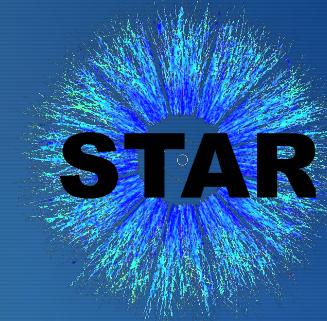




Spin'16



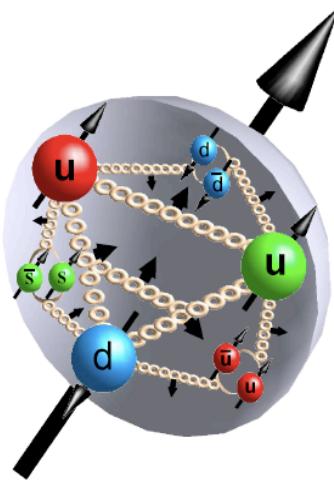
Gluon Polarization from Longitudinally Polarized Proton Collisions at STAR

*Suvarna Ramachandran
For the STAR Collaboration
University of Kentucky*

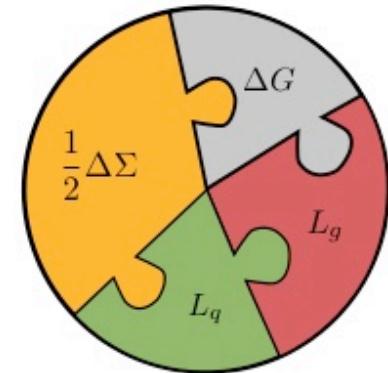


- Introduction and Motivation
- RHIC and STAR Detector
- A_{LL} Measurements at STAR
- Conclusion

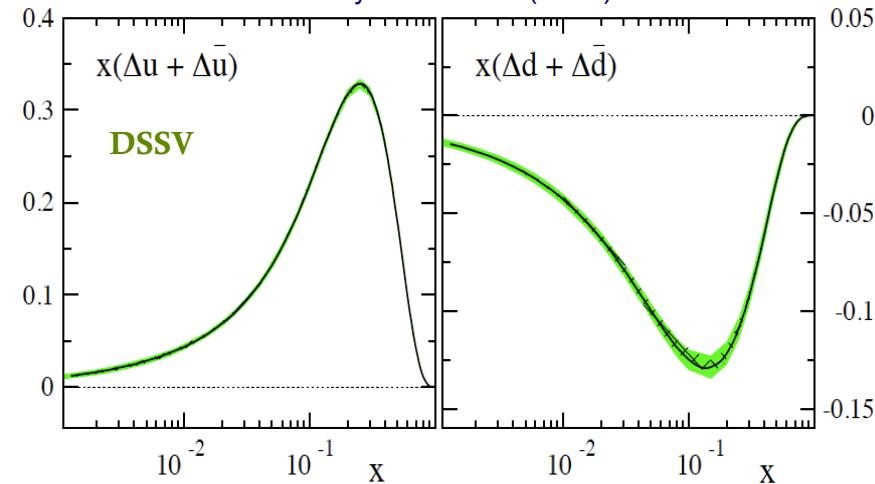
Spin of the Proton



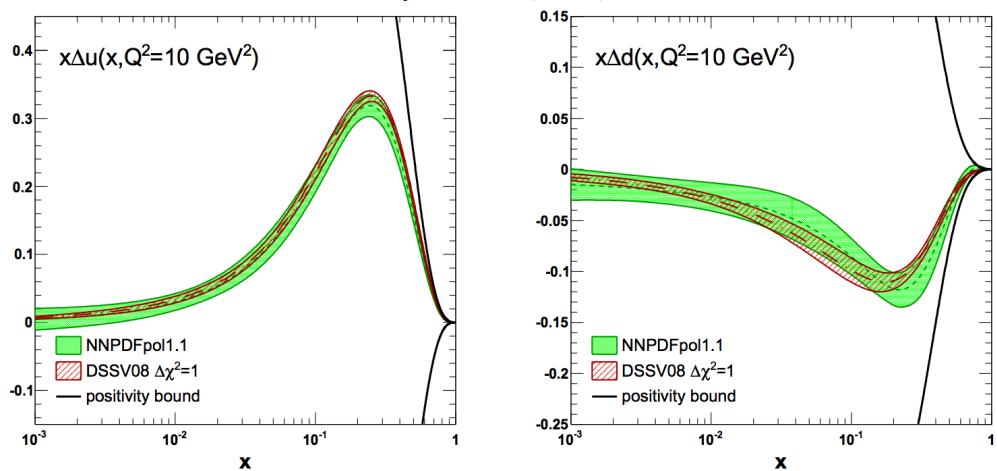
$$S_{PROTON} = \frac{\hbar}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + L_q + L_g$$



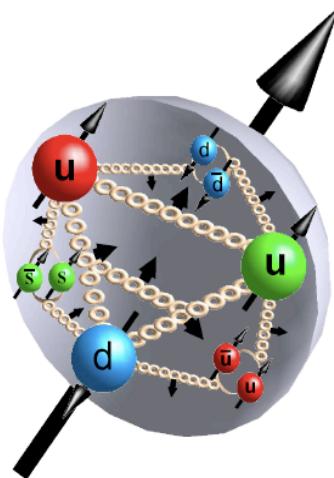
Phys. Rev. D80 (2009) 034030



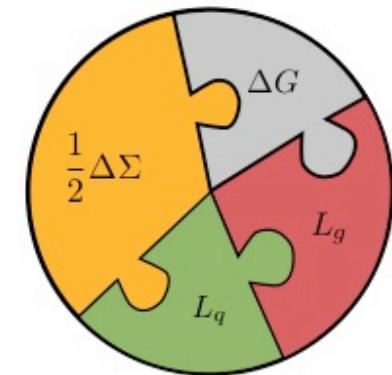
Nucl. Phys. B887 (2014) 276-308



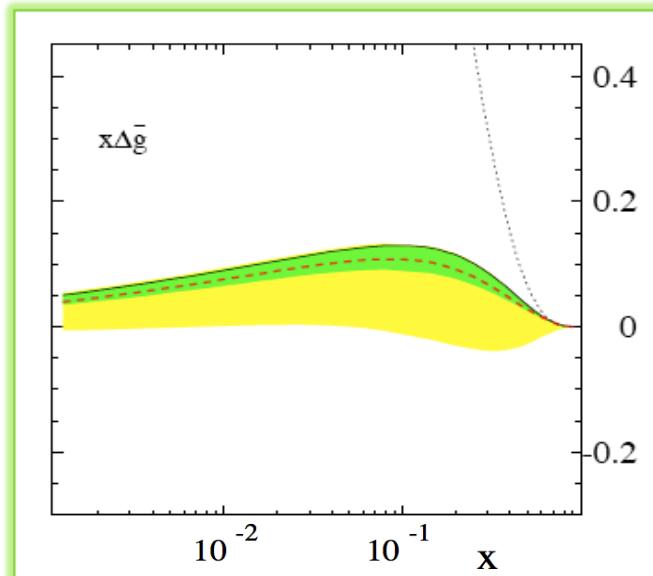
Spin of the Proton



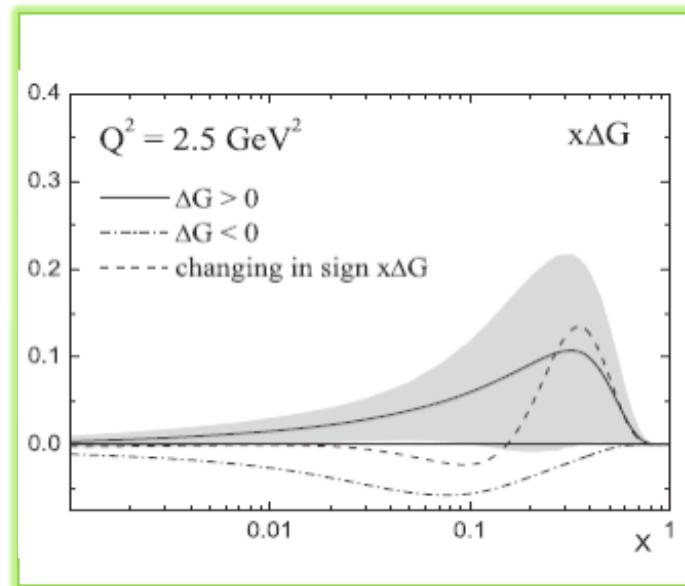
$$S_{PROTON} = \frac{\hbar}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + L_q + L_g$$



Phys. Rev. D71 094018 (2005)

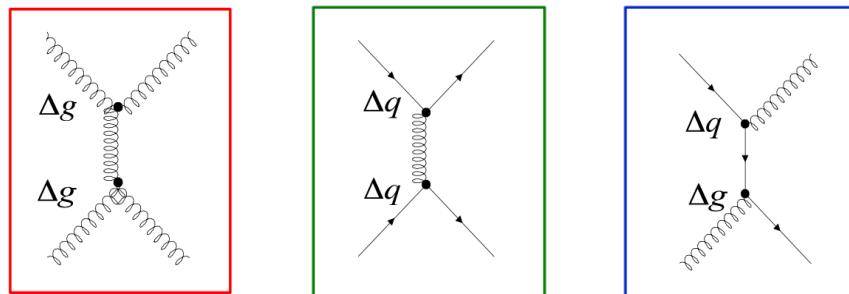


Phys. Rev. D75 074027 (2007)



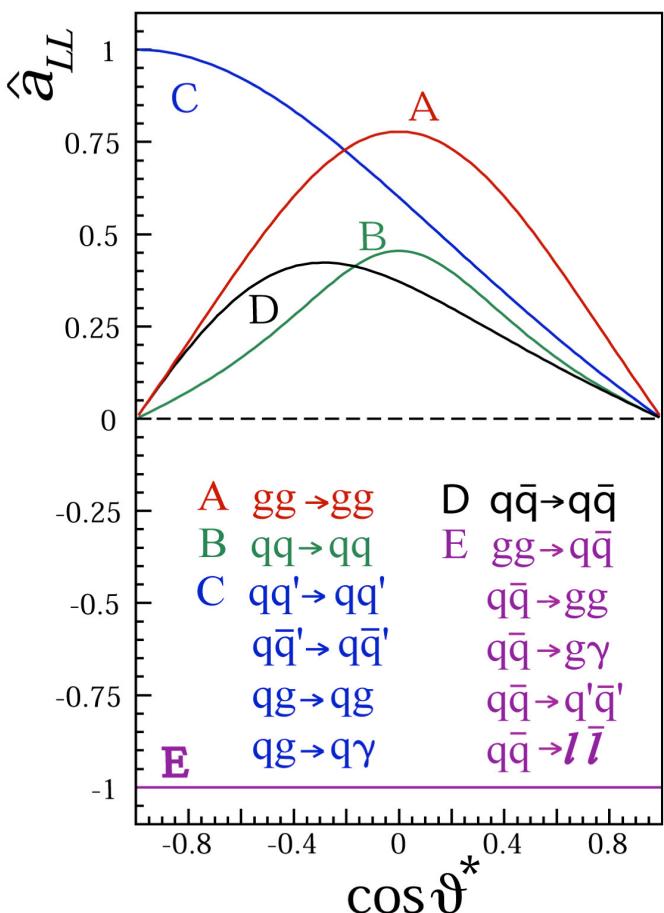
How do we access ΔG at a polarized proton collider?

