Overview of Longitudinal and Transverse Spin Physics at COMPASS

F.Kunne – CEA Saclay, France
on behalf of the COMPASS collaboration

- Gluon Polarization from charm & high p_T hadron pairs
- g_1^d and NLO QCD analysis
- Transversity

"Puzzling Spin" Workshop, BNL AGS Users Meeting
Brookhaven, May 27, 2008

COMPASS Collaboration at CERN

Common Muon and Proton Apparatus

for Structure and Spectroscopy

Czech Rep., France, Germany, India, Israel,
Italy, Japan, Poland, Portugal, Russia and CERN

Bielefeld, Bochum, Bonn, Burdwan and Calcutta, CERN, Dubna, Erlangen, Freiburg, Lisbon, Mainz, Moscow, Munich, Nagoya, Prague, Protvino, CEA Saclay, Tel Aviv, Torino, Trieste, Warsaw

240 physicists, 28 institutes, 11 countries

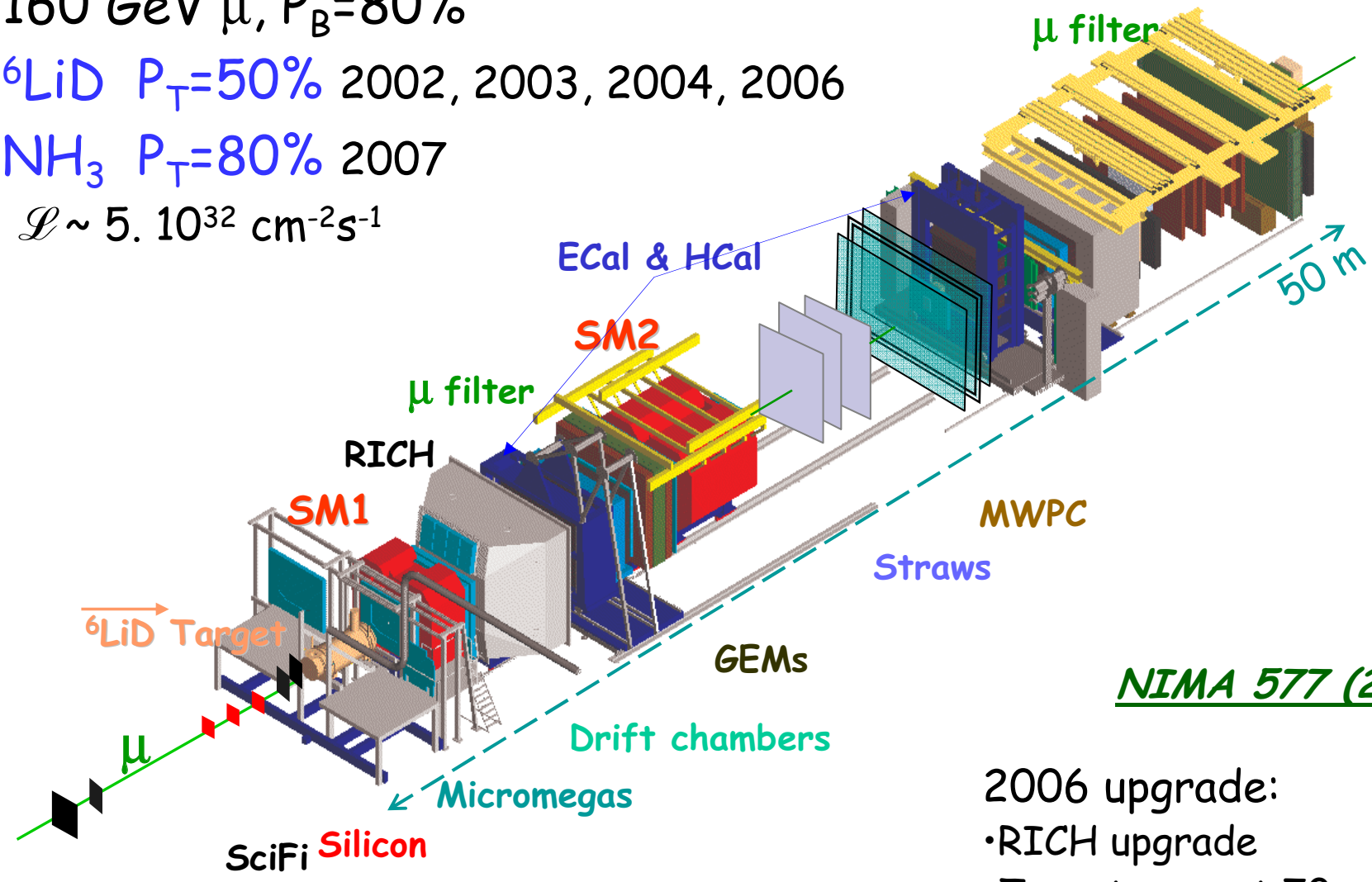
COMPASS

160 GeV μ, P_B=80%

^{6}LiD P_T=50% 2002, 2003, 2004, 2006

NH_3 P_T=80% 2007

$\mathscr{L} \sim 5.\ 10^{32}\ cm^{-2}s^{-1}$



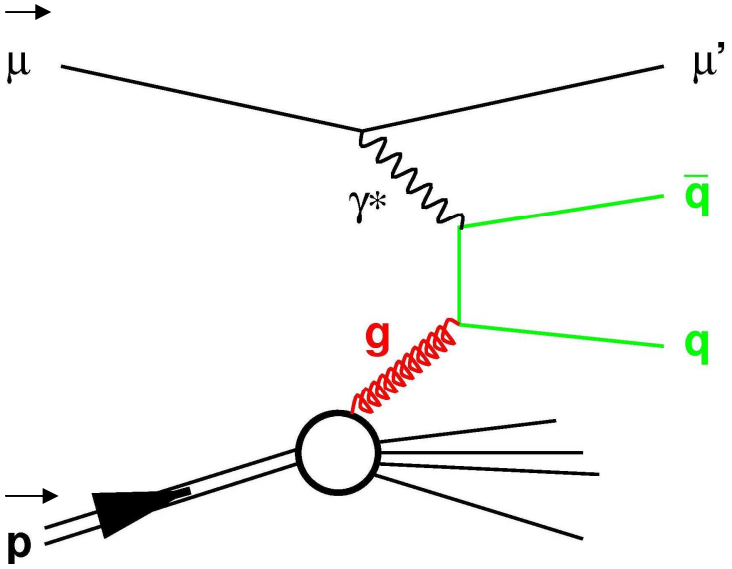
NIMA 577 (2007) 455

2006 upgrade:

- RICH upgrade
- Target magnet 70 → 180mrad
- 3-cell target

ΔG/G measurement

Photon gluon fusion $\gamma g \to q\bar{q}$



• open charm $c \to D^0 \to K\,\pi$

scale $\mu^2 = 4\,m_c^2$

No physical background, but:

combinatorial background & limited stat:

challenging experiment

• high p_T hadron pair $q\,\bar{q} \to h\,h$

scale $\mu^2 = Q^2$ or Σp_T^2

high statistics

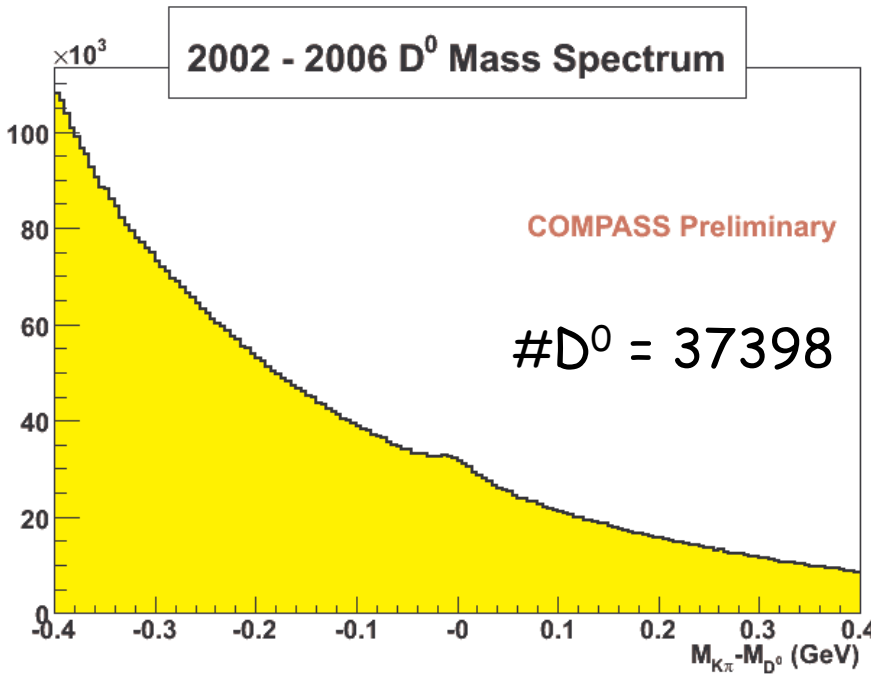
but physical background

Open charm – D^0 and D^* events

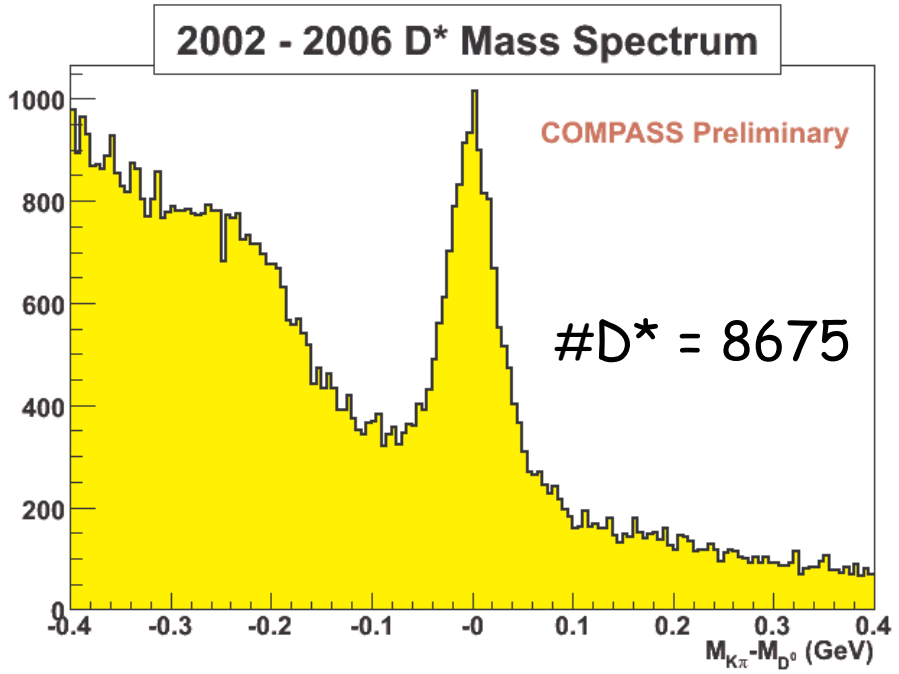
All deuterium data analyzed (2002-2006)

