COMPASS experiment
Status and reacent results

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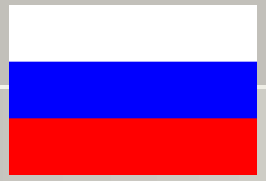
Institute for Nuclear Studies, Warsaw, Poland

Brookhaven, 3 May 2005

The COMPASS Collaboration (230 Physicists from 12 Countries)

Dubna (LPP and LNP), Moscow (INR, LPI, State University), Protvino

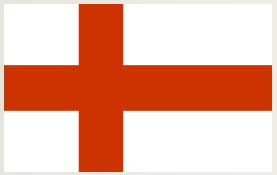


CERN

Bielefeld, Bochum, Bonn (ISKP & PI), Erlangen, Freiburg, Heidelberg, Mainz, München (LMU & TU)

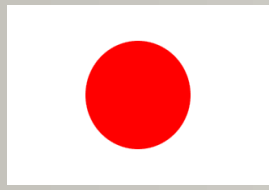
Warsaw (SINS), Warsaw (TU), Warsaw (UW)

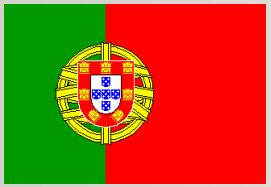
Prag



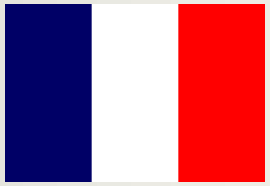
Helsinki

Nagoya





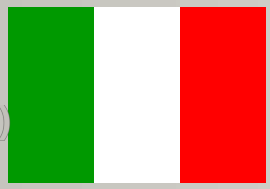
Lisboa



Saclay

Torino(University, INFN)

Trieste(University, INFN)



Tel Aviv

Burdwan, Calcutta

COMPASS: THE new fixed target facility at CERN !

COmmon Muon and Proton Apparatus for Structure and Spectroscopy. - HISTORY

- 1996 COMPASS proposal
- 1997 conditional approval
- 1998 MoU
- 1999 – 2001 construction & installation
- 2001 technical run
- 2002, 2003, 2004 data taking
- 2005 break at Cern (LHC)
- Restart in 2006
- at least until 2010

Physics Goals

Contribute to the understanding of the non-perturbative physics of the nucleon

nucleon spin structure

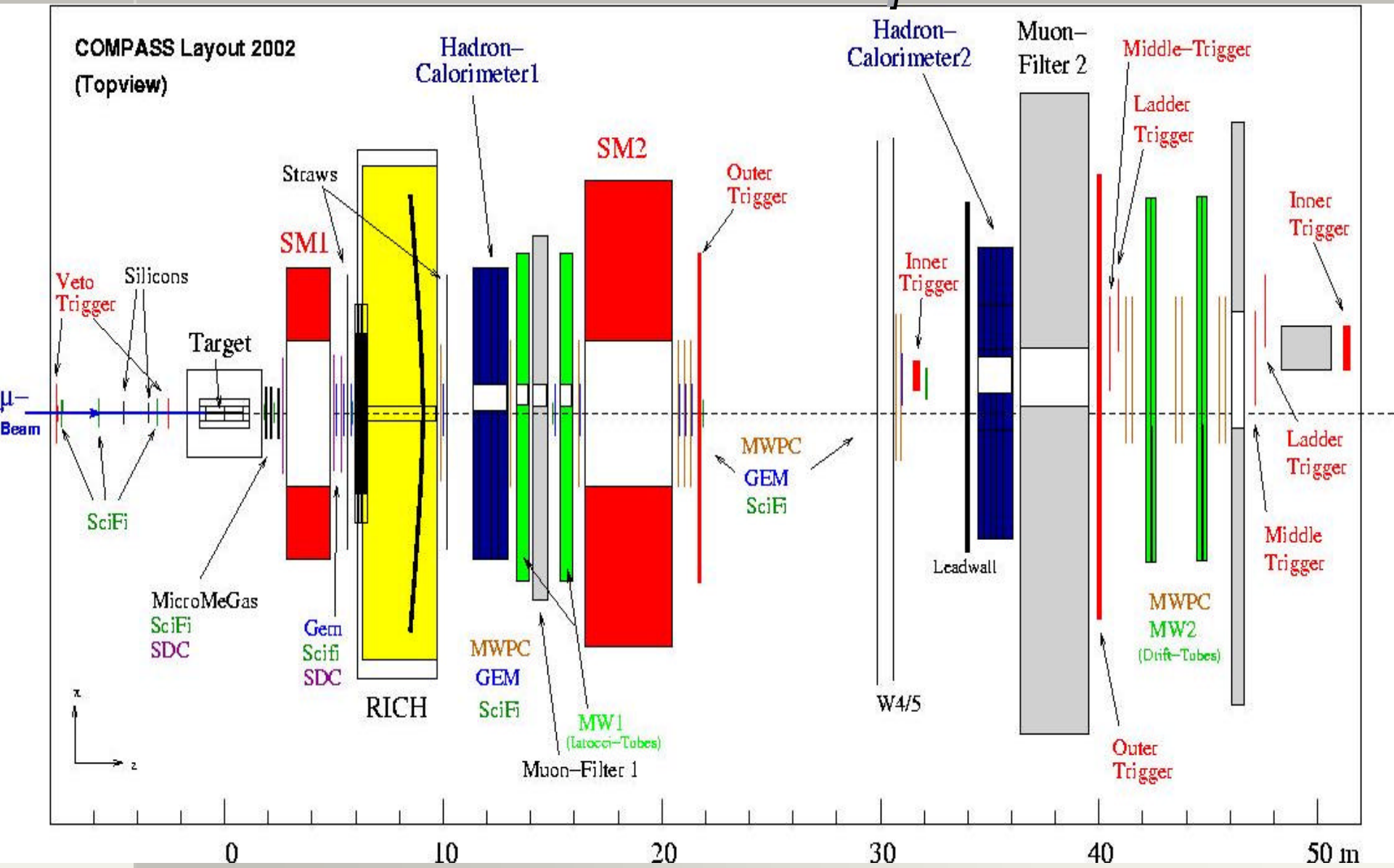
- **Gluon Polarization DG/G**
- transverse spin structure function $h_1(x)$
- Flavor dependent polarized quark helicity densities $\Delta q(x)$
- spin dependent fragmentation functions ΔD_q^{Λ}
- Exclusive VM-Production

nucleon spectroscopy

- Primakoff-Reactions
  - polarizability of π and K
- glue balls and hybrids
- charmed mesons and baryons
  - semi-leptonic decays
  - double-charmed baryons

LHC
COMPASS
SPS

The COMPASS Experiment



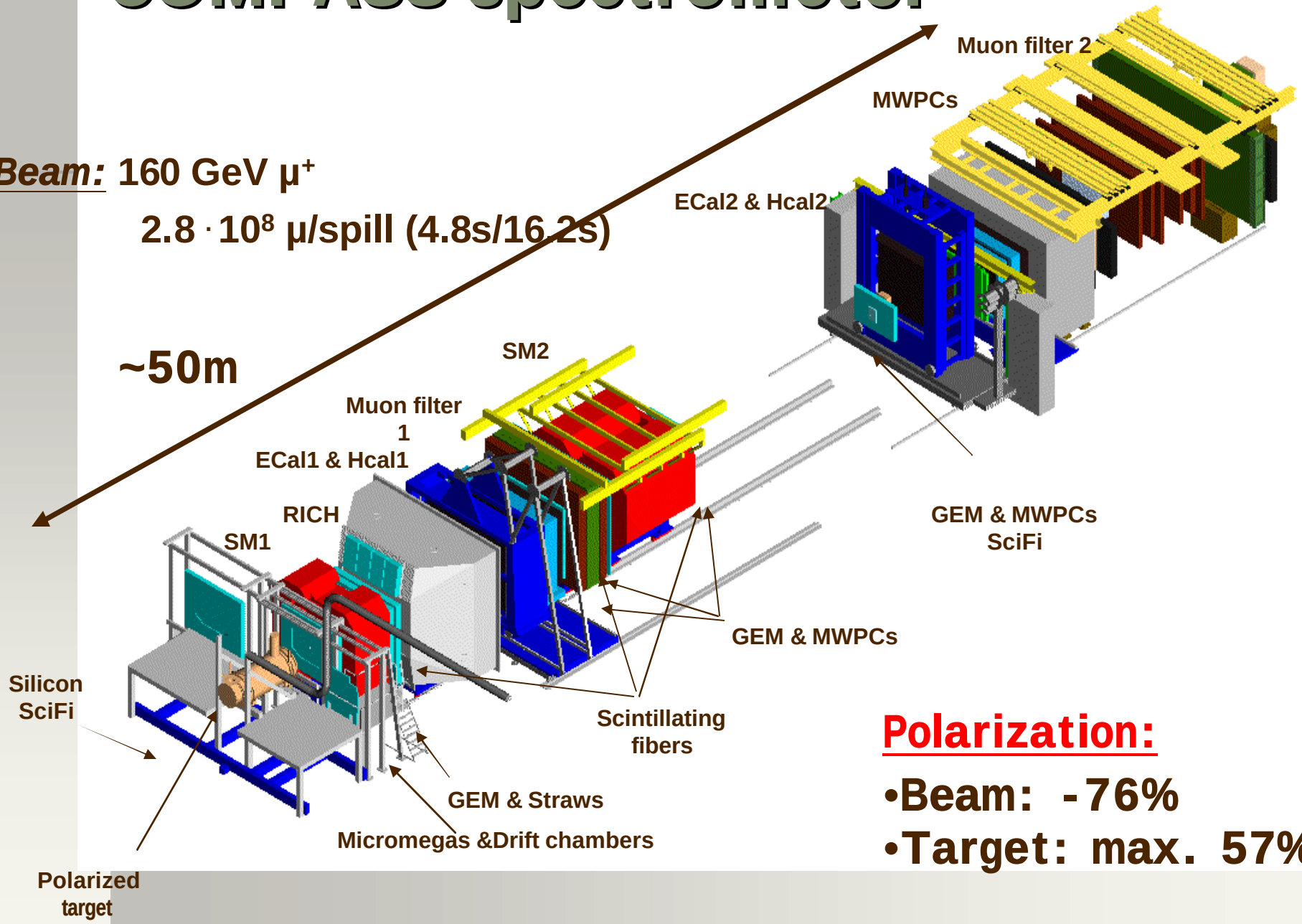
Beam: $2 \cdot 10^8$ μ^+/ spill (4.8s / 16.2s) **Beam momentum:** 160 GeV/c

Luminosity: ~$5 \cdot 10^{32}$ cm^{-2} s^{-1} **Beam polarization:** -76%

COMPASS spectrometer

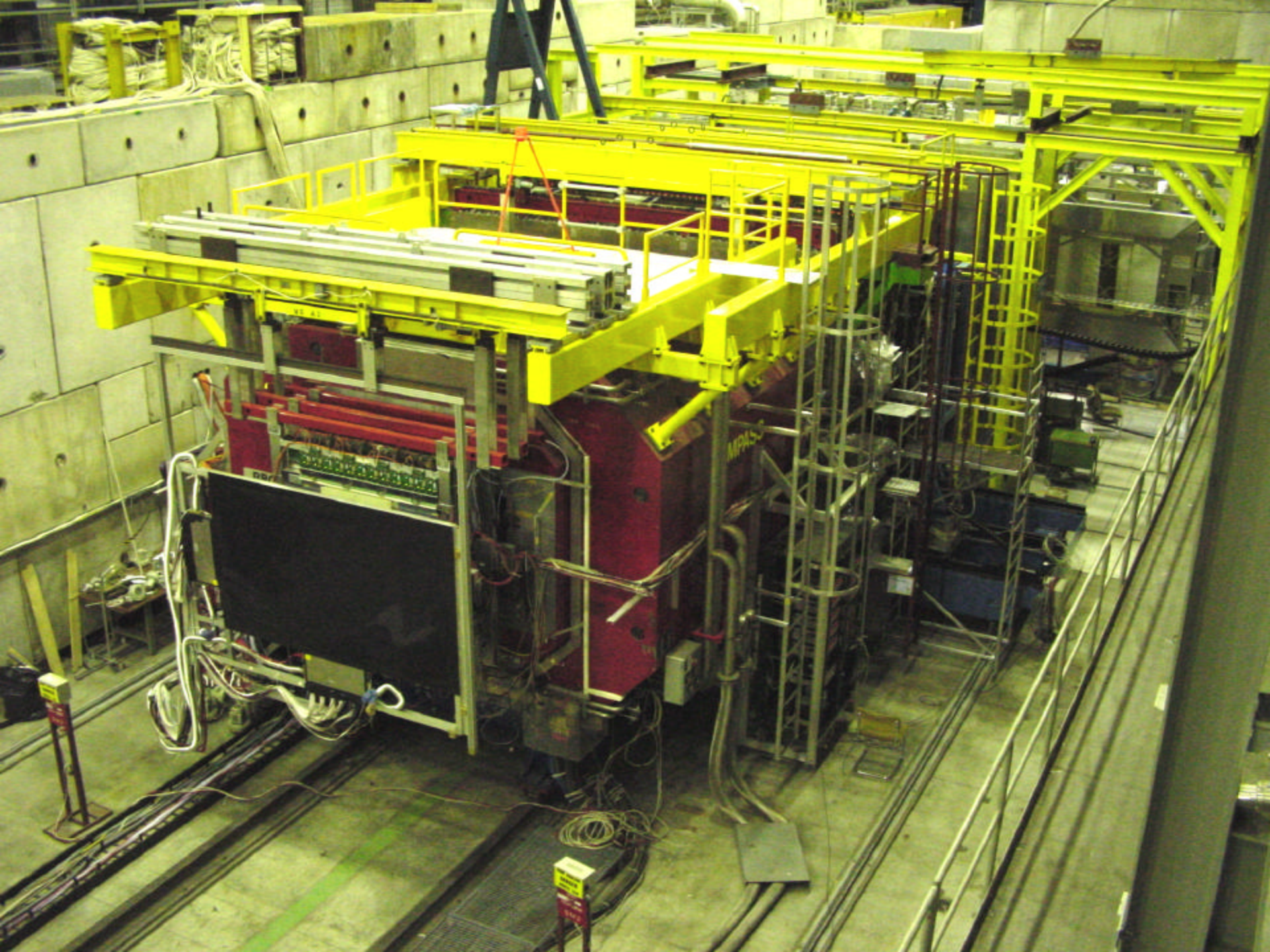
Beam: **160 GeV μ^+**

$2.8 \cdot 10^8$ μ/spill (4.8s/16.2s)

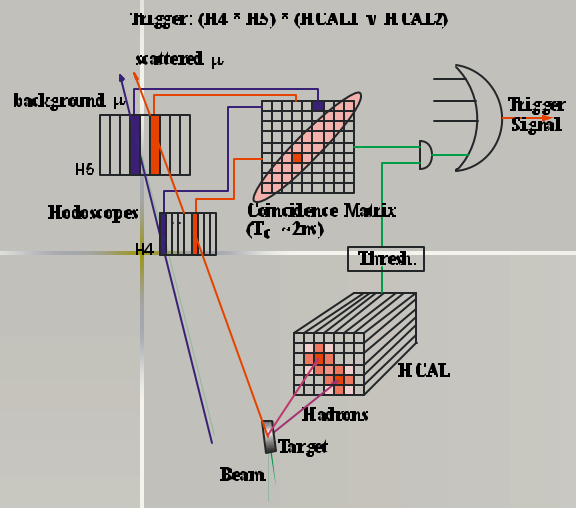


Polarization:

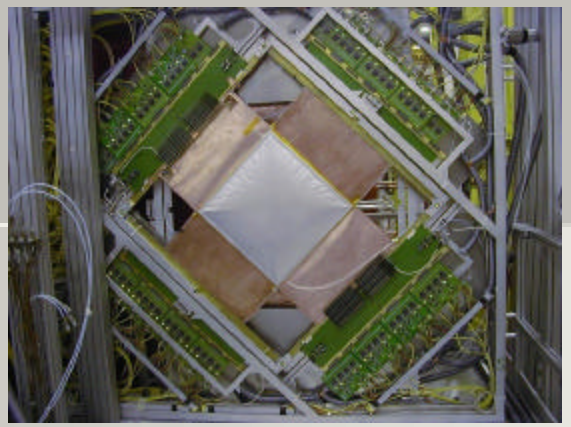
- **Beam: -76%**
- **Target: max. 57%**



New detector technologies

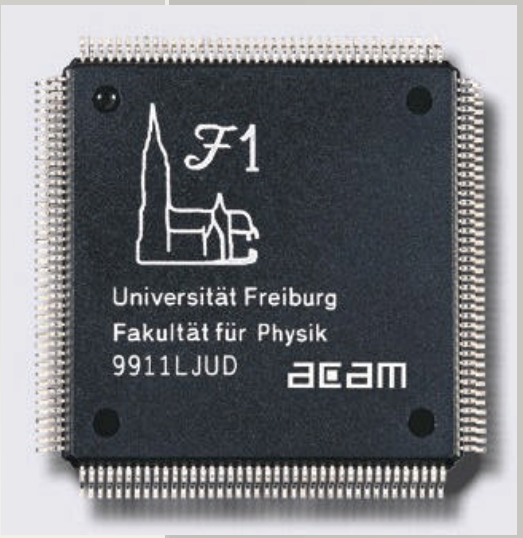


Trigger-System

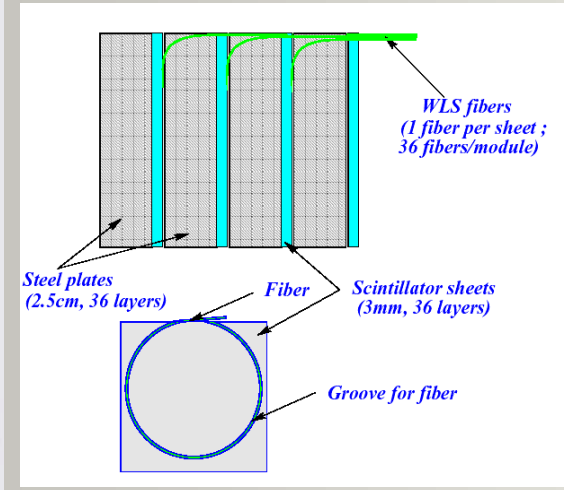


MicroMegas

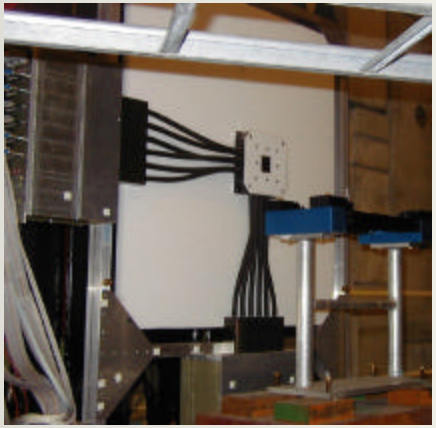
Straws



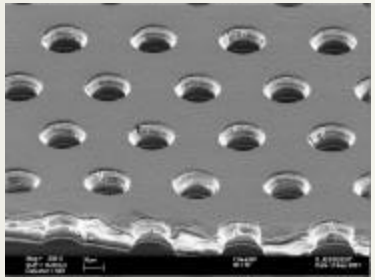
Readout electronics



calorimeter readout



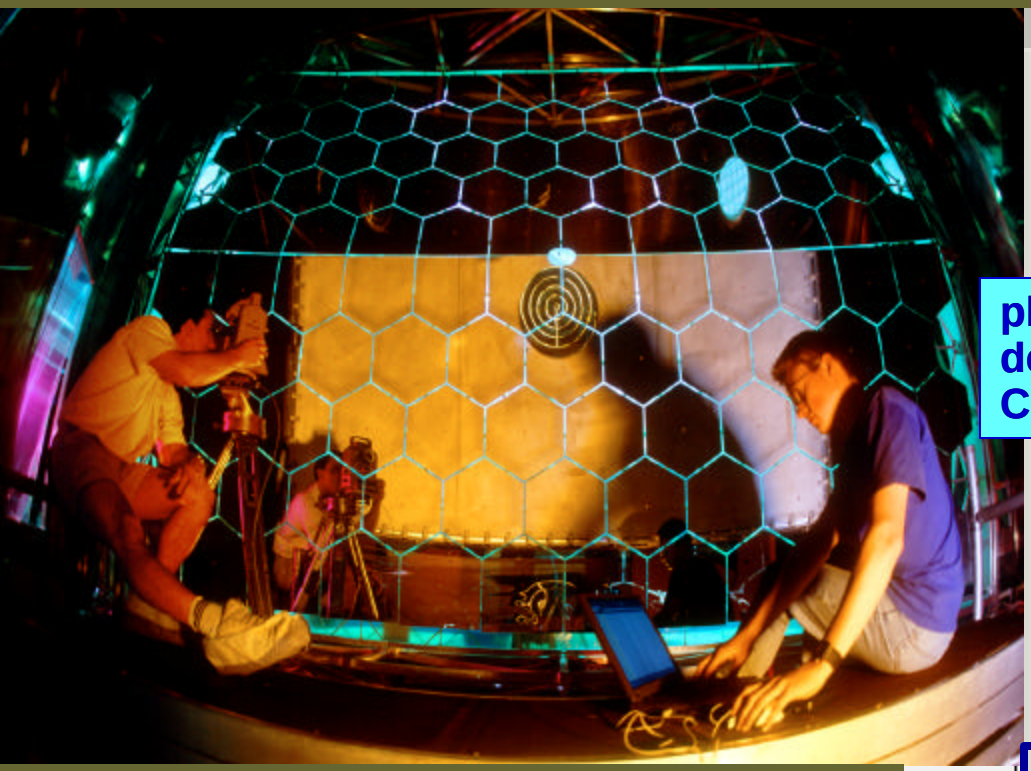
Scintillating fiber trackers

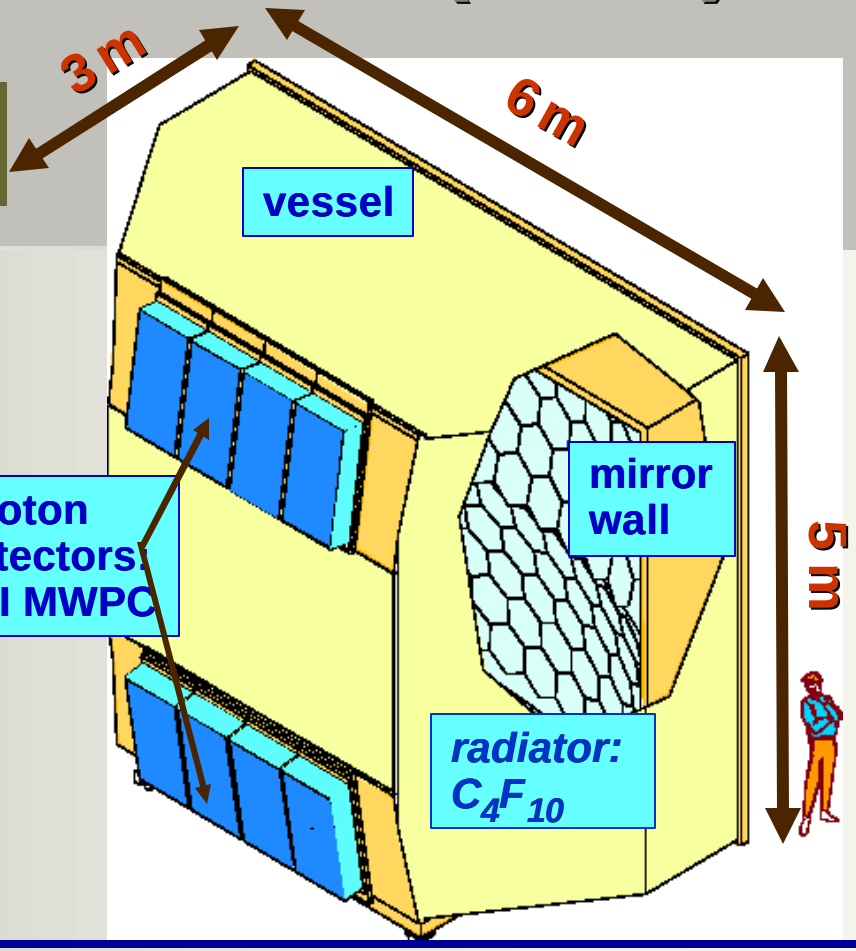


GEM

Ring Imaging CHerenkov Counter (RICH)

116 VUV mirrors, surface area: 21 m²





Photon detection

5.3 m² MWPCs

16 CsI Photocathodes

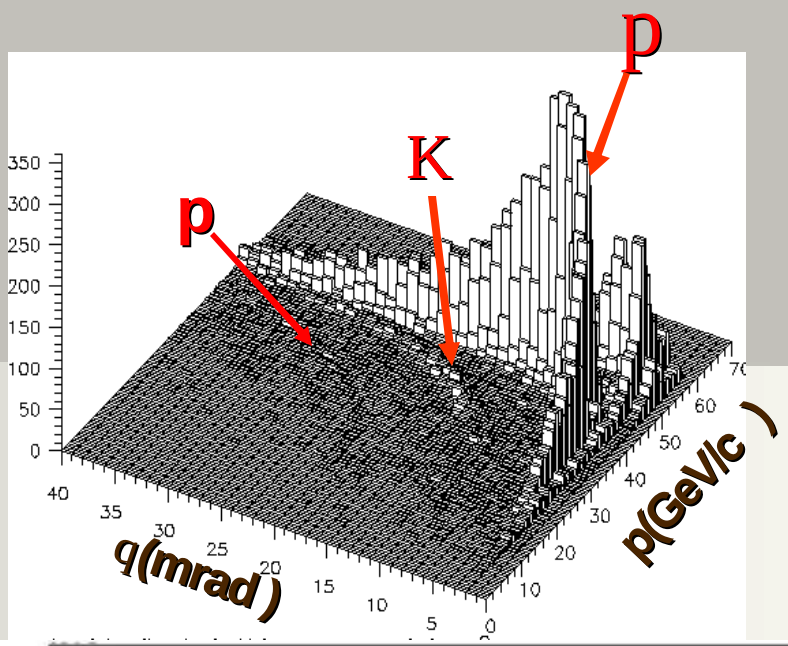
84,000 analog readout channels

detection of VUV photons (165-200 nm)

si	♦ q>1.2 mrad
ri	♦ q>0.4 mrad
photons/ring	n ~14
p/K sep.	up to 40 GeV/c

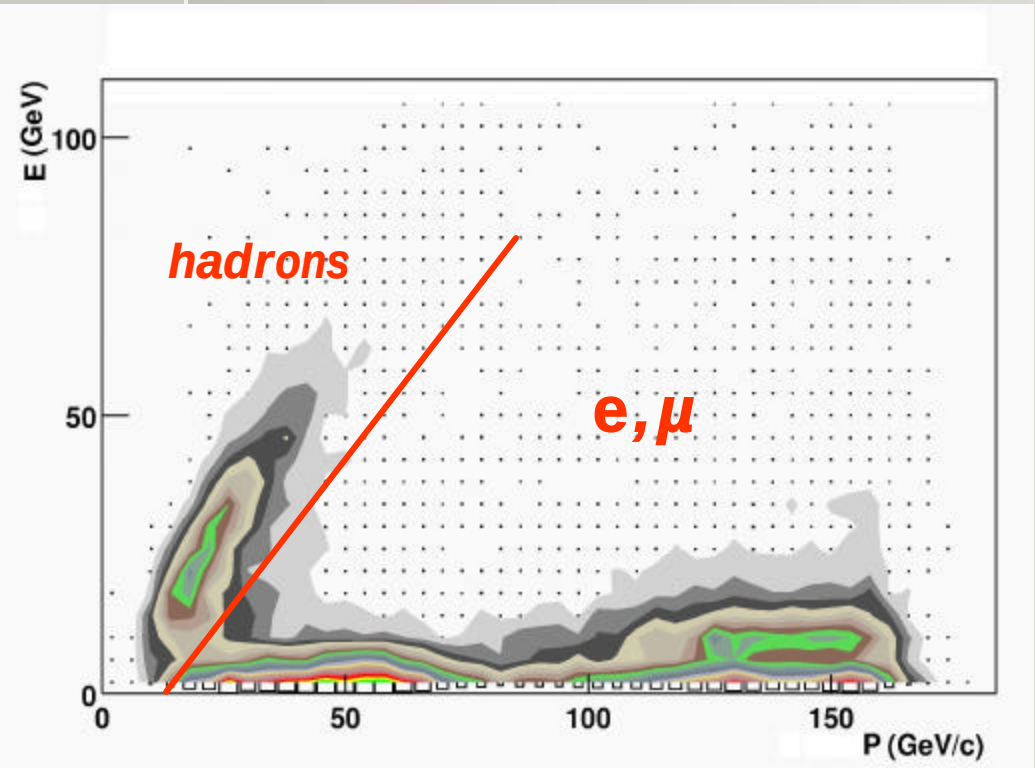
hadron identification

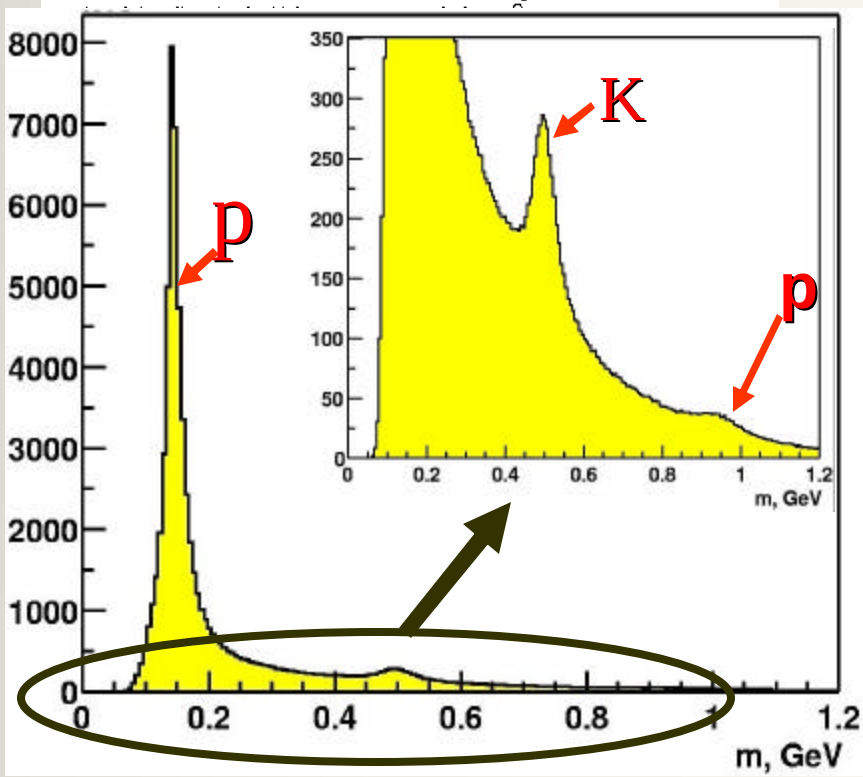
By RICH



...and

hadron calorimeters





COMPASS – two programs

→ with muon beam

- Muons:

  data taking from 2002 -> 2004
  will continue in 2006

Main goal $\frac{\Delta G}{G}$

→ with hadron beam

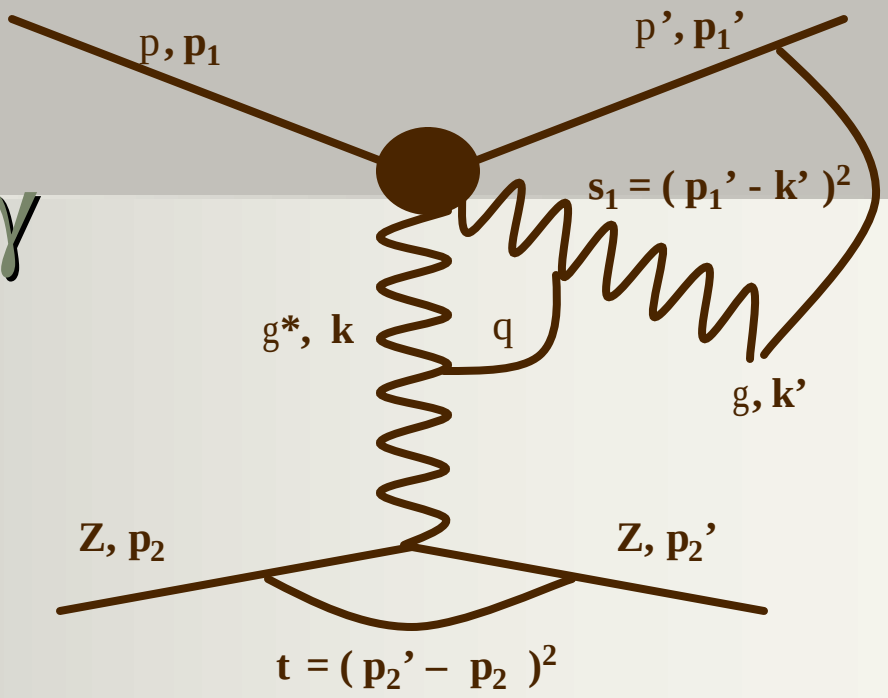
- Hadrons:

  pilot run in 2004

The Primakoff reaction

$$\pi + Z \rightarrow \pi' + Z + \gamma$$

first data taken in 2004
expected ~30k events



$$\frac{d^3 s}{dt\,dw\,d\cos J} = \frac{a_f Z^2}{pw}\frac{t-t_0}{t^2}\boxed{\frac{ds_{pg}(w,J)}{d\cos J}}\left|F_A(t)\right|^2$$

