Jet A_{LL} in PHENIX p+p $\sqrt{s}$=510 GeV

MILAP PATEL

DIS 2018

IOWA STATE UNIVERSITY

PHENIX

Outline

- Physics Background
  - Gluon polarization
- Experimental Setup
  - PHENIX detector
- Jets at PHENIX

Gluon Spin

- DIS is not directly sensitive to electrically neutral gluons.
  - Need polarized proton-proton collisions to directly study gluons.
- Gluon helicity distribution function $\Delta g(x)$ is measured to find ΔG, the gluon spin contribution.

$$\Delta G \equiv \int_0^1 \Delta g(x) dx$$

Where $x = \frac{Gluon\ Momentum}{Proton\ Momentum}$

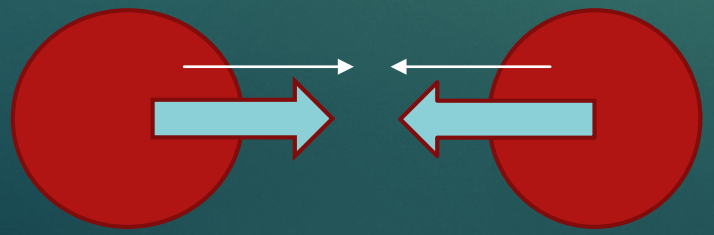
- The $\Delta g(x)$ is found via the longitudinal double spin asymmetry, A_{LL}:

$$A_{LL} = \frac{1}{P_Y P_B} \frac{N^{++} - N^{+-}}{N^{++} + N^{+-}} = \frac{\sum_{AB \to CX} \Delta f_A \Delta f_B \Delta \sigma_{AB \to CX}}{\sum_{AB \to CX} f_A f_B \sigma_{AB \to CX}}$$

Part that is measured.

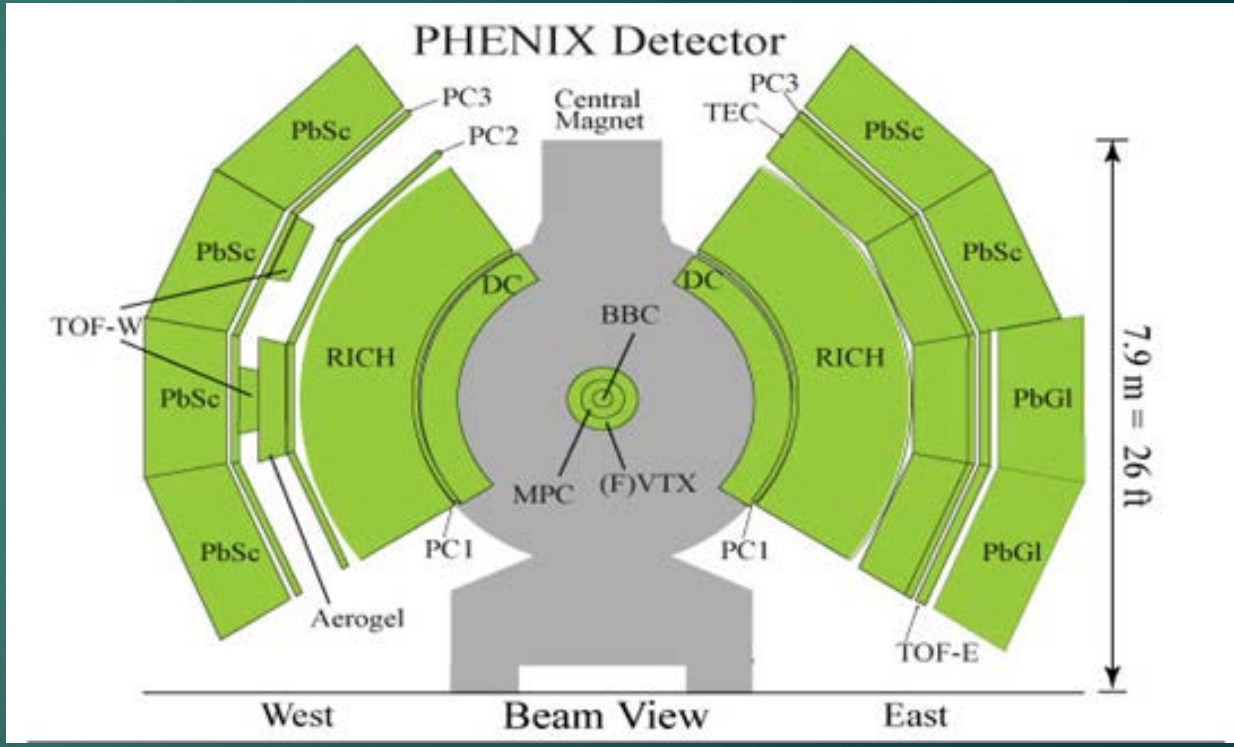
Δf (f) and Δσ (σ)are the polarized (unpolarized) parton distribution functions.

Example of spin pattern where both protons have polarization in the direction of motion. Hence a (++) event.



