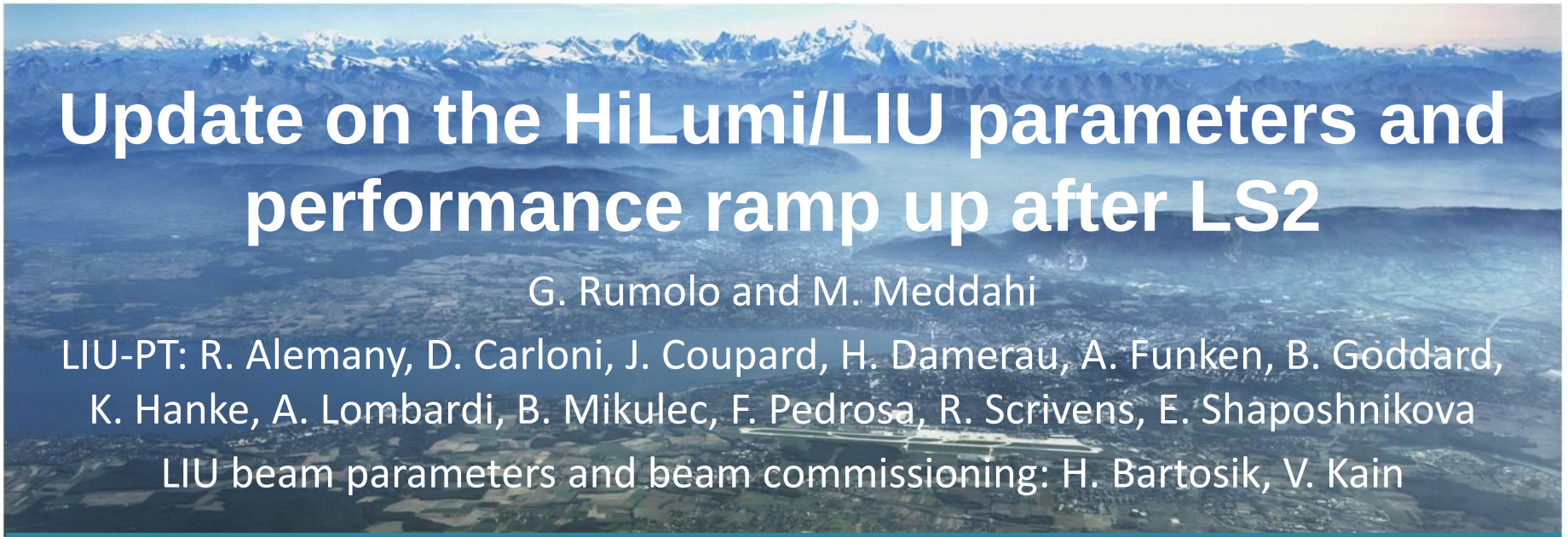


LHC Injectors Upgrade

Update on the HiLumi/LIU parameters and performance ramp up after LS2

G. Rumolo and M. Meddahi

LIU-PT: R. Alemany, D. Carloni, J. Coupard, H. Damerau, A. Funken, B. Goddard, K. Hanke, A. Lombardi, B. Mikulec, F. Pedrosa, R. Scrivens, E. Shaposhnikova

LIU beam parameters and beam commissioning: H. Bartosik, V. Kain

Outline:

- Recap of LIU baseline
- Proton and Pb ion beam parameters
  - Targets and present status
- Post-LS2 beam commissioning milestones

Present LIU baseline I (main items)

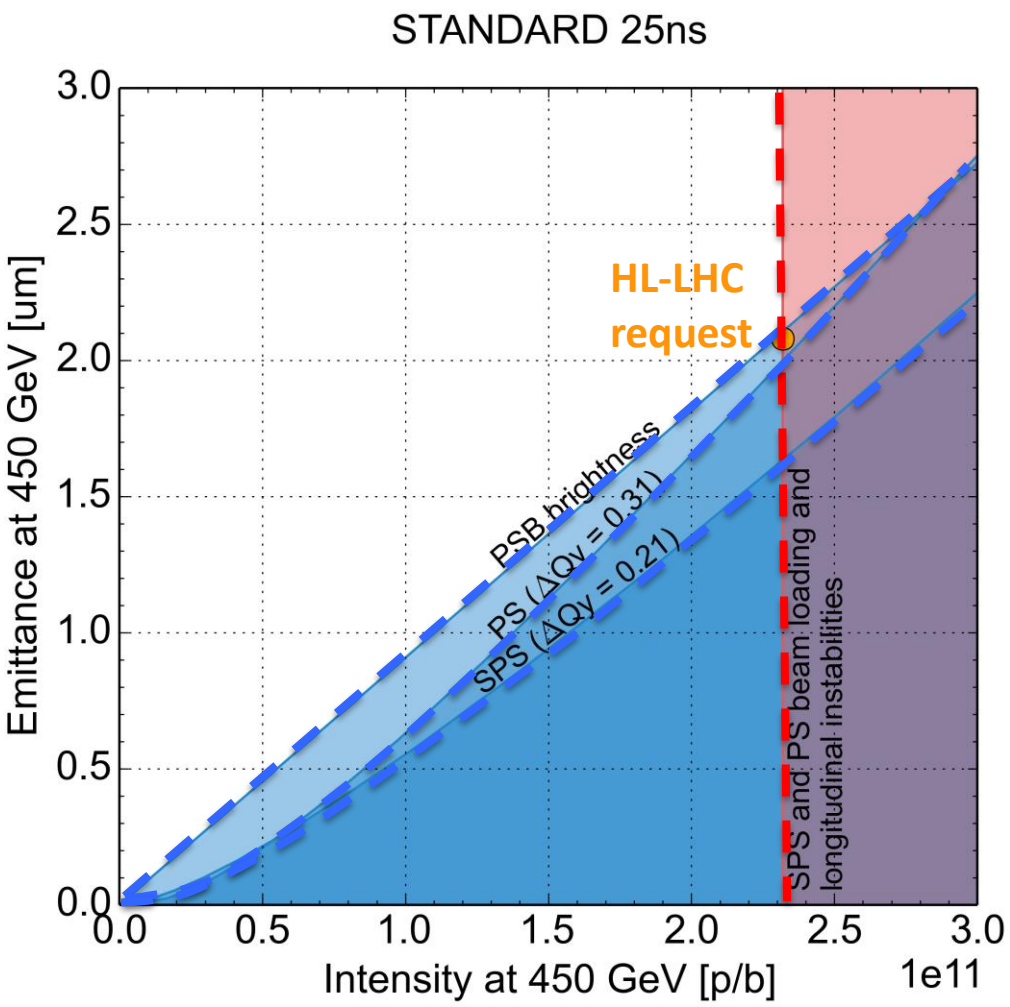
- **PSB**
  - Connection to Linac4 → New H^- charge exchange injection at 160 MeV from Linac4 to double brightness of LHC beams
  - Acceleration to 2 GeV
    - New main power supply POPS-B
    - Replacement of C02-C04-C16 RF systems by Finemet based RF system
- **Linac3 + LEIR**
  - Source and LEBT improvements to increase current from Linac3 and improve reproducibility
  - Intensive studies on LEIR modeling and monitoring to increase transmission
  - 100 ms injection rate into LEIR to accumulate larger current

