Future prospects of di-jet production at forward rapidity constraining $\Delta g(x)$ at low x in polarized p+p collisions at RHIC

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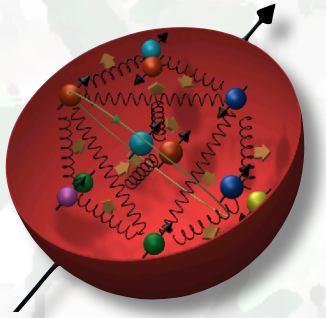
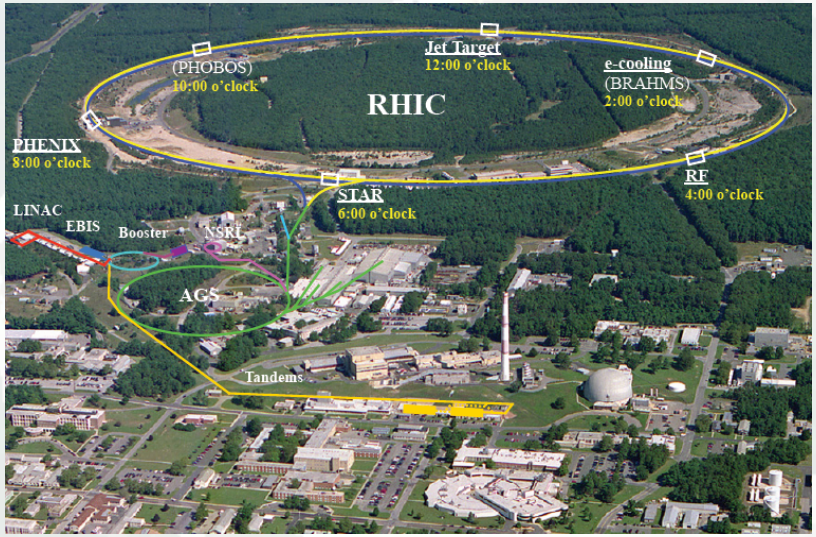


QCD Evolution Workshop

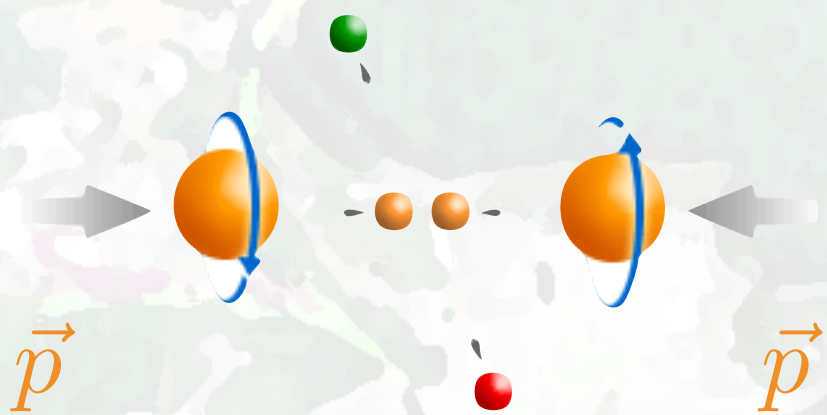
Outline



- Gluon polarization program
  - Current results / status
  - Future prospects based on forward di-jet production

- Experimental aspects: RHIC / STAR

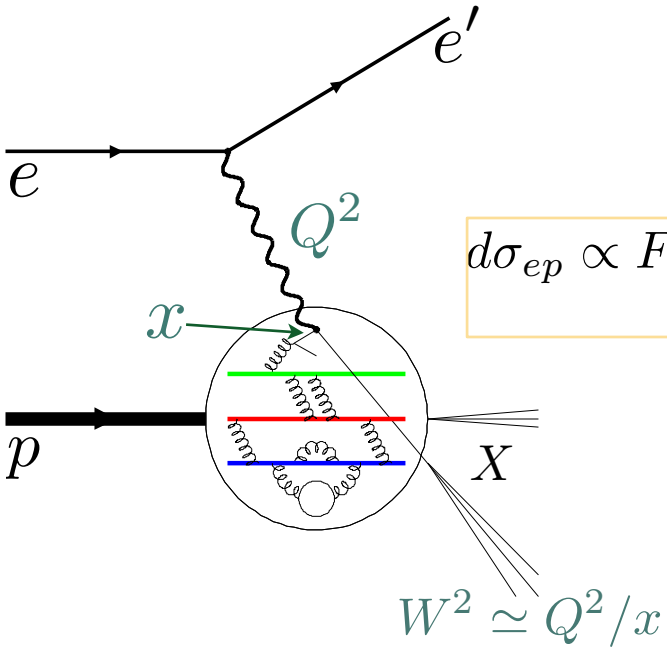
- Theoretical foundation



- Summary and Outlook

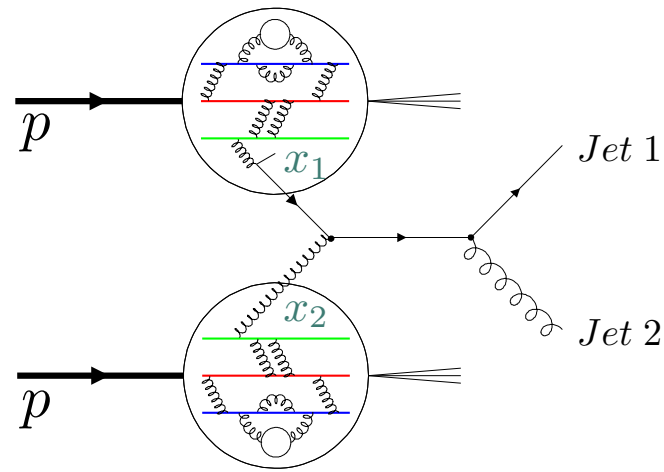
Theoretical foundation

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



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

Universality

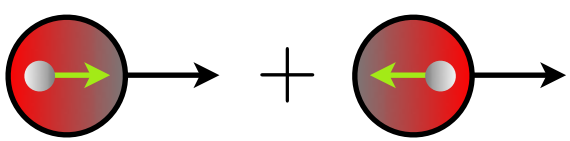


$$d\sigma_{pp} \propto f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h$$

Factorization

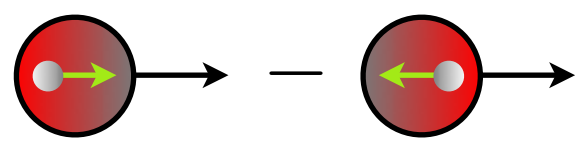
Momentum contribution

$$f(x) =$$



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

$$\Delta f(x) =$$

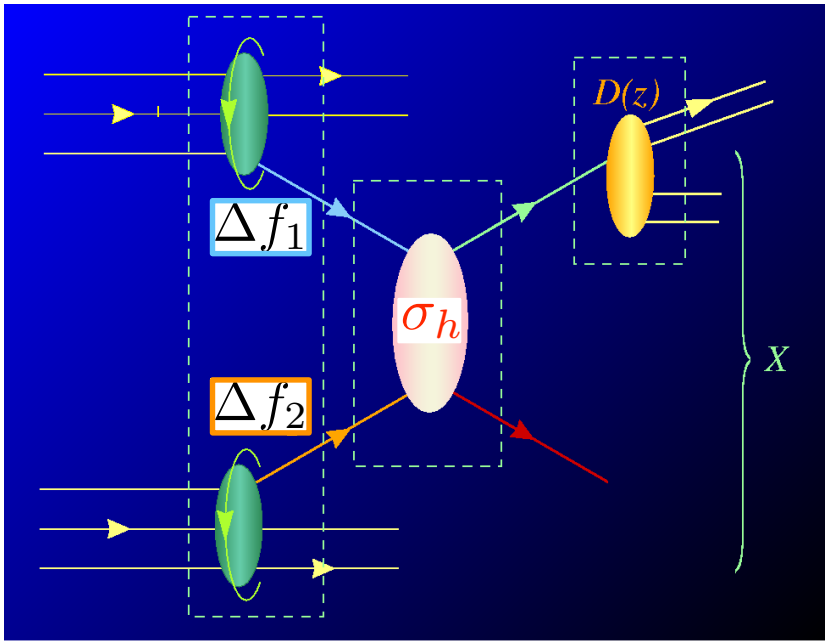


$$f^+(x) - f^-(x)$$

Spin contribution

Theoretical foundation

- Explore proton spin structure using high-energy polarized p+p collisions



- Observable: Gluon polarization (Jet/Hadron production)

long-range | short-range | long-range

Δf_1 Δf_2

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

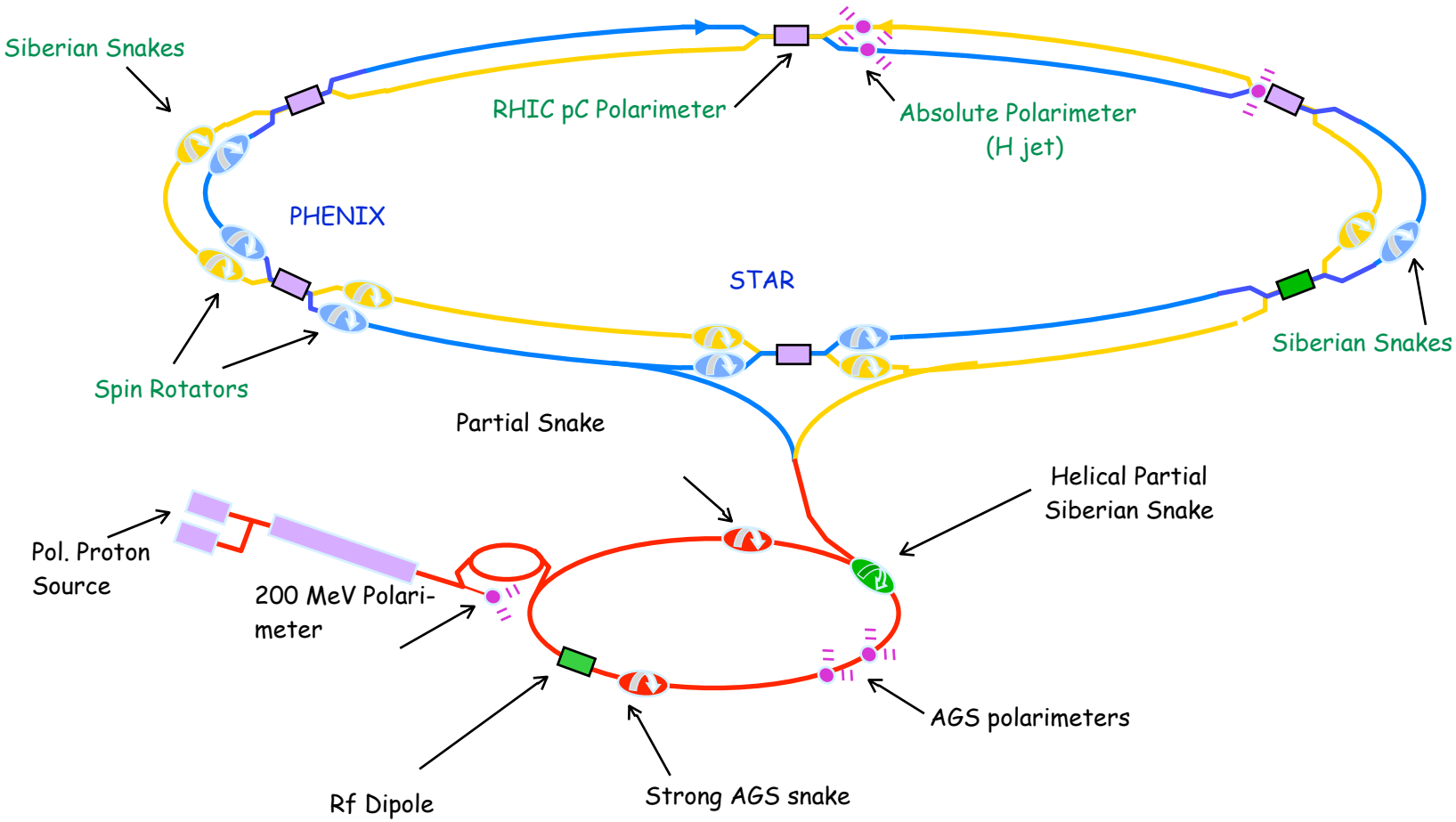
Input

  - Double longitudinal single-spin asymmetry A_{LL}

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D_f^h}{f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h}$$

