Faster ramping of LHC in 2017 and prospects for lower energy injection into LHC in 2018

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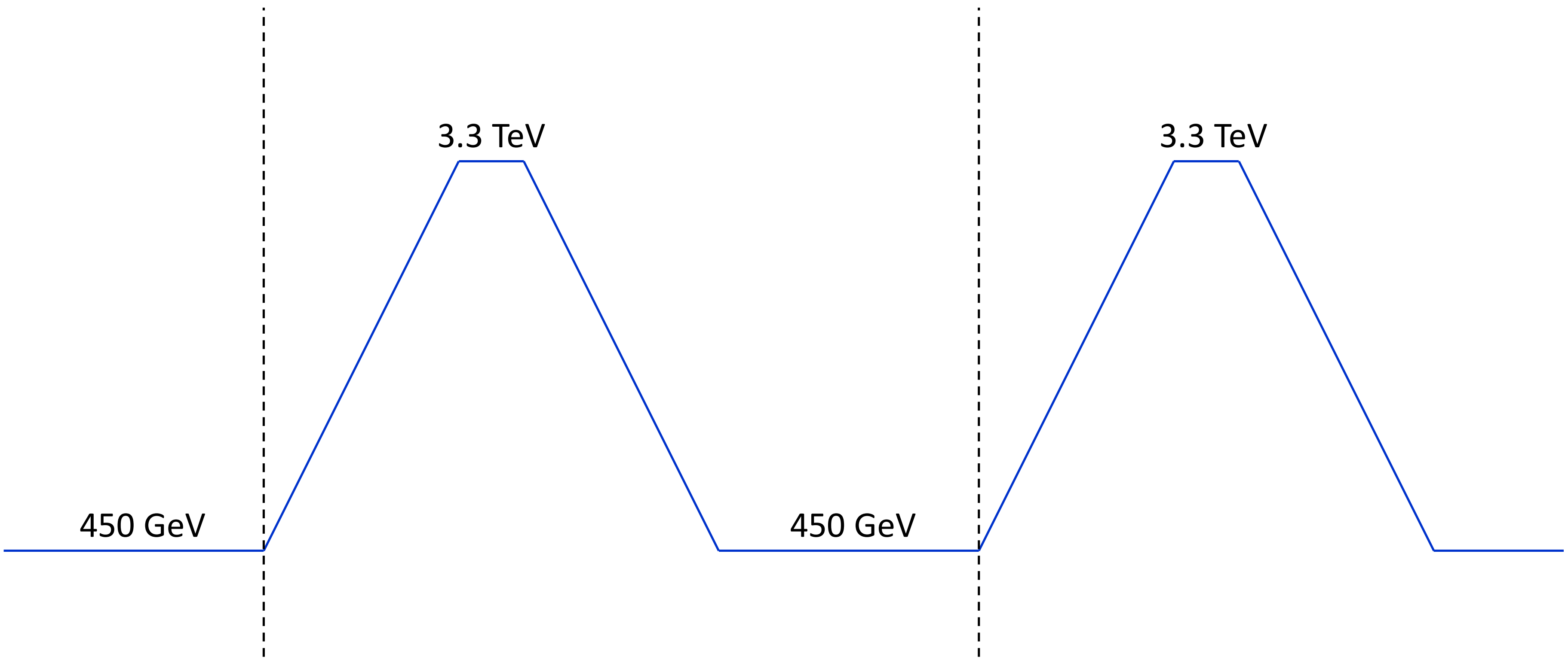
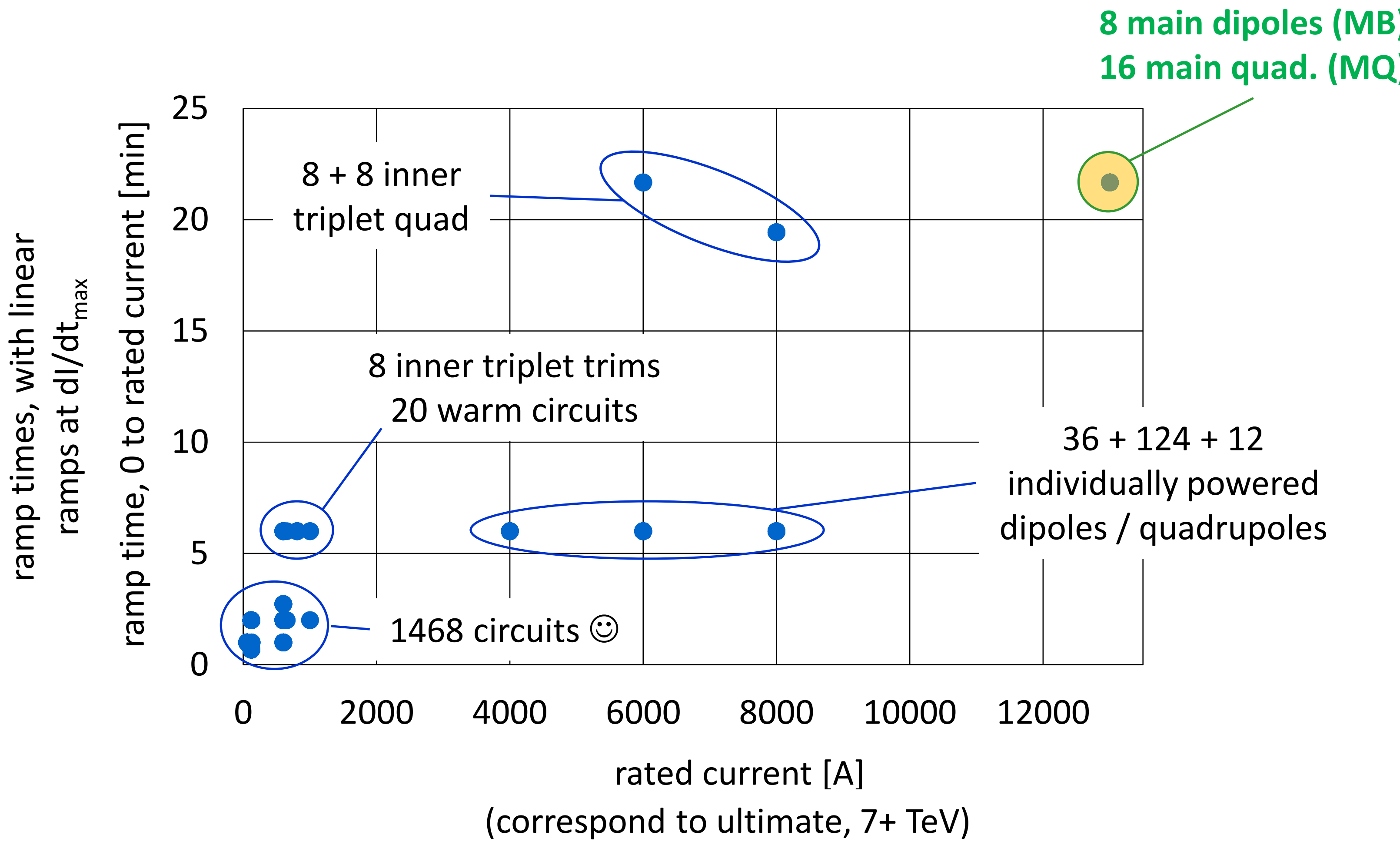
A faster ramp of the LHC is an ingredient to make it a (more attractive) High Energy Booster for FCC



