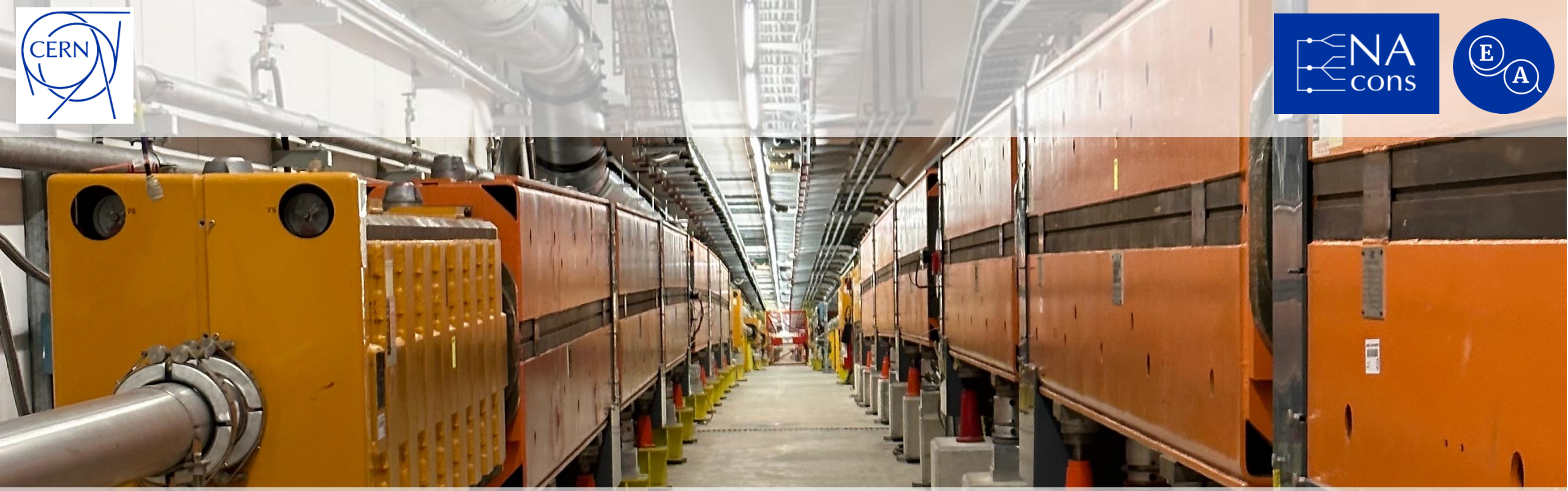


CERN North Area Consolidation and Beamline Upgrades

13th Beam Telescopes and Test Beams Workshop | Valencia

Laurie Nevay, P. Alexaki, P. Arrutia, D. Banerjee, E. Barber, J. Bernhard, M. Brugger, N. Charitonidis, G. Dal Maso, M. van Dijk, M. Fraser, A. Goillot, M. Jaekel, Y. Kadi, P. Martinengo, F. Metzger, B. Rae, M. Santos, S. Schuh, F. Stummer.

19th May 2025

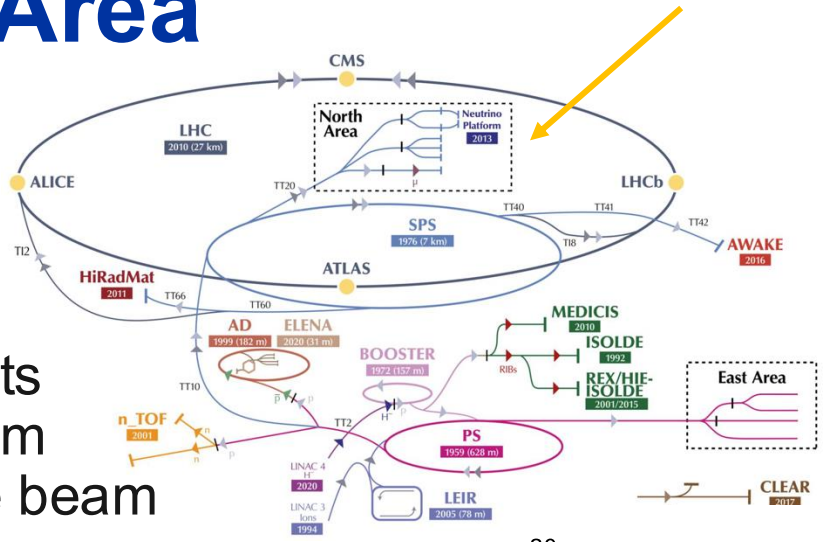
laurie.nevay@cern.ch

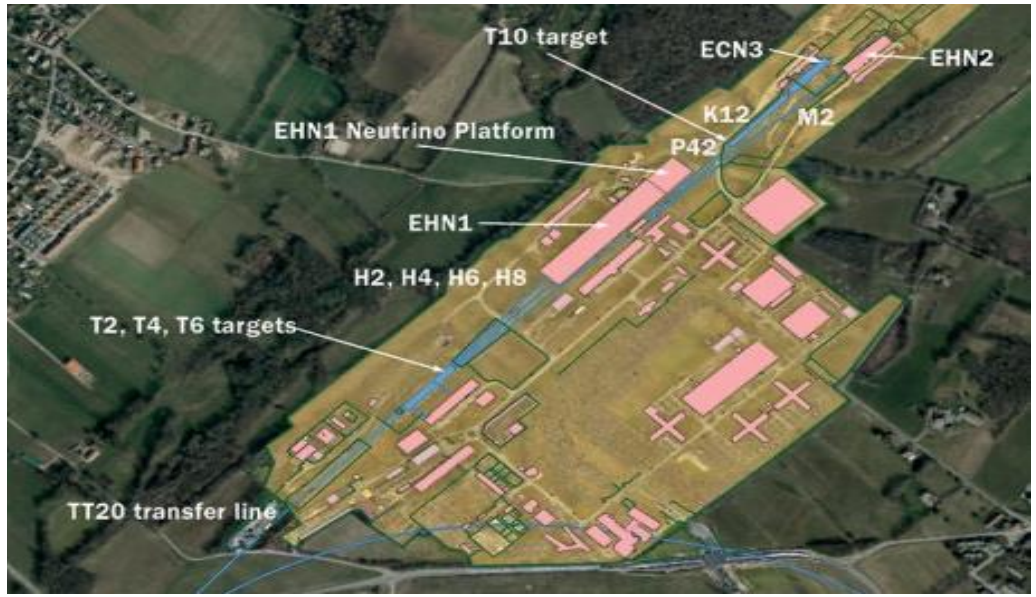
CERN Fixed-Target and Test Beam Areas

- CERN has 3 main areas for fixed-target experiments: the East Area, the North Area, and AD/ELENA
- 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 large fixed-target experiments.
- The East Area has two test beam areas, the IRRAD / CHARM irradiation facilities and serves the CLOUD experiment.
- The East Area was recently completely renovated and reopened in 2021.
- A new anti-proton test beam TELMAX was recently added to the AD

EAST AREA RENOVATION

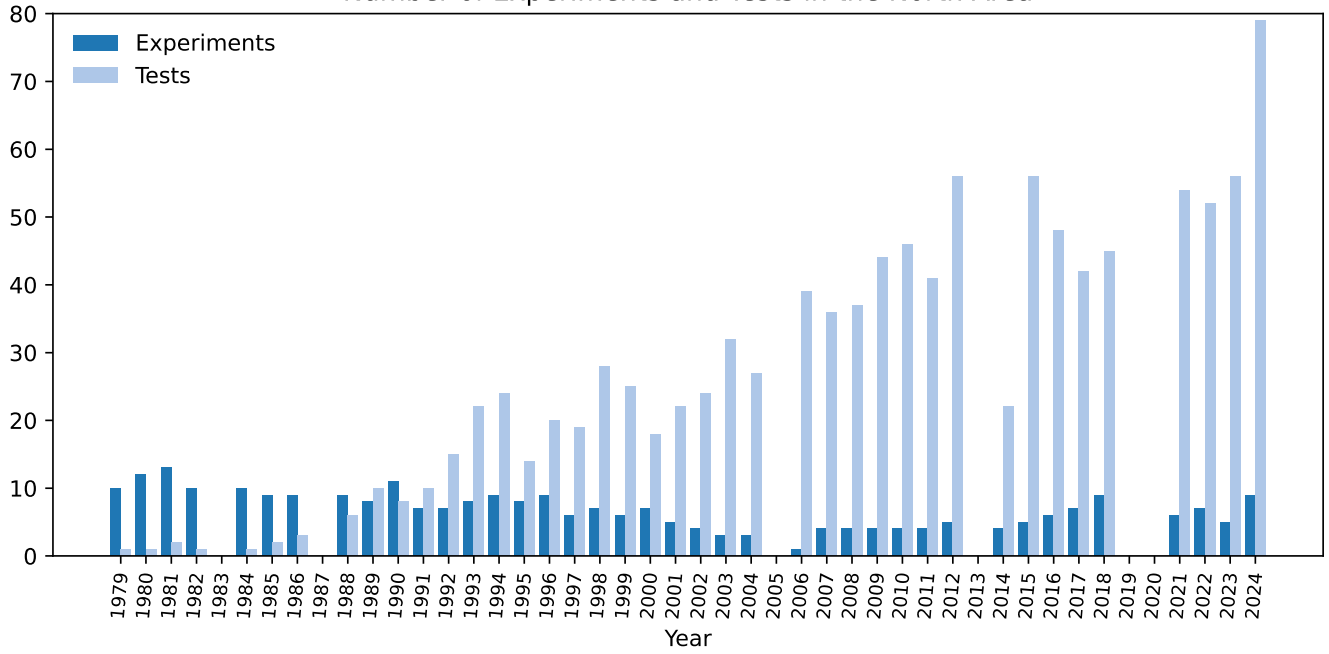
CERN North Area





- The North Area extracts 400 GeV/c protons from the SPS and splits the beam
- 6 beamlines are served from 3 targets
- 2 very low energy (“VLE”) beamlines extend H2/H4 to the neutrino platform
- The already large number of test beam users has been steadily increasing
- Strong interest from community for long term operation to 2040s

