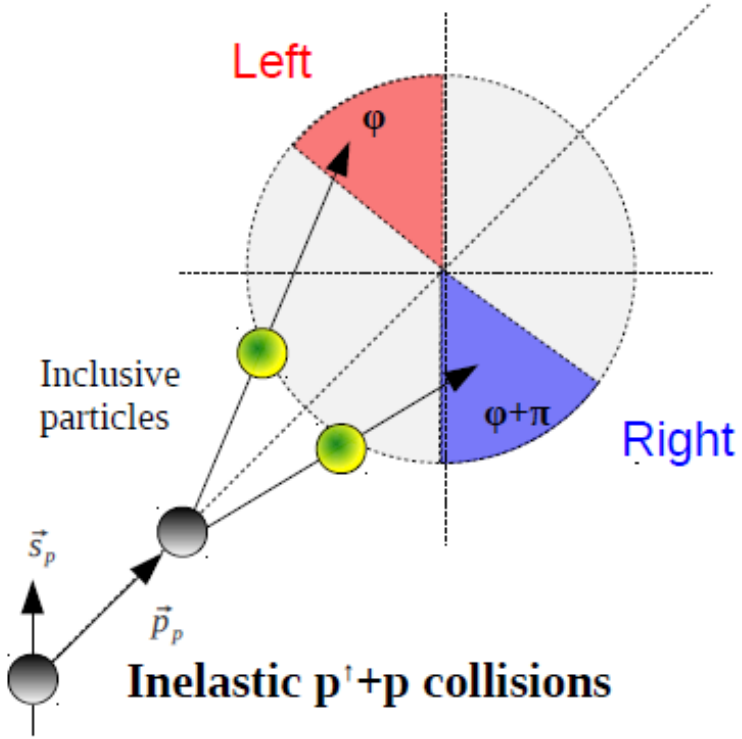
Transverse Spin Physics

What do we measure?

$$\frac{d^3\sigma(pp \to hX)}{dx_1 dx_2 dz} \propto q(x_1)q(x_2) \times \frac{d^2\hat{\sigma}(q_i q_j \to q_k q_l)}{dx_1 dx_2} \times FF_{q_k q_l}(z, p_h)$$

Structure pQCD Fragmentation

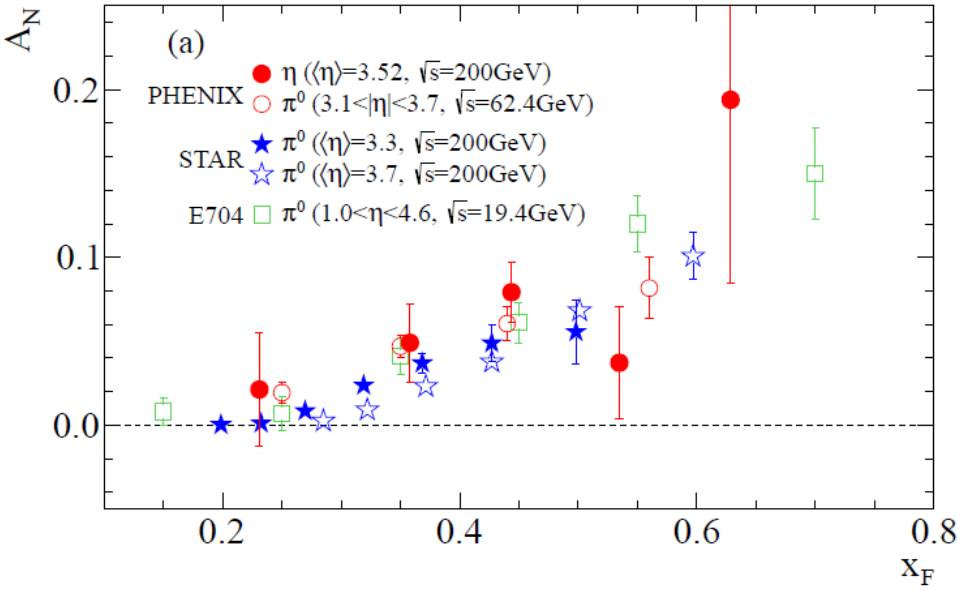
- Single (transverse) spin asymmetries
  - Modified production in azimuth w.r.t. proton spin direction
- Transversity distributions coupled to Collins TMD fragmentation
  - Correlation of proton spin with quark spin coupled with spin dependent FF
- Sivers quark distribution
  - Correlation between proton spin and quark transverse momentum
- Twist-3 effects in tri-parton correlators

