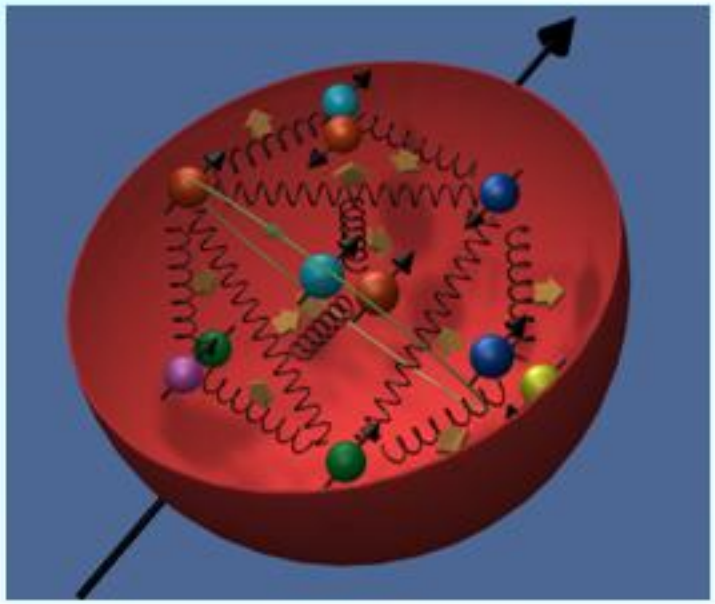
New results in lepton-nucleon spin physics

K. Rith, DIS04, 14.4.2004



- Spin-dependent SF $g_1(x)$, $g_2(x)$
- Quark helicity distr. $\Delta q_f(x)$
- Gluon polarisation $\Delta g(x)/g(x)$
- Transversity distribution $\delta q_f(x)$

hermes

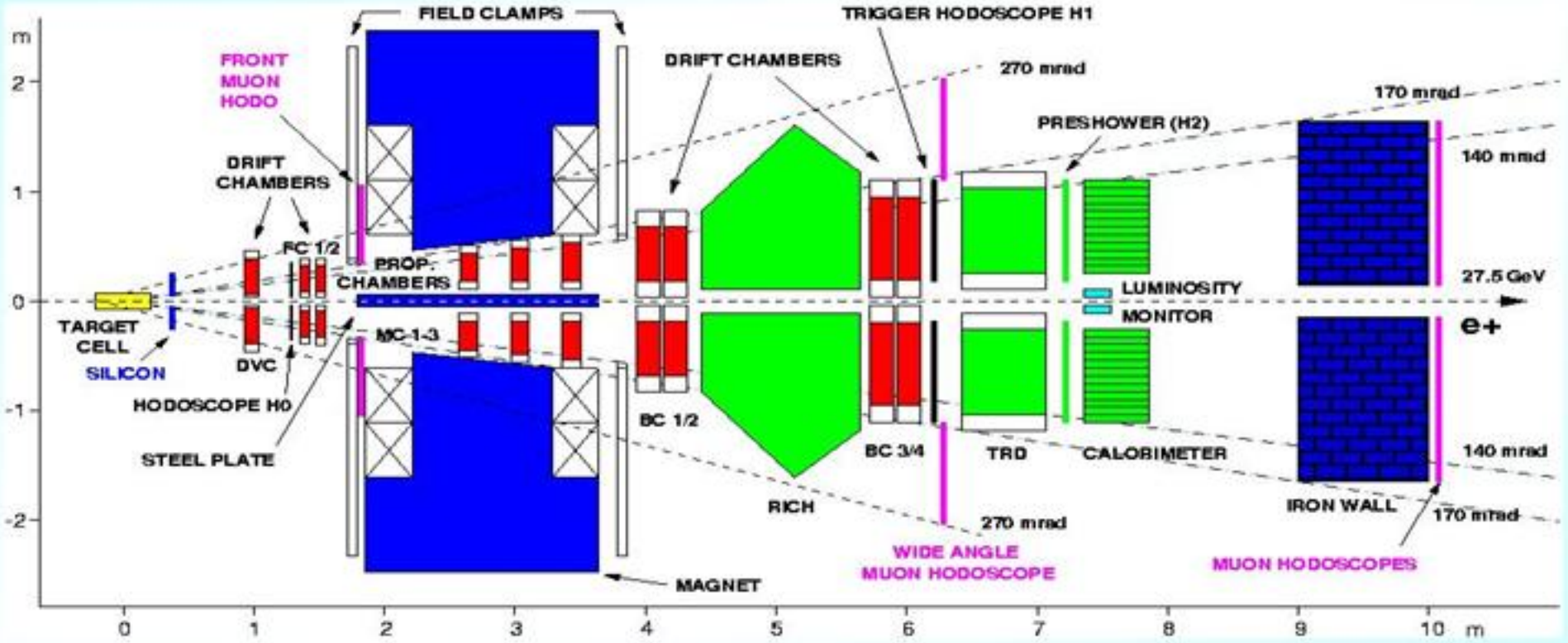
COMPASS

spin muon collaboration CERN SMC

Jefferson Lab

The HERMES spectrometer

HERA e+/e- beam of 27.6 GeV, I~50↘10 mA, beam-pol~55%

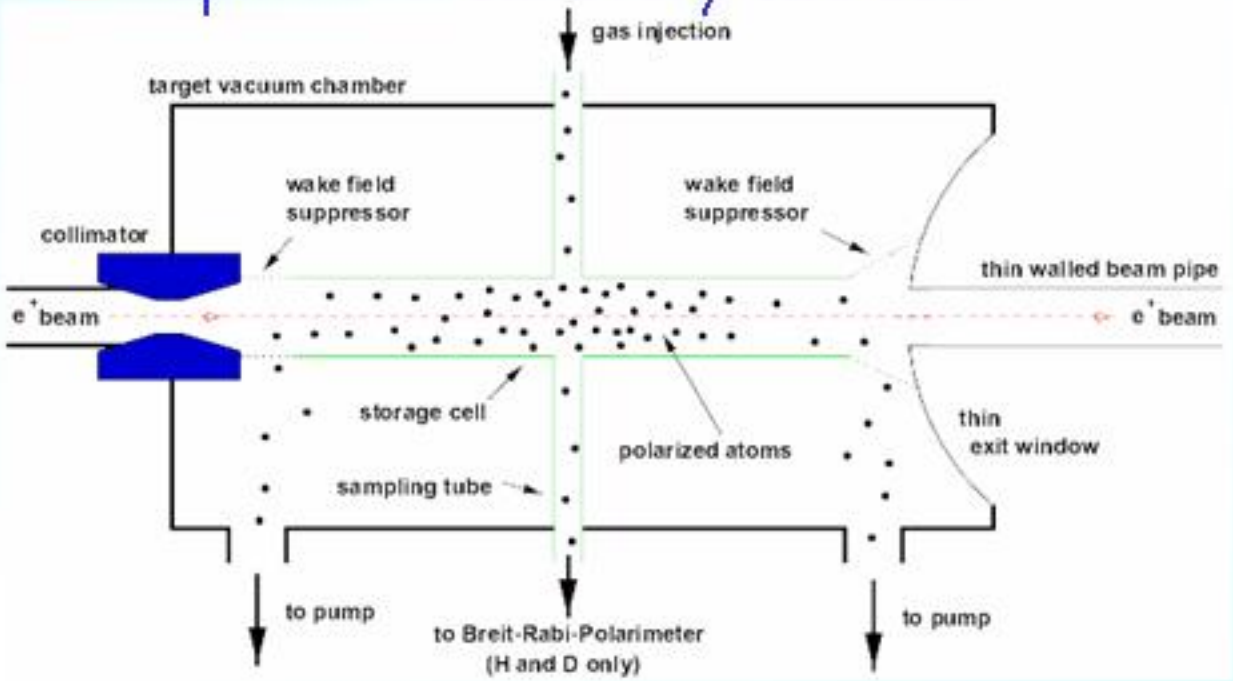


- kinematics: $0.02<x<0.6$, $1.0<Q^2<15$ GeV^2
- tracking: $\delta p/p \sim 2\%$, $\delta\Theta<0.6$ mrad, 40-220 mrad
- PID: Calorimeter, Preshower, TRD, RICH

HERMES internal target

- Pure polarised gas targets: $\vec{H}$, $\vec{D}$, $^3\vec{He}$,
- target polarisation: $p_T(\vec{H},\vec{D}) \sim 85\%$
- Luminosity: $4*10^{30}$ cm^{-2} s^{-1}($\vec{H}$ @ 10 mA)

  $\rightarrow 6*10^{33}$ cm^{-2} s^{-1} (D_2@ 50 mA)
- spin reversal every 120 sec



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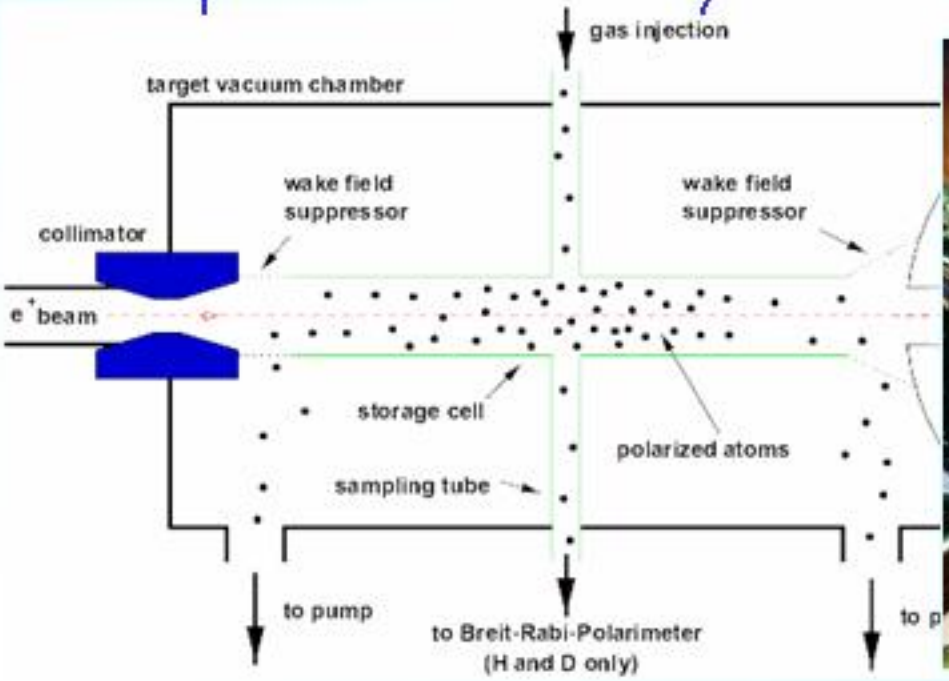
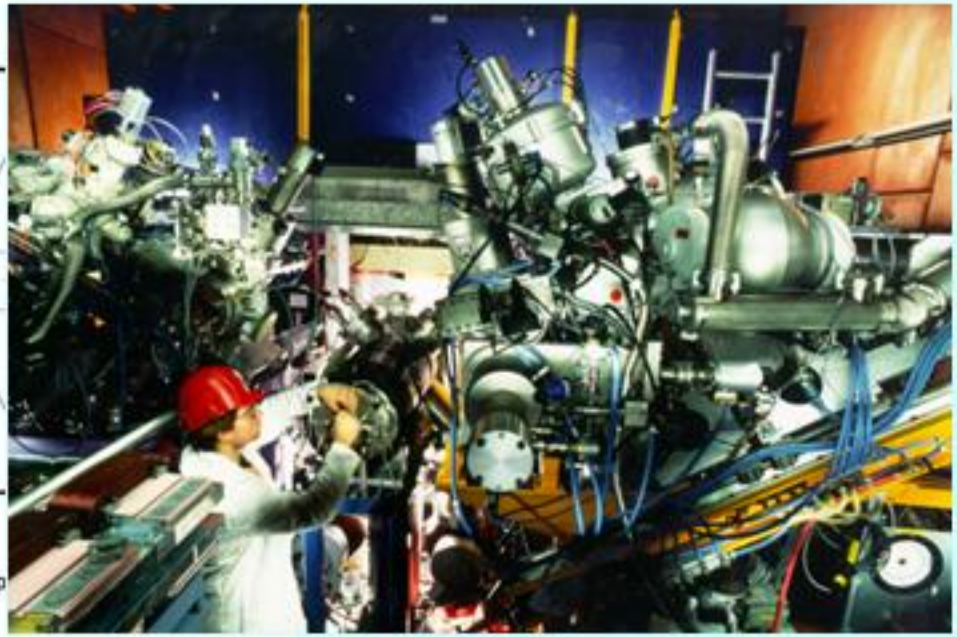
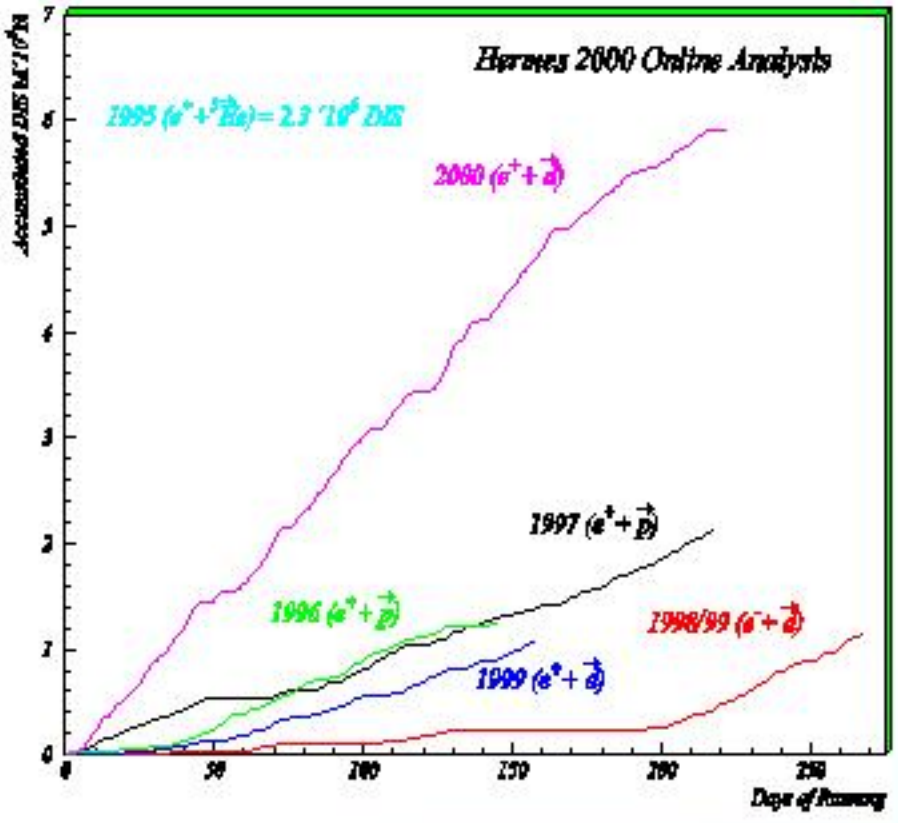


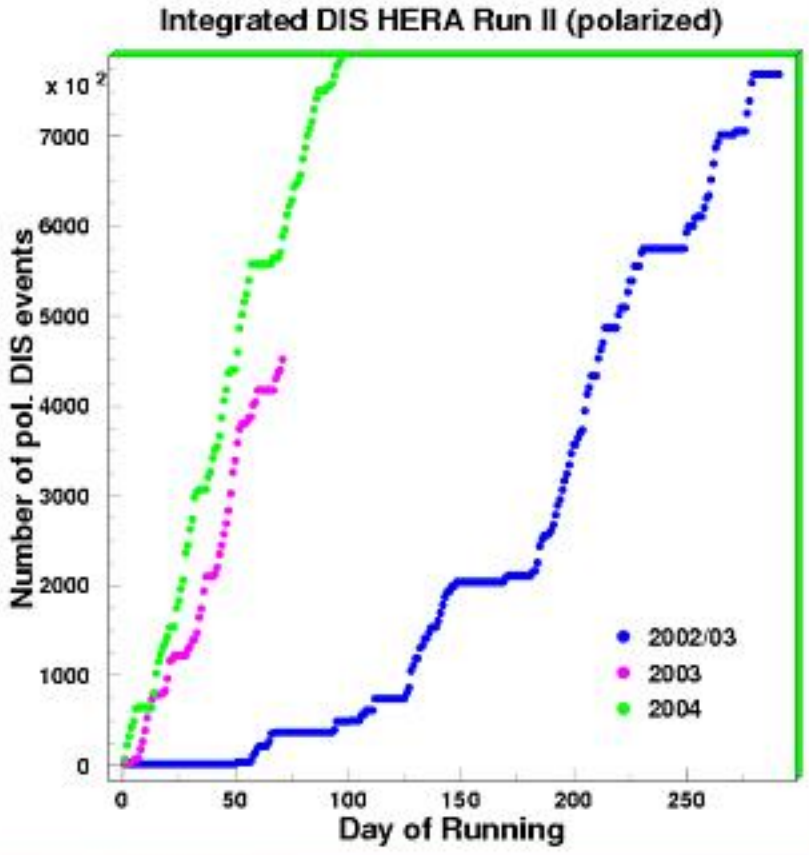


HERMES data taking

Long. Target Polarisation

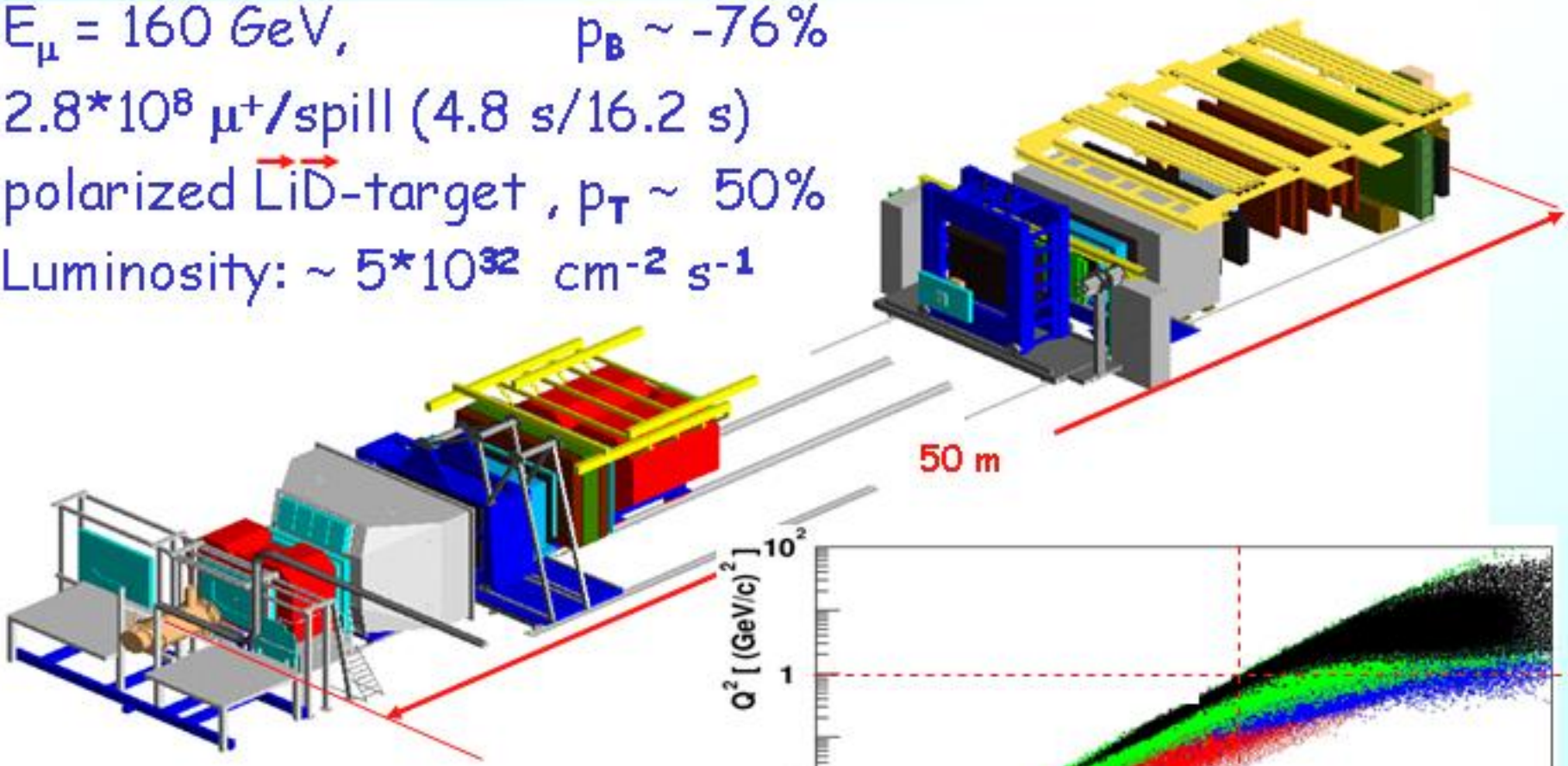


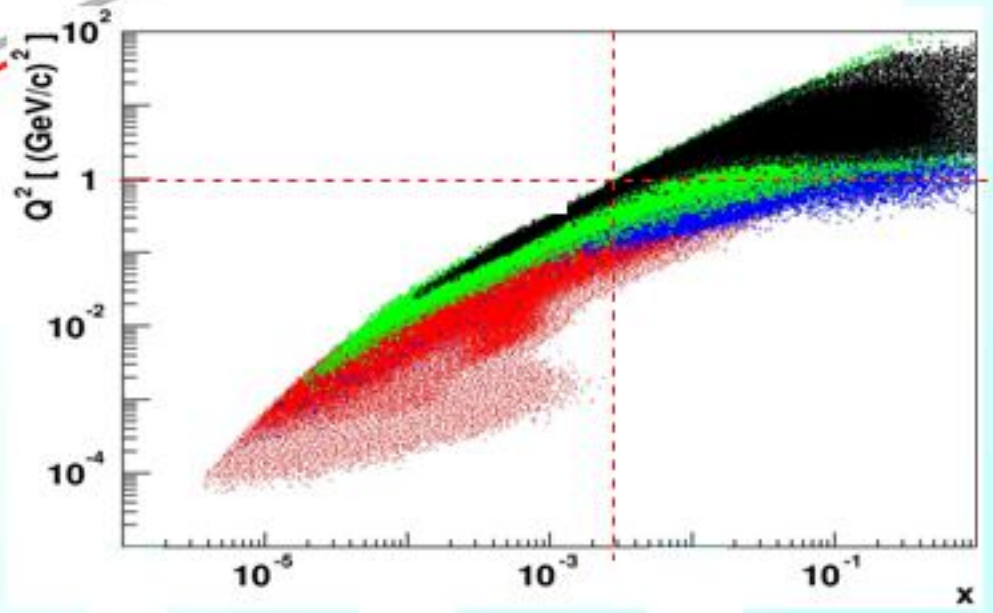
Transv. Target Polarisation



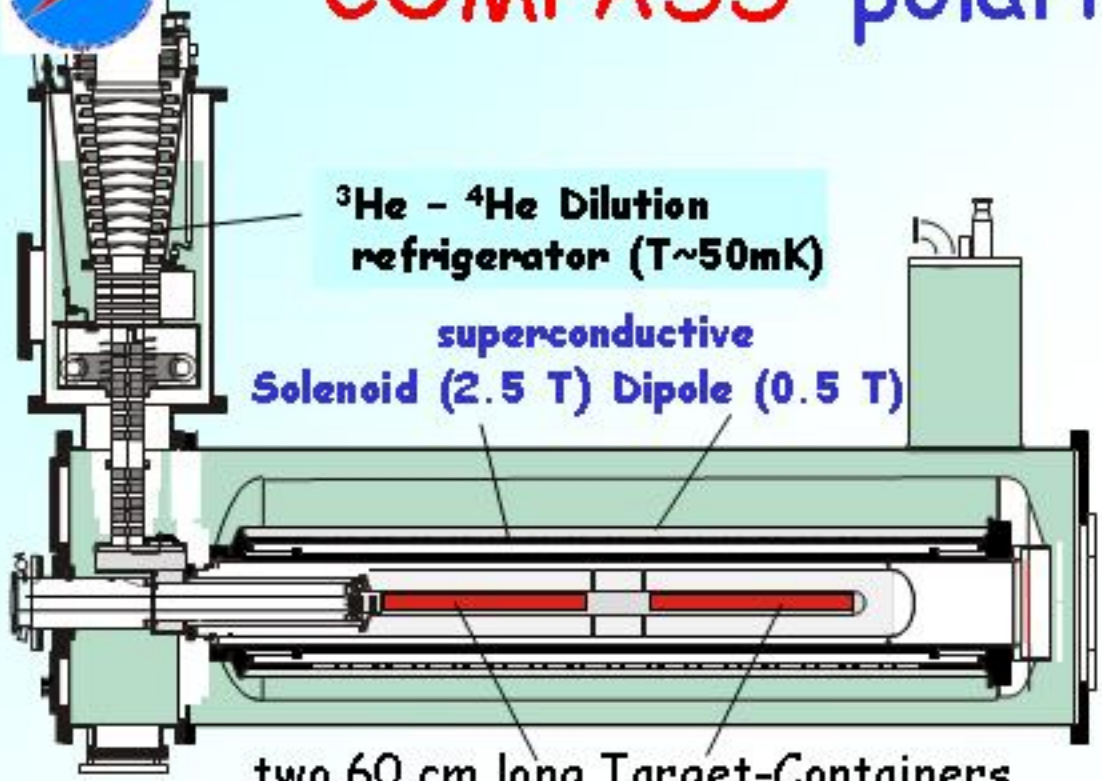
COMPASS at CERN

- E_μ = 160 GeV, $p_B \sim -76\%$
- $2.8 * 10^8$ μ^+/spill (4.8 s/16.2 s)
- polarized $\vec{L}\vec{i}D$-target , $p_T \sim 50\%$
- Luminosity: $\sim 5 * 10^{32}$ cm^{-2} s^{-1}





