



Status of LIU proton beams

F. Asvesta, Hannes Bartosik, E. de la Fuente, I. Karpov, S. Kostoglou, K. Li, I. Mases, L. Mether, G. Papotti, K. Paraschou, G. Rumolo, B. Salvant, M. Schenk, F.M. Velotti, C. Zannini

LHC Injectors Upgrade



Outline

- Operational BCMS beam in 2024
 - Optimizations applied
 - Performance evolution along the year
 - Beam degradation on SPS and LHC injection plateaus
- Status of LIU performance ramp-up
 - Intensity ramp-up
 - LIU BCMS beam
 - Other beams: standard, 8b4e, hybrid
- Summary and outlook

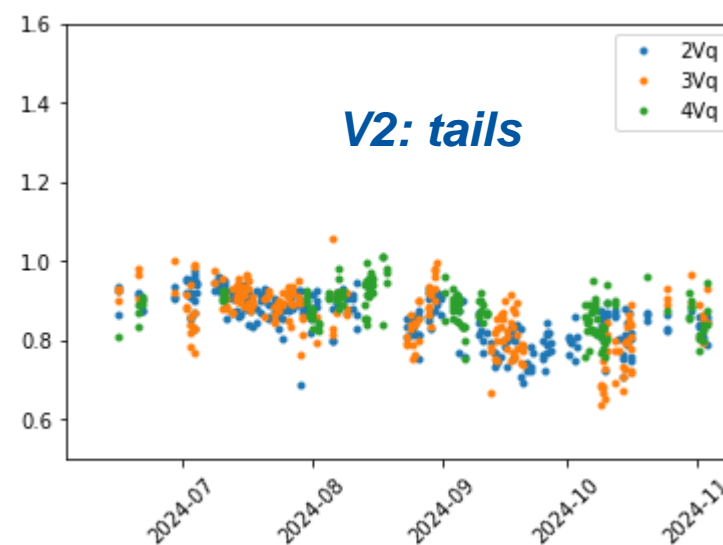
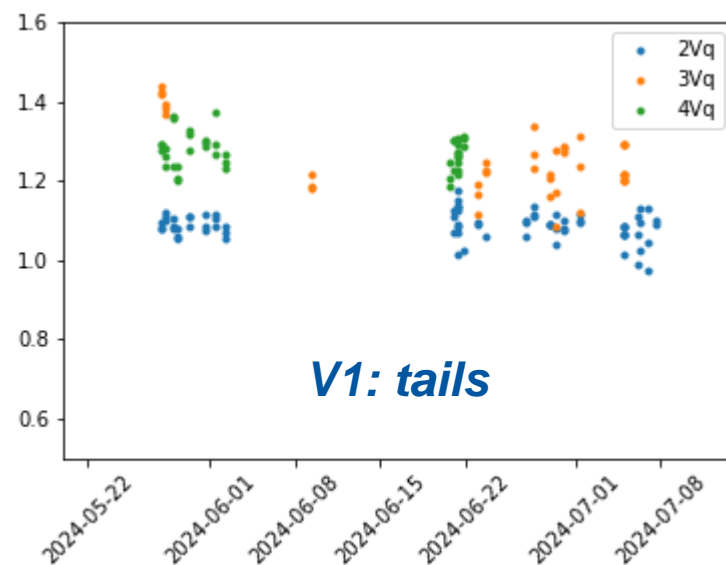


Outline

- Operational BCMS beam in 2024
 - Optimizations applied
 - Performance evolution along the year
 - Beam degradation on SPS and LHC injection plateaus
- Status of LIU performance ramp-up
 - Intensity ramp-up
 - LIU BCMS beam
 - Other beams: standard, 8b4e, hybrid
- Summary and outlook

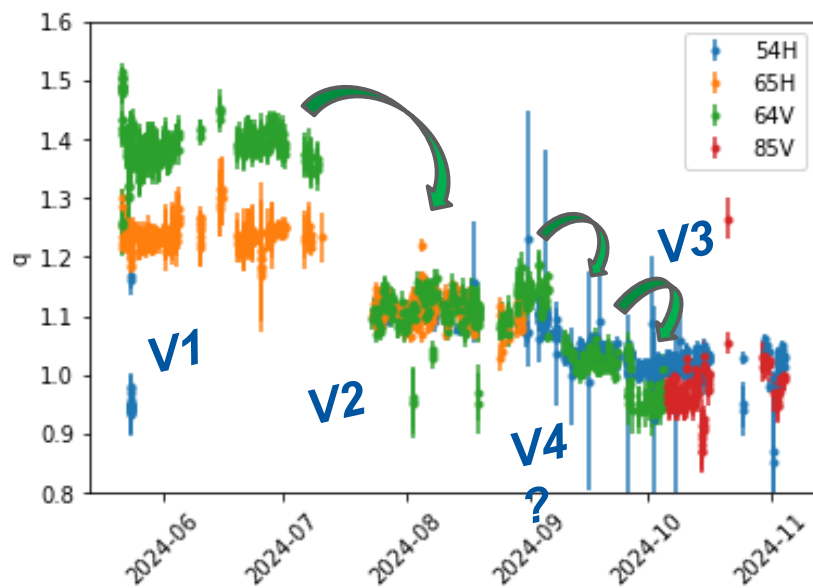
Optimization of BCMS beam in the PSB

- Effort mostly concentrated on tail reduction
 - V1: BCMS on LIU target: brightness margin was used for tails reduction ($\varepsilon \sim 1 \mu\text{m}/q \sim 1.3$ in vertical)
 - V2: Introduced scraping at low energy could give Gaussian profiles, propagated to operation ($\varepsilon \sim 1 \mu\text{m}/q \sim 1$ in vertical)

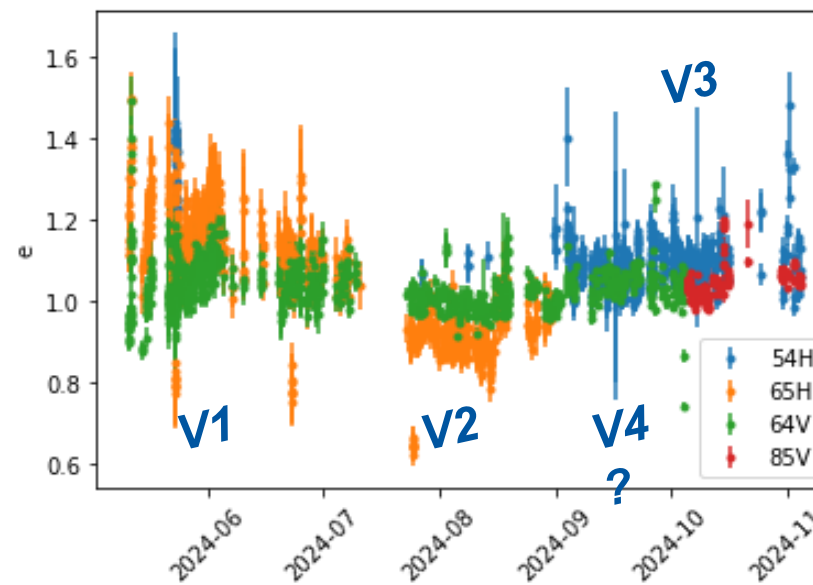


Optimization of BCMS beam in the PS

- Effort mostly concentrated on tail reduction
 - V1: close to LIU target & WP adjustments at transition for tail reduction ($\epsilon \sim 1.1 \mu\text{m} / q \sim 1.35$)
 - V2: Further optimization of WP around transition ($\epsilon \sim 1.1 \mu\text{m} / q \sim 1.15$)
 - V3: Further optimization of WP around transition & Chroma correction ($\epsilon \sim 1.1 \mu\text{m} / q \sim 1$)
 - V4?: Improvement couldn't be traced down to any particular setting or observable ...



