Talk-for-Guides: Lifecycle of the LHC

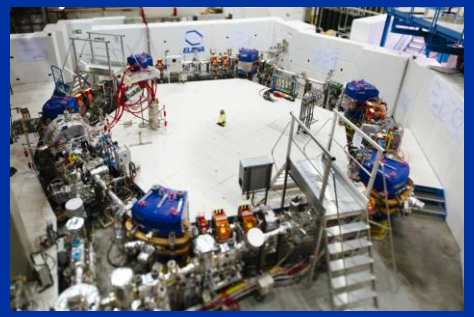
The CERN Accelerator complex and its running

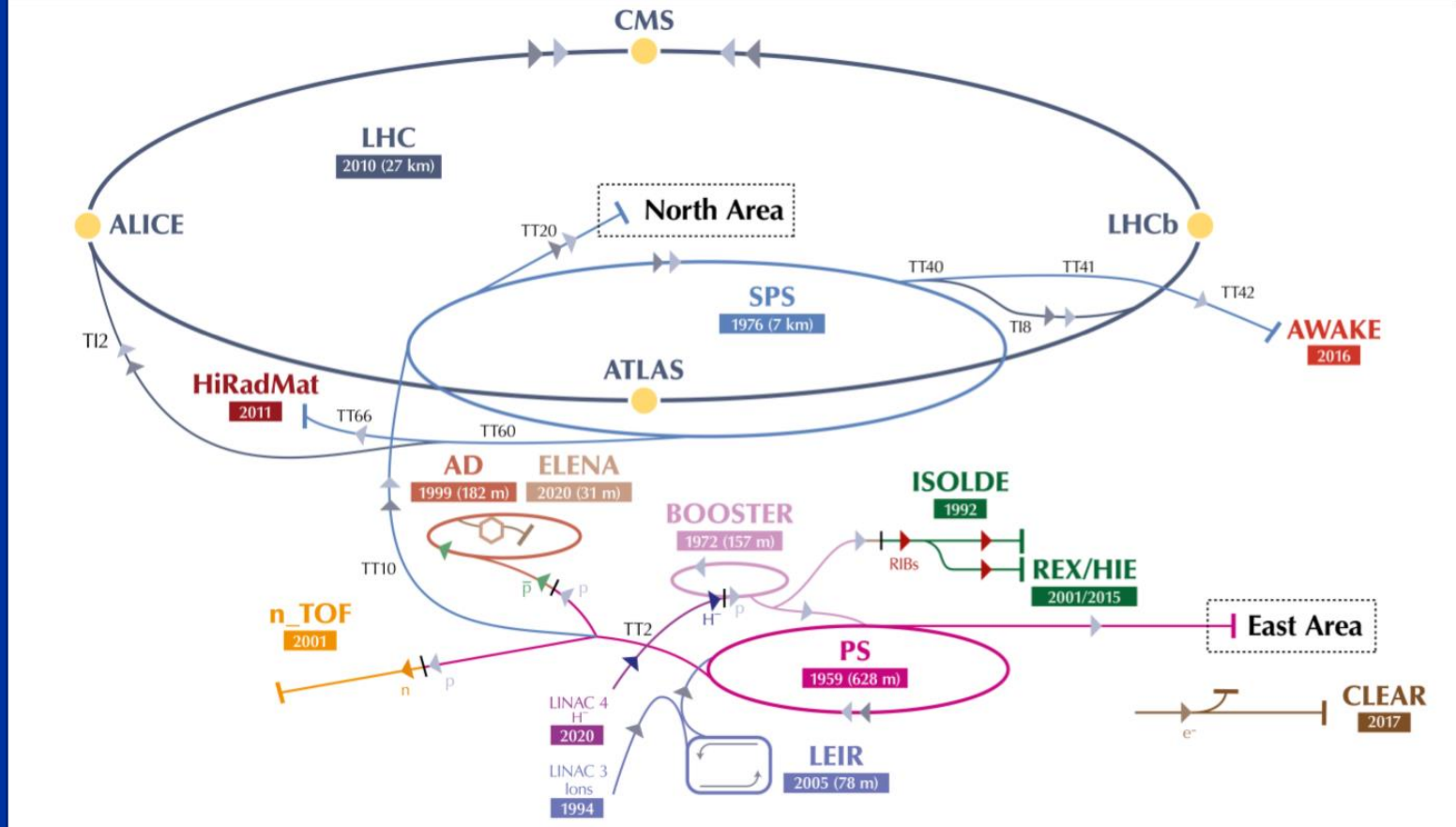
Rende Steerenberg – BE/OP

6 December 2024

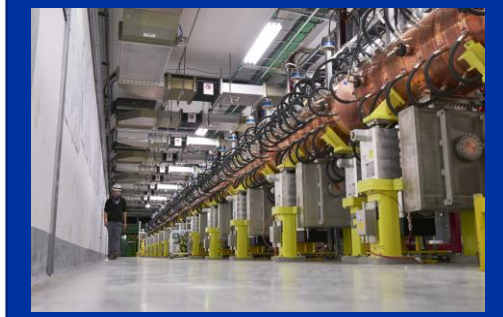
The CERN Accelerator Complex










Topics

- **Scheduling**
- **Satisfying our Users**
- **Controlling the Accelerator Complex**
- **Some things that will happen during LS3**

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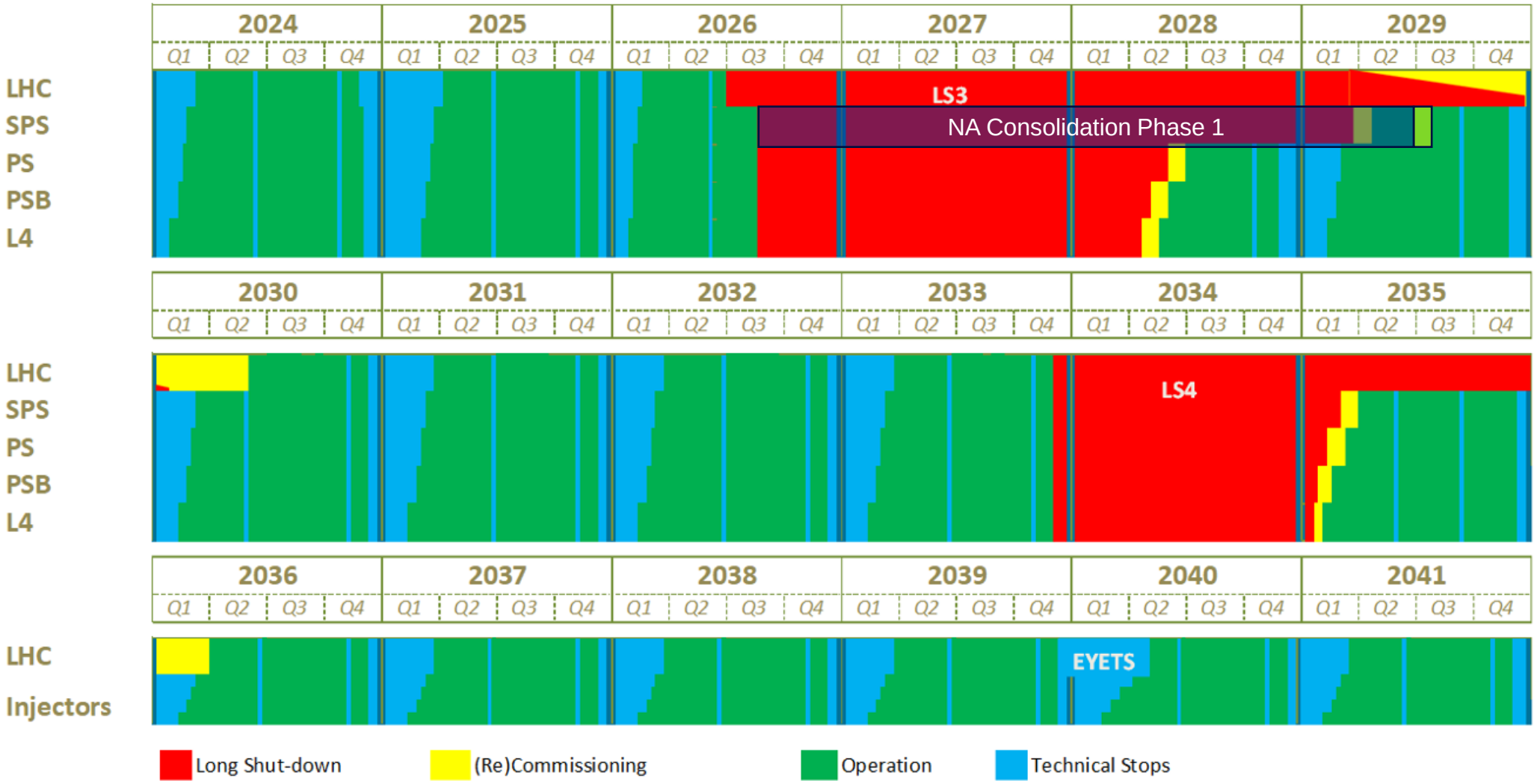
The long-term accelerator schedule



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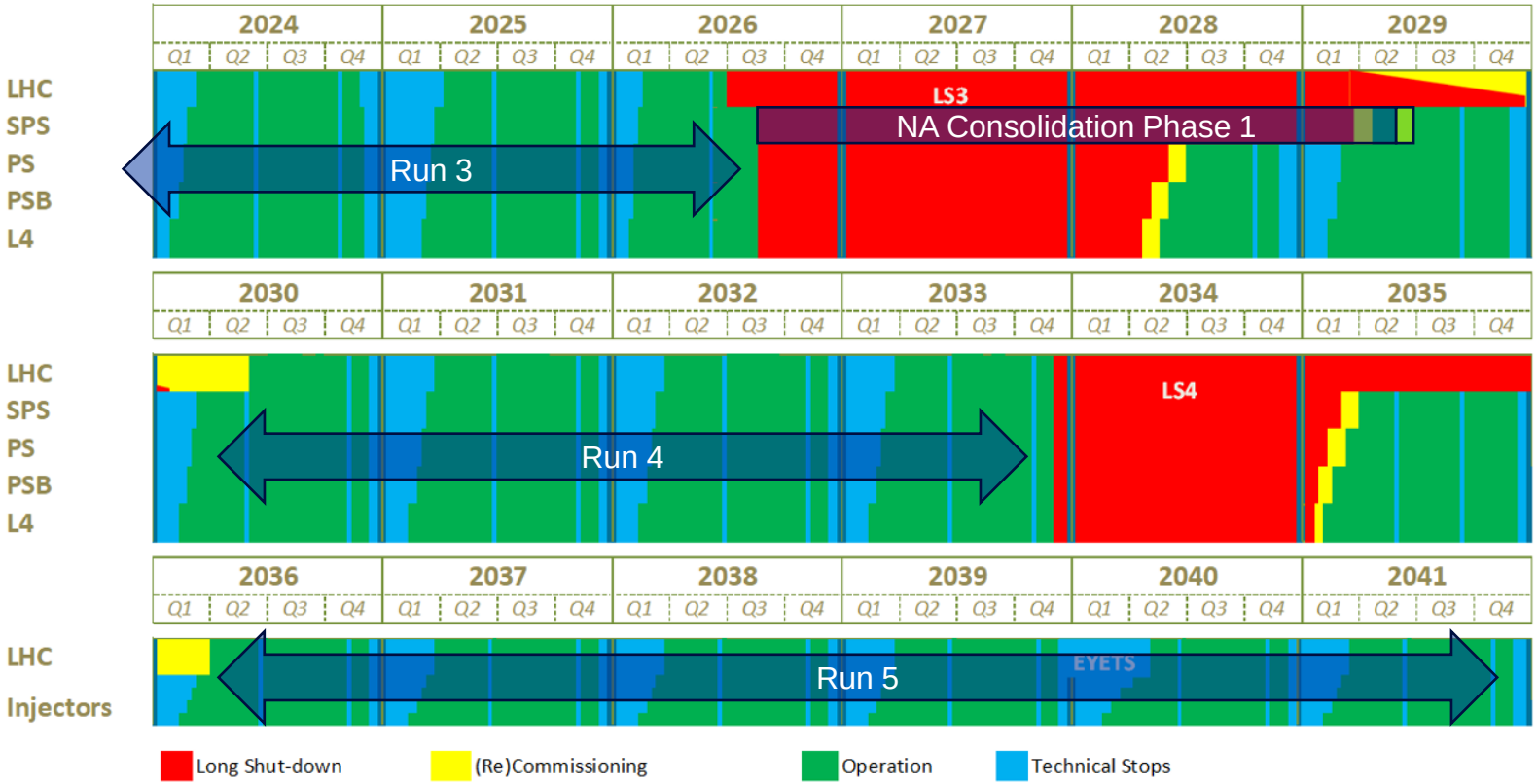
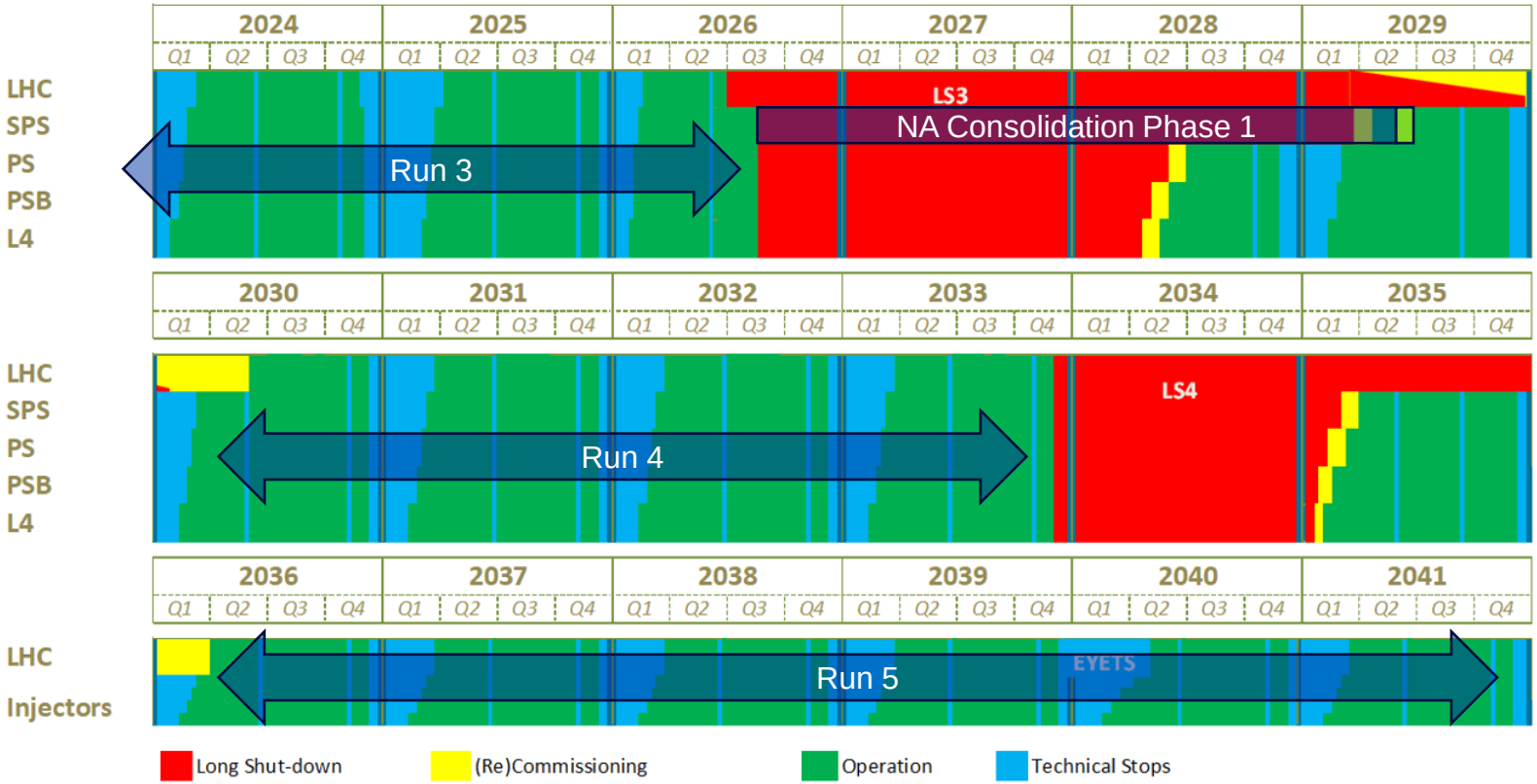


