
# Summary of the Spin Physics Working Group

## Part One – Theory

Marco Stratmann

# Summary of working group activities

convenors: Krishna Kumar, Pasquale Di Nezza, Marco Stratmann

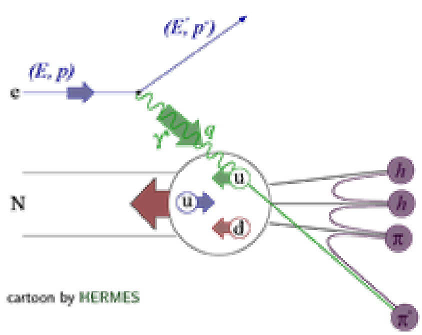
- 8 sessions, packed schedule: 39 talks (13 theory)
  (one jointly w/ „Diffraction“, one w/ „Hadronic Final States“)
- main themes:
  - (semi)-inclusive measurements & their interpretation
    R. Sassot; B. Ermolaev; G. Schierholz; T. Signal; D. Stamenov
  - single-spin asymmetries & transversity
    L. Gamberg, A. Prokudin, A. Mukherjee, D. Sivers
  - DVCS & exclusive processes
    C. Weiss, G. Schierholz
- special topics: elastic scattering; factorization; large x
  A. Afanasev; F. Yuan; S. Brodsky

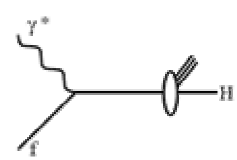
# Theme I: "(semi)-inclusive"

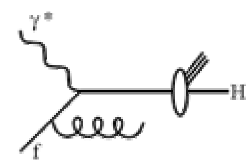
- new analyses of pol. pdfs: Sassot; Stamenov

pQCD status: NLO ✓ NNLO: only coeff. fcts. known

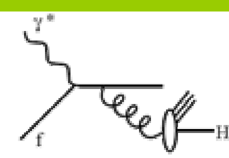
e.g. SIDIS @ NLO:

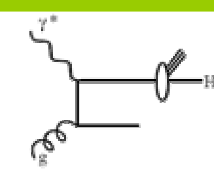



$$g_1^{N\,h}(x_{Bj}, z, Q^2) = \frac{1}{2} \sum e_q^2 \left\{ \Delta q\, D_q^h + \frac{\alpha_s}{2\pi} \left[ C_{qq} \otimes \Delta q \otimes D_q^h + C_{gq} \otimes \Delta q \otimes D_g^h + C_{qg} \otimes \Delta g \otimes D_q^h \right] \right\}$$



# “(semi)-inclusive“ (cont.)

## Sassot et al. hep-ph/0504155

focus:

- DIS & SIDIS data
  ↷ light sea densities
- stat. uncertainties

details of the fit:

- 20 parameters
- low input scale
- 313 DIS/165 SIDIS pts (incl. COMPASS & JLab)
- positivity
- no assumptions about sea

## Stamenov et al. hep-ph/0503140

focus:

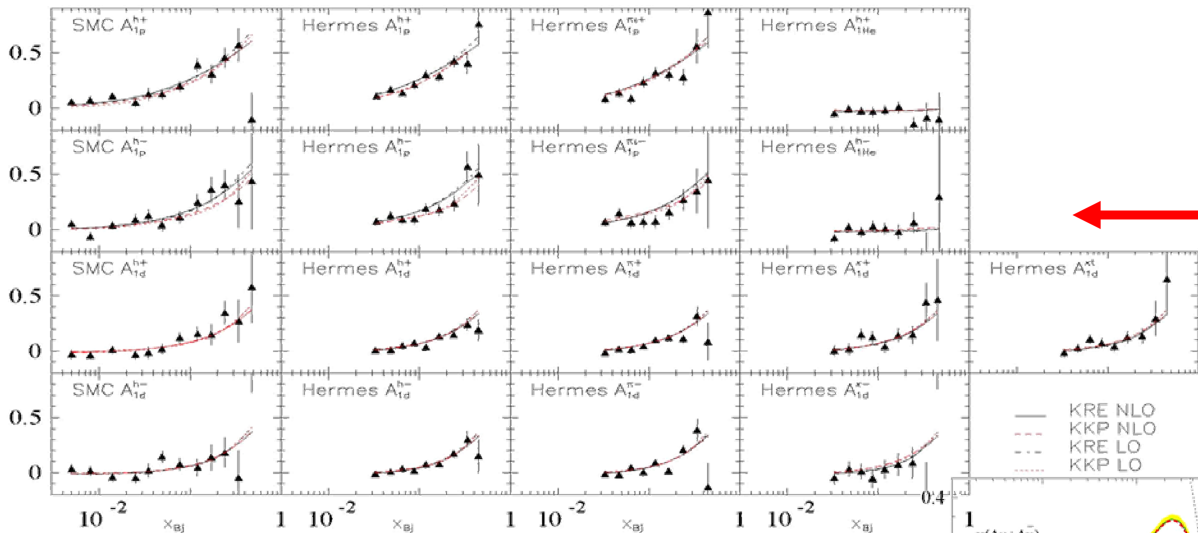
- role of higher twist
- impact of positivity
- scheme dependence

details of the fit:

- 6(pdfs) + 10(HT) parameters
- 1 GeV as input scale
- 200 DIS data pts (incl. COMPASS & JLab)
- SU(3) symmetric sea

# "(semi)-inclusive" (cont.)

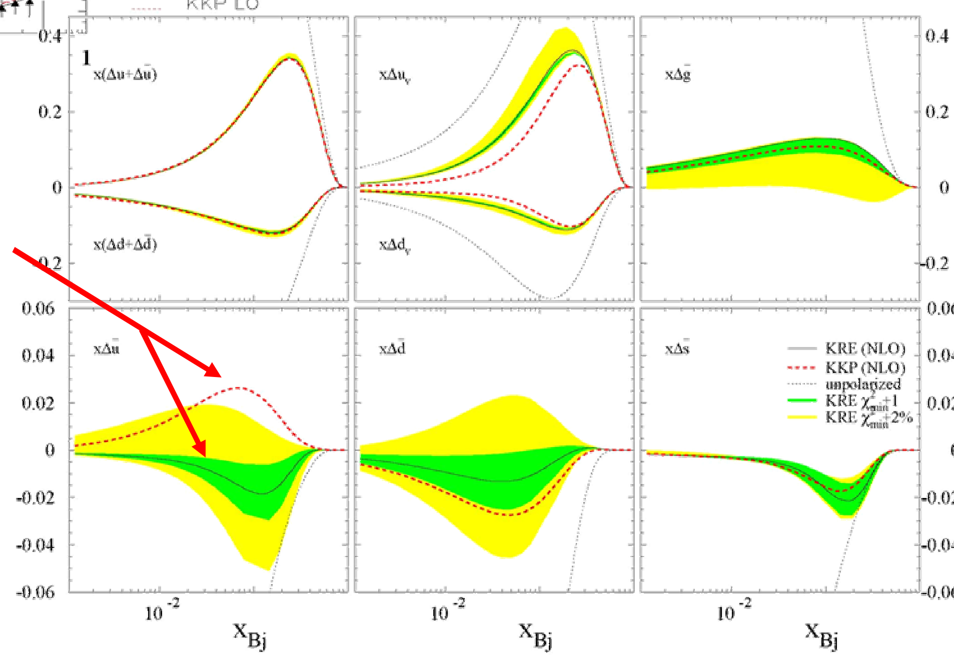
Sassot




DIS&SIDIS data nicely described

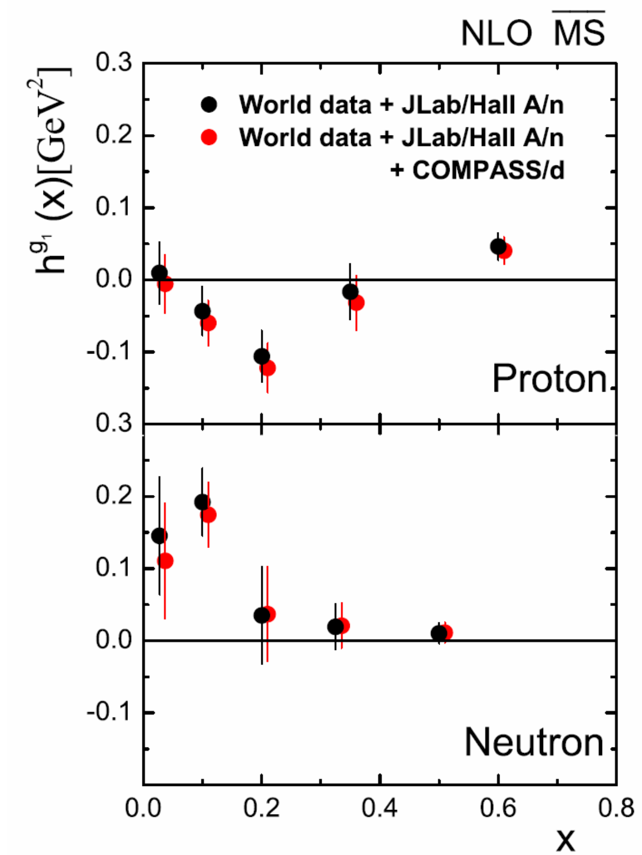
sea depends on choice of FFs
(dashed vs. solid lines)

best fit favors SU(3) sea
(solid lines)

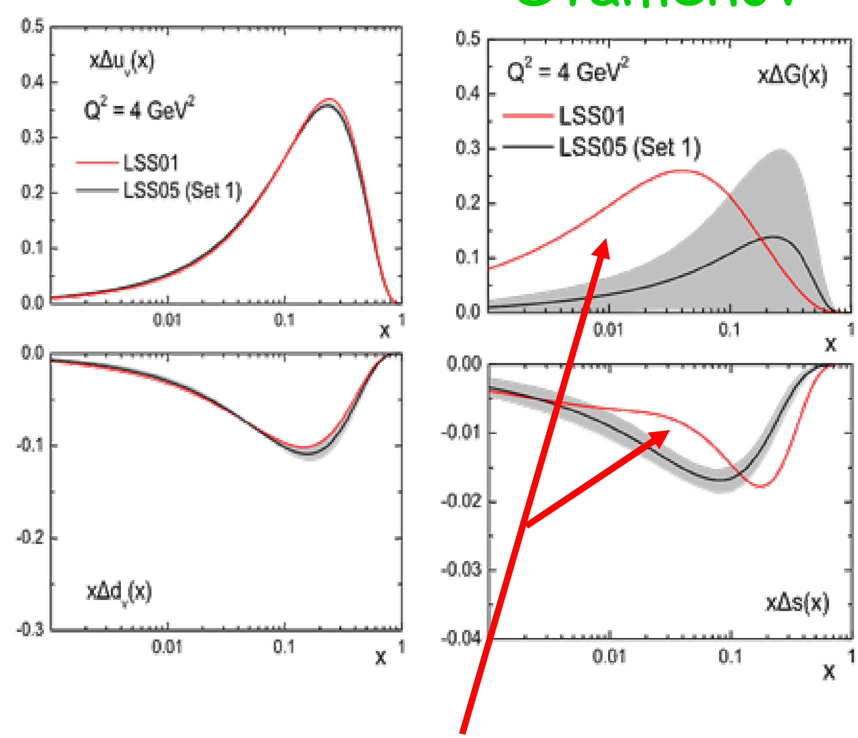


# “(semi)-inclusive“ (cont.)

HT approx. cancel in g1/F1 but are important for a g1 analysis




Stamenov




sea & gluon weakly constrained; results depend on how positivity is implemented in the fit

# “(semi)-inclusive“ (cont.)

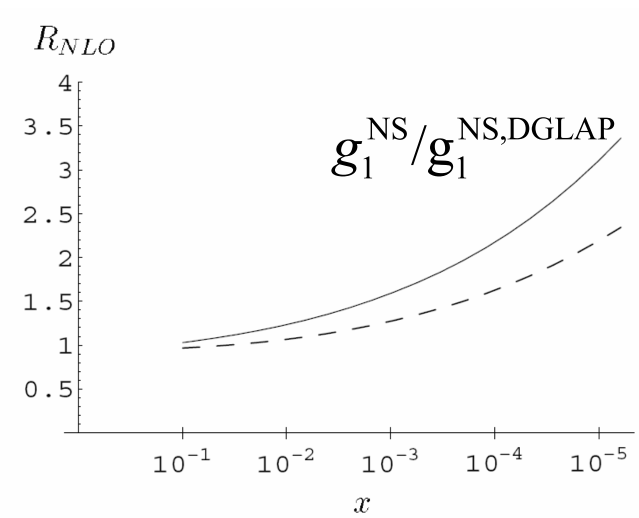
- theoretical issues – small x: Ermolaev hep-ph/0503019

small x behavior of g1 should be more than just DGLAP

DGLAP: $g_1 \approx \exp(\sqrt{C \ln(1/x) \ln\ln Q^2})$

resum (IREE) $[\alpha_s \ln^2(1/x)]^k$

DLA → $g_1 \approx (1/x)^\Delta$ $\Delta_{NS} \approx 0.43,\ \Delta_S \approx 0.86$




to describe entire x-range:
merge small-x resummation w/ DGLAP

small x behavior can be scrutinized at a future pol. ep-collider like eRHIC

# “(semi)-inclusive“ (cont.)

- calc. from 1st principles or models: Schierholz, Signal
  (Schierholz: lattice; Signal: meson cloud)

lattice simulations based on OPE → provide moments

$$a_n^q(\mu) = \int_0^1 dx\, x^n \Delta q(x,\mu^2) \quad = \Delta^n q \qquad\qquad a_0^q = \Delta q, \quad \boxed{g_A = \Delta u - \Delta d}$$

$$2\int_0^1 dx\, x^n g_1(x,Q^2) = e_{1,n}(Q^2/\mu^2, g(\mu^2))\, a_n(\mu)$$

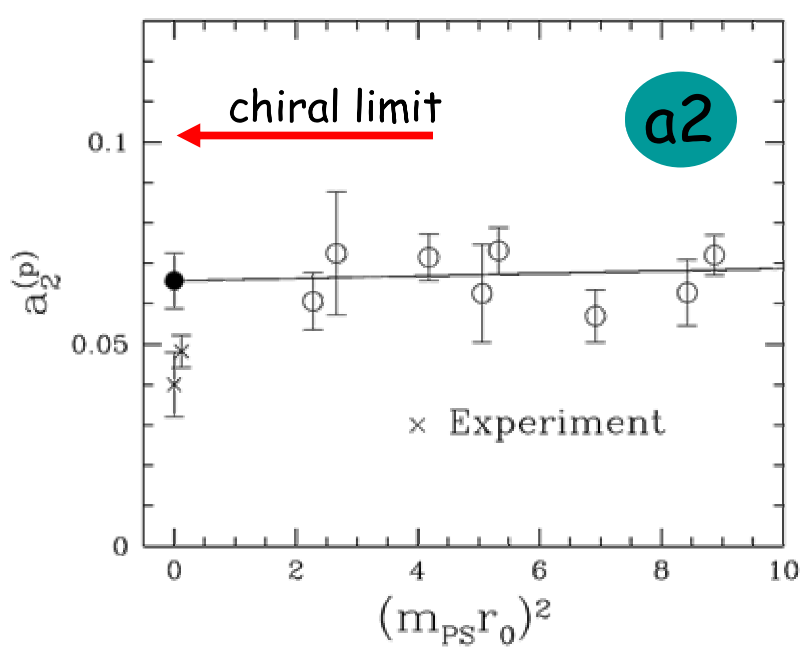
$$2\int_0^1 dx\, x^n g_2(x,Q^2) = \frac{n}{n+1}\left[e_{2,n}(Q^2/\mu^2, g(\mu^2))\, d_n(\mu) - e_{1,n}(Q^2/\mu^2, g(\mu^2))\, a_n(\mu)\right]$$

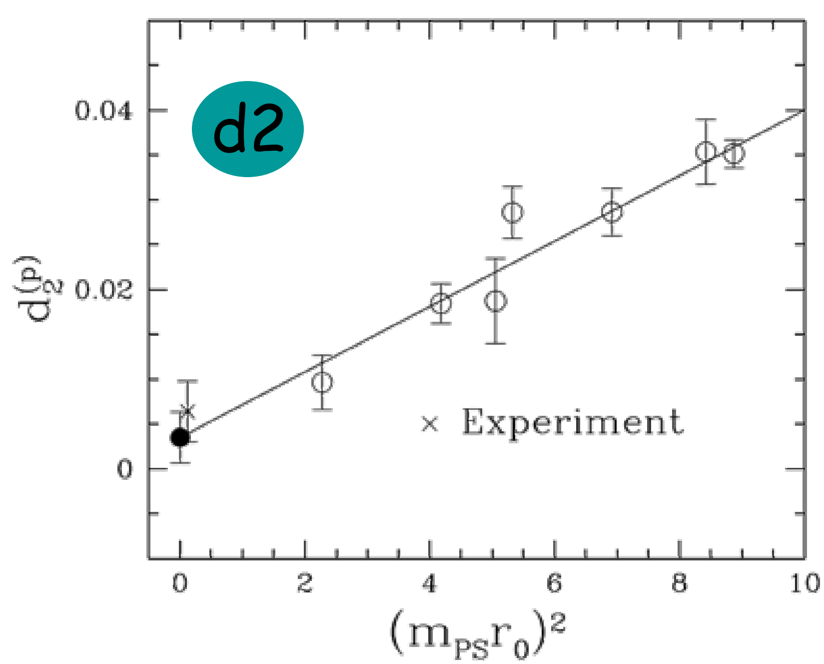
twist-3
parton-parton correlation

# “(semi)-inclusive“ (cont.)

Schierholz

e.g., 2nd moment (dyn. Wilson fermions, 2 flavors)




suggests that twist-3 might be small

# “(semi)-inclusive“ (cont.)

Signal

meson cloud = Fock expansion of wave function

$$|p\rangle_{\rm phys} = \sqrt{Z}|p\rangle_{\rm bare} + \sum_{BM} \int dy\, dk_\perp^2\, \phi_{BM}(y, k_\perp^2)|B; M\rangle$$

$p \rightarrow n\pi^+$, $\Delta^{++}\pi^-$, ...

include vector mesons & “interference“ to study spin structure

<u>predictions/features:</u>

- good description of $\bar{d} - \bar{u}$ ($\longleftrightarrow$ Gottfried sum rule)
- small SU(2) sym. breaking of pol. sea $\Delta\bar{d} - \Delta\bar{u}$ ($\longleftrightarrow$ HERMES data)
- meson cloud affects spin structure fcts. g1 and g2:

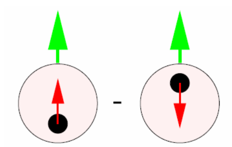
  proton: small (cancelations)     neutron: 10% effect

# Theme II: "SSA & transversity"

- transverse spin phenomena:

  very active field: lots of progress (exp & theor) recently

**main goals:**

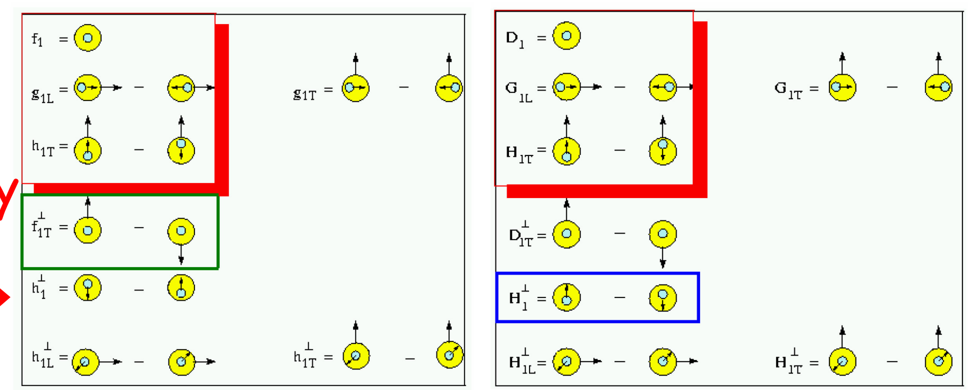


- learn about "transversity"

  last unknown twist-2 density

- understanding of SSA

  "zoo" of new pdf's and ff's




**theor./phenom. issues:**

- proper definition of TMD pdfs -> gauge link
- factorization — Yuan
- transition from small to large transv. momenta
- model calculations; interpretation of data — Prokudin, Gamberg

# “SSA & transversity“ (cont.)

Feng Yuan

hep-ph/0503015,0406302,0405085

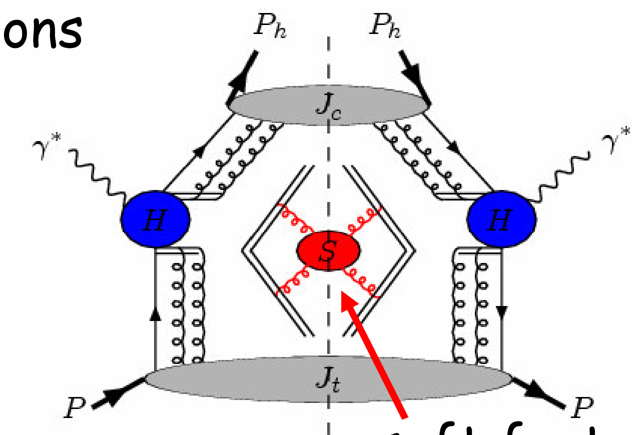
- important progress in theo. framework:

✓ gauge-invariant def. of TMD densities

role of gauge-link; final-state interactions

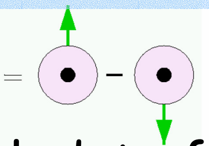
✓ proof of factorization in SIDIS

→ foundation of theor. framework




$$
\begin{aligned}
F(x_B, z_h, P_{h\perp}, Q^2) &= \sum_{q=u,d,s,\ldots} e_q^2 \int d^2\vec{k}_\perp d^2\vec{p}_\perp d^2\vec{\ell}_\perp \\
&\times q\left(x_B, k_\perp, \mu^2, x_B\zeta, \rho\right) \hat{q}_h\left(z_h, p_\perp, \mu^2, \hat{\zeta}/z_h, \rho\right) S(\vec{\ell}_\perp, \mu^2, \rho) \\
&\times H\left(Q^2, \mu^2, \rho\right) \delta^2(z_h\vec{k}_\perp + \vec{p}_\perp + \vec{\ell}_\perp - \vec{P}_{h\perp})
\end{aligned}
$$

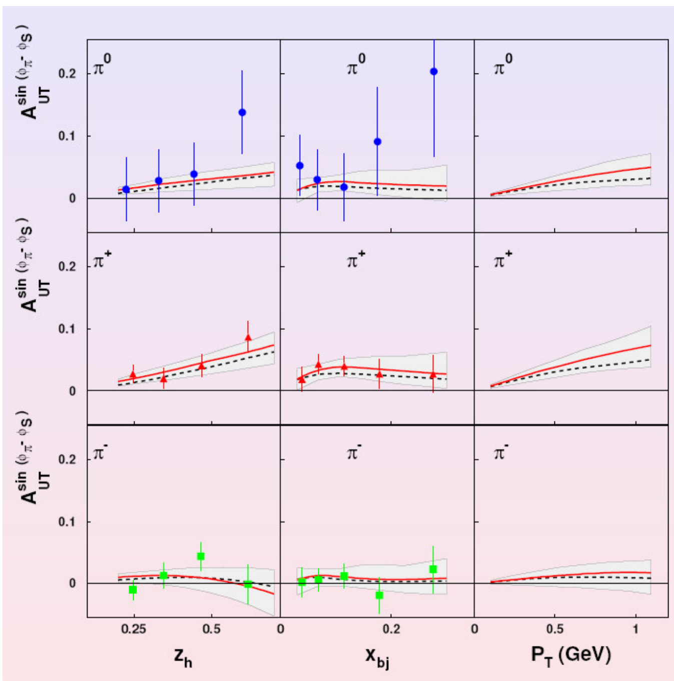
# "SSA & transversity" (cont.)

