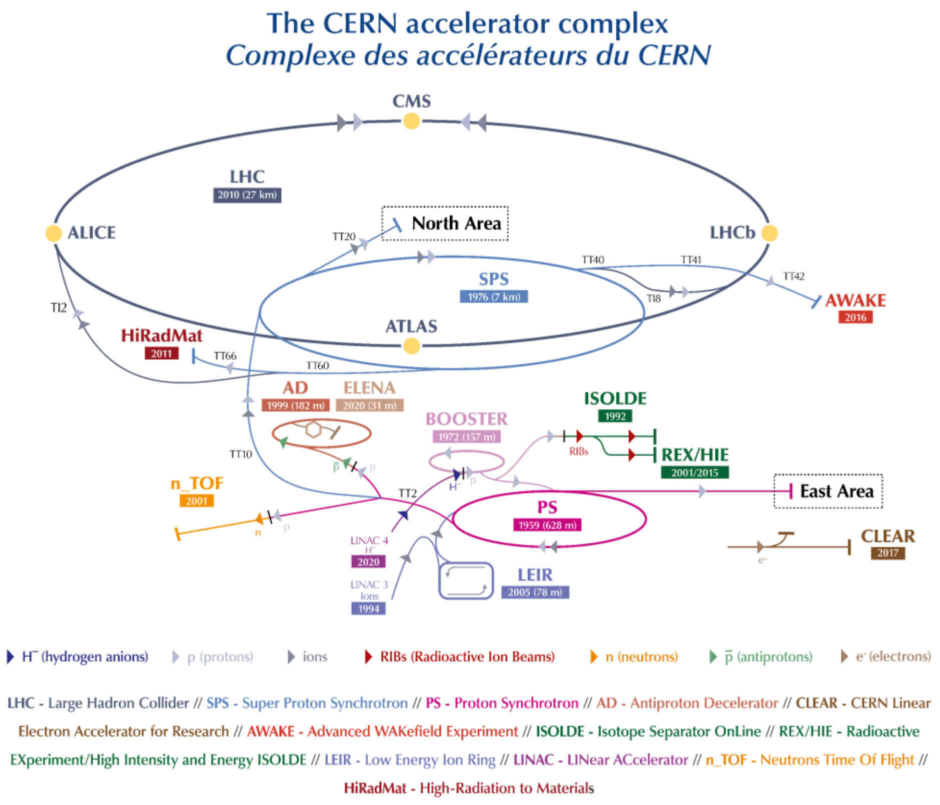
Accelerator Complex Capabilities WG in PBC

Conveners: H. Bartosik, G. Rumolo

WG composition:

- H- source development/Linac4: E. Sargsyan
- PSB: S. Albright, F. Asvesta, E. Renner
- ISOLDE-OP: J.A. Rodriguez Rodriguez
- PS: A. Huschauer, H. Damerau, A. Lasheen, B. Salvant, M. Vadai
- SPS: I. Karpov
- Ion chain: R. Alemany, N. Biancacci



Mandate

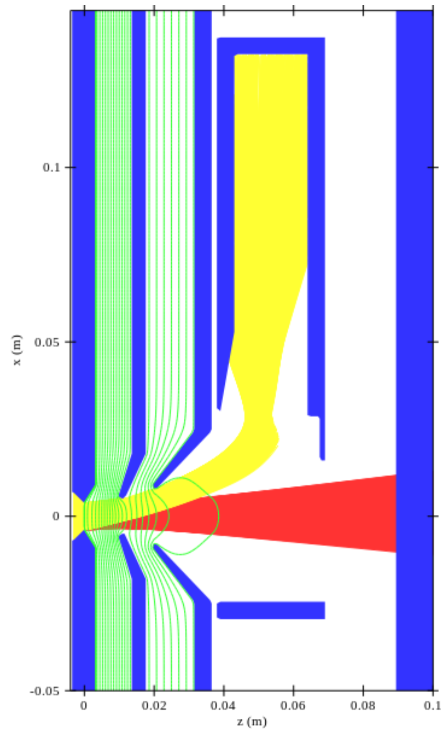
- Within the PBC Study Group the Accelerator Complex Capabilities Working Group (ACC-WG) will
  - Explore the **performance of Fixed Target beams in the whole CERN Accelerator Complex** using the full potential provided by the recently implemented **upgrade of the LHC injectors** and identifying remaining limitations in beam intensity, quality and availability;
  - Propose and document **alternatives, improvements, solutions** with the aim of **optimising proton delivery among different physics users** (proton sharing) and satisfy potential emerging physics requests.

Beam studies in 2021

- In 2021 the LHC injectors chain got back into operation after the extended upgrade executed during LS2 (mainly LIU)
- Main focus throughout the 2021 beam run
  - **Full recovery** of all the physics production beams in order to serve all the FT experiments coming back online after 2 years stop.
  - Demonstrate the **functionality of the LIU upgrades** to the production of LHC beams suitable for the HL-LHC era
- However, **a number of MDs and studies have been taking place** for high intensity (FT) beams in SPS pre-injectors, as well as for SPS slow extraction

Linac4 studies

- The present ISO3 H^- source gives 27 mA with ~35 mA into the RFQ
  - Corresponding to 1.5e13 p / PSB ring with 150 turns and 0.65 chopping factor
- **New ISNew source** (electron dump @45 keV and no Einzel lens)



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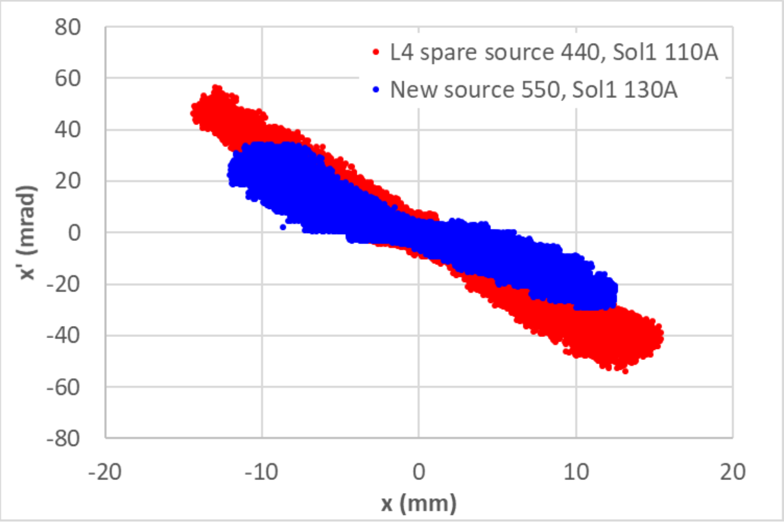
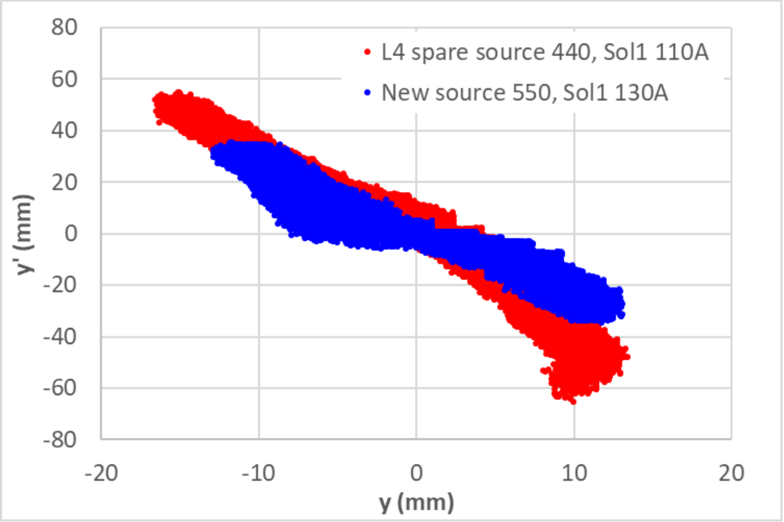
  - Better transverse emittance than ISO3 @35 mA

