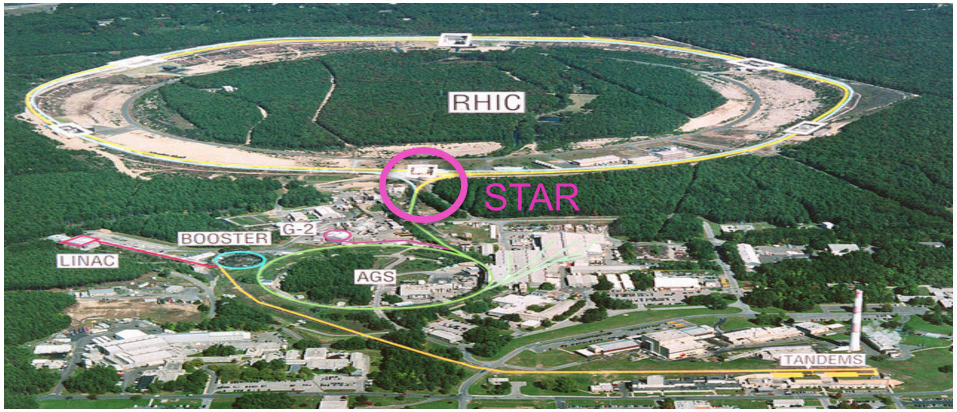
Recent results of gluon and sea quark measurements in polarized proton-proton collisions at STAR



Xuan Li for the STAR Collaboration
Temple University

Outline

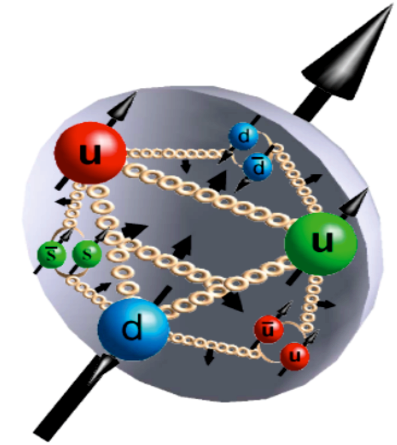
- Introduction
- Overview of RHIC and STAR
- Selected STAR measurements
  - Gluon polarization: inclusive jet A_{LL}, di-jet A_{LL}.
  - Sea quark polarization: W A_L.
- Summary and Outlook

Spin structure of the proton

- Proton spin is carried by it components (quarks and gluons).

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta G + L_g$$

DIS measured ~30% Little known

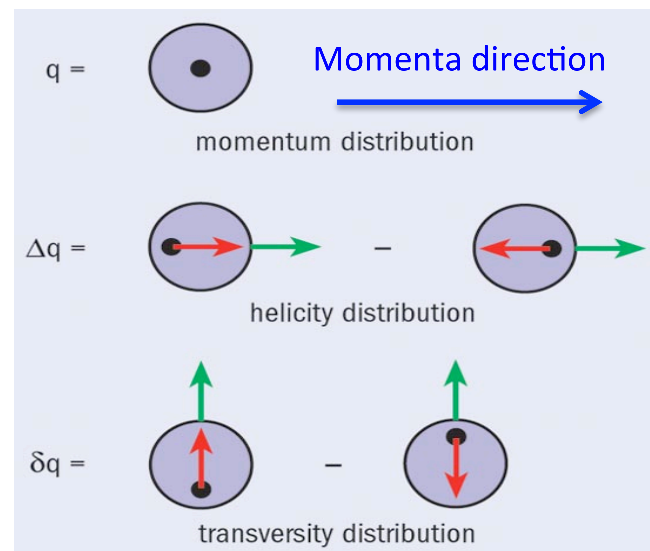


$$\Delta G = \int \Delta g(x,Q^2)\,dx$$

$$\Delta\Sigma = \int (\Delta q(x,Q^2) + \Delta\bar{q}(x,Q^2)\,dx$$

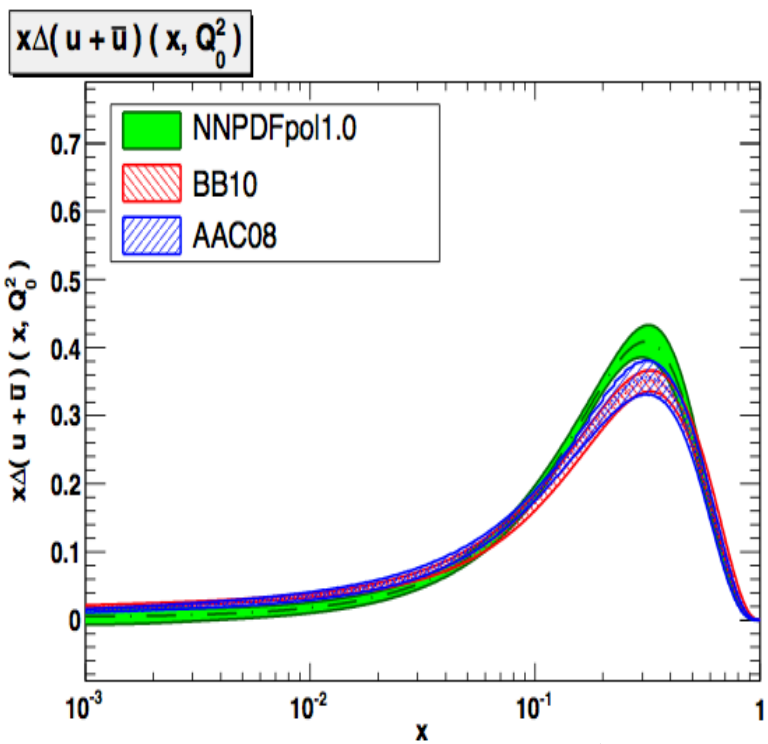
Where q = u, d, s (heavy quarks excluded)

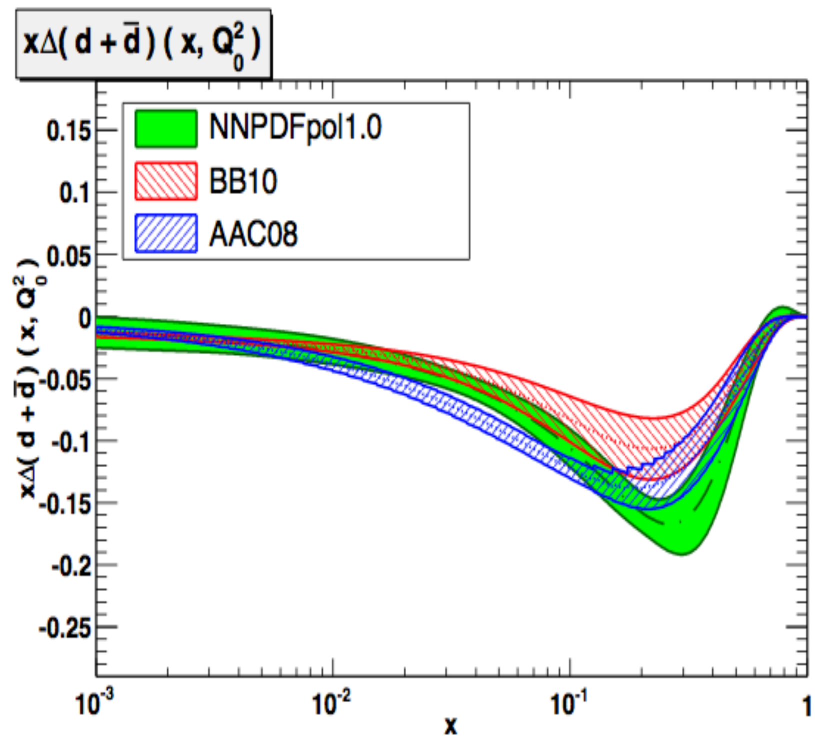
- Polarized parton distribution function (pPDF): $\Delta q(x,Q^2)/\Delta g(x,Q^2)$ is the probability to find a quark/gluon with its spin aligned minus its spin anti-aligned to the spin of the proton.



Current knowledge of pPDF

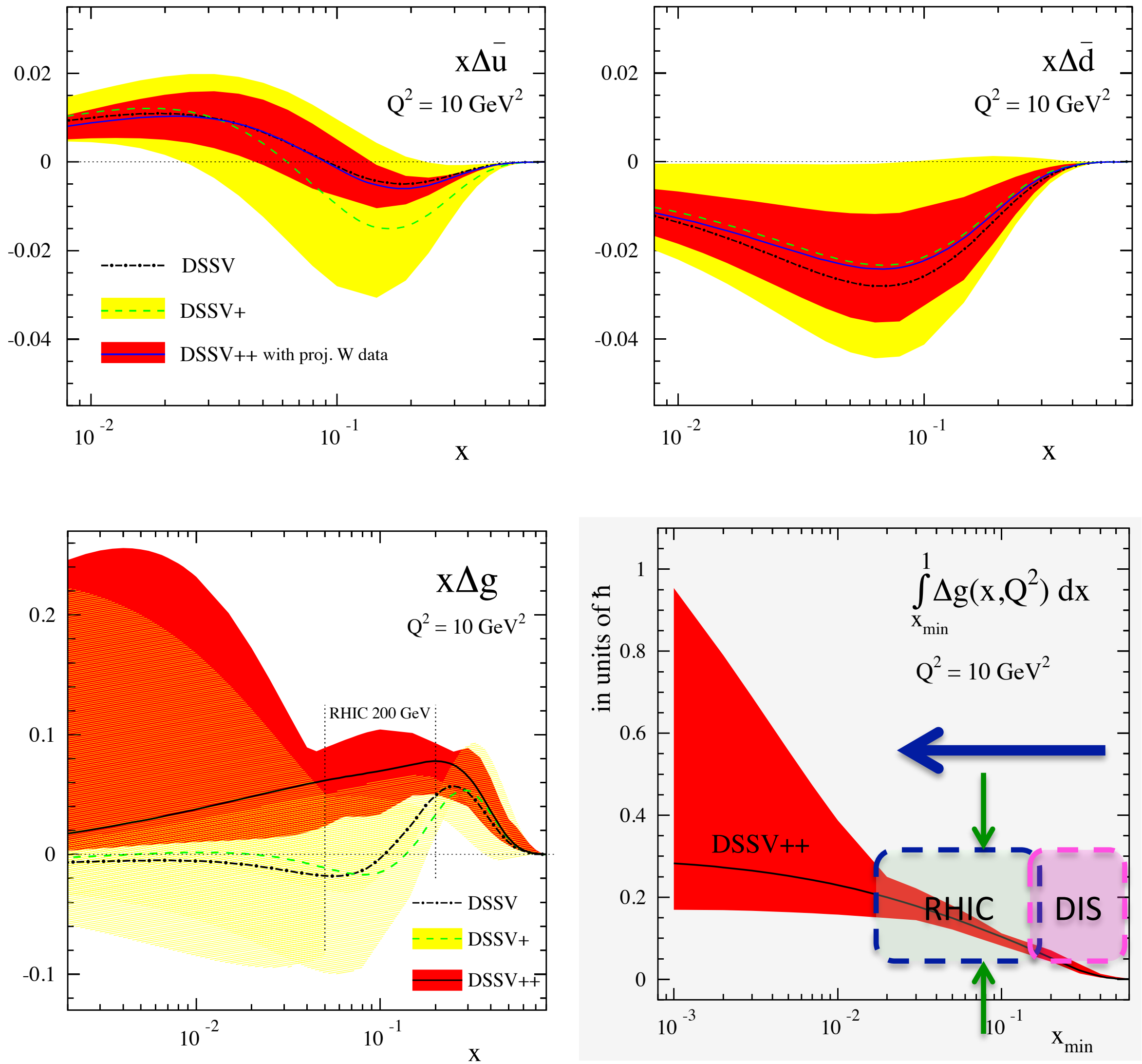
- A global QCD fit (NNPDF) on the DIS data can extract the polarization from the valence quarks with good precision.





arXiv:1303.7236

Current knowledge of pPDF

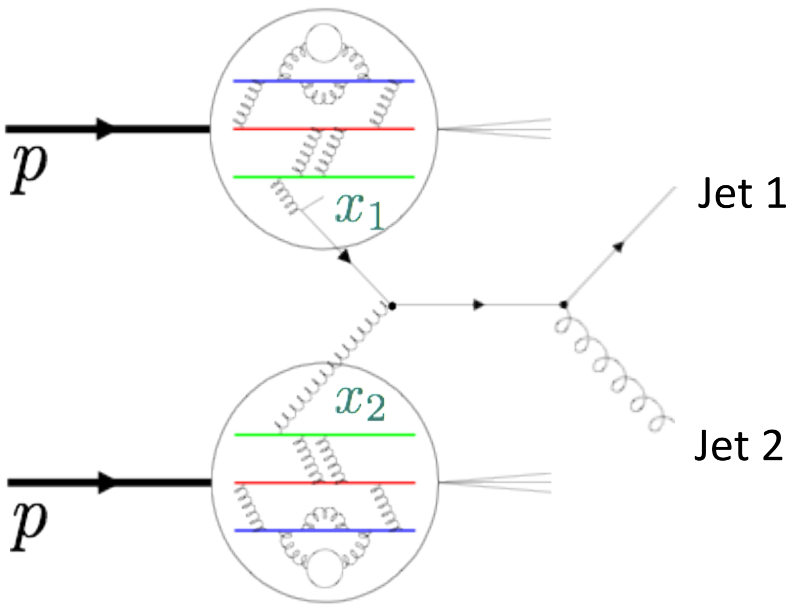


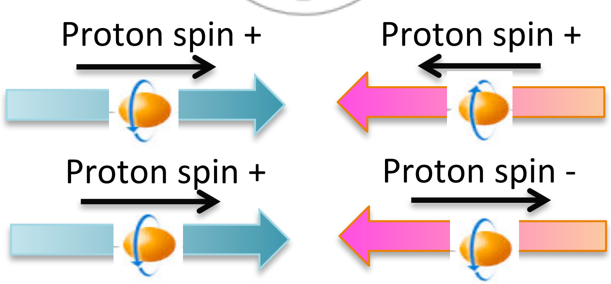
arXiv:1304.0079

- Sea quark and gluon pPDF has large uncertainties.
- DIS can only access gluons via evolution. W production in SIDIS is complicated.
- Data from polarized p+p collisions at RHIC will improve the precision and measured different x region from the DIS experiments.

How to probe parton spin contributions in p+p collisions?

- In factorization framework with the assumption of universal PDF, asymmetries of final states are proportional to the initial quarks or gluons polarization contributions.





- For example, longitudinal double-spin asymmetry A_{LL} of inclusive jet or di-jets can probe the quark or gluon helicity.

