Selected Results and Future Prospects of the COMPASS experiment at CERN

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Outline

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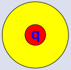
The spin structure of nucleons

Three DF are necessary to describe the structure of the nucleon at LO

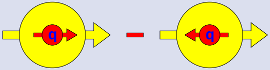
Unpolarized distribution functions $F_1(x) = u(x) + d(x) + s(x)$



= q(x)

Measured with high accuracy by unpolarized DIS experiments

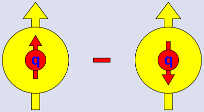
Helicity-dependent distribution functions $g_1(x) = \Delta u(x) + \Delta d(x) + \Delta s(x)$



= Δq(x)

Measured in polarized DIS
Rather well known

Transversity distribution functions $h_1(x) = \Delta_T u(x) + \Delta_T d(x) + \Delta_T s(x)$

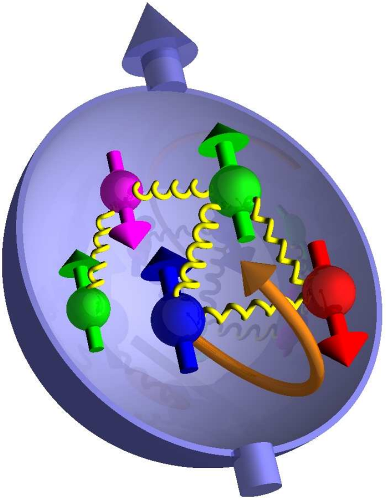


= Δ_Tq(x)

Only measurable in polarized semi-inclusive DIS
Almost unknown

Where does the spin of the nucleons come from?

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



$\Delta\Sigma$

- Static quark model: $\Delta\Sigma = \Delta u + \Delta d = 1$
- Weak baryon decays: $\Delta\Sigma \simeq 0.58$ $(\Delta s = 0)$
- QCD NLO fits: $\Delta\Sigma \simeq 0.3$
- Why such a discrepancy?
  - Δs large and < 0?
  - axial anomaly ($\Delta G \simeq 1.5 - 2$)?

ΔG?

- Fit to $g_1(x)$ data
- Open charm
- High-p_T pair production

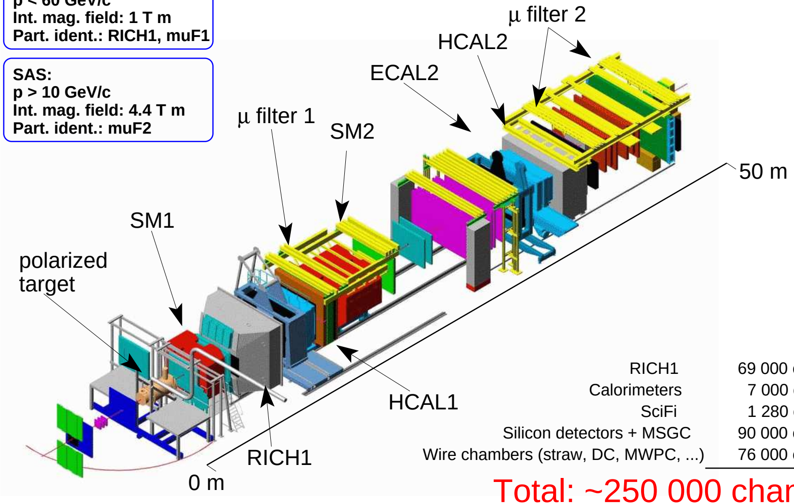
$L_{q,g}$?

- Generalized PDF

The COMPASS Experimental Setup (2004 Layout)

