COMPASS++/AMBER
A New QCD Facility at the M2 Beam Line of the CERN SPS

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Garching, Germany

12th International Workshop on the Physics of Excited Nucleons
Bonn University, 14. June 2019
The M2 Beam Line at the CERN SPS

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The M2 Beam Line at the CERN SPS
Flux of Secondary Hadron Beams

Typical SPS supercycle
- 10 s pulse length
- 48 s cycle duration
The COMPASS QCD Facility at the M2 Beam Line
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Common Muon and Proton Apparatus for Structure and Spectroscopy

≈ 220 physicists, 24 institutions, 12 countries + CERN
The COMPASS QCD Facility at the M2 Beam Line
Versatile Experimental Setup

- **Large-acceptance** two-stage spectrometer
- **Precise tracking** ($\approx 350$ planes) and **PID** (CEDAR, RICH, calorimeters, muon system)

- Various targets
  - Polarized solid-state NH$_3$ or $^6$LiD
  - Liquid H$_2$
  - Solid-state nuclear targets (e.g. Ni, W, Pb)
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### Chiral dynamics
- $\pi^\pm$ polarizabilities
- Chiral anomaly $F_{3\pi}$

### Hadron spectroscopy
- Excitation spectrum of hadrons
- Exotic hadrons

### Nucleon structure
- Helicity and transversity PDFs
- $k_\perp$-dependent PDFs
- Generalized PDFs

**$\pi\gamma$ reactions (Primakoff)**

```
\begin{align*}
\pi^- & \rightarrow \pi^- \\
\gamma^* & \rightarrow \gamma \\
\gamma & \rightarrow Q^2 \\
Z & \rightarrow Z \\
\end{align*}
```

Boris Grube, TU München

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Diffraction
- $h_{\text{beam}}$
- Target
- Recoil
- $h_1$
- $n$
- $P$, $R$
- $X$
The COMPASS QCD Facility at the M2 Beam Line
Broad Physics Program

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**Polarized SIDIS**

**Polarized Drell-Yan**
Great variety of planned measurements addressing fundamental QCD questions

**Phase 1:** after Long Shutdown 2 of LHC (2022 to 2024)
- Elastic $\mu p$ scattering: precision measurement of proton charge radius
- Drell-Yan and charmonium production: determination of pion PDFs
- Measurement of $p$-induced $\bar{p}$ production cross sections for indirect dark matter searches

**Phase 2:** after Long Shutdown 3 of LHC (from 2026 on)
- RF-separated kaon and antiproton beams
- Kaon diffraction: high-precision kaon spectroscopy
- $K$-induced Drell-Yan, charmonium, and prompt-photon production: determination of kaon PDFs
- $K$-induced Primakoff reactions: electric polarizability of the kaon
- $\bar{p} + N \uparrow$ Drell-Yan: nucleon transverse-momentum-dependent PDFs
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COMPASS++/AMBER Project

Developed within CERN’s Physics Beyond Colliders (PBC) initiative

- [http://pbc.web.cern.ch](http://pbc.web.cern.ch)
- QCD physics working group
- Conventional beams working group

Embedded into the

- [http://europeanstrategyupdate.web.cern.ch](http://europeanstrategyupdate.web.cern.ch)
- Positive feedback at Granada Symposium in May (project summary available here)
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**Website:** [https://nqf-m2.web.cern.ch](https://nqf-m2.web.cern.ch)

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Proposal for Measurements at the M2 beam line of the CERN SPS
Phase-1: 2022-2024
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Phase 1

Precision Measurement of the Proton Charge Radius
The Proton-Radius Puzzle

Contradictory proton-radius values from finite-size effects in spectroscopy of ordinary and muonic hydrogen.

- slope of form-factor measured in elastic ep scattering.

