Center for Frontiers in Nuclear Science

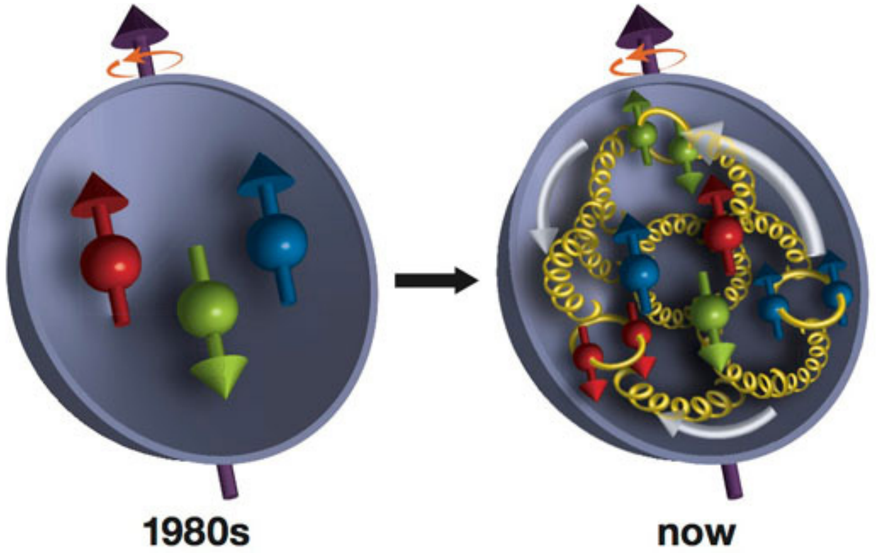
PHENIX

Recent Pion and Jet Spin Results at

Ross Corliss (for the collaboration)

Understanding Proton Spin

- No Longer a Surprise: Valence quarks do not carry all the spin. More complex dynamics are at hand.
- **Transverse** -- how are proton spin and parton transverse momentum correlated?
- **Longitudinal** -- how do partons polarize wrt the proton

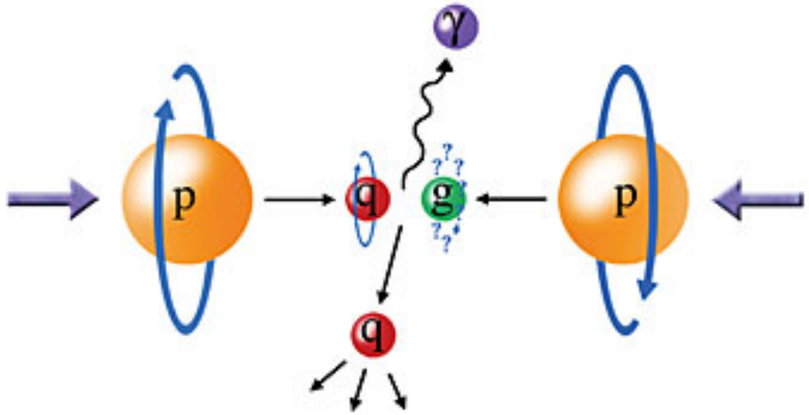


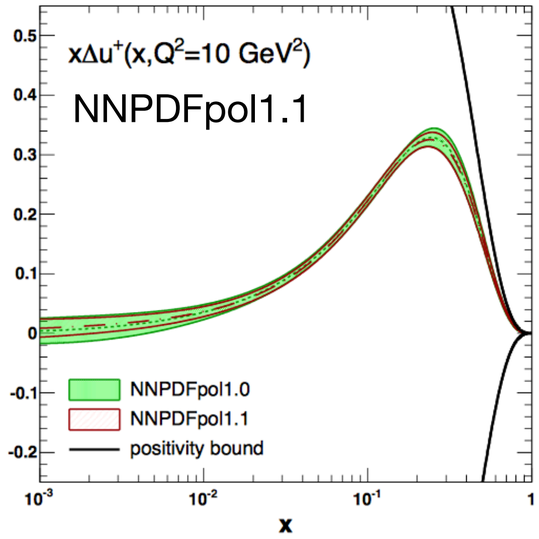
Longitudinal Asymmetries

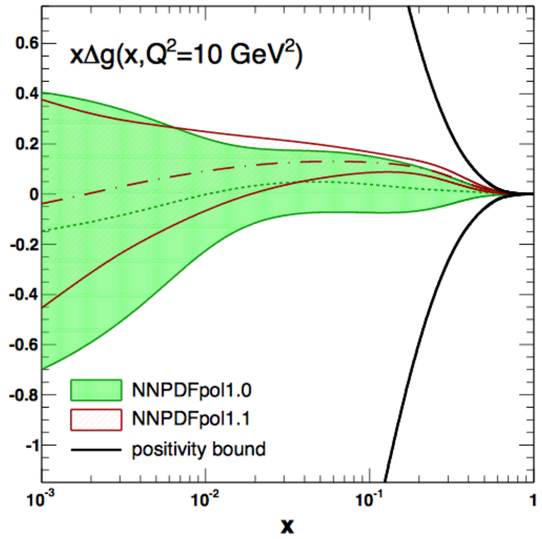
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\Delta\sigma}{\sigma}$$

$$\Delta\sigma = \sum_{a,b} \Delta f_{a/A} \otimes \Delta f_{b/B} \otimes \Delta\sigma_{ab}$$

- Partonic asymmetries can be large
- Multiple initial states contribute to each final state observable
- Combine different final states to extract underlying pPDFs via global fit
- RHIC data ==> Δg≠0







arxiv:1406.5539
Nucl.Phys.B 887, 276 (2014)

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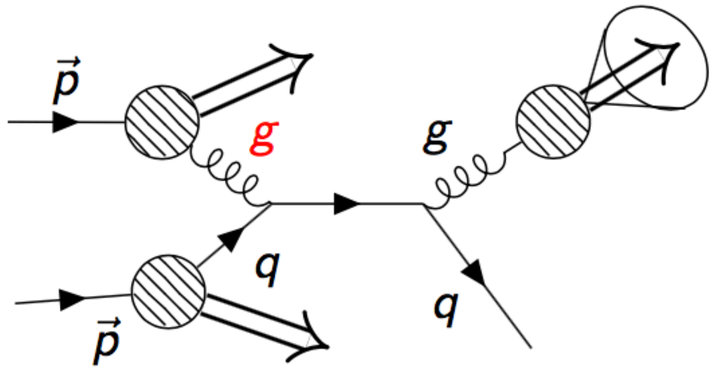
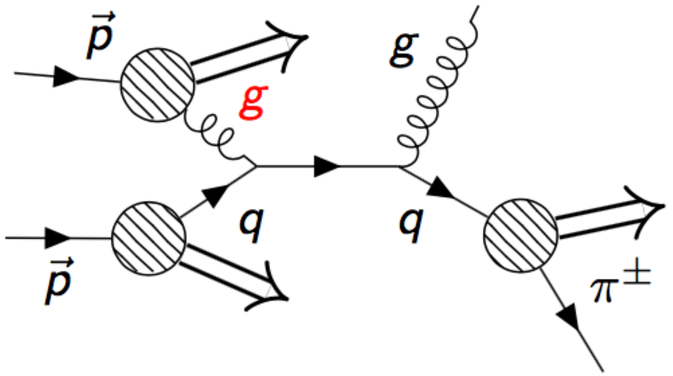
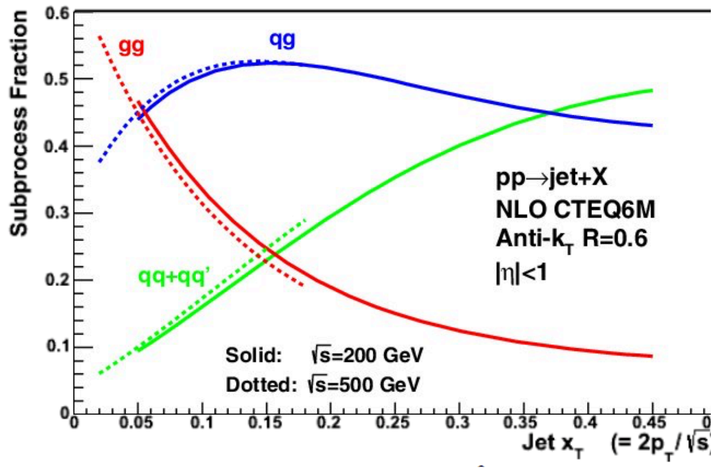
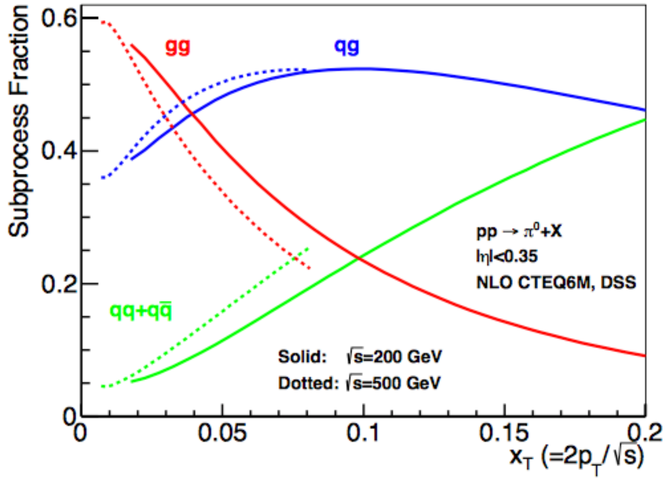
Accessing Δg

- No free gluons in the final state -- extract pPDFs via global fits of multiple observables
- Models predict how much each subprocess contributes to a particular final state
- Jets: Inclusive measurement, all initial states contribute
- Charged pions: More selective, some discrimination of initial state
- Some lever arm by changing collision energy: access lower Bjorken x at same p_T









