# LHC Injectors Upgrade

CERN

LHC Injectors Upgrade

# LIU-IONS PS Injectors: Baseline, Outcome from 2015 Operation, Performance Reach and Options

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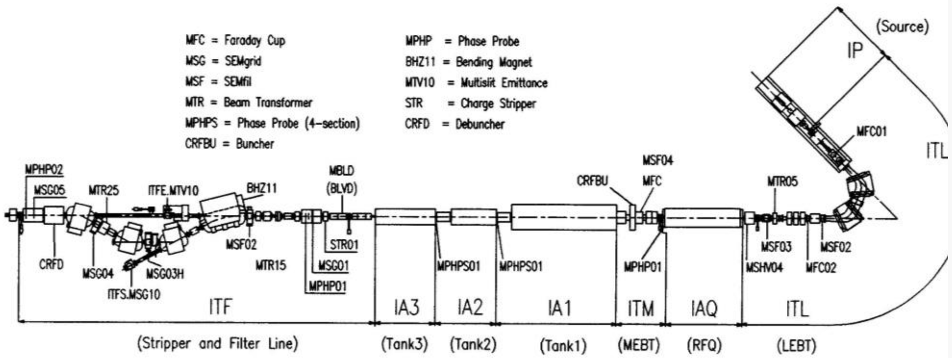
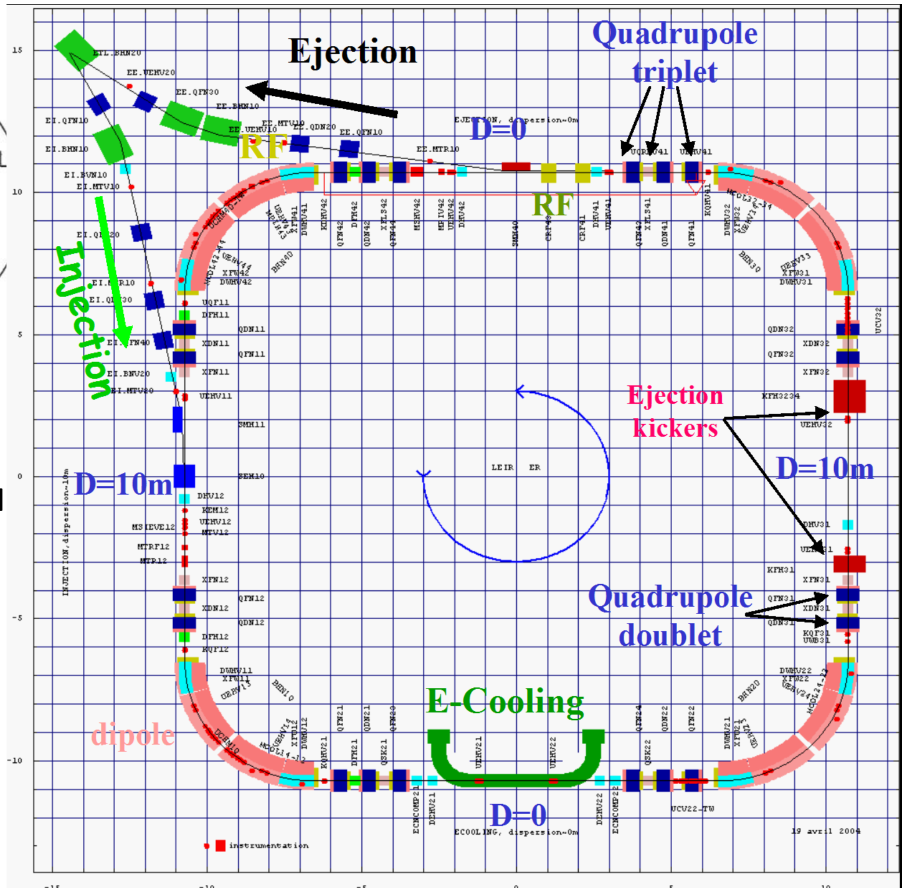
And the PS ion injector team

Chamonix 2016

# The PS Ion Injectors

The Ion Source, Linac3 and LEIR.