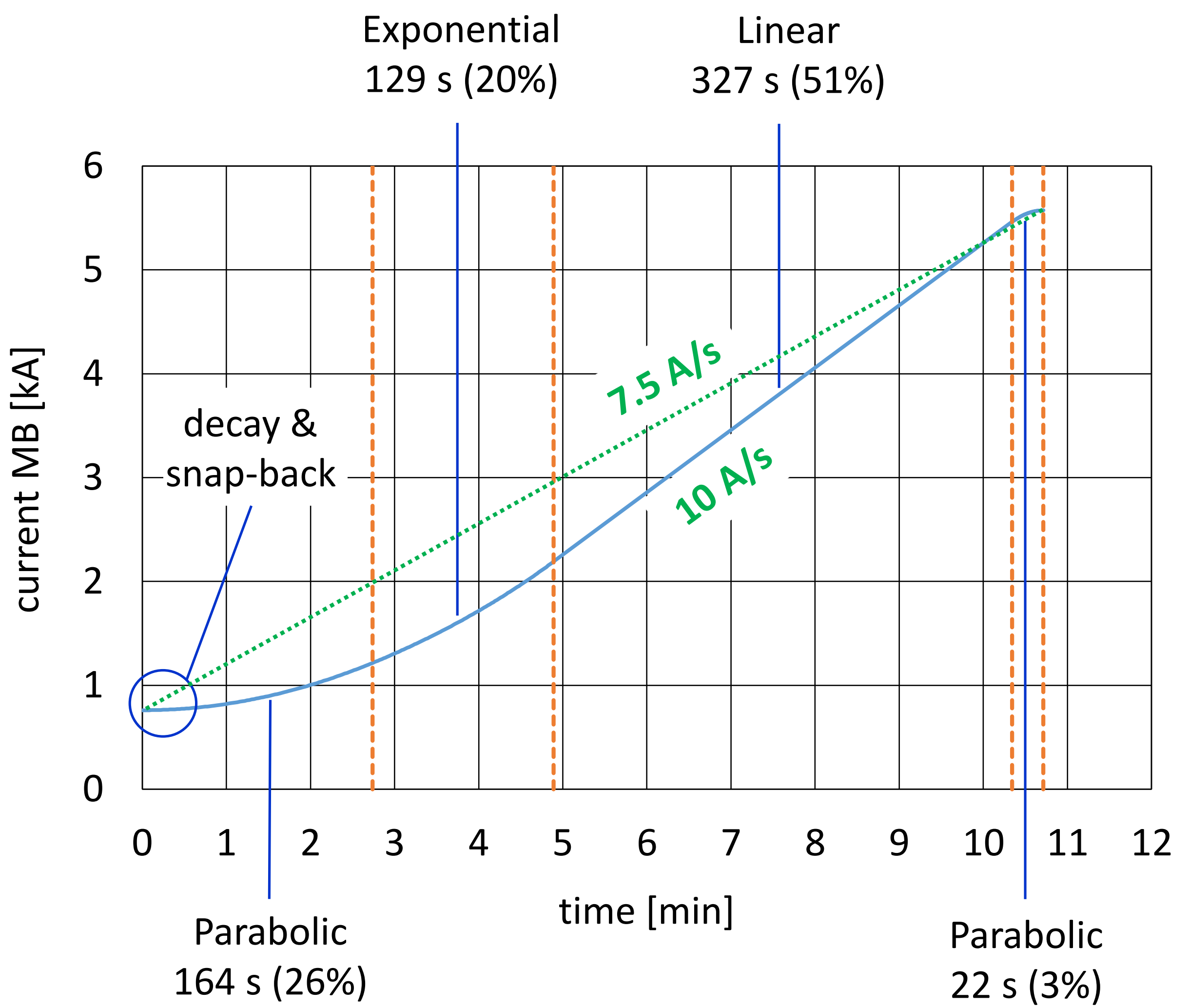
3.3 TeV is taken as baseline injection energy for FCC-hh

A ramp in the LHC involves 1700+ electrical circuits: the limiting ones – in terms of ramp rate – are the large 13 kA



data from electrical layout database

With the standard PELP ramp, going to 3.3 TeV takes 10’43’’