- extraction of "Sivers function": $f_{1T}^{\perp} =$ 

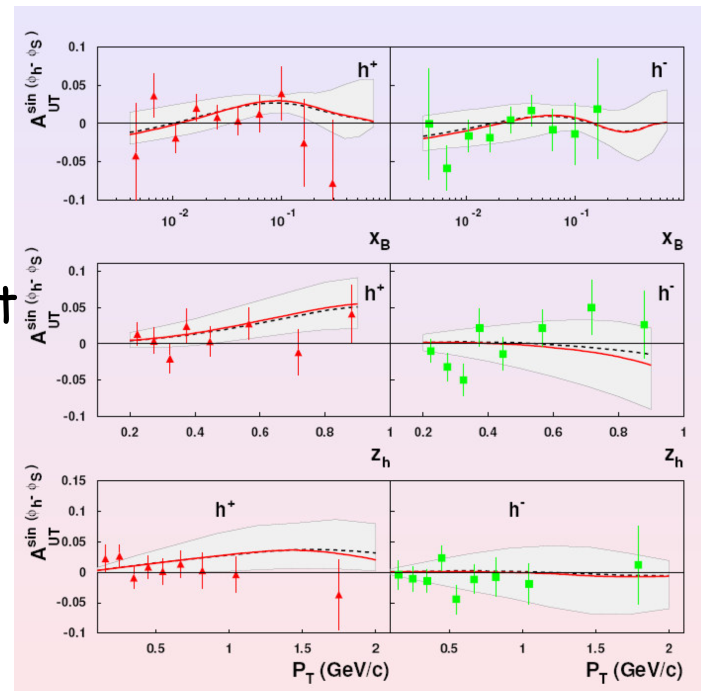
Prokudin
hep-ph/0501196

<u>strategy</u>: (1) fix intr. trans. mom. from <u>unpol</u>. data first
(2) estimate Sivers fct. from HERMES data
(3) check COMPASS data

HERMES




consistent




COMPASS

# "SSA & transversity" (cont.)

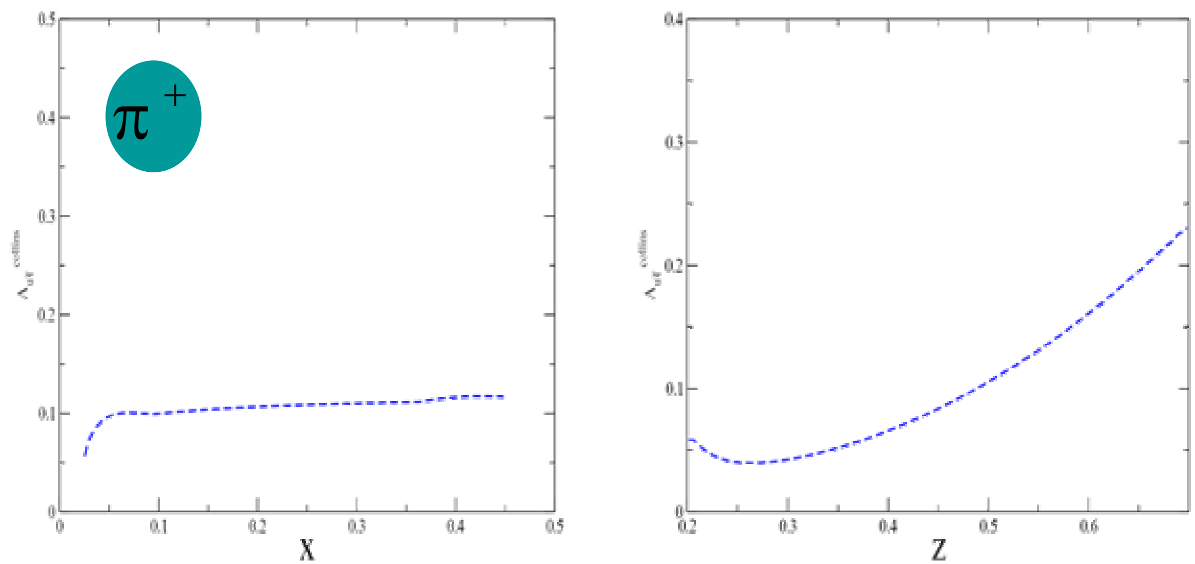
- model estimates for TMD pdf's and ff's: **Gamberg** hep-ph/0209085,0307139

e.g. Collins fragmentation fct: (use "rescattering mech." & Gaussian$\langle k_\perp^2 \rangle$)

$$H_1^\perp(z,k_\perp) = \frac{N'^2 f^2 g^2}{(2\pi)^4}\frac{1}{4z}\frac{(1-z)}{z}\frac{\mu}{\Lambda'(k_\perp^2)}\frac{M_\pi}{k_\perp^2}\mathcal{R}(z,\boldsymbol{k}_\perp^2)$$

$$\langle \frac{P_{h\perp}}{M_\pi}\sin(\phi+\phi_s)\rangle_{UT} = |S_T|\frac{2(1-y)\sum_q e_q^2 h_1(x) z H_1^{\perp(1)}(z)}{(1+(1-y)^2)\sum_q e_q^2 f_1(x) D_1(z)}$$

(HERMES kinematics)

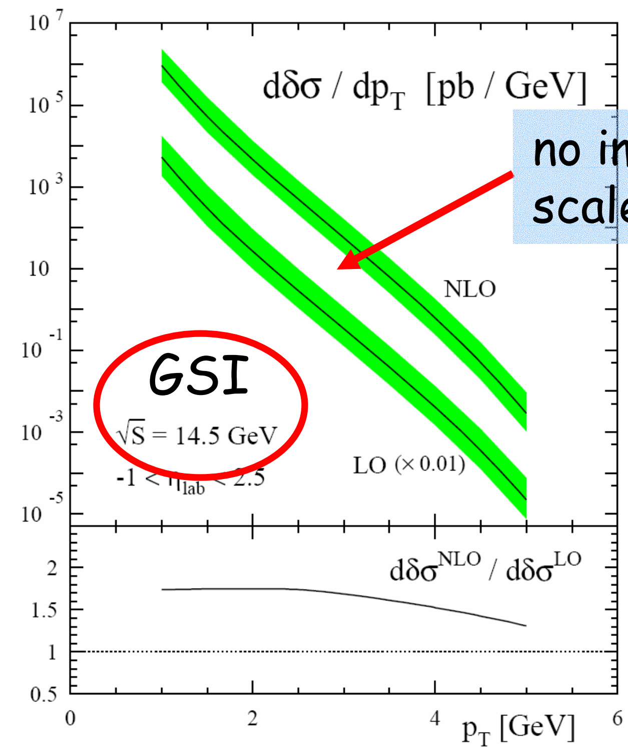



other model estimates: Sivers effect, unpol. DY $\cos 2\phi$ ,...

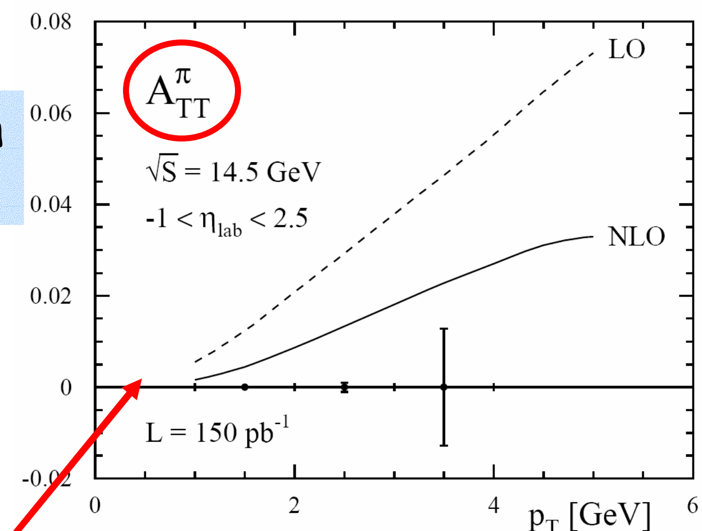
# “SSA & transversity“ (cont.)

- new NLO results: single-incl. hadrons:

Mukherjee




no improvement in scale dependence



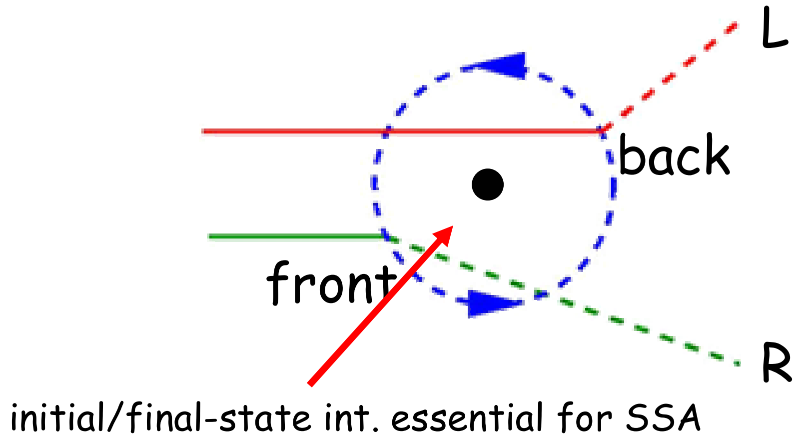

interesting tool to learn about transversity
no other unknown (TMD) fcts. involved here!

<u>at RHIC energies</u>: much improved scale dep. but small asymmetries

# "SSA & transversity" (cont.)

Sivers

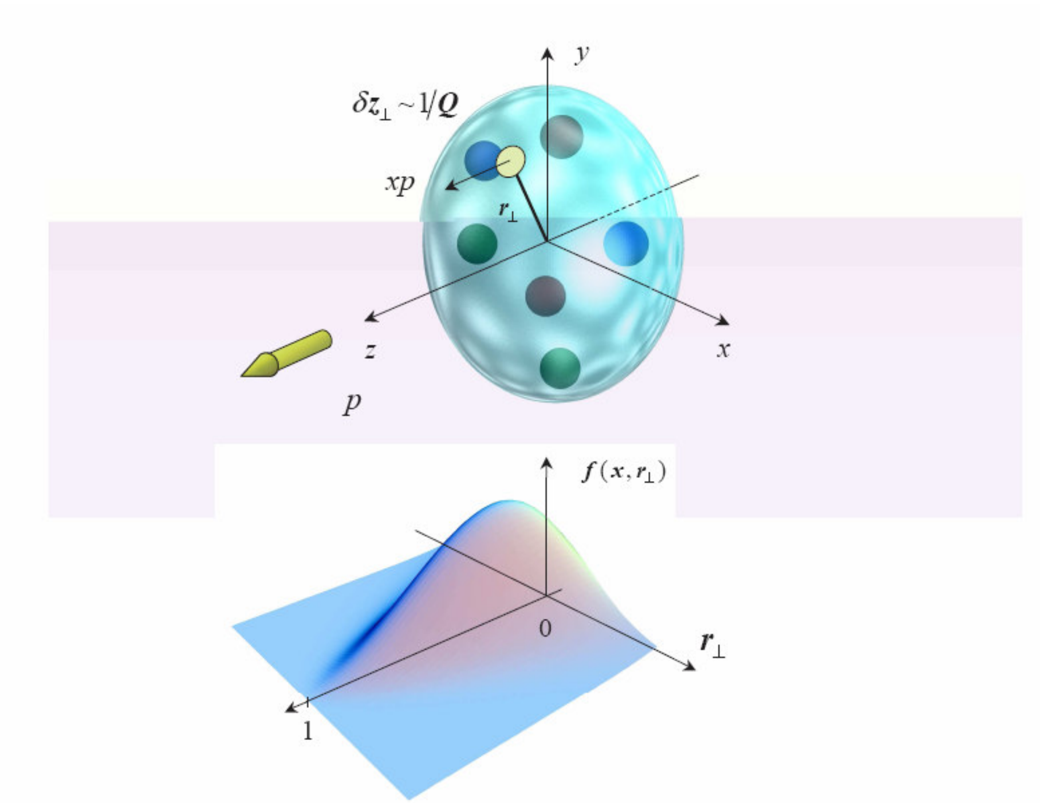
- remarks on T-oddness, SSA, factorization:
  - T-oddness of some TMD distributions must not be confused with true time reversal invariance
    → better call it <u>"artificial/naive" time reversal</u>
    (<u>all</u> SSA are odd under parity x naive time reversal)
  - simple model: scattering off a rotating object




- simple model to understand SSA (breakdown of orbital symmetry)
- possible way to understand factorization for SSA

# Theme III: “exclusive“

- GPDs are versatile objects :




- 3D structure of hadrons
- contain form factors
- contain structure fcts.
- angular momentum contribution to spin sum
- ....

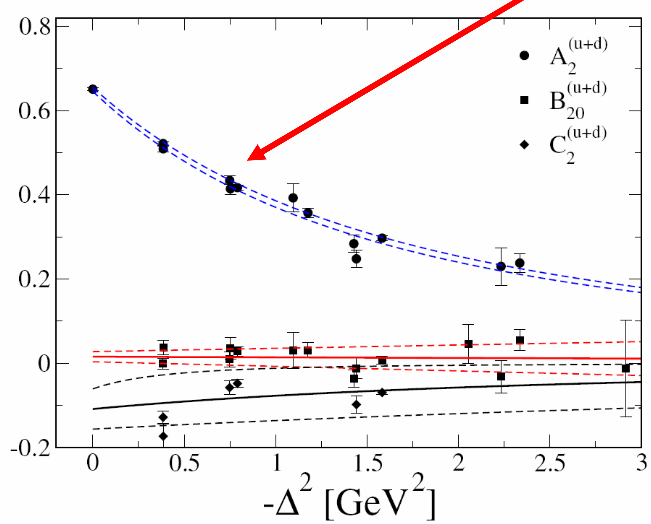
# "exclusive" (cont.)

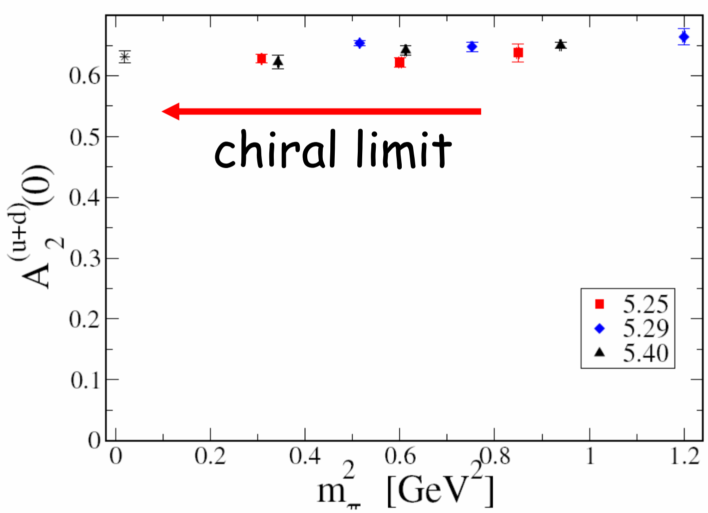
- recent lattice results:

Schierholz
hep-ph/0501029

$$\langle p_1, s|\, \mathcal{O}^q_{\{\mu_1\cdots\mu_n\}}\, |p_2, s\rangle = \bar{u}(p_1, s)\left[A^q_n(\Delta^2)\gamma_{\{\mu_1} + \frac{i\Delta^\alpha}{2m_N} B^q_n(\Delta^2)\sigma_{\alpha\{\mu_1}\right]\bar{p}_{\mu_2}\cdots\bar{p}_{\mu_n\}}\, u(p_2, s) + \cdots$$

e.g.




angular momentum:

$$A^q_2(0) + B^q_2(0) = J^q$$

$$L^{u+d} = 0.03(7)$$

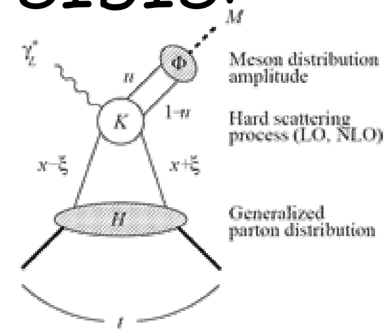
$$L^{u-d} = -0.45(6)$$

strong cancellations

# “exclusive“ (cont.)

Weiss

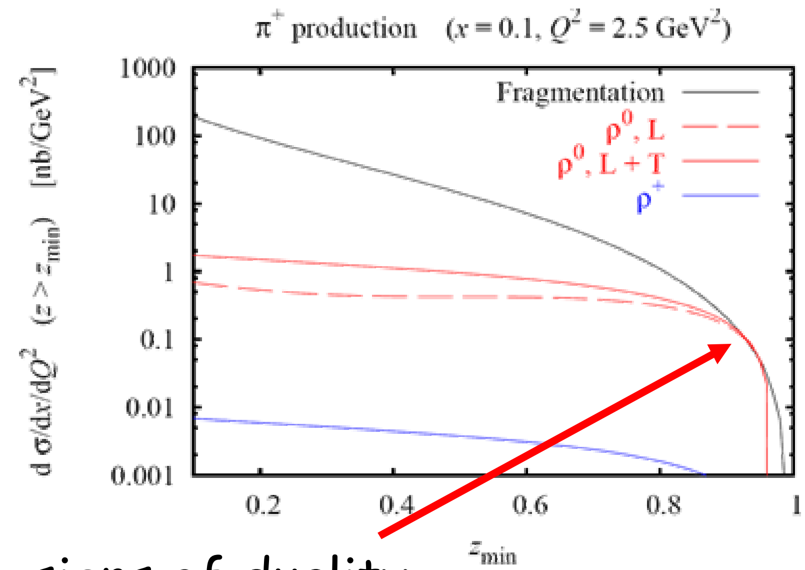
- ongoing work on role of excl. channels in SIDIS:




goals:
- quantify uncert. for excl. meson electroprod.
- duality in SIDIS for z->1 ?

tools:
- factorization
- some model for GPDs

limitations:
- higher twist contr. ?
- frag. fcts. at low scales? (in particular, for strangeness production)