	SRC 440	SRC 550	Δ (%)
ε_x^{rms} (μm)	0.34	0.26	-23.5
ε_y^{rms} (μm)	0.40	0.32	-20.0





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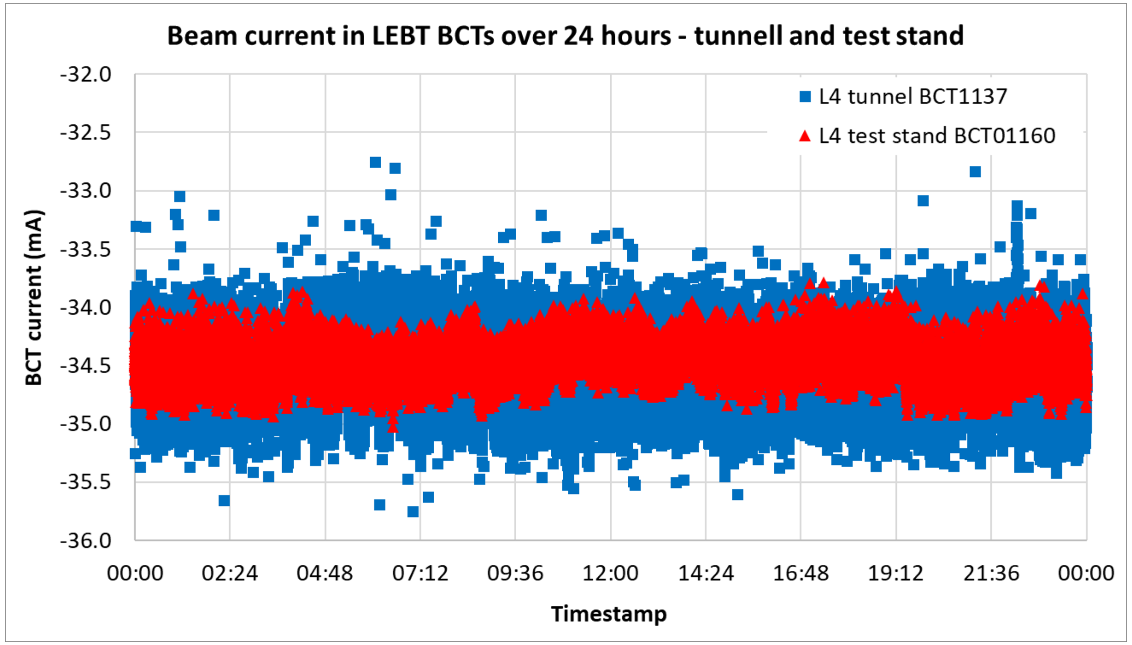

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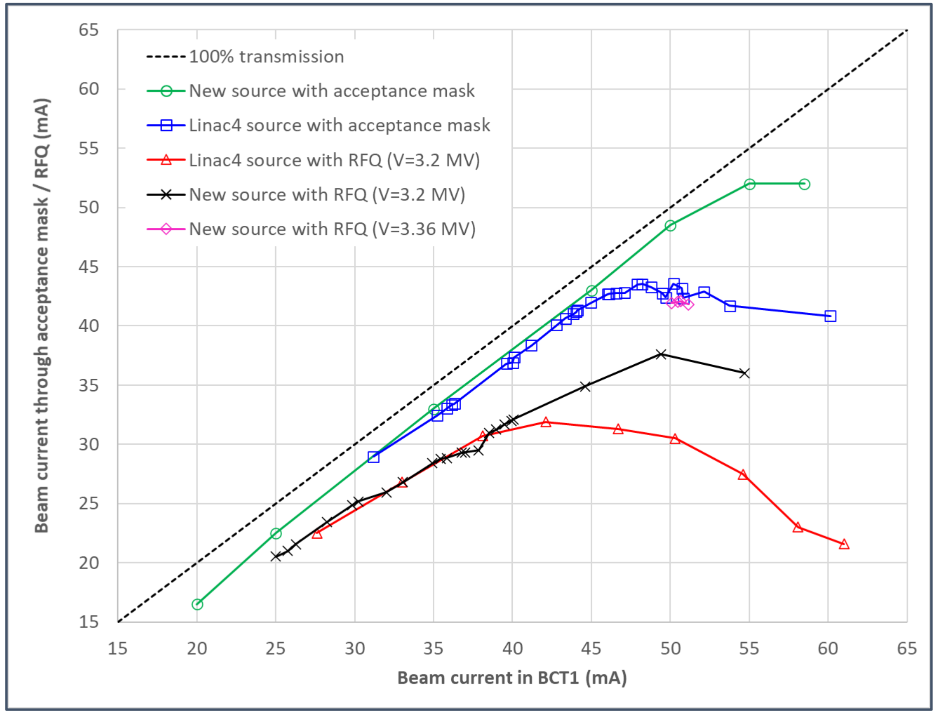
  - Better source stability
  - Better behaviour through RFQ mask
  - Better transmission also with RFQ demonstrated in Linac4 tunnel during test performed after the 2021 run



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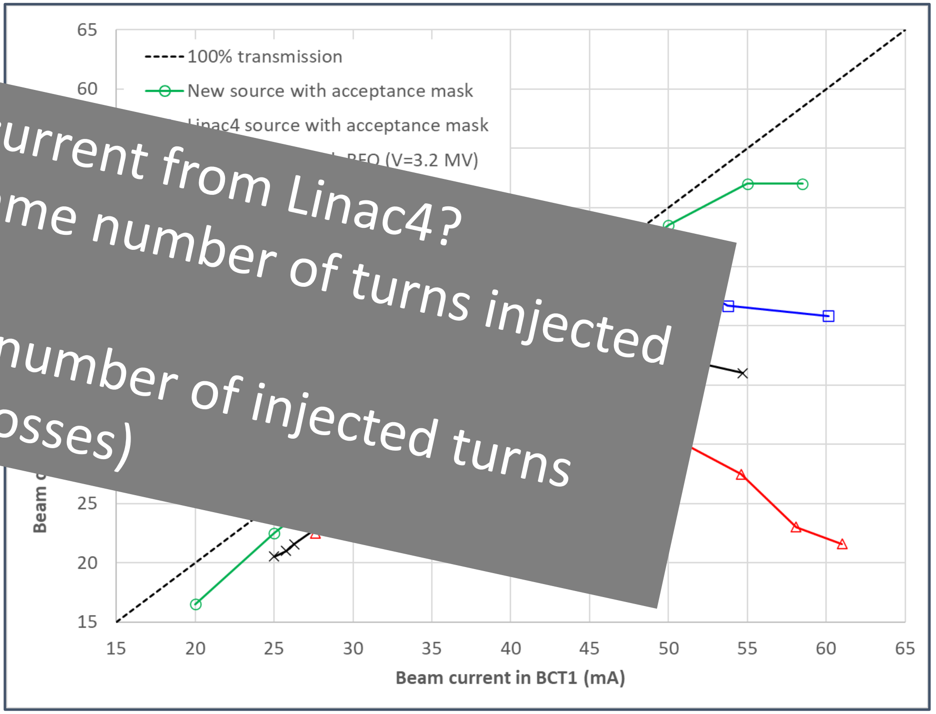
Can the PSB use a higher current from Linac4?

