
Spin physics at COMPASS

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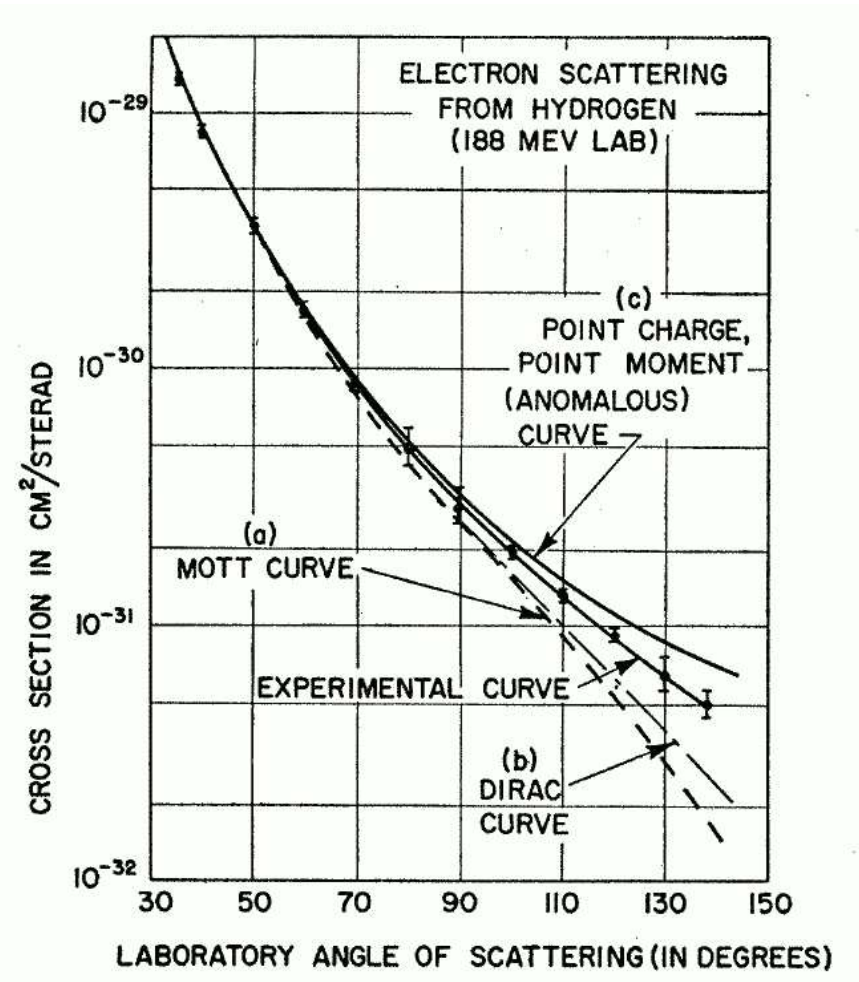
on behalf of the *COMPASS* collaboration



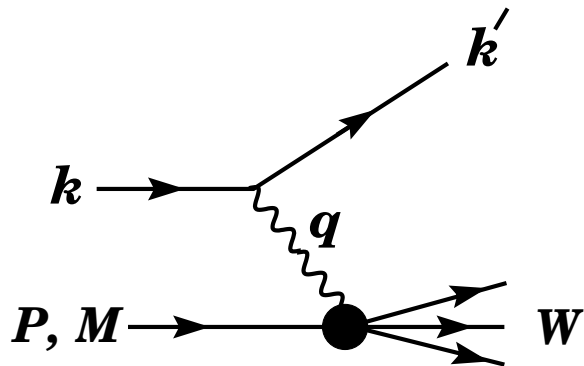
In R. Hofstadter's footsteps...

50 years ago:

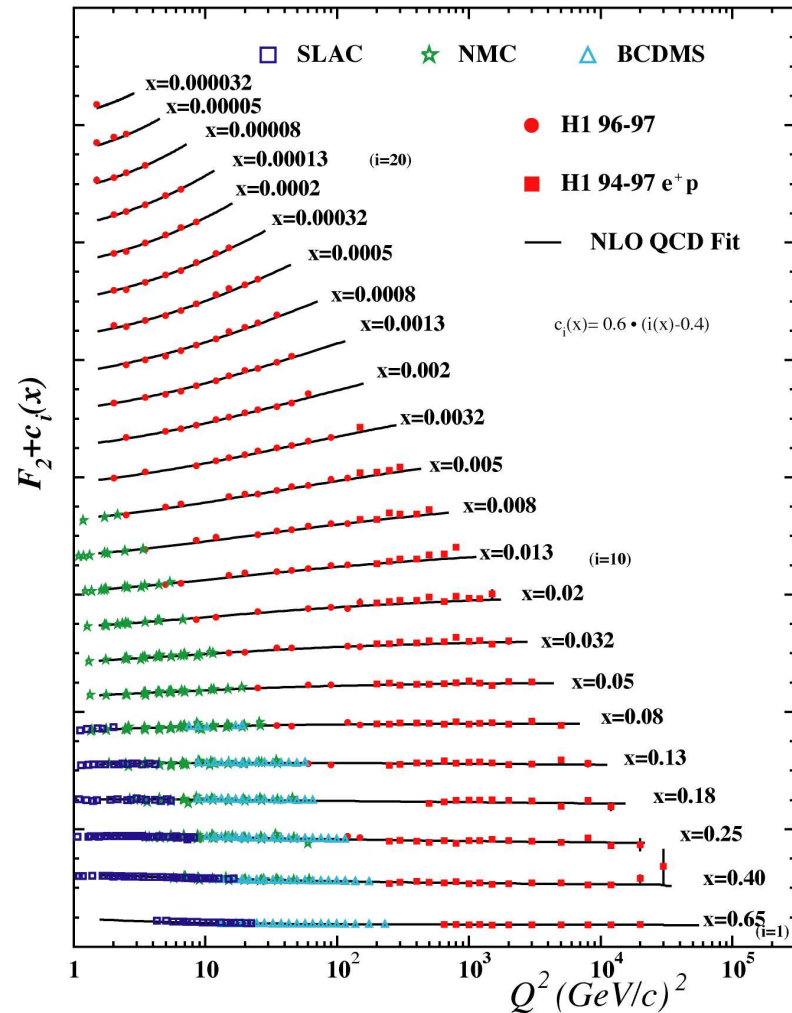
At SLAC, few-hundred-MeV
electron scattering on the
proton reveals internal
structure effect,
 $\langle r_p \rangle \approx 0.8 \text{ fm}$



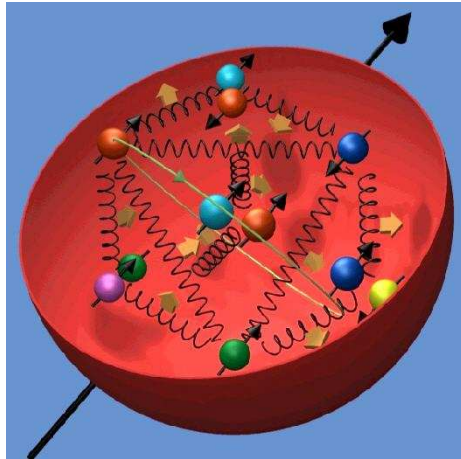
Deep Inelastic Scattering



- Scaling: Nucleon has pointlike substructure
- Scaling violation obeys perturbative QCD evolution



Nucleon Spin



$$\langle s_z \rangle = \frac{1}{2} = \frac{1}{2} \Delta\Sigma + \Delta G + L_{q+G}$$

quarks
gluons
orbital momenta

Naive quark parton model

(rel. corr.): $\Delta\Sigma \approx 0.75$

QCD Ellis-Jaffe: $\Delta\Sigma \approx 0.60$

Experimental access:

Polarised lepton-nucleon DIS, spin asymmetries

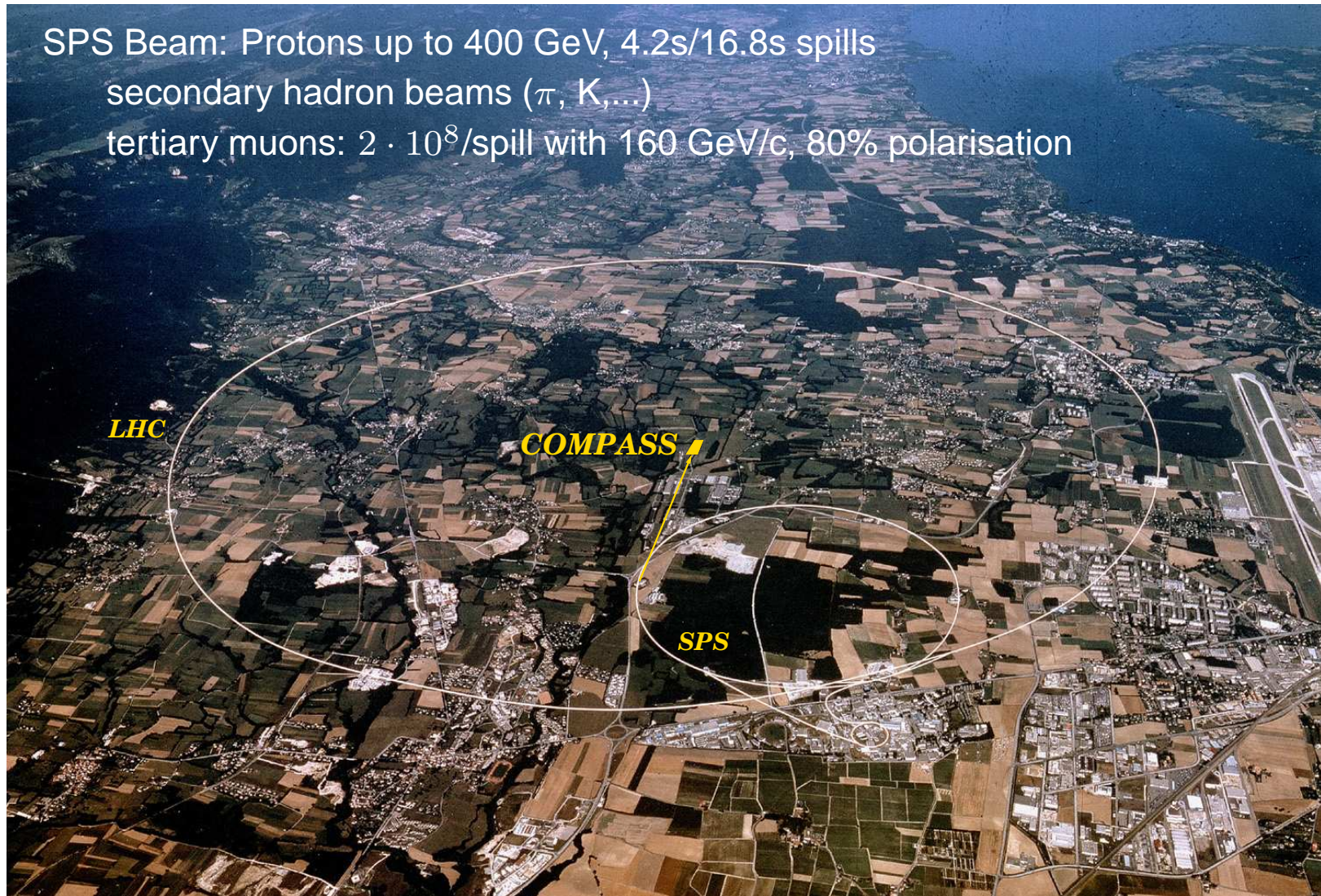
Outline

- COMPASS at CERN
- Physics program: **new results**
 - ▶ Quark and gluon polarisations: g_1^d , $\Delta G/G$
 - ▶ Transversity
 - ▶ ρ production
 - ▶ Λ polarisation
- Spectrometer upgrades and future running



CERN aerial view

SPS Beam: Protons up to 400 GeV, 4.2s/16.8s spills
secondary hadron beams (π , K,...)
tertiary muons: $2 \cdot 10^8$ /spill with 160 GeV/c, 80% polarisation



COMPASS Collaboration

Czech Republic, France, Germany, India, Israel,
Italy, Japan, Poland, Portugal, Russia, CERN