D^0 selection: $K\pi$ invariant mass + cuts on kinematics + RICH PID

$$D^0 \rightarrow K\pi$$



$$D^* \rightarrow D^0\pi_s \rightarrow K\pi\pi$$



$$\delta\left(\frac{\Delta G}{G}\right) \propto 1\Big/\sqrt{\frac{S}{S+B}\times S}$$

Open charm – from A_{LL} to $\Delta G/G$

$$\frac{\Delta G}{G} = \frac{1}{P_T P_\mu f a_{LL} \dfrac{S}{S+B}} \times \frac{\vec{\vec{N}}_d - \vec{\vec{N}}_u}{\vec{\vec{N}}_d + \vec{\vec{N}}_u}$$

event weight w

P_T : target polarization

P_μ : beam polarization

f : dilution factor

a_{LL} : analyzing power

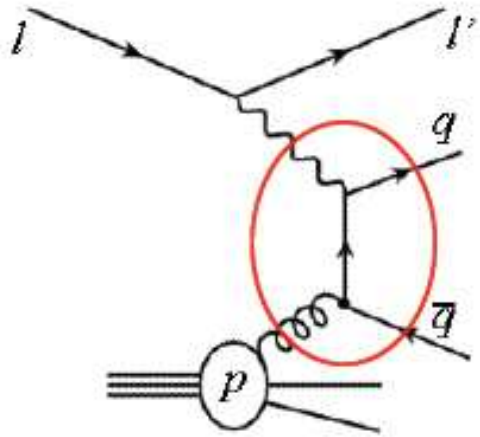
$\gamma g \rightarrow c\bar{c}$

$$\frac{\Delta G}{G} = \frac{1}{P_T} \times \frac{\sum \vec{\vec{w}}_d - \sum \vec{\vec{w}}_u}{\sum \vec{\vec{w}}_d^{\,2} + \sum \vec{\vec{w}}_u^{\,2}}$$

Statistical gain : $\dfrac{\langle w^2 \rangle}{\langle w \rangle^2}$

Weights bring significant improvement due to large variations of a_{LL} and S/(S+B) in phase-space

Open charm - a_{LL}



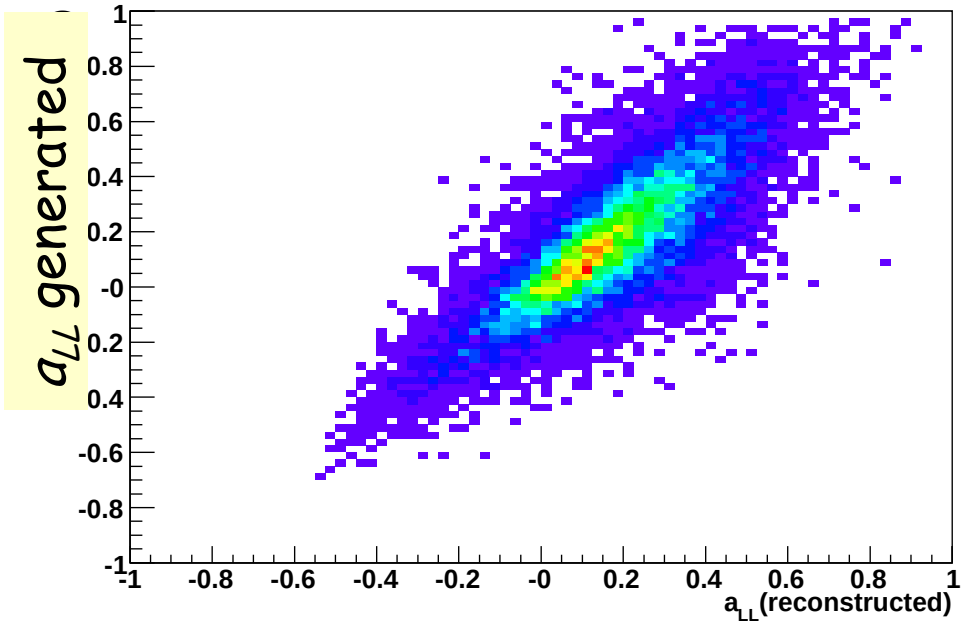
$$a_{LL} = \frac{\Delta\sigma^{PGF}}{\sigma^{PGF}}\left(y, Q^2, x_g, z_c, \phi\right)$$

- Would need full partonic kinematics to compute a_{LL}
- Already good reconstruction from one D meson only:

a_{LL} from Neural Network trained on MC (AROMA): input variables : Q^2, x_{bj}, y, p_T, z_D

- very large dispersion of values, even change of sign

- 82% correlation



a_{LL} reconstructed

Open charm – S/(S+B) weighting

- S/(S+B) probability for an event to be PGF.

Parameterized as function of kinematics & RICH response.
Given event by event.

- Weight close to 0 : high probability for background

  close to 1 : high probability for open charm

- Event weight built on data only

- Gain in statistics from weight + possibility to loose cuts:

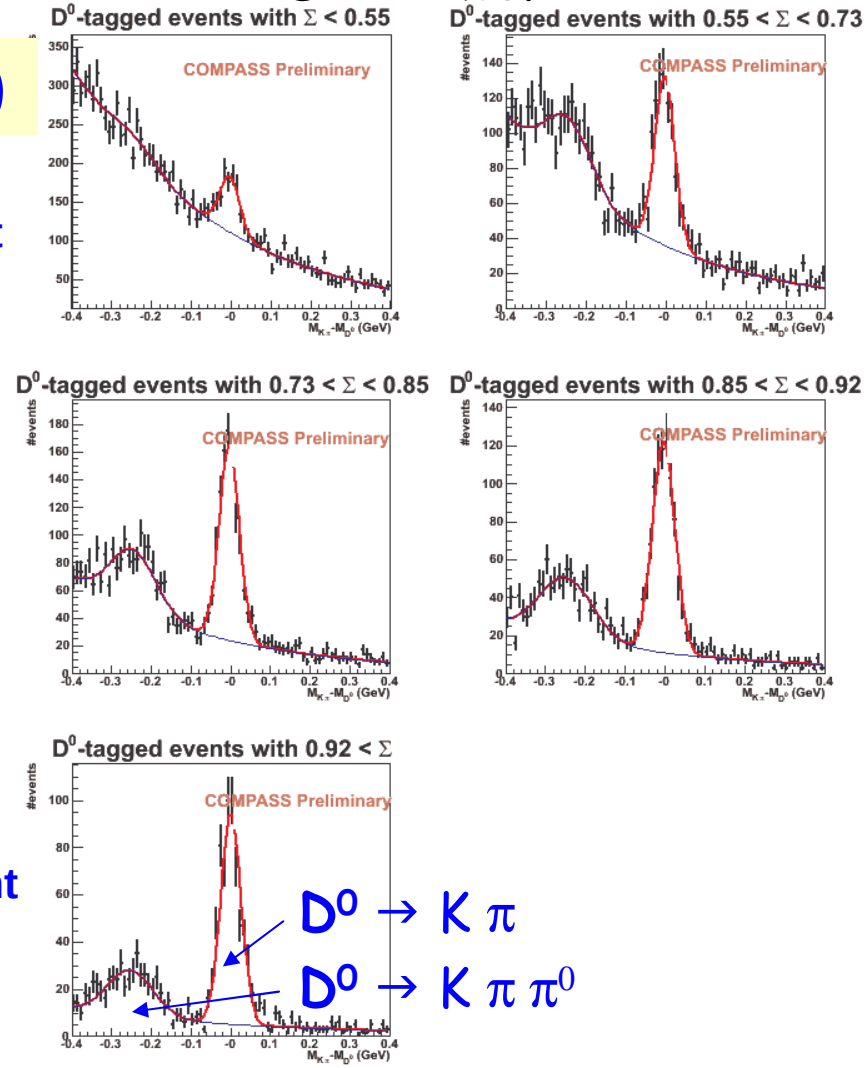
  +45% for D^0 and 15% for D^*

Open charm – S/(S+B) weighting

D^* events.

