Status and Perspective of the high-energy polarized proton-proton program at RHIC

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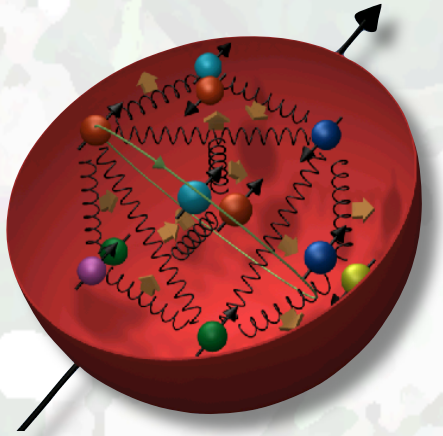
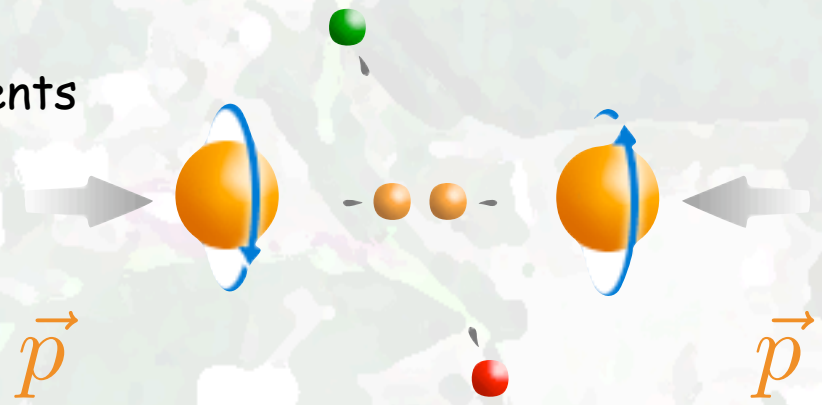


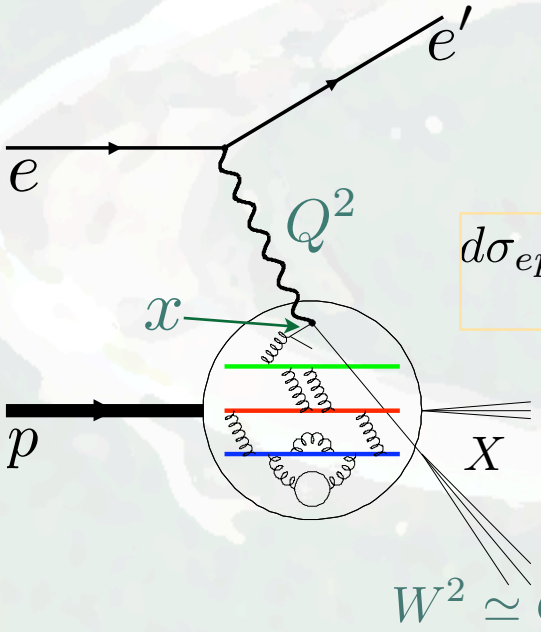
Outline

- Future polarized p-p collider performance
- Future polarized p-p physics program
  - Gluon polarization
  - Quark / Anti-Quark Polarization
  - Transverse spin dynamics
- Highlights of recent results and achievements
- Theoretical foundation
- Summary and Outlook



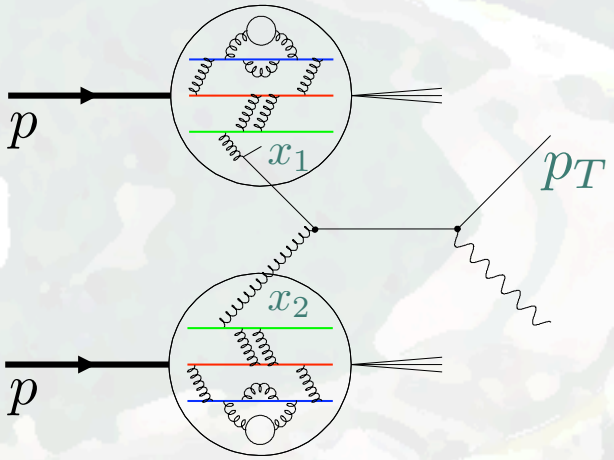
Theoretical foundation

General



$$d\sigma_{ep} \propto F_2 = \sum_q x e_q^2 f_q(x)$$

Universality



$$d\sigma_{pp} \propto f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h$$ Factorization

Momentum contribution

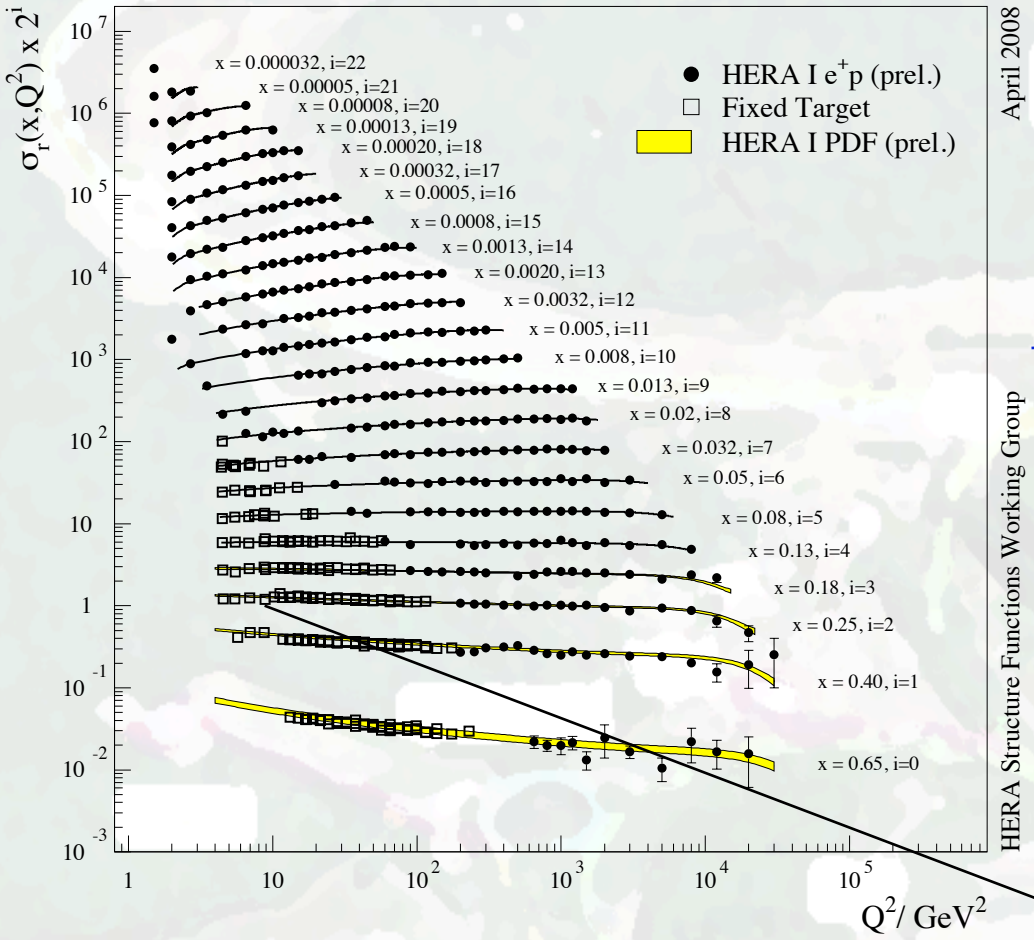
$$f(x) = f^+(x) + f^-(x)$$

$$\Delta f(x) = f^+(x) - f^-(x)$$

Spin contribution

Theoretical foundation

- Precision measurements (e.g. F_2) ⇒ Precision on quark/gluon structure

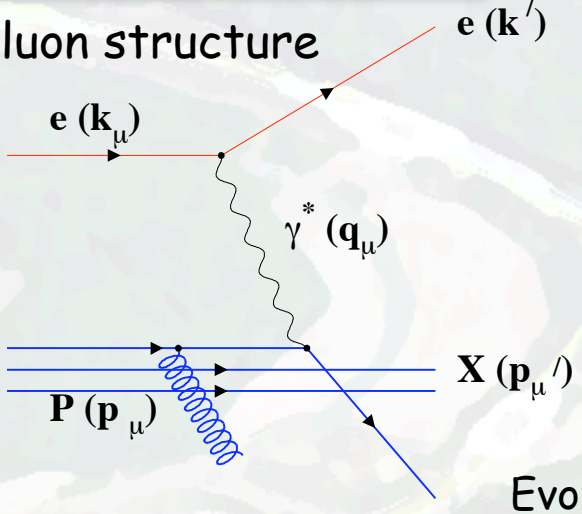


Strong violation of scaling at low x and high Q^2

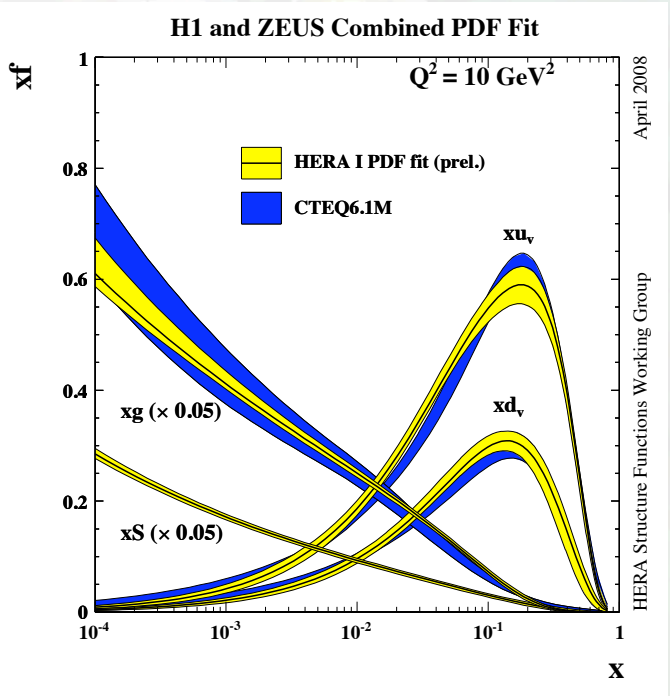
$$xg \propto \left(\frac{dF_2}{d\ln Q^2}\right)$$

In contrast to:

Low Q^2 high x!



Evolution

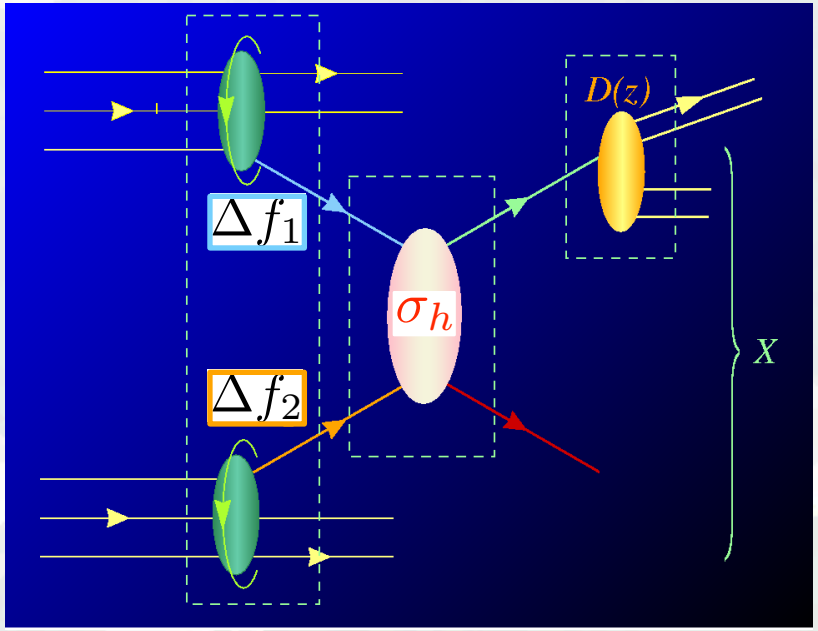


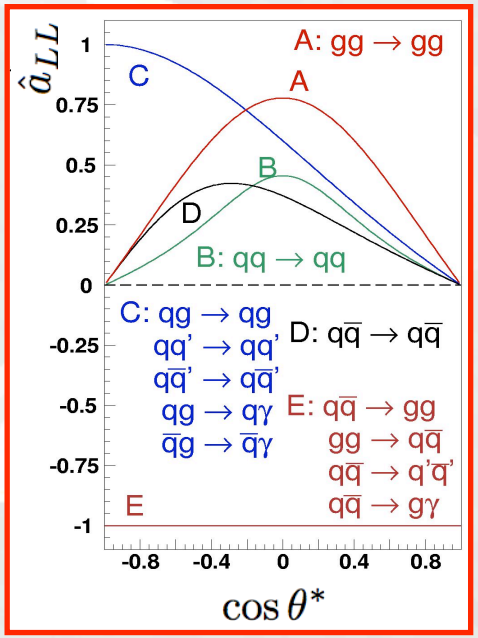
Theoretical foundation

- Gluon polarization - Extraction

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

Extract $\Delta g(x,Q^2)$ through Global Fit (Higher Order QCD analysis)!