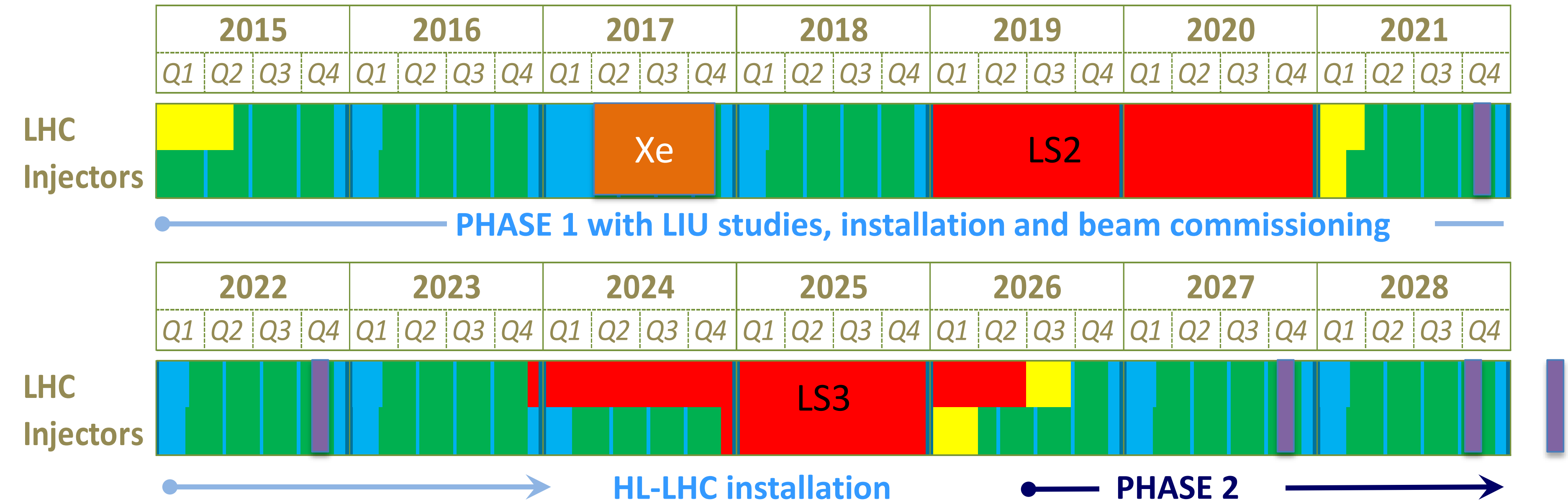




- Linac3, multi charged ECR source.
- Selection ($Pb^{29+}$) and acceleration -> 4.2MeV/u
- Stripping -> $Pb^{54+}$
- Multi-turn injection into LEIR
- Multiple injections.
- Electron cooling.
- Capture in 2 bunches.
- Acceleration ->72 MeV/u
- Extreme High Vacuum

# PS Ion Injector – Project Goal

What is the baseline goal of Linac3 - LEIR in LIU-Ions?

| | Achieved 2015 | LIU-Ions Baseline |
|---|---|---|
| Ions Before RF Capture | 7.8 x$10^8$ /bunch | 9.3 x$10^8$ /bunch |
| Ions At Extraction | 6.0 x$10^8$ /bunch | $\boxed{\text{7.4 x}10^8\text{ /bunch}}$ |
| # Injections | 7 @ 200ms | 13 @ 100ms |
| Ions At LHC Injection | - | 1.7 x$10^8$ /bunch |



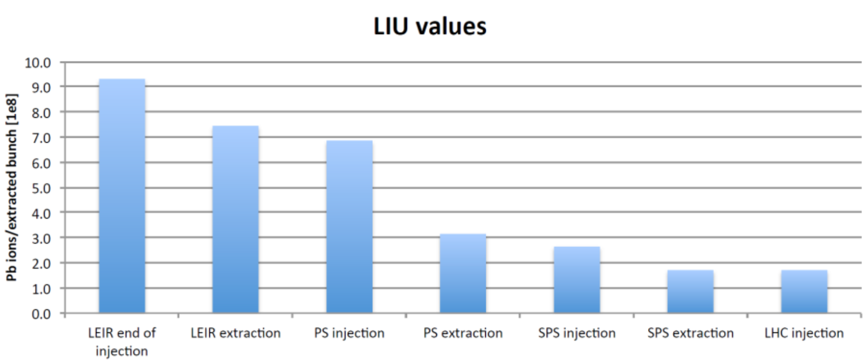
# Boundary Conditions for the ion luminosity requirements in LHC

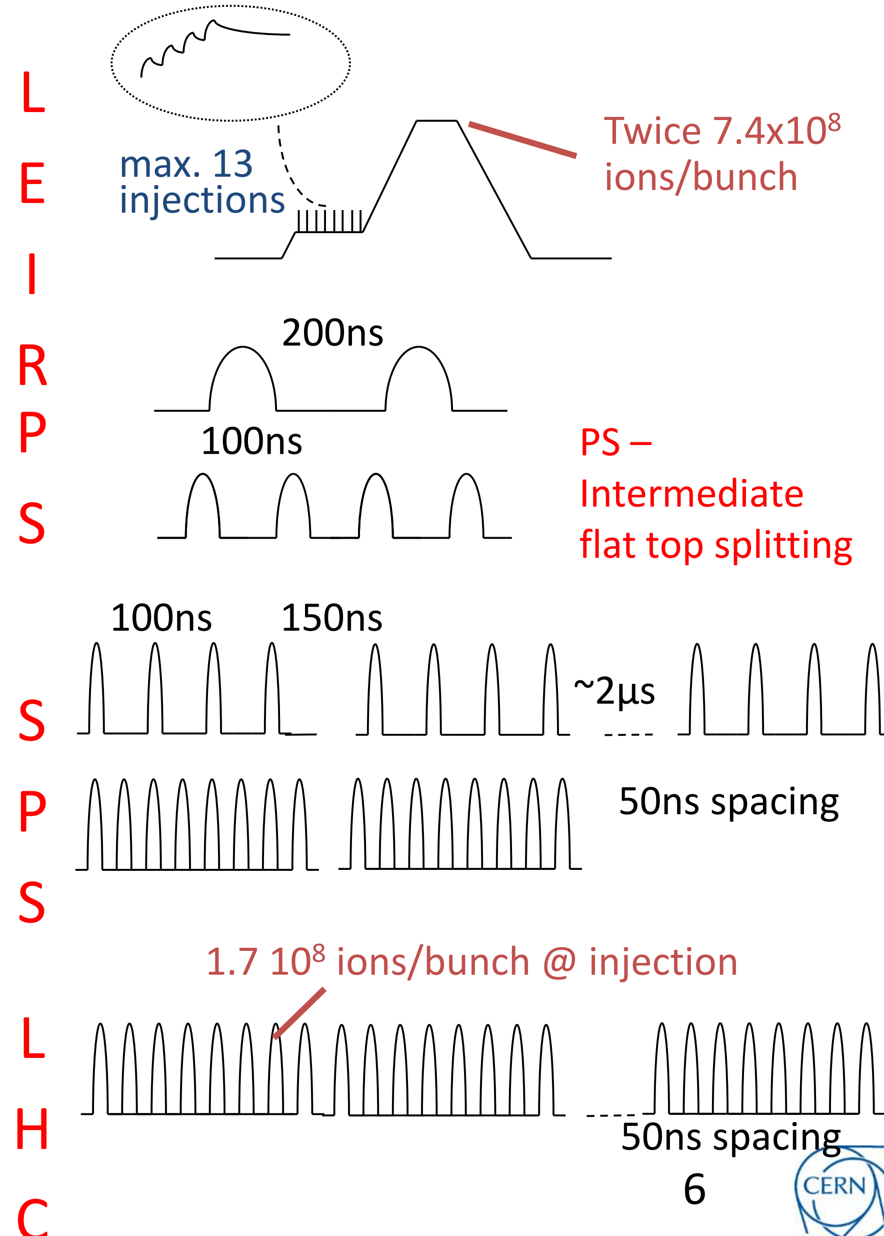
Most recent calendar shared with HL-LHC (see John's presentation)

