# Spin Physics results from

International conference on New Frontiers
in Physics 2015, Kolymbari, Greece
August 25, 2015

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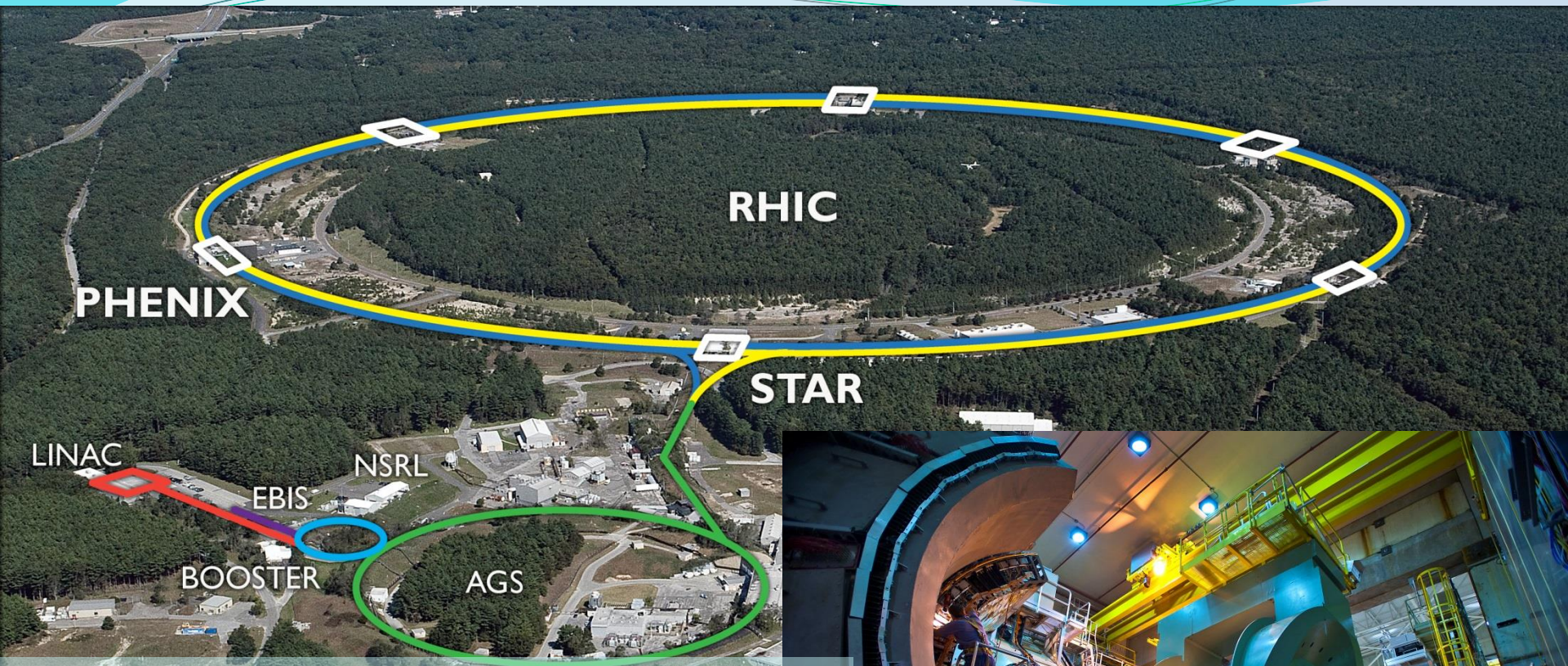
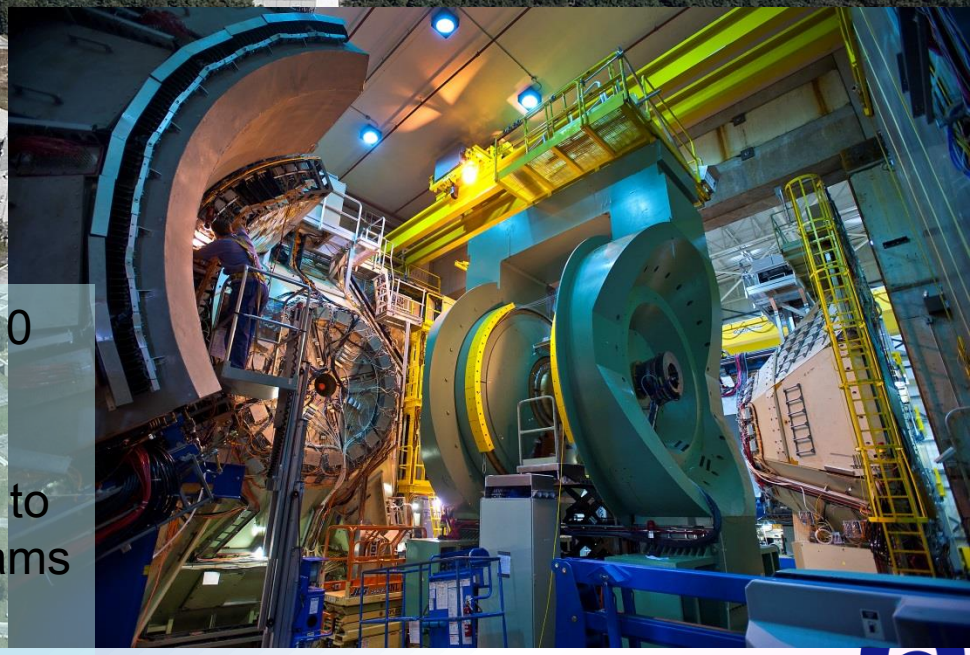
(RIKEN)
For the PHENIX collaboration

# Spin and Nucleon structure: Test-bed to theories

- Spin is extremely relevant to the understanding of matter , many surprises when studying spin quantities
- naïve spin composition by otherwise successful quark model not valid → Spin crisis
- Traditional pQCD did not care about transverse momenta and expected small transverse spin effects→ Large asymmetries seen, resulting in boost of our theoretical understanding of the nucleon AND QCD, connection to LHC