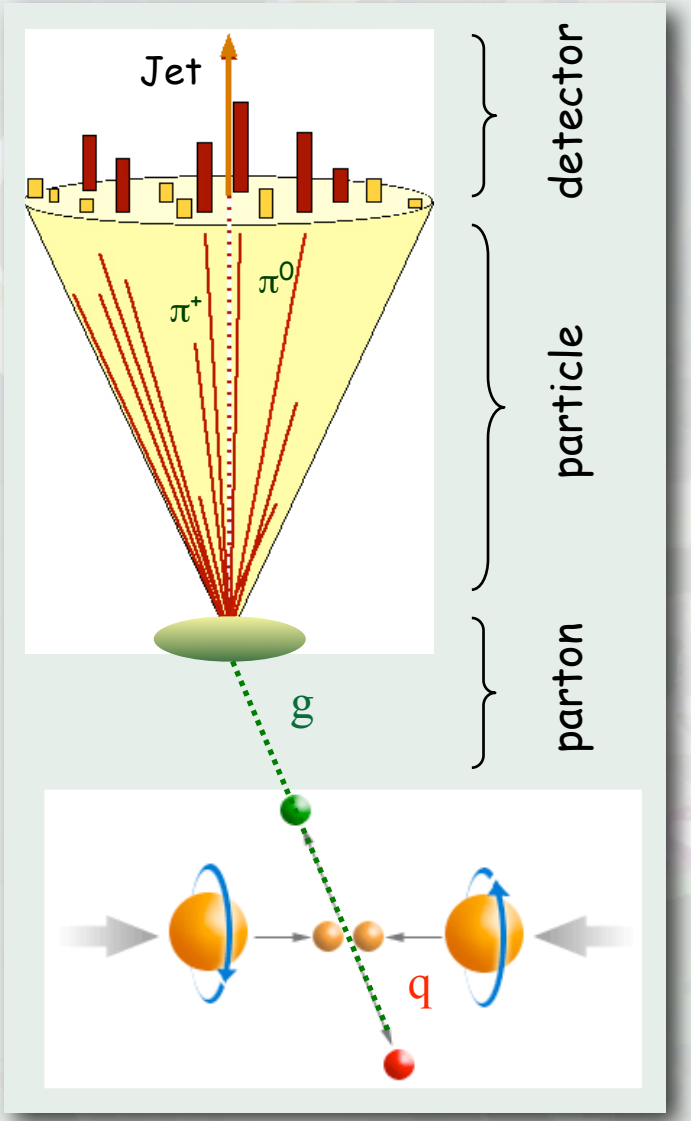
$$A_{LL} = \frac{d\Delta\sigma}{d\sigma}$$

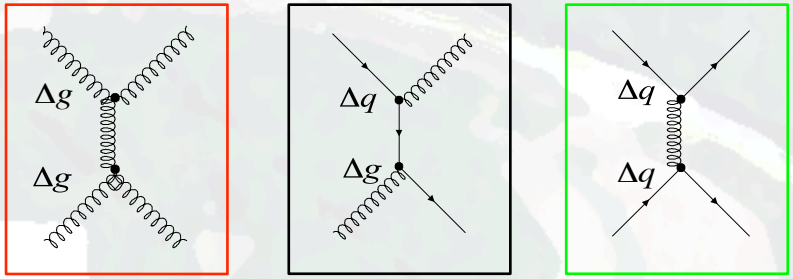
$$\propto \frac{\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D_f^h}{f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h}$$

Δf_1 Δf_2 $a_{LL} = \frac{\Delta\sigma_h}{\sigma_h}$ } Input

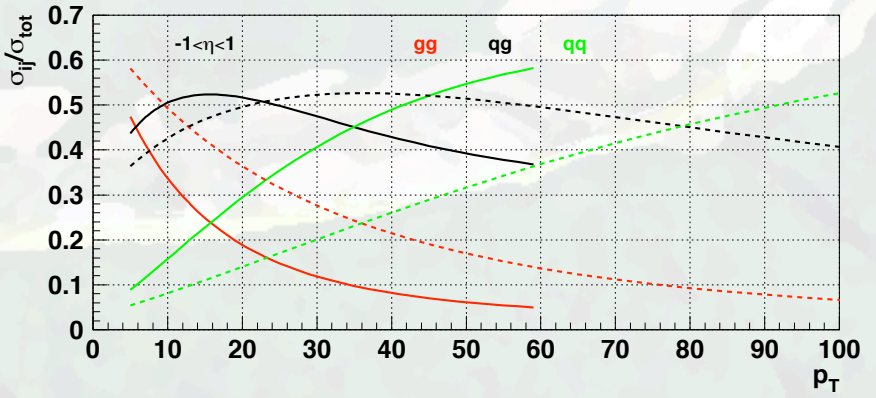
Theoretical foundation

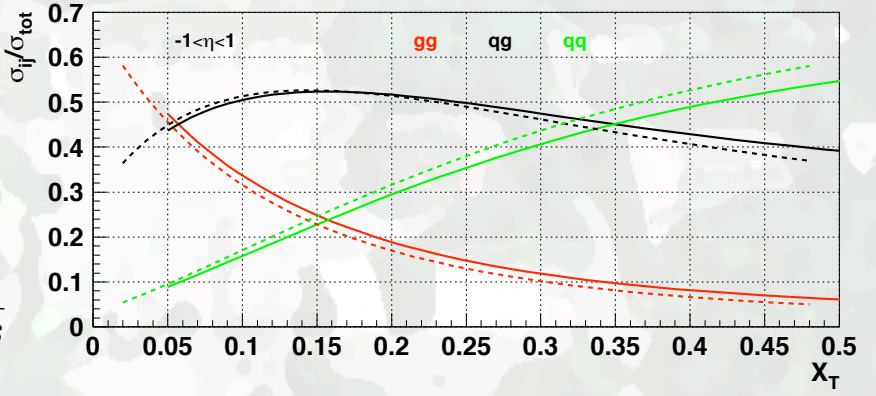
Gluon polarization - Inclusive Measurements





Inclusive Jet production (200GeV: Solid line / 500GeV: Dashed line)



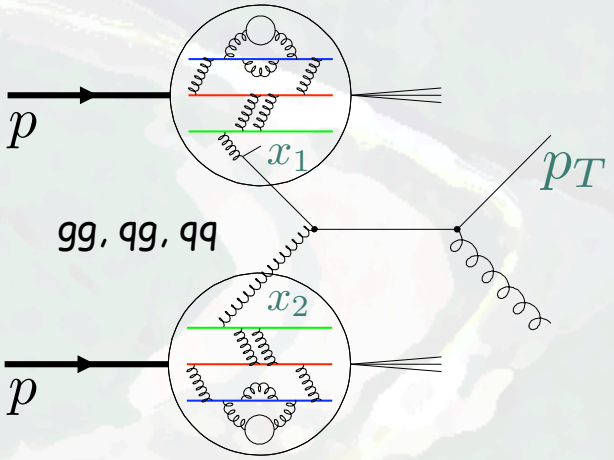


$$x_T = 2p_T/\sqrt{s}$$

Theoretical foundation

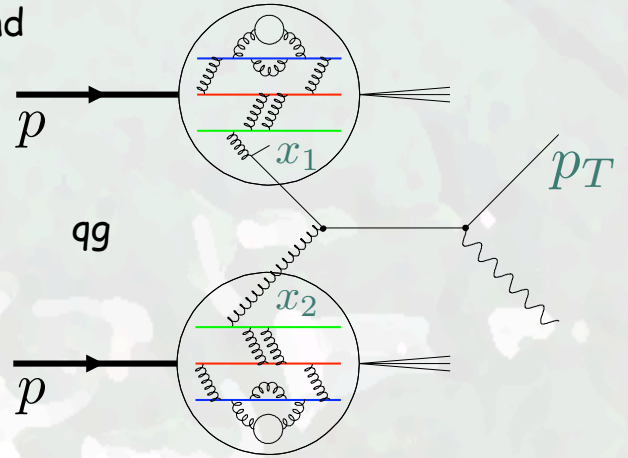
- Gluon polarization - Correlation Measurements
  - Correlation measurements provide access to partonic kinematics through Di-Jet/Hadron production and Photon-Jet production

$$M = \sqrt{x_1 x_2 s} \qquad \eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$



Di-Jet production

  - Di-Jet production / Photon-Jet production
    - Di-Jets: All three (LO) QCD-type processes contribute: gg, qg and gg with relative contribution dependent on topological coverage
    - Photon-Jet: One (LO) underlying process
    - Larger cross-section for di-jet production compared to photon related measurements
    - Photon reconstruction more challenging than jet reconstruction
    - Full NLO framework exists ⇒ Input to Global analysis

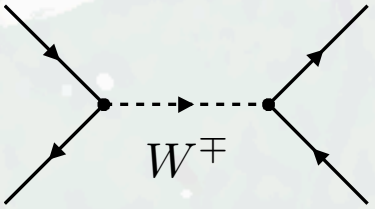


Photon-Jet production

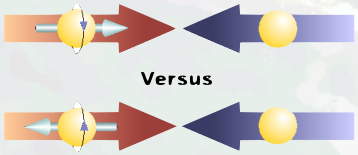
Theoretical foundation

Quark / Anti-Quark Polarization - W production

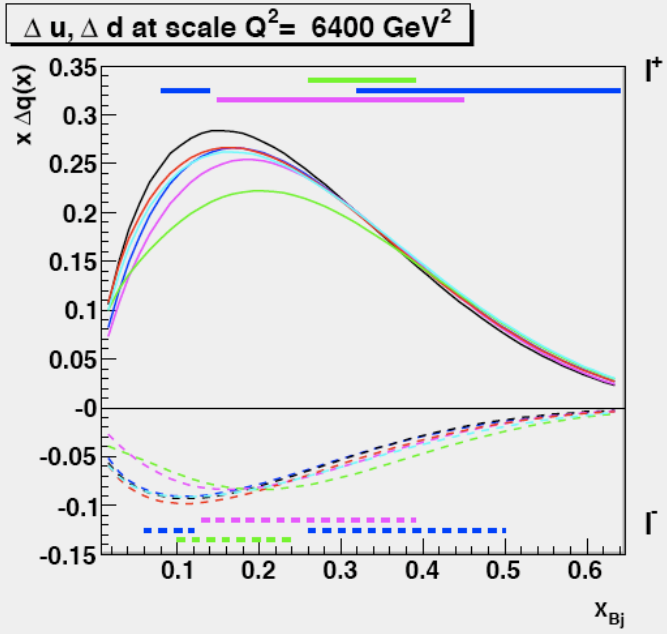
$$\Delta d + \bar{u} \rightarrow W^-$$
$$\Delta \bar{u} + d \rightarrow W^-$$
$$\Delta \bar{d} + \bar{u} \rightarrow W^+$$
$$\Delta u + \bar{d} \rightarrow W^+$$

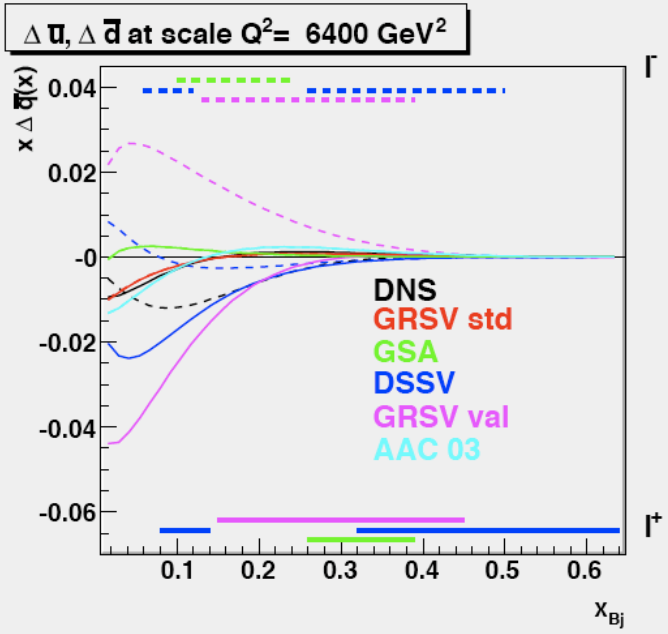


$$W^- \rightarrow e^- + \bar{\nu}_e$$
$$W^+ \rightarrow e^+ + \nu_e$$



$$A_L^W = \frac{1}{P}\frac{N^+(W) - N^-(W)}{N^+(W) - N^-(W)}$$



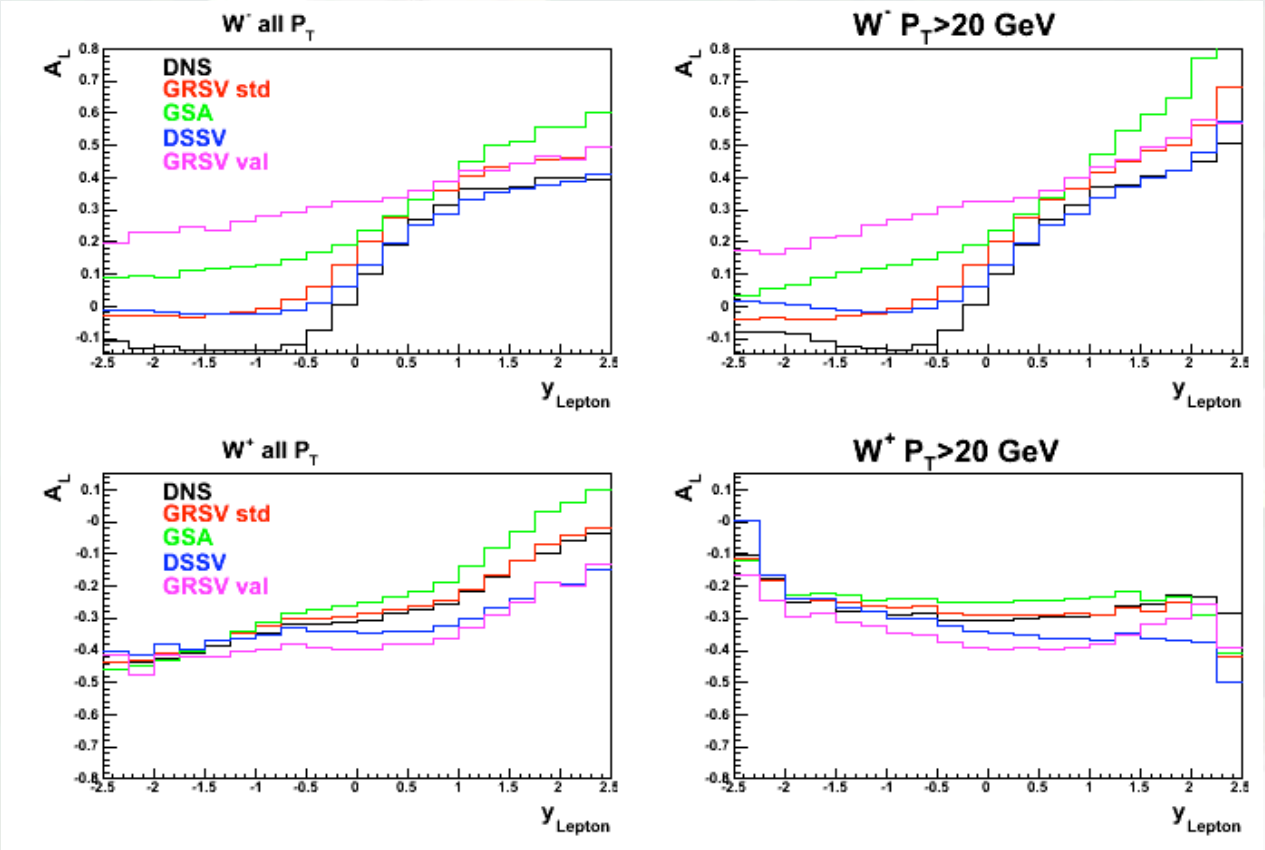


- Key signature: High p_T lepton (e^-/e^+ or μ^-/μ^+) (Max. $M_W/2$) - Selection of W-/W+: Charge sign discrimination of high p_T lepton
- Required: Lepton/ Hadron discrimination

- Large uncertainties for polarized anti-quarks!

