IBS: Emittance and bunch length evolution

S. Papadopoulou

Mini-Workshop (LBOC+LPC+CWG+LBS):
Running LHC at injection energy
15/1/19

Outline

Comparison of high beta and current injection optics
- -Optics
- -IBS growth rates
- -emittance and bunch length evolution using MAD-X

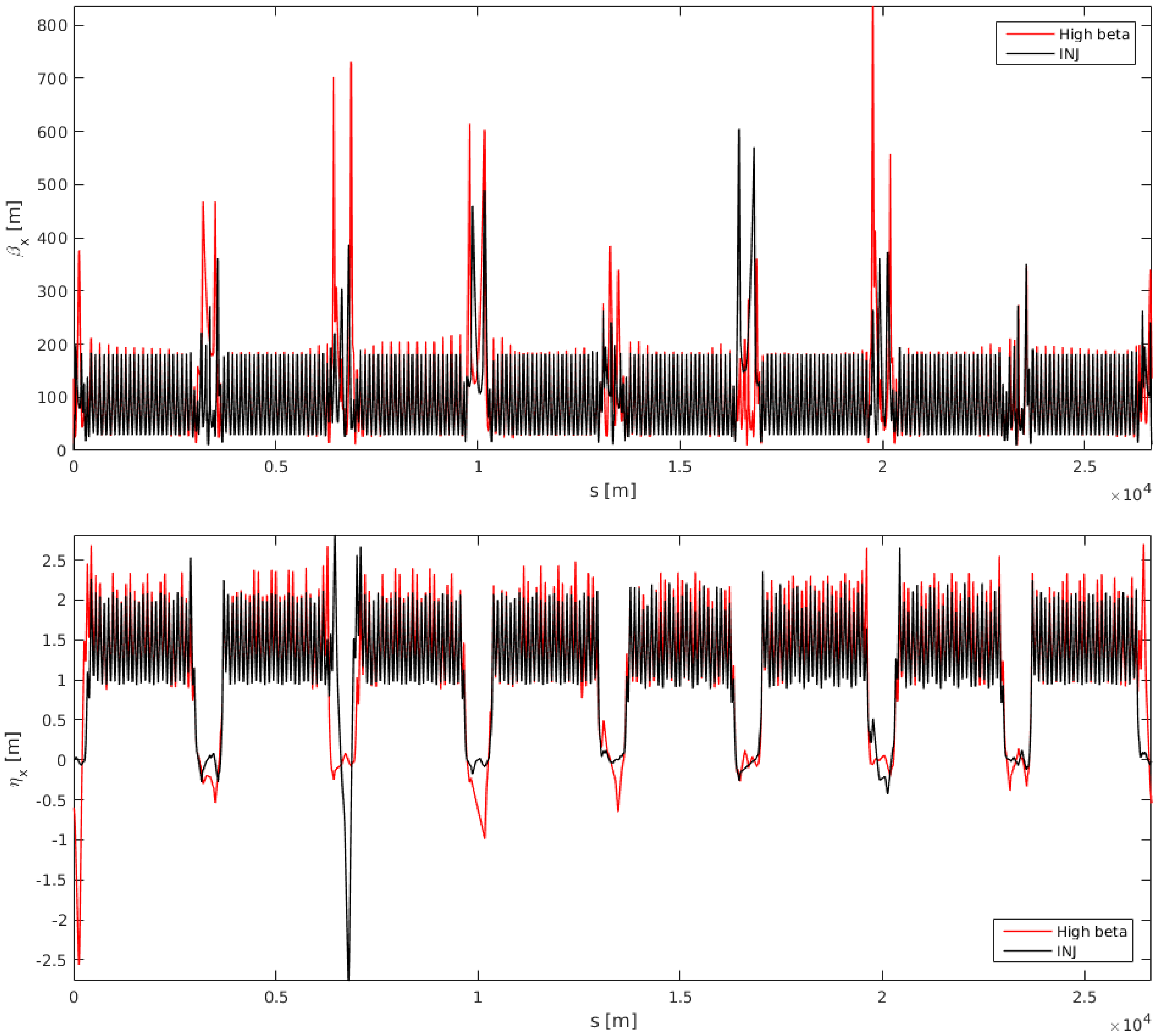
Emittance and bunch length evolution
- -from 2017 and 2018 Fill examples
- -from simulations performed with MAD-X

Comparison of emittance and bunch length evolution for the cases of 450 GeV and 900 GeV

Optics, IBS growth rates and emittance and bunch length evolution for high beta and current injection optics

