

High Intensity Upgrades for Fixed Target Experiments at CERN

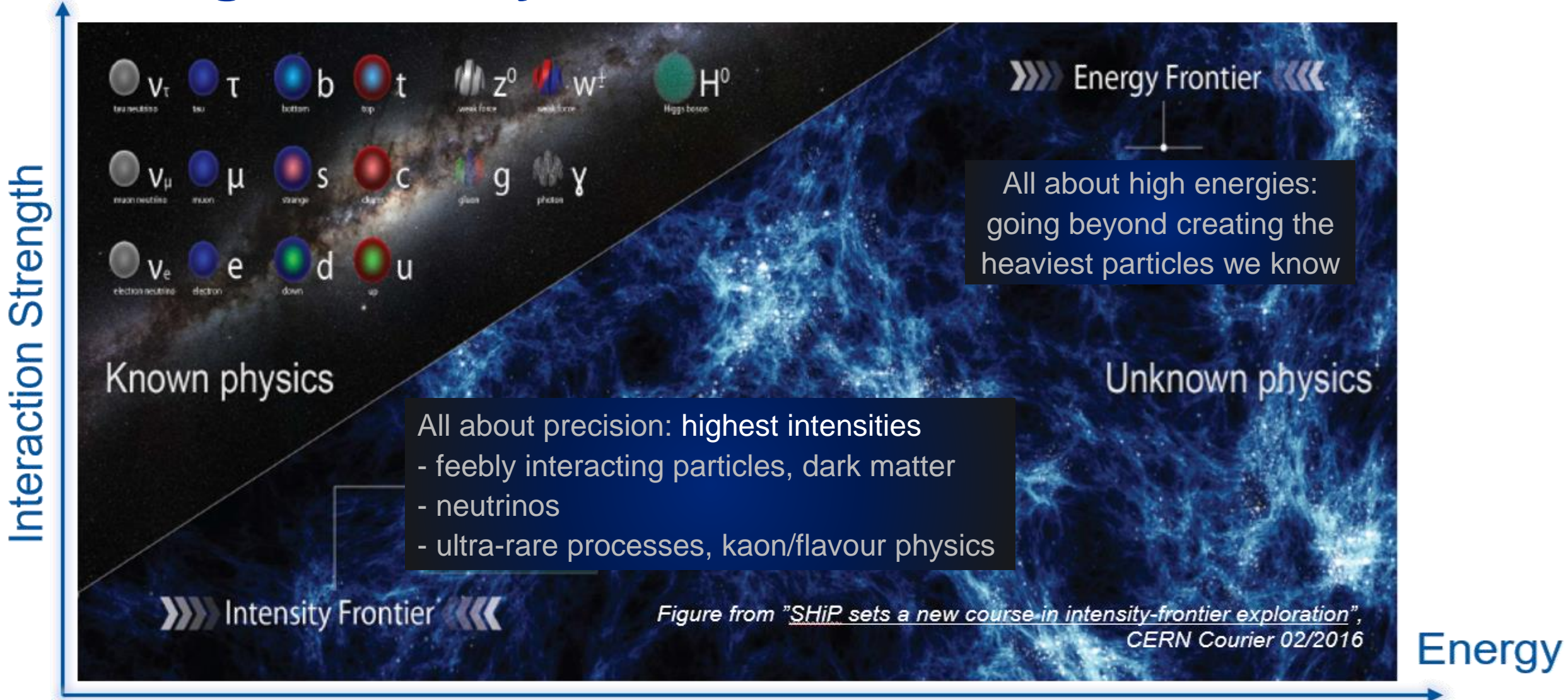
ICHEP 2024 | Prague

Johannes Bernhard (CERN) with A. Baratto Roldan, B. Rae, C. Ahdida, D. Banerjee, E. Parozzi, F. Metzger, F. Stummer, L. Nevay, L. Dyks, M. Van Dijk, M. Jebramcik, M. Brugger, M. Fraser, N. Charitonidis, R. Murphy, S. Schuh-Erhard

