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LHC Injectors Upgrade

LHC Injectors Upgrade Workshop

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LHC Injectors Upgrade

Upgrade beyond baseline: LIU2

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Introduction and overview

- **Bullet point**
  - Another bullet point

Linac4 source improvements

TO BE COMPLETED

Linac4 RFQ spare

TO BE COMPLETED

Additional Linac4 upgrade options

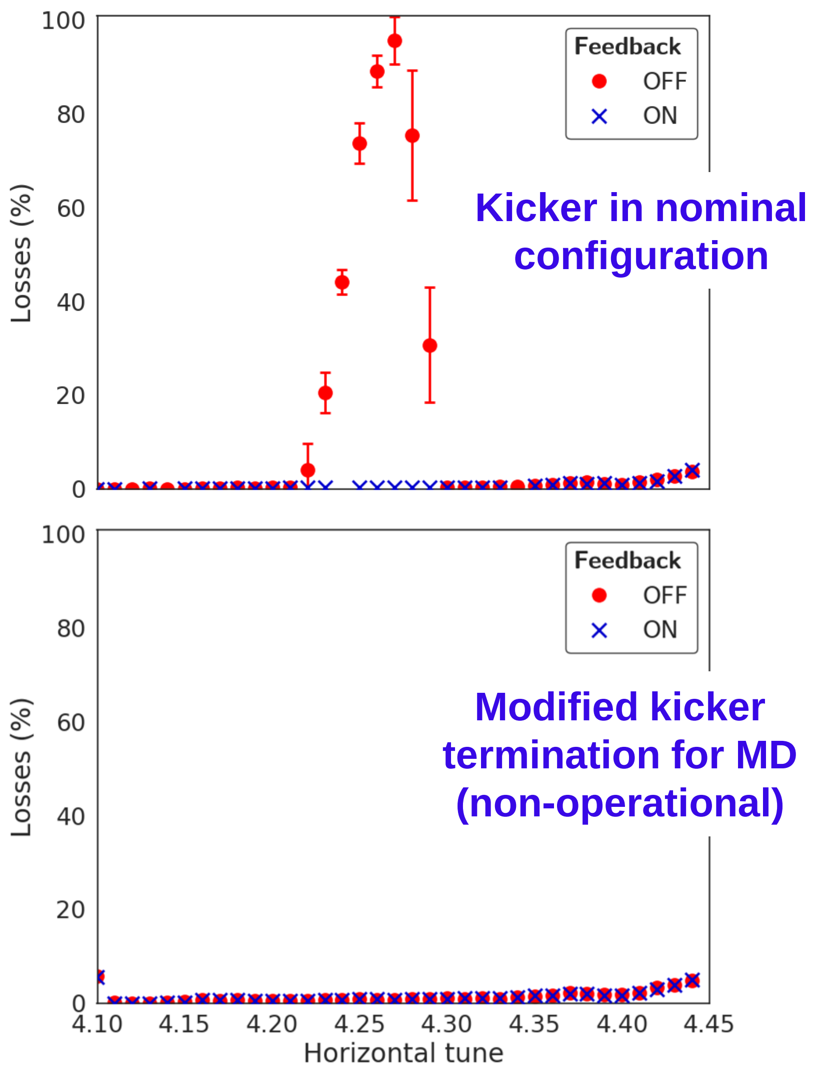
- **3 MeV injector upgrade**
  - New more compact LEBT design (beneficial for the beam quality and RFQ matching) – to be studied at the test-stand
  - Spare RFQ – cost of a new RFQ is ~1 MCHF. This RFQ will have to be operated at the test stand first (cooling station, RF power, diagnostic bench….)
  - New MEBT design: Findings on the chopper dump could lead to a different dump design and a different MEBT design
- **Upgrade the Linac4 transfer-line supports**
  - Request from survey team to speed-up and ease the alignment process
  - Would mean a total disassembly of the line and installation on girders
  - Cost ~500 kCHF (20 supports with beams and alignment jacks)
- **Additional beam instrumentation**
  - Adding a beam current transformer just before the RFQ to better assess transmission in the LEBT
  - Additional wire scanner in LEBT?

PSB extraction kicker impedance reduction

- **BE.KFA14L1 demonstrated to be source of PSB horizontal instability**
  - Presently suppressed through H feedback system
  - Instability most critical at 160 MeV for range of working points
  - Risk for post-LS2 operation: restricted choice of working points at injection if instability not suppressed by damper (injection transients)
- **Possible impedance reduction measures to be studied**
  - Add special diode-resistor network on thyratron end of cables – reliability might be a concern
  - Add Displacement Current suppression Saturating Inductor (DISI) – could reduce field rise time and move the low frequency impedance lines to higher frequency, while also increasing their magnitude (up to 15x)
- **If operational limitation encountered → launch actions in 2021 for implementation in EYETS 22/23 (~100 kCHF)**