Graph showing proton charge radius from spectroscopy or ep scattering.
Response of proton to external electromagnetic fields encoded in electric form factor $G_E$ and magnetic form factor $G_M$

$$G_E(Q^2) \approx \frac{G_M(Q^2)}{\mu_p} \approx G_{\text{dipole}}(Q^2) = \frac{1}{\left(1 + \frac{Q^2}{a^2}\right)^2}$$

with $\mu_p = 2.79$ and $a^2 = 0.71 \text{ GeV}^2$

Taylor expansion of $G_E$ for spherically symmetric charge distribution

$$\langle r_E^2 \rangle = -6\hbar \left. \frac{dG_E(Q^2)}{dQ^2} \right|_{Q^2=0}$$

At high energy and low $Q^2$

$$\frac{d\sigma}{dQ^2} \propto G_E^2 + \tau G_M^2 \quad \text{with} \quad \tau = Q^2 / (4m_p^2) \quad \text{small}$$

⇒ contribution from $G_M$ small ⇒ can be modelled
The Proton Charge Radius from Lepton Scattering

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Precision measurement of proton charge radius in high-energy elastic $\mu p$ scattering

- Advantageous/complementary systematics compared to other techniques
- Provides new and independent proton-radius value

Goals
- Cover range $10^{-3} < Q^2 < 0.04 \text{ GeV}^2$
- Statistical precision of 0.01 fm or smaller
- Could rule out lepton-flavor effects as explanation for proton-radius puzzle
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Challenging measurement

- **100 GeV muon beam with high-intensity** \(2 \times 10^6 \text{ s}^{-1}\)
- **High } Q^2 \text{ resolution down to } Q^2 = 10^{-3} \text{ GeV}^2**
  - Simultaneous measurement of scattered muon and recoil proton
  - High-precision forward tracking (MuPix8 silicon pixel detector)
  - Active-target high-pressure (20 bar) hydrogen TPC
Proposal for Measurements at the M2 beam line of the CERN SPS Phase-1: 2022-2024

1.4 m 3.5 m 3.5 m 9 m

PRM-SI01 PRM-SI02 PRM-PHC PRM-SI03 PRM-FI01 PRM-FI02 PRM-FI03

Incident muon Scattered muon Recoil proton

Scintillating-fiber tracker Silicon tracker High-pressure hydrogen time-projection chamber Helium/vacuum beam pipe

2022-2024 PRM SETUP

Scintillating-fiber tracker
GEMs / Pixel-GEMs
Electromagnetic calorimeter
Hodoscope
Magnet
Concrete

SPS M2 beam line

COMPASS spectrometer
(only relevant parts shown)

BMS1 BMS3 BMS4
BMS2

FI01 FI05 FI06 FI07

SM1 FI04

FI08 ECAL

Muon Barrier

Hodoscope

Figure 4: Layout of the experimental setup at the M2 beam line, highlighting the relevant parts of the COMPASS spectrometer and the additional detectors required for the proton radius measurement.
- 1% statistical precision of radius value requires $70 \times 10^6$ elastic events
- Resolution $\Delta Q^2 / Q^2 \approx 15\%$ at $Q^2 = 10^{-3}$ GeV$^2$
Running or Planned Lepton Scattering Experiments

MUSE (PSI)

- Low-energy elastic $\mu p$ scattering
- $E_\mu = 140$ MeV $\Rightarrow$ substantial correction (percent level) due to Coulomb distortion of wave function of non-relativistic muon
- Correction for pion contamination in beam

Electron scattering experiments

- PRad (JLab)
- Two experiments at Mainz Microtron
  1. Initial-state radiation
  2. Simultaneous detection of scattered electron (forward tracker) and recoil proton (active-target TPC)
- Low-energy $ep$ scattering
  - MAGIX at MESA (Mainz)
  - JPARC
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Phase 1

Determination of Pion Parton Distribution Functions
Motivation

- Pion is lightest hadron and Nambu-Goldstone boson of spontaneous breaking of chiral symmetry
- Explaining properties and structure of pion is cornerstone of understanding non-perturbative QCD
- Not enough data to directly constrain all pion PDFs ⇒ need sum rules, models
- More data needed
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GRV: M. Glück et al., ZPC 53 (1992) 651
SMRS: P. J. Sutton et al., PRD 45 (1992) 2349
JAM: P. C. Barry et al., PRL 121 (2018) 152001
Measurement of pion-induced Drell-Yan dimuon production

