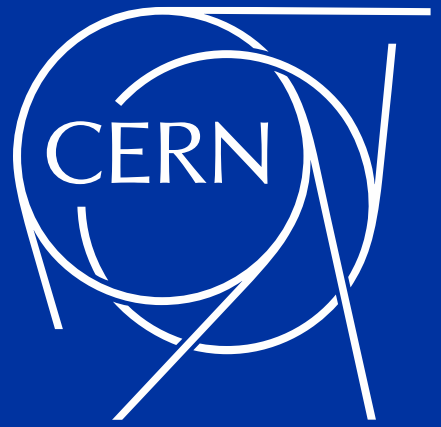


Sustainability in the operation of the machines

For the Sustainable Accelerators Panel

Rende Steerenberg BE-OP

With valuable input from many - thanks

22 March 2024

Content

- The Context
- Sustainability in Operations: some examples
- Operations Contributing to Sustainability
- Concluding Remarks

Content

- **The Context**
- **Sustainability in Operations: some examples**
- **Operations Contributing to Sustainability**
- **Concluding Remarks**

From Roberto's 1st SAP meeting

Environmental protection : integral part of CERN Objectives

One of the **main objectives** of the CERN Directorate for the years 2021-2025.

CERN aims to establish itself as a model for a transparent and ***environmentally responsible research organisation***
-> strong and proactive commitment to environmental protection, along 3 lines:

- ***Minimise the Laboratory's impact*** *on the environment*
- *Pursue actions and technologies aiming at* ***energy saving and reuse***
- ***Identify and develop CERN technologies*** *that may contribute to mitigate the impact of society on the environment.*

Environment and **sustainability** are crucial aspects of projects and activities in the HEP field.

Bringing sustainability into the desing and construction of a new accelerator is already a challenge.

Enhancing sustainability in existing accelerators and facilites is even a bigger challenges because one has to deal with legacy systems, which were not conceived with sustainability in mind.

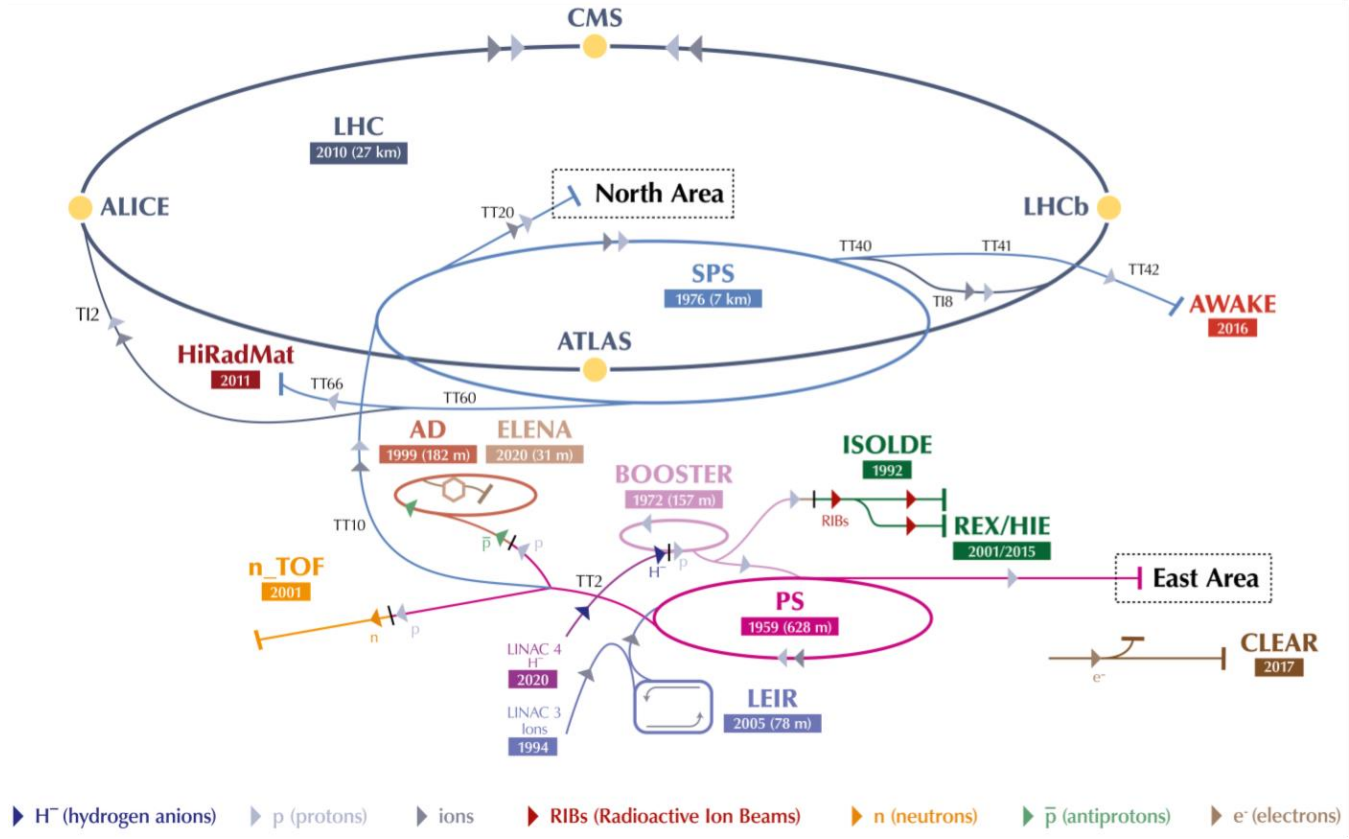
Existing Accelerators & Facilities

Is the strength of CERN also a weakness?