Electric & Magnetic polarizability

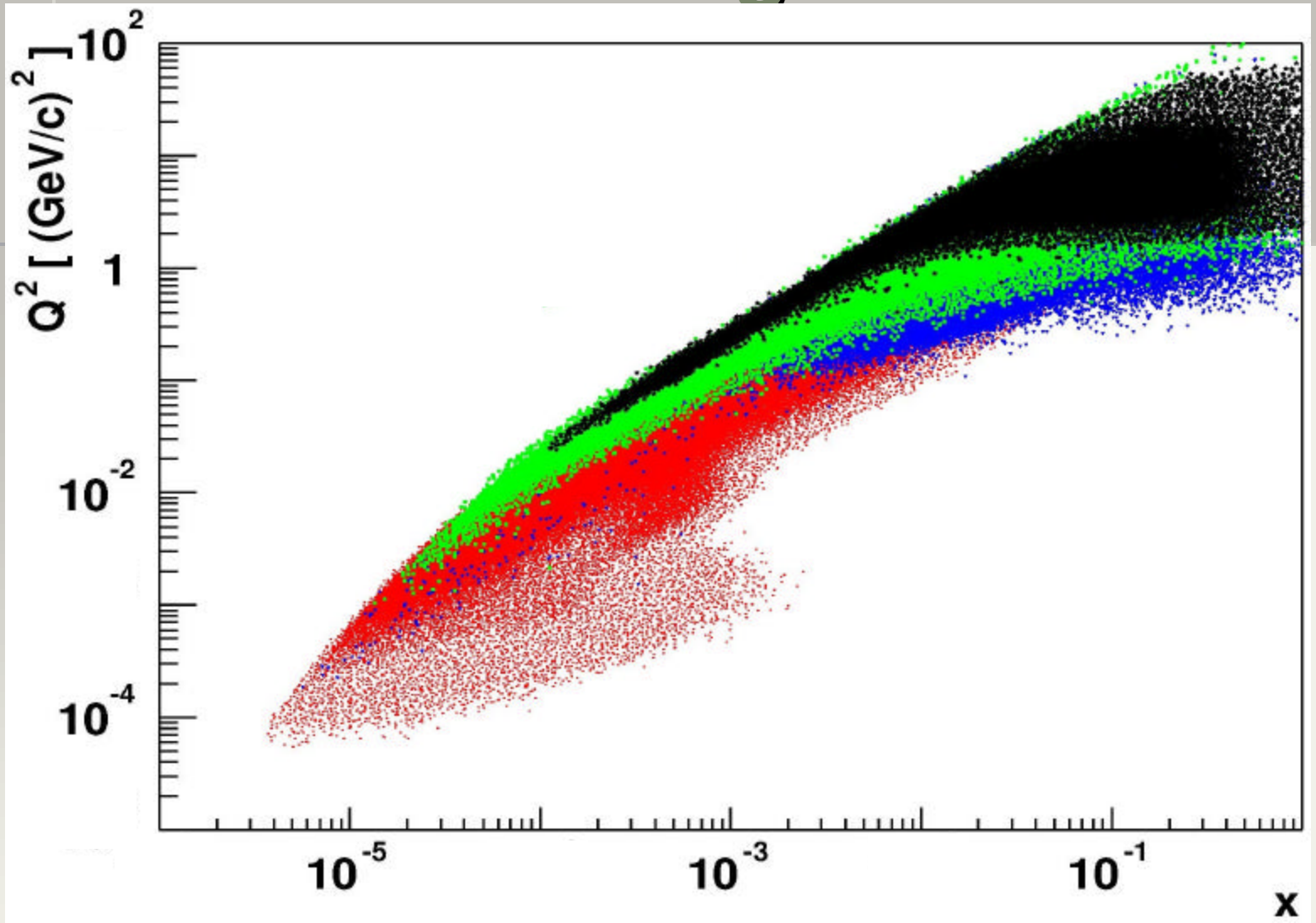
$$\frac{ds_{pg}(w,J)}{d\cos J} = \frac{2pa_f^2}{m_p^2}\cdot\left(F_{pg}^{Th} + \frac{m_p w^2}{a_f}\cdot\frac{\boxed{a_p}(1+\cos^2 J) + 2\boxed{b_p}\cos J}{\left(1+\frac{w}{m_p}(1-\cos J)\right)^3}\right)$$

Muon program : data 2002-2004 ongoing analysis

- A_1^d and influence on QCD fit
- D^o and D^{o*} for ?G/G from open charm
- ☹G/G from *„high p_T" sample:*
  perturbative region (Q^2>1GeV^2)
  and photoproduction region (Q^2<1GeV^2)
- Transversity studies (Collins and Sivers asymmetries) for single and two hadrons
- ☹ and ☹ hyperon production
- Vector mesons
- Search for pentaquarks

In this talk – results with longitudinal target polarization

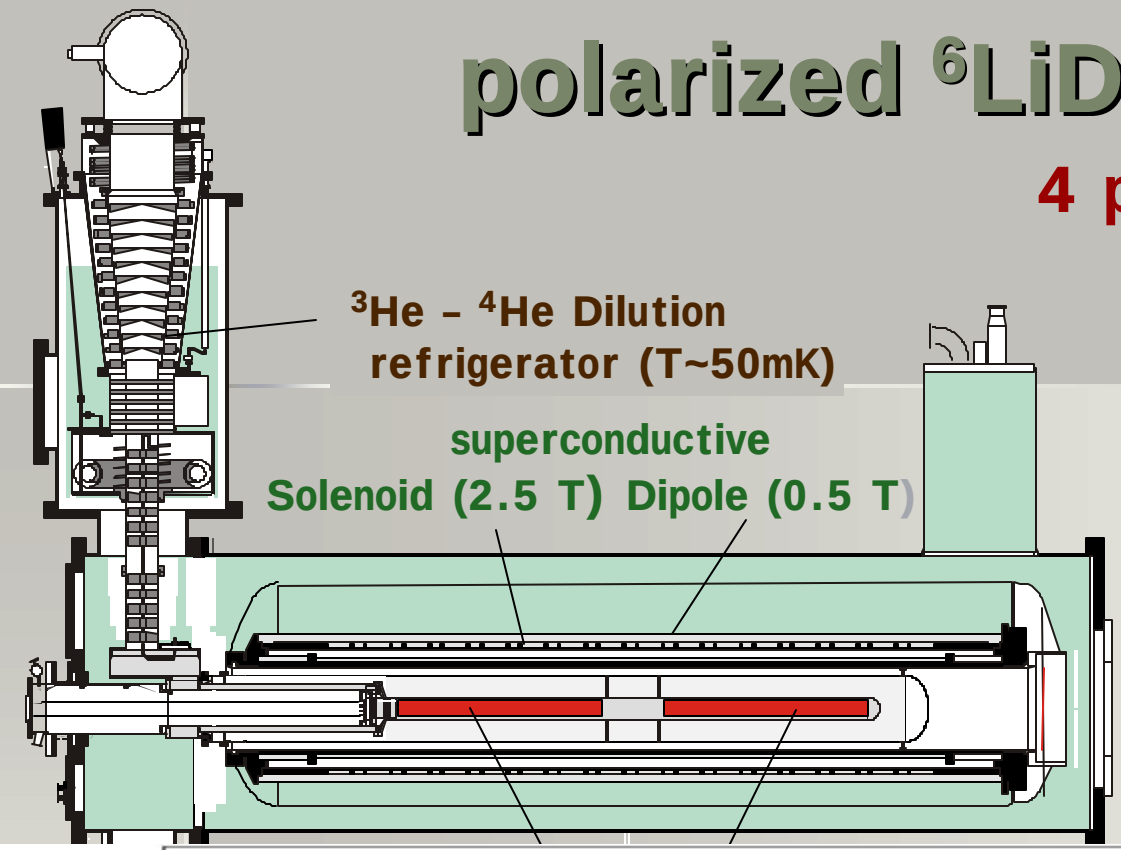
Kinematic range covered



Excellent for non-perturbative & perturbative physics

- ***small x_{Bj}***
- ***very small Q^2 → $Q^2 > 100$ (GeV/c)^2***

polarized ^{6}LiD target



4 possible spin combinations:

① → ←

② ← →

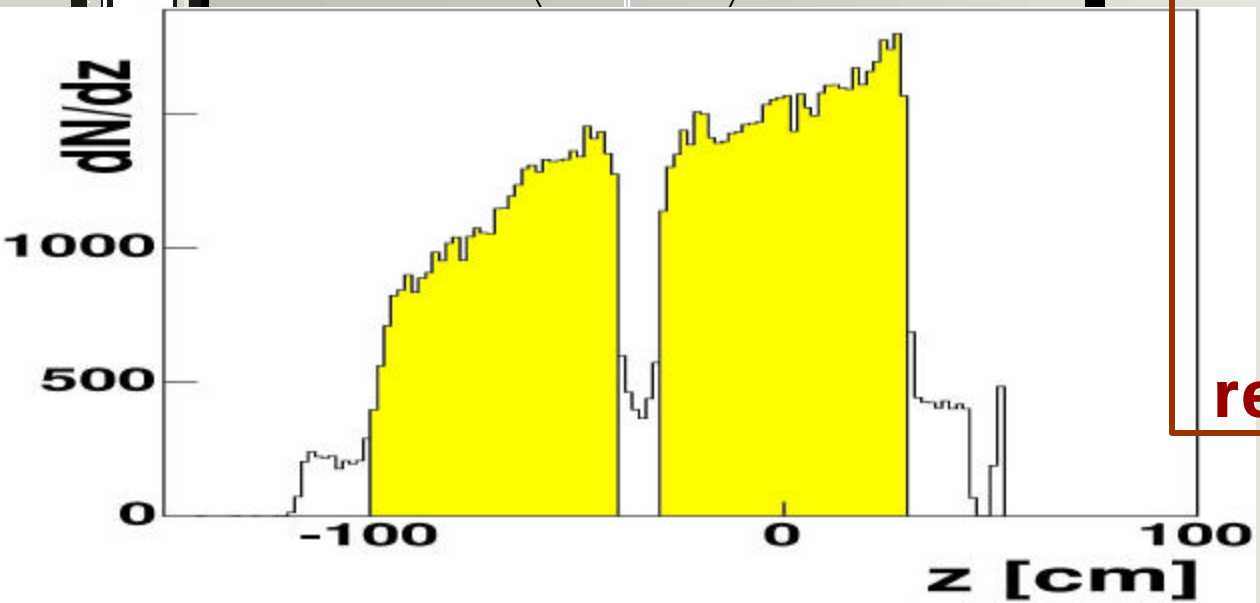
reversed every 8 hours

or:

③ ↑ ↓

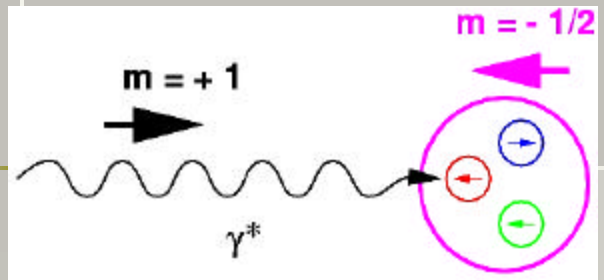
④ ↓ ↑

reversed once a week

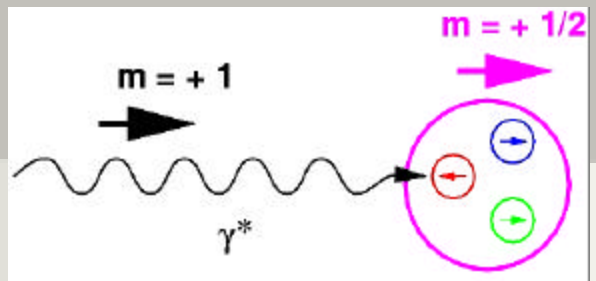


Polarization: ~50%

Asymmetry A_1



$$\sigma_{1/2} \sim \sum_i e_i^2 q_i^+$$



$$\sigma_{3/2} \sim \sum_i e_i^2 q_i^-$$

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{\sum_i e_i^2 \left(q_i^+ - q_i^-\right)}{\sum_i e_i^2 \left(q_i^+ + q_i^-\right)}$$

$$g_1(x) = \frac{1}{2} \sum_i e_i^2 \left(q_i^+ - q_i^-\right)$$

$$F_1(x) = \frac{1}{2} \sum_i e_i^2 \left(q_i^+ + q_i^-\right)$$

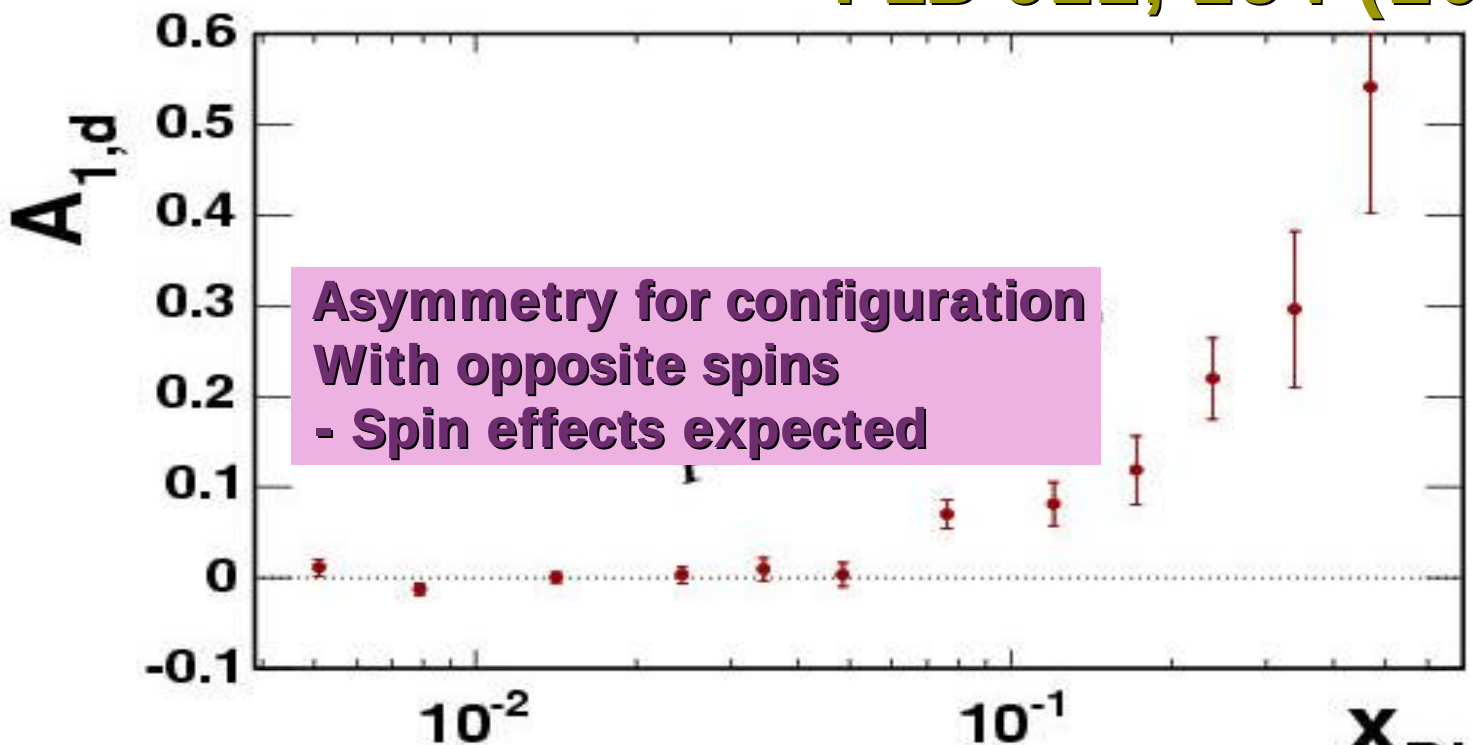
$$A_1(x) \approx \frac{g_1(x)}{F_1(x)}$$