PHENIX Detector

- Located at Brookhaven National Lab in RHIC ring.
- Two central arms (East and West) and Muon arms (North and South).
- Covers pseudorapidity range of $|\eta| < 0.35$ and azimuthal (φ) 90º.
- Magnets in central arm and muon arms.
- Central arm detectors:
  - DC and PC to track charged particles.
  - EMCal to measure energy deposited from electromagnetic showers.



PHENIX = Pioneering High Energy Nuclear Interaction eXperiment

Current Understanding

- RHIC experiments PHENIX and STAR have measured A_{LL} and provide constraint on Δg.
  - Only STAR has measured jet A_{LL} at RHIC.
  - PHENIX has measurements for pion and eta mesons.
- The various A_{LL} are fit and used to extract Δg in global analysis.
  - Jets probe higher *x* region dominated by STAR, but PHENIX can contribute.
- Current gluon contribution constraint is:

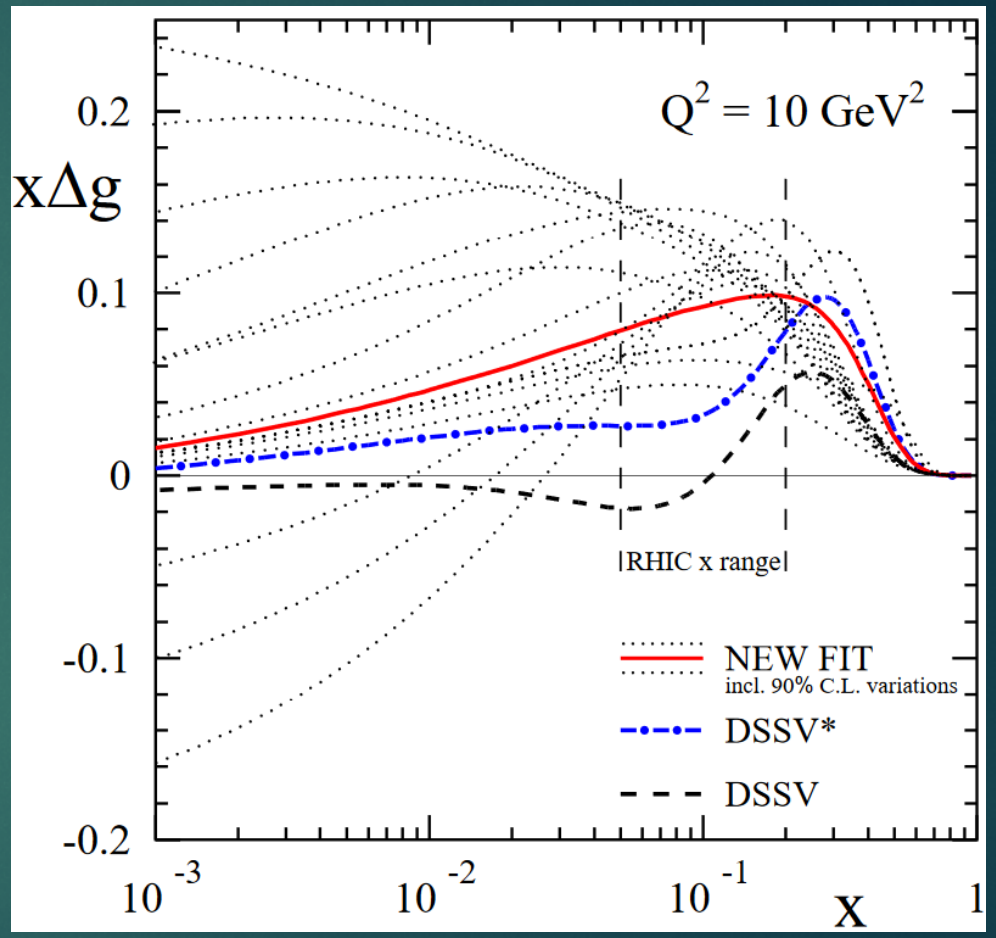
$$\int_{0.05}^{1} \Delta g \, dx \sim 0.2^{+0.06}_{-0.07} \quad (Q^2 = 10 \text{ GeV}^2)$$

Phys. Rev. Lett. 113, 012001 (2014)

