Summary of the DUBNA-SPIN-07

Jacques Soffer

Physics Department, Temple University, Philadelphia,PA, USA

Very dense programme over 5 days about 90 talks !

Theory, Experiment and Technical aspects

- Spin is all over the places, from several 100 MeV up to several TeV
- Collisions of e^+e^-, $e^{\pm}p$, $\mu^{\pm}p$, νp, pp, etc....
- Great recent progress in polarized beams and targets
- What have we learnt?
- What are the prospects?

Road maps

- Need road maps both for Experiment and Theory
- Experiment Facilities
  - RARF (Riken), HIMAC (Tokyo), Gatchina, PROZA (Protvino), FAIR (GSI, Darmstadt)
  - CLAS (JLab), HERMES, HERA (Desy), COMPASS (CERN), BELLE (KEK)
  - RHIC (BNL), ILC (?), LHC (CERN)
- Theory
  - PDF, DIS, SIDIS, TMD, GPD, DVCS, Δq, ΔG,..
  - DGLAP, BFKL, NLO, NNLO, QCD mechanisms,...
  - Asymmetry, Positivity, Sum rules, Twist,..
  - SSA, Sivers effect, Collins effect, Drell-Yan mechanism,...

Warning

- How to deal with 45 hours of lectures?
- Will not touch technical talks (Not my field)
- I had to make a drastic selection
- I apologize to those which will not be (or badly) mentioned due to lack of time and to my unability to "‘digest"’ more quickly

Very good propects for existing or future facilities: NUCLOTRON, PANDA

My special thanks to Konrad Klimaszewski who gave me a serious technical help to prepare this talk

Contents

- Experiments
  - COMPASS Festival
  - HERMES Festival
  - BNL, JLab and Belle Festival
- GPD Festival
- Theory
  - Single spin asymmetry, Collins effect, Sivers effect
  - PDF and related topics
  - Miscellanous

COMPASS FESTIVAL

COMPASS results on inclusive and semi–inclusive polarised DIS

Helena Santos

LIP - Lisboa

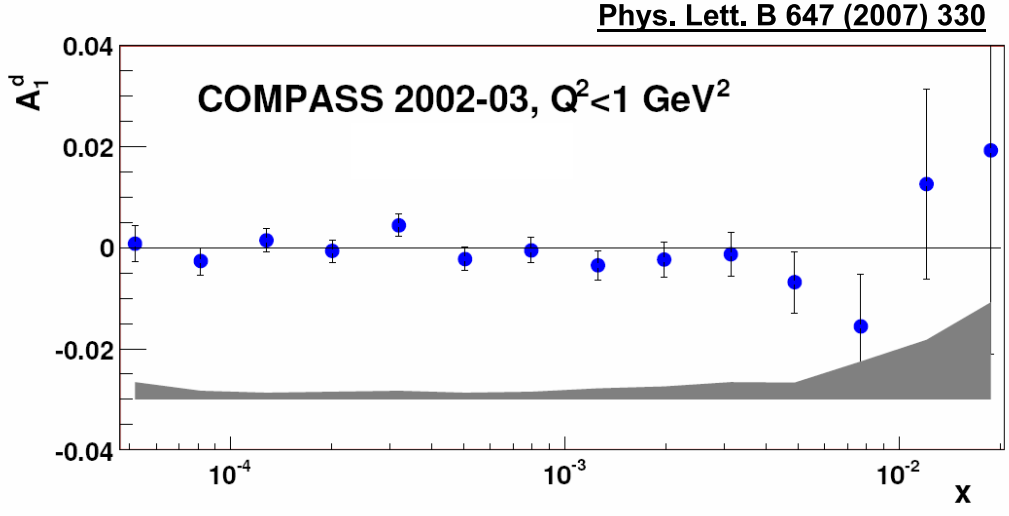
on behalf of the COMPASS Collaboration

- The nucleon spin
- The COMPASS experiment
- Longitudinal spin structure functions
- Valence quark polarisations
- Conclusions and outlook

DSPIN - 07 – XII WORKSHOP ON HIGH ENERGY SPIN PHYSICS

Inclusive Asymmetry, $Q^2 < 1$ (GeV/c)^2

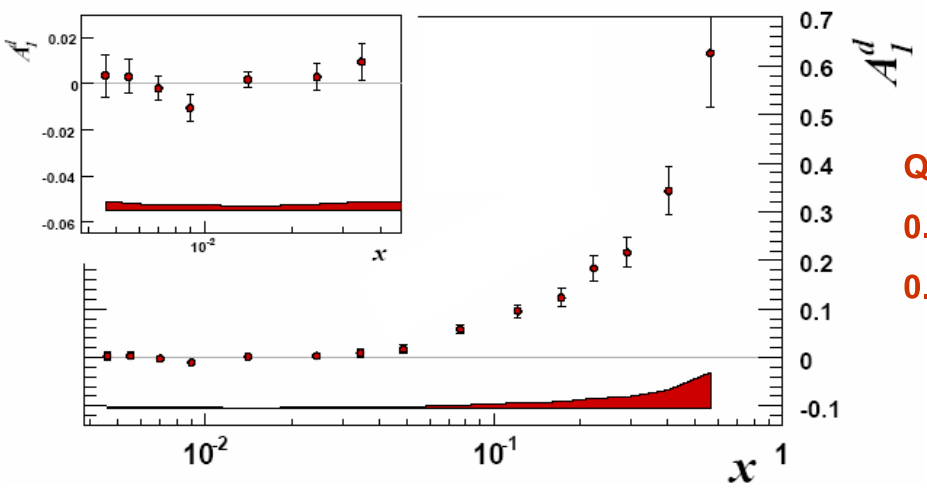
Phys. Lett. B 647 (2007) 330



- A_1^d asymmetry compatible with 0 at low x range (0.0005<x<0.02)
- At low x A_1^d has been measured only by COMPASS and SMC
- Systematic errors are mainly due to false asymmetries

Inclusive DIS Asymmetry

Phys. Lett. B 647 (2007) 8



$Q^2 > 1$ (GeV/c)^2

$0.004 < x < 0.7$

$0.1 < y < 0.9$

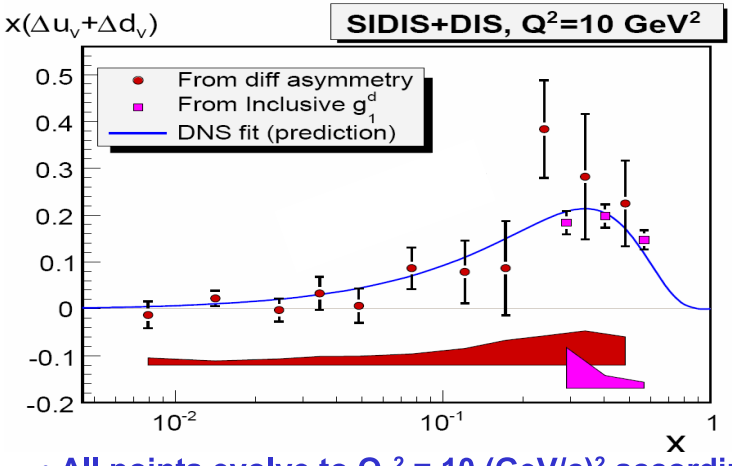
- A_1 compatible with 0 for $x < 0.05$
- Large asymmetry at large x
- Systematic errors: Multiplicative $\rightarrow \delta \cong 0.10A$ (δP_B, δP_T, δf and δD)

  Additive $\rightarrow$ rad. corrections $\approx 10^{-4}$ — 10^{-3}; $A_{false} < 0.4\delta A_{stat}$

Valence quark polarisations

CERN-PH-EP/2007-024

$$x(\Delta u_v + \Delta d_v) = \frac{x(u_v + d_v)}{(1 + R(x,Q^2))(1 - 1.5\omega_D)} A^{+-} \qquad (\omega_D = 0.05 \pm 0.01)$$



- Unpol. sea contribution to F_2 vanishes for x > 0.3
- $|\Delta\bar{u}+\Delta\bar{d}| < \bar{u}+\bar{d}$

$$\Delta u_v + \Delta d_v = \frac{36}{5}\frac{g_1^d(x,Q^2)}{(1-1.5\omega_D)} - \left[2(\Delta\bar{u}+\Delta\bar{d}) + \frac{2}{5}(\Delta\bar{s}+\Delta\bar{s})\right]$$

- Much better precision

- All points evolve to $Q_0^2 = 10$ (GeV/c)^2 accordingly to DNS parameterisation
  (D. De Florian, G.A. Navarro and R. Sassot, Phys. Rev. D71 (2005) 094018)
- LO DNS analysis, based on KKP param. of FF, includes:
  All DIS g_1 prior to COMPASS 2004 data;
  All SIDIS data from SMC and HERMES ($\Delta\bar{u} = \Delta\bar{d} = \Delta s = 0$ for x > 0.3)
- Unpolarised MRST 2004 LO PDFs have been used

$\Delta G/G$ at COMPASS

Yann Bedfer
Saclay - DAPNIA/SPhN
On behalf of the COMPASS collaboration

Conclusion

- Open charm
  $\Delta G/G = -0.57 \pm 0.41(stat.) \pm 0.17(syst.) \quad x_g \simeq 0.15 \quad \mu^2 \simeq 13\,GeV^2$
- High p_T $Q^2 < 1$ (*2002-2003 data*)
  $\Delta G/G = \quad 0.06 \pm 0.31(stat.) \;\; \pm 0.06(syst.) \quad x_g \simeq 0.13$
- High p_T $Q^2 > 1$ (*PLB 633 (2006) 25-32*)
  $\Delta G/G = 0.016 \pm 0.058(stat.) \pm 0.055(syst.) \;\; x_g \simeq 0.085 \;\; \mu^2 \simeq 3\,GeV^2$
- Favors low value of ΔG
- NLO extraction from high p_T photoproduction to be released.
- 2006 :
  - $1/2$ more statistics.
  - Larger impact on $\mathcal{F}o\mathcal{M}$ due to upgrade.
- 2007 : Polarized proton target.
  (*Not optimum for ΔG since fP_T reduced.*)
- 2008 : Hadron beam.

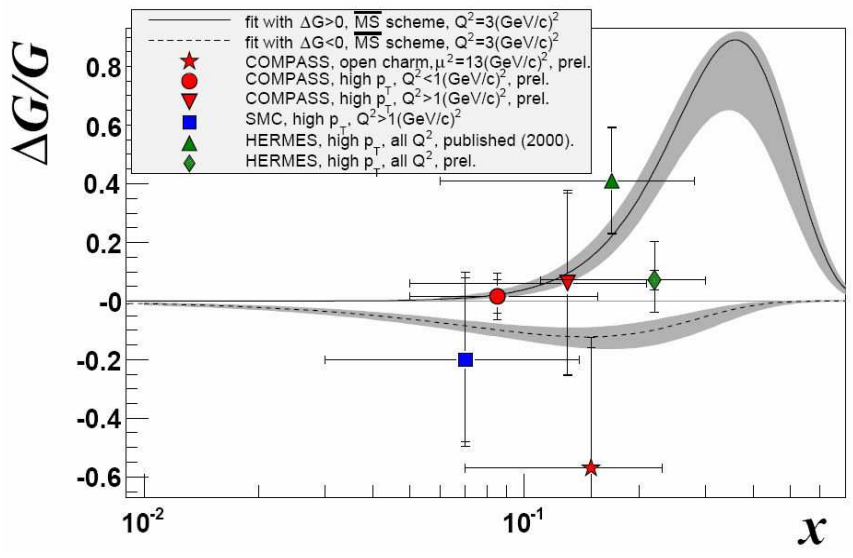
ΔG from high p_T events at COMPASS

Konrad Klimaszewski

Soltan Institute for Nuclear Studies, Warsaw
on behalf of the COMPASS collaboration

XII Workshop on High Energy Spin Physics (DSPIN-07)
Dubna 03.09.2007

Gluon Polarisation $\Delta G/G$



Comparison between direct measurement of gluon polarisation (Y. Bedfer's talk) and COMPASS NLO QCD fits to g_1

- **Unpolarised G(x) from MRST**
- **Bands correspond to statistical errors of ΔG**

HERMES FESTIVAL

Recent Results from HERMES

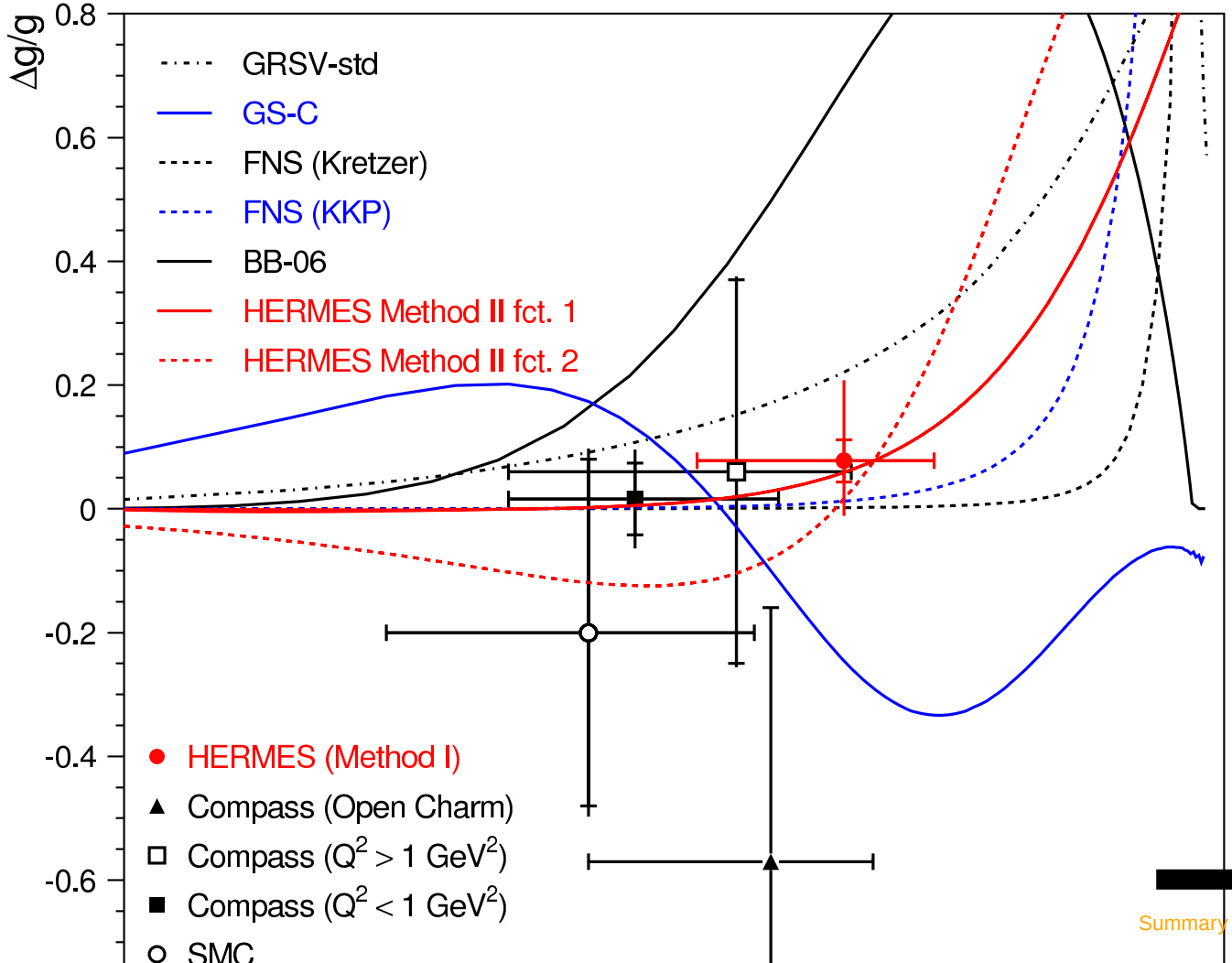
S.Belostotski

Petersburg Nuclear Physics Institute

(for HERMES collaboration)

