Introduction to the workshop
CERN, March 30th 2020

COMPASS++
AMBER

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...

Overview

Attention: The Workshop will take place by videoconference only.

Outline

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

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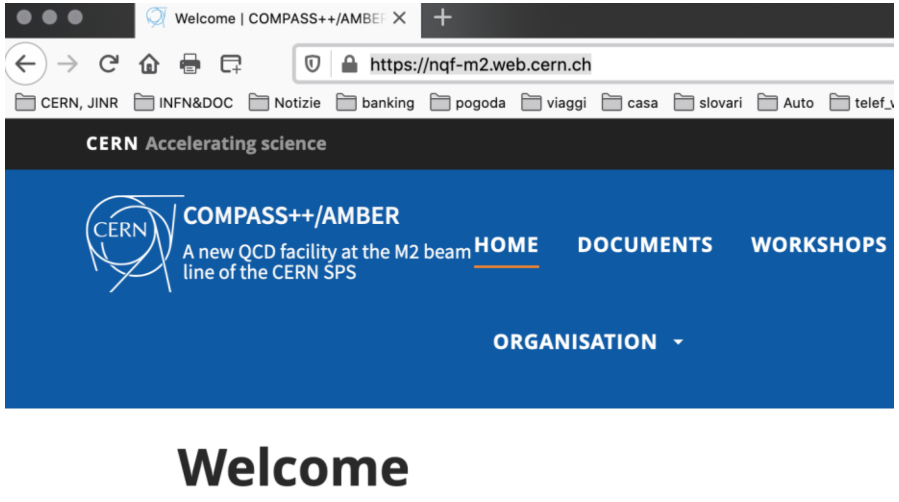
We have started to work on physics program of possible COMPASS successor ~ 10 years ago,

A Number of Workshops has been organized, for detail see COMPASS++/AMBER web page:

https://nqf-m2.web.cern.ch/



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

[hep-ex] 25 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. Aidala[1], R. Akhunzyanov[14], G.D. Alexeev[14], M.G. Alexeev[41], A. Amoroso[41,42],

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

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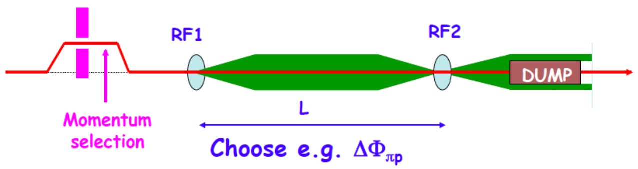
Program	Physics Goals	Beam Energy [GeV]	Beam Intensity [s^{-1}]	Trigger Rate [kHz]	Beam Type	Target	Earliest start time, duration	Hardware additions
muon-proton elastic scattering	Precision proton-radius measurement	100	$4 \cdot 10^6$	100	$\mu^\pm$	high-pressure H2	2022 1 year	active TPC, SciFi trigger,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

Conventional muon/hadron M2 beams



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

COMPASS++/AMBER PHASE-1

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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

COMPASS++/AMBER – Proposal Phase-1

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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. Aidala[1], G.D. Alexeev[15], M.G. Alexeev[42,43], A. Amoroso[42,43], V. Andrieux[45,20],

Two? bearing columns of the COMPASS++/AMBER

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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

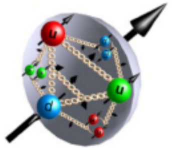
Pion

- $M_\pi \sim 140$MeV
- Spin 0
- 2 light valence quarks

Kaon

- $M_K \sim 490$MeV
- Spin 0
- 1 light and 1 "heavy" valence quarks

Proton



- $M_p \sim 940$MeV
- Spin 1/2
- 3 light valence quarks

Higgs generated masses of the valence quarks:

$M_{(u+d)}$ ~ 7 MeV $M_{(u+s)}$ ~ 100 MeV $M_{(u+u+d)}$ ~ 10 MeV

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

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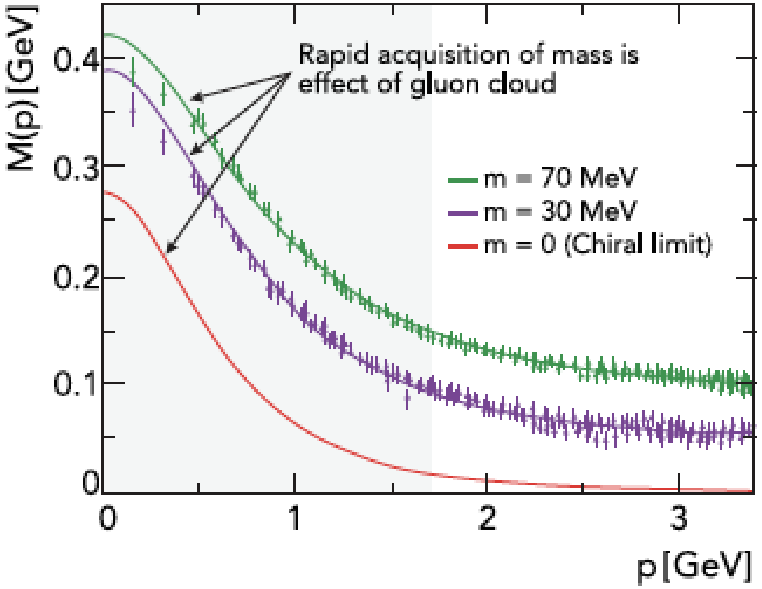
EHM

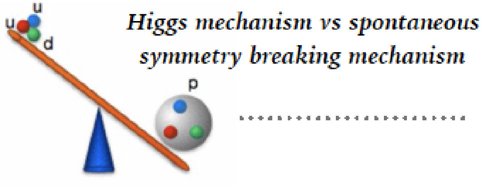
(mass budget in proton, different QCD mechanism for Nambu-Goldstone bosons)

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.

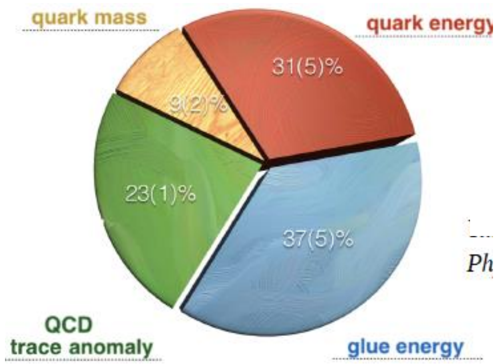
It is very different for pion and kaon (lightest Nambu-Goldstone modes) as they are massles in the chiral limit by definition.

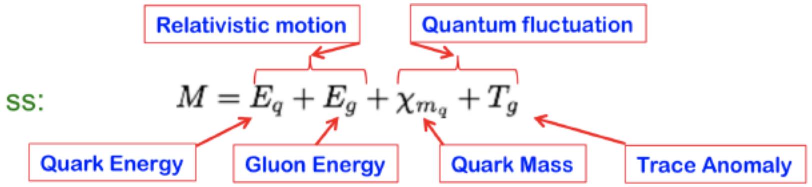


Does this mean that their gluon content is equally small and different from the proton once? ➔ Must Study PDFs

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

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





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

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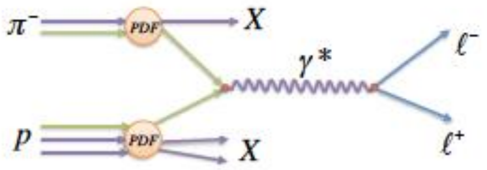
Questions to be answered (very preliminary):

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

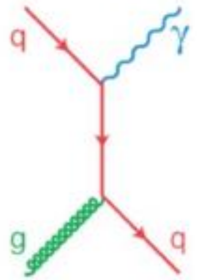
Methods:

Drell-Yan:



- 90's: NA3, NA10, E615
- 10's: COMPASS-II
- 20's: COMPASS++

Prompt photon production:



- 90's: NA24, W70
- 20's: COMPASS++

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

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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: https://indico.cern.ch/event/868625/

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

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

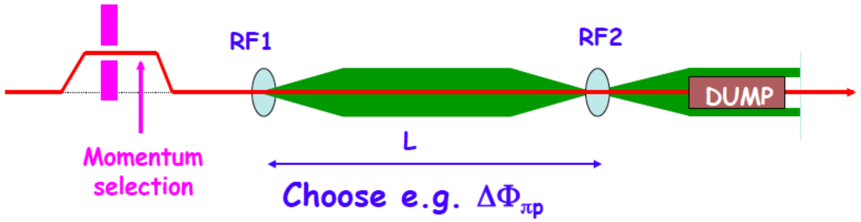
Day 4: Virtual Round Table, Plans, “task sharing”

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



$$\Delta\Phi = 2\pi\,(L\,f\,/\,c)\,(\beta_1^{-1} - \beta_2^{-1}) \text{ with } \beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2)/2p^2$$

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

Assumptions:

– 8 x 10^7 antiprotons for 10^{13} ppp (10 seconds) (optimistic estimate by Lau Gatignon);
– we assume here 4 x 10^{13} 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 6x10^7 /s dominated by π^-)

Using the same assumption for RF separated kaon beam, possible kaon beam intensity is 8 x 10^6 /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.