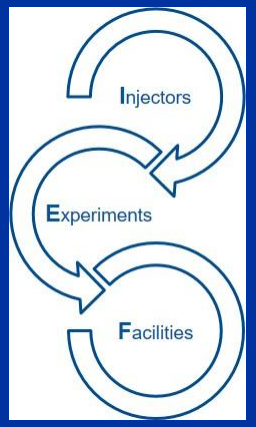


Energy efficient operation : Concrete ideas to save energy

N. Charitonidis [BE-EA]

Acknowledgements: V. Barbet, J. Bernhard, K.Brodzinski, M. Brugger, L. Gatignon, A. Huschauer, M. Schenk, V. Kain, G. Trand, K. Papastergiou, G. Rumolo, L. Mether, E. Veyrunes, J. Wenninger and many, many others....

08.12.2022

2022 Energy crisis

Electricity price at CERN

- French electrical network – Main source

The biggest component of CERN's electricity cost

EDF — Supply of Energy + Rte — Transmission costs

- Swiss electrical network – Back-up source (limited to 60 MVA)

ALPIQ — Supply of Energy + SIG — Transmission costs

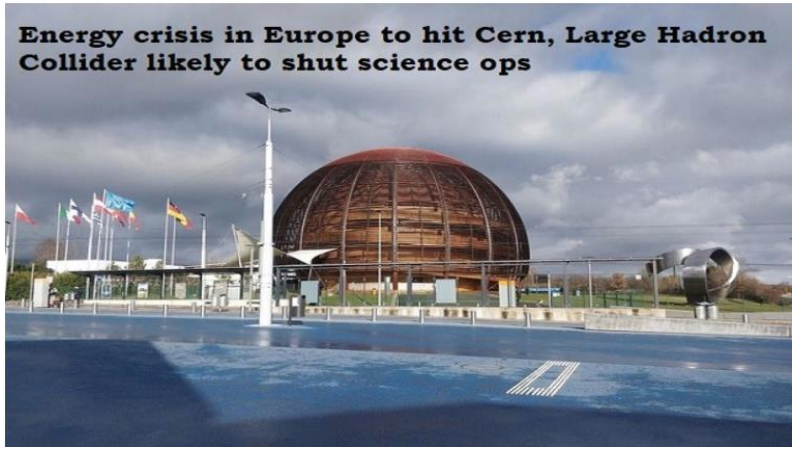
Courtesy: N. Bellegarde

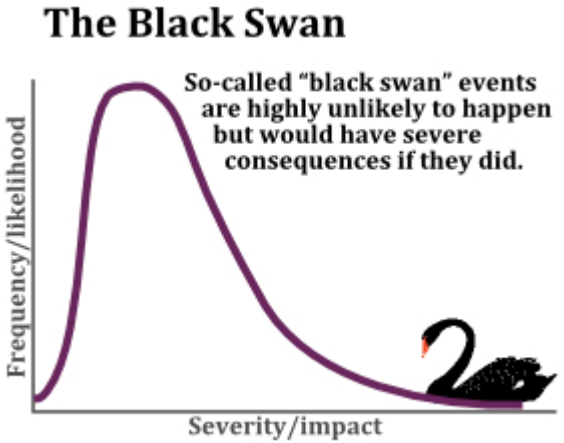
Courtesy: N. Bellegarde

SCIENCE & TECH | #CERN | RADAR
Published on September 05, 2022 17:19. Updated on September 12, 2022 19:47.