PHENIX = Pioneering High Energy Nuclear Interaction eXperiment

STAR = Solenoidal Tracker at RHIC

arXiv:1404.4293

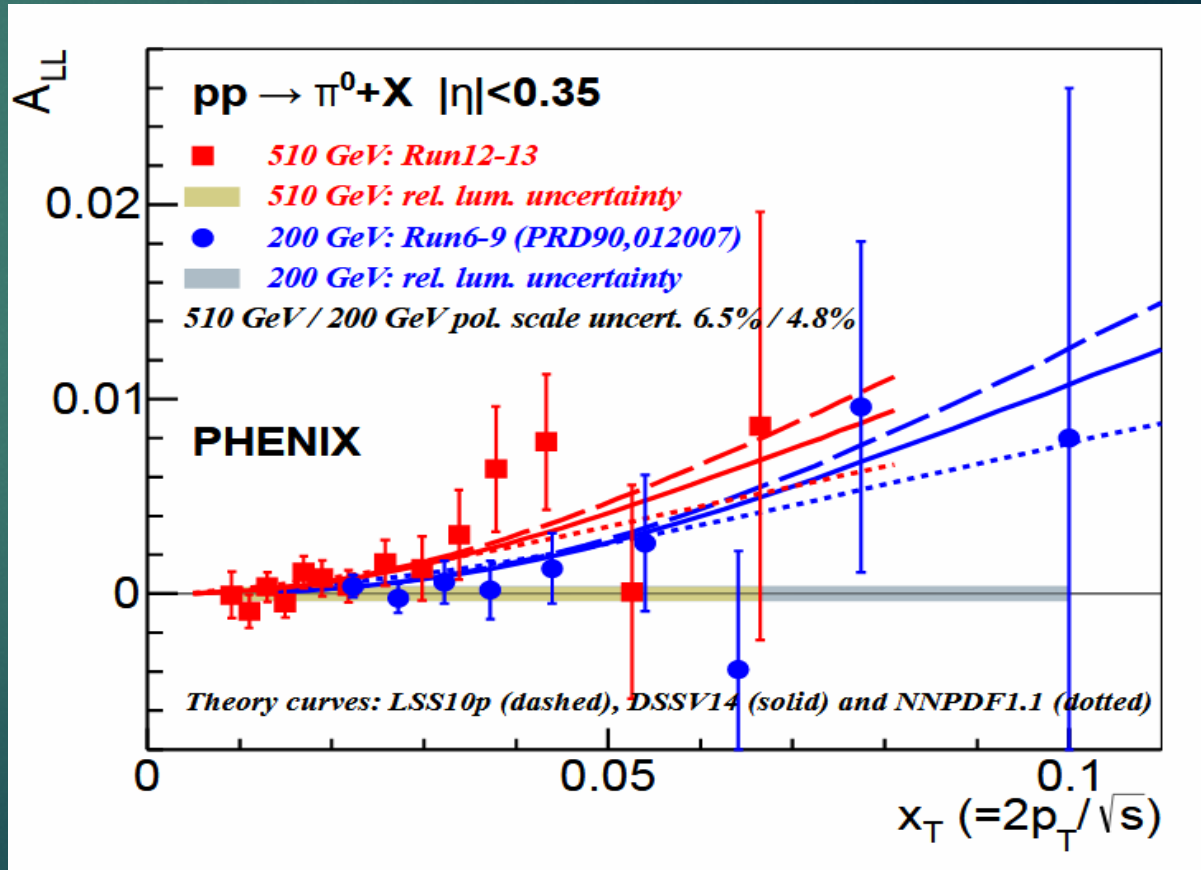


Red line is using PHENIX and STAR data until 2009. Black and blue are using older data, which did not include jet asymmetry. RHIC x range $\sqrt{s}$ = 200 GeV is: $0.05 \leq x \leq 0.2$.

PHENIX A_{LL}

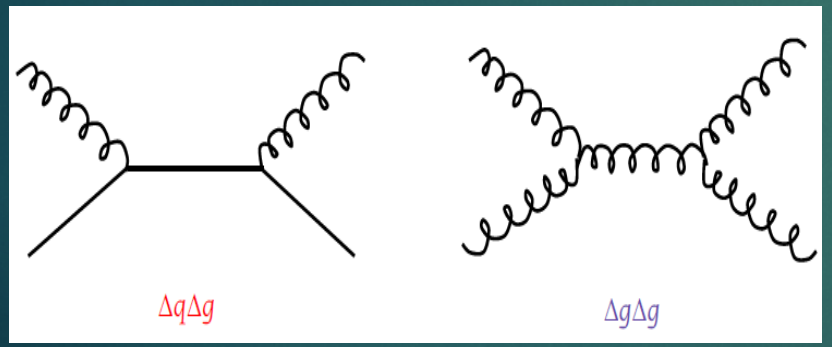
- PHENIX π^0 asymmetry measurement for $\sqrt{s}$ = 510 GeV and 200 GeV
  - Low *x* region down to ~0.01 in 510 GeV
- Other PHENIX analyses at $\sqrt{s}$ = 510 GeV:
  - Charged pion A_{LL}
  - Direct photon A_{LL}
  - MPC π^0 A_{LL} (forward measurement, x ~ 10^{-3})
  - J/Ψ A_{LL}, Phys. Rev. D 94, 112008 (2016)

Phys. Rev. D 93, 011501 (2016)



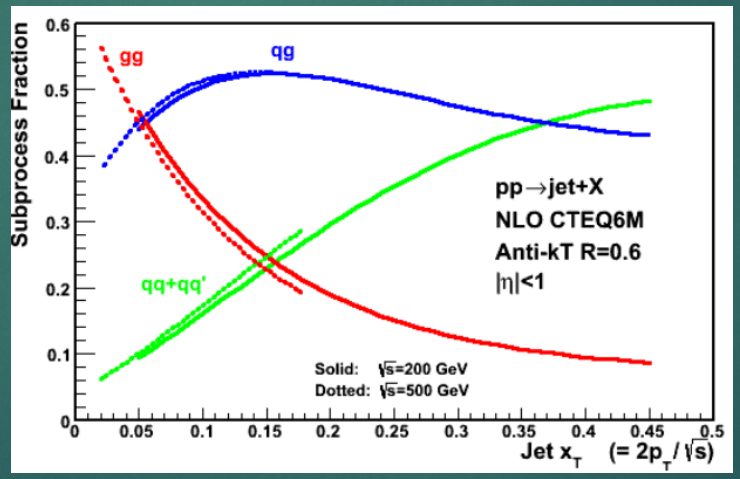
What are jets?

