LHC Injectors Upgrade

LIU beam performance ramping up phase: **PSB and PS**

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Beam performance ramp-up for proton beams during Run 3

- **Two main aspects of the LIU beam performance ramp-up of the standard beam**
  1) Intensity ramp-up → mainly occurring in the SPS
  2) Brightness ramp-up → determined by the PSB and PS performance

- **LIU target beam parameters at injection of the respective accelerator (from EDMS1296306)**

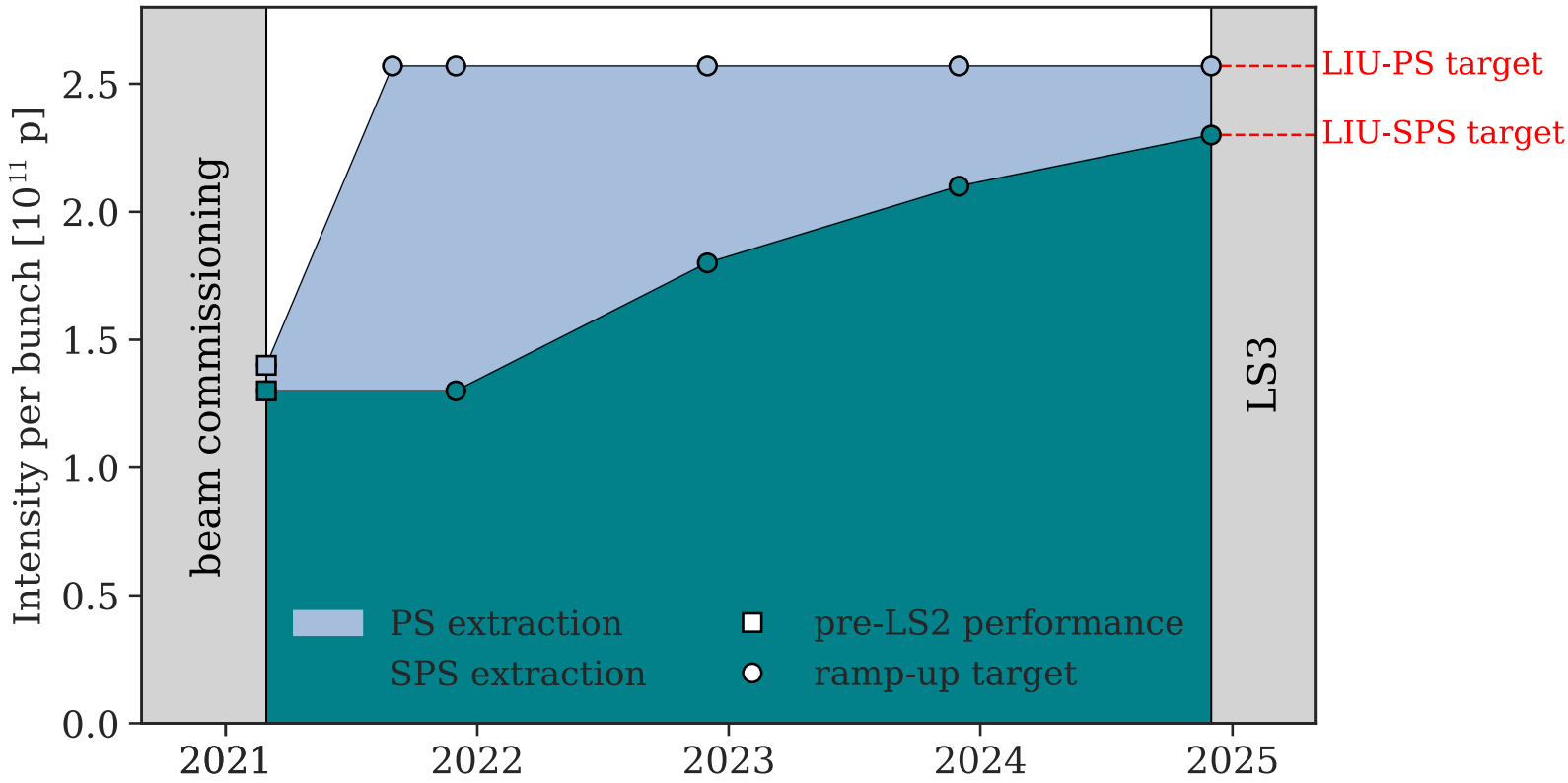
PS (Standard: 4b+2b – BCMS: 2× 4b)								
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$ (10^{-3})	$\Delta Q_{x,y}$
LIU target	Standard	32.50	1.80	2.0	3.00	205	1.5	(0.18, 0.30)
	BCMS	16.25	1.43	2.0	1.48	135	1.1	(0.20, 0.31)