CERN gets ready for Europe energy crunch

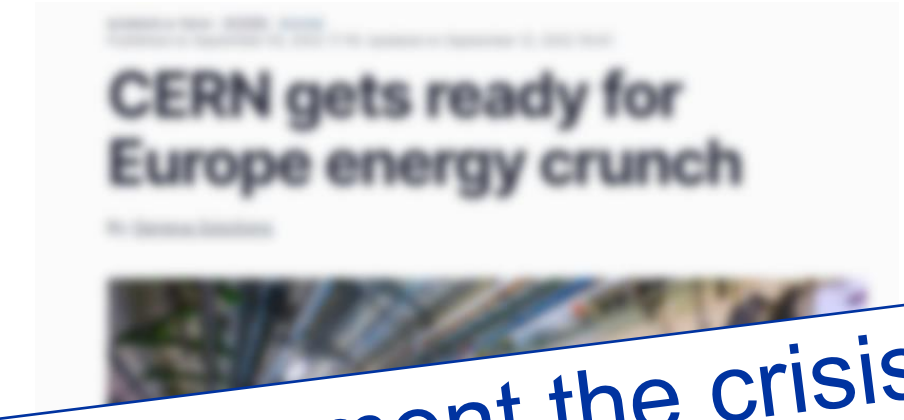
By Geneva Solutions





Courtesy: N. Taleb

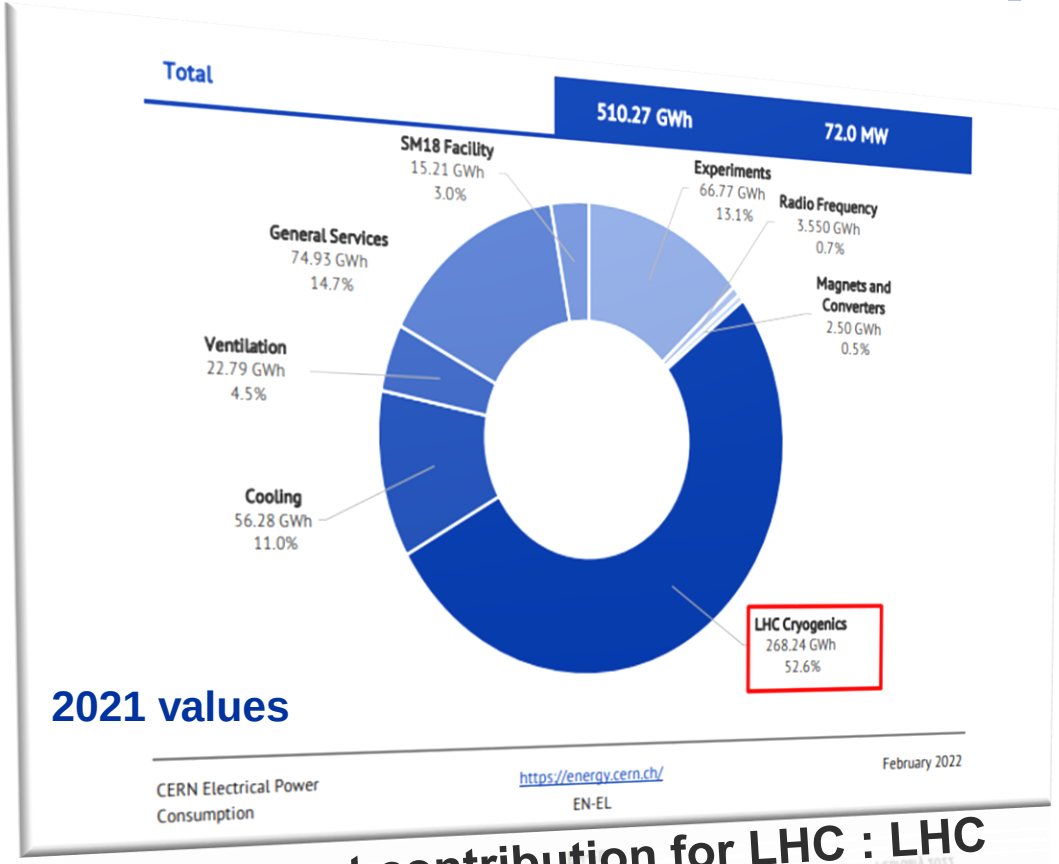
2022 Energy crisis



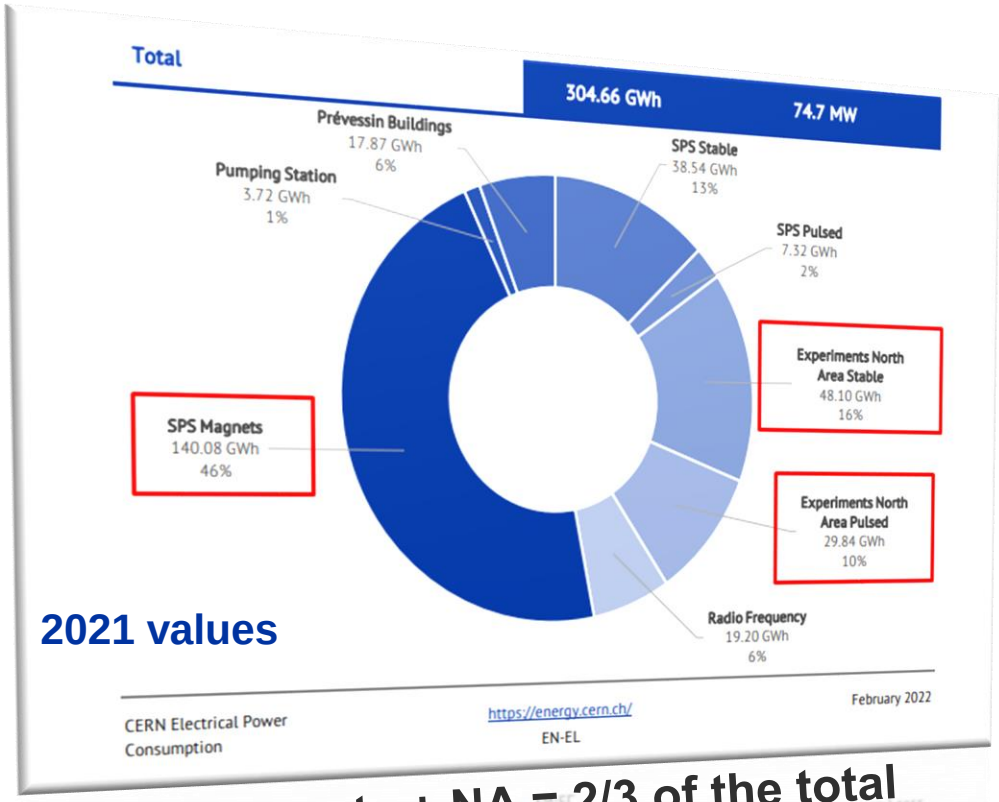
Forgetting for a moment the crisis ….

Shouldn’t we take “the opportunity” to start thinking forward towards an even more energy-efficient operation of the complex in the future ?

Possible room for improvement ?



Largest contribution for LHC : LHC cryogenics



SPS magnets + NA = 2/3 of the total consumption of the SPS

LHC + SPS (+NA) ~80% of all CERN consumption

https://edms.cern.ch/ui/file/2599454/2021.0/Electricity_Flyer.pdf

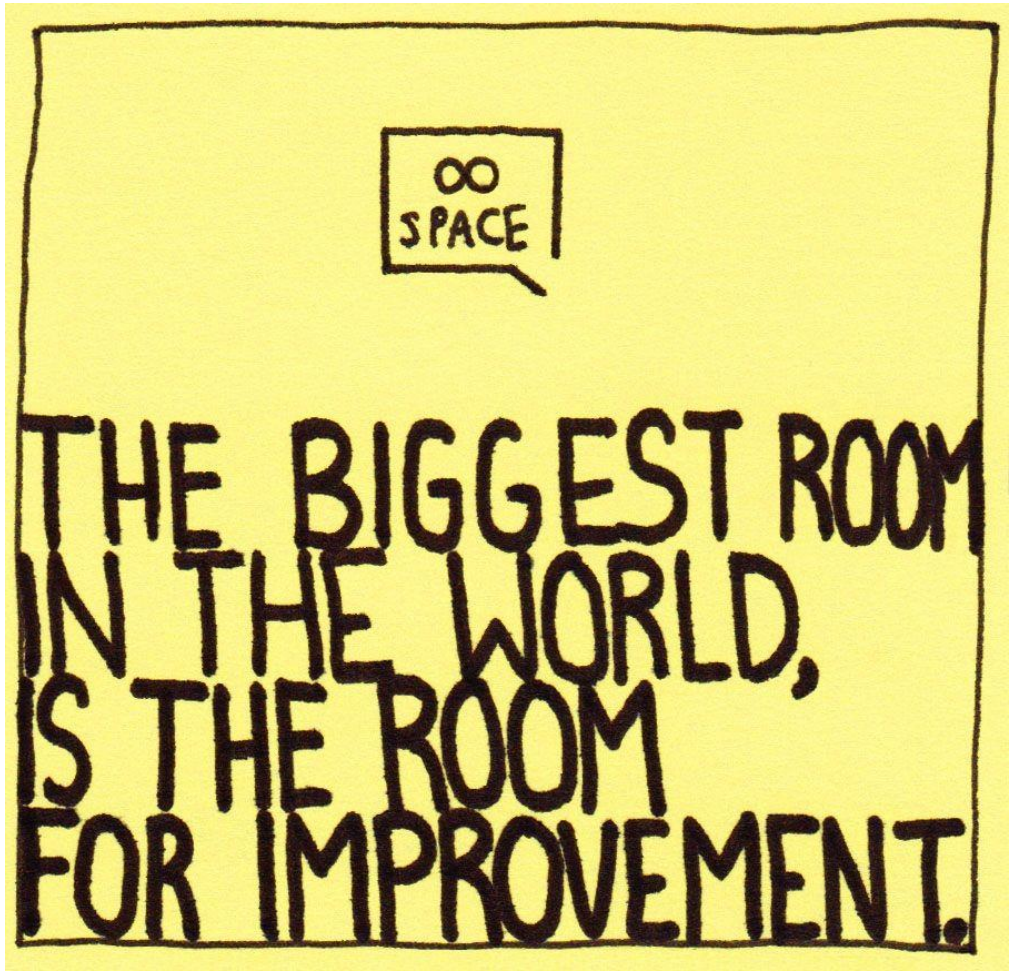
...putting this into scale...

