Physics Beyond Colliders

Experiments and decision strategies

Gianluigi Arduini

Acknowledgements: PBC Accelerator and Physics Working Groups

Joint Accelerator Performance Workshop, 8th December 2022

Outline

Will cover only studies with potential for implementation at CERN

- Post-LS3 North Area Ion Physics programme covered by Roderik
- ECN3 High Intensity already introduced by Matthew
- Forward Physics Facility
- LHC Fixed Target
- Gamma Factory & SPS Proof of Principle
- AION@CERN

Physics Beyond Colliders Study Group Updated Mandate (2021)

Explore opportunities offered by CERN's unique accelerator complex, scientific and technical infrastructure, know-how to address today's outstanding questions in particle physics

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

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

Inform the CERN Scientific Committees (INTC, SPSC or LHCC) about its findings

Oversight of PBC studies is passed to the relevant CERN Scientific Committee once they are adequately mature for:

- Scrutiny and review of possible implementation
- Possible recommendation
- Decision by CERN management

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.

ECN3 High Intensity Beams

A number of proposals requiring higher intensities (factor 6 to 12 in p/spill – factor 6 to >20 in p.o.t./year) in the ECN3 underground cavern post-LS3:

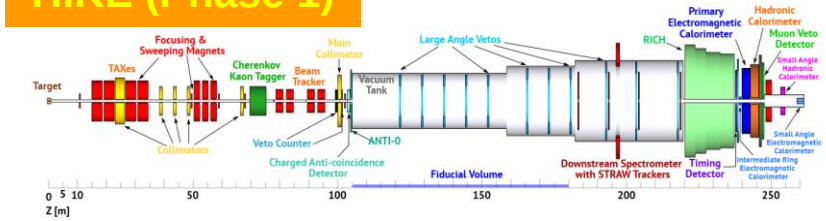
- High intensity Kaon Experiment (HIKE) with a programme to study Ultra Rare Kaon decays (e.g. $K \to \pi\nu\bar{\nu}$ - BR~10^{-10}) complemented by the search for visible decays of Feebly-Interacting Particles (FIP) in Beam Dump mode on-axis

- SHADOWS (Search for Hidden And Dark Objects With the SPS) to search for FIP visible decays in Beam Dump (BD) mode off-axis. Running in parallel to HIKE when operated in BD mode

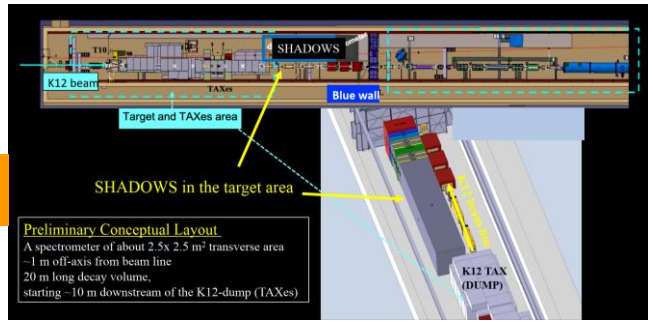
- SHiP (Search for Hidden Particle) proposing a comprehensive investigation of the Hidden Sector in the O(GeV) domain

- TauFV to search for flavour violation in τ decays (e.g. $\tau \to 3\mu$).

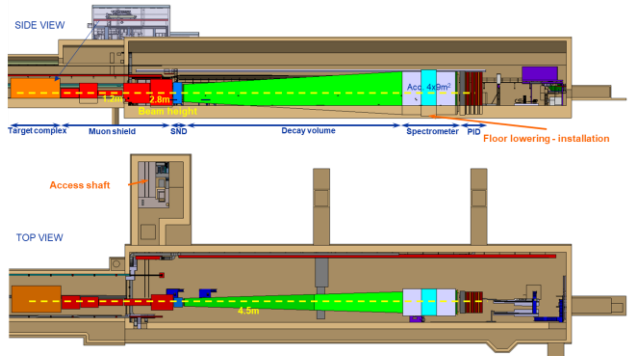
HIKE (Phase 1)



