Recent results and Future perspectives of the high-energy polarized proton-proton program at RHIC

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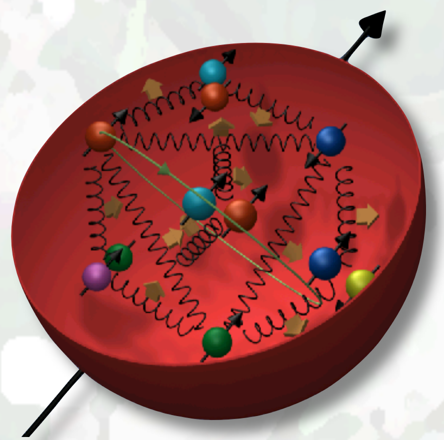
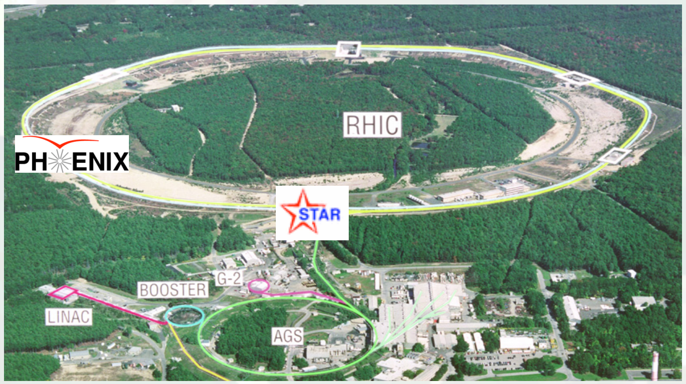


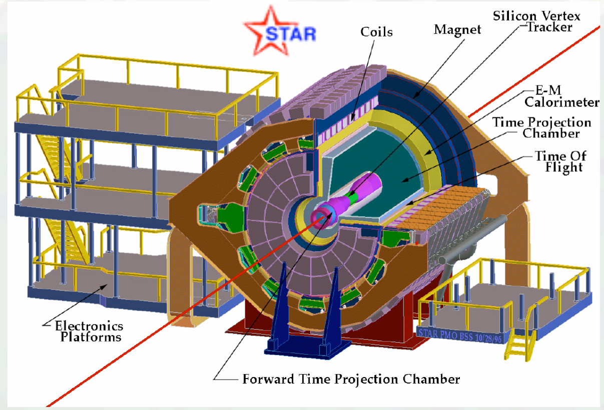
DESY, Tuesday Seminar
Hamburg, Germany, July 08, 2008

Outline

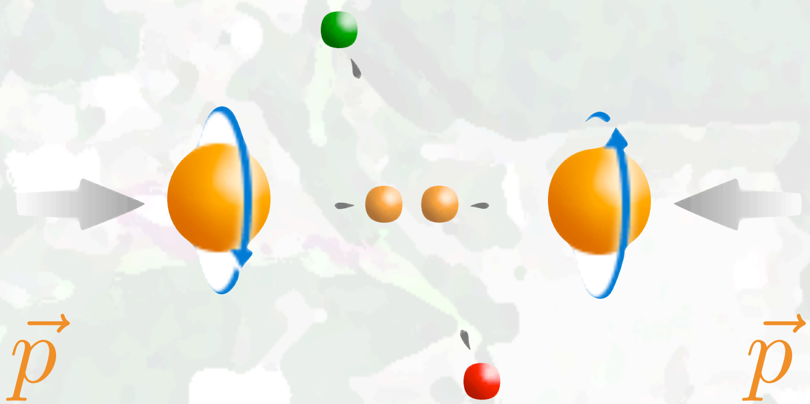
- Introduction



- Collider

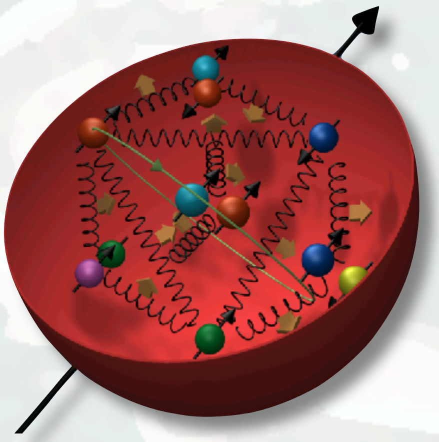


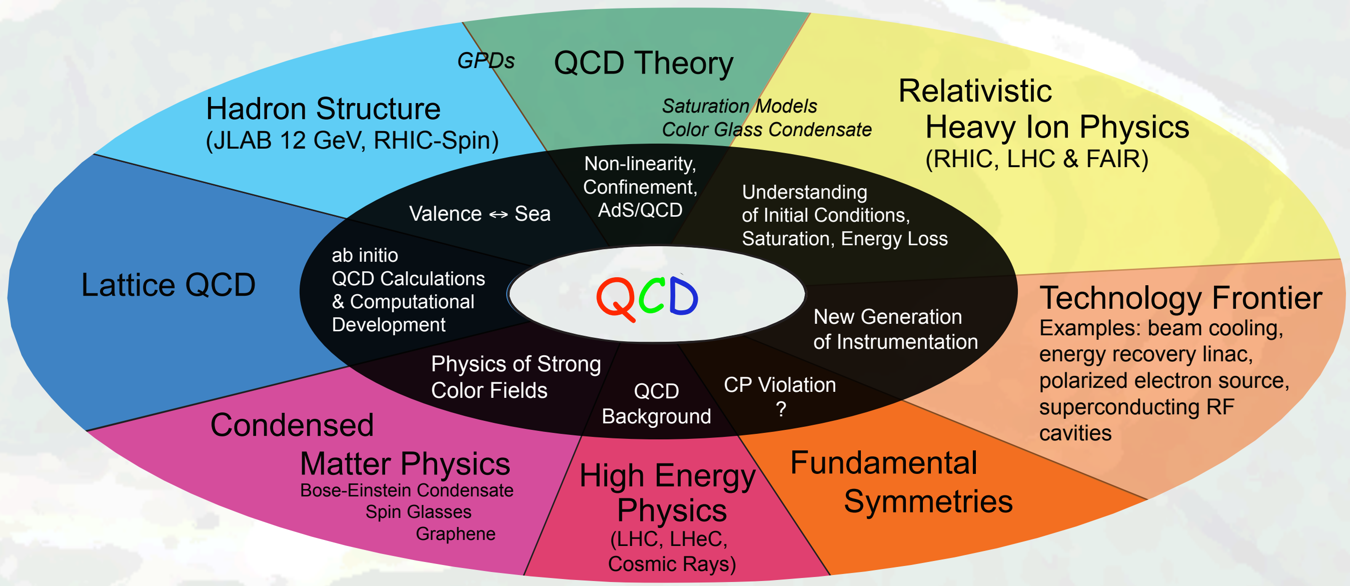
- Experiment
- Highlights of recent results and achievements
- Future polarized p-p physics program
- Summary and Outlook



Introduction

- Exploring the proton spin structure and dynamics





Structure and dynamics of proton (**mass**) ($\rightarrow$ visible universe) originates from QCD-interactions!

What about **spin** as another fundamental quantum number?

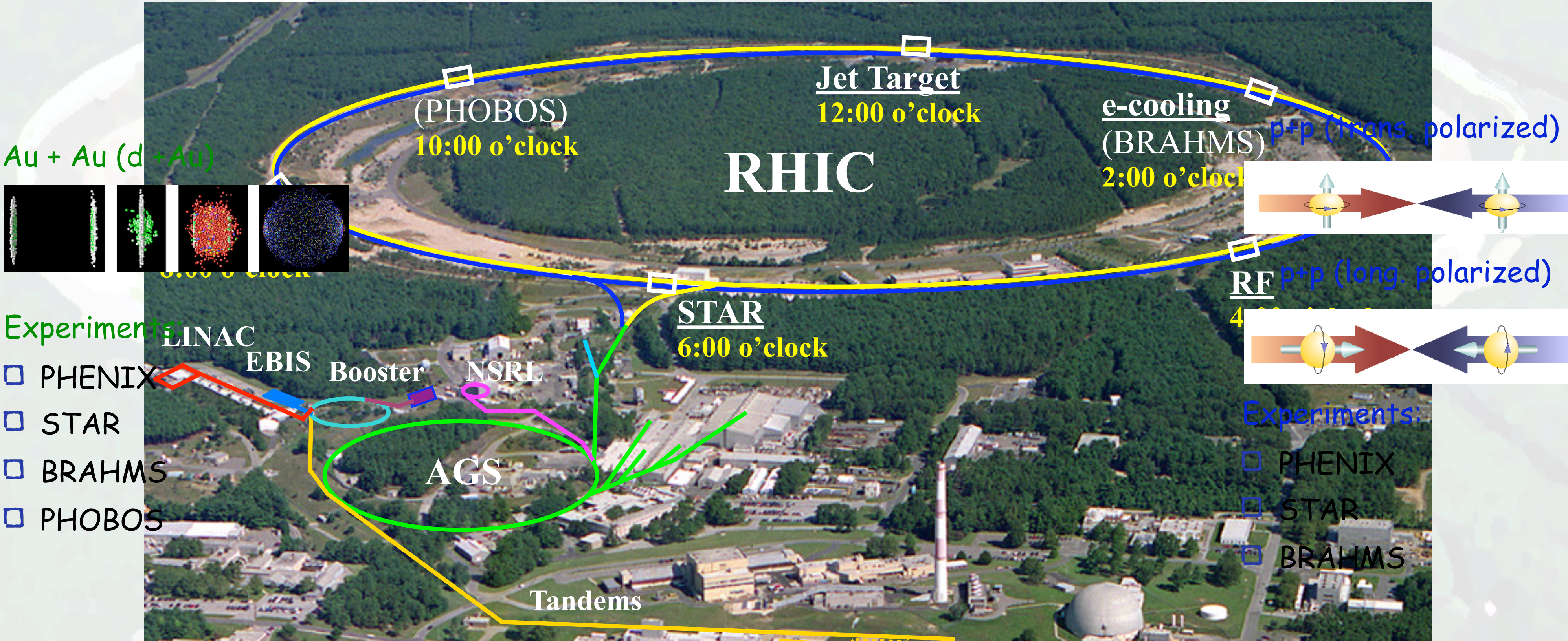
Synergy of experimental progress and theory (Lattice QCD / Phenomenology incl. phenomenological fits / Modeling) critical!

Introduction

- BNL - The QCD Lab

Au + Au (d + Au)

Experiments:
- PHENIX
- STAR
- BRAHMS
- PHOBOS



p+p (trans. polarized)

p+p (long. polarized)

Experiments:
- PHENIX
- STAR
- BRAHMS

- RHIC facility: Unique collider facility which allows to collide different species (Au-Au and d-Au as well as polarized p-p) at variable beam energy
- Explore the nature of matter under extreme conditions (RHIC relativistic-heavy ion program)
- Explore the nature of the proton spin (RHIC spin physics program)

Introduction

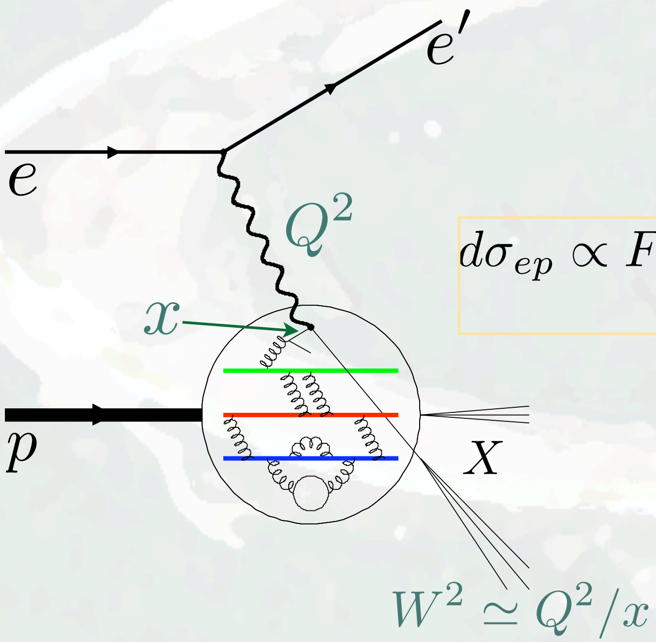
- Vision of the BNL QCD Laboratory
  - Goal: Evolve RHIC facility to address key questions on QCD
  - Four key elements of the BNL management plan:
    - Near-term upgrades to RHIC
      - Detector upgrades
      - EBIS (Electron-Beam Ion Source)
      - Enhanced luminosity and polarization
    - RHIC-II
      - Luminosity upgrade
        - Goal: Establish transverse stochastic cooling
        - Electron cooling might be necessary for eRHIC
    - eRHIC (EIC @ BNL)
    - Theory and computational QCD

Prominently featured in 2007 Long-Range planing process of the Nuclear Science Advisory Committee (NSAC)

RHIC plays a key role in the US Nuclear Science Mission

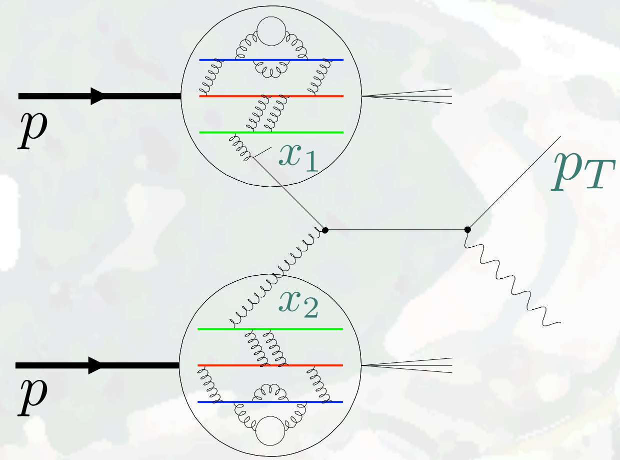
Introduction

- How do we probe the structure and dynamics of matter in ep / pp scattering?



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

Universality



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

Momentum contribution

$$f(x) =$$

$$\Delta f(x) =$$

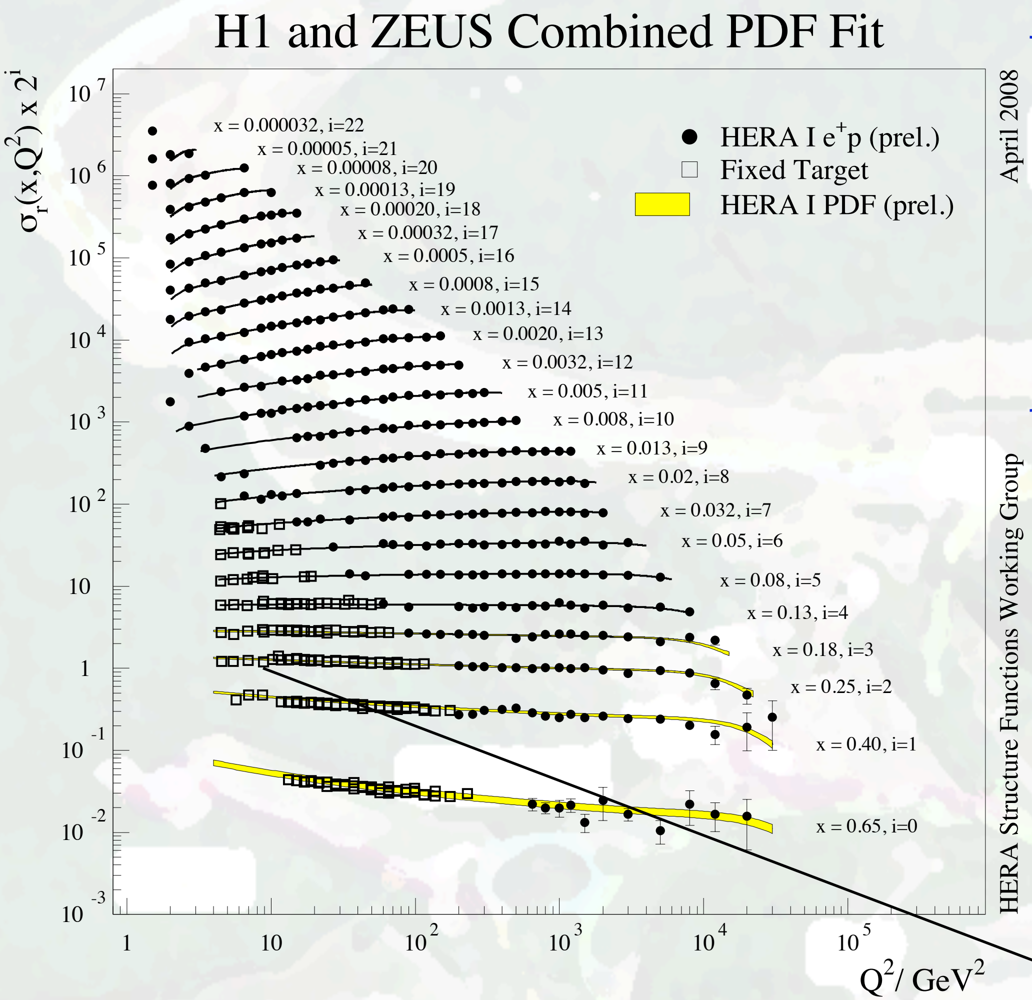
$$f^+(x) + f^-(x)$$

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

Spin contribution

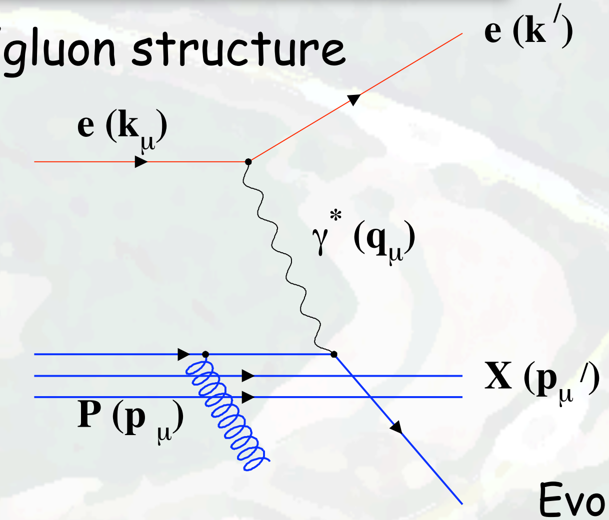
Introduction

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

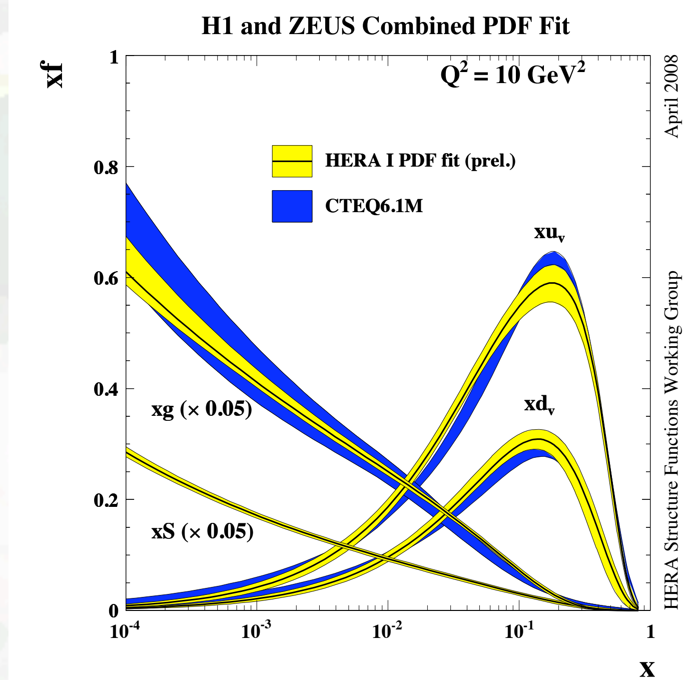


Strong violation of scaling at low x and high Q^2

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



Evolution



In contrast to:

Low Q^2 high x!

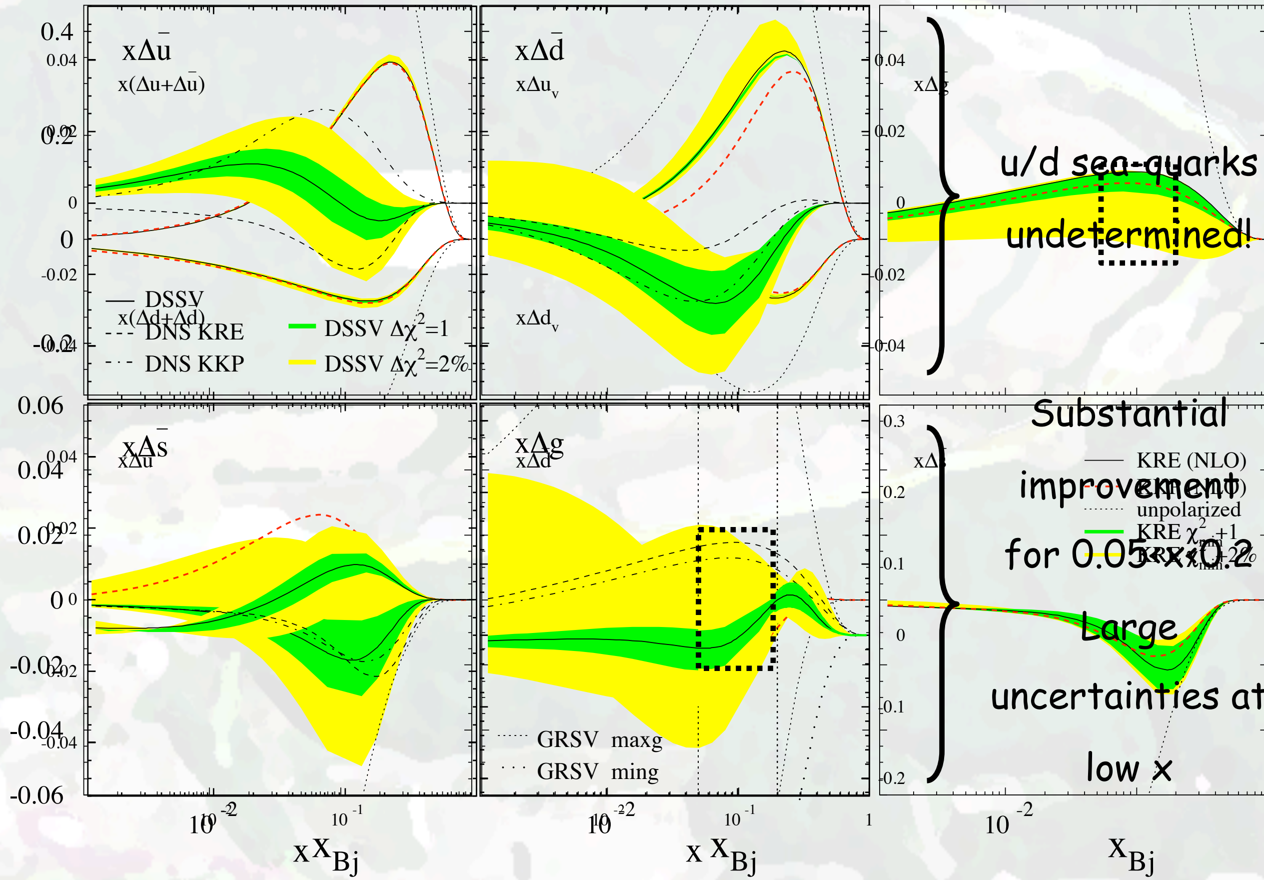
Introduction

- What do we know about the polarized quark and gluon distributions?

