# LHC Injectors Upgrade

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# Wrap-up of LHC Performance Workshop (Chamonix 2016)

# Summary of Session 6
# LHC Injectors Upgrade (LIU)

M. Meddahi and G. Rumolo

Many thanks to all the speakers and contributors!

Outline:
- LIU baseline and timelines
- Pb ion injector chain: progress and beam parameters
- Proton injector chain: progress and beam parameters
- Concluding remarks

CERN, 3 March 2016

# LIU baseline as of 1/1/16 (main items)

- **PSB**
  - New $H^-$ charge exchange injection at 160 MeV from Linac4 to double brightness
  - Acceleration to 2 GeV with new RF system and new main power supply
- **Linac3 + LEIR**
  - 100 ms injection rate into LEIR to increase accumulated ion current
- **PS**
  - New injection at 2 GeV for protons to mitigate space charge
  - Newly installed and upgraded longitudinal feedbacks (impedance reduction and against CBI)
- **SPS**
  - Upgrade of the main 200 MHz RF system (power, LLRF)
  - Electron cloud mitigation through beam induced scrubbing + a-C coating of QFs and one arc (MBBs)
  - New beam dump system in LSS5 and new design of protection devices to comply with the target HL-LHC beam parameter values
  - Impedance reduction (QF-SSS flange shielding and improvement of HOM damping in 200 MHz cavities)

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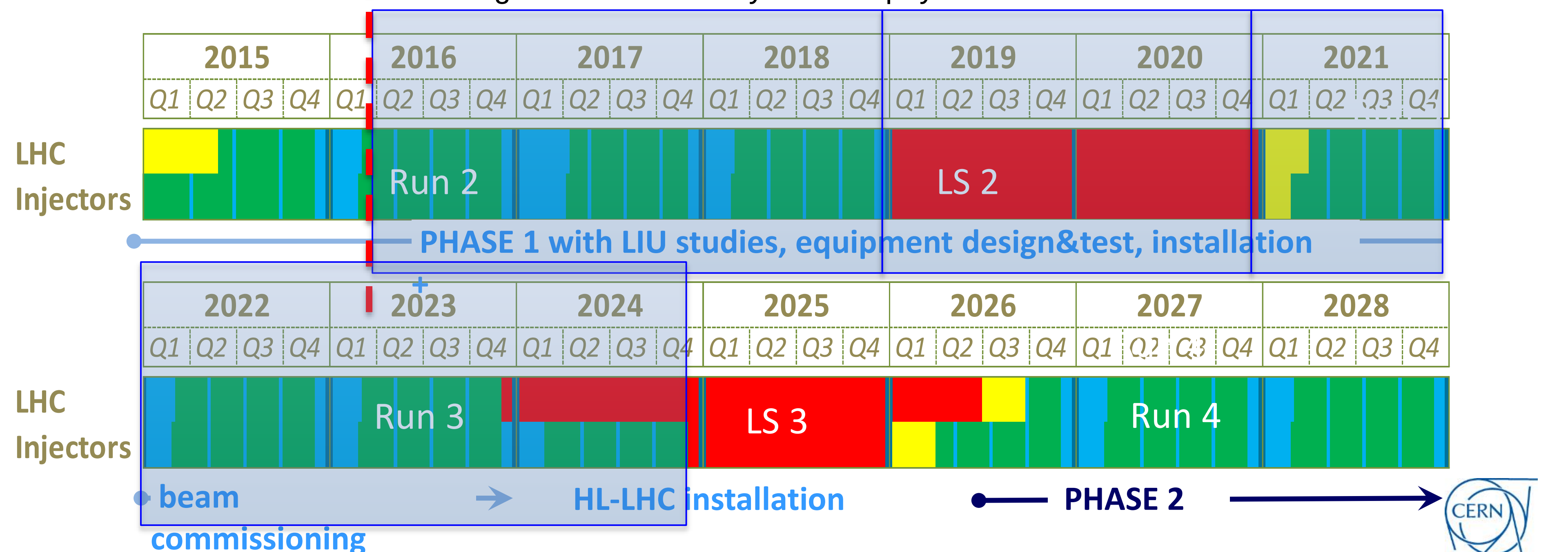
**Other LIU talks** → **Linac4 status (A. Lombardi)**
→ **RF upgrades for LIU (H. Damerau)**
→ **Transverse feedback (W. Höfle)**
→ **LS2 planning for LIU (J. Coupard)**

# Timelines of LIU

- **Activities until LS2**
  - Beam and simulation studies (e.g. space charge, electron cloud, impedance) to validate beam performance
  - Design, procurement and test of hardware (e.g. protection devices, cables, power converters, amplifiers)
  - Installation/cabling work during **(E)YETS's** when possible
  - Work on surface (e.g. civil engineering, racks), Linac4 commissioning & Half Sector Test

- **Main LIU installations and hardware work during LS2**

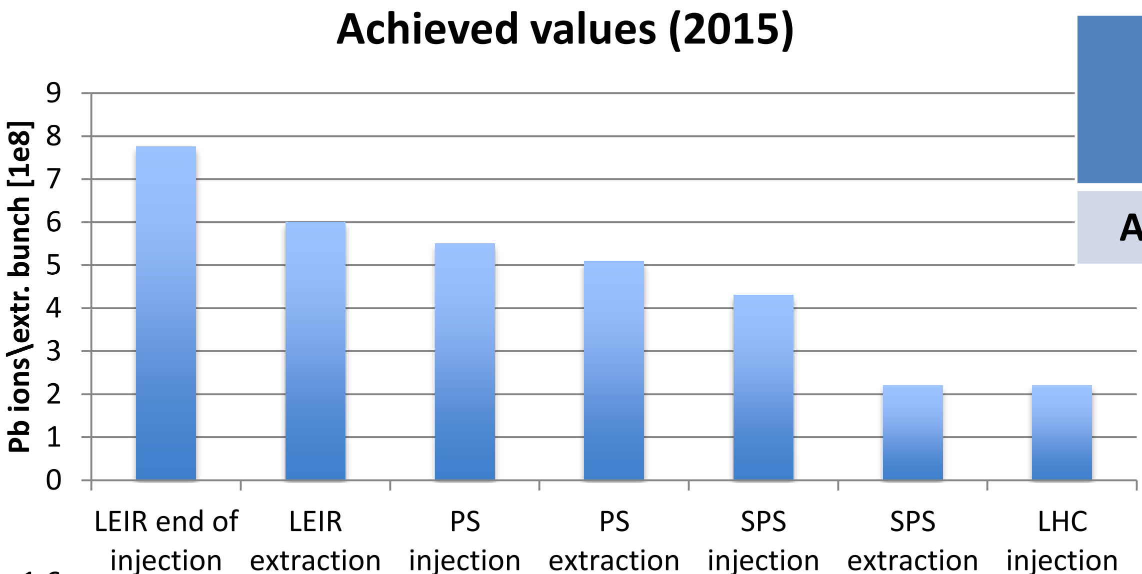
- **Beam commissioning of LIU beams after LS2**
  - **Ion beams** to be ready for **2021 LHC ion run**
  - **Proton beams** during **Run 3** to be ready for LHC physics after **LS3**