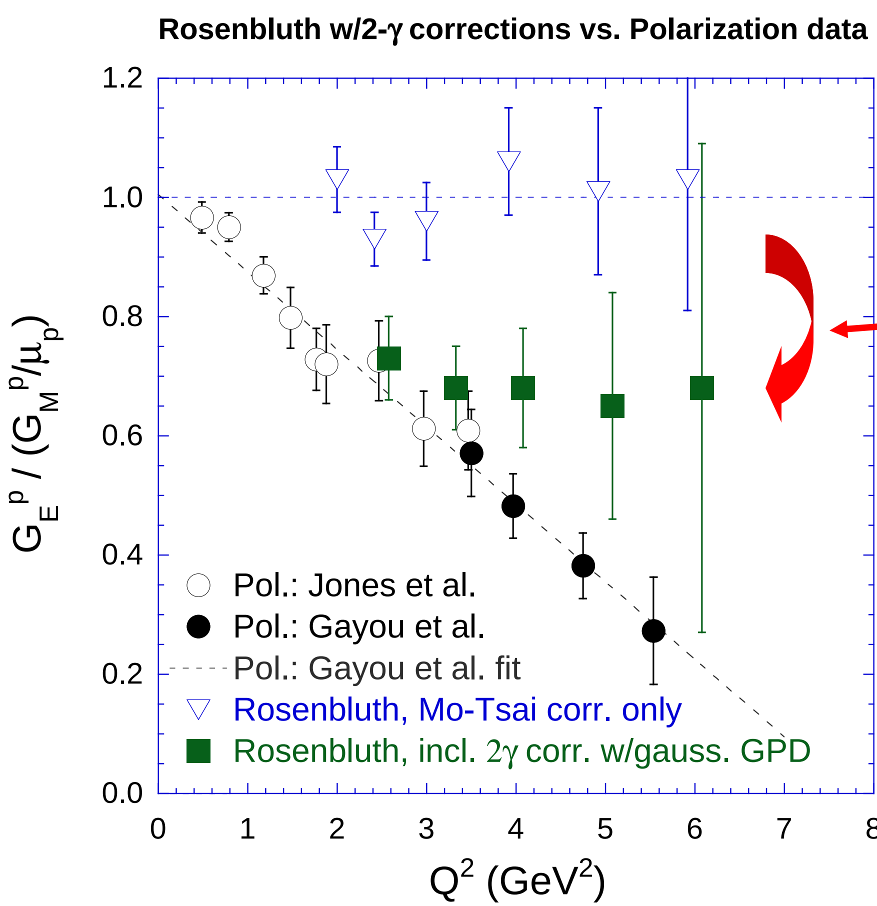



signs of duality

# Special topics

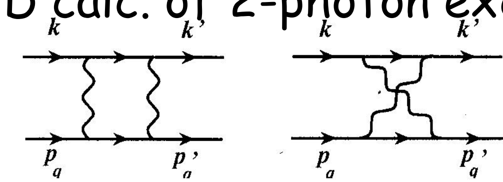
- elastic proton form factor & 2-photon exchange:

Afanasev
hep-ph/0403058,0502128




SLAC/Rosenbluth

GPD calc. of 2-photon exchange



JLab/Polarization

- par.-viol. s form factor meas. may shift by 10%
- more tests of multi-photon exchange @ JLab

# Special topics (cont.)

Brodsky

- large x phenomena as a window into hadron dynamics:

  several predictions of pQCD and AdS/CFT discussed:

  QCD as an approx. conformal theory

  - counting rules & helicity retention as x->1
  - higher twist
  - modifications of DGLAP at x->1
  - exclusive/inclusive duality
  - intrinsic charm at large x
  - GPD's at x->1
  - ....

impossible to summarize all of this, see his slides ...

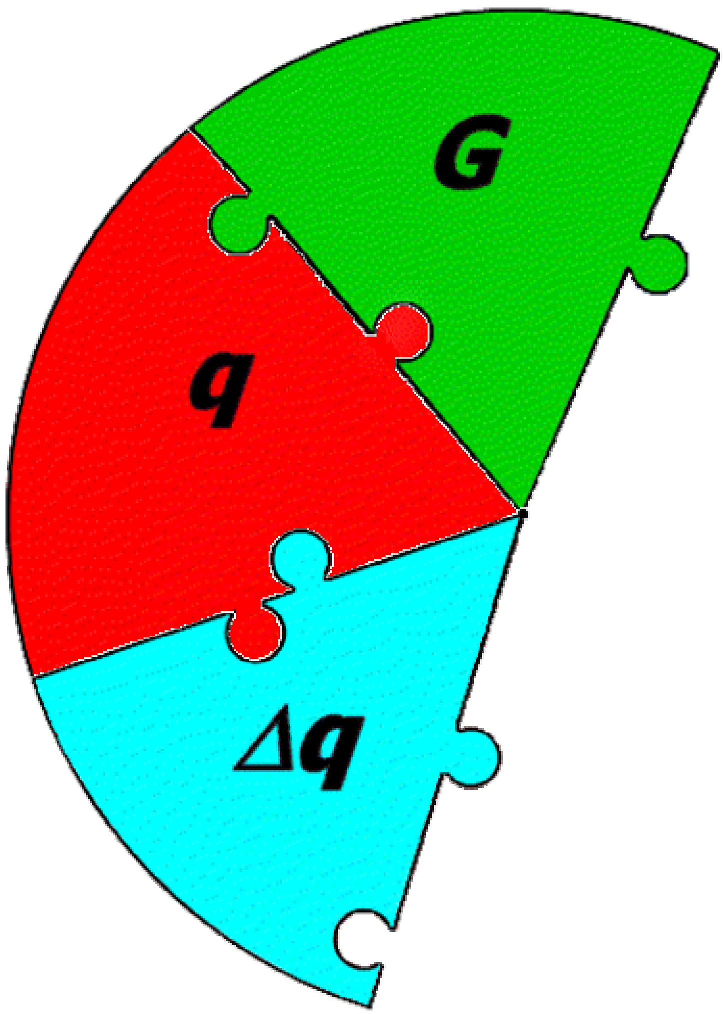

# Summary of the Spin Physics Working Group

## Part Two – Experiment

Pasquale Di Nezza

INFN Frascati

# (Spin)-Structure of the Nucleon




J.P.Chen

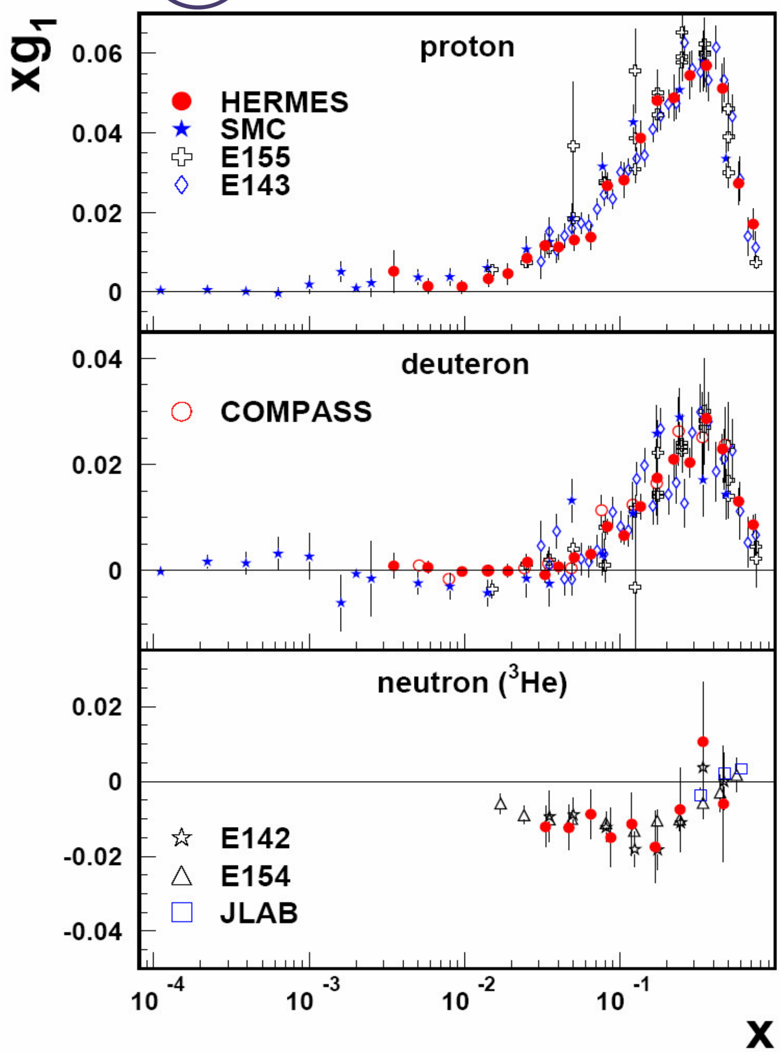
A.Deur

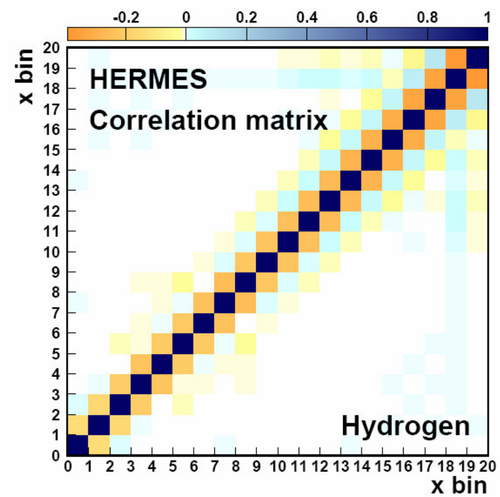
J.Hannappel

N.Liyanage

D.Reggiani

# Polarized Structure Functions: $g_1$




D.Reggiani

New treatment of smearing. Correlation matrix:

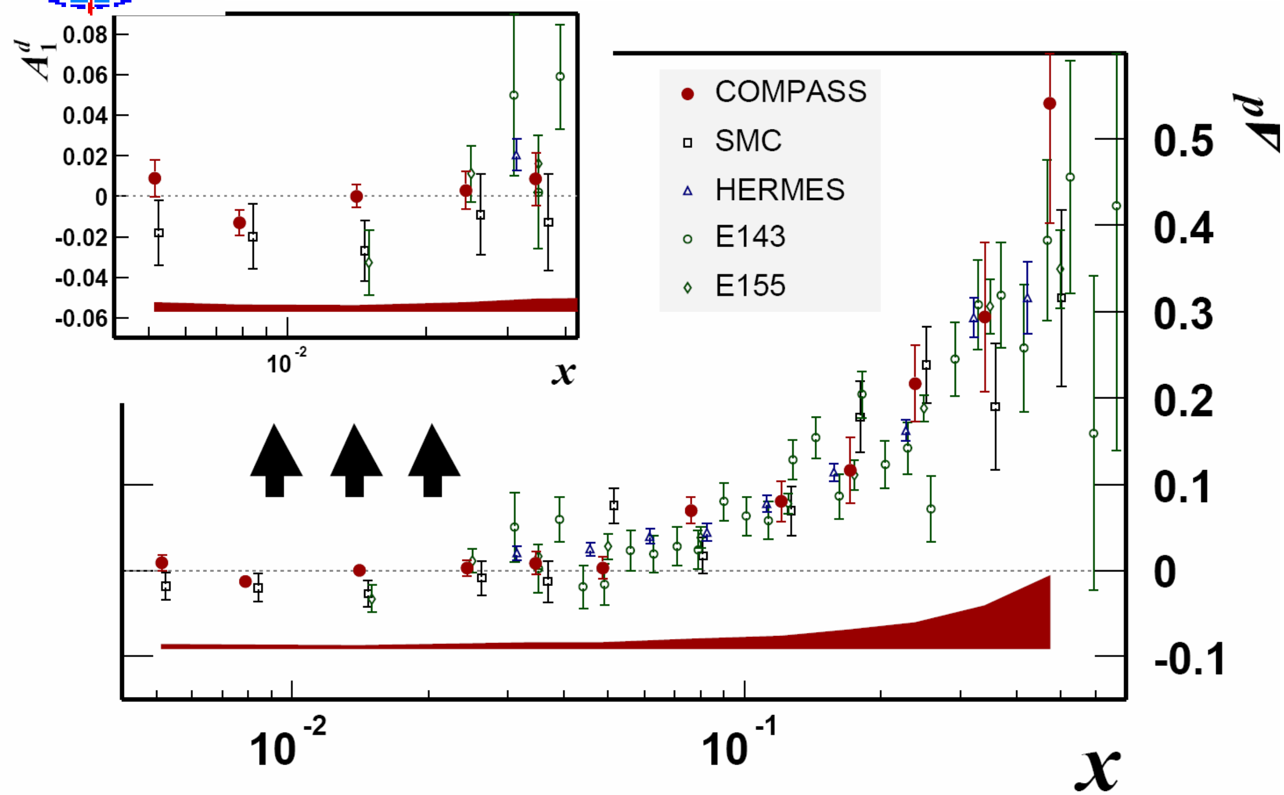
- removes systematical correlations
- introduces statistical correlations

## First Moments Calculation

| Exp. | $Q^2(\mathrm{GeV}^2)$ | x range | Target | Moment | HERMES Moment |
|---|---|---|---|---|---|
| SMC | 5 | 0.03-0.7 | p | 0.128±0.006 | **0.1141±0.0026** |
| E143 | 5 | 0.03-0.8 | p | 0.117±0.003 | **0.1174±0.0027** |
| SMC | 5 | 0.03-0.7 | d | 0.043±0.007 | **0.0416±0.0013** |
| E143 | 5 | 0.03-0.8 | d | 0.043±0.003 | **0.0433±0.0013** |

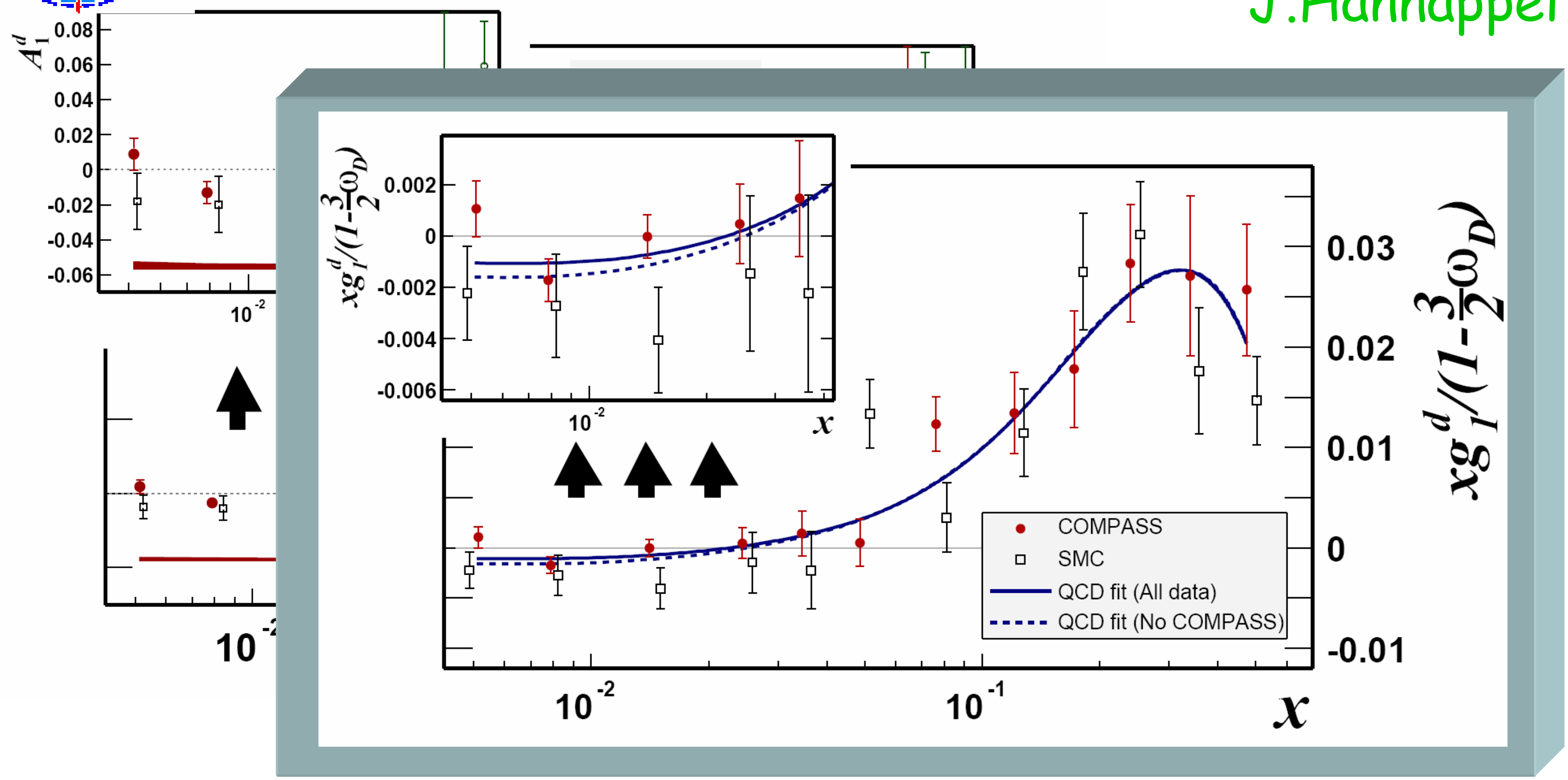
# Polarized Structure Functions: $g_1$

J.Hannappel



# Polarized Structure Functions: $g_1$

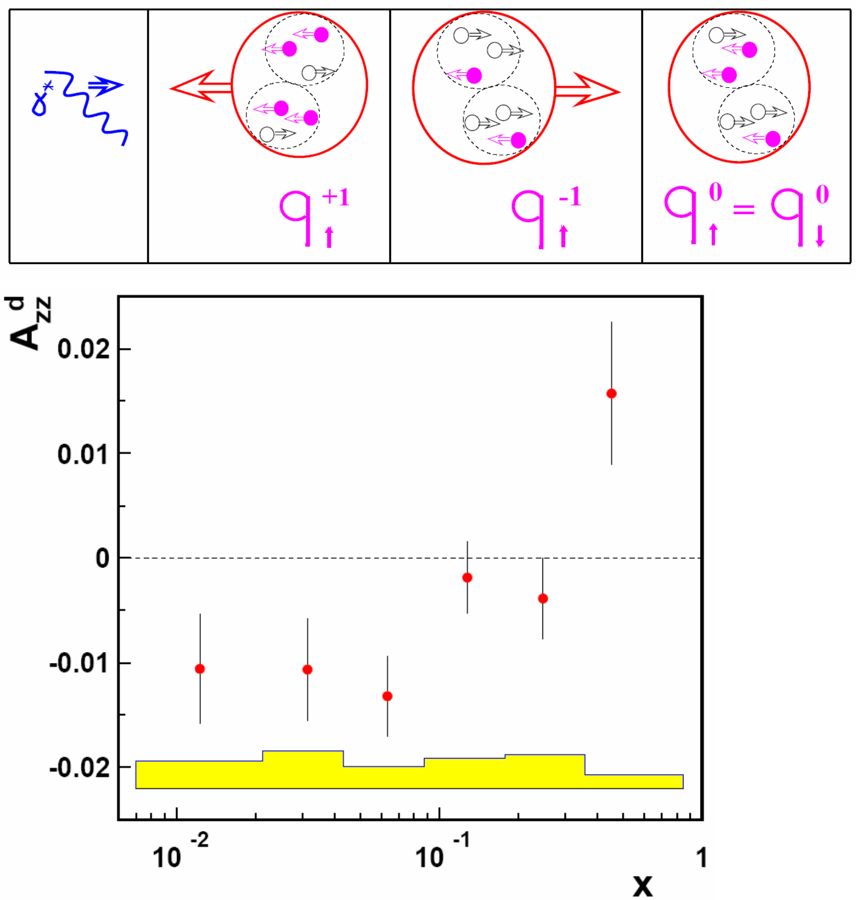
J.Hannappel



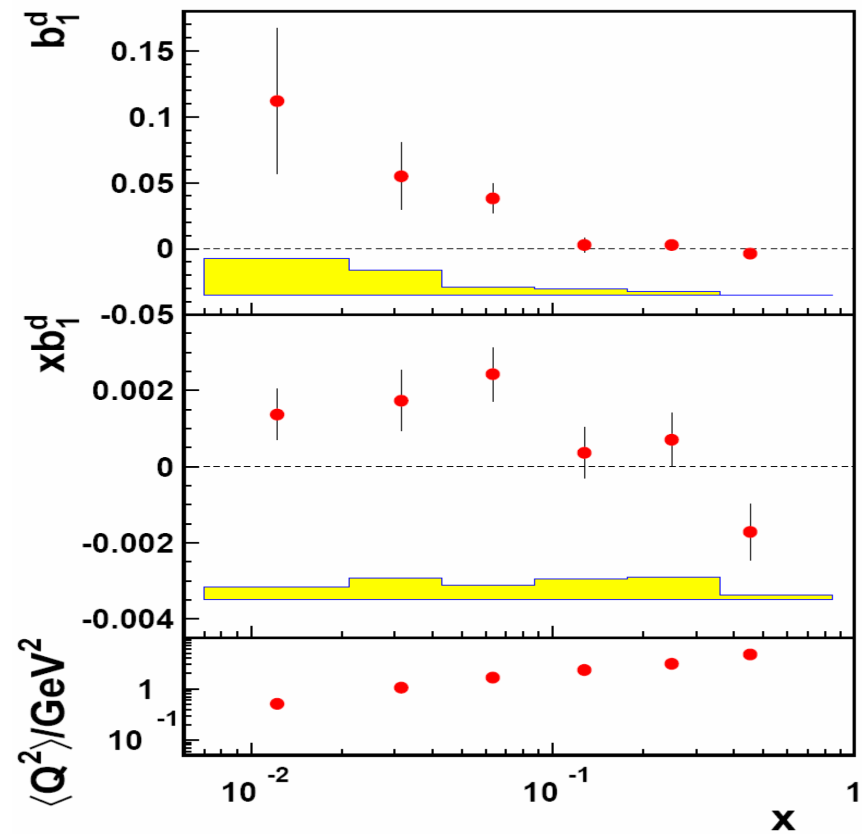

Extended x-range with higher accuracy.

