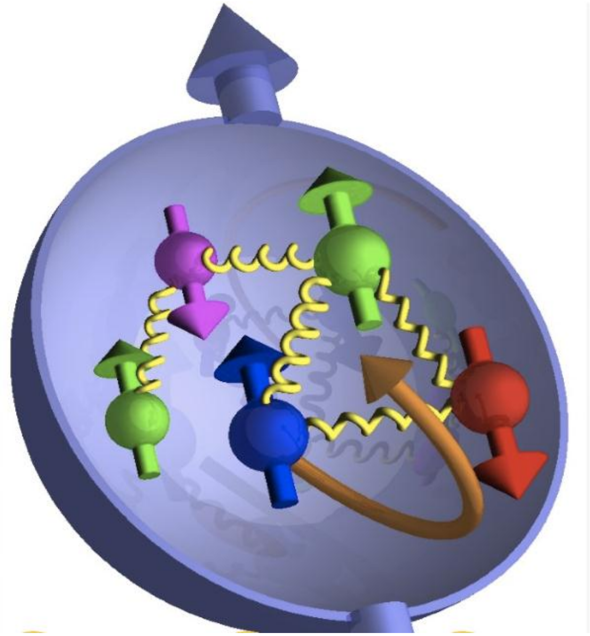
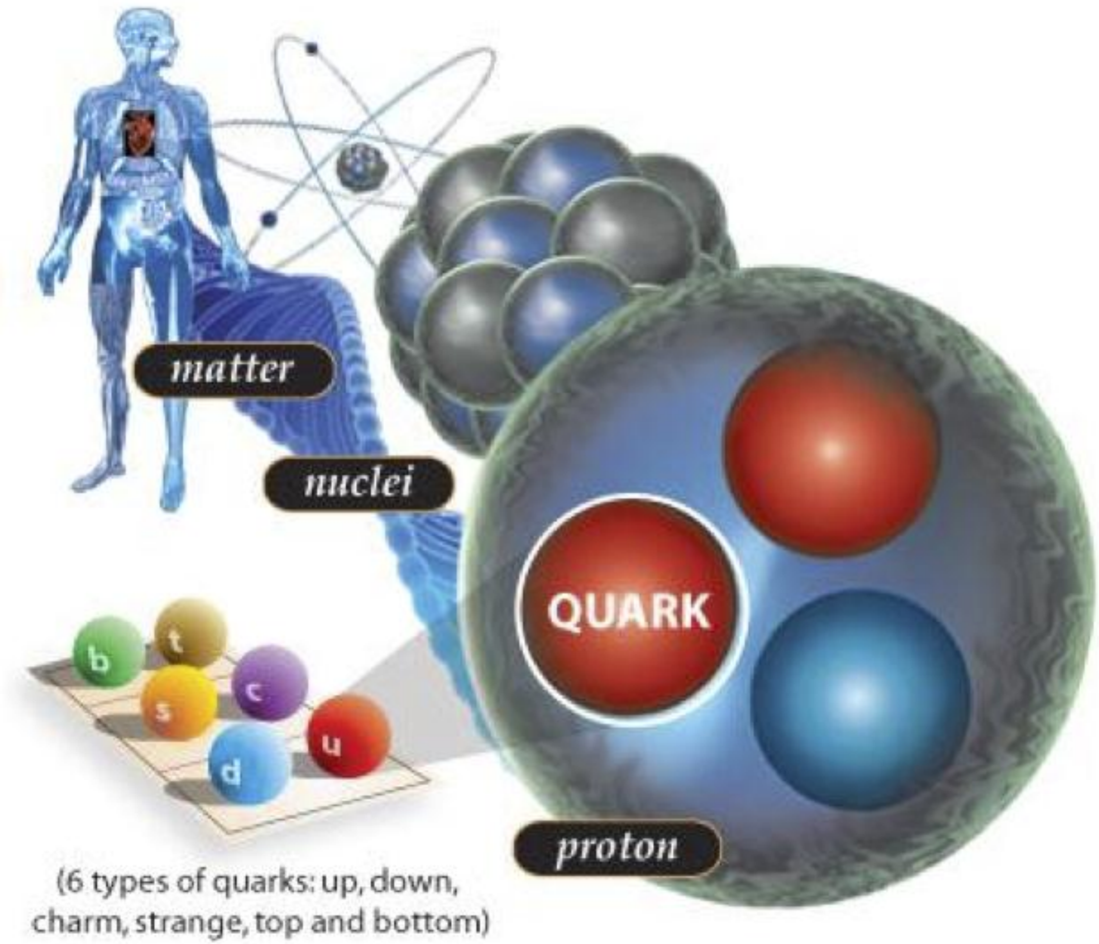
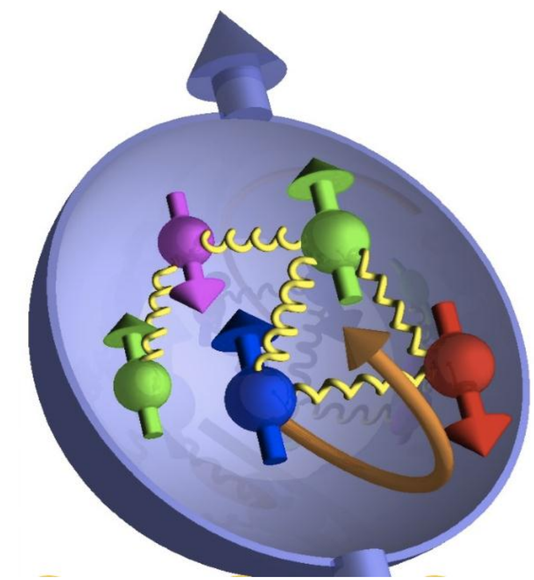
A Experiência COMPASS no SPS do CERN

A estrutura do protão e o seu spin



A Estrutura da Matéria





No núcleo dos átomos os nucleões - protões e neutrões - são constituídos de quarks ligados entre si por gluões

E o que é o Spin ?

As partículas constituintes da matéria - elementares (ex: quarks, electrões...) ou com estrutura (ex: protão, neutrão...) têm diferentes características.

Exemplos:

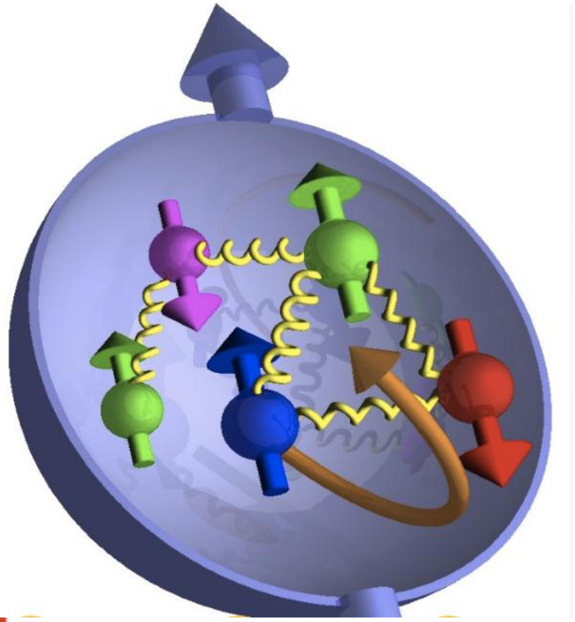
- Massa
- Spin – esta característica corresponde ao movimento rotacional intrínseco

Uma analogia clássica do spin dos nucleões (protões e neutrões) é como se fosse um pião a girar

Qual é o valor do Spin dos nucleões ?