~50% of the electricity produced by “Grande Dixence” ....

Facts & figures

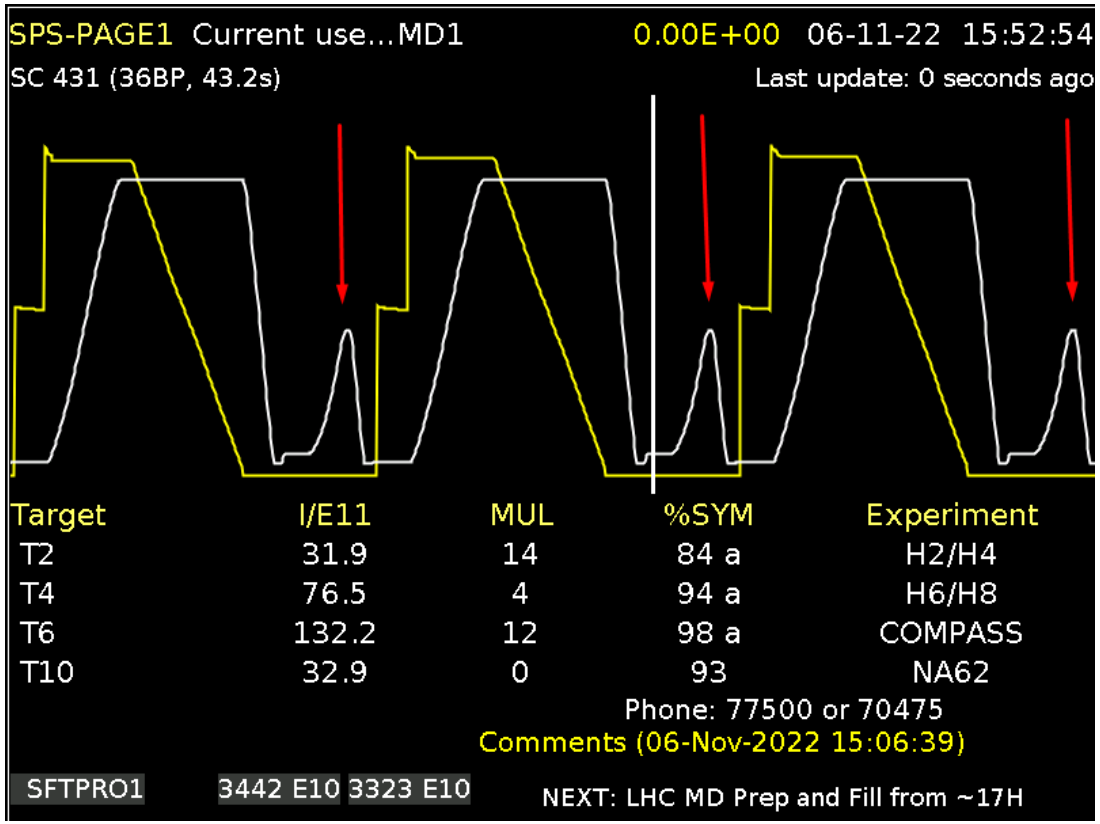
Plant type:	Storage power plant
Location:	Fionnay, Riddes, Switzerland
Number of turbines:	Fionnay: 6 x 2 Pelton turbines / Nendaz: 6 x 2 Pelton turbines
Capacity:	2,069 MW together with Bieudron (Cleuson-Dixence)
Shareholding:	60 %
Commissioning:	1961 - 1965
Average annual production:	2000 GWh together with Bieudron (Cleuson-Dixence)
Guided tours:	Yes
Status:	In service

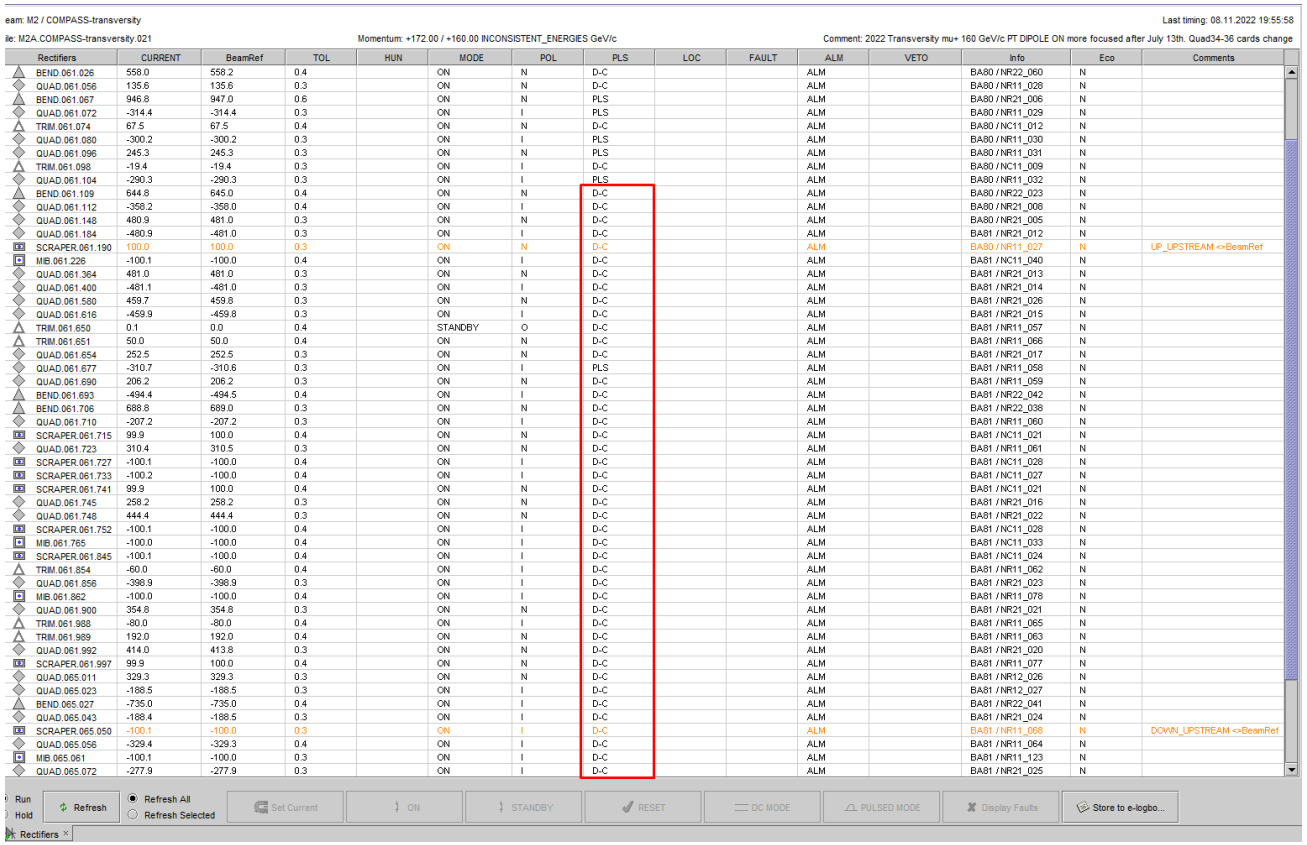
Examples of “how we can do better”