Present LIU baseline II (main items)

- **PS**
  - New injection at 2 GeV for protons to mitigate space charge
  - RF improvements to improve beam quality and increase longitudinal coupled bunch instability threshold
    - Impedance reduction of the RF systems
    - Installation of new Finemet RF system as longitudinal feedback
  - Operational deployment of transverse feedback system

- **SPS**
  - 200 MHz RF system upgrade
    - Power upgrade and rearrangement of cavities
    - New LLRF including slip stacking capability
  - Electron cloud mitigation and impedance reduction to increase intensity reach
    - a-C coating of QFs + one full arc
    - QF-type flange shielding and HOM damping in 200 MHz cavities
  - New beam dump system in LSS5 and new design of protection devices to comply with the target HL-LHC beam parameter values

LIU performance reach for protons



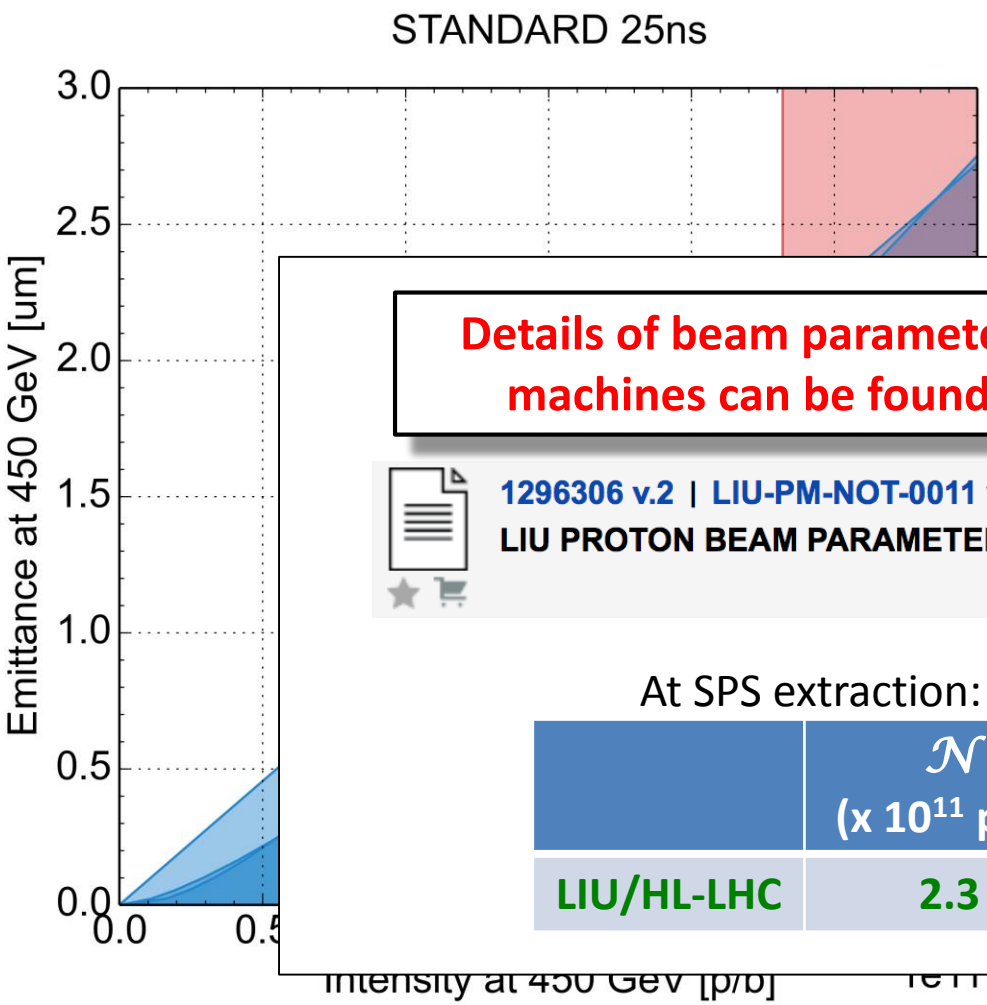
- Beam loss and emittance blow up budgets

budget	PS	SPS
losses	5%	10%
blow-up	5%	10%

- **PSB brightness** + **intensity limitations in PS and SPS** inferred from simulations
- **Space charge limitation curves in PS and SPS** based on assumed tune spreads and optimised beam parameters at transfers

	PS	SPS
$\Delta Q_{V,\,max}$	0.31	0.21

LIU performance reach for protons



- Beam loss and emittance blow up budgets

budget	PS	SPS
losses	5%	10%
		10%

Details of beam parameters at injection in all machines can be found in this document

1296306 v.2 | LIU-PM-NOT-0011 v.2 — Released — Public access

LIU PROTON BEAM PARAMETERS — *by Giovanni Rumolo*

At SPS extraction:

	$\mathcal{N}$ (x 10^{11} p/b)	ε (μm)
LIU/HL-LHC	2.3	2.1

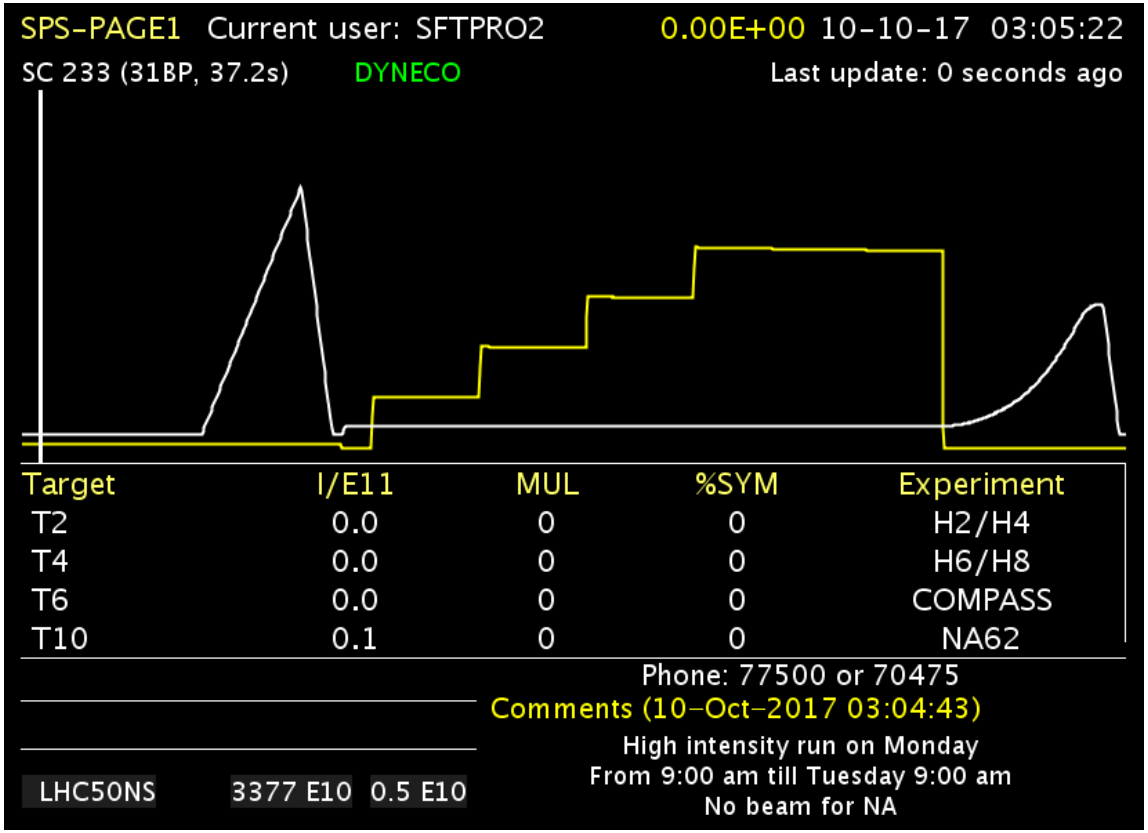
sity
PS inferred

h curves in
ssumed
sed beam

		SPS
$\Delta Q_{V,\,max}$	0.31	0.21

Where we are standing (protons)

- **Intensity limitation: experience from high intensity run 2017**
  - **2e11 p/b injected into SPS** in trains of 48 and 72 bunches (BCMS and standard) and kept along a long energy plateau at 26 GeV/c



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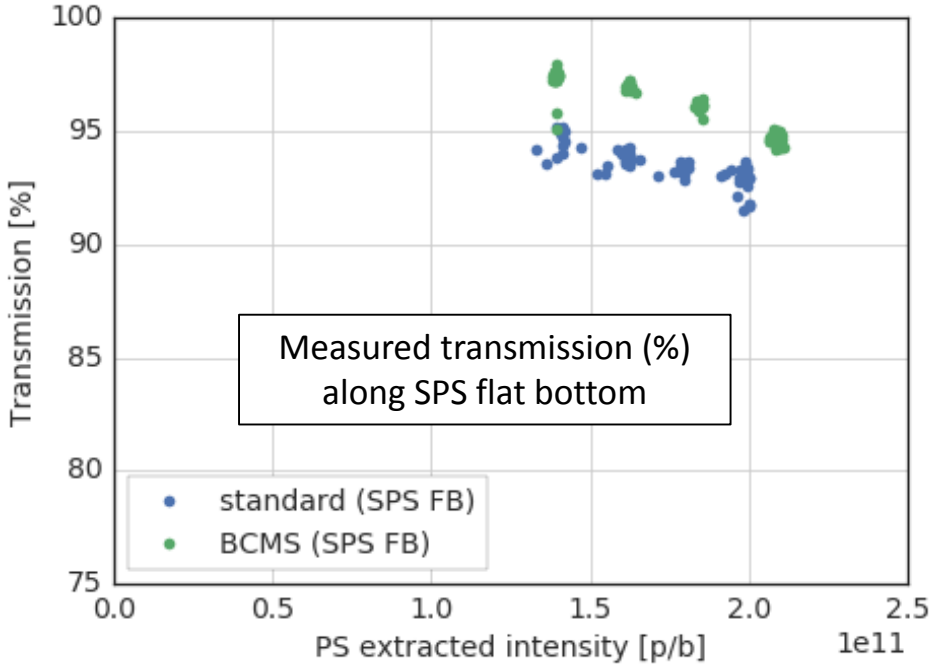
    - No important e-cloud signs in SPS, coupled bunch instability observed in 2015 not an issue
    - SPS losses at 26 GeV/c increase with intensity, but also with transverse emittance



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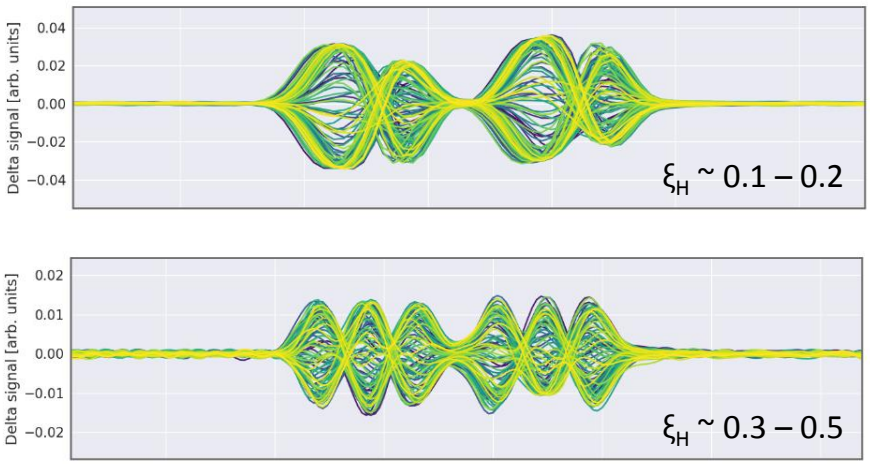
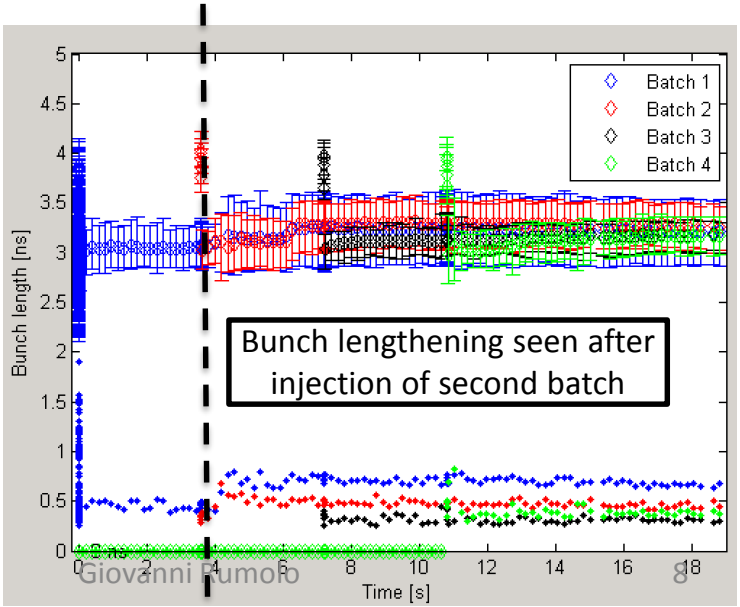
    - No important e-cloud signs in SPS, coupled bunch instability observed in 2015 not an issue
    - SPS losses at 26 GeV/c increase with intensity, but also with transverse emittance
  - Still quite some work to do:
    - Even with fully deployed longitudinal feedback, PS cannot provide higher intensity
    - Transverse single bunch and longitudinal instabilities in SPS

