



Future and Upgrades

Klaus Hanke



Outline

- Pre-LS2 Performance
- Pre-LS2 Limitations
- Overcoming the Limitations:
Upgrade & Consolidation

Pre-LS2 Performance

Fixed-target physics beams:

- main users nTOF, EAST, SPS North Area beams, and others
- routinely delivered with highest availability and performance

LHC-type beams:

- zoo of flavors (PILOT and PROBE beams, individual bunch physics beam, 25 ns spacing, 50 ns spacing, 100 ns spacing, BCMS*, ...)
- available on request with highest availability and exceeding today's specifications

* Batch Compression, Merging and Splitting



Standard 25 ns Spacing Beam

The PSB receives two consecutive injections from Linac2, one filling all four rings with one bunch each ($h=1$) and a second injection filling only two of the four rings. With this scheme the PSB produces six bunches at 1.4 GeV energy, which are transferred in two extractions (4 + 2 bunches) to the PS.

In the PS the beam is accelerated to a top energy of 26 GeV and at the same time the bunches are longitudinally split. This scheme employs consecutively the RF harmonics 21, 42 and 84, which leads to a 12-fold splitting of each bunch. The resulting number of bunches produced from the six bunches coming from the PSB is hence 72.

U 25 ns Beam: RF Manipulations in the PS

from PSB:

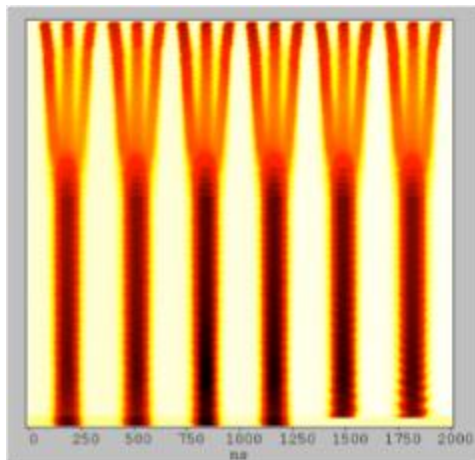
1.4 GeV

$\tau_l = 183$ ns

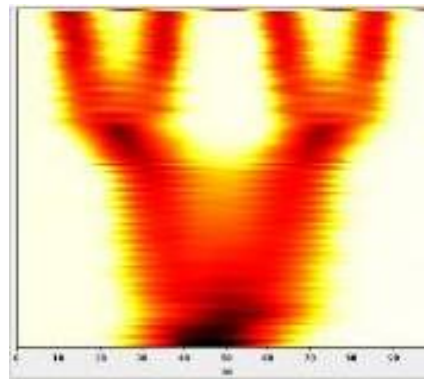
$\varepsilon_l = 1.27$ eVs

$N_b = 16.5 \times 10^{11}$

bunches: 6



RF harmonics @ 2.5 GeV:
7 - 14 - 21



RF harmonics @ 26 GeV:
21 - 42 - 84

extracted to SPS:

26 GeV

$\varepsilon_l = 0.35$ eVs

$N_b = 1.3 \times 10^{11}$

split factor: 12

bunches: 72



Main Limitations for LHC Type Beams

Brightness limit delivered by the PSB

- transverse emittance depends linearly on the intensity

Space charge on the PS flat bottom

- large tune spread, limited by resonances
- need to keep bunch intensity low to preserve brightness

Longitudinal emittance at PS extraction

- keep losses in the SPS under control; longitudinal stability

LIU Upgrade

Today the injector complex provides LHC beams well within (and beyond!) the original specifications

The **High-Luminosity LHC Project** requests beams with parameters out of today's reach

The **LHC Injectors Upgrade (LIU) project** has been put in place to enable the injector complex to deliver the requested high-brightness beams

The LIU project consists of the following building blocks:

Linac4:

- higher energy reduces space charge effects at PSB injection
- H^- stripping injection is essentially loss free and allows to tailor beam emittance

PSB:

- energy upgrade from 1.4 GeV to 2.0 GeV reduces space charge effects at PS injection
- numerous other upgrade items (power supplies, RF, instrumentation, ...)

PS:

- increase of the injection energy to 2.0 GeV
- numerous other upgrade items (power supplies, RF, instrumentation, ...)

