Recent results and prospects on exploring the helicity structure of the proton at RHIC in high-energy polarized proton-proton collisions

- Theoretical foundations
- Experimental aspects RHIC/STAR
- Inclusive measurements of gluon polarization
- Prospects for anti-quark polarization measurement with Ws
- Outlook

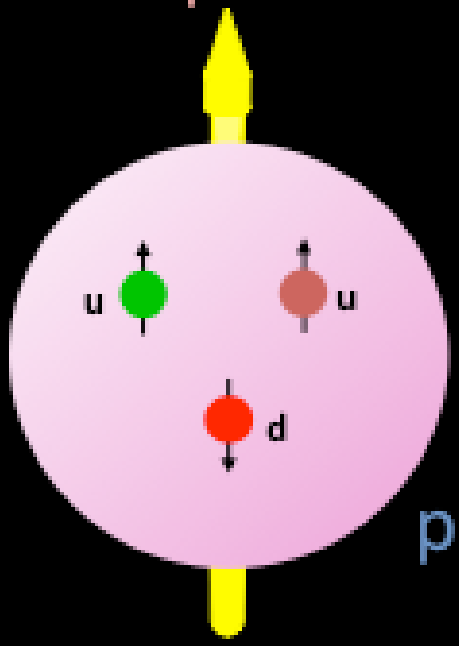
Jan Balewski

For the STAR Collaboration

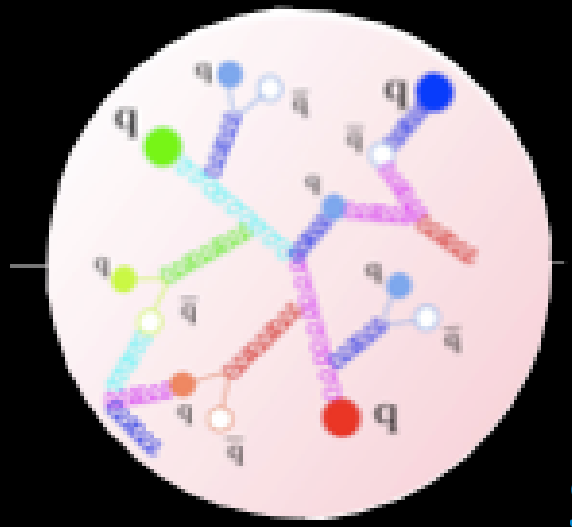
Where does the proton's spin come from?

p is made of 2 u and 1d quark

$$S = \tfrac{1}{2} = \Sigma\, S_q$$



Explains magnetic moment of baryon octet

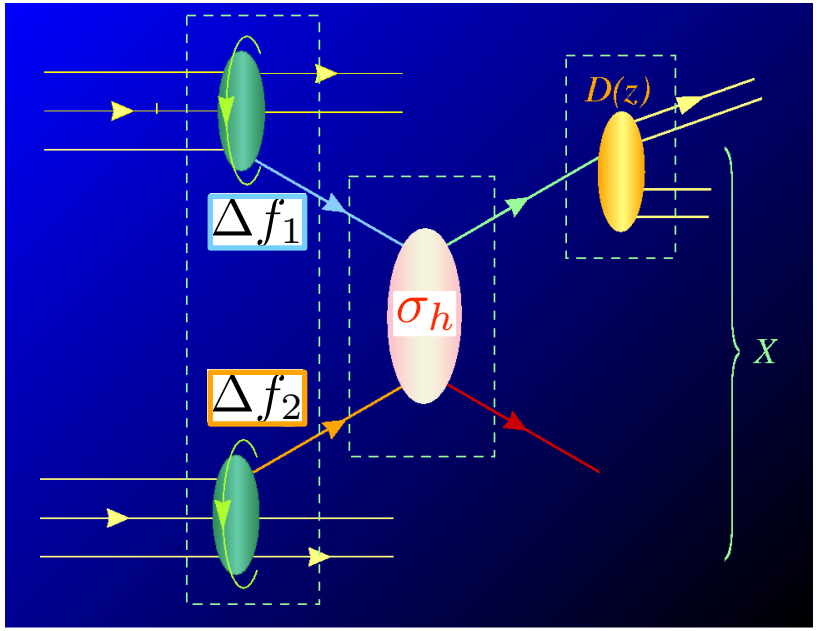


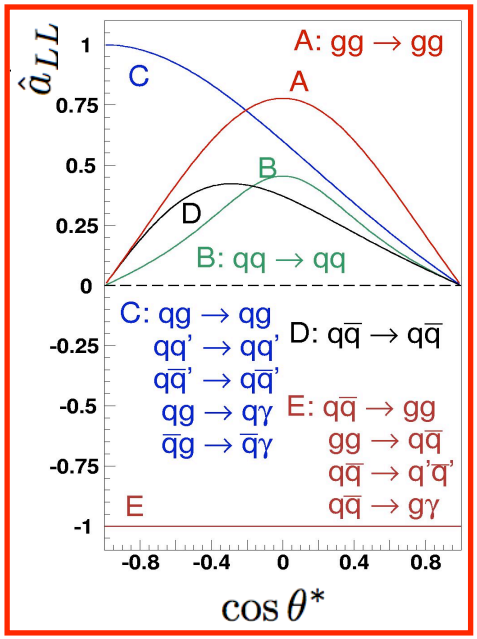
$$S_z = \tfrac{1}{2} = \tfrac{1}{2}\underbrace{\Delta\Sigma}_{u,\,d,\,s,\,\bar{u},\,\bar{d},\,\bar{s}} + \underbrace{\Delta G + L_z^{\,g}}_{J_g} + \overbrace{L_z^{\,q}}^{L}$$

Theoretical foundation of Measurement of Gluon Polarization

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

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



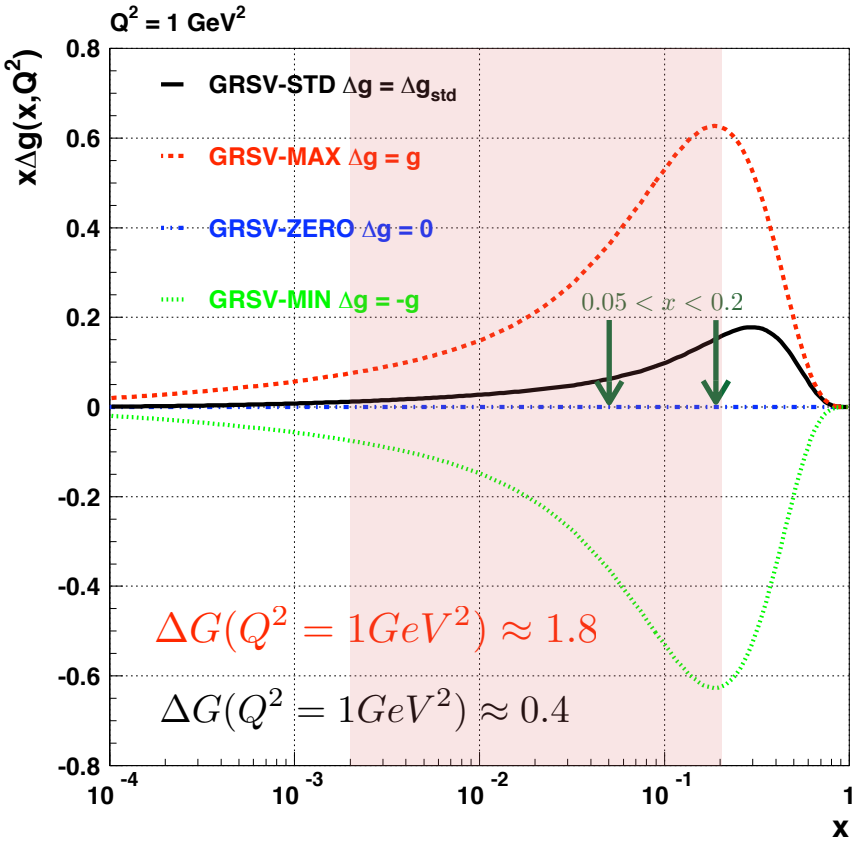


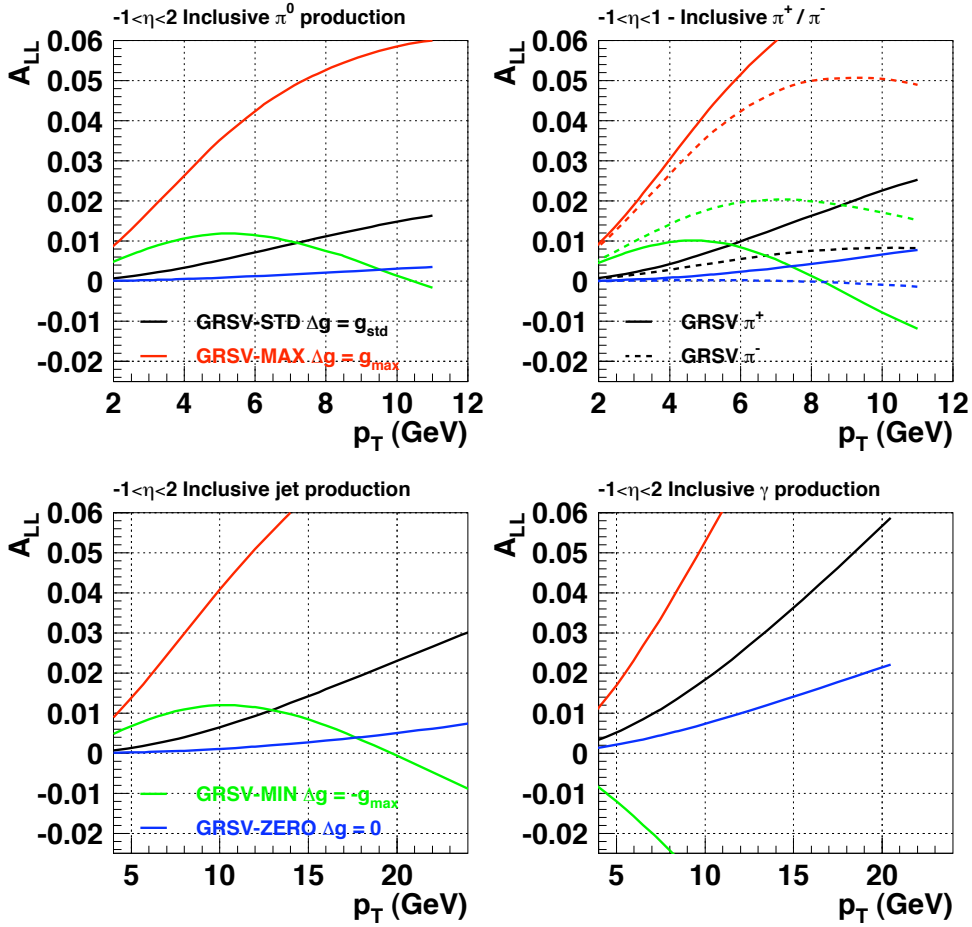
W. Vogelsang, private communication.

