New results from COMPASS

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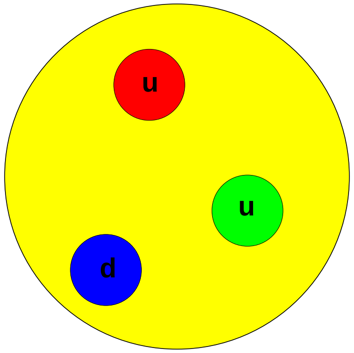
on behalf of the COMPASS collaboration

**Workshop on the Helicity Structure of the Nucleon,
BNL, June 5, 2006**

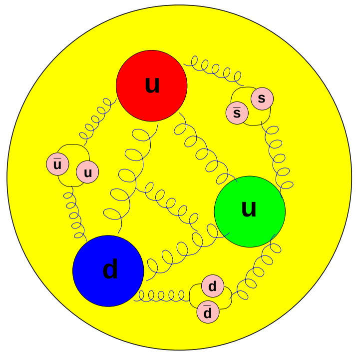
– COMPASS experiment
– Inclusive asymmetries
– Λ and ρ production
– Gluon polarisation
– Spectrometer upgrade
– Summary and outlook

The spin of the nucleon

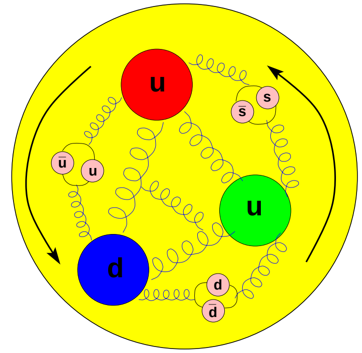


Naive parton model:
$\Rightarrow \Delta\Sigma = \Delta u_v + \Delta d_v = 1$

E155
$\Delta\Sigma = 0.23 \pm 0.07 \pm 0.19$



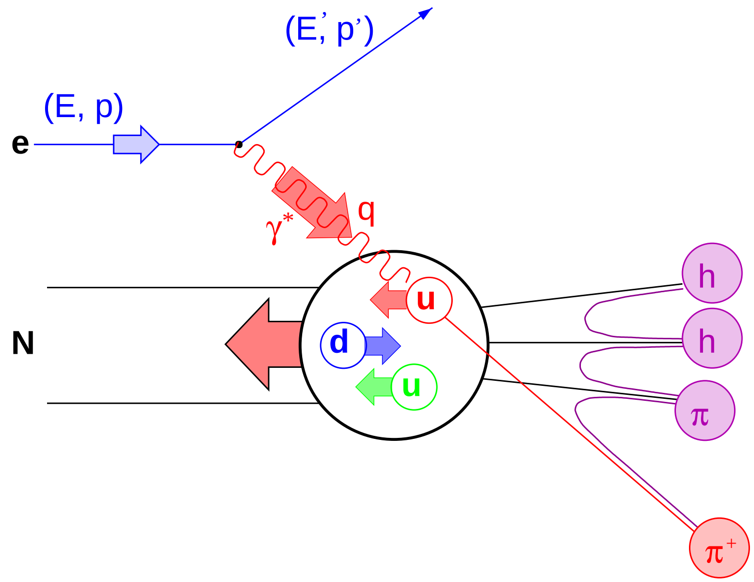
gluons important in
unpolarized case
ΔG?



complete description:
orbital angular momenta

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

Deep inelastic scattering



$$Q^2 = -q^2 \qquad x = Q^2/2M\nu$$

$$\nu = E - E' \qquad y = \nu/E$$

$z = E_h/\nu$

p_T : hadron transverse momentum

$D_q^h(x)$: fragmentation function (from quark q into hadron h)

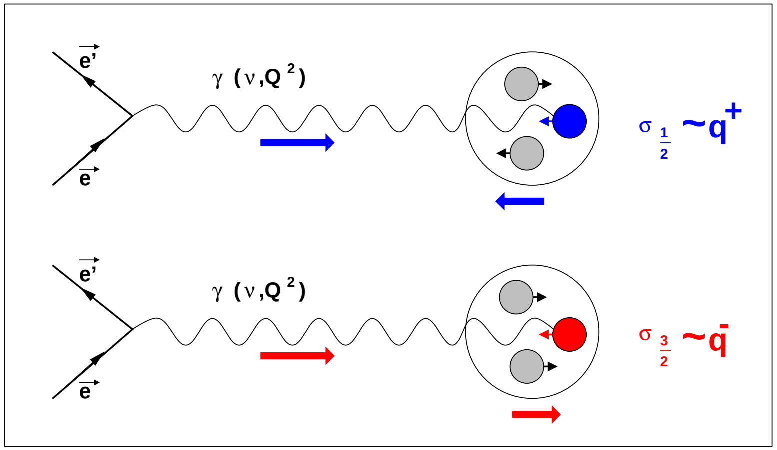
- **Inclusive cross section**

$$\frac{d^2\sigma}{d\Omega dE'} \sim \underbrace{c_1 F_1(x,Q^2) + c_2 F_2(x,Q^2)}_{\text{spin independent}} + \underbrace{c_3 g_1(x,Q^2) + c_4 g_2(x,Q^2)}_{\text{spin dependent}}$$

F_1, F_2, g_1, g_2 structure functions

Polarised deep inelastic scattering

- **absorption of polarised photons (QPM)**



$$q(x) = q(x)^{+} + q(x)^{-}$$

$$\Delta q(x) = q(x)^{+} - q(x)^{-}$$

$+$ quark ↑↑ nucleon
$-$ quark ↓↑ nucleon

- **photon nucleon asymmetry**

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

- **spin structure function**

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

COMPASS at CERN

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

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

Muon beam

Gluon polarisation

Polarised quark distributions

Polarised fragmentation functions

Transversity

Lambda polarisation

Vector meson production

DVCS

Hadron beam

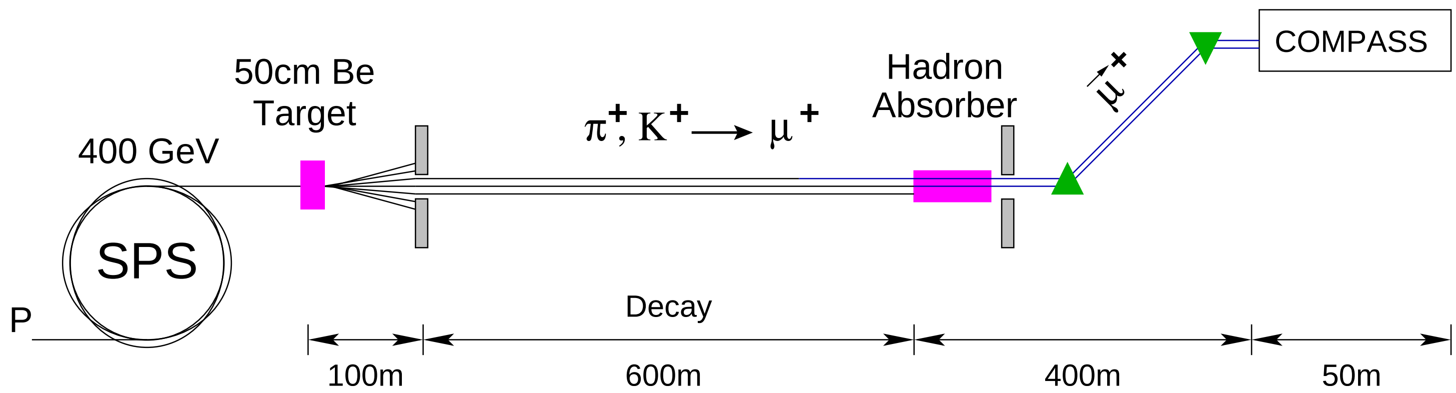
Primakoff scattering

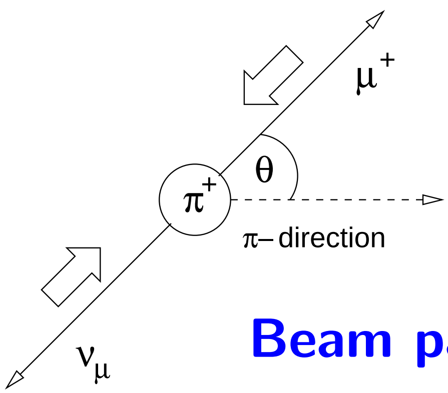
Exotic hadrons

- Glueballs
- Hybrids
- Multi-quark states

Charmed hadrons

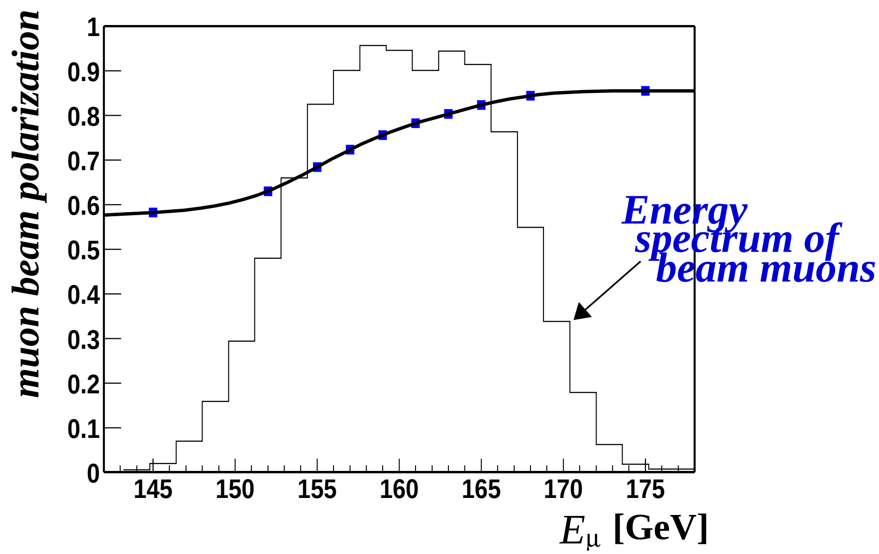
Muon beam

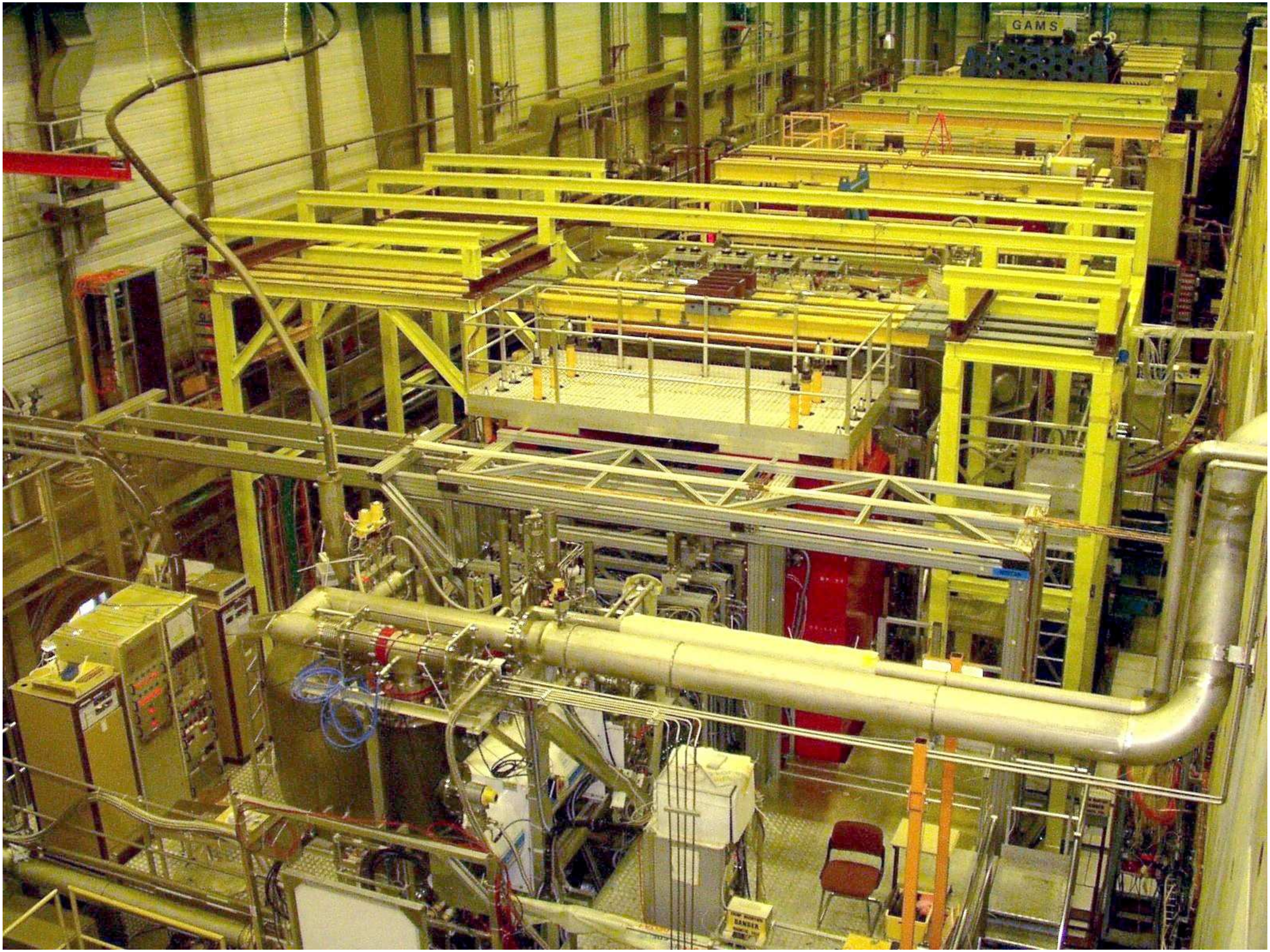




Beam parameter

- energy 160 GeV
- intensity $2 \cdot 10^8 \mu$/spill
- polarisation $\approx 76\,\%$
- emittance $\varepsilon > 6$ mm·mrad