LAS:
p < 60 GeV/c
Int. mag. field: 1 T m
Part. ident.: RICH1, muF1

SAS:
p > 10 GeV/c
Int. mag. field: 4.4 T m
Part. ident.: muF2

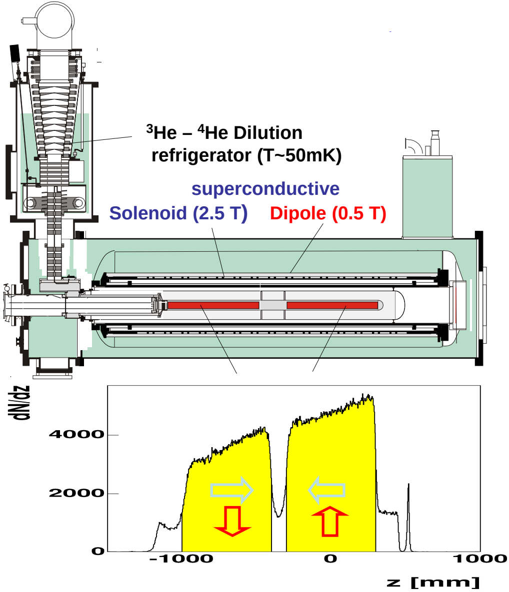


RICH1	69 000 channels
Calorimeters	7 000 channels
SciFi	1 280 channels
Silicon detectors + MSGC	90 000 channels
Wire chambers (straw, DC, MWPC, ...)	76 000 channels

Total: ~250 000 channels

Detailed description in NIM A577 (2007) 455-518

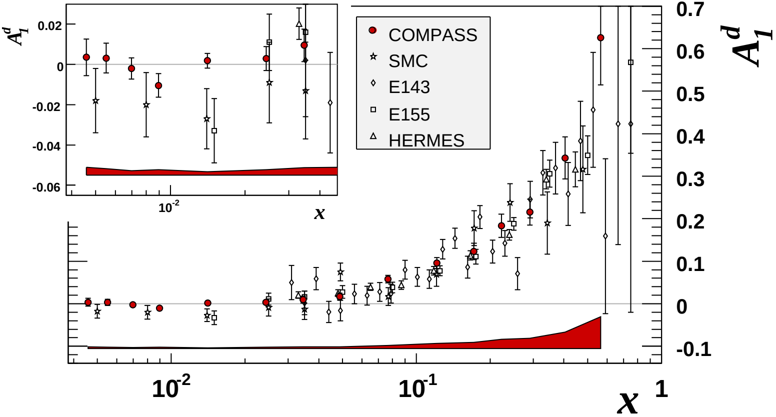
The Polarized Target



- 2 (3 from 2006) cells oppositely polarized
- Acceptance: 70 mrad (180 mrad from 2006)
- ^{6}LiD or NH_3 target materials
- ^{6}LiD polarization $> 50\%$
- 2.5 T solenoid or 0.5 T dipole fields
- Polarization reversal by field rotation every $\sim$ 8 hours
- Unpolarized scattering by averaging over target cells

Measurement of the inclusive asimmetry A_1^d

$$A_1^d \approx \frac{1}{fDP_BP_T}\frac{N^{\uparrow\Uparrow}-N^{\uparrow\Downarrow}}{N^{\uparrow\Uparrow}+N^{\uparrow\Downarrow}}$$



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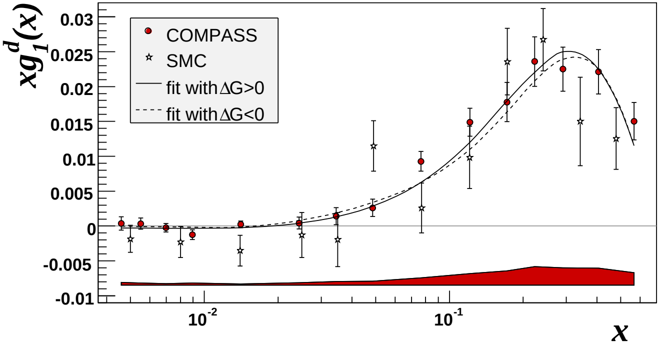
Very good agreement with previous measurements - most accurate data at low x

The structure function g_1^d

$$g_1^d(x,Q^2) \approx A_1^d(x,Q^2)\frac{F_2^d(x,Q^2)}{2x(1+R(x,Q^2))},$$

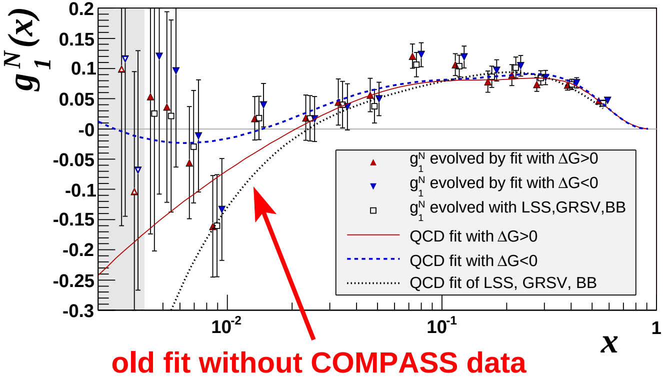
F_2^d from SMC parameterization, R from SLAC parameterization



