

New COMPASS Results

– Nucleon Spin Structure and Diffractive Meson Production –



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on behalf of the COMPASS collaboration

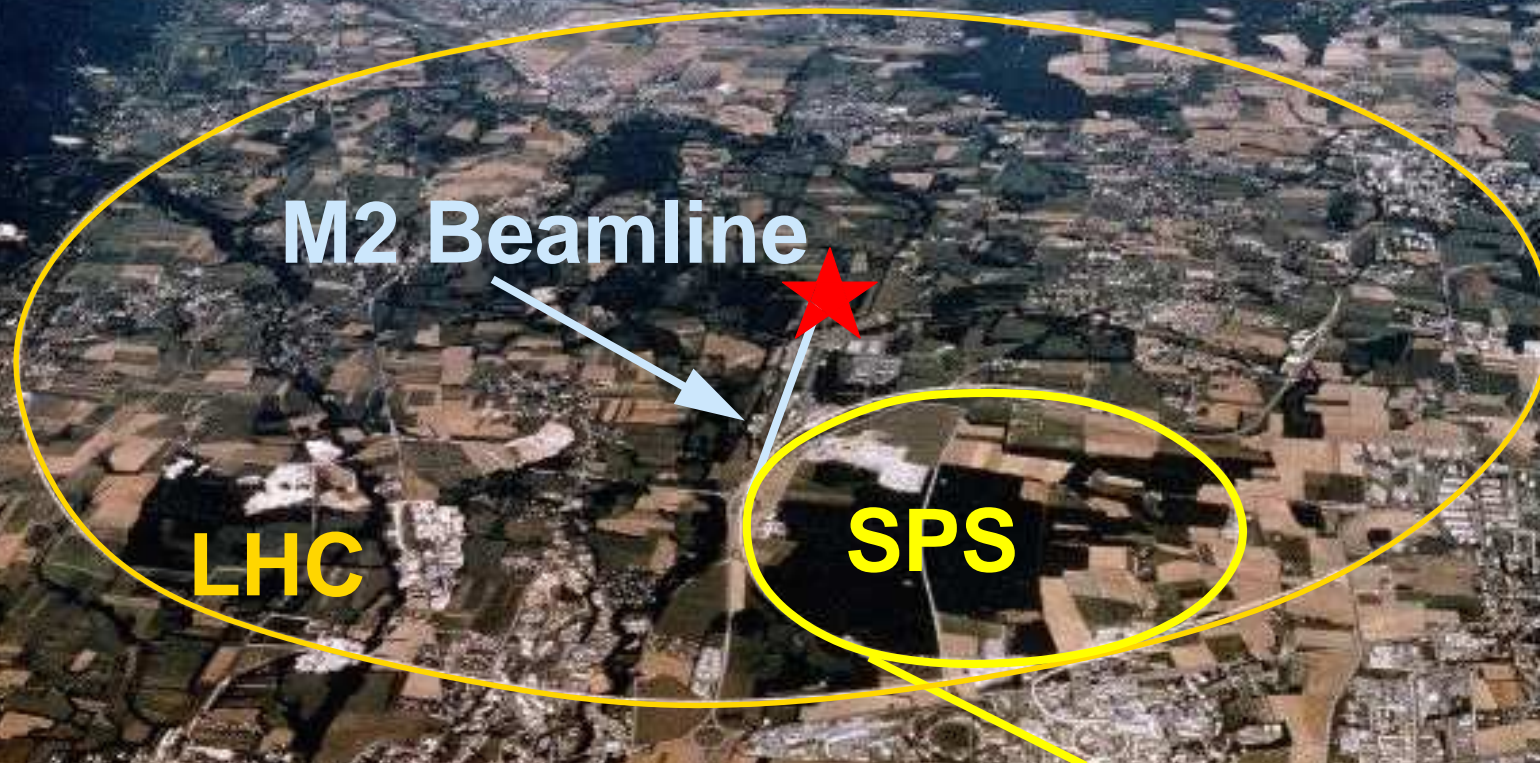


Quark Confinement and the Hadron Spectrum
Mainz, 1–6 September 2008

- COMPASS experiment
- Polarised PDFs
- Gluon polarisation
- Transversity
- Meson spectroscopy
- Status and outlook



Common Muon Proton Apparatus for Structure and Spectroscopy



COMPASS



Bielefeld, Bochum, Bonn, Burdwan/Calcutta, CERN, Dubna, Erlangen, Freiburg,
Lissabon, Mainz, Moscow, Munic, Prague, Protvino, Saclay, Tel Aviv, Turino,
Trieste, Warsaw, Yamagata
(29 institutes, 240 physicists)

Muon beam

Spin dependent structure functions

Polarised quark distributions

Gluon polarisation

Transversity

Lambda polarisation

Vector meson production

future plans:

DVCS

Hadron beam

Primakoff scattering

Mesonspectroscopy

– **Glueballs**

– **Hybrids**

– **Multi-quark states**

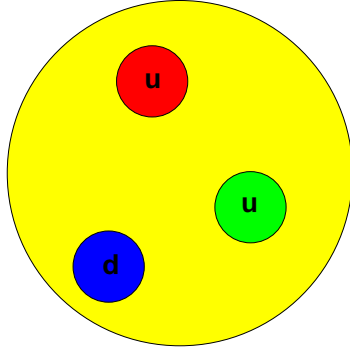
Charmed baryons

future plans:

Drell Yan measurements

Muon programme

The spin of the nucleon

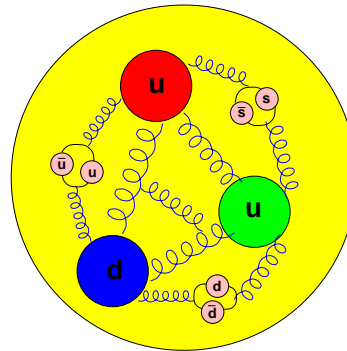


Naive parton model:

$$\Rightarrow \Delta\Sigma = \Delta u_v + \Delta d_v = 1$$

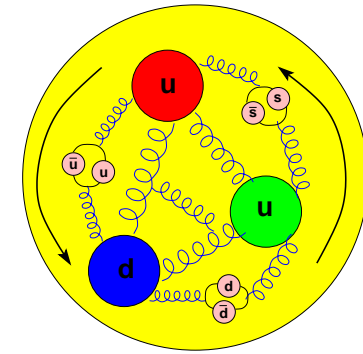
E155

$$\Delta\Sigma = 0.23 \pm 0.07 \pm 0.19$$



gluons important in unpolarized case

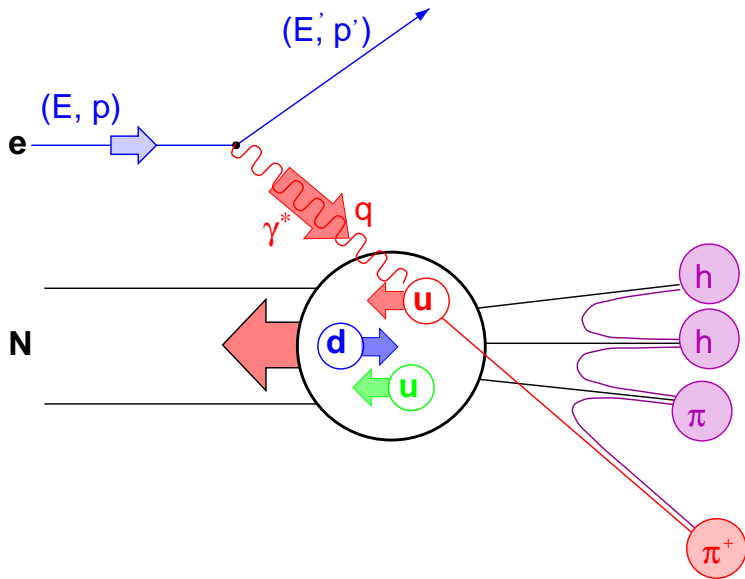
$$\Delta G?$$



complete description:
orbital angular momenta

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

Deep inelastic scattering



$$Q^2 = -q^2$$

$$z = E_h/\nu$$

$$\nu = E - E'$$

p_T^h : transverse

$$x = Q^2/2M\nu$$

momentum

$$q(x) = q(x)^+ + q(x)^- \quad + \text{quark } \uparrow\uparrow \text{ nucleon}$$

$$\Delta q(x) = q(x)^+ - q(x)^- \quad - \text{quark } \downarrow\uparrow \text{ nucleon}$$

- photon nucleon asymmetry

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{\sum_q e_q^2 (q(x)^+ - q(x)^-)}{\sum_q e_q^2 (q(x)^+ + q(x)^-)} = \frac{g_1(x)}{F_1(x)}$$

- spin structure function

$$g_1 = \frac{1}{2} \sum_q e_q^2 \Delta q(x) = A_1 \cdot \frac{F_2}{2x(1+R)} \approx \frac{A_{\parallel}}{D} \cdot \frac{F_2}{2x(1+R)}$$

