COMPASS++

Physics opportunities for a future COMPASS-like experiment

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EP-SME-CO

many slides from Oleg Denisov
Outline

• Introduction

• Physics with RF-separated beams (kaons, antiprotons)
  – Spectroscopy
  – Drell-Yan

• Physics with existing muons and hadron beams
  – SIDIS, DVCS, DVMP
  – DY

• Outlook
QCD Questions

- How in detail hadrons are made up by quarks and gluons
- What are the correlations, e.g. between transverse and spatial degrees of freedom (TMD, GPD, tomography)
- Are time-reversal-odd TMD PDFs universal?
- What is the structure of kaons (kaon DY, direct photons)
- Kaon excitation spectrum and decay modes > 1.5 GeV/c^2
- Charmonium hybrids and exotics
- Chiral dynamics – kaon polarisability

- add-on: Dark matter, supporting measurements
Future plans

- COMPASS is preparing a Letter of Intent for a new round of experiments beyond 2020
- Open to new groups and ideas
- Starting point: Beyond 2020 workshop, March 2016 at CERN
- Unique opportunity: RF separated kaon and antiproton beams (in M2)

\[ \Delta \Phi = 2\pi \left( \frac{L f}{c} \right) (\beta_1^{-1} - \beta_2^{-1}) \text{ with } \beta_1^{-1} - \beta_2^{-1} = \frac{(m_1^2 - m_2^2)}{2p^2} \]

- Goals: LoI in 2017, proposal in 2018
- Likely a 7-8 year endeavour
Ideas for a LoI

- **Spectroscopy with RF-separated beams**
  - Kaon: Hadron spectroscopy and diffraction
  - Kaon: polarisability
  - Kaon: gluon distribution with prompt photons
  - Antiproton: Charmonium hybrids and exotics (low p-bar energy)

- **Drell-Yan with RF-separated beams**
  - Kaon: DY with both polarised and unpolarised targets, kaon structure
  - Antiproton: DY, both polarised and unpolarised, TMDs
• **Physics with existing muon beam**
  – SIDIS with transverse polarised deuteron target
  – DVCS with transverse polarised proton target
• **Physics with existing pion/proton beam**
  – Pol. DY with deuteron target – flavour separation
  – Unpol. DY with various targets
  – x-section $p + \text{He} \rightarrow \bar{p} \ X$ for dark matter

Programme with present beams, likely to start right after LS2 (unless separated beams would be available already)
Versatile COMPASS in EHN2

Hadron Spectroscopy & Polarisation

COMPASS-I
1997-2011

Polarised SIDIS

COMPASS-II
2012-2018

Polarised Drell-Yan

DVCS (GPDs) + unp. SIDIS
240 physicists from 12 countries + CERN, 24 institutions
RF-separated kaon beam

Hadron spectroscopy

($\sim 10^8/s$ in spill, $\sim 100$ GeV)

\[ \Delta \Phi = 2\pi \left( \frac{L}{c} \right) (\beta_1^{-1} - \beta_2^{-1}) \text{ with } \beta_1^{-1} - \beta_2^{-1} = \frac{(m_1^2 - m_2^2)}{2p^2} \]
Light and strange meson sector

**COMPASS:** \( a_1(1420) \)

**3\pi** data sample \(~50\times10^6\) exclusive events – factor 10 to 100 more than previous experiments, advanced analysis (88 waves)

Illustration or our potential: discovery of a new axial-vector meson \( a_1(1420) \) in \( 1^{++}0^+ f_0(980)\pi P \) wave.

G.K. Mallot 01/03/2017

PBC CERN
Kaon states

- PDG lists in total 25 kaon states
  - 17 kaon states above 1450 MeV/c²
  - 12 are omitted from summary tables
  - 8 need confirmation, for 2 states $J^P$ is unknown
- All entries are older than 20 – 30 years
- Mapping out the kaon excitation spectrum and decay modes helps understanding light-meson spectrum by completing SU(3) flavour multiplets
- With an RF-separated kaon beam COMPASS++ could increase the global data set by a factor 10 and rewrite PDG for strange mesons for masses > 1.5 GeV/c²
- Unique opportunity, no real competitors
• Primakoff reaction
\[\pi \gamma \rightarrow \pi \gamma\] in nuclear field

• El. & magn. polarisabilities \((\alpha, \beta)\) are fundamental properties, predictable in \(\chi PT\)

• COMPASS measured \(\alpha\) for \(\pi\) assuming \([\alpha + \beta = 0]\)

• With RF-separated beam kaon measurement possible

• Further measurements for other processes \(\pi \gamma \rightarrow \ldots\) in parallel
Direct photons from kaons (& pions)

Production of direct photons $hN \rightarrow X\gamma$

- Under study, maybe tests during 2017 GPD run
- First observation of direct photon production with a kaon beam could be an important direct measurement of gluon contribution in kaons
- No data existing
RF-separated(?) antiproton beam

Hadron spectroscopy

($\sim 5 \times 10^6 / s$ in spill, $\sim 20$ GeV or lower)

\[ \Delta \Phi = 2\pi \left( \frac{L \, f}{c} \right) (\beta_1^{-1} - \beta_2^{-1}) \text{ with } \beta_1^{-1} - \beta_2^{-1} = \frac{(m_1^2 - m_2^2)}{2p^2} \]
`Charmonium-like’ mesons

