CERN-SPS Slow Extraction Overview

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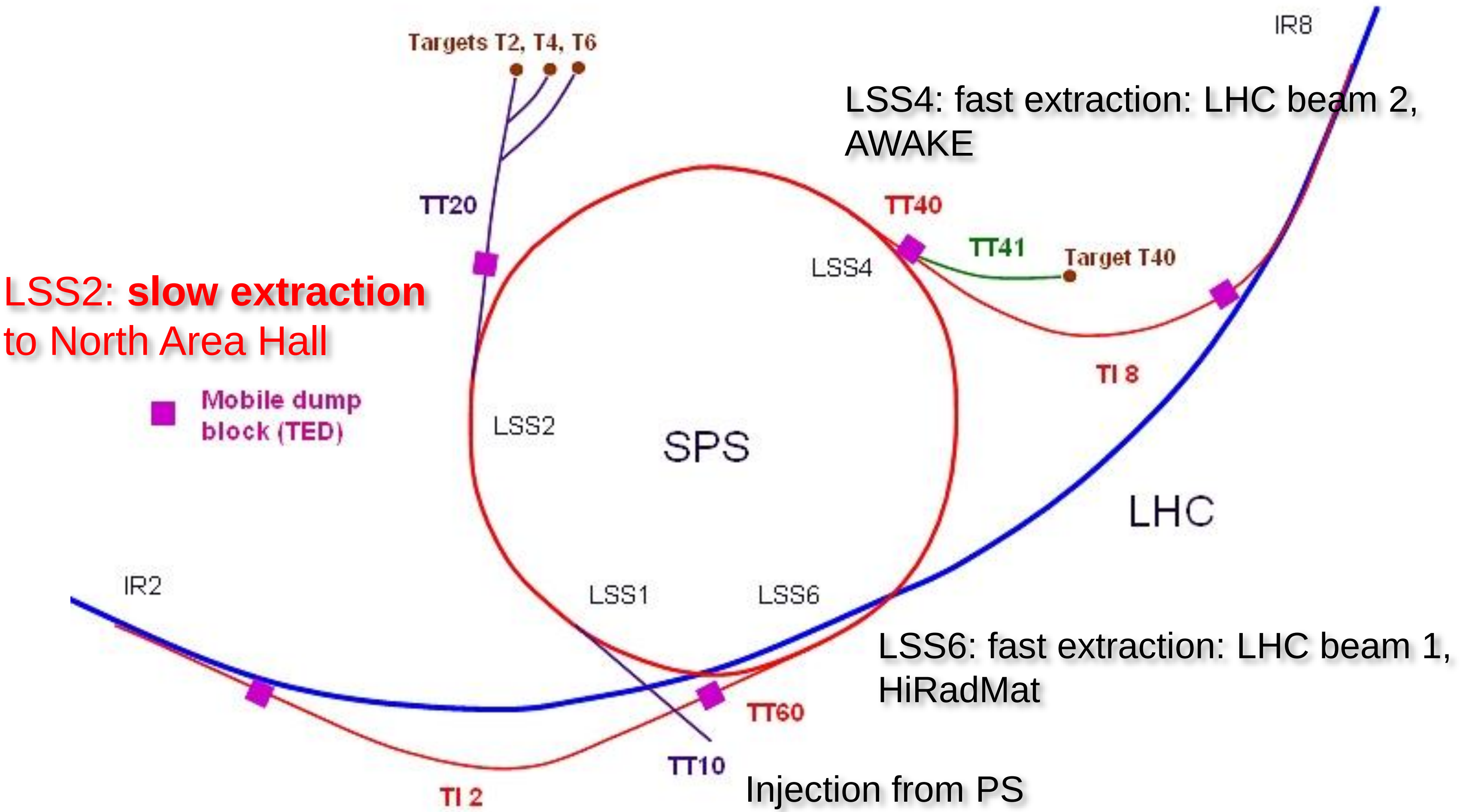
SE WS 9th of November 2017

SPS Layout and Applications

- 7 km synchrotron; maximum momentum 450 ZGeV/c
- 108 regular FODO cells; all QF/QD in series
- 6 long straight sections



SPS Applications – Multi-purpose machine

- SPS part of the LHC injector chain
  - Last pre-injector
  - Accelerates protons and heavy ions to 450 ZGeV/c. Q20 optics
  - Protons: intensity 3.5×10^{13} p^+ in 2.5 μm emittance; 8 μs pulse length

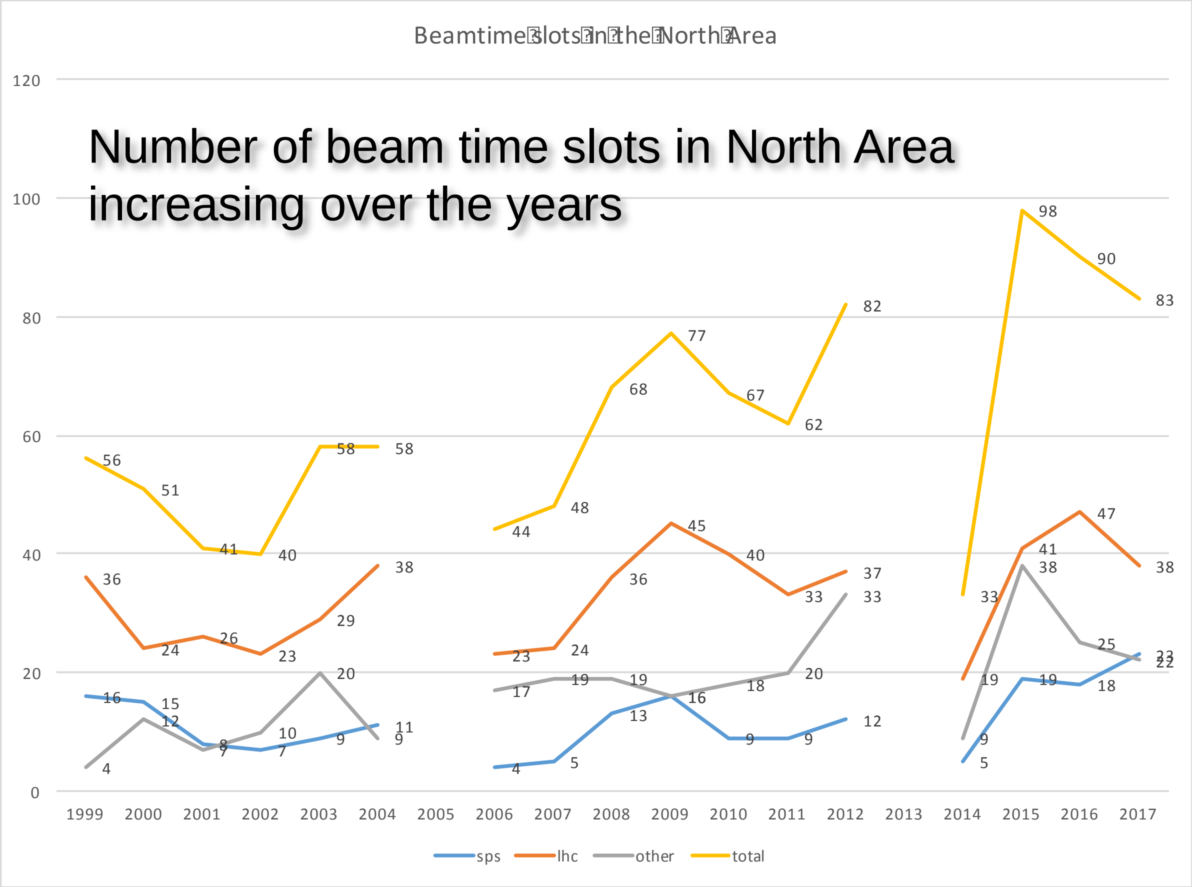
- HiRadMat
  - High radiation to material test facility
  - LHC high intensity proton beam. Extraction energy 440 GeV. Q20 optics

- AWAKE
  - Proton driven plasma wake field acceleration R&D
  - 3×10^{11} protons in 0.8 ns @ 400 GeV/c, Q20 optics

- Slow extraction to TT20 transfer line
  - 400 GeV/c protons or 31 ZGeV/c – 380 ZGeV/c heavy ions, Q26 optics
  - Intensity: up to 4×10^{13} protons, few $\times 10^{10}$ charges for ions

