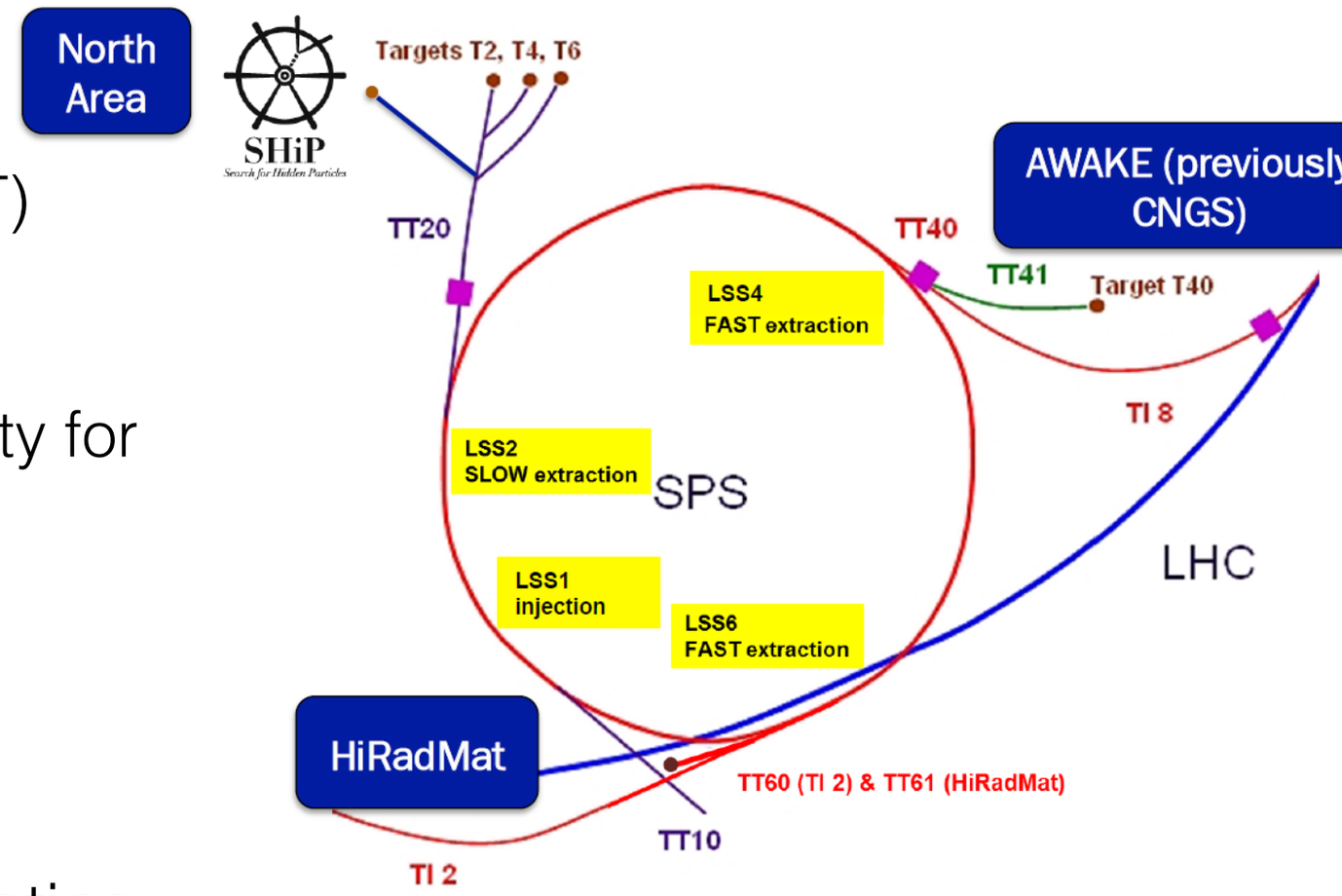
Super Proton Synchrotron (SPS)

F. M. Velotti

Introduction

- The SPS is a multi-user machine
  - Large Hadron Collider
  - North Area (NA) Fixed Target (FT) experiments
  - HiRadMat => Experimental facility for high radiation material testing
  - AWAKE => plasma acceleration experiment
- Many different beam characteristics to deal with
- Different optics (Q20, Q26LHC, Q26FT, Q22, …for now…)