5 bins in S/(S+B)

B events
low weight



large S,
high weight

$D^0 \rightarrow K\,\pi$

$D^0 \rightarrow K\,\pi\,\pi^0$

Background events, with low weight, do not affect ΔG

Open charm D^0 + D^* Result

$\Delta G/G = -0.49 \pm 0.27\ (stat) \pm 0.11\ (syst)$

Systematics :

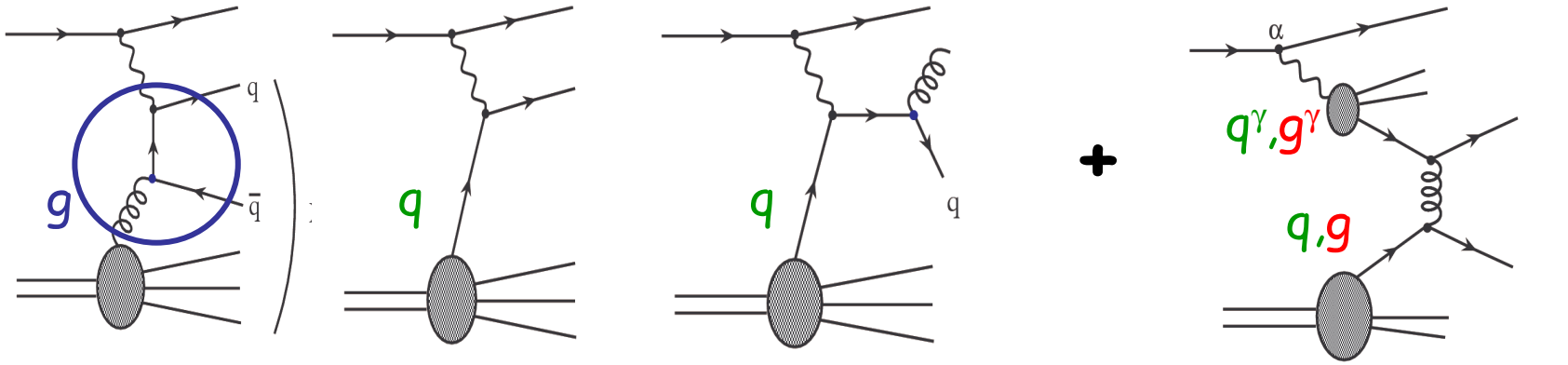
Source	D^0	D^*
Beam polar	0.025	0.025
Target polar	0.025	0.025
Dil. Fact.	0.025	0.025
False asymmetry	0.05	0.05
Signal extraction (Σ)	0.07	0.01
a_{11} (charm mass)	0.05	0.03
TOTAL	**0.11**	**0.07**

$$\langle x_g \rangle = 0.11^{+0.11}_{-0.05}$$
$$\langle \mu^2 \rangle = 13\,GeV^2$$

DIS-2008 F.Robinet

$\Delta G/G$ from high p_T hadron pairs

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



Photon Gluon Fusion ~ 30%

Leading Order

QCD Compton

Resolved γ ~50%

$$A_{LL} = R_{PGF} \times a_{LL}^{PGF} \times \frac{\Delta G}{G} + A_{BKGR}$$

$\Delta G/G$ from high p_T hadron pairs

DIS-2008 M.Stolarski

- Need to know R_{PGF}, R_{QCDC}, R_{LO}, a_{LL}^{PGF}, a_{LL}^{QCDC}, a_{LL}^{incl}, x_g, x_C...

- Parameterization based on Neural Network

  and trained on Monte Carlo (LEPTO for $Q^2 > 1$)

- Agreement data/MC important

	Final MC
$\langle a^{LO} \rangle$	0.63
$\langle a^{C} \rangle$	0.50
$\langle a^{PGF} \rangle$	-0.36
R_L	0.40
R_C	0.29
R_{PGF}	0.31

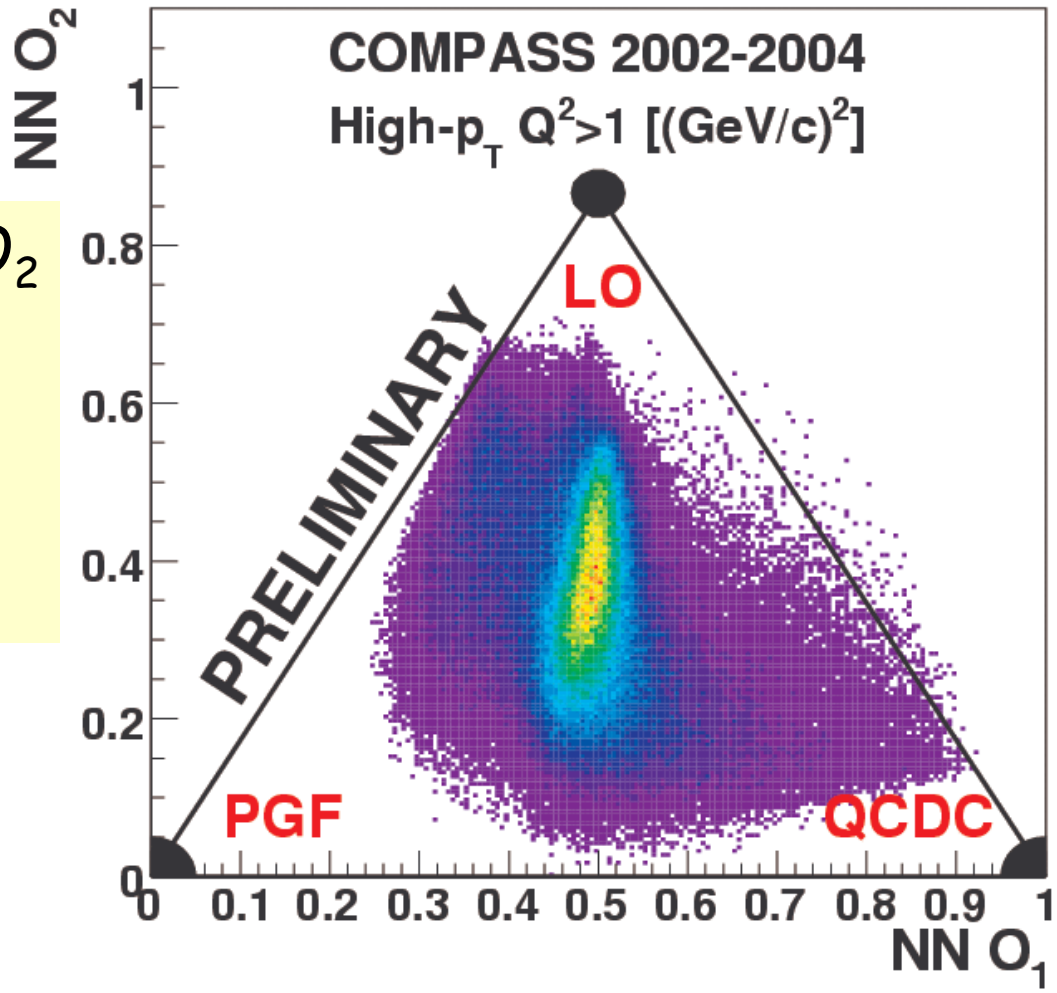
High p_T hadron pairs - NN

Two parameters: O_1 & O_2

to express fractions

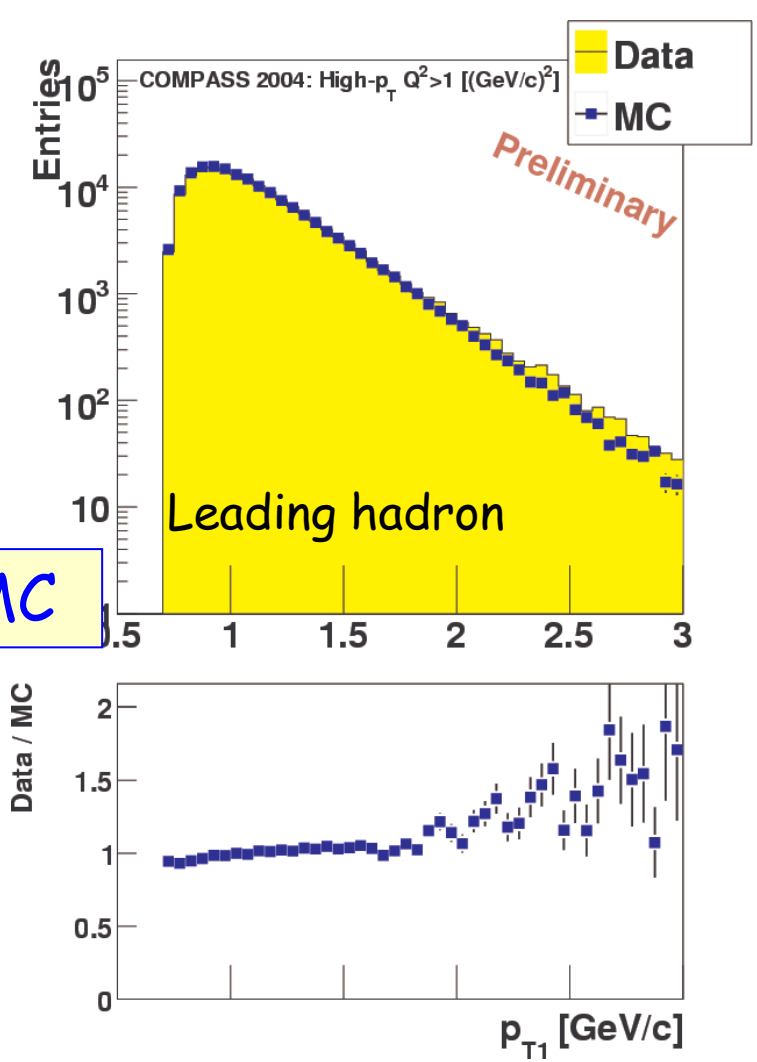
R (PGF, LO or QCDC)

