Double Spin Asymmetry of Single Electron Production on Proton-Proton Collisions

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2012/ 2/ 13

Kyoto University GCOE Symposium

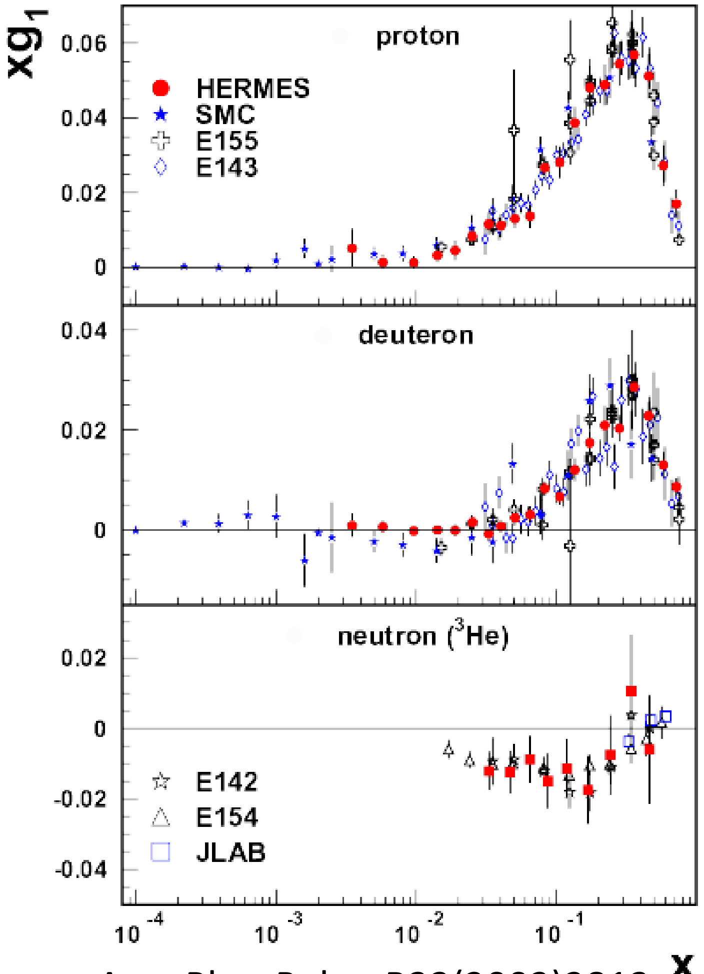
Internal Structure of a Nucleon

- **Internal structure of a nucleon ～parton model ～**
  - discovery of Bjorken scaling law
    - establishment of the parton model
    - Bjorken x : the momentum fraction of parton
  - total momentum fractions for each parton
    - $U : D : g \sim 36\% : 18\% : 46\%$
- **proton spin puzzle**

$$\underbrace{1/2}_{\text{proton spin}} = \underbrace{1/2\,\Delta\Sigma}_{\text{quark spin}} + \underbrace{\Delta G}_{\text{gluon spin}} + \underbrace{L}_{\text{orbital}}$$

  - Deeply Inelastic Scattering (DIS) experiment
  - $\Delta\Sigma \sim 25\%$!?
- ***Large contribution from gluon polarization ?***

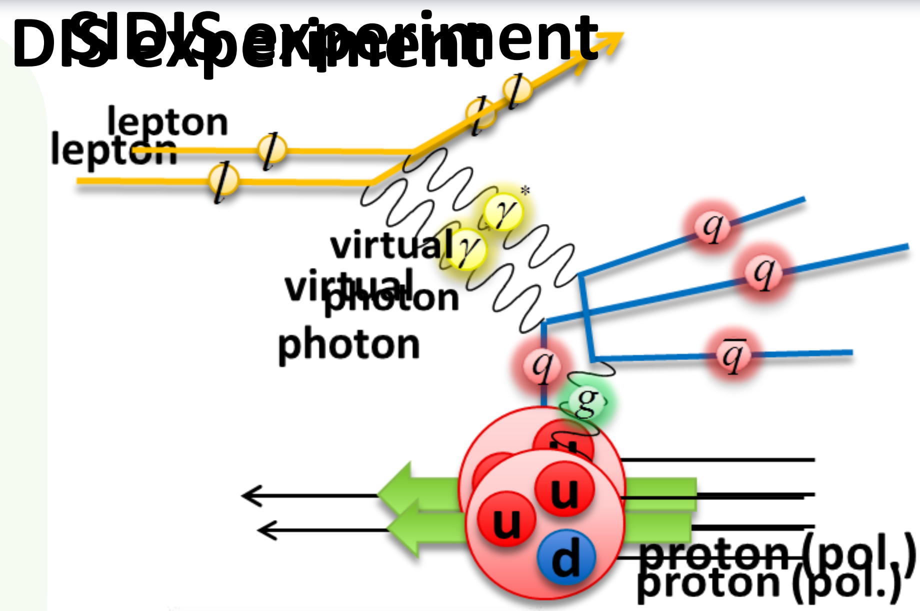
$$g_1(x) = \frac{1}{2}\sum e_q{}^2 \Delta q(x)$$

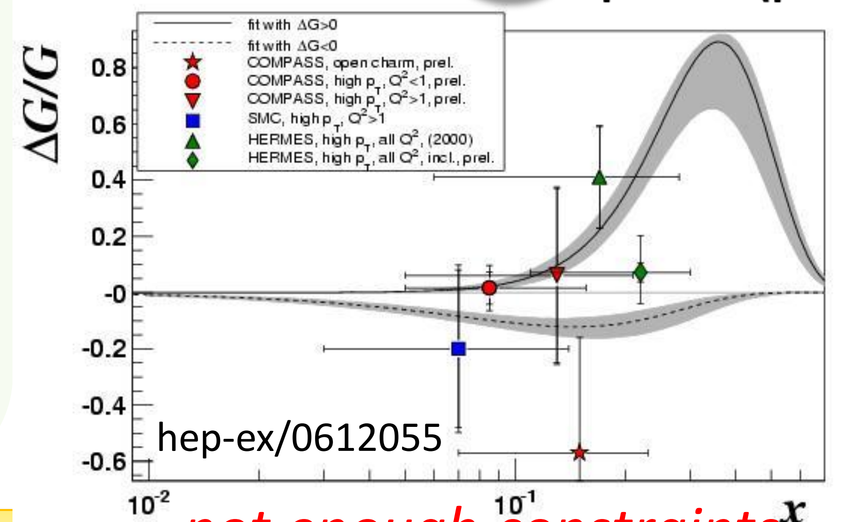


Acta.Phys.Polon.B33(2002)2813

Gluon Polarization Measurement

- **DIS experiment**
  - lepton-nucleon scattering
  - cannot access to gluon in leading order
- **semi-inclusive DIS experiment**
  - next leading order
    - high p_T hadron pair measurement
    - open charm measurement
- **difficult to constraint on ΔG effectively**





not enough constraints

Current Status of Gluon Polarization Measurement

- **Polarized p-p collision experiment**
  - direct contribution from gluon
  - π^0 measurement provides the largest constraint on ΔG
- **Weak points of the π^0 measurement**
  - large uncertainty of fragmentation functions
  - dependence on function form of Δg modeling
- ***further multiple measurements with various channels are required***