PELP function

I_{inj} = 760 A

I_{flt} = 5573 A

dI/dt_{max} = 10 A/s

ΔI_{snb} = 12 A

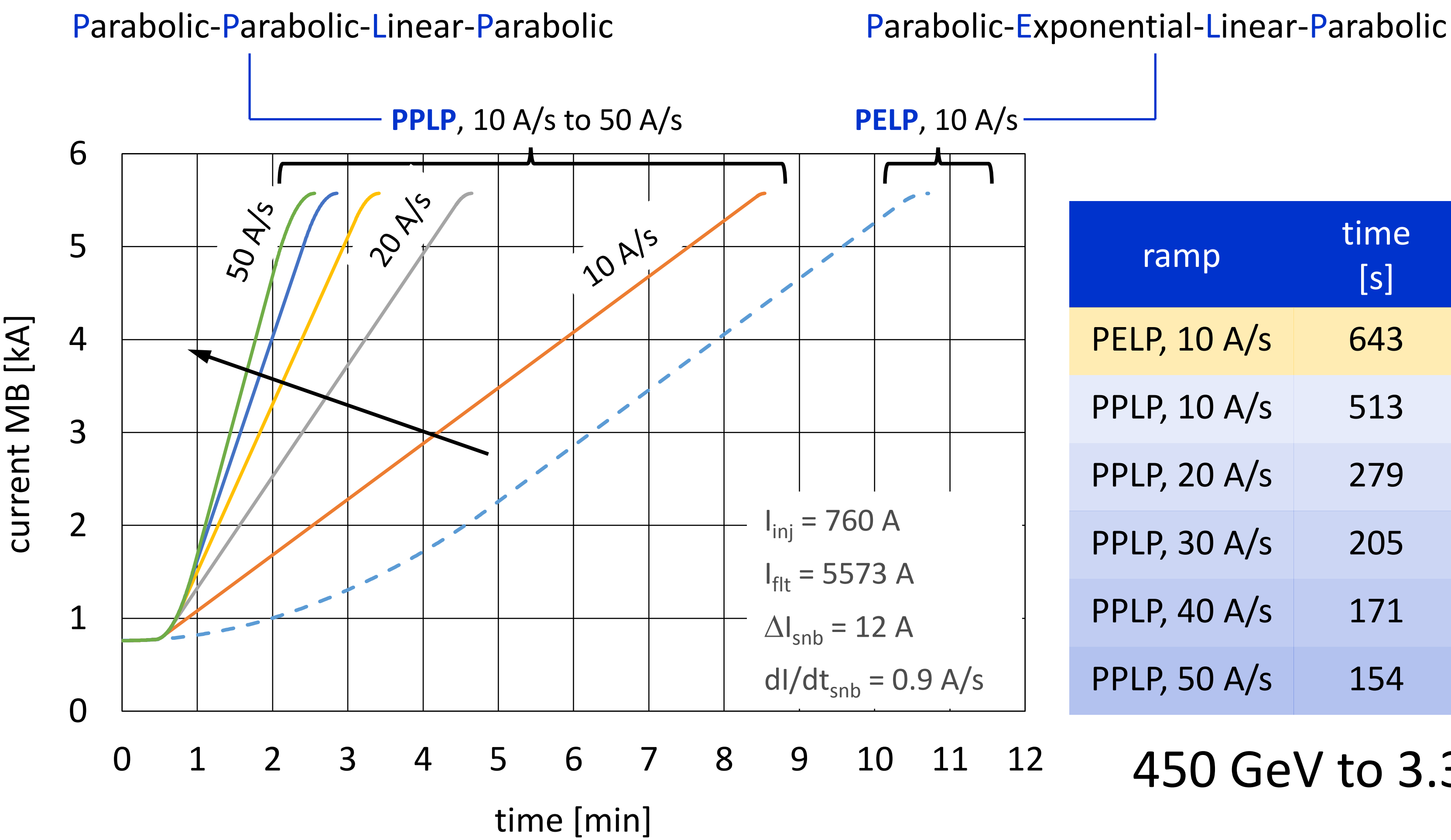
dI/dt_{snb} = 0.9 A/s

$\Delta I_{p2} = 0.02\ I_{flt}$

$B_{exp,max}$ = 1.6 T

parameters used up to 2017

To speed up the ramp, we proposed to:
- increase dI/dt_{max} (power converters voltage upgrade)
- modify the ramp function

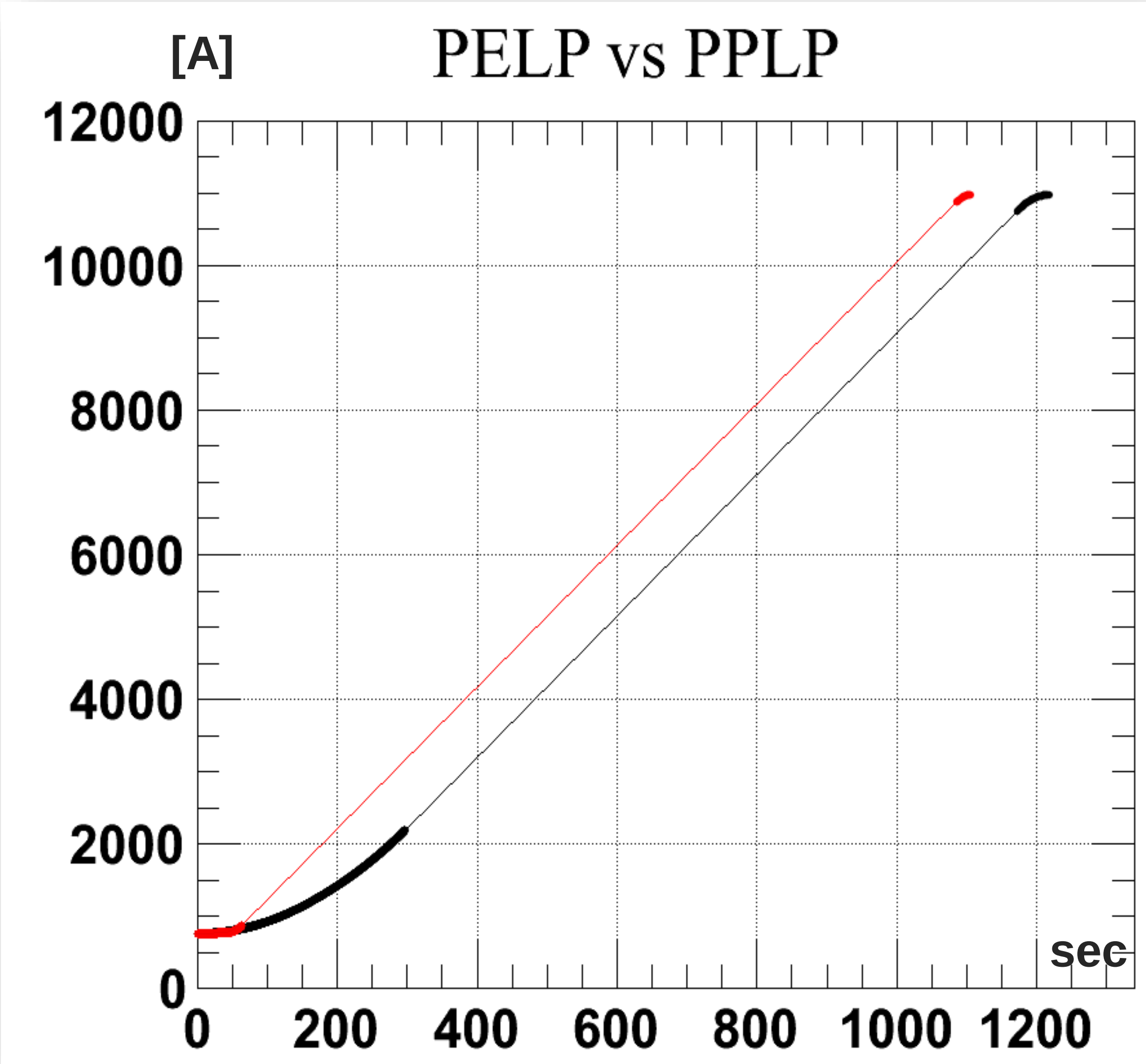


ramp	time [s]	dI/dt_{avg} [A/s]
PELP, 10 A/s	643	7.5
PPLP, 10 A/s	513	9.4
PPLP, 20 A/s	279	17.3
PPLP, 30 A/s	205	23.5
PPLP, 40 A/s	171	28.1
PPLP, 50 A/s	154	31.3

450 GeV to 3.3 TeV

PPLP ramp in 2017
(MD and operation)

The PPLP ramp to 6.5 TeV is ≈10% shorter than the PELP ramp



1100 s

vs.