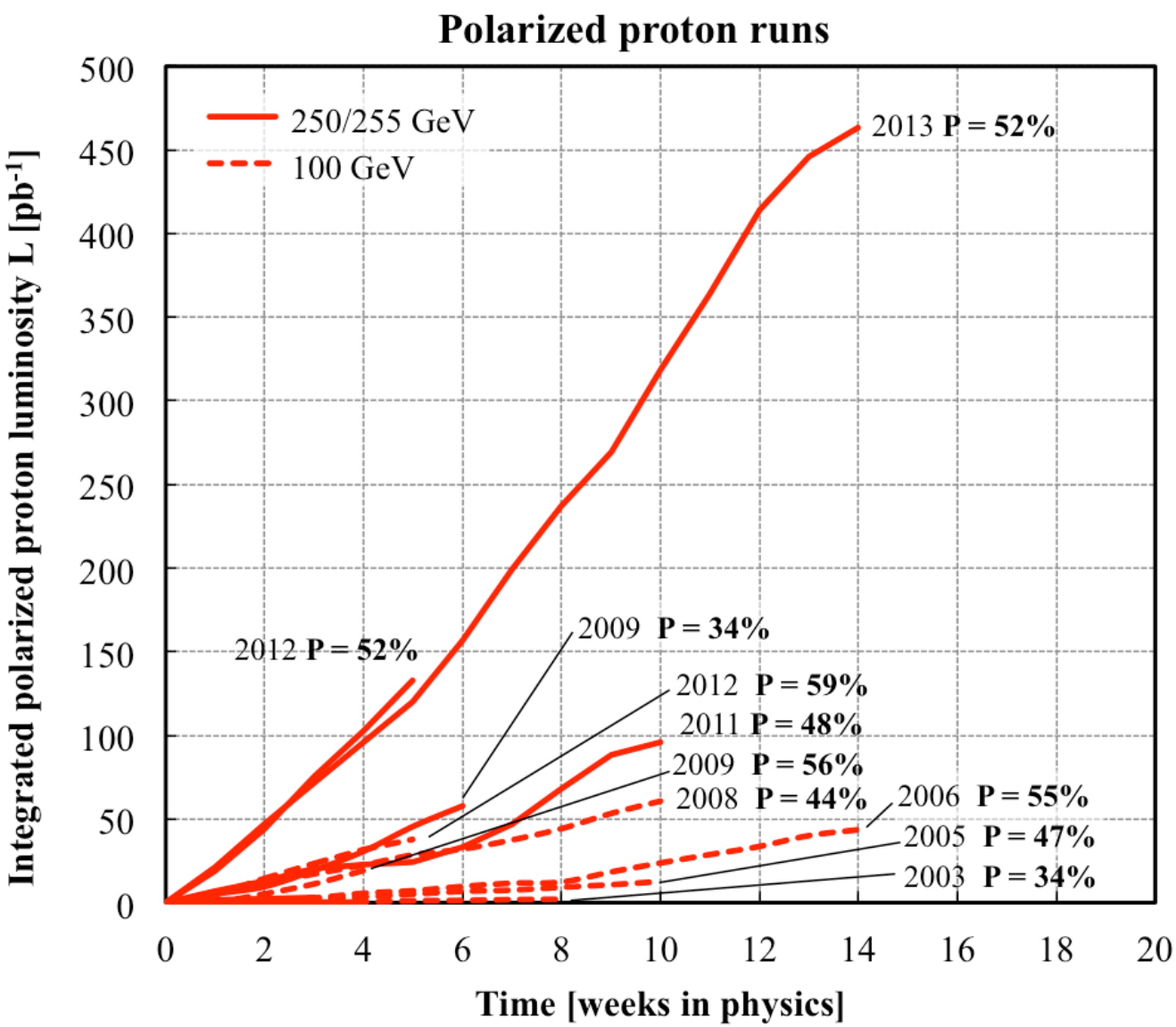
Experimental aspects - RHIC

- The world's first polarized proton-proton collider



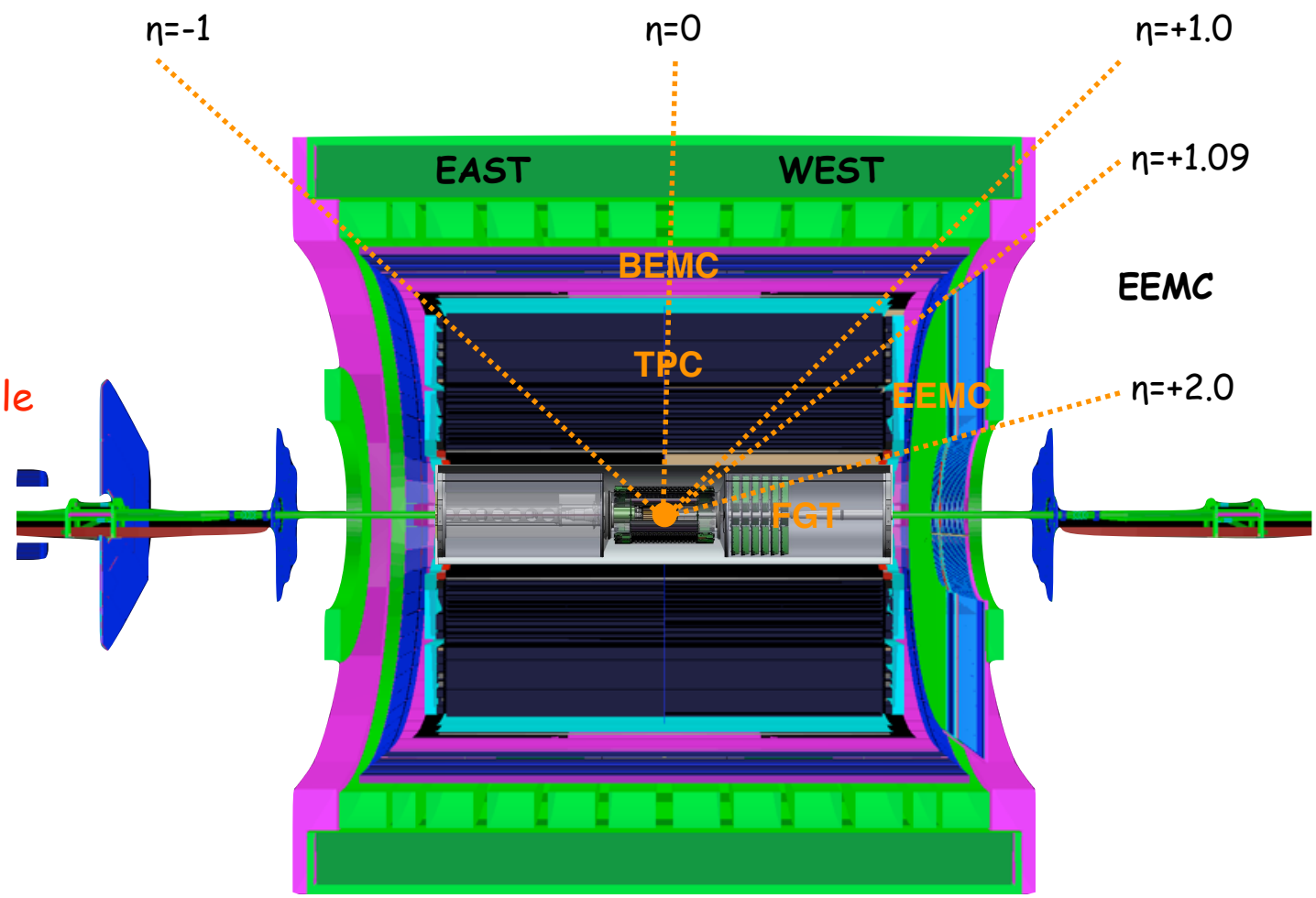
Experimental aspects - RHIC

- Polarized p-p collisions
  - Production runs at $\sqrt{s}$=200GeV (long. polarization) in 2005, 2006, 2009: Jet and Hadron production (Gluon polarization)
  - Production runs at $\sqrt{s}$=500GeV (long. polarization) in 2009, 2011, 2012 and 2013: W production (Quark polarization) / Jet and Hadron production (Gluon polarization)



Experimental aspects - STAR

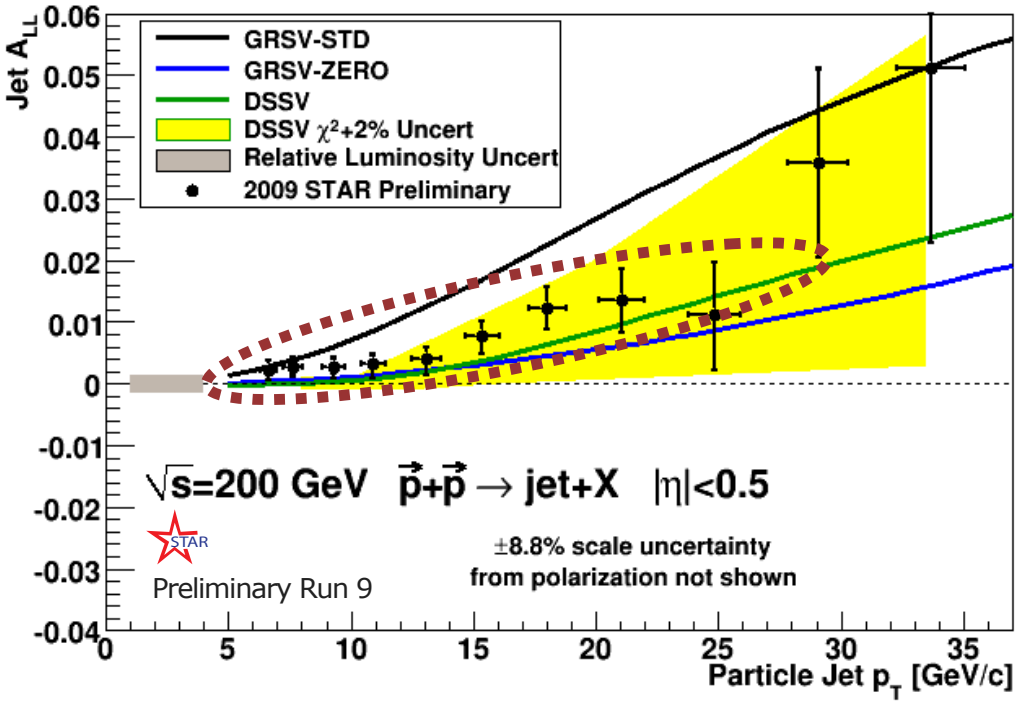
- Overview
  - Calorimetry system with 2π coverage: BEMC ($-1<\eta<1$) and EEMC ($1.09<\eta<2$)
  - TPC: Tracking and particle ID ($-1.3<\eta<1.3$)
  - FGT: Tracking ($1<\eta<2$)
  - ZDC: Relative luminosity and local polarimetry (500GeV)
  - BBC: Relative luminosity and Minimum bias trigger

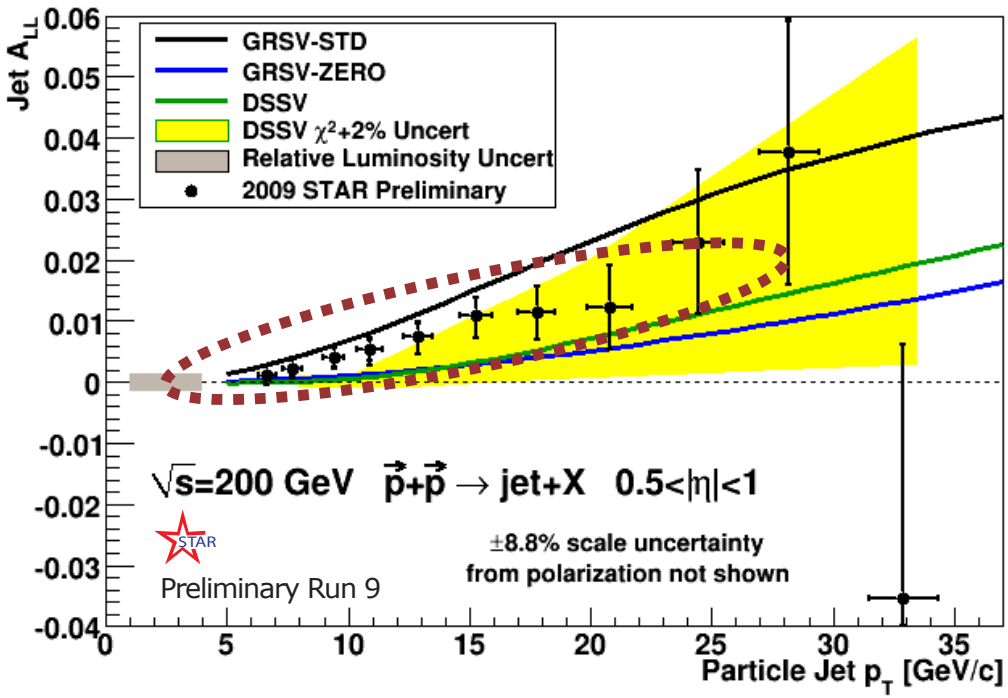


$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$

Results / Status - Gluon polarization program

- Mid-rapidity Inclusive Jet A_{LL} measurement (Run 9)