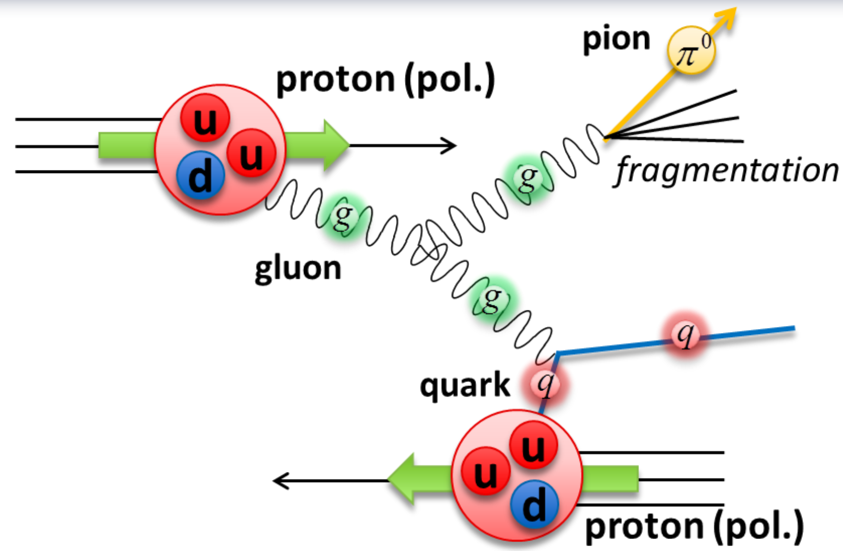
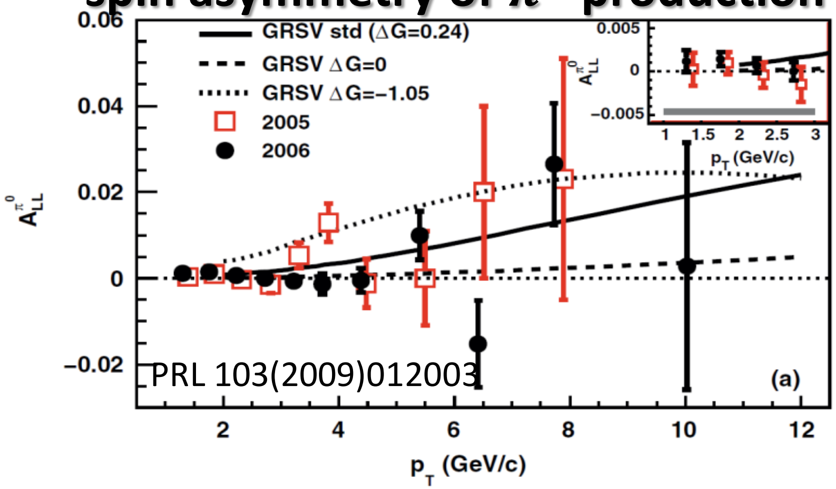
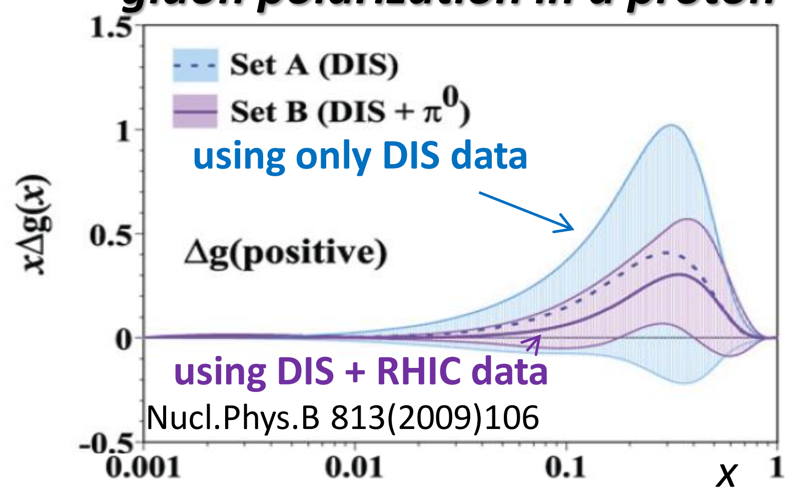


Diagram of pion production

spin asymmetry of π^0 production



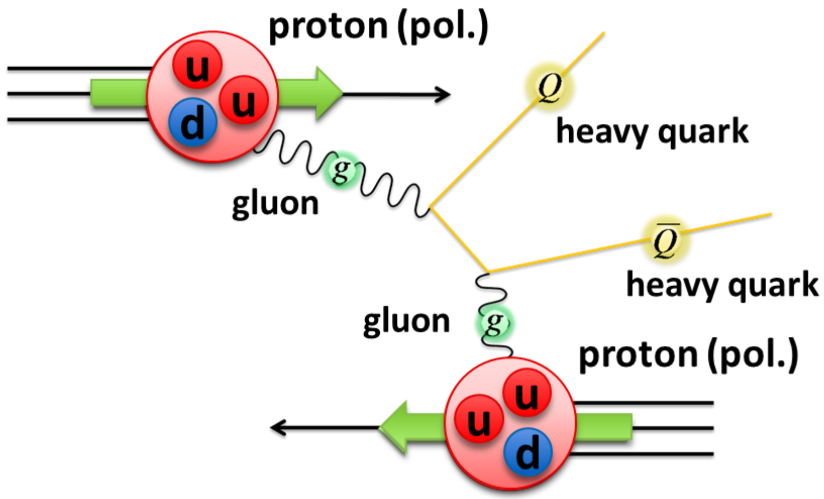
gluon polarization in a proton



Spin Asymmetry of Heavy Quark Production

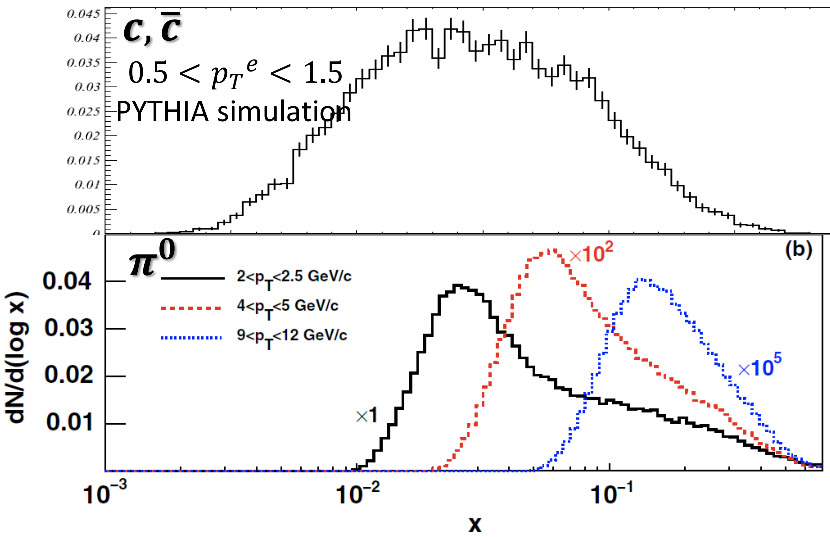
$$A_{LL}{}^{Heavy\ Quark} \equiv \frac{\sigma_{++}{}^{HQ} - \sigma_{+-}{}^{HQ}}{\sigma_{++}{}^{HQ} + \sigma_{+-}{}^{HQ}}$$

$$\sim \int dx_1 dx_2 \left(\hat{a}_{LL}{}^{gg} \frac{\Delta g}{g} \frac{\Delta g}{g} \right)$$



- **spin asymmetry of heavy quark production**
  - the main reaction is gluon-gluon scattering
  - **direct measurement for the gluon polarization**
  - **hard process → validity of pQCD**
- **an ideal channel to measure the gluon polarization**

distribution of Bjorken x of gluons contributed to each reaction

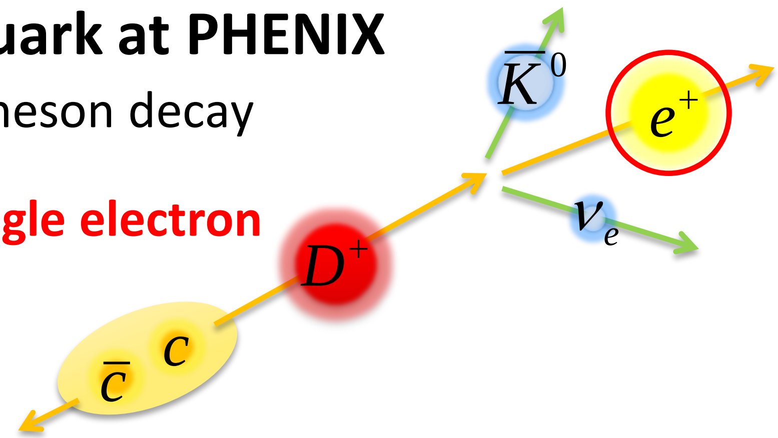


Spin Asymmetry of Single Electron Production

- **measurement of the heavy quark at PHENIX**
  - detect an electron from heavy meson decay

$$\begin{cases} D^+ \to \bar{K}^0 \nu_e e^+ \\ D^0 \to \bar{K}^- \nu_e e^+ \end{cases}$$

single electron



- **spin asymmetry of the single electron production**
  - asymmetry of inclusive (Signal+BG) electron production $A_{LL}^{\mathrm{S+BG}}$

$$A_{LL}^{\mathrm{singlee}} = \frac{1}{D} A_{LL}^{\mathrm{S+BG}} - \frac{1-D}{D} A_{LL}^{\mathrm{BG}} \approx \frac{1}{D} A_{LL}^{\mathrm{S+BG}}$$

$$D \equiv \frac{N_e^{\mathrm{singlee}}}{N_e^{\mathrm{S+BG}}} \quad : \text{Signal Occupancy}$$