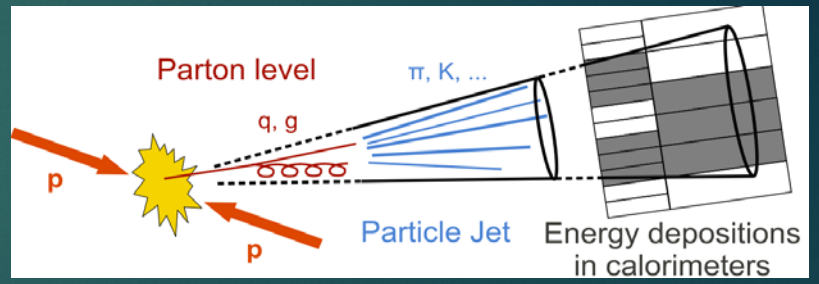
- Jet is a QCD observable which is a collimated cone of hadrons produced by hadronization of a quark or gluon.
- Jets in *pp* are contributed by 2→2 hard scattering from quark-quark (*qq*), quark-gluon (*qg*), and gluon-gluon (*gg*) processes.
  - At RHIC kinematic ranges, the *qg* and *gg* processes dominate.



The Feynman diagram of the two processes which dominate at RHIC kinematic ranges. The Δg and Δq are terms which would be in the $A_{LL}\,\Delta f_{A,B}$ (shown earlier).

arXiv:1501.01220





Collimated particles are reconstructed as tracks and clusters in detectors.

http://cms.web.cern.ch/news/jets-cms-and-determination-their-energy-scale

Jets

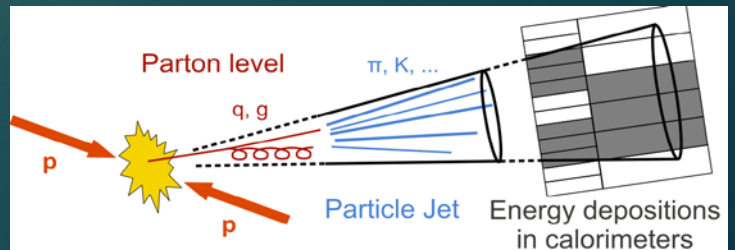
- No absolute definition of a jet, since it is just associating the shower of an original hard parton which undergoes hadronization.
  - Jet reconstruction is a procedure to combine the momenta of the fragments of the original parton, i.e. undoing the fragmentation process.
- Not possible to unambiguously separate which hadrons come from the original parton or from another process.
- The anti-k_T algorithm is used, which is an iterative procedure which clusters jets by:

$$d_{ij} = min(\frac{1}{k_{T,i}^2}, \frac{1}{k_{T,j}^2}) \frac{\Delta\phi_{ij}^2 + \Delta\eta_{ij}^2}{R^2}$$

Where d_{ij} is the anti-k_T distance between pair of particles i and j. R = 0.3 is the radius parameter used.

$$R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$$

- By placing k_T in the denominator, it helps ensure that soft particles will cluster with the hard particles.
- Fastjet+ used for jet reconstruction.