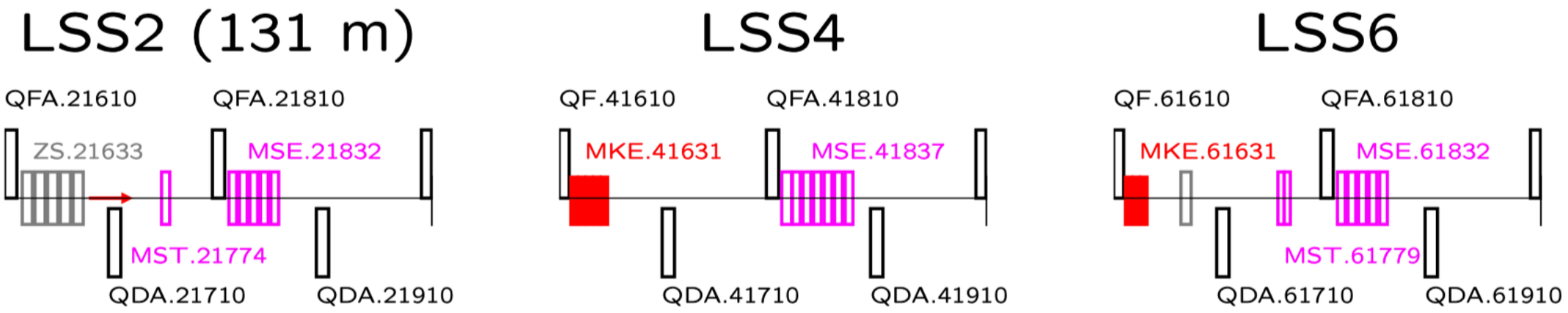


Introduction

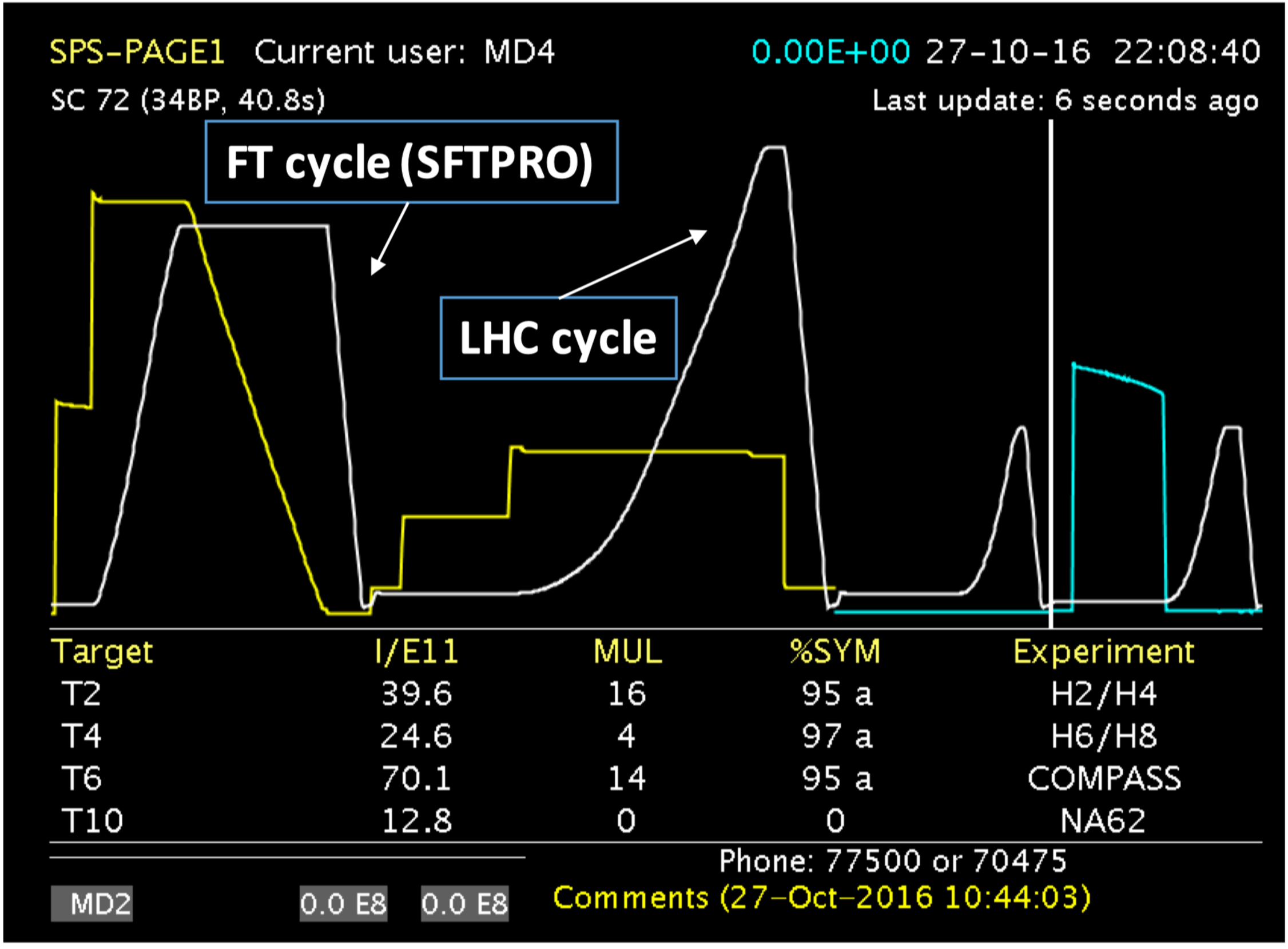
- The SPS is composed by 1317 room temperature electromagnets
- 744 main dipoles (each 6.2 m long) and 216 laminated quadrupoles
- During its history, it has accelerated a variety of particles, i.e. sulphur and oxygen nuclei, Xenon, Lead, electrons, positrons, protons and antiprotons.
- The SPS has a circumference of 6911 m
- The SPS started to operate in 1976
- In 1983 the SPS reached the most famous result of its operation with the Nobel-prize winning discovery of the W and Z bosons when working as proton-antiproton collider

Introduction

- The SPS is based on a periodic FODO lattice with a super-symmetry of six
- Each period is formed by an arc of sixteen FODO cells with a central long straight section (LSS) of two cells
- Insertion elements are installed in each LSS
  - The injection, the scraper and the dump systems are installed in LSS1
  - The LSS2 is dedicated to the slow extraction channel towards the NA
  - the LSS3 to the RF system (Fig. 3.2)
  - The LSS4 and 6 host the fast extraction systems (Fig. 3.2) used to deliver beam to the LHC, AWAKE and to the HiRadMat area
  - LSS5 instead, the UA9 experiment and other instrumentation are grouped (the dump system will be moved here during LS2)

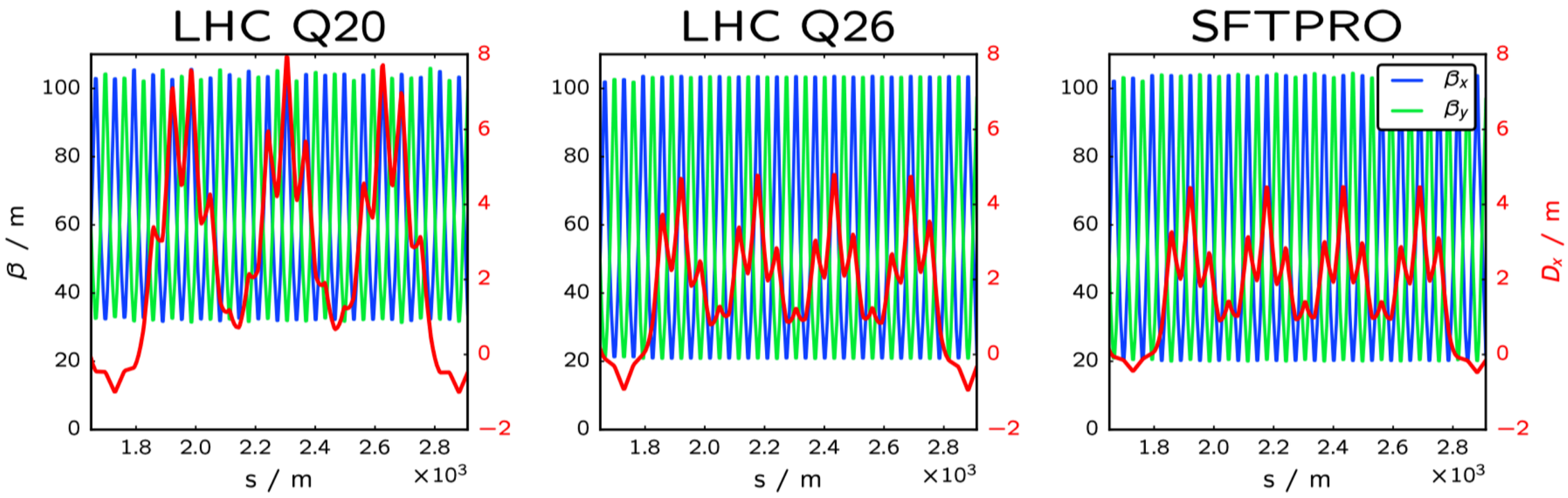


Introduction



Introduction

- Three different optics are usually used during normal operations:
  - Q20, Q26 and SFTPRO optics
  - The first is the one used to deliver beams to the LHC.
  - Together with the Q26 (previous optics for LHC beams), are the optics used for high intensity bunched beams (LHC type). The SFTPRO optics is used for slow extraction towards the NA for