- Longitudinal Double Spin Asymmetry



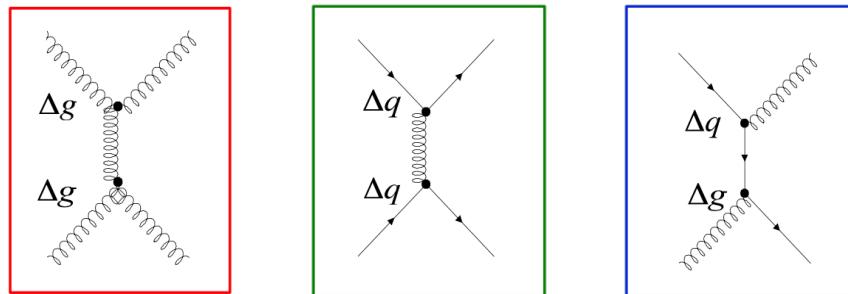
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\sum_{abc} \Delta f_a \otimes \Delta f_b \otimes \hat{\Delta \sigma}_{ab \rightarrow cx}}{\sum_{abc} f_a \otimes f_b \otimes \hat{\sigma}_{ab \rightarrow cx}}$$

- Analyses based on final states
 - Inclusive Jets
 - Dijets

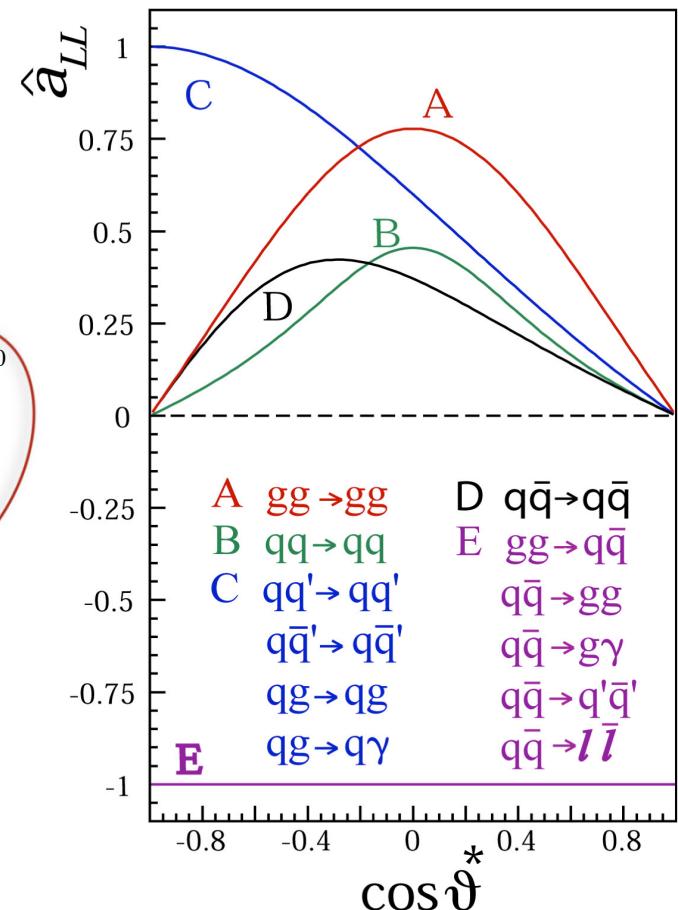


How do we access ΔG at a polarized proton collider?

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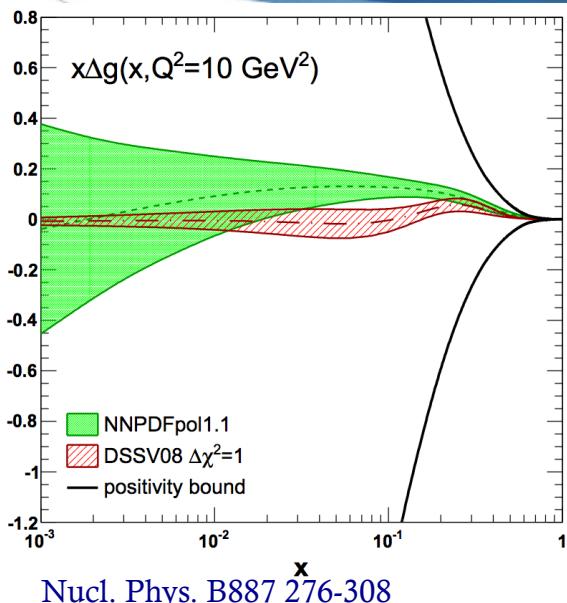


$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\sum_{abc} \Delta f_a \otimes \Delta f_b \otimes \hat{\Delta \sigma}_{ab \rightarrow cx} \otimes D_c^{\pi^0}}{\sum_{abc} f_a \otimes f_b \otimes \hat{\sigma}_{ab \rightarrow cx} \otimes D_c^{\pi^0}}$$

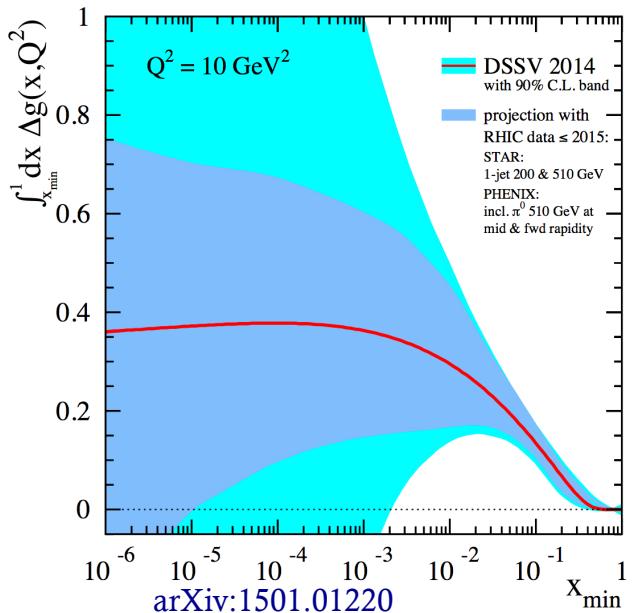


- Analyses based on final states
 - Inclusive Jets
 - Dijets
 - Pions

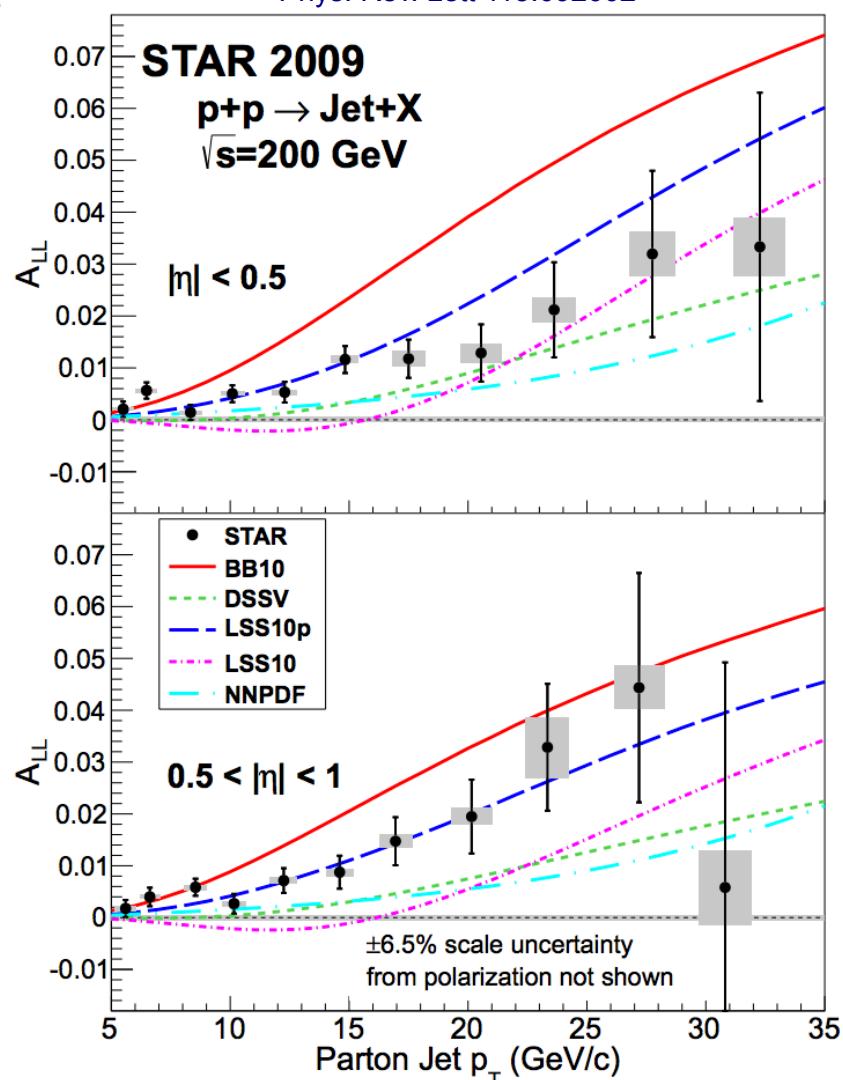
ΔG



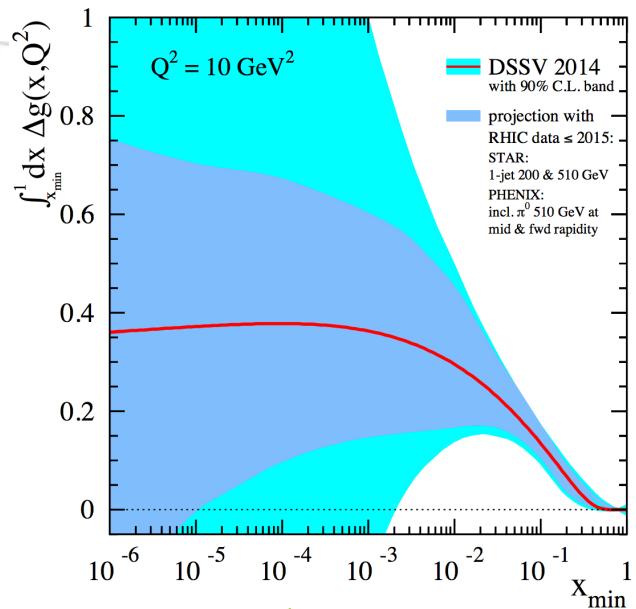
Nucl. Phys. B887 276-308



Phys. Rev. Lett 115.092002



How do we reduce the errors on ΔG at low x ?