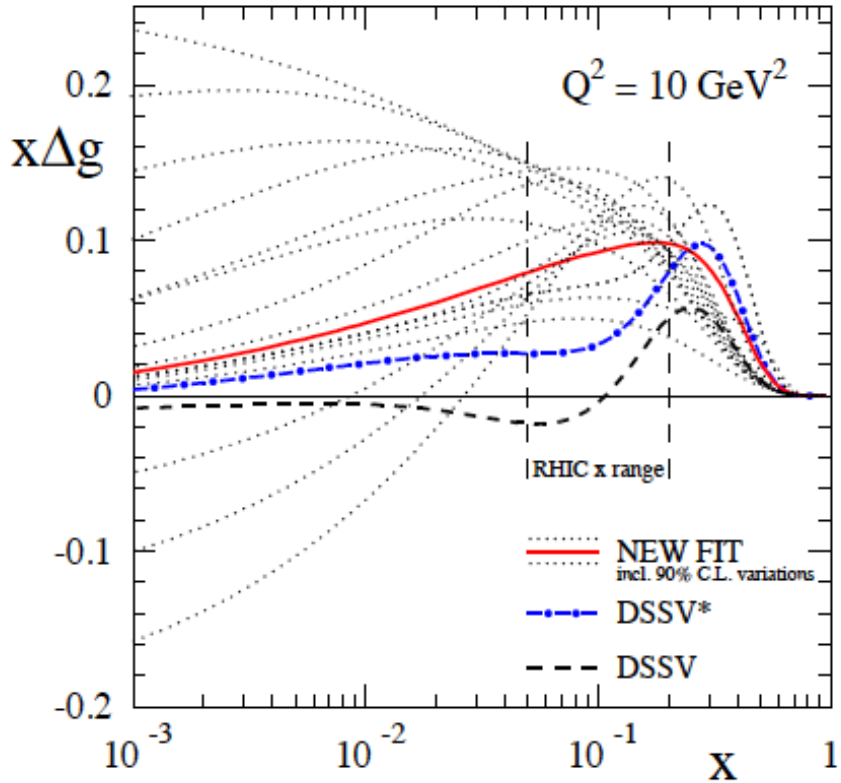
- Run 9 A_{LL} measurement between GRSV-STD and DSSV / Clearly above zero at low p_T
- Larger asymmetry at low p_T suggests larger gluon polarization compared to DSSV

Results / Status - Gluon polarization program

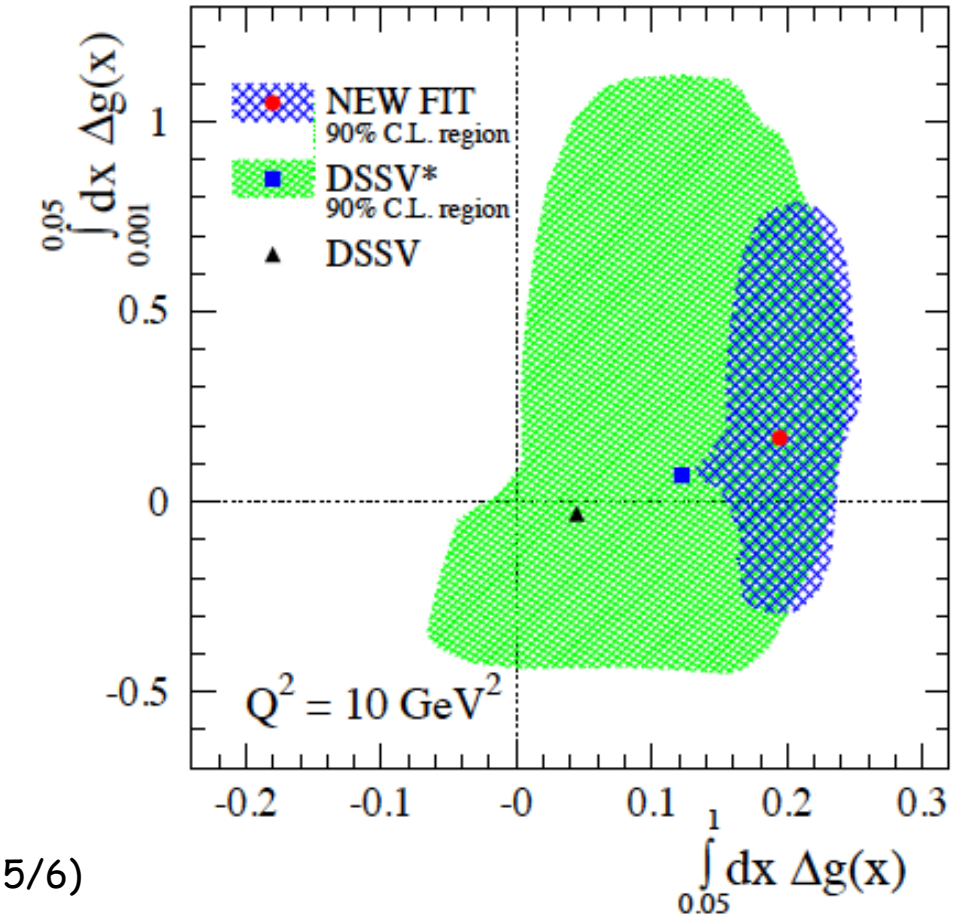
- Impact on Δg from RHIC data

D. deFlorian et al., arXiv:1404.4293

Wide spread at low x (x<0.05) of alternative fits consistent within 90% of C.L.



D. deFlorian et al., arXiv:1404.4293



- DSSV: Original global analysis incl. first RHIC results (Run 5/6)
- DSSV*: New COMPASS inclusive and semi-inclusive results in addition to Run 5/6 RHIC updates
- DSSV - NEW FIT: Strong impact on $\Delta g(x)$ with RHIC run 9 results ⇒ Positive for x > 0.05!

"...better small-x probes are badly needed."

D. deFlorian et al., arXiv:1404.4293

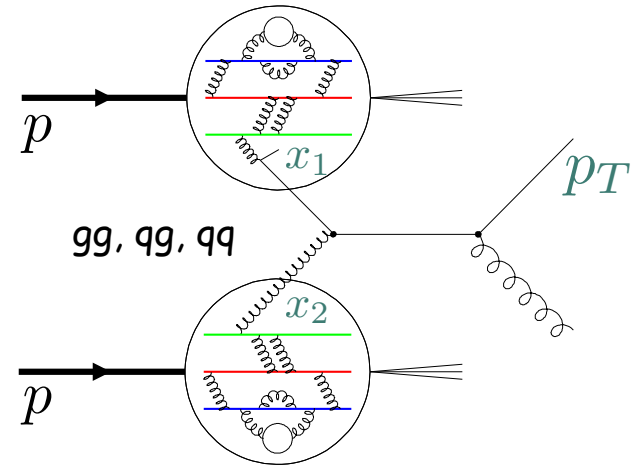
Results / Status - Gluon polarization program

RHIC Gluon polarization - Correlation Measurements

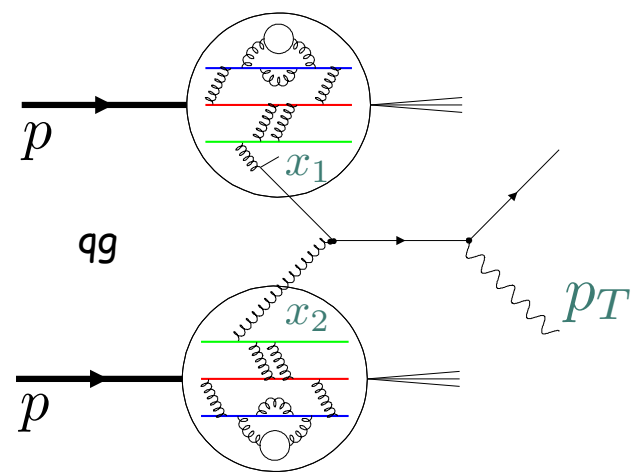
- Correlation measurements provide access to partonic kinematics through Di-Jet/Hadron production and Photon-Jet production:

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

- Di-Jet production / Photon-Jet production
  - Di-Jets: All three (LO) QCD-type processes contribute: gg, qg and qq
  - 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 QCD analysis



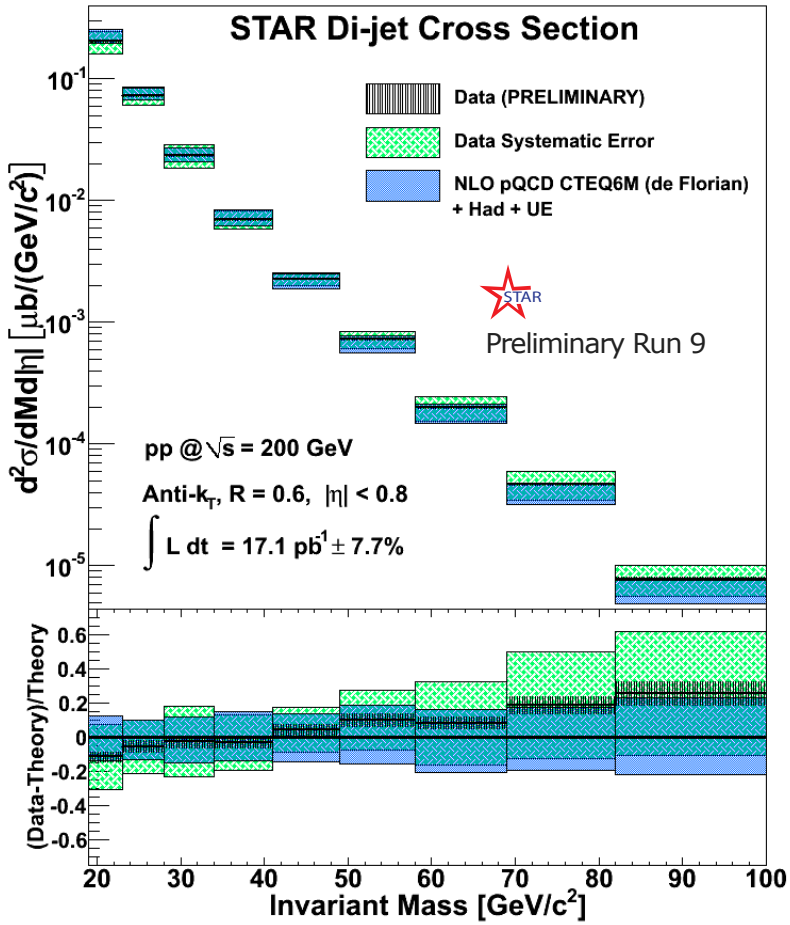
Di-Jet production



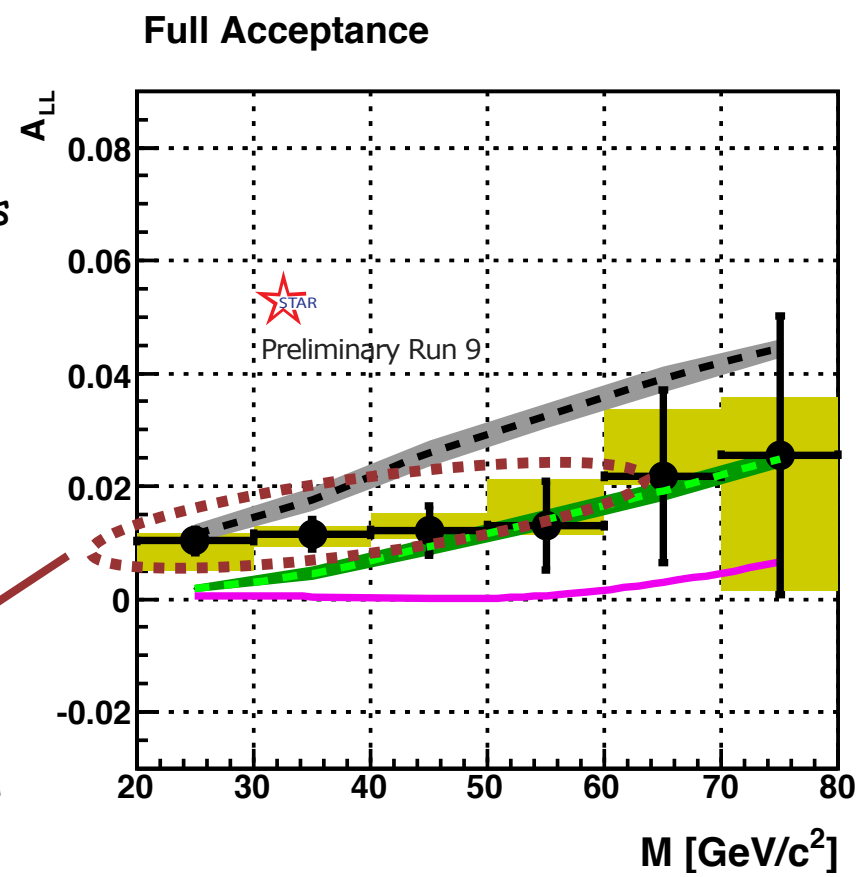
Photon-Jet production

Results / Status - Gluon polarization program

- Mid-rapidity STAR Di-Jet cross-section (Run 9) and A_{LL} measurement (Run 9)