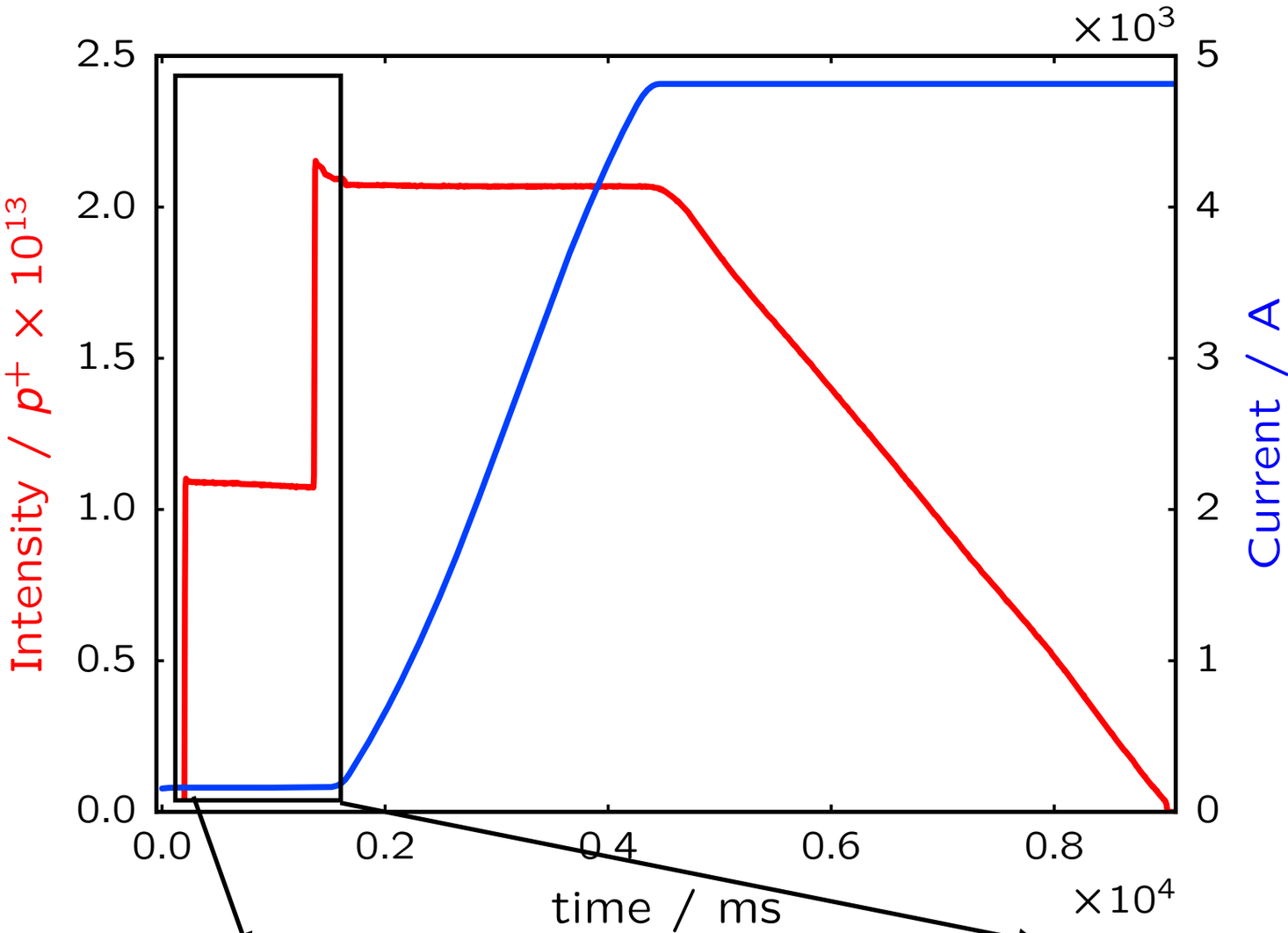


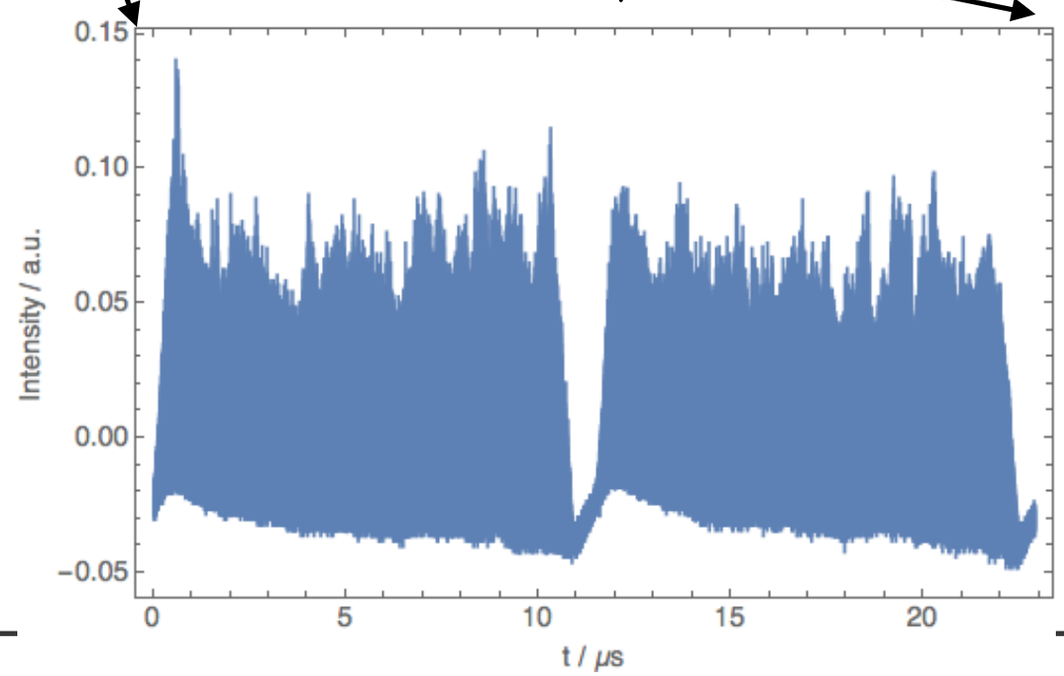
Introduction

SPS Optics	**LHC Q20**	**LHC Q26**	**SFTPRO**
Horizontal tune, ν_x	20.13	26.13	26.62
Vertical tune, ν_y	20.18	26.18	26.58
Natural chromaticity, Q'_x/Q'_y	-22.7/-22.7	-32.6/-32.63	-33.51/-33.46
Maximum betas, $\beta_x \approx \beta_y$ [m]	105	105	105
Minimum betas, $\beta_x \approx \beta_y$ [m]	30	20	20
Maximum dispersion, D_x [m]	4.5	8	4.4
Transition energy, γ_t	18	22.8	22.8
Phase advance per cell, $\mu_x \approx \mu_y$ [°]	67.5	90	90

FT Beams

- FT beam injected at 14 GeV - 2 batches from the PS
  - 200 MHz structure (5 ns bunch spacing) with 1.1 us batch spacing
- Accelerated up to 400 GeV
- Optics: Q26 (.62/.58)
- After ramp, RF gymnastic to increase momentum spread
- Then, RF OFF => no BPMs anymore
  - Tune swept trough the beam tune spread for slow extraction
  - => extraction to TT20