  - ***BG reduction for large Signal Occupancy is important for the measurement of the spin asymmetry***

Background for the Single Electron Measurement

dominant background

- photon conversion — background

$$\pi^0(\eta) \rightarrow \gamma\gamma \quad \gamma \rightarrow e^+e^- \text{ (in material)}$$

- Dalitz decay

$$\pi^0(\eta) \rightarrow \gamma\, e^+e^-$$

- direct photon conversion

sn…

rejected by HBD (shown in later)

single electrons can be estimated by subtracting photonic electrons from total inclusive electrons

- **Heavy meson decay**

$$D \rightarrow e^{\pm} + X$$ (signal)

- Kaon decay — background

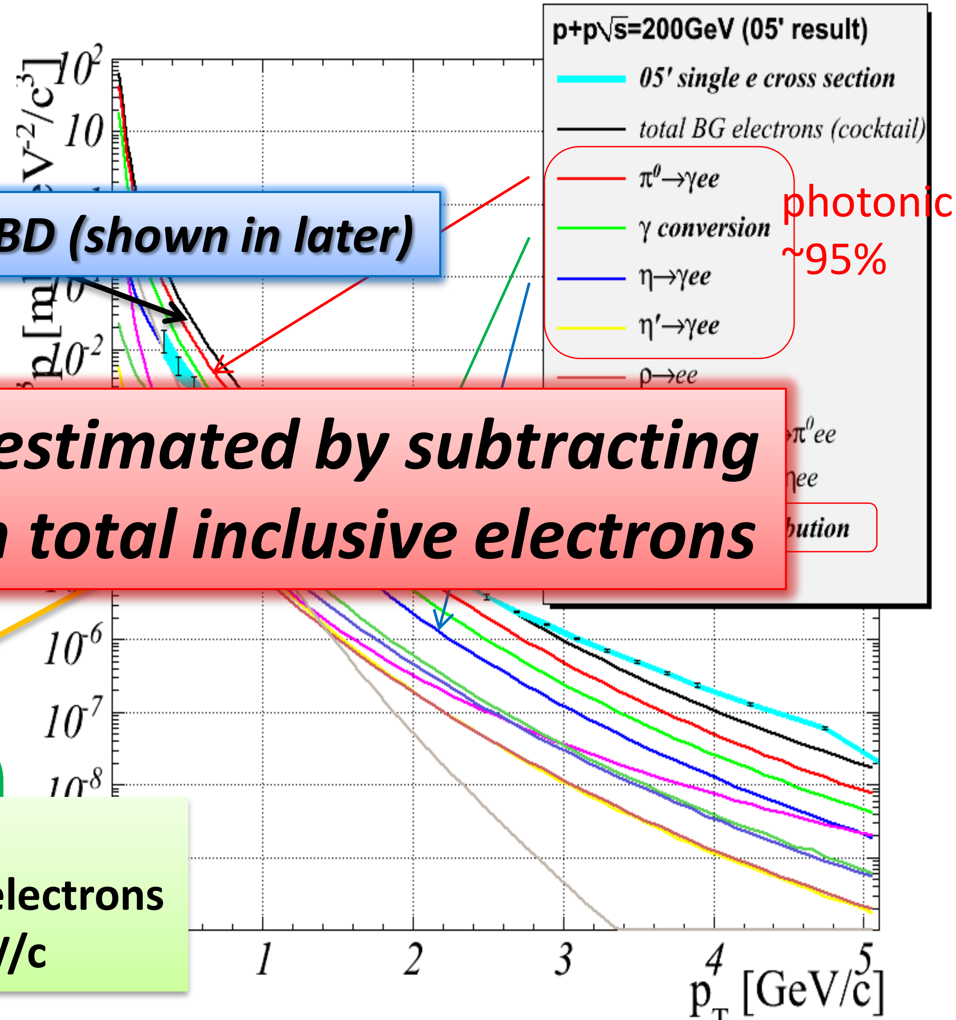
$$K_{e3} : K^{\pm} \rightarrow \pi^0 \nu_e e^{\pm}$$

- vector meson decay

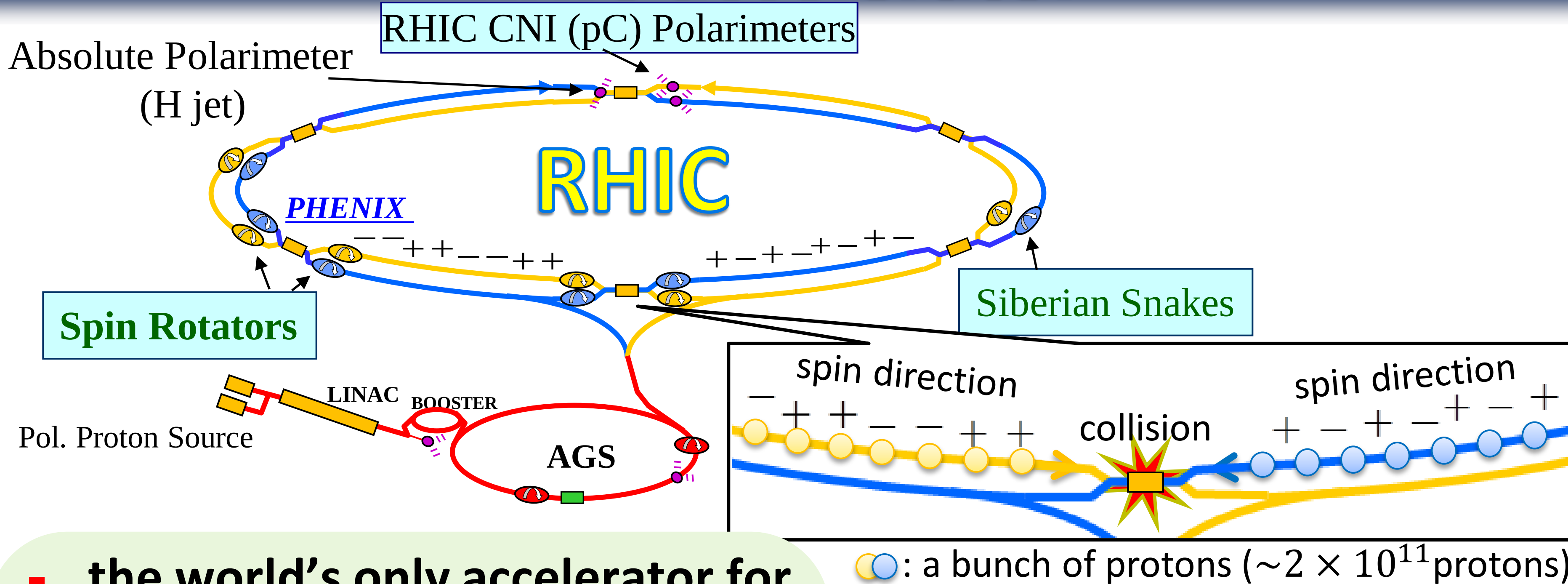
$$\omega, \rho, \phi, J/\psi, \Upsilon \rightarrow e^+ e^-$$

~ a few% of non-photonic electrons at p_T > 0.50GeV/c

PHENIX 05' single e and BG cross section



Brookhaven National Lab. (U.S.) RHIC accelerator



- **the world's only accelerator for the polarized protons**
  - bunch-by-bunch spin direction is different

