Physics Beyond Colliders

Gianluigi Arduini, Joerg Jaeckel, Gunar Schnell

Acknowledgements: PBC Accelerator and Physics Working Groups

Workshop on Neutrinos@CERN 23 January 2025

Physics Beyond Colliders Mandate 2016-2020

"Physics Beyond Colliders" Study Group established in March 2016

Mandate
Explore opportunities offered by the (very rich) CERN accelerator complex to address outstanding questions in particle physics through projects:

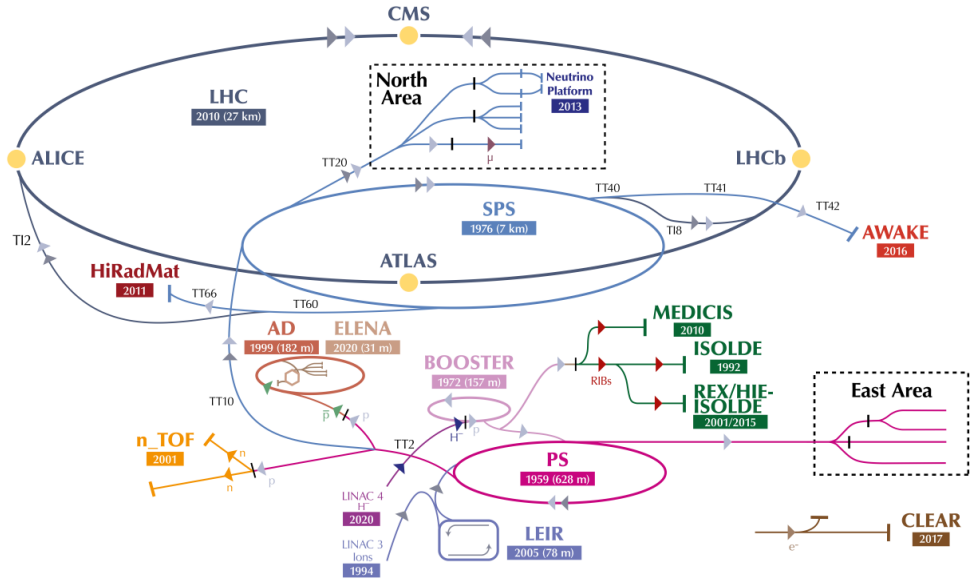
- ❑ complementary to high-energy colliders (studied at CERN: HE-LHC, CLIC, FCC)
  → we know there is new physics, we don't know where it is → we need to be as broad as possible in our exploratory approach
- ❑ exploiting the unique capabilities of CERN accelerator complex and infrastructure and complementary to other efforts in the world:
  → optimise the resources of the discipline globally

⬇

Enrich and diversify CERN's future scientific programme

Goal is to involve interested worldwide community, and to create synergies with other laboratories and institutions in Europe (and beyond).
Note: interesting ideas may emerge from these studies which do not need to be realised at CERN.

- ❑ Overall coordinators: Joerg Jaeckel (Heidelberg; theory), Mike Lamont (CERN; accelerator), Claude Vallée (CPPM and DESY; experimental physics)
- ❑ Kick-off meeting 6-7 September 2016
- ❑ Final report by end 2018 → in time for update of European Strategy

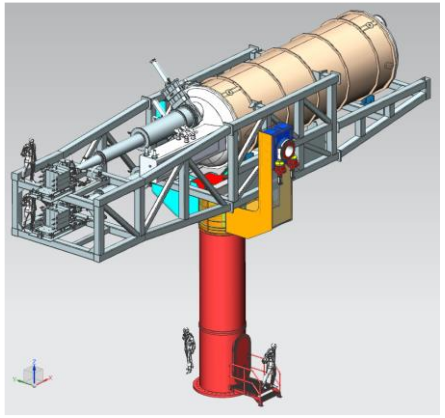


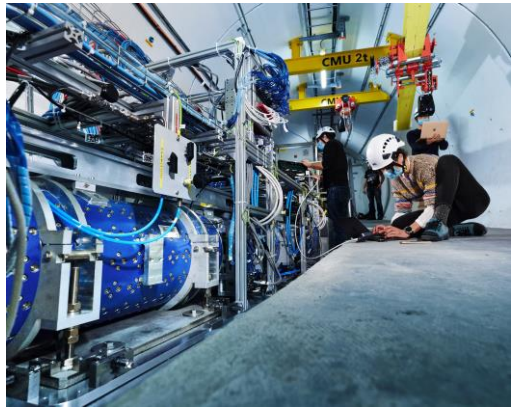
Fabiola Gianotti – PBC Kick-off Workshop – 6-7 September 2016

