

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



+



Transmission costs

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



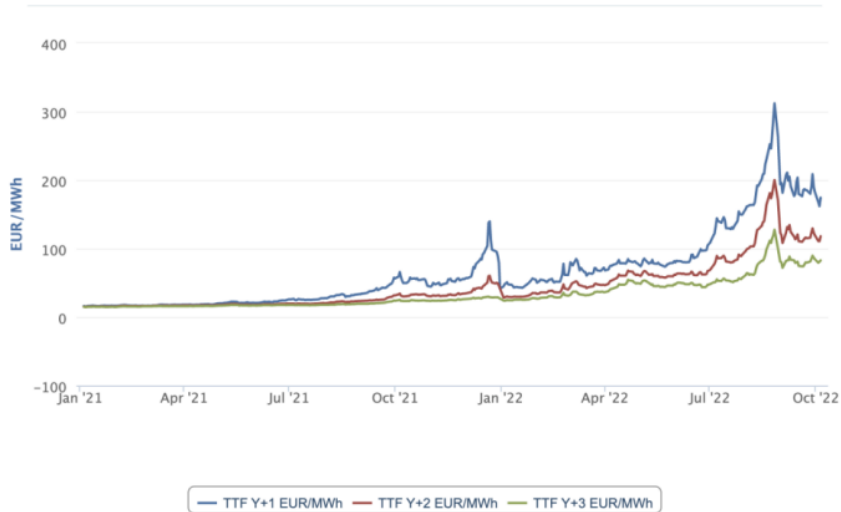
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Transmission costs

Courtesy: N. Bellegarde

NATURAL GAS FORWARD



Courtesy: N. Bellegarde

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CERN gets ready for Europe energy crunch

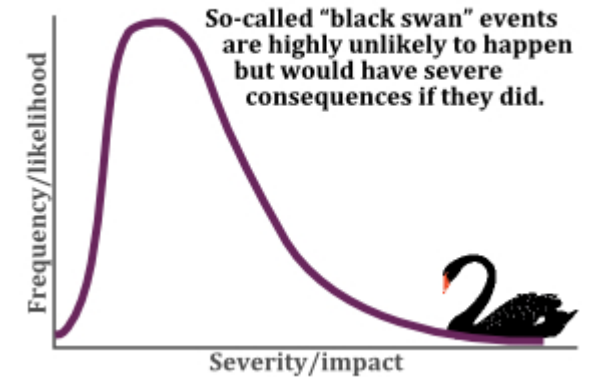
By Geneva Solutions



Energy crisis in Europe to hit Cern, Large Hadron Collider likely to shut science ops