We tend to build on the past and re-use previously flagship machines as injectors for new flagship machines

- The 'recycling' of [illegible] itself sustainable [illegible] and projects
- [illegible] often not align with the [illegible] sustainability goals
- New or consolidation, following many years of operation, is an opportunity to enhance sustainability

Answer: No, but we do not always appreciated this aspect



Sustainable Accelerator Operation

The primary challenges lies in the substantial energy requirement

- Optimising the efficiency and making efficient use of accelerators is crucial for minimising energy consumption

Waste management, including radioactive waste, is another significant aspect

- Minimising activation by reducing beam losses or managing beam losses

Fostering a sustainability culture within “Operations” is essential for driving continuous improvement in accelerator operations

- Raise awareness on environmental impact and collaborate among stakeholders

Accelerator schedules

Accelerator schedulling – can reduce electricity consumption, but also physics output

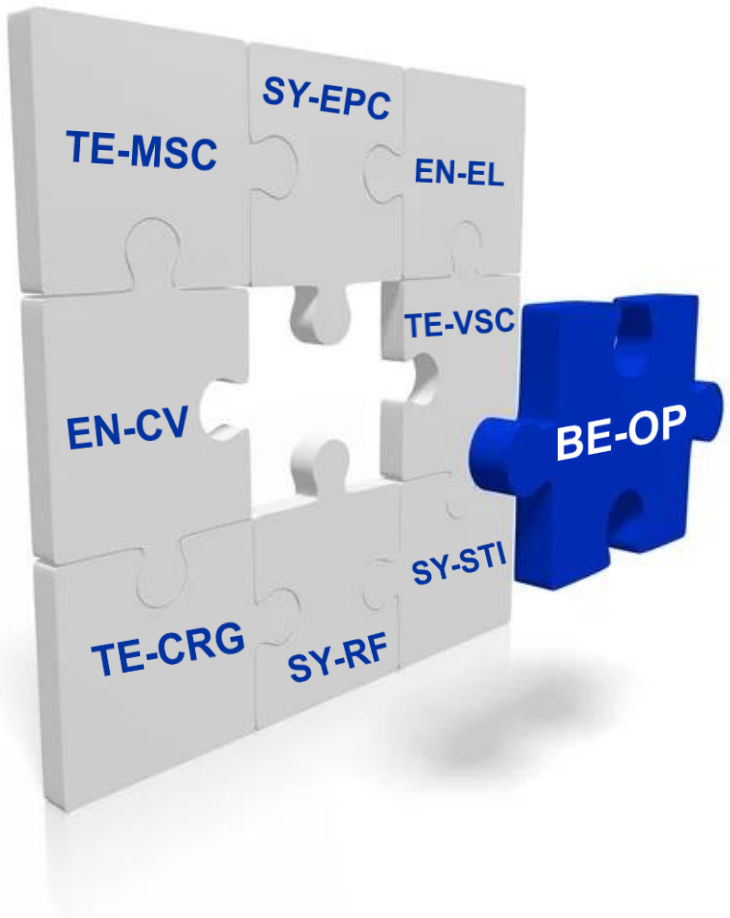
- With the energy crisis in 2022 the YETS 22-23 was anticipated and extended by 2 weeks.
- YETS 23-24 was anticipated by 6 weeks and extended by 4 weeks (15 weeks to 19 weeks) to cover the period with the high electricity costs.
- YETS 24-25 was always planned to be 19 weeks beam to beam on the request of ATLAS and CMS for the CO_2 cooling installation and commissioning but was anticipated 6 weeks too.

These measures were mainly cost driven and not necessarily with sustainability in mind

- It affects our core business directly and is in the end not sustainable
- In any case the experiments need a certain number of collisions or protons on target
- If we we have shorter runs every year the experiment wil take more years to complete – less sustainable

Effective schedulling primarily assists managing electricity cost, yet it alone does not inherently enhance the sustainability of accelerator operations

“Operation” of the Accelerator Complex



The equipments groups are responsible for the operation of their systems

- This includes design, construction or procurement, operation, consolidation and maintenance
- These groups (should) have their own sustainabiity initiatives and targets