COMPASS polarized LiD target

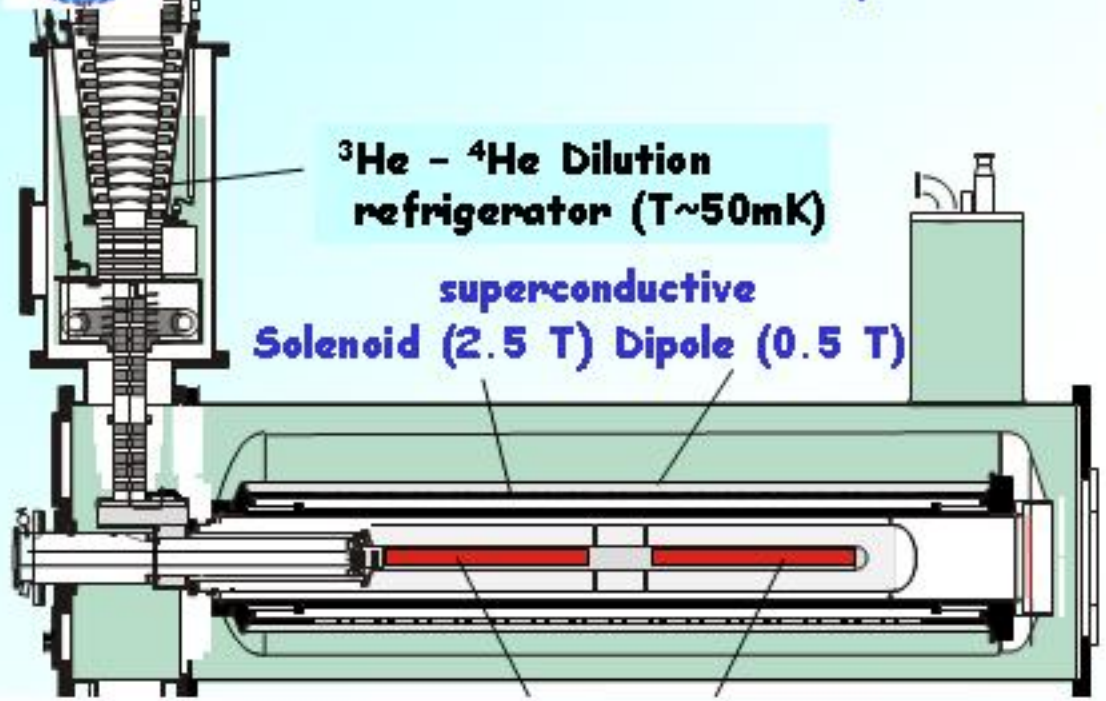


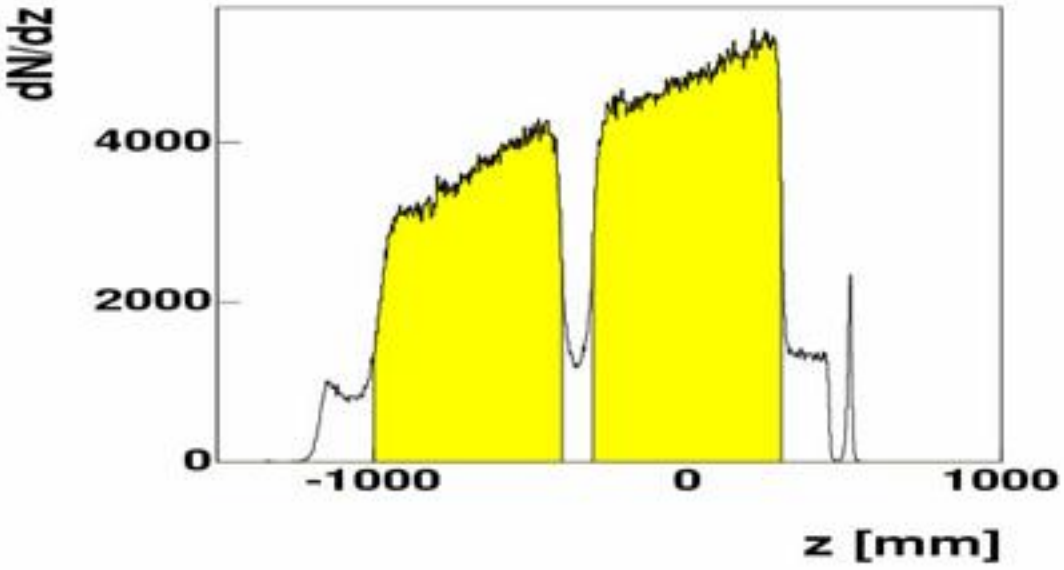
SMC PT magnet:

present acceptance 70 mrad instead of 180 mrad

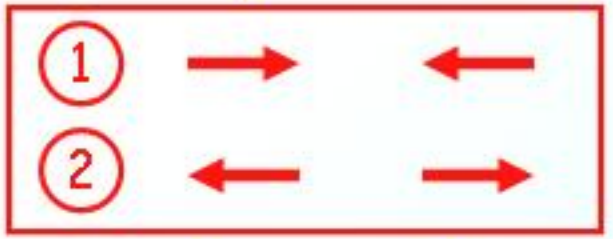
reduced acceptance for $x > 0.1$

COMPASS polarized LiD target



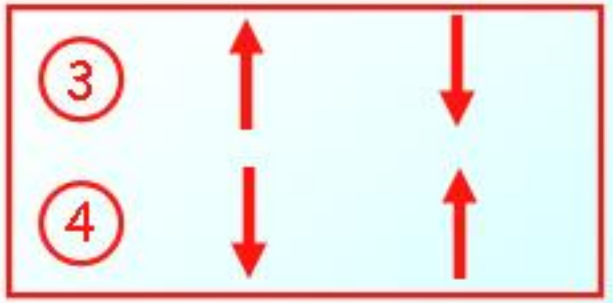


4 possible spin combinations:



reversed every 8 hours

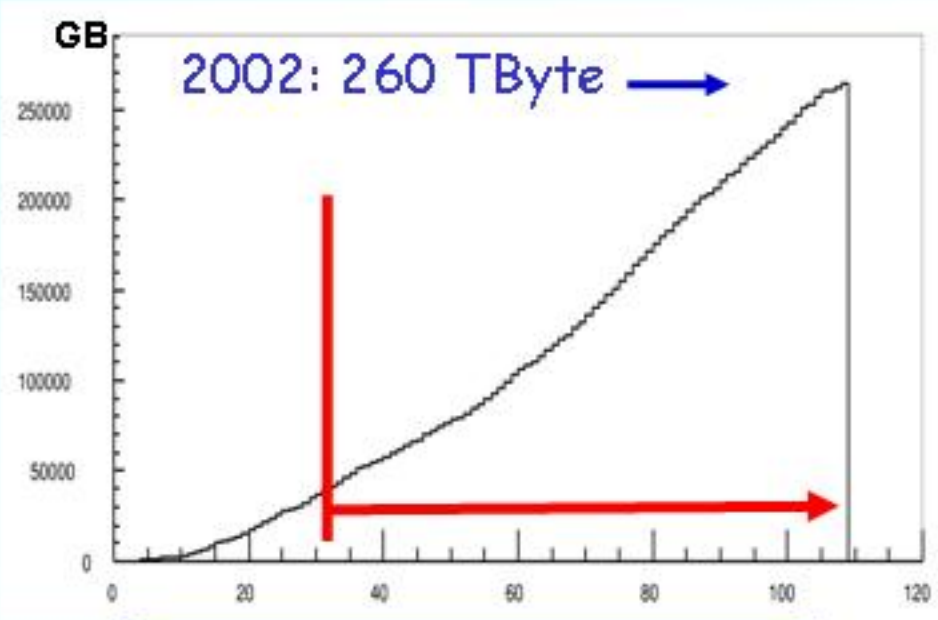
or:

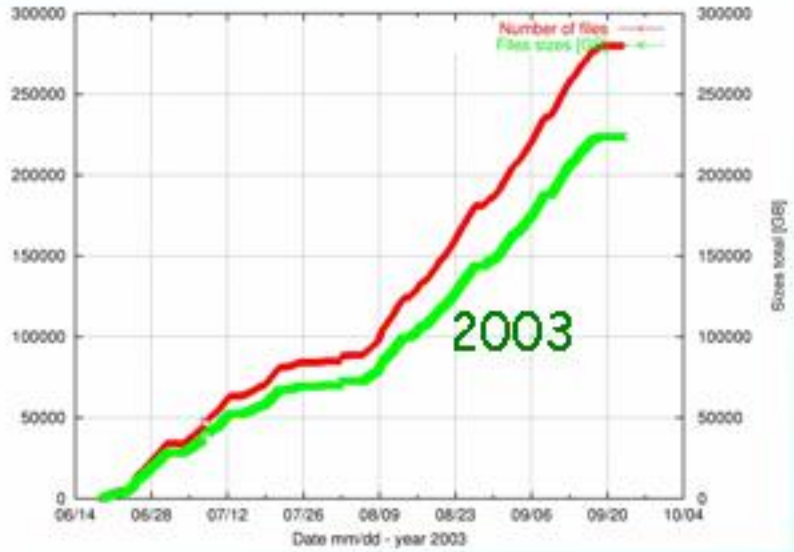


reversed once a week

Polarization: ~50%

COMPASS data taking





2002 & 2003:

- 500 TByte Data
- 10^{10} Events long. pol.
- $3 \cdot 10^{9}$ Events transv. pol.
- 0.1% with $Q^2 > 1 (GeV/c)^2$

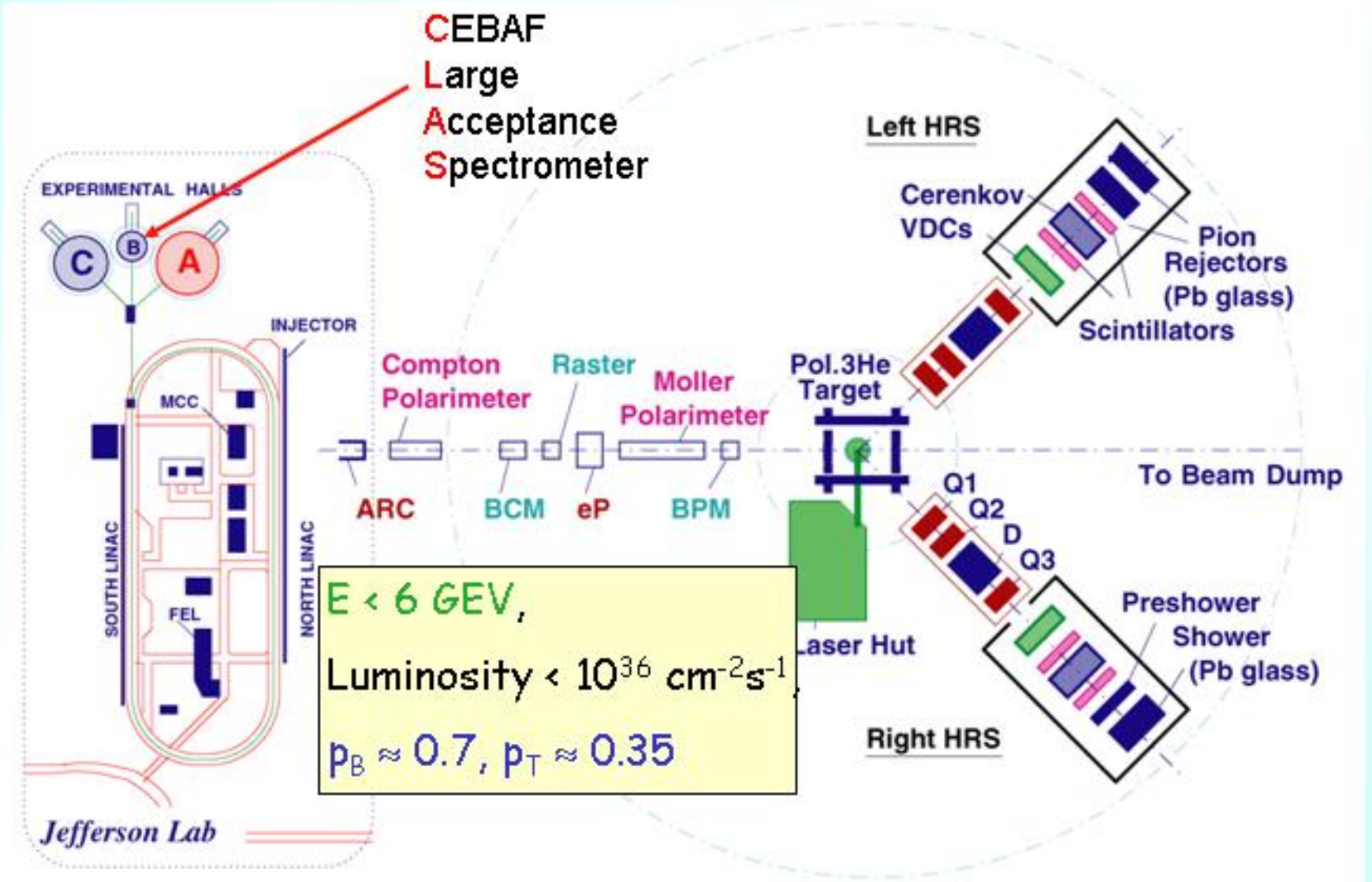
Event reconstruction:

500 TB raw data
→ 500 000 Batch jobs
(1 GByte ~ 8 hours)

Process in parallel
as much as possible
(presently: ~1000 CPUs)

Jefferson Lab

Experiments @JLAB



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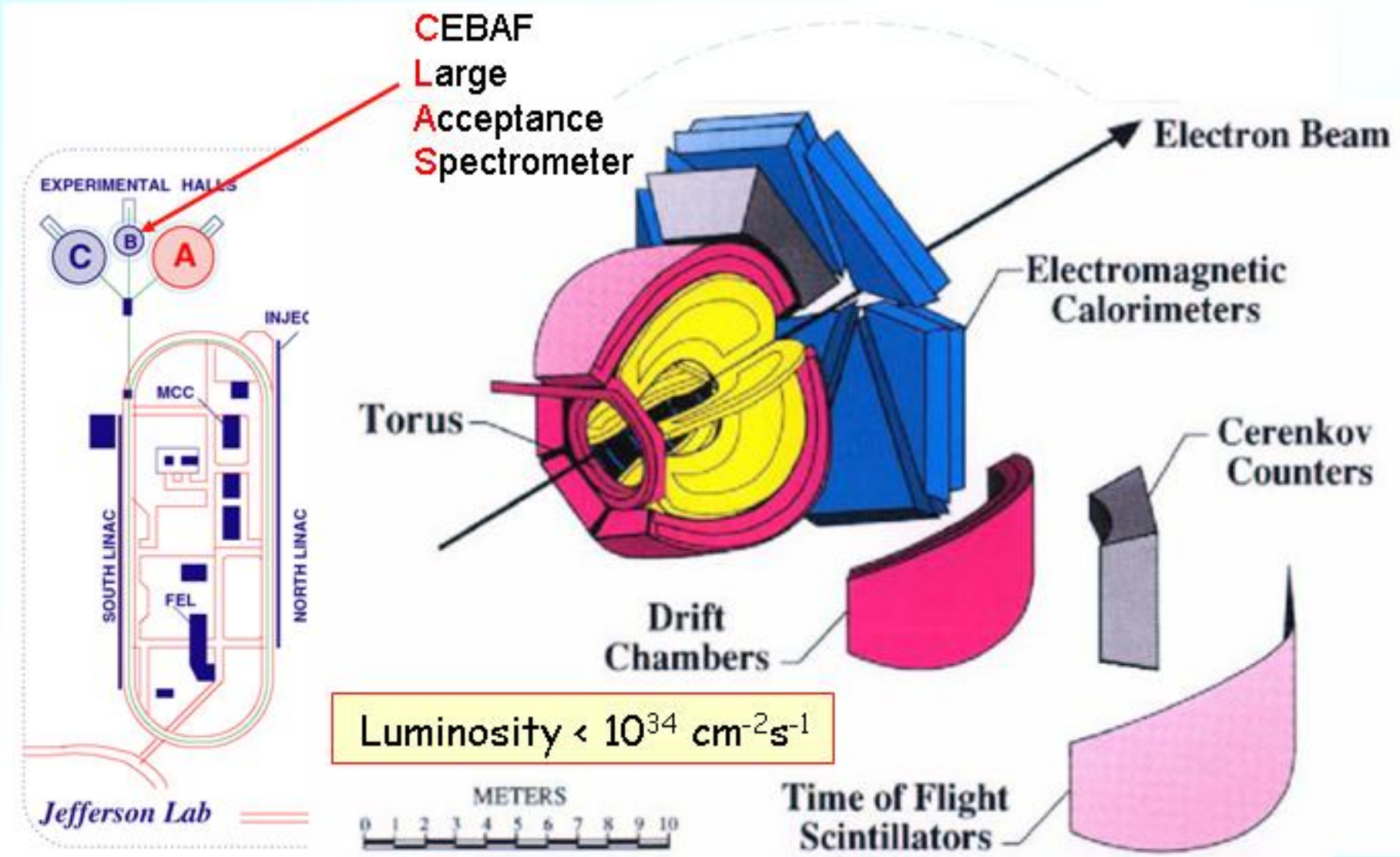
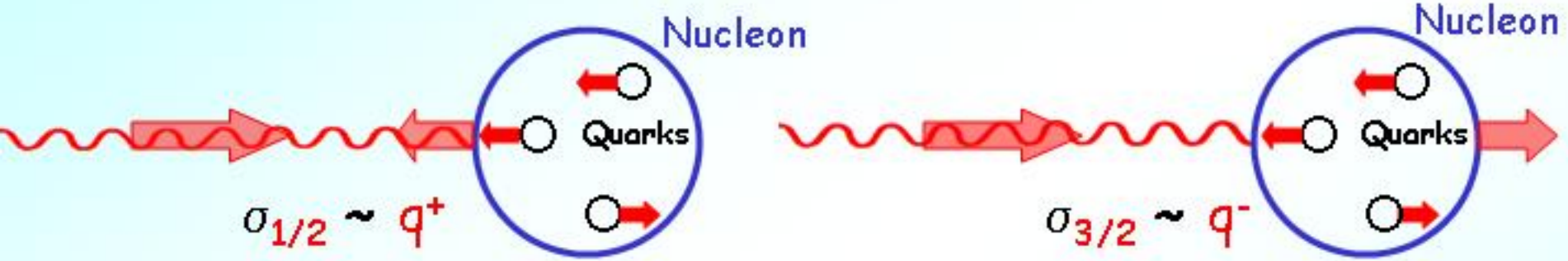


Spin-dependent Deep-Inelastic Lepton-Nucleon Scattering



Helicity distr.: $\Delta q(x) := q^+(x) - q^-(x)$

Asymmetry: $A_1 = \dfrac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \cong \dfrac{g_1}{F_1}$

$$g_1(x) := \tfrac{1}{2} \sum_q z_q^2 \, \Delta q(x)$$

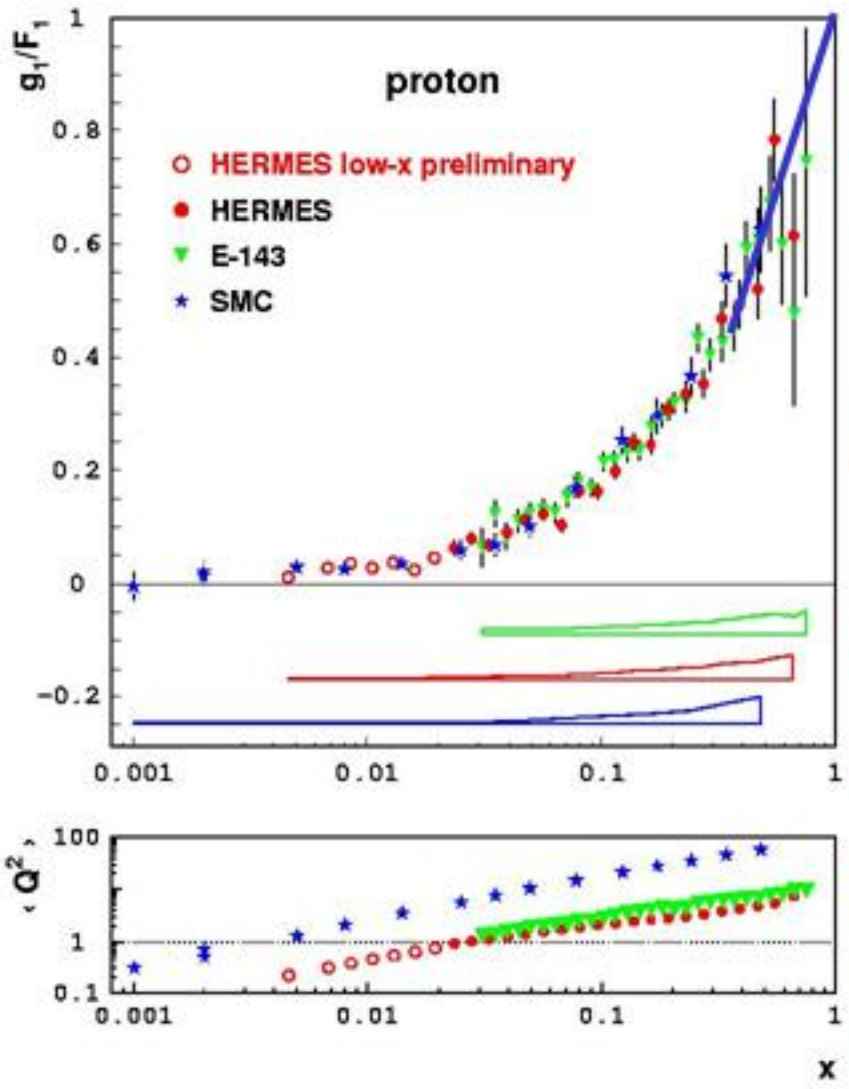
$$F_1(x) := \tfrac{1}{2} \sum_q z_q^2 \, q(x)$$