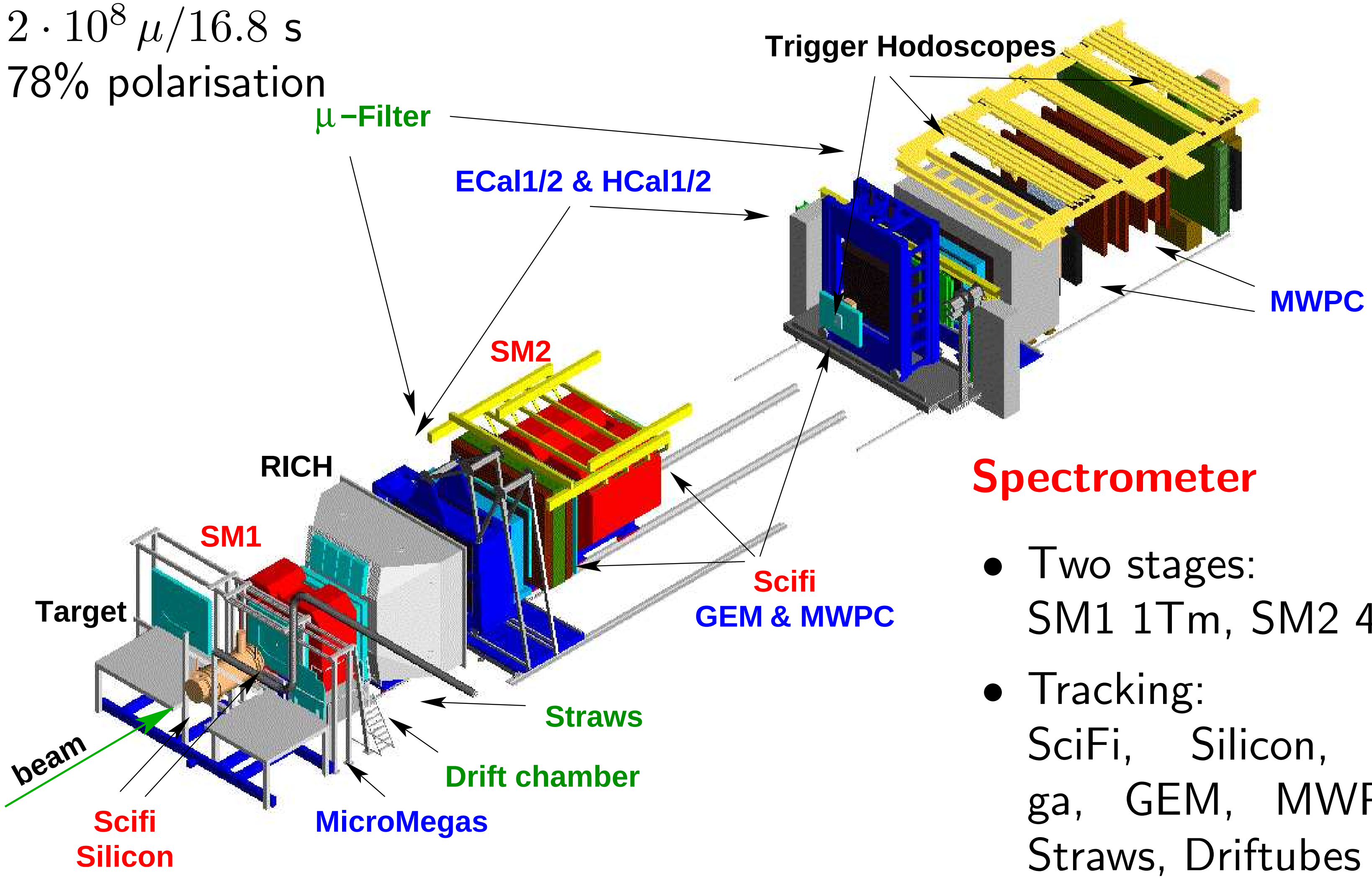



GAMS

Spectrometer

Muon beam

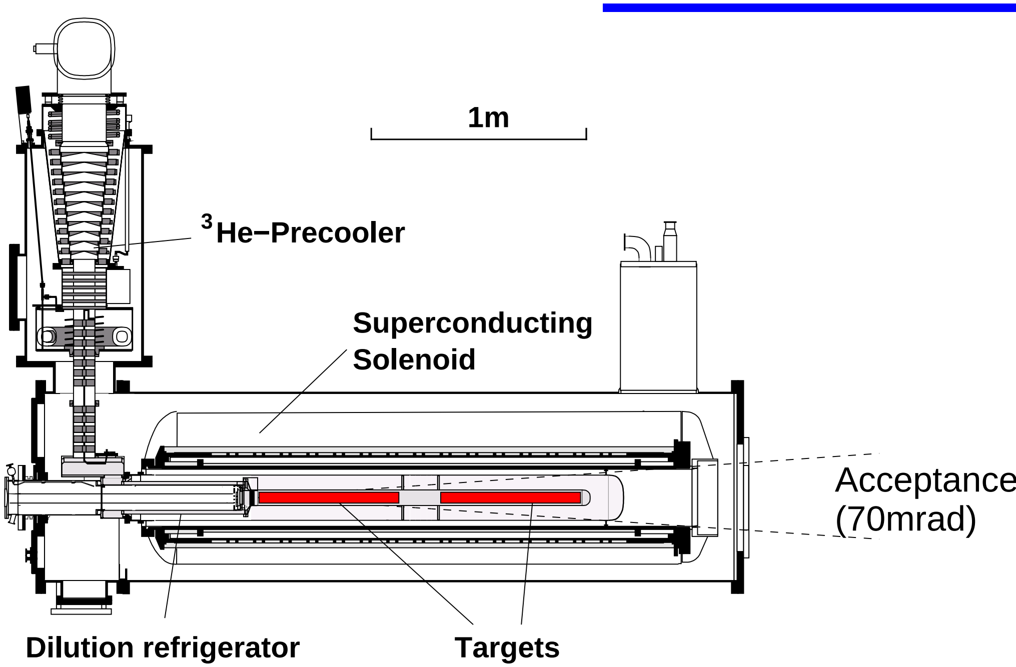
160 GeV/c
$2 \cdot 10^8 \, \mu / 16.8$ s
78% polarisation

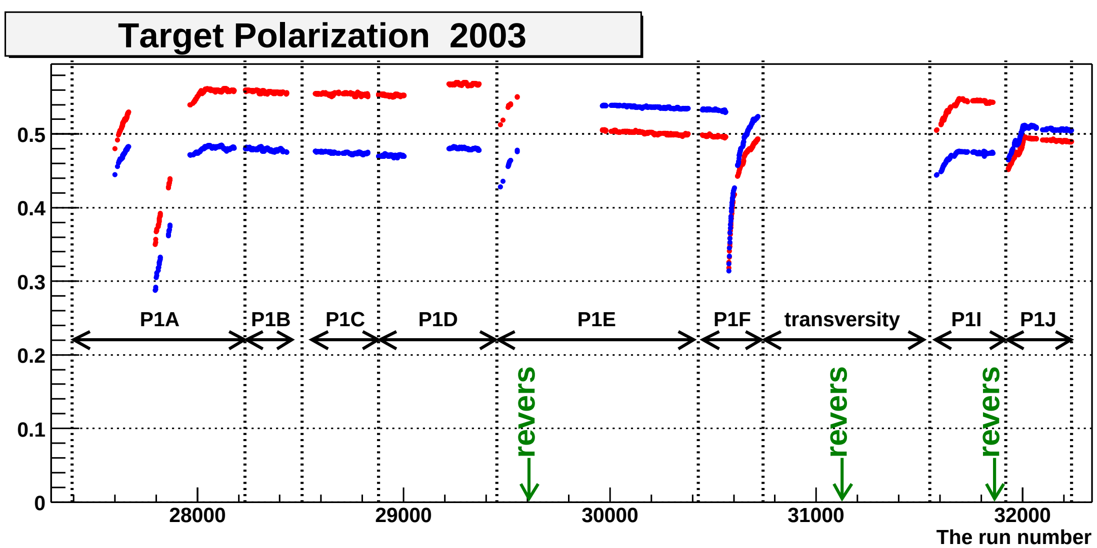


Spectrometer

- Two stages:
  SM1 1Tm, SM2 4.5Tm
- Tracking:
  SciFi, Silicon, MicroMega, GEM, MWPC, Drift, Straws, Driftubes
- PID: RICH, ECAL, HCAL, muon filter

The polarised target



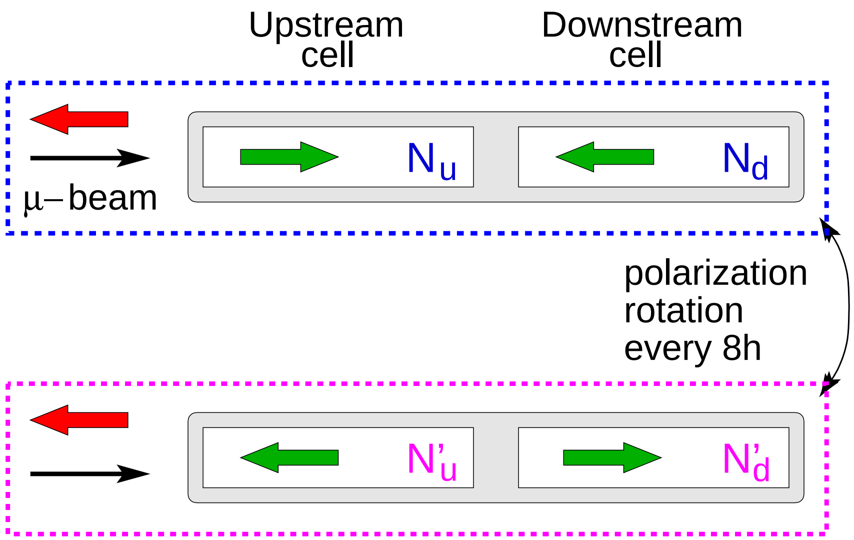


- target material: ^{6}LiD
- polarisation: $> 50\%$
- dilution factor: ~ 0.4
- Dynamic Nuclear Polarization
- solenoid field: 2.5 T
- ^{3}He/^{4}He: $T_{min} \approx$ 50 mK
- two 60 cm long target cells with opposite polarisation
- 2006 new solenoid with 180 mrad acceptance
- regular polarisation reversal by field rotation

Method

- **to be measured:**

$$A_{\parallel} = \frac{\sigma^{\Uparrow\downarrow} - \sigma^{\Uparrow\uparrow}}{\sigma^{\Uparrow\downarrow} + \sigma^{\Uparrow\uparrow}}$$



- **flux normalization:**

$$A_{\rm exp} = \frac{N_u - N_d}{N_u + N_d}$$

- **acceptance difference:**
  Polarisation rotation

- **take average asymmetry:**

$$\Rightarrow A_{\rm exp} = \frac{A + A'}{2} = \frac{1}{2}\left(\frac{N_u - N_d}{N_u + N_d} + \frac{N'_d - N'_u}{N'_u + N'_d}\right)$$