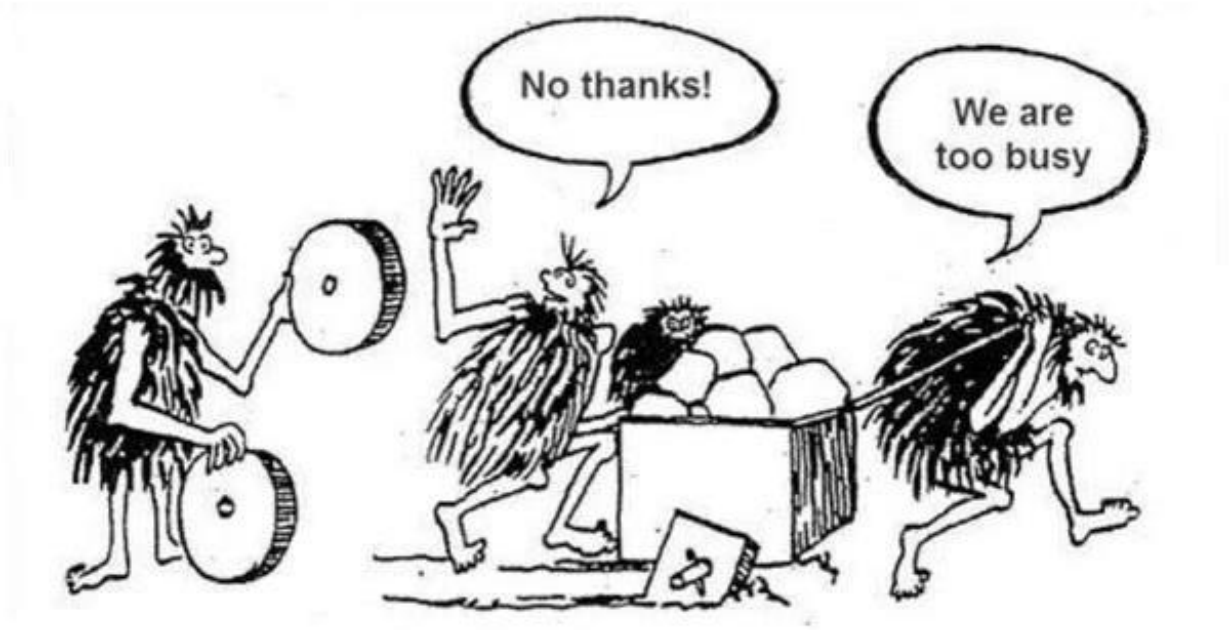
The operations group forms the glue between the pieces and runs the individual systems as a whole to produce the required particle beams

- This includes, machine configuration, settings management, development and deployment of methods and tools to produce and deliver beams
- The Operations group (should) have its own sustainability initiatives and target and collaborate with the other groups on theirs.

Content

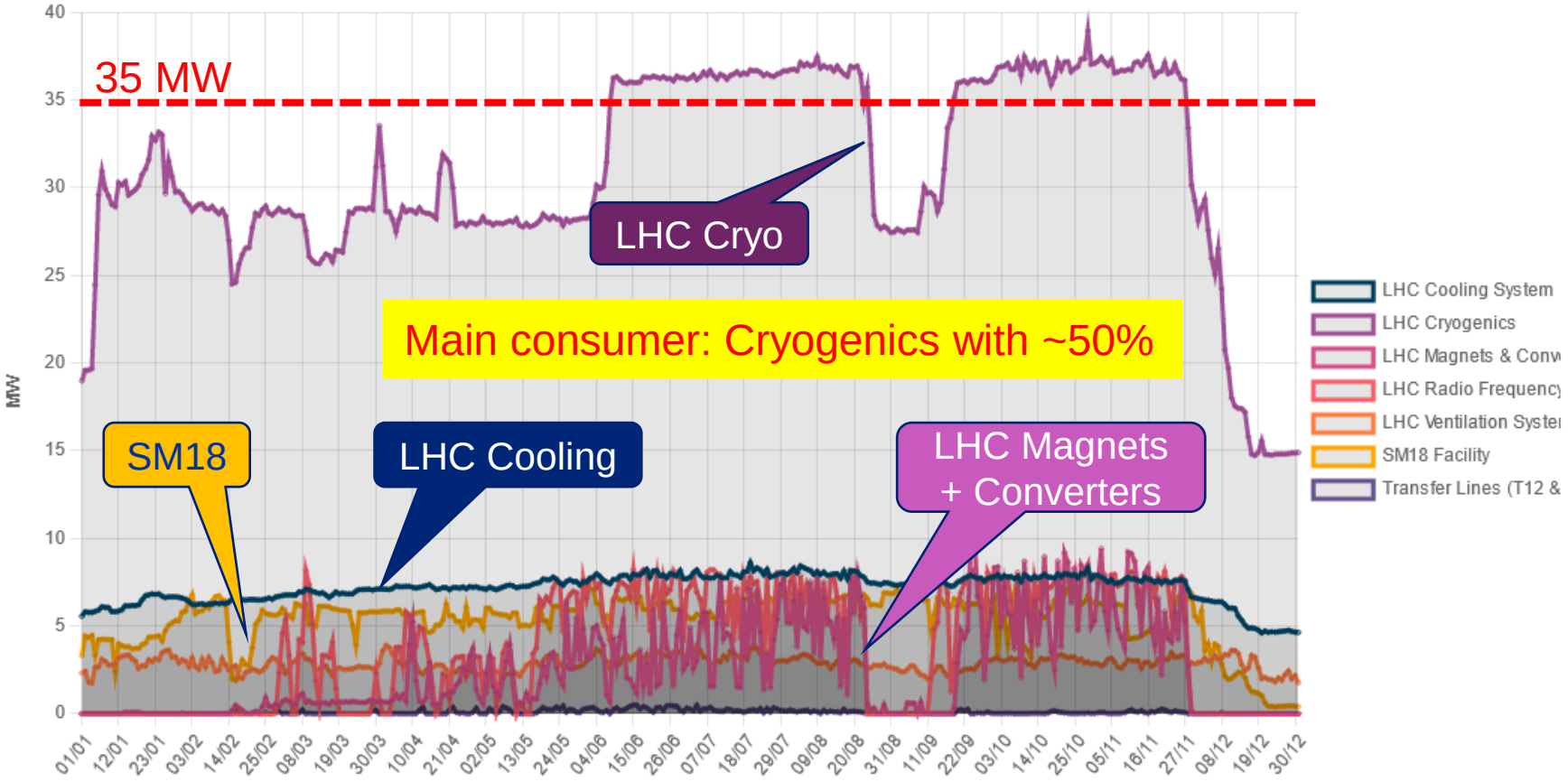
- The Context
- **Sustainability in Operations: some examples**
- Operations Contributing to Sustainability
- Concluding Remarks

