COMPASS - a facility to study QCD

Eva-Maria Kabuß
Institut für Kernphysik,
Mainz University

for the COMPASS collaboration

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Physics program: QCD at different scales

COMMON MUON AND PROTON APPARATUS
FOR STRUCTURE AND SPECTROSCOPY

Bochum, Bonn, Burdwan/Calcutta, CERN, Dubna, Erlangen, Freiburg, Illinois, Lissabon, Mainz, Moscow, Munich, Prague, Protvino, Saclay, Taipei, Tel Aviv, Turino, Trieste, Warsaw, Yamagata
(30 institutes, 225 physicists)

Chiral dynamics
- $\pi\gamma$ and $K\gamma$ reactions
- $\pi$ and $K$ polarisabilities
- Radiative decay width

Hadron spectroscopy
- Mass spectrum of hadrons
- Gluonic excitations
- Exotics

Nucleon structure
- Gluon polarisation
- Helicity and transversity PDFs
- Transverse mom. dep. distributions
- Generalised PDFs
SPS proton beam: \(1.4 \times 10^{13} / \text{spill of } 4.8 \text{s}, 400 \text{ GeV/c}\)
- Secondary hadron beams (\(\pi, K, \ldots\)): \(2 \times 10^8 / \text{spill, } 150-270 \text{ GeV/c}\)
- Tertiary muon beam (80\% pol): \(2 \times 10^8 / \text{spill, } 100-200 \text{ GeV/c}\)

-> Luminosity \(\sim 5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}\) with polarised targets
Spectrometer

- Two magnets (1 Tm, 4.5 Tm)
- Tracking ($p > 0.5$ GeV/c):
  - SciFi, Silicon, MicroMega, GEM, MWPC, Drift, Straws, Driftubes
- PID: $\pi$, $K$, $p$ (RICH)
  - above 2, 9, 18 GeV/c
- ECAL, HCAL, muon filter
Polarised target for muon beam

Target material: $^6\text{LiD, NH}_3$

Polarisation: 50%, 90%

Dilution factor: 0.4, 0.15

Longitudinal, transverse pol.

Set-up optimised for asymmetry measurements

Measurements 2002-07, 2010-11

- Muon scattering on polarised p(NH$_3$) and d($^6\text{LiD}$) with longitudinal and transverse target polarisation (2002 - 2007)
- Addendum in 2010 (transv. p) and 2011 (long. p)
- All three leading twist PDFs investigated ($f_1(x)$, $g_1(x)$, $h_1(x)$)
Nucleon structure: Results

**Longitudinal polarisation**

- quarks carry 30% of nucleon spin
- gluon contribution small (in $x$ range covered)
- quark helicities distributions

**Unpolarised**

- charm production
- Multiplicities: $p_T$ dependence
- Fragmentation functions for pion and kaons (ongoing work)
Results for transverse target polarisation

COMPASS 2007 and 2010 proton data

- sizeable transverse effect observed (for proton)
- transverse quark distributions accessible
- u- and d-quark transversity similar to helicity distributions, but about factor 2 smaller

- first look on transverse momentum dependent distributions
- clear effects observed for transverse polarisation (Sivers function) and unpol. target (Boer-Mulders function)
- hints for quark orbital angular momentum
Target region for hadron beam

- diffractive and central production with 190 GeV/c $\pi$ and $p$ beam
- target recoil detection to ensure exclusivity

- target material: unpolarised $\text{IH}_2$, Pb, Ni, Cu, W
- Si microstrip detector telescope around target (vertex resolution)
- recoil proton detector for PID and momentum measurement (TOF)
- setup optimised for exclusive channels (sandwich veto)
Example for Hadron spectroscopy

- data taking for spectroscopy 2008 and 2009, pilot run in 2004
- diffractive $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p_{slow}$
- $50 \cdot 10^6$ events: world largest data set → very challenging analysis

- PWA with isobar modell
- analysis in mass and momentum transfer bins
- new resonance $a_1(1420)$ observed
- similar analysis for $\pi^- p \rightarrow \pi^- \pi^0 \pi^0 p_{slow}$
### Spectroscopy - analysis ongoing

- Many different channels analysed
- Meson and baryon spectroscopy
- Search for exotics and glueballs
- Tests of chiral pert. theory

### Nucleon structure - open questions

- Strange quark momentum distribution?
- Fragmentation of strange quarks?
- Strange quark helicity distribution?
- Transverse momentum dependent distributions
- Orbital angular momentum of quarks and gluons?
What we will do

Improve the 1-dimensional picture of the nucleon

Study generalised parton distributions and transverse momentum dependent distributions
submitted in May 2010 for 5 years of data taking in the first phase
approved in December 2010 for *initially* 3 years of data taking in 2015-2017

**Generalized parton distribution (GPD)**

longitudinal momentum structure plus transverse spatial structure
accessible in exclusive reaction like DVCS or DVMP