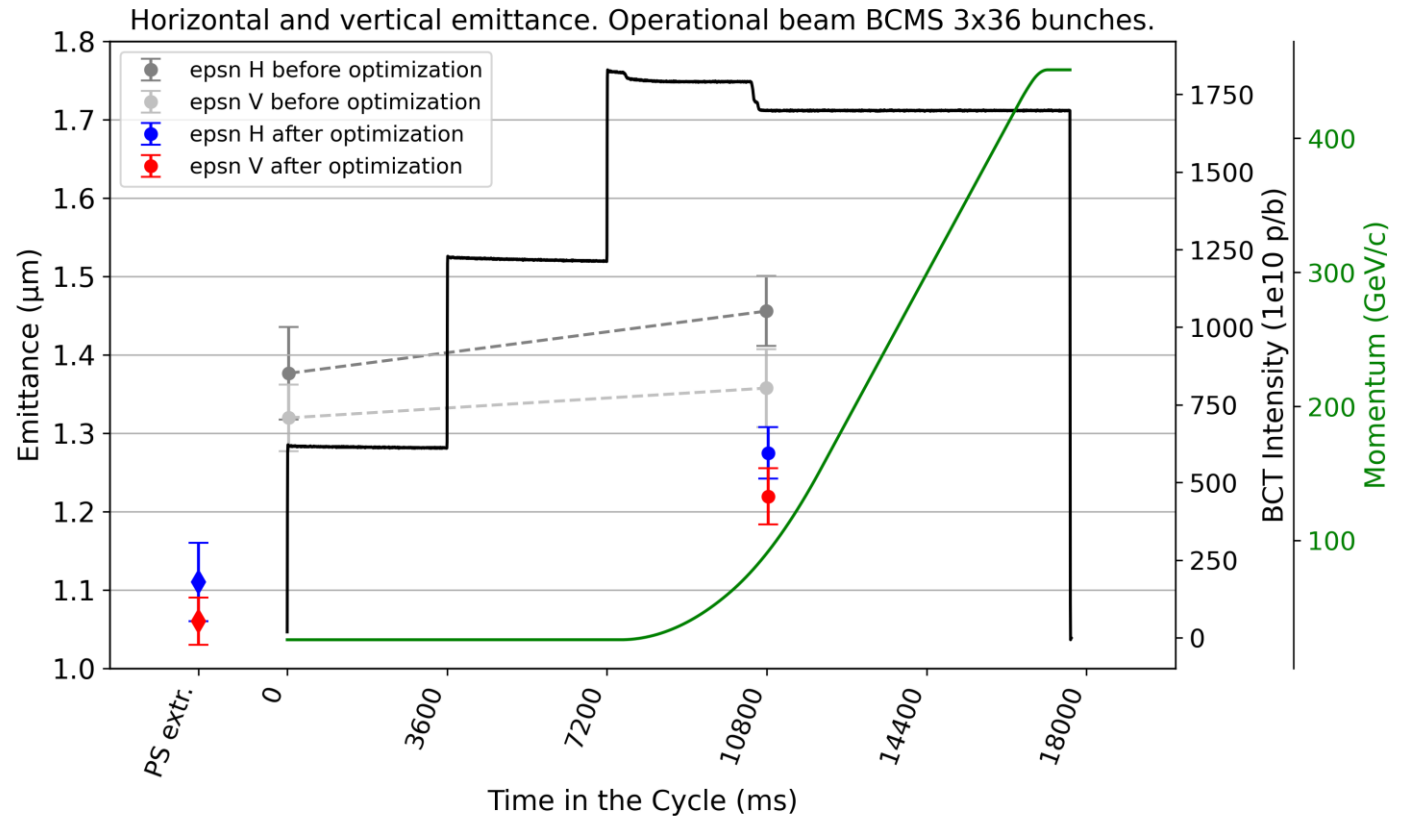
14 January 2025



HiLumi WP2 meeting, "Status of LIU beams"

Optimization of BCMS beam in SPS

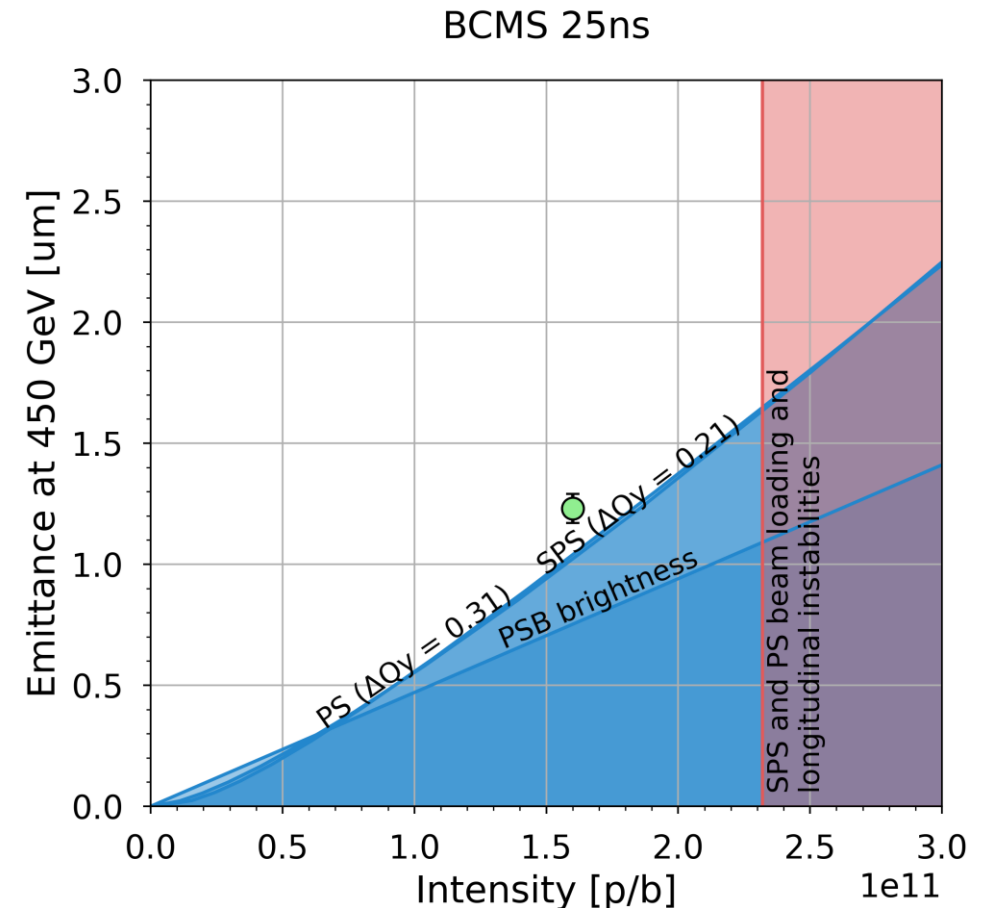
- Working point optimization to reduce emittance blow-up (23.05.2024)
 - **Keeping the incoherent tunes constant** along injection plateau (instead of coherent tunes as done in the past) to minimize blow-up from space charge