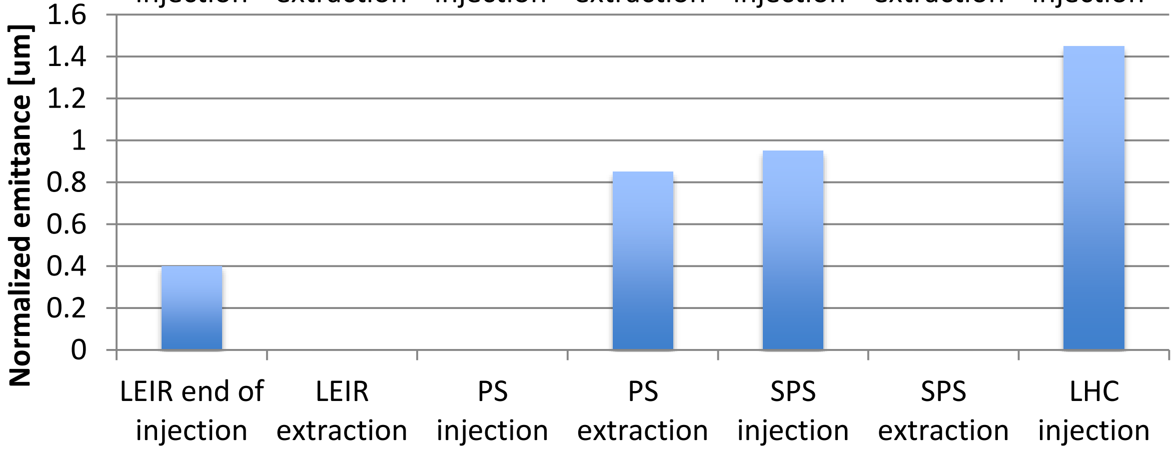


# Pb ions

# Ion beam performance

- **Intensive study program at the end of 2015 to push injector performance and systematically identify bottlenecks and loss/emittance growth distribution**




| | $\mathcal{N}$ (x $10^8$ ions/b) | ε (μm) | # of bunches |
|---|---|---|---|
| **Achieved** | **2.2** | **1.5** | **518** |

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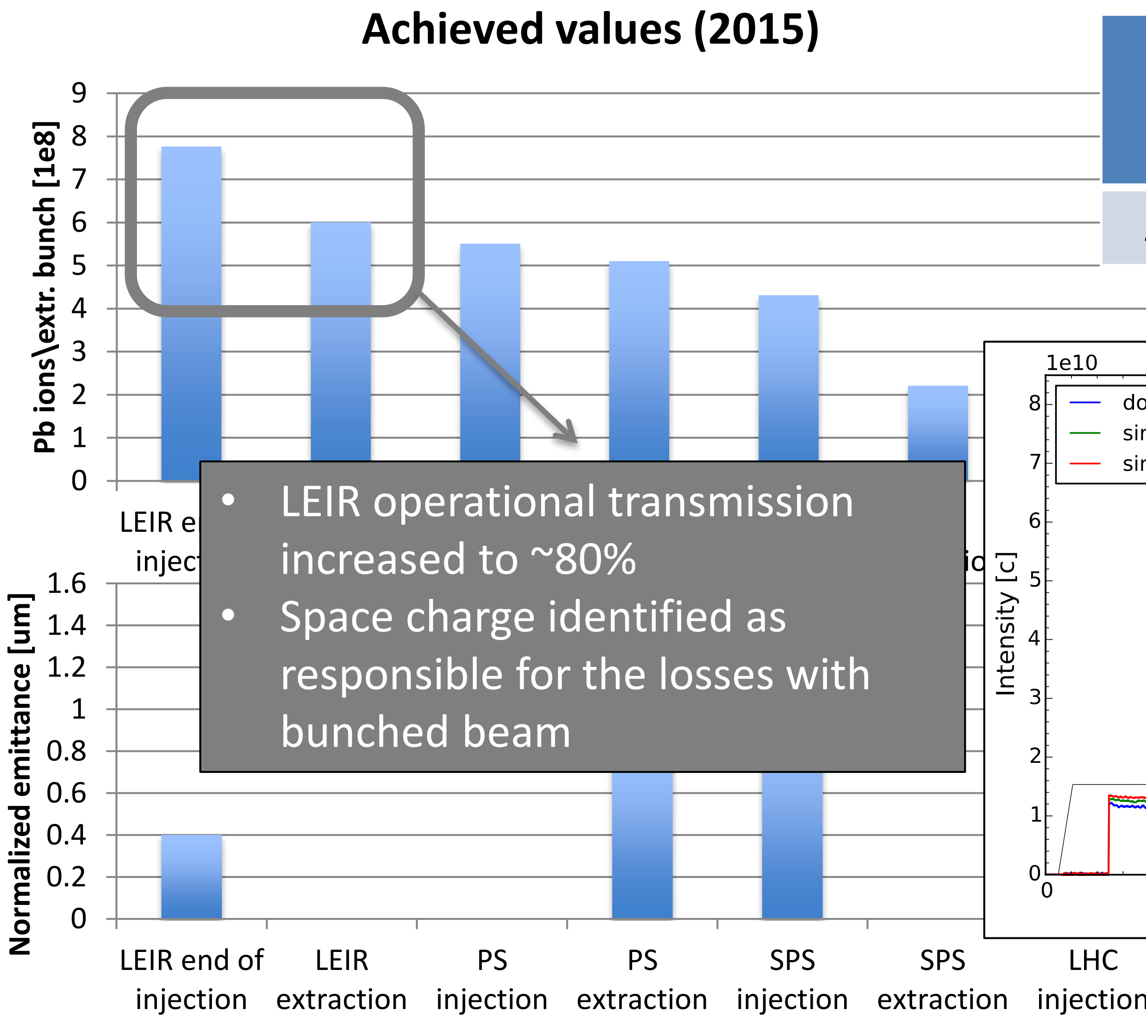


- LEIR operational transmission increased to ~80%
- Space charge identified as responsible for the losses with bunched beam