1210 s

=

potential gain

14 h per year

(for 450 ramps)

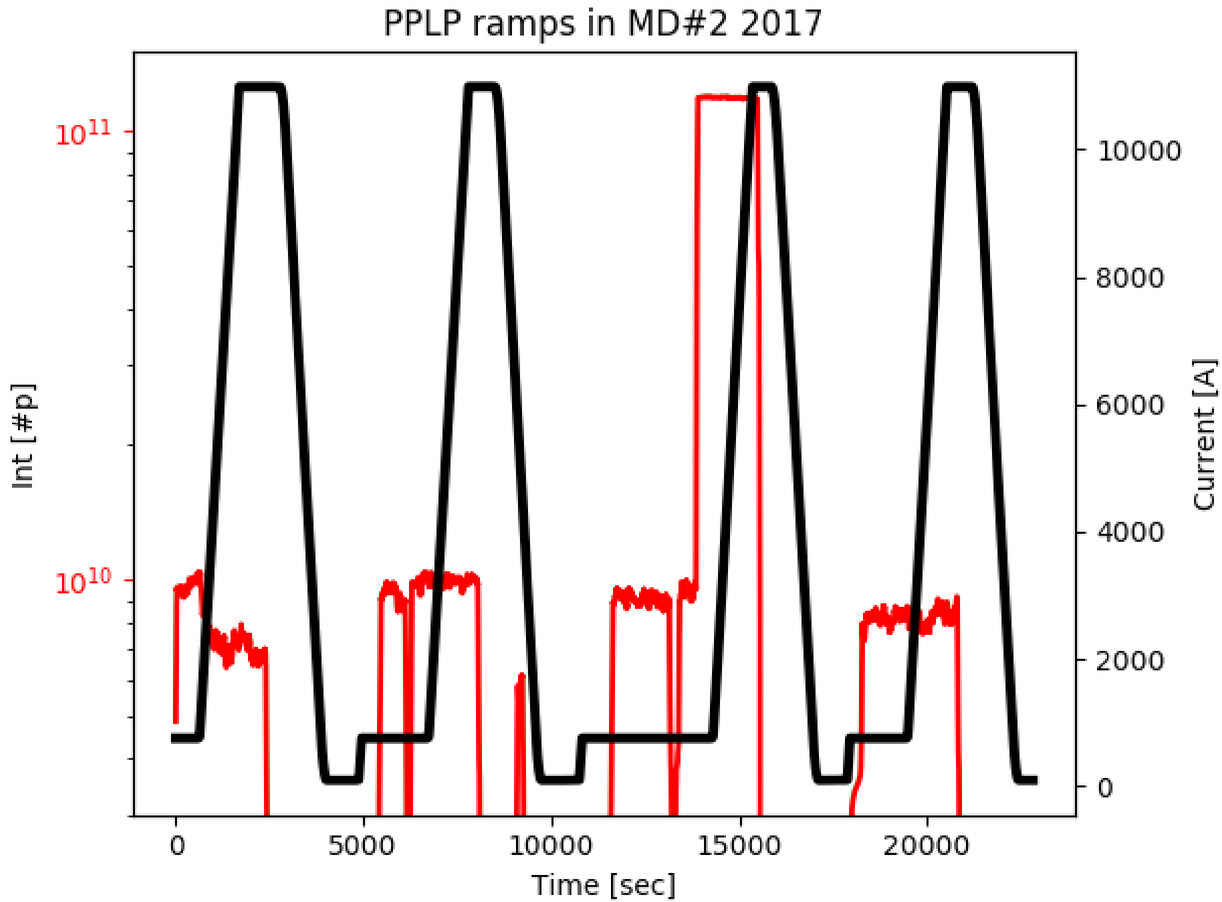
On 24/07/2017 we had an MD to test this PPLP ramp

1) Pilot, long blow-up ON: lost ≈40% during first 400 s [RF blow-up problem]

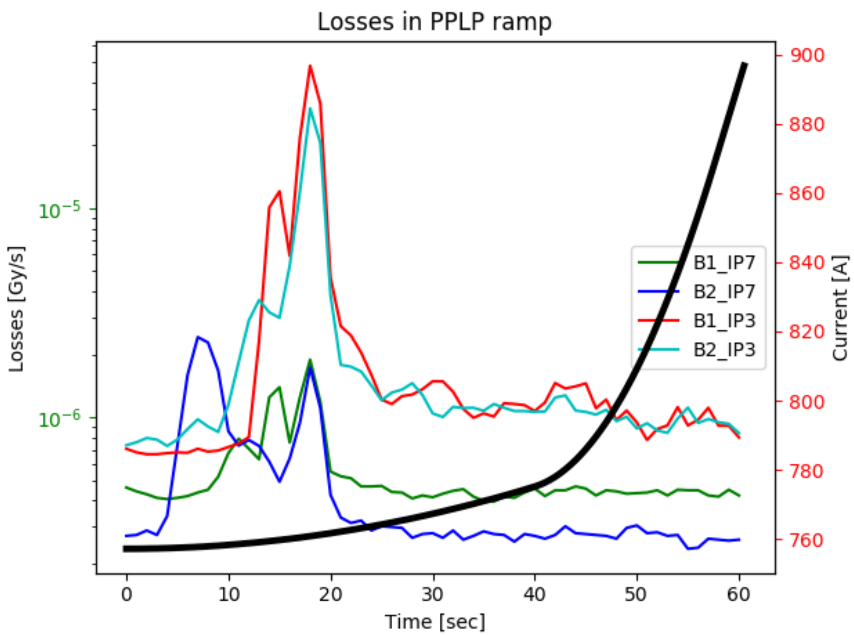
2) Pilot, NO long blow-up, tune/orbit fed-forward: GOOD!

3) INDIVs, long blow-up ON, orbit/tune (re)fed-forward, Xing & sep IN: GOOD!

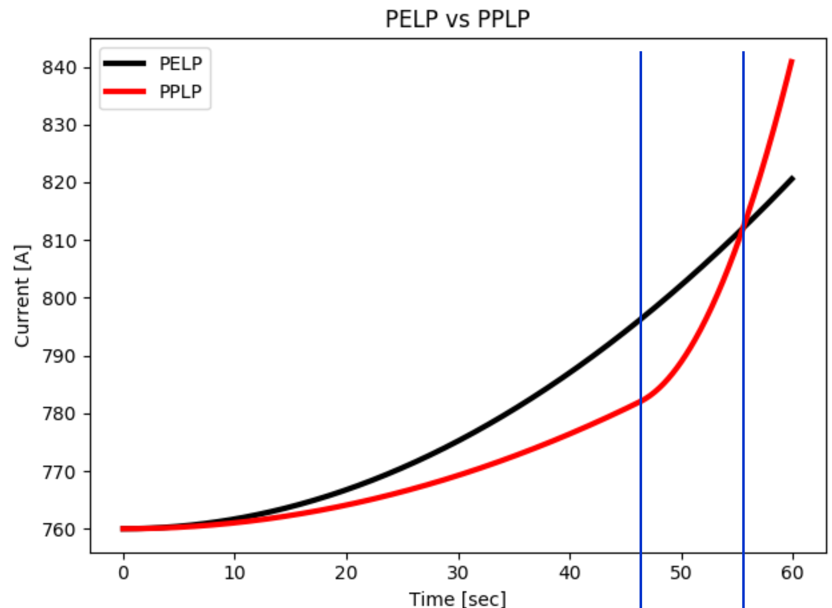
4) Pilot, tune and energy feedbacks OFF, Xing & sep IN, RF modulation ON: GOOD!



