LHC Injectors Upgrade

Q22 deployment, experience and perspectives

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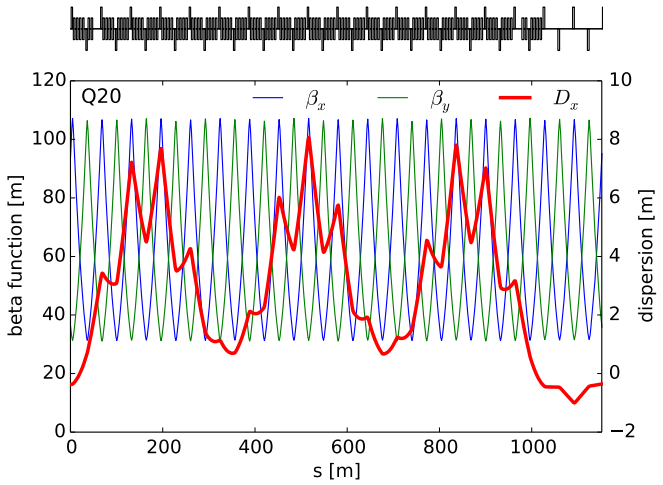
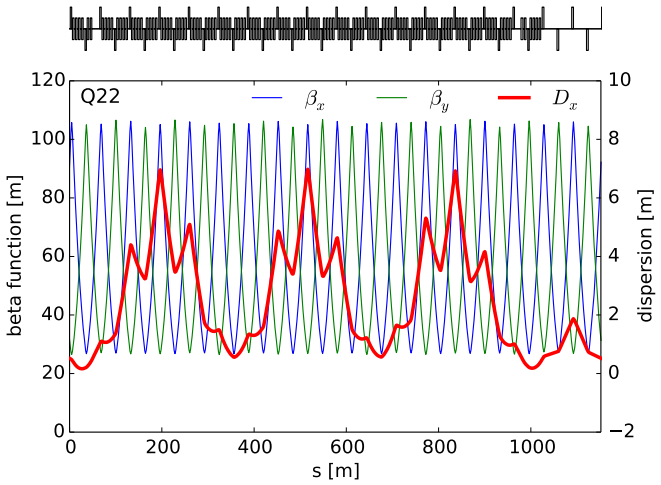
CERN

Introduction

- **Q22 in comparison to Q20**
  - **transition gamma at 20 instead of 18**
  - **less voltage required for same bucket area → less impact of limited RF power during first part of the ramp?**
  - **lower TMCI threshold → expected close to HL-LHC intensity**
  - **lower longitudinal instability thresholds → need larger longitudinal emittance for stability during the ramp**
  - **slightly smaller peak dispersion → larger momentum acceptance**
  - **smaller average dispersion → non-linear chromatic detuning is smaller**





A propos: Momentum aperture

- **LHC high intensity beams: issue of capture losses and continuous losses out of bucket during flat bottom and losses on aperture**

- **Not much flexibility: insufficient momentum acceptance with Q20**
  - Aperture restriction at QDs and large dispersion for Q20