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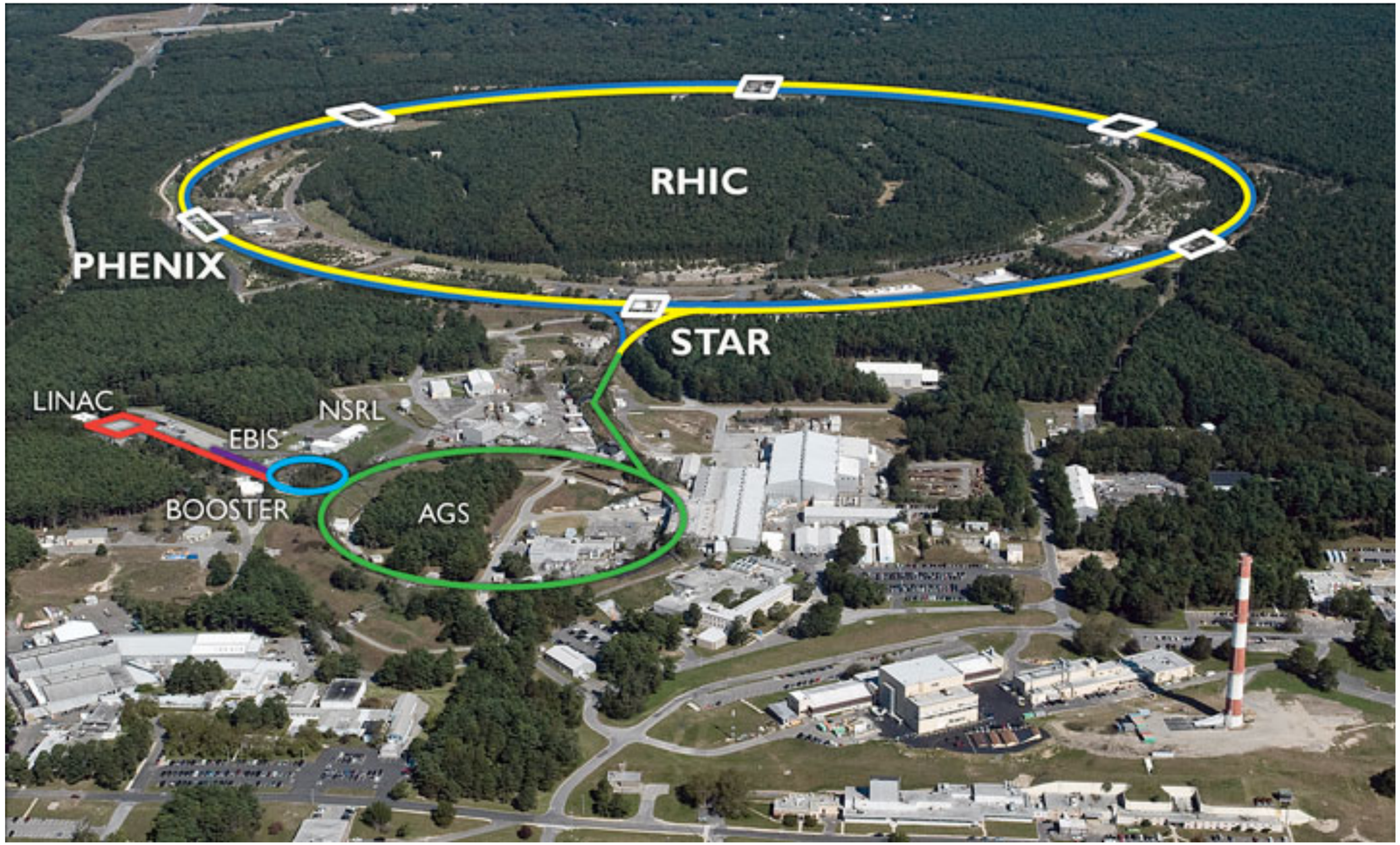
Probing Spin at RHIC

- World's only polarized p+p collider*
- Operational 2000 - (y_{EIC})
- STAR and PHENIX general-purpose detectors



*** also p↑He, p↑Al, p↑Au,...**

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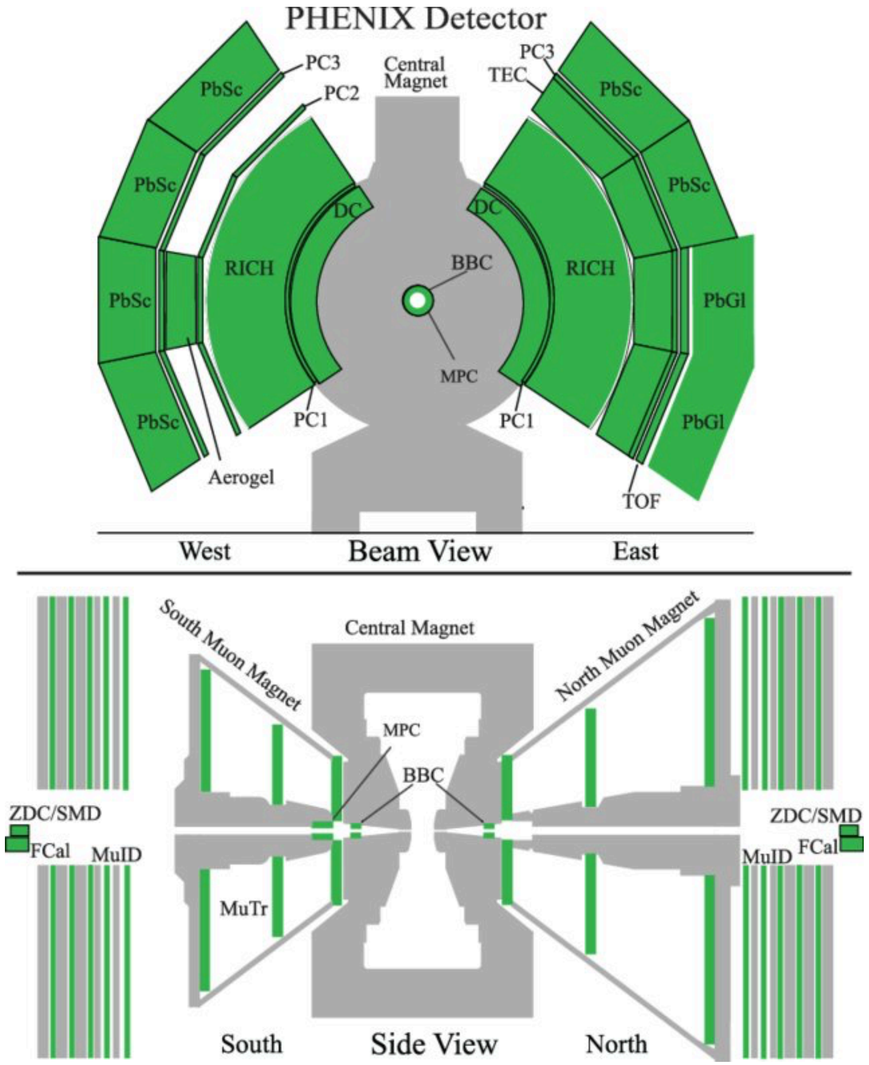
PHENIX Detector

- Took data until 2016 (==>sPHENIX)
- Wide variety of probes:
  - Central: π^0, $\pi^{\pm}$, η, γ, jets, ...
  - Forward: π^0, η, n, ...
- At mid rapidities (|η|<0.35):
  - Charged particle tracks from Pad+ Drift chambers
  - pID from RICH ($\pi^{\pm}$ >4.9GeV, $e^{\pm}$ > 20 GeV)
  - Energy and trigger with EMCal



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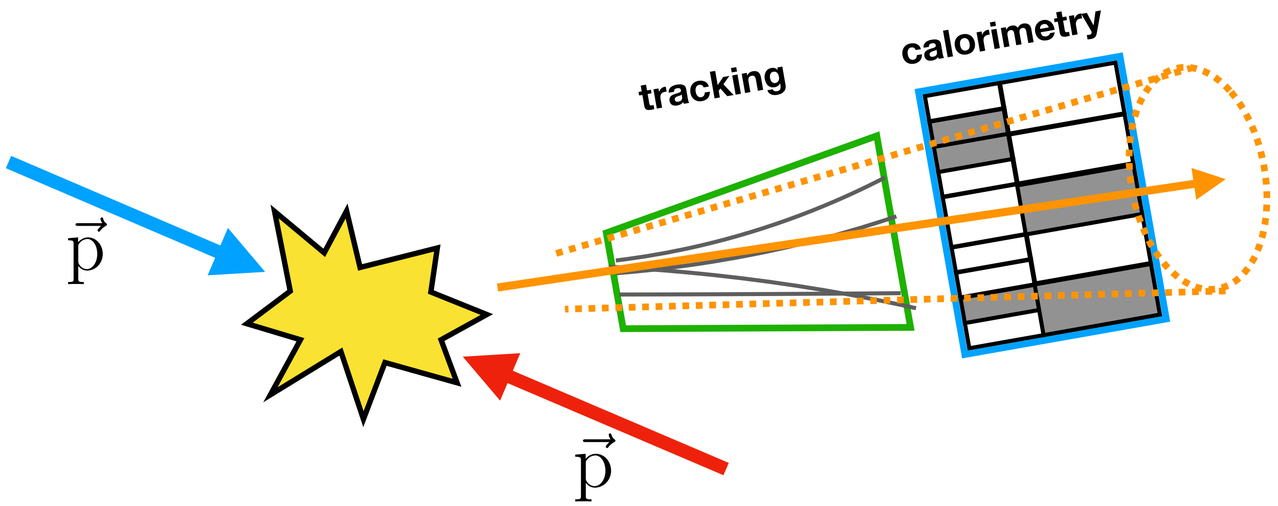
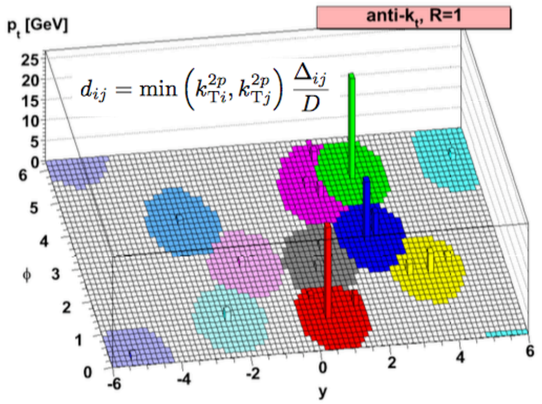
Reconstructing Jets