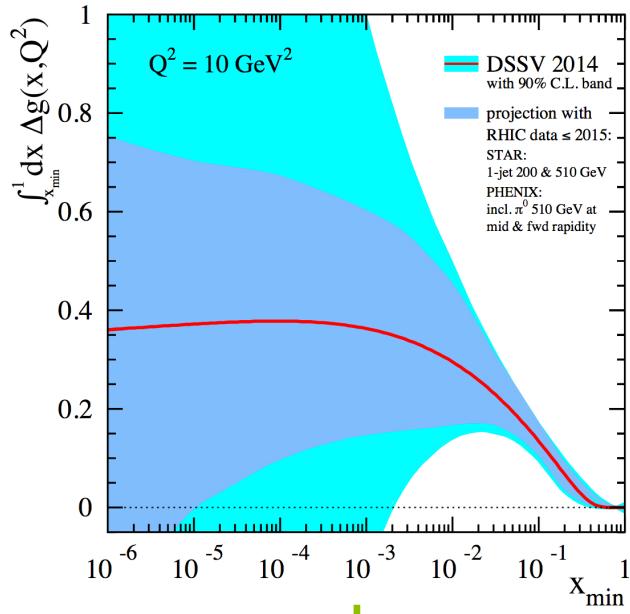


Look at higher \sqrt{s}
2012 Inclusive jet results

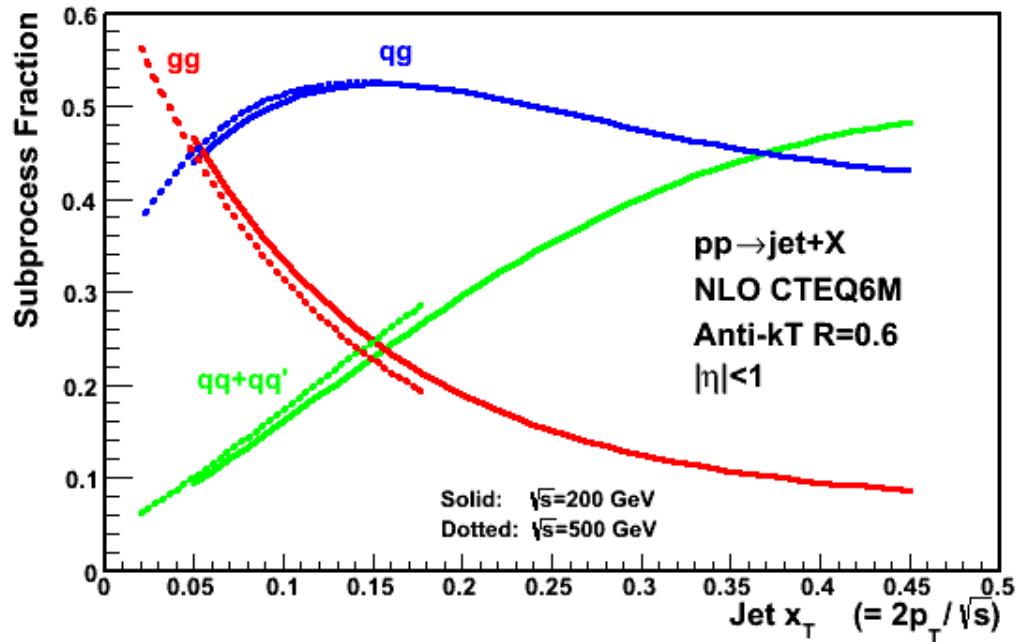
Constrain the functional form
200 GeV Dijet Results
510 GeV Dijet Results

Look at forward rapidity
EEMC π^0 Results
FMS π^0 Results

How do we reduce the errors on ΔG at low x ?



Look at higher \sqrt{s}
2012 Inclusive Jet results

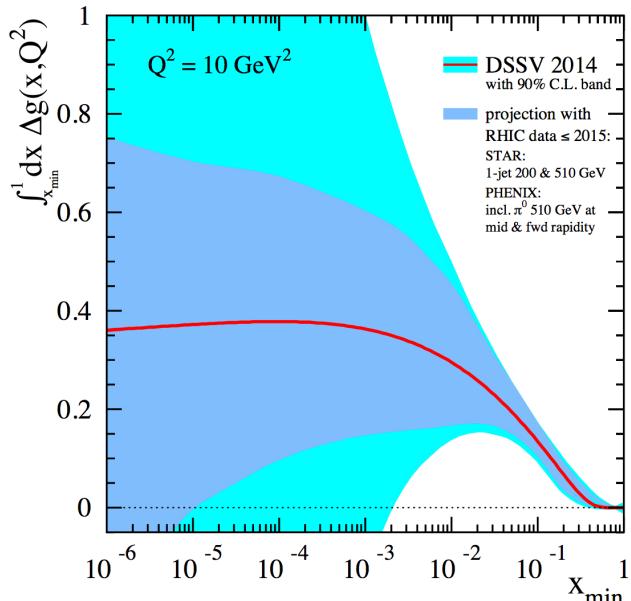


Note: No experimental access to x in inclusive observables in pp collisions!

$$x_T = 2p_T/\sqrt{s} \sim 2\sqrt{x_1 x_2}$$

$$y \sim \frac{1}{2} \log(x_1/x_2)$$

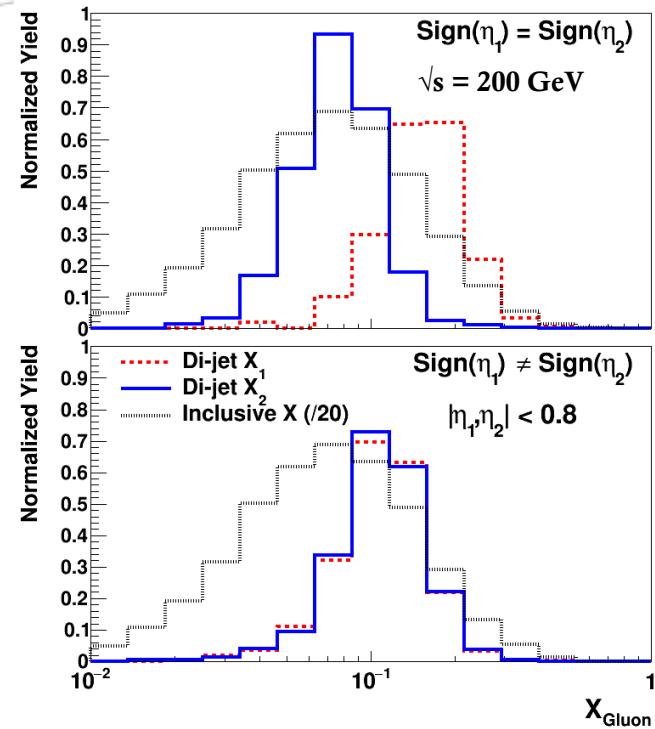
How do we reduce the errors on ΔG at low x ?



Constrain the functional form

200 GeV Dijet Results

510 GeV Dijet Results

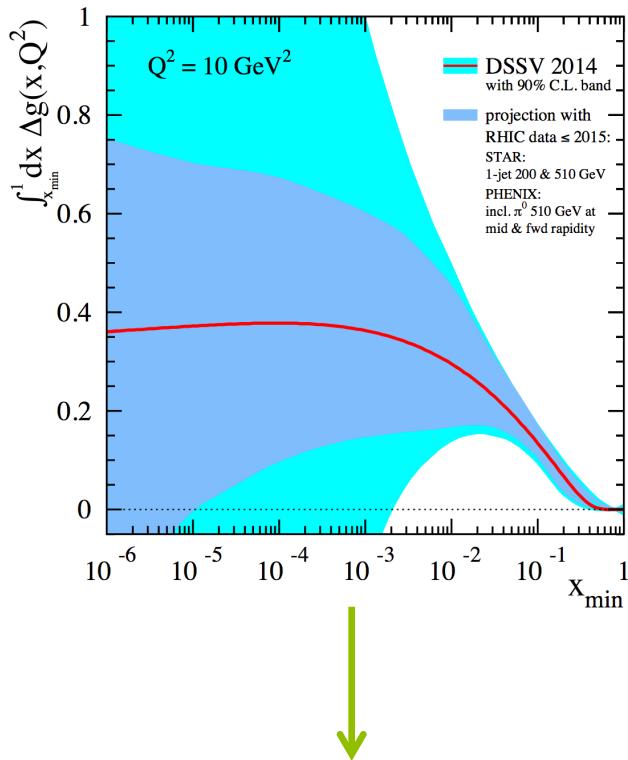


$$x_1 = \frac{1}{\sqrt{s}} (p_{T3} e^{\eta_3} + p_{T4} e^{\eta_4})$$

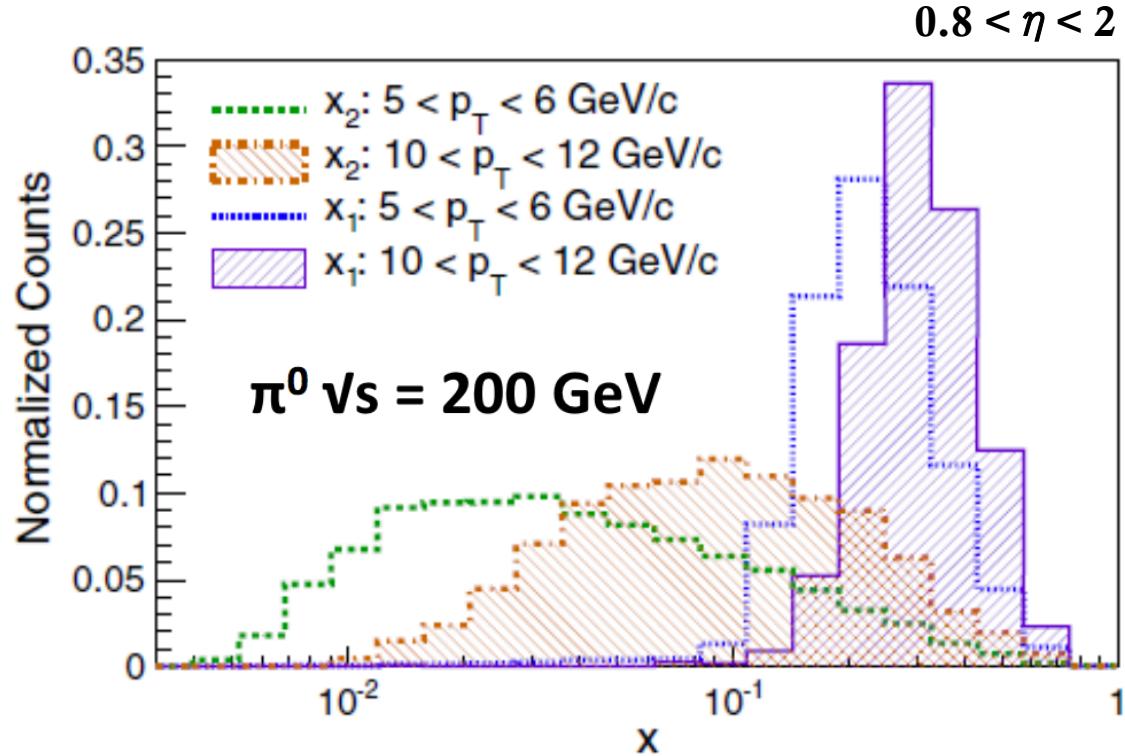
$$x_2 = \frac{1}{\sqrt{s}} (p_{T3} e^{-\eta_3} + p_{T4} e^{-\eta_4})$$

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

How do we reduce the errors on ΔG at low x ?