Number of Experiments and Tests in the North Area

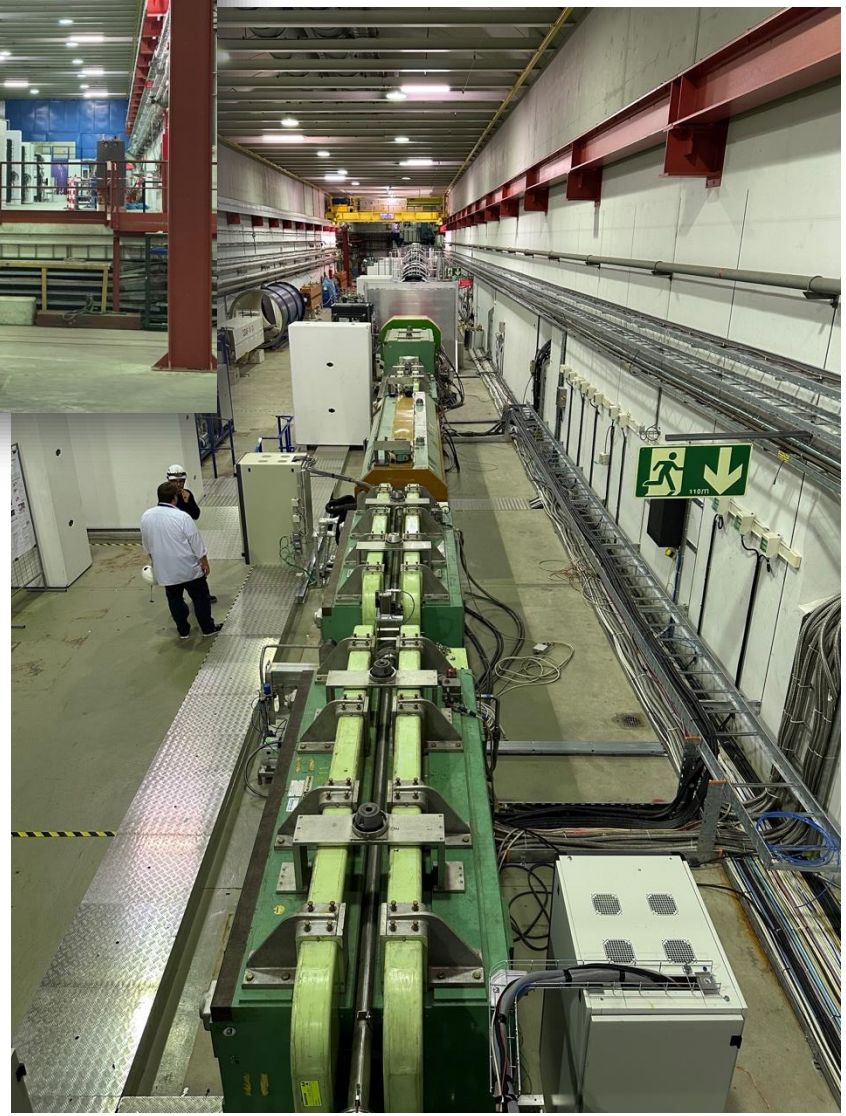


North Area In Pictures

EHN1 beamlines

ECN3 cavern
with NA62

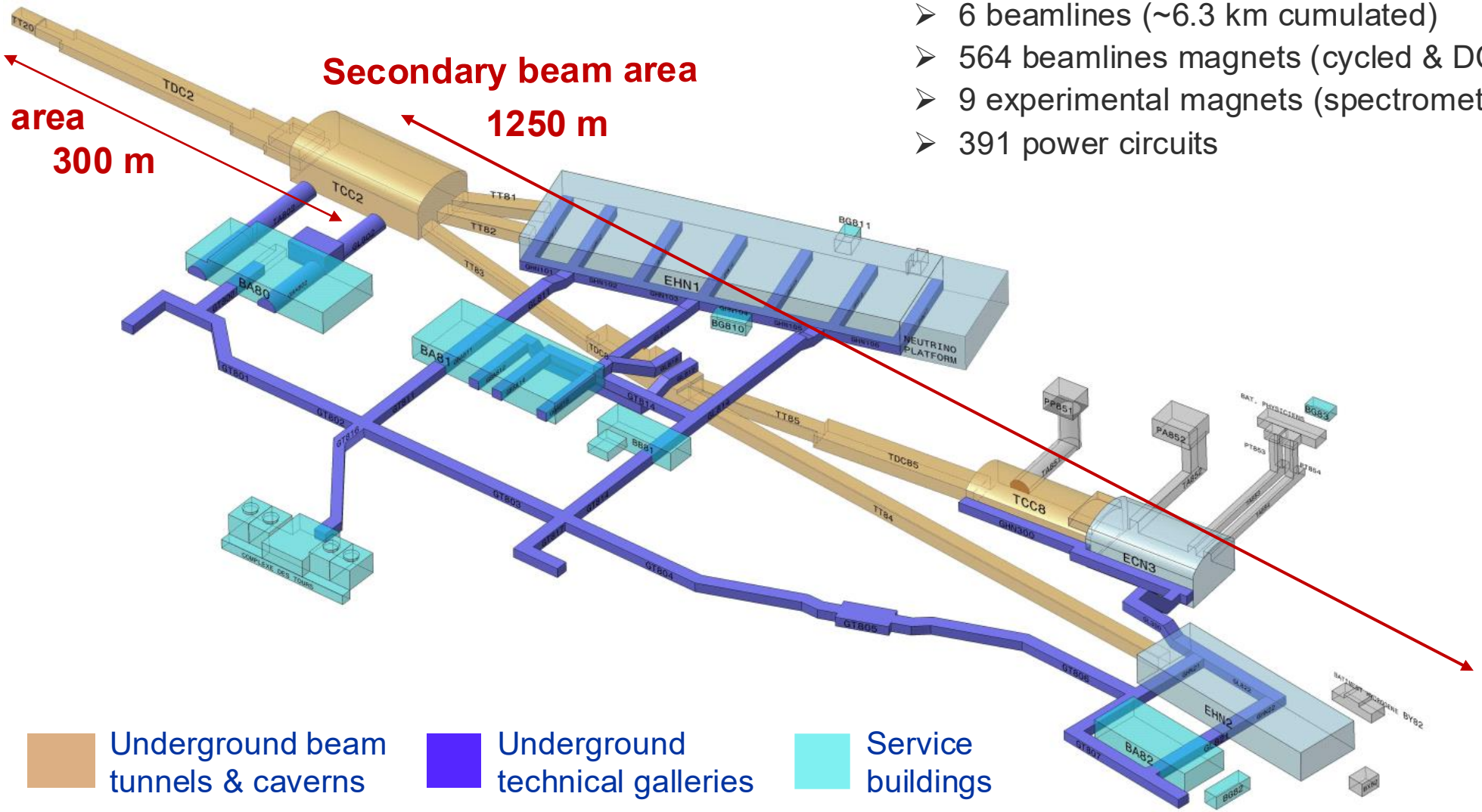
K12 kaon beamline



North Area Facilities

A few numbers:

- 6 beamlines (~6.3 km cumulated)
- 564 beamlines magnets (cycled & DC)
- 9 experimental magnets (spectrometer)
- 391 power circuits



Experimental halls

Underground beam tunnels & caverns

Underground technical galleries

Service buildings

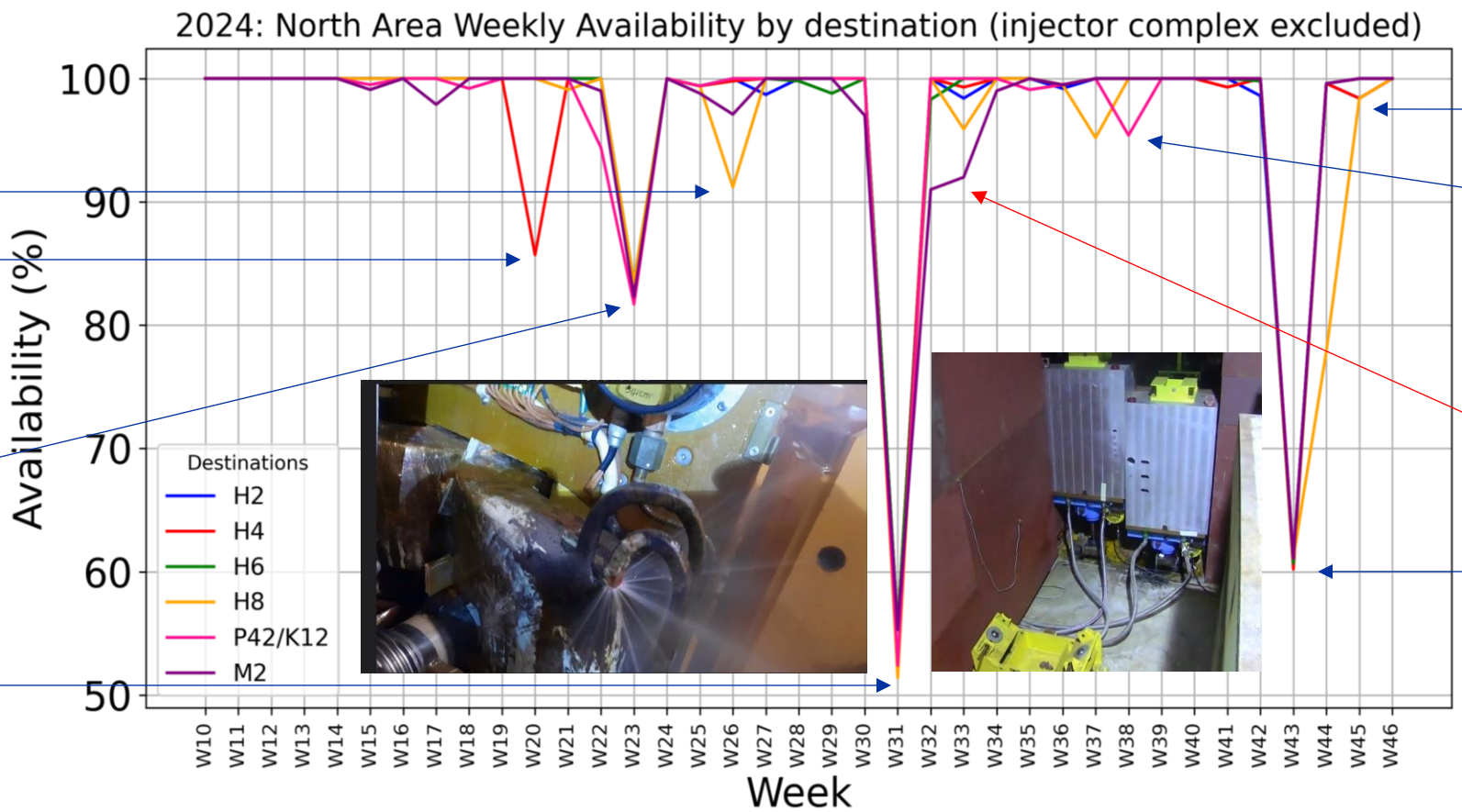
Availability Analysis

Power converter issue quadrupole QSL.X0420033 (TCC2/BA80)

Power converter issue dipole MBN.X0220053 (TCC2/BA80)

Water leak quadrupole QNL.X0210049 (TCC2)

Exchange of QNL.X0210049 (TCC2)



H4 and H8 XTAX control issues (TCC2)

Power converter issues quadrupole QSL.X0420033 (TCC2/BA80)

P42 and H8 XTAX moving issue (TCC2)

Leak on water circuit of dipole MTN.241128 (TCC2)

- In 2024, for example, nearly all of the North Area downtime stems from faults the upstream areas.
- A fault may be a small annual percentage but a very large percentage for a 7-day test beam slot

North Area Upstream

TCC2 during construction in the late 1970s

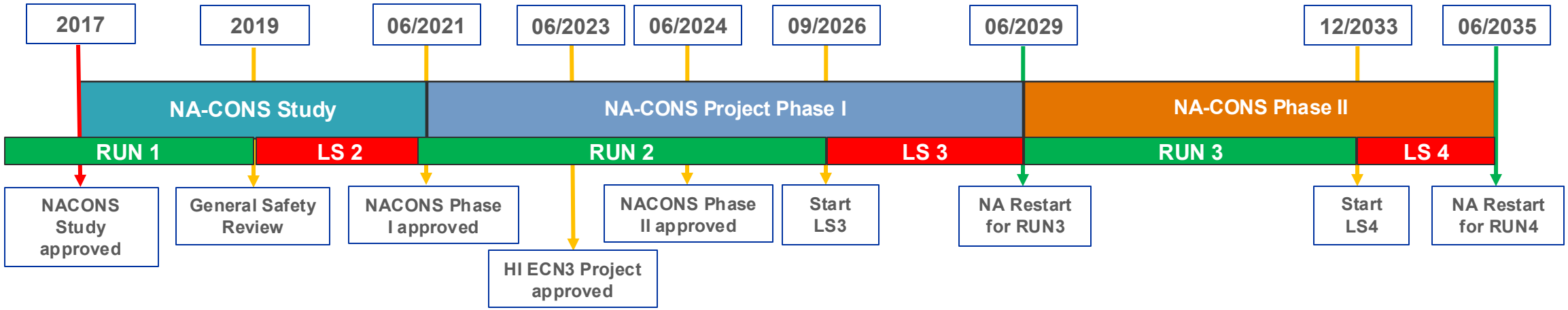
- The heart of the North Area is the TCC2 cavern where the 3 targets are housed
  - ~2100 m^2 floor area
- It is a high radiation area
- Interventions are challenging
- Key magnets are reaching their end of life

It is time for a little TLC: tender loving… consolidation

Introducing NA-CONS - North Area Consolidation

The NA-CONS project will renovate the Fixed Target Experimental Area at the CERN Prevessin site after 45 years in use with a view to:

1. Recover the availability and reliability of the beam- facility
2. Correct safety concerns and non-conformities
3. Be prepared for new projects and test beams in the next decades (e.g. SHiP in HI-ECN3)



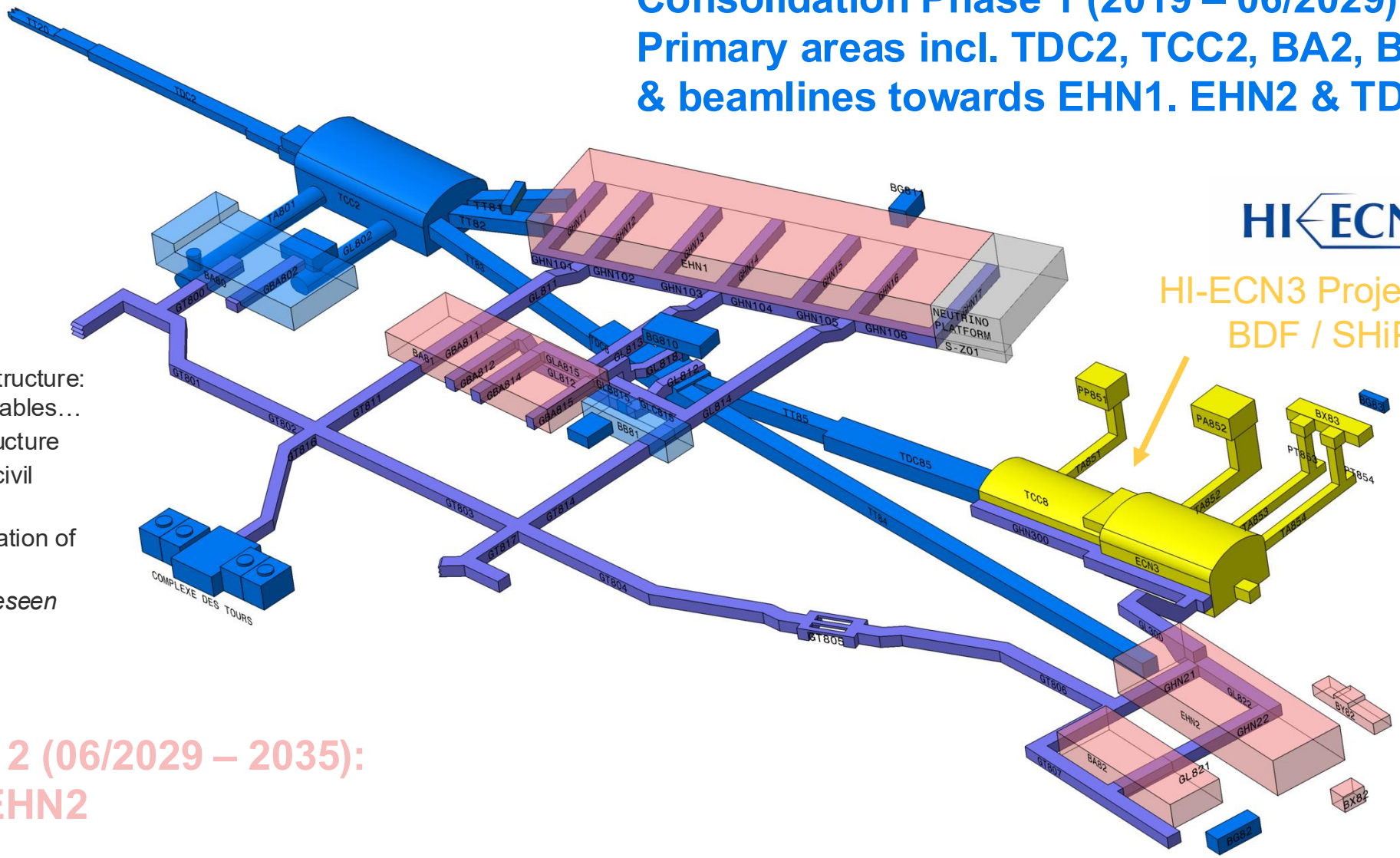
***LS** = Long Shutdown*

Scope of NA-CONS

Consolidation Phase 1 (2019 – 06/2029): Primary areas incl. TDC2, TCC2, BA2, BA80 & beamlines towards EHN1. EHN2 & TDC8

Energy-related activities:

- ✓ Systematic replacement of <u>all</u> power converters
  - ➢ BA2 & BA80 in phase 1
  - ➢ BA81 & BA82 in phase 2
- ✓ Consolidation of related EL infrastructure: transformers, switchboards, DC cables…
- ✓ Renovation of related CV infrastructure
- ✓ Renovation of surface buildings (civil engineering)
- ✓ Magnet consolidation incl. preparation of operational spares
- ✓ *Magnet replacements are not foreseen*



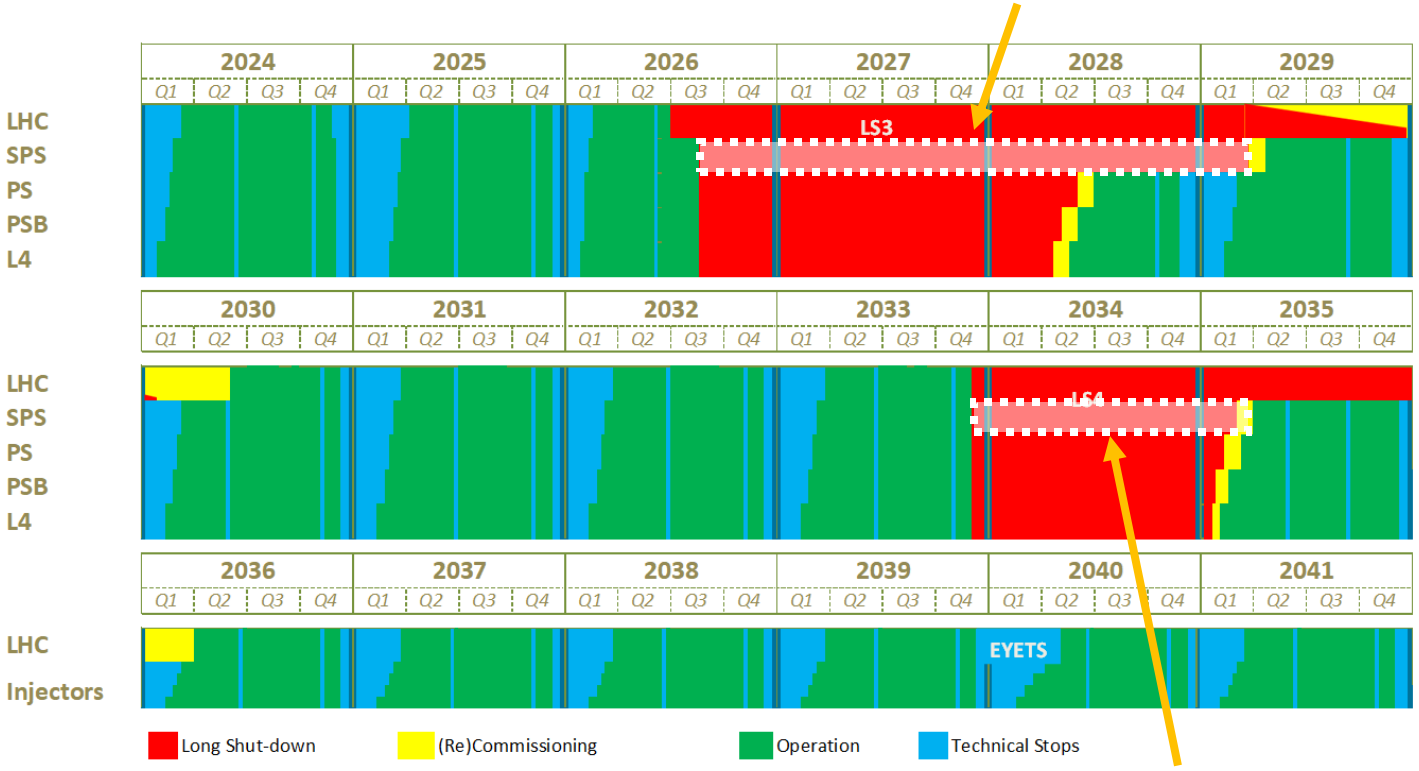
HI-ECN3 Project for BDF / SHiP

Consolidation Phase 2 (06/2029 – 2035): BA81, BA82, EHN1, EHN2

CERN Long-Term Schedule

- NA-CONS will be carried out during the Long Shutdowns making it transparent to users and experiments
- The major impact to test-beam users will be the availability - i.e. a much more reliable facility
- NA-CONS is a major CERN project and demonstrates a commitment to fixed-target physics in the long-term

NA-CONS Phase 1 during LS3

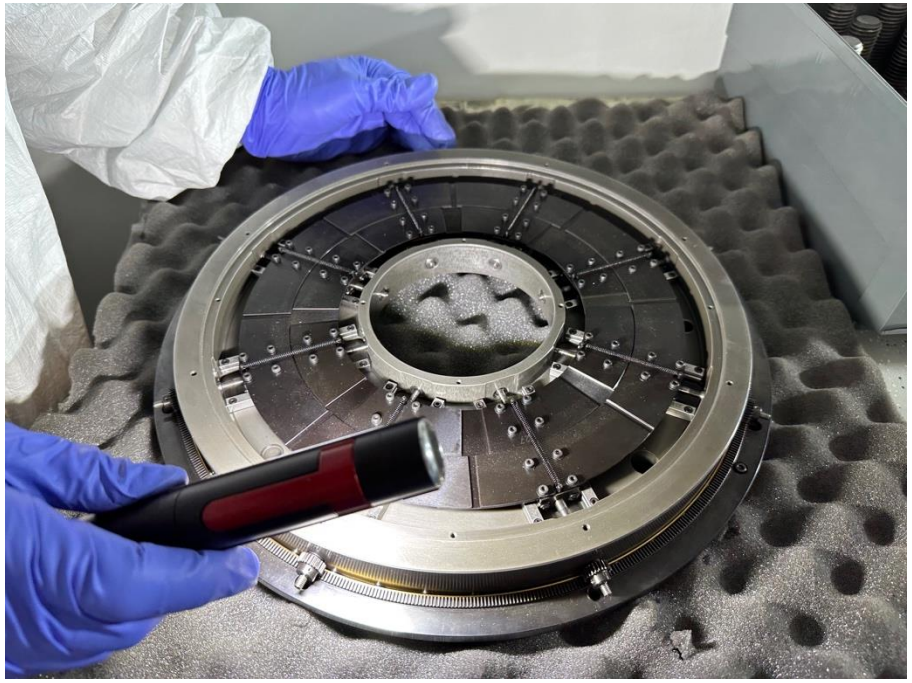


NA-CONS Phase 2 during LS4

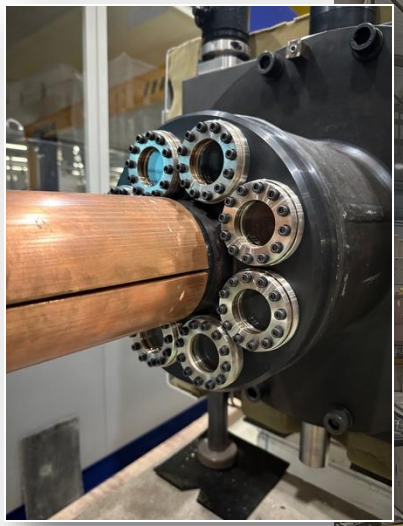
CEDAR Consolidation

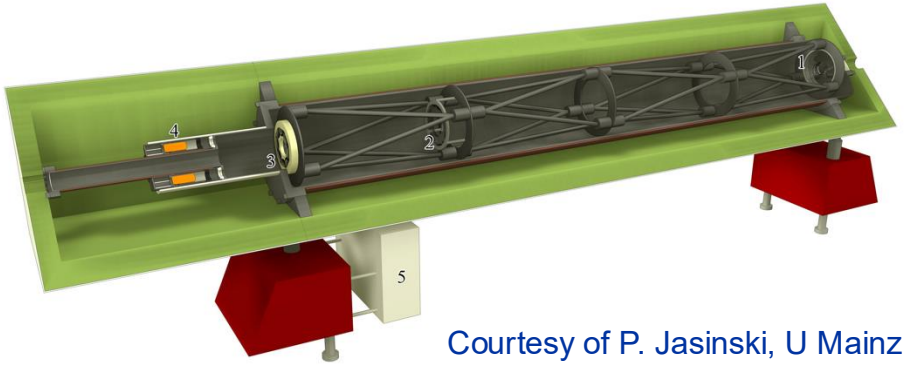
- **C**h**E**renkov **D**ifferential counter with **A**chromatic **R**ing focus
  - allow selective tagging of particles
  - 0 - 16 bar (He) gas chamber with 8x PMTs and optical telescope
- Particle ID detectors provided as a service to users
- Programme of consolidation:
  - new glass optics and PMTs
  - re-engineered diaphragm control
  - improved gas handling