  - Spin carried by quarks is very small ($\Delta\Sigma \sim 0.4$)!

$$\frac{1}{2} = \underbrace{\langle S_q \rangle}_{\frac{1}{2}\Delta\Sigma} + \underbrace{\langle S_g \rangle}_{\Delta G} + \langle L_q \rangle + \langle L_g \rangle$$

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$



D. de Florian et al., Phys. Rev. D71, 094018 (2005).

$$\boxed{\Delta q_i(Q^2) = \int_0^1 \Delta q_i(x, Q^2)\,dx}$$

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

Introduction

- Model expectations and Lattice QCD calculations (1)

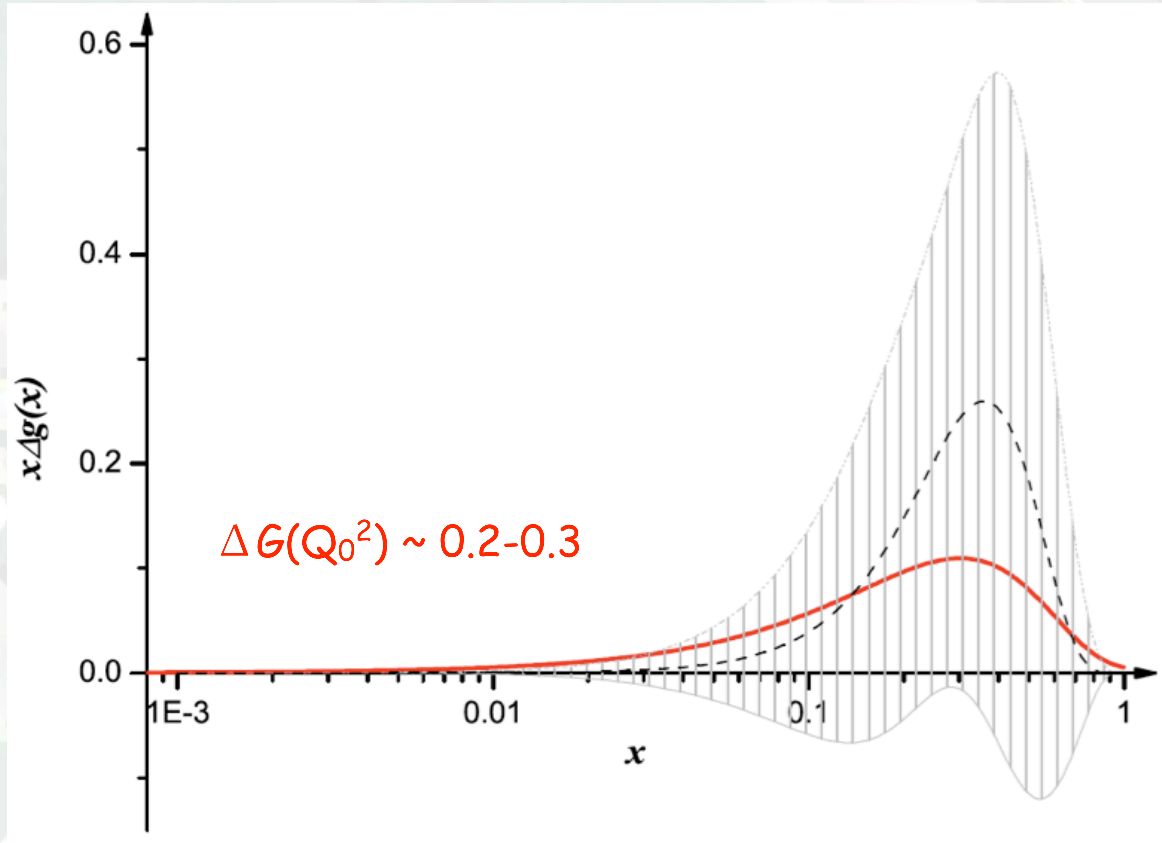
  - Following the first EMC results suggesting a very small quark spin contribution, a scenario has been discussed suggesting a large and positive gluon polarization (e.g. Altarelli and Ross): $\Delta G(Q_0^2) \sim 4\text{-}5$

    (Controversial in the literature!)

  - R. Jaffe: $\Delta G(Q_0^2) \sim -0.8$

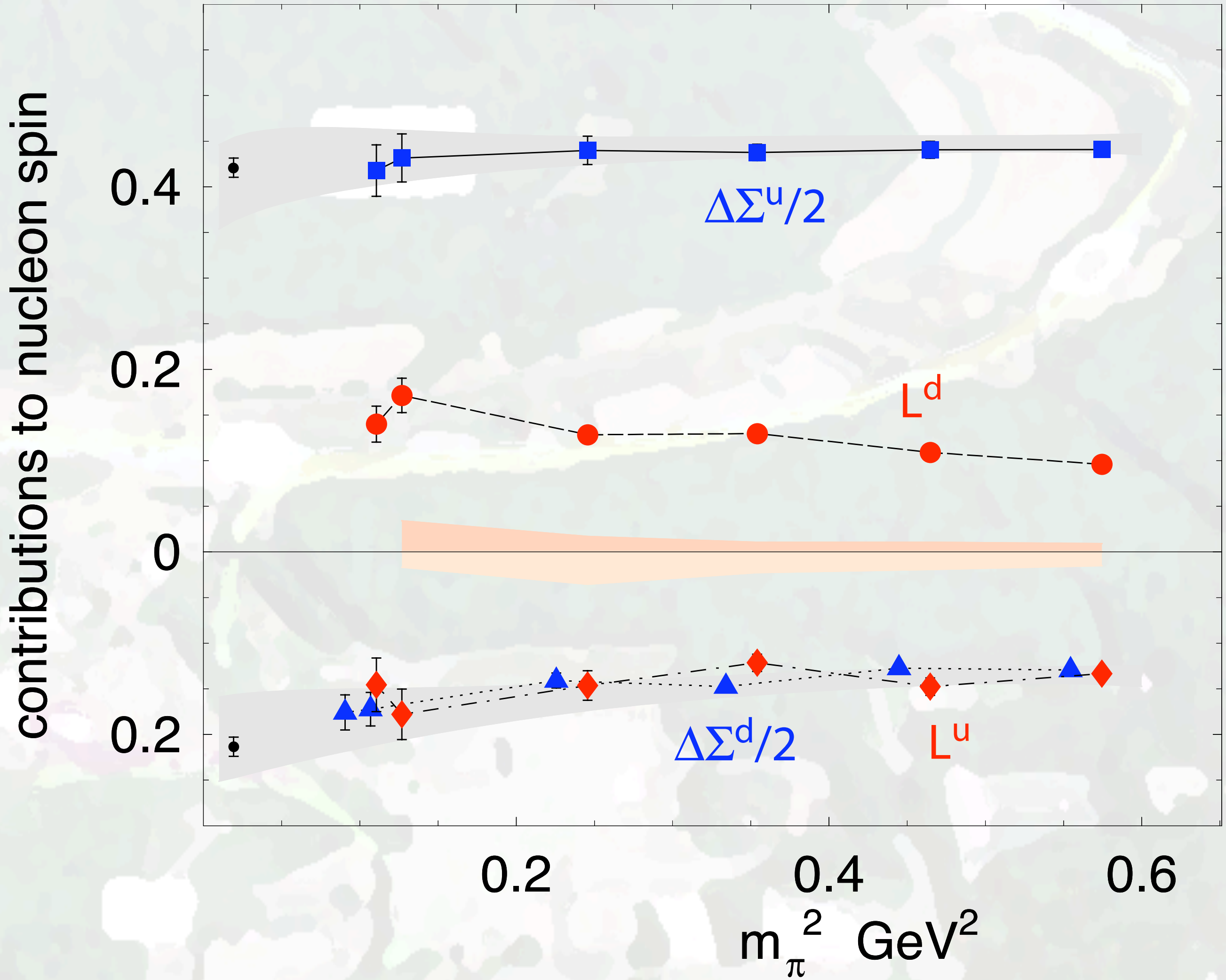
    (Large and negative gluon polarization)

  - MIT Bag-model calculations by X. Ji



Introduction

- Model expectations and Lattice QCD calculations (2)
  - Lattice QCD:
    - Total quark spin contribution ($\Delta\Sigma$) consistent with experimental extraction
    - Total quark angular momentum contribution L^{u+d} consistent with zero

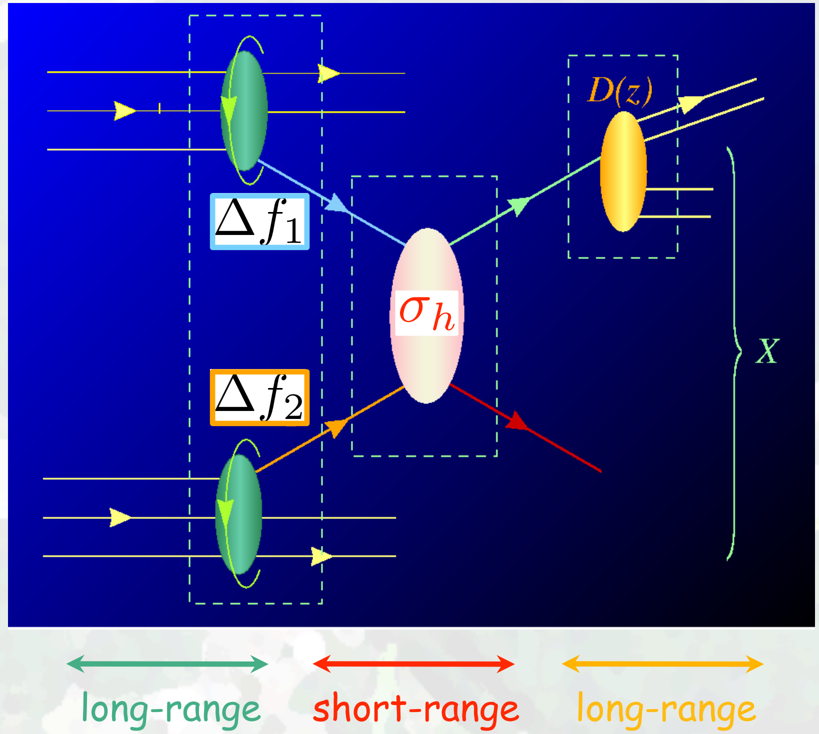


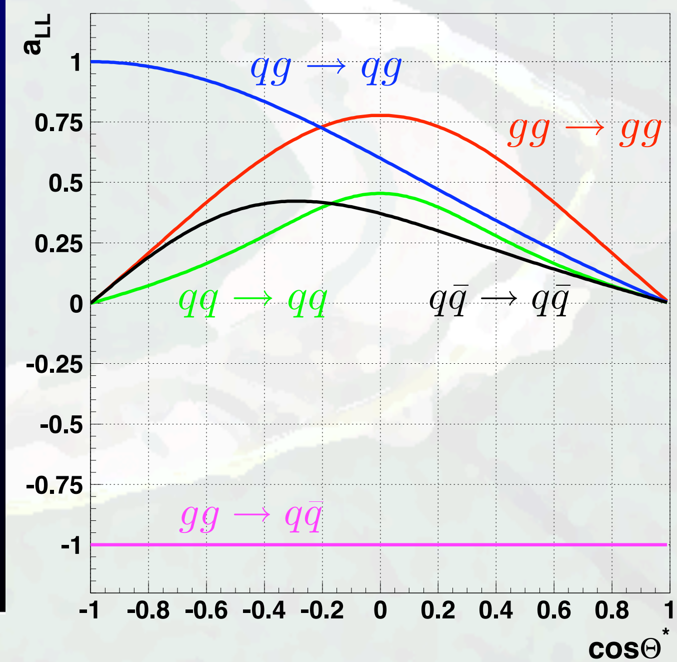
Introduction

- 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)!



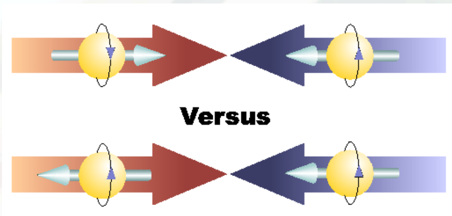


$$A_{LL} = \frac{d\Delta\sigma}{d\sigma} \propto \frac{\boxed{\Delta f_1} \otimes \boxed{\Delta f_2} \otimes \sigma_h \cdot a_{LL} \otimes D_f^h}{f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h}$$

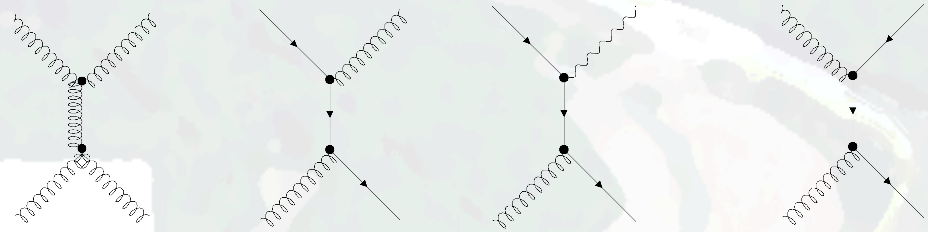
$$\left.\boxed{a_{LL} = \frac{\Delta\sigma_h}{\sigma_h}}\right\} \text{Input}$$

Introduction

- What is required experimentally to measure the gluon spin contribution?
  - Double longitudinal-spin asymmetry: A_{LL}



$$\vec{p} + \vec{p} \rightarrow$$



$\boxed{\text{jets} + X}$ $\boxed{\gamma + X}$ $\boxed{c\bar{c}\,(b\bar{b}) + X}$

- Study helicity dependent structure functions (Gluon polarization)!

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

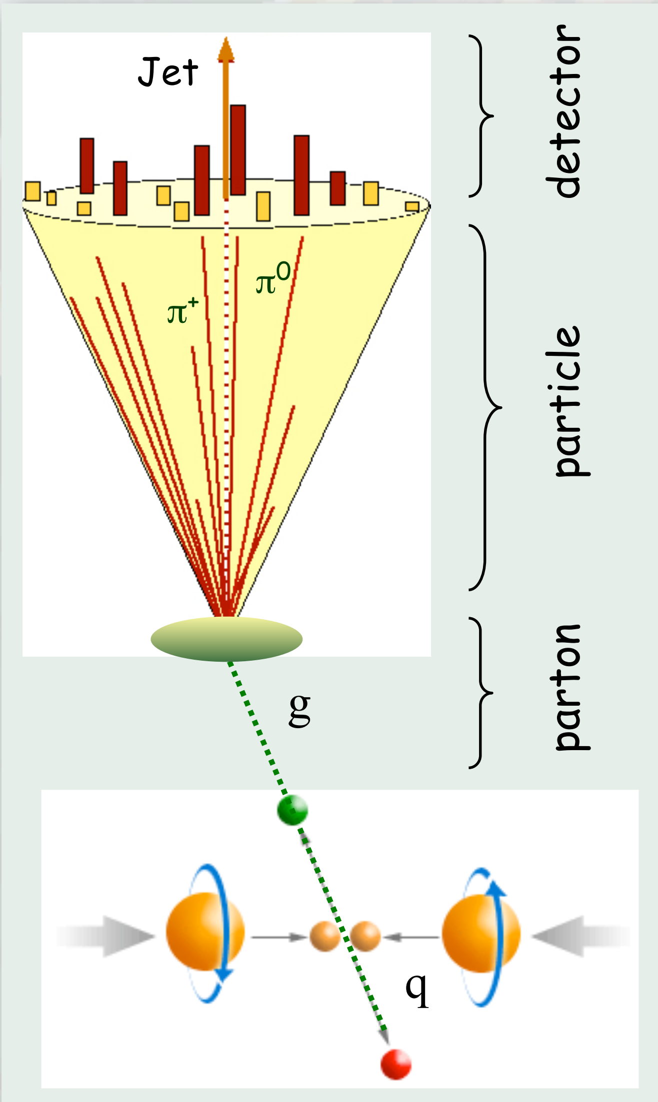
- Require concurrent measurements:
  - Magnitude of beam polarization, $P_{1(2)}$ RHIC polarimeters
  - Direction of polarization vector
  - Relative luminosity of bunch crossings with different spin directions
  - Spin dependent yields of process of interest N_{ij}

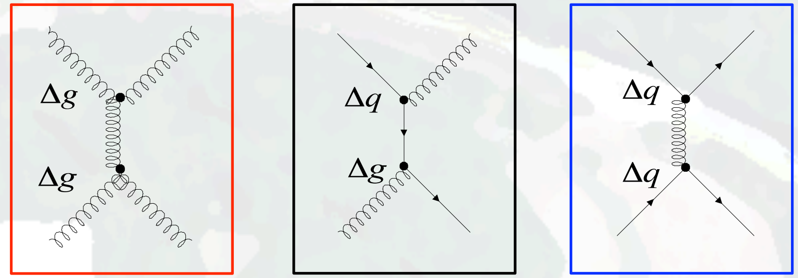
RHIC polarimeters

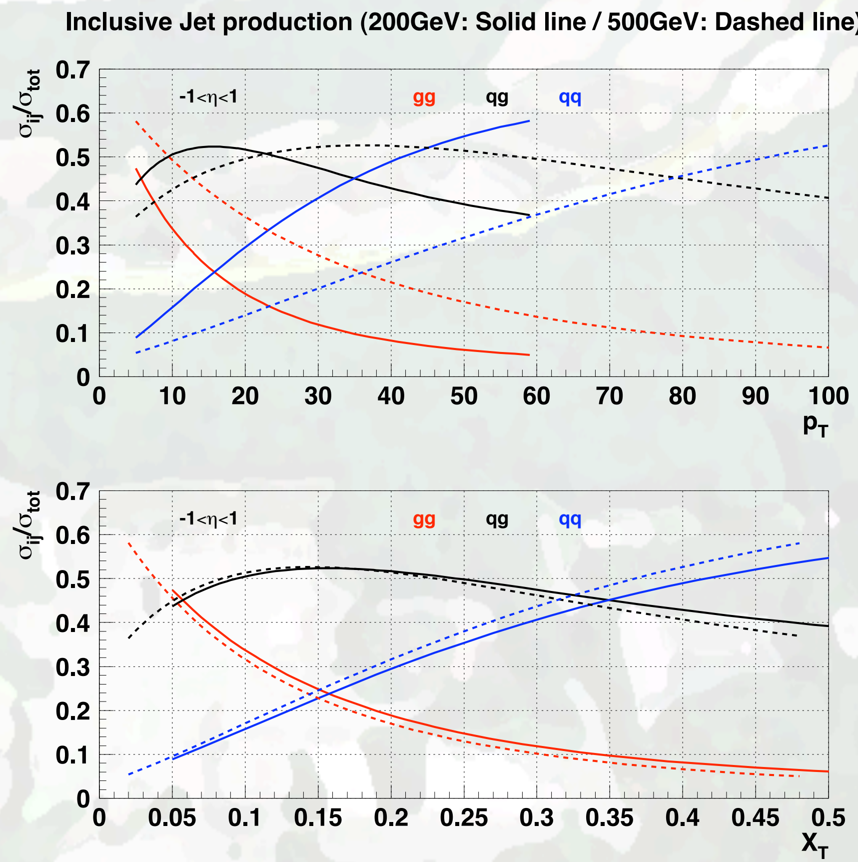
STAR experiment

Introduction

- Gluon polarization - Inclusive Measurements





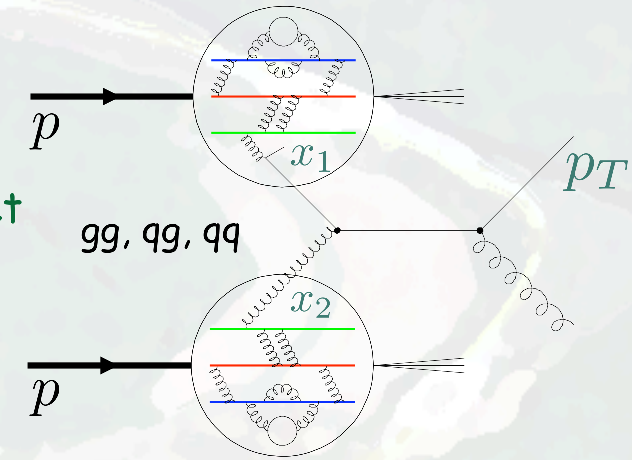


$$x_T = 2p_T/\sqrt{s}$$

Introduction

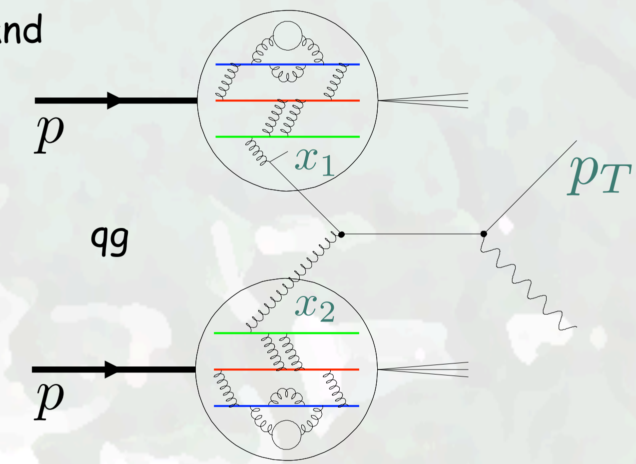
- Gluon polarization - Correlation Measurements
  - Correlation measurements provide access to partonic kinematics through Di-Jet/Hadron production and Photon-Jet production

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



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 dominant underlying (LO) 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

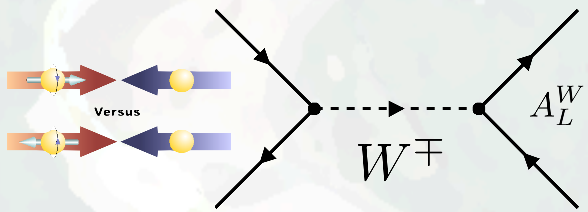
Introduction

Quark / Anti-Quark Polarization - W production

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

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

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



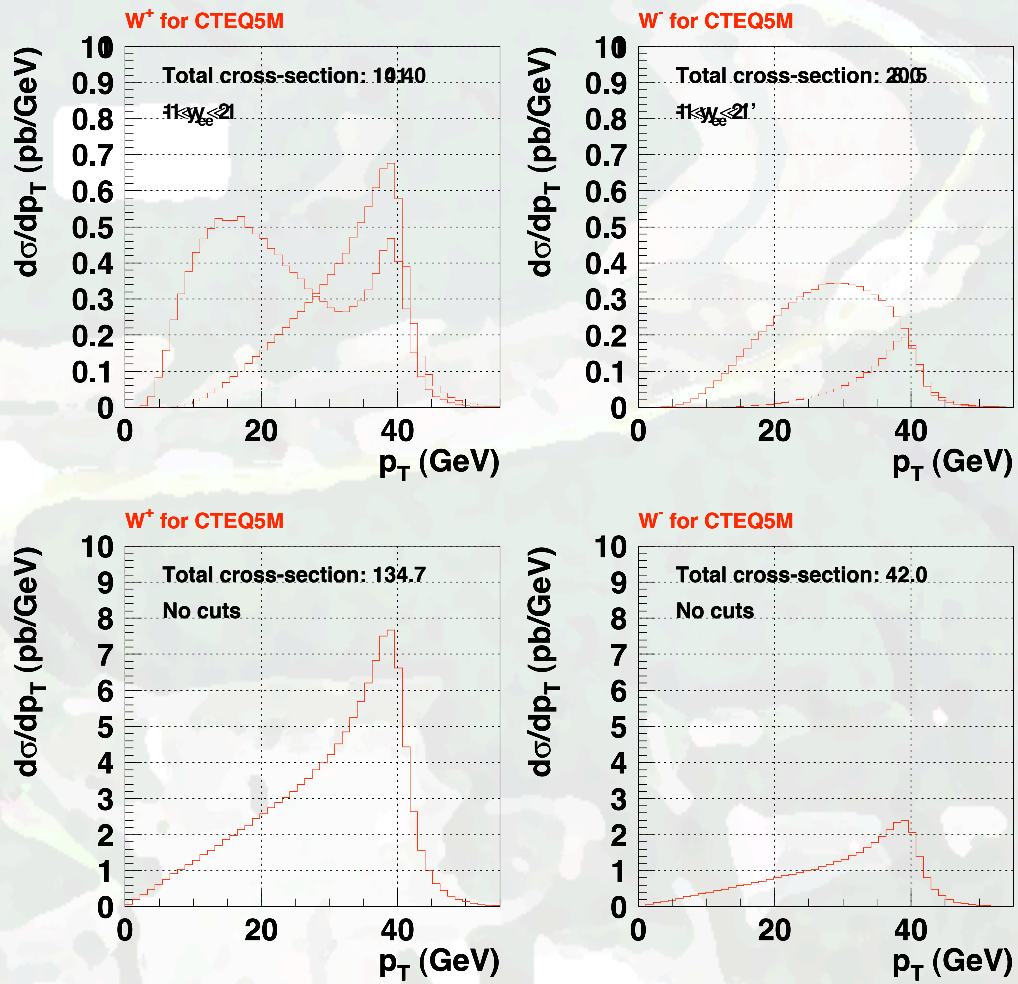
$$A_L^W = \frac{1}{P}\frac{N^+(W) - N^-(W)}{N^+(W) - N^-(W)}$$