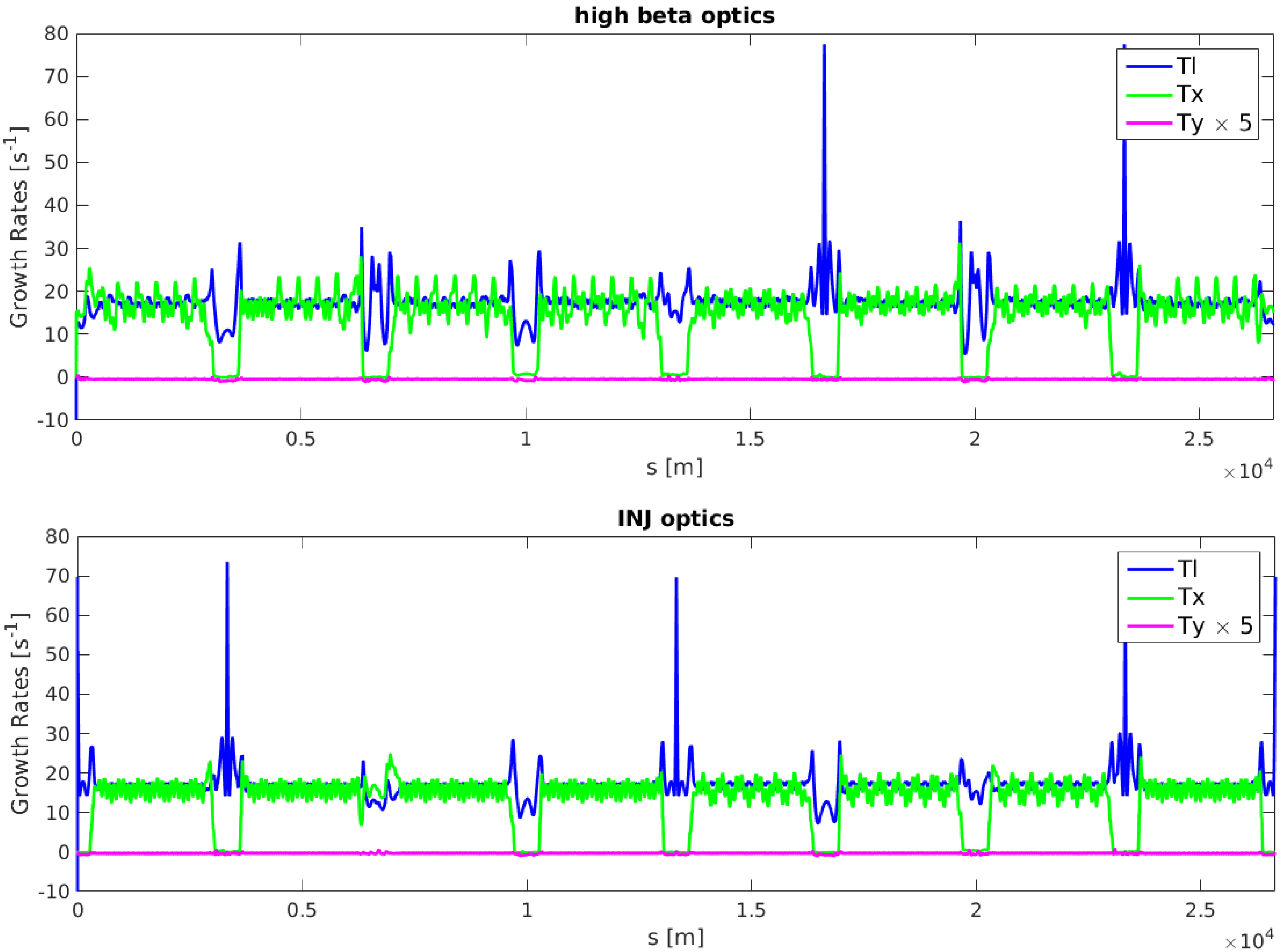
High beta and current INJ optics

Beta and dispersion
functions along the LHC



High beta and current INJ optics

IBS growth rates in transverse and longitudinal plane, along the LHC

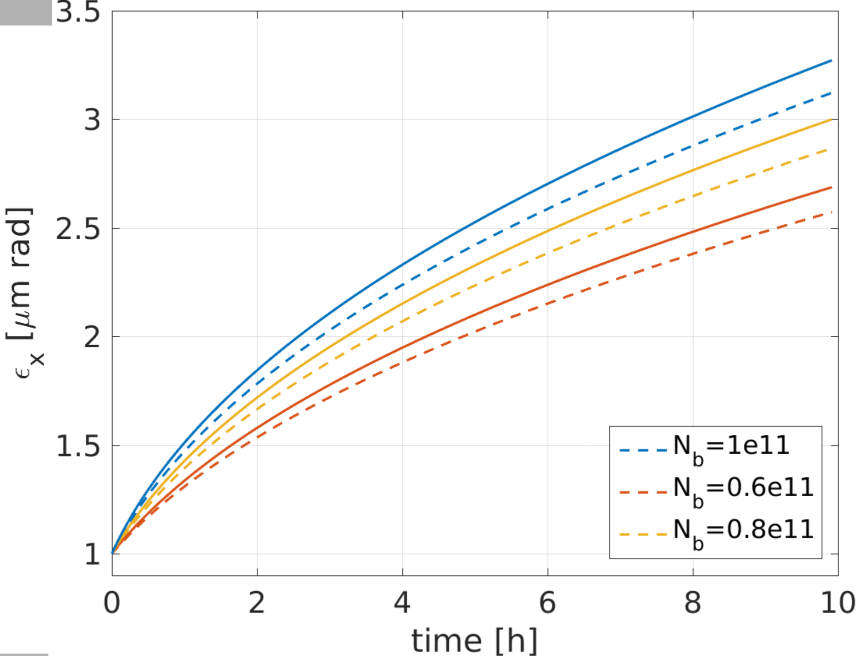


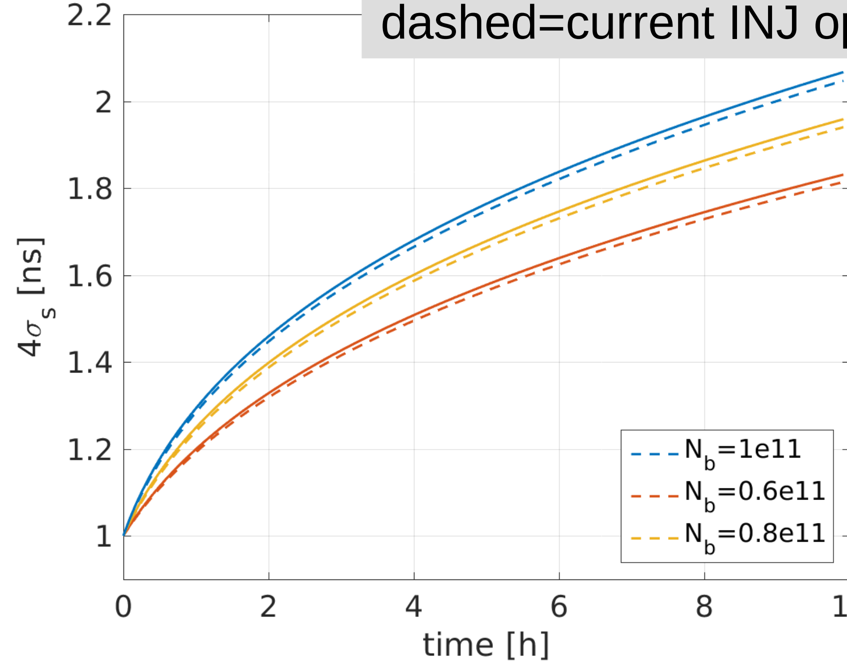
Emittance and bunch length evolution

solid=high beta optics
dashed=current INJ optics