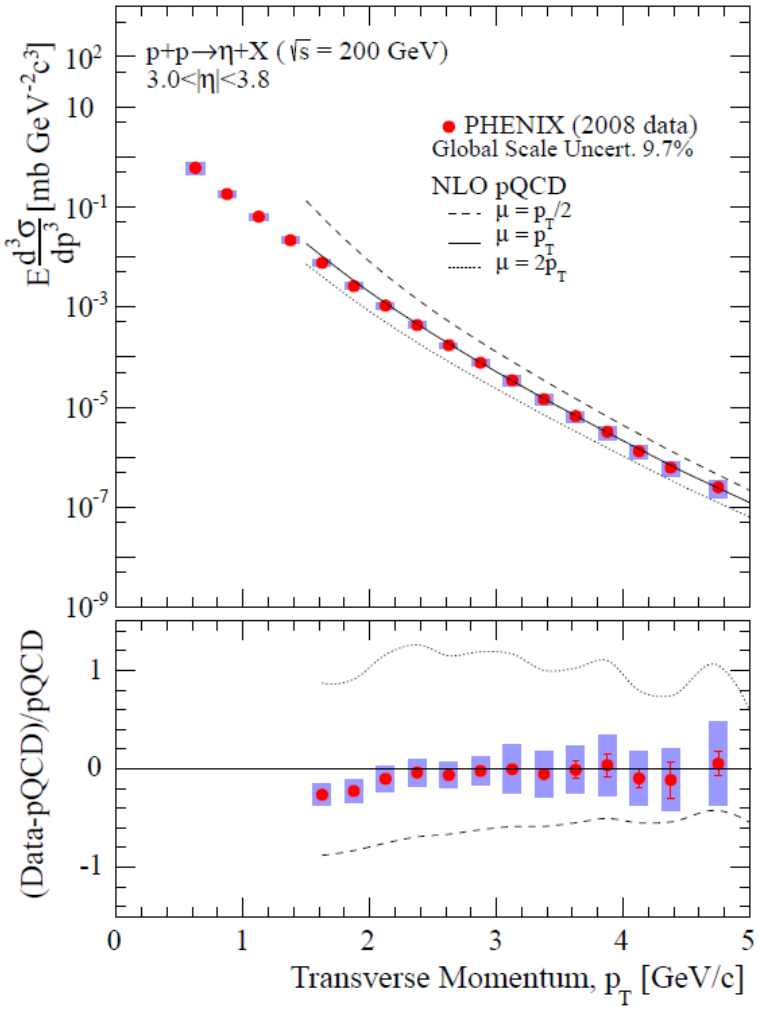


$$A_N = \frac{1}{P}\frac{\sigma^{\uparrow}(\varphi) - \sigma^{\uparrow}(\varphi+\pi)}{\sigma^{\uparrow}(\varphi) + \sigma^{\uparrow}(\varphi+\pi)}$$

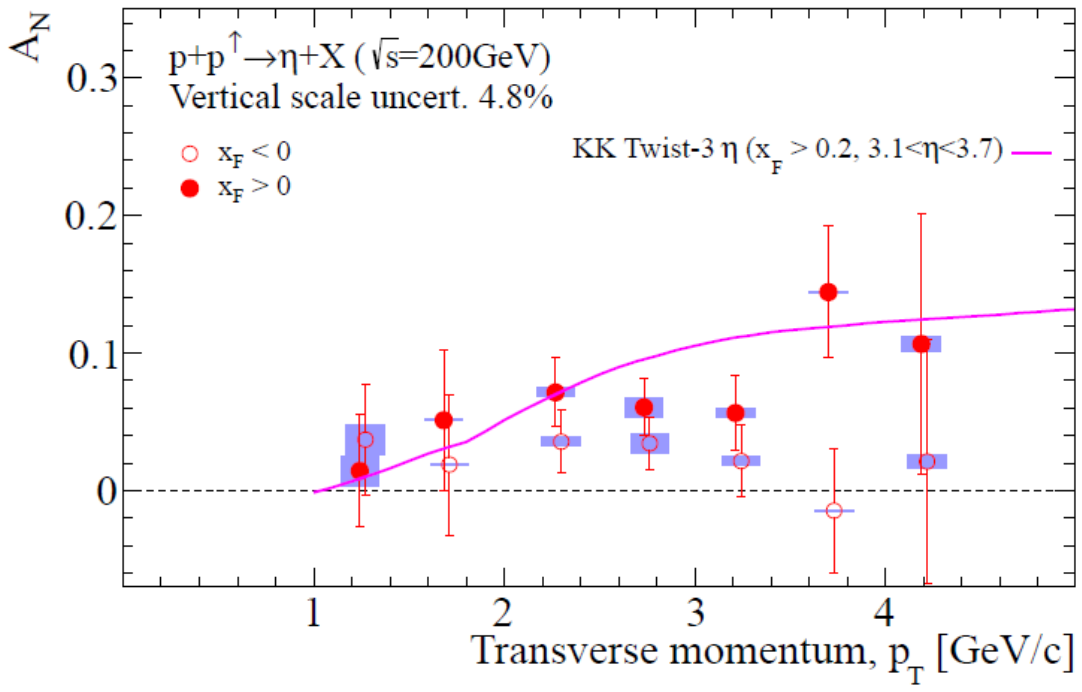
Forward A_N of Neutral Mesons

- Cross section well described by pQCD
- A_N independent of collision energy
  - x_F scaling?
- Similar for pions and etas