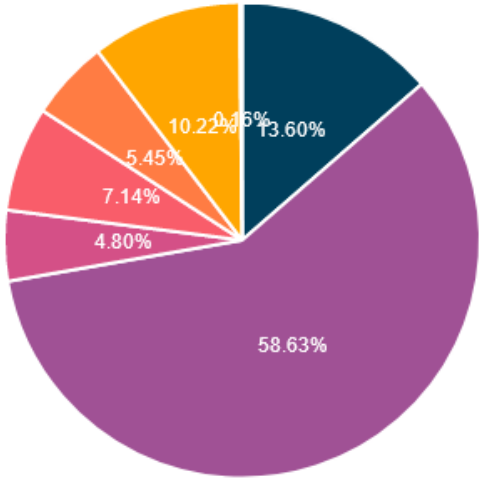
The Typical Context…



We are all very busy with many things and enhancing sustainability in accelerator operations is not always given sufficient priority

LHC Machine electrical Consumption 2022





LHC machine total power ~75 MW

Dominated by cryogenics

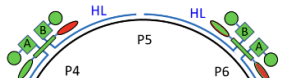
Cryogenic power is heavily modulated by e-could induced heatload

Chamonix 2023

Beam Dependend Actions by Cryogenics

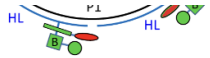
Cryoplant options for beam operation and cryo recovery impacts

Physics mode



When being a too ambitious with the eco mode, we can easily lose all savings made by the eco mode due to a much longer quench recovery time

Proton Physics
@ 25 ns (>1200 b)



- The impacts of eco mode are different in each cryo island
  - **P18/P2**: Much longer recovery in case of cryo stop or big quench
  - **P4**: Much longer recovery in case of cryo stop due to the RF cavities (priority to be given to the RF or to the Sector)

Economic mode

Reduced mode

The applied scenarios in the past

A. ***Run1 & 2*** : Always in Physics mode on all cryo islands (36.5 MW)
B. ***2022***: Eco mode on P4&P6&P8 during re-commissioning and RF burst disk recovery (29 MW)
C. ***2023***: Eco mode on all cryo islands during re-commissioning, ITL8 recovery, and Ion run (26 MW) *(but P18/P2 switched to Physics mode from 9th Oct)*
D. ***2024*** *(up to now)* : Eco mode on P6 & P8 during re-commissioning and Ions (31 MW) ➔ compromise

- *re-commissioning / VdM / high beta run*
- *pp physics in pure 8b4e until 1.8e11 ppb*
- *Ion Run*

- Example for any kind of event stopping cryogenics for ~2hr :
  - P18/P2: ~20 hr in Physics mode / ~30 hr in eco mode
  - P4: ~24 hr in Physics mode / ~35 hr in eco mode (without RF Burst Disk rupture)
  - P6 & P8 : ~20 hr in Physics mode / ~24 hr in Eco mode

Compressor station
4.5 K refrigerator
Interconnection box
1.8 K pumping unit (cold compressor)

Benjamin Bradu
LMC#481

Physics output versus Cryo power

Physics requirement: maximise number of collisions

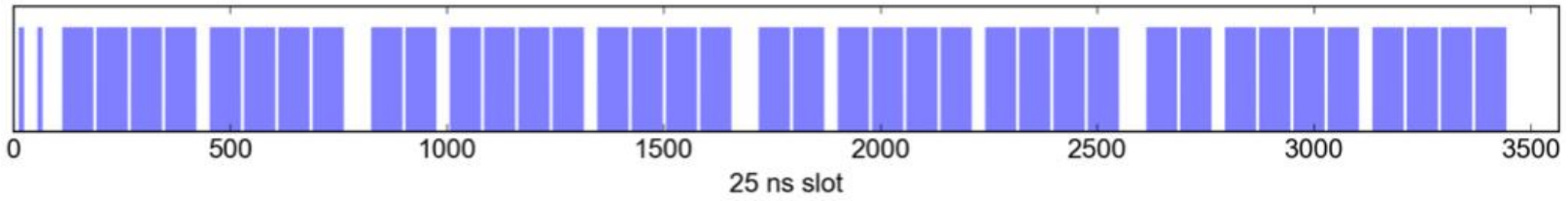
- Maximise intensity per bunch: 1.1 x 10^{11}ppb (design) → 1.6 x 10^{11} (2023) → up to 1.8 x 10^{11} (2025)
- Maximise the number of bunches: ~ 2800 b/beam (design) → ~ 2400 b/beam (average in practice)