- Fit to world $g_1(x)$ data leads to two solutions:
  - $\Delta\Sigma \simeq 0.28$ for $\Delta G > 0$, $\Delta\Sigma \simeq 0.32$ for $\Delta G < 0$ $(|\Delta G| \simeq 0.2-0.3)$
- Present $g_1(x)$ data not very sensitive to ΔG → need for a direct measurement

The structure function g_1^N

$$g_1^N(x,Q^2) = (g_1^p + g_1^n)/2 = g_1^d(x,Q^2)/(1-1.5\omega_D), \quad \omega_D = 0.05 \pm 0.01$$

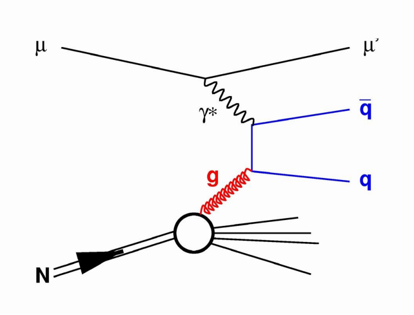


- Previous parametrizations do not reproduce COMPASS data at $x \rightarrow 0$
- New COMPASS points at low x constrain ΔG to small values ($|\Delta G| \simeq 0.2 - 0.3$)

$\Delta G/G$ measurement via $\gamma g \rightarrow q\bar{q}$

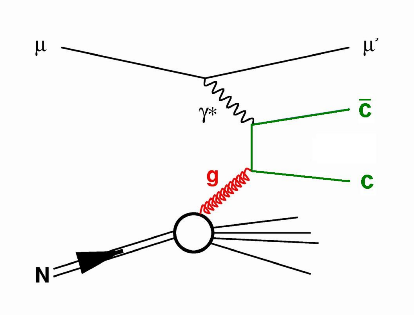
Direct measurement of $\Delta G/G$ in μN scattering though the photon-gluon fusion process

High-p_T hadron pairs



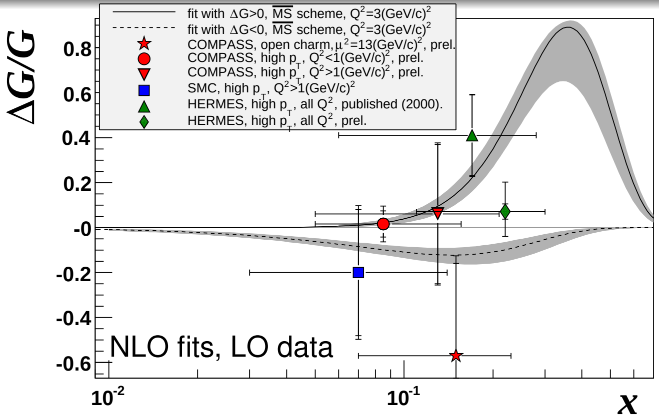
- ⇑ Large statistics
- ⇓ Physical backgrounds
- Two options:
  - $Q^2 < 1\ (GeV)^2$
  - $Q^2 > 1\ (GeV)^2$

Open charm production



- ⇑ Direct tagging via D^0/D^* production
- ⇓ Small cross-section
- ⇓ Combinatorial background
- Challenging experiment

COMPASS results for $\Delta G/G$



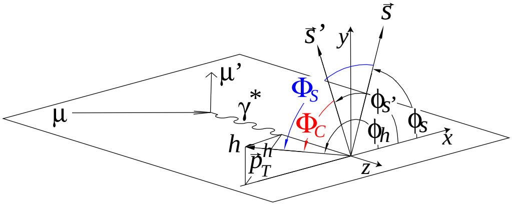
- NLO QCD fits and direct measurements point to a small value of $\Delta G \approx 0.2 - 0.3$
- $\Delta G \ll 2 \rightarrow$ axial anomaly contribution small ($a_0 \simeq \Delta\Sigma$) $\rightarrow$ two extreme scenarios?