diaphragm



PMT windows

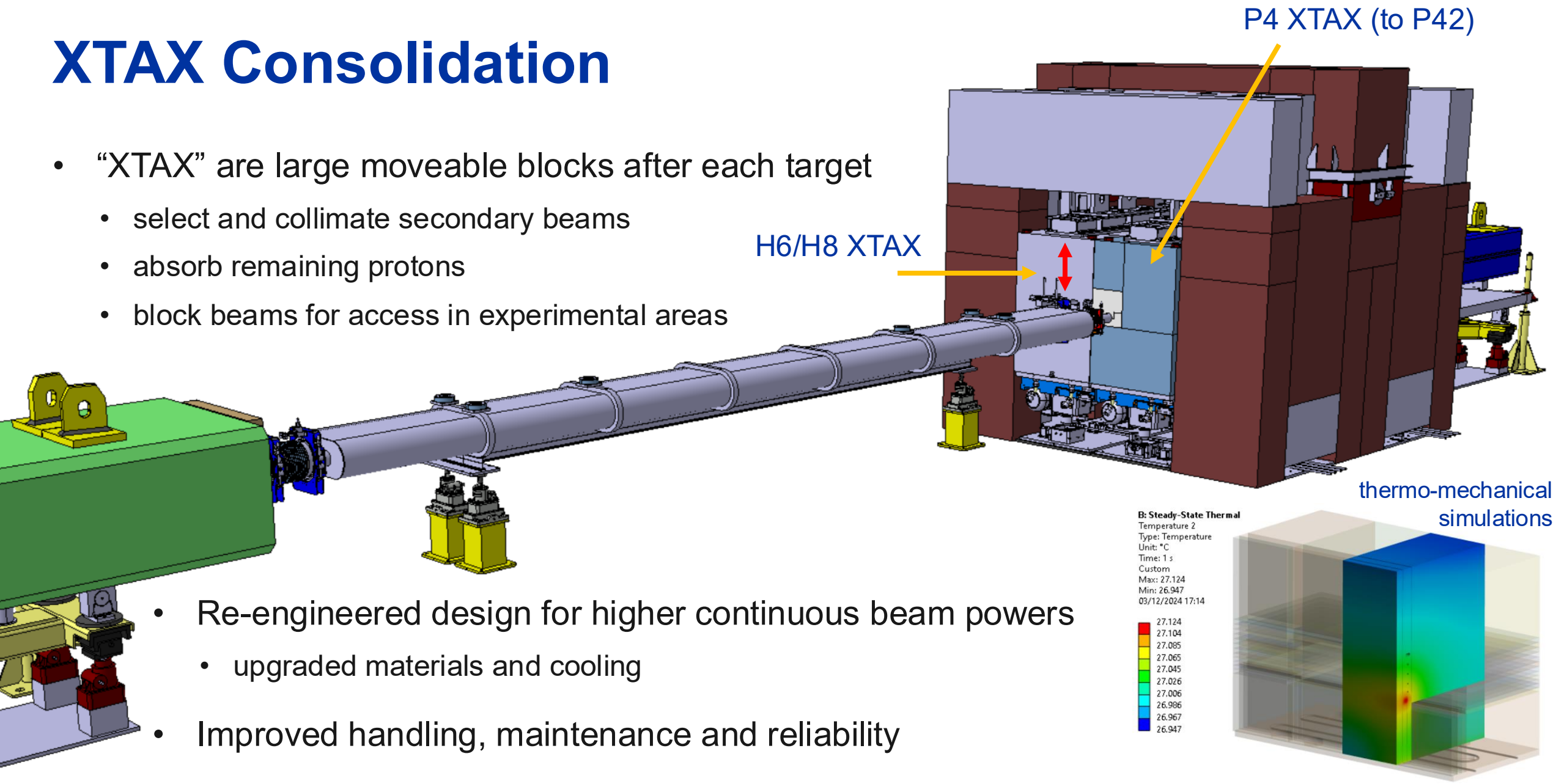




Courtesy of P. Jasinski, U Mainz

XTAX Consolidation

- “XTAX” are large moveable blocks after each target
  - select and collimate secondary beams
  - absorb remaining protons
  - block beams for access in experimental areas

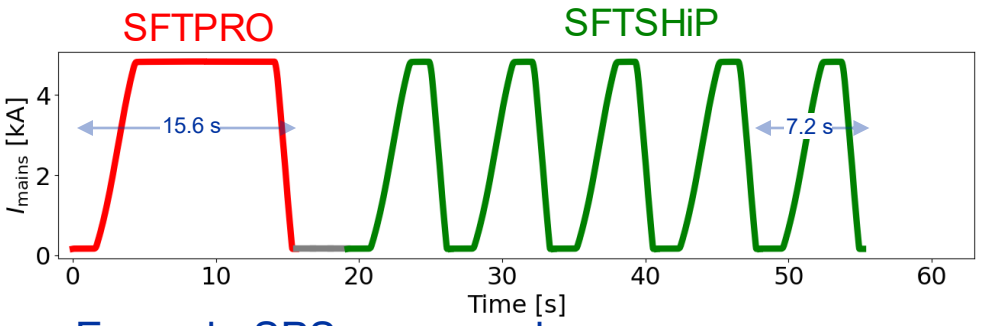


- Re-engineered design for higher continuous beam powers
  - upgraded materials and cooling
- Improved handling, maintenance and reliability

Beamline Upgrades

A New Flagship for Dark Matter Searches: SHiP

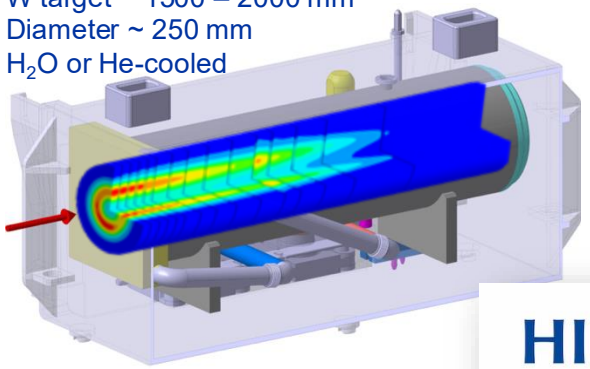
- A new Beam Dump Facility will be installed in LS3 in the search for feebly interacting particles
- New HI-ECN3 project to implement the facility
- Several extensions possible, e.g. adding an irradiation facility, adding an LAr TPC to search for milli-charged particles.