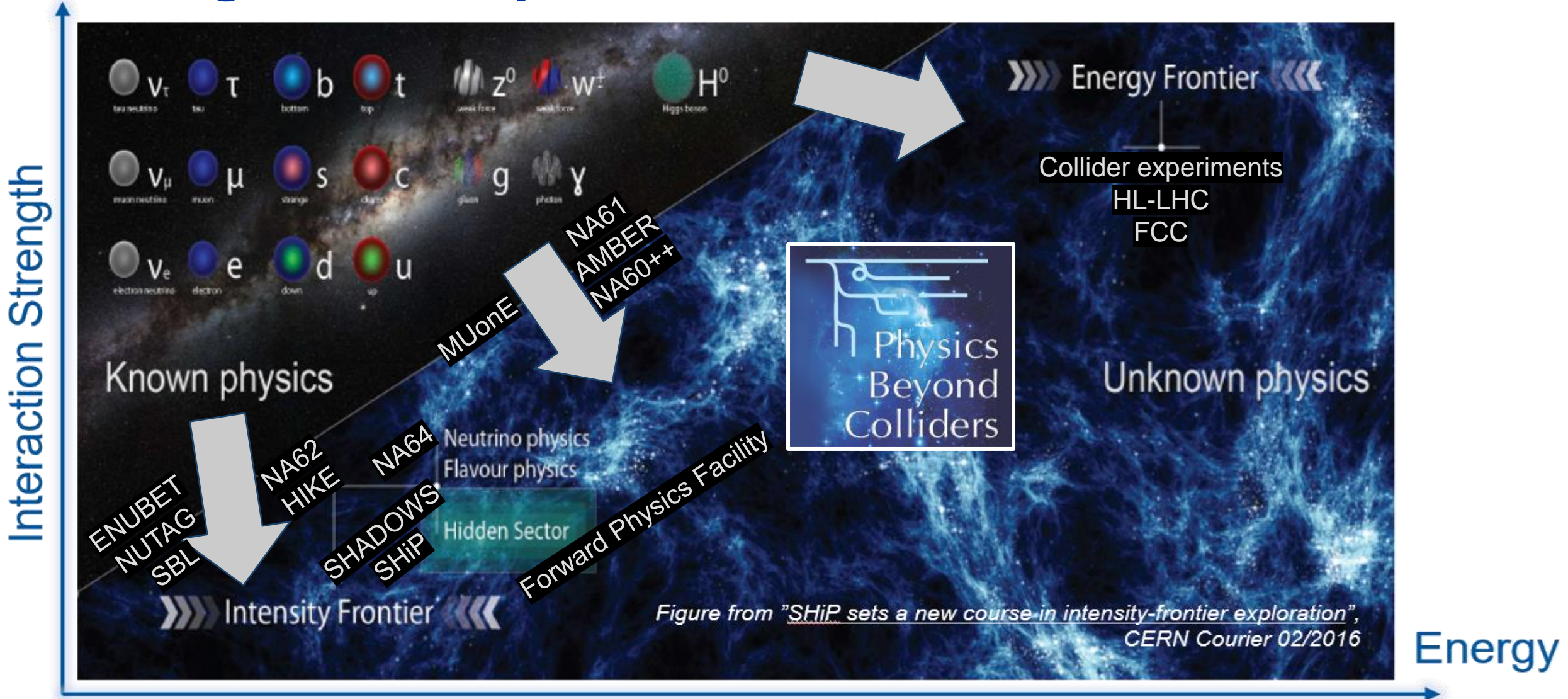
18.07.2024

johannes.bernhard@cern.ch

The High Intensity Frontier



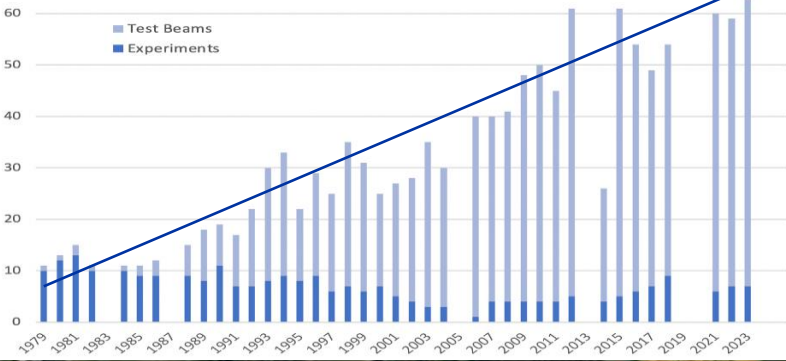
The High Intensity Frontier



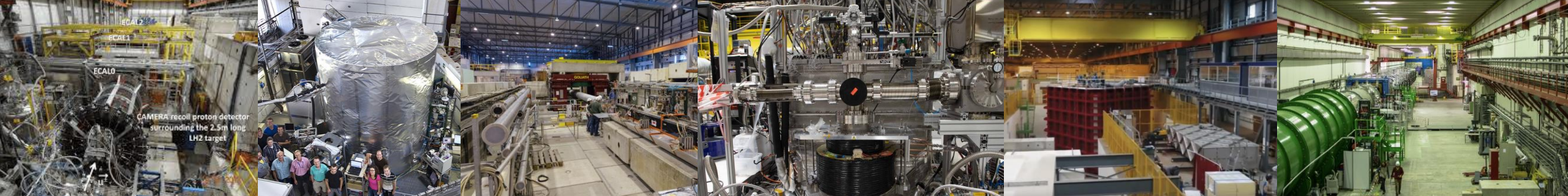
Science Diversity at CERN

Three main sites for fixed target physics:

- The **North Area** is one of the most diverse experimental facilities that currently exists, serving proton, hadron, electron, muon, and ion beams to yearly over 200 user teams for detector R&D and to the NA61, NA62, NA64, and NA66/AMBER experiments, the two large neutrino platform cryostats, as well as to the GIF++ and CERF irradiation facilities, with combined more than 2000 users. SHiP, a new dark matter search experiment, has just been approved.
- The renovated **East Area** serves the CLOUD experiment, both IRRAD and CHARM irradiation facilities, and ideas for new detectors like WCTE.
- In **AD/ELENA**, precision gets a whole new definition: BASE, BASE-STEP, ALPHA, GBAR, ASACUSA, AEgIS and PUMA set records for fundamental constants and found that anti-matter really falls down.
- Significant consolidation efforts are underway and have been carried out.



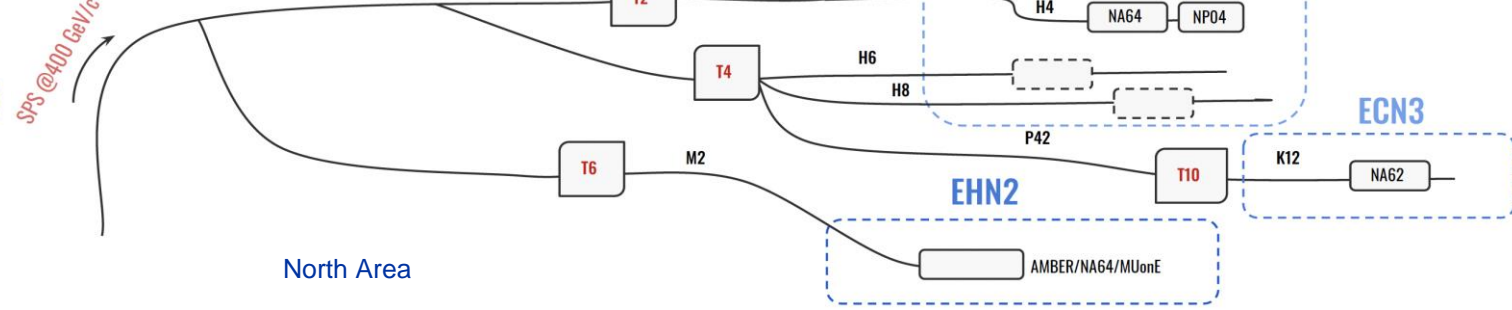
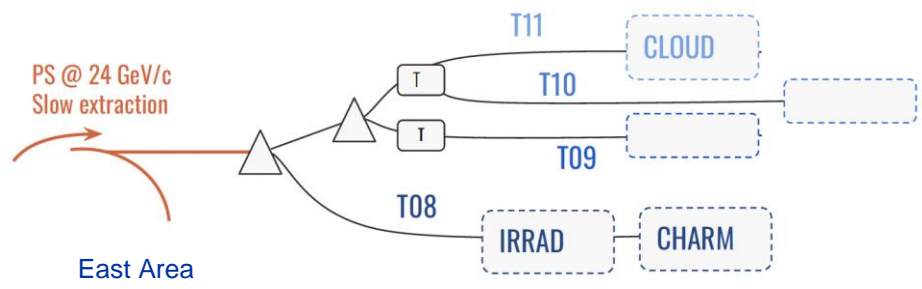
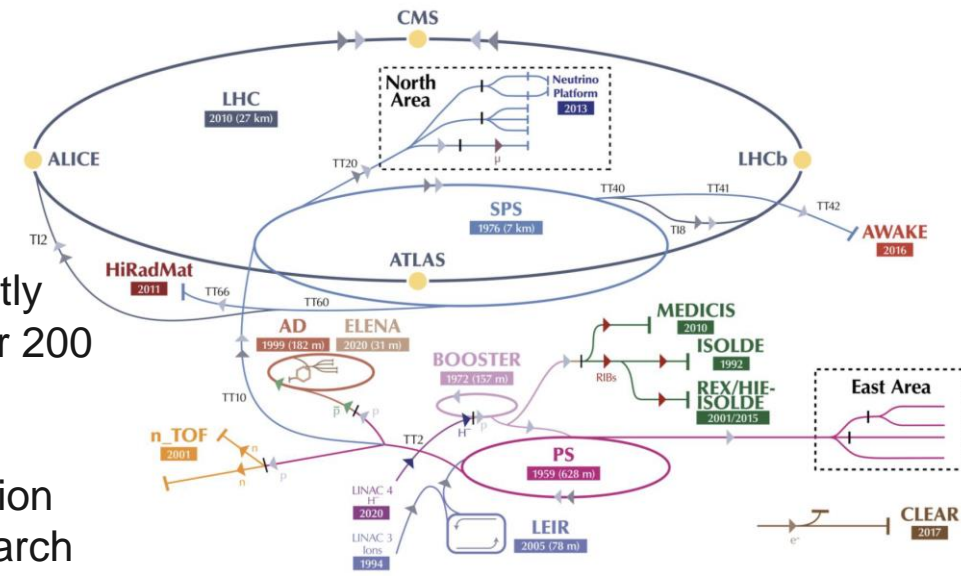
Science diversity at the intensity and precision frontiers
 27 April 2022
 The North and East experimental areas of CERN enable a wide range of measurements, from precision tests of the Standard Model to detector R&D. [Link](#)