To measure

$\Delta f_{1/2}$: Quark/gluon helicity

$$A_{LL}(jet) = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \propto \frac{\Delta f_1 \otimes \Delta f_2 \otimes a_{LL}}{f_1 \otimes f_2}$$

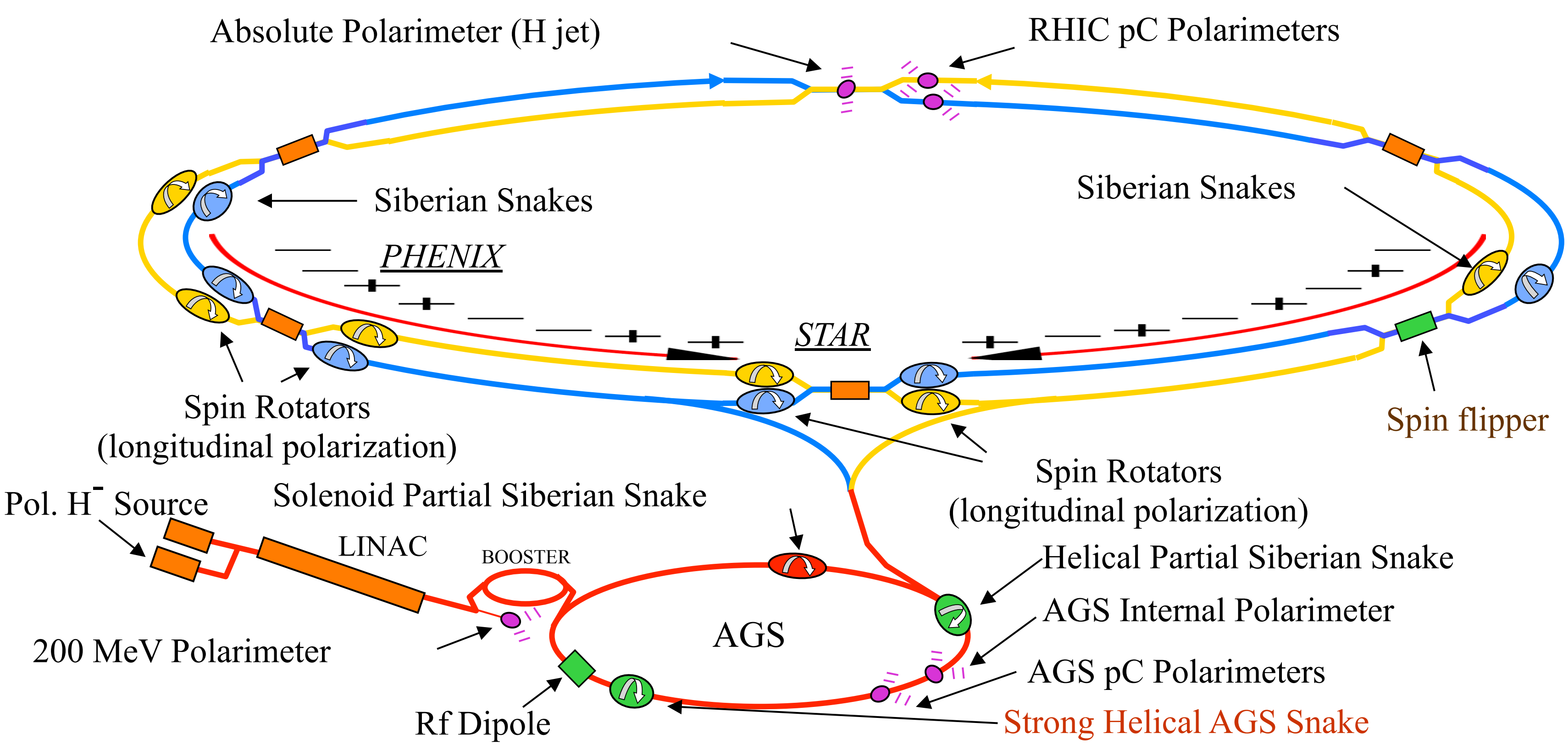
known inputs:

$f_{1/2}$= unpolarized parton distribution function.

a_{LL}: polarized parton asymmetry

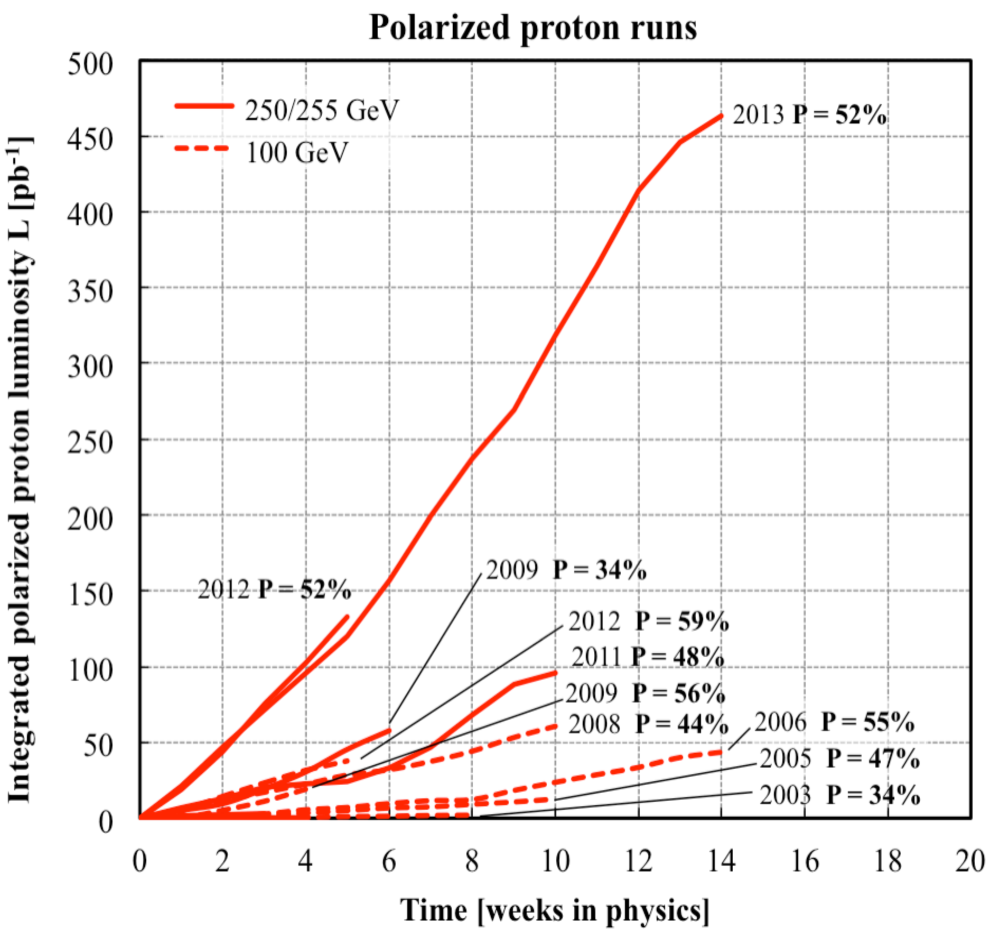
RHIC: the polarized proton-proton collider

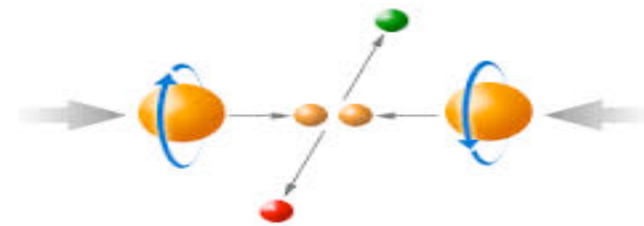
- Schematics of polarized p+p collisions at RHIC



RHIC polarized p+p collision overview

- STAR spin program explores both the longitudinal and transverse polarized proton.

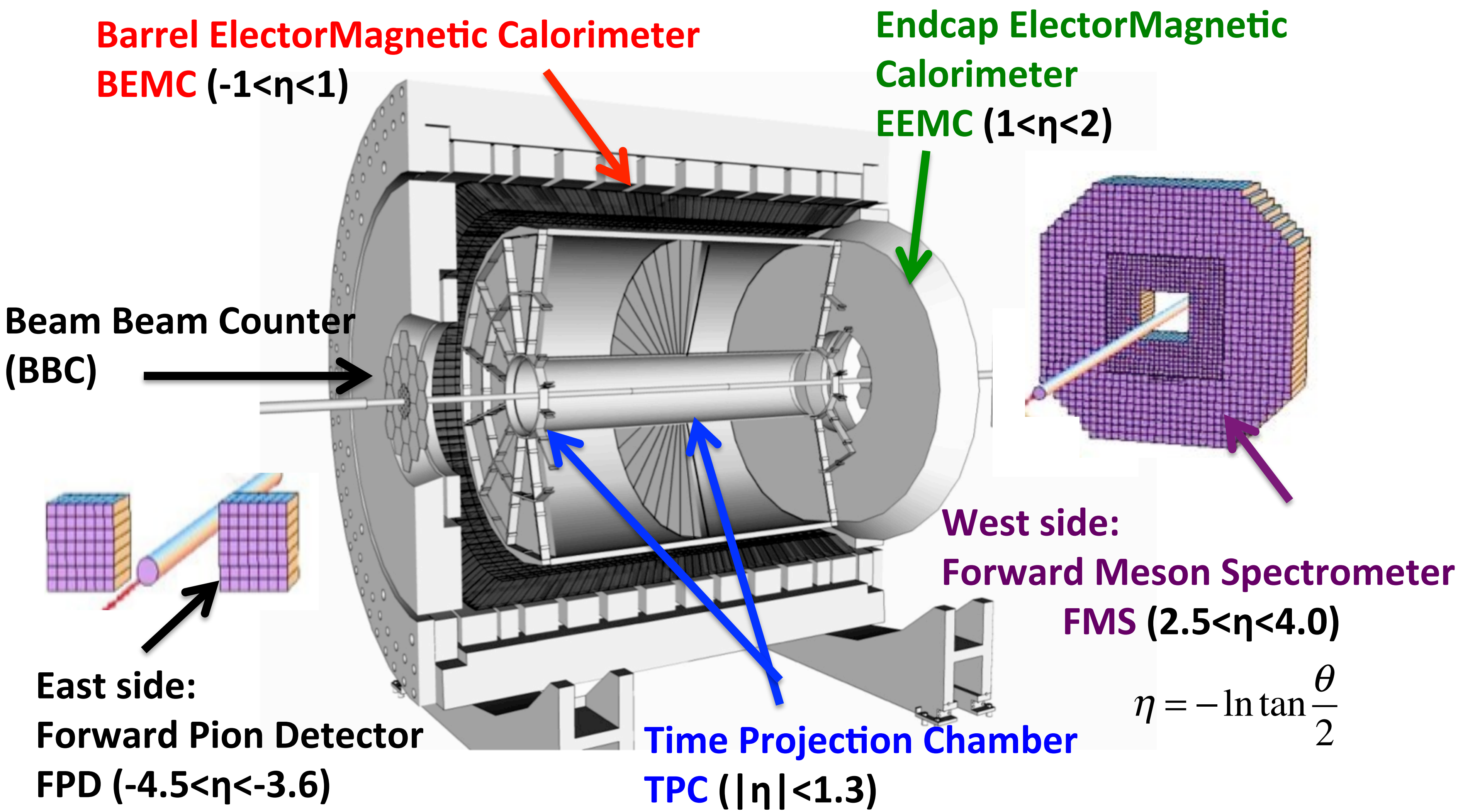




- Jet and di-jet productions in longitudinal polarized p+p collisions at √s=200/500 GeV (2009, 2012, 2013) are sensitive to the gluon polarization.
- W production in longitudinal polarized p+p collisions at √s=500 GeV (2009, 2012, 2013) can probe the sea quark polarization.

STAR Detector

- STAR has nearly full azimuthal coverage in η from -1 to 4.



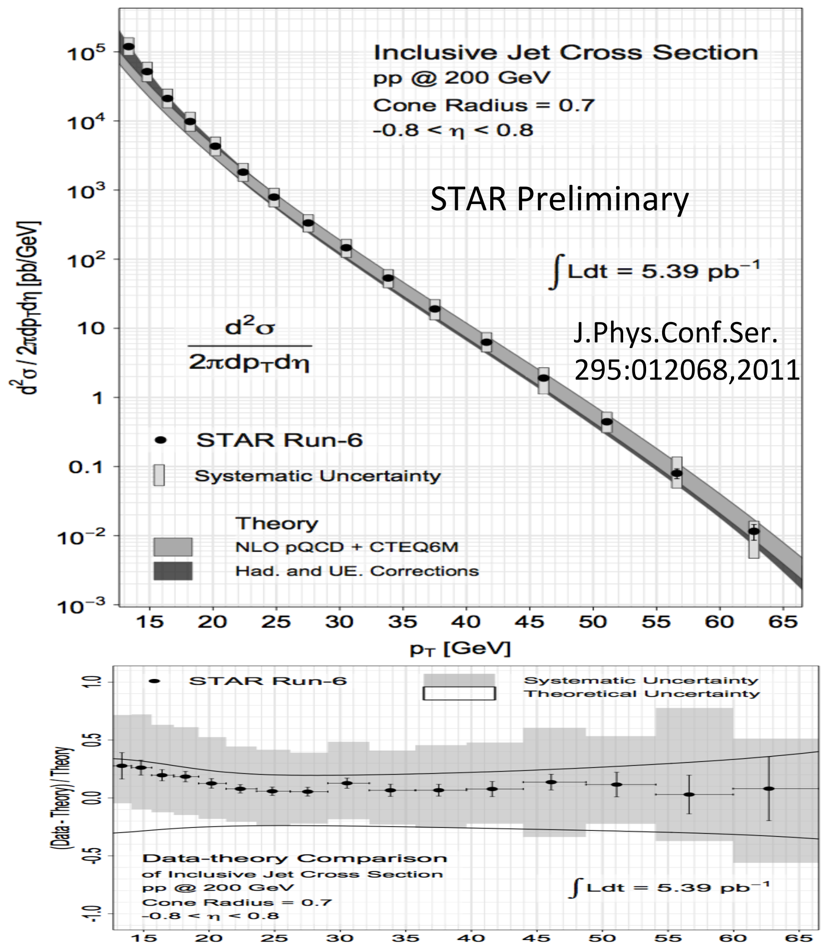
$$\eta = -\ln \tan \frac{\theta}{2}$$

$\Delta g(x,Q^2)$ (gluon polarization) related measurements

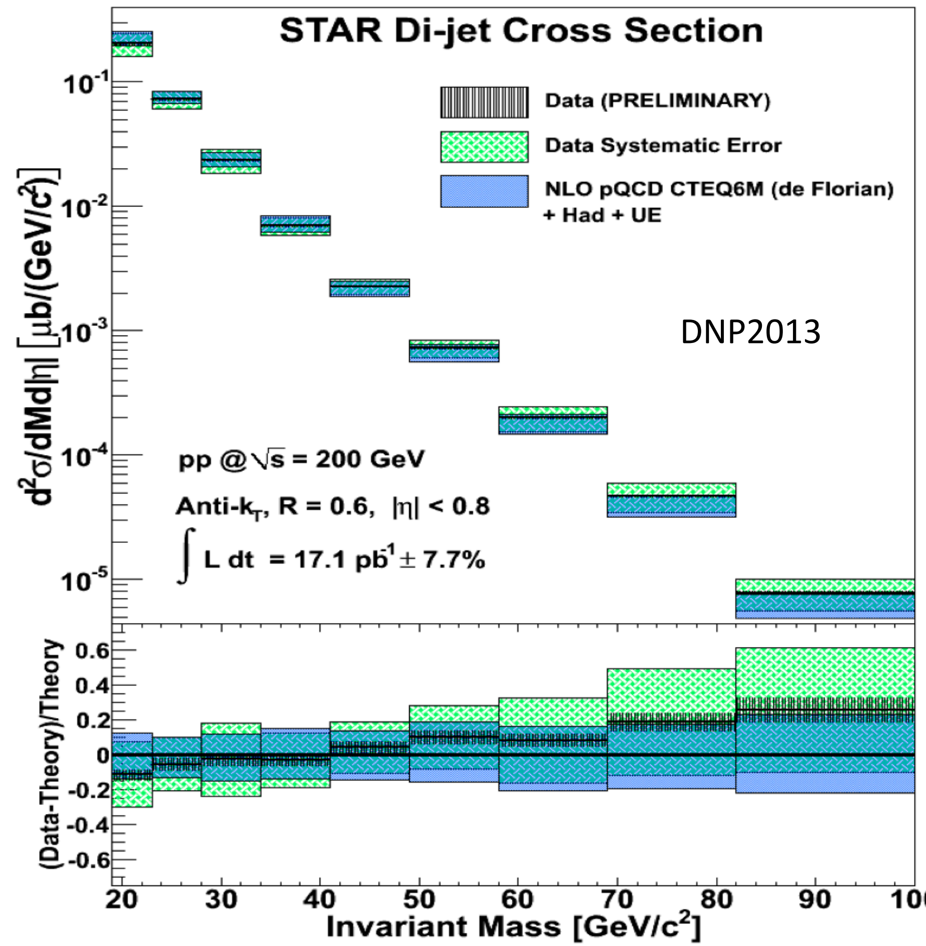
Jet cross section measurements at STAR

- Inclusive jet and di-jet cross section results in p+p collisions are consistent with NLO pQCD calculations after Had+UE corrections.