The peak losses (5E-5 Gy/s, on TCP.IR3) were comparable with what observed in PELP ramps and there was no degradation in beam quality



No losses are observed after ≈25 s, nor on the (faster) settling parabola

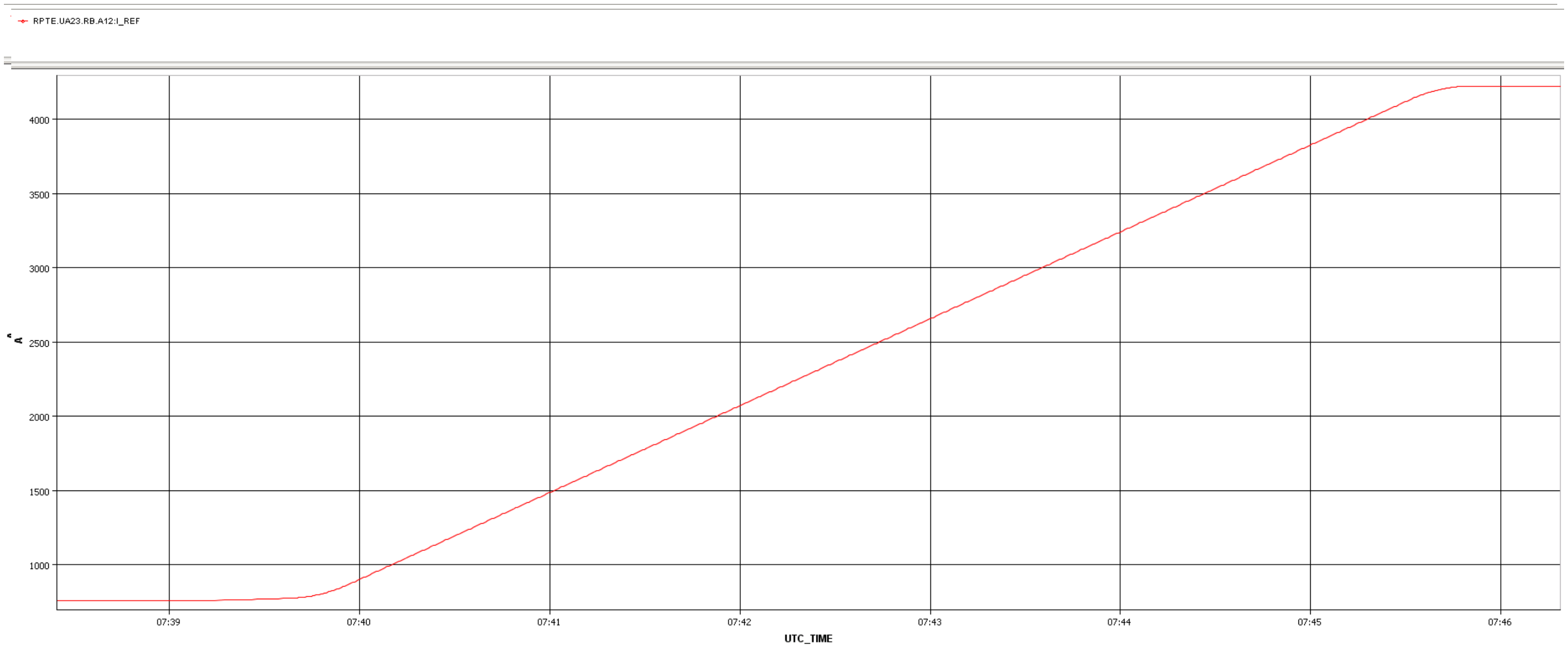


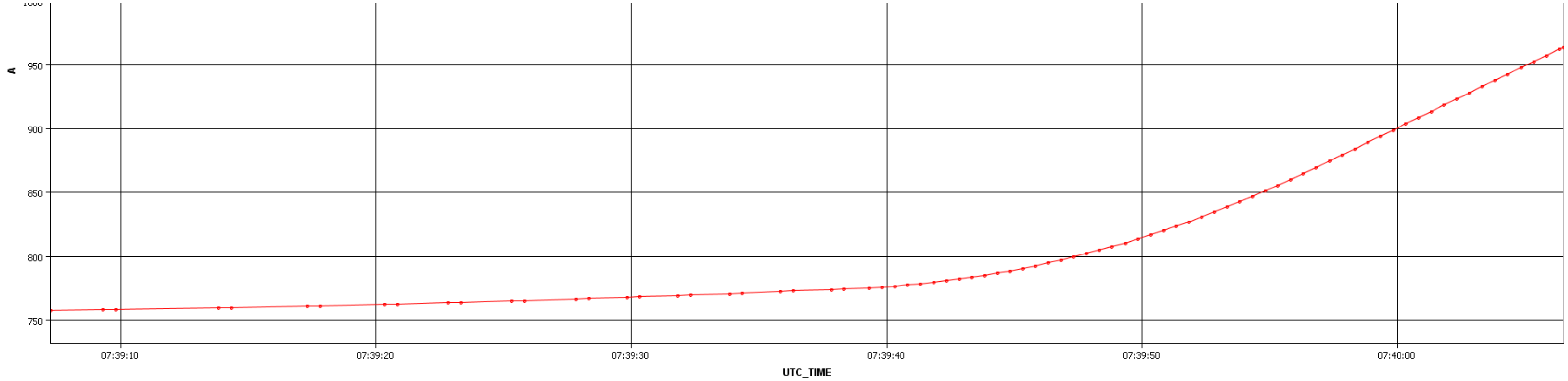
We kept a slow PPLP ramp at the beginning (snap-back); at 46 s the second parabola starts

At 55 s the PPLP overtakes the PELP

Worst case of 2016, snapback goes fully IN in ≈42 s

We then used this PPLP ramp in operation for a 2.51 TeV run with high intensity proton beams in Nov. 2017

