COMPASS experiment at CERN: recent LIP contributions

Marcin Stolarski
on behalf of LIP-Lisboa group
COMPASS at CERN

- **COmmom Muon Proton Apparatus for Structure and Spectroscopy**

- Collaboration of 12 countries and about 210 physicists

- PHASE-I data taking in 2002-2011

- Currently PHASE-II ongoing (see talk by C.Quintans)
Physics goals

• Phase I
  – muon beam program
    * gluon polarization in the nucleon
    * spin dependent structure functions
    * polarized quark distributions
    * unpolarized fragmentation functions
  – hadron beam program
    * pion polarizability
    * hadron spectroscopy
    * exotics searches (glueballs, hybrids, ...)

• Phase II
  – Transverse Momentum Dependent functions (TMDs)
  – Generalized Parton Distribution functions (GPDs)
COMPASS setup:

- DETECTOR
  - two stage spectrometer
  - 60 m length
  - 2 (3) magnets
  - about 350 detector planes

- POLARIZED TARGET
  - $^6\text{LiD (NH}_3\text{)}$ target
  - 2-3 cells (120 cm total length)
  - ± 50% (90%) polarization
  - polarization reversal every 8h-24h

- POLARIZED BEAM
  - $\mu^+$ at 160 GeV/c
    (200 GeV/c in 2011)
  - polarization −80%

- FEATURES
  - angular acceptance: ±70 mrad
    (±180 mrad from 2006)
  - track reconstruction:
    $p > 0.5$ GeV/c
  - identification $h, e, \mu$: calorimeters and muon filters
  - identification: $\pi, K, p$ (RICH)
    $p > 2, 9, 18$ GeV/c respectively
LIP group in COMPASS

- Seniors:
  - Paula Bordalo (Group leader)
  - Catarina Quintans
  - Sérgio Ramos

- Post-docs:
  - Celso Franco
  - Luís Silva
  - Marcin Stolarski

- PhD students:
  - Ana Sofia Nunes
  - Márcia Quaresma

- Master students:
  - Gonçalo Terça
  - Miguel Vasco

- Engineer:
  - Christophe Pires
LIP-Lisboa group activities

- Analysis of COMPASS-I data (content of this talk)
  - extraction of the gluon polarization from open charm events
  - extraction of the gluon polarization from high-$p_T$ events
  - measurement of the spin asymmetry $A_1$ in low $x$ and low $Q^2$ region
  - measurement of hadron multiplicities and fragmentation functions

- Preparation of COMPASS-II phase
  - one of the two main institutes behind the polarized Drell-Yan (DY) measurement proposal, which was approved in 2010
  - MC studies to optimize detector setup and the dimuon trigger
  - improvements in the muon tracking reconstruction efficiency and purity
  - MC analyses of possible backgrounds to DY process in COMPASS kinematic range
  - analyses of the DY test runs

- Full responsibility of the experiment’s Detector Control System
Idea of spin dependent measurements

- Interaction of polarized photons with nucleon

- Because of angular momentum conservation, only quarks with a spin opposite to the spin of the photon can interact with it

- Spin effects are small, precise method of extraction is needed, like asymmetry measurements
Studied processes

- **Deep Inelastic Scattering (DIS)**
- Incoming and outgoing muon four-momenta are measured
- The final state $X$ is not looked at
- The cleanest measurement

- **Semi-Inclusive Deep Inelastic Scattering (SIDIS)**
- The difference w.r.t. DIS: additional final state particle is detected
- More complicated: what is the probability that a quark of type $q$ fragments into a hadron of type $h$?
- A new non perturbative object is needed - **Fragmentation Functions (FF)**
Short story of spin measurements

- First spin asymmetry measurement in SLAC, USA in 1975, done by Vernon Hughes et al.