Science Diversity at CERN

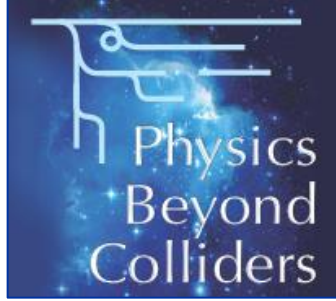
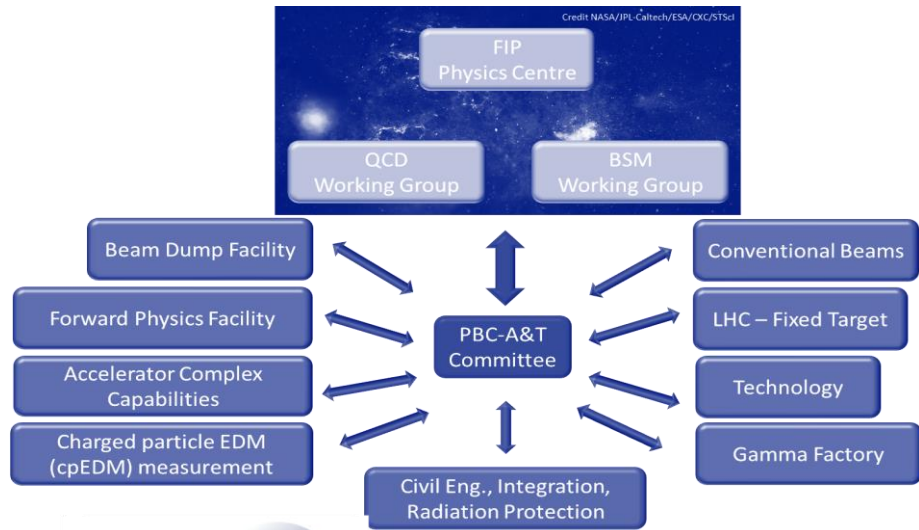
Three main sites for fixed target physics:

- The **North Area** is one of the most diverse experimental facilities that currently exists, serving proton, hadron, electron, muon, and ion beams to yearly over 200 user teams for detector R&D and to the NA61, NA62, NA64, and NA66/AMBER experiments, the two large neutrino platform cryostats, as well as to the GIF++ and CERF irradiation facilities, with combined more than 2000 users. SHiP, a new dark matter search experiment, has just been approved.
- The renovated **East Area** serves the CLOUD experiment, both IRRAD and CHARM irradiation facilities, and ideas for new detectors like WCTE.
- In **AD/ELENA**, precision gets a whole new definition: BASE, BASE-STEP, ALPHA, GBAR, ASACUSA, AEgIS and PUMA set records for fundamental constants and found that anti-matter really falls down.
- Significant consolidation efforts are underway and have been carried out.



Physics Beyond Colliders

- A driving factor for high intensity upgrades is the multitude of ideas brought forward through Physics Beyond Colliders, an exploratory study aiming at exploiting the **full scientific potential of CERN's accelerator complex** and its scientific infrastructure through projects **complementary to the LHC, HL-LHC and other possible future colliders**.
- It features projects targeting fundamental physics questions that are similar in spirit to those addressed by high-energy colliders, but that require different types of beams and experiments.
- The first PBC phase from 2016 to 2020 was an important input to the 2020 **European Strategy of Particle Physics**.
- **Several proposed experiments** of the first phase already are in operation and **taking data**, for instance NA64 μ , AMBER, and LHC Forward detectors such as FASER and SND.
- The second phase feeds input (by Q1/2025) to the next ESPP update, including ideas for new fixed target experiments.



Update of the European Strategy for Particle Physics 2020

Detector R&D

for HL-LHC, FCC, space/satellites, R2E, crystal collimation, muon collider, irradiation facilities

Dark Matter
Feebly Interacting Particles
through beam dump experiments (SHiP, Shadows, NA64e/ μ , HIKE)

4 | Other essential scientific activities for particle physics

Precision Physics
ultra-rare decays, kaon physics (NA62, HIKE), NA63, MUonE

5 | Synergies with neighbouring fields

Hot and cold QCD
emergence of mass (COMPASS, AMBER), ions and dense hadronic systems (NA61, NA60+)

Neutrino Beams
DUNE, tagged neutrino beams (ENUBET/NuTAG), production cross sections, DsTau

1 | Major developments from the 2013 Strategy

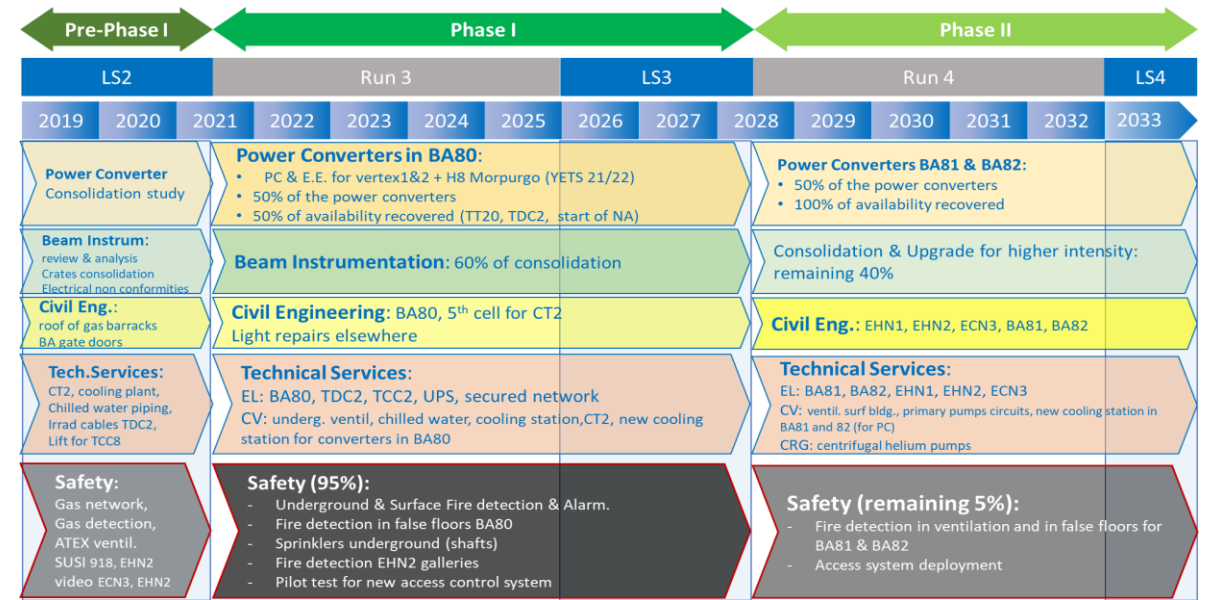


A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy. Experiments in such diverse areas that offer potential high-impact particle physics programmes at laboratories in Europe should be supported, as well as participation in such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