- Select tracks with pT>0.5GeV, EMCal clusters with E>0.5GeV
- FastJet Anti-kT algorithm produces detector jets
- Control noise with cuts on measured jet pT, charge fraction, number of constituents
- Cut on jet axis |η|<0.15 to minimize jet energy lost outside acceptance

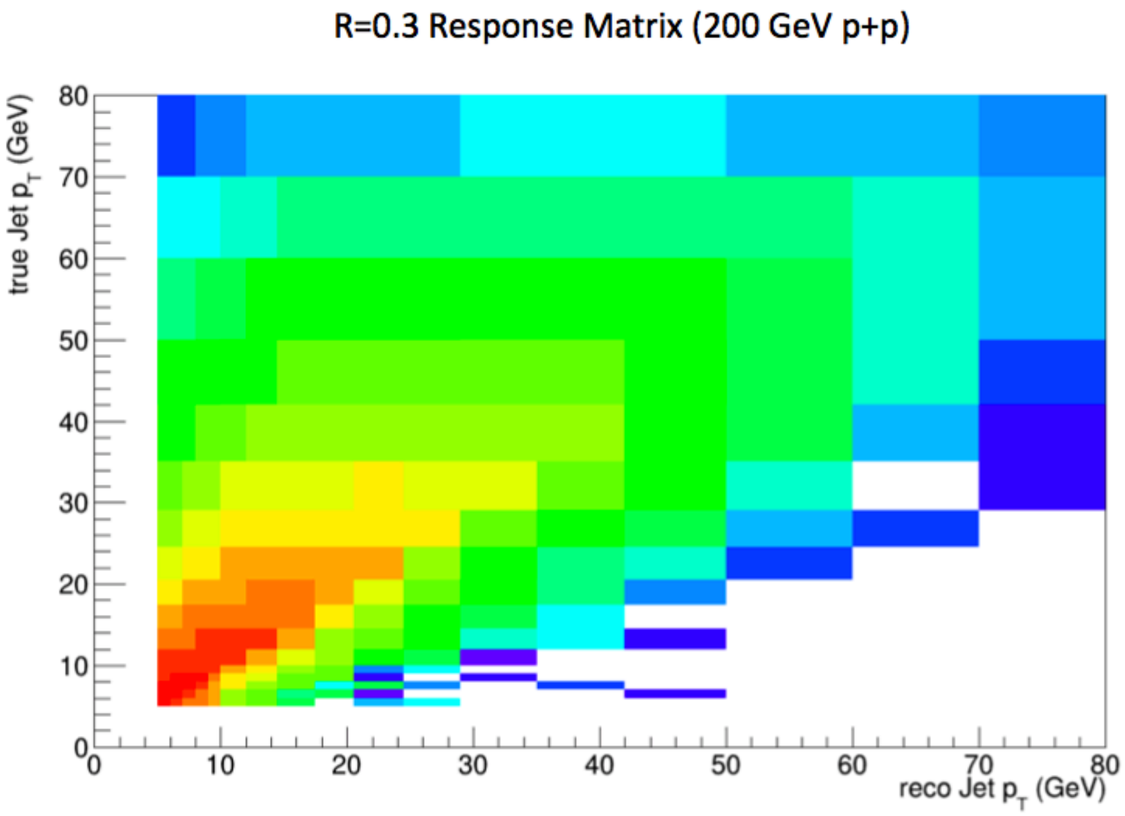




arxiv:0802.1189
JHEP 0804:063, 2008

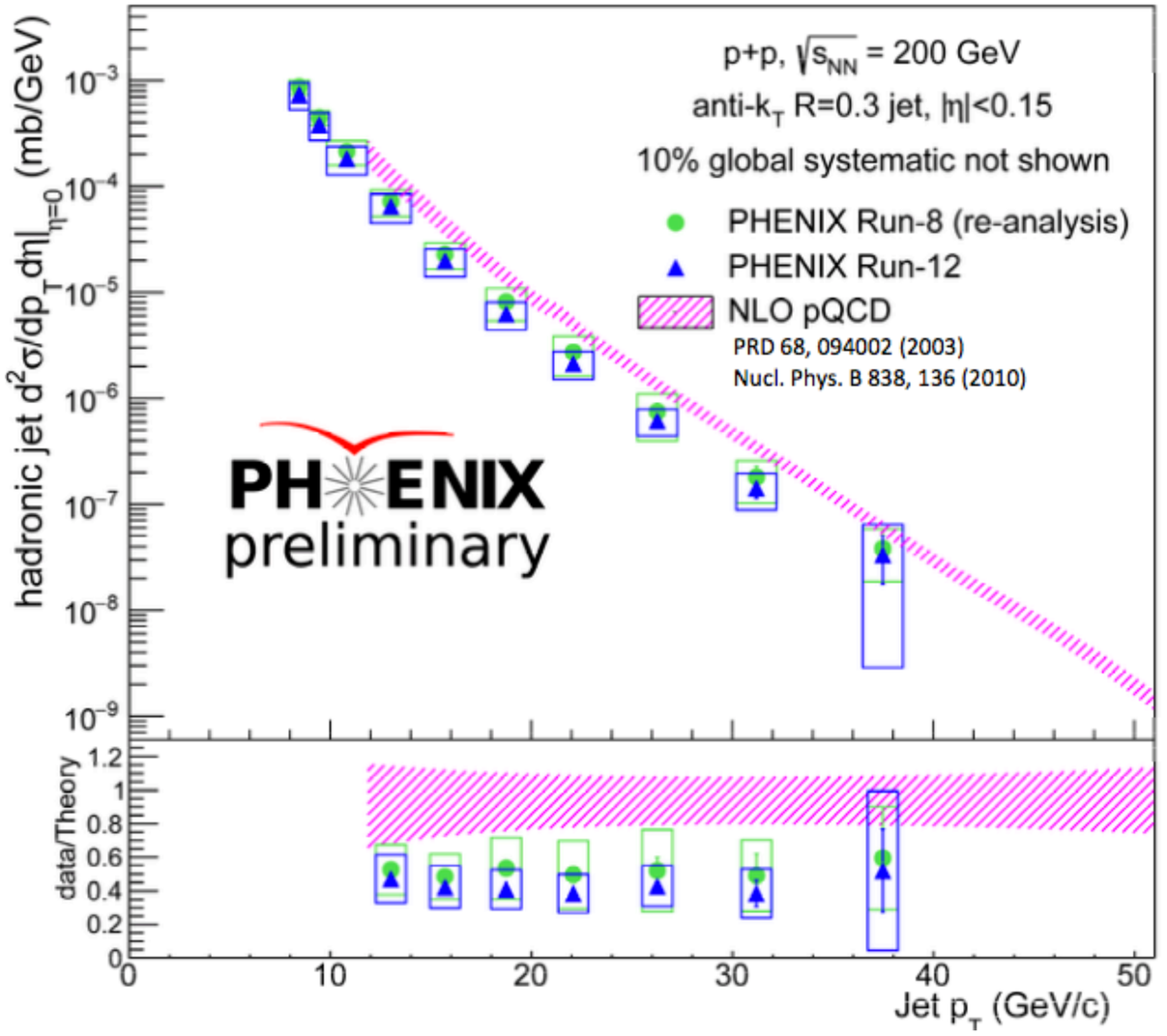
Correcting Jet Energy

- True jet energy is distorted by
  - Missing energy (punch-through / acceptance)
  - Bin migration (resolution)
  - Trigger efficiency
  - Underyling event
- Pythia events generated and studied to produce response matrix.
- RooUnfold Bayesian unfolding procedure (2 iterations)