SPS Fixed Target statistics

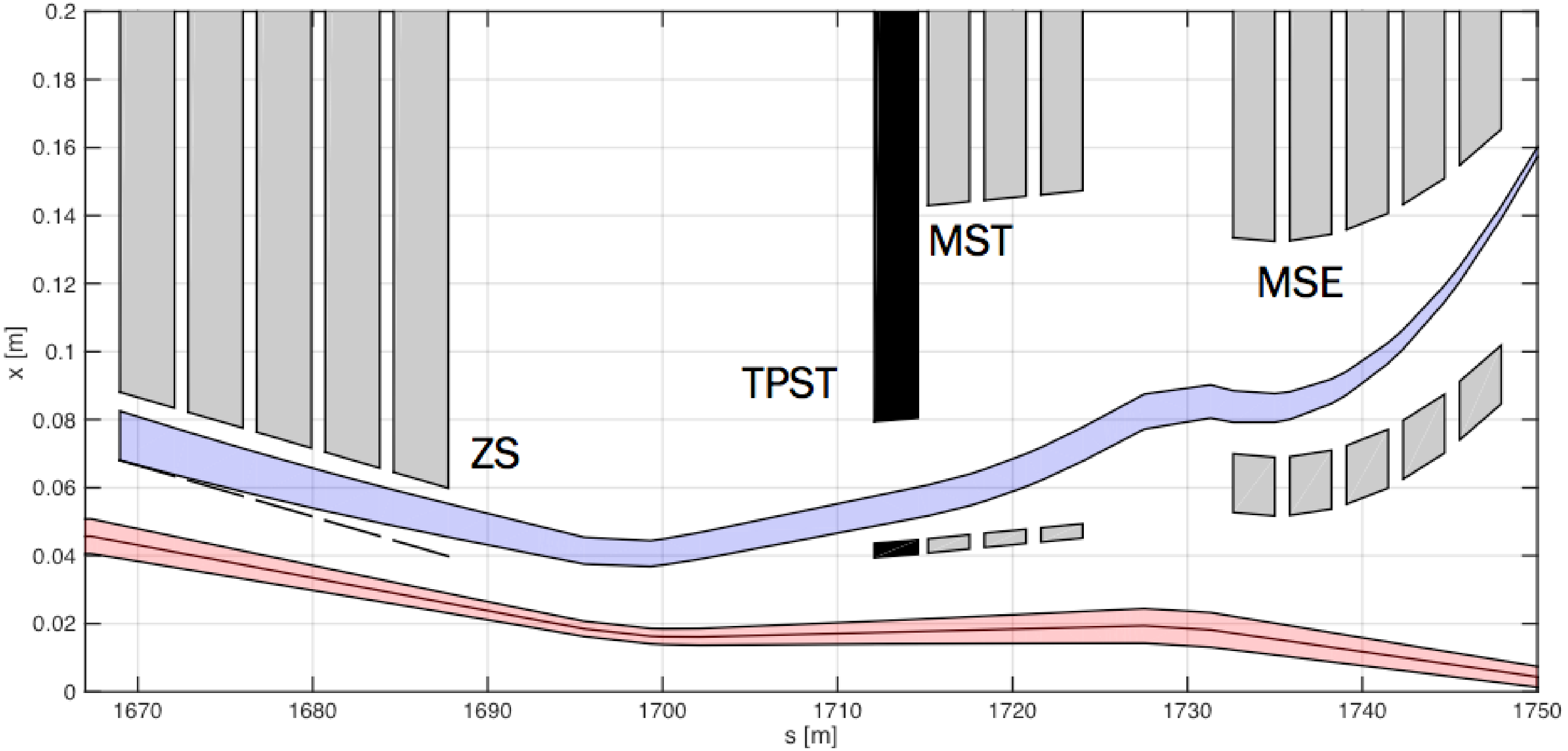
- ~ 3300 slow extracted spills a day with typical 85 % machine availability for fixed target



Slow Extraction in the SPS in LSS2

- Quadrupole driven 2/3 integer resonant slow extraction in H
- ~45 mm extraction bump, 5 electro-static septa ZS, three thin magnetic setpa, 5 thick magnetic septa

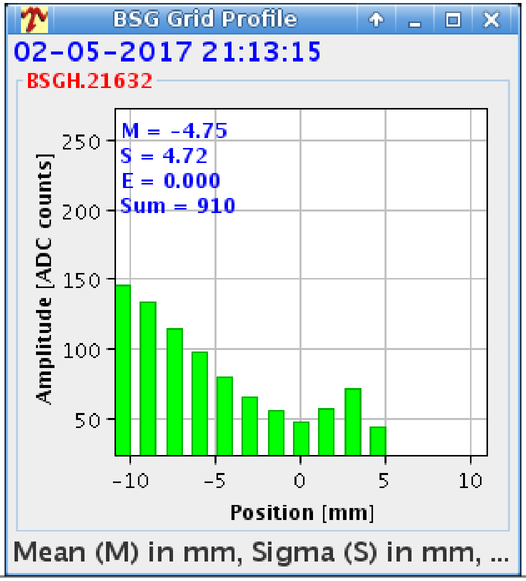
Circulating (red, ±3σ) and extracted (blue) horizontal beam envelopes and apertures in the LSS2 extraction region.



Slow Extraction in the SPS

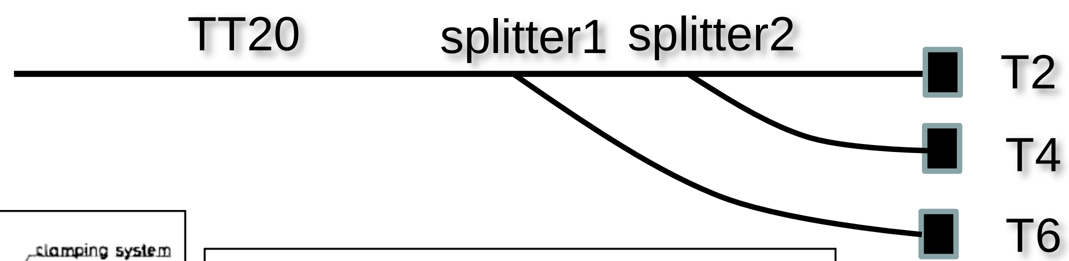
- Four extraction sextupoles LSE (~0.75 m) used
- Nominal strength:
  - LSE.10602 $K_2 = -0.11992\ m^{-3}$
  - LSE.22402 $K_2 = -0.11992\ m^{-3}$
  - LSE.40602 $K_2 = -0.11992\ m^{-3}$
  - LSE.52402 $K_2 = -0.11992\ m^{-3}$
- Spiral step at ZS is adjusted to 15 mm with bump amplitude
  - Nominal septum gap width = 20 mm

Measurement of spiral step with SEM grid:
From this year's startup with very low intensity



The TT20 transfer line

- The TT20 transfer line is used to transport the slow extracted beam to the North targets T2, T4 and T6
- Two series of splitter magnets are used to split the beam towards the different targets
  - Vertical splitting. 24 km β_V, to adjust sharing: move beam vertically



