Faster ramping of LHC as FCC-hh injector

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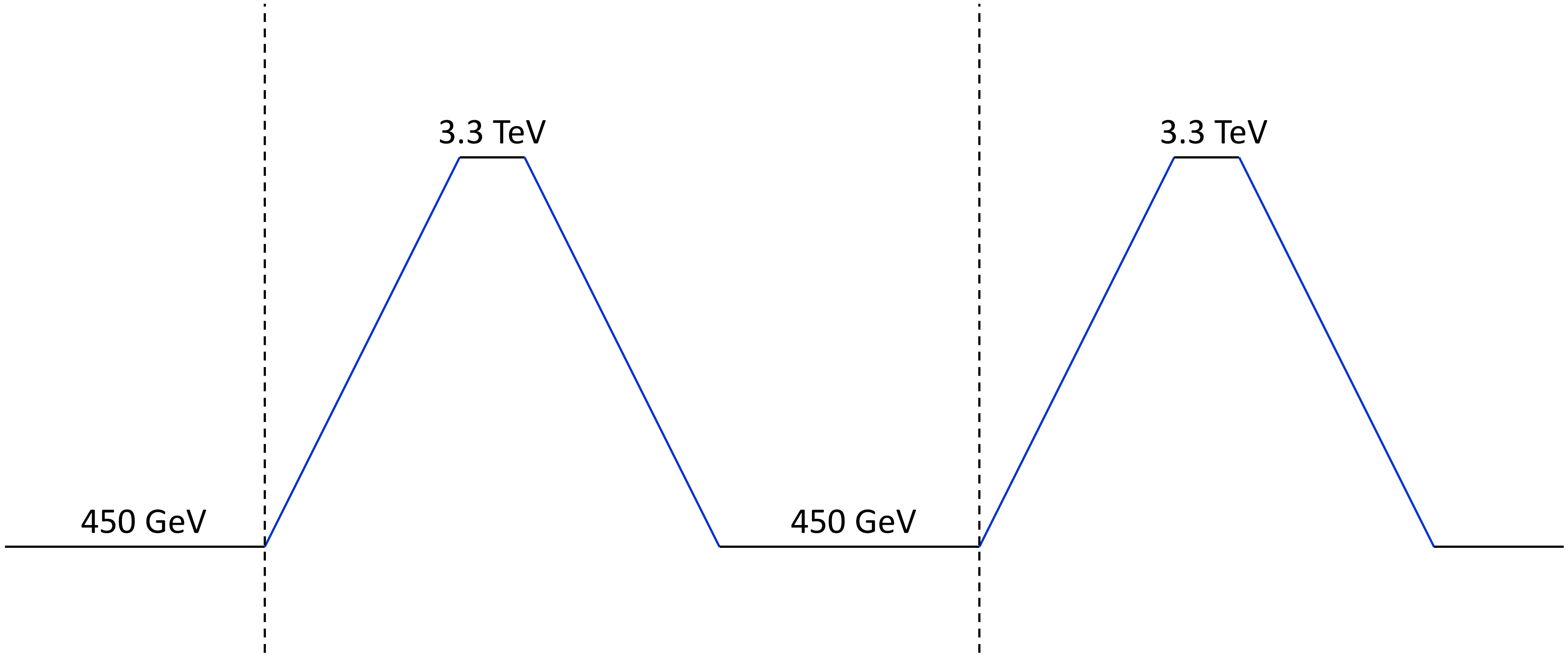
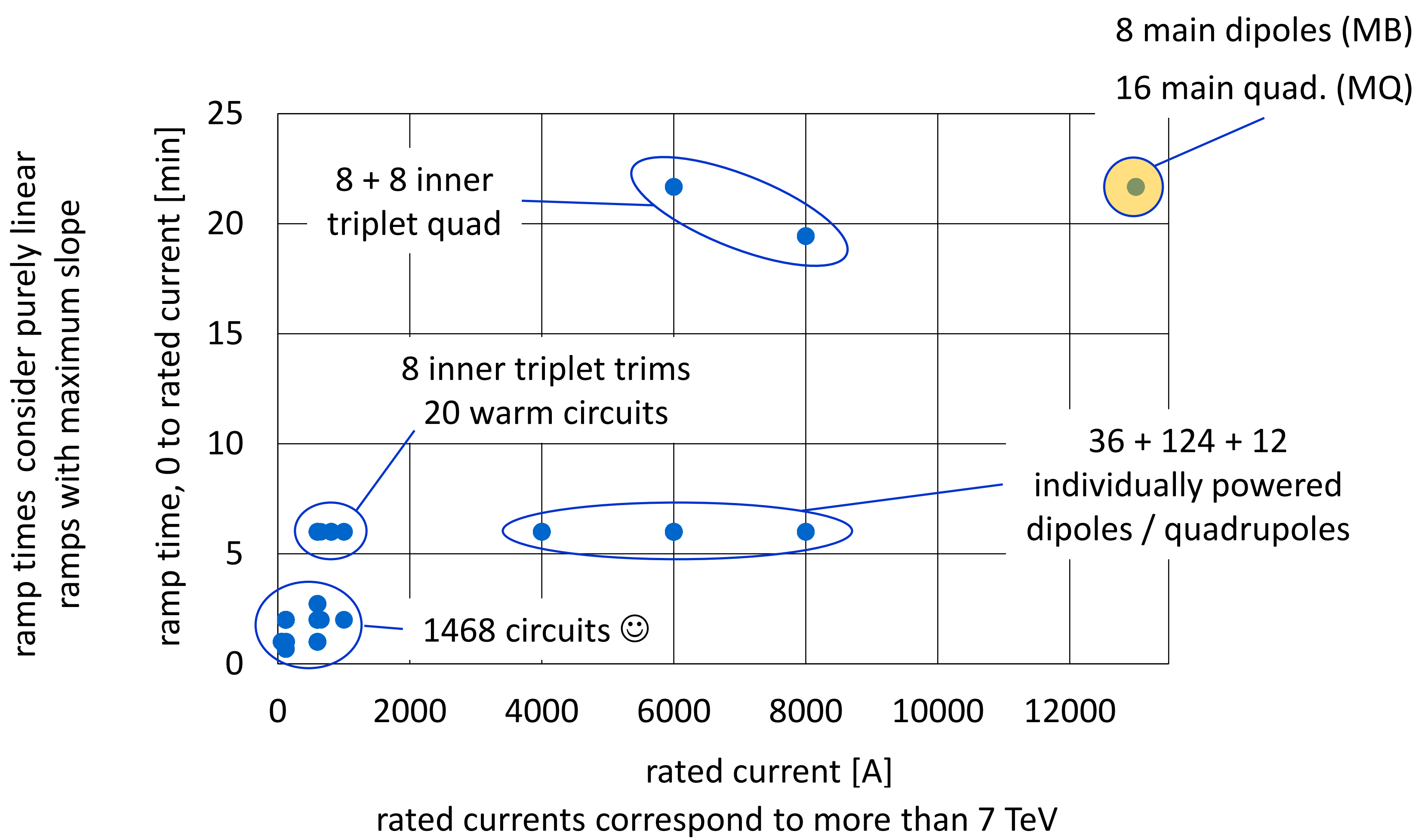
A faster ramp of the LHC is an ingredient to make it a (more effective) High Energy Booster for FCC