+ arXiv:1111.6097

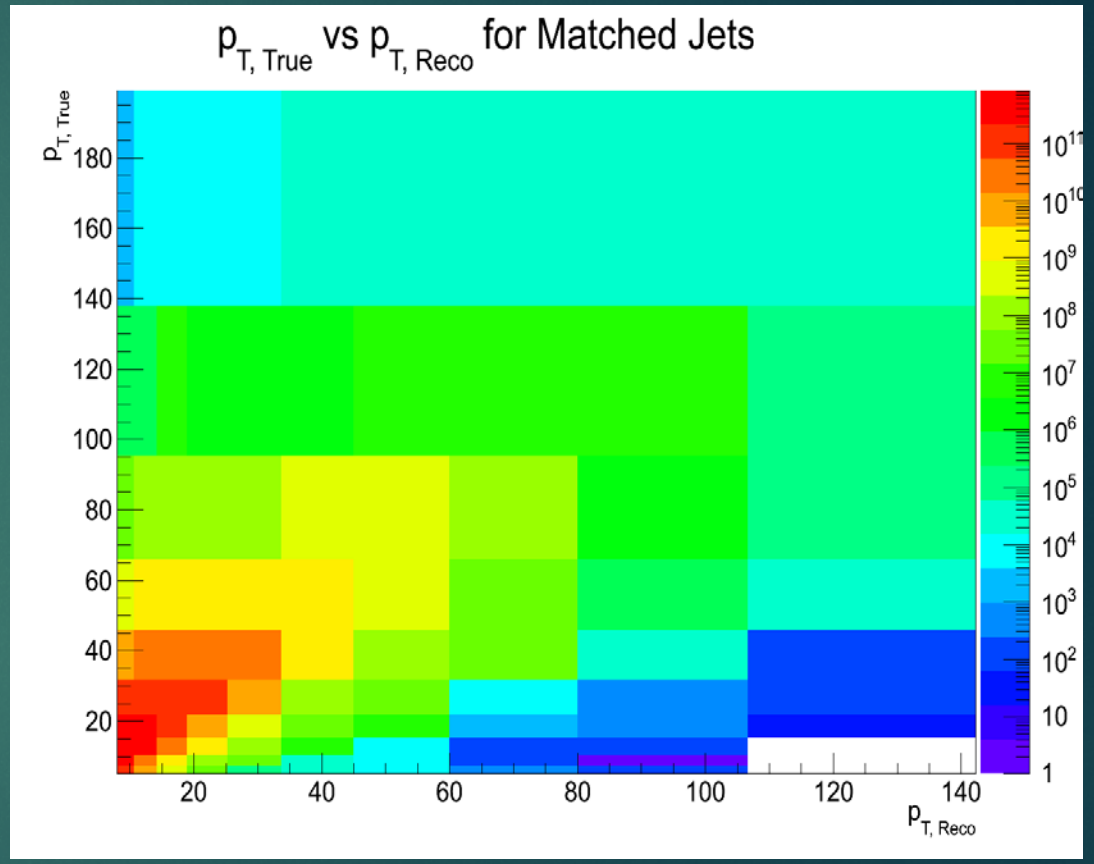
Unfolding

- Unfolding corrects for the energy resolution caused by the underlying event fluctuations and detector effects.
  - Take measured reco p_T distribution of jets and get true p_T distribution of jets.
- Need to use simulations to generate a Response Matrix.
  - Gives the probability the generated event in true p_T bin to be found in reco p_T bin.
- Simulation software called Pythia was used to generate $p+p$ $\sqrt{s}$ = 510 GeV collision events.
  - Turned on all the qq, qg, and gg processes.
- Events generated by Pythia are passed through PISA[1], a GEANT3 based software which provides a simulated version of the PHENIX detector.
  - Dead areas are set in the simulation to properly match data.
- Use Singular Value Decomposition (SVD) method to unfold.

[1]PHENIX Integrated Simulation Application

Response Matrix

- Pythia true jets are reconstructed using truth information with anti-k_T, R = 0.3.
- Particles which passed through PISA are used to determine the reconstructed jets.
  - This is similar to how the real data is reconstructed, using same cuts.
- The Pythia true jet and the PISA reconstructed jet must match to R < 0.3.
  - The corresponding $p_{T,True}$ vs. $p_{T,Reco}$ is the Response Matrix.

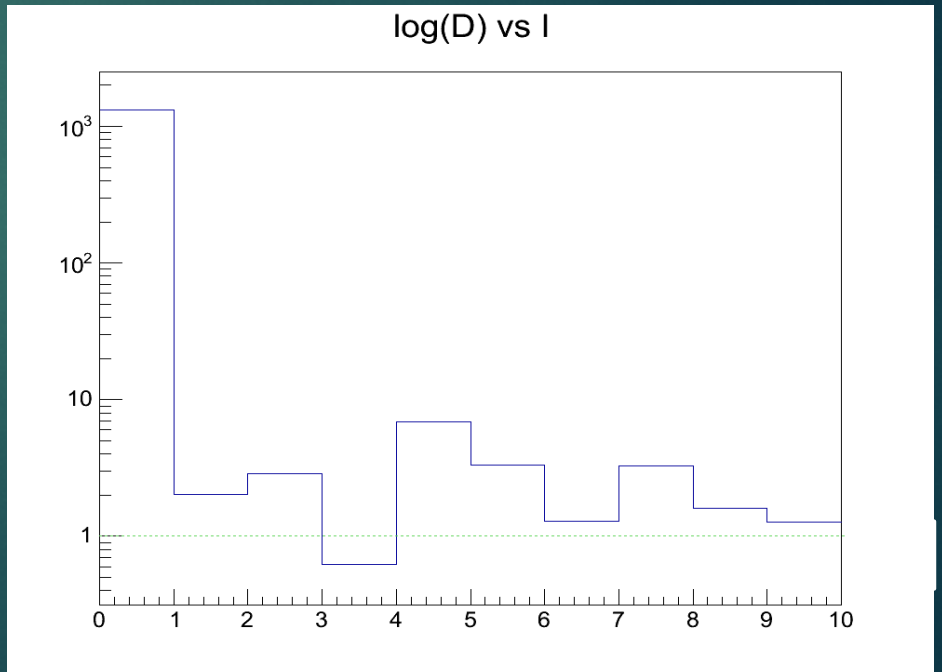


An example response matrix.

SVD Unfolding

- Singular Value Decomposition (SVD) is the method used to unfold using a software package called RooUnfold.
- Inputs needed:
  - The reco p_T jets (from data).
  - Response matrix (from simulation).
  - Total true p_T jets found (from Pythia, for proper scaling).
- Outputs the true p_T jets of data.
- SVD unfolding needs a proper regularization parameter (kReg) when doing matrix inversion.
  - Otherwise sensitive to statistical fluctuations.