Theoretical foundation

Quark / Anti-Quark Polarization - Sensitivity in W production



$$A_L^{W^+} = -\frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

$$x_1 = \frac{M_W}{\sqrt{s}}e^{y_W} \quad x_2 = \frac{M_W}{\sqrt{s}}e^{-y_W}$$

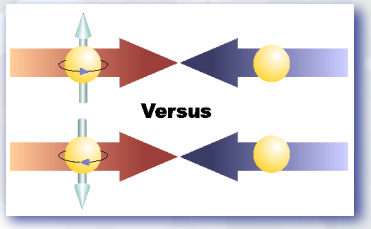
- Reconstruction of W-rapidity only possible in approximative way in forward direction
- Important contribution from forward and mid-rapidity region
- Theoretical framework for leptonic asymmetries exists (RHICBOS) ⇒ Basis for input to global analysis!

- Large uncertainties for polarized anti-quarks reflected in leptonic asymmetries!

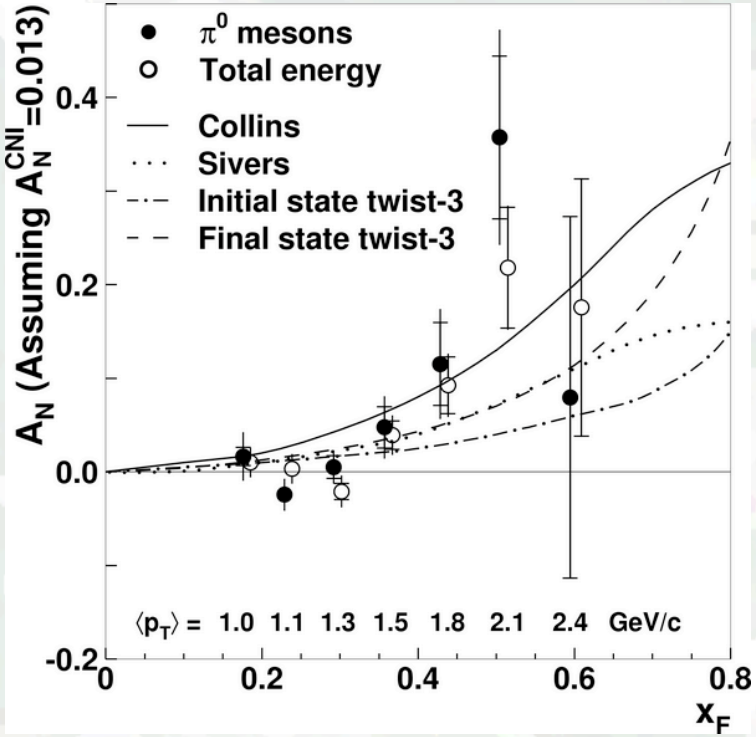
Theoretical foundation

Transverse spin dynamics

- Single transverse-spin asymmetry



$$A_N = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$$



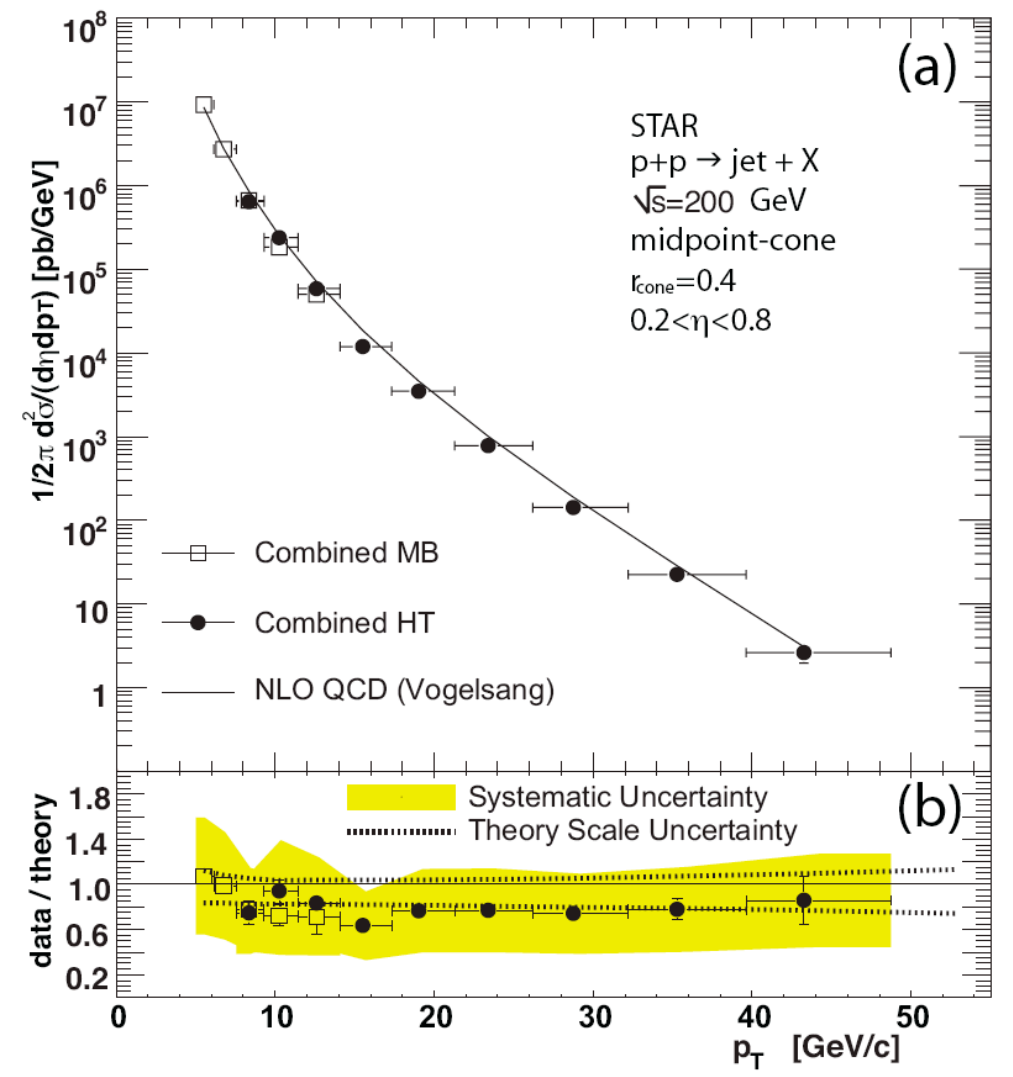
- Basic, naive QCD calculations (leading-twist, zero quark masses) predict: A_N=0 ($A_N \sim m_q/\sqrt{s}$)
- Study transverse spin effects:
  - Qiu and Sterman (Initial-state twist-3)/Koike (final-state twist-3)
  - Sivers: $k_\perp$ in initial state (Correlation of quark $k_\perp$ and transverse proton spin): ⇒ Orbital momentum
  - Collins: $k_\perp$ in final state (Correlation of transverse quark spin and $k_\perp$ of hadron): ⇒ Transversity

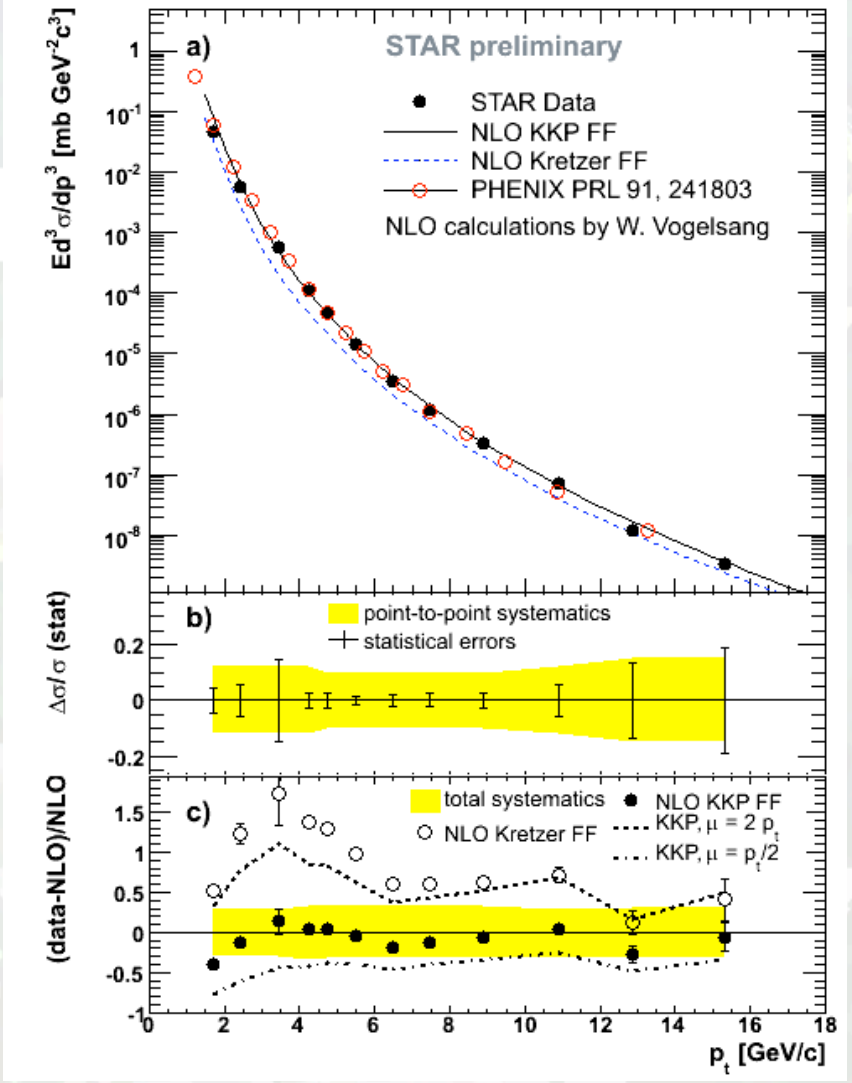
Fundamental trans. spin sum rule:

$$\frac{1}{2} = \frac{1}{2}\sum_{i=q,\bar{q}} \int dx \delta q_a(x,Q^2) + \sum_{i=q,\bar{q},g} \langle L_{S_T} \rangle_i (Q^2)$$