Copyright: Internet

Examples of possible “room for improvement” – SPS + NA

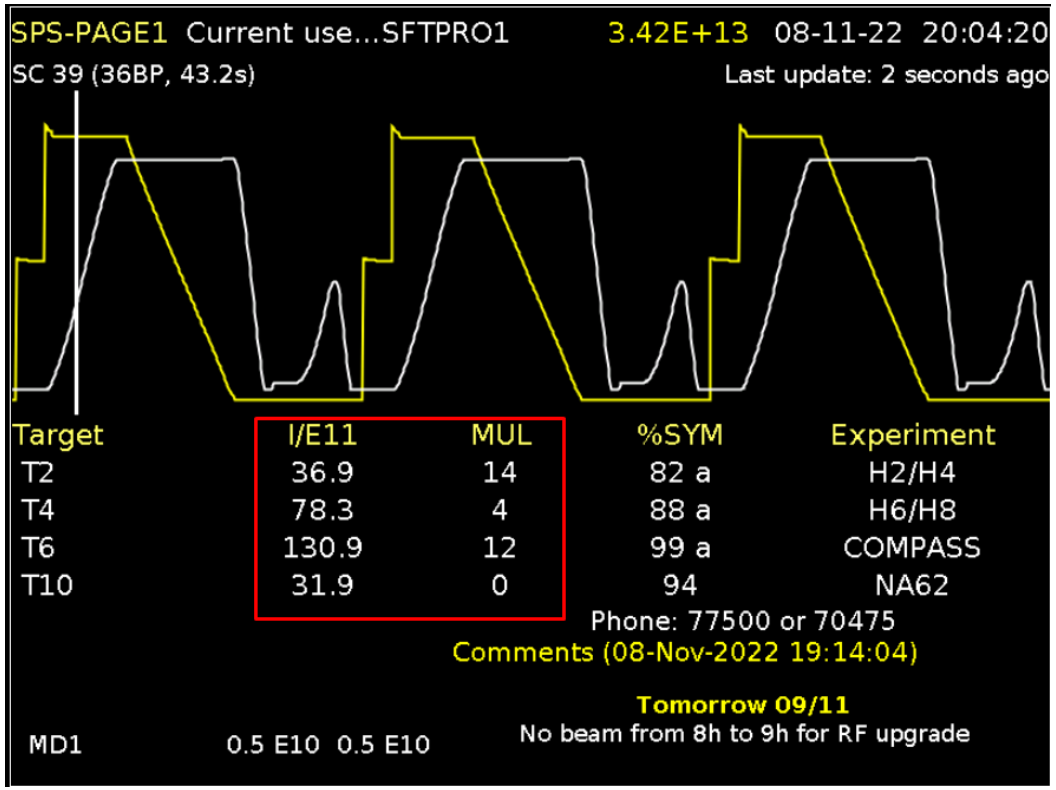




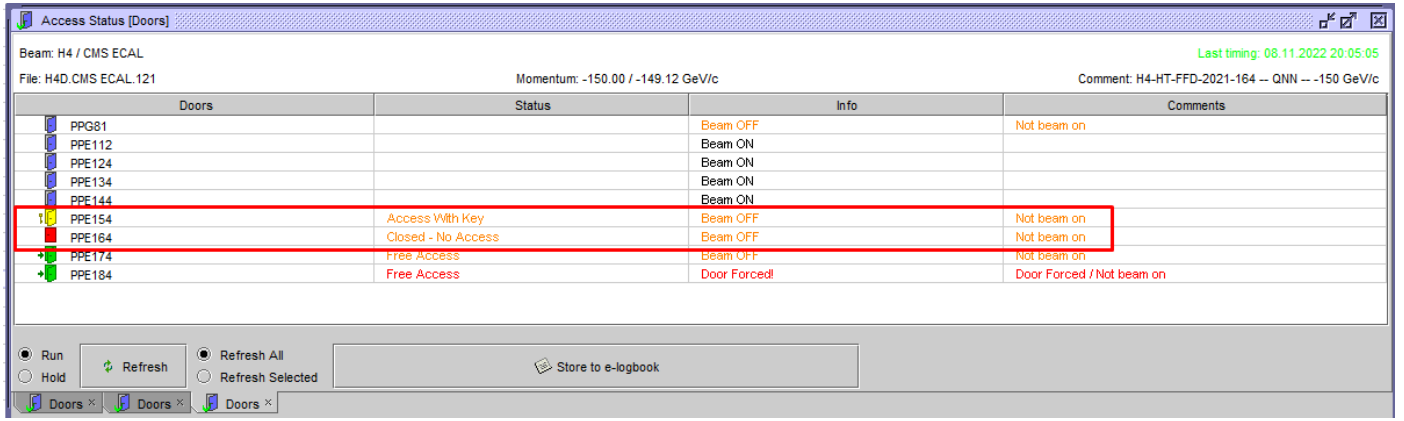
MD1 : 5kWh per cycle – 5MWh per production hour - “Just” to degauss

Many magnets in NA in DC mode, constantly on ...even when beam is not there for hours.

Examples of possible “room for improvement” – SPS TL+NA



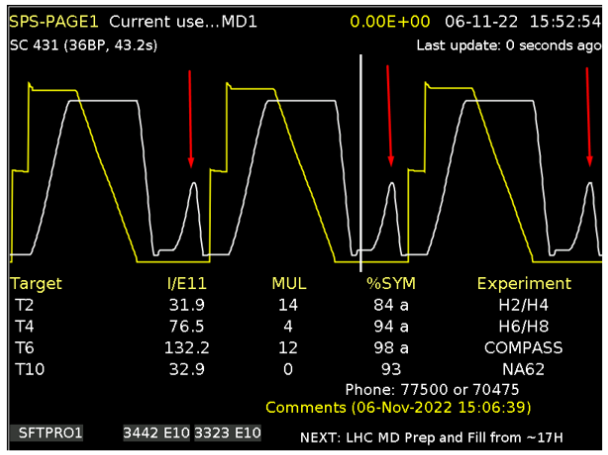
- **Stable and nice operation...beam extracted on the targets on full production from the SPS ....**
- **Meanwhile in H4 (and possibly H2)...access !**



- **LHC / HiRadMat/ AWAKE cycle often ‘playing’ without beam…too difficult and time-consuming to change**

Lack of flexibility in the supercycle composition along with dynamically changing the intensities or the sharing, with obvious energy implications e.g in a few TLs
But... can we ensure the reproducibility at the same time ?