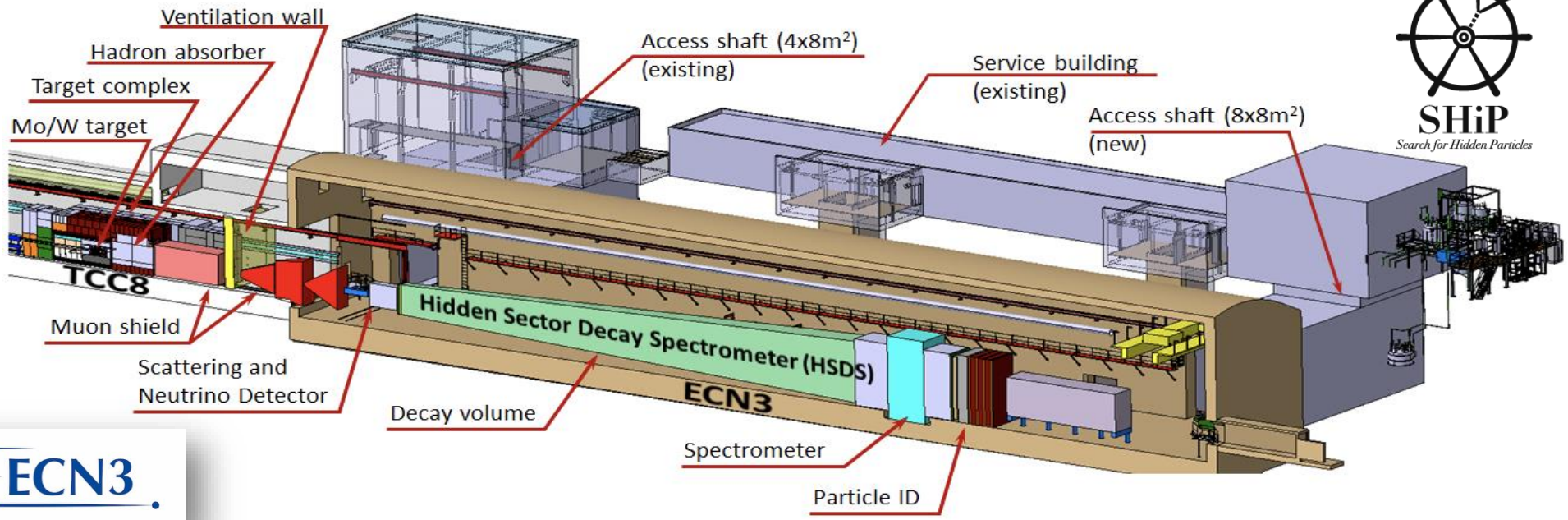


Example SPS super-cycle

BDF target design

W target ~ 1500 – 2000 mm
Diameter ~ 250 mm
H_2O or He-cooled

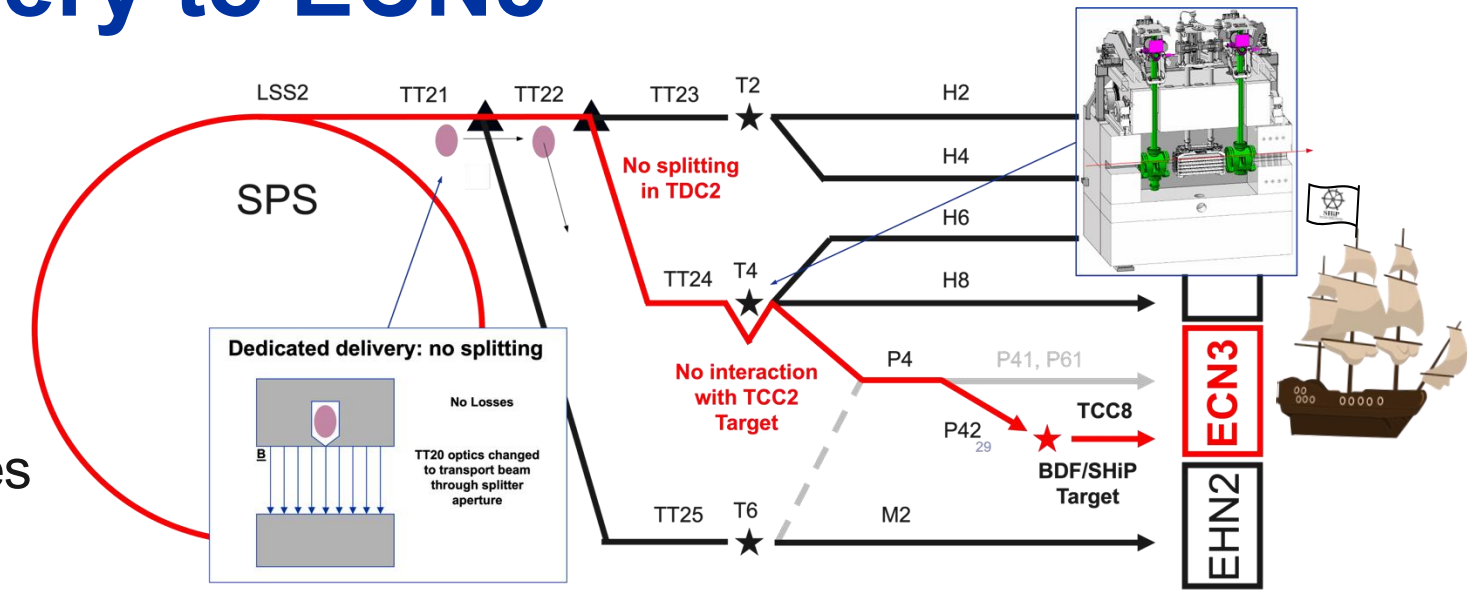


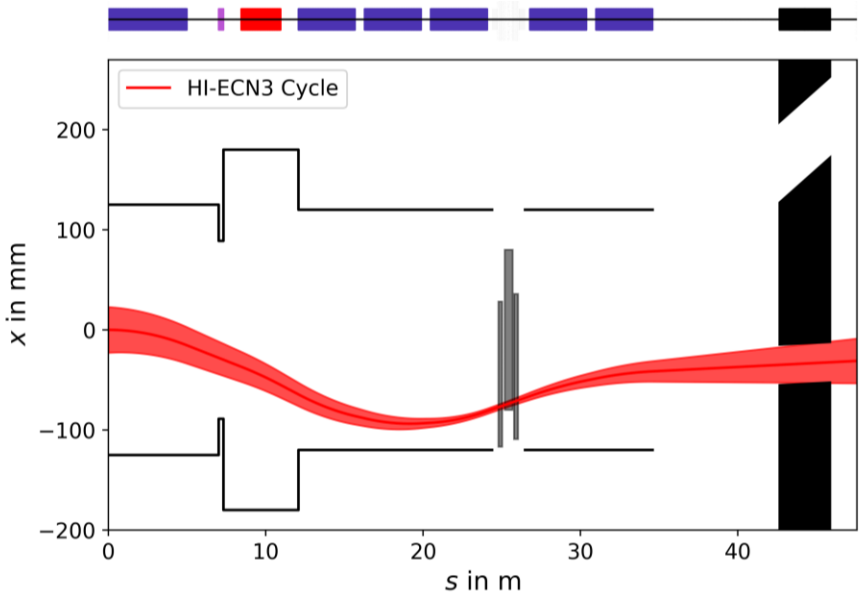


HI-ECN3

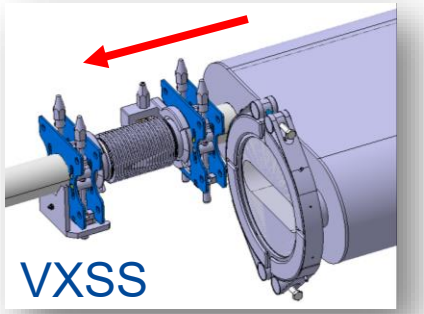
Dedicated Beam Delivery to ECN3

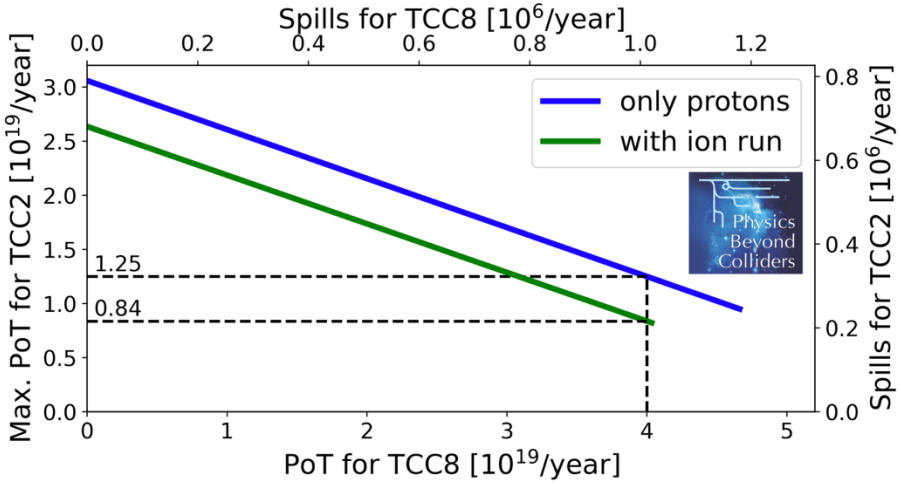
- With SHiP, there will be a dedicated extraction cycle only to ECN3
  - beam splitters will be skipped
- The T4 XTAX and wobbling will be upgraded to switch between the cycles





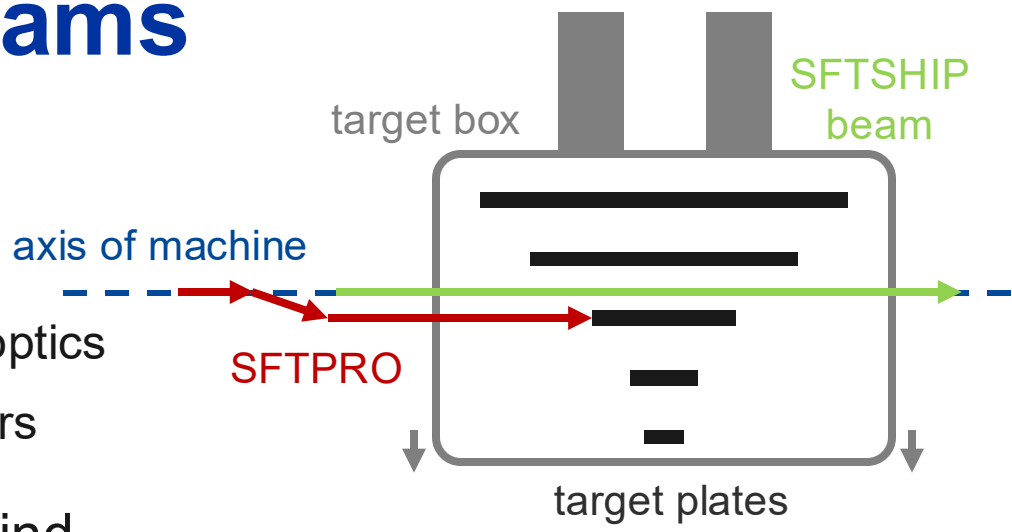
A new vacuum chamber will be installed through the XTAX



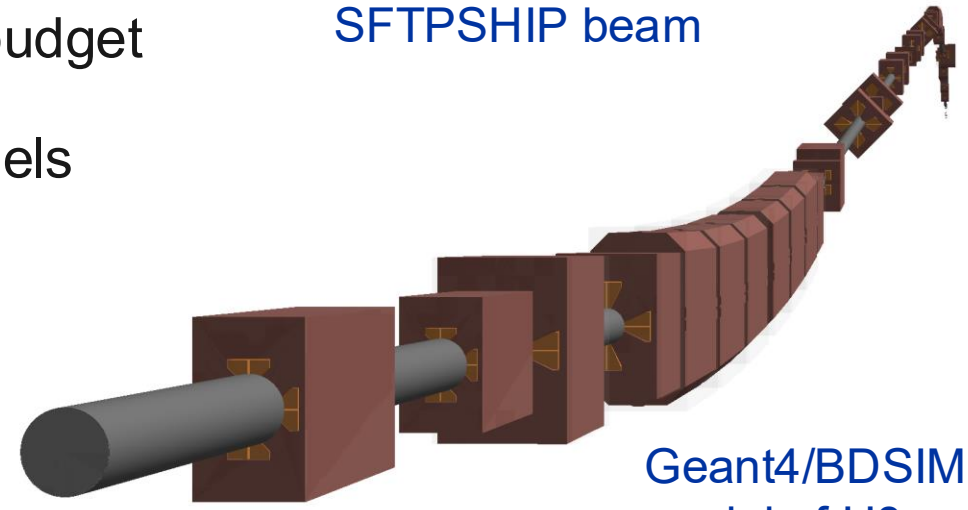


Improved Electron / Positron Beams

- Effort ongoing in North Area for improved $e^{\pm}$ beams
  - increased intensity and increased purity
  - new fellow G. Dal Maso investigating ML-based optimisation of optics
  - coupling between tracking codes / Monte-Carlo and ML optimisers
- XTAX re-engineering with high continuous intensities in mind
- In-vacuum profile monitors being built to reduce material budget
- Optimisation studies with start-to-end Geant4/BDSIM models being used to further improve quality of beam delivered
- T4 target bypass for BDF / SHiP will allow a longer target to be used for H6 and H8 more regularly
  - this will allow higher rate and purity $e^{\pm}$ beams
  - In 2029, 2030 and 2031 there will be the possibility of 400 GeV/c in H8