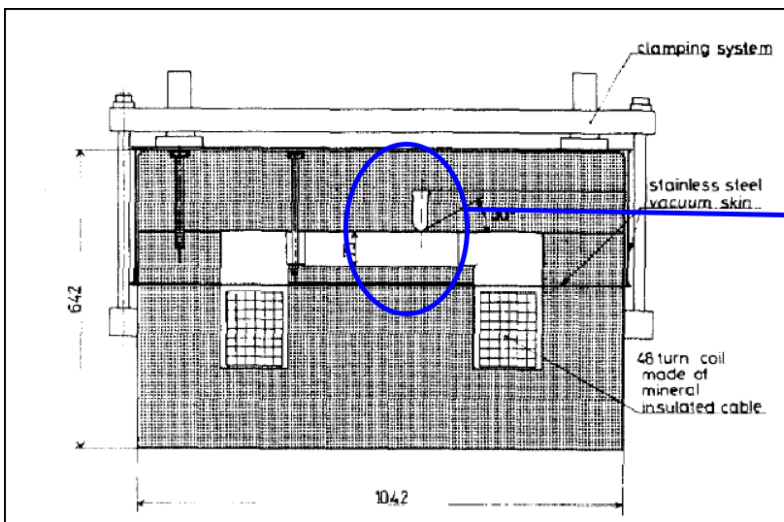
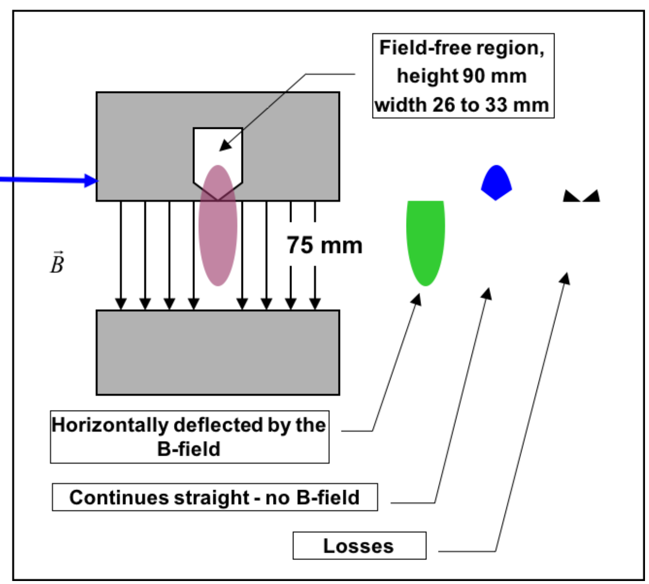
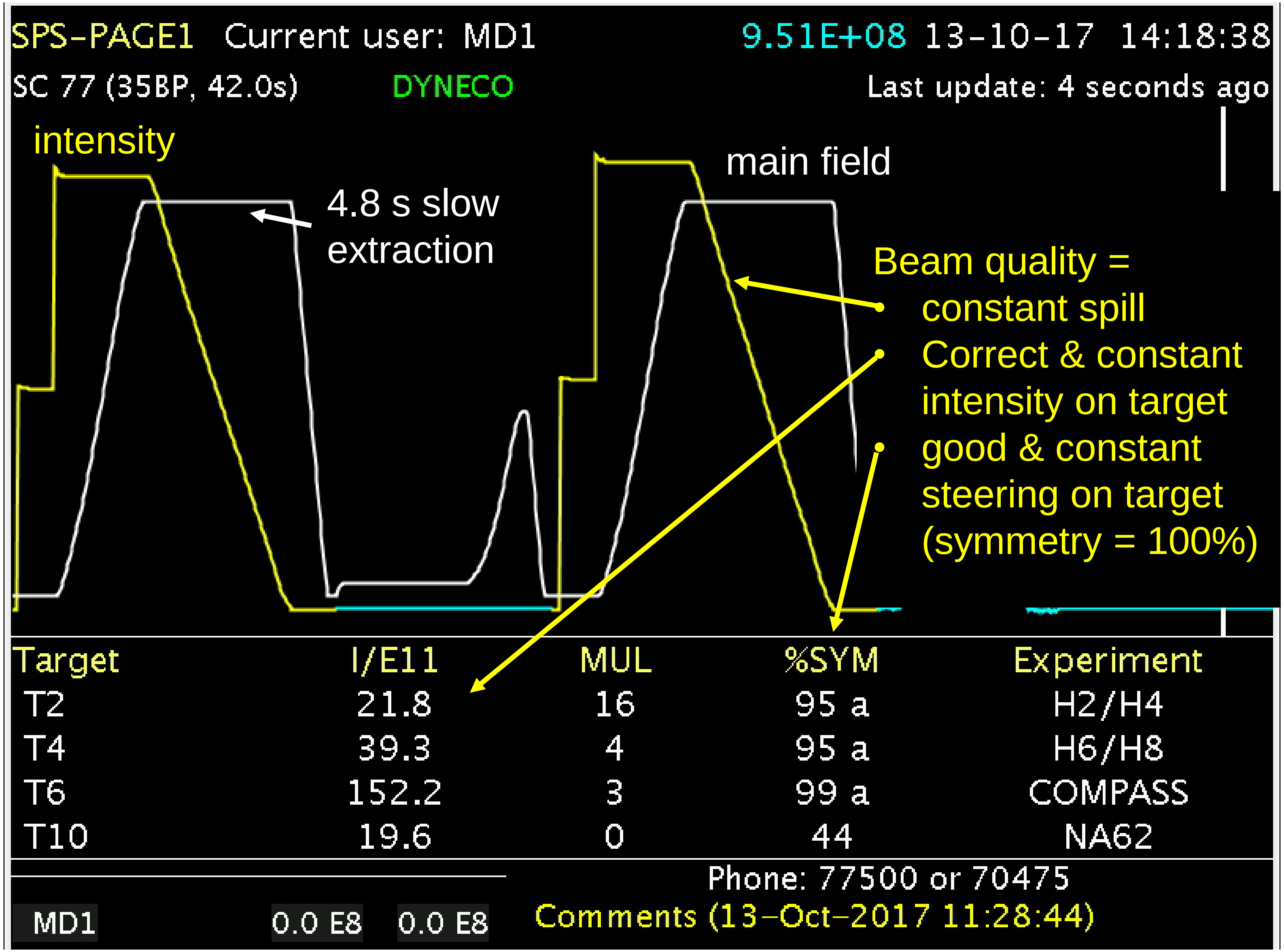


Fig. 5 Cross section of the single septum magnet.

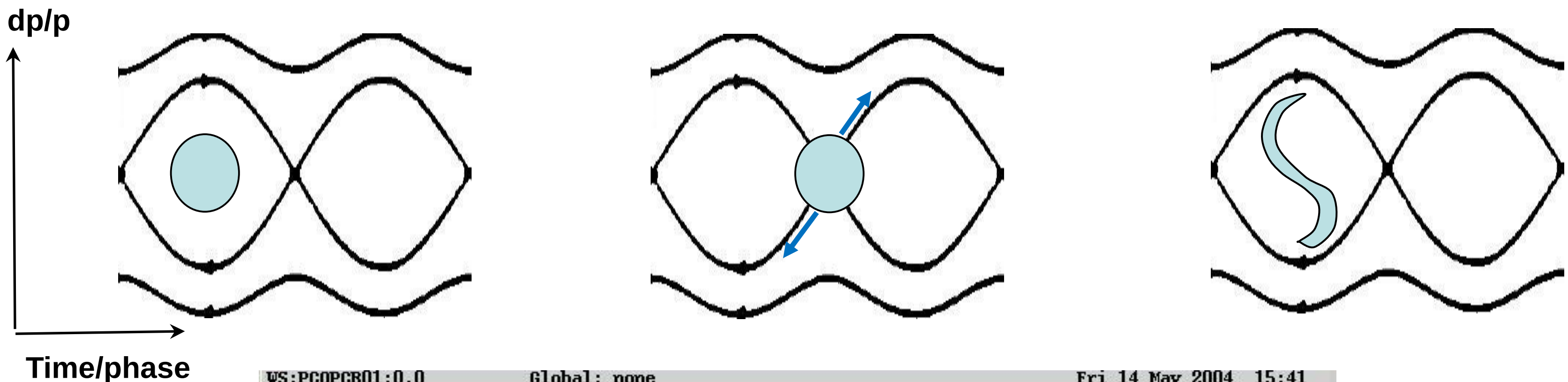


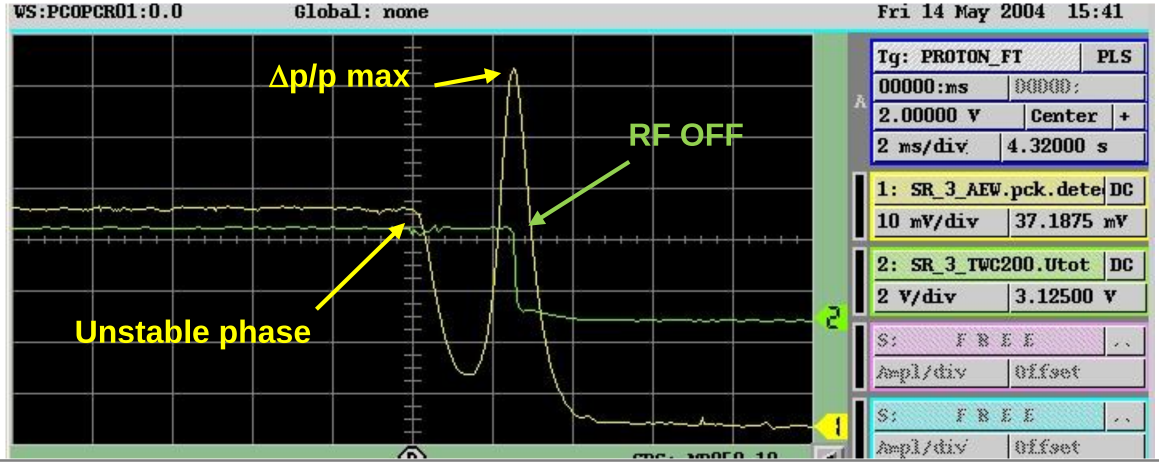
Operational key parameters



A propos: spill quality

- Debunched beam during slow extraction flattop
- Normalized Chromaticity: $\xi_H = -1$
- For faster debunching and uniform momentum distribution: RF gymnastics to increase dp/p_{rms} from ~ 0.02% to 0.04%

