Jet $A_L$ in PHENIX $p+p$

$\sqrt{s}=510$ GeV

MILAP PATEL
DIS 2018
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 $\Delta G$, the gluon spin contribution.
- The $\Delta g(x)$ is found via the longitudinal double spin asymmetry, $A_{LL}$:

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

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

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

$\Delta f(f)$ and $\Delta \sigma(\sigma)$ are the polarized (unpolarized) parton distribution functions.
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 ($\phi$) 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.
Current Understanding

- RHIC experiments PHENIX and STAR have measured $A_{LL}$ and provide constraint on $\Delta g$.
  - 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 $\Delta g$ in global analysis.
  - Jets probe higher $x$ region dominated by STAR, but PHENIX can contribute.
- Current gluon contribution constraint is:

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


PHENIX = Pioneering High Energy Nuclear Interaction eXperiment
STAR = Solenoidal Tracker at RHIC

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 $\sqrt{s} = 200 \text{ GeV}$ is $0.05 \leq x \leq 0.2$. 
**PHENIX** $A_{UL}$

- **PHENIX** $\pi^0$ asymmetry measurement for $\sqrt{s} = 510$ GeV and 200 GeV
  - Low $x$ region down to $\sim 0.01$ in 510 GeV
- **Other** PHENIX analyses at $\sqrt{s} = 510$ GeV:
  - Charged pion $A_{UL}$
  - Direct photon $A_{UL}$
  - MPC $\pi^0 A_{UL}$ (forward measurement, $x \sim 10^{-3}$)
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 \( \Delta g \) and \( \Delta q \) are terms which would be in the \( A_{LL} \Delta f_{A,B} \) (shown earlier).

Collimated particles are reconstructed as tracks and clusters in detectors.
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:

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

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

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

$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$
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 $p_{T,\text{True}}$ vs. $p_{T,\text{Reco}}$ 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.
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 divided by a fit to the data.
Analysis Status

- Currently working on understanding systematics.
- Hoping to publish results this summer.
  - Provide PHENIX Jet $A_{LL}$ for global fits to better constrain $\Delta g$. 
Future at fsPHENIX

- Upgraded fsPHENIX will be better equipped to measure jets.
  - Hadron calorimeter
  - Full azimuthal coverage
  - Covers different $x$ ranges.

- WG 7, April 17th, 12:40pm
- By Itaru Nakagawa
Thank You!
From 2005 and 2006 PHENIX data.