E. Koukoveini et al. in PHYS. REV. ACCEL. BEAMS 22, 124201 (2019)

Measurements at 160 MeV



Power supplies for remaining closed orbit correctors in PSB

- **Presently only 4 out of 12 closed orbit correctors per plane per ring equipped with power converters**
  - Choice of the operationally used closed orbit correctors for all PSB cycles usually done during startup / beam commissioning in combination of quadrupole alignment campaign
  - Change of configuration requires EPC intervention → significantly reduced operational flexibility
- **Closed orbit correction critical for beam performance**
  - To minimize losses for high intensity beams
  - To optimize brightness for LHC beams (closed orbit at injection region)
- **Would need 8x2x4=64 additional power converters + 6 spares**
  - 3x2x4=24 (+ 2 spare) power converters 50A (~260 kCHF)
  - 5x2x4=40 (+ 4 spare) power converters 10A MACAO type (~308 kCHF)
  - Requires space for 11 racks 600x900mm (should be available)
  - AC connection, DC re-cabling and the WIC
  - Lead time of 3 years from the moment of the ECR approval
  - Total ~700 kCHF

information provided by S. Pittet

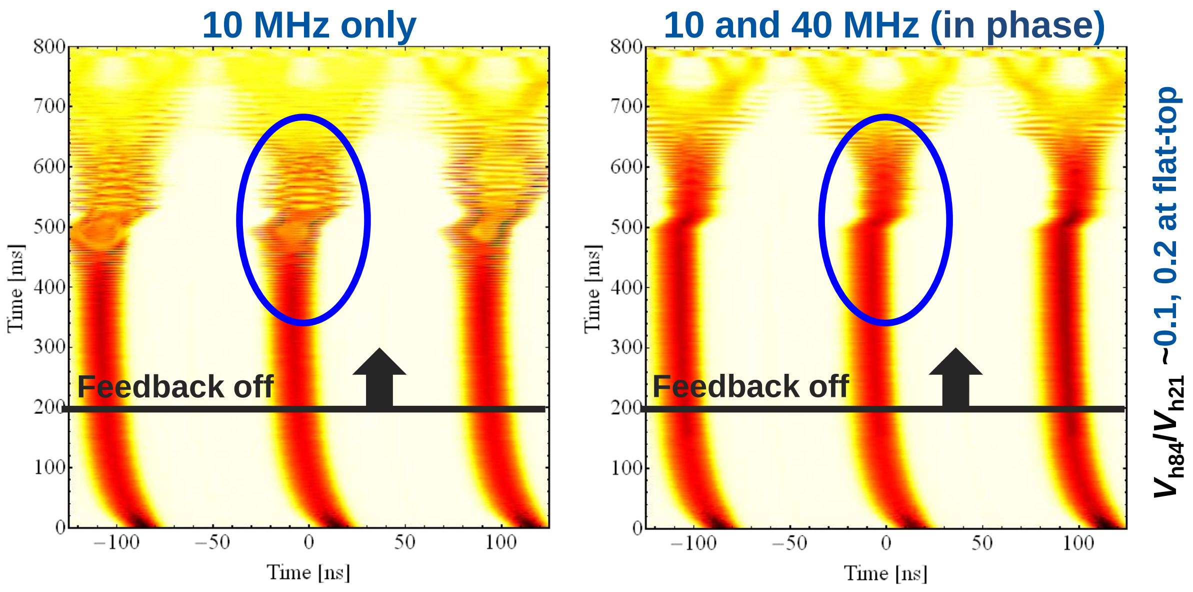
PS RF upgrades

- **New 40/80 MHz feedback amplifiers to minimize residual impedance for improved bunch-by-bunch quality**
  - Modeling of the amplifiers and feedback is progressing - basis to specify the feedback amplifier prototype
  - Budget for prototype has been kept in LIU (90 kCHF, see https://indico.cern.ch/event/800752)
  - Once validated with beam on a single cavity, the upgraded feedback must be propagated to all five cavities during YETS21/22 (70 kCHF/cavity = 350 kCHF in total, beyond LIU)
- **Fast tuner 80 MHz for improved beam quality during parallel proton/ion operation (only 2 cavities with open gap and thus no unnecessary impedance)**
  - Work on pre-series ferrite tuner and production of coupling loops advancing
  - Pre-series tuner (budgeted in LIU, 120 kCHF) to be installed during LS2 is expected to become an operational device
  - Further tuners (100 kCHF per cavity, beyond LIU)

- **10 MHz solid state feedback amplifiers**
  - Expected to reduce impedance by factor 2 beyond LIU baseline (600 kCHF, https://cds.cern.ch/record/2627602)
- **Replacement of 10 MHz 1-turn delay feedback by a multi-harmonic feedback a la 40/80 MHz**
  - Increased feedback gain reducing in particular transient beam loading for better bunch-by-bunch equality