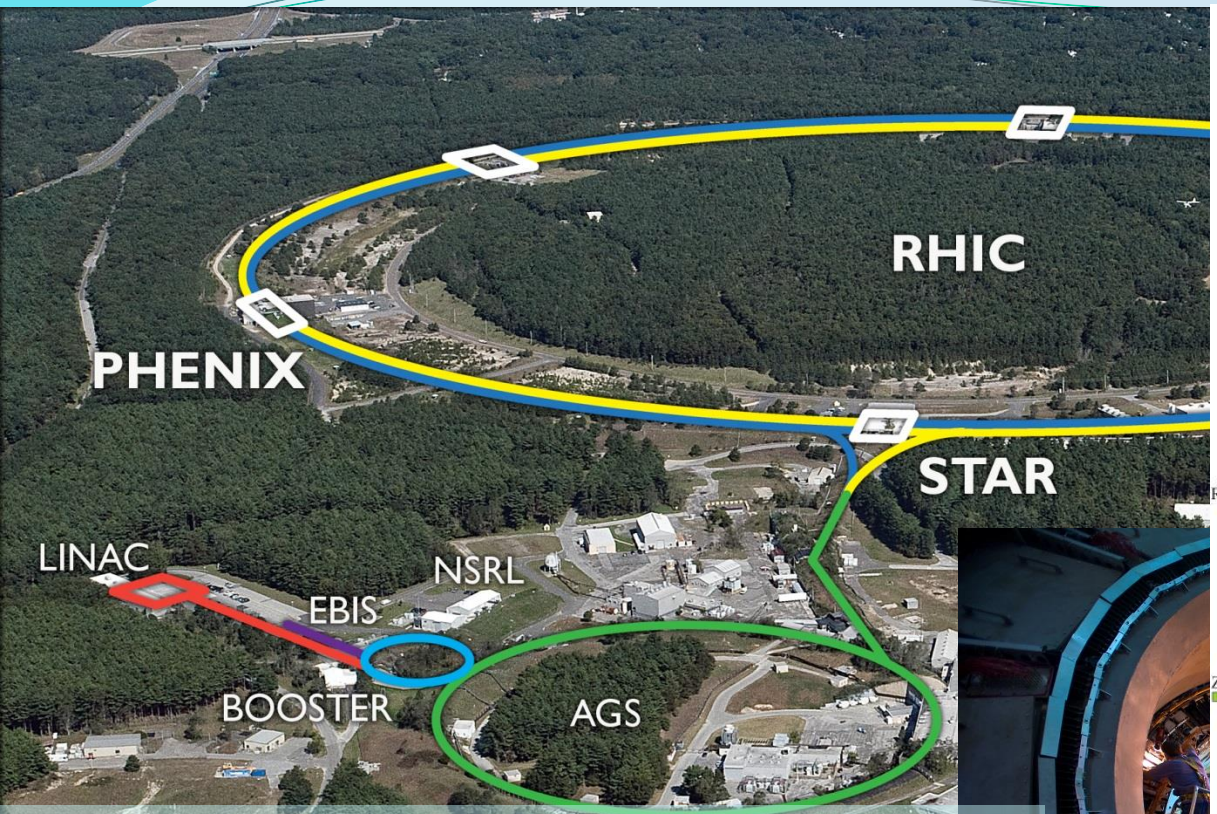
# RHIC and PHENIX

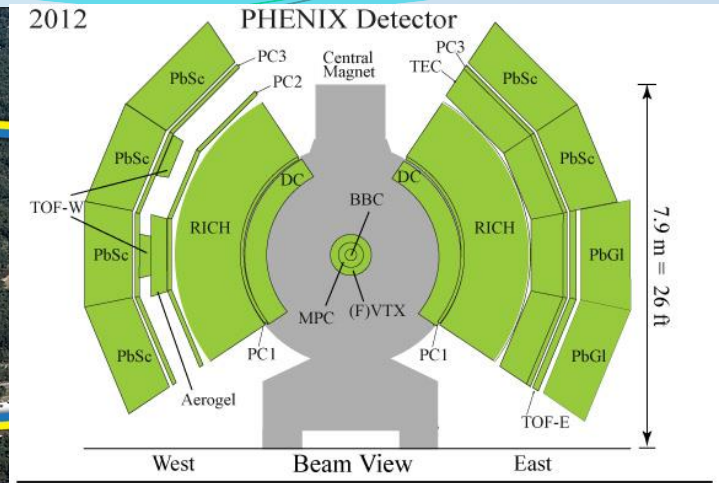


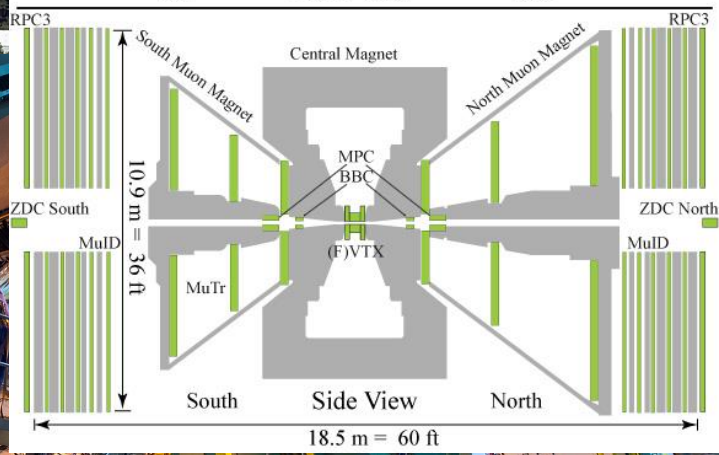



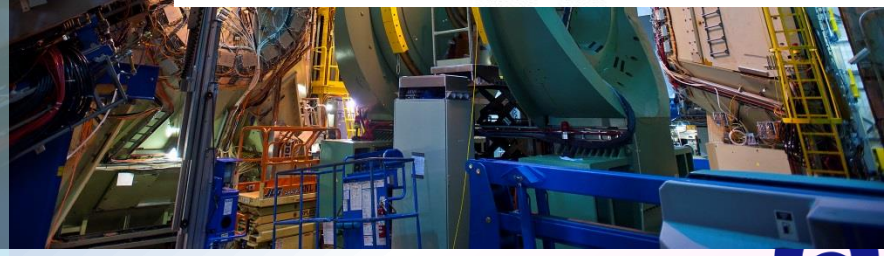
- Polarized proton beams from $\sqrt{s}$ of 62-510 GeV
- pA, AA collisions up to 200 GeV
- Spin rotators around PHENIX and STAR to select long. or transversely polarized beams
- Global and local polarimetry

# RHIC and PHENIX



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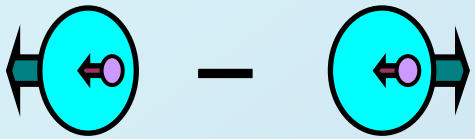
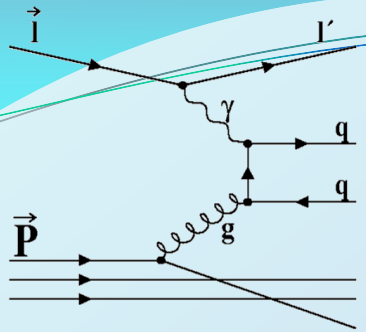
# Longitudinal Spin: Main Questions

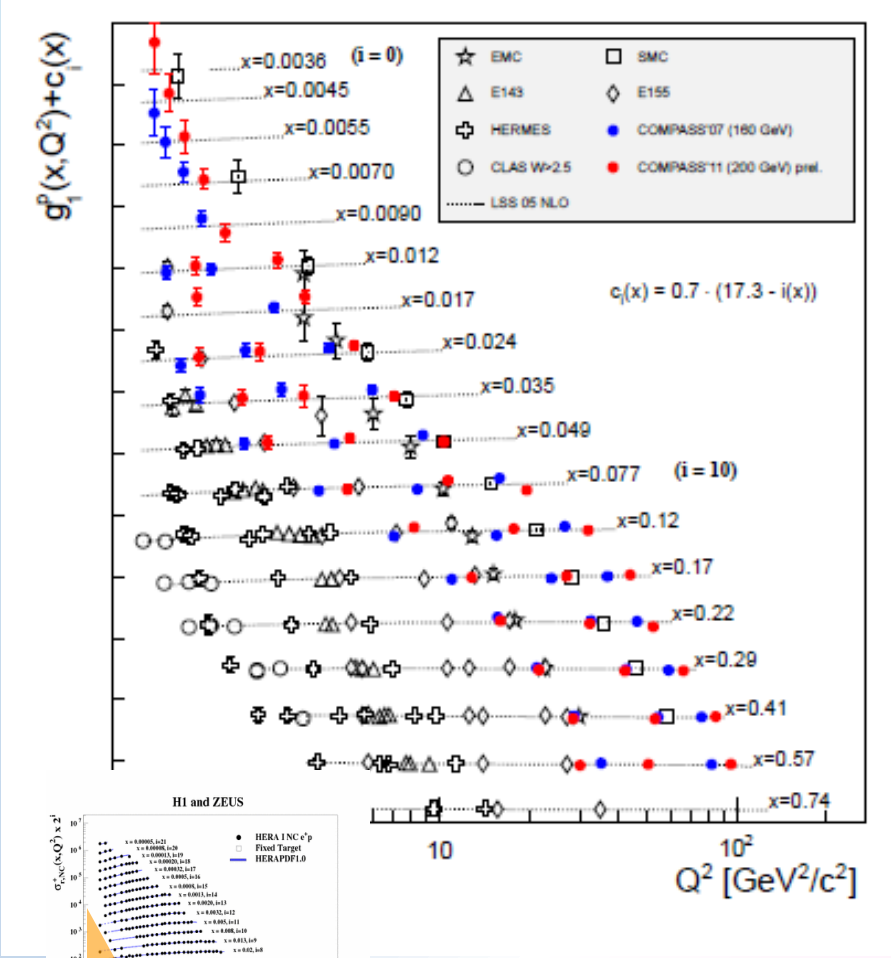


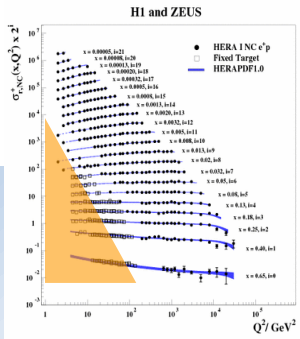
- The momentum of the proton is made up to 50% by gluons and 50% by quarks, is it similar for the spin?
- What happens to quark spins when approaching x=1, helicity retention?
- The un-polarized sea is not symmetric, is the polarized sea symmetric?
- Are the strange (and other sea) quark helicities really negative at unmeasured low x?
- Not just spins but also Orbital angular momentum can contribute – does it? If so, how much?




# Gluon polarization

- Barely access via DIS data through DGLAP evolution (no large $Q^2$ lever arm)
- Some access in SIDIS through high Pt hadrons and charmed mesons



# Gluon polarization

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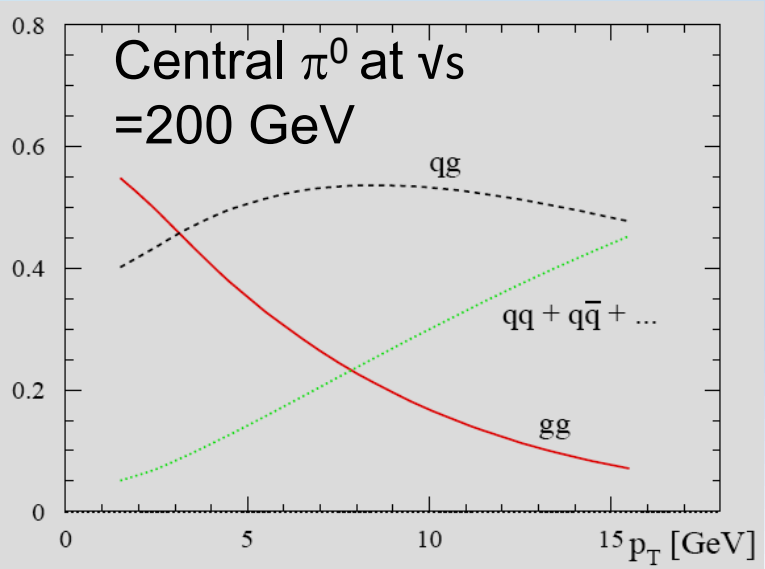
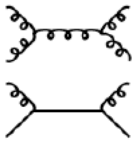
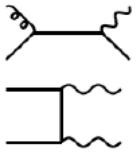
- Some access in SIDIS through high Pt hadrons and charmed mesons
- Polarized pp collisions at LO in $\alpha_S$ sensitive to gluons