SPS (Standard: 4 × 72b – BCMS: 5 × 48b)								
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$ (10^{-3})	$\Delta Q_{x,y}$
LIU target	Standard	2.57	1.89	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.10, 0.17)
	BCMS	2.57	1.50	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.12, 0.21)

LHC (≈10 injections)							
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)	bunches/train
LIU target	Standard	2.32	2.08	450	0.56 (0.58)	1.65 (1.24)	288
	BCMS	2.32	1.65	450	0.56 (0.58)	1.65 (1.24)	240

Intensity ramp-up

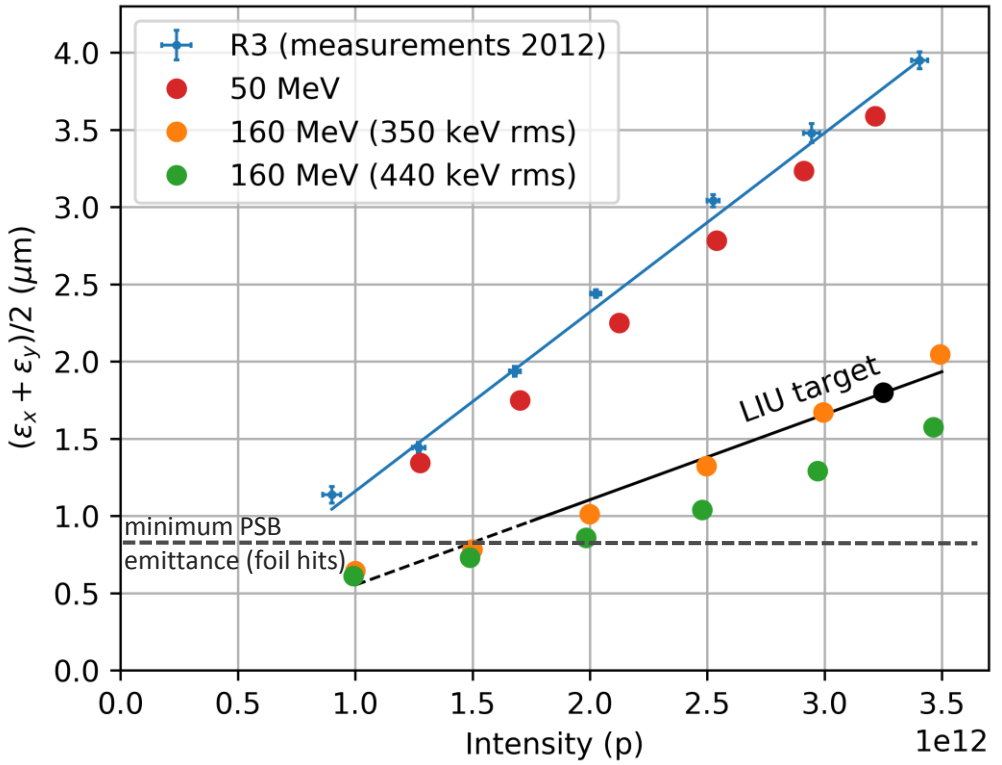
- **Intensity reach demonstrated at PS extraction pre-LS2**
  - Recovery of high-intensity beams expected by end of summer 2021
  - No major changes on the PS RF systems
    - New 10 MHZ amplifiers delivering more robust performance
    - Improved reliability of the Finemet cavity
    - No modifications to high-frequency cavities



- **Gradual intensity ramp-up in the SPS**
  - Ramp-up planned to start from 2022 due to LHC Pb-ion run at the end of 2021
  - LIU-SPS intensity target planned to be reached at the end of 2024