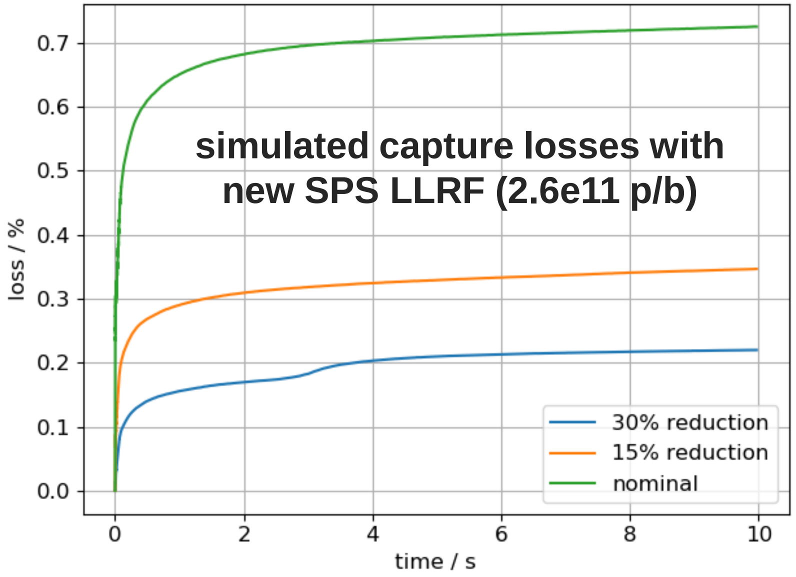
SPS losses / PS Landau cavity

- **Landau cavity in the PS**
  - In 2018 one of the existing 40 MHz cavities was used as Landau cavity and proved very beneficial for beam stability (could demonstrate LIU intensity)
  - Existing cavities limited in bandwidth and thus only usable above 13 GeV



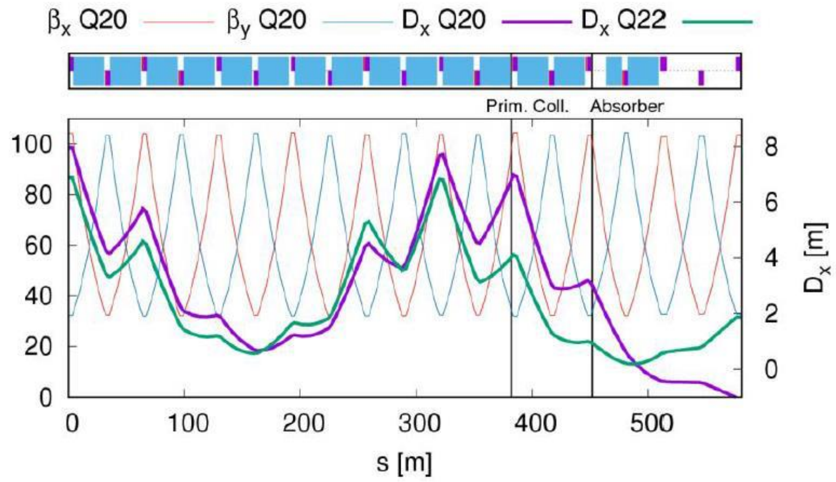
- **Capture losses in SPS depend critically on longitudinal tails and longitudinal emittance from PS**
  - SPS-LLRF upgrade should provide better beam loading compensation and thus capture losses <1% are expected

- **A dedicated PS Landau cavity would provide an option to reduce longitudinal emittance and thus losses in the PS-SPS transfer**
  - Needs to be compatible with longitudinal emittance at PSB-PS transfer and with acceptable longitudinal emittance at SPS flat bottom
  - Decision by end 2022 required for installation in LS3 (~4 MCHF)

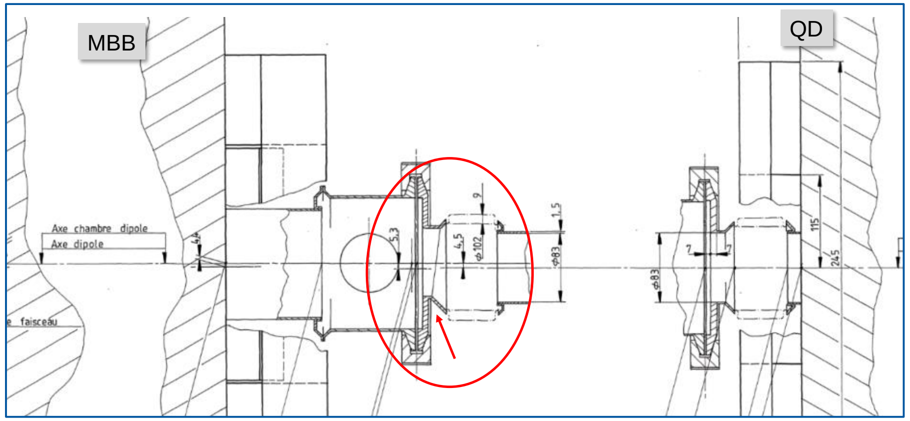


Addressing SPS losses

- **SPS momentum collimation system (EDMS 2242831)**
  - To reduce machine equipment irradiation and activation
  - Proposed baseline system compatible with all SPS beams made of new collimator (5 mm Carbon) upstream of existing TIDP used as absorber
  - Collimation system could become necessary in case off-bucket losses cannot be reduced to tolerable levels, but probably good idea in any case (even 10% losses of LIU beam correspond to 7.5e12 protons lost per cycle)
  - Decision by end 2023 for installation during LS3