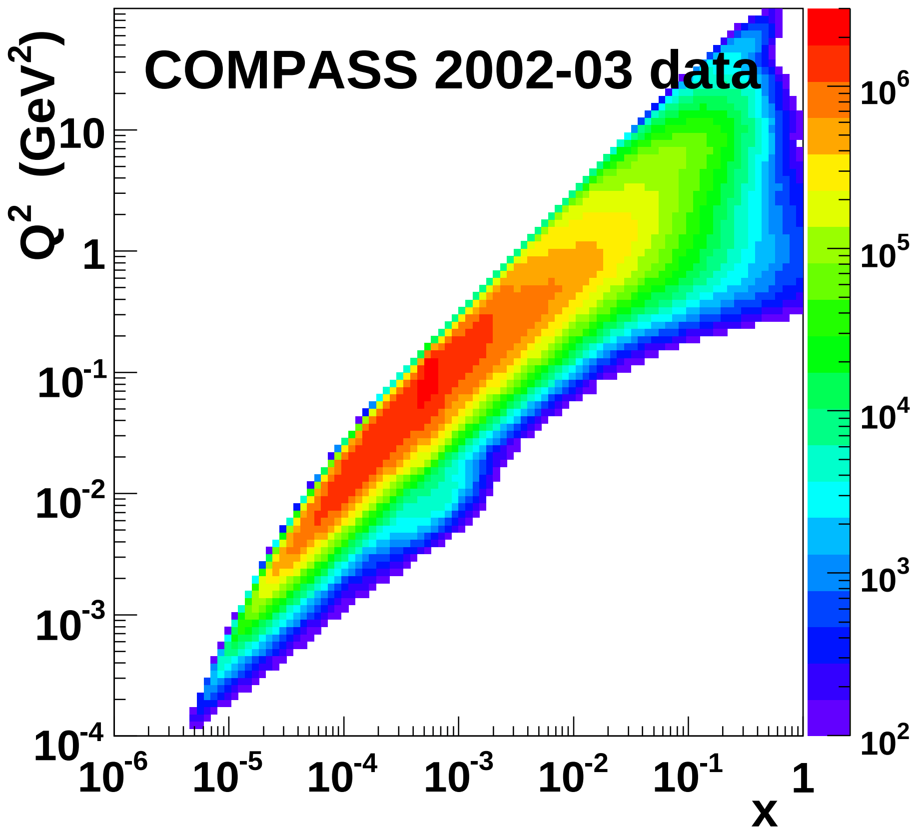
$\Rightarrow$ minimization of bias

- **experimental asymmetry**

$$A_{\rm exp} = p_\mu \; p_{\rm T} \; f \; A_{\parallel}$$

p_μ, $p_{\rm T}$ beam and target polarisation
f dilution factor

Data taking 2002 – 2004



New results on

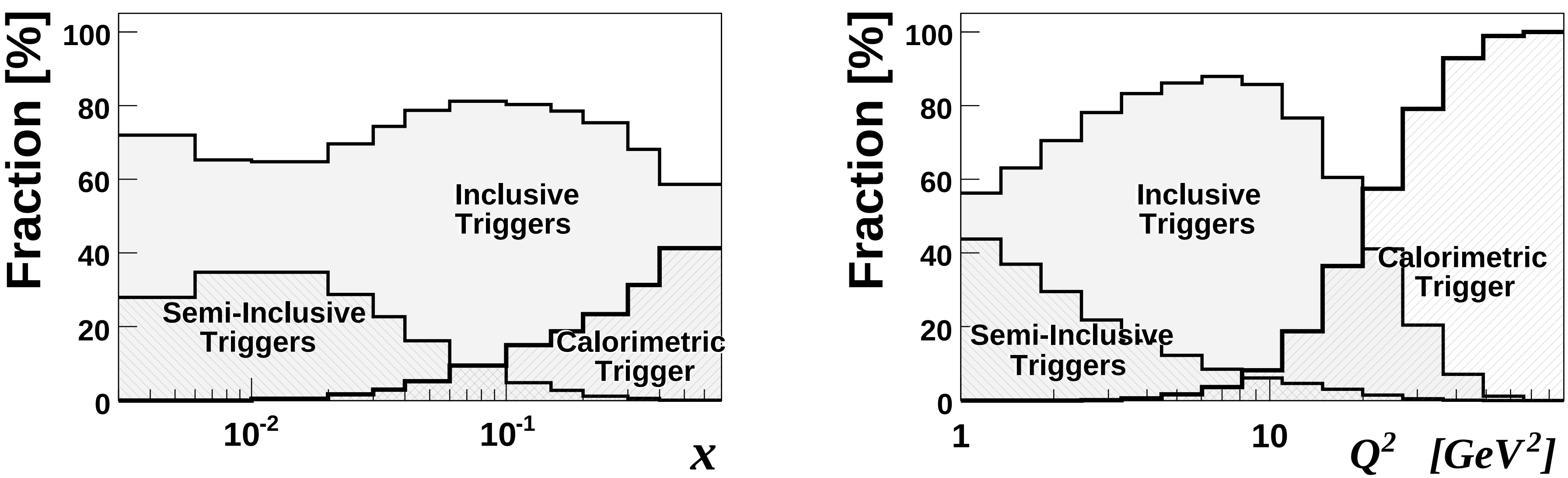
- inclusive asymmetries
- open charm production
- high p_T hadrons pairs
- Λ polarisation
- exclusive ρ production

	2002	2003	2004
Beam Time	106d	90d	110d
Preparation	30d	7d	3d
Integrated luminosity / fb^{-1}	1	1.2	$\sim$ 2.4
(20% for transverse target polarisation)			

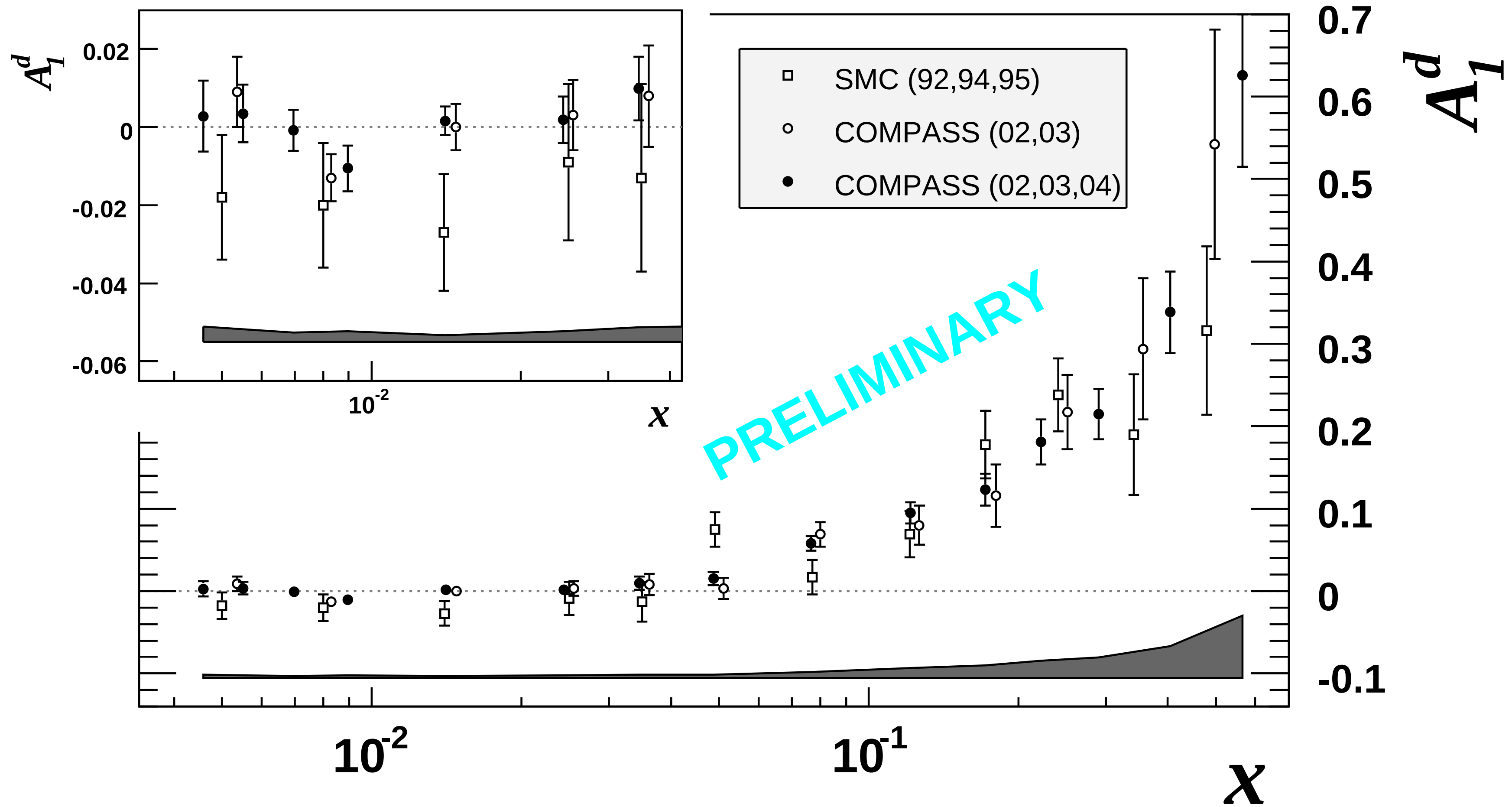
Longitudinal spin structure

Inclusive measurements ($Q^2 > 1$ GeV^2)

- new preliminary results from 2002 – 2004
  (published 02/03: PLB 612(2005) 154, improved by a factor of > 2)
- $88 \cdot 10^6$ events with $x > 0.004$, $0.1 < y < 0.9$
- 2/3 inclusive triggers, 1/3 hadronic triggers (semi-inclusive, calorimetric)
- systematics: fake configurations, compare different microwaves settings etc
  $\Longrightarrow$ no effects seen
- bin to bin migration and bias through hadronics triggers studied with MC
  $\Longrightarrow$ negligible effects

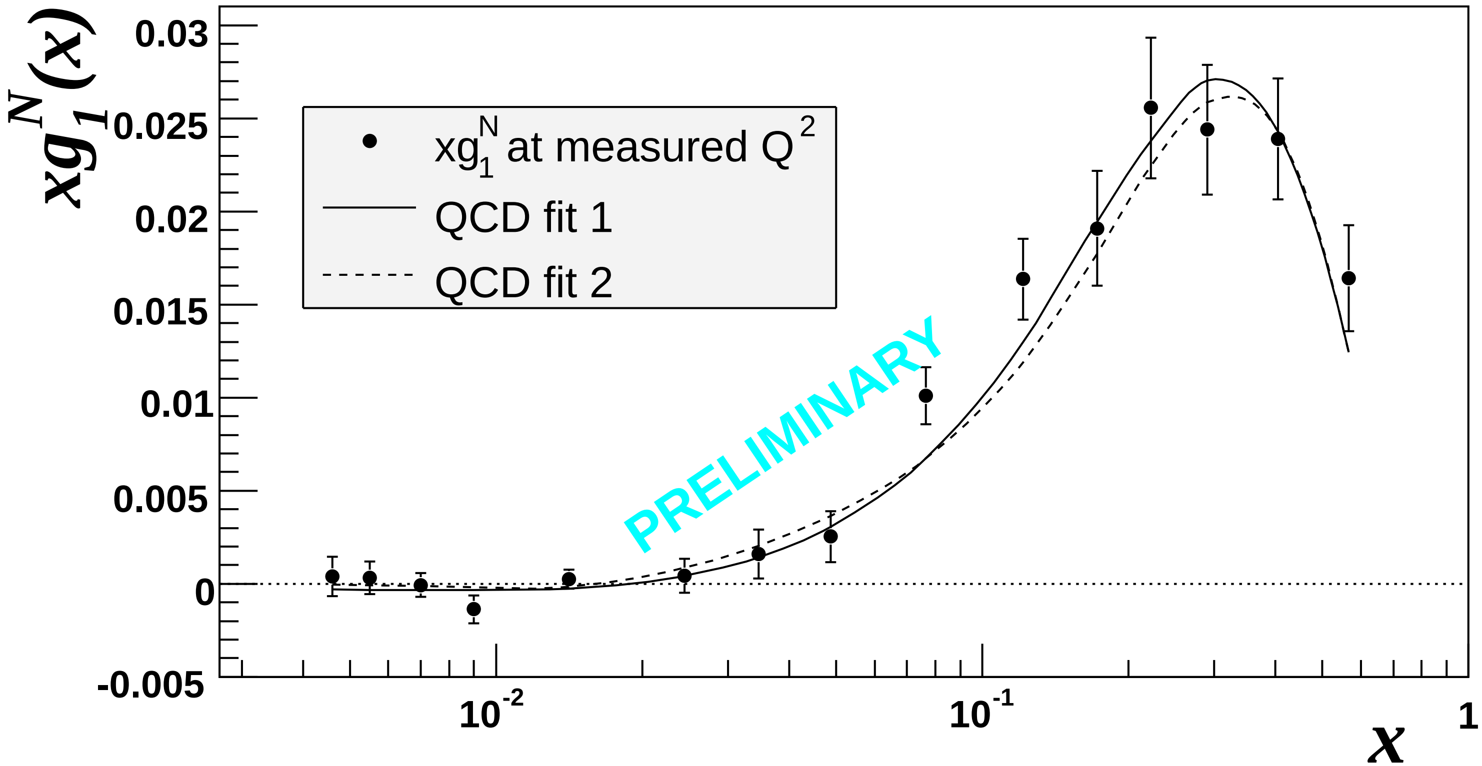


Inclusive asymmetries for $Q^2 > 1$ GeV^2



- systematic effects: error on p_μ (5%), p_T (5%, f (2–3%), D (6%) $\Longrightarrow \delta A_1 \approx 0.1 A_1$
- additional contributions from false asymmetries,radiative corrections

Spin structure function $g_1(x)$

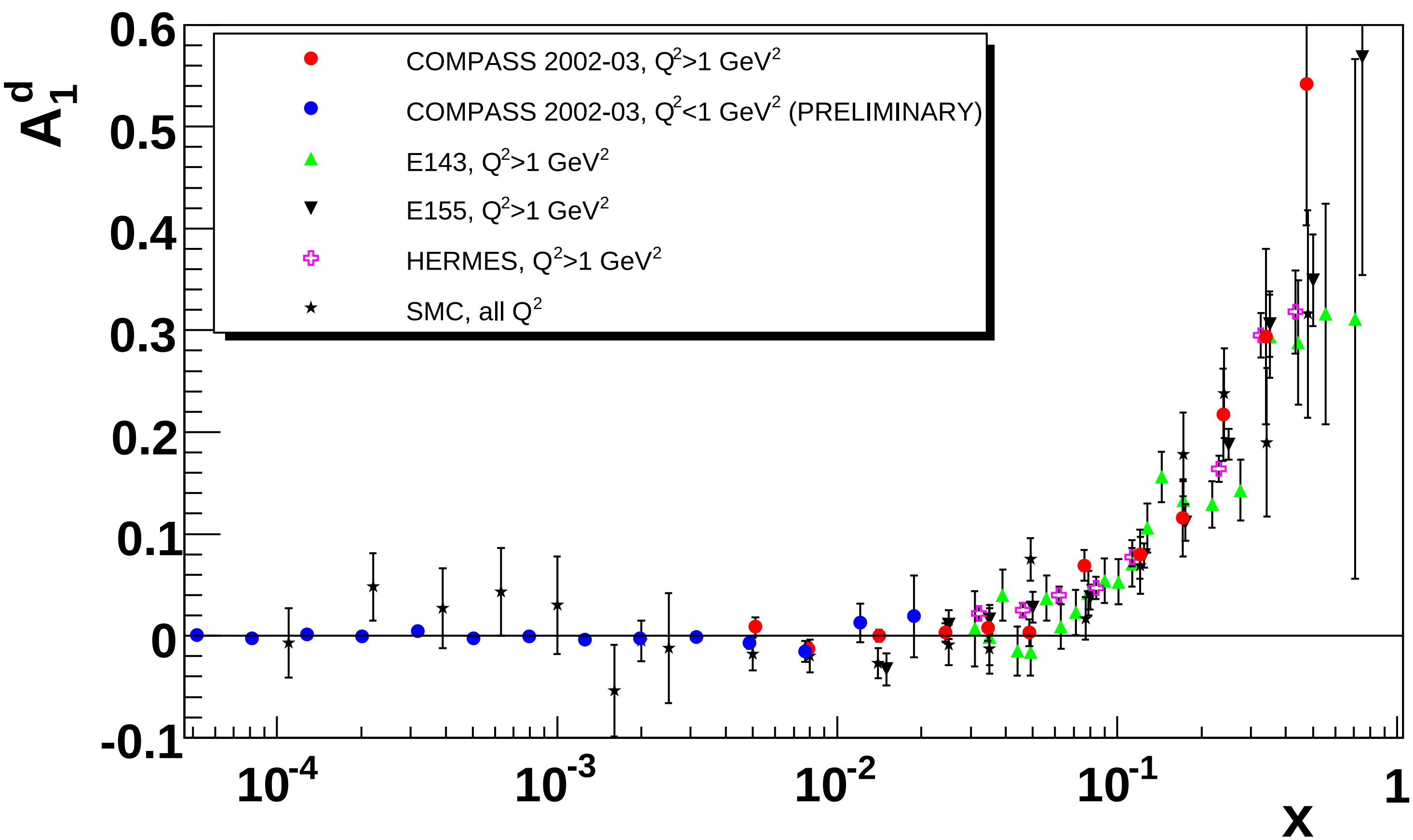


- xg_1 points at measured Q^2
- NLO QCD fit ($\overline{\mathrm{MS}}$) to world data
- preliminary result:

$$\Gamma_1^N = 0.0502 \pm 0.0028(\text{stat}) \pm 0.0020(\text{evol.}) \pm 0.0051(\text{syst.})$$