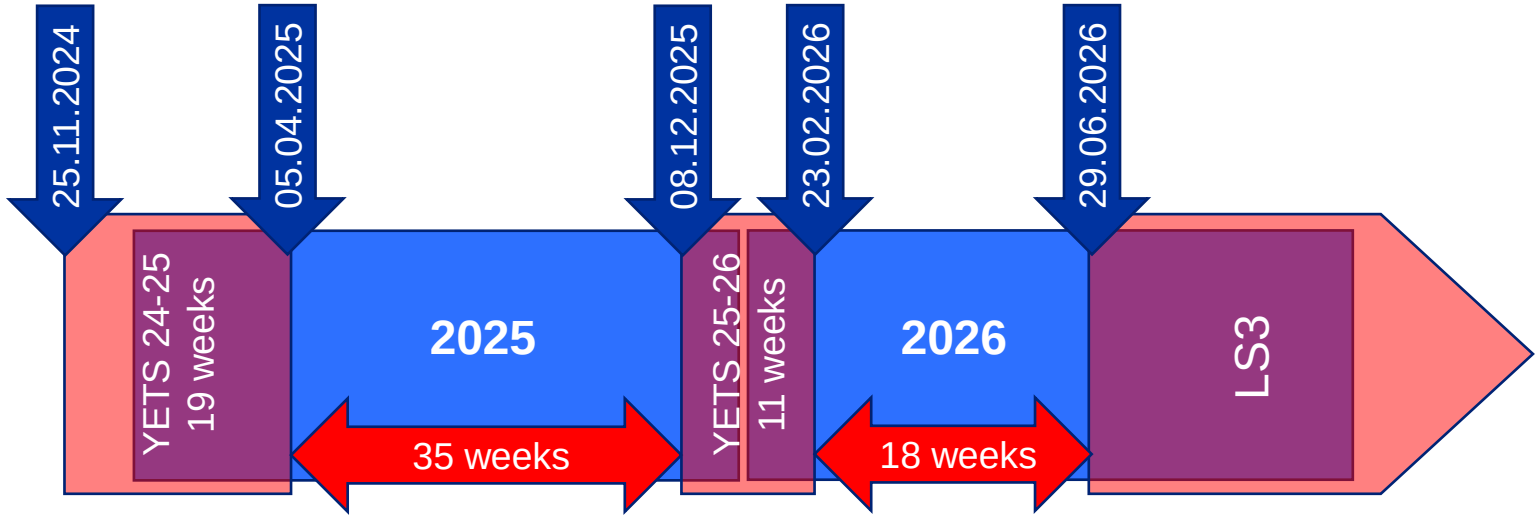
- **The running of the accelerator complex is interleaved with:**
  - Technical stops – TS
  - Year End Technical Stops - YETS
  - Long shutdowns – LS
- **The periods between the LS's are typically 4 to 5 years**
- **Yearly schedules are made and approved by the Research Board based on this long-term schedule**
- **The present Long-term schedule runs until 2041 incl.**
  - This is at present the foreseen date to complete the (HL-)LHC programme

The long-term accelerator schedule



- **End of the Run 3:**
  - LHC – last beams scheduled to be dumped on 29 June 2026
  - Injectors – End of beam production and physics scheduled for 31 August
- **Tentative dates to resume beam operation post-LS3 (still under discussion)**
  - (HL-)LHC
    - Hardware re-commissioning January 2029
    - Beam re-commissioning May 2030
  - SPS: May 2029
  - PS Complex: May/June 2028

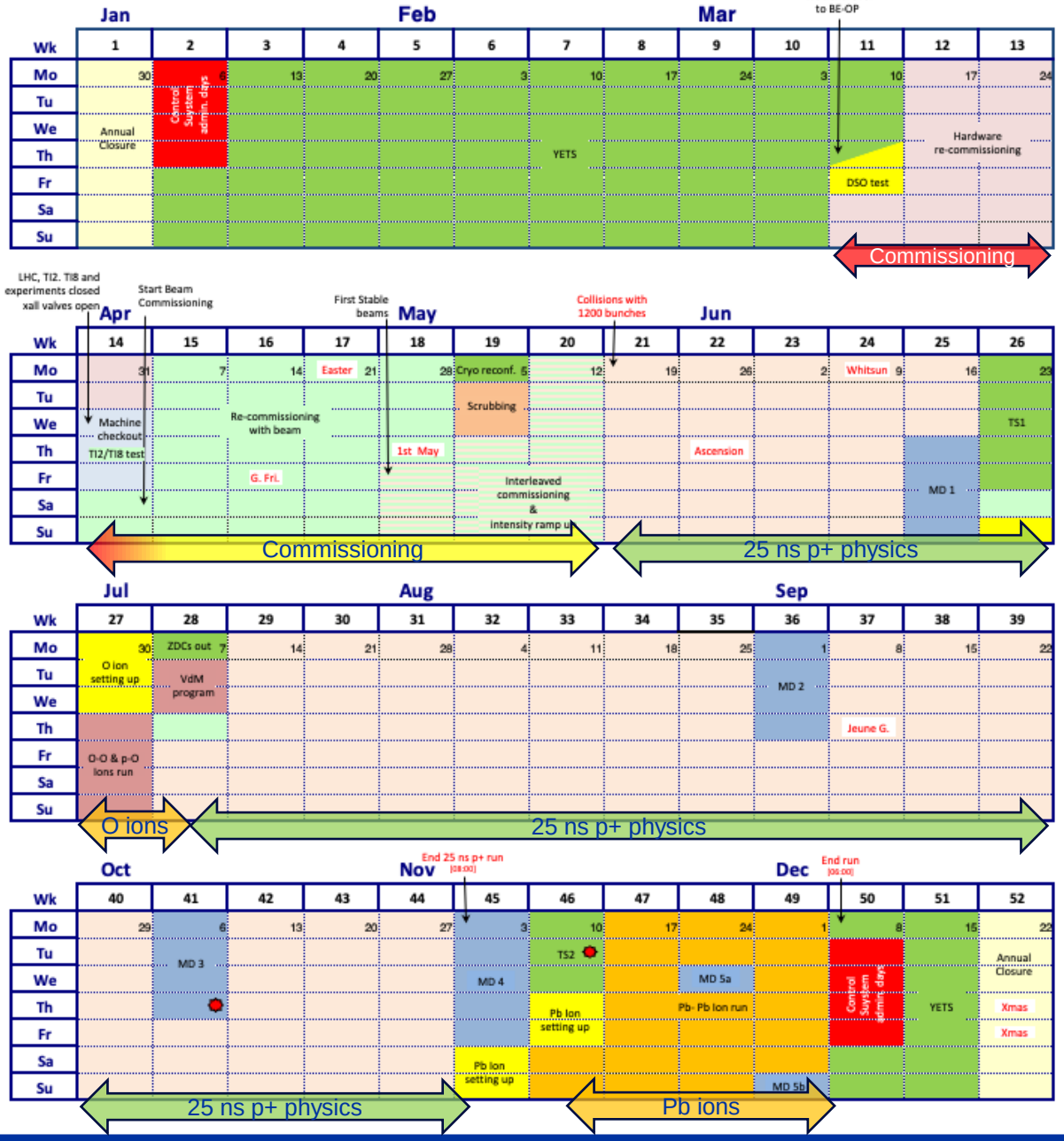
Global overview of the LHC running until LS3



- **2025:** 35 weeks YETS to YETS → 165 physics days (protons, oxygen ions and lead ions)
- **2026:** 18 weeks YETS to YETS → 88 physics days (protons and lead ions)

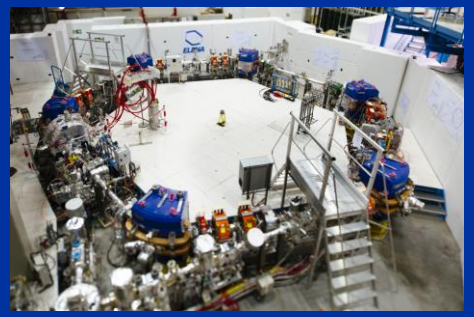
The Yearly Schedule: 2025

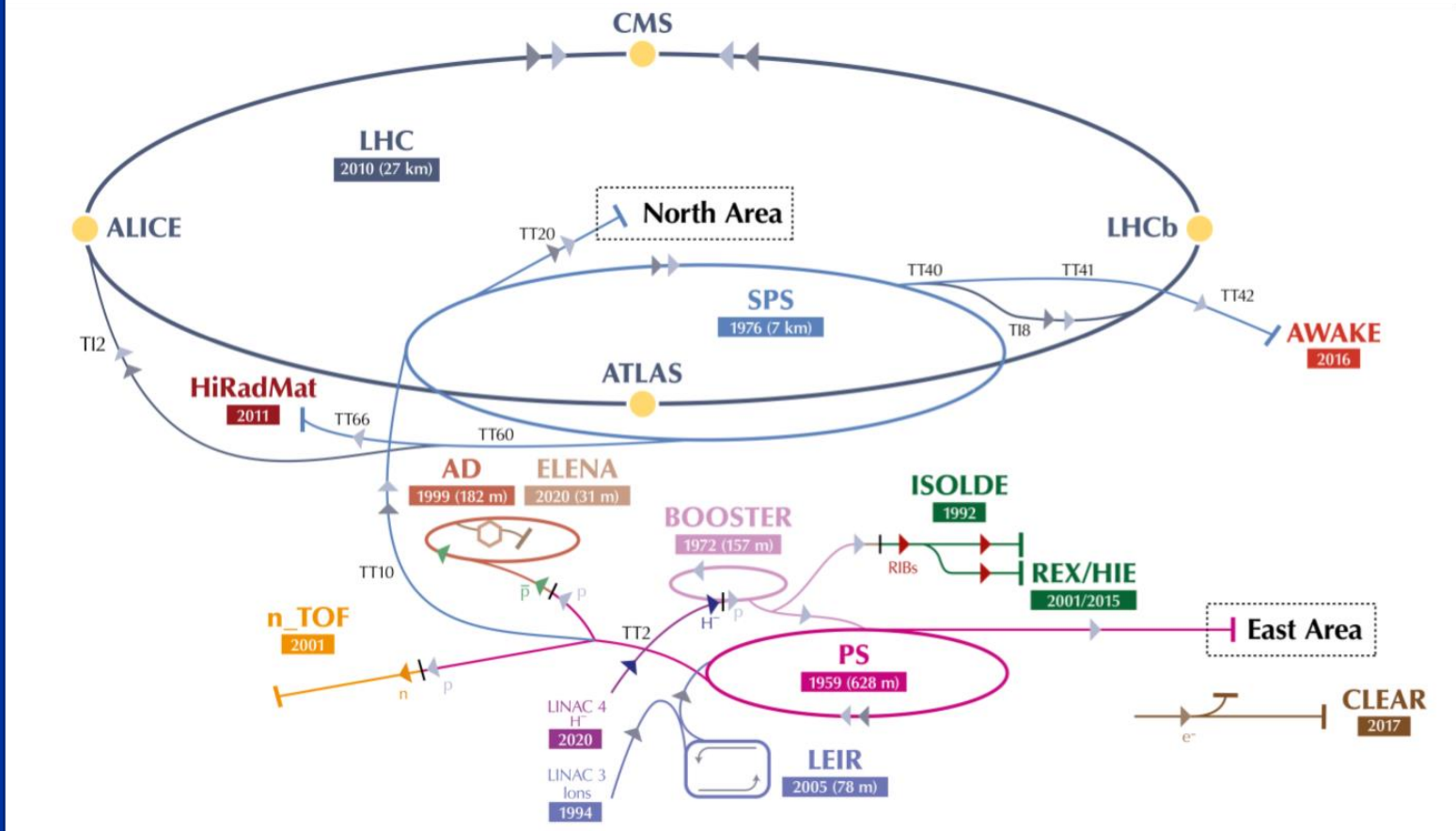
- **Yearly Schedules are based on:**
  - The long-term schedule
  - Physics needs as defined by the experimental committees and the Research board
  - The period necessary to restart the complex and to prepare the different beam types required
- **There are two yearly schedules:**
  - The LHC schedule
  - The Injectors schedule

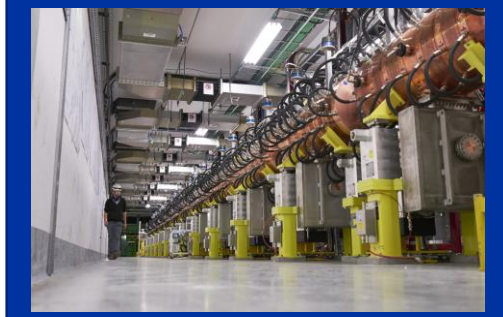


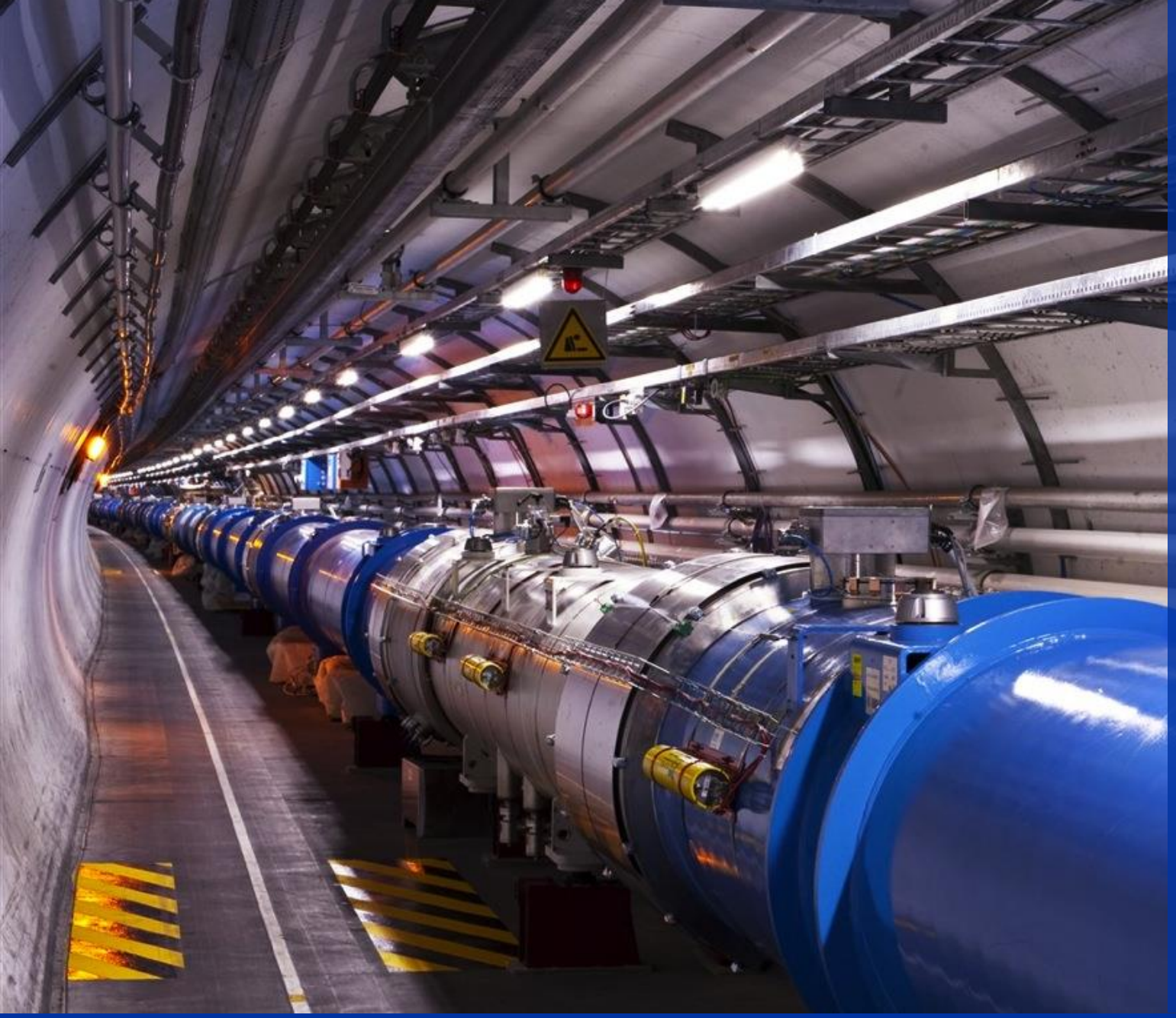
- Scheduling
- **Satisfying our Users**
- Controlling the Accelerator Complex
- Some things that will happen during LS3