- 2016 – Pb+p
- 2017 – No LHC ion run (Xe to experiment NA61)
- 2018 – Pb+Pb
- 2019/2020 – LS2 — LIU Ion project hardware installation completed
- 2021 - Pb-Pb 2.85 $nb^{-1}$ — Commissioning and full production run 1st year after LS2
- 2022 - Pb-Pb 2.85 $nb^{-1}$
- 2023 - pp reference run
- 2024, 2025.6 - LS3 — 4 years without ions – run L3 and LEIR in 2026 for training?
- 2027 - Pb-Pb 2.85 $nb^{-1}$
- 2028 - ½ Pb-Pb 1.5 $nb^{-1}$ + ½ p-Pb 50 $nb^{-1}$
- 2029 - Pb-Pb 2.85 $nb^{-1}$
- 2030 LS4

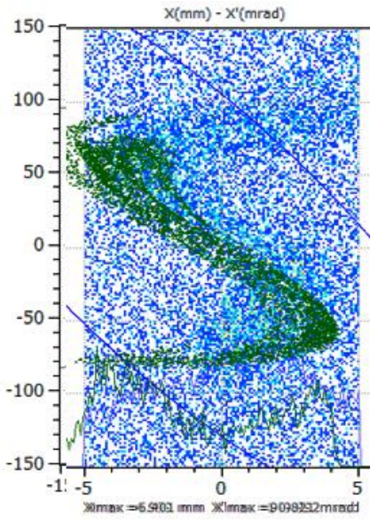
# Baseline Beam Parameters

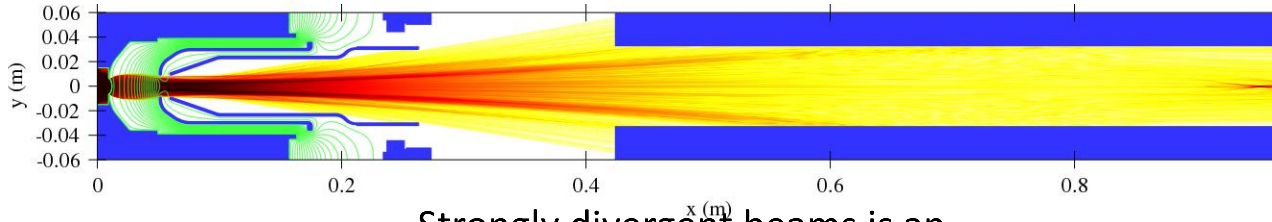
- Increase at maximum the intensity per bunch.
  - More intensity from LEIR
  - More intensity from L3 and increased rep. rate.
  - Reduction of losses at RF capture in LEIR.
- Transverse emittance is less important than intensity