- Higher current for the same number of turns injected into each ring
- Same current for a lower number of injected turns (better brightness, lower losses)

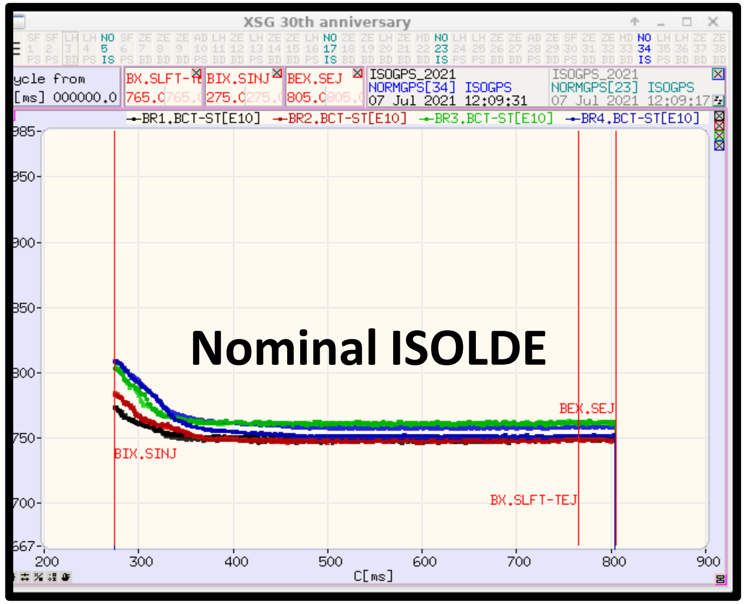


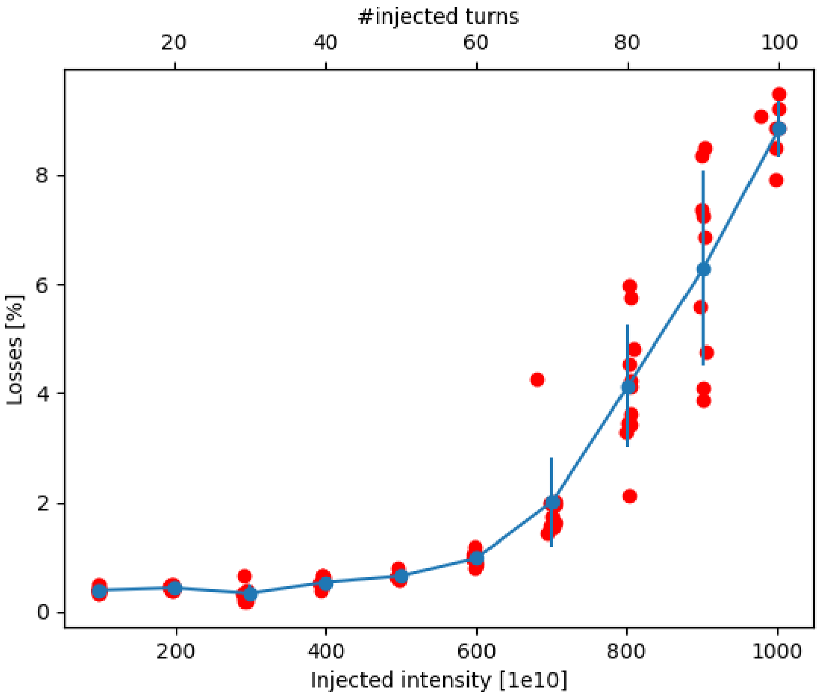
PSB high intensity studies

- Before LS2 the PSB could accelerate up to **1000e10 p/ring** with very high losses (30-40%) during the multi-turn injection process @50 MeV
- It was however regularly serving
  - ISOLDE with up to **800-850e10 p/ring**, typically 1/3 cycles in supercycle, not more than 2 μA to targets to limit irradiation in experimental hall
  - TOF with **800e10 p** out of Ring2 sent to the PS
  - MTE-type (or SFTPRO) with up to **600e10 p/ring**, extracted in 2 bunches/ring, vertical emittance below 4 μm

PSB high intensity studies

- After LS2 the PSB started serving ISOLDE in June 2021
- Losses were still relatively high in the first tens of ms after injection when increasing injected intensity

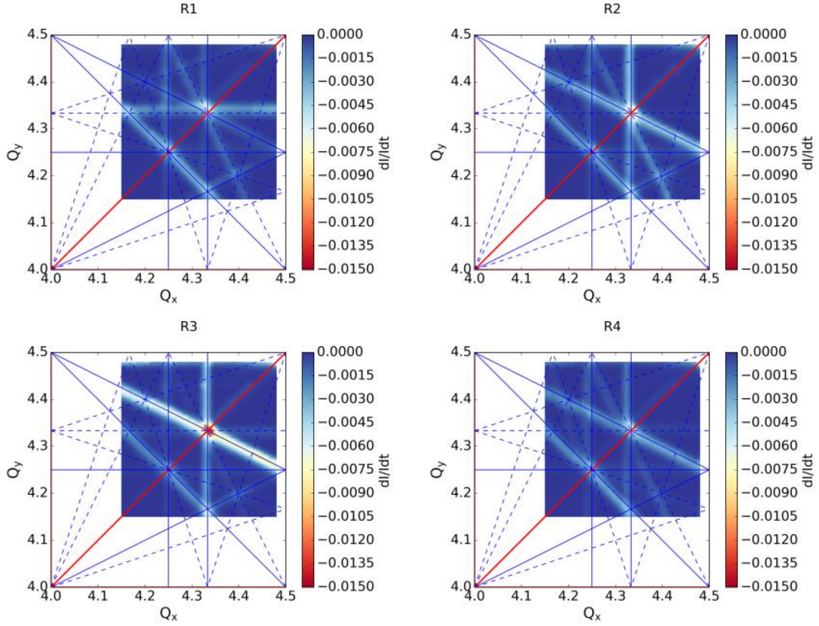




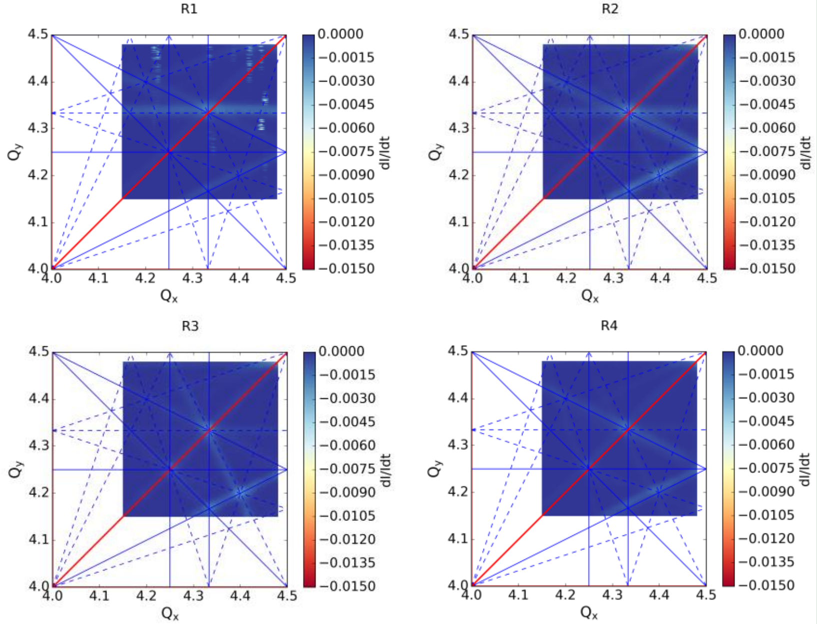
PSB high intensity studies

- Optimization of injection painting, Linac4 energy spread, resonance compensation