- Data are well described by NLO pQCD plus hadronization and underlying event corrections

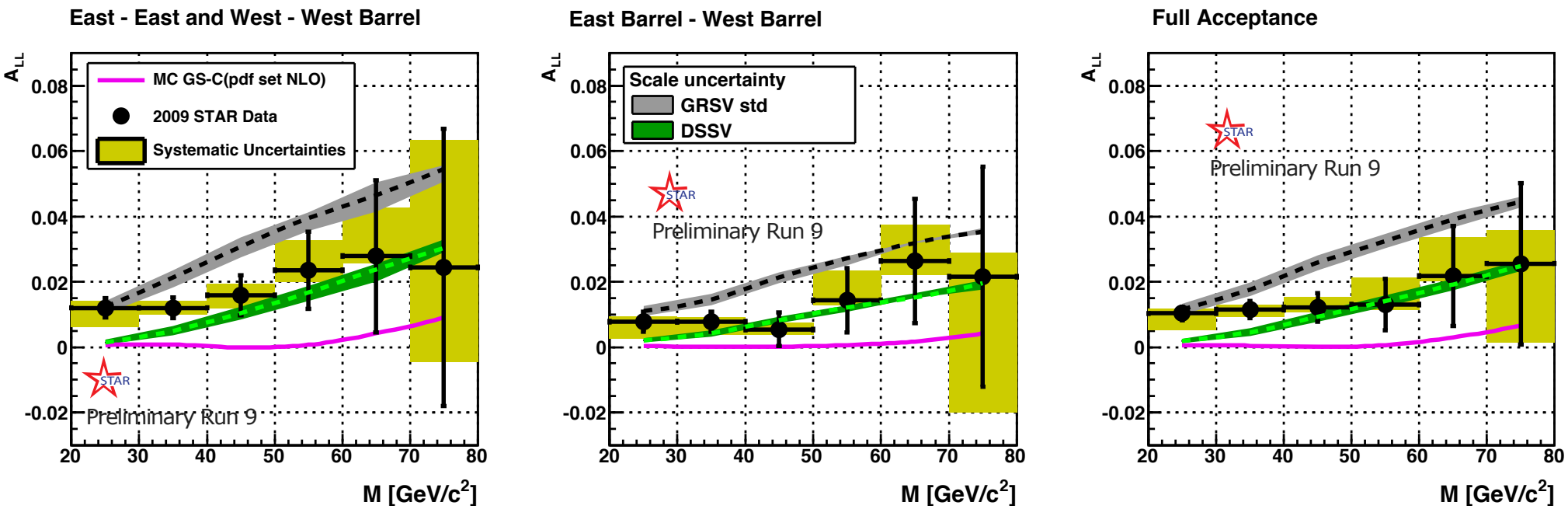


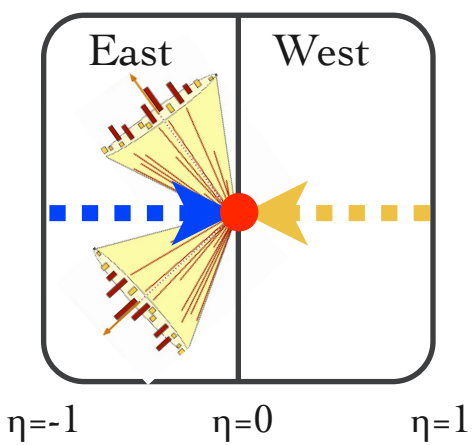
- A_{LL} measurements fall in-between GRSV-STD and DSSV

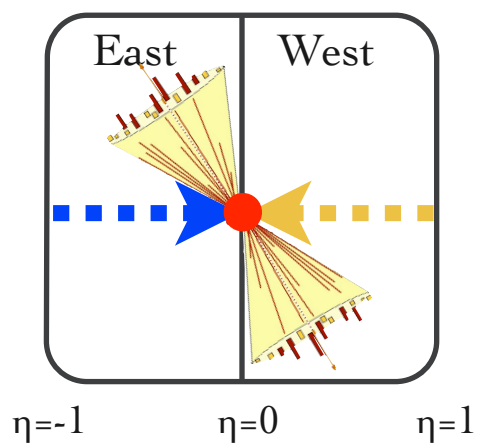
$$M = \sqrt{s}\sqrt{x_1 x_2} \qquad \eta_3 + \eta_4 = \ln\frac{x_1}{x_2}$$

Results / Status - Gluon polarization program

- Mid-rapidity STAR Di-Jet A_{LL} measurement in bins of η (Run 9)





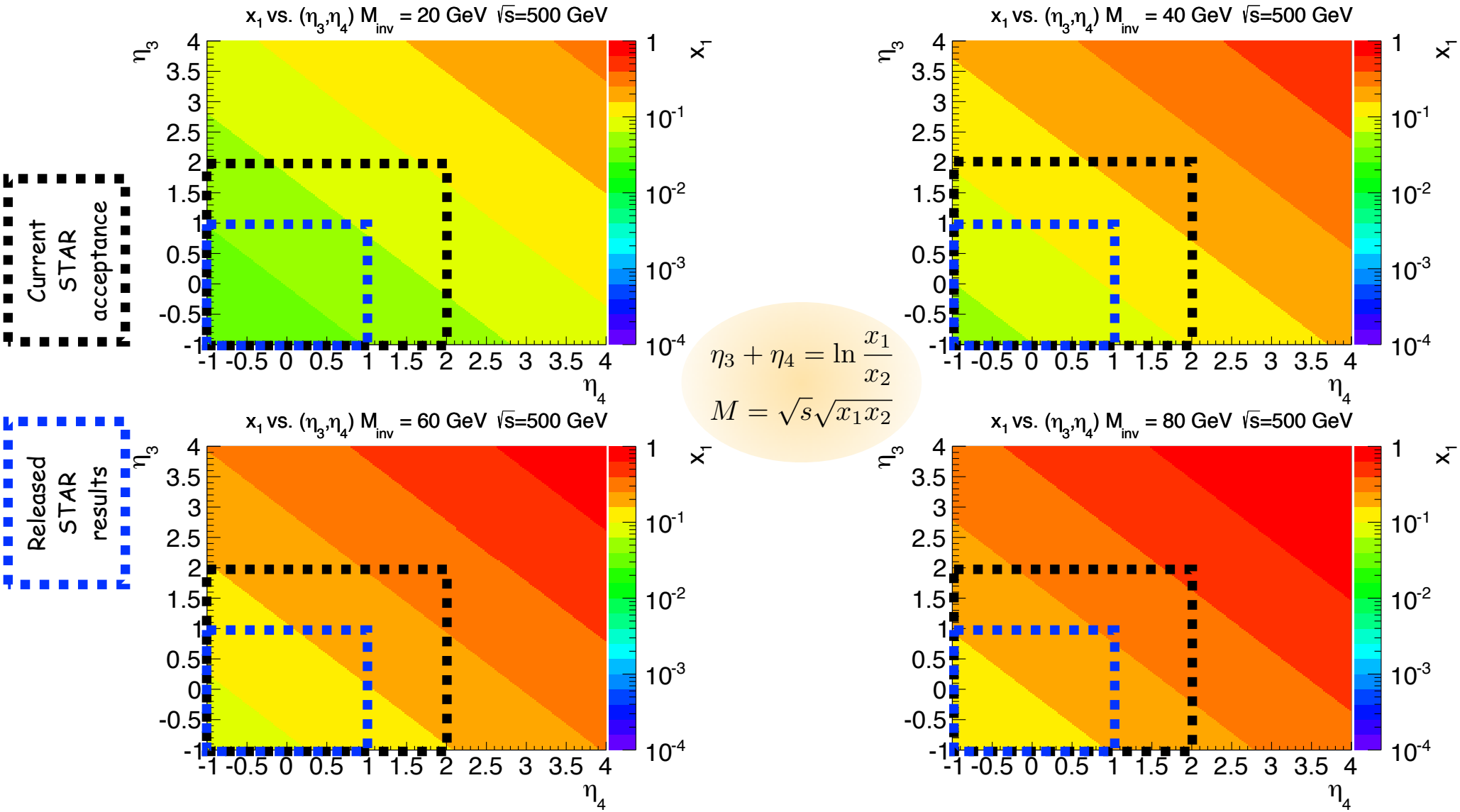


- Run 9 data: First rapidity dependent di-jet measurement
  ⇒ Constrain x dependence!