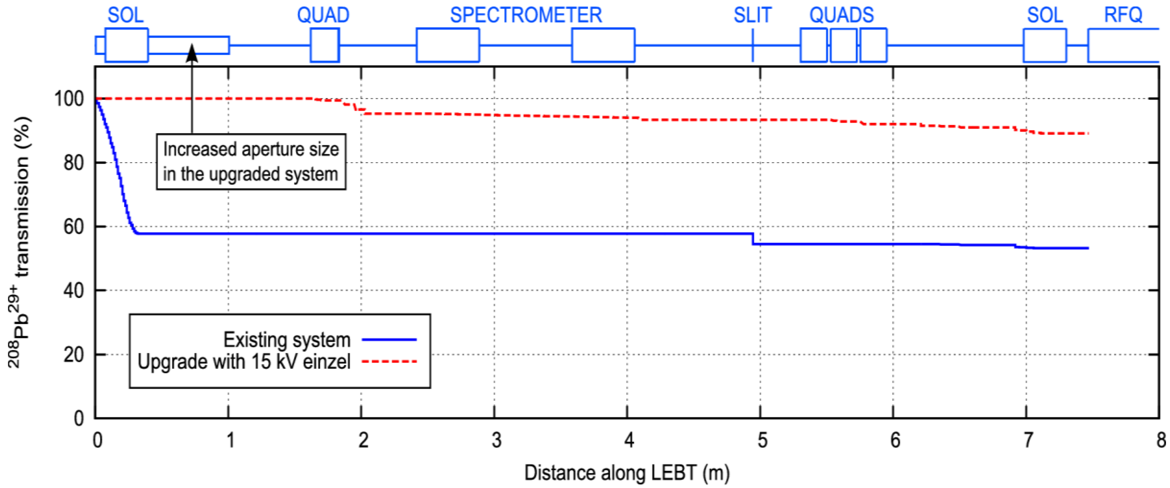
# 2015 Progress – Source and Low Energy




Extensive simulations to match model to simulation for transport through spectrometer.

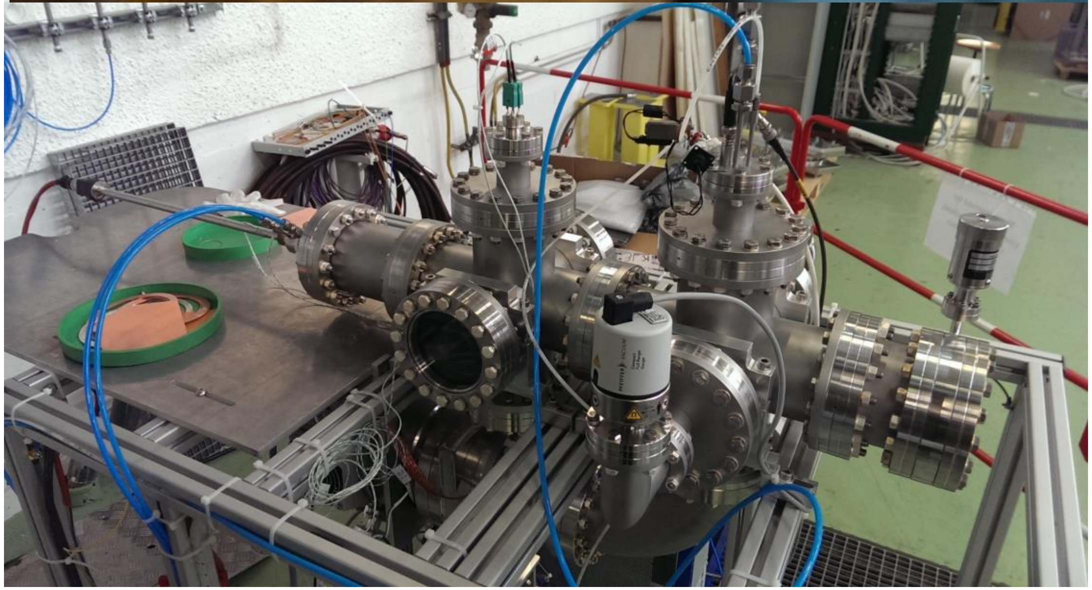
Strongly divergent beams is an inherent property of the current GTS-LHC extraction system when operated in afterglow mode.
Simulation predicts large beam loss straight after extraction.

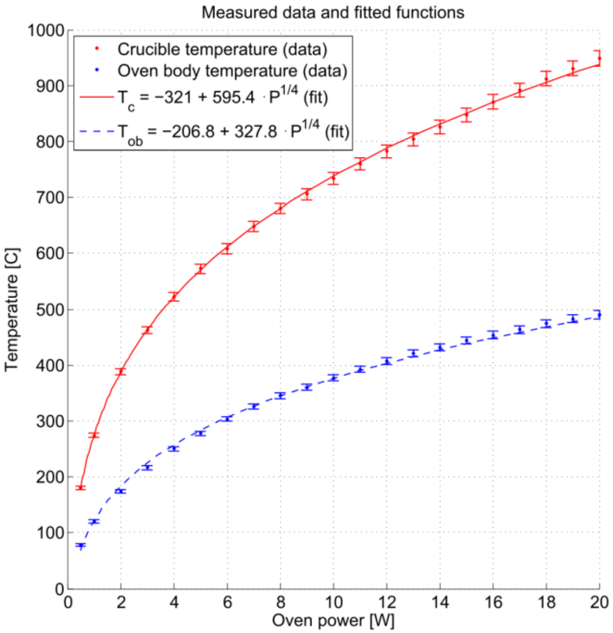



The best estimates from simulations is the 10-15% more intensity can be transported inside the acceptance of the RFQ.
Implementation in YETS15-16.

# 2015 Progress – Oven Test Stand

Oven test stand has been constructed.