Result of measurements in 2017: assume ε = 2 mm, dp/p = 0.15 %

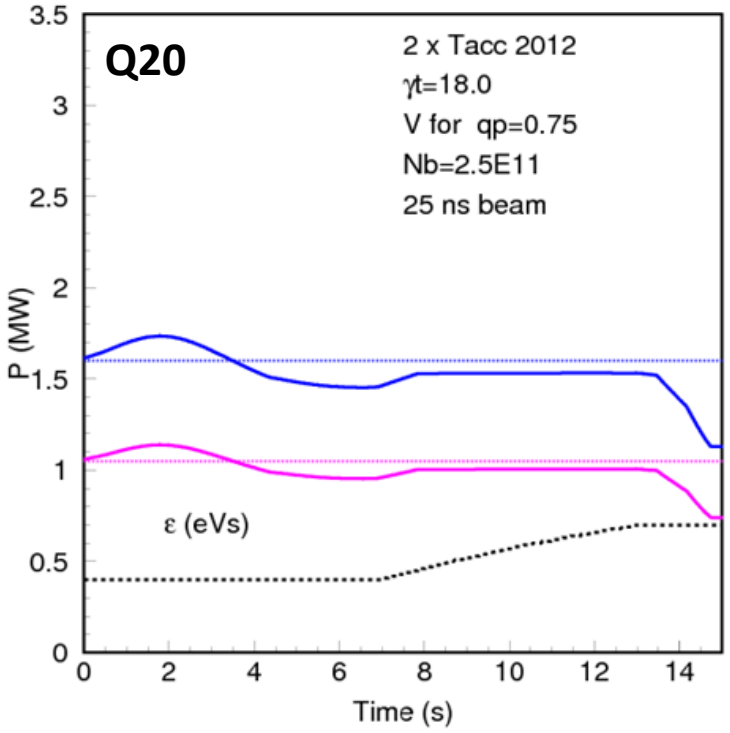
Optics	Radial limit in dp/p [%]	Aperture [s]
Q20	+0.76 / -0.59	+4.9 / - 3.8
Q22	+0.9 / - 0.73	+ 5.8 / - 4.8
Q26	+1.7 / - 1.3	+10.5 / - 8.3

- **With Q22 should gain ~ 1 σ in aperture**

A propos: RF power

- **Acceleration cycle (twice longer compared to present) with 2.5x10^{11} p/b**
  - **First part: Q22 requires less RF voltage and RF power**
  - Second part: same RF power in both optics (beam stability requires larger longitudinal emittance in Q22 and thus similar RF voltage as in Q20)

Power/cavity for 2.5x10^{11} – Longer cycle



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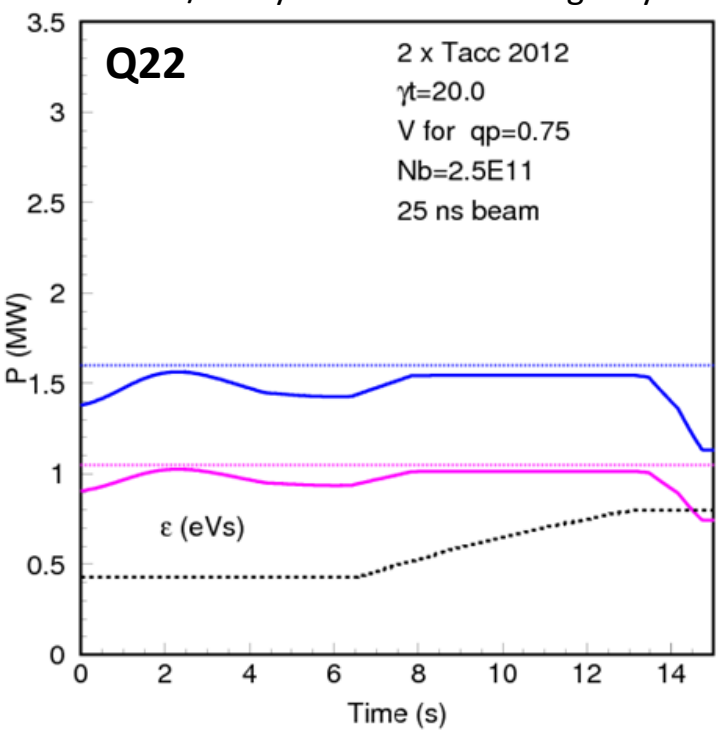
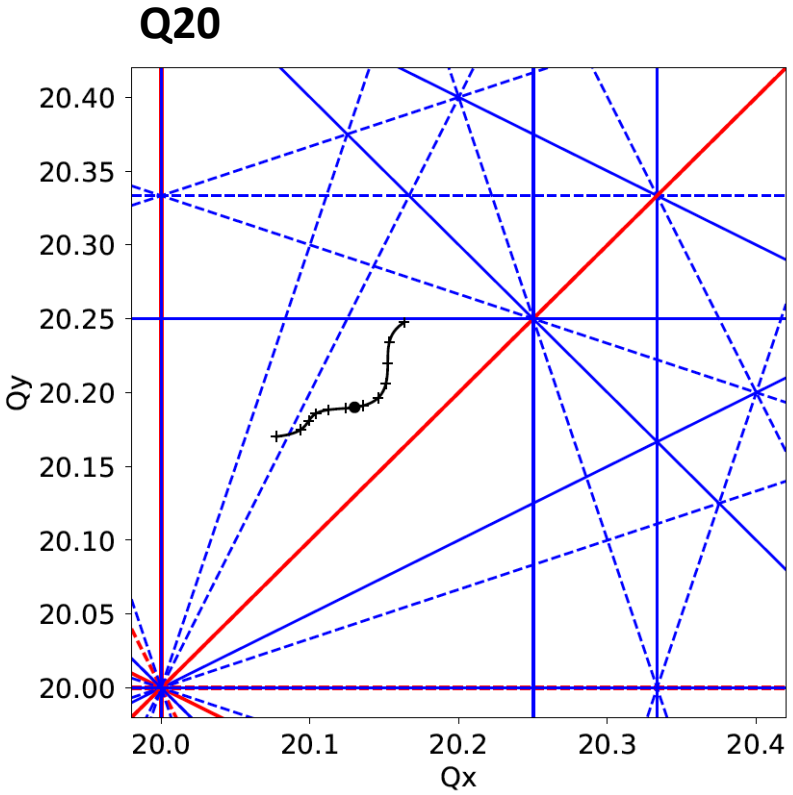