Dilutions: $A_{exp} \cong (f \; p_T \; D \; p_B) \; A_1$

$$\delta A_1 \sim (f \; p_T \; D \; p_B \sqrt{N})^{-1}$$

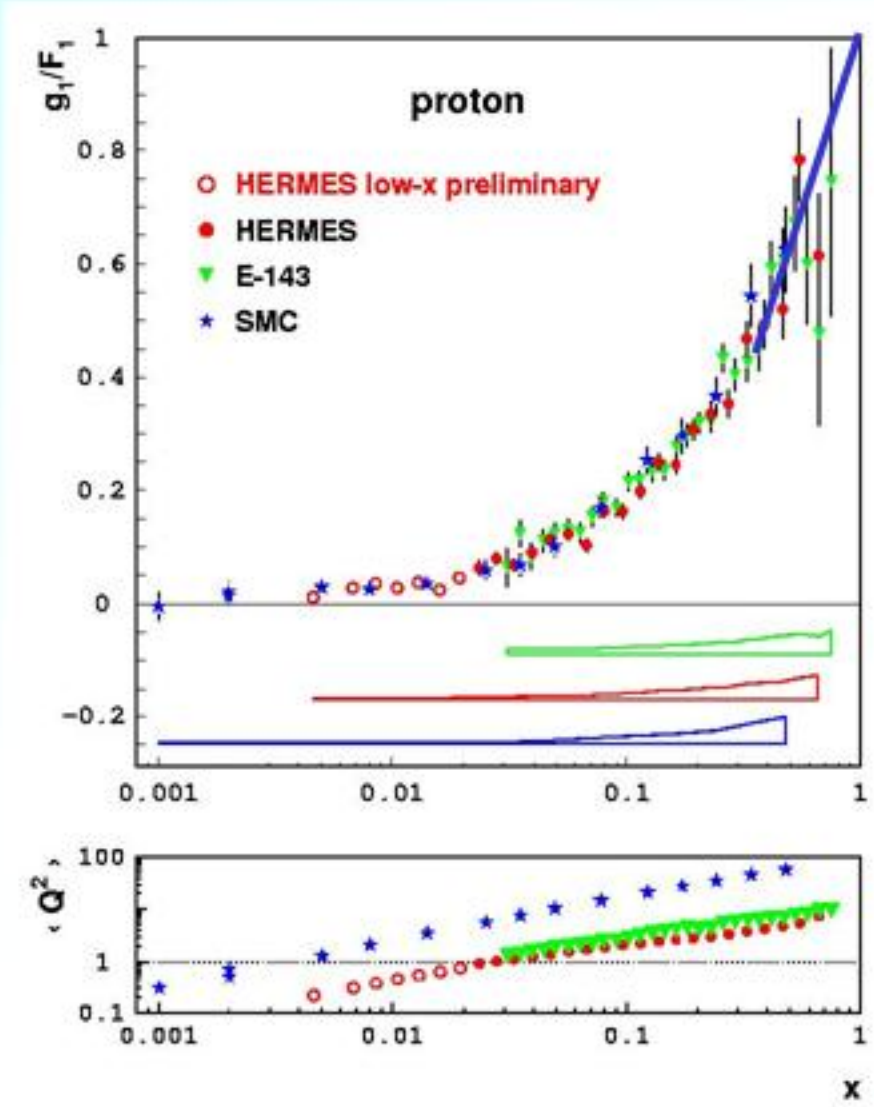
$f = 1$ for $\vec{H}, \vec{D}$
$f < 0.5$ for $\vec{LiD}$
$f < 0.33$ for $^3\vec{He}$
$f < 0.17$ for $N\vec{H}_3$

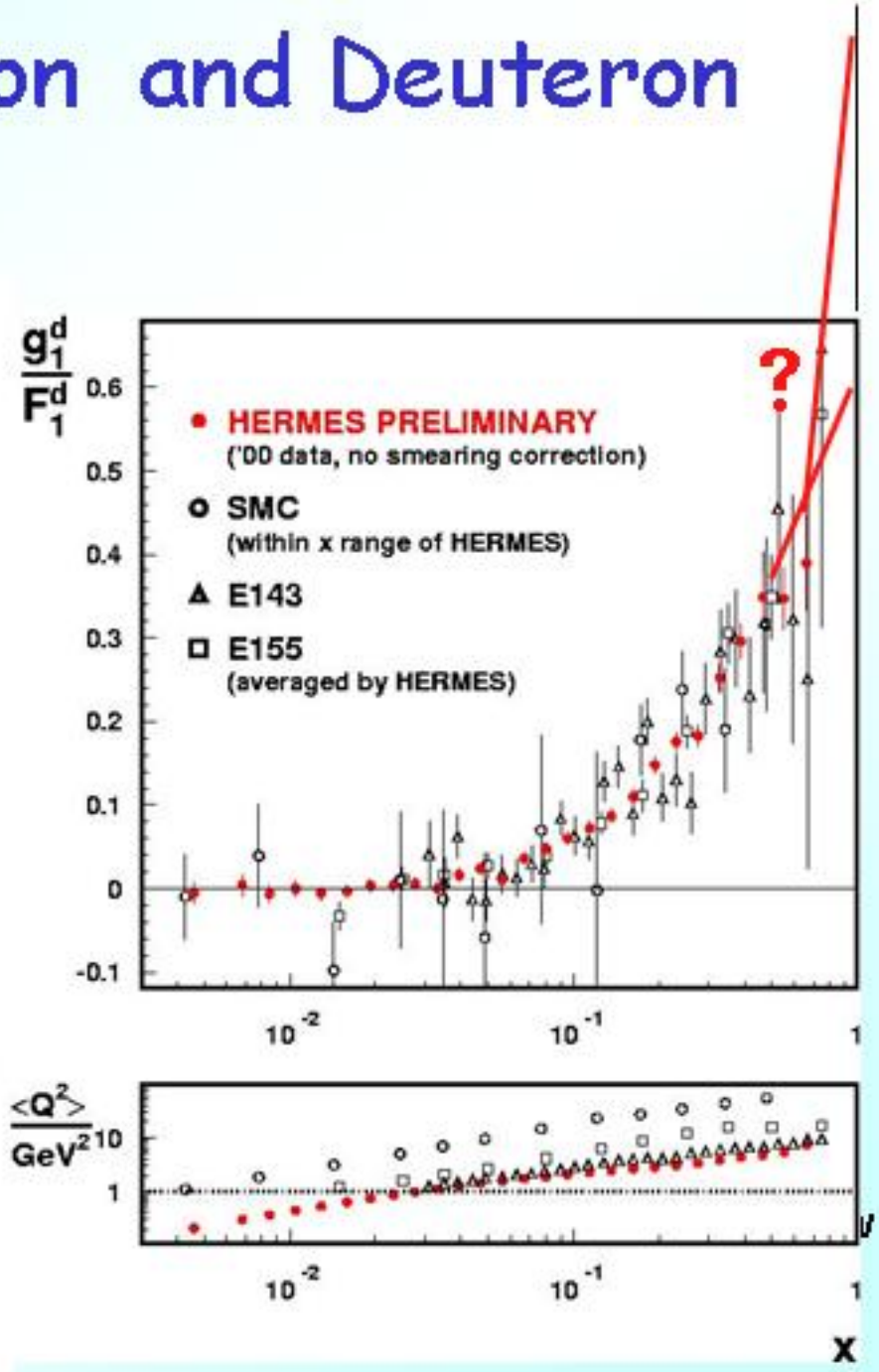
$A_1 \cong g_1/F_1$ - Proton



- g_1^p/F_1^p well known for $x \searrow 10^{-3}$?
- Excellent agreement between all experiments
- g_1^p/F_1^p (within errors) independent of Q^2; Q^2 dependence of g_1 and F_1 very similar
- $\langle Q^2 \rangle = f(x)$
- Extrapolation to $x \searrow 0$ for $Q^2 = Q_0^2$?
- HERMES errors will increase at low and high x due to unfolding corr.

$A_1 \cong g_1/F_1$ - Proton and Deuteron





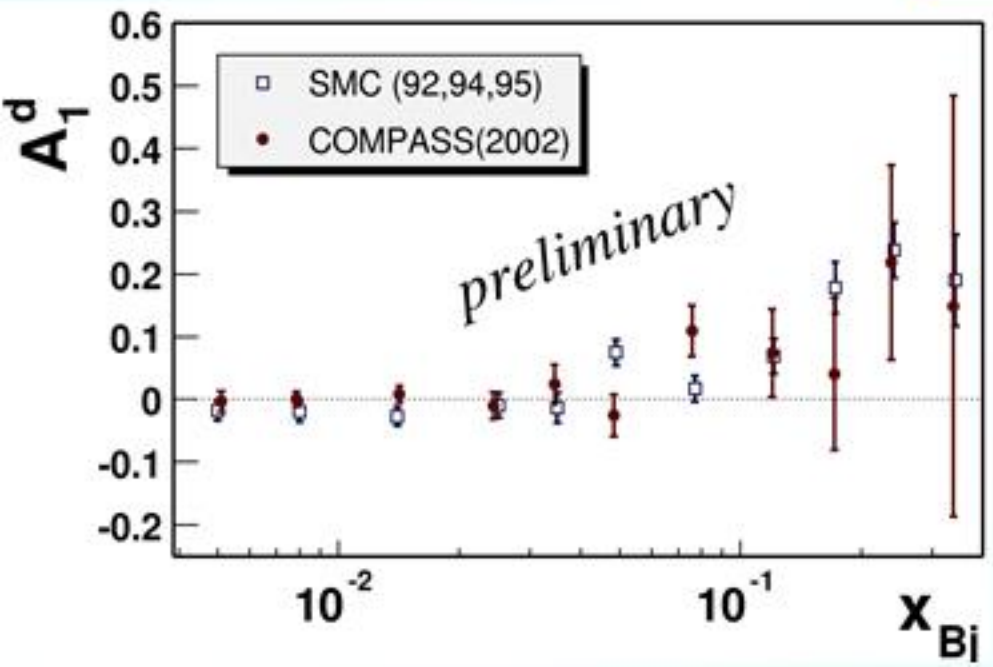
First A_1^d from COMPASS

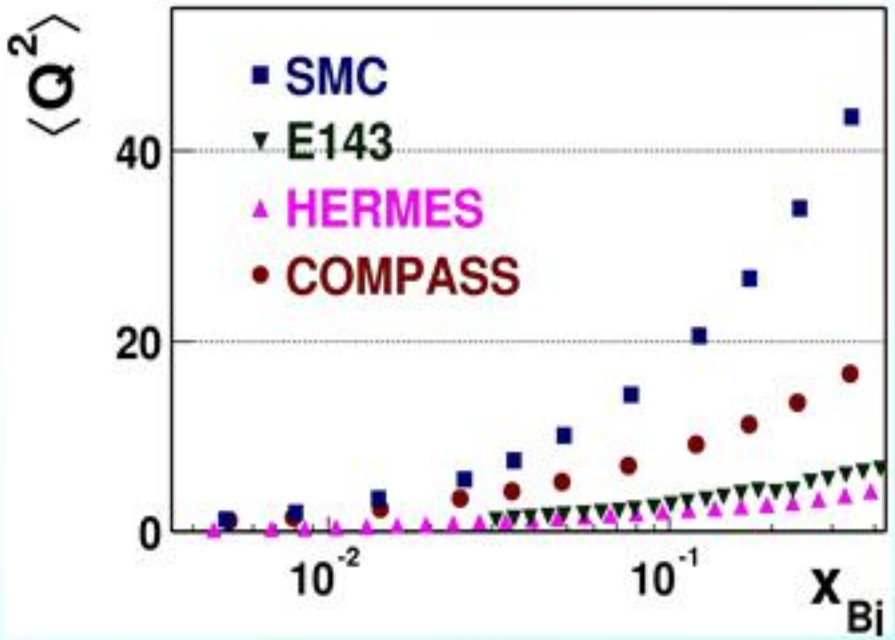
2002 data only: 6.5 Million DIS events

$Q^2 > 1\ (GeV/c)^2$, $0.1 < y < 0.9$

expect ~4 statistics by end of 2004

Details → M. Leberig, WG F

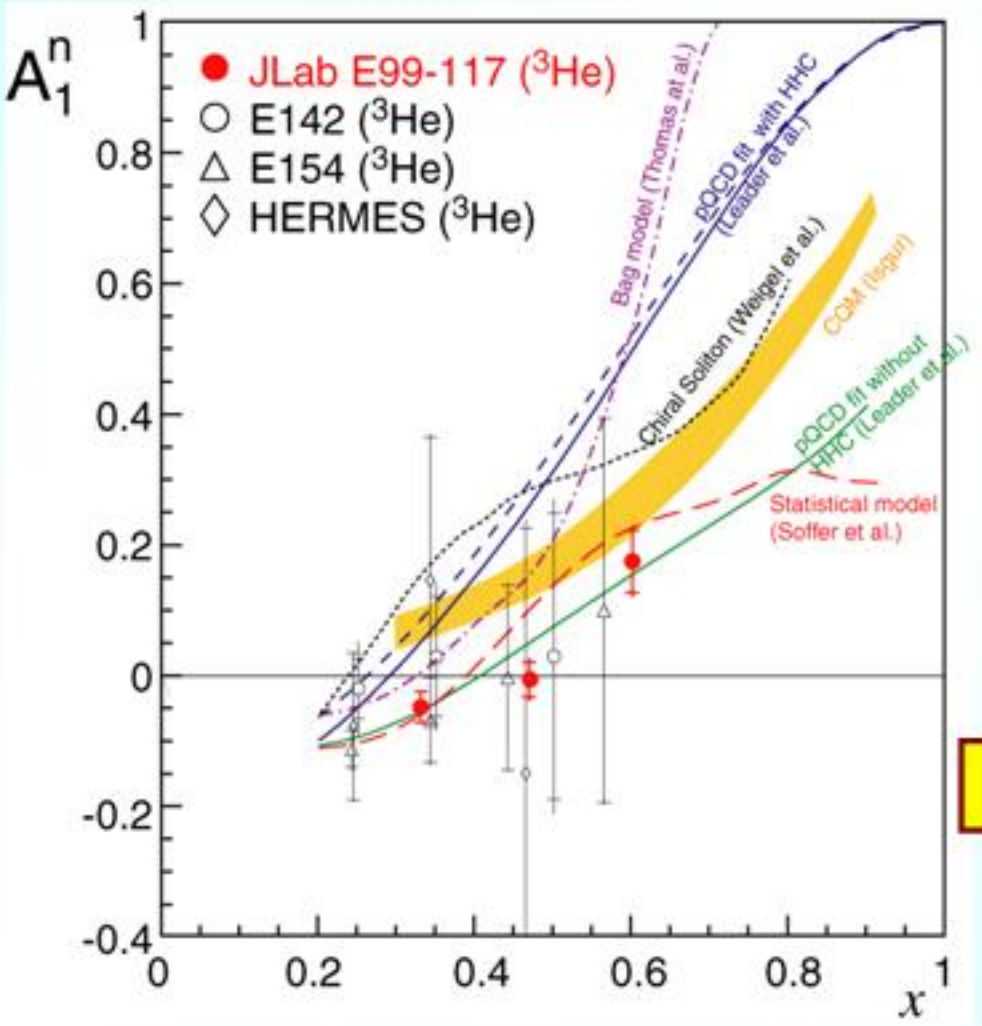




Jefferson Lab

A_1^n from Jlab E99-117

Phys. Rev. Lett. 92, 012004 (2004)



In addition:

$\Gamma_1^n(Q^2)$, $g_2^n(x,Q^2)$,

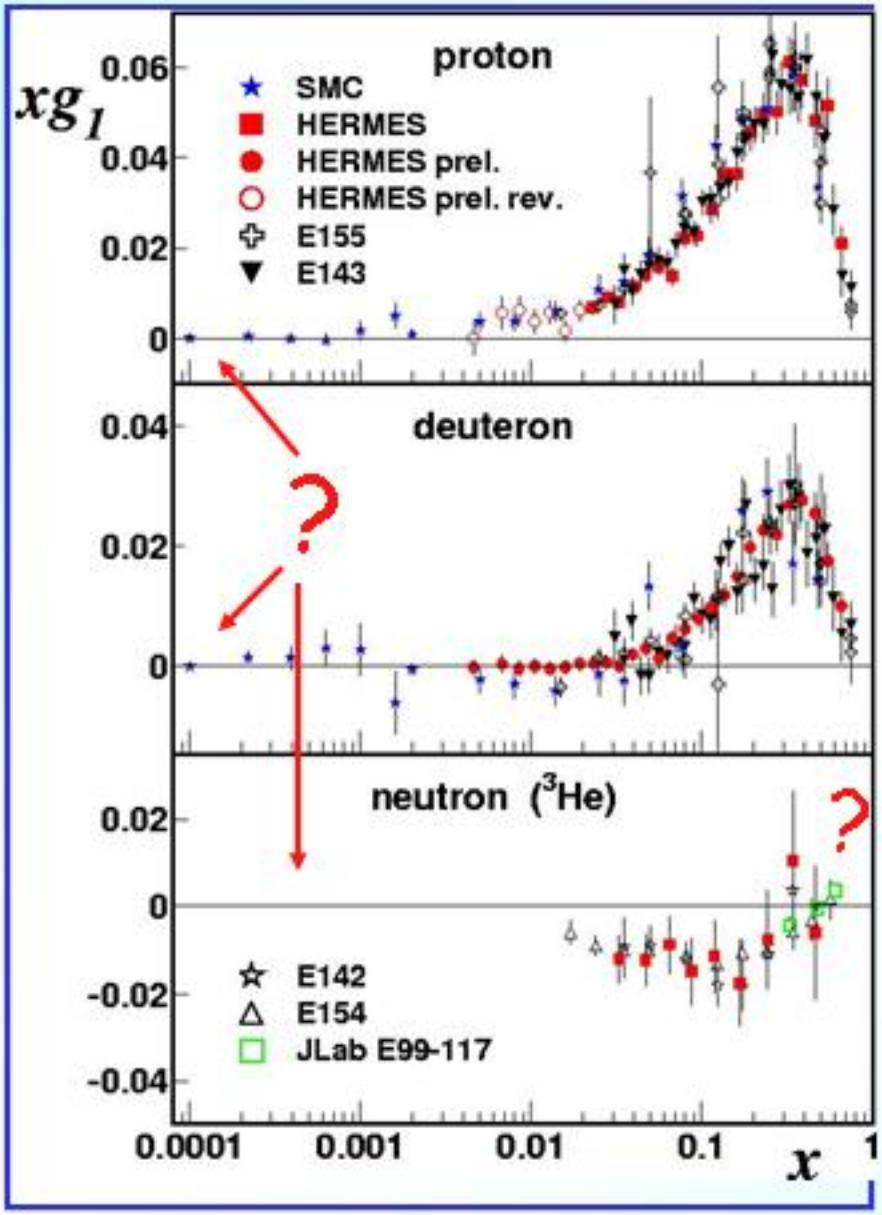
$\Gamma_2^n(Q^2)$, $d_2(Q^2)$

12 GeV upgrade:

more data at higher x

Details → N.Liyanage, WG F

$xg_1(x)$ - world data



- Integrals at $Q_0^2 = 2{,}5\ GeV^2$,

  QCD analysis of Q^2 dependence

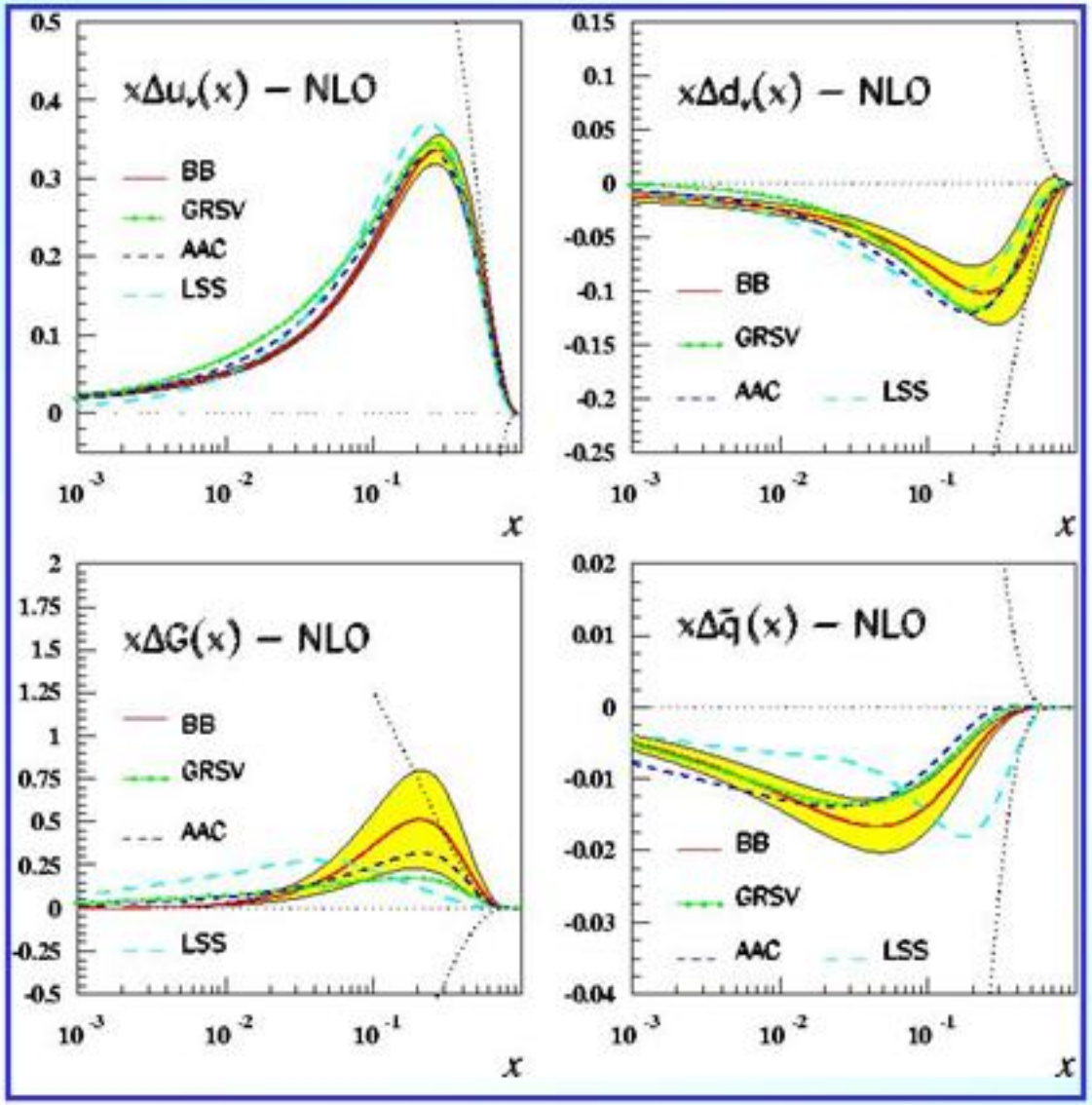
  and SU(3):

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s \cong 0{,}20 \pm 0{,}04 \pm .$$

Rest ?