COMPASS systematically > SMC at low-x.

# Tensor Structure Function $b_1^d$




D.Reggiani

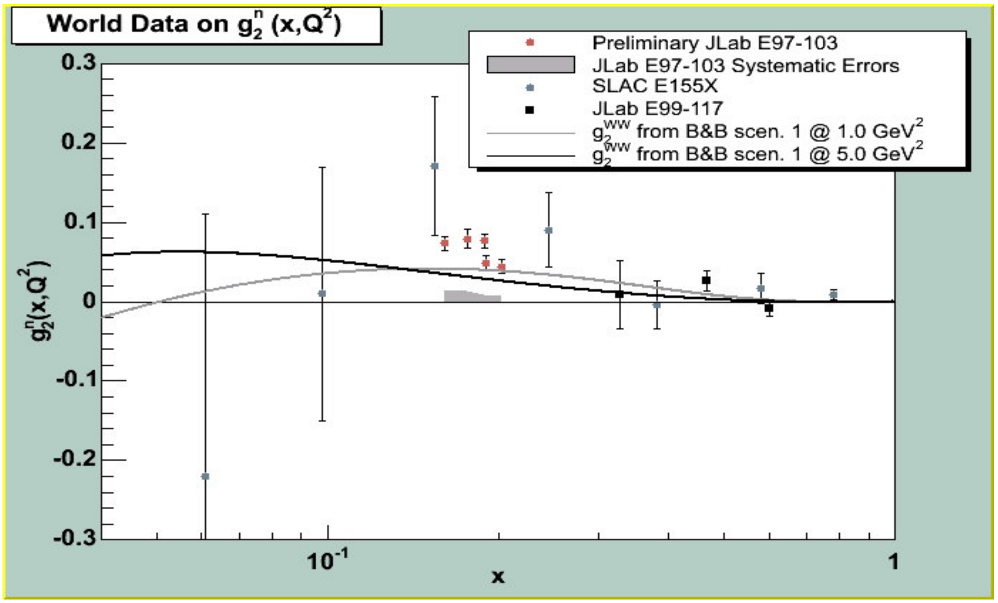


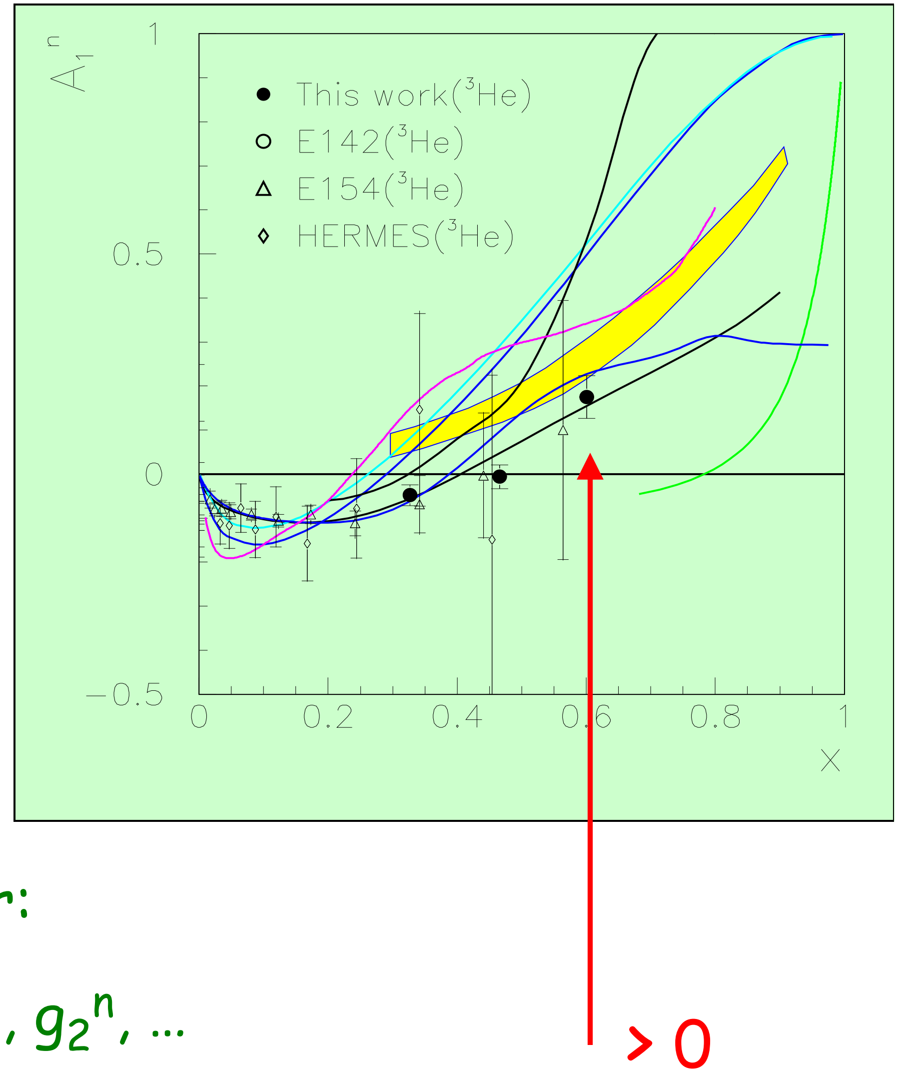

First measurement of $b_1^d$: different from 0 at small x

$A_{zz}$~O (1%) → small impact on $g_1$

# Spin Structure at high x

J.P.Chen




Precision measurements at high x for:

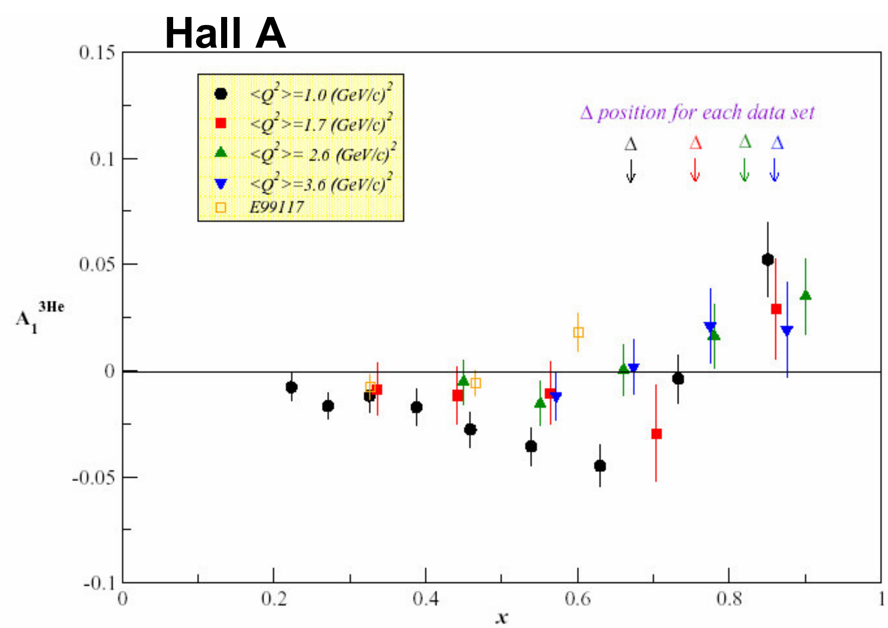
$A_1^n$, $\Delta u/u$, $\Delta d/d$, $A_2^n$, $g_1^n$, $g_2^n$, $A_1^p$, $A_1^d$, $g_2^n$, …

Sometimes statistical errors improved of 1 order of magnitude

# Duality in Spin Structure

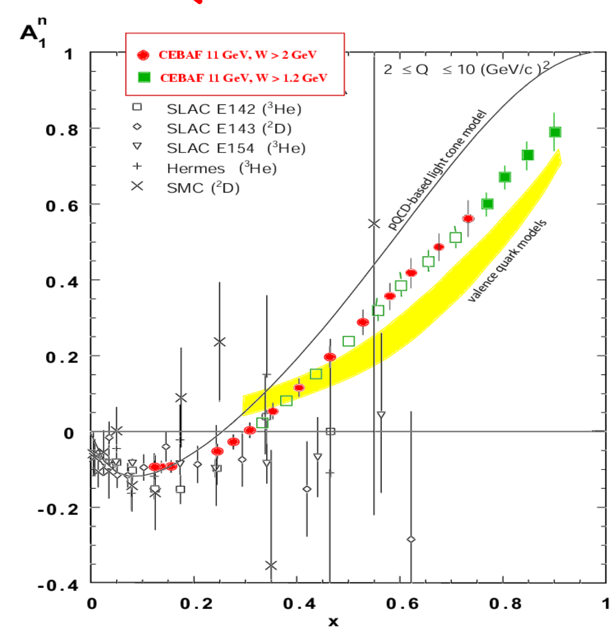
N.Liyanage

- Precision data for $1<Q^2<4$ GeV$^2$
- Direct extraction of g1 and g2 (and A1/A2)
- Test of spin-flavor dependence of duality




Data have same behavior up to x~0.55

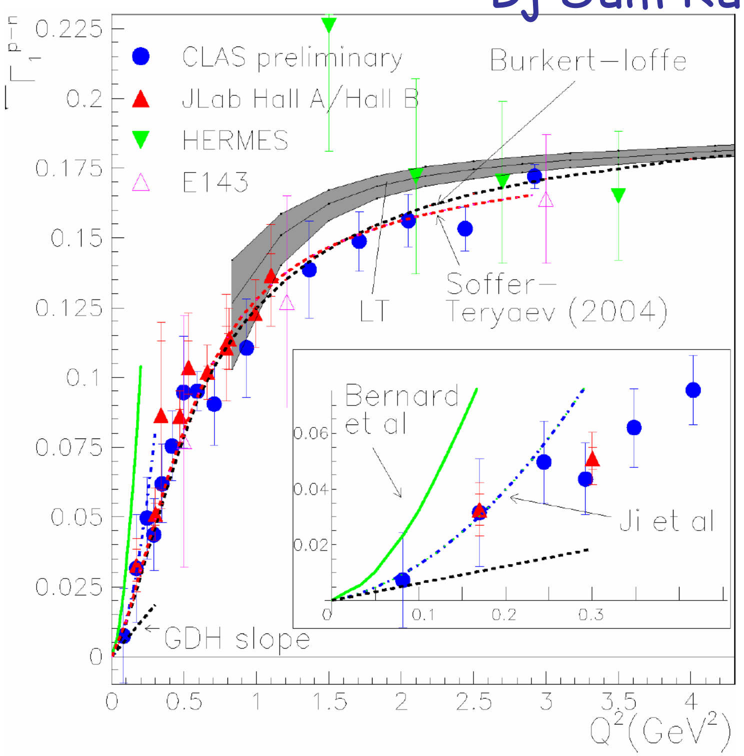
Duality starts for $Q^2$~2 GeV$^2$



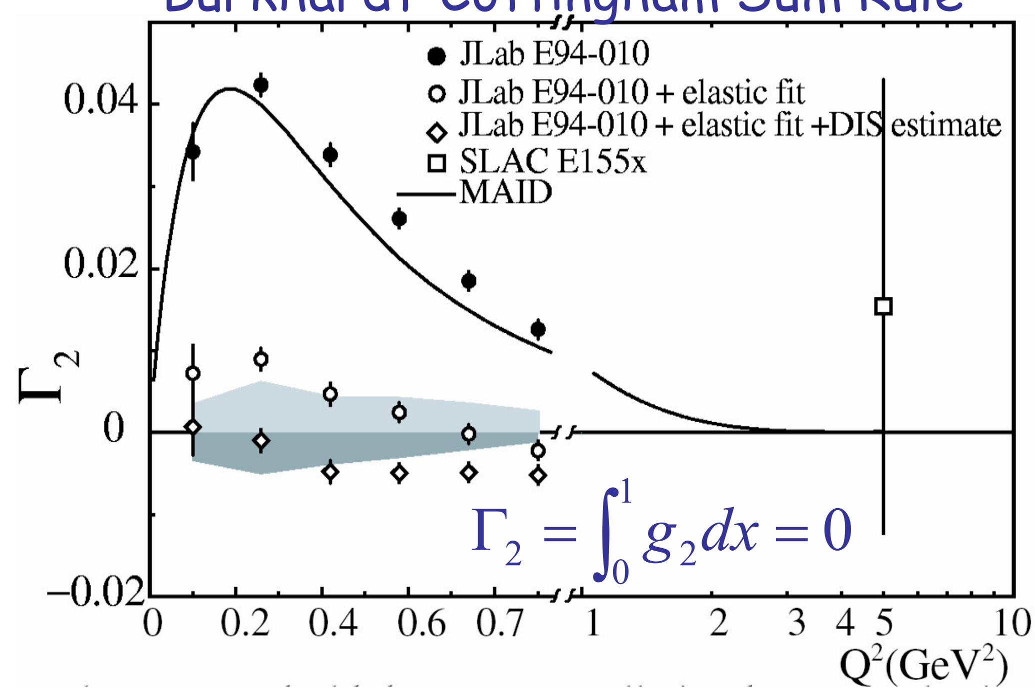
# $Q^2$ evolution of Spin Structure Functions

A.Deur

Bj Sum Rule



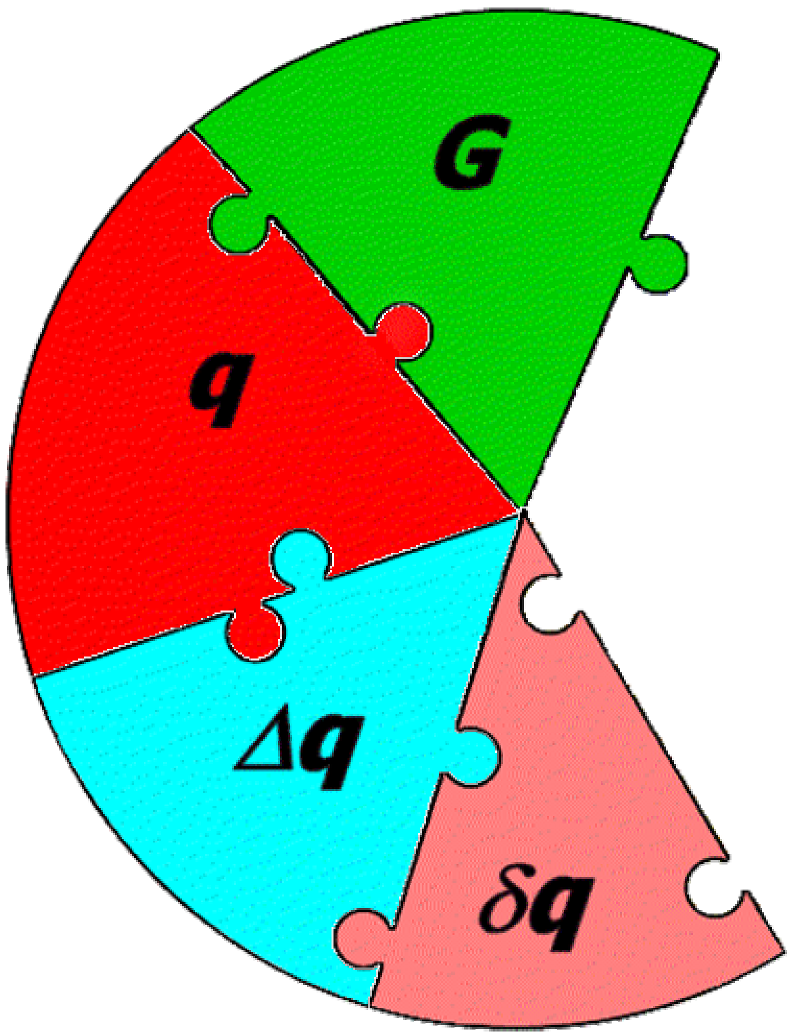

Burkhardt-Cottingham Sum Rule




It seems to hold due to a cancellation elastic-inelastic contribution

Accurate mapping of the hadron-parton transition region

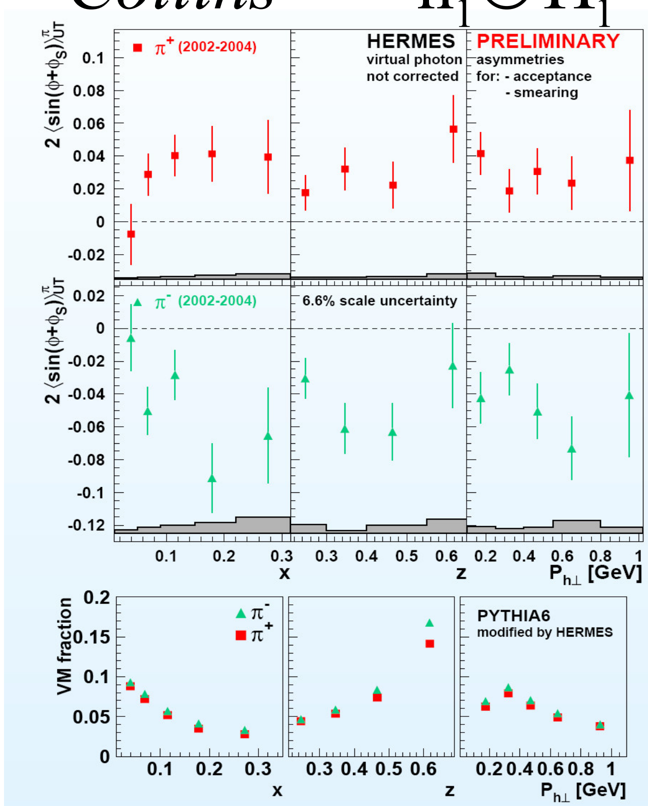
# (Spin)-Structure of the Nucleon




H.Avakian
M.Chiu
M.Diefenthaler
S.Heppelmann
R.Joosten
P.Pagano
R.Siedl
P.van der Nat
F.Videbaek