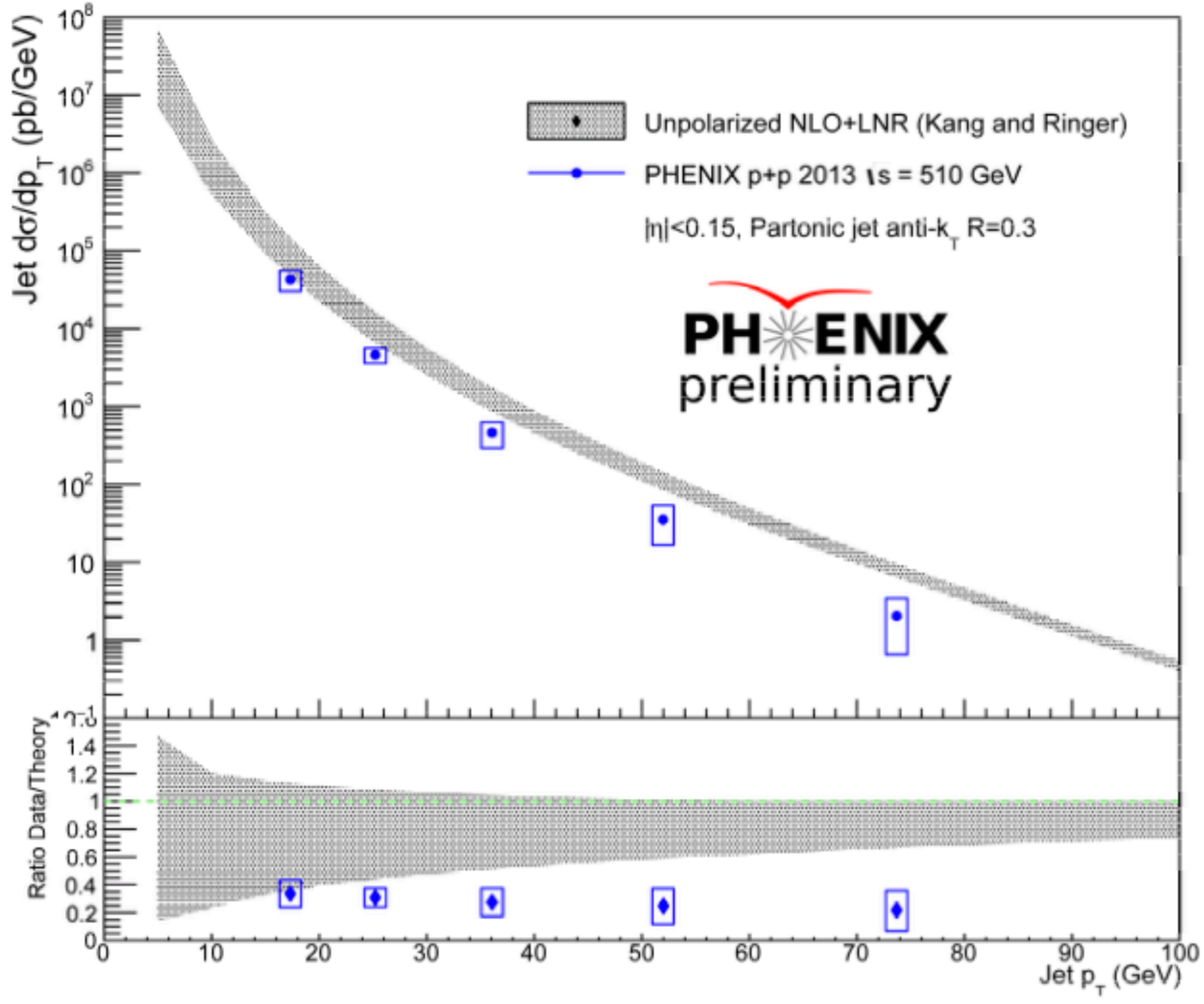
Jet Cross Section @ 200

- After unfolding, jet cross section can be plotted with 'real' jet pT
- Results are systematically lower than NLO predictions (also seen at small R in CMS)
- suggests shape of NLO jets is narrower than in data
- Wider jet radius not practical for PHENIX acceptance



Jet Cross Section @ 510

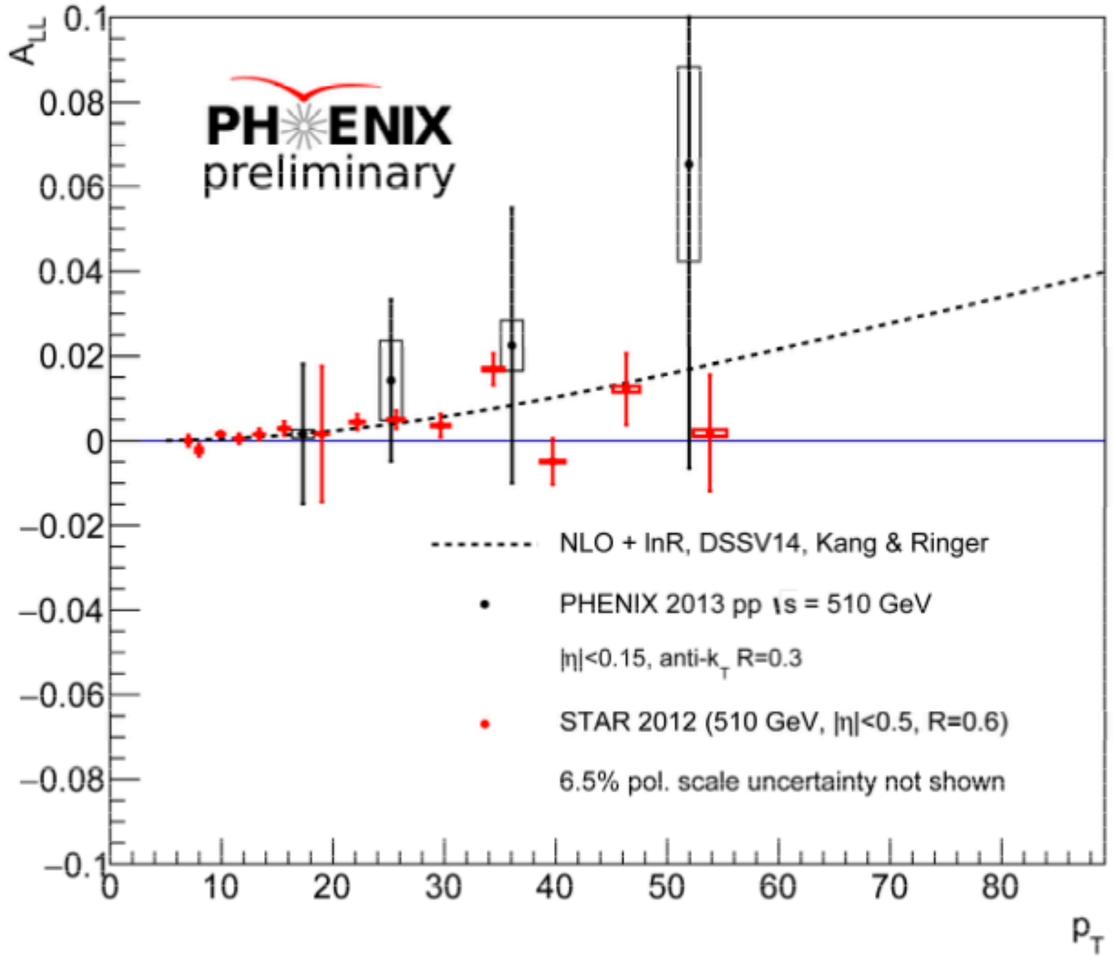
- Similar trend at 510 GeV



Jet ALL @ 510

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

- Asymmetry consistent with STAR result and theoretical prediction
- Main systematic effects from fidelity of detector simulation in unfolding studies
- Note: Statistical errors correlated by the unfolding



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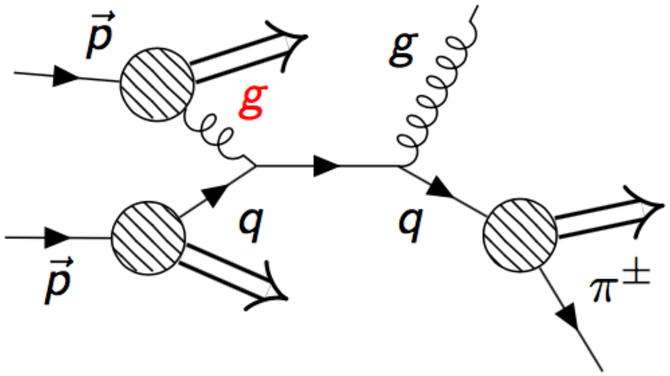
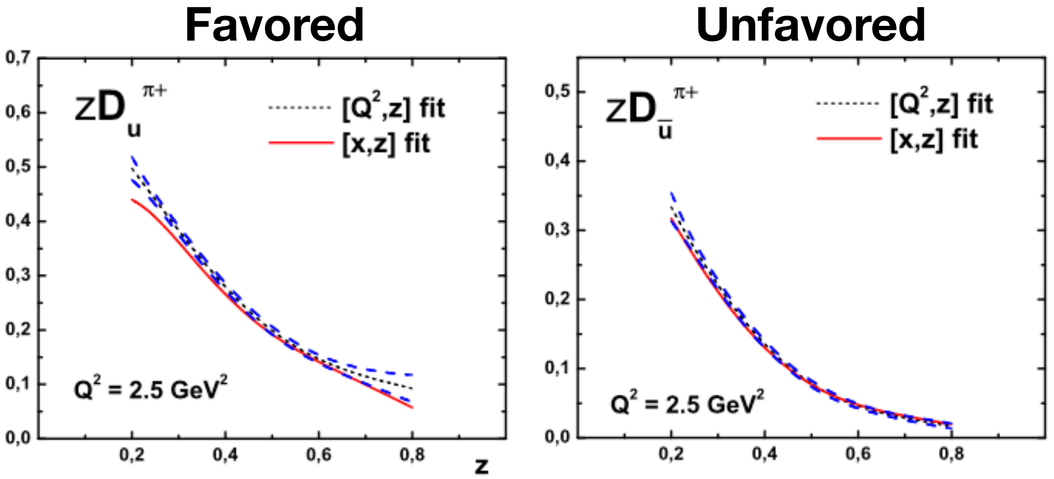
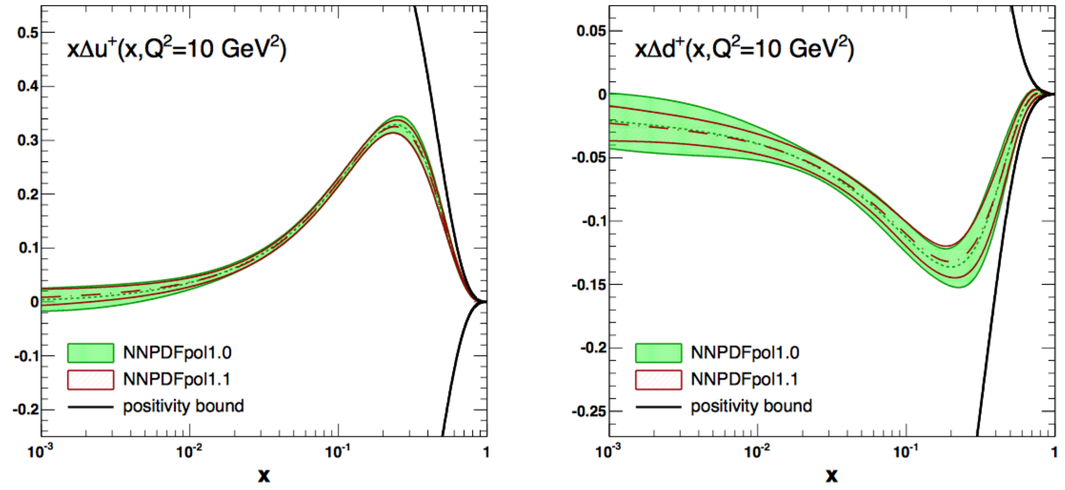
Charged Pions