HERMES results

ΔG final result compilation



Summary

- *Using well -saturated* Γ_d *and under SU(3) f.sym. assumption it is found*

at $Q^2 = 5\,\mathrm{GeV}^2$

$$\Delta\Sigma = 0.330 \pm 0.025(\mathrm{exp.}) \pm 0.011(\mathrm{theo.}) \pm 0.028(\mathrm{evol.})$$

$$(\Delta s + \Delta\bar{s}) = -0.085 \pm 0.013(\mathrm{theo.}) \pm 0.008(\mathrm{exp})$$

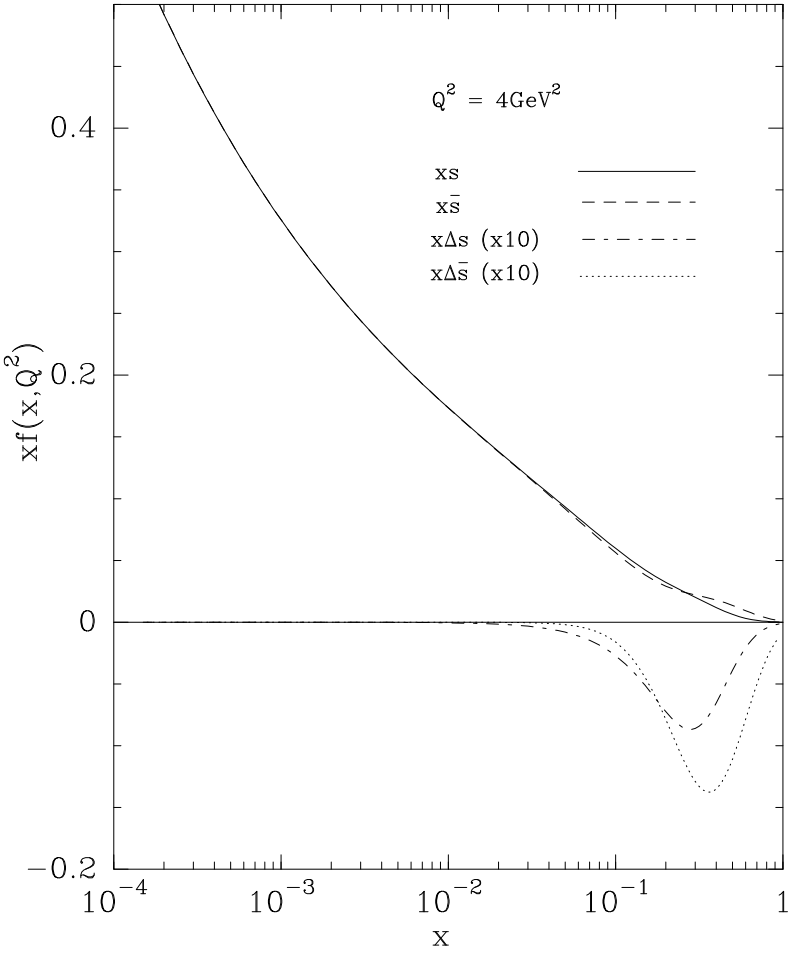
- *Quark polarizations and helicity distributions are extracted from SIDIS data for 5 quark flavors (of 6) for the first time. ΔS(x) is compatible with 0.*

talk M.Varanda

- *From analyis of high PT hadron production, ΔG/G is estimated to be* $0.078 \pm 0.034 \pm 0.011$ *with theor. uncertainty of ~0.1.*

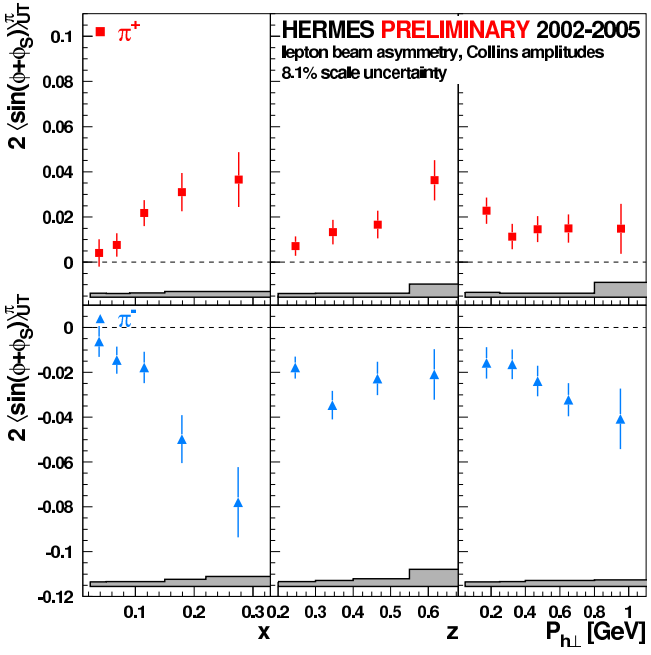
- *other hermes topics…*

Statistical strange quark distributions



Transverse spin physics at HERMES (Korotkov)

Collins amplitudes for charged pions

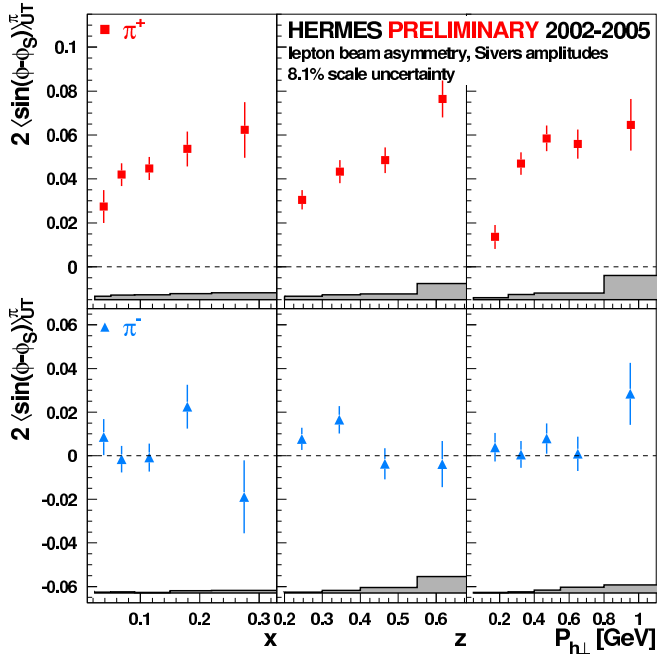


- all data (2002 - 2005) are used (PRL, 94 (2005) 012002)
- positive amplitudes for π^+
- negative amplitudes for π^-
- large negative amplitudes for π^- were unexpected
- $H_1^{\perp,unf}(z) \approx -H_1^{\perp,fav}(z)$

- $H_1{}^{fav} = H_1{}^{u\to\pi^+} = H_1{}^{d\to\pi^-} = H_1{}^{\bar{u}\to\pi^-} = H_1{}^{\bar{d}\to\pi^+}$
- $H_1{}^{unf} = H_1{}^{u\to\pi^-} = H_1{}^{d\to\pi^+} = H_1{}^{\bar{u}\to\pi^+} = H_1{}^{\bar{d}\to\pi^-}$

Transverse spin physics at HERMES (Korotkov)

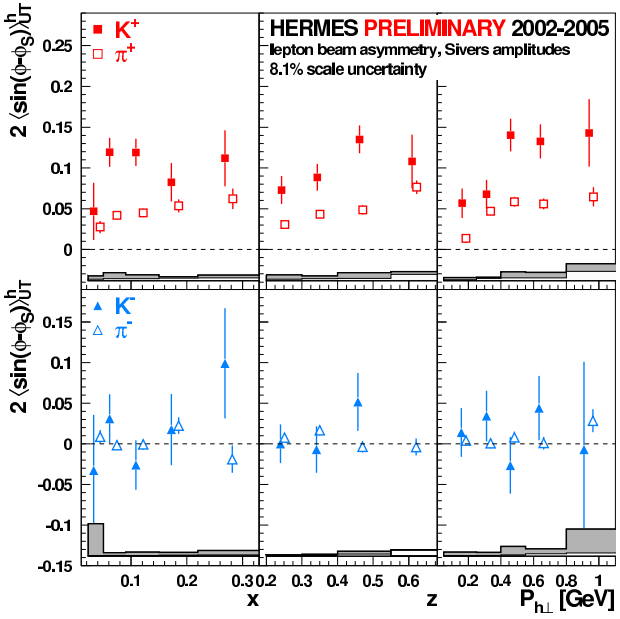
Sivers amplitudes for charged pions



- significantly positive for π^+
- a signiture of non-zero quark orbital angular momentum
- π^- amplitudes consistent with zero

Transverse spin physics at HERMES (Korotkov)

Sivers amplitudes for charged kaons



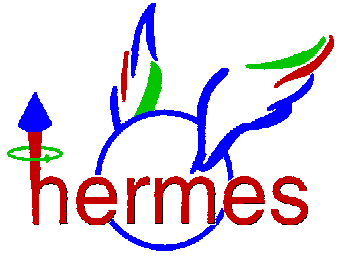
- significantly positive for K^+
- K^- amplitudes consistent with zero
- K^+ amplitude is 2.3 ± 0.3 times larger than for π^+

- $K^- = s\bar{u},\ \pi^- = d\bar{u}$ same antiquark
- $K^+ = u\bar{s},\ \pi^+ = u\bar{d}$ different antiquarks
- May suggest significant antiquark Sivers functions and strongly flavor-dependent.

Λ and $\bar{\Lambda}$ polarization and spin transfer in photoproduction at HERMES

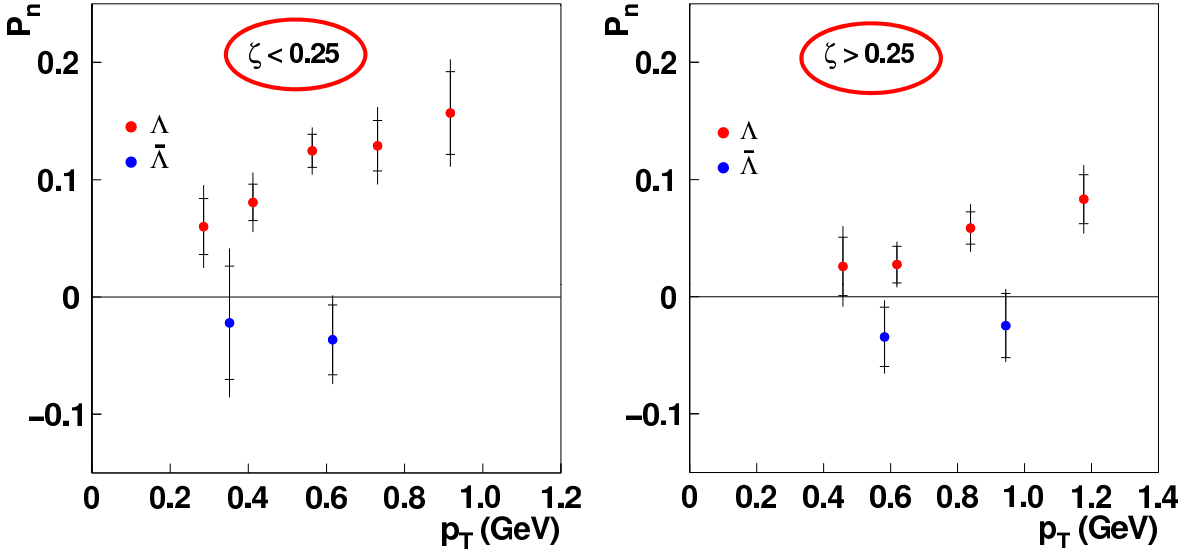
D. Veretennikov

Petersburg Nuclear Physics Institute
(for HERMES collaboration)



SPIN-07, Dubna

Lambda polarization at HERMES



Λ polarization rises linearly with p_T in both regions, effect is most pronounced at $\zeta < 0.25$