$W^+ \rightarrow e^+ + \nu_e$

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

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

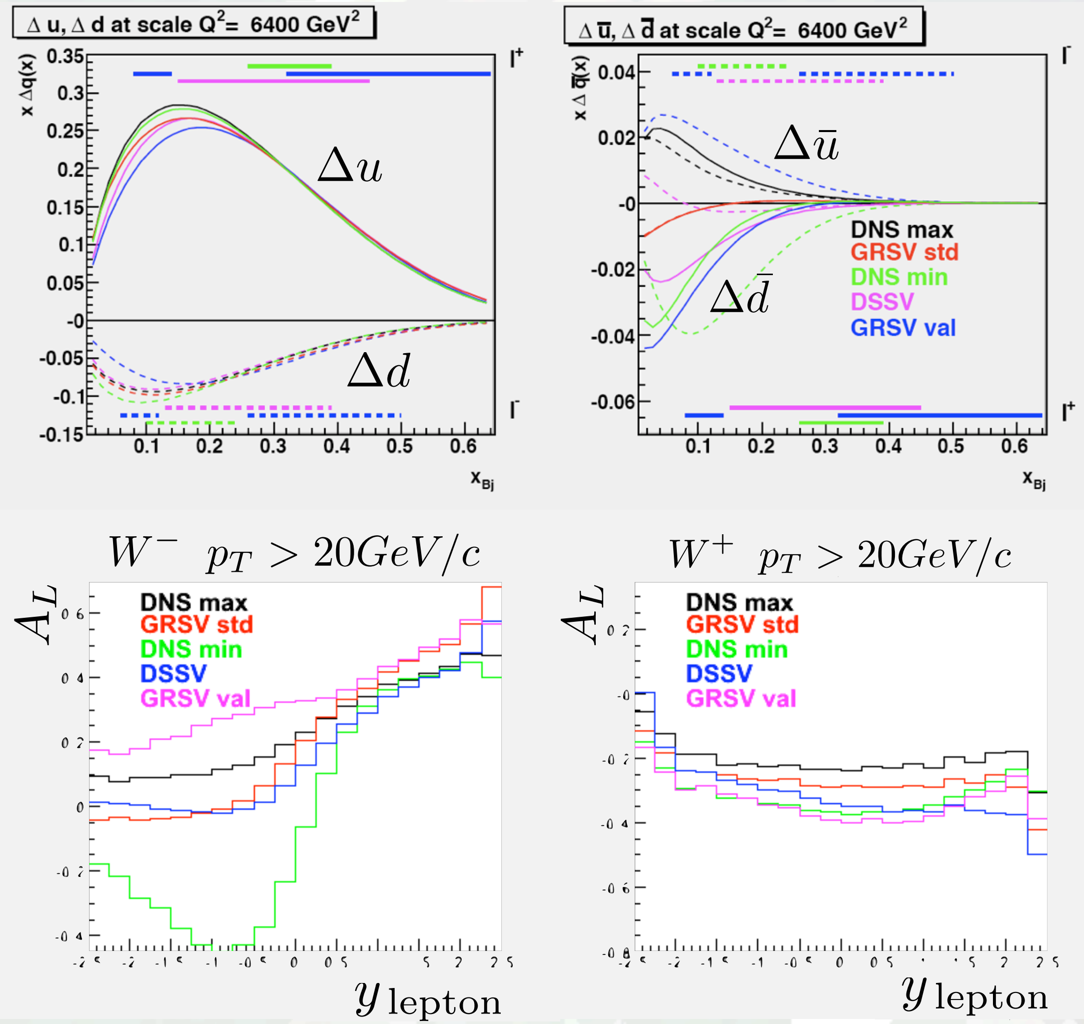
RHICBOS W simulation at 500GeV CME



- **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

Introduction

Quark / Anti-Quark Polarization - Sensitivity in W production



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

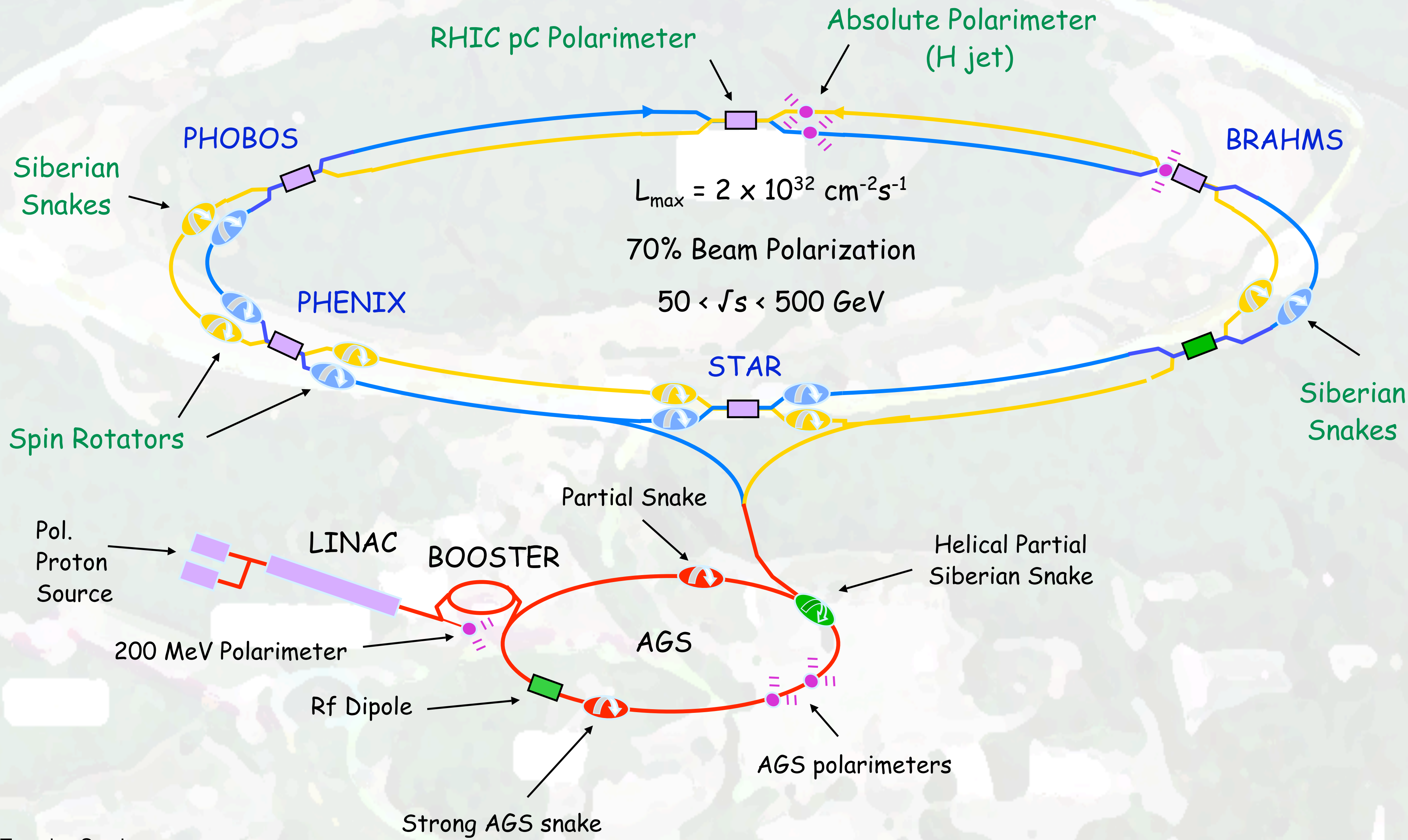
$$A_L^{W^-} = -\frac{\Delta d(x_1)\bar{u}(x_2) - \Delta\bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}$$

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

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

Collider: The First polarized p+p collider at BNL

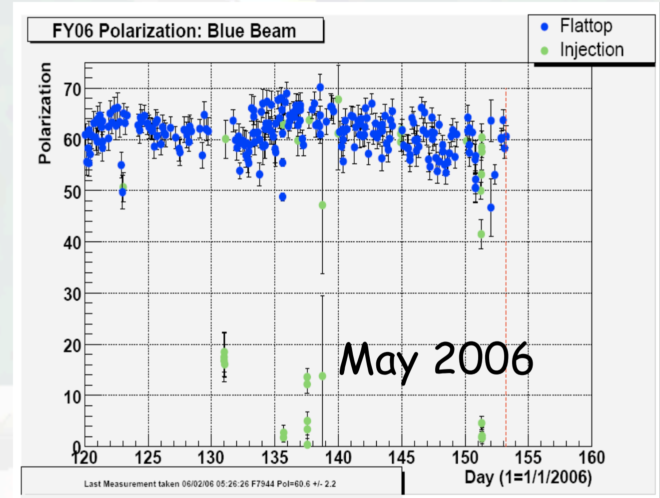
- Overview of collider complex

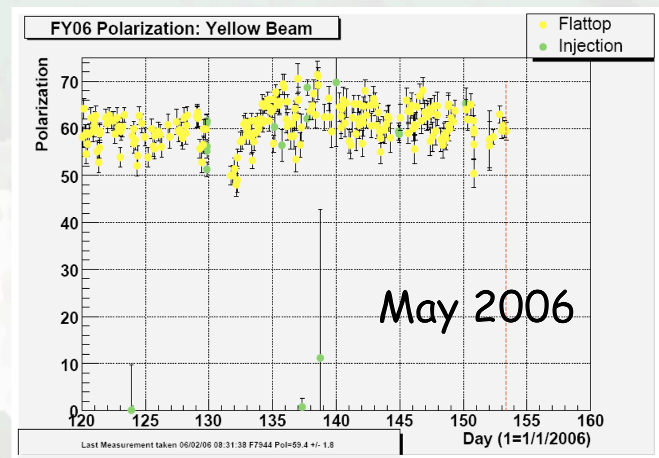


Collider: The First polarized p+p collider at BNL

- RHIC collider aspects: p-p - Performance

RHIC RUN	s [GeV]	$L_{recorded}$ [pb^{-1}] (transverse)	$L_{recorded}$ [pb^{-1}] (longitudinal)	Polarization[%]
RUN 2	200	0.15	0.3	15
RUN 3	200	0.25	0.3	30
RUN 4	200	0	0.4	45
RUN 5	200	0.4	3.1	50
RUN 6	200	3.4/6.8	8.5	60

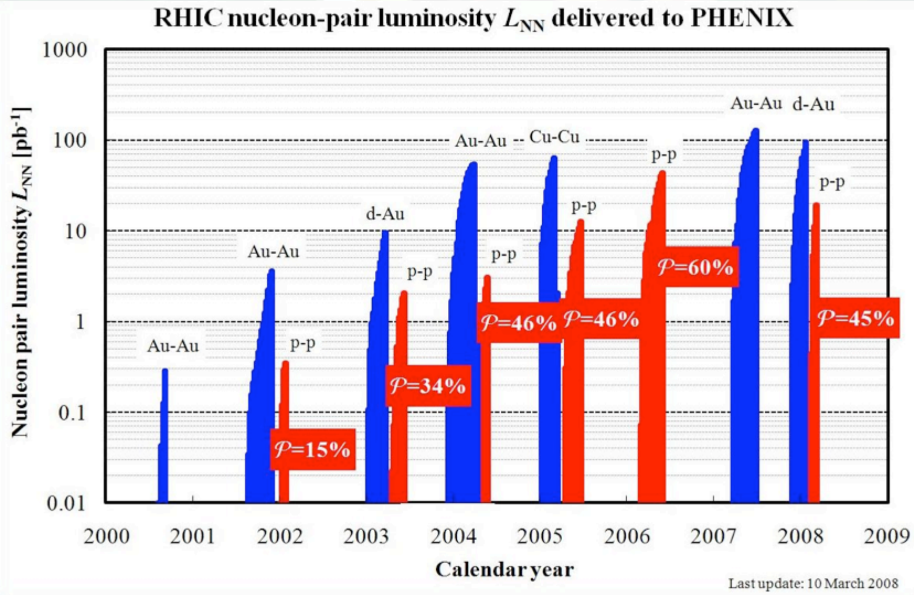


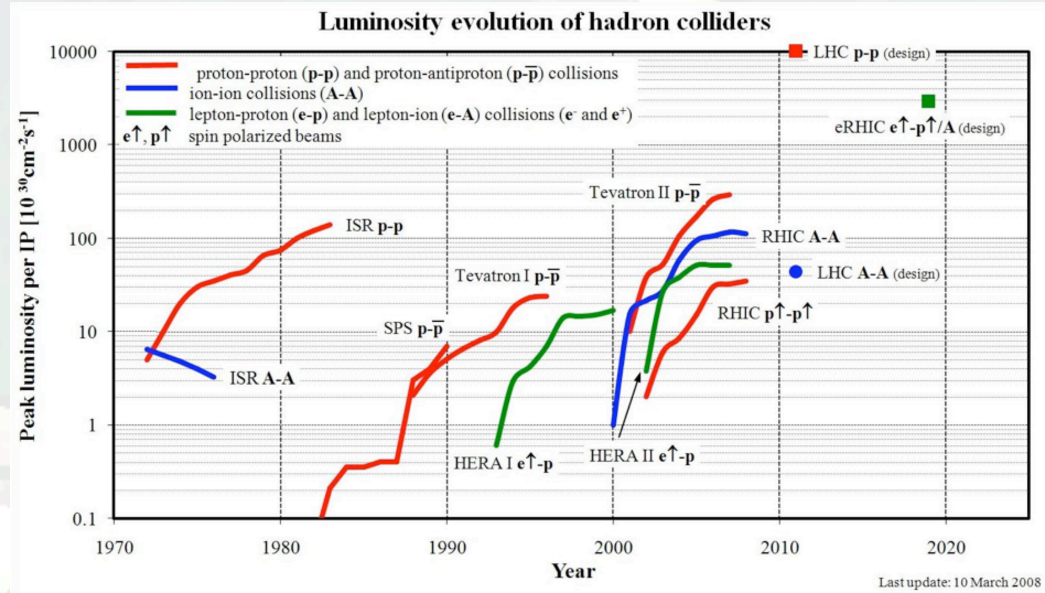


- All RHIC polarized pp accelerator components are in place!
- 2006 performance (√=200GeV): ~60% polarization (70% design) and ~1pb^{-1}/day (~3pb^{-1}/day design) delivered luminosity

Collider: The First polarized p+p collider at BNL

Performance overview - Au-Au / p-p





Nucleon-Nucleon Luminosities (peak values) (100 GeV, nucl.-pair):

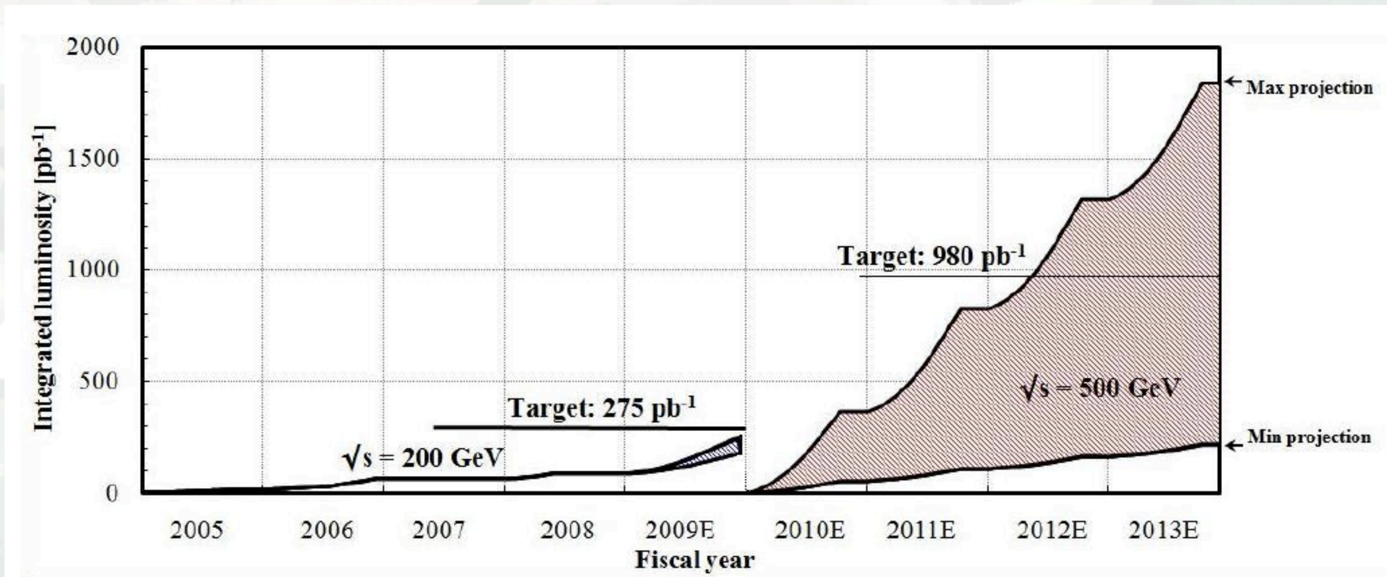
- Au–Au 120×10^{30} cm^{-2} s^{-1}
- p↑-p↑ 35×10^{30} cm^{-2} s^{-1}

Other large hadron colliders (peak values) (scaled to 100 GeV):

- Tevatron (p – pbar) 29×10^{30} cm^{-2} s^{-1}
- LHC (p – p, design) 140×10^{30} cm^{-2} s^{-1}

Collider: The First polarized p+p collider at BNL

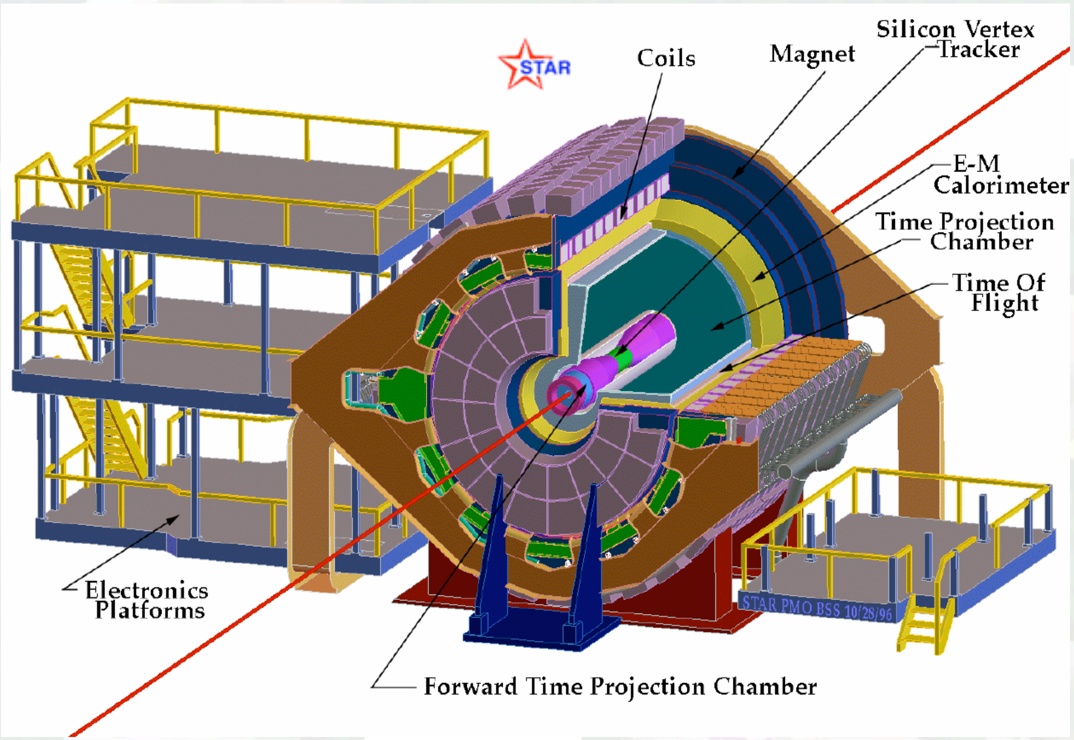
- Polarized proton-proton operation at RHIC at 200 / 500 GeV
  - During last longest polarized proton-proton run (RUN 6):
    - Luminosity: ~1pb^{-1}/day (~3pb^{-1}/day design) delivered luminosity
    - Polarization: ~60% polarization (70% design)
  - 500GeV development: Achieved 45%$^{(*)}$ beam polarization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

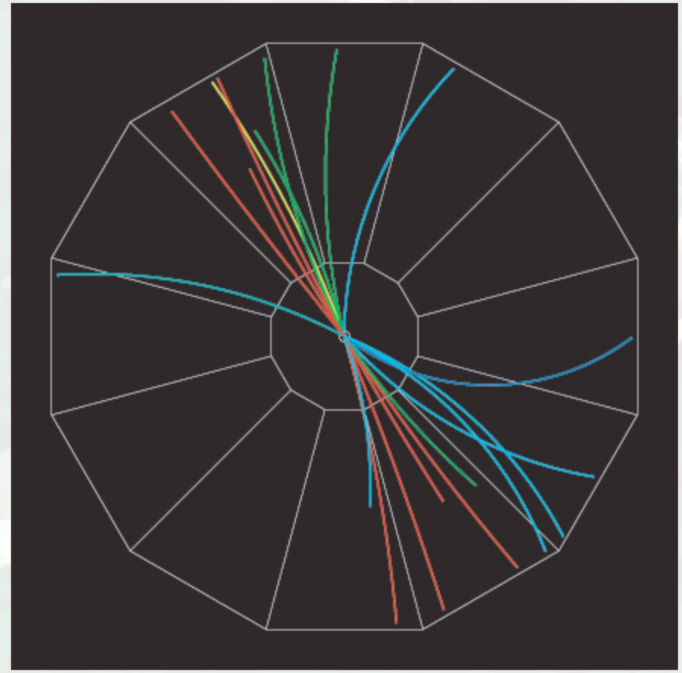


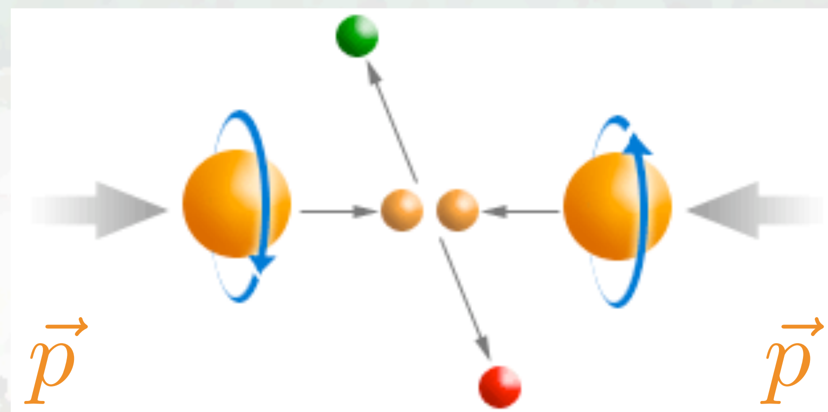
(*) Assumption: Analyzing power at 250GeV same as for 100GeV!