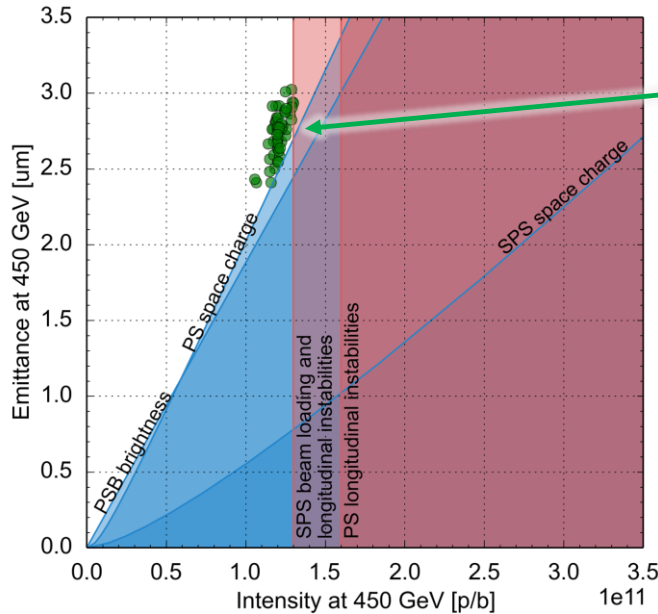
SPS:

- numerous other upgrade items (coating, RF, instrumentation, ...)



Pre-LS2 Performance Limitations

LHC beam parameters at the SPS extraction (450 GeV) resulting from intensity and brightness limitations of all injectors in the chain



Measured points:
 $N_b = 1.1 - 1.3 \times 10^{11}$ p/b
 $\epsilon_{x,y} = 2.5 - 3.0 \mu\text{m}$

PSB

- brightness (multi-turn injection with Linac2)
- space charge at injection

PS

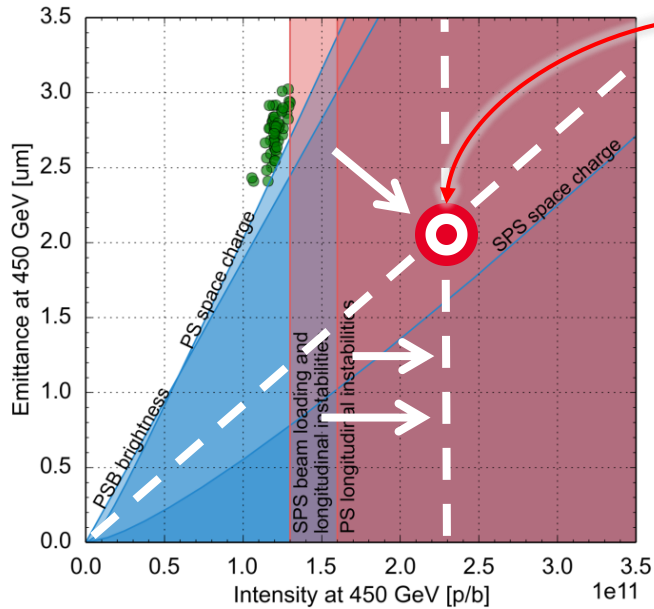
- brightness limited by space charge at injection
- intensity limited by longitudinal coupled bunch instability on the ramp and flat top

SPS

- beam loading and longitudinal instabilities on the ramp and flat top



Overcoming the Limitations



	N_b ($\times 10^{11}$ p/b)	$e_{x,y}$ (mm)
HL-LHC target	2.3	2.1
before upgrade	1.3	2.7

PSB

- brightness: H- injection with new Linac4
- space charge at injection: increased injection energy

PS

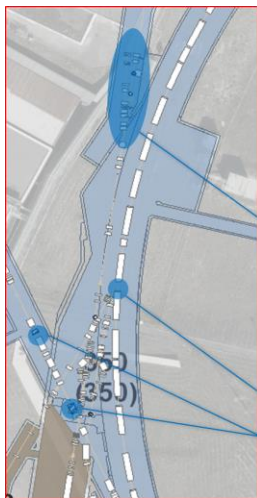
- brightness: increased injection energy
- intensity: RF upgrades, impedance reduction, ...

SPS

- beam loading and longitudinal instabilities on the ramp and flat top: RF upgrades, a-C coating, impedance reduction, ...

PS Upgrades

plus surface buildings, transfer lines, (de-)cabling...