$\bar{\Lambda}$ compatible with zero

Lambda polarization at HERMES

Conclusion

- *Transverse Λ ($\bar{\Lambda}$) polarization in quasi-real photoproduction is found to be positive for Λ and compatible with zero for $\bar{\Lambda}$*

$$P_{\Lambda} = 0.078 \pm 0.006\ (stat) \pm 0.012\ (syst)$$

$$P_{\bar{\Lambda}} = -0.025 \pm 0.015\ (stat) \pm 0.018\ (syst)$$

- *As expected, the measured transverse Λ polarization rises linearly with p_T*
- *The transverse polarization is larger for $\zeta < 0.25$ where diquark fragmentation dominates*
- *Longitudinal spin transfer for Λ is found to be positive and for $\bar{\Lambda}$ compatible with zero*

$$K_{LL}(\Lambda) = 0.026 \pm 0.009\ (stat) \pm 0.005\ (syst)$$

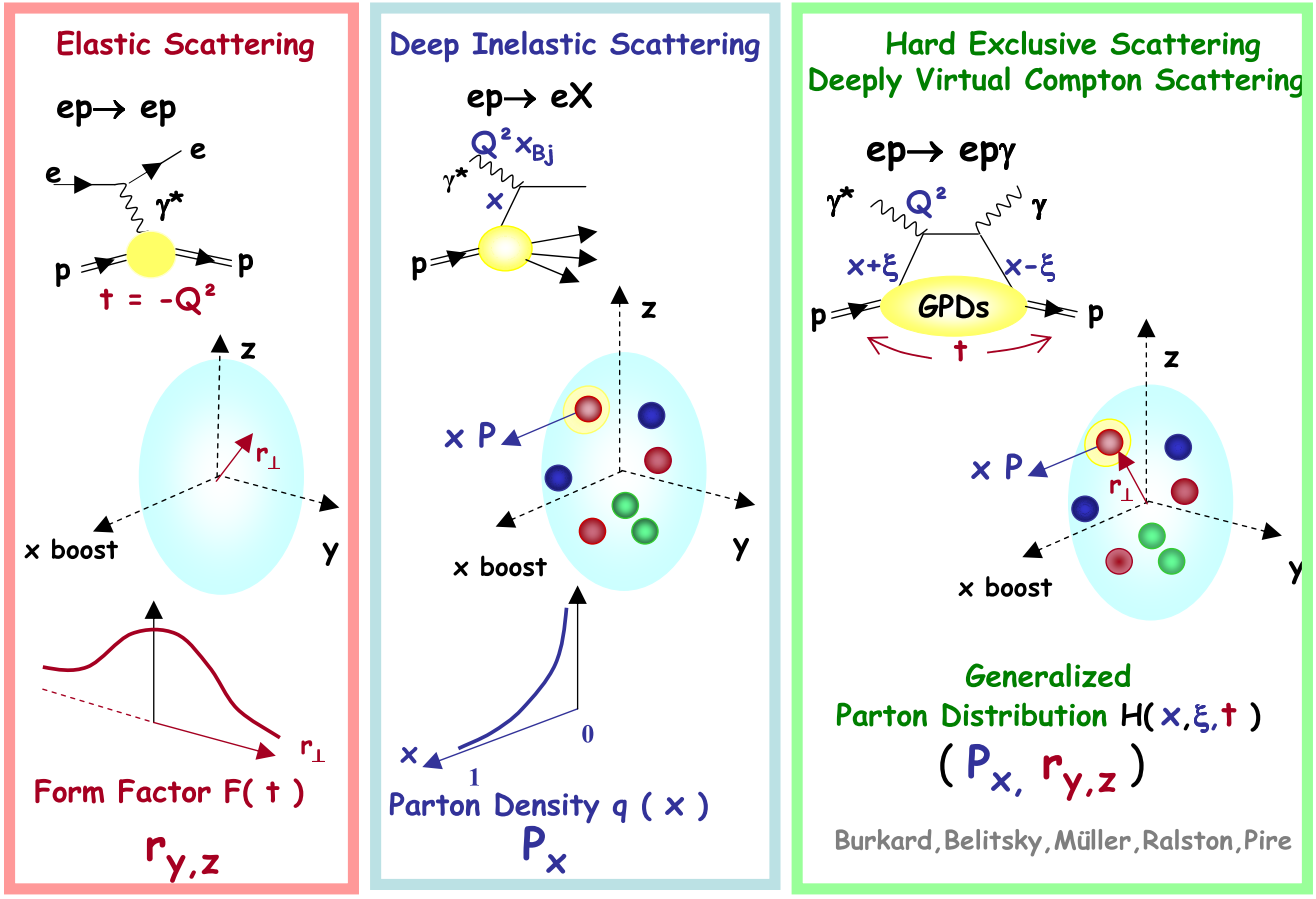
$$K_{LL}(\bar{\Lambda}) = 0.002 \pm 0.022\ (stat) \pm 0.008\ (syst)$$

- *The spin transfer is increasing for small t*
- *The measured spin transfer is p_t independent*

GPD FESTIVAL

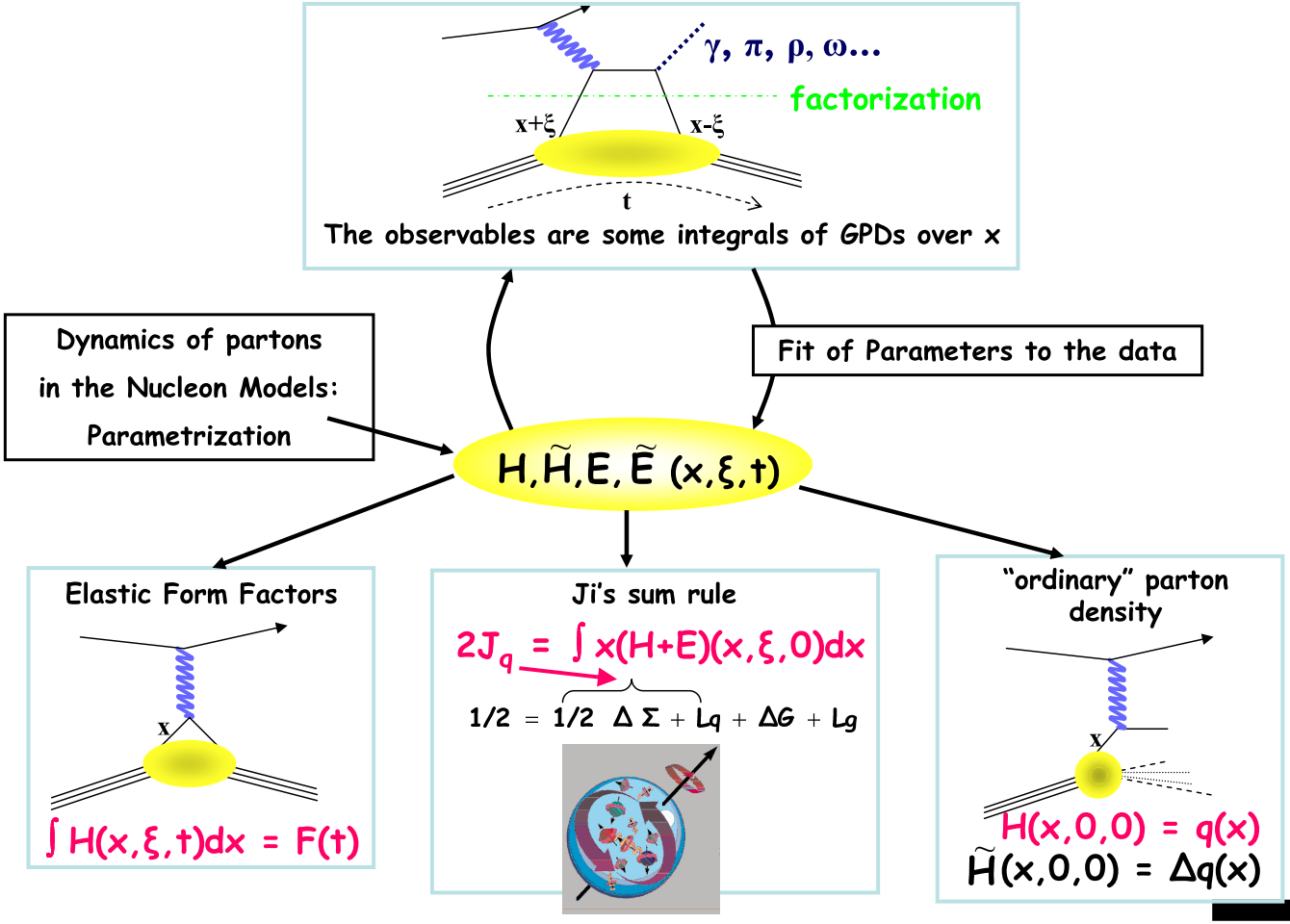
Future GPD at COMPASS (N. d'Hose)

GPDs ≡ a 3-dimensional picture of the nucleon partonic structure



Future GPD at COMPASS (N. d'Hose)

GPDs and relations to the physical observables

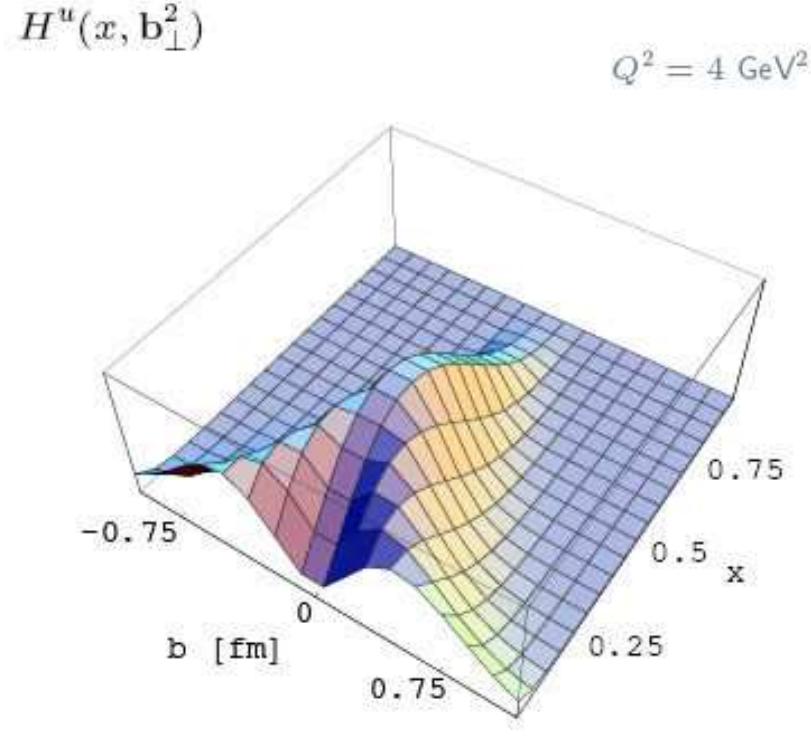


Future GPD at COMPASS (N. d'Hose)

GPDs in Lattice

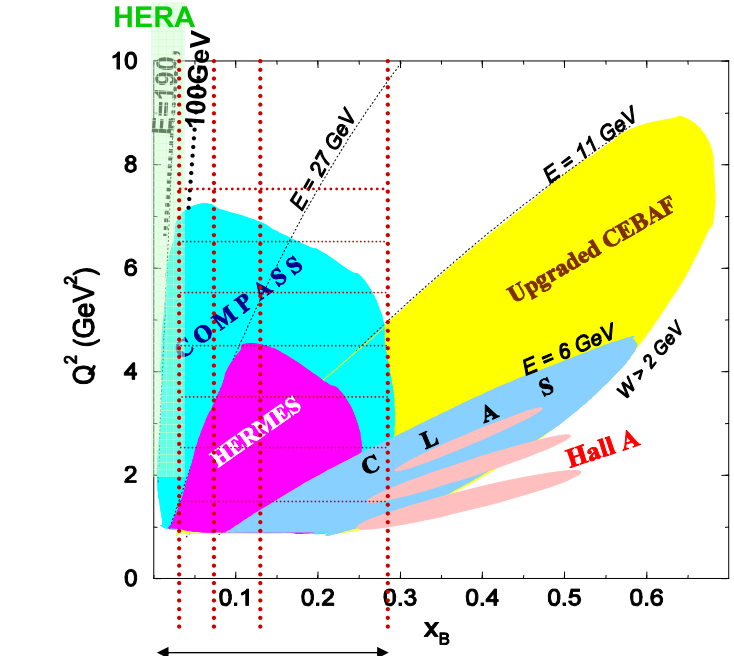
From Schierholz, JLab May 2007

probability densities of quarks and gluons
in impact parameter space



Future GPD at COMPASS (N. d'Hose)

Competition in the world and COMPASS role



Gluons — valence quarks and sea quarks and gluons — valence quarks

COMPASS 2010 — JLab 12 GeV 2014, FAIR, …

Future GPD at COMPASS (N. d'Hose)

2nd goal of the « Holy-Grail »

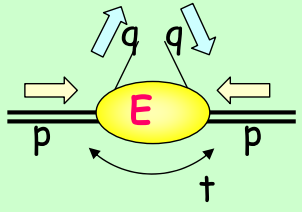
Contribution to the nucleon spin knowledge

$$\tfrac{1}{2} = \tfrac{1}{2}\,\Delta\Sigma + \Delta G + \langle L_z^q \rangle + \langle L_z^g \rangle$$

the GPDs correlation between the 2 pieces of information:
-distribution of longitudinal momentum carried by the partons $\vec{p}$
-distribution in the transverse plane $\vec{r}$

the GPD E allows nucleon helicity flip
so it is related to the angular momentum

$$2J_q = \int x\,(H^q(x,\xi,0) + E^q(x,\xi,0))\,dx$$

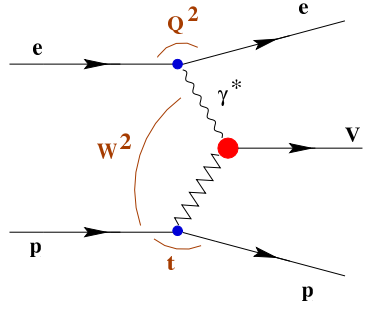


→ *with a transversely polarized target DVCS et MV*
→ *with a deuterium or neutron target DVCS*