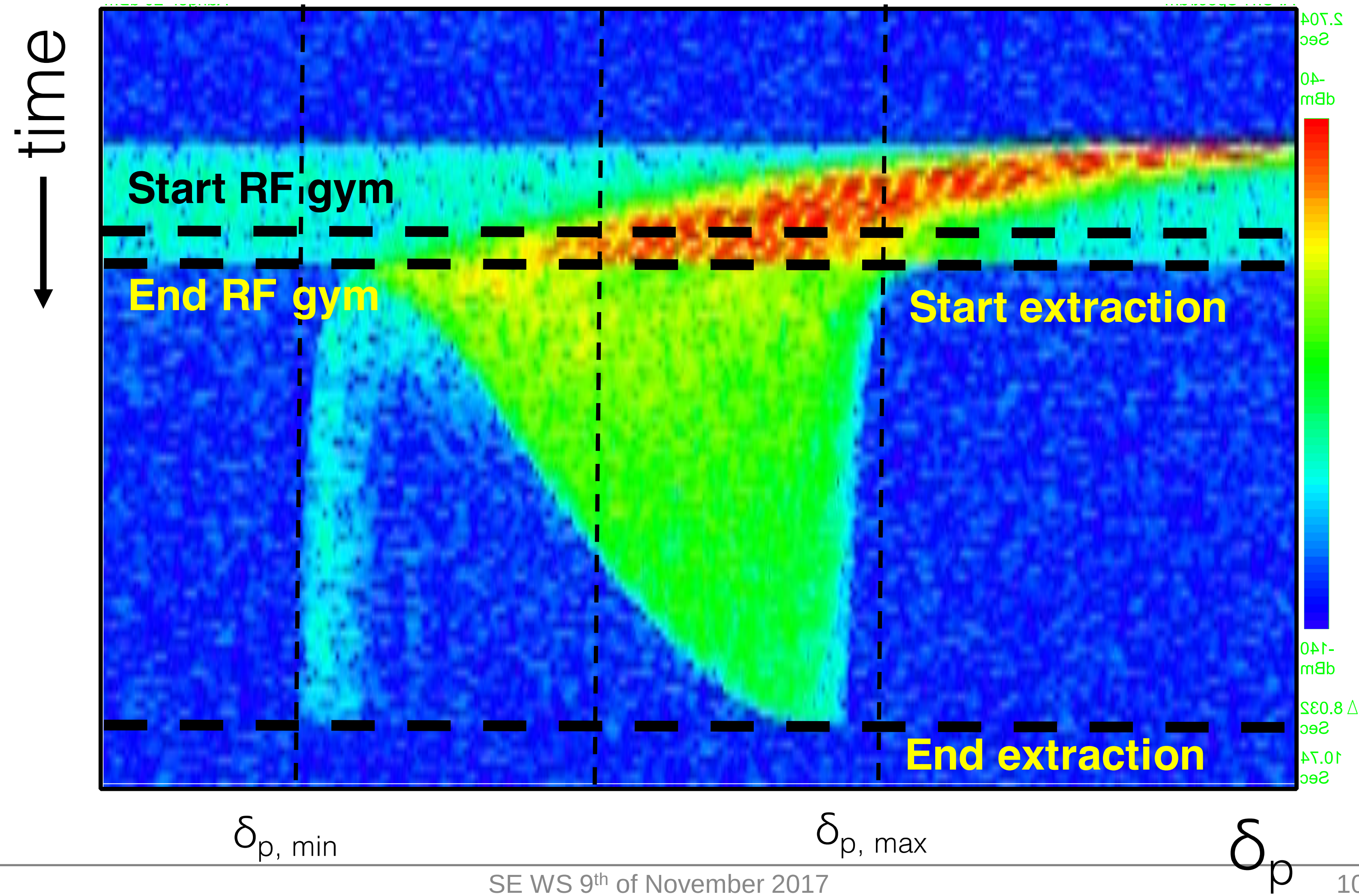




RF voltage
Peak ampl.

A propos: spill quality

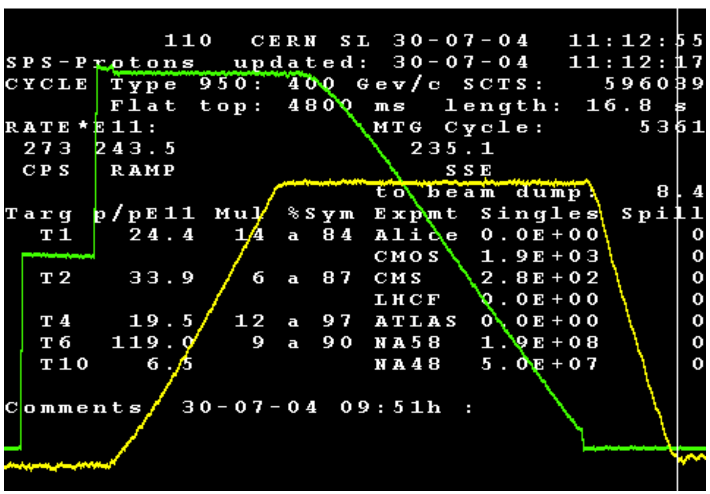
- The momentum of the beam varies during extraction



A propos: spill quality

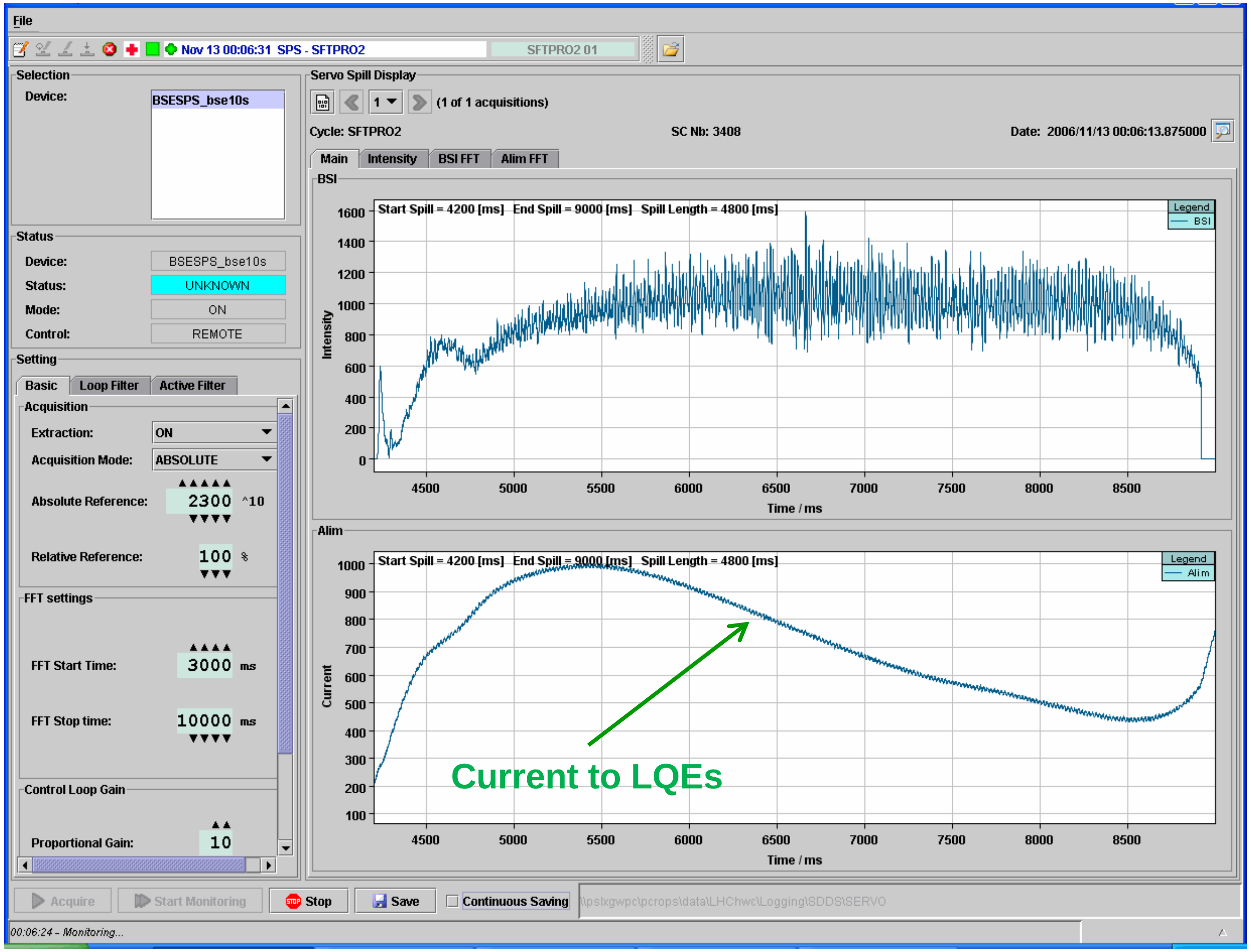
Spill control until 2015:

- Feedback loop from BSI to LQE116 quadrupole string.
  - BSI: secondary emission foil to measure extracted intensity at 2.5 kHz in transfer line towards targets