The Black Swan



Courtesy: N. Taleb

2022 Energy crisis

Electricity price at CERN



CERN gets ready for Europe energy crunch

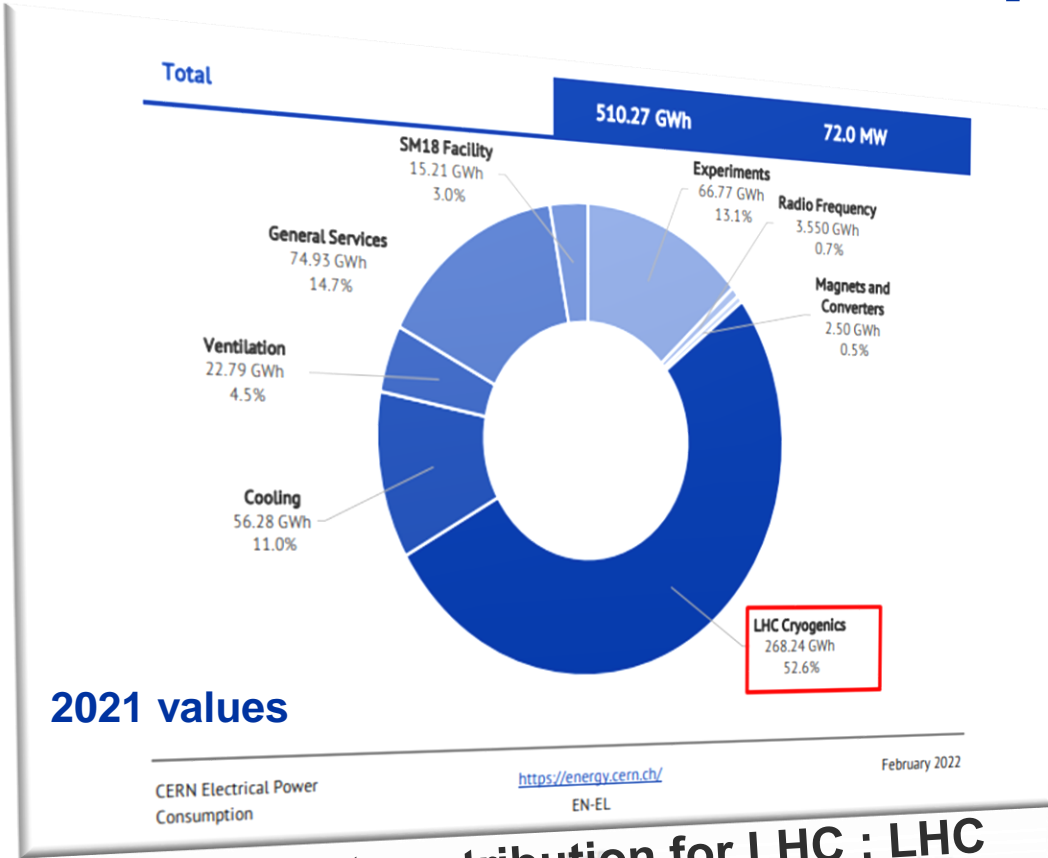


Forgetting for a moment the crisis

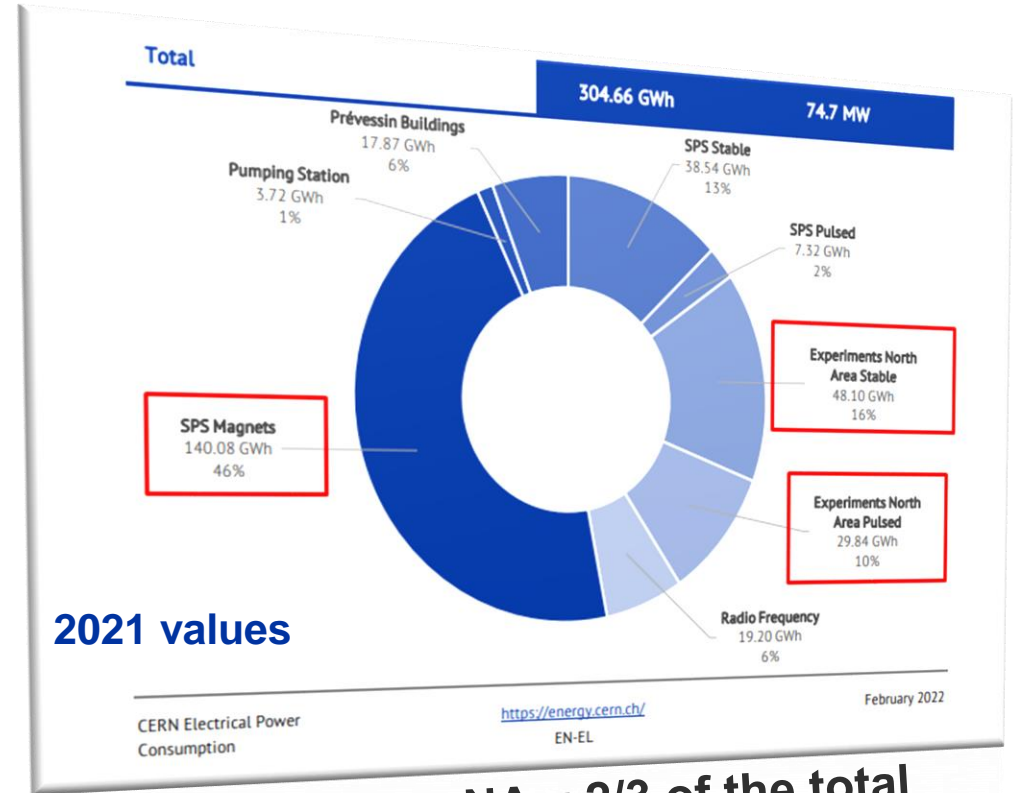
Shouldn't we take "the opportunity" to start thinking forward towards an even more energy-efficient operation of the complex in the future ?



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...

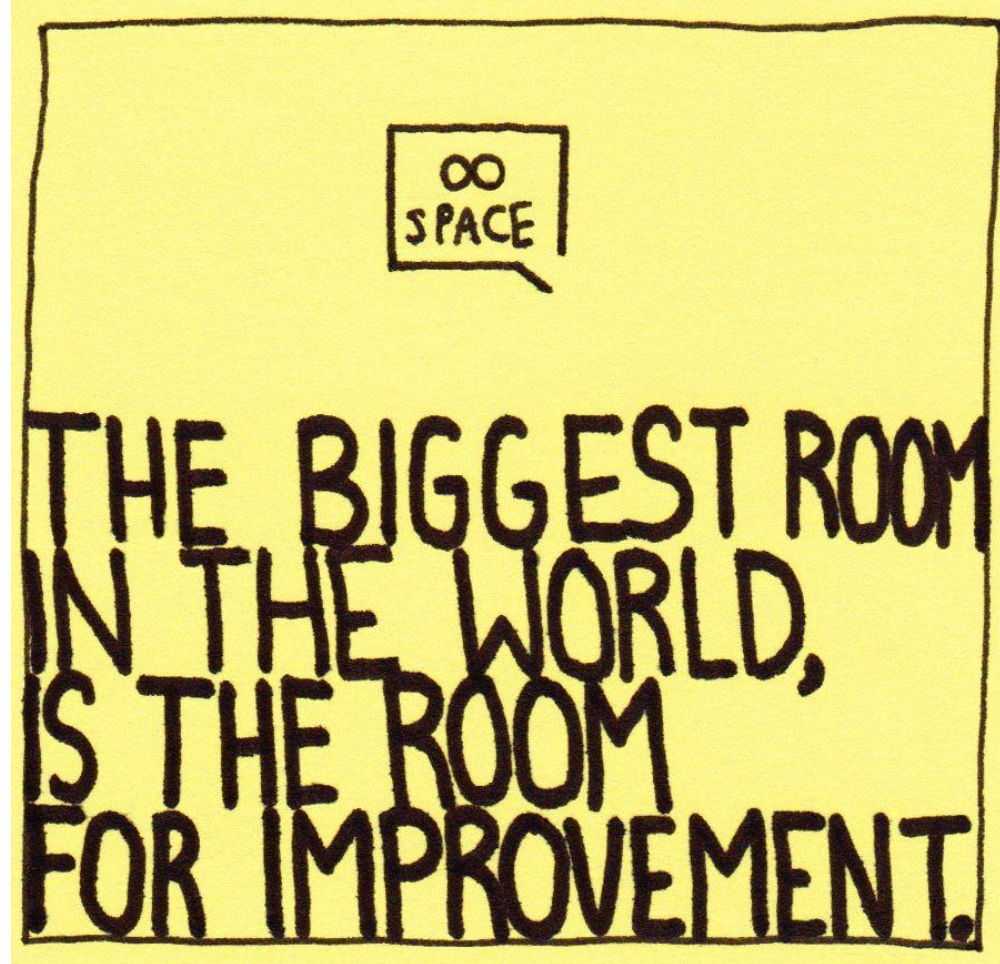
~50% of the electricity produced by “Grande Dixence”