Optimization of BCMS beam in SPS

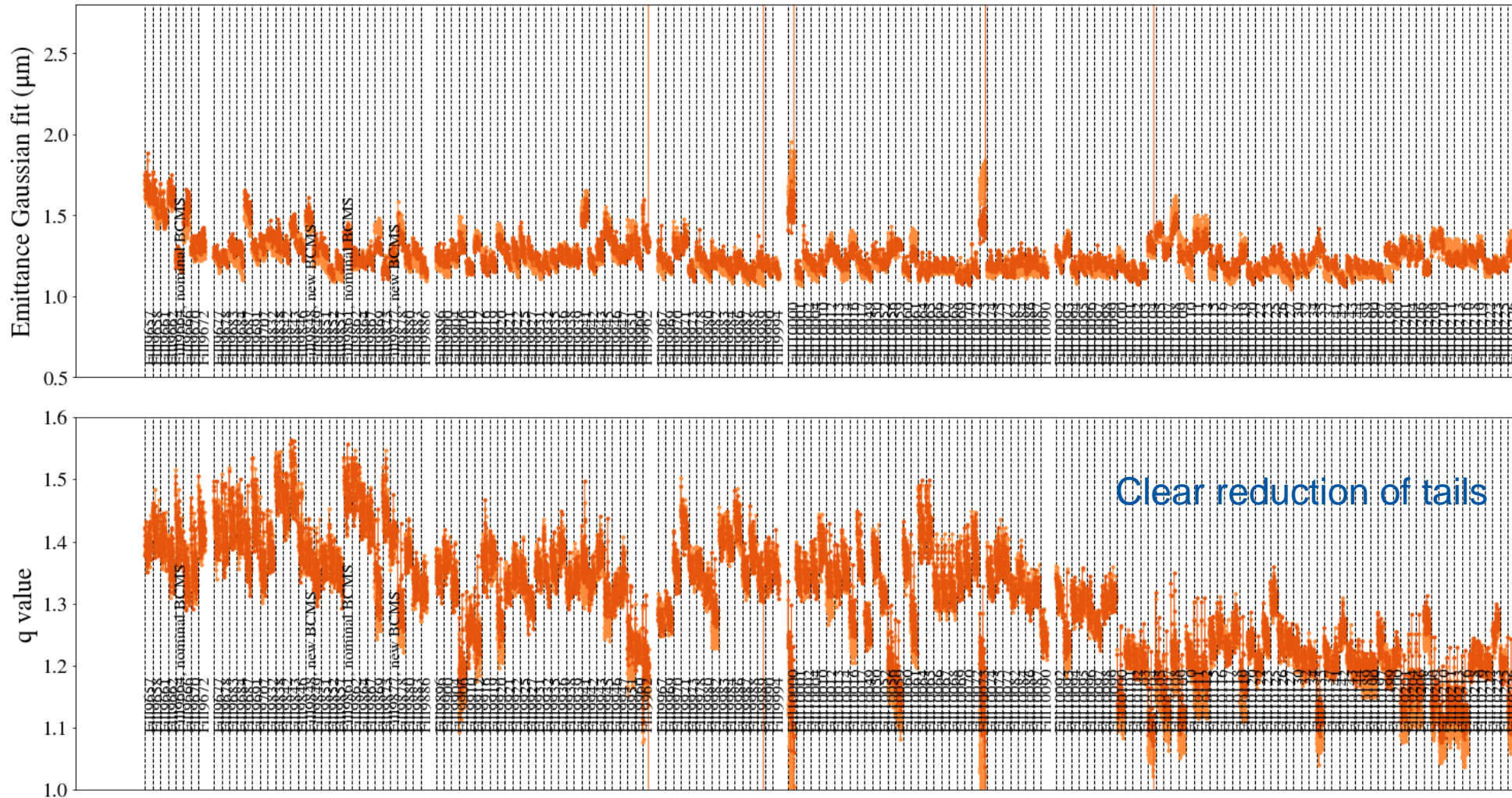


- Working point optimization to reduce emittance blow-up (23.05.2024)
 - **Keeping the incoherent tunes constant** along injection plateau (instead of coherent tunes as done in the past) to minimize blow-up from space charge
 - Within 15% of LIU brightness target
 - Further optimization of beam from pre-injectors along the year followed (mostly focused on tails)



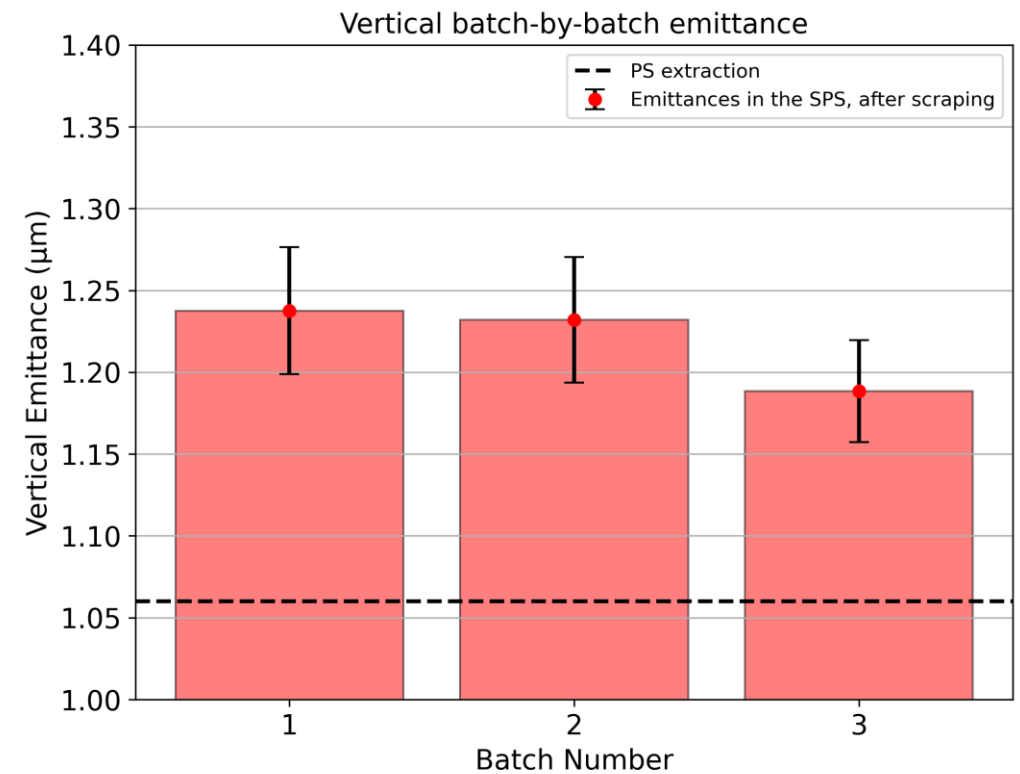
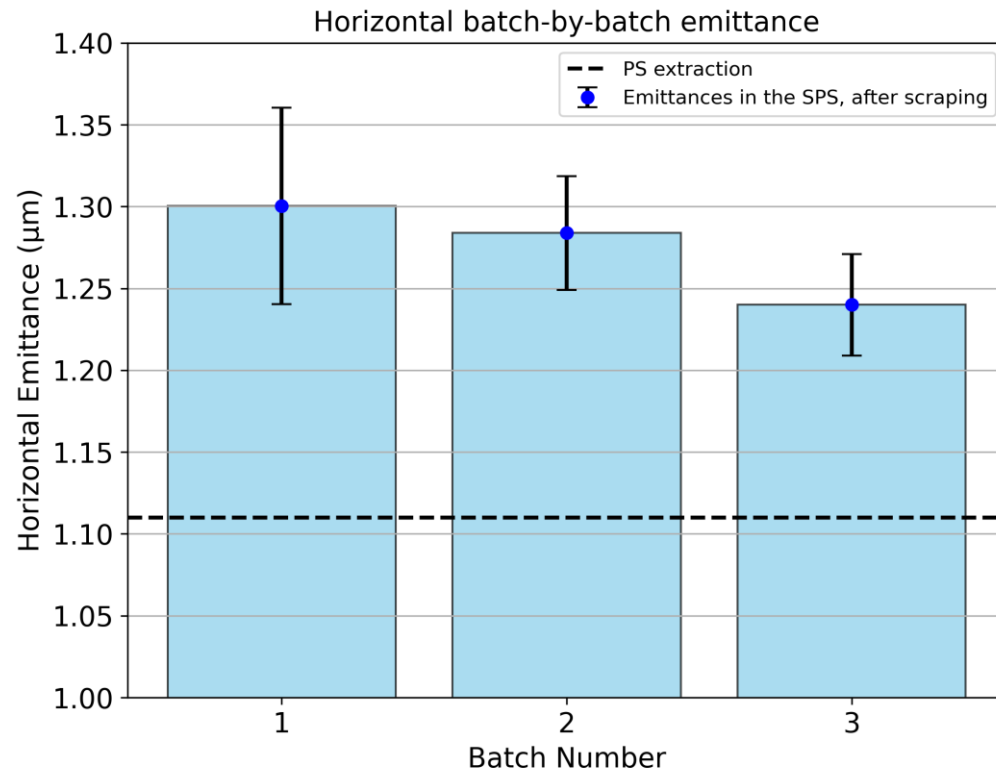
Evolution of emittances / tails at LHC injection