measurement of A_1^d

also test of the detector and of systematic effects controle

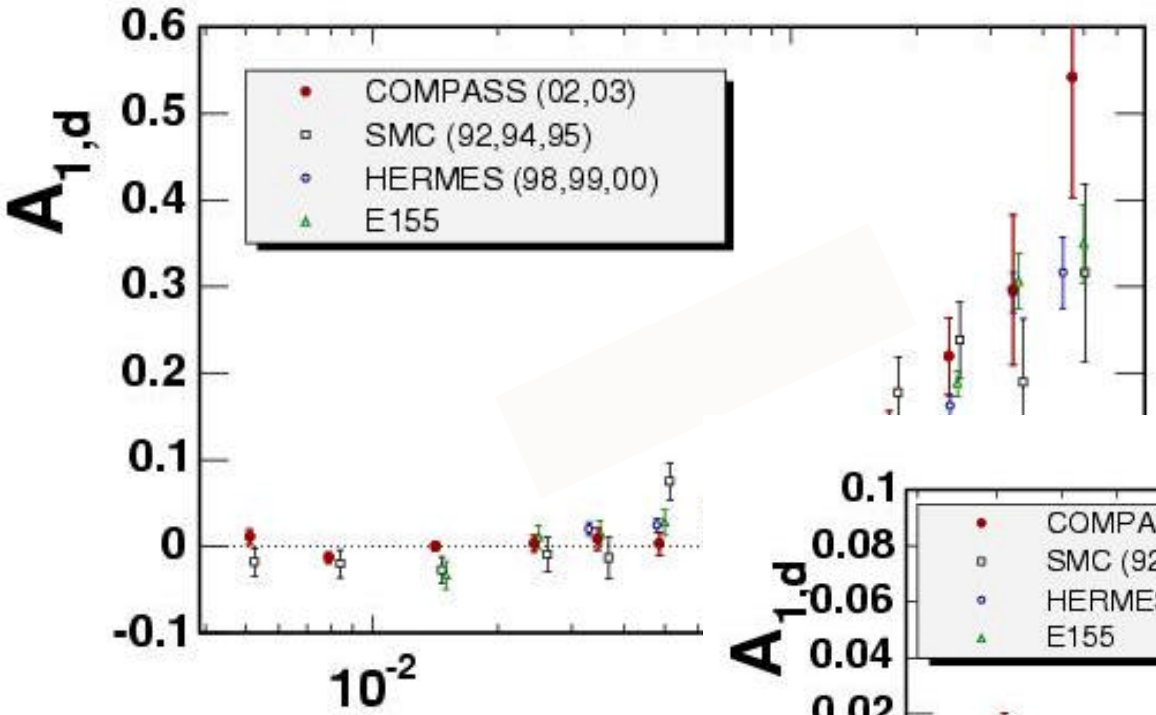
$$A_1 = \frac{1}{2\langle P_t P_b f D\rangle}\left(\frac{N_u - N_d}{N_u + N_d} - \frac{N'_u - N'_d}{N'_u + N'_d}\right)$$

PLB 612, 154 (2005)



Asymmetry for configuration
With opposite spins
- Spin effects expected

DOUBLE SPIN ASYMMETRY A_1^d



COMPASS:

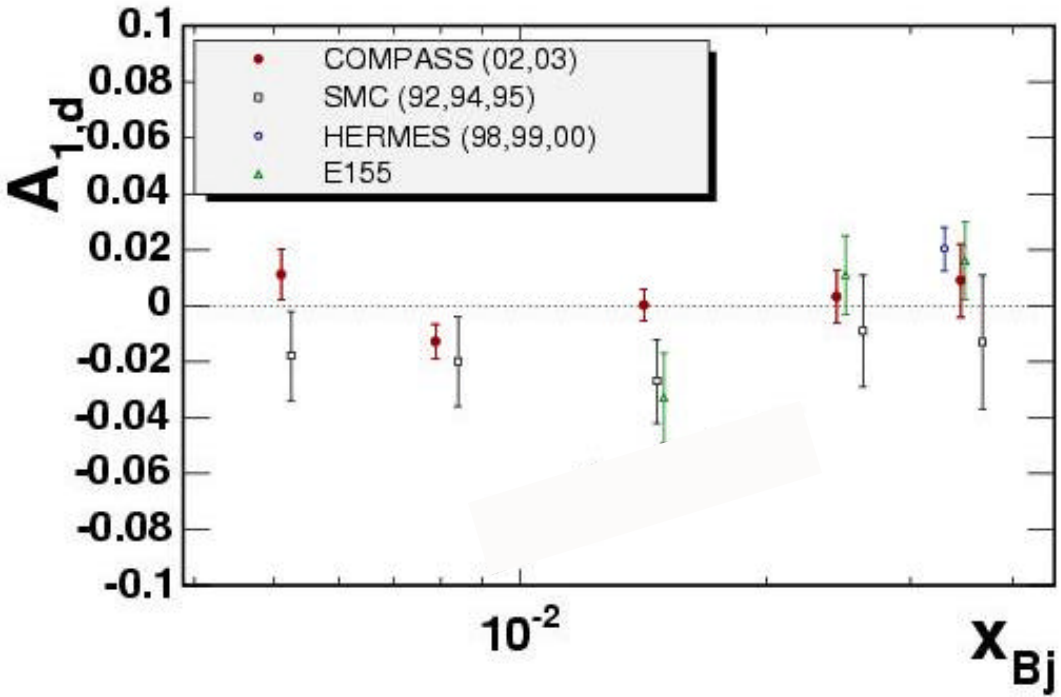
2002+2003 data

34 Million DIS events

$Q^2 > 1$ (GeV/c)^2

$0.1 < y < 0.9$

more to come ftom 2004



Data displayed at experimer

QCD fit with all DIS spin data, effect of Compass A_1^D

Exp.	Target nucl.	Nr. of points	x	Q^2	Reference
EMC	p	10	0.015-0.46	3.5-29.5	Nucl. Phys. B 328 (1989) 1
SMC	p	12	0.005-0.48	1.3-58.0	Phys.Rev.D 58 (1998) 112001
SMC	d	12	id.	id.	id.
COMPASS	d	12	0.005-0.47	1.2-47.5	hep-ex/0501073
E142	n	8	0.035-0.47	1.1-5.5	Phys. Rev.D 54 (1996) 6620
E143	p	28	0.031-0.75	1.3-9.5	Phys.Rev. D 58 (1998) 112003
E143	d	28	id.	id.	id.
E154	n	11	0.017-0.56	1.2-15.0	Phys.Rev. Lett. 79 (1997) 26
E155	d	11	0.015-0.75	1.2-16.8	Phys. Lett. B 463 (1999) 339
E155	p	11	id.	id.	Phys. Lett. B 493 (2000) 19
JLAB	n	3	0.33-0.6	2.7-4.8	Phys.Rev.Lett.92(2004)012004
HERMES	n	9	0.033-0.46	1.2-5.3	Phys. Lett. B 404 (1997) 383
HERMES	p	9	0.033-0.45	1.2-9.2	Phys.Rev. D75 (2005) 012003
HERMES	d	9	id.	id.	id.
		173			

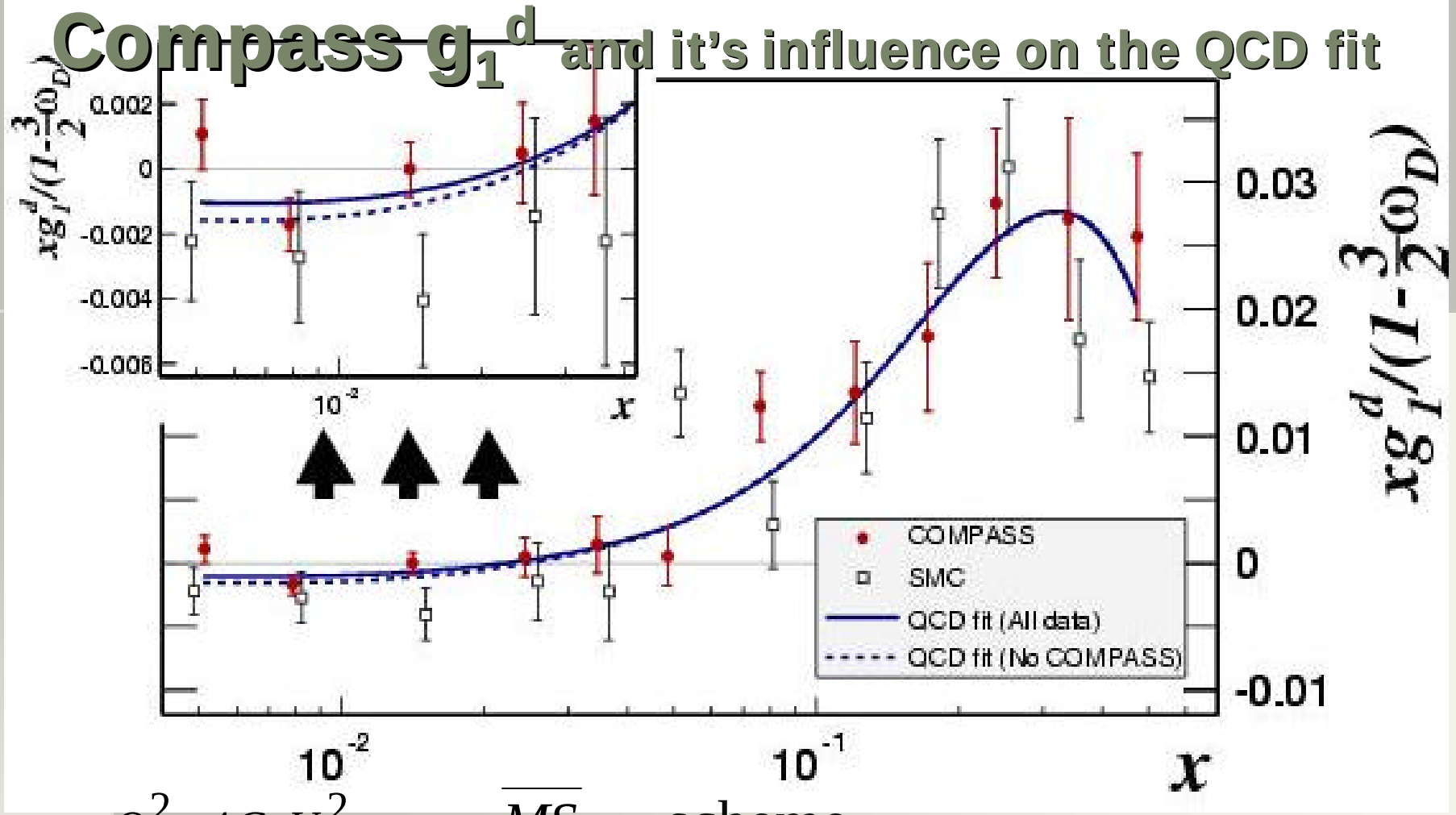
NLO evolution, calculations on grid (x,Q^2)

$\overline{MS}$ scheme, ?^{2} minimization using Minuit

PDF	Shape	Param.
$\Delta\Sigma$	$\frac{\eta}{N}x^{\alpha}(1-x)^{\beta}(1+\gamma x)$	η α β γ
ΔG	$\frac{\eta}{N}x^{\alpha}(1-x)^{4}$	η α
Δq_3	$\frac{3/4(F+D)}{N}x^{\alpha}(1-x)^{\beta}$	α β
Δq_8	$\frac{1/4(3F-D)}{N}x^{\alpha}(1-x)^{\beta}$	α β

- 10 parameters fitted
- NDF : 173-10
- ?^{2} probability 14%

Compass g_1^d and it's influence on the QCD fit



$Q^2 = 4 GeV^2$ $\overline{MS}$ scheme

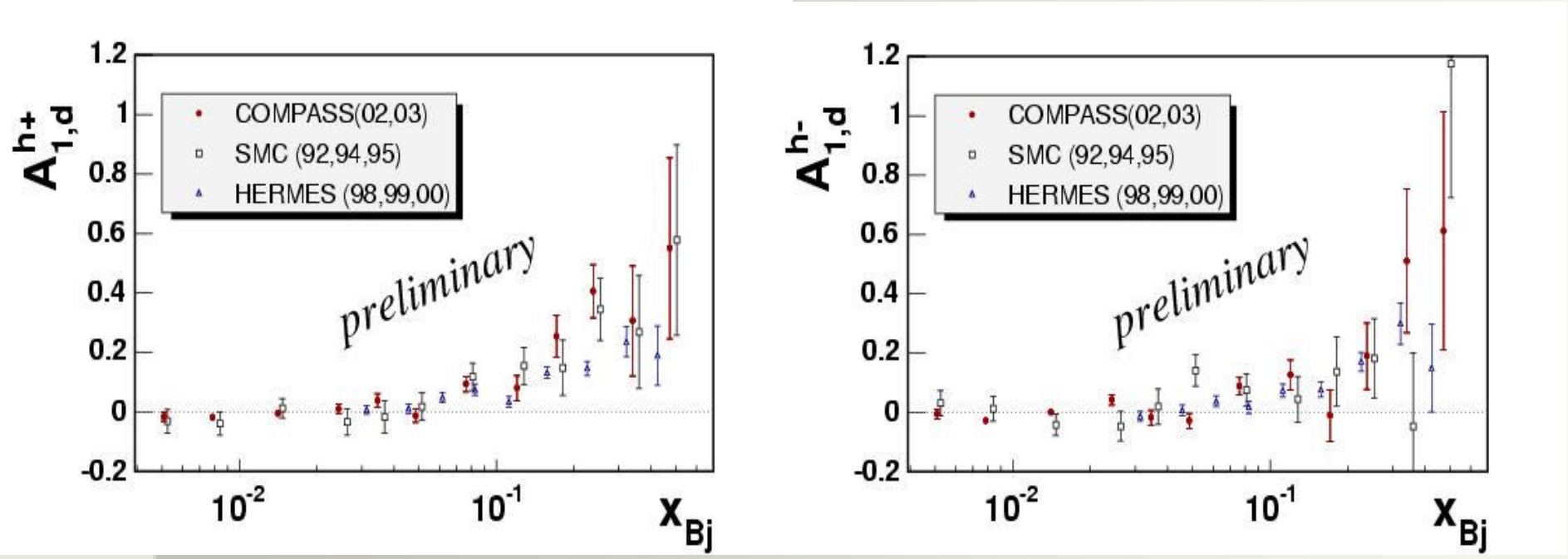
$$\Delta\Sigma = 0.237^{+0.024}_{-0.029}$$

with Compass new deuterium g_1 data

$$\Delta\Sigma = 0.202^{+0.042}_{-0.077}$$

without

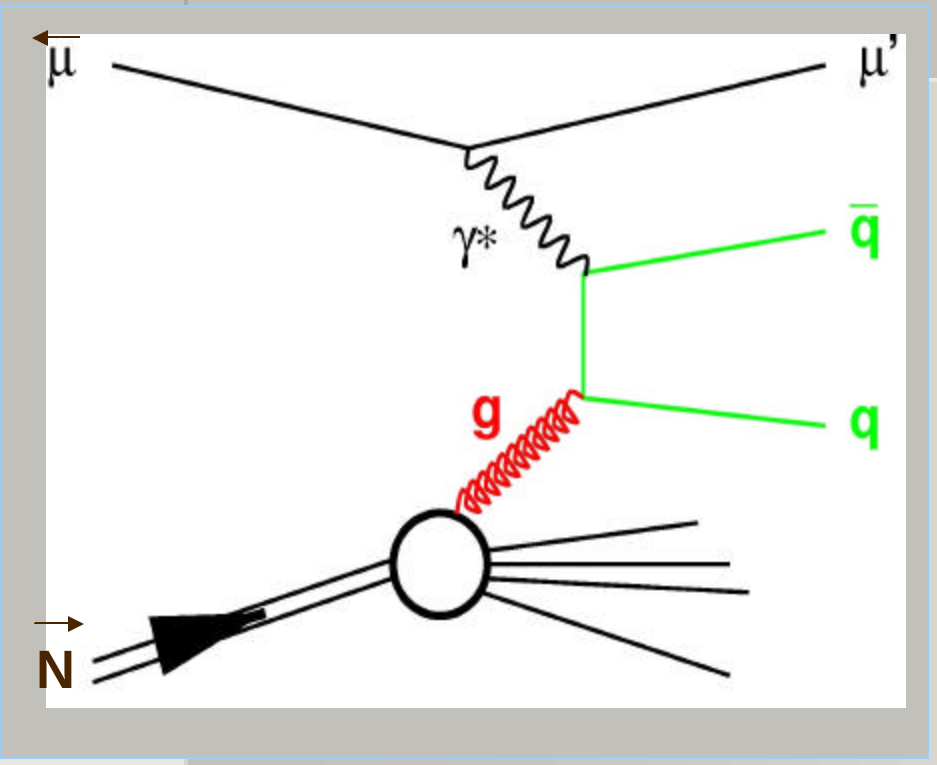
Semi-inclusive asymmetries – also avalaiable



