COMPASS++/AMBER
Outcome of the 2020 update of the European Strategy for Particle Physics

Perceiving the Emergence of Hadron Mass through AMBER@CERN, CERN, e-conference, Aug. 6-7 2020
Outline

1. Intro/LoI COMPASS++/AMBER
2. COMPASS++/AMBER Physics case:
   • Emergence of the hadronic mass (meson structure)
   • Proton spin structure
3. Physics Beyond Colliders at CERN initiative – a part of the European Strategy for Particle Physics Update process
4. Outcome of the PBC as reported to the final ESPP Granada May 2019 open meeting
6. Outcome of the ESPP update
7. Summary
We have started to work on physics program of possible COMPASS successor ~ 10 years ago, A Number of Workshops has been organized, for detail see COMPASS++/AMBER web page: https://nqf-m2.web.cern.ch/

http://arxiv.org/abs/1808.00848
Apparatus for Meson and Baryon Experimental Research > 270 authors
COMPASS++/AMBER
A New QCD Facility at CERN SPS M2 beam line

<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>muon-proton elastic</td>
<td>Precision proton-radius measurement</td>
<td>100</td>
<td>4 - 10⁶</td>
<td>100</td>
<td>$\mu^\pm$</td>
<td>high-pressure H2</td>
<td>2022 1 year</td>
<td>active TPC, SciFi trigger, silicon veto, recoil silicon, modified polarised target magnet</td>
</tr>
<tr>
<td>Hard exclusive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reactions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional muon/hadron M2 beams</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Requirements for future programmes at the M2 beam line after 2021. Muon beams are in blue, conventional hadron beams in green, and RF-separated hadron beams in red.
## COMPASS++/AMBER PHASE-1

<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>Muon-proton elastic scattering</td>
<td>Precision proton-radius measurement</td>
<td>100</td>
<td>4 - $10^6$</td>
<td>100</td>
<td>$\mu^\pm$</td>
<td>H2</td>
<td>2022 1 year</td>
<td>active TPC, SciFi trigger, silicon veto, recoil silicon, modified polarised target magnet</td>
</tr>
<tr>
<td>Hard exclusive reactions</td>
<td>GPD $E$</td>
<td>160</td>
<td>2 - $10^3$</td>
<td>10</td>
<td>$\mu^\pm$</td>
<td>NH$_1$</td>
<td>2022 2 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>20-280</td>
<td>5 - $10^3$</td>
<td>25</td>
<td>$\rho$</td>
<td>LH$_2$, LH$_e$</td>
<td>2022 1 month</td>
<td>liquid helium target</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12, 20</td>
<td>5 - $10^3$</td>
<td>25</td>
<td>$\bar{\rho}$</td>
<td>LH$_2$</td>
<td>2022 2 years</td>
<td>target spectrometer, tracking, calorimetry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>190</td>
<td>7 - $10^3$</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 &amp; Nucleon TMDs</td>
<td>~100</td>
<td>10$^8$</td>
<td>25-50</td>
<td>$K^\pm$, $\pi^\pm$</td>
<td>NH$_1$, C/W</td>
<td>2026 2-3 years</td>
<td>&quot;active absorber&quot;, vertex detector</td>
</tr>
<tr>
<td></td>
<td>Kaon polarisability &amp; pion life time</td>
<td>~100</td>
<td>5 - $10^6$</td>
<td>&gt; 10</td>
<td>$K^-$</td>
<td>Ni</td>
<td>non-exclusive 2026 1 year</td>
<td></td>
</tr>
<tr>
<td>Prompt Photons (RF)</td>
<td>Meson gluon PDFs</td>
<td>$\geq$ 100</td>
<td>5 - $10^6$</td>
<td>10-100</td>
<td>$K^\pm$, $\pi^\pm$</td>
<td>LH$_2$, Ni</td>
<td>non-exclusive 2026 1-2 years</td>
<td>hodoscope</td>
</tr>
<tr>
<td>$K^-$ induced</td>
<td>High-precision strange-meson spectrum</td>
<td>50-100</td>
<td>5 - $10^6$</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>Spectroscopy (RF)</td>
<td>Spin Density Matrix Elements</td>
<td>50-100</td>
<td>5 - $10^6$</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 2: Requirements for future programmes at the M2 beam line after 2021. Muon beams are in blue, conventional hadron beams in green, and RF-separated hadron beams in red.