COMPASS spectrometer

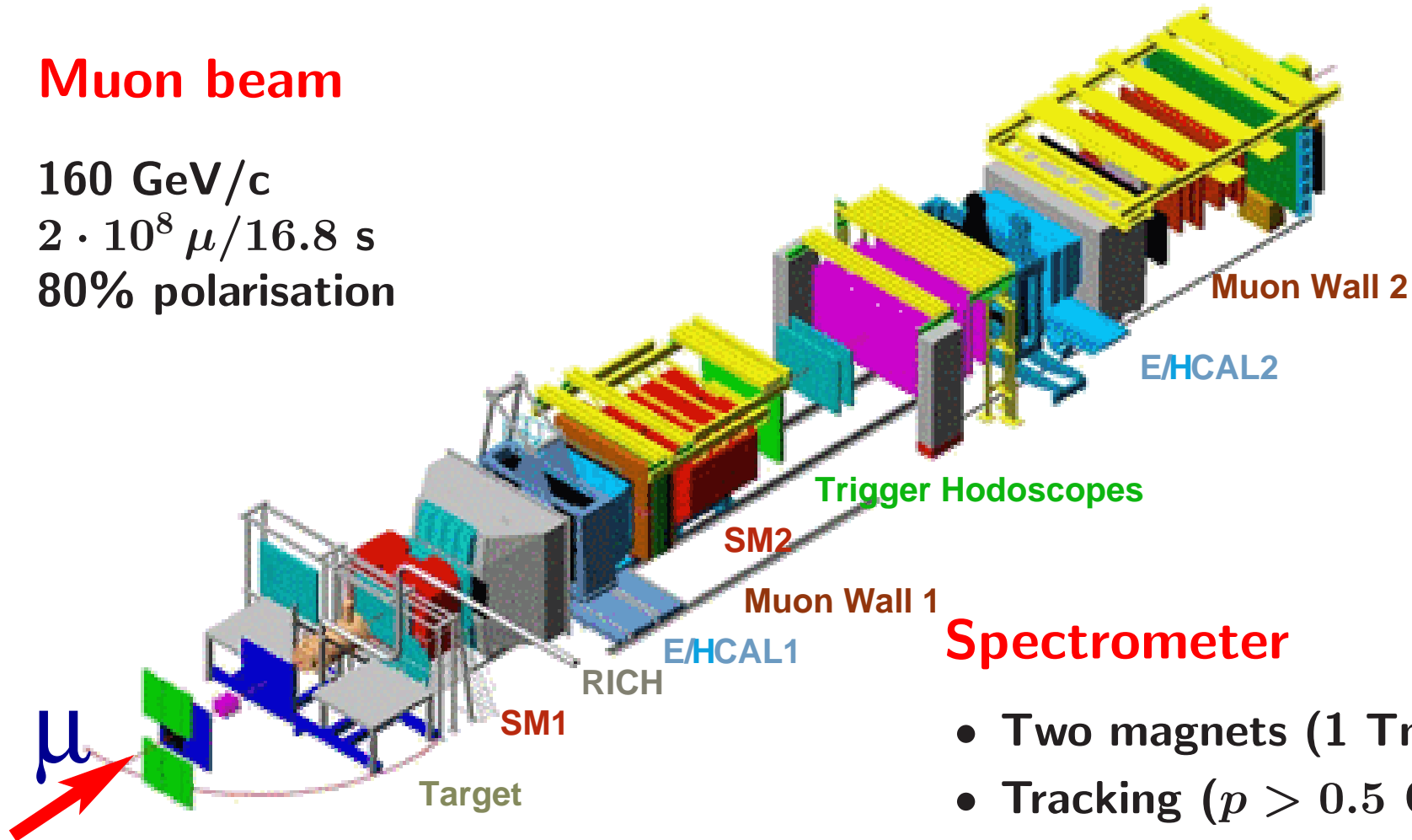


Muon beam

160 GeV/c

$2 \cdot 10^8 \mu / 16.8 \text{ s}$

80% polarisation



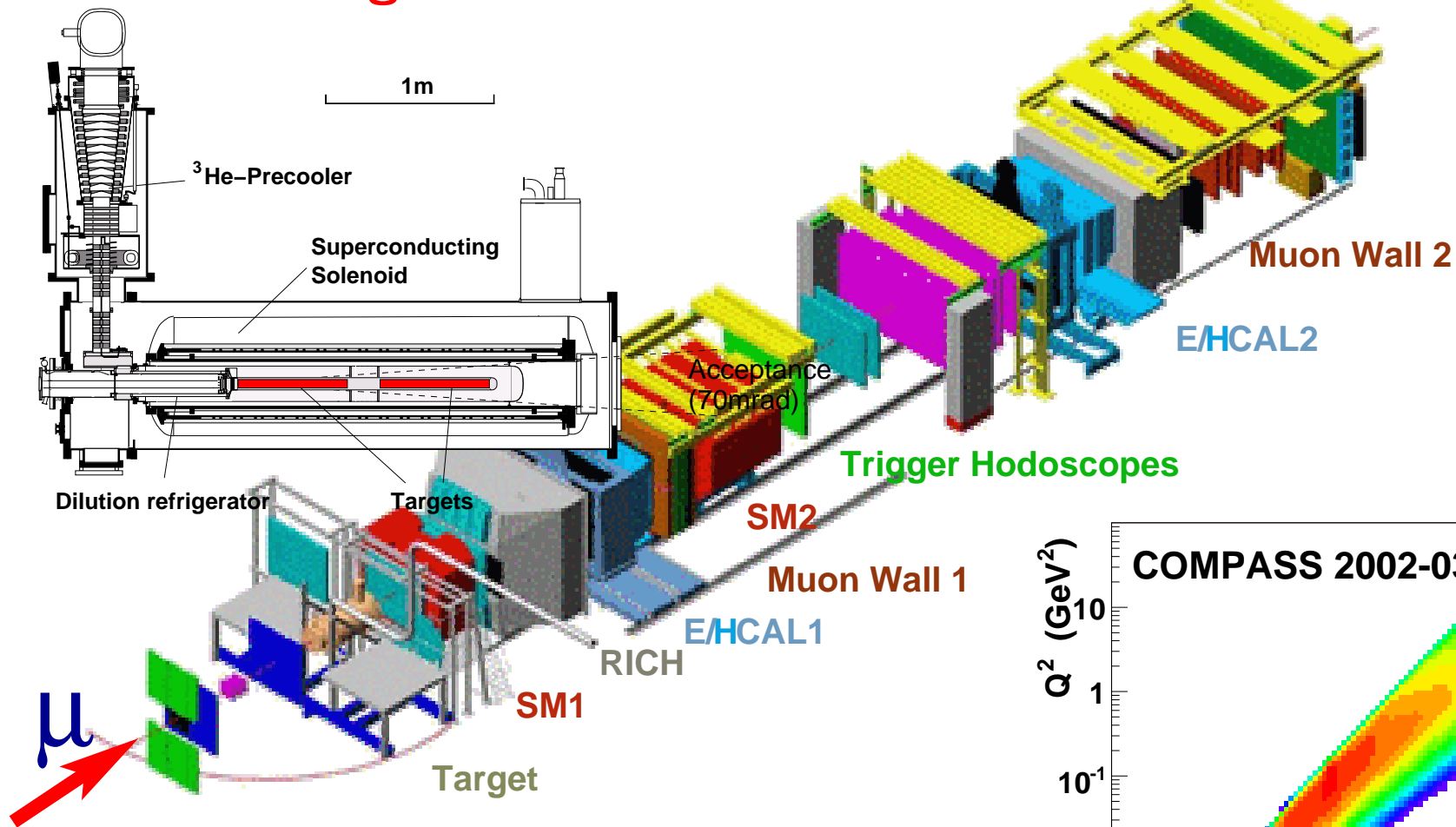
Spectrometer

- Two magnets (1 Tm, 4.5 Tm)
- Tracking ($p > 0.5 \text{ GeV}/c$):
SciFi, Silicon, MicroMega, GEM,
MWPC, Drift, Straws, Drifttubes
- PID: π , k , p (RICH)
above 2, 9, 18 GeV/c
- ECAL, HCAL, muon filter