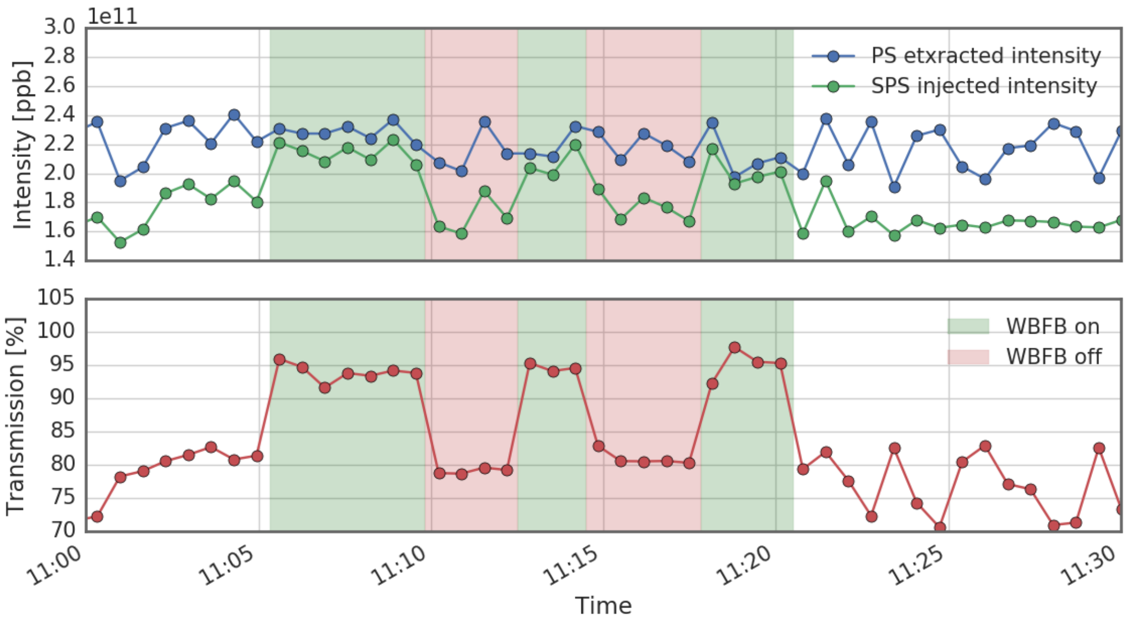


- **Remaining QD aperture improvement**
  - Upgrade of remaining MBB-SSS flanges to rectify design flaw causing aperture restriction for negative dp/p
  - Replacement at 25 selected locations in LS2 already gains 1-sigma aperture and reduces large momentum losses
  - If further aperture restrictions during commissioning of high intensity LIU beams found, can implement new flanges at remaining locations for ~7 kCHF per location (~80 remaining locations)



SPS Wideband feedback system for horizontal plane

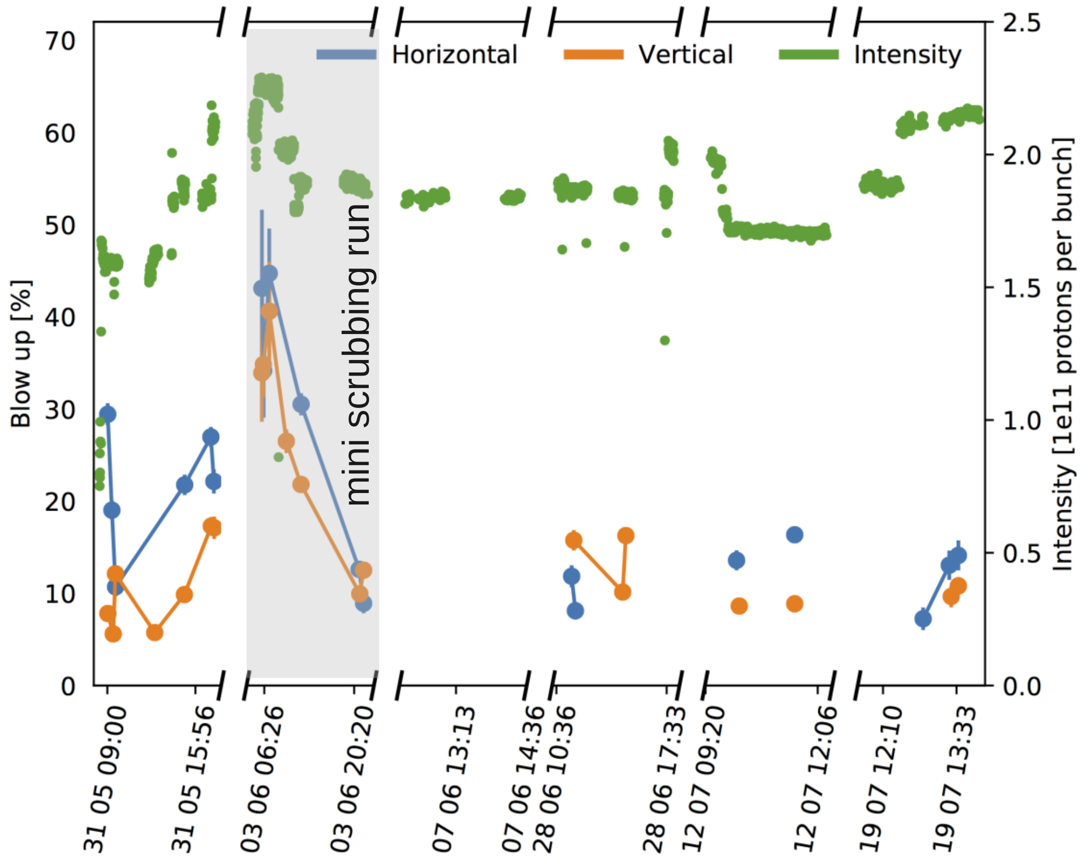
- **Prototype of vertical WBFS deployed at SPS**
  - Proof-of-principle with bandwidth up to 1 GHz
  - Limited in power, with two sets of amplifiers installed on two stripline kickers for a total power of 1 kW and complementary slotline kicker installed in YETS 2017-18
  - TMCI suppression proven experimentally in SPS with Q22