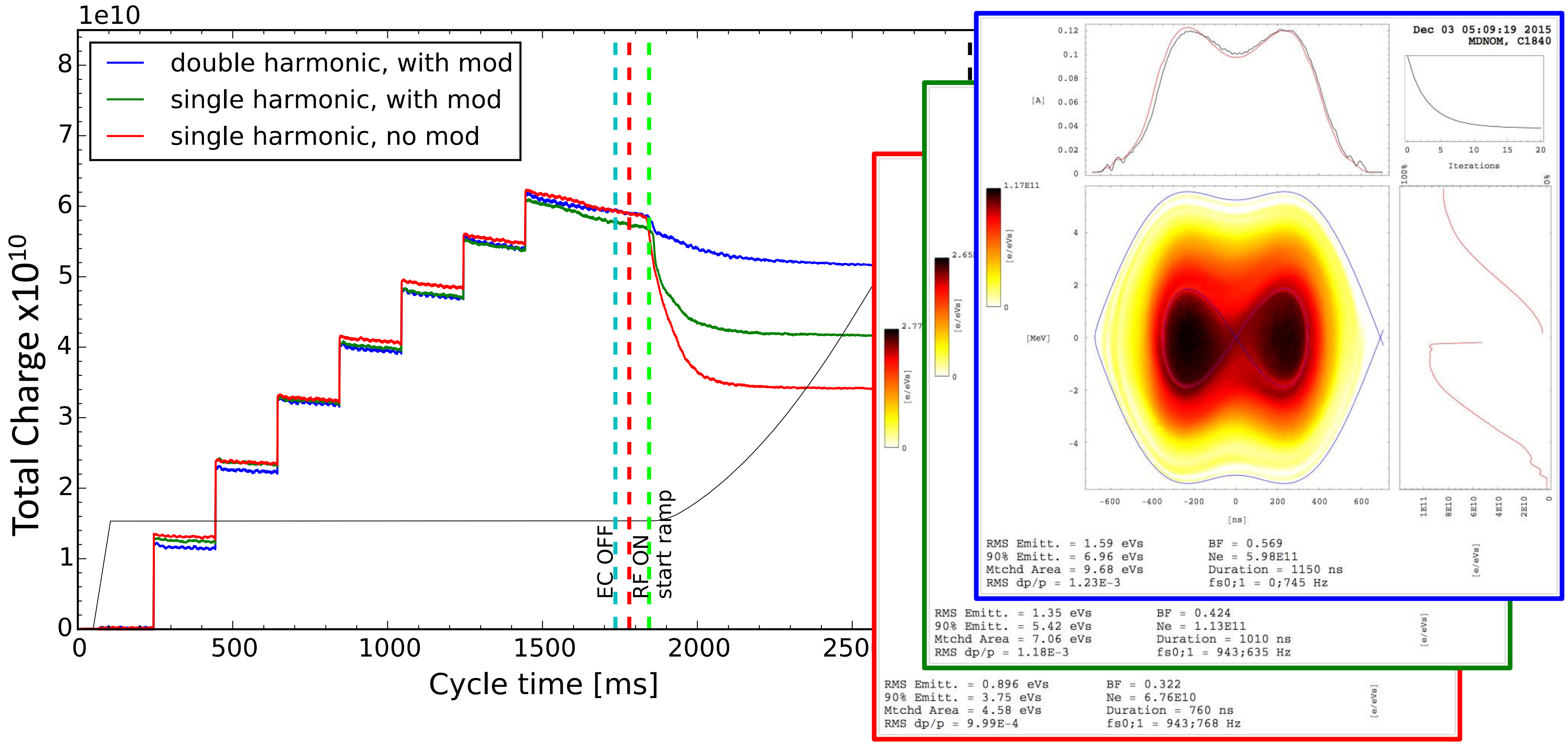




# 2015 Progress

- From October 2015 an **intensive** study programme started, with new team members.
- Using the available equipment, the performance could already be increased for the 2015 Pb-Pb run.
- The studies converged on the likely reason for the losses at RF capture.