SHADOWS



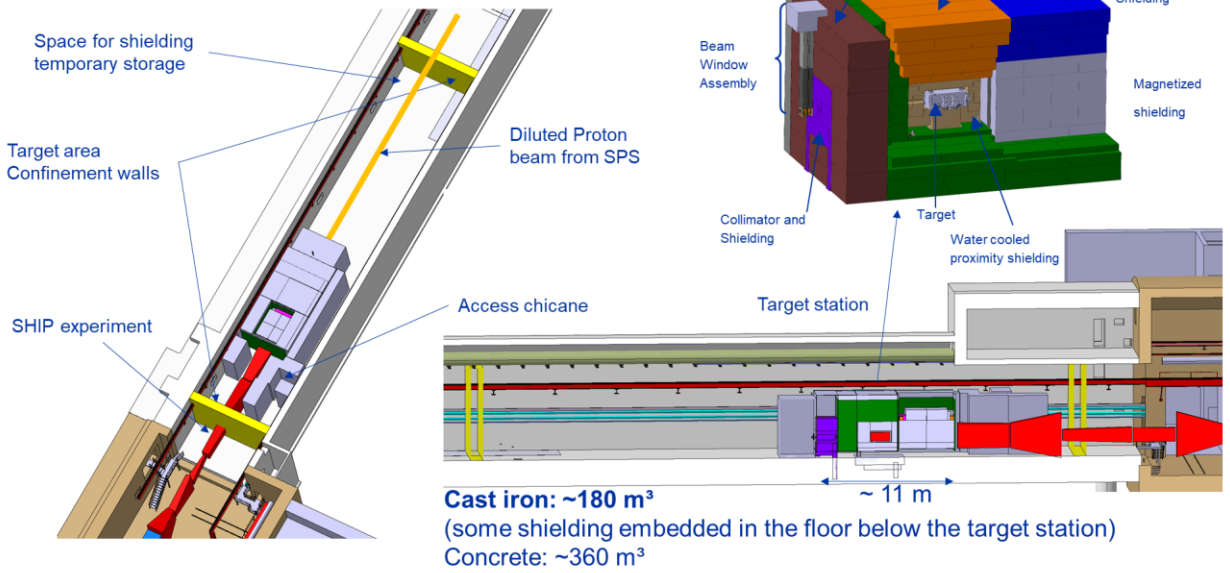
SHiP@ECN3



North Area High Intensity Beams ECN3

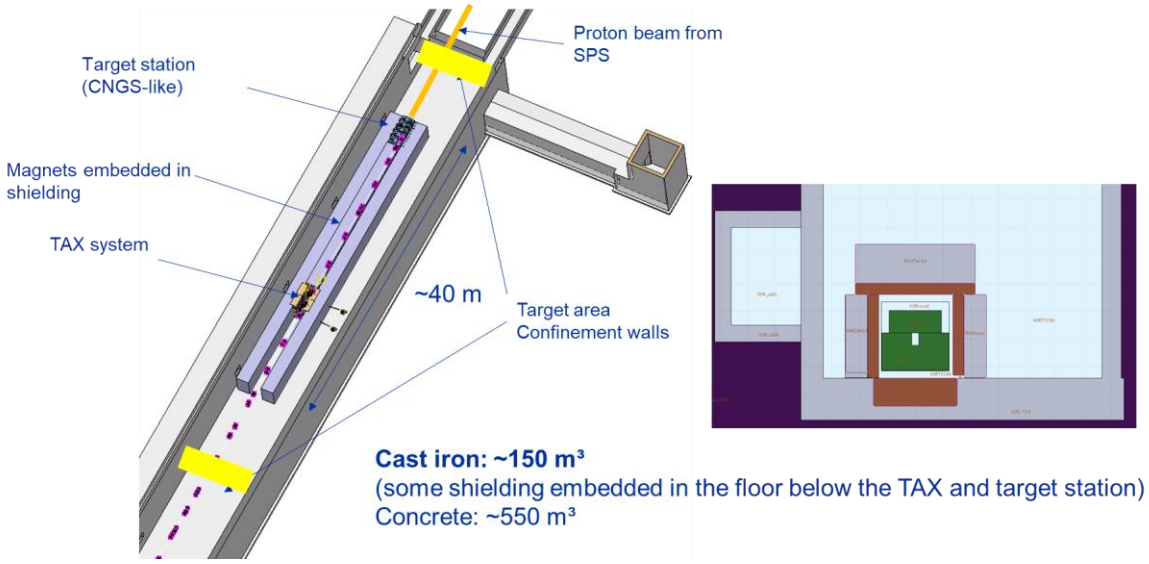
Quite some work ongoing in the ECN3 task force (Matthew's presentation) but also in the Conventional Beams and Beam Dump Facility WGs for the experiment specific aspects (e.g. target stations, ..)

BDF



Cast iron: ~180 m³
(some shielding embedded in the floor below the target station)
Concrete: ~360 m³

Kaon Physics



Cast iron: ~150 m³
(some shielding embedded in the floor below the TAX and target station)
Concrete: ~550 m³

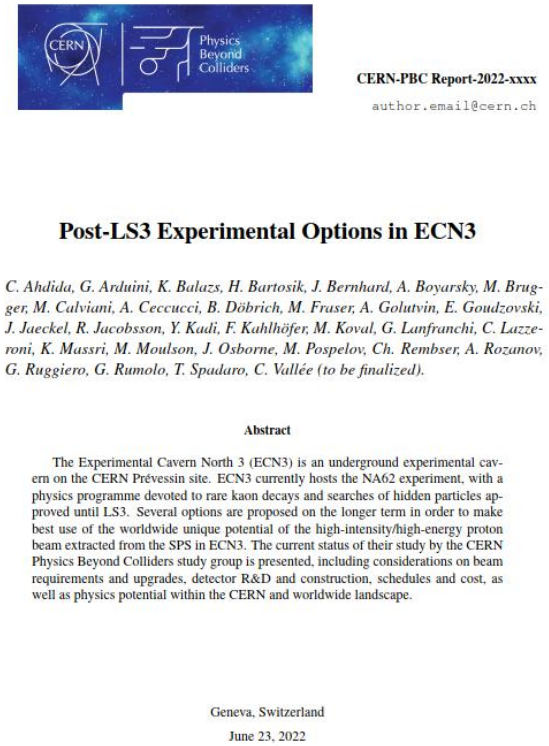
Decision Timeline: ECN3

- **PBC ECN3 Beam Delivery Task Force (Dec. 2022)**
  - To deliver document on ‘physics agnostic’ feasibility for high intensity facility in ECN3
- **IEFC (Jan. 2023)**
  - To scrutinise outcome of feasibility study on facility side
- **Scope, Cost & Schedule Review for NA-CONS (Jan. 2023)**
  - To include input from the Task Force, BDF, CB WGs and IEFC
- **SPSC (Feb. 2023): statement on the physics interest for high int. facility**
  - Initial review of physics cases for high intensity experiments in ECN3
  - Input form PBC ECN3 studies
- **RB (Mar. 2023) to endorse launch of preparatory work for beam delivery upgrade**
  - Input from SPSC on physics interest for such a facility
  - Conclusions from IEFC scrutiny
- **MTP 2023**
  - ATS to put forward upgrade plan for high intensity beam delivery to ECN3

Decision Timeline: ECN3

PBC document on ECN3 options post-LS3 to SPSC and Management (Mid 2023) in preparation of SPSC Nov 2023

Final recommendation/decision on which experiment to host (SPSC & RB November/December 2023)



CERN-PBC Report-2022-xxxx

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Post-LS3 Experimental Options in ECN3

C. Ahdida, G. Arduini, K. Balazs, H. Bartosik, J. Bernhard, A. Boyarsky, M. Brugger, M. Calviani, A. Ceccucci, B. Döbrich, M. Fraser, A. Golutvin, E. Goudzovski, J. Jaeckel, R. Jacobsson, Y. Kadi, F. Kahlhöfer, M. Koval, G. Lanfranchi, C. Lazzeroni, K. Massri, M. Moulson, J. Osborne, M. Pospelov, Ch. Rembser, A. Rozanov, G. Ruggiero, G. Rumolo, T. Spadaro, C. Vallée (to be finalized).

Abstract

The Experimental Cavern North 3 (ECN3) is an underground experimental cavern on the CERN Prévessin site. ECN3 currently hosts the NA62 experiment, with a physics programme devoted to rare kaon decays and searches of hidden particles approved until LS3. Several options are proposed on the longer term in order to make best use of the worldwide unique potential of the high-intensity/high-energy proton beam extracted from the SPS in ECN3. The current status of their study by the CERN Physics Beyond Colliders study group is presented, including considerations on beam requirements and upgrades, detector R&D and construction, schedules and cost, as well as physics potential within the CERN and worldwide landscape.

Geneva, Switzerland

June 23, 2022

Critical input from:

- Experiments
- BSM WGs and FIP Physics Centre
- ECN3 Beam Delivery Task Force, BDF and CB WGs
- NA-CONS