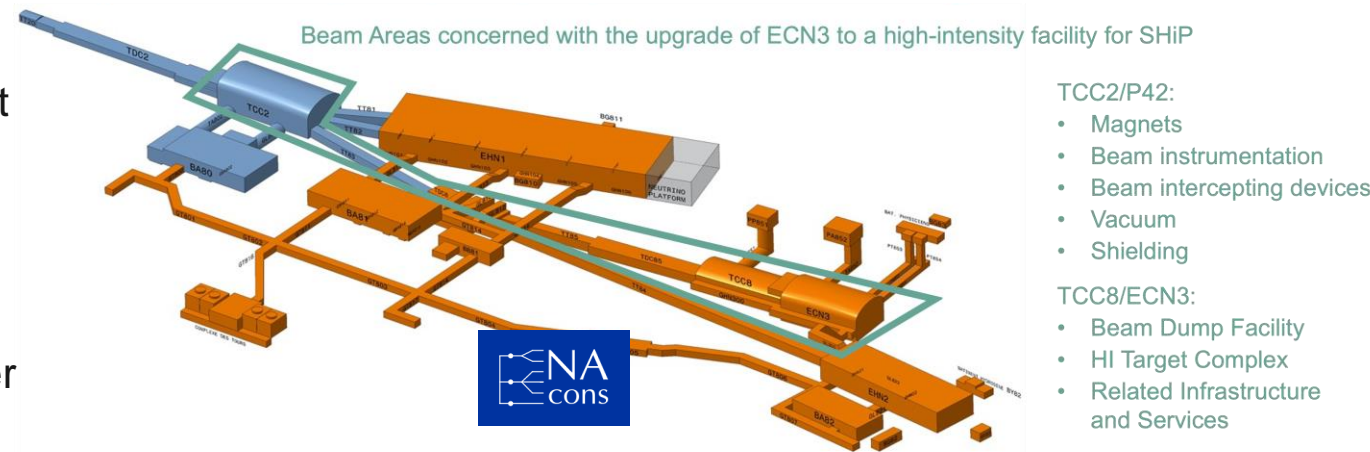
<https://europeanstrategy.cern/>

North Area Upgrades

- The recently approved North Area consolidation programme **NA-CONS** offers a unique possibility to adjust the facility to high intensity demands. At the moment, the maximum is $1.5e13$ protons per 4.8 s extraction per production target, however often limited by radiation protection considerations and experiment detector / DAQ capabilities.
- An **upgrade ideally would increase the intensity per target by at least 50%**, followed by an adaptation of the experimental areas and an upgrade programme for the experiment capabilities.
- In addition, **quality of the provided beams** shall be enhanced, e.g. better electron beam purity, availability at more beam lines in view of FCCee R&D, and smooth beam extraction without time structures.
- Just this year, a **new high-intensity beam dump experiment** has been approved for which the existing ECN3 cavern will be upgraded to stand $4e13$ protons per 1.2 s extraction at 400 GeV/c. This beam dump facility will deliver about $4e19$ protons per running year.

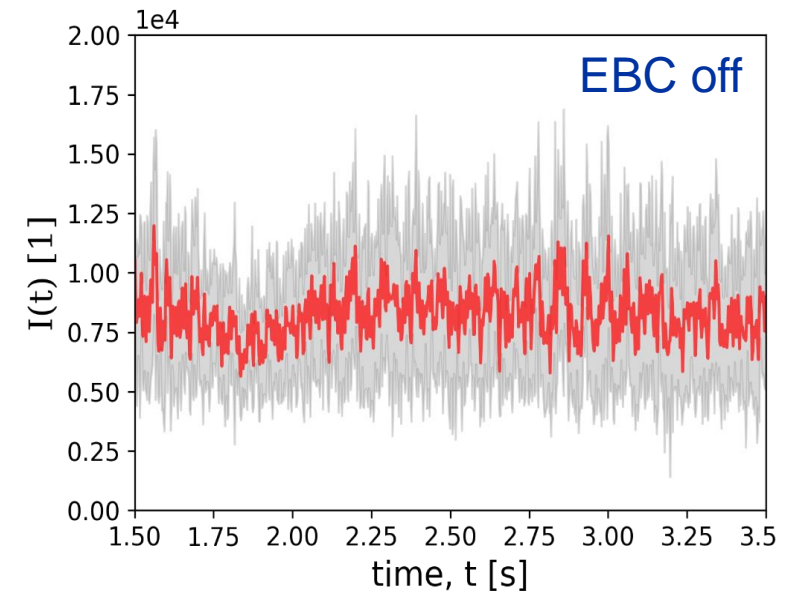
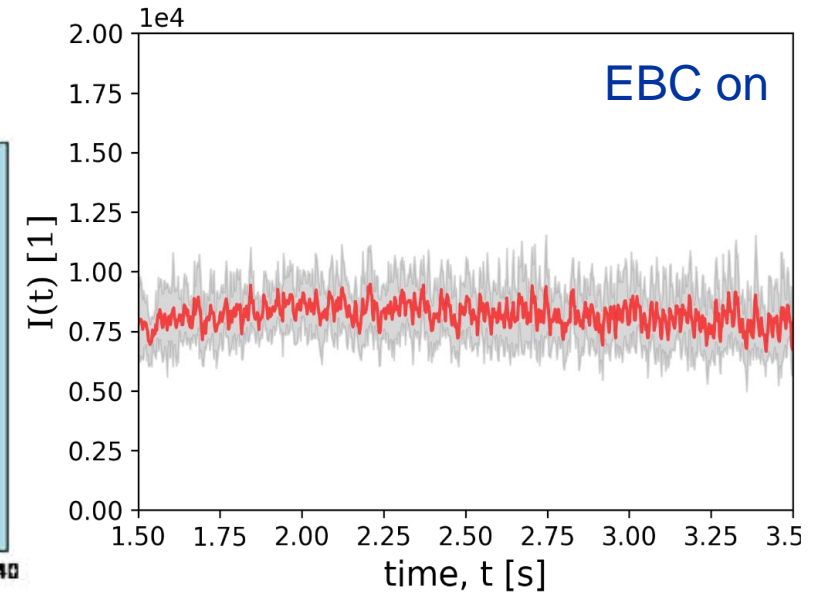
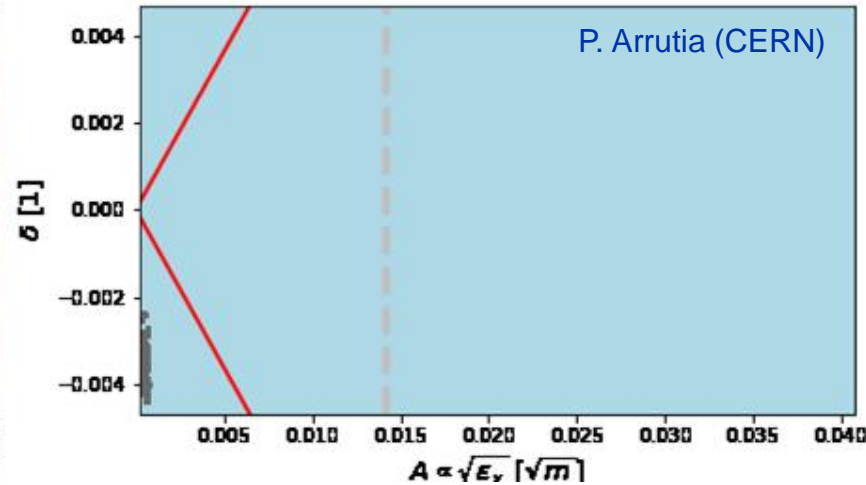
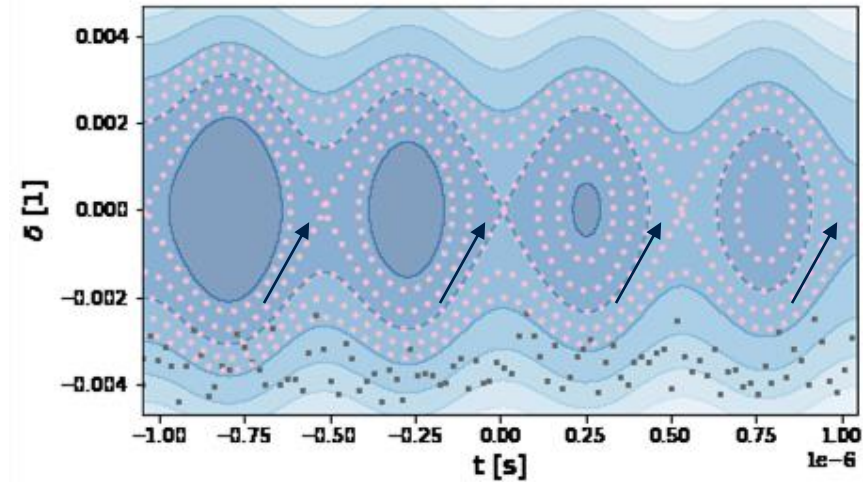


Consolidation Phase 1 (2019 – 2028):
Primary areas incl. TT20, TDC2, TCC2, BA2, BA80 & beamlines leading to EHN1, EHN2 & TCC8



Consolidation Phase 2 (2029 – 2034): BA81, BA82, EHN1, EHN2 & associated beamlines

