Spin Physics
with COMPASS

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on behalf of the
COMPASS Collaboration
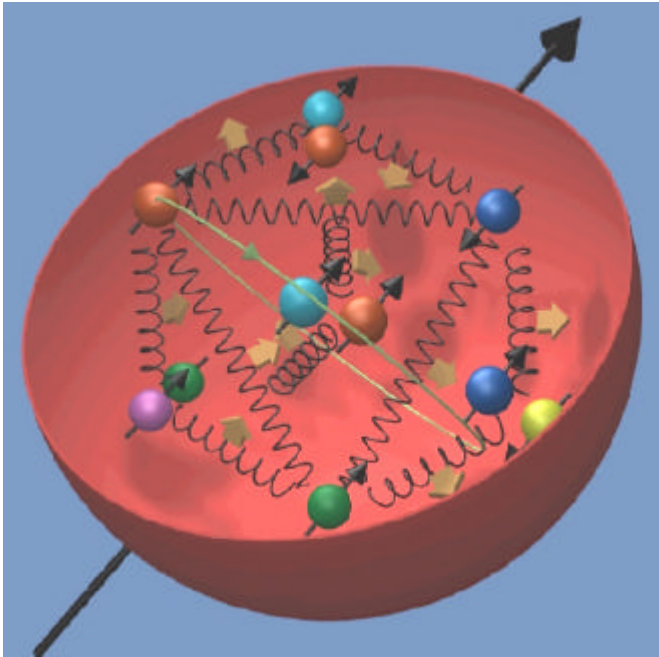
1. The Nucleon Spin
2. The COMPASS Experiment
3. Measurement of the Gluon Polarisation $\Delta G/G$
4. Transversity, Lambda Polarisation

bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen
Grundlagenforschung

The Nucleon Spin

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

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$
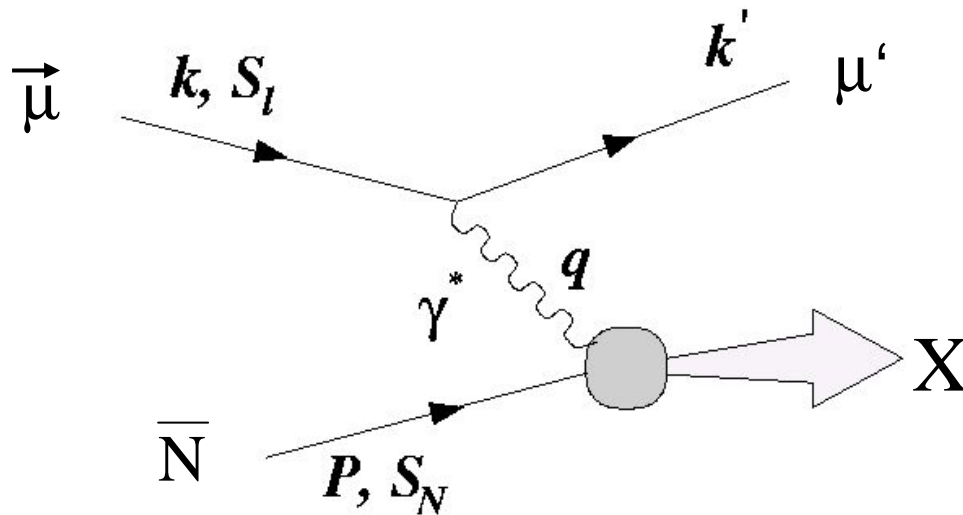
- naive model: $\Delta\Sigma = 1$

- expectation from SU(3) (Ellis/Jaffe 1974), baryon decay (assumption $\Delta s = 0$): $\Delta\Sigma \approx 0.6$

- but DIS experiments (EMC/SMC, SLAC, HERMES): $\Delta\Sigma \approx 0.3$
  (Phys. Lett **B464**, 123 (1999))

**Where is the rest ?
Gluon polarisation ?** ⟶ **Measurement of** $\Delta G/G$ **by COMPASS**

Deep Inelastic Scattering

$$Q^2 = -(k - k')^2$$

$$y = \frac{P \cdot q}{P \cdot k} \overset{\text{lab}}{=} \frac{E - E'}{E} = \frac{?}{E}$$

$$x = \frac{Q^2}{2P \cdot q} \overset{\text{lab}}{=} \frac{Q^2}{2M?}$$

Differential Cross Section:

$$\frac{d^2s}{dO \, dE'} = \frac{a^2}{MQ^4} \frac{E'}{E} L_{\mu?} W^{\mu?}$$

Hadronic tensor parameterised by the use of structure functions:

spin indepenent: $F_1(x,Q^2), F_2(x,Q^2),$

spin dependent: $g_1(x,Q^2), g_2(x,Q^2),$

Experimental Access to Spin Effects

$\sigma^{\uparrow\uparrow}$

helicity conservation

$\sigma^{\uparrow\downarrow}$
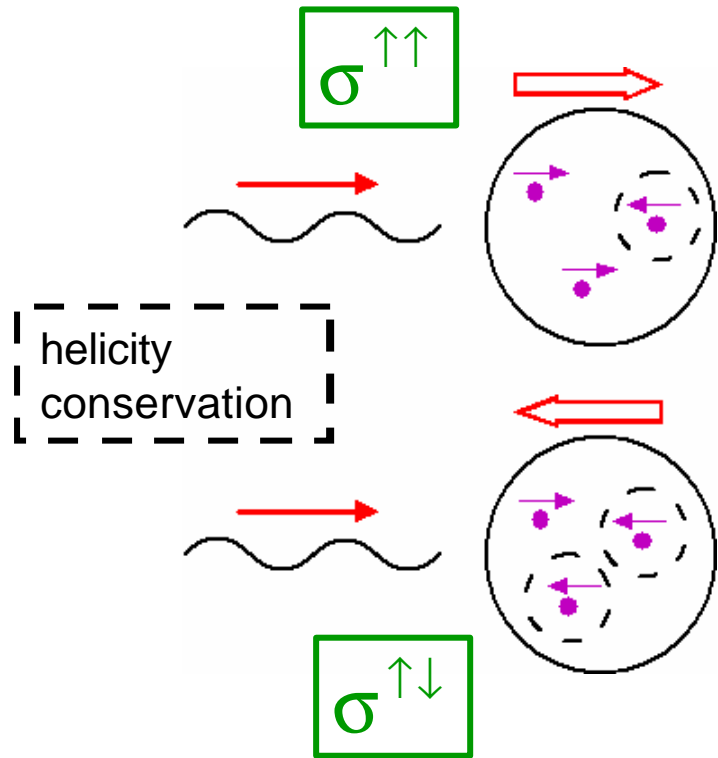
- by meassurement of asymmetries:

$$\frac{1}{D\,P_{beam}\,f\,P_{target}}\frac{N^{\uparrow\downarrow}-N^{\uparrow\uparrow}}{N^{\uparrow\downarrow}+N^{\uparrow\uparrow}}$$

$$= A_1^{\gamma^*N\to X} = \frac{\sigma^{\uparrow\downarrow}-\sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow}+\sigma^{\uparrow\uparrow}} \approx \frac{g_1(x,Q^2)}{F_1(x,Q^2)}$$
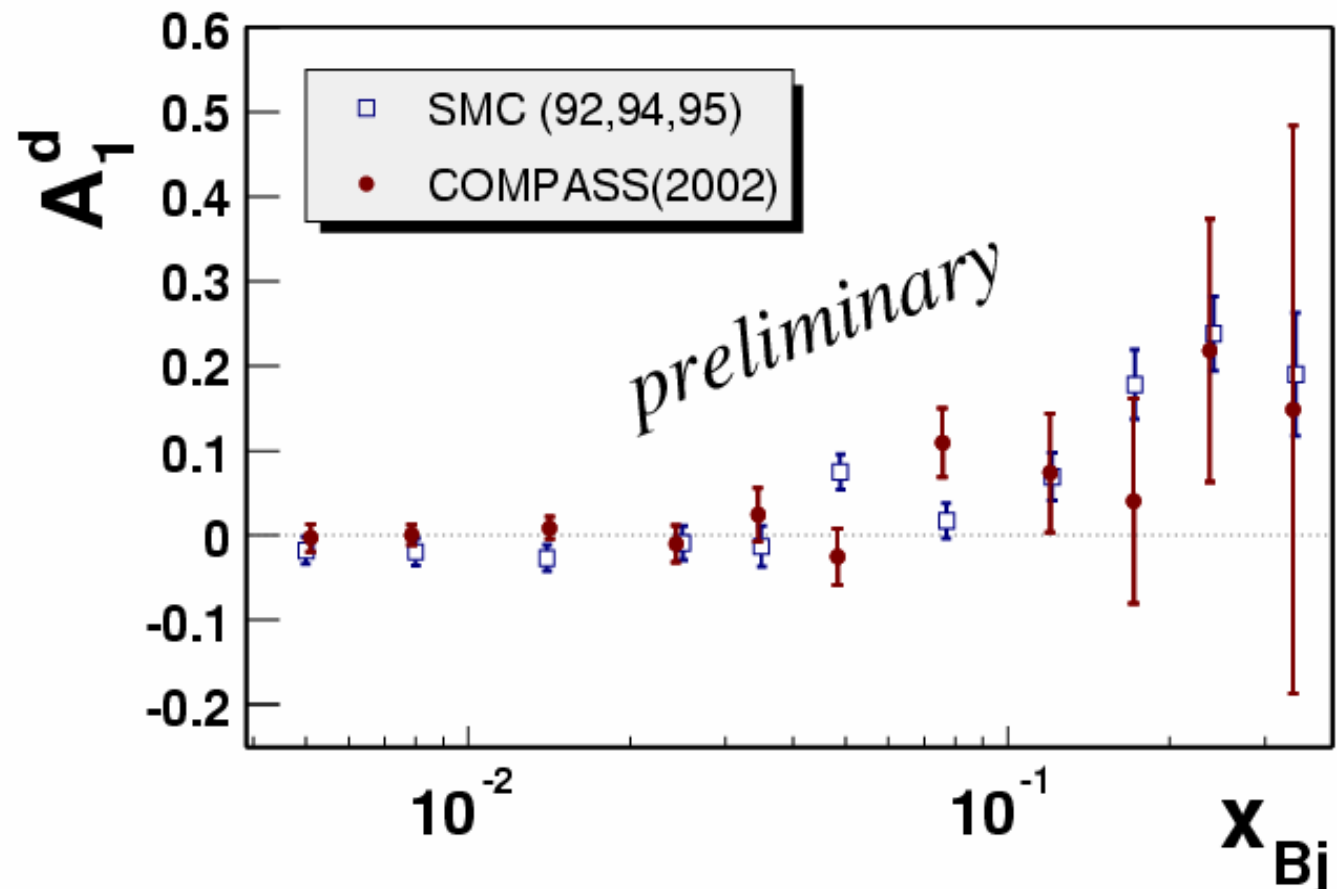
Inclusive Asymmetry A_1

- quark parton model and nQCD extensions:

$$g_1(x,Q^2) = \frac{1}{2}\left\langle e^2\right\rangle\left\{C^{NS}\otimes\Delta q_{NS} + C^S\otimes\Delta\Sigma + C^G\otimes\Delta G\right\}$$

$$\text{with}\quad \left\langle e^2\right\rangle = \sum_{i=1}^{nf} e_i/n_f \quad,\quad \Delta q_{NS} = \sum_{i=1}^{nf}\left(e_i^2/\left\langle e^2\right\rangle - 1\right)$$
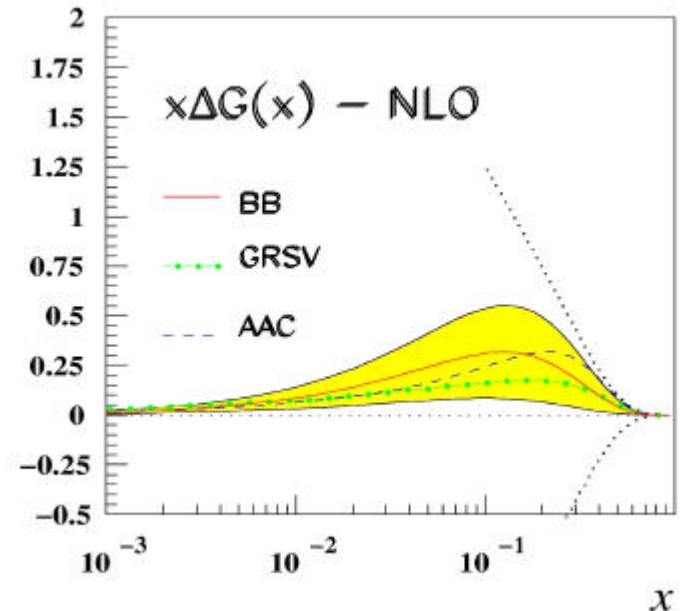
Inclusive Asymmetry A_1