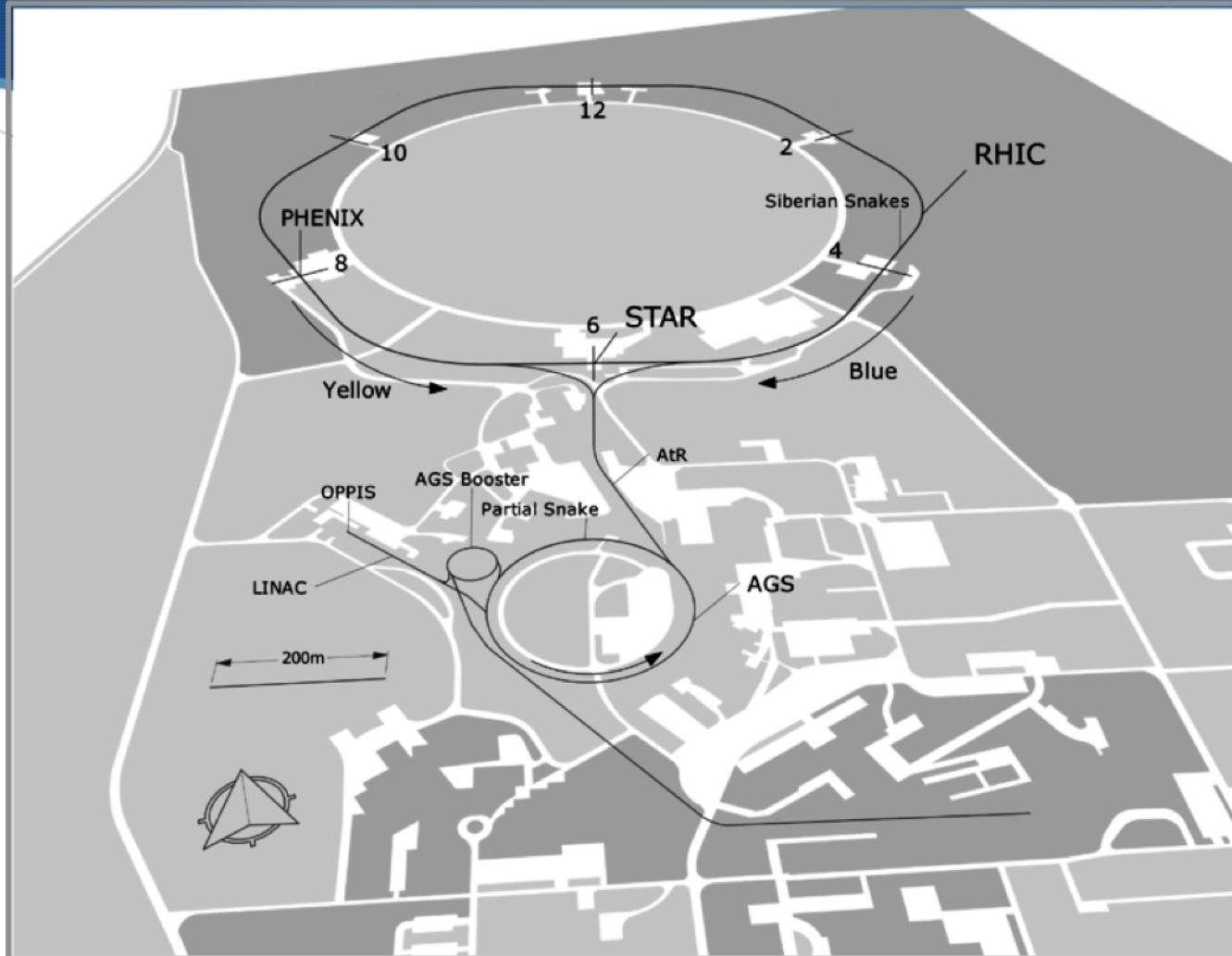
Look at forward rapidity
 EEMC π^0 Results
 FMS π^0 Results



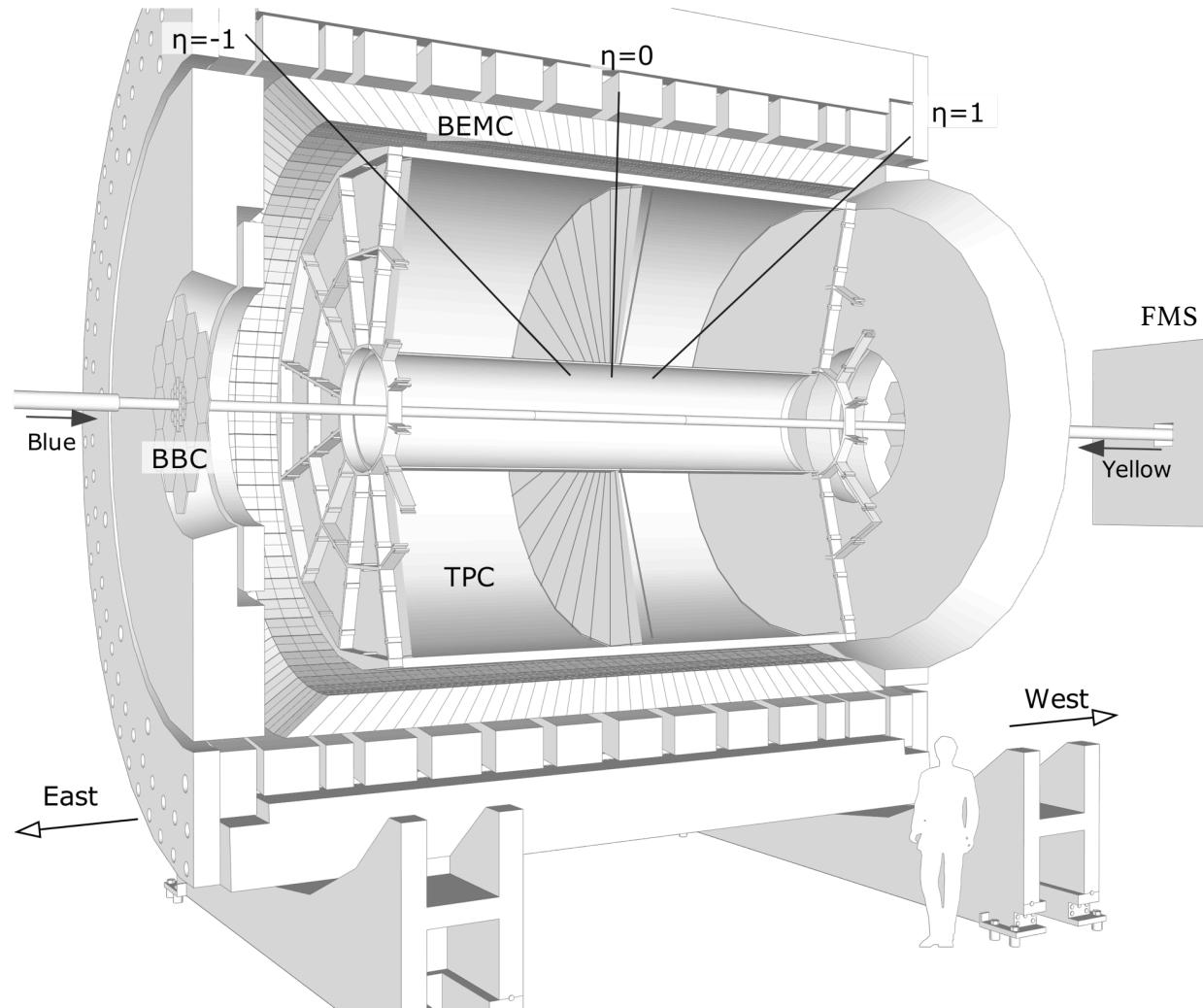
Looking at the $2.5 < \eta < 4$ region pushes the access down to $x \sim 10^{-3}$ regime for $\sqrt{s} = 510 \text{ GeV}$

- Introduction and Motivation
- RHIC and STAR Detector
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- Conclusion

Relativistic Heavy Ion Collider



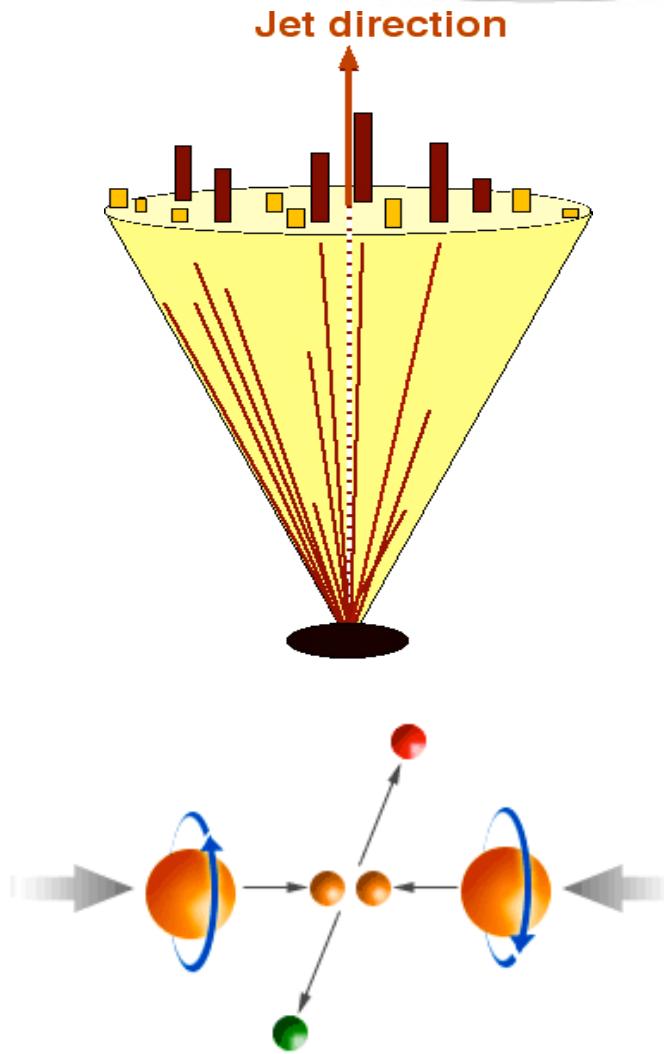
Solenoidal Tracker At RHIC



- Introduction and Motivation
- RHIC and STAR Detector
- A_{LL} Measurements at STAR
- Conclusion

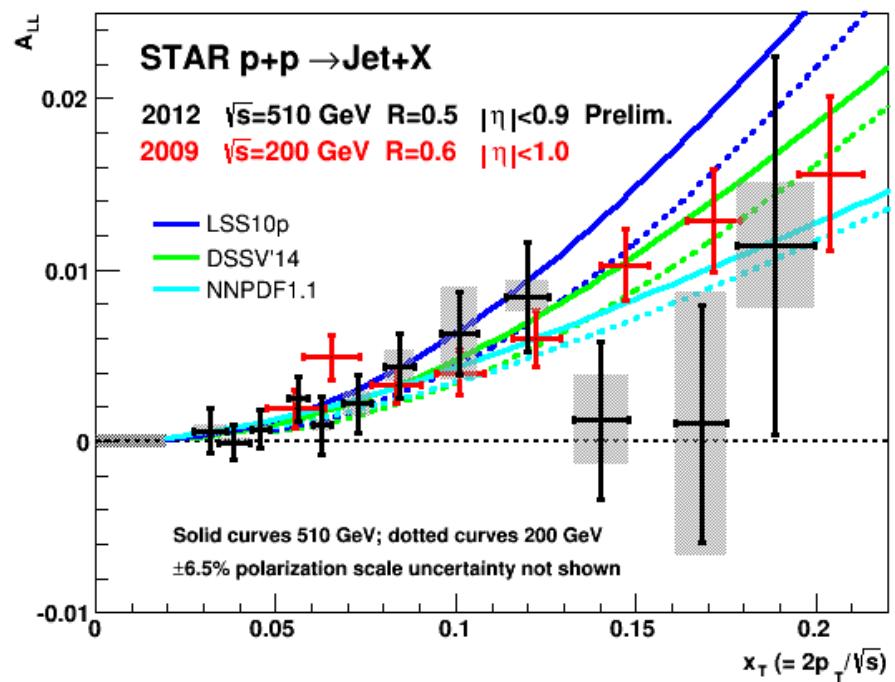
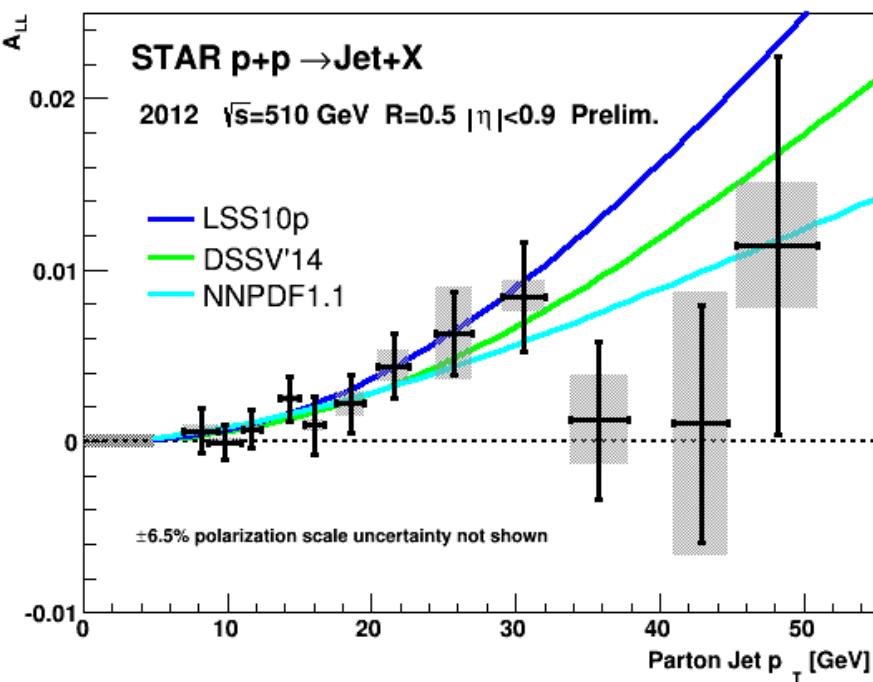
Jet Reconstruction at STAR