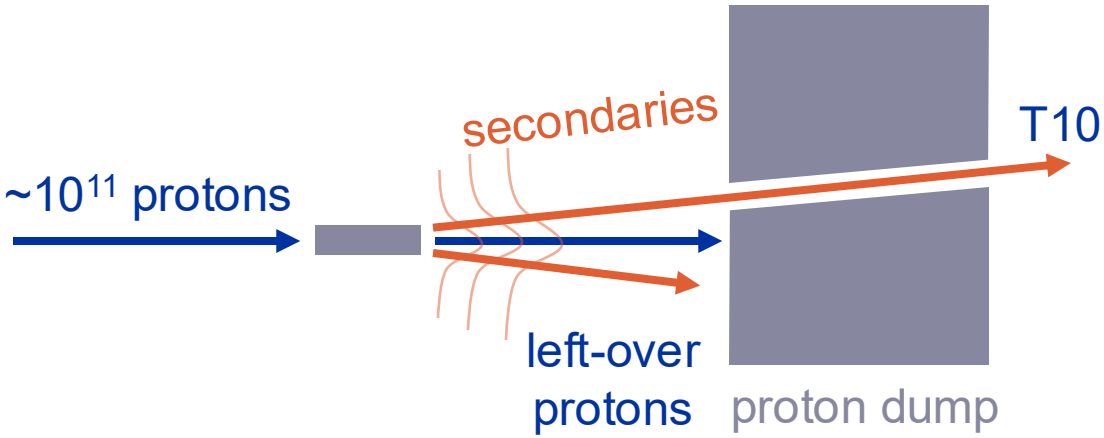
T4 target bypass for SFTPSHIP beam



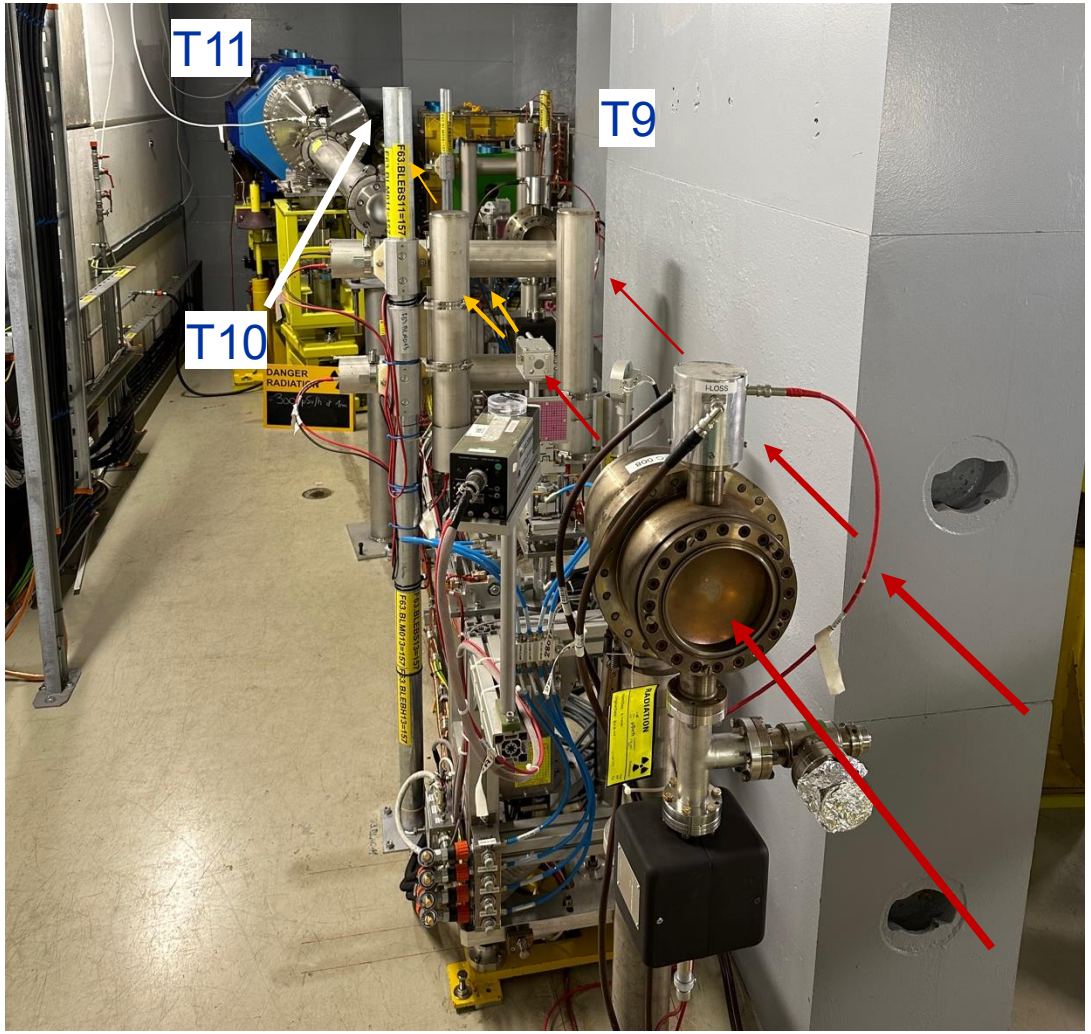
Geant4/BDSIM model of H8

Improved Electron / Positron Beams: T10

- Study underway to improve purity of $e^{\pm}$ beams in the T10 beamline in the East Area
- Investigation of using gammas to produce $e^{\pm}$ and using magnets before to sweep away charged particles (as done in T9)
- Very tight space-wise but studying options that could be implemented in LS3



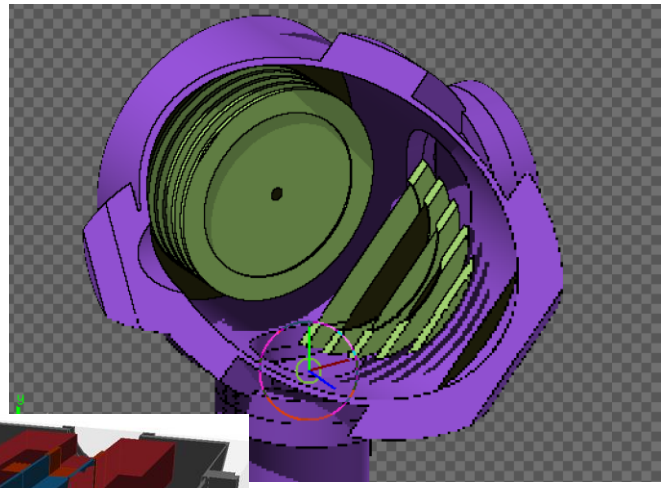
two targets - the start of T9 / T10 / T11



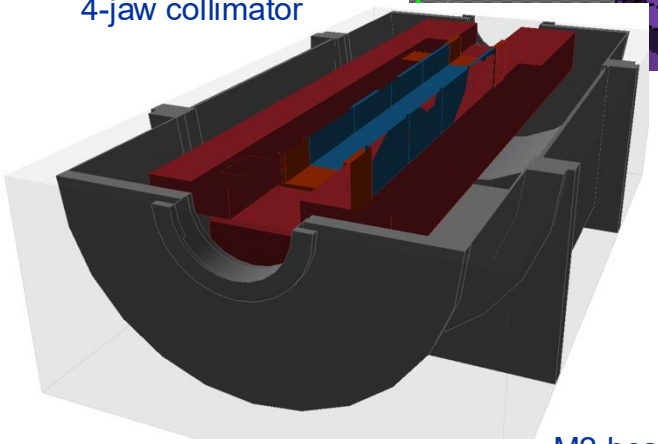
Monte-Carlo Modelling

- Many upgrades require beamline simulations
- We use BDSIM (Geant4) and FLUKA for start-to-end Monte Carlo simulations
  - i.e. from the proton on target to the secondary / tertiary beam ~1 km away
- Huge effort invested in modelling each and every magnet, window, collimator, etc.
- Most secondary beamlines have a high attenuation of $10^{-3} \rightarrow 10^{-8}$ → very challenging
- A goal is to have ready-to-use Monte Carlo for all beamlines that users can use

