Measurement of Double Helicity Asymmetry in Multi-particle Productions at PHENIX

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Introduction

- Nucleon spin problem (EMC 1988), gluon polarization in the proton Δg

$$\frac{1}{2}_{\text{proton}} = \frac{1}{2}\sum_q \Delta q + \Delta g + L_{q,g}$$

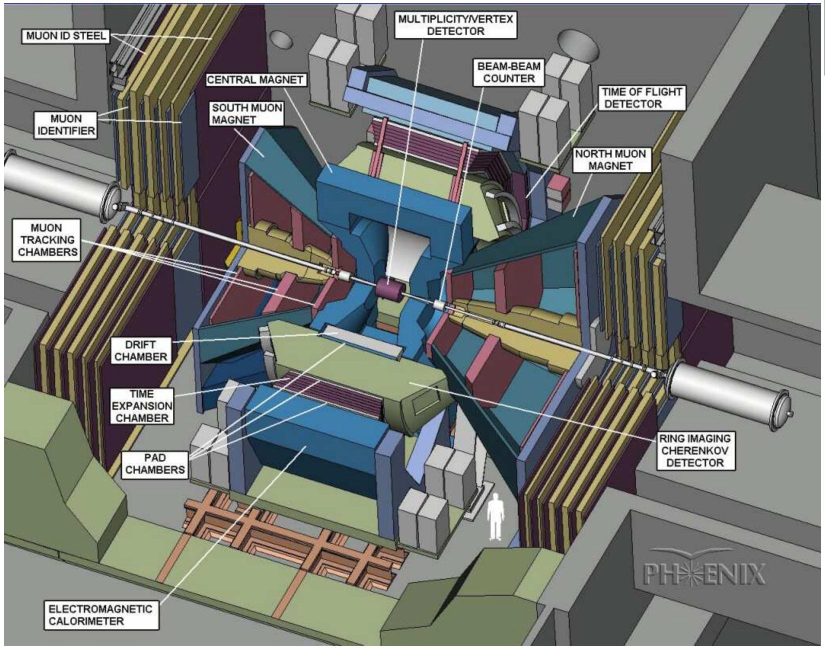
  - reactions accessible to Δg in p+p collision ... jet, inclusive π^0, direct γ, etc.
- Double helicity asymmetry (A_{LL}) in jet production

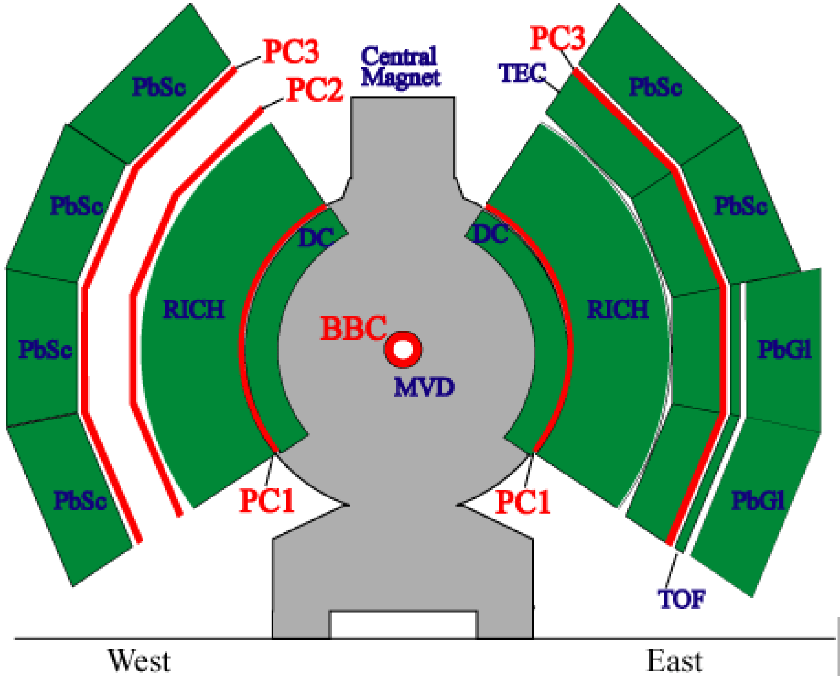
$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y}\frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \quad , \quad R \equiv \frac{L_{++}}{L_{+-}}$$