Detector
Particle
Parton



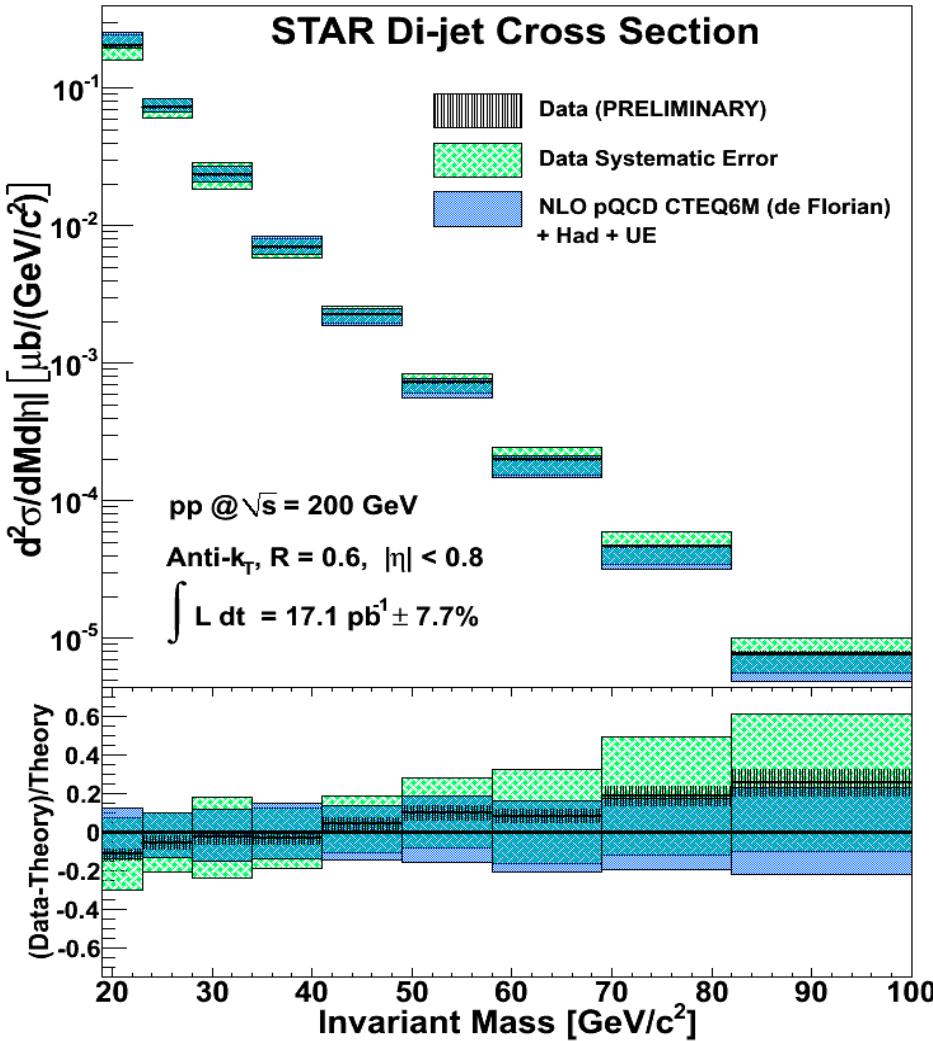
- Anti k_T algorithm *JHEP 0804 (2008) 063*
 - Sequential clustering algorithm
 - Infrared and collinear safe by design
- Jet and Dijet analyses
 - Anti k_T algorithm
 - $R = 0.5 - 0.6$
- Triggers used:
 - Jet Patch Triggers: JP0, JP1, JP2

Inclusive Jet Results



arXiv:1512.05400

Dijet Results

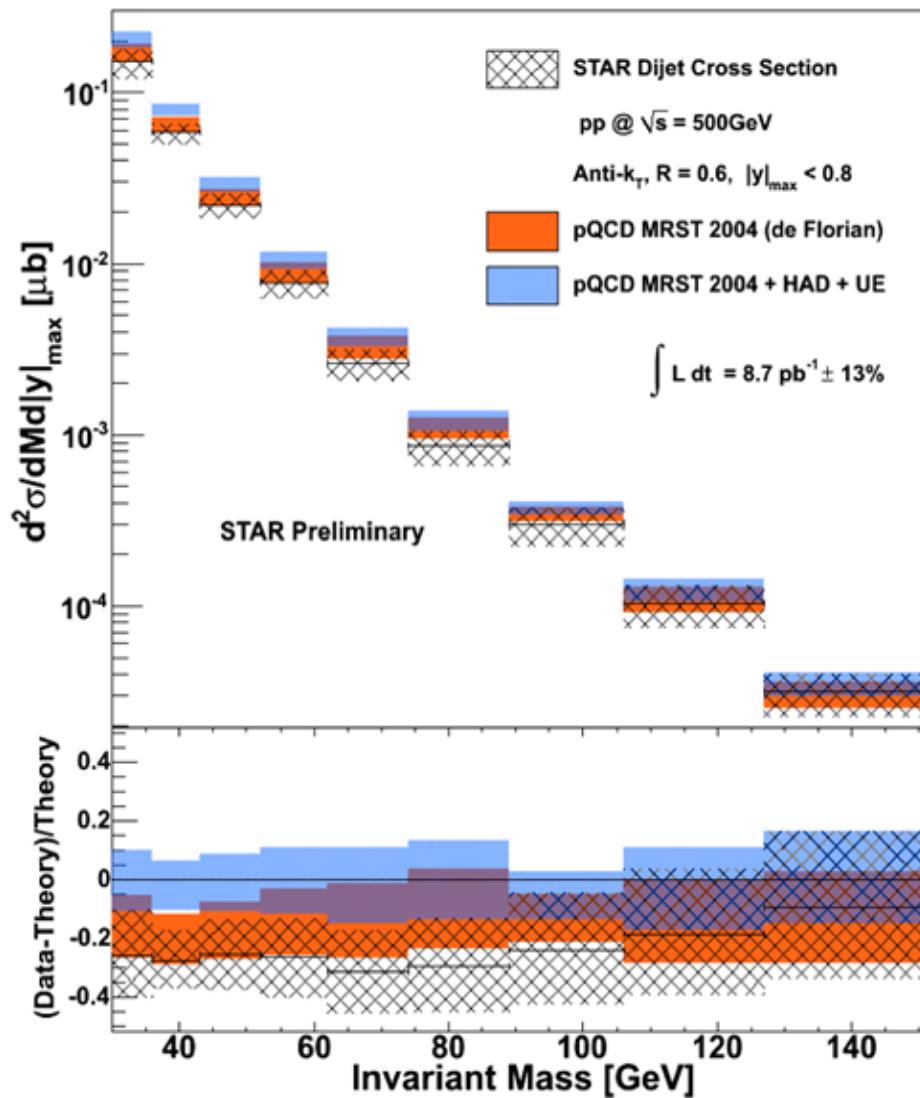


Dijet Analysis cuts

- Asymmetric p_{T} cut (8,6 GeV)
- Back-to-back cut
- Require one jet of the pair to point to a trigger jet patch
- $-0.8 < \eta_{\text{Physics}} < 0.8$
- Contribution from the calorimeters towards the total jet energy required to be less than 95%