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

$$R \equiv \frac{L_{++}}{L_{+-}}$$: relative luminosity

- **analyzed data**

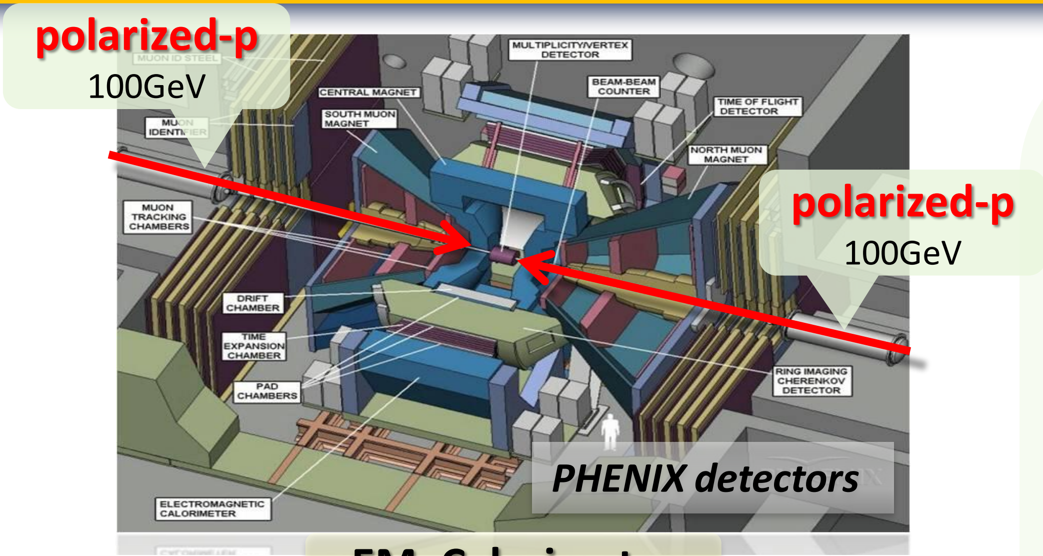
proton-proton collisions

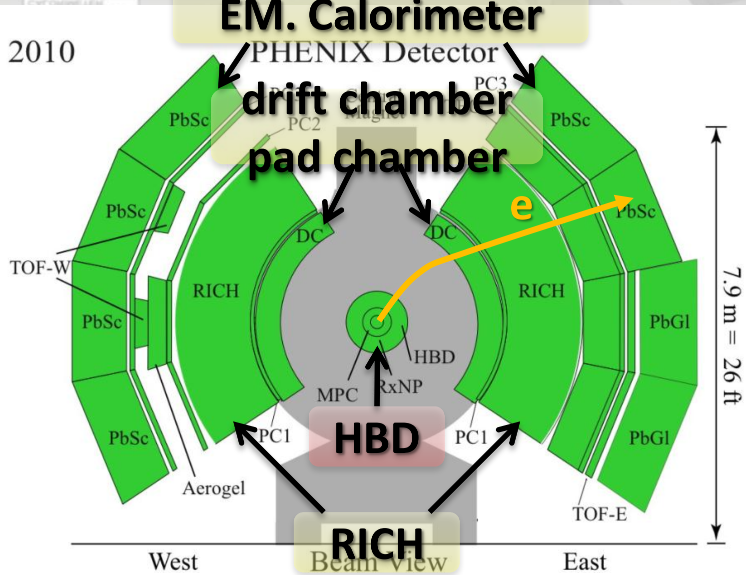
at $\sqrt{s}$ =200GeV

integrated luminosity ～6.1pb^{-1}

<beam polarization> ～ 57%

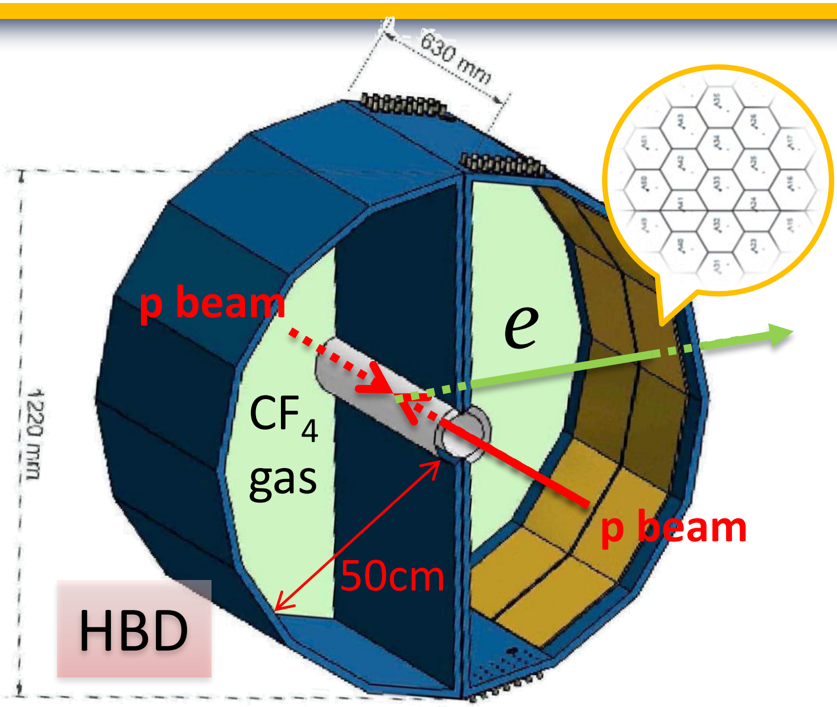
RHIC PHENIX detector

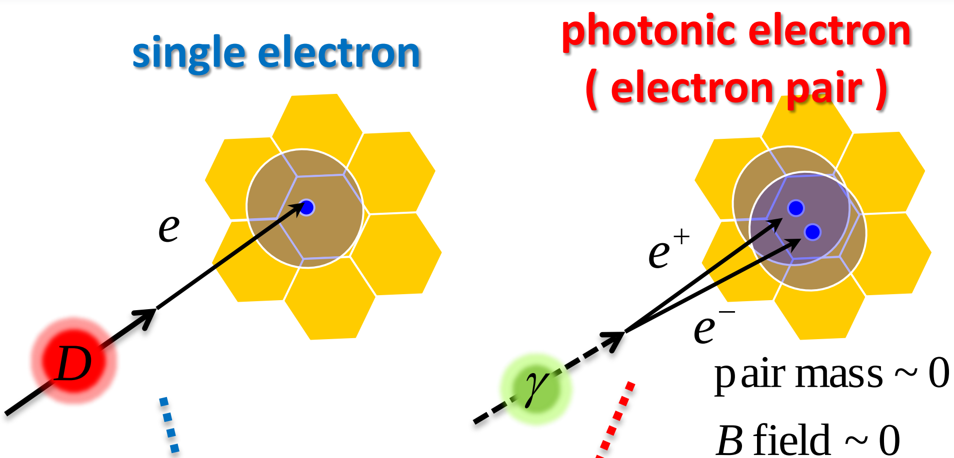




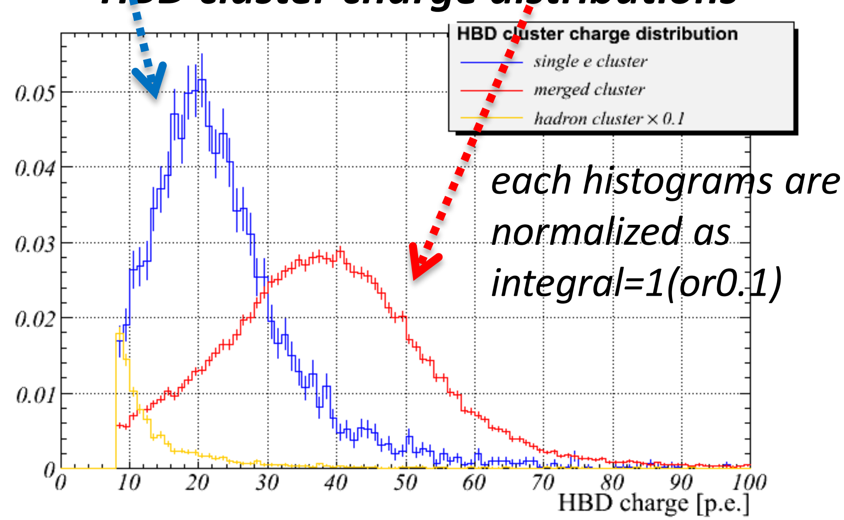
- **PHENIX : detector complex**
  - pseudrapidity: $|\eta| < 0.35$
  - azimuthal coverage: $\Delta\phi = 2 \times \pi/2$
- **Drift Chamber + Pad Chamber (DC + PC)**
  - tracking & momentum reconstruction for charged tracks
- **RICH Counter**
  - electron identification
- **Electromagnetic Calorimeter (EMCal)**
  - energy measurement for electrons & photons
- **Hadron Blind Detector (HBD)**
  - BG rejection for the electron measurement
  - this measurement is the first operation of the HBD
  - important detector for the measurement

Hadron Blind Detector (HBD)