XII WORKSHOP ON HIGH ENERGY SPIN PHYSICS

Dubna, Russia, 04.09.2007

New results on exclusive ρ^0 and ϕ meson production at hermes

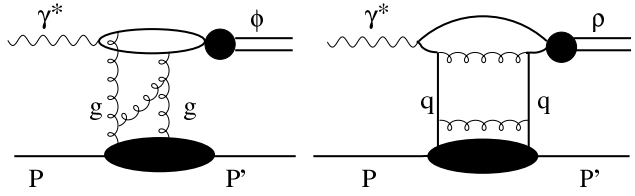


- Objectives: Generalized Parton Distributions
- Total and Longitudinal Cross Sections of ρ^0 and ϕ
- ρ^0 and ϕ Meson Spin Density Matrix Elements
  - Longitudinal-to-Transverse Cross-Section Ratios
  - Kinematic dependences
  - Hierarchy of Helicity Amplitudes
  - Unnatural Parity Exchange
- Beam and target polarization asymmetries
- Summary and Outlook

Alexander Borissov, DESY, on behalf of HERMES Collaboration

Summary

- HERMES data are unique due to the sensitivity to *both quark and two-gluon exchange processes* at sufficiently large W and Q^2 for the comparison with GPD handbag diagram based calculations:



- *First comprehensive comparision* of data on vector meson production with GK model calculations is in fair agreement for:
  - longitudinal and total cross sections of ρ^0 and ϕ mesons
  - values of SDMEs and hierarchy of corresponding amplitudes
  - violation of SCHC in ρ^0 prioduction
  - W-dependence of ρ^0 and ϕ SDMEs and σ_L/σ_T ratios

- Constraints of HERMES data in GPDs are for:
  - *phase difference* in the interference of $\gamma^*_L \to \rho^0_L \& \gamma^*_T \to \rho^0_T$ transitions
  - $\tilde{H}^{u,d}_{val}$ contribution in Unnatural Parity Exchange amplitude and A^{ρ}_{LL}
  - $E^{u,d}_{val}$ contribution in $A^{\rho^0}_{UT}$ asymmetry

Electroproduction of light vector mesons

S.V. Goloskokov

Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research,

Dubna 141980, Moscow region, Russia

In collaboration with P. Kroll, Wuppertal , hep-ph/0708.3569;
Euro. Phys. J. **C50**, (2007) 829

- Factorization of Vector meson leptoproduction .
- Model for GPDs.
- Modified PA for hard scattering amplitude
  - transverse degrees of freedom in wave function, hard subprocess ,
  -Sudakov suppression .
- Cross section in a wide energy range $5\text{GeV} < W < 75\text{GeV}$.
- SDME from HERMES, COMPASS to HERA energies.

XII WORKSHOP ON HIGH ENERGY SPIN PHYSICS Dubna, September 3 - 7, 2007

XII Workshop on
High Energy Spin Physics

Dubna, Sept. 3-7, 2007

Towards a GPD fitting procedure

D. Müller, Ruhr-Universität Bochum

- *Generalized parton distributions*
- *How to get a realistic GPD ansatz?*
- *Ready for a fitting procedure?*
- *Conclusions*

in collaboration with K. Kumerički and K. Passek-Kumerički (Zagreb)

BNL,JLab and Belle FESTIVAL

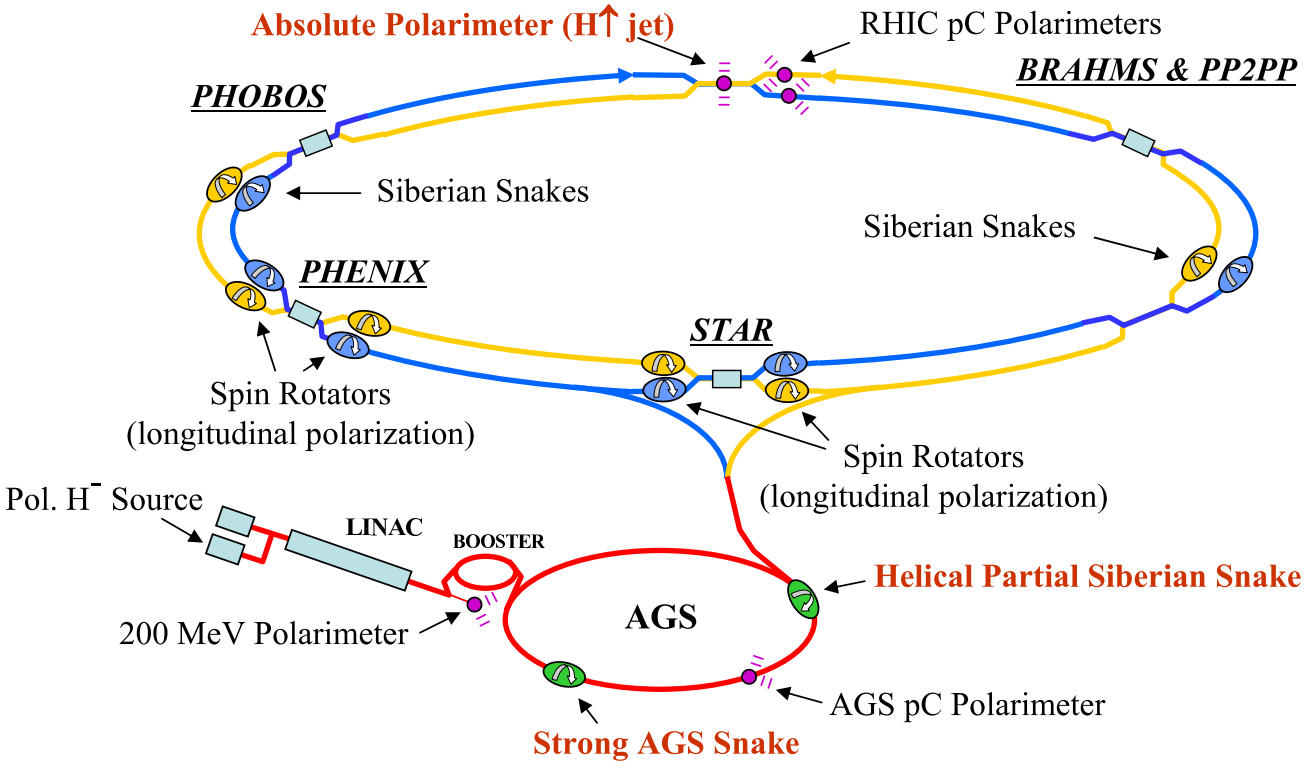
G. Bunce
Dubna Spin07, September 2007

The RHIC Spin Program

I would like to thank Les Bland, Werner Vogelsang, Abhay Deshpande, Sasha Bazilevsky, Matthias Grosse Perdekamp, for their advice and many plots.

The RHIC spin programme

RHIC Polarized Collider



2006: 1 MHz collision rate; P=0.6

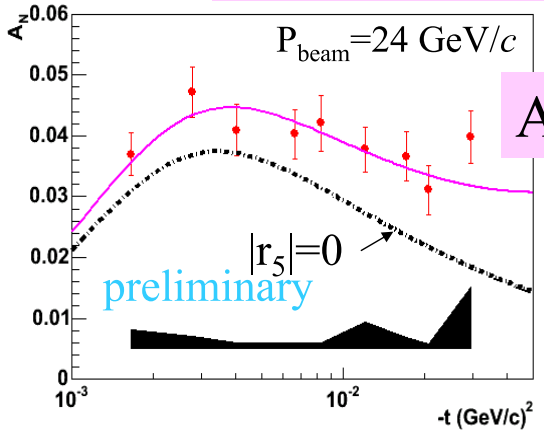
The RHIC spin programme

RHIC Spin Runs

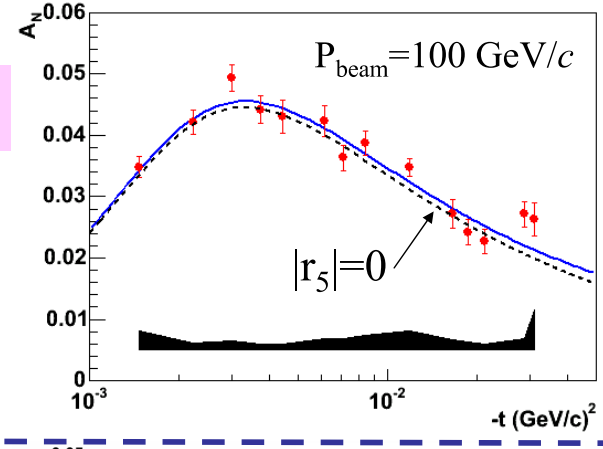
	P	L(pb^-1)	Results
2002	15%	0.15	first pol. pp collisions! disc. large n asymmetry
2003	30%	1.6	pi^0, photon cross section, A_LL(pi^0), 3 PRLs
2004	40%	3.0	polarized hydrogen jet, PLB
2005	50%	13	warm snake (RIKEN); large
	(P^4 x L = 0.8)		gluon pol. ruled out
2006	60%	46	cold snake; first long spin
	(P^4 x L = 6)		run (prelim. to Kyoto)

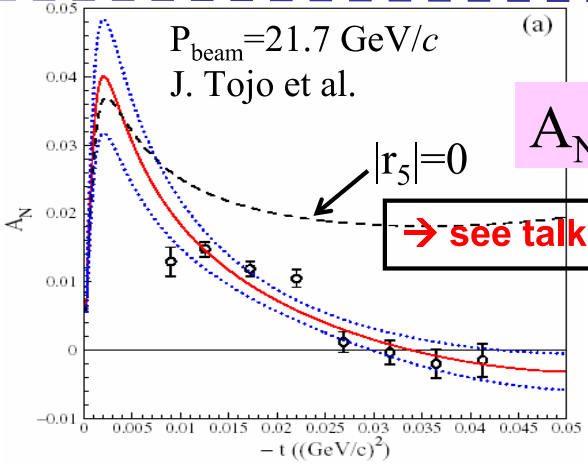
The RHIC spin programme

A_N collection in the CNI region



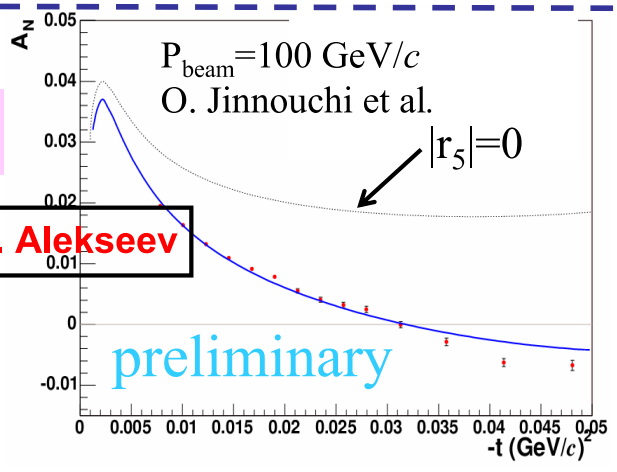
A_N^{pp}





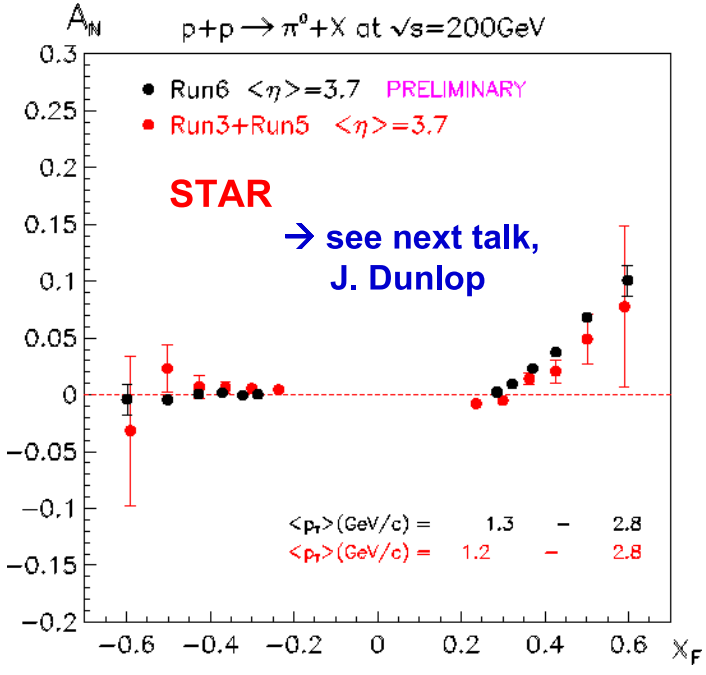
A_N^{pC}

→ see talk by I. Alekseev

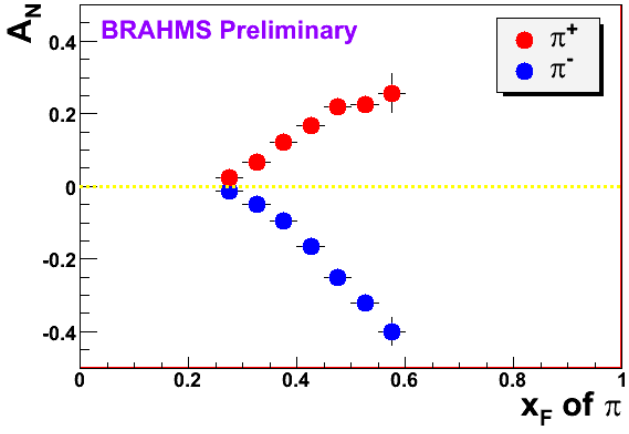


The RHIC spin programme

Transverse spin: pion A_N
--very large forward asymmetries



$A_N(\pi)$ at 62 GeV

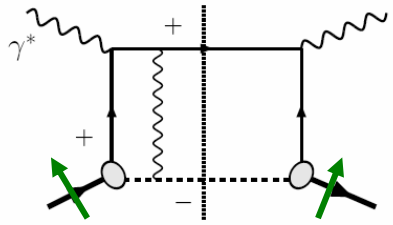


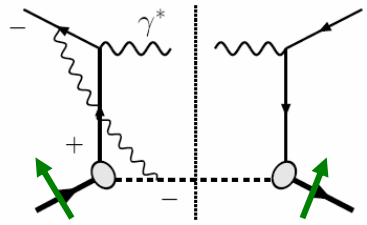
Kyoto Spin2006

Attractive vs Repulsive Sivers Effects

Unique Prediction of Gauge Theory !