Filling the LHC







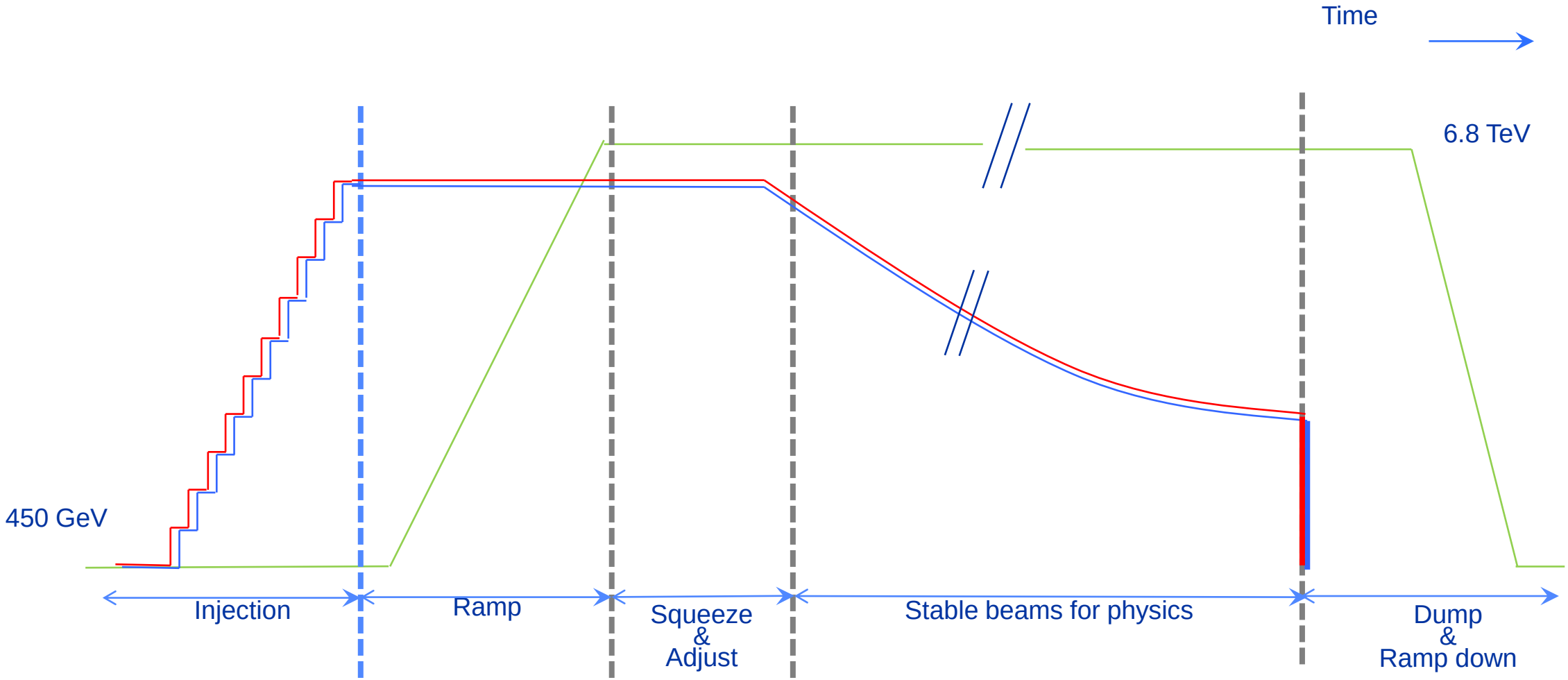


LHC

- 1232 main dipoles of 15 m each that deviate the beams around the 27 km circumference
- 858 main quadrupoles that keep the beam focused
- 6000 corrector magnets to preserve the beam quality
- Main magnets use superconducting cables (Cu-clad Nb-Ti)
- 12’000 A provides a nominal field of 8.33 Tesla
- Operating in superfluid helium at 1.9K

The LHC Cycle

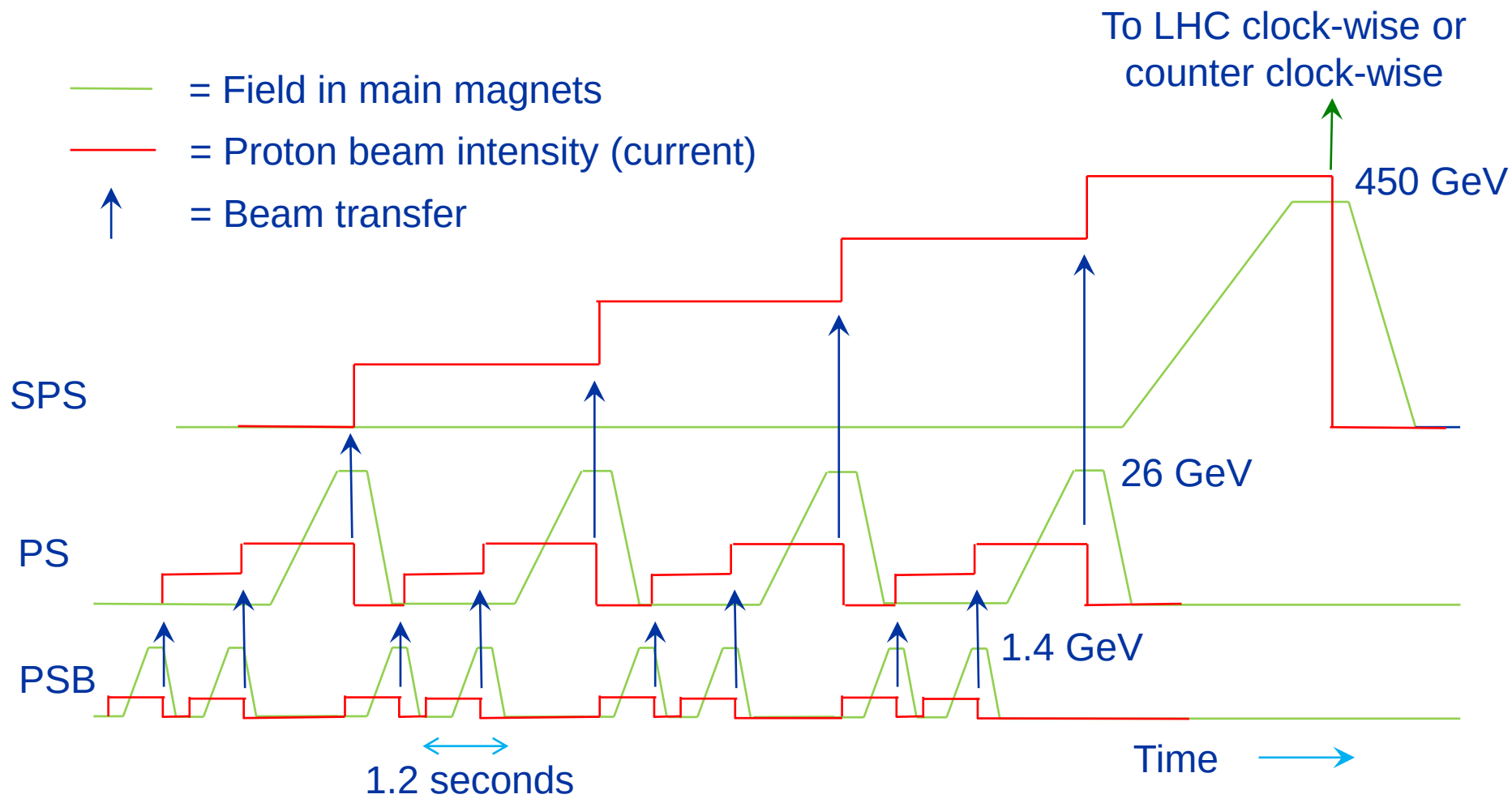
= Field in main magnets
= Beam 1 intensity (current)
= Beam 2 intensity (current)



Stored Beam Energy in the LHC

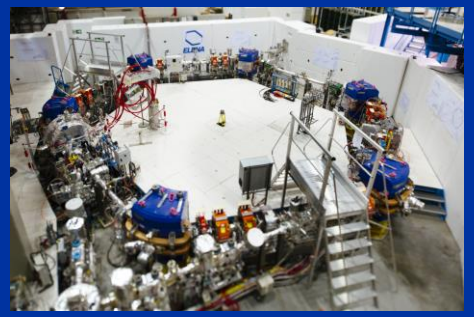
- The stored energy in one LHC beam at 6.8 TeV nowadays is about **400 Million Joules**
- This corresponds to the energy of a TGV train going at ~160 km/h
- ..... but then concentrated in the size of a hair

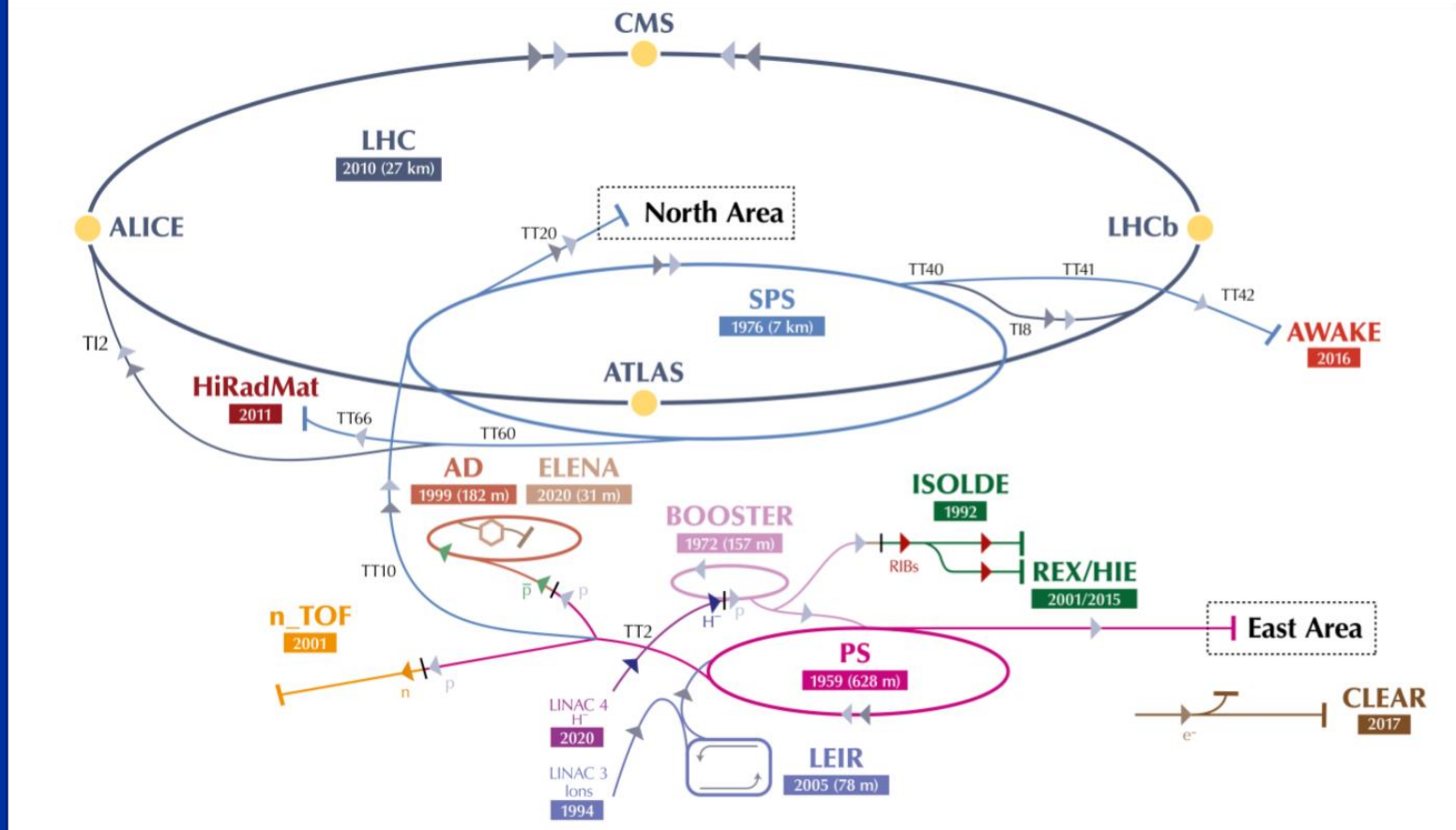
Filling the LHC & Satisfying Fixed Target users