- **Isoscalar target**: $^{12}$C to minimize nuclear effects
- **$\pi^+$ and $\pi^-$ beams**: separation of valence and sea-quark contributions
  \[
  \Sigma_{\text{val}} = \sigma_{\pi^-} - \sigma_{\pi^+} \quad \text{only valence-valence}
  \]
  \[
  \Sigma_{\text{sea}} = 4\sigma_{\pi^+} - \sigma_{\pi^-} \quad \text{no valence-valence}
  \]

**Goals**
- Collect $10\times$ more data than currently available
- First precise and direct measurement of the sea contribution in the pion
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Goals

• Collect 10× more data than currently available

• First precise and direct measurement of the sea contribution in the pion
- 190 GeV beams $\pi^+$ ($1.7 \times 10^7$ s$^{-1}$) $\pi^-$ ($6.8 \times 10^7$ s$^{-1}$)
- Precise beam tracking and beam PID

- Dedicated vertex detector
- Excellent dimuon mass resolution
- High-efficiency dimuon trigger

The beam enters from the left.
The ratio \( \frac{\Sigma_{\text{sea}}}{\Sigma_{\text{val}}} \) as a function of \( x \), using three different sea-quark distributions from SMRS \cite{48} for two mass ranges. The ratio is also calculated with the sea-quark distribution from JAM \cite{53}, which includes leading-neutron DIS data from ZEUS \cite{51} and H1 \cite{52}. The shown statistical accuracy is expected when using the data-taking conditions presented in the text. The blue shaded area is the uncertainty derived from the statistics quoted in the NA3 paper \cite{37}.

In this expression, \( \text{Acc}(0.4) \) is the geometrical acceptance of the spectrometer for the considered dimuon-mass range, and \( X \) contains the estimated efficiencies of beam extraction (0.85), experiment data-taking availability (0.8), trigger (0.8), CEDARs (0.9) and dimuon offline reconstruction (0.8). The considered values take into account the experience gathered during earlier measurements in fixed-target mode at the SPS M2 beam line. The global efficiency is estimated to be \( \approx 0.16 \).

In order to minimize the systematic uncertainties when evaluating Eqs. 22 and 23, precise cross-section determinations are required. We aim at absolute cross-section measurements at the level of a 3% systematic uncertainty. A cross check of the relative normalisation can be performed by comparing the \( J/\psi \) cross sections for \( \pi^- + p \) and \( \pi^+ + p \), as for isoscalar targets the \( J/\psi \) cross section does not depend on the charge of the incident meson. The cross-section ratio for \( \pi^- + p \)- and \( \pi^+ + p \)-induced \( J/\psi \) production on a platinum target was measured to be \((1.016 \pm 0.006)\) by NA3 \cite{56}.

Figure 11 shows accuracy estimates for the ratio \( \frac{\Sigma_{\text{sea}}}{\Sigma_{\text{val}}} \) as a function of \( x \), in the dimuon mass range \( 4.3 < M_{\mu\mu}/(\text{GeV}/c^2) < 8.5 \), which is a background-free Drell-Yan mass range. The dimuon mass range \( 4.0 < M_{\mu\mu}/(\text{GeV}/c^2) < 8.5 \), accessible with an improved mass resolution thanks to new vertex detectors, is also represented. The curves labelled SMRS represent the predictions \cite{48} for three possible contributions of the sea quarks to the pion momentum, ranging from 10% to 20%. The three different assumptions for the pion sea yield increasingly different predictions for \( x \) values below 0.5. The shaded area represents the uncertainty band on the sea distribution as estimated from the sea-valence separation of NA3 that is based solely on their own data.

In Tab. 4, the achievable statistics for a running period of two years, i.e. 2140 days is compared to the Drell-Yan statistics of earlier experiments. In the experimental conditions assumed above, the sea contribution to the pion momentum could be evaluated with an accuracy better than 5%.

\[
\begin{align*}
\Sigma_{\text{val}} &= \sigma_{\pi^-} - \sigma_{\pi^+} \\
\Sigma_{\text{sea}} &= 4\sigma_{\pi^+} - \sigma_{\pi^-}
\end{align*}
\]

- \( \approx 25\,000 \) Drell-Yan events
- Dimuon mass resolution \( \approx 100 \text{ MeV} \)
  - Extension of analyzed range to \( 4.0 < M_{\mu\mu} < 8.5 \text{ GeV} \) possible
  - 35\% larger sample