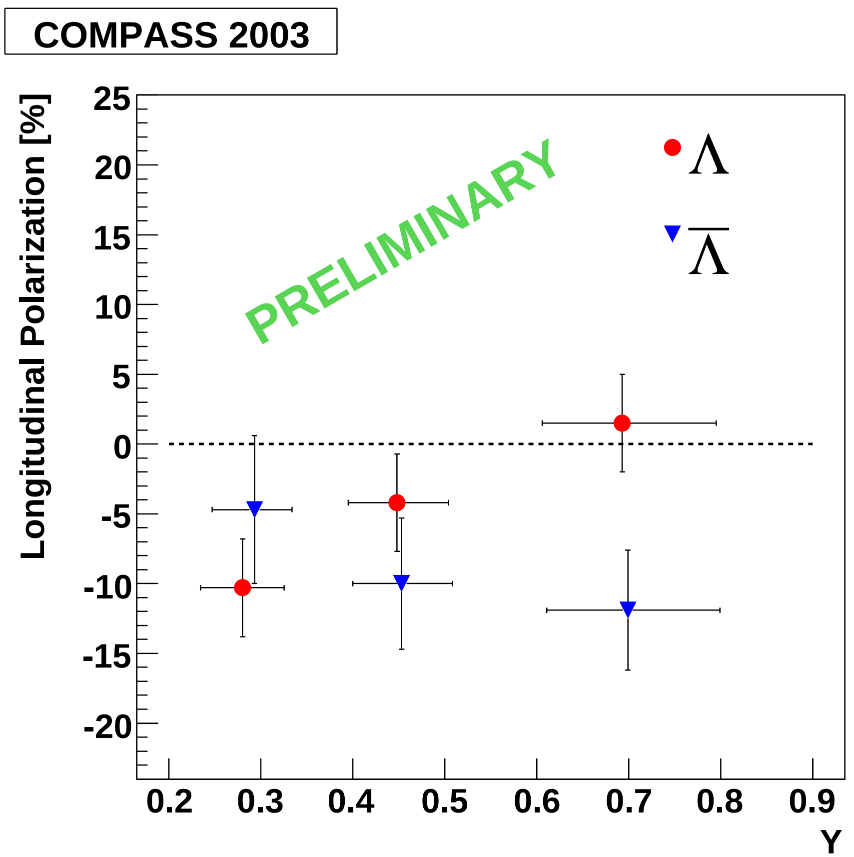
- data for $0.004 < x < 0.7$, QCD fit used for extrapolation
- contribution of unmeasured region about 3 %

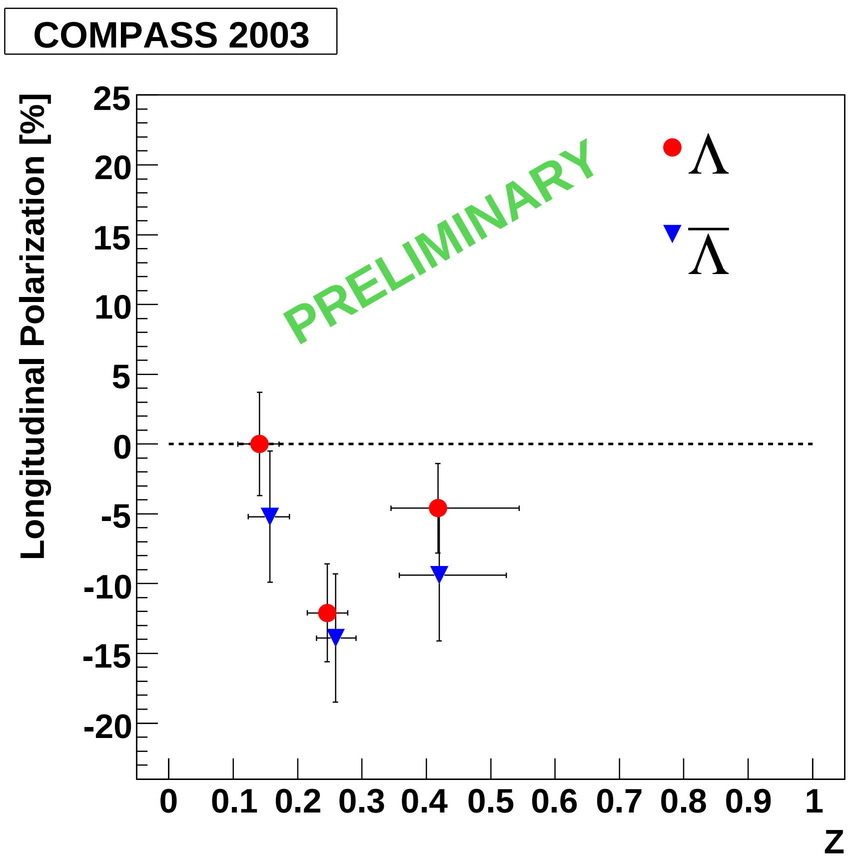
Inclusive asymmetries for $Q^2 < 1$ GeV^2



- 2002 – 2003 data, COMPASS error 10 times smaller than previous measurement
- $A_1^{\rm d}$ is compatible with 0 at small x
- more data for $Q^2 < 1$ GeV^2 and $Q^2 > 1$ GeV^2, semi-inclusive asymmetries

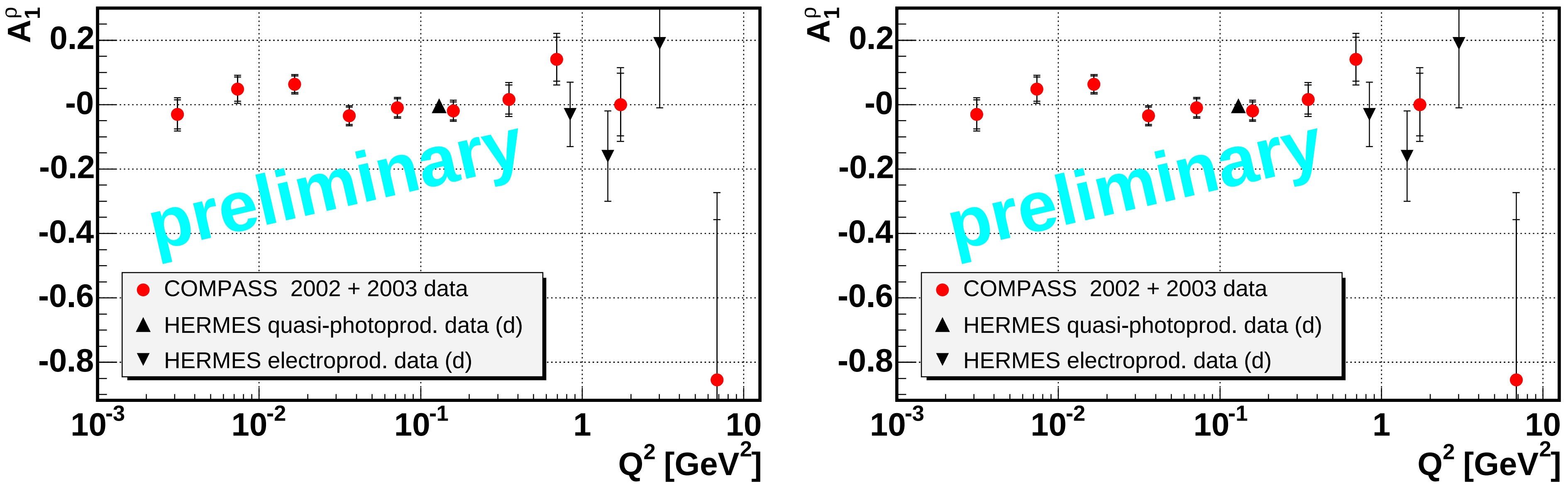
Longitudinal Λ and $\bar{\Lambda}$ polarisation





- Λ polarisation related to spin transfer from struck quark $\longrightarrow$ sensitivity to Δs?
- 2003 data: 31000 Λ, 18000 $\bar{\Lambda}$ for $Q^2 > 1$ GeV^2
- more data from 2004

Hard exclusive ρ^0 production

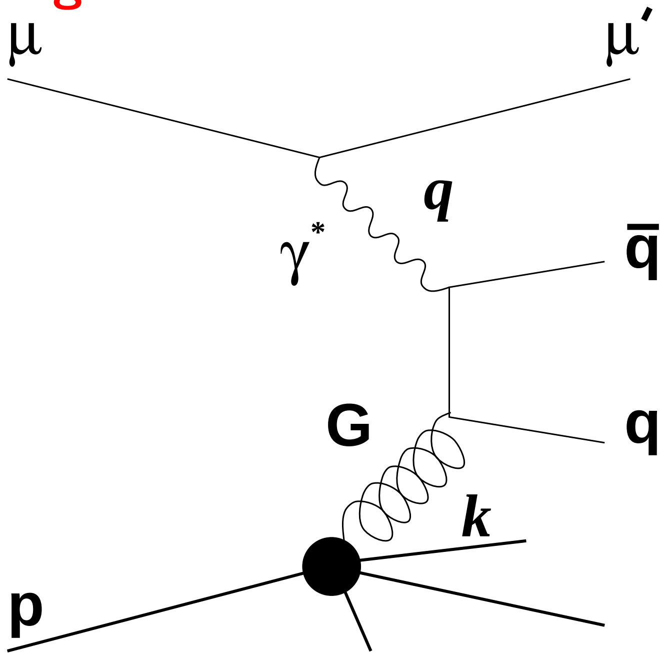


- large statistics of diffractive ρ, Φ, J/Ψ
- 2.4 M events with ρ^0 from 2002 and 2003
- large range in Q^2 and x
- A_1 for ρ^0 compatible with zero, more data from 2004
- measurement of spin density matrix elements

Gluon polarisation

$\Delta G/G$ measurement in DIS

- **Photon gluon fusion**



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

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

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

- **Methods**
  - **Open charm production**

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

    $\rightarrow D^0 \rightarrow \pi K$ BR: 4%

    hard scale: m_c^2

    clean channel,
    limited staticstics

  - **High p_T hadron pairs**

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

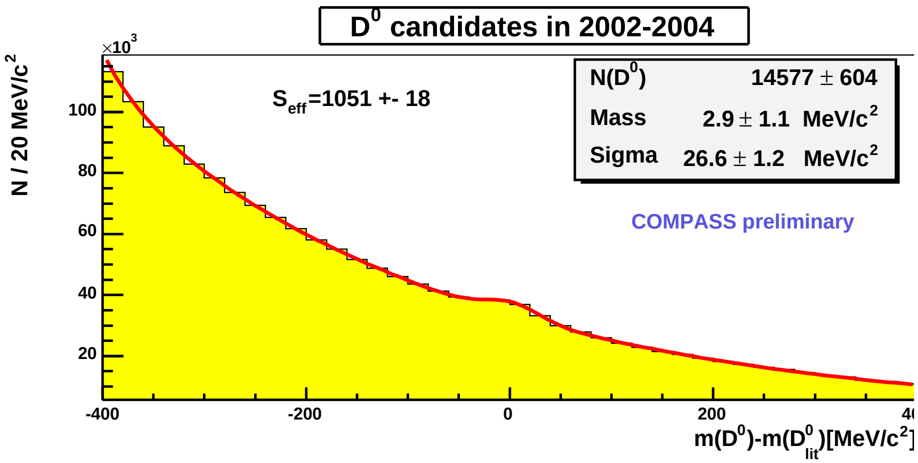
    $\rightarrow$ 2 jets or H^+H^-

    hard scale: Q^2 or Σp_T^2

    oppositely charged hadrons pairs with large p_T und $\Delta\Phi \approx \pi$

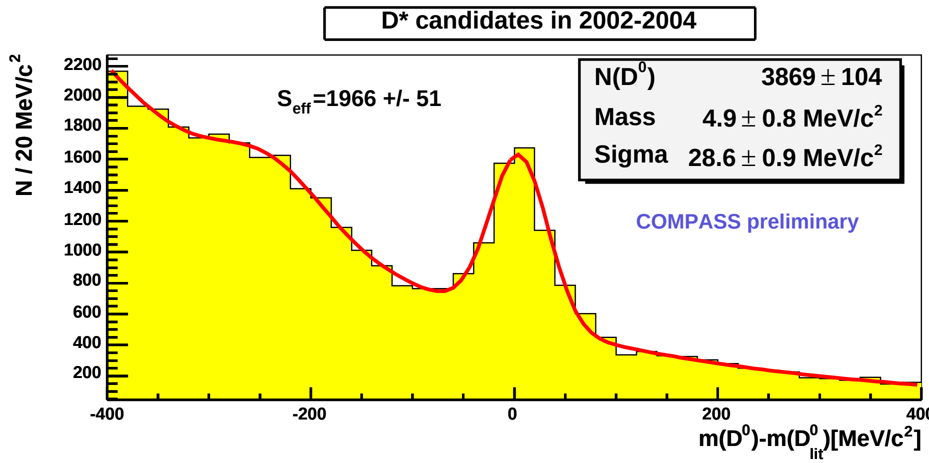
ΔG from open charm: Mass spectra

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



- no decay vertex reconstruction
- Kaon identification by RICH essential
- cut on D^0 kinematics (z_{D^0}, $\cos(\theta)$)
- effective signal: $S_{\text{eff}} = \frac{S}{1+S/B}$