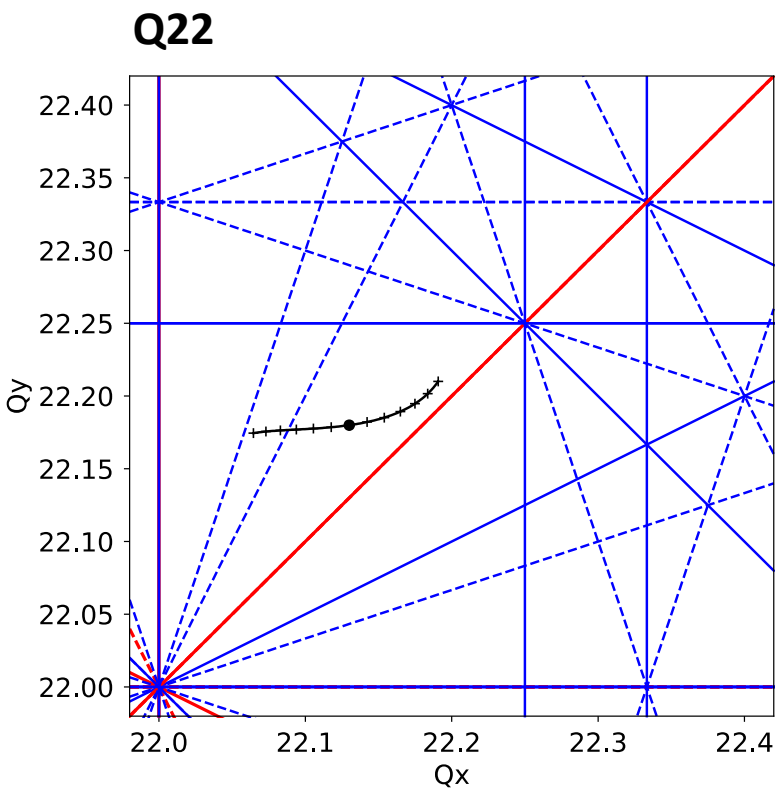
Overview of studies up to now

- **2016**
  - Preparation of optics for LSA (TT10 and SPS ring)
  - First injection into “MD” cycle (flat bottom only), chromaticity and tune knobs checked
- **2017**
  - Setting up and first studies with acceleration of LHC 25 ns beam
  - Studies with high bandwidth feedback system → see Kevin’s talk
  - Measurements of TMCI threshold → see Kevin’s talk
  - Measurements of non-linear chromaticity
  - Studies of losses (in comparison to Q20)