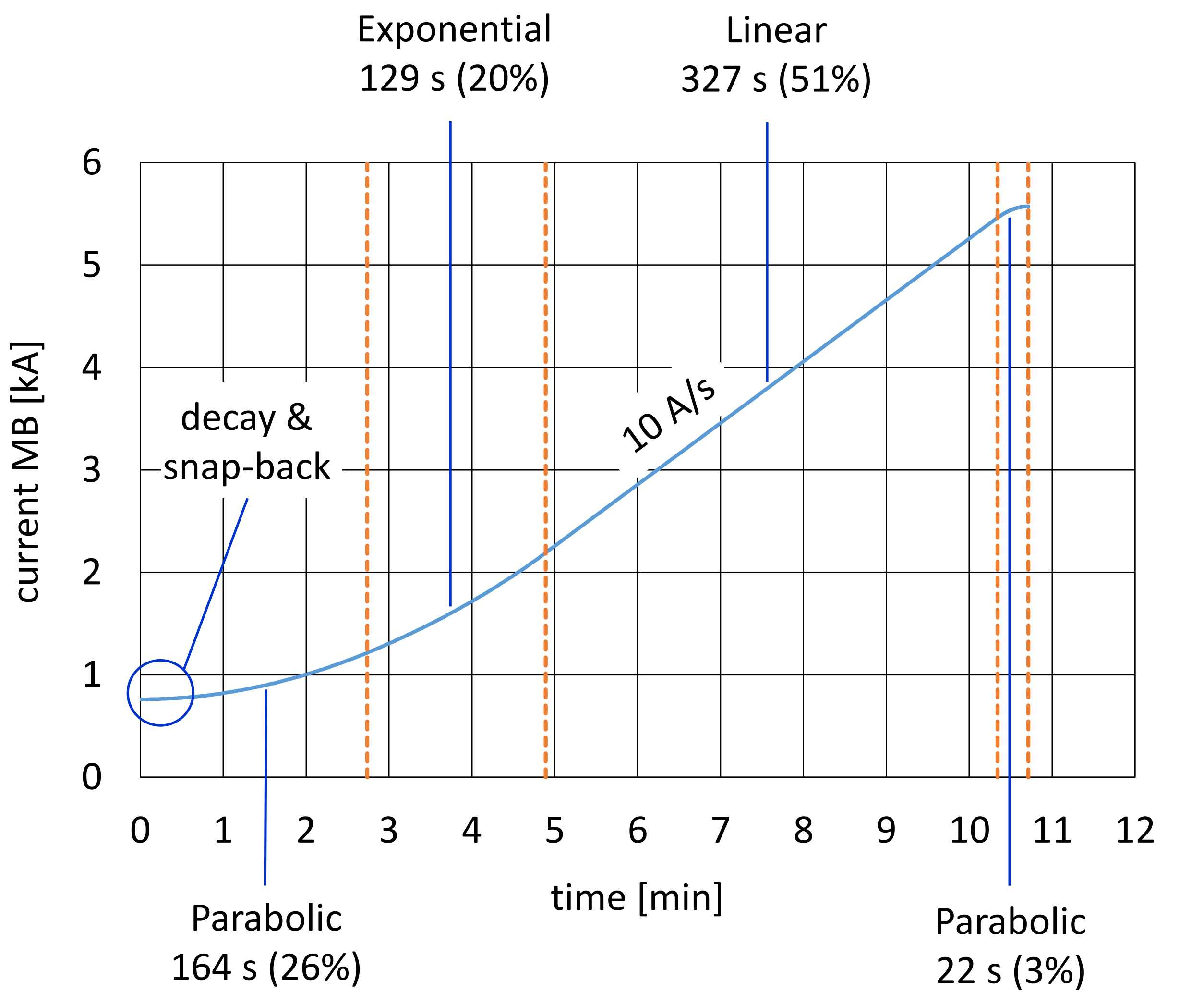
3.3 TeV as baseline injection energy for FCC-hh here