Experiment: The STAR detector

- Overview

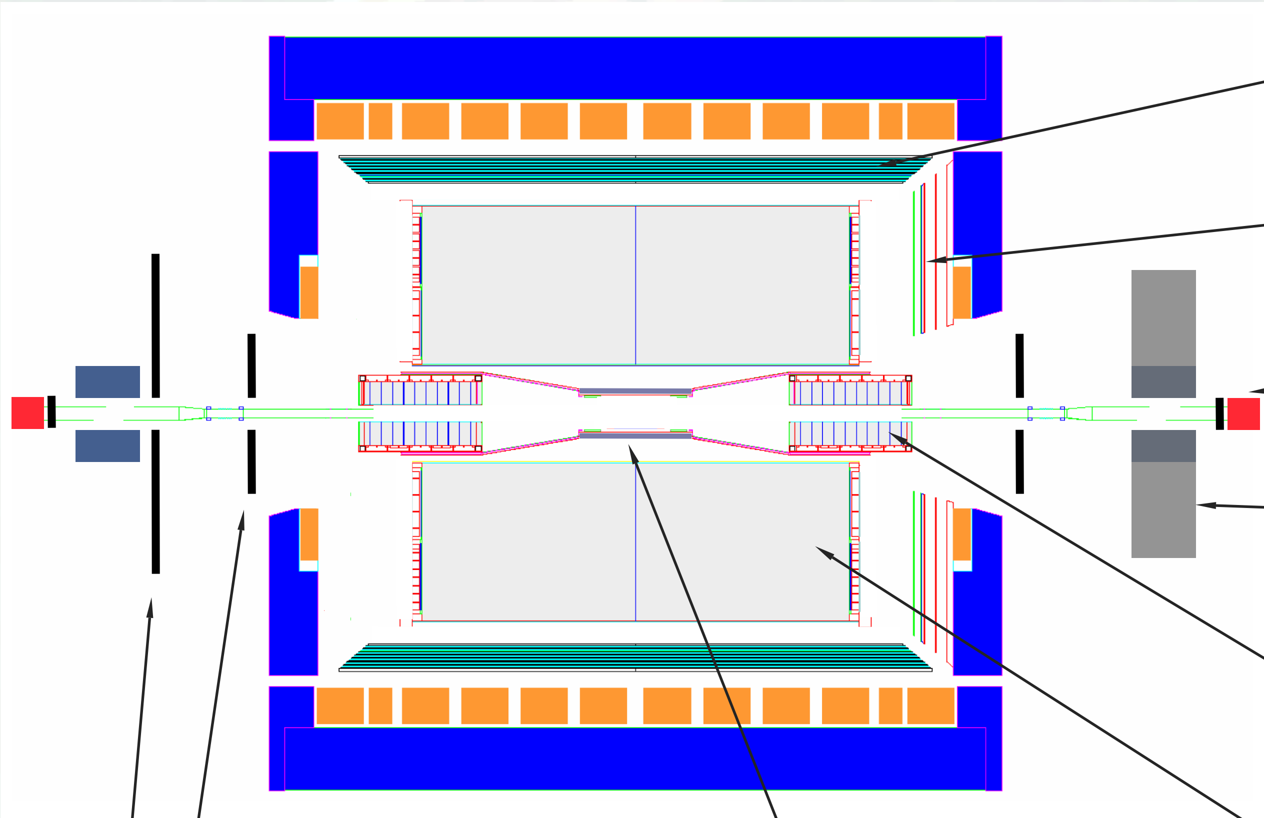






Experiment: The STAR detector

- Detector sub-systems - STAR



BEMC (Barrel Electromagnetic Calorimeter: $-1 < \eta < 1$)

EEMC (Electromagnetic Endcap Calorimeter: $1.09 < \eta < 2$)

ZDC (Zero-Degree Calorimeter)

FMS (Forward Meson Spectrometer: $2.5 < \eta < 4$)

FTPC (Forward Time Projection Chamber)

TPC (Time Projection Chamber)

BBC (Beam-Beam Counter)

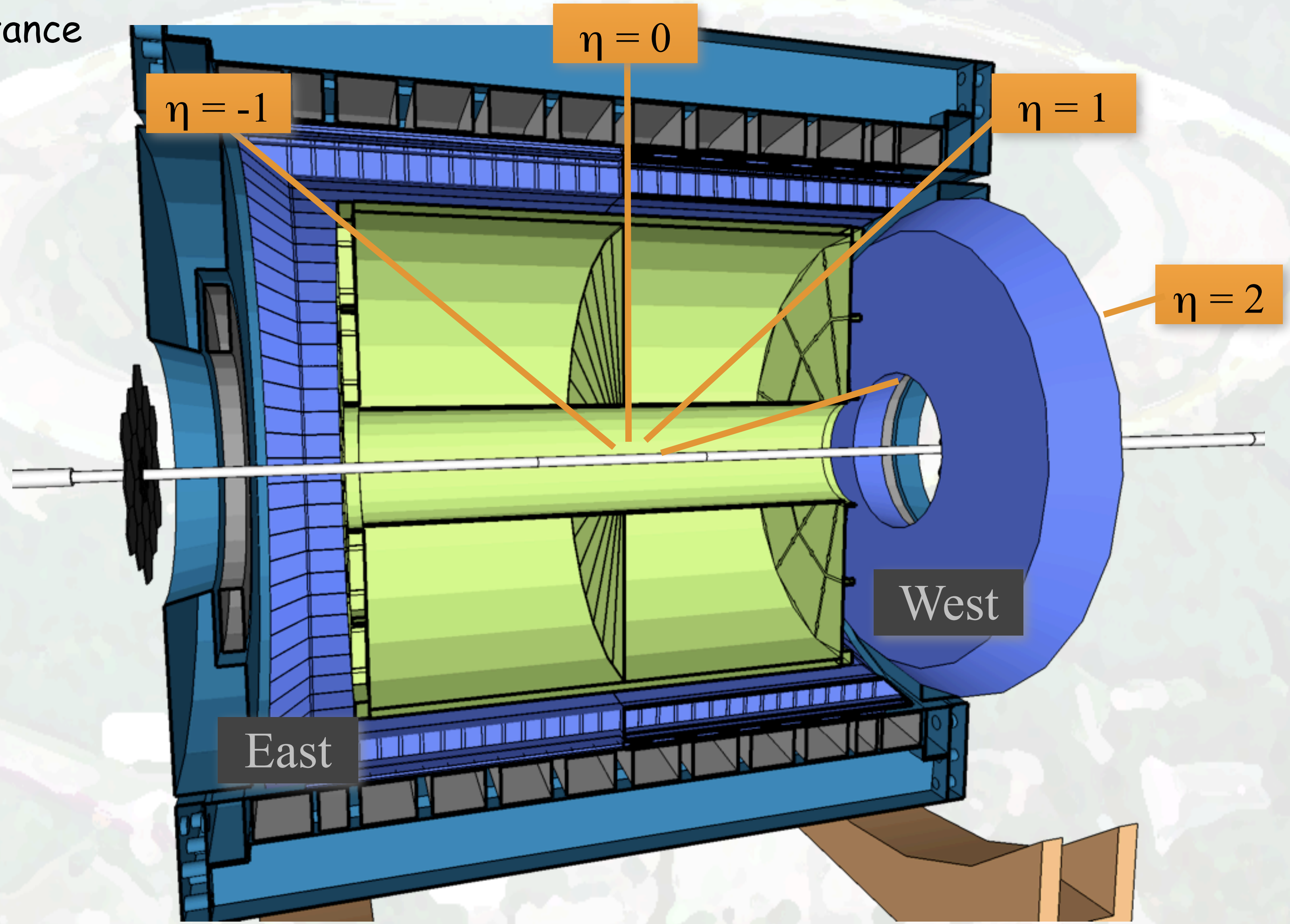
PMD (Photon Multiplicity Detector)

SVT (Silicon-Vertex Detector - removed)

SSD (Silicon-Strip Detector)

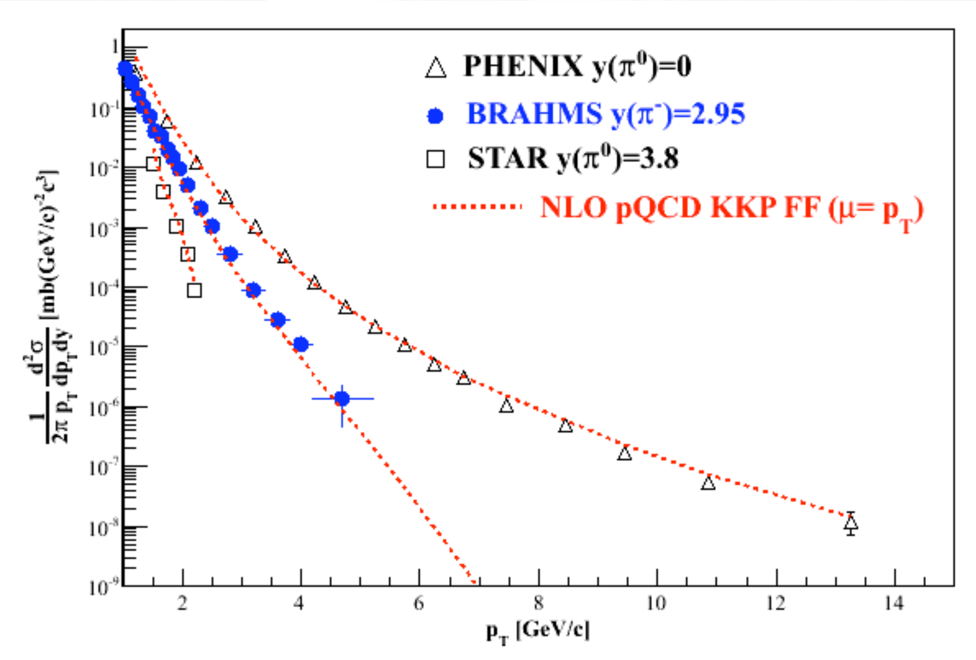
Experiment: The STAR detector

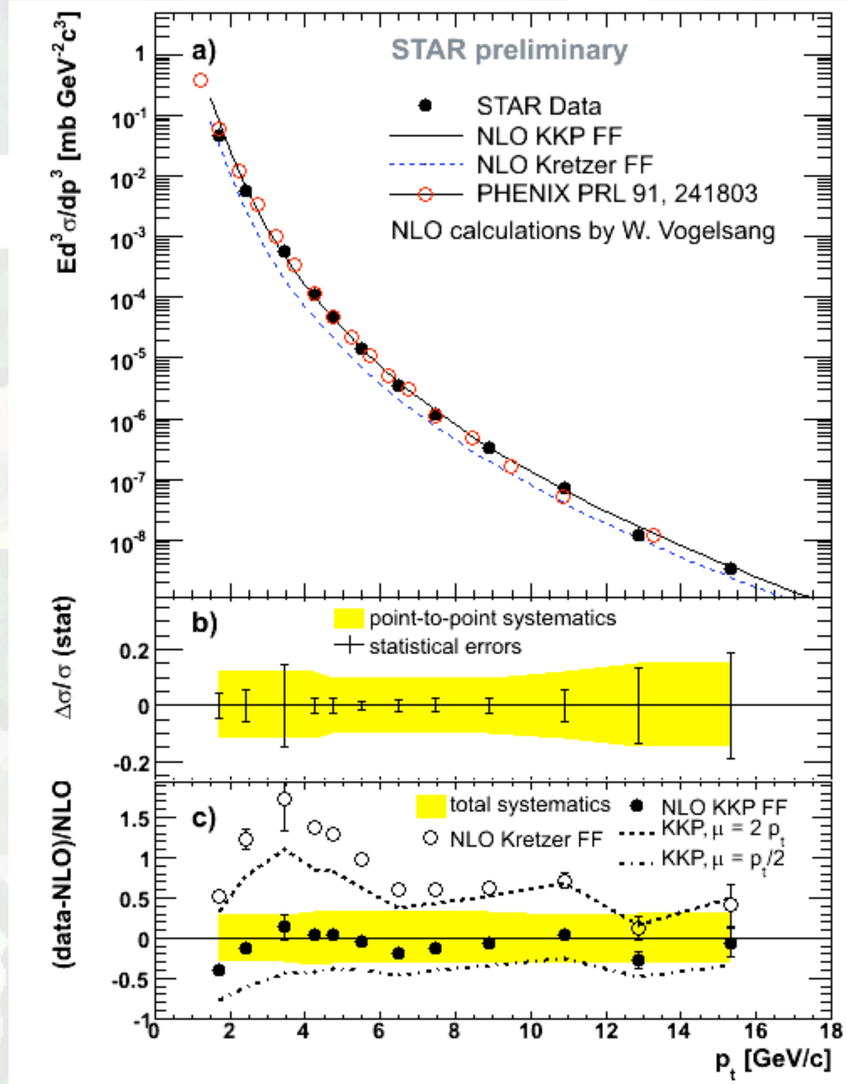
- Acceptance



Highlights of recent results and achievements

Cross Section Results

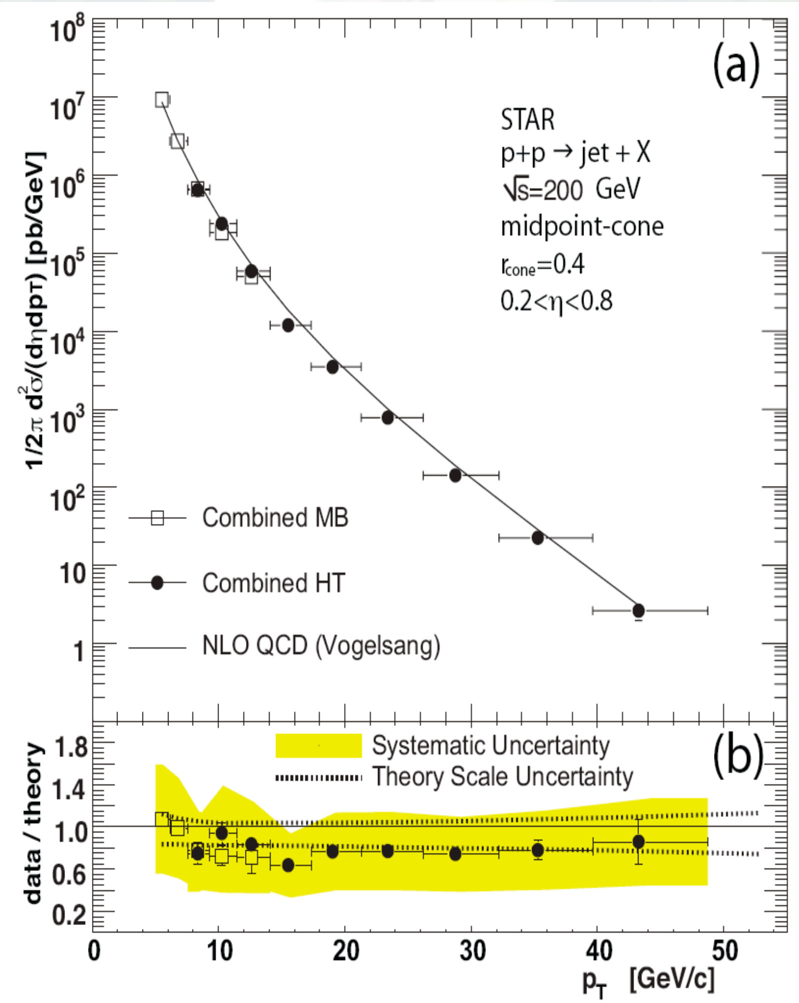


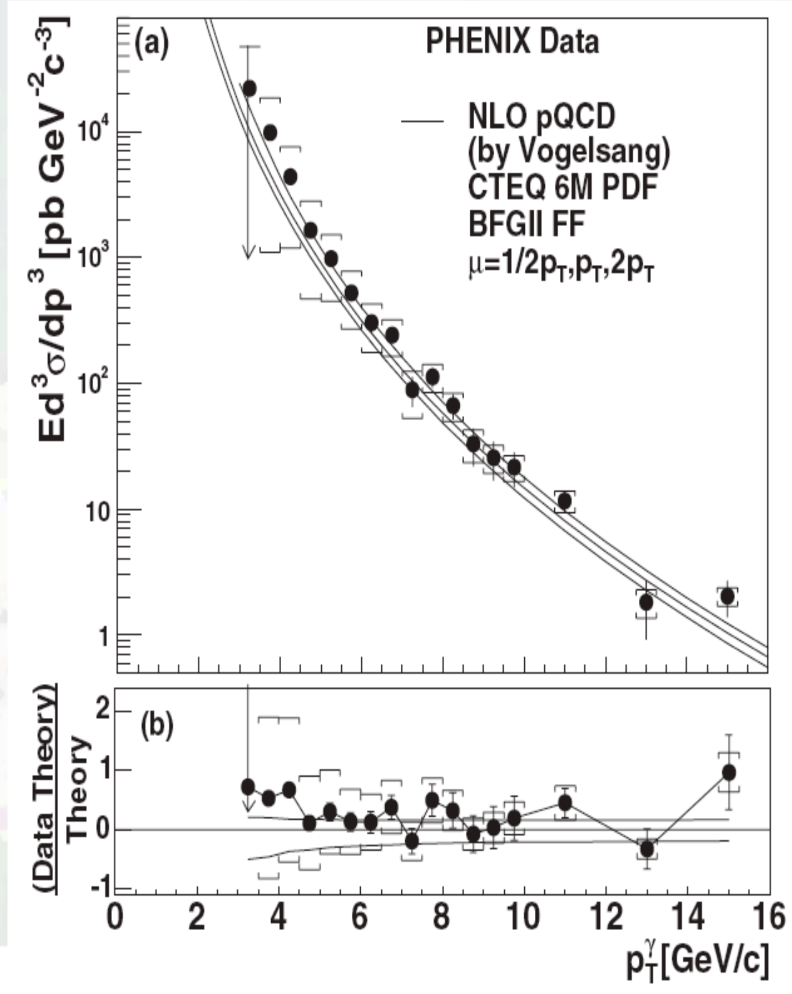


- Good agreement between data and NLO calculations for neutral pion production at forward and central rapidity

Highlights of recent results and achievements

- Cross Section Results

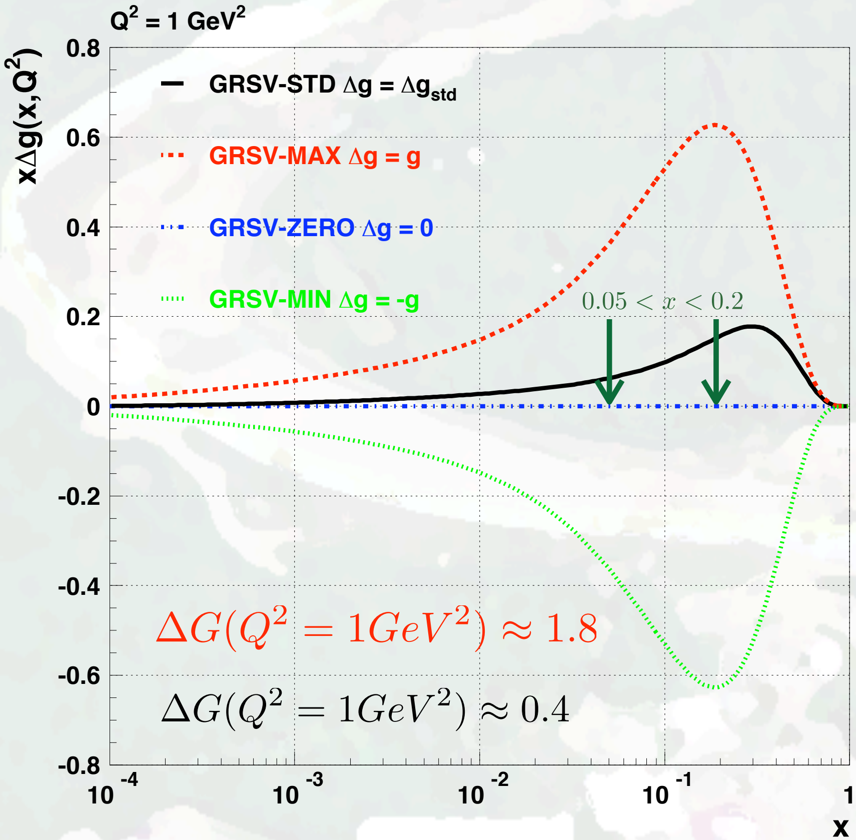


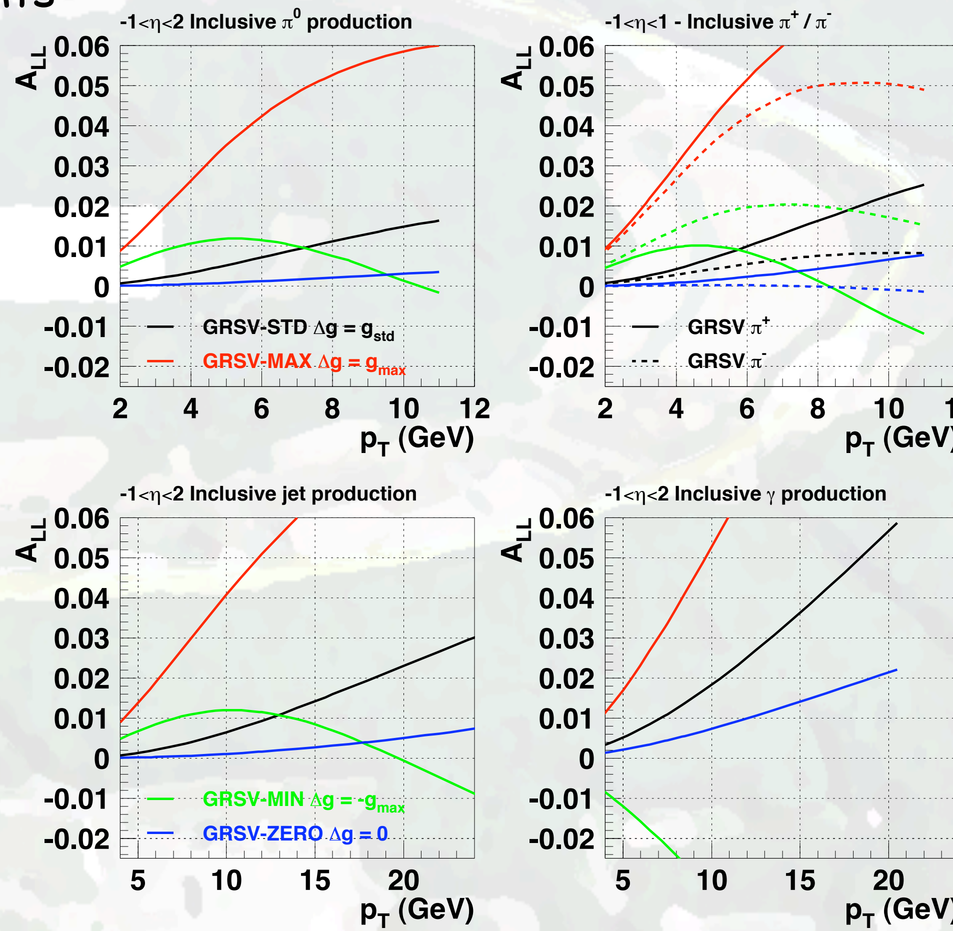


- Good agreement between data and NLO calculations for jet production and prompt photon production at central rapidity

Highlights of recent results and achievements

Gluon polarization - Inclusive Measurements





- Examine wide range in Δg: $-g < \Delta g < +g$
- GRSV-STD: Higher order QCD analysis of polarized DIS experiments!