- Single particle signal reduces acceptance issues
- Pion production in jets *favors* sign that matches the hard-scatter quark
- Existing knowledge of Δu and Δd gives a lever arm to look at Δg

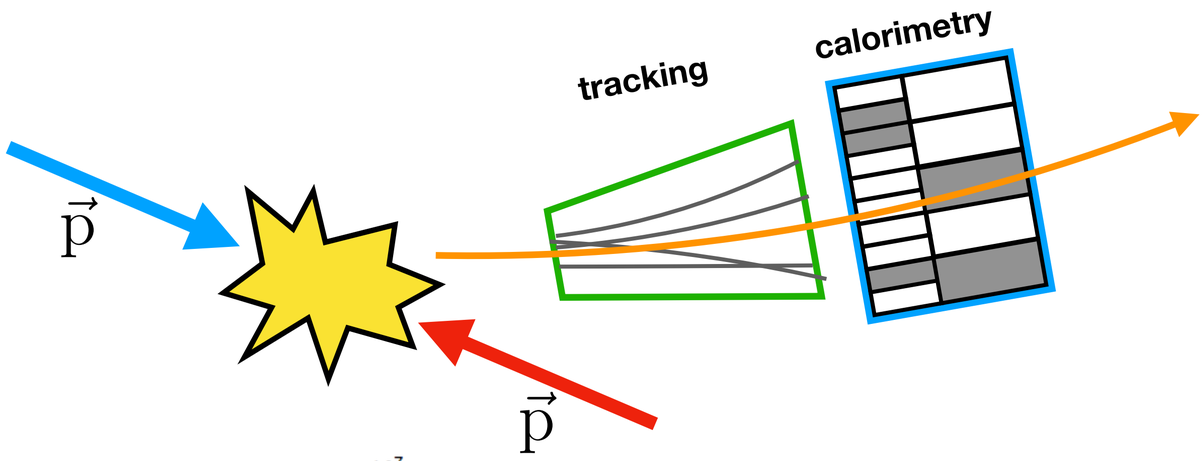


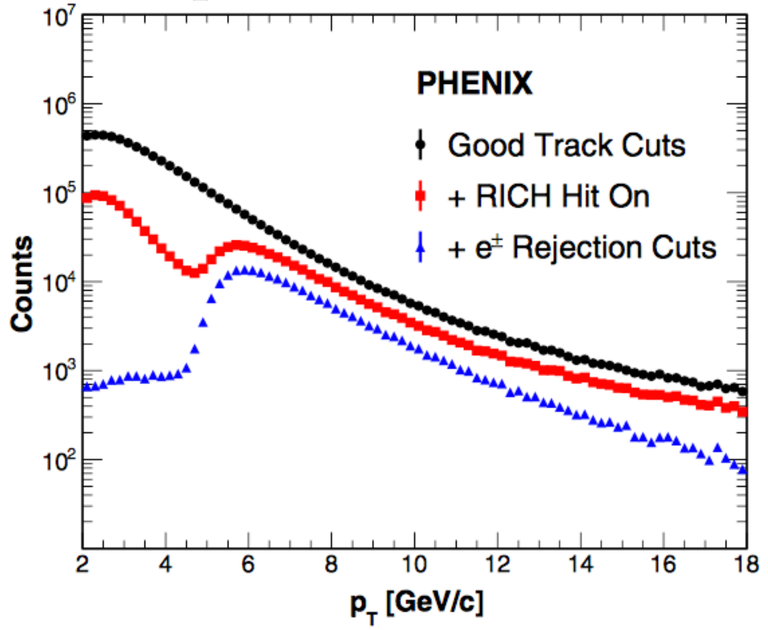
arxiv:1506.06381 Phys. Rev. D 93, 074026 (2016)



Reconstructing Charged Pions

- Trigger on EMCal energy, candidate track must match to tower
- Challenge: ~50% of pions have significant EMCal punch-through
- Pion ID:
  - >1 PMT in RICH must fire (4.9- 17.3GeV fires only for pions and electrons)
  - 0.2<E/p<0.8 -- punchthrough to disfavor electrons
  - Require bad match to EM shower shape
- Remaining BG studied in PYTHIA+GEANT





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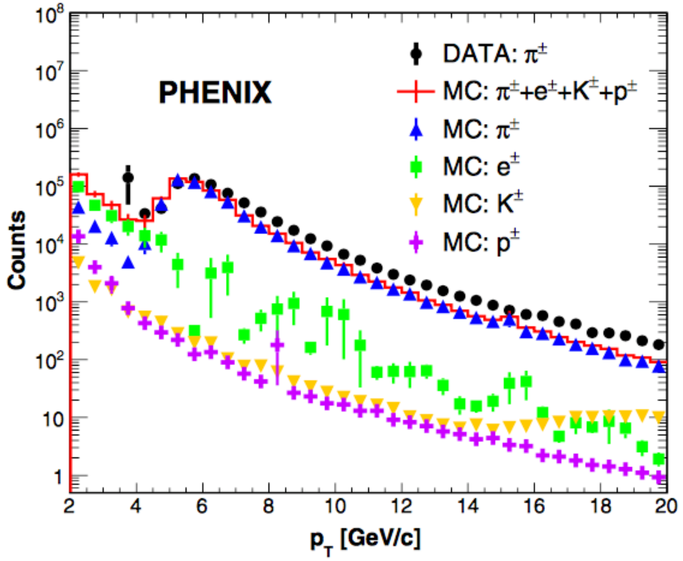
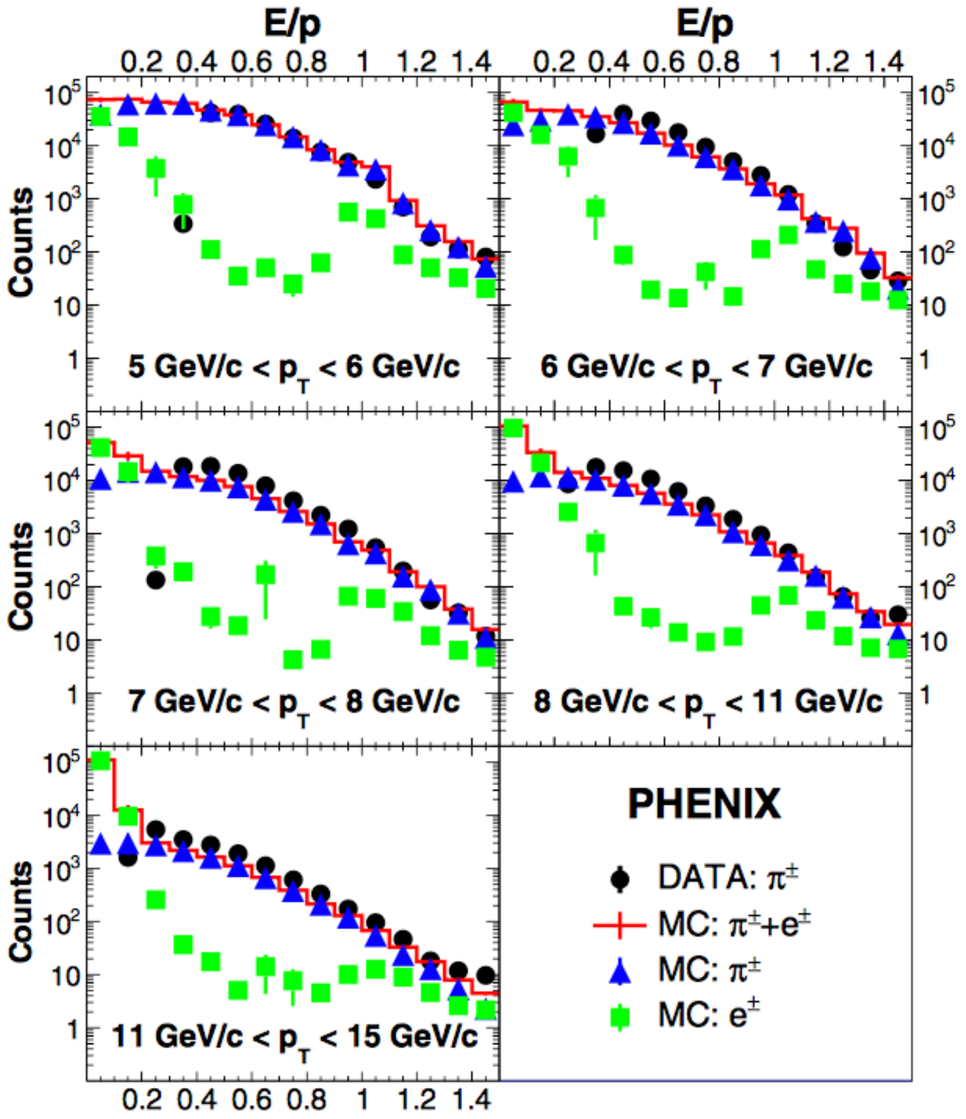
Pion Background Studies





- MC studies show electrons dominate:
  - below threshold and until kaons can fire the RICH
  - at high E/p (EM shower fully captured)
  - at low E/p (late conversion)