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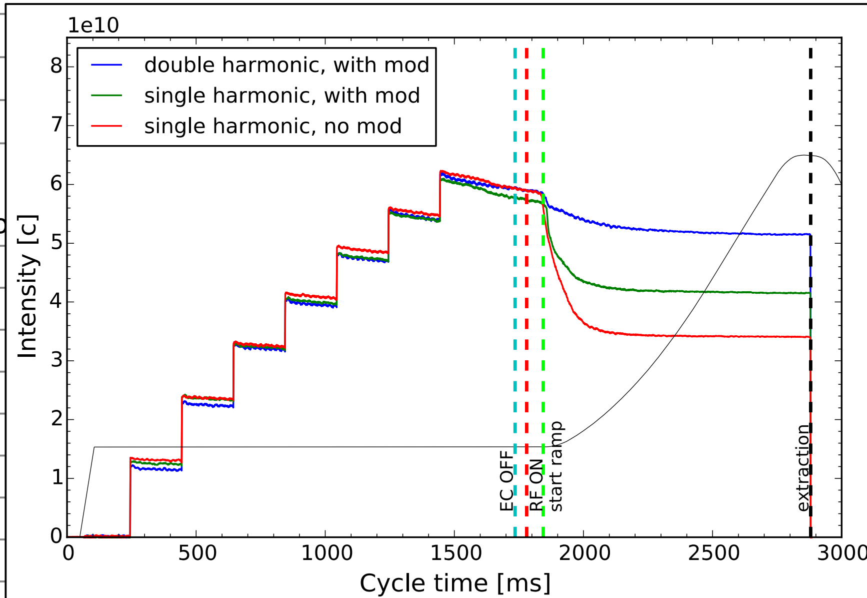

# Ion beam performance

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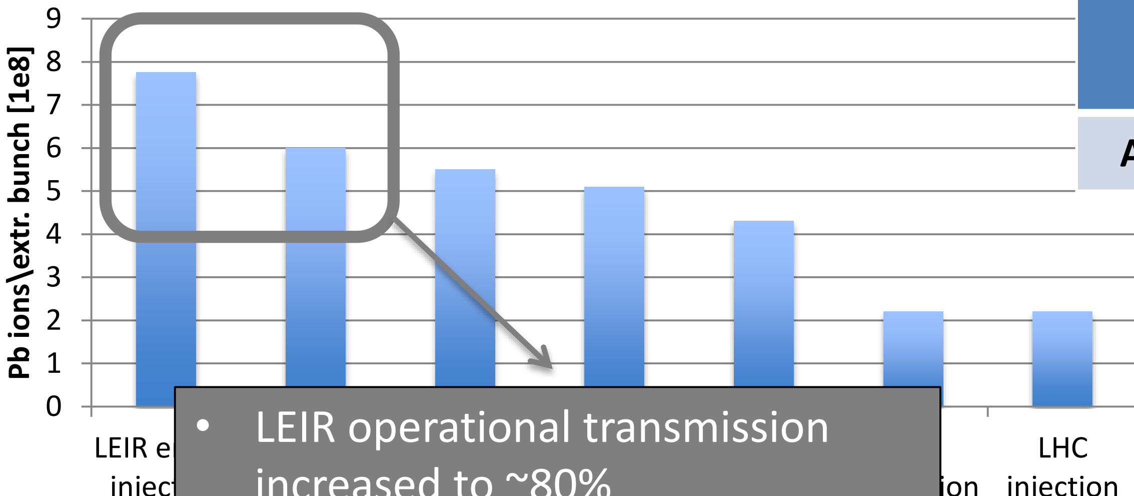
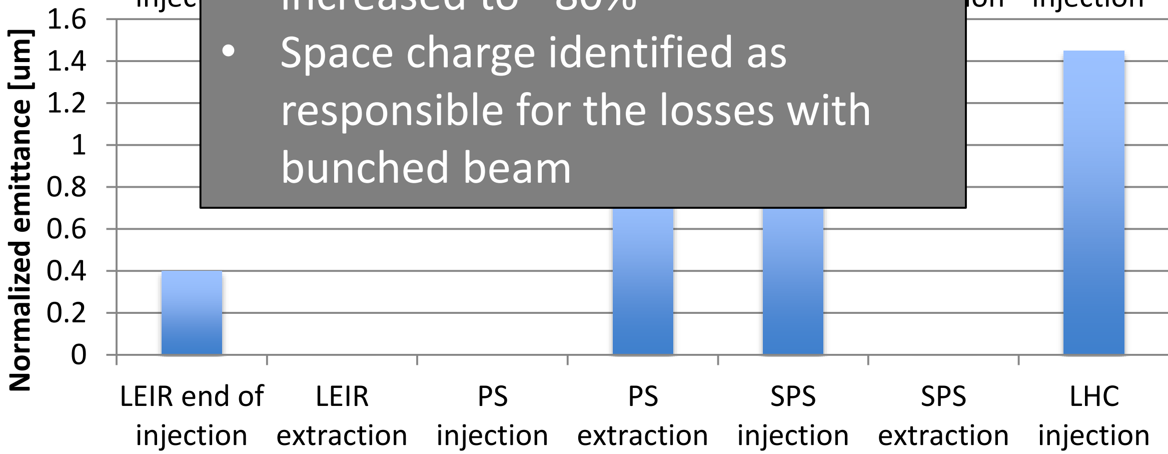
**Achieved values (2015)**

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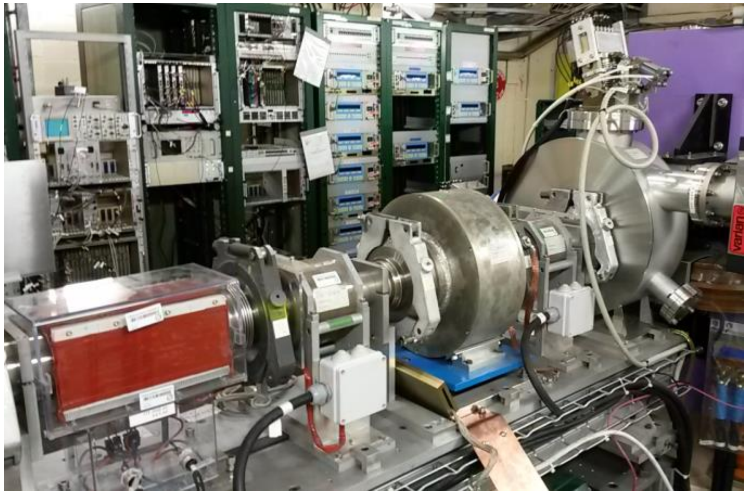
- Losses at SPS flat bottom and transition decreased
- MKP rise time significantly improved to enable 150 ns batch spacing in SPS

# LIU upgrades for ions

- **YETS 2015-16 → Baseline implementations towards more intensity:**
  - Linac3/transfer line upgrades to allow 100ms spaced injections into LEIR in 2016 (available for testing but not for production until LS2)
  - Modification to source + low energy region to remove aperture limitation and add focusing