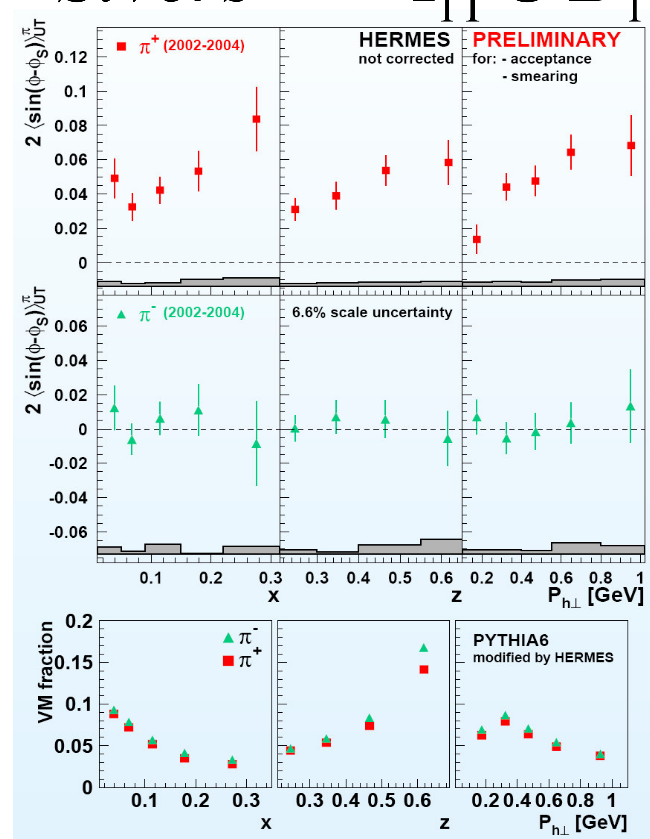
# Transversity

Collins $h_1 \otimes H_1^{\perp}$




M.Diefenthaler

Sivers $f_{1T}^{\perp} \otimes D_1$

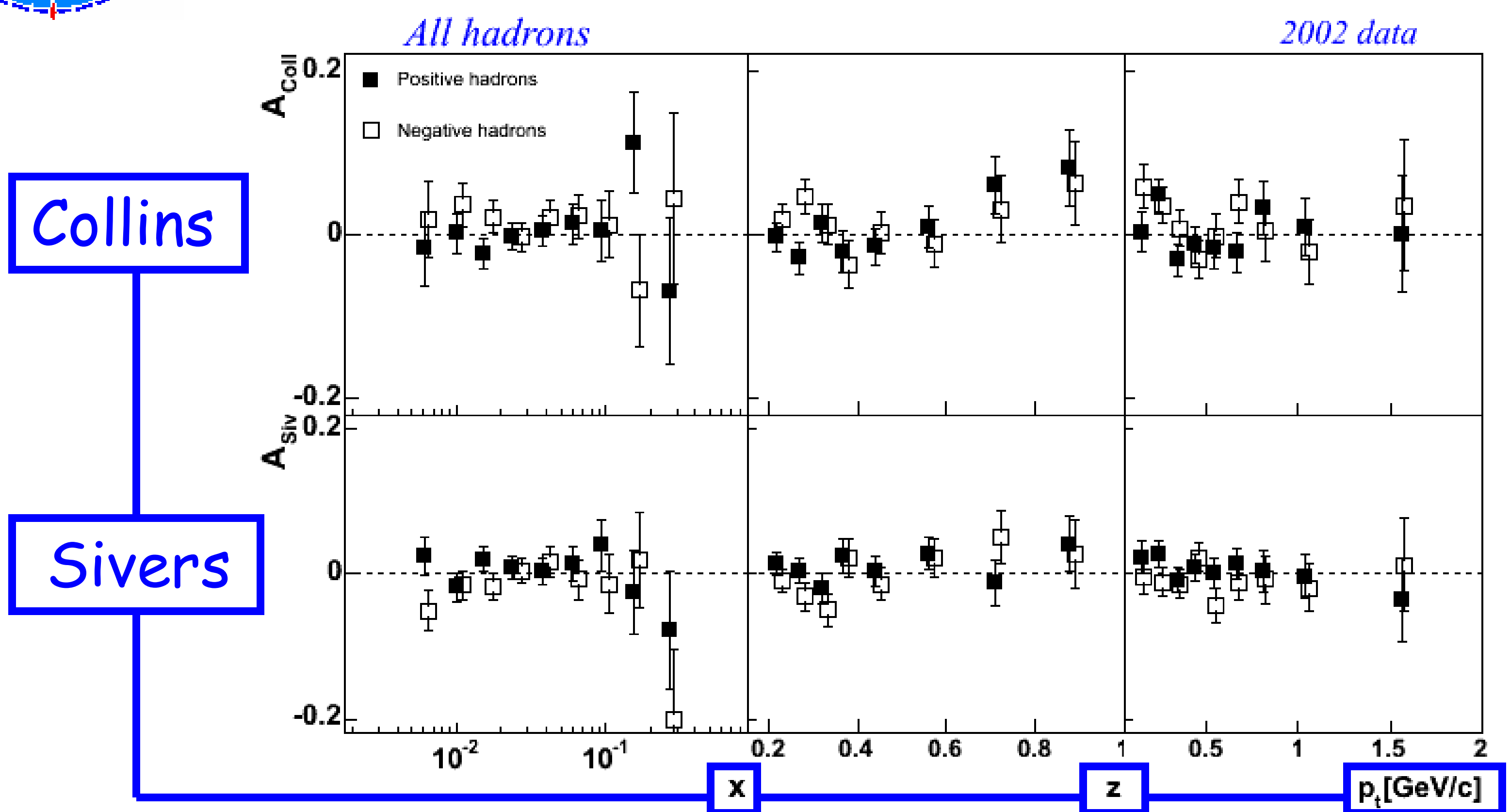



Statistical sample (not final) largely improved. Clear evidence for both Collins and Sivers asymmetry

→ Non vanish $L_q$

# Transversity

P.Pagano




No sizeable effect.

Possible cancellations in isoscalar target ($^6LiD$)

⟹ Expected 3*statistic, 2006 runs on p target ($NH_3$)

# Transversity

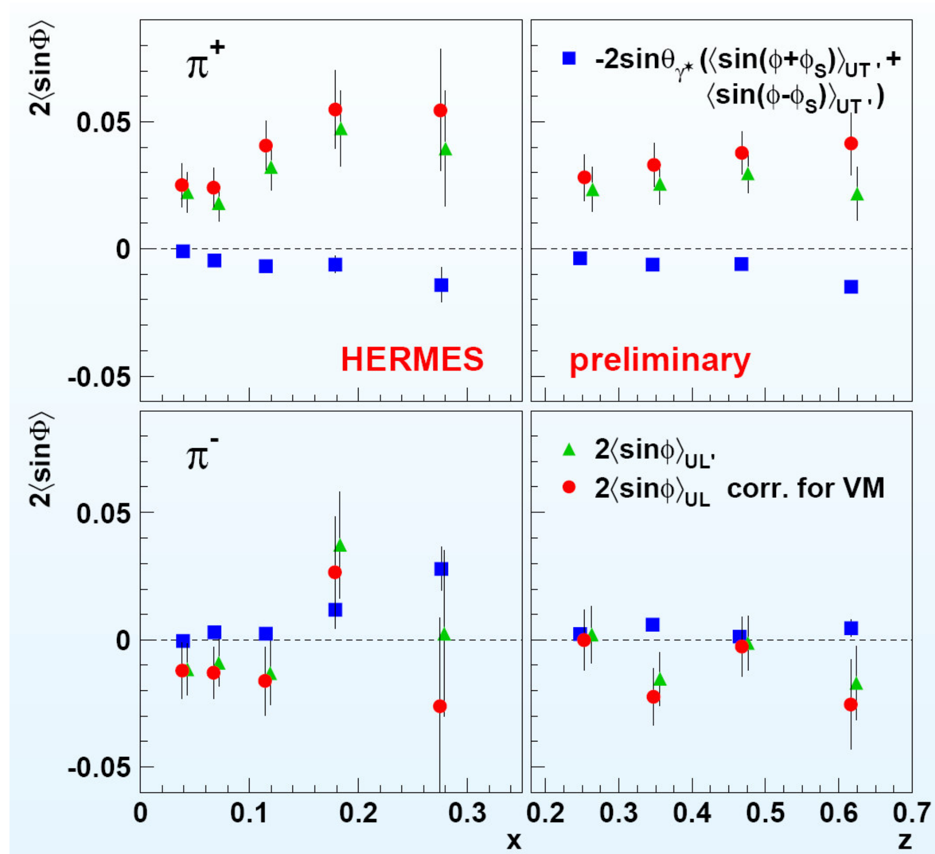
In transverse polarised target

M.Diefenthaler

- Theory: polarization w.r.t. $\gamma^*$
- Exp: polarization w.r.t. lepton beam

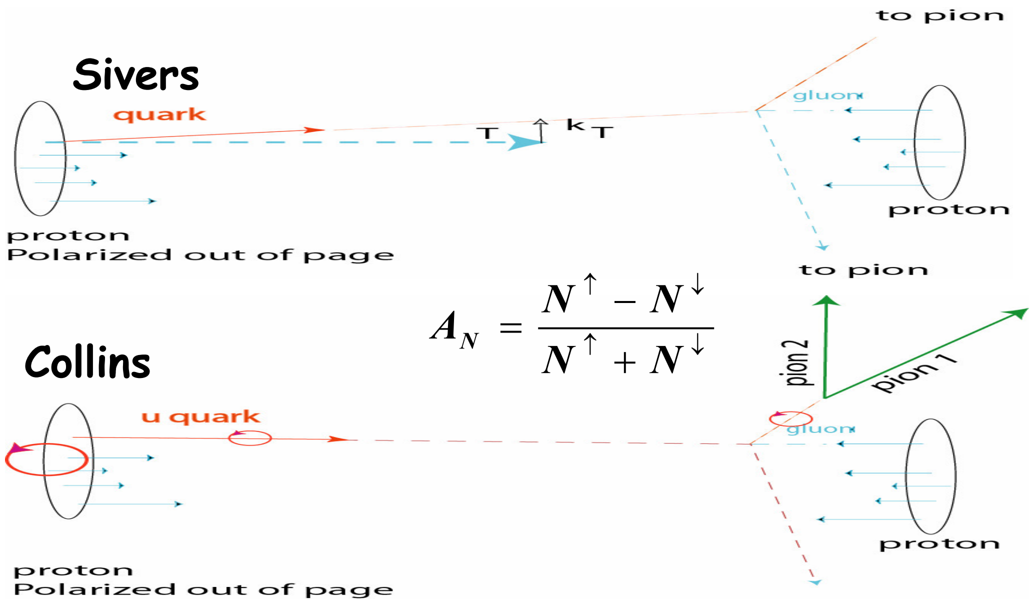
**Conversion** with subleading-twist term:

$$A_{UT,q}^{\sin(\Phi\pm\Phi_S)} \approx A_{UT,l}^{\sin(\Phi\pm\Phi_S)} - \frac{1}{2}\sin\theta_{\gamma^*} A_{UL,l}^{\sin\Phi}$$



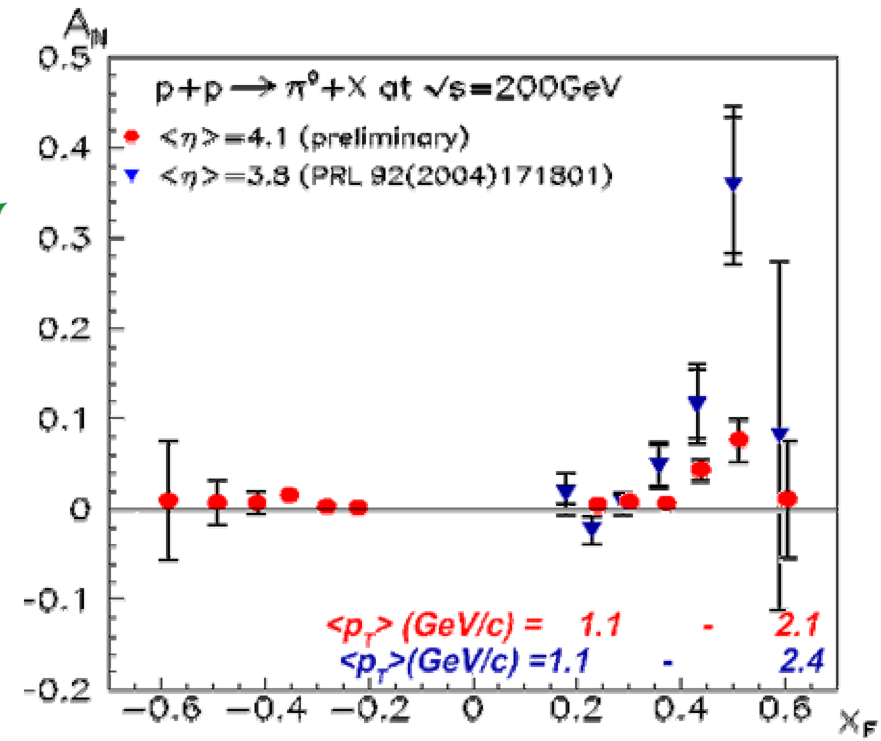

- $A_{UL,q}^{\sin\Phi}$ is about $2-5\%$ for $\pi^+$
- and approximately zero for $\pi^-$
- Systematic uncertainty is less than $0.003$.
- Maximum difference $|A_{UT,q} - A_{UT,l}| < 0.004$

# Transversity




$$A_N = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

S.Heppelmann

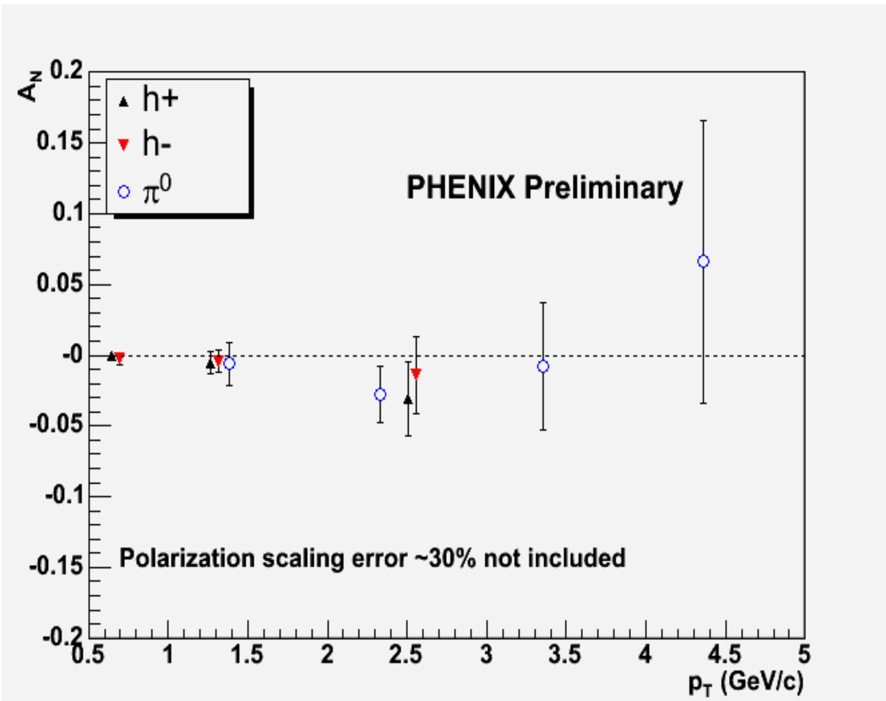


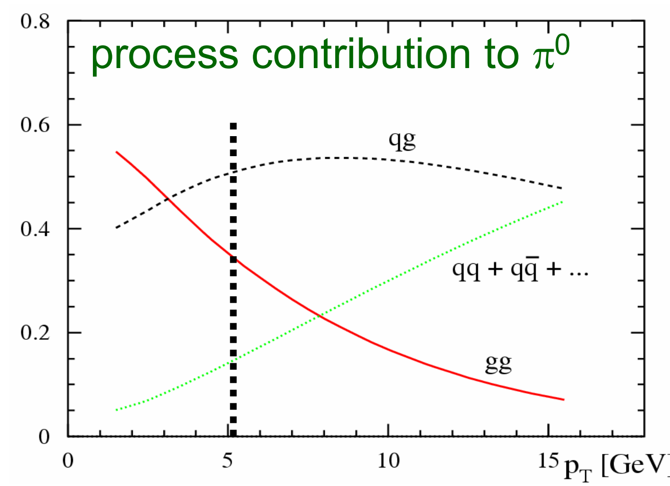

- Large spin effects for forward $\pi^0$ similar to that seen at FNAL.
- No significant asymmetry observed at backward angles.
- A new Forward Calorimeter (proposal) could resolve origin of $A_N$ and characterization of nuclear shadowing at small x.
  - Initial state (Sivers)
  - Final State (Collins).

PHENIX

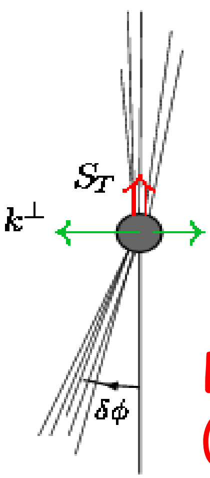
# Transversity

M.Chiu



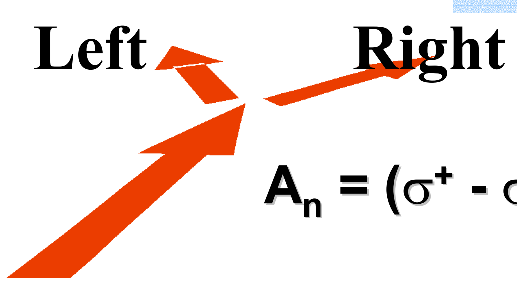

Possibility to map out pT↔ x ↔ g/q dependence




$A_N$ for both charged hadrons and neutral pions consistent with zero at midrapidity.
(Data taken 0.15 $pb^{-1}$ and 15 % beam polarization)
Last week: ~50% beam polarization!

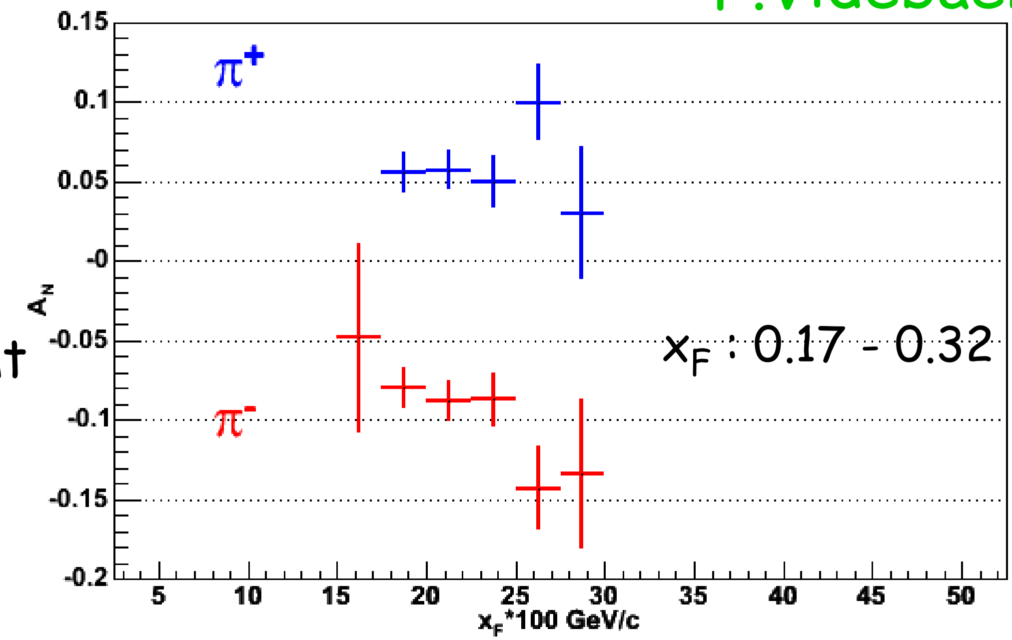
Back to back di-hadron correlations identifies Sivers effects (deconvolute specific effects in $A_N$) … soon accuracy of 1%

# Transversity

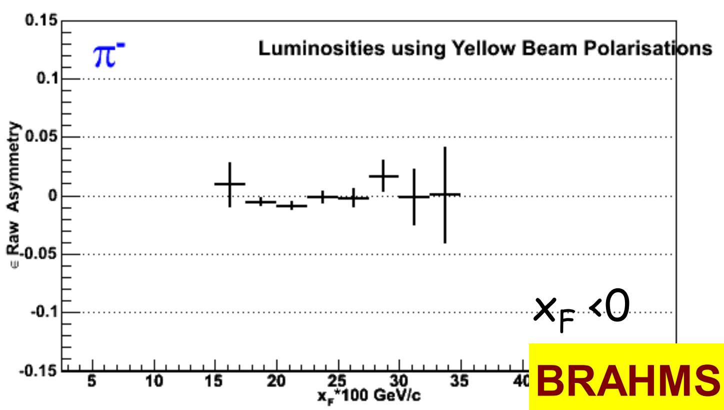


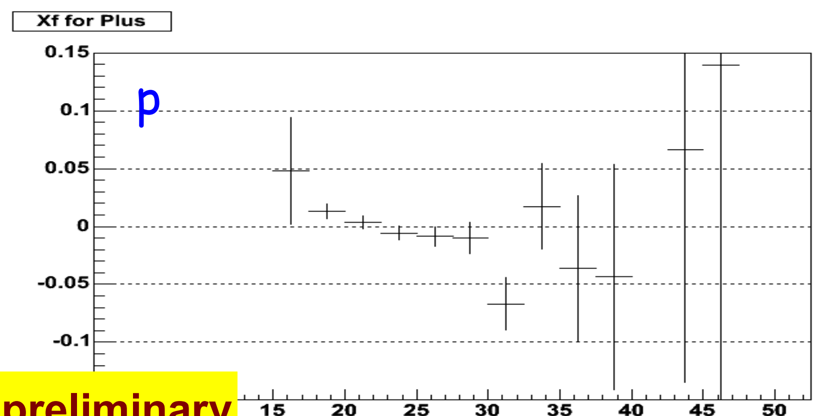

$A_n = (\sigma^+ - \sigma^-) / (\sigma^+ + \sigma^-)$

F.Videbaek

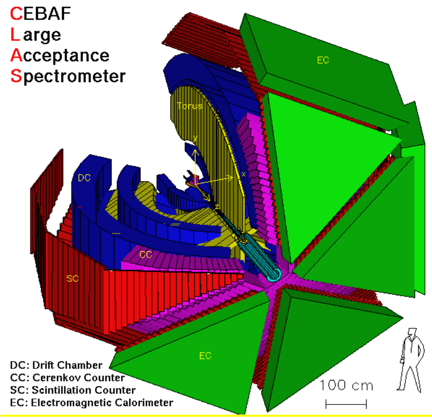



- $\pi^-$ < 0 at ~ 3 sigma, $\pi^+$ >0 at ~1.5 sigma level. Sign consistent with lower energy results.
- $A_n$ at negative $x_F$ for $\pi^+$ and $\pi^-$ are consistent with 0 (as also found by STAR for $\pi^0$)
- The protons are found to have $A_N$ ~0