Electron cloud induced heat load is the limiting factor for cryogenics

- Heat induced on the beam screen needs to be evacuated → Electrical power consumption through cryo
- Possible operational mitigations:
  - Scrubbing, but has limits.
  - Adapt filling scheme to reduce electron cloud production – leave regular gaps in the bunch trains
  - Each filling scheme with reduced number of bunches affects physics output – optimum continuously being explored

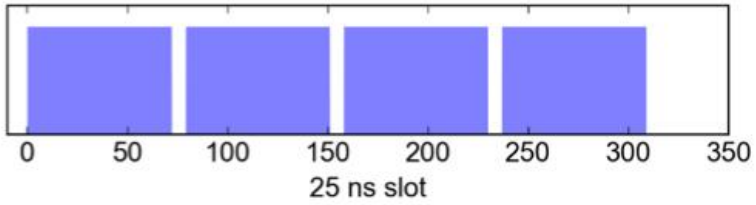
Electron Cloud Mitigation Through the Filling Scheme

Nominal filling scheme (25 ns, 2760 bunches)

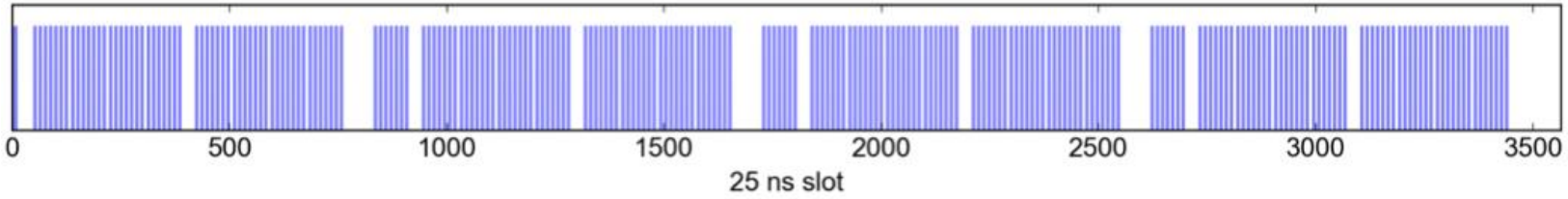


Required pattern from the injectors:

4 x 72 bunches

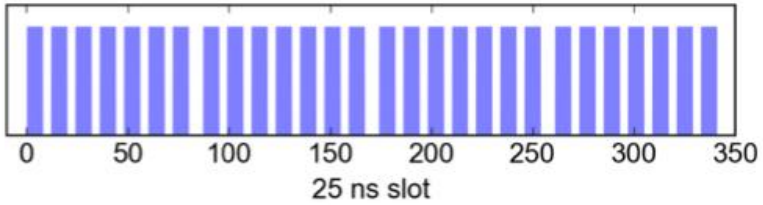


Backup filling scheme (8b+4e, 1972 bunches)



Required pattern from the injectors:

4 x 56 bunches



G. Skripka and G. Iadarola

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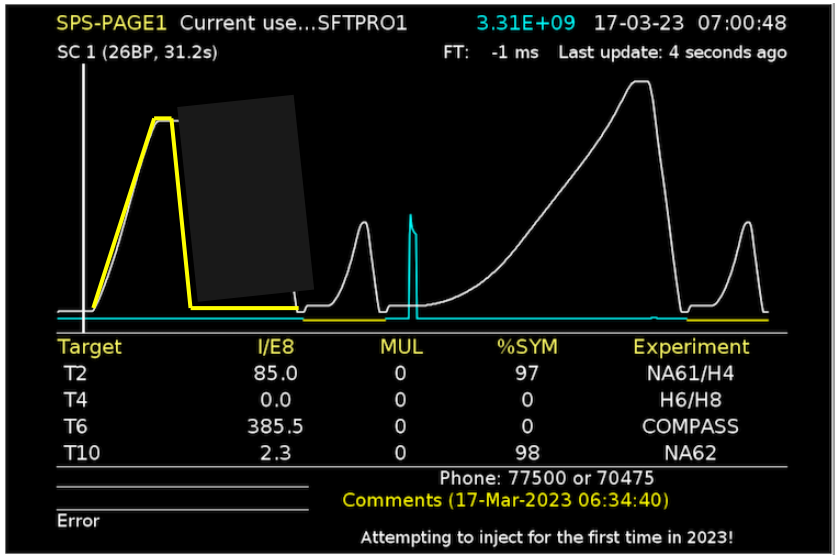
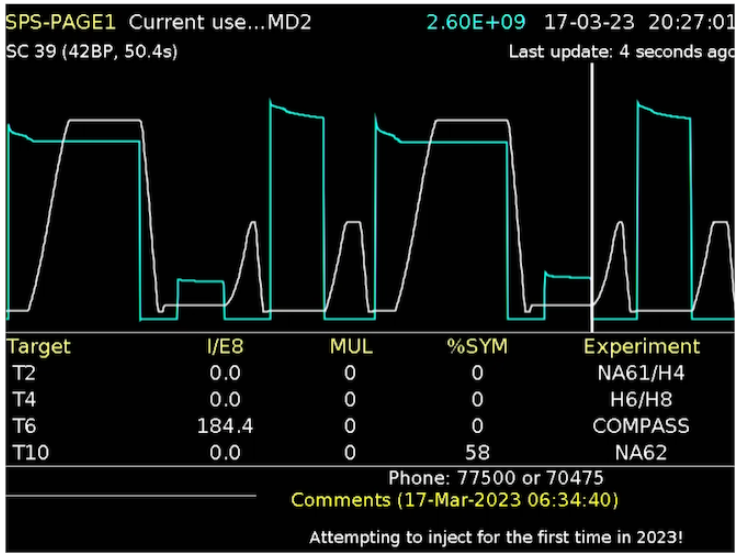
Ultimate mitigation (non-operations):