- New internal beam dumps (SS47 and SS48)

New injection septum + bumper SMH42:

- New SEMGrid (MU42)
- New bumper (SS42)

- Replace injection extra kicker (KFA45)

- New injection bumpers (40, 41, 43, 44)

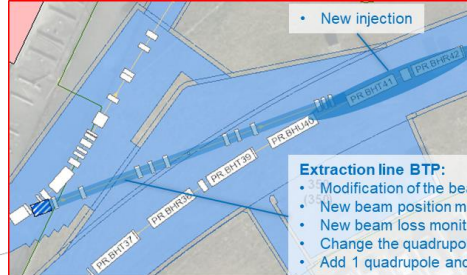
- Upgrade the emittance measurement line LBE
- Upgrade and consolidation of the spectrometer measurement line LBS
- Remove beam stopper on the PSB injection line BI

- New beam loss monitors
- Remove beam stopper on LTB line

- Remove orbit correction quadrupoles (SS25)

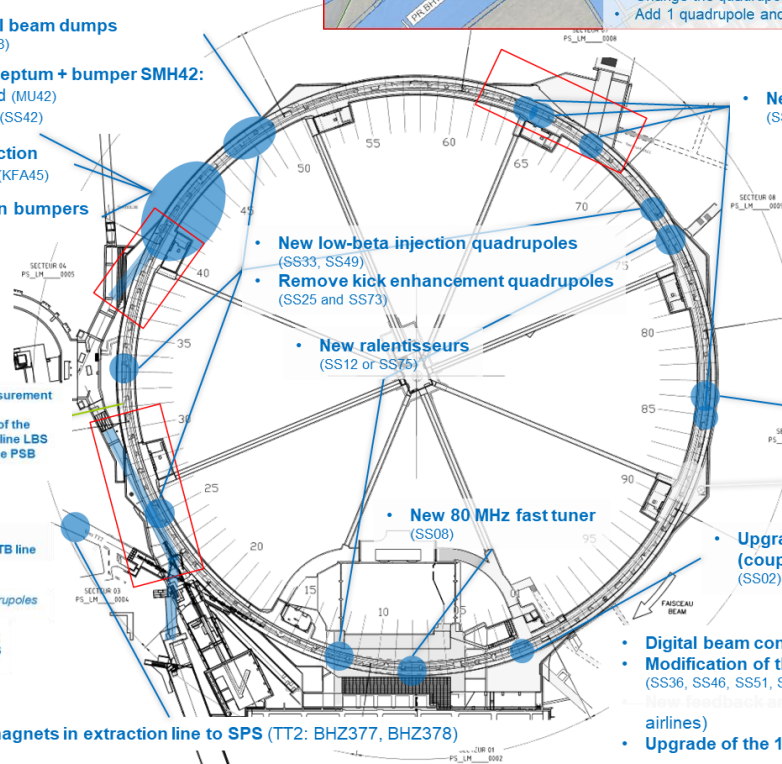
- Upgrade the beam stoppers on the extraction line to SPS (TT2: F16.STP152, F16.STP176)

- Replace 2 magnets in extraction line to SPS (TT2: BHZ377, BHZ378)



Extraction line BTP:

- Modification of the beam instrumentations
- New beam position monitor
- New beam loss monitors
- Change the quadrupoles
- Add 1 quadrupole and 1 BCT



- New low-beta injection quadrupoles (SS33, SS49)
- Remove kick enhancement quadrupoles (SS25 and SS73)

- New ralentisseurs (SS12 or SS75)

- New 80 MHz fast tuner (SS08)

- New beam wire scanners (SS64, SS65, SS68, SS85)

- New vertical beam gas ionization profile monitor (SS84)

- New 80 MHz fast tuner (SS08 and SS09)

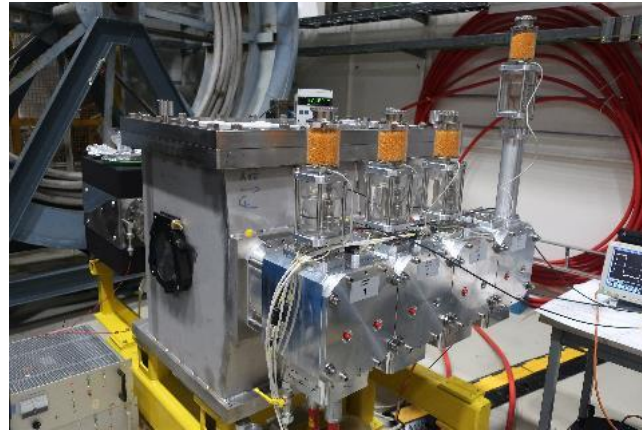
- Upgrade of Finemet RF system (coupled-bunch feedback) (SS02)

- Digital beam control
- Modification of the 10 MHz water cooling circuit (SS36, SS46, SS51, SS56, SS66, SS76, SS81, SS86, SS91, SS96)
- New particle monitors for the 40/50 MHz (fast coaxial airlines)
- Upgrade of the 10 MHz feedback amplifiers