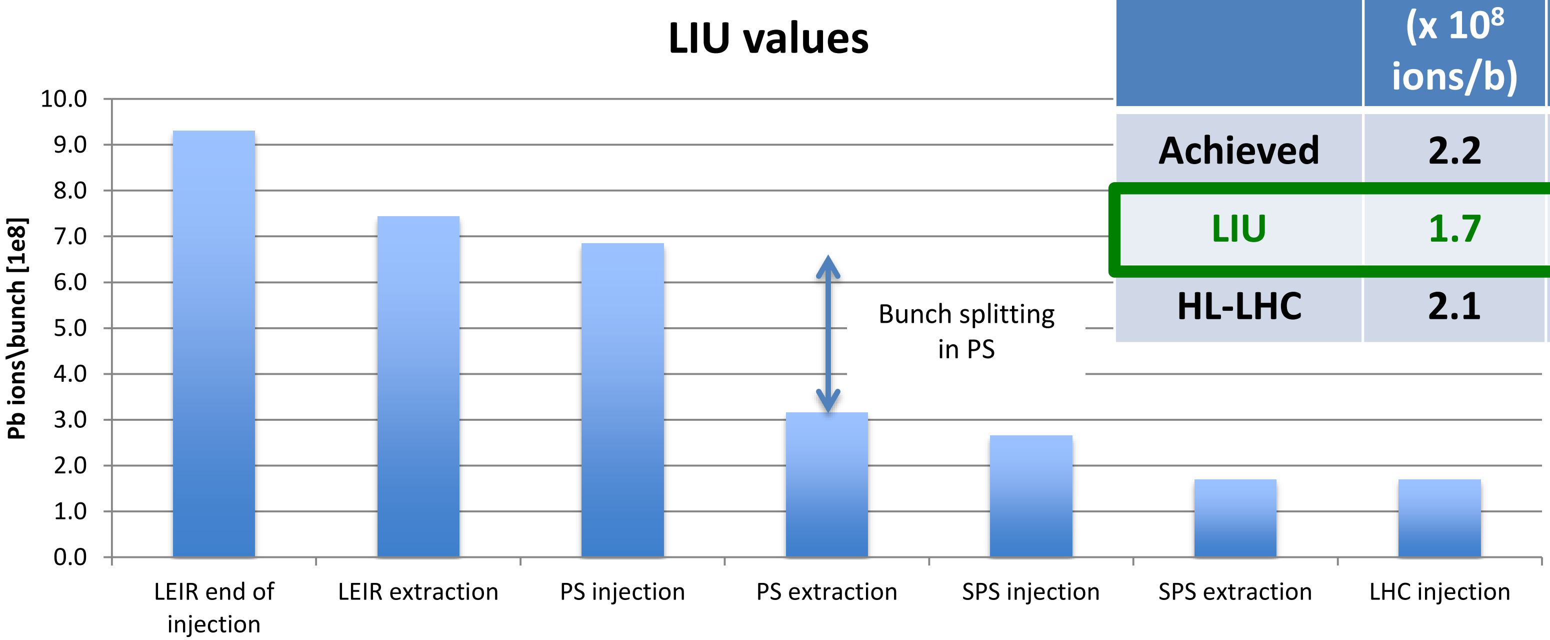
- **Until LS2 + LS2:**
  - Continue beam studies to further improve transmission through injector chain
    - Higher intensity in LEIR
    - SPS losses: optics, working point, tests for slip stacking/RF noise at flat bottom
    - Reduce losses in transfers
  - LEIR dump
  - LLRF deployment for slip stacking in SPS (in LS2)

→ **Machine studies in 2016-18 crucial for progress!**

# LIU performance reach with ion beams

- **LIU achievable parameter table obtained by combining**
  - Extrapolation from information collected in 2015 (transmission, emittance growth)
  - Predicted performance after baseline upgrades

- **The gap with the parameters needed to fulfill the experiment luminosity goal is already being addressed by the LIU and HL-LHC projects together**
  - LIU beam parameters specifications for ions at the exit of the SPS, [EDMS 1581381]

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| **Achieved** | **2.2** | **1.5** | **518** |
| **LIU** | **1.7** | **1.3** | **1152** |
| **HL-LHC** | **2.1** | **1.3** | **1248** |

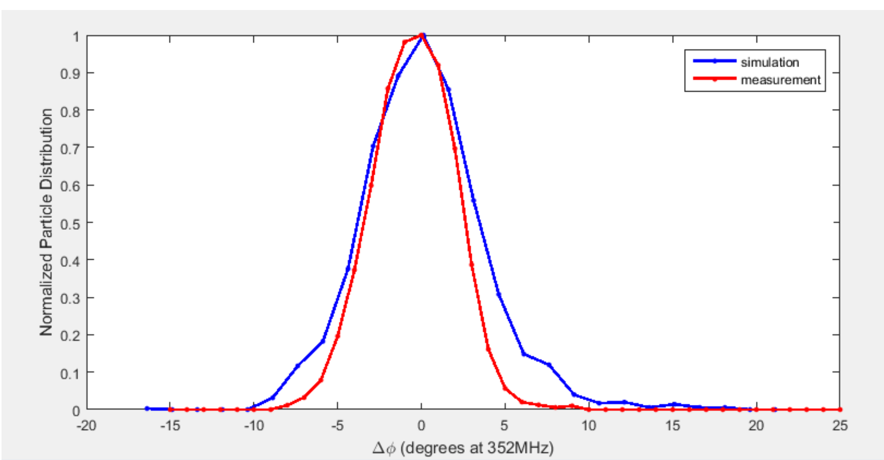
# Protons

# Linac4 progress

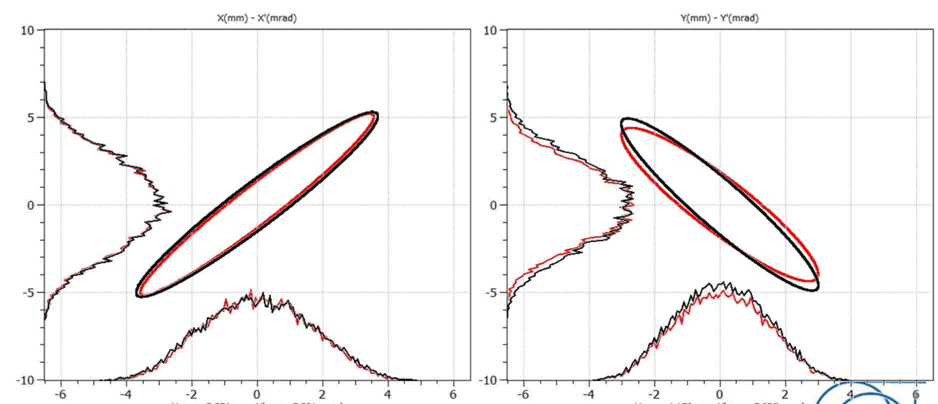
- **Commissioning of 50 MeV**
  - $H^-$ source can reliably produce **50 mA,** but only 2/3 of the current can be transmitted through the RFQ (emittance larger than nominal)
  - **20 mA** with **0.45 μm** at 50 MeV
  - Transversally and longitudinally the beam is as predicted → Both **tracking codes and beam diagnostics** work as expected.