Non-linear chromaticity

- **Non-linearity less pronounced → might be beneficial for incoherent losses**

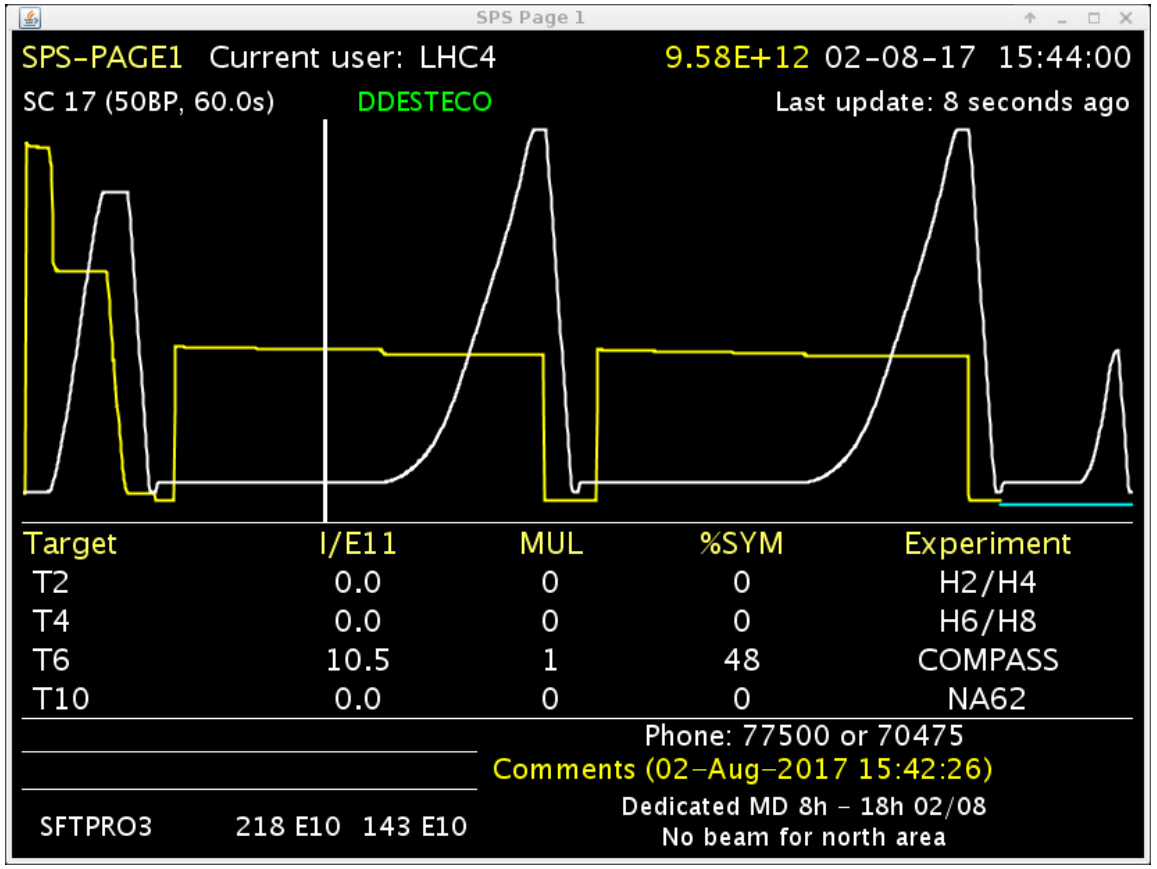




- **Energy spread -/+ 5e-3, chromaticity as during high intensity run (Q'_x ~ 13, Q'_y ~ 3.5)**