V_{RF}=6MV

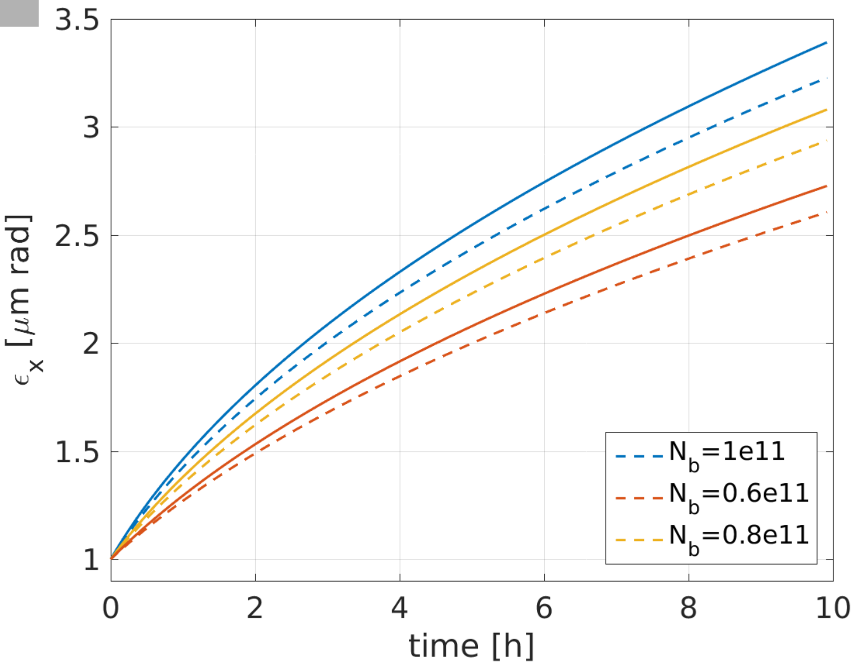
ε_x=1μm, σ_l=1ns

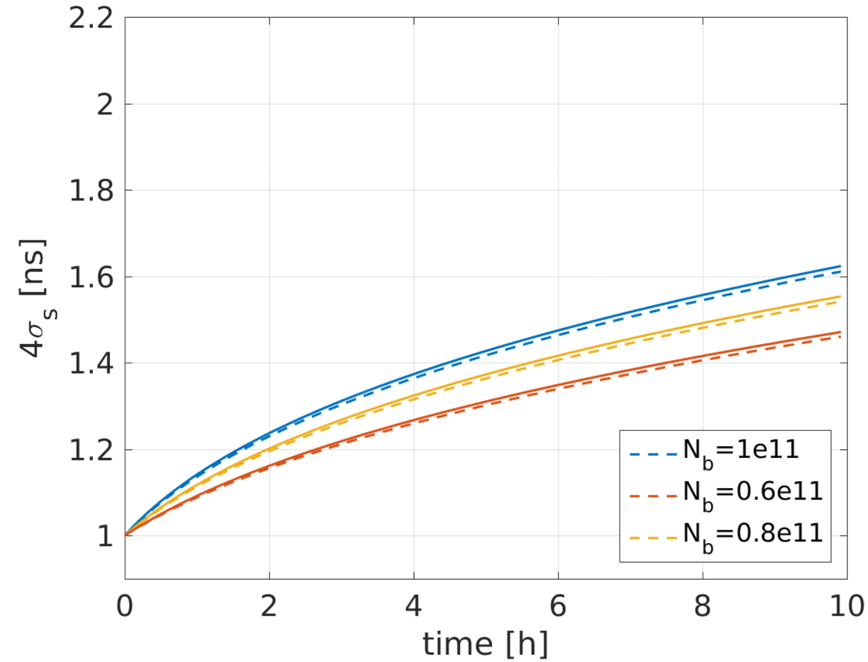




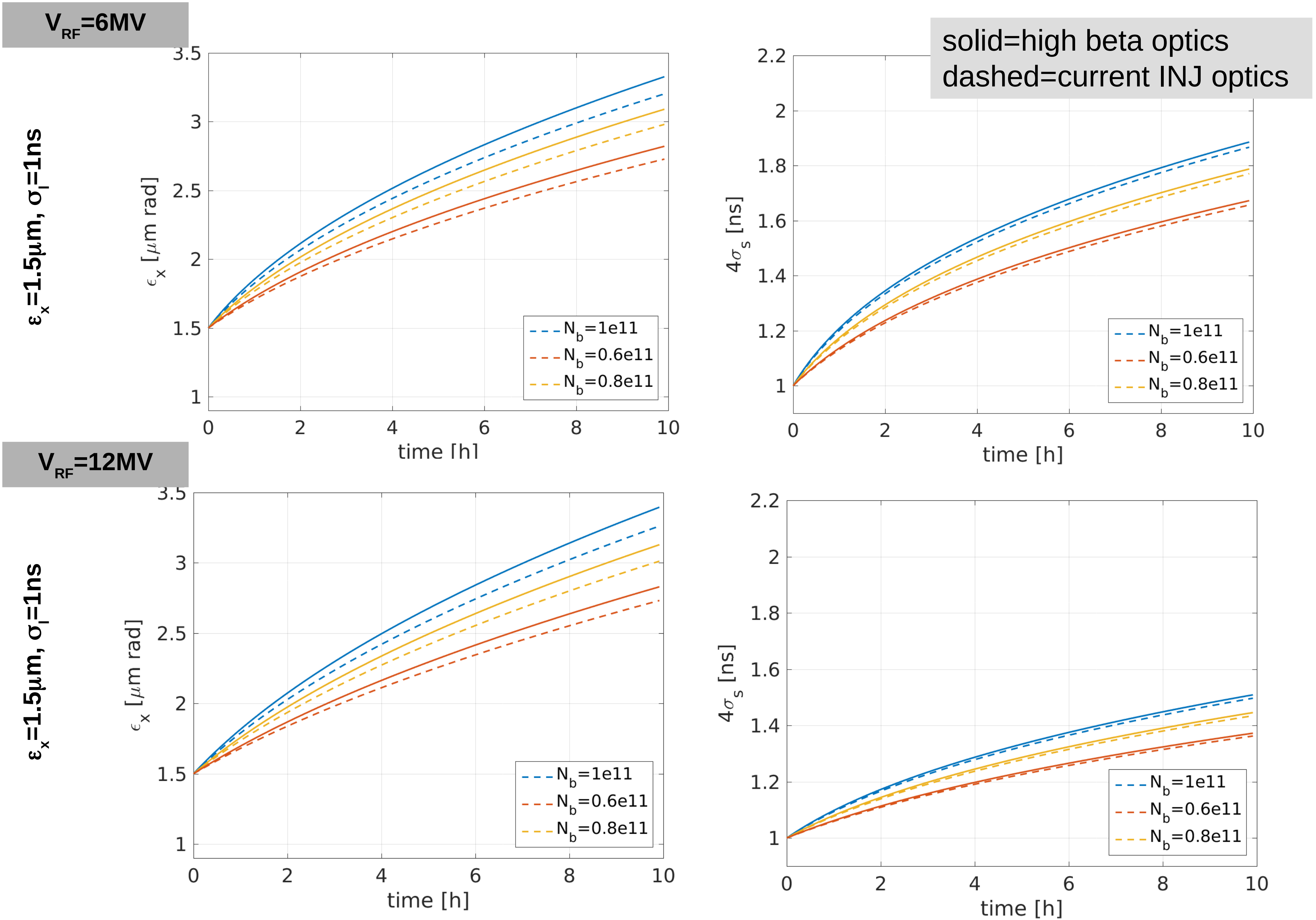
V_{RF}=12MV

ε_x=1μm, σ_l=1ns



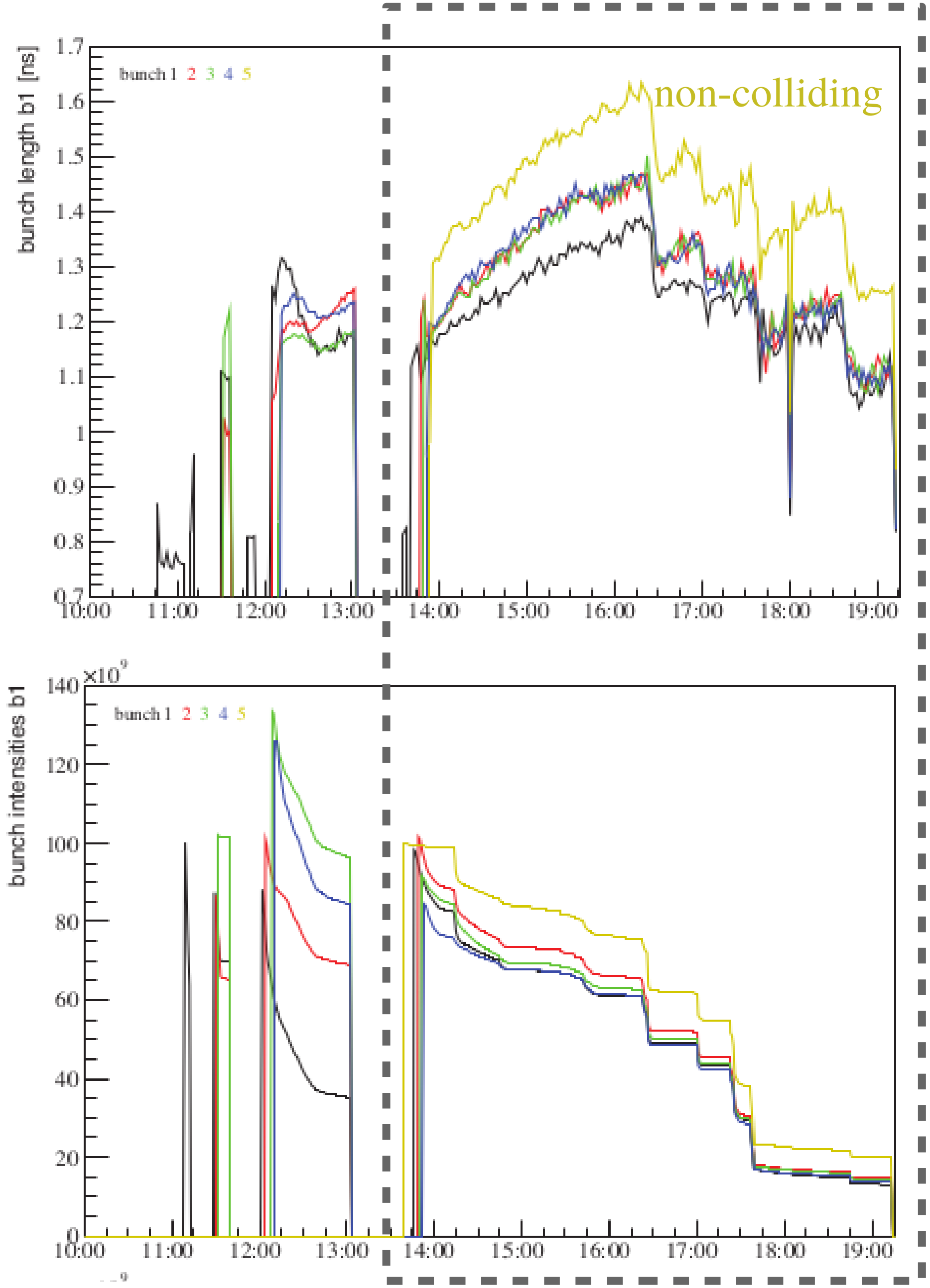


Emittance and bunch length evolution



Emittance and bunch length evolution from 2017 and 2018 Fill examples and comparison to simulations performed with MAD-X