Brightness ramp-up

- **Achievable PSB brightness limited by the injection scheme and acceleration at low energy**
- **PSB space charge simulation studies were performed to reproduce pre-LS2 and investigate LIU performance**
  - **Simulations at 50 MeV (beam from Linac2)**
    - capture of coasting beam (1e-3 dp/p rms) with operational voltage program
    - capture losses of about 15% (as observed in measurements)
    - single turn injection on the ramp (no multi-turn stacking)
    - 1 μm transverse emittance at injection
    - Q_x / Q_y = 4.40 / 4.45
    - **5% beta-beating included**
  - **Simulations at 160 MeV (beam from Linac4)**
    - 25 mA at PSB injection
    - 350 keV rms energy spread with chopping factor 0.6
    - 440 keV rms energy spread with chopping factor 0.7
    - "flat1" cycle and voltage program provided by S. Albright
    - injection on flat bottom, with injection chicane and foil
    - 0.4 μm transverse emittance at injection
    - Q_x / Q_y = 4.40 / 4.45
    - **15% beta-beating included**



➔ **large energy spread (~440 keV rms) from Linac4 required**

Brightness ramp-up

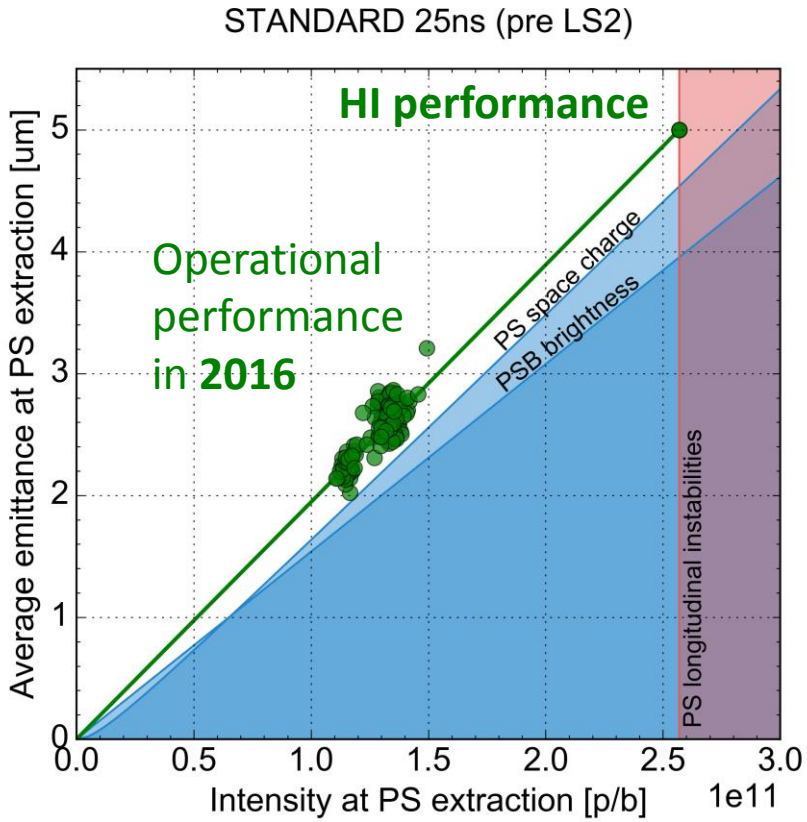
- **Achievable brightness along the chain for the standard beam will be limited by space charge effects on the PS flat bottom**
  - LIU baseline: beams with large longitudinal emittance at PS injection to overcome this limitation
  - → Brightness ramp-up therefore determined by the evolution of the longitudinal emittance at PS injection

- **Longitudinal emittance at PS injection will be gradually increased during Run 3**
  - Brightness ramp-up is foreseen to take place until the end of 2023
  - Only limited experience with beams of large longitudinal emittance and their impact on transverse emittances
  - → Transverse emittance preservation at PS injection and on the flat bottom is expected to be the most critical aspect

Pre-LS2 performance of the standard beam

- **Experience with the standard beam**
  - Operational experience limited to 2016
  - LIU intensity target achieved in MDs in 2018
    - Reliable beam production at high-intensity achieved after transverse optimization