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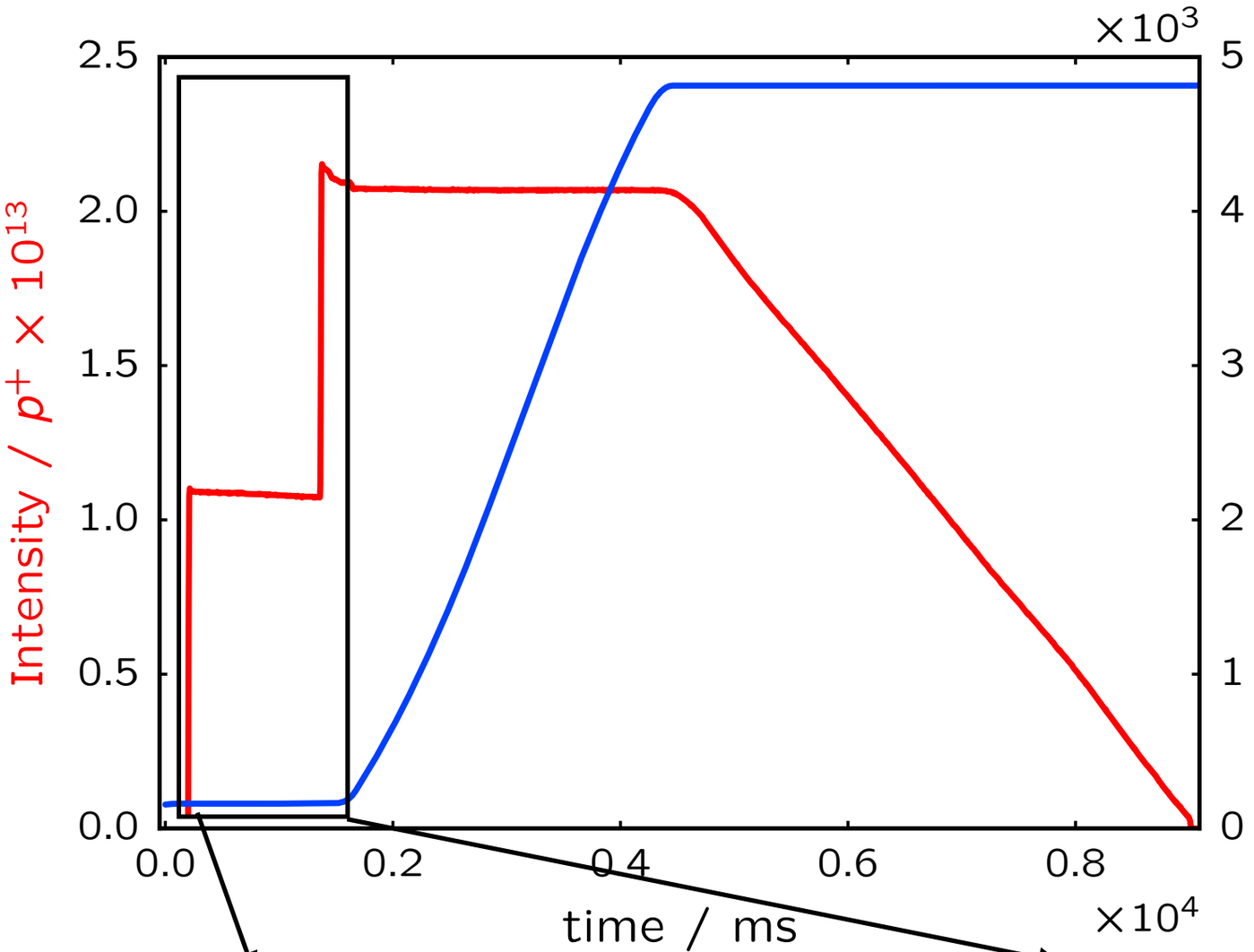