Fill 6410

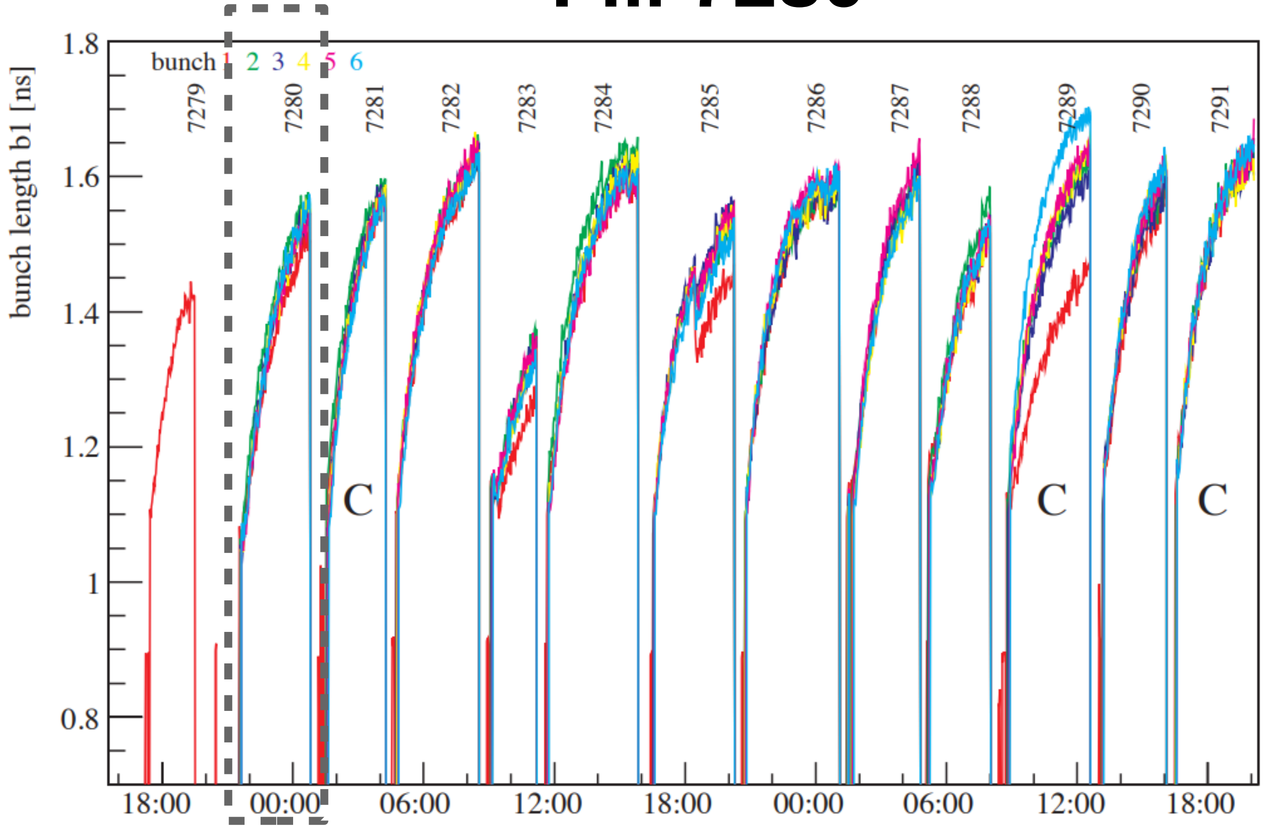


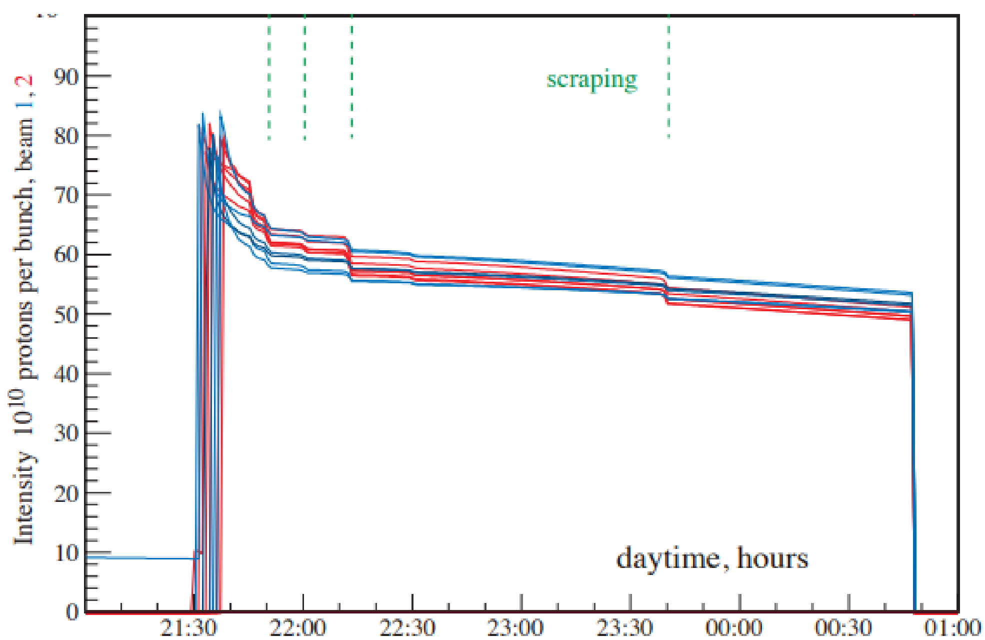
WS emittances ~1.0um.

-emittance and bunch length growth, background, RF-voltage 6.2 MV—> 12 MV (at end)

H. Burkhardt

Fill 7280





WS emittances ~1.2-1.4um

H. Burkhardt

lboc23102018

Beam parameters

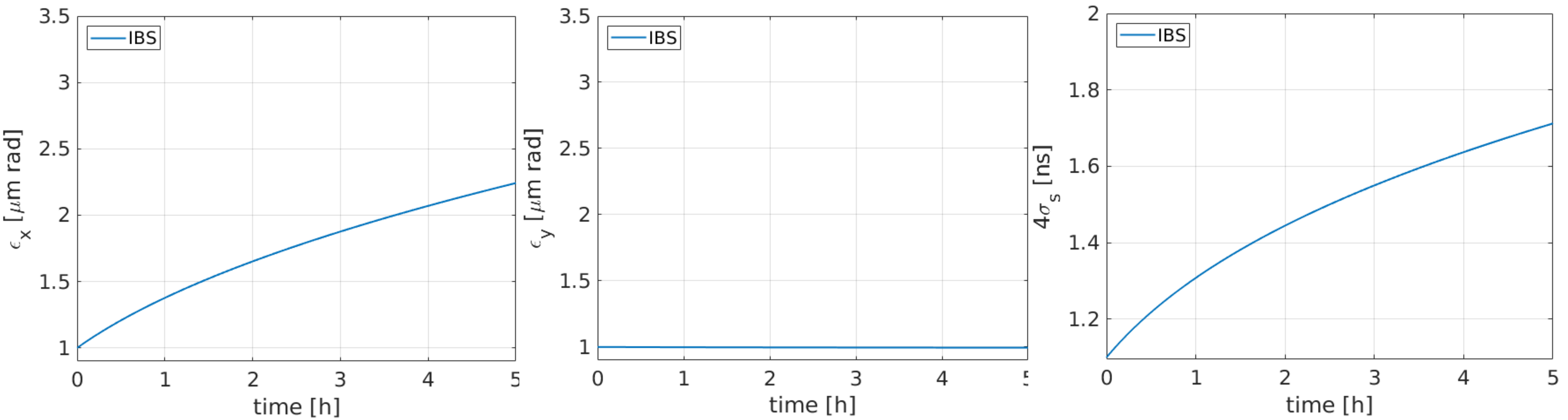
	Fill 6410	Fill 7280
V_{RF} [MV]	6	4
ε [μm]	1.0	1.4 (B1) , 1.2 (B2)
σ_l [ns]	1.1	
N_b [10^{11}]	0.8	
$beta^*_{x,y}$ [m]	50, 100 (IP1)	
extra emittance blow up (on top of IBS and e-cloud)	~0.25 μm/h and ~0.42 μm/h in the horizontal and vertical plane, respectively	

An extra transverse emittance growth, on top of IBS and e-cloud, is observed at the LHC FB energy.