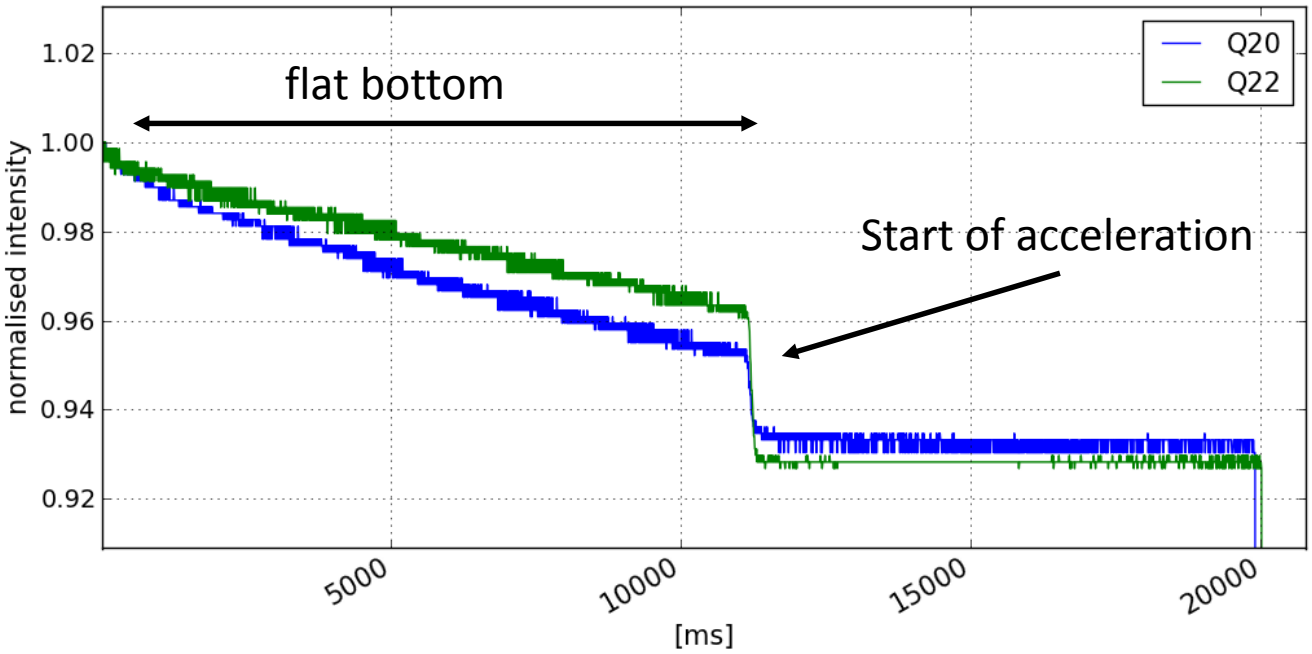
Comparison Q20 – Q22

- **MD 2/8/2017: 72 bunches on Q20 and Q22 cycle with up to 1.6e+11 ppb**
- **Same bucket area for both beams at injection**
  - 4.5 MV for Q20 and 2.7 MV for Q22