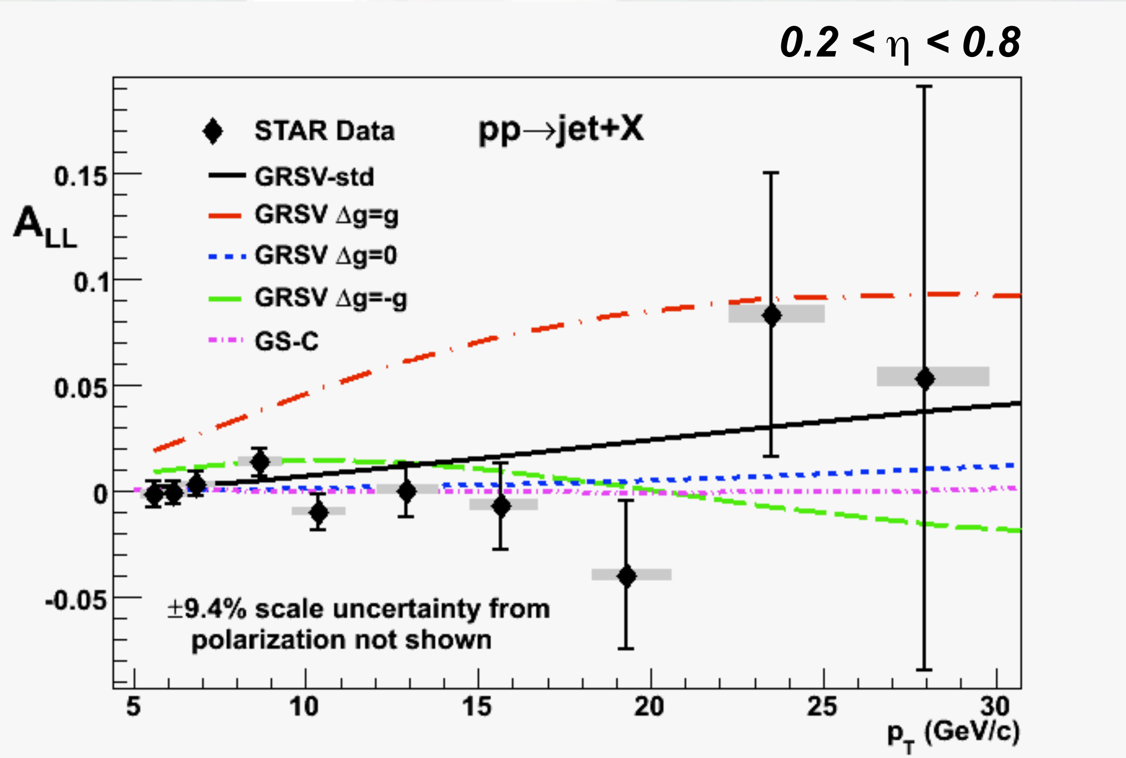
$$x_{\rm parton} \simeq 2p_T/\sqrt{s}$$

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

Publication status - Longitudinal spin results

- A_{LL} Inclusive Jet 2005 result - STAR

STAR Collaboration, PRL **100**, 232003 (2008).



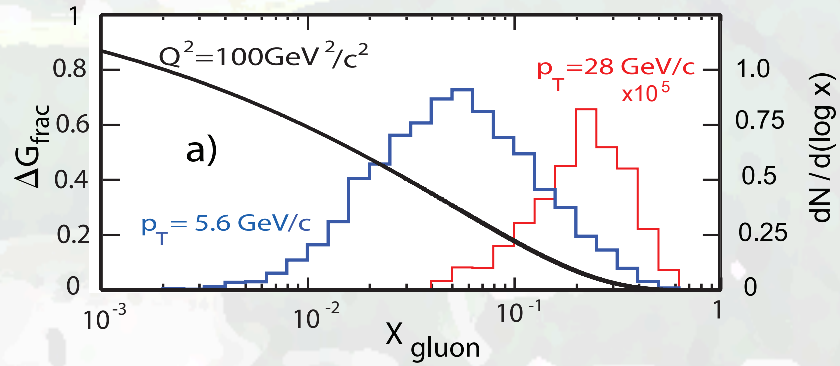
$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)dx$$

$$\Delta G(Q^2 = 1GeV^2) \approx 1.8$$

$$\Delta G(Q^2 = 1GeV^2) \approx 0.4$$

$$\Delta G(Q^2 = 1GeV^2) \approx 1.0$$

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

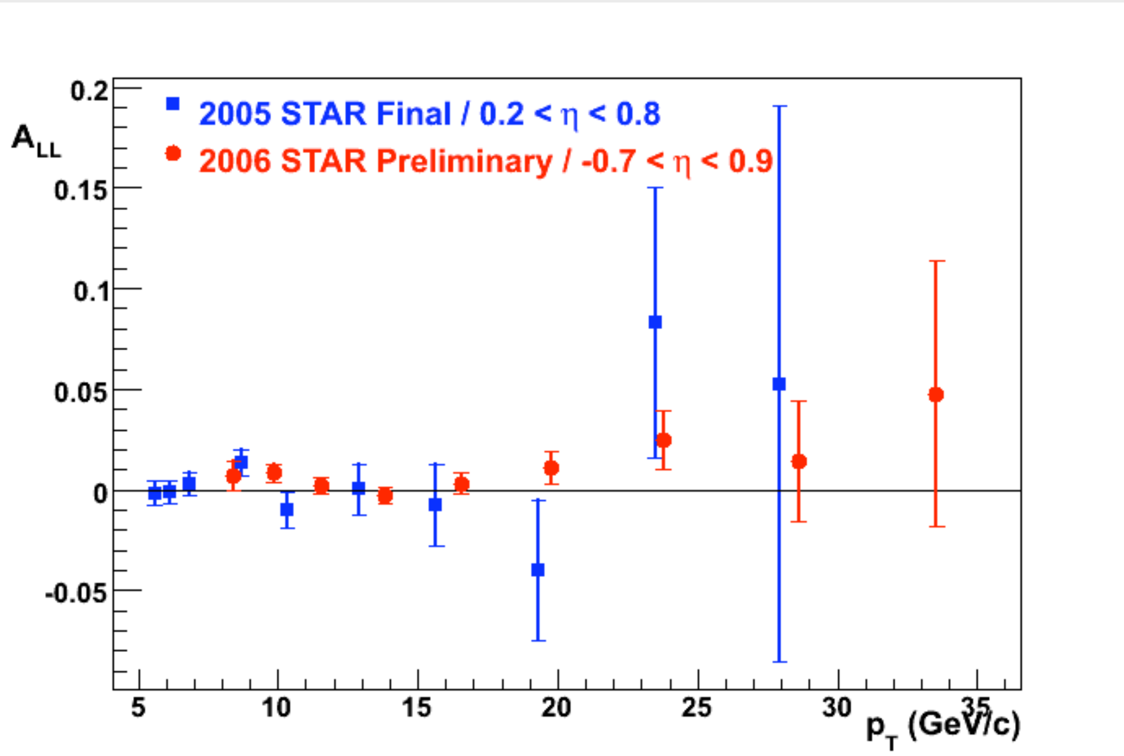


- Maximum gluon polarization scenario (GRSV-MAX) ruled out
- A_{LL} inclusive jet result (Run 5) consistent with previous Run 3/4 result

STAR Collaboration, PRL **97**, 252001 (2006).

Highlights of recent results and achievements

- A_{LL} Inclusive Jet 2006 result - STAR



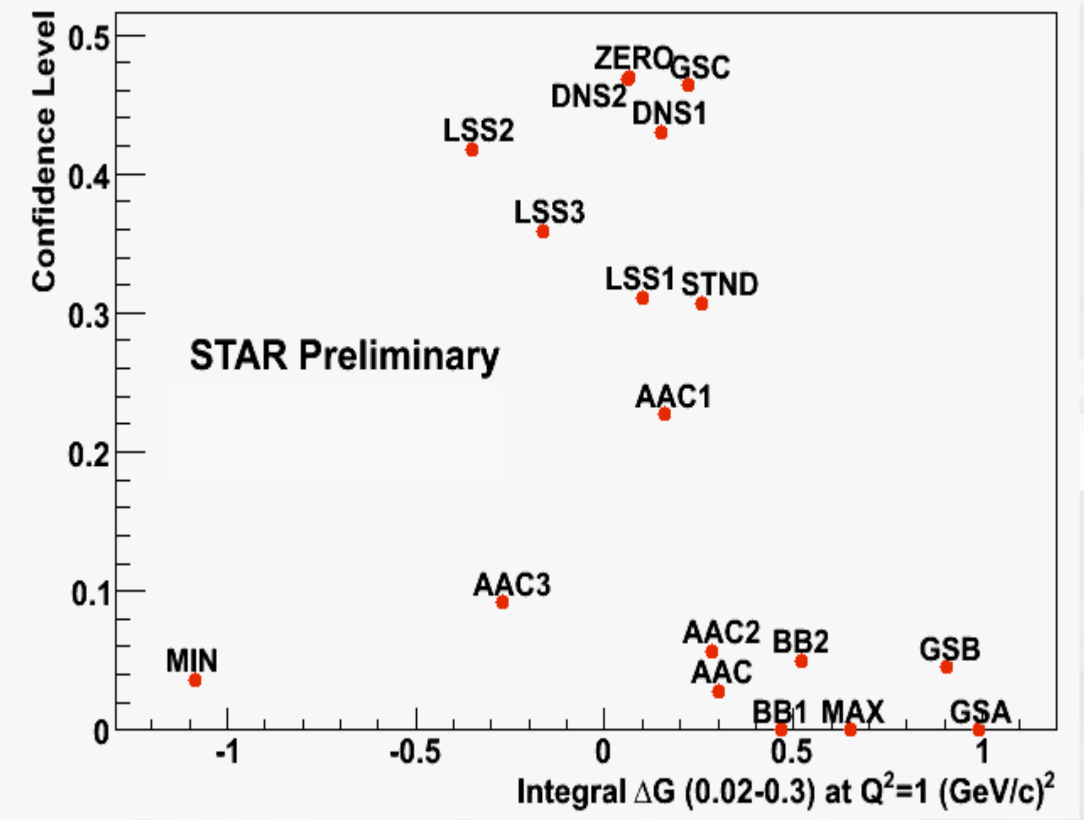
A_{LL} systematics	($\times 10^{-3}$)
Reconstruction + Trigger Bias	[-1,+3] (p_T dep)
Non-longitudinal Polarization	~ 0.03 (p_T dep)
Relative Luminosity	0.94
Backgrounds	1st bin ~ 0.5 else ~ 0.1

p_T systematic	± 6.7%

- 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

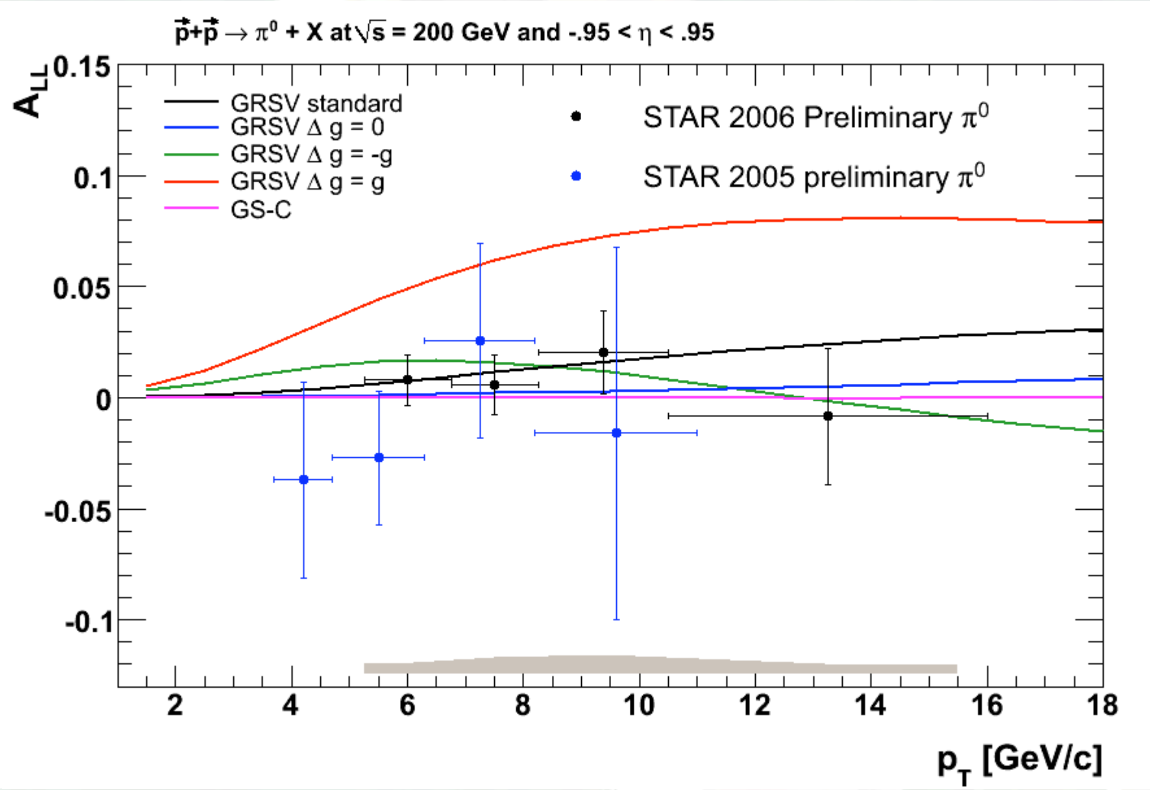
- Quantify theory comparison of measured A_{LL} for 2006 inclusive jet result



- The STAR data exclude a broad range of global fit results that have a larger first moment (ΔG) than that in GRSV-STD
- Counterexample is GS-C: Large and positive at low x and negative at high x (Note at x ~ 0.1)

Results: Gluon Spin contribution

- A_{LL} neutral pion 2005/2006 result - STAR



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

$$\Delta G(Q^2 = 1GeV^2) \approx 1.8$$

$$\Delta G(Q^2 = 1GeV^2) \approx 0.4$$

$$\Delta G(Q^2 = 1GeV^2) \approx 1.0$$

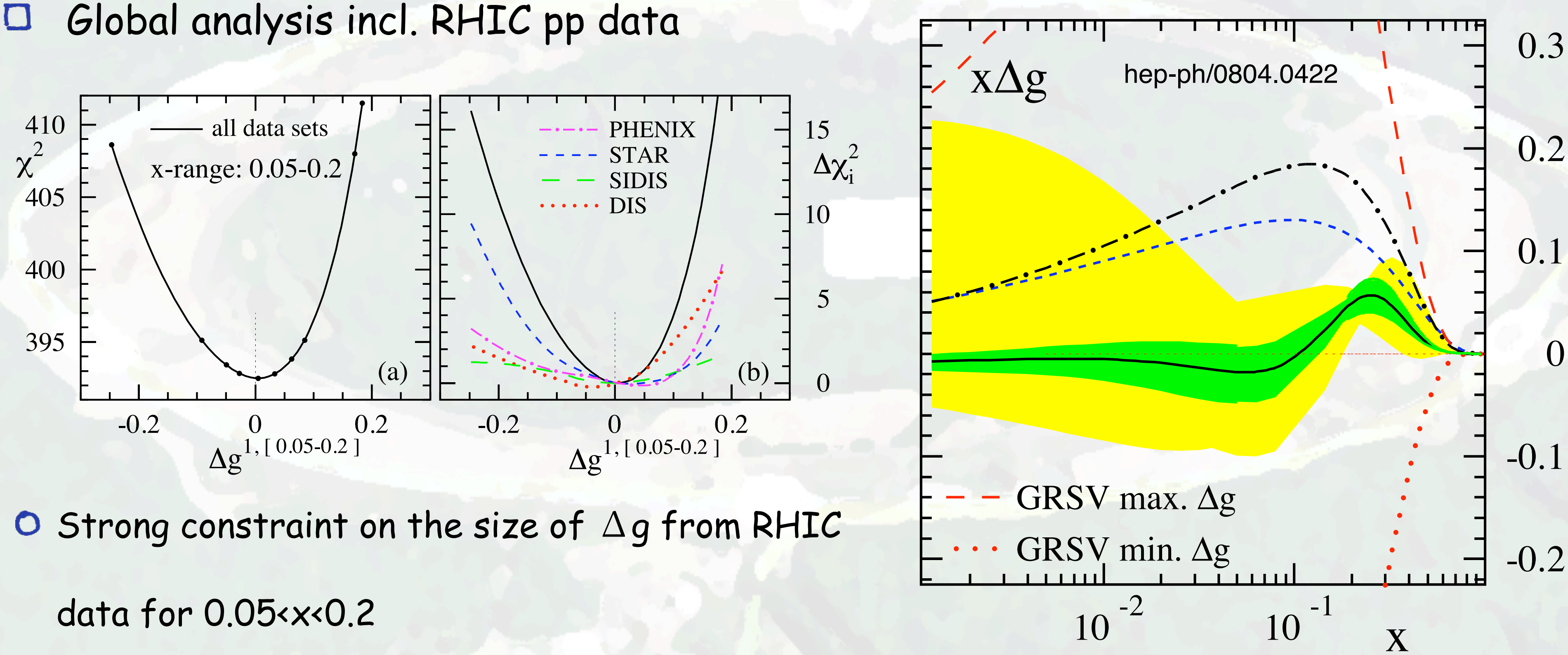
χ^2/ndf for NLO Models:

GRSV Std:	0.3
GRSV Max:	11.4
GRSV Min:	0.3
GRSV Zero:	0.4
GS-C:	0.5

- RUN 6 results: GRSV-MAX ruled out
- Significant increase in statistical precision as well as greater p_T reach compared to previous Run 5 Neutral Pion result

Highlights of recent results and achievements

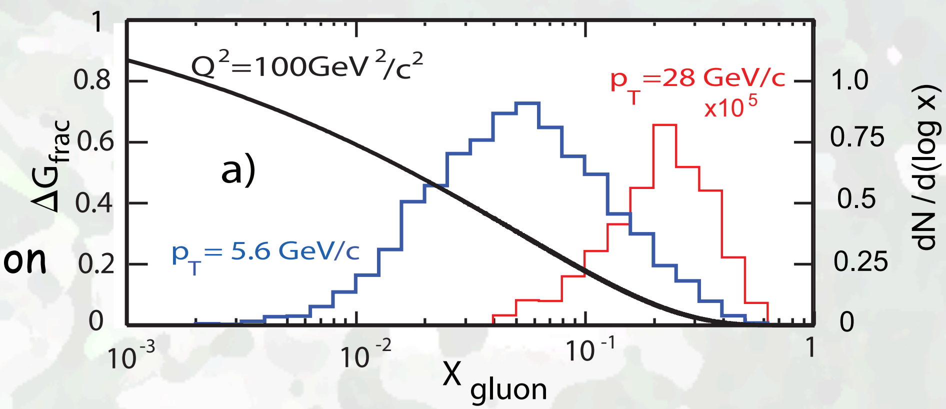
- Global analysis incl. RHIC pp data



- Strong constraint on the size of Δg from RHIC data for $0.05<x<0.2$

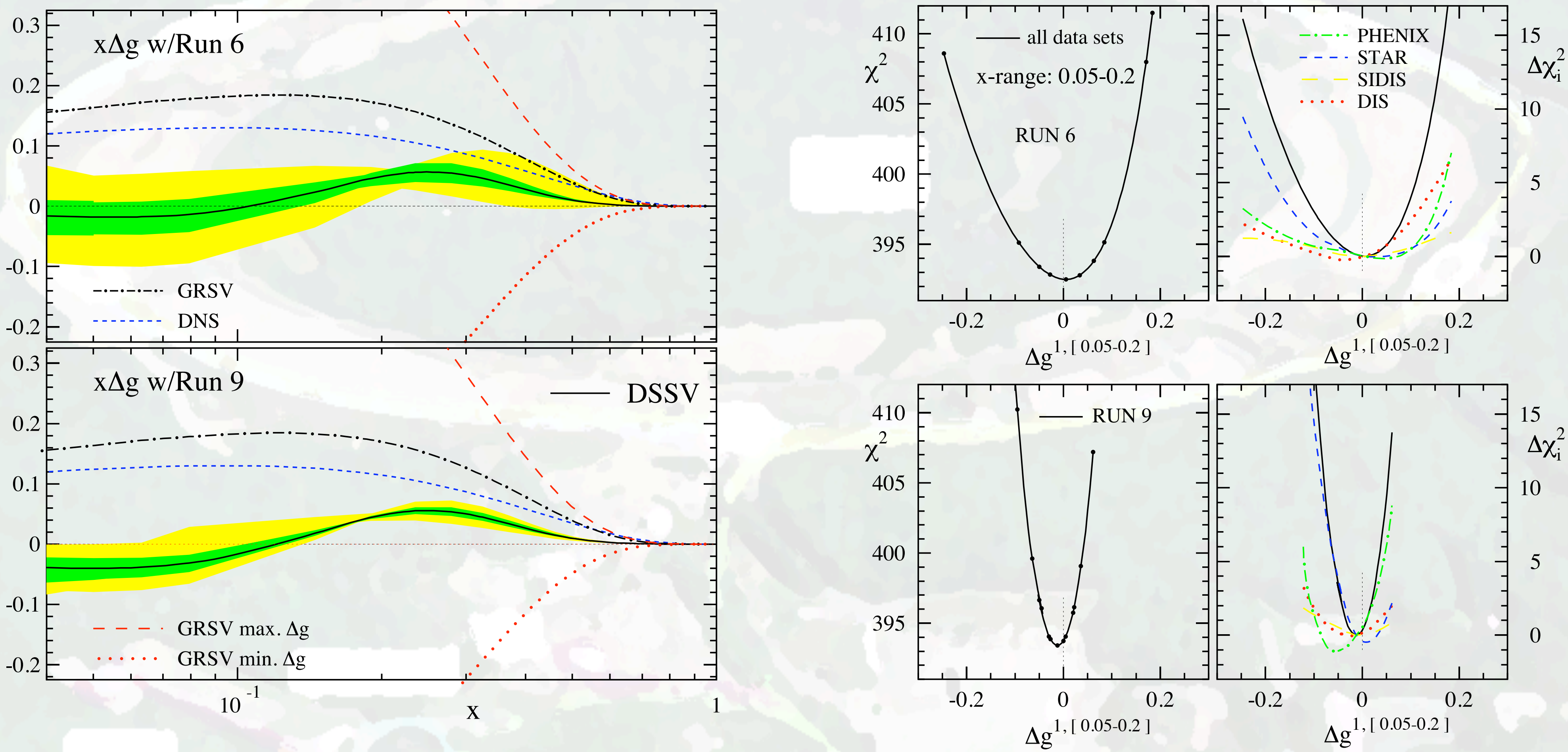
- Evidence for a small gluon polarization over a limited region of momentum fraction

- Important: Mapping x-dependence and extension of x-coverage needed!