  - A_{LL} has information on Δg
    - g+g and q+g reactions are dominant in mid-p_T jet production
    - for gg –> gg reaction, $A_{LL}^{gg\to gg} = \int dx_1 dx_2 \frac{\Delta g(x_1)}{g(x_1)} \cdot \frac{\Delta g(x_2)}{g(x_2)} \cdot \hat{a}_{LL}^{gg\to gg}$
- Measurement of multi-particle as a part of jet with PHENIX Central Arm ($\Delta\phi$ = 90^o x 2, $|\eta| < 0.35$)

Experimental Setup – PHENIX@RHIC

- Longitudinally polarized proton-proton collision at $\sqrt{s}$ = 200 GeV at RHIC
  - Run 2005, L = 2.2 pb^{-1}, P = 46%
- PHENIX Central Arms: $\Delta\phi = 90^{o} \times 2$, $|\eta| < 0.35$
- Event selection
  - p_T(photon) > 2 GeV/c (offline trigger)
- Particle selection
  - photon: detected with PbGl & PbSc EMCal
    - $p_T > 0.4$ GeV/c
    - elemag shower shape cut
    - veto of charged particle
  - charged particle: detected with Drift Chamber & Pad Chamber 1
    - $0.4 < p_T < 4.0$ GeV/c
    - track quality cut

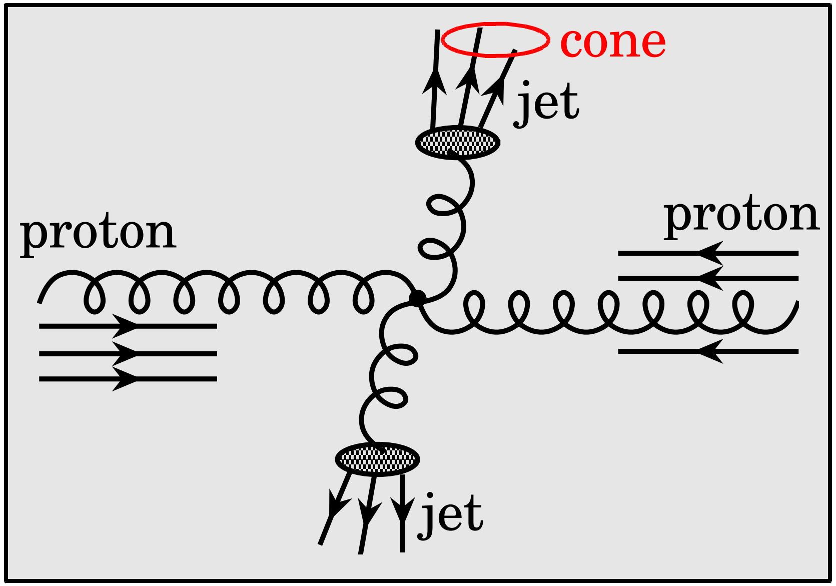




Methods of Multi-particle Measurement

- Particle clustering with cone
  - photons (p_T > 0.4 GeV/c) and charged particles (0.4 < p_T < 4.0 GeV/c) with offline high-p_T (> 2.0 GeV/c) photon trigger
  - make cones by using all particles as seed
    - cone radius $R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.3$
    - cone momentum = vector sum of mementa of particles in the cone
    - cone axis = direction of cone momentum (dir. of seed particle at first)
    - iterate above until cone axis becomes stable
  - use cone with highest p_T^{cone} in each event

$$p_T^{\text{cone}} \equiv \left| \sum_{i \text{ in cone}} \vec{p}_{Ti} \right|$$