Improvement at low x, consistent with SMC

DG/G at COMPASS

Photon Gluon Fusion



q = c cross section difference in charmed meson production

? *theory well understood*

? *experiment challenging*

q= u,d,s cross section difference in 2+1 jet production in COMPASS: events with 2 hadrons with high p_T

? *experimentaly easier*

? *theory difficult*

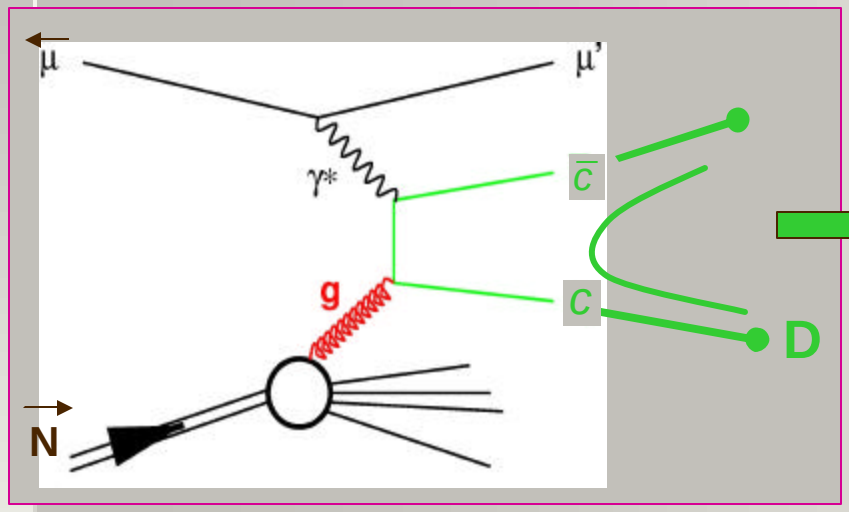
DG / G: OPEN CHARM

$$A_{gN}^{c\bar{c}} = \frac{\Delta s^{\,gN\to c\bar{c}X}}{s^{\,gN\to c\bar{c}X}} = \frac{\int d\hat{s}\,\Delta s^{\,\mathrm{PGF}}(\hat{s})\,\Delta G(x_G,\hat{s})}{\int d\hat{s}\,s^{\,\mathrm{PGF}}(\hat{s})\,G(x_G,\hat{s})} \approx \langle a_{LL}\rangle \left\langle \frac{\Delta G}{G} \right\rangle$$

$$\hat{s} = M_{c\bar{c}}^2$$

$\Delta\sigma^{\mathrm{PGF}}$ at NLO: Bojak, Stratmann NPB 540 (1999) 345; Contogouris *et al.*

Photon-Gluon Fusion



$$D^0 \to K^- p^+ \qquad \text{(BR 4 \%)}$$

$$D^{*+} \to D^0 p^+ \to \left(K^- p^+\right) p^+$$

$$A_{raw} = \frac{N_{c\bar{c}}^{\text{Þ}} - N_{c\bar{c}}^{\text{Ü}}}{N_{c\bar{c}}^{\text{Þ}} + N_{c\bar{c}}^{\text{Ü}}} = P_m P_T f\, D\, A_{gN}^{c\bar{c}}$$

$P_m \approx -0.76$ $\qquad f \approx 0.4$

$P_T \approx 0.5$ $\qquad D(y)$

Comparison with 2002 data

	2002	P1I+J/2003	Gain
Flux/#days	$1.70 \cdot 10^{13}\mu$/38.6 days	$9.58 \cdot 10^{12}\mu$/13.7 days	1.8
D* D*/Flux	281±26 $1.65 \cdot 10^{-11}$	270±25 $2.82 \cdot 10^{-11}$	1.7±0.2
D^0 D^0/Flux	1587±179 $9.34 \cdot 10^{-11}$	1327±161 $13.85 \cdot 10^{-11}$	1.5±0.2
S/B	0.78±0.08	0.90±0.09	1.2±0.2
Bckgrd Bckgrd/Flux	4141816 $2.44 \cdot 10^{-7}$	2653933 $2.77 \cdot 10^{-7}$	1.1

Known factors: - Beam rec.: 1.05
(JMLG) - Trigger: 1.20
- DAQ: 1.03

1.31

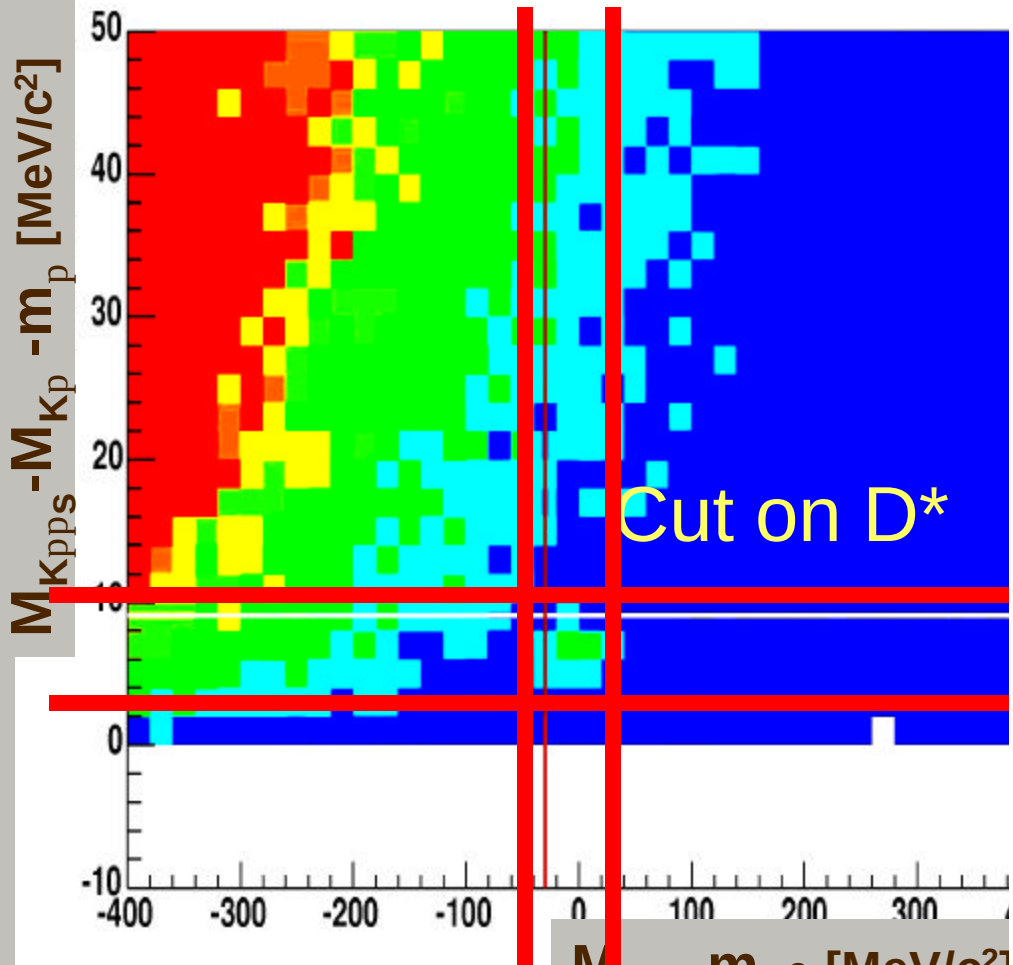
And about the RICH (…)

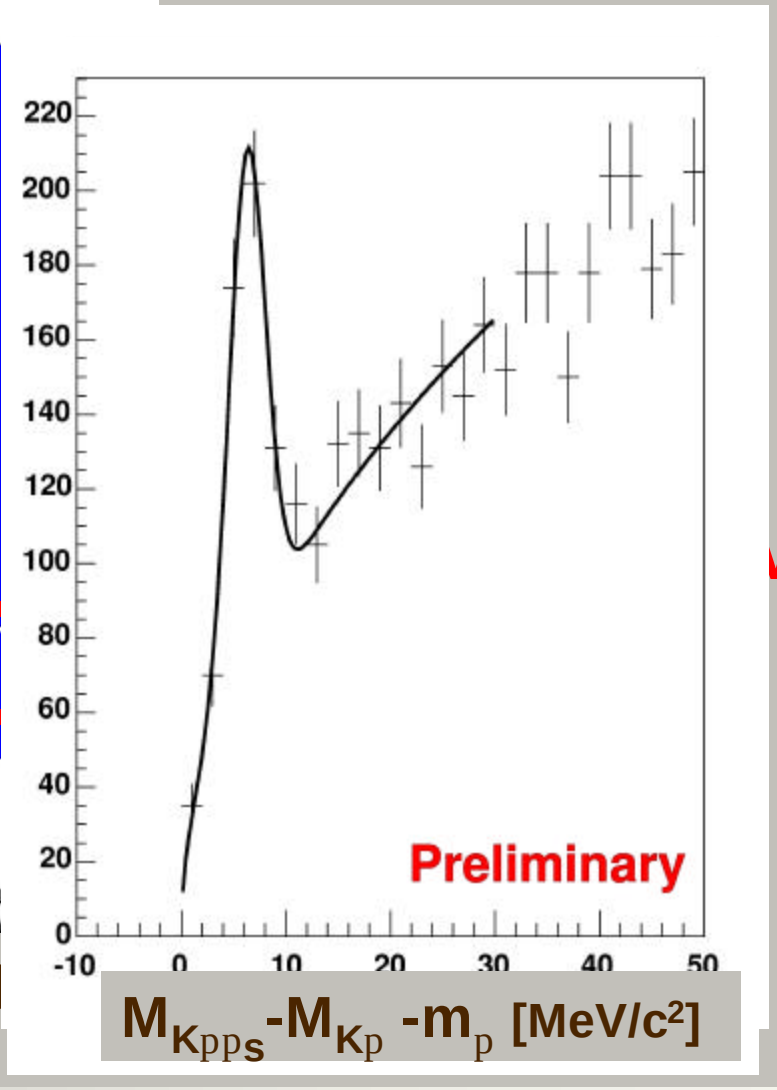
ε: 52 ± 9 ⟶ 67 ± 10 ⟶ 1.3 ± 0.3
p: 60 ± 11 ⟶ 56 ± 11 ⟶ 0.9 ± 0.3

D* tagging: D*? D^0 p

$D^* \to (Kp)p$

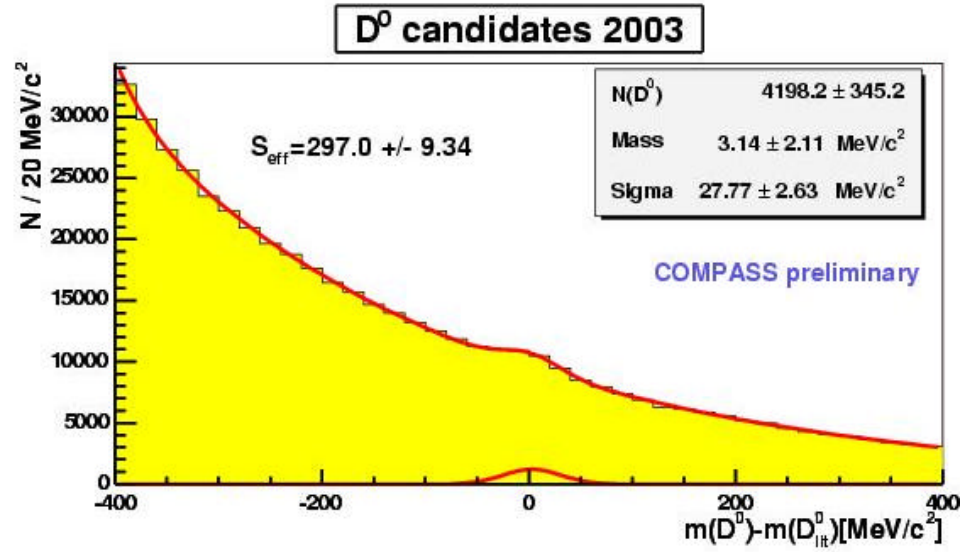
$D^0 \to Kp$

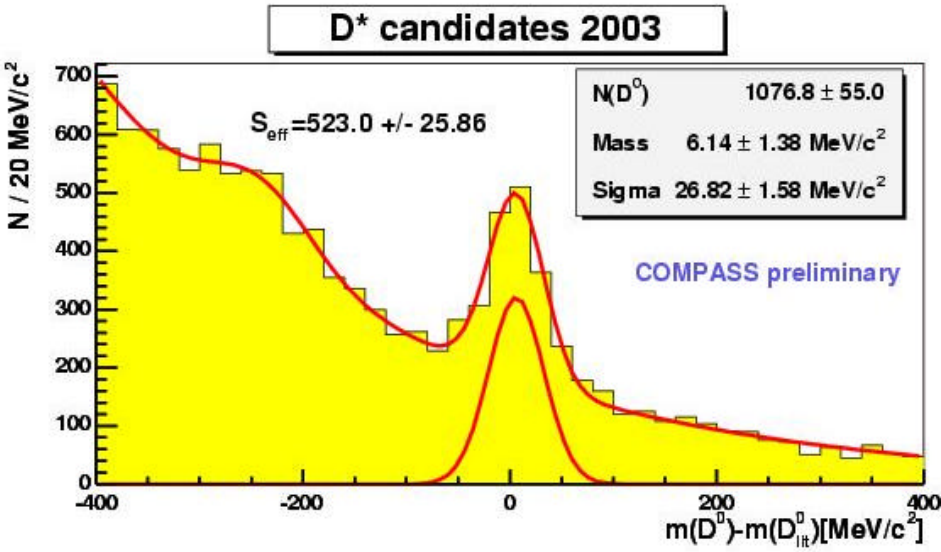


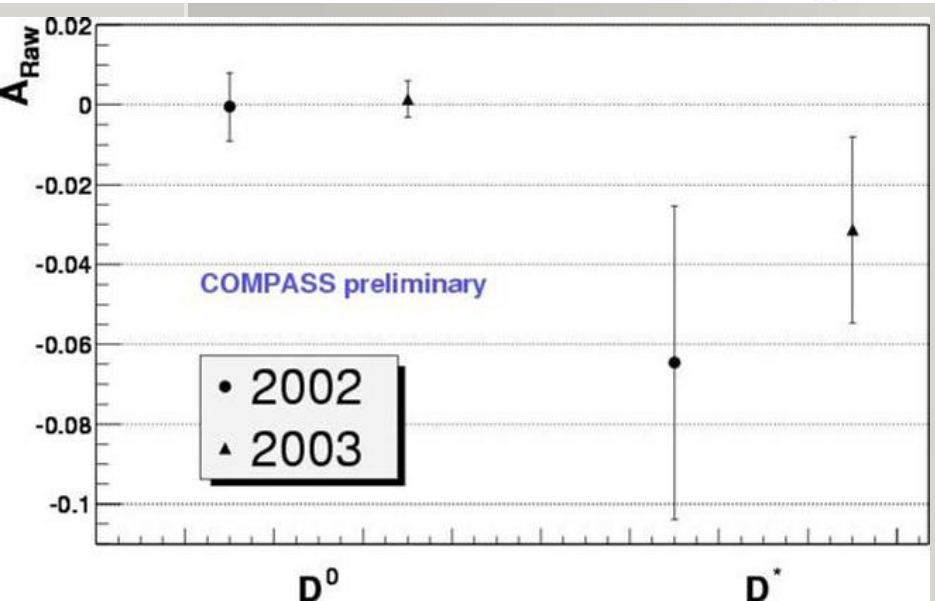


$D^0 \to Kp$

Asymmetry for events with charm production (D^0 and D^*)