O Spin dos protões (neutrões) = 1/2

E de onde provém ?



Sendo os nucleões constituídos por quarks e gluões, então o spin total será A soma dos spins de cada um deles

$$\textbf{Spin do nucleão: } \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_Z$$

spin dos quarks

spin dos gluões

mom. ang. orbital

A “Crise” do Spin

A primeira vez que se mediu o spin do conjunto dos 3 quarks dos nucleões foi nos anos 80 – pela experiência EMC do CERN

E o resultado foi: apenas 0.15 !!

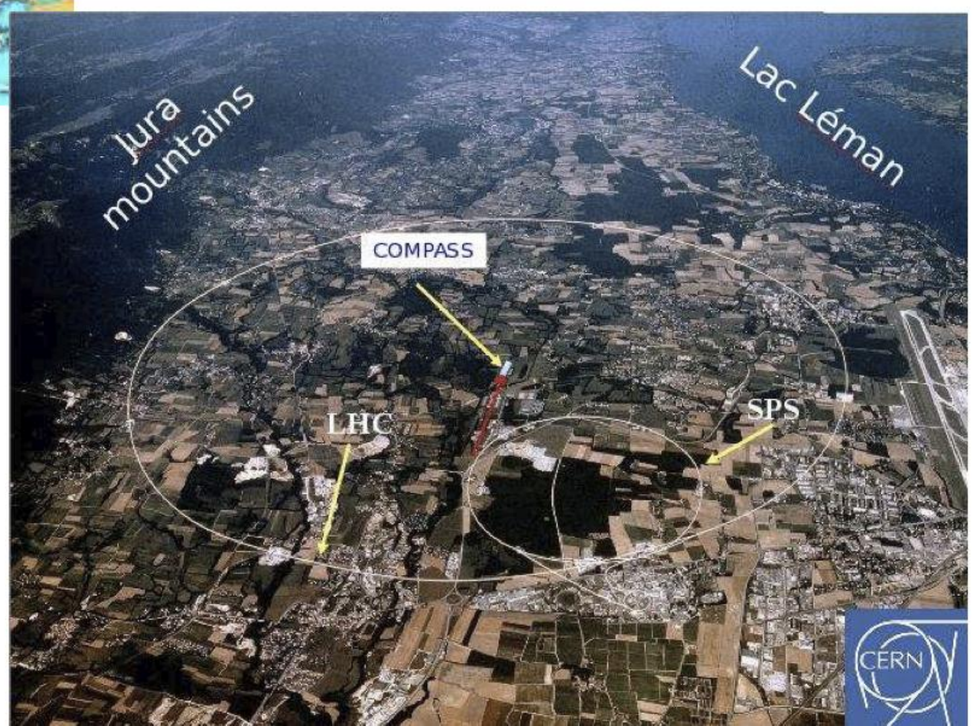
Spin do nucleão: $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_Z$

spin dos quarks | spin dos gluões | mom. ang. orbital

Um dos objectivos da experiência COMPASS do CERN é o de medir a contribuição dos <u>gluões para o spin dos nucleões</u>

COMPASS no CERN

COMPASS é uma colaboração de cerca de 230 físicos, de 30 institutos e 12 países.

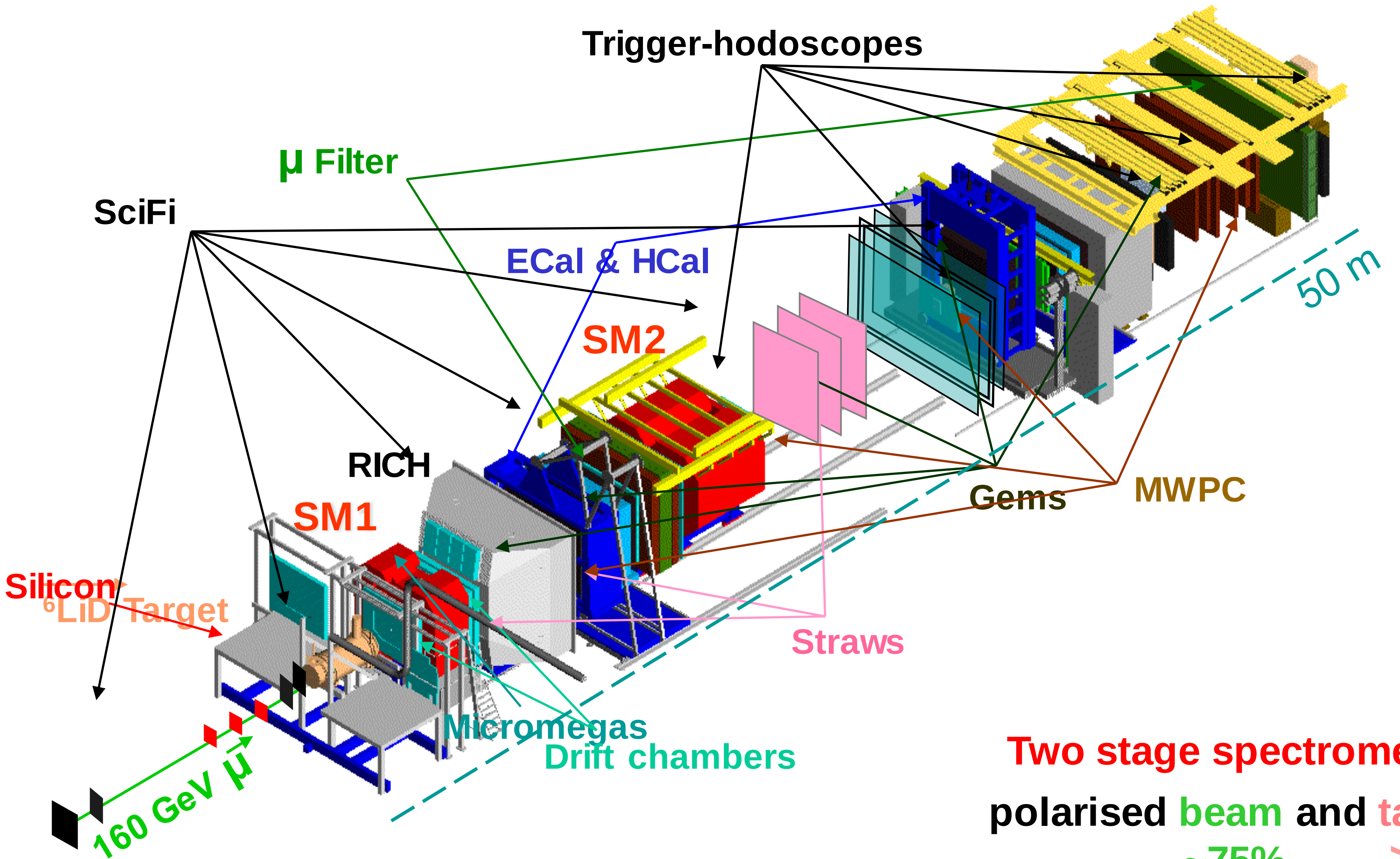


Recentemente o programa de Drell-Yan de COMPASS-II

atraiu:
2 labs USA
1 de Taiwan

A Experiência COMPASS

COmmon Muon Proton Apparatus for Structure & Spectroscopy



Two stage spectrometer

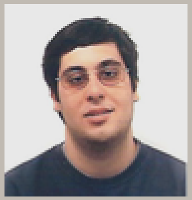
polarised beam and target

~75% ≥50%

LIP-COMPASS COLLABORATORS

Seniors: Paula Bordalo, Sérgio Ramos, Catarina Quintans

Post-Docs: Marcin Stolarski, Luís Silva, Celso Franco



PhD Students: Márcia Quaresma, Sofia Nunes

Master Student: Diogo Coutinho

Diploma Student: Bruno Jorge

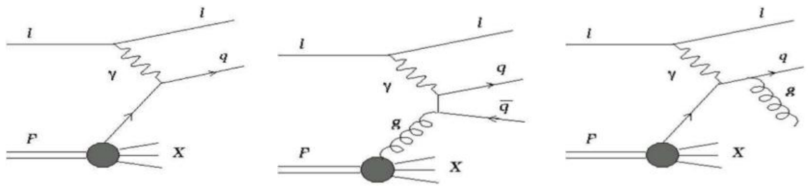
Engineers: Gonçalo Terça, Christophe Pires

THANK YOU !