$$\begin{array}{ccccccccc} & & & \Delta\Sigma & & \Delta G & & L_q & & L_g \\ 1/2 & = & 1/2 \times & \mathbf{0.30} & + & \mathbf{0.35} & + & 0 & + & 0 \\ 1/2 & = & 1/2 \times & \mathbf{0.30} & + & 0 & + & & & \mathbf{0.35} \end{array}$$

Transverse spin distribution functions

Collins effect: a quark moving “horizontally” and polarized “upwards” would emit the leading meson preferentially on the “left” side of the jet

Sivers effect: intrinsic asymmetry in the parton transverse momentum distribution induced by the nucleon spin



$\phi_{S'}$: azimuthal angle of spin vector of fragmenting quark

ϕ_h: azimuthal angle of hadron momentum

$\Phi_C = \phi_h - \phi_{S'}$: Collins angle

$\Phi_S = \phi_h - \phi_S$: Sivers angle

Collins asymmetry

$$N_h^{\pm}(\Phi_C) = N_h^0 \cdot \{1 \pm A_C^h \sin\Phi_C\}$$

$$A_{Coll} = \frac{1}{f \cdot P_T \cdot D_{nn}} \cdot A_C^h = \frac{\sum_a e_a^2 \, \Delta_T q_a \, \Delta D_a^h}{\sum_a e_a^2 \, q_a \, D_a^h}$$

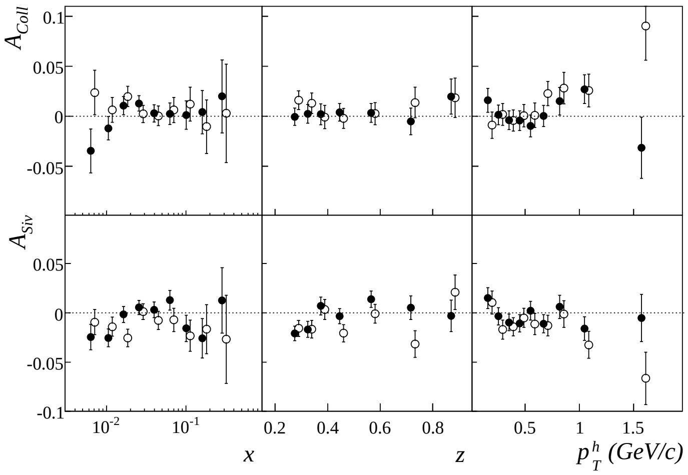
Sivers asymmetry

$$N_h^{\pm}(\Phi_S) = N_h^0 \cdot \{1 \pm A_S^h \sin\Phi_S\}$$

$$A_{Siv} = \frac{1}{f \cdot P_T} \cdot A_S^h = \frac{\sum_a e_a^2 \, \Delta_0^T q_a \, D_a^h}{\sum_a e_a^2 \, q_a \, D_a^h}$$

Collins and Sivers asymmetries from Deuteron target

● leading positive hadrons ○ leading negative hadrons



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No significant deviation from zero in deuteron data → proton-neutron cancellation?

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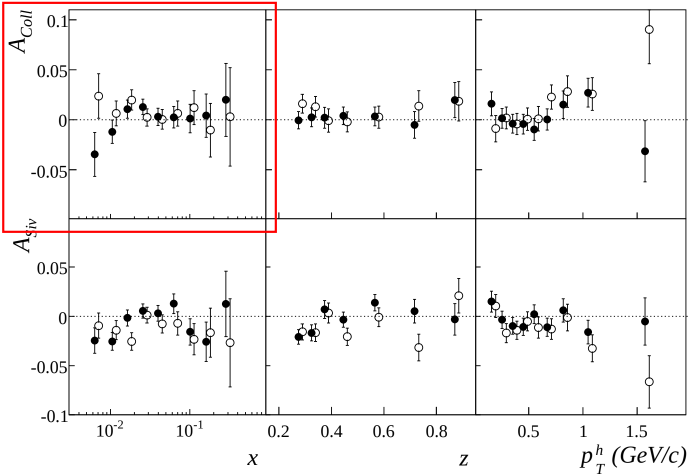