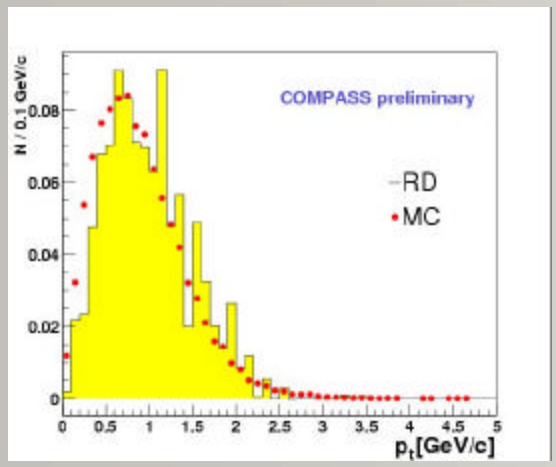
D* is cleaner, but low statistics

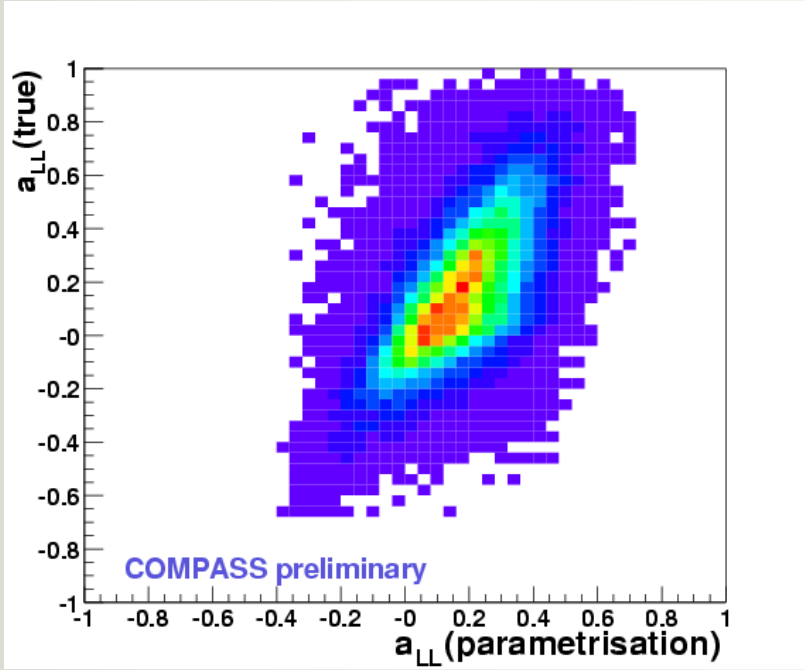
From here to ?G/G
→ partonic asymmetrirs a_{LL}^{PGF} are needed

Partonic asymmetries are calculated from parametrization obtained for MC simulated events

→ good description of data with MC is required

→ what MC parameters are best





- Result on ?G/G can be expected soon from 2002-2004:

s (DG/G) = 0.24 from open charm

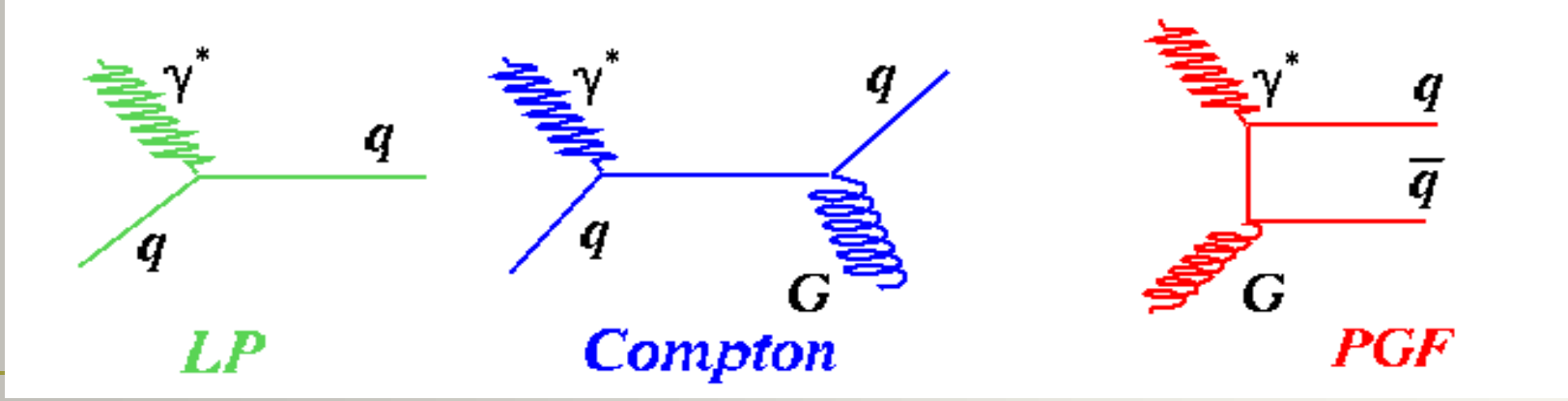
Hadron pairs with z „large” p_T

Idea proposed by

- R.D.Carlitz, J.C.Collins and A.H.Mueller, Phys.Lett.B 214, 229 (1988).
- A.Bravar,D.von Harrach and A.Kotzinian, Phys.Lett.B 421, 349 (1998) .

Used in the analysis :

- HERMES, A.Airapetian et al., Phys.Rev.Lett.84, 2584 (2000).
- SMC, B.Adeva et al., Phys.Rev.D 70, 0102002 (2004)



$$A^{lN \to lhhX} = \frac{?G}{G} \langle \hat{a}_{LL} \rangle^{PGF} R^{PGF} + \frac{\Delta q}{q} \left[\langle \hat{a}_{LL} \rangle^{LP} R^{LP} + \langle \hat{a}_{LL} \rangle^{QCDC} R^{QCDC} \right]$$

where: $A^{lN \to lhhX}$ measured asymmetry,

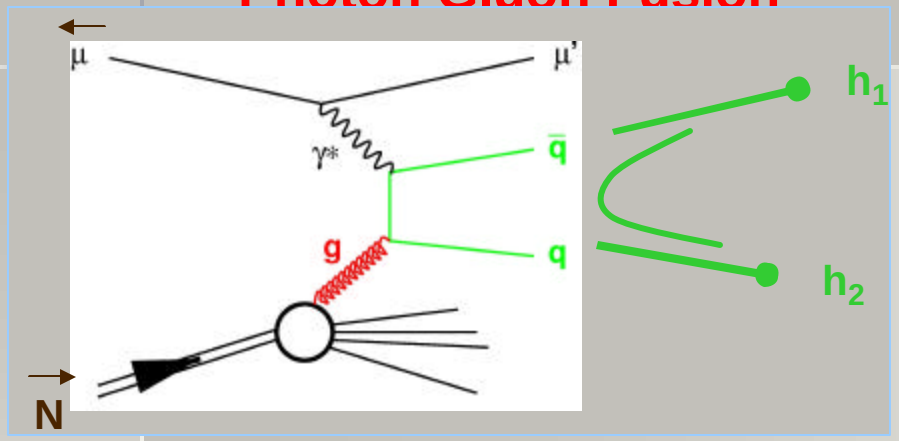
$?q/q$ approximated using A_1 asymmetry γN,

$\langle a_{LL} \rangle$ partonic asymmetry,

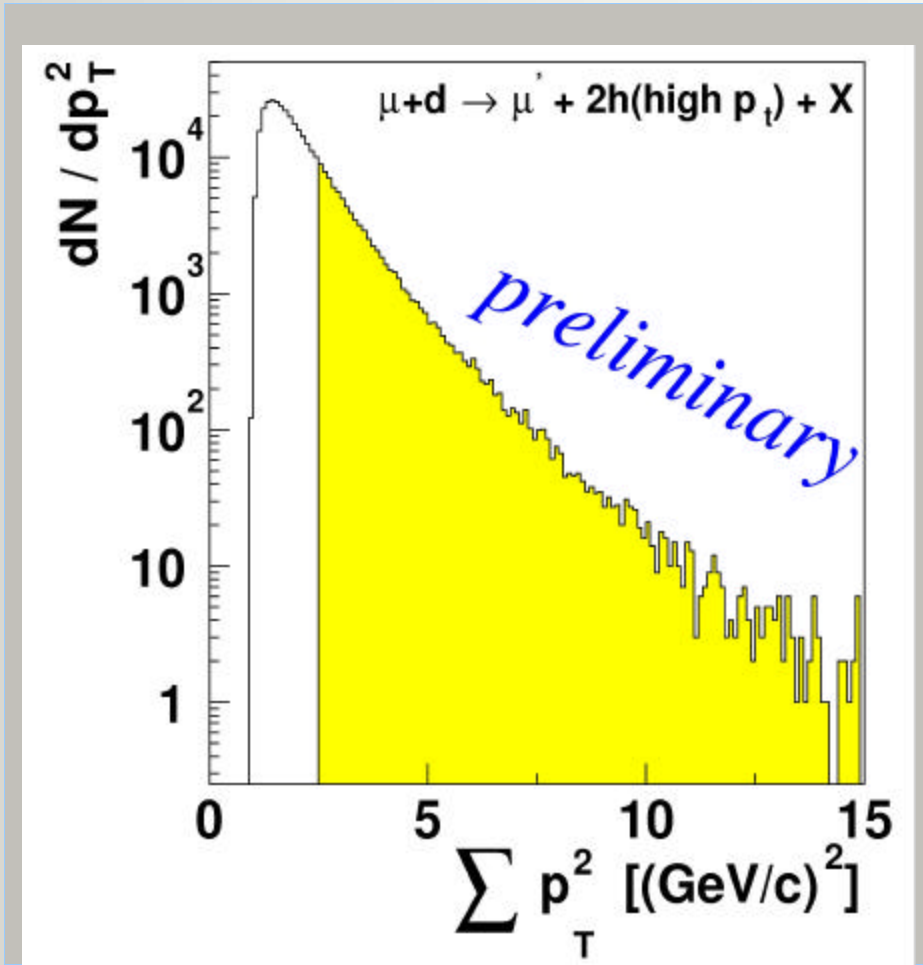
R fraction of contributing processes

DG/G: pairs of high p_T hadrons

Photon Gluon Fusion



- Current fragmentation
  - $x_F > 0.1$
  - $z > 0.1$
- 2 high p_T hadrons
  - $p_T > 0.7$ GeV/c
  - $p_{T1}^2 + p_{T2}^2 > 2.5$ GeV^2
  - $m(h_1h_2) > 1.5$ GeV



DG/G: pairs of high p_T hadrons

- with Q2 >1 GeV^2, 0.4 < y < 0.9

Asymmetry in production of hadron pairs with high p_T: result for 2002+2003 data

$$\frac{A^{hh}}{D} = -0.015 \pm 0.080(stat) \pm 0.013(syst)$$

from this using R^{PGF} obtained from MC

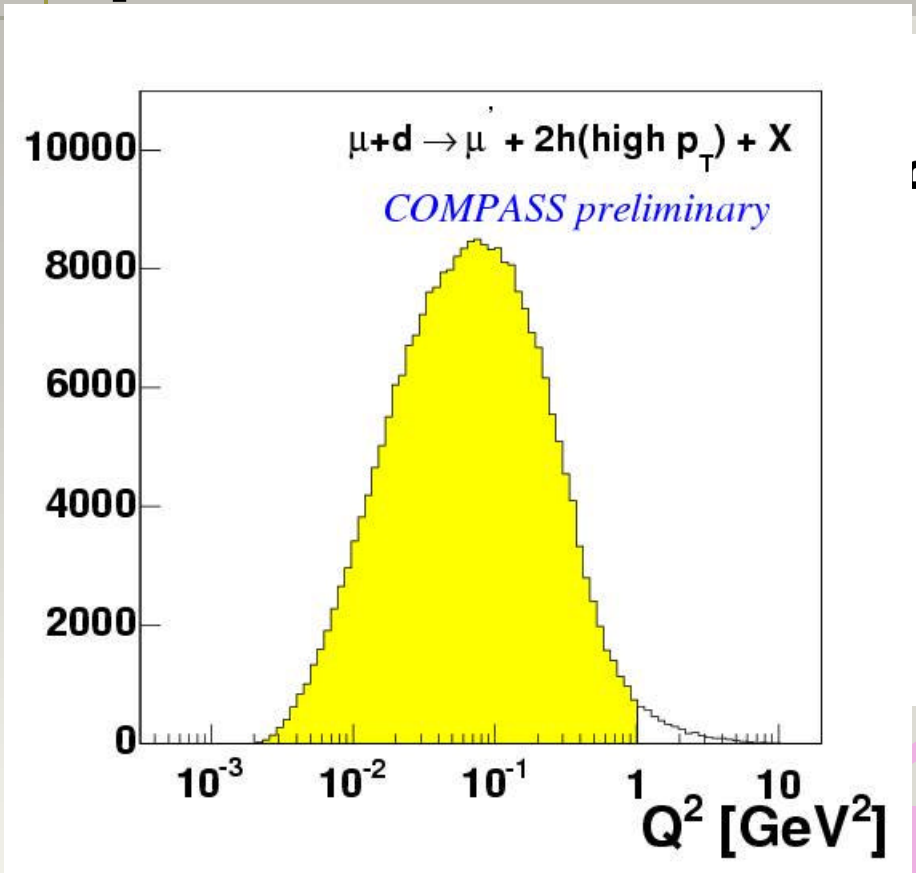
$$\frac{\Delta G}{G} = 0.06 \pm 0.31 \pm 0.06 \quad \text{with} \quad \langle h \rangle = 0.13$$

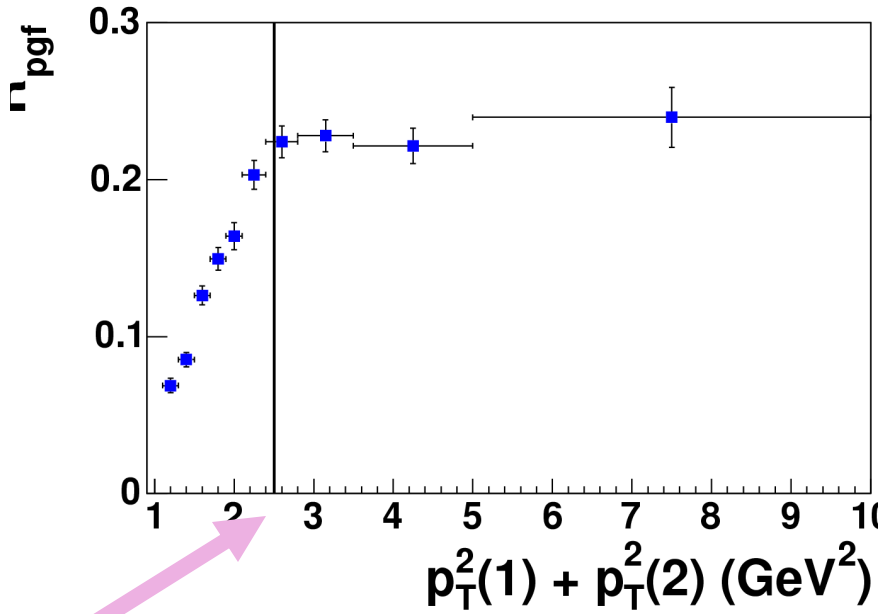
Analysis done with LEPTO generator

- **Initial and final state parton showers used**
- **Fragmentation function parameters modified**
- **k_T statndard value (0.44)**

Uses only ~10% of data

For $Q^2 < 1 GeV^2$ much more data difficulties with additional processes contributing (Pythia)