# 2015 Progress – Understanding LEIR limitation 1

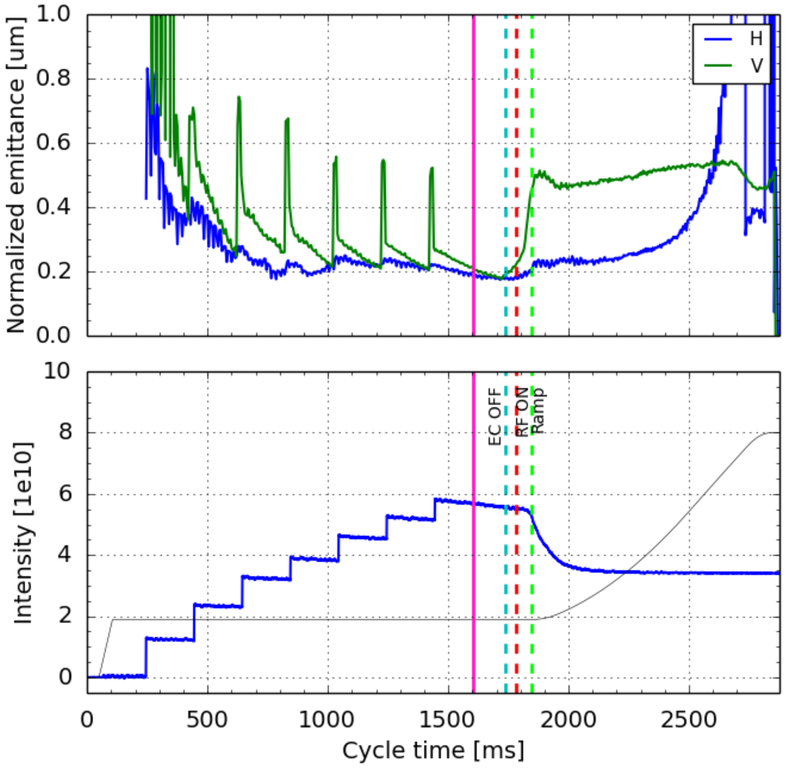


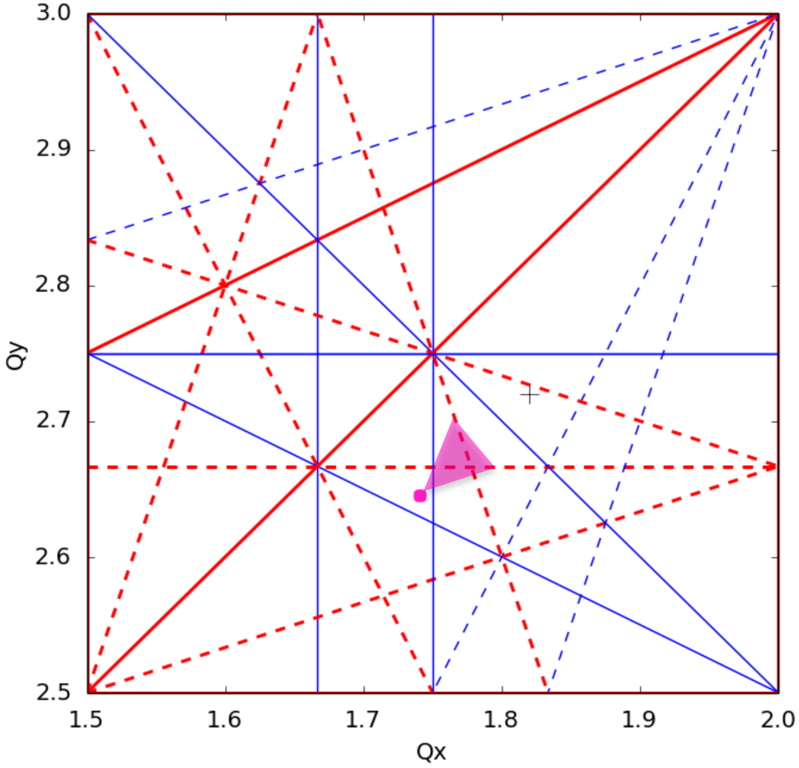

- Iso-adiabatic capture in single/double RF with and without gun modulation (longitudinal blow-up)
- Clear dependence of losses on line charge density
- Highest intensities achieved with flat bunch profile in double harmonic (hollow distribution)

# 2015 Progress – Understanding LEIR limitation 1

Accumulation

- Space charge tune spread increases along with injections and cooling



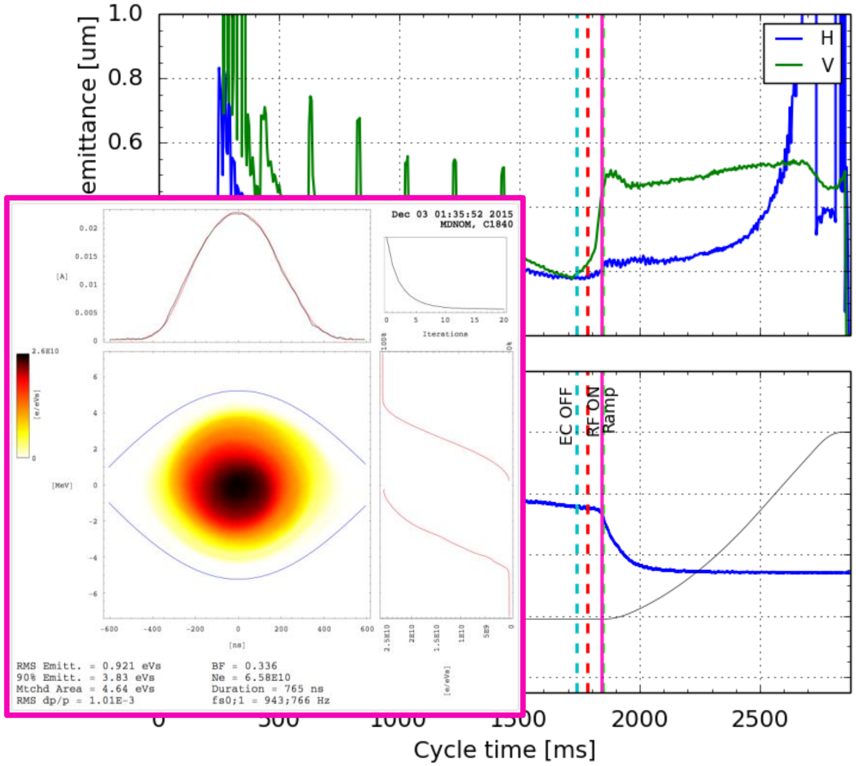
# 2015 Progress – Understanding LEIR limitation 1