240 physicists from 28 institutes

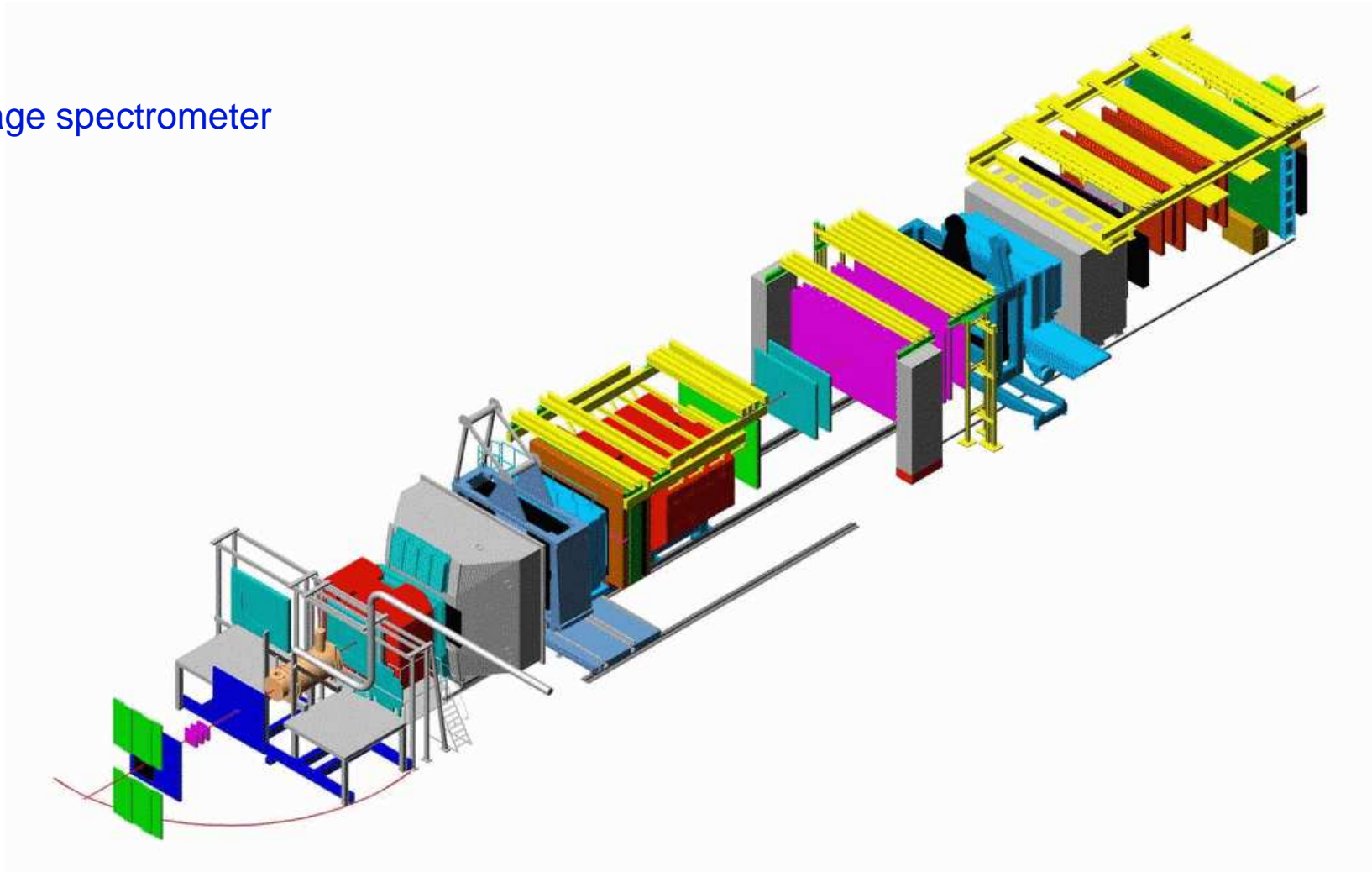
Bielefeld, Bochum, Bonn, Burdwan/Calcutta, CERN, Dubna,
Erlangen, Freiburg, Lisboa, Mainz, Moscow, Munich, Nagoya,
Parg, Protvino, Saclay, Tel Aviv, Torino, Trieste, Warsaw

Data acquisition 2002, 03, 04 with muon beam
on polarised LiD target
Oct. 2004: pilot hadron run (π^-)



The COmmon Muon and Proton Apparatus for Structure and Spectroscopy

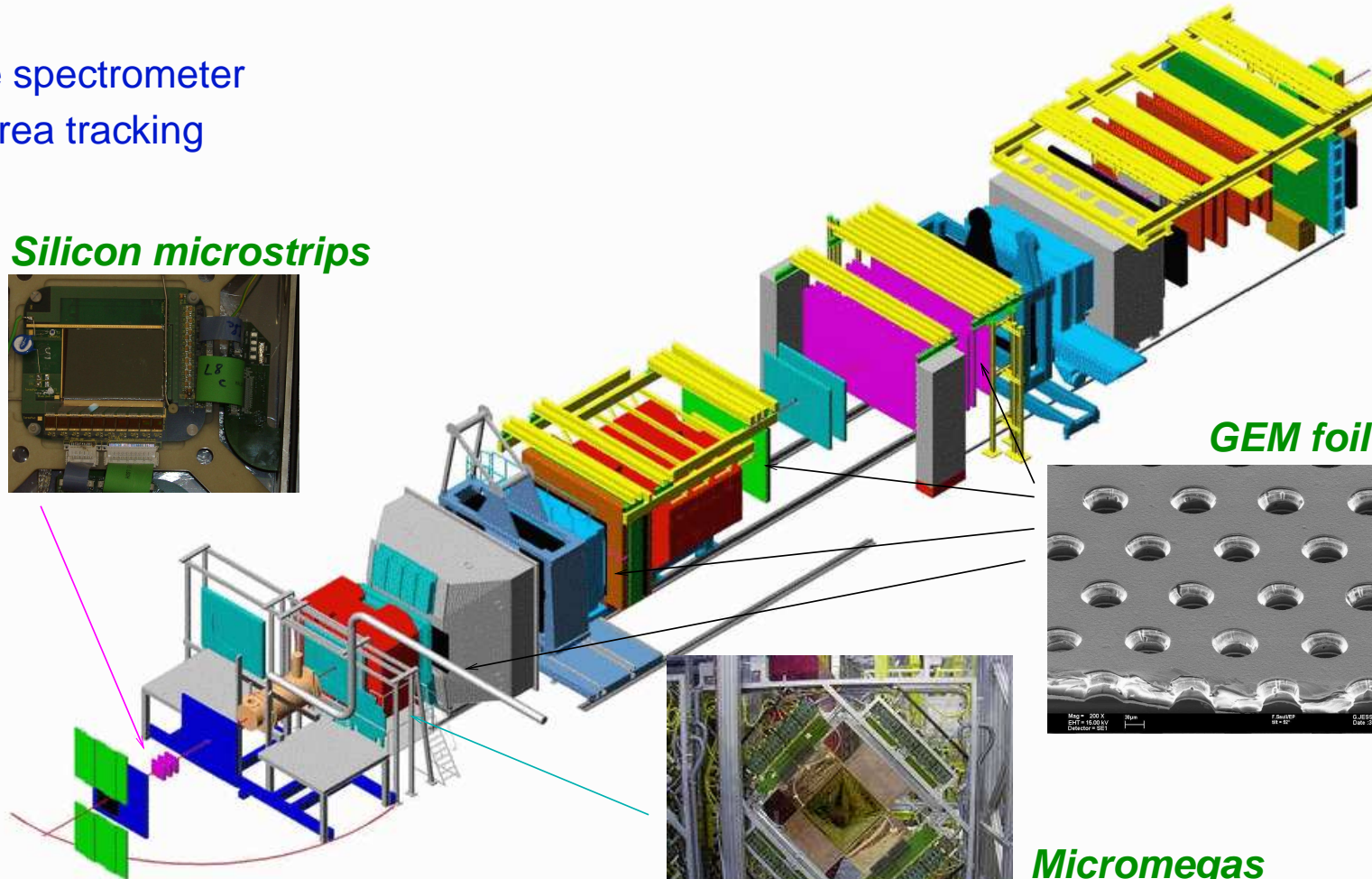
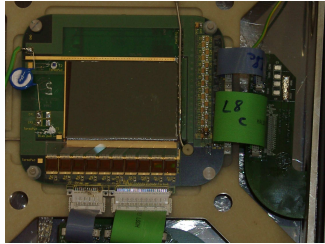
2 stage spectrometer



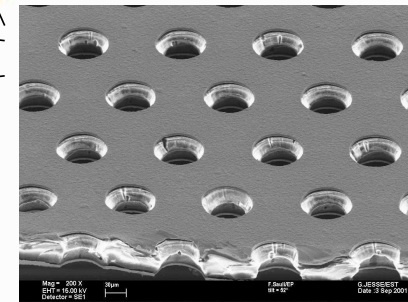
The COmmon Muon and Proton Apparatus for Structure and Spectroscopy