- **Performance at different intensities followed constant brightness**



Target performance of the standard beam at the end of 2021

- **PSB will deliver beams of significantly increased brightness already in 2021**

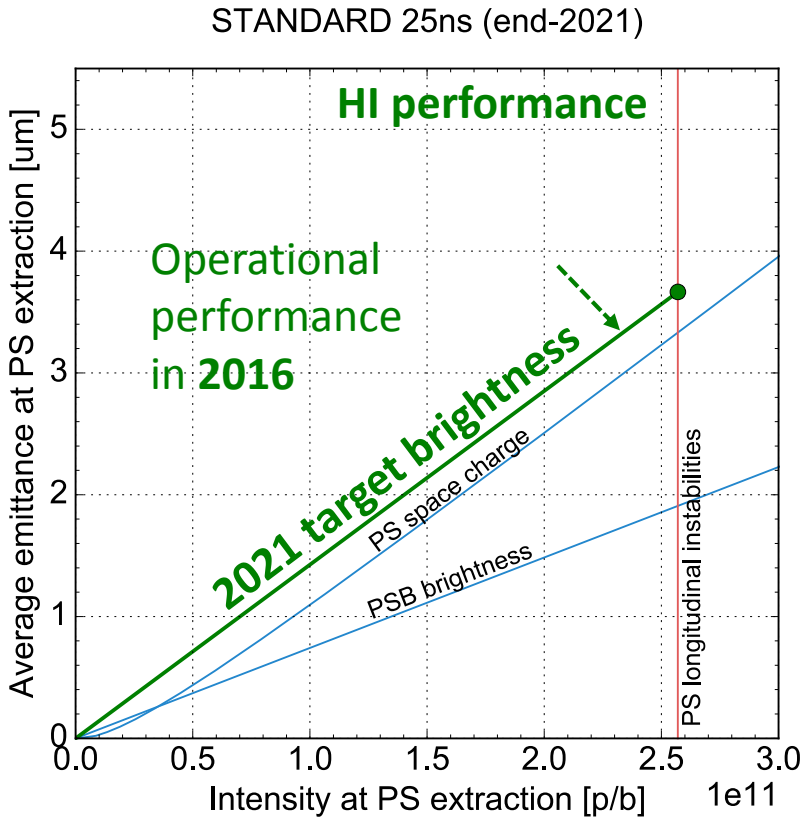
- **Longitudinal parameter target at PS injection in 2021**

ε_z [eVs]*	σ_z [ns]*	$\delta p/p$ [10^{-3}]*
1.5	135	1.1

* parameter conventions according to EDMS1296306

→ **Achievable brightness will be limited by space charge effects on the PS flat bottom**

- **First important brightness increase expected to be achieved at the end of 2021**
  - Including a 10% margin on the transverse emittances with respect to the maximum achievable performance



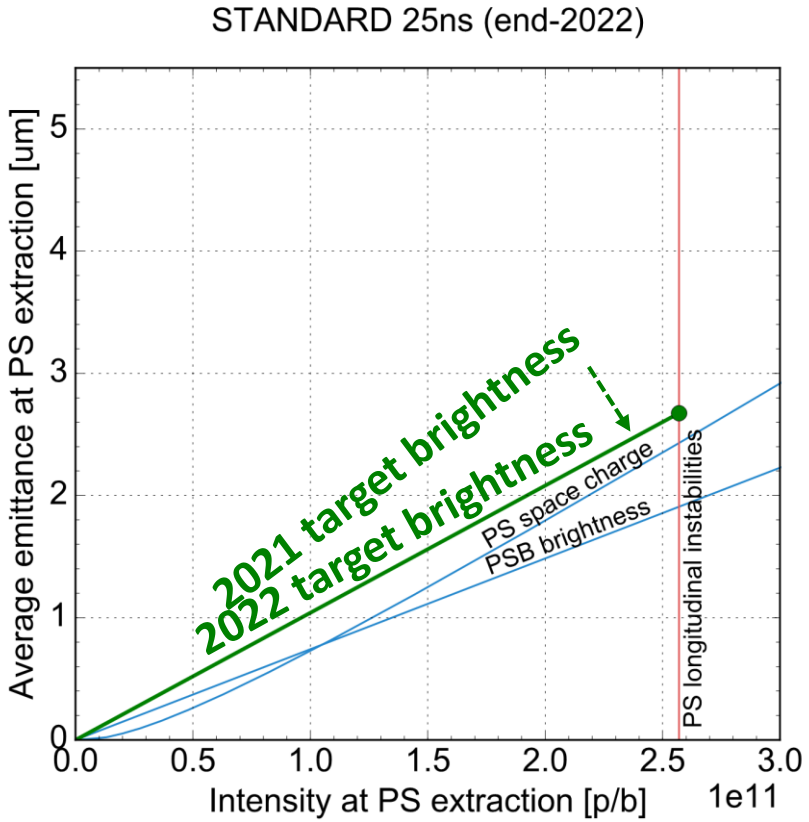
Target performance of the standard beam at the end of 2022