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

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

Model dependent predictions of A_{LL}





W. Vogelsang, private communication.

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

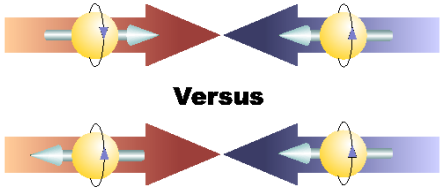
$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

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

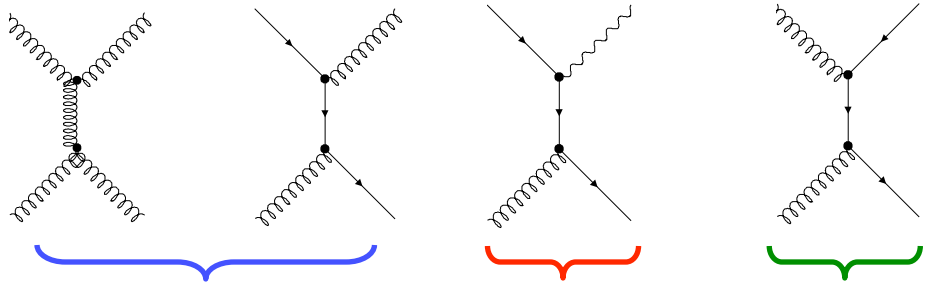
(central rapidity)

Components of experiment

- Double longitudinal-spin asymmetry: A_{LL}



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



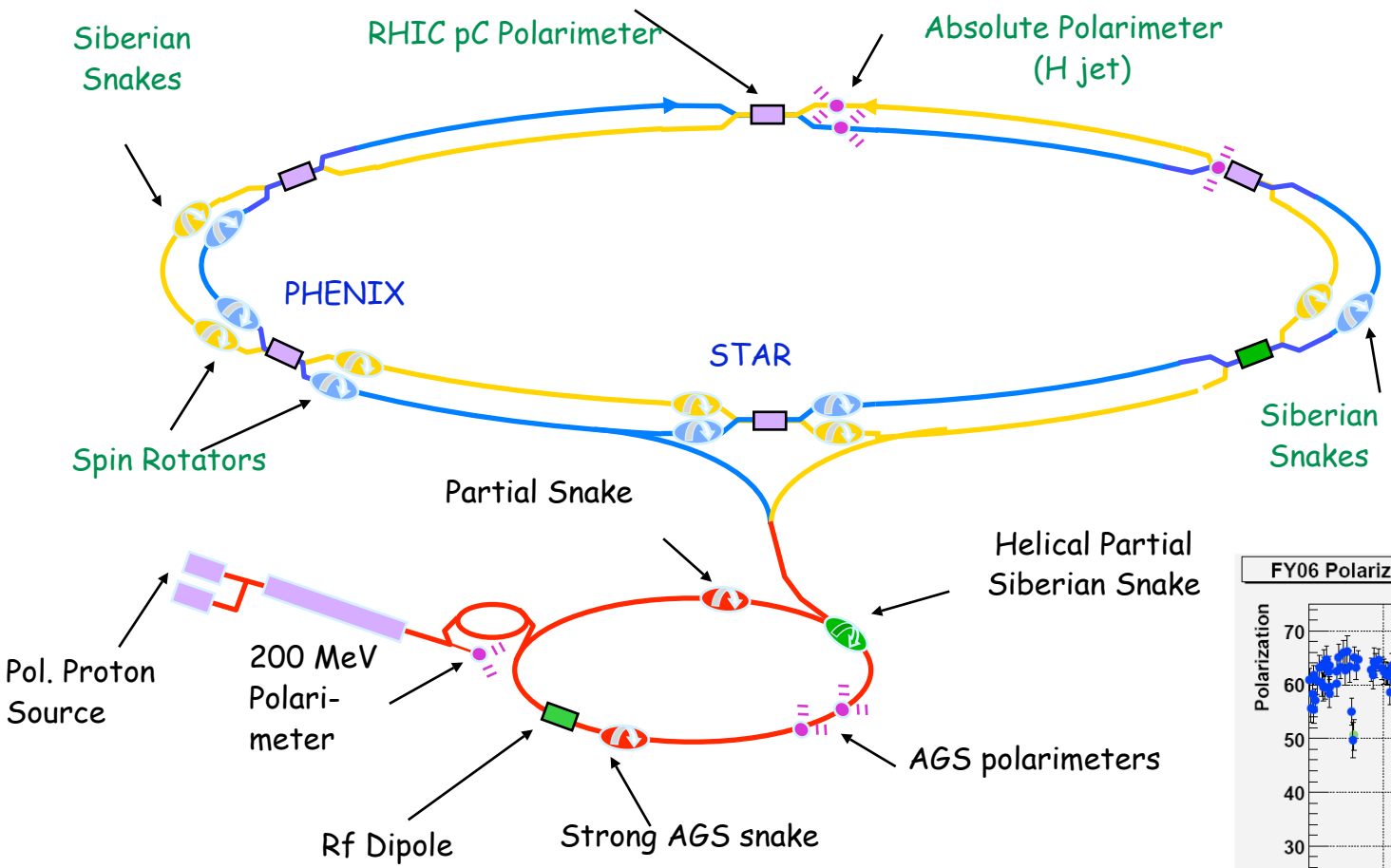
$\text{jets} + X$ $\quad \gamma + X$ $\quad c\bar{c}\,(b\bar{b}) + X$

  - Study helicity dependent structure functions (Gluon polarization)!

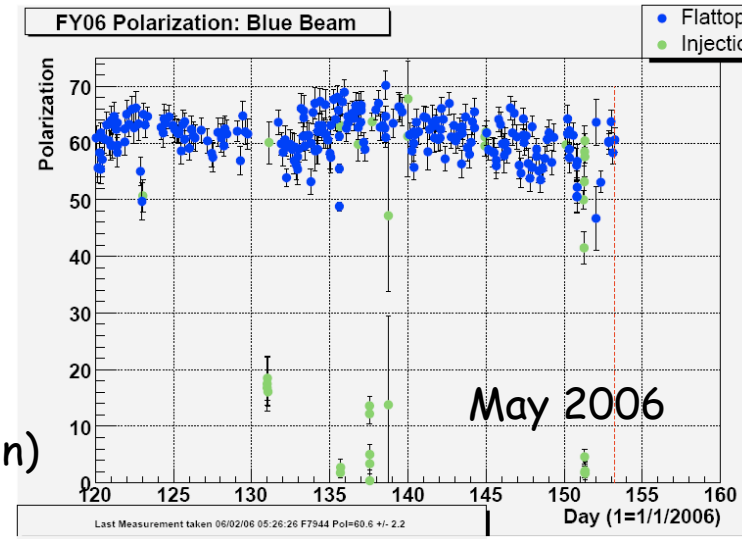
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