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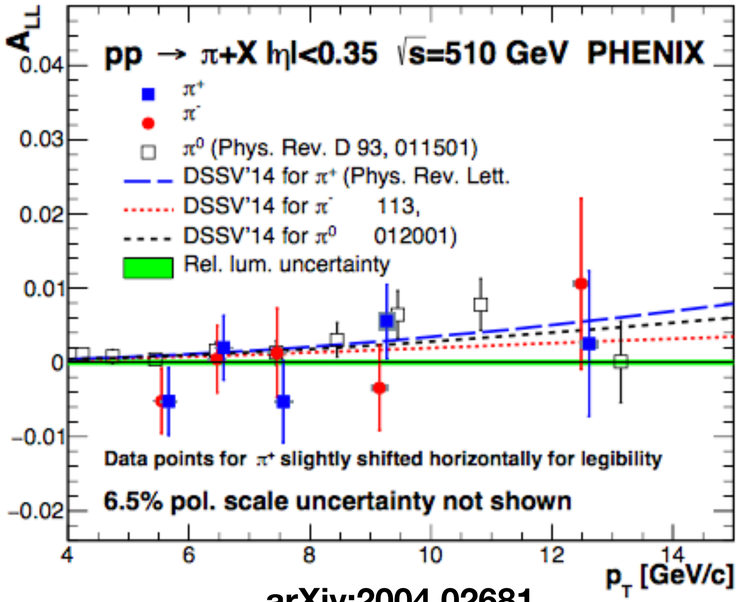
Charged Pion A_{LL} @ 510

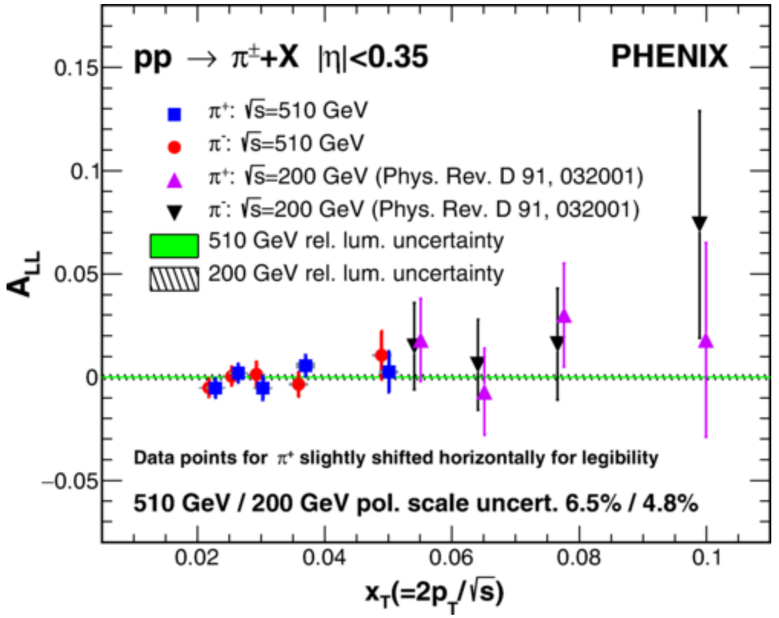
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

$$= \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

$$A_{\mathrm{LL}}^{\mathrm{tot}} = (1 - \Sigma r_i) A_{\mathrm{LL}}^{\pi} + \Sigma (r_i A_{\mathrm{LL}}^{i})$$

$\pi^{\pm}$ A_{LL} @ 510





arXiv:2004.02681
Phys.Rev.D102, 032001 (2020)

- Background asymmetry consistent with zero, fraction also small
- Consistent with DSSV fits of 200 GeV data: positive gluon polarization
- Complementary xT range, corresponds to $0.04 \lesssim x_B \lesssim 0.09$

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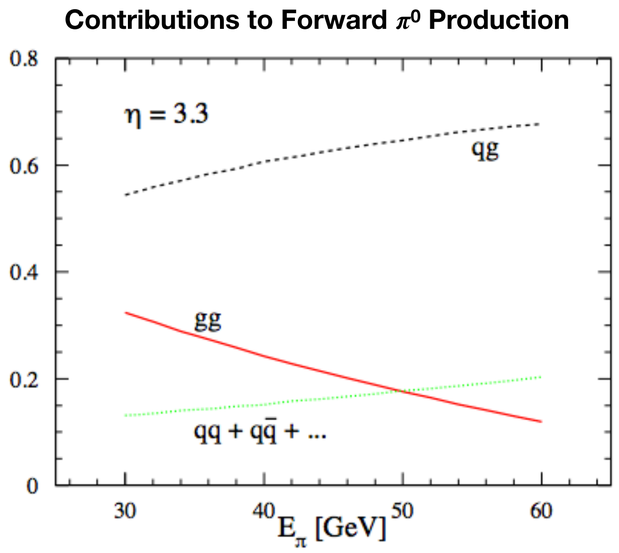
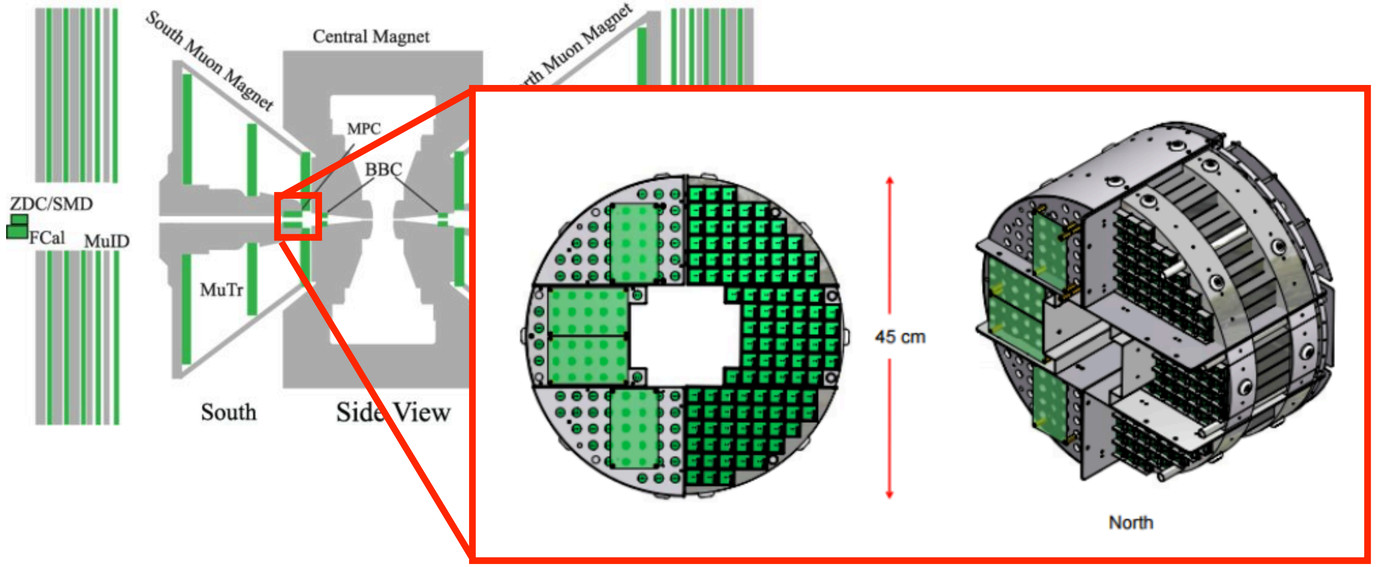
Pions Going Forward





- *qg* subprocess increasingly dominates at forward angles and larger energies
- PHENIX Muon Piston Calorimeter covers 3.1<η<3.9(3.7) North(South)
- Most likely: high-*x* valence quark, low-*x* gluon ==> ΔG down to *x*~0.001
- Analysis of √s=510GeV (Run13) data in progress

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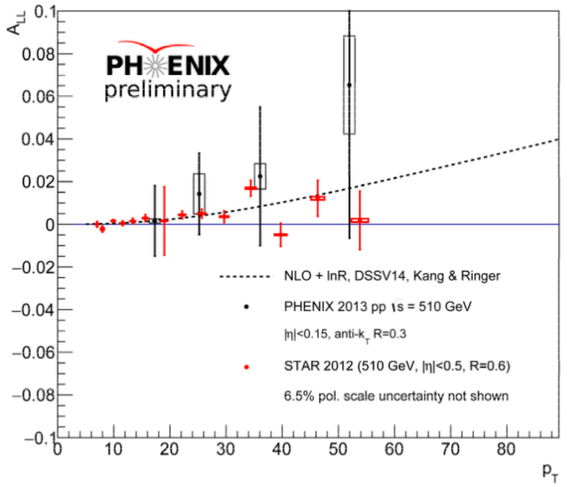
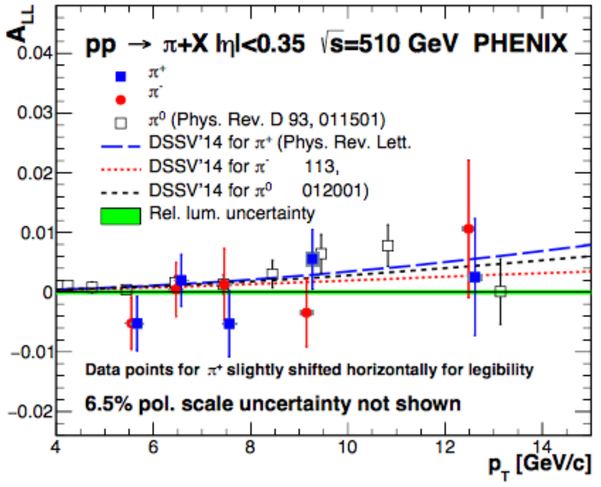
Summary and Outlook

- PHENIX jet and $\pi^{\pm}$ A_{LL} measurements at 510 GeV further corroborate $\Delta G>0$
- Analysis ongoing in other channels as well
- Now: Transition to sPHENIX
- Soon(ish): EIC, and significantly improved access to small x