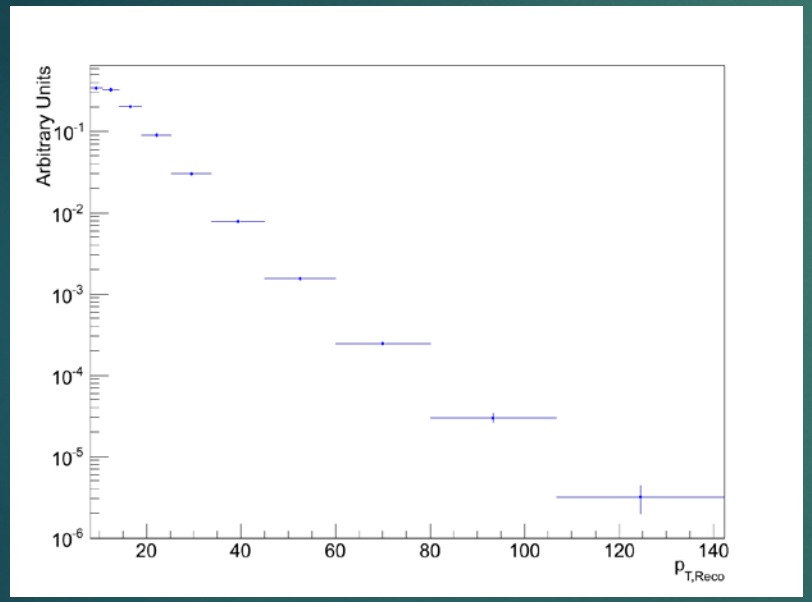
The plot gives hint of which kReg should be chosen. The value where the plot stabilizes before a large drop-off is chosen. Don't want to choose too high of a kReg to avoid sensitivity to statistical fluctuations.