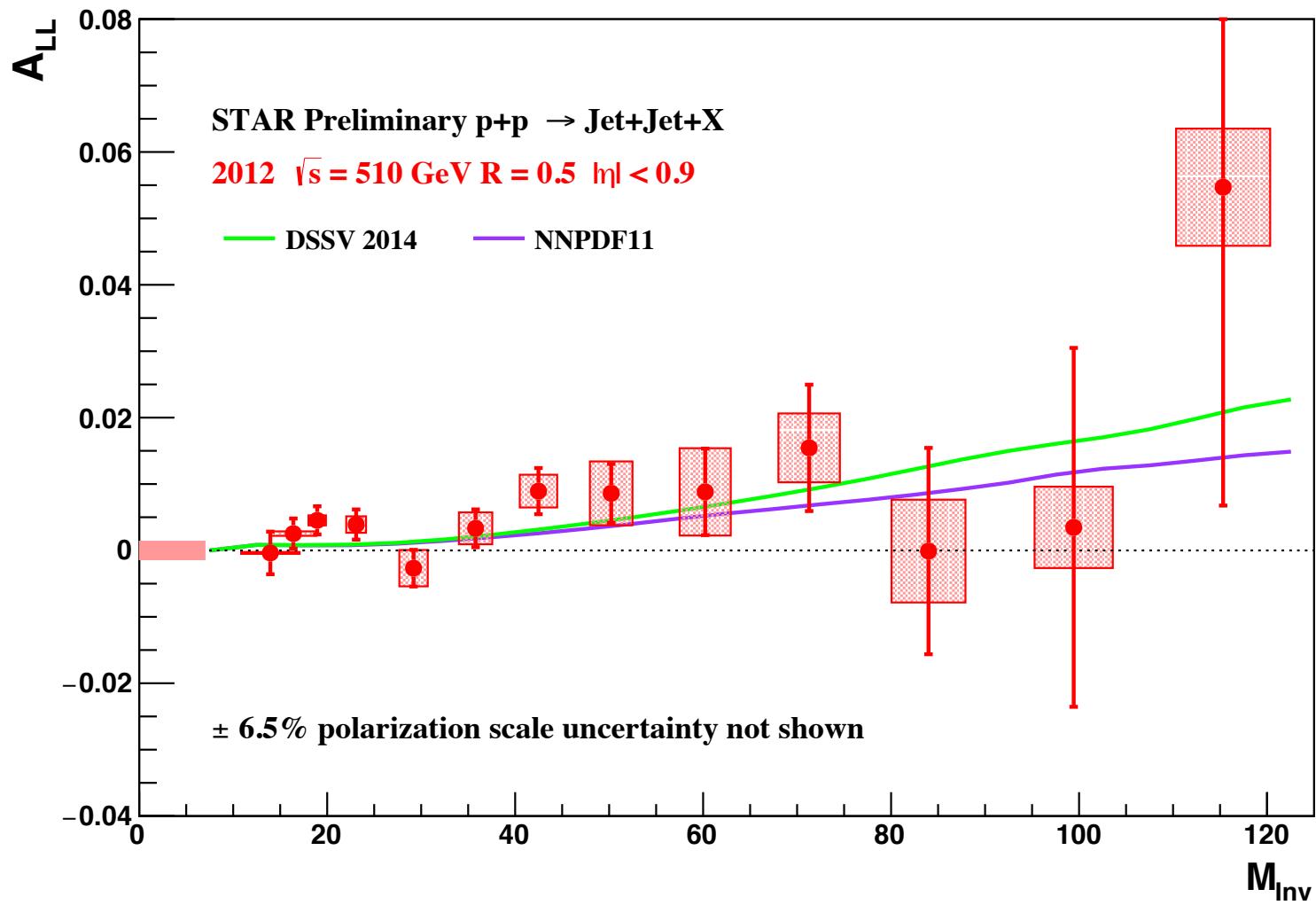
Dijets at 510 GeV

PoS (DIS 2013) 215



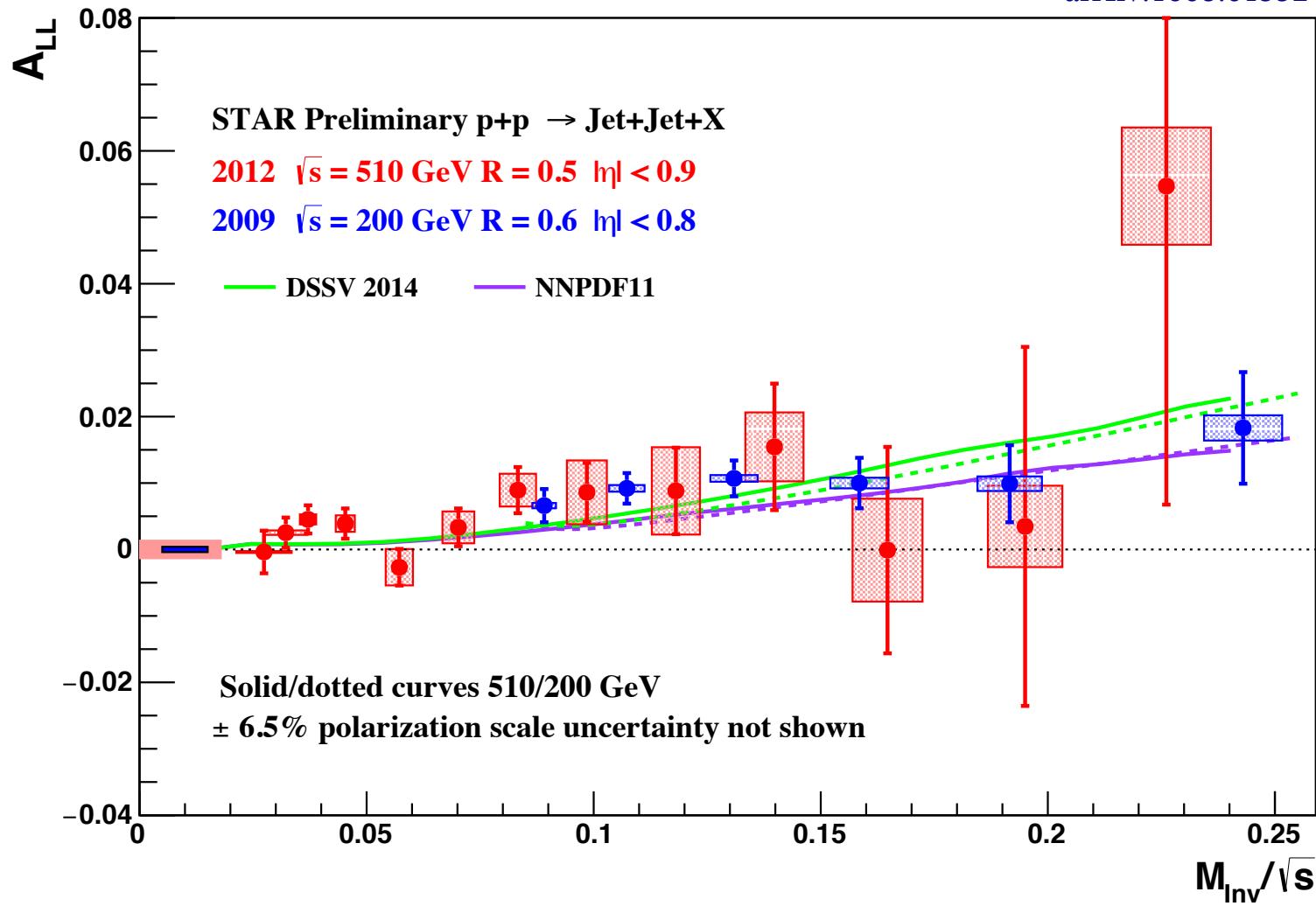
Dijet A_{LL} at 510 GeV

arXiv:1608.01332



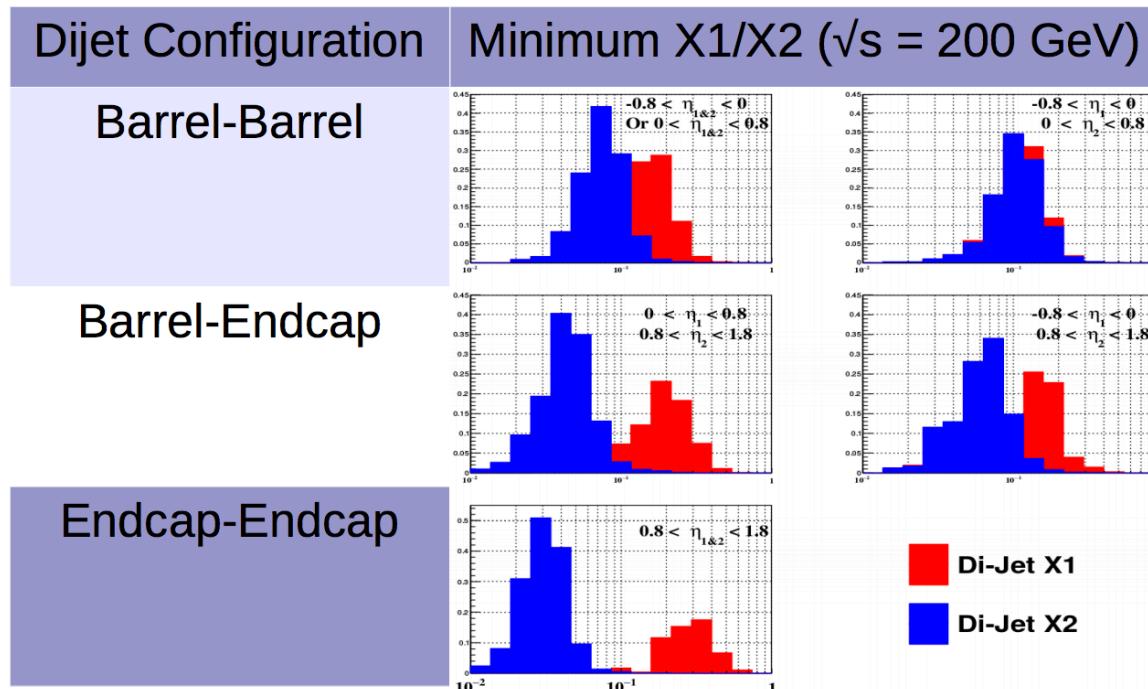
Dijet A_{LL} at 510 GeV

arXiv:1608.01332



2009 Forward Dijet A_{LL}

Pushing dijets forward into the endcap allows us to probe lower x range



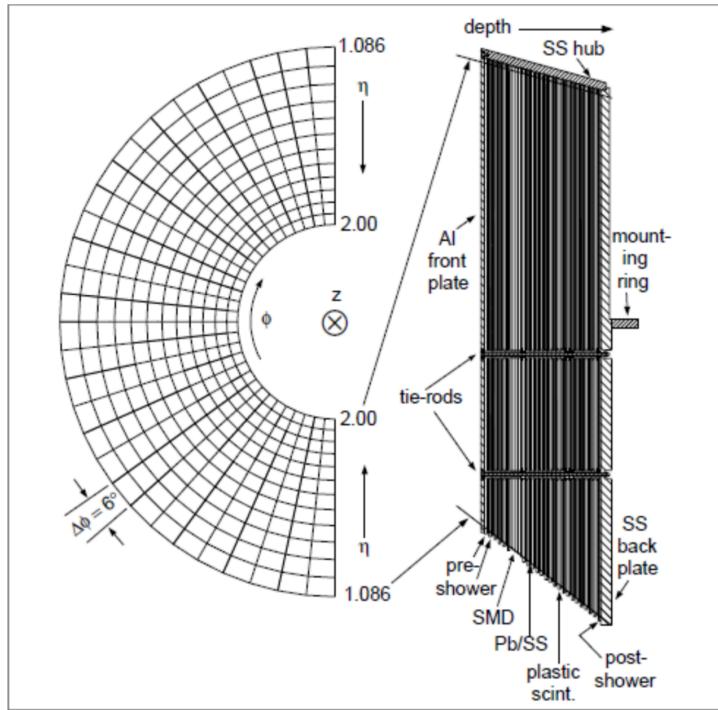
Note: Ting Lin will show the first fully reconstructed dijet A_{LL} in the forward region with the endcap detector - see Thursday poster session!

Pions at STAR

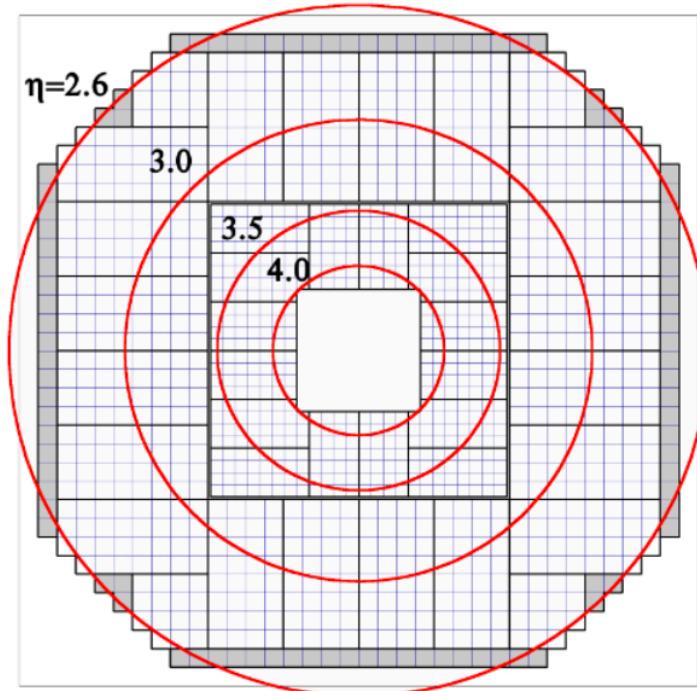
- Looking at Jets

- Tracking only extends to $\eta \sim 1.4$
- Challenge to look at jets in the forward region
- Alternative → looking at pions