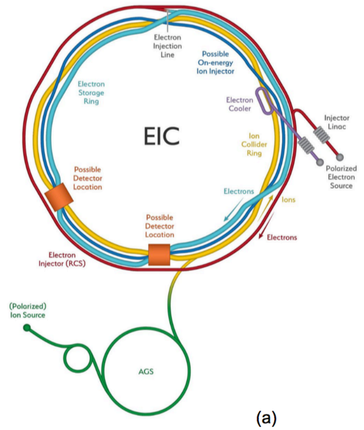
Jet A_{LL} @ 510



$\pi^{\pm}$ A_{LL} @ 510

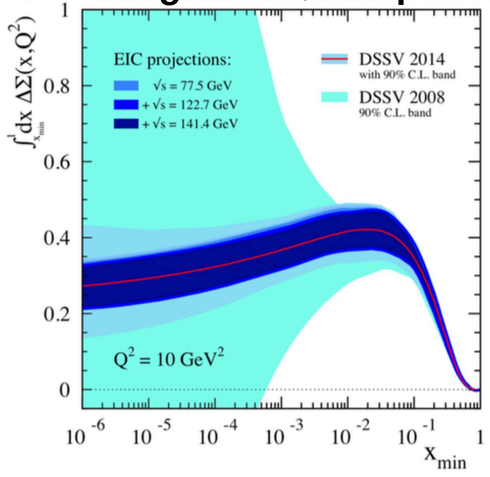


Electron Ion Collider

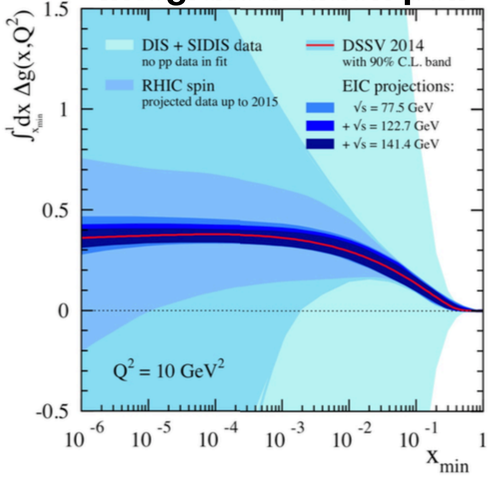


(a)

Integrated Quark pol.



Integrated Gluon pol.



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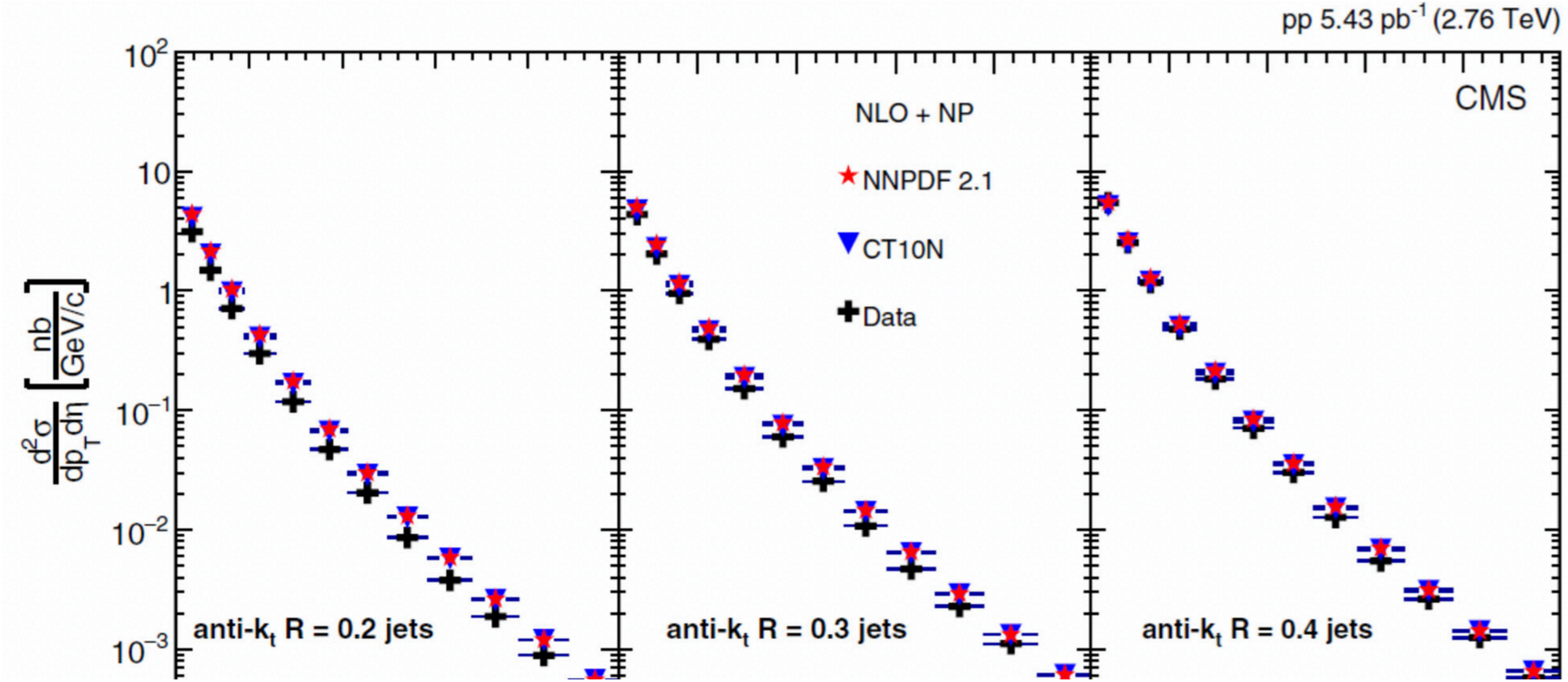
NLO Jets at CMS



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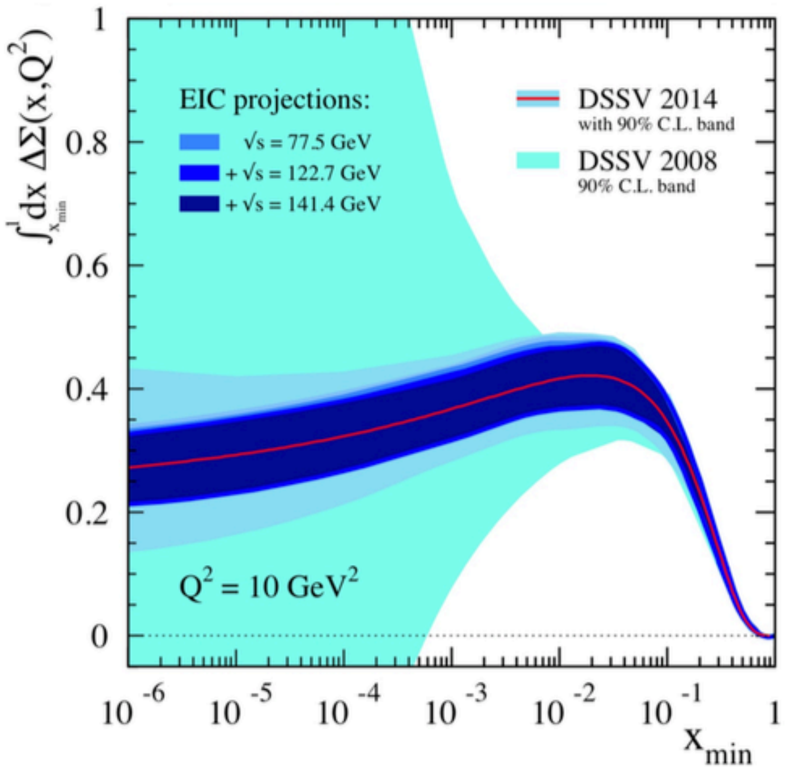
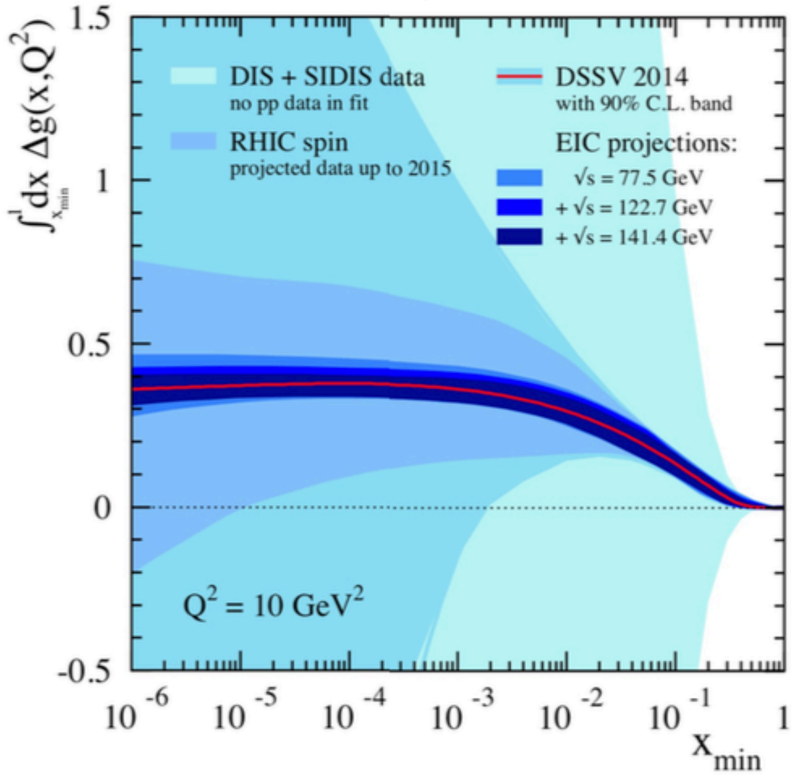
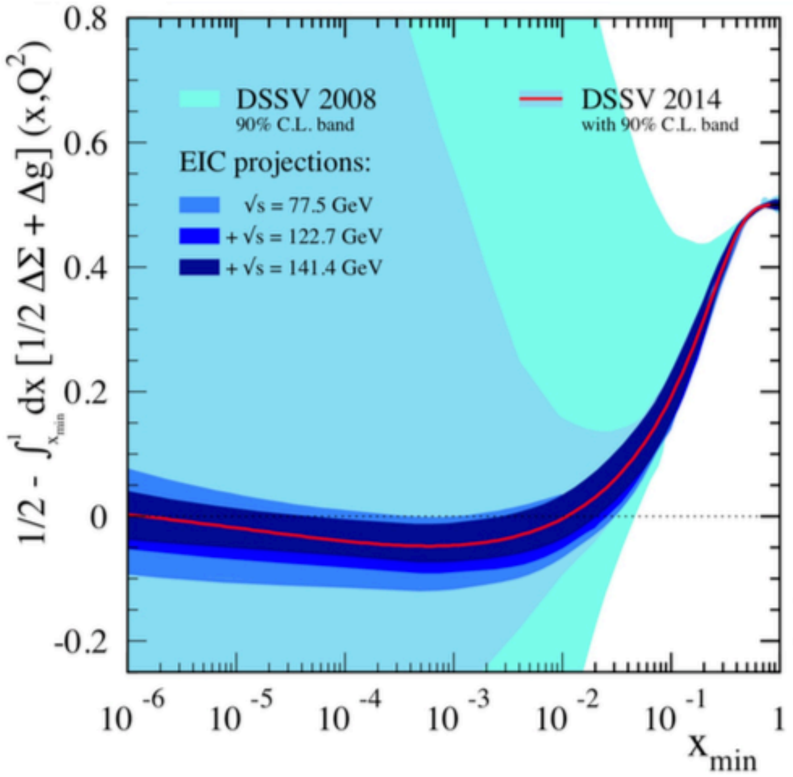
EIC projections