SMRS: P. J. Sutton \textit{et al.}, PRD 45 (1992) 2349
JAM: P. C. Barry \textit{et al.}, PRL 121 (2018) 152001
Study of charmonium production

- Drell-Yan samples
  - $\pi + C$: $1.2 \times 10^6 \ J/\psi$
  - $\pi + W$: $0.75 \times 10^6 \ J/\psi$
  - Similar amounts for $p + C$ and $p + W$
  - $\psi(2S)$ cross section $10 \times$ lower

- Low-$p_T$ region dominated by $q\bar{q}, gg \to J/\psi$

- Polarization of colliding partons directly transferred to $J/\psi$

- Test theory of quarkonium production in low-$p_T$ domain
  - Verify hadronization model
  - Constrain pion PDFs
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V. Cheung et al., PRD 98 (2018) 114029
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V. Cheung et al., PRD 98 (2018) 114029
Study of nuclear dependence

- **Open question:** flavor dependence of modification of nuclear PDFs w.r.t. nucleon PDFs
- **Ideal tool:** Drell-Yan dimuon production with $\pi^+$ and $\pi^-$ beams

P. Paakkinen *et al.*, PLB 768 (2017) 7

nCTEQ15: K. Kovarik *et al.*, PRD 93 (2016) 085037

EPS09: K. Eskola *et al.*, JHEP 04 (2009) 065
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![Graph showing comparison of nCTEQ15 and EPPS16 with projections for 280 days on C-target.](image)

nCTEQ15: K. Kovarik *et al.*, PRD **93** (2016) 085037

EPPS16: K. Eskola *et al.*, EPJC **77** (2017) 163
Phase 1

Measurement of $p$-Induced $\bar{p}$ Production Cross Section
Measurement of $p$-induced $\bar{p}$ production cross section

- AMS-02: precise data on cosmic antiparticle flux
- Sources: standard model processes and annihilation of dark matter particles
- Limiting factor: prediction of standard model contribution to antiproton flux
  - Dominant processes: $\bar{p}$ production in scattering of $p$ and $^4$He
- $p + p \rightarrow \bar{p} + X$ cross section: several measurements
- $p + ^4$He $\rightarrow \bar{p} + X$ cross section: only LHCb at 4 TeV and 6.5 TeV
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Goals

- Measure cross section for $p + p$ and $p + ^4$He $\rightarrow \bar{p} + X$ in 10 bins in $\bar{p}$ momentum and rapidity
- Statistical uncertainty of $\approx 0.5\%$ per data point
- **Systematic uncertainty** $\approx 5\%$
- $p$ beam energies: 60, 100, 150, 200, and 280 GeV
Phase 2

Large Variety of Proposed Measurements
**Proposed COMPASS++/AMBER Phase-2 Measurements**

### Pion beam
- Direct measurement of $\pi^0$ lifetime
- Color-screening effects in vector-meson production off nuclei

### Muon beam and transversely polarized target
- Measurement of GPD $E$ in deeply virtual Compton scattering
- Measurements of deeply virtual exclusive meson production

### Low-energy antiproton beam
- Heavy-quark meson spectroscopy

### RF-separated antiproton beam
- Drell-Yan with transversely polarized target: nucleon transverse-momentum-dependent PDFs

### RF-separated kaon beam
- Drell-Yan, charmonium, and prompt-photon production: determination of kaon PDFs
- Primakoff reactions: electric polarizability of the kaon
- Color-screening effects in strange vector-meson production off nuclei
- Kaon diffraction: high-precision kaon spectroscopy
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### RF-separated antiproton beam
- Drell-Yan with transversely polarized target: nucleon transverse-momentum-dependent PDFs

### RF-separated kaon beam
- Drell-Yan, charmonium, and prompt-photon production: determination of kaon PDFs
- Primakoff reactions: electric polarizability of the kaon
- Color-screening effects in strange vector-meson production off nuclei
- Kaon diffraction: high-precision kaon spectroscopy
Proposed COMPASS++/AMBER Phase-2 Measurements

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RF-Separated Kaon and Antiproton Beams
Panofsky-Schnell Method