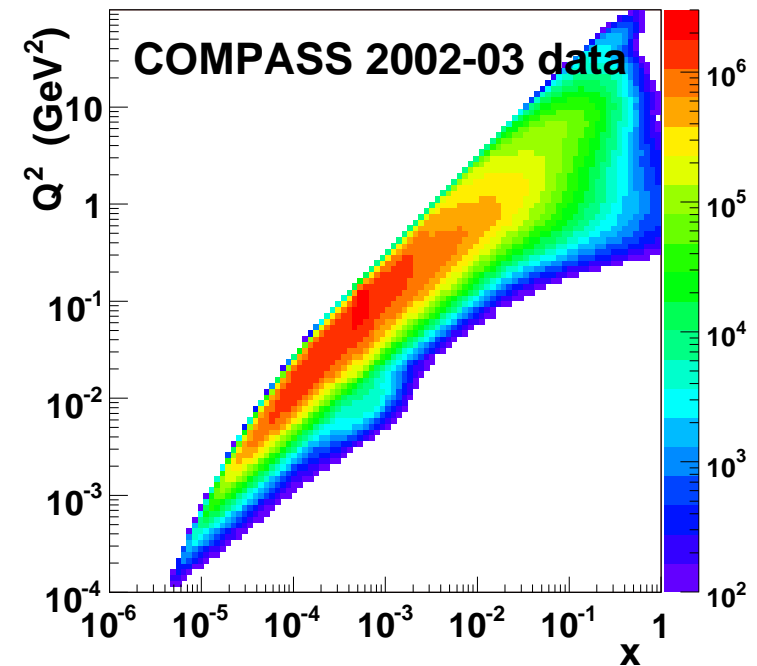
COMPASS spectrometer



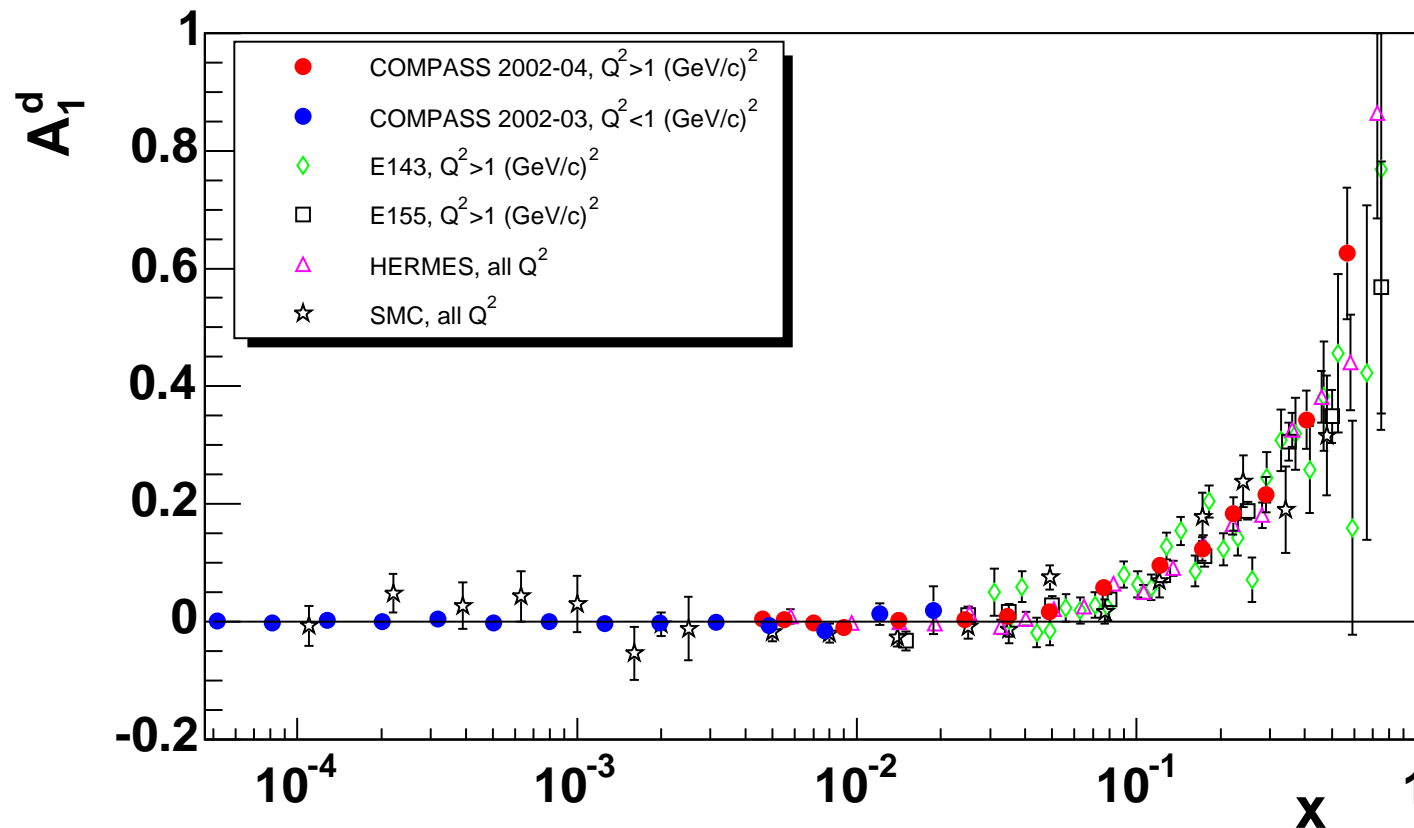
Polarised target



target material: ${}^6\text{LiD}$, NH_3
polarisation: 50%, 90%

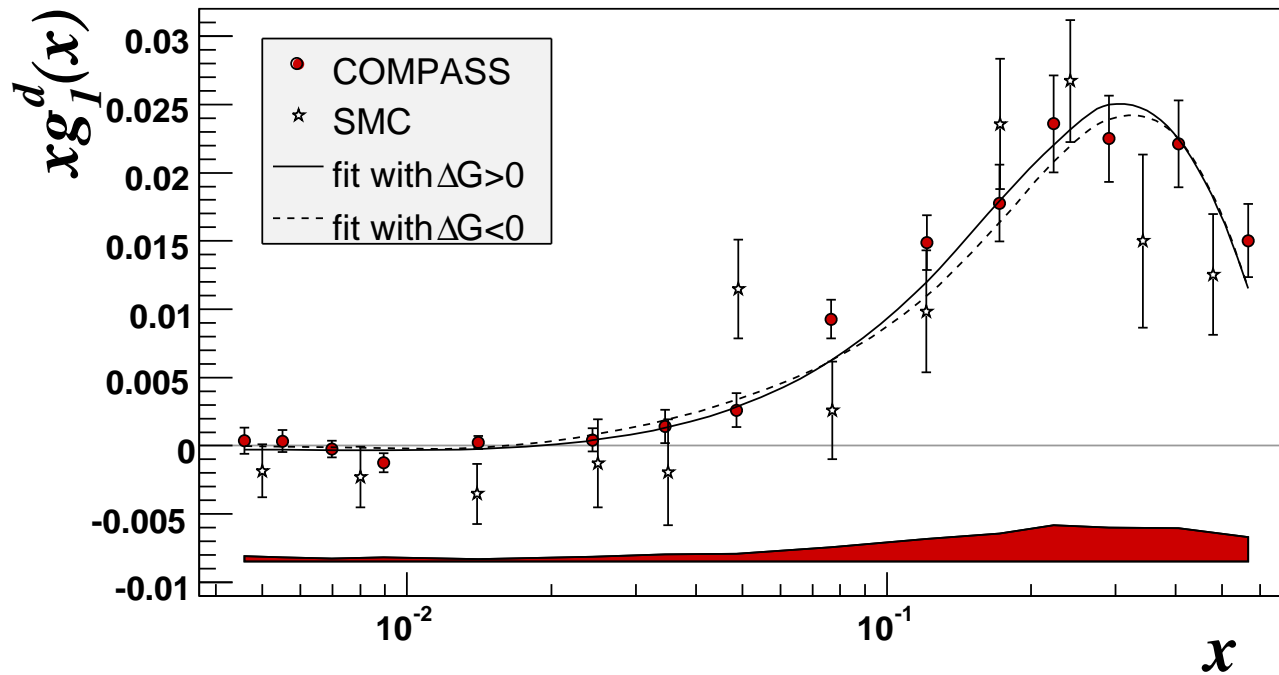


Inclusive asymmetry A_1^d

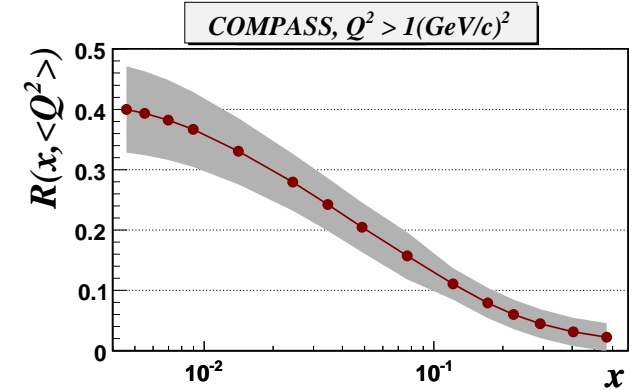
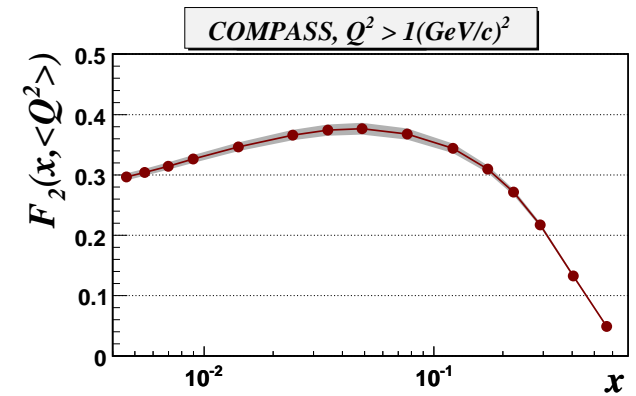