Highlights of recent results and achievements

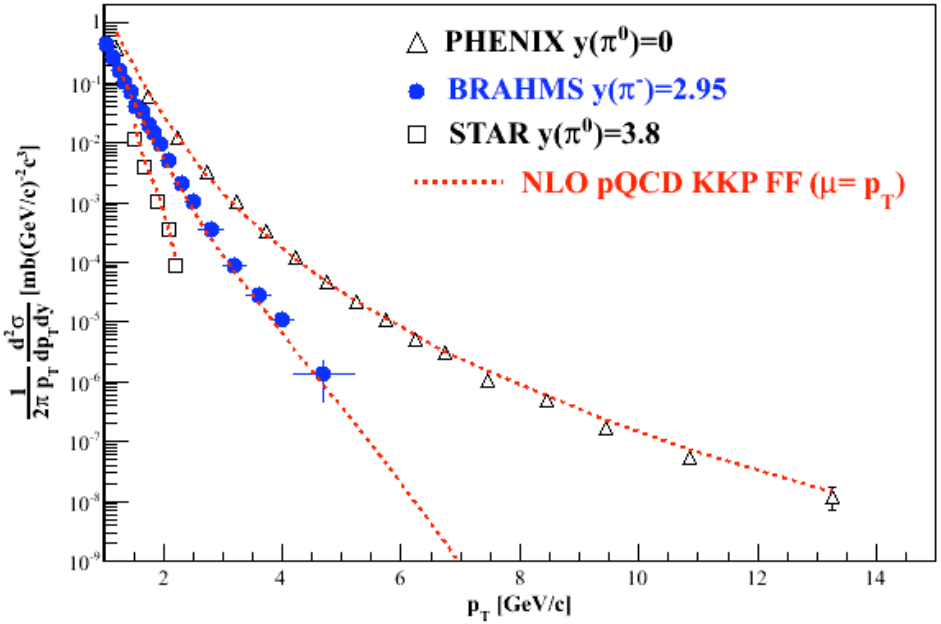
Cross Section Results

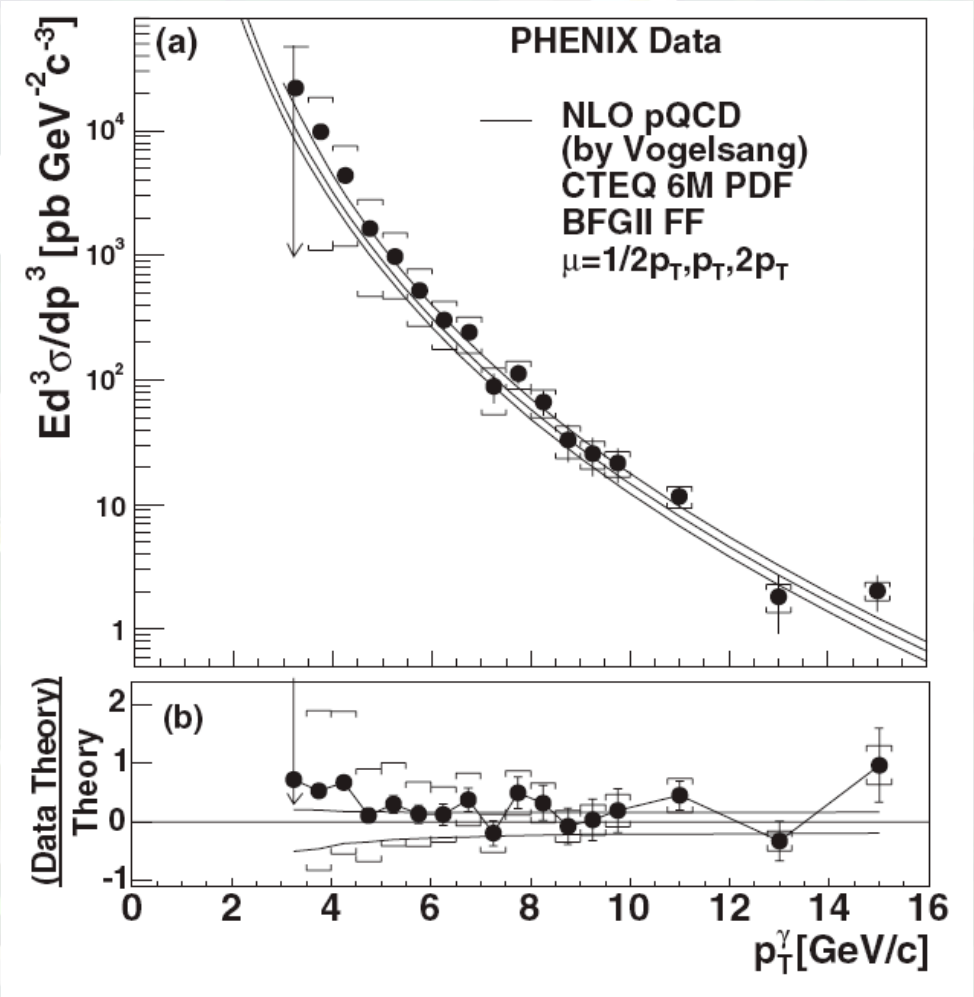




Highlights of recent results and achievements

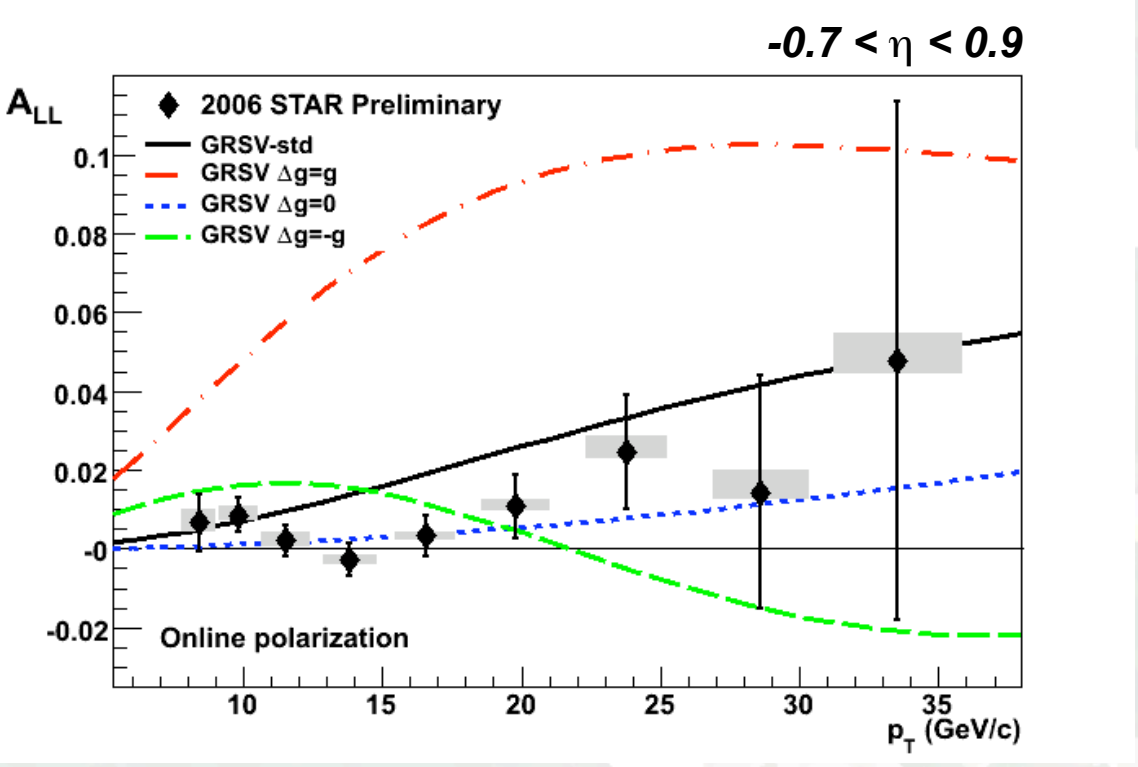
Cross Section Results





Highlights of recent results and achievements

A_{LL} Results

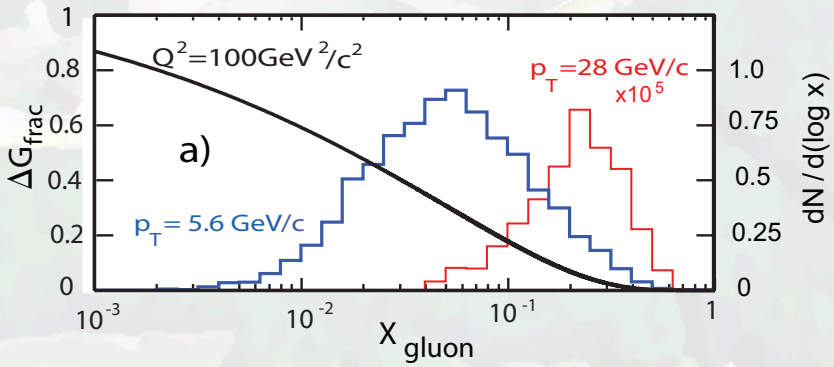


$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

$$\Delta G(Q^2 = 1\,\mathrm{GeV}^2) \approx 1.8$$

$$\Delta G(Q^2 = 1\,\mathrm{GeV}^2) \approx 0.4$$

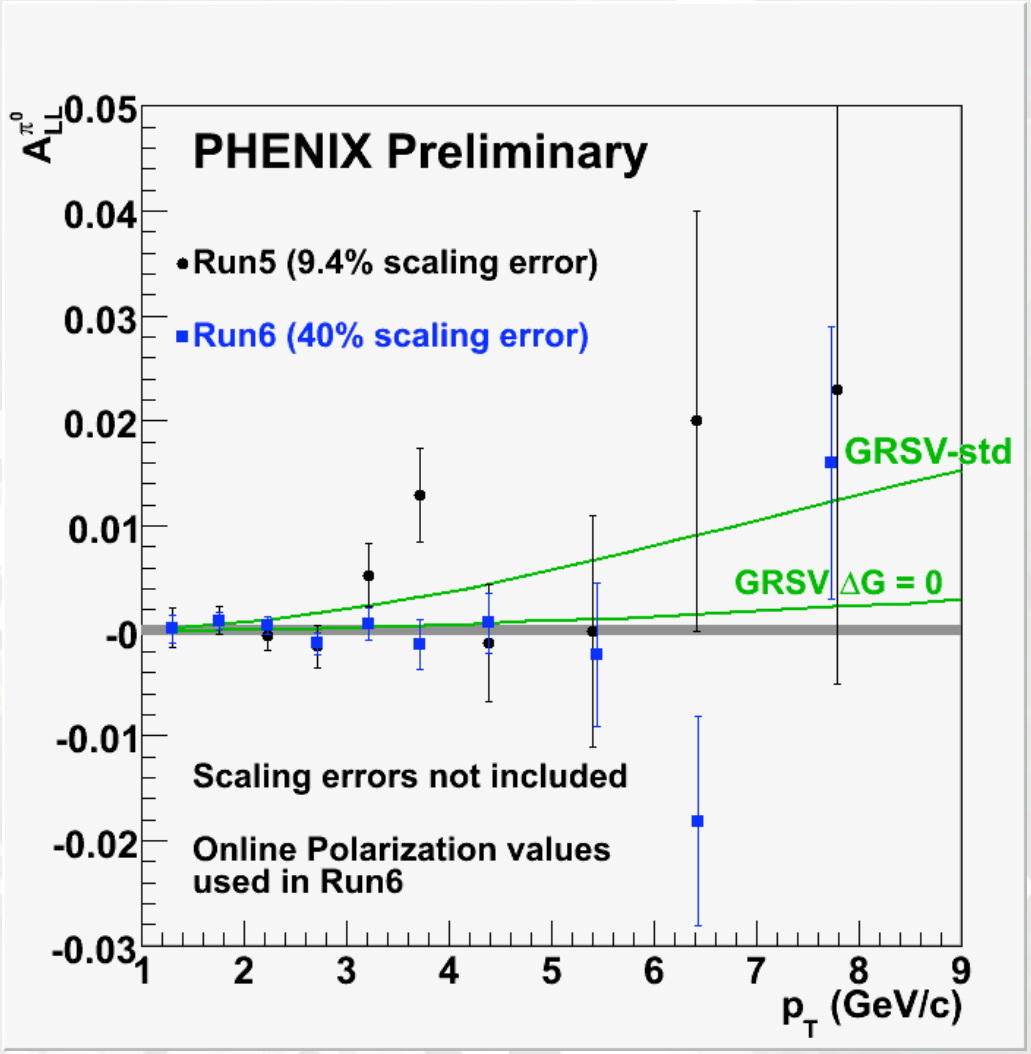
$$x_{\mathrm{parton}} \simeq 2p_T/\sqrt{s}$$



- RUN 6 results: GRSV-MAX / GRSV-MIN ruled out - A_{LL} result favor a gluon polarization in the measured x-region which falls in-between GRSV-STD and GRSV-ZERO
- Consistent with RUN 5 result (Factor 3-4 improved statistical precision for p_T>13GeV/c)

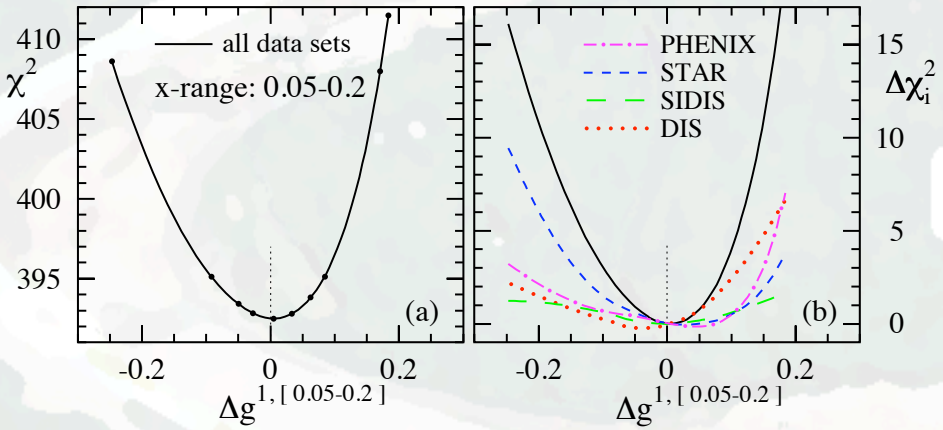
Highlights of recent results and achievements