- **Further brightness increase by increasing the longitudinal emittance at PS injection**
  - Longitudinal parameter target at PS injection in 2022

ε_z [eVs]*	σ_z [ns]*	$\delta p/p$ [10^{-3}]*
2.25	170	1.3

* parameter conventions according to EDMS1296306

→ Achievable brightness will still be limited by space charge effects on the PS flat bottom

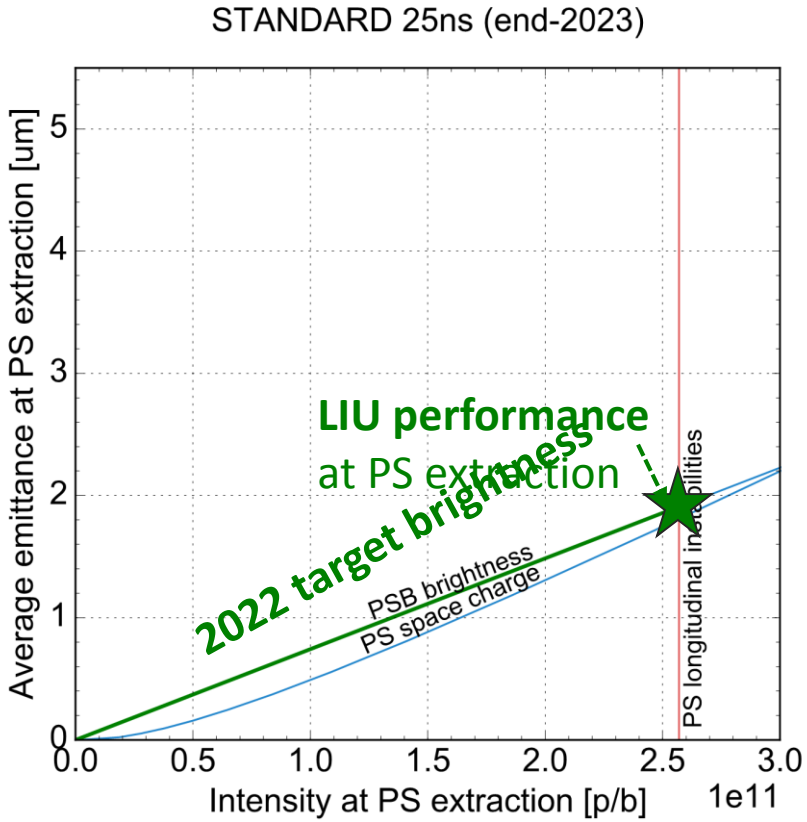


Target performance of the standard beam at the end of 2023

- **Final step in longitudinal emittance foreseen in 2023**
  - Longitudinal parameter target at PS injection in 2023 (= LIU parameters)