- $Q^2 > 1 \text{ (GeV/c)}^2$: results from 2002–2004, $88 \cdot 10^6$ events (PLB 647 (2007) 8)
- $Q^2 < 1 \text{ (GeV/c)}^2$: results from 2002/2003, $300 \cdot 10^6$ events (PLB 647 (2007) 330)
- A_1^d compatible with 0 for $x < 0.05$
- good agreement with previous experiments

Spin structure function g_1



$$g_1 = A_1 \cdot \frac{F_2}{2x(1 + R)}$$



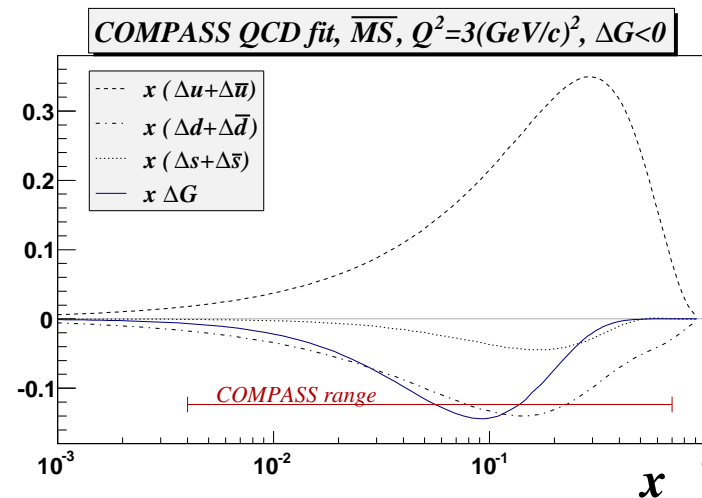
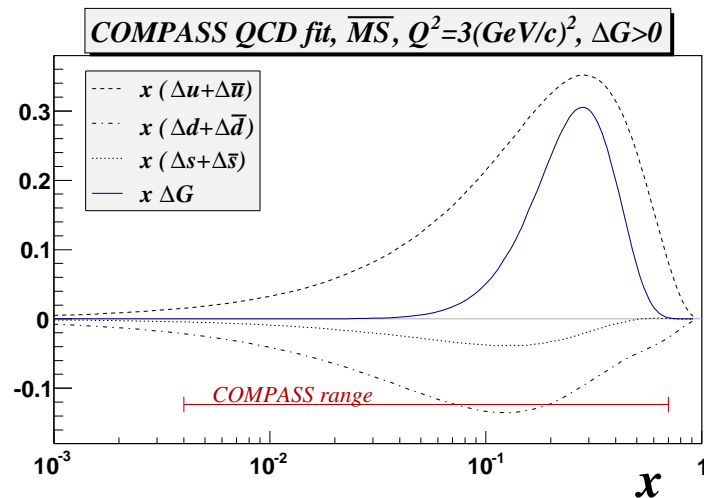
First moment:

$$\begin{aligned} \Gamma_1^N(Q^2 = 3(\text{GeV}/c)^2) &= \int_0^1 g_1^N(x) dx \\ &= 0.0502 \pm 0.0028(\text{stat}) \pm 0.0020(\text{evol}) \pm 0.0051(\text{syst}) \end{aligned}$$

Polarised parton distributions

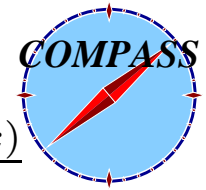


- NLO QCD analysis of world data (2 methods)
 - numerical integration in (x, Q^2) space (PRD 58 (1998) 112002)
 - solution of DGLAP in space of moments (PRD 70 (2004) 074032)
- data well described by two solutions with $\Delta G > 0$ and $\Delta G < 0$

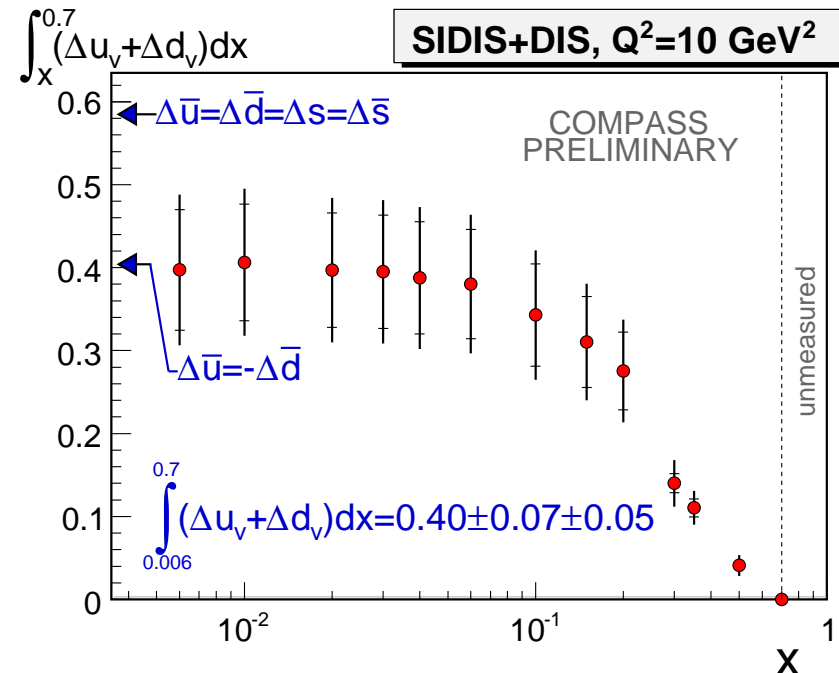
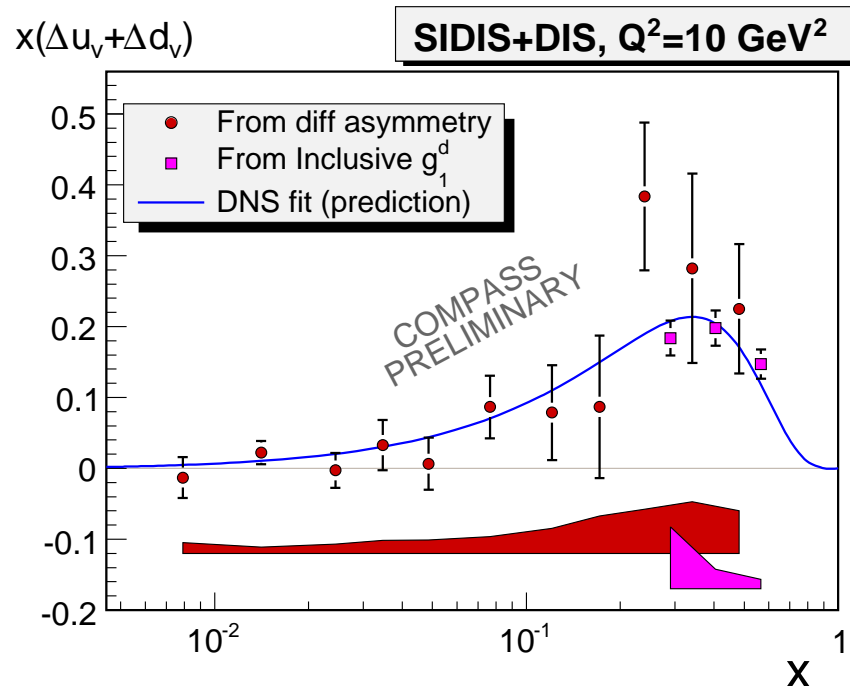


- small sensitivity to light sea and gluon polarisation
- quark polarisation $\Delta\Sigma = 0.30 \pm 0.01(\text{stat}) \pm 0.02(\text{evol})$
(stat. error factor 2 larger without COMPASS)
- gluon polarisation $|\Delta G| \approx 0.2 - 0.3 \implies$ direct measurement needed

Towards polarised sea quarks



Difference asymmetry (LO): $A_d^{\pi^+-\pi^-}(x) = A_d^{K^+-K^-}(x) = \frac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)}$