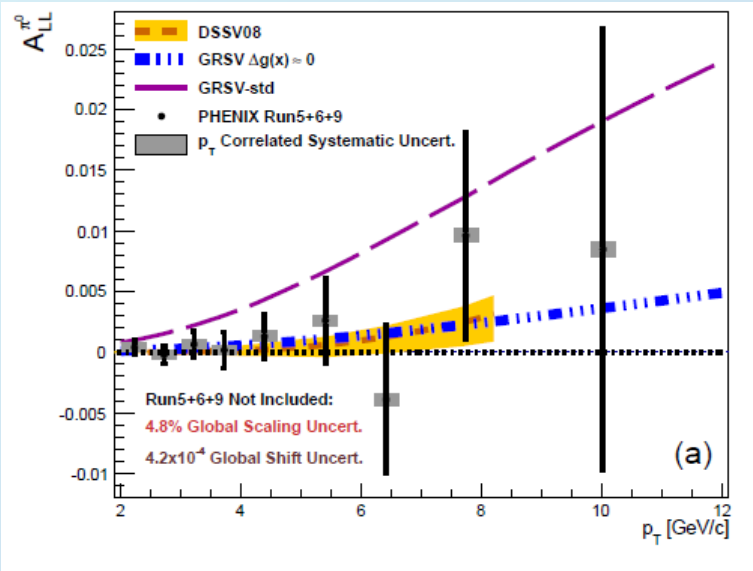
➔long. double spin asymmetries $A_{LL}$ access $\Delta g$



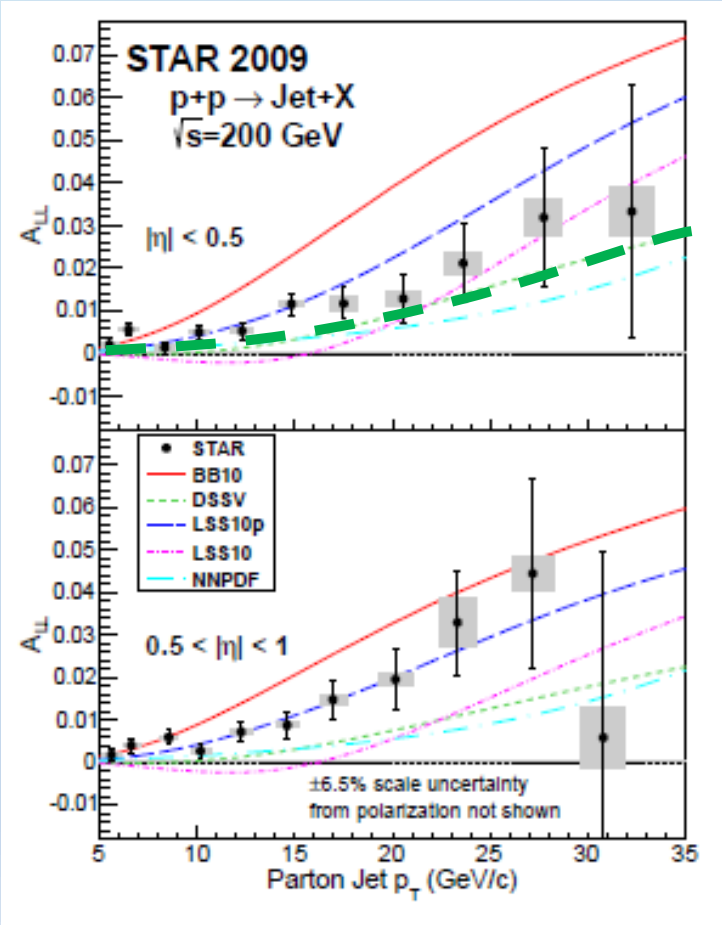

| Reaction | Dom. partonic process | probes | LO Feynman diagram |
|---|---|---|---|
| $\vec{p}\vec{p} \to \pi + X$ | $\vec{g}\vec{g} \to gg$<br>$\vec{q}\vec{g} \to qg$ | $\Delta g$ |  |
| $\vec{p}\vec{p} \to \text{jet(s)} + X$ | $\vec{g}\vec{g} \to gg$<br>$\vec{q}\vec{g} \to qg$ | $\Delta g$ | (as above) |
| $\vec{p}\vec{p} \to \gamma + X$<br>$\vec{p}\vec{p} \to \gamma + \text{jet} + X$<br>$\vec{p}\vec{p} \to \gamma\gamma + X$ | $\vec{q}\vec{g} \to \gamma q$<br>$\vec{q}\vec{g} \to \gamma q$<br>$\vec{q}\vec{\bar{q}} \to \gamma\gamma$ | $\Delta g$<br>$\Delta g$<br>$\Delta q, \Delta\bar{q}$ |  |
| $\vec{p}\vec{p} \to DX, BX$ | $\vec{g}\vec{g} \to c\bar{c}, b\bar{b}$ | $\Delta g$ | |

# Current highlights: gluon helicities

PHENIX: Phys.Rev. D90 (2014) 012007



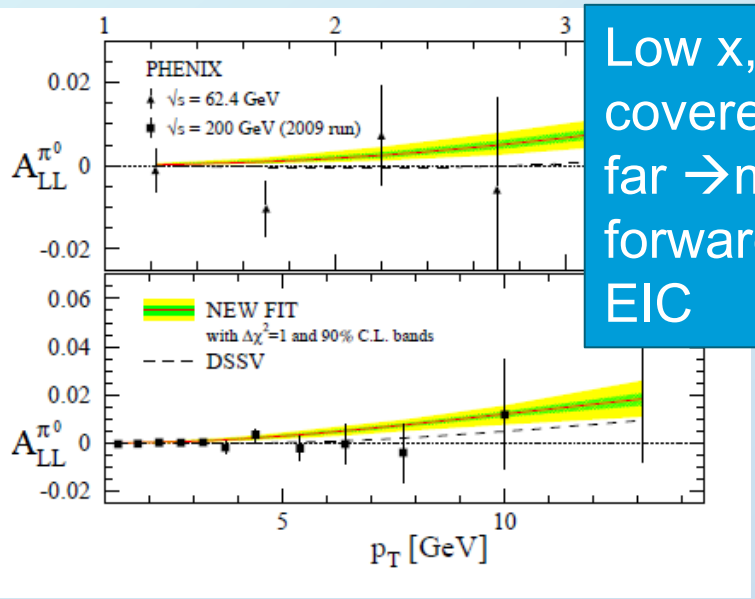

STAR: arXiv:1405.5134



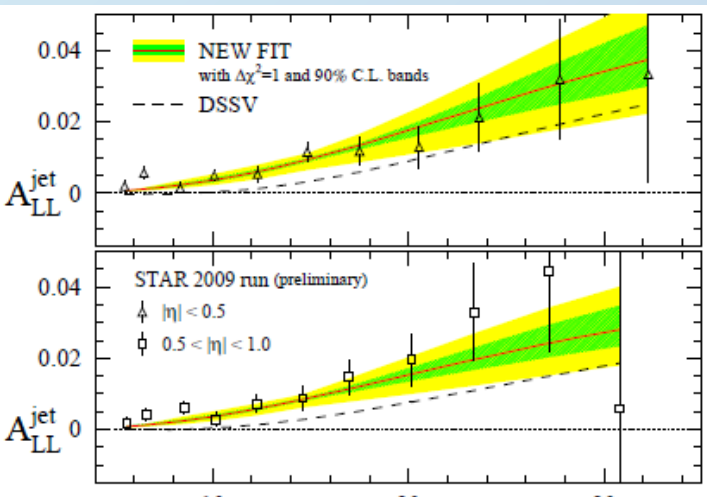

- 200 GeV up to 2009 did not show any large $A_{LL}$
- First indications of nonzero gluons in 2009 data, especiall Star's jet $A_{LL}$s