ε_z [eVs]*	σ_z [ns]*	$\delta p/p$ [10^{-3}]*
3.0	205	1.5

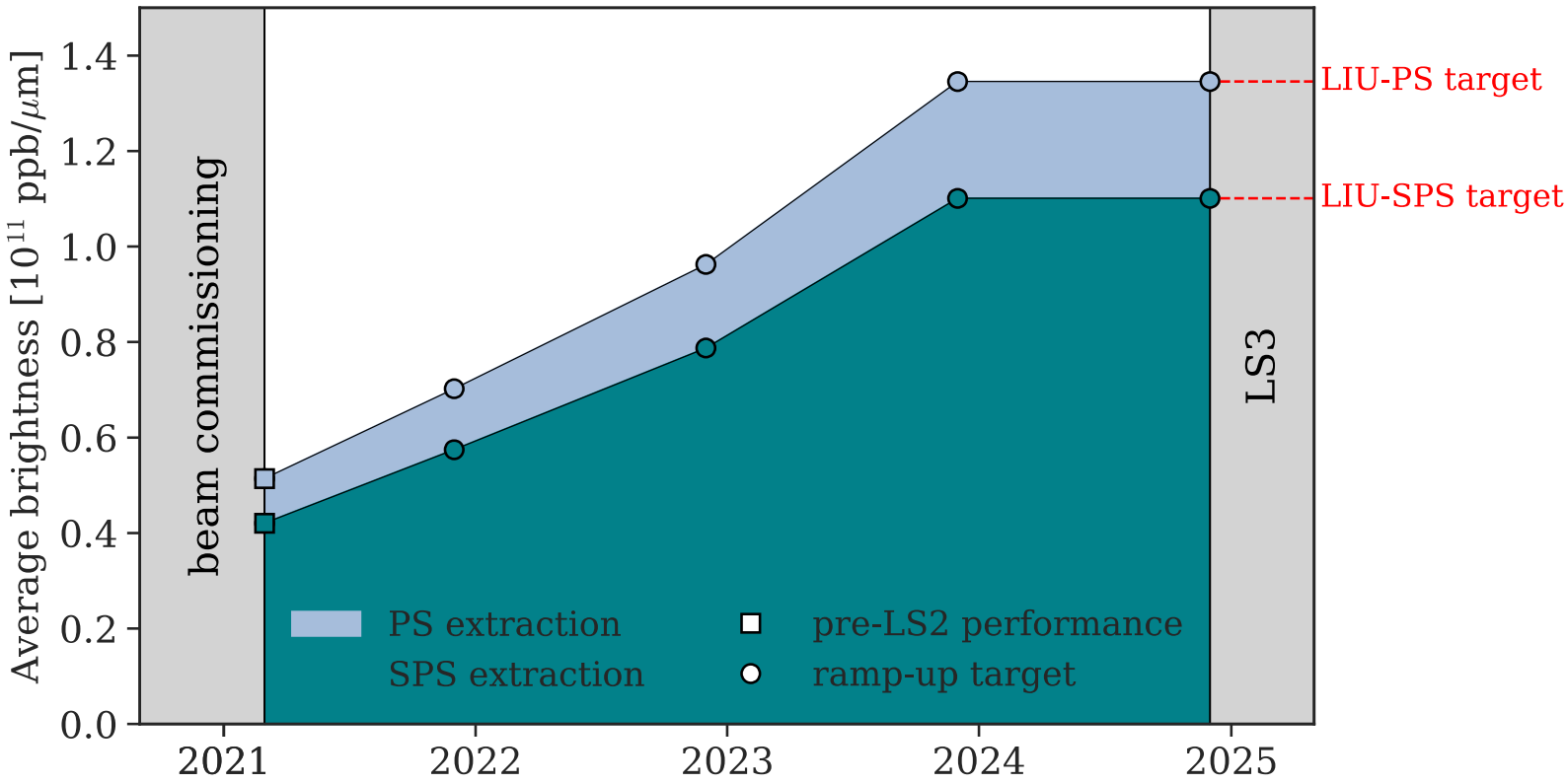
* parameter conventions according to EDMS1296306