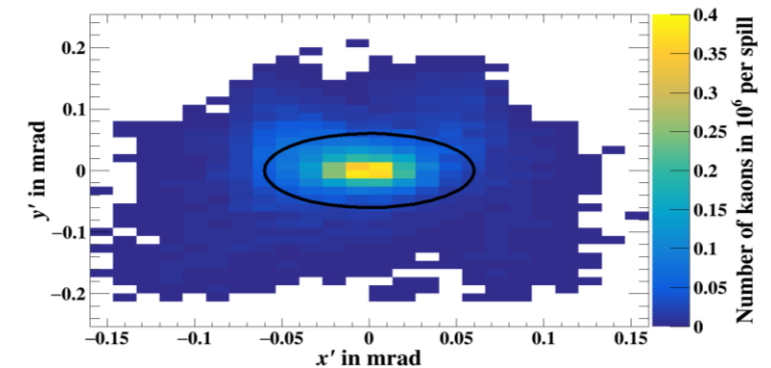
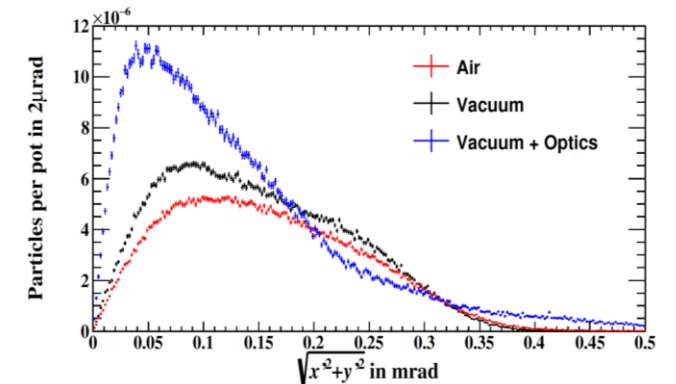
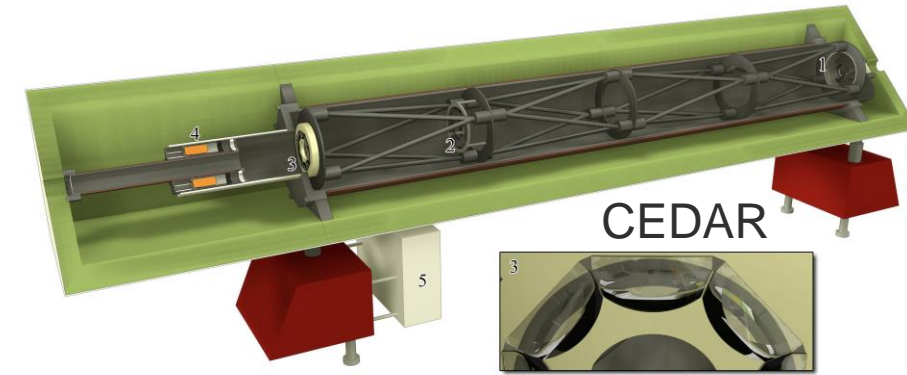
Beam Extraction – Time Structures



- With experiments requiring to run at highest intensities, the extraction quality becomes more important.
- Especially time structures at 50 Hz and 150 Hz, introduced via power converters, can easily lead to data acquisition issues due to peaks in the instantaneous intensity.
- Amongst several improvements on the hardware and controls-side, empty bucket channelling looks very promising: the de-bunched beam is forced up and “channelled” between the empty buckets.

Upgrade Plans for QCD experiments: AMBER

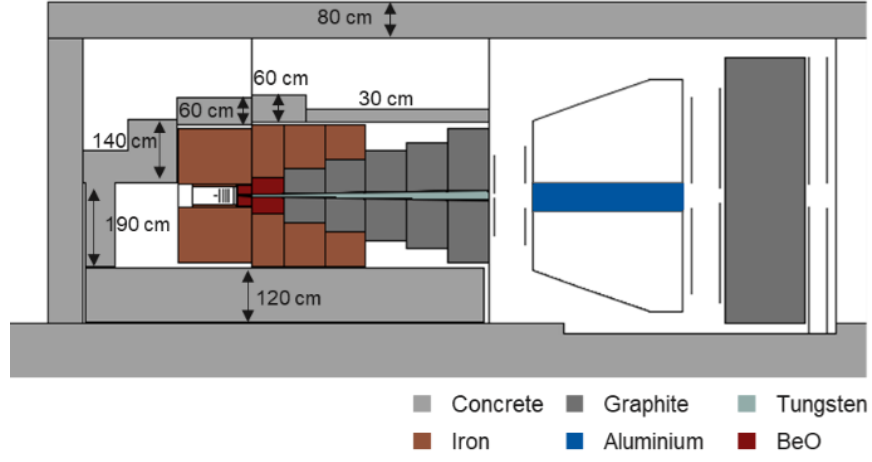
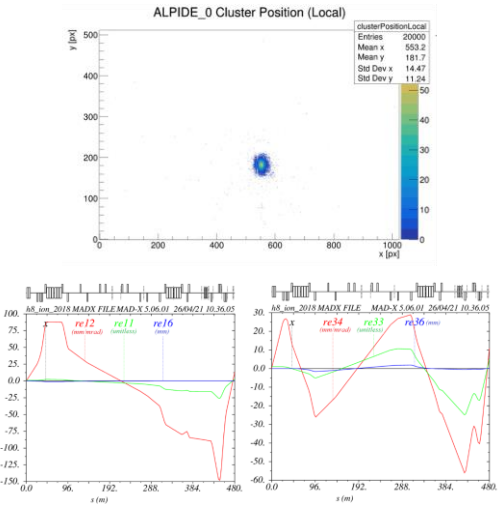
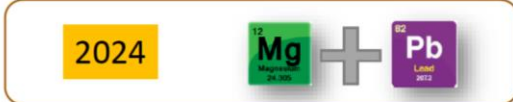
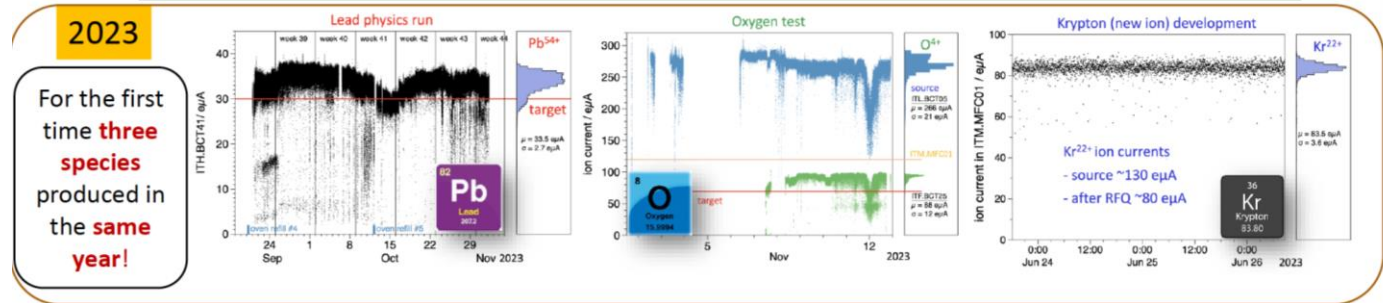
- The AMBER experiment has a wide range of QCD-related measurements with needs of muon and hadron beams of high intensities.
- So far, the limit of the hadron beam intensity is 4×10^8 per 4.8 s extraction for the Drell-Yan measurement, constrained by radiation protection (overground hall).
- As the beam contains hadrons of all sorts, differential Cherenkov detectors (CEDARs) are used for beam particle identification, which are sensitive to the beam divergence.
- Combined with an upgrade of the CEDAR PMT readout, additional heavy shielding aims at increasing the intensity to a max. 1×10^9 hadrons per 4.8 s spill, still being able to discriminate minority particles in the beam, e.g. Kaons.
- In order to reduce beam losses and to reduce the beam divergence for better PID, the vacuum of the M2 line is going to be completed (about 80 m out of 1.2 km in air) and will be upgraded. An additional collimator will improve the collimation scheme and clean beam tails with higher divergence.
- Outcome of the study: 6×10^6 kaons per spill within $60 \mu\text{rad}$ divergence (now 2.7×10^6).
- See also D. Giordano's [talk](#).