BRAHMS preliminary



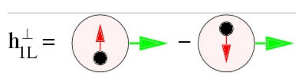

# Transversity & Friends

SIDIS-SSA on L-polarised target: H.Avakian

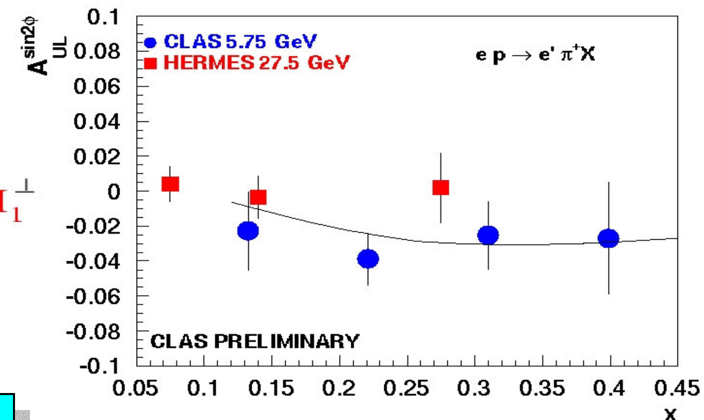
- Probes of $L_q$ through quark transverse momentum distribution
- Access to new PDF not accessible in DIS

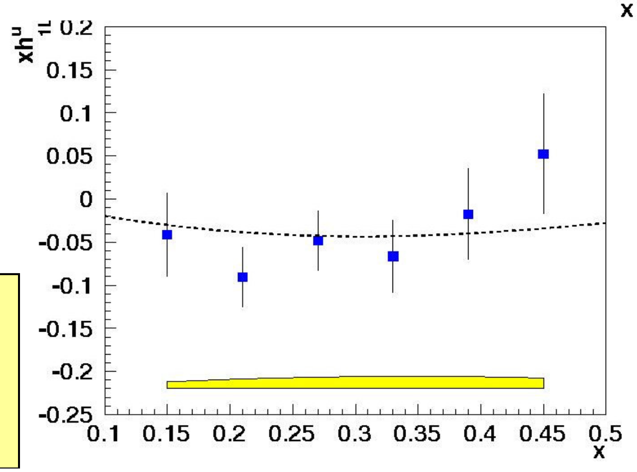
| N \ q | U | L | T |
|---|---|---|---|
| U | $f_1$ | | $h_1^\perp$ |
| L | | $g_1$ | $h_{1L}^\perp$ → Mulders |
| T | $f_{1T}^\perp$ | $g_{1T}$ | $h_1$ $h_{1T}^\perp$ |

Sivers ($f_{1T}^\perp$) — transversity ($h_1$)




$$\sigma_{UL}^{KM} \sim (1-y) h_{1L}^\perp H_1^\perp$$




- $A_{UL}^{\sin2\phi}$ seems $\neq 0$, mainly at large x
- By some assumption for $H_1^\perp$, first glimpse of Tw-2 Transverse Momentum Distribution $h_{1L}^\perp$

**New inner calorimeter will open new avenue for studies of SSA of exclusive and semi-inclusive** $\gamma$, $\pi^0,\eta,\rho^+$

# Transversity & Friends

## 2π fragmentation xsection(UT):

$$
\begin{aligned}
d^9\sigma_{OT} = & \sum_a \frac{\alpha^2 e_a^2}{2\pi Q^2 y} |\vec{S}_T|\, A(y) \Bigg\{ \frac{|\vec{R}_T|}{M_h} \sin(\phi_R - \phi_S)\, \mathcal{I}\left[\frac{\vec{p}_T \cdot \vec{k}_T}{2MM_h} g_{1T}\, G_1^\perp\right] \\
& - \frac{|\vec{R}_T|}{M_h} \cos(\phi_R - \phi_S)\, \mathcal{I}\left[\frac{(\vec{p}_T \cdot \hat{P}_{h\perp})(\hat{P}_{h\perp} \wedge \vec{k}_T) - (\vec{k}_T \cdot \hat{P}_{h\perp})(\hat{P}_{h\perp} \wedge \vec{p}_T)}{2MM_h} g_{1T}\, G_1^\perp\right] \\
& - \frac{|\vec{R}_T|}{M_h} \sin(2\phi_h - \phi_R - \phi_S)\, \mathcal{I}\left[\frac{2(\vec{p}_T \cdot \hat{P}_{h\perp})(\vec{k}_T \cdot \hat{P}_{h\perp}) - \vec{p}_T \cdot \vec{k}_T}{2MM_h} g_{1T}\, G_1^\perp\right] \\
& - \frac{|\vec{R}_T|}{M_h} \cos(2\phi_h - \phi_R - \phi_S)\, \mathcal{I}\left[\frac{(\vec{p}_T \cdot \hat{P}_{h\perp})(\hat{P}_{h\perp} \wedge \vec{k}_T) + (\vec{k}_T \cdot \hat{P}_{h\perp})(\hat{P}_{h\perp} \wedge \vec{p}_T)}{2MM_h} g_{1T}\, G_1^\perp\right] \\
& + \sin(\phi_h - \phi_S)\, \mathcal{I}\left[\frac{\vec{p}_T \cdot \hat{P}_{h\perp}}{M} f_{1T}^\perp\, D_1\right] + \cos(\phi_h - \phi_S)\, \mathcal{I}\left[\frac{\hat{P}_{h\perp} \wedge \vec{p}_T}{M} f_{1T}^\perp\, D_1\right]\Bigg\} \\
& + \sum_a \frac{\alpha^2 e_a^2}{2\pi Q^2 y} |\vec{S}_T|\, B(y) \Bigg\{ \sin(\phi_h + \phi_S)\, \mathcal{I}\left[\frac{\vec{k}_T \cdot \hat{P}_{h\perp}}{M_h} h_1\, H_1^\perp\right] \\
& + \cos(\phi_h + \phi_S)\, \mathcal{I}\left[\frac{\hat{P}_{h\perp} \wedge \vec{k}_T}{M_h} h_1\, H_1^\perp\right] + \boxed{\frac{|\vec{R}_T|}{M_h} \sin(\phi_R + \phi_S)\, \mathcal{I}\left[h_1\, \bar{H}_1^\sphericalangle\right]} + \sin(3\phi_h - \phi_S) \\
& \times \mathcal{I}\left[\frac{4(\vec{p}_T \cdot \hat{P}_{h\perp})^2(\vec{k}_T \cdot \hat{P}_{h\perp}) - 2(\vec{p}_T \cdot \hat{P}_{h\perp})(\vec{p}_T \cdot \vec{k}_T) - \vec{p}_T^{\,2}(\vec{k}_T \cdot \hat{P}_{h\perp})}{2M^2 M_h} h_{1T}^\perp\, H_1^\perp\right] \\
& + \cos(3\phi_h - \phi_S)\, \mathcal{I}\Bigg[\Bigg(\frac{2(\vec{p}_T \cdot \hat{P}_{h\perp})^2(\hat{P}_{h\perp} \wedge \vec{k}_T) + 2(\vec{k}_T \cdot \hat{P}_{h\perp})(\vec{p}_T \cdot \hat{P}_{h\perp})(\hat{P}_{h\perp} \wedge \vec{p}_T)}{2M^2 M_h} \\
& - \frac{\vec{p}_T^{\,2}(\hat{P}_{h\perp} \wedge \vec{k}_T)}{2M^2 M_h}\Bigg) h_{1T}^\perp\, H_1^\perp\Bigg] + \frac{|\vec{R}_T|}{M_h} \sin(2\phi_h + \phi_R - \phi_S)\, \mathcal{I}\left[\frac{2(\vec{p}_T \cdot \hat{P}_{h\perp})^2 - \vec{p}_T^{\,2}}{2M^2} h_{1T}^\perp\, \bar{H}_1^\sphericalangle\right] \\
& + \frac{|\vec{R}_T|}{M_h} \cos(2\phi_h + \phi_R - \phi_S)\, \mathcal{I}\left[\frac{(\vec{p}_T \cdot \hat{P}_{h\perp})(\hat{P}_{h\perp} \wedge \vec{p}_T)}{2M^2} h_{1T}^\perp\, \bar{H}_1^\sphericalangle\right]\Bigg\}
\end{aligned}
$$

## After integration over $P_{h\perp}$

$$\boxed{\sigma_{UT} \propto \sum_q e_q^2 \sin(\phi_{R\perp} + \phi_S) h_1 H_1^\sphericalangle}$$

Advantages:

- cross section asymmetry directly proportional to $h_1 H_1^\sphericalangle$ (No weighting needed)
- No Collins/Sivers ‘entanglement’
- Completely independent from $1\pi$ analysis

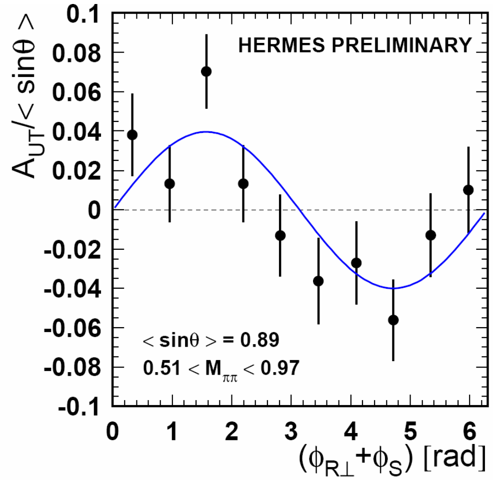
Disadvantages:

- less statistics
- $H_1^\sphericalangle$ unknown (but can be measured at Belle & Babar)

# Transversity & Friends

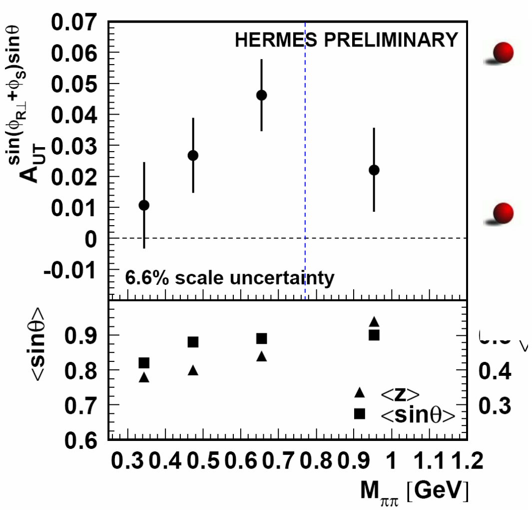
P.van der Nat

p target




significant $\sin(\phi_{R\perp} + \phi_S)$ behavior!

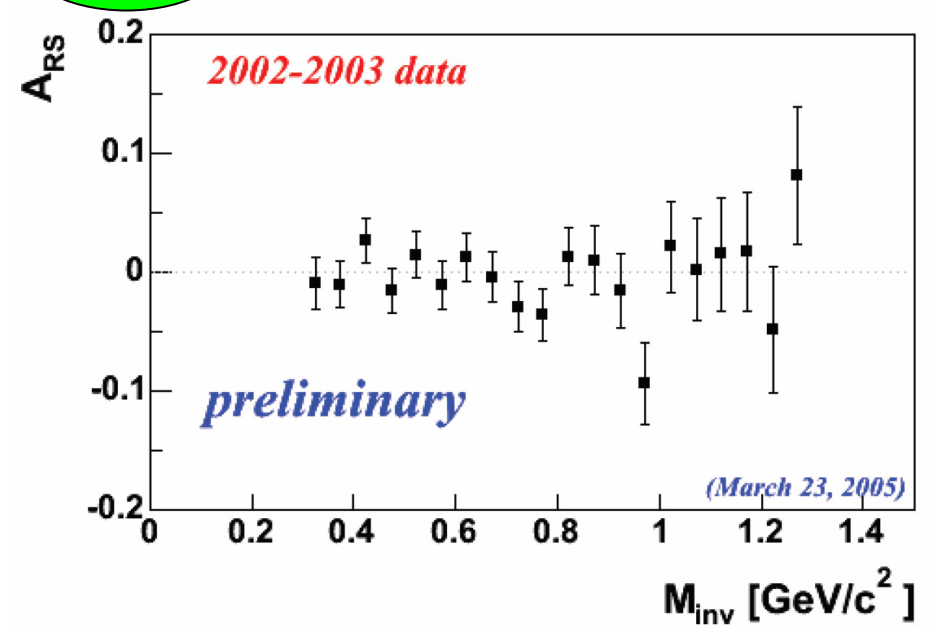
$$A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta} = 0.040 \pm 0.009 \text{ (stat)} \pm 0.003 \text{ (syst)}$$




- positive asymmetry moment for all invariant mass bins
- result rules out predicted sign change at the $\rho^0$ mass (Jaffe et al.)

R.Joosten

D target




Asymmetry vs $M_{inv}$, x, z consistent with 0 or small.

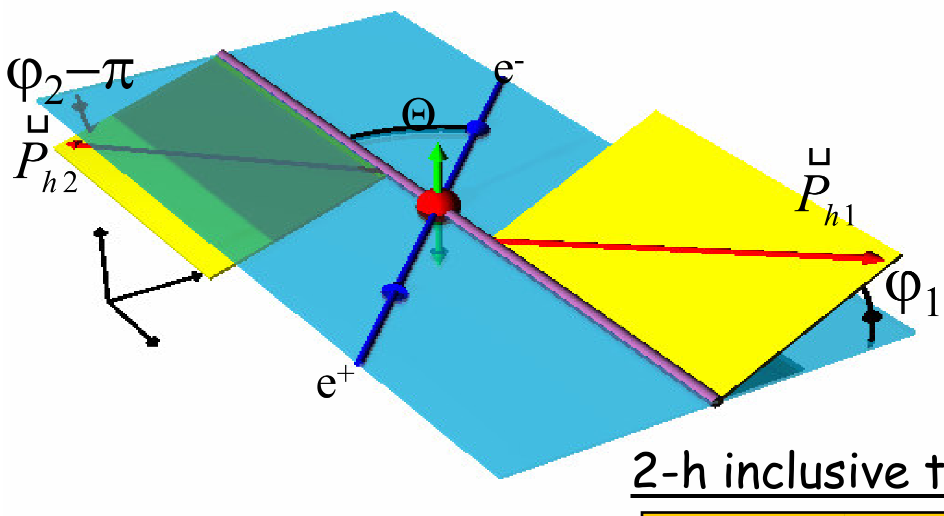
More results expected with:

- •Improved statistic
- •RICH information
- •Runs using p-target ($NH_3$)

# Transversity & Friends

R.Seidl

All the previous Spin dependent Fragmentation function analyses yields information on the Collins and the Interference Fragmentation function !
→Always 2 unknown functions involved which cannot be measured independently




In e+e- only the Collins FF appears!

2-h inclusive transverse momentum dependent Xsection:

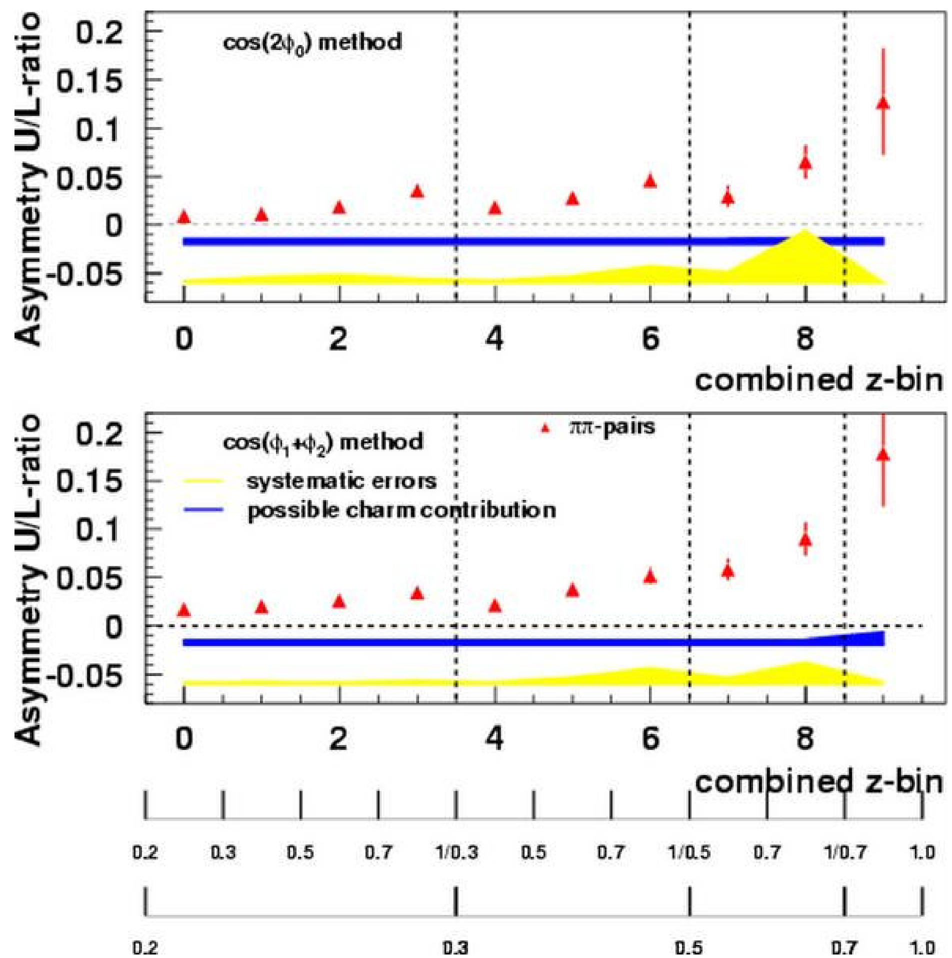
$$\frac{d\sigma(e^+e^- \to h_1h_2X)}{d\Omega dz_1dz_2d^2\boldsymbol{q}_T} = \ldots B(y)\cos(\varphi_1+\varphi_2)H_1^{\perp 1}(z_1)\overline{H}_1^{\perp 1}(z_2)$$

$$B(y) = y(1-y) \overset{cm}{=} \frac{1}{4}\sin^2\Theta$$

# Transversity & Friends

Milestone!

R.Seidl




The double ratio method shows:

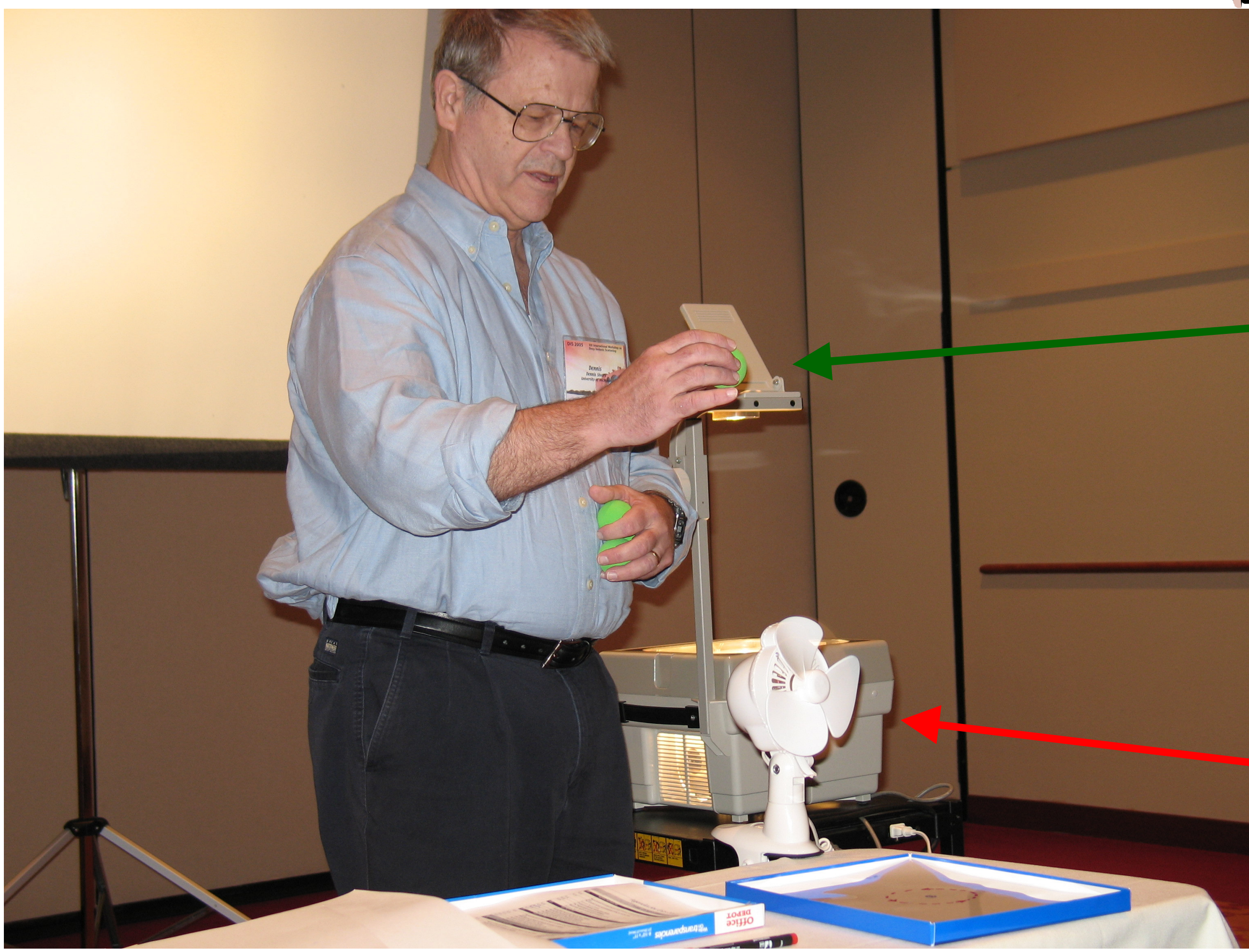
- Significant non-zero asymmetries
- Rising behaviour vs. z
- First direct measurement of the Collins function

Only first steps, however:
Naïve LO analysis shows significant Collins effect

# Transversity

On line experiment by a theoretician ...

