

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 W s
- Outlook



European Physical Society
HEP 2009
16-22 July 2009 Krakow, Poland

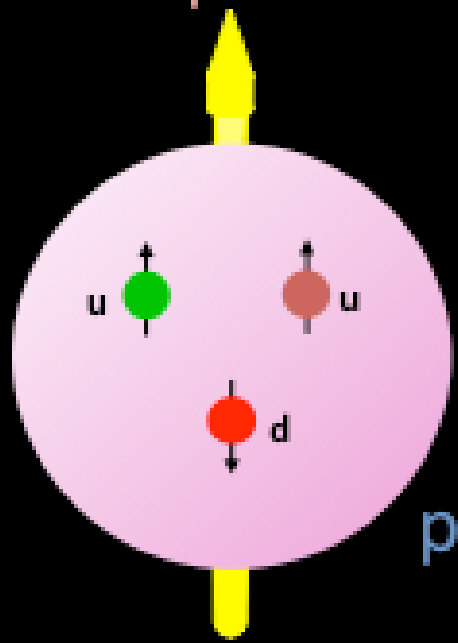
Jan Balewski 
For the STAR Collaboration

Where does the proton's spin come from?

p is made of 2 u and 1d quark

$$S = \frac{1}{2} = \sum S_q$$

Explains magnetic moment of baryon octet



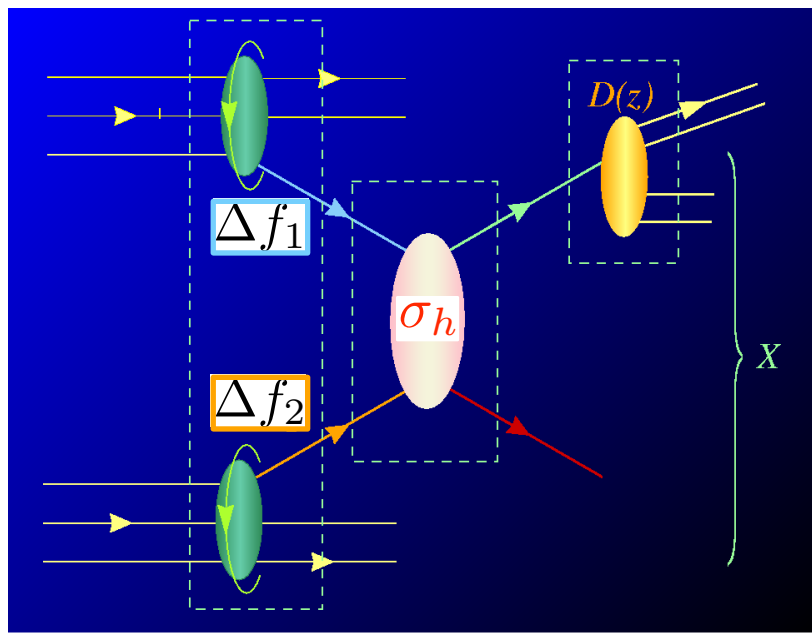
$$S_z = \frac{1}{2} = \frac{1}{2} \underbrace{\Delta\Sigma}_{\overline{u, d, s}, \overline{\overline{u}, \overline{d}, \overline{s}}} + \underbrace{\Delta G}_{J_{gg}} + \underbrace{L_z^g + L_z^q}_L$$

Theoretical foundation of Measurement of Gluon Polarization

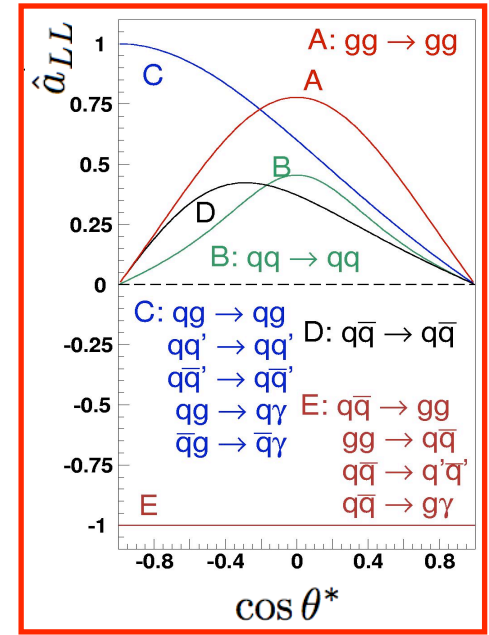
$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$



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



long-range short-range long-range

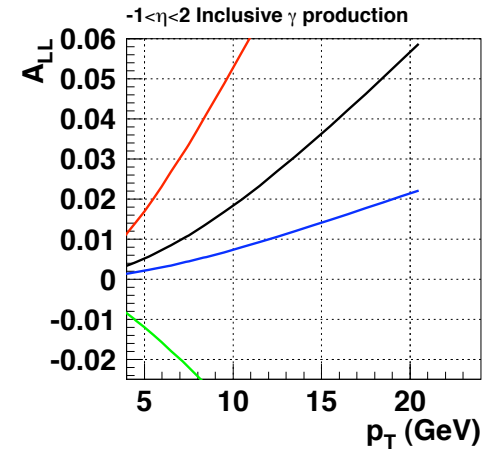
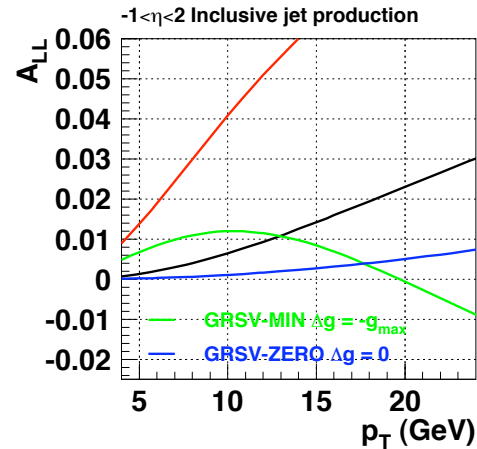
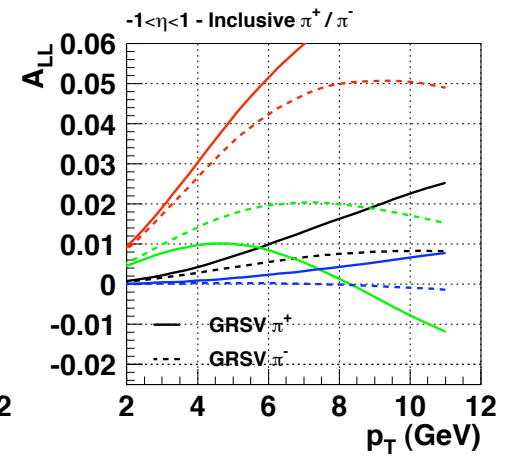
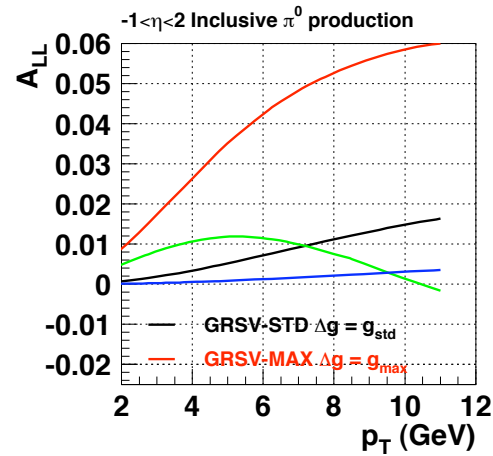
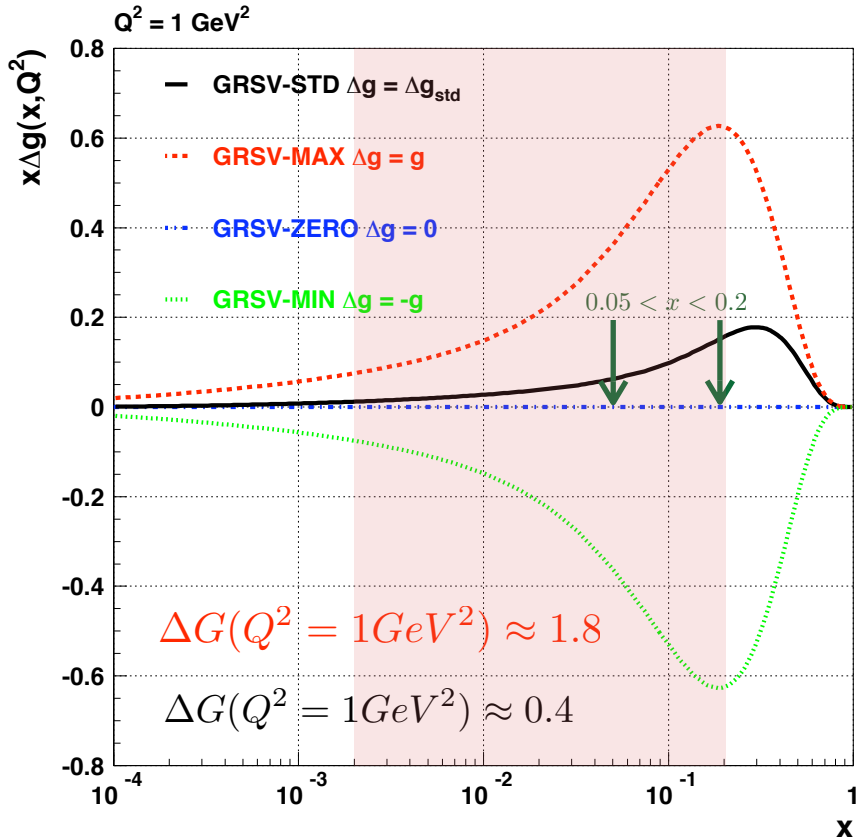


W. Vogelsang, private communication.

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

$a_{LL} = \frac{\Delta\sigma_h}{\sigma_h}$ } 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!