Gluon Polarisation – LIP results

High-p_T Analysis, $Q^2 > 1$ GeV^2

In helicity asymmetries measurement with 2 high-p_T hadron events, 3 processes contribute in LO:



LP PGF QCDC

$$A_{LL}^{2h} = a_{LL}^{PGF} R_{PGF} \Delta G/G(x_G) + D R_{LP} A_1(x_{Bj}) + a_{LL}^{QCDC} R_C A_1(x_C)$$

a_{LL}s and Rs are taken from MC

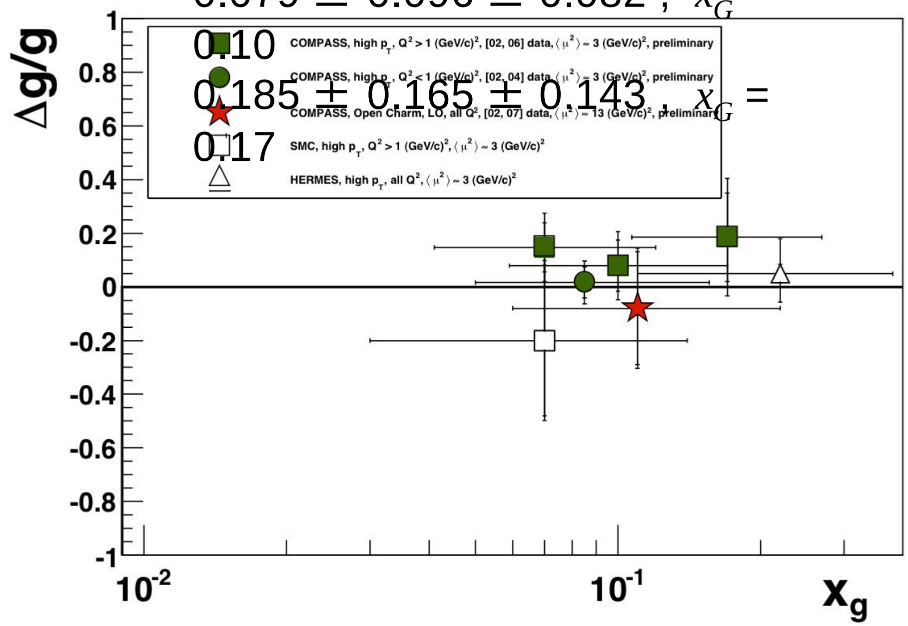
Higher $p_T \Rightarrow$ higher PGF probability

COMPASS is the **first experiment** providing measurement of ΔG/G in bins of x_G :

0.147 ± 0.091 ± 0.088 , x_G = 0.07

0.079 ± 0.096 ± 0.082 , x_G = 0.10

0.185 ± 0.165 ± 0.143 , x_G = 0.17

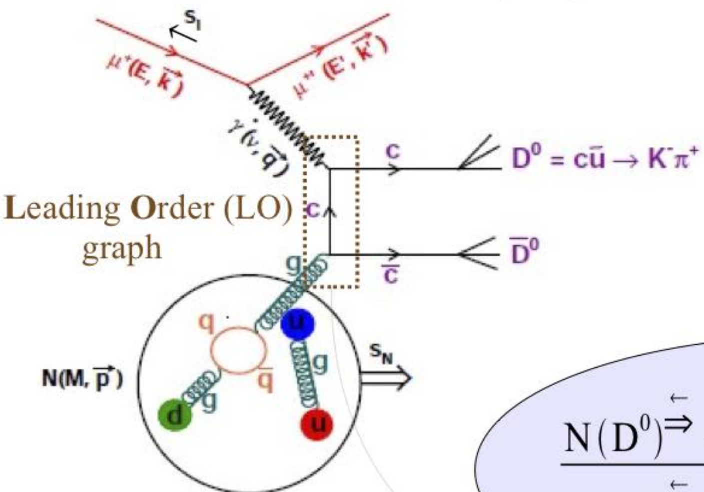


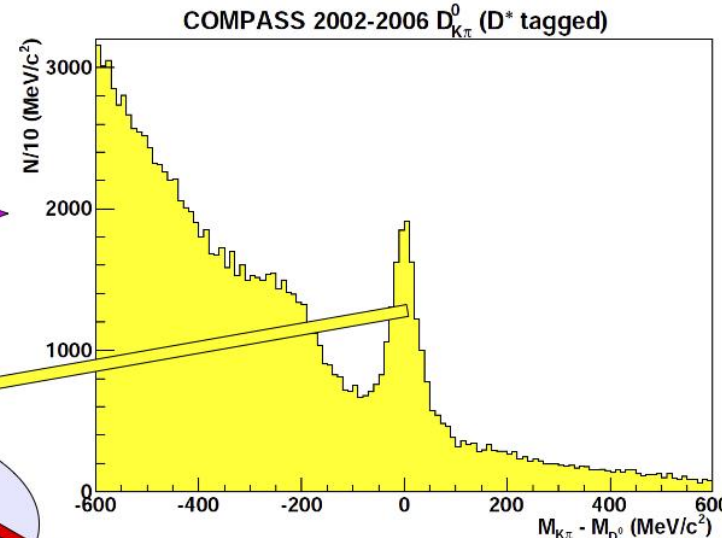
We are developing a new method of ΔG/G extraction from all p_T sample

- expected ΔG/G error reduction by a factor of 1.5 – 1.8
- easier way to deal with systematics
- allows tests of the MC models used in the analysis

ΔG/G from open charm - LIP results
(First world NLO analysis)

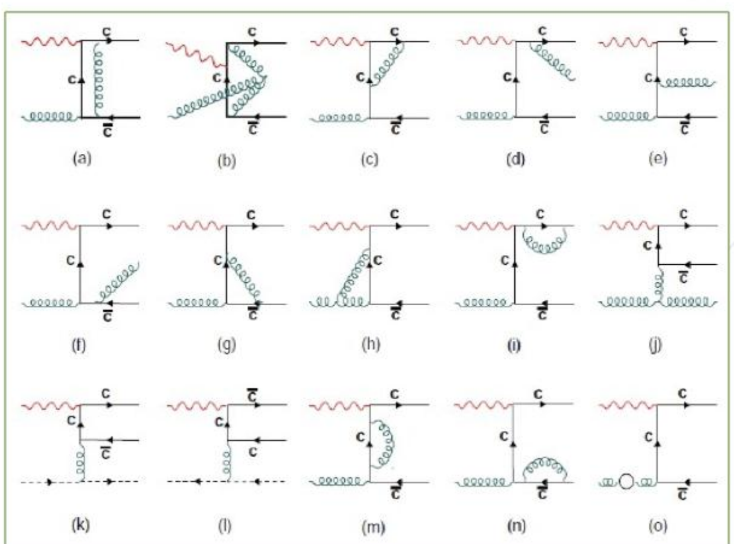
Polarised Photon-Gluon Fusion (PGF)