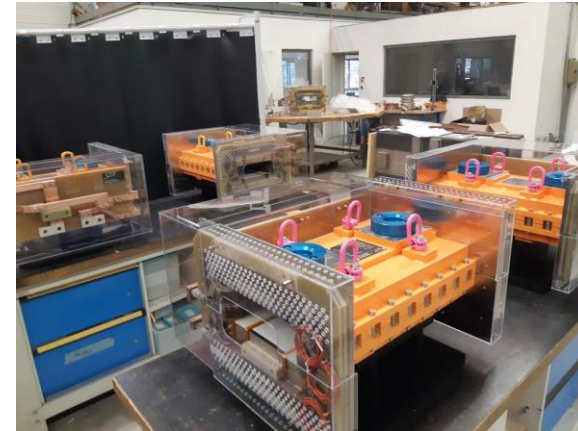
PS new 2 GeV Injection



2 GeV injection septum



new injection kicker



new injection bumpers

PS RF Upgrades



10 MHz feedback amplifiers



80 MHz fast tuner



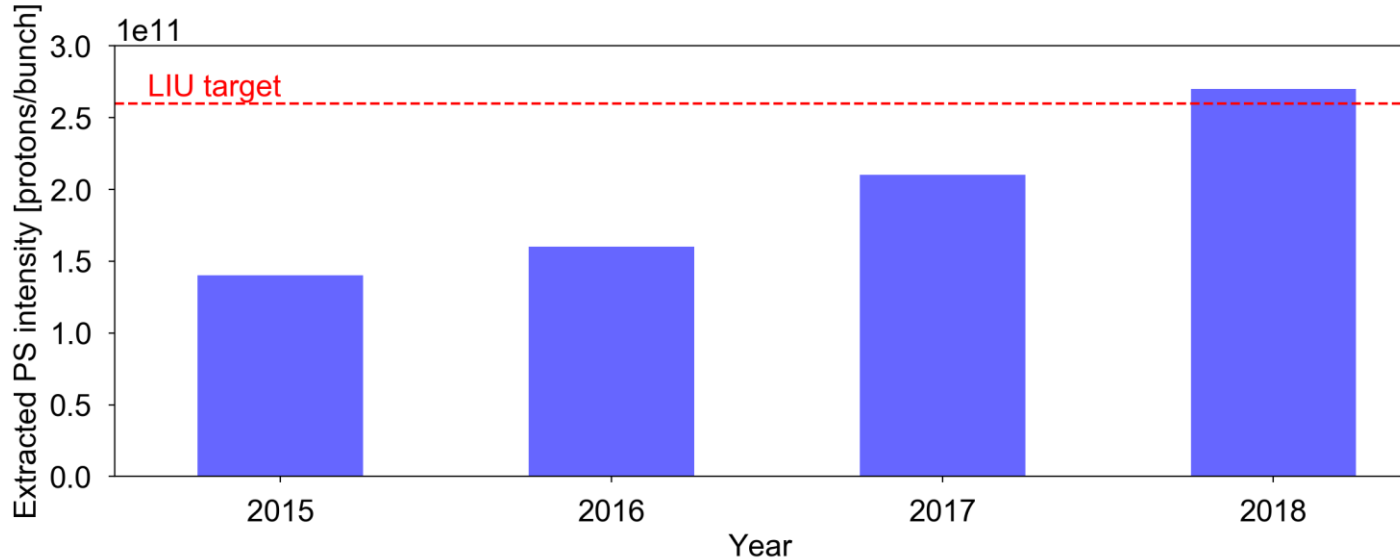
transverse damper amplifiers



wideband Finemet cavity



PS Intensity Reach



commissioning of coupled bunch feedback with broadband cavity and operational optimization

new power converters for 40/80 MHz and broadband cavities + multi-harmonic feedbacks and 40 MHz as Landau system + transverse optimisation