B1H, WS 2x36b



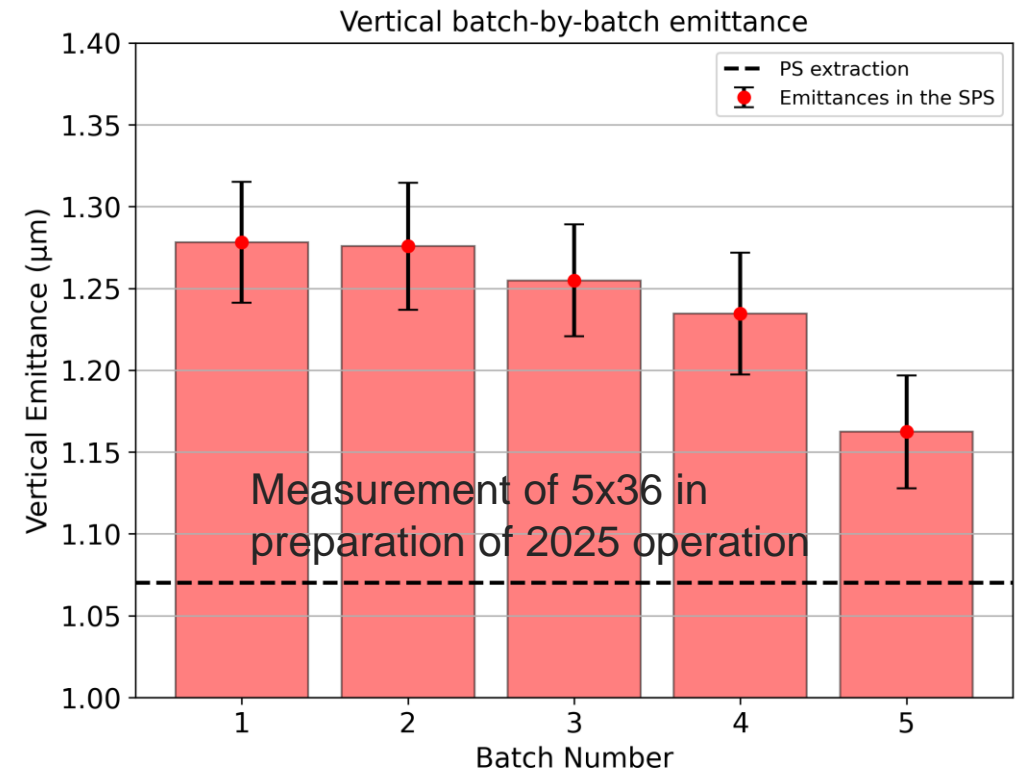
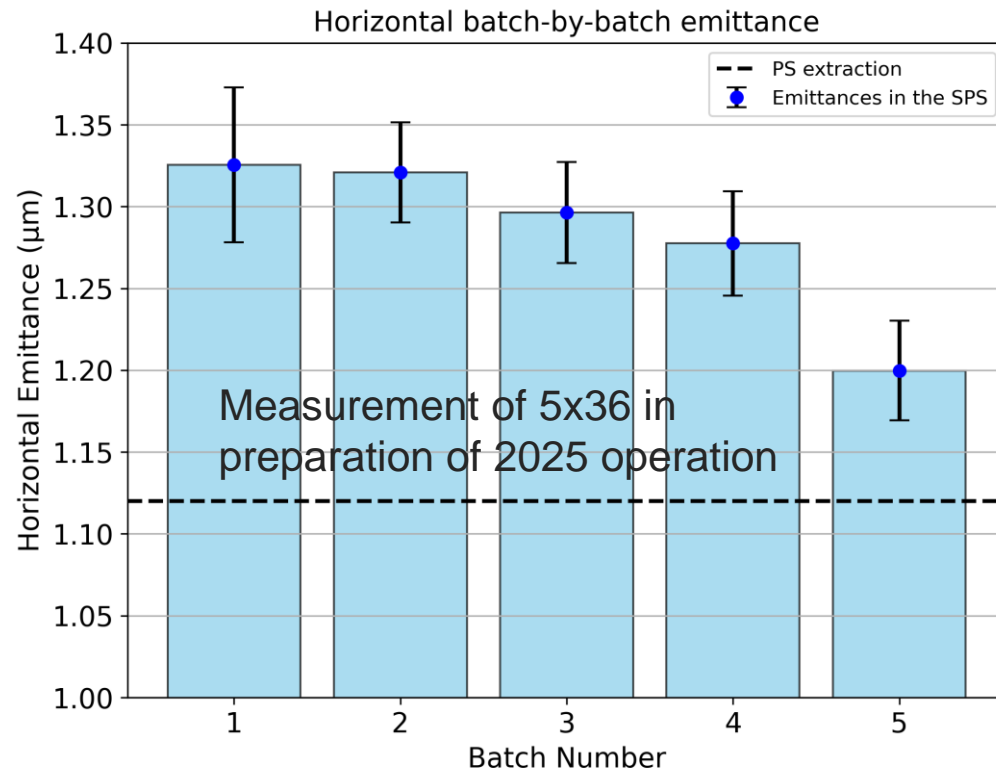
Beam quality degradation – to be improved

- Emittance growth (and tail generation) on SPS injection plateau
 - Around 10% emittance growth from PS-to-SPS, and around 10% in SPS