2 stage spectrometer
small area tracking

Silicon microstrips



GEM foil

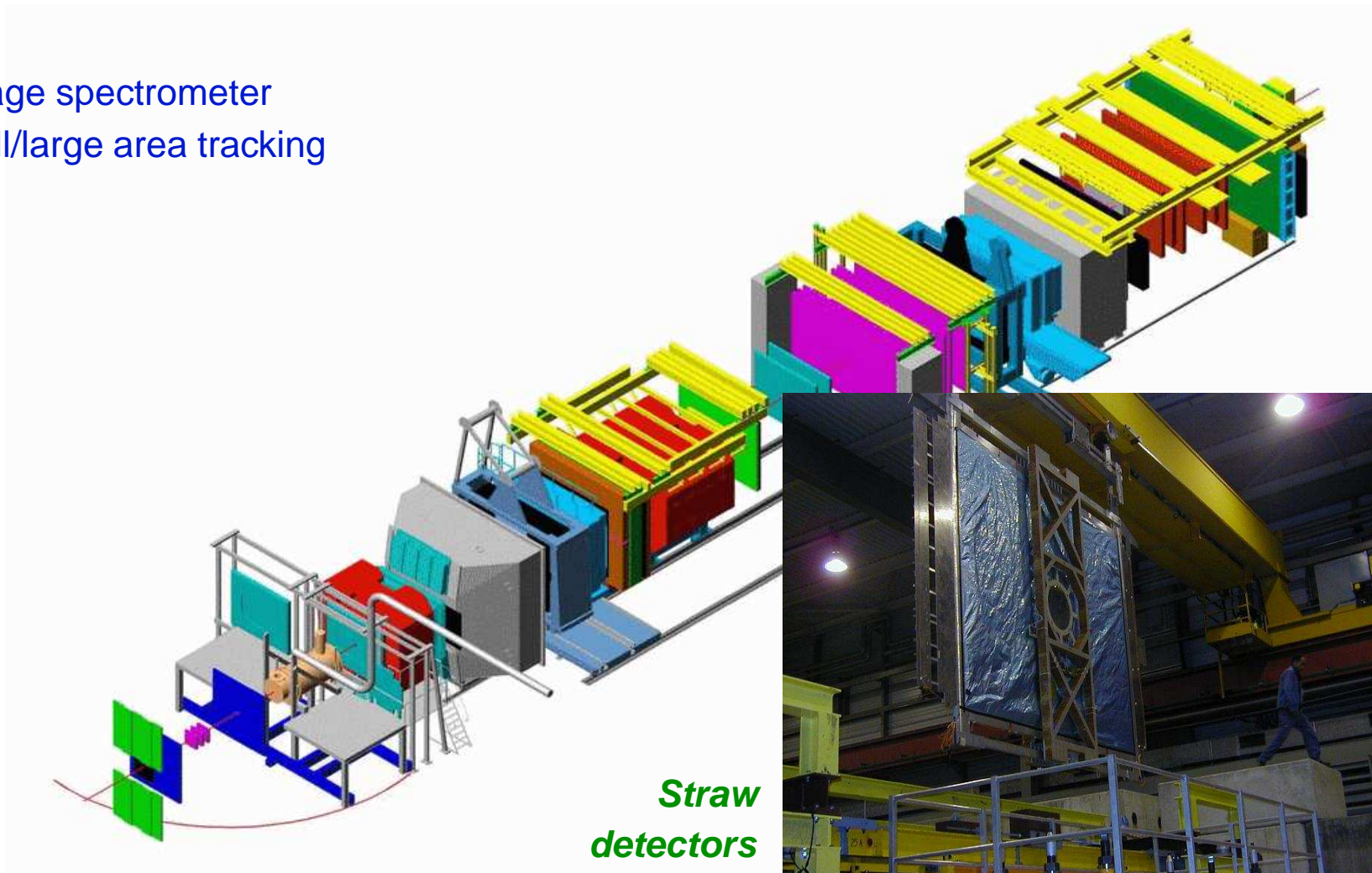


Micromegas



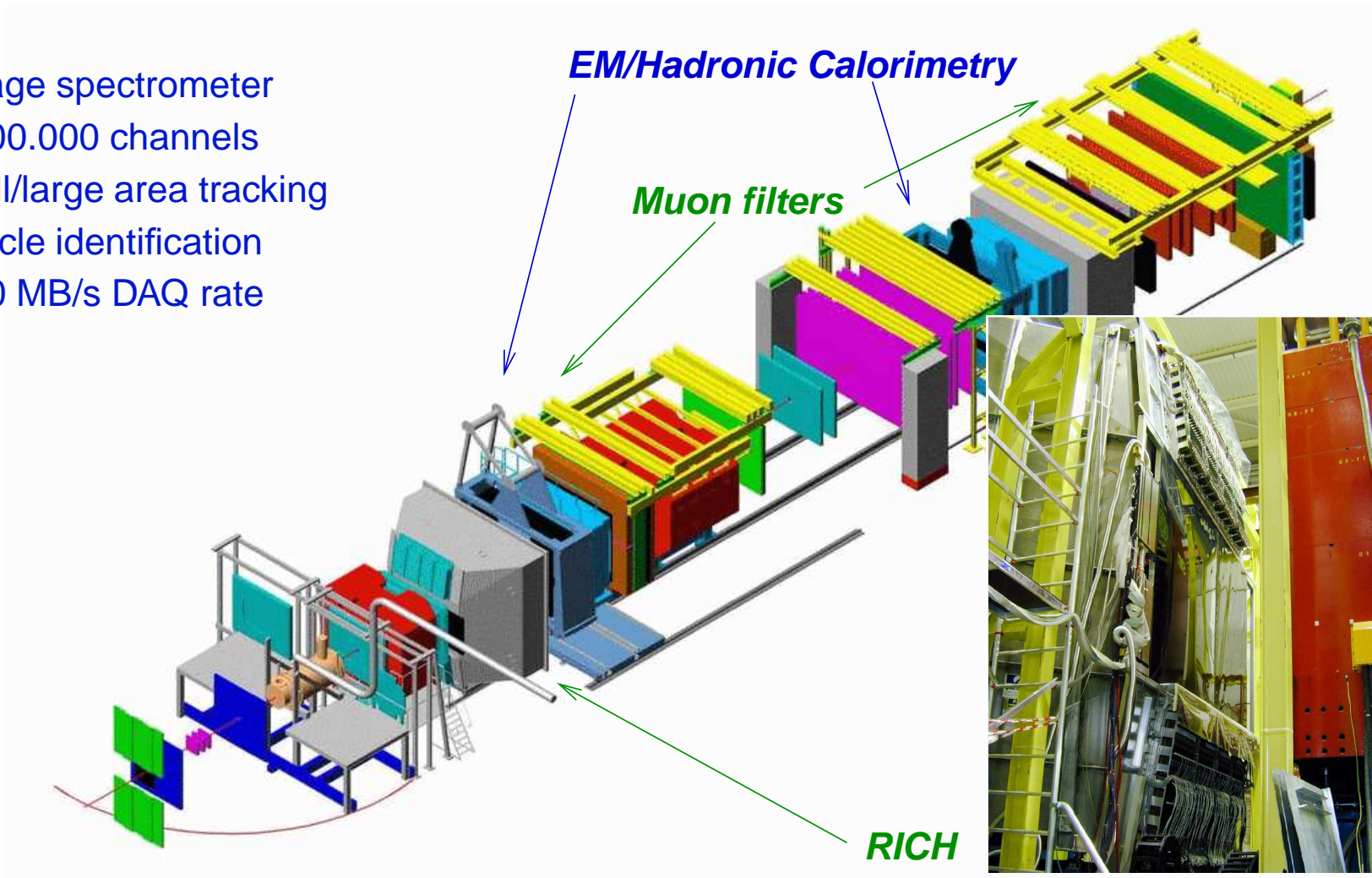
The COmmon Muon and Proton Apparatus for Structure and Spectroscopy

2 stage spectrometer
small/large area tracking

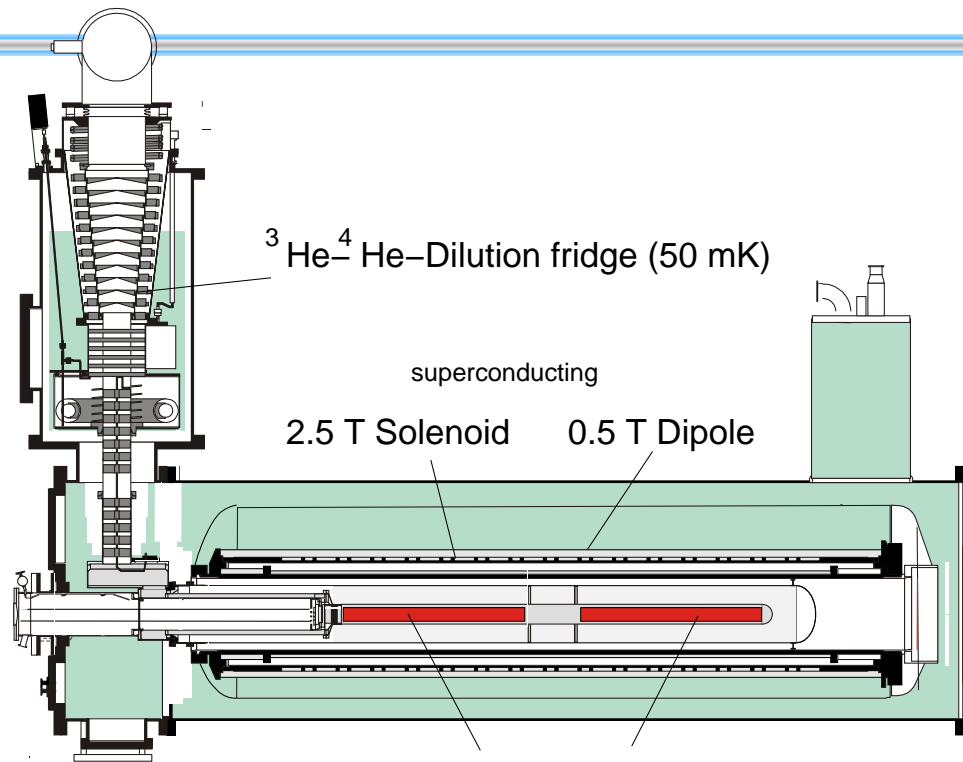


The COmmon Muon and Proton Apparatus for Structure and Spectroscopy

2 stage spectrometer
~ 200.000 channels
small/large area tracking
particle identification
~ 50 MB/s DAQ rate



The polarised target



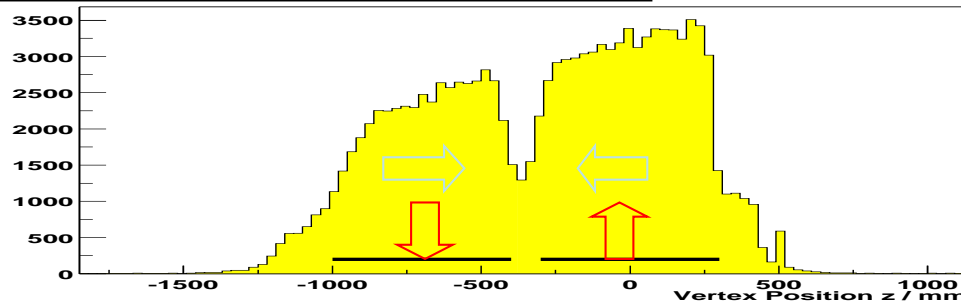
Material: ${}^6\text{LiD}$

50% polarisation

Dilution factor 0.4

two 60 cm long cells
oppositely polarised

Vertex distribution along Z, $N_{\text{trk}} > 2$



reversal:

longitudinal every 8h

transverse every week

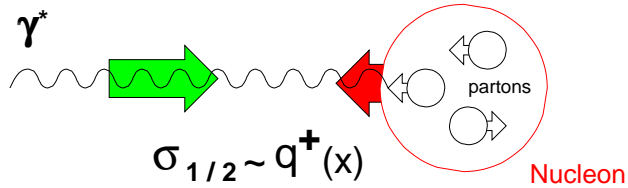


Physics Program

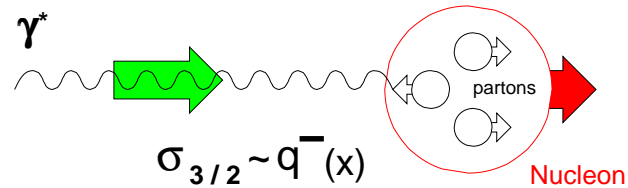
	muon beam	hadron beam
structure	gluon polarisation $\Delta G/G$ longitudinal/transverse quark spin distributions Λ polarisation diffractive vector meson production	hadron structure via Primakoff effect
spec- troscopy	muoproduction of hadrons dominated by quasi-real photoproduction	charmed baryons gluonic systems exotic hadrons diffractive reactions



Polarised DIS



$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{g_1}{F_1}$$



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

$$\stackrel{NLO-QCD}{=} \frac{1}{2} \sum_q^{N_f} e_q^2 \left[\Delta q \otimes \left(1 + \frac{\alpha_s(Q^2)}{2\pi} \delta C_q \right) + \frac{\alpha_s(Q^2)}{2\pi} \Delta G \otimes \frac{\delta C_G}{N_f} \right]$$