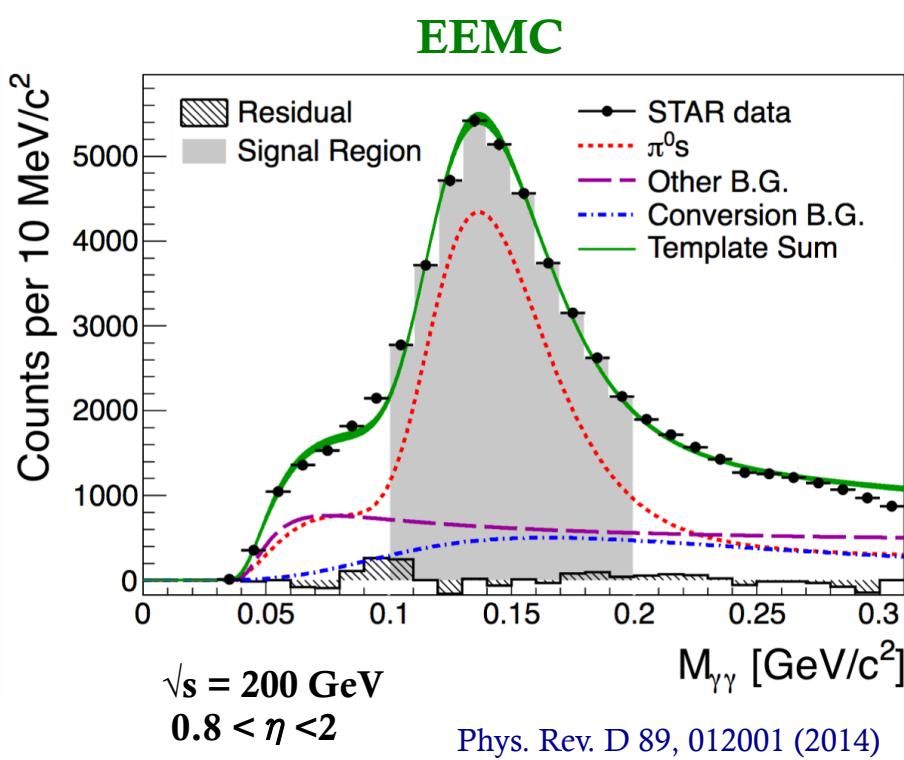
EEMC



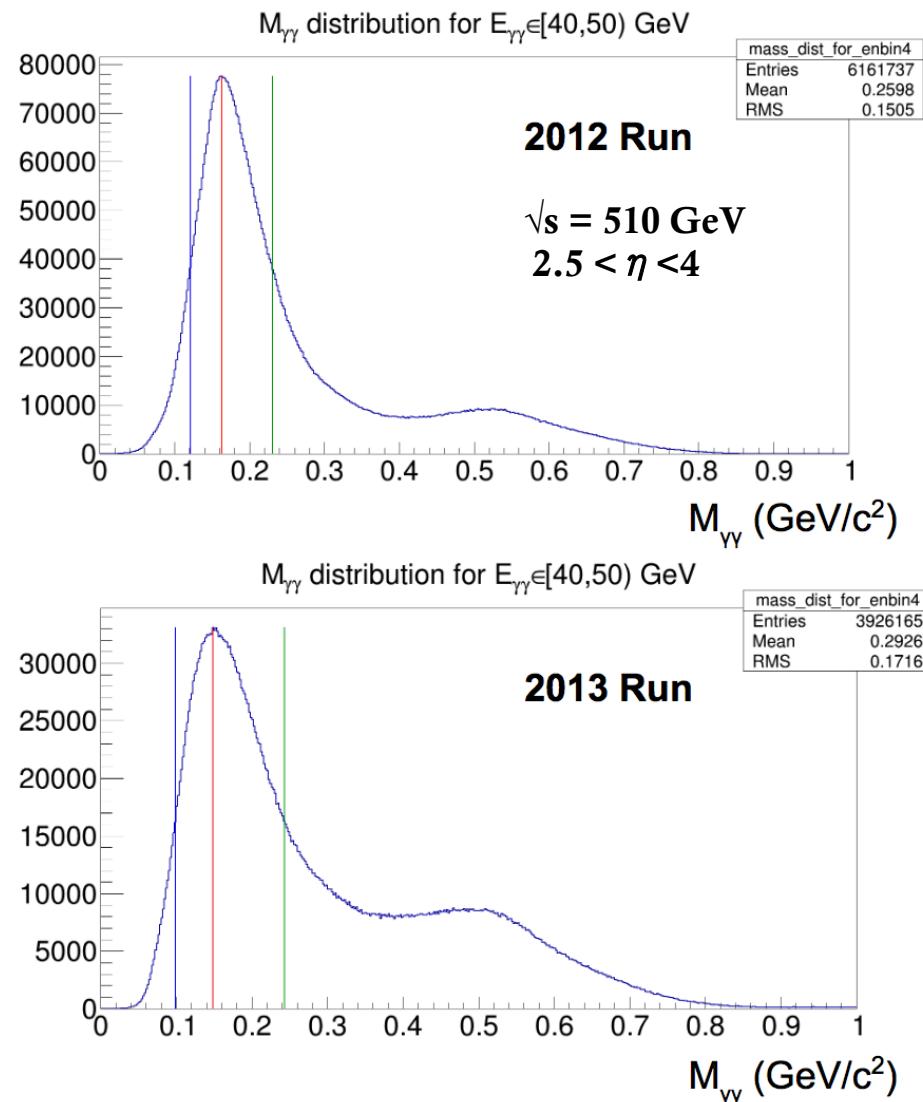
FMS



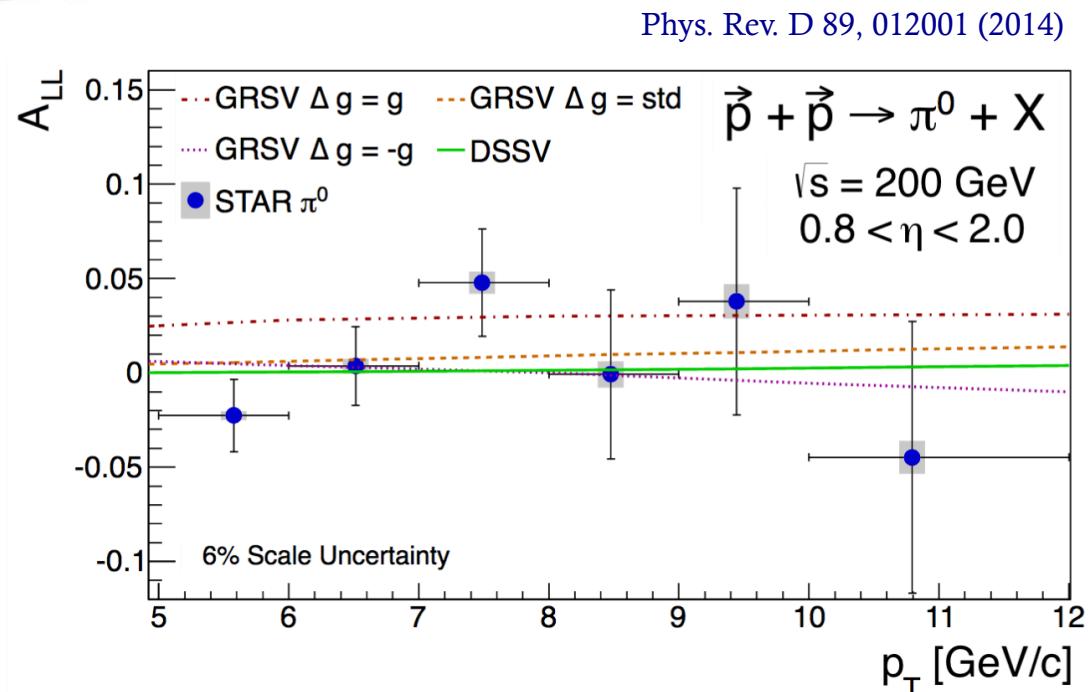
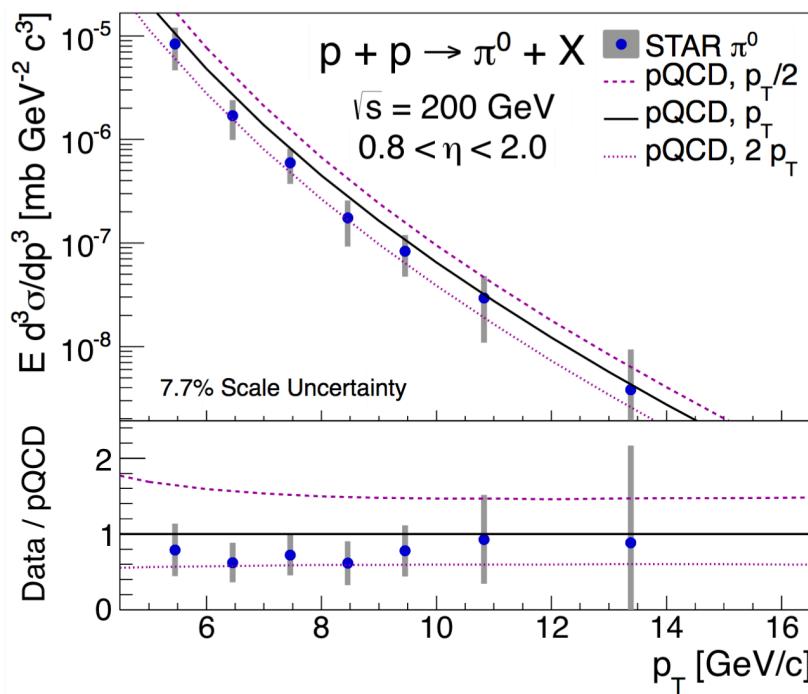
π^0 at STAR