→ **LIU performance at PS extraction planned to be reached at the end of 2023**

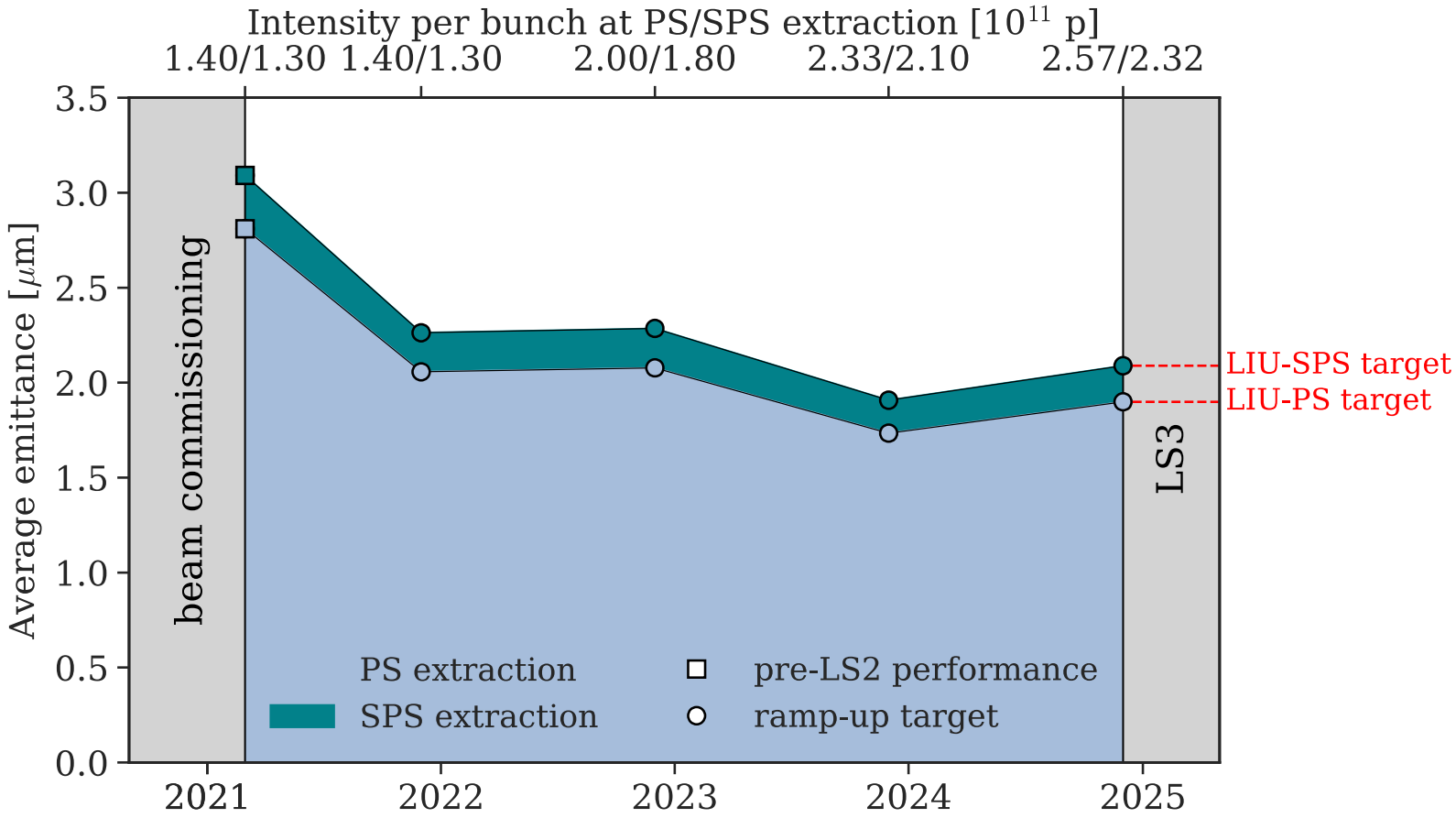
Summary of the brightness ramp-up during Run 3

- **Brightness ramp-up determined by the evolution of longitudinal parameters at PS injection**
  - Ramp-up foreseen to gradually occur until the end of 2023
- **Brightness in the SPS will follow the ramp-up in the PS**
  - Including the 10%-budgets for beam loss and transverse emittance growth
- **The LIU brightness goal will therefore also be reached in the SPS at the end of 2023**
  - Reach of the full LIU performance will require the last intensity step in the SPS in 2024



Emittance evolution according to SPS intensity ramp-up

- **The intensity and brightness ramp-up determine the emittance evolution of the standard beam during Run 3**
- **The emittance during 2024 is expected to increase as the last step of the intensity ramp-up occurs at constant brightness**