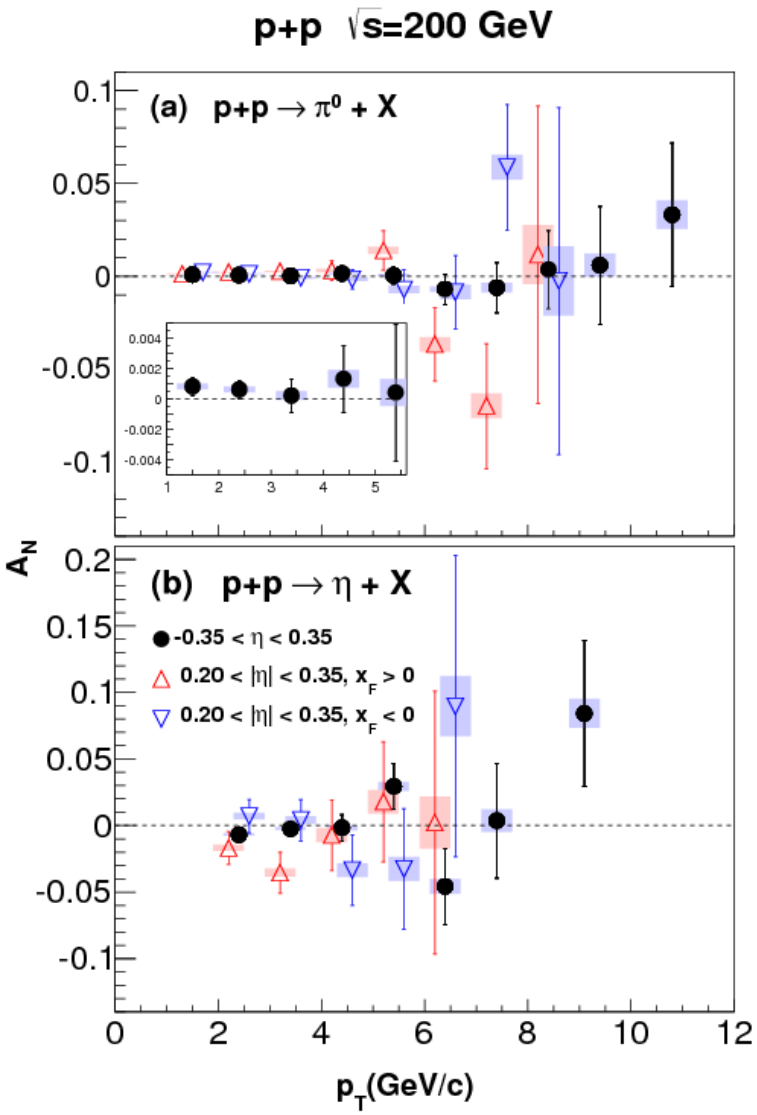


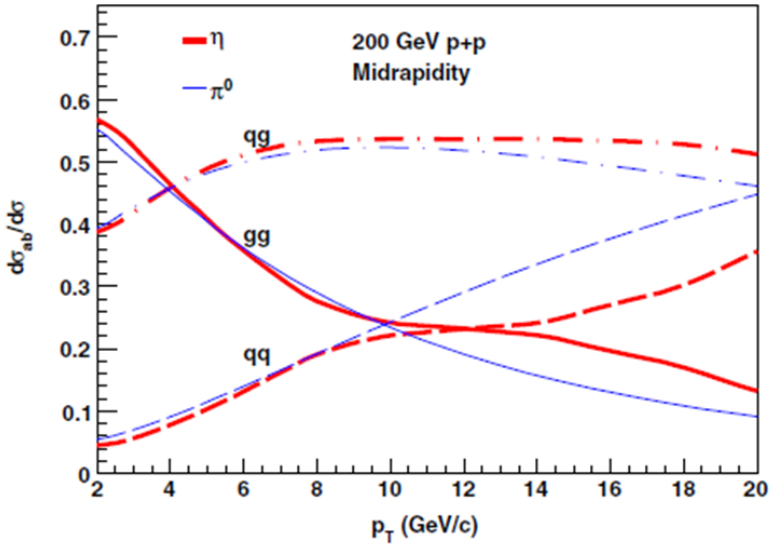
Forward η p_T Dependence



- Little variation with p_T
- Naïve expectation of $A_N \sim 1/Q \sim 1/p_T$
- Recent theoretical work describes plateau