- from first year of data taking (2002)

- large uncertainty for $x > 0.04$

    - trigger upgrade 2003 for large Q^2

- 2003 & 2004 data: four times the statistics

$\mathbf{\Delta}$G from QCD Analysis of g_1

Hermes (2000)
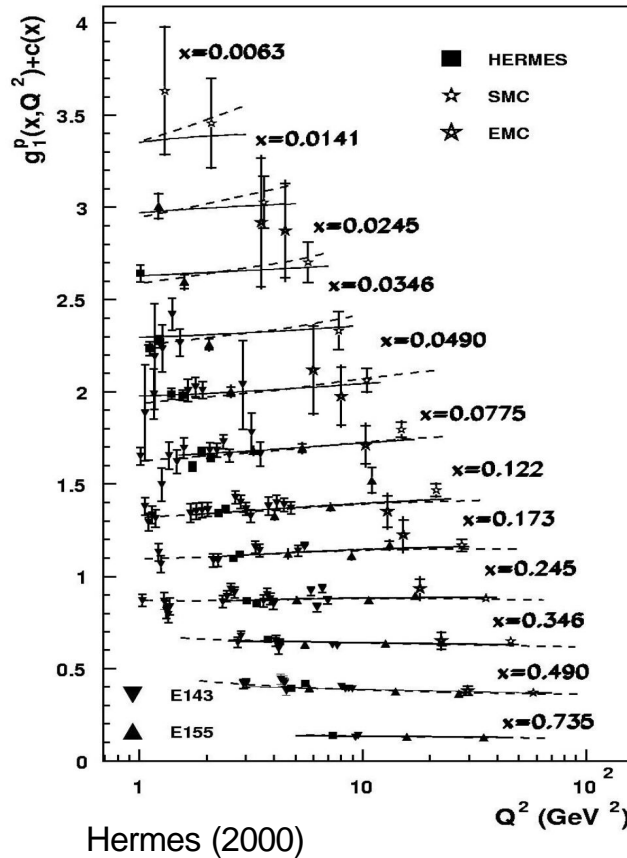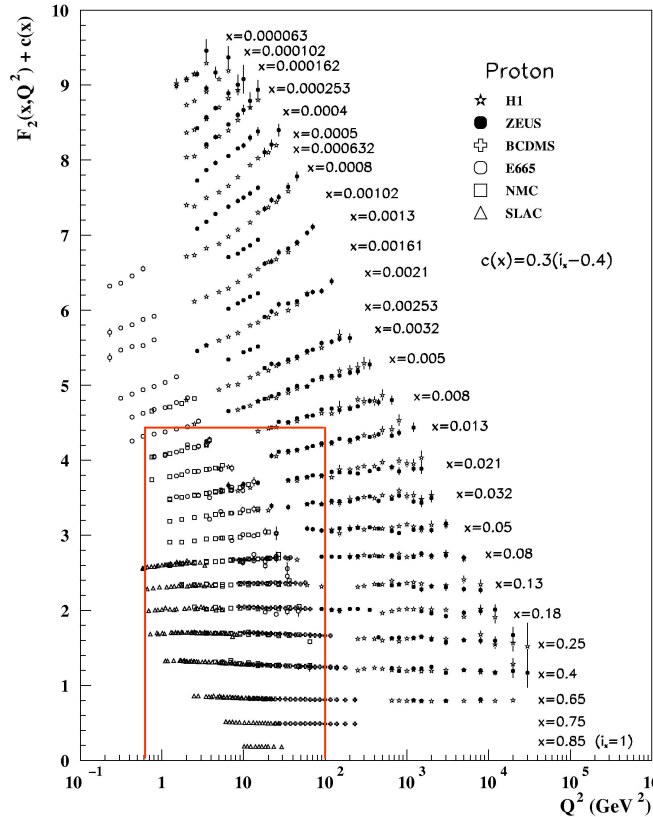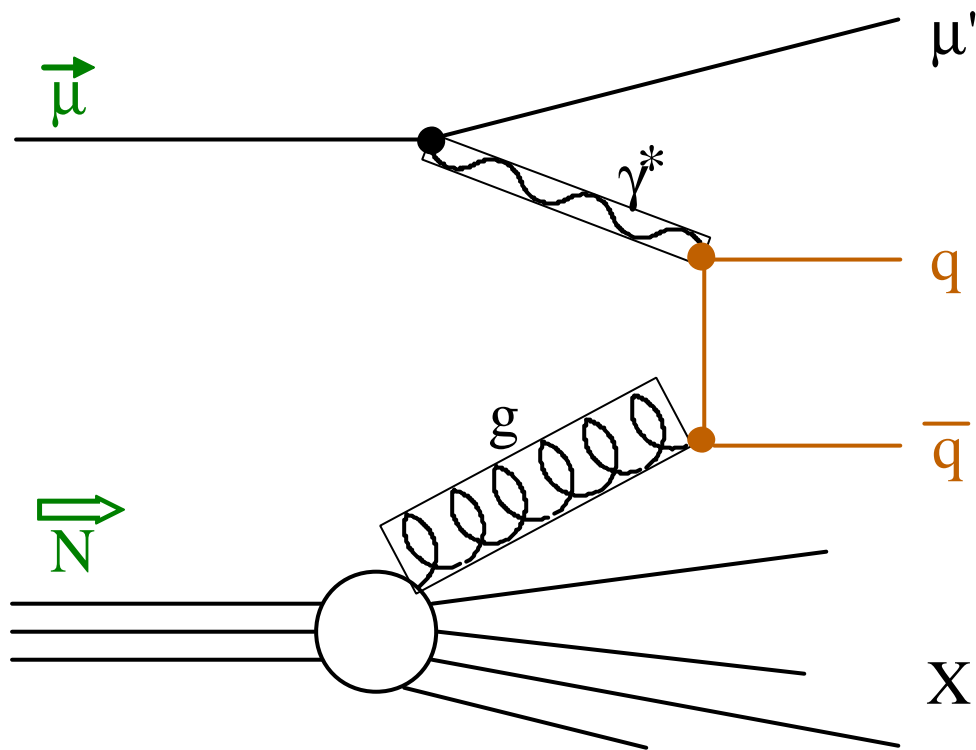
polarised gluon distribution from QCD fits:

Blümlein & Böttcher: fit to polarised data of
EMC, E142, E143, E155, SMC, Hermes

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$\mathbf{\Delta}$G/G at COMPASS

• using polarized beam and target
• selecting the photon-gluon fusion process
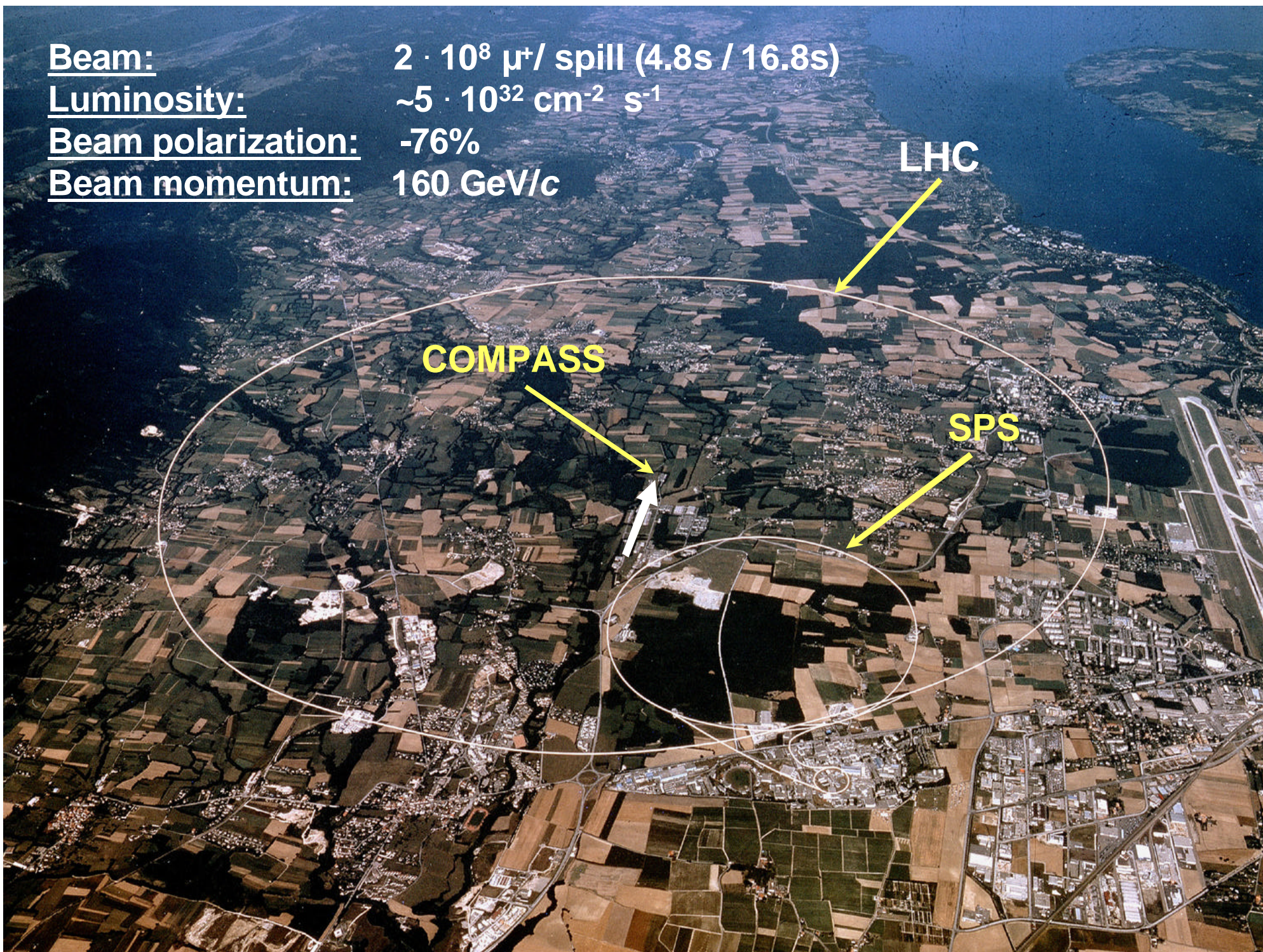• measuring cross-section asymmetries