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

Future prospects - Gluon polarization program

- Kinematic coverage - STAR (4-Vector Kinematics): x_1

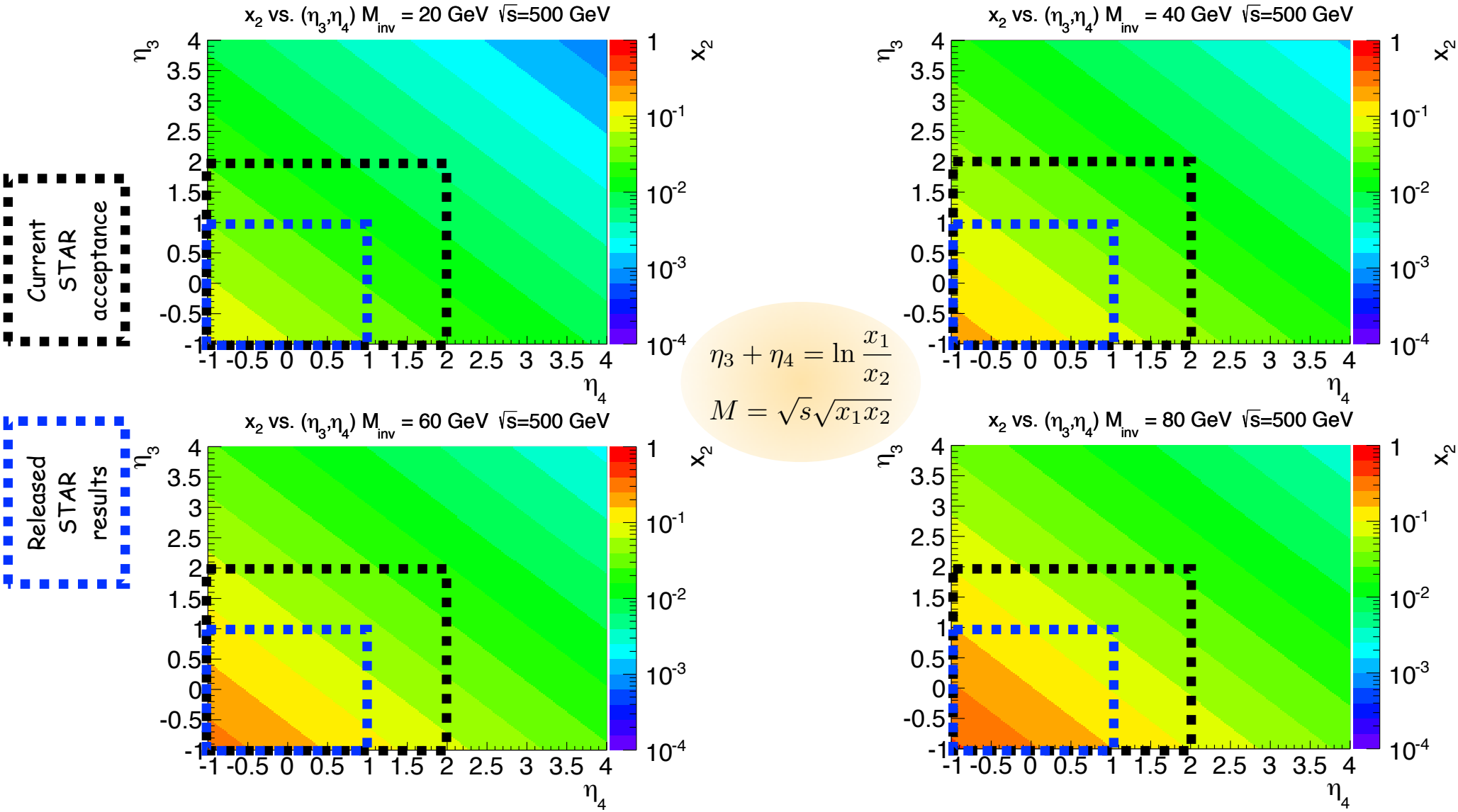


$$\eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$

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

Future prospects - Gluon polarization program

- Kinematic coverage - STAR (4-Vector Kinematics): x_2

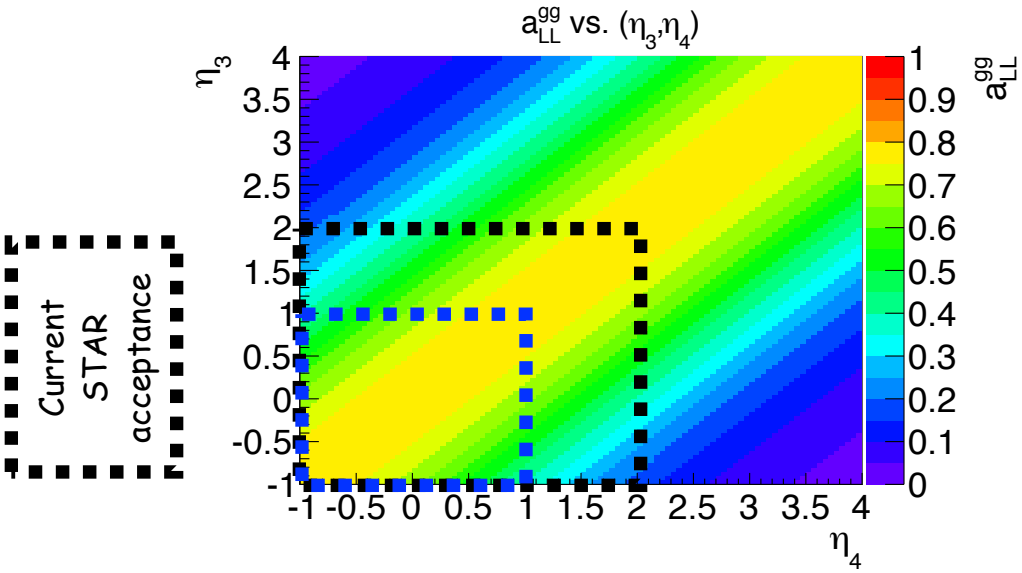


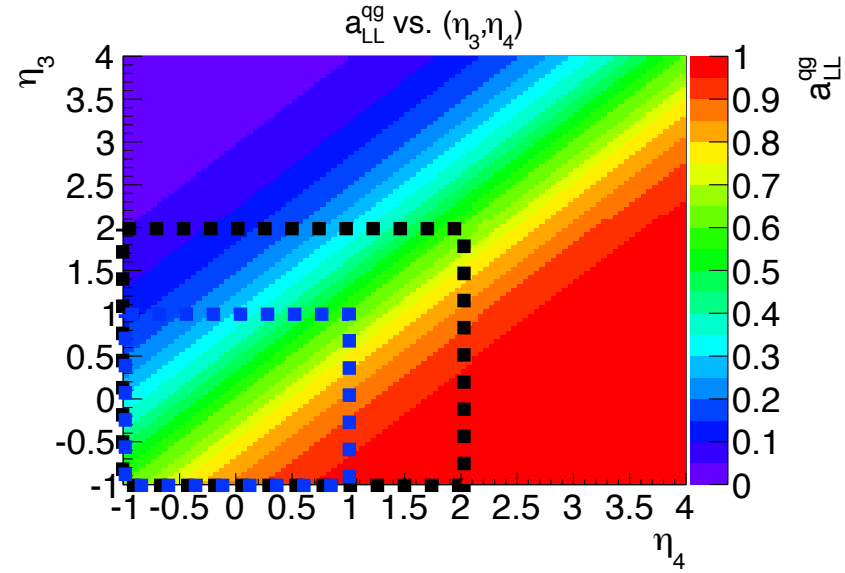
$$\eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$

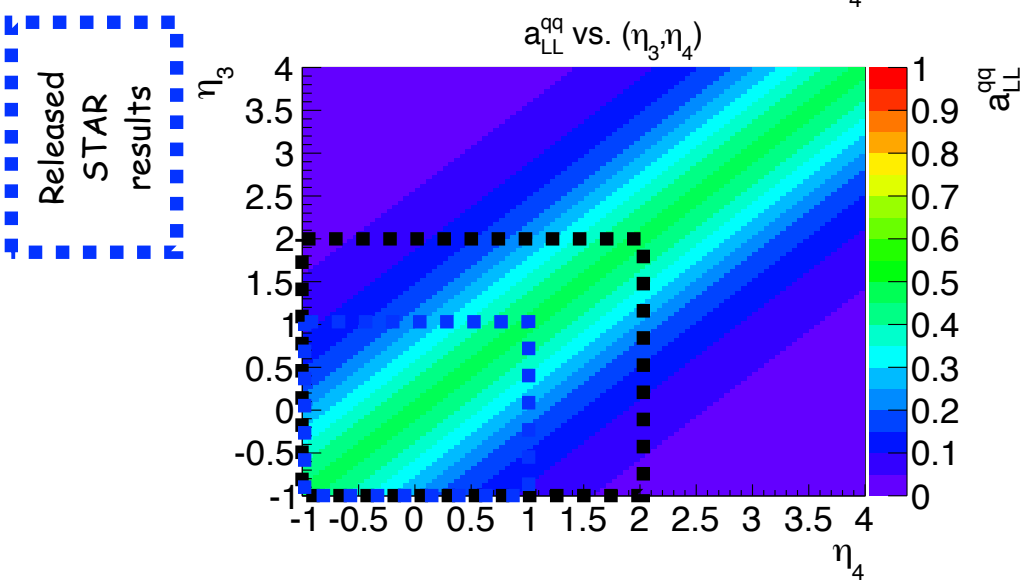
$$M = \sqrt{s}\sqrt{x_1 x_2}$$

Future prospects - Gluon polarization program

- Individual Partonic asymmetries



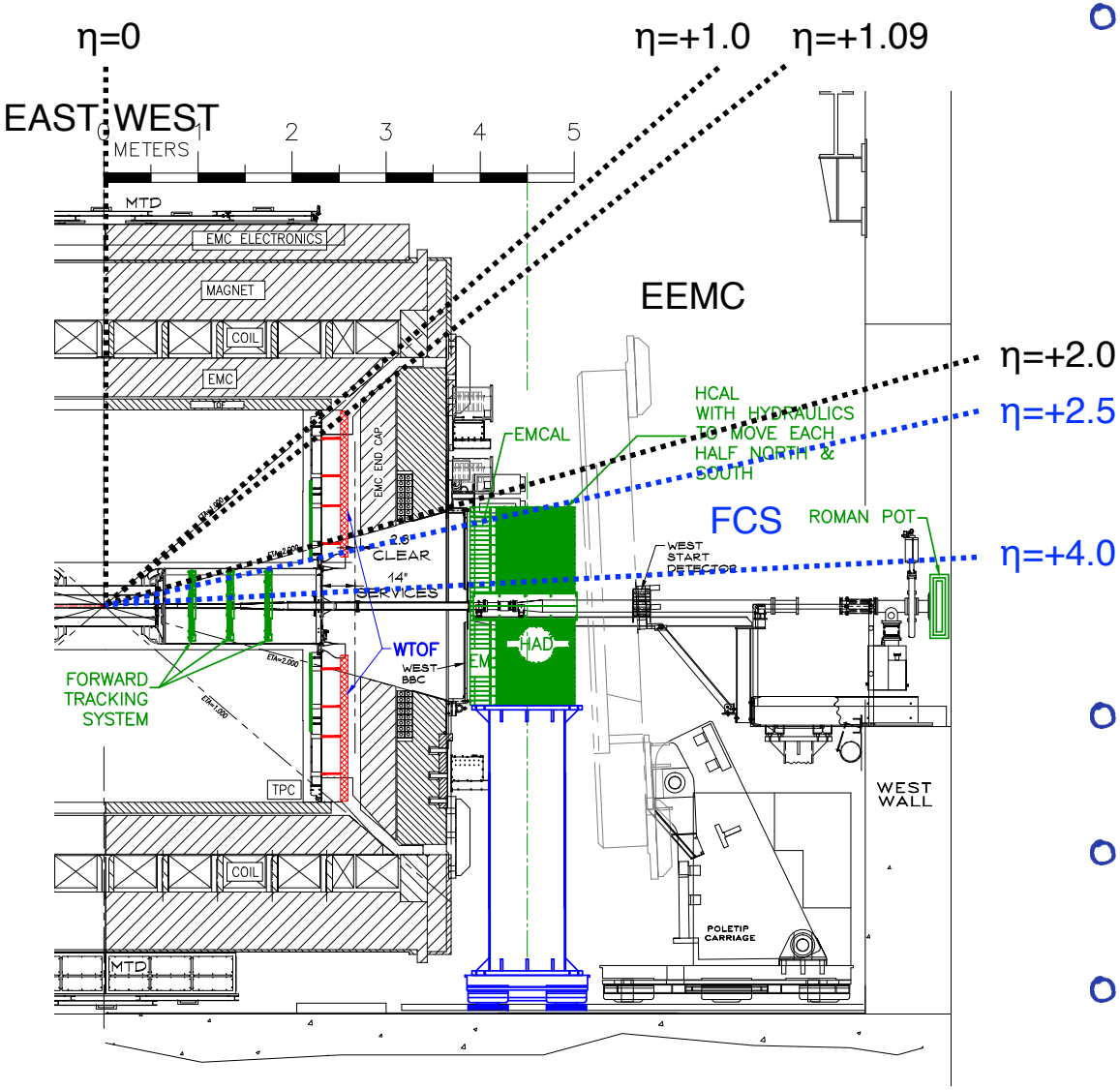




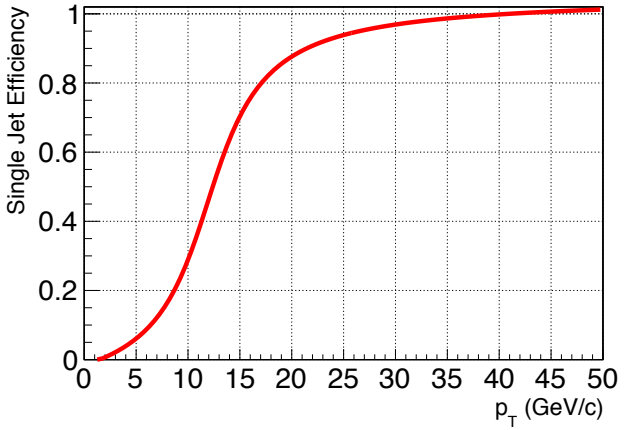
- Jet measurements do not distinguish between gg / qg and qq jets
- Size and thus weight of partonic asymmetries (Here LO) different for different topological configurations

Future prospects - Gluon polarization program

- Forward detector concept / Assumptions on projections



- Efficiencies for EAST / WEST / EEMC all defined using STAR jet efficiencies. For new forward system FCS, assume hadronic calorimetry with 0.9