Central A_N of Neutral Mesons

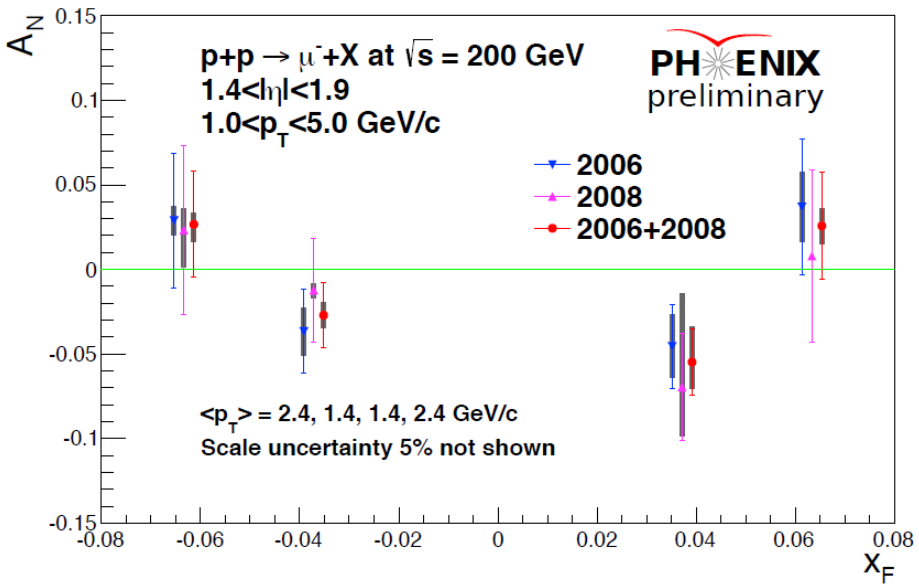




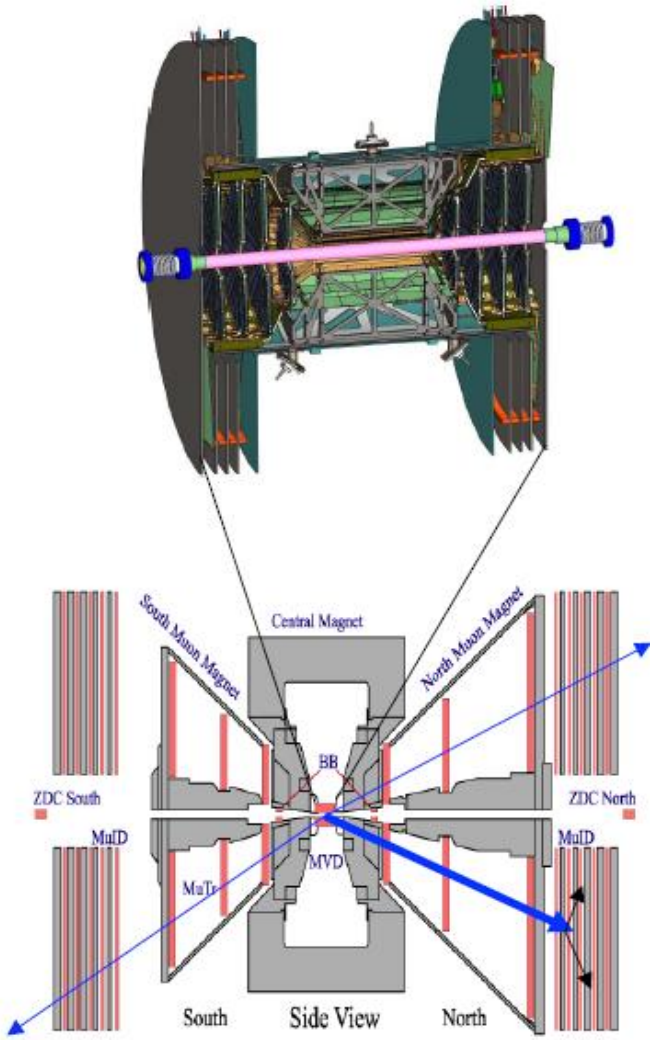
- New results 20x better statistics
- Sensitive to q-g and g-g processes
- Consistent with zero, compared to forward production

Forward Heavy Flavor

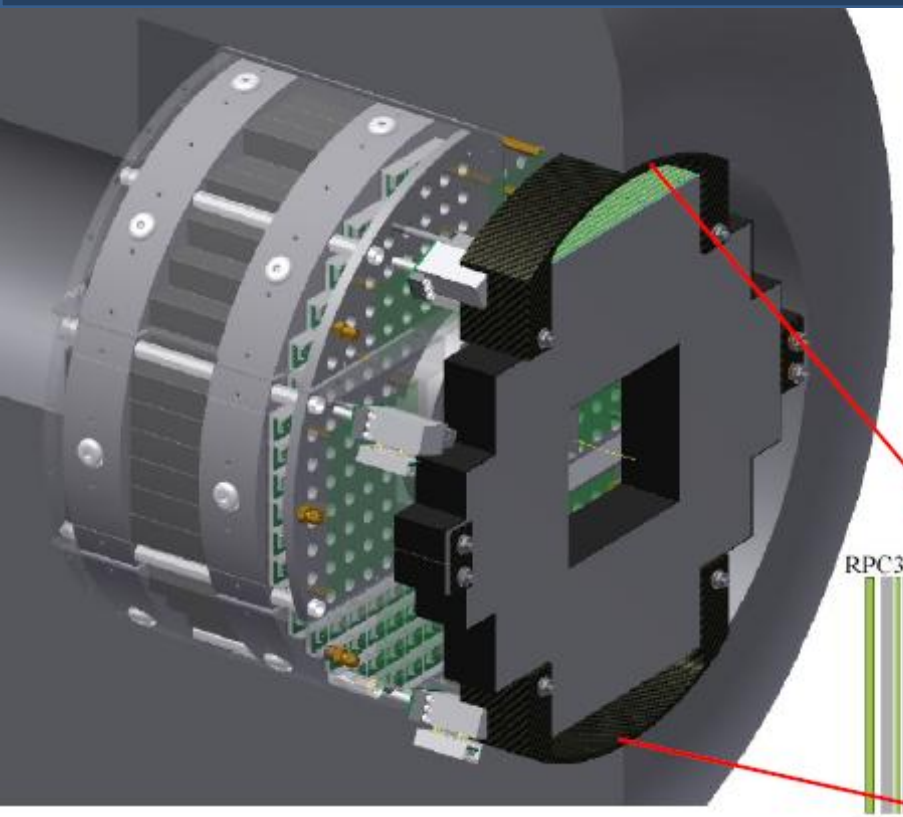
- Heavy flavor probes tri-gluon correlation
- A_N consistent with zero
- Future data will significantly constrain A_N
  - 2012 data close to finished
  - 2015 data to be taken
  - FVTX for both sets helps with reconstruction/background rejection