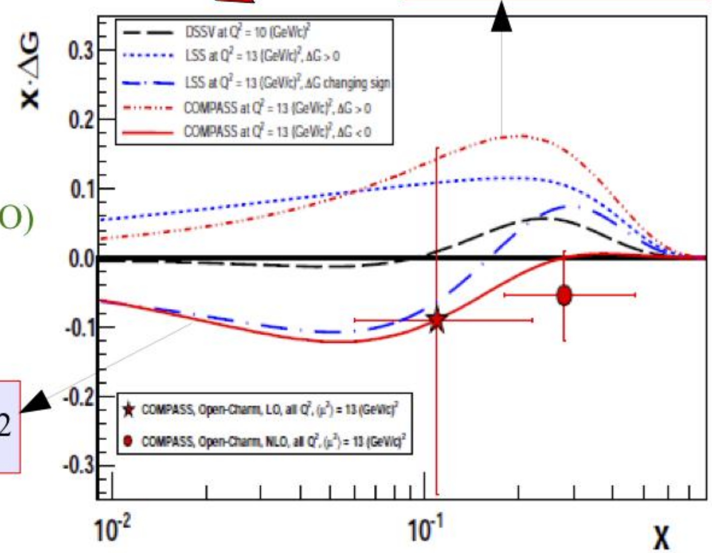
$$\frac{N(D^0)^{\overleftarrow{\Rightarrow}} - N(D^0)^{\overleftarrow{\Leftarrow}}}{N(D^0)^{\overleftarrow{\Rightarrow}} + N(D^0)^{\overleftarrow{\Leftarrow}}} \propto \boxed{\frac{\Delta\sigma_{\gamma^* g}^{\overleftarrow{\Leftarrow}}}{\sigma_{\gamma^* g}^{\overleftarrow{\Leftarrow}}}} \frac{\Delta G}{G}$$

$$\int_0^1 \Delta G dx = 0.27 \pm 0.09$$



Next-to-Leading Order (NLO) corrections to PGF

$$\int_0^1 \Delta G dx = -0.34 \pm 0.12$$



A_1^p Helicity Asymmetry in the low x_{Bj} and low Q^2 region

The photon-nucleon interaction is theoretically well explained in 2 regimes:

✓ real photons (Q^2=0)

✓ virtual photons in the perturbative region $Q^2 > 1$ GeV^2/c ^{2}

In the region 0< Q^2 <1 GeV^2/c ^{2} only models exist $\Rightarrow$ they needed to be tested

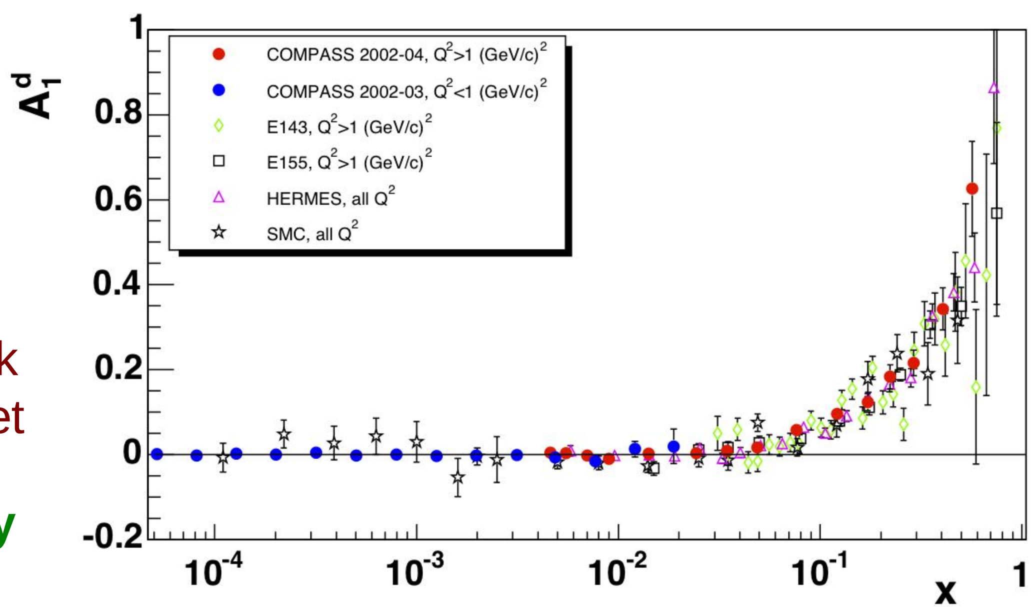
Advantages:

- high statistics: 90% of the μ–N interactions are in $Q^2 < 1$ GeV^2/c ^{2}
- low x_{Bj} region is very interesting - it is the region with very high parton densities

➢ So far, COMPASS has measured A_1^d asymmetry for the deuteron target with an increased precision of a factor of 10 w.r.t. previous measurements

➢ A_1^p measurements are not at the same level of precision; COMPASS took data in 2007 and 2011 w/ a proton target

➢ **d & p analyses are complementary and allow to discriminate theoretical models**



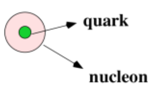
TMD Parton Distribution Functions

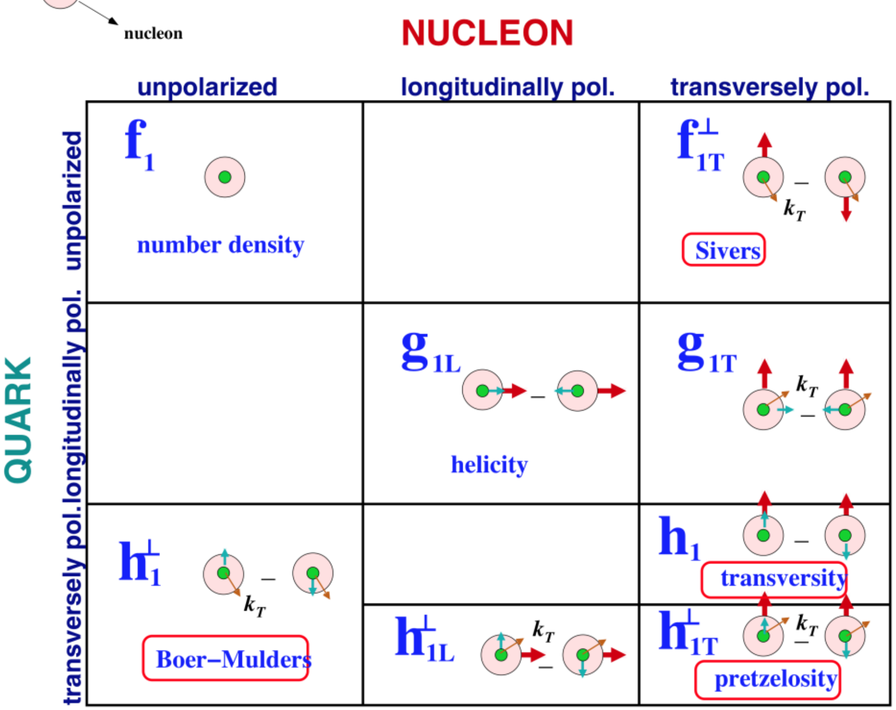
Transverse Momentum Dependent (TMD) PDFs give us a dynamic picture of the nucleon spin dynamics.

In LO and if k_T of quarks is not neglected, 8 PDFs are needed to fully describe the nucleon.