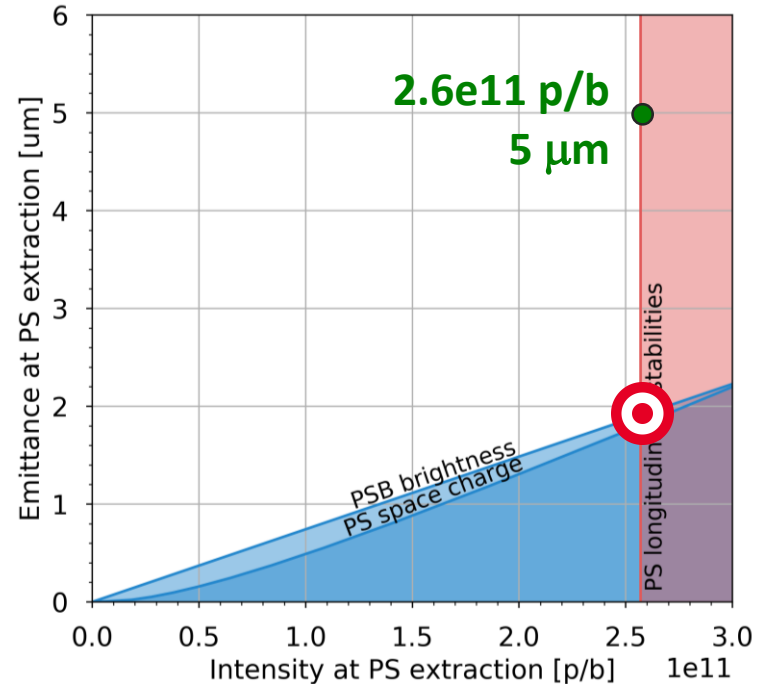


PS Intensity Reach vs Brightness

Broadband cavity to act as kicker for longitudinal feedback system in PS was studied during Run 1 and installed during LS1 (2013-14)

Thanks to operational deployment + further RF improvements, the LIU target intensity at PS extraction has been achieved

- LIU brightness only available after LS2 with Linac4 and 2 GeV PSB
- margin is slim, need to deploy other means if lower longitudinal emittance or higher intensity required to cope with SPS injection losses



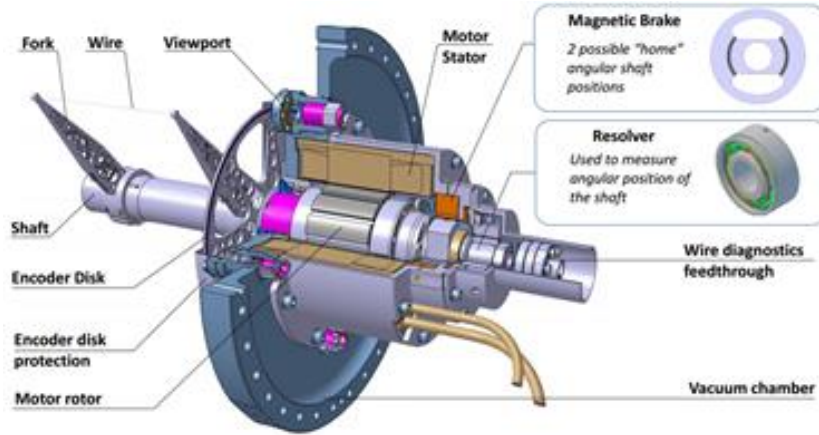


How to measure bright Beams?

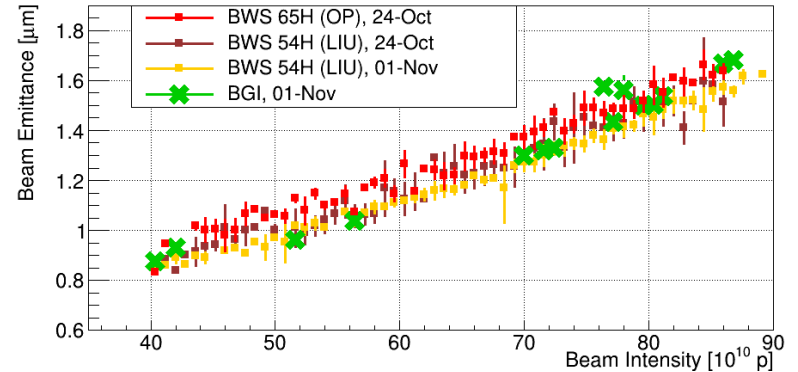
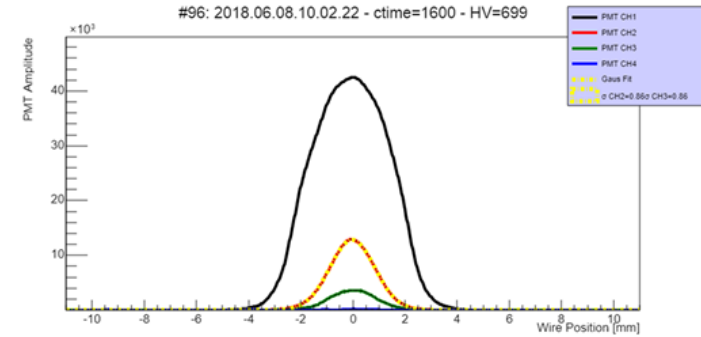
- new challenges for the precision of instruments
- turn-by-turn measurement gives indication of injection mismatch
- if possible non-destructive...