- Several ATS groups involved

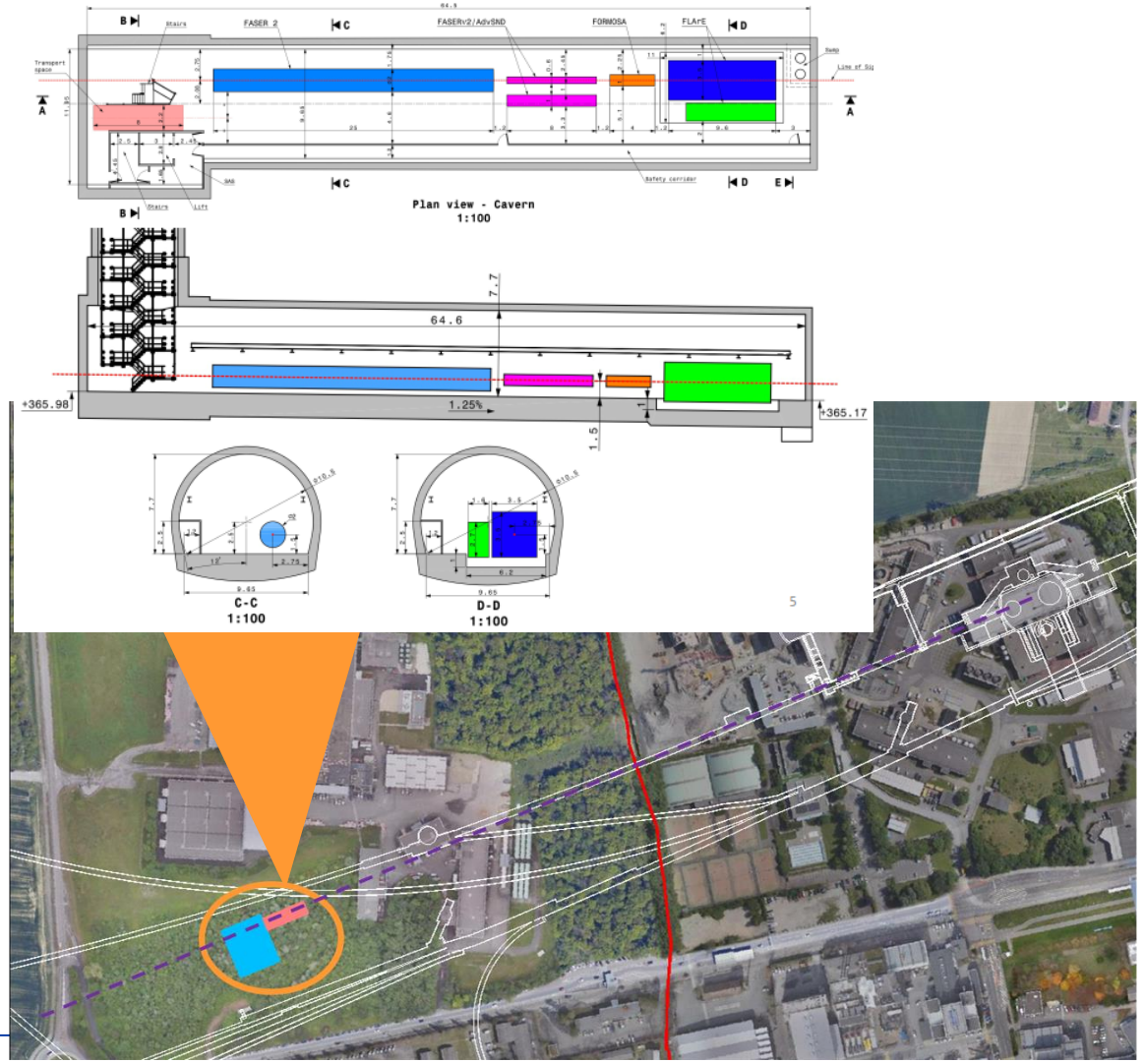
Forward Physics Facility

It builds on the experience of FASER and SND@LHC

A new facility on LHC IP1 Line of Sight (like FASER@LHC)

Would take advantage of (so far unexploited) particles already produced in LHC collisions maximizing the physics output from the LHC (Very Weakly Interacting Particles, Very High Energy ν physics, QCD/PDF)

Cavern hosting large-scale forward detectors in the HL-LHC era



Forward Physics Facility

Extensive White Paper submitted to Snowmass
(arXiv:2203.05090**)**

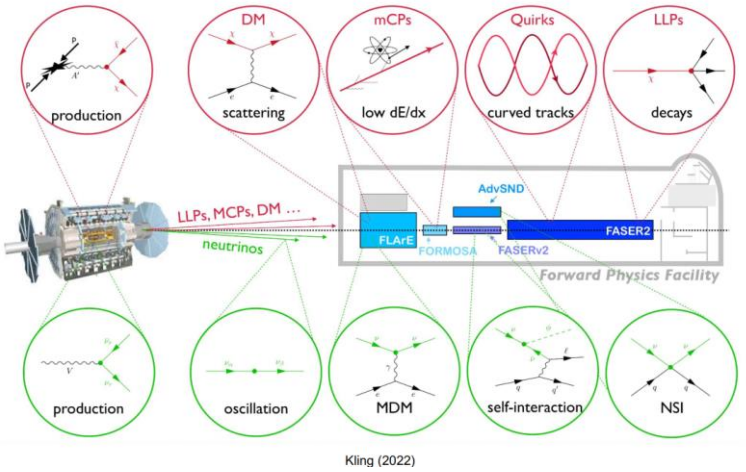
- ~400 authors/endorsers from 200 institutions

Strong support from Snowmass Energy & Neutrino Frontiers (~O(M$) grants already attributed in the US)

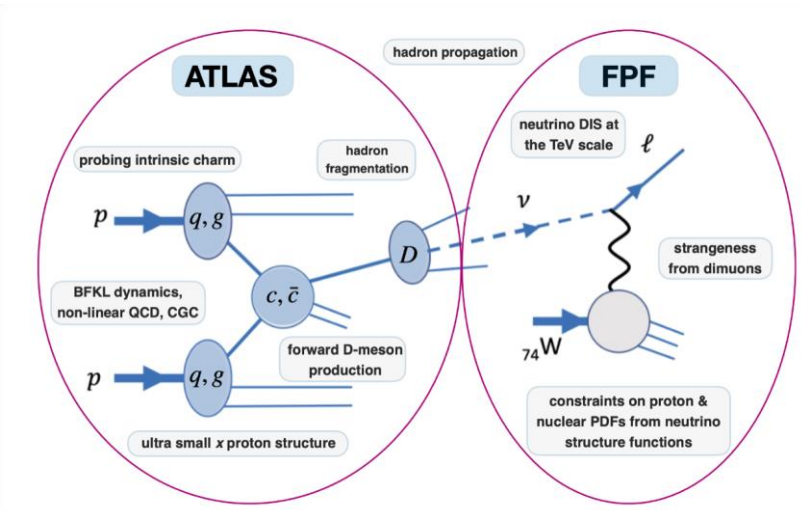
2022 Snowmass Energy Frontier Summary

Our highest immediate priority accelerator and project is the HL-LHC, the successful completion of the detector upgrades, operations of the detectors at the HL-LHC, data taking and analysis, including the construction of auxiliary experiments that extend the reach of HL-LHC in kinematic regions uncovered by the detector upgrades.

Resource needs and plan for the 5-year period starting 2025:
1. Prioritize HL-LHC physics program, including auxiliary experiments.