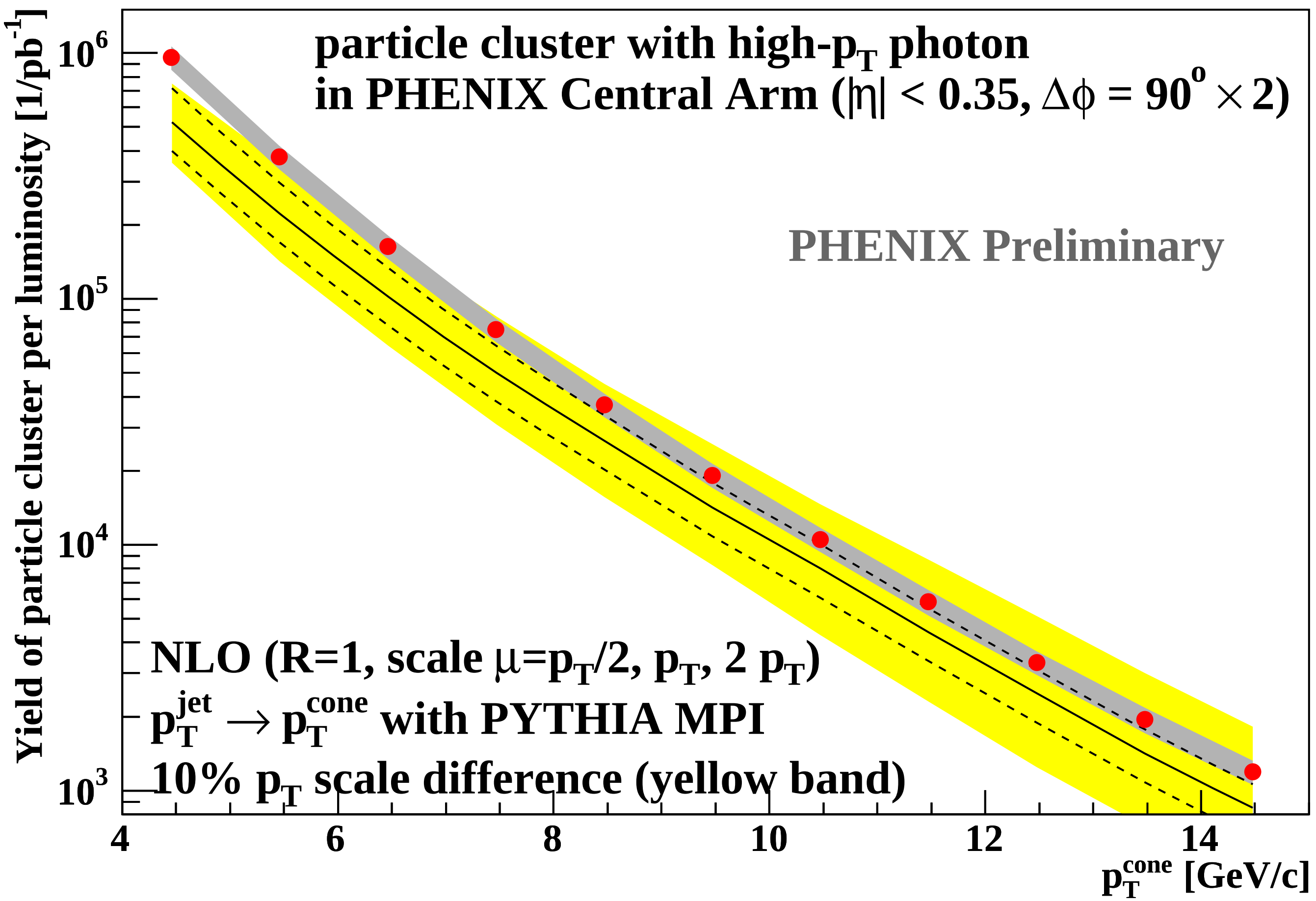
Results – Yield of Particle Cluster per Lumi.

- Purpose: evaluate p_T scale uncertainty on A_{LL} measurement
  - originate from the difference in p_T definition between measurement and theory calculation
  - normally there exists >10% p_T scale uncertainty (one reason: change in theoretical cone size causes ~10% p_T variation)
  - confirm this uncertainty by evaluating a kind of cross section
- Real data

$$y^{icone} \equiv \frac{C_{\mathrm{corr}}}{f_{\mathrm{BBC}}} \cdot \frac{N^{icone}_{\mathrm{cone+ph}}}{L}$$

  - $C_{\mathrm{corr}} / f_{\mathrm{BBC}}$ … correction factor for the yield loss due to trigger efficiencies (high-p_T photon trigger & BBC trigger)
  - $N_{\mathrm{cone+ph}}$ … yield of cone+high-p_T-photon events
  - L … luminosity (2.2 pb^{-1})
- Jet cross section by NLO theory calculation was converted into y^{icone} by using PYTHIA MPI (Multi-Parton Interaction tune) and GEANT simulations

Results – Yield of Particle Cluster per Lumi.



main systematic errors on real data	
luminosity	10%
EMCal ene. scale	5~6%
track mom. scale	0~3%