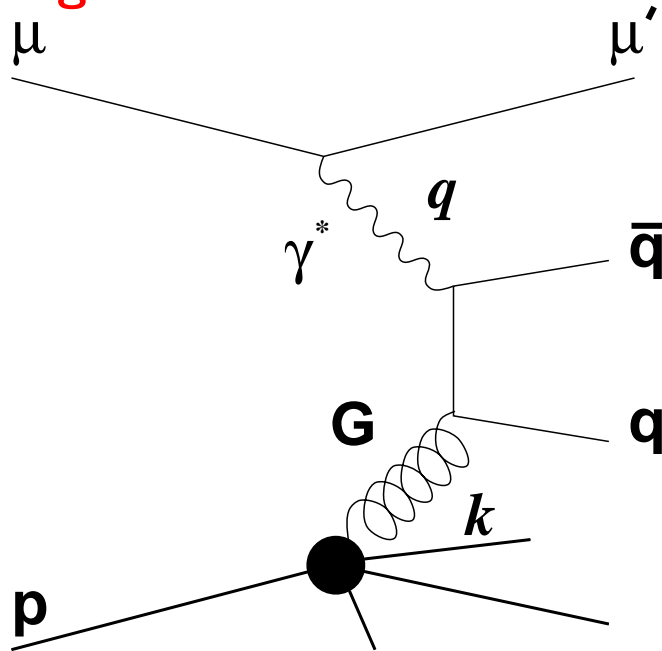


- first moment $\Gamma_v = \int_0^1 (\Delta u_v(x) + \Delta d_v(x)) dx$
- with Γ_1^N and a_8 : $\Delta \bar{u} + \Delta \bar{d} = 3 \Gamma_1^N - \frac{1}{2} \Gamma_v + \frac{1}{12} a_8$ a_8 from hyperon decays
- disentangle between flavour **symmetric** ($\Delta \bar{u} = \Delta \bar{d} = \Delta \bar{s} = \Delta \bar{s}$) and **asymmetric** ($\Delta \bar{u} = -\Delta \bar{d}$) sea: **asymmetric** sea favoured ($2.5 \sigma_{\text{stat}}$) (PLB 660 (2008) 458)
- next step: K^\pm asymmetries $\longrightarrow \Delta s$

$\Delta G/G$ measurement in DIS



- Photon gluon fusion**



$$A_{\gamma N}^{\text{PGF}} = \frac{\int d\hat{s} \Delta\sigma^{\text{PGF}} \Delta G(x_g, \hat{s})}{\int d\hat{s} \sigma^{\text{PGF}} G(x_g, \hat{s})}$$

$$\approx \langle a_{LL}^{\text{PGF}} \rangle \frac{\Delta G}{G}$$

$\langle a_{LL}^{\text{PGF}} \rangle$ analysing power

- Methods**

- **Open charm production**

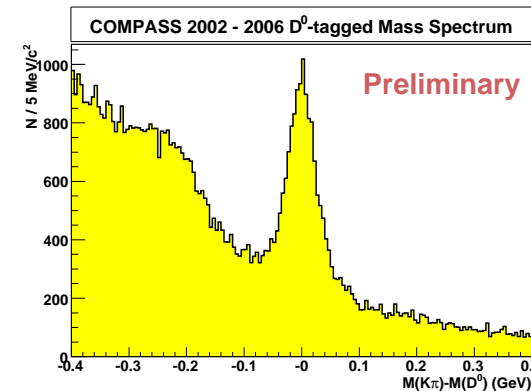
$$\gamma g \rightarrow c\bar{c}$$

$$\rightarrow D^0 \rightarrow \pi K \quad \text{BR: 4\%}$$

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

hard scale: m_c^2

clean channel, limited statistics



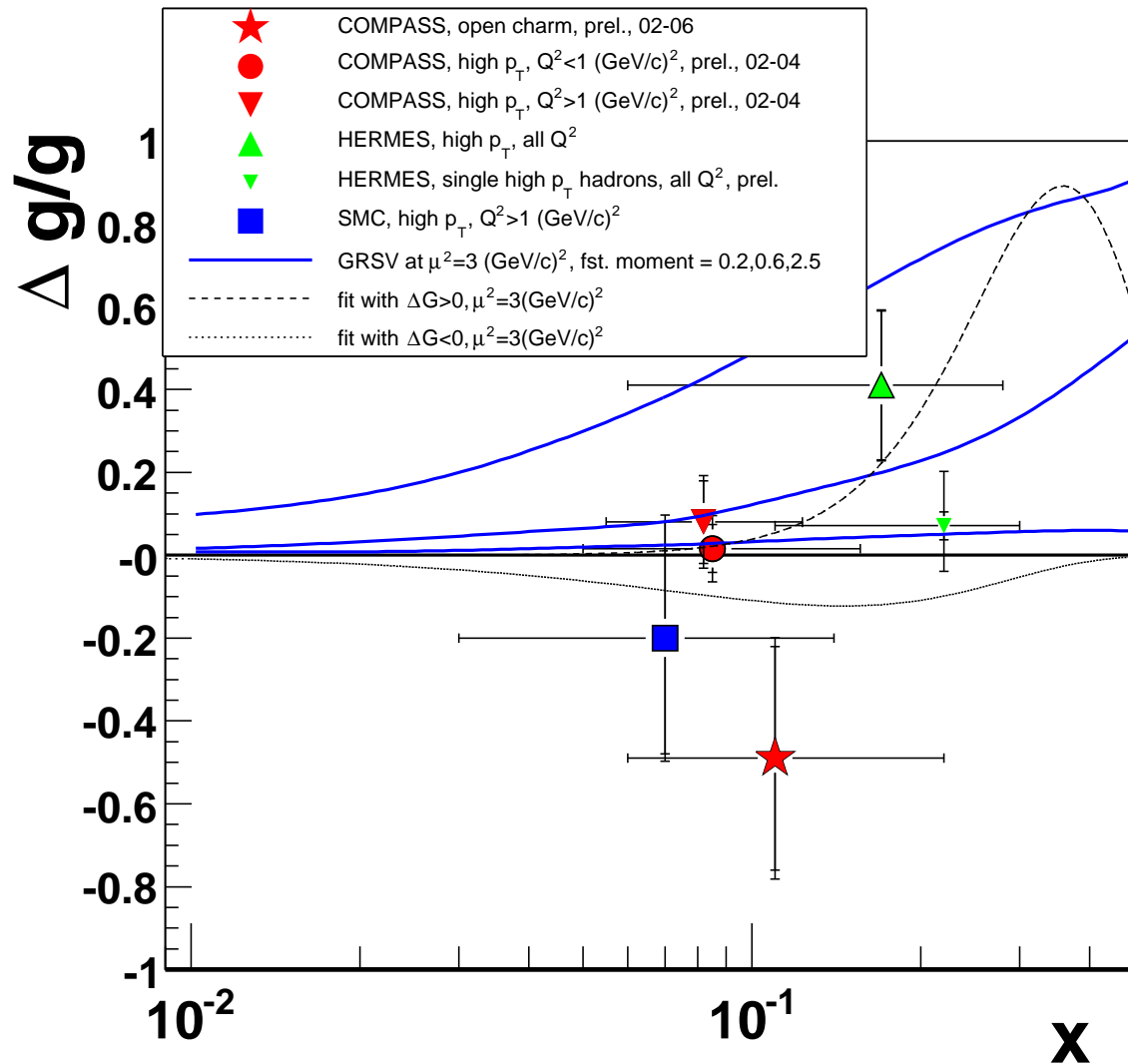
- **High p_T hadron pairs**

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

$$\rightarrow 2 \text{ jets or } H^+ H^-$$

hard scale: Q^2 or Σp_T^2

Results for $\Delta G/G$



$$\int G^{\text{GRVS}}(x) dx =$$

2.5

0.6

0.2

- $\Delta G/G$ is small or has a node around $x_g \approx 0.1$
- supported by recent PHENIX and STAR results from pp-collisions

Transverse single spin asymmetries



- **measurement of transversity**
only possible in SIDIS

$$\Delta_T q(x) = \text{[diagram of a yellow circle with a red dot and an upward arrow]} - \text{[diagram of a yellow circle with a red dot and a downward arrow]}$$

- **Method:** measurement of $\Delta_T q(x) \otimes$ fragmentation function

$$lN^\uparrow \rightarrow l'hX$$

Collins asymmetries

Collins ff (measured in e^+e^- at BELLE)

$$lN^\uparrow \rightarrow l'hhX$$

2 hadron asymmetries

interference ff (BELLE?)