A lot of work produced

A number projects now operating or being implemented:

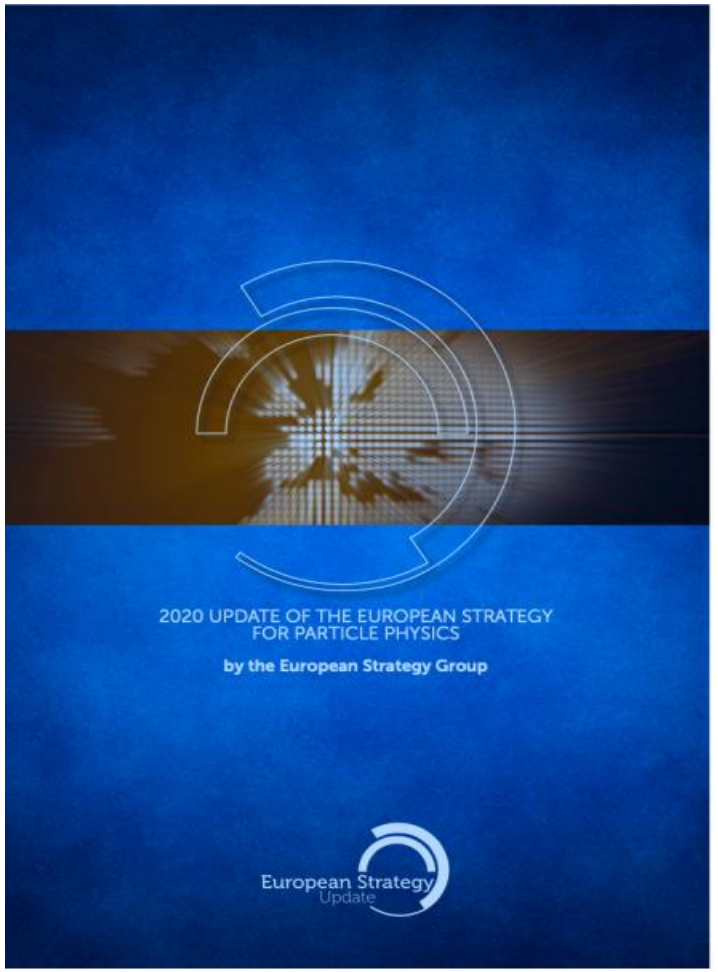
- North Area Experiments (MUonE, NA64e/μ, AMBER,…)
- LHC Forward detectors (FASER, SND,…) and Gas Target (SMOG2)
- BabyIAXO/IAXO @ DESY





ESPP & PBC

…..A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy. ***Experiments in such diverse areas that offer potential high-impact particle physics programmes at laboratories in Europe should be supported, as well as participation in such experiments in other regions of the world…..***



Physics Beyond Colliders New Mandate (2021)

Complementarity** to the goals **of the main experiments of the Laboratory's collider programme

Supporting projects using **experimental techniques of nuclear, atomic, and astroparticle physics** as well as emerging technologies such as **quantum sensors** benefitting form CERN competence and expertise

***Central forum for exchanges between PBC experimental community and theorists** to assess the physics reach of proposed projects in a global landscape*

CERN's initial portal for new ideas, facilitating and supporting the evaluation of their relevance and technical feasibility

Coordinators: G. Arduini (CERN), J. Jaeckel (Heidelberg), C. Vallée ➔ G. Schnell (Bilbao)

Mandate of the "Physics Beyond Colliders" Study Group

(Revised January 2021)

Context

The PBC study was launched in 2016 to explore the scientific potential of the CERN accelerator complex and infrastructure for projects complementary to high-energy frontier colliders, and to provide input to the European Particle Physics Strategy Update (EPPSU). The EPPSU deliberations were supportive of PBC studies, and recommended an enhanced collaboration of CERN with other laboratories in Europe and beyond. As a consequence, the CERN Directorate wishes to maintain the PBC study group as a long-term activity, with a mandate and organization updated to take into account the EPPSU recommendations.