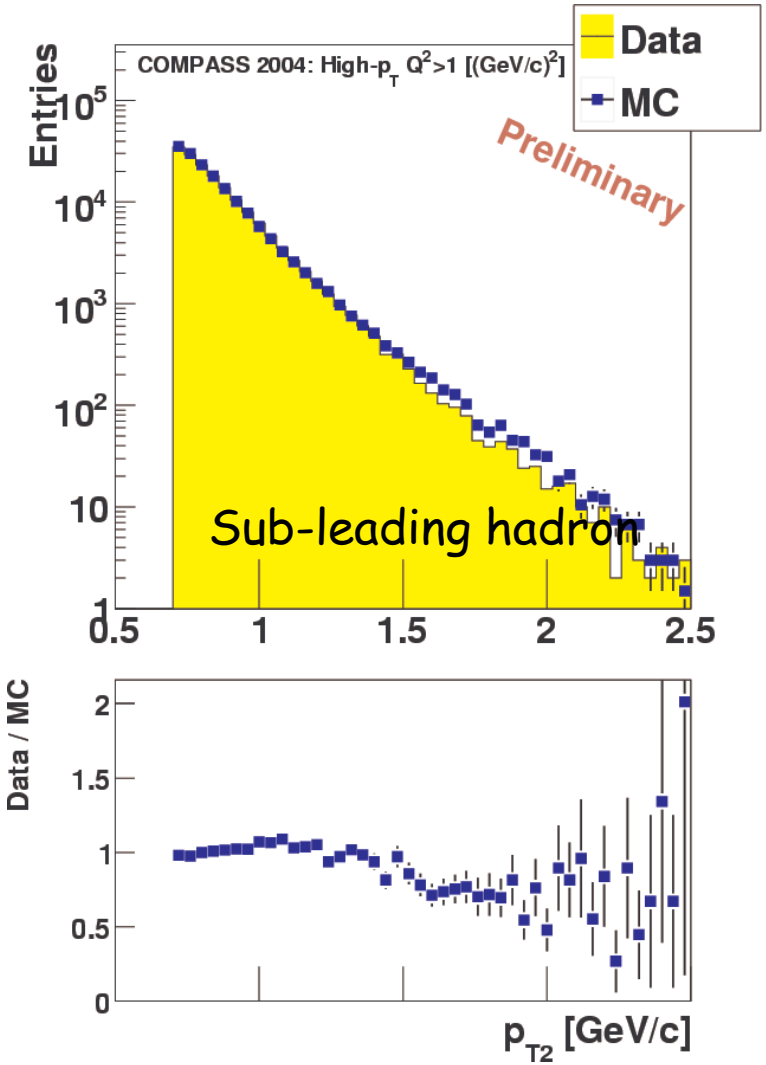
for each high p_T event



High p_T hadron pairs - Data / MC

Data /MC





High p_T , $Q^2 > 1\ GeV^2$ - systematics

$\delta(\Delta G/G)_{NN}$	0.006
$\delta(\Delta G/G)_{MC}$	0.040
$\delta(\Delta G/G)_{f,Pb,Pt}$	0.006
$\delta(\Delta G/G)_{false}$	0.011
$\delta(\Delta G/G)_{A1}$	0.008
$\delta(\Delta G/G)_{formula}$	0.013
Total	0.045

$\Delta G/G$ from high p_T hadron pairs

Result 2002-2004 data: $Q^2 > 1\ GeV/c^2$

$\Delta G/G$ = 0.08 ± 0.10 (stat) ± 0.05(syst)

$\langle x_g \rangle$ = 0.082 (range: 0.055 – 0.123) $\mu^2 \sim 3\ (GeV/c)^2$

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2006, 2007 data, still to come…

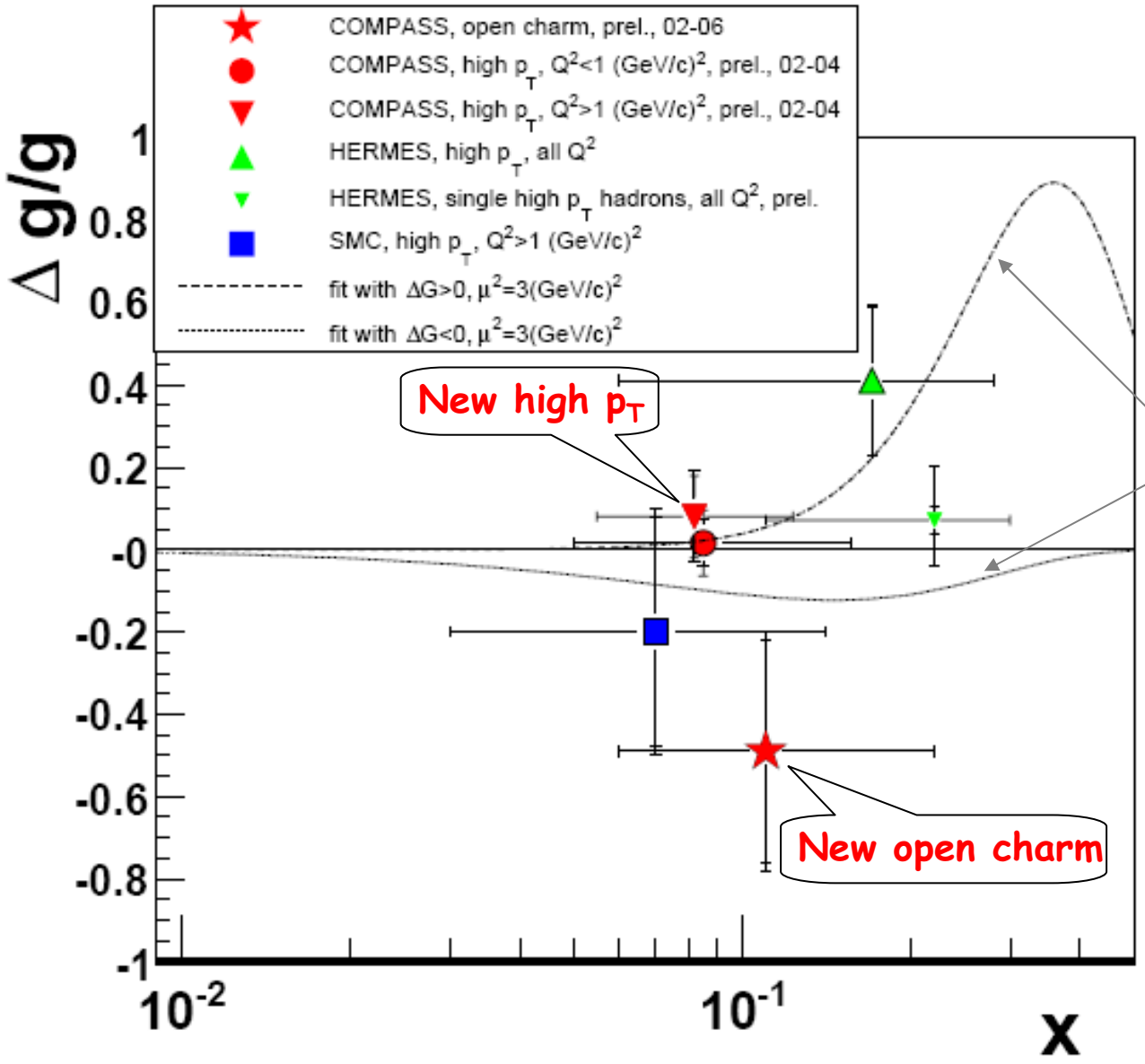
Recall 2002-2004 data: $Q^2 < 1\ GeV/c^2$

$\Delta G/G$ = 0.016 ± 0.058 (stat) ± 0.055 (syst)