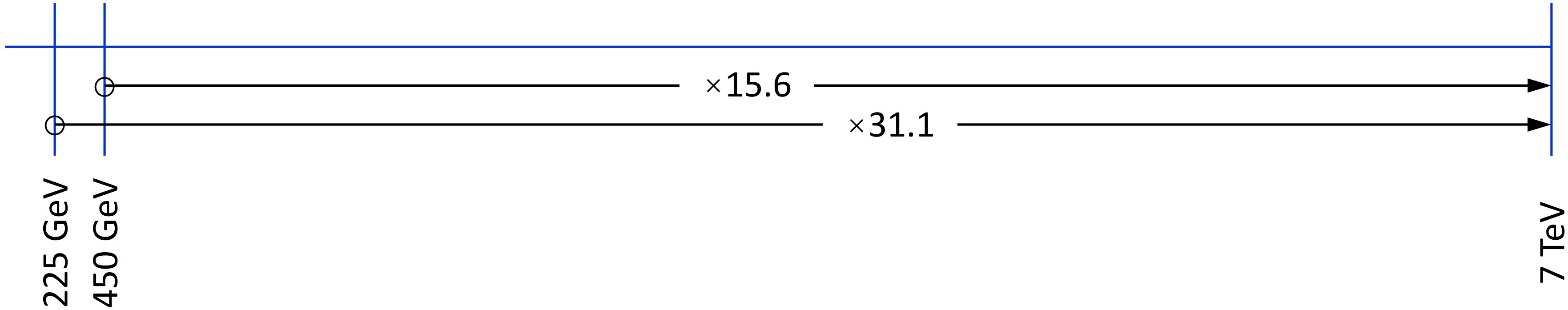




The 225 GeV injection and ramp test (the Mother-of-All LHC MD?)

Brennan Goddard, Matteo Solfaroli, Ezio Todesco,
Davide Tommasini, Jan Uythoven

This 225 GeV injection MD is relevant for FCC-hh and HE-LHC, and LHC itself



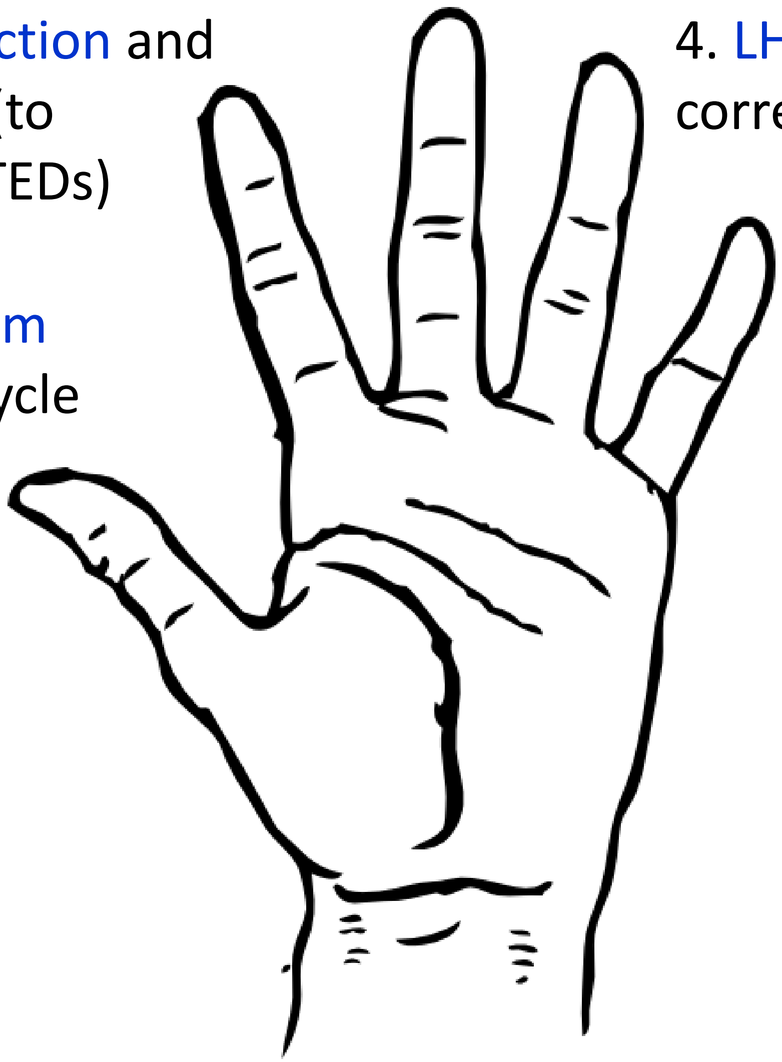
- It was recommended by the FCC injection energy review (Oct. 2015): one of the crucial parameters in the overall design is the injection energy into the FCC-hh collider
- Is a ×30 energy swing feasible in the LHC? If so, it might be the case also for HE-LHC and FCC, with the proper scaling considering the magnet technology and injection field
- It could also be beneficial for operating the LHC, to increase knowledge on dynamic magnetic effects, and to have more relaxed injection parameters (transfer lines, kickers)