$$lN^\uparrow \rightarrow l'\Lambda X$$

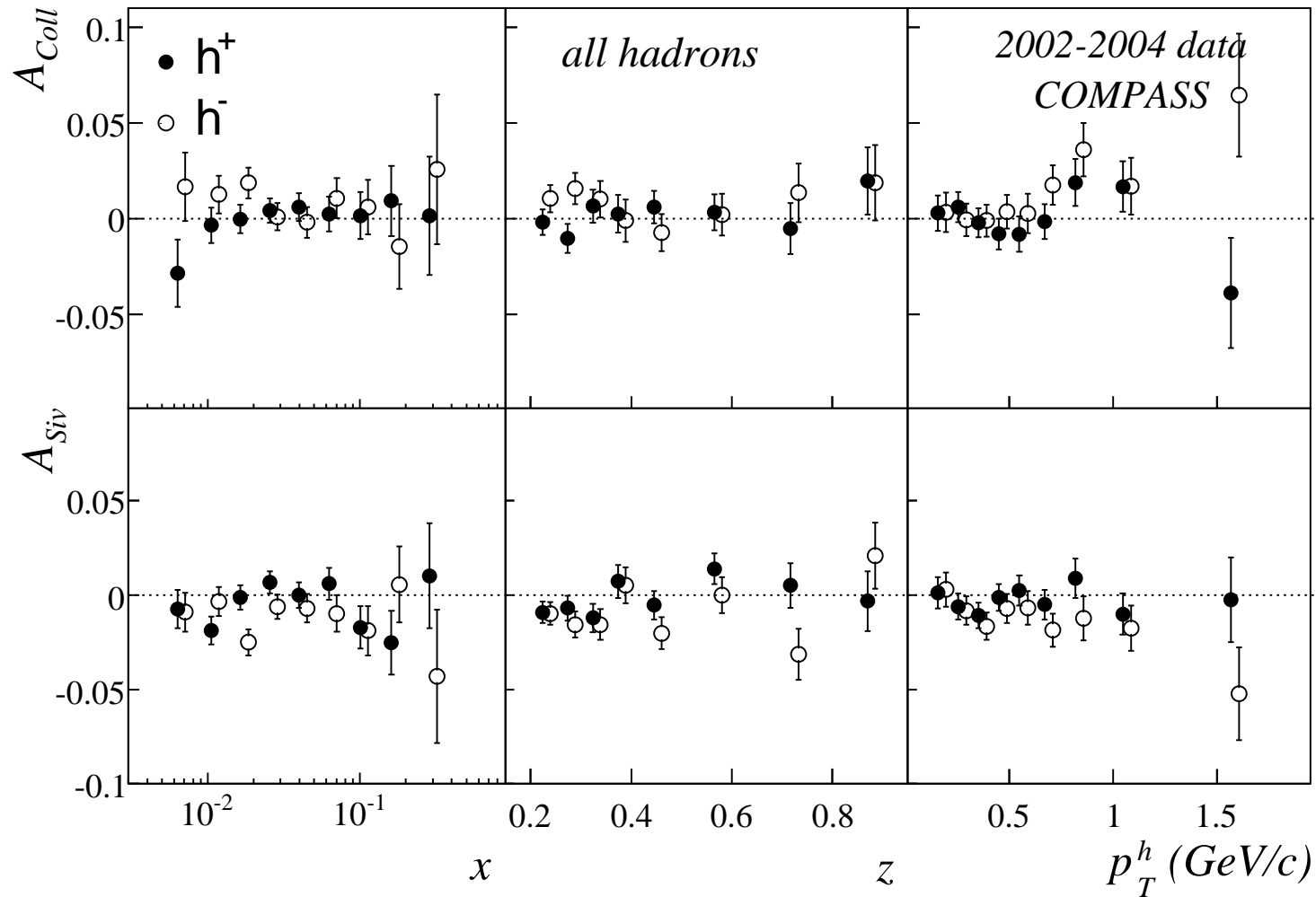
Λ polarisation

with ff($q^\uparrow \rightarrow \Lambda$)

h: positive or negative hadrons, pions, kaons

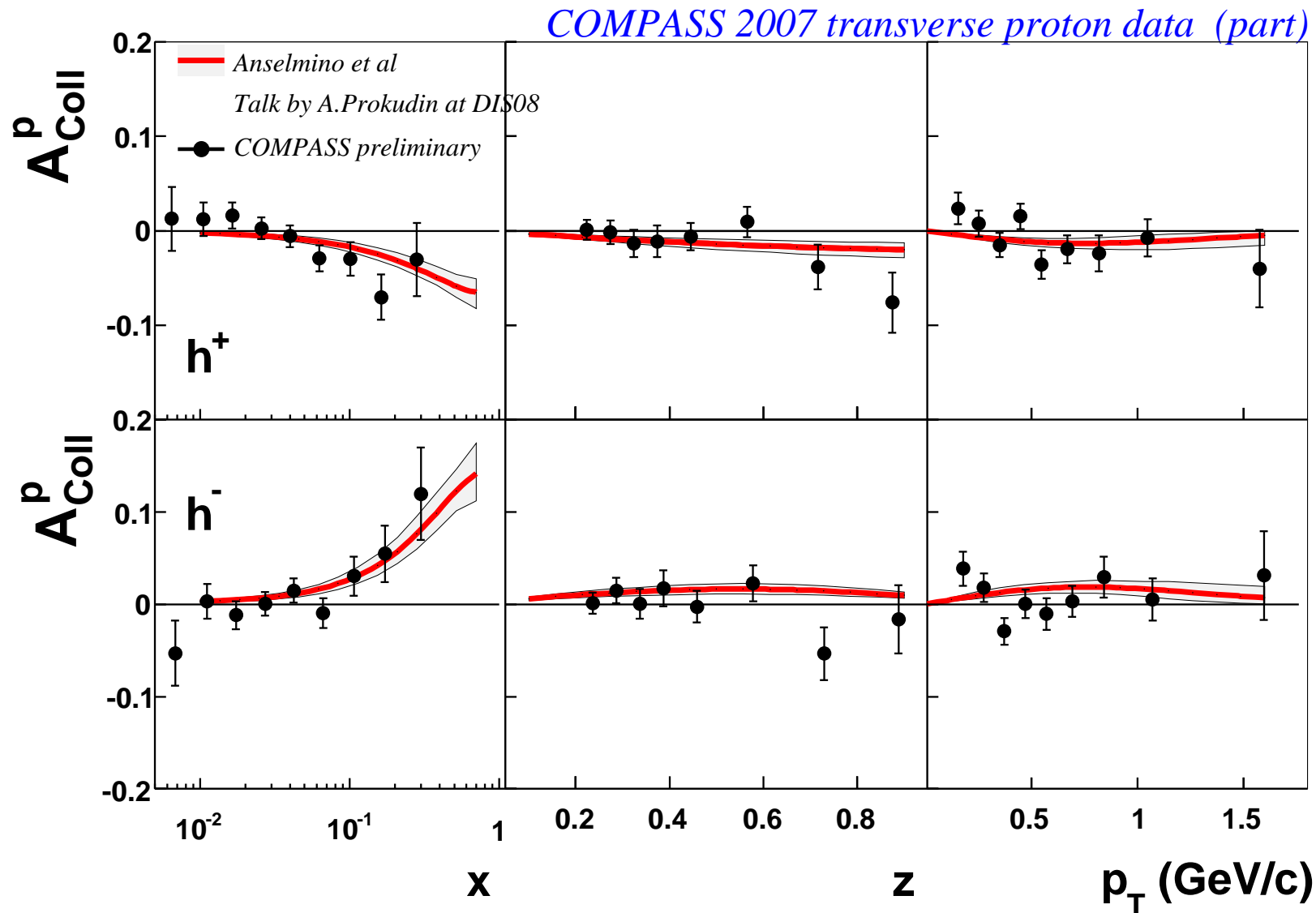
- **in addition** effects of transverse momentum: **Sivers function**

COMPASS results (deuteron)



- deuteron **Collins** and **Sivers** asymmetries compatible with 0 (NPB 765 (2007) 31)
- together with HERMES results: **Cancellation of u and d-quarks**
- identified hadrons and other methods: asymmetries also compatible with 0

COMPASS results (proton)