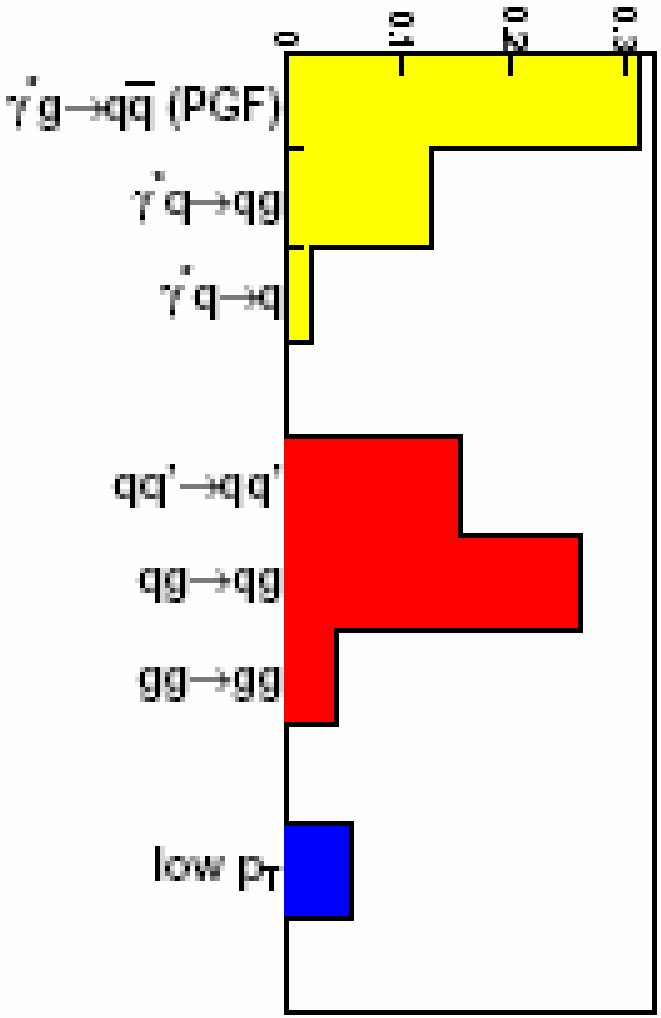




$$\frac{r_{\square}}{D} = 0.002 \pm 0.019(stat) \pm 0.003(syst)$$

Low Q^2 scattering – Pythia simulation

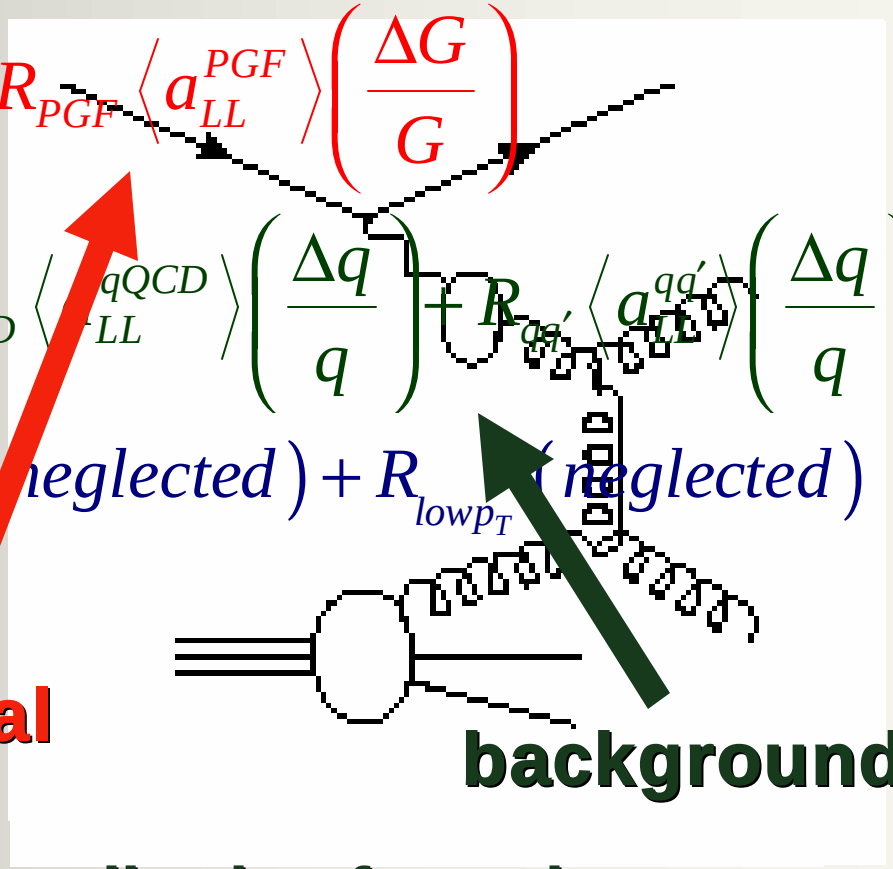
Contributing processes - sample after „high p_T" selections



$$A_{LL} = R_{PGF}\left\langle a_{LL}^{PGF}\right\rangle\left(\frac{\Delta G}{G}\right)$$

$$+R_{qQCD}\left\langle a_{LL}^{qQCD}\right\rangle\left(\frac{\Delta q}{q}\right)+R_{qq'}\left\langle a_{LL}^{qq'}\right\rangle\left(\frac{\Delta q}{q}\right)$$

$$+R_{LO}\left(neglected\right)+R_{lowp_T}\left(neglected\right)$$



signal

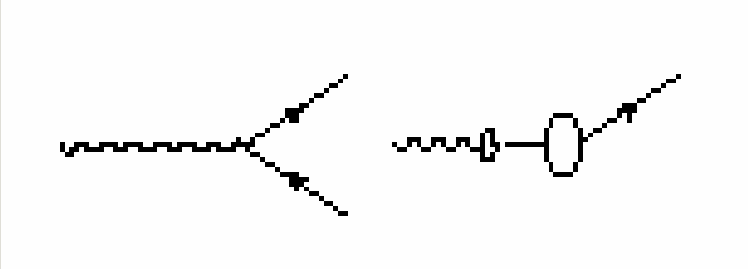
background

Contribution from the structure of the nucleon

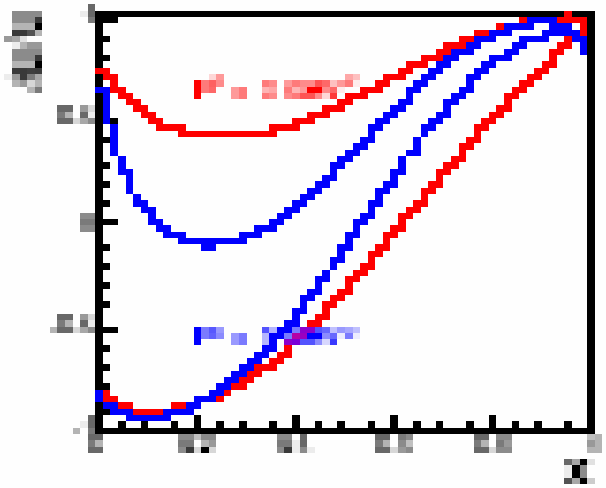
Contribution from the structure of the photon

Systematic errors :

- Quark polarization in the photon



$$\Delta q^g = \Delta q^g_{q\bar{q}} + \Delta q^g_{VMD}$$



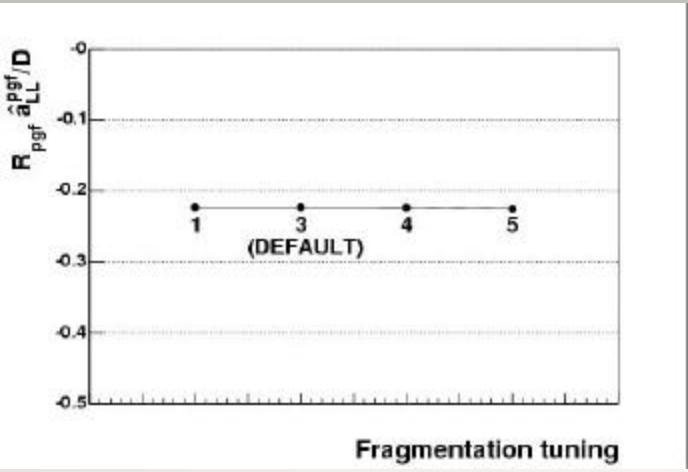
(Glück, Reya, Sieg)

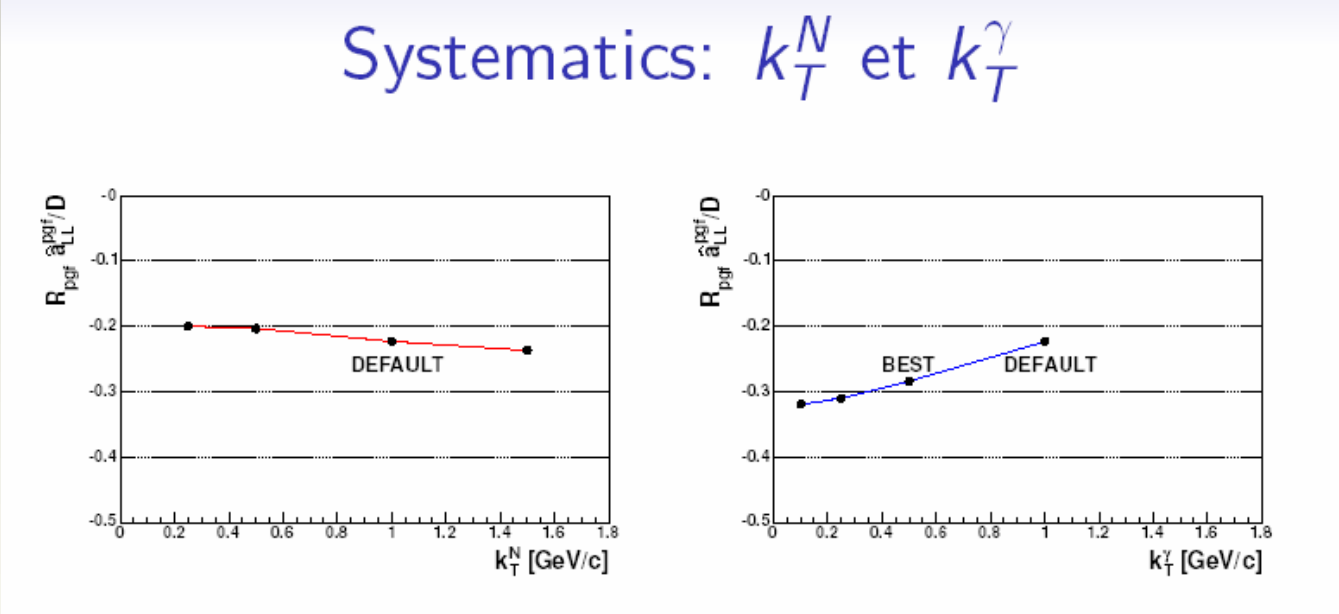
for VMD – minimum and maximum scenarios

$$-q^g_{VMD} \le \Delta q^g_{VMD} \le q^g_{VMD}$$

MC uncertainties

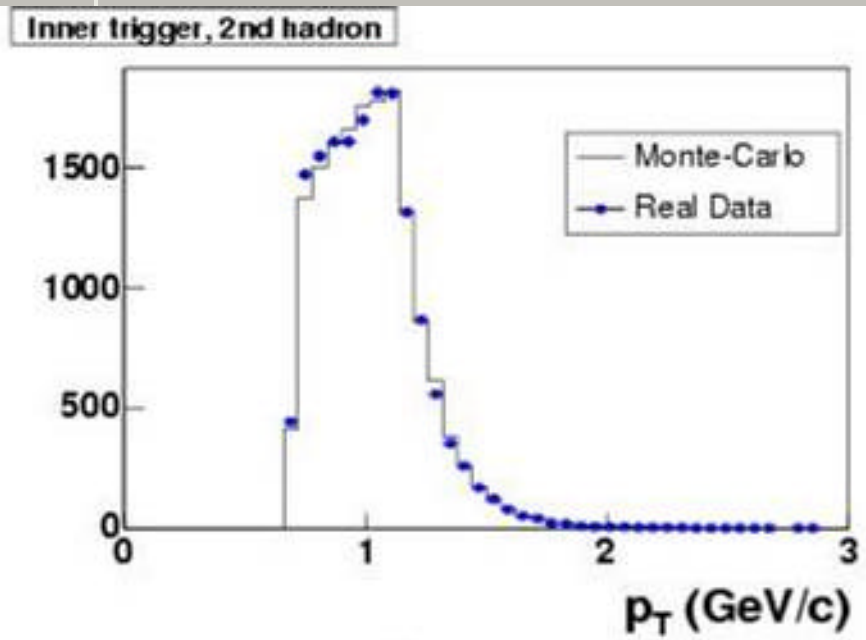
- Missing NLO: scale dependence, parton shower on/off
- tuning of parameters and data/MC
  - parton fragmentation
  - partons k_T in nucleon and photon

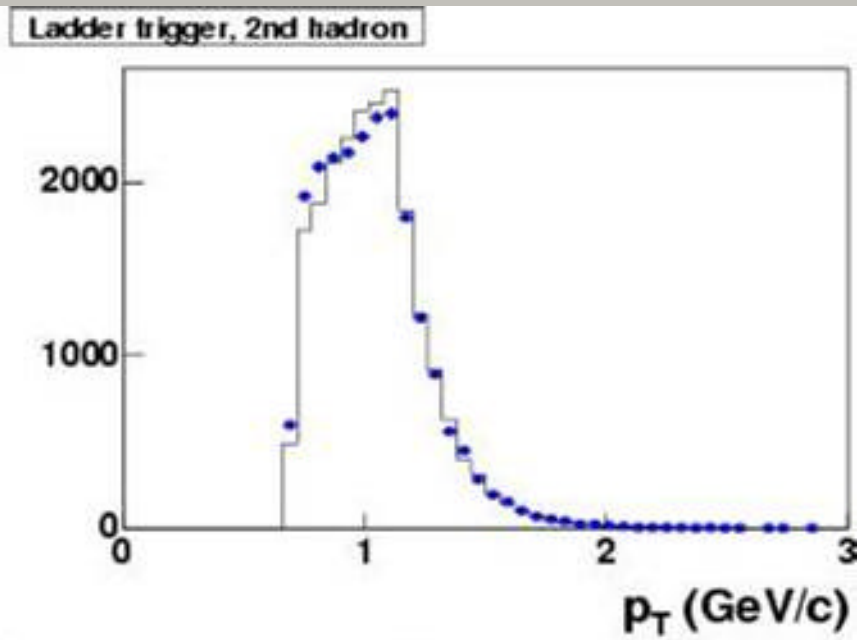


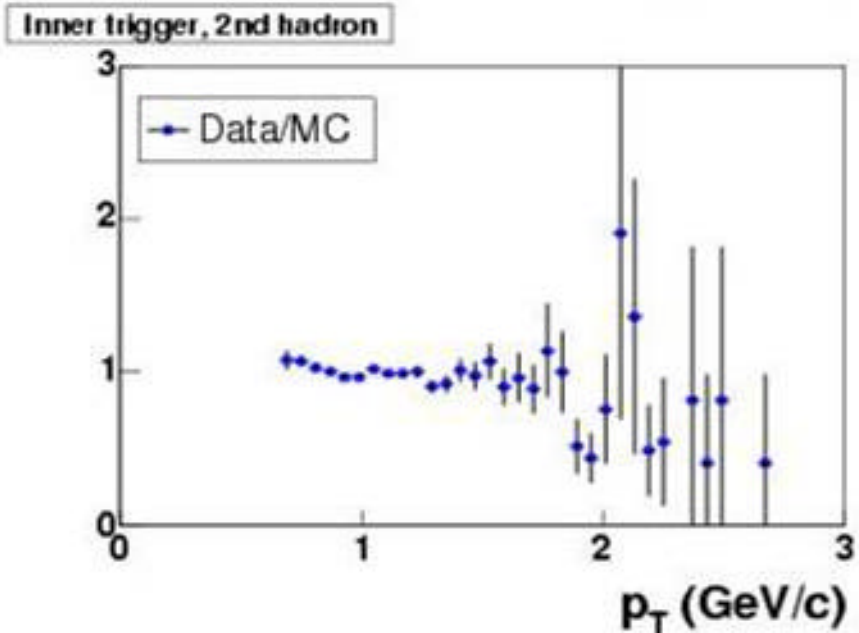


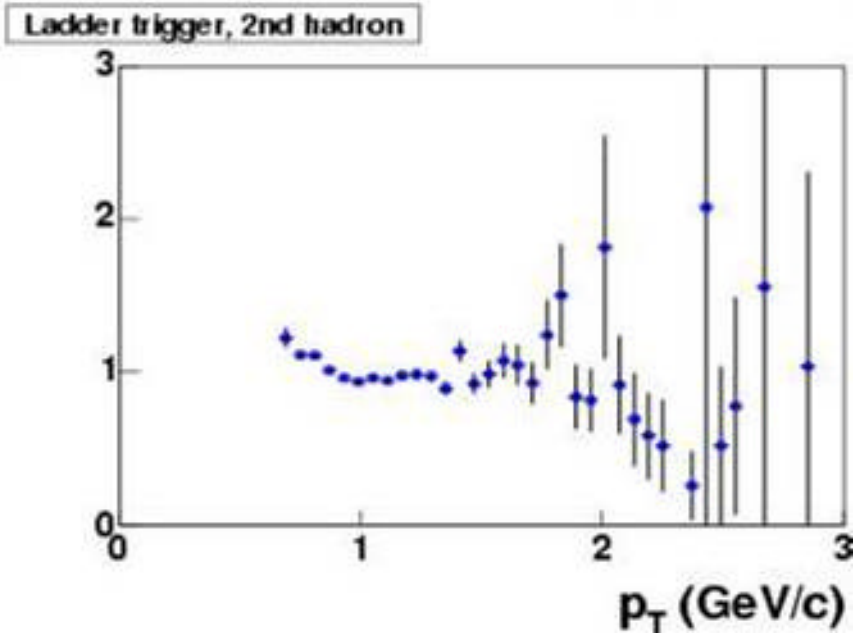
biggest uncertainty from k_T in photon

Data / MC


Inner trigger, 2nd hadron
Monte-Carlo
Real Data
1500
1000
500
0
0
1
2
3
p_T (GeV/c)