Simple QED example:

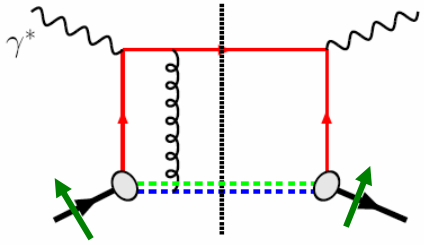


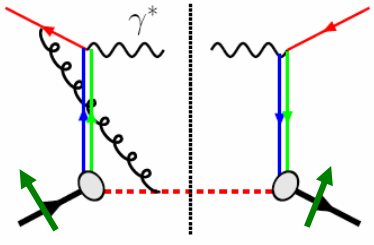


DIS: attractive

Drell-Yan: repulsive

Same in QCD:



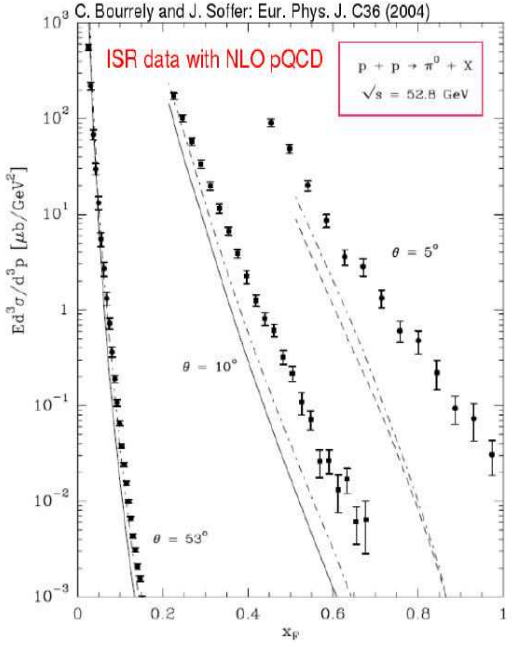


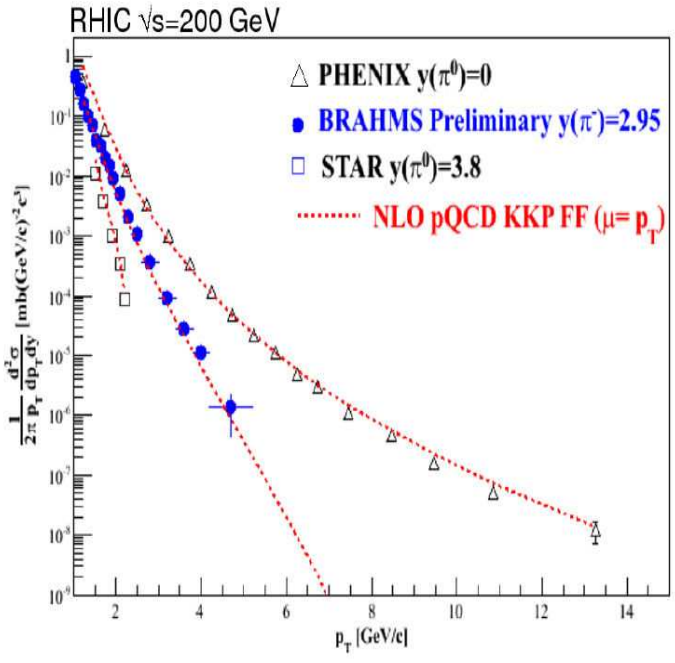
As a result:

$$\text{Sivers}|_{\text{DIS}} = -\text{Sivers}|_{\text{DY}}$$

Applicability of pQCD: forward angles

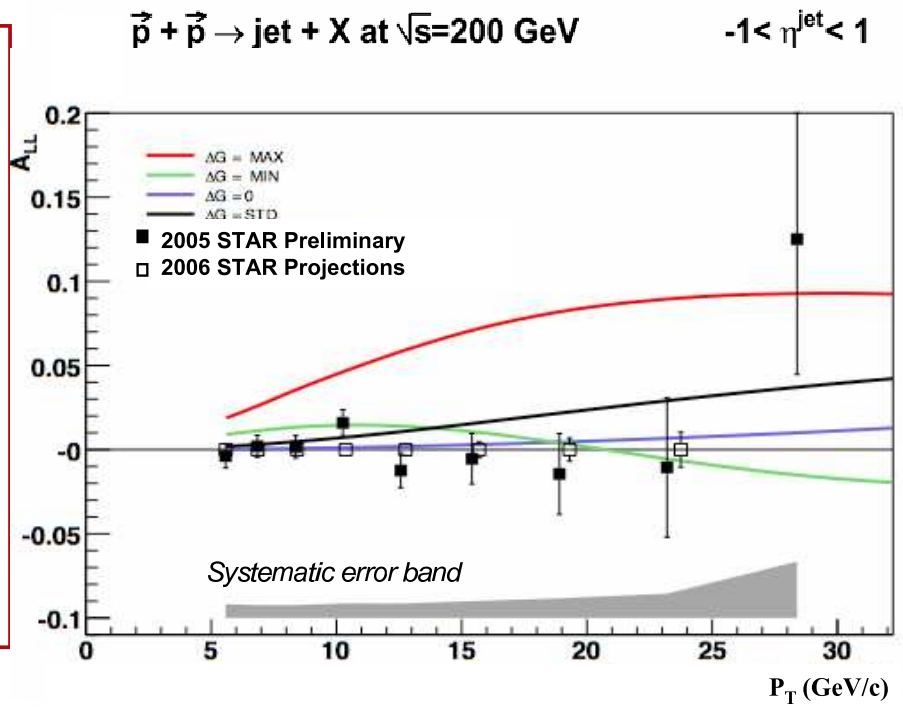
At RHIC, pQCD works also in the forward direction





Estimated 2006 Inclusive Jet Asymmetry

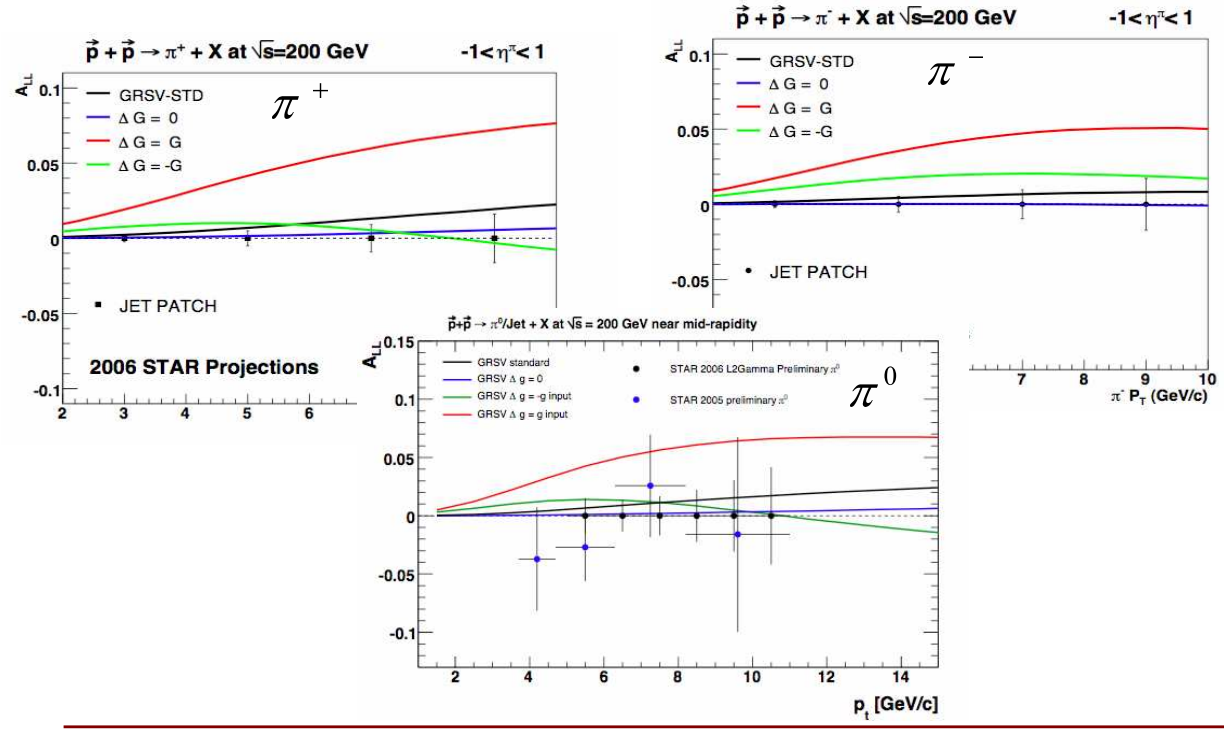
- Increase in sampled luminosity
- Polarization ~ 60% (FOM is P^4L)
- Entire BEMC instrumented
- Beamline shielding installed
- Greater emphasis on high p_T jets and dijets with triggers



STAR results

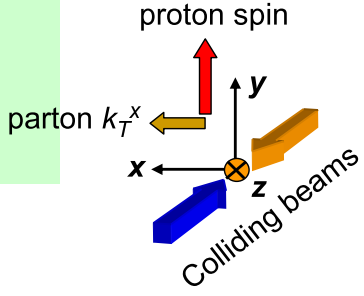
Inclusive π A_{LL} Sensitivity in 2006 Data at mid-rapidity

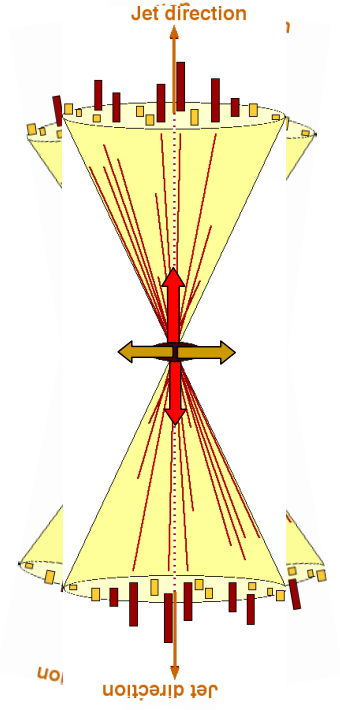
Dramatic increase in precision in Run 2006



Sivers Effect: Spin-dependent k_T kick to Di-Jets

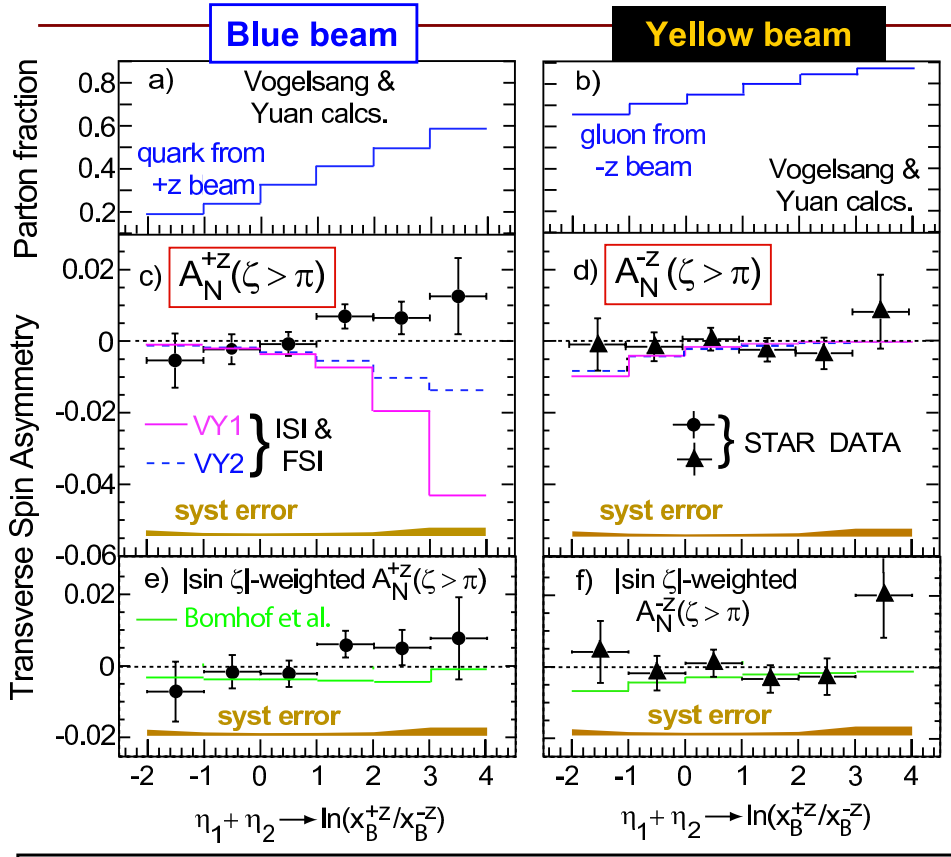
Sivers effect in $\vec{p}p \Rightarrow$ spin-dependent sideways boost to di-jets, suggested by Boer & Vogelsang (PRD 69, 094025 (2004))





STAR results

STAR Di-Jet Sivers Results vs. Jet Pseudorapidity Sum



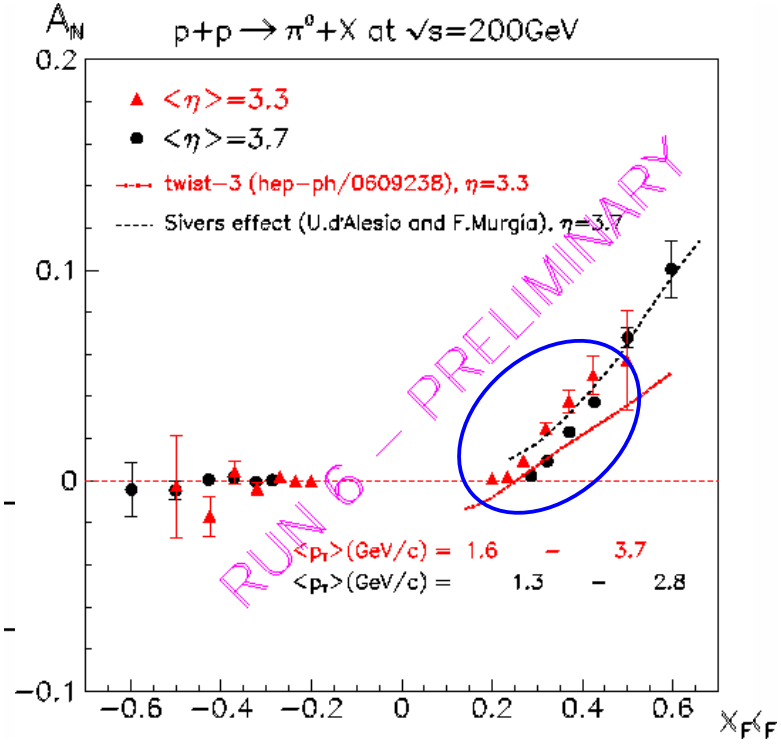
arXiv:0705.4629
Accepted by PRL

- All calcs. for STAR η acceptance
- Reverse calc. A_N signs for Madison convention
- Scale Bomhof calcs by $1/\langle|\sin\zeta|\rangle \approx 3.0$ to get A_N of unit max. magnitude
- u vs d and FSI vs ISI cancellations ⇒ sizable SSA in inclusive fwd. h prod'n and SIDIS (weighted SSA) compatible with small weighted di-jet SSA -- test via LCP flavor select

STAR A_N all consistent with zero ⇒ both net high-*x* parton and low-*x* gluon Sivers effects ~10x smaller in $\vec{p}p \rightarrow$ di-jets than SIDIS quark Sivers asym.!