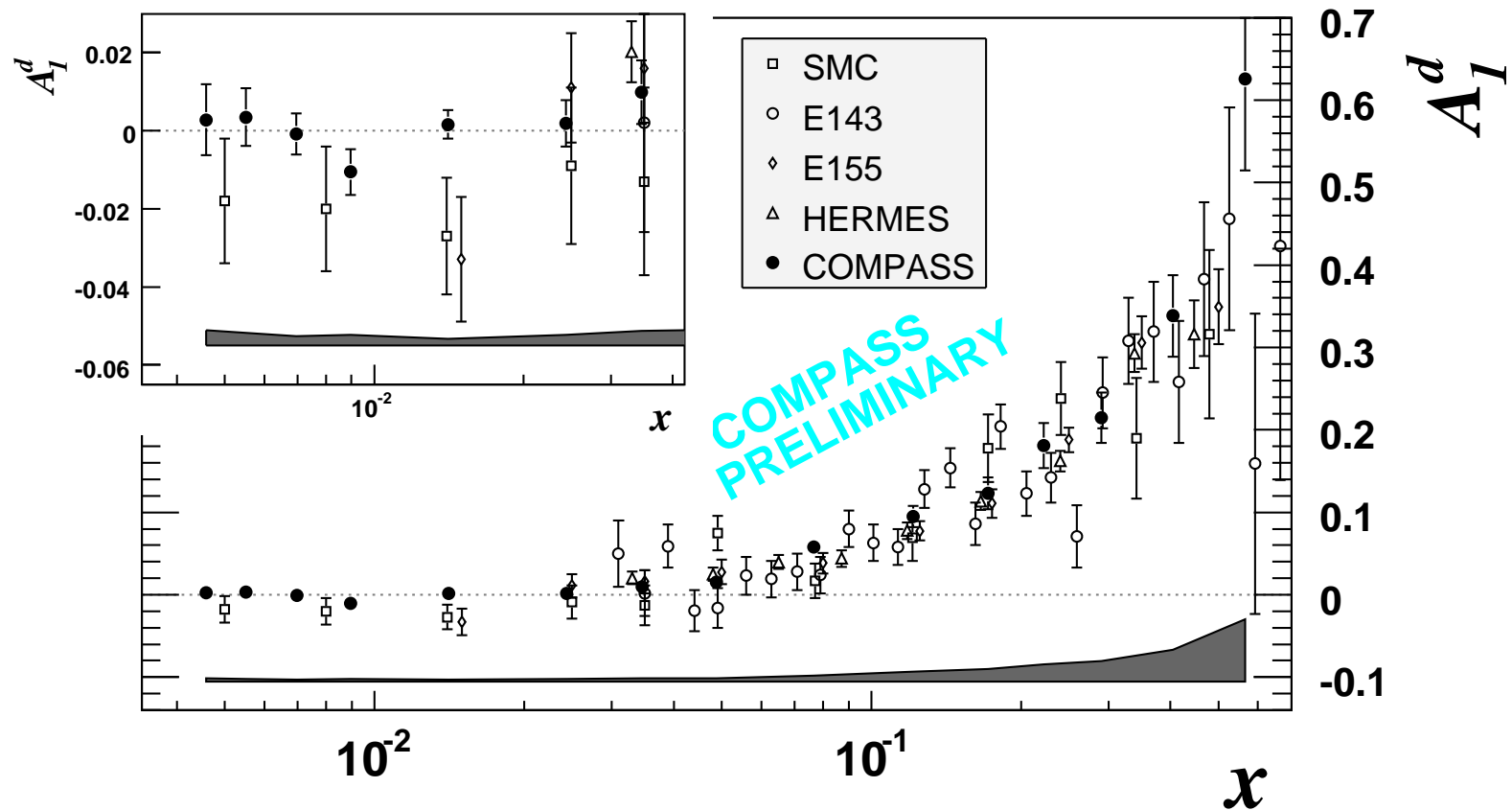
↑
indirect access

renormalization/factorization scheme dependent



New COMPASS result for A_1^d

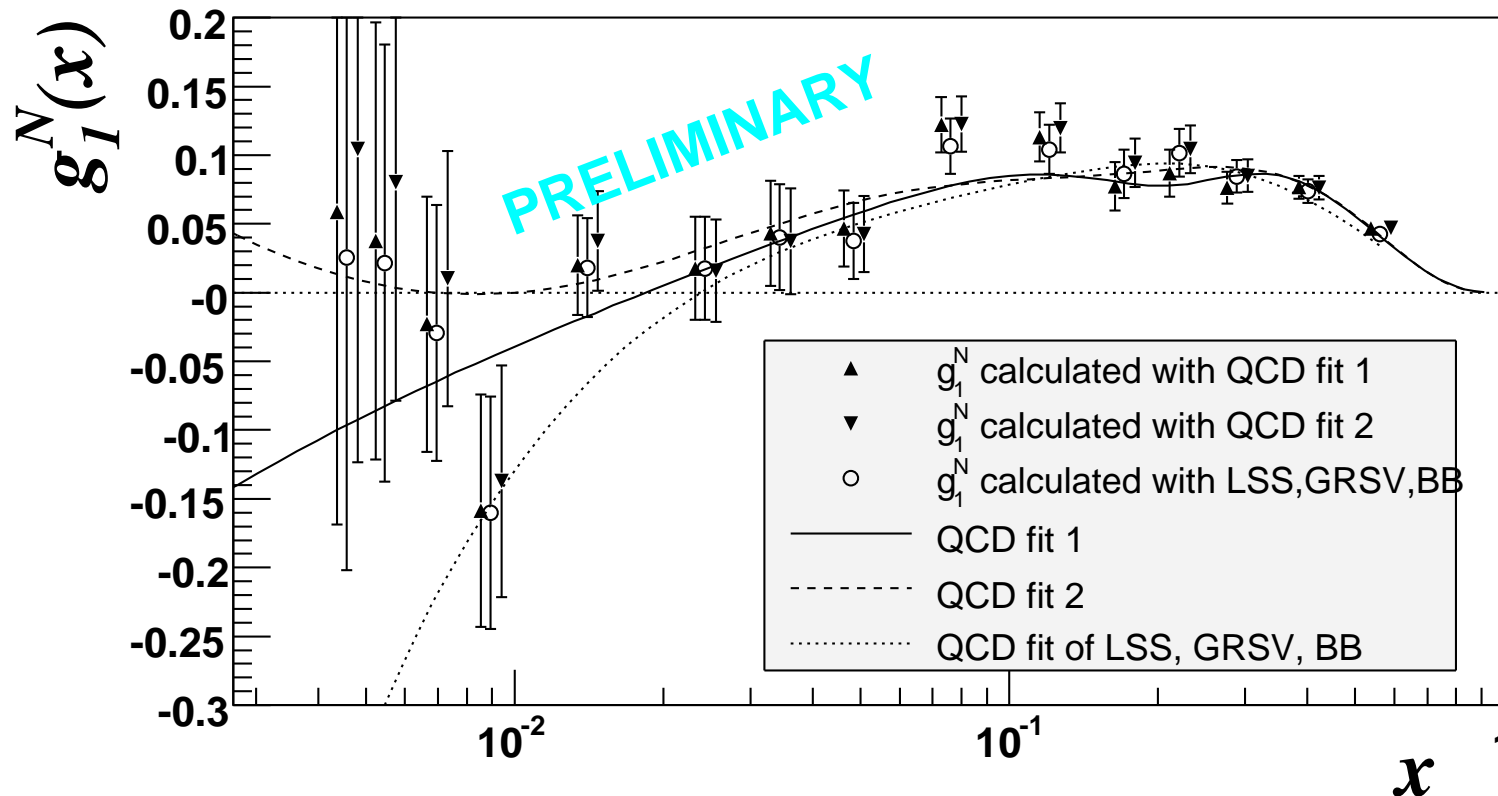
(summary Alex Korzenev's talk)



2002-04 data



New COMPASS data for g_1^d



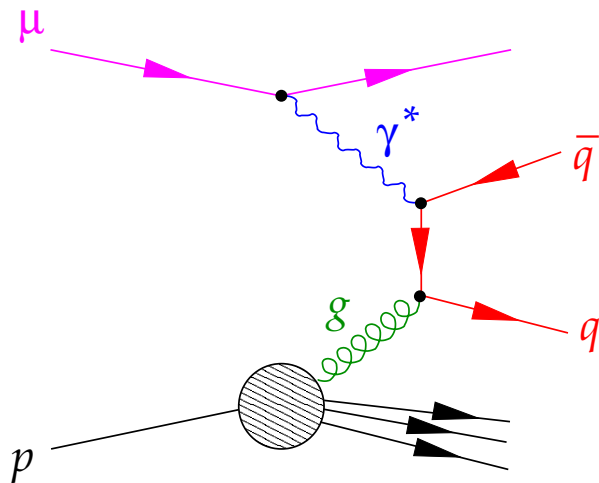
COMPASS data only: $\Gamma_1^N(Q^2 = 3\text{GeV}^2) = 0.0502 \pm 0.0028_{\text{stat}} \pm 0.0020_{\text{evol}} \pm 0.0051_{\text{sys}}$

$$\Delta\Sigma = 0.33 \pm 0.03_{\text{stat}} \pm 0.06_{\text{sys}}$$



$$\Delta G / G$$

Direct measurement of $\Delta G/G$



Photon Gluon Fusion

- $q = u, d, (s)$: high p_T hadron pair
 - ▶ scale Q^2 or $\sum p_T^2$
 - ▶ high statistics
 - ▶ (theor.) difficult background
- $q = c$: open charm
 - ▶ scale $\geq 4m_c^2$
 - ▶ theor. cleaner channel
 - ▶ hard to access experimentally

Experimental asymmetry and $\Delta G/G$

$$A_{LL}^{\mu N} = \frac{1}{P_T f P_b D} \cdot \frac{N \overset{\leftarrow}{\rightleftarrows} - N \overset{\rightarrow}{\rightleftarrows}}{N \overset{\leftarrow}{\rightleftarrows} + N \overset{\rightarrow}{\rightleftarrows}}$$

target polarisation $P_T \approx 0.5$

dilution factor $f = 0.4$

beam polarisation $P_B \approx 0.8$

depolarisation factor $D \approx 0.6$

$$A_{LL}^{\mu N} = a_{LL}^{PGF} \cdot \frac{\Delta G}{G} \cdot \frac{S}{S + B} + A_{LL}^{Background}$$

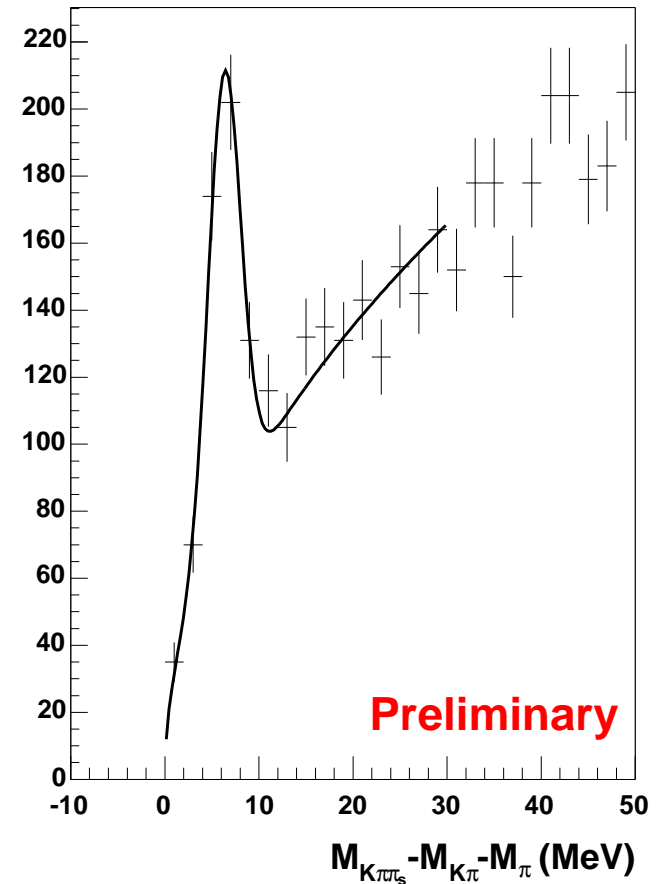
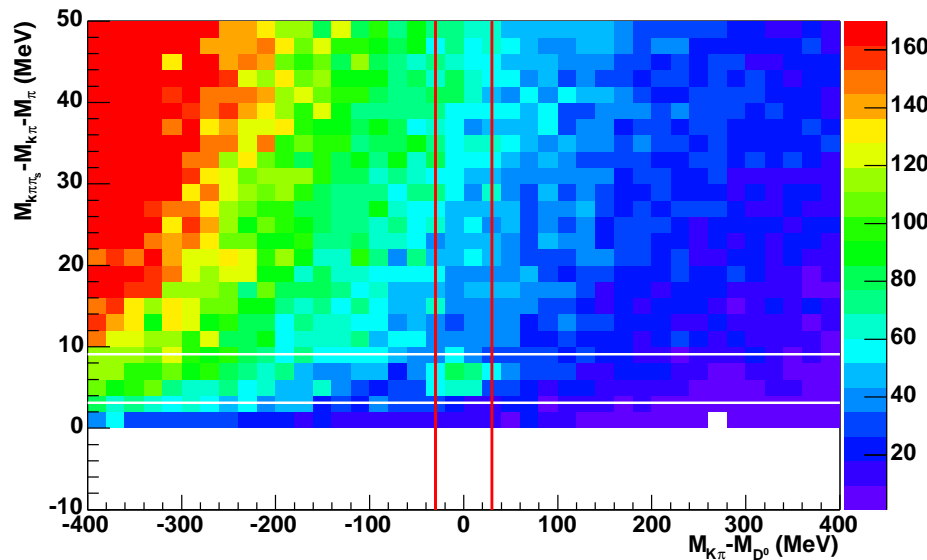
a_{LL}^{PGF} from leading order M.E. (γ -g-kinematics from AROMA MC)



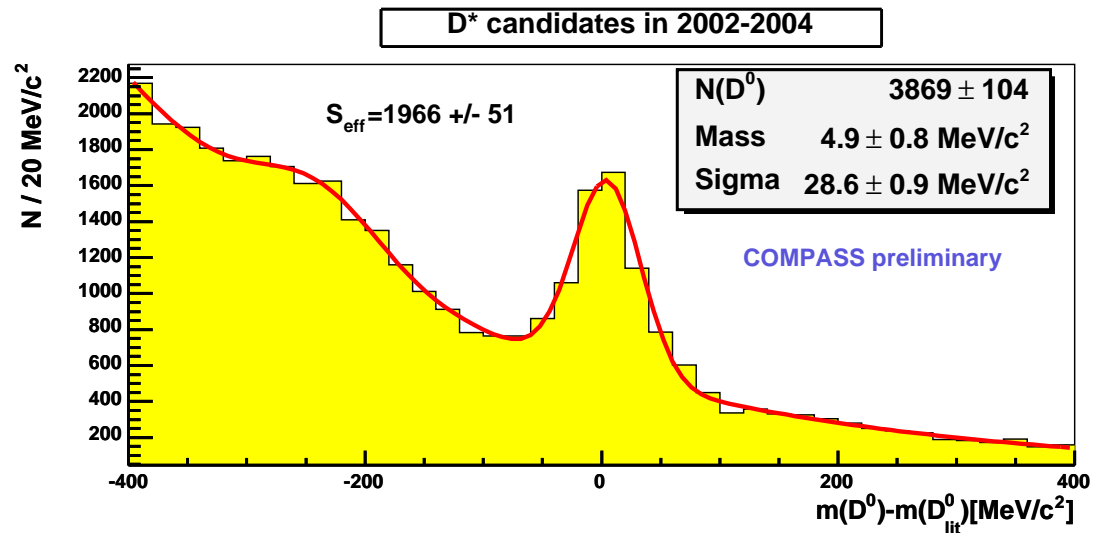
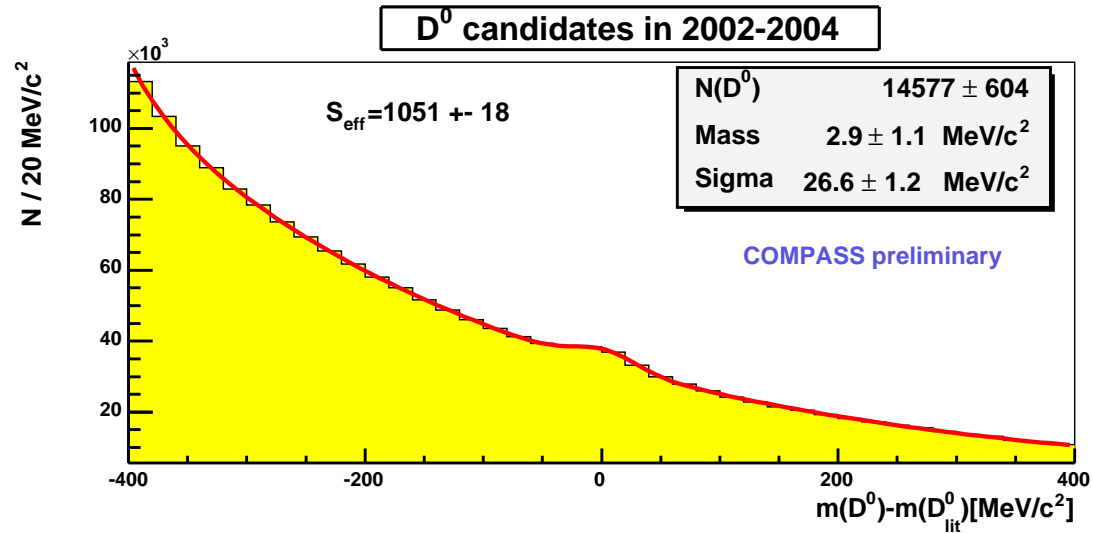
Open charm via D_0 and D^* decays