New Wire Scanners

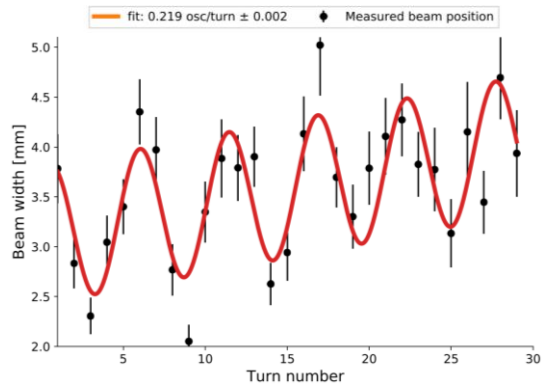
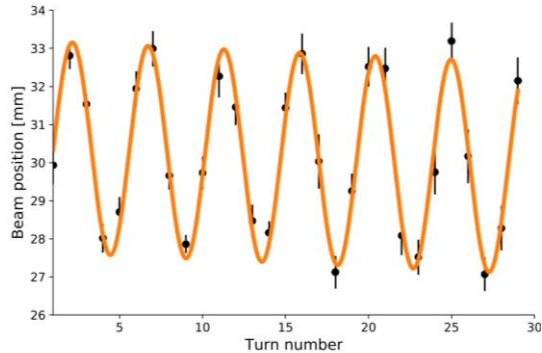


new generation of wire scanners

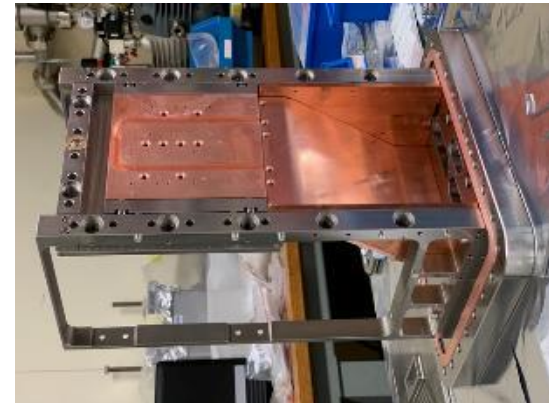




New Beam Gas Ionisation Monitor



horizontal monitor
deployed (left),
vertical monitor
under construction
(right)

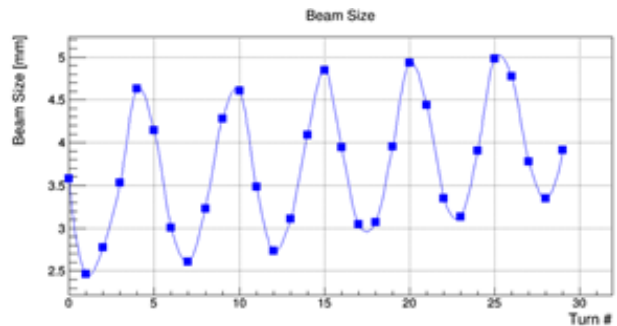
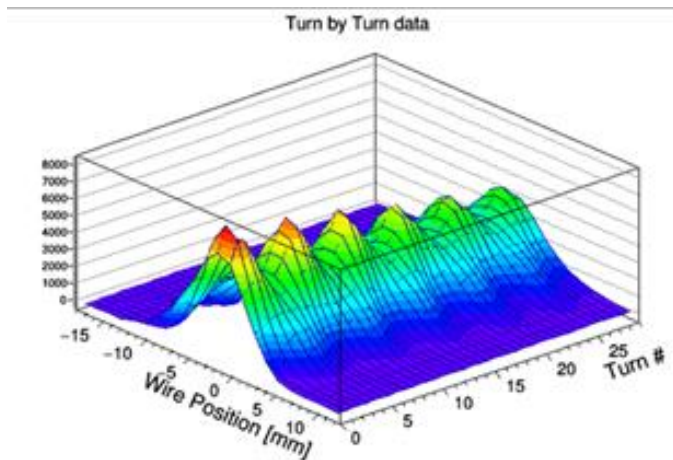