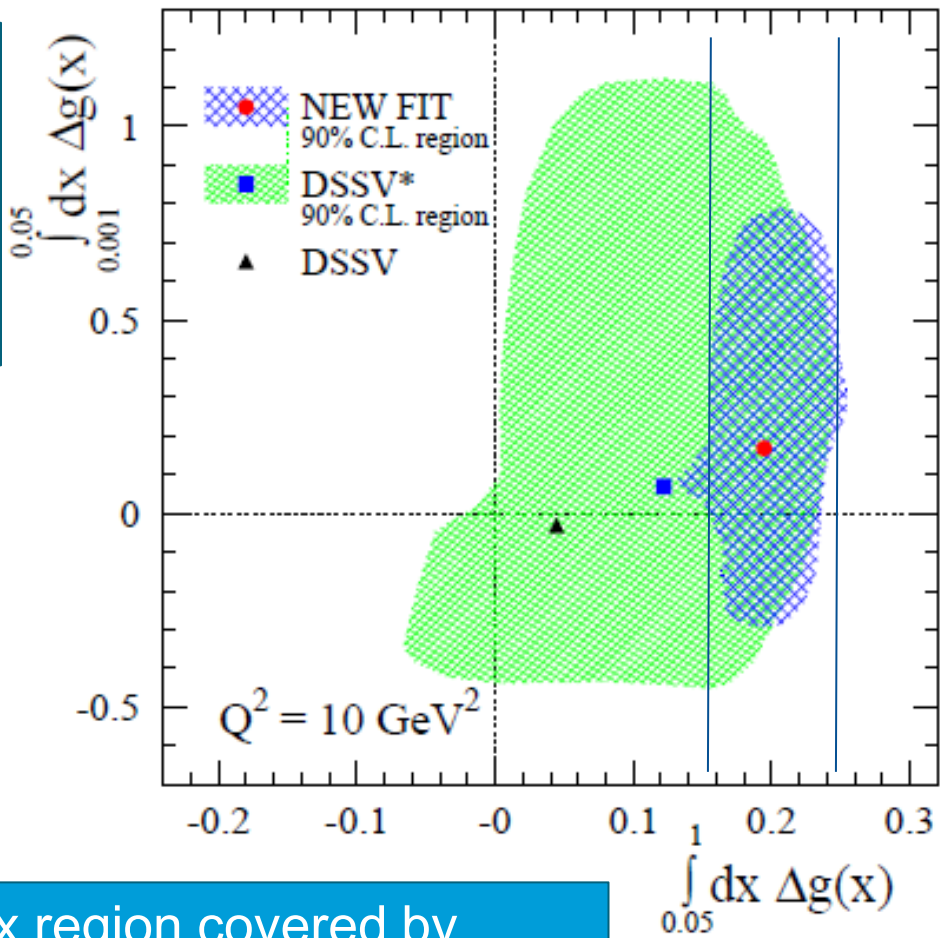
# First nonzero gluon spin indication

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




Low x, not covered so far →more forward pp, EIC

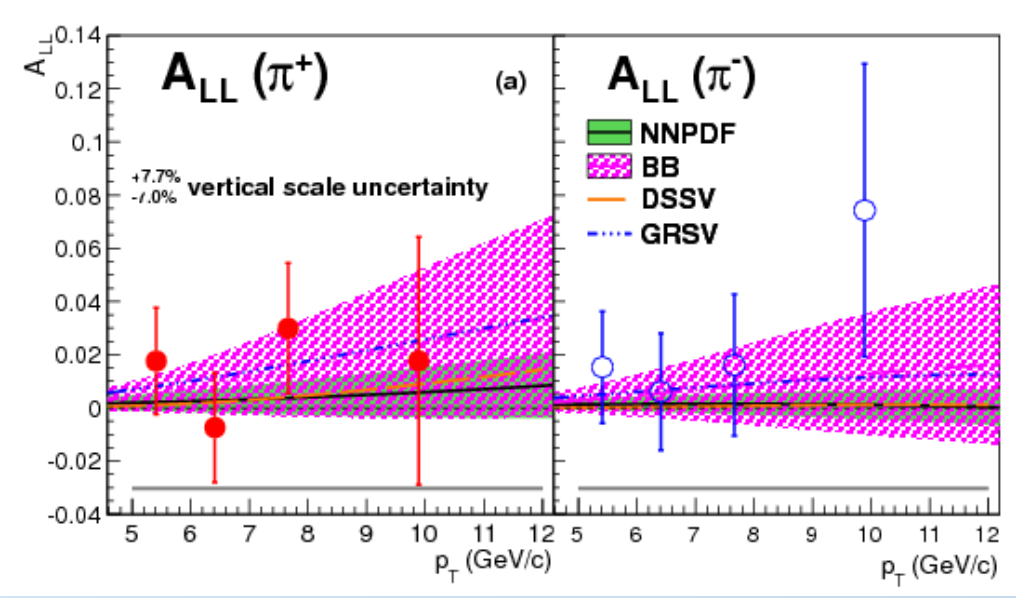



x region covered by current RHIC and DIS results

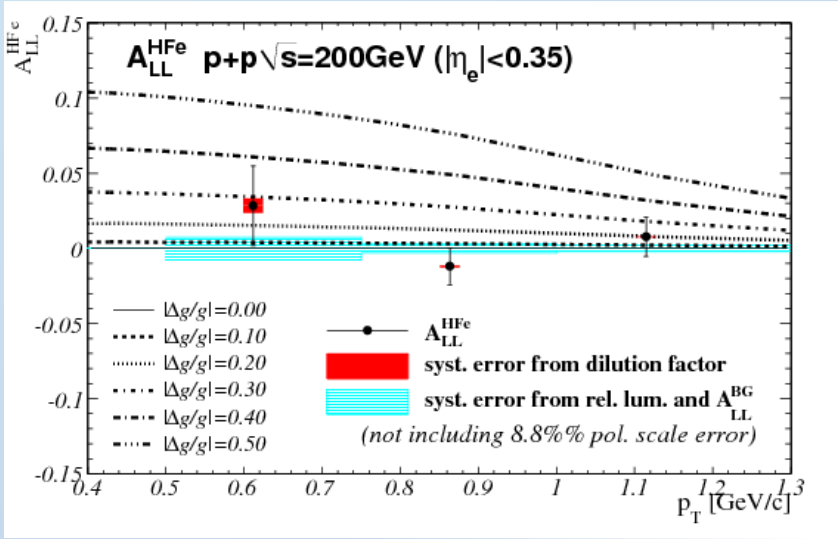
# Other 200 GeV results not yet used in global fit

**Phys.Rev. D91 (2015) 3, 032001**




- Charged pions as potential direct indicator for sign of $\Delta g$ via pion $A_{LL}$ ordering
- 500 GeV analysis ongoing
- Reduced statistics compared to $\pi^0$ due to triggering
- Also central $\eta$

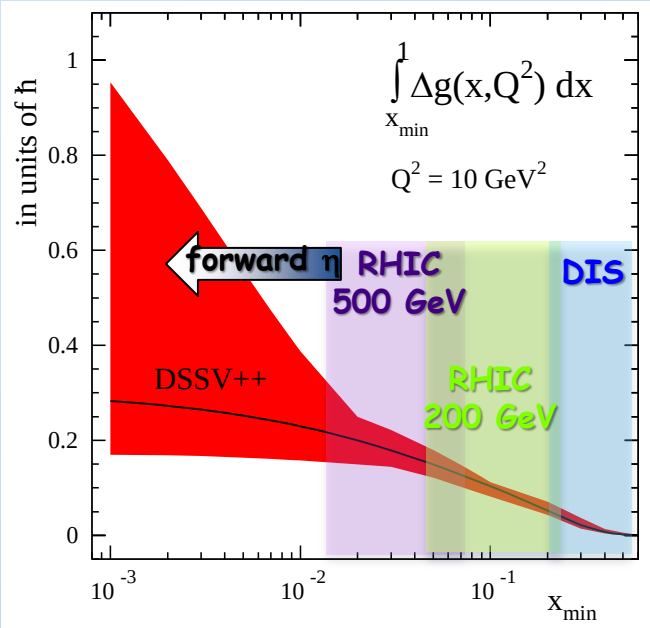
**Phys.Rev. D87 (2013) 012011**




- Single electrons at central rapidity from heavy flavor production directly sensitive to gluon helicity
- Large scale given by the HF quark masses

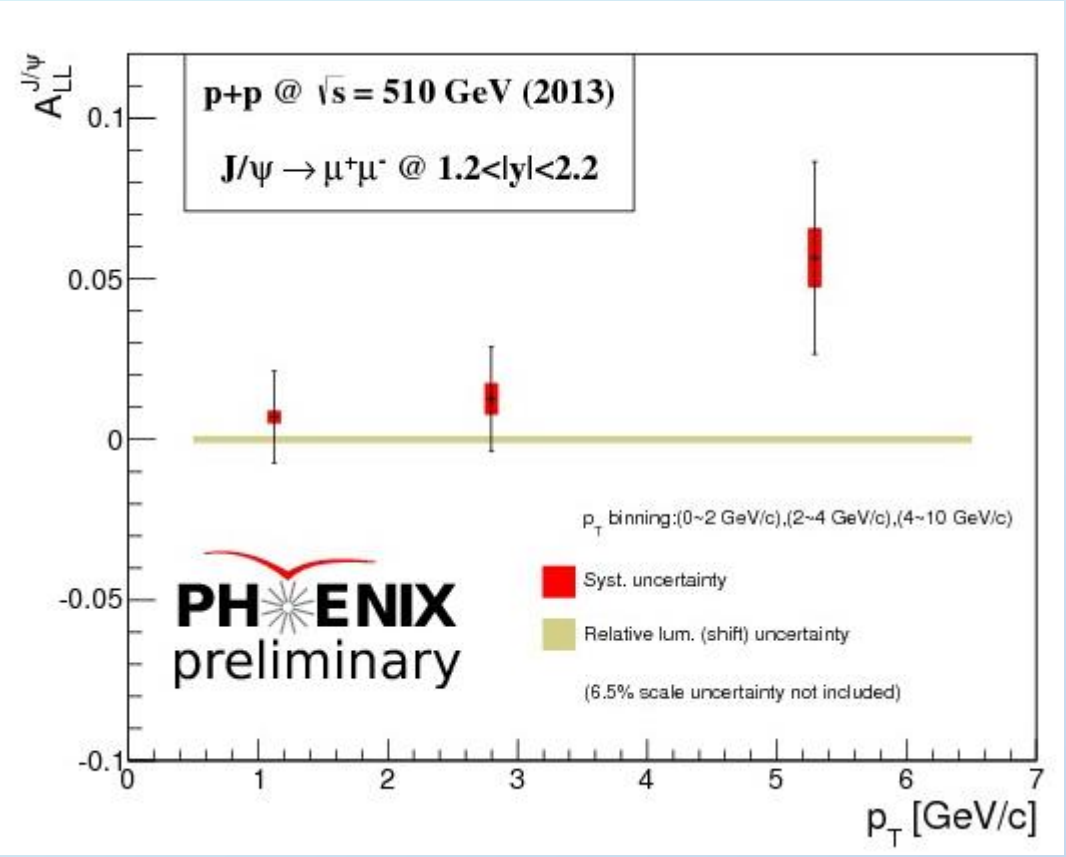
# Next steps: extend gluon x range

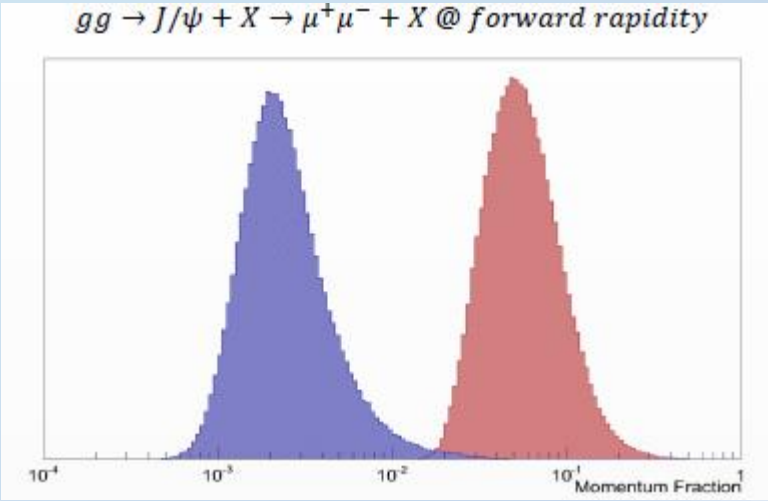
- Higher beam energies at 510 GeV in 2011-2013 increase sensitivity towards lower x for workhorse measurements (central pions and Jets)
- Forward measurements will access more asymmetric collisions and even lower x to below $x=10^{-2}$ in forward pion and jet measurements
- Improved precision in central jet and pion measurements
- Later: Forward jet and Di-jets to scan x range