---

**PHASE-1**

Conventional hadron and muon beams

2022 ➔ 2025 and beyond

**PHASE-2**

Conventional and RF-separated Hadron/Hadron and muon beam

2026 and beyond
Two bearing columns of the COMPASS++/AMBER

There are two bearing columns of the facility:

1. The issue of the emergence of the hadron mass
2. Proton spin (largely addressed by COMPASS)

FIRST, EHM:
How does the all visible matter in the universe come about and what defines its mass scale?

Unfortunately, the Higgs-boson discovery (even if extremely important) does NOT help to answer this question:

✓ The Higgs-boson mechanism produces only a small fraction of all visible mass
✓ The Higgs-generated mass scales explain neither the “huge” proton mass nor the ‘nearly-masslessness’ of the pion

As Higgs mechanism produces a few percent of visible mass, thus the mass scale is defined by QCD mechanisms

Higgs generated masses of the valence quarks:

\[ M_{(u+d)} \sim 7 \text{ MeV} \quad M_{(u+s)} \sim 100 \text{ MeV} \quad M_{(u+u+d)} \sim 10 \text{ MeV} \]
Dressed-quark mass function $M(p)$

The proton mass in the chiral limit is close to its nominal mass, as quark «gain» a mass evolving in to constituent one as its momentum became smaller.

It is very different for pion and kaon (lightest Nambu-Goldstone modes) as they are massless in the chiral limit by definition.

Does this mean that their gluon content is equally small and different from the proton once? ➔ Must Study PDFs

One of the possible proton mass decomposition (calculation on lattice)

Yi-Bo Yong et al.,
The goal of the PBC initiative (on request of CERN DG F. Gianotti) was to make a review of complete set of a newly proposed non-collider experiments at CERN. Those proposals were in a different stage of reparation and were belonging to a different fields of physics: QCD physics, nuclear physics, search for dark matter etc. COMPASS++/AMBER was represented in 2 working groups (QCD Physics and Extracted Beams) by O.Denisov and G.Mallot (substituted by J.Friedrich)

The final goal of the PBC initiative was to submit a summary review document as input to the 2020 European Strategy for Particle Physics update process. The final public ESPP update event took place in Granada in May 2019. The ESPP update process is restarted once in 7 years.
Proposals and studies within PBC-QCD

- experiments at SPS and fixed-target installations at LHC
- cover a broad range of topics in QCD
  - parton densities, proton and nuclear structure
  - heavy-ion physics
  - low-energy dynamics
- measurements for other fields of HEP: (g-2)$_\mu$, cosmic rays, neutrinos

J-P. Lansberg, T. Galatyuk

AMBER (aka COMPASS++)

- a comprehensive physics program suggested to run at the M2 beam line
  - includes measurements with
    - conventional muon and hadron beams
    - upgraded RF-separated hadron beams
- spanning several LHC runs
- RF-separated beams would basically eliminate the high-E/high-I muon beam (unique in the world!)
- not all topics to be covered here!

Table 1: Requirements for future programmes at the M2 beam line after 2021. Muon beams are in blue, conventional hadron beams in green, and RF-separated hadron beams in red.

Table 1. Schematic overview of the physics topics addressed by the studies presented in the QCD working group.
COMPASS++/AMBER – being a new proposal was examined in the period 2016-2020 within Physics Beyond Colliders initiative (CERN) III
time lines and (possible!) locations of PBC-QCD projects
ESPP update document became public (after some delay because of the COVID-19) in June 2020. A summary presentation of the outcome of the update process (valid for the time period 2021-2027) was reported to the CERN community (open CERN Council session) by Halina Abramowicz on June 19th 2020.

The main part of the document and talk was dedicated to the the next large collider project of CERN, but we as QCD (or hadron physics community) got what we wanted.
The most important output of the ESPP 2020 update ➔ COMPASS++/AMBER is on the list of future facilities in the period 2021-2030.