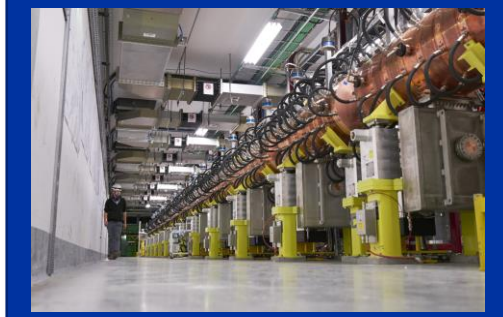
Satisfying the Fixed Target Users







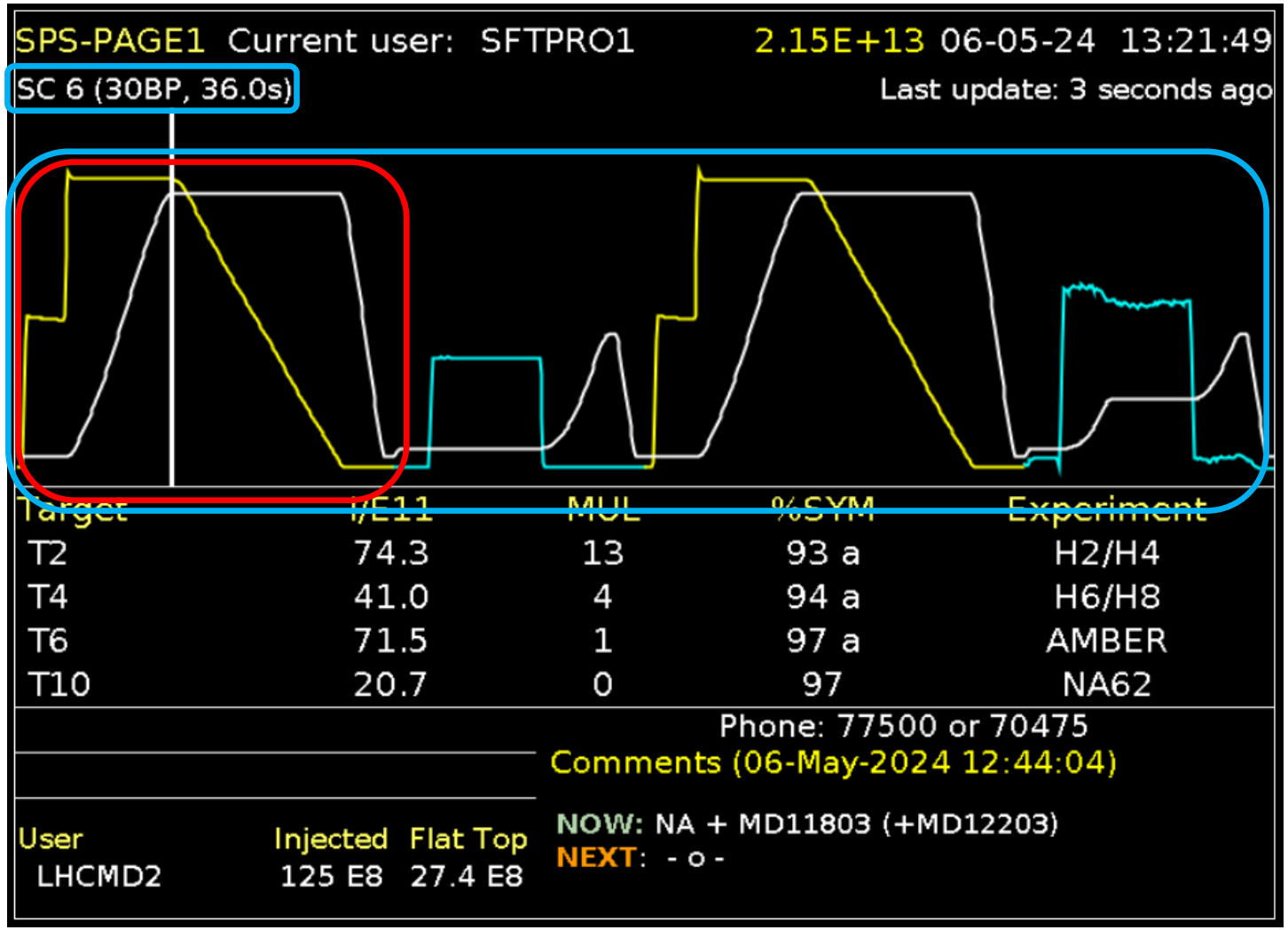



Satisfying Fixed Target users, when LHC is not filling

Example SPS:
https://op-webtools.web.cern.ch/vistar/?usr=SPS1

- **Cycle (e.g. SFTPRO1):**
  - Flat bottom – injection
  - Ramp – acceleration
  - Flattop – extraction
  - Ramp down – no beam

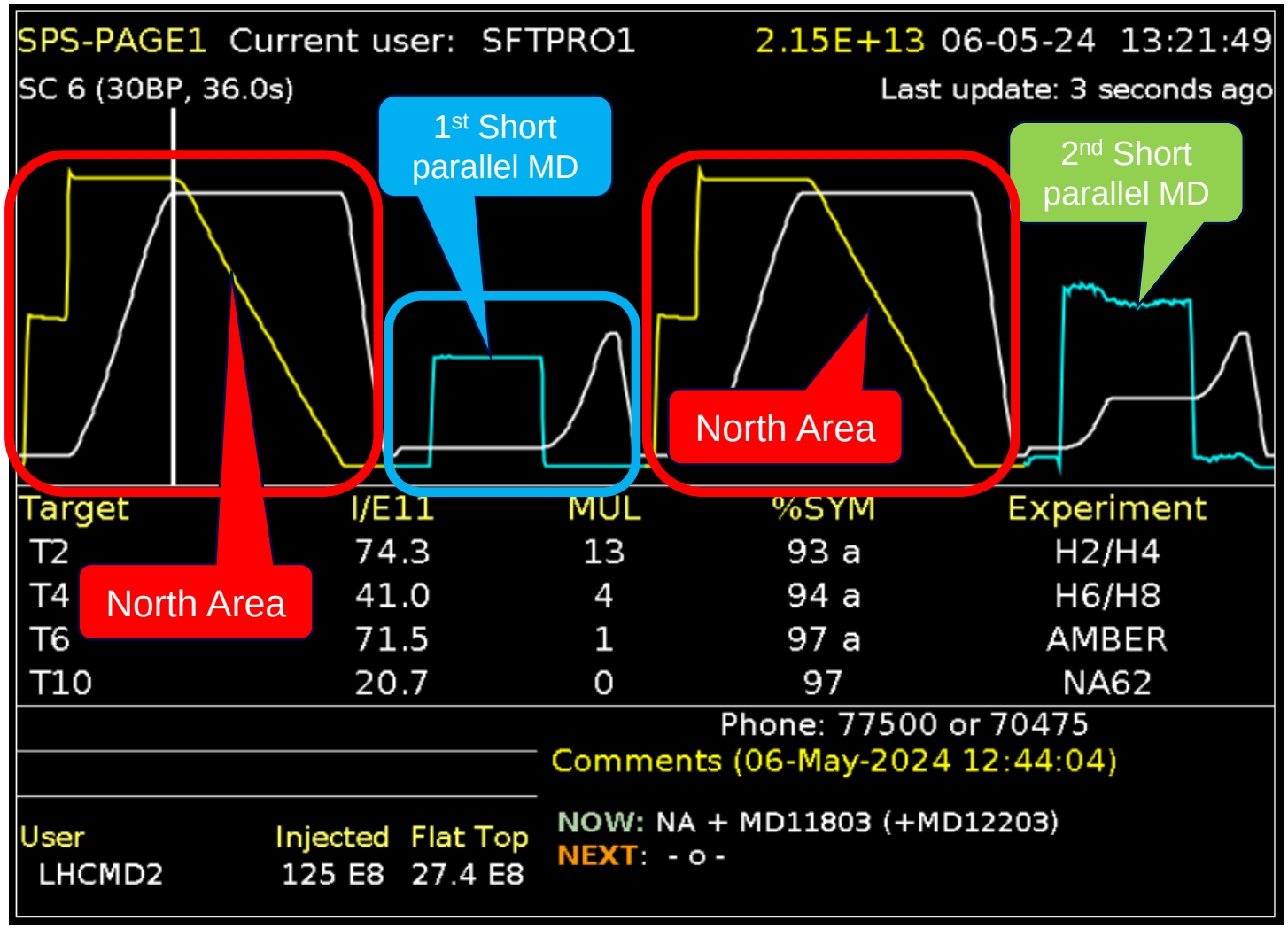
- **Super Cycle & Basic Periods:**
  - Sequence of multiple cycles of the same or different type that repeats itself
  - Length 30BP, 36.0s



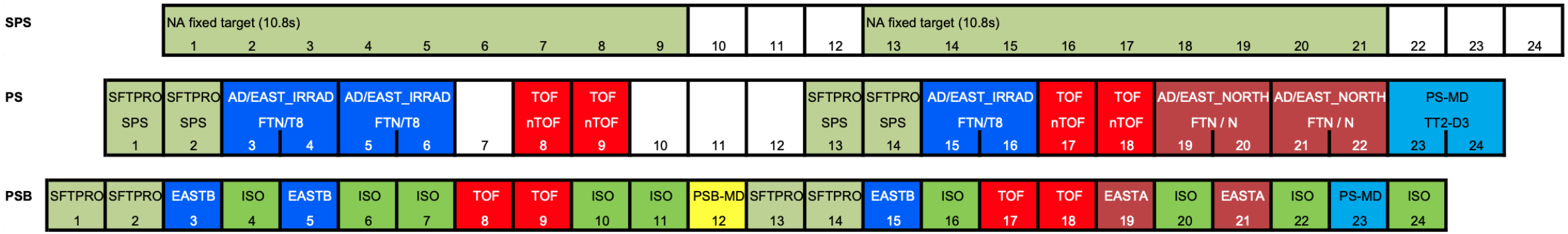
Satisfying Fixed Target users, when LHC is not filling

- **Cycle SFTPRO1:**
  - Two injections from the PS
    - Each PS cycle injecting takes 1.2S
  - Final destination North Area
  - Slow extraction over ~ 4.5 sec.
  - Total cycle duration 9BP, 10.8s
  - Used for physics

- **Cycle MD1:**
  - One injections from the PS
  - Destination internal beam dump
  - Total cycle duration 6BP, 7.2s
  - Used for Machine development studies (MD)

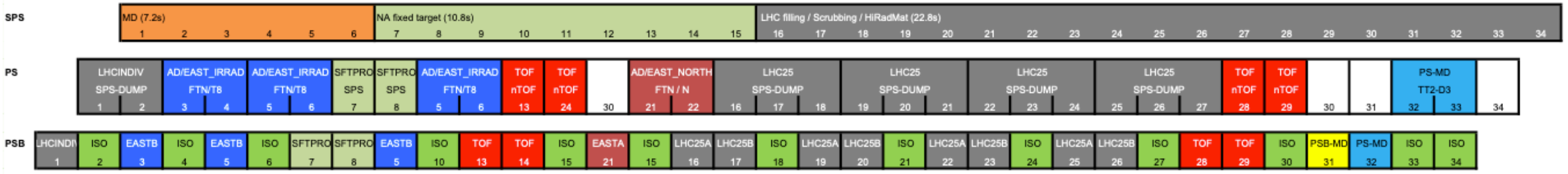


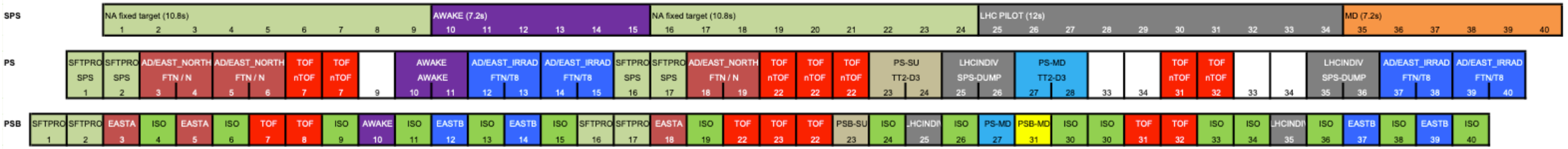
PSB, PS and SPS super cycle composition example



- **SPS Fixed target (=SFTPRO1):**
  - Requires 2 cycles in the PSB injecting into the PS injecting into the SPS
  - While SPS is accelerating and extracting PS can PSB can serve ‘their’ users
    - PS: 2 x East Area requiring each 1 cycle in the PSB + 2 x nTOF requiring each 1 cycles in the PSB
    - PSB: in the shadow of the PS accelerating and extracting for East Area, PSB can produce ISOLDE
    - PSB can also use the cycles for ISOLDE that are not required by PS or PS and SPS

Other examples

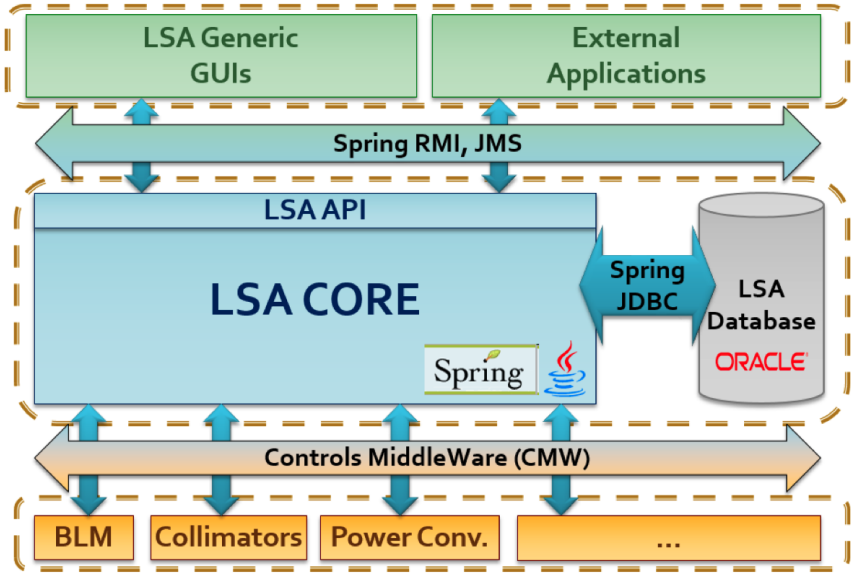




Infinitely other combinations possible….