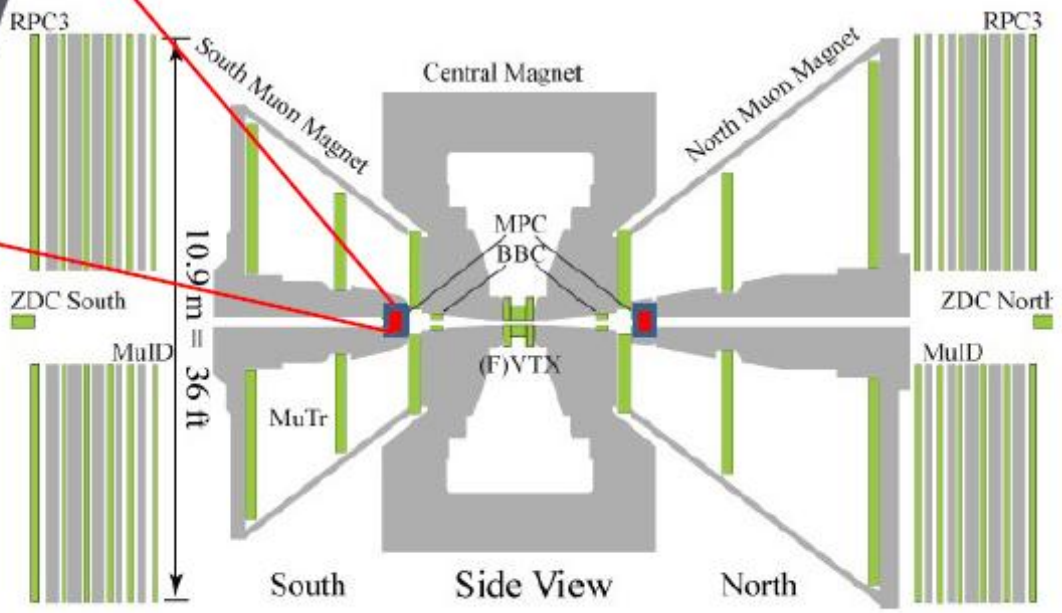
Forward Vertex Detector



MPC-EX



- New tracking and pre-shower in front of MPC
- Reject merged π^0 photon clusters
- Future measurement of direct photon A_N and cross section



- Excited for physics in 2015
  - p-p and p-Au

Summary

- ΔG probed at PHENIX
  - High statistics π^0 included in global analysis
  - Other channels available
  - New measurements coming from 500 GeV runs

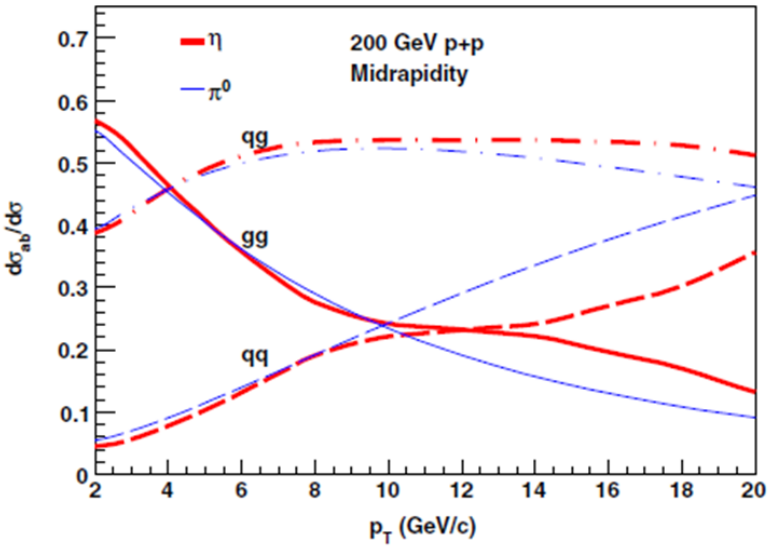
- Sea quark helicity accessed via W boson production
  - Clean probe, clean interpretation
  - Full dataset close to analyzed