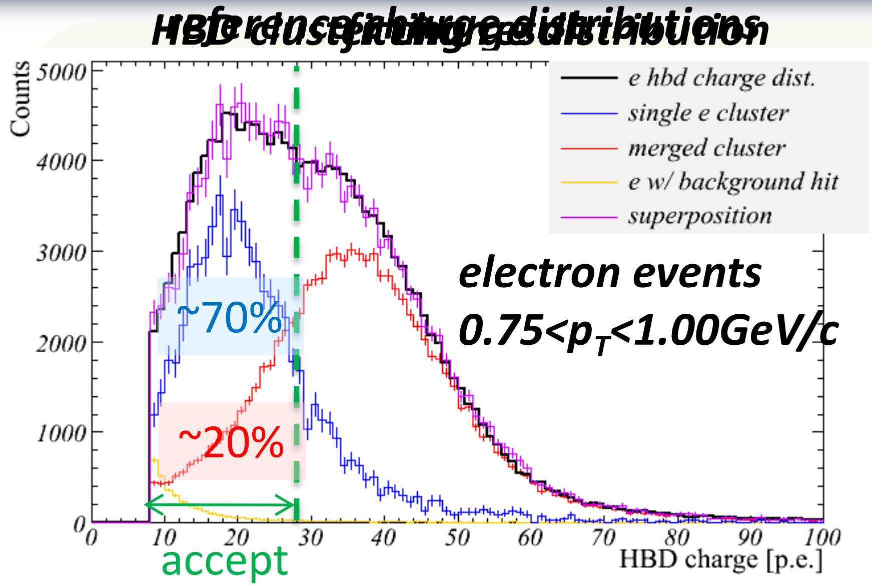


HBD cluster charge distributions



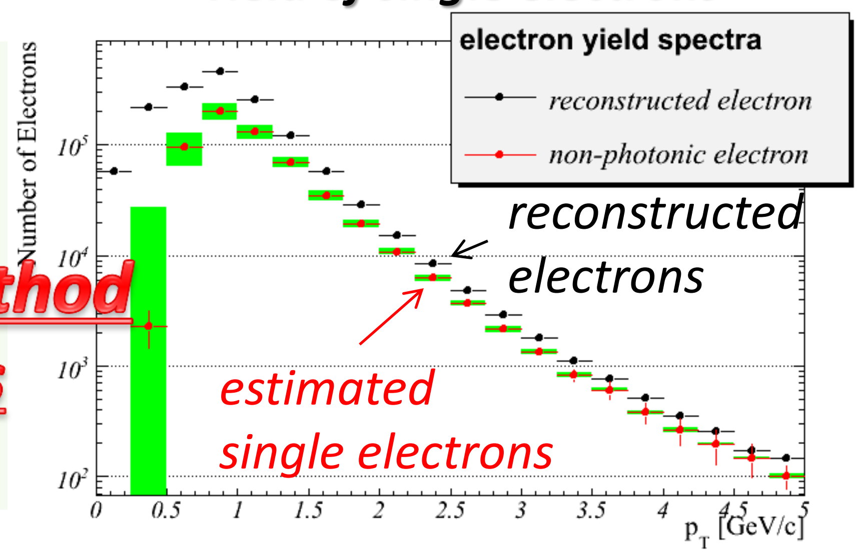
- **Hadron Blind Detector**
  - gas Cerenkov detector read out with CsI evaporated GEM
  - ***electron identification***
- **this analysis is the first time of physics measurement with HBD**

New Analysis Method for the Single Electron



- **electron analysis with HBD**
  - estimate the fractions of single e clusters and merged clusters by fitting HBD charge distribution
  - reject merged clusters with HBD charge cut effectively

Yield of single electrons



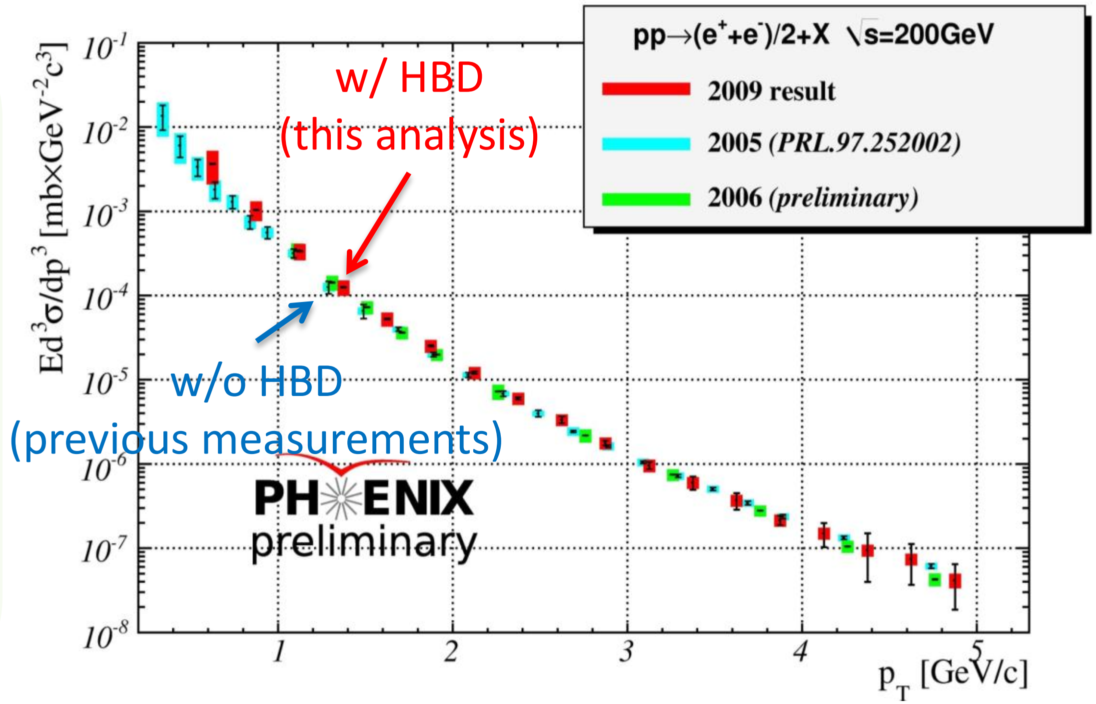
- **Yield of single electrons is estimated with this method**

established a new analysis method for single electron analysis

Check of Cross Section Spectrum

- **cross section of single electron production**
  - good consistency with previous measurements
- **different analysis method from previous measurements**
  - converter & cocktail method for 2005 and 2006 results

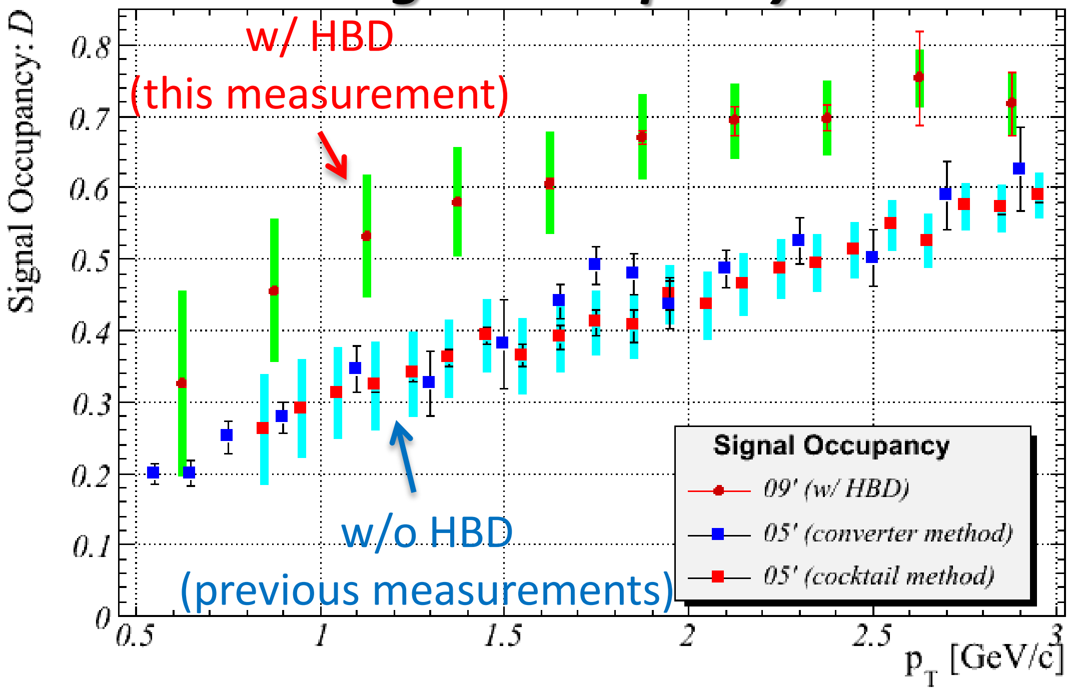
cross section of single electron production