- Results with large uncertainties were agreeing with the expectations

- Unexpected results of EMC (1987) started the so-called “spin crisis”: quarks carry only $\Delta \Sigma = 10\% \pm 15\%$ of the proton spin ($\Delta \Sigma = \Delta u + \Delta d + \Delta s$)
  
  
  - Nucl. Phys. B328 (1989), 1; cited 1422 times

- Second generation of experiments, at CERN and USA (early-mid of 90’) confirmed EMC results

- $S_p = 1/2 = 1/2 \Delta \Sigma + \Delta G + L_{q,G}$

- Third generation of experiments is trying to solve the spin puzzle, COMPASS @ CERN, HERMES @ DESY, experiments at USA in RHIC and JLab laboratories

- Fourth generation is being planed
Modern Results – COMPASS NLO QCD fit

\[ \Delta \Sigma \approx 0.25 - 0.30 \]

\[ \Delta G \text{ not constrained} \]

\[ \text{Negative } \Delta s \text{ in the whole } x \text{ range} \]
**$\Delta g/g$ measurement**

- $S_p = 1/2 = 1/2 \Delta \Sigma + \Delta G + L_{q,G}$
- Gluons may carry missing spin of the proton
- Problem: photon doesn’t directly interact with gluons ($q=0$)
- In order to measure $\Delta g/g$ higher order processes in $\alpha_s$ must be studied, namely photon–gluon fusion (PGF) from e.g.
  - open-charm events
  - high-$p_T$ hadron pairs
\textbf{$\Delta g/g$ measurement: COMPASS results}

- Both analyses were published last year (with outstanding contribution from LIP)
  - High-$p_T$ - PLB 718 (2013) 922 (LO analysis)
  - Open Charm - PRD 87 (2013) 052018 (LO and NLO analyses)

- Results:
$\Delta g/g$ measurement: method improvement

- At LIP we developed a new method of $\Delta g/g$ extraction - all–$p_T$ method
  ⇒ Reduction of the statistical error of $\Delta g/g$ by about 60% with respect to the last COMPASS publication PLB 718 (2013) 922
ΔS puzzle

- From NLO QCD fits, a negative ΔS is expected in the whole x range

- However, by selecting kaons in the final state, one enhances the contribution of strange quarks

- Examples of previous analyses:
  - HERMES analysis, PLB 666 (2008) 446
  - the curve from LSS group NLO QCD PRD 73 034023

- Clear disagreement of HERMES data with global NLO QCD fit is visible
**ΔS** studies at COMPASS

- The results of the SIDIS-type analysis depend on the choice of the Fragmentation Functions (FF),
  - \( D_{str}(z) \): \( \bar{s} \rightarrow K^+ \) and c.c.
  - \( D_{fav}(z) \): \( u \rightarrow K^+ \) and c.c.
  - \( D_{unf}(z) \): \( \bar{u}, d, \bar{d} \rightarrow K^+ \) and c.c.

- FF can be studied by analysing hadron multiplicities, *e.g.*, kaon multiplicity sum

- \( 5 \frac{dN^K(x)}{dN^{DIS}(x)} \approx \int D^K_Q(z)dz + S(x)/Q(x) \int D^K_S(z) \)
\( \Delta S \) puzzle: comparison of experimental results

- Clear disagreement is seen between preliminary COMPASS results and HERMES published data
- The discrepancy between the two experiments is being investigated
Asymmetry $A_1^p$ at low $x$ and low $Q^2$

- The low $x$ region is very interesting because of high parton densities in the nucleon
- However, in COMPASS there is a strong correlation between $x$ and $Q^2$
- Low $x$ measurement is in the non-perturbative region of QCD
$A_1^p$ at low $x$ and low $Q^2$ - COMPASS results

- The $A_1^p$ is positive, about 1% in the low $x$ region
- For the first time non zero spin effects are observed for so low $x_{Bj}$
- Measurements at the two beam energies give similar results as functions of $x_{Bj}$ and $\nu$
$A_1^p$ at low $x$ and low $Q^2$:
comparison of experimental results

- The statistical precision obtained at COMPASS is by a factor of 10-20 better than in the previous experiments
Summary & Conclusions

• COMPASS Phase I data taking is finished

• However,
  – new results are being published
  – analysis methods are being improved

• LIP group has an important role in COMPASS data analyses and in the preparation of the following physics program

⇒ At the next International Conference DIS2014, 3 members of LIP group will give oral presentations of their work on behalf of the COMPASS Collaboration