- **Similar system might be needed for horizontal plane**
  - If multi-bunch horizontal instability at injection cannot be suppressed by other means (e.g. existing transverse damper together with high chromaticity and octupoles) or by other mitigations (e.g. impedance reduction)
  - Technology developed for vertical can be transferred to horizontal (but new kickers need to be developed)
  - Decision in 2022/23 if H system is required to be ready for installation during LS3 (cost ~3 MCHF)

SPS e-cloud suppression

- **Original scope of a-C coating all MBB, quad and wide drift chambers was downsized**
  - 2015: After the LIU-SPS scrubbing vs. coating review, it was decided that only a-C coating of one sextant would be retained to demonstrate concept
  - 2018: a-C coating of MBB and wide drift chambers was cut for money saving within LIU (only QF-SSS and new wide drifts are being coated during LS2)
- **Suppression of e-cloud presently relies on scrubbing**
  - Scrubbing effect clearly observed for high intensity in 2018
  - Residual emittance growth + possible contribution to instabilities might persist even after extensive scrubbing
- **Fall-back scenario: a-C coating of all MBB magnets**
  - If beam degradation due to e-cloud persists
  - Decision by 2023/24 for implementation in LS3 (~5 MCHF)



SPS injection kicker MKP-L

- **Kicker heating and outgassing could restrict operation of HL-LHC beams**
  - Concept with longitudinal serigraphy exists (4 and 6 stripes), would benefit kicker heating and longitudinal stability
  - Construction and validation of full-sized low-impedance MKPL scope reduced during 2018 LIU saving exercise to construction and validation of 2-cell prototype
  - Other options: installation of cooling and additional pumping

