Outline

1. New QCD Facility at CERN SPS (COMPASS++/AMBER)
   • Web page
   • Summary for ESPP
   • LoI submitted
   • Physics
   • Community
2. PBC QCD summary
3. Proton radius – first results of 2018 beam test
4. Next steps
5. Summary
COMPASS QCD facility at SPS M2 beam line (CERN) (secondary hadron and lepton beams)

Exotic states, chiral dynamics

COMPASS-I
1997-2011

Hadron Spectroscopy & Polarisability

COMPASS-II
2012-2020

Polarised SIDIS

3D hadron structure, Proton spin decomposition (spin crisis)

Polarised Drell-Yan

DVCS (GPDs) + unp. SIDIS

Exotic states, chiral dynamics
Welcome

Over the past four decades, measurements at the external beam lines of the CERN SPS have been at the center of worldwide attention. These experimental results have challenged QCD as our theory describing visible matter, thus serving as important input to develop improvements of the theory.

As of today, these beam lines remain unique and bear great potential for a significant future advancement of our understanding of hadronic matter. Hence we propose to establish a world-unique QCD facility that will use the external SPS M2 beam line in conjunction with a universal spectrometer in the experimental hall EHN2. After a major upgrade in a second phase, it will be possible to produce unique beams with considerably enhanced fractions of kaons or anti-protons, thereby opening access to a wide range of new physics opportunities.

The Letter of Intent available on this site is summarizing most of the present ideas for possible future measurements to be performed at the CERN M2 beam line. It was prepared with the objective to serve as a basis for building a broad community dedicated to these new studies. During the forthcoming year the document is expected to evolve towards a full proposal for a new experimental facility. It is planned to be ready in time for the 2019/2020 Update of the European Strategy for Particle Physics.
Workshops

List of workshops where a New QCD facility at the M2 beam line of the CERN SPS was discussed.

10. **Mapping Parton Distribution Amplitudes and Functions", ECT***
        - Studying meson and proton structure at the CERN M2 beam line, V. Andrieux [https://indico.ectstar.eu/event/22/contributions/502/attachments/390/535/Andrieux_Trento10092018.pdf](https://indico.ectstar.eu/event/22/contributions/502/attachments/390/535/Andrieux_Trento10092018.pdf)

9. **MiniWorkshop on A New QCD Facility at the SPS (CERN) after 2021**
    20. 6. 2018, CERN, [https://indico.cern.ch/event/737176/](https://indico.cern.ch/event/737176/)

8. **PBC Working Group Meeting**
        - O. Denisov for the LoI group
        [https://indico.cern.ch/event/706741/contributions/2938769/attachments/1668114/2674995/PBC_2018_06_14_Oleg.pdf](https://indico.cern.ch/event/706741/contributions/2938769/attachments/1668114/2674995/PBC_2018_06_14_Oleg.pdf)

7. **IWHSS’18 Workshop**
    19. 3. 2018 - 21. 3. 2018, Bonn, Germany, [https://indico.cern.ch/event/658983/](https://indico.cern.ch/event/658983/)
Timelines

Timelines for LoI submission to the SPSC and timelines for Proposal preparation

- End of July 2018: LoI available worldwide, start of the promotion campaign. The goal is threefold:
  - to advertise the project and to win new collaborators
  - to collect new ideas
  - to establish the priority list of all possible experiments
- In parallel start of the Proposal preparation and New Collaboration formation
- Beginning of January 2019: LoI submission to the SPSC
A New QCD Facility at the M2 beam line of the CERN SPS

Document for the 2020 update of the European Strategy for Particle Physics

Abstract
This document summarises the physics interest, sensitivity reach and competitiveness of a future general-purpose fixed-target facility for Particle Physics research. Based upon the versatile M2 beam line of the CERN SPS, a great variety of measurements is proposed to address fundamental issues of Quantum Chromodynamics. In phase-1 of the project, operating with muons a complementary result on the average charged proton radius will be obtained and the elusive General Parton Distribution function $E$ can be accessed, operating with pions the quark structure of the pion will be revealed, operating with antiprotons completely new results in the search of exotic XYZ states are expected, and operating with protons the antiproton production cross section will be measured as important input for future Dark Matter searches. Upgrading the M2 beam line in phase-2 of the project will provide unrivalled radio-frequency separated high-intensity and high-energy beams. Operating with kaons the virgin field of high-precision strange-meson spectroscopy becomes accessible, the Primakoff process will be used for a first measurement of the kaon polarisability, and the Drell-Yan process opens access to the
A New QCD facility at the M2 beam line of the CERN SPS