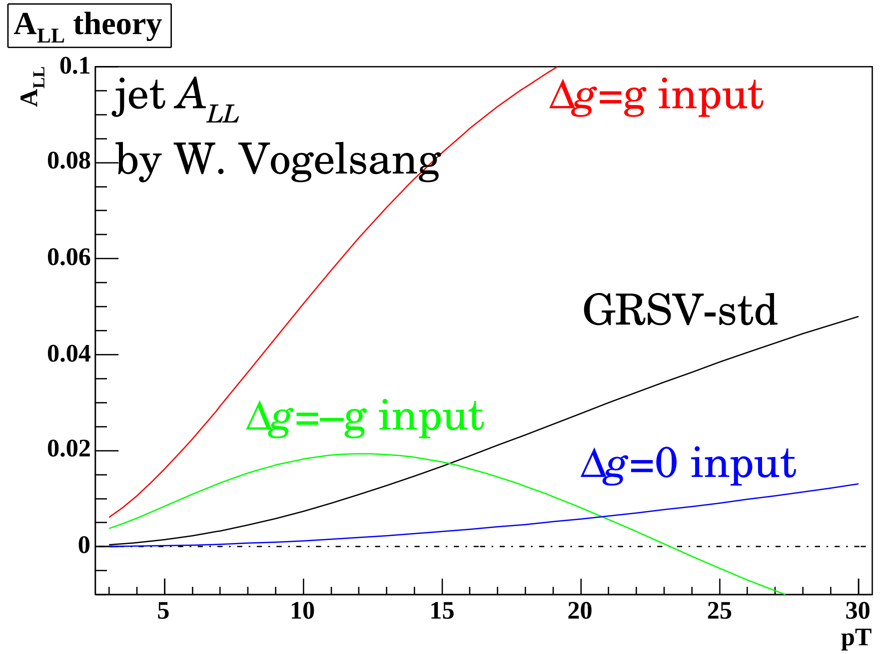
- slope by NLO+PYTHIA matches with real data over 3 orders of magnitude
- 10% p_T scale difference makes ~50% variation on yield
  - this variation covers the distance between real data and NLO+PYTHIA
- 10% p_T scale uncertainty was assigned to A_{LL} curve

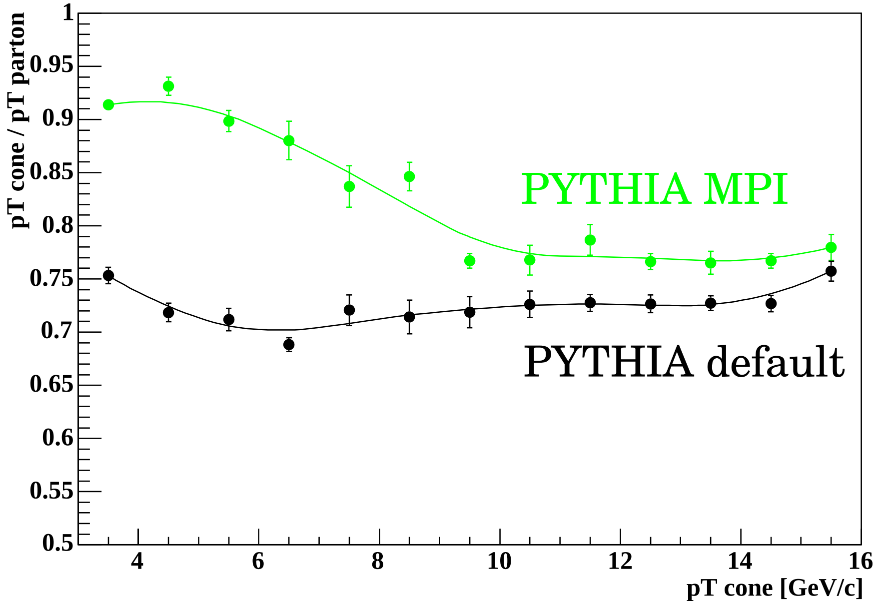
Results – Multi-particle A_{LL}

- A_{LL} was measured as a function of p_T^{cone}

$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \quad , \quad R \equiv \frac{L_{++}}{L_{+-}}$$