Even lower x accessible eventually at EIC

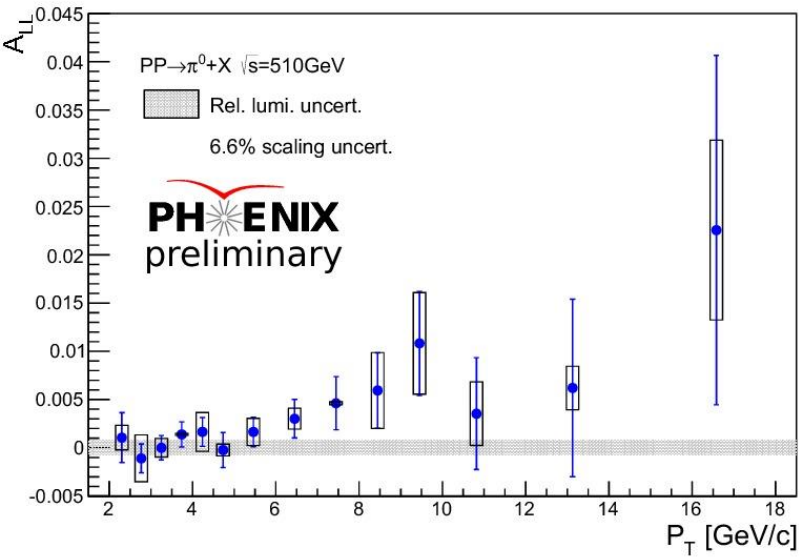
# Forward J/Psi asymmetries @ 510 GeV

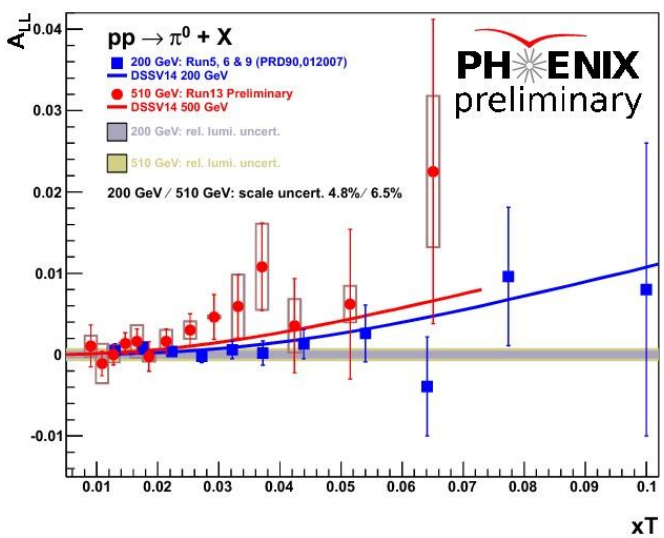



- J/Psi predominantly produced via gluon-gluon scattering
- Access to $x_g$~2-3 $10^{-3}$
- production mechanism still not entirely clear
- Feed down with similar gluon dependence

# 510 GeV $\pi^0$ results



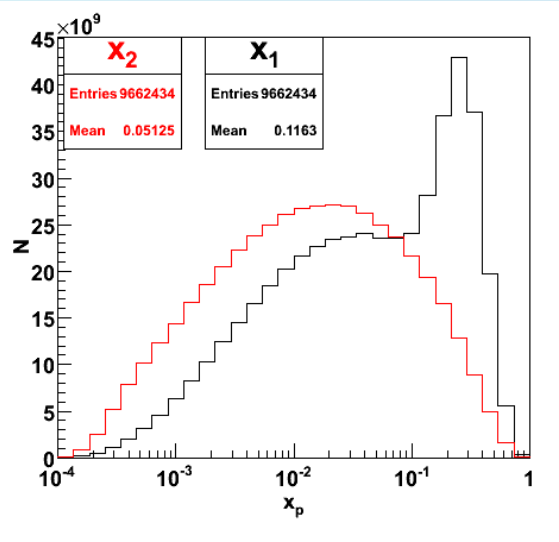




- Large 2013 data set provides very sizeable, nonzero asymmetry
- Consistent with latest DSSV14 results
- Effect of DGLAP evolution visible between 200 and 510 GeV data
- Systematics due to luminosity normalization between same and opposite helicity collisions reduced to be smaller than low $P_T$ statistical uncertainties

# Expected impact of existing RHIC data

Forward $\pi^0$ in $3.1<\eta<3.9$, $p_T>1$GeV

RHIC Spin LRP white paper:
http://arxiv.org/abs/arXiv:1501.01220




- 2013 data analysis of forward p0/clusters sensitive to lower x
- Analysis ongoing

- Running integral of the total gluon helicity

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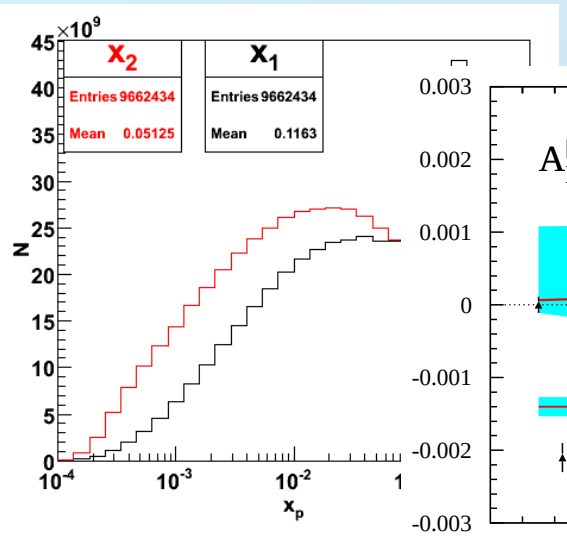


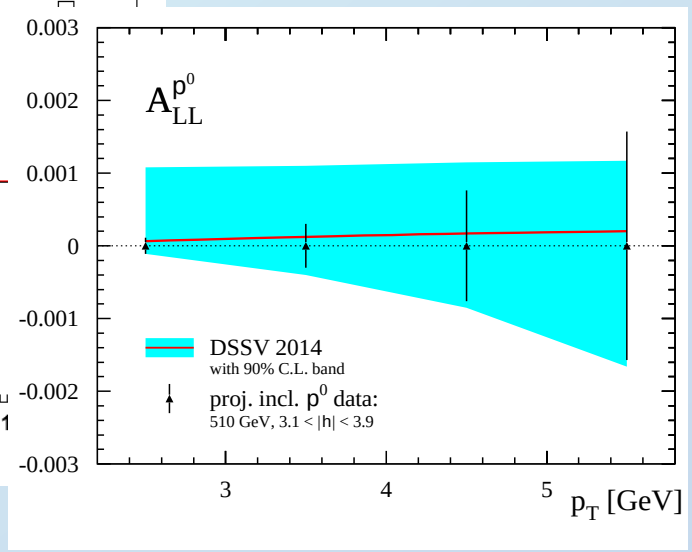


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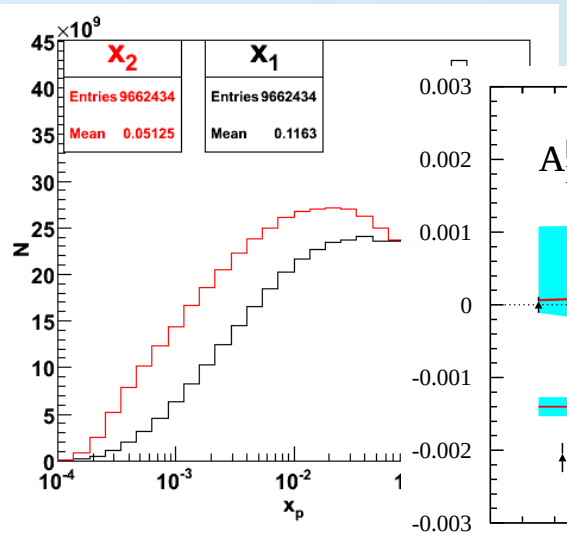