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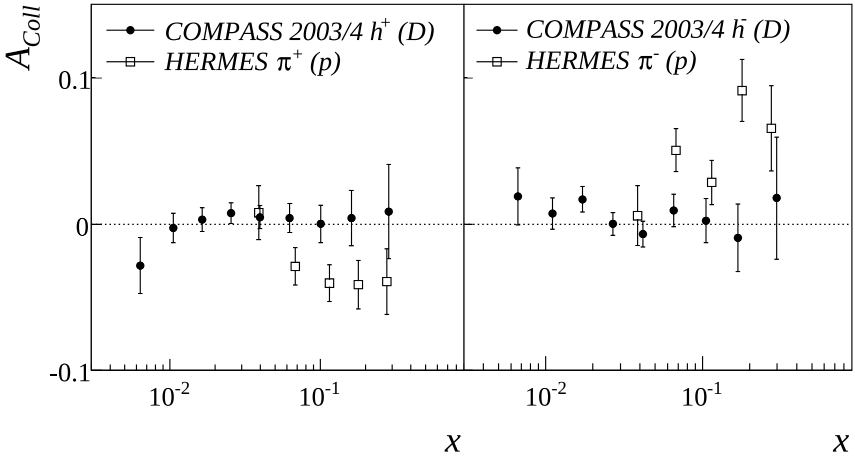
Comparison of COMPASS and HERMES data

left: leading positive hadrons right: leading negative hadrons

(Sign of Hermes points changed due to different angles convention in COMPASS)



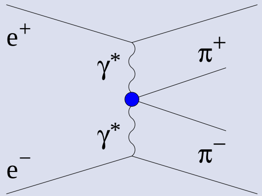
Non-zero values are measured in proton data at large x → COMPASS 2007

Outline

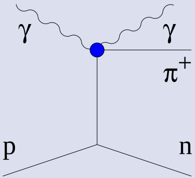
π Polarizabilities - Theoretical Predictions and Experimental Tools

- The polarizabilities α_π, β_π characterize the rigidity of the meson in an external E.M. field
- Theoretical predictions:
  - χ-PT (2-loop): $\alpha_\pi + \beta_\pi = 0.16 \cdot 10^{-4}$ fm^3, $\alpha_\pi - \beta_\pi = (5.7 \pm 1.0) \cdot 10^{-4}$ fm^3
  - QCM: $\alpha_\pi + \beta_\pi = 0.23 \cdot 10^{-4}$ fm^3, $\alpha_\pi - \beta_\pi = 7.05 \cdot 10^{-4}$ fm^3
  - QCD sum rules: $\alpha_\pi = (5.6 \pm 0.5) \cdot 10^{-4}$ fm^3
  - Disp. sum rules: $\alpha_\pi + \beta_\pi = (0.166 \pm 0.024) \cdot 10^{-4}$ fm^3, $\alpha_\pi - \beta_\pi = (13.60 \pm 2.15) \cdot 10^{-4}$ fm^3
- Large discrepancies between theoretical models
- α_π and β_π can be measured in different ways:

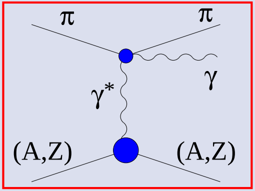
e^+e^- collisions
$\gamma\gamma \rightarrow \pi^+\pi^-$



radiative π photoprod.
$\gamma p \rightarrow \gamma\pi^+ n$

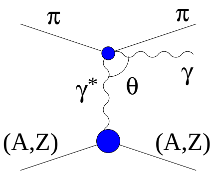


Primakoff scattering
$\pi(A,Z) \rightarrow \pi\gamma(A,Z)$



Measurement of α_π and β_π in Primakoff Scattering

$$\frac{d\sigma^2_{\gamma\pi}}{dE_{\gamma^*}\, d\cos\theta} = Z^2 \left\{ F^{pt}_{\gamma\pi}(\theta) + \frac{m_\pi E_{\gamma^*}}{\alpha} \cdot \frac{\alpha_\pi(1+\cos^2\theta) + \beta_\pi \cos\theta}{\left[1 + E_{\gamma^*}/m_\pi(1-\cos\theta)\right]^3} \right\}$$