This statement does not mean an approval, but invitation to go ahead with the project and submit a proposal on a long term plans, no show stopper.
Many of the proposals for new experiments at CERN are on a scale such that they could be considered for approval in the usual manner by the scientific committees and the Research Board.
1. COMPASS++/AMBER is on the list of future facilities at CERN, as stated by ESPP 2020 Update process

2. Importance of QCD physics is recognized

3. Complementarity with respect to EIC underlined

4. The only possible large scale “competitor” which might cause a delay for C++/AMBER (Beam Dump facility aka SHIP experiment) is turned down/postponed for the next ESPP review process

5. The idea of new (i.e. RF separated) hadron beams found a support and interest in the SPSC

6. We were encouraged to go ahead with our plans and submit Phase-2 Proposal in a shortest possible time (according to our plans we will submit is in the end of 2020, beginning of 2021)
We had two session of questions-answers with our SPSC referees, which results in ~100 page long document. The review process is till ongoing, we still have to address few question circulated to us after April 2020 meeting of SPSC.

VERY IMPORTANT: we receive for the first time very positive statement from the April SPSC meeting: The physics potential of 150d mu-p elastic scattering and of a hadron-beam program for measuring the anti-p production cross-section in p-He collision as well as for pion-induced Drell-Yan and charmonium production have been recognized.
Summary

• Pion and Kaon structure and Emergence of Hadron Mass study is a major goal of the whole COMPASS++/AMBER enterprise

• Huge work which has been done by us in a framework of PBC and ESPP update brought us positive and important results: COMPASS++/AMBER facility is on the list of long term CERN fix target programs

• We are going in full swing with preparation of the Phase-2 proposal to be submitted at the end of 2020/beginning of 2021.
RF separated antiproton/kaon beam – a missing ingredient in the spin/mass crises resolving

Assumptions:
- $8 \times 10^7$ antiprotons for $10^{13}$ ppp (10 seconds) (optimistic estimate by Lau Gatignon);
- we assume here $4 \times 10^{13}$ protons.

Antiprotons RF separated beam: $3.2 \times 10^7$ /s - Gain is a factor of 50 compared to the standard $h^−$ beam for Drell-Yan experiment (~1% of $h^−$ beam $6 \times 10^7$ /s dominated by $\pi^−$)

Using the same assumption for RF separated kaon beam, possible kaon beam intensity is $8 \times 10^6$ /s - Gain is a factor of 80 compared to the standard “spectroscopy” $h^−$ beam.

High intensity RF separated beam will provide unique opportunities for Hadron Spectroscopy, Drell-Yan physics, Prompt Photon production etc.
The committee was created at the end of 1989 to replace the SPSC and PSCC Committees. The mandate of the committee is to referee the requests from the experimental teams on the basis of their physics interest and of the availability of the accelerators. It meets 4 times a year. The SPSC recommendations are sent to the Research Board, which takes the decisions.

The Phase-1 Proposal was submitted to the SPSC in the end of September 2019, it was discussed at the SPSC meetings in October 2019, January and April 2020.

We had two session of questions-answers with our SPSC referees, which results in ~100 page long document. The review process is till ongoing, we still have to address few question circulated to us after April 2020 meeting of SPSC.

VERY IMPORTANT: we receive for the first time very positive statement from the April SPSC meeting: The physics potential of 150d mu-p elastic scattering and of a hadron-beam program for measuring the anti-p production cross-section in p-He collision as well as for pion-induced Drell-Yan and charmonium production have been recognized.
In May we had a first very positive input on COMPASS++/AMBER Phase-2 (physics with RF separated kaon/antiproton beams mostly) from CERN Authorities (RD E.Elsen)

- The idea of new (i.e. RF separated) hadron beams found a support and interest in the SPSC

- The proposal is not competing or in any case might not be conditioned by the decision on new BeamDump facility construction in the North Area (SHIP experiment etc.)

- We were encouraged to go ahead with our plans and submit Phase-2 Proposal in a shortest possible time (according to our plans we will submit is in the end of 2020, beginning of 2021)

Thus we will proceed in full swing with a preparation of the AMBER Phase-2 Proposal, major part of it dedicated to the pion/kaon structure study