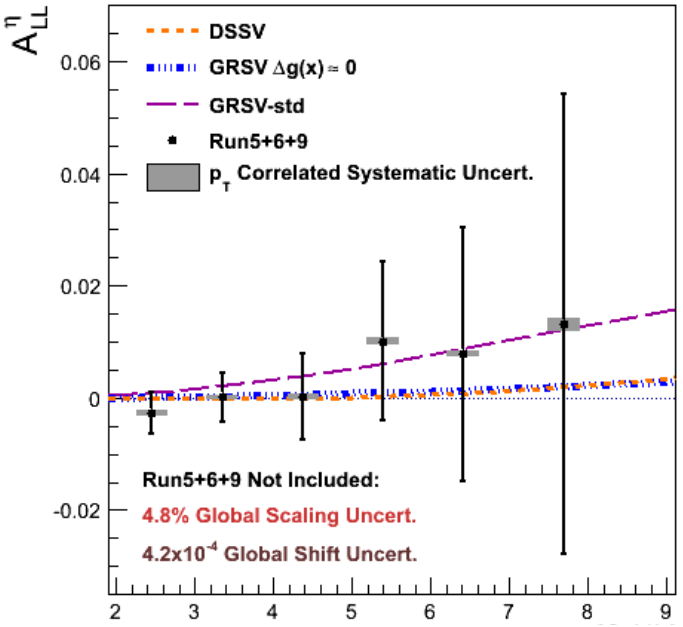
- Transverse spin asymmetries persist to RHIC energies
  - Forward production of mesons consistent with previous measurements
  - Mid-rapidity asymmetries consistent with zero
  - Promising new results with FVTX, MPC-EX in coming run

