PHYSICS BEYOND COLLIDERS at CERN

Study Group mandated by the CERN Management to prepare the next European HEP strategy update (2019-20)
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Excerpt from the PBC mandate:
“Explore the opportunities offered by the CERN accelerator complex to address some of today’s outstanding questions in particle physics through experiments complementary to high-energy colliders and other initiatives in the world.”

Time scale: next 2 decades
PBC KICK-OFF WORKSHOP, CERN, Sept. 6-7, 2016
Call for abstracts → 33 abstracts submitted, 20 selected for presentation

1st GENERAL WORKING GROUP MEETING, CERN, March 1-2, 2017
Identification of main issues to be studied

FOLLOW-UP WORKSHOP, CERN, November 21-22, 2017
Working groups project reports
New call for abstracts → 10 abstracts submitted, 7 selected for presentation

2nd GENERAL WORKING GROUP MEETING, CERN, June 13-14, 2018
Status of studies for PBC deliverables

CLOSE-OUT WORKSHOP FORESEEN AT CERN early-2019

NB: PBC meetings and activities documented on pbc.web.cern.ch
(credit to Collaborations for the plots shown in this presentation)
A DECADE OF VIBRANT “DIVERSITY” PHYSICS AT CERN!

~1000 physicists on ~20 experiments

Completed

Full swing

Expanding

Starting

CNGS (ν)
DIRAC (QCD)
COMPASS (QCD)
NA61 (QCD)
ANTIMATTER FACTORY (CPT)
NA62 & NA64 (BSM)
ν Platform (det. R&D)
AWAKE (acc. R&D)

...+ CAST, OSQAR, etc...

Recent stop of major programs (e.g. CNGS) leaves room to new significant initiatives
1) QCD–oriented

2) BSM-oriented

3) Some new long term facilities
COMPASS

a large acceptance spectrometer in the intermediate x-domain between H1/ZEUS and HERMES/JLAB

COMPASS I (< 2012): Spin content of the proton constituents with polarized DIS

COMPASS II (2014-18): Orbital momentum with DVCS
Transverse Momentum Dependent effects with polarized DY
**Wish RF separated antiproton and kaon beams (1 x 50)**

- High statistics strange meson spectroscopy
- Exotic states spectroscopy complementary to LHCb/PANDA
- Kaon and antiproton structure

Main issues: Competition, cost/schedule of RF separated beam, Collaboration support

→ Shorter term LS2↔LS3 program under definition
MUonE
Direct measurement of the dominant contribution to the theoretical error on \((g-2)_\mu\) from \(\mu\)-e elastic scattering

High statistics space-like measurement could reduce by factor 2 the current error derived from time-like processes

Full t range accessible thanks to high energy \(\mu\) beam boost, self normalized measurement
Might be feasible with reasonable resources within the (modified) COMPASS setup

Main issue: systematic effects (control needed at 10\(^{-5}\) level)
NA61/SHINE

Search for QCD Critical Point by scan in the \((T, \mu_B)\) plane

**AFTER LS2:**
wish to further study QCD deconfinement with open charm

Clear motivation to revisit QCD phase transition with charm

Main issues:
- factor 10 increase in beam intensity and high rate data taking

NB: NA61 large acceptance TPC still unique after LS2 to constrain \(\nu\) beam fluxes (T2K\(^+\), HK, LBNF)
Fixed Target physics with LHC beams

3 options under study by LHCb and ALICE

Opens a unique new kinematical domain to structure & deconfinement measurements

Main issue of LHC internal fixed targets: compatibility with other LHC programs/goals
**NA62**

Rare $K$ decays

Regular data taking started after many years of intensive construction and commissioning

$$K \rightarrow \pi \nu \bar{\nu} \quad (BR \sim 10^{-10})$$

75 GeV/c $K^+$ (6%)

Hadron Beam 800 MHz

Kaon identification in CEDAR

Measure Kaon:
- Time
- Angles
- Momentum

Veto

Photons and Muons

π Identification

Decay Region 65m

STRAW Tracker

RICH

LKR MUV

C. Vallée LHCP2018
Rare $K \rightarrow \pi \nu \bar{\nu}$ (BR ~ $10^{-10}$)

**NA62**

Promising result with 2016 data proves validity of the in-flight method for the future

~20 signal events expected until LS2
KLEVER: $K^0 \rightarrow \pi^0\nu\bar{\nu}$ rare decay

$K^0$ decays complementary to $K^+$ decays for the CKM matrix and BSM searches. 