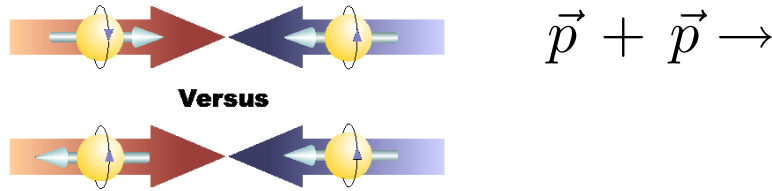
$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

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

(central rapidity)

Components of experiment

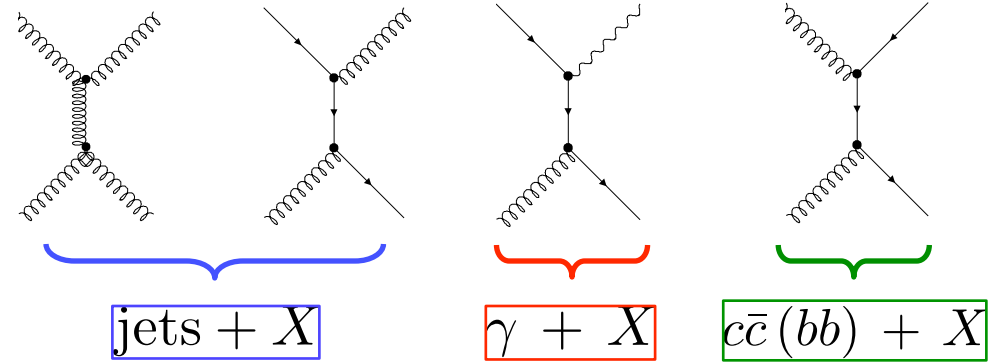
○ Double longitudinal-spin asymmetry: A_{LL}



- Study helicity dependent structure functions (*Gluon polarization*)!

○ 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}

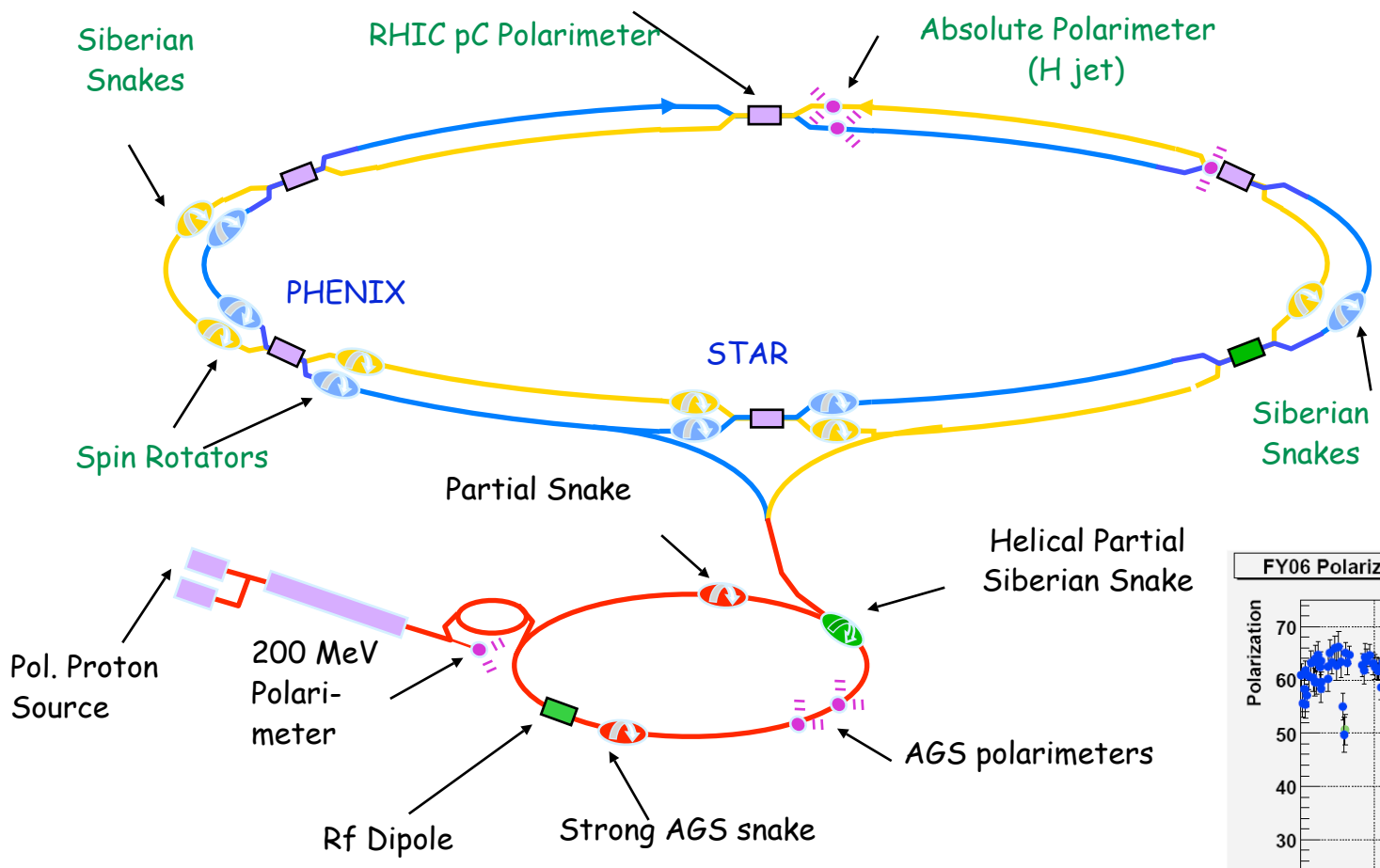


$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

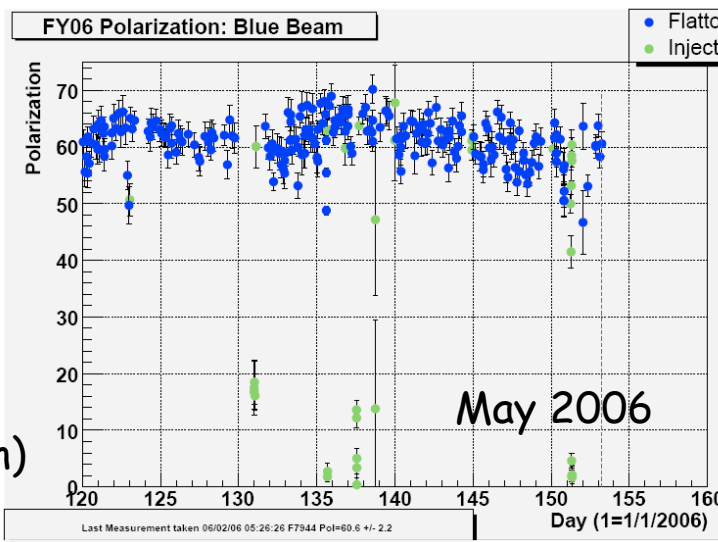
} RHIC polarimeters

} STAR experiment

Collider: The First polarized p+p collider at BNL



Performance



- All RHIC polarized pp accelerator components in place!
- 2006 performance ($\sqrt{s}=200\text{GeV}$): **~60% polarization** (70% design) and **~1pb⁻¹/day** (~3pb⁻¹/day design) **delivered luminosity**



The STAR Experiment

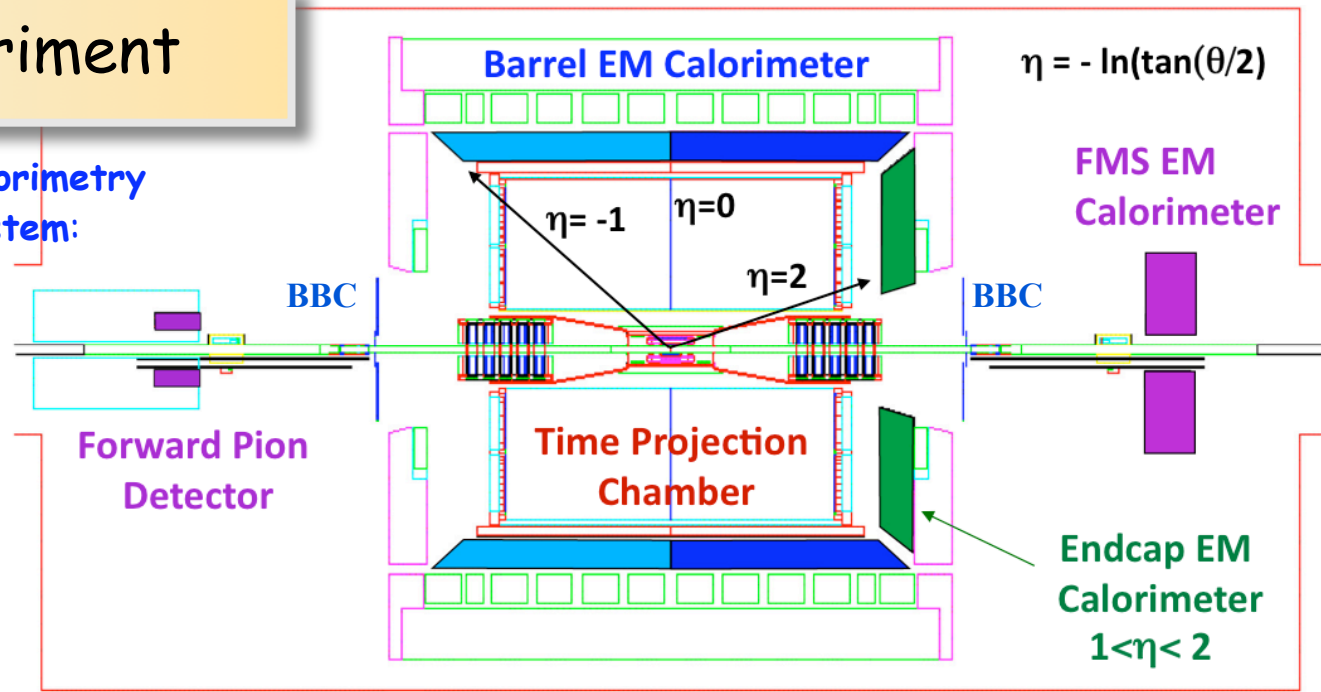
Wide rapidity coverage of STAR calorimetry (Jets / Neutral Pions / Photons) system:

BEMC: $-1.0 < \eta < 1.0$

EEMC: $1.09 < \eta < 2.0$

FPD: $4.1 < \eta < 3.3$

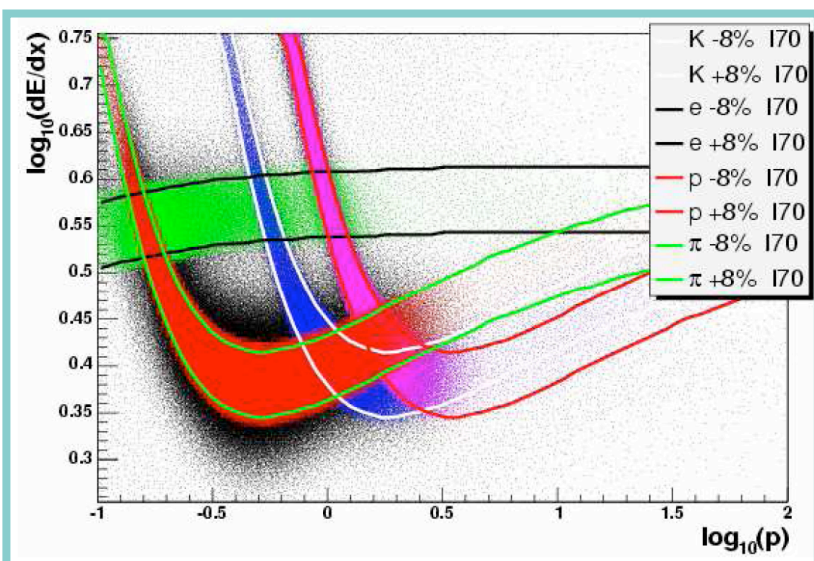
TPC: Tracking and PID using dE/dx for $|\eta| < 1.3$ and $p_T < 15 \text{ GeV}/c$



BBC: Relative luminosity and Minimum bias trigger

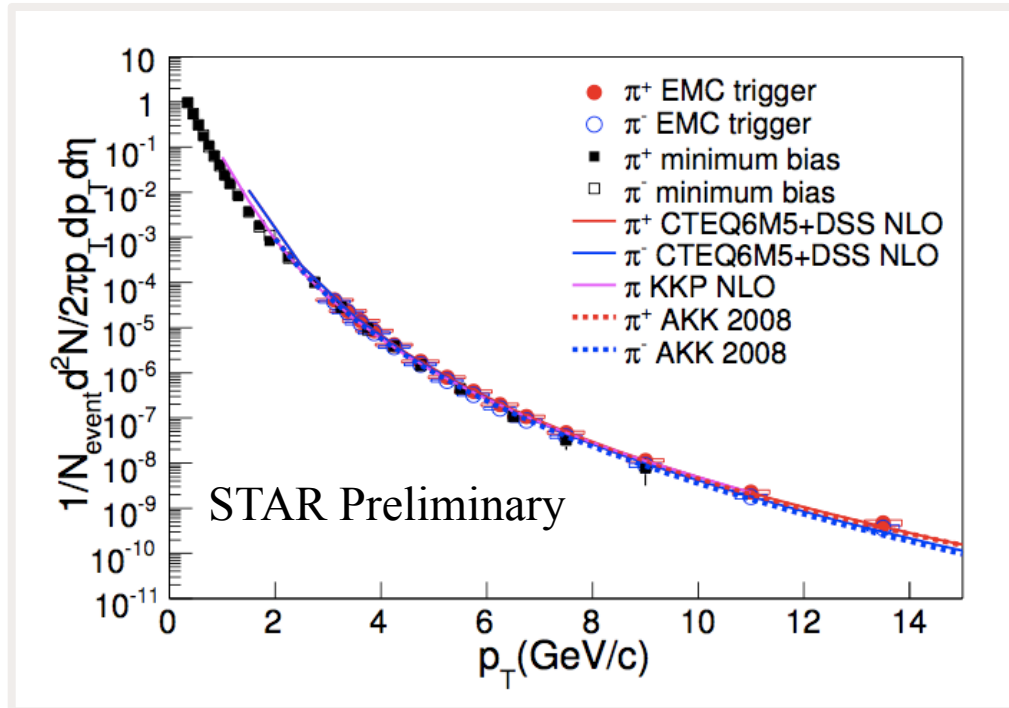
Key elements for STAR $\Delta g(x)$ program:

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



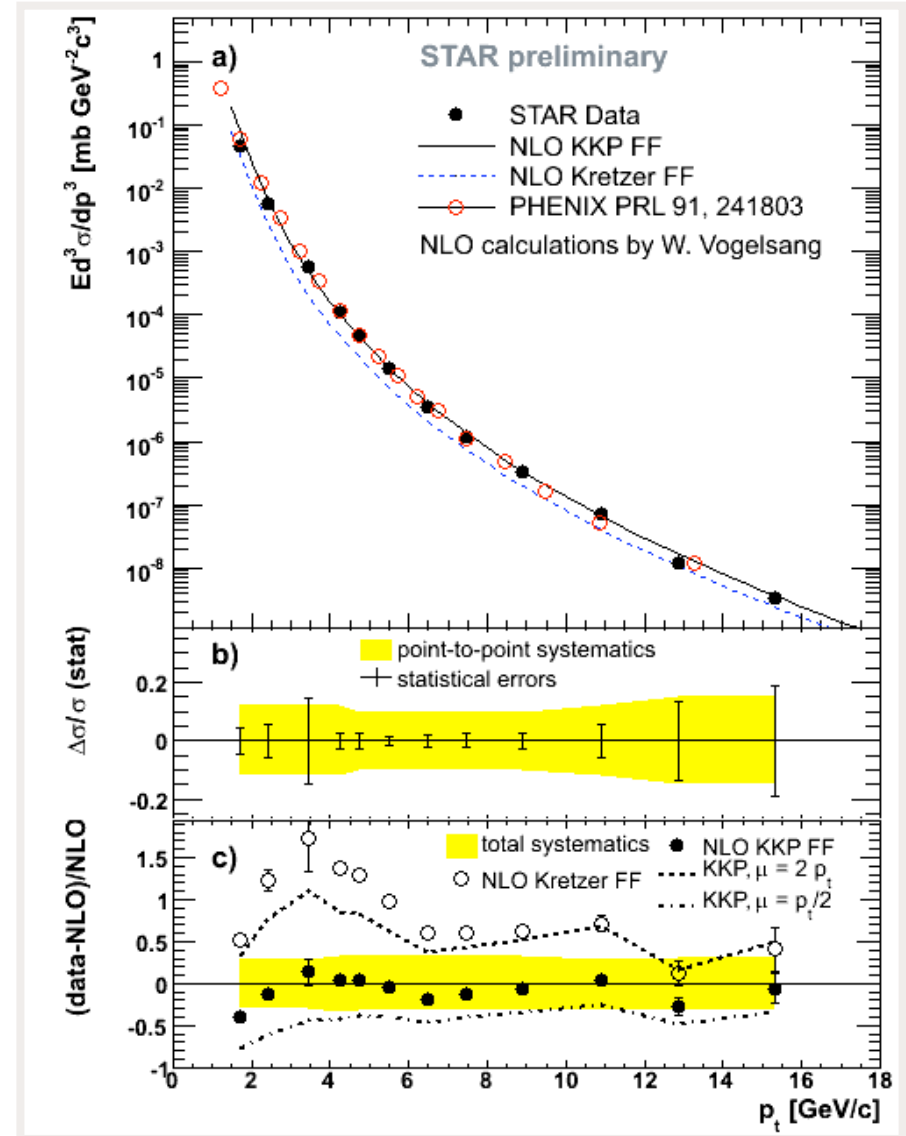
Recent results: Neutral / Charged Pion production

