ΔG from high p_T events at COMPASS

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COMPASS experiment

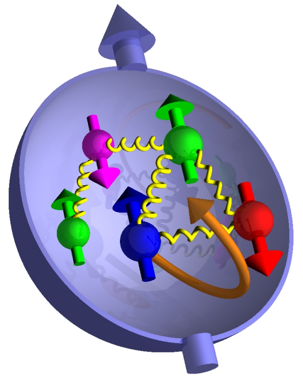
COmmon Muon and Proton Apparatus for Structure and Spectroscopy

Nucleon spin

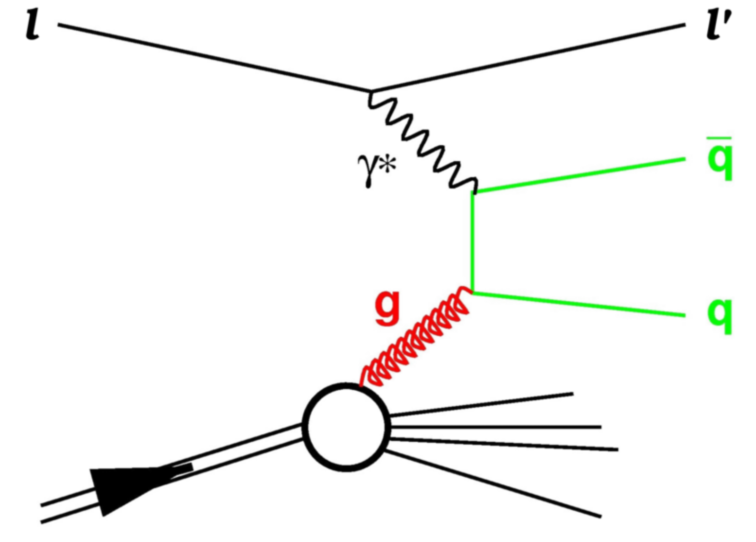
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

"Spin Crisis"

- Only a small fraction of nucleon spin is carried by quarks
  $\Delta\Sigma = 0.30 \pm 0.01(\text{stat.}) \pm 0.02(\text{evol.})$
  (QCD NLO fits)
- How big is the contribution of gluons and orbital momentum?
- Precision of ΔG determined from QCD fits is poor.
- Answer: directly measure polarization of the gluons and orbital momentum of partons.



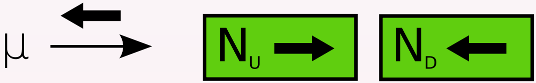
Photon Gluon Fusion - PGF



Experimental asymmetry

- Extract asymmetry (asymmetries are sensitive to small effects):

$$A_{exp} = \frac{N_U - N_D}{N_U + N_D}$$



- One cell polarized parallel and one cell polarized antiparallel to the beam.
- Both cells exposed to same beam flux.
- Spectrometer acceptance is not the same for both cells.

Experimental asymmetry

- Solution: reverse polarization every 8 hours.

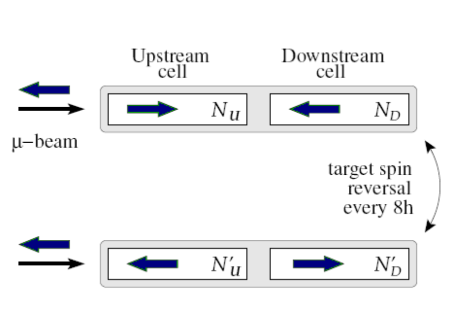
$$A_{exp} = 1/2\left(\frac{N_U - N_D}{N_U + N_D} + \frac{N'_D - N'_U}{N'_D + N'_U}\right)$$

- Experimental asymmetry is related to cross-section asymmetry:

$$A_{exp} = P_T P_B f A_{||}$$

where:

P_T - Target polarization (measured with NMR probes)
P_B - Beam polarization (parametrization)
f - dilution factor (parametrisation)



ΔG/G from PGF

$$A^{IN} \equiv A_{||} \equiv \frac{\Delta\sigma}{\sigma} \equiv \frac{\sigma^{\downarrow\Uparrow} - \sigma^{\downarrow\Downarrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\downarrow\Downarrow}}$$