Facts & figures

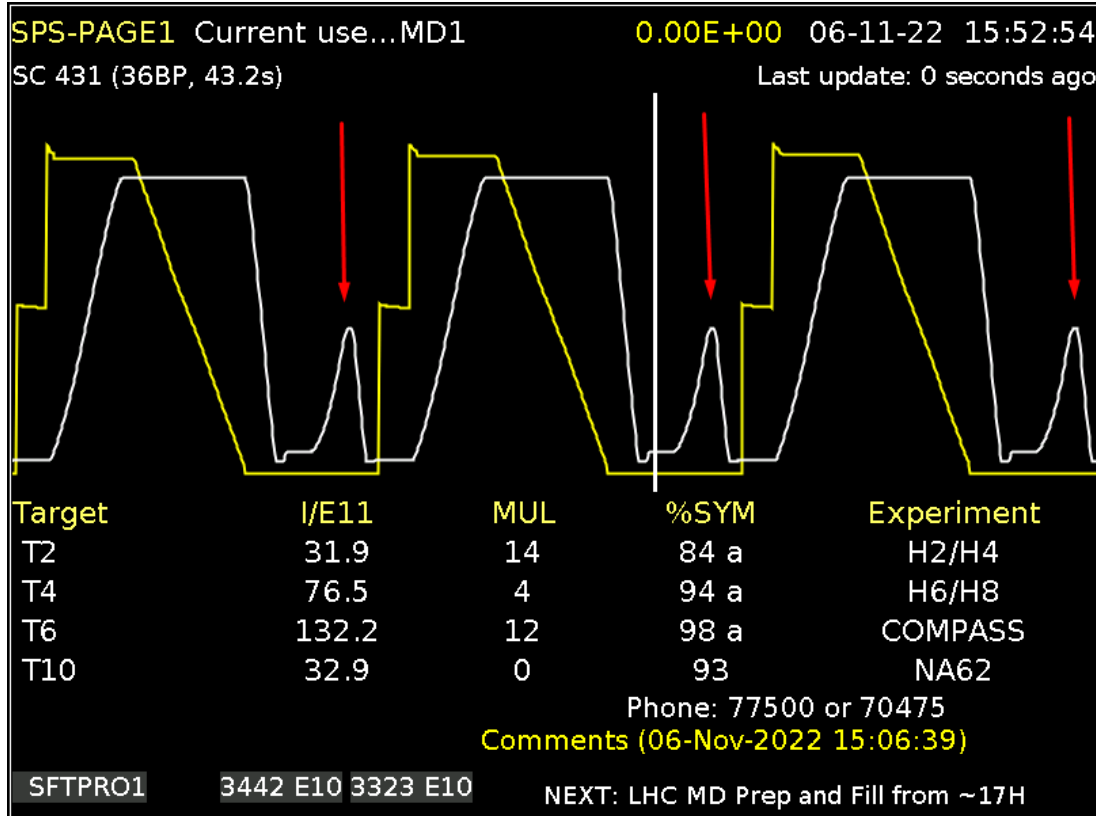
Plant type:	Storage power plant
Location:	Fionnay, Riddes, Switzerland
Number of turbines:	Fionnay: 6 x 2 Pelton turbines / Nendaz: 6 x 2 Pelton turbines
Capacity:	2,069 MW together with Bieudron (Cleuson-Dixence)
Shareholding:	60 %
Commissioning:	1961 - 1965
Average annual production:	2000 GWh together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



eam: M2 / COMPASS-transversity
 le: M2A COMPASS-transversity 021 Momentum: +172.00 / +160.00 INCONSISTENT_ENERGIES GeV/c Comment: 2022 Transversity mu+ 160 GeV/c FT DIPOLE ON more focused after July 13th. Quad34-36 cards change Last timing: 08.11.2022 19:55:58