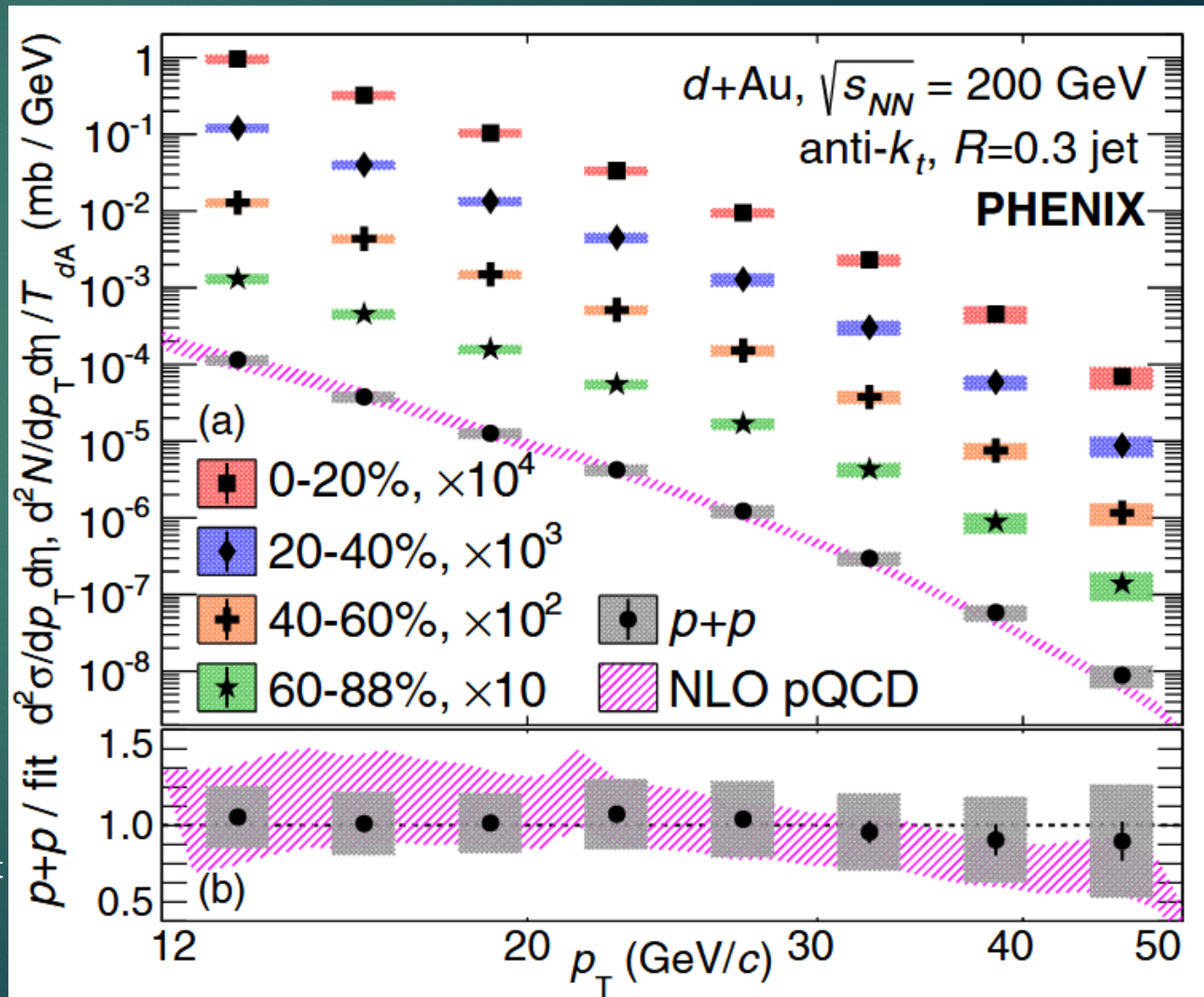


Jets at PHENIX

10.1103/PhysRevLett.116.122301

- Jet unfolding procedure follows previous PHENIX jet analyses.

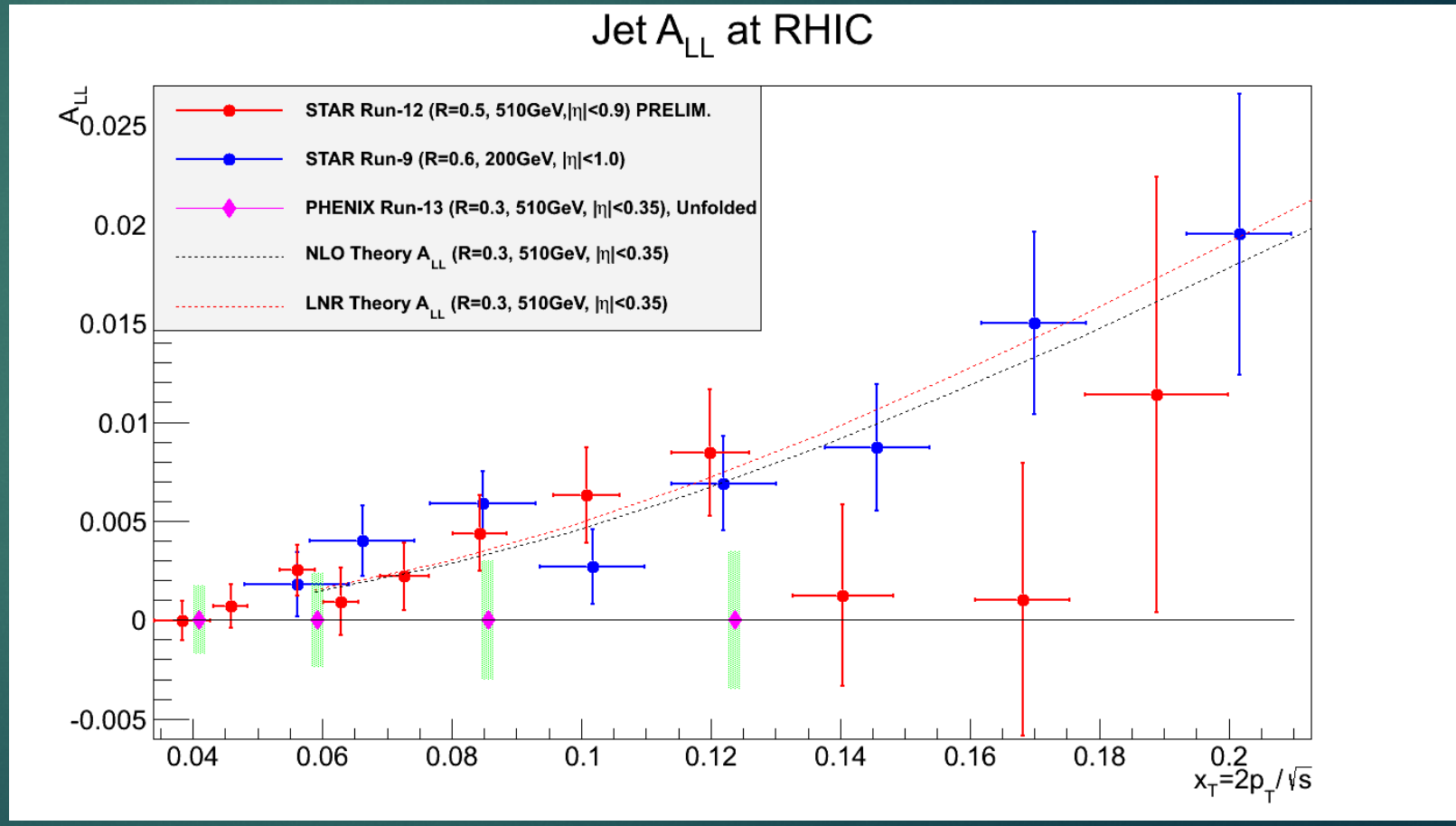




(a) Measured anti-kt, R = 0.3 jet yields in d+Au at different centralities.
(b) p+p data and perturbative QCD calculation are dividided by a fit to the data.