Letter of Intent:
A New QCD facility at the M2 beam line of the CERN SPS

COMPASS++\textsuperscript{f}/AMBER\textsuperscript{f}

B. Adams\textsuperscript{13,12}, C.A. Aidala\textsuperscript{1}, R. Akhunzyanov\textsuperscript{14}, G.D. Alexeev\textsuperscript{14}, M.G. Alexeev\textsuperscript{41}, A. Amoroso\textsuperscript{41,42},
The content of the LoI has been reported at several PBC meetings in 2016, 2017 and 2018. 10 projects for the moment, at first stage we are going to use available hadron/muon beam, at the second – RF separated kaon and antiproton beam. All beams we are going to use are unique worldwide.
It is difficult to give exact cost estimate right now: it stays in the range 10-20 MCHF
<table>
<thead>
<tr>
<th>Program</th>
<th>Physics Goals</th>
<th>Beam Energy [GeV]</th>
<th>Beam Intensity [s^{-1}]</th>
<th>Trigger Rate [kHz]</th>
<th>Beam Type</th>
<th>Target</th>
<th>Earliest start time, duration</th>
<th>Hardware Additions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu p$ elastic scattering</td>
<td>Precision proton-radius measurement</td>
<td>100</td>
<td>$4 \cdot 10^6$</td>
<td>100</td>
<td>$\mu^\pm$</td>
<td>high-pr. H2</td>
<td>2022 1 year</td>
<td>active TPC SciFi trigger silicon veto</td>
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<tr>
<td>Hard exclusive reactions</td>
<td>GPD $E$</td>
<td>160</td>
<td>$10^7$</td>
<td>10</td>
<td>$\mu^\pm$</td>
<td>NH$_3^\uparrow$</td>
<td>2022 2 years</td>
<td>recoil silicon, modified PT magnet</td>
</tr>
<tr>
<td>Input for DMS</td>
<td>$\bar{p}$ production cross-section</td>
<td>20-280</td>
<td>$5 \cdot 10^5$</td>
<td>25</td>
<td>$p$</td>
<td>LH$_2$, LHe</td>
<td>2022 1 month</td>
<td>LHe target</td>
</tr>
<tr>
<td>$\bar{p}$-induced Spectroscopy</td>
<td>Heavy quark exotics</td>
<td>12, 20</td>
<td>$5 \cdot 10^7$</td>
<td>25</td>
<td>$\bar{p}$</td>
<td>LH$_2$</td>
<td>2022 2 years</td>
<td>target spectr.: tracking, calorimetry</td>
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<tr>
<td>Drell-Yan</td>
<td>Pion PDFs</td>
<td>190</td>
<td>$7 \cdot 10^7$</td>
<td>25</td>
<td>$\pi^\pm$</td>
<td>C/W</td>
<td>2022 1-2 years</td>
<td></td>
</tr>
<tr>
<td>Drell-Yan (RF)</td>
<td>Kaon PDFs Nucleon TMDs</td>
<td>$\sim 100$</td>
<td>$10^8$</td>
<td>25-50</td>
<td>$K^\pm, \bar{p}$</td>
<td>NH$_3^\uparrow$, C/W</td>
<td>2026 2-3 years</td>
<td>“active absorber”, vertex det.</td>
</tr>
<tr>
<td>Primakoff (RF)</td>
<td>Kaon polarizability &amp; pion life time</td>
<td>$\sim 100$</td>
<td>$5 \cdot 10^6$</td>
<td>$&gt; 10$</td>
<td>$K^-$</td>
<td>Ni</td>
<td>n/e 1 year</td>
<td></td>
</tr>
<tr>
<td>Prompt Photons (RF)</td>
<td>Meson gluon PDFs</td>
<td>$\geq 100$</td>
<td>$5 \cdot 10^6$</td>
<td>10-100</td>
<td>$K^\pm, \pi^\pm$</td>
<td>LH$_2$, Ni</td>
<td>n/e 2026 1-2 years</td>
<td>hodoscope</td>
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<tr>
<td>$K$-induced Spectroscopy (RF)</td>
<td>High-precision strange-meson spectrum</td>
<td>50-100</td>
<td>$5 \cdot 10^6$</td>
<td>25</td>
<td>$K^-$</td>
<td>LH$_2$</td>
<td>2026 1 year</td>
<td>recoil TOF forward PID</td>
</tr>
<tr>
<td>Vector mesons (RF)</td>
<td>Spin Density Matrix Elements</td>
<td>50-100</td>
<td>$5 \cdot 10^6$</td>
<td>10-100</td>
<td>$K^\pm, \pi^\pm$</td>
<td>from H to Pb</td>
<td>2026 1 year</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Requirements for future programs at the M2 beam line after 2021. **Standard muon beams** are in blue, **standard hadron beams** in green, and **RF-separated hadron beams** in red.
Two stages program:
First stage (shorter term) – existing extracted beams
Second stage (longer term) – RF-separated extracted kaon and antiproton beams