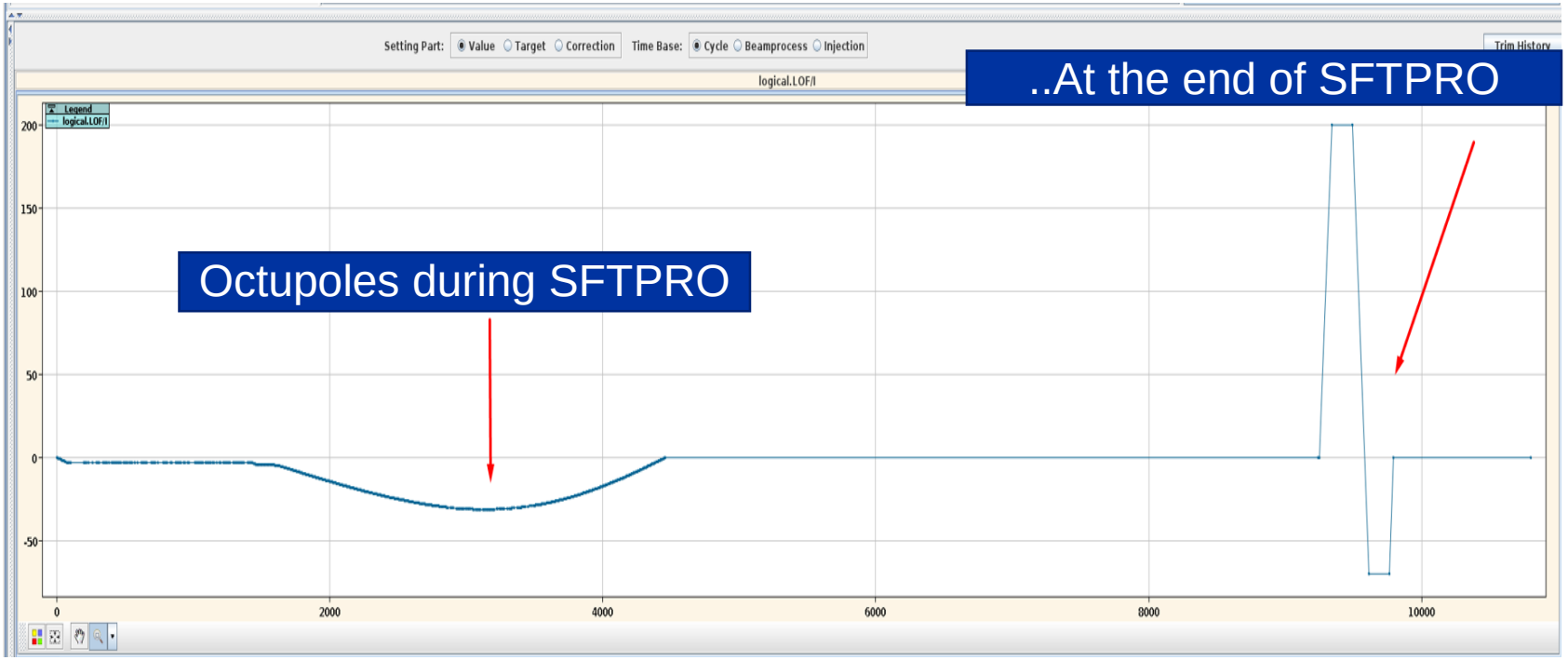
Examples of possible “room for improvement” - SPS



MD1 : 5MWh when in production (3xNA + 3xMD1).
“Just” for degaussing….

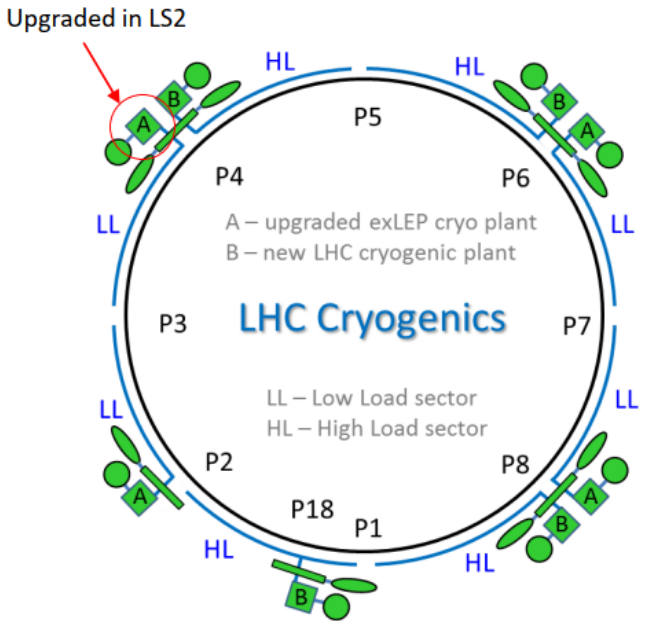
Hysteresis causes large instabilities and non reproducibility cycle by cycle

On top: over-dimensioning of power supplies, e.g for 8poles → See talk of K. Papastergiou



Today we need these degauss cycles...But could we solve this problem otherwise ?

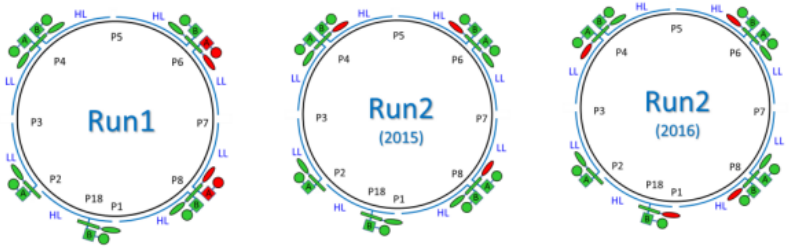
Examples of possible “room for improvement” - LHC



Cooling capacity of A and B are designed to cover nominal LHC operation with equal margins on LL and HL sectors.
BUT:

1. w/o dynamic load B has more capacity margin than A -> easier recoveries,
2. B is more powerful for operation because of its design *(except upgraded P4 A)*

Thanks to build-in interplant connections some special configurations were possible during Run1 and Run2 for problems mitigation, lower power consumption or optimize for availability and helium losses.



Basic question regarding the energy consumption and availability is:
Do we have to always run all cryoplants? ➔ Answer is: No, we can optimize depending on required heat load compensation!