- Scheduling
- Satisfying our Users
- **Controlling the Accelerator Complex**
- Some things that will happen during LS3

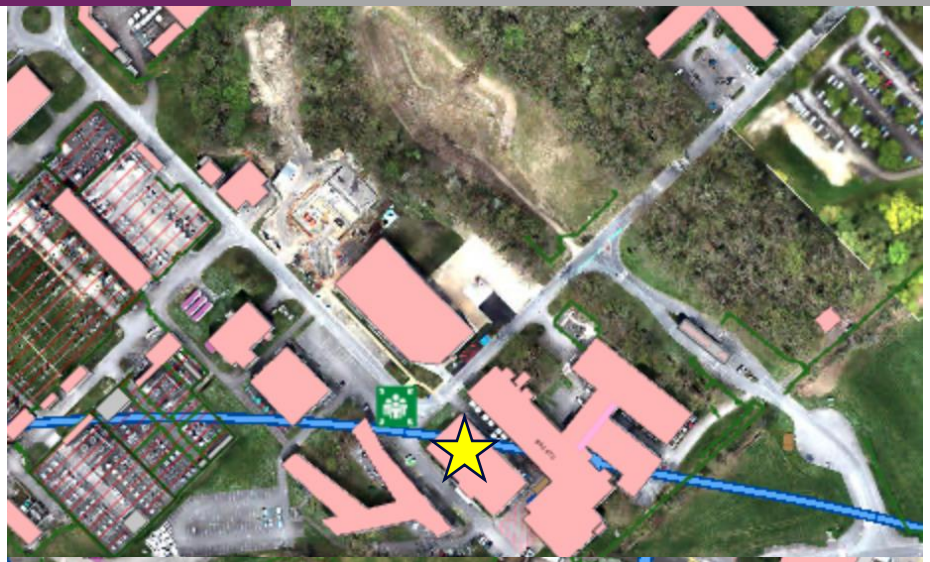
Settings Management

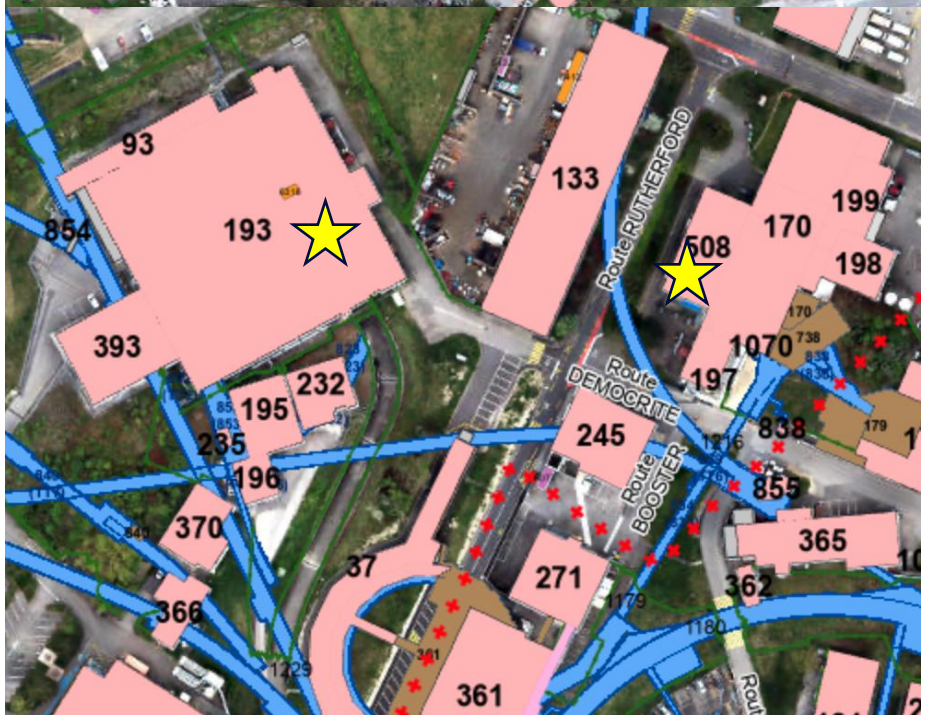


- **All machine equipment (e.g. power converters, RF cavities, beam instrumentation, …) are items in a database with various properties**
- **Each cycle has a label (e.g. SFTPRO1, MD1, LHCINDIV, ISO,….) which are stored in a database**
- **The database contains settings (values, functions) for each cycles in each machine**
- **Every time a cycle is executed:**
  - These values are sent to the equipment
  - The values and functions are activated by timing events that are also programmed in a database
- **This allows to program each cycle differently enabling the production of very different types of beams**

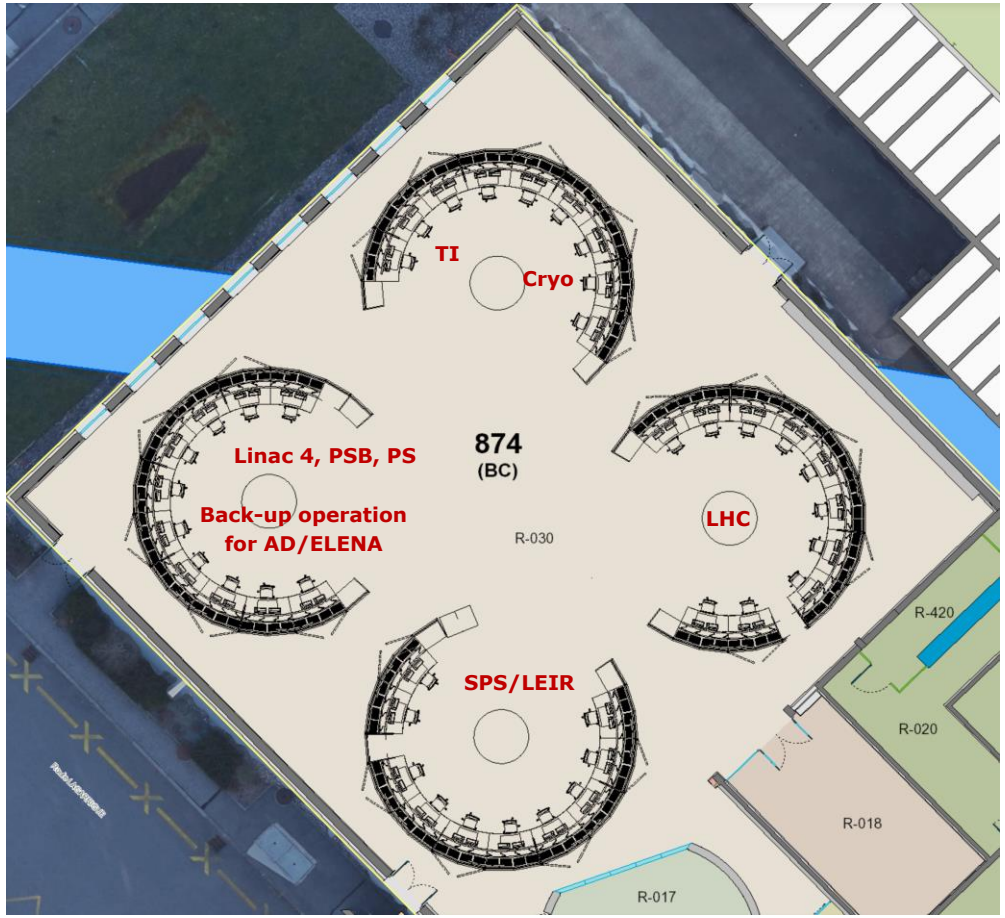
Control Rooms

- **CERN Control Centre (CCC) – Prevessin**
  - 24/7 shifts
  - Linac4, PSB, PS, SPS, LHC
  - LINAC3, LEIR
  - Technical Infrastructure, Cryogenics
- **AD Control Room (ACR) - Meyrin**
  - Day time operation
  - Back-up operation from CCC during nights & weekends
  - Standby service by AD/ELENA operator
- **ISOLDE Control Room (ICR) - Meyrin**
  - Day time operation
  - Limited back-up operation by experimentalists during nights & weekends
  - Standby service by ISOLDE operator





CERN Control Centre (CCC) lay-out

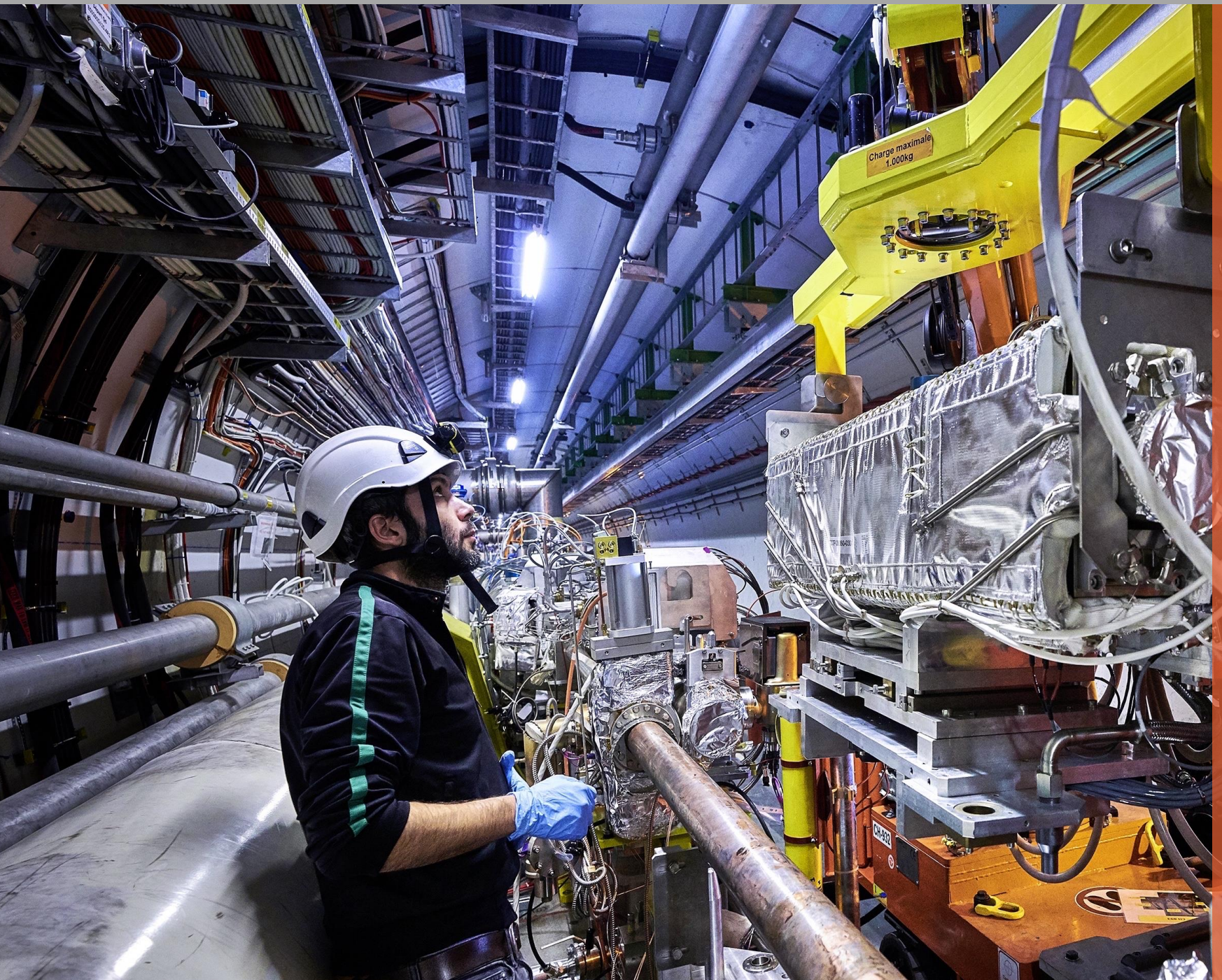


- **PS island**
  - 1 Shift leader + 1 or 2 Operators
- **SPS island**
  - 1 Shift leader + 1 Operator
- **LHC island**
  - 1 Engineer in charge (LHC-EiC)
- **TI/Cryo island**
  - 1 Technical infrastructure operator
  - 1 (or 2) Cryo operator(s)
- **During daytime 20 to 30 people extra for studies, setting-up new beams, issues, etc.**

- Scheduling
- Satisfying our Users
- Controlling the Accelerator Complex
- **Some things that will happen during LS3**

What will happen during LS3?

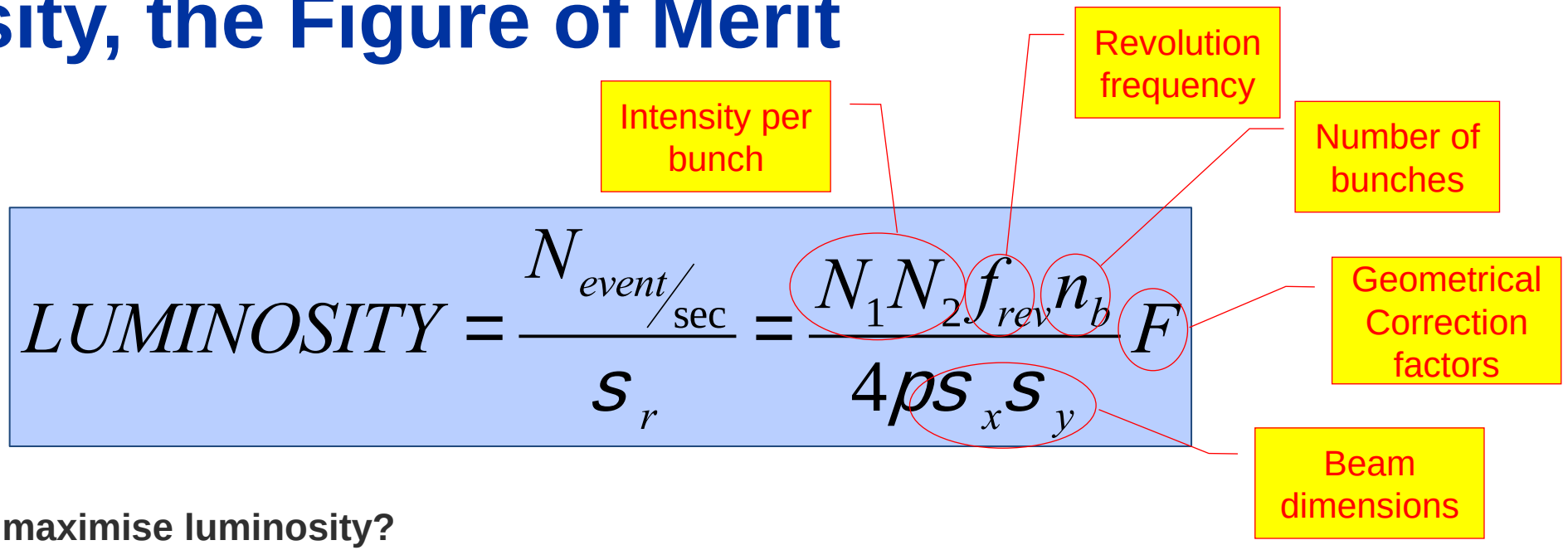
- **HL-LHC project will be deployed**
  - The LHC Injector Upgrade (LIU) project was completed during LS2
  - During run the performance potential given to the injectors has been exploited and HL-LHC beam parameters have been achieved in the injectors.
  - Now LHC will be prepared to be able to cope with the high intensity and high brightness beams



Upgrade to the High-Luminosity LHC is under way

- The HL-LHC will use new technologies to provide 10 times more collisions than the LHC.
- The stored beam energy will increase from ~300 MJ to ~600 MJ.
- It will give access to rare phenomena, greater precision and larger discovery potential.
- It will start operating in 2030, and run until 2041.

Luminosity, the Figure of Merit



What to do to maximise luminosity?