- Reduce secondary emission yield by coating → Partially planned for LS3
- Strategy was presented at Chamonix 2024

SPS Eco Mode and Hysteresis Compensation

- **The versatility of the SPS super cycle comes with advantages & challenges**





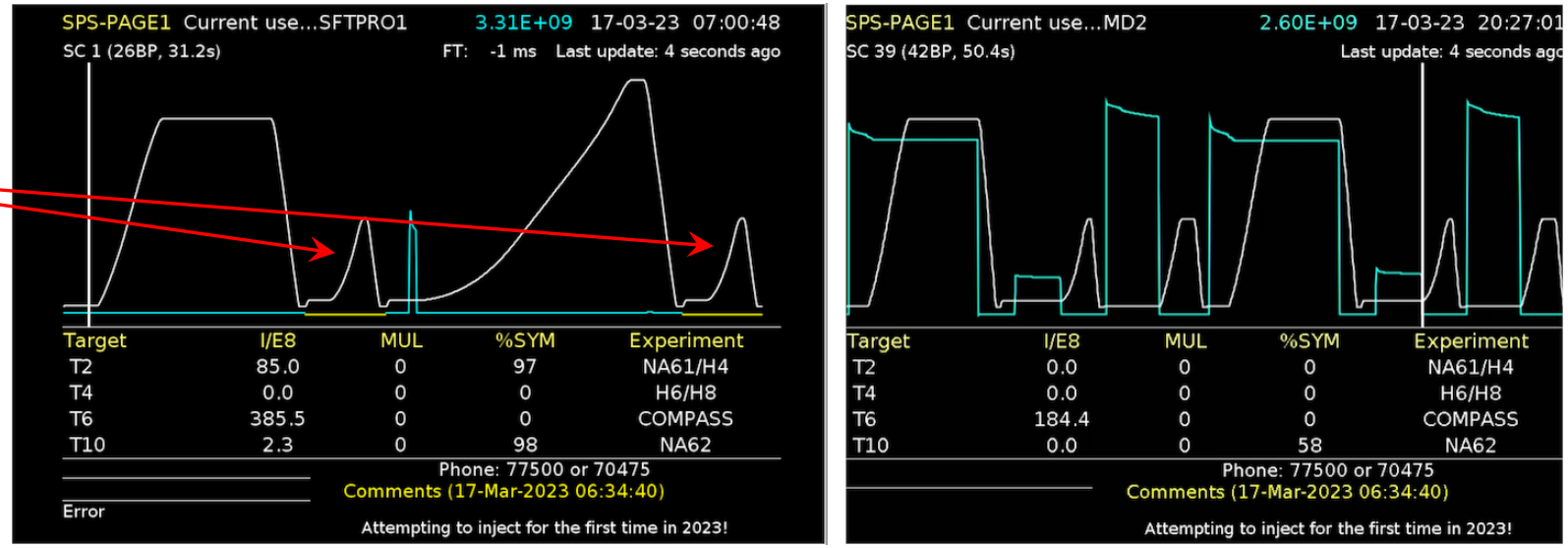
- **In case beam is not detected the SPS will go into dynamic economy mode**
  - Reducing the power consumption, but ensuring the magnetic hysteresis is managed correctly
  - If magentic hysteresis could be managed differently one could perhaps avoid pulsing at all if no beam is detected

Hysteresis Compensation Using Machine Learning

- **Hysteresis cycle are needed to guarantee as much as possible similar magentic conditions for different instances of the same cycle in the super cycle**