- **Can we optimize the cryoplants operation ?**
- **Cryo necessary not only for operation, but also for He storage when beam off...**

K.Brodzinski_LBOC_2022.03.15

What are the various possibilities ?

Disclaimer :

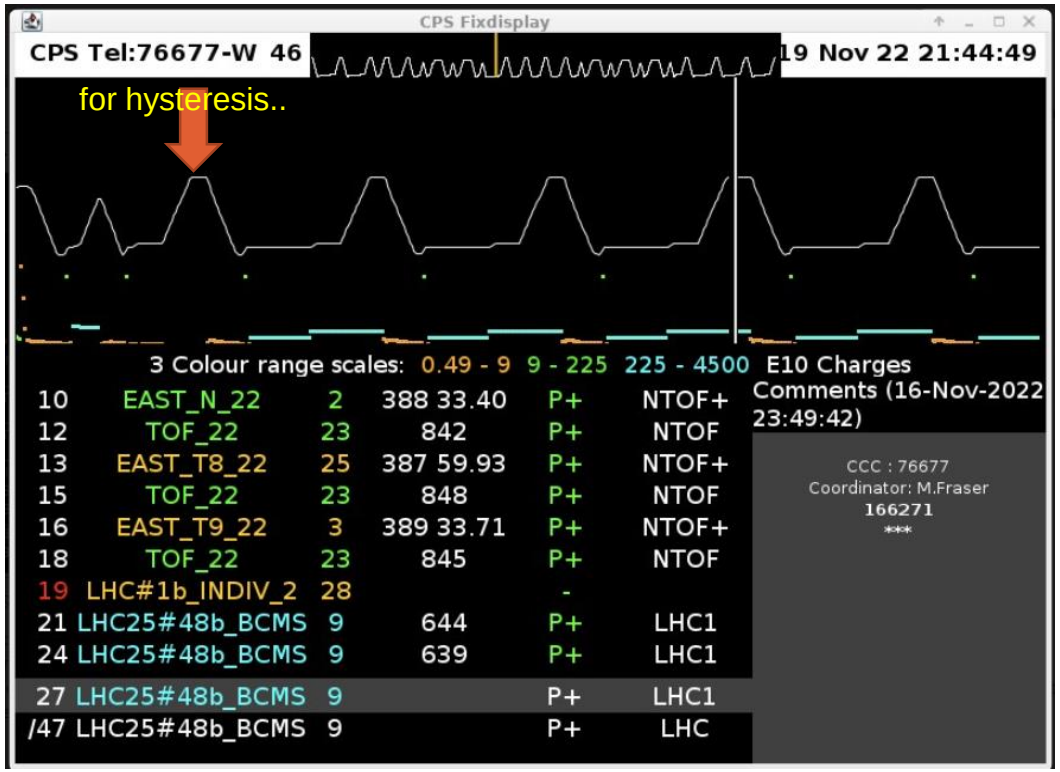
A few ideas follow based on discussions with many of you.

Some of them (quite) feasible, some need R&D, some imply rather strategic choices, some lack the technical implementation, and some may be not possible....

Ideas towards “energy-efficient” complex – L4+PSB+PS

- **All transfer lines with FGC are already well-optimised with the economy mode in L4, PSB & PS**

- **In PSB + PS already POPS(-B) and ring converters are not pulsed when no requests**
  - This works when a zero spare cycle is programmed



“Dynamic” economy already in place but could be improved further towards a “full”economy ?

- **Putting POPS(-B) in standby automatically under well defined conditions**

- **ML for magnetic hysteresis instead of empty cycles?**
  - ***See next slide***

- **Proposal : reducing the total pulse length for L4 from 600us to 400us will be tested in 2023**

Courtesy: A. Huschauer & G. P. Di Giovanni

Ideas towards “energy-efficient” complex - SPS

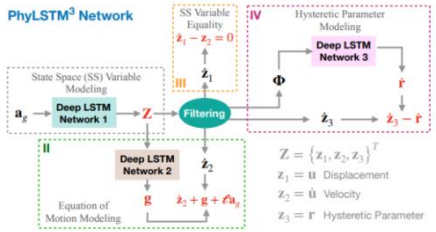
- Using a neural network, the exact behaviour of the magnets can become “predictable” and thefore could be compensated for ...

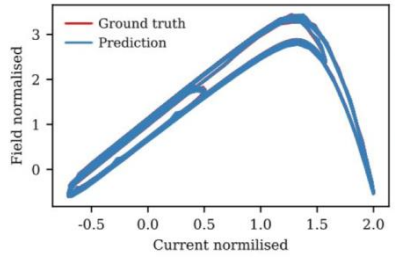
→ No need for degaussing…?

- Optimize as possible procedures like the ZS alignment towards a more efficient commissioning ?

- …make an “energy analysis” to existing procedures and try to optimize, when and where this is possible ?

$B(t_n, B_{n-1}, \ldots, B_0)$ can be learned → time series prediction with physics inspired neural nets





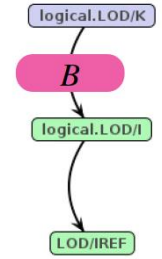
Example: Measurement and modelling of SPS MQ

F. Velotti & V. Di Capua

→ MLP to manage networks and parameters

→ LSA: new parameter tree: include B (as target and correction)

→ UCAP(?) for cycle-by-cycle feedforward correction, or realtime input?



Maybe BTRAIN systems will become obsolete!

Courtesy: V. Kain & F.M. Velotti

Ideas towards “energy-efficient” complex – SPS-NA

Possibilities :

- **Lower momentum in the SPS ?**
  - **With increased flat-top ?**
- **Be faster in comissioning and setting up ?**
- **Redesign the spectrometer magnets**
- **Replace the remaining DC magnets with laminated ones (NACONS analysis ongoing) along relevant infrastructure H&V upgrades**
- **…more realistic to stop the physics run earlier ?**

NA62 – Kaons

Proton momentum (GeV/c)	Rel. K^+ flux/proton	Rel. K^+ fraction
400	1	6.14%
350	0.91	6.01%
300	0.78	5.83%
200	0.61	5.38%

Courtesy: L. Gatignon

Proton momentum	160 GeV/c		190 GeV/c	
(GeV/c)	μ^+	μ^-	μ^+	μ^-
400	1	1	1	1
350	0.66	0.6	0.6	0.5
300	0.38	0.3	0.3	0.22
250	0.16	0.1	0.1	0.06