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

Collider: The First polarized p+p collider at BNL



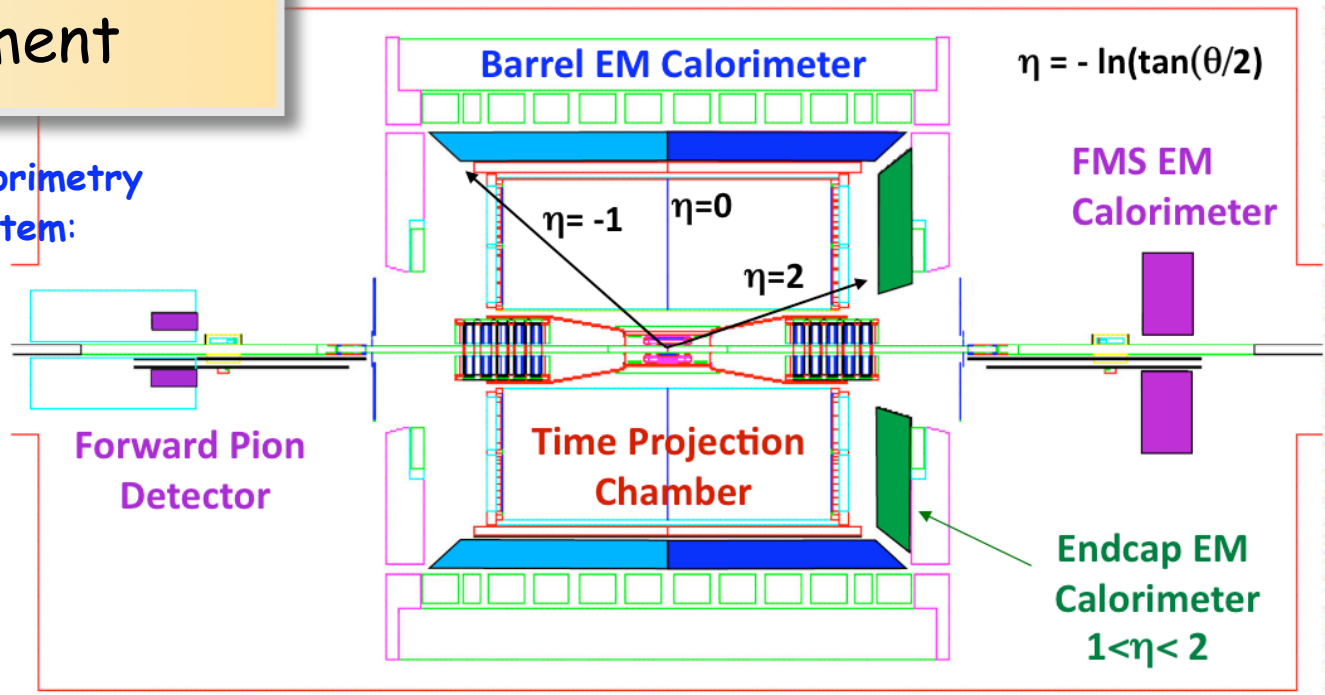
- Performance



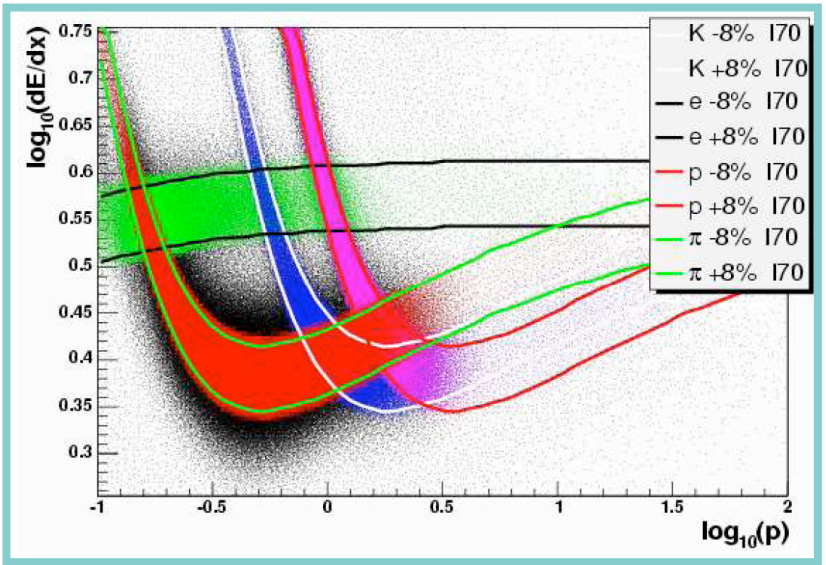
- All RHIC polarized pp accelerator components in place!
- 2006 performance (√=200GeV): ~60% polarization (70% design) and ~1pb^{-1}/day (~3pb^{-1}/day design) delivered luminosity

The STAR Experiment

- Wide rapidity coverage of **STAR calorimetry (Jets /Neutral Pions / Photons) system**:
  - BEMC: $-1.0 < \eta < 1.0$
  - EEMC: $1.09 < \eta < 2.0$
  - FPD: $4.1 < \eta < 3.3$



- **TPC**: Tracking and PID using dE/dx for $|\eta| < 1.3$ and $p_T < 15$ GeV/c



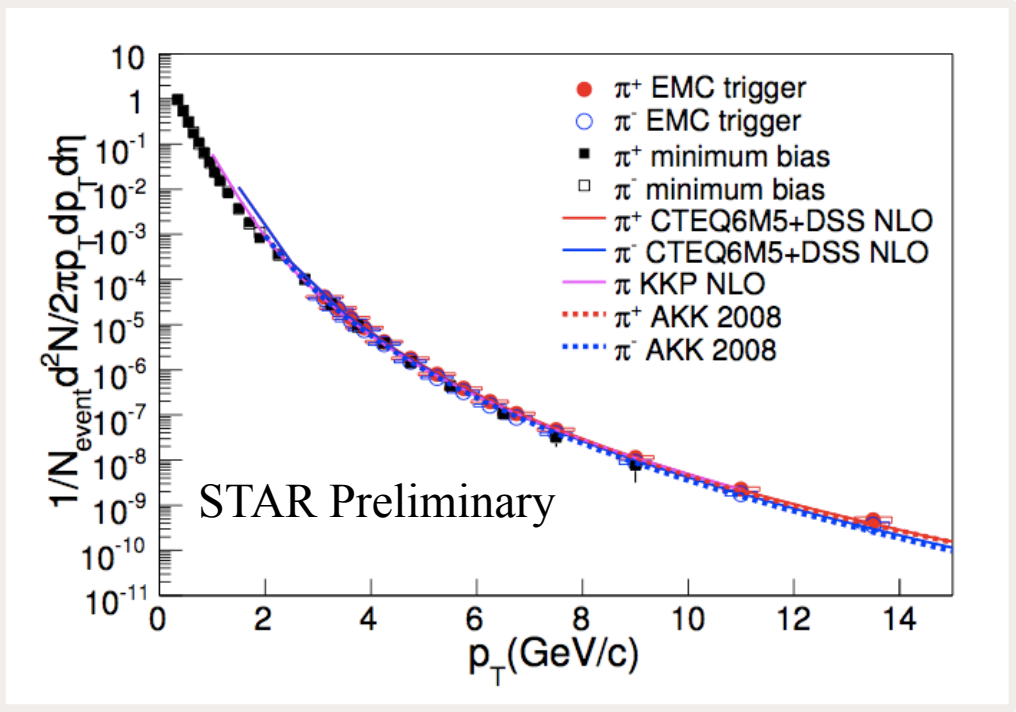
- **BBC**: Relative luminosity and Minimum bias trigger

Key elements for STAR Δg(x) program:

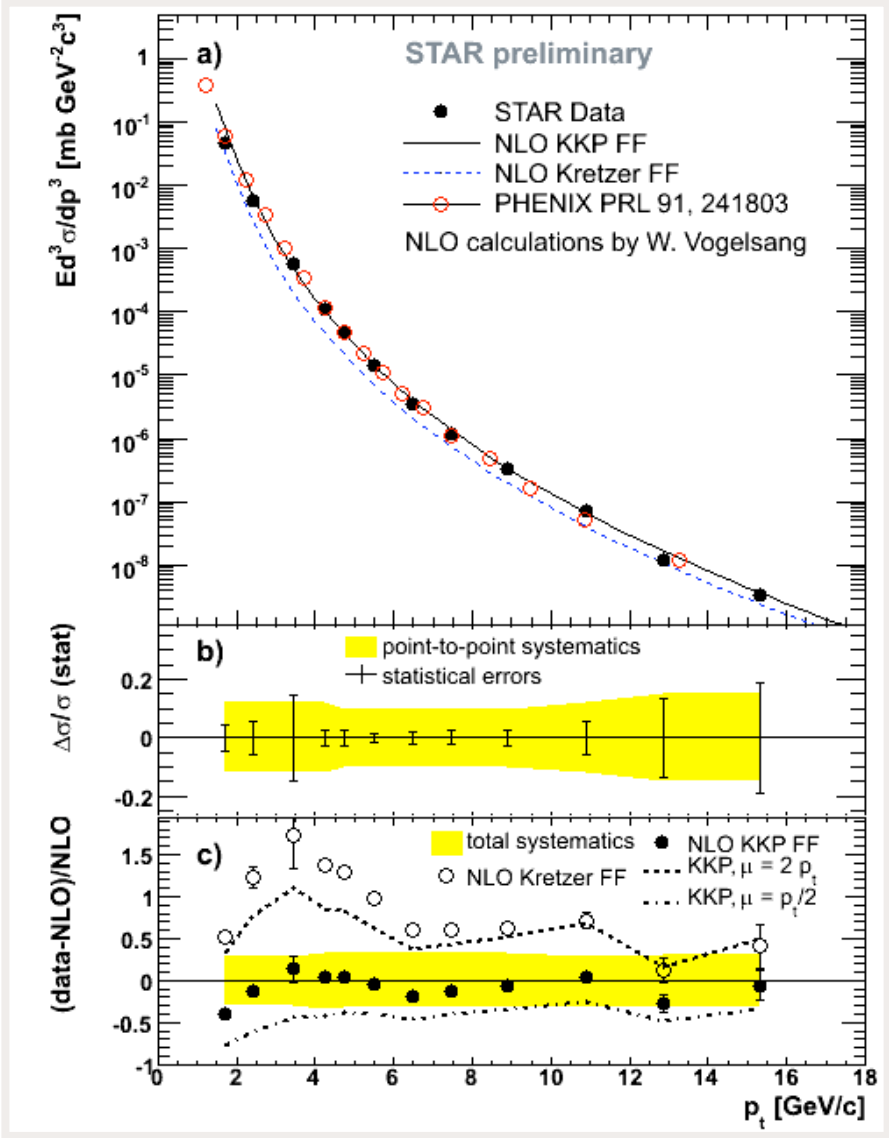
- Higher precision on Δg(x) : Luminosity / DAQ upgrade (DAQ 1000)
- Sensitivity to shape of Δg(x): Correlation measurements
- Low-x region of Δg(x): 500GeV program / Asymmetric collisions (Forward calorimetry)

Recent results: Neutral / Charged Pion production

- STAR Run 5 Cross-section results: Mid-rapidity charged and neutral pion production