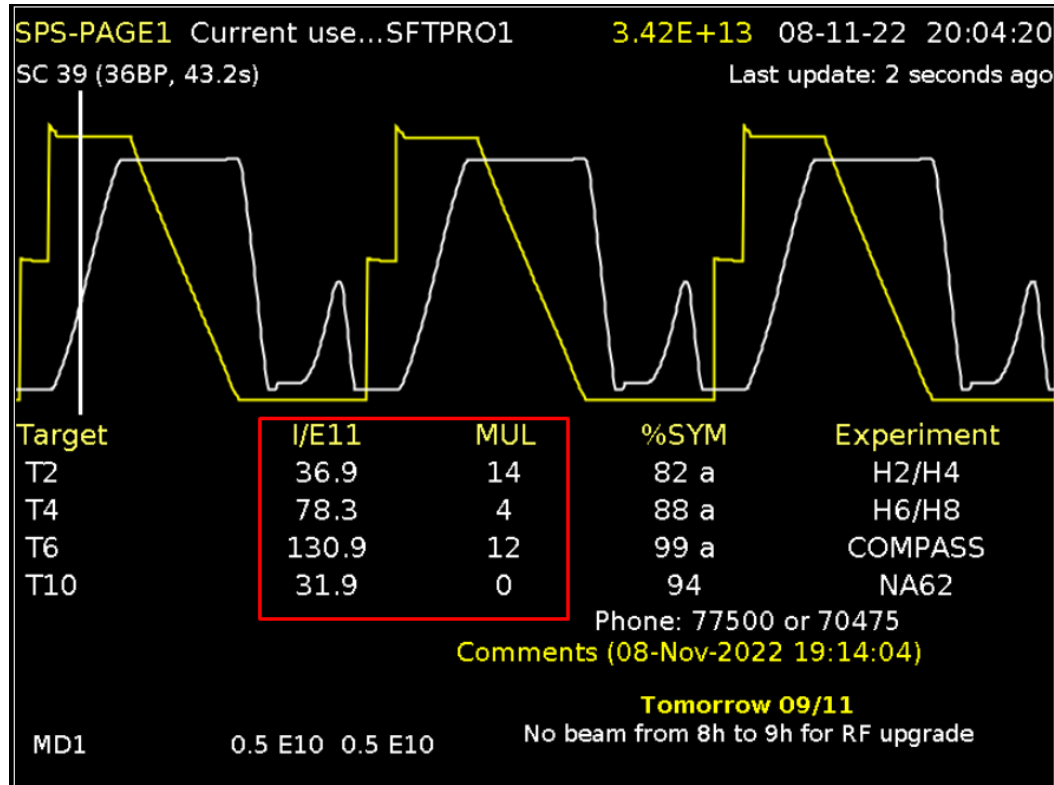
Rectifiers	CURRENT	BeamRef	TOL	HUN	MODE	POL	PLS	LOC	FAULT	ALM	VETO	Info	Eco	Comments
▲ BEND 061 026	558.0	558.2	0.4		ON	N	D-C			ALM		BA80 / NR22_050	N	
▲ QUAD 061 056	135.6	135.6	0.3		ON	N	D-C			ALM		BA80 / NR11_028	N	
▲ BEND 061 067	946.8	947.0	0.6		ON	N	PLS			ALM		BA80 / NR11_006	N	
▲ QUAD 061 072	-314.4	-314.4	0.3		ON	I	PLS			ALM		BA80 / NR11_029	N	
▲ TRM 061 074	67.5	67.5	0.4		ON	N	D-C			ALM		BA80 / NC11_012	N	
▲ QUAD 061 080	-300.2	-300.2	0.3		ON	I	PLS			ALM		BA80 / NR11_030	N	
▲ QUAD 061 096	245.3	245.3	0.3		ON	N	PLS			ALM		BA80 / NR11_031	N	
▲ TRM 061 098	-19.4	-19.4	0.3		ON	I	D-C			ALM		BA80 / NC11_009	N	
▲ QUAD 061 104	-290.3	-290.3	0.3		ON	I	PLS			ALM		BA80 / NR11_032	N	
▲ BEND 061 109	644.8	645.0	0.4		ON	N	D-C			ALM		BA80 / NR22_023	N	
▲ QUAD 061 112	-358.2	-358.0	0.4		ON	I	D-C			ALM		BA80 / NR21_006	N	
▲ QUAD 061 148	480.9	481.0	0.3		ON	N	D-C			ALM		BA80 / NR21_005	N	
▲ QUAD 061 154	-480.9	-481.0	0.3		ON	I	D-C			ALM		BA81 / NR21_012	N	
■ SCRAPER 061 190	100.0	100.0	0.3		ON	N	D-C			ALM		BA80 / NR11_027	N	LIP_LIPSTREAM ↔ BeamRef
■ MB 061 226	-100.1	-100.0	0.4		ON	I	D-C			ALM		BA81 / NC11_040	N	
▲ QUAD 061 364	481.0	481.0	0.3		ON	N	D-C			ALM		BA81 / NR21_013	N	
▲ QUAD 061 400	-481.1	-481.0	0.3		ON	I	D-C			ALM		BA81 / NR21_014	N	
▲ QUAD 061 580	459.7	459.8	0.3		ON	N	D-C			ALM		BA81 / NR21_026	N	
▲ QUAD 061 616	-459.9	-459.8	0.3		ON	I	D-C			ALM		BA81 / NR21_015	N	
▲ TRM 061 650	0.1	0.0	0.4		STANDBY	N	D-C			ALM		BA81 / NR11_057	N	
▲ TRM 061 651	50.0	50.0	0.4		ON	N	D-C			ALM		BA81 / NR11_066	N	
▲ QUAD 061 654	252.5	252.5	0.3		ON	N	D-C			ALM		BA81 / NR21_017	N	
▲ QUAD 061 677	-310.7	-310.6	0.3		ON	I	PLS			ALM		BA81 / NR11_058	N	
▲ QUAD 061 690	206.2	206.2	0.3		ON	N	D-C			ALM		BA81 / NR11_059	N	
▲ BEND 061 693	-494.4	-494.5	0.4		ON	I	D-C			ALM		BA81 / NR22_042	N	
▲ BEND 061 706	888.8	889.0	0.3		ON	N	D-C			ALM		BA81 / NR22_038	N	
▲ QUAD 061 710	-207.2	-207.2	0.3		ON	I	D-C			ALM		BA81 / NR11_060	N	
■ SCRAPER 061 715	99.9	100.0	0.4		ON	N	D-C			ALM		BA81 / NC11_021	N	
▲ QUAD 061 723	310.4	310.5	0.3		ON	N	D-C			ALM		BA81 / NR11_061	N	
■ SCRAPER 061 727	-100.1	-100.0	0.4		ON	I	D-C			ALM		BA81 / NC11_028	N	
■ SCRAPER 061 733	-100.2	-100.0	0.4		ON	I	D-C			ALM		BA81 / NC11_027	N	
■ SCRAPER 061 741	99.9	100.0	0.4		ON	N	D-C			ALM		BA81 / NC11_021	N	
▲ QUAD 061 745	258.2	258.2	0.3		ON	N	D-C			ALM		BA81 / NR21_016	N	
▲ QUAD 061 748	444.4	444.4	0.3		ON	N	D-C			ALM		BA81 / NR21_022	N	
■ SCRAPER 061 752	-100.1	-100.0	0.4		ON	I	D-C			ALM		BA81 / NC11_028	N	
■ MB 061 765	-100.0	-100.0	0.4		ON	I	D-C			ALM		BA81 / NC11_033	N	
■ SCRAPER 061 845	-100.1	-100.0	0.4		ON	I	D-C			ALM		BA81 / NC11_024	N	
▲ TRM 061 854	-80.0	-80.0	0.4		ON	I	D-C			ALM		BA81 / NR11_062	N	
▲ QUAD 061 856	-398.9	-398.9	0.3		ON	I	D-C			ALM		BA81 / NR21_023	N	
■ MB 061 882	-100.0	-100.0	0.4		ON	I	D-C			ALM		BA81 / NR11_078	N	
▲ QUAD 061 900	354.8	354.8	0.3		ON	N	D-C			ALM		BA81 / NR21_021	N	
▲ TRM 061 988	-80.0	-80.0	0.4		ON	I	D-C			ALM		BA81 / NR11_065	N	
▲ TRM 061 989	192.0	192.0	0.4		ON	N	D-C			ALM		BA81 / NR11_063	N	
▲ QUAD 061 992	414.0	413.8	0.3		ON	N	D-C			ALM		BA81 / NR21_020	N	
■ SCRAPER 061 997	99.9	100.0	0.4		ON	N	D-C			ALM		BA81 / NR11_077	N	
▲ QUAD 065 011	329.3	329.3	0.3		ON	N	D-C			ALM		BA81 / NR12_026	N	
▲ QUAD 065 023	-188.5	-188.5	0.3		ON	I	D-C			ALM		BA81 / NR12_027	N	
▲ BEND 065 027	-735.0	-735.0	0.4		ON	I	D-C			ALM		BA81 / NR22_041	N	
▲ QUAD 065 043	-188.4	-188.5	0.3		ON	I	D-C			ALM		BA81 / NR21_024	N	
■ SCRAPER 065 050	-100.1	-100.1	0.3		ON	I	D-C			ALM		BA81 / NR11_069	N	DOWN_LIPSTREAM ↔ BeamRef
▲ QUAD 065 056	-329.4	-329.3	0.4		ON	I	D-C			ALM		BA81 / NR11_064	N	
■ MB 065 061	-100.1	-100.0	0.3		ON	I	D-C			ALM		BA81 / NR11_123	N	
▲ QUAD 065 072	-277.9	-277.9	0.3		ON	I	D-C			ALM		BA81 / NR21_025	N	