TMDs approach is valid when

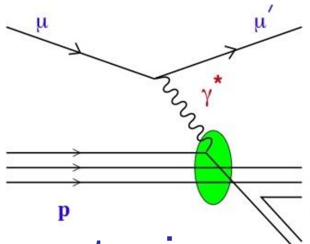
$$Q \gg q_T \gtrsim \Lambda_{QCD}$$





In COMPASS TMD PDFs are accessed by measuring azimuthal asymmetries, in 2 ways:

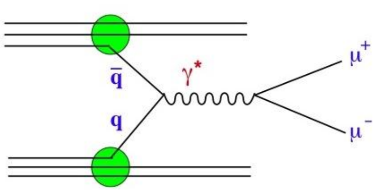
- **SIDIS**



The spin asymmetry is proportional to PDF ✪ FF:

$$A_{Sivers} \propto \frac{\sum_q e_q^2 f_{1T}^{\perp(1)}(x) D_q^h(z)}{\sum_q e_q^2 f_1(x) D_q^h(z)}$$

- **Drell-Yan**



The spin asymmetry is proportional to PDF_{Beam} ✪ PDF_{Tgt}. If unpolarised beam and transversely polarised target:

$$A_{Sivers} \propto 2\frac{\sum_q e_q^2 \bar{f}_{1q}(x_1) f_{1Tq}^{\perp(1)}(x_2)}{\sum_q e_q^2 \bar{f}_{1q}(x_1) f_{1q}(x_2)}$$

COMPASS DRELL-YAN Program

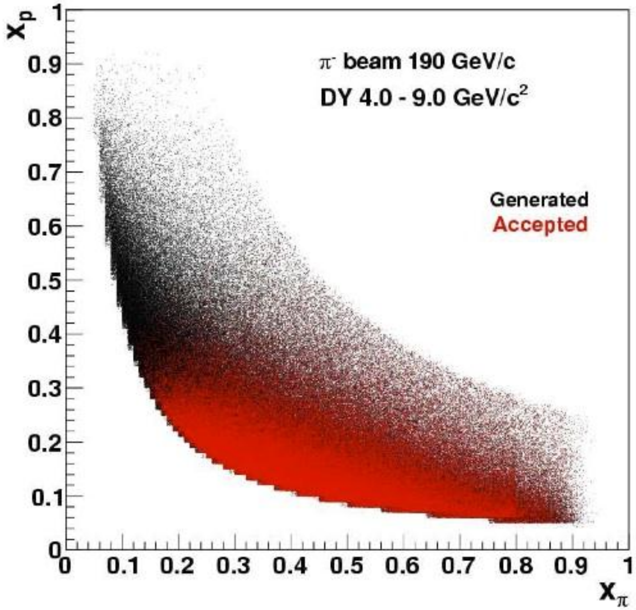
As Sivers and Boer-Mulders are T-odd PDFs:

Sivers: $\boxed{f_{1T}^{\perp}(DY) = -f_{1T}^{\perp}(SIDIS)}$

Boer-Mulders: $\boxed{h_1^{\perp}(DY) = -h_1^{\perp}(SIDIS)}$

✓**An important test of non-pertubative QCD and of TMDs approach**

Collisions of **π^- @ 190 GeV/c on NH3 transversely polarised target** give access to 4 azimuthal modulations related to Boer-Mulders, Sivers, pretzelosity and transversity PDFs

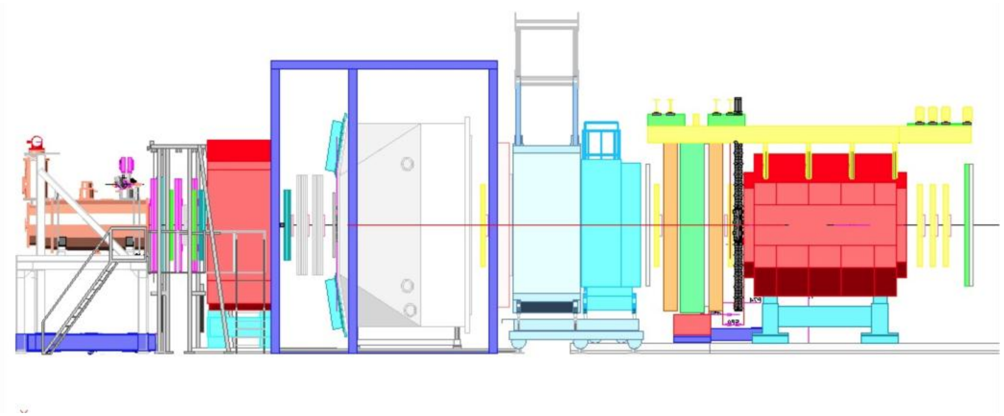


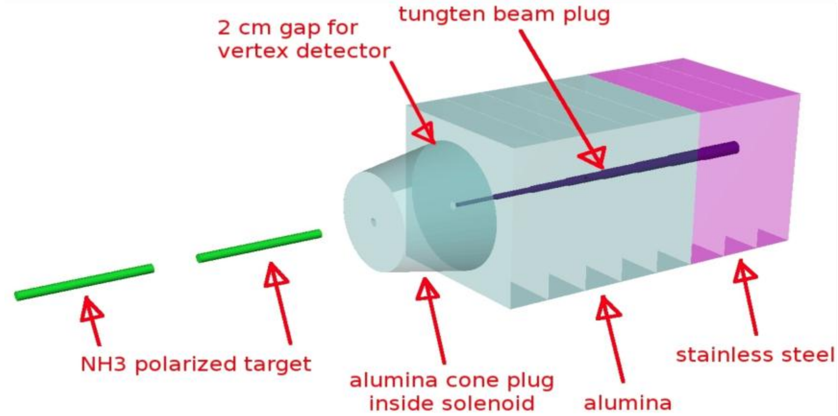
- All 4 asymmetries predicted to be sizable in the valence quarks region.
- COMPASS acceptance is very favorable: $x_p > 0.05$.
- Study Drell-Yan in $4 < M_{\mu\mu} < 9$ GeV/c^2, where background is negligible.
- TMD approach validity guaranteed by $M_{\mu\mu} \gg p_T^{\mu\mu} \approx 1$ GeV.

Short Drell-Yan beam tests performed in 2007, 2008 and 2009 have shown the feasibility of the Drell-Yan measurement in COMPASS.