Spill control with servo-spill feedback

- Spill control with servo-spill quadrupole feedback loop



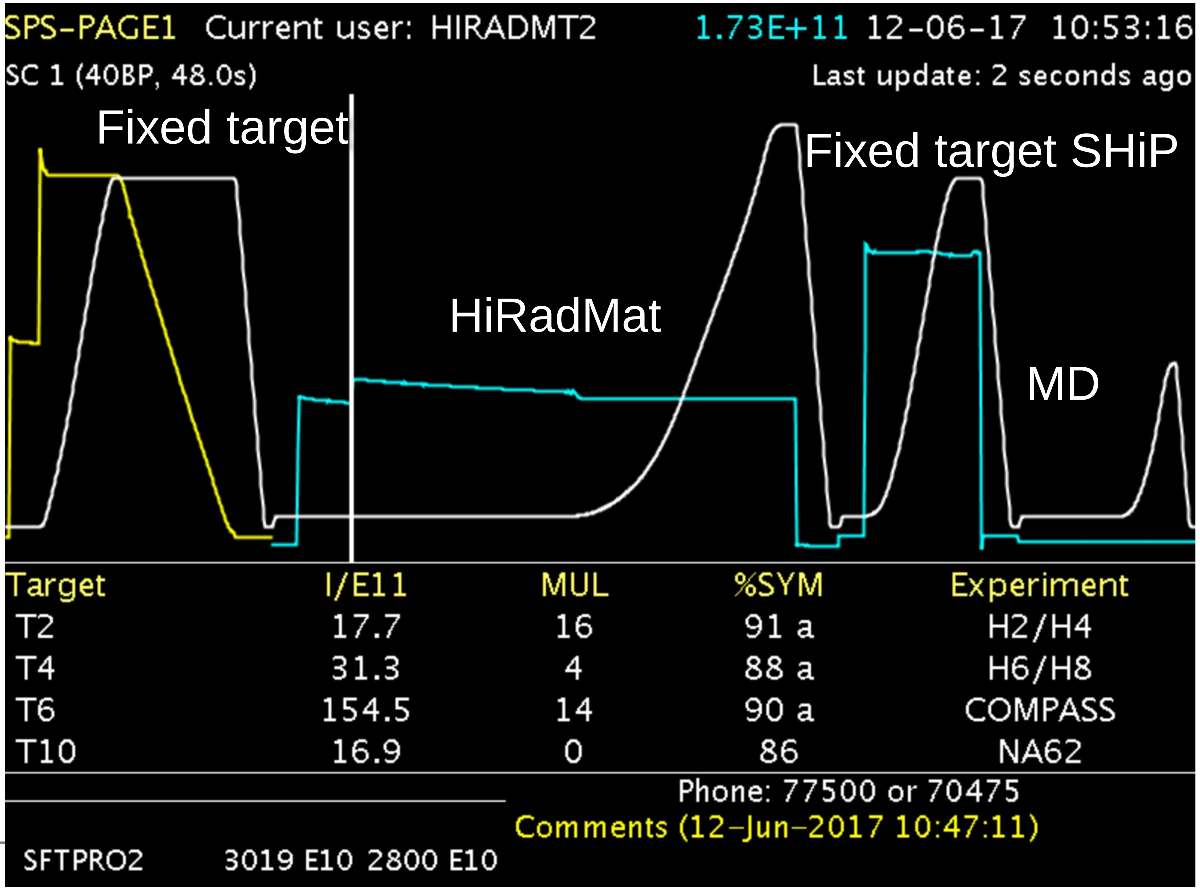
BSI measurement

Spill quality and multi-cycling SPS

- Since 2014 mode of operation of the SPS has changed
  - Multi-cycling and frequent “supercycle” changes
  - Dynamic economy
  - Insufficient hysteresis information and lack of compensation

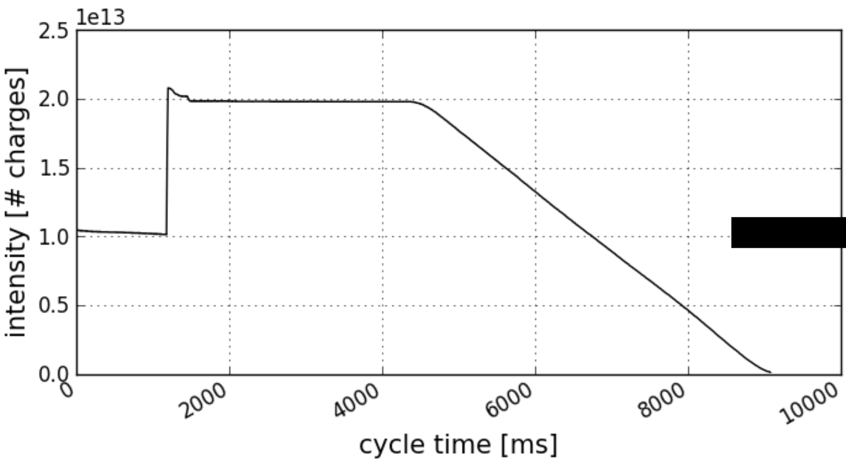
Example of supercycle:

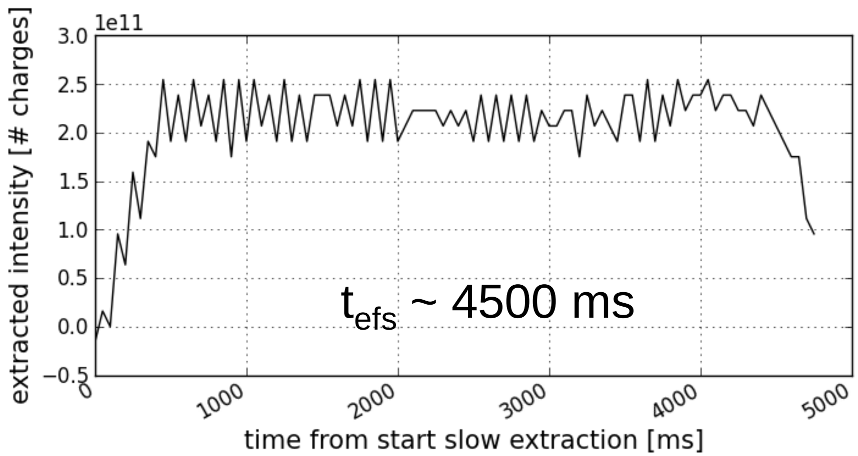
Only Fixed Target cycle is always in supercycle



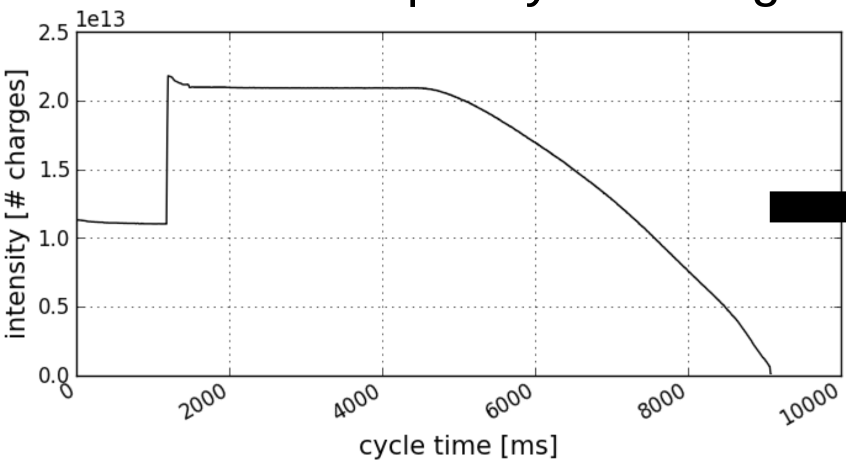
Effect on Spill of cycle changes

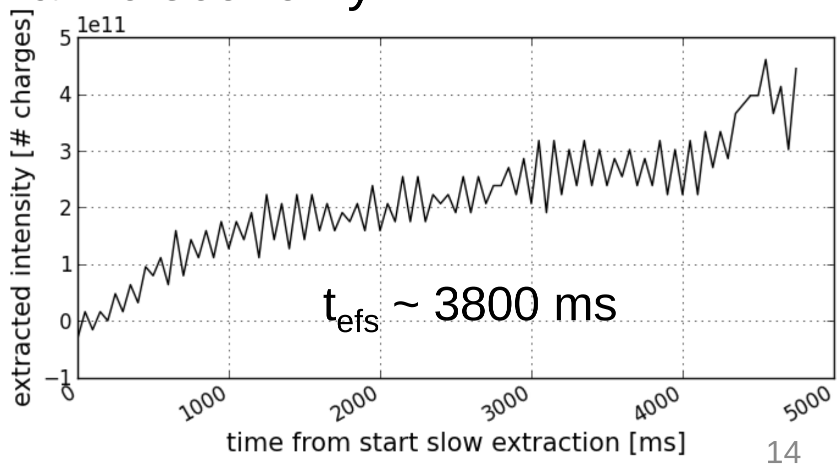
- Extraction flattop is 4800 ms long
- Typical effective spill length is 4500 ms





