# AMBER@CERN A new QCD facility



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# AMBER history

Work on physics program for new experiments at M2 beamline started >10 years ago

 Lol submitted in January 2019 (>270 authors)

#### EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



Jan	Letter of Intent:
22	New QCD facility at the M2 beam line of the CERN SPS
	COMP SS++ / MBER <sup>1</sup>

- Proposal for stage 1 submitted in October 2019 (CERN-SPSC-2019-022)
- currently 190 physicists from 40 institutions
- Approved by research board in December 2020 as NA66
  - E.M. Kabuß

### accompanied by a series of workshops:

 5 workshops on "Perceiving the Emergence of Hadron Mass"



 Preparation of proposal for stage 2 ongoing

### What is the origin of mass of all the visible matter in the universe?





- Spin 0
- 2 light valence quarks



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



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

### Higgs generated masses:

 $M_{u+d} \sim 7 \,\, {
m MeV} \qquad M_{u+s} \sim 100 \,\, {
m MeV} \qquad M_{u+u+d} \sim 10 \,\, {
m MeV}$ 

Higgs mechanism: generates small fraction of mass of visible matter does not explain large proton mass or small pion mass

Where does the rest come from?

 $\longrightarrow$  QCD in Standard Model

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# Emergence of hadron mass

### Dynamical mass generation in continuum QCD



PRD D26 (1981) 1453

- massless gluon generates dressed gluons due to self interaction
- result: generation of mass, large at infrared scales

- quarks emit und absorb gluons
- acquire mass in infrared region



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### Comparison of lattice and continuum QCD calculation with experimental data

requires data for:

- quark and gluon PDFs for mesons
- hadron radii and polarisabilities (confinement)
- excitation spectrum of mesons



**AMBER stage 1:** using existing M2 beam line with high energy  $\mu$ ,  $\pi$  and p beams

- 1. Proton charge radius measurement
  - $\longrightarrow$  elastic scattering of muons off protons using an active high pressure hydrogen target
- 2. Antiproton production input for dark matter searches e.g. AMS
  - $\longrightarrow$  interaction of protons with  ${}^{4}\mathrm{He}$  cross section measurement
- 3. Pion induced Drell-Yan and charmonium production
  - $\longrightarrow$  interaction of pions with nuclear target muon pair production will be used to extract pion PDFs

approved since Dec. 2020, PRM pilot run in October 2021

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# RF separated hadron beam

AMBER stage 2: upgrade of M2 beam line to RF-separated hadron beam

composition of standard hadron beam: negative beam: mainly  $\pi^-$  postive beam: mainly p

# enrich kaon and antiprotons by RF separation:





- deflection with 2 cavities
- length should increase with p<sup>2</sup> for given f
- limits beam momentum
  - $\sim 80~\text{GeV}$  for kaons
  - $\sim 110~\text{GeV}$  for  $\bar{p}$

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# Physics program cont.

### AMBER stage 2: proposed measurements

- Kaon induced Drell-Yan and charmonium production

 $\longrightarrow$  valence/sea separation using  $K^+$  and  $K^-$  beams ratio of kaon and pion u-quark PDF gluon PDF

- Prompt photon productions
  - $\longrightarrow$  gluon distributions of mesons
- Primakoff reactions with  ${\sf K}/\pi$  beams
- Kaon induced spectroscopy
  - $\longrightarrow$  strange meson spectrum
- Meson scattering on H
  - $\rightarrow$  meson charge radii
    - E.M. Kabuß



# Proton charge radius puzzle

### In 2010 discrepancy in $r_p$ results from laser spectroscopy and scattering experiments



new: scattering experiments with muons **MUSE** at PSI with low energy  $\mu$ **AMBER** at CERN with high energy  $\mu$ 

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# Experimental method

New method: measure proton recoil  $E_p$ ,  $\Theta_p$  (instead of lepton  $E'_l$  and  $\Theta_l$ )

- active hydrogen target: high pressure hydrogen TPC

planned for PRES at MAMI ( $E_e = 720 \text{ MeV}$ ) AMBER ( $E_\mu = 50 - 100 \text{ GeV}$ )



- Si-pixel trackers precise measurement of  $\boldsymbol{\mu}$  scattering angle
- scint. fibre detectors for timing and triggering
- correlation of variables allows for suppression of backgrounds

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# Planned setup



- TPC with up to 20 bar, 160 cm target length, anodes plates with azimuthal segmentation
- electromagnetic calorimeter to measure radiative photons
- muon identification system
- continuously running DAQ

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### using about 200 days of running time (plus control measurements)



### Dark matter search in cosmic rays



# Antiproton production

### Measurement of p-He interactions

- using proton beam of 50 280 GeV/c
- AMBER spectrometer to reconstruct inelastic events
- RICH detector to identify antiprotons
- $\longrightarrow$  cross section determination
- complementary to LHCb measurement at 7 TeV
- pilot run planned for 2022 (using infrastructure of COMPASS polarised target)



expected AMBER measurement

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### Pion structure



- different results for pion PDFs from different groups
- not enough data to constrain all PDFs
- measurement planned using: π<sup>+</sup> and π<sup>-</sup> beams with isoscalar target
- $\begin{array}{ll} \bullet \quad \mbox{yields two linear combinations:} \\ -\sigma^{\pi^+ D} + \sigma^{\pi^- D} & \mbox{sensitive to valence only} \\ 4\sigma^{\pi^+ D} \sigma^{\pi^- D} & \mbox{sensitive to sea} \end{array}$

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# Drell-Yan setup



### First steps

### PRM test in 2018

- TPC from Mainz experiment installed behind COMPASS DY setup
- use of decay muons
- correlate TPC signals with SciFi and Si detector signals



- scheduled after COMPASS deuteron DIS data taking
- recoil proton detection in real muon beam environment (position before COMPASS setup)
- ▶ IKAR TPC from GSI will be used (half length of AMBER TPC)
- test of new continous readout scheme and new tracking station

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# Pilotrun 2021

#### IKAR TPC



- 2 drift cells with 40cm length
- identical anode structure to final TPC
- smaller diameter
- operation with max. 10 bar

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#### Tracking station

- houses SciFi and Si-pixel detectors
- small distance between detectors
- precise positioning
- compatible with He bags for beamline



- ▶ a new QCD facility will be set up at the CERN M2 beamline
- measurements planned covering the full accessible Q<sup>2</sup> range
- stage 1 with conventional muon and hadron beams is starting this year with the proton radius pilot run
- > proposal for stage 2 with RF separated hadron beam is being prepared
- new ideas and new collaborators are welcome