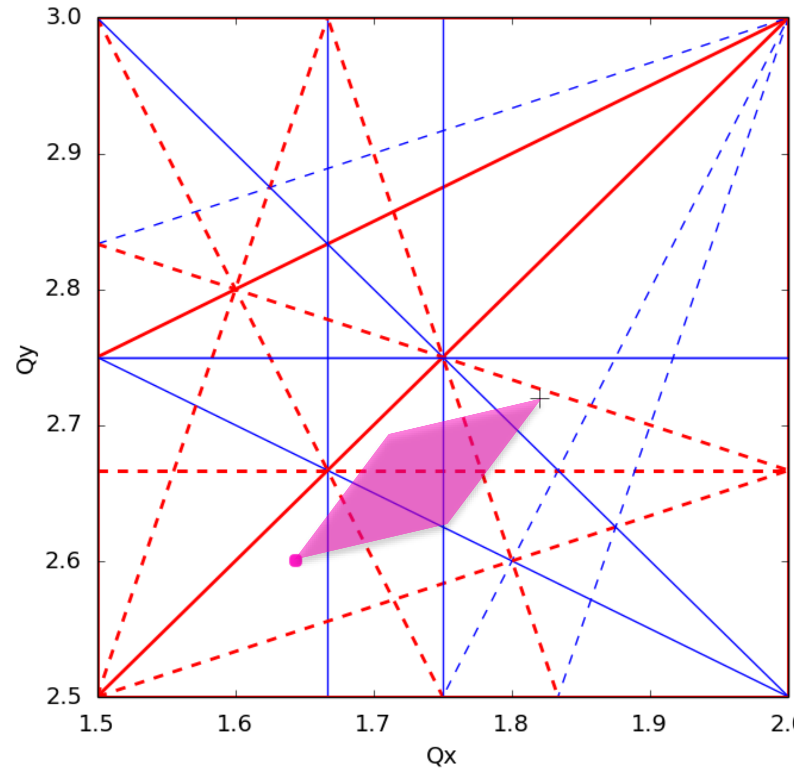
Accumulation

- Space charge tune spread increases along with injections and cooling.

Capture

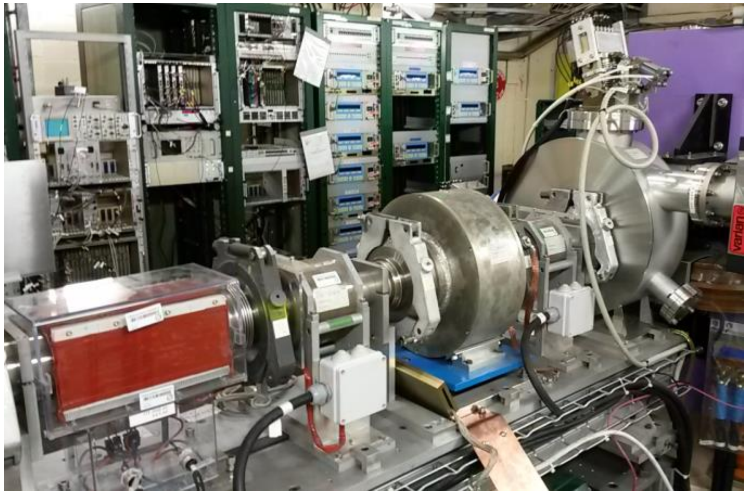
- Space charge tune spread increases (~ factor 2) and particles are pushed onto betatron resonances → emittance blow-up and losses.



# YETS 2015-16 : What is happening

- Baseline implementations, towards more intensity:
  - Upgrade of power convertors in Linac3 and transfer line, magnet thermal interlocks, and Linac RF to allow 100ms spaced injections into LEIR in 2016. The schedule for these is advanced to take advantage of the 2016 Pb running.
    - Caveat: Available for testing but not for production until consolidation of Linac hall ventilation in LS2.



  - Modification to source / Low energy region to remove aperture limitation and add focusing.
- Improvements in instrumentation:
  - Changes to intensity (Linac3) and profile (transfer line) and low Linac energy emittance measurement hardware.
  - More Transverse feedback signals to be available.
- Open the LEIR extraction sector to look for an obstacle that required a large bump to be created in 2015.

# 2016 Priorities

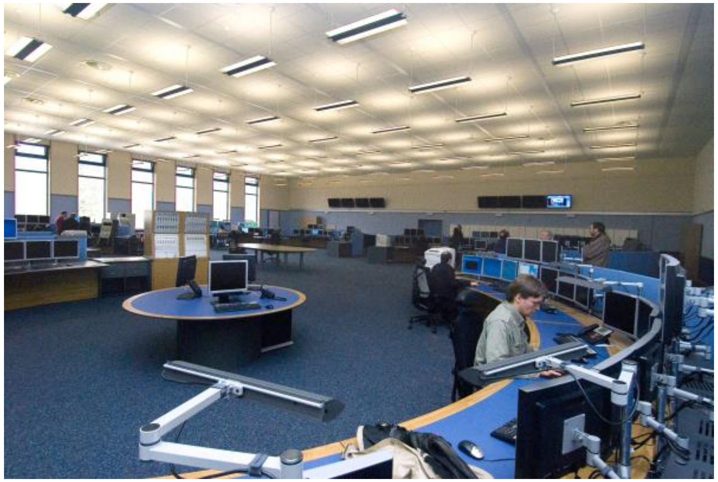
- Commission the Linac3 modifications.
- Test LEIR performance with more (higher rep-rate) injections in June.
- Complete studies (with beam and simulation) to identify more clearly brightness limitations, and what can be done to reduce losses e.g.:
  - Further increase bunching factor / longitudinal emittance (further advances could be made with 2 cavity operation, requires DLLRF modifications – manpower limitations).
  - Move to a working point further from resonances (optics study).
  - Understand and implement resonance compensation with available magnets.
  - Impedance model of LEIR.
- Decide on further improvements to instruments. Several improvements desired, but not yet included fully into the baseline. As examples:
  - Turn by turn position trajectory to look for resonances.
  - Online pick ups in the (100m) transfer line would improve operability.