- **Staged plan to increase current up to 40 mA by**
  - improving the current/reducing the emittance from the source
  - improving the matching through the LEBT

  → Results expected by summer




Longitudinal structure




Transverse phase spaces

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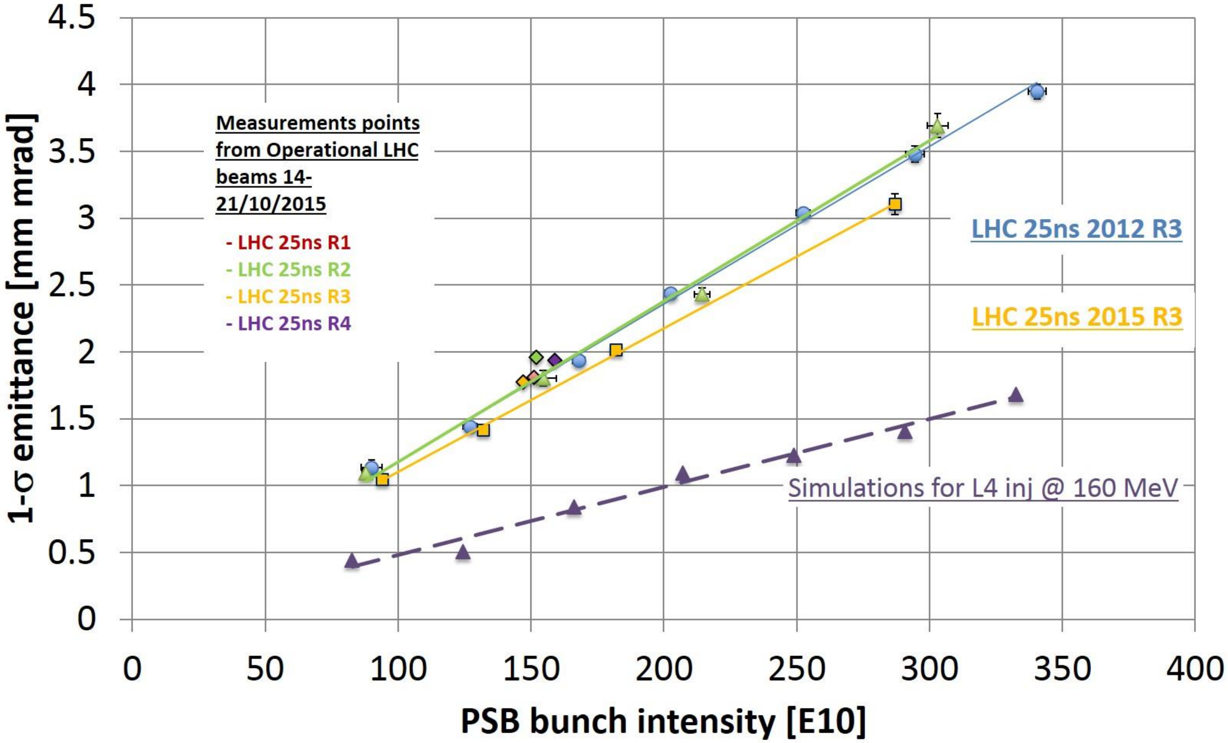
- **Next steps: commission 100 MeV, then 160MeV (from September 2016), and deliver first beam to the Half Sector Test (HST) by October 2016.**

# PSB

- **New H⁻ injection at 160 MeV from Linac4**
  - All new equipment **on track to be ready by end 2016** (in the unlikely event of an early Linac4 connection)
  - **Half Sector Test** has to start in October 2016, no further delay can be tolerated as it is supposed to feed back into the hardware design
  - Detailed simulations of PSB with Linac4 confirm the expectation of **double brightness**



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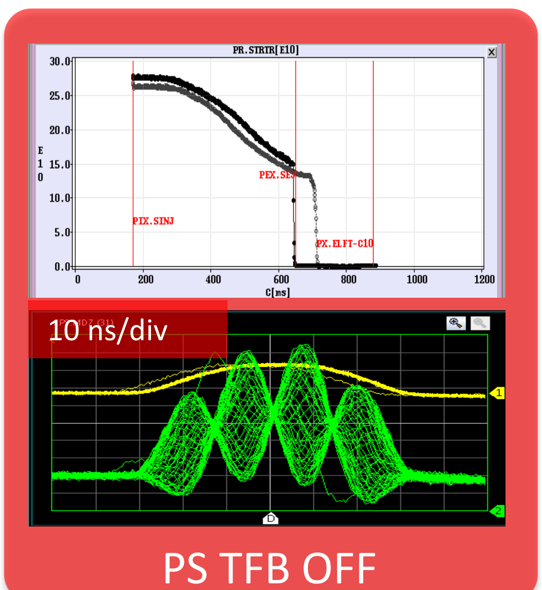
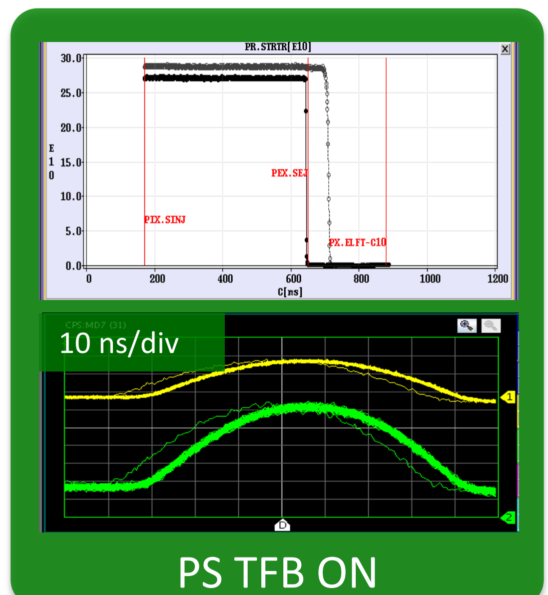
  - Detailed simulations of PSB with Linac4 confirm the expectation of **double brightness**
- **New RF system**
  - 10 prototype Finemet modules installed in Ring 4 widely tested throughout 2015
  - Review in September led to the decision to **replace all PSB RF systems (C02, C04 and C16) with a Finemet based RF system (LS2)**
- **MPS building (including infrastructure) in progress, to be ready by end Q1 2016**
- **Magnets and extraction elements on track to be ready for LS2**
- **Decabling campaign successfully proceeding**
  - ~2700 cables (previously identified and tagged) disconnected
  - PSB start up going well so far, only 2-3 cables found with wrong connections!
  - Cables will be removed in EYETS

# PS

- **New injection at 2 GeV from PSB**
  - All design choices for **injection region** frozen (new bumpers, new septum, upgraded kicker)
  - Partly in EYETS, mainly for LS2
  - **Space charge limit** due to structural resonance identified at injection energy, more studies ongoing (different optics, longitudinal beam parameters at PSB-PS transfer)

- **Feedbacks**
  - **Longitudinal feedback** with Finemet cavity as kicker, endorsed at the September review
  - New power amplifiers for the **transverse feedback** under design