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



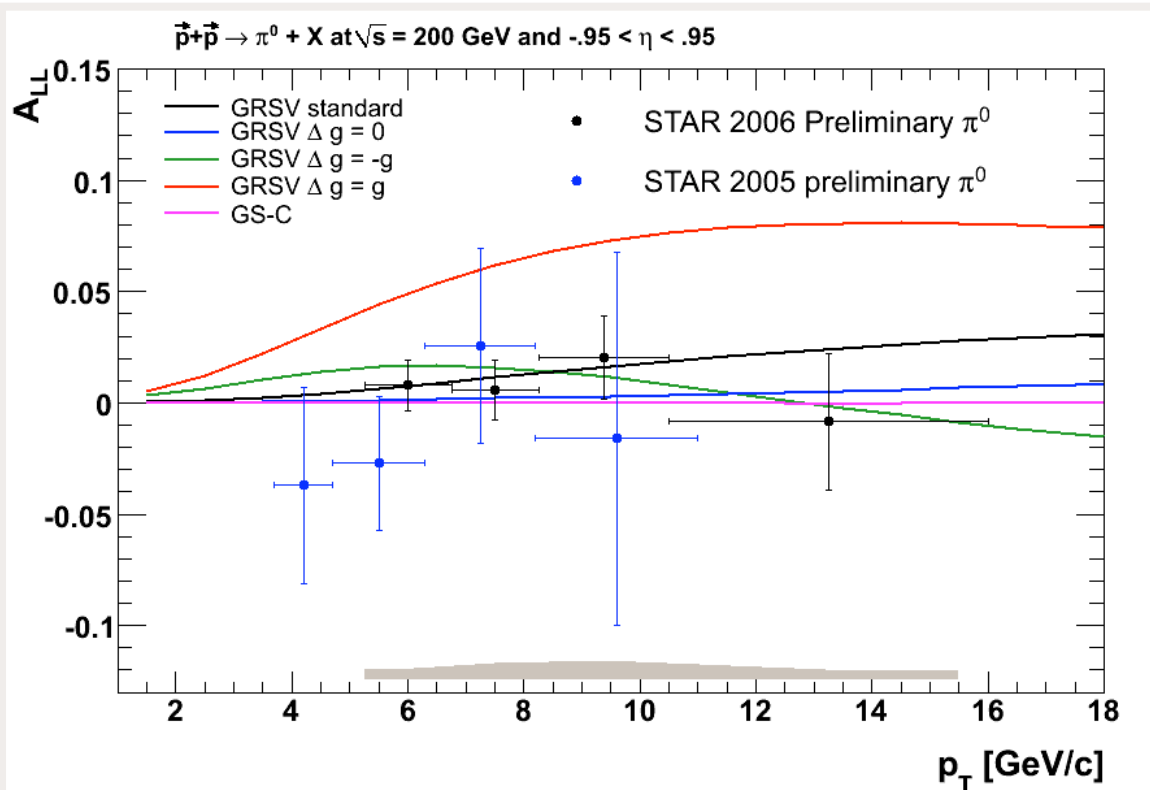
STAR Collaboration, Phys. Lett. B637 (2006) 161.

- 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



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

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

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

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

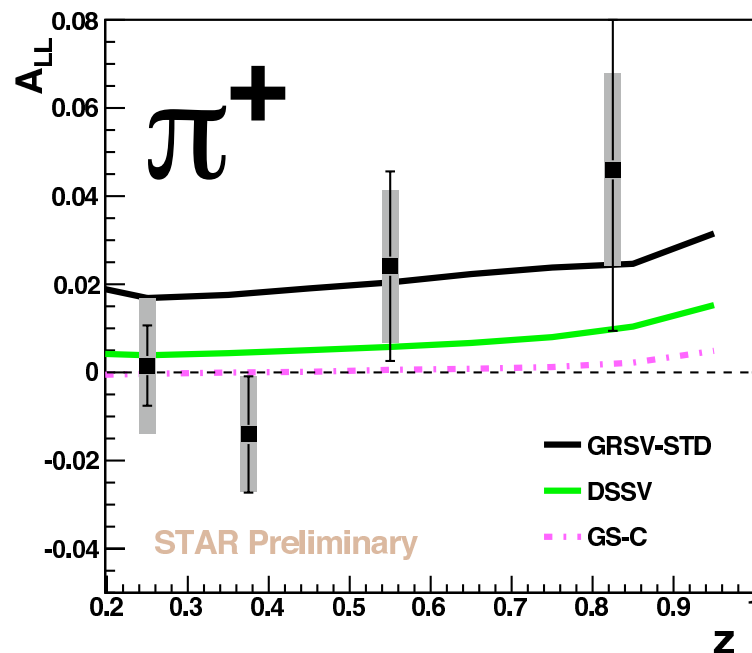
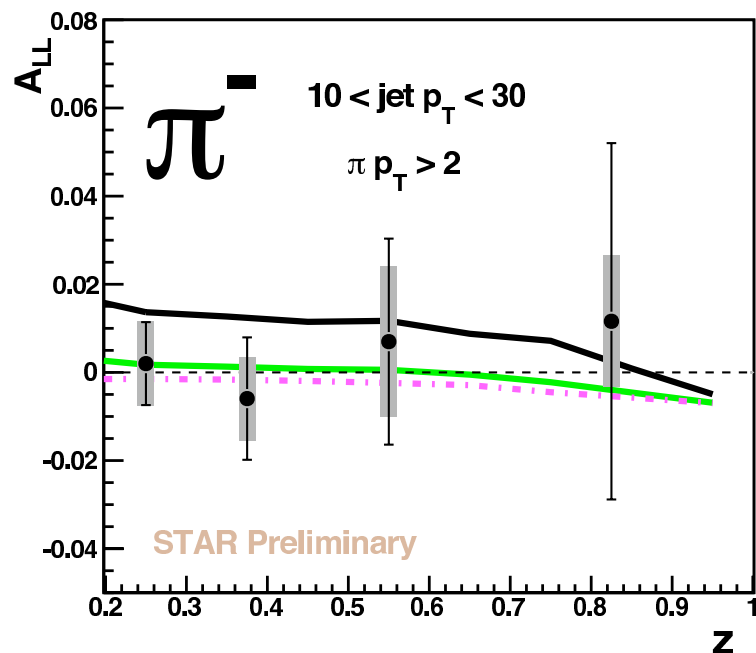
p_T range [GeV/c]	$A_{LL} \pm \text{Stat.} \pm \text{Sys.}$
5.2 - 6.75	$0.0080 \pm 0.0115 \pm 0.002$
6.75 - 8.25	$0.0058 \pm 0.0136 \pm 0.004$
8.25 - 10.5	$0.0203 \pm 0.0189 \pm 0.004$
10.5 - 16.0	$-0.0084 \pm 0.0306 \pm 0.002$

○ 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

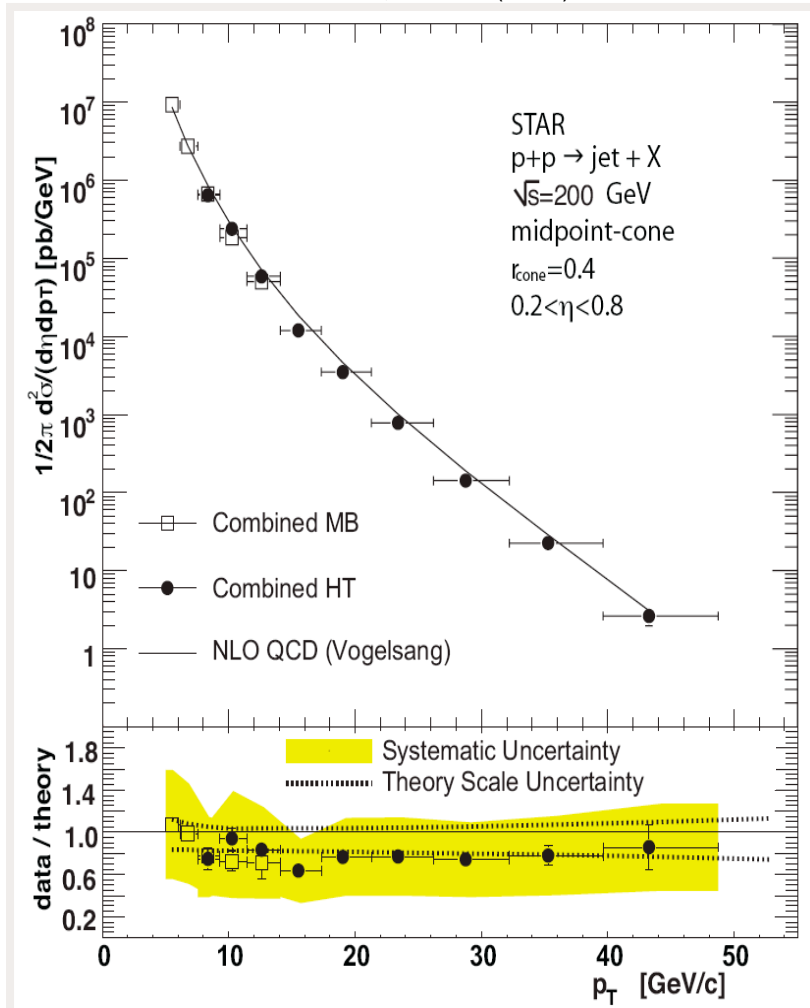


- Full NLO pQCD , D. de Florian et al. arXiv:0904.4402
- These curves generated by sampling a_{LL} and parton distribution functions at kinematics of PYTHIA event.
- NLO suggests significant sensitivity at high z of π^+

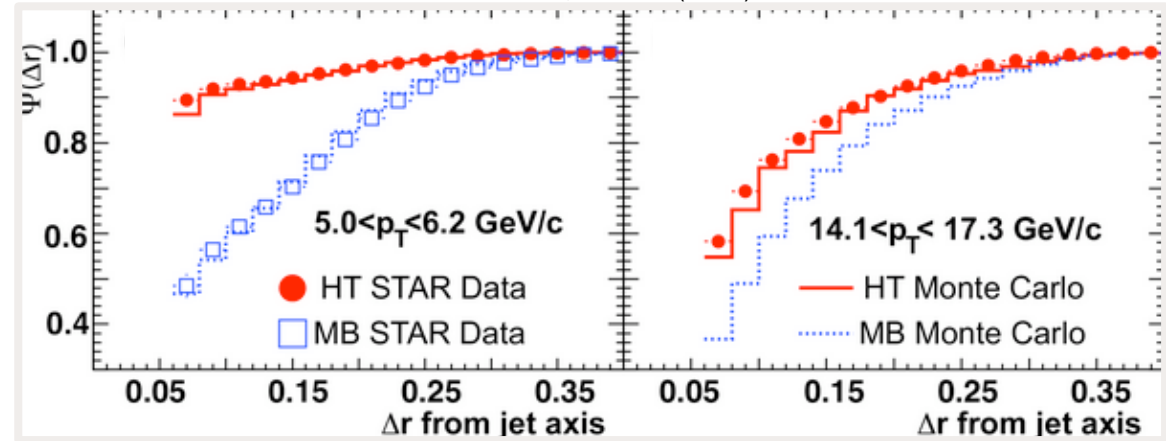
Recent results: Jet production

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

STAR Collaboration, PRL 97 (2006) 252001.