1. open-charm production

➢ $c, \overline{c}$
➢ $D^0 \rightarrow K^- + \pi^+$

➢ low statistics

➢ small background

2. high-p_T hadron prodution

➢ light quarks
➢ pair of hadrons with high transverse momentum
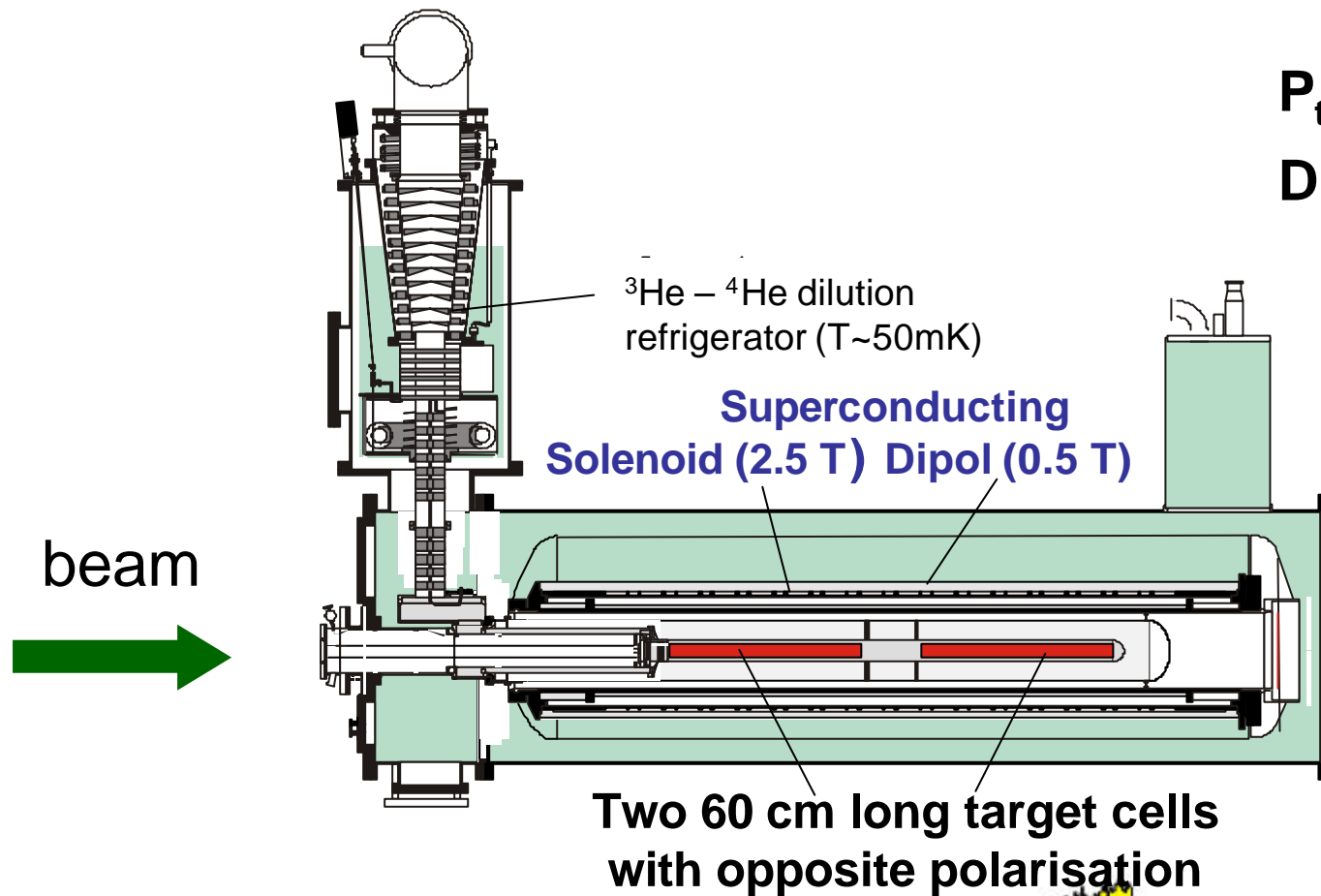
➢ high statistics

➢ competing processes

Beam: $2 \cdot 10^8$ µ⁺/ spill (4.8s / 16.8s)
Luminosity: ~$5 \cdot 10^{32}$ cm⁻² s⁻¹
Beam polarization: -76%
Beam momentum: 160 GeV/c

LHC

COMPASS

SPS

Polarised ^{6}LiD Target

P_{target}:   50%

Dilution: 40%

^{3}He – ^{4}He dilution
refrigerator (T~50mK)

**Superconducting
Solenoid (2.5 T) Dipol (0.5 T)**

beam

**Two 60 cm long target cells
with opposite polarisation**

Reconstructed
interaction vertices
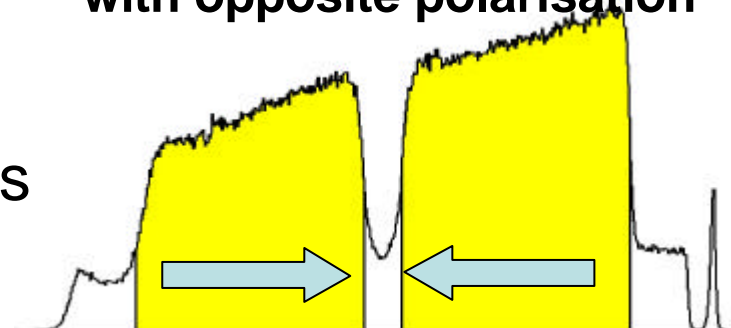
COMPASS

(SPS @ CERN, Geneva, Switzerland)

Small
Angle
Spectrometer

Large
Angle
Spectrometer

beam

total legth: 54m
cross section: 5m×5m
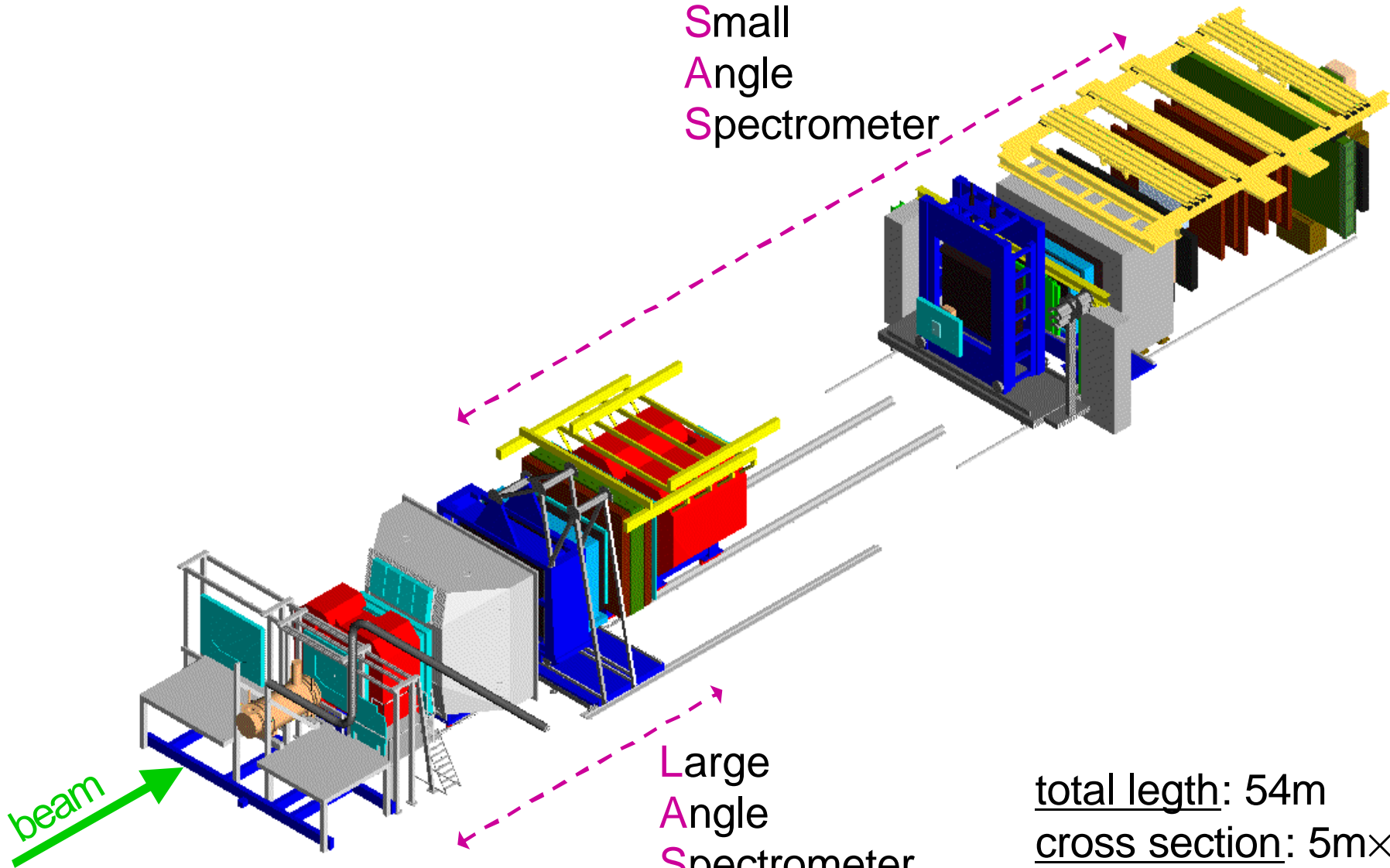
COMPASS Setup 2003/04
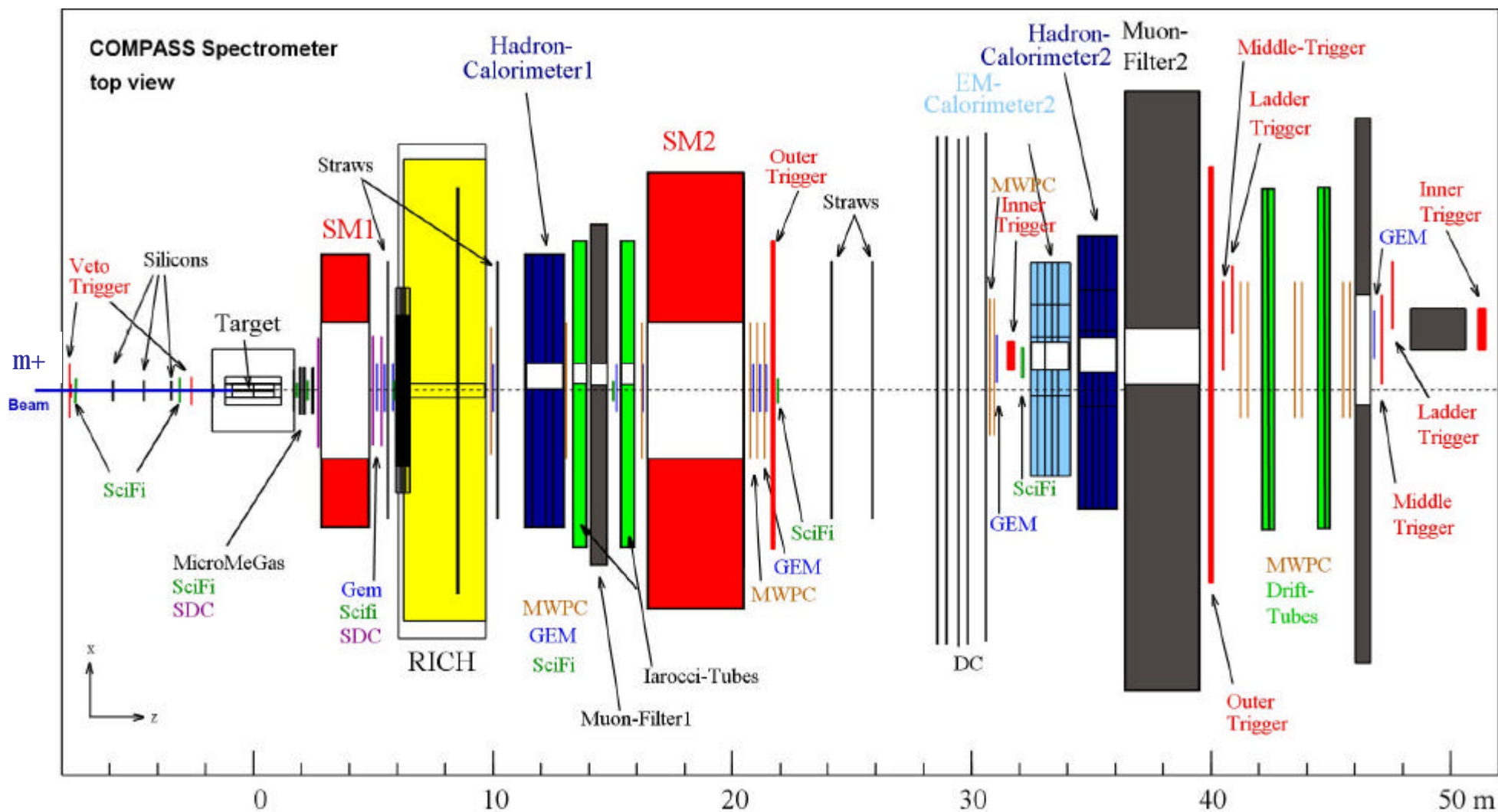
Acceptance

run 2002:

3800×10^6 trigger

570×10^6 recontructable events with μ/μ'

29×10^6 inclusive events with $Q^2 > 1$ (GeV/c)²

access to

➤ **small x_{Bj}**

➤ **very small Q^2**
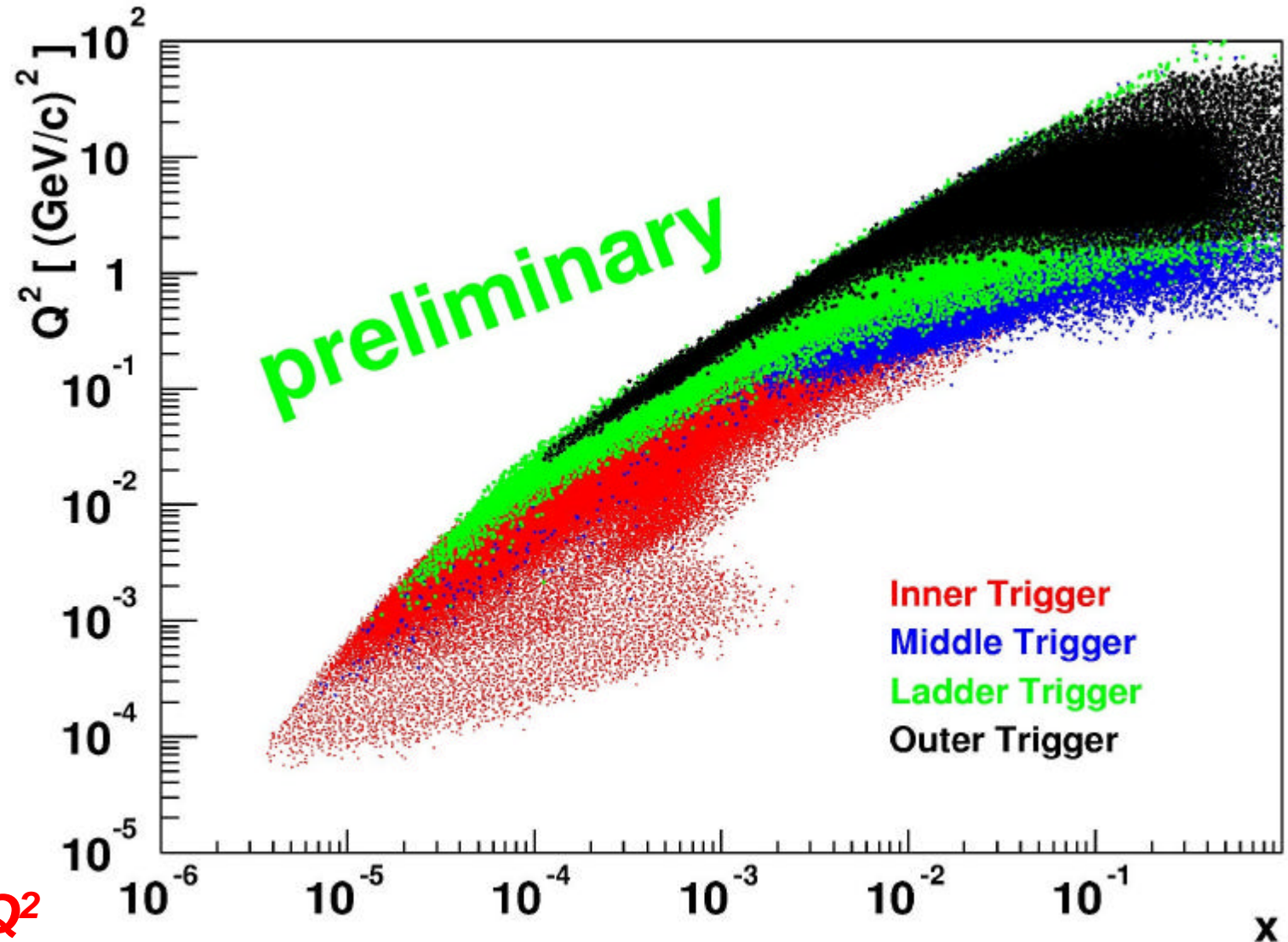
run 2003: double 2002; trigger upgrade

run 2004: 2002 + 2003

DG/G ® Open-Charm Production

μ'

$\vec{\mu}$

γ*

c

g

$\bar{c}$

$\vec{N}$

X
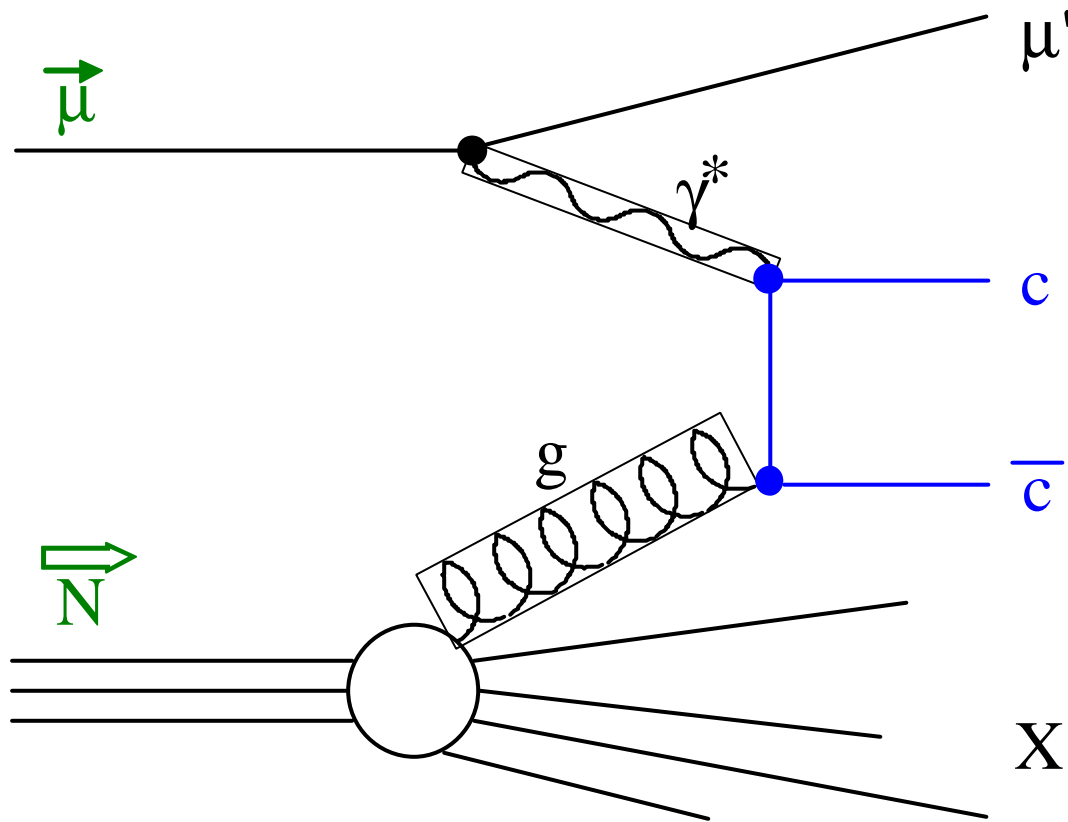
1. open-charm production

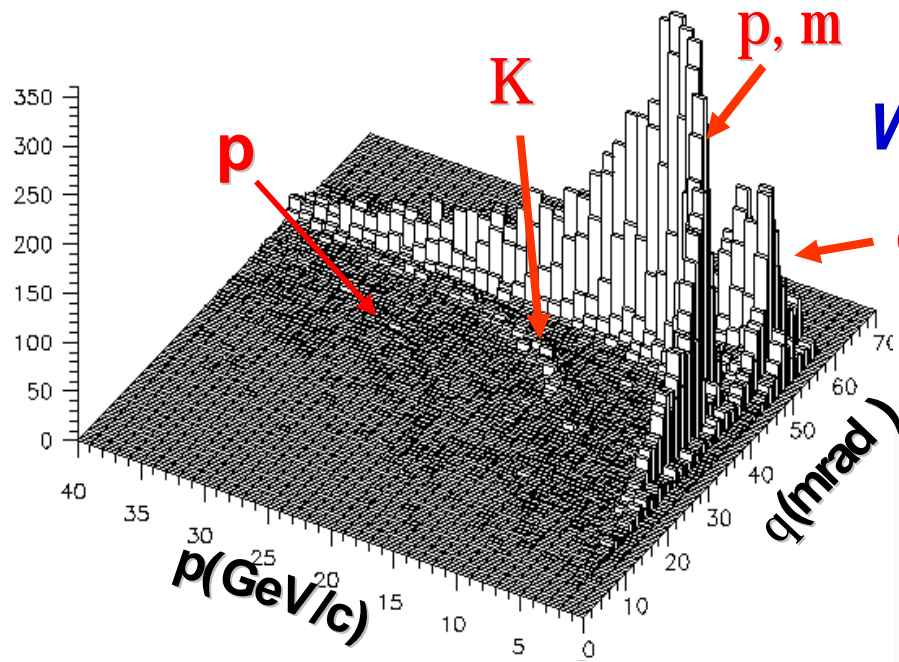➢ c, $\bar{c}$

➢ $D^0 \to K^- + \pi^+$
     $\overline{D^0} \to K^+ + \pi^-$

➢ theory well
     understood
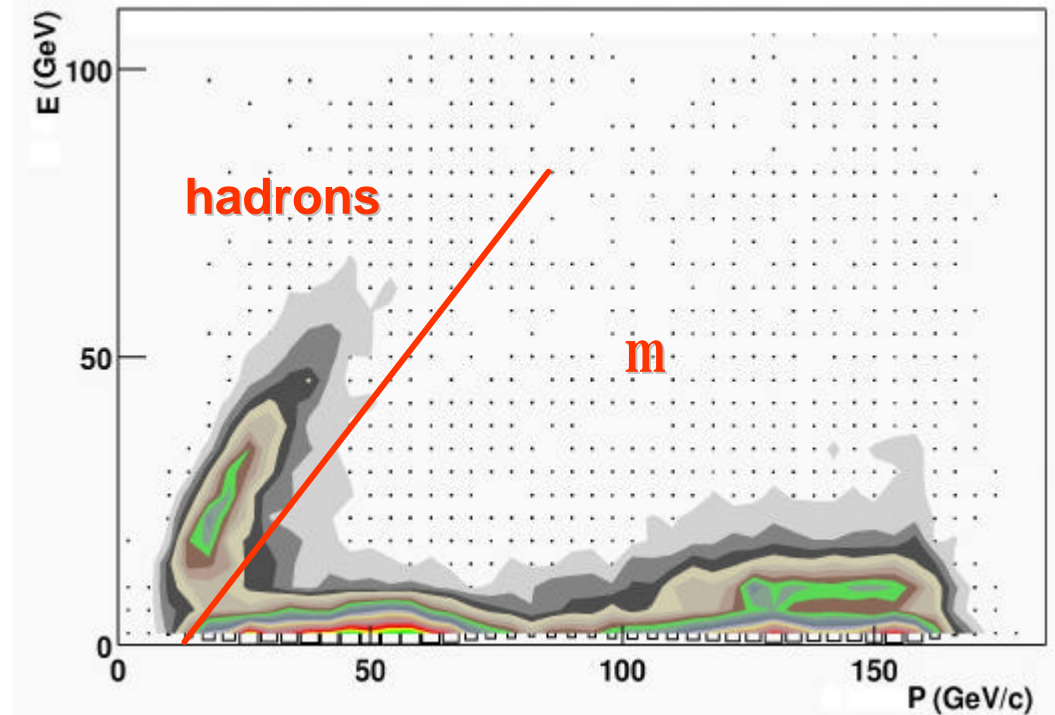
➢ experiment
     challenging
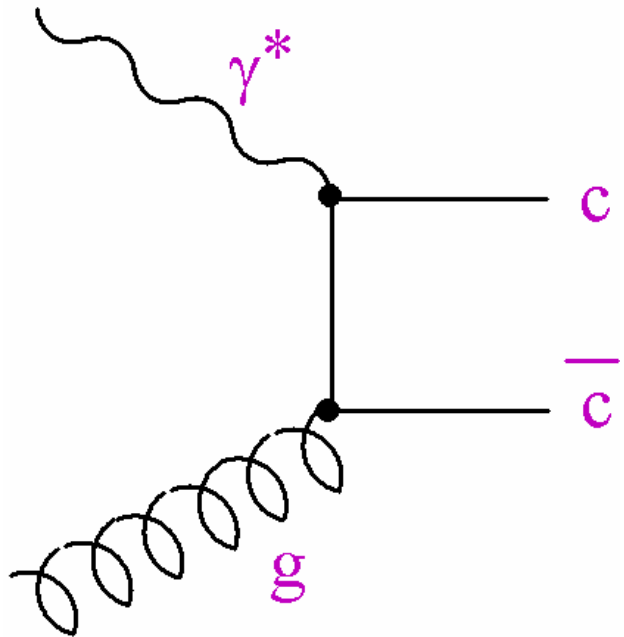
Particle Identification