$\langle x_g \rangle$ = 0.085, μ^2 = 3 $(GeV/c)^2$

SPIN-2006

$\Delta G/G$ direct measurements



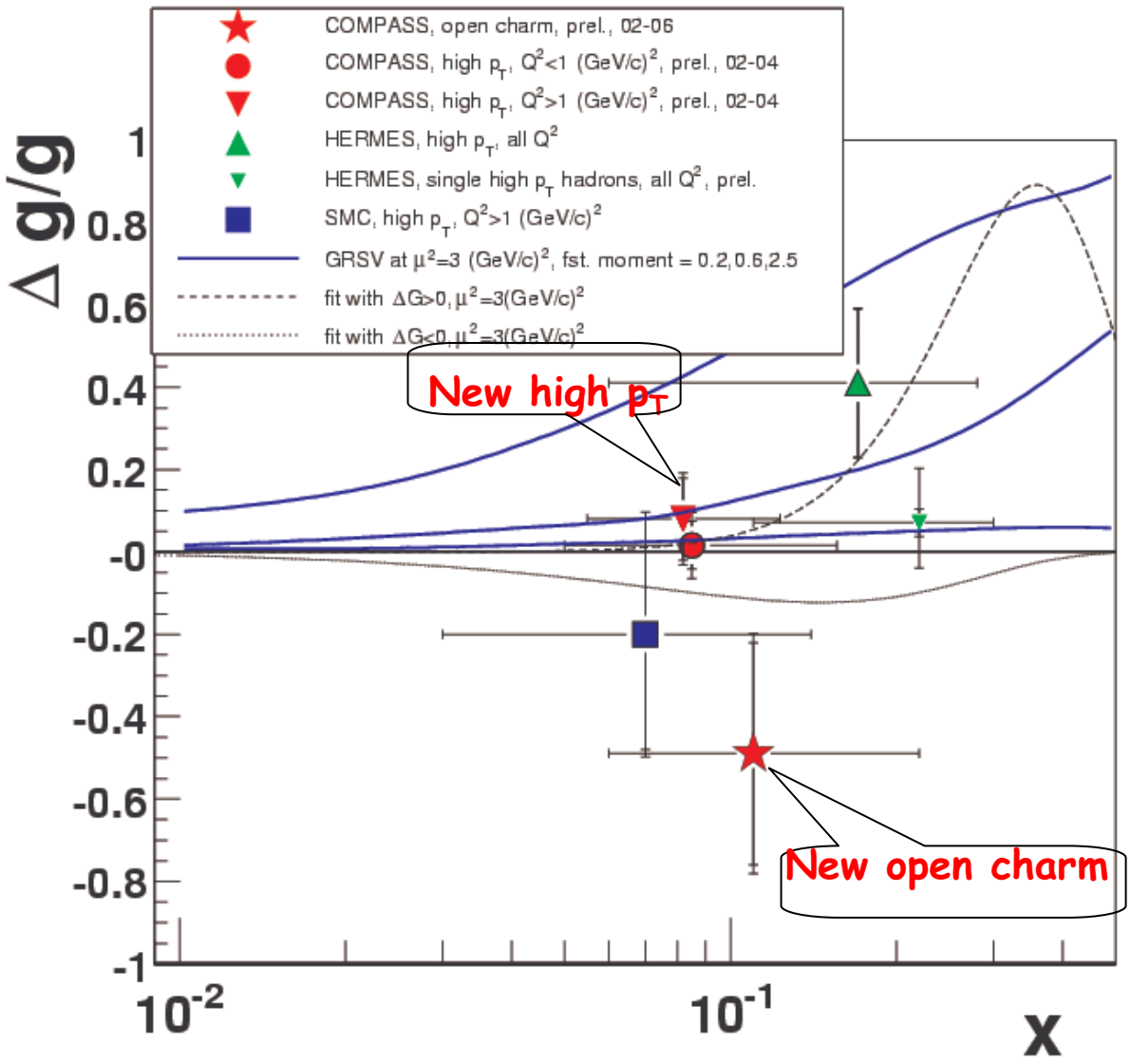
COMPASS

QCD fits to g_1

$|\Delta G| \sim 0.2\text{-}0.3$

$Q^2=3$ (GeV/c)^2

$\Delta G/G$ direct measurements



GRSV
QCD fit to g_1
ΔG max :2.5

std:0.6

min: 0.2

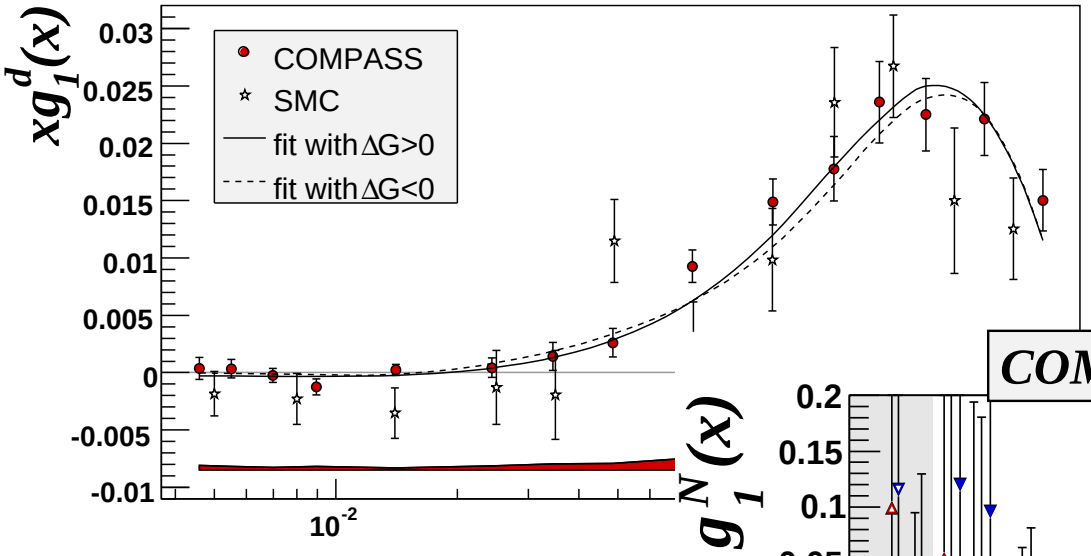
COMPASS
QCD fits to g_1
$|\Delta G| \sim 0.3$

$\Delta G/G$ direct measurements

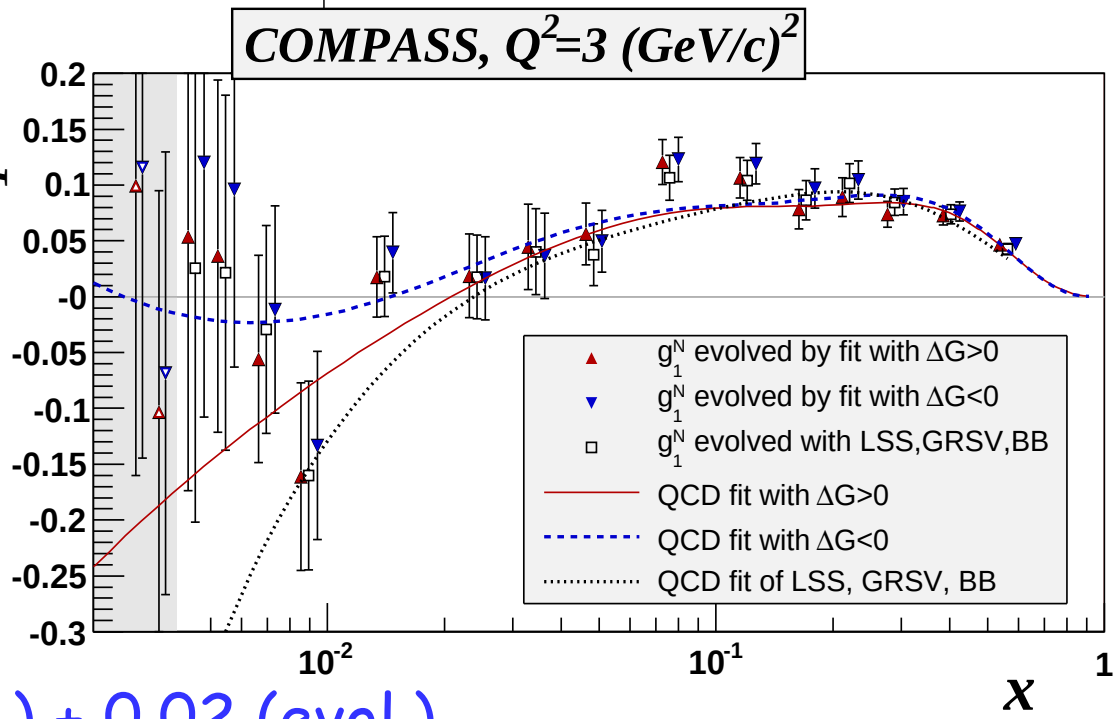
- High p_T pairs: accurate $\Delta G/G$ from 2002 – 2004 data
  $Q^2 < 1$ GeV/c^2 and $Q^2 > 1$ GeV/c^2 (new)
  $\Delta G/G$ compatible with 0 at $\langle x_g \rangle = 0.08$

- Open charm : significant improvement for $\Delta G/G$
  $\Delta G/G$ at $\langle x_g \rangle = 0.11$ prefers negative value,
  but still less than 2σ away from 0.

QCD fit- Impact of g_1^d low x data



$\Gamma_1 = \int g_1(x)dx$:
only 2% correction from unmeasured low x
(was 50% negative before)



Disagreement of new data with earlier QCD fits

- $\Delta\Sigma$=0.30 ± 0.01 (stat.) ± 0.02 (evol.)
- Δs=–0.08 ± 0.01 ± 0.02 (← COMPASS data alone)

Gluon polarization and nucleon spin

- $\Delta G = \int \Delta G(x)dx$ not large
  (both from direct measurements and g_1 QCD fit)

$\Rightarrow$ $\Delta\Sigma \sim a_0 = 0.3$ small ($\neq$ predictions)

- Consequence for spin decomposition (from Compass alone)

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

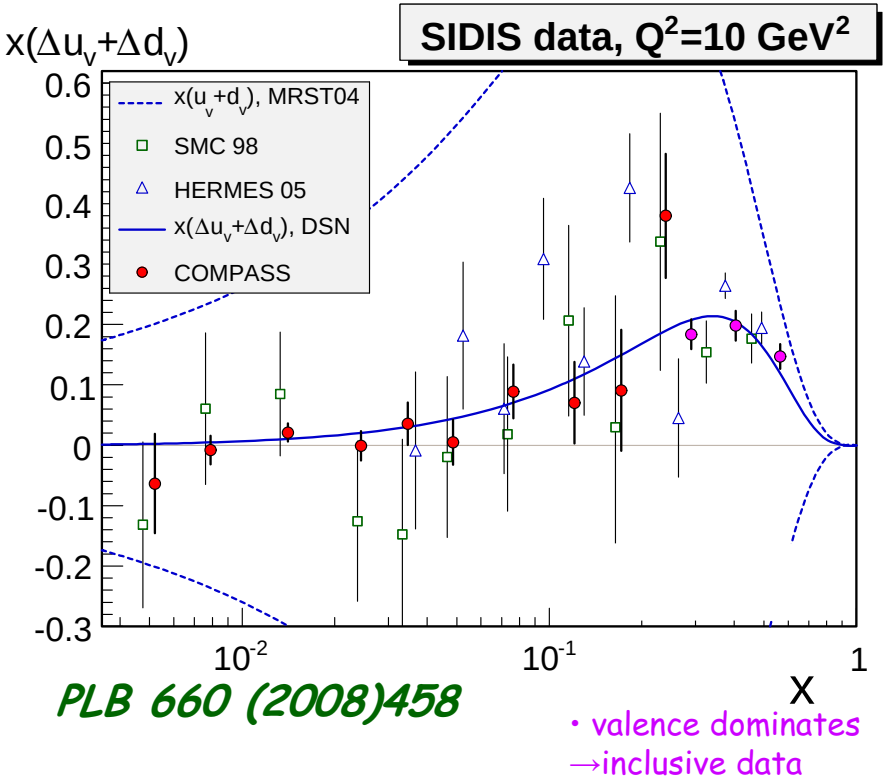
possible scenarios:

$$\begin{cases} \tfrac{1}{2}0.3 + 0.35 + 0.0 \\ \tfrac{1}{2}0.3 + 0.0 + 0.35 \\ \tfrac{1}{2}0.3 - 0.35 + 0.7 \end{cases}$$