*Would require a new high intensity $K^0$ beam.*

~50 events could be collected with a similar but basically new detector.

**Competition from starting KOTO at JPARC:**

few events expected in coming years, upgrade by factor ~10 foreseen > 2025

Main issues: actual sensitivity vs competition, cost of new beam and upgraded detector
Flagship program for a comprehensive investigation of the Hidden Sector in the few GeV domain

Similar layout as NA62, with larger acceptance to reach the c / b mass range

SHiP

... to be compared with e.g. LHC-LLP projects (Trojanowski)
Foreseen to be sited close to the North Area Conceptual design well advanced at CERN.

Magnetized hadron absorber and light-weight active muon shield minimize punch through in decay volume
Muon yields and charm cross sections to be measured in test beams

An opportunity for a new post-CNGS high intensity general facility at CERN
Recently revived idea to intercept small BDF beam fraction to look for $\tau \rightarrow 3\mu$ decays

Could set limits on branching ratio better than $10^{-10}$ level (> BELLE-II reach)

Implementation layout upstream of BDF target under study

A promising option to maximize the physics reach of the Beam Dump Facility
Hidden sector search from invisible decays with missing energy

Implemented in 2016 on e test beam

Fast analysis excluding \((g-2)_{\mu}\) interpretation confirms the potential of the method

**AFTER LS2:**
Wish to extend the method to higher e intensity and \(\mu / \pi / K / p\) beams

**Main issues:** e beam intensity and CERN siting for other beams
Next generation Axion Helioscope beyond CAST

Support from CERN for magnet design within PBC
DESY considered as candidate site
Storage Ring for proton/deuterium EDM

Electrostatic option for proton
Magnetic option for deuterium

~160 m Ø

Design sensitivity: $4 \times 10^{-29}$ e-cm
Requires:
-- electrostatic deflector 8MV/m
-- magnetic shielding
-- high precision SQUID BPMs to monitor the total radial magnetic field by vertical beam position separation between CW/CCW

$10^{-29}$ e-cm sensitivity would correspond to 100 TeV for new physics energy scale

+ recent idea to look for axion DM through oscillating EDMs

Ring design ongoing with CERN, srEDM and JEDI collaborations

Main issue: control of systematic effects (e.g. B fields)
Gamma Factory

New idea to use LHC to convert laser photons into 0.1 - 400 MeV γ rays

LHC filled with Partially Stripped Ions

γ- beam

Expect factor $10^7$ intensity increase compared to present e-driven γ ray beams, would open a completely new field of physics measurements and applications.

NB: encouraging lifetime > 1s measured in SPS for 39+Xe PSI
3 GeV e-LINAC with CLIC technology connected to SPS for acceleration to ~10 GeV

Would provide a unique testbed for R&D on linear acceleration techniques

Slow extraction from SPS would allow hidden sector searches in the invisible mode (~$10^{16}$ e/year to expts à la NA64/LDMX)
R&D for electron acceleration with a plasma cell excited by proton bunches

First accelerated electrons expected in 2018
Could provide $\sim 10^{15}$ $\sim 30$ GeV pulsed e$^-$s/year in the post-LS3 era to an experiment located in the CNGS decay tunnel
One main overview document supplemented by BSM/QCD context documents and project CDR/CDS at a level of details matched to the maturity of the projects. To be submitted end 2018 as input to the next European Particle Physics strategy update.

NB: no arbitration between projects to be done by PBC. Guidelines will come later from the Strategy update.

One of the main added values of PBC: a forum for exchanges between communities with similar motivations, under CERN “umbrella”: SHiP/NA62/LHC-LLP, COMPASS/LHC-FT, COMPASS/MUonE, NA60/NA61/LHC-FT, JEDI/srEDM, OSQAR/ALPS, etc…