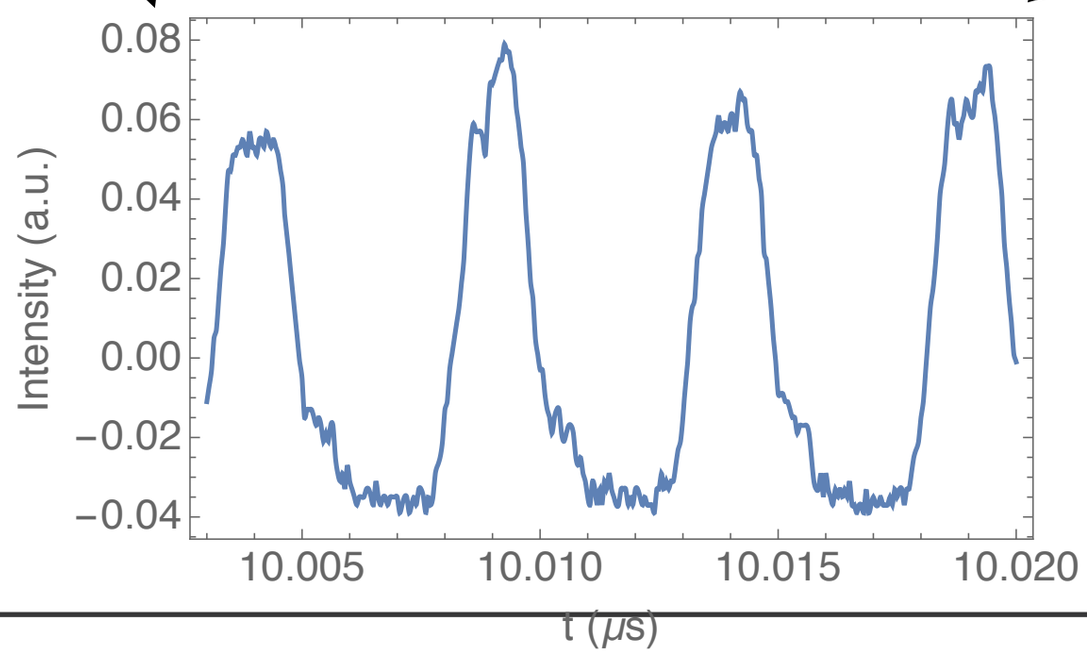

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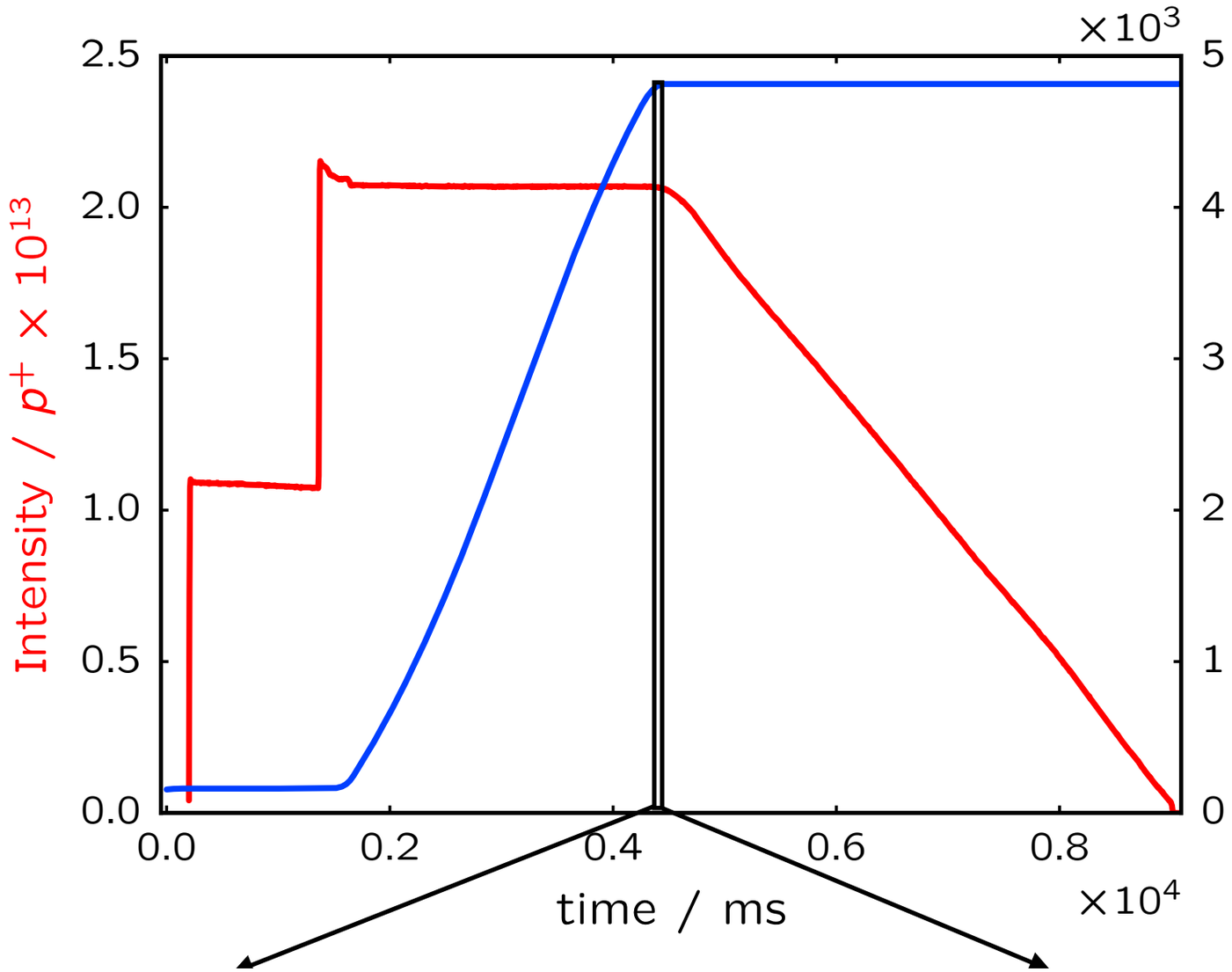