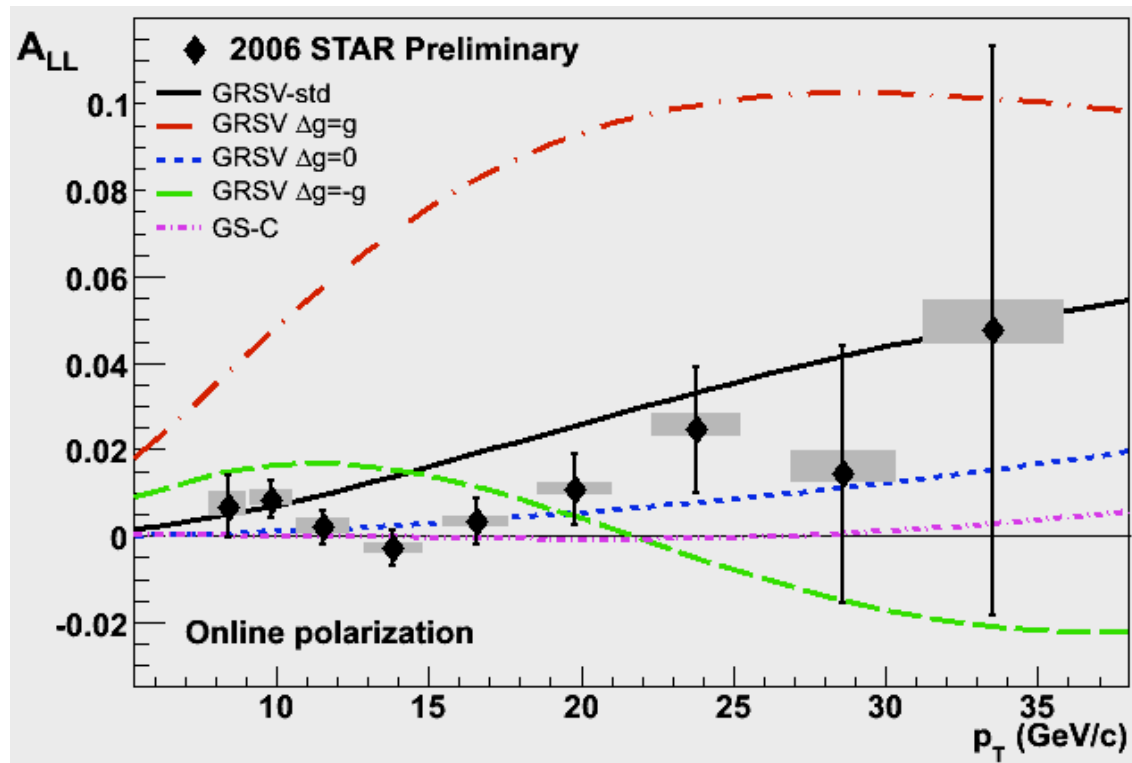
STAR Collaboration, PRL 99 (2007) 142003.



- 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)



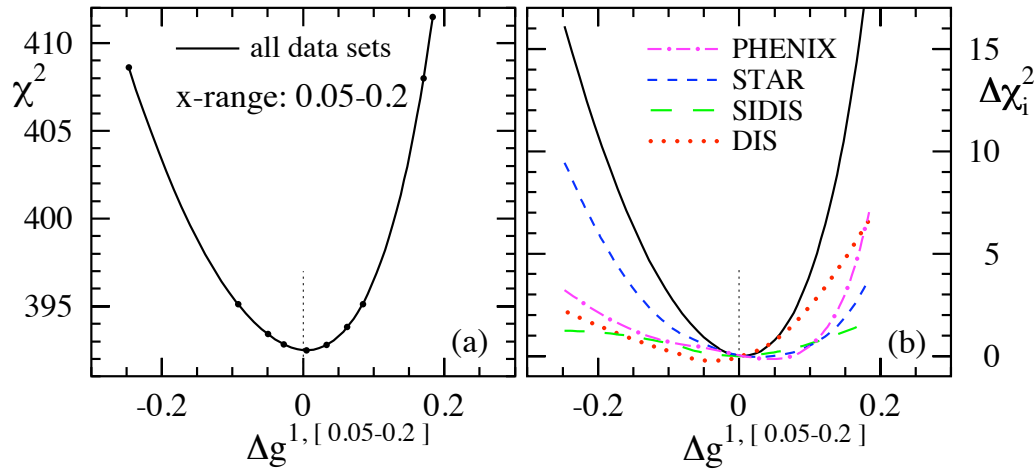
STAR Collaboration, PRL 100 (2008) 232003.

- 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 $p_T > 13 \text{ GeV}/c$)

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	1 st bin ~ 0.5 else ~ 0.1
p_T systematic	$\pm 6.7\%$

Global analysis incorporates RHIC data

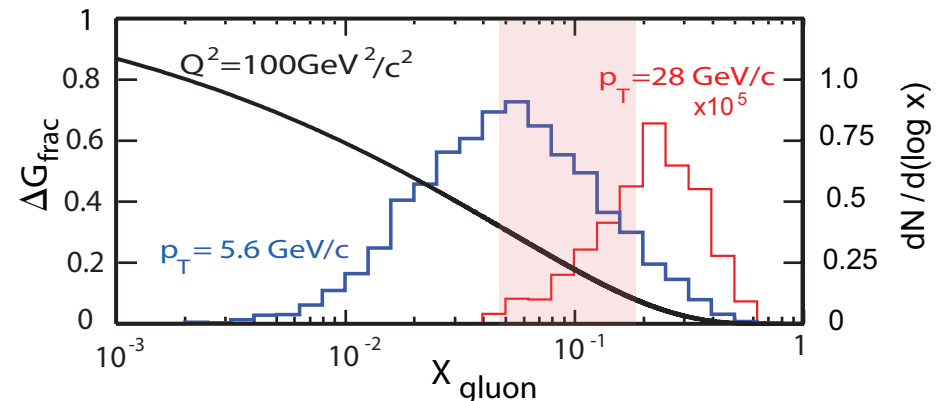
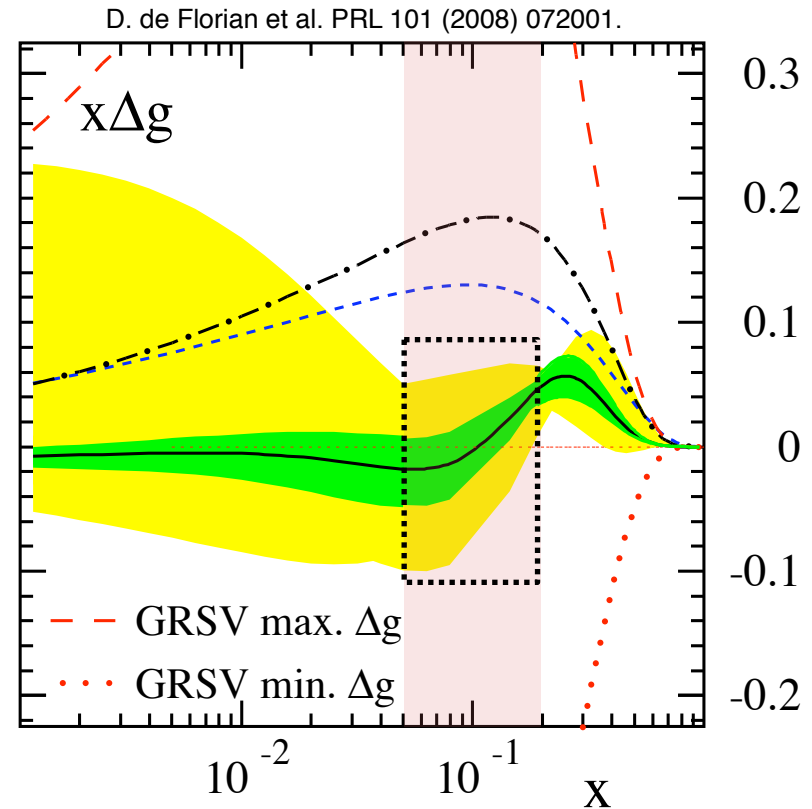
Global analysis incl. RHIC pp data



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

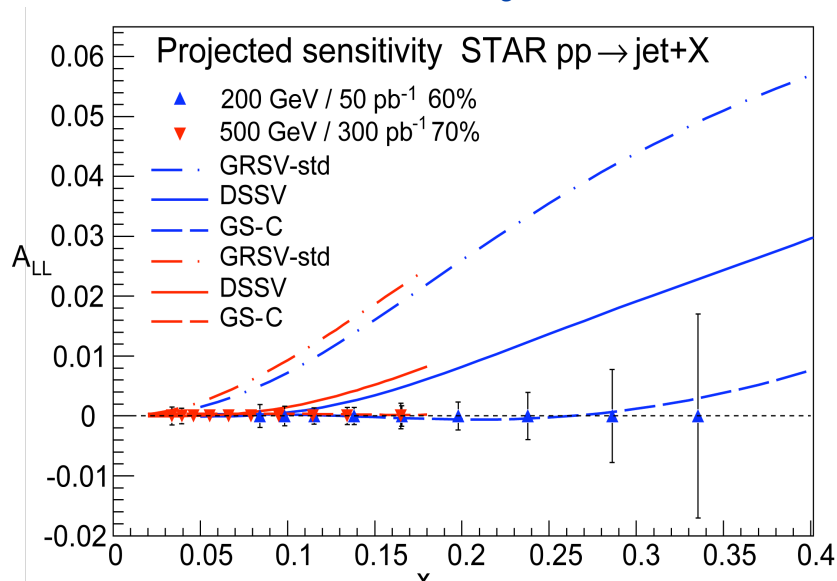
Evidence for a small gluon polarization over a limited region of momentum fraction