w/o resonance compensation



resonances compensated

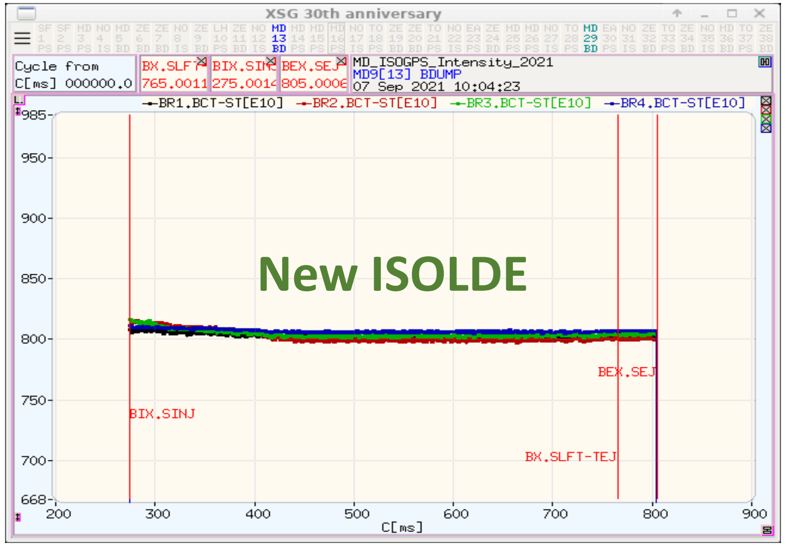


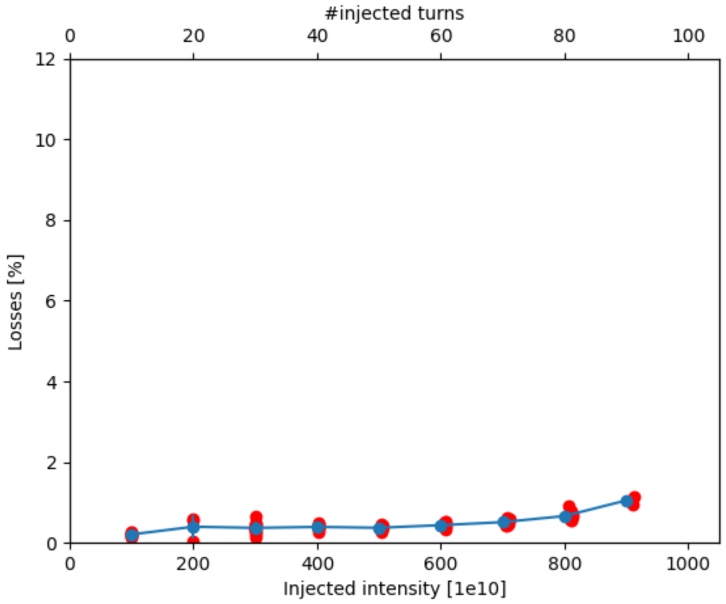
→ **Combining experimental, analytical & optimizer:**

✓ **Resonances satisfactory suppressed in the operational regime**

PSB high intensity studies

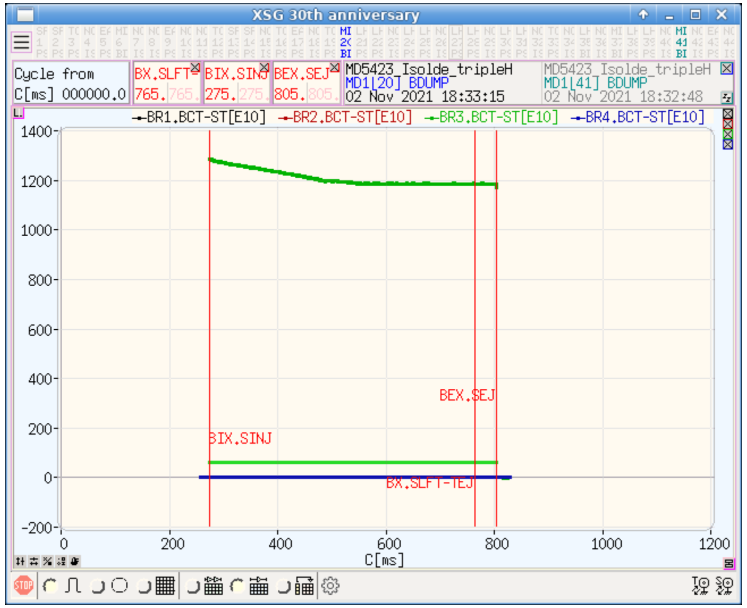
- Optimization of injection painting, Linac4 energy spread, resonance compensation
- Losses drastically reduced along the cycle, but above **900e10 p/ring** vertical emittance >6 μm causing losses on recombination septum





PSB high intensity studies

- Optimization of injection painting, Linac4 energy spread, resonance compensation
- Losses drastically reduced along the cycle, but above **900e10 p/ring** vertical emittance >6 μm causing losses on recombination septum
- **Work in progress**: Capture in triple harmonic allows for **1200e10 p/ring** with acceptable losses (<5%) and emittances!



PSB high intensity studies: outlook

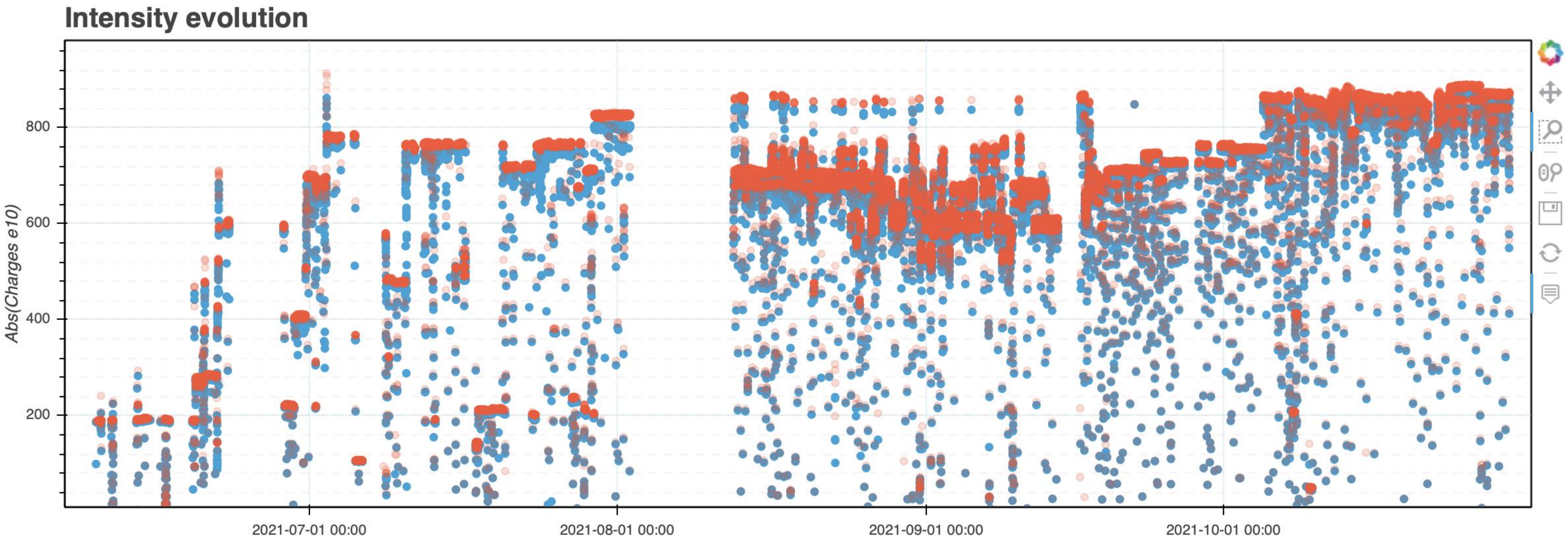
- Explore **intensity reach with maximum number of turns** injected and pin down limitations in different operational setting ranges
  - Continue triple harmonic capture deployment
  - Further optimise resonance compensation along the cycle
  - Test longitudinal painting
- **Input from RP on acceptable losses** along the cycle and @extraction to be able to perform these studies – first discussions took place
- **Simulations of PSB beam production** to
  - Match current operational experience
  - Extrapolate to higher Linac4 current to determine benefits in intensity reach, brightness, expected losses