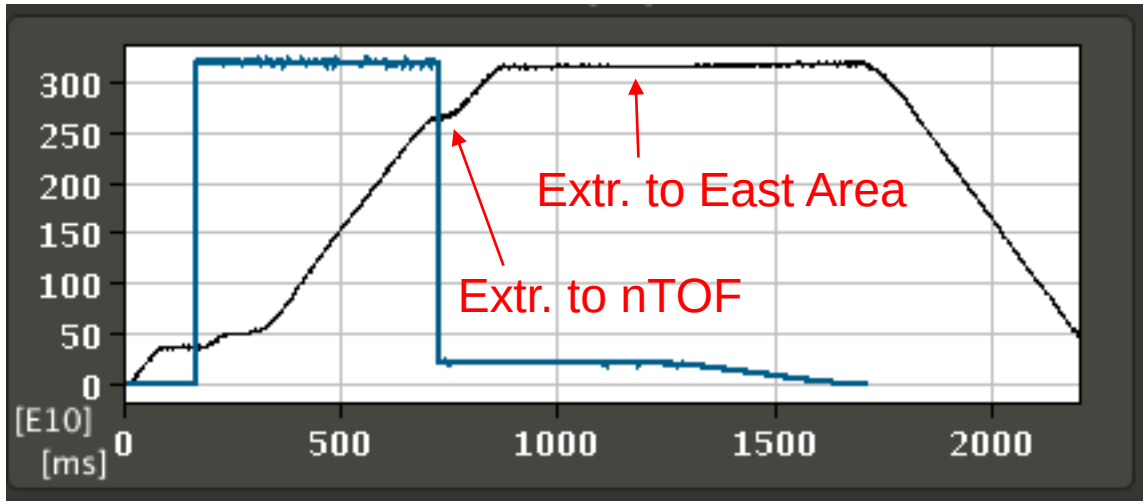
Needed to:
- Limit max rms current
- Manage hysteresis

May consume ~ 25 MWh/day



- **Predicting hysteresis and feeding this forward into the next cycle could potentially avoid the the need for “empty” pulses between cycles**
  - This is being addressed through the EPA project in BE-CSS in collaboraiton with BE-OP

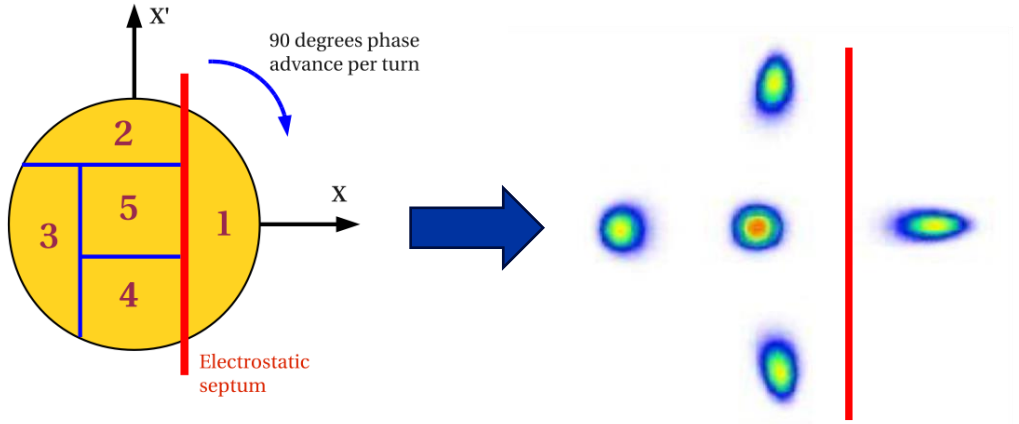
Combined Beam Production on a Single Cycle



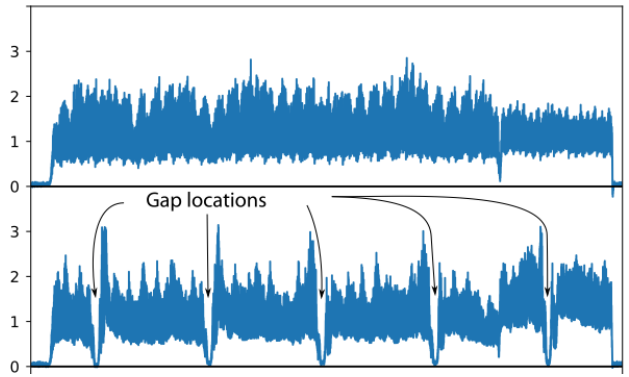
- PS East Area operation would use the full cycle in the PS Booster and PS to accelerate only one bunch in one of the 4 rings
- Combining PS East Area and nTOF operation in a single cycle provide more physics output for the same energy consumed
- This still leaves two PSB rings unused
- **This could be even further enhance if the PS Booster could send two rings to ISOLDE and two rings to the PS**

Beam loss management

- **Continuous loss reduction during routine beam operation is a priority**
  - Is done through manual or automated optimisation of beam trajectory, extraction process, etc.
  - Reduce induced radiation, shorten downtime in case of interventions and minimise radioactive waste
- **MTE – Multi-turn Extraction**
  - A completed project that reduces drastically loses at PS extraction for the SPS fixed target beam
  - Project lead by BE-ABP, involved many groups among which BE-OP



Recenltly the introduction of a barrier bucket further reduced the remaining extraction losses