With RICH

and hadron calorimeters

Essential for reconstruction of D-Mesons !

Open-Charm Produktion

- cross section:

$$\sigma^{\gamma N \to c\bar{c}} = \Delta\sigma^{\gamma g \to c\bar{c}} \otimes \Delta G$$

$$+ \sigma^{\gamma g \to c\bar{c}} \otimes G$$

can be calculated
(in LO and NLO) !

searched gluon-spin
distribution !

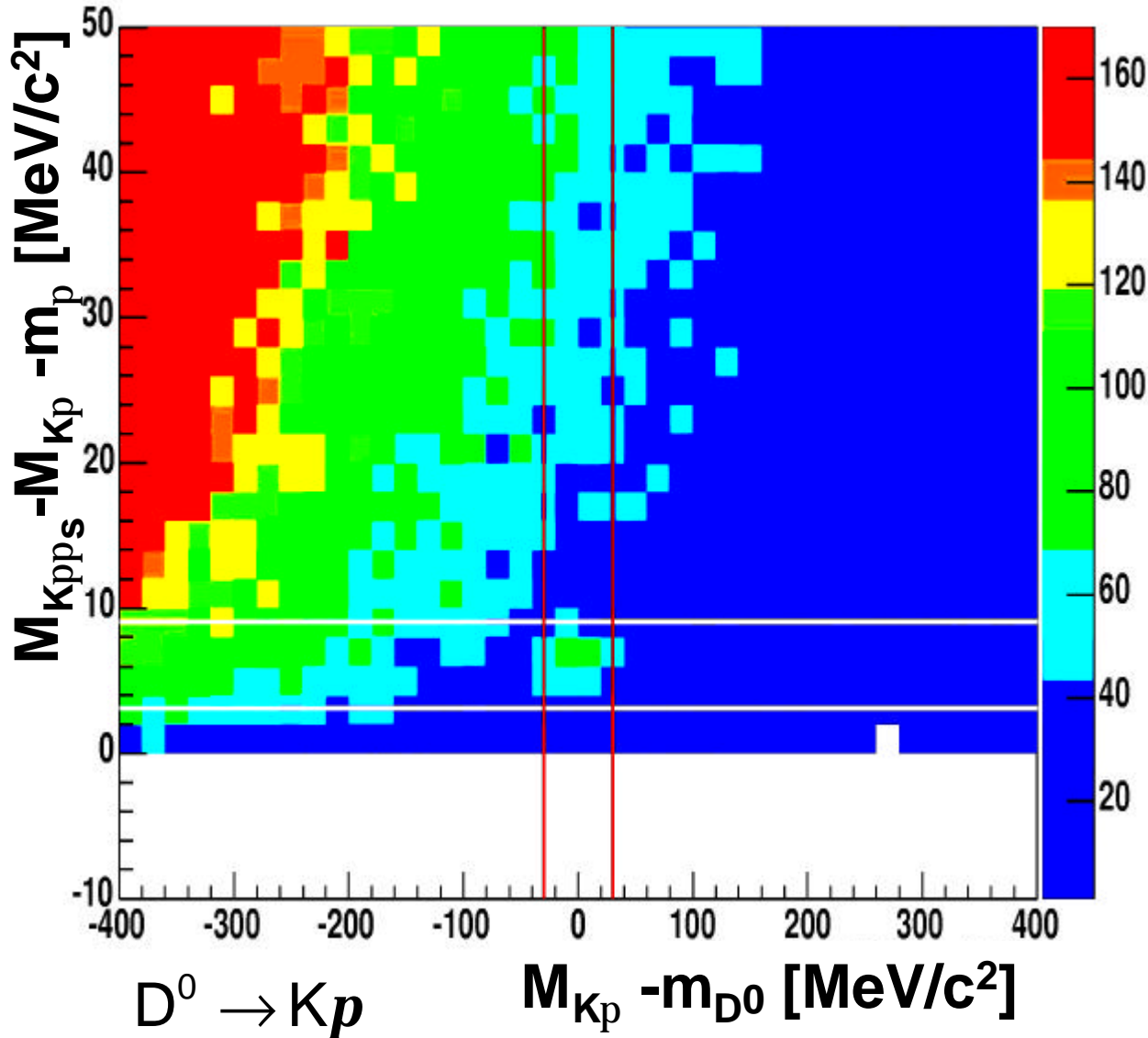- measured, semi-inclusive asymmetry:

$$A^{\mu N \to c\bar{c}X} = \frac{1}{D\, P_{beam}\, f\, P_{target}} \frac{N_{PGF}^{\uparrow\downarrow} - N_{PGF}^{\uparrow\uparrow}}{N_{PGF}^{\uparrow\downarrow} + N_{PGF}^{\uparrow\uparrow}}$$

$$\approx \frac{\Delta\sigma^{\gamma g \to c\bar{c}} \otimes \Delta G}{\sigma^{\gamma g \to c\bar{c}} \otimes G} \implies \boxed{\frac{\Delta G}{G}}$$

γ^*

c

$\bar{c}$

g

D* tagging: D*? D⁰ p

$D^* \rightarrow (Kp)p$

$M_{Kpp_S} - M_{Kp} - m_p$ [MeV/c²]

$M_{Kp} - m_{D^0}$ [MeV/c²]

$D^0 \rightarrow Kp$

Cuts:

$z_D = E_D/n > 0.2$

$|\cos q^*| < 0.85$

(Background)

$10 < p_K < 35$ **GeV/c**

(RICH PID)

D* tagging: D*? D⁰ p

$D^* \to (Kp)p$

$M_{Kpp_s} - M_{Kp} - m_p$ [MeV/c²]

$D^0 \to Kp$

$M_{Kp} - m_{D0}$ [MeV/c²]

Cut on D⁰

$D^* \to (Kp)p$

Preliminary

$M_{Kpp_s} - M_{Kp} - m_p$ [MeV/c²]
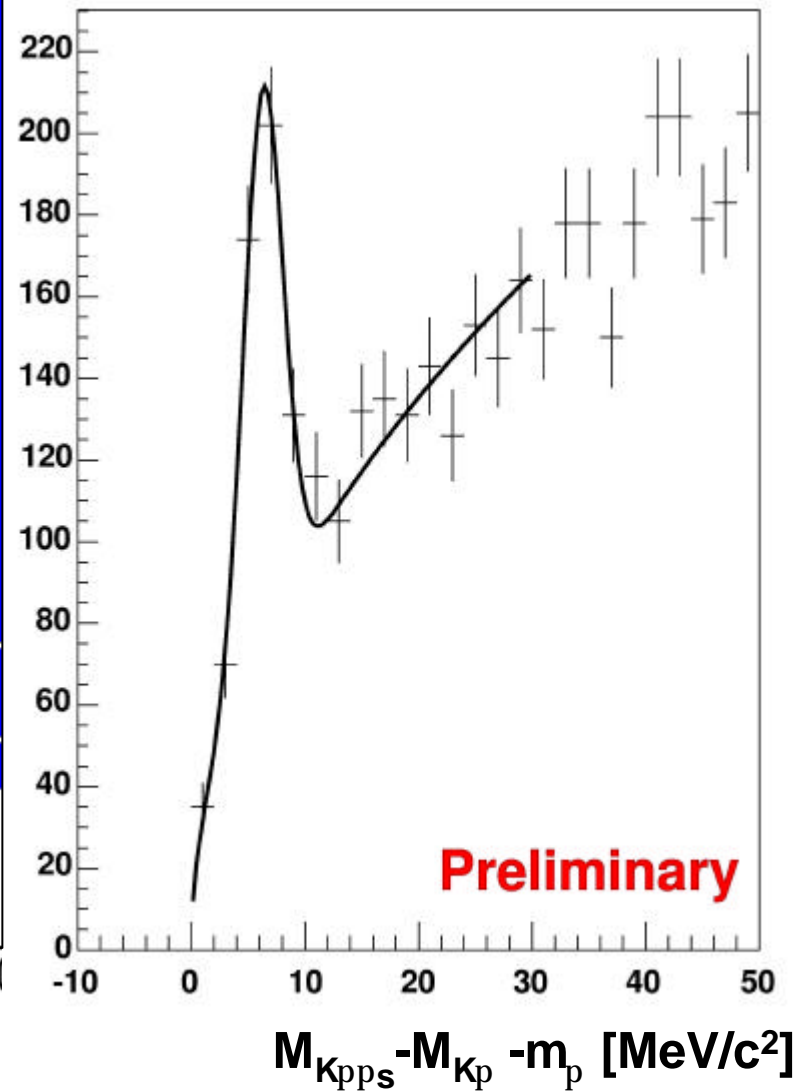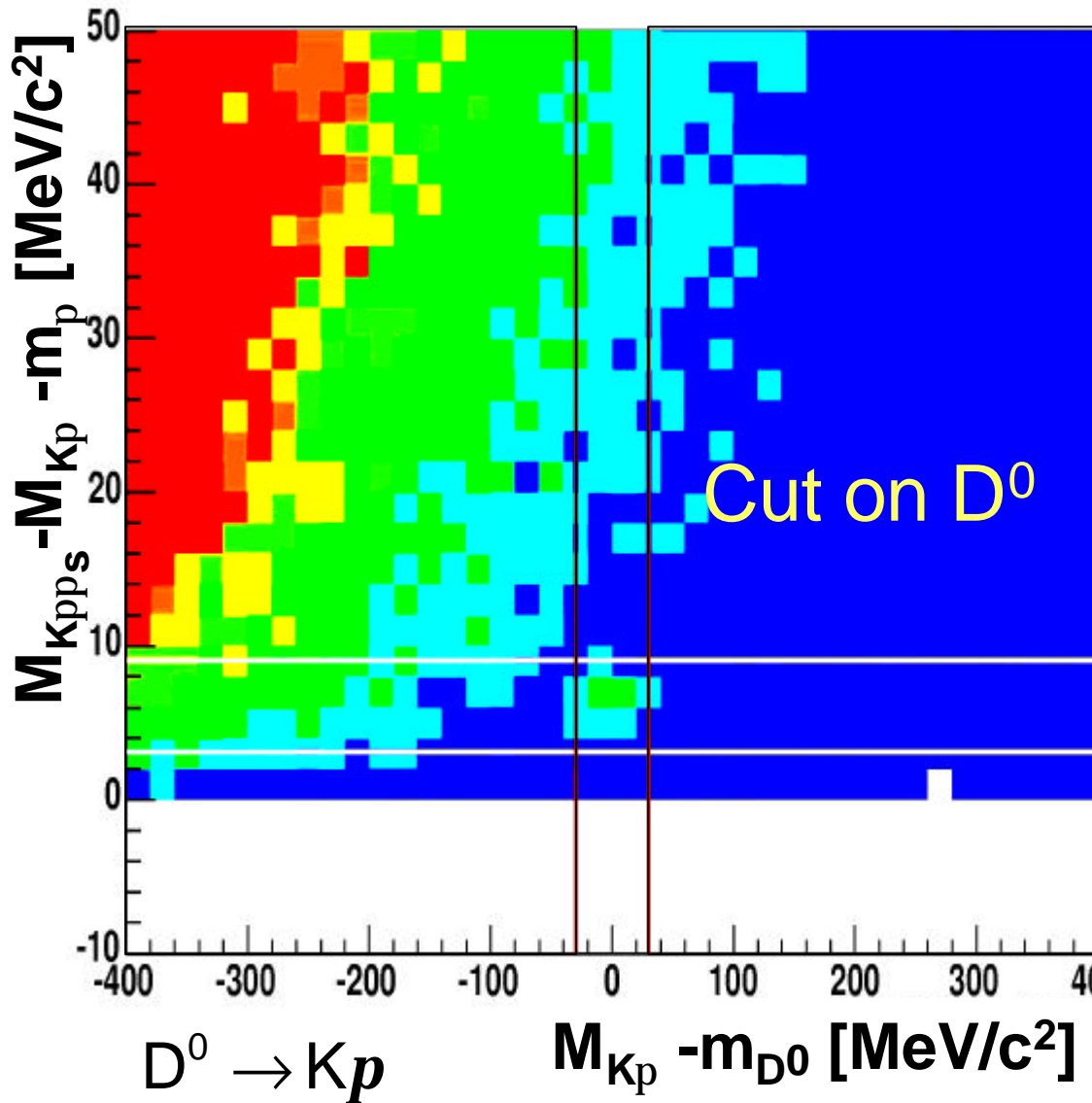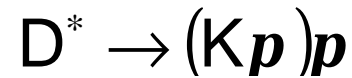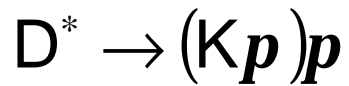
D* tagging : D*? $D^0\,p$, D^0? $K\,p$