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 !



Access Status [Doors]
 Beam: H4 / CMS ECAL
 File: H4D.CMS ECAL.121 Momentum: -150.00 / -149.12 GeV/c
 Last timing: 08.11.2022 20:05:05
 Comment: H4-HT-FFD-2021-164 -- QNN -- -150 GeV/c

Doors	Status	Info	Comments
PPG81		Beam OFF	
PPE112		Beam ON	Not beam on
PPE124		Beam ON	
PPE134		Beam ON	
PPE144		Beam ON	
PPE154	Access With Key	Beam OFF	Not beam on
PPE164	Closed - No Access	Beam OFF	Not beam on
PPE174	Free Access	Beam OFF	Not beam on
PPE184	Free Access	Door Forced!	Door Forced / Not beam on

Run Hold Refresh Refresh All Refresh Selected Store to e-logbook

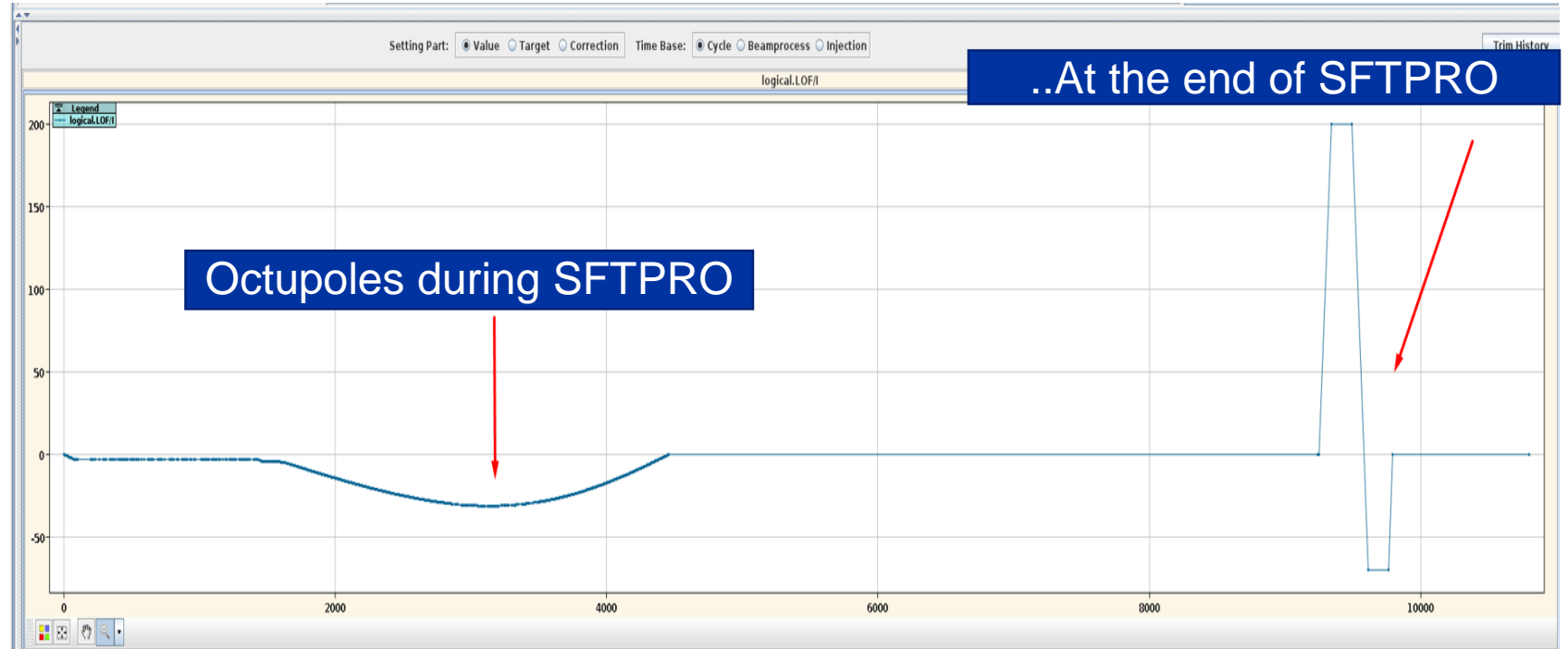
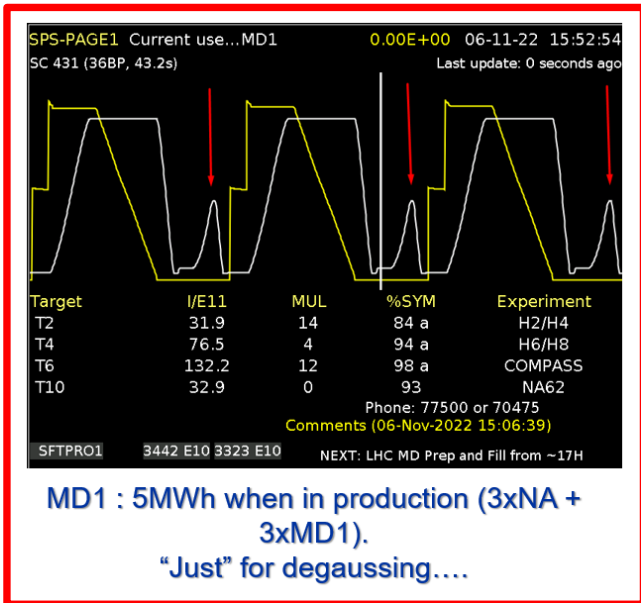
- LHC / HiRadMat/ AWAKE cycle often ‘playing’ without beam...too difficult and time-consuming to change