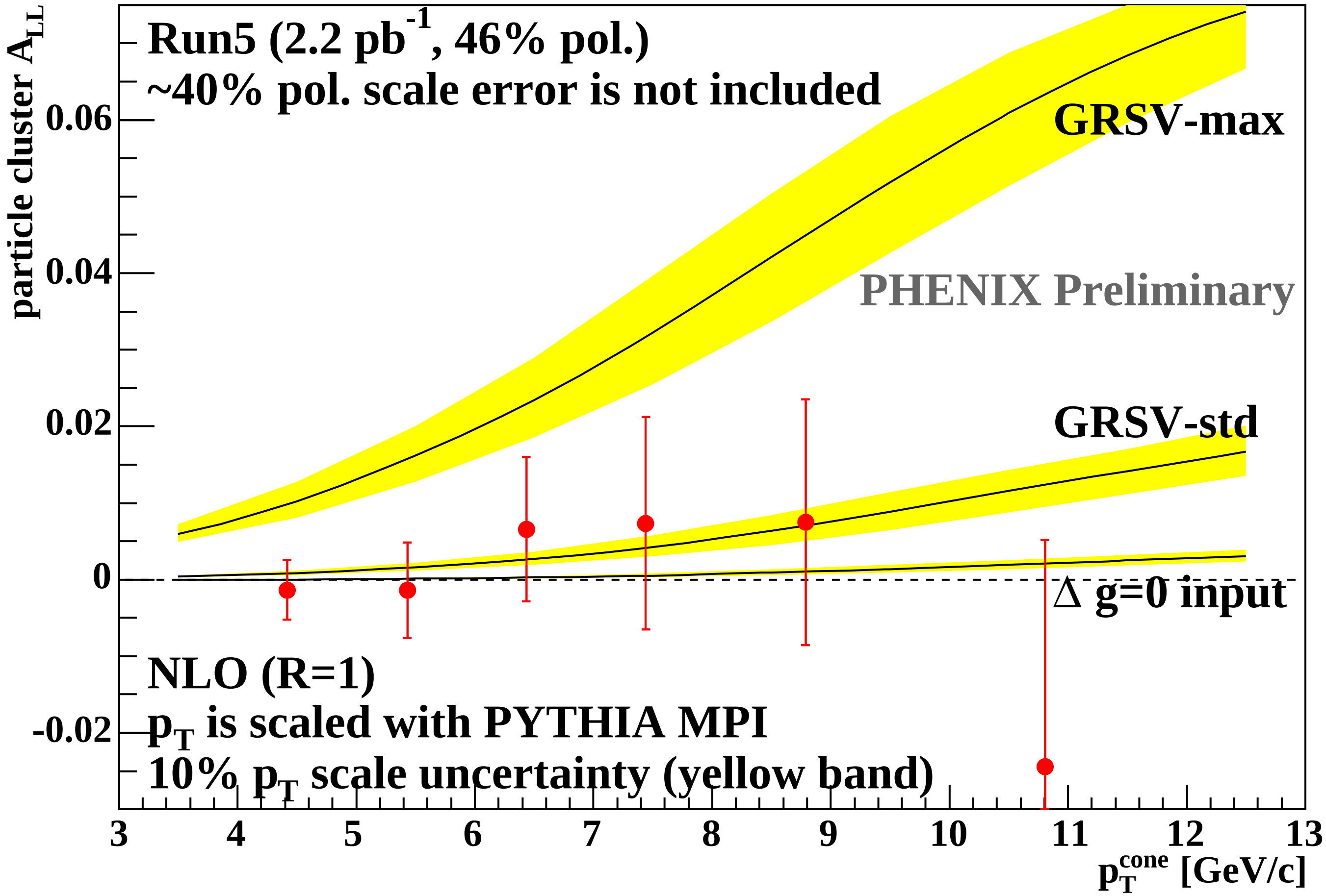
- Theory predictions
  - jet A_{LL} in PHENIX Central Arm acceptance (|η|< 0.35)
  - the ratio p_T^{cone}/p_T^{jet} was evaluated with PYTHIA MPI + GEANT simulations
  - p_T^{jet} in theory calculation was scaled to p_T^{cone} by ratios estimated with PYTHIA+GEANT