confirmation of the reliability of the analysis method with HBD

measurement of spin asymmetry of single electron production

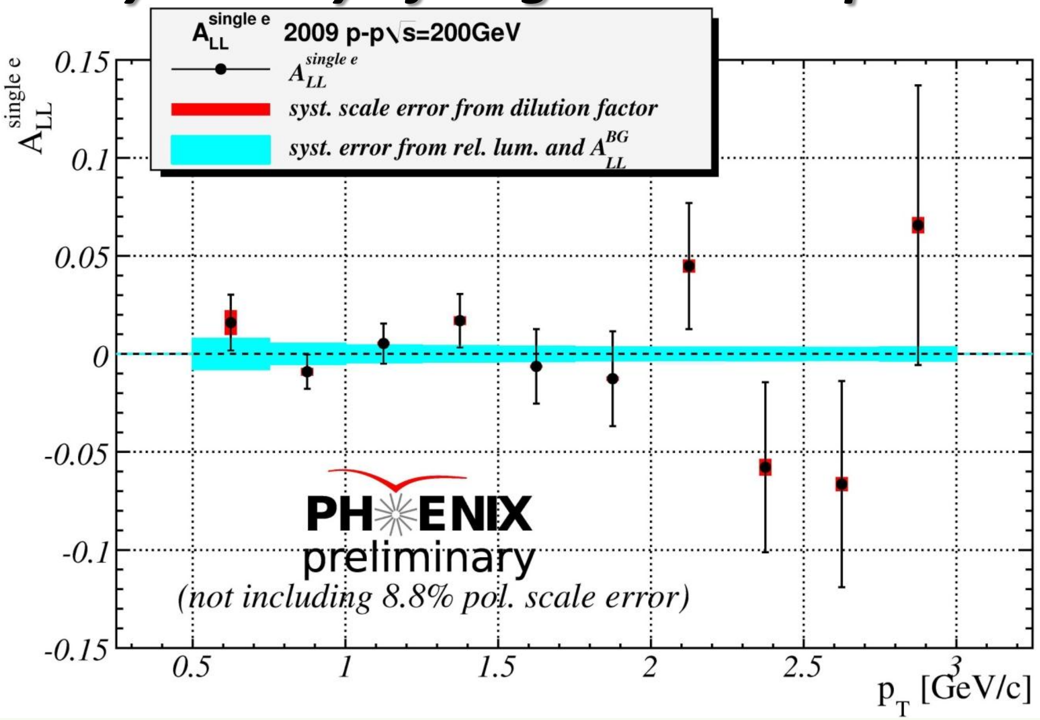
signal occupancy



- **Signal Occupancy: _D_**
  - the important value for the asymmetry measurement
  - increase by about ***factor of 1.5*** from previous measurements due to the HBD performance

Spin Asymmetry for Single Electron Production

spin asymmetry of single electron production



- **success of an approach to $\Delta g/g(x)$ by using the very clean channel**
  - $A_{LL}{}^{single\ e}\ (0.5 < p_T < 1.5\ \mathrm{GeV/c}) = (\ 3.1 \pm 5.5^{stat.} \pm 5.7^{syst.}\ ) \times 10^{-3}$
  - **estimation of the constraint for $\Delta g/g(x)$ from the result is on going now**

Summary

Summary

- **Spin asymmetry of single electron production is an ideal probe to measure the gluon polarization in a proton.**

- **A new analysis method for the single electron with HBD is established and confirmed its reliability.**
- **The new method increases the "Signal Occupancy" by a factor of about 1.5 compared with previous measurements**
- **The approach to the $\Delta g/g(x)$ with the very clean channel is succeeded.**
  - $A_{LL}{}^{single\ e}\ (0.5 < p_T < 1.5\ \mathrm{GeV/c}) = (\ 3.1 \pm 5.5^{stat.} \pm 5.2^{syst.}\ ) \times 10^{-3}$

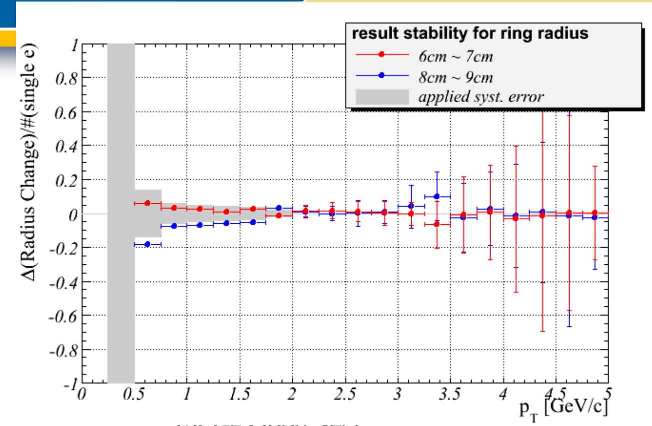
Future Prospect

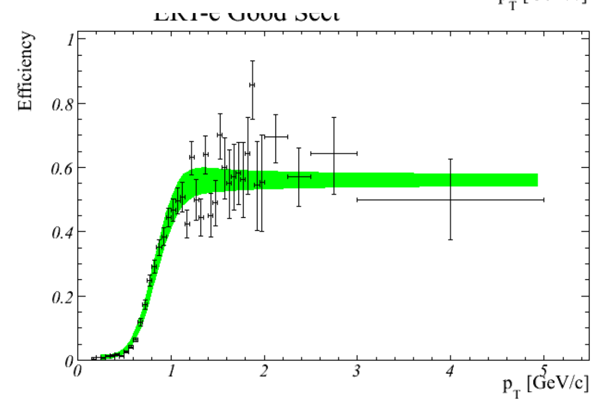
- **estimation of constraint on $\Delta g/g(x)$ from the result is on going now**

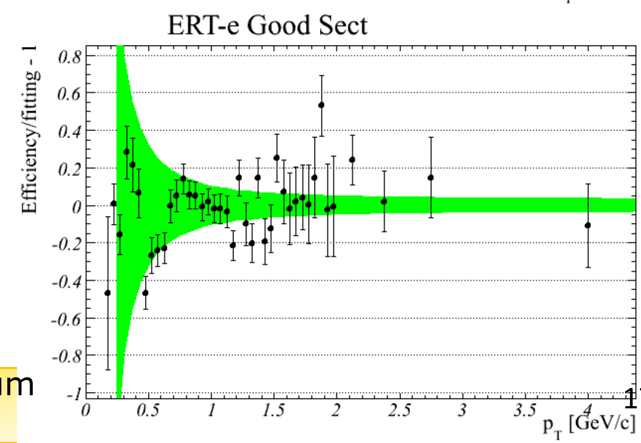
backup slides

Table of systematic errors

- **Single Electron Yield**
  - HBD cluster charge fitting
    - 25% of merged clusters
  - HBD ring charge fitting
  - analysis cut
    - ~ 6%
- **Cross Section**
  - MB cross section
    - 9.7%
  - MB trigger bias
    - 2.5%
  - acceptance x reco eff
    - 8%
  - trigger efficiency

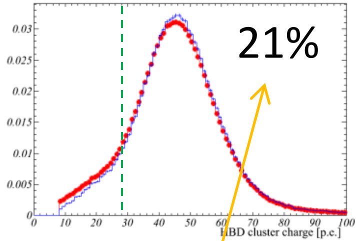






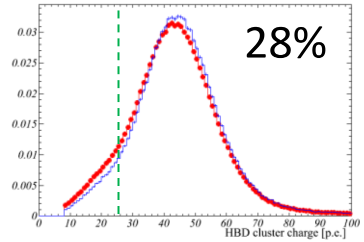
charge distribution of merged clusters (pi0 combined events)