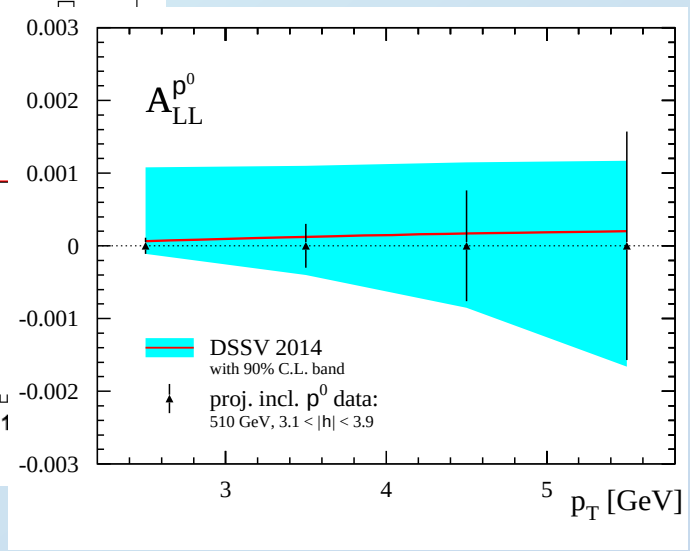


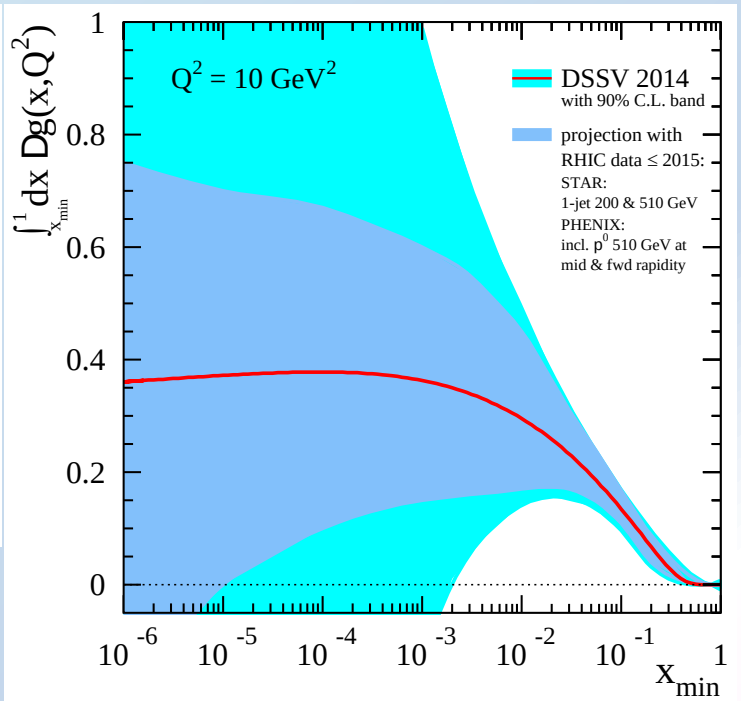


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- Running integral of the total gluon helicity

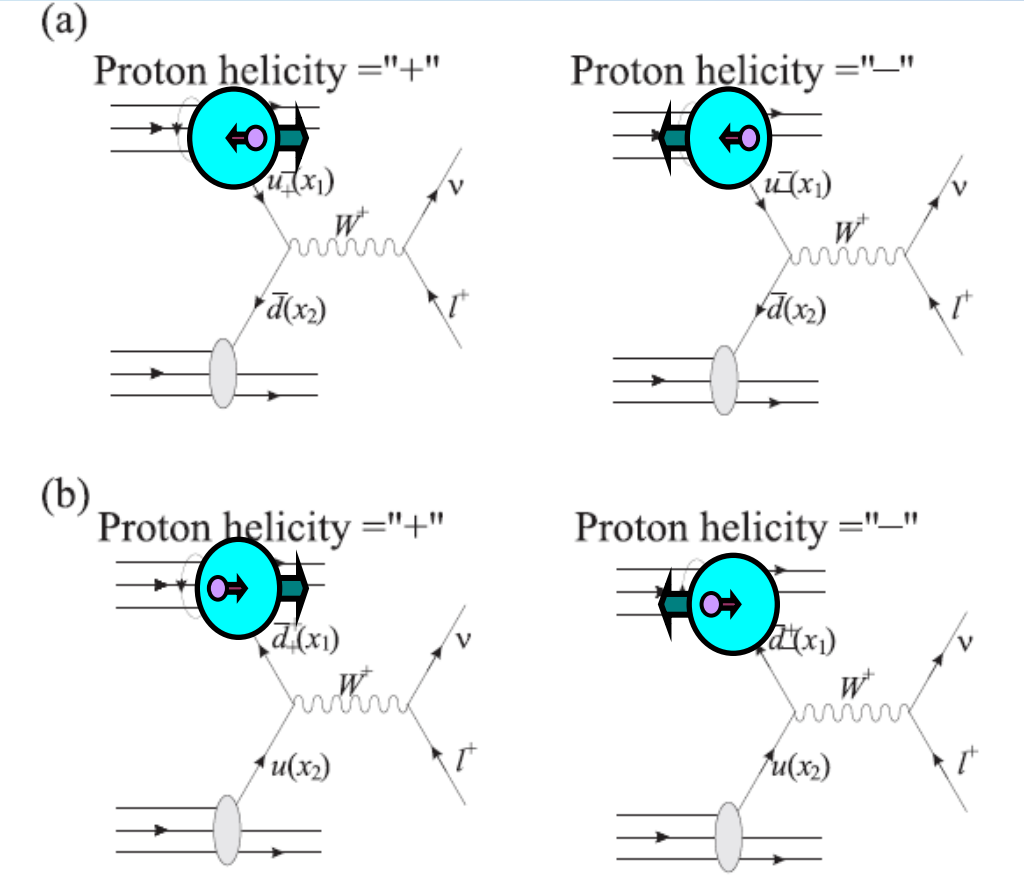
# Real W production as access to quark helicities

- Maximally parity violating V-A interaction selects only lefthanded quarks and righthanded antiquarks:

➔Having different helicities for the incoming proton then selects spin parallel or antiparallel of the quarks

➔Difference of the cross sections gives quark helicities $\Delta q(x)$

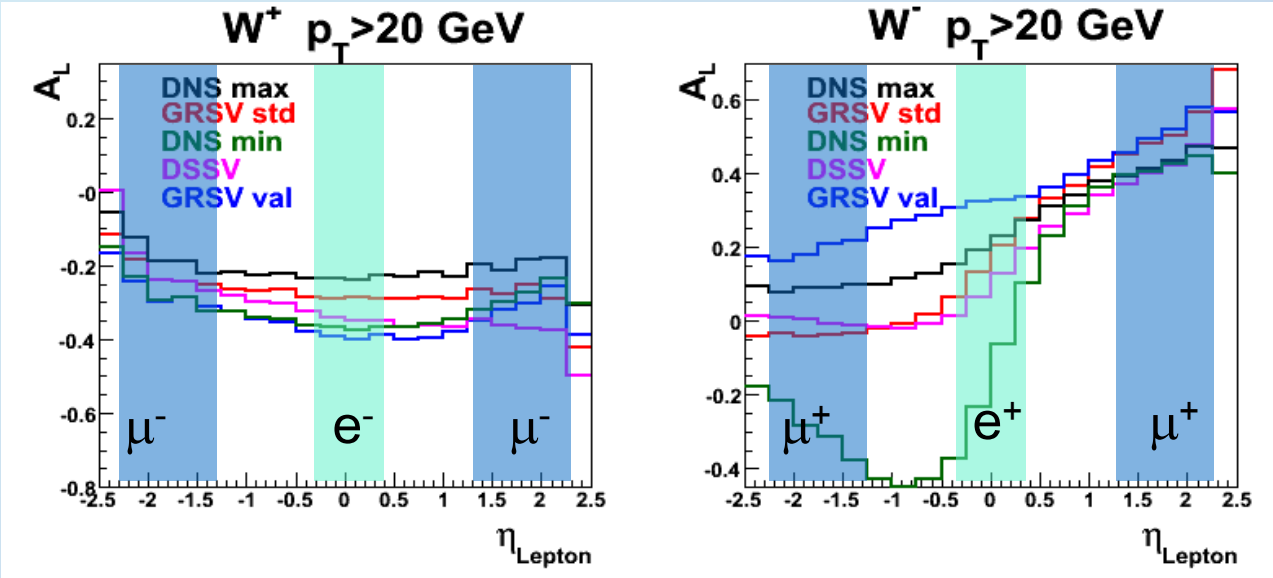
- No Fragmentation function required
- Very high scale defined by W mass




Bourrely , Soffer
Nucl.Phys. B423 (1994) 329-348

# Sea quark polarization via W production

- Single spin asymmetry proportional to quark polarizations
- Large asymmetries
- Forward/backward separation smeared by W decay kinematics