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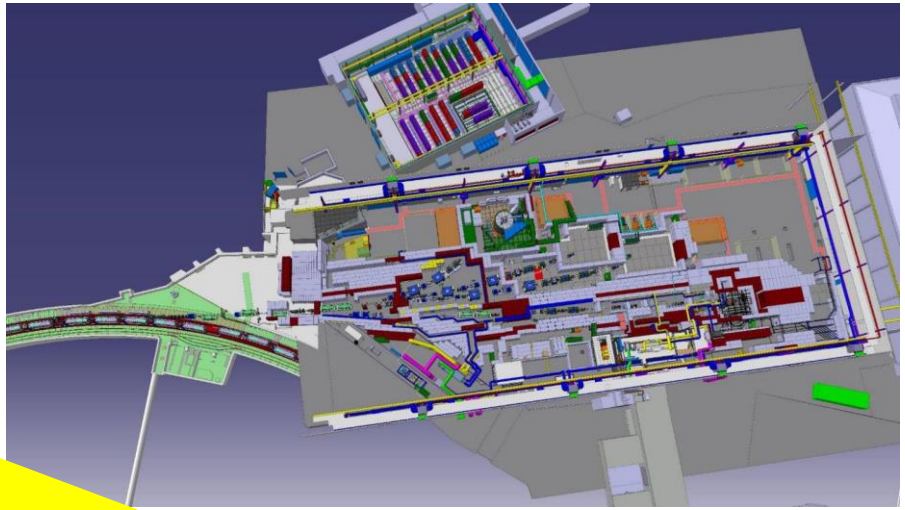
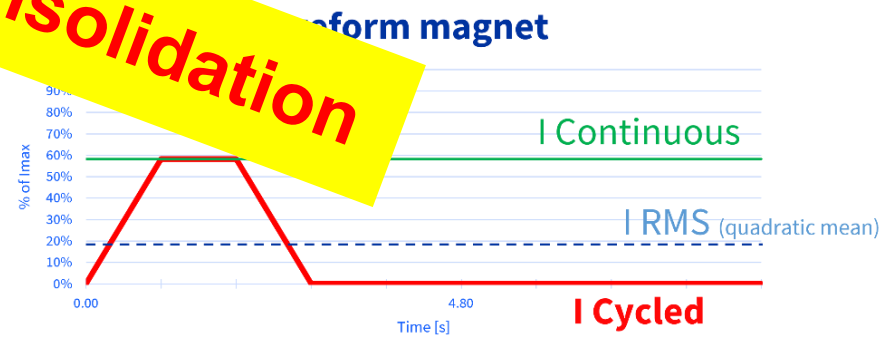
Sustainable PS East Area Consolidation

- **Good example of changing fundamental operational modes through good collaboration between many groups including BE-OP:**
  - Optimising operational requireme[illegible] reducing power consumption
  - Pulsing the magnets during beam pas[illegible] mode saves ~ 6 GWh/yr
- **Together with other measures taken on the building, CV and EL this results in energy savings amounting to ~ 600 kCHF/yr**
- **OP can contribute to projects and provide a coherent optimised operational point of view**

Next: North Area Consolidation





Energy Management Panel #33

Content

- The Context
- Sustainability in Operations: some examples
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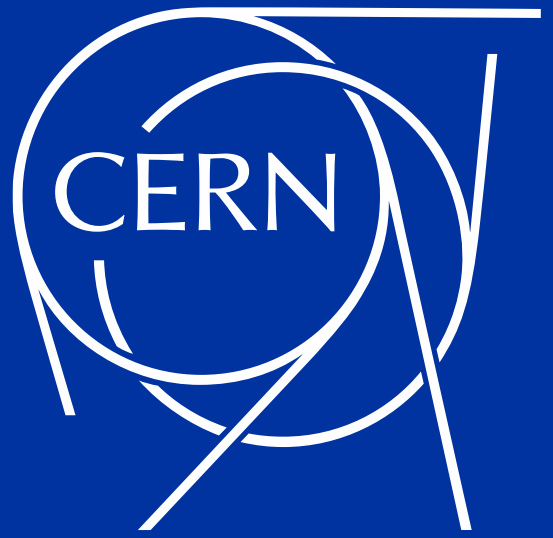
- **Concluding Remarks**

Concluding Remarks

- **OP areas of biggest impact are electricity consumption and radioactive waste**
- **Most of the accelerators contain legacy equipment and consolidation offers opportunities to enhance sustainability**
  - BE-OP can provide input to projects and contribute to a coherent approach through collaboration
  - A good examples are the the MTE project and PS East Area consolidation project – we can do the same for the other consolidation subjects like NA-Cons.
- **Operations can positively influence sustainability, but we may need to create more awareness**
  - We can investigate further optimising operational processes – mainly small contributions
  - We should profit from the period leading up to LS3 to gather more ideas, even with a small impact, and benefit from LS3 to develop and deploy them
  - Possibly we can address awareness through a dedicated presentation and discussions during an OP group meeting or as part of the BE-OP shut-down lectures
- **Suggestions, support and collaboration always welcome !!!**


CERN