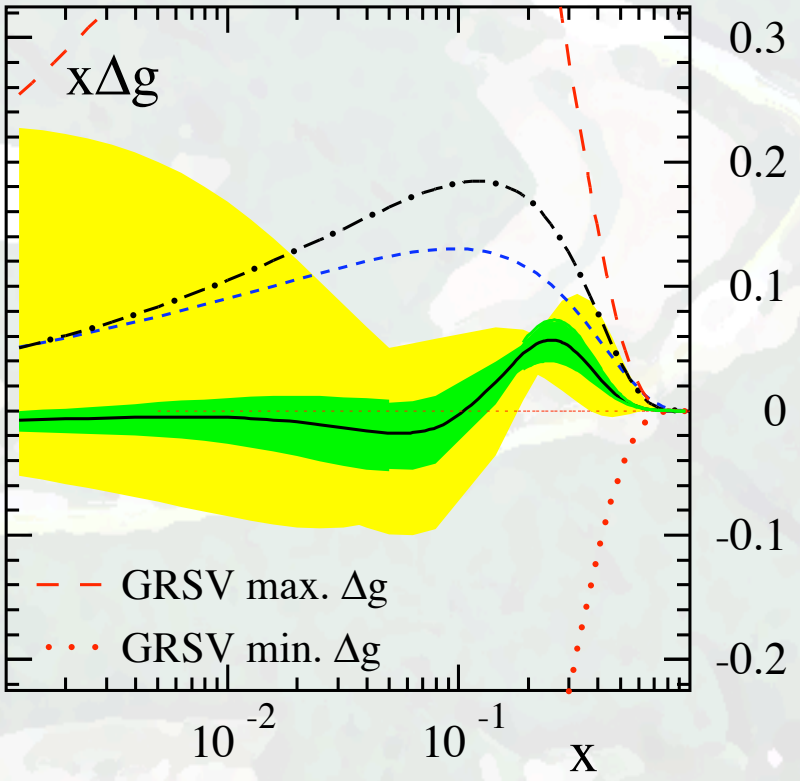
- A_{LL} Results



Highlights of recent results and achievements

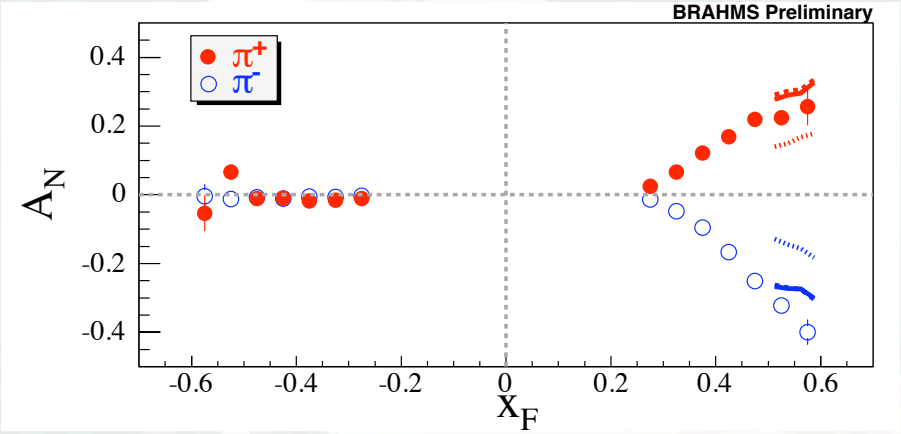
- Global analysis and open questions

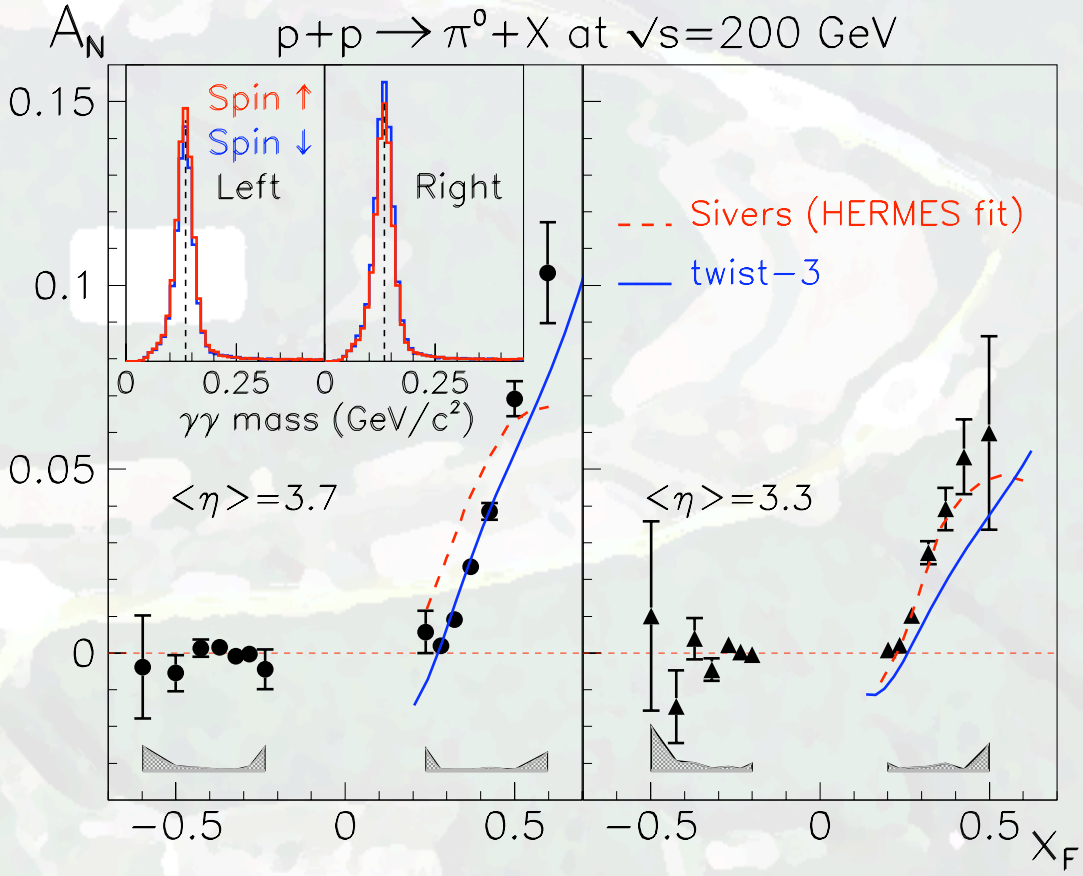




Highlights of recent results and achievements

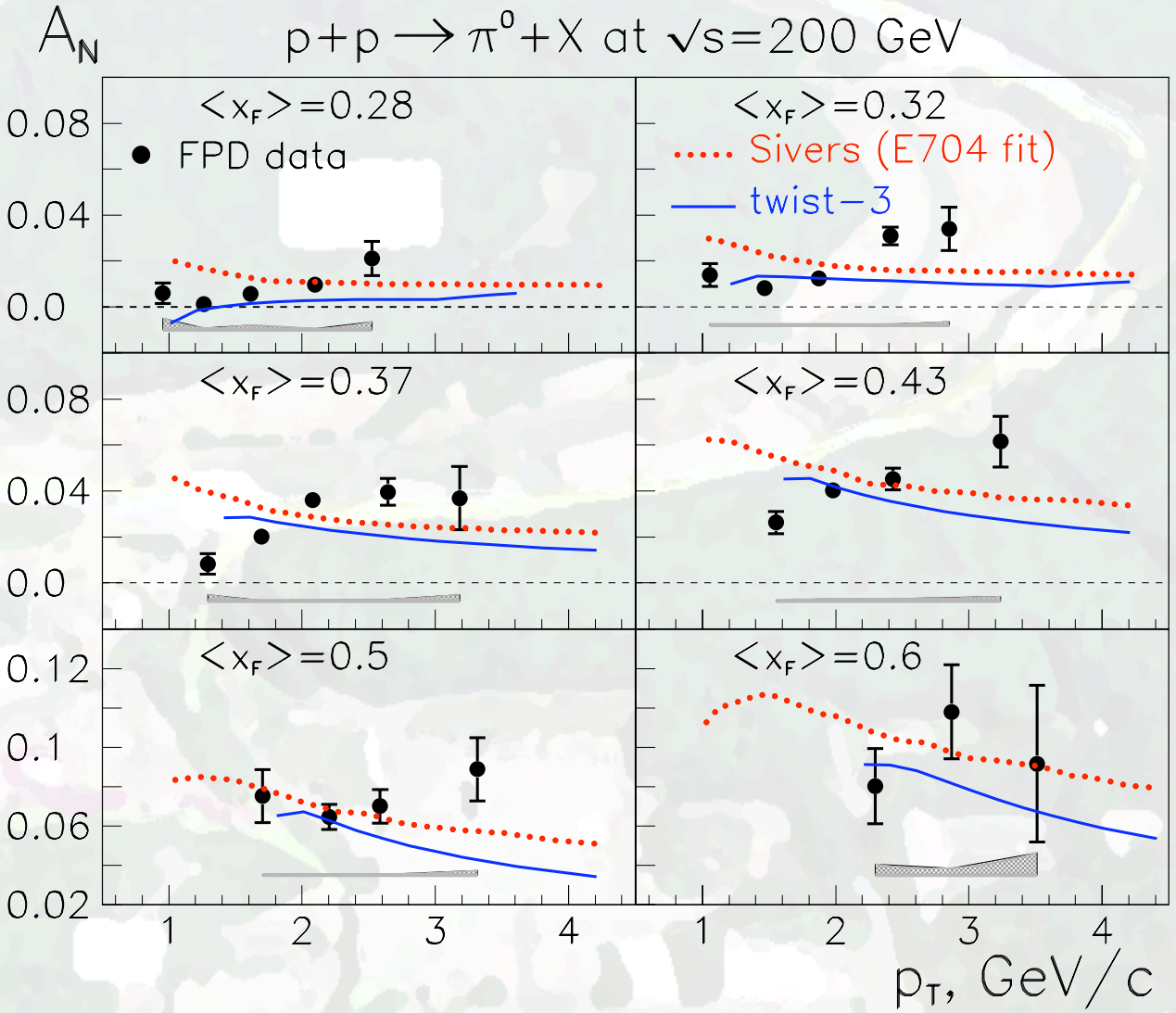
- A_N results





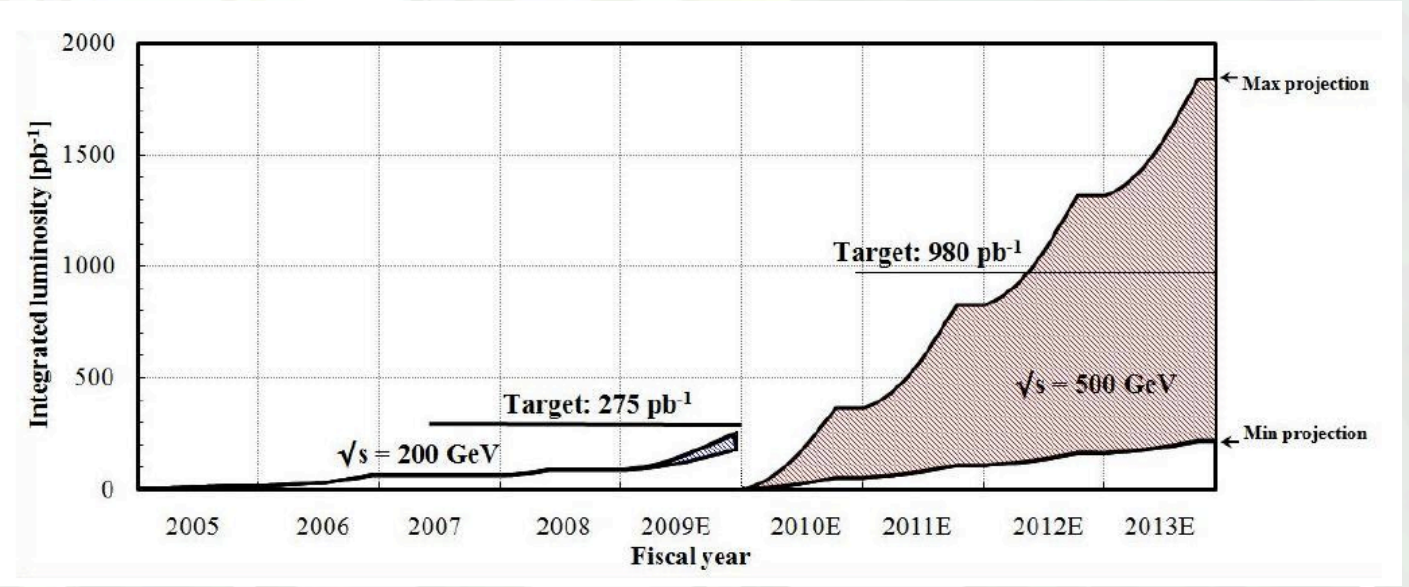
Highlights of recent results and achievements

- A_N results



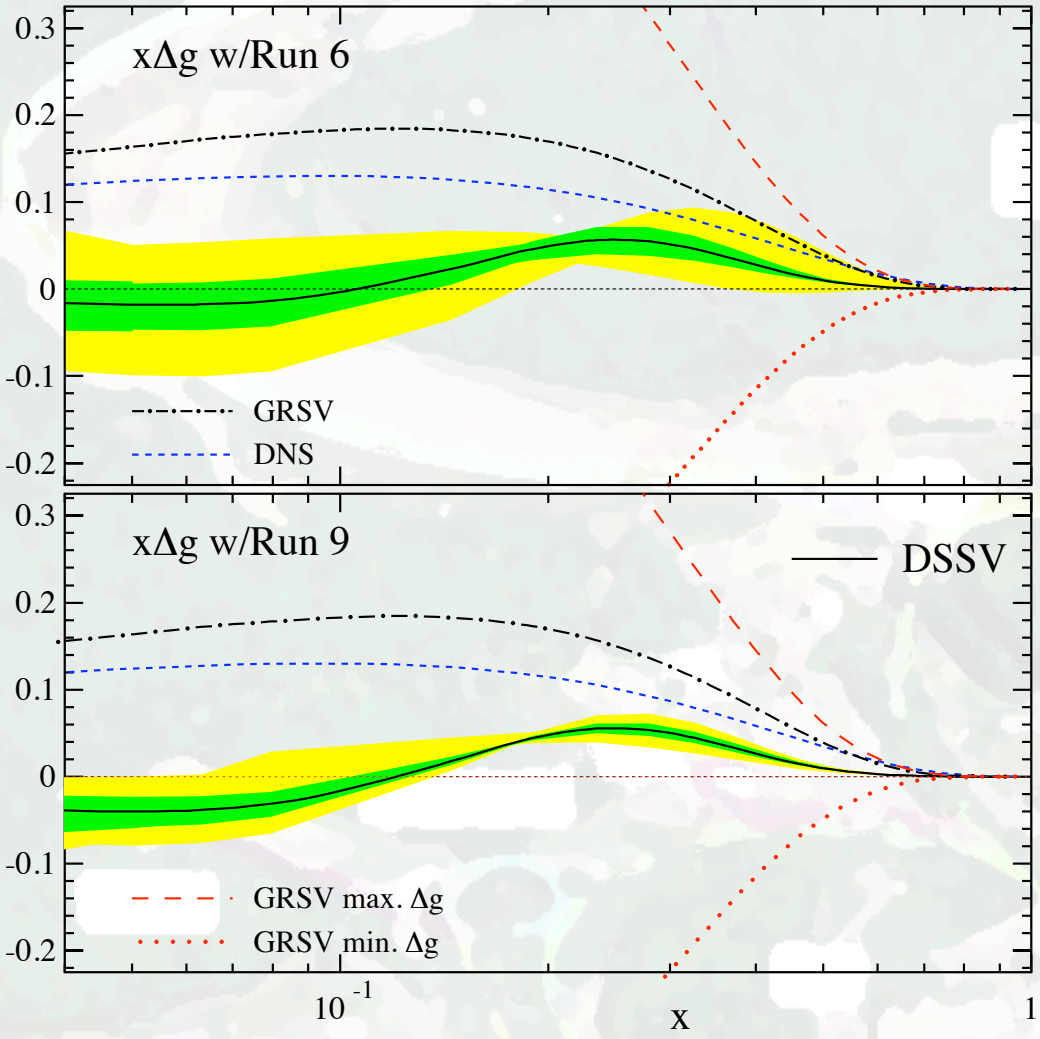
Future polarized p-p collider performance