This (lengthy) MD involves several main phases

3. LHC injection
threading and RF capture

2. Beam extraction and
transfer lines (to
downstream TEDs)

4. LHC circulating beam
correction and measurement



5. LHC ramp
from 225 to >450 GeV

1. SPS circulating beam
225 GeV dedicated cycle

Several systems are impacted and need a reconfiguration

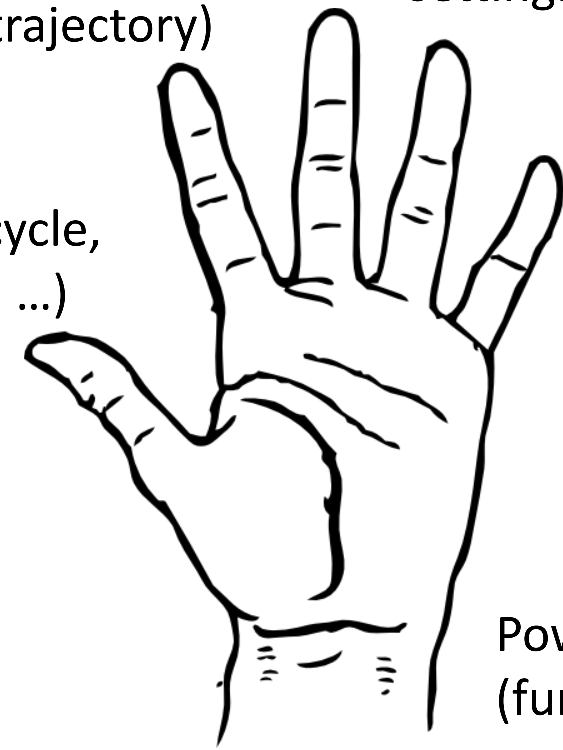
LHC orbit feedback

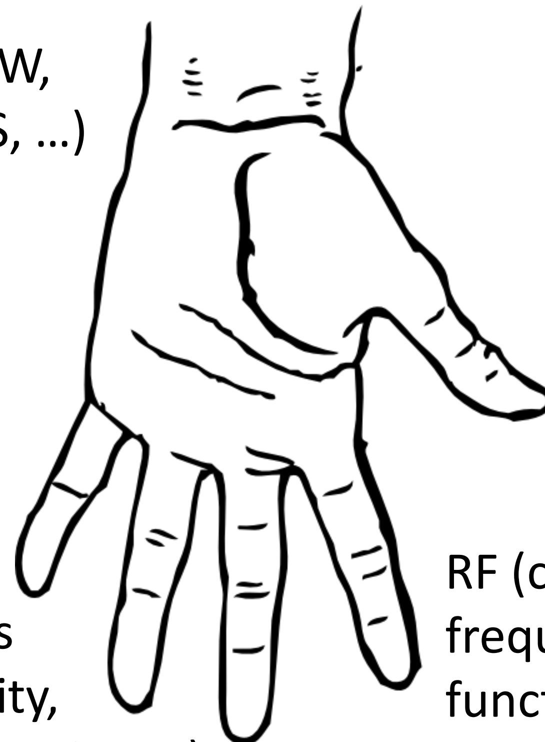
Injection (kicker settings, BETS, …)

TLs (new energy, aperture, trajectory)

Interlocks (HW, BETS, SIS, BIS, …)

SPS (new cycle, extraction, …)





Magnets (dynamic effects)

RF (capture, frequency, ramp functions, …)

Power converters (functions, stability, new settings for optics, …)

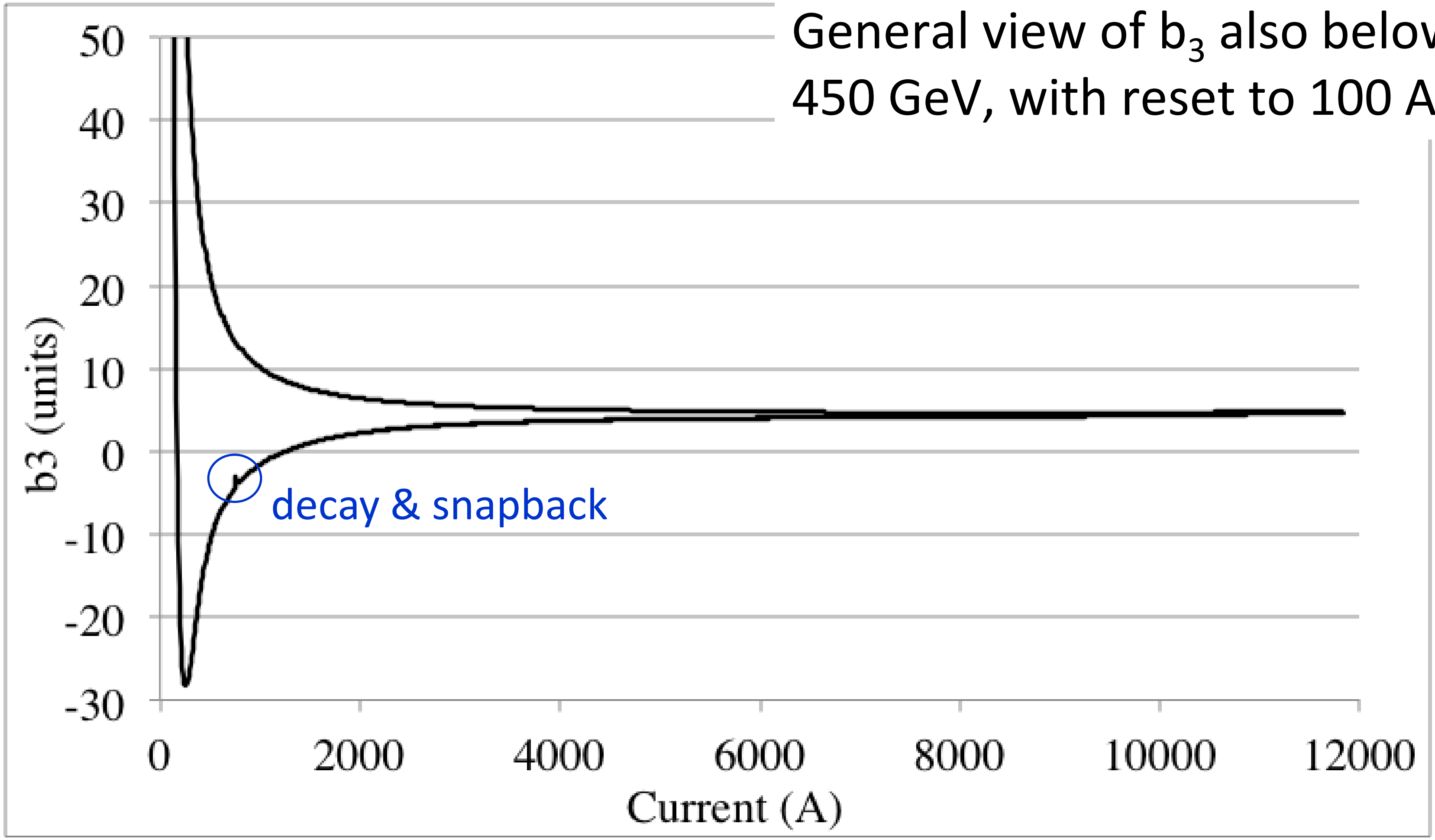
Beam dump (BETS, energy tracking, MKD/B switch voltages, …)

Instrumentation (dynamic ranges, BLM thresholds, BSRT, …)

NO showstopper identified

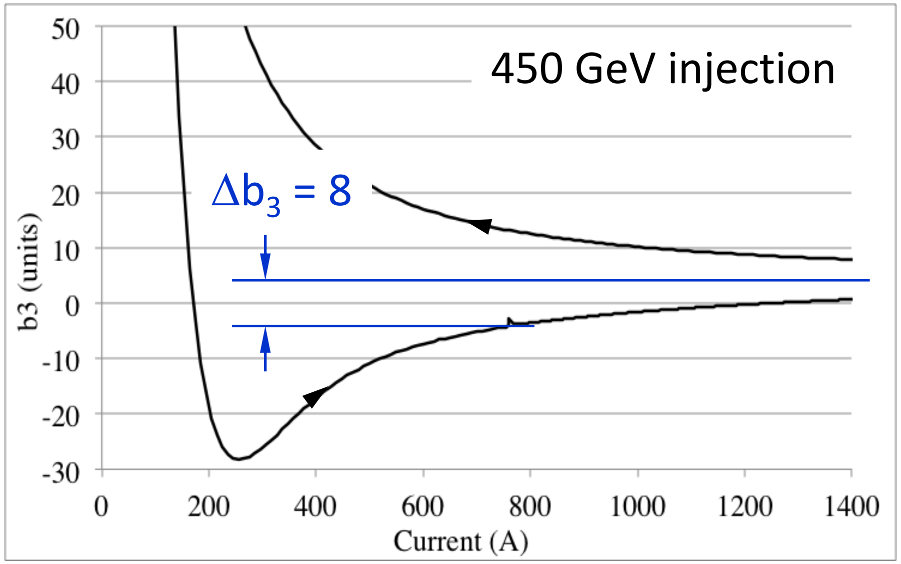
Effects related to persistent currents in the main sc magnets affect B_1 and b_3 (MB) and B_2 (MQ): here we focus on b_3