Upgrade Plans for QCD experiments: NA60+ and NA61

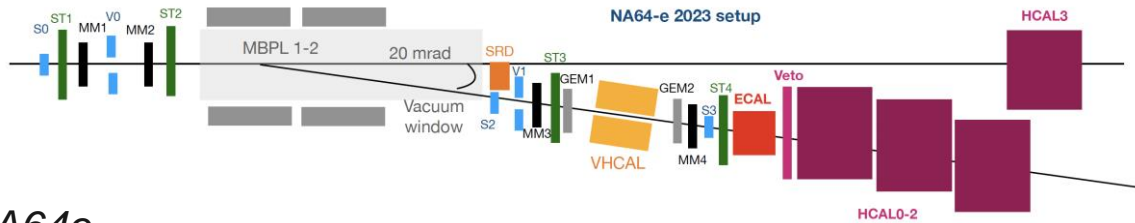
- The running NA61 experiment benefits already from an intensity upgrade done during Long Stop 2 and wishes now for more available ion species in the future
- A new experiment, NA60+, aims at measuring dilepton and heavy quark production in Pb-Pb collisions. They have brought forward a request for a Pb beam with 1e7 primary lead ion per 4.8 s spill at several energies in order to reach about 1e12 Pb ions per energy in total.
- It is important to have control measurements with proton beams at different momenta, requiring to collect about 5e13 protons per energy point.
- A feasibility study is currently being completed. A test beam confirmed already the possibility to extract 2.4e6 ions at the highest energy with a beam spot size of only 280 by 280 μm^2 .
- Radiation studies performed to be able to reach higher intensities in NA60+. New shielding design proposed, and implementation/installation being finalised.

STUDIES FOR FUTURE IONS



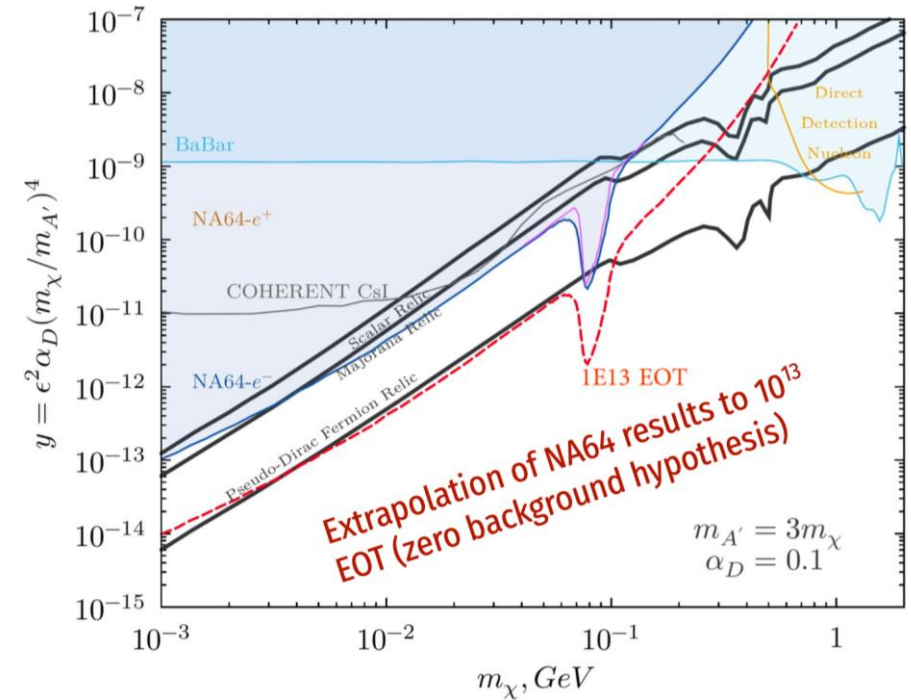
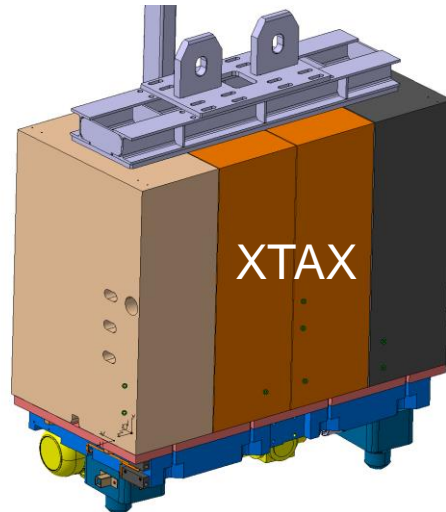
Upgrade Plans for Dark Matter Searches: NA64

NA64 is an active target beam dump experiment that uses the missing energy technique in both electron (NA64e) and muon beams (NA64 μ), see A. Marini's [talk](#).



NA64e

- So far collected 1.5E12 electrons on target (EOT) since 2016 at 1e6 up to 5e6 electrons per 4.8 s spill intensity.
- Aim to double statistics post-LS3 and a total of 1E13 EOT at 1E7 electrons/spill.
- Key: Upgrade of beam dump for non-interacting primary beam at the production target (XTAX).
- A new measurement method with positron beams has been tested (POKER) and boosts sensitivity around the 100 MeV mass range.



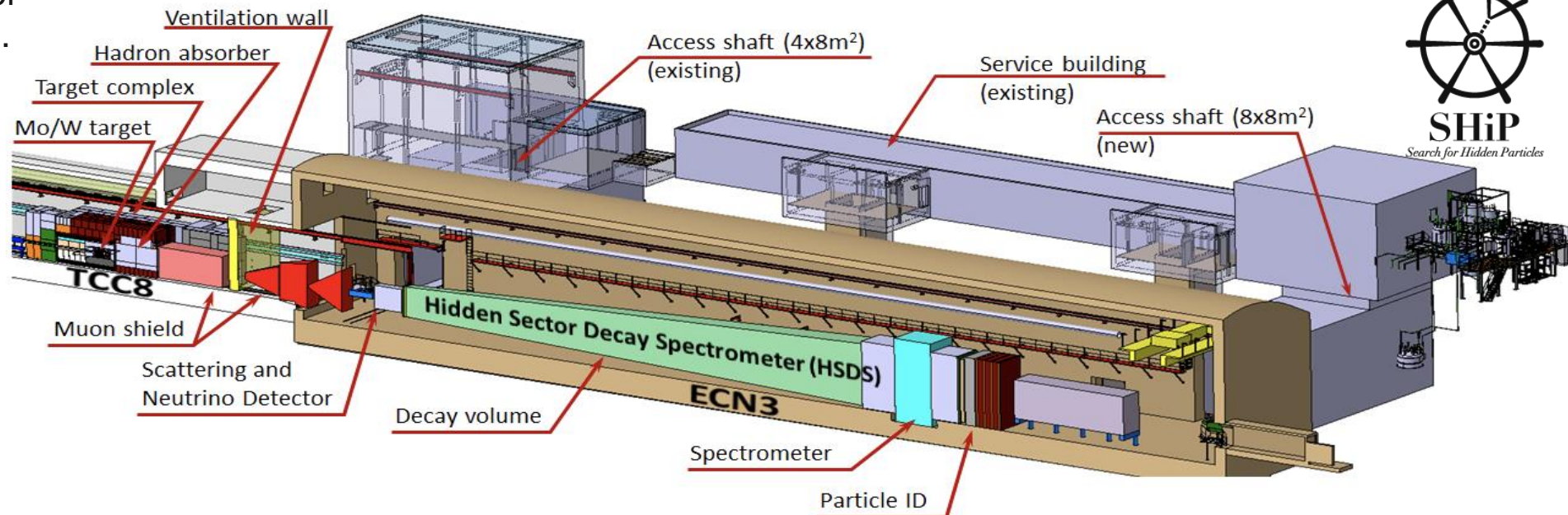
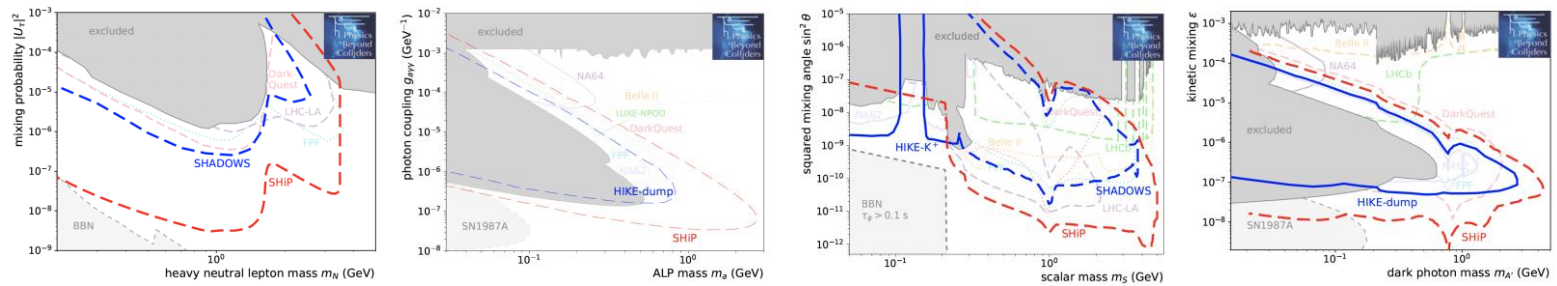
NA64 μ