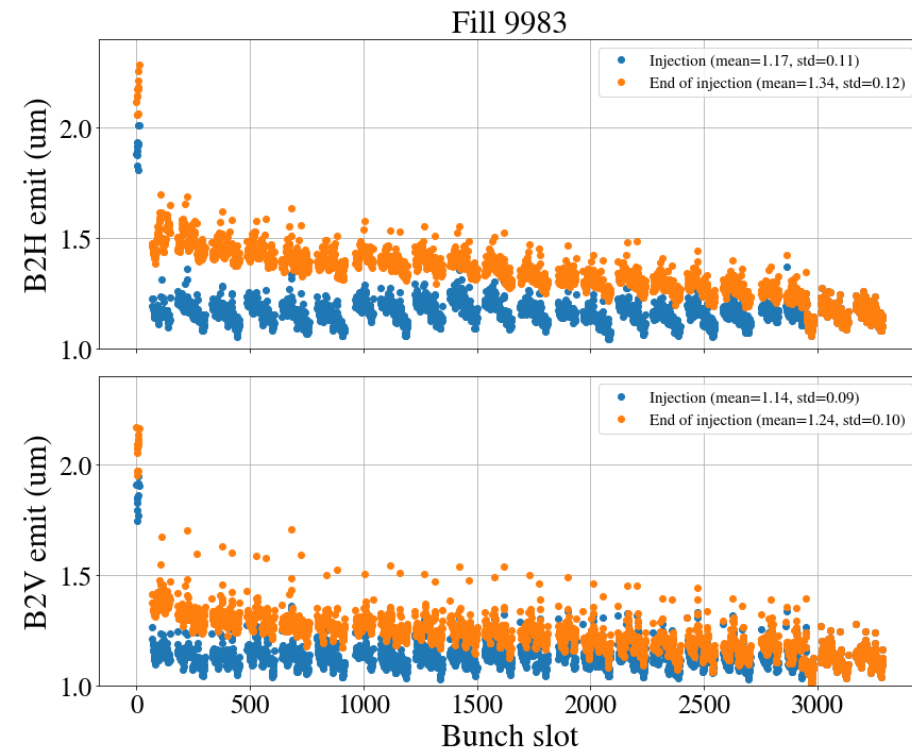
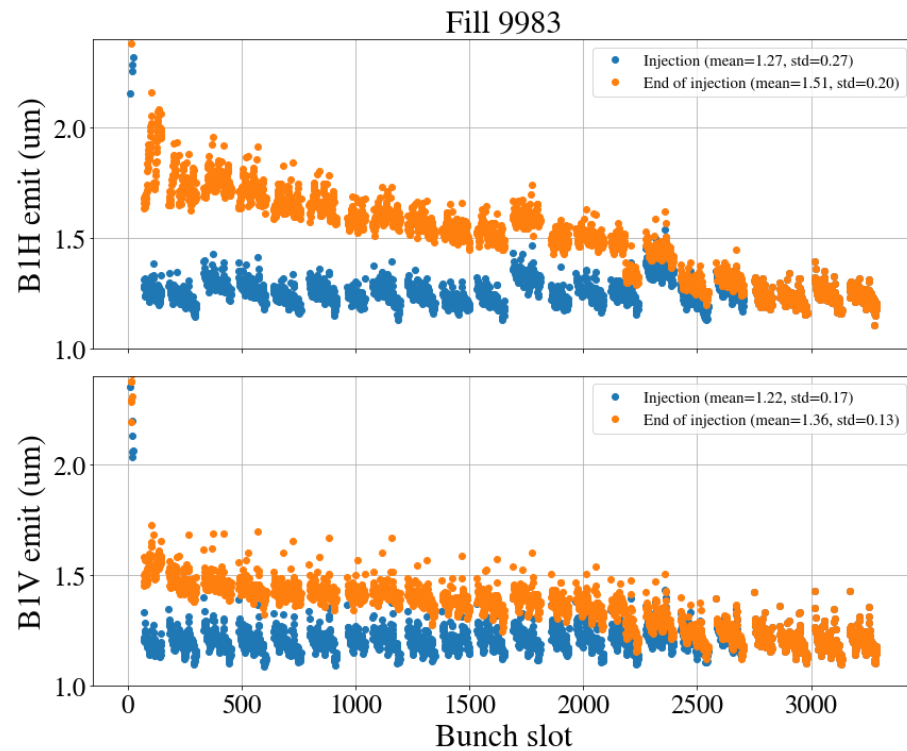
Beam quality degradation – to be improved

- Emittance growth (and tail generation) on SPS injection plateau
 - Around 10% emittance growth from PS-to-SPS, and around 10% in SPS



Beam quality degradation – to be improved

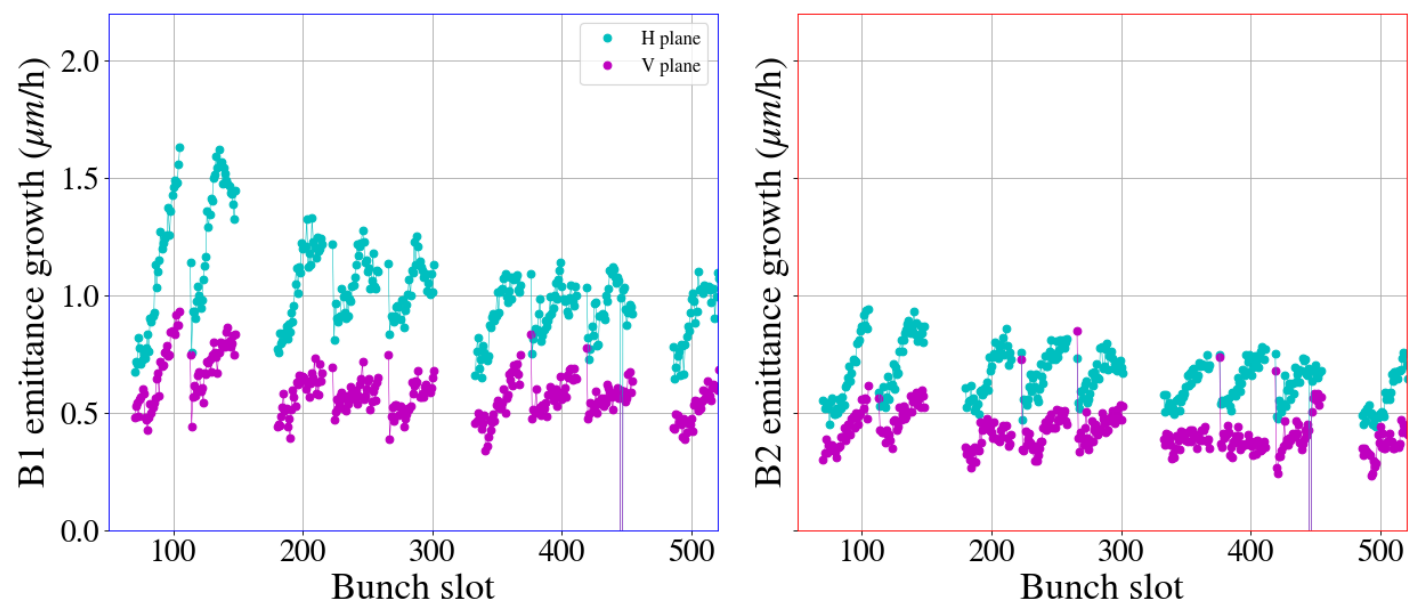
- Emittance growth (and tail generation) on SPS injection plateau
- Emittance growth on LHC injection plateau