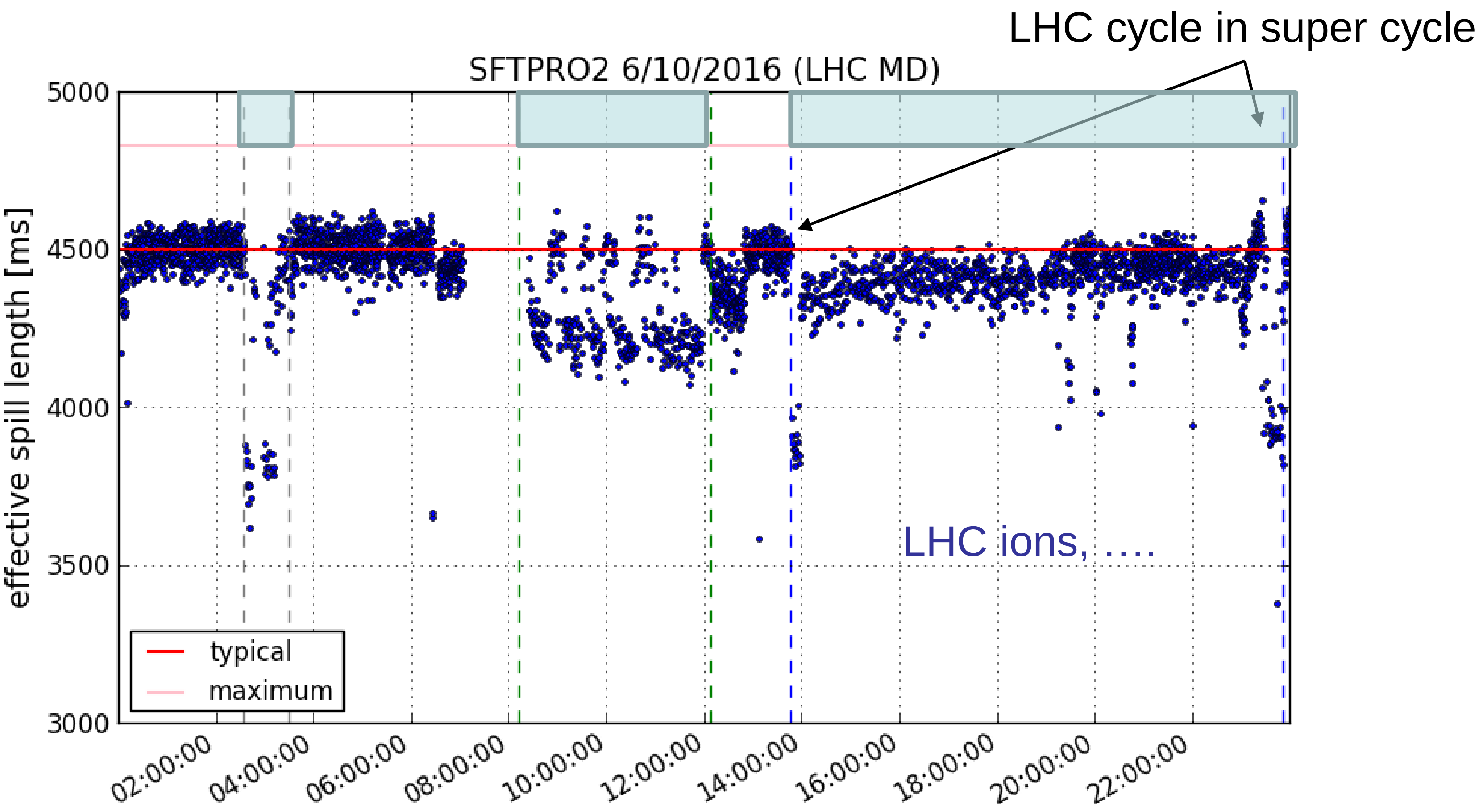
- Effect of super cycle change or dynamic economy





Evolution of effective spill length

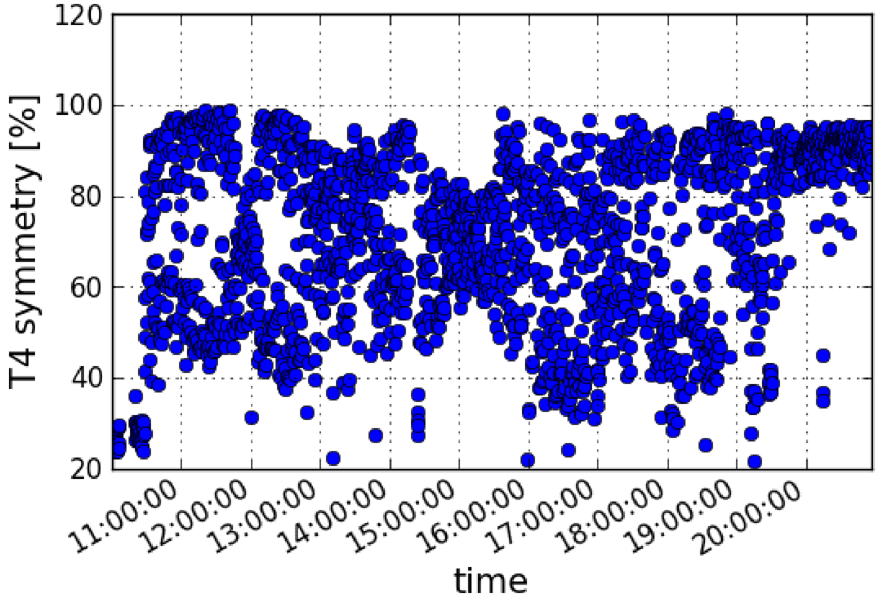
- LHC MD week. 6/10/2016, 24 h
  - Time between dashed lines indicates LHC cycle in super cycle



Unacceptable trajectory changes in TT20

- Especially during periods with the LHC cycles in the super-cycle, the spill is constantly changing
- The servo spill corrects for it and through feed-down moves the beam in the ring and in TT20

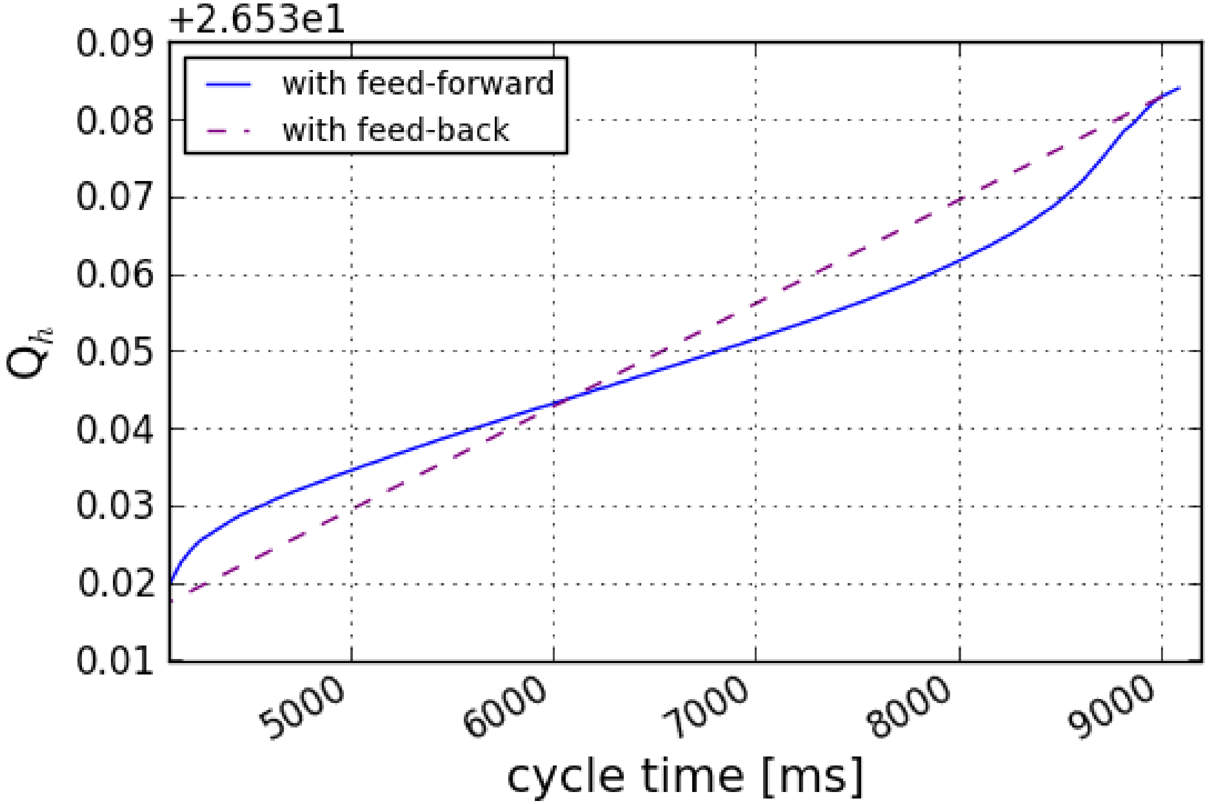
Shot-by-shot symmetry variations on target T4 with dynamic economy and servo-spill feedback became unacceptable in 2014