Scientific goal

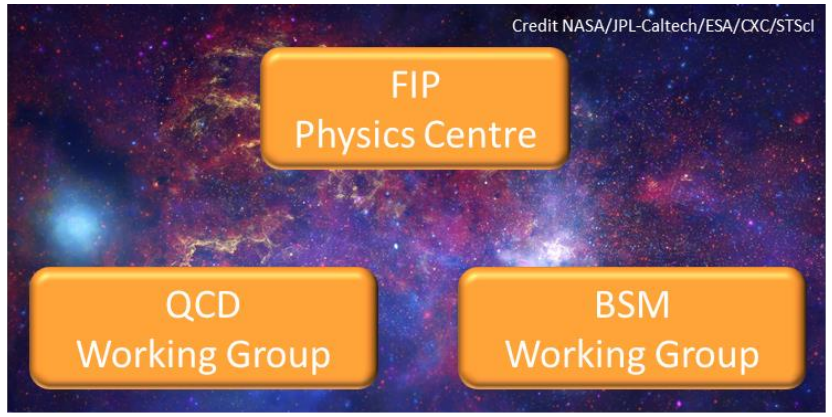
The main goal of the Study Group remains to explore the opportunities offered by CERN's unique accelerator complex, its scientific and technical infrastructure, and its know-how in accelerator and detector science and technology, to address today's outstanding questions in particle physics through initiatives that complement the goals of the main experiments of the Laboratory's collider programme. Examples of physics objectives include dedicated experiments for studies of rare processes and searches for feebly interacting particles. The physics objectives also include projects aimed at addressing fundamental particle physics questions using the experimental techniques of nuclear, atomic, and astroparticle physics, as well as emerging technologies such as quantum sensors, that would benefit from the contribution of CERN competences and expertise. The study group will primarily investigate, and, where appropriate, provide support to, projects expected to be sited at CERN. The study group may also examine ideas and provide initial support for contributions to projects external to CERN. The study group is also expected to act as a central forum for exchanges between the PBC experimental community and theorists for assessment of the physics reach of the proposed projects in a global landscape.

Organization

The group will continue to be led by three coordinators representing the scientific communities of accelerator, experimental, and theoretical particle physics. The coordination team reports to the CERN Directorate. The coordinators will update the PBC working group structure to reflect the updated PBC mandate and input from the community.

The PBC study group will act as CERN's initial portal for new ideas which may come in spontaneously or through specific calls launched by the PBC coordination team. The group will facilitate and support an initial evaluation of the relevance and technical feasibility of the ideas in a global context, and will regularly inform the CERN scientific committees (INTC, SPSC or LHCC) about their findings. Where appropriate, oversight of PBC studies will be passed to the relevant CERN scientific committee once they are adequately mature for scrutiny and review of possible implementation.

Organization



Beam Dump Facility

Forward Physics Facility

Accelerator Complex Capabilities

Charged particle EDM (cpEDM) measurement

PBC-A&T Committee

Civil Eng., Integration, Radiation Protection

Conventional Beams

LHC – Fixed Target

Technology

Gamma Factory

https://pbc.web.cern.ch/

ESPP 2020 and Neutrinos

Only some excerpts!

From the Brochure of the 2020 update of the European Strategy for Particle Physics:

…. *CERN through the Neutrino Platform, should continue to support long baseline experiments in Japan and the United States. In particular, they should continue to collaborate with the United States and other international partners towards the successful implementation of the Long-Baseline Neutrino Facility (LBNF) and the Deep Underground Neutrino Experiment (DUNE).* ….