$$D^* \rightarrow D_0 \pi_{\text{soft}}$$

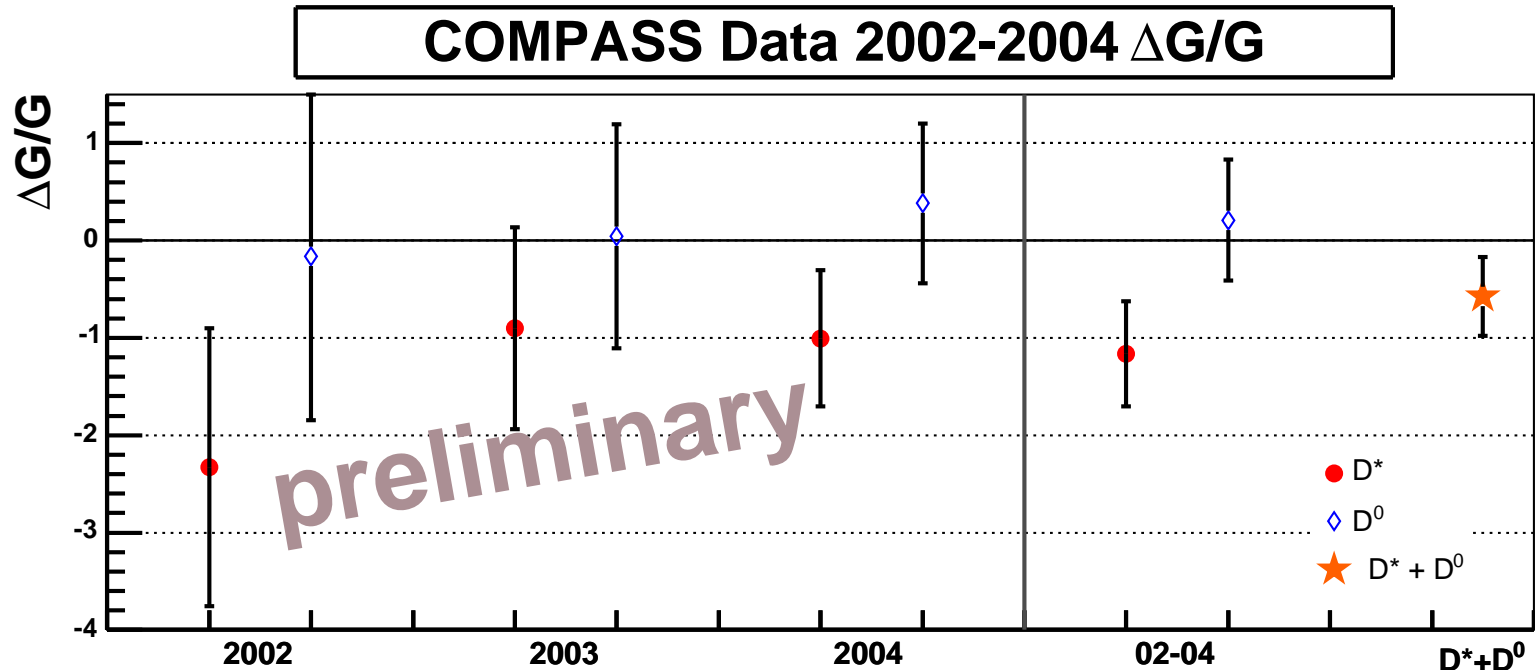
$$D_0 \rightarrow K^- \pi^+$$



D_0 signals



$\Delta G/G$ from open charm



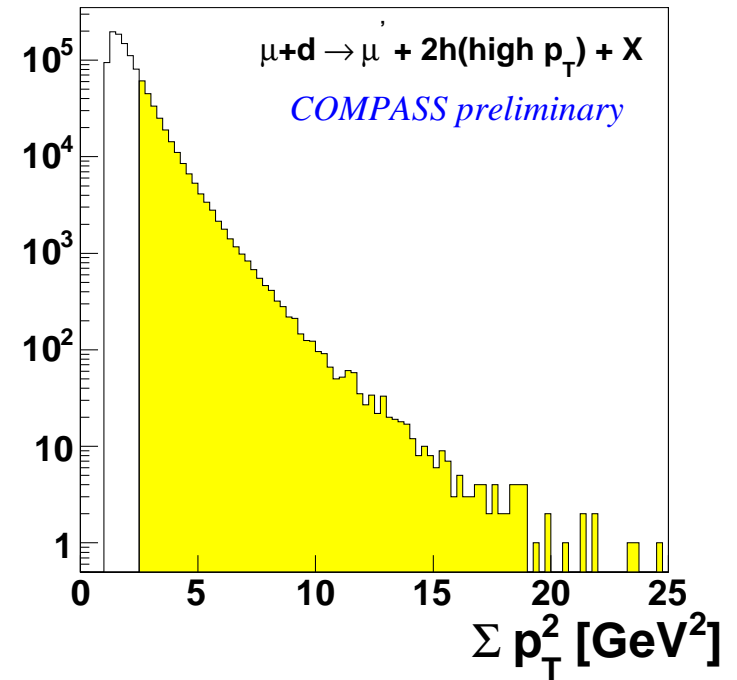
$$\Delta G/G = -0.57 \pm 0.41_{\text{stat}}$$

at $\langle x_g \rangle = 0.15$ and $\langle \mu^2 \rangle = 13 \text{ GeV}^2$



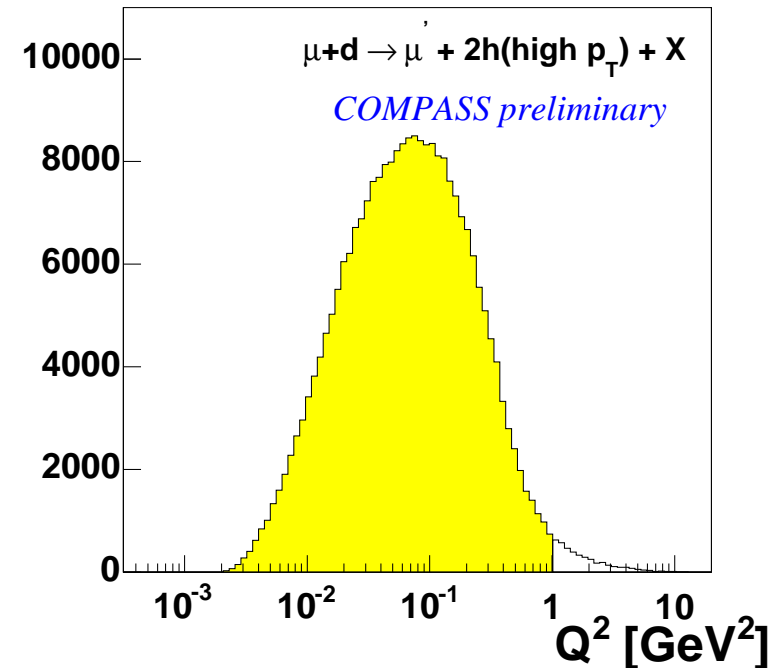
$\Delta G/G$ from high- p_T pairs

- enrich PGF events with high- p_T cuts
 - $p_T > 0.7 \text{ GeV}/c$
 - $p_{T1}^2 + p_{T2}^2 > 2.5 \text{ GeV}/c^2$
 - $x_F > 0.1, z > 0.1$
 - $m(h1, h2) > 1.5 \text{ GeV}/c^2$

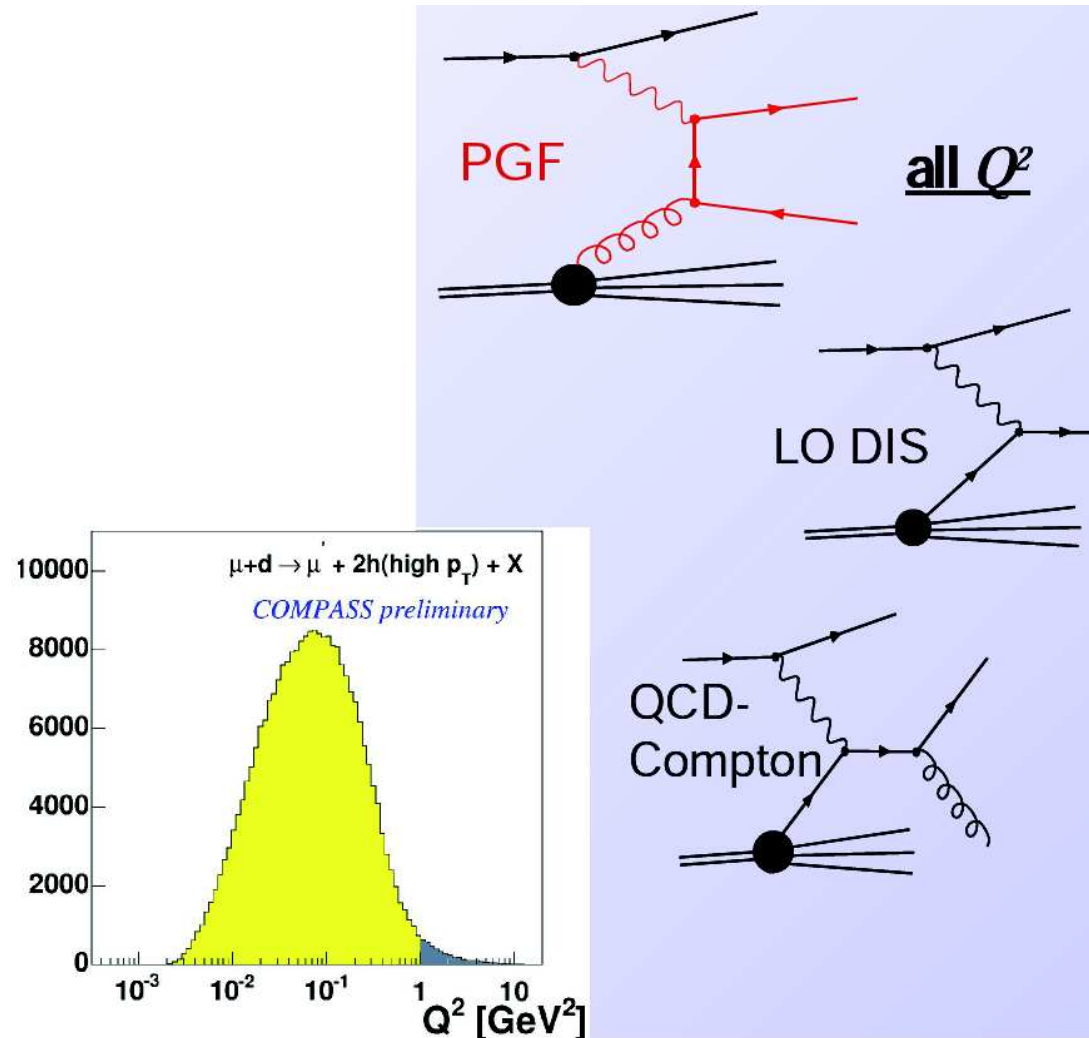


$\Delta G/G$ from high- p_T pairs

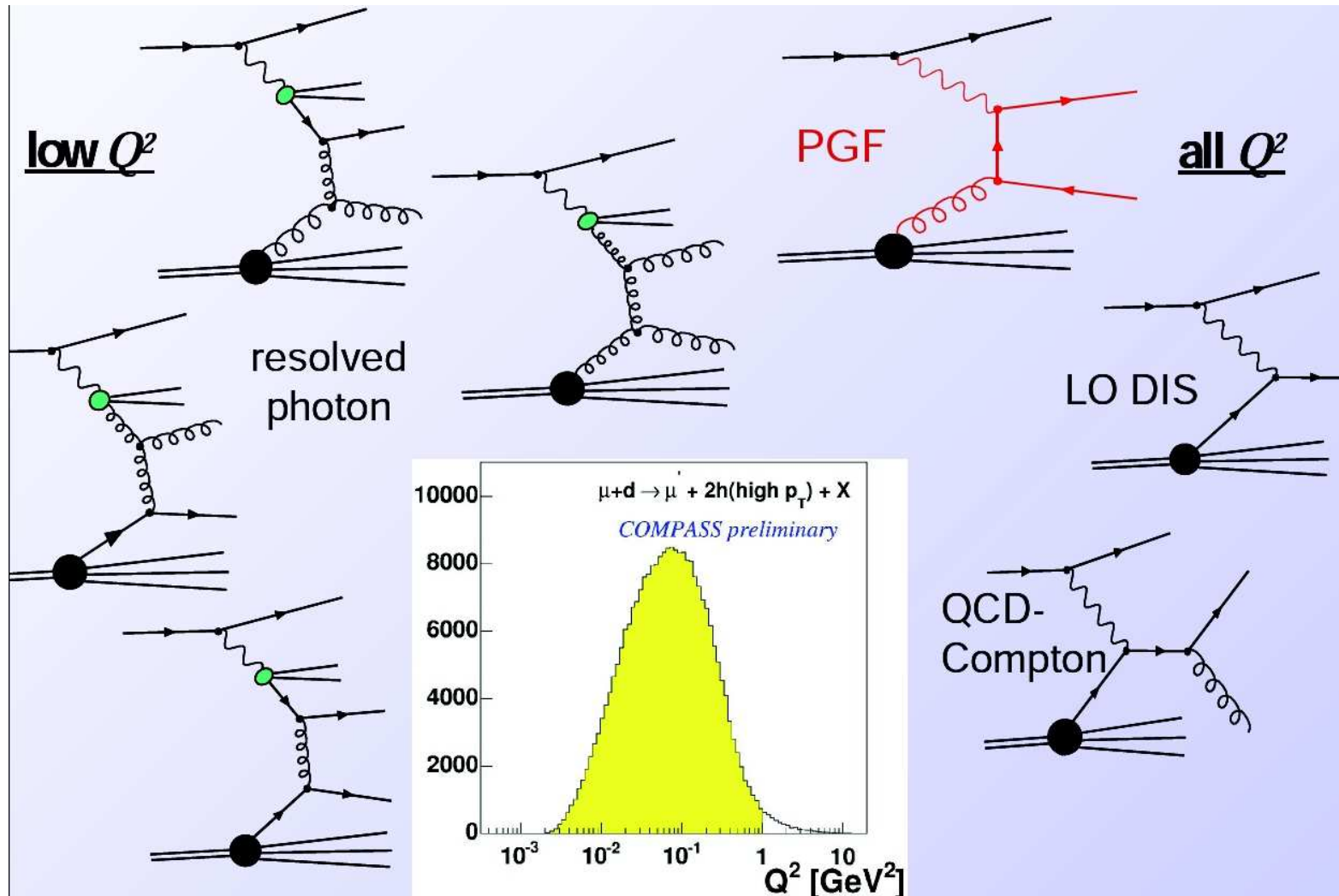
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 - $x_F > 0.1, z > 0.1$
 - $m(h1, h2) > 1.5 \text{ GeV}/c^2$
- distinguish Q^2 regions