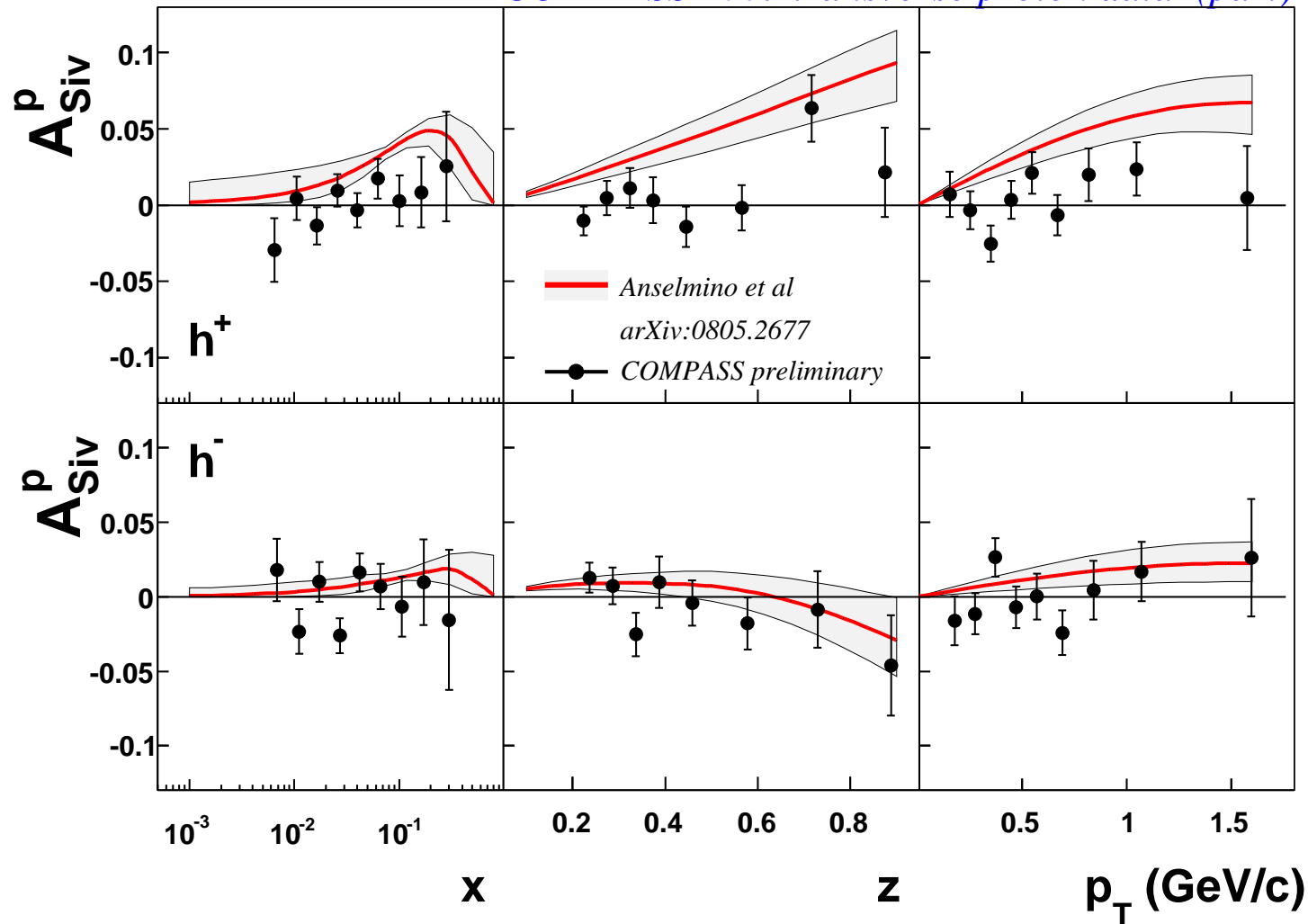


results for **Collins asymmetries** agree with predictions
 (using from **HERMES** proton, **COMPASS** deuteron and **BELLE** data)

COMPASS results (proton)



COMPASS 2007 transverse proton data (part)



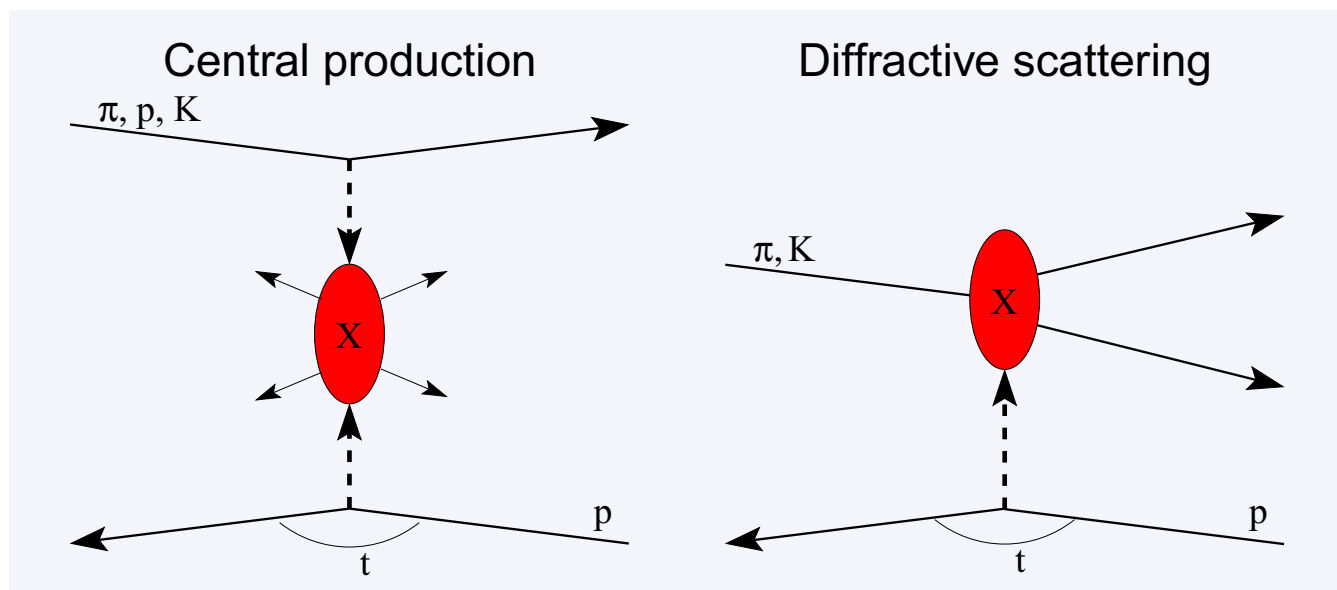
Sivers asymmetries compared to predictions
(using HERMES proton and COMPASS deuteron data)
more data needed to draw firm conclusions

Hadron programme

Meson spectroscopy

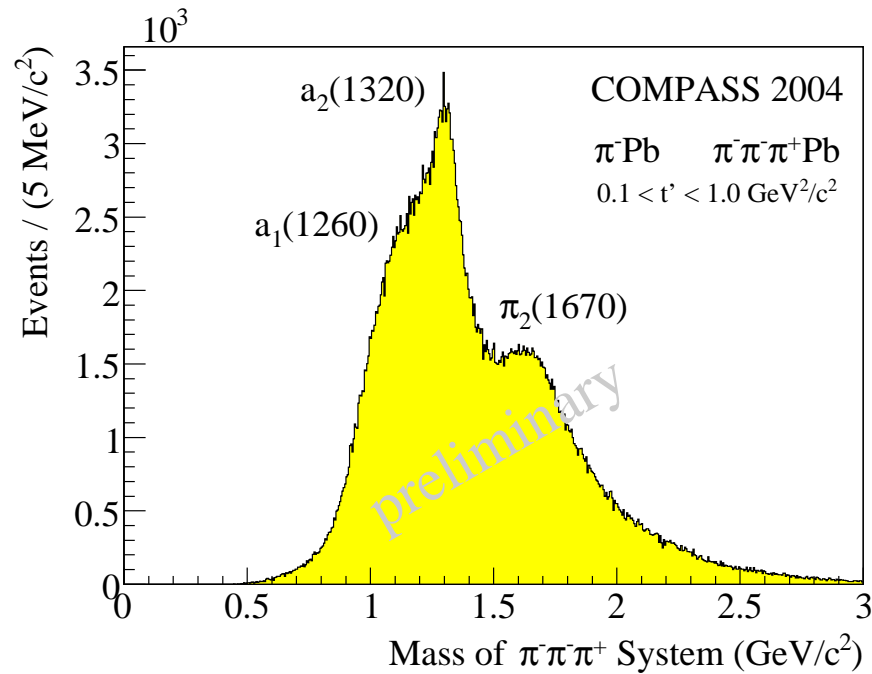


- **2008:** data taking with 190 GeV/c hadron (π) beam on liquid H_2 target search for exotic mesons and glue balls using



- **2004:** pilot hadron run with 190 GeV/c π^- beam on Pb
 - main goal: pion polarisability
 - in addition: diffractive meson production
 - results from: $\pi^- Pb \rightarrow \pi^- \pi^- \pi^+ Pb$
 - momentum transfer: $0.1 (\text{GeV}/c)^2 < t' < 1 (\text{GeV}/c)^2$ with $t' = |t| - |t|^{min}$
scattering on nucleons dominating