P. Bernard et al., CERN-1968-029

Beam momentum limited by length of beam line

Estimated intensities
- Kaon: $5 \times 10^6 \text{ s}^{-1}$
- Antiproton: $5 \times 10^7 \text{ s}^{-1}$

More detailed studies needed to determine beam parameters more precisely

Requires major investment
RF-Separated Kaon and Antiproton Beams
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Kaon

Antiproton

$p$ [GeV/c]  

$L$ [km]
PDG 2016: 25 kaon states below 3.1 GeV/$c^2$

- Only 12 kaon states in summary table, 13 need confirmation
- Most PDG entries more than 30 years old
- Since 1990 only 4 kaon states added to PDG (only 1 to summary table)

Mass [GeV/$c^2$]

[Courtesy S. Wallner, TUM]
Example: Diffractive Production of $K^−\pi^+\pi^−$ Final State

$K^-_{\text{beam}} \rightarrow X^- \rightarrow X^- (\pi^+\pi^-)$

$P \rightarrow K^-_{\text{beam}} p \rightarrow p_{\text{target}} p_{\text{recoil}}$

COMPASS

$0.07 < t' < 0.7 \ (\text{GeV}/c)^2$

WA03 (CERN)

$0 < t' < 0.7 \ (\text{GeV}/c)^2$

Events / 10 $[\text{MeV}/c^2]$

COMPASS 2008 negative hadron beam

$K^- p \rightarrow K^- \pi^+ \pi^- p_{\text{recoil}}$

Acc not acceptance corrected

$K_1(1270)$ $K_1(1400)$ $K_2(1770)$

ACCMOR, NPB 187 (1981) 1
**Example: Diffractive Production of** \( K^- \pi^+ \pi^- \) **Final State**

\[ K^-_{\text{beam}} \rightarrow X^- \rightarrow K^-\pi^+\pi^- \rightarrow p_{\text{target}} \rightarrow p_{\text{recoil}} \]

**COMPASS data**
- Only subset of available sample
- Total sample \( \approx 700,000 \) events
  - (3.5 \( \times \) WA03)

**COMPASS**
\[ 0.07 < t' < 0.7 \ (\text{GeV/c})^2 \]

**Events / 10 [MeV/c]^2**

- \( K_1(1270) \)
- \( K_1(1400) \)
- \( K_2(1770) \)
**Example: Diffractive Production of $K^- \pi^+ \pi^-$ Final State**

![Diagram](image)

**COMPASS++/AMBER goal**

- $> 10 \times 10^6$ $K^- \pi^+ \pi^-$ events
- Apply partial-wave analysis methods developed for COMPASS
- High-precision kaon spectroscopy
  - Complete flavor multiplets
  - Look for partners of non-strange exotic states

**(x10^3) COMPASS 2008 negative hadron beam $K^- p \rightarrow K^- \pi^+ \pi^- p_{\text{recoil}}$ not acceptance corrected**

**Events / 10 [MeV/c^2]**

- $K_1(1270)$
- $K_1(1400)$
- $K_2(1770)$

**$0.07 < t' < 0.7$ (GeV/c)^2**

**Graph:**

- $M(K^- \pi^+ \pi^-)[GeV/c^2]$ range from 0.5 to 2.5
- Graph showing distribution of events for various masses.

**Graph legend:**

- Preliminary
3 Measurements proposed for phase 1 (2022-24)

1. Proton radius in high-energy muon-proton scattering
2. Pion PDFs in pion-induced Drell-Yan
3. Antiproton production in $pp$ and $p$He collisions

- Formation of a new collaboration is on track
- Various hardware developments and upgrades are ongoing

Phase 2 (after LS3)

- Broad physics program using conventional and RF-separated beams

New ideas and collaborators are welcome!

https://nqf-m2.web.cern.ch
A New QCD Facility at the M2 Beam Line of the CERN SPS

3 Measurements proposed for phase 1 (2022-24)

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https://nqf-m2.web.cern.ch
Spares
PBC-QCD

all starting dates are "estimated earliest running"

future facilities (selection)

M2 beamline

H2 beamline

ECN 3 cavern: presently used by NA62
Proton radius measurement from muon-proton high-energy scattering