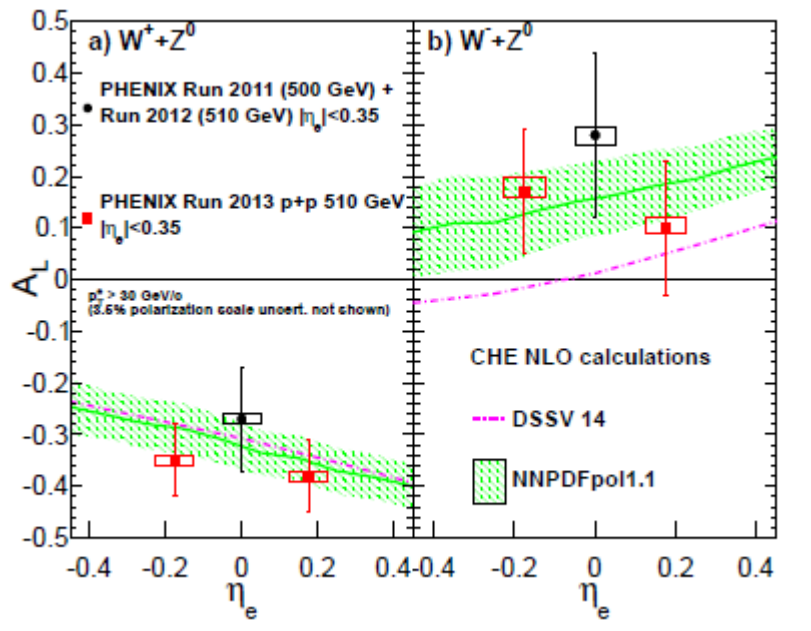


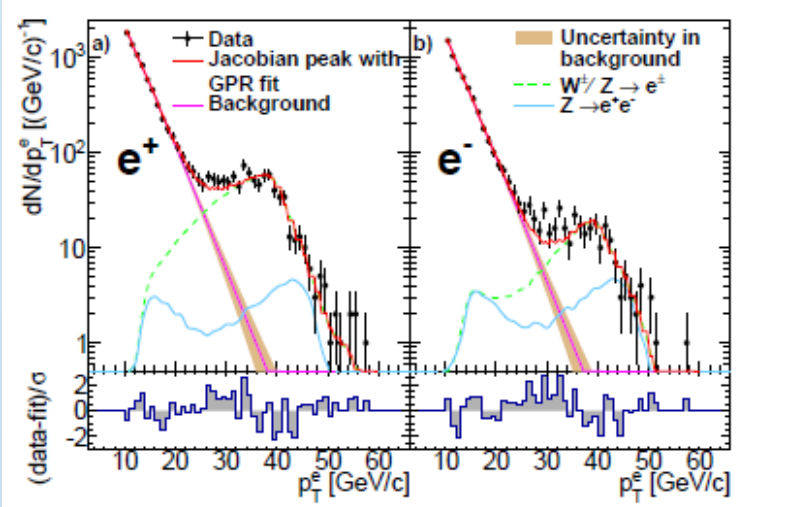

$$A_L^{W^+} \approx \frac{-\Delta u(x_1)\bar{d}(x_2)(1-\cos\theta)^2 + \Delta\bar{d}(x_1)u(x_2)(1+\cos\theta)^2}{u(x_1)\bar{d}(x_2)(1-\cos\theta)^2 + \bar{d}(x_1)u(x_2)(1+\cos\theta)^2}$$

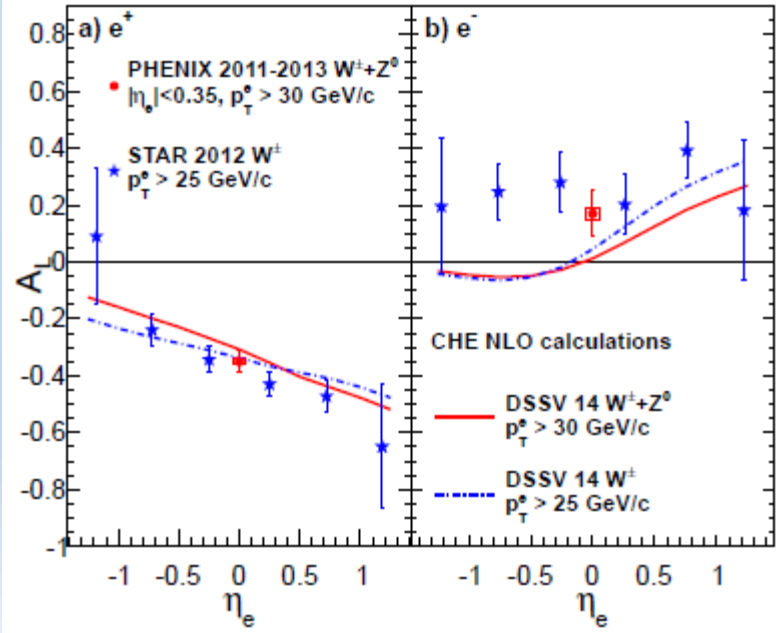
$$A_L^{W^-} \approx \frac{-\Delta d(x_1)\bar{u}(x_2)(1+\cos\theta)^2 + \Delta\bar{u}(x_1)d(x_2)(1-\cos\theta)^2}{d(x_1)\bar{u}(x_2)(1+\cos\theta)^2 + \bar{u}(x_1)d(x_2)(1-\cos\theta)^2}$$

# Central W+Z→e asymmetries

arXiv:1504.07451

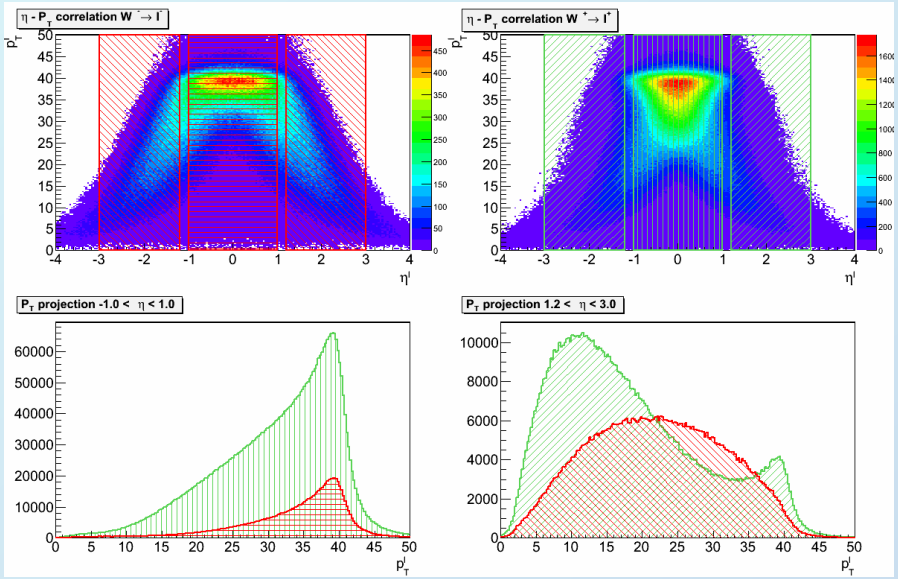


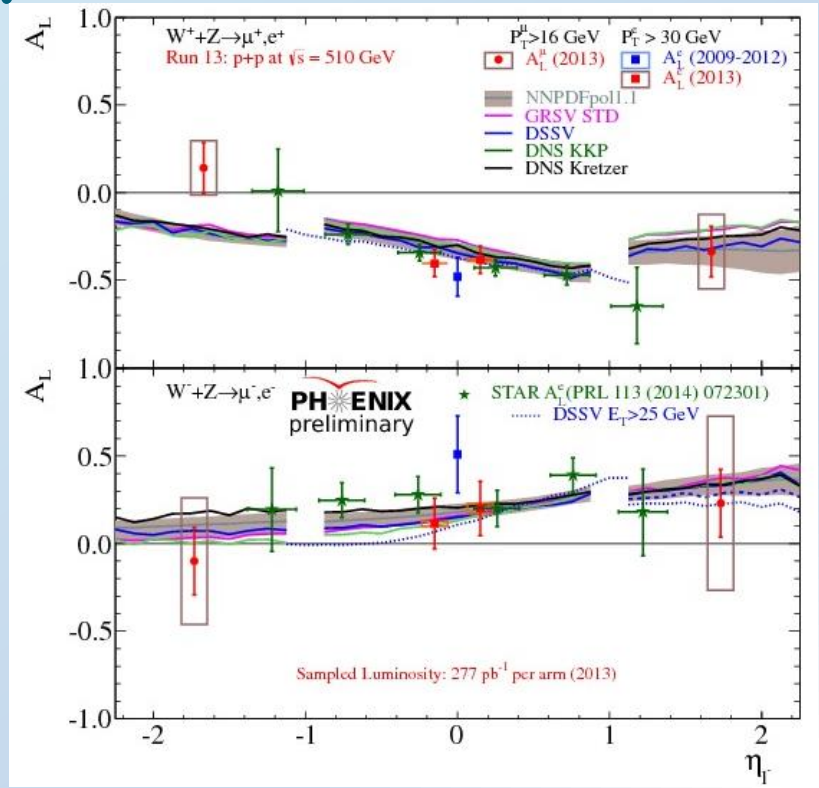




- Leptonic W decays very clearly visible via Jacobian peak
- Large asymmetries found, consistent with STAR 2012 data
- $e^-$ significantly above latest global fit

# Forward W+Z →μ asymmetries




- At forward rapidities no Gaussian peak to identify W decay muons
- Lower $P_T$ hadrons as fake high $P_T$ "muons"
- Successfully performed unbinned max likelihood analysis to identify signal




- Asymmetries as expected
- Still working on improving the uncertainties

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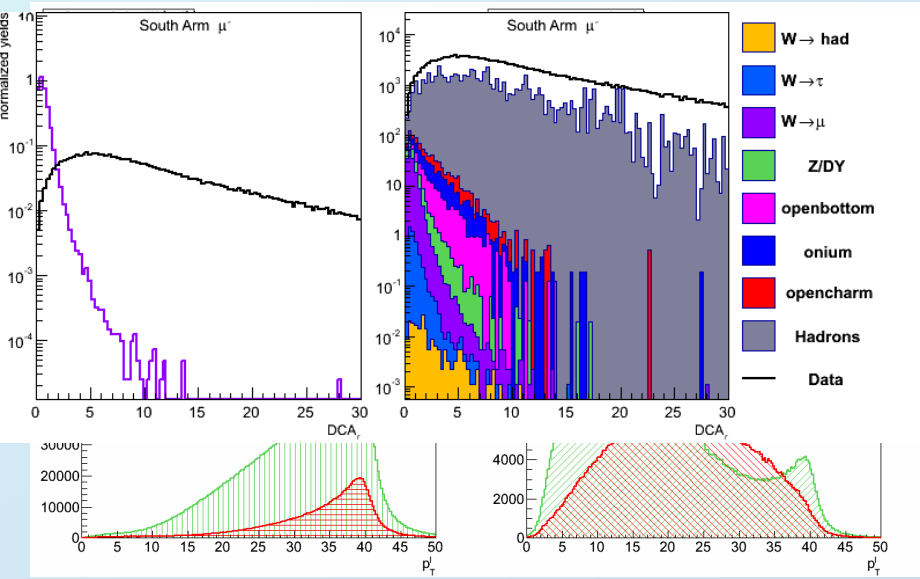