TOF in the PSB

- Produced in the PSB with up to **1.05e13 p** with 110 turns injected, albeit with 8% beam loss
  - Further development similar to ISOLDE beams
- **Horizontal instability close to 2 GeV** encountered, had to be **stabilized with linear coupling**
  - Not caused by unmatched termination of extraction kicker**, impedance source still to be pinned down**

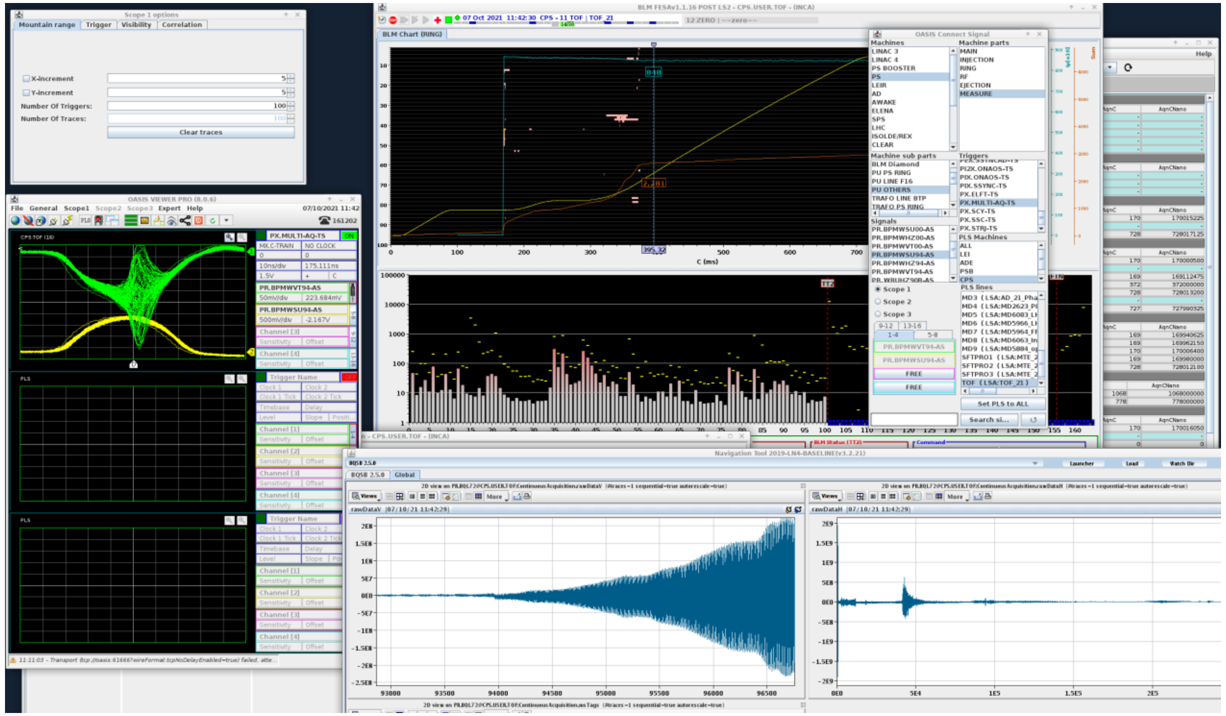
TOF in the PS

- Operationally delivered **850×10^{10} ppb** on the dedicated cycle
  - Parasitic TOF bunch on the EAST cycle available up to ~350×10^{10} ppb (only 200×10^{10} ppb requested this year)



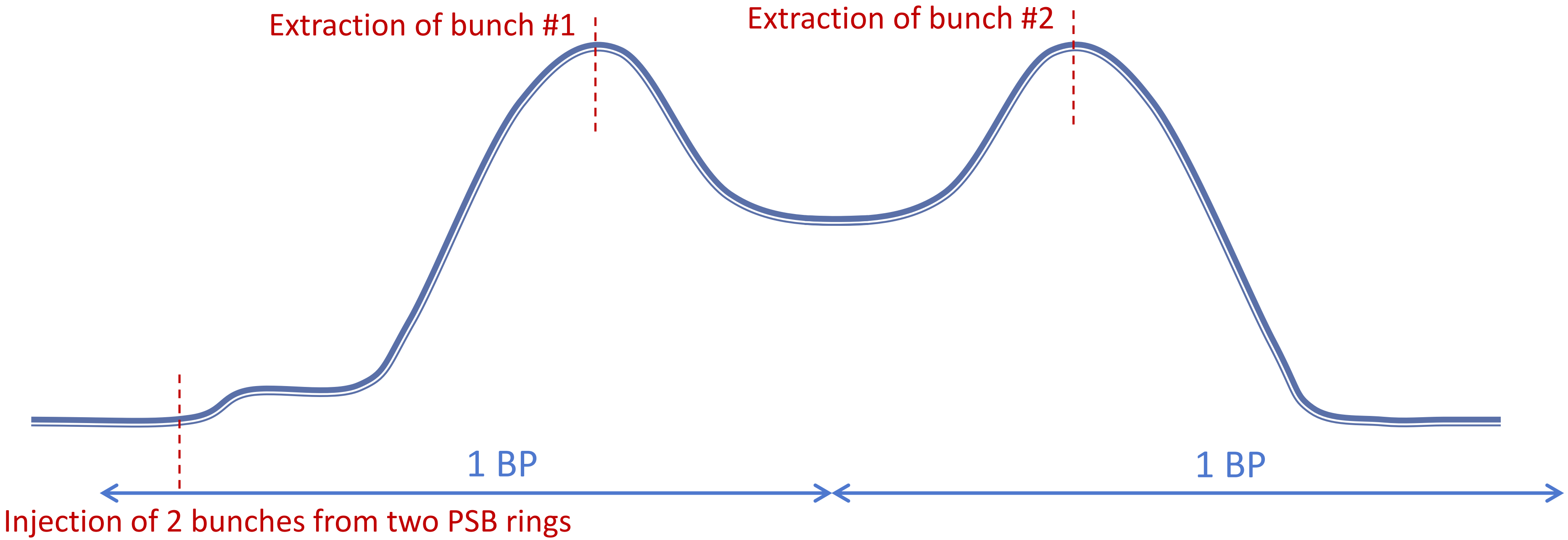
TOF in the PS

- Operationally delivered **850x10^{10} ppb** on the dedicated cycle
- Sometimes more important losses at transition crossing due to a **vertical instability**
  - **Currently cured with optimization of transition timings & γ-jump**, in the future more studies when pushing intensity to **>900e10 ppb**