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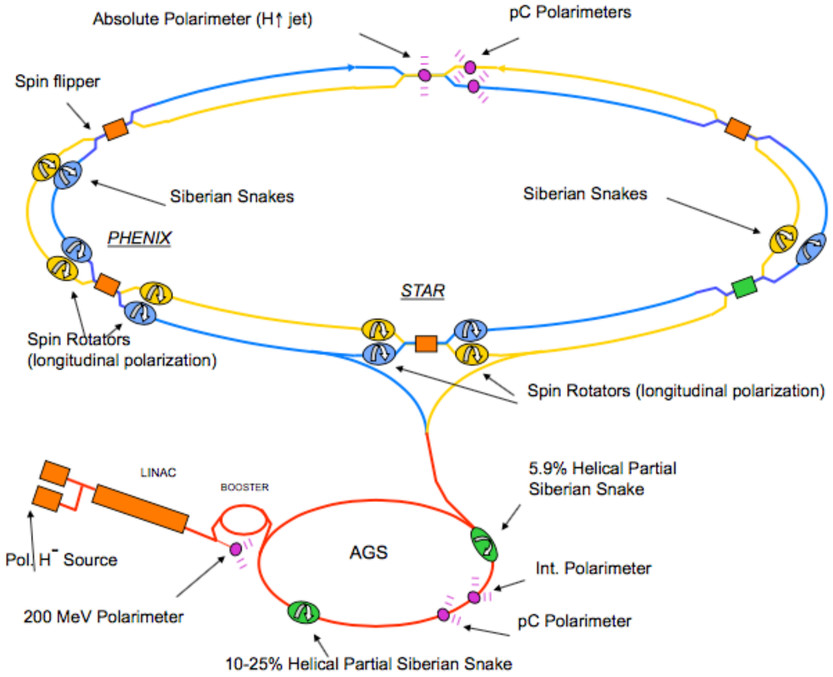
RHIC Runs

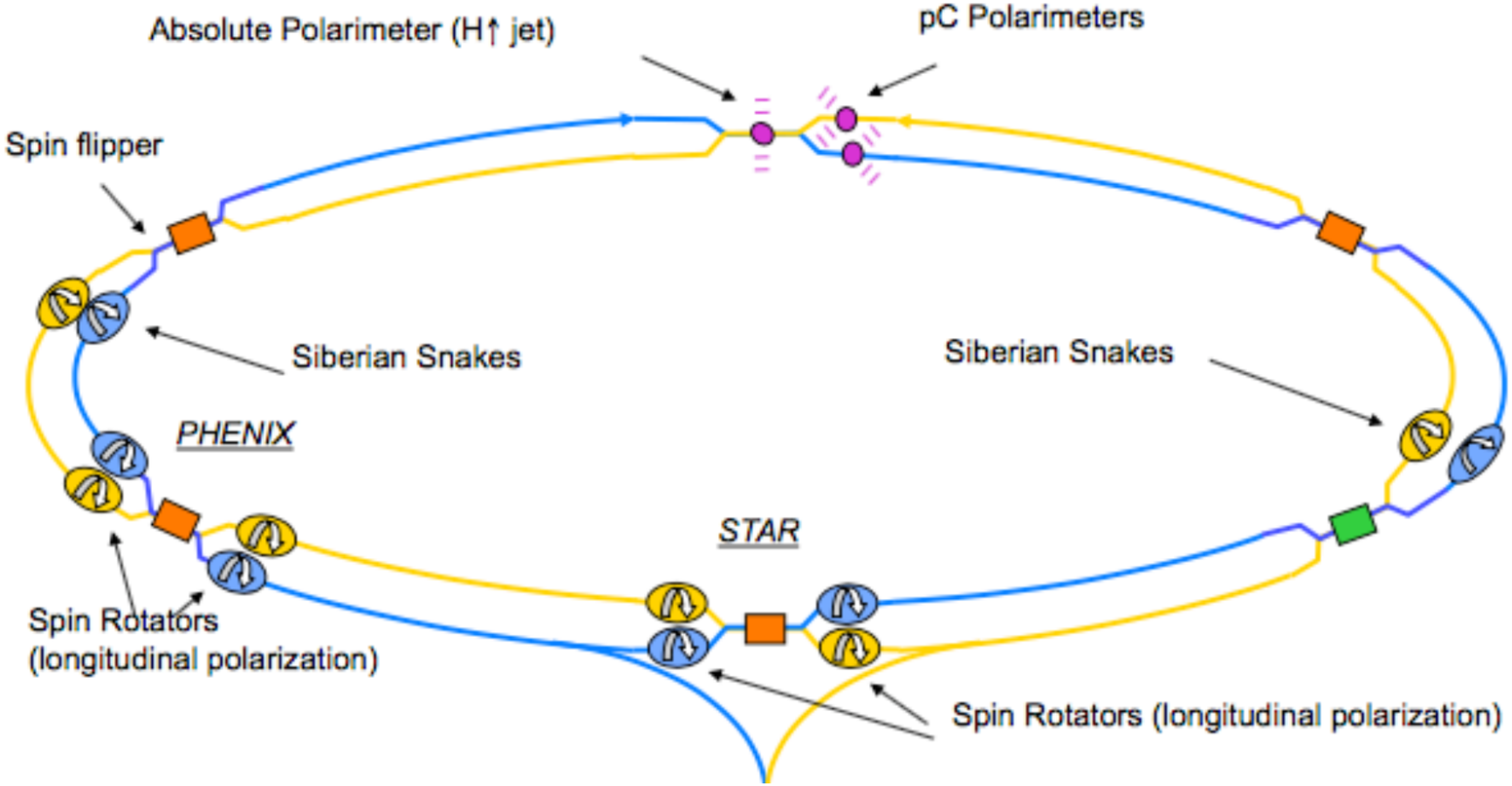
- Large datasets available in longitudinal and transverse polarizations
- Run 13:
  long 510GeV run
- Run 15:
  first $p^{\uparrow}$ on nuclei
- (Heavy Ion not shown)

Year	$\sqrt{s}$ (GeV)	Recorded Luminosity for longitudinally / transverse polarized p+p STAR	Recorded Luminosity for longitudinally / transverse polarized p+p PHENIX	<P> in %
2006	62.4	-- pb^{-1} / 0.2 pb^{-1}	0.08 pb^{-1} / 0.02 pb^{-1}	48
	200	6.8 pb^{-1} / 8.5 pb^{-1}	7.5 pb^{-1} / 2.7 pb^{-1}	57
2008	200	-- pb^{-1} / 7.8 pb^{-1}	-- pb^{-1} / 5.2 pb^{-1}	45
2009	200	25 pb^{-1} / -- pb^{-1}	16 pb^{-1} / -- pb^{-1}	55
	500	10 pb^{-1} / -- pb^{-1}	14 pb^{-1} / -- pb^{-1}	39
2011	500	12 pb^{-1} / 25 pb^{-1}	18 pb^{-1} / -- pb^{-1}	48
2012	200	-- pb^{-1} / 22 pb^{-1}	-- pb^{-1} / 9.7 pb^{-1}	61/56
	510	82 pb^{-1} / -- pb^{-1}	32 pb^{-1} / -- pb^{-1}	50/53
2013	510	300 pb^{-1} / -- pb^{-1}	155 pb^{-1}/ -- pb^{-1}	51/52
2015	200	52 pb^{-1} / 52 pb^{-1}	-- pb^{-1}/ 60 pb^{-1}	53/57
2015	200 *p* Au	total delivered Luminosity = 1.27 pb^{-1}		60
2015	200 *p* Al	total delivered Luminosity = 3.97 pb^{-1}		54

= Transversely polarized

RHIC Ring


Absolute Polarimeter (H↑ jet)
pC Polarimeters
Spin flipper
Siberian Snakes
Siberian Snakes
PHENIX
STAR
Spin Rotators
(longitudinal polarization)
Spin Rotators (longitudinal polarization)
LINAC
BOOSTER
5.9% Helical Partial
Siberian Snake
Pol. H⁻ Source
AGS
Int. Polarimeter
200 MeV Polarimeter
pC Polarimeter
10-25% Helical Partial Siberian Snake


Absolute Polarimeter (H↑ jet)
pC Polarimeters
Spin flipper
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Siberian Snakes
PHENIX
STAR
Spin Rotators
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Spin Rotators (longitudinal polarization)