Beam quality degradation – to be improved

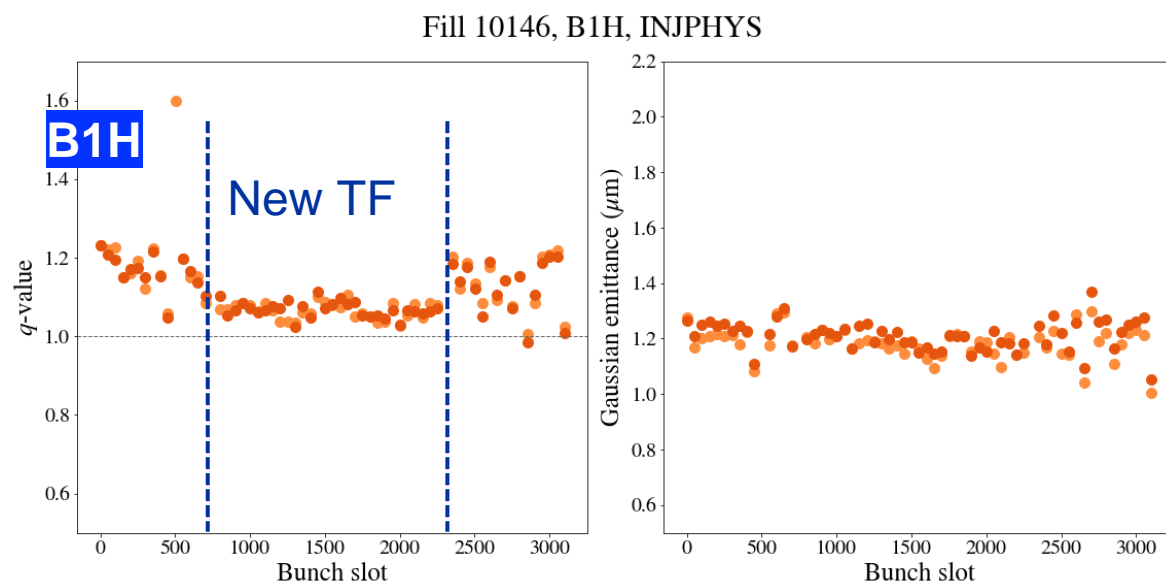
- Emittance growth (and tail generation) on SPS injection plateau
- Emittance growth on LHC injection plateau
 - About $0.4 \mu\text{m} / \text{hour}$ (only partially explained by IBS) + e-cloud effects (B1H worse)

Fill 9983 Injection, VRF=5.4 MV



Beam quality degradation – to be improved

- Emittance growth (and tail generation) on SPS injection plateau
- Emittance growth on LHC injection plateau
- Tail generation for B1H at SPS-to-LHC transfer
 - Known error in quadrupole transfer function – will be corrected for 2025





Outline

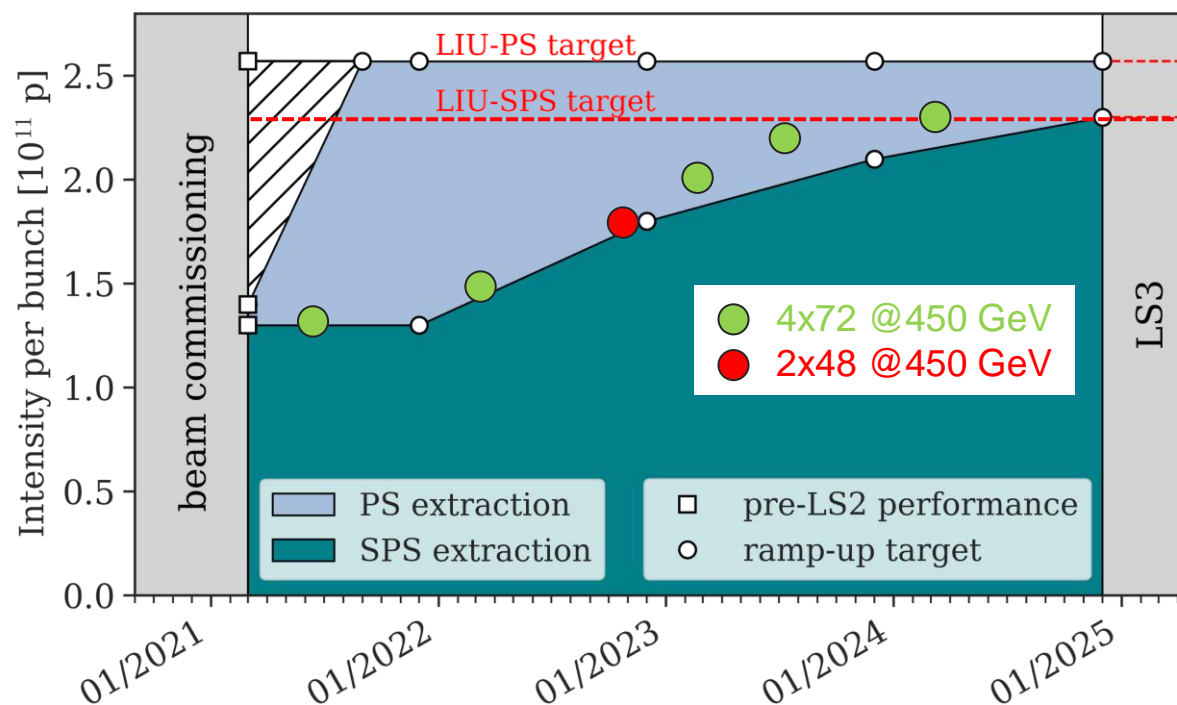
- Operational BCMS beam in 2024
 - Optimizations applied
 - Performance evolution along the year
 - Beam degradation on SPS and LHC injection plateaus
- **Status of LIU performance ramp-up**
 - Intensity ramp-up
 - LIU BCMS beam
 - Other beams: standard, 8b4e, hybrid
- Summary and outlook