Inclusive jet in p+p 200GeV



Di-jet in p+p 200GeV



Jet cross section measurements at STAR

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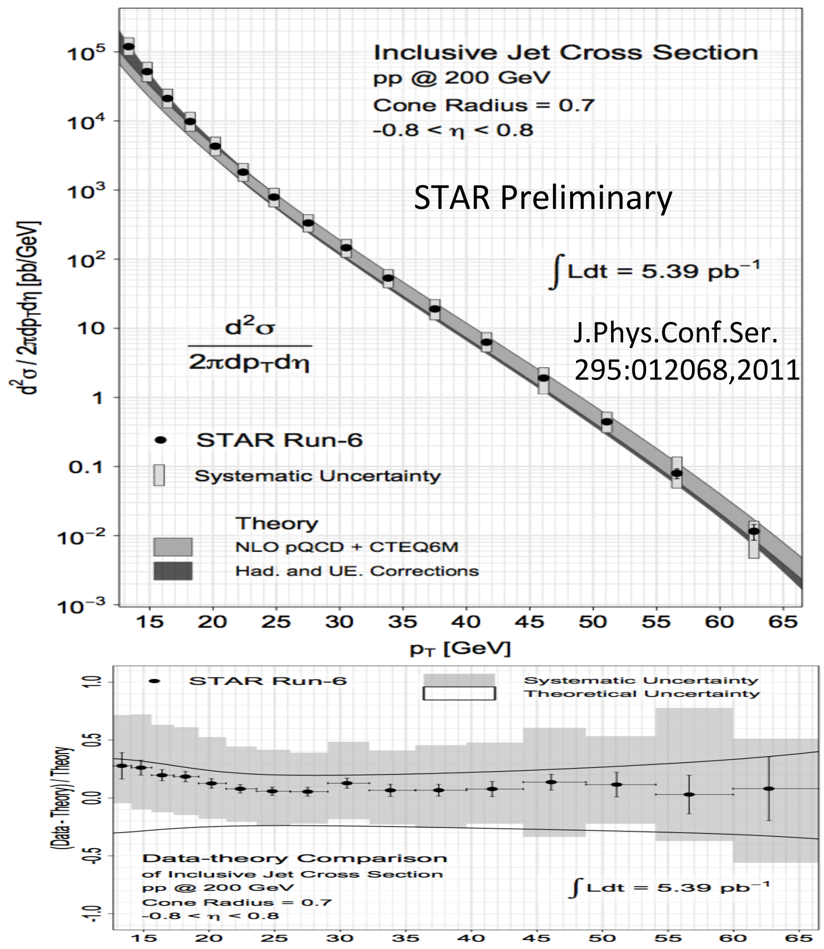
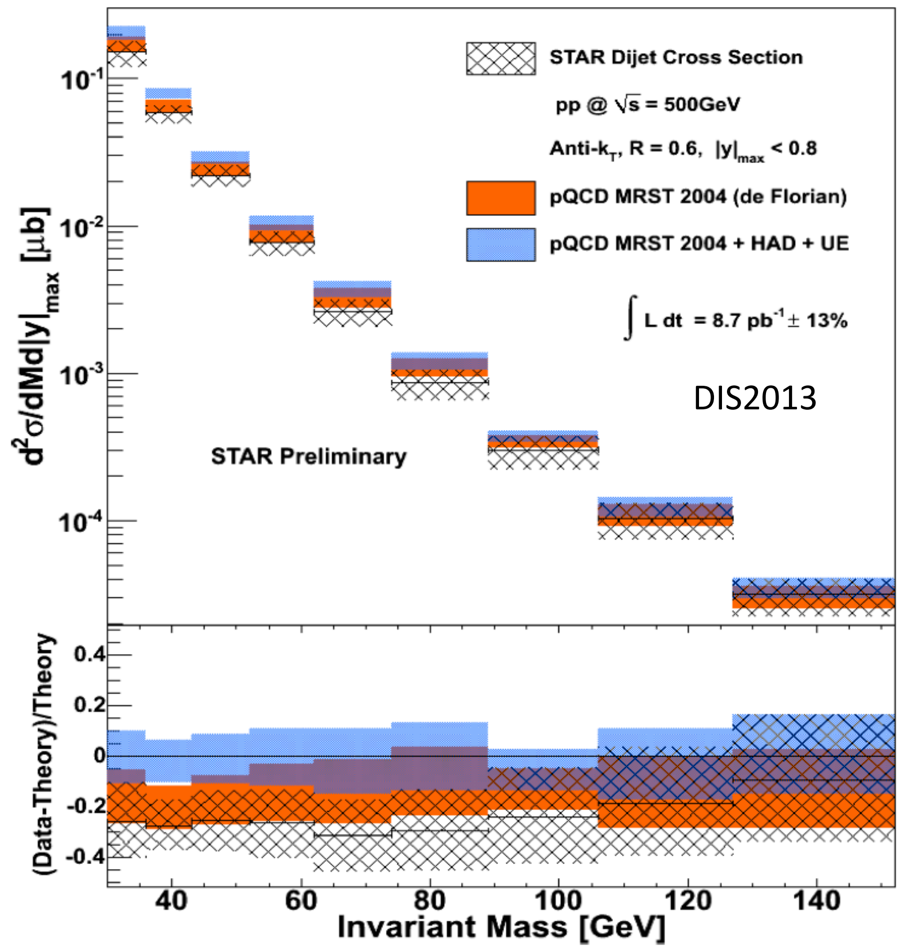
Inclusive jet in p+p 200GeV

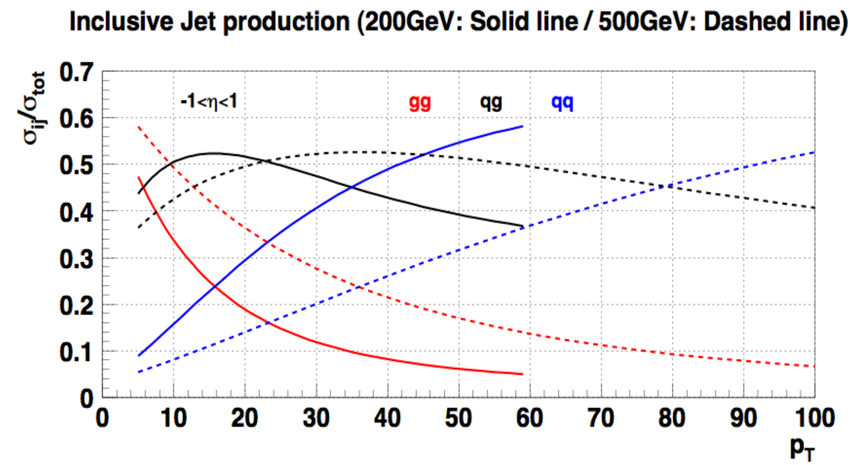


Di-jet in p+p 500GeV

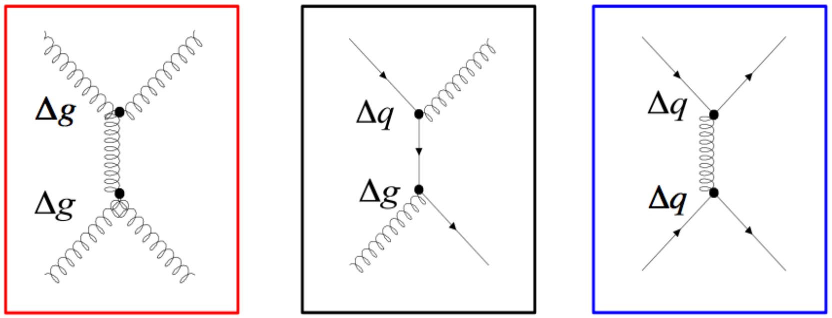


Inclusive jet A_{LL}

- Mid-rapidity inclusive jet production is dominated by g+g and q+g processes in RHIC 500 GeV p+p collisions (q+g process at 200 GeV p+p collisions).



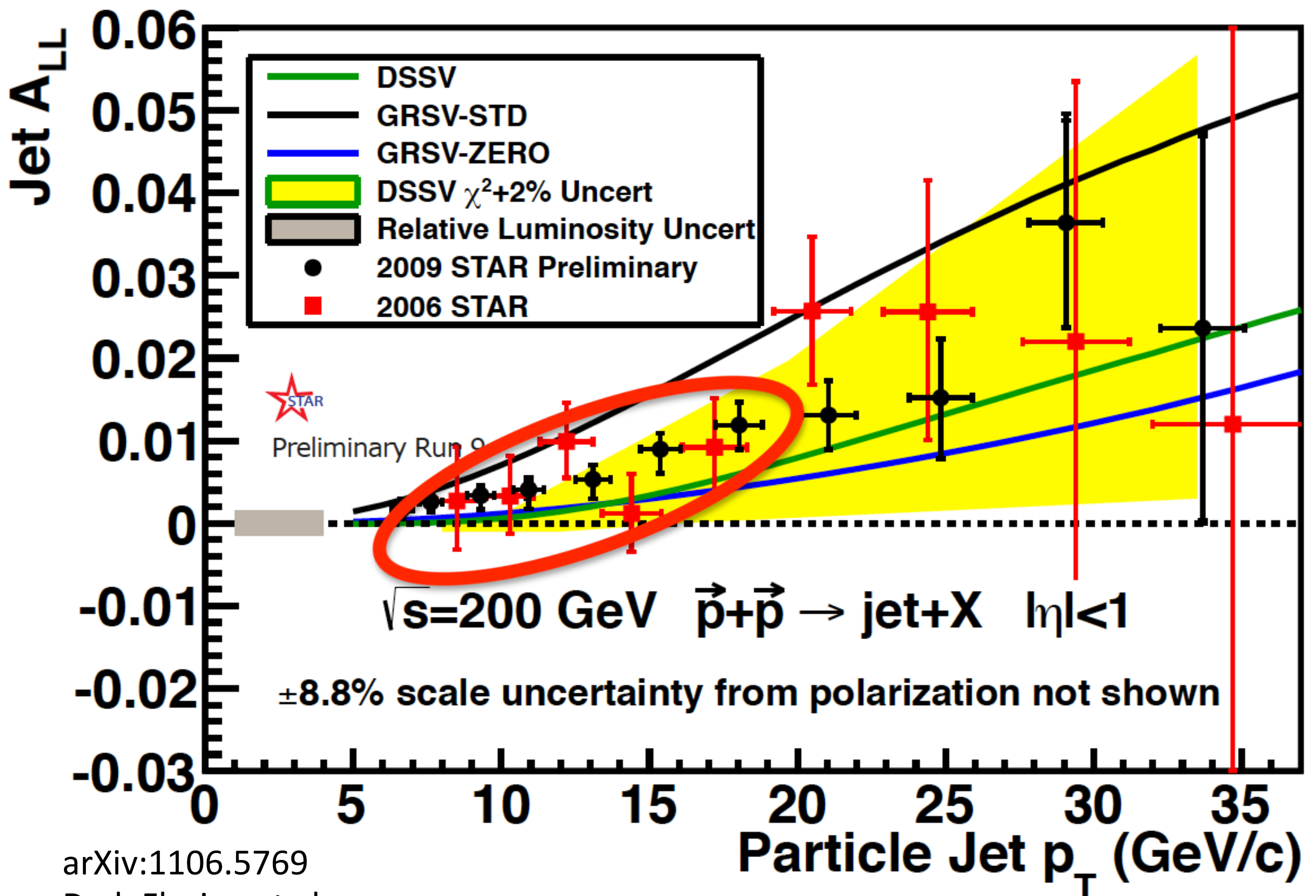
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$



- Inclusive jet A_{LL} is sensitive to the gluon contribution to polarized proton.

STAR inclusive jet A_{LL} in 2009 (p+p 200GeV)

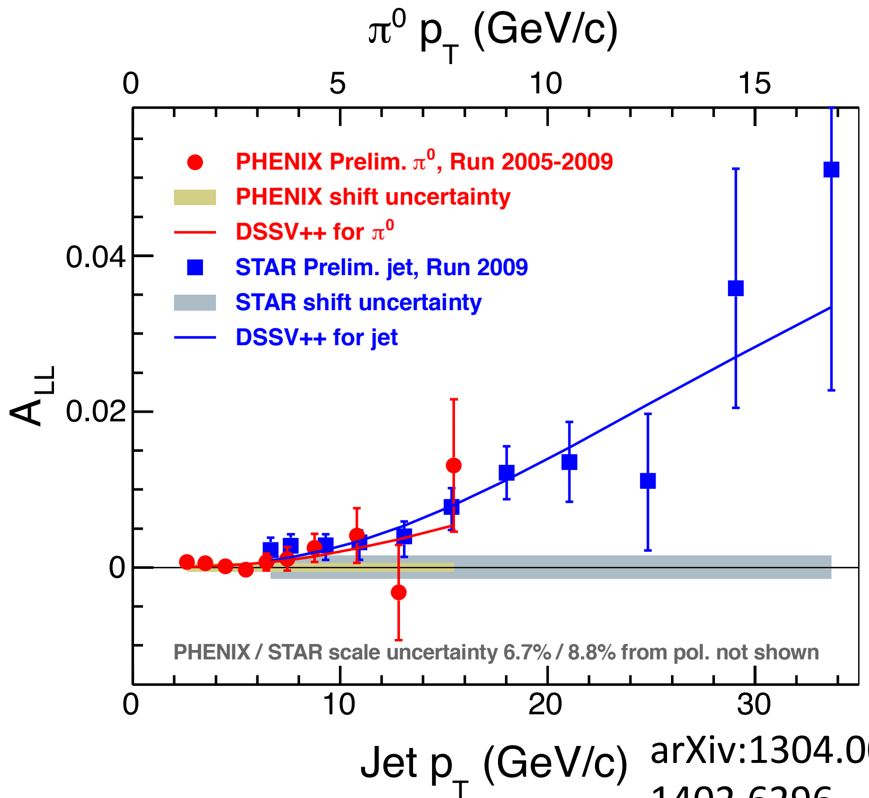
- STAR inclusive jet A_{LL} falls between DSSV and GRSV-STD, but larger than GRSV-ZERO for p_T<15GeV/c region.