Sect2 South

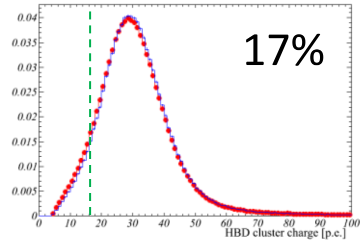


(fraction-fraction)/fraction

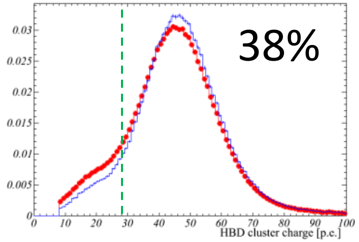
Sect2 North



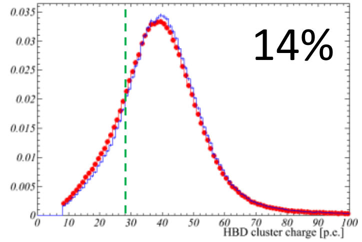
Sect3 North



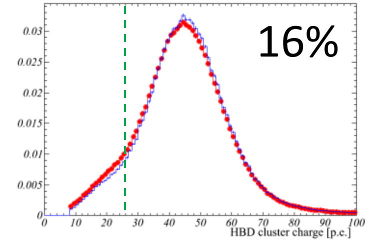
Sect4 South



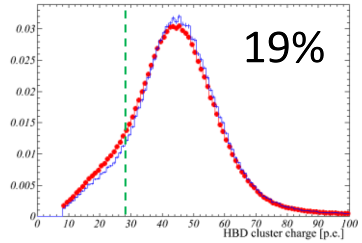
Sect8 South



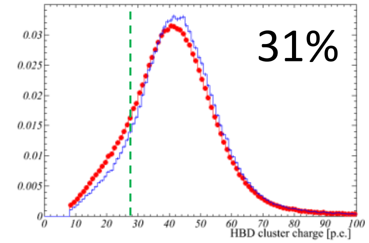
Sect8 North



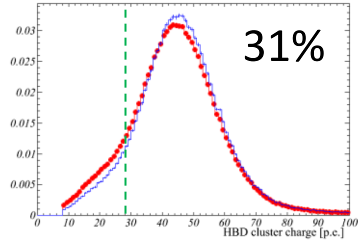
Sect9 South



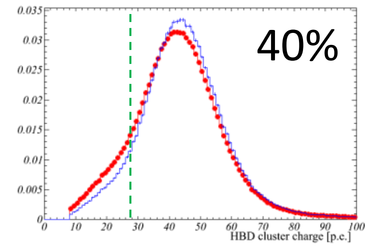
Sect9 North



Sect10 South



Sect10 North



Blue: definition in offline code

Red: ideal definition

- **slightly different**

Spin Puzzle ~EMC measurement~

- polarized DIS measurement

$$g_1 \approx \frac{F_2}{2x(1+R)} A_1$$

$$g_1(x) = \frac{1}{2} \sum_q e_q^{\ 2} \Delta q(x)$$

  - SLAC (1976, 1983)
  - EMC (1988)
    - quarks polarization is only 0.012±0.116±0.234 of the proton spin
    - (assuming Ellis-Jaffe sum rule)
- current quark polarization
  - ~ 25% of the proton spin (SIDIS)

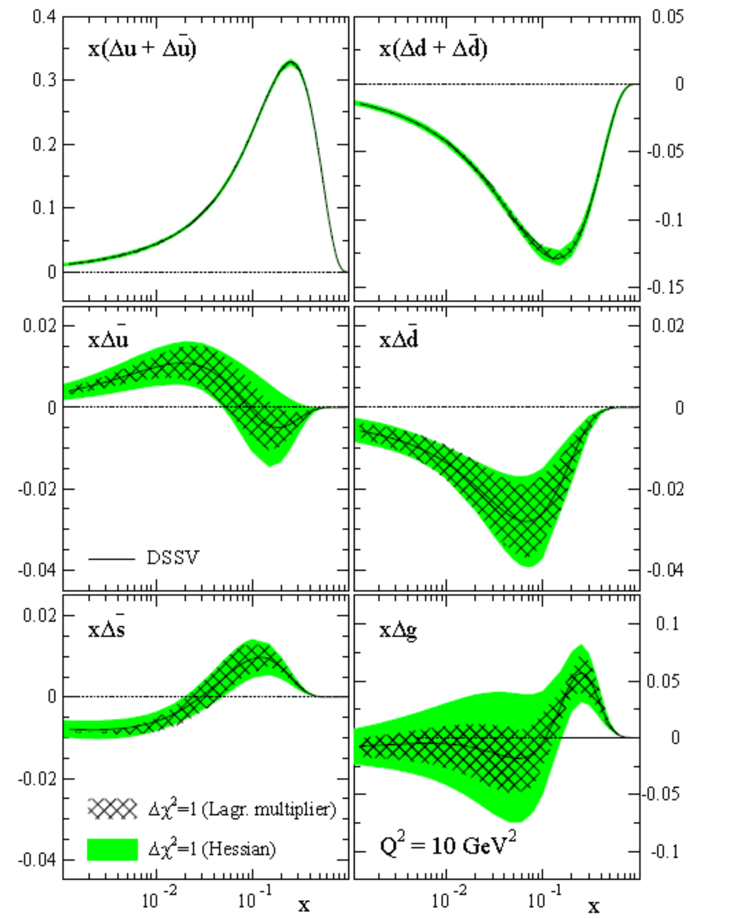


FIG. 3: Our polarized PDFs of the proton at $Q^2 = 10\ \mathrm{GeV}^2$ in the $\overline{\mathrm{MS}}$ scheme, along with their $\Delta\chi^2 = 1$ uncertainty bands computed with Lagrange multipliers and the improved Hessian approach, as described in the text.

パートンの軌道角運動量

Generalized Parton Distribution (GPD)

- GPD is all-inclusive distribution function of parton
  - PDF: momentum distribution of parton
  - FF: spatial distribution of parton
- spatial x momentum → orbital angular momentum

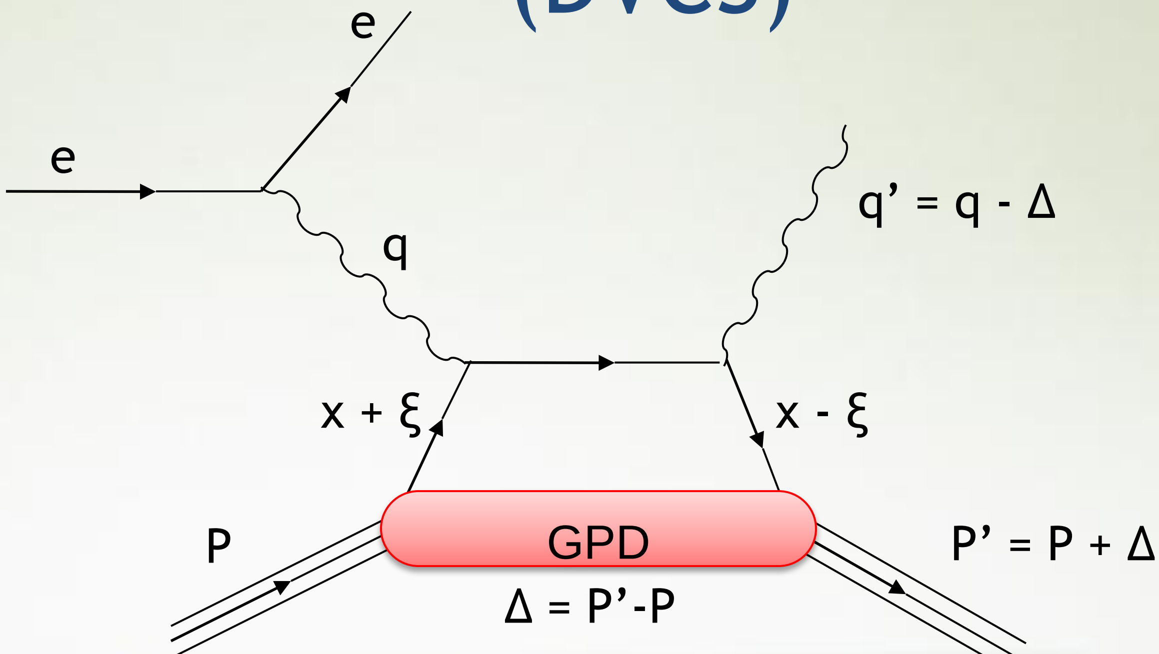
definition:

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle P' | \overline{\psi}(-\lambda n/2) \gamma^{\mu} \psi(\lambda n/2) | P \rangle = H(x, \Delta^2, \xi) \overline{U}(P') \gamma^{\mu} U(P) + E(x, \Delta^2, \xi) \overline{U}(P') \frac{i\sigma^{\mu\nu}\Delta_{\nu}}{2M} U(P) + \cdots$$

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle P' | \overline{\psi}(-\lambda n/2) \gamma^{\mu} \gamma^5 \psi(\lambda n/2) | P \rangle = \widetilde{H}(x, \Delta^2, \xi) \overline{U}(P') \gamma^{\mu} \gamma^5 U(P) + \widetilde{E}(x, \Delta^2, \xi) \overline{U}(P') \frac{\gamma^5 \Delta^{\mu}}{2M} U(P) + \cdots$$