Comparison Q20 - Q22: Overview

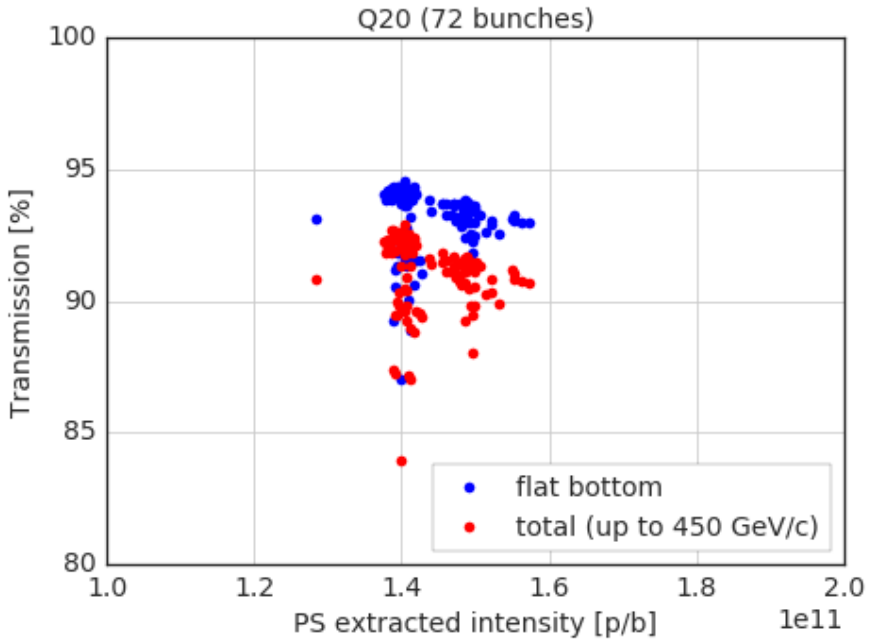
- **Q22 better transmission on flat bottom; Q22 higher losses at start of acceleration**
  - More momentum aperture, but 2.7 MV too low for sufficient beam loading compensation
- **→ Overall transmission roughly the same**

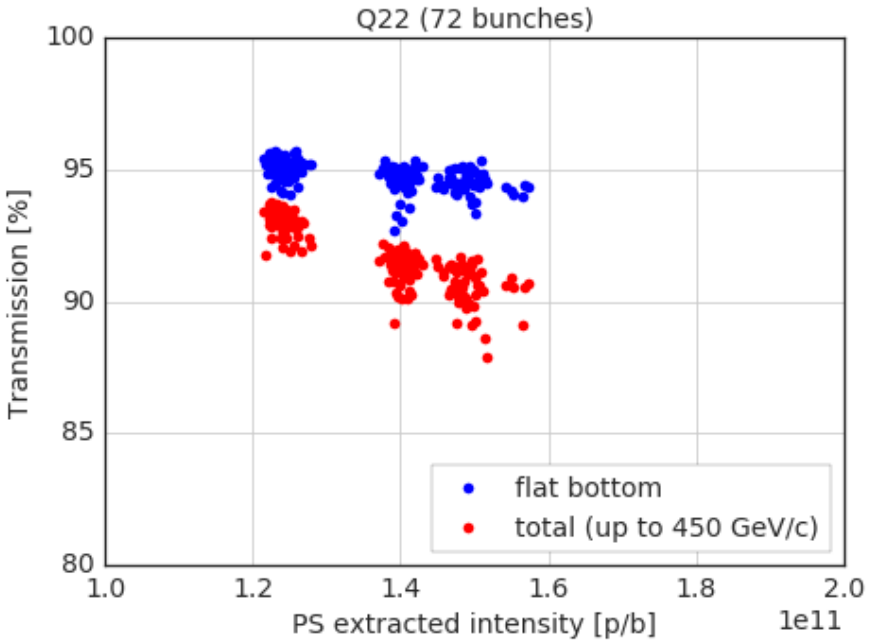


- **Voltage margin in Q22 was not exploited in MD (main losses due to uncaptured beam / losses out of bucket)**