COMPASS Semi inclusive : valence/sea

Only deuteron data $\mu\, d \rightarrow \mu'\, h\, X$ $D_q^h \neq D_{\bar{q}}^h$ → separate valence and sea

$$u_v = u - \bar{u}$$



PLB 660 (2008)458

LO: $A^{h^+-h^-}(x) = \dfrac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)}$

Integrals:

- $\Delta u_v + \Delta d_v = 0.41 \pm 0.07 \pm 0.05$

- using $\Delta u_v + \Delta d_v$, Γ_1 and a_8:
  $\Delta\bar{u} + \Delta\bar{d} = 0.00 \pm 0.04 \pm 0.03$

• valence dominates
→inclusive data

Data favor $\Delta\bar{u} = -\Delta\bar{d}$, in contrast with usual assumption:
$\Delta\bar{u} = \Delta\bar{d} = \Delta s = \Delta\bar{s}$, leading to $\Delta u_v + \Delta d_v = a_8 = 0.58$

Transversity

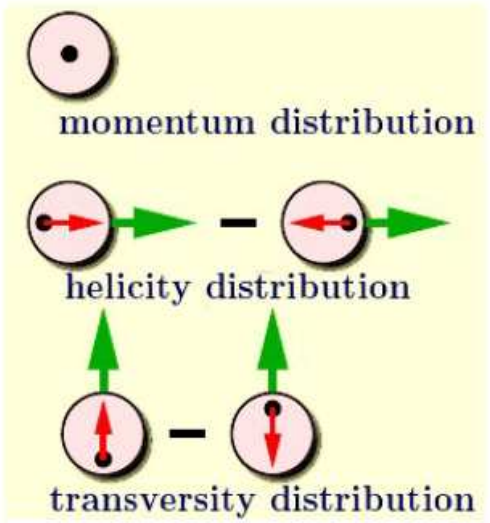
Transversity $h_1(x)$

To describe nucleon spin structure
3 functions, all of equal importance

$q(x)$ — momentum distribution — $F_2(x)$

$\Delta q(x)$ — helicity distribution — $g_1(x)$

$\Delta_T q(x)$ — transversity distribution — $h_1(x)$



h_1 accessible with

transversely polarized target and 'quark polarimetry':

- azimuthal asymmetry of outgoing hadron

  ''Collins''asymmetry

- 2 hadrons
- lambda

transverse distributions

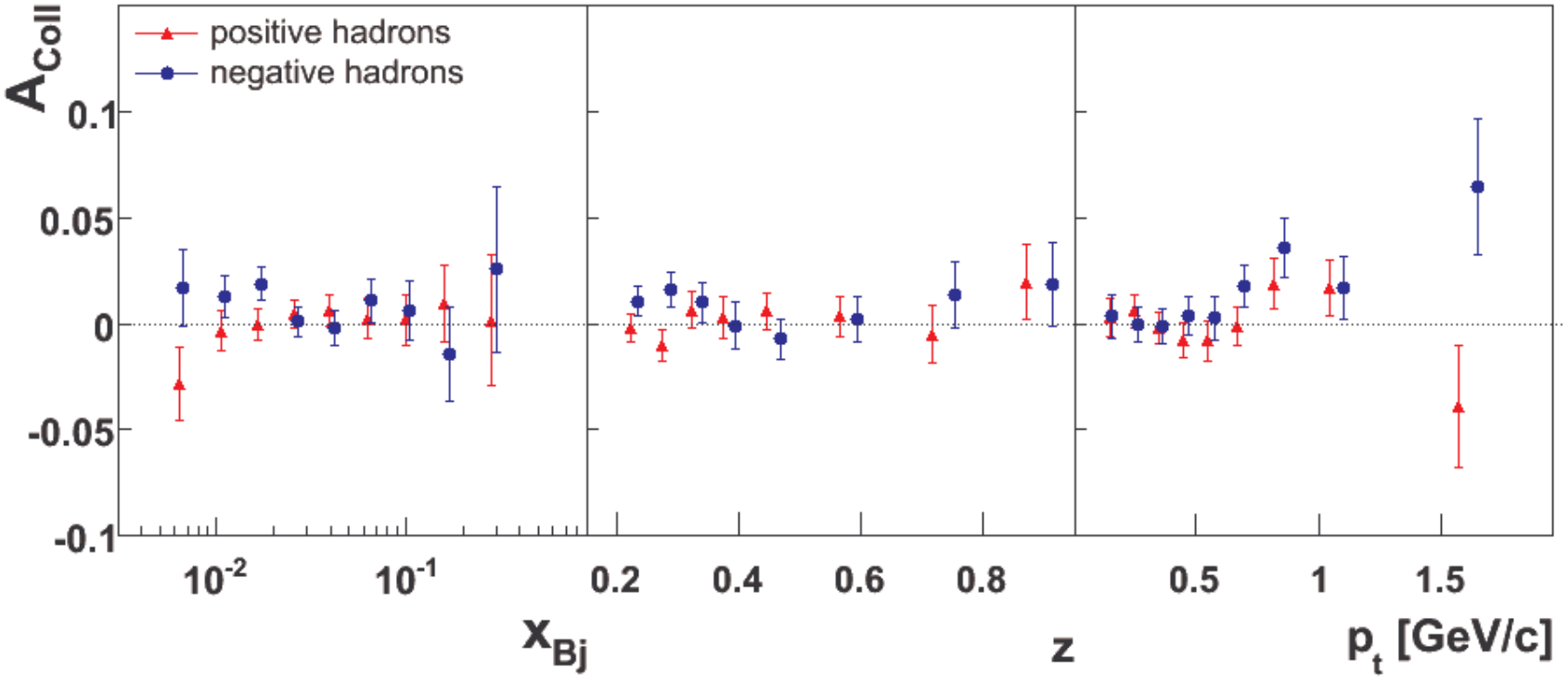
$$A_{Coll} = \frac{\sum_q e_q^2 \cdot \Delta_T q \, \Delta D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

Fragmentation function

Collins Asymmetry – all hadrons

Deuteron target

COMPASS: 2002-2004



- only statistical errors shown (~1%), systematic errors much smaller

NPB 765 (2007) 31-70

Asymmetries compatible with 0 for both + and – hadrons

Collins: Hermes (p) and COMPASS (d)

Naive interpretation; parton model, valence region.

proton

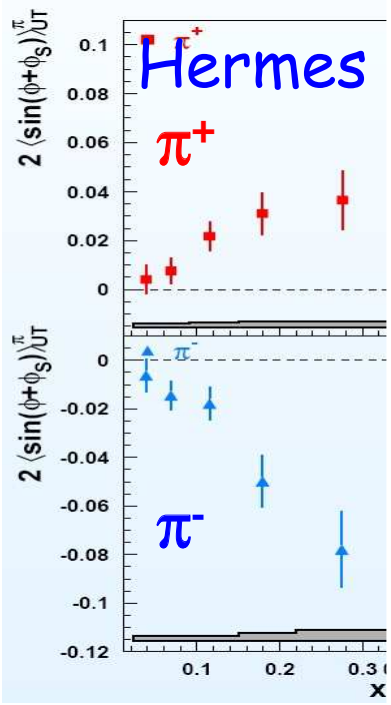
$$A_{Coll}^{p,\pi^+} \simeq \frac{4\Delta_T u_v \Delta_T^0 D_1 + \Delta_T d_v \Delta_T^0 D_2}{4u_v D_1 + d_v D_2}$$

$$A_{Coll}^{p,\pi^-} \simeq \frac{4\Delta_T u_v \Delta_T^0 D_2 + \Delta_T d_v \Delta_T^0 D_1}{4u_v D_2 + d_v D_1}$$

u quark dominance (constrains $\Delta_T u$ (x))

unfavored Collins FF ~ - favored Collins FF $\Delta_T^0 D_2 \approx -\Delta_T^0 D_1$

at variance with unpol. case



deuteron

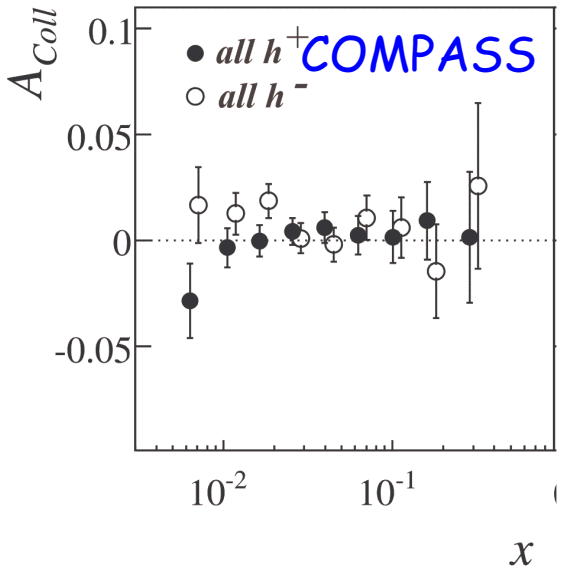
$$A_{Coll}^{d,\pi^+} \simeq \frac{\Delta_T u_v + \Delta_T d_v}{u_v + d_v} \frac{4\Delta_T^0 D_1 + \Delta_T^0 D_2}{4D_1 + D_2}$$

$$A_{Coll}^{d,\pi^-} \simeq \frac{\Delta_T u_v + \Delta_T d_v}{u_v + d_v} \frac{\Delta_T^0 D_1 + 4\Delta_T^0 D_2}{D_1 + 4D_2}$$

access to $\Delta_T d$ (x)

some (small) effect expected even if $\Delta_T^0 D_2 \approx -\Delta_T^0 D_1$

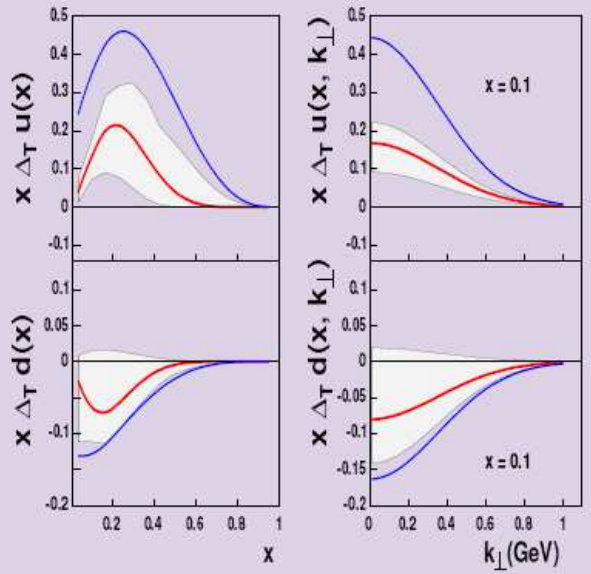
cancellation between $\Delta_T u$ (x) and $\Delta_T d$ (x)