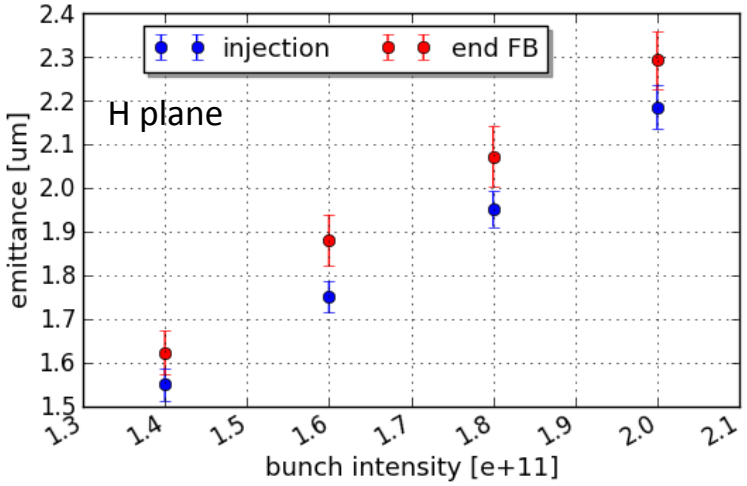
Measured horizontal intra-bunch oscillations

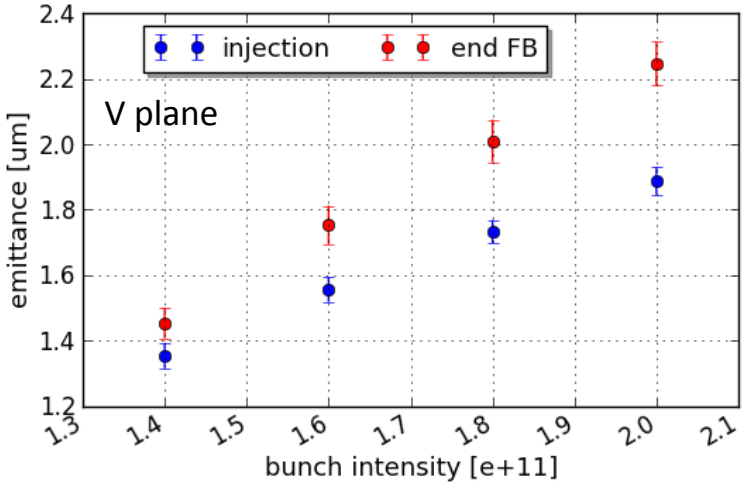




Where we are standing (protons)

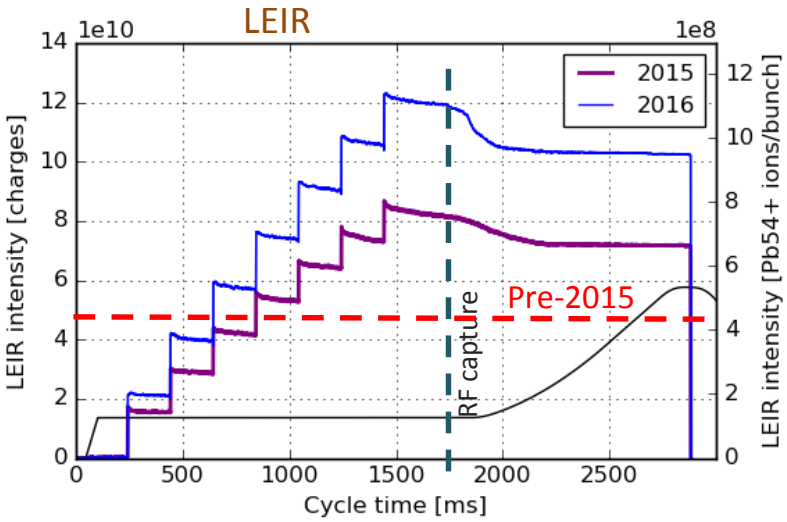
- **Brightness limitation: experience from 2017**
  - Emittance blow up **at PSB-PS transfer** intensively under study
    - Observed also on operational beams
    - No benefit observed when transferring large longitudinal emittances
    - Many potential contributors (mismatch, injection scheme, space charge, accuracy of measurements)
  - Emittance blow up **in the SPS**
    - Increasing with increasing intensity in the vertical plane
    - Mechanism to be understood

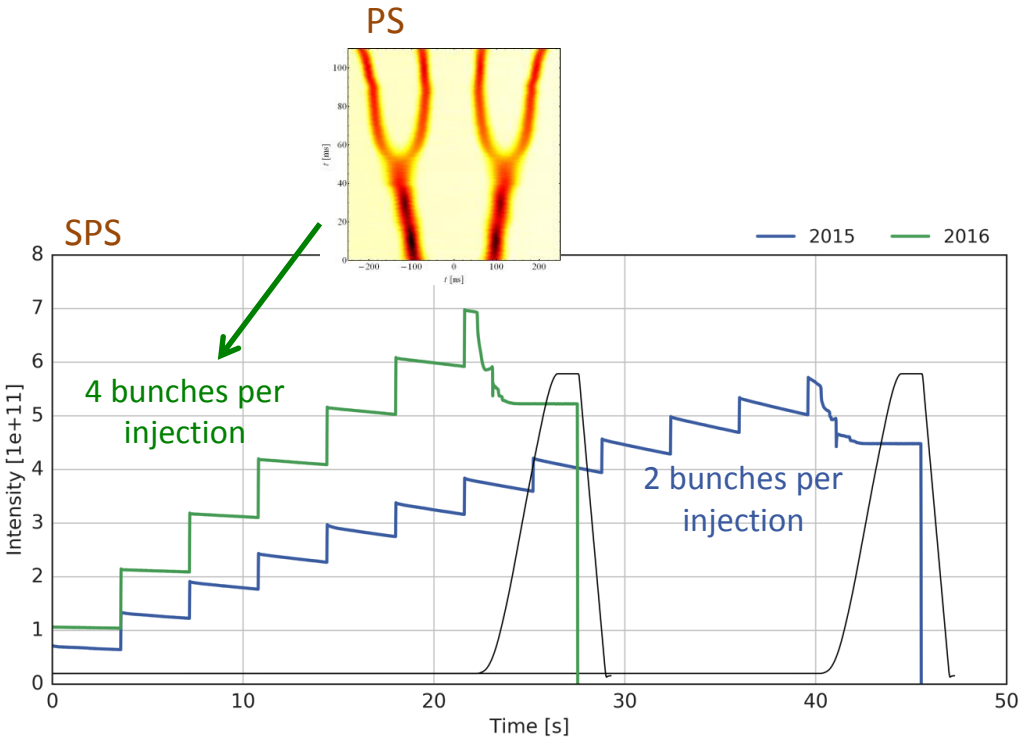




LIU performance reach for Pb ions

- **Intensive study program in 2015-2016 across injector chain**
  - Performance in 2015 was already outstanding thanks to improved LEIR performance
  - Performance in 2016 was pushed even further thanks to improvements in source + Linac3, continued LEIR studies, bunch splitting in PS, 7 injections in SPS