COMPASS DRELL-YAN & LIP

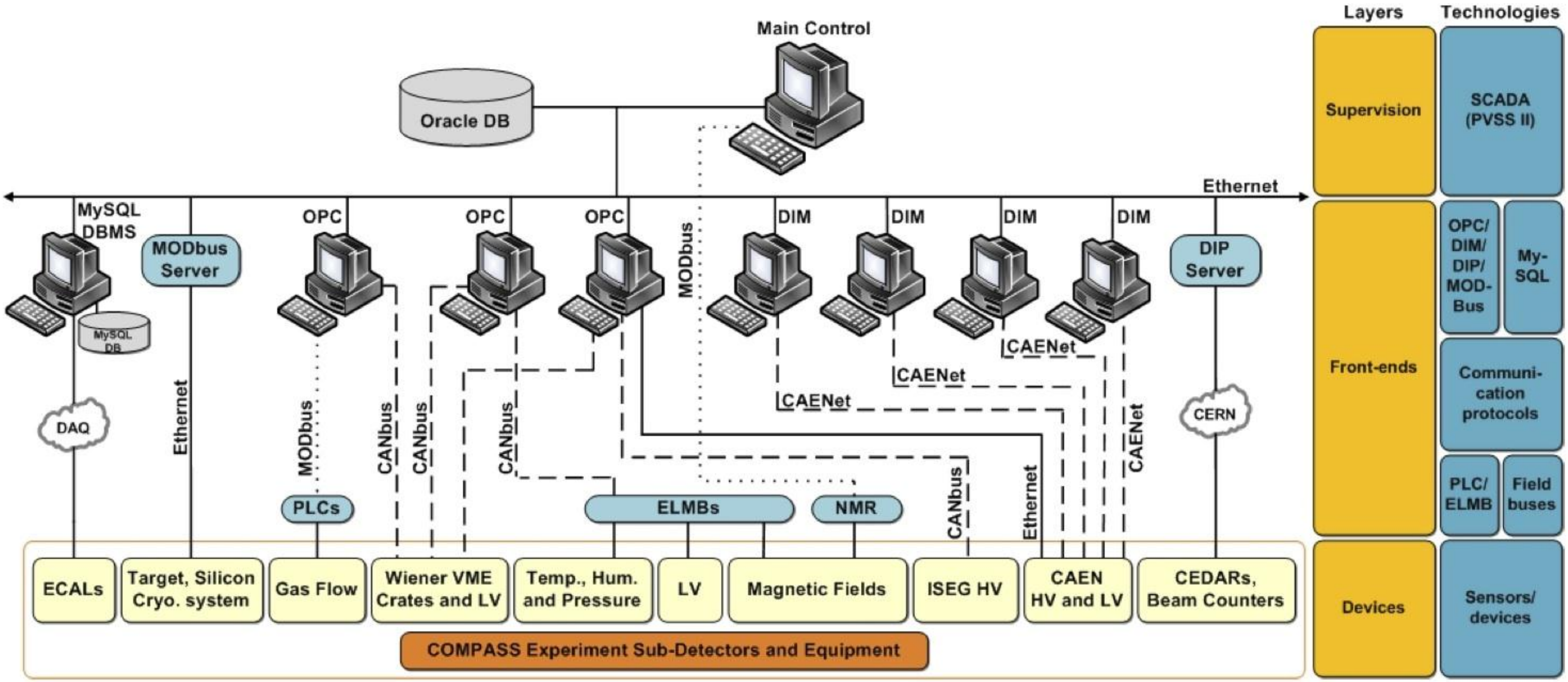
- **CERN has approved DY and DVCS program of the COMPASS-II proposal for the period 2012-2016**
- The present setup must be modified to include a **hadron absorber** and a **dimuon trigger** with large angular coverage



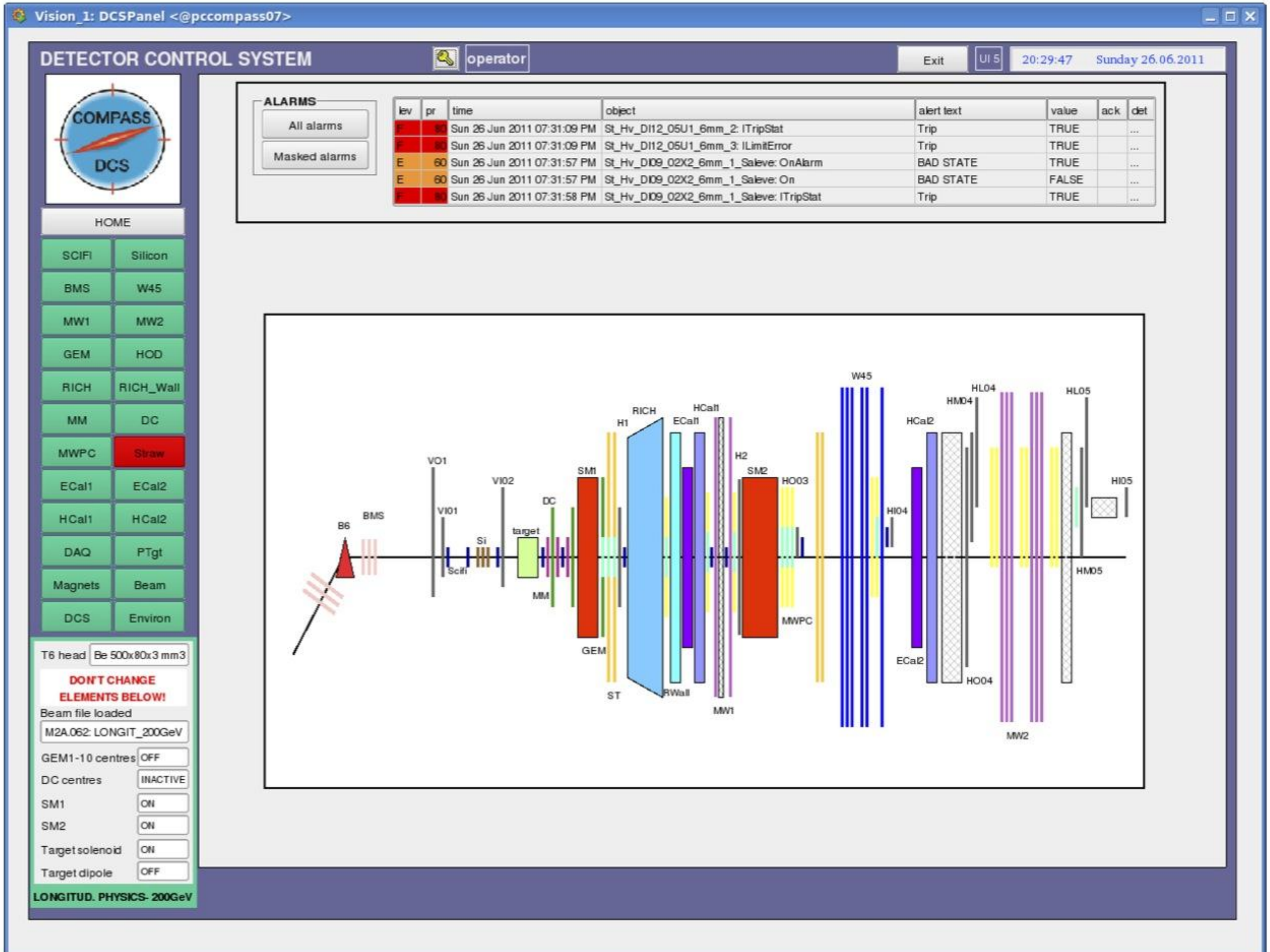


- **LIP group is strongly involved in the Drell-Yan project**
- The DY measurement is planned for 2014 – setup modifications **must start to be prepared immediately**, including equipments/detectors and manpower
- COMPASS can become **the first experiment to do polarised Drell-Yan**, and check the QCD change predictions in T-odd TMDs