Kling (2022)

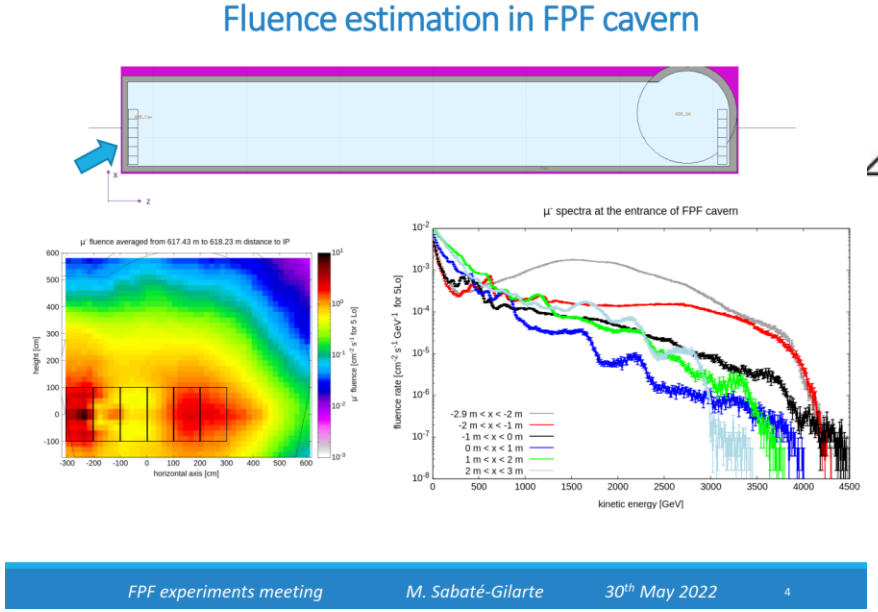


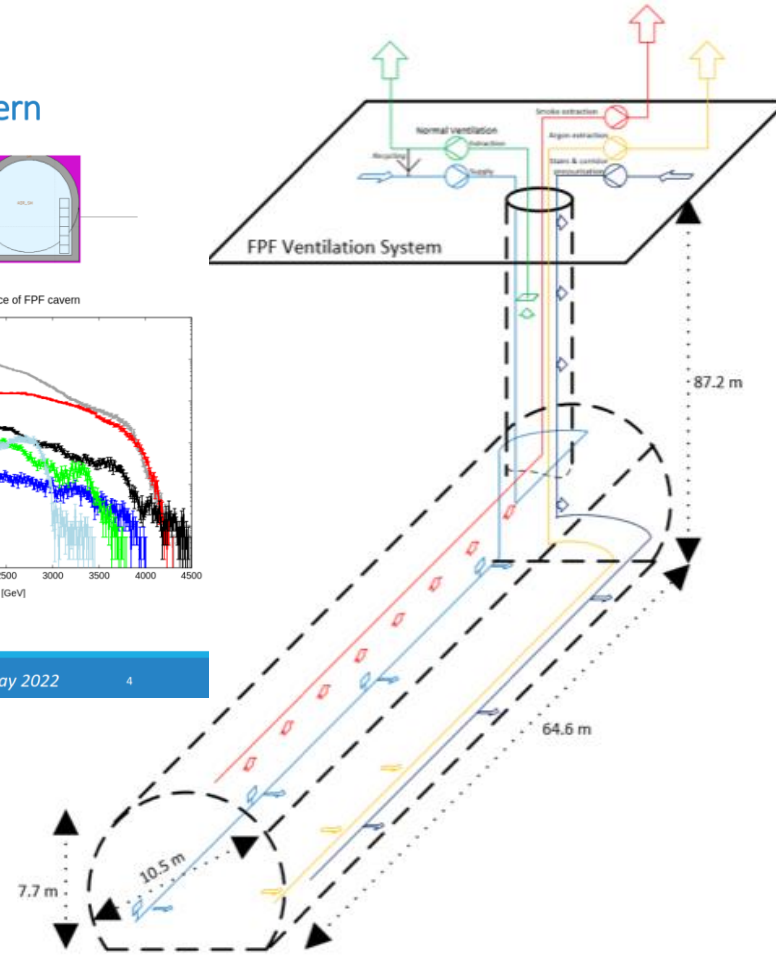
Forward Physics Facility

Quite some progress in the conceptual design of the infrastructure:

- Now decoupled from LHC schedule (pending results of the study of vibrations due to civil engineering)
- Technical system requirements and costs being refined
- μ background appears to be under control ➔ FLUKA estimates validated at FASER/SND
- Site investigations planned for early next year

Growing experimental community with structure in place now focused on the development of detector concepts/complementarity



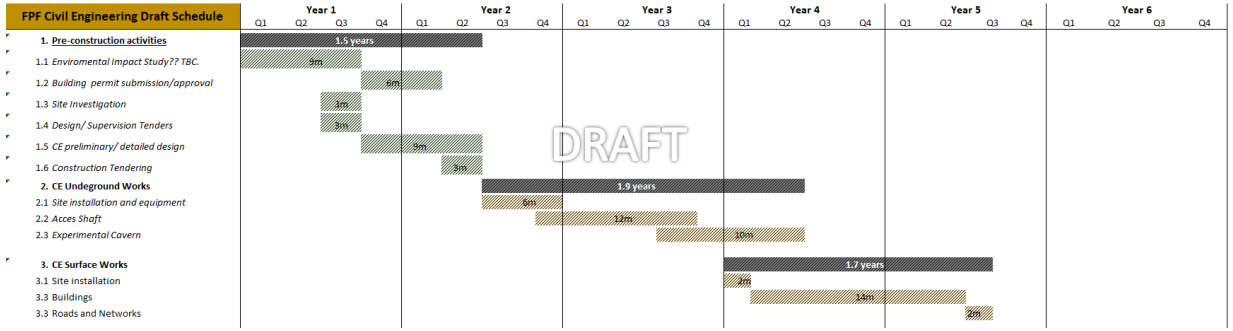


Forward Physics Facility

Aim for commissioning before the end of Run 4 to profit of HL integrated luminosity

Possible implementation timeline

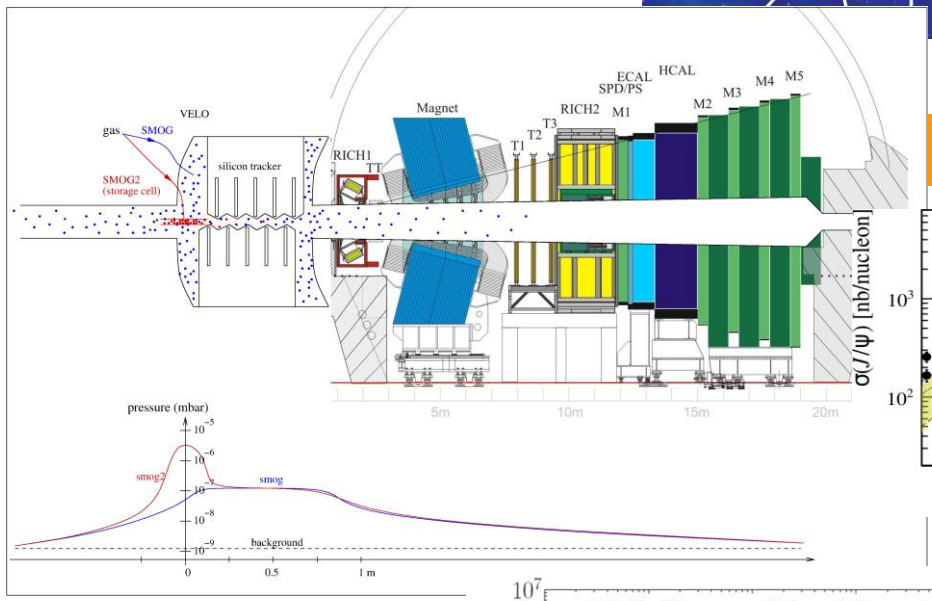
- 2023 - LoI to LHCC
- 2024-2025 - Facility CDR
- 2024-2025 - Experiment(s) CDR / Physics CDR
- If decision during 2025:
  - 2025-2026 - Facility TDR
  - 2026-2027 - Experiment TDRs
  - Civil Engineering 2027-2029
  - Staged Installation & commissioning 2029-2031