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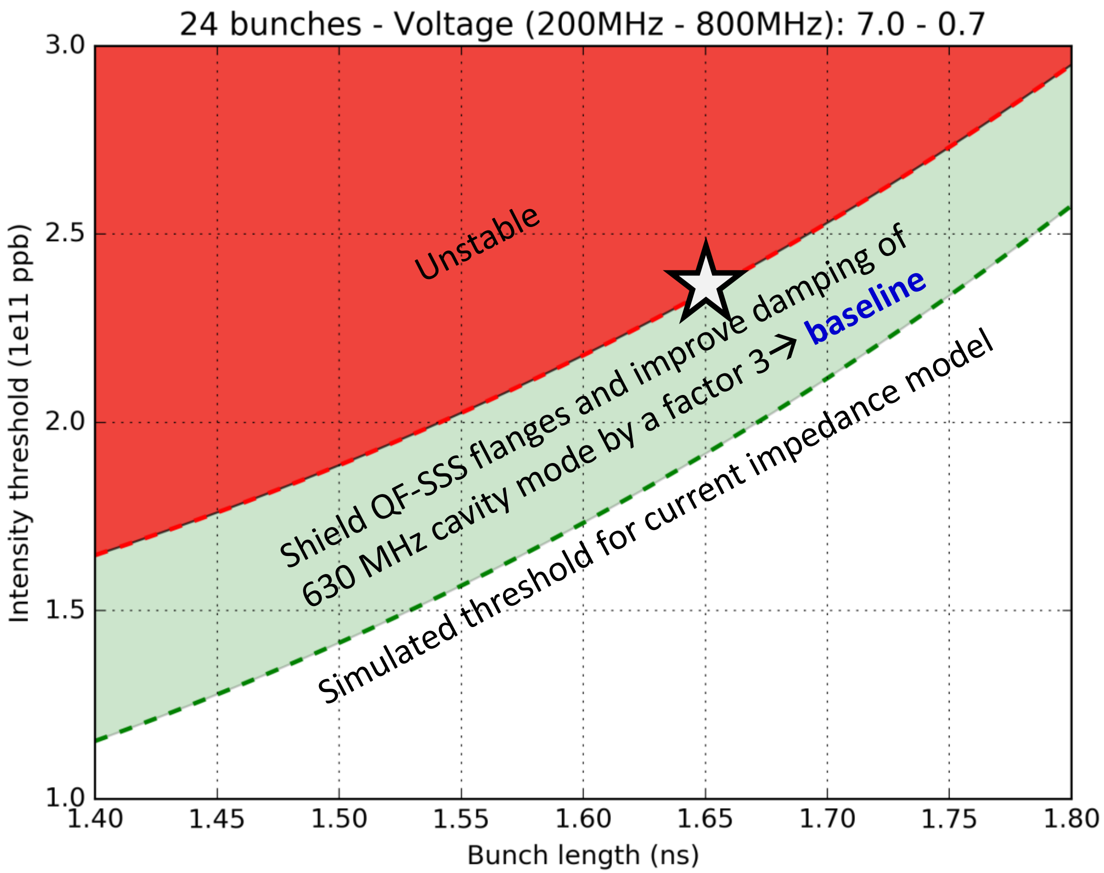
- **RF systems**
  - Improved wide-band feedback for **10 MHz** (EYETS + LS2)
  - New 1-turn delay feedbacks for **20, 40 and 80 MHz** for beam stability and bunch-to-bunch equalisation during splittings (EYETS)
  - New anode power supplies for **40 MHz and 80 MHz** and upgrade to a **digital beam control** for reliability and long term maintainability (LS2)
  - New ferrite tuners for **80 MHz** to use cavities simultaneously for protons and ions (LS2)

- **Internal dumps under design (with shielding and support structure) – LS2**

- **TT2 recently introduced in LIU-PS scope**

# SPS

- **Impedance reduction**
  - Identified **QF-SSS vacuum flanges** and **200 MHz HOMs** as main remaining impedance sources driving longitudinal coupled bunch instability
  - Shielding of flanges (EYETS and LS2) and enhancement the HOM damping (under study)



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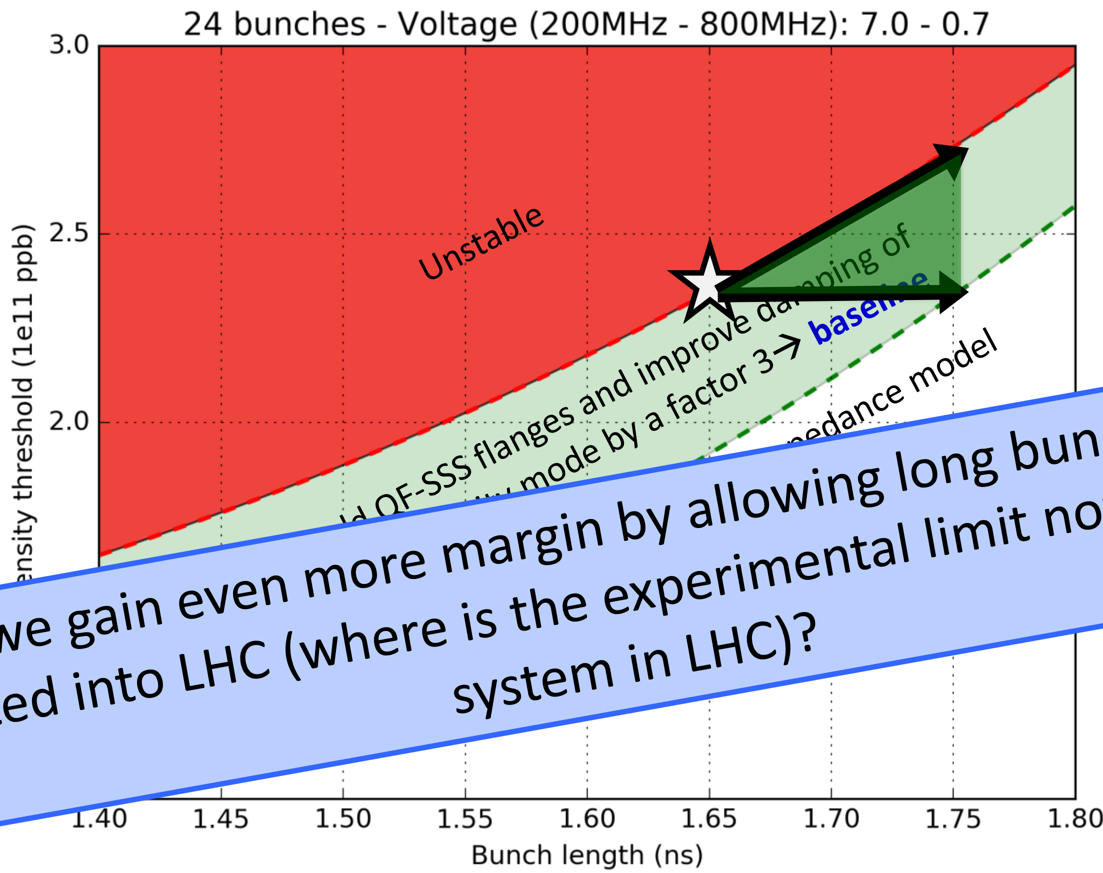


Can we gain even more margin by allowing long bunches to be injected into LHC (where is the experimental limit now, 200 MHz system in LHC)?