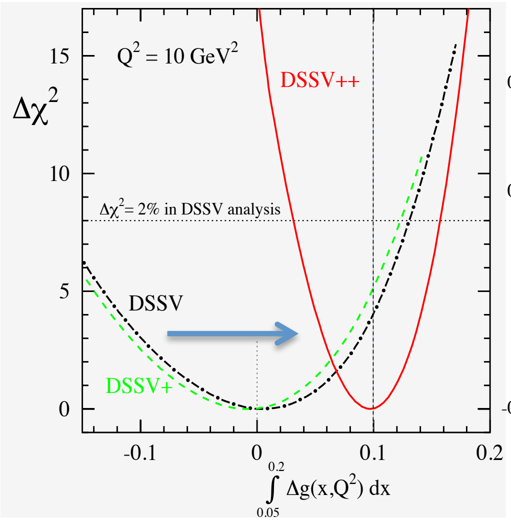
arXiv:1106.5769
D. deFlorian et al.,
Prog. Nucl. Part. Phys. 67, 251 (2012)

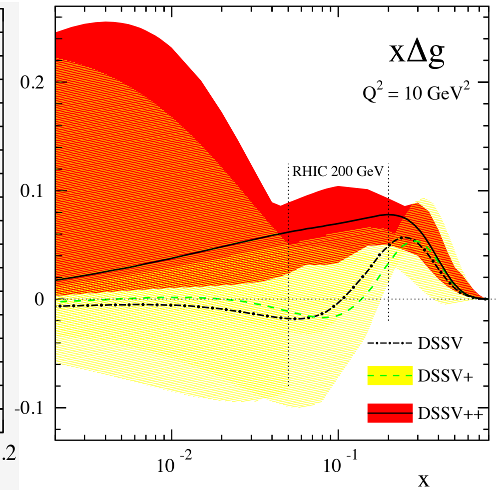
STAR inclusive jet A_{LL} in 2009 (p+p 200GeV)

- Inclusive jet A_{LL} indicates non-zero gluon polarization in 0.05<x<0.2.



arXiv:1304.0079, 1402.6296

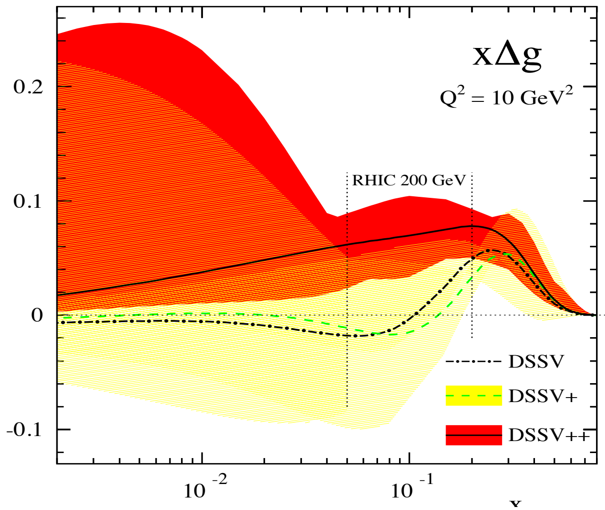


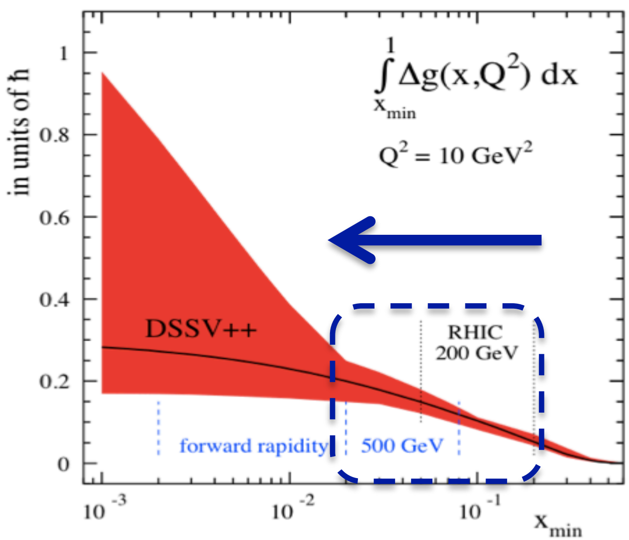


$$\int_{0.05}^{0.2} \Delta g(x, Q^2 = 10GeV^2)dx = 0.1^{+0.06}_{-0.07}$$

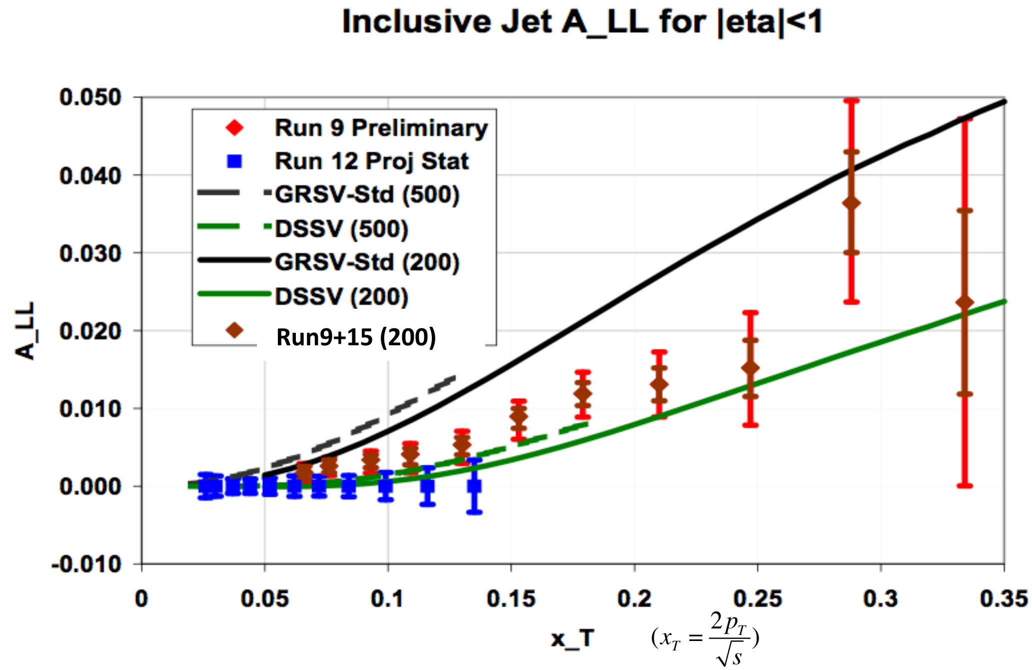
- RHIC A_{LL} results narrow the uncertainties of the fitted Δg and shift the central value of ΔG.
- DSSV++ fit provides first non-zero ΔG in the RHIC sensitive region.

Projections for inclusive jet A_{LL} (p+p 200/500GeV)



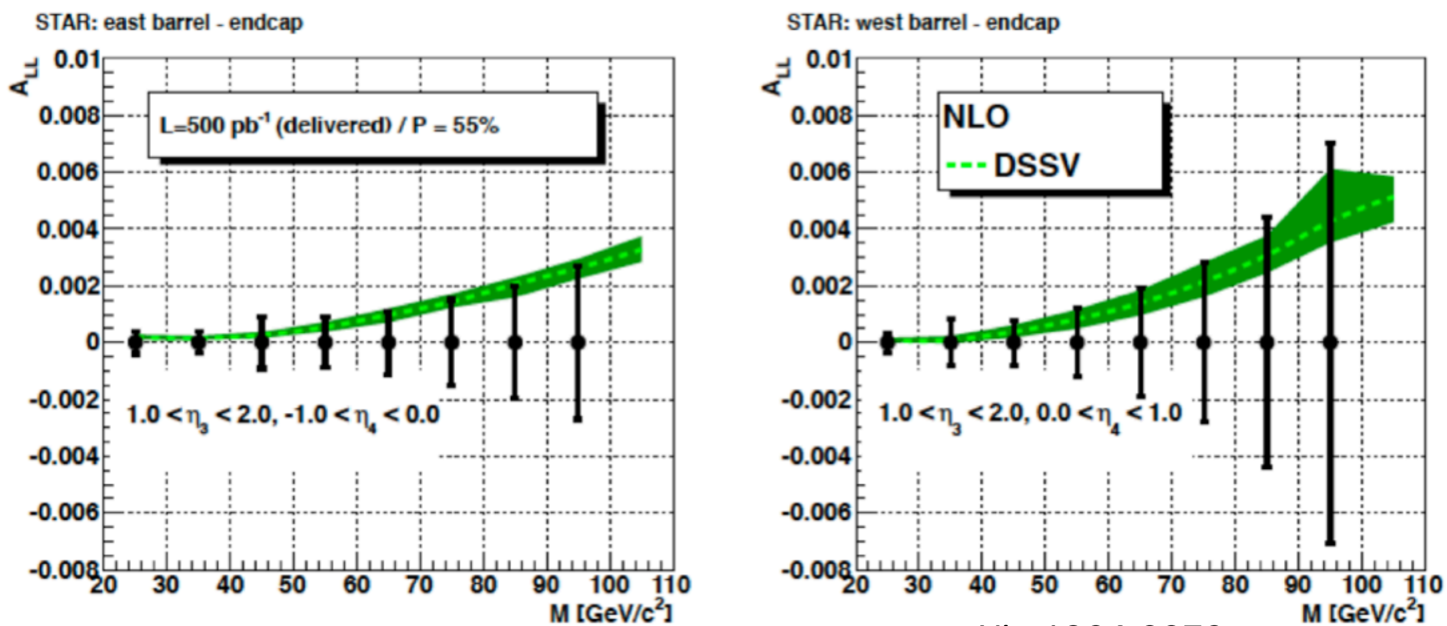


arXiv:1304.0079

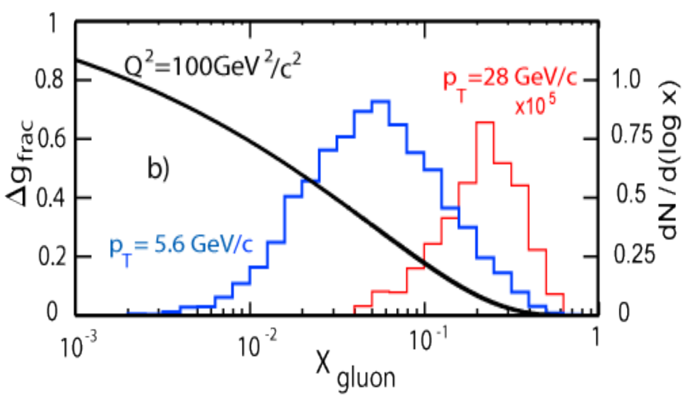


- In 2012 and 2013, RHIC has large longitudinal √s = 500GeV p+p data sample which allows us to access lower x region with higher √s.
- For 2015 200GeV p+p run, expect to reduce the stat. errors.

Projections for di-jet A_{LL} (p+p 500GeV)



arXiv:1304.0079



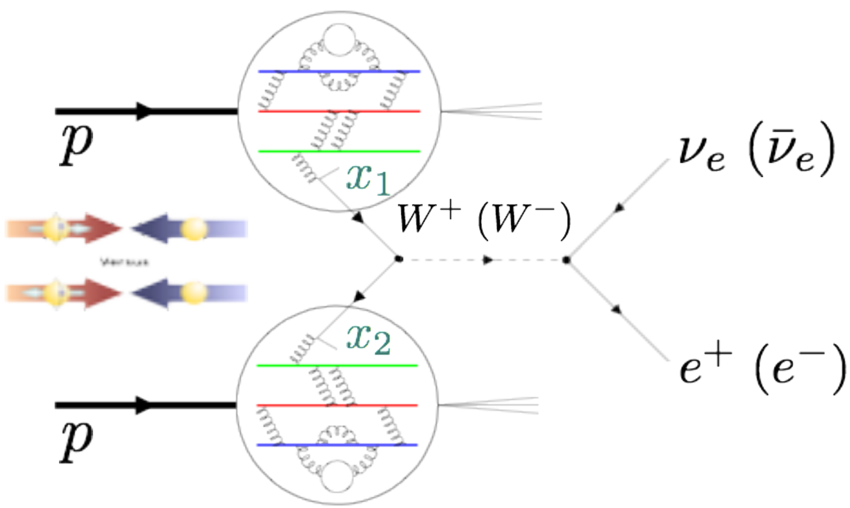
PRL 100, 232003

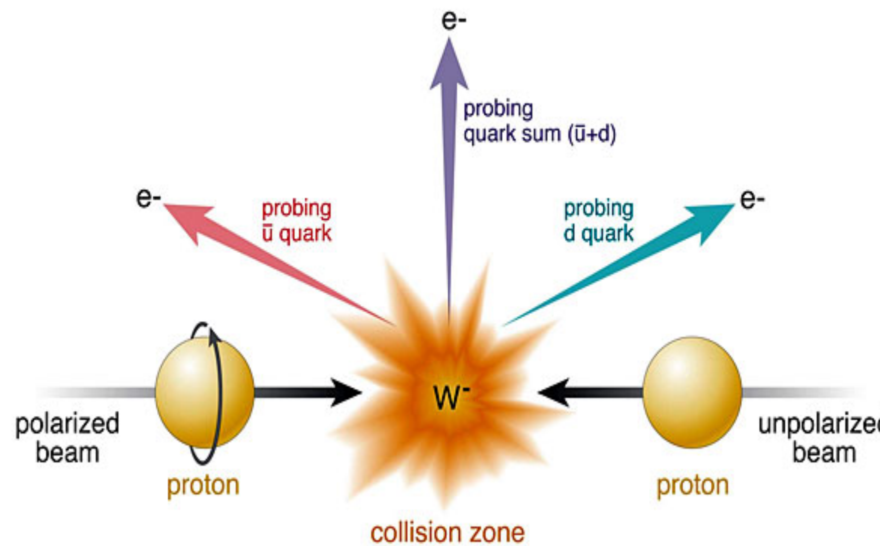
- At fixed Q^2, di-jet production constrains the probed gluon x region.
- Correlations in different η regions access different x region, higher η lower x.

$\Delta\bar{q}(x,Q^2)$ (sea quark polarization) related measurements

W production is a direct probe for sea quark polarization

- Parity violating $W^{\pm}$ single spin asymmetry A_L probes $\Delta\bar{u}$ and $\Delta\bar{d}$ in 500GeV p+p collisions.