Summary of the projected beam parameter evolution at PS injection during Run 3

- **Brightness ramp-up of the standard beam during Run 3 determined by the gradual increase of the longitudinal emittance at PS injection**

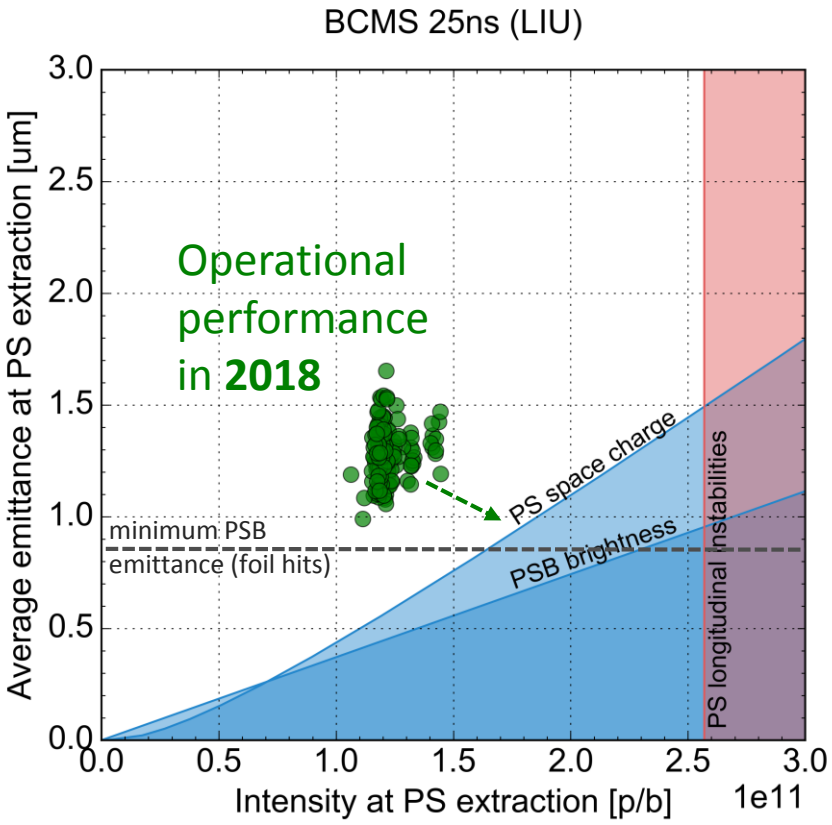
- **Beams expected to be operationally available according to the table below**
  - LIU performance at PS extraction planned to be reached at the end of 2023

End of year	N [10^{11} ppb]	$\varepsilon_{x,y}$ [μm]*	ε_z [eVs]*	σ_z [ns]*	$\delta p/p$ [10^{-3}]*	$\Delta Q_{x,y}$	Remarks
2021	325	3.49	1.50	135	1.1	(0.23, 0.28)	natural post-LS2 PSB performance for longitudinal parameters
2022	325	2.54	2.25	170	1.3	(0.20, 0.29)	
2023	325	1.80	3.00	205	1.5	(0.18, 0.30)	LIU performance reached

* parameter conventions according to EDMS1296306

Operational LHC beam during Run 3 - BCMS

- **BCMS beam considered as operational LHC beam during Run3**
  - Based on the report from the Run 3 configuration working group at the 2019 Evian Workshop
- **BCMS beam production expected to be less critical than the standard beam in the PS**
- **LHC will benefit from increased performance as PS brightness and SPS intensity are ramped up**



Conclusions

- **Two main aspects of the LIU beam performance ramp-up for the standard beam during Run 3**
  - Intensity ramp-up
  - Brightness ramp-up

- **Brightness ramp-up determined by the evolution of longitudinal parameters at PS injection**

- **LIU beam performance expected to be reached at PS extraction at the end of 2023**
  - One additional year required to achieve LIU performance at SPS extraction

- **BCMS beam considered as operational LHC beam during Run 3**
  - BCMS performance will gradually improve as the performance ramp-up progresses