Future polarized p-p physics program

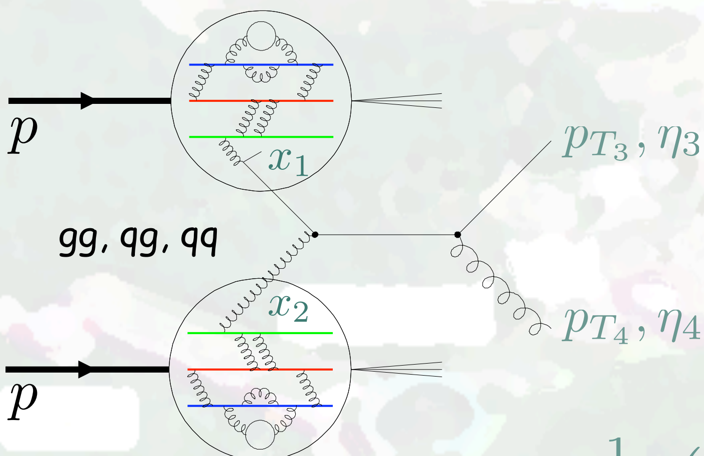
Gluon polarization - Projection Run 9

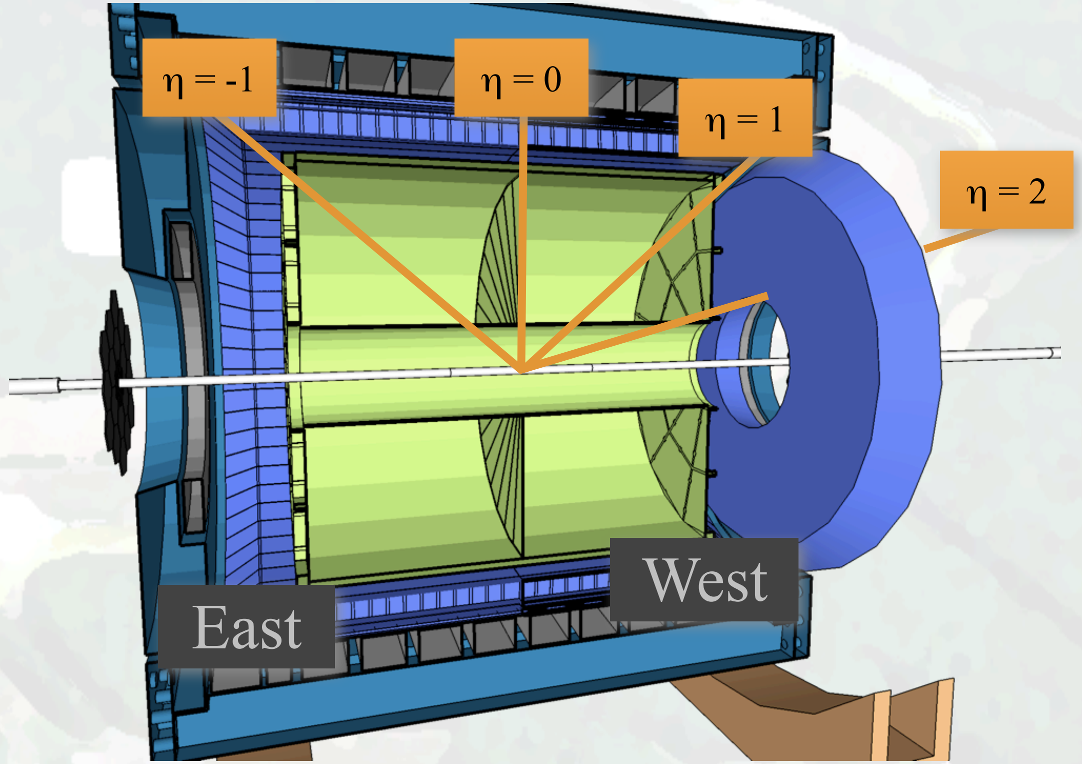


- Substantial improvement on gluon polarization from inclusive measurements
- Complementary information from STAR and PHENIX

Future polarized p-p physics program

- Gluon polarization - Correlation Measurements
  - Correlation measurements provide access to partonic kinematics through Di-Jet/Hadron production and Photon-Jet production
  - 2-2 processes:





$$x_{1\,(2)} = \frac{1}{\sqrt{s}} \left(p_{T_3} e^{\eta_3 (-\eta_3)} + p_{T_4} e^{\eta_4 (-\eta_4)} \right)$$

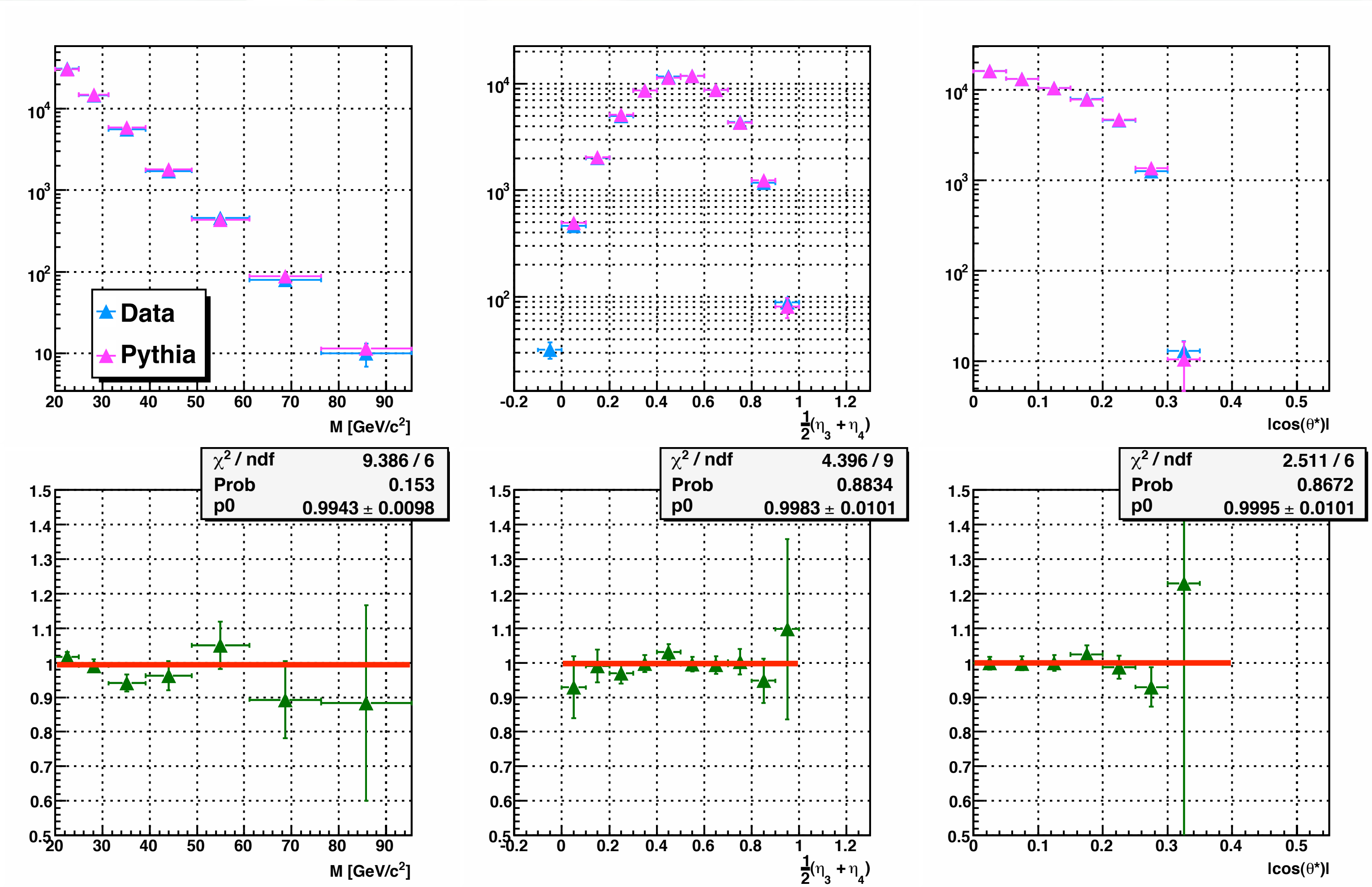
$$M = \sqrt{x_1 x_2 s}$$

$$\eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$

$$\cos\theta^* = \tanh\left(\frac{\eta_3 - \eta_4}{2}\right)$$

Future polarized p-p physics program

- Correlation measurements: Di-Jet production - Data Understanding



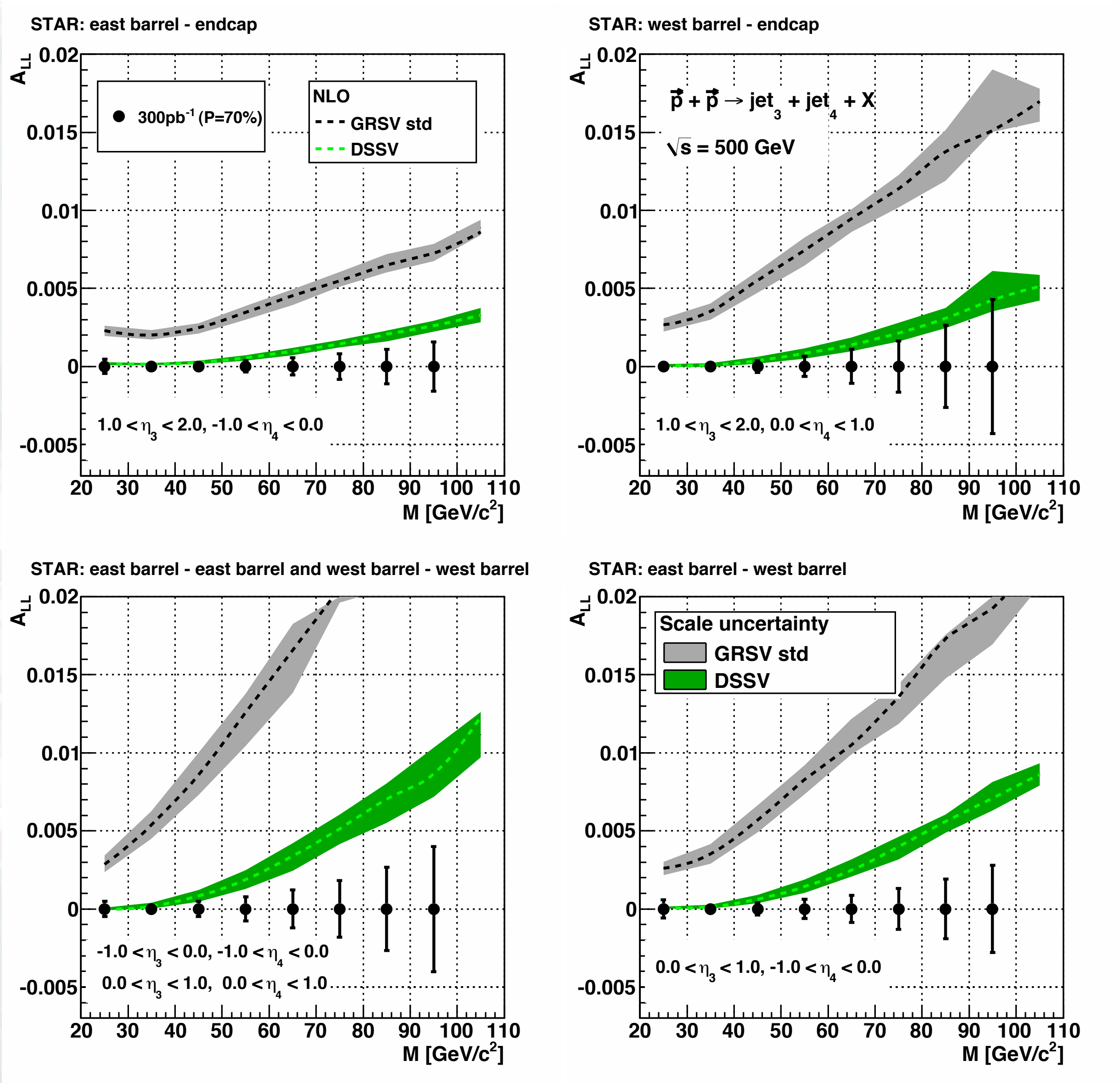
- Data/MC comparison complete - Good agreement in Di-Jet variables
- First cross-section and A_{LL} measurement in progress

$$M = \sqrt{x_1 x_2 s} \qquad \eta_3 + \eta_4 = \ln\frac{x_1}{x_2} \qquad \cos\theta^* = \tanh\left(\frac{\eta_3 - \eta_4}{2}\right)$$

Future polarized p-p physics program

- Gluon polarization - Di-Jets
  - Substantial improvement in Run 9 from Di-Jet production
  - Good agreement between LO MC evaluation and full NLO calculations

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



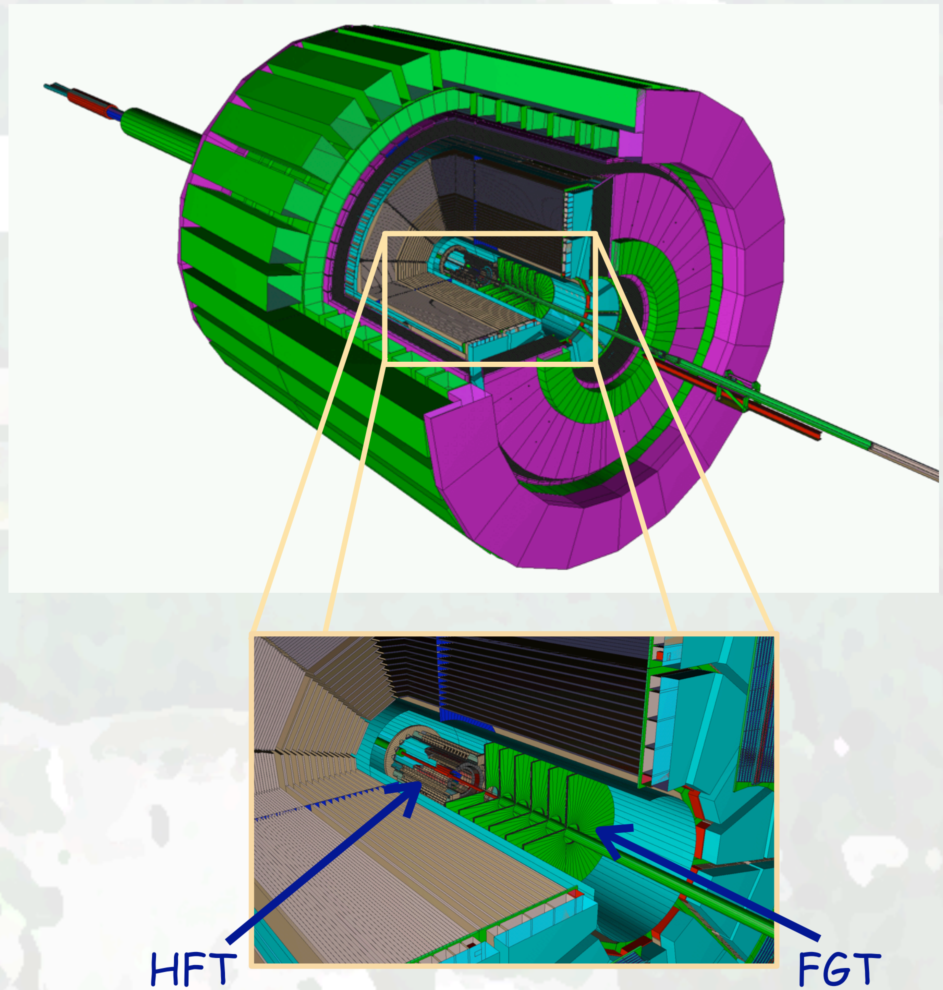
Future polarized p-p physics program

- Quark / Anti-Quark polarization program at STAR

Forward GEM Tracker: FGT

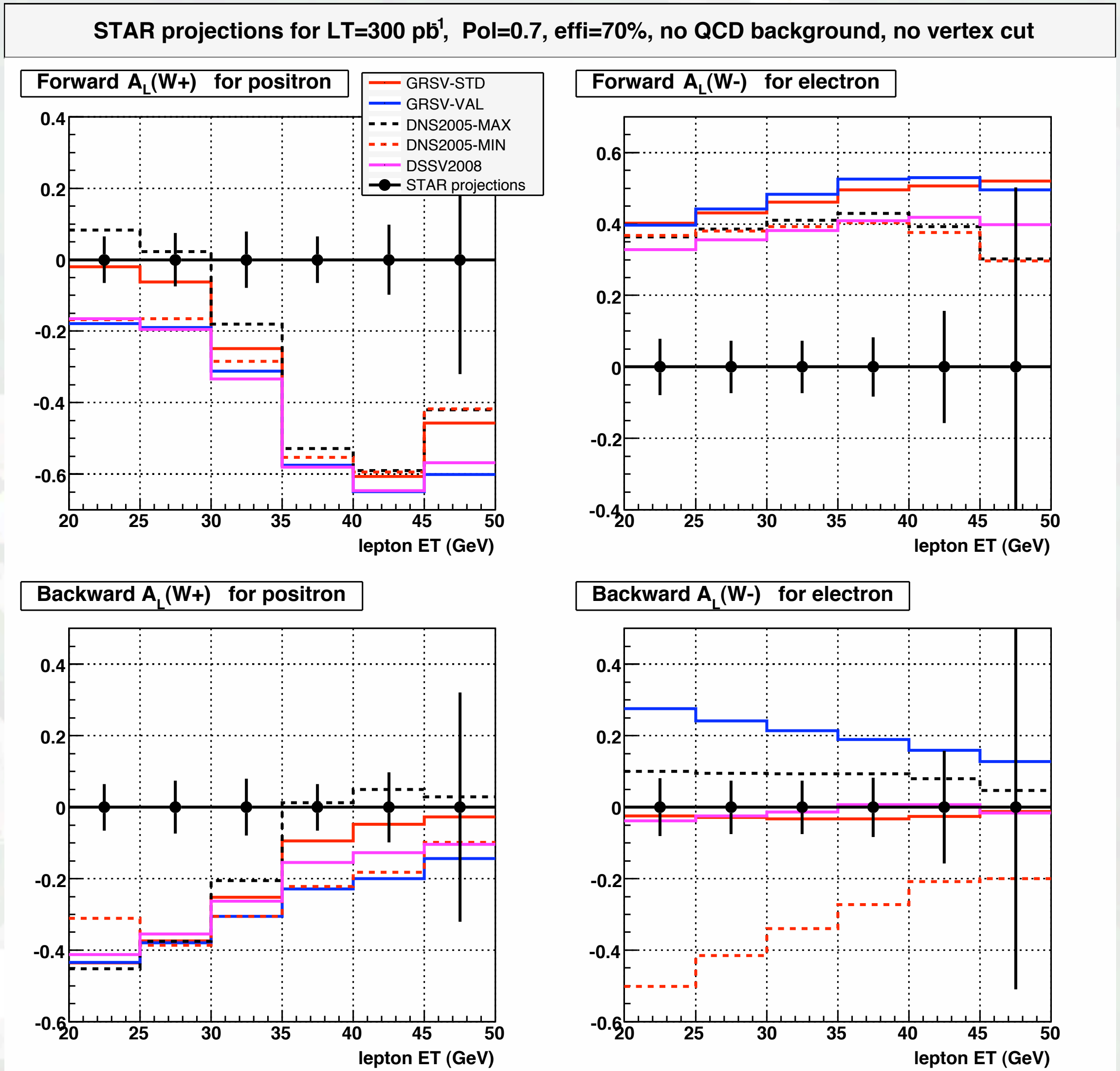
- Charge sign identification for high momentum electrons from $W^{\pm}$ decay (Energy determined with EEMC)
- Triple-GEM technology
- FGT project:

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



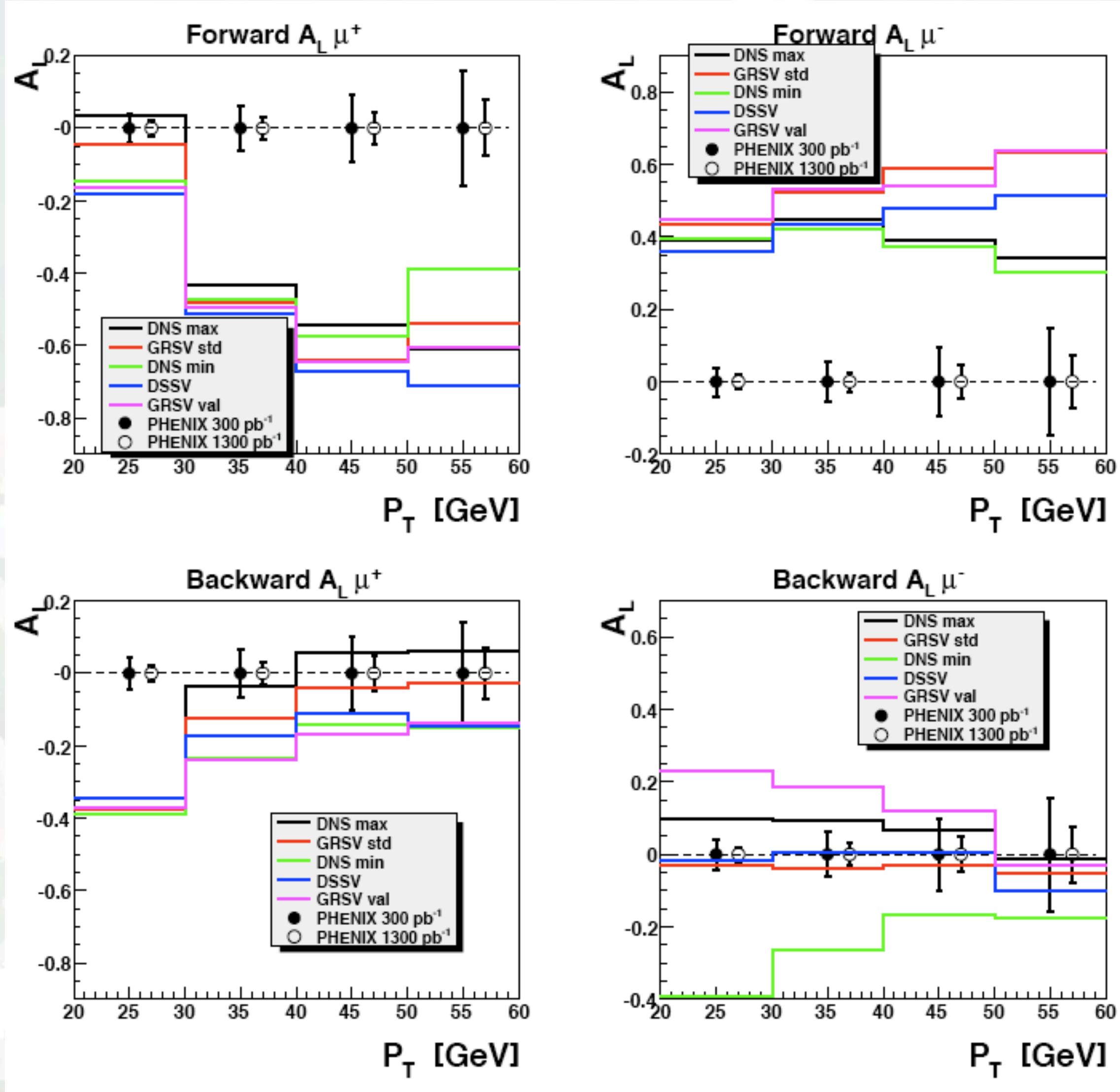
Future polarized p-p physics program

- Quark / Anti-Quark polarization program at STAR (Forward rapidity)
  - Large asymmetries dominated by quark polarization - Important consistency check to existing DIS data with 100pb^{-1} (Phase I)
  - Strong impact constraining unknown antiquark polarization requires luminosity sample at the level of 300pb^{-1} for 70% beam polarization (Phase II)



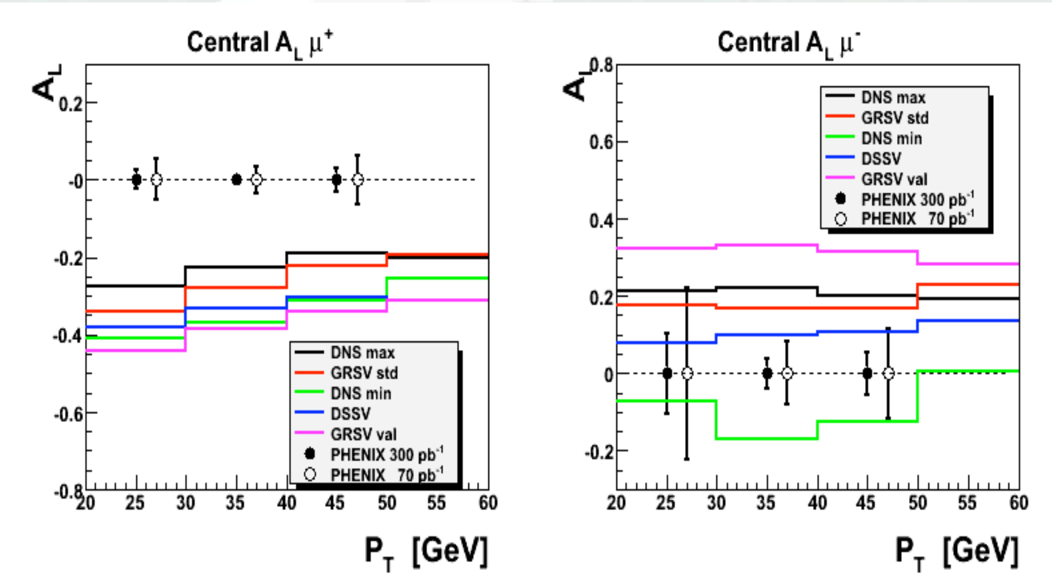
Future polarized p-p physics program

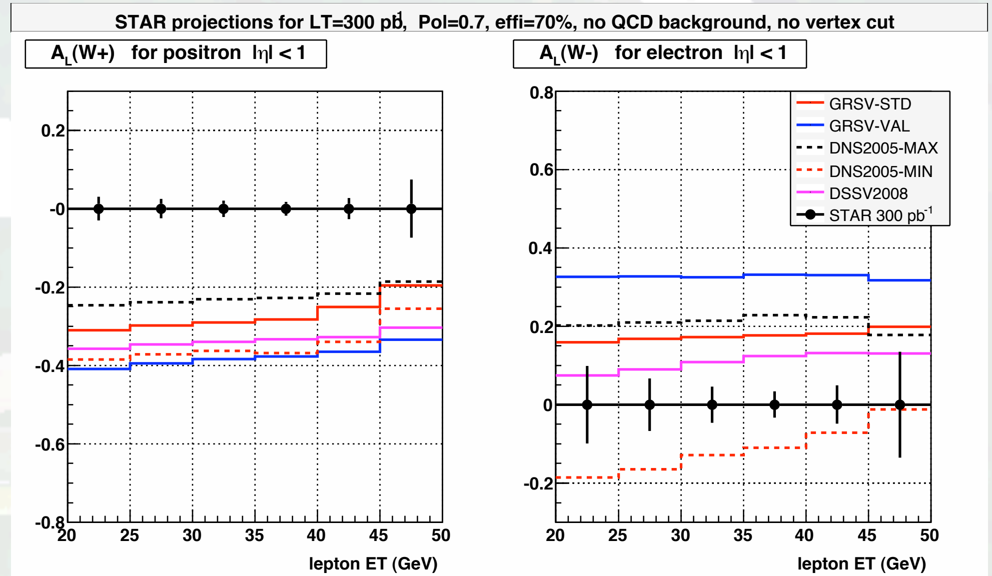
- Quark / Anti-Quark polarization program at PHENIX (Forward rapidity)
  - Large asymmetries dominated by quark polarization - Important consistency check to existing DIS data with 100pb^{-1} (Phase I)
  - Strong impact constraining unknown antiquark polarization requires luminosity sample at the level of 300pb^{-1} for 70% beam polarization (Phase II)



Future polarized p-p physics program

- Quark / Anti-Quark polarization program at PHENIX / STAR (Mid-rapidity)

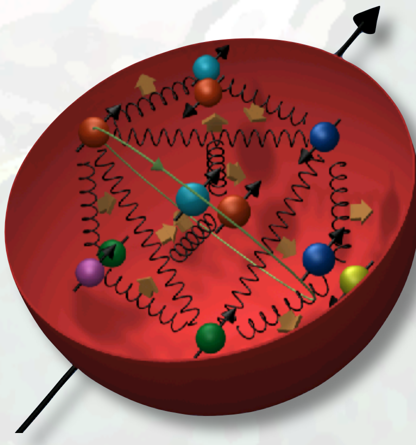




- Preliminary projections at mid-rapidity (No QCD background effects included)
- Important constraint on anti-u and in particular anti-d distribution functions at mid-rapidity!