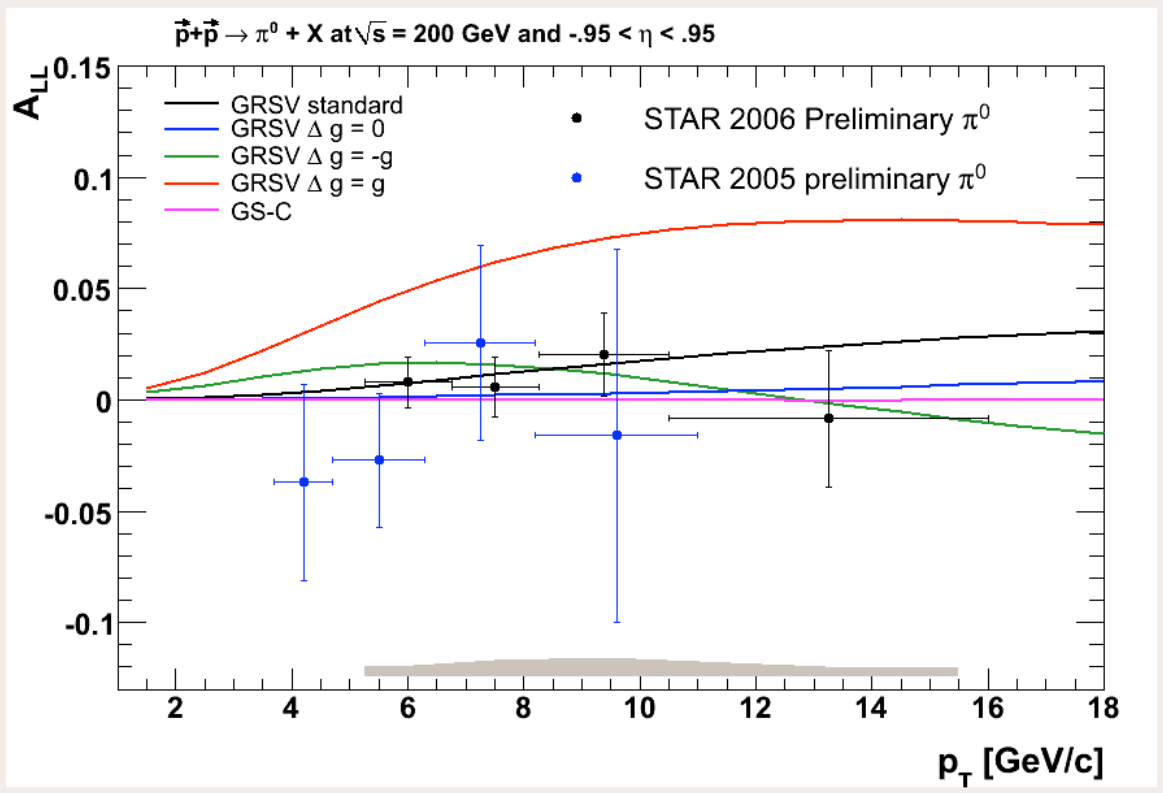
STAR Collaboration, Phys. Lett. B637 (2006) 161.



- Sophisticated TPC (dE/dx) calibrations improve precision at high p_T (arXiv:0807.4303-physics)
- Good agreement between data and NLO calculations for charged and neutral pion production

Recent results: Neutral Pion production (mid-rapidity)

- STAR Run 5 / 6 A_{LL} result: Mid-rapidity neutral pion production



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

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

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

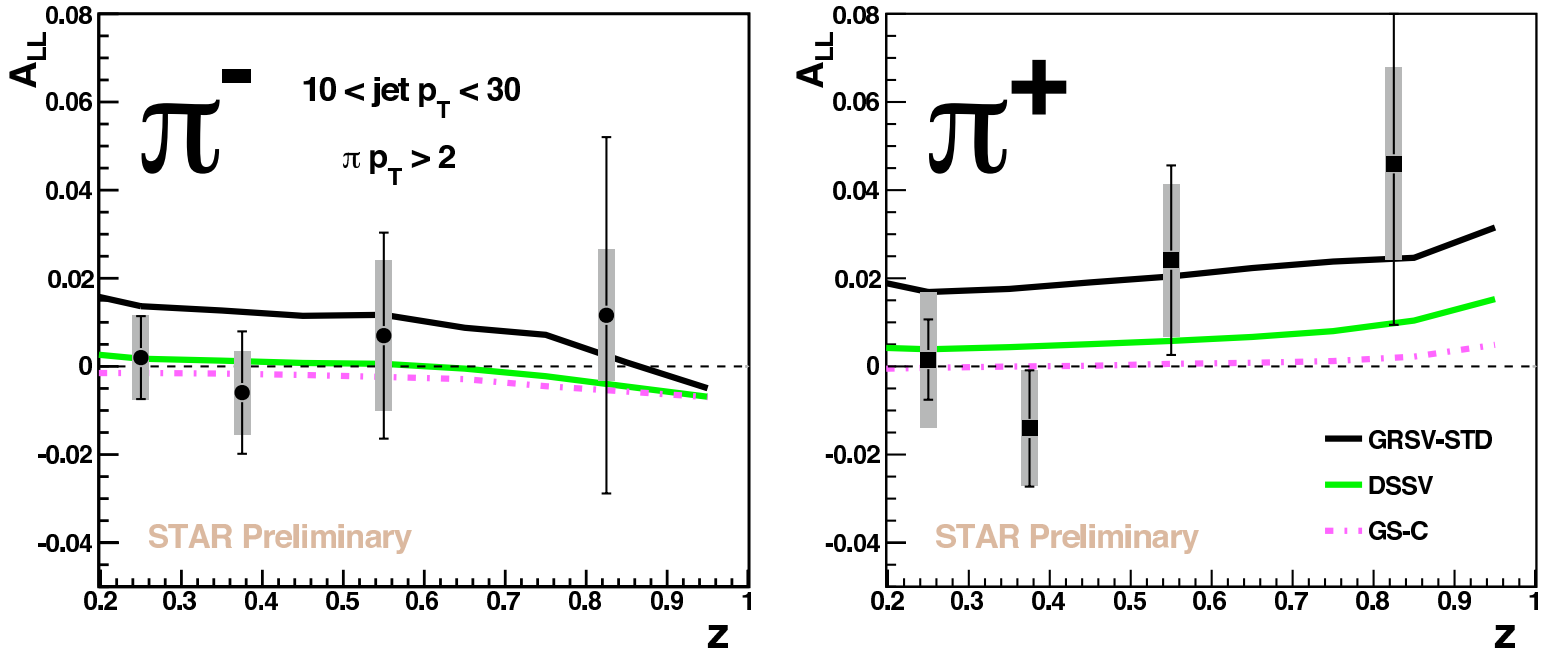
$\Delta G(Q^2 = 1GeV^2) \approx 1.0$

p_T range [GeV/c]	A_{LL} ± Stat. ± Sys.
5.2 - 6.75	0.0080 ± 0.0115 ± 0.002
6.75 - 8.25	0.0058 ± 0.0136 ± 0.004
8.25 - 10.5	0.0203 ± 0.0189 ± 0.004
10.5 - 16.0	-0.0084 ± 0.0306 ± 0.002

- 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

Recent results: Charged Pion Asymmetry

- STAR Run 6 A_{LL} result: Mid-rapidity charged pion production

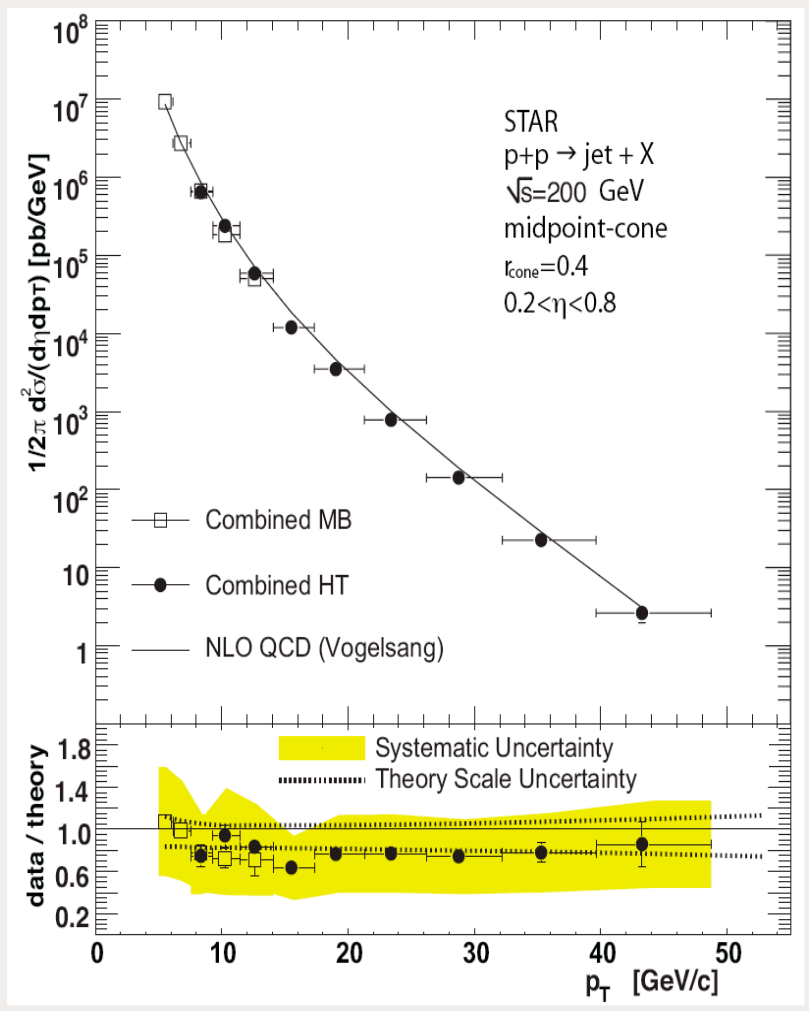


- Full NLO pQCD , D. de Florian et al. arXiv:0904.4402
- These curves generated by sampling a_{LL} and parton distribution functions at kinematics of PYTHIA event.
- NLO suggests significant sensitivity at high z of π^+

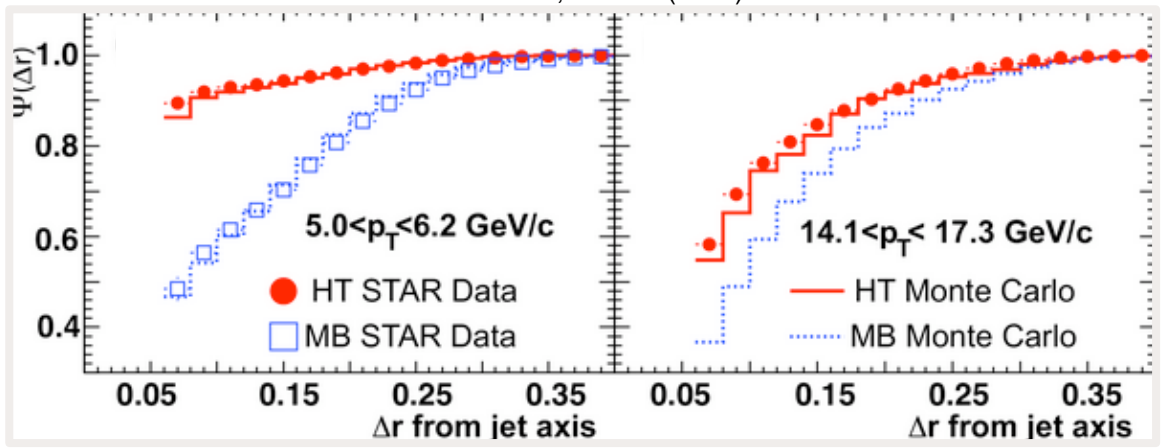
Recent results: Jet production

- STAR Run 3&4 Cross-section result: Mid-rapidity inclusive jet production

STAR Collaboration, PRL 97 (2006) 252001.