LIU beam commissioning in Run 3: ramp-up plan

- Defined at the LIU Montreux workshop in 2020

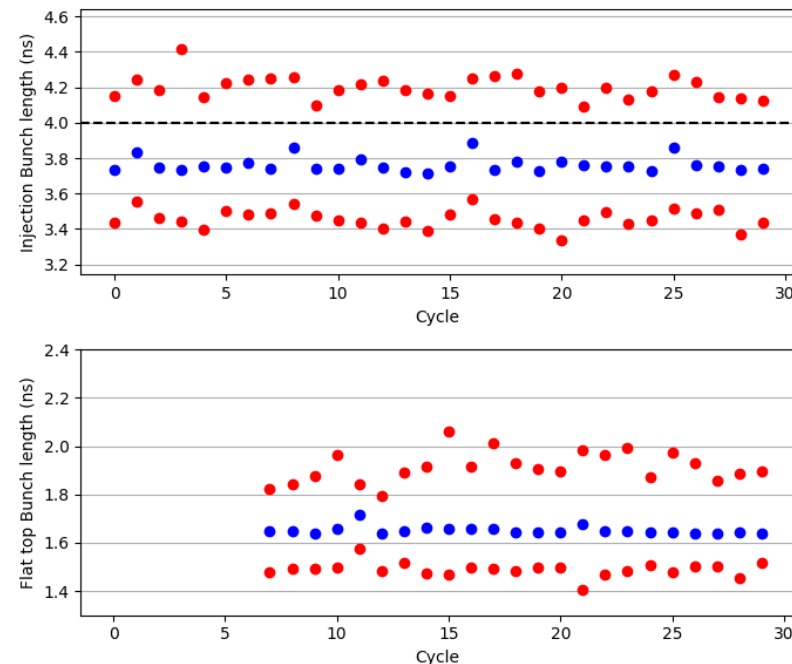
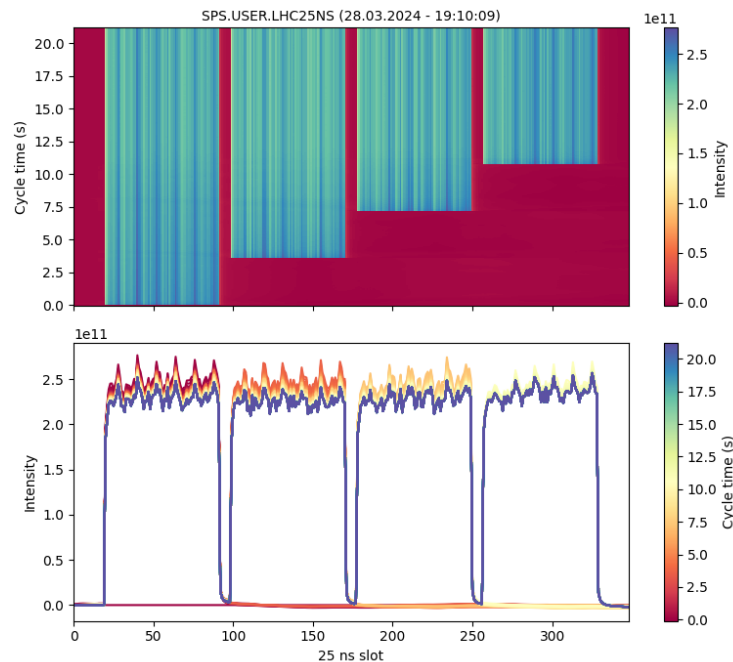
[A. Huschauer et al., LIU workshop 2020](#)

- Year-by-year intensity goals
- **LIU intensity demonstrated in 2024 with 4x72 bunches at 450 GeV**



LIU intensity at 450 GeV demonstrated in 2024

- **Scrubbing run: reached with 4x72 bunches with nominal bunch length**
 - Transverse emittances not yet optimized for standard beam at LIU intensity
 - Further studies limited by RF (vacuum spikes, RF modules breaking) → work is ongoing during the YETS24/25 to make the RF system ready for LIU intensity (improved modules)



Nominal bunch length
(1.65 ns) reproducibly
achieved

Emittances of BCMS beam at ~LIU intensity



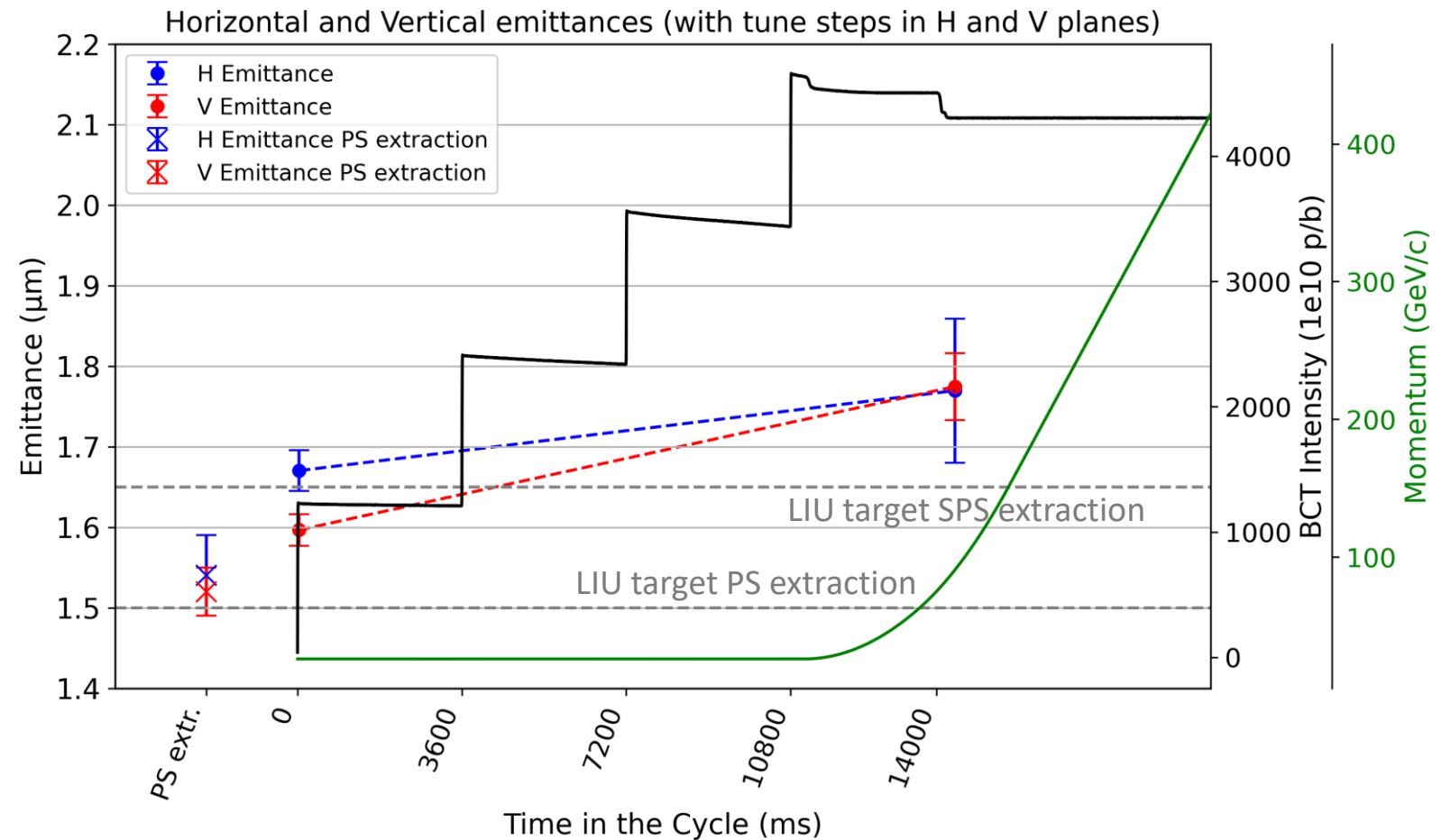
(2024.10.03)
4x48 bunches,
2.6e11 p/b injected intensity

Measurements at
PS extraction.

Measurements at **SPS:**

- Injection (35 ms after inj.)
- After scraping

q-value ~1.06 at injection
q-value ~1.17 before scraping
q-value ~1.11 after scraping