Collins: Hermes (p), COMPASS (d) and BELLE

- Complete analysis by Anselmino et al., Efremov et al., Vogelsang al....

M. Anselmino, M. Boglione, U. D'Alesio, A. Kotzinian, F. Murgia, A. P., C. Turk, Phys.Rev.D75:054032,2007



- This is the first extraction of transversity from experimental data.
- $\Delta_T u(x) > 0$ and $\Delta_T d(x) < 0$
- Neither $\Delta_T u(x)$ nor $\Delta_T d(x)$ saturates Soffer bound.

A. Prokudin et al. DIS2008

- Then, by adding new Belle / Hermes / Compass data :

errors decrease a lot and $\Delta_T u$ is larger

Collins Asymmetry : π^+, π^-, K^+, K^-, K^0

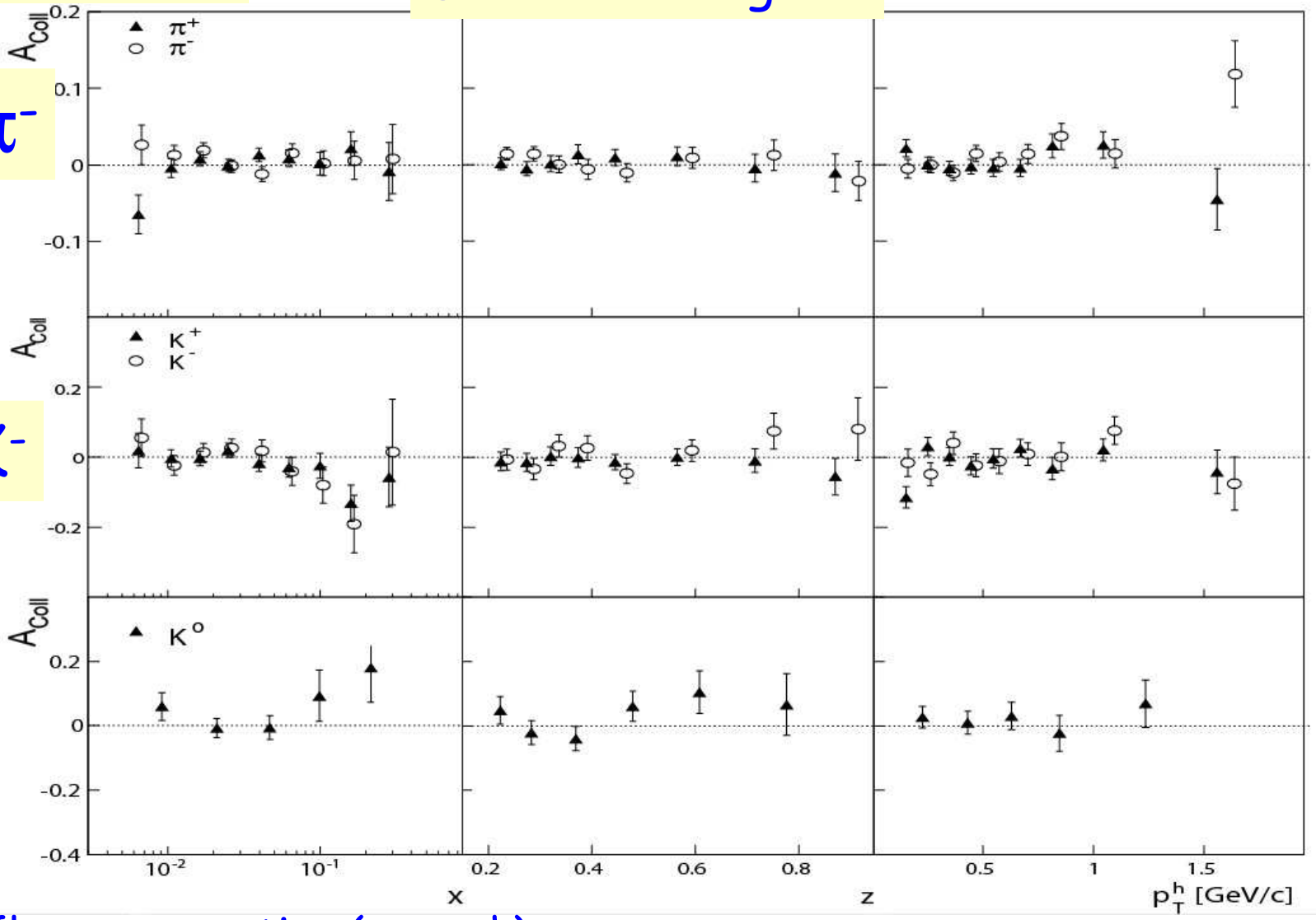
1 identified hadrons

Deuteron target

π^+, π^-

K^+, K^-

K^0

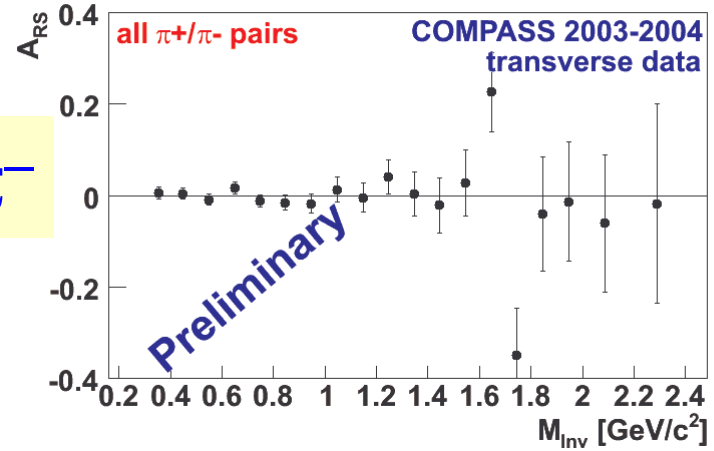


→ flavor separation (s quark) …

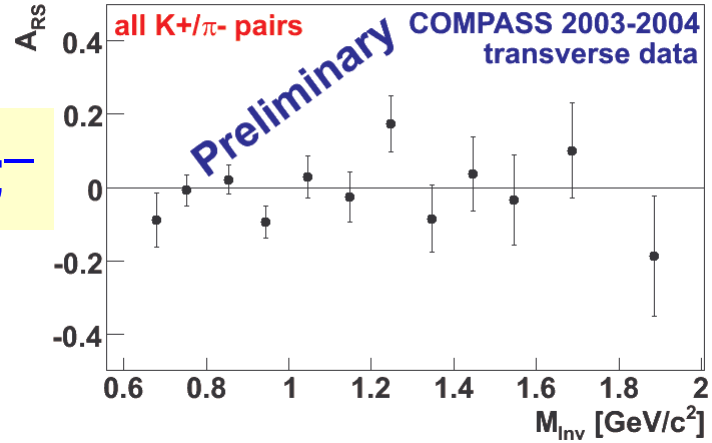
hep-ex/0802.2160

Transversity – identified hadron pairs

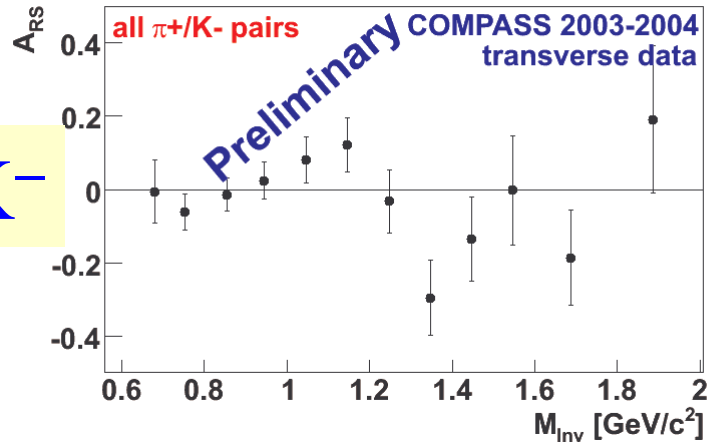
$\pi^+ \pi^-$



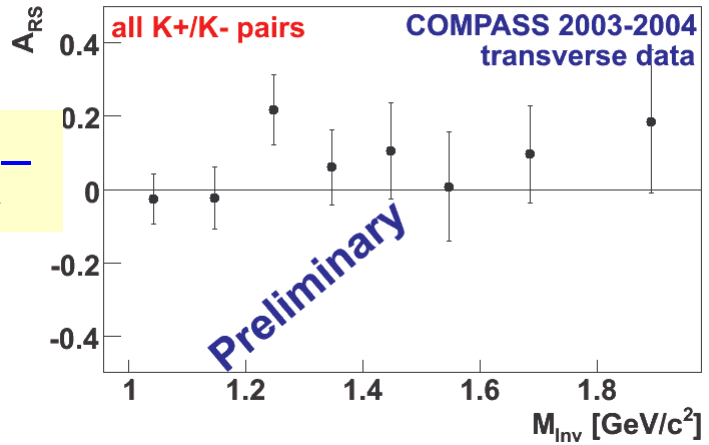
$K^+ \pi^-$



$\pi^+ K^-$



$K^+ K^-$



- Need interference fragm. function (from Belle)
- See Jaffe, Artru 02, Bacchetta-Radici 04,…