From the Deliberation Document on the 2020 update of the European Strategy for Particle Physics

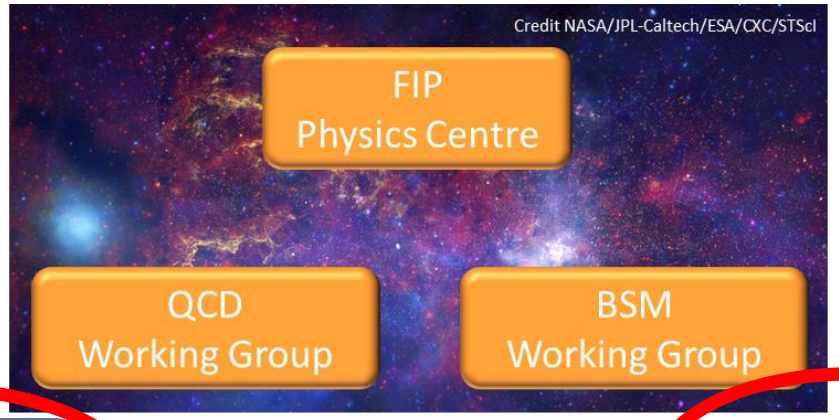
…..*To extract the most physics from DUNE and Hyper-Kamiokande, a complementary programme of experimentation to determine neutrino cross-sections and fluxes is required. Several experiments aimed at determining neutrino fluxes exist worldwide. The possible implementation and impact of a facility to measure neutrino cross-sections at the percent level should continue to be studied*. …..

Neutrinos in PBC today

✓ BDF/SHIP @ ECN3 HI

LoI in preparation

ENUBET/NUTAG → SBN



Beam Dump Facility

Forward Physics Facility

Accelerator Complex
Capabilities

Charged particle EDM
(cpEDM) measurement

PBC-A&T
Committee

Civil Eng., Integration,
Radiation Protection

Conventional Beams

LHC – Fixed Target

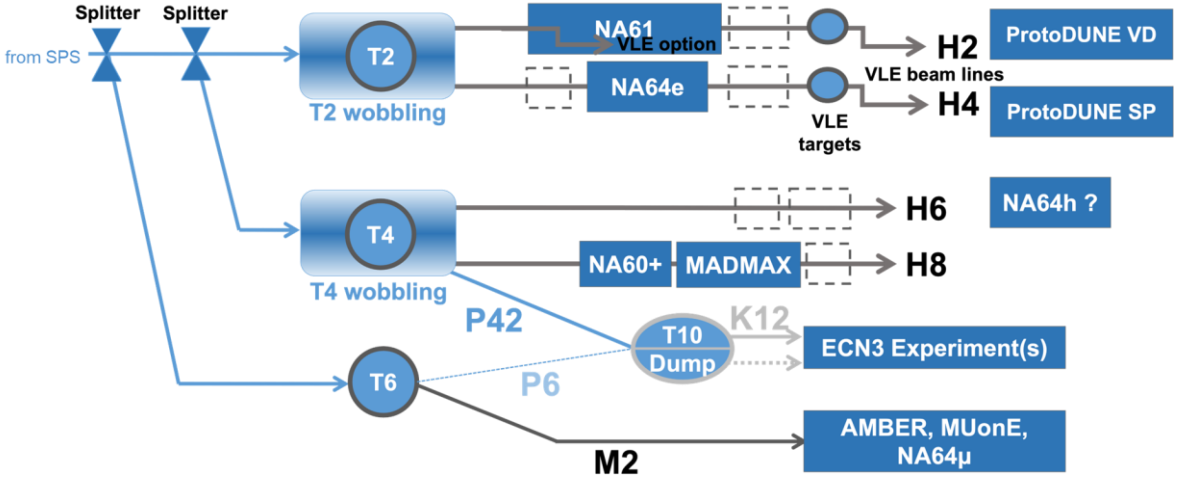
Technology

Gamma Factory

High Energy (SPS) Proton beams Competition

Any new requirement in terms of protons on target MUST be compatible with known future commitments:

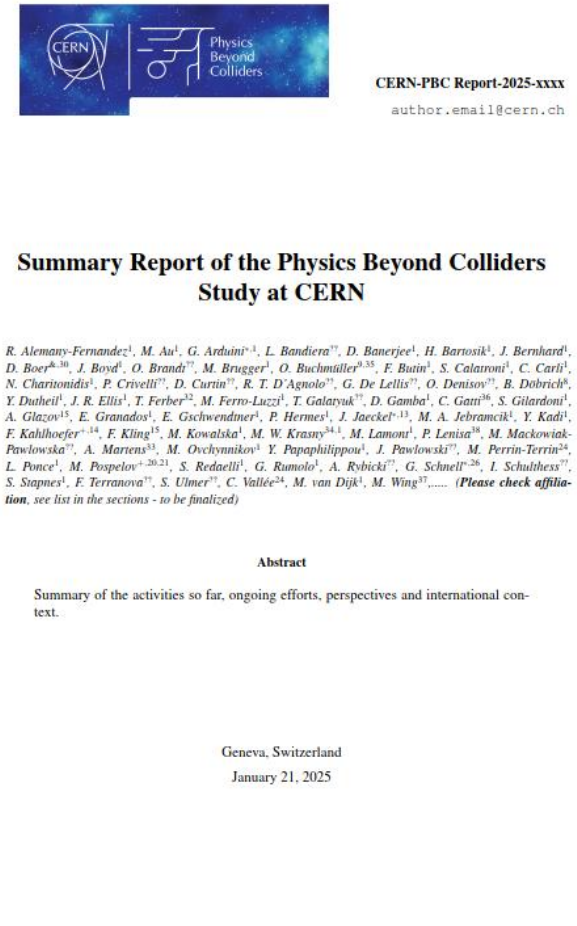
- **BDF/SHiP ➔ 4 x 10^{19} pot/year**
- **but also other North Area experiments (with overall requests of O(few 10^{18} pot/year))**
  - NA64e @ EHN1:
    - Configuration optimized to detect dark photons from missing energy, adaptable to e+e- visible decay mode
  - AMBER QCD facility @ EHN2:
    - High precision π structure measurements
    - Strange spectroscopy (requiring possibly new RF-separated beam under study)
  - NA64μ, MUonE @ EHN2….



Update of the ESPP 2026

PBC in the process of preparing summary document for the Update of the ESPP 2026

- Summary of all PBC-related projects
- Dedicated FPF and SBN sections
- Physics sections including:
  - Neutrino
  - Hadron structure
  - Hidden Sector



CERN-PBC Report-2025-xxxx

author.email@cern.ch

Summary Report of the Physics Beyond Colliders Study at CERN

R. Alemany-Fernandez[1], M. Au[1], G. Arduini[*,1], *L. Bandiera[37], D. Banerjee[1], H. Bartosik[1], J. Bernhard[1], D. Boer*[&,30], *J. Boyd[1], O. Brandt[77], M. Brugger[1], O. Buchmüller*[9,55], *F. Butin[1], S. Calatroni[1], C. Carli[1], N. Charitonidis[1], P. Crivelli[77], D. Curtin[77], R. T. D'Agnolo[77], G. De Lellis[77], O. Denisov[77], B. Döbrich[8], Y. Dutheil[1], J. R. Ellis[1], T. Ferber[32], M. Ferro-Luzzi[1], T. Galatyuk[77], D. Gamba[1], C. Gatti[36], S. Gilardoni[1], A. Glazov[15], E. Granados[1], E. Gschwendtner[1], P. Hermes[1], J. Jaeckel*[*,13], *M. A. Jebramcik[1], Y. Kadi[1], F. Kahlhoefer*[*,14], *F. Kling[15], M. Kowalska[1], M. W. Krasny*[34,1], *M. Lamont[1], P. Lenisa[38], M. Mackowiak-Pawlowska[77], A. Martens[33], M. Ovchynnikov[1] Y. Papaphilippou[1], J. Pawlowski[77], M. Perrin-Terrin[24], L. Ponce[1], M. Pospelov*[*,20,21], *S. Redaelli[1], G. Rumolo[1], A. Rybicki[77], G. Schnell*[*,28], *I. Schulthess[77], S. Stapnes[1], F. Terranova[37], S. Ulmer[77], C. Vallée[24], M. van Dijk[1], M. Wing[37],..... (**Please check affiliation**, see list in the sections - to be finalized)*

Abstract

Summary of the activities so far, ongoing efforts, perspectives and international context.