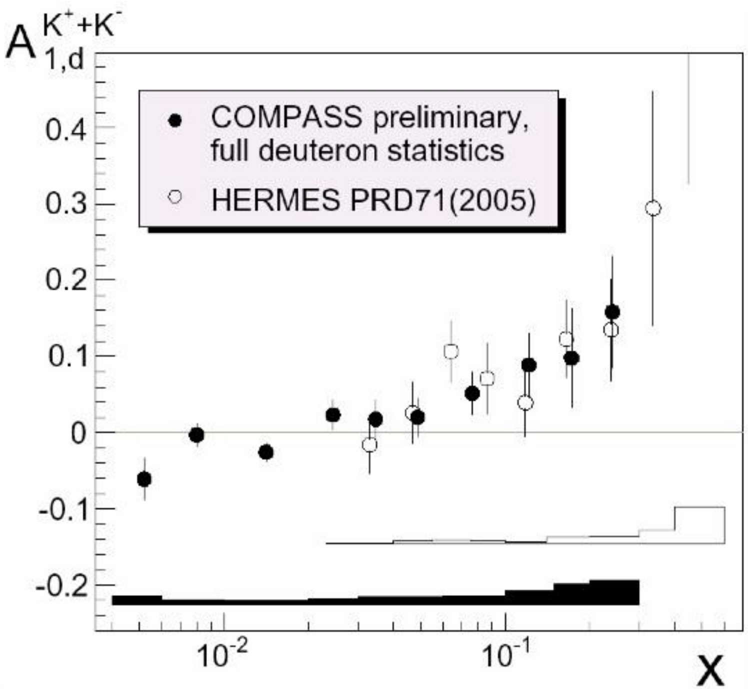
Full LIP Responsibility – DCS
Detector Control System

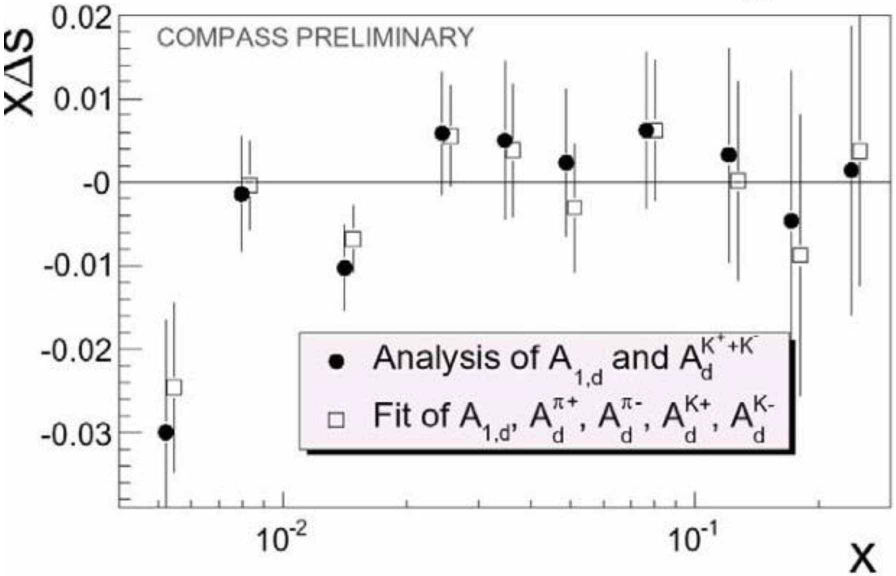


Full LIP Responsibility – DCS
COMPASS DCS User Interface



Δs from charged kaon asymmetry





$$\boxed{\frac{\Delta s}{s} = A_1^d + \left(A_1^{K^+ + K^-} - A_1^d\right)\frac{Q/s + \alpha}{\alpha - 4/5}}$$

$$\alpha = \frac{2R_{UF} + 2R_{SF}}{3R_{UF} + 2} \qquad Q = u + \bar{u} + d + \bar{d}$$

$$R_{UF} = \frac{\int D_d^{K^+}(z)dz}{\int D_u^{K^+}(z)dz} \qquad R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)dz}{\int D_u^{K^+}(z)dz}$$

From the first moment of g_1^d and semi-inclusive asymmetries, we extract the Δs contribution to the nucleon spin :

Δs (inclusive) = –0.045 ± 0.005 ± 0.010

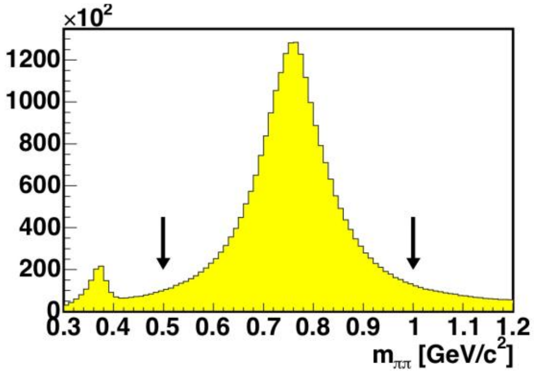
Δs (SIDIS) = –0.01 ± 0.01 ± 0.01

Up to now, RICH detector is a FULL responsibility of the big TRIESTE Group

This group has very good expertise in RICH physics and technology. Trieste laboratory has **an important workshop and manpower** (engineers and technicians) ⇒ workshop needs to work steadily

So, Trieste proposed to the COMPASS Technical Board a RICH upgrade with ThGEM (under RD51 studies). The project is feasible and so accepted in this board. At that time, no contribution of the Collaboration was asked.

Some months later, with the financial Italy crisis, the RICH-COMPASS leader (which is also the INFN Director), tried to find other groups which could share the ThGEM upgrade expenses.



However RICH is NOT used in the Physics Programs of 2012-2016 :

- NOT used in Primakoff studies (2012)
- NOT used in Drell-Yan studies (2014)
- NOT used in Deep Virtual Compton Scattering studies (2015-2016)
- could be used in Deep Virtual Meson Production, but:
  - clear signal with low background present without RICH usage
  - background level further reduced by RPD
- will be used for studies of strange quark fragmentation but, studies are not limited by the efficiency or purity of RICH, and kaons only with momentum between 10-50 GeV can be identified ⇒ limiting factor

RICH eventually will be used **after 2016**, in the physics program not yet fully specified and still not accepted by the COMPASS Collaboration and CERN

In the Physics Program of 2012-2016, LIP-Lisbon needs specific budget to participate in the building effort of COMPASS-II upgrade spectrometer :

✓ **DY spectrometer upgrade (absorber & trigger)** (to cover part of the expenses ⇒ 36 K€)
✓ **Detector Control System of the new detectors** (DCS support costs more than 70 K€ per year)

Due to current difficult economical situation, we suggest :

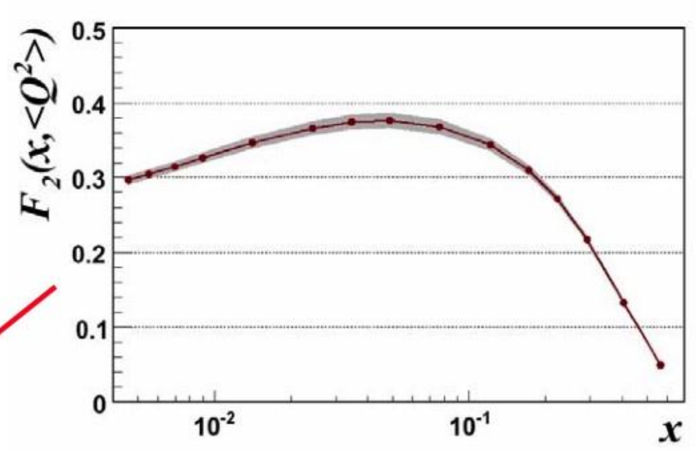
✧ to concentrate Portuguese efforts on the Drell-Yan project, as already a lot of effort and money was spent there
✧ to postpone the participation in RICH upgrade program until more details of the physics program are known