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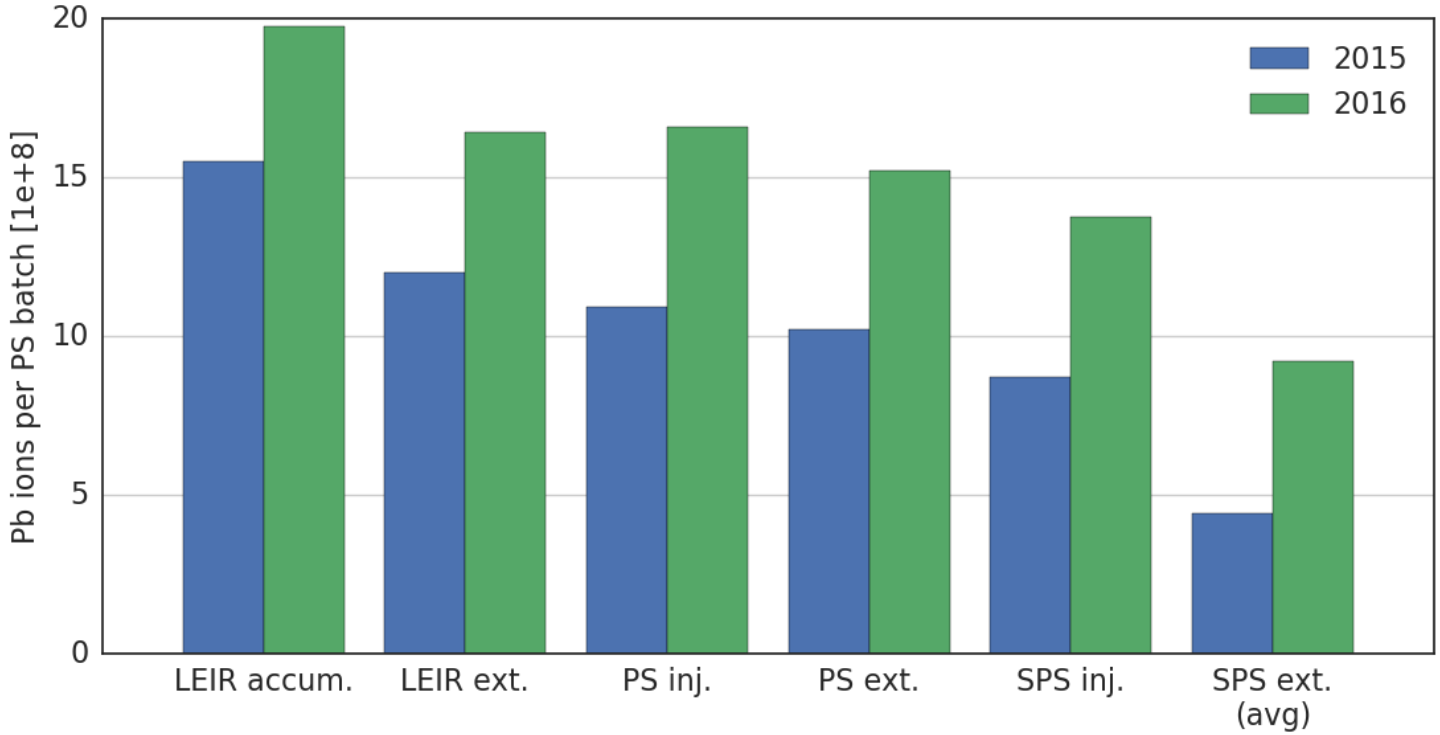

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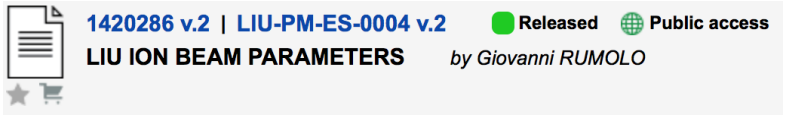
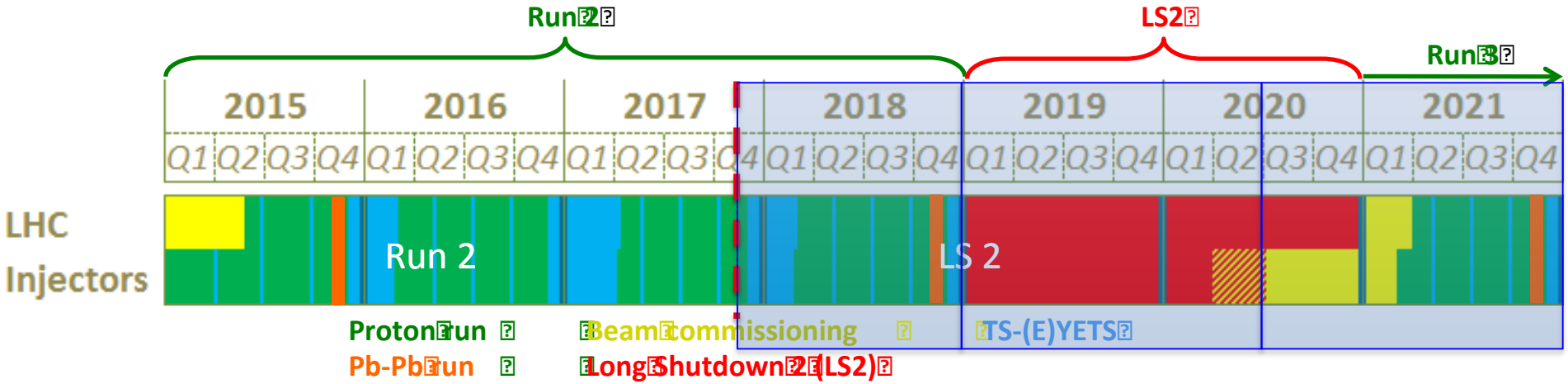
- **Baseline LIU Pb ion parameters compliant with HL-LHC request**
  - Single bunch parameters at SPS extraction from 2016 experience translate into requested ones when including additional losses in SPS due to longer injection plateau and slip stacking
  - Number of bunches can be achieved including slip stacking in the SPS (otherwise only 60% of integrated lumi target)

	$\mathcal{N}$ (x 10^8 ions/b)	ε (μm)	# of bunches
Achieved	**2.2**	**1.5**	**548**
LIU/HL-LHC	**1.9**	**1.5**	**1248**