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

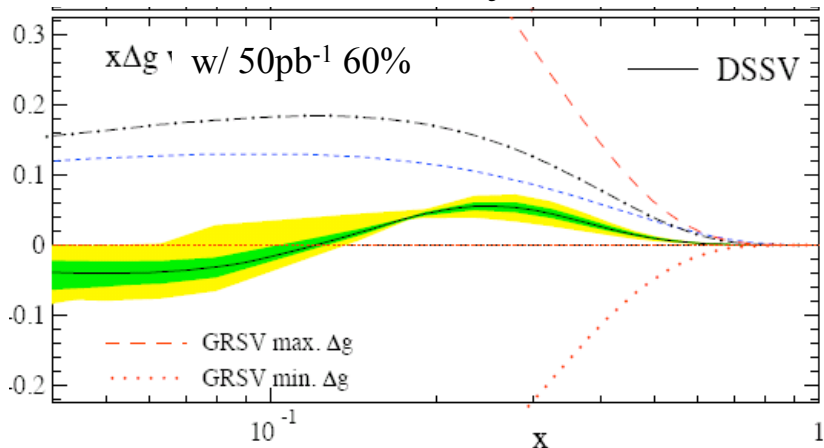


Future Δg measurements at STAR

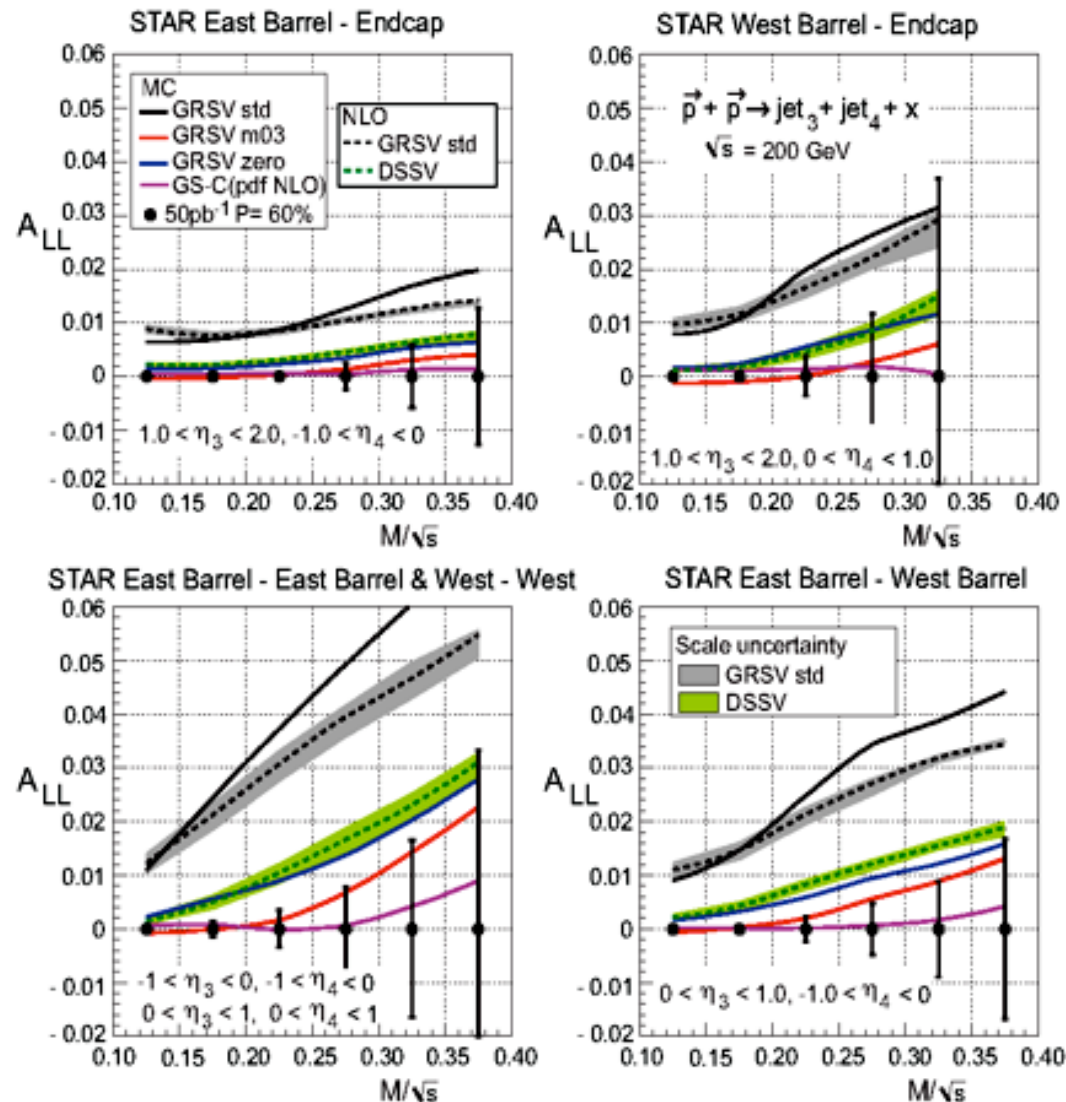
Inclusive jets



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



Projections for di-jets improve understanding of x-dependence

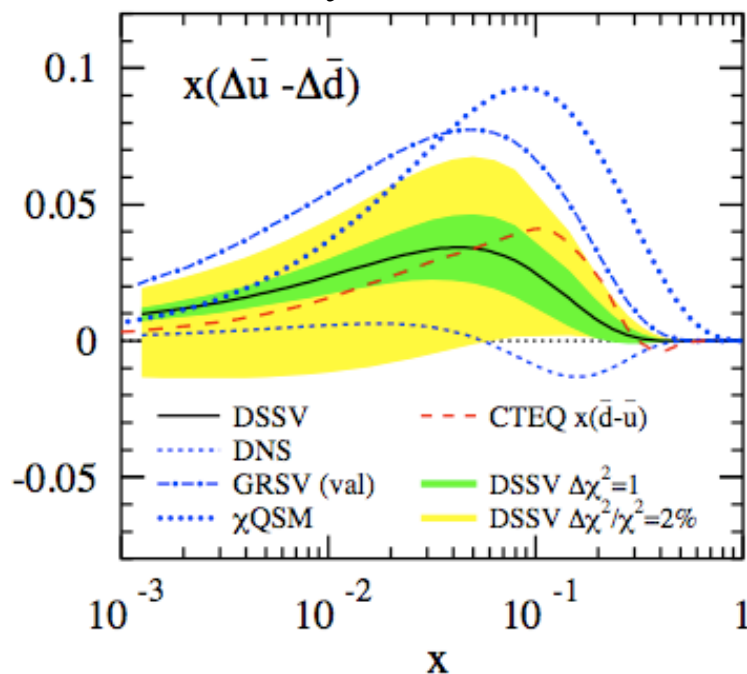


Asymmetry in the sea quarks: STAR W program

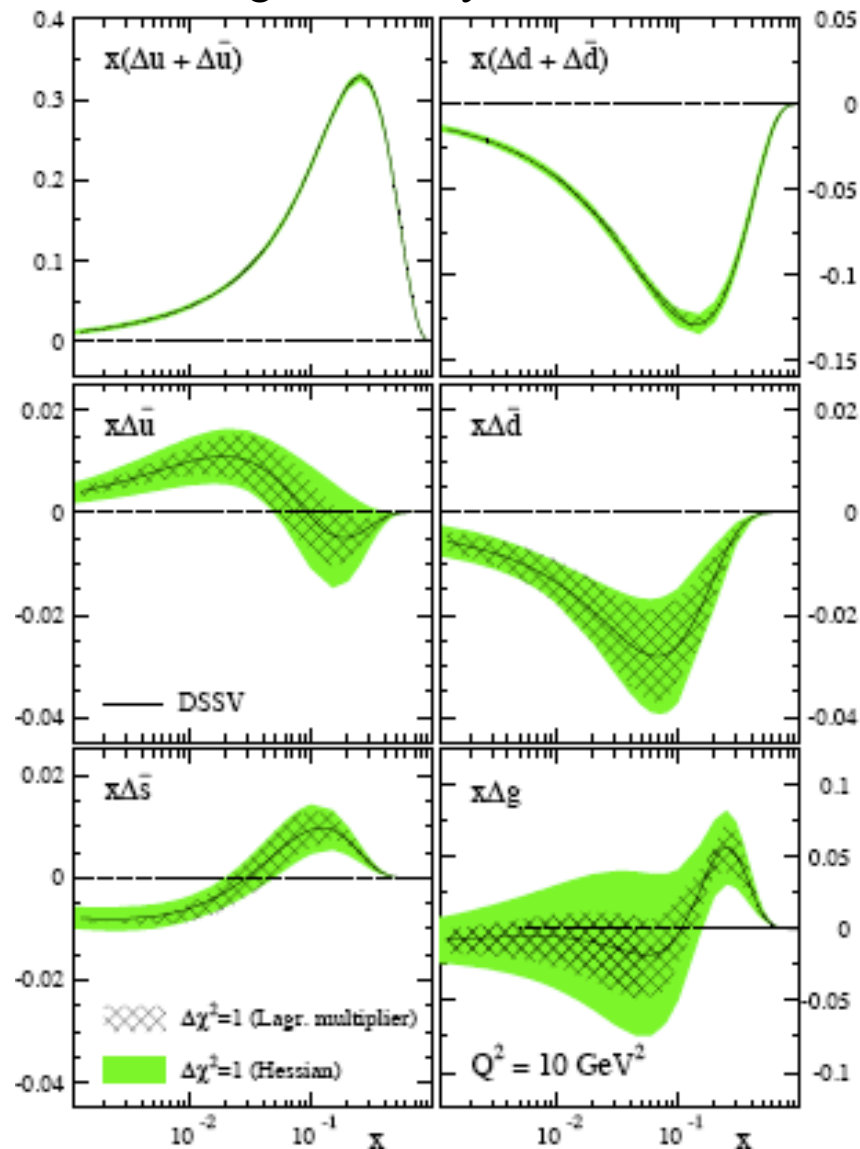
$$S_z = \frac{1}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + L_z^g + L_z^q$$