- Increase the number of bunches and revolution frequency → constraint
- Increase the bunch intensity
- Reduce the transverse beam size (emittance)

→ LHC Injectors Upgrade

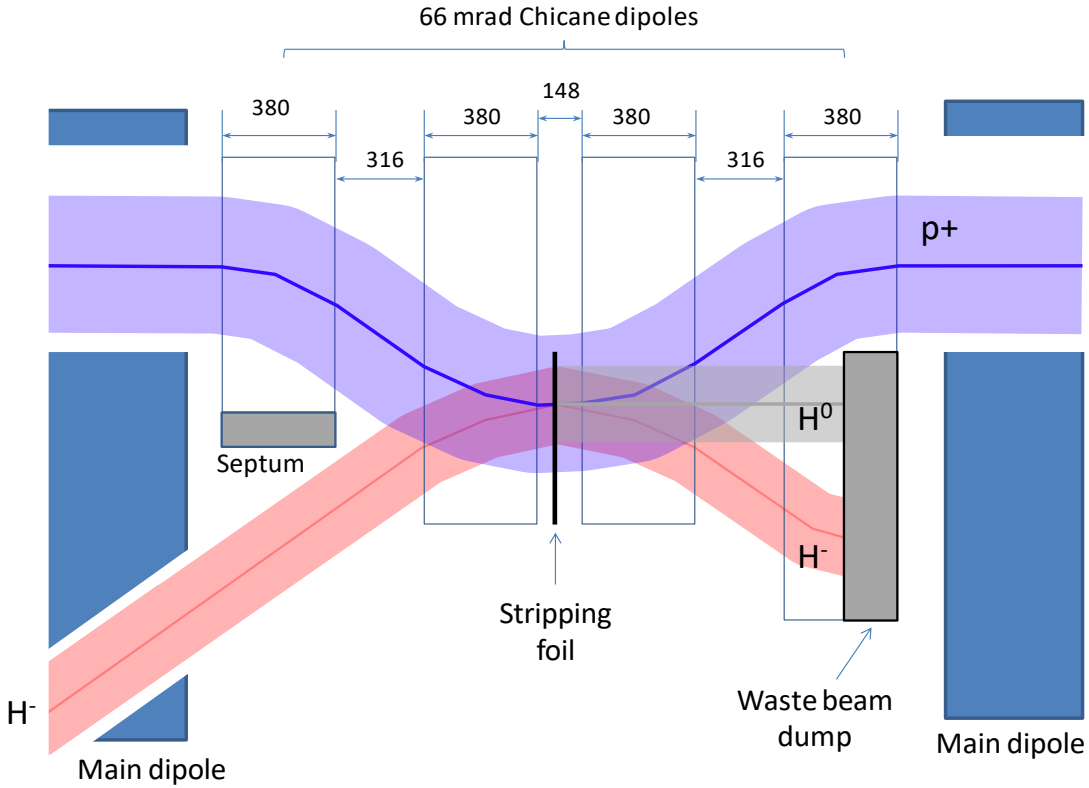
- Reduce the beam size at the collision point
- Minimise the crossing angle

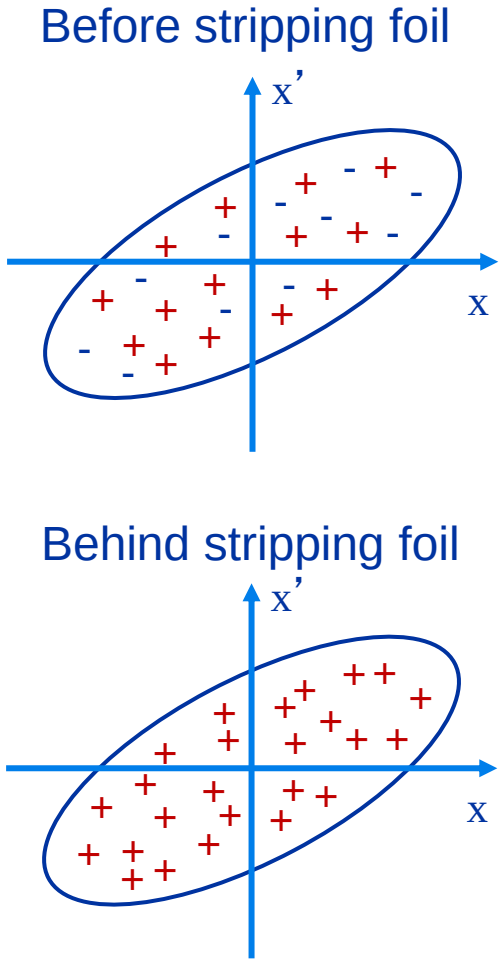
→ HL-LHC Upgrade

- Ensure good machine availability to increase integrated luminosity

Key Ingredient Injector Upgrade

- Charge exchange injection with H^-



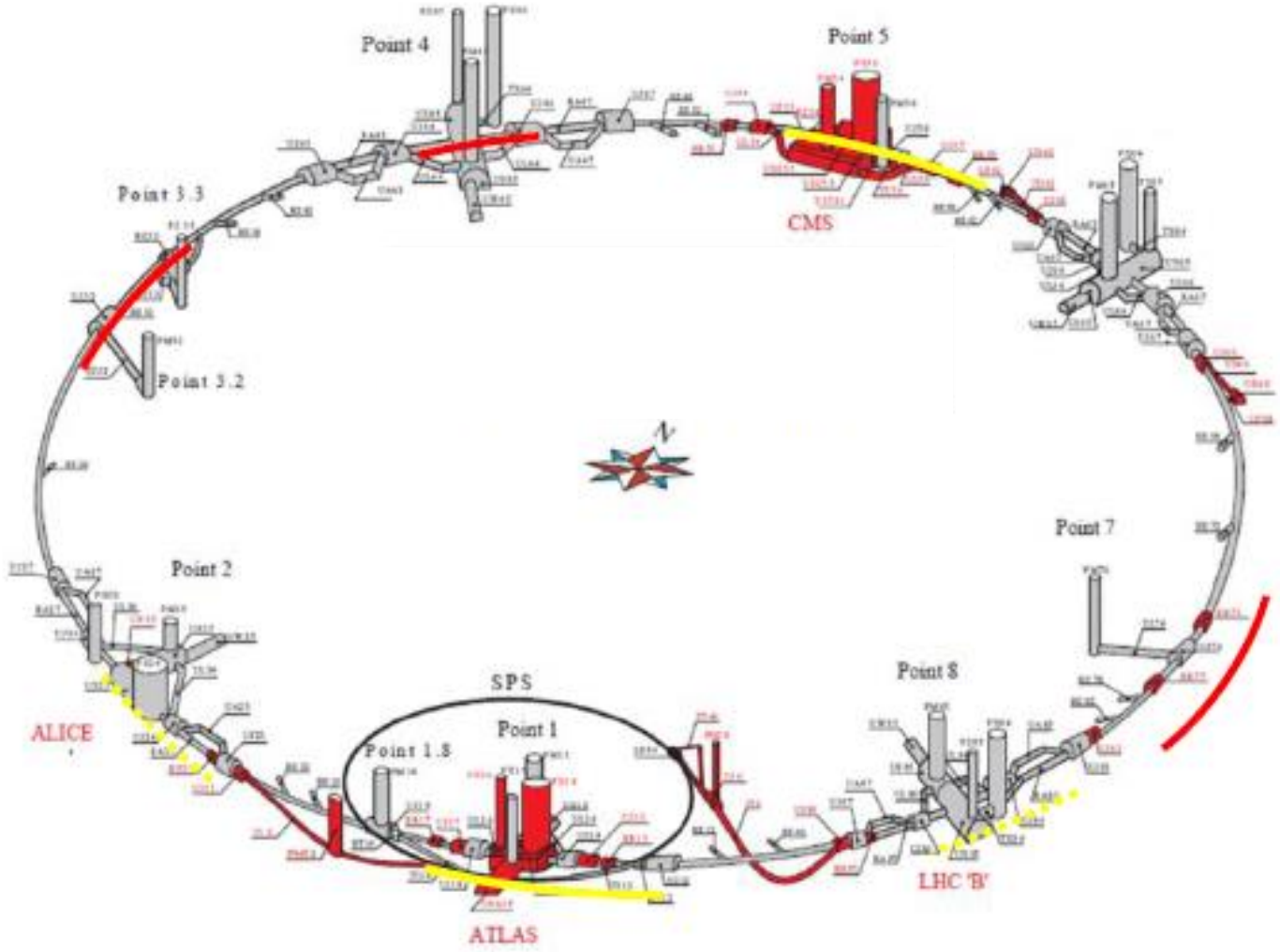


Phase Space Painting is possible (various particle distributions)

The High Luminosity LHC Project

Major civil engineering

- **New interaction region magnets**
- **Collimation** upgrade
- **Cryogenics** upgrade
- **Crab Cavities** to reduce crossing angle
- **Cold powering**
- **Machine protection**
- …and much **more**…



New Facilities and Equipement Being Added

The HL-LHC is to be commissioned in 2030
….stay tuned….

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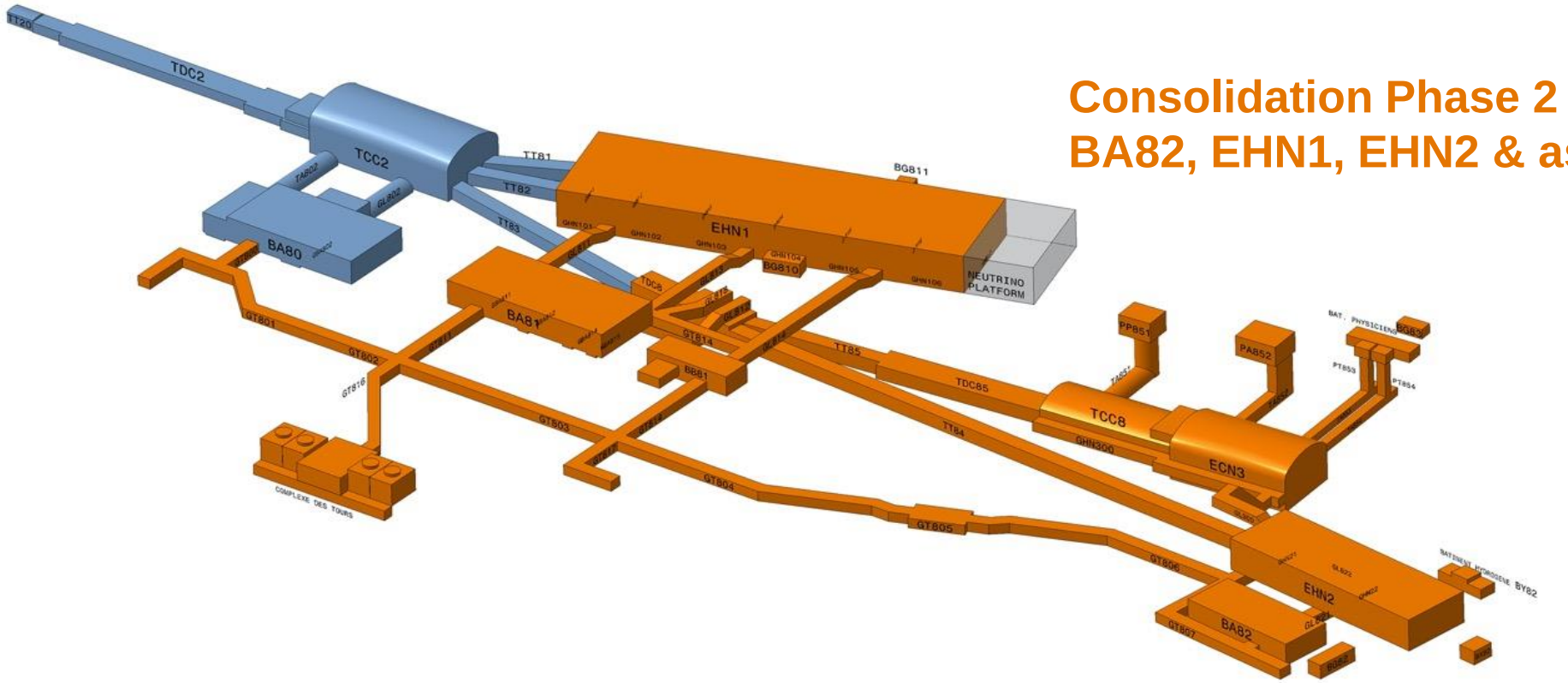
  - Now LHC will be prepared to be able to cope with the high intensity and high brightness beams
- **SPS North Area consolidation phase 1 & HI-ECN3 in view of the SHiP experiment**

Scope of SPS North Area Consolidation

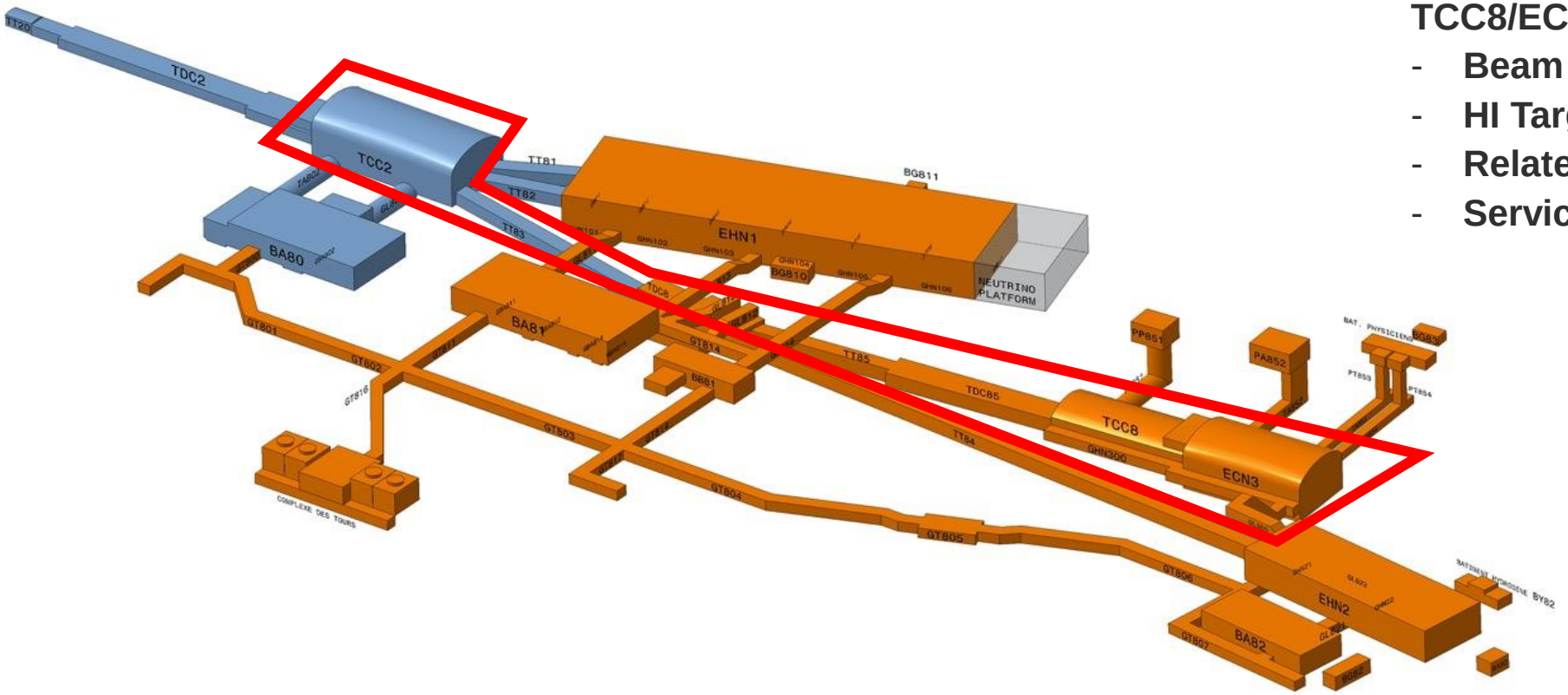
Consolidation Phase 1 (2019 – 2028)

- Primary areas incl. TDC2, TCC2, BA2, BA80 & beam lines towards EHN1 & TDC8



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

High Intensity ECN3 for the SHiP experiment



TCC8/ECN3:

- **Beam Dump Facility**
- **HI Target Complex**
- **Related Infrastructure &**
- **Services**

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- **SPS North Area consolidation phase 1 & HI-ECN3**
- **ISOLDE beam dumps replacement in view of possible energy and intensity upgrade**