- Gluons ΔG
- Orbital angular momenta $L_{q,g}$

NLO QCD ($\overline{MS}$) fit



Assumptions:

-Helicity distribution of sea quarks flavour symmetric

- Δu_v and Δd_v constraint by F and D (SU(3) symmetry)

Results for $Q_0^2 = 4\ GeV^2$:

$\Delta u_v \cong 0.73$ .....0.86 (± 0.10)

$\Delta d_v \cong -0.40$...-0.46 (± 0.10)

$\Delta q_s \cong -0.04$ ...-0.09

$\Delta\Sigma \cong 0.14$ ...0.20

$\Delta G \cong 0.68$ ...1.26

BB: Blümlein, Böttcher hep/ph 0203155

LSS: Leader et al., hep/ph 0111267

GRSV: Glück et al., hep/ph 0011215

AAC: Goto et. Al., hep/ph 0001046

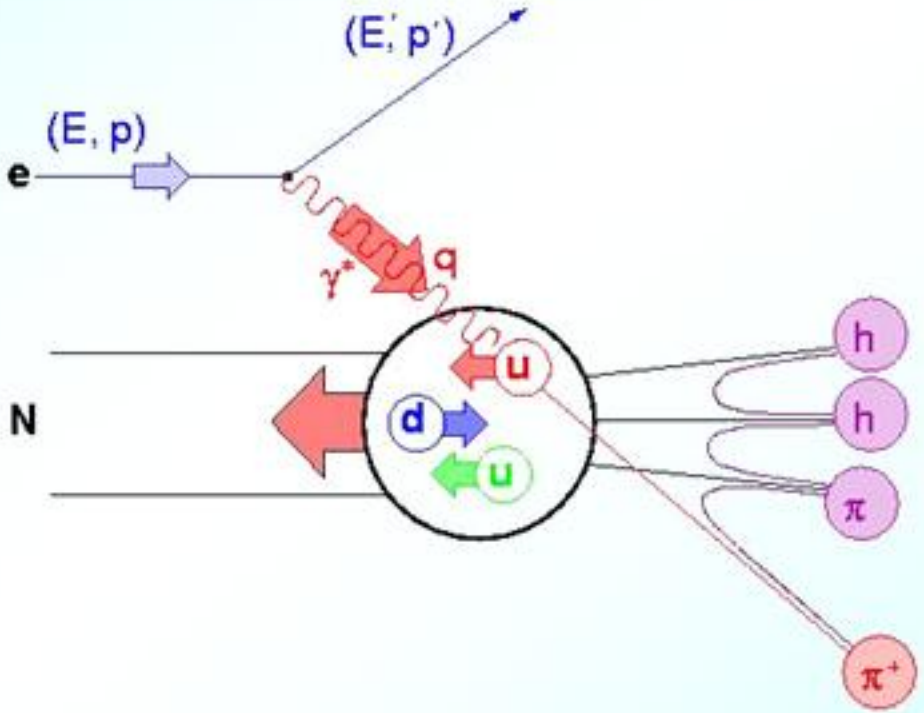
NLO QCD ($\overline{MS}$) fit

Concern:

- Δu_v and Δd_v constraint by F and D (SU(3) symmetry)
- g_a/g_v = 1.0 instead of 1.254 give same quality of fit in measured region
- All the difference is shifted to the unmeasured low-x region
- low-x extrapolation and results for moments questionable

→ HERMES will only state partial moments over measured region

Quark helicity distributions from semi-inclusive asymmetries



$\nu = E - E'$

$z = E_h / \nu$

Leading hadron originates with large probability from struck quark

D(z):= Fragmentation function

Semi-inclusive asymmetries-1

In leading order:

$$A_1^h(x,z) = \frac{\sum_q z_q^2 \Delta q(x)\, D_q^h(z)}{\sum_q z_q^2 q(x)\, D_q^h(z)}$$

$$= \sum_q \frac{z_q^2 q(x)\, D_q^h(z)}{\sum_{q'} z_{q'}^2 q'(x)\, D_{q'}^h(z)} \frac{\Delta q(x)}{q(x)}$$

Quark-'Purity' P^h_q

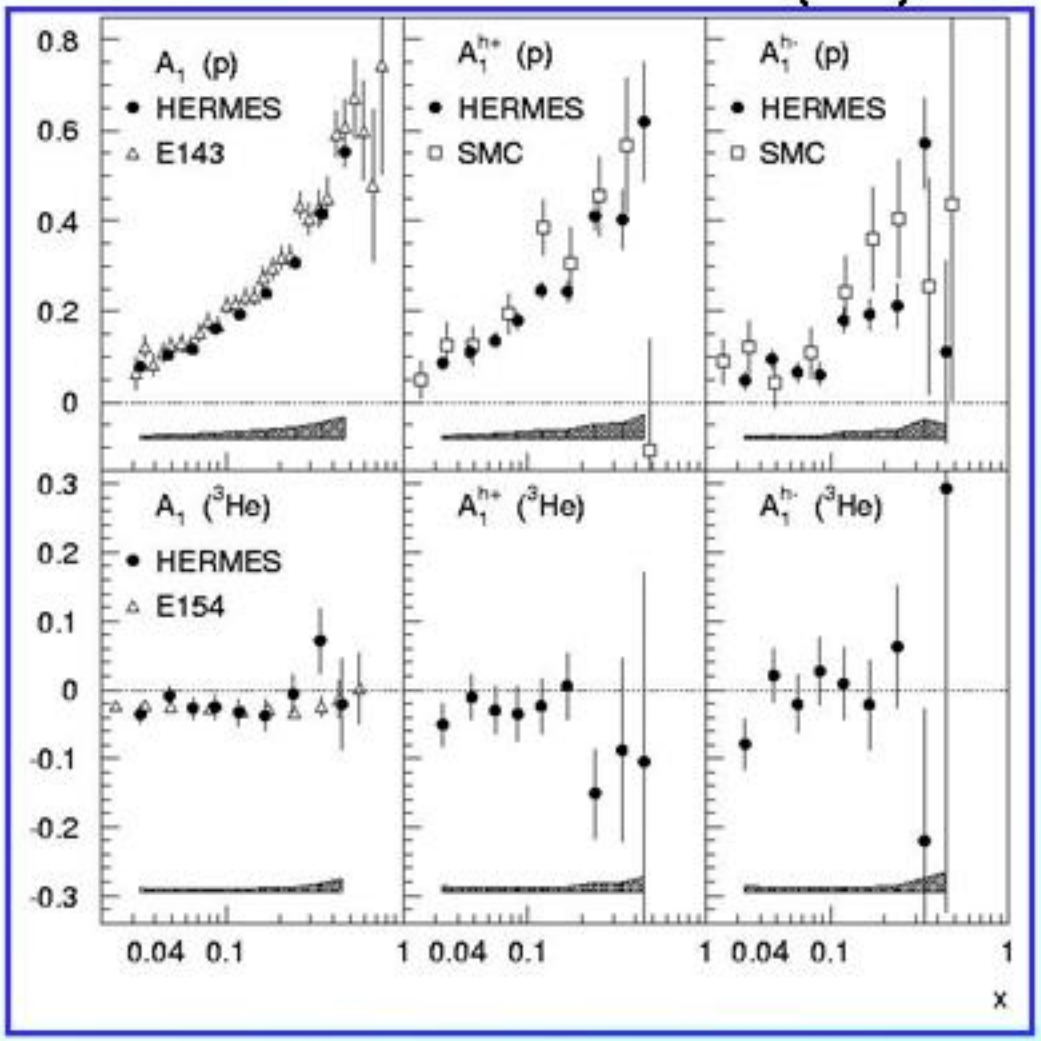
Different targets and hadrons h:

Solve linear system for $\vec{Q}$ with

$\vec{A} = (A_{1,p}, A_{1,d}, A_{1,p}^{\pi^\pm}, A_{1,d}^{\pi^\pm}, A_{1,p}^{K^\pm})$

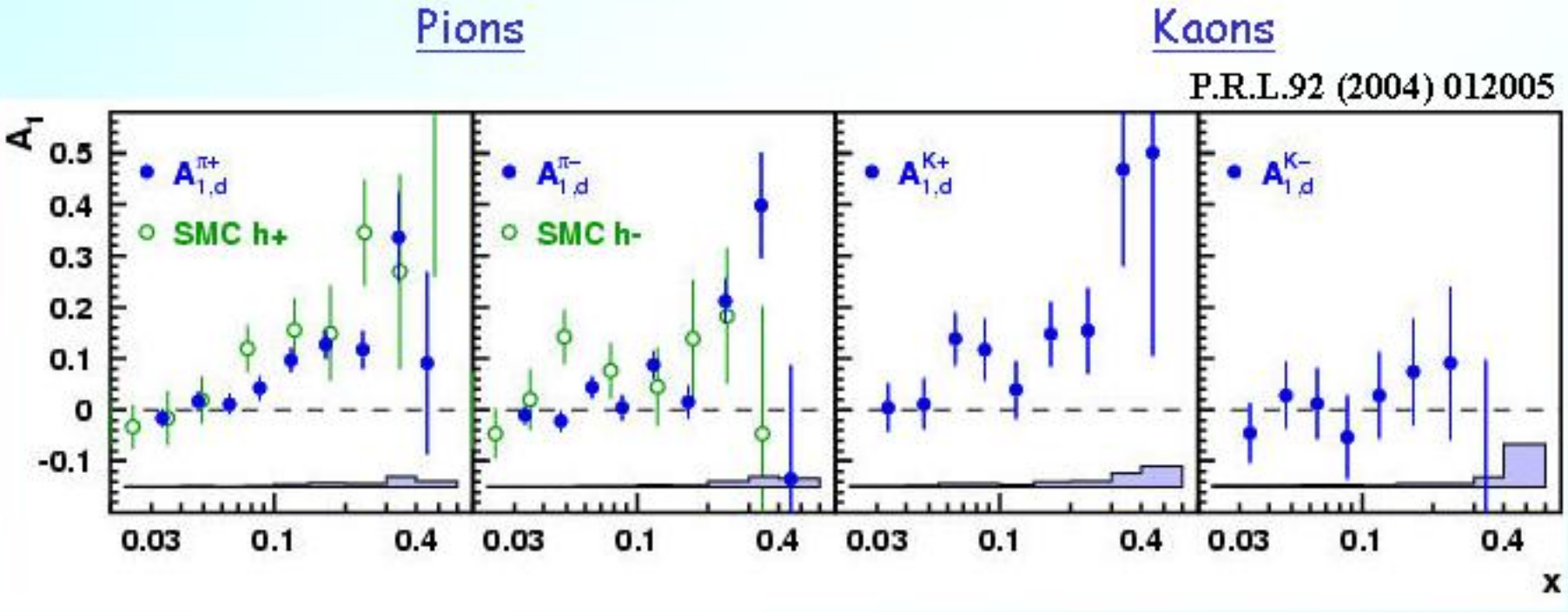
$$\vec{A} = P\,\vec{Q}$$

P.L. B 464 (1999) 123



Semi-inclusive asymmetries -Deuteron

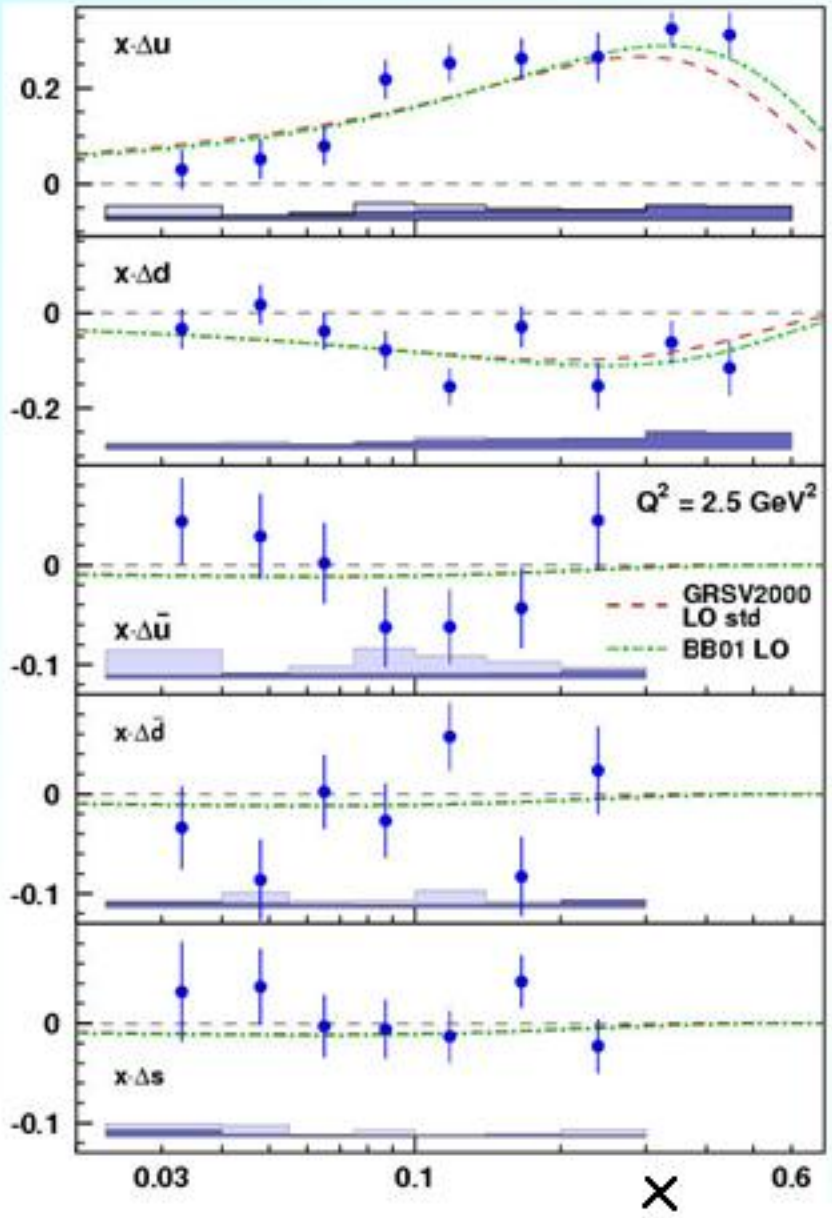
- π, K, p asymmetries identified with RICH



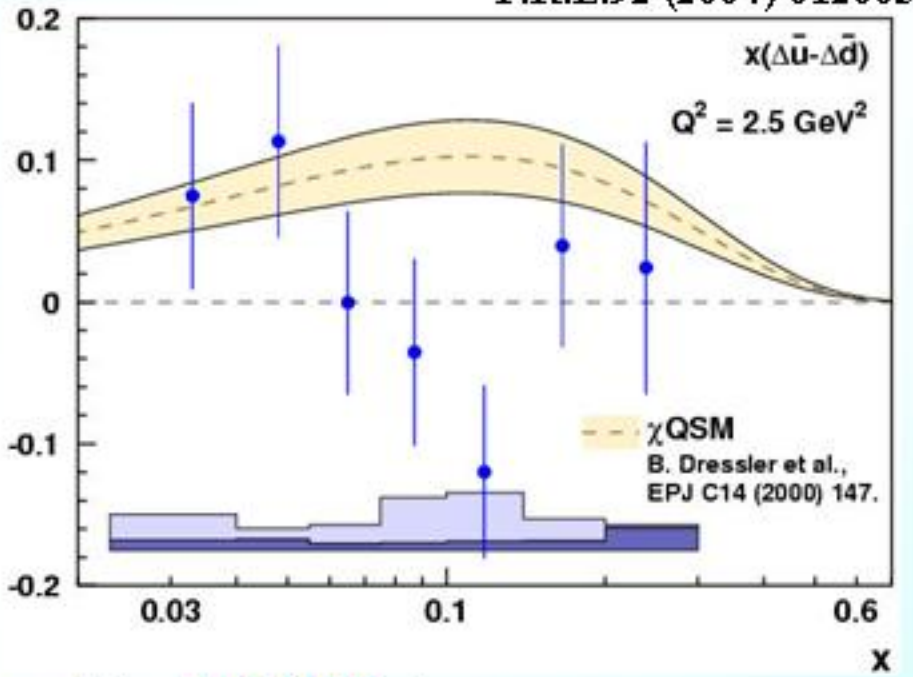
- Statistics sufficient for 5-parameter-fit

$\vec{Q}(x) = (\Delta u(x)/u(x), \Delta d(x)/d(x), \Delta \bar{u}(x)/\bar{u}(x), \Delta \bar{d}(x)/\bar{d}(x), \Delta s(x)/s(x))$

Extracted quark helicity distributions

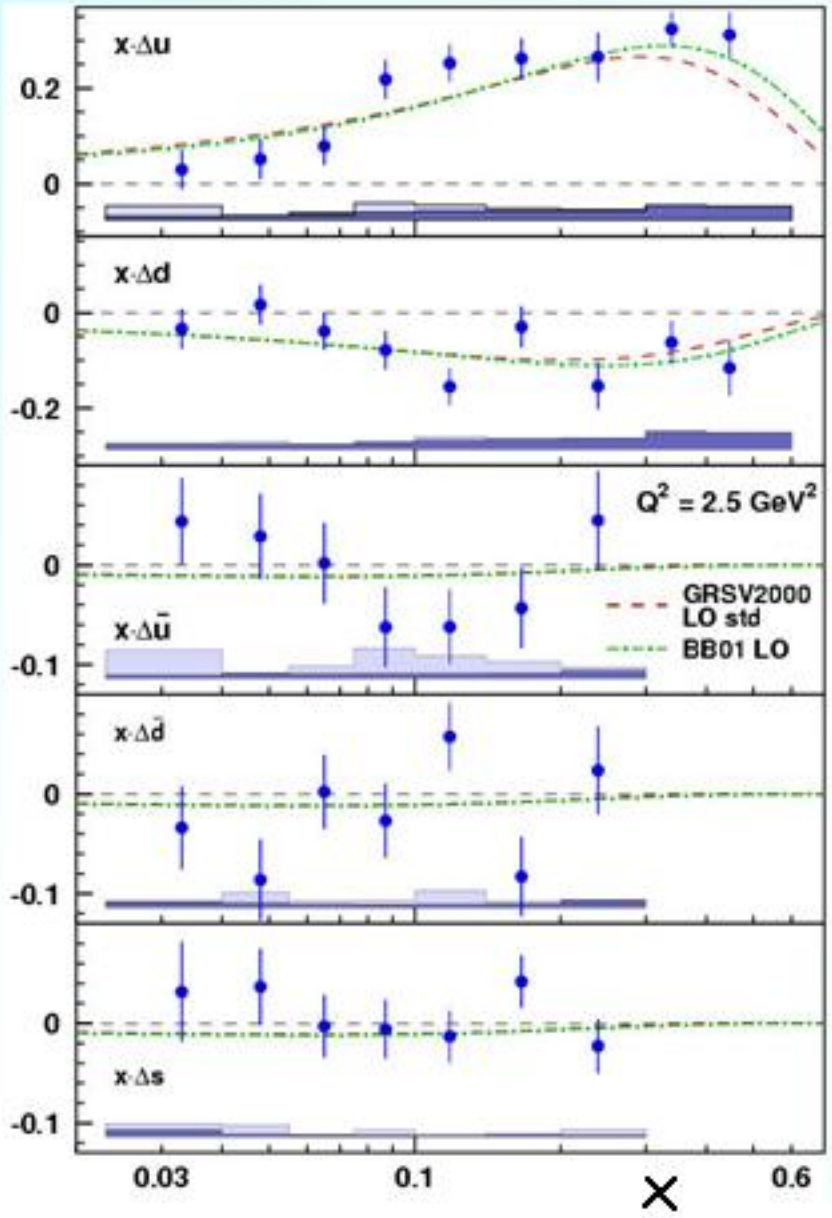


P.R.L.92 (2004) 012005

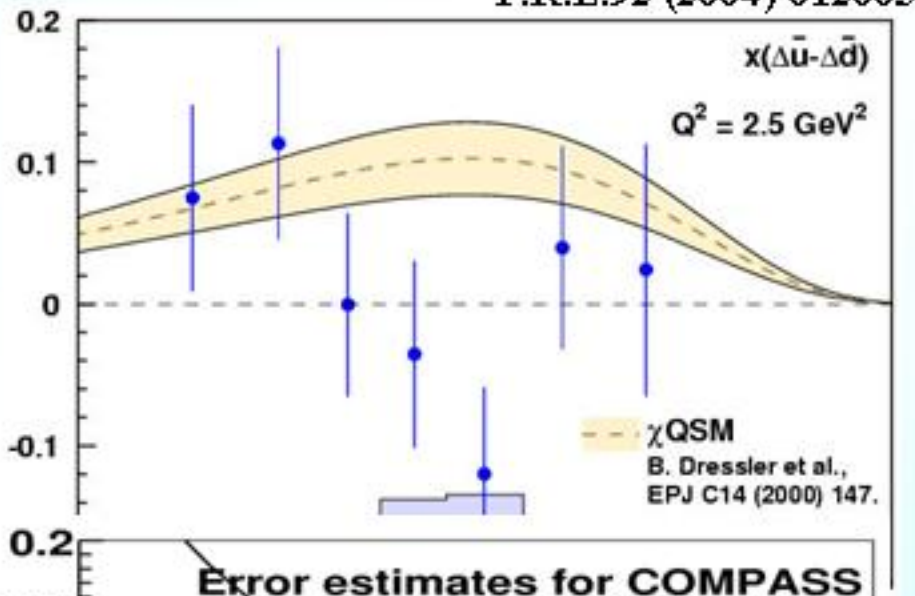


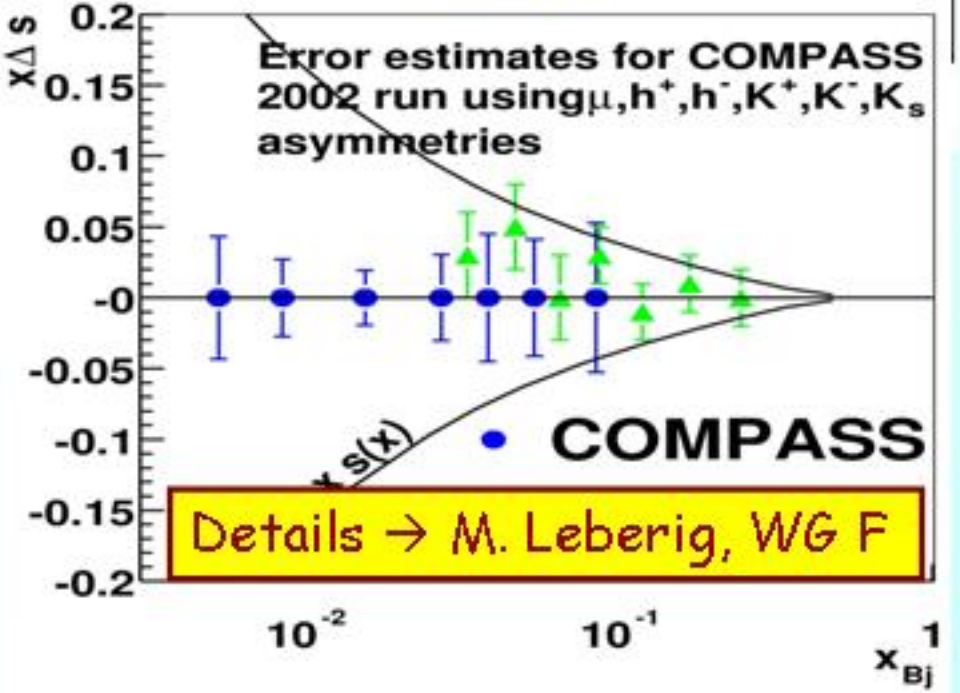
- The HERMES data are consistent with flavour symmetry of sea quark helicity distributions
- $\Delta d(x) \cong -0.4\, \Delta u(x)$ (!?)
  What is the dynamics behind this??
- Data with much higher statistical accuracy urgently needed

hermes Extracted quark helicity distributions



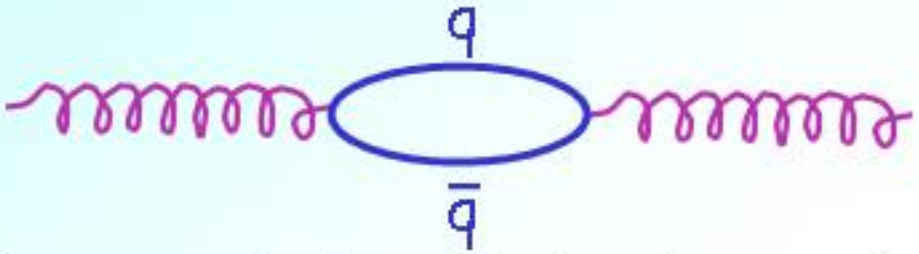
P.R.L.92 (2004) 012005





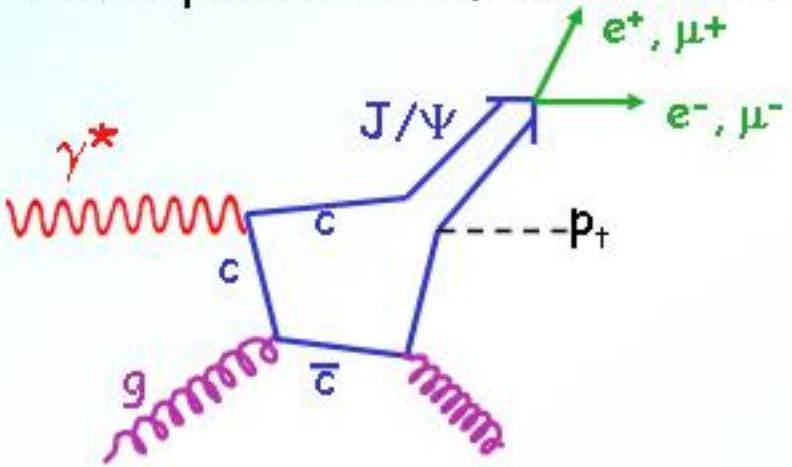
The gluon polarisation $\Delta G/G$

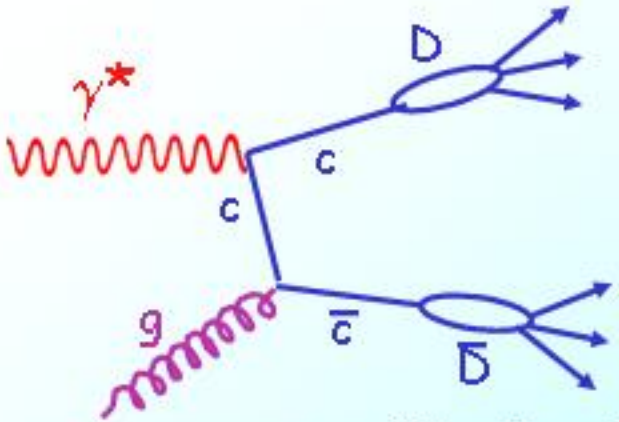
Method: Photon-Gluon-Fusion



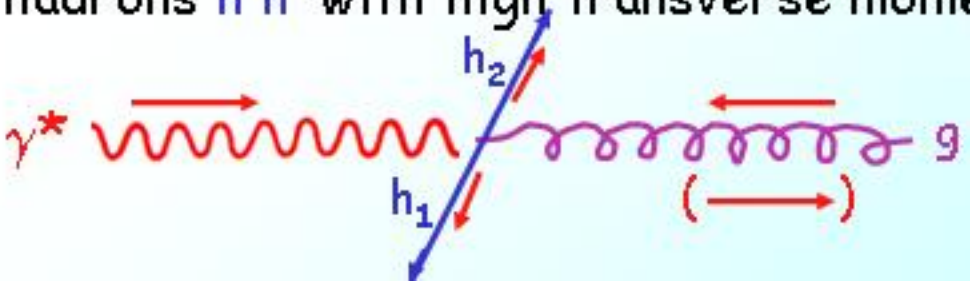
$\Delta t \sim \hbar/2m_q$

- Charm-production (Hard scale: mass of c-quark)