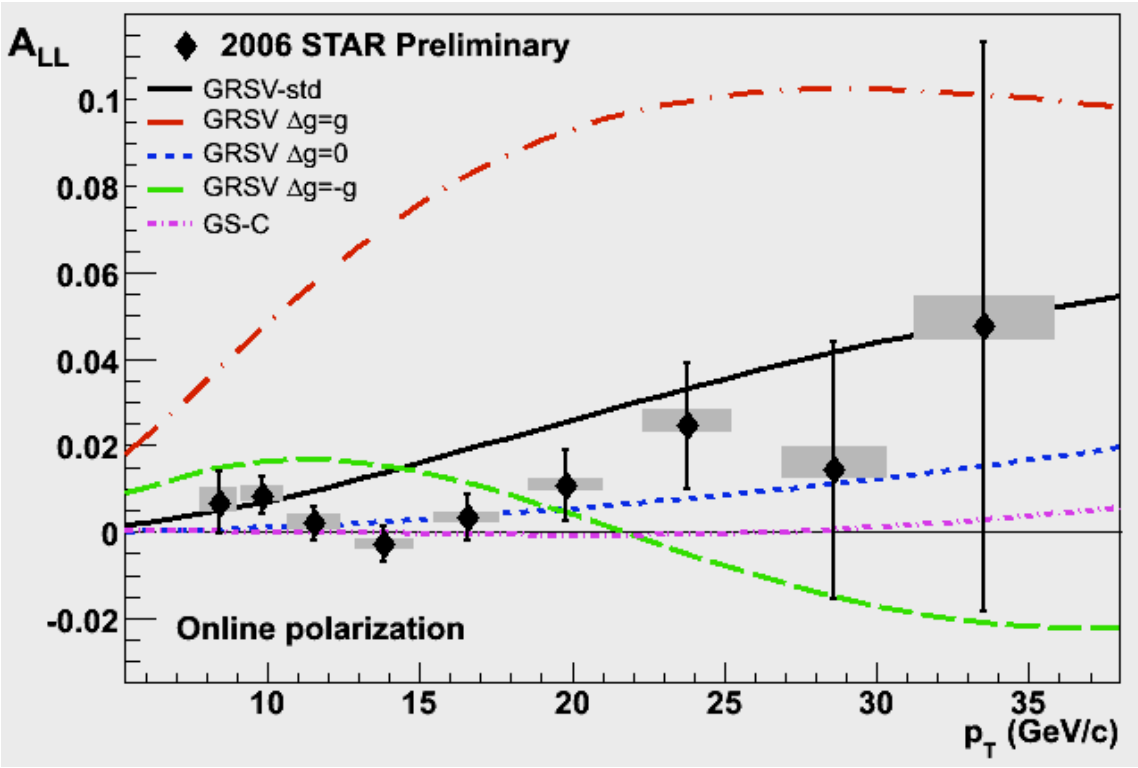
STAR Collaboration, PRL 99 (2007) 142003.



- Inclusive Jet production - Well understood in comparison to Full PYHTIA-based MC simulations
- Good agreement between data and NLO pQCD calculations at mid-rapidity

Recent results: Jet production

- STAR Run 6 A_{LL} result: Mid-rapidity inclusive jet production
  (jet cone radius of 0.7 radians)



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

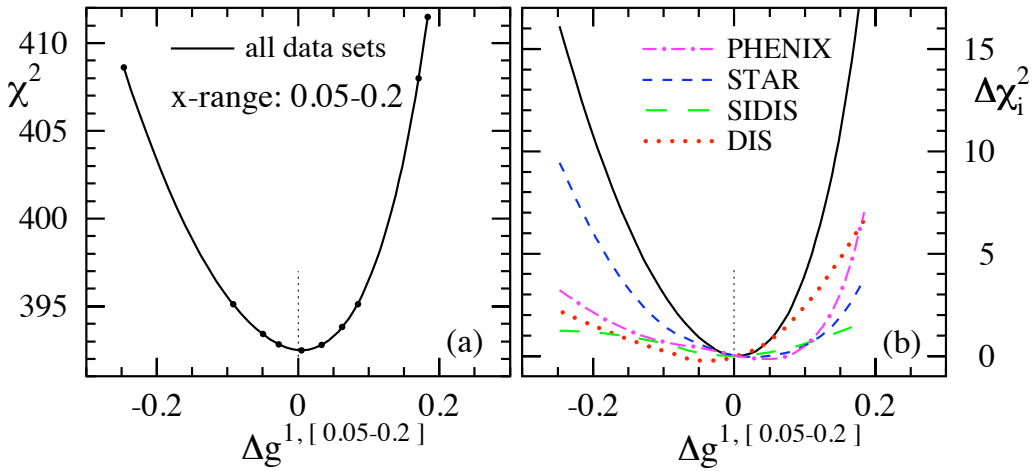
p_T systematic	± 6.7%

STAR Collaboration, PRL 100 (2008) 232003.

- 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 3-5 result (Factor 3-4 improved statistical precision for p_T>13GeV/c)

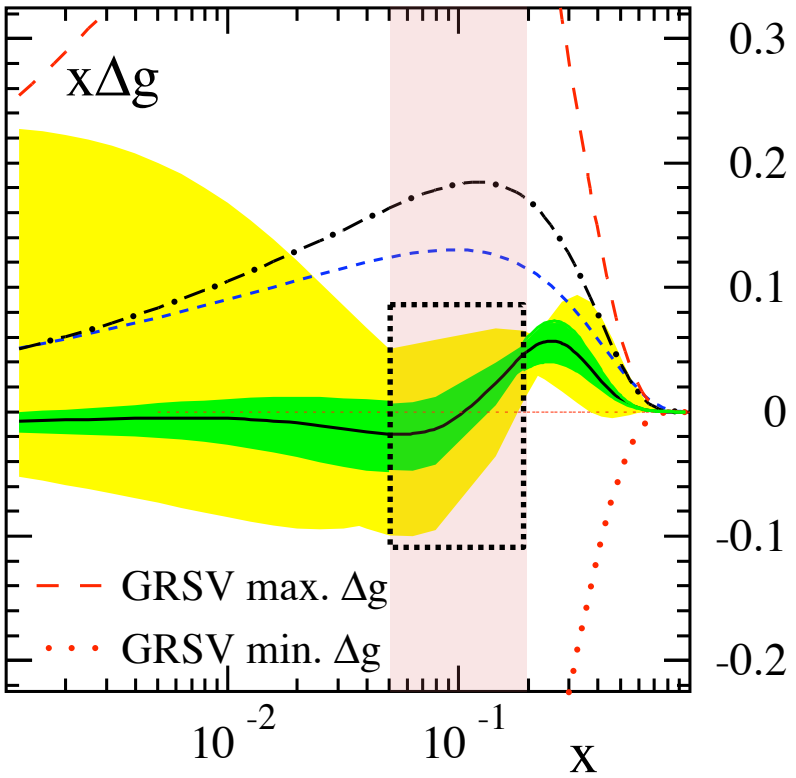
Global analysis incorporates RHIC data

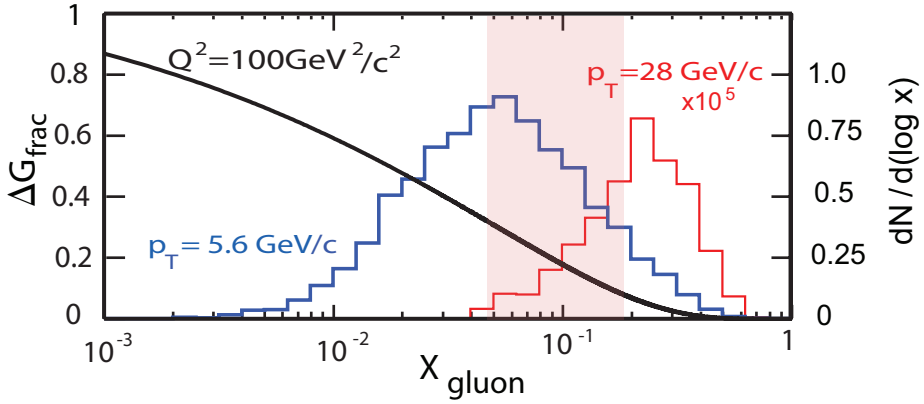
- Global analysis incl. RHIC pp data



- 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 of x-dependence and extension of x-coverage needed!

D. de Florian et al. PRL 101 (2008) 072001.

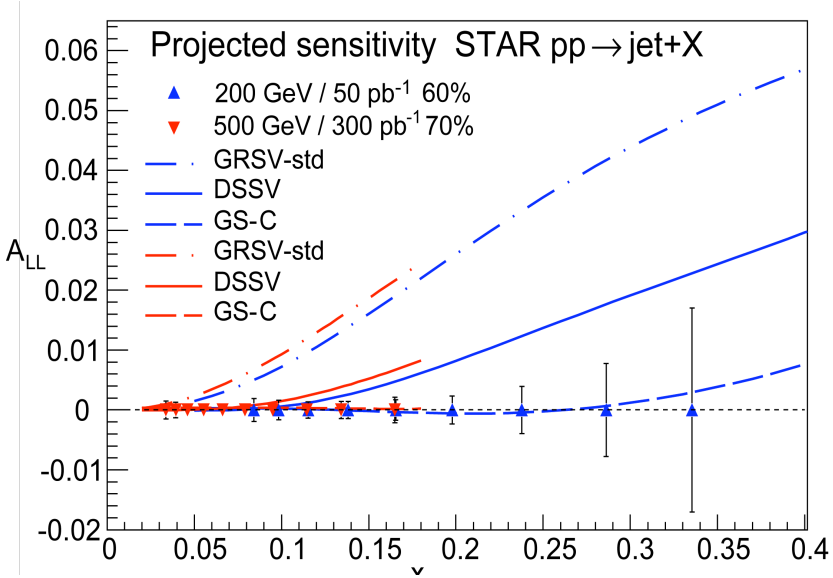




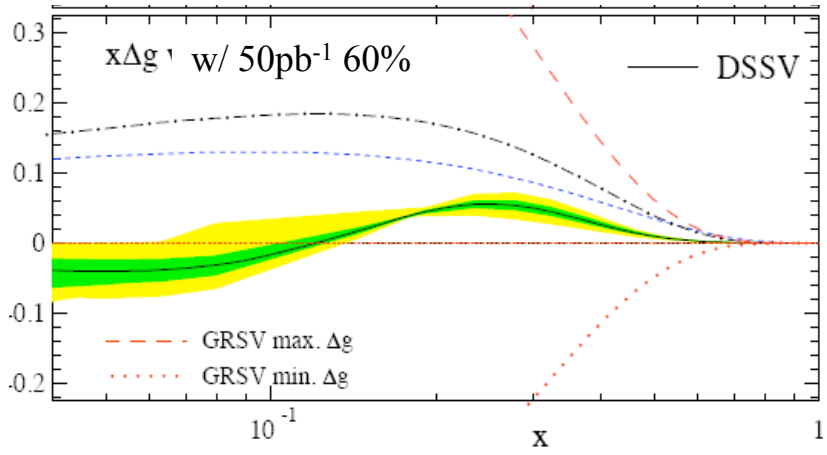
STAR Collaboration, PRL 100 (2008) 232003.