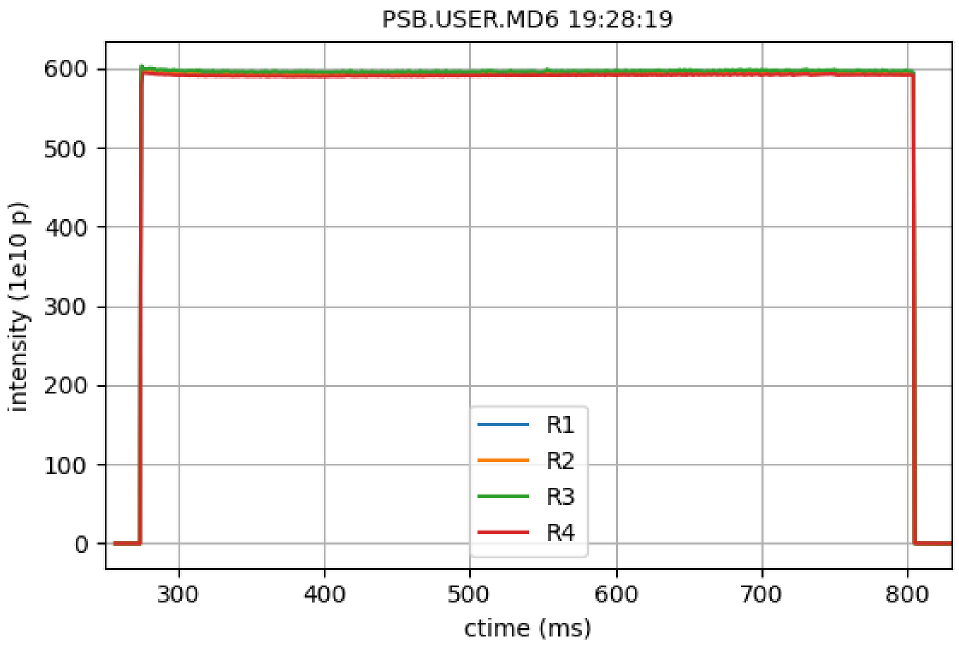
TOF in the PS: developments

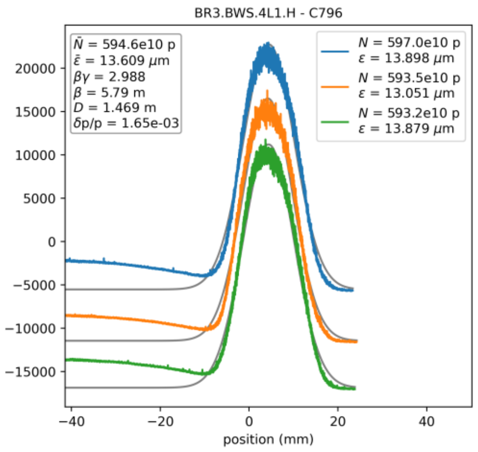
- For the future, the commissioning of the **M-TOF cycle** is foreseen to be deployed in order to free slots in the PSB
  - Tests done, intensity reach of two bunches in this configuration to be yet explored

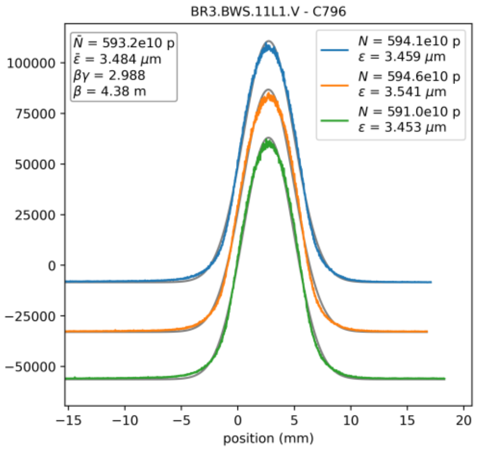


SFTPRO in the PSB

- Ready at PSB since April 2021 with up to **600e10 p/ring**
  - Excellent transmission
  - Suitable transverse emittances for PS-SPS (i.e. low vertical emittance)