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

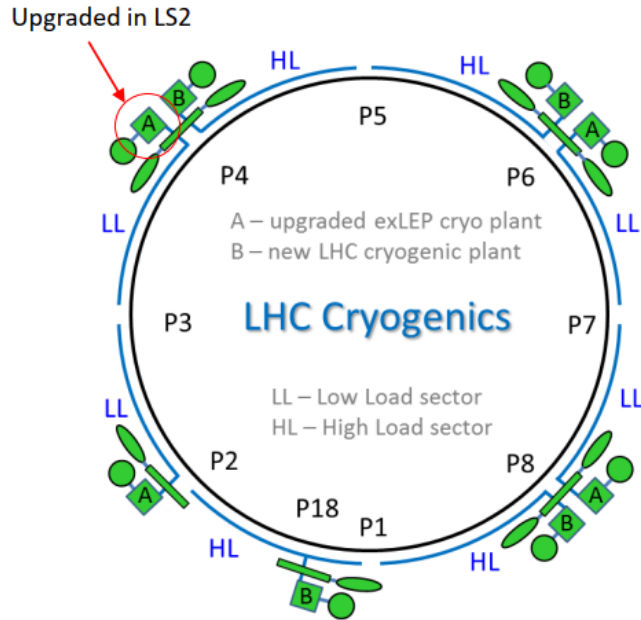
Hysteresis causes large instabilities and non reproducibility cycle by cycle

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

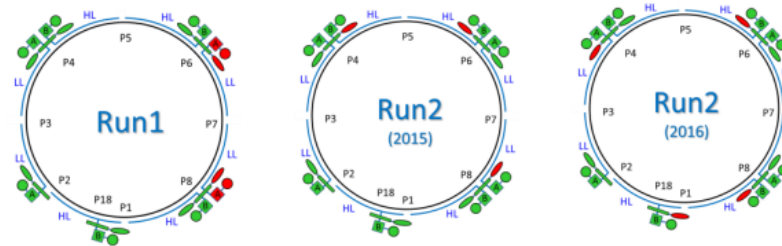


Cooling capacity of A and B are designed to cover nominal LHC operation with equal margins on LL and HL sectors.

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.**



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

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

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!

K.Brodzinski_LBOC_2022.03.15

What are the various possibilities ?



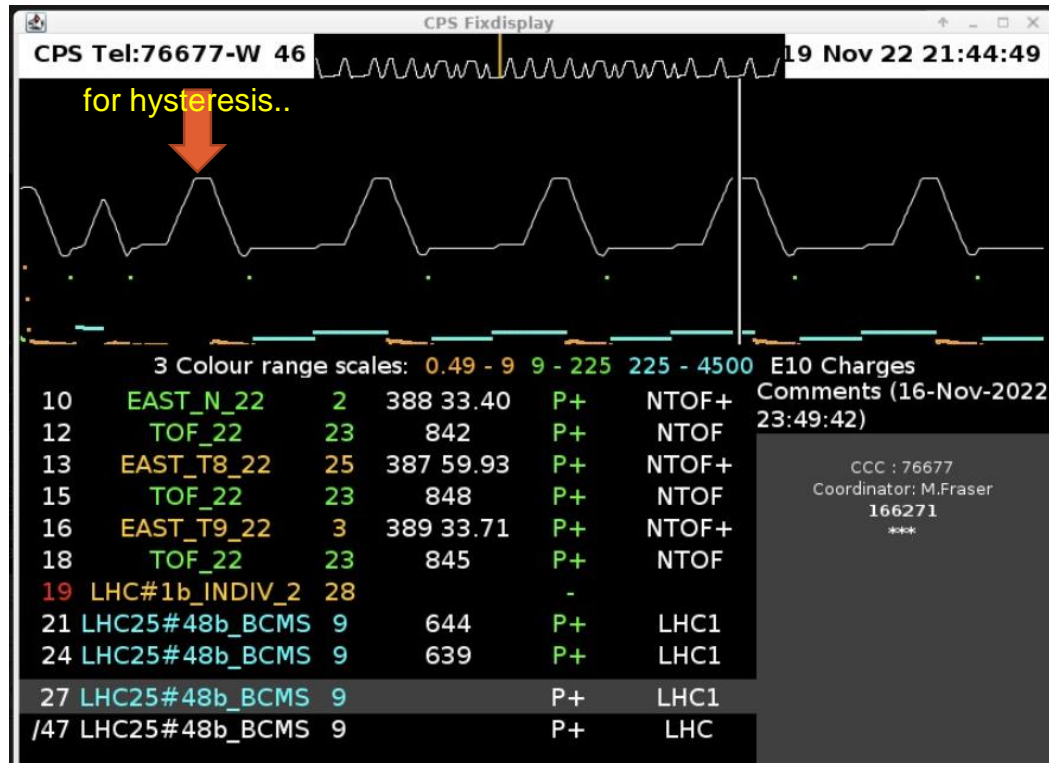
Disclaimer :

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-optimized 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

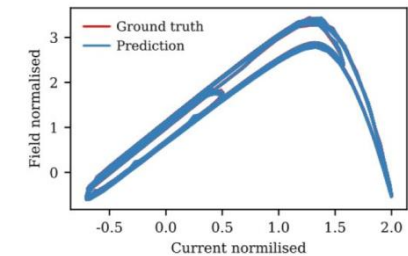
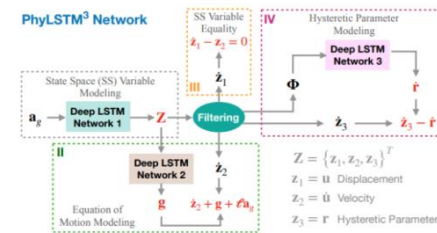
- Using a neural network, the exact behaviour of the magnets can become “predictable” and therefore could be compensated for ...

