

Introduction to the workshop CERN, March 30th 2020



Perceiving the Emergence of Hadron Mass through AMBER@CERN

30 March 2020 to 2 April 2020 CERN, Geneve - Switzerland

30 March 2020 to 2 April 2020 Europe/Zurich timezone

Search...

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Overview

Attention: The Workshop will take place by videoconference only.



- 1. Intro COMPASS++/AMBER
- 2. COMPASS++/AMBER Physics case:
- 3. EHM Theory initiative



COMPASS++/AMBER approximately 10 years-long effort, LoI is submitted in Jan. 2019

COMPASS++ AMBER

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/

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CERN Accelerating science								
		PASS++/AMBI QCD facility at th the CERN SPS	e M2 beam HO		DOCUM		WORK	SHOPS
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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



CERN-SPSC-2019-003 SPSC-I-250 January 25, 2019

http://arxiv.org/abs/1808.00848 Apparatus for Meson and Baryon Experimental Research > 270 authors Jan 2019

Letter of Intent:

A New QCD facility at the M2 beam line of the CERN SPS^{*}

COMPASS++[†]/AMBER[‡]

B. Adams^{13,12}, C.A. Aidala¹, R. Akhunzyanov¹⁴, G.D. Alexeev¹⁴, M.G. Alexeev⁴¹, A. Amoroso^{41,42},

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[hep-ex]

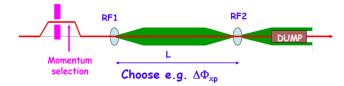


COMPASS++/AMBER A New QCD Facility at CERN SPS M2 beam line

COMPASS++
AMBER

Program	Physics Goals	Beam Energy [GeV]	Beam Intensity [s ⁻¹]	Trigger Rate [kHz]	Beam Type	Target	Earliest start time, duration	Hardware additions
muon-proton elastic scattering	Precision proton-radius measurement	100	4 · 10 ⁶	100	μ^{\pm}	high- pressure H2	2022 1 year	active TPC, SciFi trigger, silicon veto,
Hard exclusive reactions	GPD E	160	2 · 10 ⁷	10	μ^{\pm}	NH_3^\dagger	2022 2 years	recoil silicon, modified polarised target magnet
Input for Dark Matter Search	p production cross section	20-280	$5 \cdot 10^{5}$	25	р	LH2, LHe	2022 1 month	liquid helium
p-induced spectroscopy Drell-Yan	Heavy quark exotics Pion PDFs	12, 20 190	$5 \cdot 10^7$ $7 \cdot 10^7$	25 25	\overline{p} π^{\pm}	LH2 C/W	2022 2 years 2022 1-2 years	target target spectrometer: tracking, calorimetry
Drell-Yan (RF)	Kaon PDFs & Nucleon TMDs	~100	10 ⁸	25-50	K^{\pm}, \overline{p}	NH [↑] ₃ , C/W	2026 2-3 years	"active absorber", vertex detector
Primakoff (RF)	Kaon polarisa- bility & pion life time	~100	5 · 10 ⁶	> 10	<i>K</i> ⁻	Ni	non-exclusive 2026 1 year	
Prompt Photons (RF)	Meson gluon PDFs	≥ 100	5 · 10 ⁶	10-100	$\frac{K^{\pm}}{\pi^{\pm}}$	LH2, Ni	non-exclusive 2026 1-2 years	hodoscope
K-induced Spectroscopy (RF)	High-precision strange-meson spectrum	50-100	5 · 10 ⁶	25	K ⁻	LH2	2026 1 year	recoil TOF, forward PID
Vector mesons (RF)	Spin Density Matrix Elements	50-100	5 · 10 ⁶	10-100	K^{\pm}, π^{\pm}	from H to Pb	2026 1 year	

Conventional muon/hadron M2 beams



 $[\]Delta \Phi$ = 2 π (L f / c) ($\beta_1^{-1} - \beta_2^{-1}$) with $\beta_1^{-1} - \beta_2^{-1}$ = ($m_1^2 - m_2^2$)/2p²