Future Δg measurements at STAR

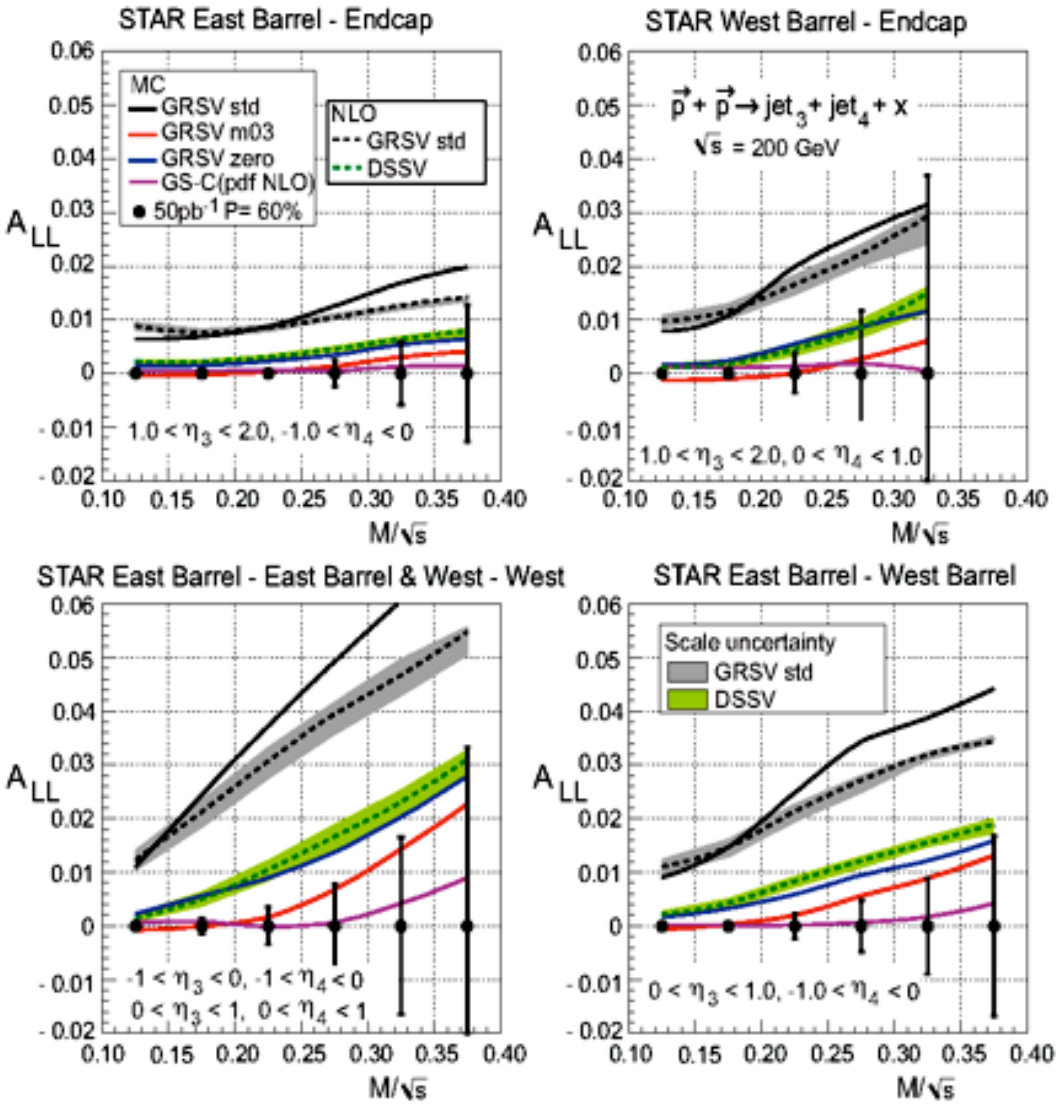
Inclusive jets



Projected constrain on $\Delta g(x)$ with future STAR inclusive jet data



Projections for di-jets improve understanding of x-dependence

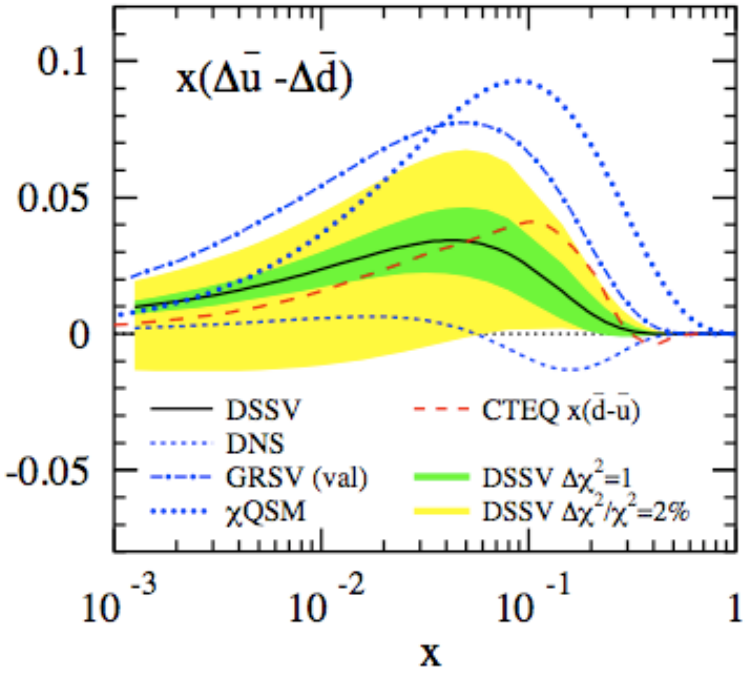


Asymmetry in the sea quarks: STAR W program

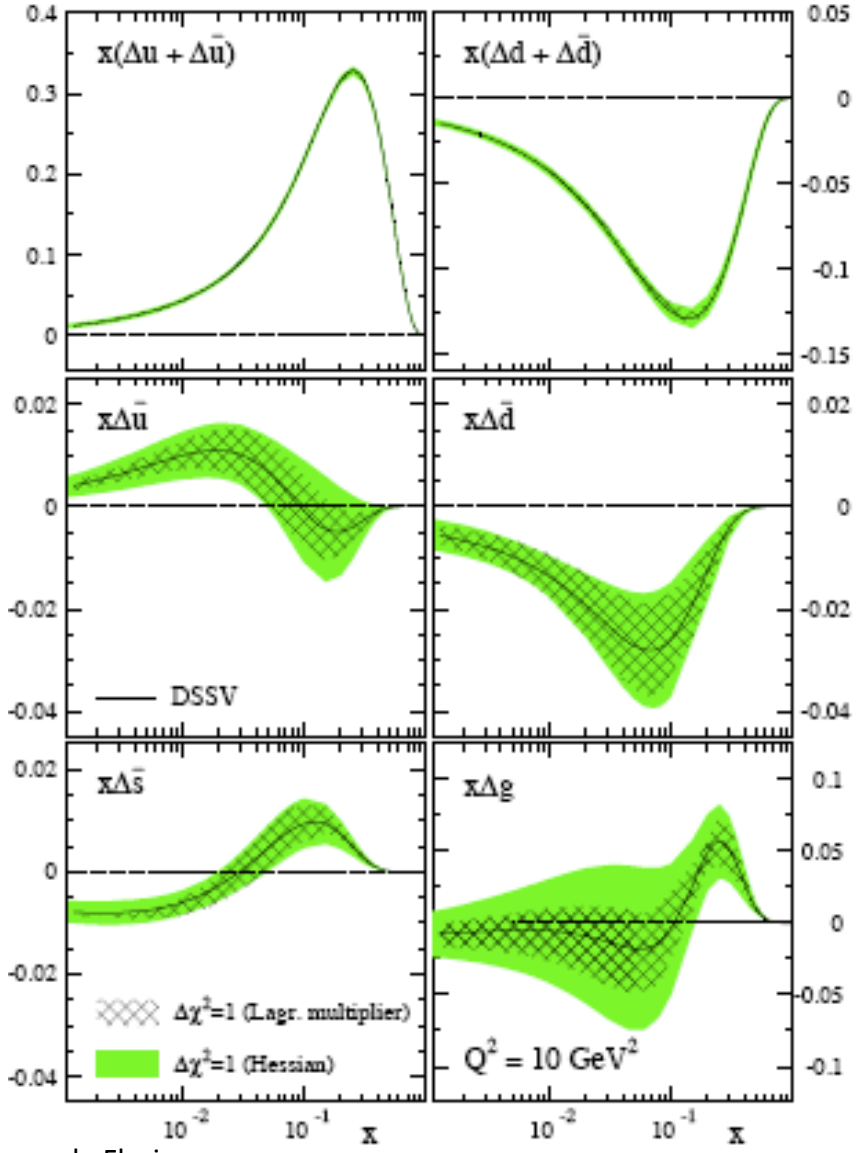
$$S_z = \tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + L_z^g + L_z^q \qquad (L = L_z^g + L_z^q)$$