- Just started physics data taking recently, limited mostly by detector and DAQ rate capability to about 1e6 muons per 4.8 extraction.
- M2 beam can already deliver 4e8 muons / 4.8 s extraction.

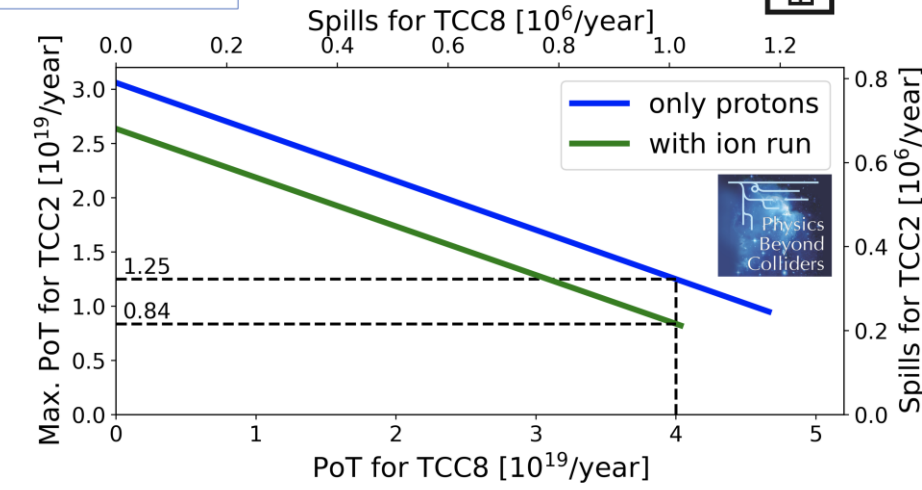
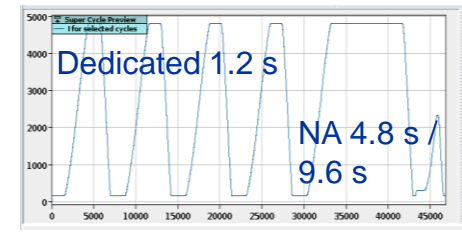
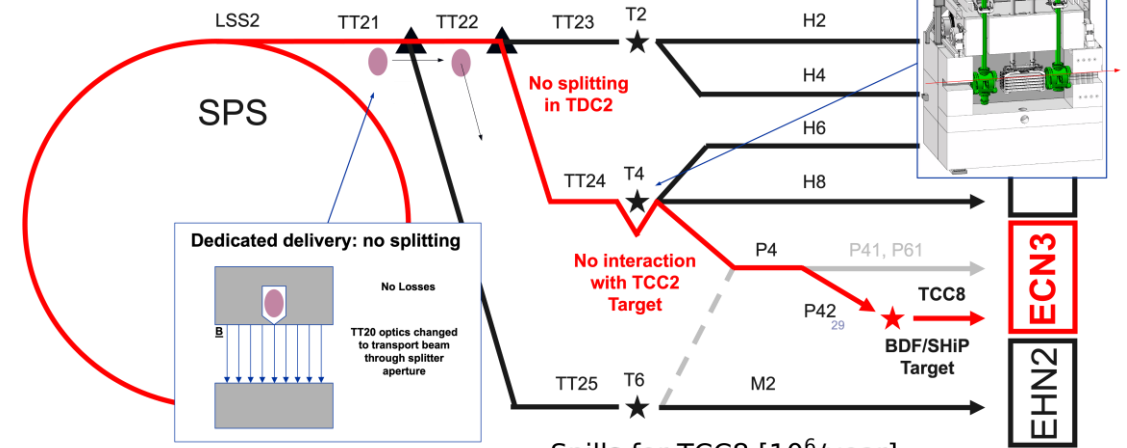
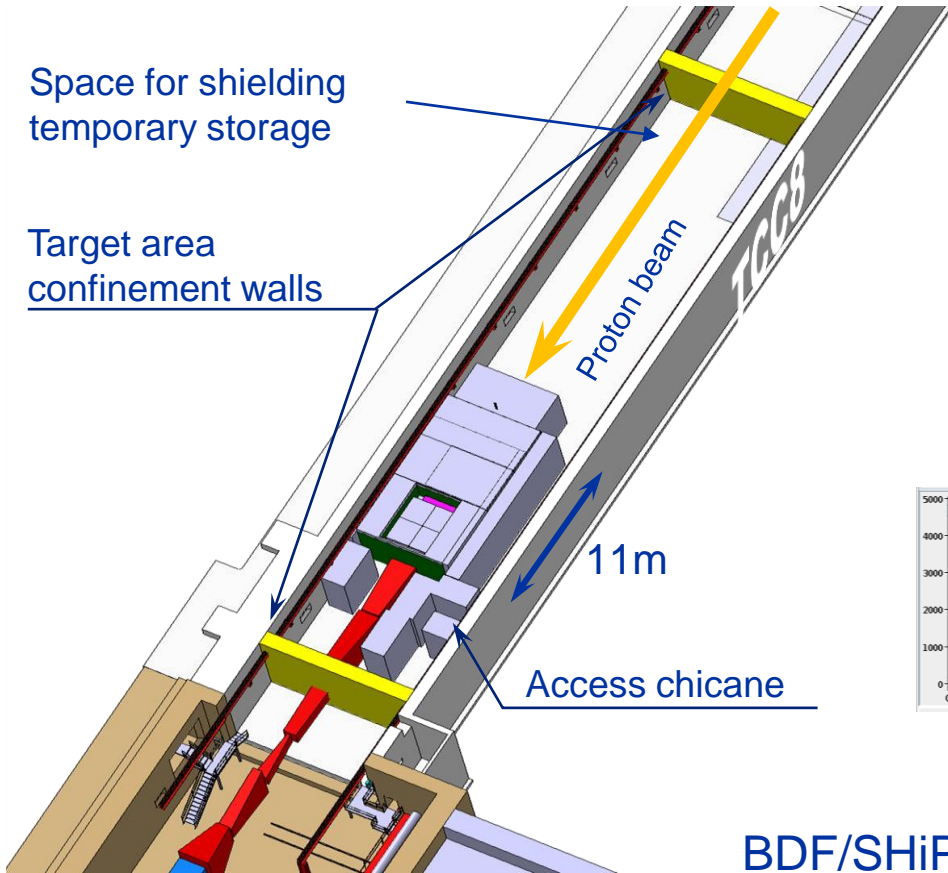
A New Flagship for Dark Matter Searches: SHiP

General-purpose beam dump experiment to search for feebly interacting particles (FIPs)

- Highlights of the physics programme are
 - Ability to search for a variety of FIPs, i.e., heavy neutral leptons, dark photons, dark scalars, axion-like particles, and light supersymmetric particles.
 - Access an abundance of tau and muon neutrinos.
 - Several extensions possible, e.g. adding an irradiation facility, adding an LAr TPC to search for milli-charged particles.
 - See A. Golutvin's [talk](#) for more details on the experimental programme.