FMS

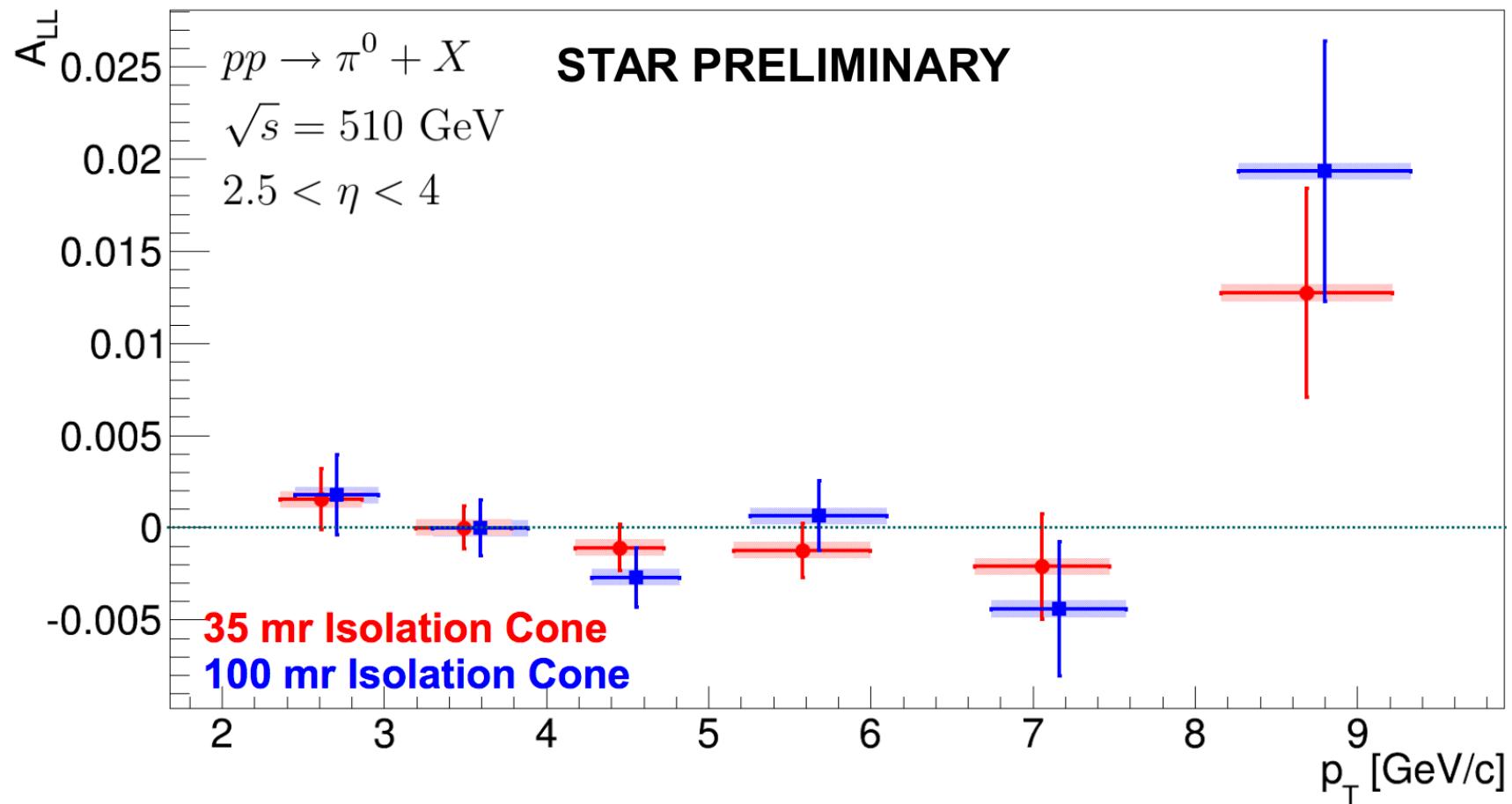


EEMC π^0 Results



FMS π^0 Results

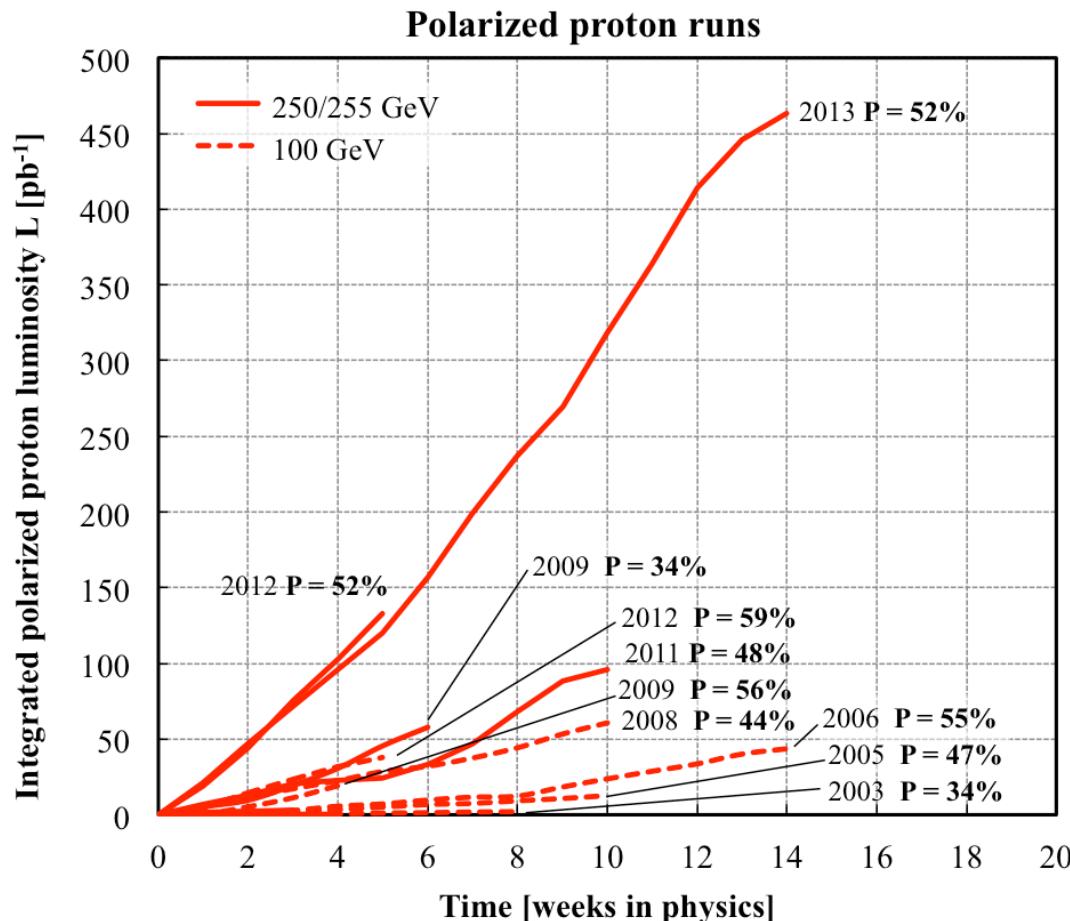
Int.J.Mod.Phys.Conf.Ser. 40 (2016) 1660024



Conclusion

- RHIC's highly polarized proton beams have facilitated a robust spin program at STAR. STAR utilizes its wide acceptance at mid-rapidity for jet reconstruction and dedicated calorimeters at forward rapidities for pion reconstruction.
- STAR inclusive jet measurements at $\sqrt{s} = 200$ GeV have provided the first evidence of a significant polarized gluon distribution for $x > 0.05$.
- By extending these measurements to higher \sqrt{s} and more forward regions it is possible to constrain the $x < 0.05$ region. Dijet observables allow for reconstruction of the partonic kinematics at leading order.
- In 2013 STAR collected 3 times more data, of longitudinally polarized proton collisions at $\sqrt{s} = 510$ GeV.

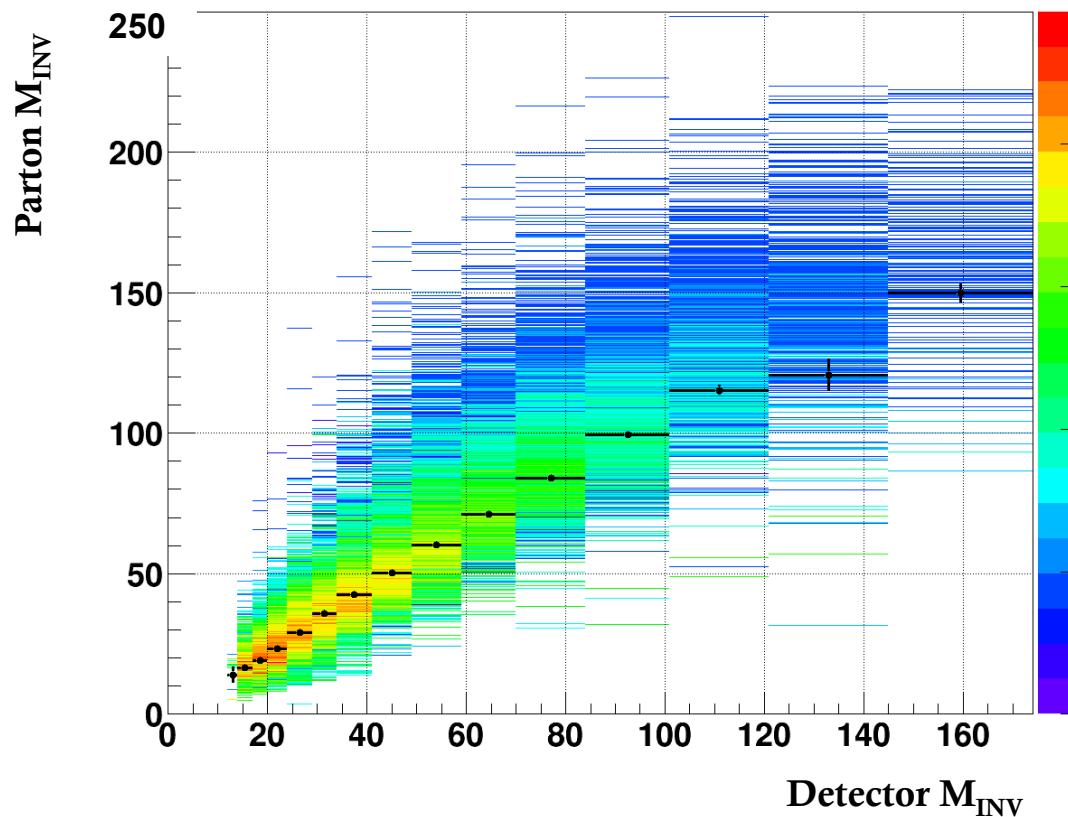
Stay Tuned!



Thank You

Backup

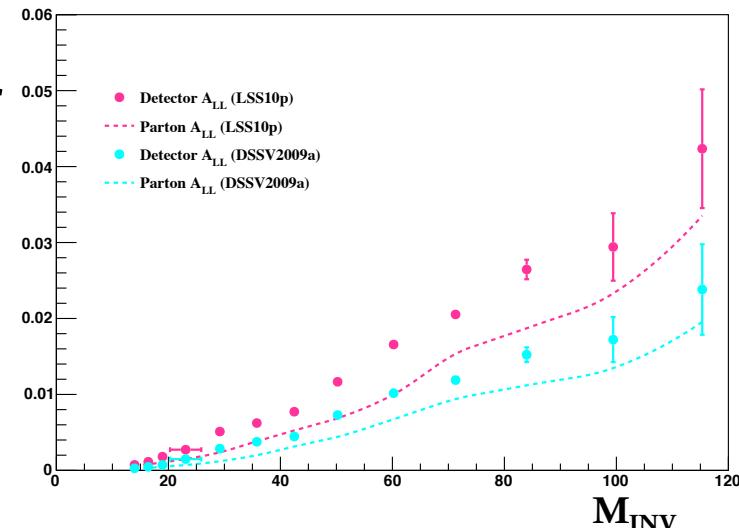
Jet Energy Scale corrections



- ◆ The systematic error on the reconstructed dijet M_{INV} is due to the jet energy scale uncertainty
 - ◆ Includes contributions from BEMC calibration and tracking efficiency uncertainty.

Trigger Bias Studies

- Detector resolutions and inefficiencies distort our measured jet distributions from the true jet distributions
- The bias of the jet patch triggers towards a quark jet vs. a gluon jet
 - Sub-process fractions in the events are affected, and the “expected” asymmetry changes
- We use different theoretical parameterizations, and create A_{LL} predictions at the detector and parton levels.
- The uncertainty is calculated as the difference between the parton & detector A_{LL}
- Process repeated for different models, and the uncertainty is taken from the model with the largest difference



π^0 at STAR (EEMC)

- ◆ 2006 Run
- ◆ Towers in EEMC measure the photon energy by summing up the energy deposited
- ◆ Cuts imposed
 - ◆ Minimum energy 2 GeV in the towers
 - ◆ $0.8 < \eta < 2$
 - ◆ $p_T(\pi^0 \text{ candidate}) > 5 \text{ GeV}$
 - ◆ TPC vertex within 120 cm of nominal vertex
- ◆ Signal fraction – fitting a combination of template functions to the 2 photon mass distribution (0,0.3).
- ◆ Three template functions were determined by fitting MC data to represent- π^0 signal, conversion background, all other backgrounds.
- ◆ Signal – Matching momentum direction of reconstructed pairs to that of generated π^0 's in the eta-phi space
- ◆ Conversion background - Matching momentum direction of reconstructed pairs to that of decay photons in the eta-phi space
- ◆ Other backgrounds – Non matched reconstructed pairs

π^0 at STAR (FMS)

- ◆ Relative Luminosity calculated using Vertex Position Detector ($4.2 < |\text{eta}| < 5.1$) and Zero Degree Calorimeter ($6.5 < |\text{eta}| < 7.5$)
- ◆ Invariant mass distribution for the 2-photon clusters which pass the analysis cuts
 - ◆ $p_T \geq 2.5 \text{ GeV}$ (2012) , $p_T \geq 2 \text{ GeV}$ (2013)
 - ◆ $p_T < 10 \text{ GeV}$
 - ◆ $30 \leq E_{\gamma\gamma} < 100 \text{ GeV}$
 - ◆ $|E_1 - E_2|/E_{\gamma\gamma} < 0.8$
 - ◆ $E_{\gamma\gamma}$ dependent $M_{\gamma\gamma}$ cut
 - ◆ Isolation cone cut (both 35 mrad and 100 mrad analyzed)
 - ◆ The use of isolation cones – motivated by the dependence of transverse single spin asymmetry A_N on π^0 isolation, more isolated π^0 's exhibited higher asymmetries
 - ◆ Goal of the study was to verify that A_{LL} is independent of π^0 isolation
- ◆ Widths of the pion mass peaks determined by –
 - ◆ The cluster position resolution for the two closely spaced photons
 - ◆ The width of the vertex distribution (60-80 cms).
- ◆ The dominant systematic error for this measurement is from the relative luminosity and beam polarization measurements (vertical shading in the plot).