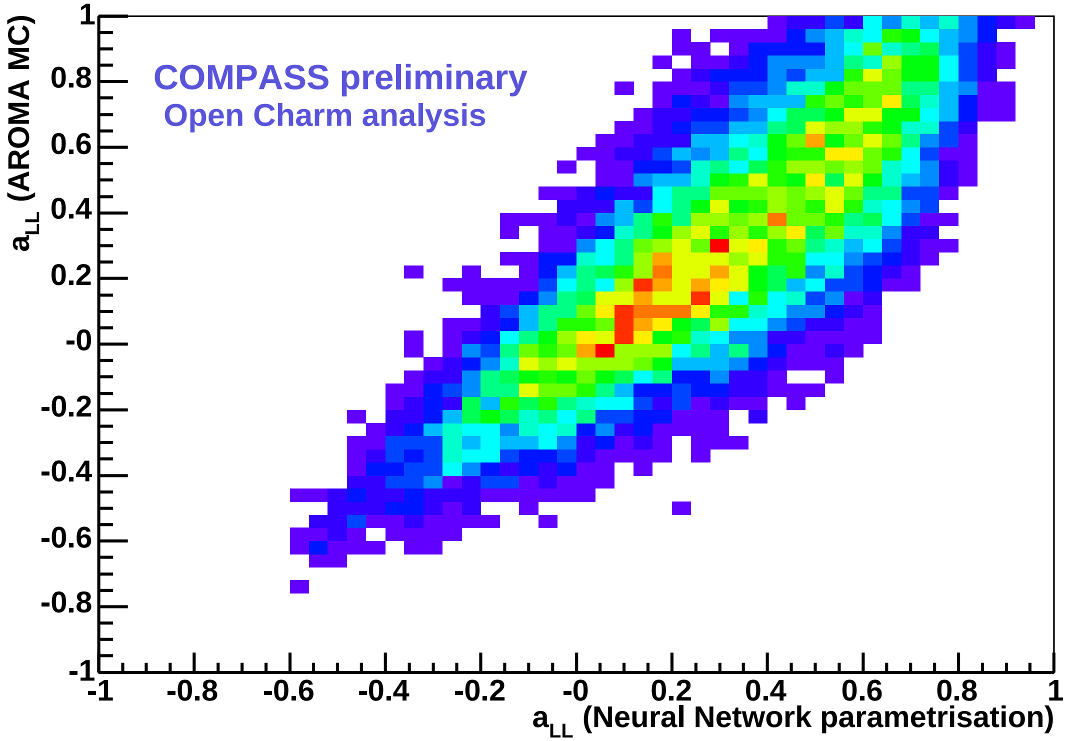
Tagged: $D^* \rightarrow D^0\pi_{\text{slow}} \rightarrow (K\pi)\pi_{\text{slow}}$



- cut on mass difference $M_{K\pi\pi} - M_{K\pi} - M_{\pi}$
- 3900 D^0 from D^*

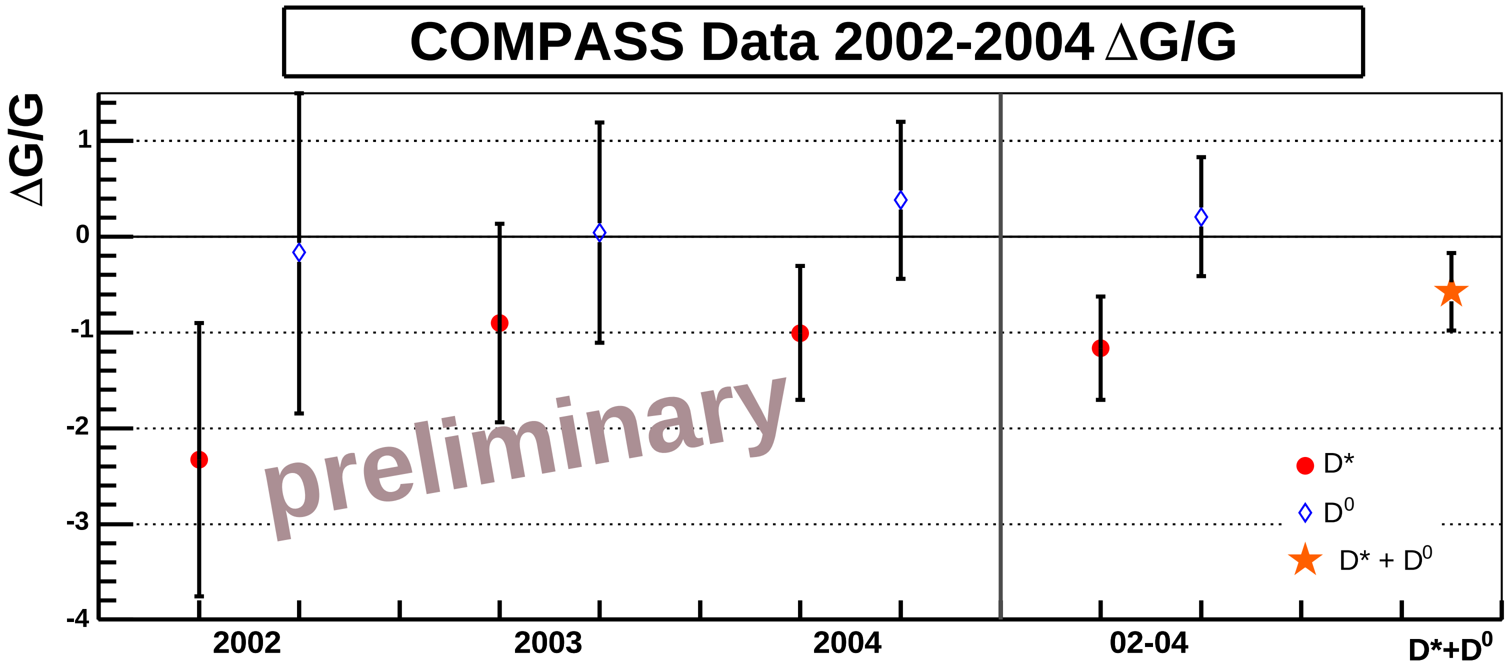
Extraction of $\Delta G/G$

- experimental asymmmetry $A_{\mathrm{exp}} = p_\mu \, p_{\mathrm{T}} \, f \, a_{\mathrm{LL}} \frac{S}{S+B} \frac{\Delta G}{G}$
- weighting method used $(p_\mu f a_{\mathrm{LL}} \frac{S}{S+B})$
- needs $\langle a_{\mathrm{LL}}^{\mathrm{PGF}} \rangle$, not exactly calculable from data



- use neural net trained on MC
- AROMA generator for MC
- good description of data distributions by MC

Result for $\Delta G/G$



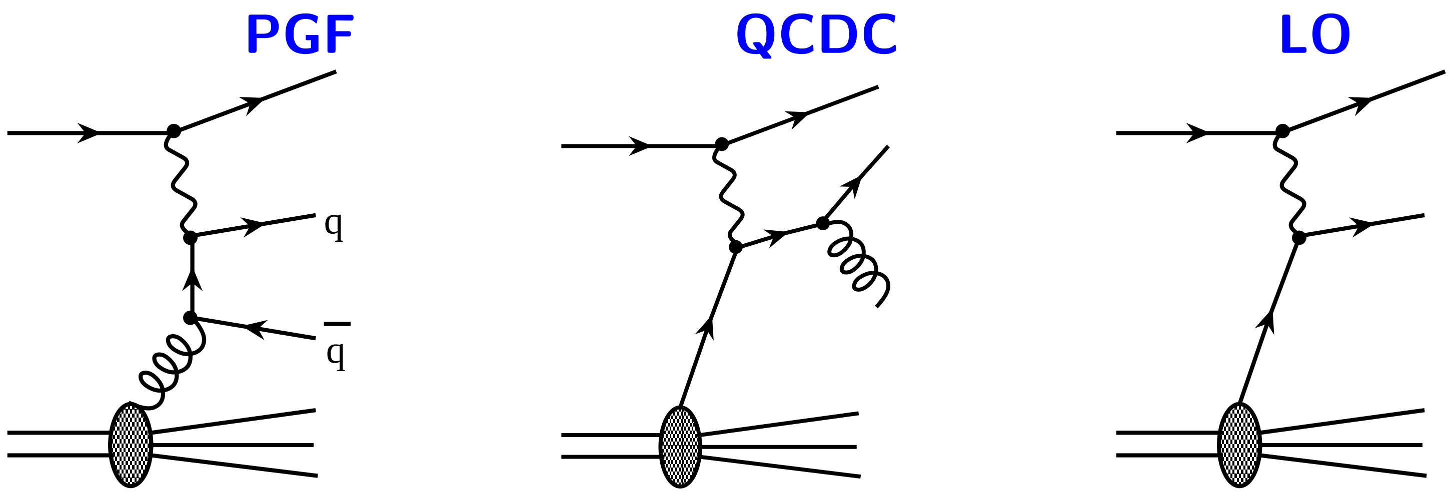
- preliminary result at $\langle x_{\mathrm{g}} \rangle = 0.15$ (RMS: 0.08) from 2002–2004

$$\Delta G/G = -0.57 \pm 0.41\,(\text{stat})$$

- systematic error under study
- plans: absolute cross sections, NLO analysis, more channels

High p_T hadron pairs ($Q^2 > 1$ GeV^2)

- contributions to experimental asymmetry



$$\frac{A_\parallel}{D} = R_\mathrm{PGF} \left\langle \frac{A_{LL}^\mathrm{PGF}}{D} \right\rangle \frac{\Delta G}{G} + \left(R_\mathrm{QCDC} \left\langle A_{LL}^\mathrm{QCDC} \right\rangle + R_\mathrm{LO} \left\langle A_{LL}^\mathrm{LO} \right\rangle \right) A_1^\mathrm{d}$$

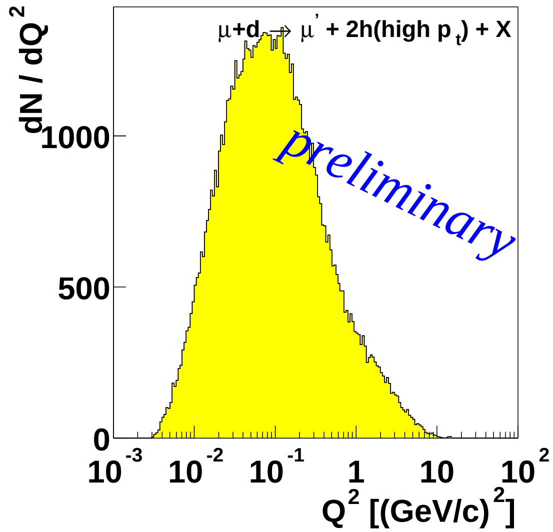
- Monte Carlo for R, $\langle A_{LL} \rangle$
- data selection

Current fragmentation: $x_F > 0.1$ and $z > 0.1$
Radiative corrections/ photon polarisation: $0.1 < y < 0.9$
High p_T: $p_{\mathrm{T},1}, p_{\mathrm{T},2} > 0.7$ GeV and $p_{\mathrm{T},1}^2 + p_{\mathrm{T},2}^2 > 2.5$ GeV^2

$\Delta G/G$ for $Q^2 > 1$ GeV^2

- 2002/03 data (prelim.)