→ 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 ?



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

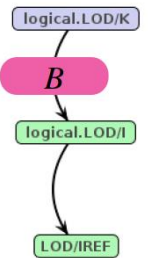


Example:
Measurement and modelling of SPS MQ

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 commissioning 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 (GeV/c)	160 GeV/c		190 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

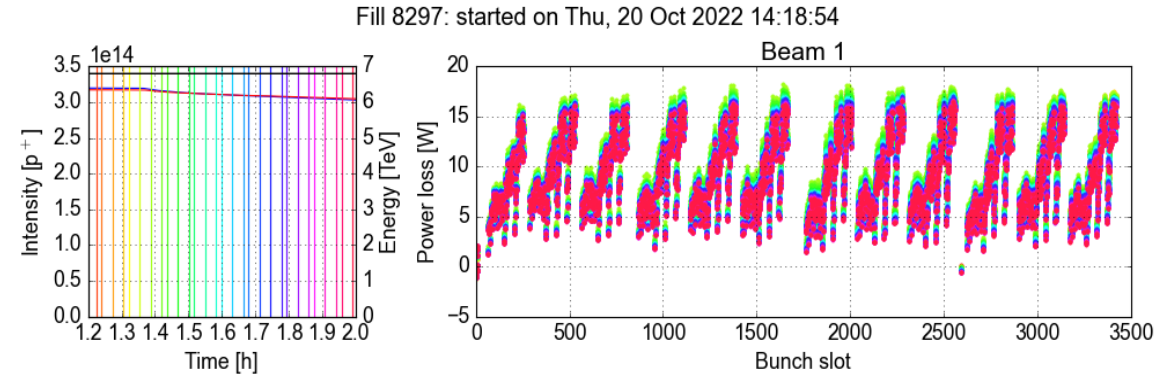
AMBER – Muons & NA64 electrons similar

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



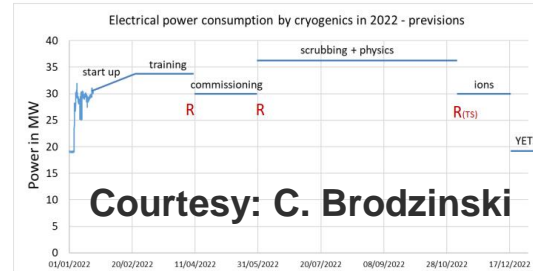
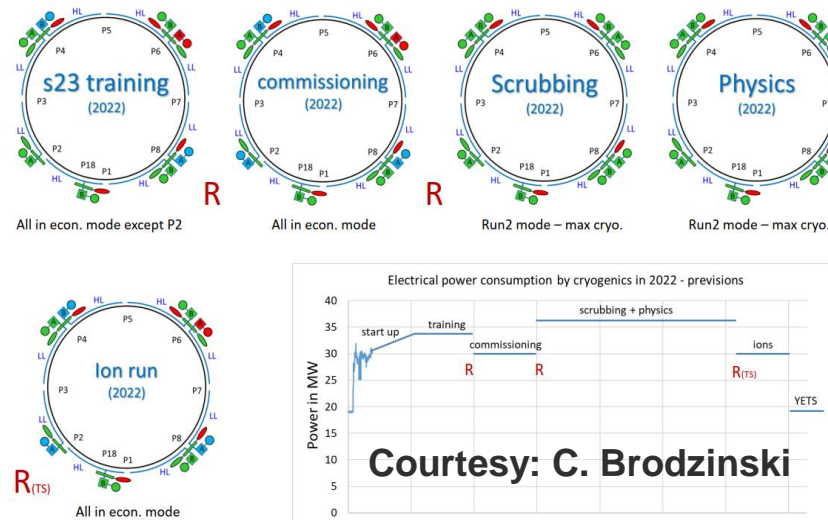
Courtesy: L. Mette, G. Iadarola, G. Rumolo

LHC Performance Workshop 2022

24–27 Jan 2022
Europe/Zurich timezone

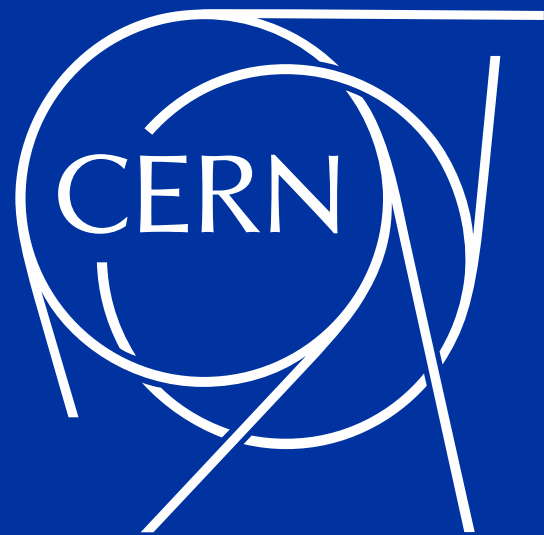
More discussions expected in
Chamonix !