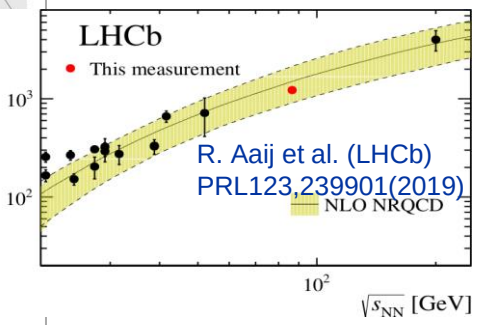
LHC Fixed Target

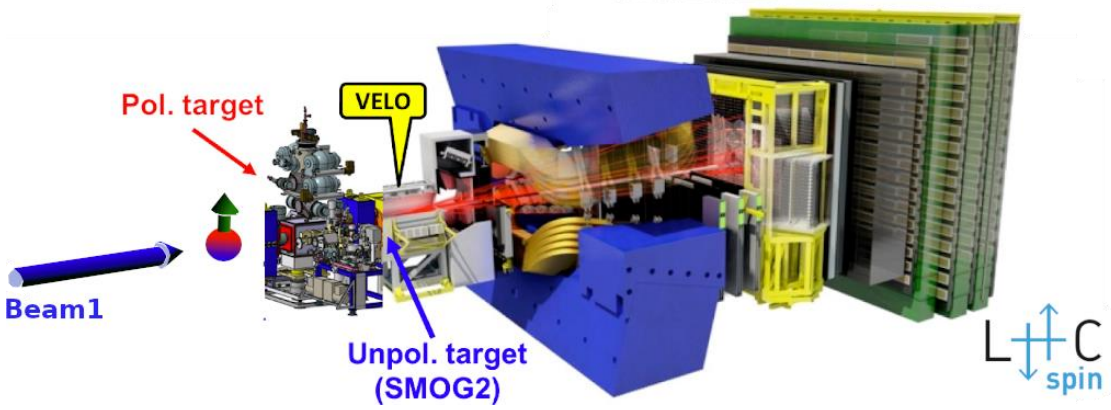
New era opened by SMOG and SMOG2

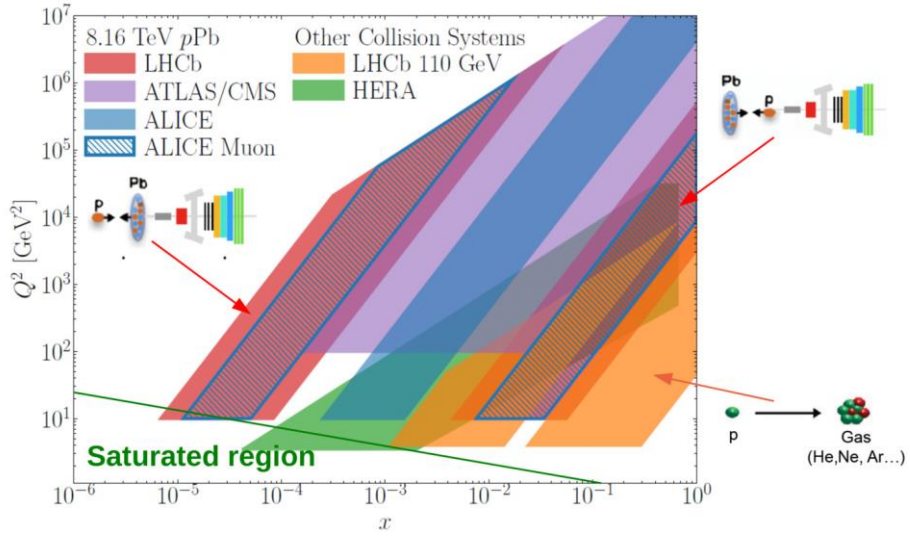
- Complementary to collider mode
- Connection with Astrophysics
- QCD, QGP, nucleon structure
- Possible development:



Charm production

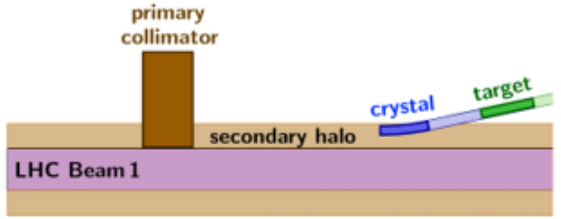






LHC Fixed Target: Crystals

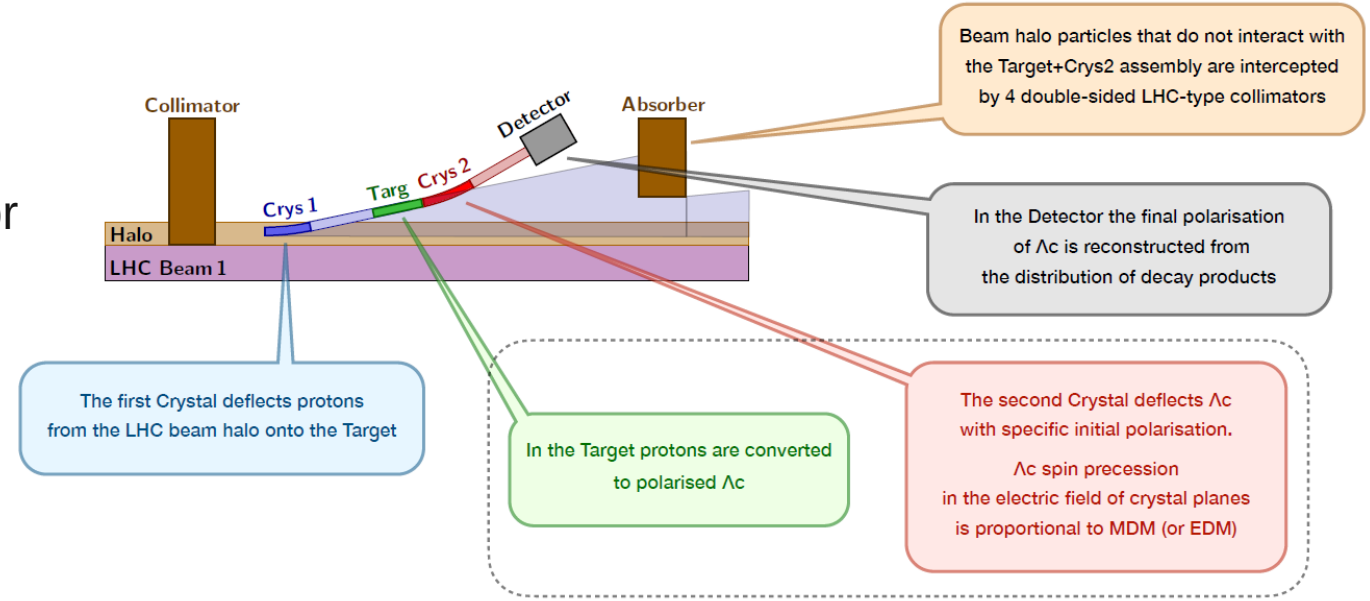
Extract the proton secondary halo by means of crystals for measurements of PDF (single crystal) or Magnetic and Electric Dipole moments of Λ_c^+ (double crystal)