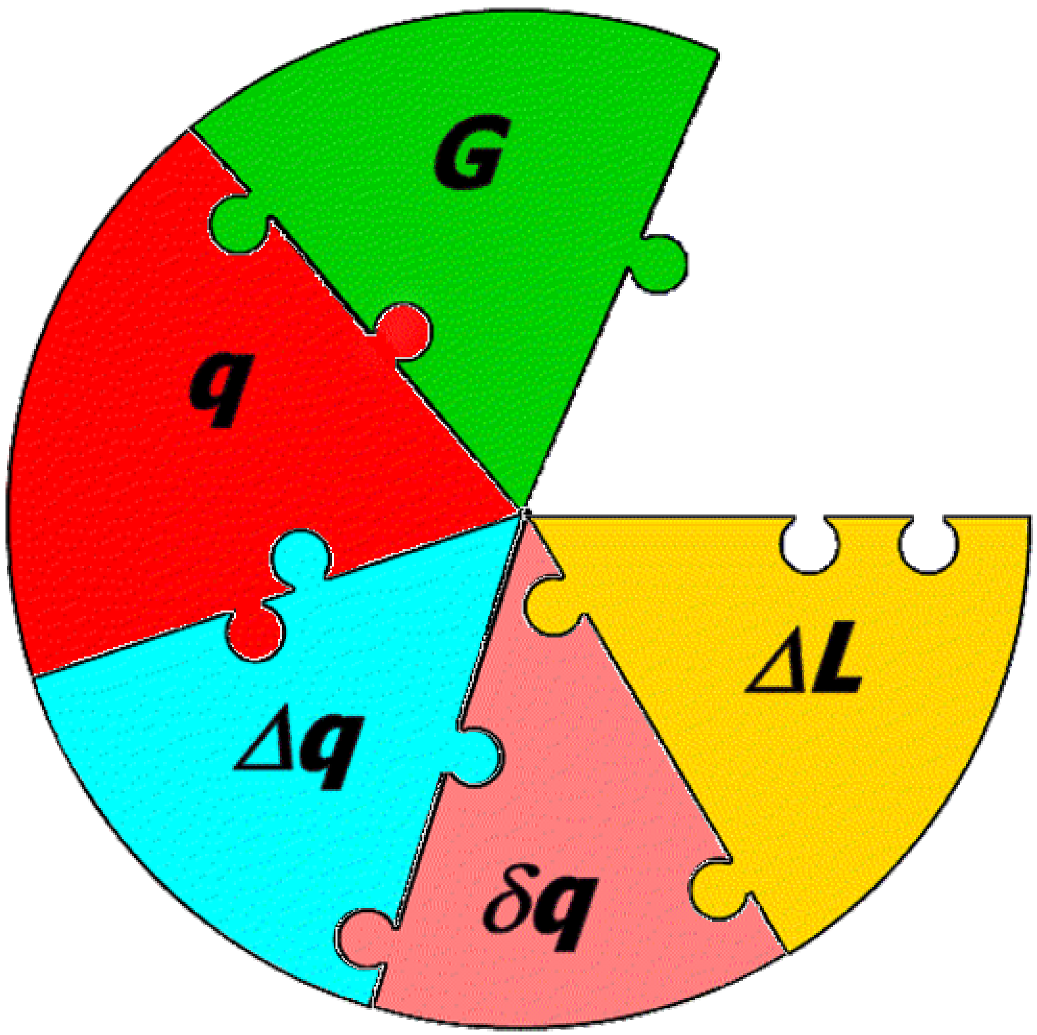
D.Sivers



Unpolarized
green beam

Electrical
solid target

# (Spin)-Structure of the Nucleon




G.Gavalian

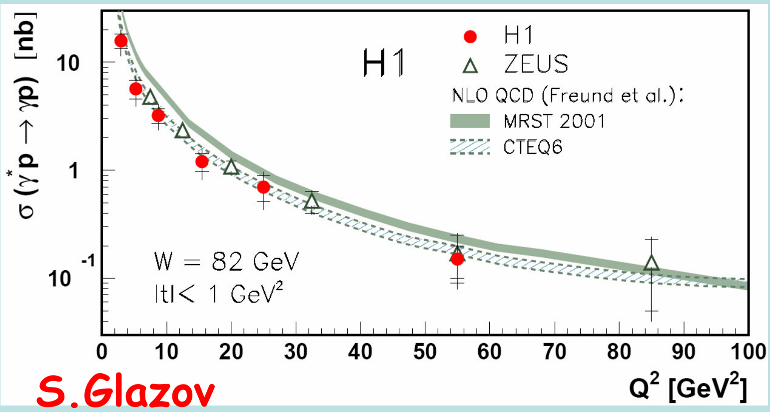
S.Glazov

M.Kopytin

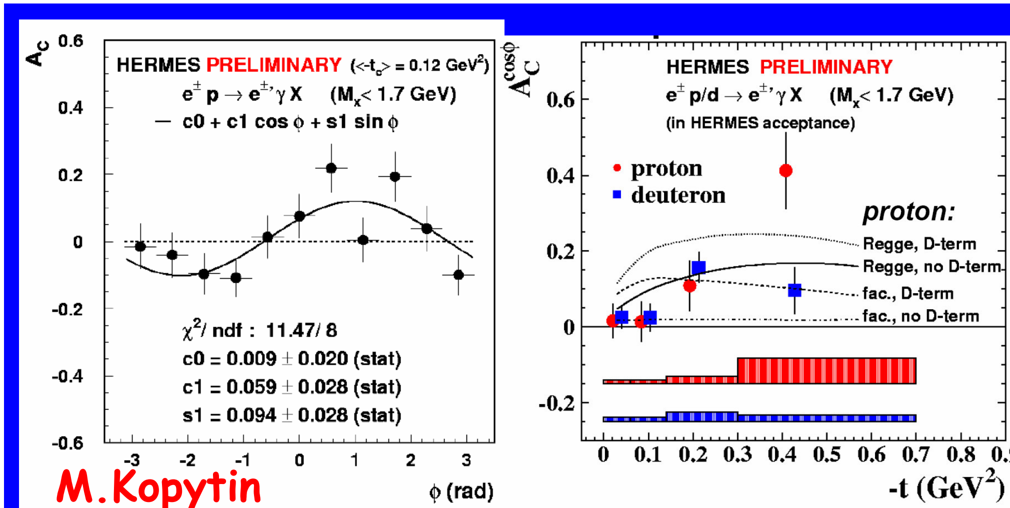
A.Vandenbroucke

# GPDs and Exclusive Processes

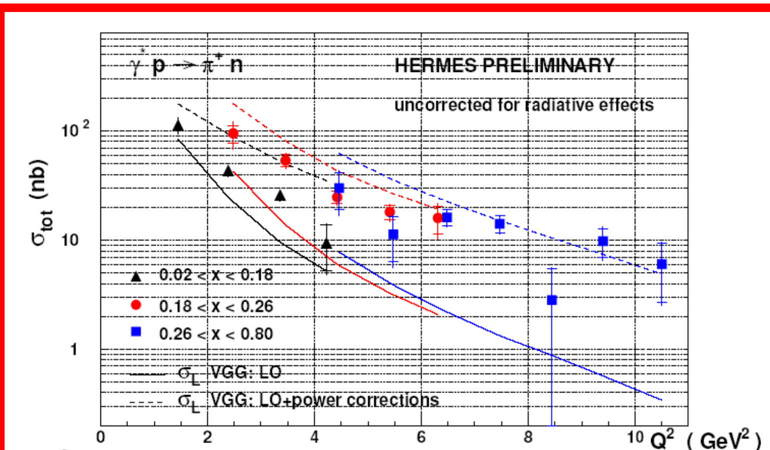
## Joint Working Groups: Spin Physics + Diffraction & VM
## Results already summarized.



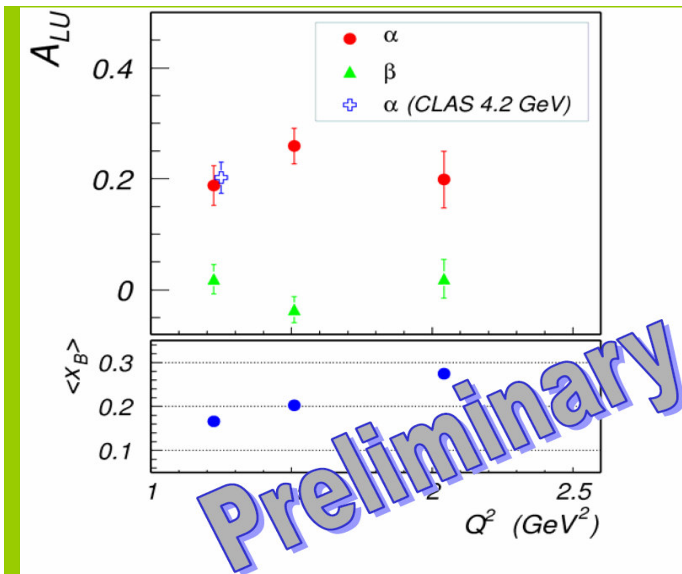

S.Glazov




M.Kopytin

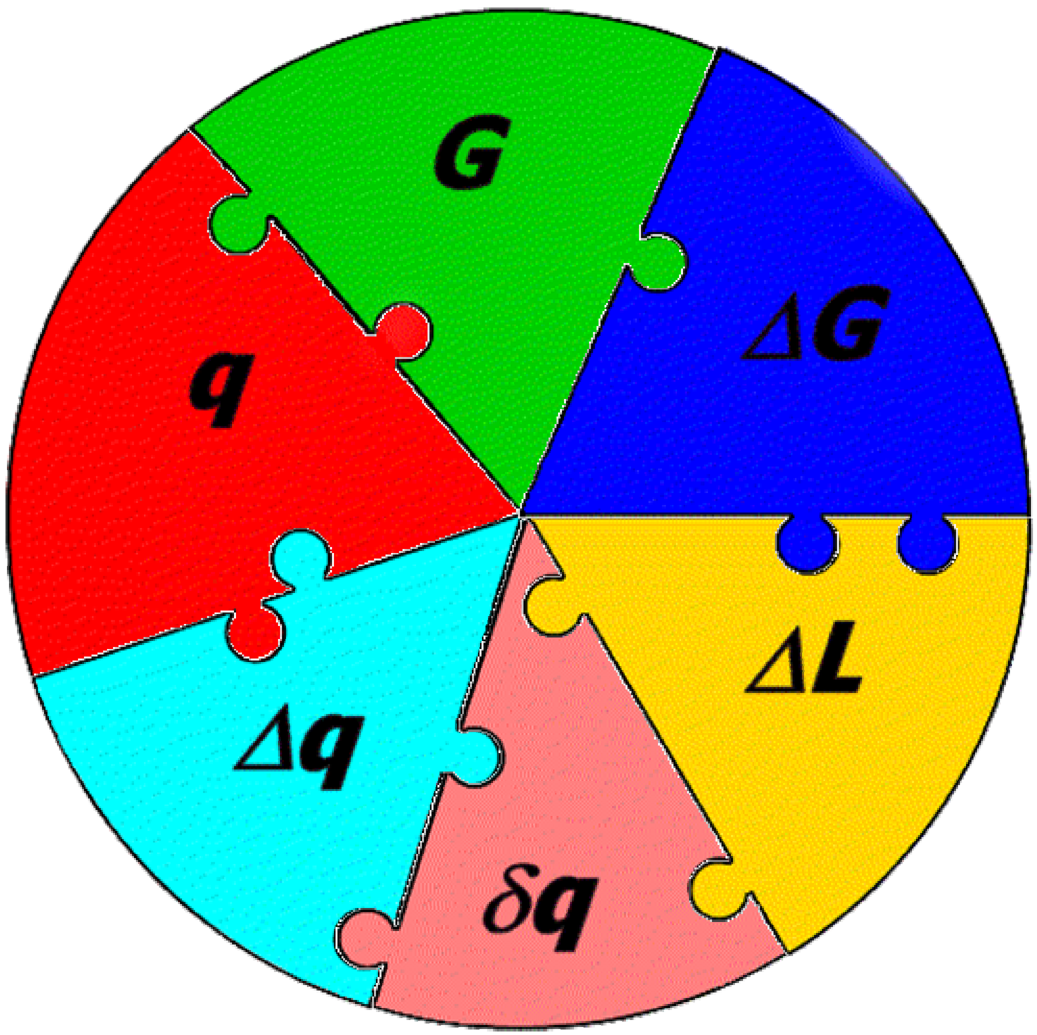



A.Vandenbroucke




G.Gavalian

# (Spin)-Structure of the Nucleon



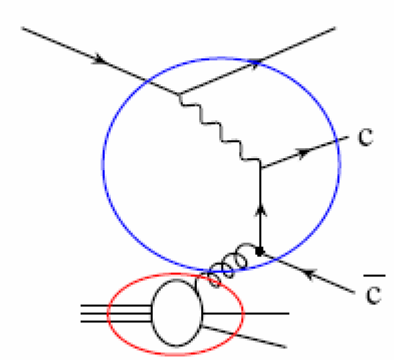


C.Bernet

R.Cadman

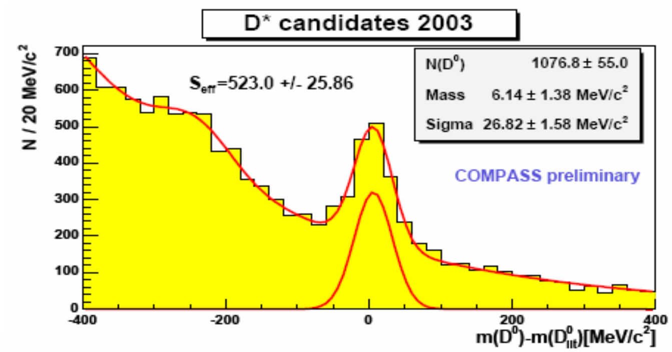
A.Deshpande

# Gluon Polarization




Direct measurement of $\Delta G/G$ via open charm production has still too few events.

C.Bernet



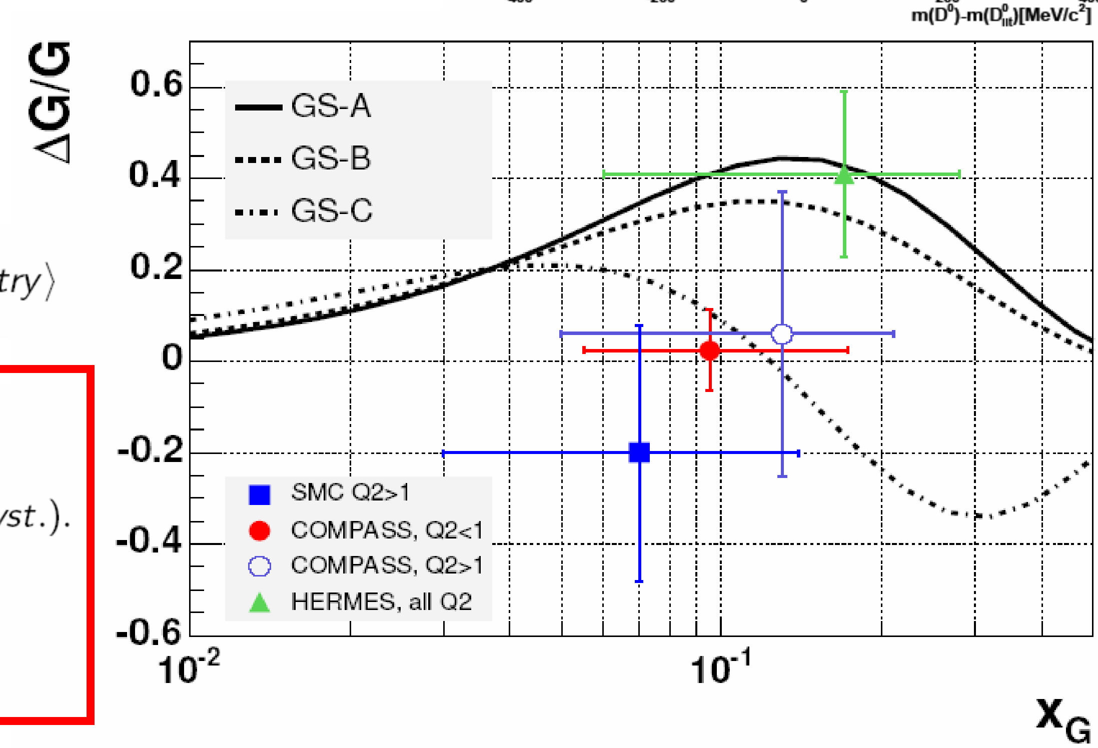

Measurement of $\Delta G/G$ via high Pt hadrons more powerful but model dependent

$$A_{\|} = R_{pgf} \langle \hat{a}_{pgf} \rangle \frac{\Delta G}{G} + \langle background\ asymmetry \rangle$$

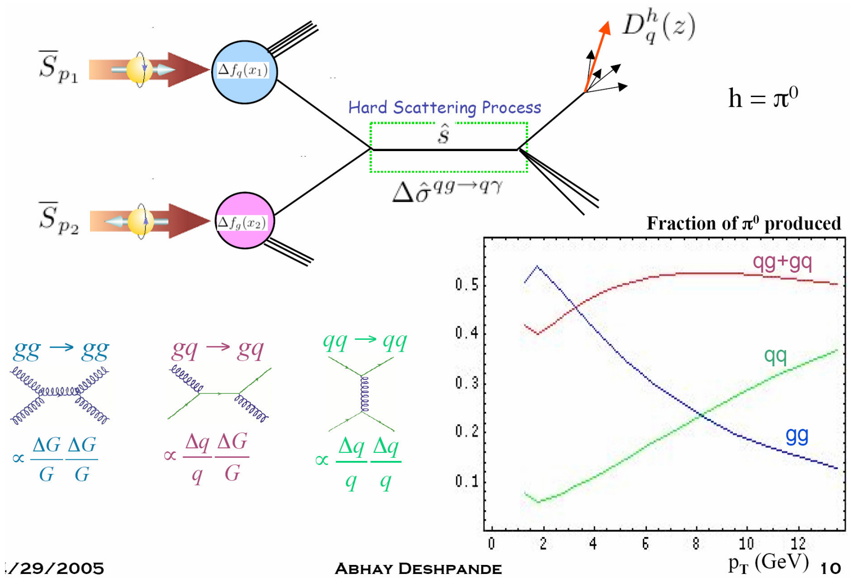
2002+2003 data, $Q^2 < 1$ GeV$^2$

$$\frac{\Delta G}{G} = 0.024 \pm 0.089(stat.) \pm 0.057(syst.).$$

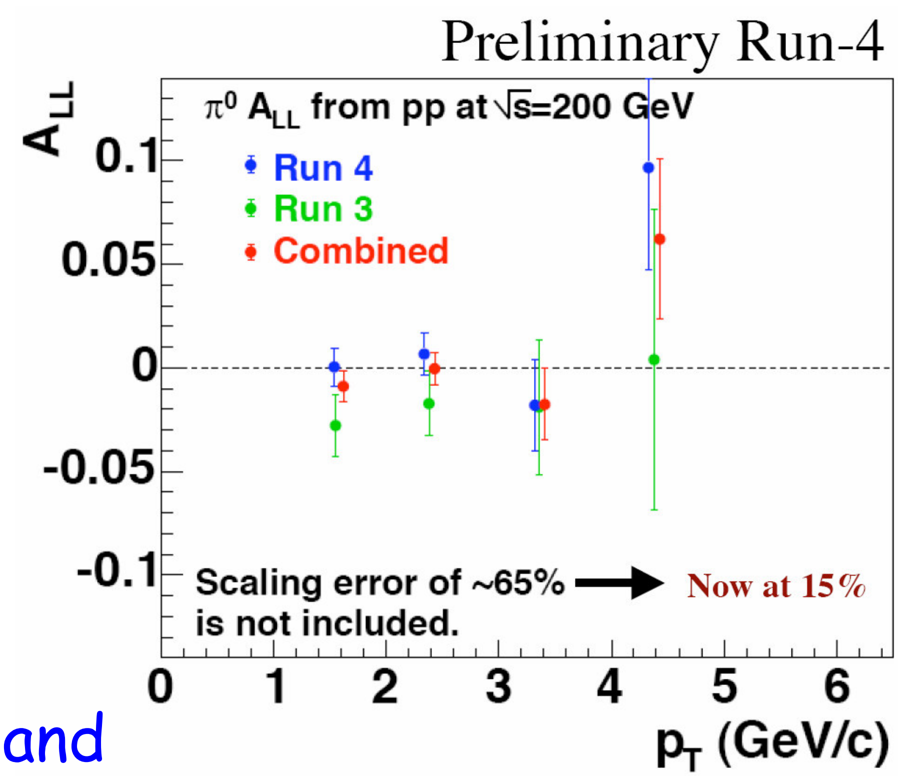
- either $\Delta G$ is small,
- either $\Delta G/G$ has to cross 0 around $x_G = 0.1$.