- $\Delta\sigma = \Delta F \otimes \Delta\hat{\sigma} \otimes \tilde{D}$; $\sigma = F \otimes \hat{\sigma} \otimes \tilde{D}$

  ΔF, F: ΔG, Δq, G, q

  $\Delta q = \sum_f e_f^2 \left(\Delta q_f(x) + \Delta\bar{q}_f(x)\right)$

  $q = \sum_f e_f^2 \left(q_f(x) + \bar{q}_f(x)\right)$

  $\Delta\hat{\sigma}, \hat{\sigma}$ - hard process cross-sections

  $\tilde{D}$ - fragmentation functions

- $A_{||} = R_{sig} < a_{LL}^{sig} > \frac{\Delta G}{G} + R_{bg} A_{bg}$

  R_i - fraction of process "i"

  $< a_{LL} > = < \Delta\hat{\sigma}/\hat{\sigma} >$

  A_{bg} - background asymmetry

- **To minimise statistical error a weighting method is used**

  Events are weighted with $w = fDP_B$ instead of using mean values

  D - depolarisation factor of the virtual photon

$$\frac{A_{||}}{D} = -\frac{1}{2|P_t|}\left(\frac{\Sigma w_u - \Sigma w_d}{\Sigma w_u^2 + \Sigma w_d^2} - \frac{\Sigma w'_u - \Sigma w'_d}{\Sigma w'^2_u + \Sigma w'^2_d}\right)$$

$$\delta\left(\frac{A_{||}}{D}\right) = \frac{1}{2|P_t|}\sqrt{\frac{1}{\Sigma w_u^2 + \Sigma w_d^2} - \frac{1}{\Sigma w'^2_u + \Sigma w'^2_d}}$$

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- $\Delta\sigma = \Delta F \otimes \Delta\hat{\sigma} \otimes \tilde{D}$; $\sigma = F \otimes \hat{\sigma} \otimes \tilde{D}$

  $\Delta F,\ F$: $\Delta G,\ \Delta q,\ G,\ q$

  $\Delta q \quad = \sum_f e_f^2 \left(\Delta q_f(x) + \Delta\bar{q}_f(x)\right)$

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  ΔF, F: ΔG, Δq, G, q

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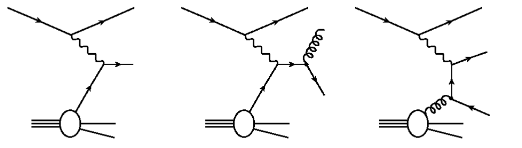
PGF selection

- Open charm production
  - $c\bar{c}$ production
  - hard scale set by $4m_c^2$
  - no background asymmetry
  - limited statistics
- 2 high p_T hadrons ($Q^2 > 1\text{GeV}^2$)
  - hard scale set by Q^2
  - large statistics
  - contamination by other processes
- 2 high p_T hadrons ($Q^2 < 1\text{GeV}^2$)
  - hard scale set by p_T
  - very large statistics
  - contamination by other processes (resolved photon not negligible)

High p_T background processes

Contributing diagrams ($Q^2 > 1\text{GeV}^2$)



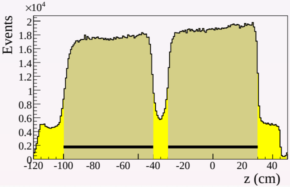
LP | QCDC | PGF
Leading Process | QCD Compton | Photon Gluon Fusion

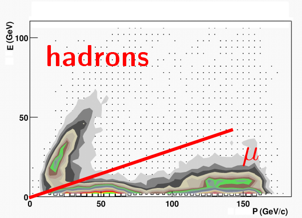
- For Leading Process struck quark goes along photon direction
- p_T of hadron in the final state is small
- Non zero p_T can originate from fragmentation or intrinsic p_T of quark
- Selection of events with high p_T suppresses Leading Process

High p_T selection

Event selection:

- Primary vertex is reconstructed within target volume.
- Extrapolated beam track goes through both target cells.
- Hadron identification
    - For hadron candidates that have an energy measurement in calorimeter: $E_{cal}/p > 0.3$
    - Hadron candidates don't have associated clusters behind muon filters