LIU timeline and milestones

- **Activities until LS2**
  - Beam studies to further test performance, evaluate risks and study mitigations
  - Final design, procurement and test of hardware (e.g. protection devices, cables, power converters, amplifiers)
  - Anticipated installation/cabling work during **YETS**
  - Work on surface (e.g. civil engineering, racks), Linac4 Reliability Run & commissioning to desired performance
- **Main LIU installations and hardware work during LS2**
- **Beam commissioning of LIU beams after LS2**
  - **Ion beams** to be ready for **2021 LHC ion run**
  - **Proton beams** during **Run 3** to be ready for LHC physics after **LS3**



Post-LS2 beam commissioning

- **The first year of Run 3 (2021) will have to be fully devoted to**
  - Recovery of needed pre-LS2 proton beams (LHC and FT) with all new LIU (and CONS) equipment
  - Production of Pb ion beams with slip stacking in SPS for 2021 ion run

2020-21
Commissioning
newly installed
Pb ion be

Post-LS2 beam commissioning

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  - Recovery of needed pre-LS2 proton beams (LHC and FT) with all new LIU (and CONS) equipment
  - Production of Pb ion beams with slip stacking in SPS for 2021 ion run
- **2022 should be devoted to accelerating 2e11 p/b in the SPS**
  - Build on 2017-18 experience
  - Overcome stability issues in PS-SPS in new operating conditions + acceleration in SPS
- **Further intensity steps (additional 15% and 10%) in 2023 and 2024**
  - These intensity steps are unprecedented and will require dedicated scrubbing runs in the SPS and fine transverse and longitudinal optimisations
  - While high intensity is being commissioned, corrective actions could be applied in YETS's or planned for LS3, as identified and needed.

2020-21 Commissioning of pre-LS2 beams with Linac4 and newly installed equipment + commissioning of the Pb ion beams with slip stacking in SPS

2022 Commissioning of 1.8 10^{11} p/b with the desired brightness and loss budgets out of SPS

2023 Commissioning of 2.1 10^{11} p/b up to SPS extraction and tests of higher intensity at least up to the SPS injection

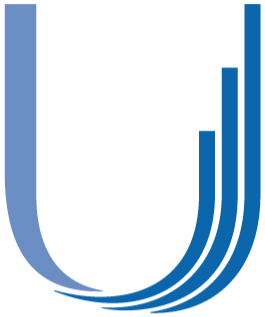
2024 Commissioning of 2.3 10^{11} p/b up to SPS extraction with the desired brightness and loss budgets

Conclusions

- **LIU beam performance with baseline upgrades has been analysed leading to the estimation of robust beam parameter sets**
  - Future operation scenarios are based on **simulations and present knowledge of the machines** – constant improvement and validation with better simulations and machine studies using already installed hardware
  - **LIU beam parameters match HL-LHC requests both for protons and ions**
  - Performance **risk items** have been identified for both protons (intensity limitation in PS, losses in SPS) and ions (slip stacking in SPS) and mitigations are under study

- **Beam commissioning after LS2 will mainly follow physics requests**
  - **LHC and FT proton beams** re-commissioned to pre-LS2 performance with new hardware in 2020-2021
  - Ion beams to be commissioned **to full LIU performance** in 2021
  - **Gradual** intensity ramp up of LHC beams to LIU/HL-LHC values over Run 3

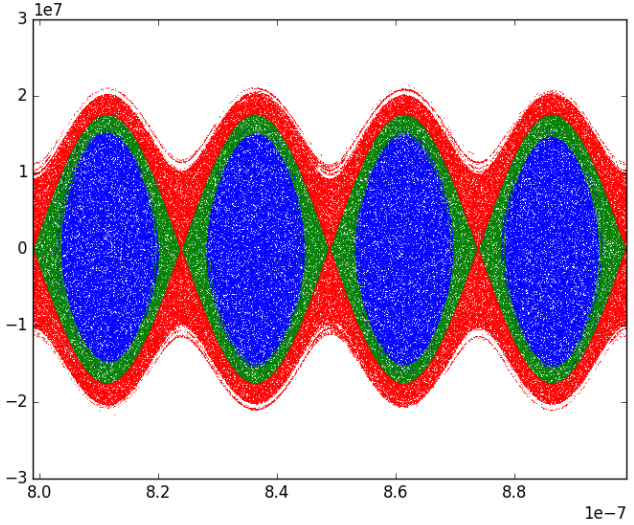
→ **Beam commissioning working group** for injectors to prepare, coordinate and oversee post-LS2 return to operation and beam production to LIU specifications

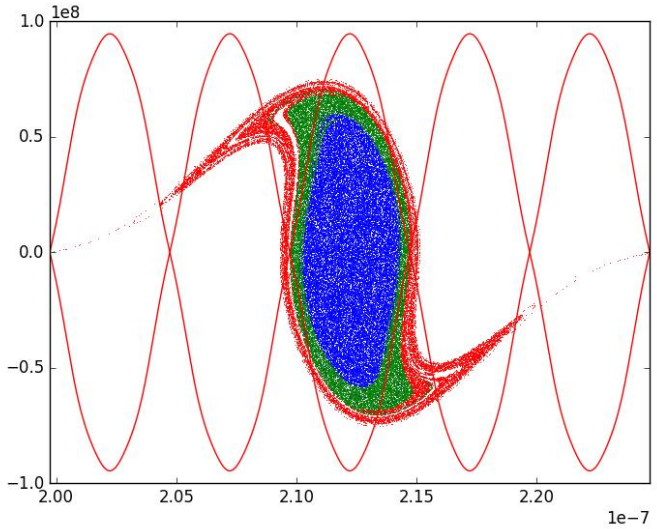


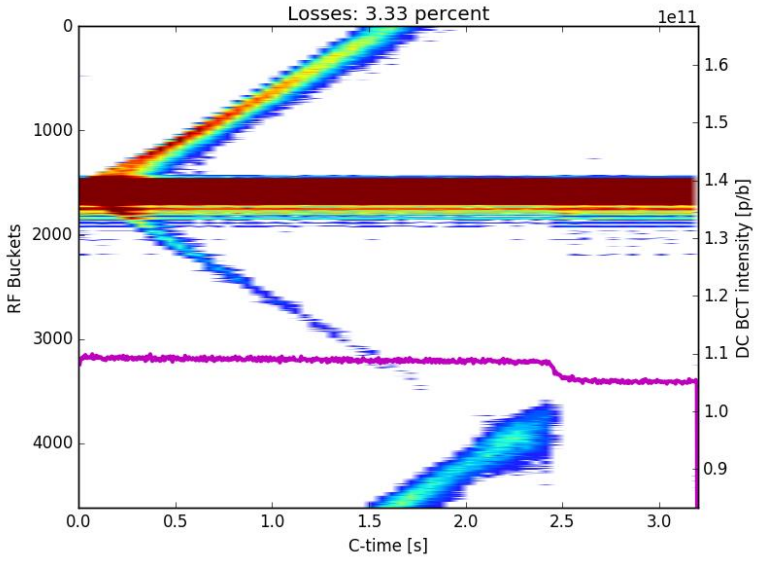
LHC Injectors Upgrade

THANK YOU FOR YOUR ATTENTION!