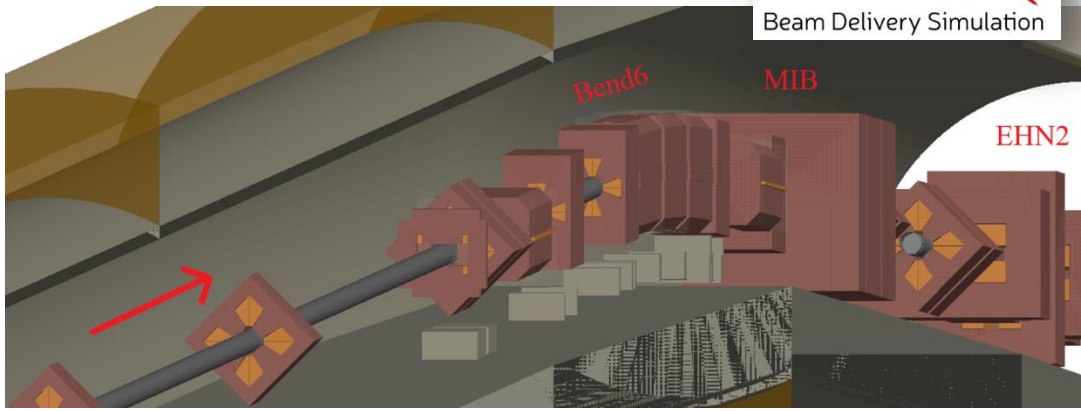
target instrumentation



4-jaw collimator

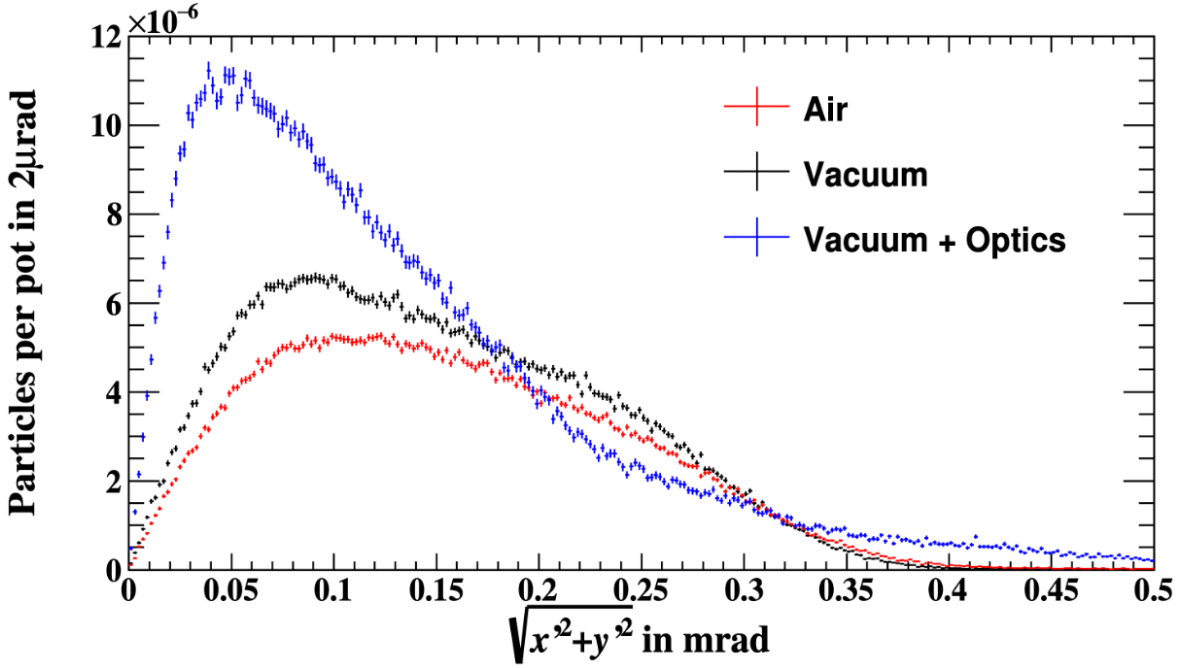


M2 beamline

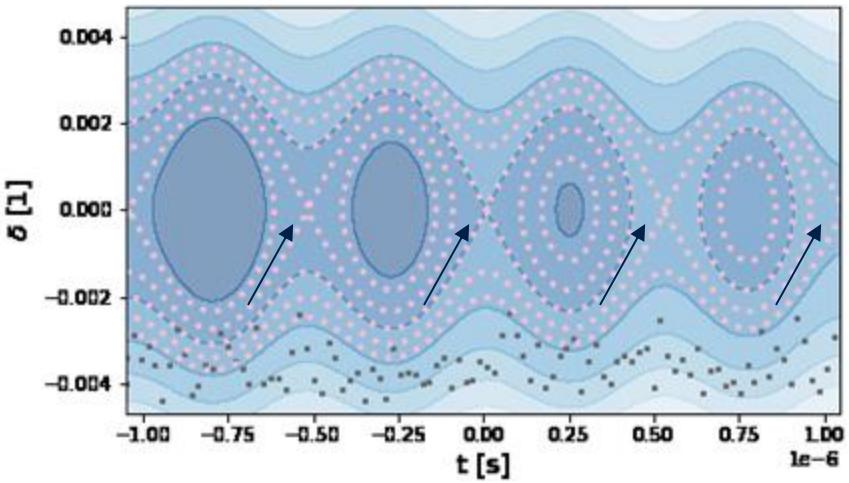


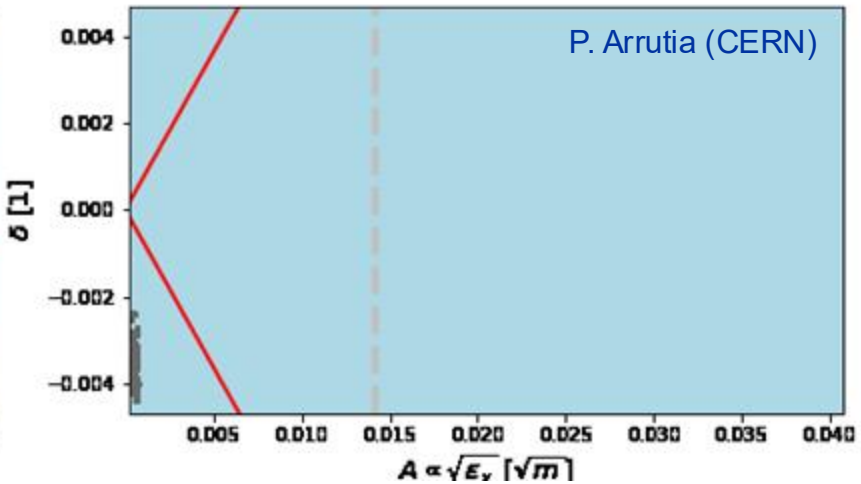
M2 Upgrades

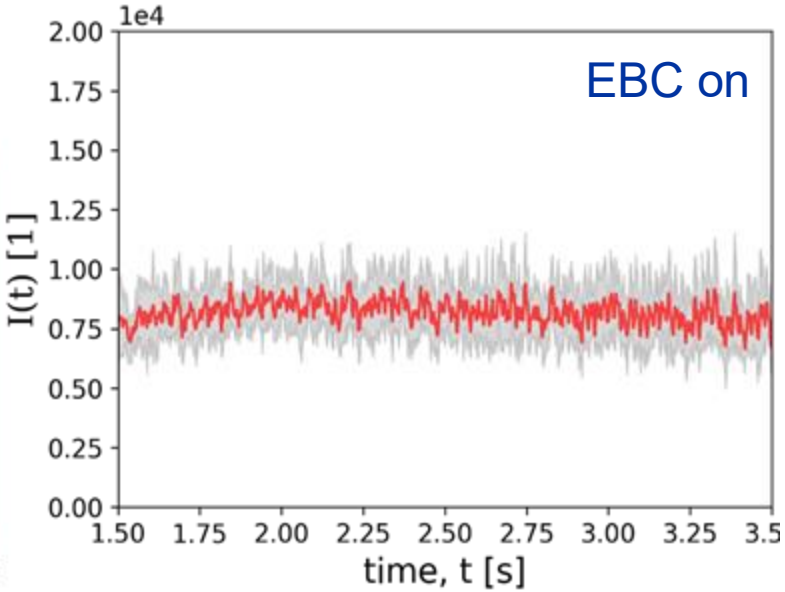
- M2 beamline getting upgrades for higher muon beam intensities (factor 2x) and kaon beams
  - there is approximately ~80 m of air in many places - for example, the magnetic scrapers
  - completing the vacuum will improve the flux of kaons by 48% within 60 μrad divergence
- A new collimator will further reduce the divergence and therefore increase the relative intensity inside the 60 μrad acceptance
- Collimation + vacuum upgrades will give a factor 3 increase in the kaon flux
  - i.e. 6 x 10^6 K/spill per spill within 60 μrad
  - today the flux is 2.7 x 10^6 K/sill
- Installation of the new collimator integrated in vacuum planned for LS3

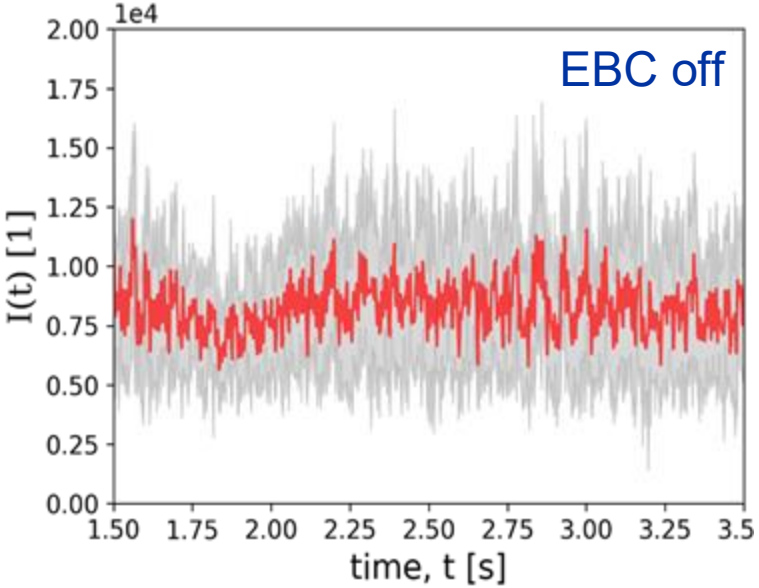


Beam Extraction – Time Structures





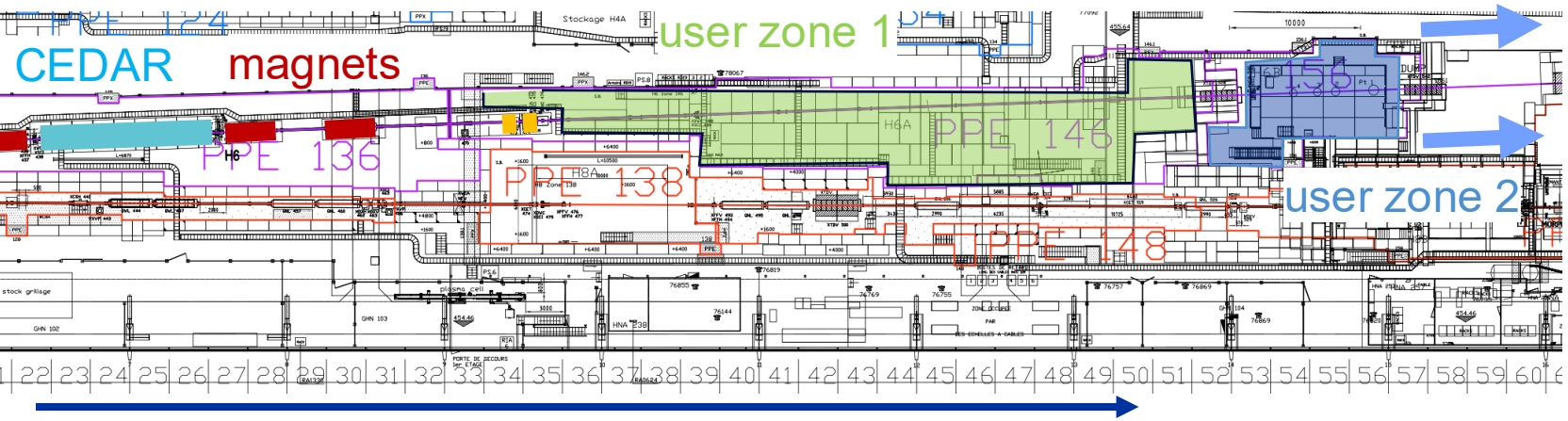


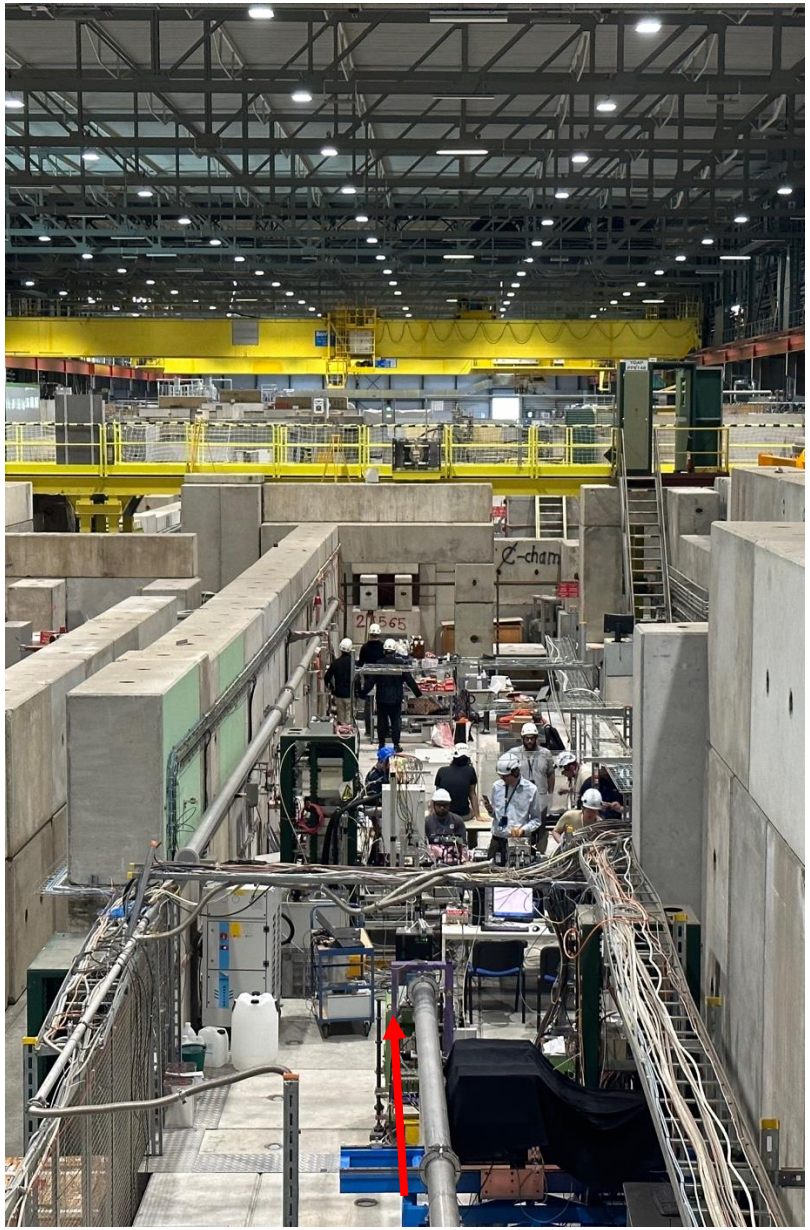


- With experiments requiring to run at highest intensities, the extraction quality becomes more important.
- Especially time structures at 50 Hz and 150 Hz, introduced via power converters, can easily lead to data acquisition issues due to peaks in the instantaneous intensity.
- Amongst several improvements 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.

H6 Smaller Beams and Extension

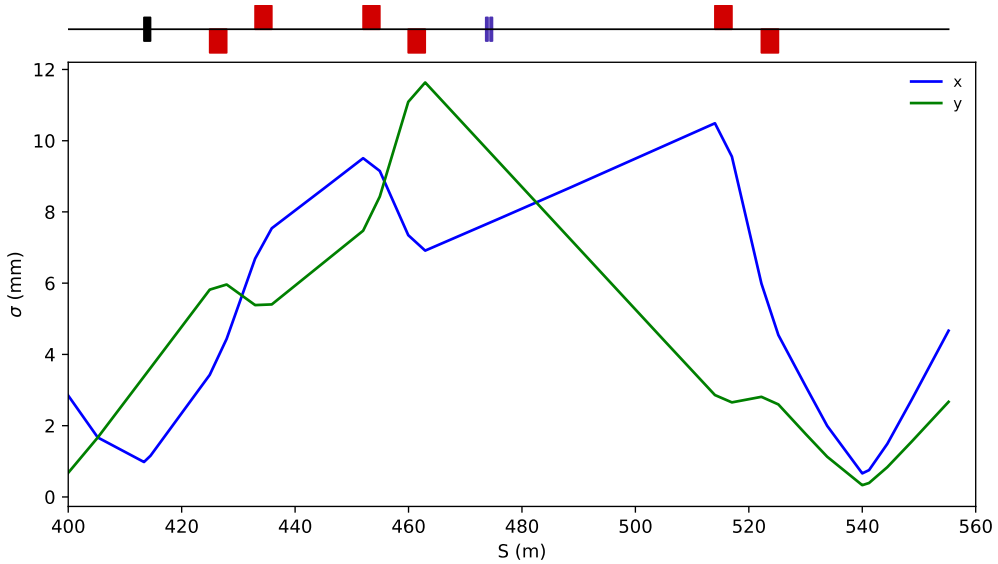
- H6 is a beamline in the EHN1 hall capable of up to 205 GeV/c
  - most commonly used for MIPs beams with tracking telescopes
  - also for e± beams (high purity below 70 GeV/c)
- Two user zones over 50 m - independently accessible
  - downstream zone much more compact
- Demand for smaller beam sizes to test small sensors
  - small sensors capture only a very small fraction of the beam