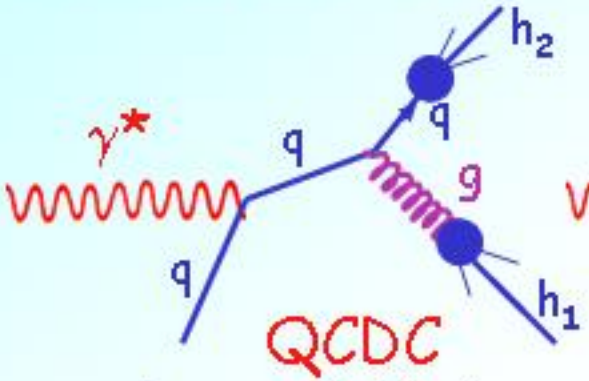


- Pairs of hadrons h^+h^- with high transverse momenta (Hard scale: p_T)



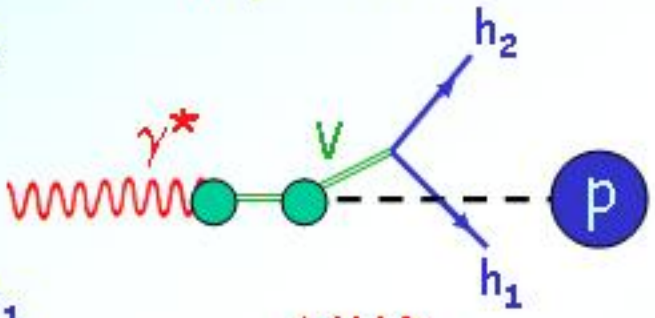
$\Delta G/G$ from high-p_T hadron pairs

3 main contributions to $\gamma^* p \rightarrow h^+h^- X$:



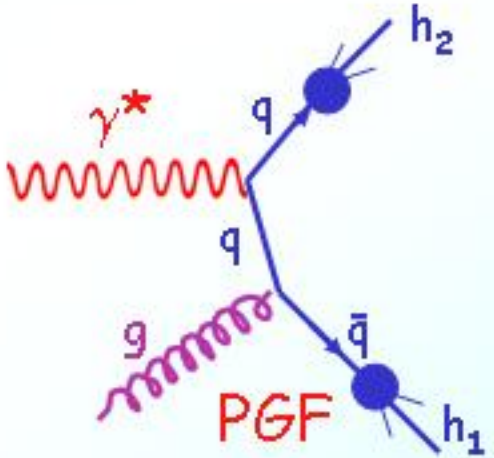
QCDC

$A_{VDM} \approx +0.5\ \Delta q/q$



VMD

$A_{VDM} = 0$



PGF

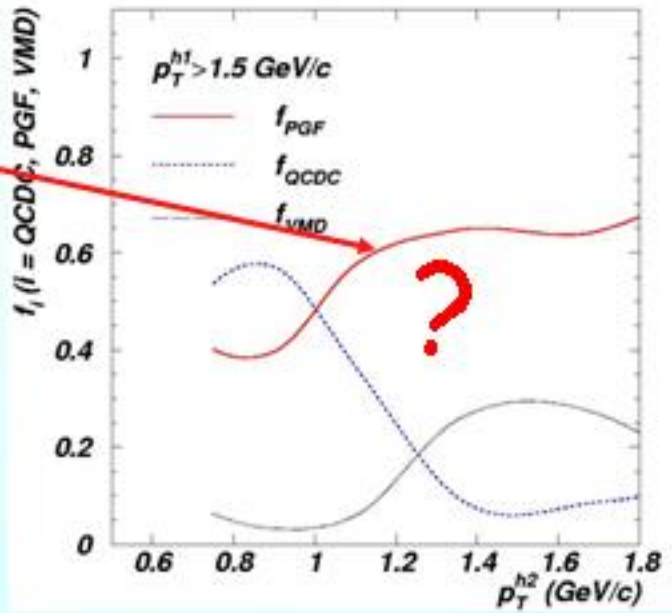
$A_{PGF} \sim -1 \cdot \Delta G/G$

Relative contributions:

Monte Carlo simulation - PYTHIA(5)

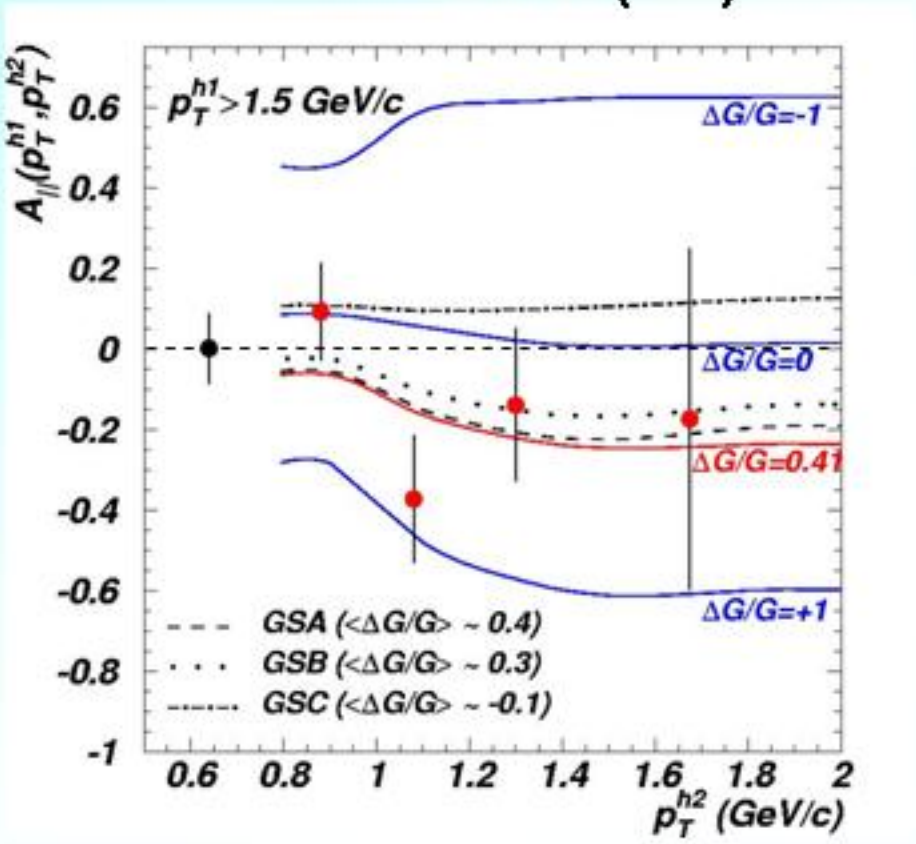
But: applicable at HERMES (COMPASS) kinematics?
Resolved photons?
Intrinsic k_T?

Tuned PYTHIA6 gives much smaller f_{PGF}



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

P.R.L. 84 (2000) 2584

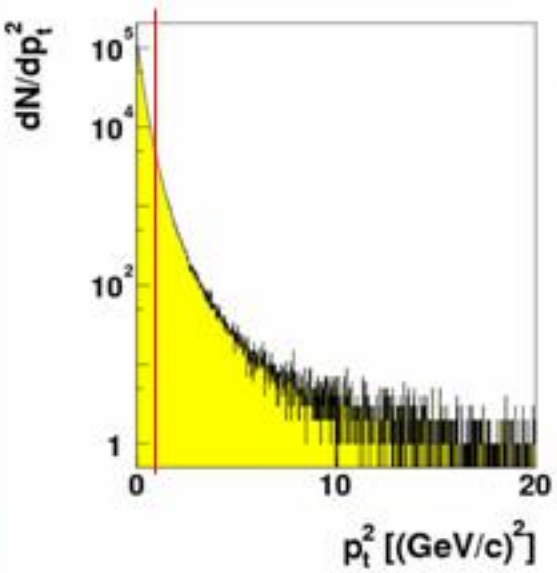


- Quasi-real photoproduction
- Proton target
- $0.06 < x < 0.28$
- $\langle Q^2 \rangle = 0.06$ (GeV/c)^2

Asymmetry is negative

$A_{\parallel} = -0.28 \pm 0.12 \pm 0.02$ ⇒ $\Delta G/G = 0.41 \pm 0.18 \pm 0.03$

High-p_T hadron pairs: COMPASS



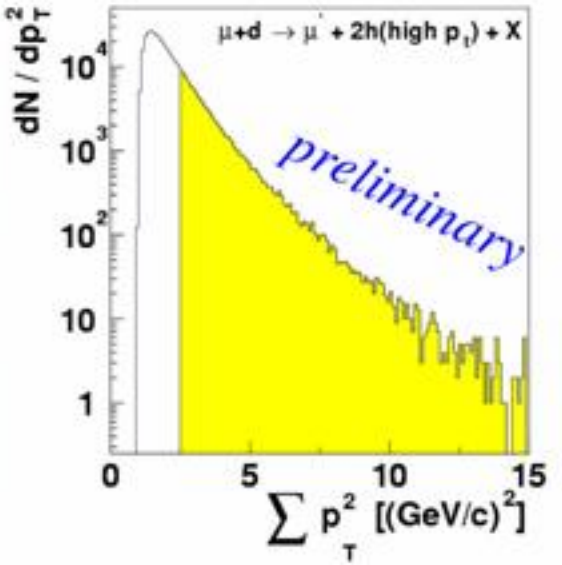
Cuts:

- $0.4 < y < 0.9$, $z > 0.1$, $x_F > 0.1$

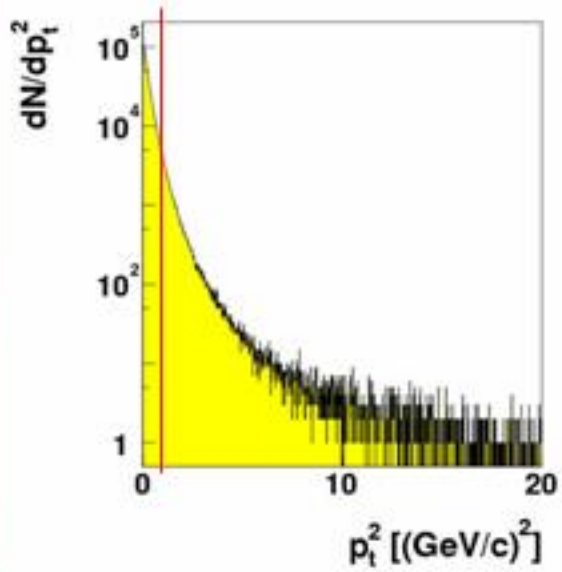
  no Q^2 cut, $\langle \log Q^2 \rangle \approx -1$

- p_{T1}, $p_{T2} > 0{,}7$ GeV/c

  $p^2_{T1} + p^2_{T2} > 2.5$ GeV^2/c^2



High-p_T hadron pairs: COMPASS



Cuts:

- $0.4 < y < 0.9$, $z > 0.1$, $x_F > 0.1$

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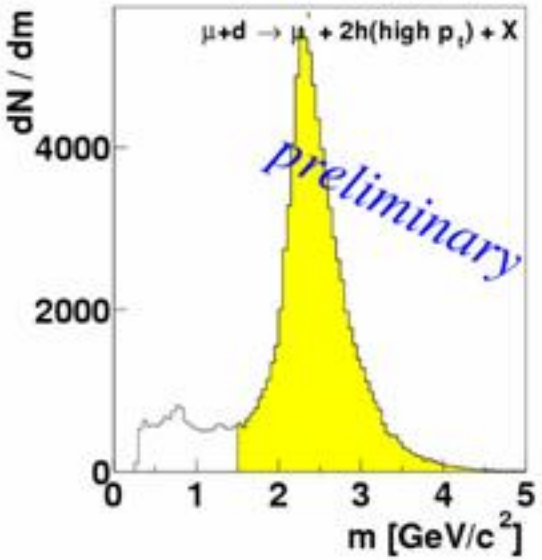
- p_{T1}, $p_{T2} > 0{,}7$ GeV/c

  $p^2_{T1} + p^2_{T2} > 2.5$ GeV^2/c^2

- $m(h_1 h_2) > 1.5$ GeV/c^2 (removes VM)



Result:

$A_{II}/D = -0.065 \pm 0.036(\text{stat}) \pm 0.01(\text{syst})$

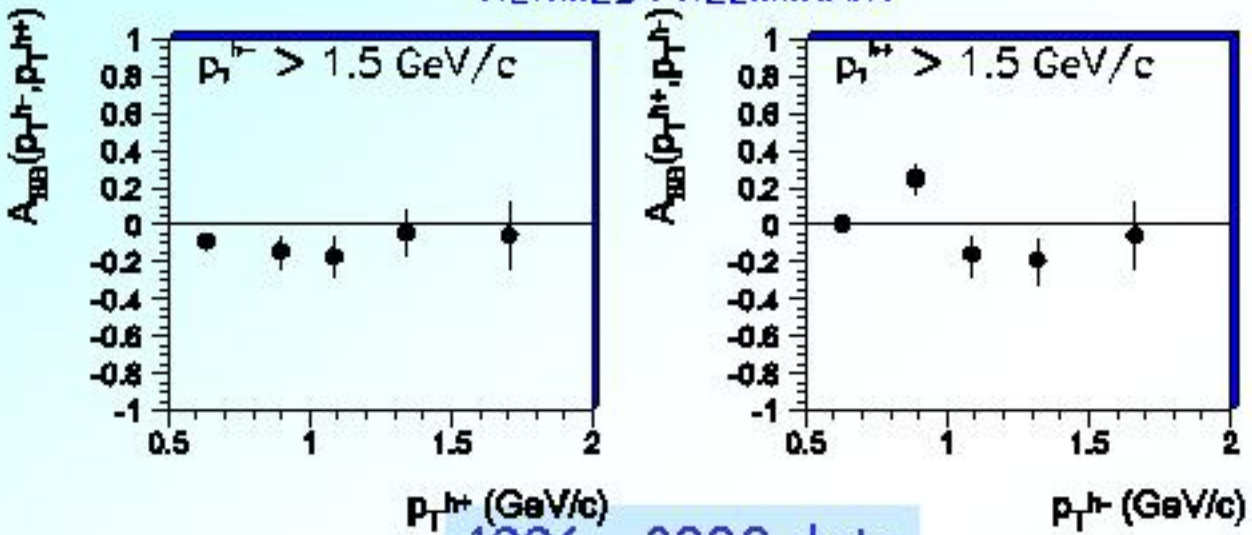
Error for asymmetry already very small

projected stat. error (incl. 2003/04): 0.018

But: data dominated by low p_T

$\Delta G/G$ from high-p_t hadron pairs

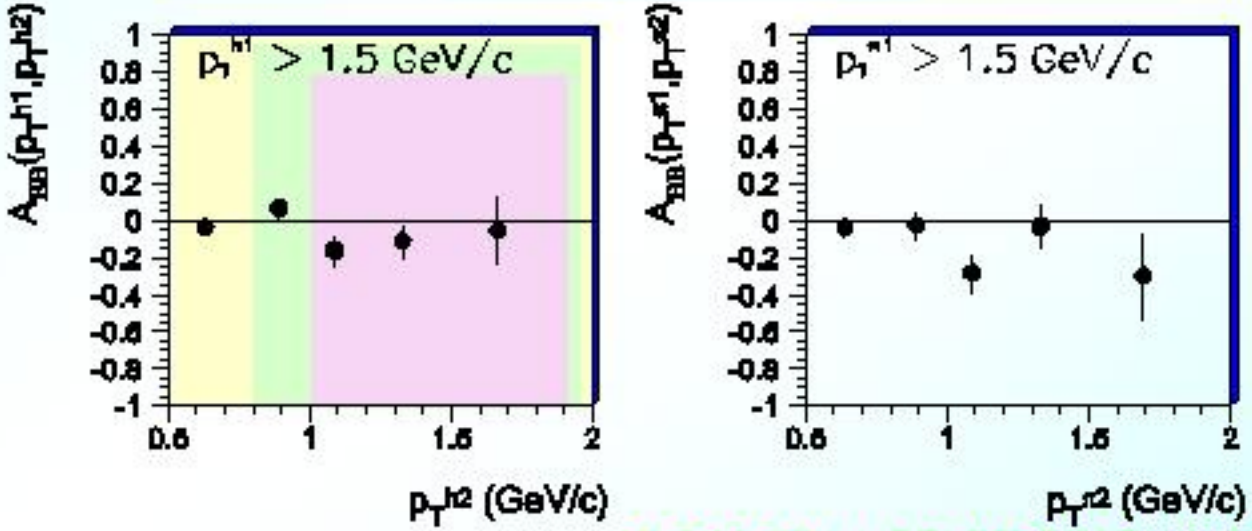
HERMES PRELIMINARY



$A = -0.133 \pm 0.058$

1996 - 2000 data

$A = -0.040 \pm 0.042$



$A = -0.039 \pm 0.028$

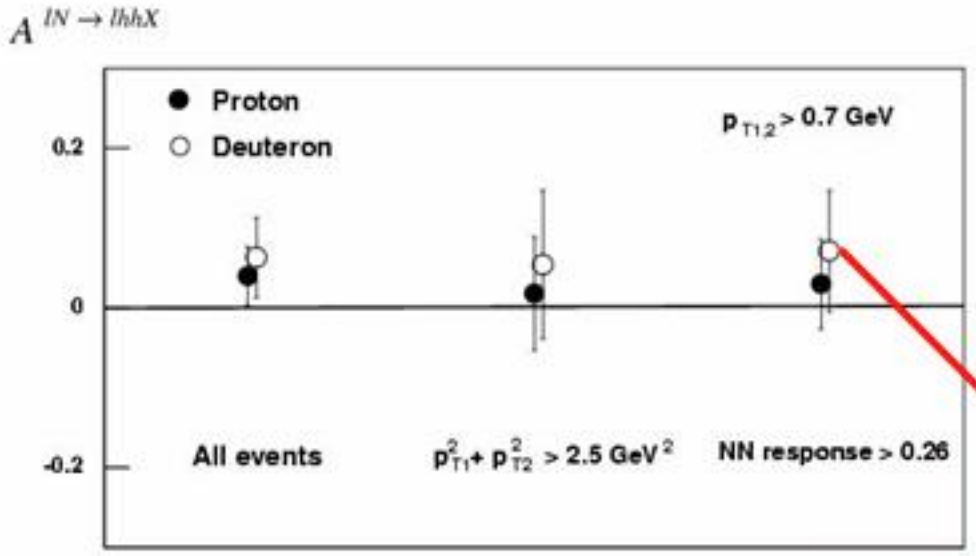
Systematic error 8.1%

HYDROGEN + DEUTERIUM Target

$\Delta G/G$ from high-p_T hadron pairs: SMC

- E_μ = 190 GeV
- Cuts: as COMPASS
- exception: $Q^2 > 1\ GeV^2/c^2$ ➡ DIS regime
- optimization of f_{PGF}: p_T-cuts and neural network -(NN)
  ➡ $f_{PGF} \approx 0.3$

hep-ex/0402010



Result:

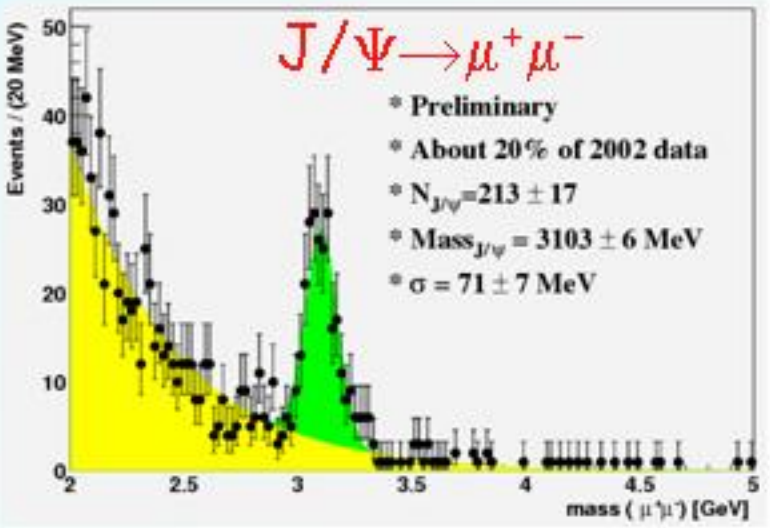
Asymmetry is positive ! ?

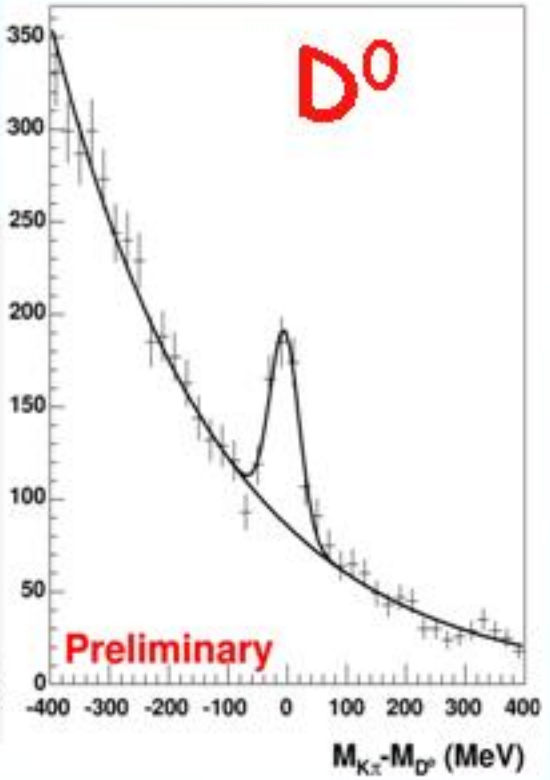
Proton plus deuteron data,
NN classification:

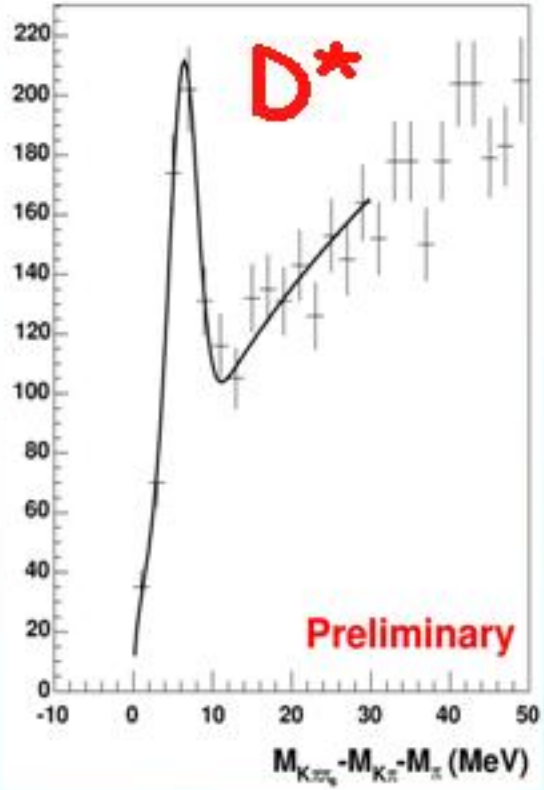
$\Delta G/G = -0.20 \pm 0.28 \pm 0.10$

Charm production: COMPASS

Details → F.H. Heinsius, WG F







2002: mostly "elastic" background

2003: dedicated trigger (2*yield)
- study diffractive and elastic processes

Signal seen, but limited statistics, (remind dilution factors !)