Currently COMPASS LIP group is heavily involved in the future Drell-Yan program

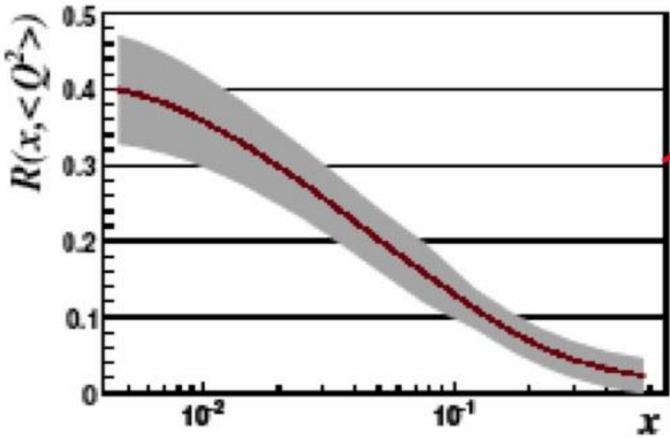
- ✓ measurement is accepted by CERN and should take place in 2014
- ✓ current work force is 3 seniors, 1 PHD and 1 master student fully dedicated to this program
- ✓ a work of 10 person x year was already involved in this program
- ✓ next year the group will be further reinforced by two post-docs
- ✓ more detector related expenses are needed since COMPASS spectrometer needs upgrade for CERN approved data taking period 2012-2016
- ✓ LIP-Lisbon is assumed to cover part of these expenses

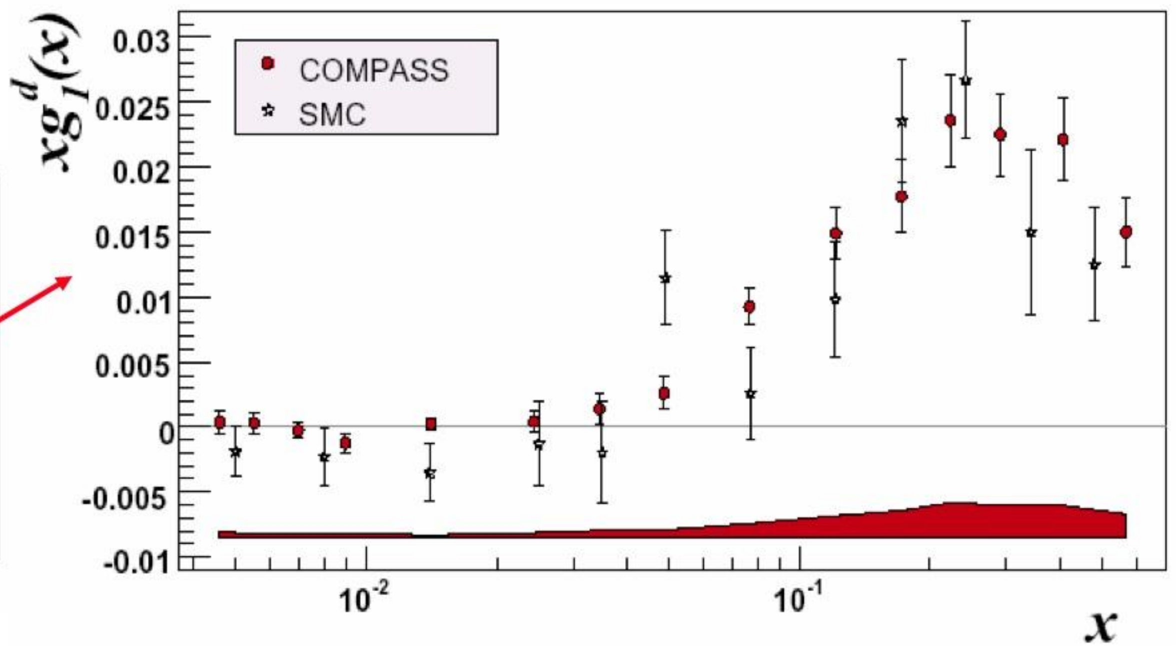
The $g_1^d(x)$ Structure Function

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



$$R(x,Q^2) = \sigma_L / \sigma_T$$





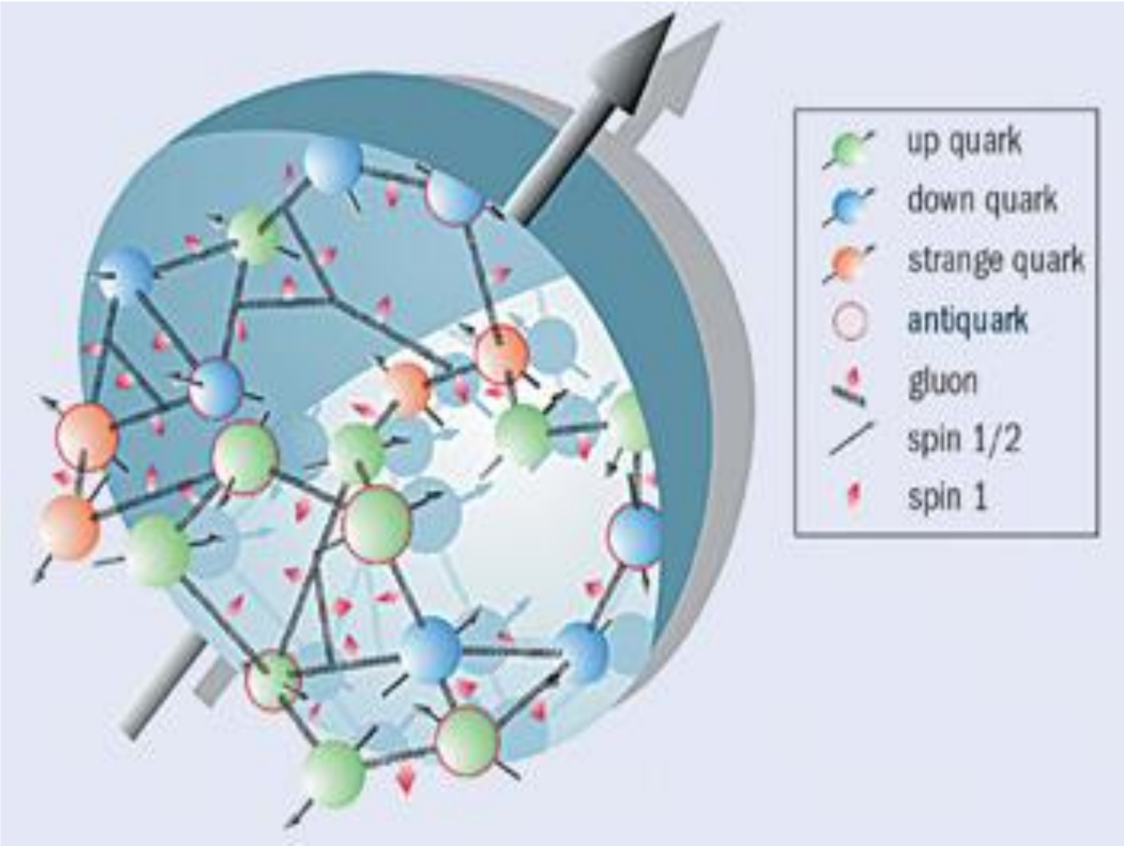
Why Nucleon (Spin)-structure?

Nucleon is more complex as we had anticipated…

$$\Sigma x_q \approx 0.5, \quad \Sigma x_g \approx 0.5$$

$$q_{\bar{d}} > q_{\bar{u}}$$

$$\Delta q_{\bar{d}}\,,\ \Delta q_{\bar{u}}\ \ ?$$



$$\left\langle S_z^N \right\rangle = \tfrac{1}{2} = J_q + J_g$$

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

HERMES

next generation

COMPASS

EMC:

$$\Delta\Sigma = 0.12 \pm 0.20$$

Today´s world:

$$\Delta\Sigma = 0.30 \pm 0.10$$

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$