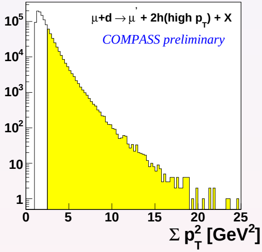


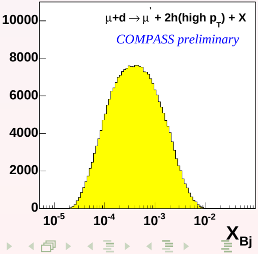


High p_T selection

Kinematic cuts:

- Enhance PGF contribution also ensure factorisation for $Q^2 < 1 \text{ GeV}^2$sample:
  - $p_T > 0.7$ GeV (for both hadrons)
  - $\Sigma p_T^2 > 2.5$ GeV^2
- $0.1 < y$: $Q^2 > 1 \text{ GeV}^2$
  $0.35 < y$: $Q^2 < 1 \text{ GeV}^2$
  - suppress region with low contribution to $\Delta G/G$
- $y < 0.9$ - suppress region with large radiative corrections
- $x_F, z > 0.1$: current fragmentation region
- $m(h_1, h_2) > 1.5$ GeV : remove ρ resonance

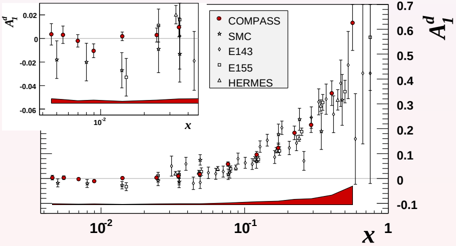




High p_T ($Q^2 > 1$ GeV^2): $\Delta G/G$ extraction

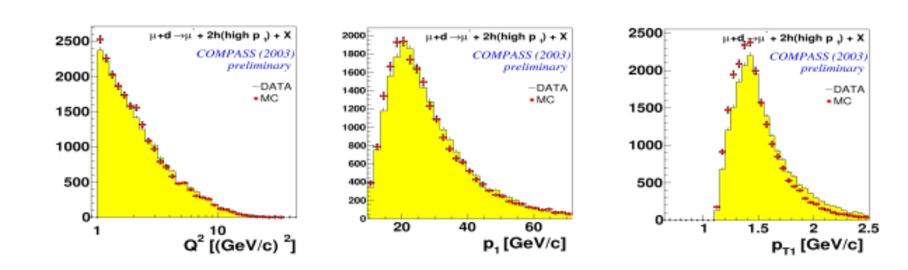
$$\frac{A_{||}}{D} = A_1 \left(\left\langle \frac{a_{LL}^{LP}}{D} \right\rangle R_{LP} + \left\langle \frac{a_{LL}^{QCDC}}{D} \right\rangle R_{QCDC} \right) + \frac{\Delta G}{G} \left\langle \frac{a_{LL}^{PGF}}{D} \right\rangle R_{PGF}$$

- For region x < 0.05 A_1 is small - we can neglect contribution from LP and QCDC (included in systematic error)
- R_{PGF} - fraction of PGF events - determined from MC simulations



High p_T ($Q^2 > 1$ GeV^2): Monte Carlo

- Monte Carlo generator: LEPTO
- Reasonable agreement with data



High p_T ($Q^2 > 1$ GeV^2): result

- Result based on data collected in 2002-2003:

$$\frac{\Delta G}{G} = 0.06 \pm 0.31(stat.) \pm 0.06(syst.)$$

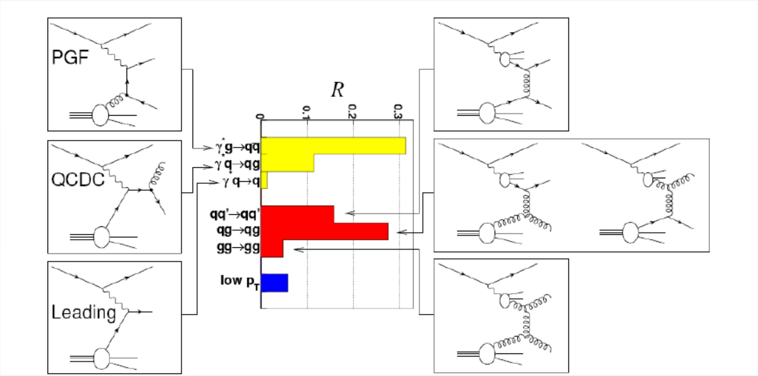
$$R_{PGF} = 0.34 \pm 0.7$$

$$< x_g >= 0.13$$

- Analysis of 2004 and 2006 data ongoing.
- We are working on methods to improve sample selection.