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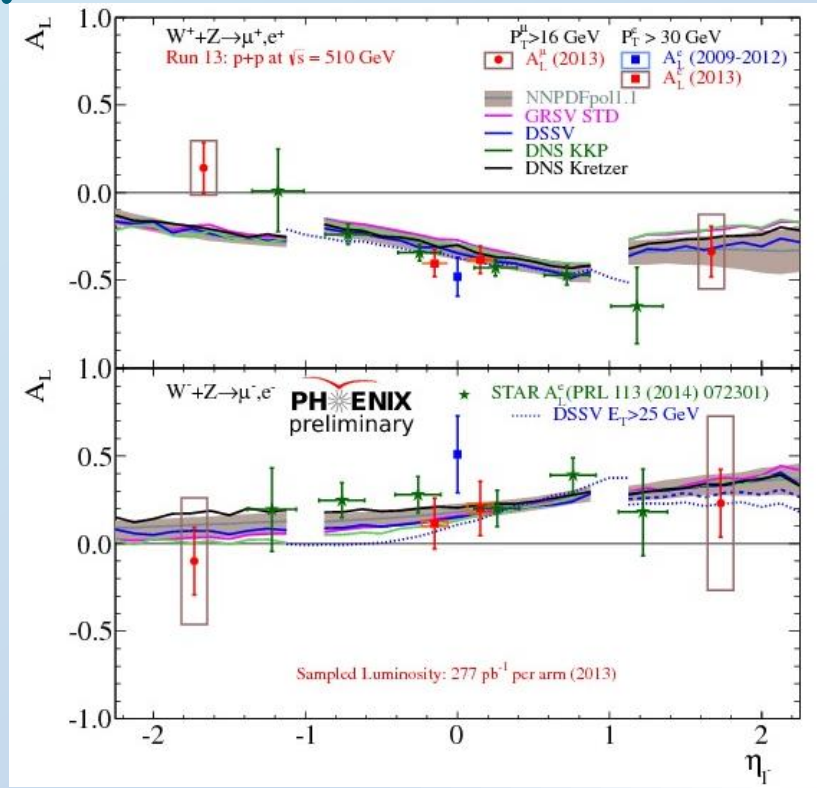


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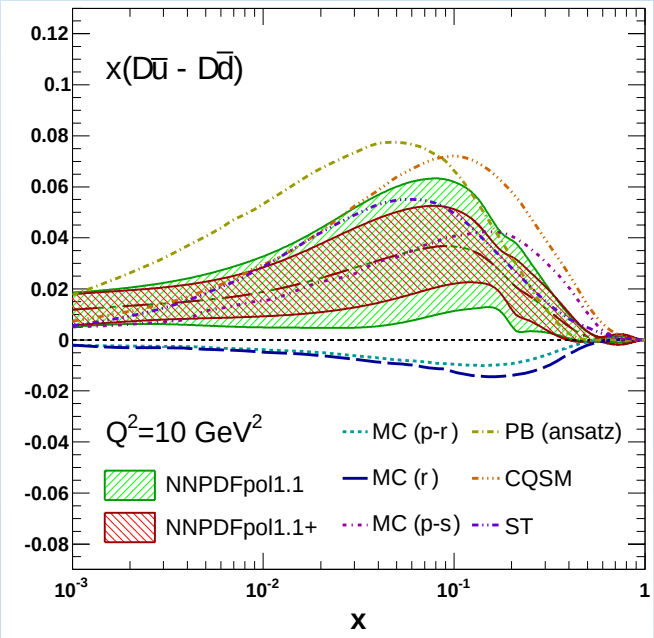
# Expected impact on sea quark helicities

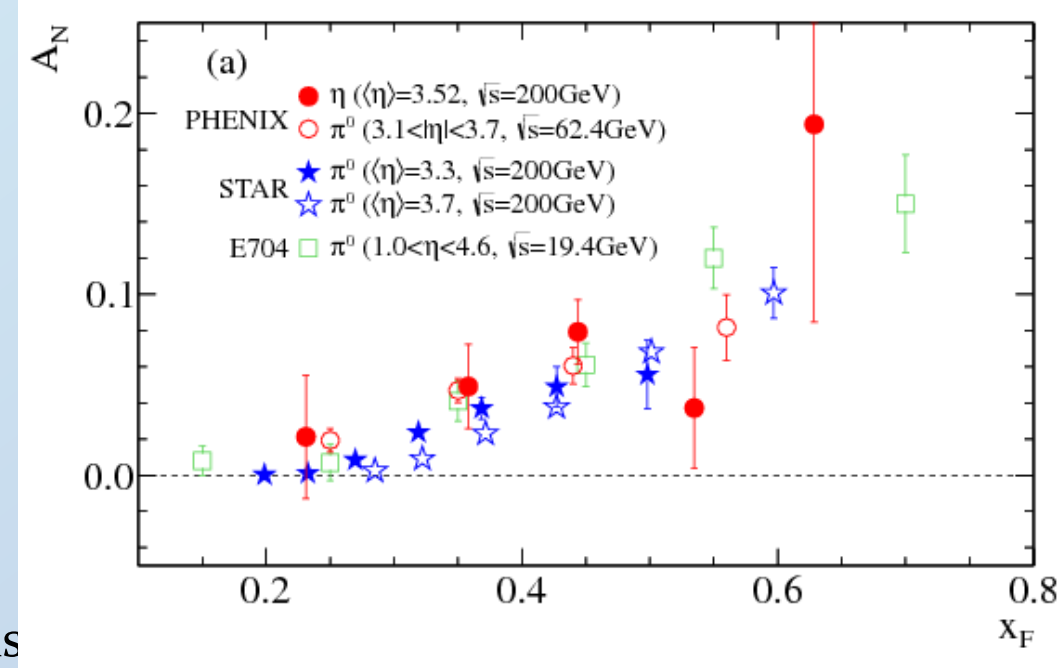
- Already from existing data indication of asymmetric polarized light sea
- Opposite sign to un-polarized light sea asymmetry disfavors pion cloud based models



# Transverse single spin asymmetries

- Large left-right asymmetries AN seen in polarized pp collisions from low energies up to RHIC energies
- Both initial state and final state effects contribute
- Some indications for potentially other origins
- Near term: concentrate on disentangling initial state (direct γ, jets) from final state (Collins in jet), coincidence with Roman pots and forward neutrons
- Drell Yan as test for our understanding in sign change compared to SIDIS Sivers asymmetries

Phys.Rev. D90 (2014) 7, 072008
Phys.Rev. D90 (2014) 1, 012006



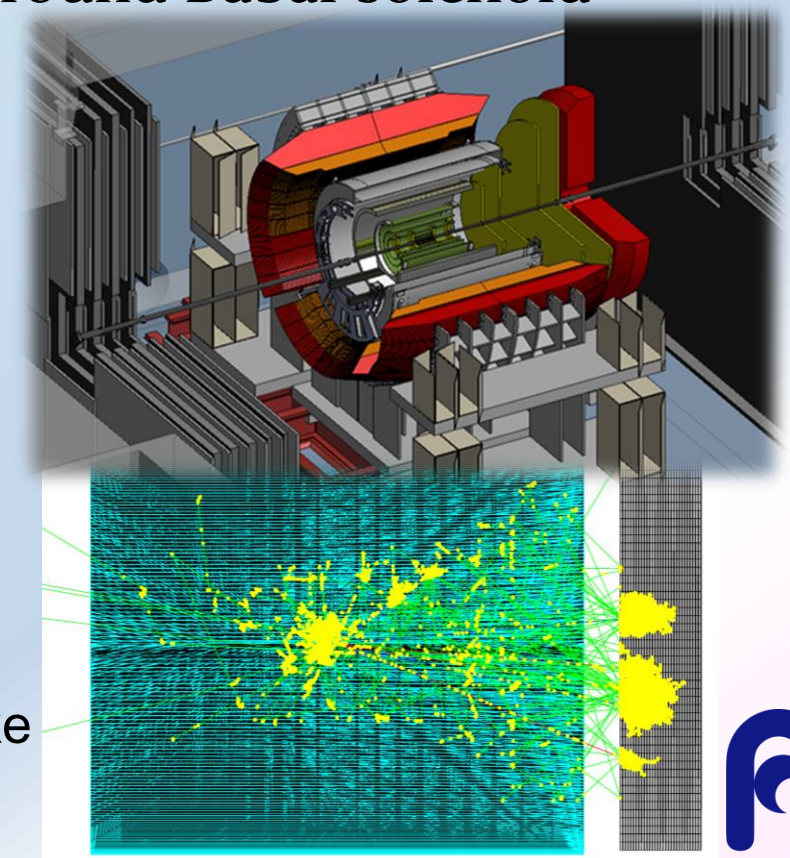

- Polarized pA collisions taken in 2015 of interest for low x behavior of cold nuclear matter → A dependence of single spin asymmetries?

# Outlook:
# a new detector + Babar magnet

- Open questions in spin accessible in pp before EIC:
  - Lower x gluon access via more forward jets and di-jets
  - Remaining open questions about large single transverse spin asymmetries in pp (unique to RHIC): jet $A_N$, direct $\gamma$ $A_N$, Drell Yan

➔For spin forward rapidities 2-4 are most interesting

- PHENIX will finish data-taking in 2016 → construction of new detector around Babar solenoid



➔ More in Talk by Mike McCumber tomorrow