Results – Multi-particle A_{LL}

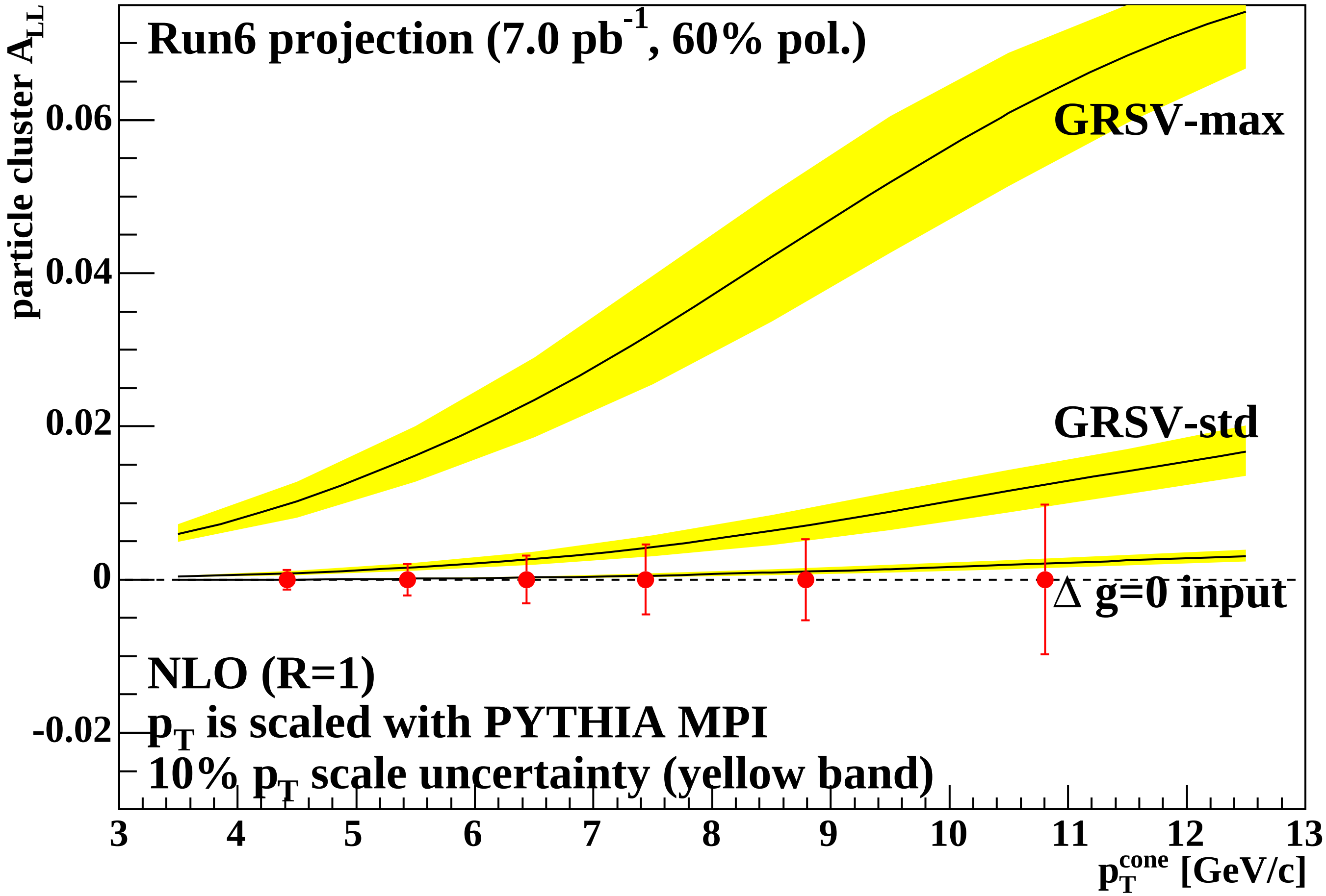
- PHENIX Run5pp (L = 2.2 pb^{-1}, P = 46%) result



- GRSV-max was excluded (zero C.L.) with this result
- GRSV-std and Δg=0 input have a similar C.L.

Results – Multi-particle A_{LL}

- PHENIX Run6pp (L = 7.0 pb^{-1}, P = 60%) projection



- statistical error will reach the size of GRSV-std

Conclusion

- Nucleon spin problem (EMC 1988), gluon polarization in the proton Δg
- Longitudinally polarized proton-proton collisions at $\sqrt{s}$ = 200 GeV at RHIC
  - Run 2005, L = 2.2 pb^{-1}, P = 46%
- Multi-particle measurement as a part of jet with PHENIX Central Arm
  - photons and charged particles with high-p_T photon
  - particle clustering with cone method
- Multi-particle A_{LL} has been measured
  - 10% p_T scale uncertainty
  - theory predictions scaled from p_T^{jet} to p_T^{cone} with PYTHIA MPI
  - GRSV-max was excluded, GRSV-std and Δg=0 input have a similar C.L.
  - statistical error with Run6 data will reach the size of GRSV-std

Backup...

Yield of Particle Cluster per Lumi.