- $x = \dfrac{Q^2}{2P \cdot q}$ Bjorken x
- $\Delta^2 = -t = -(P' - P)^2$ Mandelstam-t
- $n \propto (1,0,0,-1)$ light-cone vector
- $\xi = n(P' + P)$ difference of longitudinal momentum

Deeply Virtual Compton Scattering (DVCS)



- DVCS amplitude → measurement of GPD

$$T^{\mu\nu}(P,q,\Delta) = -\frac{1}{2}(p^{\mu}n^{\nu} + p^{\nu}n^{\mu} - g^{\mu\nu})\int_{-1}^{1} dx\left(\frac{1}{x-\xi/2+i\varepsilon} + \frac{1}{x+\xi/2-i\varepsilon}\right)\times$$
$$\left[H(x,\Delta^2,\xi)\overline{U}(P')\not{n}U(P) + E(x,\Delta^2,\xi)\overline{U}(P')\frac{i\sigma^{\alpha\beta}n_{\alpha}\Delta_{\beta}}{2M}U(P)\right]$$
$$-\frac{i}{2}\varepsilon^{\mu\nu\alpha\beta}p_{\alpha}n_{\beta}\int_{-1}^{1} dx\left(\frac{1}{x-\xi/2+i\varepsilon} + \frac{1}{x+\xi/2-i\varepsilon}\right)\times$$
$$\left[\widetilde{H}(x,\Delta^2,\xi)\overline{U}(P')\not{n}\gamma^5U(P) + \widetilde{E}(x,\Delta^2,\xi)\overline{U}(P')\frac{\gamma^5\Delta_{\beta}}{2M}U(P)\right]$$

Model-dependent constraints on J_u and J_d

- large model dependence
- cannot refer about quark angular momentum contribution for the proton spin yet

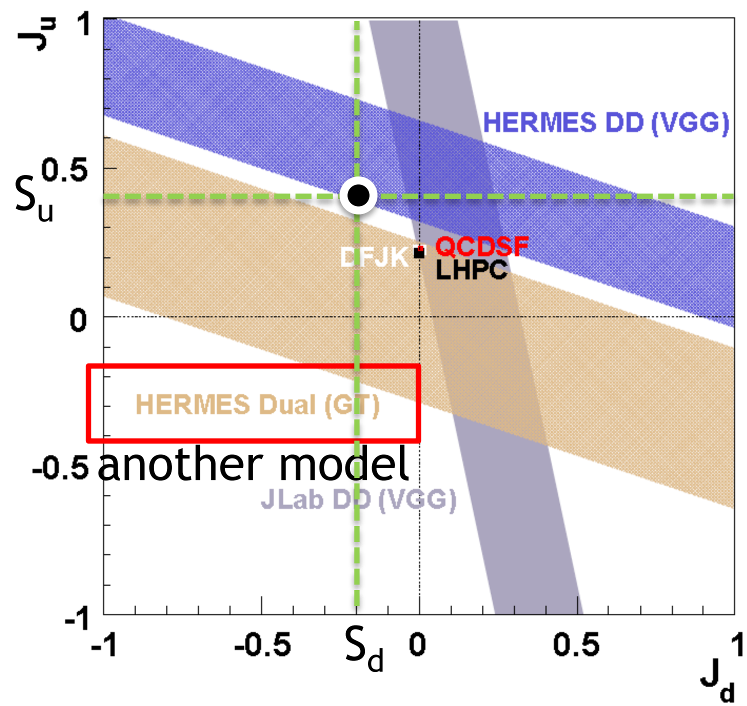
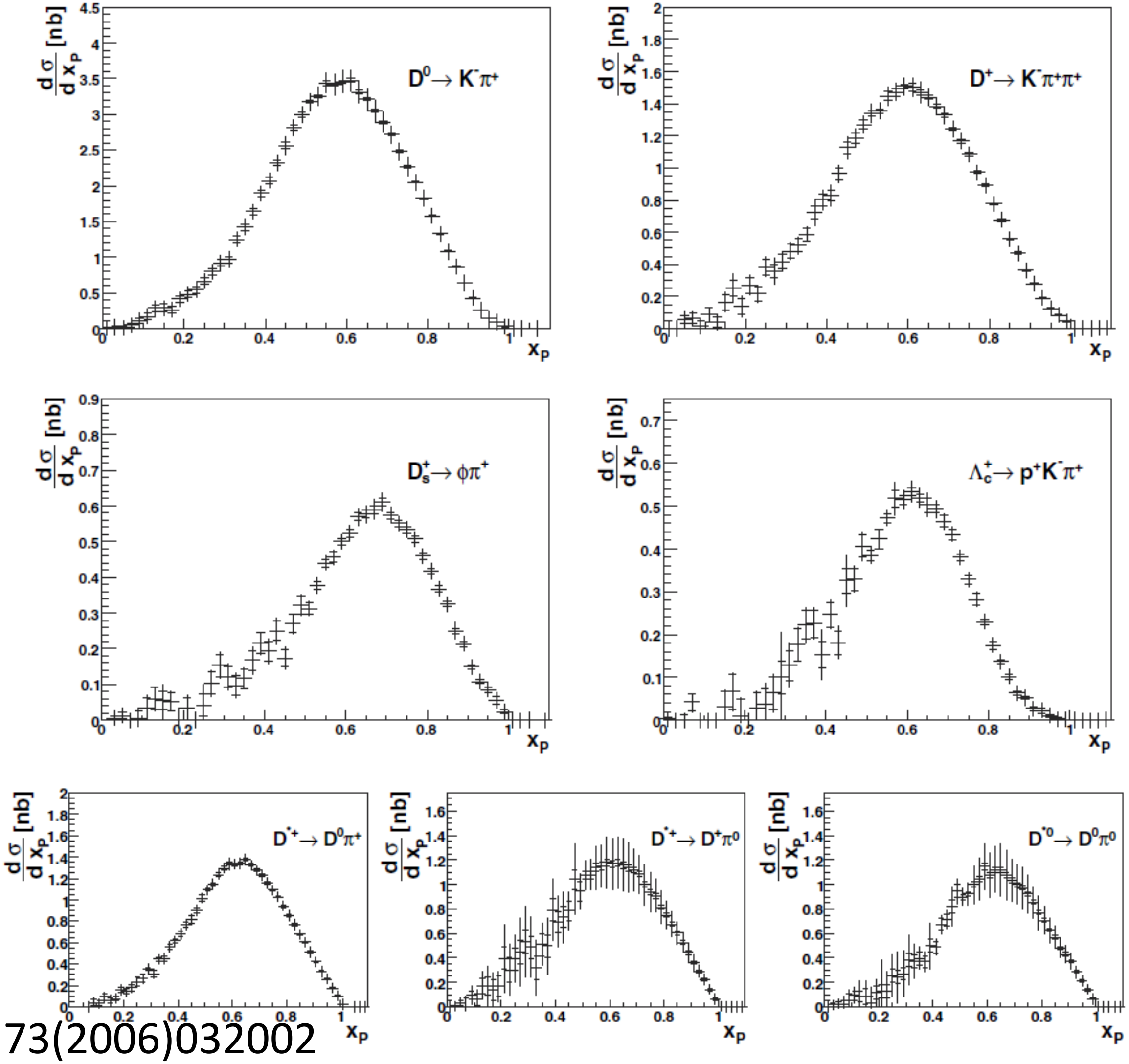


Figure 10. Model-dependent constraints on u-quark total angular momentum J_u vs d-quark total angular momentum J_d, obtained by comparing DVCS experimental results and theoretical calculations. The constraints based on the HERMES data for the TTSA amplitudes $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ and $A_{UT,I}^{\sin(\phi-\phi_S)}$ use the double-distribution (HERMES DD) [32, 39] or dual-parameterisation (HERMES Dual) [49] GPD models. The additional band (JLab DD) is derived from the comparison of the double-distribution GPD model with neutron cross section data [55]. Also shown as small (overlapping) rectangles are results from lattice gauge theory by the QCDSF [52] and LHPC [47] collaborations, as well as a result for only the valence quark contribution (DFJK) based on zero-skewness GPDs extracted from nucleon form factor data [53, 54]. The sizes of the small rectangles represent the statistical uncertainties of the lattice gauge results, and the parameter range for which a good DFJK fit to the nucleon form factor data was achieved. Theoretical uncertainties are unavailable.

charm quark fragmentation function



PRD 73(2006)032002