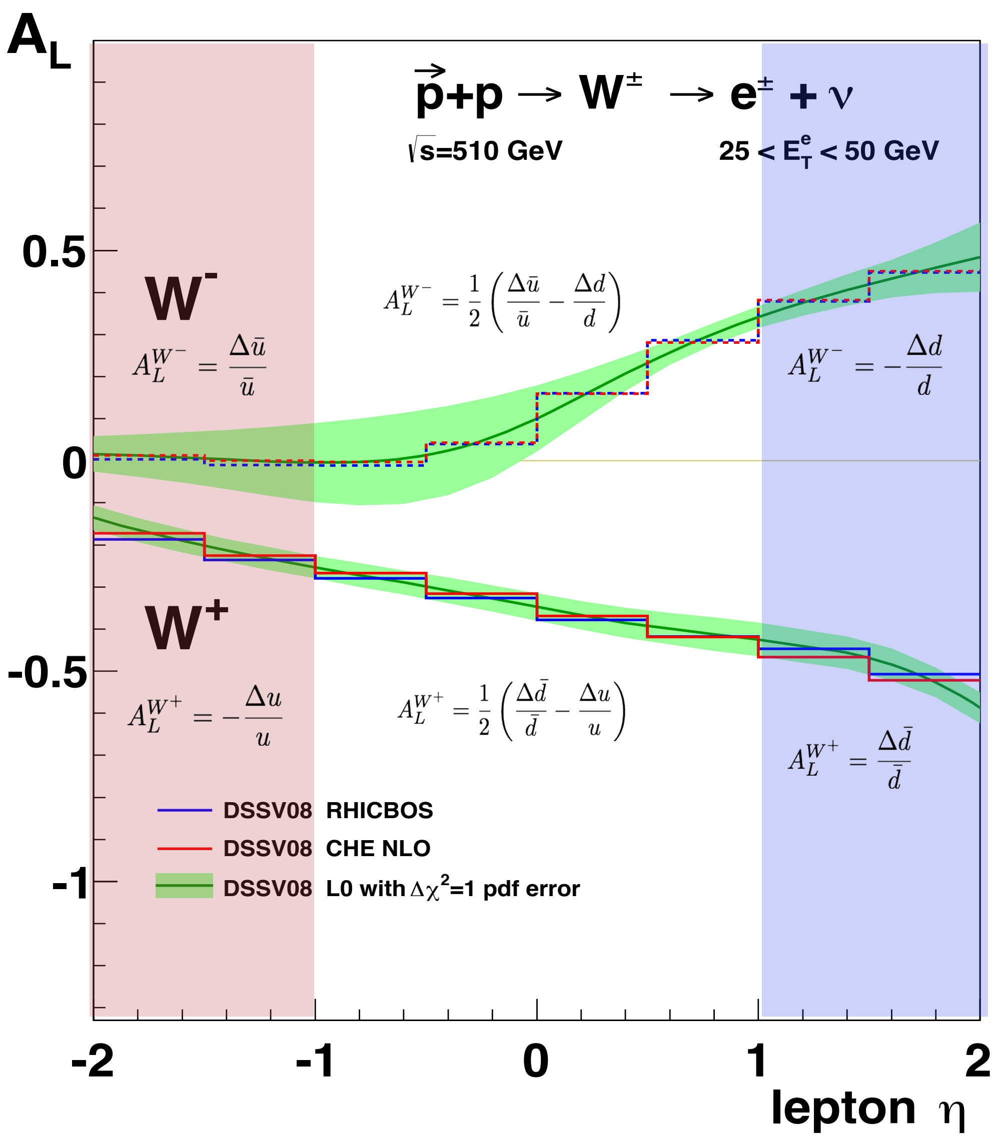


$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

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

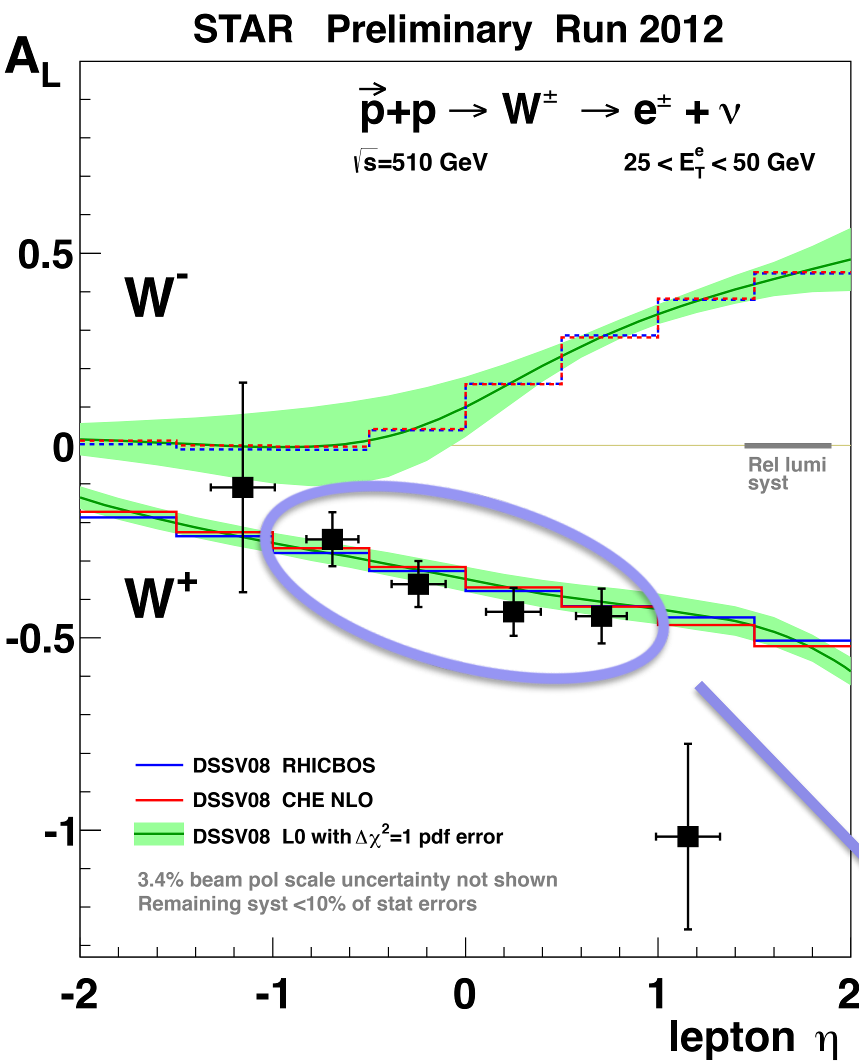
$$A_L^{W^+} \propto \frac{-\Delta u(x_1,Q^2)\bar{d}(x_2,Q^2) + \Delta\bar{d}(x_1,Q^2)u(x_2,Q^2)}{u(x_1,Q^2)\bar{d}(x_2,Q^2) + \bar{d}(x_1,Q^2)u(x_2,Q^2)} \qquad A_L^{W^-} \propto \frac{-\Delta d(x_1,Q^2)\bar{u}(x_2,Q^2) + \Delta\bar{u}(x_1,Q^2)d(x_2,Q^2)}{d(x_1,Q^2)\bar{u}(x_2,Q^2) + \bar{u}(x_1,Q^2)d(x_2,Q^2)}$$

Theory predictions on $W^{\pm}$ A_L



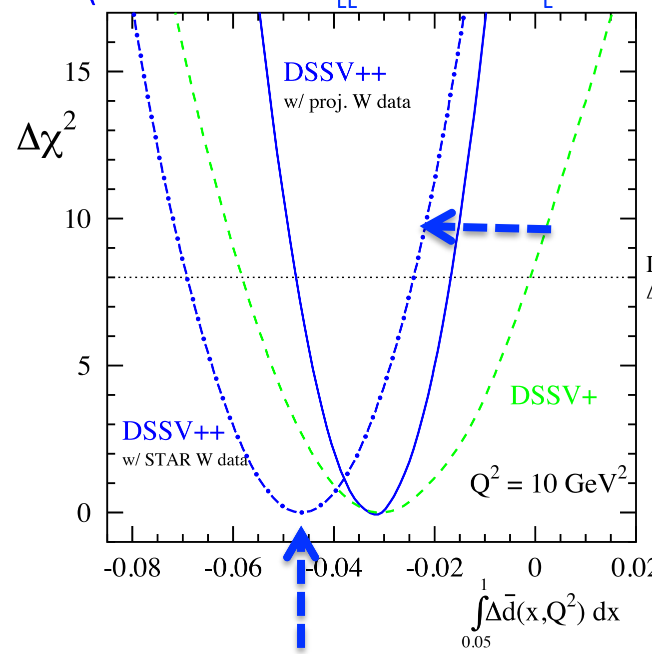
- Mid-rapidity W production probes the sum of valence quark and sea quark contributions.
- Forward/Backward W production directly probes the sea quarks.
- Critical to measure the W^+ and W^- asymmetries as a function η_e

First W rapidity dependent results at STAR



DSSV++ fit $\Delta\bar{d}(x,Q^2)$

(includes 2009 A_{LL} and 2012 A_L results)



DSSV+: DSSV08+COMPASS

DSSV++ dashed line: DSSV+ with 2012 STAR-W data

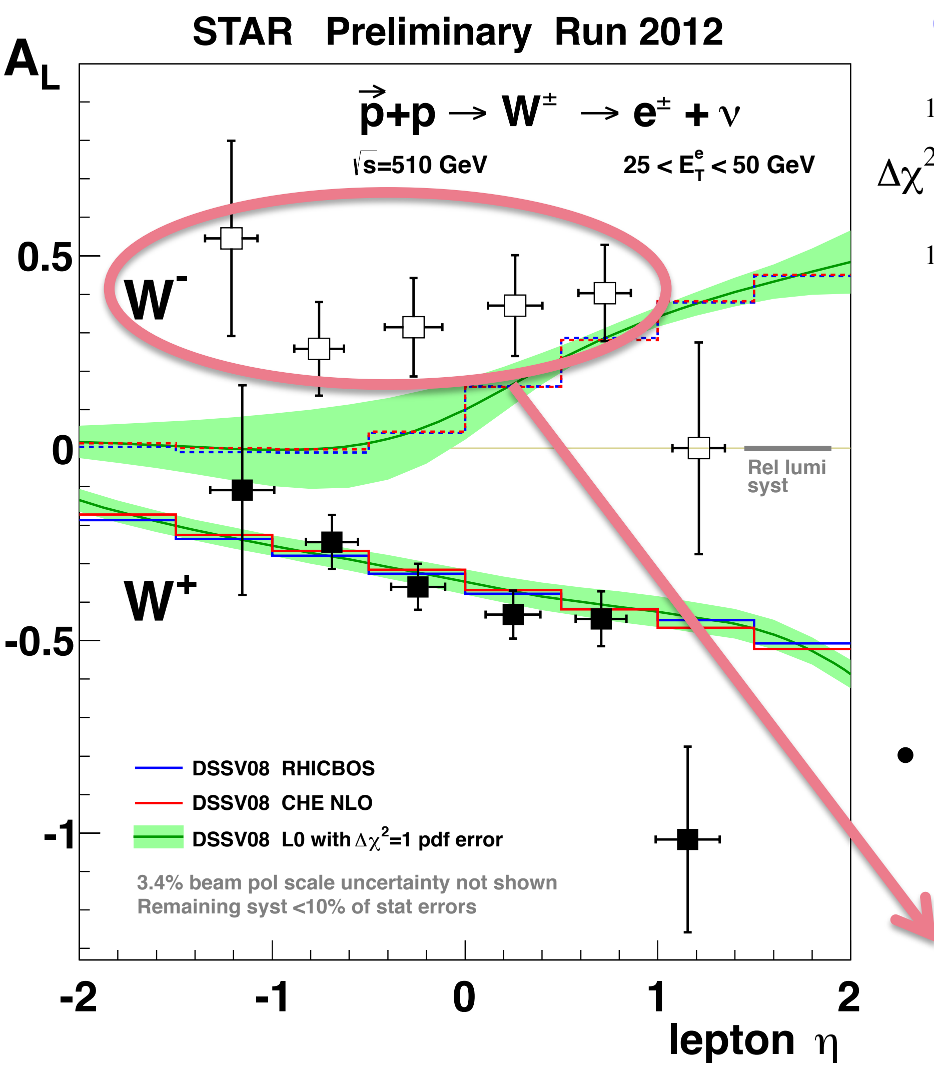
DSSV $\Delta\chi^2$=2%

DSSV++ solid line: DSSV+ with RHIC-W projection (2009-2013)

- Extrapolation from the new theory fit (DSSV++) the STAR 2012 W^+ A_L,

$$\int_{0.05}^{1} \Delta\bar{d}(x,Q^2)\,dx \approx -0.05$$

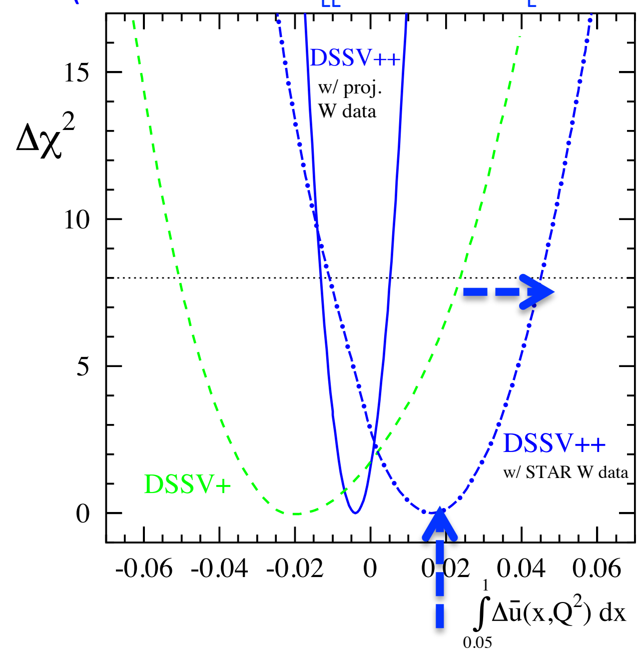
First W rapidity dependent results at STAR



arXiv:1302.6639

DSSV++ fit $\Delta\bar{u}(x,Q^2)$

(includes 2009 A_{LL} and 2012 A_L results)



DSSV+: DSSV08+COMPASS

DSSV++ dashed line: DSSV+ with 2012 STAR-W data

DSSV++ solid line: DSSV+ with RHIC-W projection (2009-2013)

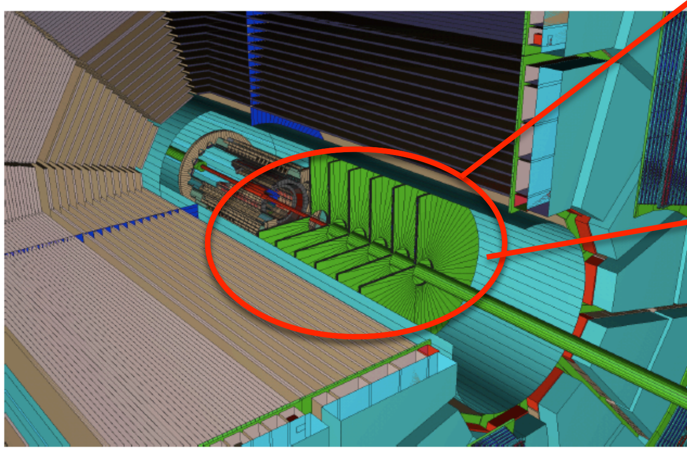
- Extrapolation from the new theory fit (DSSV++) the STAR 2012 W⁻ A_L,