Example of 12 h T4 symmetry evolution in 2014

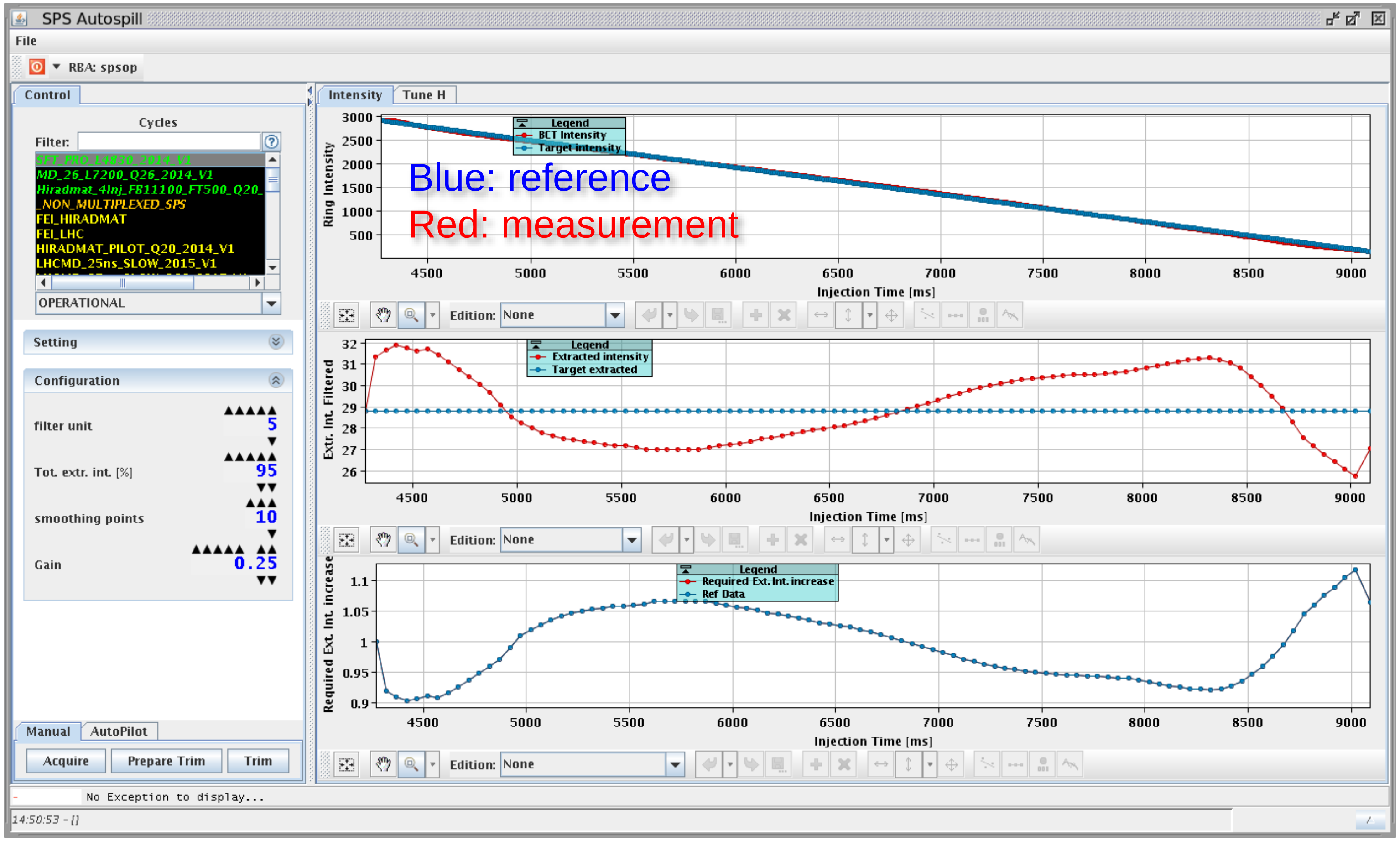
Solution: spill control with main quadrupoles in feed-forward

- Feedforward on Q_H function through main quadrupoles all around the ring instead of one location
- Advantage: can correct spill without moving extracted trajectory
- Variations in effective spill length remain – feed-forward !



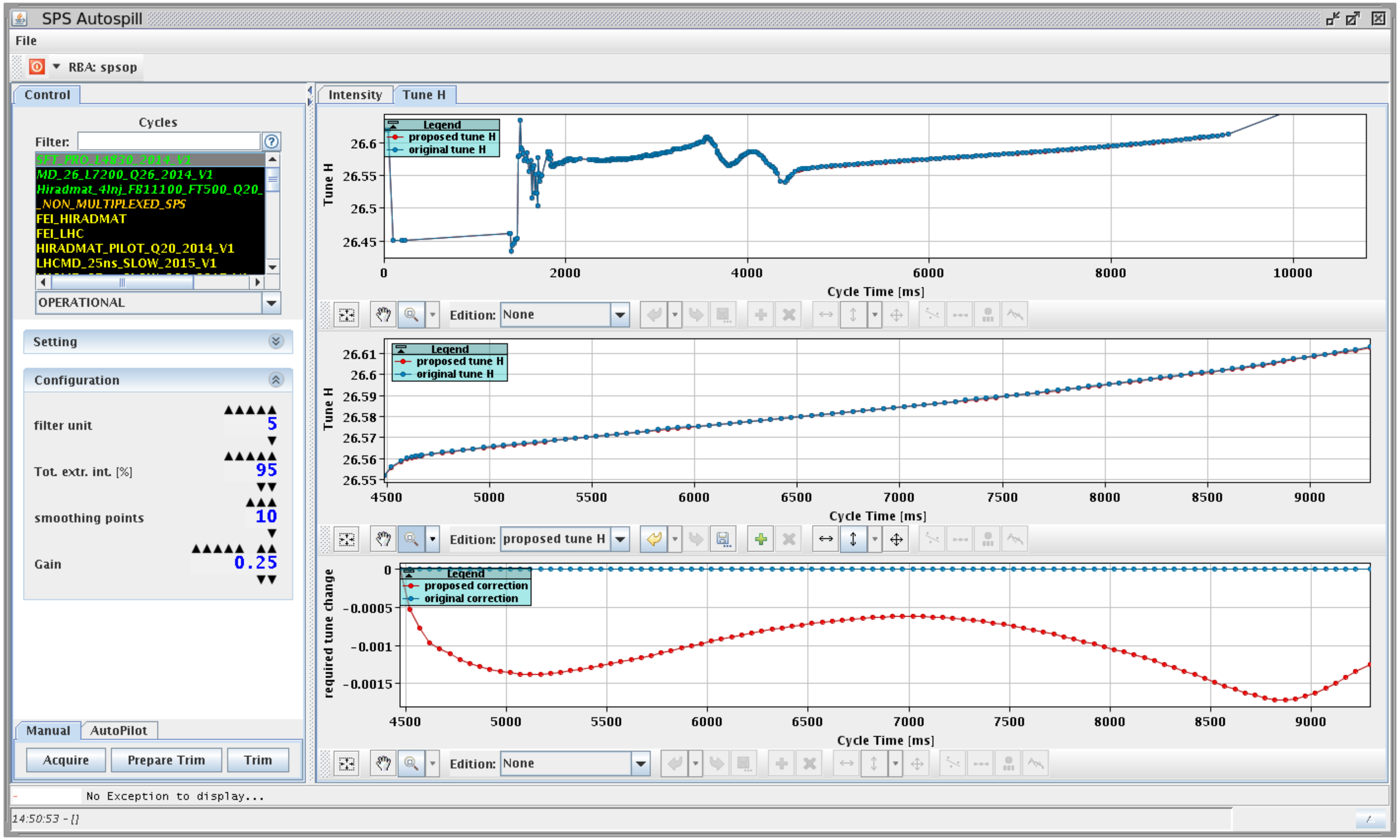
Spill control with main quadrupoles in feed-forward