$\underbrace{\quad\quad\quad}_{\substack{u, d, s, \bar{u}, \bar{d}, \bar{s}}} \quad \underbrace{\quad\quad\quad}_{J_g} \quad \underbrace{\quad\quad\quad}_L$

Global analysis predicts positive net helicity difference



Recent global analysis results

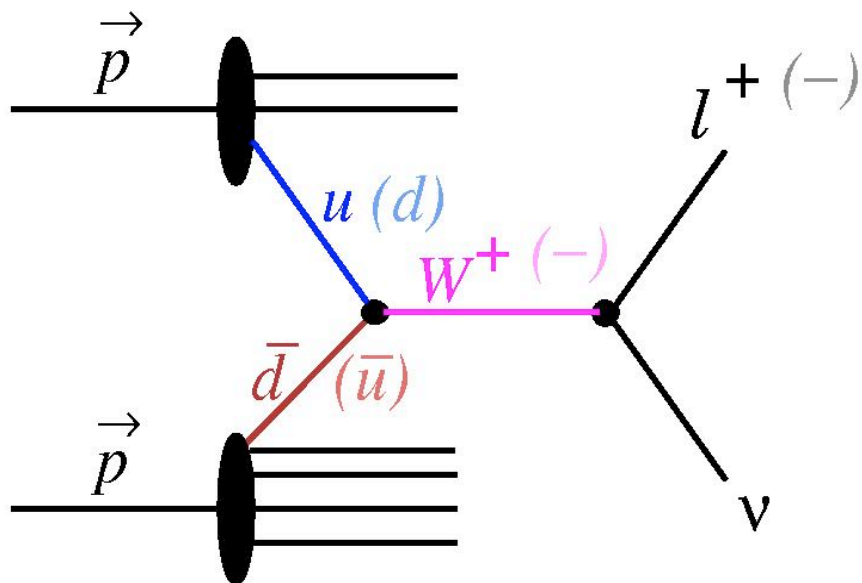


de Florian:

<http://arxiv.org/pdf/0904.3821v1>

Jan Balewski, MIT

W measurement sensitive to anti-quark helicity

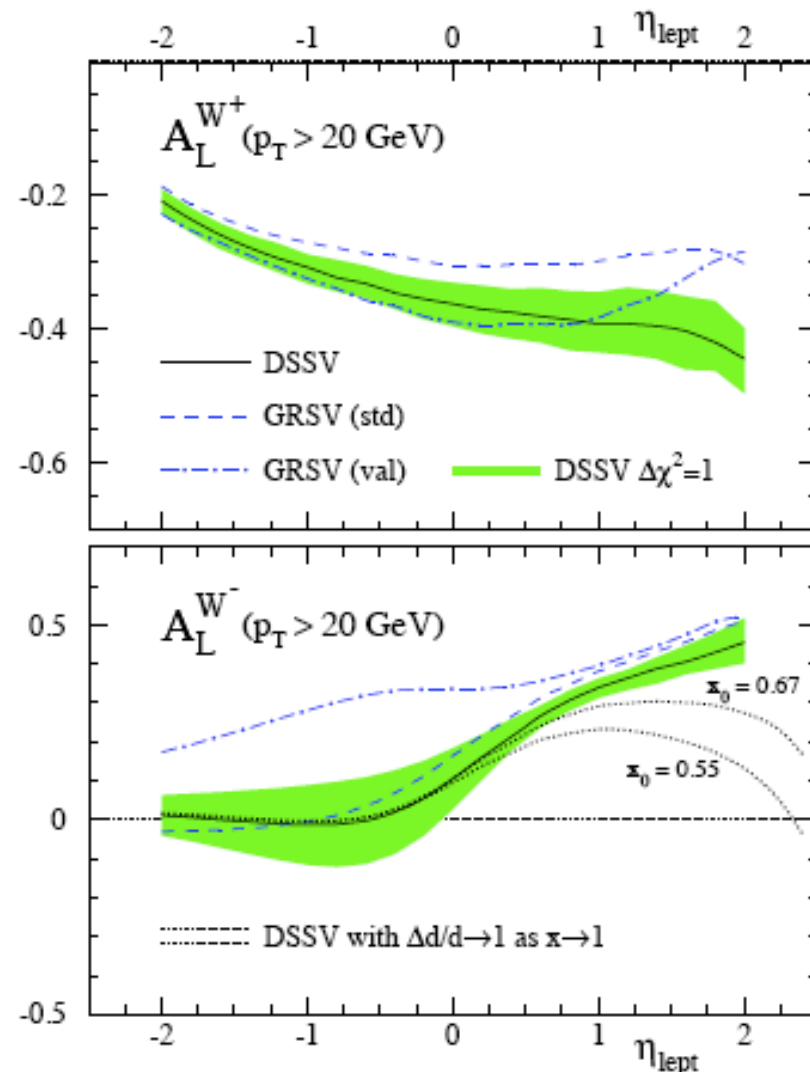


Parity violating single spin asymmetry A_L

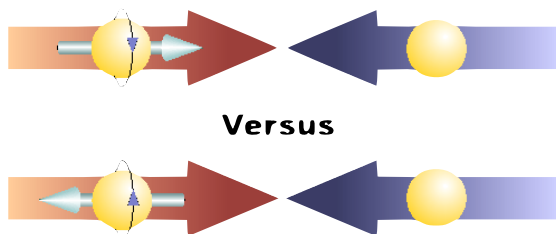
$$A_L^{W^+} \sim u(x_1)\Delta\bar{d}(x_2) + \bar{d}(x_1)\Delta u(x_2)$$

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

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



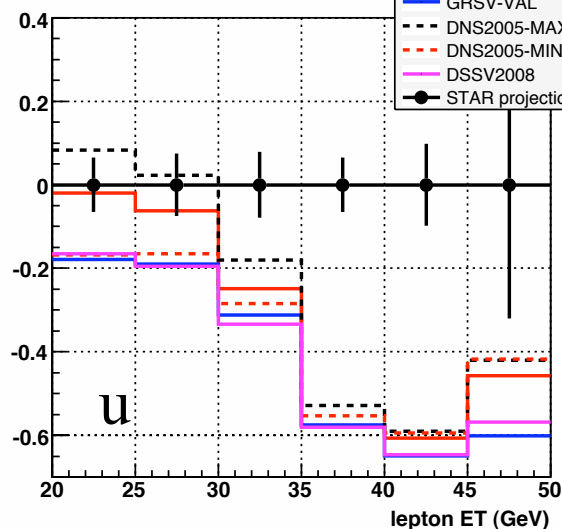
STAR Projections: $q/q\bar{q}$ polarization at forward rapidity

 A_L


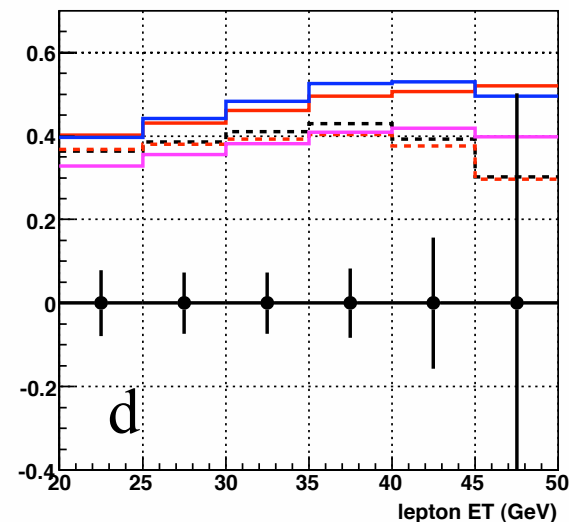
- integrated over many years
LT=300/pb (RHIC SPIN document submitted to DOE)
- Large asymmetries dominated by quark polarization - Important consistency check to existing DIS data with 100pb^{-1} (Phase I)
- measure precisely the anti-up and anti-down quark polarizations with a high luminosity sample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

STAR projections for LT=300 pb¹, Pol=0.7, effi=70%, no QCD background, no vertex cut