AMBER – Muons & NA64 electrons similar

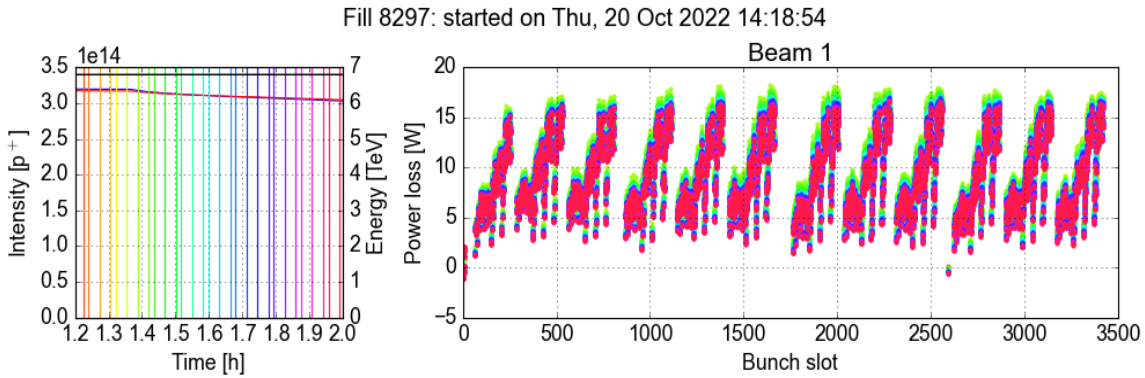
Reducing the SPS momentum has a quadratic effect on the consumed electrical power.
However: at a significant cost for the physics

e.g: NA62 1 additional year of running (beyond LS3) and x2 time for NA64-e in the overbooked H4 beam line

Ideas towards a more “energy- efficient”complex - LHC

- **Optimisation of cryo-plants has been already looked-up by TE-CRG and BE-OP**
- **Pure 8b4e (not mixed with normal batches) could help with heat loads...**

→ **But coming at a significant cost on physics**

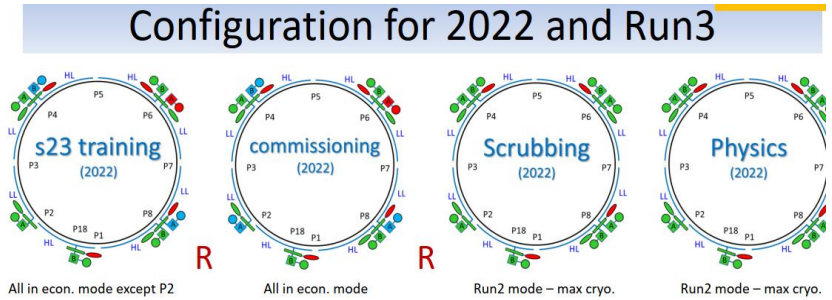


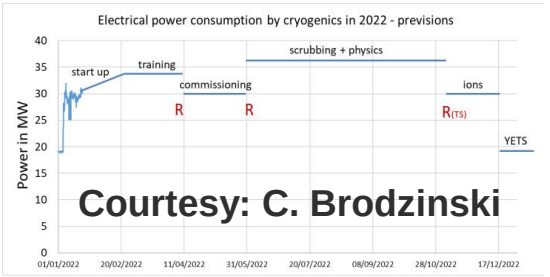
Courtesy: L. Mette, G. Iadarola, G. Rumolo

LHC Performance Workshop 2022

24–27 Jan 2022
Europe/Zurich timezone

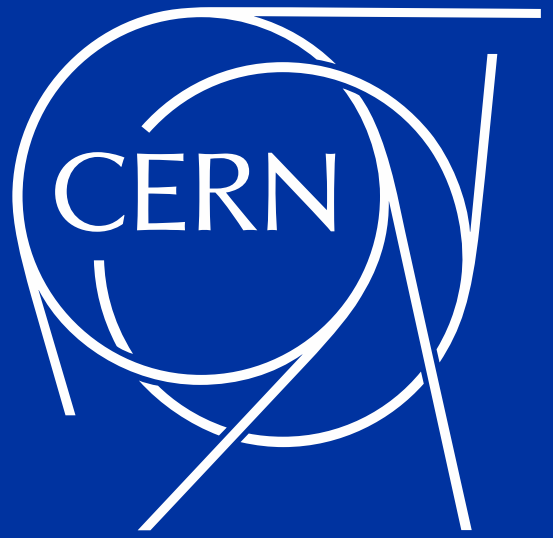
More discussions expected in Chamonix !