STAR results

x_F dependence of A_N

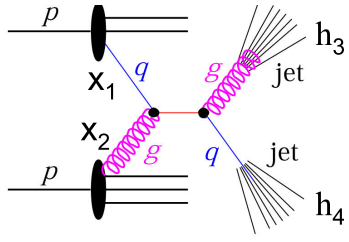


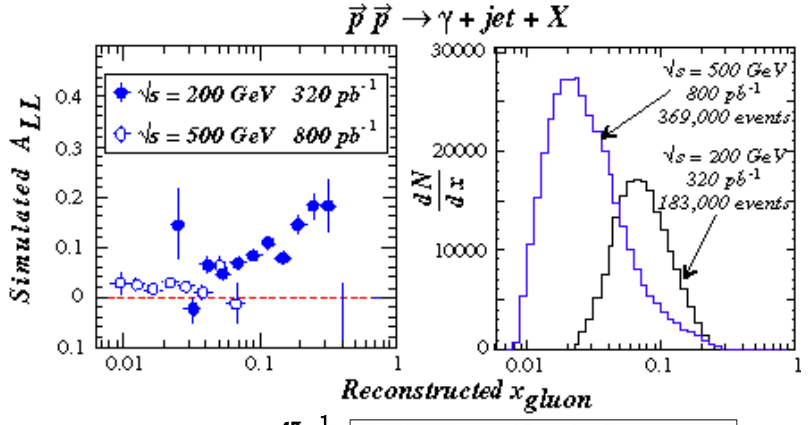
- A_N increases with X_F at positive x_F
- A_N is consistent with 0 at negative x_F
- Small errors allow quantitative comparison to the theory
- Run 6 added data points at η = 3.3 → ***The first map of x_F and p_T dependence***

hep-ex/0612030

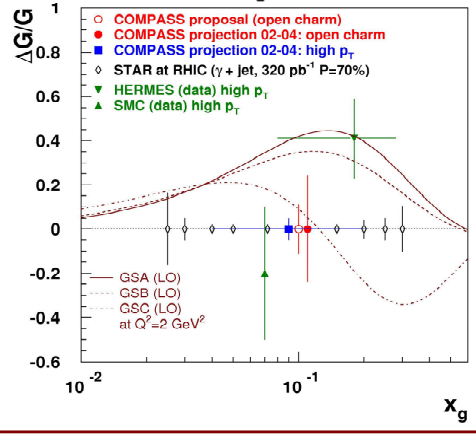
STAR results

Future of ΔG(x)





- Differential ΔG(x)
  - γ-jet and jet-jet
- Significant constraints from inclusive, but shape uncertainty remains
- High speed TPC DAQ + improved luminosity: approach 200 GeV and 500 GeV goals over next 5 years

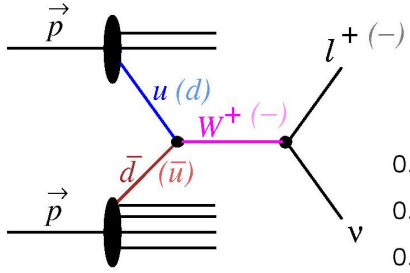


Polarization of the sea: A_L of W Production

Polarized $\bar{q}$ Flavor Asymmetry related to the nature of the sea

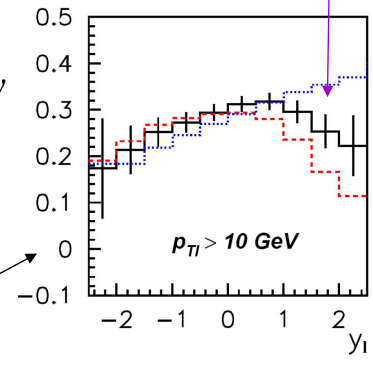
Parity violating long. asymmetry in W production allows extraction of

$$A_L^{W^-} \sim \bar{u}(x_1)\Delta d(x_2) + d(x_1)\Delta\bar{u}(x_2)$$



$\Delta\bar{u}(x)$-$\Delta\bar{d}(x)$

Nadolsky and Yuan, Nucl. Phys. B666 (2003) 31.



$\Delta_L p\ p \rightarrow (W^- \rightarrow l\ \bar{\nu}_l)\ X$

$\sqrt{s} = 500$ GeV, $L = 800\ pb^{-1}$

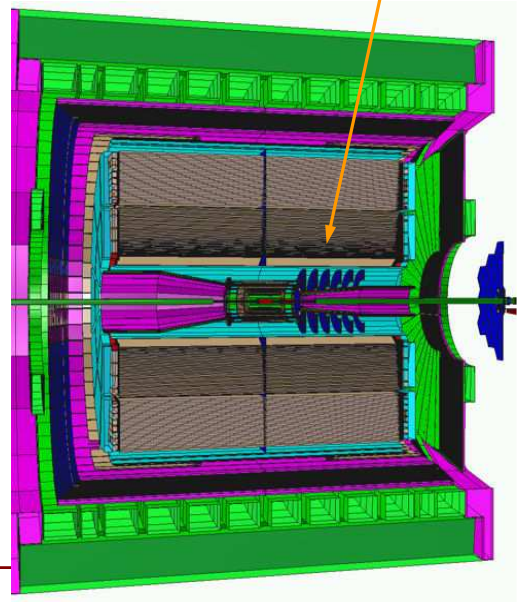
GS-A

GS-B

GRSV-2000 valence

← Large $\Delta\bar{d}$-$\Delta\bar{u}$

- Sensitivity in forward region
- Requires tracking for up to p_T~40 GeV e^+/e^- sign determination
- Tracking upgrade FGT



JLab results

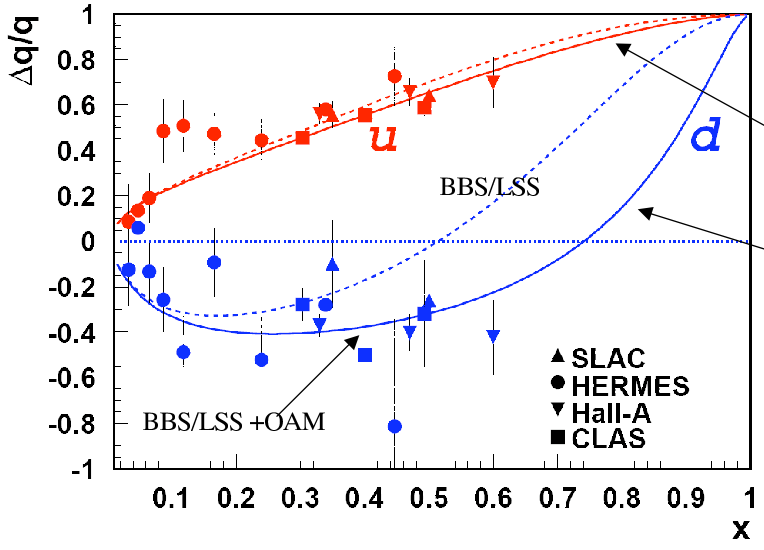
Spin Physics with CLAS

Gail Dodge
Old Dominion University

for the CLAS Collaboration

JLab results

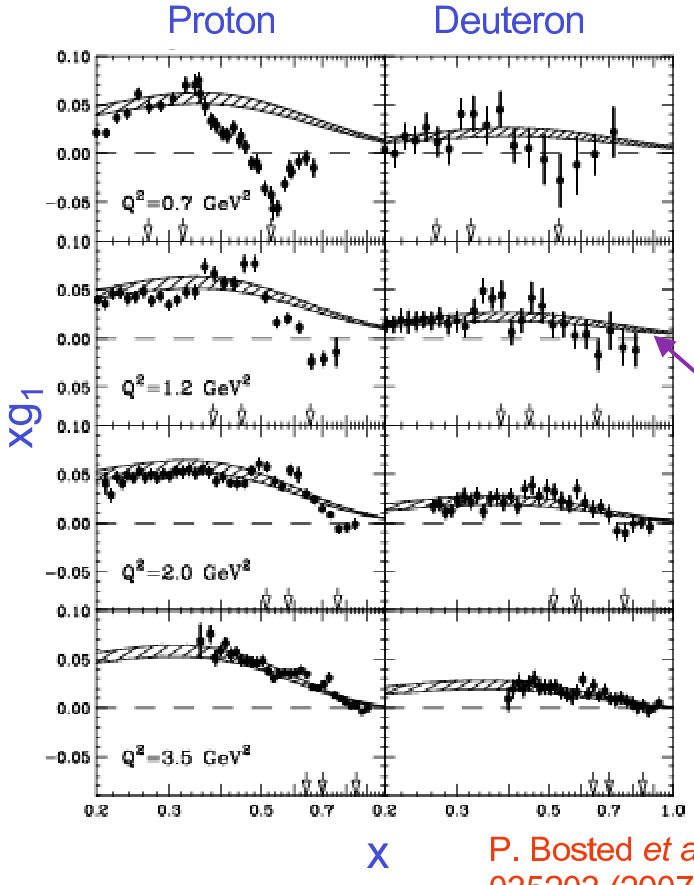
The Effect of Orbital Angular Momentum



includes L = 1 in nucleon wavefunction

H. Avakian, S. Brodsky, A. Deur, F. Yuan
hep-ph/0705.1553

JLab results



Duality in g_1

Curve represents range in g_1 from NLO parton distribution functions with target mass corrections applied and evolved to the Q^2 of the data:

AAC: PRD **69**, 054021 (2004)

GRSV: PRD **63**, 094005 (2001)

As Q^2 increases the data begin to average to the PDF curve.

The $\Delta(1232)$ resonance lies below the DIS curve, as expected.

P. Bosted *et al.*, Phys. Rev C 75, 035203 (2007)

JLab results

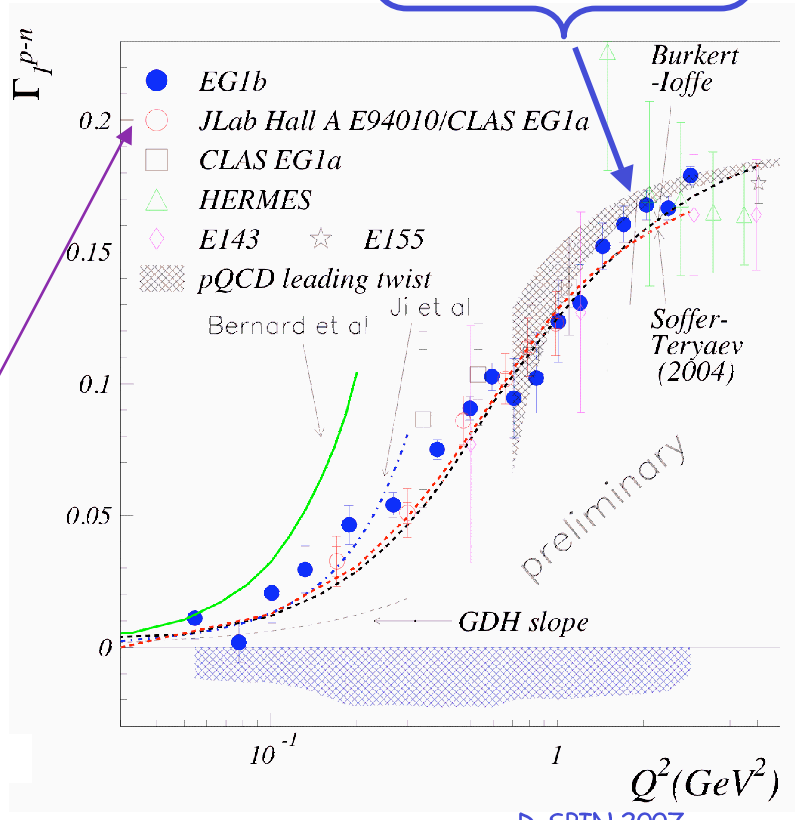
Bjorken Sum

$$\Gamma_1^p - \Gamma_1^n = \frac{g_A}{6} + Q^2 \text{ evolution}$$

Agreement with χPT up to higher Q^2

NNLO PQCD in reasonable agreement with the data

→ Higher twist is small even down to Q^2 = 0.5 GeV^2



Hall A data:

Amarian *etal.*, Phys. Rev. Lett. **89**, (2002) 242301

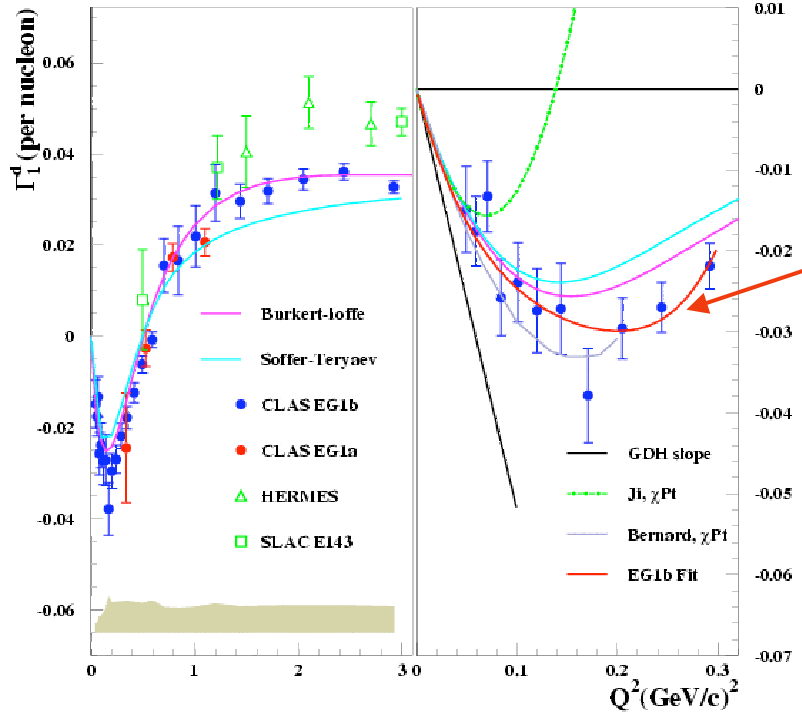
Amarian *etal.*, Phys. Rev. Lett. **92**, (2004) 022301

Figure from Alexandre Deur

JLab results

Deuteron: $\Gamma_1^d(Q^2)$ (per nucleon)

Ph.D. work: V. Dharmawardane – ODU



Like the proton, shows expected behavior at low and high Q^2

Agreement with χPT at the lowest points.