A proof of principle experiment of crystal-assisted extraction of secondary halo is being designed for LHC LSS3. Aims:

- Experimental validation of channeling efficiency for long crystals @ O(TeV)
- Control/management of secondary halo
- Validate P.o.T. rate capability
- Measure background environment with a track/vertexing detector

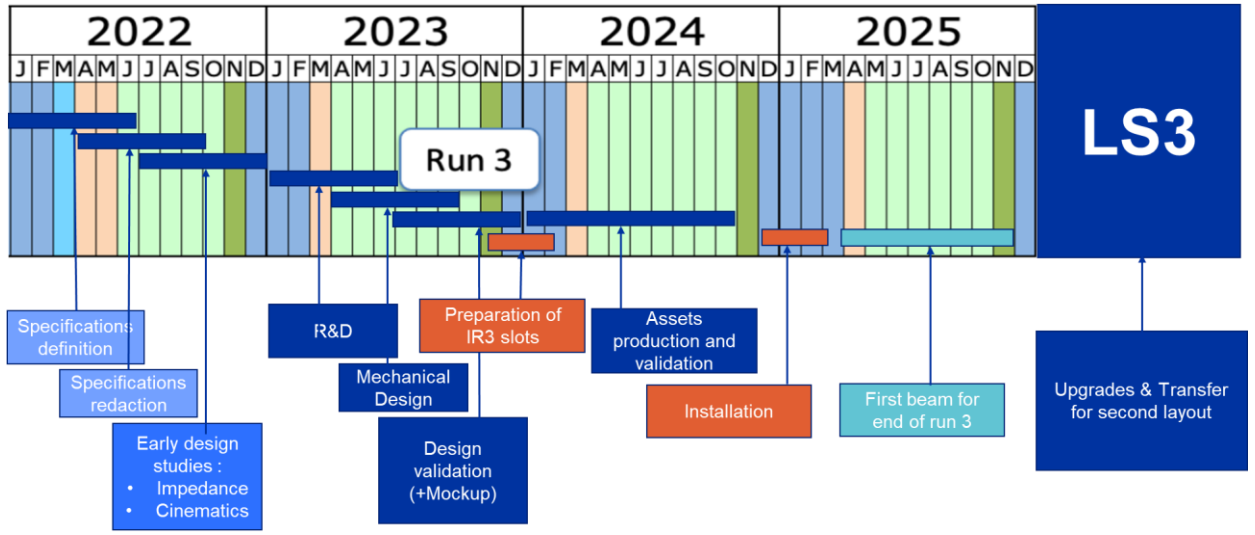
D. Mirarchi et al., Eur. Phys. J. C 80, 929 (2020)



LHC Fixed Target: Crystals

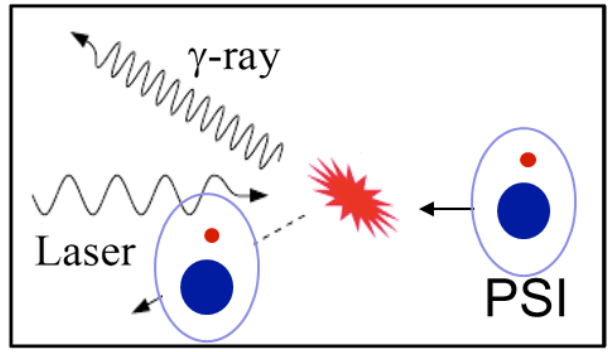
Preparation LSS3 proof of principle:

- MoU for TWOCRYST Collaboration being signed (INFN Milano/Padova/Ferrara, IJCLab, Valencia University, ….)
- Locations for installation of equipment identified
- Functional and operational specifications for double-crystal setup in LHC IR3 released
- TWOCRYST Work Breakdown Structure (WBS) being prepared in discussion with the relevant groups at CERN and outside
- Aim for endorsement ATSMB/LMC beginning 2023 for test before the end of Run 3



In parallel, LoIs will be submitted to LHCC during 2023 for experiments profiting of this technique during LS3/Run 4

Gamma Factory



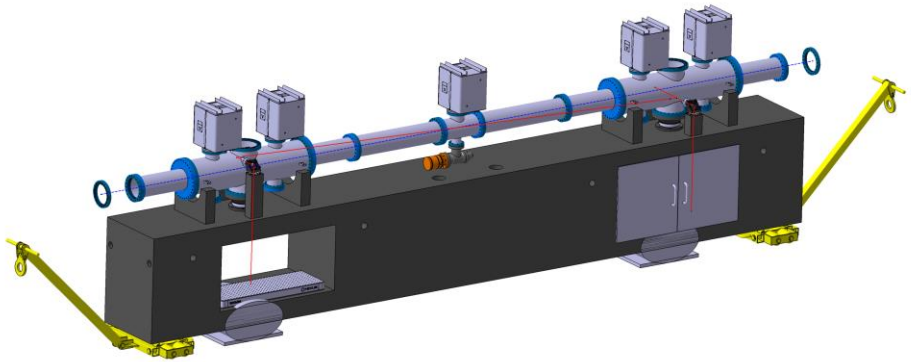
Quite a number of possible ideas for SPS and LHC

Experimental community to gather around one at least

- Could be used to cool transversally light ion beams in the SPS for LHC ion experiments provided LHC can preserve the beam brightness and the integrated luminosity is visibly increased

A proof of principle is required:

- R&D for low noise laser oscillator and high finesse Fabry-Perot Cavity (~5 mJ per pulse - up to 40 MHz) ➔ ongoing collaboration with IJCLab
- Integration of Fabry Perot Cavity + operation in a high intensity hadron machine



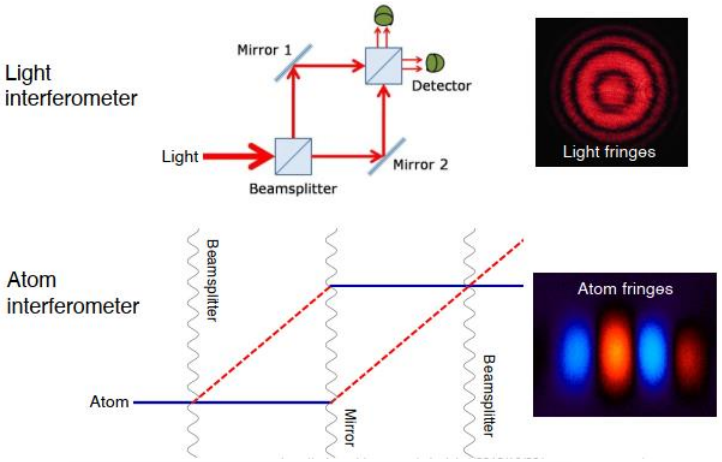
Gamma Factory SPS Proof of Principle

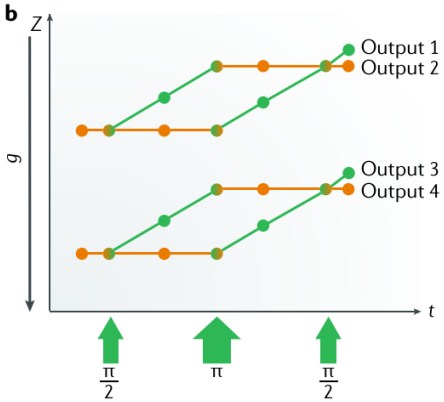
- European INFRA-DEV Grant as a bootstrap for this activity aiming for test during Run 4: cover a fraction of material and personnel costs of the design and proof of principle for a Gamma Factory (next call: beg 2024)
  - Need to enlarge the collaboration and seek support from TIARA (ongoing)
  - At least 50% of the contributions should come from the participants to the Grant
  - Very useful Workshop at the end of October to review required resources and contributions
- It could lay the foundation for a possible ATS project if the benefit for a future LHC light ion programme is demonstrated (at least on paper)