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

ProgramGoalsEnergy (GeV)Intensity (s^-1)Rate (kHz)TypeTarget start time, durationadditionsmuon-protonPrecision (GeV)100 μ^{\pm} high- pressureactive TPC, SciFi trigger, 1 yearactive TPC, SciFi trigger, silcon veto, recoil silicon, recoil silico		Physics	Beam	Beam	Trigger	Beam		Earliest	Hardware	
muon-proton elastic scatteringPrecision proton-radius measurement1004 · 10^6100 μ^{\pm} high- pressure H2active TPC, SciFi rigger, slicon veto, recoil slicon, modified polarised targetConventional hadron and muon beamsHard exclusive reactionsGPD E1602 · 10^710 μ^{\pm} NH $_3^{\pm}$ 2022 1 yearactive TPC, sciFi rigger, slicon veto, modified polarised targetConventional hadron and muon beamsImput for Dark matter Search cross section \overline{p} production 20-280 $20-280$ $5 \cdot 10^5$ 25 p LH2, LH2, 2022 2022 tracking, calorimetrylarget spectrometer. tracking, calorimetry \overline{p} -induced spectroscopyHeavy quark exotics $12, 20$ $5 \cdot 10^7$ 25 \overline{p} LH2, 2022 2022 tracking, calorimetrylarget spectrometer. tracking, calorimetry $2022 \rightarrow$ 2025 and beyondDrell-Yan (RF)Kaon PDFs & 190 $7 \cdot 10^7$ 25 π^{\pm} C/W 23 years 2026 recoil 2326 Primakoff (RF)bility & bion PDFs 100 $5 \cdot 10^6$ > 10 K^{\pm} Ni 2026 recoil 2026 Ni PHASE-2Prompt (RF)PDFs & filon bility & bion (RF) > 100 $5 \cdot 10^6$ 25 $K^ K^ Ni$ 2026 recoil TOF, forward PIDConventional and RF- separated Hadron/Hadron and muon beamVector meosons Matrix Vector meosons $5 \cdot 10^6$ 25 <	Program	Goals				Туре	Target	,	additions	
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Vector mesonsSpin Density Matrix50-100 $5 \cdot 10^6$ 10-100 K^{\pm}, π^{\pm} from H2026and muon beam	Spectroscopy	strange-meson	50-100	$5 \cdot 10^{6}$	25	K^{-}	LH2	2026	recoil TOF,	
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	(RF)	Elements					to Pb	1 year		

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.

2026 and beyond

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COMPASS++/AMBER – Proposal Phase-1



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



CERN-SPSC-2019–022 SPSC-P-360 September 30, 2019

51 institutions, ~260 authors, 19 new institutions with respect to COMPASS (Majority from USA, also Germany, Italy, Russia etc.)

Proposal for Measurements at the M2 beam line of the CERN SPS

– Phase-1 –

COMPASS++*/AMBER[†]

B. Adams^{14,13}, C.A. Aidala¹, G.D. Alexeev¹⁵, M.G. Alexeev^{42,43}, A. Amoroso^{42,43}, V. Andrieux^{45,20},

Oleg Denisov



Two? bearing columns of the COMPASS++/AMBER

There are two bearing columns of the facility:

- **1.** The issue of the Emergence of Hadron Mass
- 2. Proton spin (largely addressed by COMPASS)

FIRST, EHM:

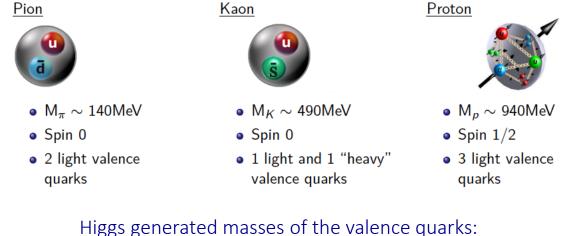
How does the all visible matter in the universe come about and what defines its mass scale?

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



 $M_{(u+d)} \sim 7 \text{ MeV}$ $M_{(u+s)} \sim 100 \text{ MeV}$ $M_{(u+u+d)} \sim 10 \text{ MeV}$

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



(mass budget in proton, different QCD mechanism for Nambu-Goldstone bosons)

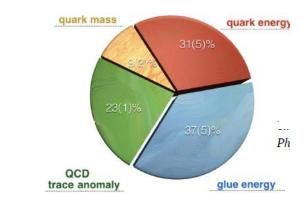
EHM

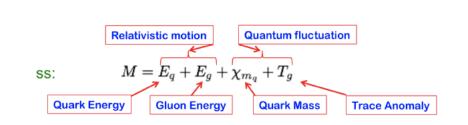


The proton mass in the chiral limit is close to its nominal mass, as quark «gain» a mass evolving in to constituent one as its momentum became smaller.