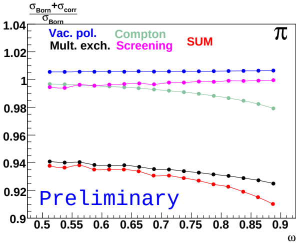


E_{γ^*} and θ given in the anti-laboratory system

In the hypothesis of $\alpha_\pi = -\beta_\pi$, β_π can be extracted from the ratio

$$R(\omega) = \frac{d\sigma_{exp}}{d\sigma^{pt}_{MC}} \approx 1 + \frac{3}{2}\frac{m_\pi^2}{\alpha}\frac{\omega^2}{1-\omega}\beta_\pi \quad (\omega = E_\gamma/E_{beam} \text{ in labo.})$$

- Measured at COMPASS with 190 GeV π^- beam and 3mm thick Pb target
- Additional data collected with 190 GeV μ^- beam
  $\rightarrow$ point-like projectile to check systematics **UNIQUE**
- Denominator of $R(\omega)$ is calculated from MonteCarlo simulations
- Radiative corrections are applied to the experimental measurements to calculate $R(\omega)$
  - Vacuum polarization
  - Compton vertex
  - Multiple photon exchange
  - Screening by atomic electrons



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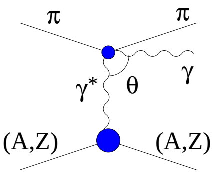

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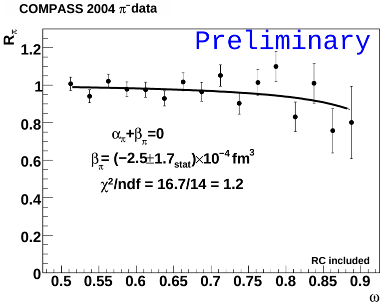

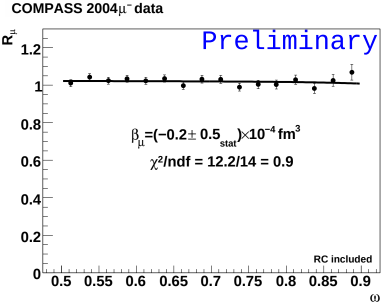

Preliminary result: $\alpha_\pi = -\beta_\pi = (2.5 \pm 1.7_{stat} \pm 0.6_{sys})\cdot 10^{-4}\text{fm}^3$

Measurement of α_π and β_π in Primakoff Scattering

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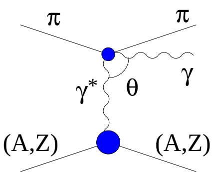

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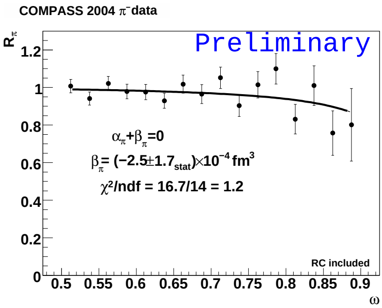
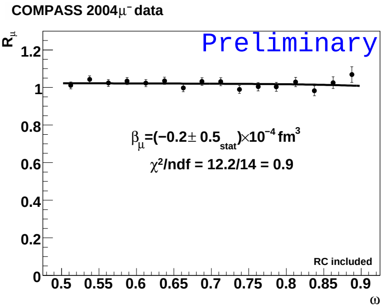
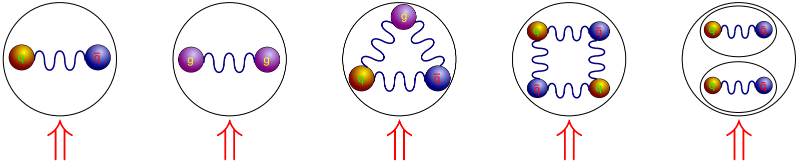




For details, see J. Friedrich's talk this afternoon

Mesons beyond the NQM

- COMPASS will start the meson spectroscopy program in 2008 → glueballs and hybrids