# Gluon Polarization



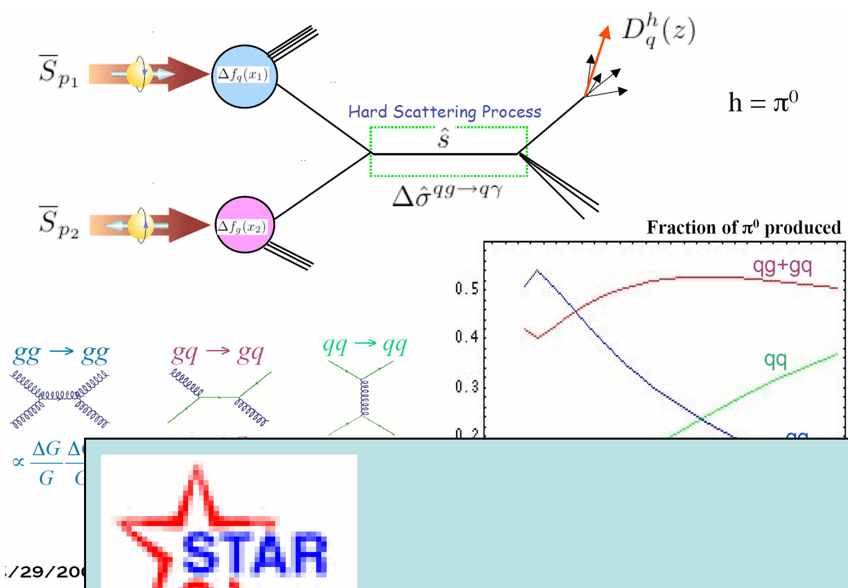

A.Desphande



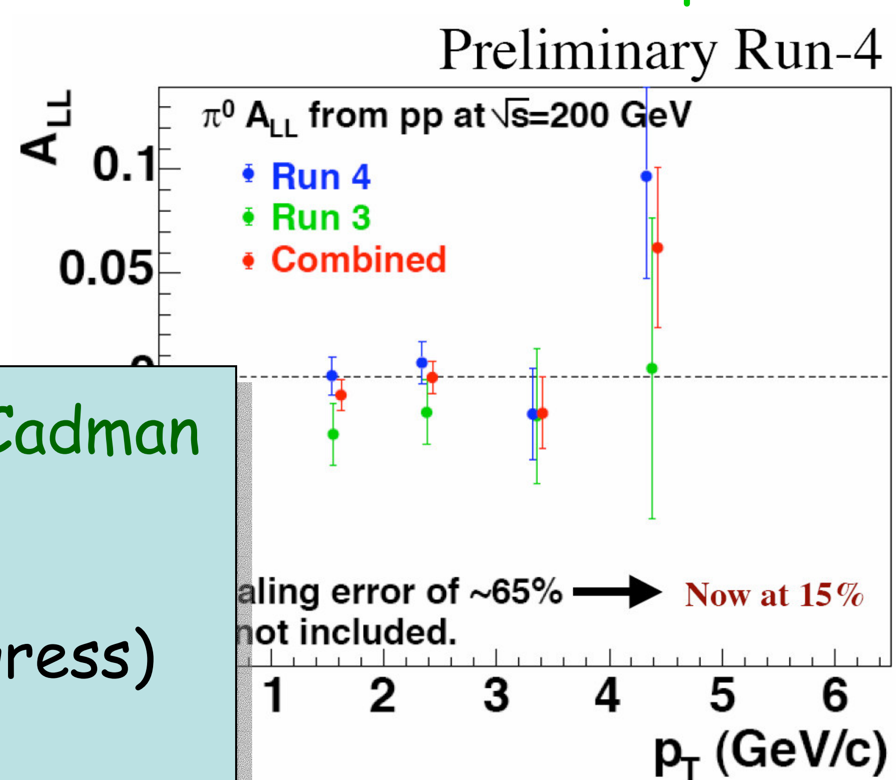

- Uncertainty still large $P^2\sqrt{L}$ .
- Dramatic improvement by lumi and beam polarization (~70%)

New silicon VTX will increase the x range coverage for $\Delta G$

# Gluon Polarization




A.Desphande




•U
•D
be

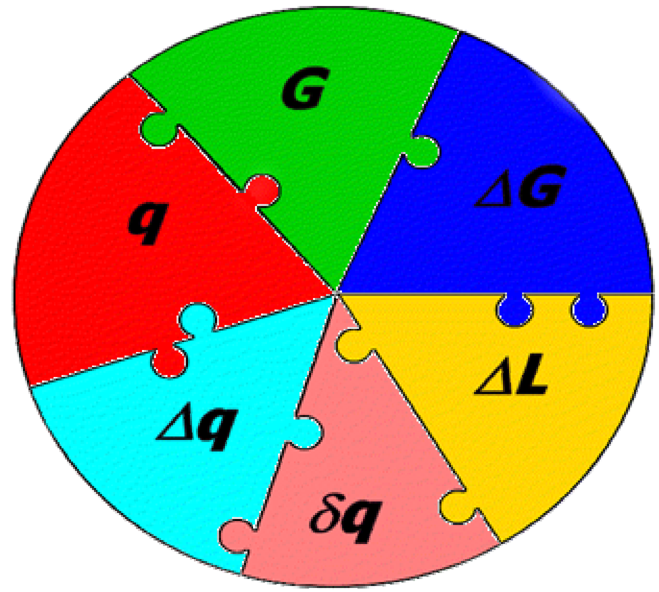
N ge coverage for $\Delta G$

R.Cadman

Calorimetry upgrade (in progress) crucial for the spin program ($A_{LL}\to\pi^0$, jets, etc...)

Gluon Spin Program has just begun!

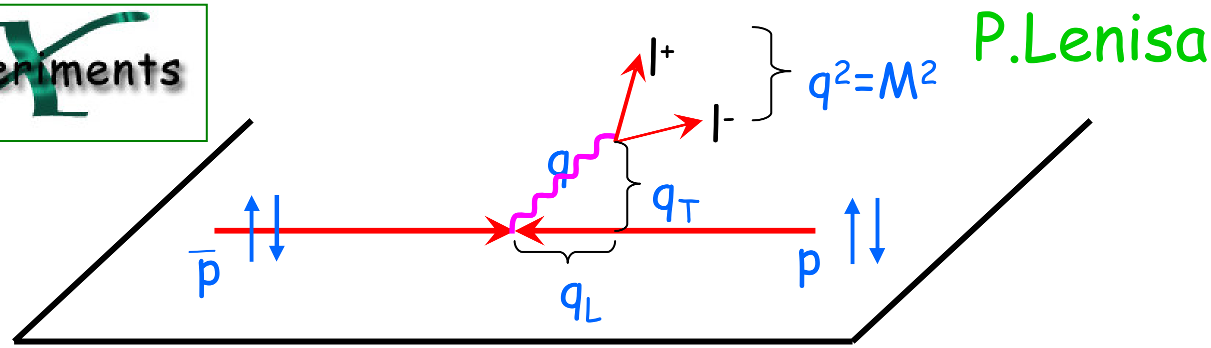
The nucleon puzzle is going FAR to be completed …



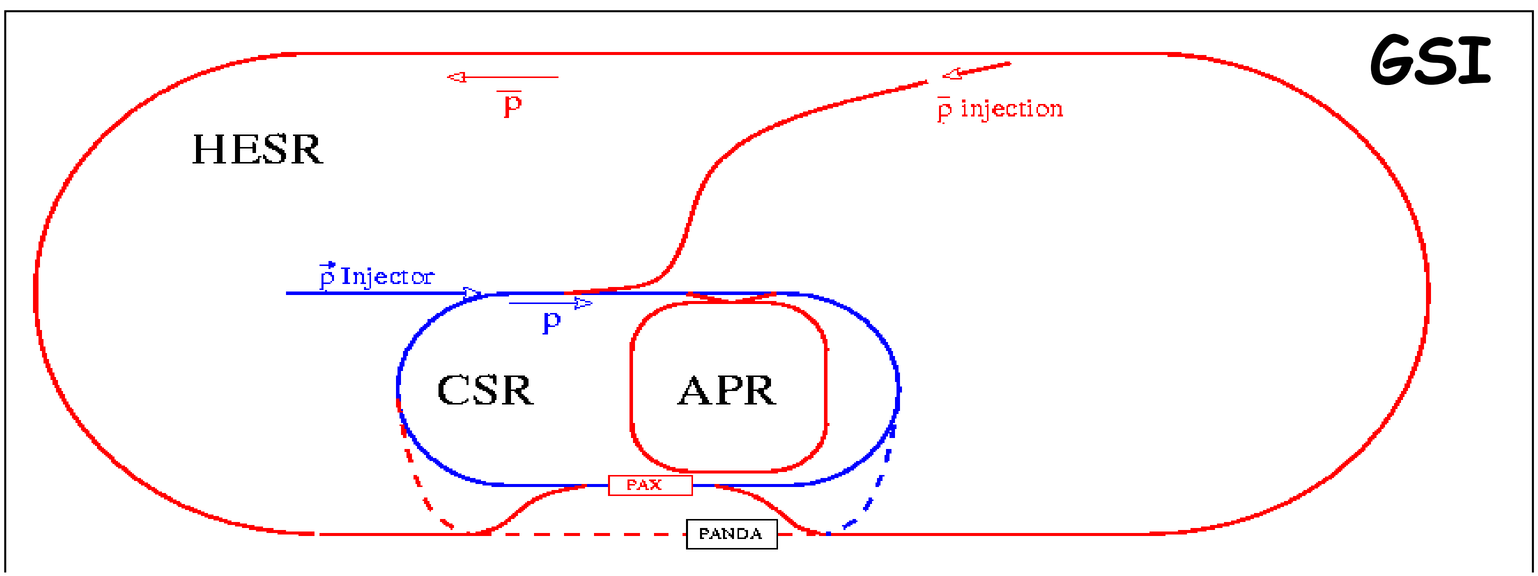
# Future: Transversity in DY

**P**olarized **A**ntiproton E**X**periments

P.Lenisa



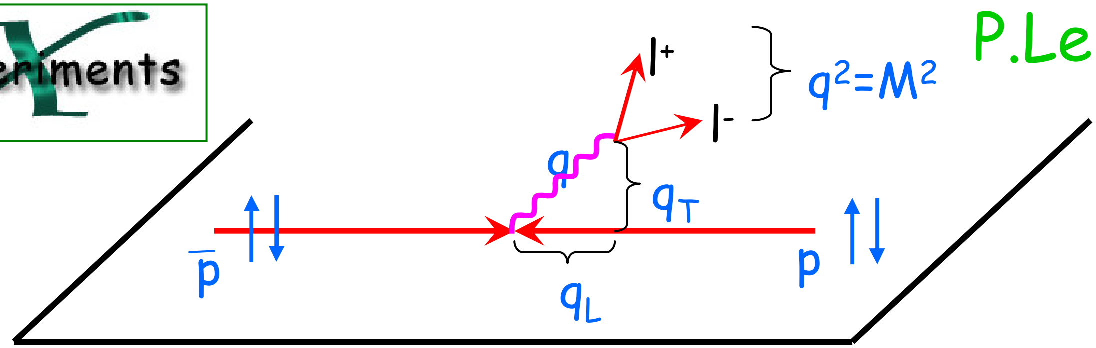

$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 h_1^q(x_1, M^2) h_1^{\bar{q}}(x_2, M^2)}{\sum_q e_q^2 q(x_1, M^2)\bar{q}(x_2, M^2)}$$



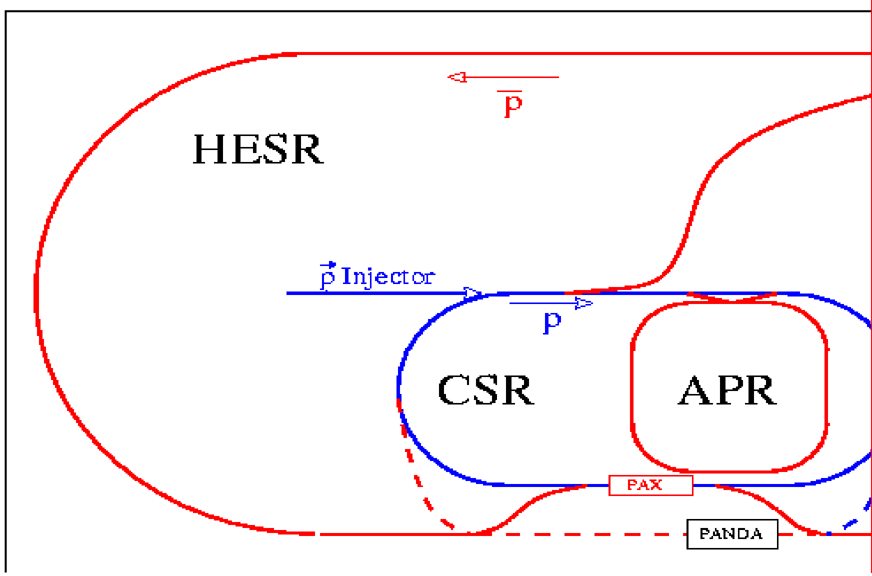
# Future: Transversity in DY

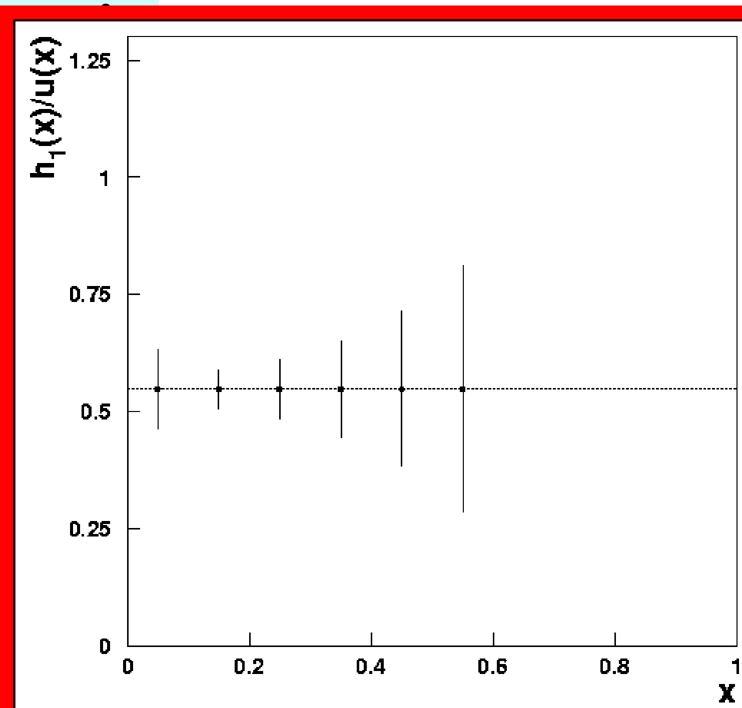
**P**olarized **A**ntiproton E**X**periments

P.Lenisa




$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \frac{\sum_q e_q^2 h_1^q(x_1, M^2) h_1^{\bar{q}}(x \ldots}{\sum_q e_q^2 q(x_1, M^2) \bar{q}(x_2 \ldots}$$



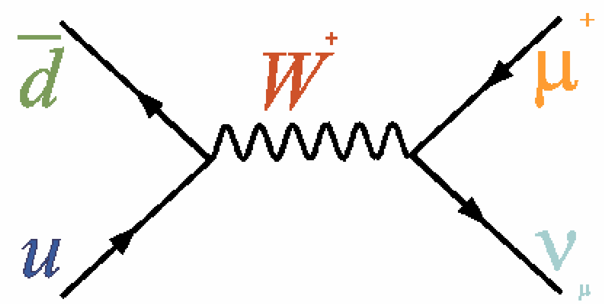

1 yr of data taking

# Quark Contribution to Proton Spin Structure at RHIC

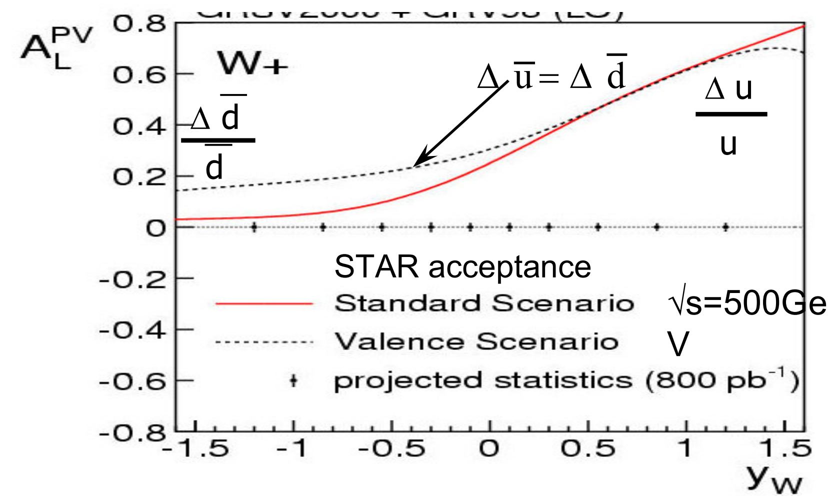
Relativistic Heavy Ion Collider

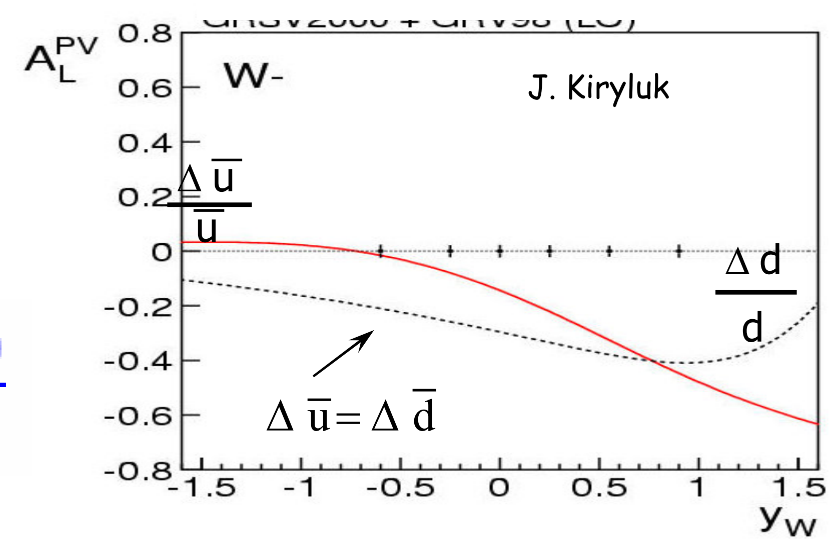
W.Xie

- Parity violating single-spin asymmetries at RHIC provide direct access to the quark flavor structure of the proton spin:




$$A_L^{W^+}(y) = \frac{-\Delta u(x_a)\bar{d}(x_b) + \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)}$$



# Polarimetry

Future colliders will aim for 1% precision in many asymmetry processes

Bravar

Proton Polarimetry: Jet target

A precision of 3% is achievable @RHIC

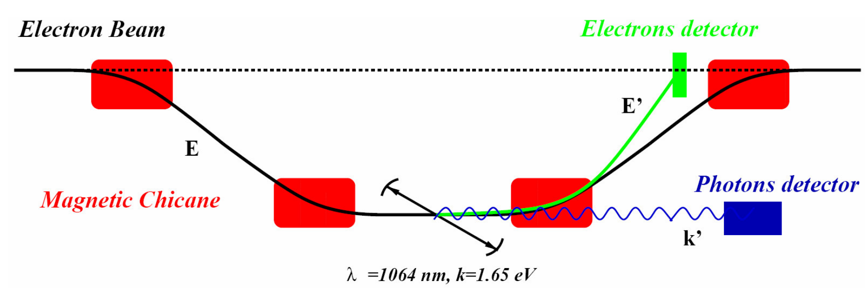
A precision of <2% desirable @eRHIC

E.Chudakov

Electron polarimetry:

Accuracy of 1% achievable in near future

Long term 0.5% desirable for future fix target experiments



# Spin physics is a very active field

Many experimental results and theories

High precision measurements (other just around the corner)

New dedicated experiments and detectors

Stimulating discussion … including homework