**Flavour separation and fragmentation in SIDIS**

strange quark distribution and fragmentation functions

**Transverse momentum dependent distributions (TMD)**

dynamic picture using intrinsic transverse momenta of partons
accessible in SIDIS and Drell-Yan processes

**QCD at very low momentum transfers**

pion/kaon polarisabilities, testing chiral perturbation theory
Polarisabilities using $\pi^- Z \rightarrow \pi^- Z \gamma$

- measurement of deviation from pointlike behaviour due to pion structure
- unique at COMPASS: comparison with muon
- prediction of low energy behaviour from chiral pert. theory
- first measurement with Ni target in 2009 $\rightarrow$ preliminary value for $\alpha_\pi$

COMPASS phase 2:
- measurement of electric $\alpha_\pi$ and magnetic $\beta_\pi$ polarisabilities separately
- first look of kaon polarisability
- data already taken in 2012
Generalised parton distributions

**Access GPD through DVCS mechanism**

- generalised parton distributions for quarks and gluons $H^f, E^f, \tilde{H}^f, \tilde{E}^f(x, \xi, t)$
- limits: $q(x) = H(x, 0, 0)$
  
  $F(t) = \int dx \: H(x, \xi, t)$
- GPDs contained in Compton form factors

**Ji’s sumrule**

$$J^f = \frac{1}{2} \lim_{t \to 0} \int_{-1}^{1} dx \: x \left[ H^f(x, \xi, t) + E^f(x, \xi, t) \right]$$

$J^f$: total angular momentum contribution of quark $f$

- unpolarised hydrogen target $\Rightarrow$ GPD $H$
- transversely polarised target $\Rightarrow$ GPD $E$
What we do measure

\[ \mu^\pm p \rightarrow \mu^\pm \gamma p \]

- Competing: DVCS and BH \( \rightarrow \) measurement with \( \mu^+ \) and \( \mu^- \)
- Yields \( \text{Re}(H) \) and \( \text{Im}(H) \)

- 2009 Test measurement: clear DVCS signal
Target region for DVCS

- 2.5m long liquid hydrogen target
- 4m long recoil proton detector (CAMERA) (Freiburg, Mainz)
- Hermetic coverage with electromagnetic calorimetry
- New ECAL0 added
- Readout (TUM)
- Start counter (SciFi) (Bonn HISKP, Erlangen)

- Measurement with 160 GeV $\mu^+ \ (1/3)$ and $\mu^- \ (2/3)$
- 2 years of data taking approved
- Pilot run 2012
TMDs

- dynamic picture of the nucleon using intrinsic transverse momentum $k_T$ of partons
- sensitivity to quark orbital angular momentum
- at leading twist: full description with 8 TMDs
- 3 survive integration over $k_T$: $f_1$, $g_1$ and $h_1$

TMDs are accessed by azimuthal asymmetries in SIDIS and DY
- studied in SIDIS using unpolarised and transversely polarised target
- in SIDIS convolution with fragmentation function
TMDs

**Boer-Mulders function** $h_{1T}^\perp$:
- correlation of quark $k_T$
- and transverse quark spin in unpol. nucleons

**Sivers function** $f_{1T}^\perp$:
- correlation of quark $k_T$ and nucleon transverse spin

Sivers and BM functions T-odd

→ process dependent

**Prediction**

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

$$h_{1T}^\perp(SIDIS) = -h_{1T}^\perp(DY)$$

→ Crucial test of non-perturbative QCD and of TMD approach
DY at COMPASS

\[ \pi^- p^\uparrow \rightarrow \mu^+ \mu^- X \]

- convolution of two TMDs measured
- access to 4 azimuthal modulations: Boer-Mulders, Sivers, pretzelosity and transversity PDFs
- ideal DY measurement: \( \bar{p}p \)
- good compromise \( \pi^- p \)
- annihilation of valence anti-quark from \( \pi^- \) and valence quark from polarised proton
- large acceptance of COMPASS in the valence region
Target region for DY

- **first** DY measurement with pol. target
- high intensity 190 GeV/c pions
- transversely polarised NH$_3$ (Bochum)
- hadron absorber, beam plug
- vertex detector, beam telescope (Bonn HISKP, Erlangen)
- dimuon trigger system (Bonn PI, Mainz)
- DAQ upgrade (TUM)

- pilot run planned for 2014 (few weeks)
- 1 year of data taking approved
Outlook

**Plans**
- DY pilot run in 2014
- 2015 DY with transversely polarised NH$_3$
- 2016/7 DVCS with hydrogen target

**Perspectives**
- DVCS: Ji’s sumrule →
  measurement with transverse polarisation and recoil detector
- SIDIS: evolution of transversity and TMDs →
  considerable increase of stat., transverse target pol.
- DY: precision, flavour separation →
  deuteron target, exploit antiprotons in the beam
- Hadron spectroscopy: photoproduction
  study of reaction mechanism