Emittance and bunch length evolution

V_{RF}=6MV

ε_x=1μm, σ_l=1.1ns

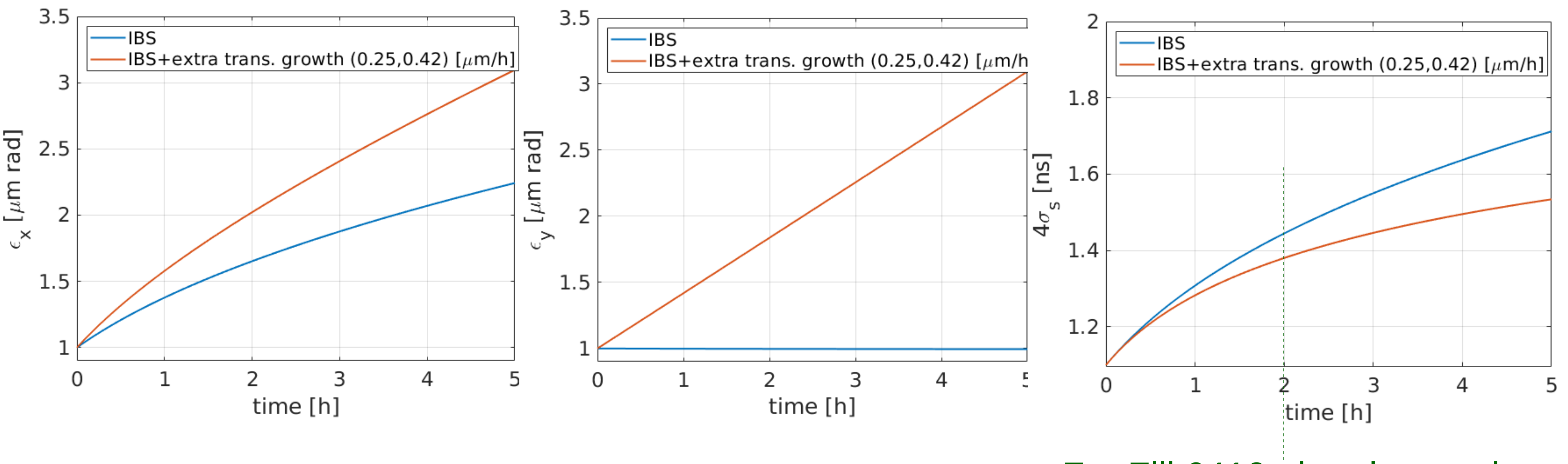


Emittance and bunch length evolution

V_{RF}=6MV

+observed extra emittance blow up (on top of IBS and ecloud) at FB

ε_x=1μm, σ_l=1.1ns

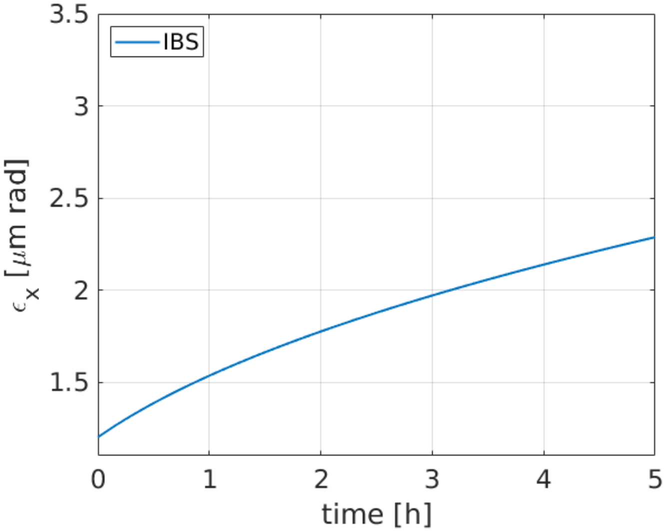


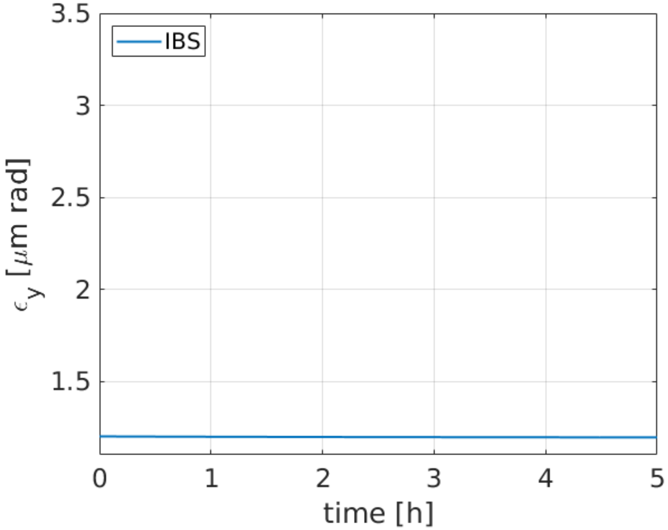
For Fill 6410, the observed bunch length after 2h is 1.4ns