$$A_{\|}/D = -0.015 \pm 0.080\,(\text{stat.}) \pm 0.013\,(\text{syst.})$$



- Monte Carlo sample generated with LEPTO reasonable agreement with data
- additional x cut $\Rightarrow$ A_1^{d} small, LO and QCDC neglected
- preliminary result:
  $\langle \frac{A_{LL}^{\mathrm{PGF}}}{D} \rangle = -0.75 \pm 0.05$
  $R_{\mathrm{PGF}} = 0.33 \pm 0.07$, $\langle x_g \rangle = 0.13$ (RMS=0.08)

$$\Delta G/G = 0.06 \pm 0.31\,(\text{stat.}) \pm 0.06\,(\text{syst.})$$

- main contribution to systematic error: false asymmetries

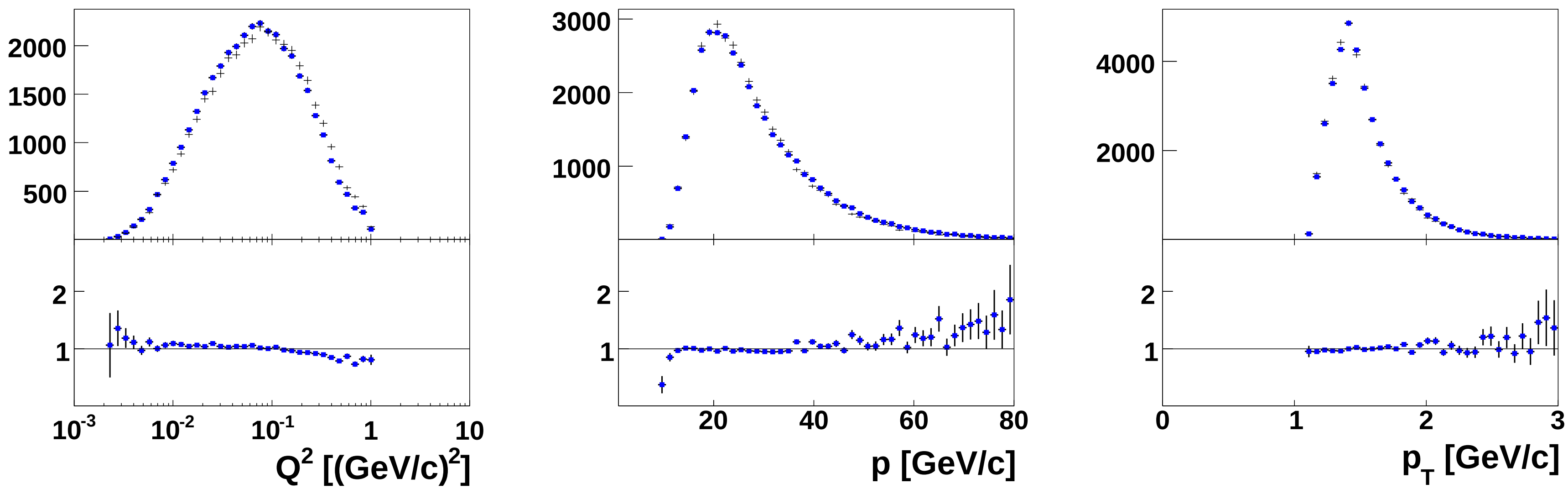
- only 10% of statistics at $Q^2 > 1$ GeV^2
- expectation for 2002-2004: $\delta(\Delta G/G) = 0.22$
- improvement by neural net selection studied
- single hadron analysis started

High p_T hadron pairs ($Q^2 < 1$ GeV^2)

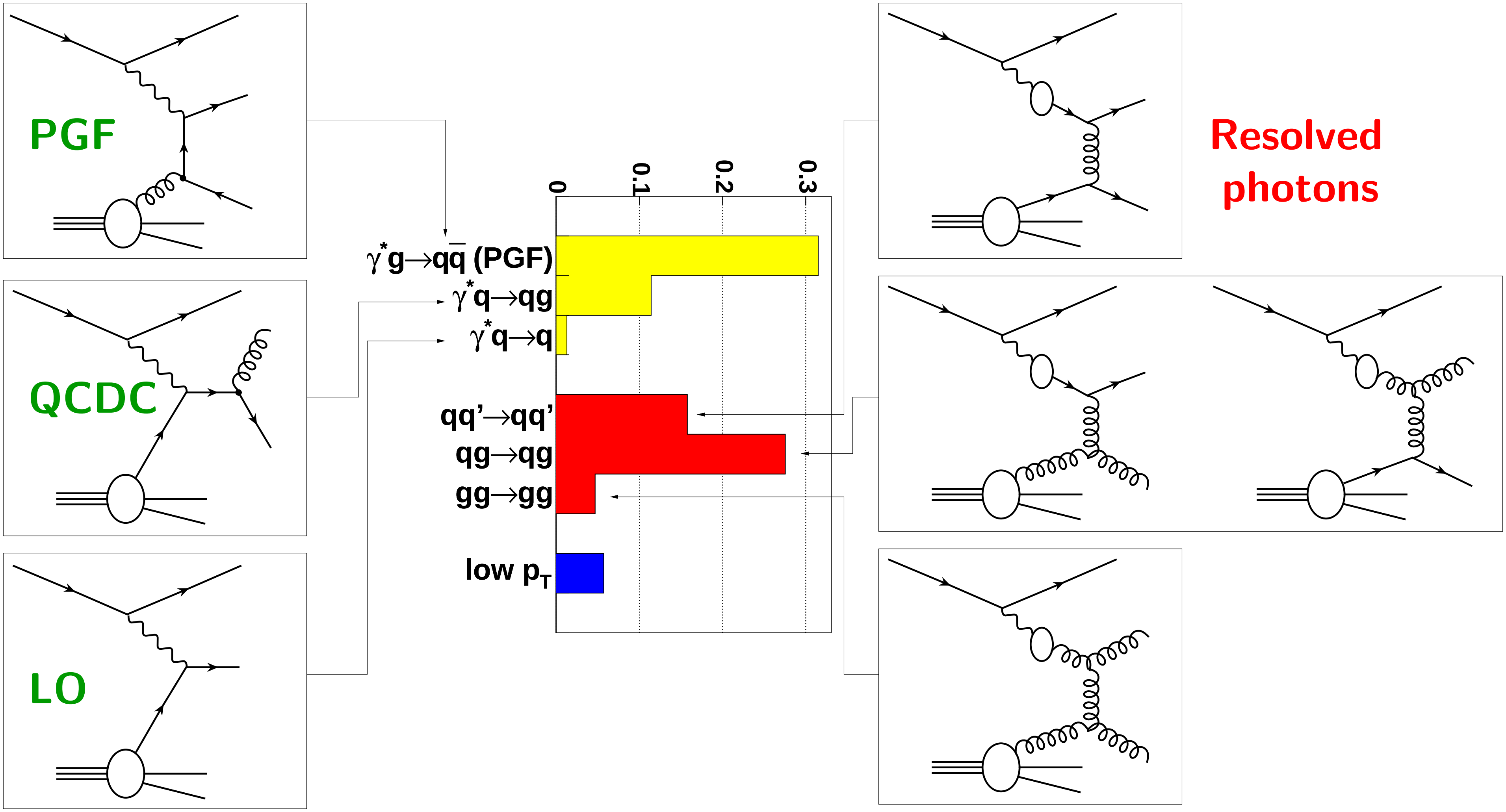
- much more statistics (500k events from 2002–2004)
  but additional background from resolved photon processes
- 2002–2003 published (PLB 633 (2006) 25)
- data selection similar to large Q^2 but $0.35 < y < 0.9$
- preliminary result with $\langle D \rangle = 0.64$

$$A_{||}/D = 0.004 \pm 0.013\,(\text{stat.}) \pm 0.003\,(\text{exp.syst.})$$

- MC simulation with PYTHIA compared to data (blue points)



Contributions to asymmetry



- LO, low p_{T} neglected

Extraction of $\Delta G/G$

COMPASS

Estimate of resolved photon contribution

- polarised PDFs in deuteron and photon needed
- polarised photon PDFs are sum of non perturbative and perturbative part
- estimate non perturbative contribution from unpolarised photon PDFs:

$$-q^{\gamma}_{\mathrm{VMD}} < \Delta q^{\gamma}_{\mathrm{VMD}} < q^{\gamma}_{\mathrm{VMD}}$$

- use as contribution to systematic error

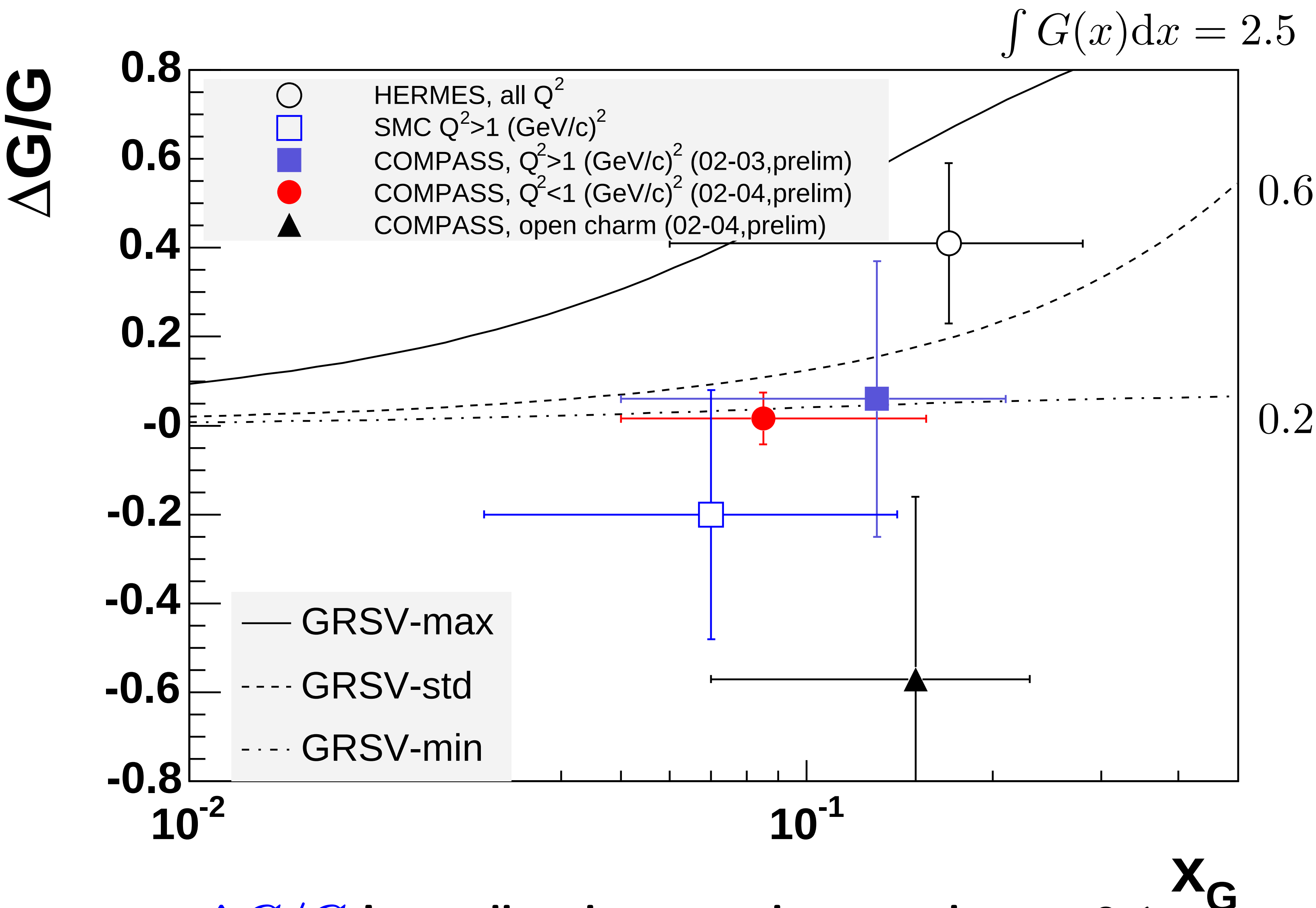
Preliminary result

- determination of R_{PGF} and a_{LL} from Monte Carlo
- most sensitive parameters in PYTHIA: $k^{\mathrm{N}}_{\mathrm{T}}$ and k^{N}_{γ}

$$\Delta G/G(x_{\mathrm{g}} = 0.085^{+0.07}_{-0.035}, \mu^2 = 3\ \mathrm{GeV}^2) = 0.016 \pm 0.058(\mathrm{stat.}) \pm 0.055(\mathrm{syst.})$$

- systematic error includes exp. syst.(0.014) (mainly false asymmetries), MC syst.(0.052) and estimate of photon contribution (0.013)