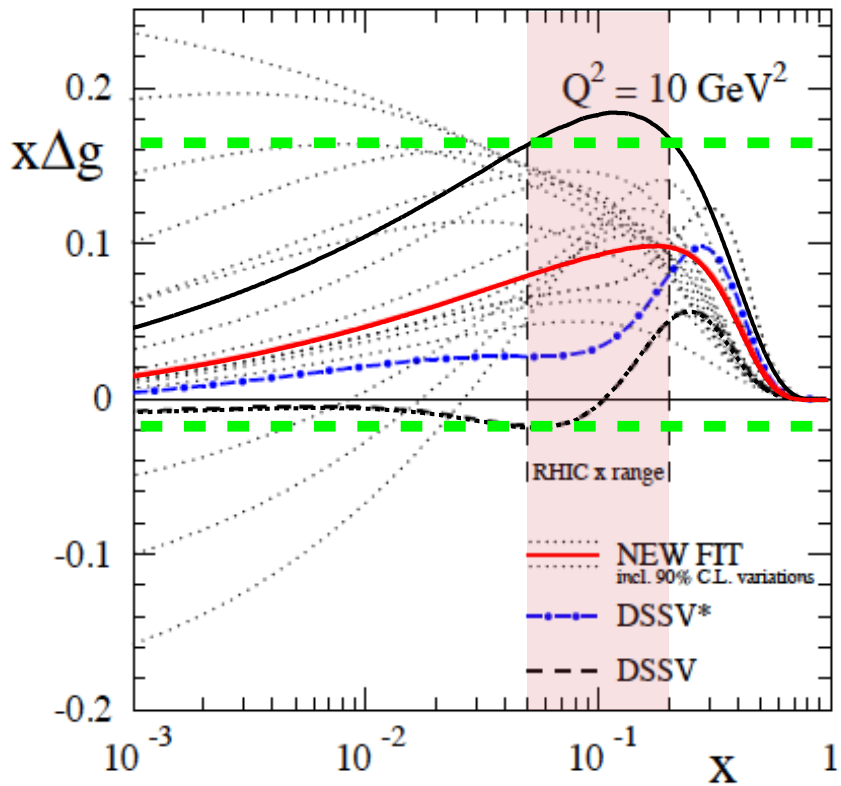
- All jet calculations at NLO (Code: D. deFlorian and W. Vogelsang) / simulations with 5GeV/8GeV cuts
- Systematics: Relative luminosity use $\delta R = 5 \cdot 10^{-4}$ (Run 9 Inclusive Jet value)
- P/L numbers : P = 60% and $L_{delivered}$ = 1000pb^{-1} with 2/3 for $L_{recorded}$ / $L_{delivered}$ (~ 1 long RHIC run!)

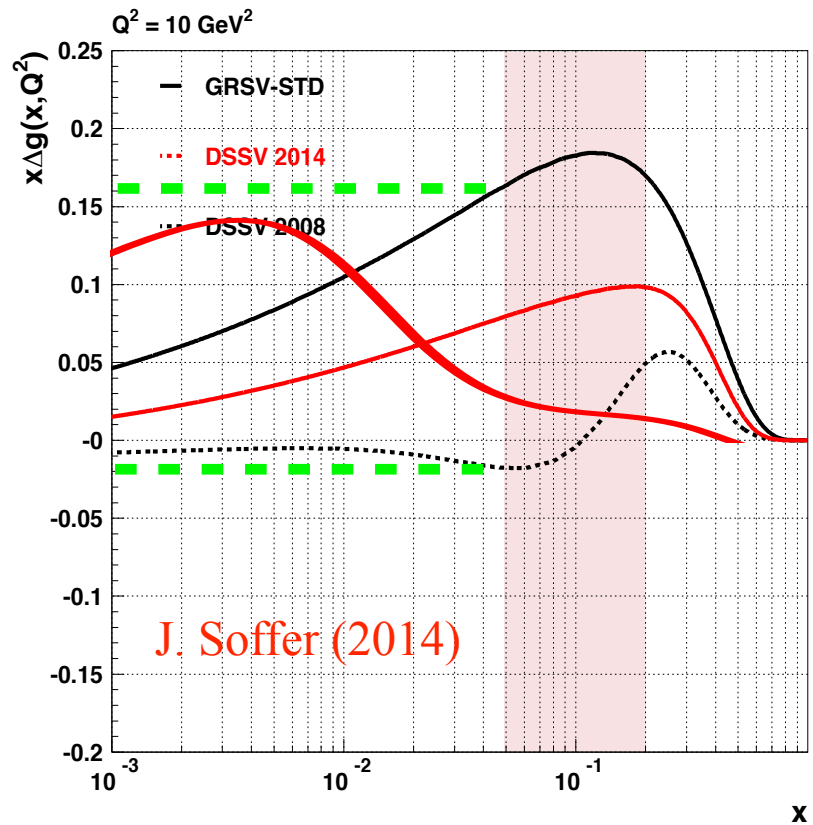
Future prospects - Gluon polarization program

- Sensitivity range

Wide spread at low x (x<0.05) of alternative fits consistent within 90% of C.L.

D. deFlorian et al., arXiv:1404.4293



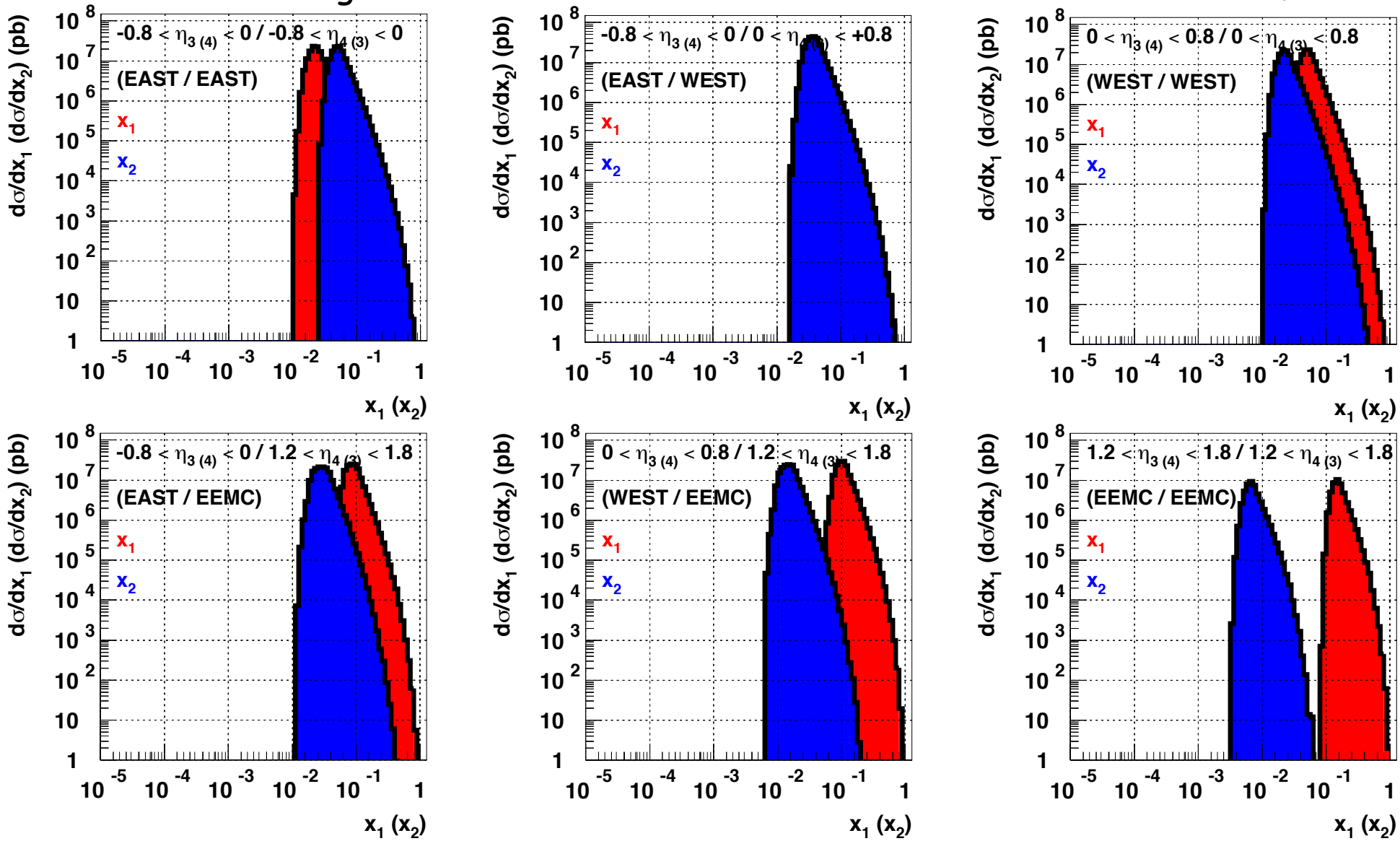


- DSSV (2008) and GRSV-STD have been used for all projections in A_{LL}
- NOTE: GRSV-STD is much smaller than 90% C.L. envelope for x < 0.05 AND DSSV (2008) is smaller in magnitude for x<0.05 compared to 90% C.L. envelope
- Therefore: Uncertainties for x < 0.05 are larger than by the range of DSSV (2008) and GRSV-STD!

Future prospects - Gluon polarization program

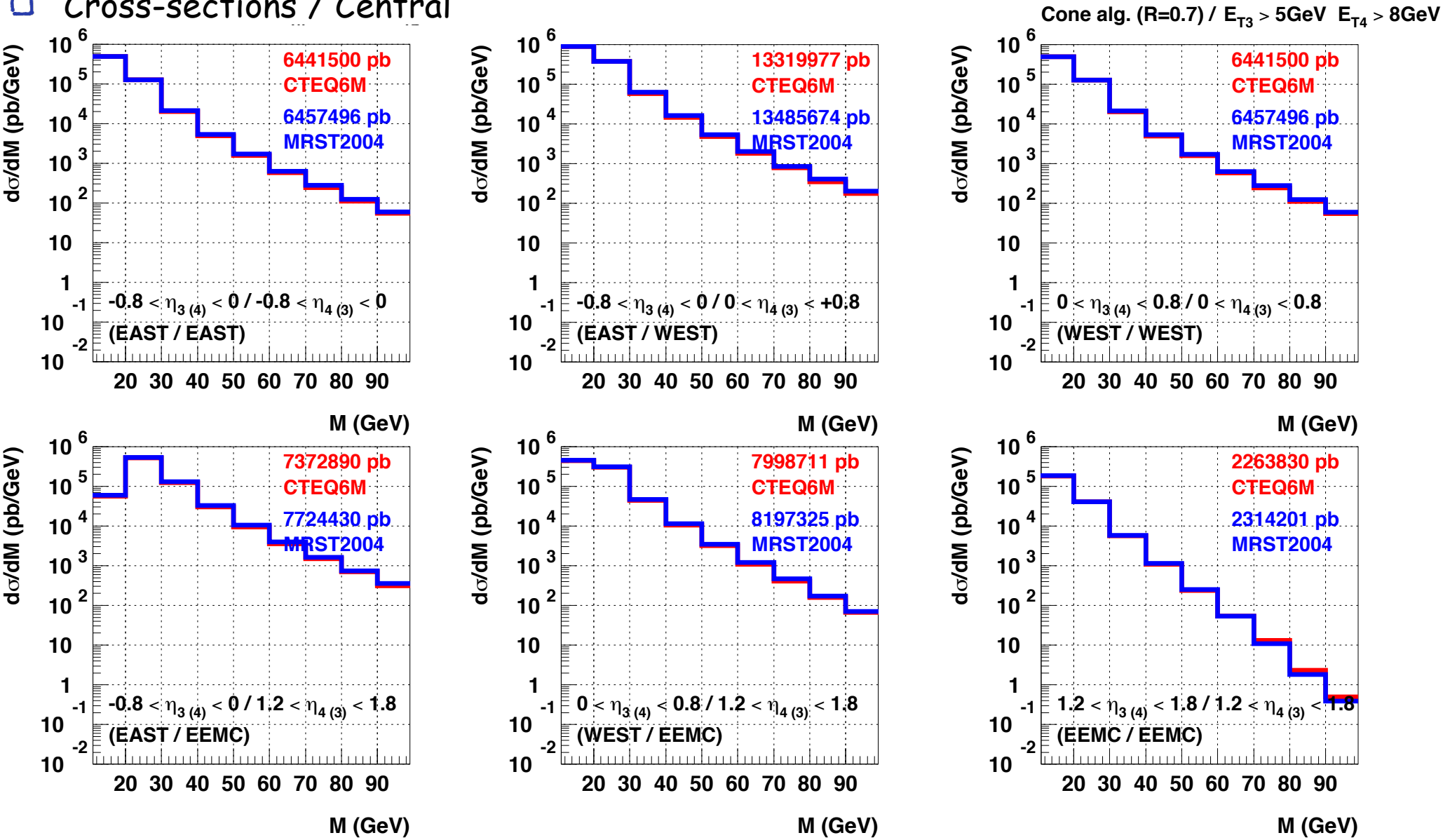
- Kinematic coverage - Simulations / Central