Summary and Outlook

- Summary - RHIC-SPIN
  - Successful polarized proton collisions at high energies at RHIC at Brookhaven National Laboratory
  - QCD: Critical role to interpret measured asymmetries - First global analysis
  - Strong constraint on the size of Δg from RHIC data for $0.05 < x < 0.2$
  - Evidence for a small gluon polarization over a limited region of momentum fraction ($0.05 < x < 0.2$)
  - Important: Mapping x-dependence and extension of x-coverage needed - Critical to reduce large uncertainties on first moment of Δg
  - Next critical step: Improved precision and Measurements to constrain shape of Δg (Di-Jet production and Photon-Jet production)



Summary and Outlook

- Outlook - RHIC SPIN
  - Three key elements:
    - Gluon polarization
    - Quark / Anti-Quark Polarization
    - Transverse spin dynamics
  - Critical:

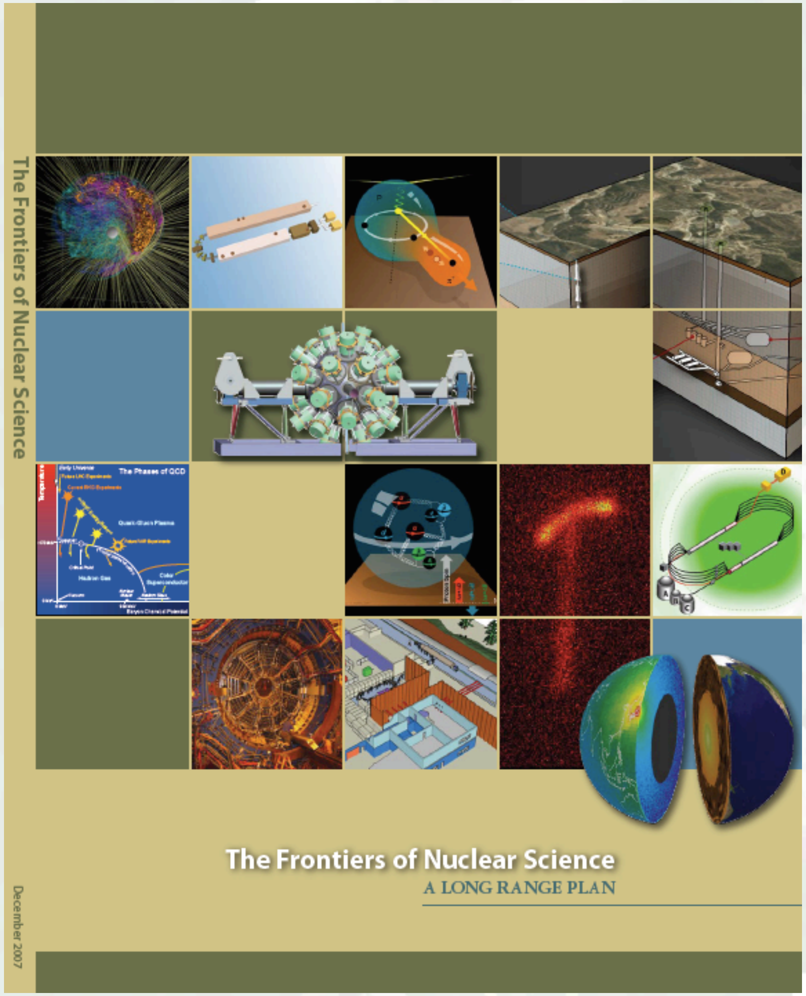
Recorded Luminosity	Main physics Objective	Remarks
~50pb^{-1}	Gluon polarization using di-jets and precision inclusive measurements	200 GeV
~100pb^{-1}	W production (Important consistency check to DIS results - Phase I) Gluon polarization (Di-Jets / Photon-Jets)	500 GeV
~300pb^{-1}	W production (Constrain antiquark polarization - Phase II) Gluon polarization (Di-Jets / Photon-Jets)	500 GeV
~30pb^{-1}	Transverse spin gamma-jet	200 GeV
~250pb^{-1}	Transverse spin Drell-Yan (Long term)	200 GeV

- Beam polarization: 70% / Narrow vertex region / Spin flipper for high precision asymmetry measurements
- Critical: Sufficient running time!

http://spin.riken.bnl.gov/rsc/

Summary and Outlook

- NSAC recommendations 2007 - QCD physics at RHIC



NSAC Recommendation (2007): RHIC II

The experiments at the Relativistic Heavy Ion Collider have discovered a new state of matter at extreme temperature and density - a quark-gluon plasma that exhibits unexpected, almost perfect liquid dynamical behavior. We recommend implementation of the RHIC II luminosity upgrade, together with detector improvements, to determine the properties of this new state of matter.

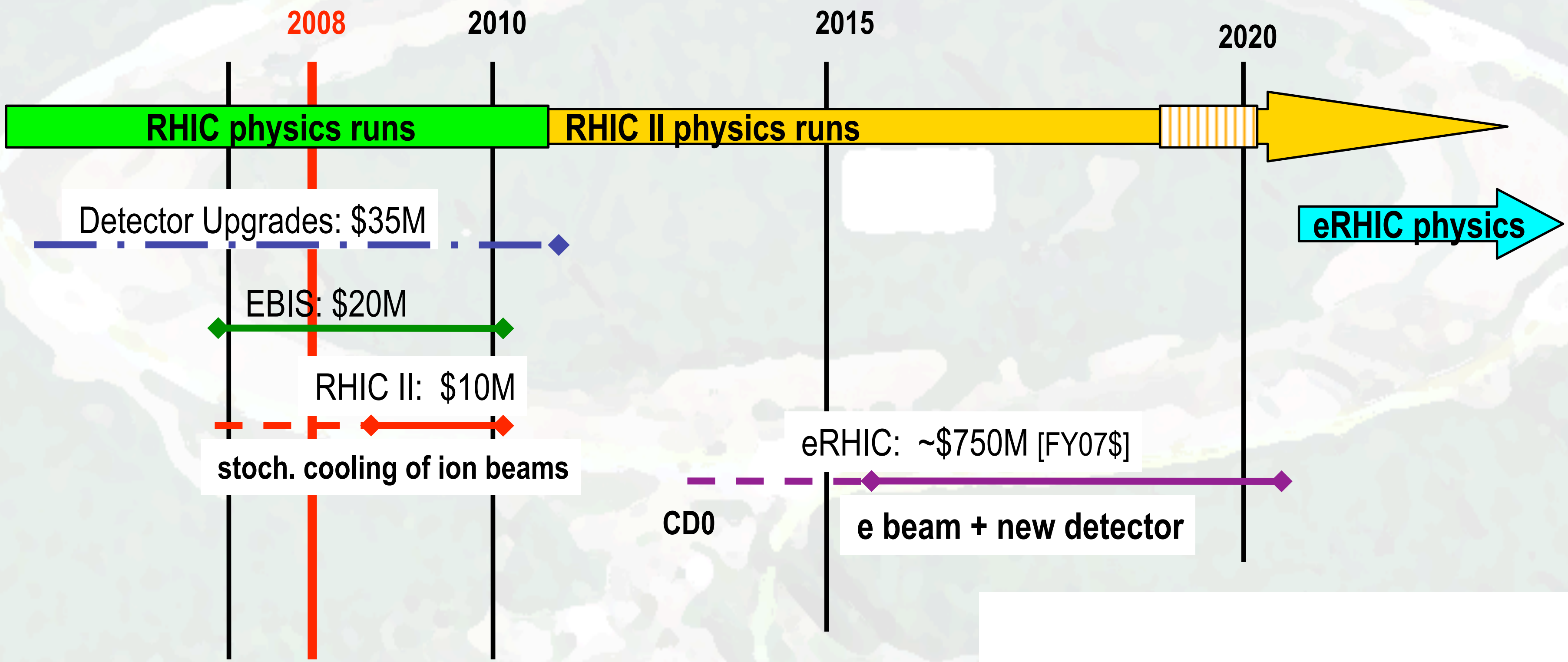
NSAC Recommendation (2007): EIC

We recommend the allocation of resources to develop accelerator and detector technology necessary to lay the foundation for a polarized Electron-Ion Collider. The EIC would explore new QCD frontier of strong color fields in nuclei and precisely image the gluons in the proton.

http://www.er.doe.gov/np/nsac/docs/Nuclear-Science.Low-Res.pdf

Summary and Outlook

- RHIC program evolution



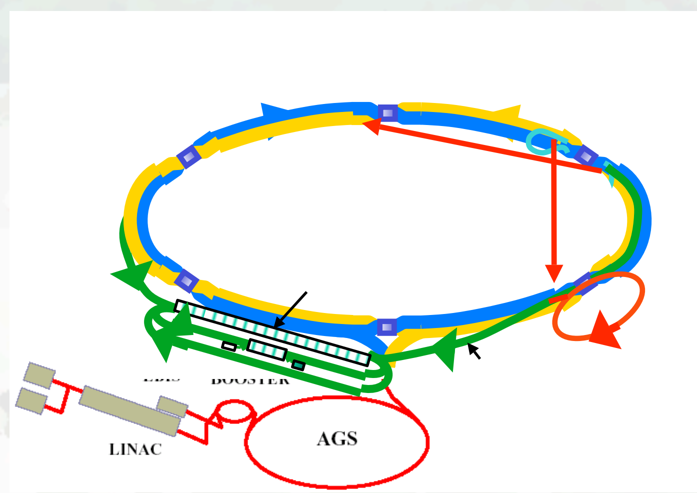
Legend:

R&D

Construction

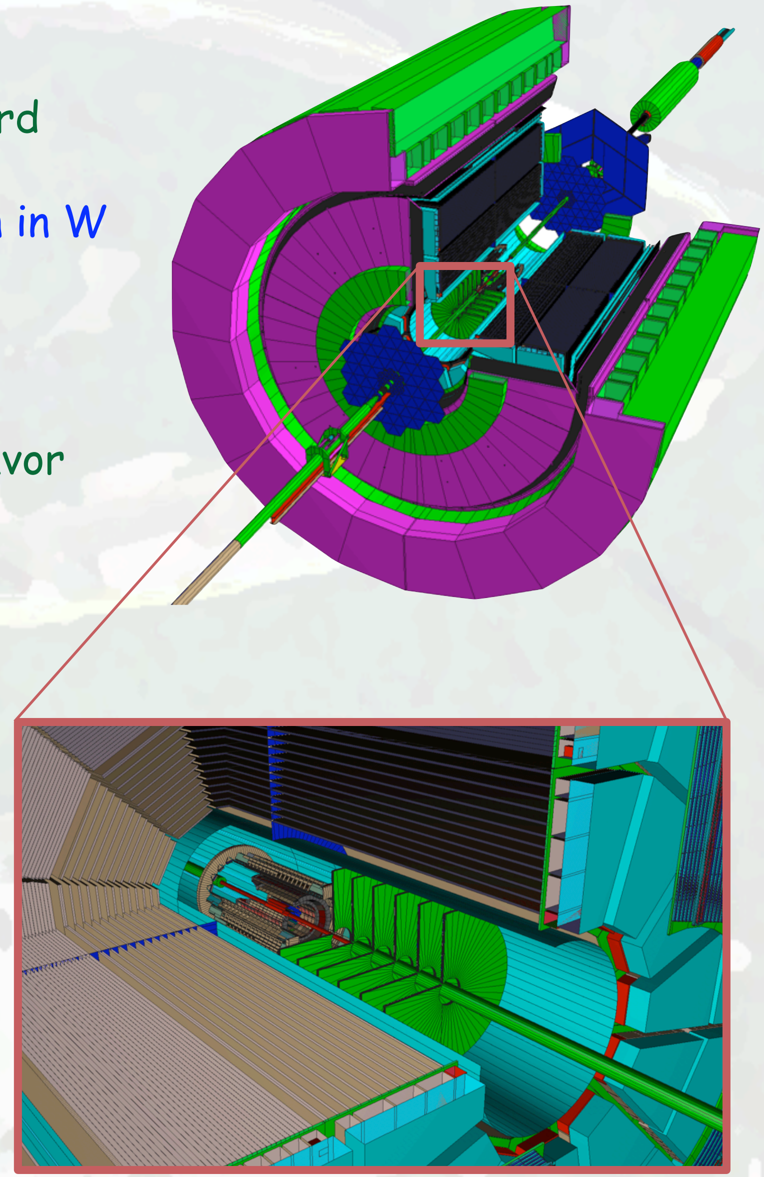
Multiple small projects

CD0: DOE Critical Decision, mission need



Backup - RHIC detector upgrades

- Outlook - Detector Upgrades
  - Upgrade of STAR Forward Tracking System (Forward GEM Tracker - FGT) to study anti-quark polarization in W production in polarized p+p collisions
  - Upgrade of STAR Inner Tracking System (Heavy Flavor Tracker - HFT) to study heavy flavor physics in relativistic-heavy ion and p+p collisions

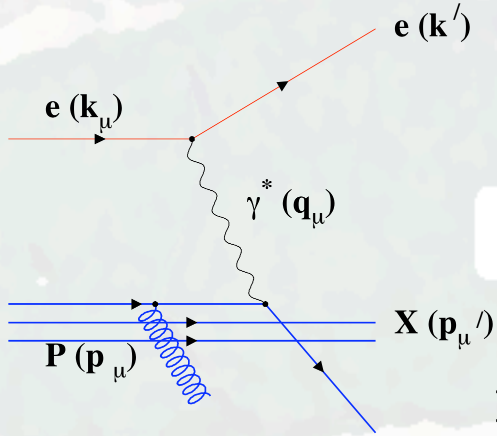


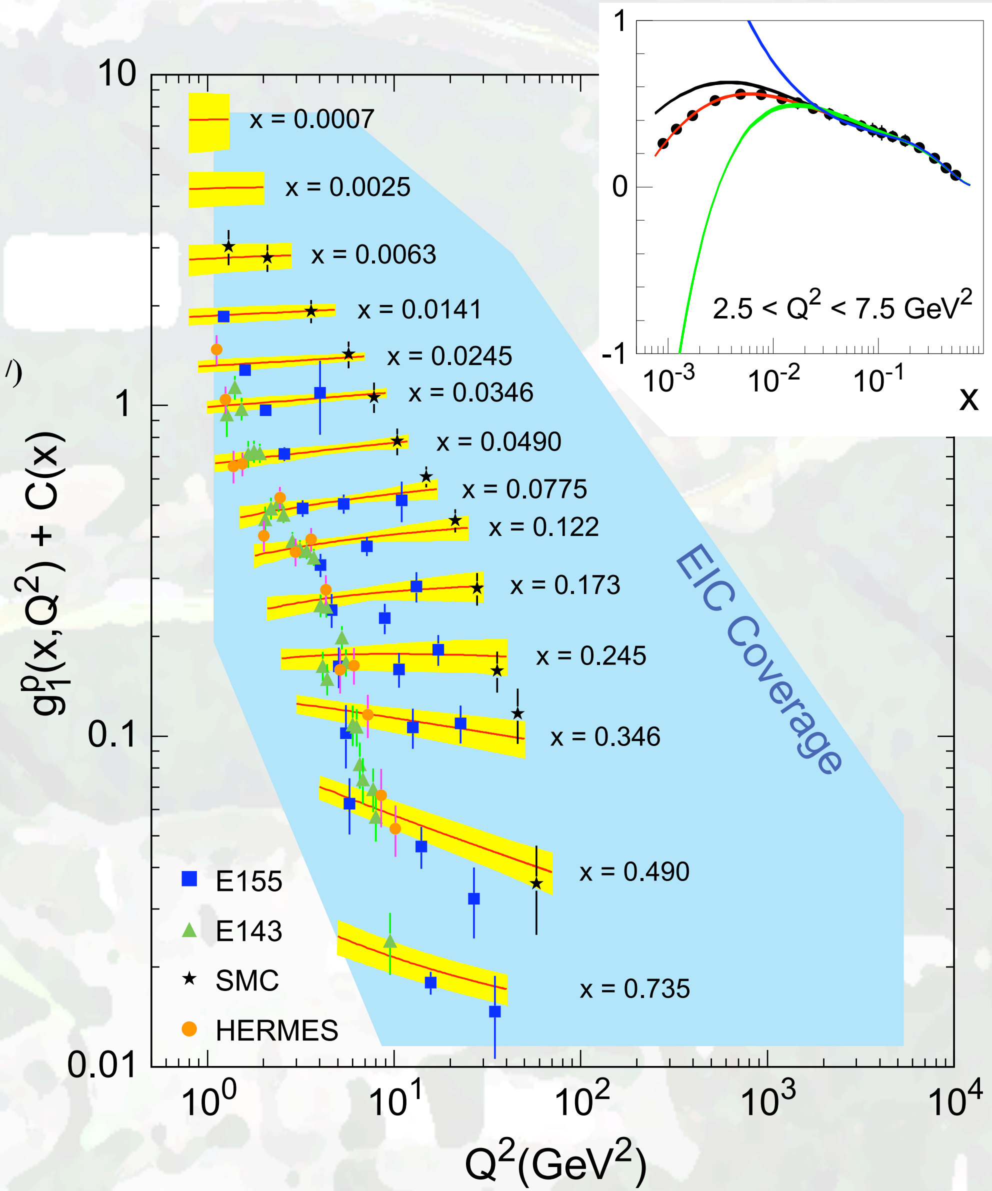
NSAC Recommendation (2007): RHIC II

"...we recommend implementation of the RHIC II luminosity upgrade, together with detector improvements...!