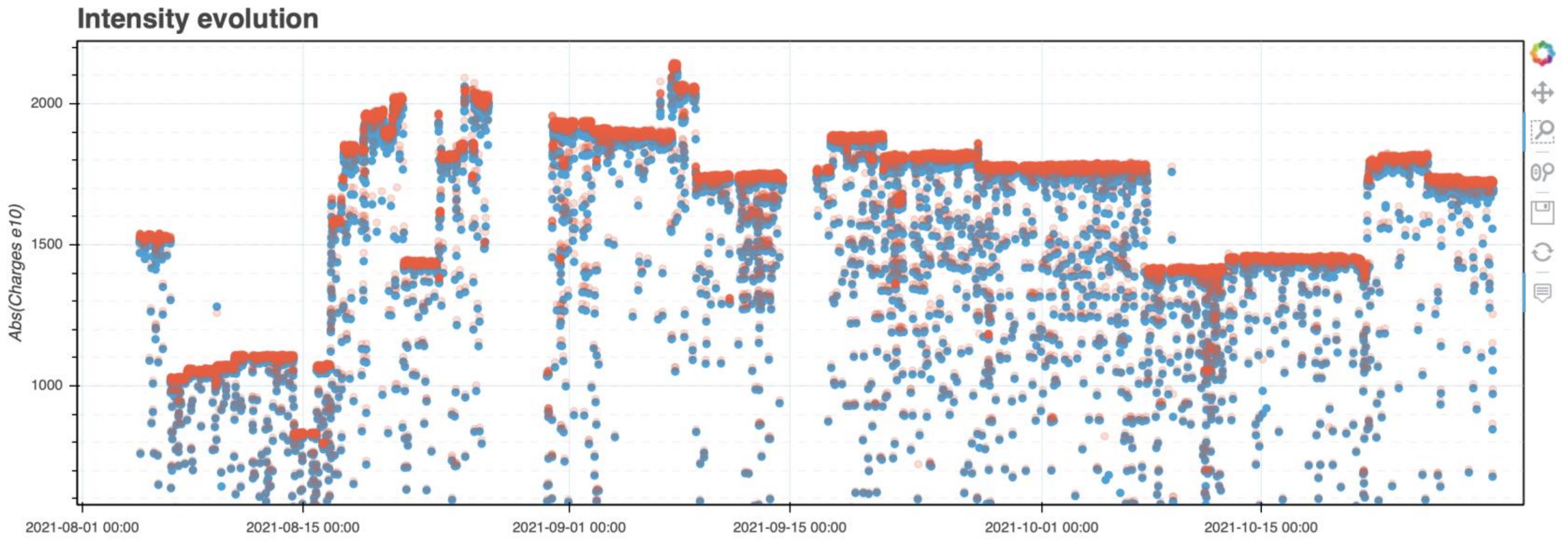




	N [ppr]	ε_x [μm]	ε_y [μm]
Achieved	600e10	13.5	3.5

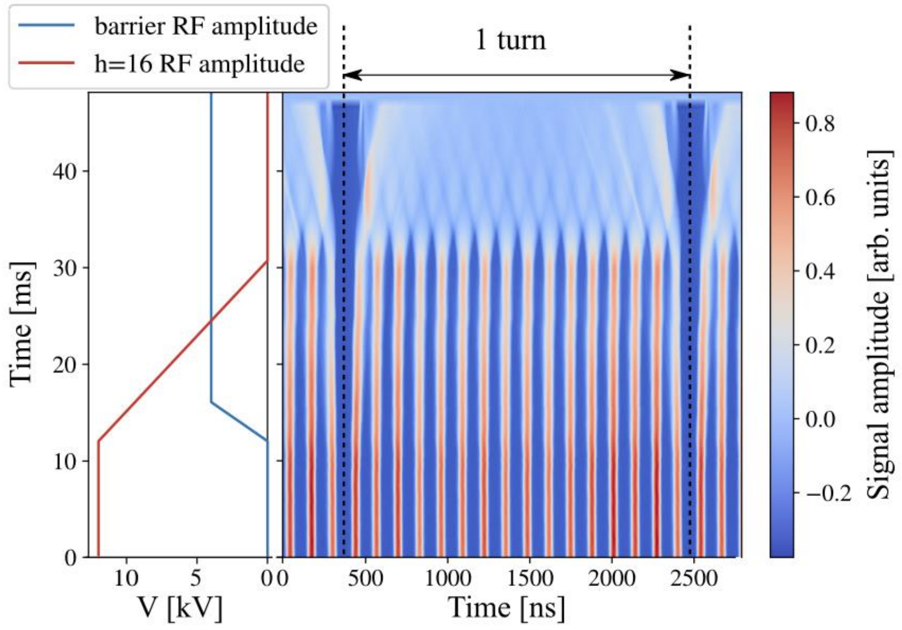
SFTPRO in the PS & SPS

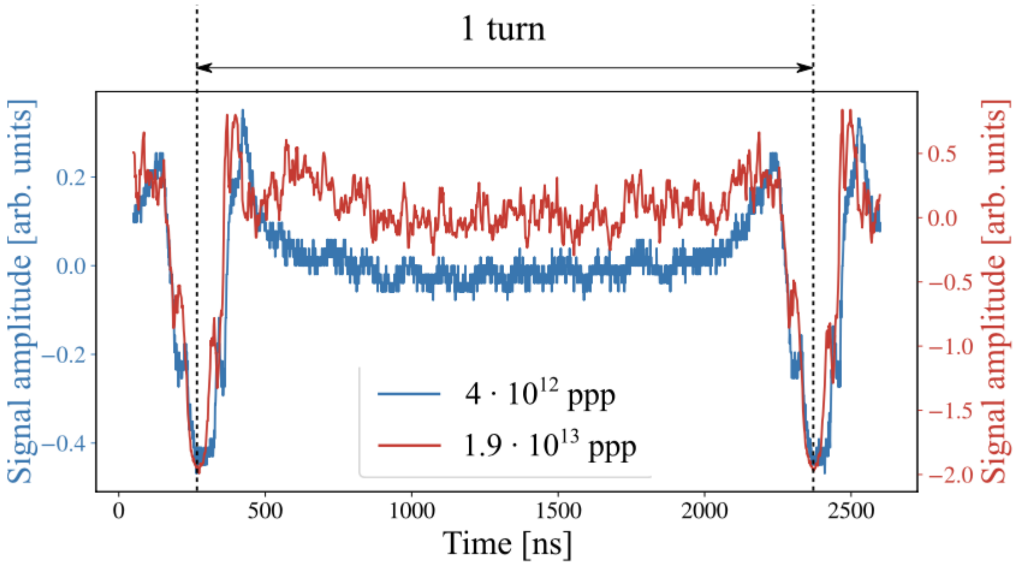
- Mostly operating at ~**1800x10^{10} p per PS cycle**
  - Different intensity steps during the year as required by users
  - Beam operation extremely stable with little need for operator interventions
  - Successful commissioning of SFTPRO cycle in SPS with new LL-RF



SFTPRO in the PS: developments

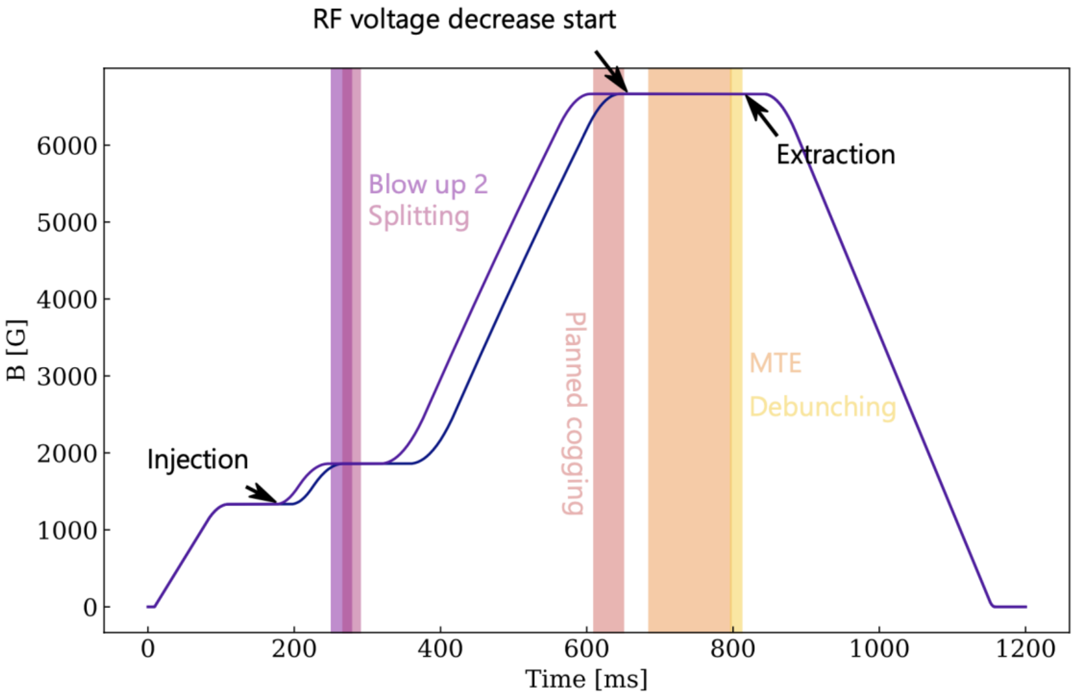
- Progress with barrier bucket to further reduce extraction losses
  - 2018 MD demonstrated the capture in barrier bucket (using the Finemet cavity) before extraction – no synchro to SPS