Low Q^2 fit to data:

$$\Gamma_1 = -\frac{\kappa^2}{8M^2}Q^2 + bQ^4 + cQ^6 + dQ^8$$

Ji predicts b = 3.26

Fit: b = 2.91 ± 0.52 (stat) ± 0.69 (syst)

Y. Prok *et al.*, to be submitted to PRL

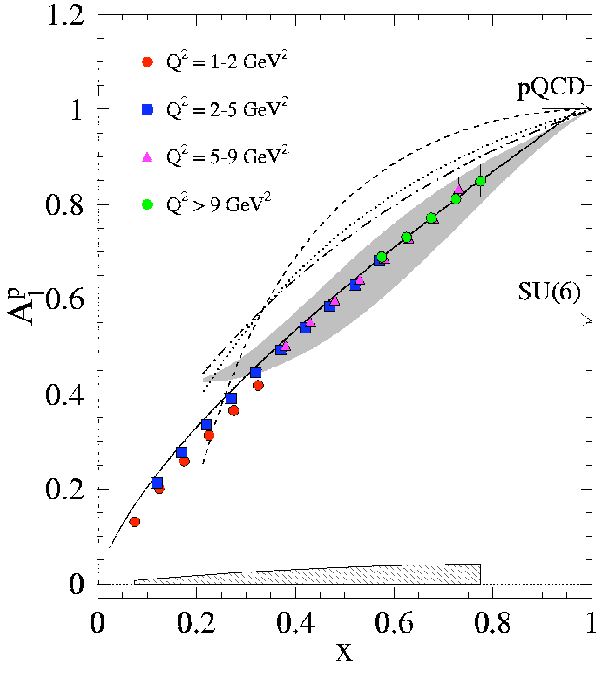
Ji: PLB **472**, 1 (2000)

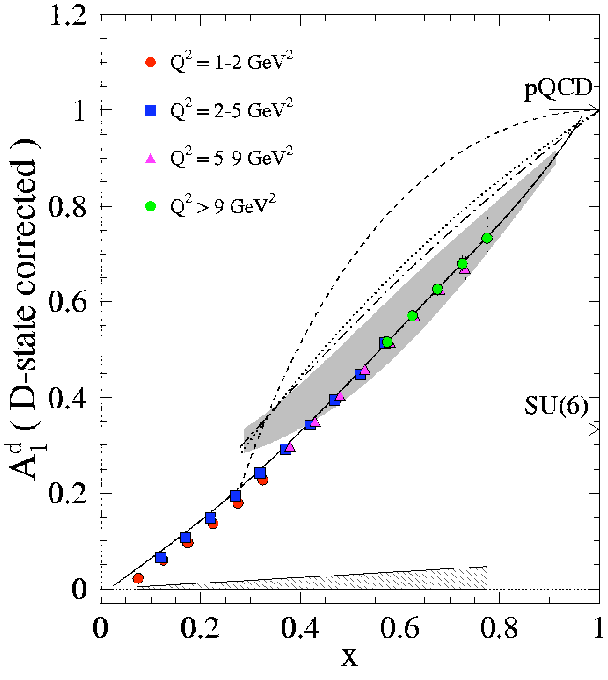
Bernard: PRD **67**, 078008 (2003)

JLab results

Predicted Data with CLAS12

Proton $W > 2$; $Q^2 > 1$ Deuteron





Gail Dodge, Old Dominion University

D-SPIN 2007

DVCS and meson production (Kubarovsky)

Outline

- Physics Motivation
- DVCS results (CLAS/Jlab)
  - Beam-spin asymmetry
  - Comparison with theoretical models
- π^0/η electroproduction
  - Cross section
  - Beam spin asymmetry
  - Cross section ratio
- Conclusion

DVCS and meson production (Kubarovsky)

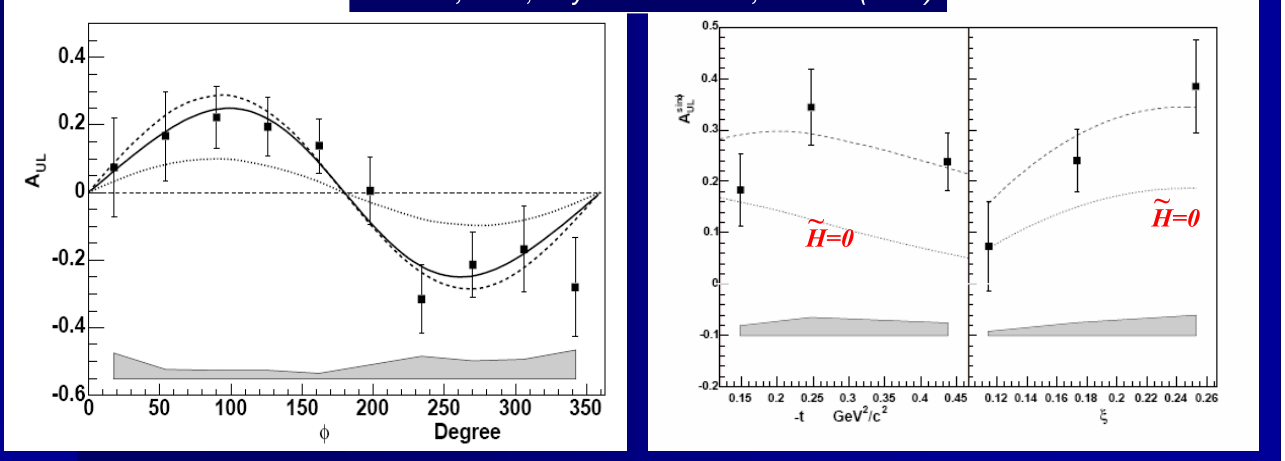
First DVCS measurement with spin-aligned target

Unpolarized beam, longitudinally spin-aligned target:

$$\Delta\sigma_{UL} \sim \sin\phi\, \mathrm{Im}\{F_1\widetilde{H}+\xi(F_1+F_2)H+\dots\}d\phi$$

A_{UL} sensitive to GPD $\widetilde{H}$

S. Chen, et al., Phys. Rev. Lett 97, 072002 (2006)



$\alpha = 0.252 \pm 0.042$
$\beta = -0.022 \pm 0.045$

Planned experiment in 2009 will improve accuracy dramatically.

Measurement of Collins Asymmetries in e^+e^- Annihilation at the KEK B-Factory

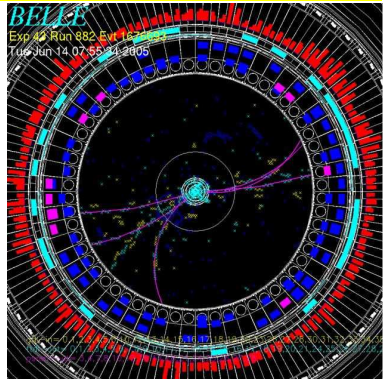
M. Grosse Perdekamp. Illinois

XII Workshop on High Energy Spin 2007

Joint Institute for Nuclear Research, Dubna, September 6th

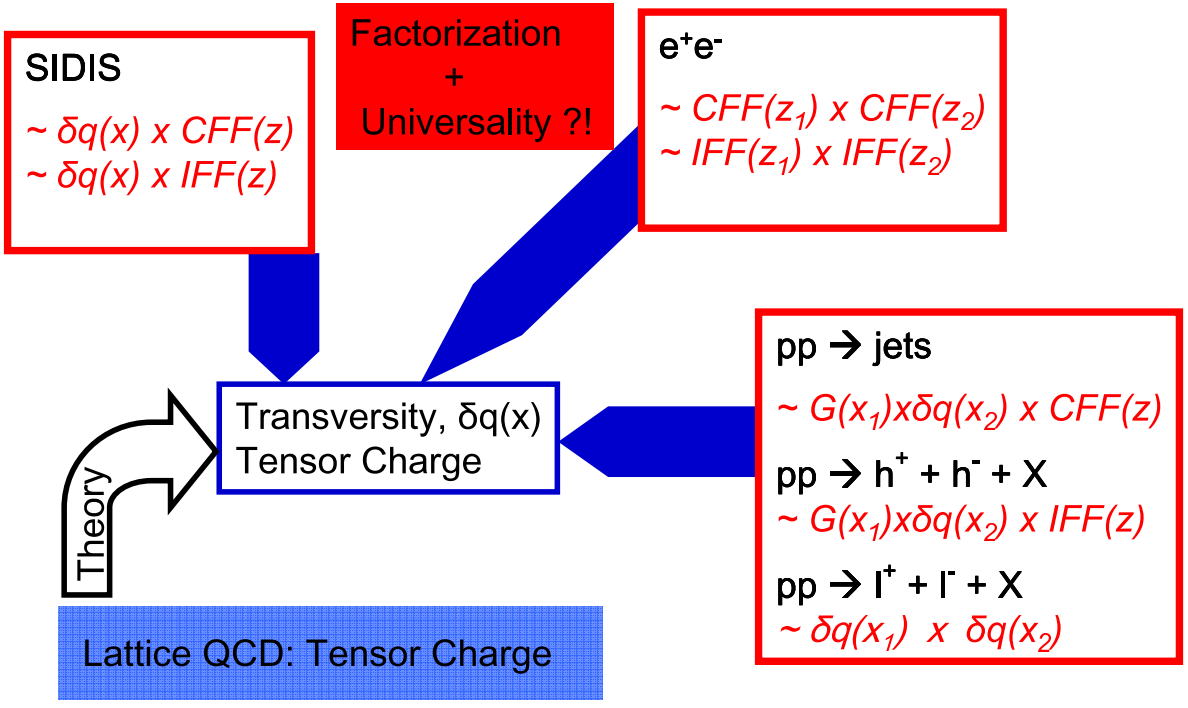
D. Gabbert	Illinois and RBRC
M. Grosse Perdekamp	Illinois and RBRC
K. Hasuko	RIKEN and RBRC
S. Lange	Frankfurt
M. Leitgab	Illinois
D. Mertens	Illinois
A. Ogawa	BNL and RBRC
R. Seidl	Illinois and RBRC
V. Siegle	RBRC

for the Belle Collaboration



Global Analysis: Extract Transversity Distributions

RBRC Transversity Workshop 2000



THEORY FESTIVAL

SSA Collins, Sivers

XII Workshop on high energy spin physics (DSPIN-07)
Dubna, September 3–7, 2007

Sivers and Collins Single Spin Asymmetries

A. Efremov,
JINR, Dubna, Russia

In collaboration with *J.C.Collins, K.Goeke, M.Grosse Perdekamp, S.Menzel, B.Meredith, A.Metz and P.Schweitzer*

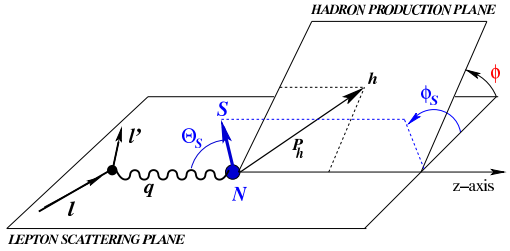
Based on PLB 612 (2005) 233, PRD 73 (2006) 014021, PRD 73 (2006) 094023, PRD 73 (2006) 094025.

Overview:

- What is Sivers effect?
- Sivers effect in SIDIS & Drell-Yan $\longrightarrow$ testing QCD predictions.
- Sivers effect for kaons — daily impact of new data!
- What is Collins effect?
- Collins effect in SIDIS & e^+e^--annihilation.
- Emerging picture of Collins function & transversity.
- Summary & Conclusions.

SIDIS on transv. polarized target

Expressions in LO $1/Q$ (Kotzinian, Boer, Mulders, ... 90s)
Factorization with k_T (Ji, Ma, Yuan&Collins, Metz 2004)



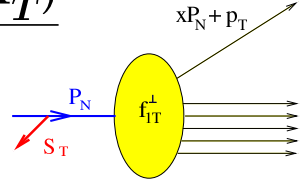
$$\frac{\mathrm{d}^3\boldsymbol{\sigma_T}}{\mathrm{d}\boldsymbol{x}\mathrm{d}\boldsymbol{z}\mathrm{d}\boldsymbol{\phi}} = \frac{\mathrm{d}^3\boldsymbol{\sigma_{\rm unp}}}{\mathrm{d}\boldsymbol{x}\mathrm{d}\boldsymbol{z}\mathrm{d}\boldsymbol{\phi}}\{1 + \boldsymbol{S_T}\,[\,\underbrace{\sin(\boldsymbol{\phi}-\boldsymbol{\phi_S})\;\boldsymbol{A_{UT}^{\sin(\phi-\phi_S)}}}_{\textbf{Sivers effect}} + \underbrace{\sin(\boldsymbol{\phi}+\boldsymbol{\phi_S})\;\boldsymbol{A_{UT}^{\sin(\phi+\phi_S)}}}_{\textbf{Collins effect}} + \cdots]\}$$

- Sivers function $f_{1T}^{\perp}(x, \mathbf{p}_T^2)$ "twist-2", naively/artificially "T-odd" (Teryaev talk) .
- Left-right asymmetry of PDF.