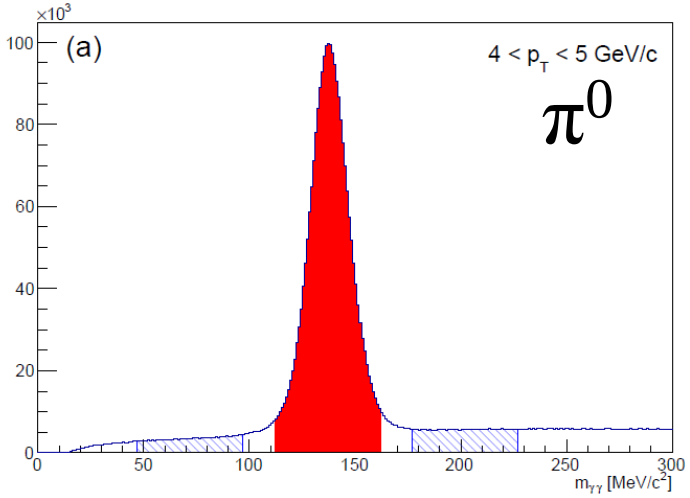
Thank You

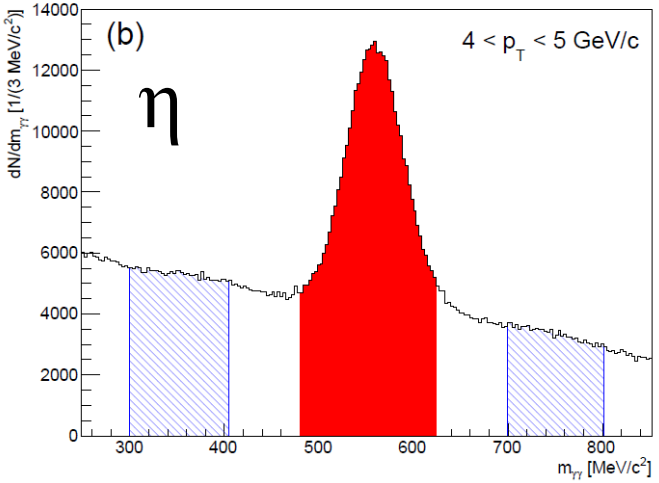
Backup

π^0 & η

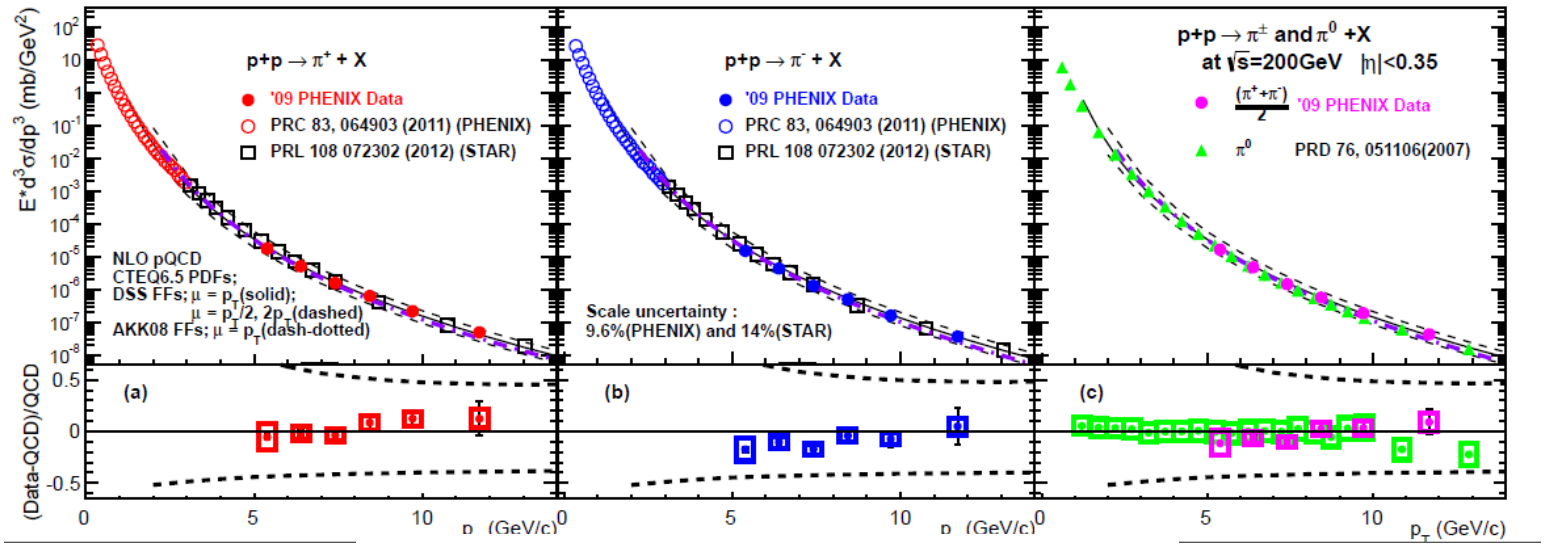

η
π0
200 GeV p+p
Midrapidity
qg
gg
qq
dσab/dσ
pT (GeV/c)

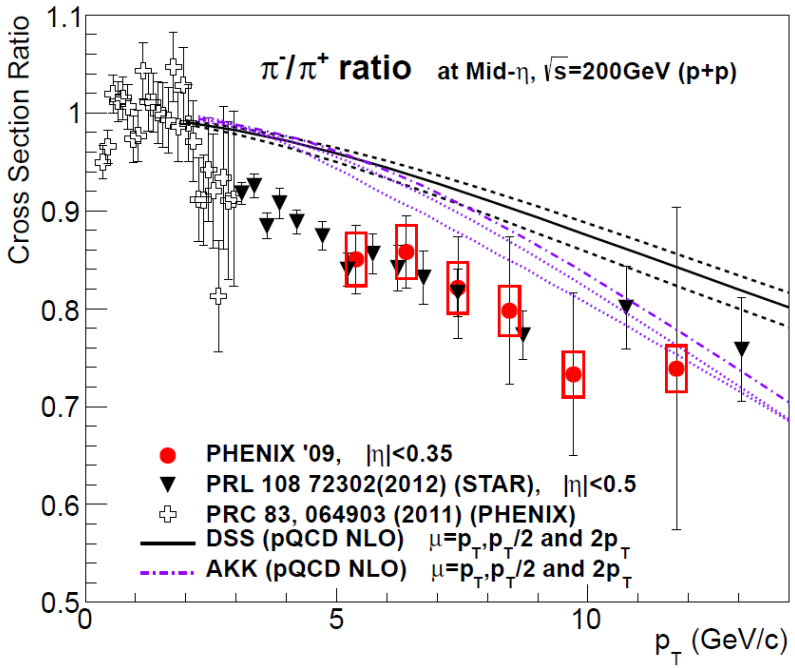

A_LL^η
DSSV
GRSV Δg(x) = 0
GRSV-std
Run5+6+9
pT Correlated Systematic Uncert.
Run5+6+9 Not Included:
4.8% Global Scaling Uncert.
4.2x10-4 Global Shift Uncert.


(a)
4 < pT < 5 GeV/c
π0
mγγ [MeV/c2]

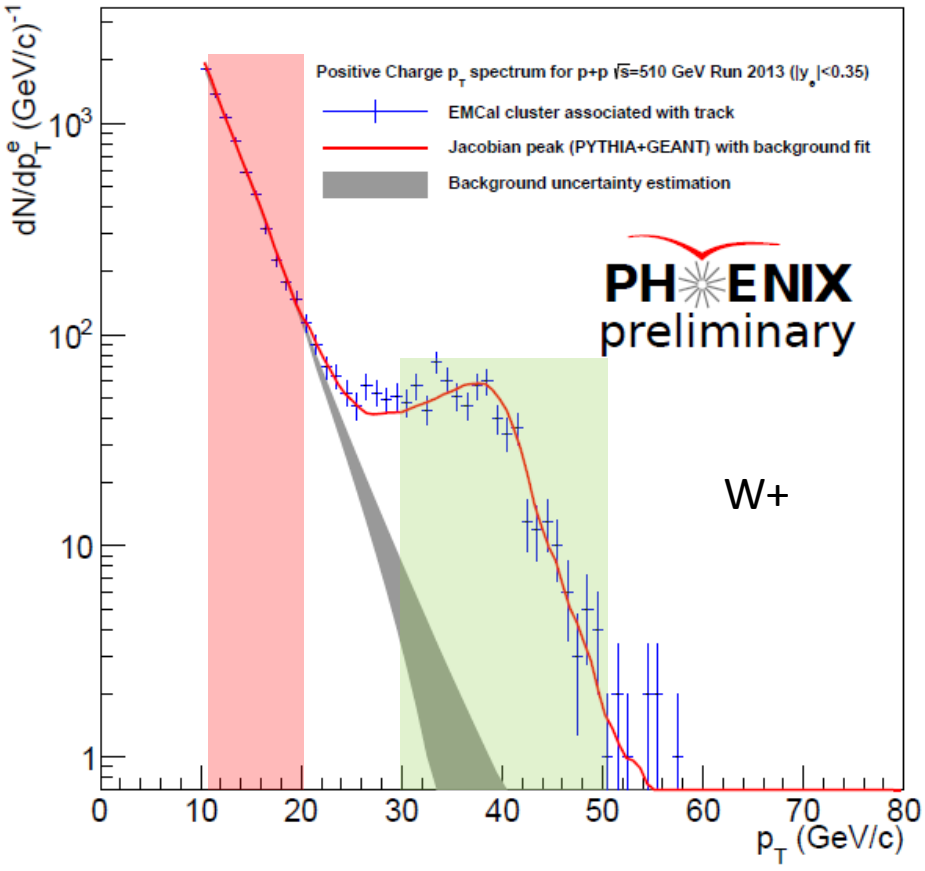

(b)
4 < pT < 5 GeV/c
η
dN/dmγγ [1/(3 MeV/c2)]
mγγ [MeV/c2]