Ladder trigger, 2nd hadron
2000
1000
0
0
1
2
3
p_T (GeV/c)


Inner trigger, 2nd hadron
Data/MC
3
2
1
0
0
1
2
3
p_T (GeV/c)


Ladder trigger, 2nd hadron
3
2
1
0
0
1
2
3
p_T (GeV/c)

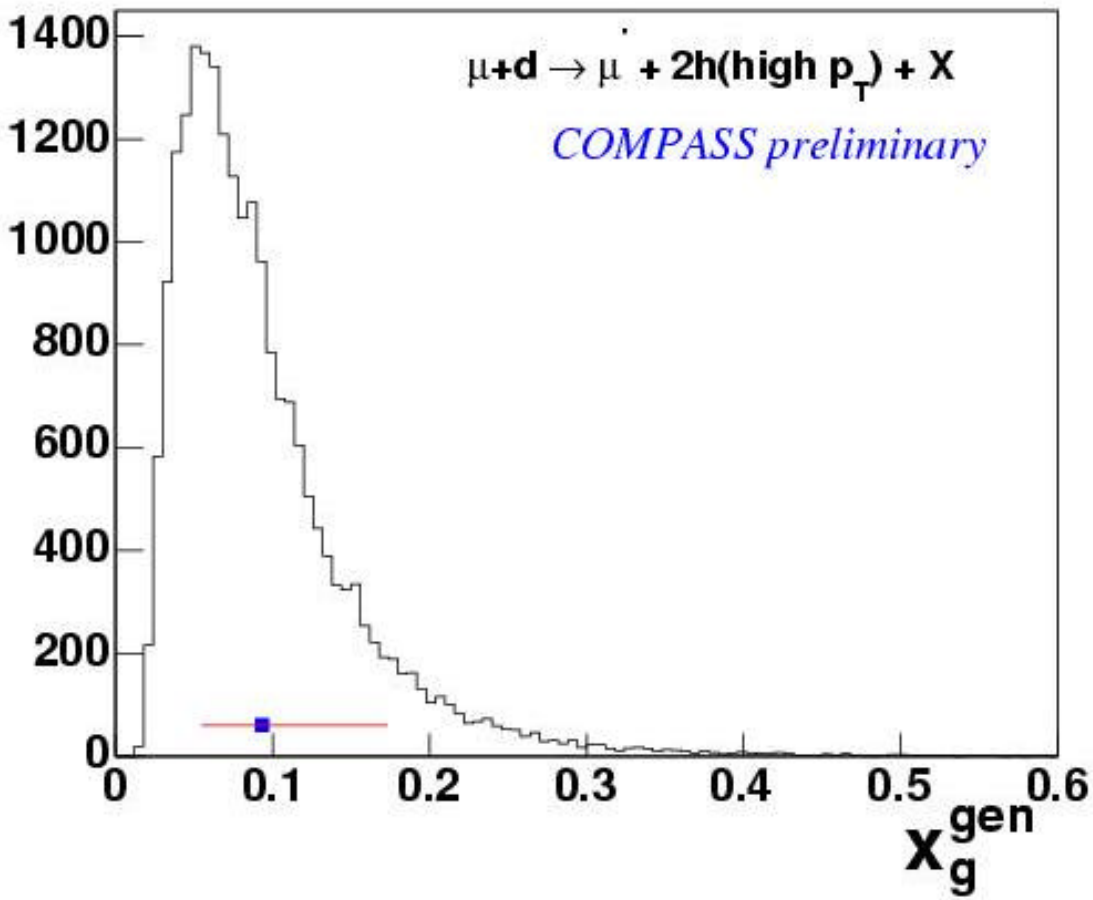
From 2002 and 2003 data

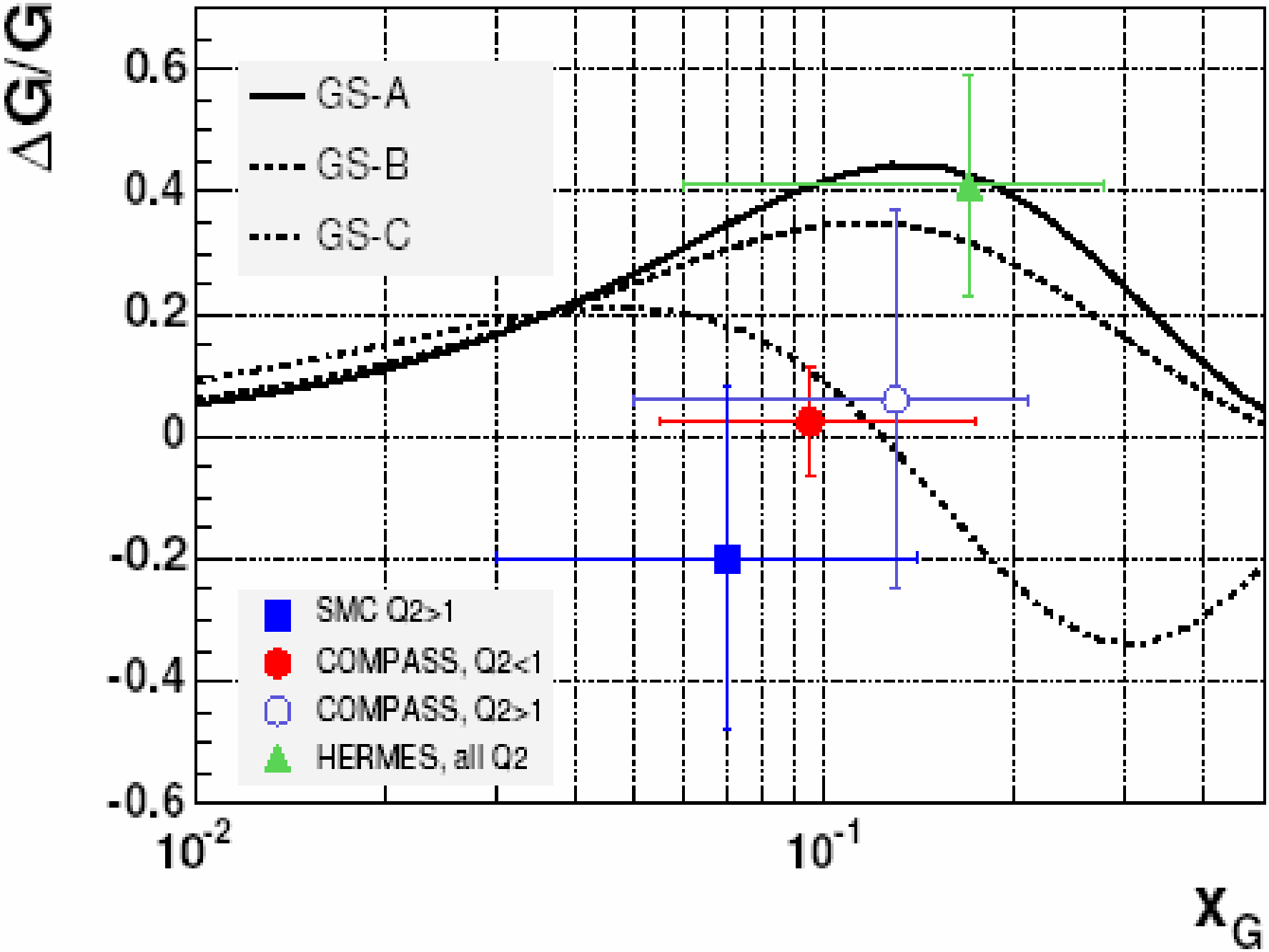
$$\frac{\Delta G}{G} = 0.024 \pm 0.089(stat) \pm 0.057(syst)$$

Obtained by ave
for min. and ma

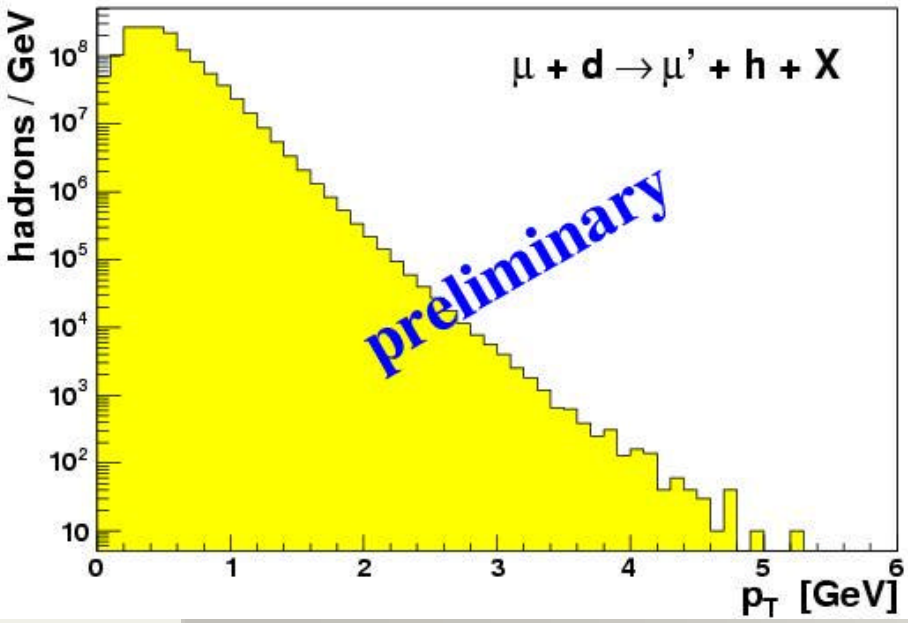
$$\left(\frac{\Delta G}{G}\right)_{min} = 0.016 \pm 0.068($$

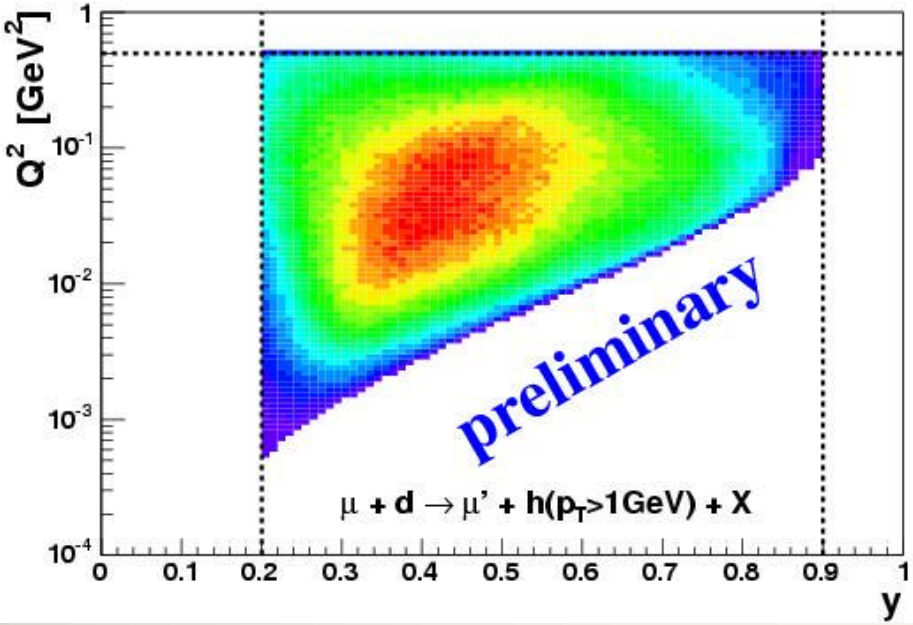
$$\left(\frac{\Delta G}{G}\right)_{max} = 0.031 \pm 0.089($$



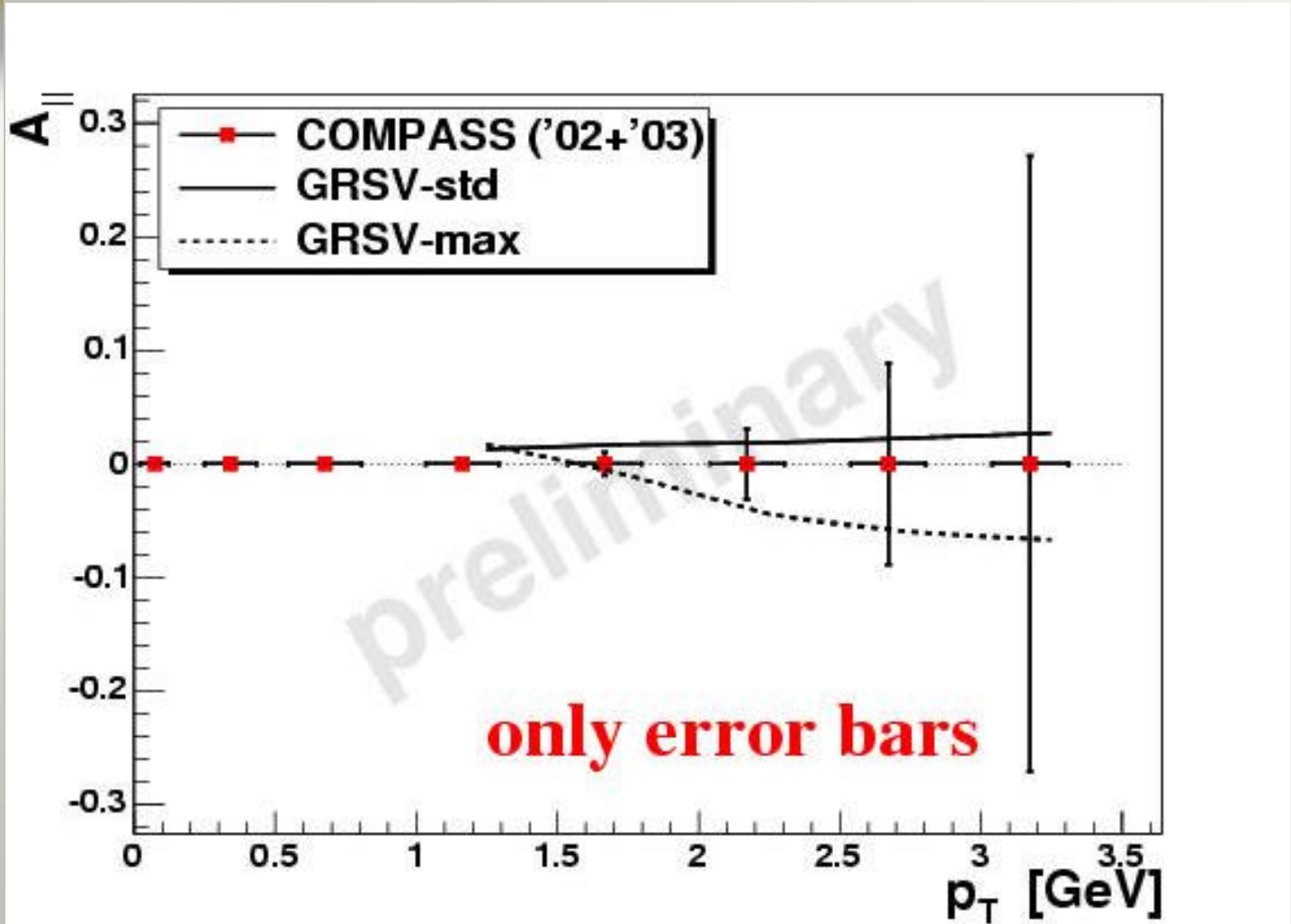

ΔG/G
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
GS-A
GS-B
GS-C
SMC Q2>1
COMPASS, Q2<1
COMPASS, Q2>1
HERMES, all Q2
10^-2
10^-1
x_G

Single hadons, low Q^2





Expected precission on the asymmetry
teoretical calculations by
B. Jaeger, A. Schaefer and M. Stratmann in NLO



SUMMARY AND OUTLOOK

- CERN is again contributing to the *NUCLEON SPIN PUZZLE*

- Compass running in 2002-2004 brought interesting PHYSICS RESULTS, some already published

  MANY MORE IN PREPARATION

  data taking restarts in 2006

- Approved program untill ~2010 with muon beams on polarized targets and hadron beams

After → study of GPDS with DVCS and exclusive mezon production on hydrogen target (+recoil detector)