Losses with acceleration to 450 GeV/c

- **Flat bottom losses better in Q22 but similar transmission to 450 GeV/c**



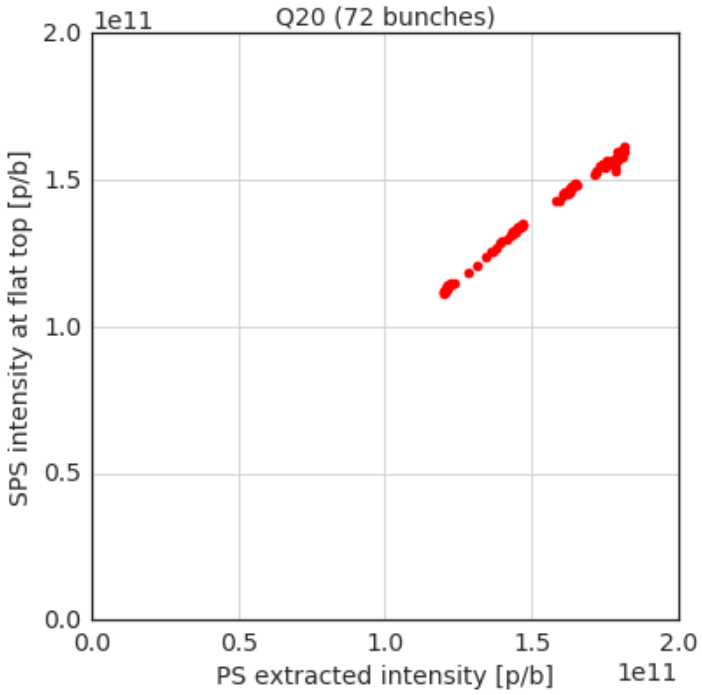


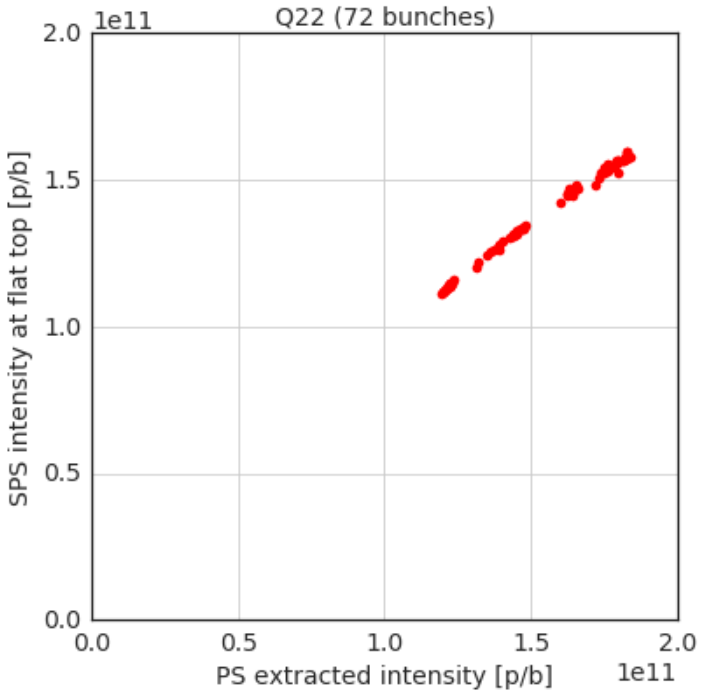
Losses with acceleration to 450 GeV/c

- **MD with very high intensity 25 ns beam (up to 1.8e11 p/b injected, more than 1.6e11 p/b extracted)**