A ramp in the LHC involves 1700+ electrical circuits: we focus on the limiting ones, the 13 kA



data from electrical layout database

With the present settings, the ramp to 3.3 TeV takes 643 s, with an average ramp rate in the main dipoles of 7.5 A/s



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

from parameters used in 4 TeV and 6.5 TeV operation

Hardware constraints for a faster ramp up (1/2)

protection diode of main dipoles

cold turn-on voltage of 6 V limits the ramp rate at ≈60 A/s

inductive voltage on the string of 154 main dipoles

at 10 A/s, the inductive voltage is 150 V

at 50 A/s 750 V

[the dipoles are tested at 1.9 kV and see ±475 V at the beginning of a fast extraction]

10 A/s corresponds to the voltage limit of the power converters

splitting each MB circuit in two implies 375 V at 50 A/s

cryogenic load from AC losses

3.3 TeV at 50 A/s is similar to 7 TeV at 10 A/s for AC loss per cycle

the power is still ≈30 times less than the design value, which assures the helium bath stays below the λ line in a fast ramp down in 80 s

Hardware constraints for a faster ramp up (2/2)

premature quenches

main dipoles: ok up to 100+ A/s, at high field

[no quench-back at 125 A/s during a fast extraction]

other magnets: not more limiting, including Nb_3Sn HL-LHC magnets

quench detection

possibly special corrections for MB with *unbalanced apertures*

possibly improved inductive compensation for circuits with no middle voltage taps – upgrade of electronics anyway likely for FCC era

field quality

snap-back in MB: slow crossing can be kept at the beginning of the ramp

eddy currents: for the MB and MQ, no significant contributions on the harmonics up to 100+ A/s, a possible impact on the transfer function

A maximum target for a faster ramp up is 50 A/s for the main dipoles, instead of the current 10 A/s