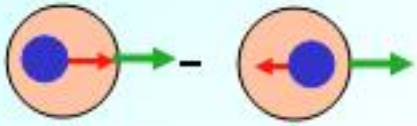
Still some way to go for $\Delta G/G$

'Transversity' h_1

Complete description of nucleon in leading order QCD: 3 DF

f_1 = 

Quark momenta, ~ $\bar{q}\gamma^\mu q$, V

g_1 = 

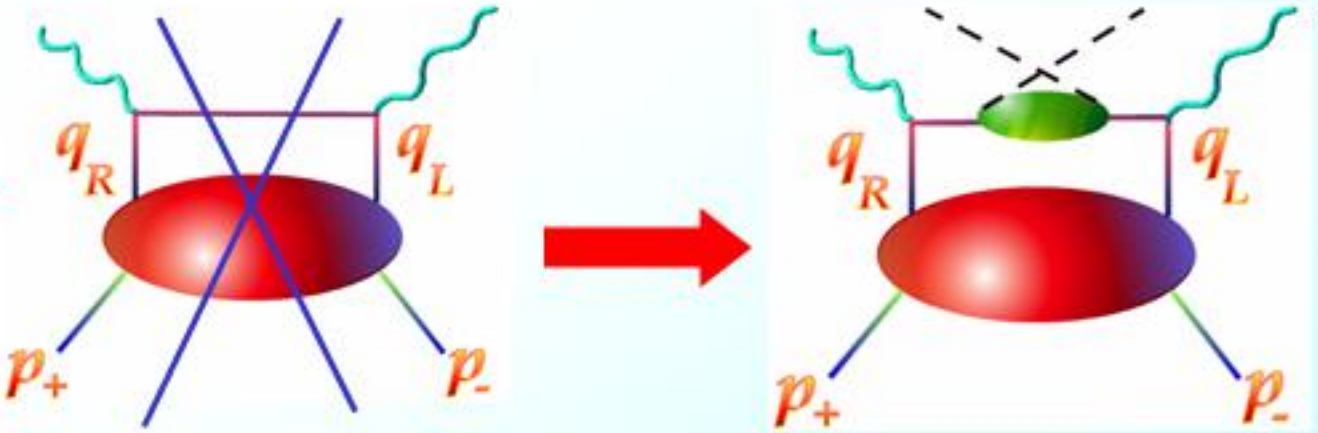
longitudinal quark spin, $\Delta\Sigma$, ~ $\bar{q}\gamma^\mu\gamma^5 q$, A

h_1 = 

transverse quark spin, $\delta\Sigma$, ~ $\bar{q}\sigma^{\mu\nu}\gamma_5 q$, T

h_1 is chiral odd, measurement requires other chiral odd DF (e.g. Drell-Yan), or FF (SIDIS) like the Collins FF $H_1^\perp(z)$

single helicity flip



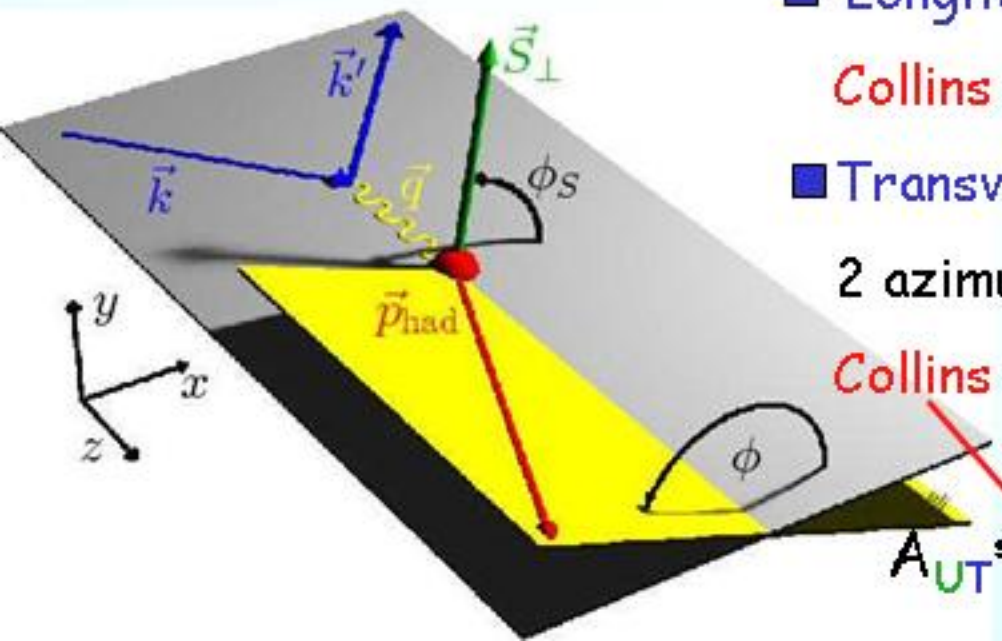
***Collins* FF**

double helicity flip

Azimuthal asymmetries: Collins vs Sivers effect

2 different possible sources for azimuthal asymmetry:

- product of chiral-odd transversity distribution $h_1(x)$ and chiral-odd fragmentation function $H_1^{\perp}(z)$ (Collins)
- product of naive time-reversal odd distribution function $f_{1T}^{\perp}$ and familiar unpolarised fragmentation function $D_1(z)$ (Sivers) (requires orbital angular momentum of quarks)



- Longitudinally polarised target:

  Collins and Sivers effect indistinguishable

- Transversely polarised target:

  2 azimuthal angles,

  Collins and Sivers effect distinguishable

$A_{UT}^{\sin(\phi + \phi_S)}$ $A_{UT}^{\sin(\phi - \phi_S)}$

Single Spin Asymmetries (SSA)

$$\vec{e}\vec{p}(\vec{d}) \longrightarrow e'h^{\pm}X$$

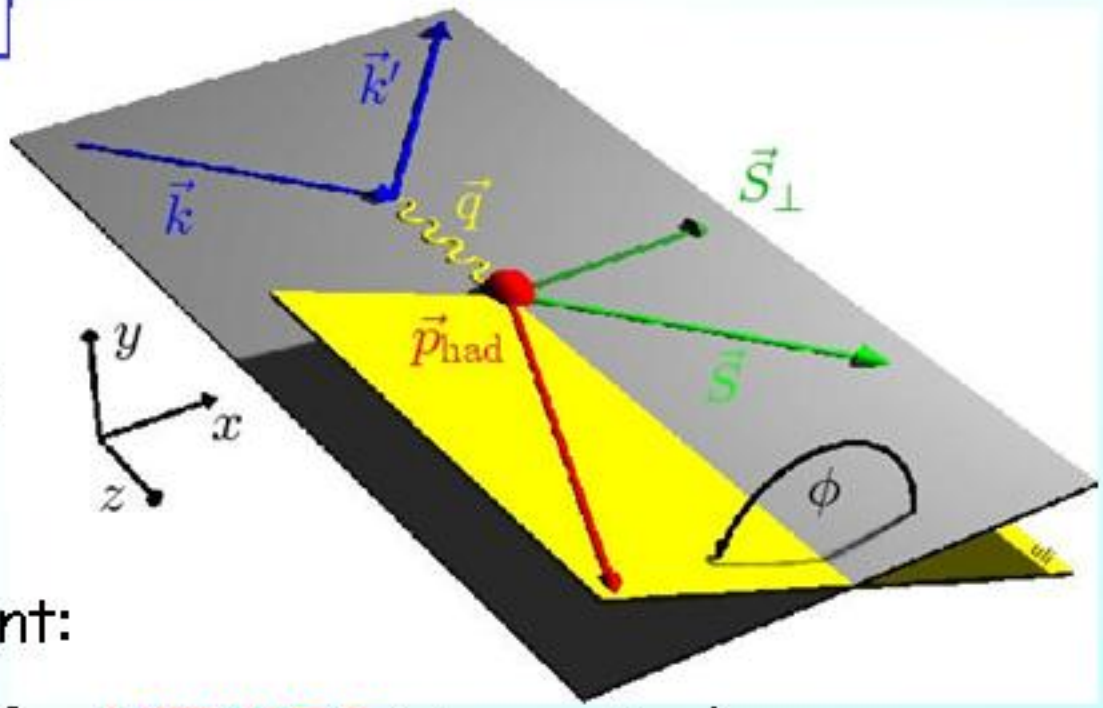
$$A_{UL}(\phi) = \frac{N^{+}(\phi) - N^{-}(\phi)}{N^{+}(\phi) + N^{-}(\phi)}$$

U: unpol. $e^{\pm}$-beam

L: long. pol. Target

Fit sin(ϕ) to asymmetries

$\Rightarrow$ $A_{UL}^{\sin(\phi)}$



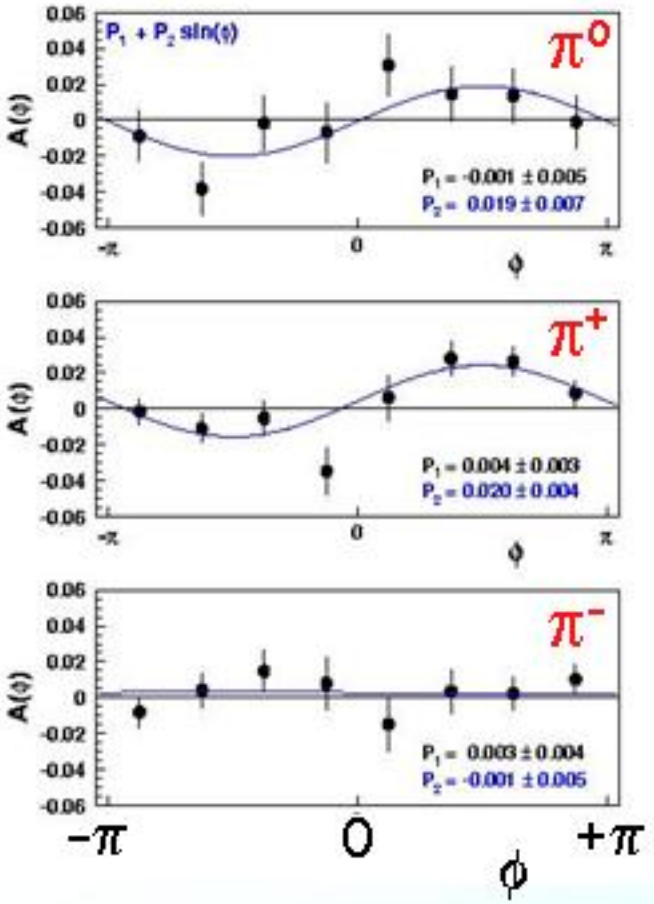
transverse spin component:

$S_T \propto \sin\Theta_\gamma$ (15% - 20%) (for HERMES kinematics)

SSA from long. polarized target

Proton

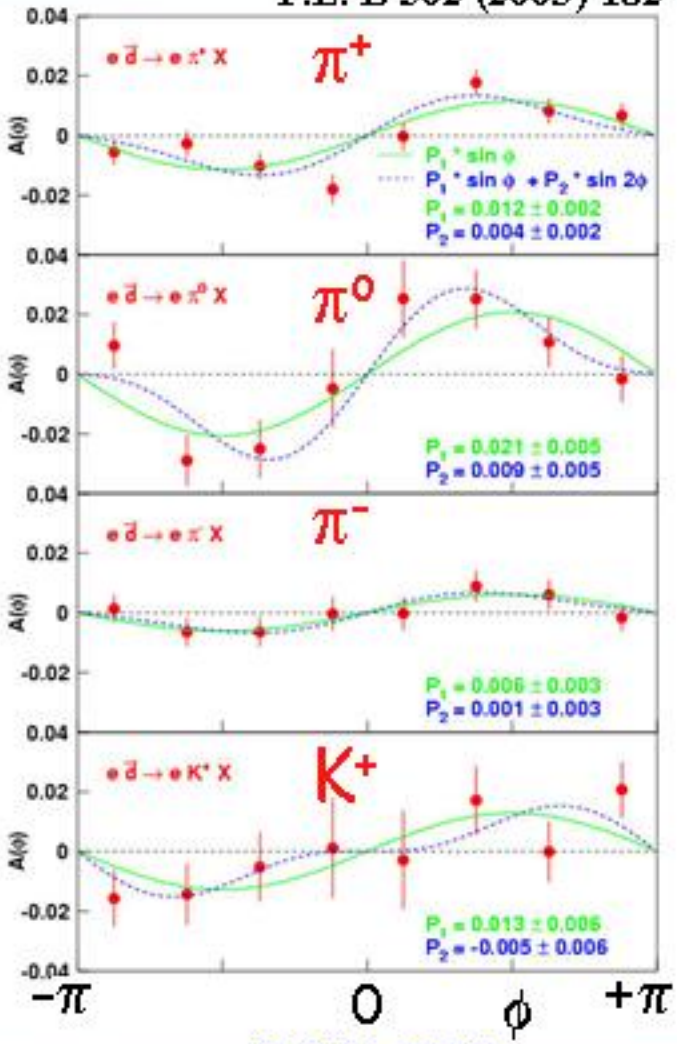
P.R. D 64 (2001) 097101.



2.4 M DIS

Deuteron

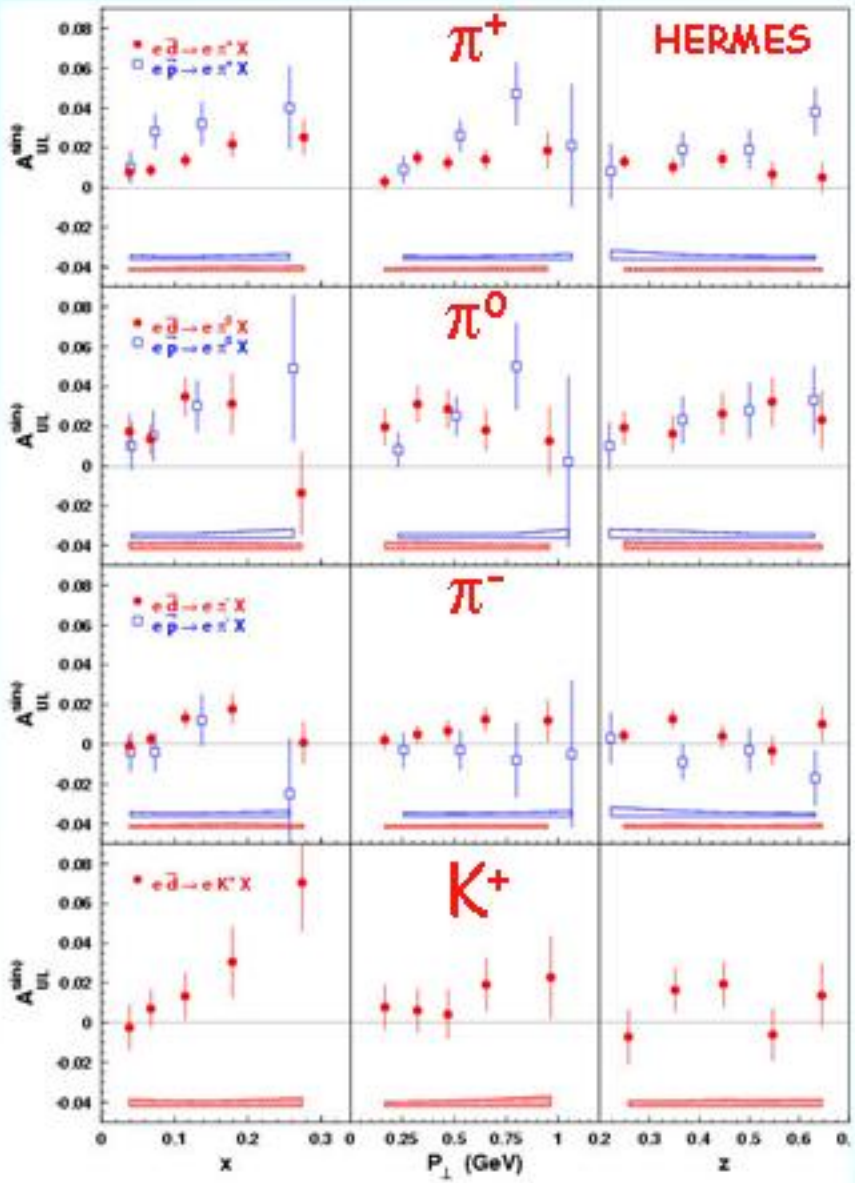
P.L. B 562 (2003) 182

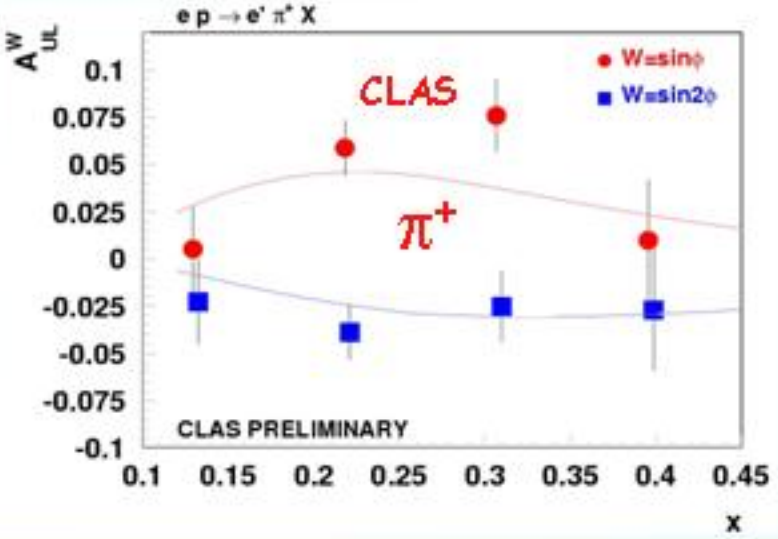


8.9 M DIS

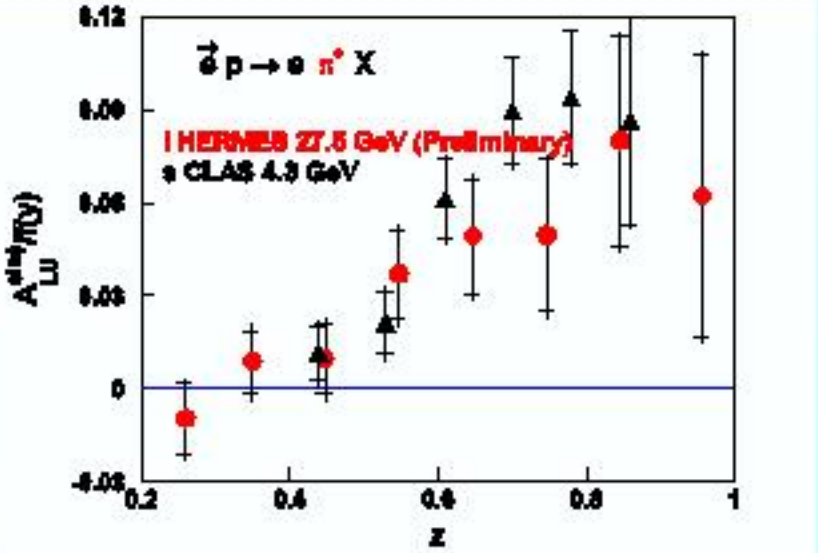
$A_{UL}^{\sin(\phi)}$ from long. polarized target

P.L. B 562 (2003) 182





Furthermore: $A_{LU}^{\sin(\phi)}$ (~ e(x))



$A_{UL}^{\sin(\phi)}$ from longitudinally polarized target

$$A_{UL}^{\sin\phi} \propto S_L (M/Q) \sum z_a^2 \times [h_L^a(x)\, H_1^{\perp a}(z) - \times h_{1L}^{\perp a}(x)\, H^a(z)/z + ..]$$

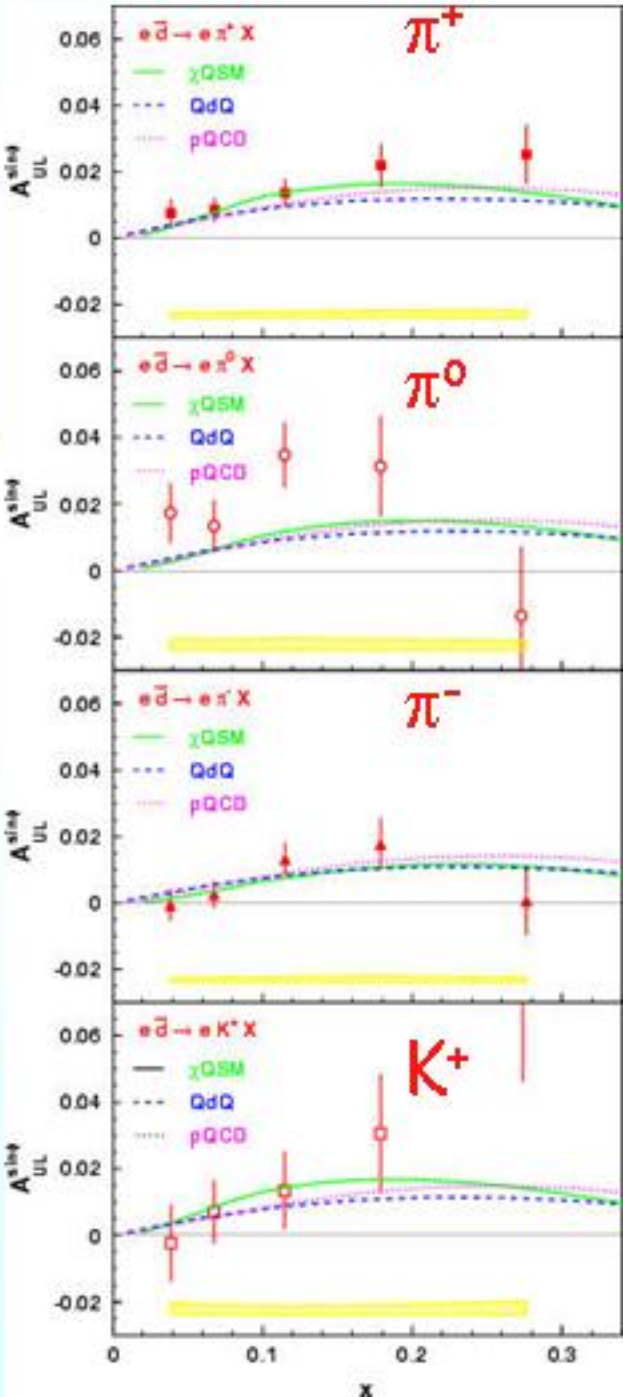
$$- S_T \sum z_a^2 \times h_1^a(x)\, H_1^{\perp a}(z)$$

$S_L \gg S_T$

Collins fragmentation function

- Theory predictions seem to explain the data well
  - A.V. Efremov et al., Eur. Phys. J. C 24 (2002) 47
  - B. Ma et al., P.R. D66 (2002) 094001
- but contain a lot of assumptions:
  - magnitude of $H_1^{\perp}/D1 \approx 4$ ...12%
  - only part of Twist-3 contribution taken into account
  - no Sivers contribution

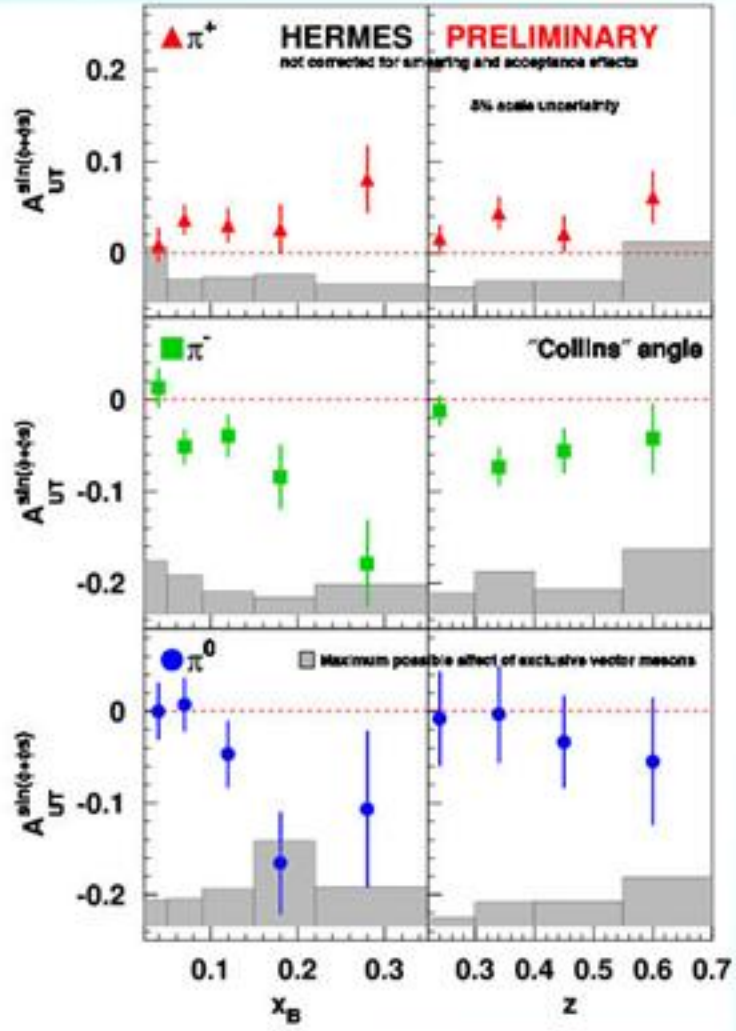
    taken into account



$A_{UT}^{\sin(\phi)}$ from transv. pol. H target

Simultaneous fit to $\sin(\phi + \phi_s)$ and $\sin(\phi - \phi_s)$

„Collins" moments



- Unexpected pattern:
  expect $A\pi+ > A\pi o > 0$ and
  $A\pi- \leq 0$
  and <u>smaller</u> in magnitude
- Data show $A\pi+ > 0$
  but $A\pi o \cong A\pi- < 0$ and <u>larger</u> in magnitude
- Possible source: $H_{1,disf} \approx - H_{1,fav}$?