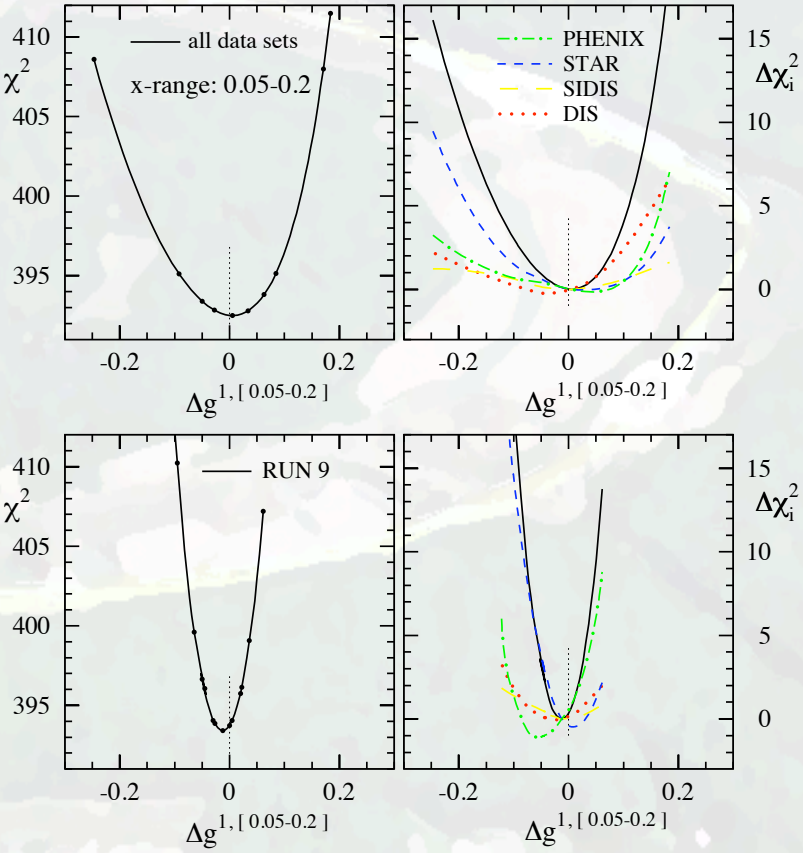
- Polarized proton-proton operation at RHIC at 200 / 500 GeV
  - During last longest polarized proton-proton run (RUN 6):
    - Luminosity: ~1pb^{-1}/day (~3pb^{-1}/day design) delivered luminosity
    - Polarization: ~60% polarization (70% design)
  - 500GeV development: Achieved 45% beam polarization for single beam at 250GeV
  - Goal: At 70% beam polarization
    - 200GeV: $60 \cdot 10^{30} cm^{-2} s^{-1}$
    - 500GeV: $150 \cdot 10^{30} cm^{-2} s^{-1}$



Future polarized p-p physics program

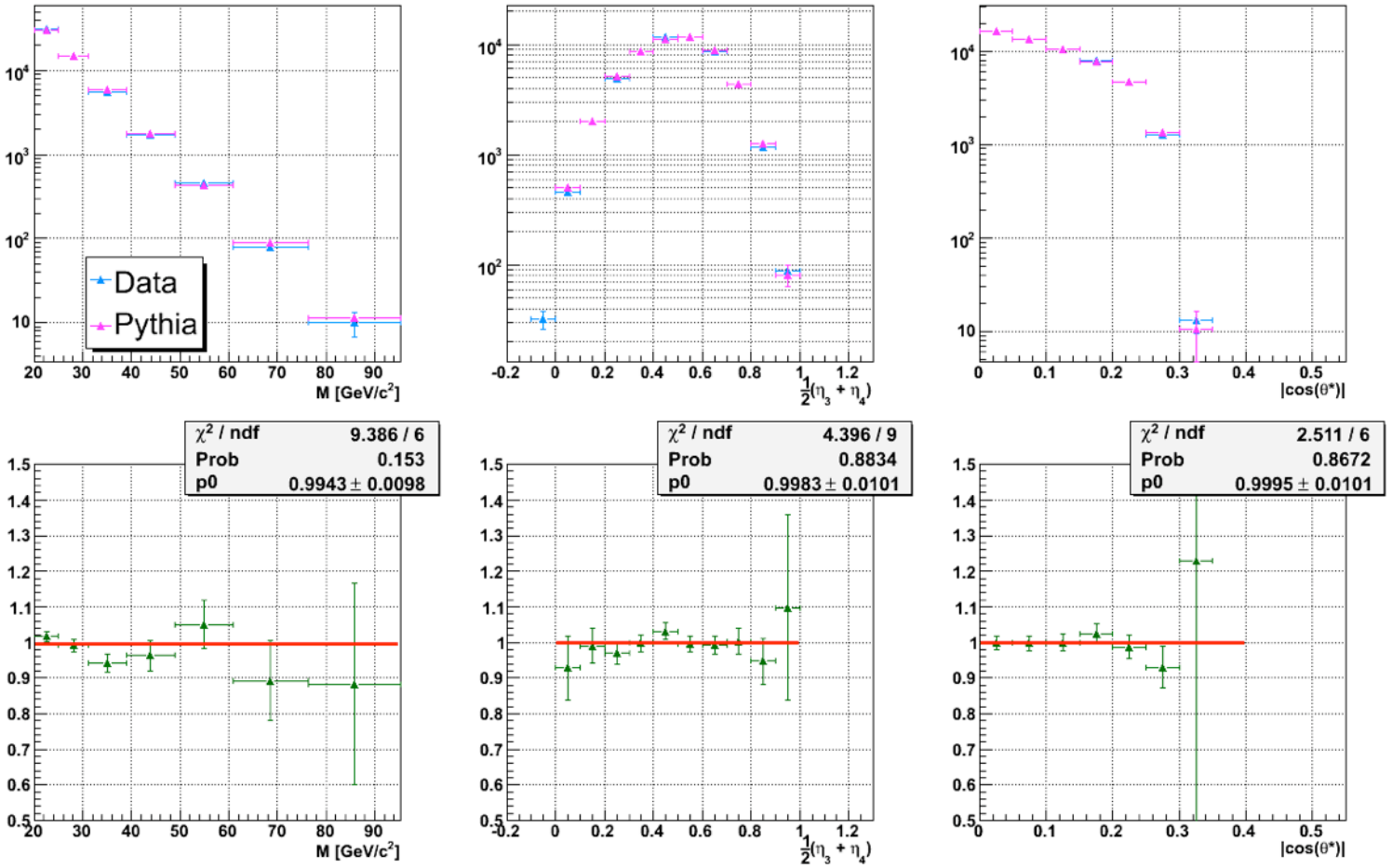
Gluon polarization





Results: Gluon Spin contribution

Di-Jet production - Data Understanding

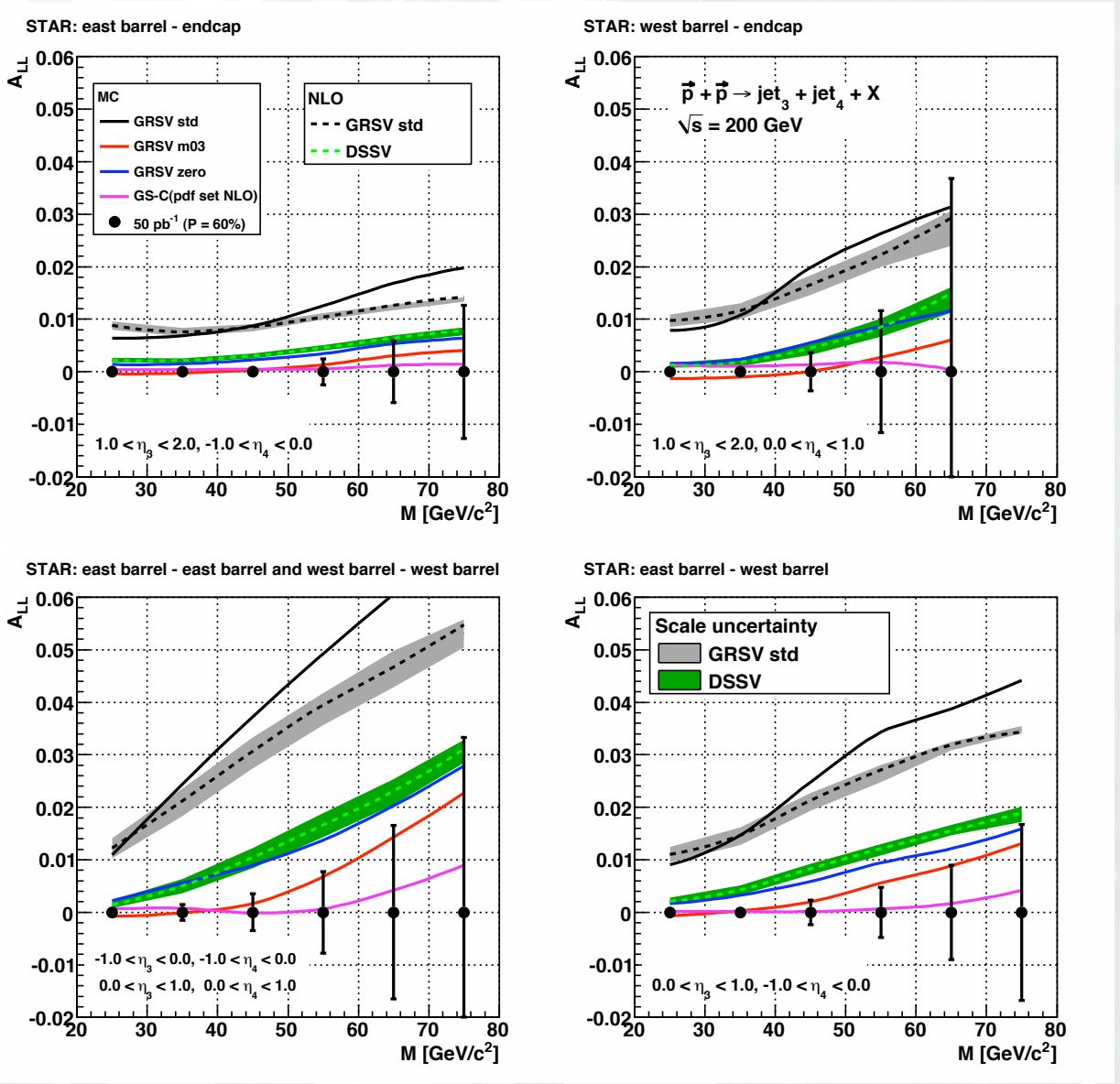


- Data/MC comparison complete - Good agreement in Di-Jet variables
- First cross-section and A_{LL} measurement in progress

$$M \propto \sqrt{x_1 x_2} \qquad \eta_3 + \eta_4 \propto \log\left(\frac{x_1}{x_2}\right)$$

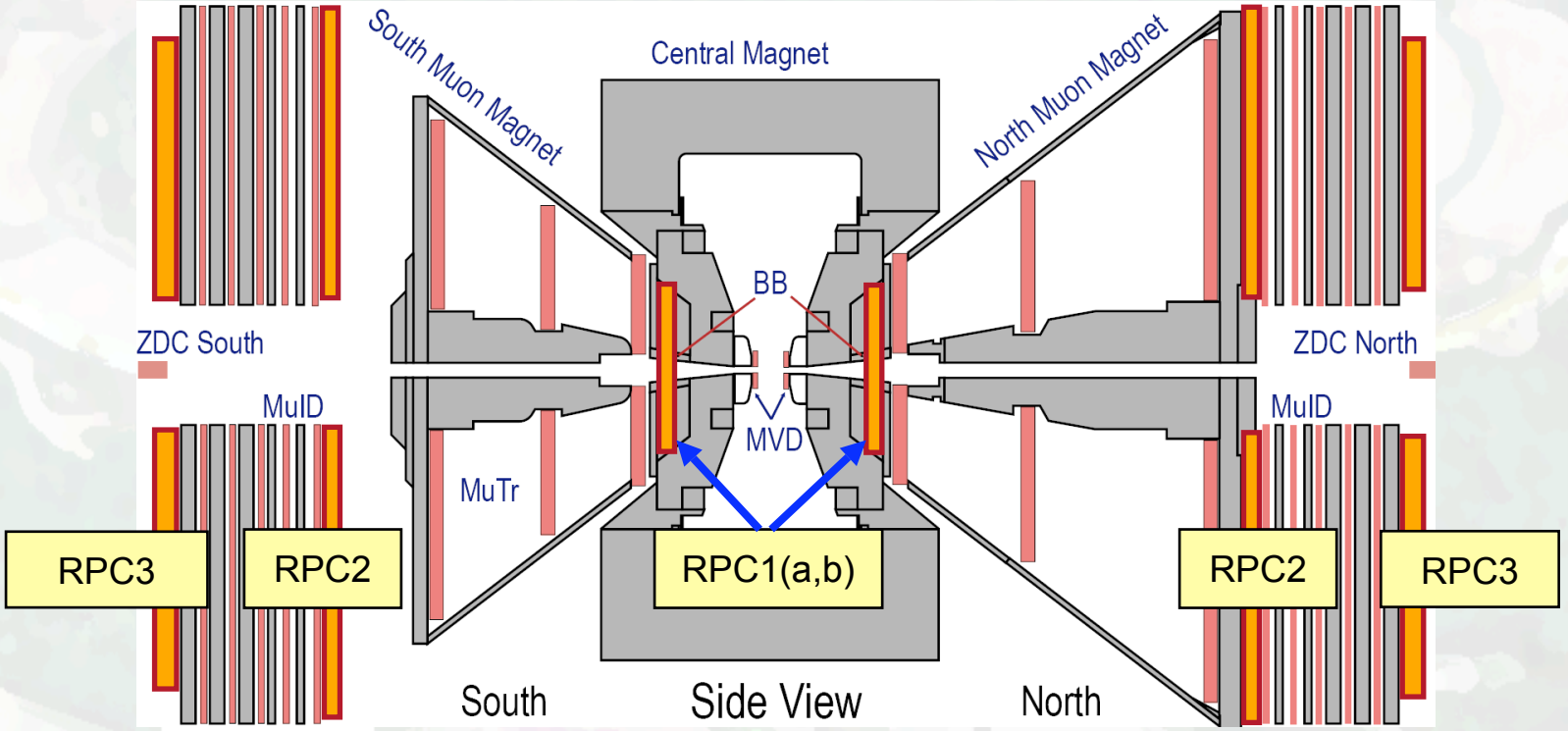
Future polarized p-p physics program

- Gluon polarization



Future polarized p-p physics program

- Quark / Anti-Quark polarization program at PHENIX
  - Forward Muon Trigger layout