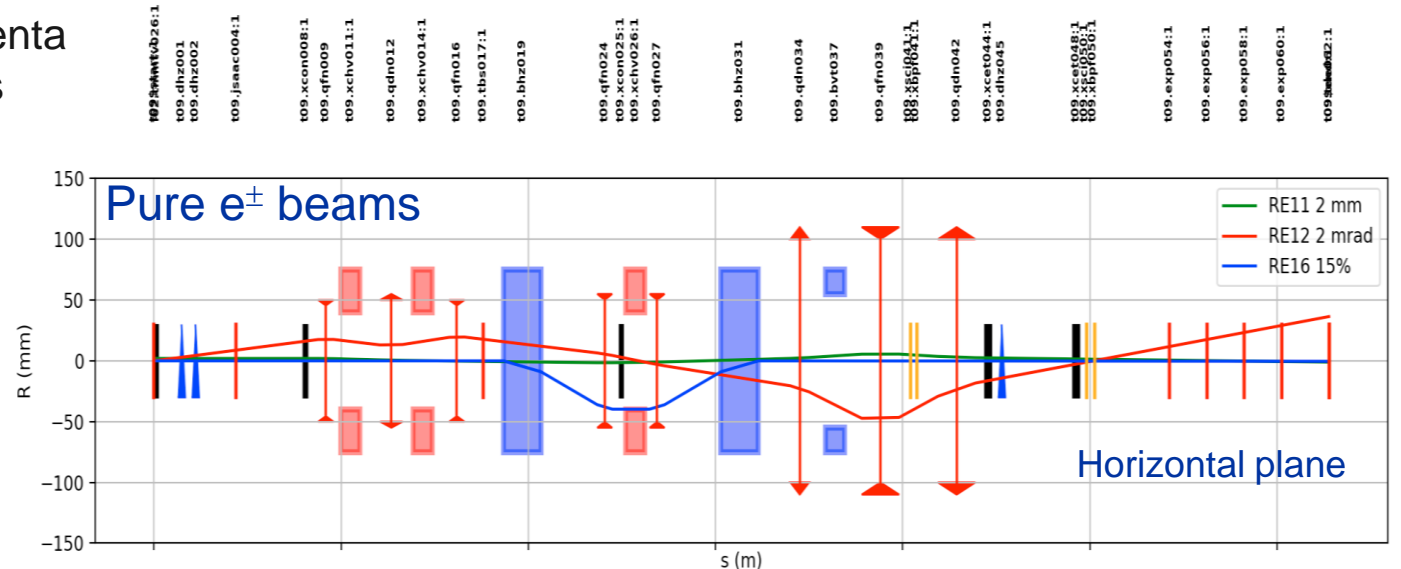
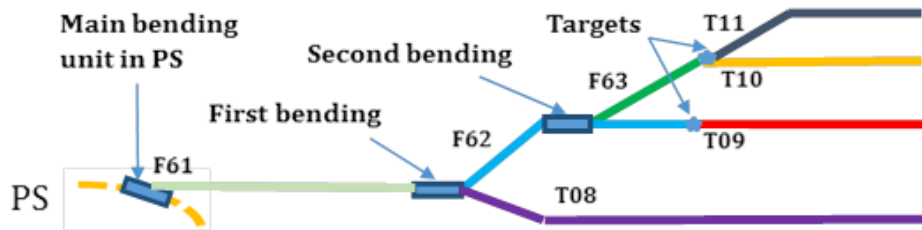
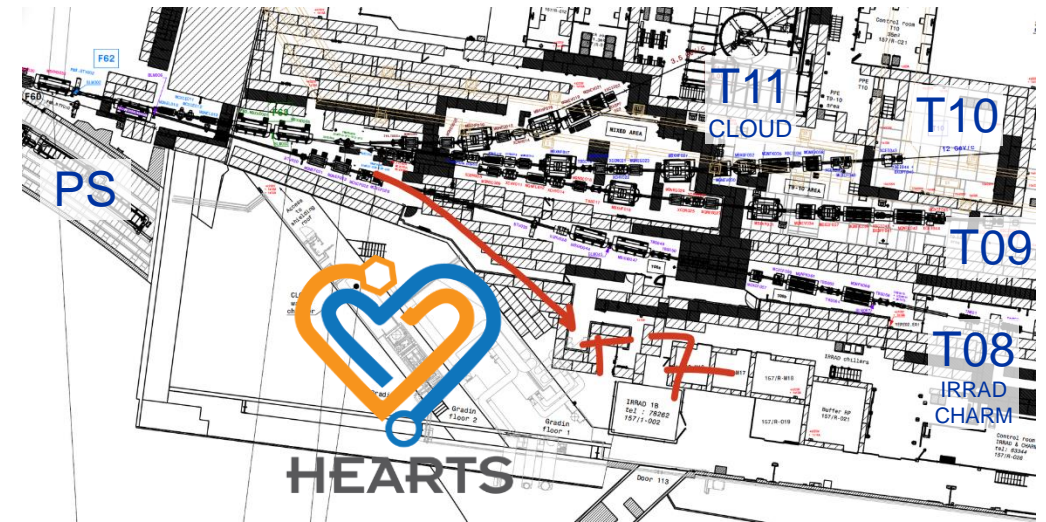
A New Flagship for Dark Matter Searches: SHiP



- A **new target complex** will make sure that the new intensity step can be optimally exploited while upgrading the facility to modern radiation protection and handling standards.
- With SHiP, there will be a **dedicated extraction** only to ECN3, interleaved with extractions serving the other NA experiments and test beam users.

Upgrade Plans in the East Area

- The PS East Area has been renovated during LS3 and now provides high quality beam in the 1-24 GeV/c range for the CLOUD experiment, test beam users, and the two irradiation facilities IRRAD and CHARM.
- Within the European project HEARTS, a new beam line for ion beams of up to 500 MeV/n with different species (Pb, O, Ar, Kr) has been proposed with an intensity of about $4e8$ ions per 0.5 s extraction. Design studies are underway.
- The new T09 line provides also electron beams of high purity with reasonable intensities up to momenta of 6 GeV/c with the help of conversion of gammas from a production target. Studies are ongoing with the aim to provide a similar capability in T10 in view of detector R&D, e.g. for FCCee.



Summary and Outlook

- High intensity beams are key for the future of CERN's fixed target experiment landscape with exciting ideas for dark matter searches and QCD experiments at the precision frontier complementary to the flagship collider programme – I presented today merely a small sample of the ongoing activities.
- CERN's unique fixed target facilities and test beams will drive also detector R&D for experiments at future accelerators.
- Consolidation efforts at CERN such as NA-CONS provide an exceptional opportunity to get ready for the intensity needs of the future, allowing at the same time for better reliability, beam availability, and a safe work environment for service and equipment teams.



Thank you very much for your attention!

home.cern

johannes.bernhard@cern.ch