# SPS

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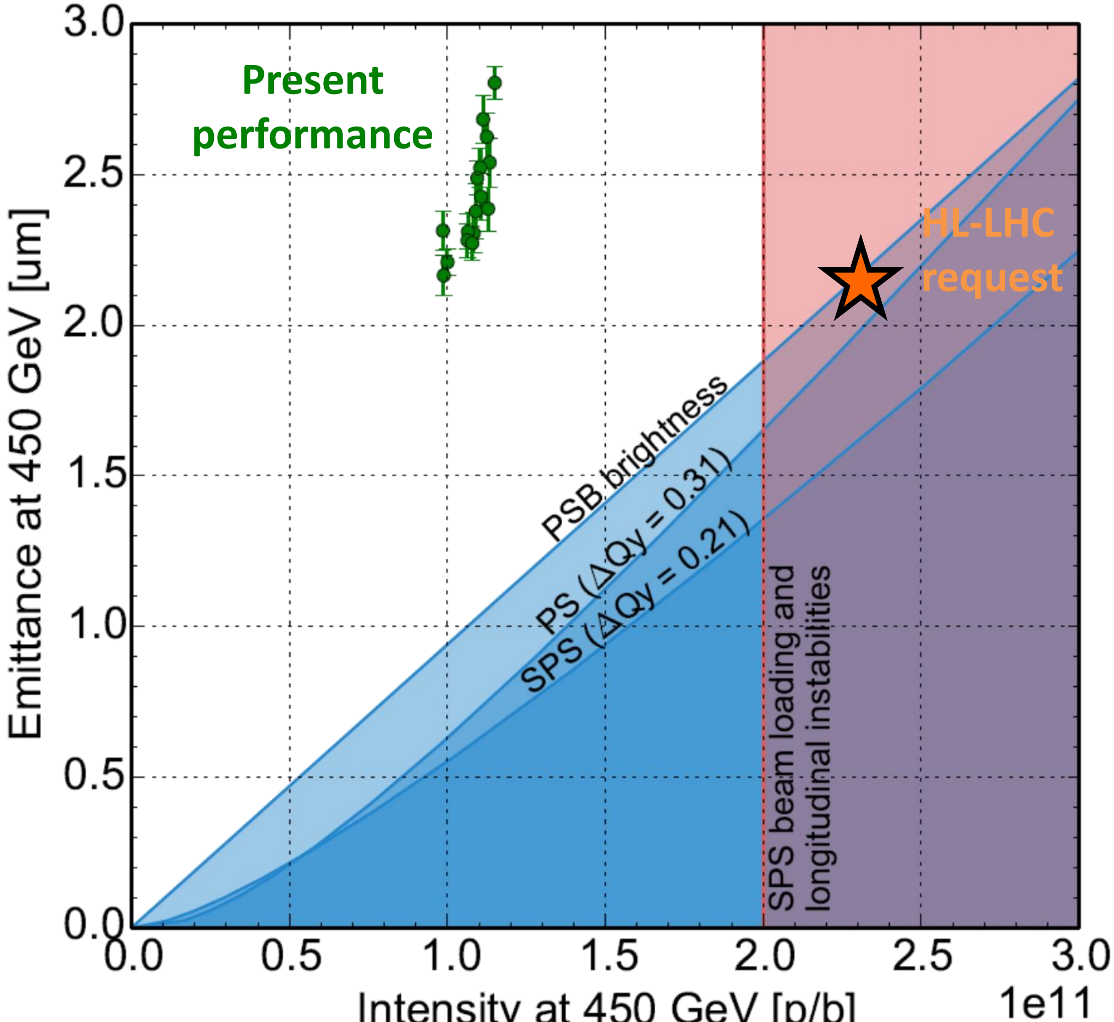
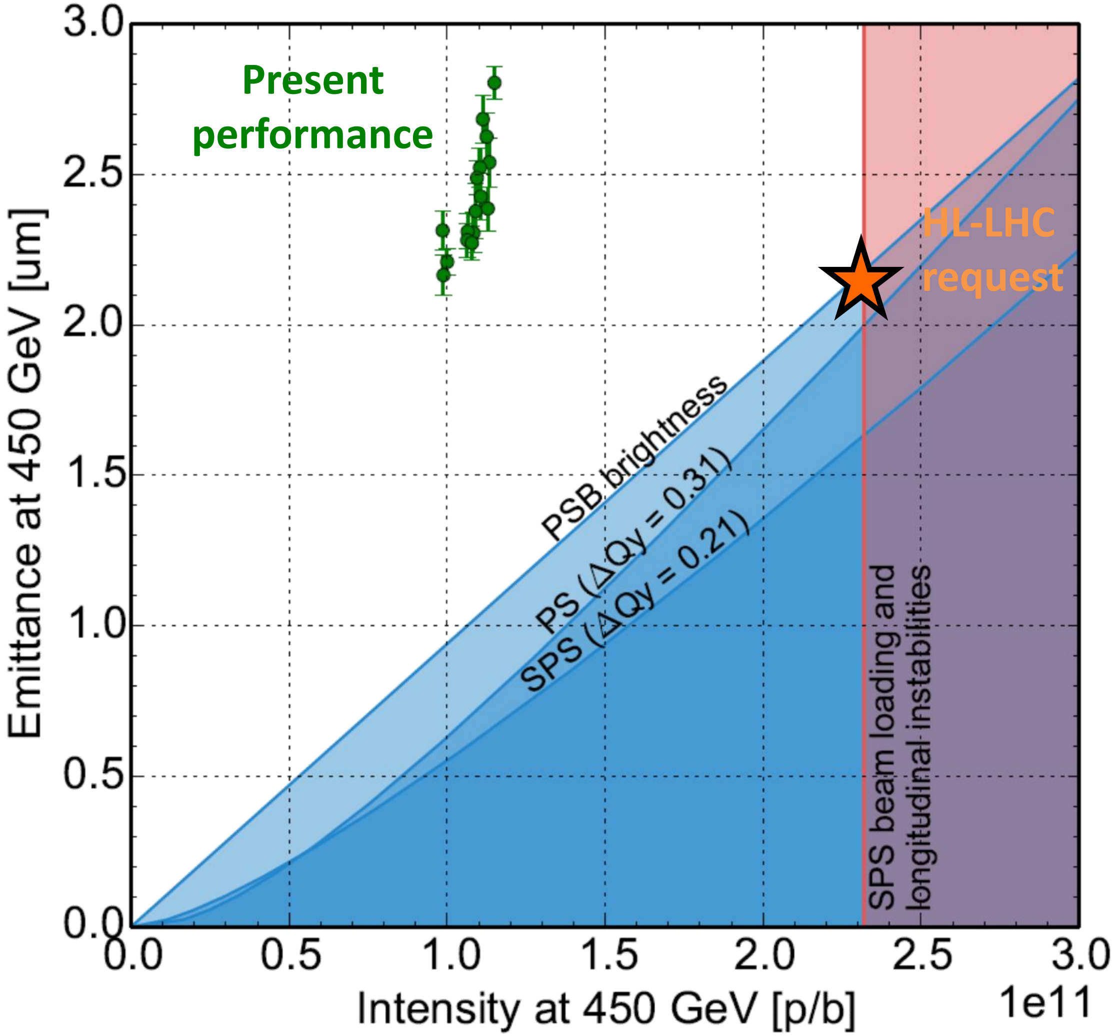
  - Shielding of flanges (EYETS and LS2) and enhancement the HOM damping (under study)
- **Upgrade of the 200 MHz RF system**
  - **Rearrangement** of main 200 MHz cavities
  - Two **additional RF power plants** (new amplifiers with solid state technology, new building)
  - **LLRF upgrade** for beam stability and slip stacking for the ions
- **Electron cloud mitigation**
  - Decision to rely on **scrubbing**, while a-C coating of all QFs + one arc including MBBs during LS2 → Validation in Run 3, when intensity could be limited by enhanced beam losses
  - **Transverse feedback systems** to stabilise beam (current and wide-band prototype)
- **Dumps and protection devices**
  - **LSS5 dump system**: layout and specs finalised, relocation of other systems defined, preparatory civil engineering and cabling begun
  - Upgrade defined for **extraction protection, transfer line stoppers and collimators**, few technical details to be finalised (HiRadMat tests), new interlocking systems needed