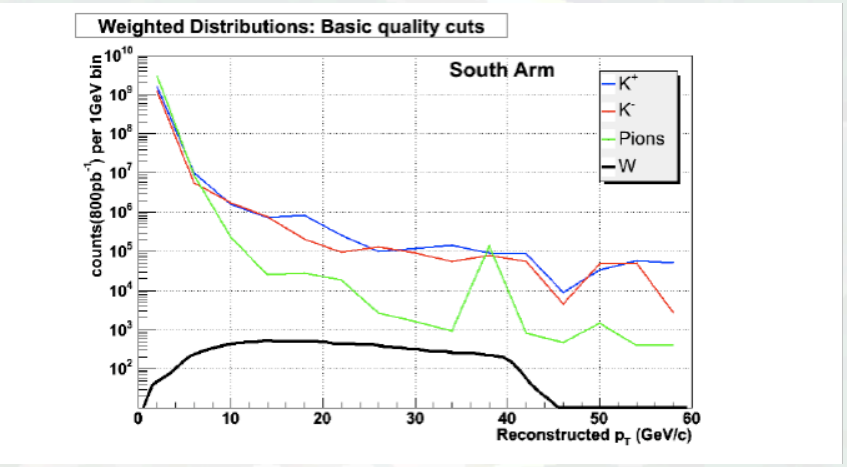


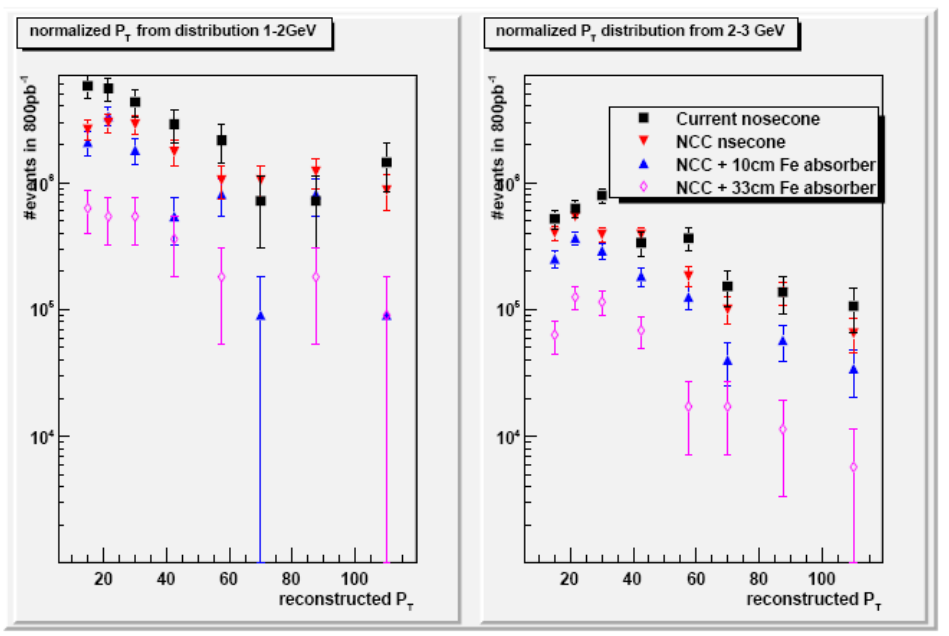
- 3 RPC planes for each muon chamber - Expected installation: Stations 2/3-North in 2009 - 2/3-South in 2010
- FEE upgrade of muon tracking - Expected installation: North in Summer 2008 / South in Summery 2009

Future polarized p-p physics program

- Quark / Anti-Quark polarization program at PHENIX

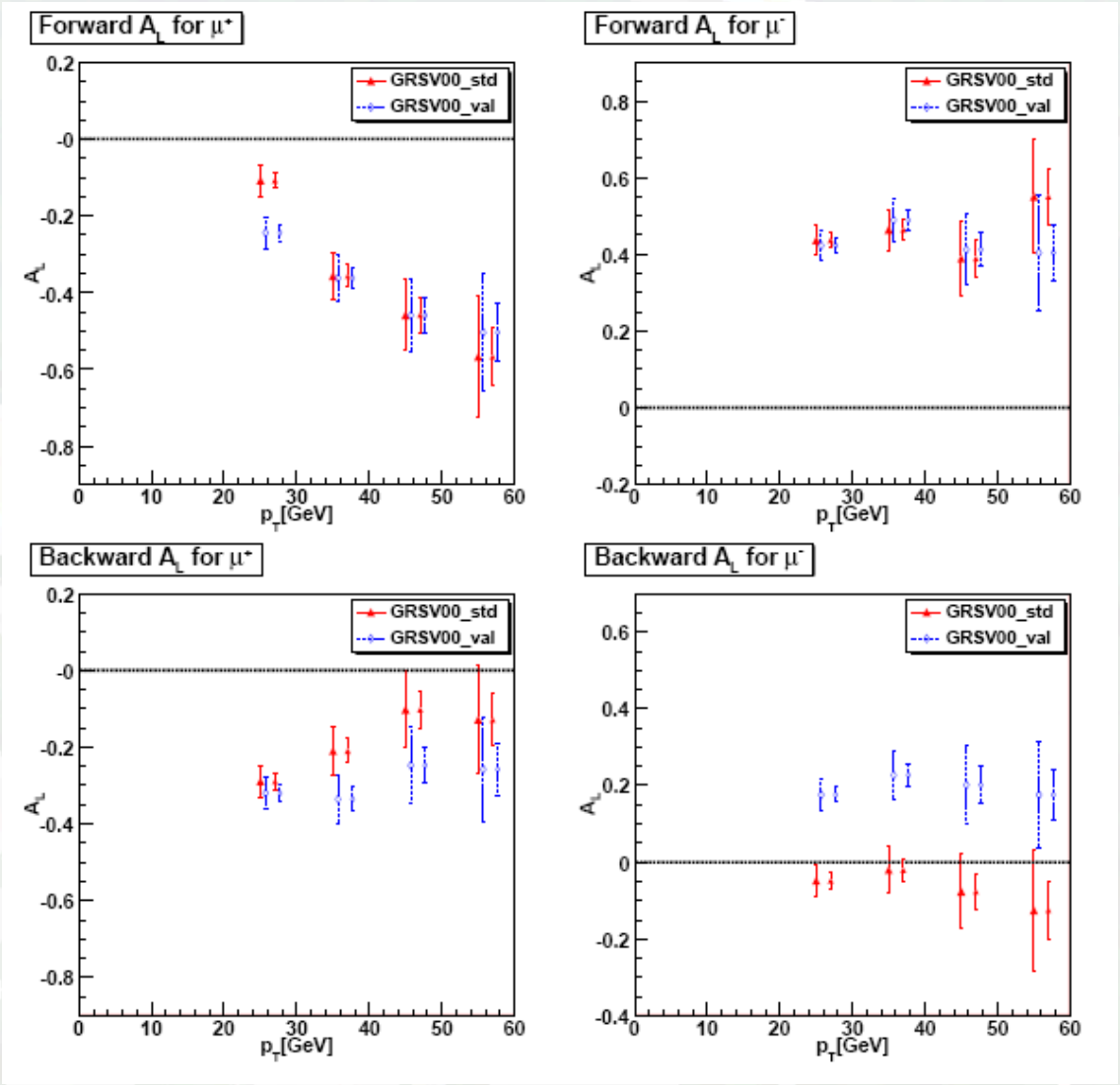
  - Main offline background: Low pT hadrons decaying within muon tracker volume mimicking a high pT track
  - Tights cuts reduce S/B to 1/3
  - Central magnet yoke to obtain 3/1 ratio





Future polarized p-p physics program

- Quark / Anti-Quark polarization program at PHENIX
  - Large asymmetries dominated by quark polarization - Important consistency check to existing DIS data (Phase I)
  - Strong impact constraining unknown antiquark polarization requires luminosity sample at the level of 300pb^{-1} for 70% beam polarization (Phase II)



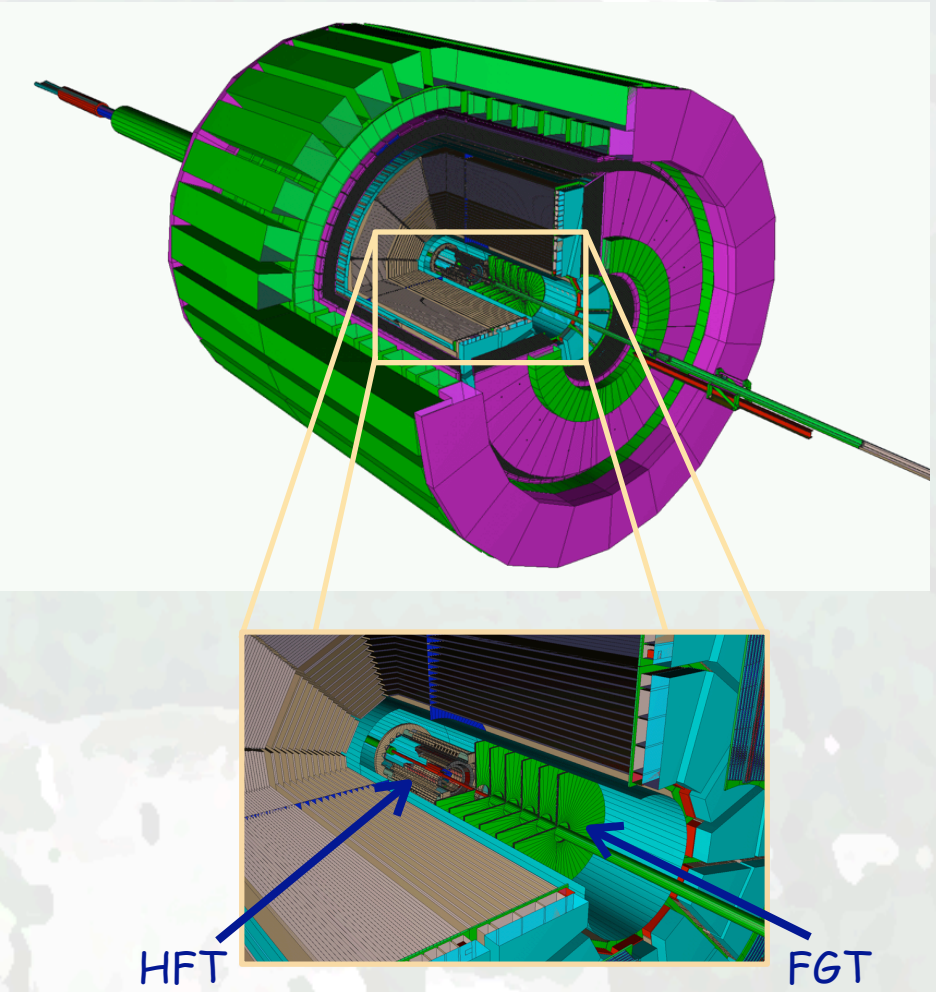
Future polarized p-p physics program

- Quark / Anti-Quark polarization program at STAR

Forward GEM Tracker: FGT

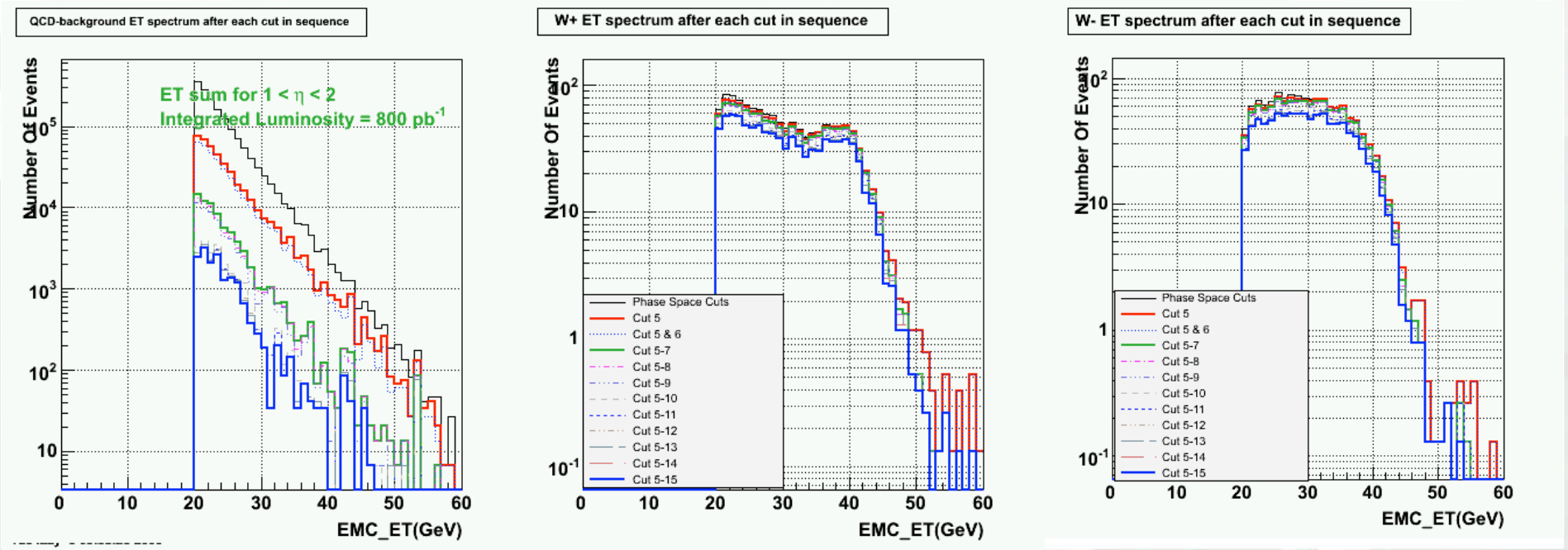
- Charge sign identification for high momentum electrons from $W^{\pm}$ decay (Energy determined with EEMC)
- Triple-GEM technology
- FGT project:

  ANL, IUCF, LBL, MIT, University of Kentucky, Valparaiso University, Yale
- Successful project review (Capital equipment funding): January 2008
- Expected installation: Summer 2010