Cone alg. (R=0.7) / E_{T3} > 5GeV E_{T4} > 8GeV



Future prospects - Gluon polarization program

- Cross-sections / Central



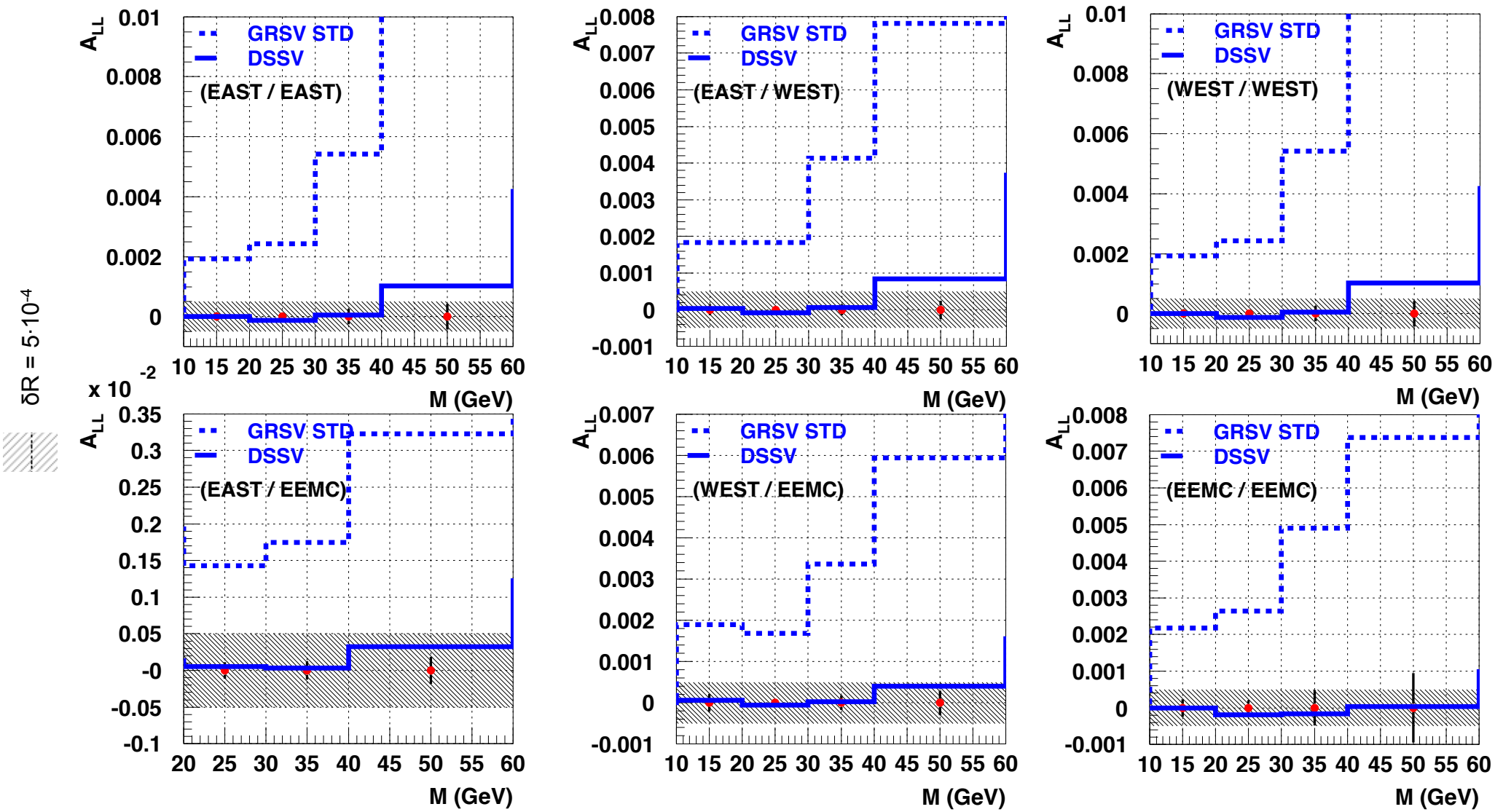
Future prospects - Gluon polarization program

- A_{LL} projections / Central

Cone alg. (R=0.7) / E_{T3} > 5GeV E_{T4} > 8GeV

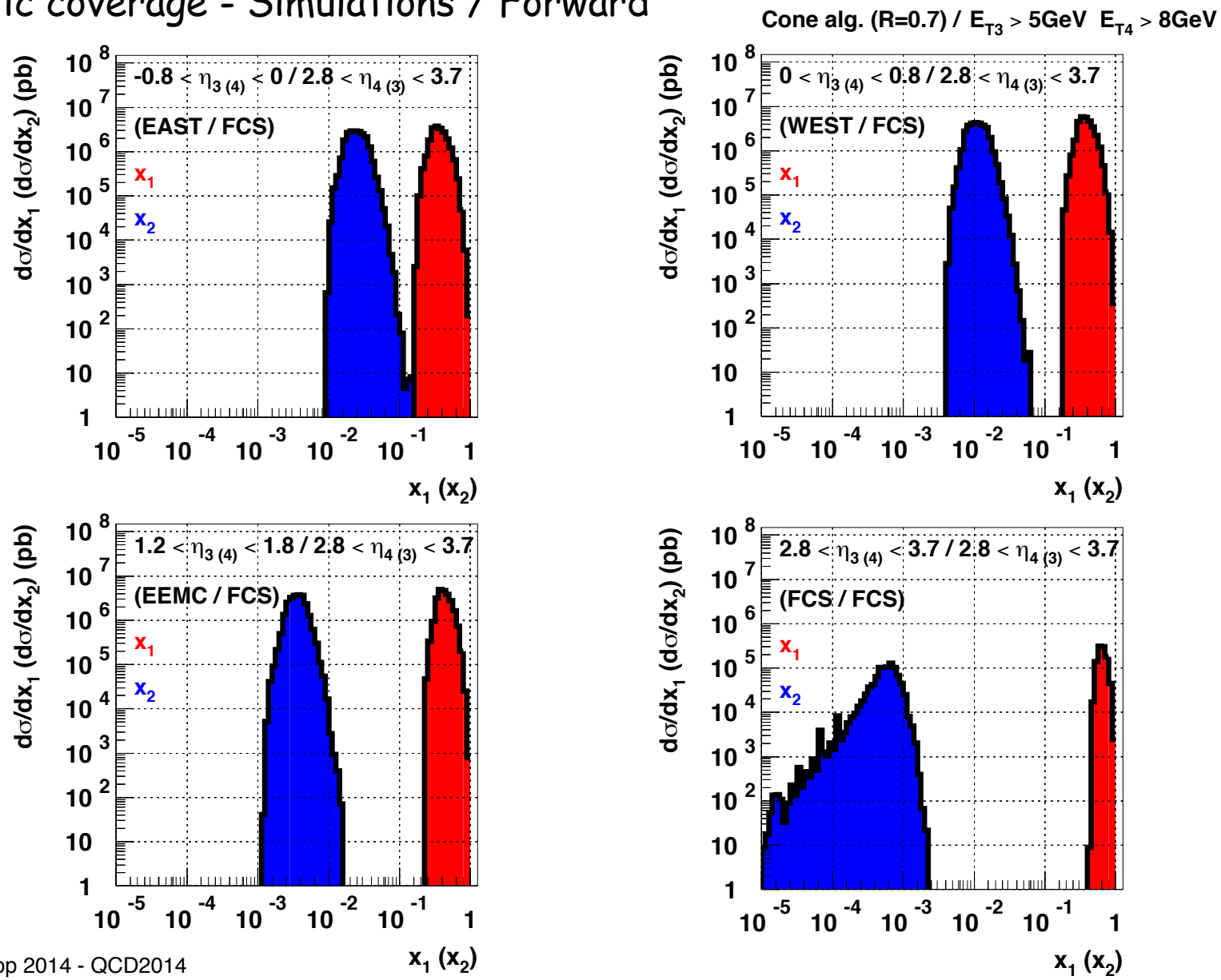
Delivered Luminosity = 1000pb^{-1}

Polarization = 60%



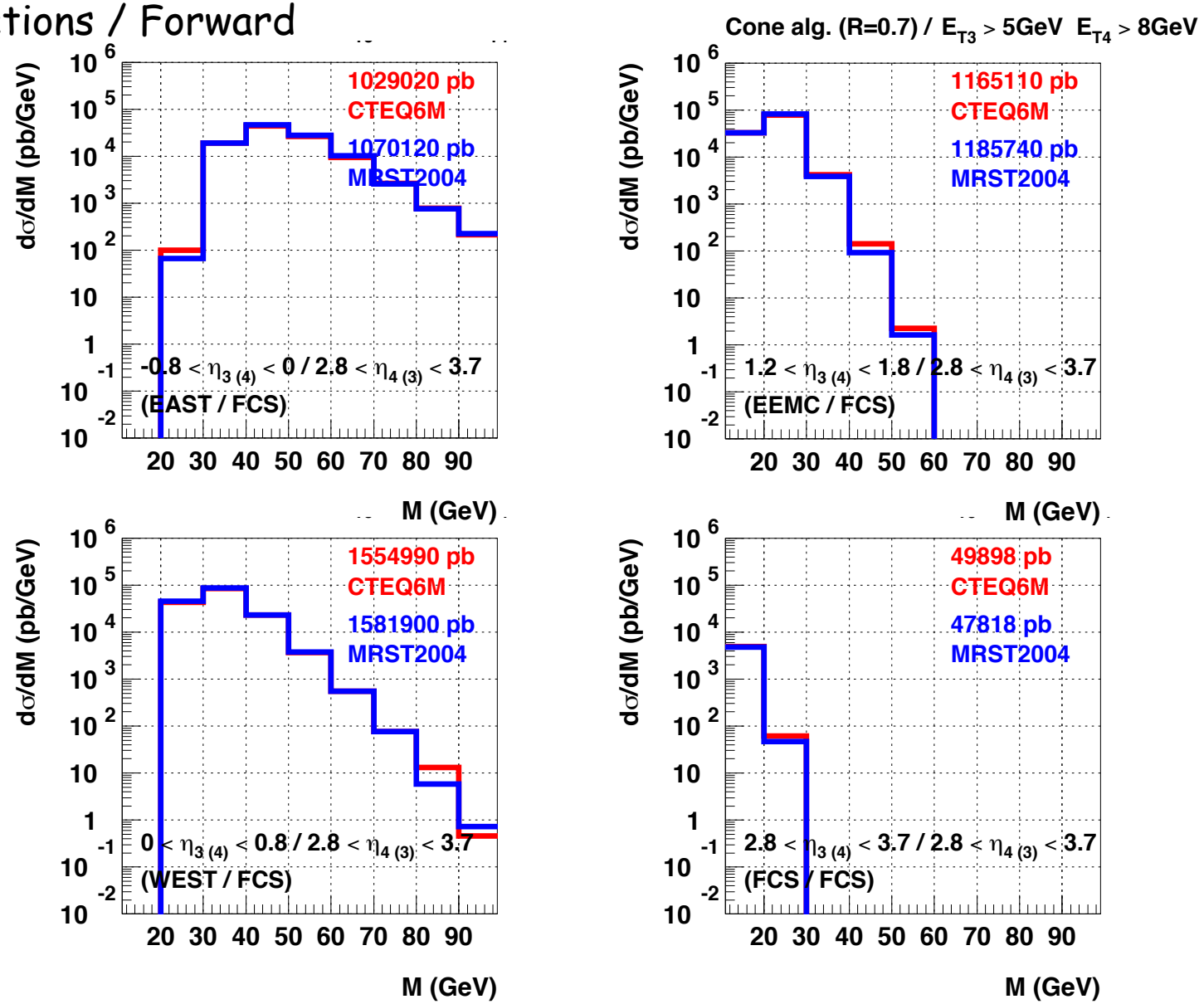
Future prospects - Gluon polarization program