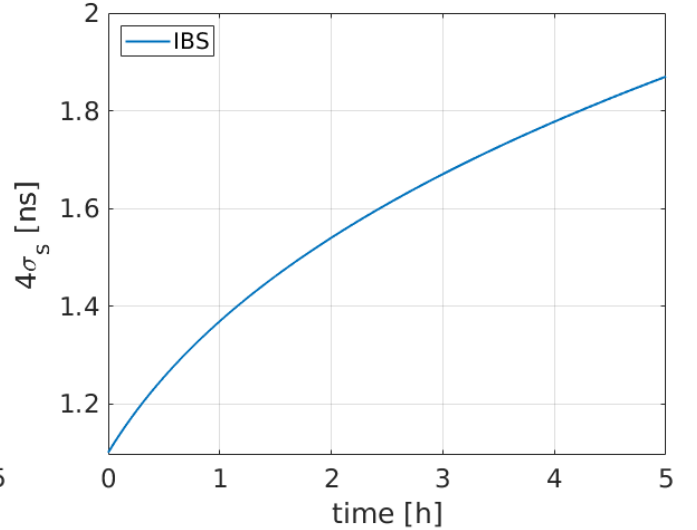
Emittance and bunch length evolution

V_{RF}=4MV

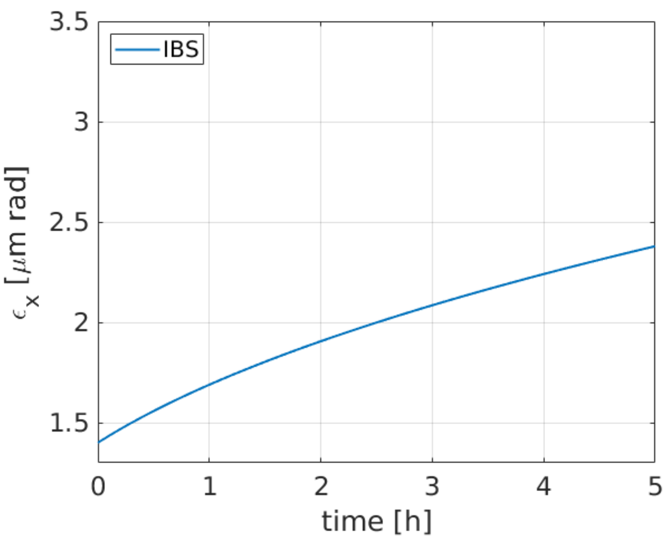
ε_x=1.2μm, σ_l=1.1ns

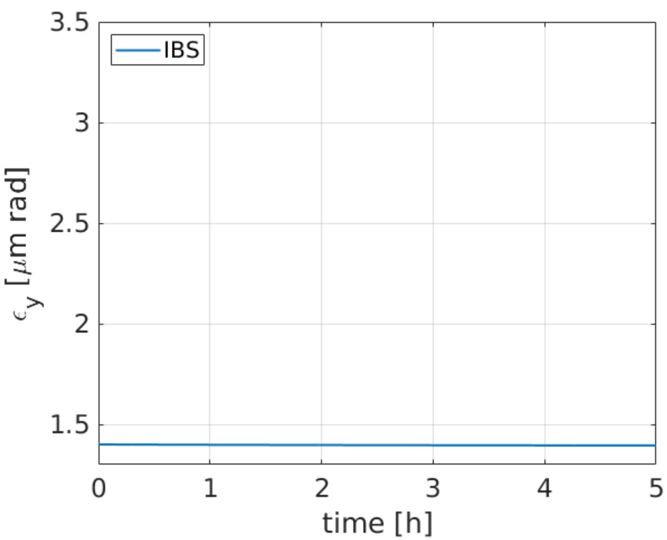


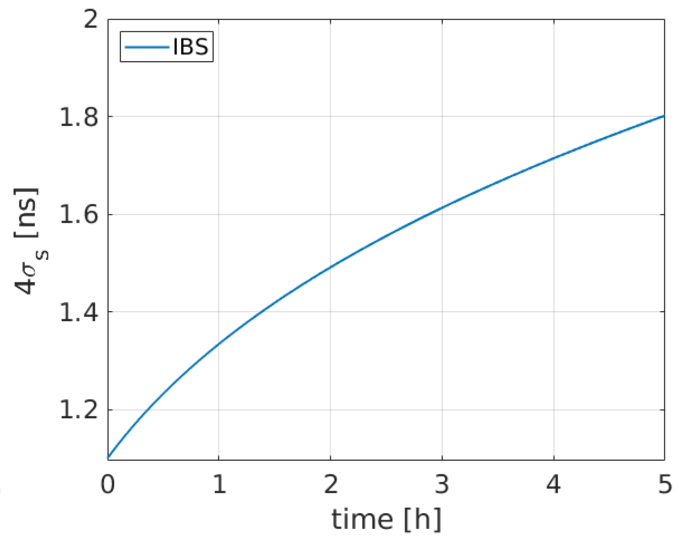




ε_x=1.4μm, σ_l=1.1ns





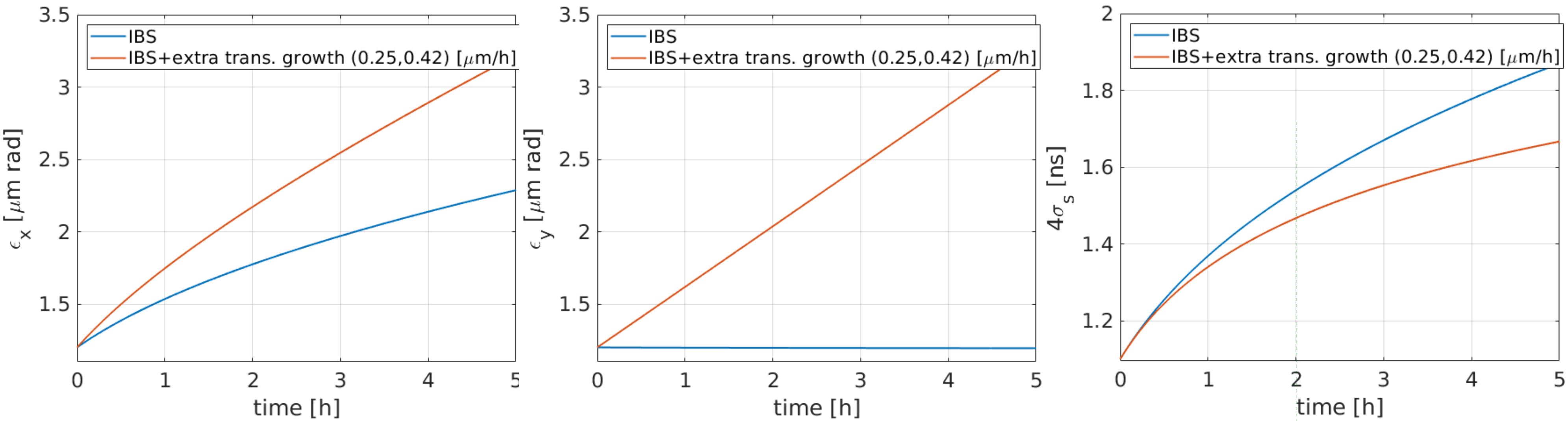


Emittance and bunch length evolution

V_{RF}=4MV

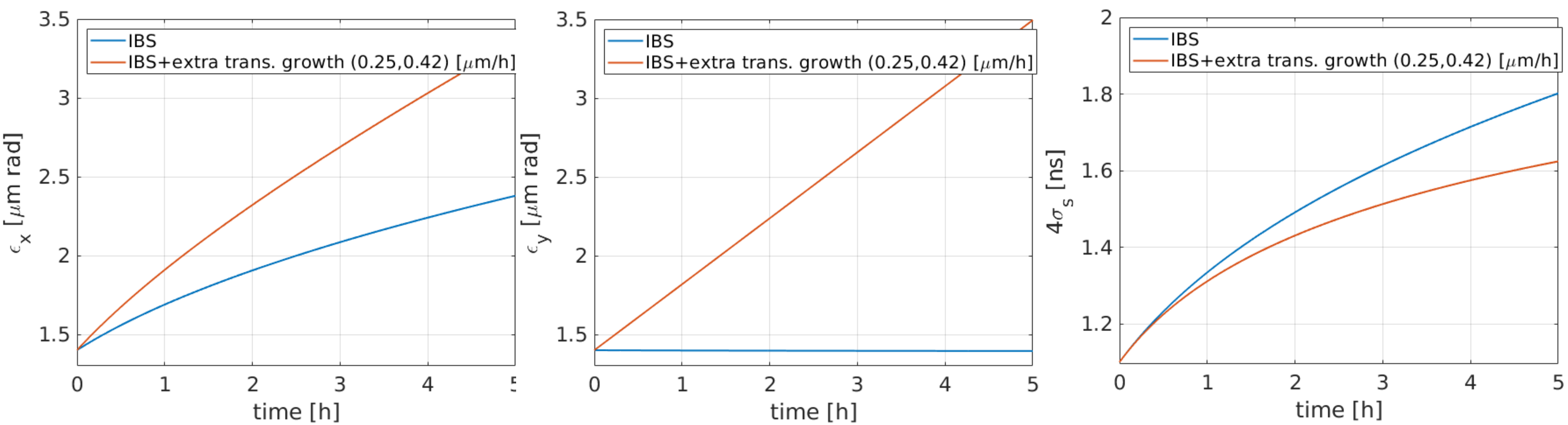
+observed extra emittance blow up (on top of IBS and ecloud) at FB