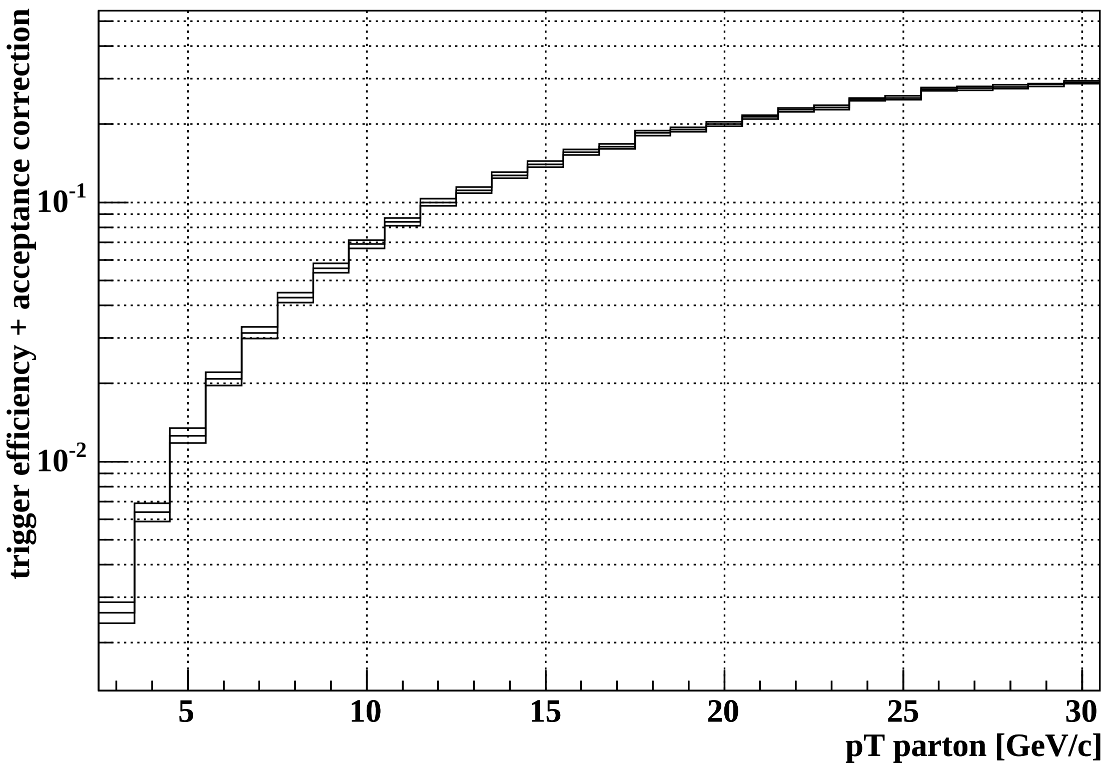
- Real data
$$\mathcal{Y}^{icone} \equiv \frac{C_{\mathrm{corr}}}{f_{\mathrm{BBC}}} \cdot \frac{N^{icone}_{\mathrm{cone+ph}}}{L}$$
  - $C_{\mathrm{corr}} / f_{\mathrm{BBC}}$... correction factor for the yield loss due to trigger efficiencies (high-p_T photon trigger & BBC trigger)
  - $N_{\mathrm{cone+ph}}$ ... yield of cone+high-p_T-photon events
  - L ... luminosity (2.2 pb^{-1})
- NLO theory + PYTHIA
$$\mathcal{Y}^{icone} = \sum_{ijet} f^{icone}_{ijet} \cdot \epsilon^{ijet}_{\mathrm{trig+acc}} \cdot N^{ijet}_{\mathrm{theo}}$$
  - PYTHIA with Multi-Parton Interaction (MPI) tune
    - PYTHIA MPI agrees with real data in terms of event shape (thrust in PHENIX Central Arm, particle multiplicity, and p_T density in $\Delta\phi$)
  - N_{theo}^{ijet} ... jet yield per luminosity calculated from NLO jet cross section
  - $\varepsilon_{\mathrm{trig+acc}}^{ijet}$ ... the prob. that a trigger photon exists + jet acceptance corr.
  - f_{ijet}^{icone} ... the prob. that an event with p_T^{jet} in *ijet* bin makes p_T^{cone} in *icone* bin

Yield of Particle Cluster per Lumi.

- $\varepsilon_{trig+acc}^{ijet}$ in NLO+PYTHIA calculation ... the prob. that a trigger photon exists + jet acceptance corr.