$D^* \rightarrow (Kp)p$

$D^0 \rightarrow Kp$

80% 2002 data

Cut on D*

317 D^0

Preliminary

$D^0 \rightarrow Kp$

$M_{Kp} - m_{D0}$ [MeV/c^2]

$M_{Kpp_s} - M_{Kp} - m_p$ [MeV/c^2]

$M_{Kp} - m_{D0}$ [MeV/c^2]
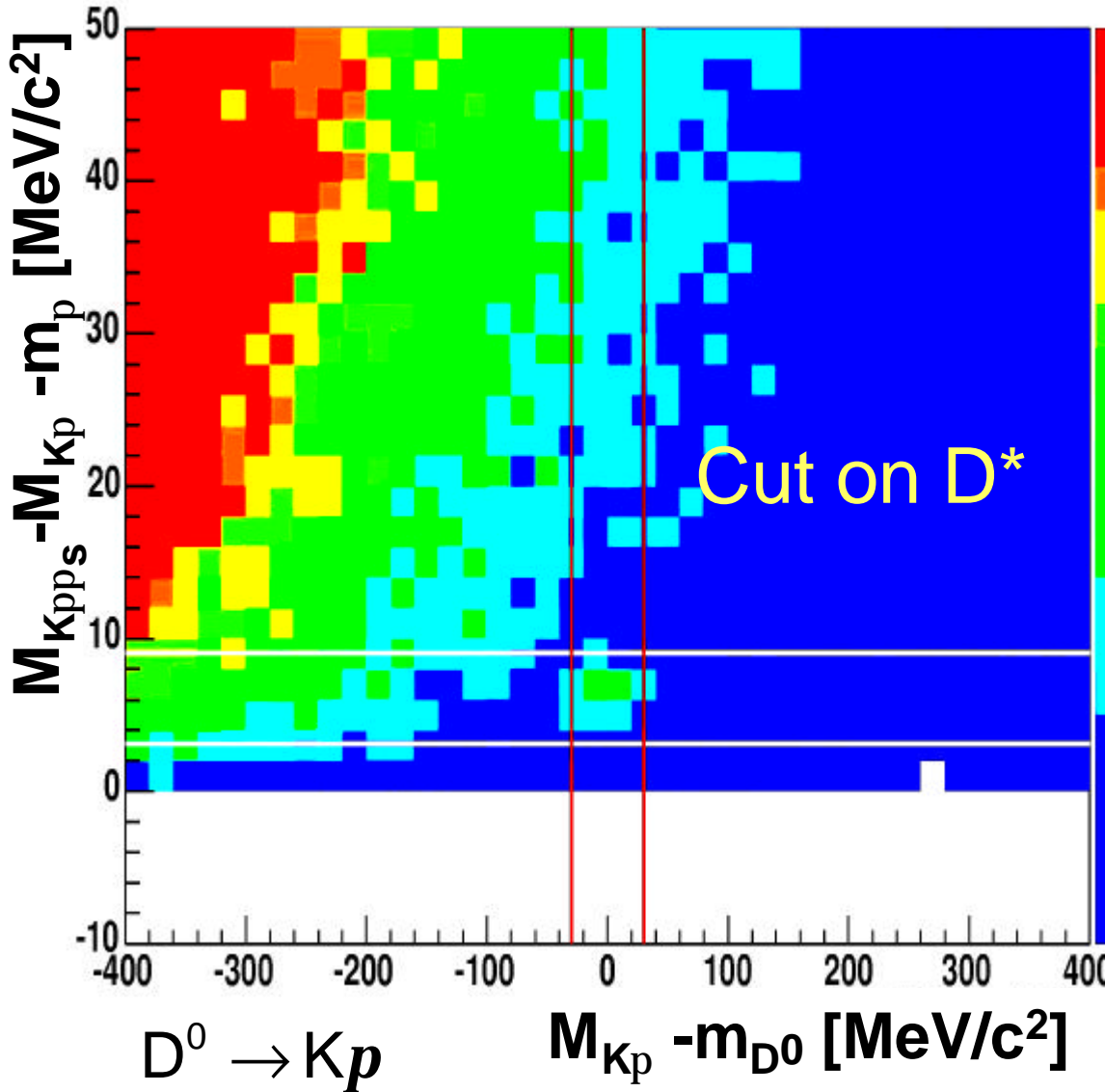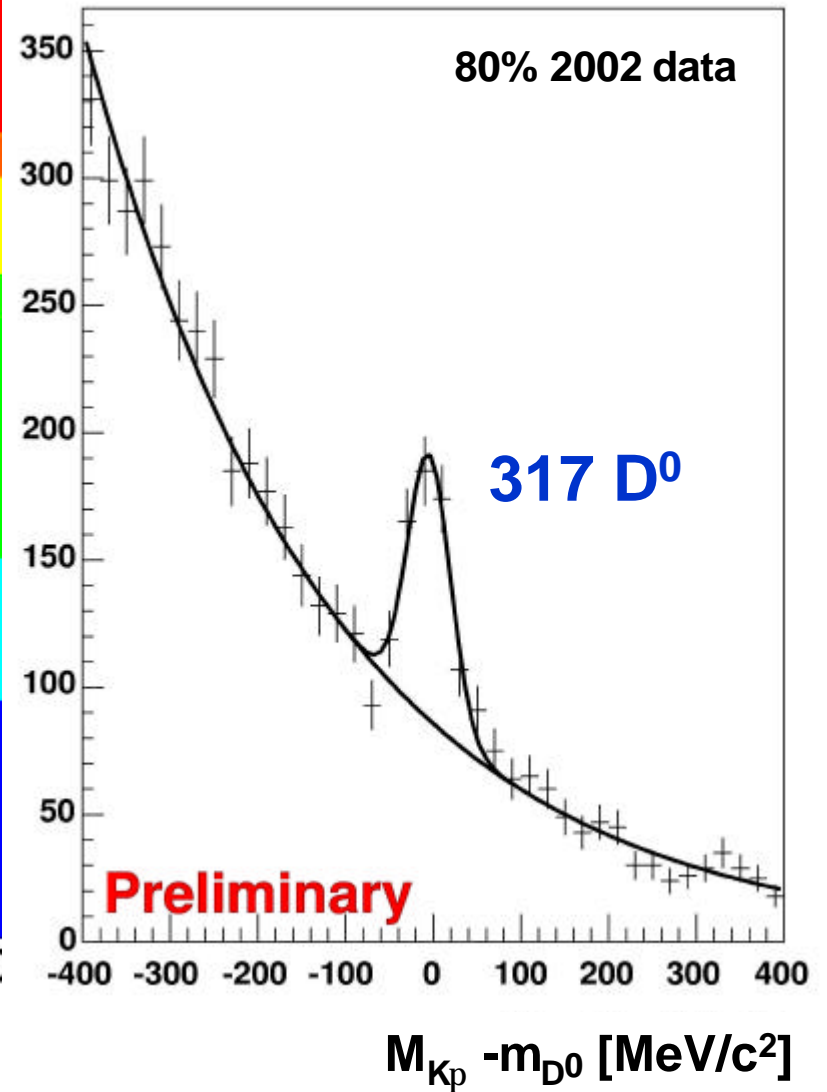
DG/G ® Pairs of High p_T Hadrons
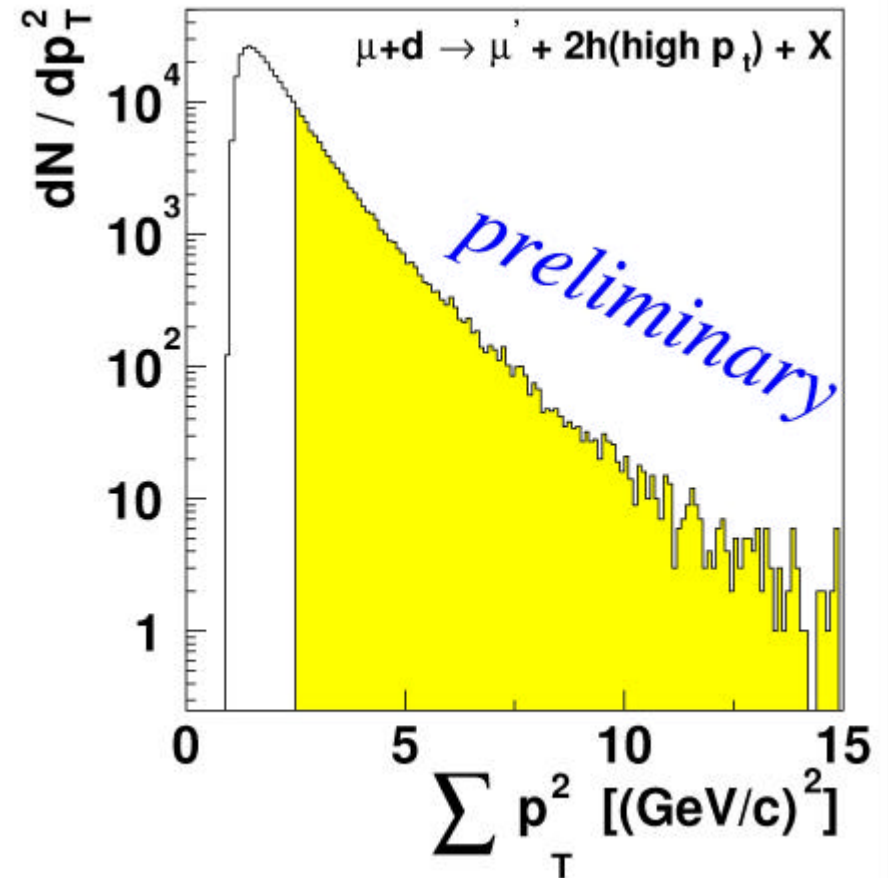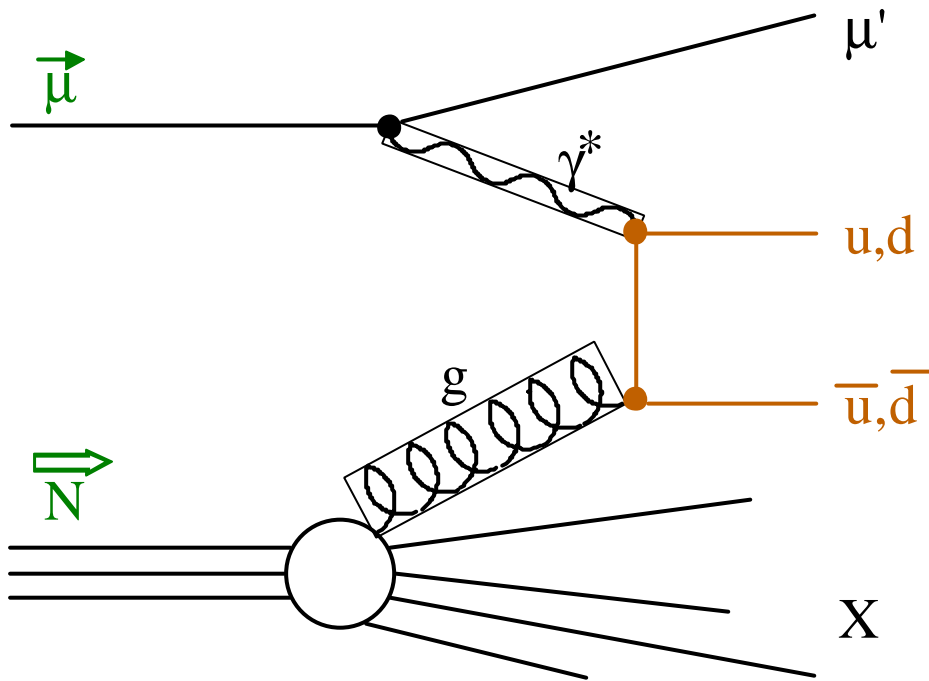
High-p_T-Hadron