contributing high- p_T processes



contributing high- p_T processes



high p_T , low $Q^2 < 1 \text{ (GeV/c)}^2$

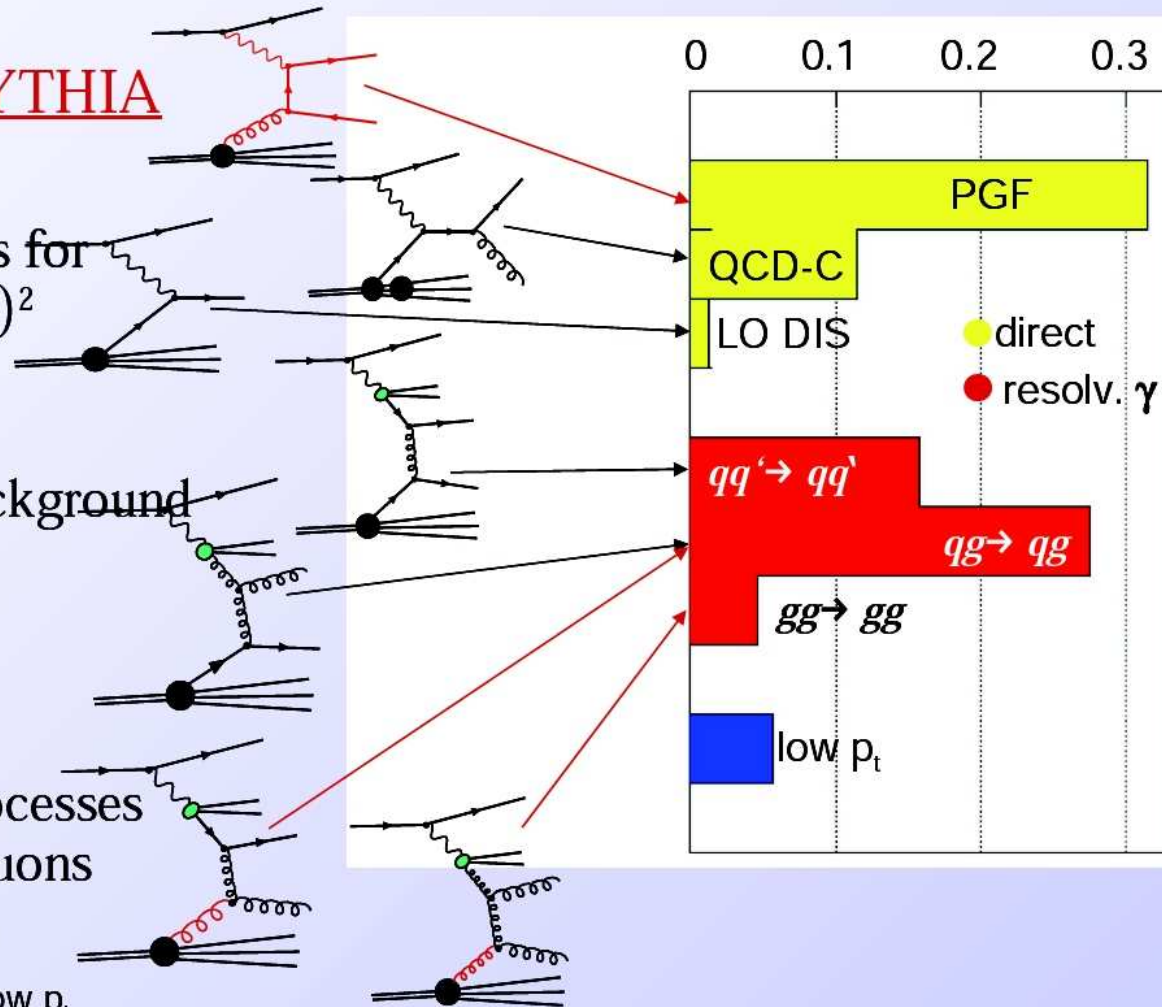
Results from PYTHIA

- Background as for $Q^2 > 1 \text{ (GeV/c)}^2$

- Additional background from resolved photon events

- Additional processes sensitive to gluons in the nucleon

neglect LO DIS and low p_t



Results for $\Delta G/G$ from high- p_T

$Q^2 > 1(\text{GeV}/c)^2$ preliminary from 2002-2003 data:

$$\Delta G/G = 0.06 \pm 0.31_{\text{stat}} \pm 0.06_{\text{syst}} \quad \langle x_g \rangle \sim 0.13$$

$Q^2 < 1(\text{GeV}/c)^2$ new result including 2004 data:

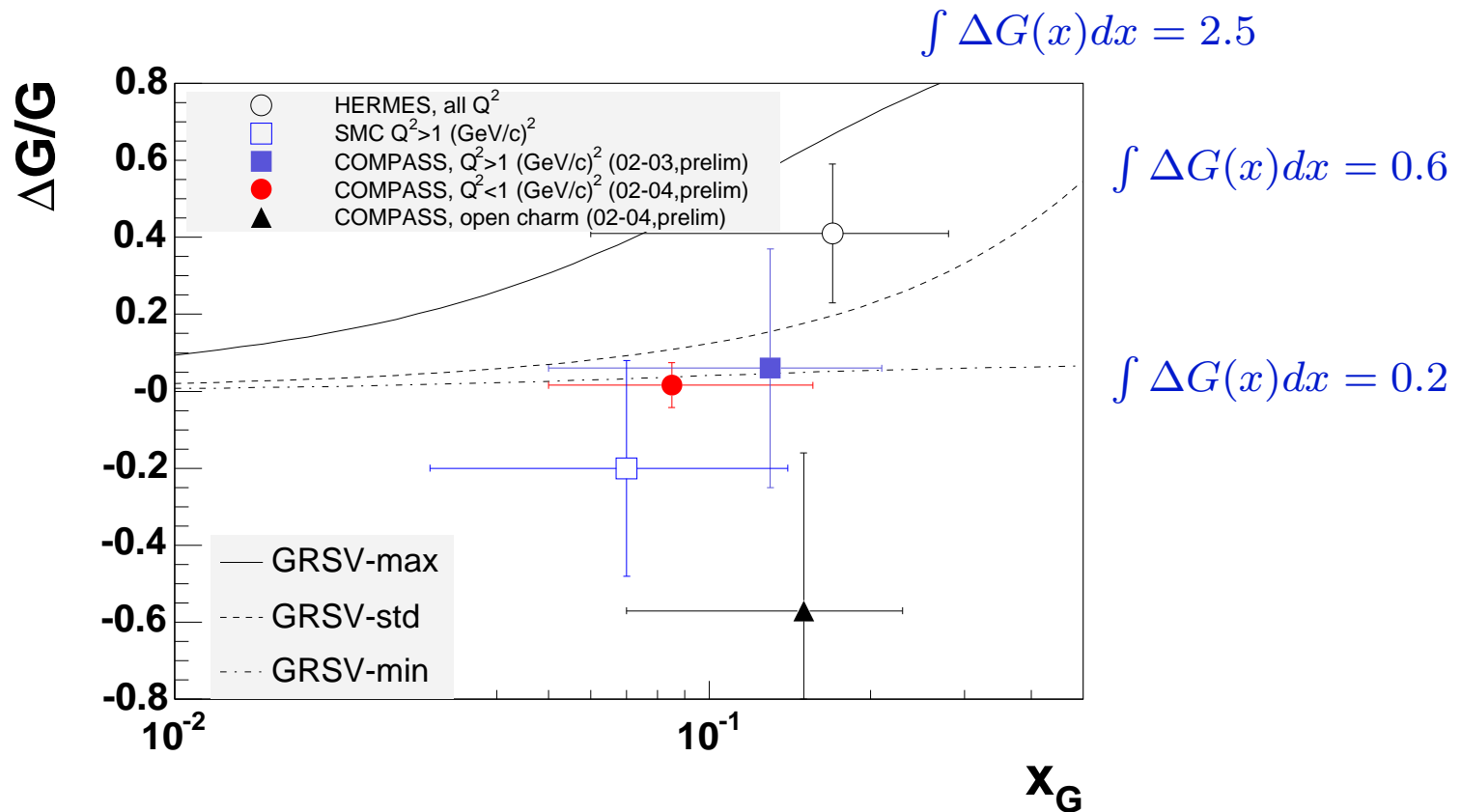
$$\Delta G/G = 0.016 \pm 0.058_{\text{stat}} \pm 0.055_{\text{syst}} \quad \langle x_g \rangle \sim 0.085$$

2002-03: $0.024 \pm 0.089_{\text{stat}} \pm 0.057_{\text{syst}}$, published in PLB 633 (2006) 25

Scale in both cases $\mu^2 = 3 \text{ GeV}^2$



Results on $\Delta G/G$



Also consistent with the RHIC $A_{LL}(\pi^0)$ measurement



Transversity

Transversity

$$\Delta q = \left| \begin{array}{c} \text{red circle with white dot and right-pointing arrow} \end{array} \right. - \left. \begin{array}{c} \text{red circle with white dot and left-pointing arrow} \end{array} \right.$$
$$\Delta_T q = \left| \begin{array}{c} \text{red circle with white dot and up-pointing arrow} \end{array} \right. - \left. \begin{array}{c} \text{red circle with white dot and down-pointing arrow} \end{array} \right.$$

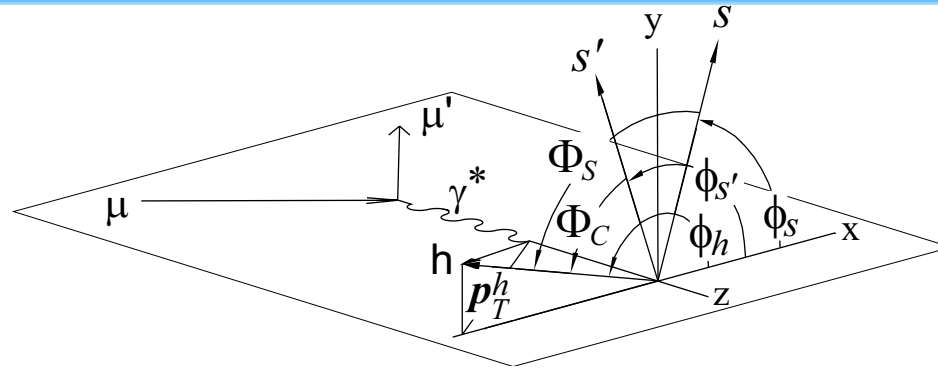
Accessible at COMPASS via

- Azimuthal single hadron **Collins** asymmetry
- Azimuthal distribution of 2-hadron plane
- Transverse Λ polarisation as analyser

COMPASS measured $\sim 25\%$ with transversely polarised Deuteron target.