Emittances of BCMS beam at ~LIU intensity



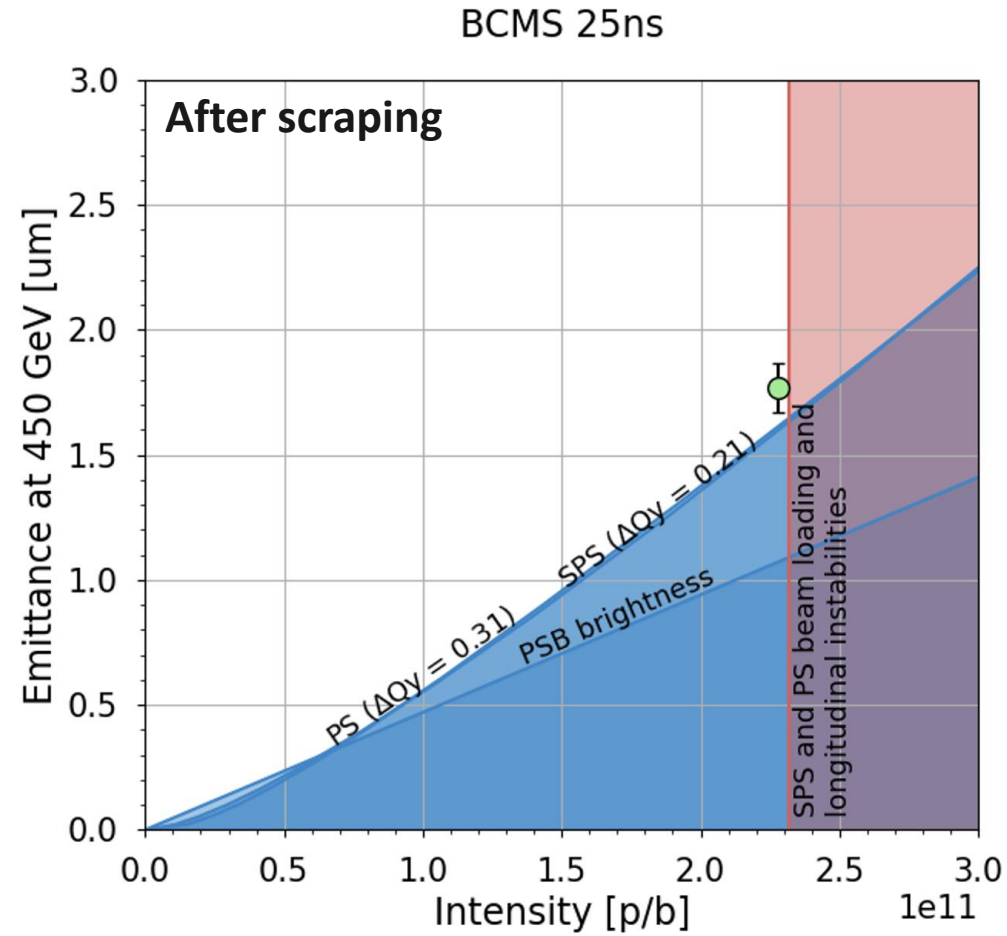
(2024.10.03)
4x48 bunches,
2.6e11 p/b injected intensity

Measurements at
PS extraction.

Measurements at **SPS:**

- Injection (35 ms after inj.)
- After scraping

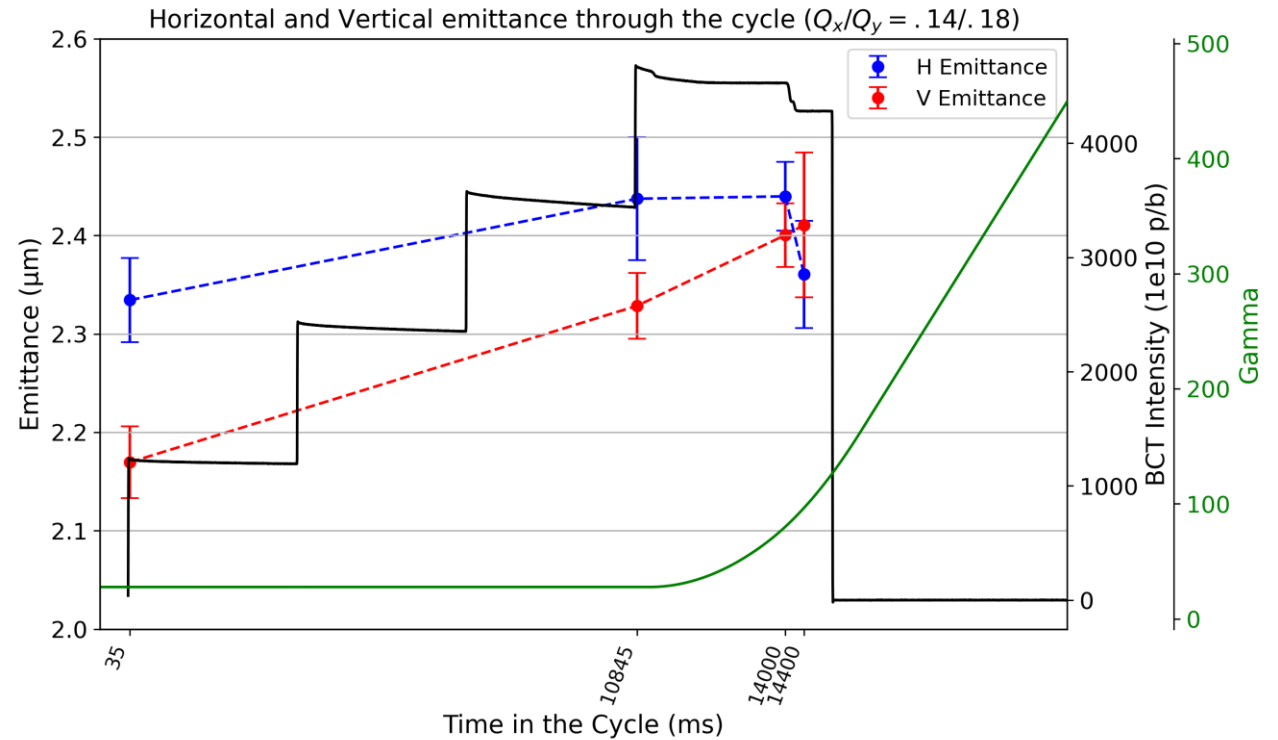
q-value ~ 1.06 at injection
q-value ~ 1.17 before scraping
q-value ~ 1.11 after scraping



Other beams



- **Standard beam at ~LIU intensity (4x48 due to limited RF power in 2024)**
 - Emittances of about 2.4 μm after scraping (LIU target is 2.1 μm)
 - Tails are larger than for BCMS beam



Other beams

- **Standard beam** at ~LIU intensity (4x48 due to limited RF power in 2024)
 - Emittances of about $2.4 \mu\text{m}$ after scraping (LIU target is $2.1 \mu\text{m}$)
 - Tails are larger than for BCMS beam
- **8b4e**
 - Maximum intensity reached so far: 2.15×10^{11} p/b at extraction of 4x56 bunches with nominal bunch length (1.65 ns)
 - Was not a priority in 2024
- **Hybrid beam**
 - Not worked on in 2024



Outline

- Operational BCMS beam in 2024
 - Optimizations applied
 - Performance evolution along the year
 - Beam degradation on SPS and LHC injection plateaus
- Status of LIU performance ramp-up
 - Intensity ramp-up
 - LIU BCMS beam
 - Other beams: standard, 8b4e, hybrid
- **Summary and outlook**

Summary & Outlook

- BCMS beam with improved beam quality (reduced tails) in 2024 operation → clear impact on LHC performance (operating close to burn-off limit)
- LIU intensity demonstrated with 4x72 bunches and nominal bunch length
 - Emittance and brightness (after scraping) achieved so far with 4x48 bunches

4x48 bunches	Intensity	Emittance	Brightness	Target brightness
standard	2.3e11 p/b	2.40 μm	0.95e11 p/b / μm	1.1 p/b / μm
BCMS	2.3e11 p/b	1.75 μm	1.3e11 p/b / μm	1.4 p/b / μm

- Outlook for 2025
 - Continue optimization of BCMS beam (emittance, tails)
 - Optimization of other beams depending on priority from HL-LHC (8b4e, standard, hybrid?)



www.cern.ch

THANK YOU FOR
YOUR ATTENTION