$\Delta G/G$ measurements in DIS



$\Delta G/G$ **is small or has a node around** $x_{\mathrm{g}} \approx 0.1$

Detector upgrade

Upgrades in 2006

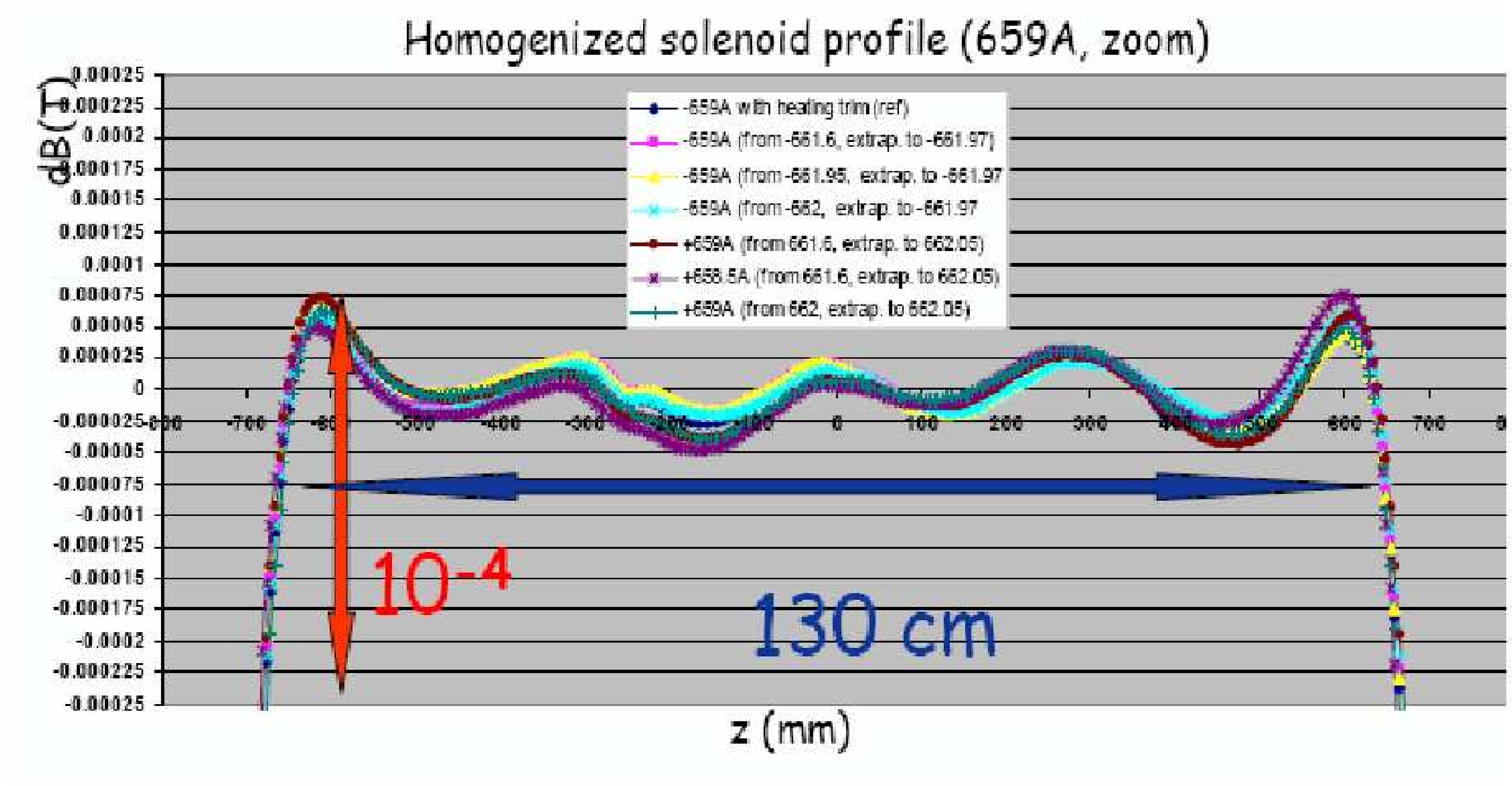
- **Polarised target:** large acceptance magnet system
- **RICH1**: central photon detectors replaced by MAPMTs
- new read out using APVs for outer photon detectors
- **RICH wall** (preshower for ECAL1)
- **ECAL1** Electromagnetic calorimeter in first stage
- More **large angle tracking** in first stage
- **DAQ** and **DCS** consolidation and upgrades
- Other small additions

Polarised target magnet

COMPASS

- new target magnet: SMC (70 mrad) $\Longrightarrow$ COMPASS (180 mrad)
- gain in statistics at least 30%
- testing of magnet completed, few problems identified

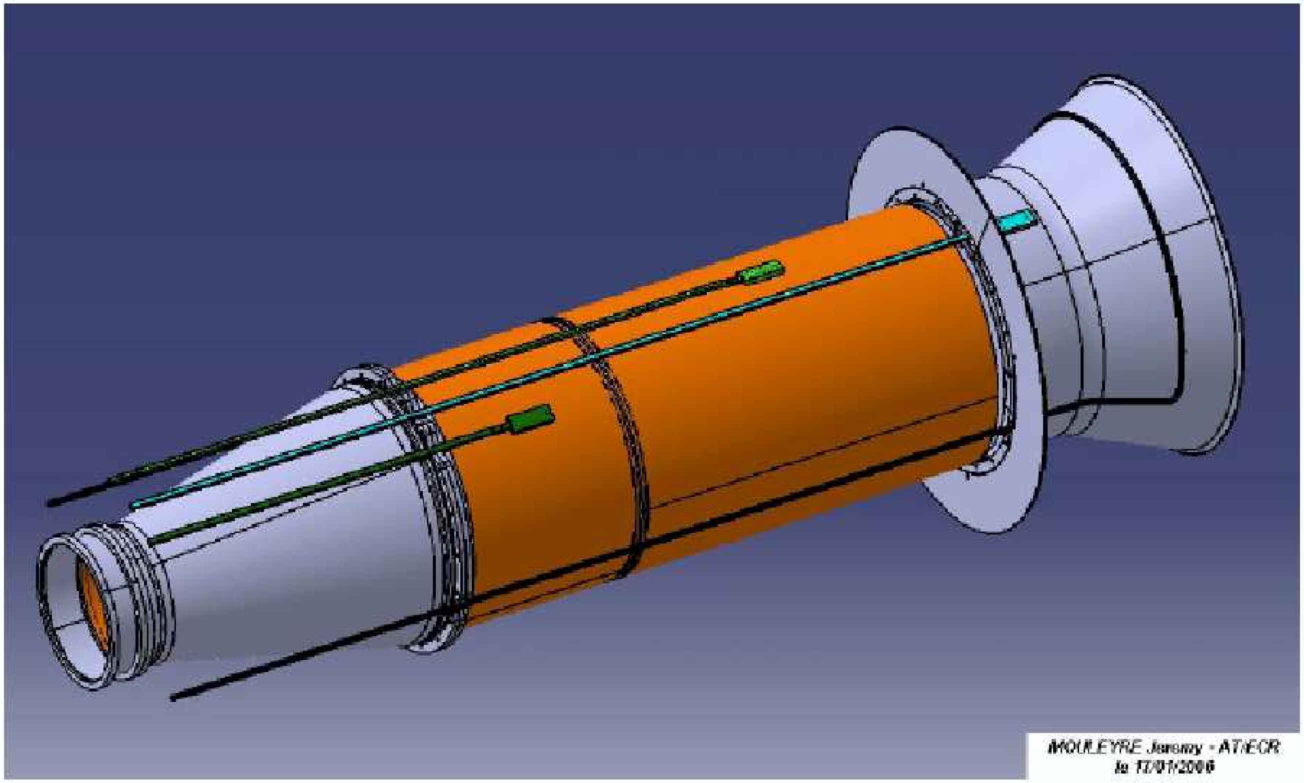
Polarised target magnet



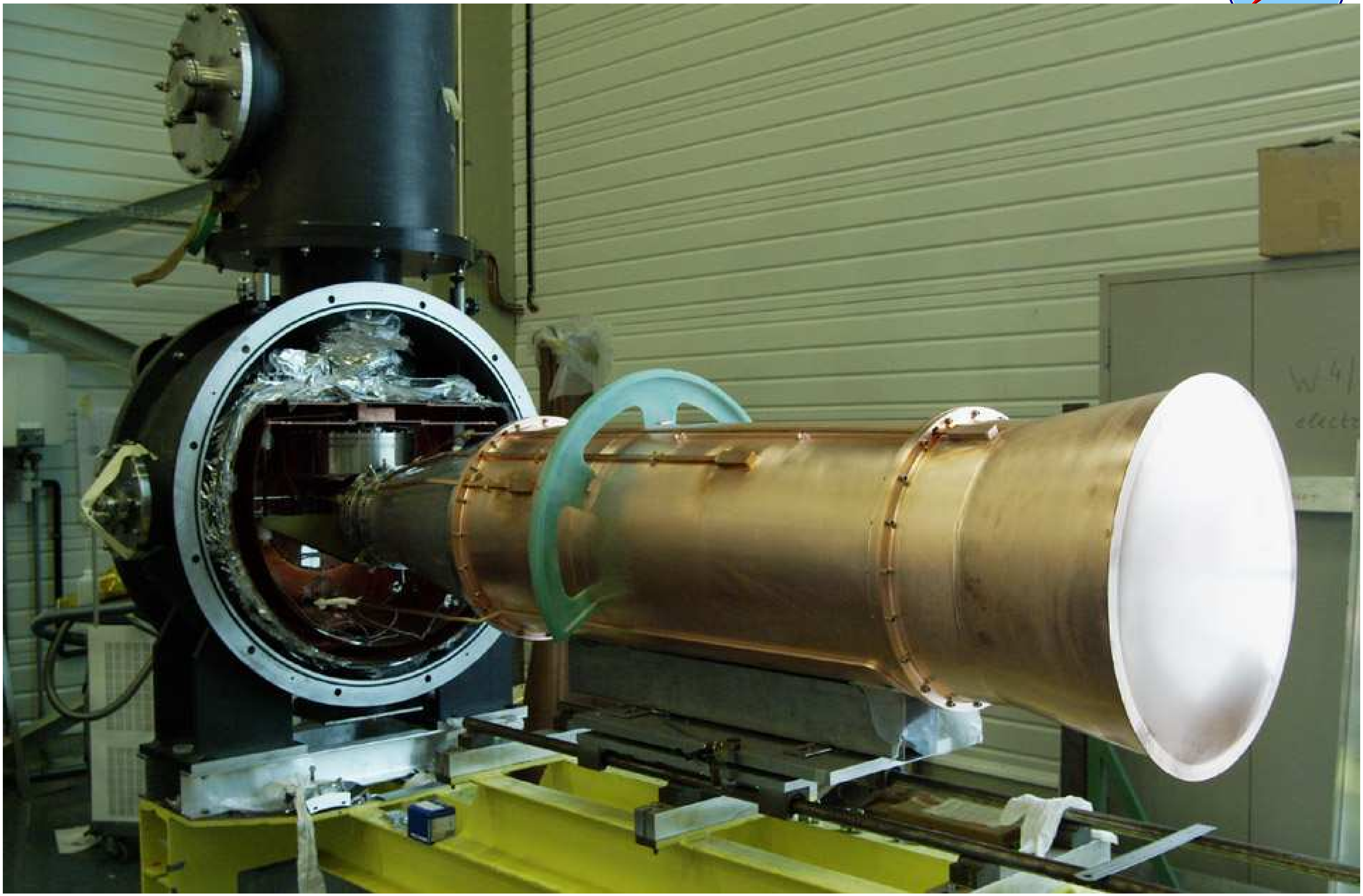
- Field homogeneity of $3 \cdot 10^{-5}$ at Saclay
- $7 \cdot 10^{-5}$ reached in presence of SM1 dipole field
- delicate operation due to short in one correction coil

Polarised target microwave cavity

- match for larger acceptance
- new 3 cell microwave cavity (- ++ -)
- reduction of false asymmetries



New microwave cavity



RICH upgrade

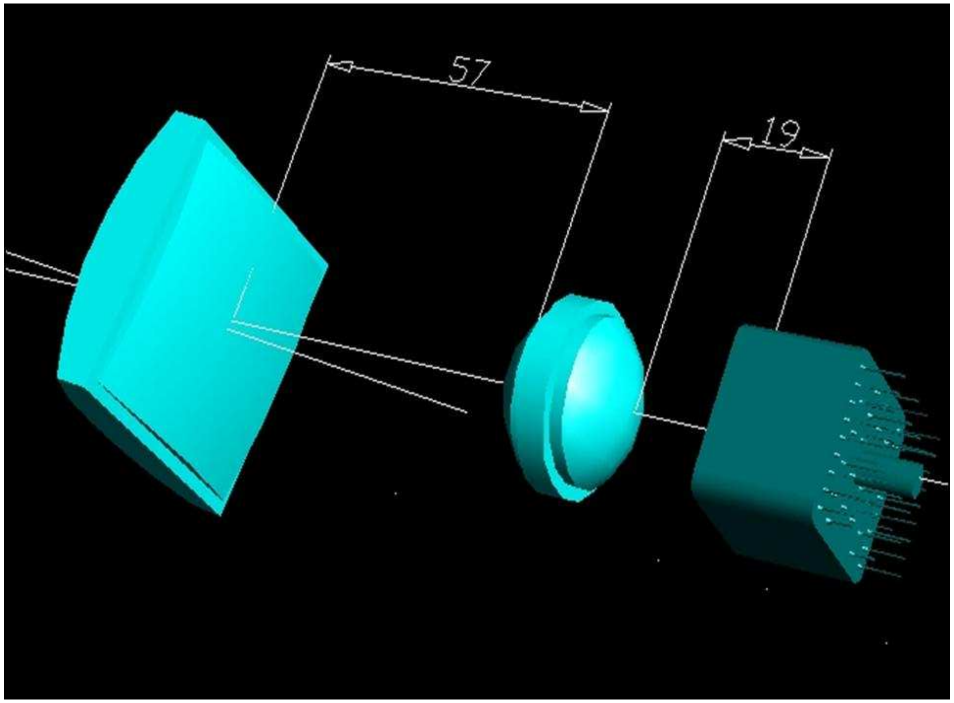
Inner photon detectors

- read out changed from MWPCs to MAPMTs for the inner quarter
- telescope in front of MAPMT for cost effectiveness and to avoid dead reagions
- significant increase in number of photons
- space resolution a bit worse but in total increase in precision
- excellent timing, no dead time, improved efficiency