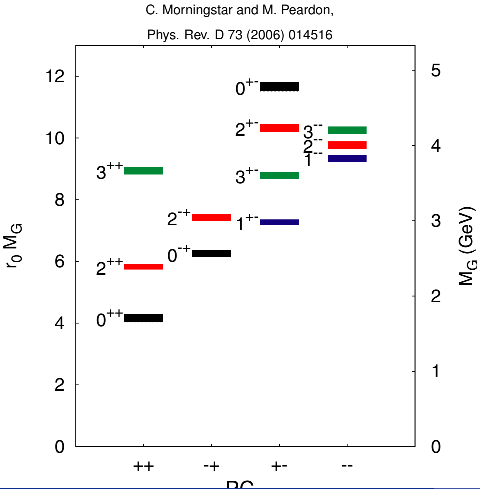
- The NQM only predicts mesons composed of $q\bar{q}$
- However, gluons carry color charge and can appear as valence constituents:
  - Glueballs: states with only valence gluons (gg, ggg)
  - Hybrids: $q\bar{q}$-systems with one additional valence gluon
- quarks can also form $q\bar{q}q\bar{q}$ bound states and meson-meson molecules
- non-$q\bar{q}$ mesons can have exotic J^{PC} combinations:

$$J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$$

- The unabiguous experimental identification of such states represents a fundamental test of non-perturbative QCD

Glueballs mass spectrum

Lattice calculations (numerical solution of the QCD Lagrangian over a space-time grid) provide the most accurate predictions for the glueballs spectrum



- Lower mass glueballs:
  - $J^{PC} = 0^{++}$ scalar $M \sim 1700$ MeV/c^2
  - $J^{PC} = 2^{++}$ tensor $M \sim 2400$ MeV/c^2
- The light glueballs have conventional J^{PC}

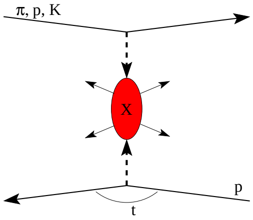
mixing with nearby $q\bar{q}$ mesons

- The lightest exotic glueball (2^{+-}) is above 4 GeV/c^2

Central production and diffractive scattering @ COMPASS

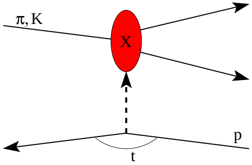
COMPASS will collect central production and diffractive scattering data IN PARALLEL, using pion and kaon projectiles (UNIQUE)

Central production



WA76, WA91, NA12/2, WA102 and E690

Diffractive scattering



VES and E852

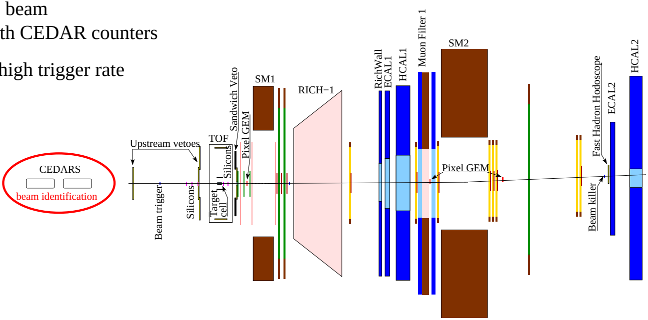
- Large rapidity gap between scattered beam and X
- Beam particle looses $\sim$ 10% of its energy
- Particles at large angles from X decays
- Possible source of glueballs

- Foward kinematics
- Large cross-section ($\sim$mbarn)
- Need to separate particles at very small angles
- Study of J^{PC}-exotic mesons

The 2008 COMPASS experimental apparatus

190 GeV π^- beam
Beam PID with CEDAR counters

Fast DAQ & high trigger rate



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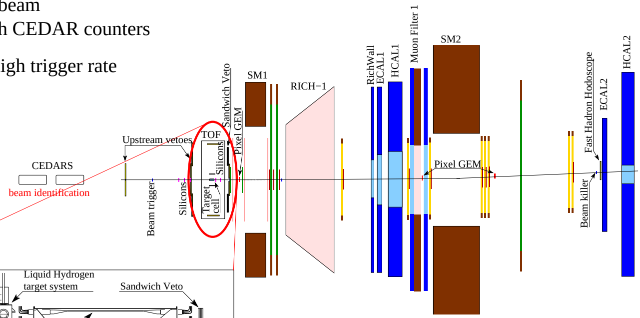