a.) Standard muon beam:
   - 1. DVCS with trans. polarised proton target
   - 2. Proton radius measurement in elastic muon proton scattering

b.) Standard hadron beam:
   - 1. Unpolarised DY with various targets
   - 2. Absolute cross-section measurements p + He -> pbar X
   - 3. Hadron spectroscopy with antiproton beam

Longer term (New RF-separated beam will be ready ≥ 2026):

- 1. Hadron spectroscopy
- 2. Drell-Yan physics
- 3. Primakoff with kaon beam
- 4. Direct Photons with kaon beam
All in All:

we have for the moment 15 new groups (wrt COMPASS II) signed the LoI, among them there are 5 groups form USA (Georgia State Uni., Los Alamos NL, Uni. Of Chicago, Uni. Of Michigan, Stony Brook Uni.).
In 2019 we expect some more USA groups (2-3) to join the project.

Apart of that we have 4 more new countries: Armenia (1), Belarus (1), China (2) and Kazakhstan (1), so we have widen our geography.

The total number of authors (PhD students and higher) is 267.

According to our experience in order to carry out the research program depicted in LoI the collaboration of 250-300 physicists would be adequate.
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Proton Radius measurement

Physics case: determine the proton radius in high-energy muon-proton scattering

- elastic $\mu p$ scattering at low $Q^2$
- key advantages over $ep$
  - measure electric form factor $G_E$, essentially no contribution from magnetic one $G_M$ (high $E$)
  - much smaller QED rad. corr. (muon mass)
- remains: theory uncertainty from fitting the form factor slope

- 100 GeV SPS M2 muon beam
- high-pressure hydrogen TPC active-target cell (PNPI development)
- measure cross-section shape over broad $Q^2$ range $10^{-4} ... 10^{-1}$
- fit from $10^{-3} ... 2 \times 10^{-2}$ the proton radius (slope of electric form factor)
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 ✓
Test in 2018 for Proton Radius measurement

- demonstrated the measurement principle employing the active TPC and silicon detectors
- $Q^2$ range was limited by geometry
  - lower limit ca. $3 \times 10^{-3}$ due to short SI detector baseline and high beam energy (ca. 180 GeV)
  - upper limit ca. $6 \times 10^{-3}$ due to proton range in 8bar $H_2$
- observed event rate and structure roughly within expectations, calibrations and data analysis ongoing

a hot physics topic – this experiment should run in 2022 at M2 and needs soon CERN support statement for realization
Timelines

• LoI is submitted to SPSC, would be very useful to have a statement and encouragement to proceed with Proposal preparation

• The intention is to have a first draft of the Proposal ready by the end of 2019

• Proposal submission to SPSC – May 2019
SUMMARY

1. Existing SPS extracted hadron/lepton beams are unique worldwide, RF separated beam option is unique as well

2. Physics case for the new QCD facility is there

3. Community is there

4. Work on full scale Proposal is started
Thank you!