F.Sozzi, DIS 2008

Sivers

$$A_{Siv} = \frac{\sum_q e_q^2 \cdot f_{1Tq}^{\perp} \cdot D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

- Correlation between intrinsic transverse momentum and transverse spin
- Measured simultaneously with Collins asymmetry

Sivers Asymmetry : π^+, π^-, K^+, K^-, K^0

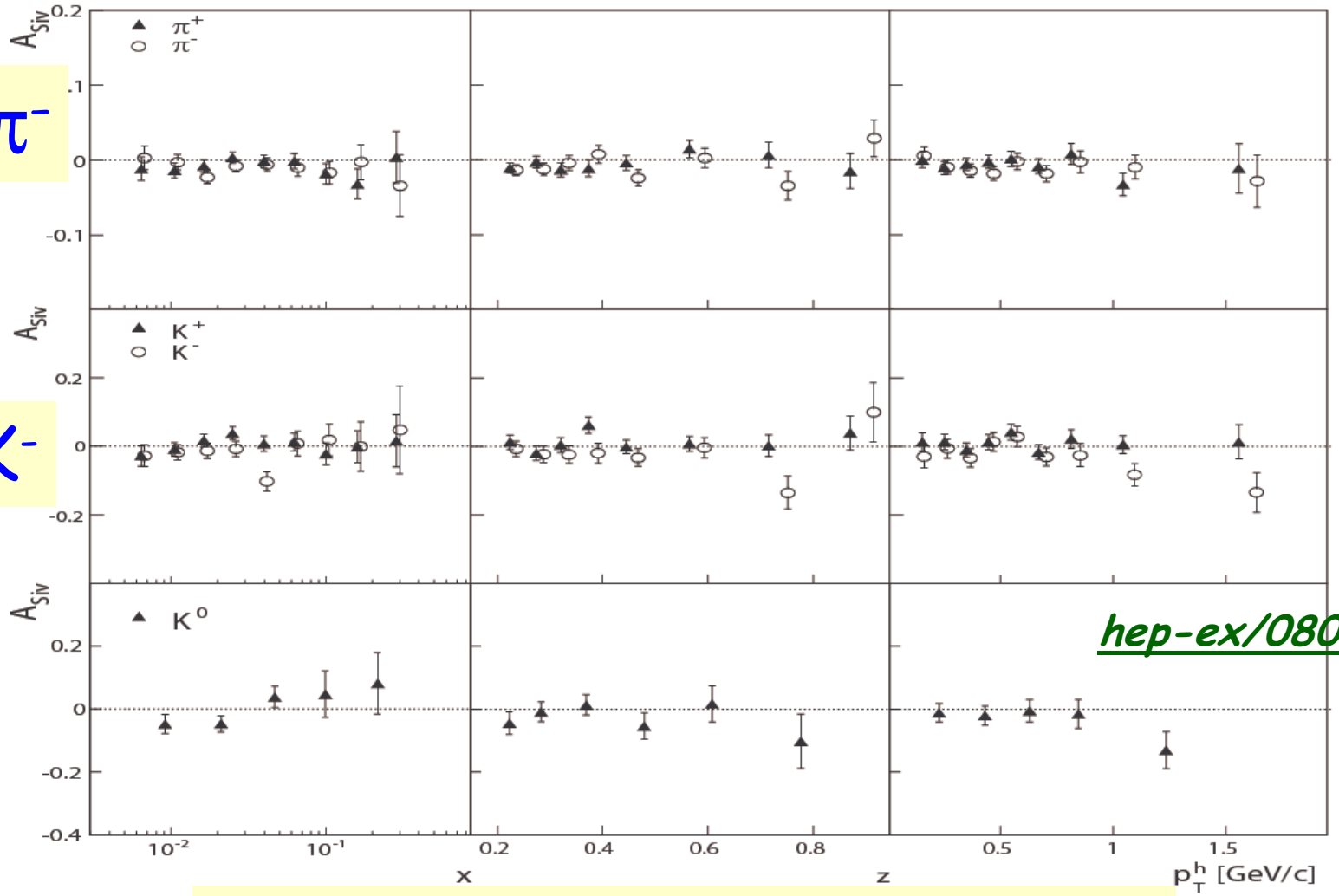
1 identified hadron

Deuteron target 2002-2004 data

π^+, π^-

K^+, K^-

K^0



hep-ex/0802.2160

All asymmetries compatible with 0

Small SIVERS on deuteron: hint for small L_g ? *Brodsky-Gardner 2006*

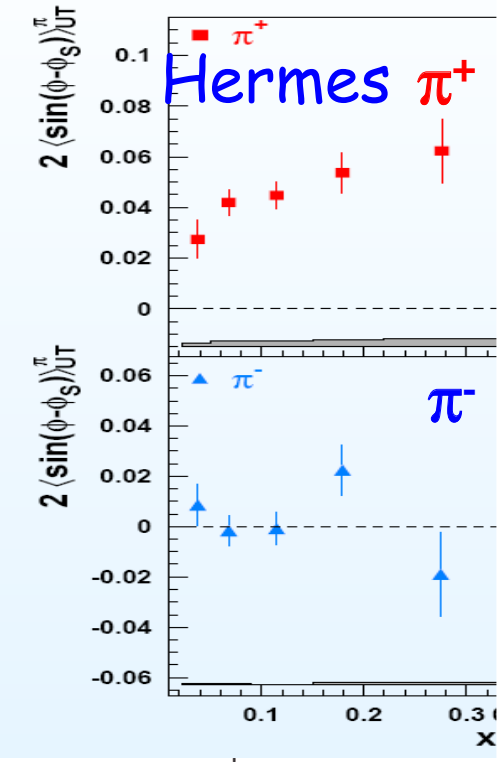
Sivers: Hermes (p) and COMPASS (d)

proton

$$A_{Siv}^{p,\pi^+} \simeq \frac{4\Delta_0^T u_v D_1 + \Delta_0^T d_v D_2}{4u_v D_1 + d_v D_2} \qquad A_{Siv}^{p,\pi^-} \simeq \frac{4\Delta_0^T u_v D_2 + \Delta_0^T d_v D_1}{4u_v D_2 + d_v D_1}$$

favored D_1 and unfavored D_2 unpol. FF

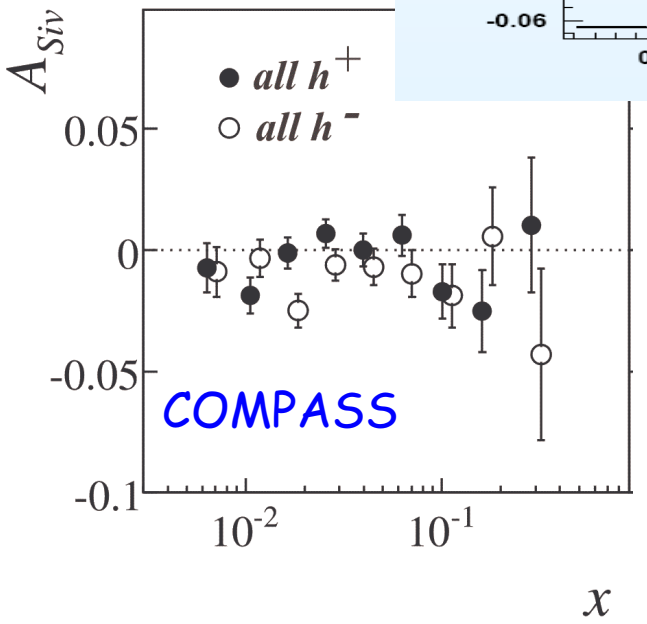
$$\Delta_0^T d_v \simeq -\,2\;\Delta_0^T u_v$$



deuteron

$$A_{Siv}^{d,\pi^+} \simeq A_{Siv}^{d,\pi^-} \simeq \frac{\Delta_0^T u_v + \Delta_0^T d_v}{u_v + d_v}$$

$$\Delta_0^T d_v \simeq -\Delta_0^T u_v$$



See also analysis by Efremov et al.,...

COMPASS - Summary

- $\Delta G/G$ ~ 0 at x ~ 0.1 direct measurement, high p_T
  two independent and precise results $Q^2 > 1$ and < 1 GeV^2

- $\Delta G/G$ open charm -0.47 ± 0.27

- Inclusive DIS : precise g_1^d low x→ improves QCD fits for $\Delta\Sigma$ and ΔG

- Semi-inclusive : Δq_v=0.41 ± 0.07 $\quad\quad \Delta\bar{u} \sim -\Delta\bar{d}$

- Transversity: all d data analyzed, asymmetries compatible ~ 0
  Collins and Sivers for $h^\pm$, $\pi^\pm$, $K^\pm$ + 6 other TMDs
  Two hadron asymmetries ππ, πK, KK
  $\Delta_T q$ and Sivers DF from BELLE (FF) + HERMES (p) + COMPASS (d)

- Complementary approach to RHIC Spin physics program
- To come : - ΔG high p_T 2006+2007 data, 2 x bins
  - Transversity proton data 2007→ *at Ferrara this week!*