# 2016 Further Mitigations to be Explored

- Consider alternative methods of gaining intensity (within specs).
  - Source second frequency tuning test of Linac3 – First test in Spring 2016.
  - Different Linac stripper foil type – First test in 2016.
  - Alternative RF schemes in the ion chain…
  - Shorter LEIR cycles (2.4 s cycle with approx. 2015 intensity)…
- Work is already underway to quantify these proposals, to give the cost and performance improvement.

# Making LEIR like the other LHC injectors

- Operation – Long term goal to better integrate LEIR into operation of SPS:
  - Use more LSA and YASP to speed up operational setting up and tuning.
  - Develop applications for some tasks, (by SPS operators, with look and feel of SPS, e.g. equip state).
  - Training for operators.
  - Get the operators involved in:
    - Cold check out
    - Beam setting up through scanning (specifically for optimization).

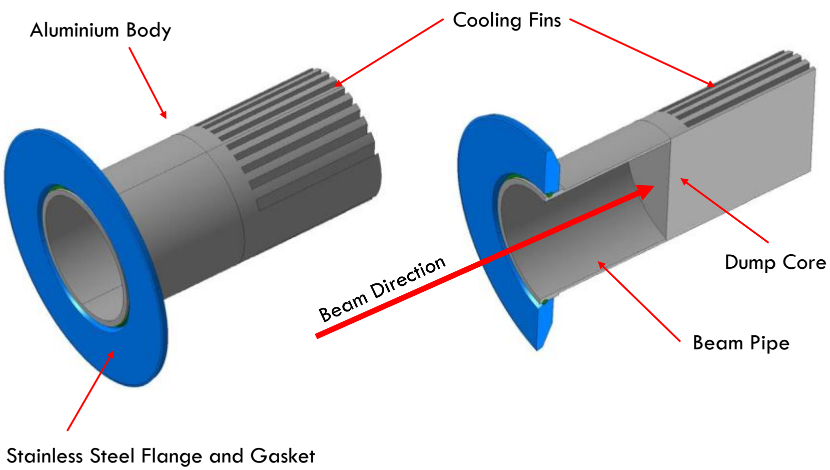


# Making LEIR like the other LHC injectors

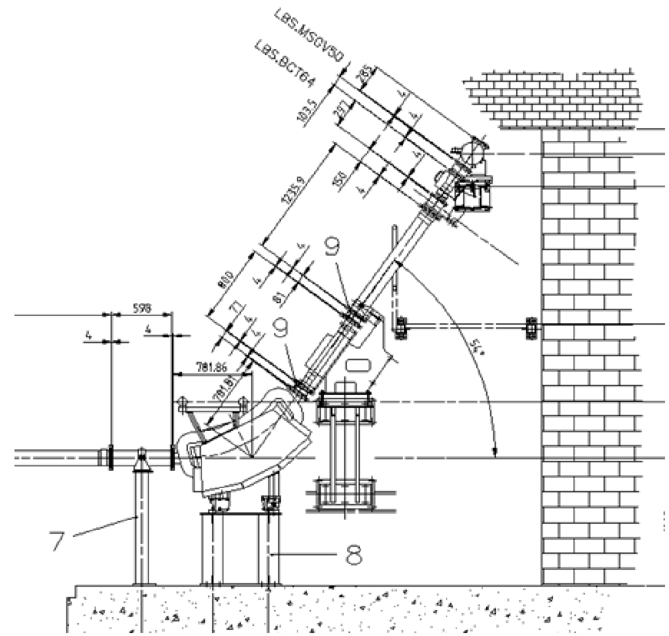
- Beam Physics
  - Reinforced accelerator physics (ABP / RF / OP / electron cooling) measuring, analysing and modelling LEIR. This support (and from other groups) needs to be maintained at a high level.
  - Dedicated time for Machine Development in 2016 (~18 weeks – restart).

# Other Hardware Baseline Modifications

- LEIR External beam dump.
- Provide a safe beam dump for accelerated ions not request by the PS.
- Thermal and radiation modelling ongoing.
- Layout and integration needs finalisation.
- Aim to install in YETS 17-18. Activity coordinator(s) will pick this up very soon with all the stake holders.




- Linac High Energy Spectrometer Line (LBS)
- Recover this for ion use. Replace magnet, power convertor and improve controls.
- Will lead to same accuracy but better operability.



# Summary

- The PS Ion Injectors have been profited from a lot of beam study in 2015. The achieved intensity has increased by 30% over LEIR/LHC nominal parameters.
- For the present LIU-IONS baseline a **~25%** increase (over 2015) to **$7.4x10^8$** ions per bunch are expected out of LEIR.
- Several methods for doing this are in progress, and will be tested in 2016 Machine Developments:
  - 7 -> 13 Linac3 injections with 10-15% more intensity.
  - Further machine modelling, and tests of ways to increase the space charge limit.
  - By the end of 2016, all hardware modifications for intensity improvement will have been implemented.
- The beam performance and operations team have been reinforced, and the ions project reorganised to confirm the importance of ions.
- 2016 is a ***critical year for development and study***, and it is ***vital*** that the high level of support towards Linac3/LEIR is maintained throughout the LIU project.

# Thanks

## Thanks for your attention

And thanks to the work of the whole Linac3 and LEIR LIU team…

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