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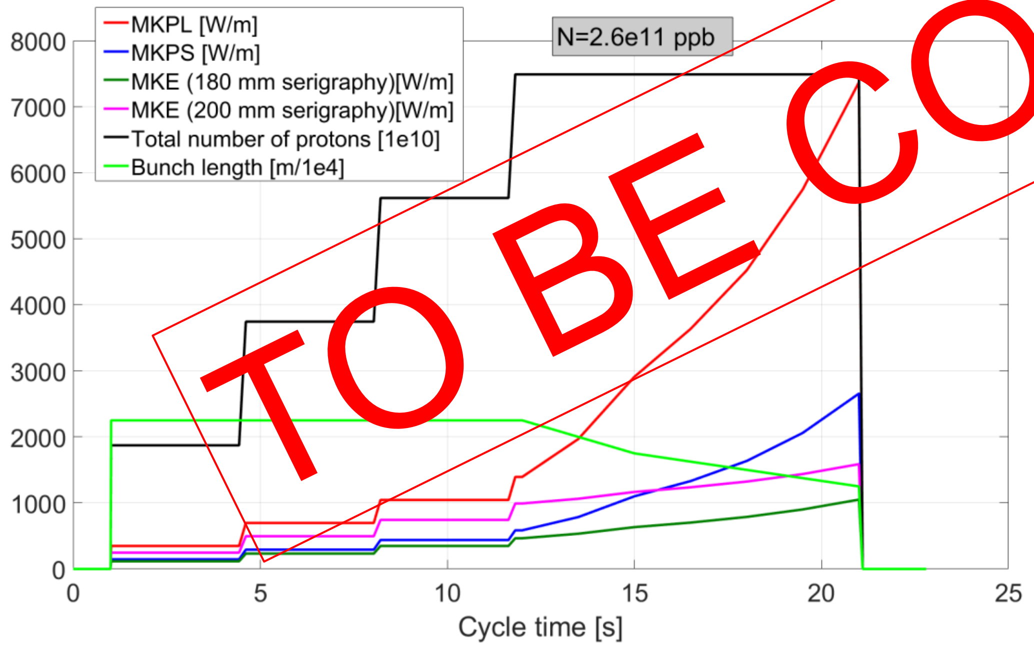
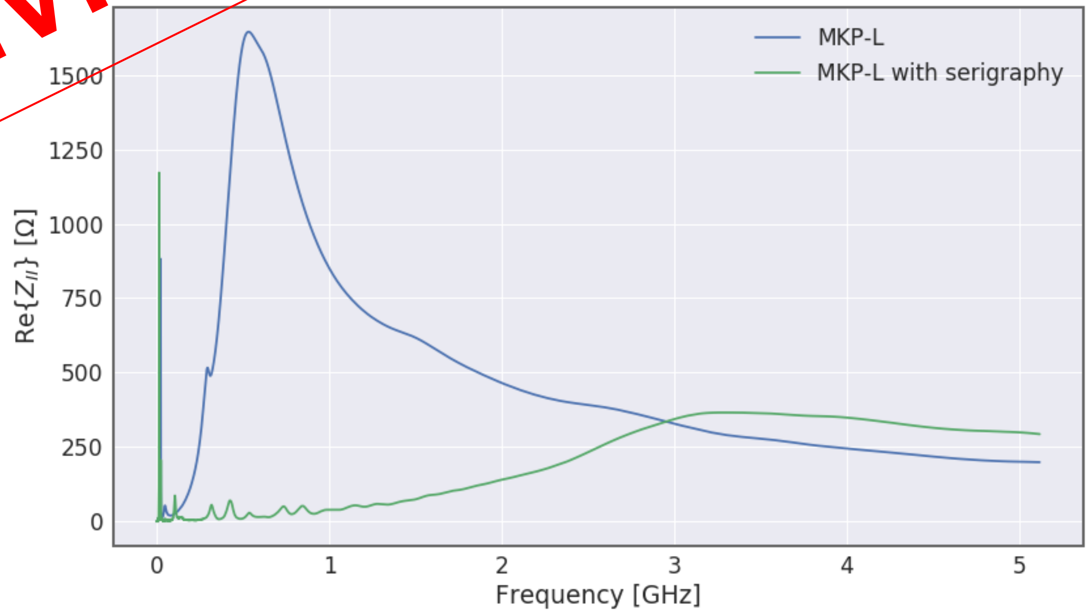
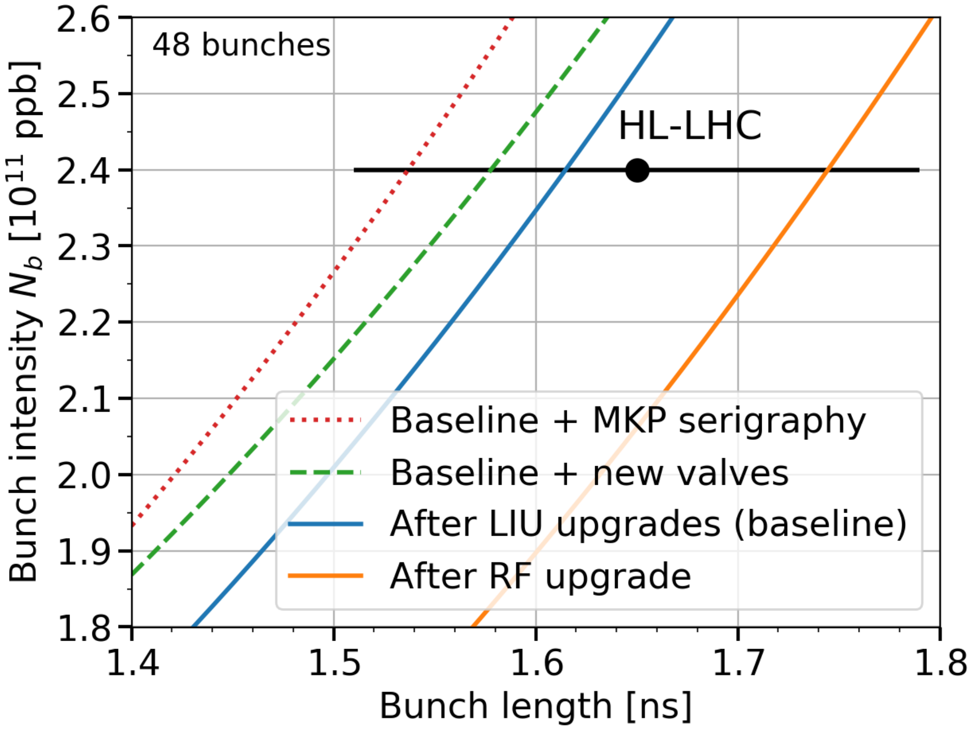




SPS impedance reduction

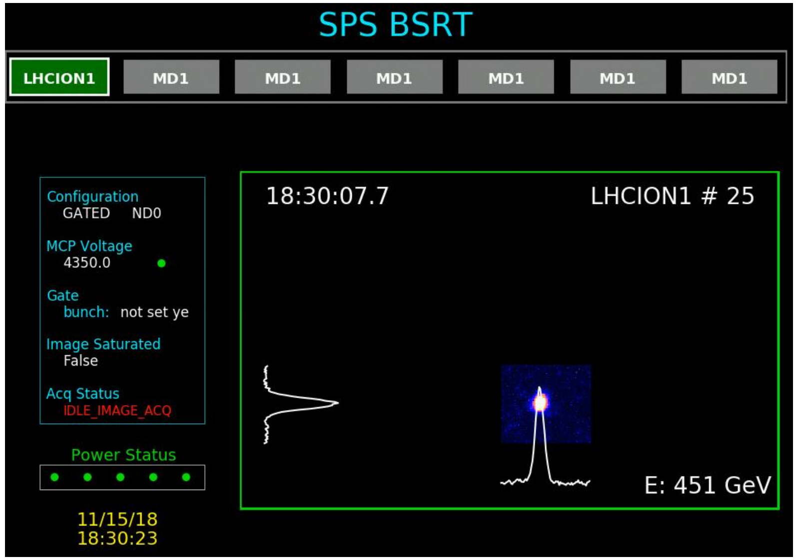
- **SPS longitudinal impedance reduction included in LIU-SPS baseline**
  - Shielding of QF-SSS flanges
  - Damping of HOMs of the 200 MHz cavities by an additional factor 3