$\Delta\Sigma$: u, d, s, $\bar{u}$, $\bar{d}$, $\bar{s}$ — ΔG: J_g

Global analysis predicts positive net helicity difference

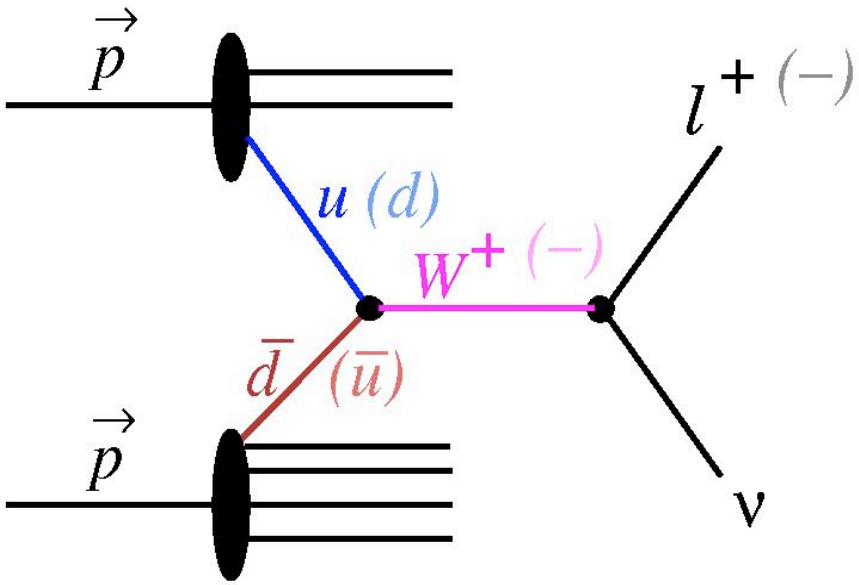


Recent global analysis results

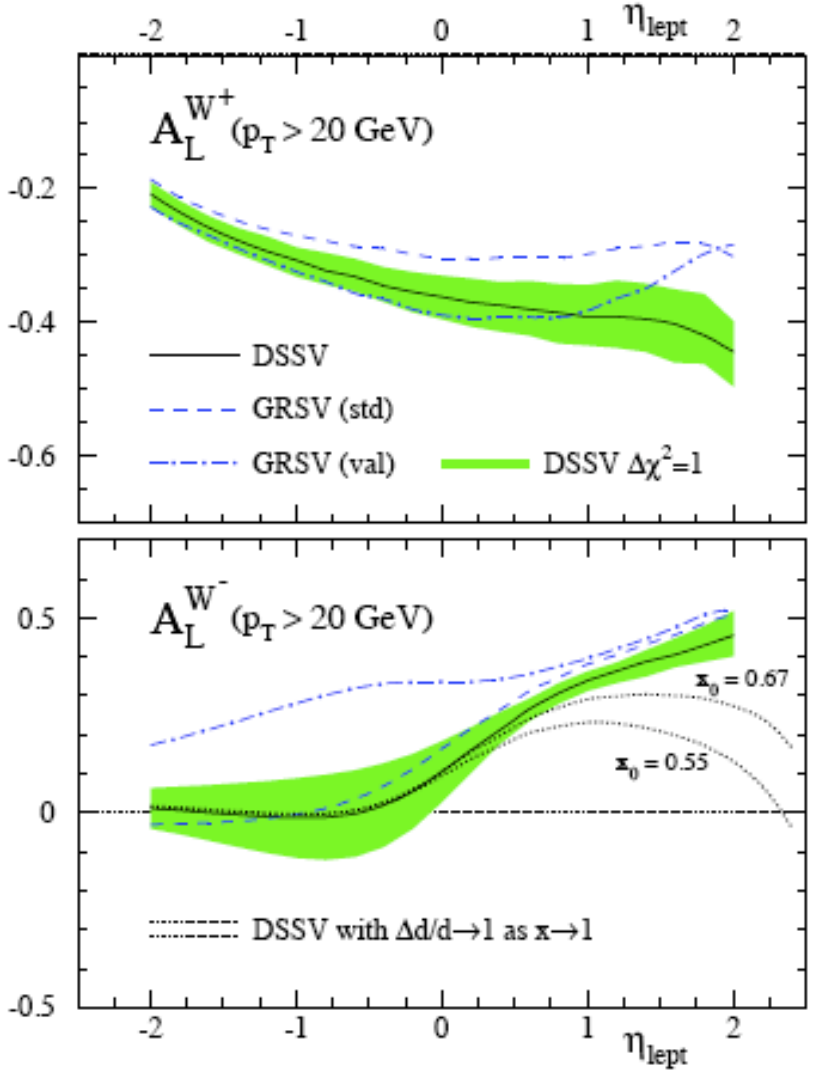


de Florian: http://arxiv.org/pdf/0904.3821v1

W measurement sensitive to anti-quark helicity



Predicted sizable A_L for Ws at mid rapidity to be measured at STAR



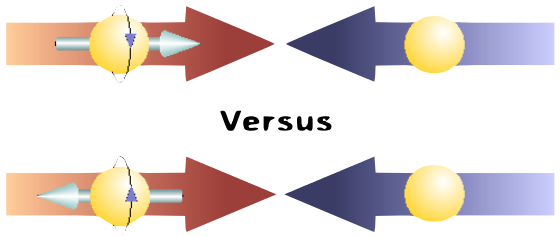
Parity violating single spin asymmetry A_L

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

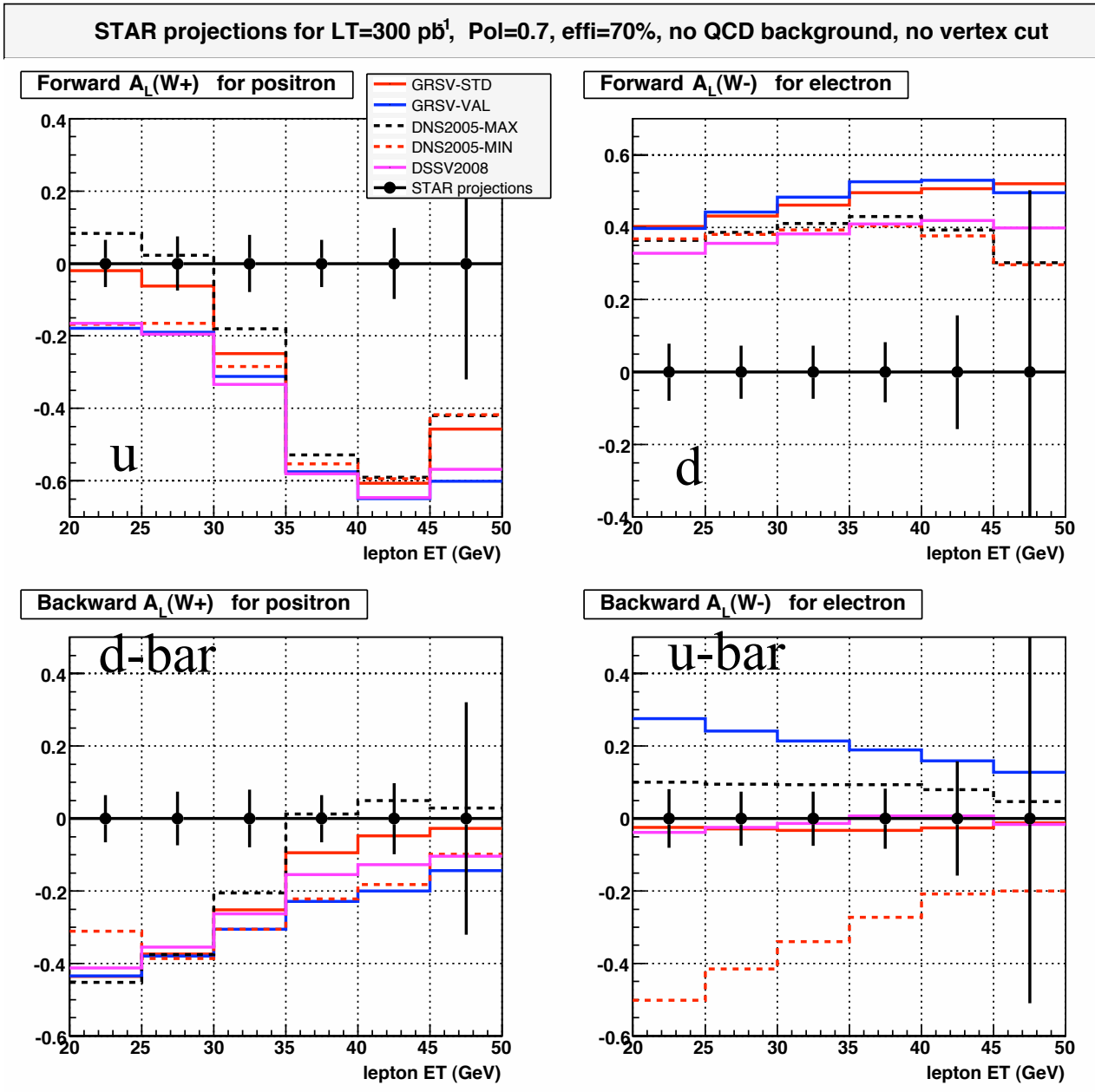
$$A_L^{W^-} \sim \bar{u}(x_1)\Delta d(x_2) + d(x_1)\Delta\bar{u}(x_2)$$