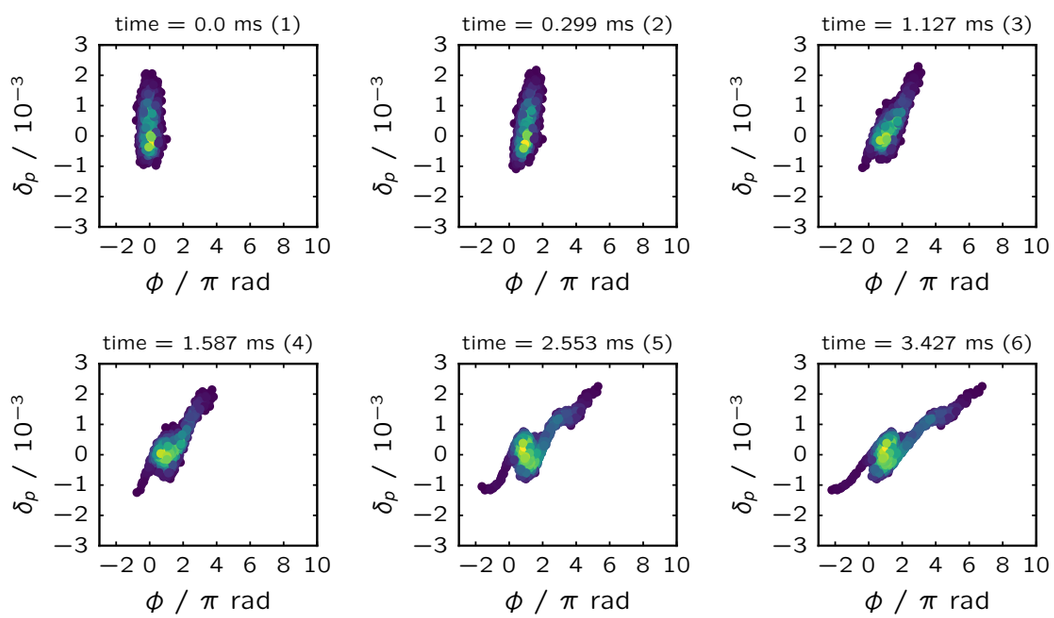

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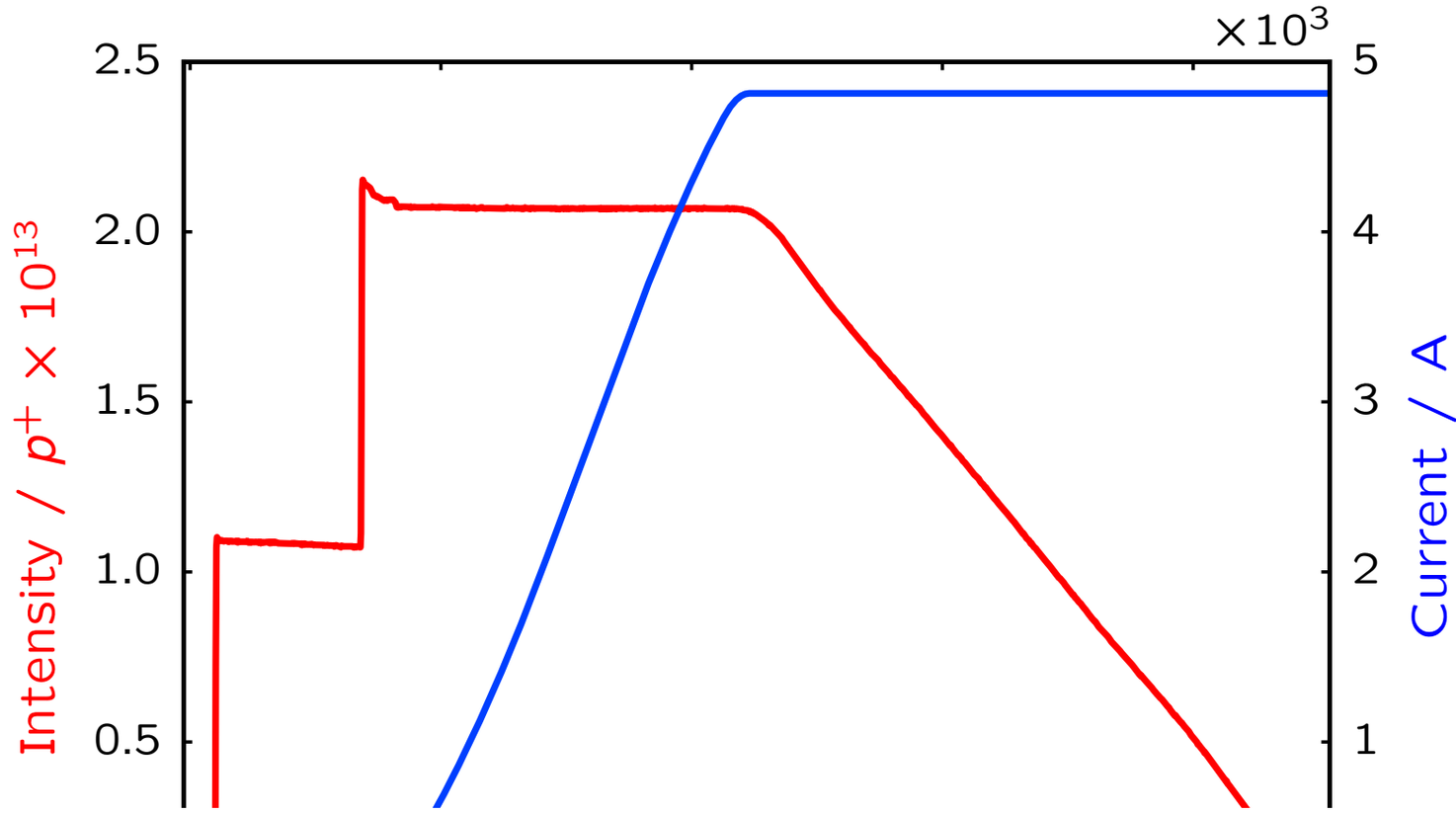

- After ramp, RF gymnastic to increase momentum spread