50 A/s on the main dipoles is dictated by the cold diode and the inductive voltage on the string

this ×5 factor is for the linear ramp, not the overall ramp

the other magnets can cope with this 5x factor

some power converters would need an upgrade

- 13 kA (MB, MQ) circuits
- ≈200 individually powered quadrupoles / dipoles and some warm circuits, which can now run 3.6x faster than MB: some will be modified for HL-LHC

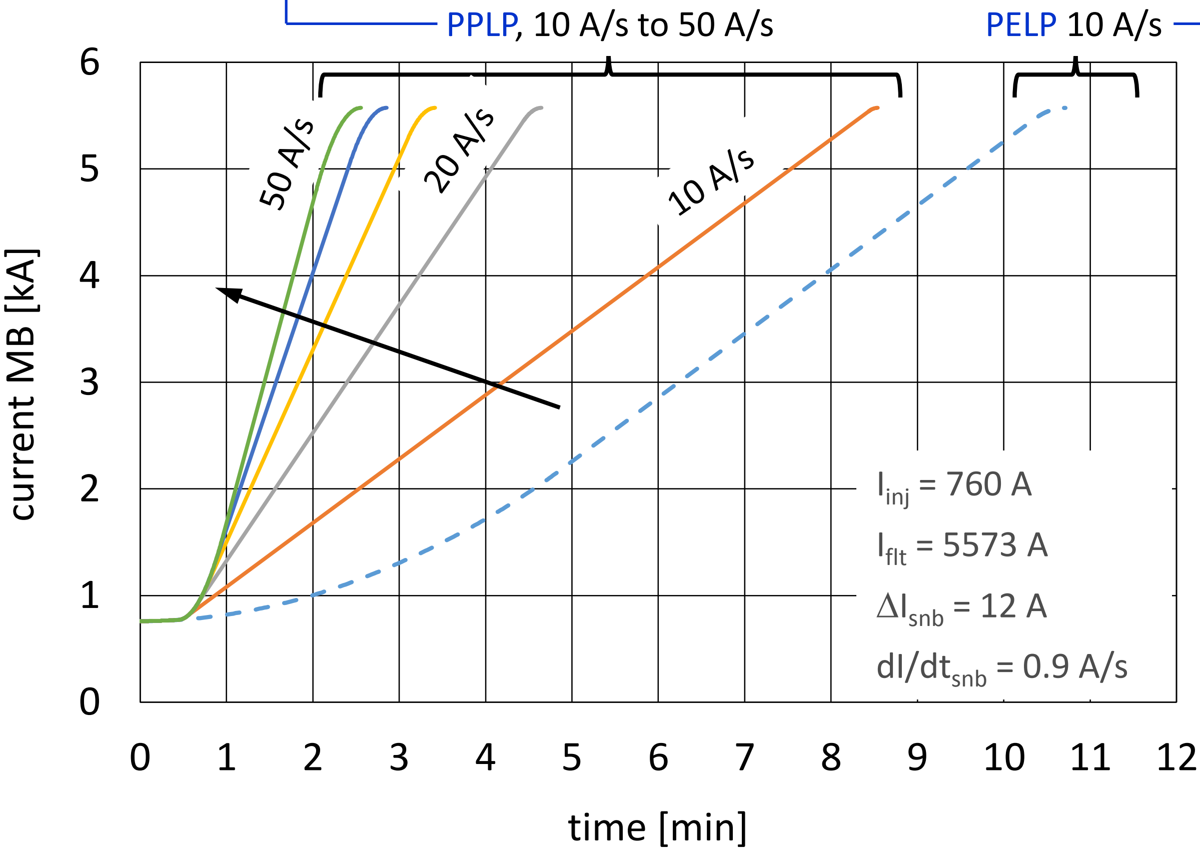
the RF can already follow this ×5 increase

These are several options for faster ramps up to 3.3 TeV

Parabolic-Parabolic-Linear-Parabolic instead of Parabolic-Exponential-Linear-Parabolic