Diffraction 3 Pion-Produktion

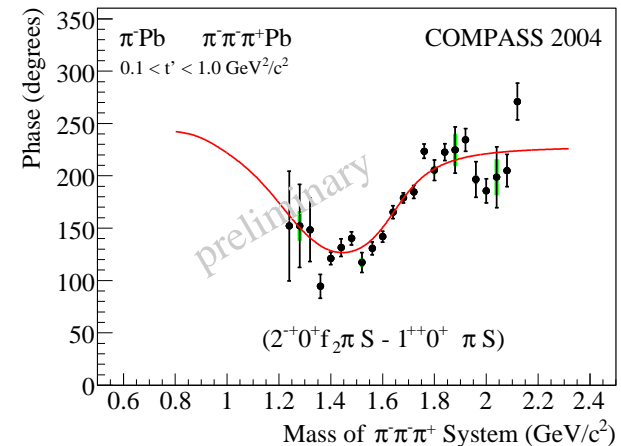
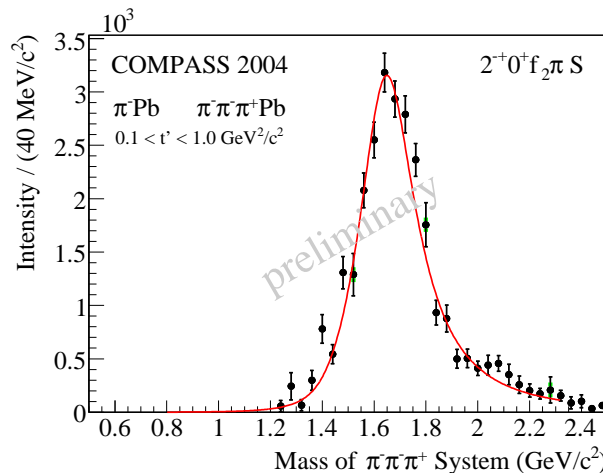
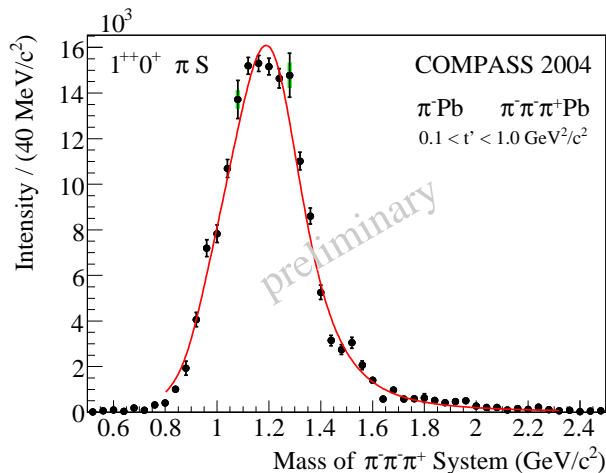


- partial wave analysis in two steps

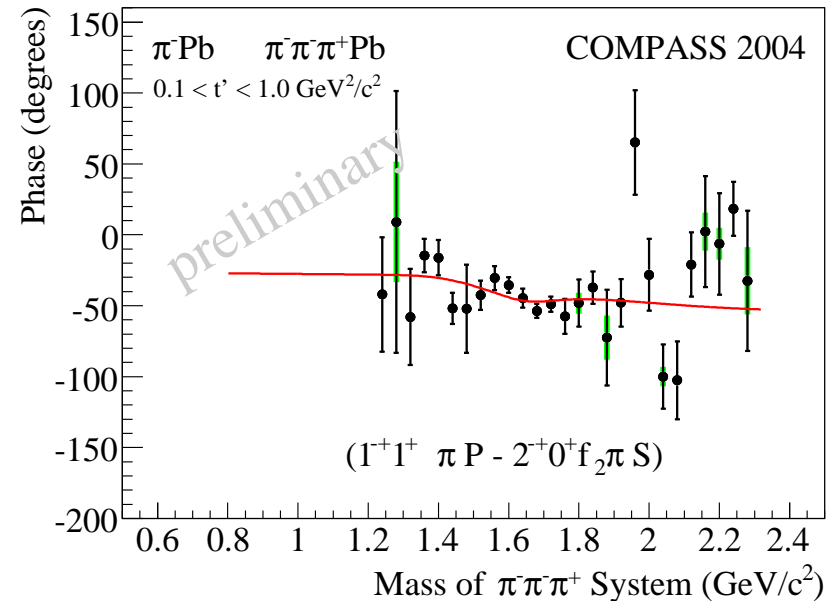
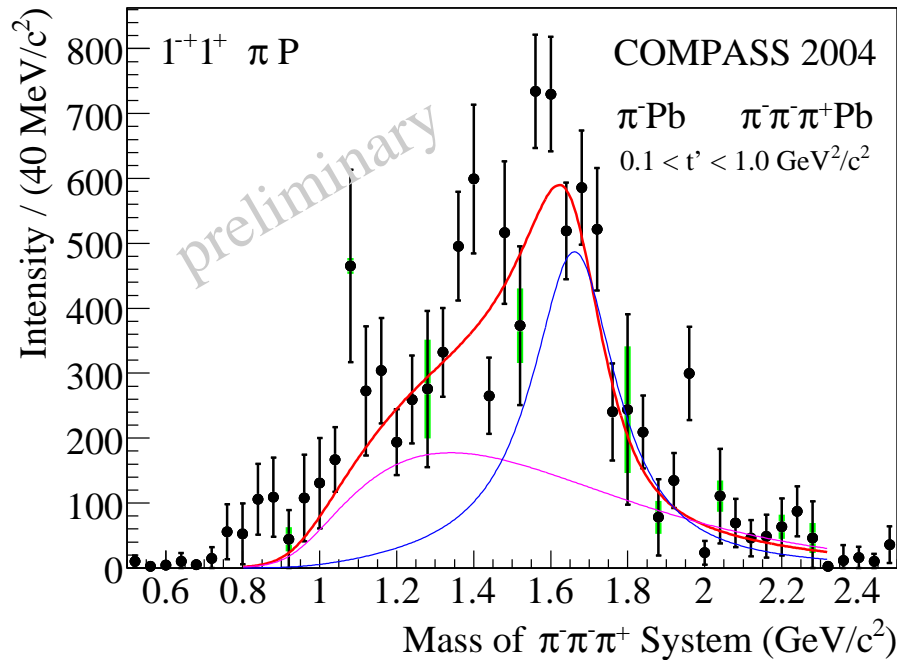
- mass-independent analysis
40 MeV/C² mass bins
42 waves used
- mass-dependent analysis
using 7 selected waves

- dominant waves:

$a_1(1260)$, $a_2(1320)$, $\pi_2(1670)$



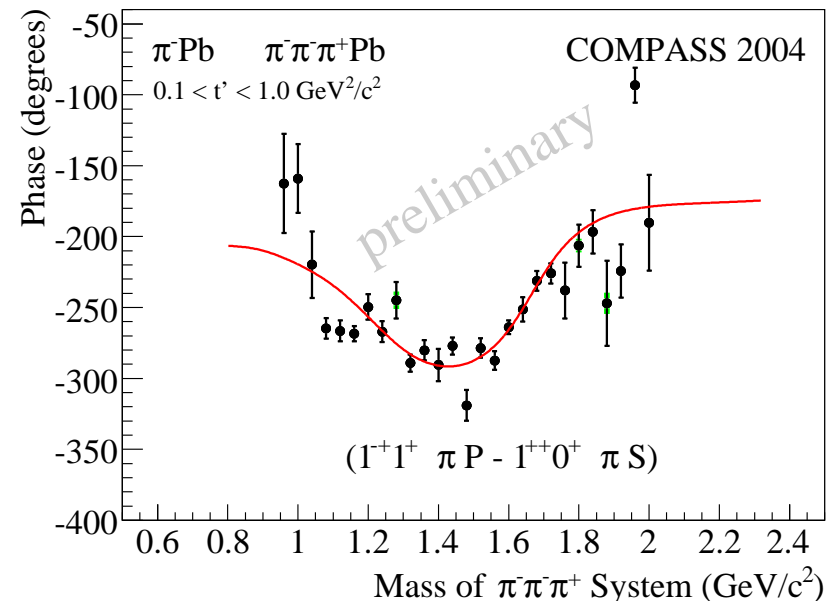
Exotic wave ($1^+1^+\rho\pi P$)



- significant 1^{-+} amplitude
- no leakage observed
- Breit-Wigner (preliminary):

$$M = (1.660 \pm 0.010_{-0.064}^{+0.000}) \text{ GeV}/c^2$$

$$\Gamma = (0.269 \pm 0.021_{-0.064}^{+0.042}) \text{ GeV}/c^2$$



Summary and outlook



Muon programme

- results on polarised PDFs and gluon polarisation
- measurement of transversity and Sivers function
- many other results, e.g. ρ asymmetries, λ polarisation, azimuthal asymmetries
- more results to come from 2006 (d) and 2007 (p) data

Hadron programme

- data taking 2008 on diffractive and central production in full swing
- results on diffractive 3π production from 2004 pilot hadron run
- many new results to come!

Future plans include DVCS and DY measurements