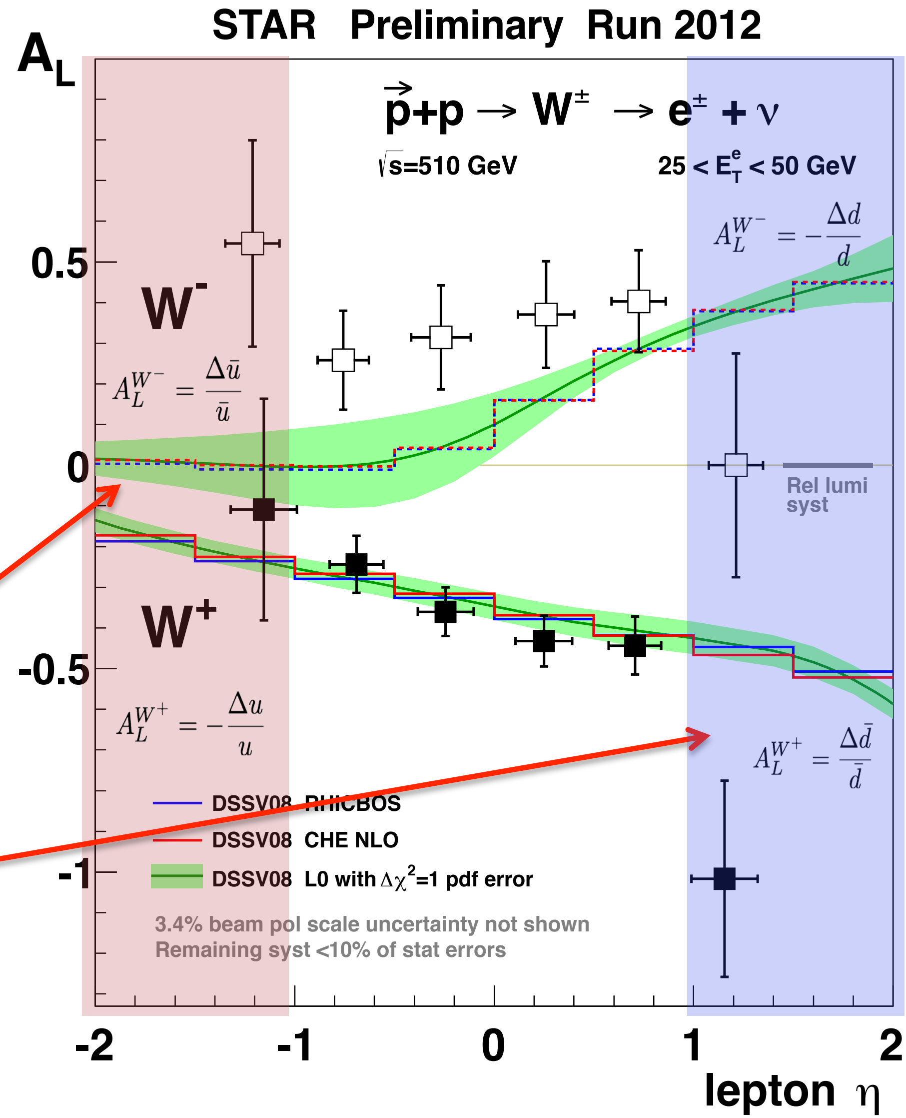
$$\int_{0.05}^{1}\Delta\bar{u}(x,Q^2)\,dx \approx 0.02$$

Extend the rapidity to isolate sea quark contribution

- Extension of backward / forward η_e acceptance enhances the sensitivity to anti-u / anti-d quark polarization

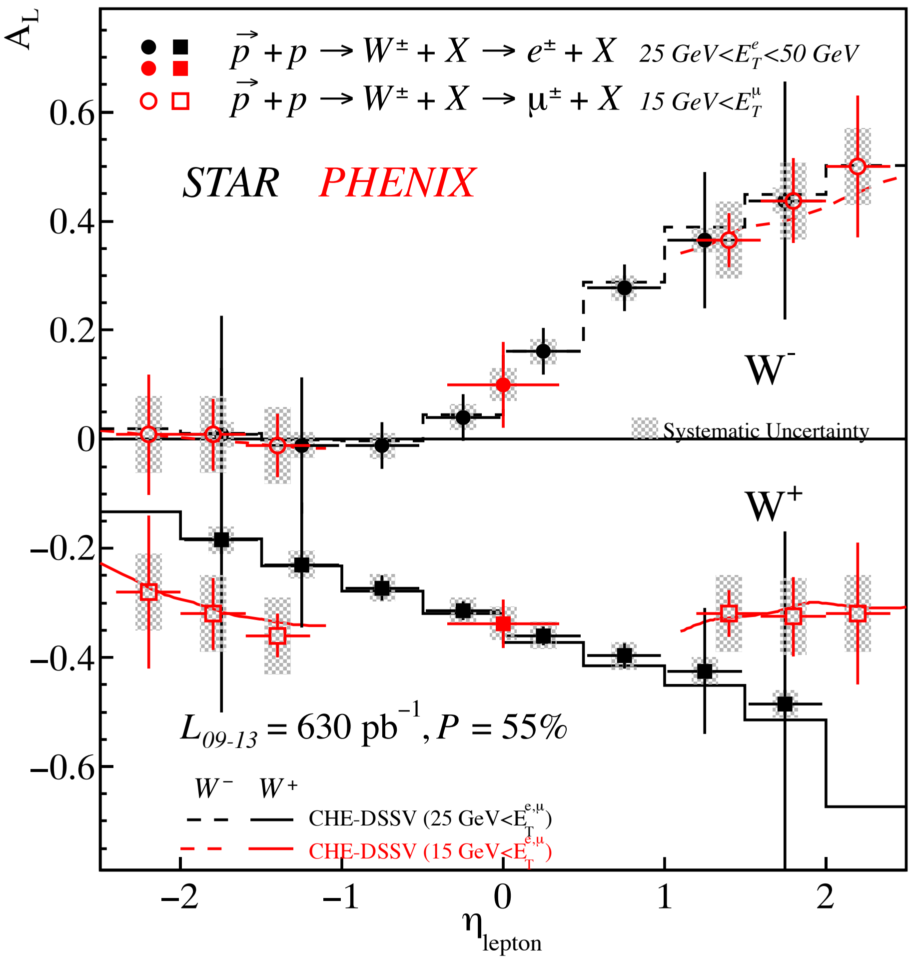
  ⇒ STAR Forward GEM Tracker ($1<|\eta_e|<2$) fully installed for 2013 run.

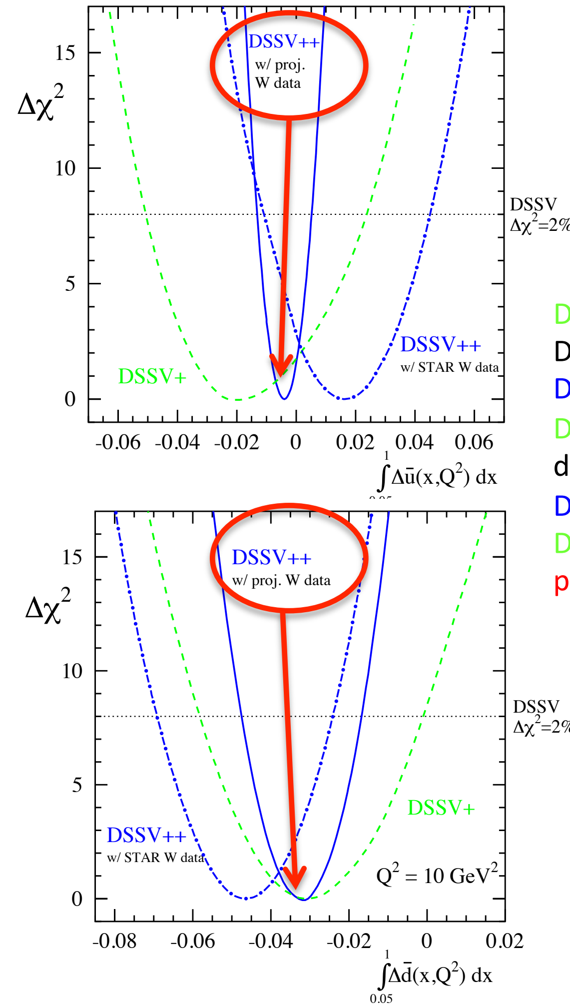




Projection of W A_L (2009-2013)

RHIC pseud-data randomized around DSSV



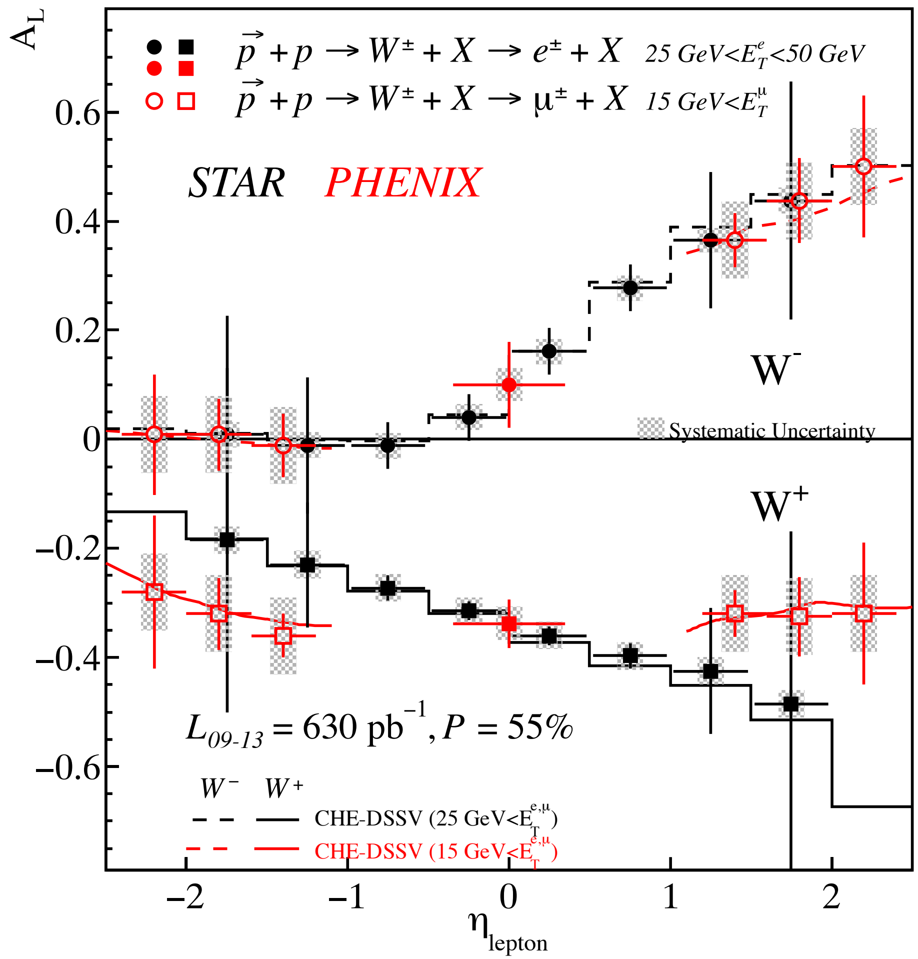


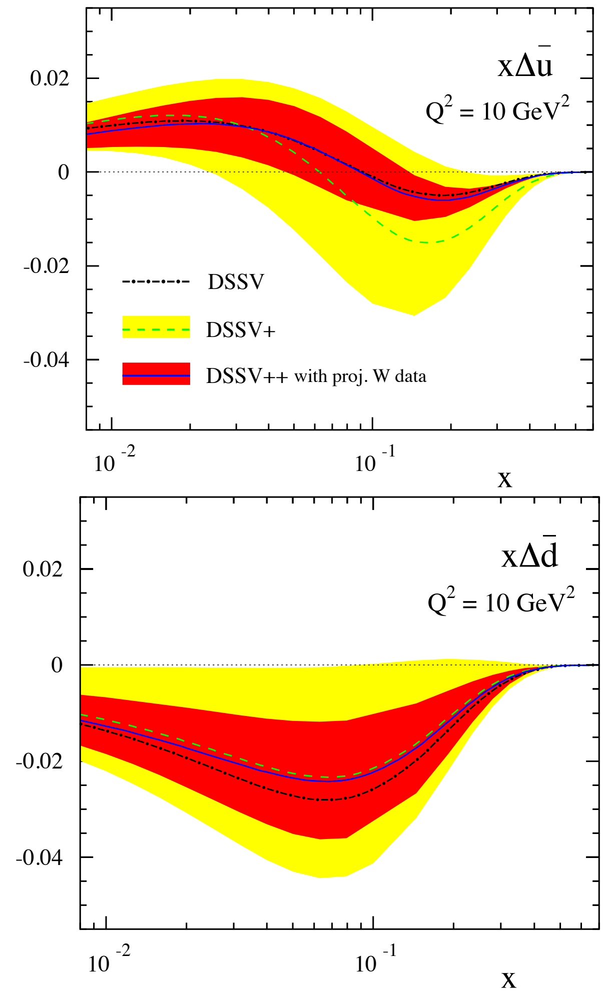
DSSV+:
DSSV08+COMPASS
DSSV++ dashed line:
DSSV+ with 2012 STAR-W data
DSSV++ solid line:
DSSV+ with RHIC-W projection (2009-2013)

- Large data sample already collected in 2013 (~310pb^{-1} , half of the projection) will further improve the constraints on the sea quark polarization.

Projection of W A_L (2009-2013)

RHIC pseud-data randomized around DSSV





Without RHIC W data

Projection of RHIC $W_{09\text{-}13}$

arXiv:1304.0079

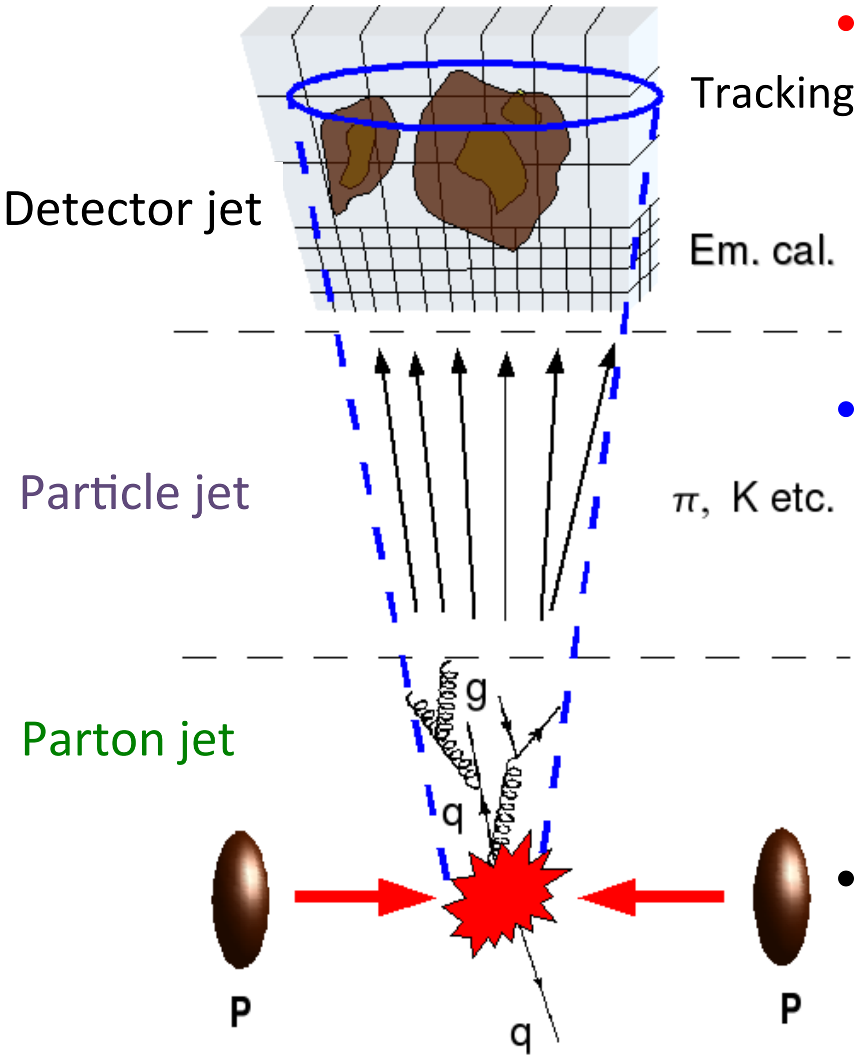
- Large data sample already collected in 2013 (~310pb^{-1} , half of the projection) will further improve the constraints on the sea quark polarization.