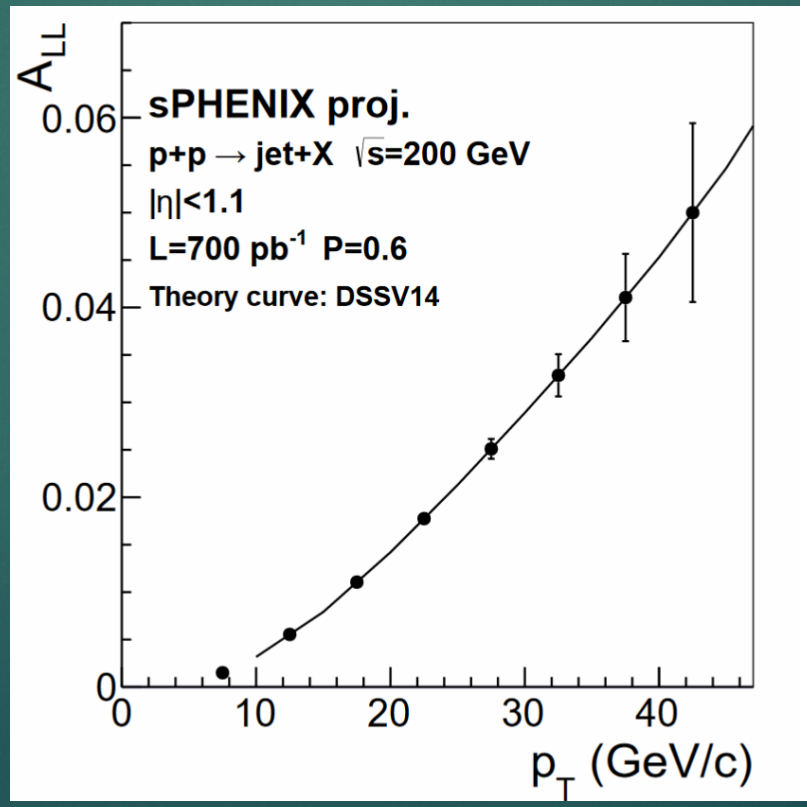
Analysis Status

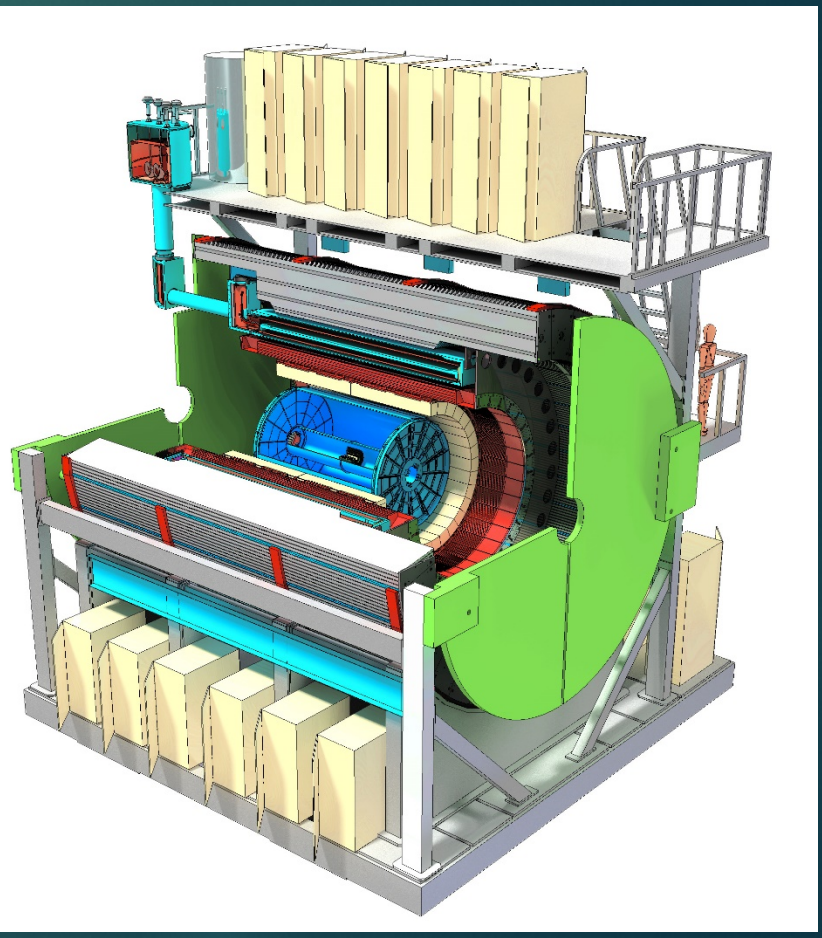
- Currently working on understand systematics.
- Hoping to publish results this summer.
  - Provide PHENIX Jet A_{LL} for global fits to better constrain Δg.



Future at fsPHENIX

- Upgraded fsPHENIX will be better equipped to measure jets.
  - Hadron calorimeter
  - Full azimuthal coverage
  - Covers different *x* ranges.
- WG7, April 17th, 12:40pm
  - By Itaru Nakagawa





sPH-cQCD-2017-002

Thank You!

Eta A_{LL}

- From 2005 and 2006 PHENIX data.

PhysRevD.83.032001