STAR Projections: q/qbar polarization at **forward rapidity**

A_L



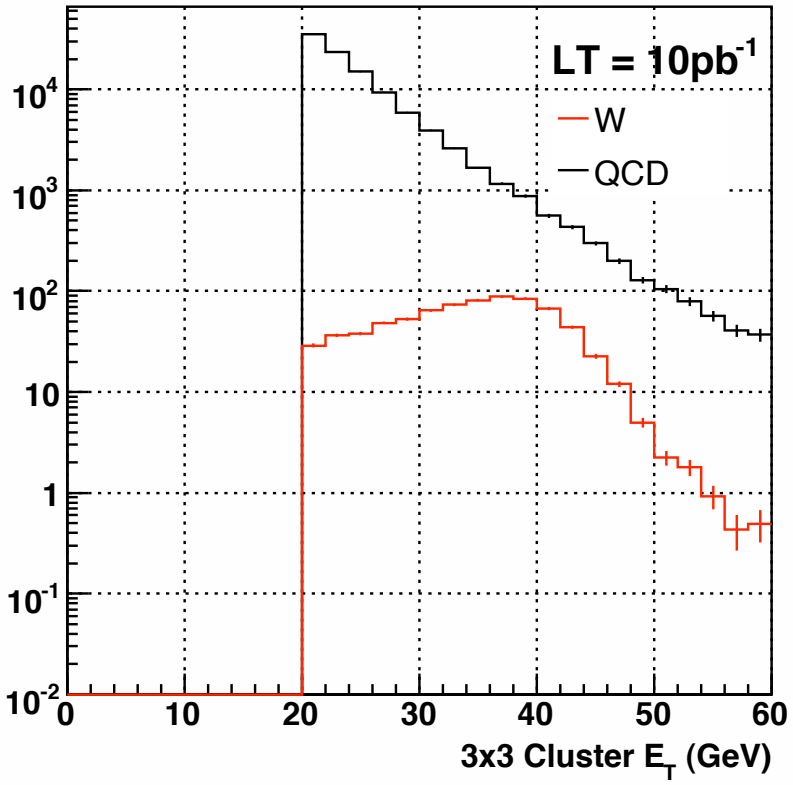
- integrated over amny years LT=300/pb (RHIC SPIN document submitted to DOE)
- Large asymmetries dominated by quark polarization - Important consistency check to existing DIS data with 100pb^{-1} (Phase I)
- measure precisely the anti-up and anti-down quark polarizations with a high luminosity sample of ~300 pb^-1 and 70% beam polarization (Phase II)



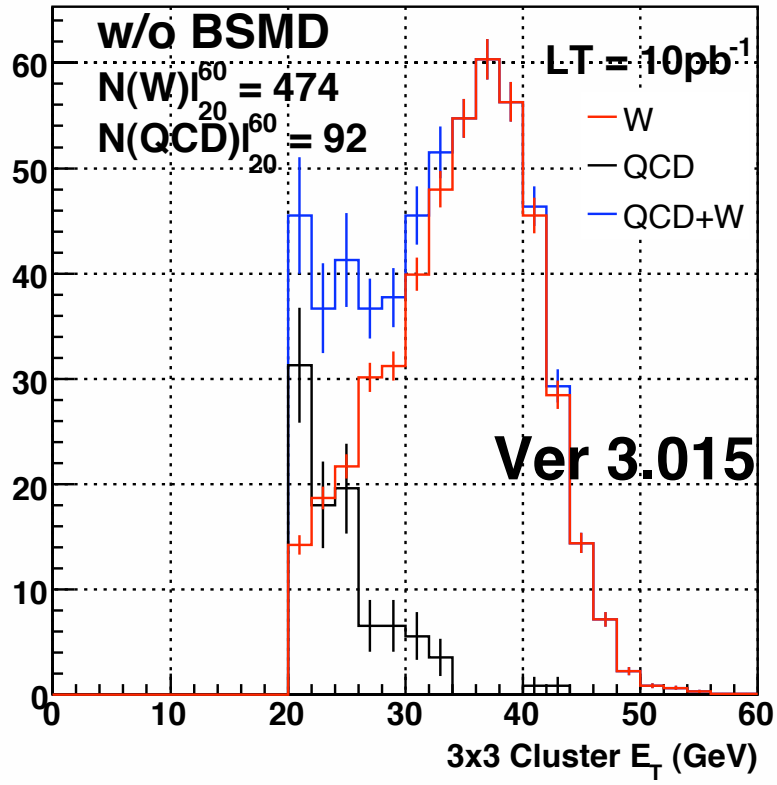
QCD Physics Background Suppression at Mid Rapidity

MC simulations of Run 9 sensitivity

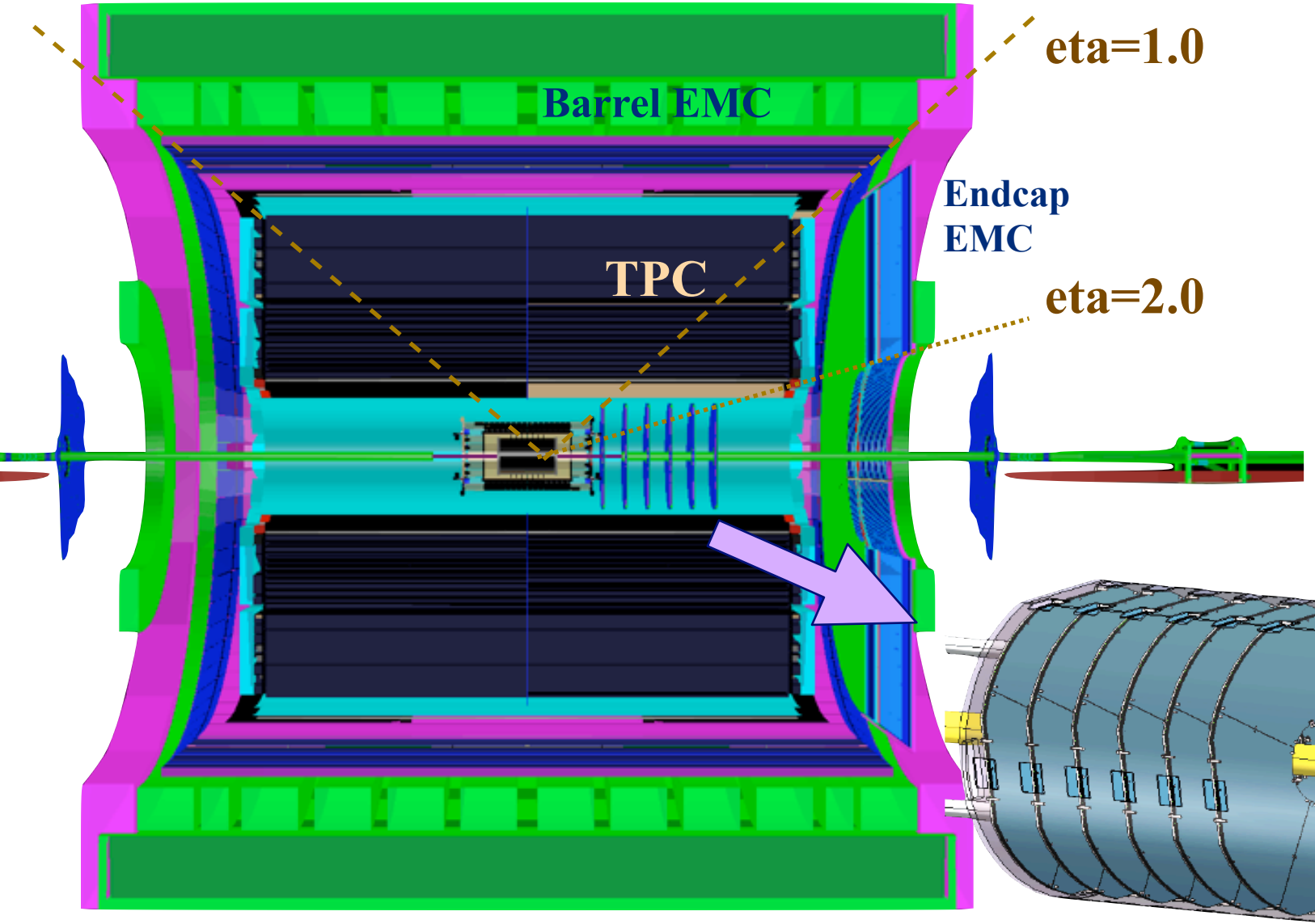
QCD and W for mid-rapidity before cuts

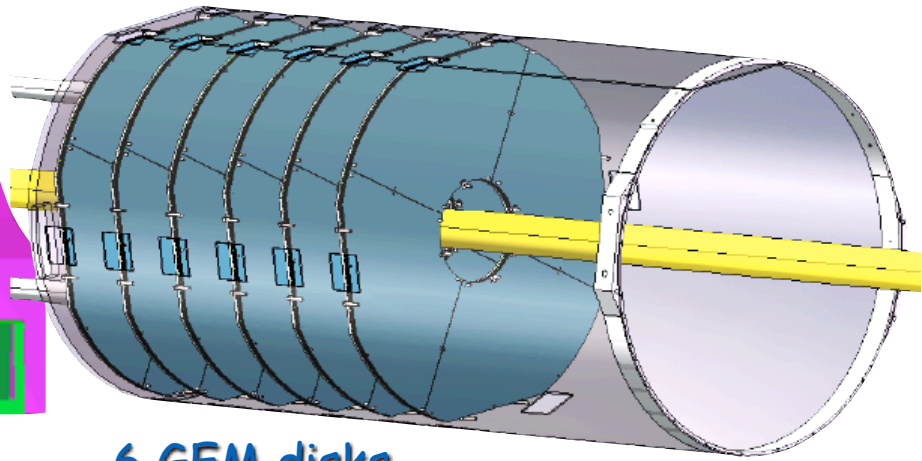


QCD and W for mid-rapidity after cuts



STAR detector with extended forward tracking





6 GEM disks

Summary and Outlook

- pQCD: Critical role to interpret measured asymmetries
- 2006 results: First hadron A_{LL} result at forward rapidity / Improved precision at mid-rapidity (hadron and jet A_{LL}) / Improve π^+ analyzing power at high z
- First global analysis incl. RHIC SPIN data ⇒ Evidence for small gluon polarization for $0.05<x<0.2$
- Correlation measurements (Di-Jets / γ-Jets) will allow to provide needed constraint on the partonic kinematics
- 500GeV program together with wide rapidity coverage in STAR ($-1<\eta<4$) will allow to extend the currently measured kinematic region towards small-x ($x \sim 10^{-3}$)
- **Run 9: First 500GeV run completed (~10pb^{-1}) and large 200GeV data set (~22pb^{-1})**
- Awaiting forward rapidity A_L measurement from Ws within next few years

Thank you Alma Matter !

Ph.D. Nomination
Jagiellonian University, Krakow 1992