Backup - EIC physics

- Outlook - EIC
  - New insight into spin structure and dynamics of the proton at a future Electron-Ion Collider facility:

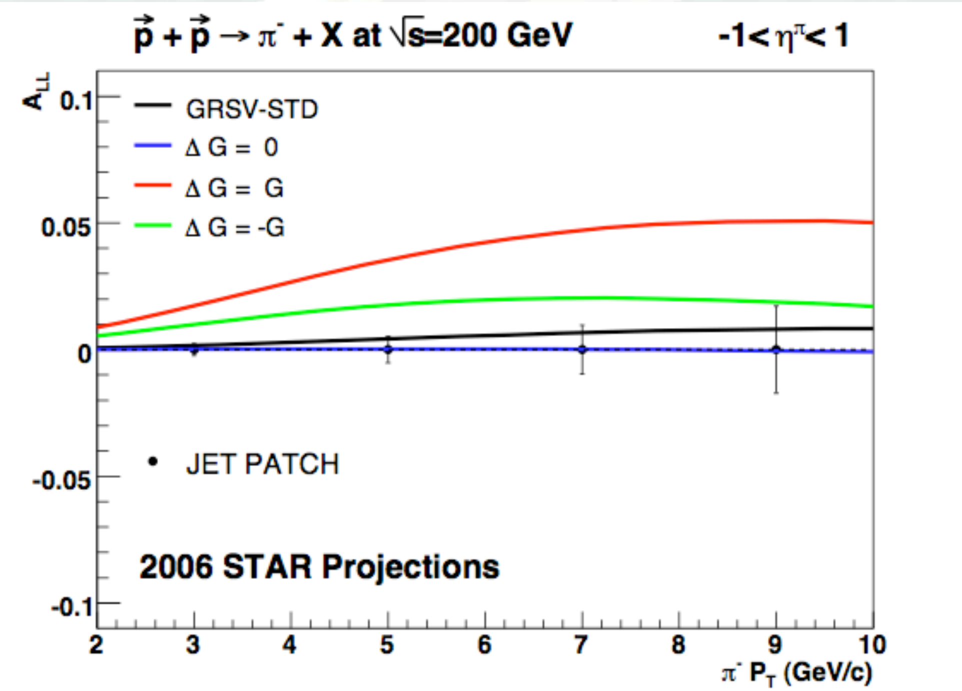


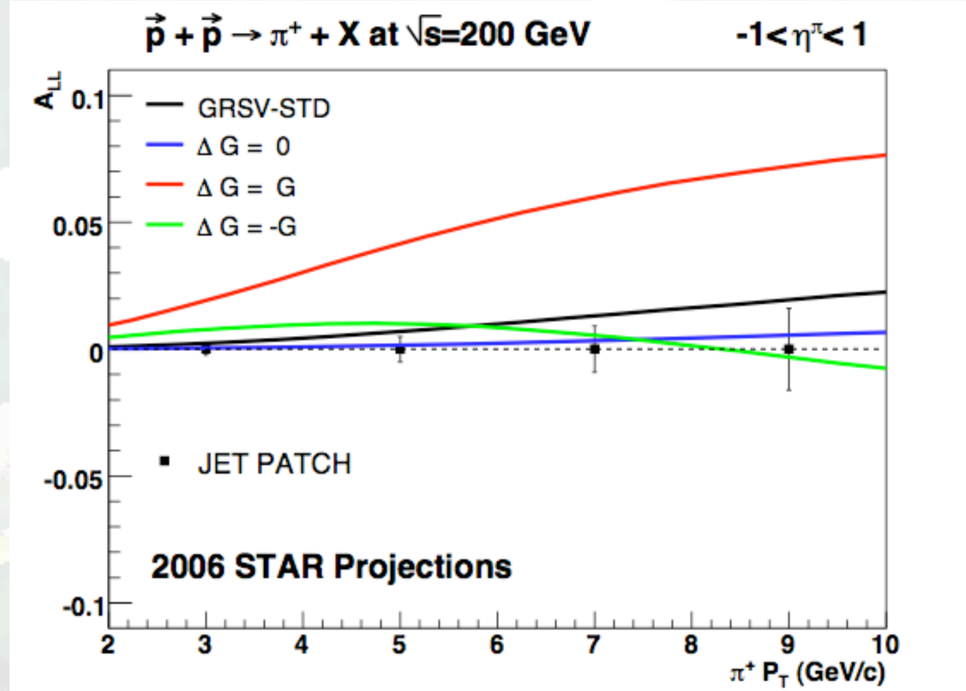


- Precision inclusive measurements - Scaling violation of g_1^p
  - ⇒ Gluon polarization at low x
- Semi-Inclusive measurements
  - ⇒ Quark flavor studies at low x

Backup - A_{LL} charged pions

- A_{LL} charged pion 2005 result - STAR

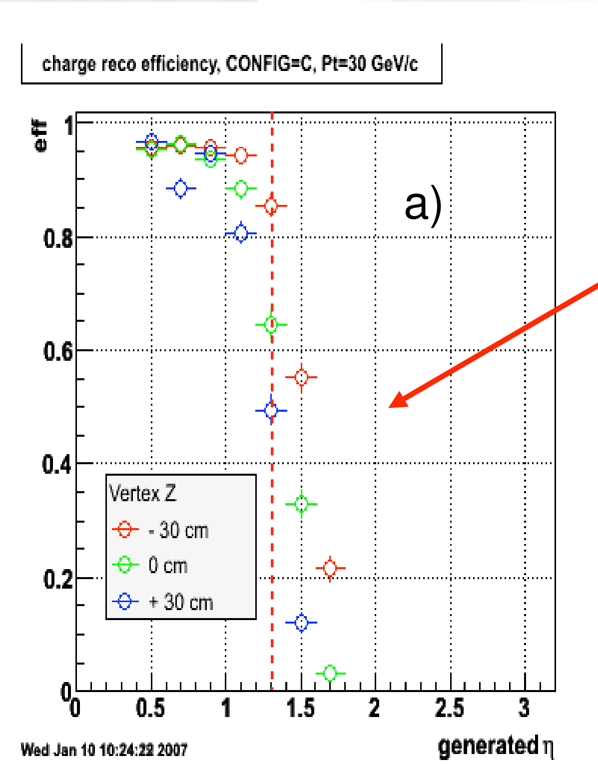




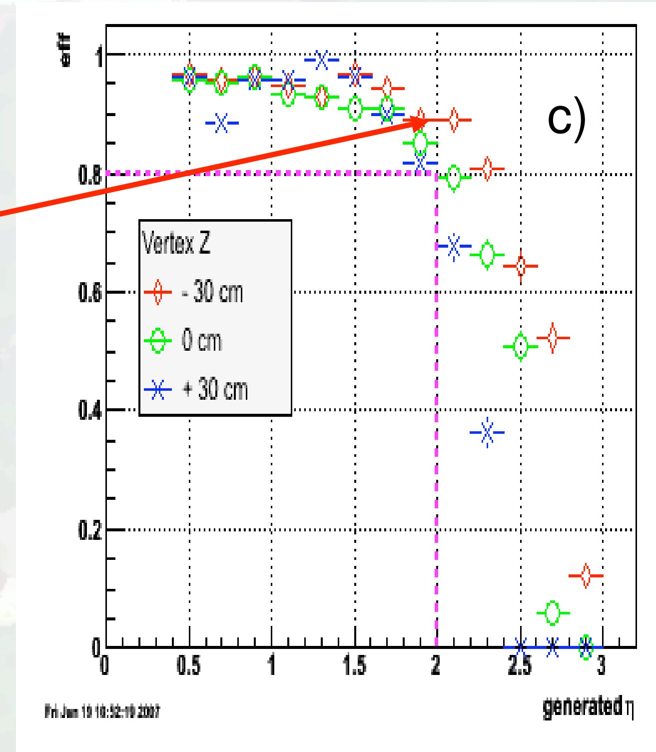
- $A_{LL}(\pi^-)$ / $A_{LL}(\pi^+)$ allows to track sign of ΔG at high p_T (qg process dominates)
- Maximum gluon polarization (GRSV-MAX) scenario disfavored
- Improved precision with Run 6 data

Backup - e^+/e^- separation

- Quark / Anti-Quark polarization program at STAR



Reach of EEMC Acceptance



TPC + FGT Tracking, p_T = 30 GeV/c

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

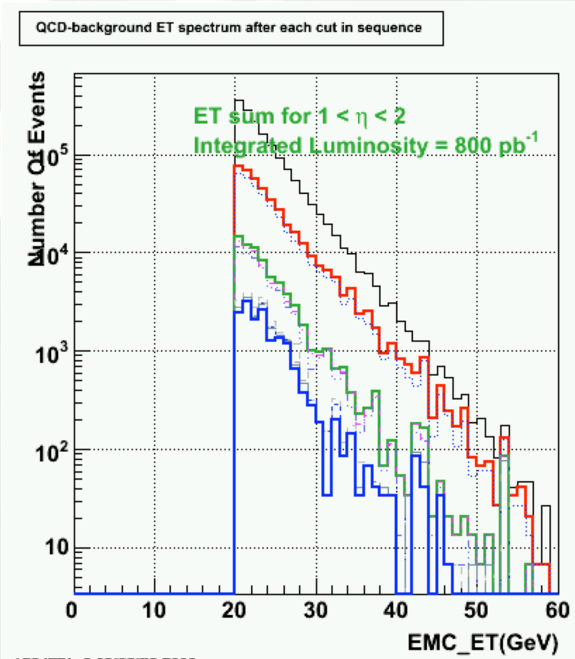
Conclusion:

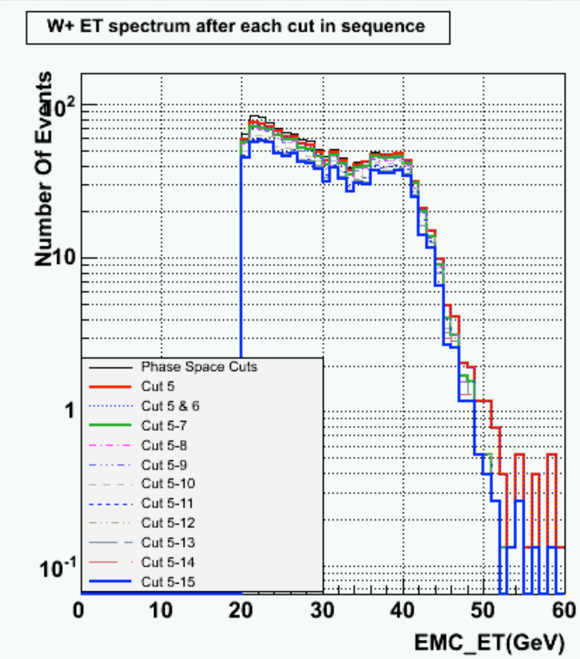
Charge sign reconstruction impossible beyond η = ~1.3

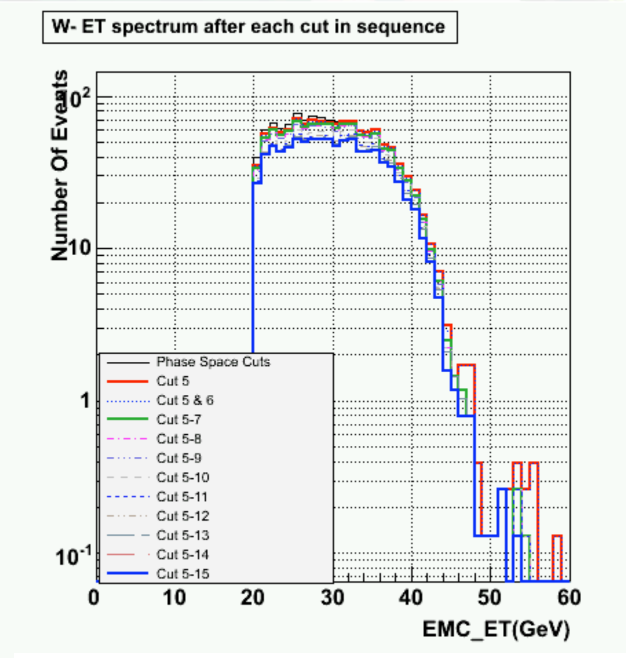
Charge sign reconstruction probability above 90% for 30 GeV p_T over the full acceptance of the EEMC for the full vertex spread

Backup - e/h separation

- 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 (isolation/missing E_T) and EEMC specific cuts as
- With current algorithm: $E_T > 25$GeV yields $S/B > 1$ (For $E_T < 25$GeV $S/B \sim 1/5$) used for A_L uncertainty estimates

Backup - EIC options

- EIC facilities

eRHIC (BNL): Add Energy Recovery Linac to RHIC

E_e = 10 (20) GeV

E_A = 100 GeV (up to U)

$\sqrt{s_{eN}}$ = 63 (90) GeV

L_{eAu} (peak)/n ~ $2.9 \cdot 10^{33}$ cm^{-2} s^{-1}

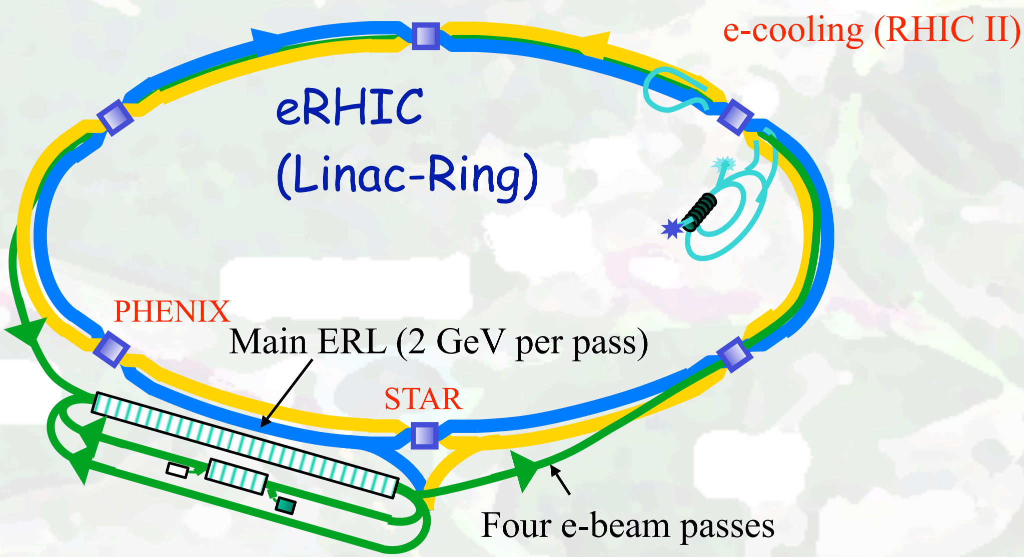
ELIC (JLAB): Add hadron beam facility to existing electron facility CEBAF

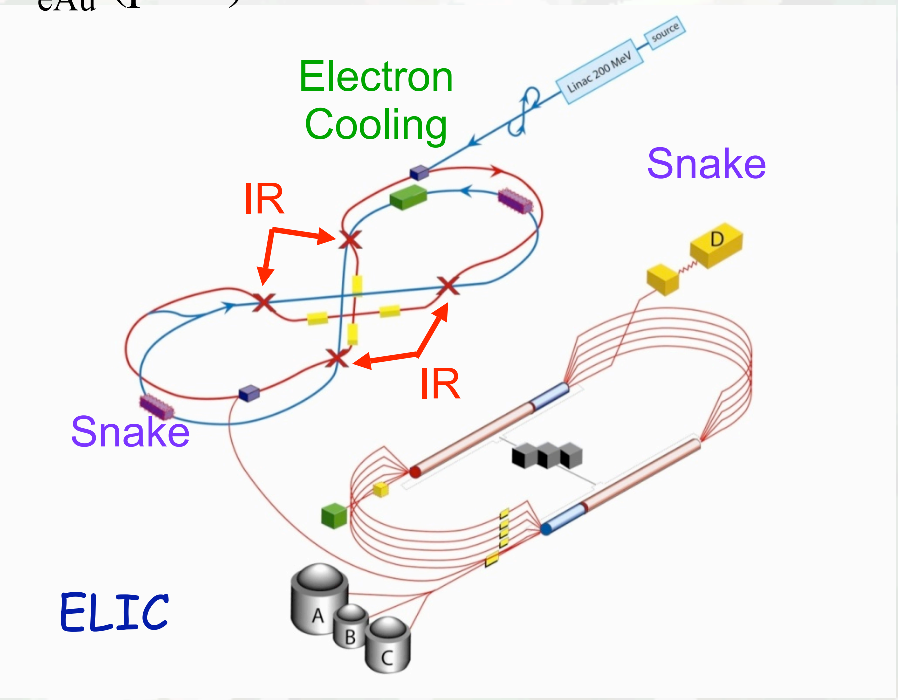
E_e = 9 GeV

E_A = 90 GeV (up to Au)

$\sqrt{s_{eN}}$ = 57 GeV

L_{eAu} (peak)/n ~ $1.6 \cdot 10^{35}$ cm^{-2} s^{-1}





Backup - EIC roadmap

- Timeline
  - NSAC Long Range Plan 2007
  - Recommendation: $6M/year for 5 years for machine and detector R&D
  - Goal for Next Long Range Plan ~2012
  - High-level (top) recommendation for construction
  - EIC Roadmap (Technology Driven)
    - Finalize Detector Requirements from Physics 2008
    - Revised/Initial Cost Estimates for eRHIC/ELIC 2008
    - Investigate Potential Cost Reductions 2009
    - Establish process for EIC design decision 2010
    - Conceptual detector designs 2010
    - R&D to guide EIC design decision 2011
    - EIC design decision 2011
    - MOU's with foreign countries? 2012

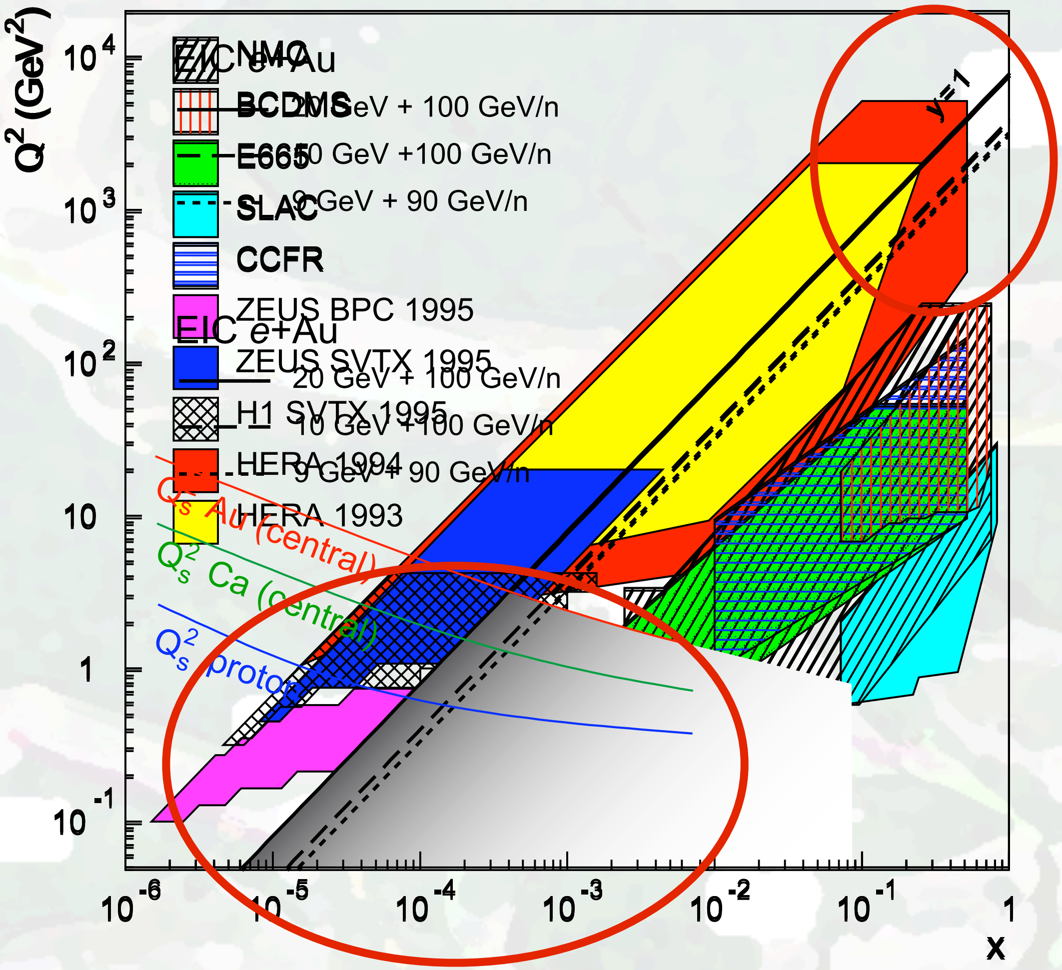
Goal I: High-level recommendation at next LRP

Goal II: CD-0 Mission Need before next LRP

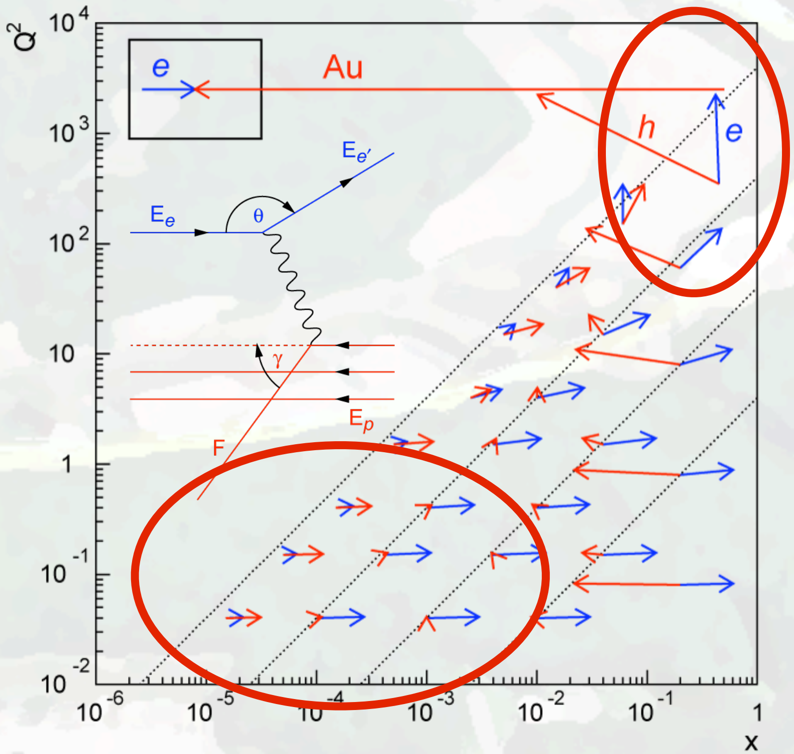
Goal III: Decision on EIC design before next LRP

Backup - EIC kinematic region

- Kinematics
  - Comparison HERA / EIC / Fixed-target experiments



EIC (eA) event topology (E_e=10 GeV, $E_{h/A}$=100 GeV)



Terra incognita:

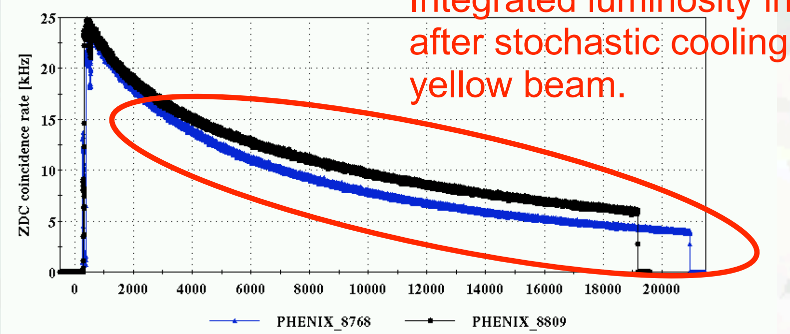
small-x, $Q \approx Q_s$

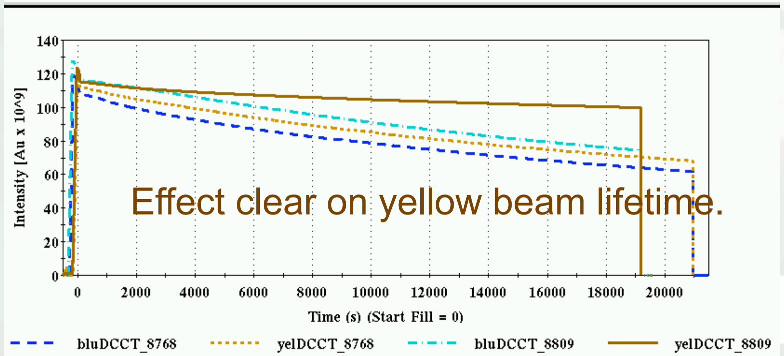
high-x, large Q^2

Backup - RHIC program and RHIC II

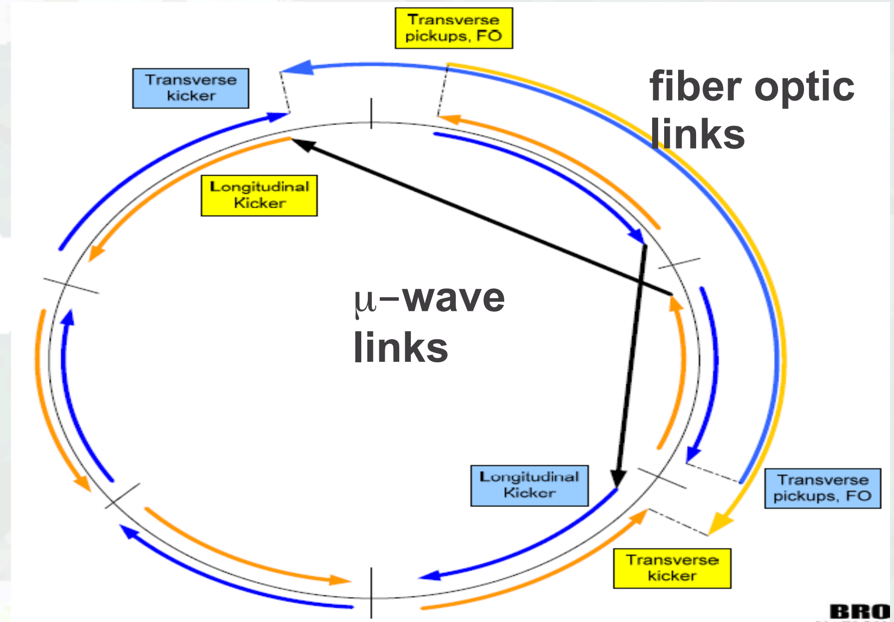
- Collider upgrades: Cooling
  - Stochastic Cooling can help reduce beam emittance
  - Less effective than e⁻ cooling, but cheaper and earlier implementation
  - First test with longitudinal cooling in yellow ring

Integrated luminosity increased 10-20% after stochastic cooling introduced for yellow beam.





Effect clear on yellow beam lifetime.



Backup - RHIC program and RHIC II

- Collider upgrades: EBIS source
  - New high brightness, high charge-state pulsed ion source
  - Replaces 35 year old Tandem Van de Graafs
  - Improved reliability, lower operations costs
  - Enables new beams: noble gas ions, Uranium, polarized ^{3}He
  - Construction schedule: FY2006 - FY2010