Future polarized p-p physics program

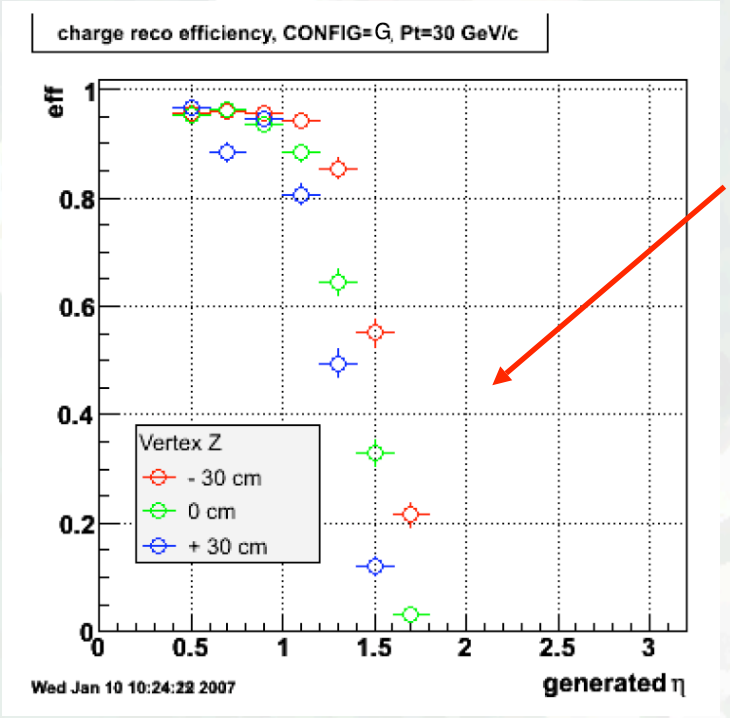
- Quark / Anti-Quark polarization program at STAR
  - e/h separation: Full PYTHIA QCD background and W signal sample including detector effects



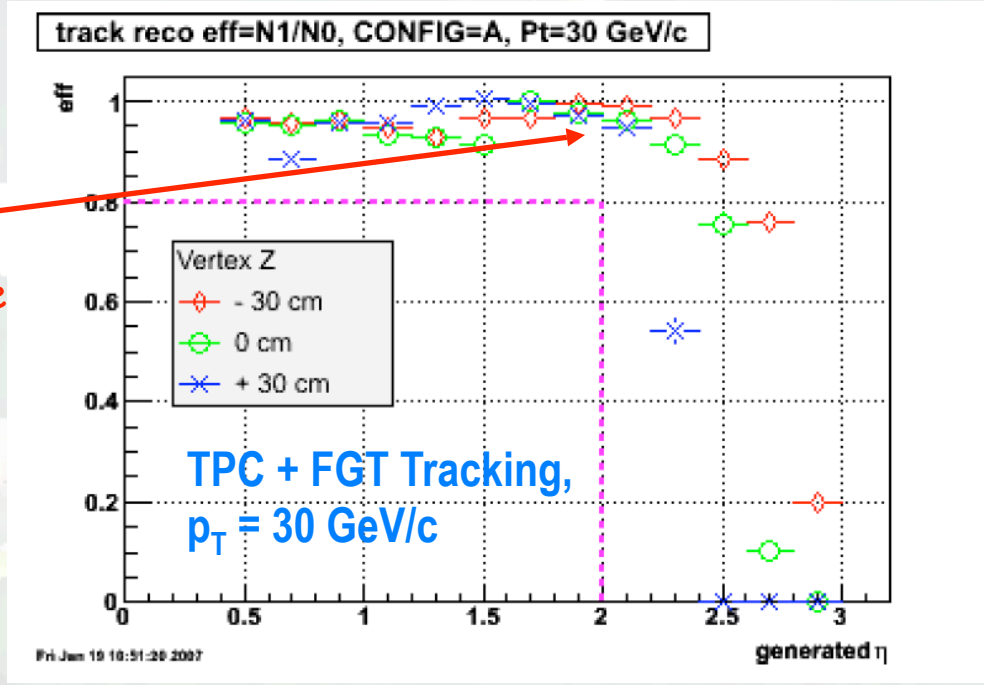
- e/h separation based on global cuts (isolution/missing E_T) and EEMC specific cuts as
- With current algorithm: $E_T > 25$GeV yields S/B > 1 (For $E_T < 25$GeV S/B ~ 1/5) used for A_L uncertainty estimates

Future polarized p-p physics program

- Quark / Anti-Quark polarization program at STAR



Reach of EEMC Acceptance



Conclusion:

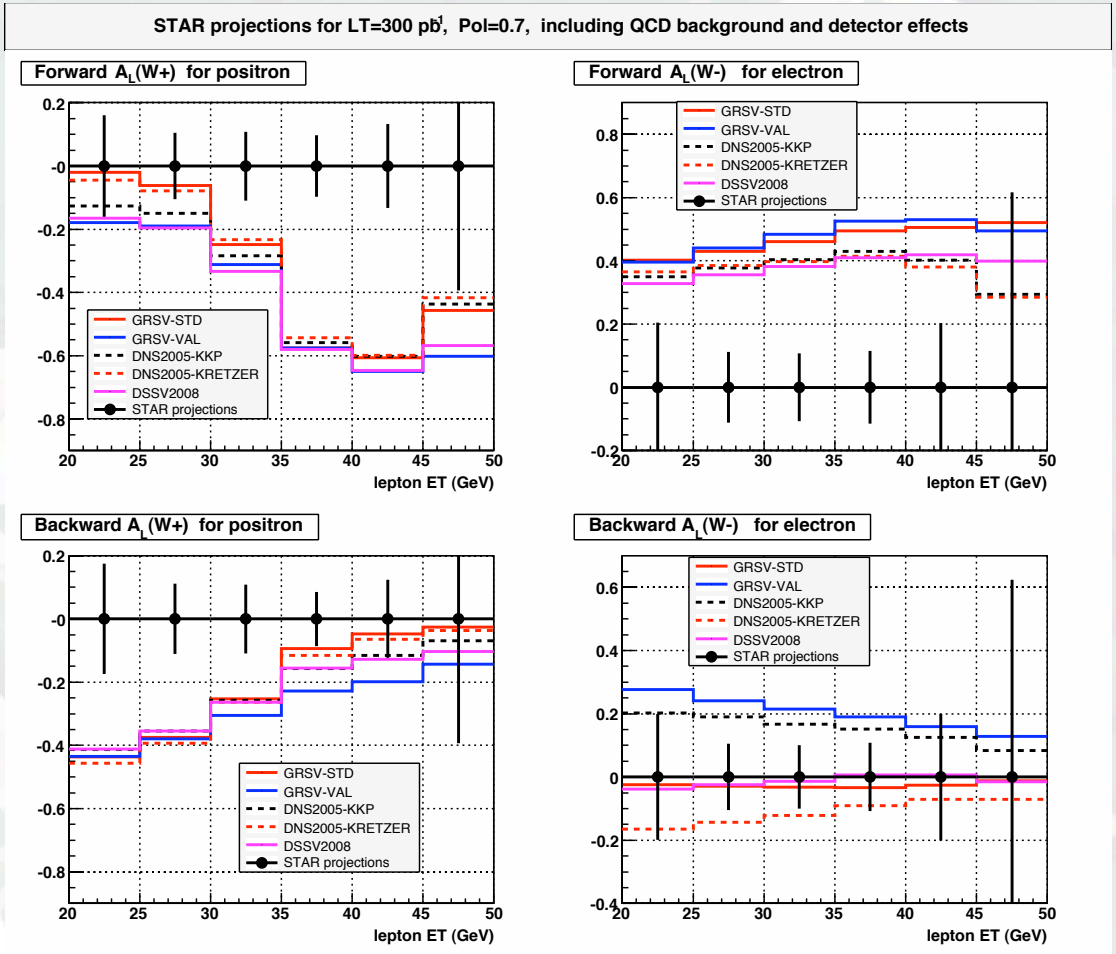
Charge sign reconstruction impossible beyond η = ~1.3

Conclusion: for 6 triple-GEM disks, assumed spatial resolution 60 μm in x and y (Fairly insensitive for 60-100 μm)

Charge sign reconstruction probability above 90% for 30 GeV p_T over the full acceptance of the EEMC for the full vertex spread

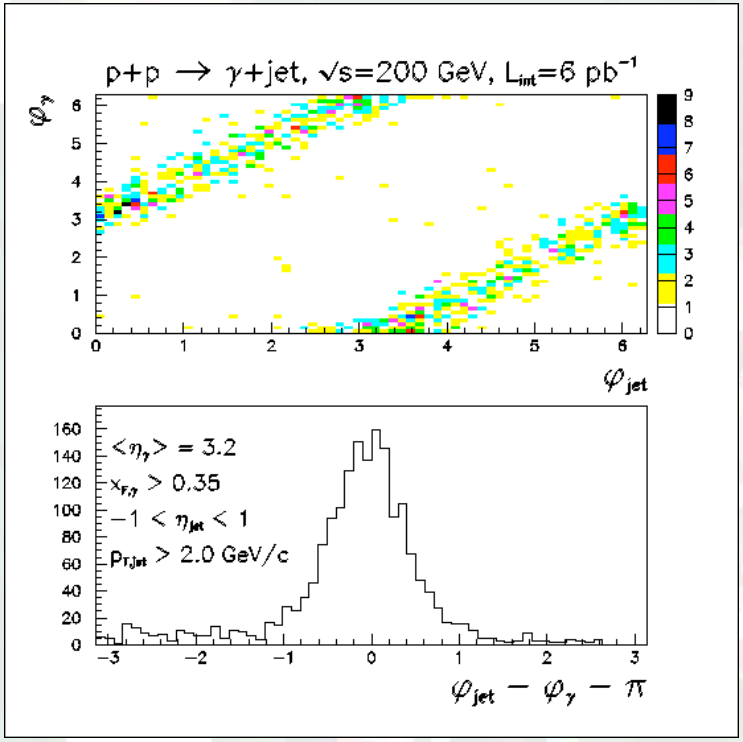
Future polarized p-p physics program

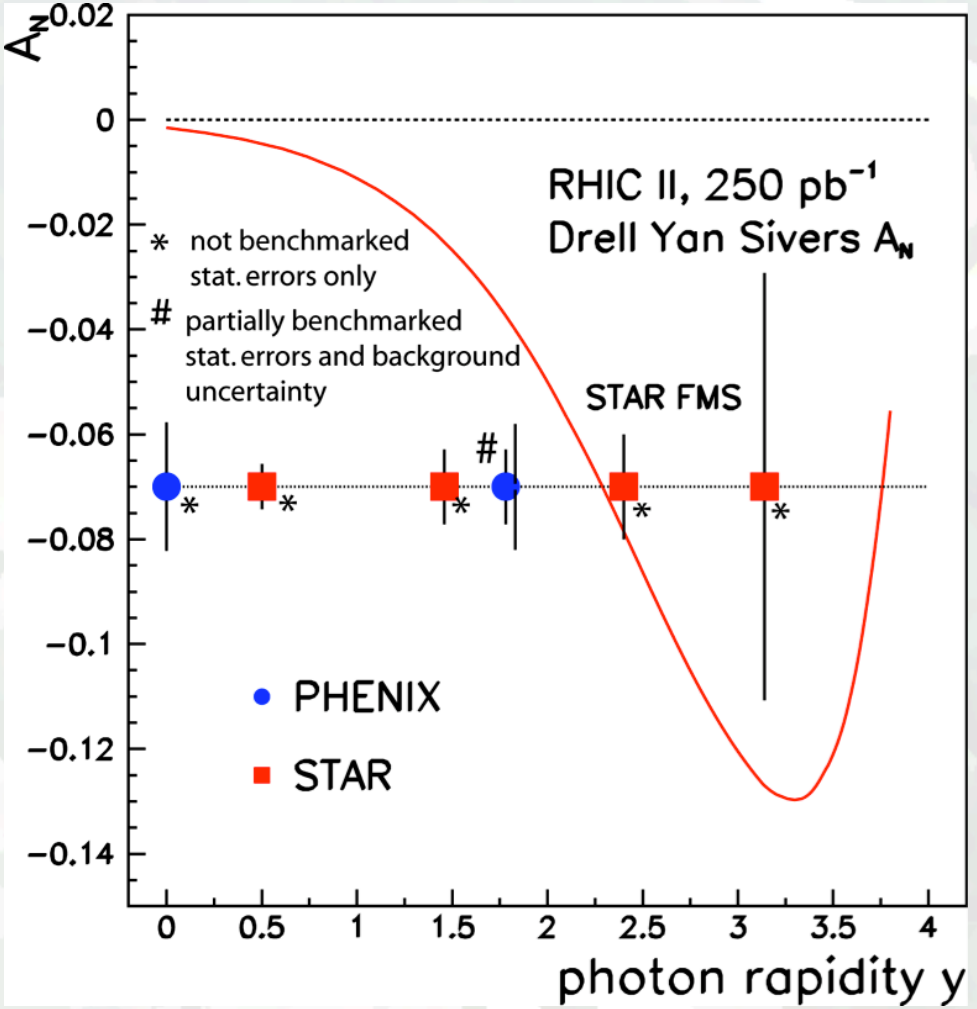
- Quark / Anti-Quark polarization program at STAR
  - Large asymmetries dominated by quark polarization - Important consistency check to existing DIS data (Phase I)
  - Strong impact constraining unknown antiquark polarization requires luminosity sample at the level of 300pb^{-1} for 70% beam polarization (Phase II)



Future polarized p-p physics program

- Transverse spin dynamics





Summary and Outlook

- RHIC SPIN Plan - Document
  - Accelerator
    - Anticipated increase in luminosity by factor 2-3
    - Anticipated increase in polarization from 60% to 70%
    - Confident that large luminosity samples can be provided assuming sufficient running time
  - Gluon polarization
    - Sensitivity on the gluon spin contribution to the proton spin will improve significantly by about a factor 4 in uncertainty with new precision inclusive measurements planned in 2009
    - Correlation measurements will provide access to partonic kinematics and help to to constrain the shape of the gluon spin contribution
    - Further measurements in later years will expand sampled gluon momentum range (Rapidity coverage and 500GeV operation)

Summary and Outlook

- RHIC SPIN Plan - Document
  - Quark and Anti-Quark polarization
    - W production at RHIC provides a unique handle on the polarization of quarks and antiquarks
    - Proposed start of program: ~ 2010
    - PHENIX and STAR upgrade programs required to address W program
    - Full simulations including background and detector effects show clear sensitivity to antiquark polarization for 300pb^{-1} at 70% beam polarization
  - Transverse spin dynamics
    - Precision transverse spin program at RHIC exploring large transverse spin asymmetries
    - Study transversity and orbital momentum generated effects
    - pQCD prediction based on orbital momentum description connecting forward asymmetries at RHIC to asymmetries observed in DIS
    - A transversely polarized beam producing Drell-Yan pairs at RHIC tests predicted direct connection between DIS and Drell-Yan asymmetries - Anticipated start of such an experimental program ~2013