Sivers SSA: $\boldsymbol{A_{UT}^{\sin(\phi-\phi_S)}} \propto \dfrac{\boldsymbol{f_{1T}^{\perp a}(x, \mathrm{p}_T^2) \otimes D_1^a(z, \mathrm{K}_T^2)}}{\boldsymbol{f_1^a(x) D_1^a(z)}}$

(Sivers 1991, Brodsky, Hwang, Schmidt & Collins 2002)

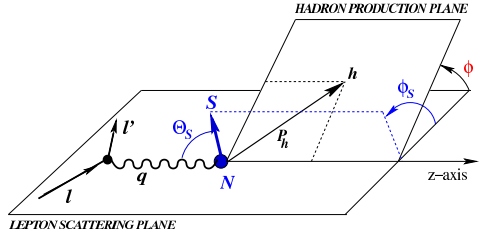
(Belitsky, Ji, Yuan & Boer, Mulders, Pijlman 2003)



- Remarkable **universality** property $\boldsymbol{f_{1T}^{\perp}|_{DIS} = -f_{1T}^{\perp}|_{DY}}$ (Collins 2002).

Of absolute importance to be tested experimentally!

Collins effect in SIDIS



- **SIDIS, transversely polarized target**
- Expressions in LO, $1/Q$ (Kotzinian, Boer, Mulders, ... 1990s)
- k_T–factorization (Ji, Ma, Yuan&Collins, Metz 2004)

$$\frac{\mathrm{d}^3\boldsymbol{\sigma_{UT}}}{\mathrm{d}x\mathrm{d}z\mathrm{d}\phi} = \frac{\mathrm{d}^3\boldsymbol{\sigma_{\rm unp}}}{\mathrm{d}x\mathrm{d}z\mathrm{d}\phi}\{1 + S_T\,[\underbrace{\sin(\phi-\phi_S)\,A_{UT}^{\sin(\phi-\phi_S)}}_{\text{Sivers effect}} + \underbrace{\sin(\phi+\phi_S)\,A_{UT}^{\sin(\phi+\phi_S)}}_{\text{Collins effect}} + \cdots]\}$$

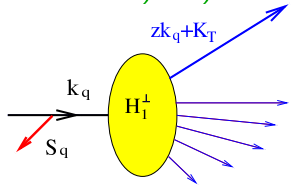
$$\Rightarrow \text{Collins SSA}: \quad A_{UT}^{\sin(\phi+\phi_S)} \propto \frac{h_1^a(x,\mathrm{p}_T^2)\otimes H_1^{\perp a}(z,\mathrm{K}_T^2)}{f_1^a(x)D_1^a(z)}$$

- $H_1^\perp(z,\mathrm{K}_T^2)$ **"twist-2", chirally odd & "naively T-odd"**

(Collins 1992, Efremov, Mankiewicz, Tornquist 1992 (transversal handedness $\equiv$ interference PFF), ...)

- Left-right asymmetry in fragmentation process
- **Transversity** $h_1^a(x)$**, twist-2, chirally odd**

(Ralston&Soper 1979, ...)



- **Long. polarized target**: $A_{UL}^{\sin 2\phi} \propto H_1^\perp$ at HERMES ~ 0; promising preliminary CLAS data.

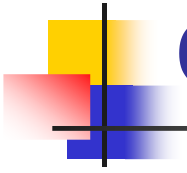
Sivers from small to large p_T (O. Teryaev)

Sivers function: from small to large transverse momenta

SPIN-07, JINR, Dubna,
September 3, 2007

Oleg Teryaev
JINR, Dubna
(in collaboration with P.G. Ratcliffe, University of Insubria, Como)

Sivers from small to large p_T (O. Teryaev)



Outline

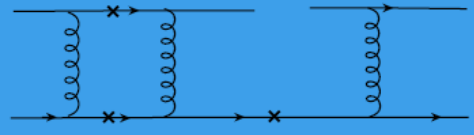
- Single Spin Asymmetries in QCD - Sources of Imaginary Phases
- Unsuppressed by 1/Q twist 3
- Non-universality of Sivers function: Colour modification at large -pT
- Sum rules for effective Sivers function from twist 3 effects in spn-dependent DIS
- Sivers function and GPDs
- Conclusions

Sivers from small to large p_T (O. Teryaev)

Perturbative PHASES IN QCD

QCD factorization: where to borrow imaginary parts?

Simplest way: from short distances - loops in partonic subprocess. Quarks elastic scattering (like $q - e$ scattering in DIS):



$$A \sim \frac{\alpha_S m p_T}{p_T^2 + m^2}$$

Large SSA "...contradict QCD or its applicability"

Global Analysis

Transversity, Collins and Sivers Effects from COMPASS, HERMES and BELLE Data: New Global Analysis

Alexei Prokudin

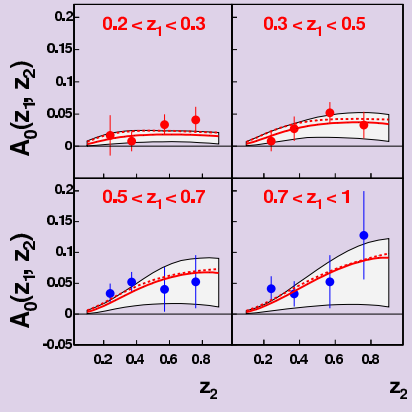
Università di Alessandria and INFN Sezione di Alessandria

XII Workshop on High Energy Spin Physics

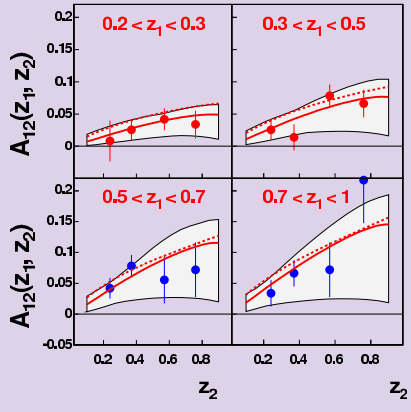
In collaboration with M. Anselmino, M. Boglione, U. D'Alesio, F. Murgia, A. Kotzinian and C.Turk

Global Analysis

BELLE $\cos(\varphi_0)$



BELLE $\cos(\varphi_1 + \varphi_2)$

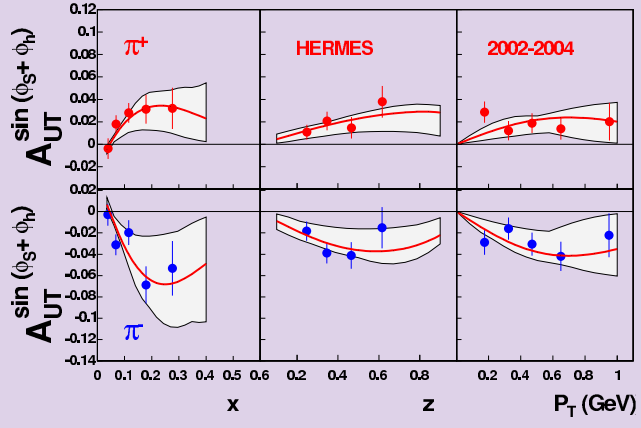


Solid line corresponds to FIT II, dashed line corresponds to FIT I

Global Analysis

HERMES $A_{UT}^{\sin(\phi_h+\phi_S)}$

$ep \to e\pi X$, $p_{lab} = 27.57$ GeV.



HERMES Collaboration, L. Pappalardo *et al.*, in the proceedings of the XIV International Workshop on Deep Inelastic Scattering, Tsukuba city, Japan, April 20th - April 24th. (2006).

Global Analysis

CONCLUSIONS

- *First* extraction of transversity for u and d quarks, $\Delta_T u(x)$ and $\Delta_T d(x)$, from HERMES, COMPASS and BELLE data is presented.
- Transversity $\Delta_T q(x)$ is found not to saturate Soffer bound $(q(x) + \Delta q(x))/2$.
  $\Delta_T u(x) > 0$ and $\Delta_T d(x) < 0$
- Estimates of the Collins fragmentation functions for favoured and unfavoured fragmentation have been obtained.
  $\Delta^N D_h^{fav}(z, |p_\perp|) > 0$ and $\Delta^N D_h^{unf}(z, |p_\perp|) < 0$
- Sivers functions for u, d and *sea* quarks are extracted from HERMES and COMPASS data.
- Predictions for Collins and Sivers asymmetries at JLab and COMPASS (with the proton target) are presented and expected to be sizable.

Dominant contributions in pion-production single-spin asymmetries

Marco Ramilli
Philip G. Ratcliffe

Universita` degli Studi dell'Insubria

DSPIN 07 - Dubna, 3 - 7 September, 2007

Spin-Orbit Dynamics from the Gluon Asymmetry

Gordon P. Ramsey

Loyola University Chicago and

Argonne National Lab

Collaboration with Y. Binder & D. Sivers

D. Sivers made the demonstration that SSA always involves a spin oriented momentum

XII WORKSHOP ON HIGH ENERGY SPIN PHYSICS (DSPIN-07)
Dubna, September 3 - 7, 2007

Progress in the Determination of Polarized PDFs and Higher Twist

E. Leader (London), A. Sidorov (Dubna), D. Stamenov (Sofia)

SUMMARY

- The low Q^2 *CLAS* data improve essentially our knowledge of higher twist corrections to g_1 structure function
- The central values of polarized PD are NOT affected, but the accuracy of its determination is essentially improved
- The *COMPASS* data (mainly at large Q^2) influence $|\Delta s|$ and ΔG which slightly decrease, but practically do NOT change HT

  ⇒ **Strong support of the QCD framework**

- Large (40%) contribution of HT to $(g_1)^d$ at small x (low Q^2)
- The present inclusive DIS data cannot rule out the negative and changing in sign gluon densities
- Good agreement with the directly measured $\Delta G/G$

OPEN QUESTIONS

- To constrain better ΔG ⟹ directly from *COMPASS, RHIC*;
  more precise experiments on g_1^d - *JLab Hall C*
- $\Delta\bar{u}$, $\Delta\bar{d}$ ⟹ from SIDIS (*COMPASS, JLab*) and $A_L(W^{+(-)})$ at *RHIC*
- L_q (from generalized PD - *HERMES, COMPASS, JLab*) and L_g ?
- a_8 ≠ 3F – D = 0.585 ? (how much $SU(3)_f$ is broken) → NA48 at CERN
- HT corrections in SIDIS, $O(\Lambda^4/Q^4)$ term in HT expansion in Bjorken x-space

  …etc.

Spin-07 3-7 Sept 2007, Dubna

Spin Structure Function g_1 at arbitrary x and Q^2

B.I. Ermolaev

talk based on results obtained in collaboration with M. Greco and S.I. Troyan

Positivity domains for pairs or triples of spin observables

Xavier Artru a)

Jean-Marc Richard b)

Jacques Soffer c)

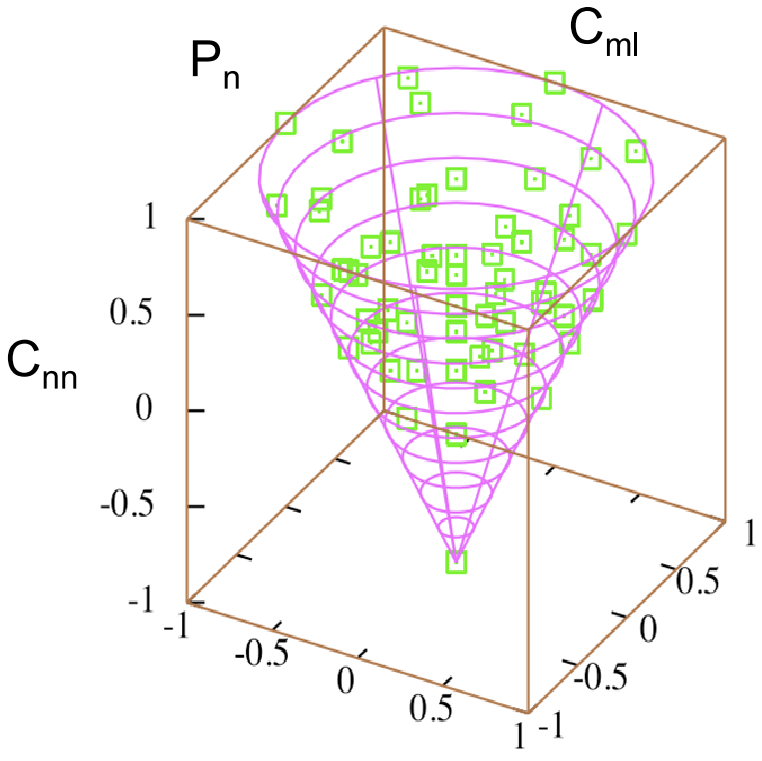
a) *IPN-Lyon, France*

b) *LPSC, Grenoble, France*

c) *Temple University, USA*

Domains for triples. Exemple:

- simulation with random amplitudes



Dubna Spin-07

Classical and quantum constraints in spin physics

X.Artru

IPN-Lyon, France

- Symmetry constraints
- Positivity constraints

Contact Interaction Searches at e^+e^- International Linear Collider: Role of Polarization

A.A. Pankov
The Abdus Salam ICTP Affiliated Centre,
Technical University of Gomel, Belarus

XII-th Workshop on High Energy Spin Physics,
DSPIN-07, Dubna, September 3 - 7, 2007

with *N. Paver* (Trieste) & *A.V. Tsytrinov* (Gomel & Trieste)

- Many Thanks to Anatoly and his co-workers for making this great Workshop
- See you at Spin2007 and in 2008 for the next Workshop