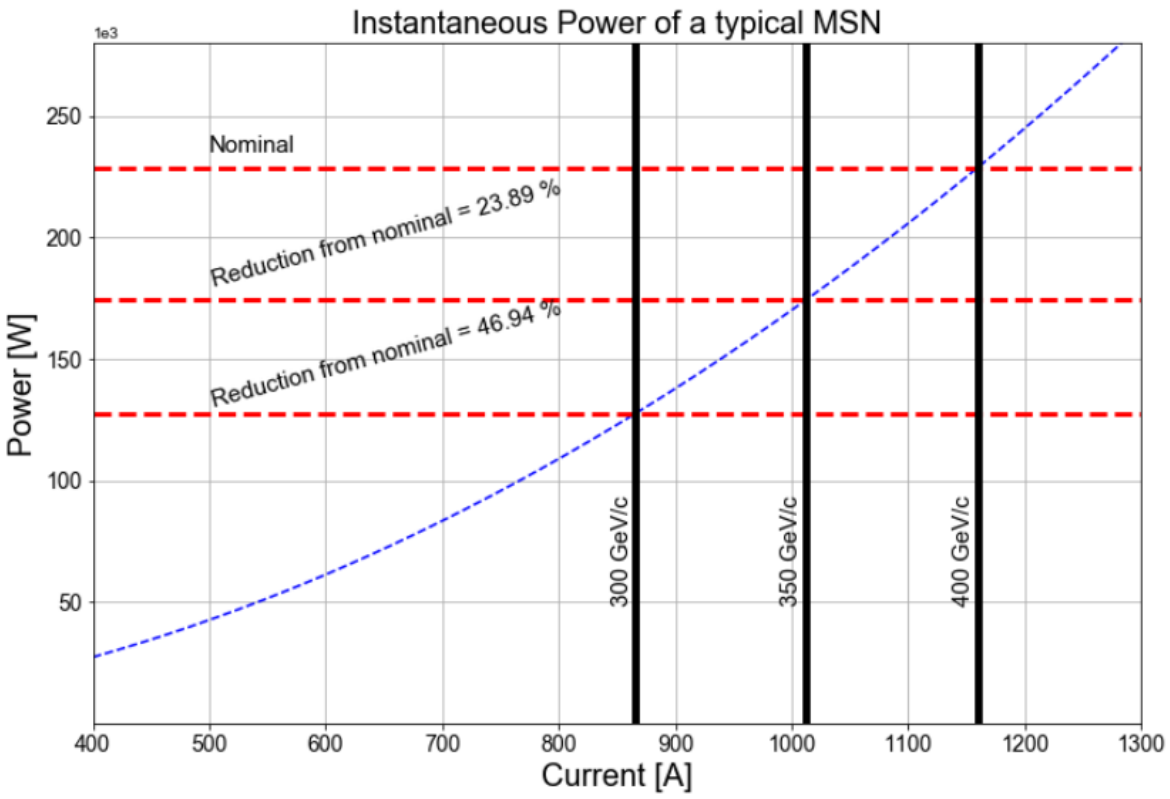


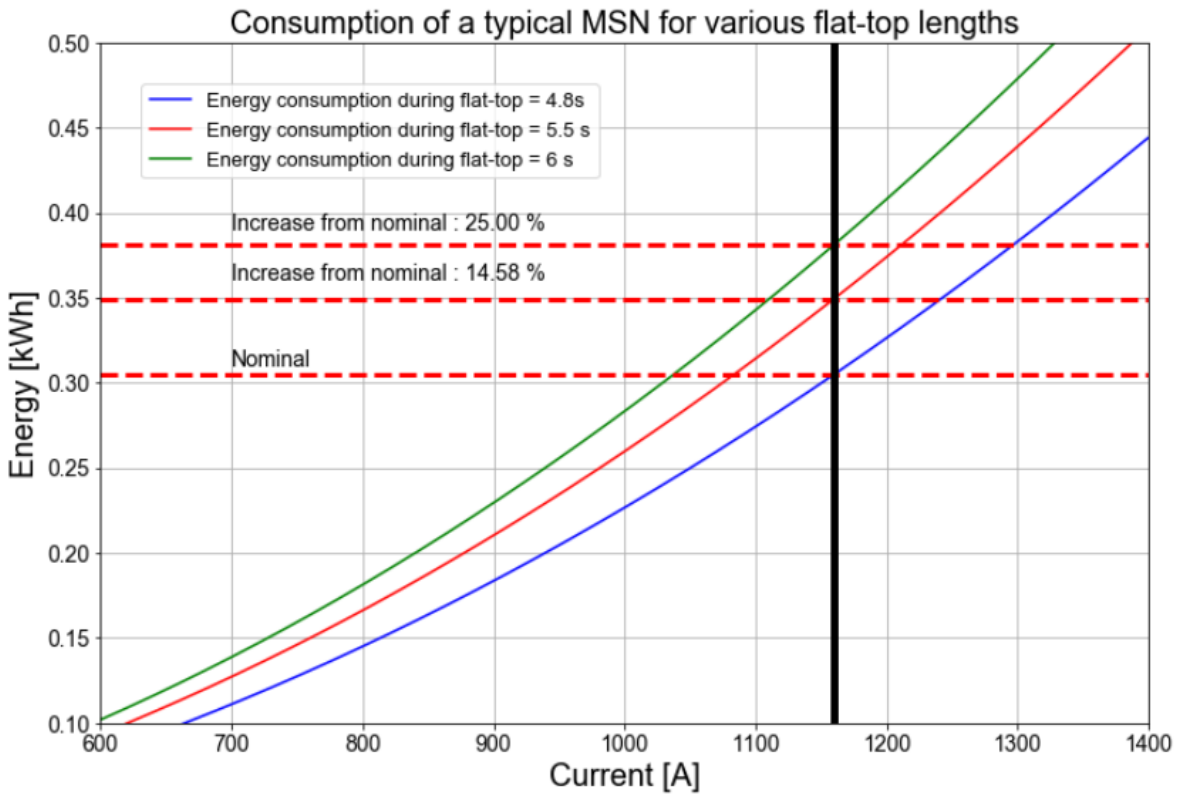
Conclusions & thoughts for the future

- **A large part of the complex is already optimized to the maximum – further optimisation would not bring any extra gain**
  - There is room for improvement in some parts that we would possibly like to pursue !
- **The energy crisis can possibly be an opportunity to rethink the way we operate some aspects of the complex**
- **The SPS seems the “lowest hanging fruit” to start towards this endeavour with the largest gain**
- **Futher studies will be necessary in order to establish a roadmap for an “energy efficient operation” of the CERN injectors complex**


CERN

Extra slides





Magnet & infrastructure renovation ‘a la East’

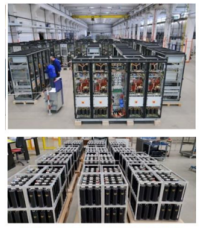
Scope of the East Area Renovation Project

Courtesy: S. Evrard

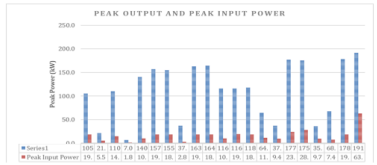
- Main goal: ensure long-term operation of EA beamline and facilities
- New beam line layout
  - better cope with physics requirements (maximum momentum and choice of particle type (e, h, μ))
  - minimise dose rates to personnel, and allow faster repair times by improving equipment accessibility
  - respect todays norms for radiation protection: new primary area ventilation + new dump system
- New cycled powering scheme ← ENERGY SAVINGS
  - replace massive magnet yokes by laminated ones to allow cycling them
  - new Sirius power converters with energy recovery
  - annual energy consumption reduction
- Infrastructure Renovation ← ENERGY SAVINGS
  - upgrade of Building 157 including heating and ventilation
  - renewal of wall and roof cladding, asbestos removal
  - separation of primary and secondary beams & zones cooling circuits

Magnet powering scheme

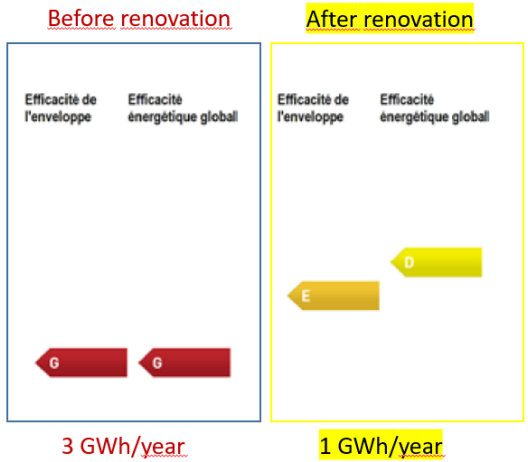
The East Area consumes energy continuously whereas it is used only during 7.5% of the PS Supercycle time



Courtesy
K. Papastergiou



- After LS2, power supply to the new laminated magnets is achieved on a cyclical basis, with an energy recovery stage between each cycle.
- The energy returned by the magnets during their de-magnetisation is now stored in capacitor banks connected to the new power converters and immediately reused during the next cycle to re-magnetise the magnets
- Pulsed operation requires a di/dt through the magnet
  - 23/55 magnets did not support cycling due to a solid steel yoke
  - Eddy currents would heat up the yoke material
  - Procurement of new laminated magnets



Energy savings (Electricity) – Estimates – Results