New Turn-by-Turn Profile Monitor

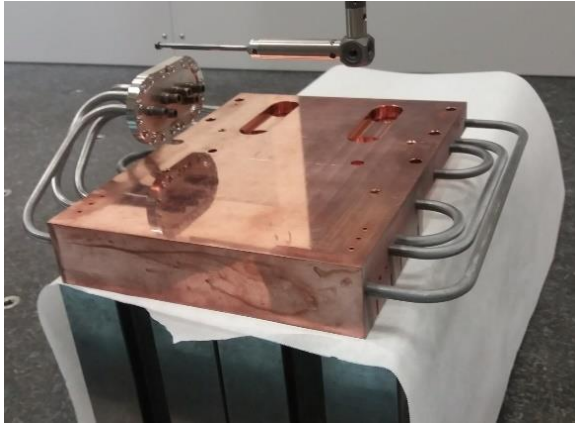
SEM grid at injection equipped with dedicated electronics for turn-by-turn read-out

used for matching studies pre-LS2

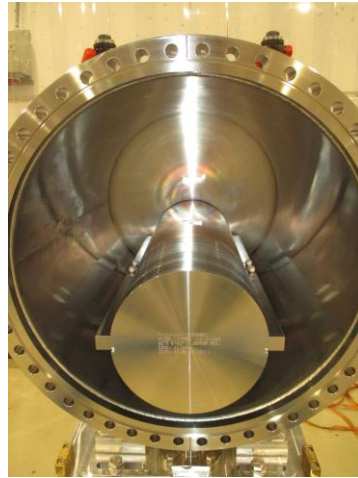


Beam Intercepting Devices

Bright beams = new challenges!



PS Dump Core



PS Beam stoppers



PS "Ralentisseur"



Consolidation & Maintenance





Consolidation: Magnets

- the PS is running today still with the original magnets!
- several refurbishment campaigns

Number of PS Main Units:

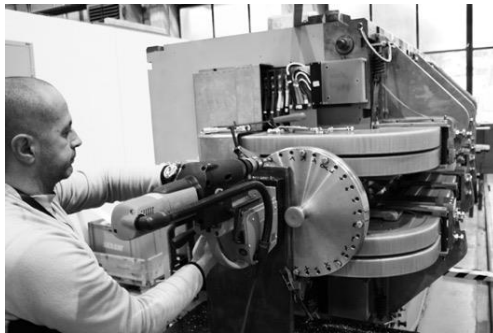
Ring:	100
Reference:	1
Spares:	4
Measurement:	1 (w/o PFW)
—	
Total	106



2005-06	2006-07	2007-08	2008-09	2013	2019
26	8	8	9	7	43

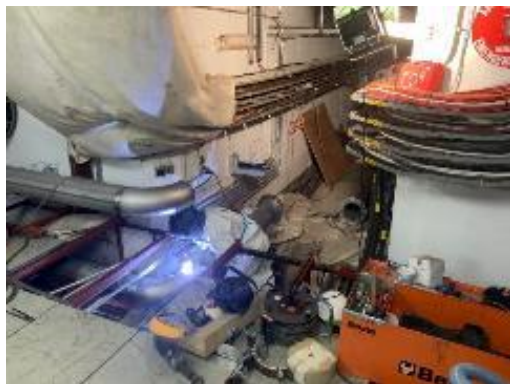


PS Main Unit Refurbishment



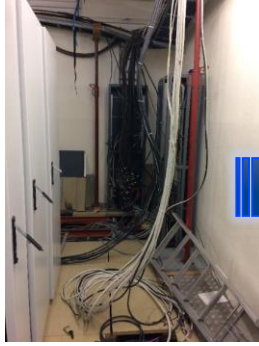


Consolidation: Cooling & Ventilation



Cabling and De-Cabling

~ **63 000 cables** installed in the PS Ring and service buildings 1959 – 2019
220 km of obsolete cables removed during YETS and LS2



installation of 1400 new cables (110 km) for LIU ongoing

CHECKED			CABLE SCHEDULE		REFERS TO CABLE DIAGRAM :
NO.	DATE	SIGN.	DATE	SIGN.	SHEETS / SHEET
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Kubricino (Fast Section)