Highlight: 1.6e+11 accelerated to flattop for Q22 and Q20

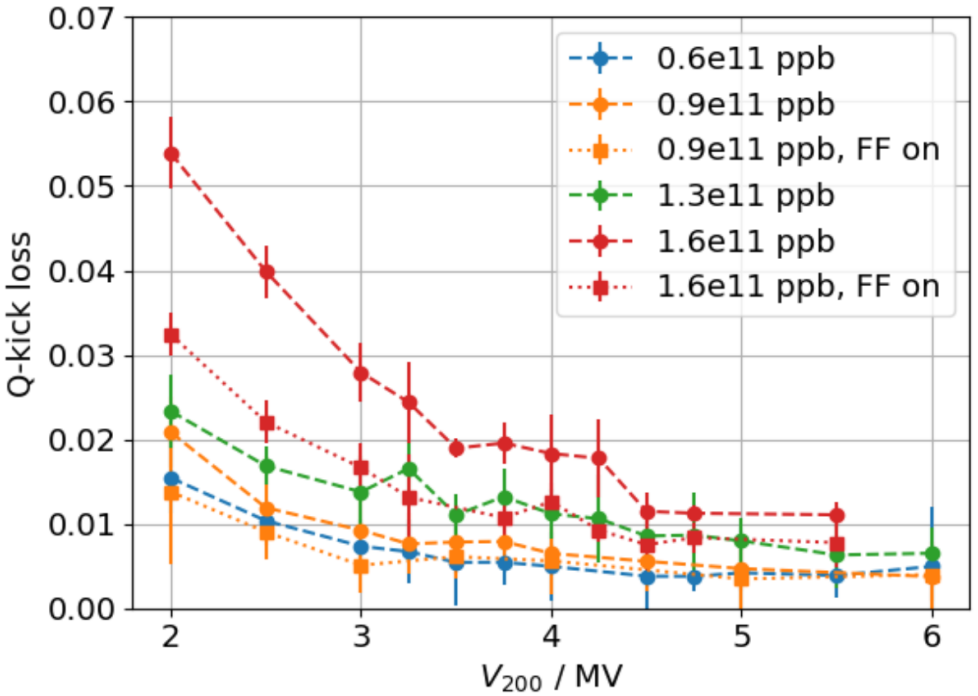
- Longitudinal beam quality not sufficient for LHC

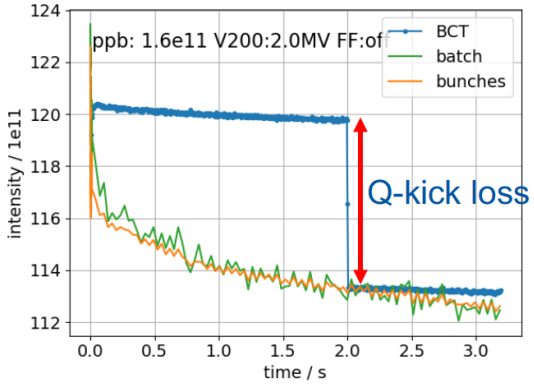




A propos: voltage margin and capture losses

- 72 bunches, 25 ns, Q22
- 800 MHz off, losses as function of V_{200} with forward on/off





Capture losses significantly reduced with e.g. 4.5 MV

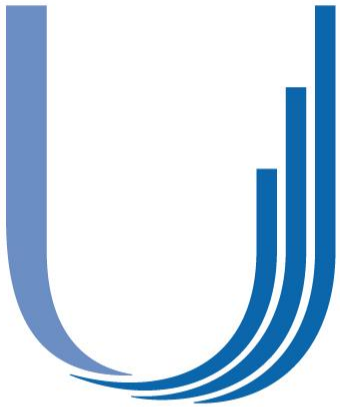
- Momentum aperture OK up to 5 MV

2.7 MV “operational” voltage

- Losses saturate at V_{200}: uncaptured halo from PS
- Losses increase with intensity: induced voltage in SPS

Conclusions & Outlook

- **Very fast commissioning of Q22 in the SPS**
  - Extraction and transfer not deployed yet
- **Status and conclusions from studies performed this year**
  - TMCI threshold close to expected value (i.e. at around intensity required for HL-LHC)
  - WBFB demonstrated to control TMCI (WBFB might be crucial for reliable operation with HL-LHC parameters)
  - Accelerated up to 1.6e11 p/b (72 bunches) to 450 GeV/c – longitudinal stability to be addressed (both at flat bottom and high energy)
  - Flat bottom losses slightly better compared to Q20 but no gain in total transmission – losses for intensities studied seem dominated by capture losses similar in both optics, but larger momentum acceptance in Q22 shifts BCT losses from flat bottom to start ramp
  - **In MDs so far no gain observed with Q22, voltage margin possibly not fully exploited**
- **Studies 2018**
  - Intensity reach with present RF and optimized RF voltage flat bottom/ramp
  - Characterization of longitudinal instability thresholds (also flat bottom)
  - Multi-batch
  - Further exploration of intensity reach with WBFB
  - Transfer to LHC



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Thank you for your attention!