- contradictory findings for the proton radius 0.84…0.88 fm from different experimental and theoretical approaches on the 5% level
- direct determination as slope of the electric form factor $G_E$ at $Q^2$ near zero
- proposed experiment reaches a precision 0.01 fm
- competitive to JLab, MAMI, MUSE

Figure 2: Compilation of the proton radius puzzle, figure taken from [7].
New hardware: The active-target TPC for the proton radius measurement

Figure 45: Engineering design for the four-cell hydrogen TPC.
Test in 2018 for Proton Radius measurement

Test setup during 2018 DY run downstream COMPASS, check
• TPC operation in muon beam ✅
• vertex reconstruction with silicon telescopes ✅
• coincidence detection of scattered muon and recoiling proton ✅

ongoing analysis
Ring energies — matched events

Ring 1 & 2 energies (data + simulation)
Mass spectrum

Background less than 4% in $4.3 < M_{\mu\mu}/(\text{GeV}) < 8.5$
What do we know about kaon structure?

Sole measurement from NA3
J. Badier et al., PLB93 354 (1984)

- Limited statistics: 700 events with $K^-$
- Sensitivity to $SU(3)_f$ breaking
- Mostly only model predictions

Interesting observation: At hadronic scale gluons carry only 5% of $K$'s momentum vs $\sim 30\%$ in $\pi$

- Scarce data on $u$-valence
- No measurements on gluons
- No measurements on sea quarks

How to improve the situation?
Kaon RF separated

**DY cross-section**

- Highest beam energy to access low $x$
- Highest beam energy to increase signal/bgd ratio
- Favorable also COMPASS-like apparatus

**Prompt photon cross-section**

- $p_T > 2.5 \text{ GeV/c}$
- $q\ g \rightarrow q\ g$ for $K^0$, $K^-$
- $q\bar{q} \rightarrow g\ g$ for $K^+$

Vincent Andrieux (UIUC/CERN)  
Trento Sep-2018
Projections for Kaon structure

- More data points and more precise compared to NA3
- Discriminating power between models
- 1 year with $2 \times 10^7$ s$^{-1}$ 100 GeV $K^-$ beam
- $\pi$ taken simultaneously

**Unique and Promising**
So far, I talked only about mesons but what about the nucleon? At LO QCD, the nucleon can be decomposed into 8 twist-2 TMD PDFs.

Using a transversally polarised target, one can access in SIDIS as well as in Drell-Yan:

- Sivers
- Transversity
- Pretzelosity
Drell-Yan and SIDIS cross-section modulations

SIDIS:

\[
\frac{d\sigma}{dxdydzd\phi d\phi_h dP^2_{hT}}_{\text{LO}} = \frac{\alpha^2}{xyQ^2} \frac{y^2}{2(1-\epsilon)} \left( 1 + \frac{\epsilon y^2}{2x} \right) \sigma_U \left\{ 1 + \epsilon A_{UU}^{\cos(2\phi_h)} \cos(2\phi_h) \right. \\
+ S_T \left[ A_{UT}^{\sin(\phi_h - \phi_s)} \sin(\phi_h - \phi_s) + \epsilon A_{UT}^{\sin(\phi_h + \phi_s)} \sin(\phi_h - \phi_s) \right. \\
+ \left. \epsilon A_{UT}^{\sin(3\phi_h - \phi_s)} \sin(3\phi_h - \phi_s) \right] \\
+ \left. S_T P_I \left[ \sqrt{1 - \epsilon^2 \cos(\phi_h - \phi_s)} A_{LT}^{\cos(\phi_h - \phi_s)} \right] \right\}
\]

DY:

\[
\frac{d\sigma}{d^4q d\Omega} \text{LO} = \frac{\alpha^2}{F q^2} \sigma_U \left\{ \left( 1 + \cos^2(\theta) + \sin^2(\theta) A_{UU}^{\cos(2\phi)} \cos(2\phi) \right) \right. \\
+ S_T \left[ (1 + \cos^2(\theta)) A_{UT}^{\sin(\phi_s)} \sin(\phi_s) \right. \\
+ \left. \sin^2(\theta) \left( A_{UT}^{\sin(2\phi + \phi_s)} \sin(2\phi + \phi_s) + A_{UT}^{\sin(2\phi - \phi_s)} \sin(2\phi - \phi_s) \right) \right] \right\}
\]
Synergy DY vs SIDIS