not effective - the initial part is very slow

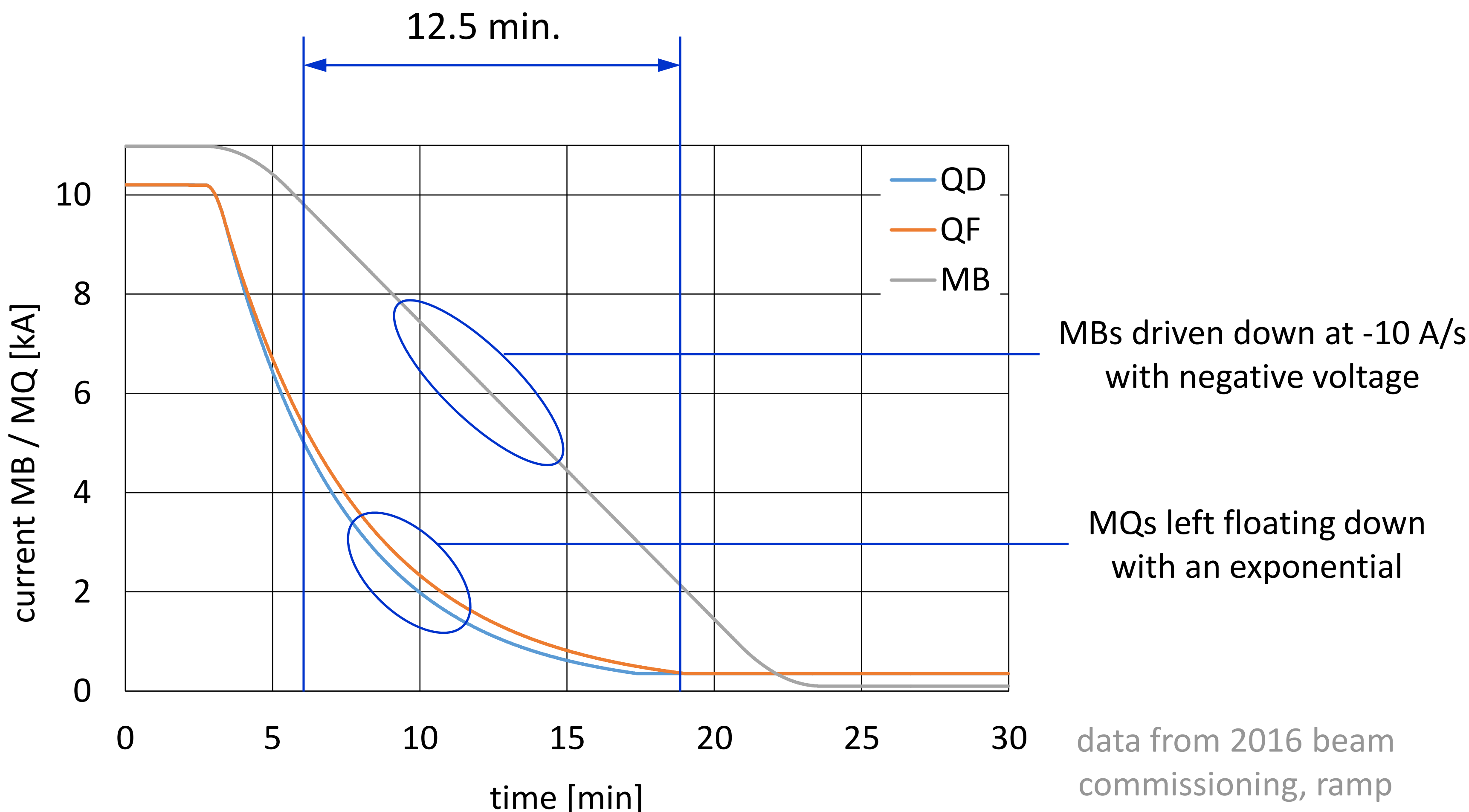
(the exponential is there for historical eddy currents reasons)