- Then, RF OFF => no BPMs anymore
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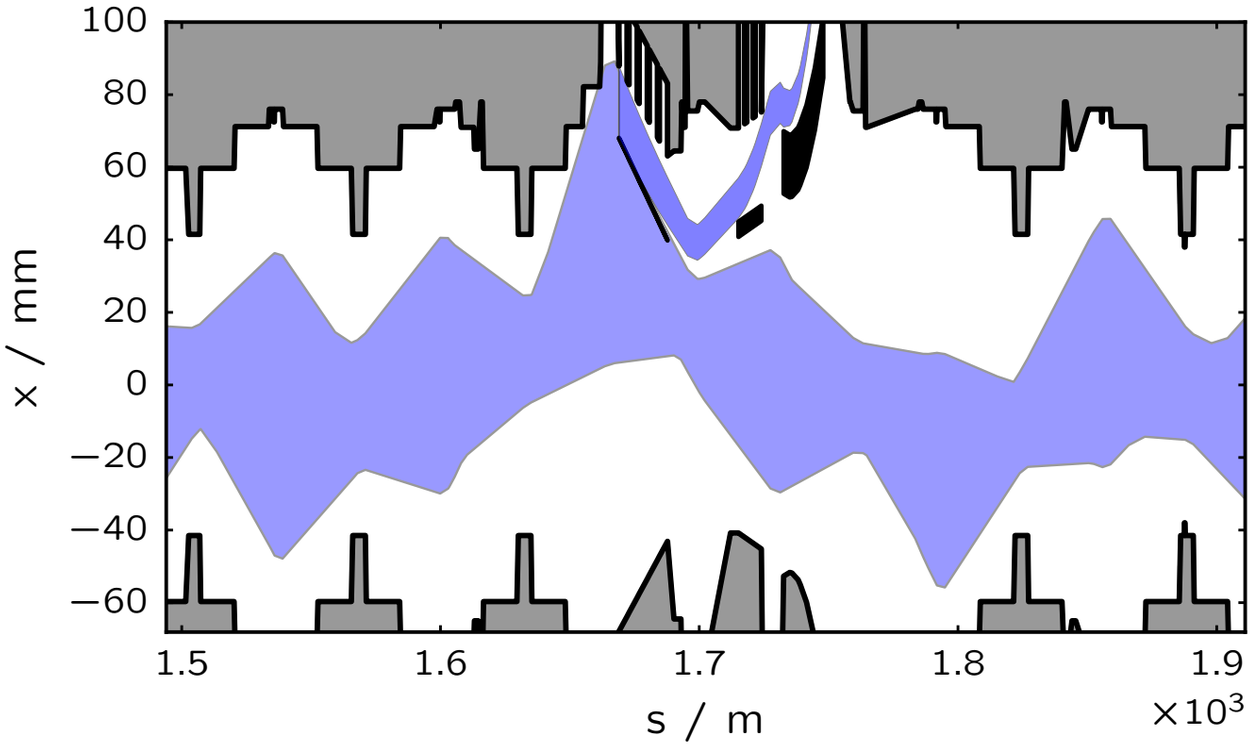
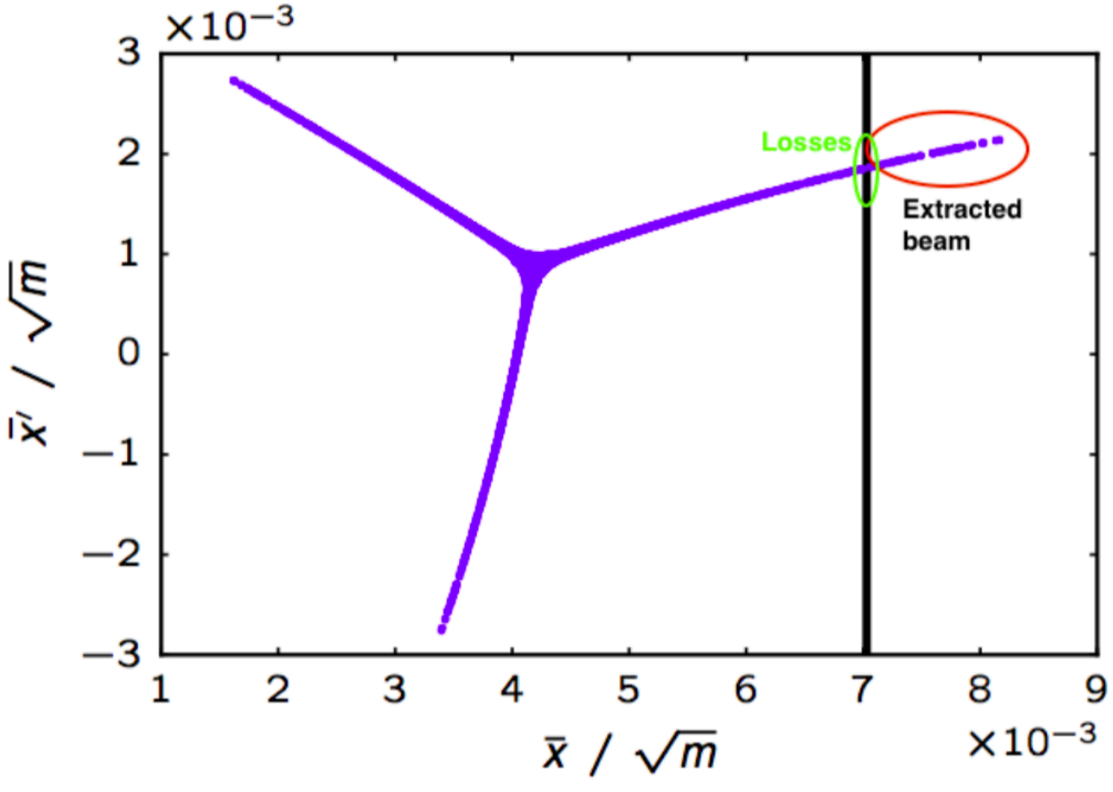
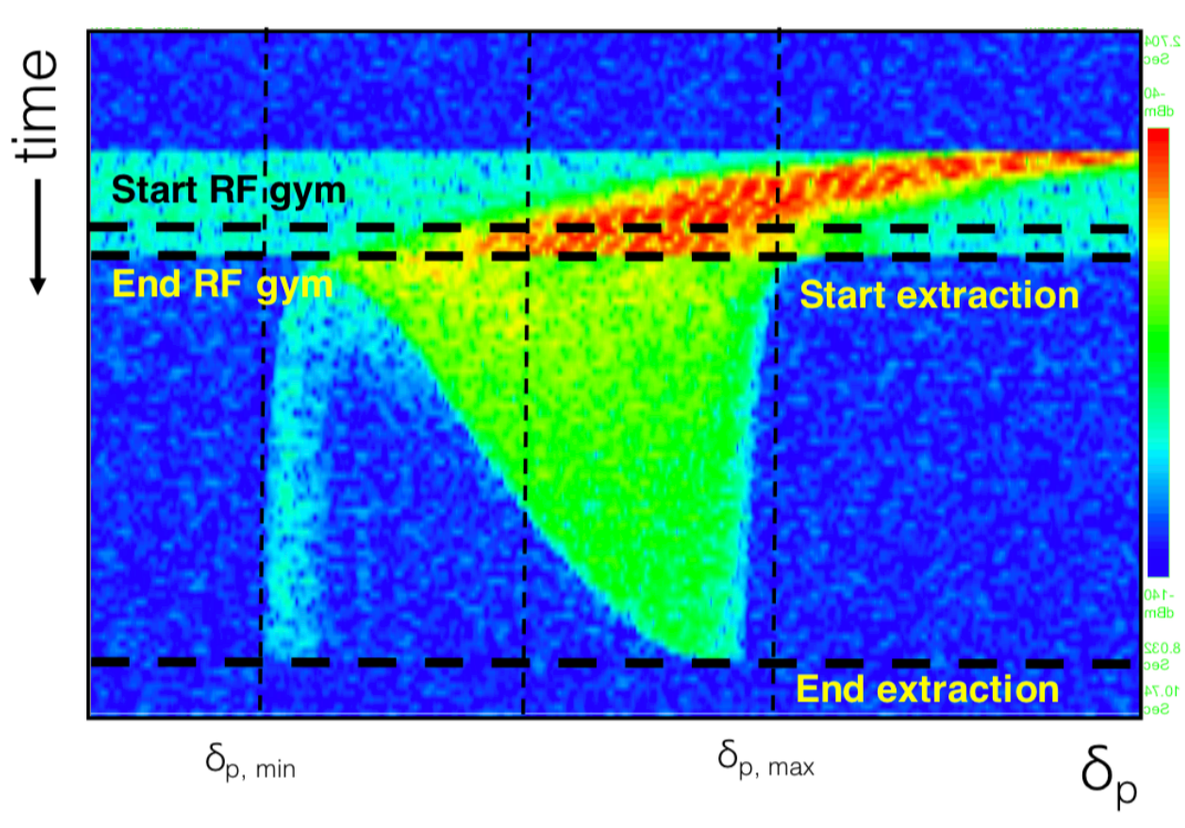