It is very different for pion and kaon (lightest Nambu-Goldstone modes) as they are massles in the chiral limit by definition. Higgs mechanism vs spontaneous symmetry breaking mechanism

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)

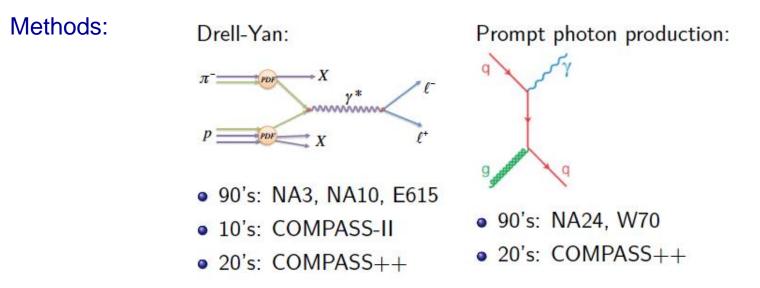
Yi-Bo Yong et al., Phys.Rev.Lett. 121 (2018) no.21, 212001



COMPASS++/AMBER physics program the issue of the Emergence of Hadron Mass (EHM) COMPASS++ AMBER

Questions to be answered (very preliminary):

- Mass difference pion/proton/kaon
- Mass generation mechanism (emergent mass .vs. Higgs)
- Gluon content, especially important pion/kaon striking difference



As well Charmonia production, Hadron spectroscopy, pi/K diffractive scattering



COMPASS++/AMBER physics program Could we consider the issue of the Emergence of Hadron Mass (EHM) as an umbrella term



Certainly the physics case is potentially very strong and interesting but it requires further development by both theory and experiment in order to define:

- the list of most important and best accessible observables;
- kinematic ranges/regimes;
- required sensitivity / accuracy;
- the most valid probes (physics mechanisms) to be used

Thus we need to set-up the "task force" as a join effort theory-experiment in order to Better sharpen the physics program of COMPASS++/AMBER.

First step has been already taken: "Emergence of Hadronic Mass Working Group" ("EHM WG") Kick-off meeting took place on December 11 2019. Large interest and very good attendance, material can be found here: <u>https://indico.cern.ch/event/868625/</u>

We were very well on track for the second step: CERN TH Department based Theory institute (thanks a lot indeed to Urs Wiedemann and TH colleagues for their support and interest), BUT COVID'19

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COMPASS++/AMBER physics program Perceiving the Emergence of Hadron Mass though AMBER@CERN



FORMAT of the Workshop:

- Day 1: Intro, Scene setting, Drell-Yan
- Day 2: Drell-Yan cont., Charmonia, Prompt Photons, Diffractive scattering
- Day 3: Hadron Spectroscopy
- Day 4: Virtual Round Table, Plans, "task sharing"



COMPASS++/AMBER physics program Perceiving the Emergence of Hadron Mass though AMBER@CERN



Instead of SUMMARY:

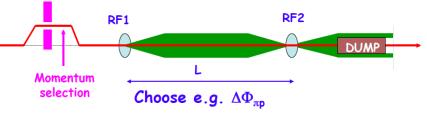
Strong support of theory is highly appreciated to pave the way towards solving the conondrum of the Emergence of Hadron Mass



BACK UP



RF separated antiproton/kaon beam – a missing ingredient in the spin/mass crises resolving



 $\Delta \Phi$ = 2 π (L f / c) ($\beta_1^{-1} - \beta_2^{-1}$) with $\beta_1^{-1} - \beta_2^{-1}$ = ($m_1^2 - m_2^2$)/2p²

"Normal" h⁻ beam composition: ~97% (π) ~2.5%(K) ~0.5% (pbar)

Assumptions:

8 x 10⁷ antiprotons for 10¹³ ppp (10 seconds) (optimistic estimate by Lau Gatignon);
 we assume here 4 x 10¹³ protons.

Antiprotons RF separated beam: 3.2 x 10^7 /s - Gain is a factor of 50 compared to the standard h⁻ beam for Drell-Yan experiment (~1% of h⁻ beam 6x10⁷ /s dominated by π^-)

Using the same assumption for RF separated kaon beam, possible kaon beam intensity is 8 x 10⁶ /s - Gain is a factor of 80 compared to 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.

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