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
PtLP, 50 A/s	154	31.3

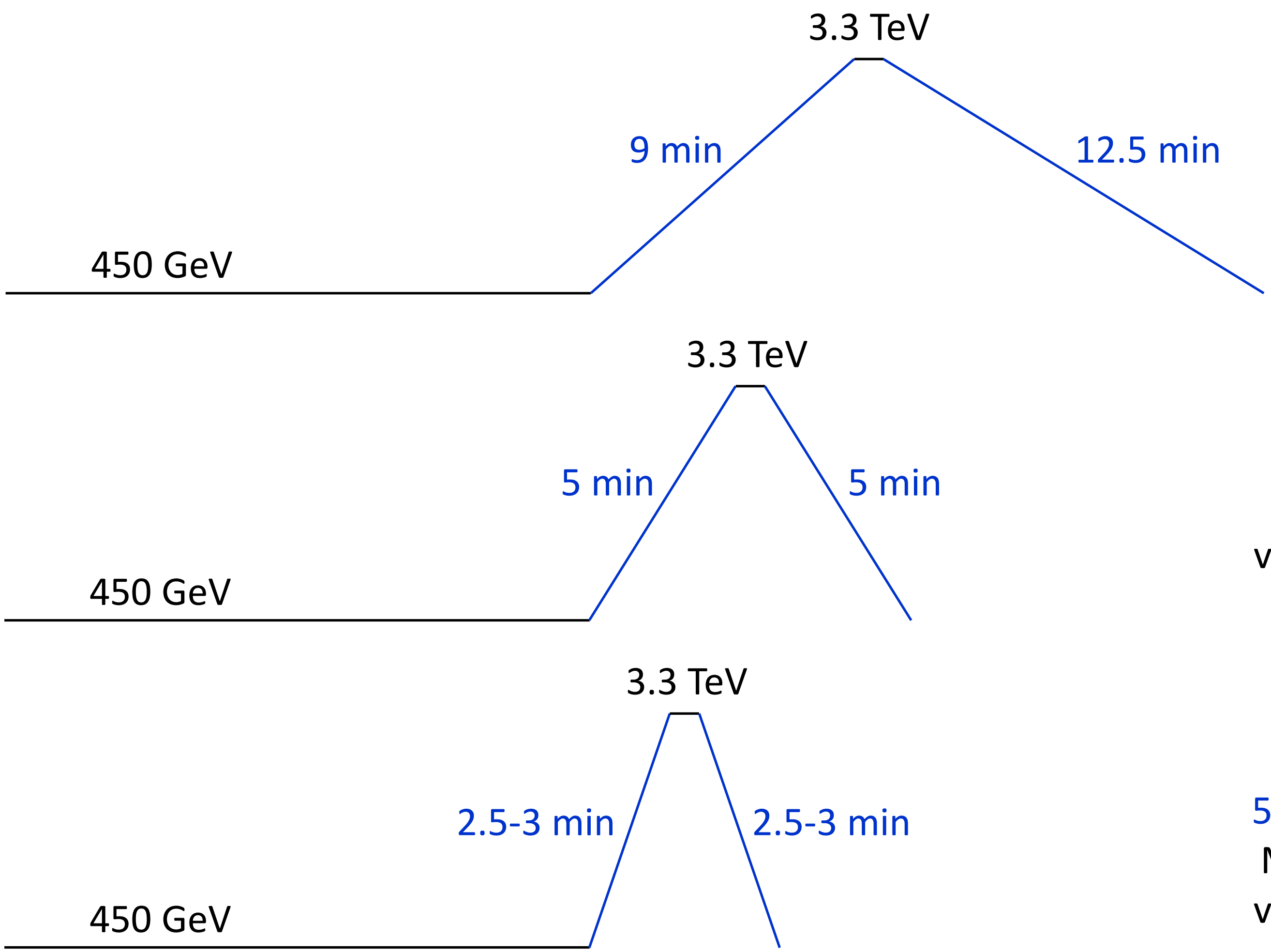
the gain is not linear with dI/dt_{max}

For the ramp down, a further limitation comes from the one-quadrant power converters of the main quadrupoles and individually powered quadrupoles and dipoles (6 kA)



data from 2016 beam commissioning, ramp down from 6.5 TeV

These are 3 possible ramp up / down scenarios – drawn to scale considering a 20 min injection into the LHC



today

(10 A/s for MB)

upgraded power converters

20 A/s for MB & negative voltage for other 13 kA – 6 kA

upgraded power converters

50 A/s & (possibly) splitting of MB circuits in 1/2 & negative voltage for other 13 kA – 6 kA

Conclusions

1. Ramping the LHC faster up to a factor × 5 is possible for the magnets, with upgraded main 13 kA and 6 kA power converters
   - limited by inductive voltage
   - limited during ramp down for one-quadrant converters

2. A ramp up / down to / from 3.3 TeV lasts
   - 9 min / 12.5 min — current hardware, 10 A/s
   - 5 min / 5 min — hardware upgraded to 20 A/s
   - 2.5-3 min / 2.5-3 min — hardware upgraded to 50 A/s

3. Machine studies in the LHC are being proposed, for testing
   - a PPLP instead of PELP scheme (Parabolic instead of Exponential) [the ramp to 6.5 TeV could be ≈2.5 min shorter]
   - slower ramps (like 5 A/s), to scale ramp rate dependent effects

For more details

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(future) proceedings in FCCW2016 Special Edition of Physical Review – Accelerators and Beams (PRAB) thank you