ε_x=1.2μm, σ_l=1.1ns



For Fill 7280, the observed bunch length after 2h is 1.5ns

ε_x=1.4μm, σ_l=1.1ns

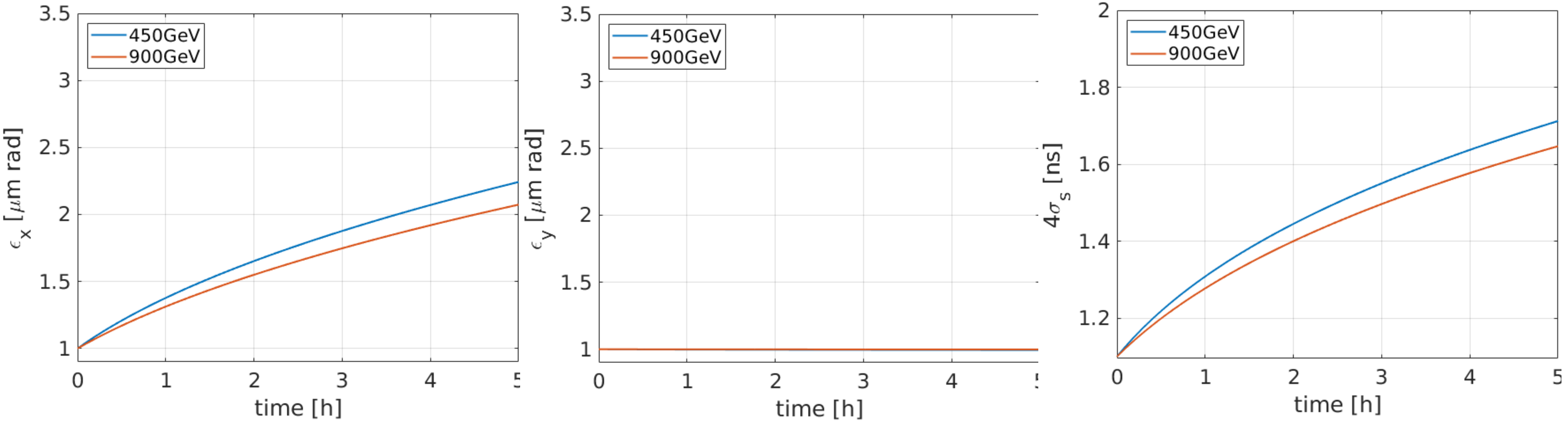


Emittance and bunch length evolution for 450GeV and 900GeV

Emittance and bunch length evolution

V_{RF}=6MV

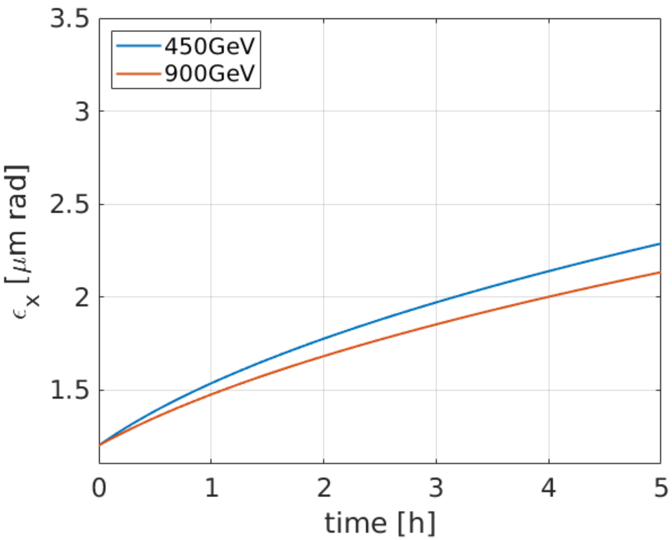
ε_x=1μm, σ_l=1.1ns

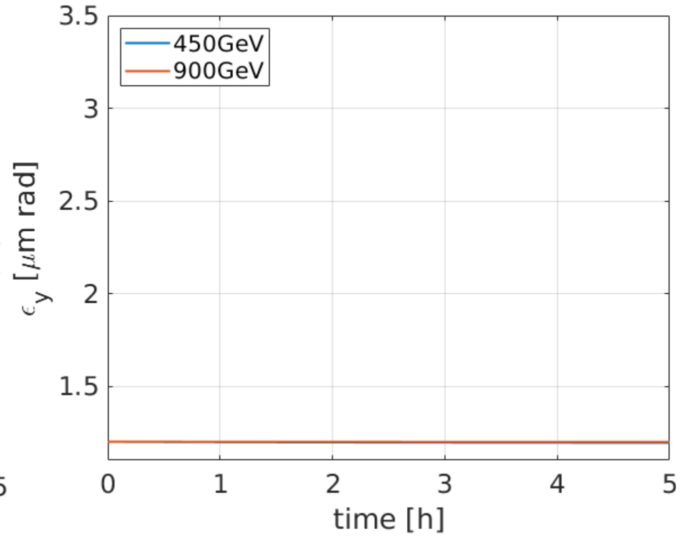


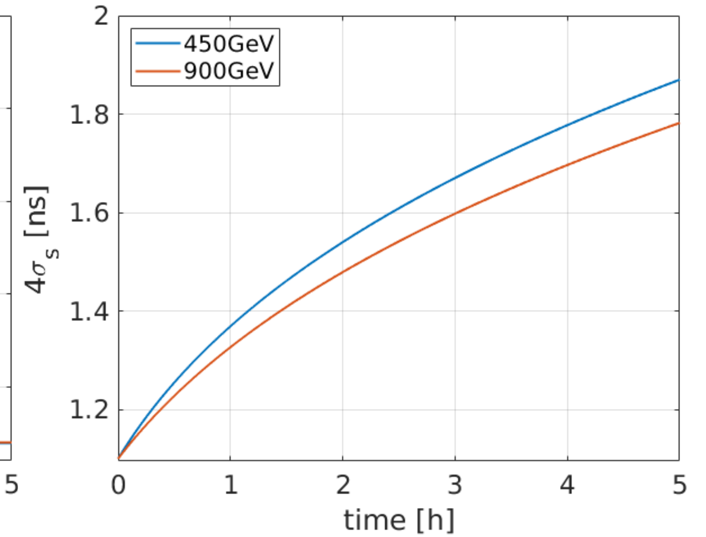
Emittance and bunch length evolution

V_{RF}=4MV

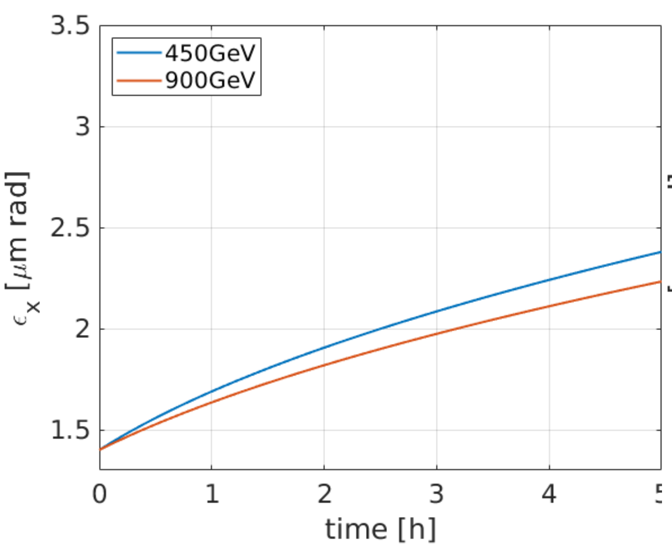
ε_x=1.2µm, σ_l=1.1ns

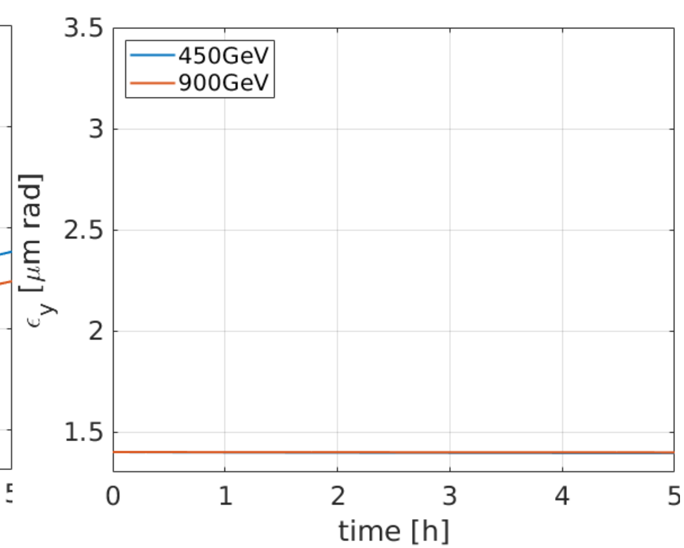


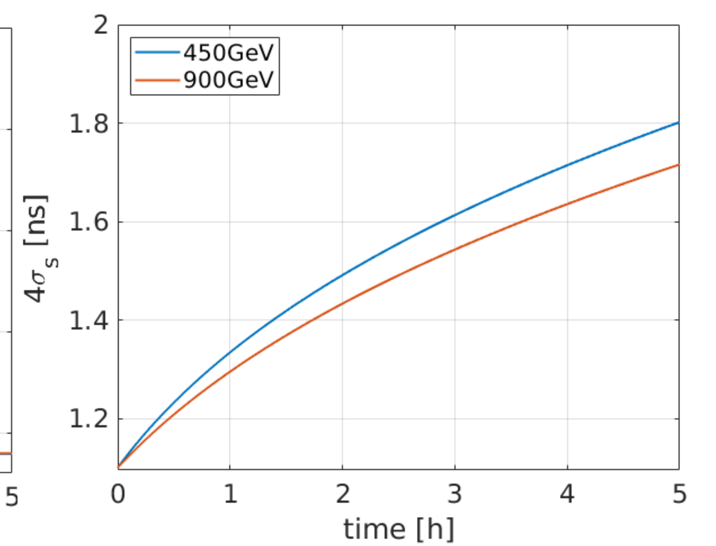




ε_x=1.4µm, σ_l=1.1ns







Summary

Different IBS growth rates for high beta and current injection optics, resulting in different emittance and bunch length evolution

Parameter scans for emittance and bunch length evolution estimations, based on the IBS module of MAD-X

Taking the beam parameters from some example Fills as input parameters for simulations, the agreement of data and simulations is in general good

Comparison of emittance and bunch length evolution for the cases of 450 GeV and 900 GeV, shows a ~10% difference in horizontal and ~6% difference in the longitudinal plane

Extra slides

High beta, test3 on 22/11/17

http://lhc-optics.web.cern.ch/lhc-optics/runII/2017/job_highbeta.madx

Using standard injection + my special high beta IR1,5 files
IR1/IP1_0100_v4.madx   betay* = 100m, betax* = 50 m
IR5/IP5_0100_v3b.madx   betay* = 100m, betax* = 70 m

Idea roughly :
→ Show we understand the observed growth
→ Propose parameters which would allow us to measure 2-3 hours before debunching.

Also work with collimation Roderik, Hector on collimation including off-momentum collimation, down to cut in dp/p of about 1.2e-3.

22/11/17 test3

Summary of high beta run tests
R.Bruce, H.Burkhardt, M.Deile, P.Fassnacht, H.Garcia, S.Jakobsen, J.Kaspar

In this third test with high-beta at injection we tested several collimator configurations to evaluate the background in ALFA and TOTEM.
It took a while to get satisfactory beam conditions to start with.
First attempts had poor lifetimes for beam1. At least part of the problem was caused by beam-beam effects - as visible at 11:35 when we dumped beam2 which cured the lifetime problems on beam1.
By 14:00 we had a good beams, with similar intensities and lifetimes and could start the collimation and background studies.