- Kinematic coverage - Simulations / Forward



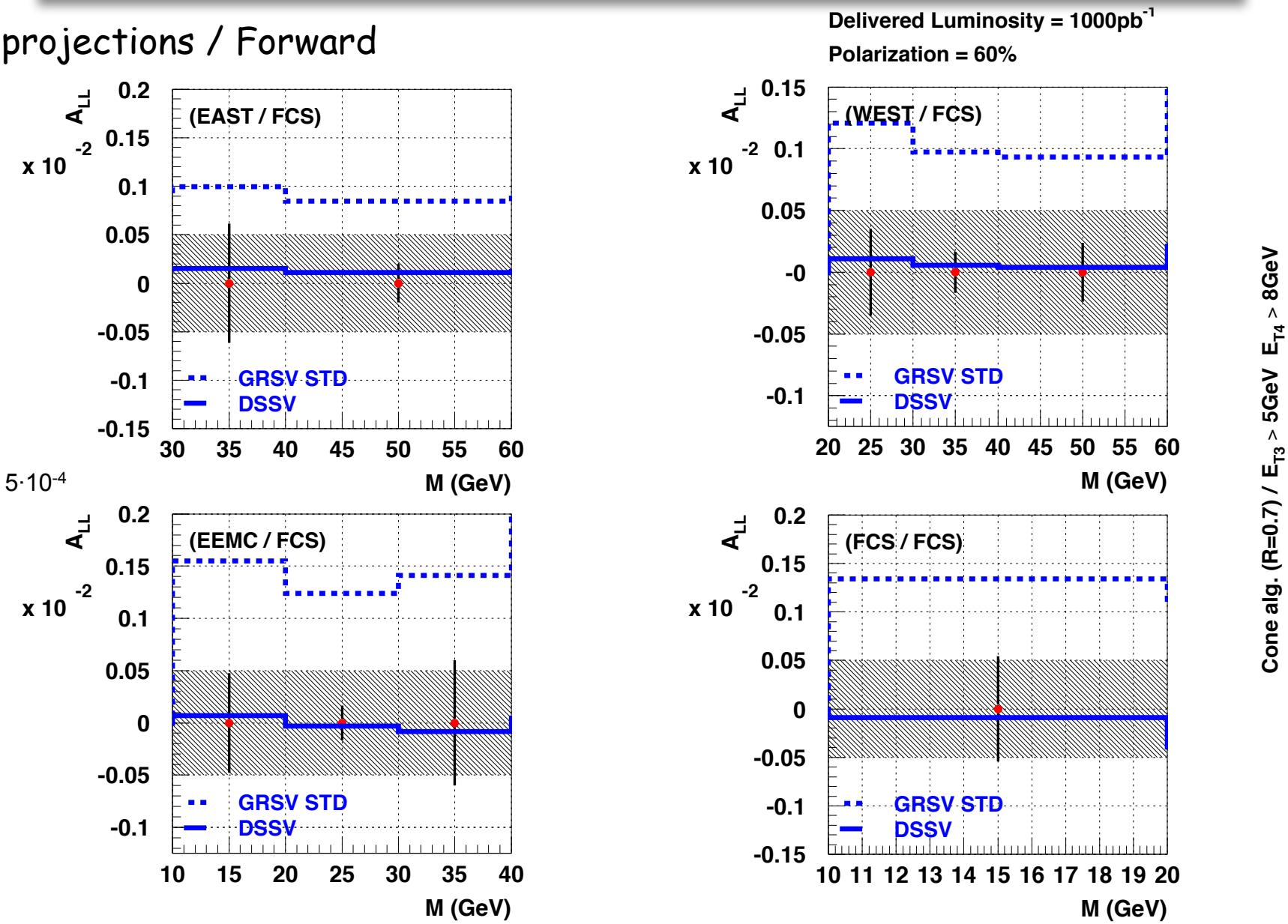
Future prospects - Gluon polarization program

- Cross-sections / Forward



Future prospects - Gluon polarization program

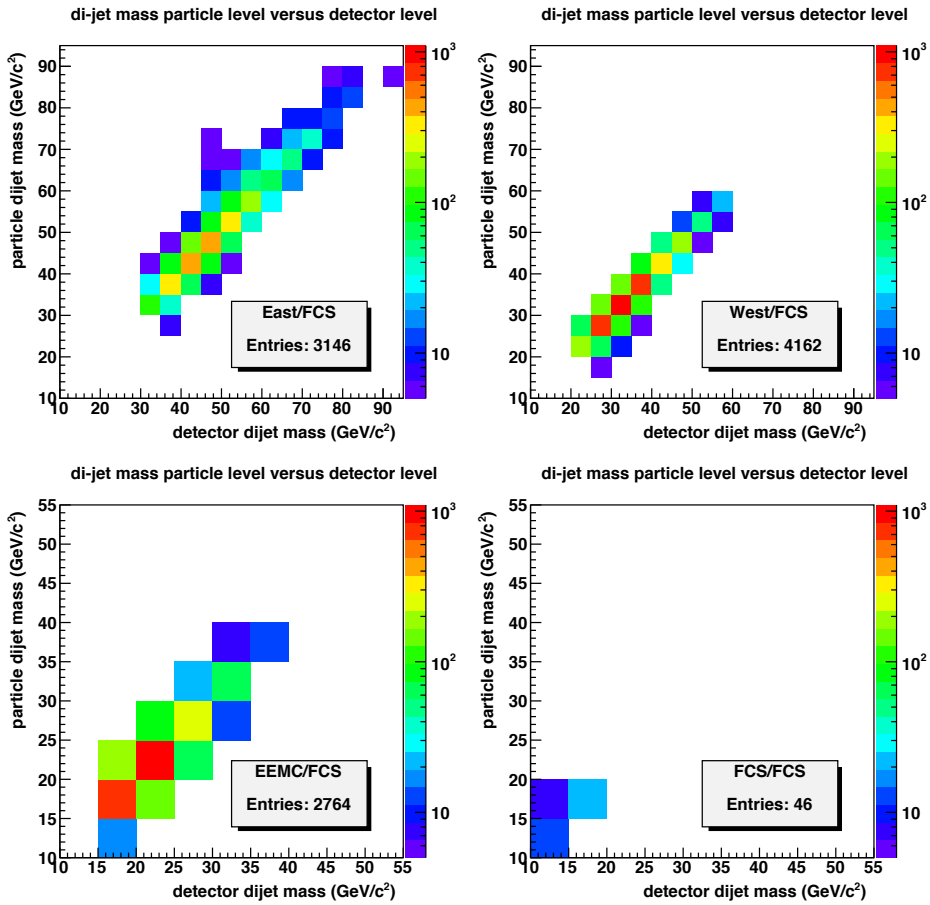
- A_{LL} projections / Forward



$\delta R = 5 \cdot 10^{-4}$

Future prospects - Gluon polarization program

- PYTHIA simulations incl. detector effects



- Invariant mass distribution based on PYTHIA simulations incl. detector effects (Only calorimetry!)
- Next: Specify resolution of forward detector system / UE events studies / Jet reconstruction studies

Summary

- Status: Gluon polarization program:
  - First Di-Jet measurement opens the path to constrain the shape of Δg
  - Run 9 results: Precise A_{LL} measurement suggesting non-zero ΔG
- New global analysis by DSSV:
  - Non-zero $\Delta g(x)$ for $x > 0.05$
  - Larger uncertainties for $x < 0.05$, i.e. below current RHIC kinematic region!
- Run 14 STAR BUR request:
  - 6 weeks with $L_{delivered} = 75 pb^{-1}$ and 60%
- Forward jet production:
  - Extend jet measurements at forward rapidity probing $\Delta g(x)$ as low as 10^{-3} in x
  - Challenging measurement with good control of sys. uncertainties important (Assume ~ 1 long RHIC run!)
  - Additional probes to be studied: π^0-jet correlations!
  - Important step prior to a future Electron-Ion Collider (EIC) ~2025!

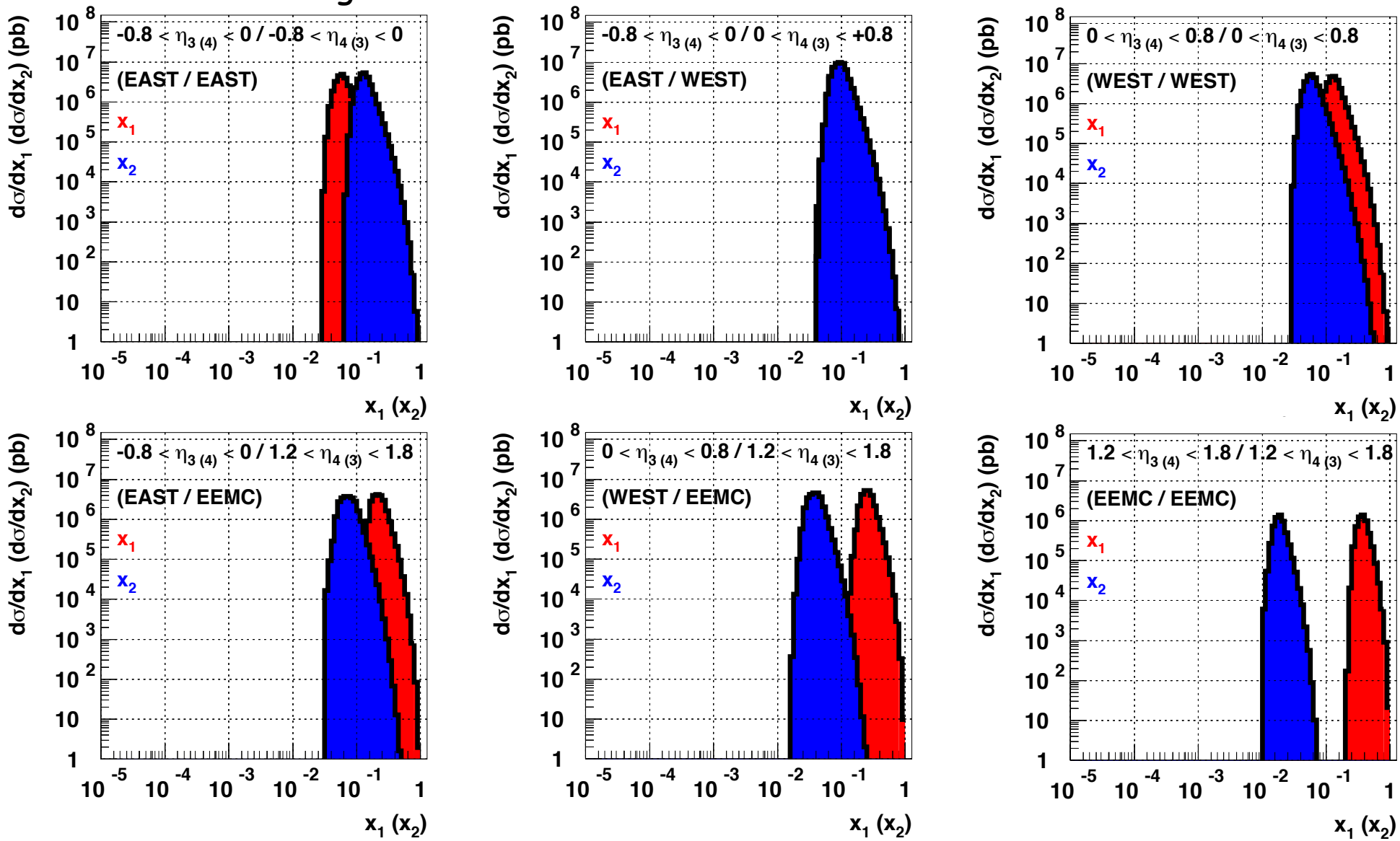
STAR

LOI for forward STAR upgrade focusing on forward pp/pA program in preparation!

Outlook - Run 14 (200GeV)

- Kinematic coverage - Simulations / Central

Cone alg. (R=0.7) / E_{T3} > 5GeV E_{T4} > 8GeV



Outlook - Run 14 (200GeV)

- A_{LL} projections / Central

Cone alg. (R=0.7) / E_{T3} > 5GeV E_{T4} > 8GeV

Delivered Luminosity = 75pb^{-1}

Polarization = 60%