CERN-PS GENEVE
GENERAL + temporary experiments





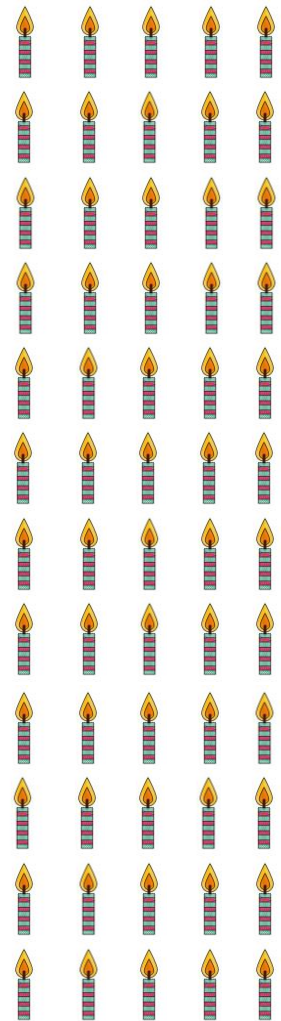
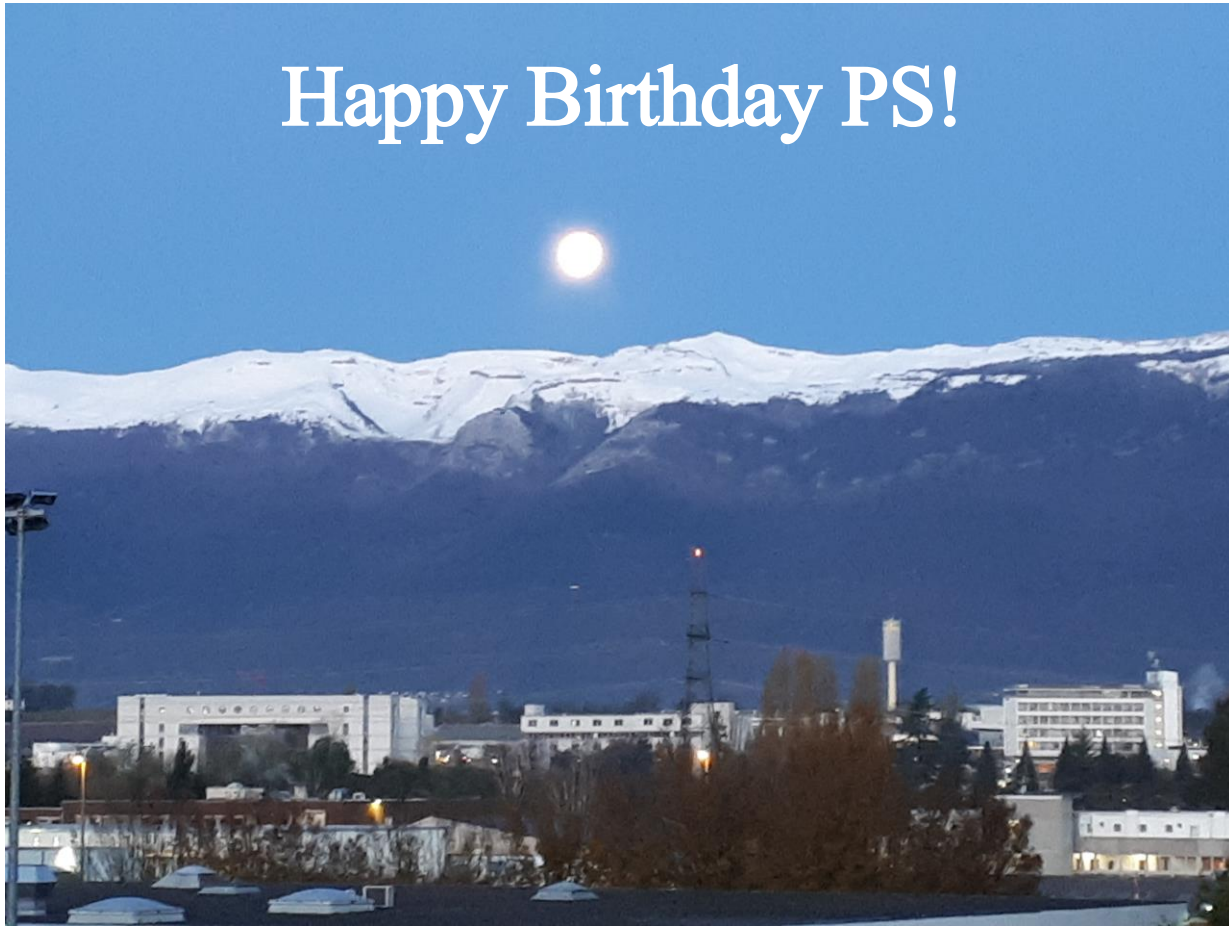
Post LS2

- Review November 2019: “LIU is considered completed”
- Every end is also a beginning...
- Interesting commissioning phase ahead of us
- Progressively ramping up the performance during run 3 and taking our machines into a new parameter regime





Happy Birthday PS!





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