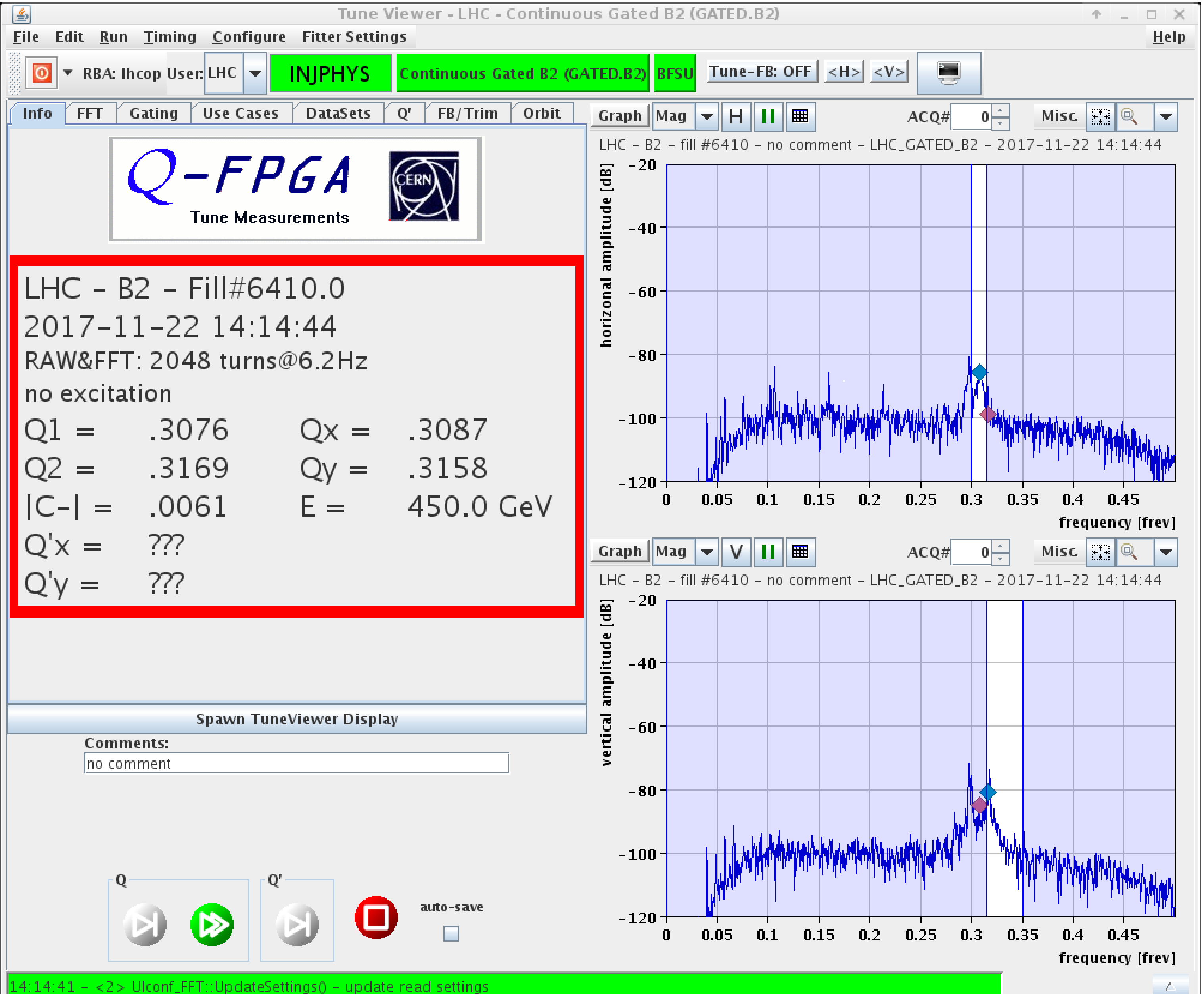
Test 1: The momentum cut with the primary collimator was set to 5 sigma. We scraped with the vertical TCP to 2 sigma and with the horizontal TCP to 3 sigma. Then, TCTPV in IR2 for B1, TCTPV in IR8 for beam 2 and TCLA.A5[L/R]3 where set to 2 sigma. RPs were set to 3 sigma. Then TCTPVs and TCLAs where retracted to 2.5 sigma and horizontal TCP to 5.5. Then the background was evaluated for 30 minutes.
Test 2: Same case as Test 1 but with a deeper off-momentum scraping to 3 sigma with TCP in IR3. Then, TCLA.6[R/L]3 was set to 5 sigmas acting as the primary momentum collimator. TCTPV in IR2 for B1, TCTPV in IR8 for beam 2 and TCLA.A5[L/R]3 where set to 2.5 sigma after scraping to 2 sigma. RPs were set to 3 sigma and the momentum cut was set to about 4e-3. Then TCTPVs and TCLAs where retracted to 2.5 sigma and horizontal TCP to 5.5, and IR3 TCP to 10 sigma. Then the background was evaluated for 30 minutes.
Test 3: Same case as Test 2 but with a deeper scraping until setting the off-momentum cut to 1e-3 (2.5 betatron sigma of the TCP in IR3), then retracted IR3 TCP to 10 sigma. It should be noted that the deeper IR3 scraping caused significant beam loss. RPs @ 3.5 sigma.
Test 3bis: Same case as Test 3 but with RP gap at 3.0 sigma.
Test 4: In this case we created a tungsten collimator hierarchy placing TCTPV in IR2 for B1, TCTPV in IR8 for beam 2 at 2.0 sigmas and TCLA.A5[L/R]3 where to 2.5 sigma after scraping to 1.5 sigma with TCTs. Then, background was evaluated for 30 minutes. Momentum scraping done with IR3 TCP to 2.5 sigma and retracted to 10 sigma. Significant beam losses observed when scraping to 1.5 sigma.
Test 5: We repeated Test 1 but scraping with the horizontal IR7 TCP to 2.5 sigmas in order to disentangle the contribution from off-momentum halo.
Test 6: In the final test, we increased the RF voltage to 12 MV in order to close the gap between the bucket and the momentum cut. background at ALFA and TOTEM was acquired. Same collimator scrapings as in test 3.
All background results from ALFA and TOTEM are to be evaluated offline in order to judge whether any of the configurations is acceptable for physics runs.

22/11/17 test3

Fill 6410

8poles

Variable Name	# Values	MIN Timestamp	MAX Timestamp	MIN Value	MAX Value	AVG Value	Standard Deviation	Frequency
RPMBB.RR17.ROD.A12B2:I_REF	849	2017-11-22 12:04:48.940	2017-11-22 18:20:15.940	-13.04	0	-11.38	3.968	2/min



Intra Beam Scattering

The growth times for the longitudinal phase space and momentum and bunch distributions are:

$$\frac{1}{\tau_p}=\frac{1}{2\sigma_p^2}\frac{d\sigma_p^2}{dt}=A\frac{\sigma_h^2}{\sigma_p^2}f(a,b,c)$$

$$\frac{1}{\tau_x}=\frac{1}{2\sigma_{x\beta}^2}\frac{d\sigma_{x\beta}^2}{dt}=A\frac{\sigma_h^2}{\sigma_p^2}\left[f\left(\frac{1}{a},\frac{b}{a},\frac{c}{a}\right)+\frac{\eta^2\sigma_p^2}{\sigma_{x\beta}}f(a,b,c)\right]$$

$$\frac{1}{\tau_y}=\frac{1}{2\sigma_{y\beta}^2}\frac{d\sigma_{y\beta}^2}{dt}=A\frac{\sigma_h^2}{\sigma_p^2}f\left(\frac{1}{b},\frac{a}{b},\frac{c}{b}\right)$$

with $A=\dfrac{r_e^2 cN_b}{64\pi^2\sigma_s\sigma_p\sigma_{x\beta}\sigma_{y\beta}\sigma_{x'}\sigma_{y'}\beta^3\gamma^4}$ the particle bunch density.

Note γ^4 energy dependence

The function f is: $f(a,b,c)=8\pi\int_0^1\left\{\ln\left[\frac{c^2}{2}\left(\frac{1}{\sqrt{p}}+\frac{1}{\sqrt{q}}\right)\right]-0.577..\right\}\frac{1-3x^2}{\sqrt{pq}}dx$

and $p=\left(\frac{\sigma_h}{\gamma\sigma_{x'}}\right)^2+x^2\left(1-\left(\frac{\sigma_h}{\gamma\sigma_{x'}}\right)^2\right)$ $\quad q=\left(\frac{\sigma_h}{\gamma\sigma_{y'}}\right)^2+x^2\left(1-\left(\frac{\sigma_h}{\gamma\sigma_{y'}}\right)^2\right)$

$$\sigma_h^2=\frac{\sigma_p^2\sigma_{x\beta}^2}{\sigma_{x\beta}^2+\alpha_c^2\sigma_p^2} \qquad c^2=\beta^2\sigma_h^2\frac{\sqrt{2\pi}\sigma_{y\beta}}{r_e}$$