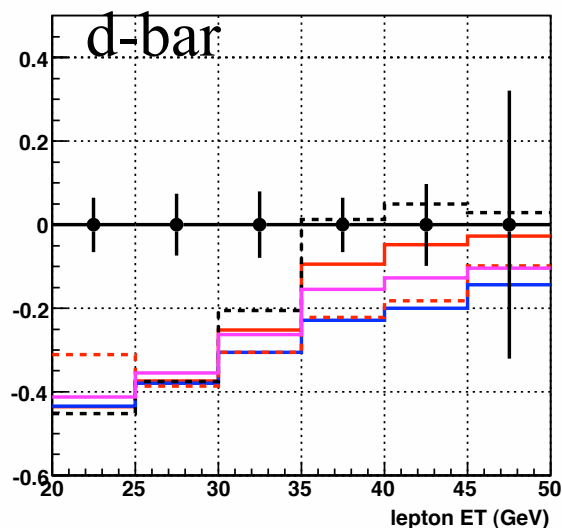
Forward $A_L(W^+)$ for positron



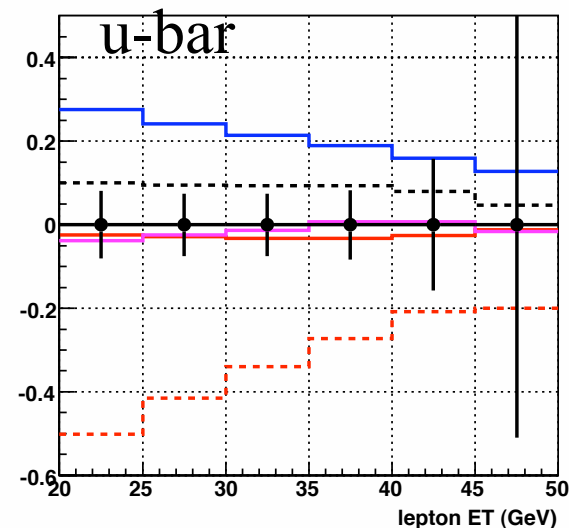
Forward $A_L(W^-)$ for electron



Backward $A_L(W^+)$ for positron



Backward $A_L(W^-)$ for electron

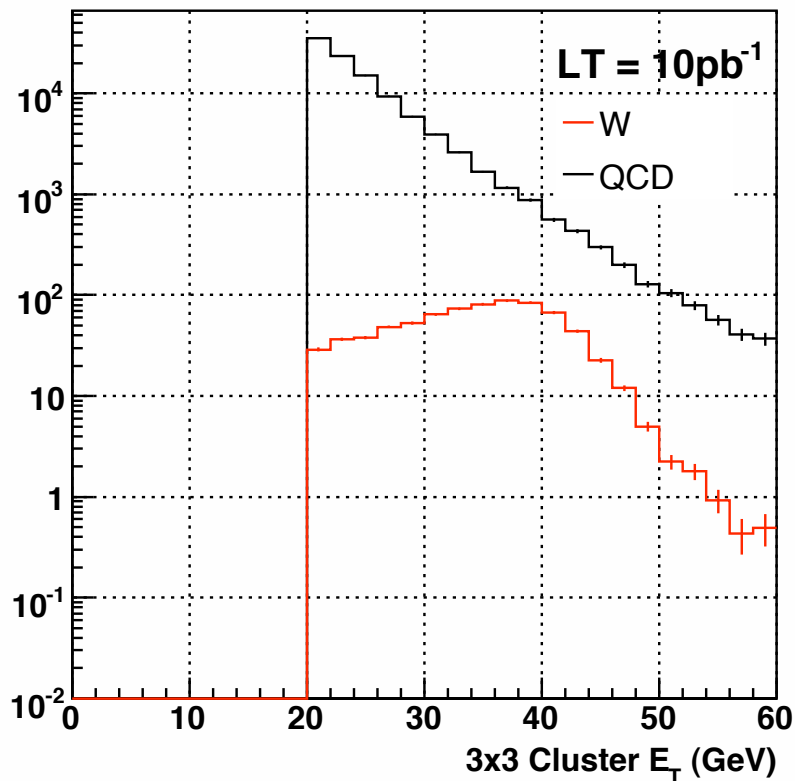




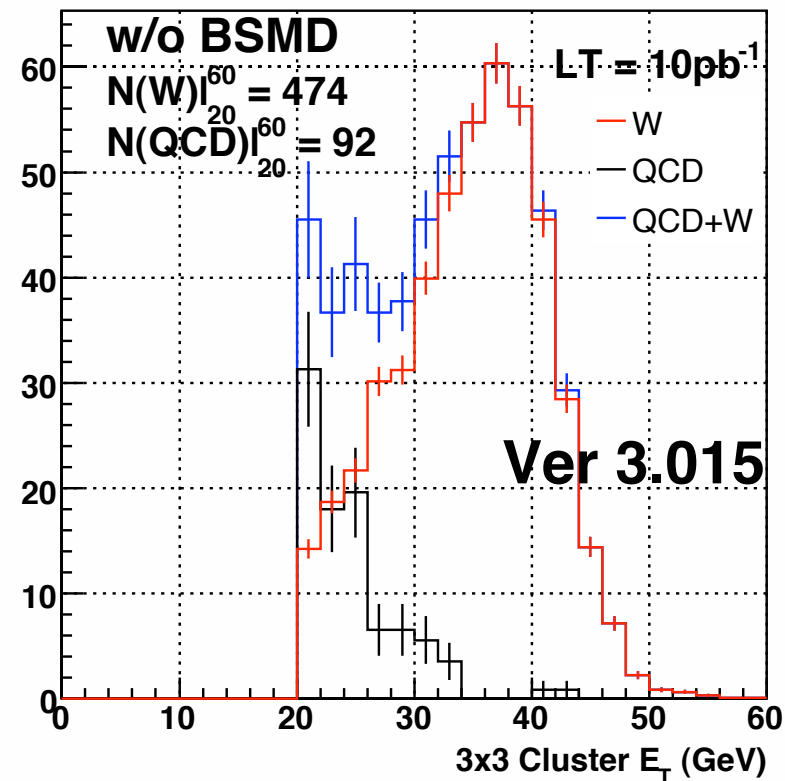
QCD Physics Background Suppression at Mid Rapidity

MC simulations of Run 9 sensitivity

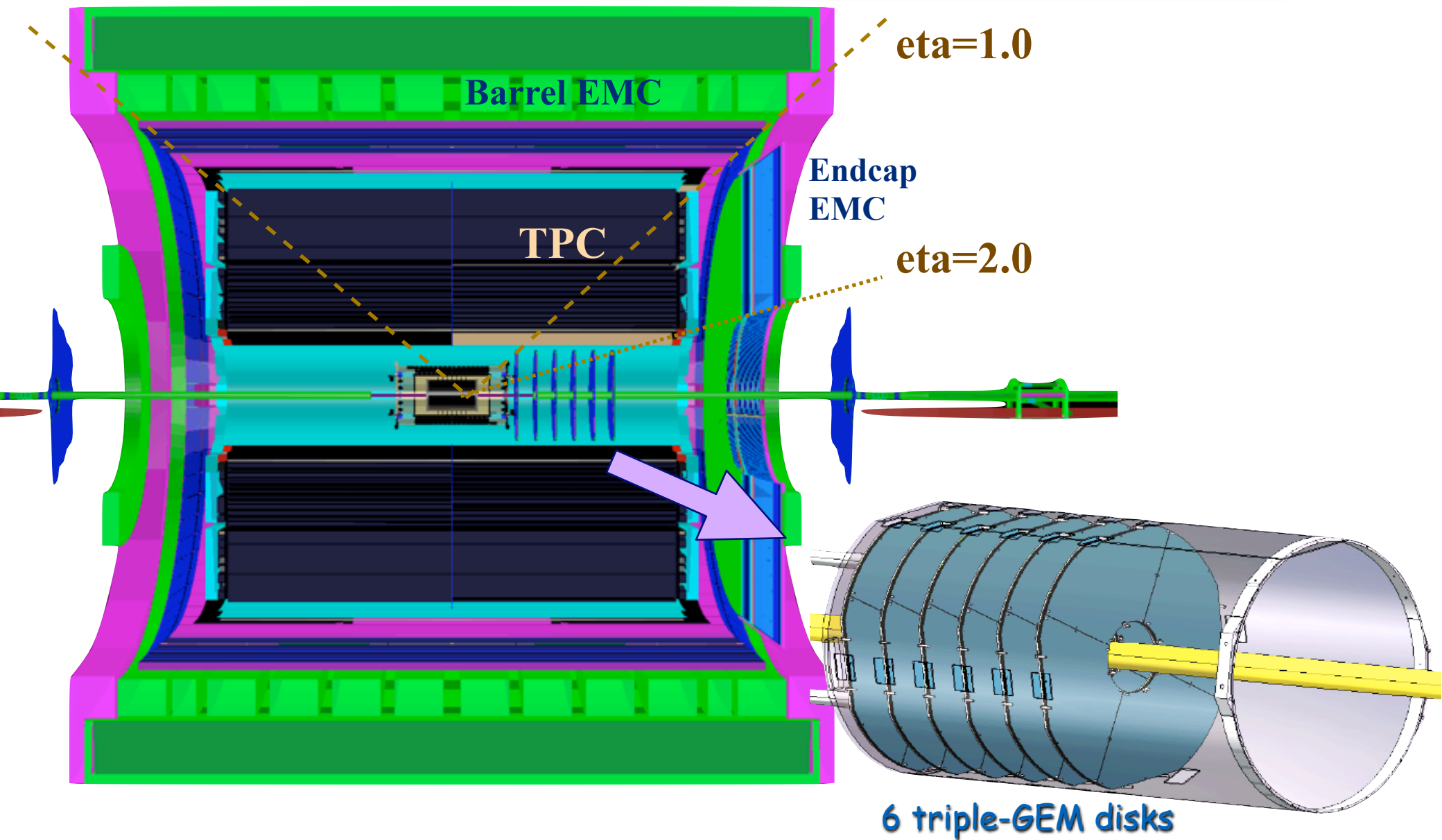
QCD and W for mid-rapidity before cuts



QCD and W for mid-rapidity after cuts



STAR detector with extended forward tracking





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 \Rightarrow 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 ($\sim 10\text{pb}^{-1}$) and large 200GeV data set ($\sim 22\text{pb}^{-1}$)
- Awaiting forward rapidity A_L measurement from W s within next few years

Thank you Alma Matter !