Geneva, Switzerland

January 21, 2025

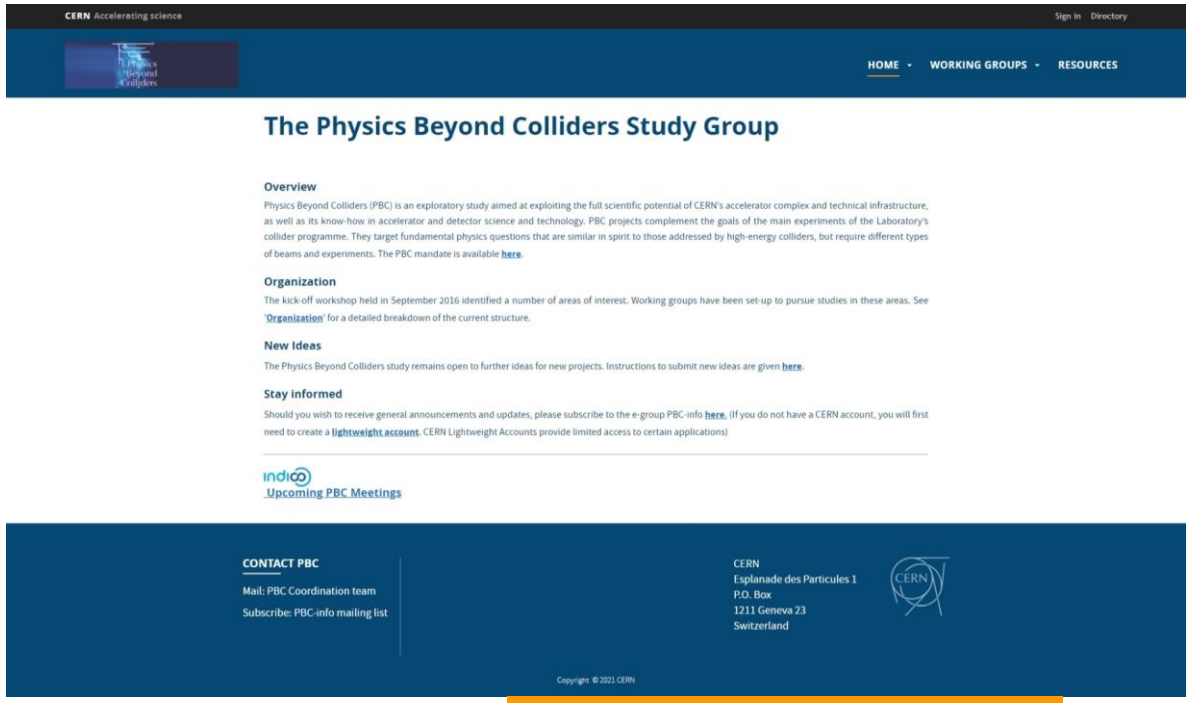
Summary & Outlook

CERN PBC Study Group extended in 2021 as a long term activity with updated mandate following the ESPP Recommendations

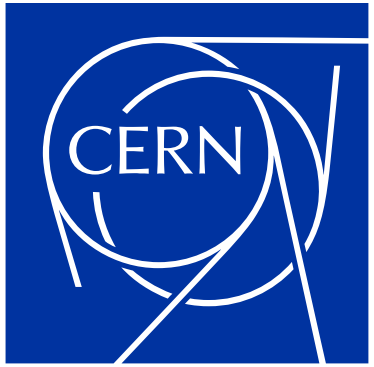
Support has been/is being provided for Neutrino (and other) physics proposals, keeping in mind:

- **reuse of the existing infrastructure**
- **compatibility with existing constraints (proton availability, technical feasibility, ….cost)**
- **physics landscape**

Preparing for the Update of the ESPP 2026



https://pbc.web.cern.ch/



beams.cern