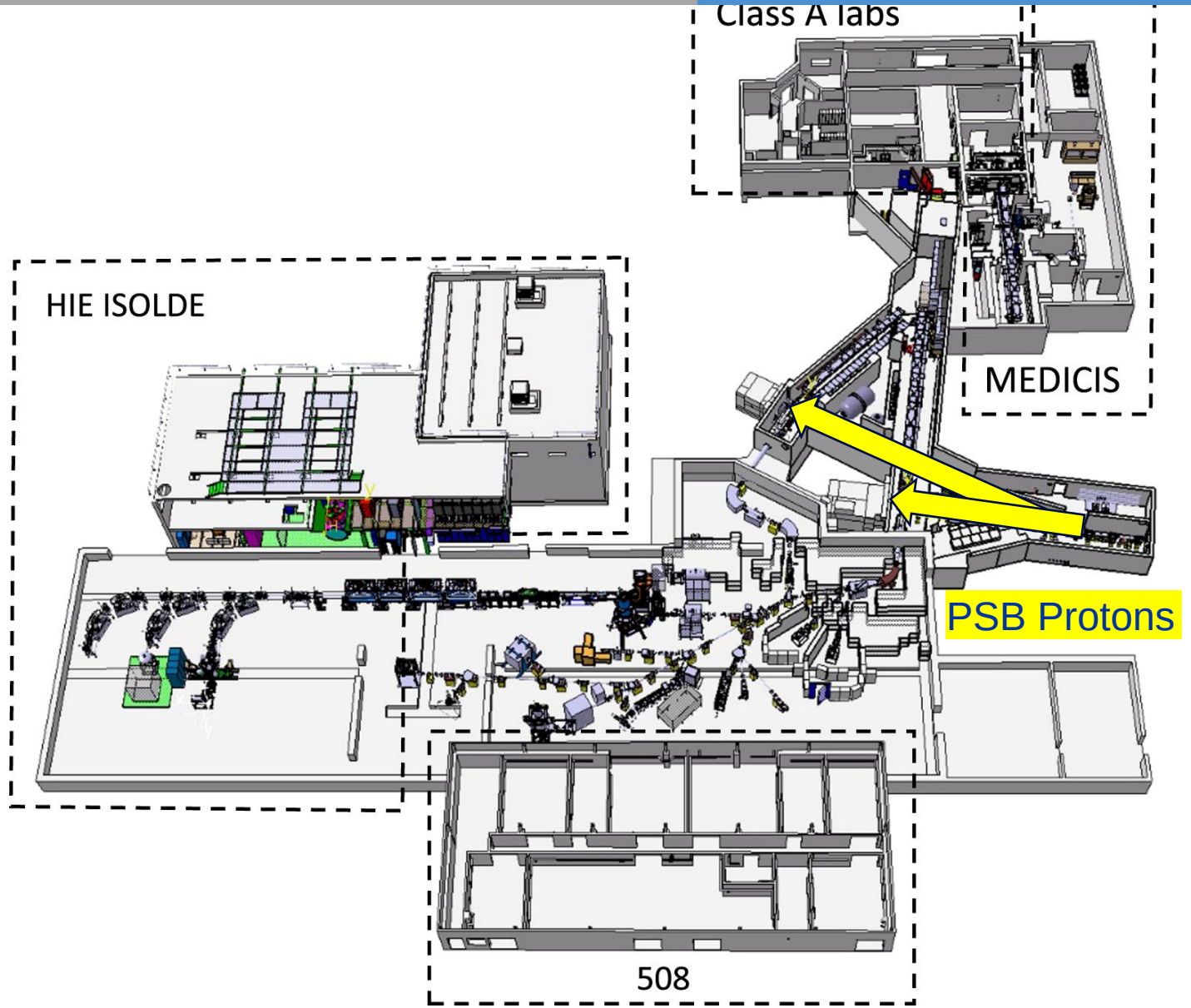
The ISOLDE layout

With the LIU upgrade the PSB:

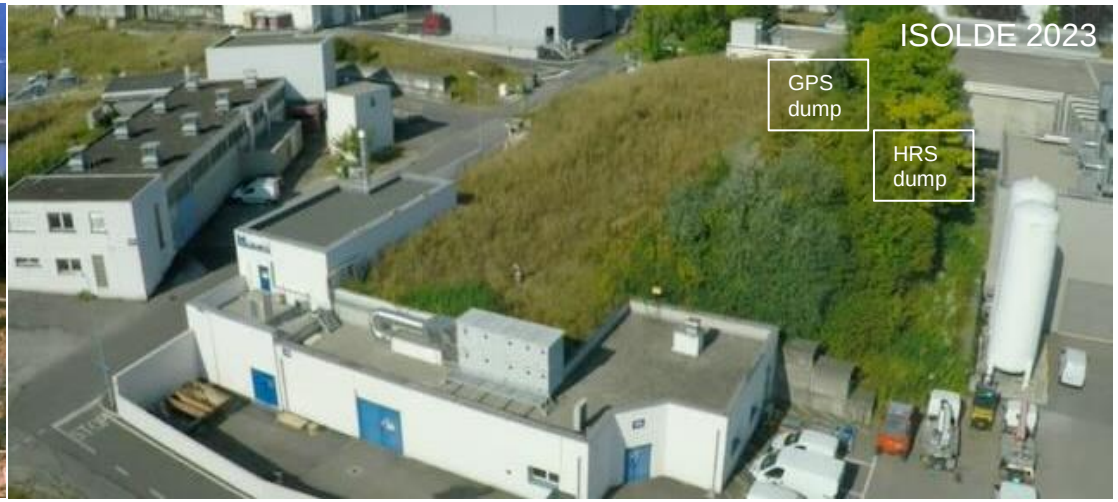
- Can provide higher energy beam at 2 GeV instead of 1.4 GeV
- Has the potential to provide higher intensity beam to ISOLDE

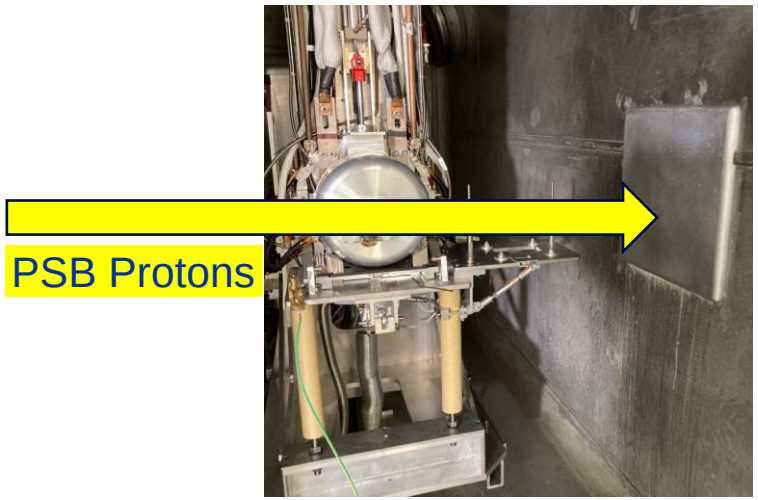
To allow for this ISOLDE will need to be consolidated and possibly upgraded

- One major ingredient for this is the replacement of the beam dumps



ISOLDE Beam Dump Replacement





Dumps already operate at their limit in terms of **temperature and mechanical stresses**

Suffering from: Corrosion

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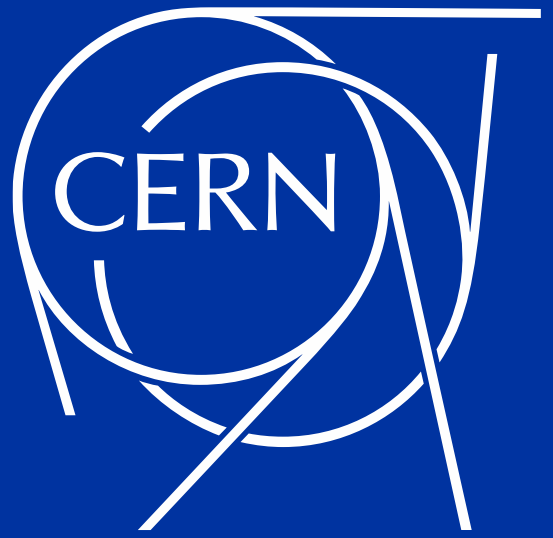
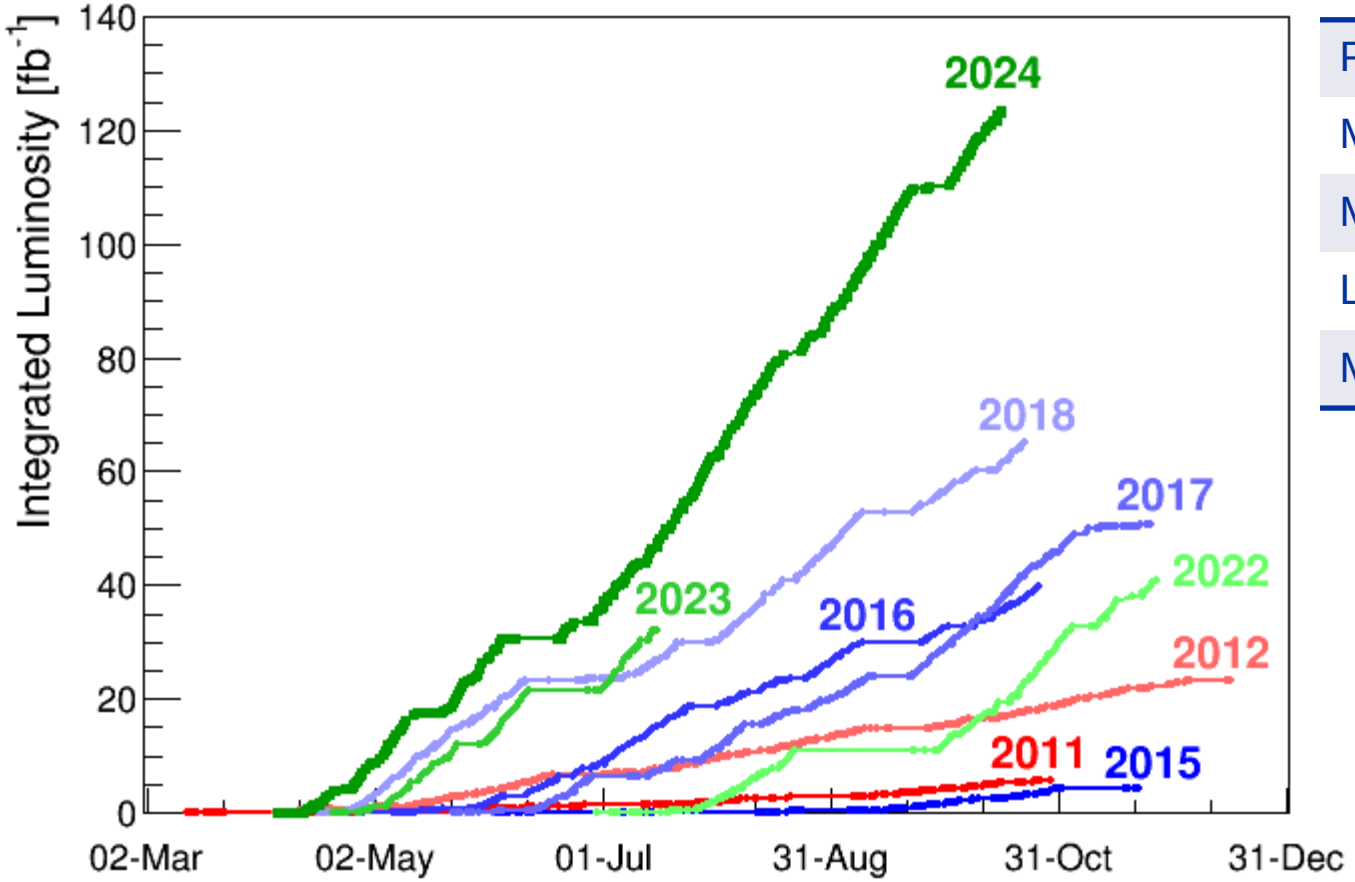
- **SPS North Area consolidation phase 1 & HI-ECN3**
- **ISOLDE beam dumps replacement in view of possible energy and intensity upgrade**
- **Massive consolidation work (e.g. electrical infrastructure, …)**
- **…. Many more… plus… the usual preventive and corrective maintenance**

But until then the focus will be on beam production for physics

Stay tuned…!


CERN

Breaking Performance Records



Peak Luminosity	2.33×10^{34} cm^{-2}s^{-1}
Max. Luminosity in one day	1.525 fb^{-1}
Max. Luminosity in 7 days	8.342 fb^{-1}
Longest time in Stable Beams	5 days 3 hr 35 min
Max. Charge per bunch	1.64×10^{11}

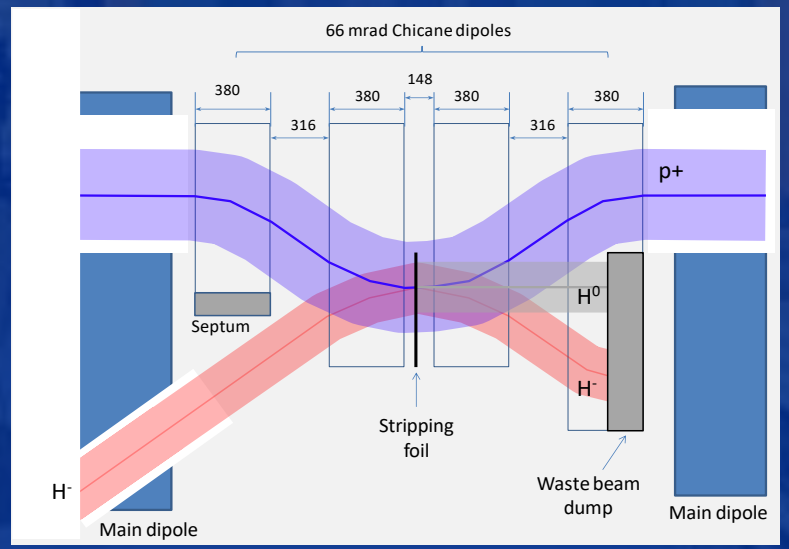
The integrated luminosity for proton physics during Run 3 so far stands at an impressive 196 fb^{-1}, surpassing the combined total of Runs 1 and 2 - and Run 3 is far from over, with 2025 and 2026 still ahead of us.