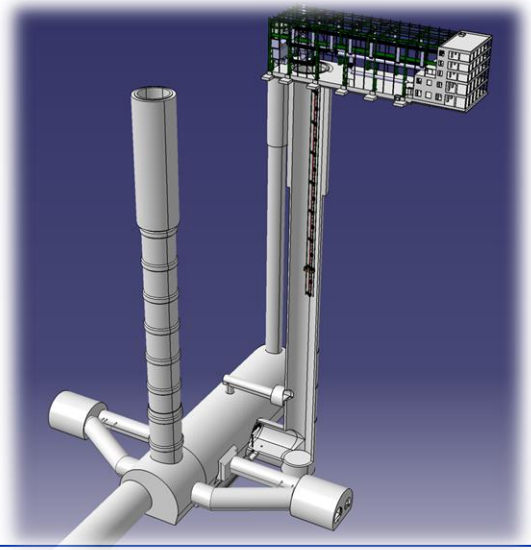
AION-100@CERN

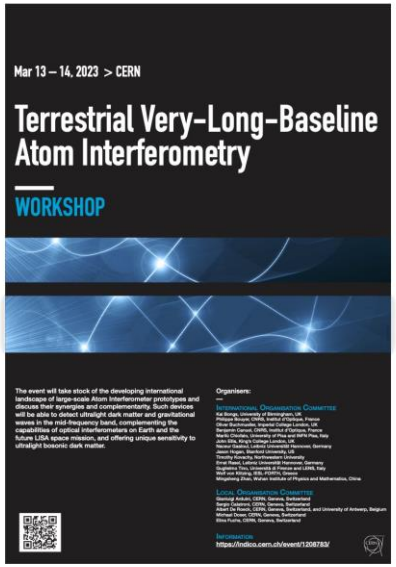
AION (Atom Interferometer Observatory and Network) for mid-frequency gravitational waves and ultra-light Dark Matter detection

- Proof-of-Principle (10m) being built in UK
- Siting of a 100m setup in an LHC shaft (PX46) under investigation in PBC (Integration, RP & general safety, evaluation of EM interference -RF zone- and seismic noise /vibrations).
- Timeline:
  - Feasibility study for CERN implementation by beginning 2023
  - Selection of preferred location (CERN, Boulby Mine, Daresbury Tower – UK) during 2023
  - LoI submission to CERN by end 2023-beginning 2024 (LHCC or SPSC) if CERN is retained
  - Preparations (access, shielding, safety…) should occur during LS3