# LIU performance reach for protons before SPS impedance reduction




| | $\mathcal{N}$ (x $10^{11}$ p/b) | ε (μm) |
|---|---|---|
| LIU Baseline | 2.0 | 1.9 |
| HL-LHC | 2.3 | 2.1 |

# LIU performance reach for protons with SPS impedance reduction




| | $\mathcal{N}$ (x $10^{11}$ p/b) | ε (μm) |
|---|---|---|
| LIU Baseline | 2.3 | 2.2 |
| HL-LHC | 2.3 | 2.1 |

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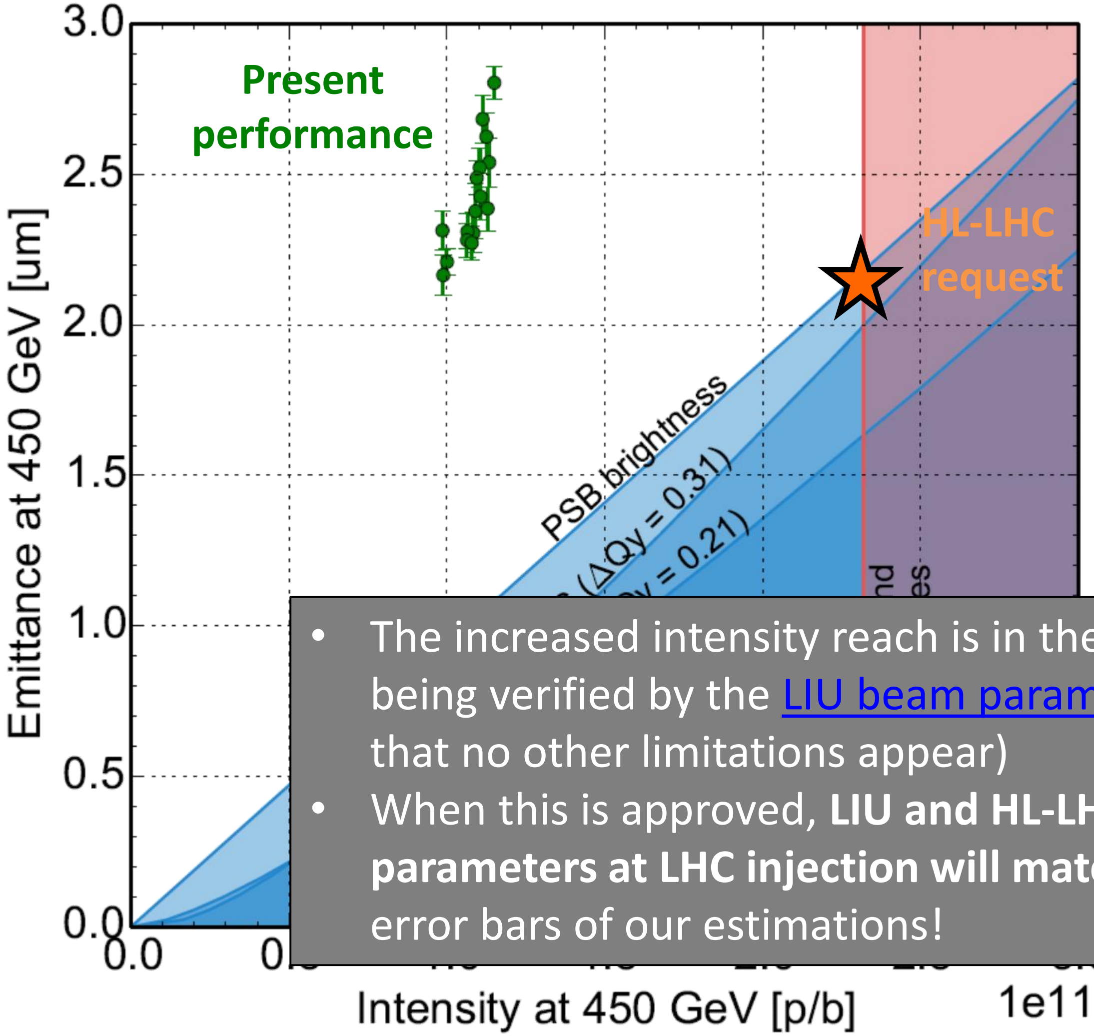


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- The increased intensity reach is in the process of being verified by the LIU beam parameter WG (check that no other limitations appear)
- When this is approved, **LIU and HL-LHC beam parameters at LHC injection will match** within the error bars of our estimations!

# In summary

- **LIU project on track to be ready for hardware installations during LS2**
  - Meanwhile, significant amount of work advanced in YETS's and EYETS, equipment design/ procurement/test, work on surface, beam (machine and simulation) studies in progress
  - **End-2016 deadline** for Linac4 connection still valid and **Half Sector Test** to be completed by beginning 2017
  - **Resources need to be secured** for upgrade of critical systems, whose functionality and reliability are crucial for LIU, like **RF systems and transverse dampers**

- **Important progress on beam parameter match between LIU and HL-LHC**
  - **Ions**:
    - Both HL-LHC request and LIU performance reach defined
    - Gap with HL-LHC only ~20% in luminosity at this stage, LIU and HL-LHC closely collaborating to identify best options to bridge it
  - **Protons**:
    - LIU beam parameter WG actively working to follow baseline evolution
    - SPS impedance reduction expected to enable SPS to deliver beams that meet the HL-LHC requirements
    - LIU and HL-LHC investigating together on means to gain additional margin
  - The commissioning of **LIU beams during Run 3** will validate LIU anti-ecloud strategy in SPS (scrubbing, losses) and allow testing important design options for HL-LHC

LHC Injectors Upgrade

# THANK YOU FOR YOUR ATTENTION!

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