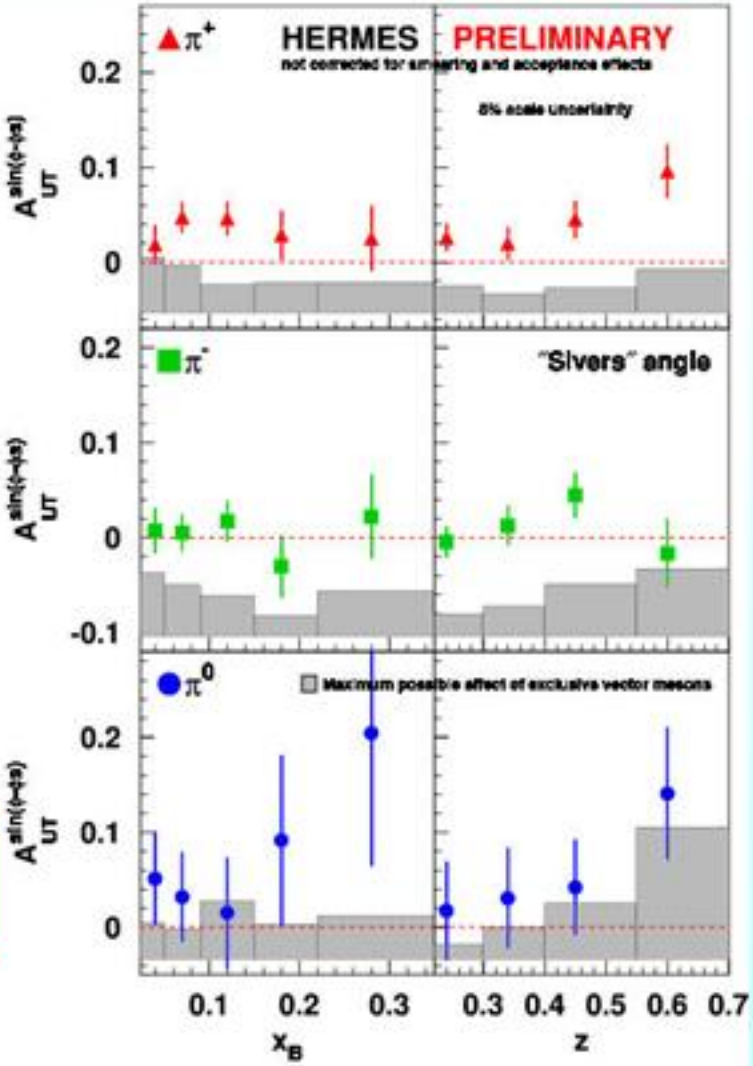
$A_{UT}^{\sin(\phi)}$ from transv. pol. H target

Simultaneous fit to $\sin(\phi + \phi_s)$ and $\sin(\phi - \phi_s)$

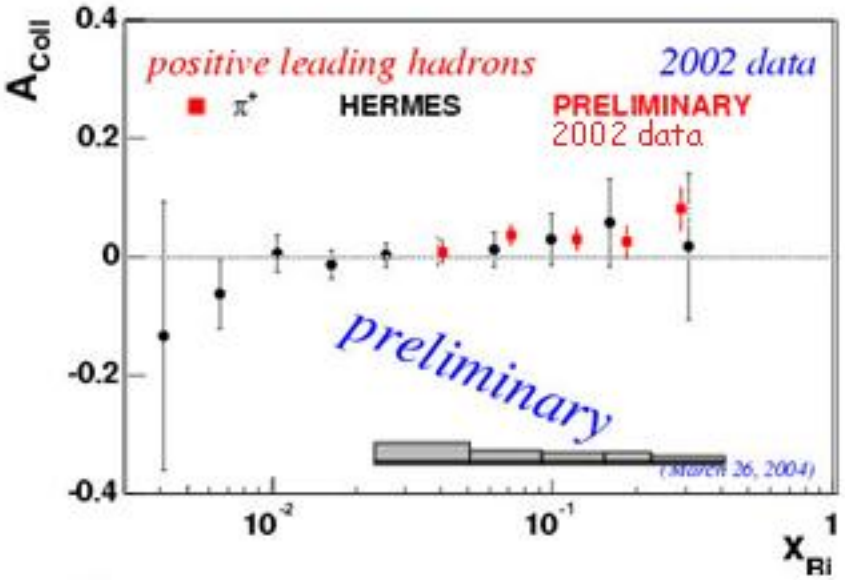
„Sivers" moments

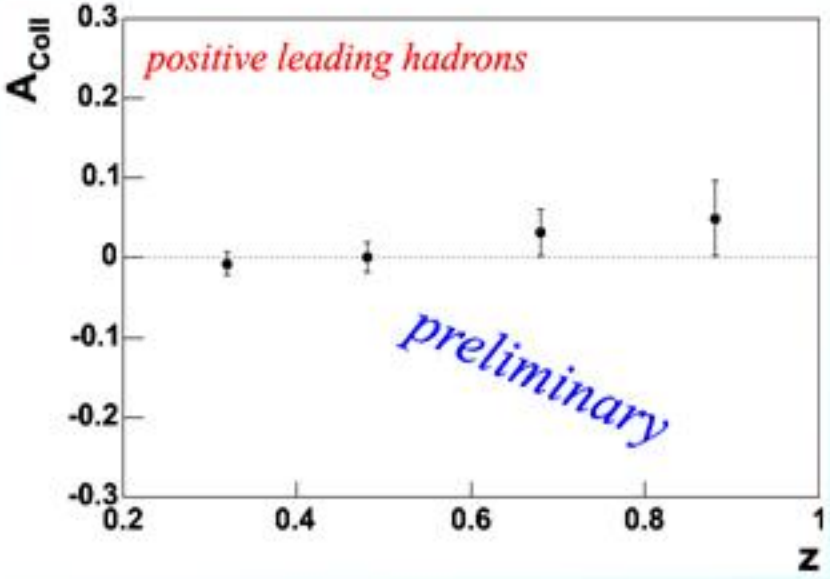
- First measurement of Sivers asymmetry
- Sivers function nonzero → orbital angular momentum of quarks
- Sivers flavor separation possible and underway

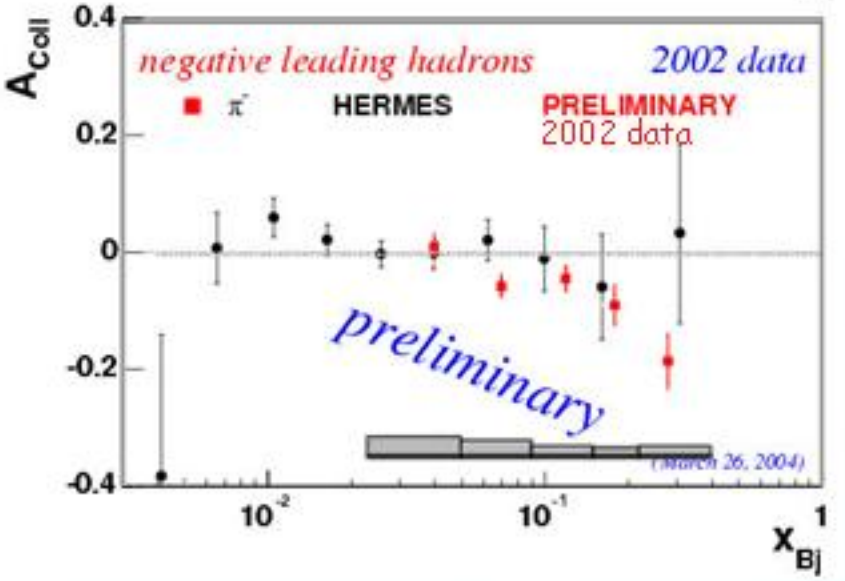
HERMES 2002-2005 data:
Hope for factor of 4-9 in statistics



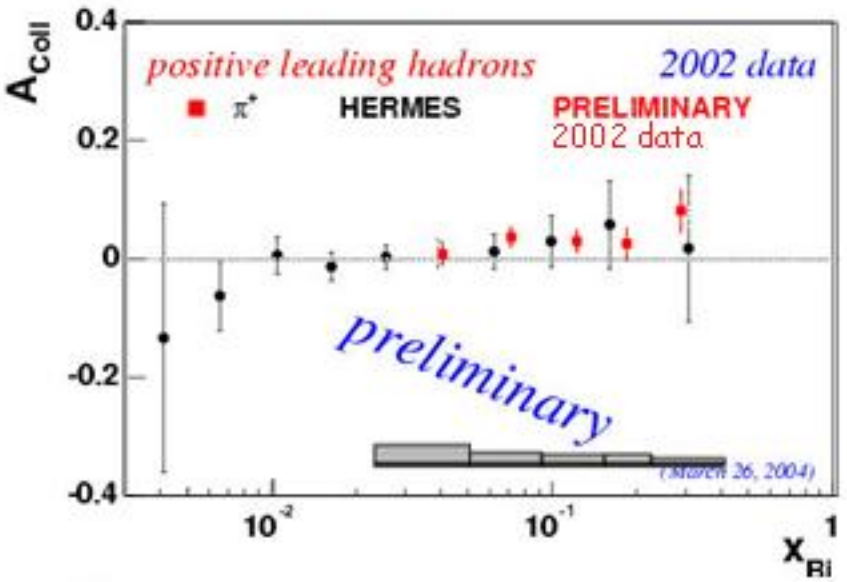
Collins asymmetry from COMPASS

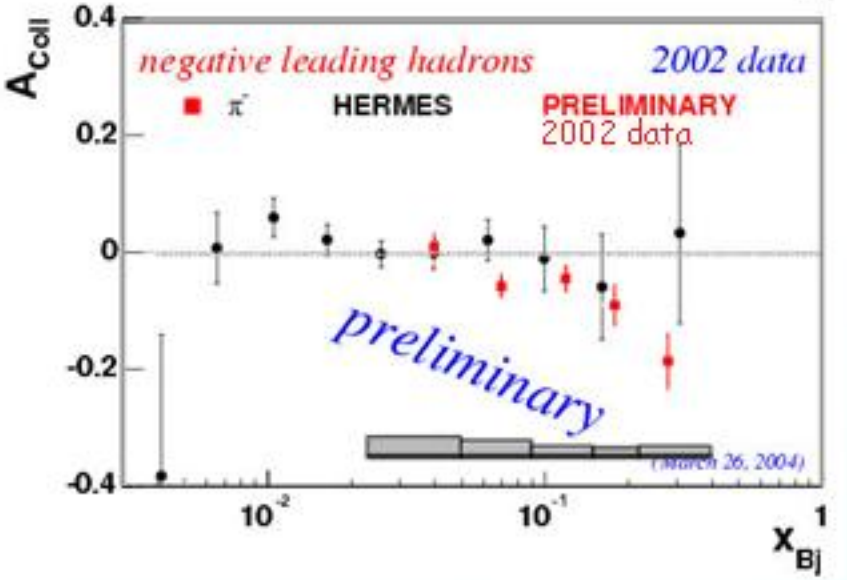


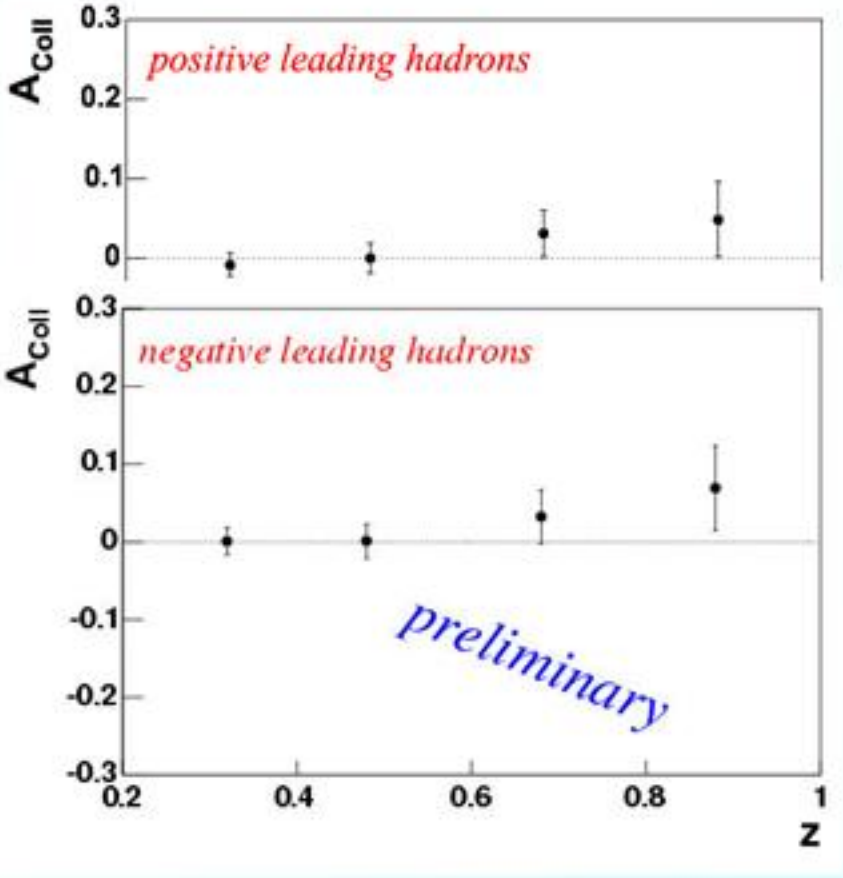




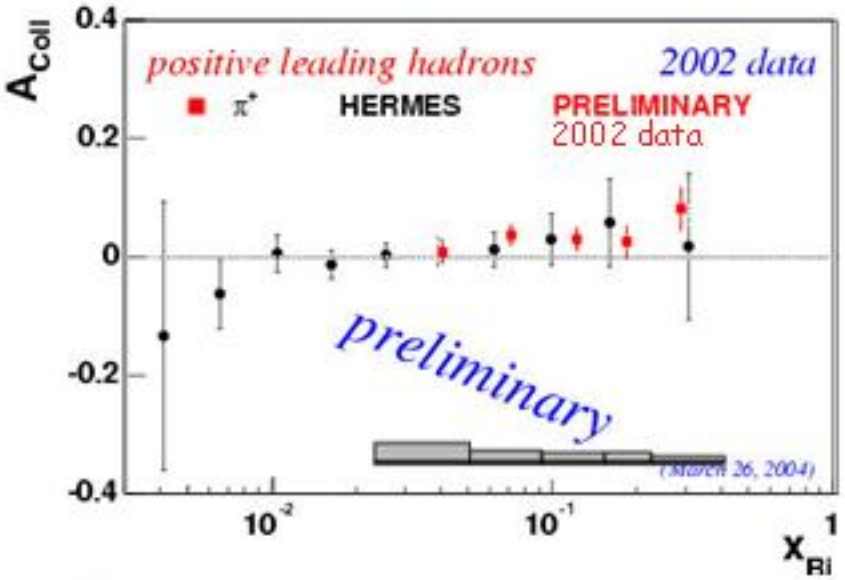
Collins asymmetry from COMPASS

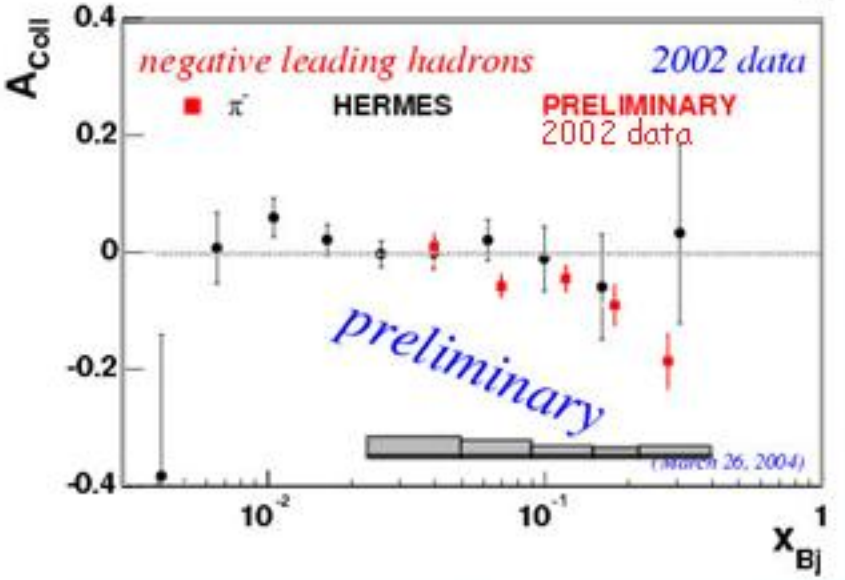


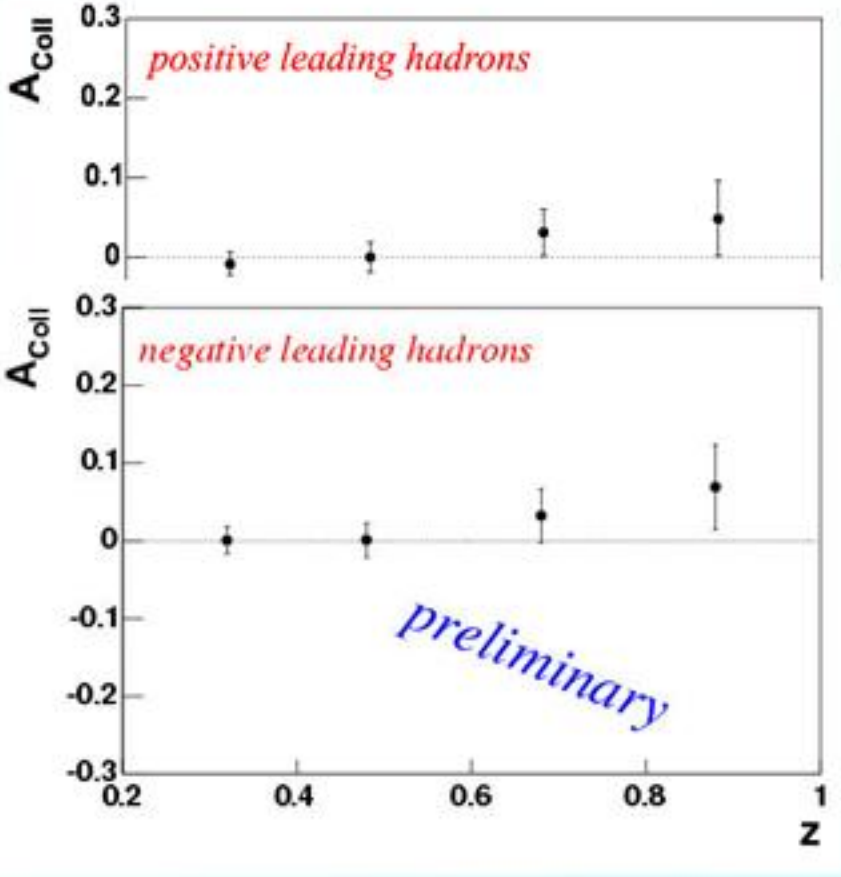




Collins asymmetry from COMPASS

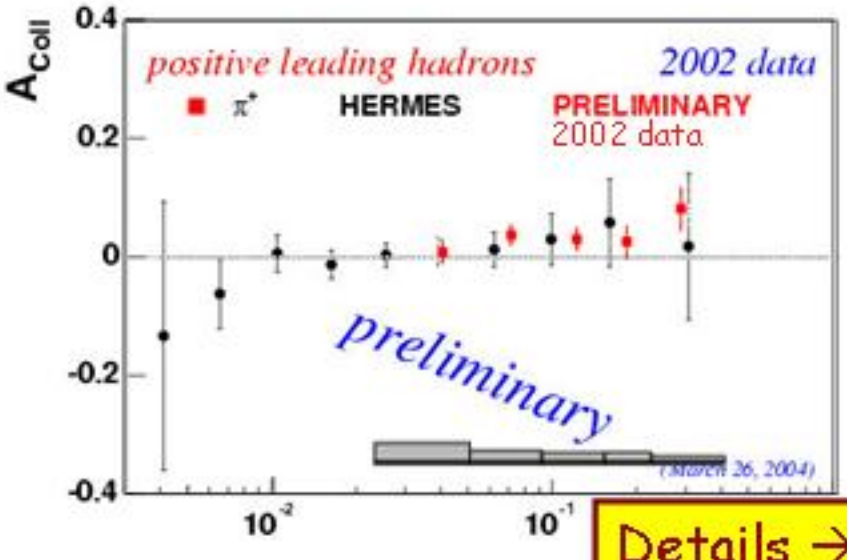


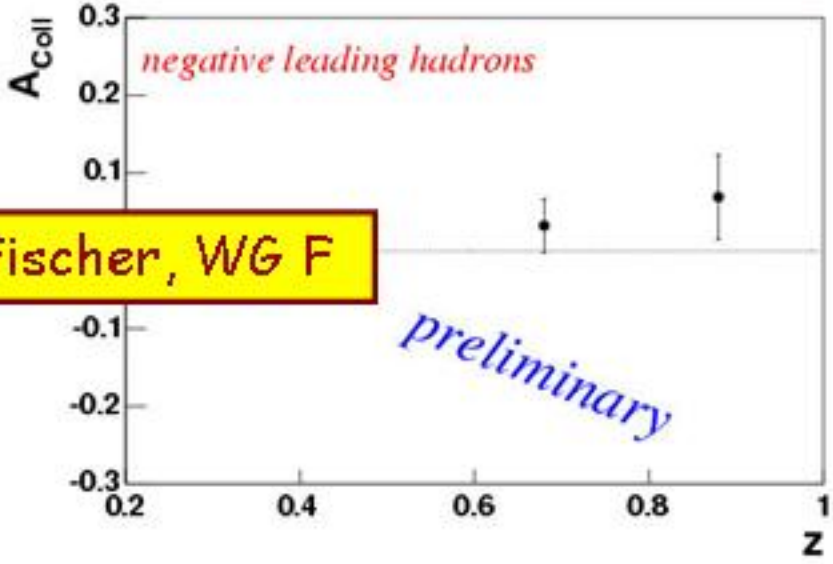


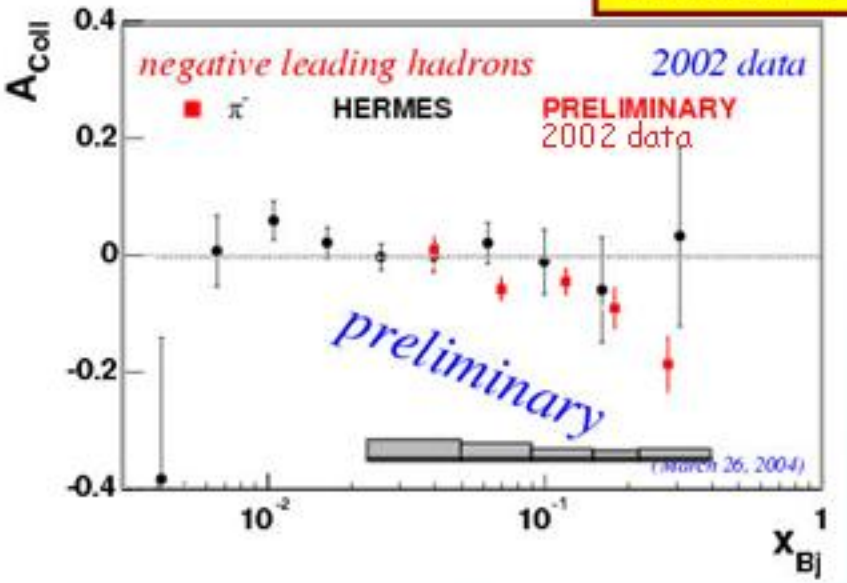


COMPASS 2002-2004 data:
~ factor of 4 in statistics

Collins asymmetry from COMPASS







Details → H. Fischer, WG F

COMPASS 2002-2004 data:
~ factor of 4 in statistics

Conclusions

- Plenty of new data from COMPASS, HERMES, JLAB, SMC
- Rather precise results on asymmetries, spin-dependent SF and quark helicity distributions.
- Further improvements on measurement of sea quark polarisation desirable
- $\Delta G/G$ results puzzling, we still wait for a clean and precise experimental determination
- First results on Transversity and Sivers effect very promising

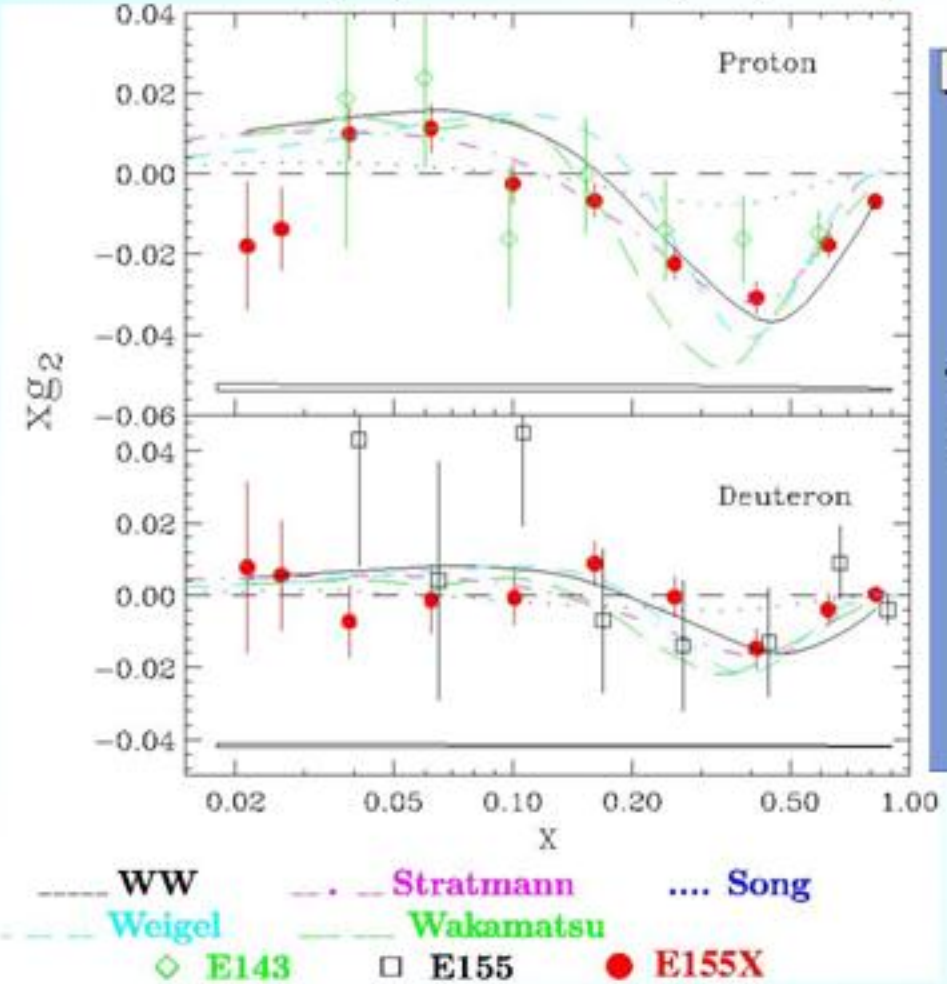
Stay tuned ...
New exiting results will come soon!