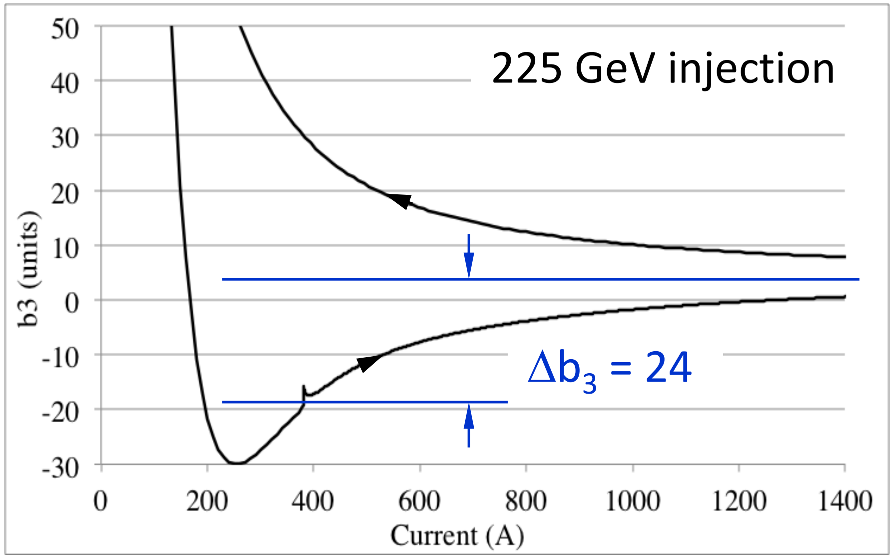
General view of b_3 also below 450 GeV, with reset to 100 A



Courtesy of Ezio Todesco

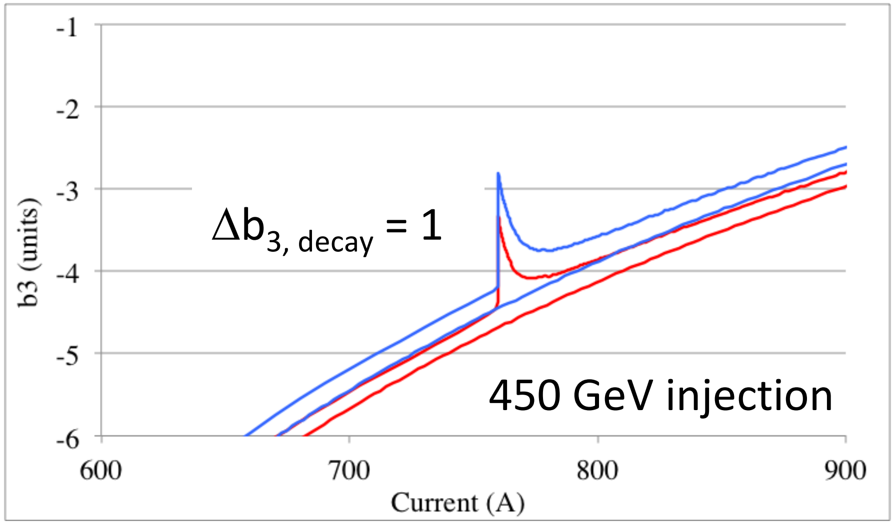
In terms of b_3, injecting at (and ramping from) 225 GeV instead of 450 GeV is about 3 times harder, overall…

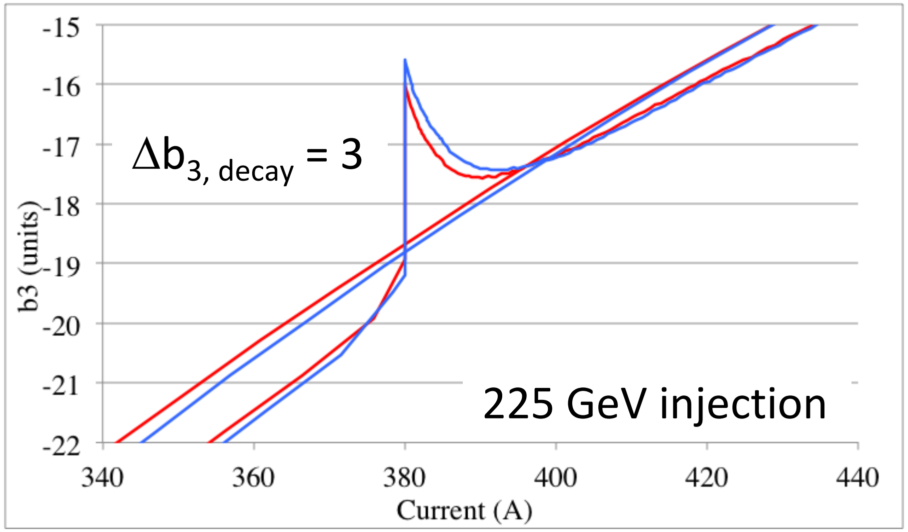




Courtesy of Ezio Todesco

… and also locally, in the decay - snapback part: we are still well above the knee





[details are taken from 2017 measurements on the two apertures of dipole 4001]

Courtesy of Ezio Todesco and Lucio Fiscarelli

The change in b_3 implies a (challenging) change in chroma

In the LHC (450 GeV to high energy) the swing of chroma is 360 units:
8 units $\Delta b_3 \times 45$ chroma units/b_3; today this is mastered in two step:

- FiDeL setting (giving a 5-10% residual error)
- feed forward based on chroma measurements

In FCC with 3 TeV injection we aim at 1000 units swing of chroma
during ramp: ≈10 units of $\Delta b_3 \times 90$ chroma units/b_3

- the sensitivity on b_3 doubles due to longer cells

With this MD in the LHC we explore the same chroma swing thanks to a 3 times larger b_3

Conclusions

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In 2017 we performed a successful LHC MD to test the PPLP ramp

- This is a key ingredient in speeding up LHC ramps up to intermediate energies
- In fact, it was already implemented in Nov. 2017 for 2.51 TeV runs
- The PPLP ramp scheme is the baseline for 6.5 TeV operation in 2018

We have been studying a more ambitious LHC MD – to inject at and ramp from 225 GeV

- A decision from the management for an implementation this year is pending

Thank you