Single hadron asymmetries



Collins

Correlation of outgoing
hadron direction and
transverse quark spin

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

Sivers

Correlation of nucleon spin
and transverse quark
momentum

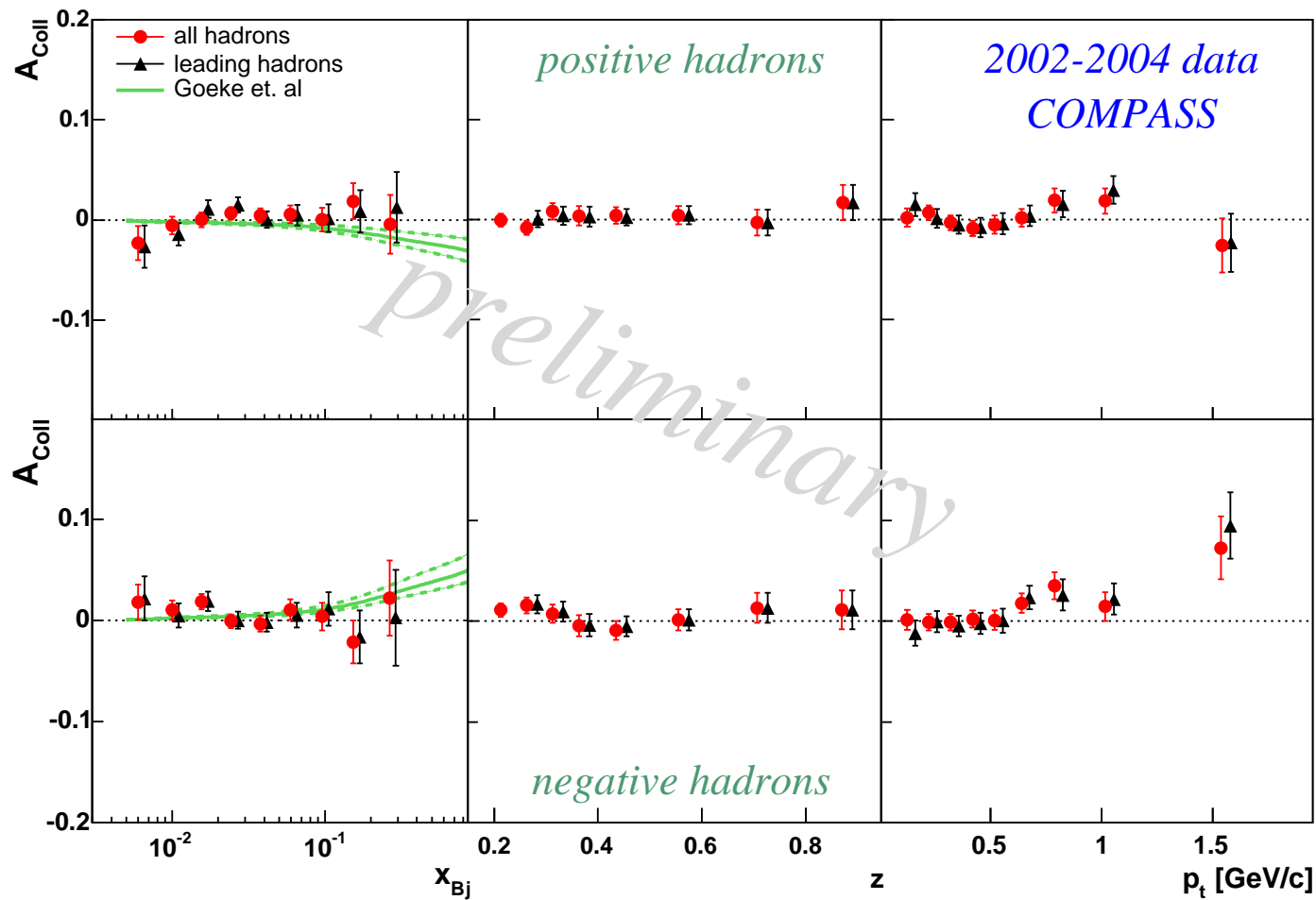
$$A_{\text{Siv}} = \frac{\sum_q e_q^2 \cdot f_{1Tq}^\perp \cdot D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

published results from 2002: [PRL 94 \(2005\) 202002](#)



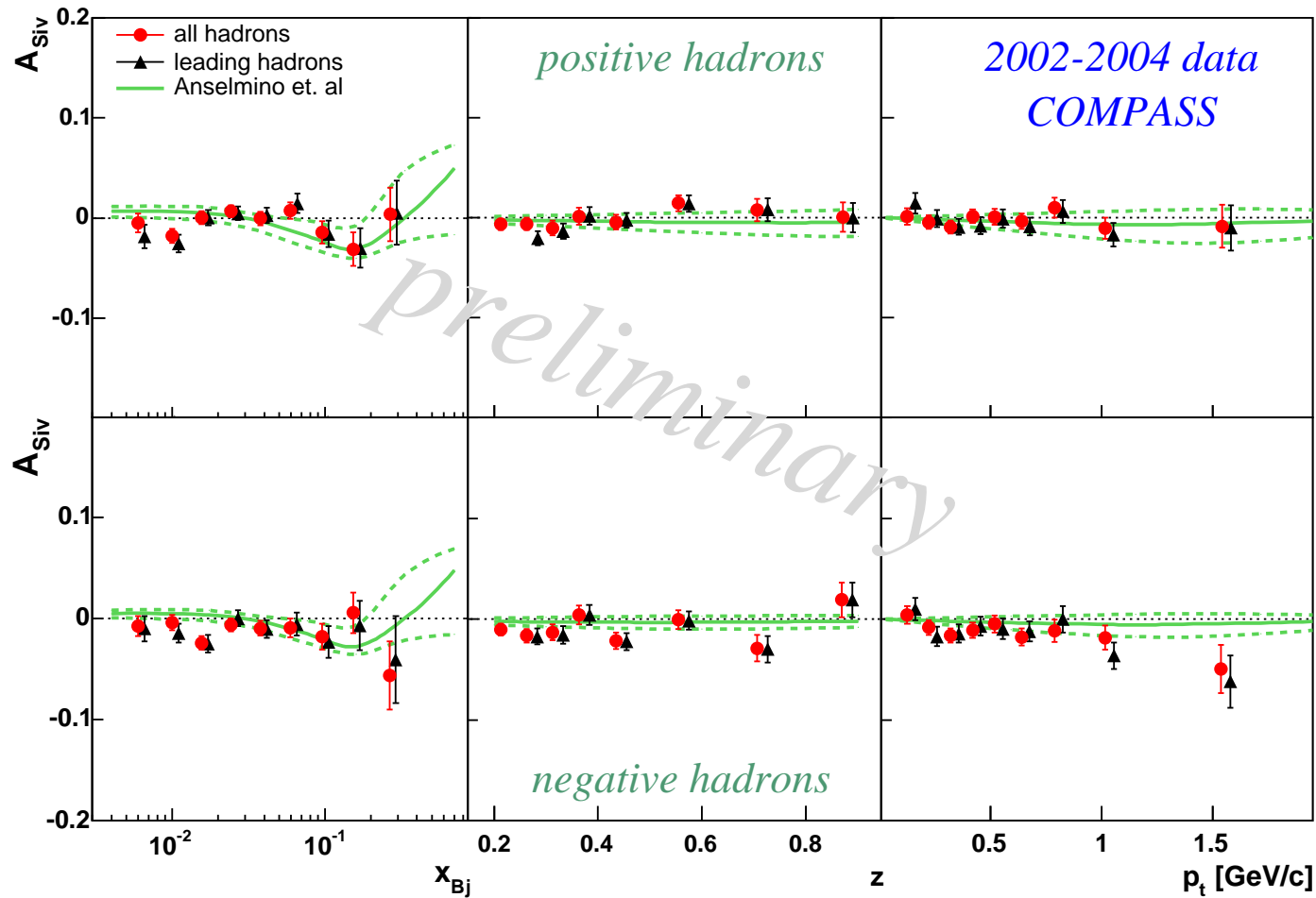
Collins asymmetry

theoretical calc. Efremov *et al.* PRD73 (2006) 094025



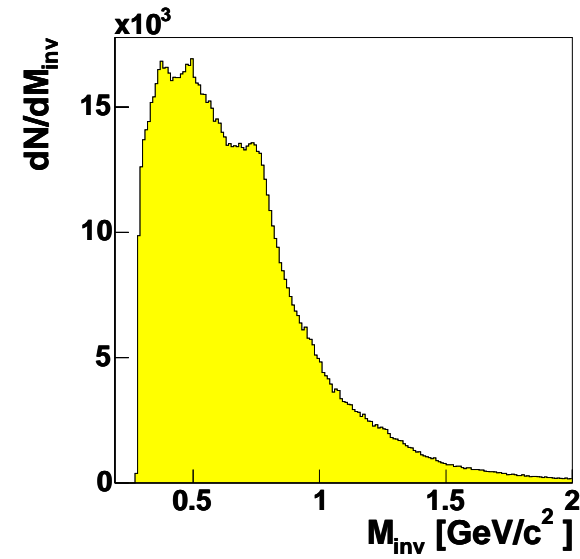
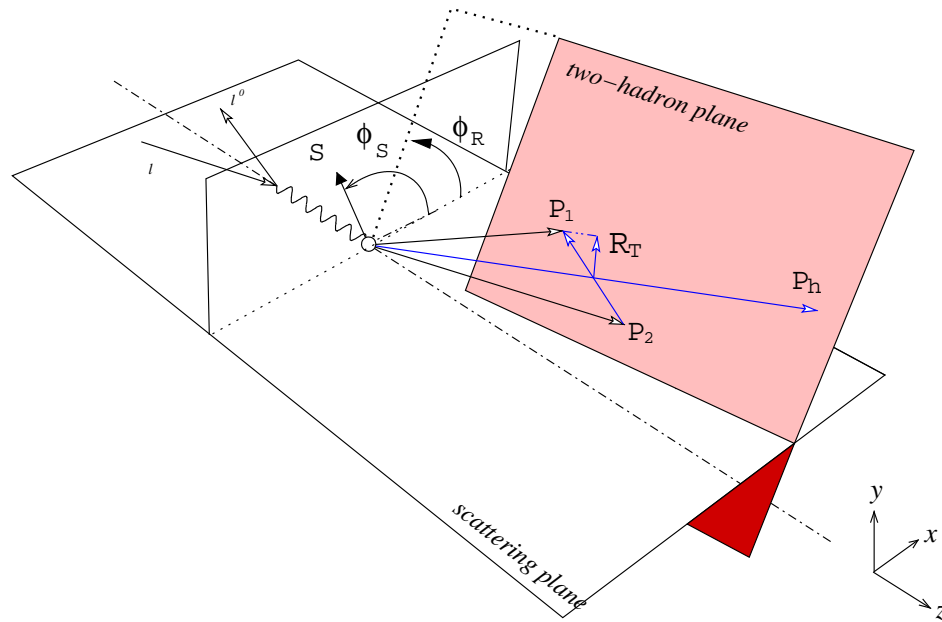
Sivers asymmetry