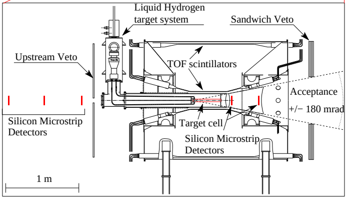

40 cm long liquid H2 target cell
high precision silicon microstrip telescopes
$\pm$ 180 mrad acceptance

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Beam PID with CEDAR counters

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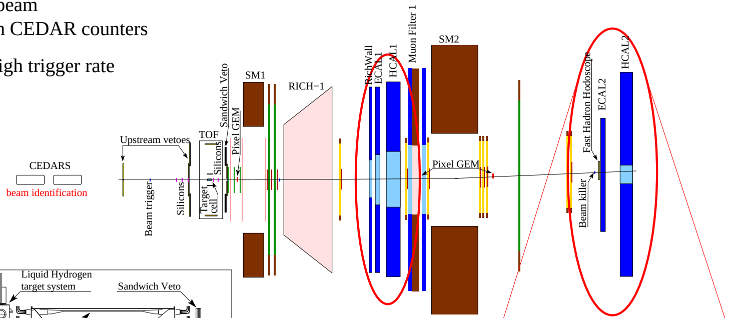

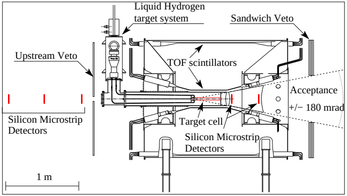

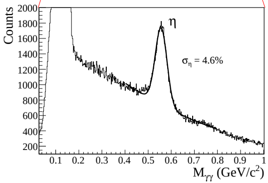

Electromagnetic calorimetry

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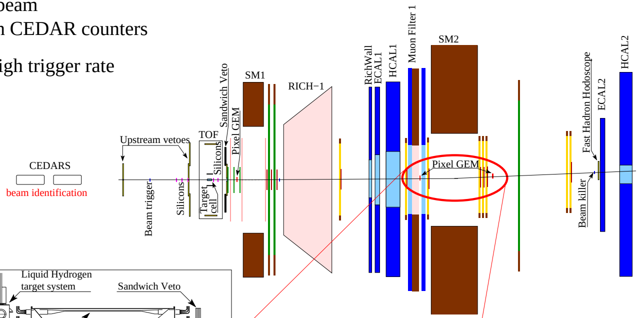

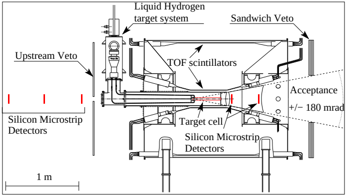

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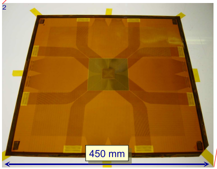
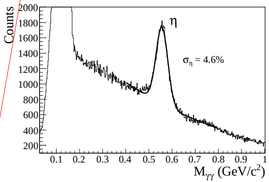
high precision silicon microstrip telescopes
$\pm$ 180 mrad acceptance



GEM−based beam tracking



Electromagnetic calorimetry

Outline

Conclusions

- COMPASS has extended the measured range of $g_1^d(x)$ down to ~ 0.002
  - Statistical error on $\Delta\Sigma$ improved by a factor 2
  - 98% of Γ_1^N obtained from data (was 50% in SMC)
- Small ΔG ($\ll 2$) more and more likely
  - axial anomaly contribution small ($a_0 \simeq \Delta\Sigma$)
  - two extreme scenarios?

$$\begin{array}{lcccccc} & & \Delta\Sigma & & \Delta G & L_q & L_g \\ 1/2 & = & 1/2 \times \mathbf{0.30} & + & \mathbf{0.35} & + 0 & + 0 \\ 1/2 & = & 1/2 \times \mathbf{0.30} & + & 0 & + & \mathbf{0.35} \end{array}$$

- Data on semi-inclusive asymmetries will provide additional knowledge on the quark polarization $\rightarrow$ measurement on proton in 2007
- Collins and Sivers effects found to be compatible with zero on Deuteron $\rightarrow$ measurement on proton in 2007
- Preliminary measurement of pion polarizabilities from 2004 hadron beam data
- A wide and challenging meson spectroscopy program will start in 2008