SPS losses

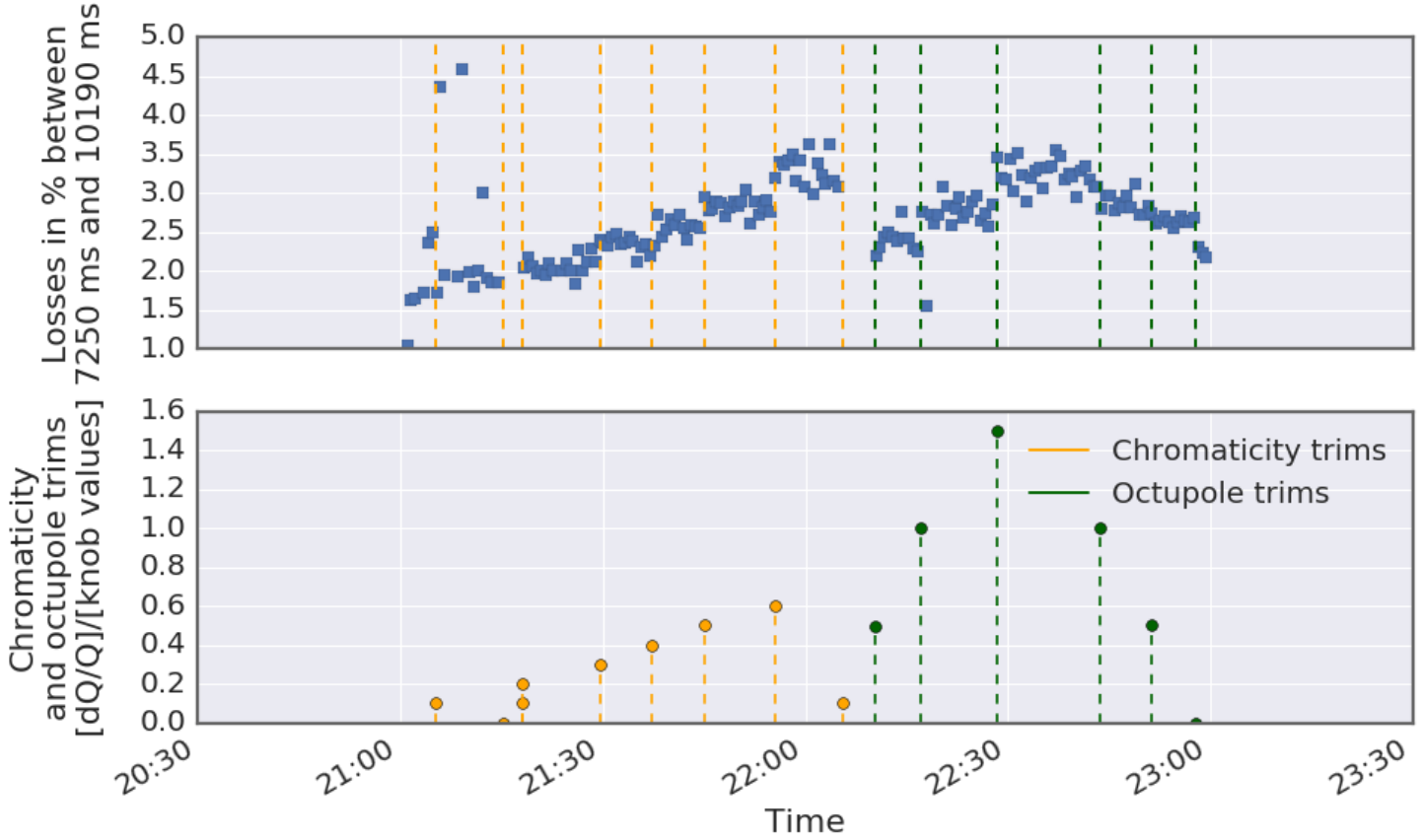






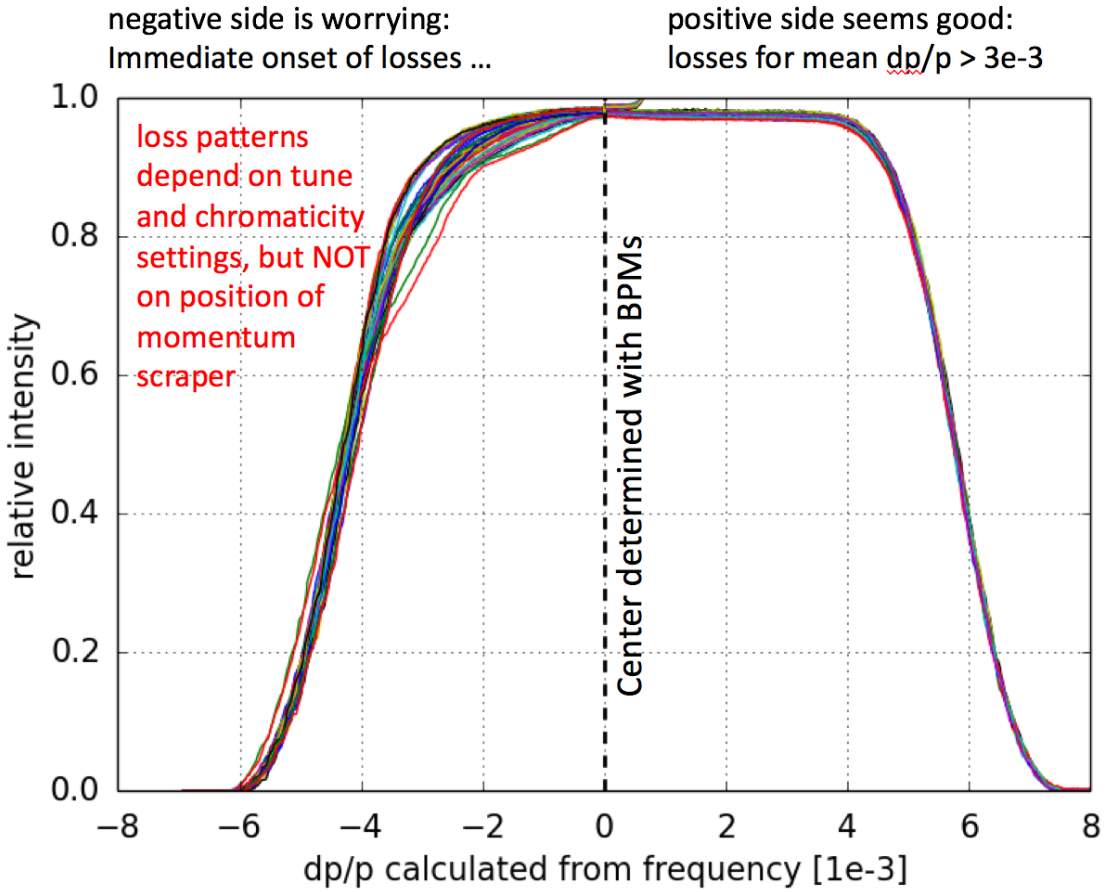
A. Lasheen

SPS losses



K. Li

SPS momentum aperture



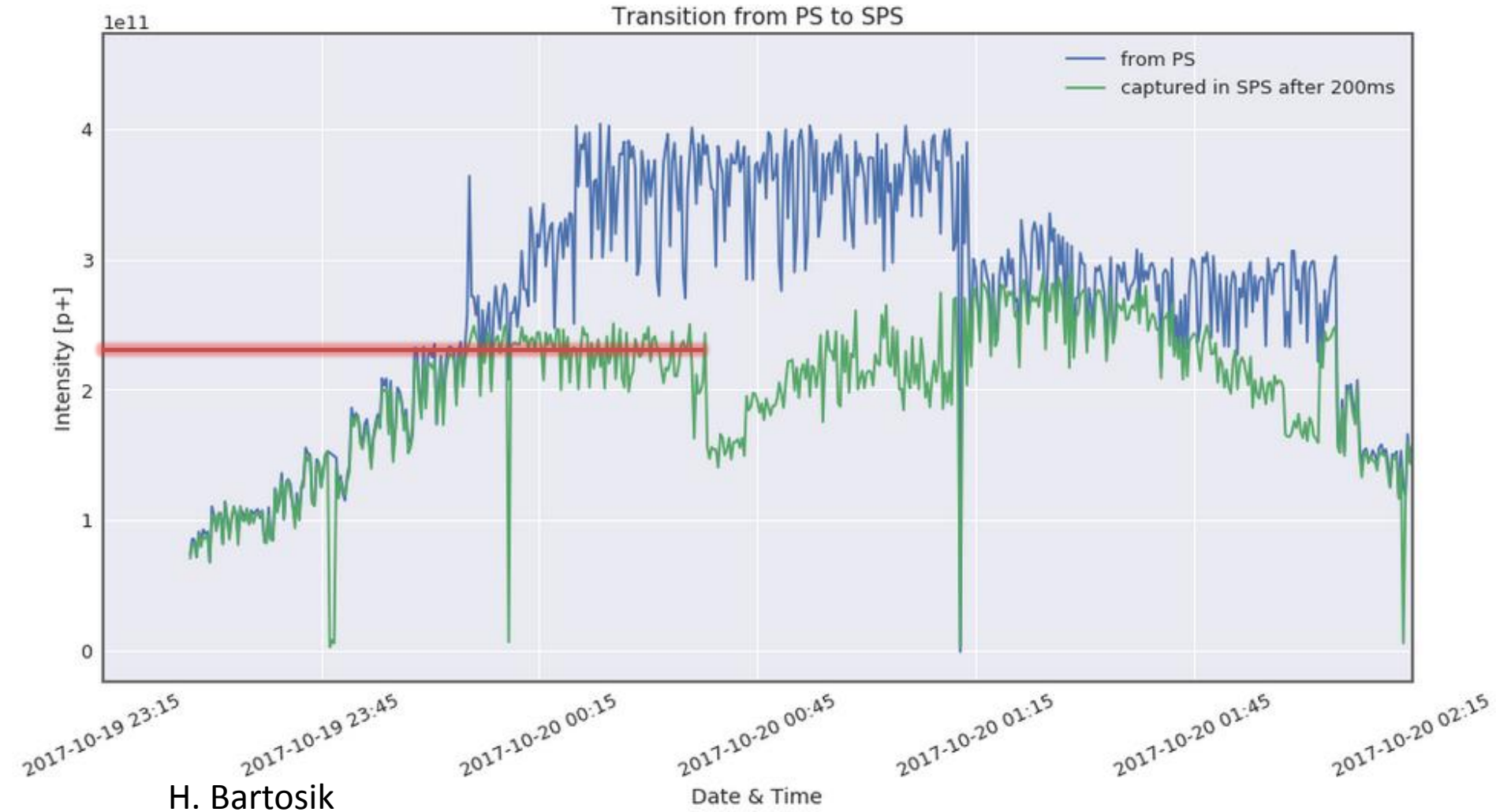
Aperture measurement:
+0.76 % / -0.59 %

V. Kain

Optics	dp/p [%]	Aperture [σ]
Q20	+0.76 / -0.59	+4.9 / - 3.8
Q22	+0.9 / - 0.73	+ 5.8 / - 4.8