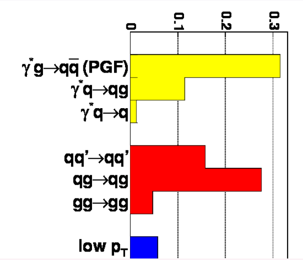
High p_T ($Q^2 < 1$ GeV^2): additional processes

Direct processes	Resolved Photon processes



High p_T ($Q^2 < 1$ GeV^2): additional processes

$$
\begin{aligned}
A_{||}/D &= R_{PGF}\left\langle \frac{a_{LL}^{PGF}}{D}\right\rangle \frac{\Delta G}{G} \\
&+ R_{QCDC}\left\langle \frac{a_{LL}^{QCDC}}{D}\right\rangle A_1 \\
&+ R_{qq}\left\langle \frac{a_{LL}^{qq}}{D}\right\rangle \frac{\Delta q}{q}\frac{\Delta q^{\gamma}}{q^{\gamma}} \\
&+ R_{qg}\left\langle \frac{a_{LL}^{qg}}{D}\right\rangle \frac{\Delta q}{q}\frac{\Delta G^{\gamma}}{G^{\gamma}} \\
&+ R_{gq}\left\langle \frac{q}{D}\right\rangle \frac{\Delta G}{G}\frac{\Delta q^{\gamma}}{q^{\gamma}} \\
&+ R_{gg}\left\langle \frac{a_{LL}^{gg}}{D}\right\rangle \frac{\Delta G}{G}\frac{\Delta G^{\gamma}}{G^{\gamma}}
\end{aligned}
$$



- R_i - process fraction (MC).
- a_i - hard process asymmetry (QCD).
- A_1, q, Δq - parton distributions in the nucleon (parametrisation).
- q^{γ}, G^{γ} - unpolarised PDFs in photon (parametrisation).
- Δq^{γ}, ΔG^{γ} - polarised PDFs in photon (min-max scenario).

High p_T ($Q^2 < 1$ GeV^2): Parametrisations

- A_1 - parametrisation based on the E143 and SMC data.
- q, Δq - parametrisations GRV98LO and GRSV2000 respectively.
- q^γ, G^γ - parametrisation by *Glück, Reya, and Schienbein* [Phys. Rev. **D60**, 054019]
- Δq^γ, ΔG^γ- can be decomposed into two terms:

$$\Delta f^\gamma = \Delta f^\gamma_{VMD} + \Delta f^\gamma_{pl}$$

Δf^γ_{pl} - photon fluctuates into $q\bar{q}$ pair
- term calculable in QCD + QED

Δf^γ_{VMD} - photon fluctuates into a vector meson
- this term is non perturbative.

We can only estimate it via max-min scenarios:

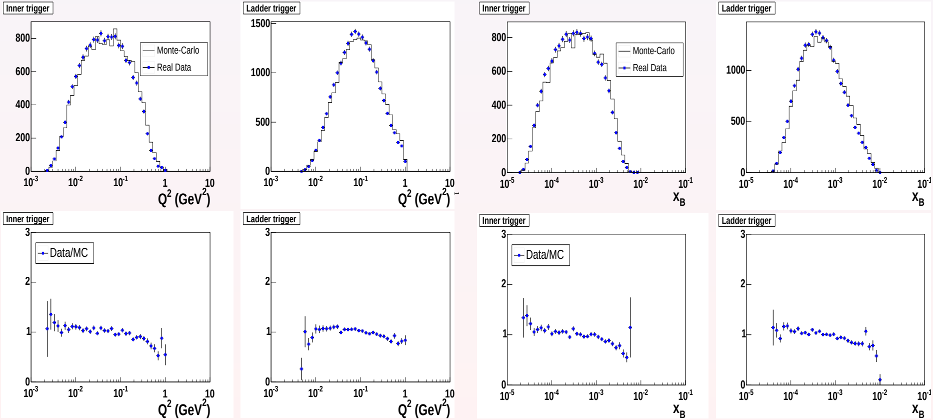
$-f^\gamma_{VMD} < \Delta f^\gamma_{VMD} < f^\gamma_{VMD}$

Unpolarised distribution are constrained by data.