- Many narrow states discovered in recent years [LHCb, Belle, ...]
- Assignment not clear, hybrids and exotics
- Study states in $p\bar{p}$ annihilation, gluon rich
- ass range beyond PANDA

- Complementary to LHCb, otherwise no competitors for the next at least 10 years
RF-separated beams (>120 GeV)

neg. kaons  \((\sim 8 \times 10^6 / s \text{ in spill})\)

antiprotons  \((\sim 4 \times 10^7 / s \text{ in spill})\)

Drell-Yan
Kaon-induced DY

• Kaon-induced DY is the only source of information on kaon structure
• Compare pion and kaon-induced DY x-sections
• Unpolarised case, possibility to use different nuclear targets (like LH\textsubscript{2}, Al, W, Cu):
  1. Kaon structure functions (PDFs)
  2. Nucleon strange quark structure
  3. Fundamental Lam-Tung relation for the kaon
  4. Boer-Mulders TMDs (quark-spin – quark-\text{k}_T correl.) for kaons
  5. ...
• Unique opportunity
Antiproton-induced Drell-Yan

Model-independent TMD extraction

- TMD (restricted) universality
- TMD-induced asymmetries in both High-Mass and $J/\psi$ regions:
  1. Boer-Mulders (quark-spin – quark-$k_T$ correl.) extraction (CPT)
  2. Transversity extraction
  3. Lam-Tung relation for antiprotons (QCD effects)
  4. Sivers asymmetry (nucleon-spin–quark-$k_T$ correlations) without uncertainty from pion PDFs
  5. Sivers function for gluons ($J/\psi$ regions)
  6. ...
- Unique data
Drell-Yan rates

- Assuming flux of $1 \times 10^7$ /s for kaon/antiproton,
- High mass range $4 < M_{\mu\mu} < 9$ GeV/$c^2$
- 140 days of data taking with the efficiency of 2015 Drell-Yan run assuming a flux of $1 \times 10^7$ /s for kaons/antiprotons
- The overall gain for RF-separated beams wrt previous experiments is a factor 50 to 100

<table>
<thead>
<tr>
<th>Beam</th>
<th>COMPASS++ (proj.)</th>
<th>NA3</th>
<th>E537</th>
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<tbody>
<tr>
<td></td>
<td>NH3</td>
<td>Al</td>
<td>W</td>
</tr>
<tr>
<td>$K^-$</td>
<td>14’000</td>
<td>2’800</td>
<td>29’600</td>
</tr>
<tr>
<td>$\bar{p}$</td>
<td>15’750</td>
<td>2’750</td>
<td>22’500</td>
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Existing muon beams

Exclusive processes (GPD)
SIDIS with deuteron target

Existing hadron beams
pol. DY with deuteron target
Excl. measurements with transv. polarised target

- Generalised Parton Distribution (GPD) $E$ and access to Orbital Angular Momentum
  - DVCS ($\mu p \uparrow \rightarrow \mu p \gamma$)
  - DVMP ($\mu p \uparrow \rightarrow \mu p (\omega) \gamma$)
- Recoil detector to be inserted into the PT magnet
  - Several options being studied
- unique kinematic range, small $x$
Deuteron transversity and TMDs (SIDIS)

- Only existing deuteron/neutron data sets:
  - COMPASS ($^6$LiD) and CLAS ($^3$He)
- COMPASS data only from 2002–2004
- Data set factor 4 smaller than proton set
- For flavour separation equal statistics is optimal

![Graphs showing transversity PDFs](image)

*Fig. 6:* $xh_T^p(x)$ (left) and $xh_T^d(x)$ (right) from the ‘two hadron’ asymmetries of 2010 proton and of 2002-2004 deuteron data (from[30]). The curves show the transversity PDFs obtained from a fit of Collins asymmetries [29]
Pion-induced Drell-Yan ($^6$LiD, LH$_2$)

- Pol. proton DY data in 2015/2018
- Pol. deuteron DY data needed for flavour separation of PDFs
- Shorter run with unpolarised LH2 target is required
  - to test fundamental Lam-Tung relation
  - to extract Boer-Mulders TMD using “clean” (no nuclear effects) LH target – complementary to SIDIS.
- Simulation for 140 days of beam:

Unique, no competitors
Astrophysics – search for dark matter, possible contribution from COMPASS

- New AMS(2) data – the antiparticle flux is well known now (few % pres.);
- Two types of processes contribute – SM interactions (proton on the ISM with the production for example antiprotons in the FS.) and contribution from dark matter annihilation;
- In order to detect a possible excess in the antiparticle flux a good knowledge of inclusive cross sections of p-He interaction with antiparticles in the FS is a must, currently the typical precision is of 30-50%.

Thus the primary goal is to measure inclusive antiproton (positron, gamma) production cross section in a wide kinematical range with the precision <10%. Compared to NA49 COMPASS has factor ~1000 in luminosity. COMPASS:
- Proton beam energy range 50-250 GeV
- Secondary particles identification:
  - Antiprotons (RICH)
  - Positrons and Gamma (ECals)
Outlook

• Many open questions and important measurements remain on hadron structure and spectroscopy
• The COMPASS spectrometer is a unique facility and well adapted to the proposed measurements
• Upgrades in various places are inevitable for a 7–8 year programme after 2020
• An extended collaboration has to be built on the COMPASS nucleus
• RF-separated kaon and antiproton beams would open a new chapter in structure and spectroscopy studies

M2 muon beam option should be kept if possible