Q26	+1.7 / - 1.3	+10.5 / - 8.3

Q22 TMCI

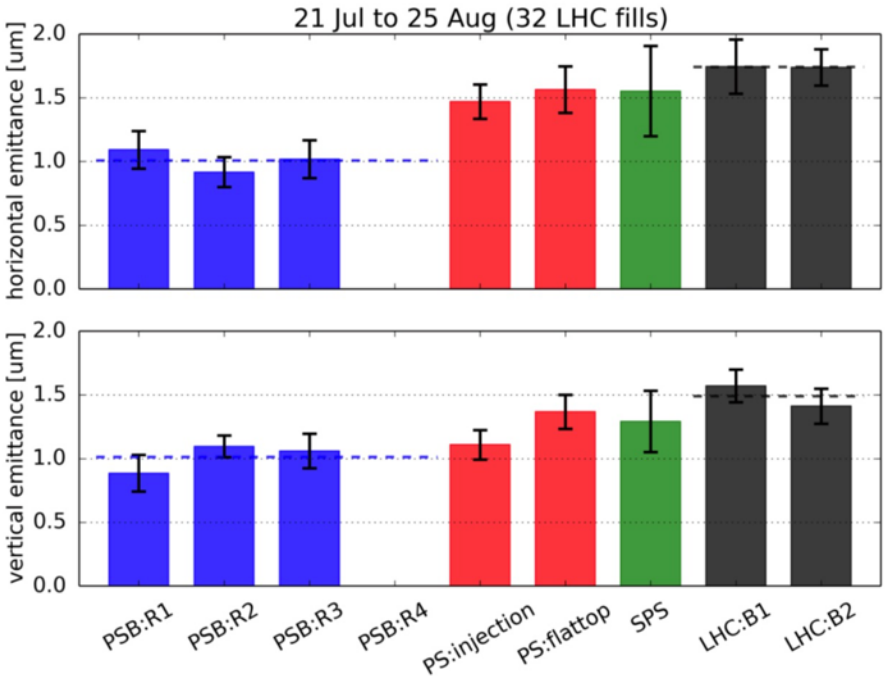
Threshold at 2.7 MV around 2.4e11



H. Bartosik

Emittance blow up in PS

- **Challenging LIU baseline**
  - transfer of bunches with large longitudinal emittance (3.0 eVs)
- **Observation in 2016: significant blow-up of the horizontal emittance at injection**



F. Asvesta, H. Bartosik