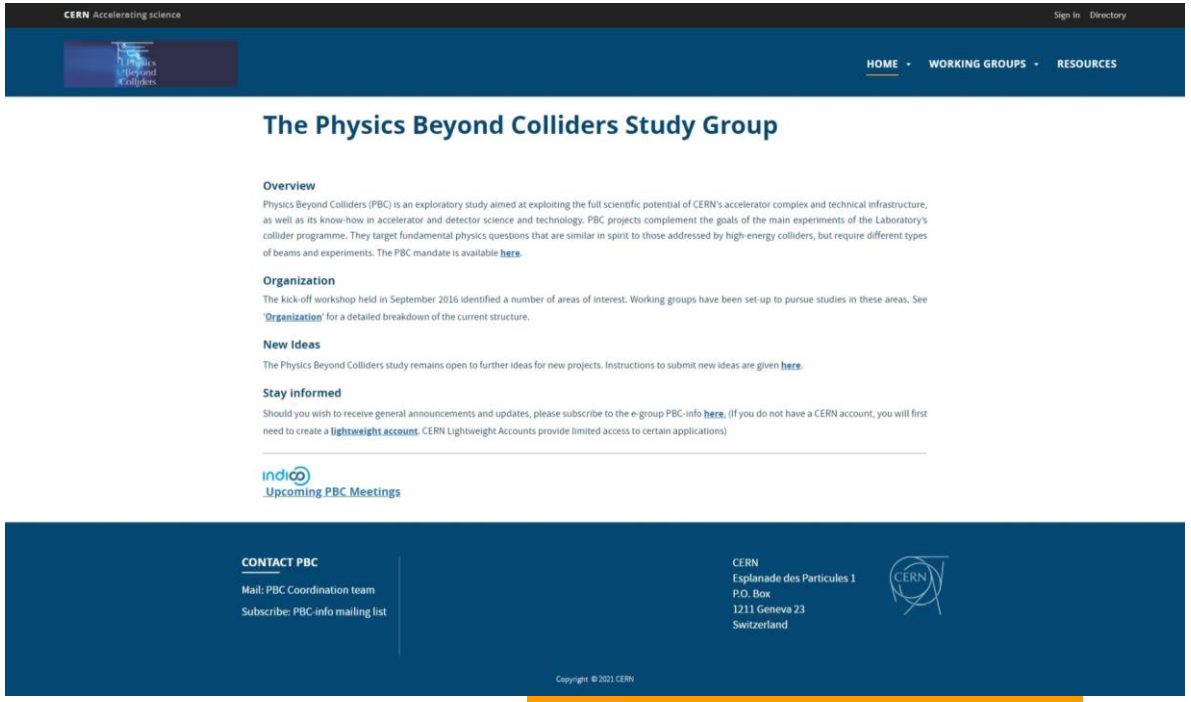




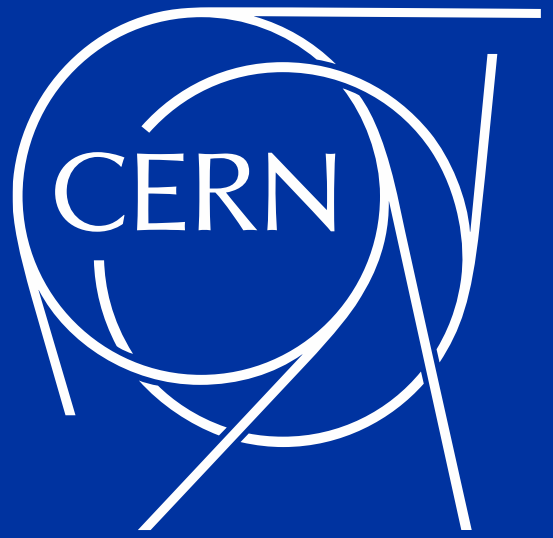


Summary

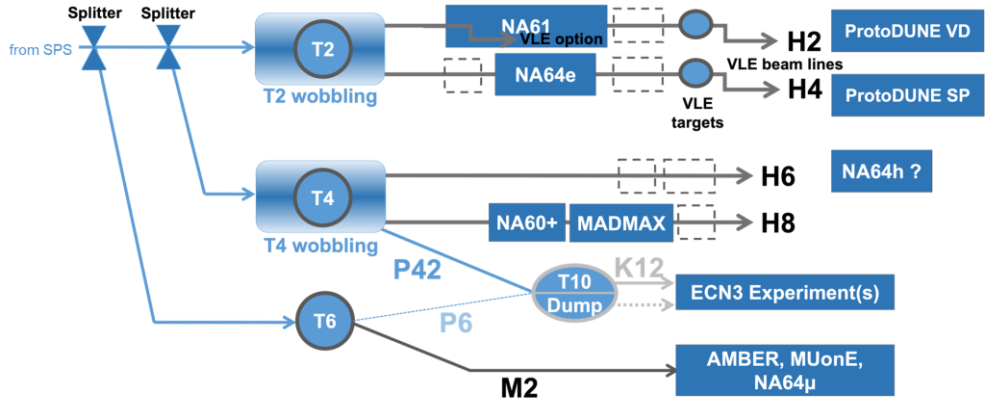
- PBC is supporting projects, benefitting from CERN competence and expertise, in view of the submission of proposals to the relevant CERN Scientific Committees
- Those with a potential implementation at CERN have been presented
- The support of the ATS Groups is vital and warmly acknowledged



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


CERN

North Area High Intensity Beams ECN3

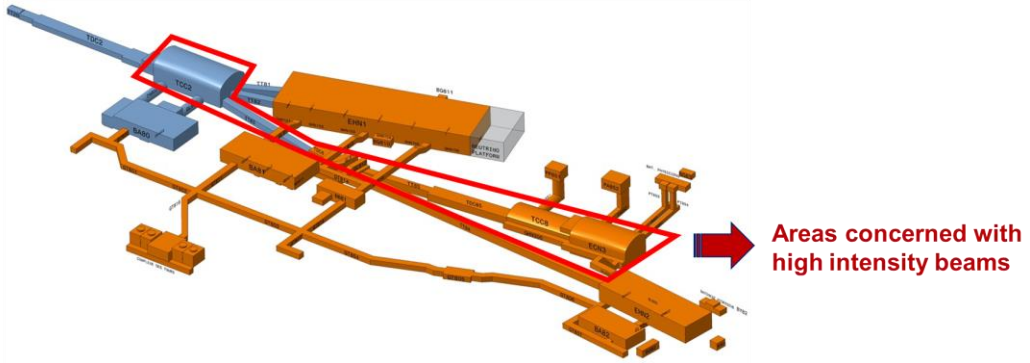


High Intensity programme @ ECN3 must be compatible with expected requirements for the other North Experimental Areas (EHN1 and EHN2) and SPS capabilities

Beam loss/radiation control, beam quality (reproducibility, spill structure etc.) are challenging future requirements

Consolidation programme ongoing

Consolidation Phase 1 (funded): 2019 – 2027



Consolidation Phase 2 (not yet funded): 2028 – 2033

Important to identify synergies and implications of a future ECN3 High Intensity programme on North Area Consolidation

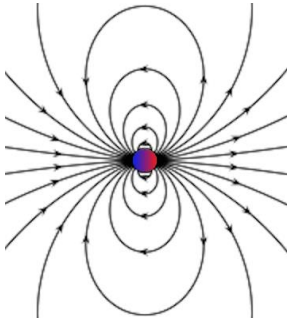
Gamma Factory: SPS PoP

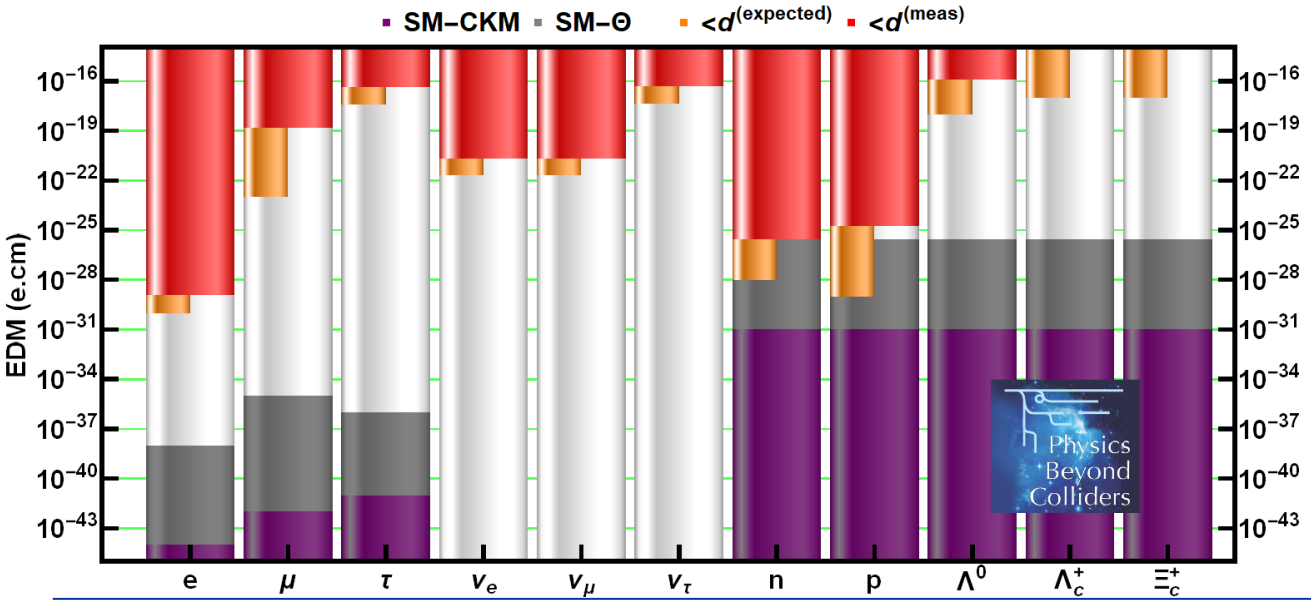
- Assuming delivery of cooled ions for ALICE3 ion operation (Run 5) as a goal
  - More invasive and time-consuming preparations for the PoP during LS3
  - Demonstrate the principle in the first half of Run 4
  - Specify and implement required modifications to the laser system for the selected ion specie
  - Commission the injectors and the corresponding cooling scheme in the SPS before the start/beginning of LHC Run 5

LHC Fixed Target

Magnetic Dipole Moments

- Fundamental static property of particles
- MDM measurement for c/b hadrons, tau missing
  - Short flight distances
  - Possible at LHC with suitable experiment!





Electric Dipole Moments

- EDM of an elementary particle violates T and P
- CP violation in SM is not sufficient to explain antimatter/matter asymmetry in the universe.
- Need new source(s) of a large CP violation