Summary and Outlook

- Gluon polarization program:
  - 2009 inclusive jet A_{LL} measurement suggests non-zero ΔG.
  - 2009 di-jet measurement opens the path to constrain the shape of Δg.
- Sea quark (W boson) program:
  - Mid-rapidity: 2012 W^- A_L suggests a larger anti-u quark polarization contribution.
  - Forward/Backward rapidity: STAR FGT upgrade.
- 2012 run and future
  - Long. 500GeV runs in 2012 (~85pb^{-1}) and 2013(~310pb^{-1}) allows us to achieve higher precision measurements.
  - Longer term upgrades are planned to prepare for the transition from RHIC to an EIC.

Backup

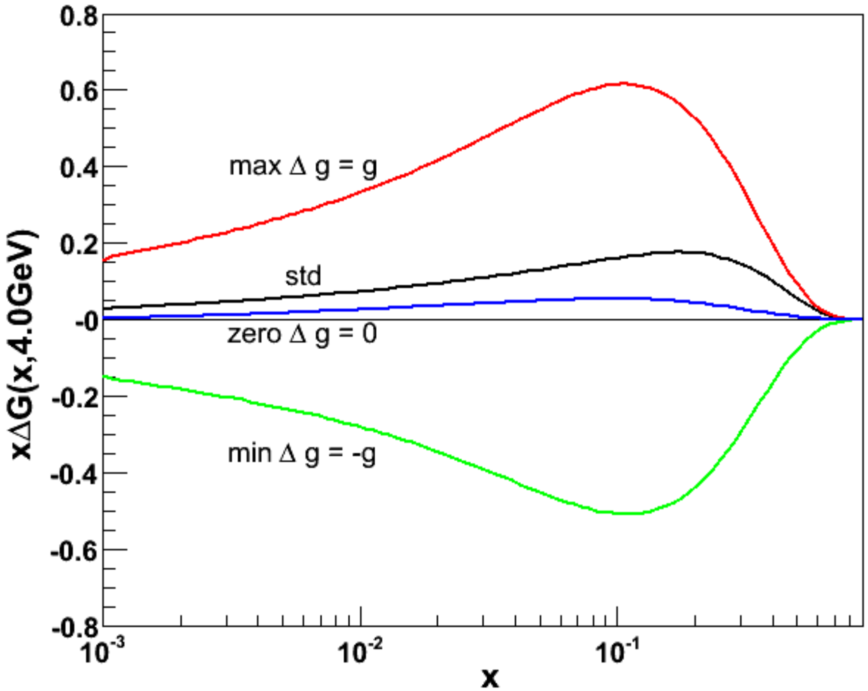
Jet Reconstruction



- Midpoint Cone algorithm[aXiv:hep-exp/0005012]:
  - Collect towers+tracks within a cone of radius ($R=\sqrt{\Delta\eta^2+\Delta\phi^2}$) 0.7.
  - Split/Merge fraction 0.5.
- Anti-k_T algorithm[JHEP 0804:063,2008]:
  - $d_{ij} = \min(\frac{1}{k_{T,i}^2}, \frac{1}{k_{T,j}^2}) \frac{\Delta_{ij}^2}{R^2}$ $\Delta_{ij}^2 = (y_i - y_j)^2 + (\varphi_i - \varphi_j)^2$
  - Collect towers+tracks based on particle $1/k_{T,i}^2$. Select R=0.6.
  - less UE and pile up.
  - Infrared and collinear safe.
- Apply both jet algorithms on detector, particle and parton jet in data and embedding.

Global fit

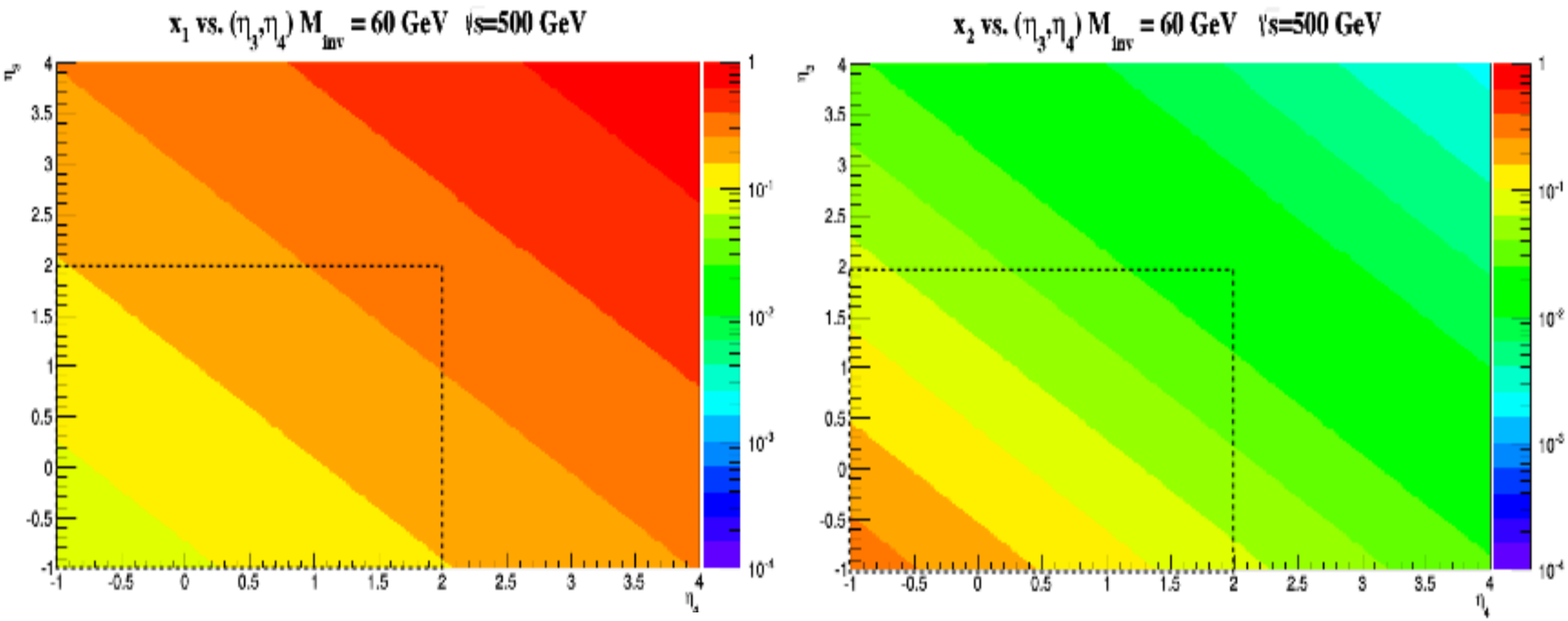
- GRSV



PRD 63 (2001) 094005

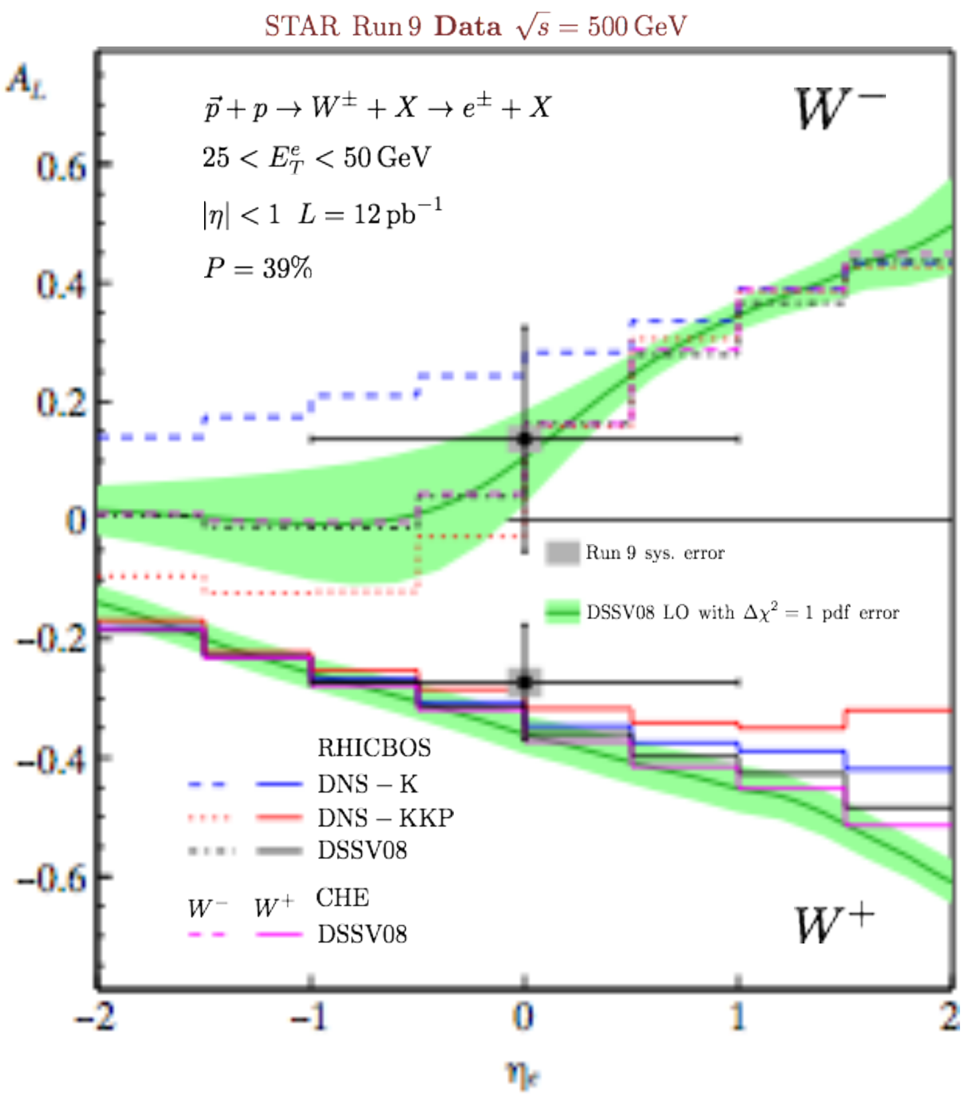
Di-jet kinematics in 500GeV p+p collisions (simulation)

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



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

First W measurement at STAR

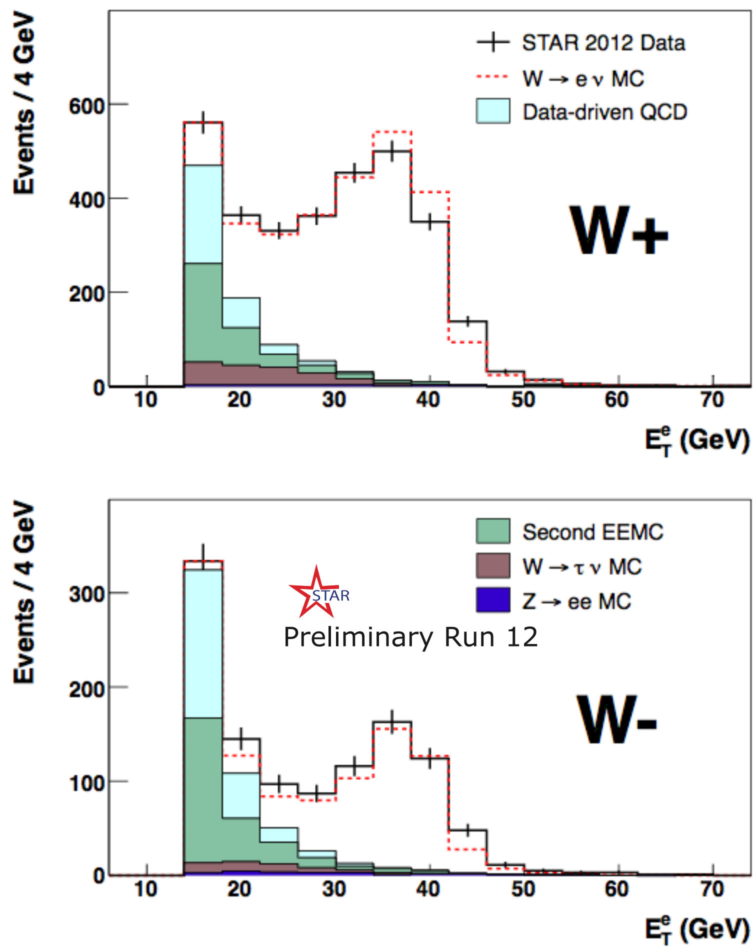


- 2009 $W^{\pm}$ asymmetries are in agreement with theory evaluations using polarized pdf's (DSSV) constrained by polarized DIS data ⇒ Universality of helicity distr. functions!

Phys. Rev. Lett. **106** (2011) 62002

W reconstruction

- Run12

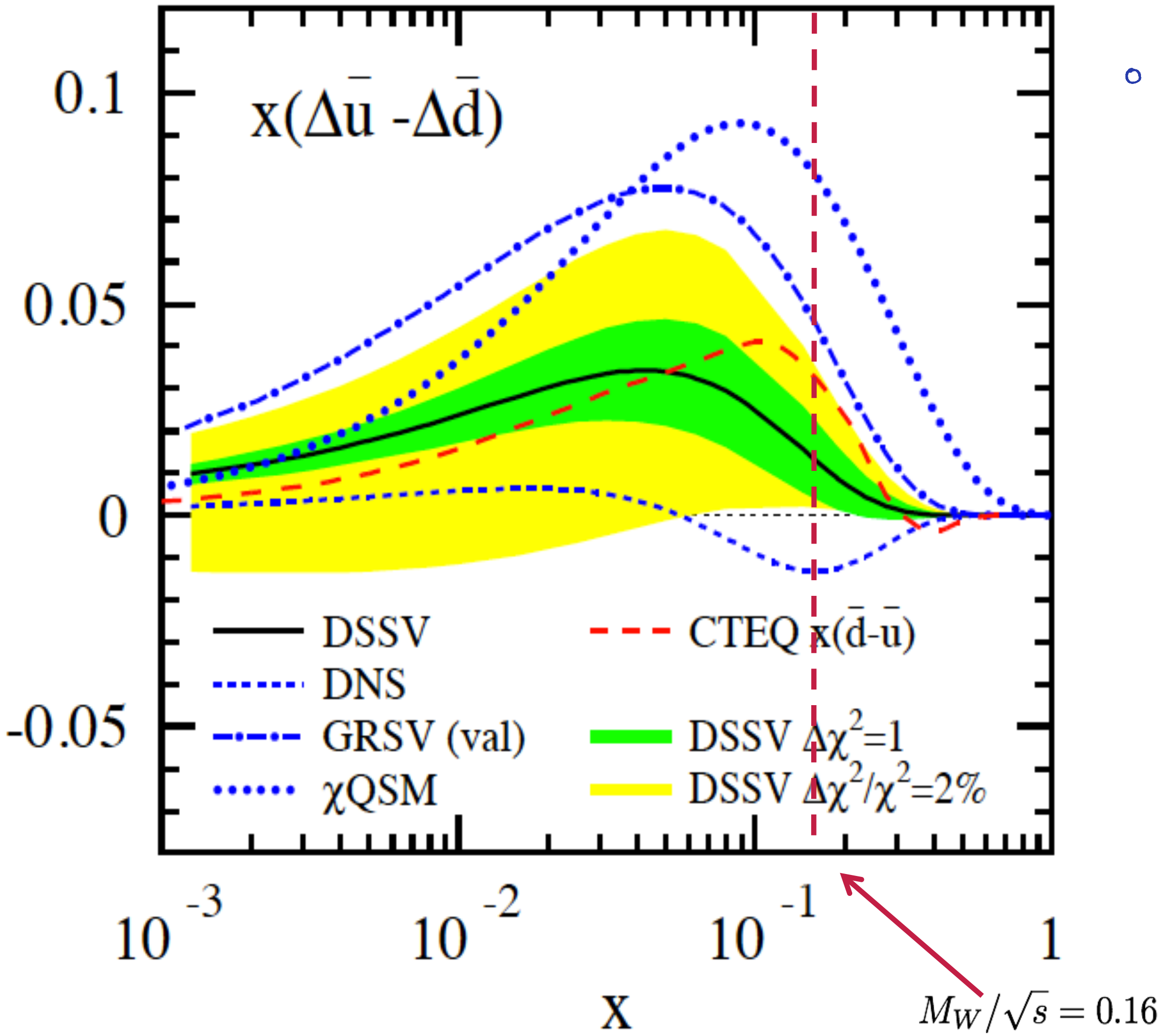


arXiv:1302.6639

Recent results - W production

- Impact of new DSSV result

D. de Florian et al., Phys. Rev. Lett. 101 (2008) 072001



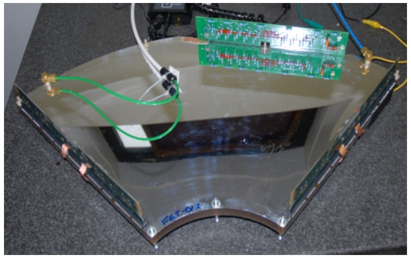
- From recent DSSV++ result incl. STAR A_L data:

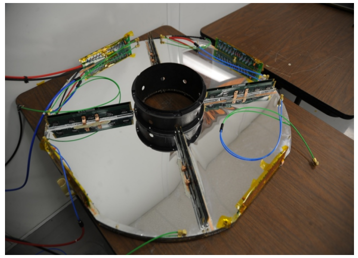
$$\int_{0.05}^{1} \Delta\bar{u}(x,Q^2)dx \approx 0.02$$

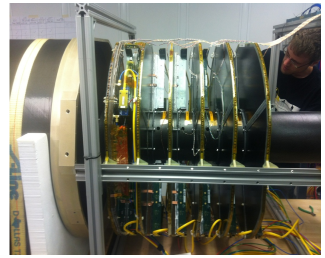
$$\int_{0.05}^{1} \Delta\bar{d}(x,Q^2)dx \approx -0.05$$

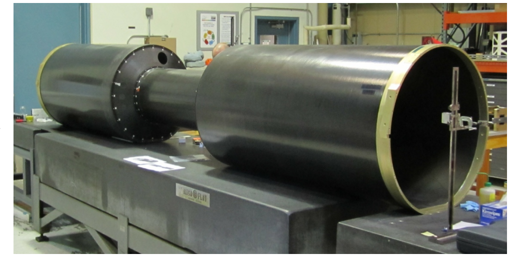
Future prospects - W production / STAR

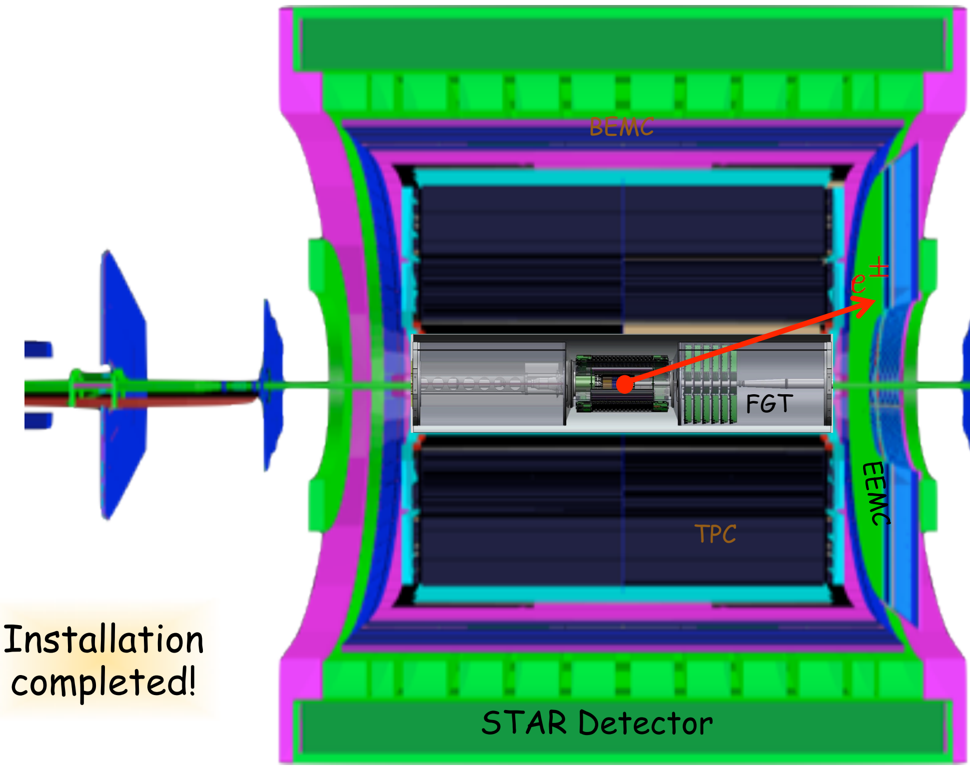
☐ STAR Forward GEM Tracker - Layout

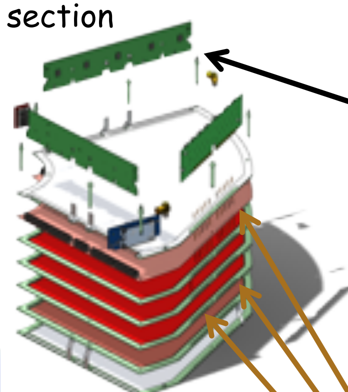

Quarter section


Disk

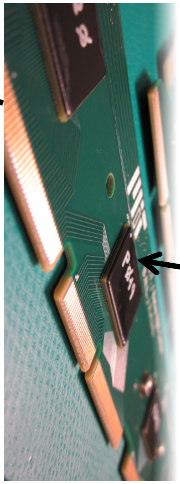

Quarter section







APV module



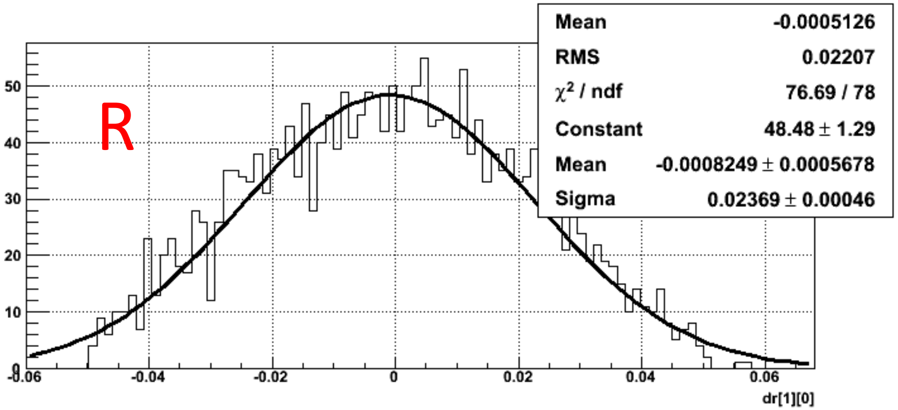
Packaged APV chip

FGT GEM foil

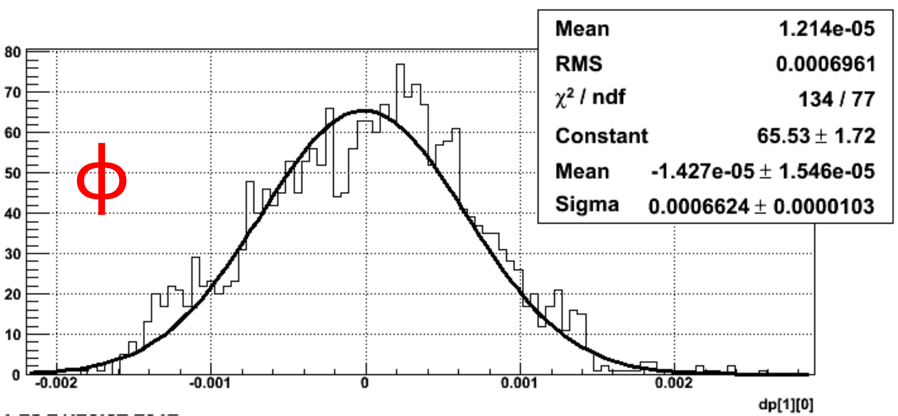
Installation completed!

FGT cosmic ray - residual

- Use the top and bottom quadrants to determine the projected value for the middle quadrant.



Sigma = 240um



Sigma = 0.6mrad
=> 180um @ R=30cm

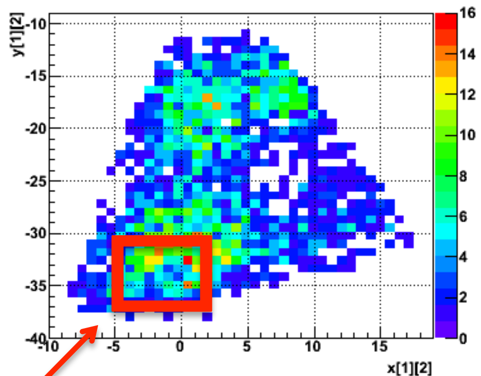
Assuming all quadrants have same resolution:
Single detector position resolution = Residual at middle quad/1.22 (from simple geometry)

180um residual @ Middle => 150um resolution at each detector

FGT cosmic ray - efficiency

- "Good event": with clean one cluster in R&φ of two quadrants and calculate efficiency for third quadrant within good trigger area.
- Sensitive to noise at higher HV & low Threshold.

Top-Short "Golden event" Hit Map



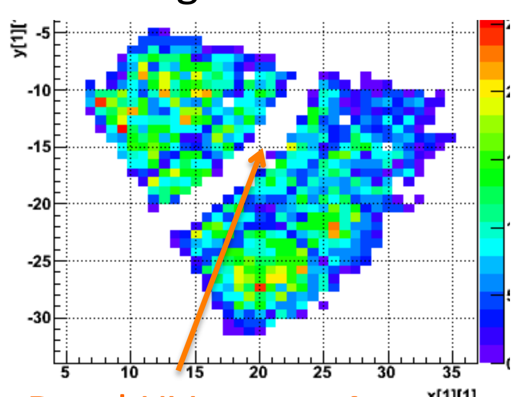
Efficiency calculated in this area only

Reading the short octant

	Top	Middle	Bottom
3.3kV	73%	83%	81% → higher thr 76%
3.4kV	83%	88%	78% → higher thr 86%
3.5kV	87%	95%	61% → higher thr 86%

Default Thr= 4*PedRMS(~40)*3timebin ~ 500
Higher Thr = 7 * PedRMS(~40)*3timebin ~ 850

Middle-Long "Golden event" Hit Map



Dead HV sector 4

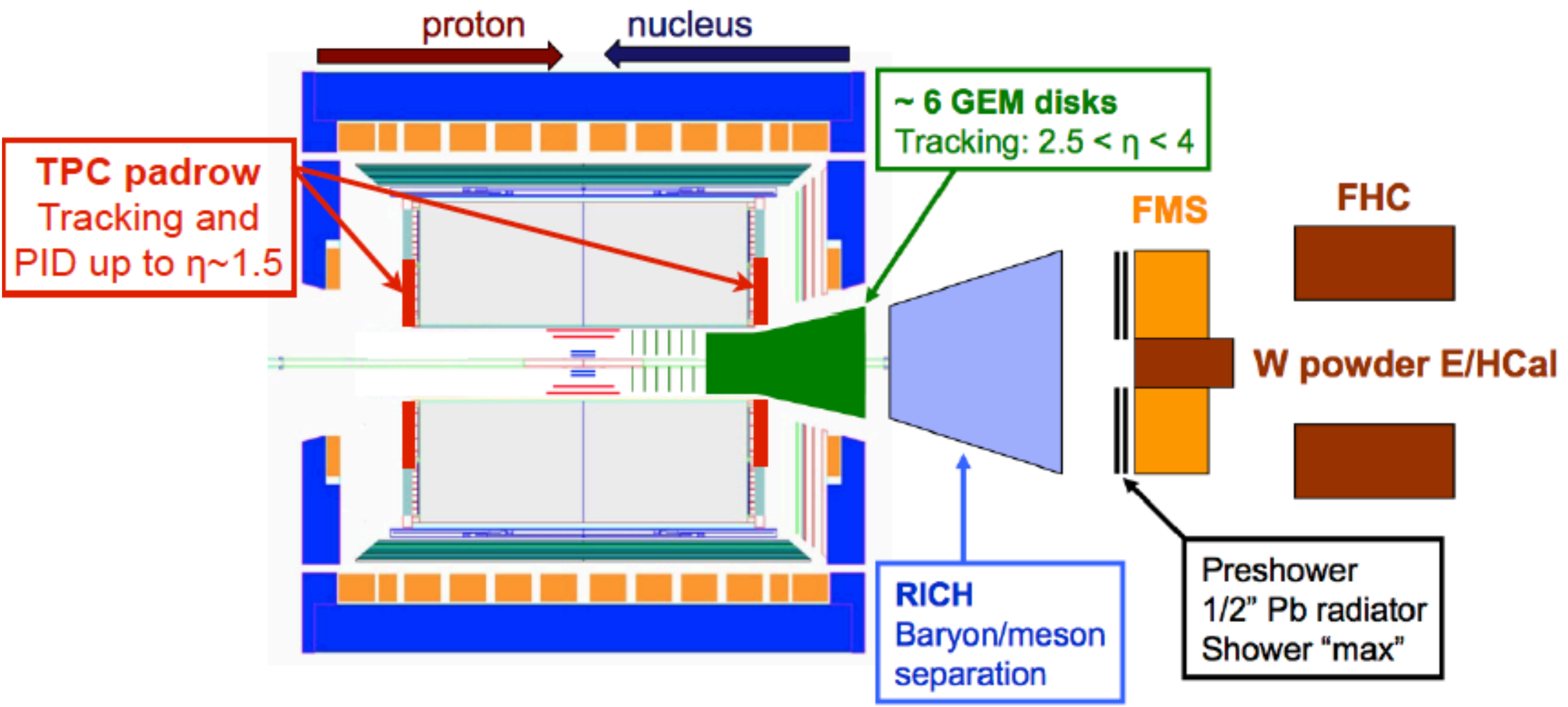
	Top	Middle	Bottom
3.4kV	72%	60%	70%

Efficiency calculated in whole octant

- Use the cosmic ray results to decide which quadrant for final installation.

STAR Forward Upgrade

- Detector concept



arXiv:1304.0079