➢ light quarks
➢ with high transverse momentum
   (hard scale, enrich PGF)
➢ theory complicated
➢ experiment easy

- Current fragmentation
- 2 high p_T hadrons
  - $p_T > 0.7$ GeV/c
  - $p_{T1}^2 + p_{T2}^2 > 2.5$ (GeV/c)^2
  - $m(h_1 h_2) > 1.5$ GeV/c^2

Asymmetry

$$A^{g^*d} = \frac{1}{2P_T\, f\, D P_B} \left[\frac{N_1^{\Rightarrow} - N_2^{\Leftarrow}}{N_1^{\Rightarrow} + N_2^{\Leftarrow}} + \frac{N_2^{\Rightarrow} - N_1^{\Leftarrow}}{N_2^{\Rightarrow} + N_1^{\Leftarrow}} \right]$$

two target cells, opposite polarisation, polarisation flipped every 8 hours

Asymmetry in production of hadron pairs with high p_T:
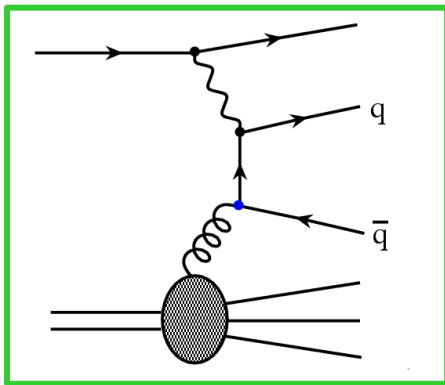
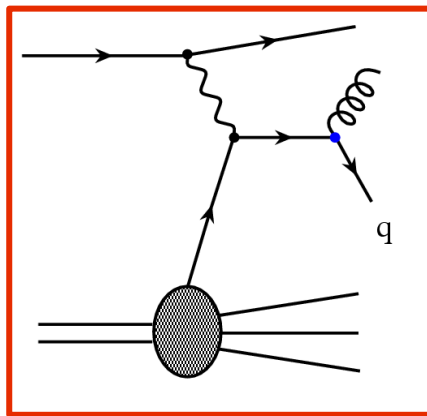$$A^{g^*d} = -0.065 \pm 0.036_{stat.} \pm 0.010_{syst.}$$

2002 data

up to now systematic error contains only studies on false asymmetries due to target or spectrometer effects
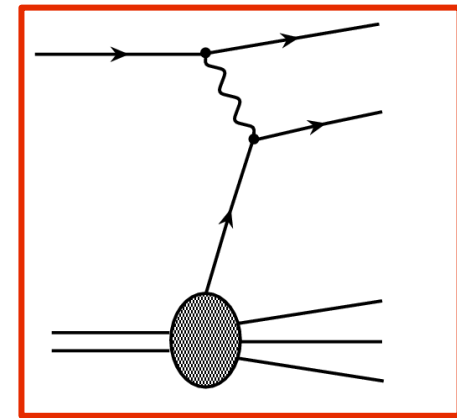
How to get $\Delta G/G$

$$A^{\gamma^* d} = \frac{A_{LL}^{\mu N \to hh}}{D} \approx \left\langle \frac{\hat{a}_{LL}^{PGF}}{D} \right\rangle \left\langle \frac{\Delta G}{G} \right\rangle \frac{\sigma^{PGF}}{\sigma^{tot}} + \left\langle \frac{\hat{a}_{LL}^{Com}}{D} \right\rangle \left\langle \frac{\Delta q}{q} \right\rangle \frac{\sigma^{Com}}{\sigma^{tot}} + LO \quad DIS$$
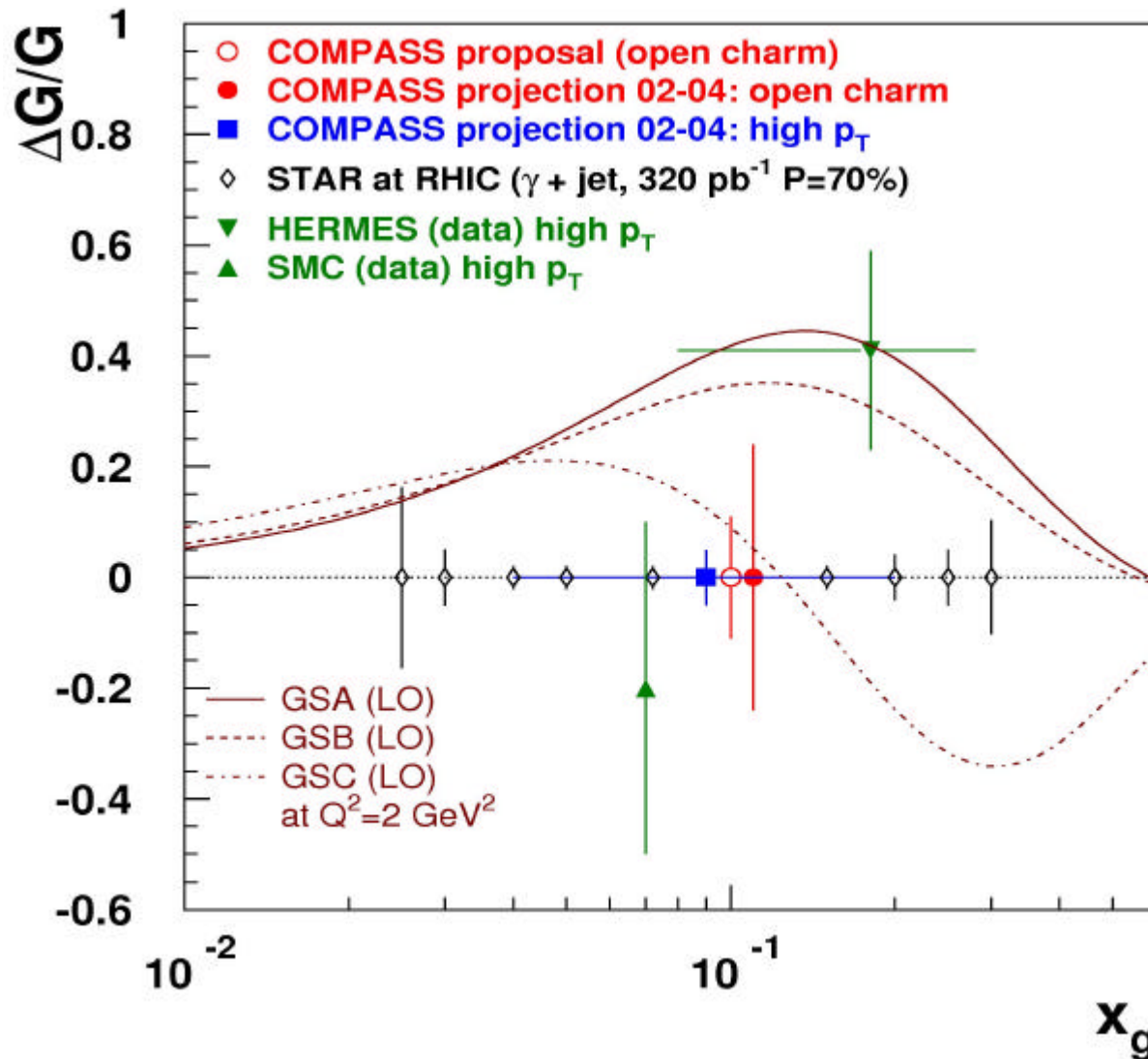

Photon Gluon Fusion

QCD-Compton

Leading Order

$$\hat{a}_{LL}^{PGF} \approx -1 \text{ and } \hat{a}_{LL}^{Com} \approx 0.5$$

fractions of cross section determined by Monte Carlo
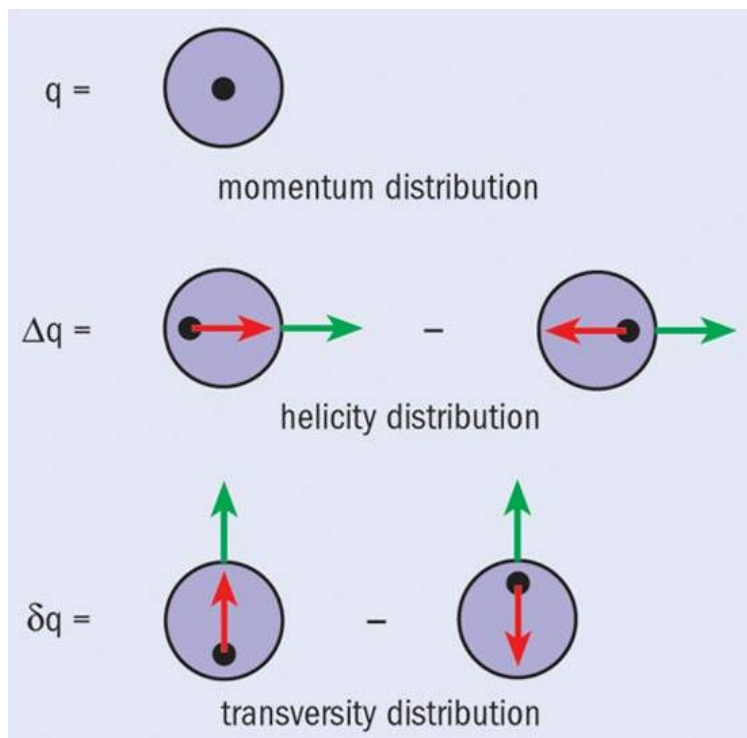
Projected error on ΔG/G for 2002-2004 data

- from open-charm : **0.24**

- from high p_T: **0.05**

  (assuming fraction of
  PGF events is ¼)

Transversity

• 3 structure functions neccessary to describe the spin structure of the nucleon at LO:

$\rightarrow F_1(x)$

$\rightarrow g_1(x)$

$\rightarrow h_1(x)$

All of equal importance !

run 2002:

   $1,6 \times 10^6$ events with transversal polarised ^{6}LiD-target after cuts
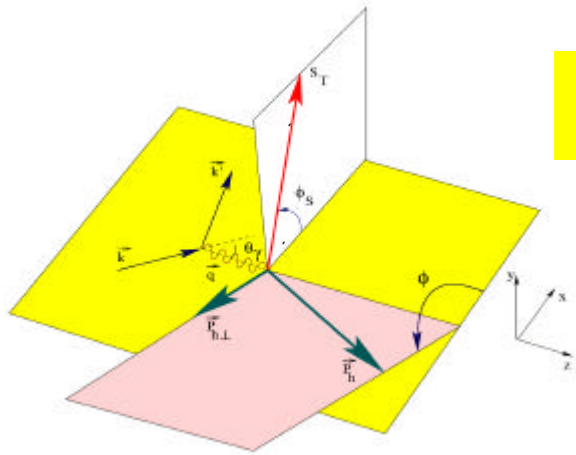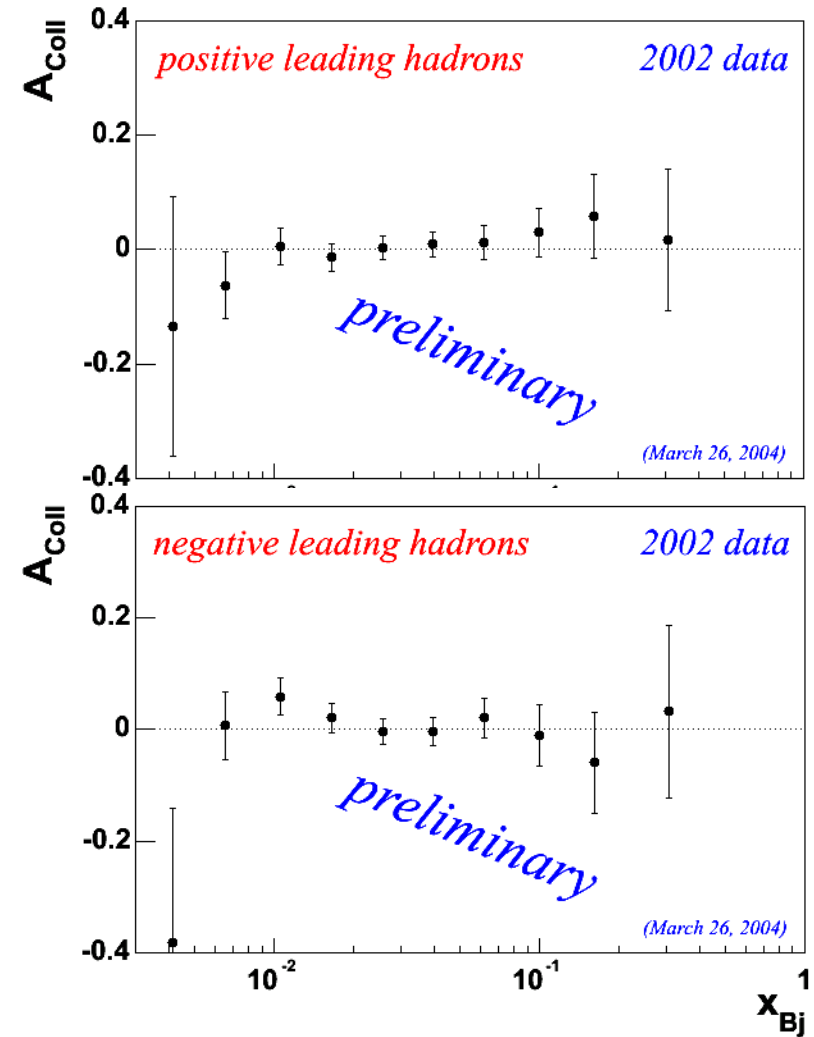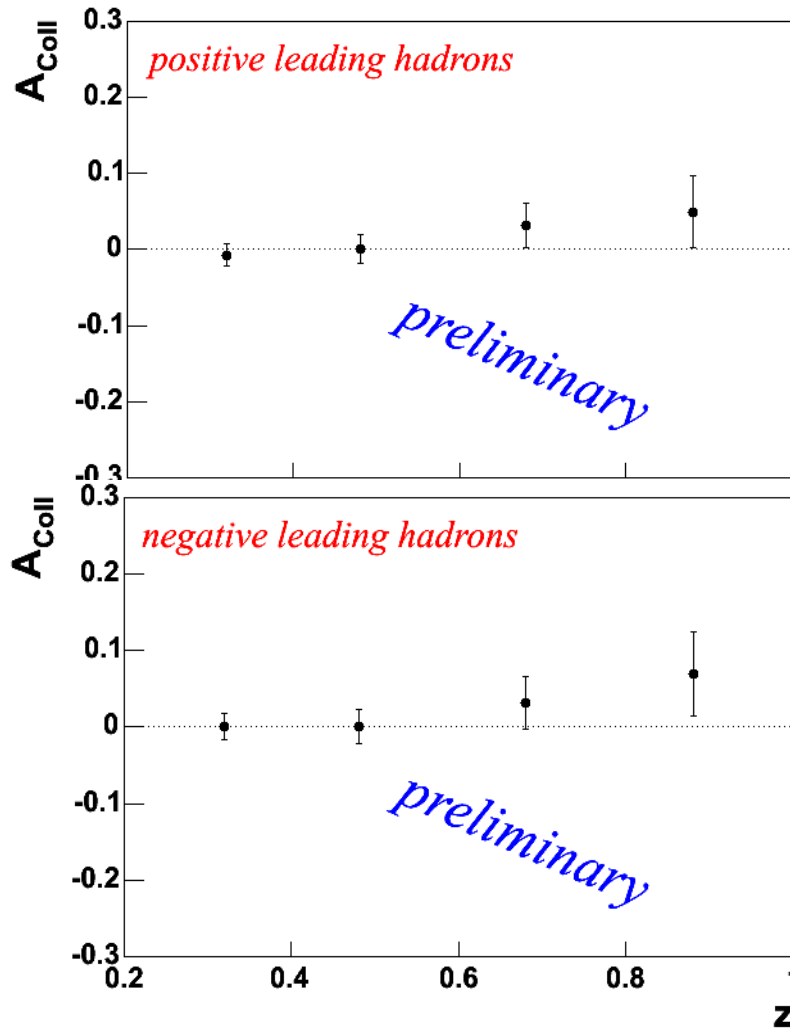
(preliminary)

run 2003:

   double 2002

run 2004:

   2002 + 2003

Collins-Asymmetrie

$$A_{Coll} = \frac{A_{UT}^{(\sin\phi_{\varepsilon})}}{D_{NN} \cdot f \cdot P} \propto \frac{\sum_q e^2\, h_1(x,Q^2) \cdot H_1^{\perp(1)q}(z,Q^2)}{\sum_q e^2\, f_1(x,Q^2) \cdot D_1^q(z,Q^2)}$$

positive leading hadrons

preliminary

positive leading hadrons   *2002 data*

preliminary

(March 26, 2004)

negative leading hadrons

preliminary

negative leading hadrons   *2002 data*

preliminary

(March 26, 2004)

Lambda Polarisation

- Lambda-polarisation

- measurement of spin-dependant Λ-fragmentation (ΔD^{Λ}_{q})

- test of strange-sea-quark symmetrie in the nucleon
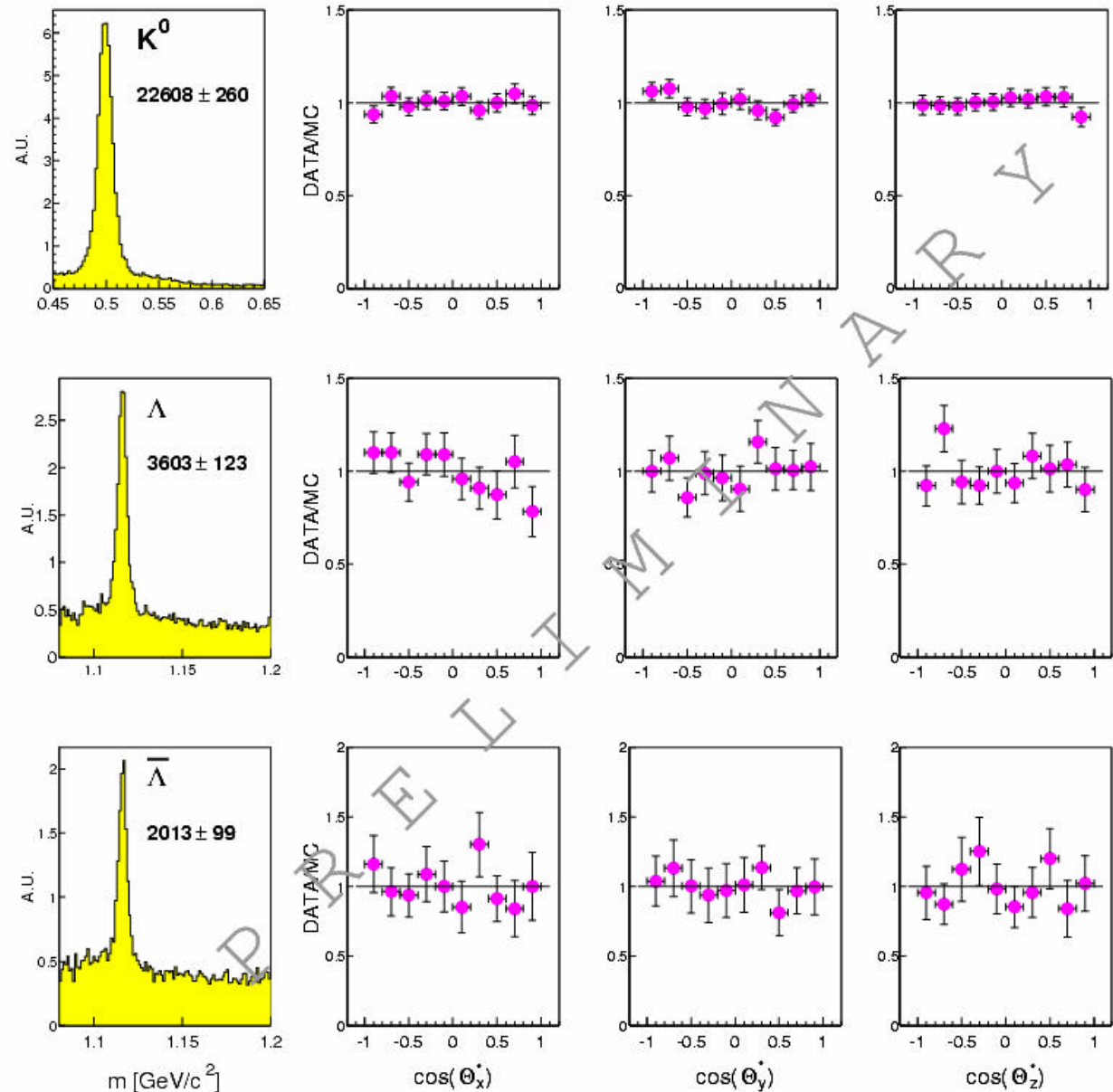
Outlook: COMPASS Physics Program

2004 <u>nucleon spin structure</u> (μ-beam)

- collect more statistics

    (DG/G, transversity, Lambda polarisation, …)

break in 2005 upgrade of COMPASS

    (target-solenoide, RICH-wall,…)

starting 2006 <u>in addition nucleon spectroscopy</u> (π-,K- and p-beam)

- hadron-beam:
    - Primakoff-reactions: polarisibility of π, K
    - glue-balls and hybrid-mesons
    - charmed mesons and baryons:
        - semi-leptonic decays
        - double-charmed baryons

- μ-beam:
    - generalised parton distributions