Outer photon detectors

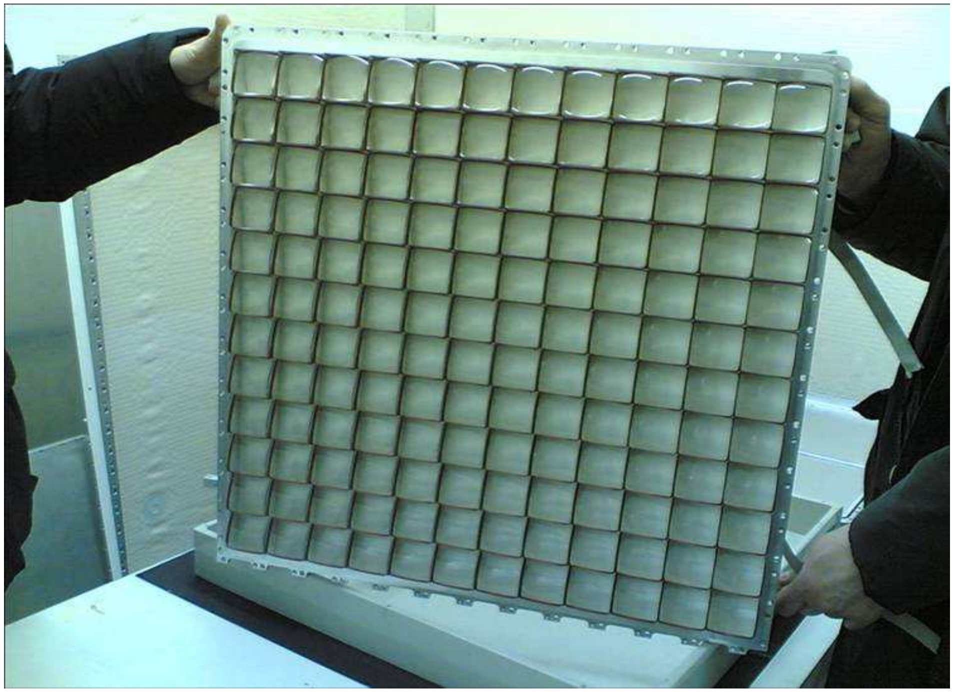
- new APV readout for the outer 75% of the photon detectors
- large reduction of uncorellated background
- much smaller dead time

RICH1 central photon detectors

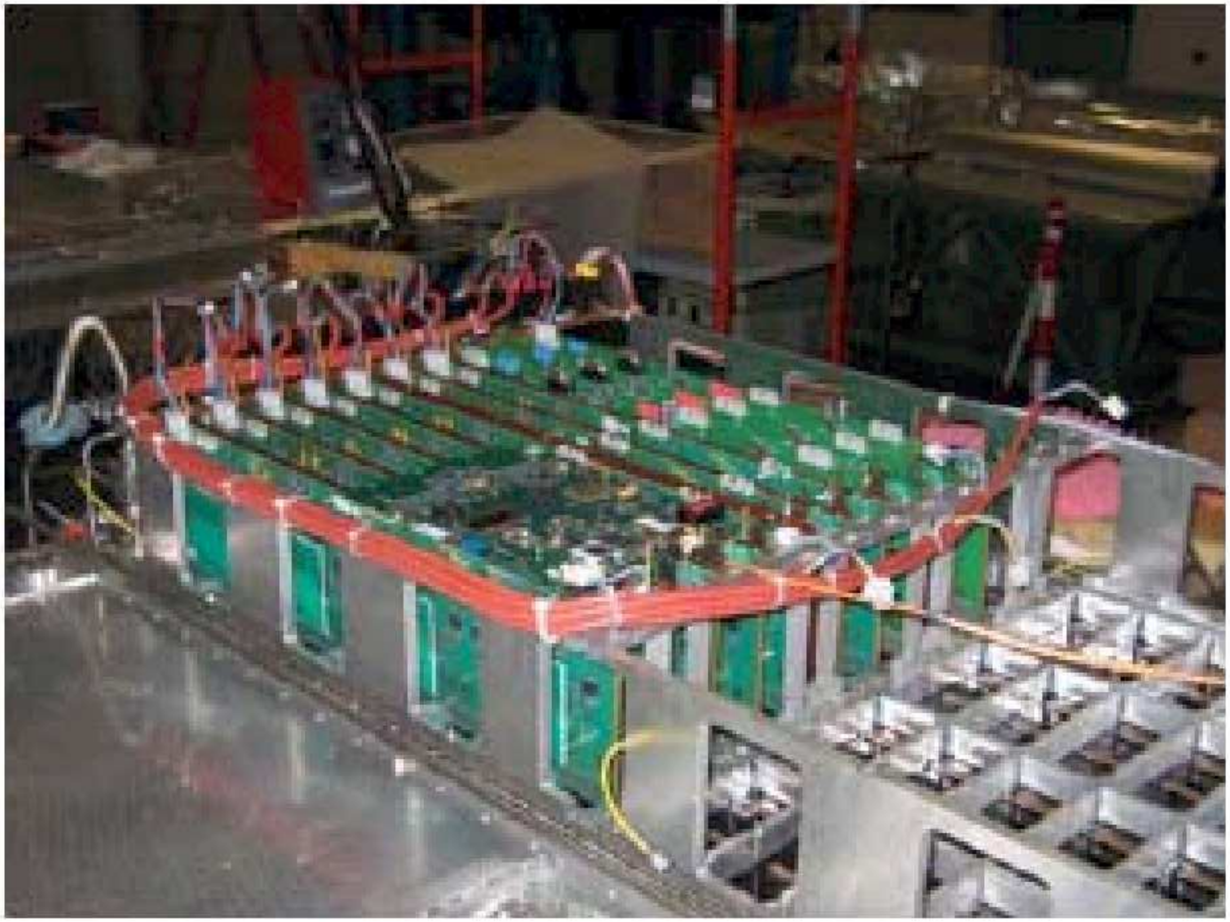


- sketch of telescope in front of MAPMT

- Complete panel of field lenses



RICH1 outer photon detector

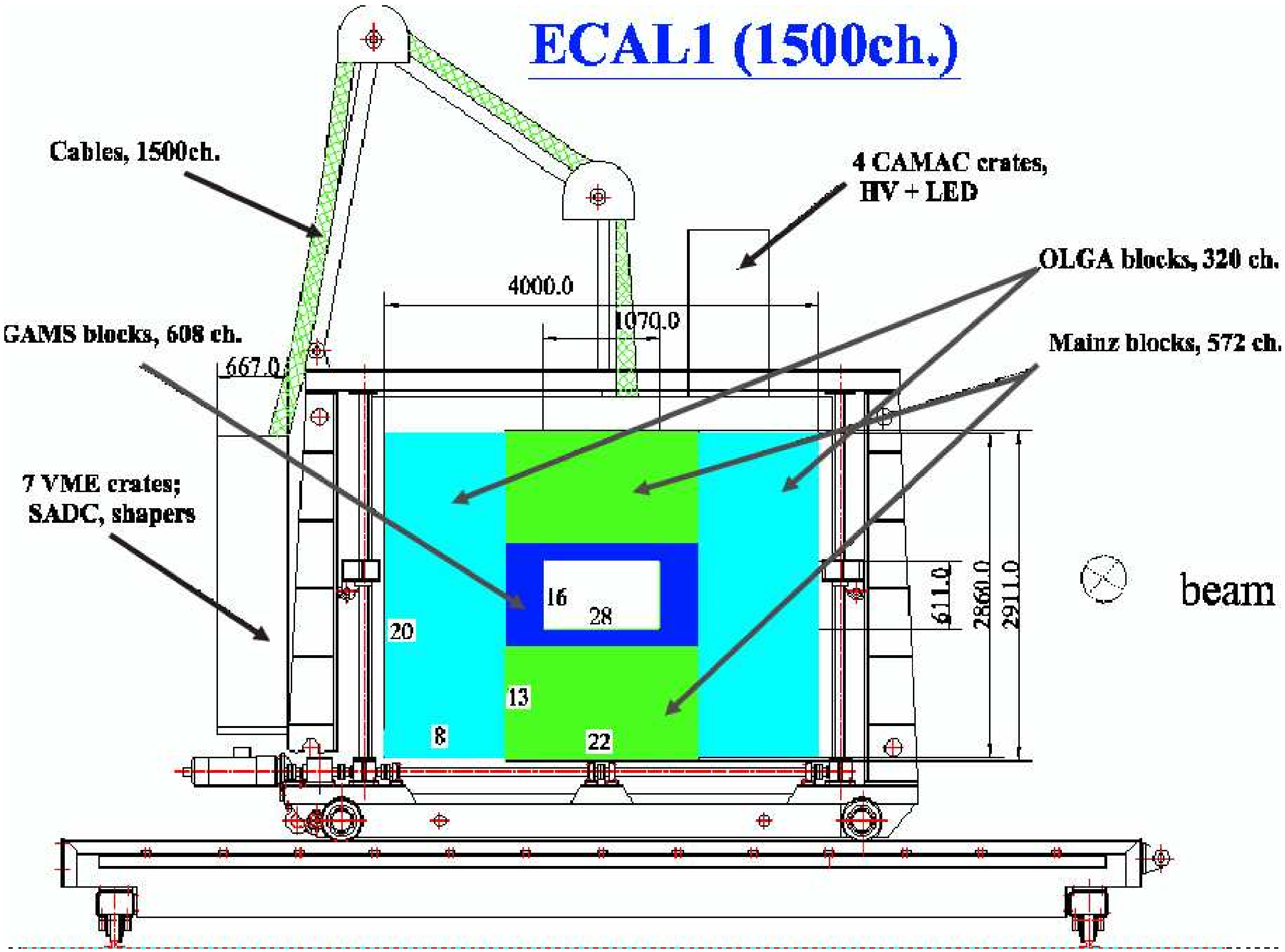


- new APV readout electronics for outer photon detectors
- number of photons same as before
- uncorellated background at least factor 6 smaller

RICH wall

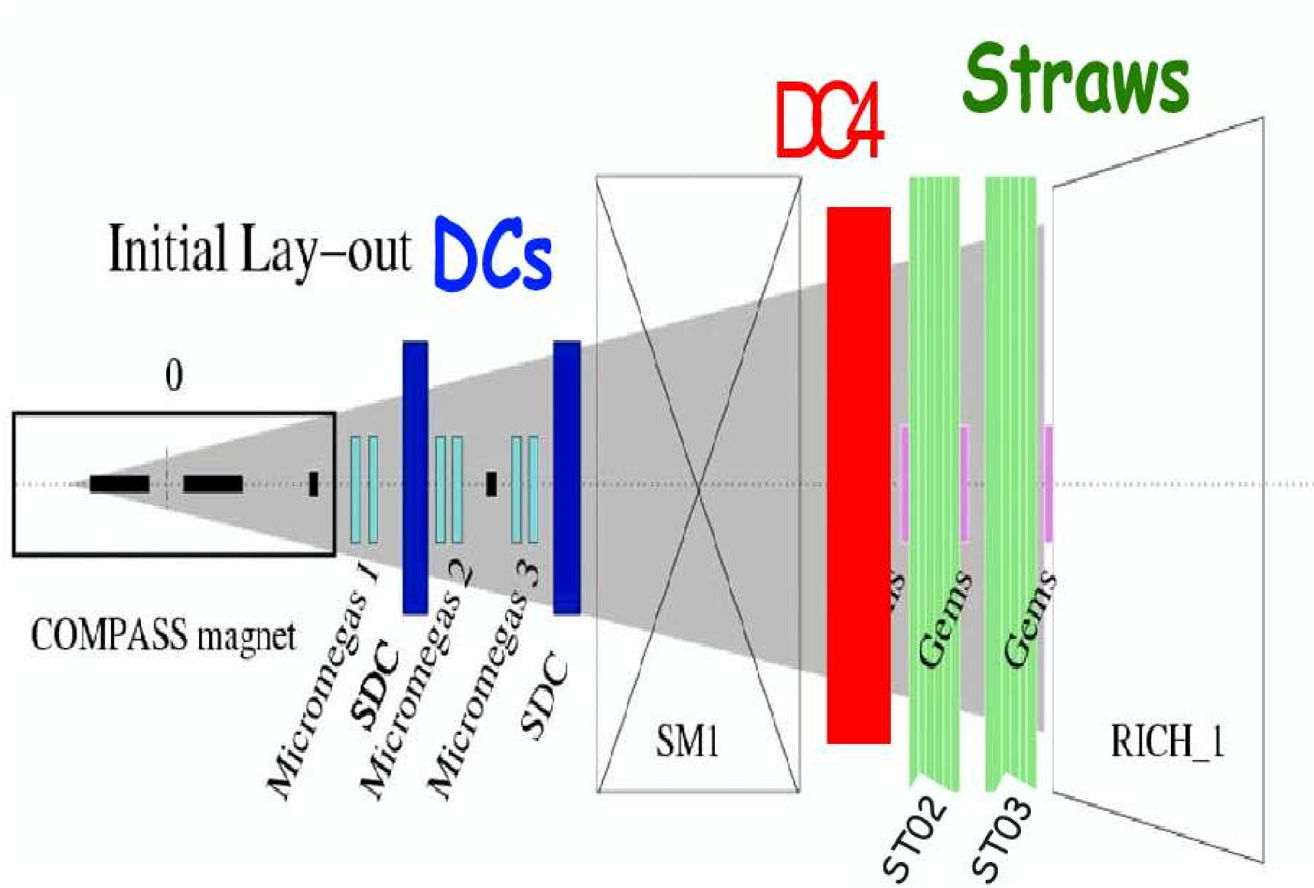
- large area tracker (drift tubes)
- lead converter
- preshower for ECAL1

ECAL1



- new electromagnetic calorimeter (lead glass) in first stage
- plan to include ECAL1 into trigger

LAT around SM1



- new large area detectors in large angle spectrometer
- new straw module
- new large drift chamber DC4

Summary and outlook

Results:

- Analysis of 2002 –2004 data
- Precise results for the longitudinal spin structure function
- Inclusive aymmetries at small Q^2
- Gluon polarisation measured with several methods
- Results on ρ meson production, Λ polarisation

Plans:

- new target solenoid $\Longrightarrow$ larger hadron acceptance
- improvement of RICH $\Longrightarrow$ background, efficiency improved
- detector upgrades for enlarged acceptance
- data with ^{6}LID for longitudinal polarisation, NH_3 for transverse polarisation

$\Longrightarrow$ we hope to double the statistics for most channels