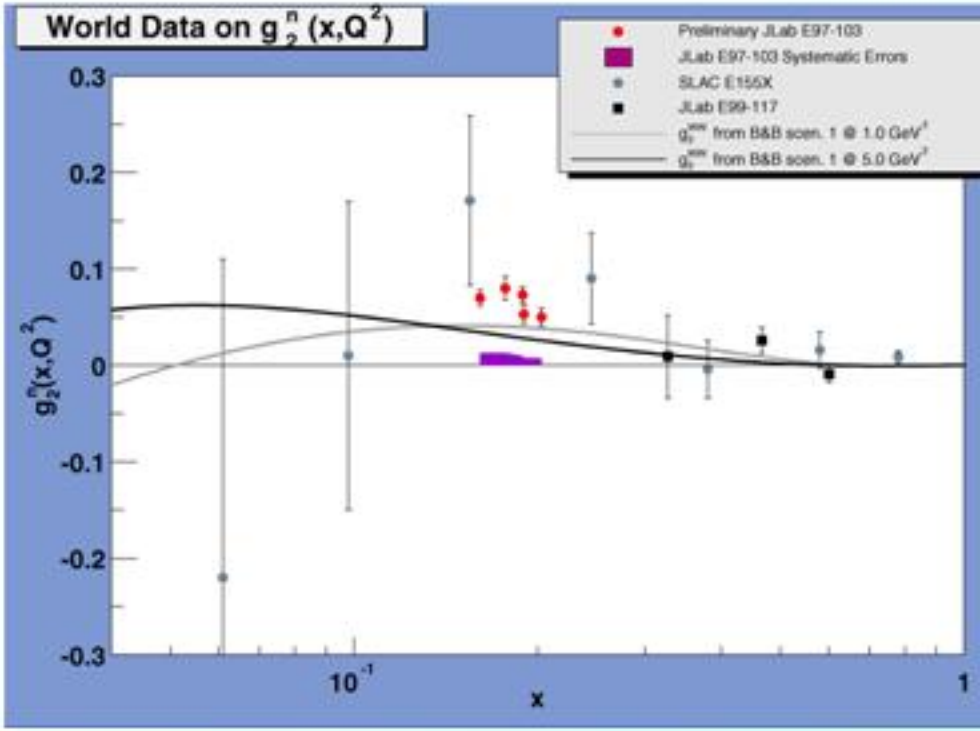
Special thanks to H. Fischer and Z.-E. Meziani

$g_2(x)$

$$g_2(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(z,Q^2)\,dz/z + \tilde{g}_2(x,Q^2) = g_2^{WW}(x,Q^2) + \tilde{g}_2(x,Q^2)$$

E155x, Phys. Lett. B 553 (2003) 18 Quark-Gluon Correlation (Twist-3 Operator)



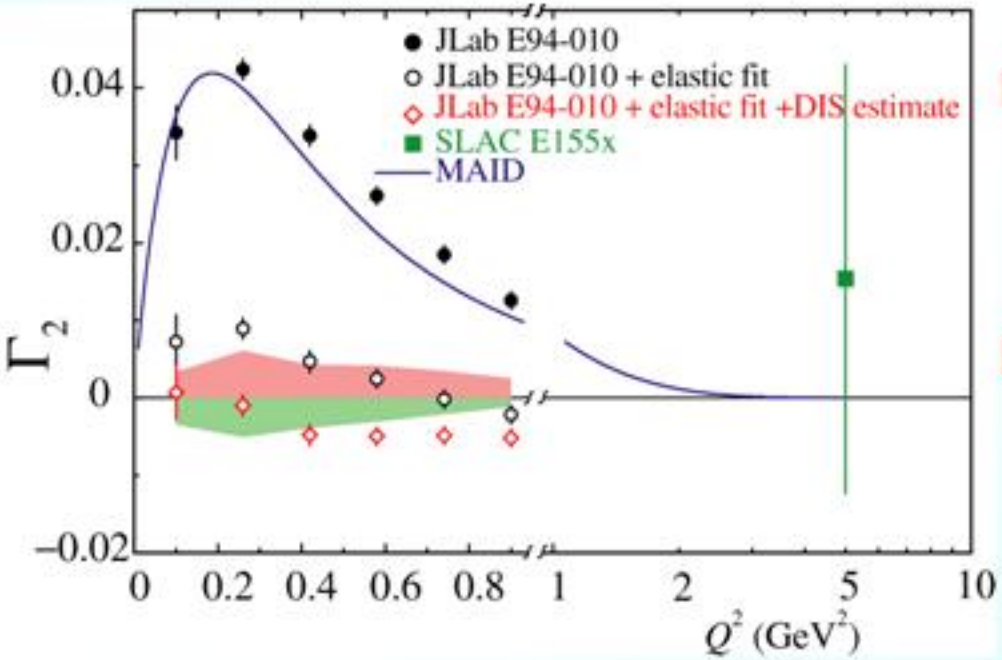


Further improvement by HERMES and COMPASS very unlikely

Test of Burkhardt-Cottingham SR

$$\Gamma_2(Q^2) = \int_0^1 g_2(x, Q^2)\, dx = 0$$

- valid at all Q^2
- Many scenarios of g_2's low x behavior which would invalidate the sum rule are discussed in the literature.



- Courageous extrapolations to high and low x
- Conclusion of authors: BC-sum rule fullfilled within errors

Details → N.Liyanage, WG F

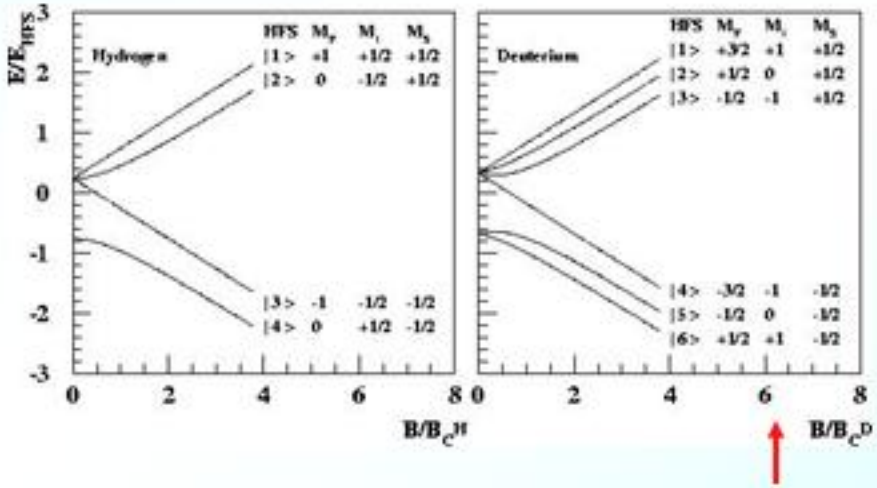
A_T, b_1 and b_2 - deuteron

- Deuteron is spin-1 target

$V = P_z = p^+ - p^-$, $|P_z| \leq 1$

$T = P_{zz} = p^+ + p^- - 2p^0$, $-2 \leq P_{zz} \leq +1$

- More structure functions



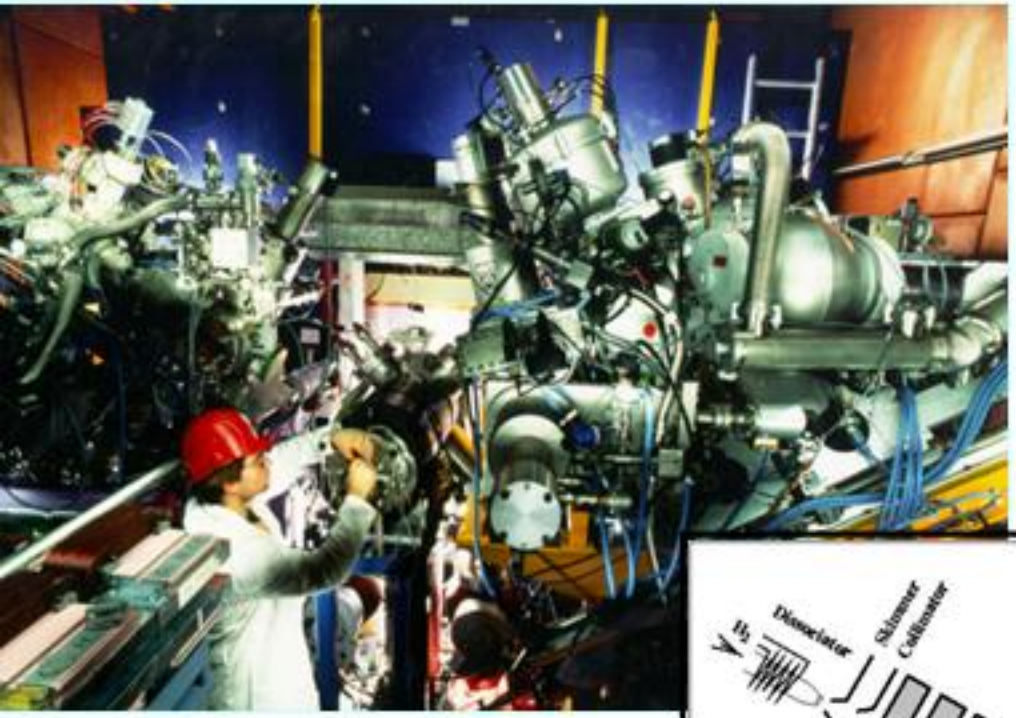
	Proton	Deuteron
F_1	$\frac{1}{2}\sum z_q^2 [q^+ + q^-]$	$1/3 \sum z_q^2 [q^+ + q^- + q^0]$
F_2	$2xF_1$	$2xF_1$
g_1	$\frac{1}{2}\sum z_q^2 [q^+ - q^-]$	$\frac{1}{2}\sum z_q^2 [q^+ - q^-]$
b_1		$\frac{1}{2}\sum z_q^2 [2q^0 - (q^+ + q^-)]$
b_2		$2xb_1$

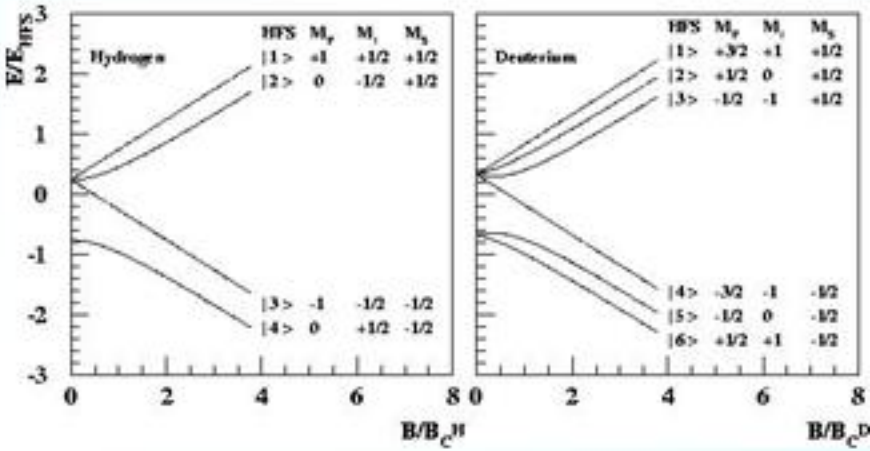
$$\sigma_{meas} = \sigma_u [1 + P_b V A_{||} + \tfrac{1}{2} T A_T]$$

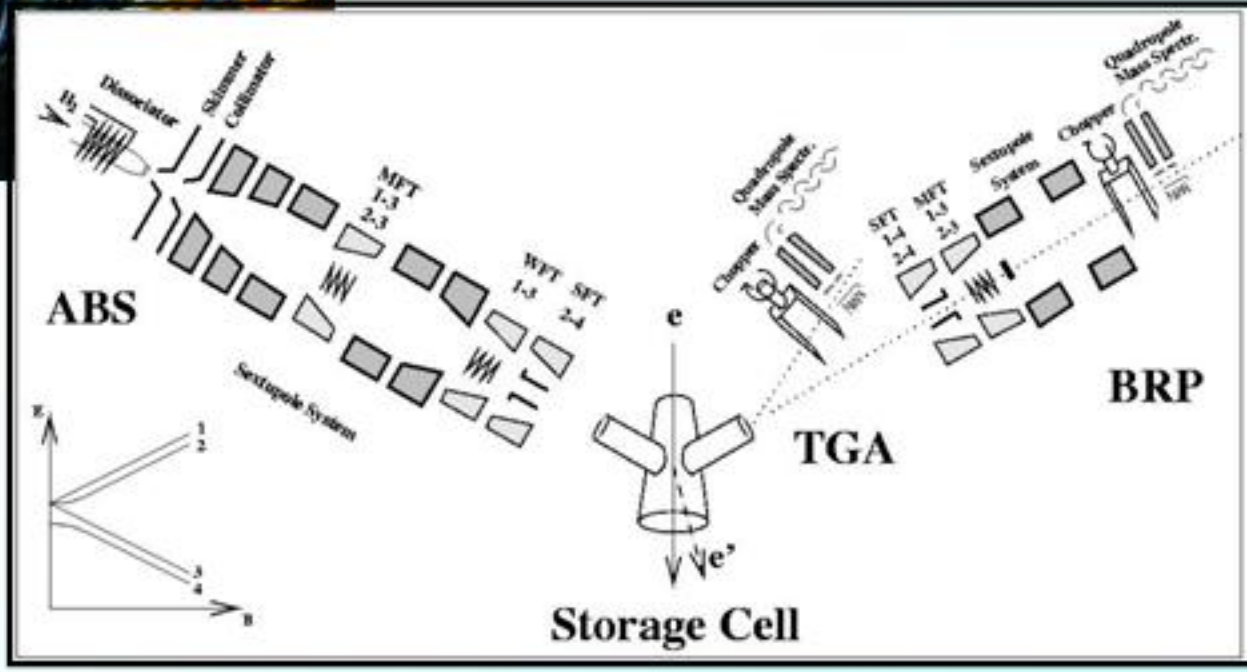
$$A_{||} \cong g_1/F_1 [1 + \tfrac{1}{2} T A_T]$$

$$A_T \cong 2/3\ b_1/F_1$$

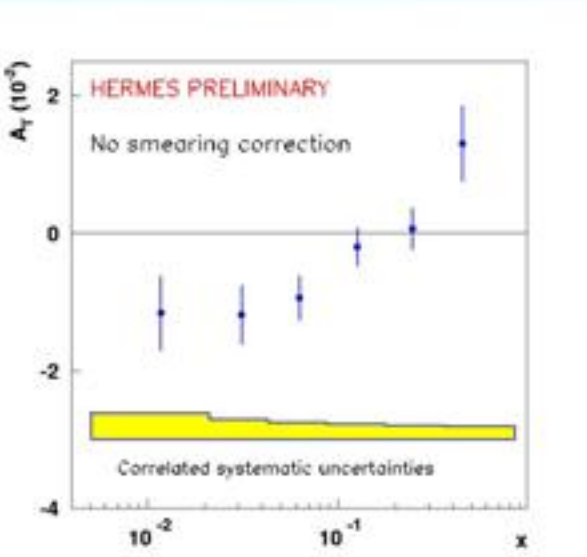
The HERMES polarised internal gas target

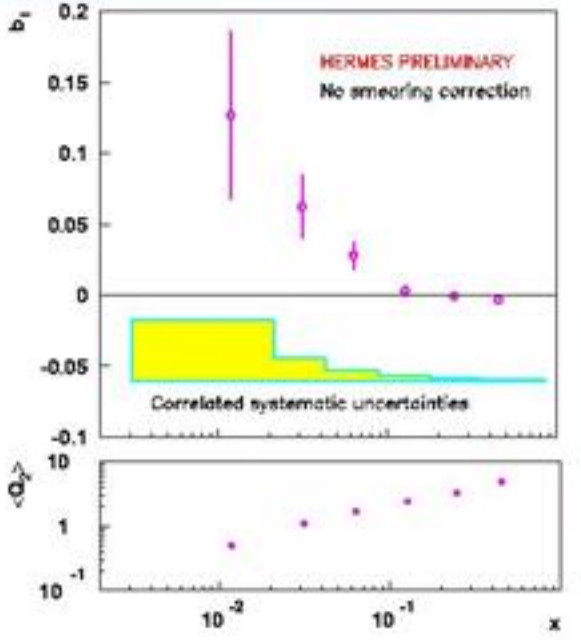


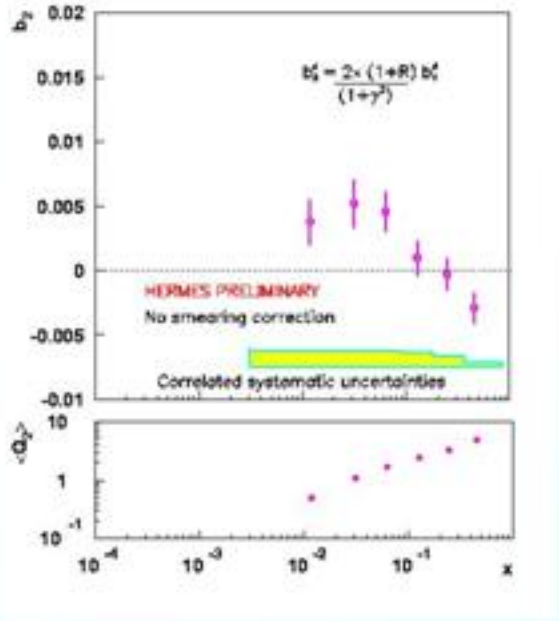


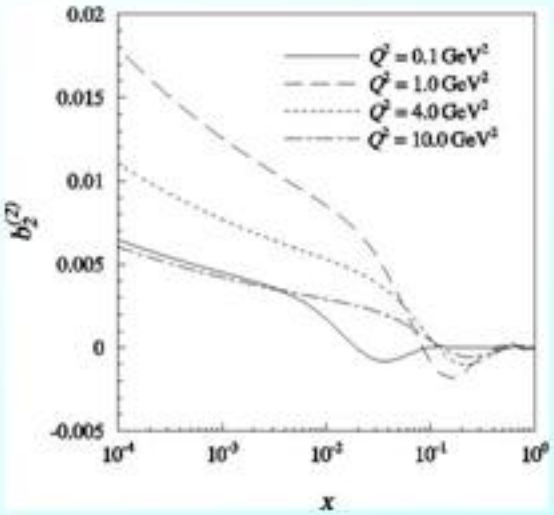


A_T, b_1 and b_2 - deuteron









- First measurement, only possible with atomic gas target

Model: K. Bora, R.L. Jaffe, PRD 57 (1998) 6906

A_T, b_1 and b_2 - deuteron

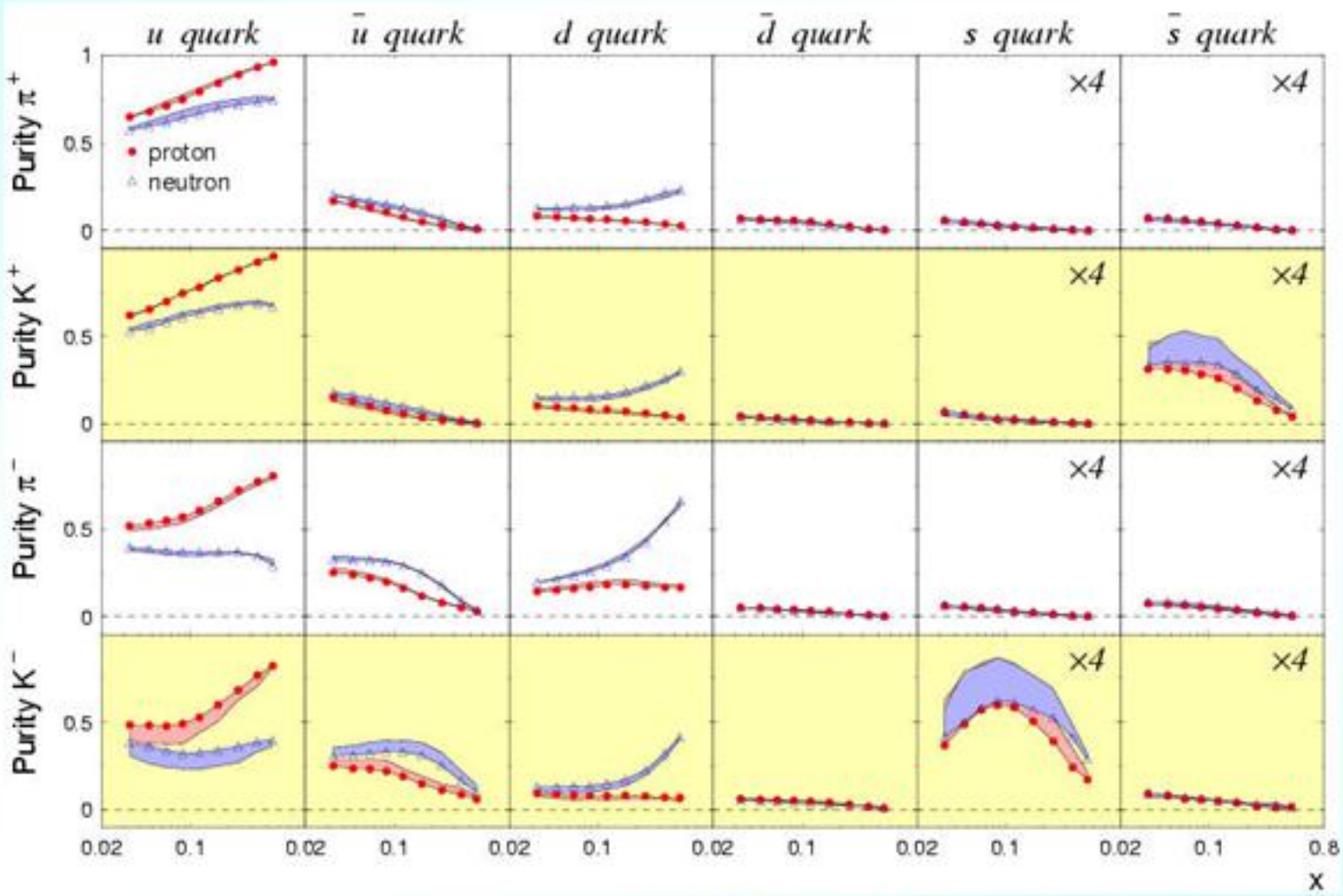
- Deuteron is spin-1 target
- $A_T \cong 10^{-2}$
- little impact on det. of g_1
- b_1^d is sizeable !
  and interesting by itself
  related to
  - nuclear binding
  - D-state admixture
  - diffractive nuclear shadowing
  - nuclear excess pions in D
  - VMD + double scattering
  -
  -

See e.g.:

- P. Hoodboy et al., N.P. B312 (89) 571
- R.L. Jaffe & A. Manohar N.P. B321 (89) 343
- X. Artru & M. Mekhfi, Z. Phys. C45 (90) 669
- N.N. Nikolaec & W. Schäfer, P.L. B398 (97) 245
- J. Edelmann et al., Z. Phys. A357 (97) 129,
  P.R. C57 (98) 3392
- K. Bora & R.L. Jaffe, P.R. D57 (98) 6906
-
-

Purities

(Probability that observed hadron originates from quark of type f)



- Adequate degree of orthogonality:
- Shaded bands: systematic uncertainties
- Kaons have about 10% sensitivity to the strange sea