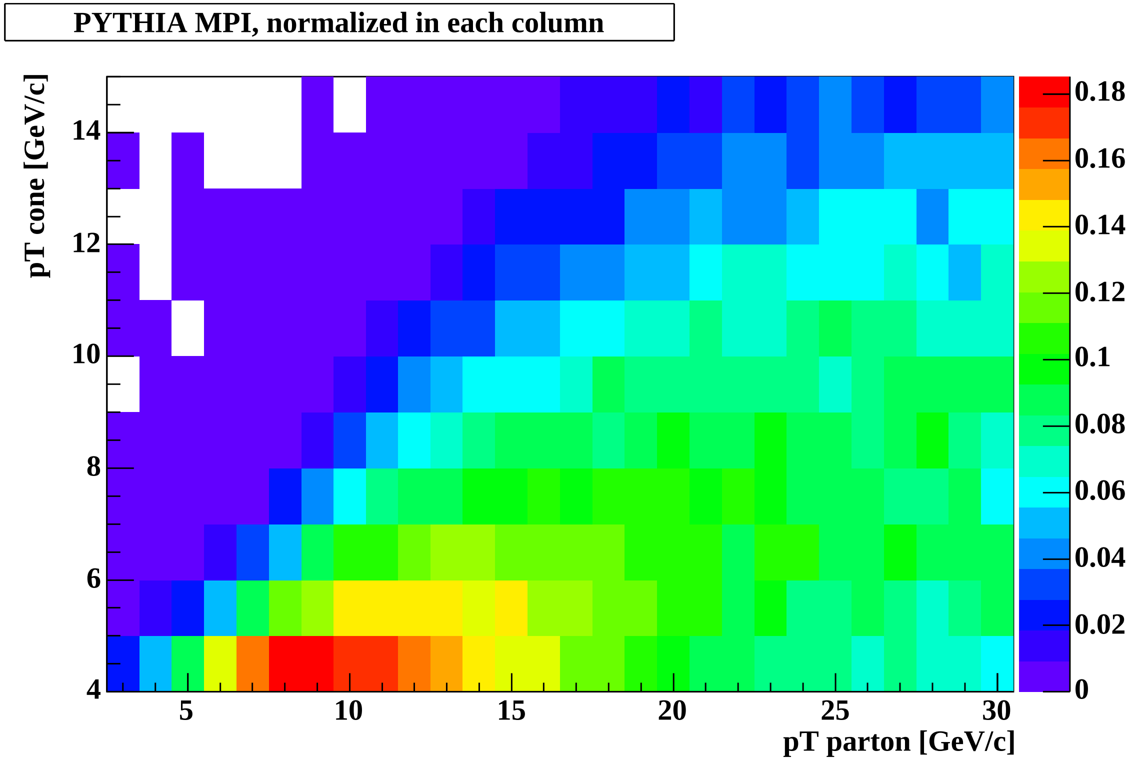
$$\epsilon = \frac{p_T^{\rm ph} > 2.0 \ \&\& \ \{\eta_{\rm ph} \text{ and } \phi_{\rm ph} \text{ in EMCal acceptance}\}}{|\eta_{\rm jet}| < 0.35}$$

  - EMCal acceptance ... $\Delta\eta$ = 0.7 and $\Delta\phi^{sector}$ = 0.34 for PbSc and 0.32 for PbGl (two towers from sector edges were not included)
  - it was estimated with PYTHIA MPI



Yield of Particle Cluster per Lumi.

- f_{ijet}^{icone} in NLO+PYTHIA calculation … the prob. that an event with p_T^{jet} in *ijet* bin makes p_T^{cone} in *icone* bin
  - it was estimated with PYTHIA MPI + PISA



  - this p_T^{jet} –> p_T^{cone} folding used a range of $2.5 < p_T^{jet} < 30.5$ GeV/c, where N_{theo} was available. The contributions from the outside of the p_T^{jet} range to each p_T^{cone} bin was not included. According to PYTHIA, it was 6% at the lowest p_T^{cone} bin (from $p_T^{jet} < 2.5$) and 4% at the highest p_T^{cone} bin (from $p_T^{jet} > 30.5$).

Simulation Condition

- PYTHIA event generator ... same as Run3 analysis
  - version 6.220
  - proton-proton collision at √s = 200 GeV
  - high-p_T QCD process (MSEL=1)
  - CTEQ5L PDF
  - p_T > 1.5 GeV/c (CKIN(3))
  - two PYTHIA settings
    - "PYTHIA default" ... PYTHIA ver. 6.220 default
    - "PYTHIA MPI" ... Multi-Parton-Interaction-tuned setting
      - Rick Field Tune A ... tuned with CDF Run2 data
      - MPI setting is adopted as default from ver. 6.226

- PISA detector simulator
  - Run5pp settings
  - the event and particle selections same as real data

Trigger Bias for Fraction of Subprocesses

- Trigger bias effect is evaluated with PYTHIA as the modification of subprocess fractions (*qq*, *qg*, *gg*)
  - *gg* subprocess are suppressed by trigger photon requirement at low p_T