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TMD PDFs are universal but final state interaction (SIDIS) vs. initial state interaction (DY) → Sign flip for naive T-odd TMD PDFs

$\begin{align*}
 f^q_{1,T} \big|_{\text{SIDIS}} &= -f^q_{1,T} \big|_{\text{DY}} \\
 h^\perp_{1} \big|_{\text{SIDIS}} &= -h^\perp_{1} \big|_{\text{DY}}
\end{align*}$

Crucial test of TMD framework in QCD
Existing beam line, antiproton-enriched beam
Charmonium-like mesons

M2 SPS beam line has to be retuned to extract
Antiproton beam (momentum ~ 20 GeV)

Method: antiproton-proton annihilation

Goal: charmed hybrids and exotics study in the mass range higher than reachable in PANDA

Complementary to LHCb
(p-pbar annihilation – gluon rich environment and it allows high spin states)
Otherwise no competitors for the next at least 10 years
more new planned hardware

- silicon pixel detectors
- upgrades: large-area pixelGEM and MPGD
- CEDARs at high rates
- Beam Momentum Station for proton radius measurement
- elastic muon-scattering with SciFi detectors
New ideas for silicon detectors ready for continuous readout – Igor and team

Silicon prototype (MuPix8)

- 80 x 80 μm² pixel size
- 17 x 10 mm² active area
- 128 x 200 pixels
- 3 matrix partitions
- Test setup available in Munich
- Under construction

C. Dreisbach (christian.dreisbach@cern.ch) - Proton Radius Meeting, 23. January 2019
QCD facility – future fixed target experiment at M2
Spectrometer upgrades

- New type of FEE and trigger logic compatible with trigger-less readout
  - FPGA-based TDC with time resolution down to 100 ps (iFTDC)
- Higher trigger rates: 90-200 kHz (factor of 2.5-5)
- Digital trigger
- First tests in 2018

General upgrades of COMPASS-II apparatus:
- New large-size PixelGEMs
- GEMs or Micromegas to replace aging MWPCs
- High-aperture “RICH0” for some programs, p < 10-15 GeV?

Could be Large-Area Picosecond Photo-Detectors based on micro-channel plates with time resolution < 50 ps, spatial resolution ~ 0.5 mm. LAPPD™ by IncomInc.
- High-rate-capable CEDARs for beam PID for all hadron programs.

Proton radius:
- High-pressure active TPC target or hydrogen tube surrounded by SciFi, 4-8 layers with U/V projections
- SciFi trigger system on scattered muon
- Silicon trackers
QCD facility – future fixed target experiment at M2
Spectrometer upgrades

Drell-Yan general:
- High-purity and efficiency di-muon trigger
- Dedicated precise luminosity measurement
- Dedicated vertex-detection system
- Beam trackers

Drell-Yan RF separated beams:
- Due to lower beam energy, need wide aperture ± 200 mrad
- High-rate and high-multiplicity capability
- Active absorber (magnetic field, calorimetry?)
- TPCs?
- GEMs?

Prompt Photons
- Shielder
(20-30 cm steel)
upstream of target
- New hodoscope upstream of ECAL0
- Transparent setup

Anti-matter cross section
- LH2 and LHe targets
- RICH0 for lower momentum to ID anti-protons?

Spectroscopy with low-energy anti-p:
- RICH & CEDAR, RICH0 for low p?
- Target spectrometer (tracking, barrel calorimeter) similar to WASA

Spectroscopy with high-energy K—:
- RICH & CEDAR
- Uniform acceptance, ECals
- Good vertexing
- Recoil TOF detector
Improvement of acceptance

Requirements: Active absorber
- Trackers
- Magnetic field
- Good resolution for vertexing
- Large area
- Capability to collect $e^+e^-$ DY pairs

Initial detector consideration:
Combination of
- Baby-Mind detector
  M. Antonova et al. arXiv:1704.08079
- W-Si detectors, a la BNL

AnDY Phenix MPCEX Phenix NCC