[Ref: *Glück, Reya, and Sieg*, Eur. Phys. J. **C20**, 271-281]

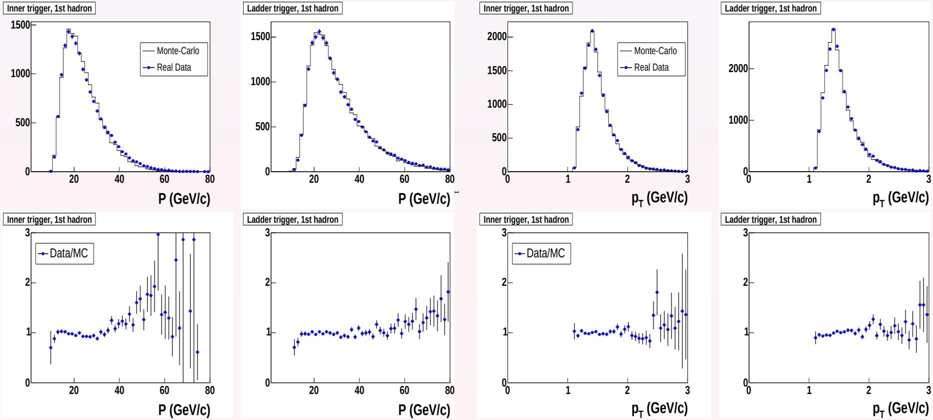
High p_T ($Q^2 < 1$ GeV^2): Monte Carlo

Monte Carlo generator: PYTHIA (GRV98LO)
Agreement between Real Data (blue points) and Monte Carlo



High p_T ($Q^2 < 1$ GeV^2): Monte Carlo (*cont'd*)

Intrinsic k_T^γ in the resolved photon was tuned to obtain agreement in p and p_T for both leading and second hadrons.



High p_T ($Q^2 < 1$ GeV^2): systematics

Main contributions to systematic errors

- False asymmetries (experimental systematics): 0.014
- Resolved photon contribution (min - max scenario): 0.013
- Monte Carlo: 0.052

- False Asymmetries (FA) can be decomposed into:
  - Reproducible FA - appears if properties of the apparatus depend on the sign of solenoid filed.
    - Almost completely cancelled out thanks to two MW settings:
    $A_{rep} = \frac{1}{2}(A_+ - A_-)$; $A_R = A_{rep} \times \frac{(\delta A_-)^2 - (\delta A_+)^2}{(\delta A_-)^2 + (\delta A_+)^2}$
  - Random FA - originate from random fluctuation. Estimated using "pulls" method on large number of data groups, after correction for A_{rep}.
  - Systematic FA - eg. efficiency of a detector degrades in time. Constant on-line monitoring during data taking. Can be decomposed into A_{rep} and A_{rand} parts.

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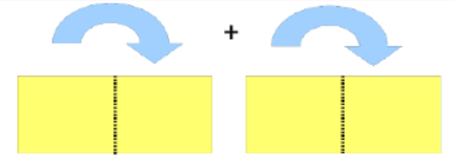
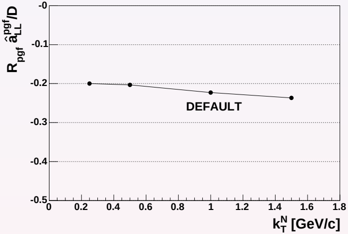
High p_T ($Q^2 < 1$ GeV^2): systematics

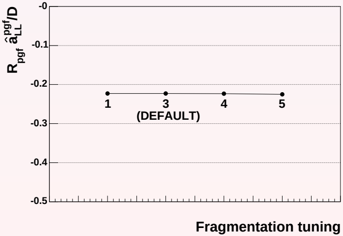
- False asymmetries (*cont'd*)
  - Studied on low p_T sample: $\sim 250\otimes$ more statistics
  - Considered scenarios:
    - Microwave setting "+" vs "-"
    - Upper vs Lower part of spectrometer
    - Left vs Right part of the spectrometer
    - Asymmetries within one target cell