theoretical calc. Anselmino *et al.* hep-ph/0511249

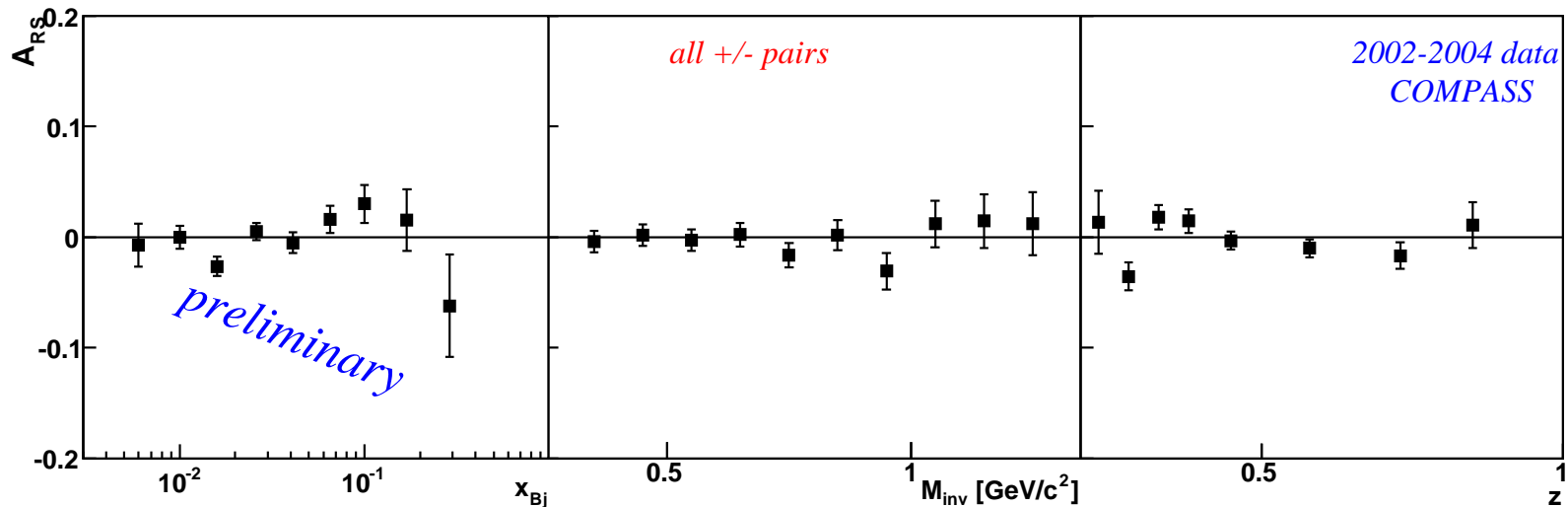


2-hadron asymmetries

Independent access to $\Delta_T q$



Transversity from 2 hadrons



$$A_{\Phi_{RS}} \propto \Delta_T q(x) H_q^{\angle h}(z, M_h)$$

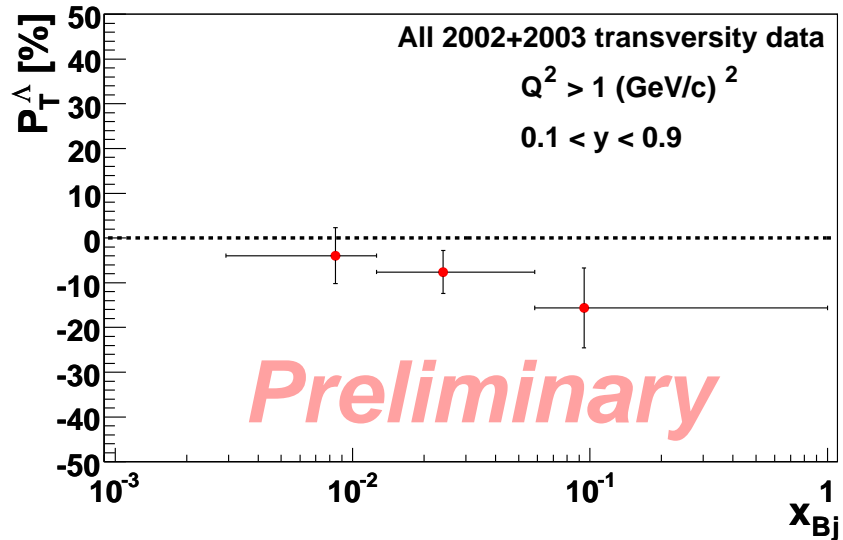
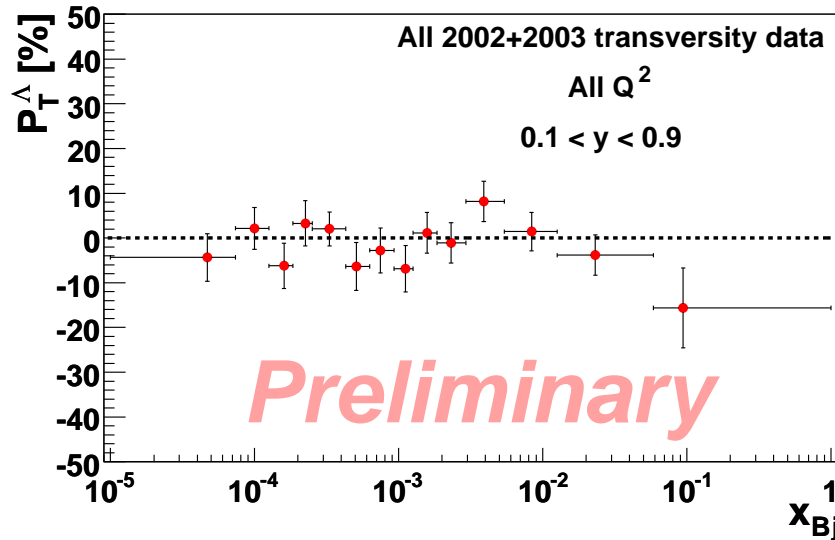
- transversity signal compatible with zero
- $\Delta_T q(x)$ or $H_q^{\angle h}(z, M_h)$ small

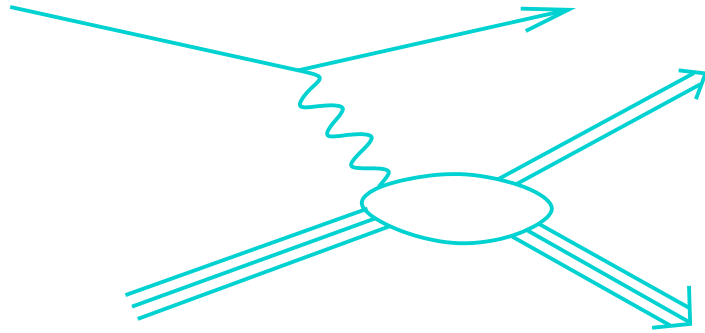


Transversity in Λ polarisation

Self-analysing weak decay with asymmetry $\alpha = 64.2\%$

$$P_T^\Lambda = f \cdot P_N \cdot D_T(y) \frac{\sum_q e_q^2 \Delta_{Tq} \Delta_T D_{\Lambda/q}(z)}{\sum_q e_q^2 q D_{\Lambda/q}(z)}$$

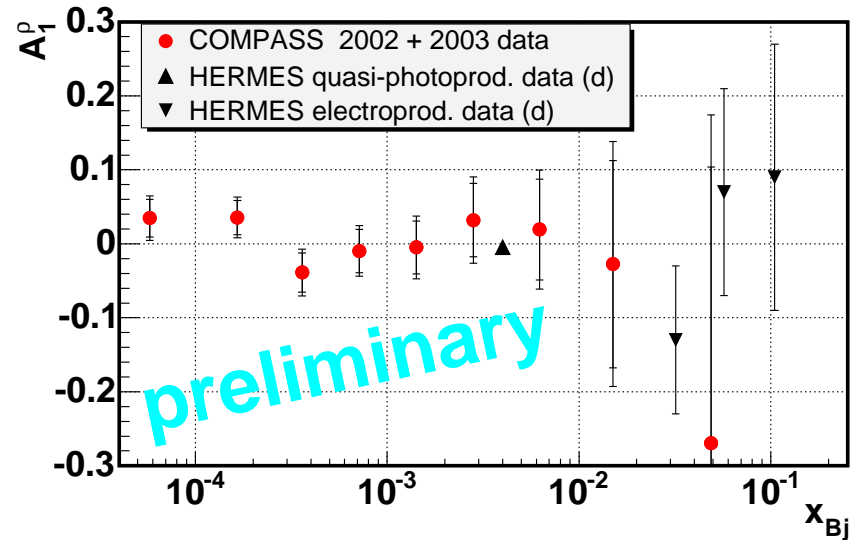
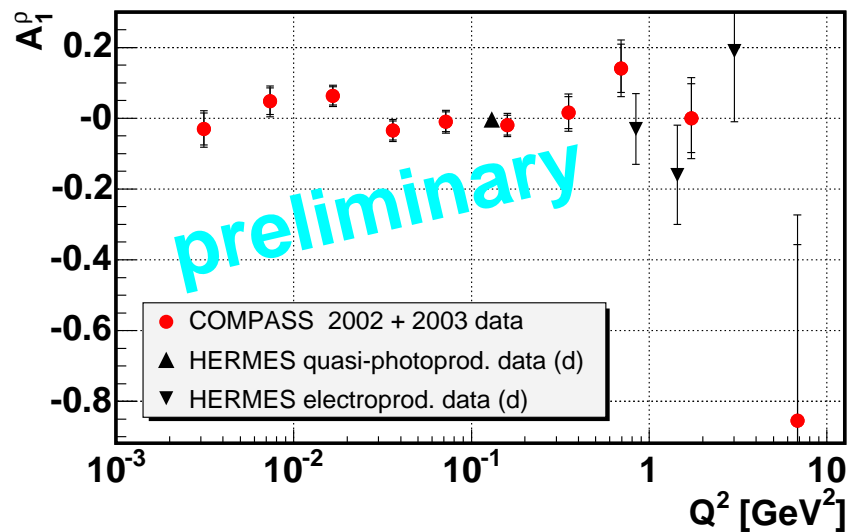




Exclusive vector meson production

Exclusive ρ production

Diffraction production of $\rho, \phi, J/\Psi$
measures spin density matrix elements
(double spin asymmetry)

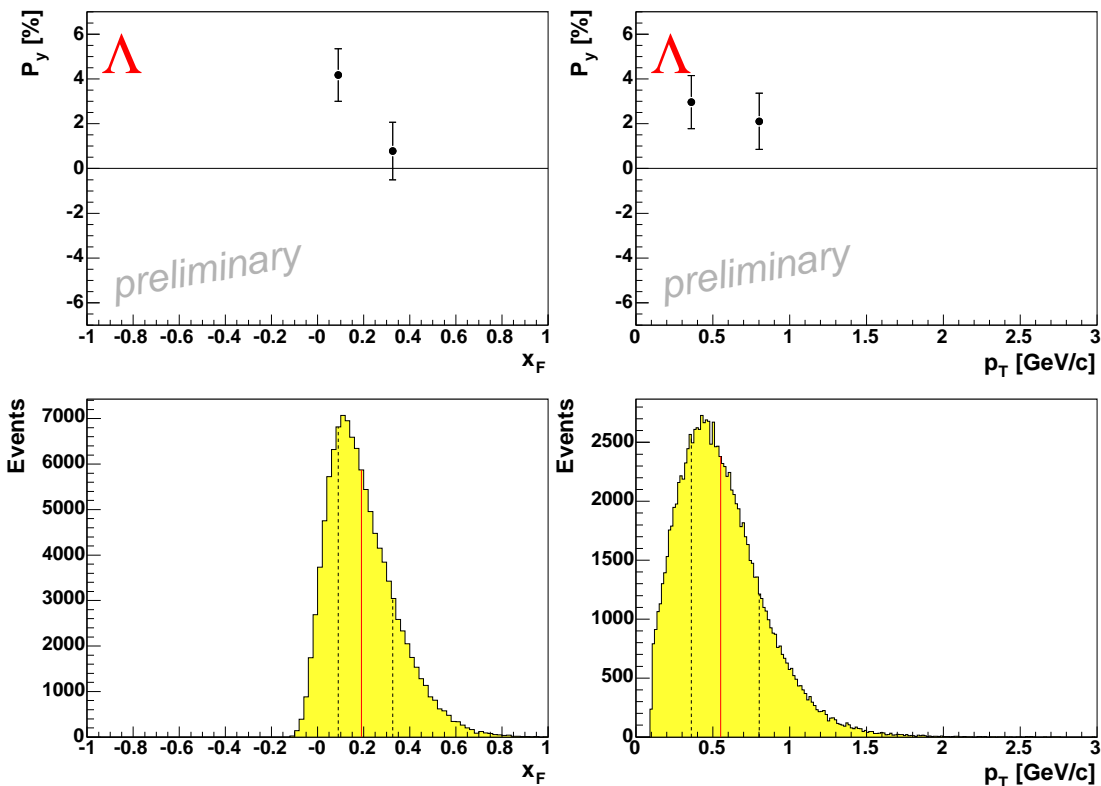


wide Q^2 region covered
high $Q^2 \rightarrow$ measurement of **GPD's** (future!)



Spontaneous Λ polarisation

Large polarisations known from (unpolarised) hadron production $p + \text{Be} \rightarrow \Lambda^\uparrow X$ (Fermilab at 300 GeV/c: 28%)



$$P_T^\Lambda = +2.7 \pm 0.9_{\text{stat}} \pm 1.1_{\text{sys}} \%$$

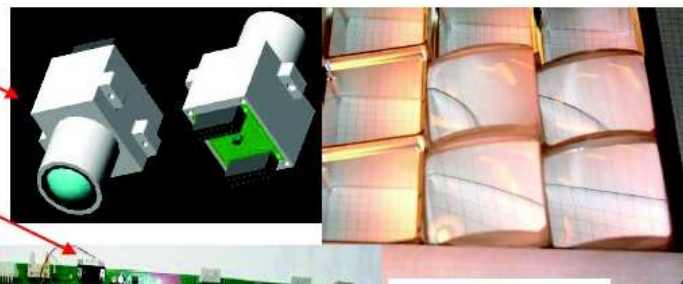
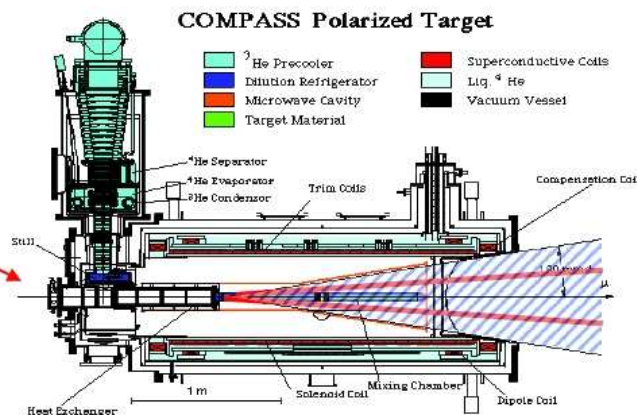


COMPASS upgrades 2006

- **New solenoid magnet**
 - Larger acceptance
 - 70 mrad → 180 mrad
- Expect +30% FOM

- **RICH upgrade**
 - Central region: maPMT system
 - More photons
 - Improved S/N
 - Outer region: New faster electronics
 - Improved S/N
- Expect +60% FOM

- **Other upgrades:**
 - Large Drift Chamber
 - Full ECAL coverage
 - Etc...



Summary

- New COMPASS results

- ▶ Improved measurement of g_1^d Phys. Lett. B612 (2005)154
- ▶ Precise g_1^d data as input for QCD fits
- ▶ High- p_T : Most precise $\Delta G/G$ measurement up to now
(is it small? - or a node at $x_g \sim 0.1$)
PLB 633 (2006) 25
direct measurement via open charm
- ▶ **Transversity**: Very precise (small) deuteron
asymmetries
PRL 94 (2005) 202002

- More precise results on the way!



Outlook

- Improved setup in 2006
 - ▶ FoM expected to be increased by ~ 2.3
 - ▶ Transverse spin: First COMPASS measurements with proton (NH_3) target
- Hadron beam in 2007 (central production with 300 GeV protons on IH_2 target)
- 2008-2010 complete the approved COMPASS programme
- beyond: potential for GPD, transversity, spectroscopy