- **Other items identified to gain margin in beam stability to accommodate bunch length spread or underestimations of other impedances**
  - **MKP impedance reduction** (also motivated by heating)
  - **Shielding of vacuum valves**: Impedance WG and BE/RF team recommended that all newly installed vacuum valves in SPS be equipped with RF shields (IEFC on 9/12/16 and Engineering Specification in 07/17) + complete retro-fit of existing valves with shielded ones **(~3.5 MCHF)**

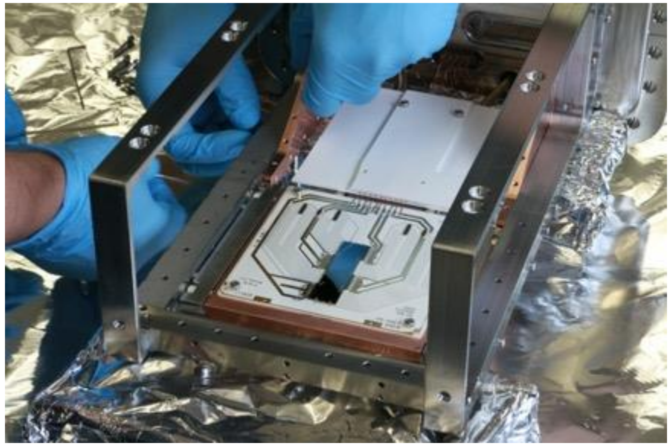


SPS beam instrumentation

- **BSRT**
  - Present BSRT in 521 used for protons and ions at flat top in 2018
  - Only tool to measure transverse emittance of full proton beam (288 bunches) at 450 GeV and possible candidate for transverse BQM
  - New system in 516 desirable because of better H measurement (beta x2, dispersion /5) – preparation made during LS2 (replacement of QF with QFA) and now ready for installation of new system during EYETS22/23 or LS3 (300 kCHF beyond LIU baseline)



- **New SPS BGI based on Timepix3 detector (similar to BGI in PS)**
  - Enhanced performance – would be the only system capable of *bunch by bunch* transverse profile measurements for high intensity LIU beams at SPS top energy
  - Saving of 50 kCHF/year on operation budget (no need for regular replacement of components of existing BGI) and addresses reliance on single US manufacturer for radiation hard cameras
  - Total cost ~360 kCHF – request to CONS has been made by BI starting in 2021