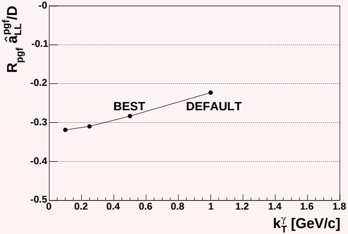


High p_T $(Q^2 < 1\ \mathrm{GeV}^2)$: MC systematics

- MC parameters were varied in a range with reasonable Data/MC agreement:
  - parton fragmentation
  - k_T of partons in nucleon and in photon
  - renormalisation and factorisation scales
  - parton showers

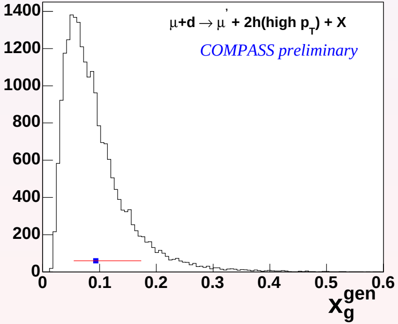






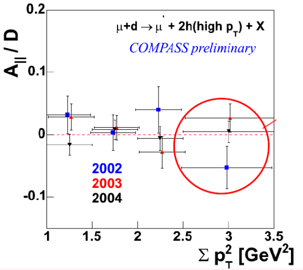
High p_T ($Q^2 < 1$ GeV^2): estimation of x_g

- x_g estimated using MC.
- Each process probes $\Delta G/G$ at different x_g.
- Contributions from processes are weighted by sensitivity to $\Delta G/G$.



$$x_g \approx 0.085^{+0.071}_{-0.035} \text{ (RMS 0.8)}$$

High p_T ($Q^2 < 1$ GeV^2): result



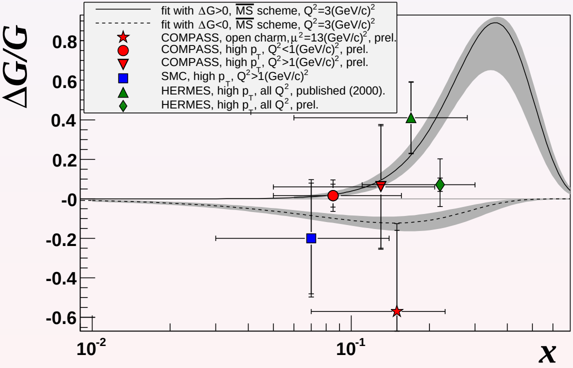
- 2002-2003 data (PLB 633 (2006) 25-32)
  $\frac{\Delta G}{G} = 0.024 \pm 0.089(stat.) \pm 0.057(syst.)$
- 2004 data:
  $\frac{\Delta G}{G} = 0.015 \pm 0.077(stat.) \pm 0.056(syst.)$

- Preliminary result based on 2002-2004 data:

$$\frac{\Delta G}{G} = 0.016 \pm 0.058(stat.) \pm 0.055(syst.)$$

- $x_g \approx 0.085^{+0.071}_{-0.035}$ (RMS 0.8)
- Scale 3GeV^2

$\Delta G/G$



QCD fits:

- Lines obtained from NLO QCD fits including a new COMPASS deuteron results on g_1^d (PLB 647 (2007) 8-17).
- Two equally good solutions for $\Delta G/G$ were found. For both $|\Delta G| = 0.2 - 0.3$.

Prospects

- 2006 and 2007 data to be analysed
- Increased statistics in 2006 and 2007 due to new COMPASS magnet
- 2004 data for High p_T ($Q^2 > 1$ GeV^2) sample is being analysed
- Usage of neural networks is studied as a tool for selecting PGF events

Summary

- Recent results of $\Delta G/G$ from COMPASS were presented
- Present measurements indicate that $\Delta G/G$ is consistent with zero at $x_g \approx 0.1$
- We are working on further analysis and hope to show new results with even better precision in near future
- Measurement of orbital momentum of partons in nucleon is needed to solve "nucleon spin puzzle"