Configuration for 2022 and Run3

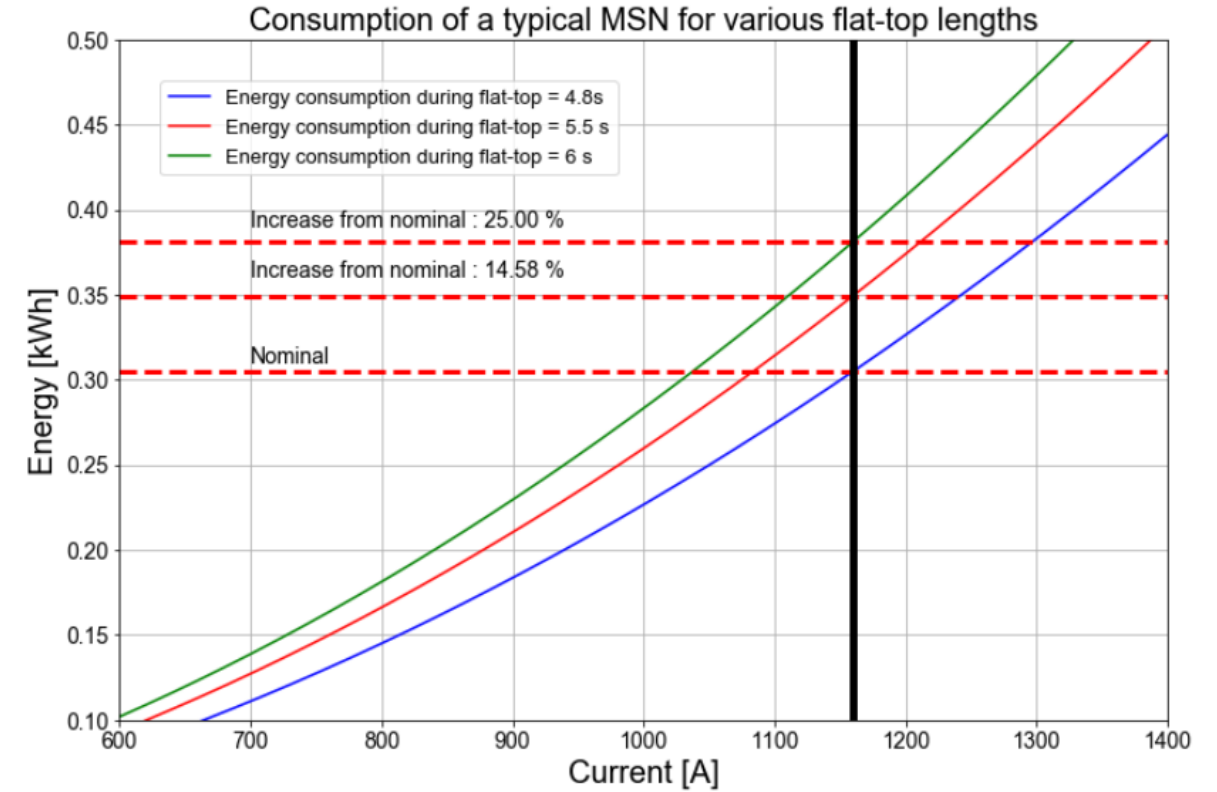
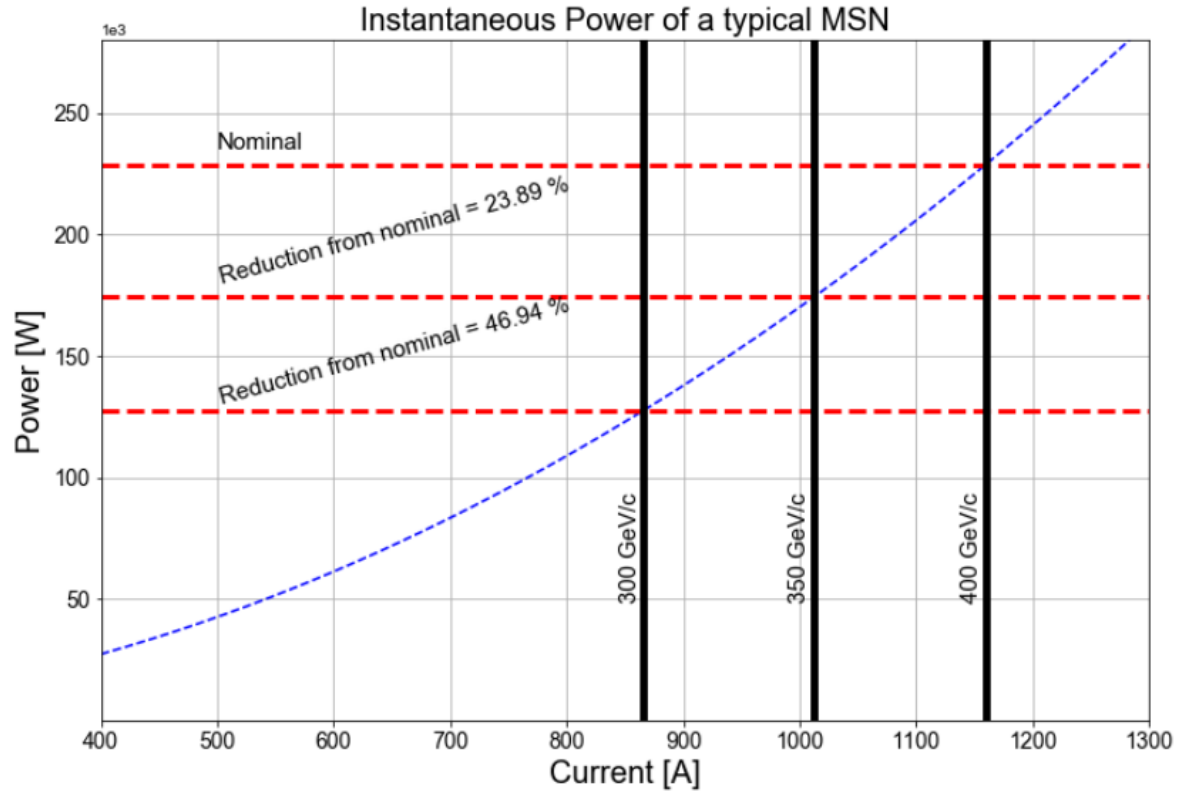


Conclusions & thoughts for the future

- **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**
- **Further studies will be necessary in order to establish a roadmap for an “energy efficient operation” of the CERN injectors complex**



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 today's 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

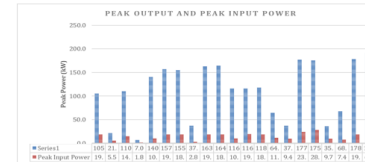
Magnet powering scheme



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