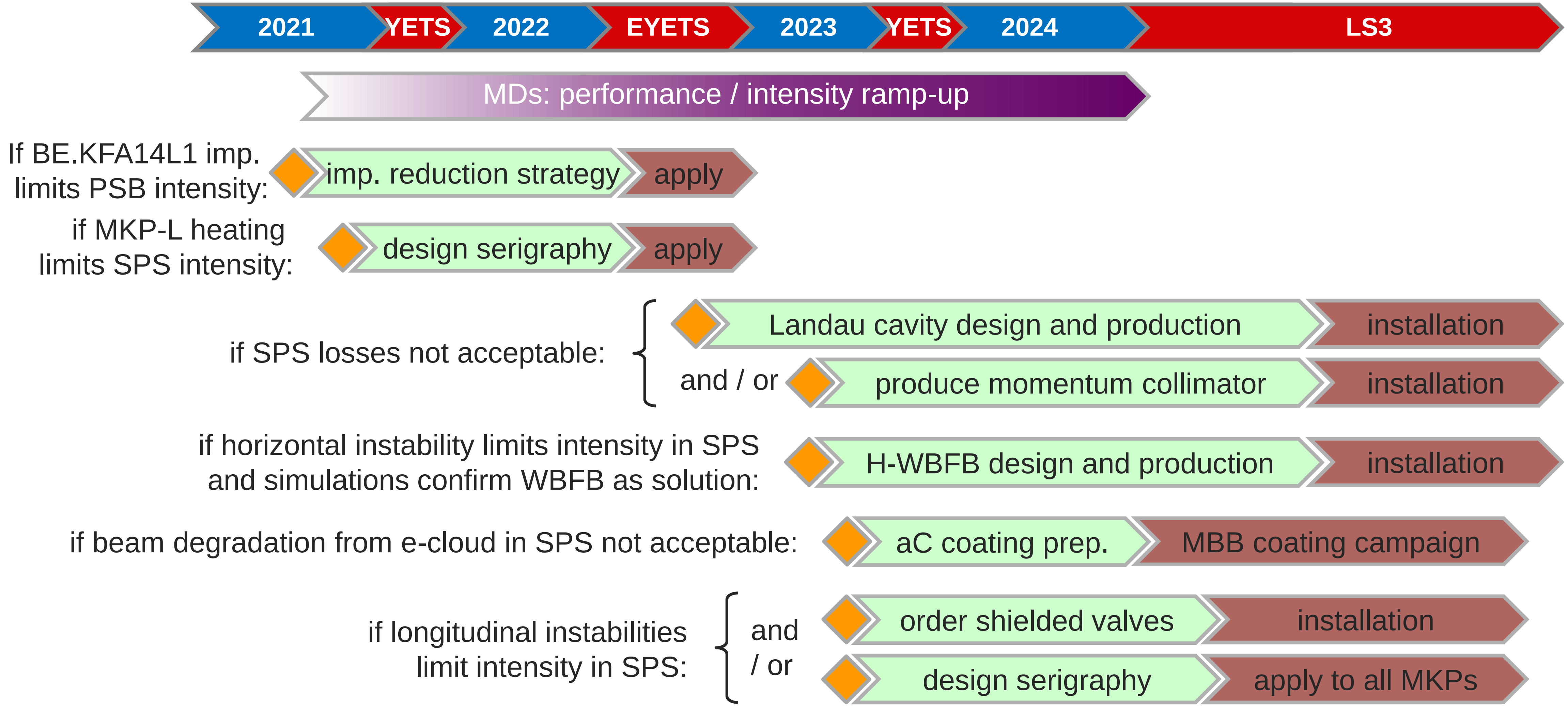


SPS CONS items for LS3

- **Consolidation of existing 200 MHz power amplifiers**
  - Was postponed to add resources to solve SSPA issues (decision taken during 200 MHz upgrade crash program in first half 2018)
  - Descoping detailed in RF memo (by Erk and Eric on 27 March 2018)
  - No impact expected on machine availability or beam parameters during Run 3

- **TCDIL controls renovation**
  - New TCDIL needs a renovation of the control system as part of wider LHC collimator controls CONS
  - ~300 kCHF originally planned for this have been returned to LIU project (item postponed to LS3)

Decision points based on beam observations during Run3



Protons summary table – part I

	Item	Impact	Cost	Decision	Installation
Linac4	Source improvements				
Linac4	RFQ spare		1 MCHF		
Linac4	3 MeV injector upgrade	Improved beam quality and RFQ matching			
Linac4	Linac4 transfer-line supports	Faster and easier alignment	500 kCHF		
Linac4	Additional BSM in LTB line	Better characterization of longitudinal profile	250 kCHF		
PSB	BE.KFA14L1 impedance reduction	Suppression of horizontal instabilities	100 kCHF	2021	EYETS 22/23
PSB	Power supplies for CODs	Improved closed orbit correction and losses	700 kCHF		3 y lead time
PS	Landau cavity	SPS loss reduction	4 MCHF	end 2022	LS3
PS	Final stage of 40/80 MHz amplifiers	Improved bunch-by-bunch equality	350 kCHF	2021	YETS 21/22
PS	Fast ferrite tuner for 2nd 80 MHz cavity	PPM operation of protons and ions	100 kCHF	2021	EYETS 22/23
PS	10 MHz solid state feedback amplfs.	Improved bunch-by-bunch equality	600 kCHF		
PS	Multi-harmonic feedback for 10 MHz	Improved bunch-by-bunch equality			

Protons summary table – part II

SPS

Item	Impact	Cost	Decision	Installation
a-C coating of all MBBs and quads	e-cloud suppression (emittance blow-up)	5 MCHF	end 2023	LS3
Impedance reduction MKP	Reduced heating + improved beam stability		2023/24	LS3
Impedance reduction flanges & valves				
HOMs damping + FMC matching				
Wideband feedback system for H	Increased H instability threshold	>2 MCHF	mid 2023	LS3
Momentum collimation system	Coping with losses and machine activation		end 2023	LS3
Remaining QD aperture improvement	Increased momentum acceptance	80 kCHF	2023/24	LS3
Final BSRT	Improved emittance measurements	300 kCHF	2021	EYETS 22/23
New BGI	Emittance measurement throughout cycle	360 kCHF		
200 MHz (CONS)	Increase of RF power			LS3
TCDIL controls renovation (CONS)	Availability, standardisation, maintainability	300 kCHF		LS3

Ions summary table

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Summary and conclusions

- **Bullet point**
  - Another bullet point

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Charges

- **Decision trees for post-LIU upgrade options and associated cost estimates**
  - To correct “failure scenarios” or nonconformities causing underperformance or low reliability?
  - Include Linac4 (e.g. source developments for higher current, RFQ strategy, reliability improving upgrades?)
  - Include the benefit from other items dropped from LIU (or downsized), like the PSB orbit correctors, PS RF upgrades (amplifiers for 40/80 MHz cavities, additional ferrite tuner)
- **Strategy during Run 3 to follow-up the need for additional upgrades during ramp up phase (and beyond) – assess necessity, endorse, finance, execute**
  - How much MD time needed in Run 3 for the ramp up and to identify showstoppers (Thursday long parallel MD slots and impact on the possible reduction wrt 2018)

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Additional Linac4 upgrade options

- **3 MeV injector upgrade**
  - New more compact LEBT design (beneficial for the beam quality and RFQ matching) – to be studied at the test-stand
  - Spare RFQ – cost of a new RFQ is ~1 MCHF. This RFQ will have to be operated at the test stand first (cooling station, RF power, diagnostic bench….)
  - New MEBT design: Findings on the chopper dump could lead to a different dump design and a different MEBT design
- **Upgrade the Linac4 transfer-line supports**
  - Request from survey team to speed-up and ease the alignment process
  - Would mean a total disassembly of the line and installation on girders
  - Cost ~500 kCHF (20 supports with beams and alignment jacks)
- **Second debuncher cavity**
  - For maximum flexibility of delivering a painted, variable energy spread beam
- **Additional beam instrumentation**
  - Adding a beam current transformer just before the RFQ to better assess transmission in the LEBT
  - Adding extra BSM in LTB transfer-line for better characterization of the longitudinal profile close to PSB (~250 kCHF)

Decision points based on beam observations during Run3