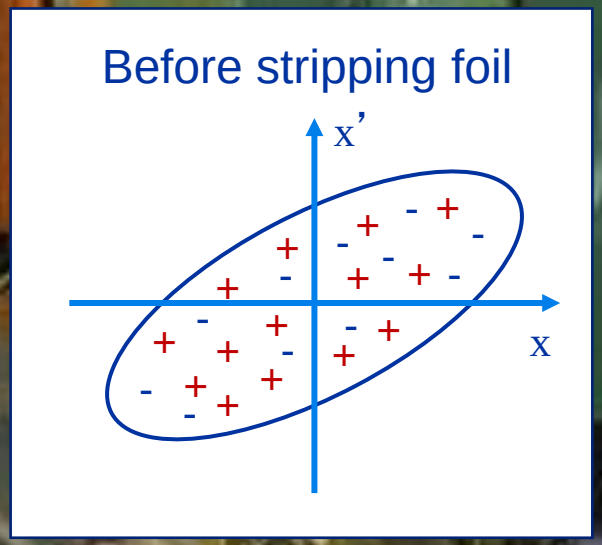
Linac 4

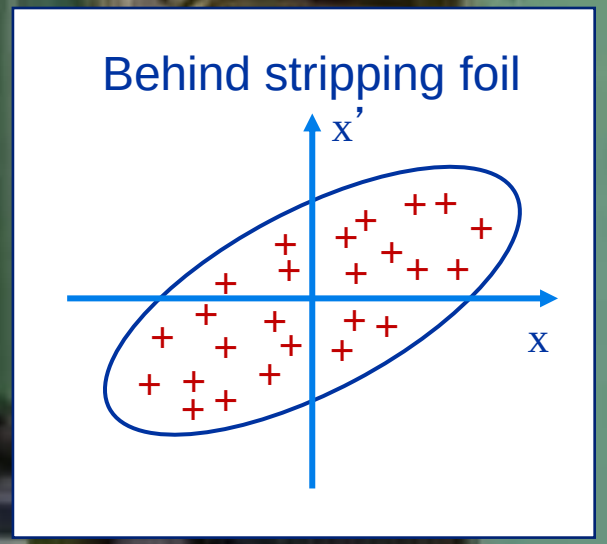
- H^- ion source at 45 keV
- Accelerates beam up to 160 MeV
- The chopping scheme allows removing some of the Linac bunches to make the beam fit into the PS Booster RF buckets
- Pulse rate 1.2 s

PS Booster

- 1st Synchrotron with 4 superposed rings
- Circumference of 157 m
- Proton energy from 160 MeV to 2 GeV
- Can cycle every 1.2 s
- Each ring will inject over multi-turns, using charge exchange injection

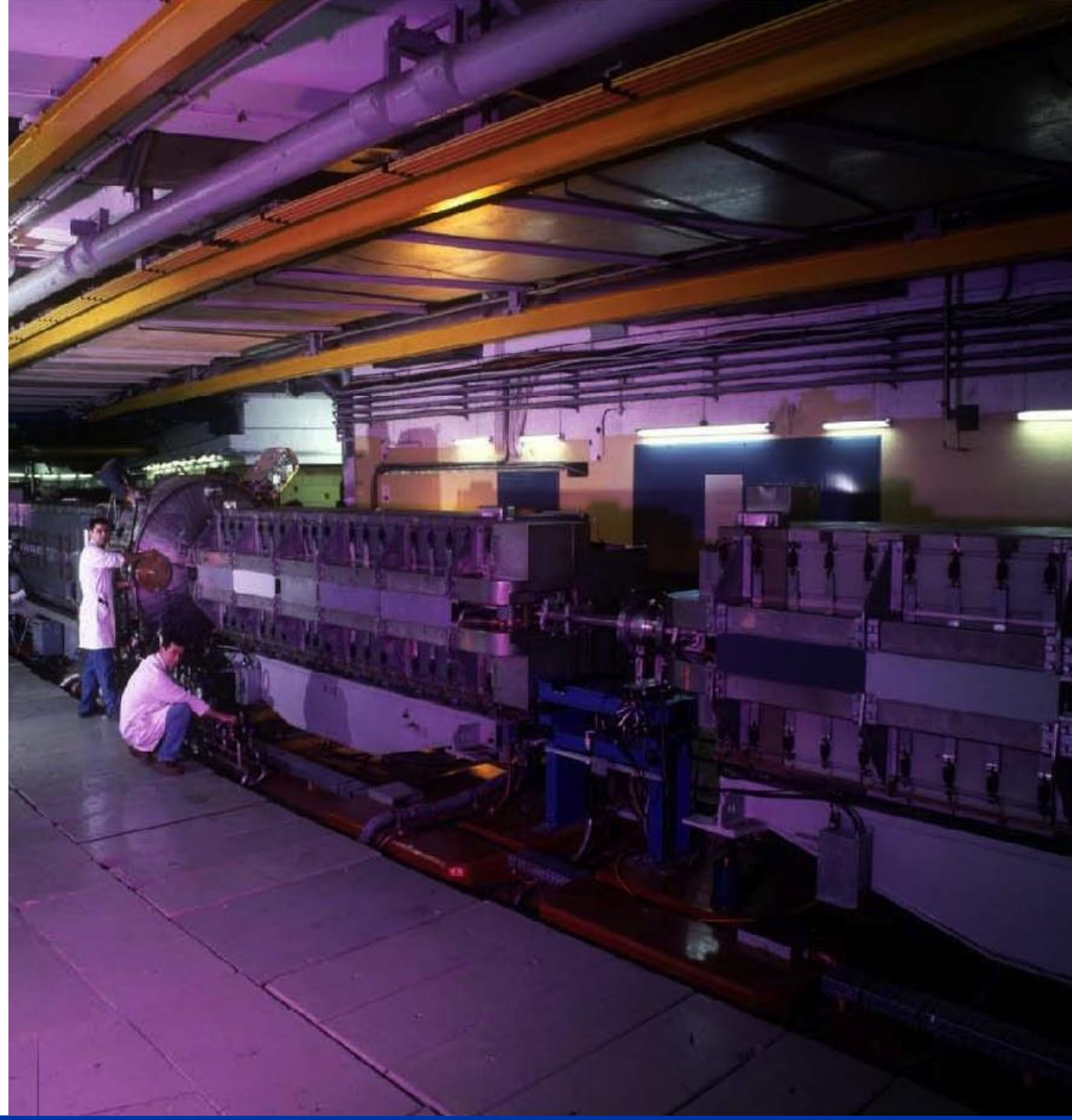






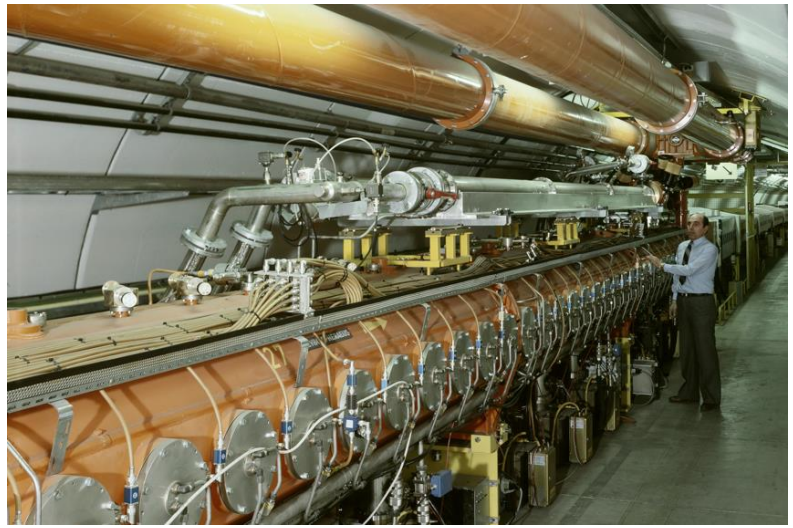
PS

- **The oldest operating synchrotron at CERN**
- **Circumference of 628m**
  - 4 x PSB circumference
- **Increases proton energy from 2 GeV to max. 26 GeV**
- **Cycle length ranges from 1.2s to 3.6s**
- **Many RF systems allow for complex RF gymnastics**
- **Various types of extractions:**
  - Fast extraction
  - Multi-turn extraction (MTE)
  - Slow extraction

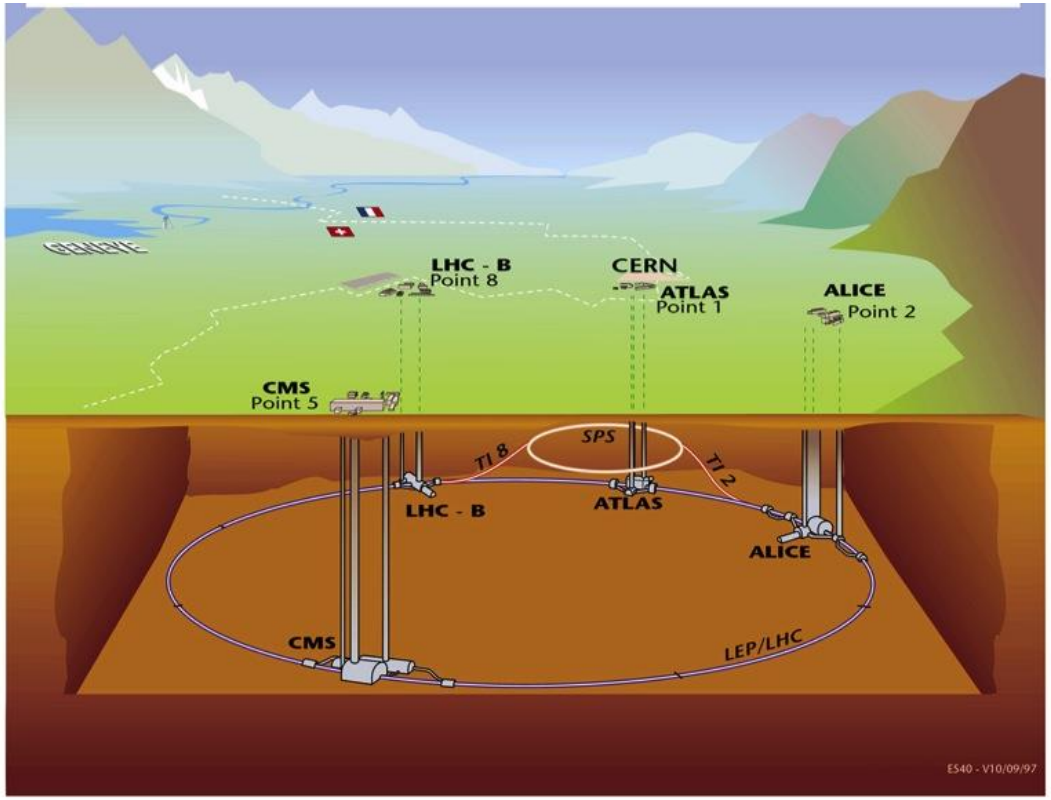


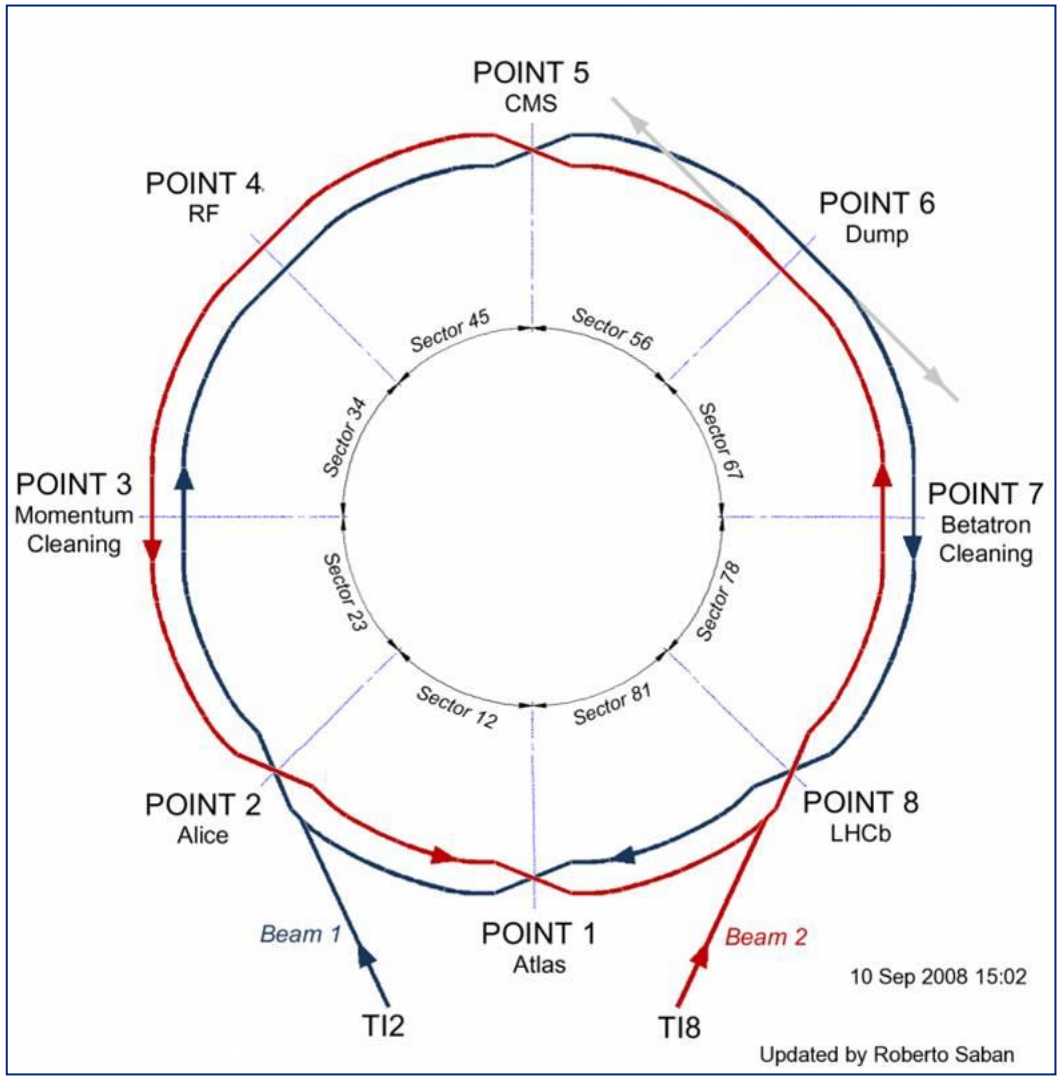
SPS

- **The first synchrotron in the chain at ~30m under ground**
- **Circumference of 6.9 km**
  - 11 x PS circumference
- **Increases proton beam energy up to 450 GeV with up to ~5x10^{13} protons per cycle**
- **Provides slow extracted beam to the North Area**
- **Provides fast extracted beam to LHC, AWAKE and HiRadMat**



LHC



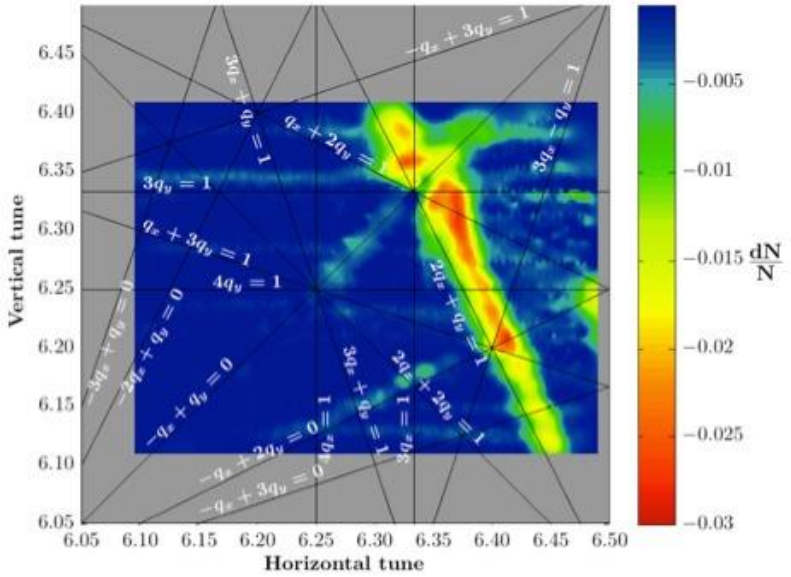


- **Situated on average ~100 m under ground**
- **Four major experiments**
- **Circumference 26.7 km**
- **Two separate beam pipes going through the same cold mass 19.4 cm apart**
- **150 tons of liquid helium to keep the magnets cold and superconducting**

The LIU Project was completed in LS2

- LINAC4 – PS Booster:
  - New LINAC 4 with H^- injection
  - Higher injection energy
  - New Finemet® RF cavity system
  - Increase of extraction energy

- PS:
  - Injection energy increase from 1.4 GeV to 2 GeV
  - New Finemet® RF Longitudinal feedback system
  - New RF beam manipulation scheme to increase beam brightness



- SPS
  - Machine Impedance reduction (instabilities)
  - New 200 MHz RF system
  - Vacuum chamber coating against e-cloud

These are only the main modifications and this list is not exhaustive