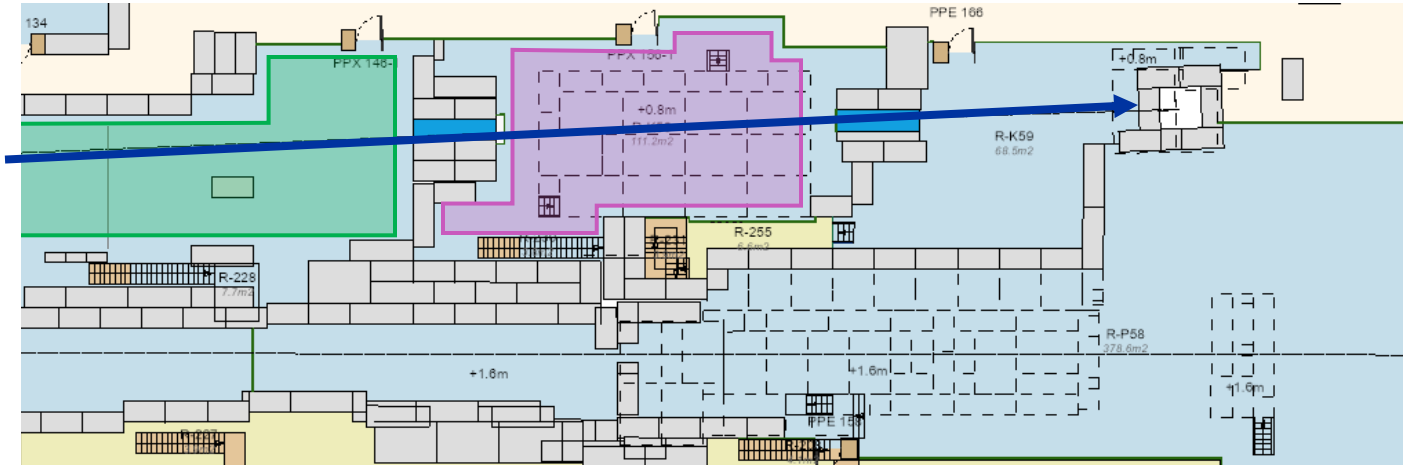


H6 Smaller Beams and Extension

- Two new quadrupoles to be installed to refocus beam (end of 2025)
- Currently ~50 m from last quadrupole to end of line in second zone (in air)
- Aim to reduce size by factor >3 and reduce the beam spot area by factor >10x

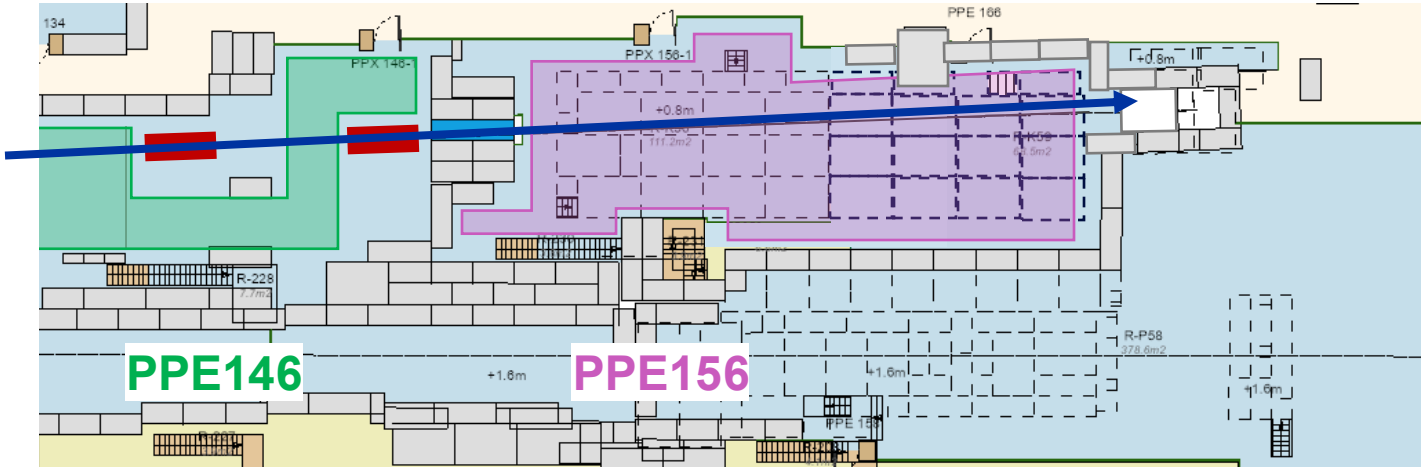


CURRENT



PPE146 **PPE156**

PROPOSED



H6 Extension

- Merge zones to create more space
- Feedback welcome

PPE156
(upstream)

PPE166
(downstream)

beam

Summary and Outlook

- NA-CONS will provide a much more reliable facility for test beams and fixed-target experiments
  - better reliability, availability and safety
- CERN's unique fixed target facilities and test beams will drive also detector R&D for experiments at future accelerators.
- Consolidation provides an exceptional opportunity to get ready for future intensity needs.
  - 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 LHC

A **big thank you** to all who contributed to the material in these slides and to all the diverse groups who are making these consolidation and upgrades possible. Such large projects are mobilising a huge effort across CERN.

Thank you to colleagues in the injectors and transfer lines: OP, ABP, ABT, SME

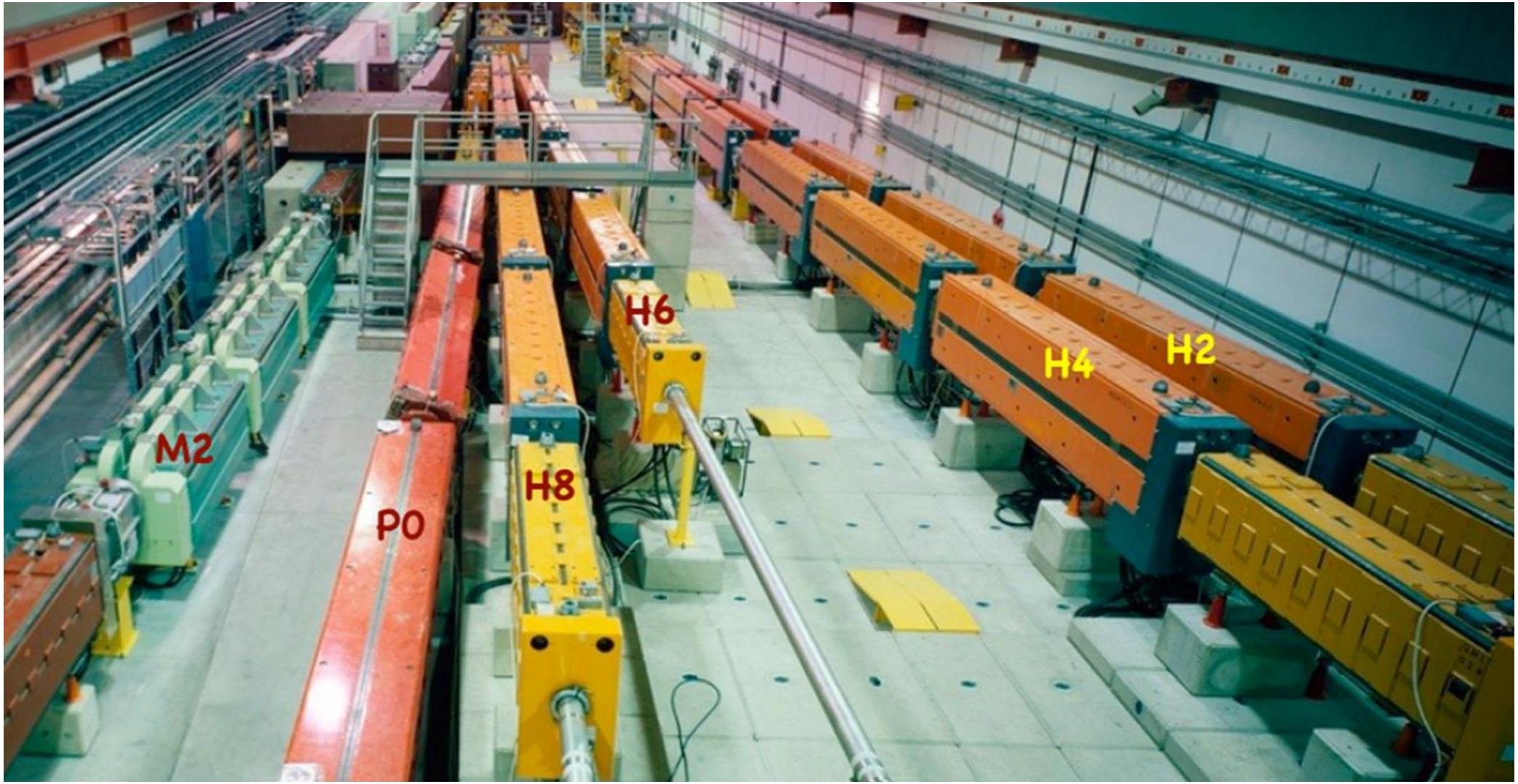
Thank you to the many equipment and service groups: EPC, MSC, BI, STI

laurie.nevay@cern.ch
Experimental Areas Group, CERN

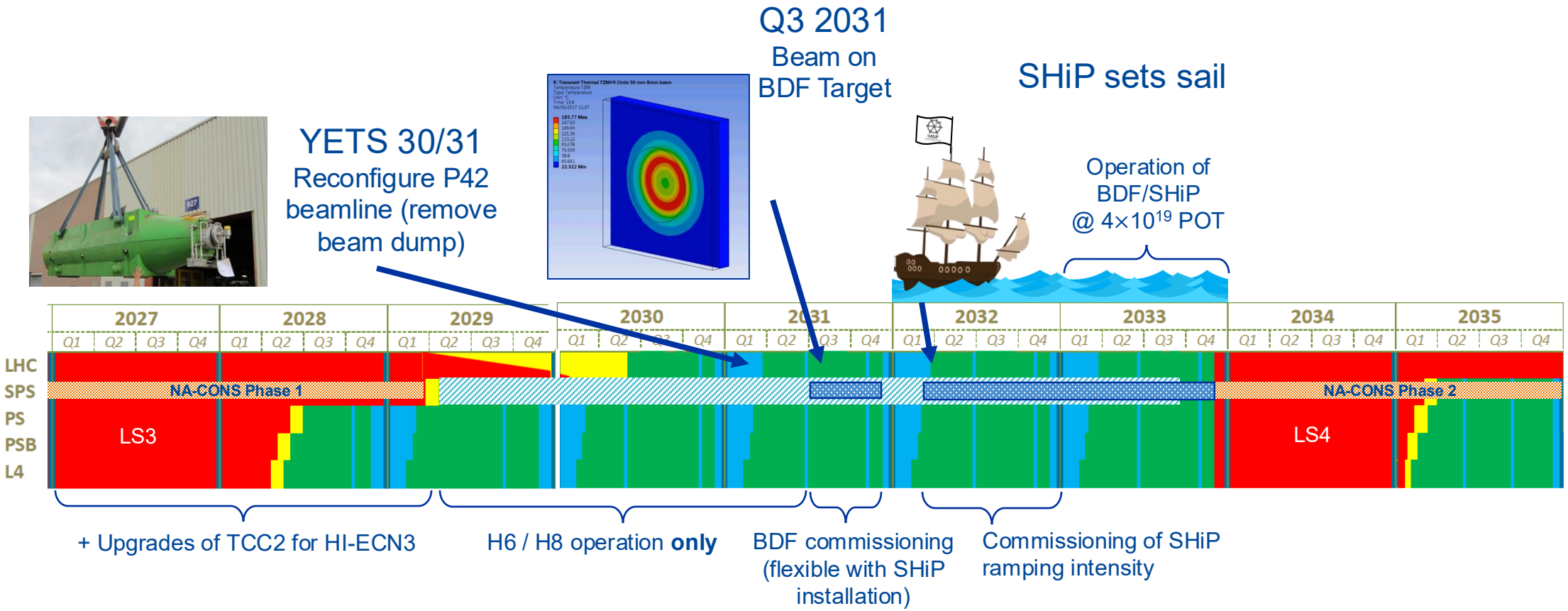
Thank you very much for your attention!

Backup

TCC2 looking Upstream



Timeline



- H6 / H8 will run for 2 years before SHiP starts - ECN3 must be accessible during that time
- Operation of ECN3 must remain independent of the North Area