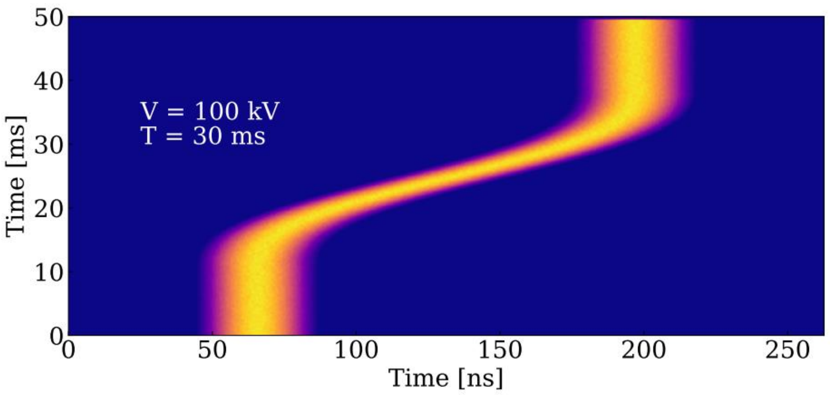
SFTPRO in the PS: developments

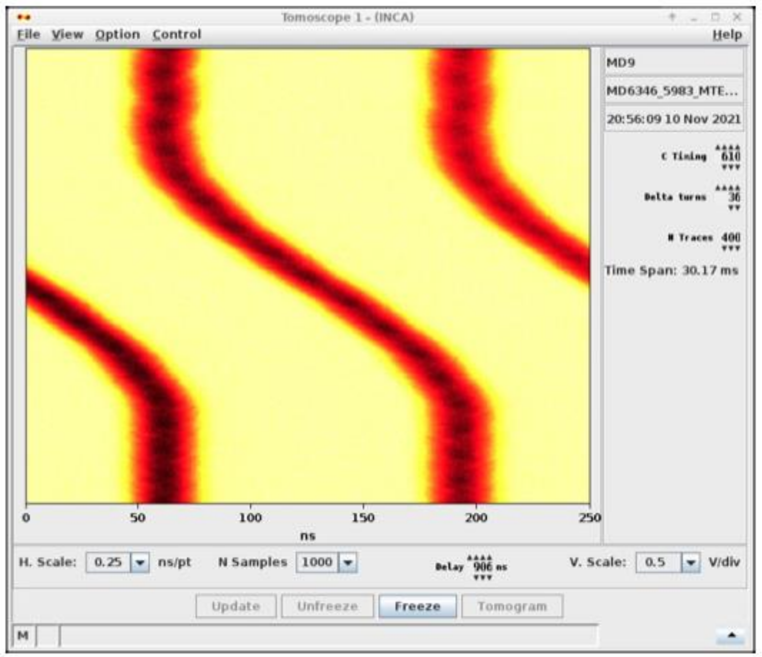
- Progress with barrier bucket to further reduce extraction losses
  - New SFTPRO cycle in 2021 with time for synchro at beginning of flat top



SFTPRO in the PS: developments

- Progress with barrier bucket to further reduce extraction losses
  - New SFTPRO cycle in 2021 with time for synchro at beginning of flat top
  - New hardware for cogging was finalized and connected to the LLRF chain
  - Phase correction for synchro over 30 ms, as tested in beam dynamics simulations, demonstrated with beam





SFTPRO: outlook

- Left to do with barrier bucket in the PS
  - Synchronisation to SPS using cogging
  - Increase of intensity (push to ~2500 – 3000 x 1010 p per PS cycle), which will require longitudinal stabilization and high intensity MTE on longer flat top
- SPS studies (especially when high intensity available in 2022)
  - Experimentally quantify the benefit of LIU-RF upgrades on fixed target beam
  - Operate fixed target beam with 800 MHz RF system active and use controlled longitudinal emittance blow-up to ensure longitudinal stability
  - Study possibility to optimise transverse settings to reduce losses

One word on the ions

- This year focus on recovery of LHC beams and PoP of beam stabilization and slip stacking in the SPS
- **Studies for the gamma factory**
  - One aspect is related to the **production of the PSI nominal beam** across the injectors chain and what limitations can be found at the different stages
  - **Beam dynamics of laser cooled ions needs to be included in our software framework** in order to make reliable predictions
- Additional studies
  - Possible benefits from further stripping ions before the PS injection (e.g., higher injection energy into SPS)
  - Any other ion beam types to PS EA or SPS NA?

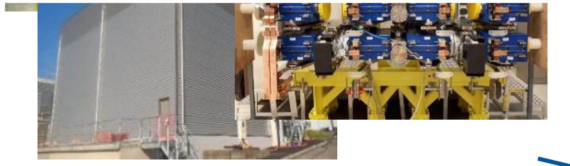
Conclusions

- LHC injectors have successfully returned to operation in 2021 after major upgrade implemented in LS2
- PSB high intensity
  - Reached **1200e10 p/ring @1.4 GeV** (20% more wrt pre-LS2) with <5% losses
  - Pushing intensity is key for Linac4 source/RFQ studies and future ISOLDE
- TOF beam
  - Currently in specs, higher intensities and new cycle to be tested in PS
- SFTPRO
  - Studies with barrier bucket hold promise of near operational deployment
  - High intensity to be tested in PS and SPS for possible future operational use

Backup

Quick overview on LIU

- Main **RF** system (200 MHz) upgrade → Increased RF power and improved controls
- **Impedance** reduction & partial a-C coating → Increased instability thresholds
- New **beam dump**

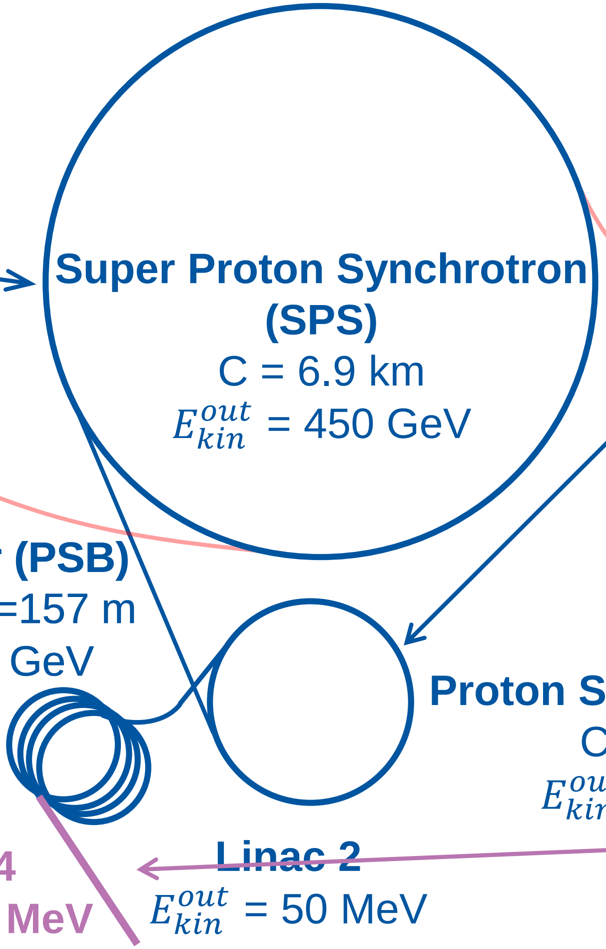


- **160 MeV** H^- charge exchange injection → Reduced space charge at PSB injection
- Acceleration to **2 GeV** with new main power supply and new RF systems

- **2 GeV** injection → Reduced space charge at PS injection

For all injectors :

- New/upgraded beam instrumentation and diagnostics devices
- Improved vacuum systems, software tools, protection devices and interlocks
- Upgrade of general services (i.e. cabling, electrical distribution, cooling and ventilation)



Super Proton Synchrotron (SPS)
C = 6.9 km
E_{kin}^{out} = 450 GeV

PS-Booster (PSB)
4 rings of C =157 m
E_{kin}^{out} = 1.4/2.0 GeV

Proton Synchrotron (PS)
C = 628 m
E_{kin}^{out} = 25 GeV

Linac 2
E_{kin}^{out} = 50 MeV

Linac 4
E_{kin}^{out} = **160 MeV**

- Acceleration of H^- to **160 MeV**
- Target 25 mA within 0.3 μm