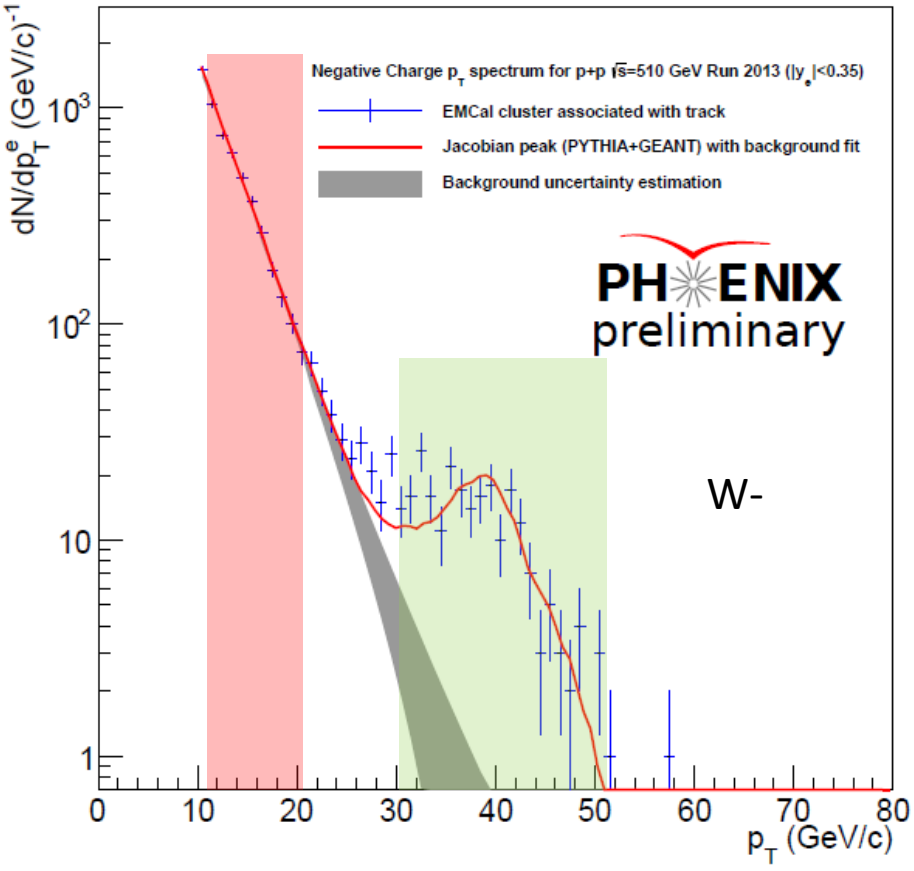
$\pi^{\pm}$


p+p → π+ + X
'09 PHENIX Data
PRC 83, 064903 (2011) (PHENIX)
PRL 108 072302 (2012) (STAR)
NLO pQCD
CTEQ6.5 PDFs;
DSS FFs; μ = p_T(solid);
μ = p_T/2, 2p_T(dashed)
AKK08 FFs; μ = p_T(dash-dotted)
p+p → π- + X
'09 PHENIX Data
PRC 83, 064903 (2011) (PHENIX)
PRL 108 072302 (2012) (STAR)
Scale uncertainty :
9.6%(PHENIX) and 14%(STAR)
p+p → π± and π0 +X
at √s=200GeV |η|<0.35
(π+ + π-)/2 '09 PHENIX Data
π0 PRD 76, 051106(2007)
E*d3σ/dp3 (mb/GeV2)
(Data-QCD)/QCD
(a)
(b)
(c)
p_T (GeV/c)


π-/π+ ratio at Mid-η, √s=200GeV (p+p)
Cross Section Ratio
PHENIX '09, |η|<0.35
PRL 108 72302(2012) (STAR), |η|<0.5
PRC 83, 064903 (2011) (PHENIX)
DSS (pQCD NLO) μ=p_T,p_T/2 and 2p_T
AKK (pQCD NLO) μ=p_T,p_T/2 and 2p_T
p_T (GeV/c)

W Spectra


Positive Charge p_T spectrum for p+p $\sqrt{s}$=510 GeV Run 2013 ($|y_e|$<0.35)
EMCal cluster associated with track
Jacobian peak (PYTHIA+GEANT) with background fit
Background uncertainty estimation
PHENIX
preliminary
W+
dN/dp_T^e (GeV/c)$^{-1}$
p_T (GeV/c)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preliminary
W-
dN/dp_T^e (GeV/c)$^{-1}$
p_T (GeV/c)

Forward A_N for MPC