Slow extraction in the SPS

- Particles are extracted when their tune is close enough to the 1/3 resonance, i.e. $\nu_x \approx N + 1/3$
- In the SPS this is done keeping the extraction sextupoles fixed and sweeping the tune from $\nu_x(1 - \xi\delta_{p,max})$ to $\nu_x(1 - \xi\delta_{p,min})$





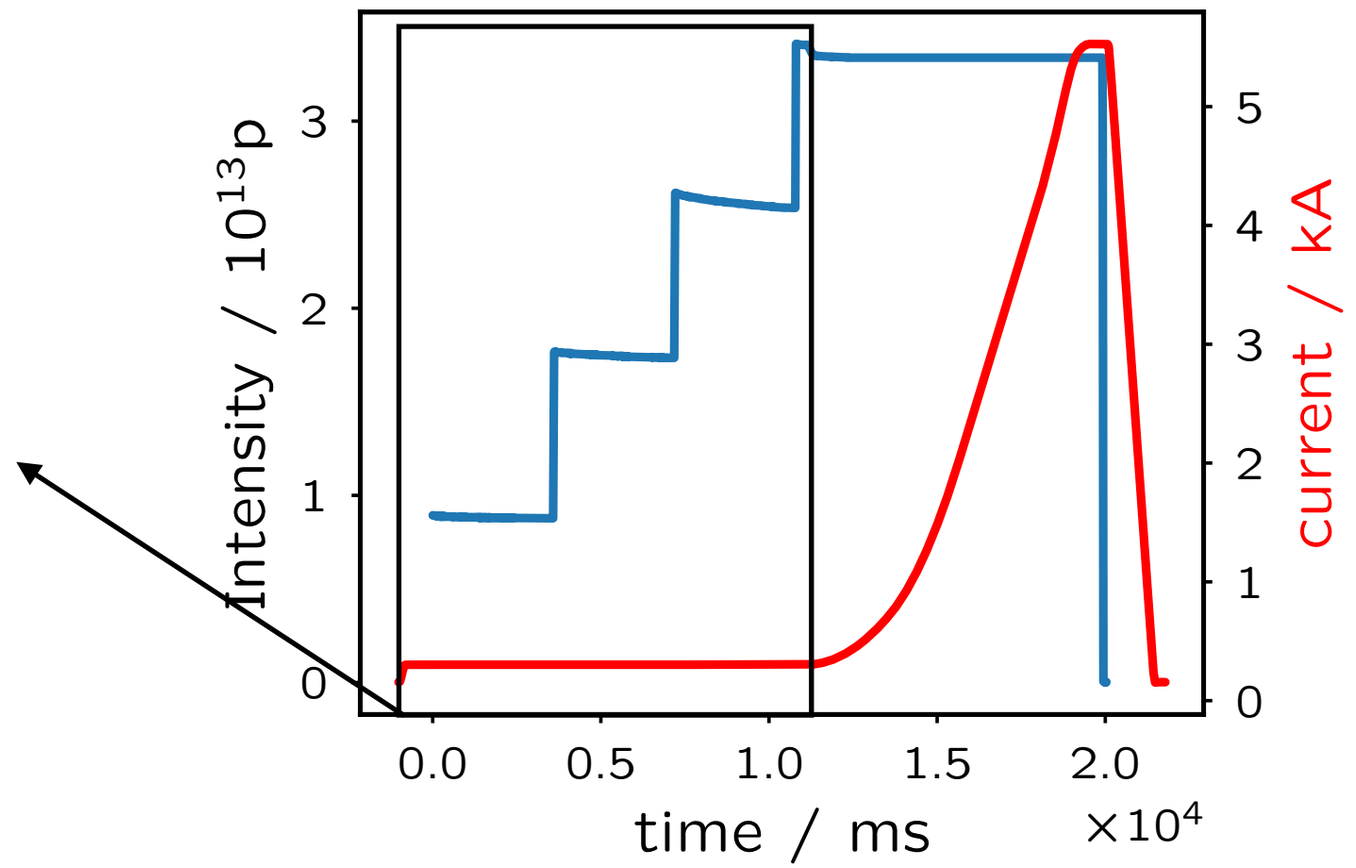
LHC Beams

- LHC beam are injected at 26 GeV and accelerated up to 400 (AWAKE), 440 (HiRadMat) and 450 (LHC) GeV

- 25 ns bunch spacing for a max of 288 bunches
  - Batch spacing from 200 to 250 ns

- Optics: Q20 (.13/.18)

- Fast extraction from LSS4 (AWAKE and LHCB2) or LSS6 (HiRadMat or LHCB1)



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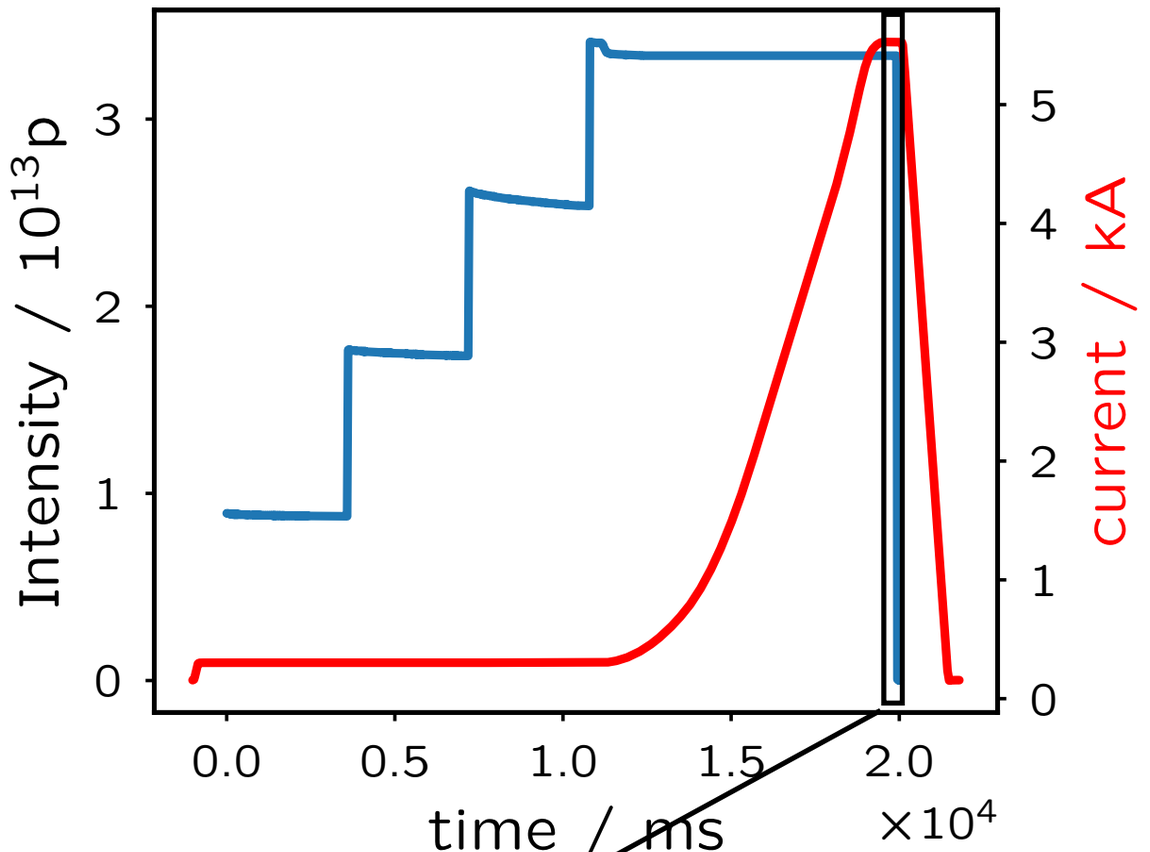

Beam parameters

- Parameters achieved and foreseen for LHC beam in the SPS from injection to extraction

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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})	$\Delta Q_{x,y}$
Achieved	Standard	1.33	2.36	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.05, 0.07)
	BCMS	1.27	1.27	26	0.35	4.0 (3.0)	0.9 (1.5)	(0.07, 0.12)
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
Achieved	Standard	1.20	2.60	450	0.45 (0.50)	1.65 (1.24)	288
	BCMS	1.15	1.39	450	0.35 (0.39)	1.50 (1.05)	144
LIU target	Standard	2.32	2.08	450	0.56	1.65	288
	BCMS	2.32	1.65	450	0.56	1.65	240

https://edms.cern.ch/document/1296306/2

Beam parameters

- Parameters foreseen for present and future operation of FT beams

Parameters	Value	Unit
Momentum	400	GeV/c
ϵ_x^N	8-12	mm.mrad
ϵ_y^N	5-8	mm.mrad
Minimum intensity	2×10^{12}	protons
Maximum intensity	7×10^{13}	protons
Long. Structure	De-bunched	-

Table 2: SFTPRO Beam Parameters in the SPS

Parameter	**Unit**	**SPS-FT North**		**SPS-FT SHiP**	
		Low Energy	High Energy	Low Energy	High Energy
Energy	GeV	14	400	14	400
Bunch intensity	10^{10} p/b	1.47(1)	1.40	1.12(1)	1.07
Number of bunches per batch		4200		4200	
Batch length	ns	22100		22100	
Total intensity per batch	10^{13} p+	5.88(2)		4.49(2)	
Bunch spacing	ns	5		5	
Number of trains per batch		2		2	
Number of bunches per train		2100		2100	
Train spacing	ns	1100		1100	
Train length	ns	10500		10500	
Emittance H (norm.)	µm	8.0		8.0	
Emittance V (norm.)	µm	5.0		5.0	

(1) : At flat-bottom before capture, assuming 5% reduction after capture

(2) : At flat-top energy

- Minimum intensity - used the value for FT setting up (T. Bohl)
- Maximum intensity from max achievable with RF