- Observable: extracted intensity calculated from ring BCT



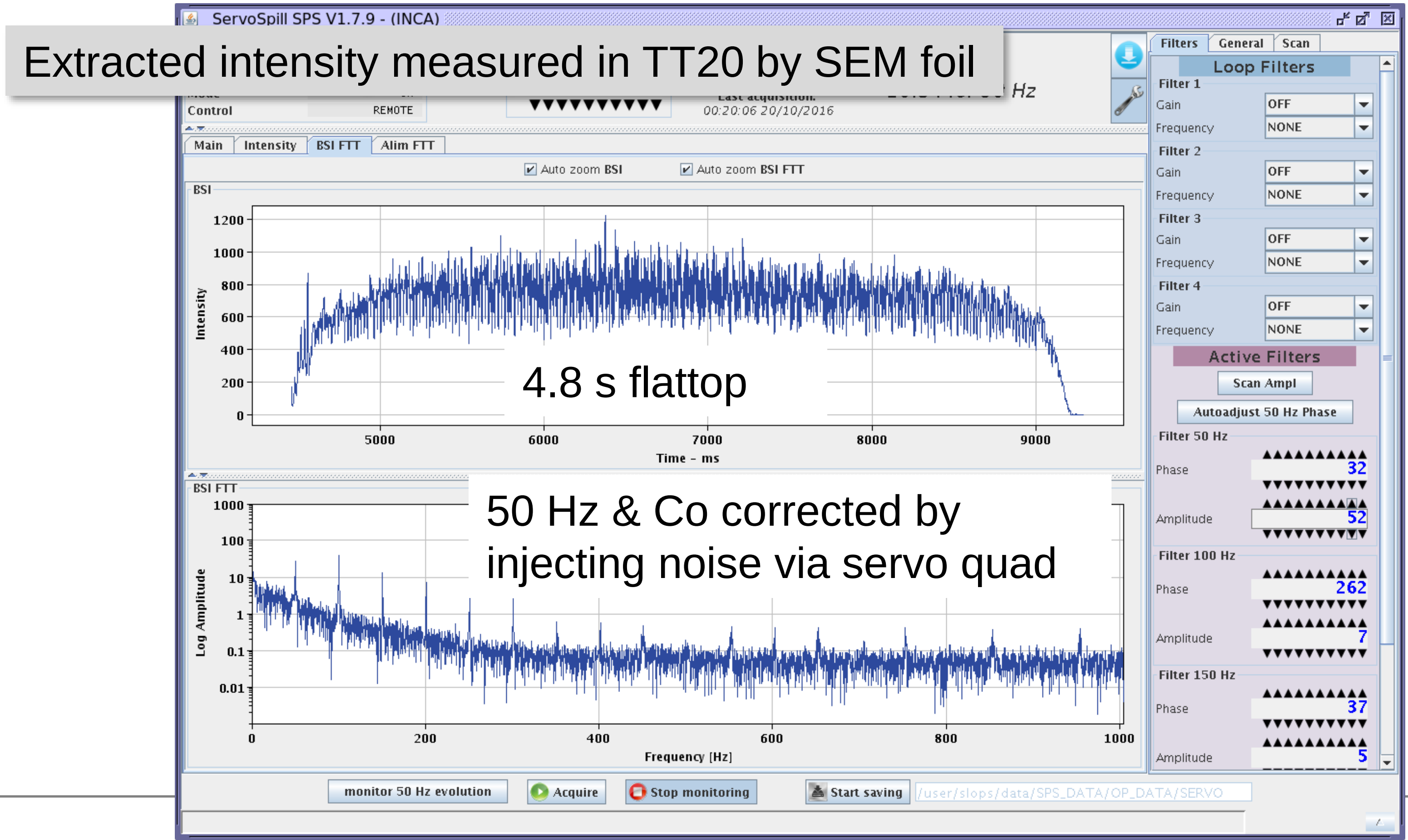
Spill control with main quadrupoles in feed-forward

- The SPS works with high level parameters: Q, ξ,…
- The new tune function is calculated according to $\frac{\Delta I_{ext}}{\Delta t} \propto \frac{\Delta Q}{\Delta t}$



50 Hz & multiples correction

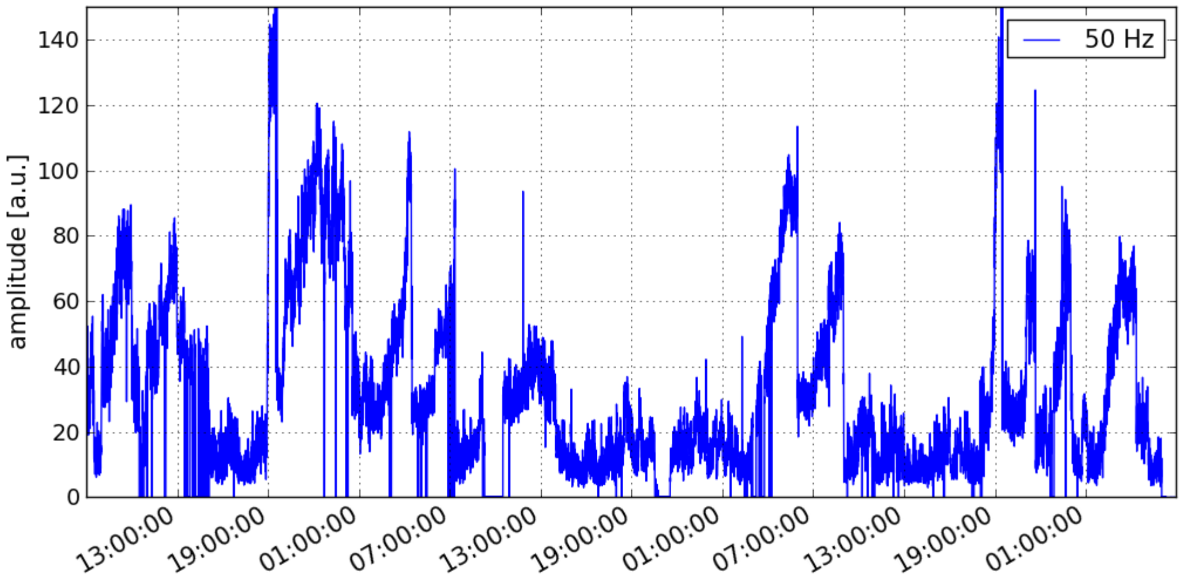
- Can inject noise at 50 Hz and multiples through servo quad power supply.
- Done in feedforward and hence relies on reproducibility
  - Unfortunately phase drifts…



50 Hz & multiples correction

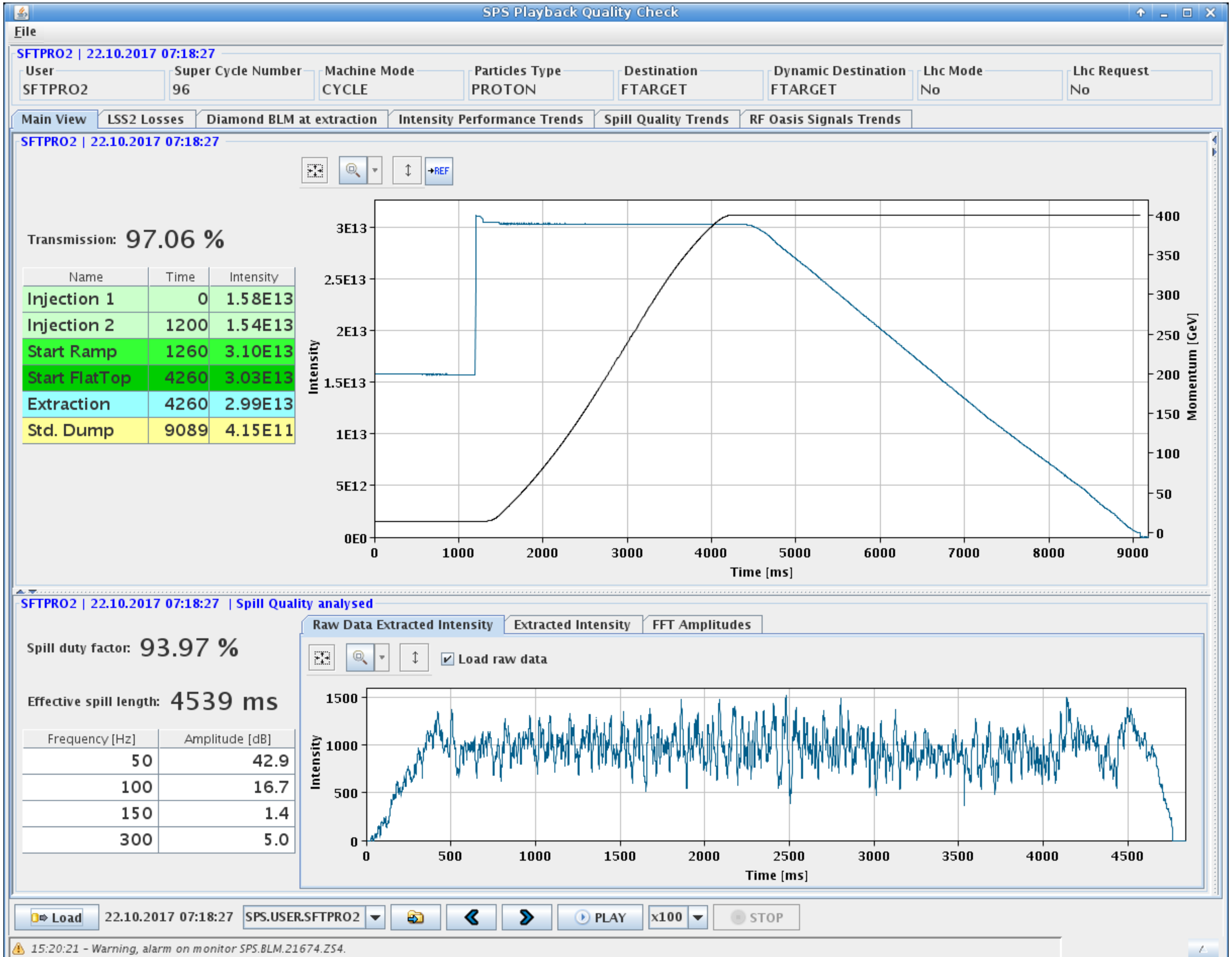
- Typical evolution of 50 Hz amplitude over 24 h
  - Desired value 50 Hz amplitude < 50.

Data from last weekend of proton run 20th-23rd of October 2017

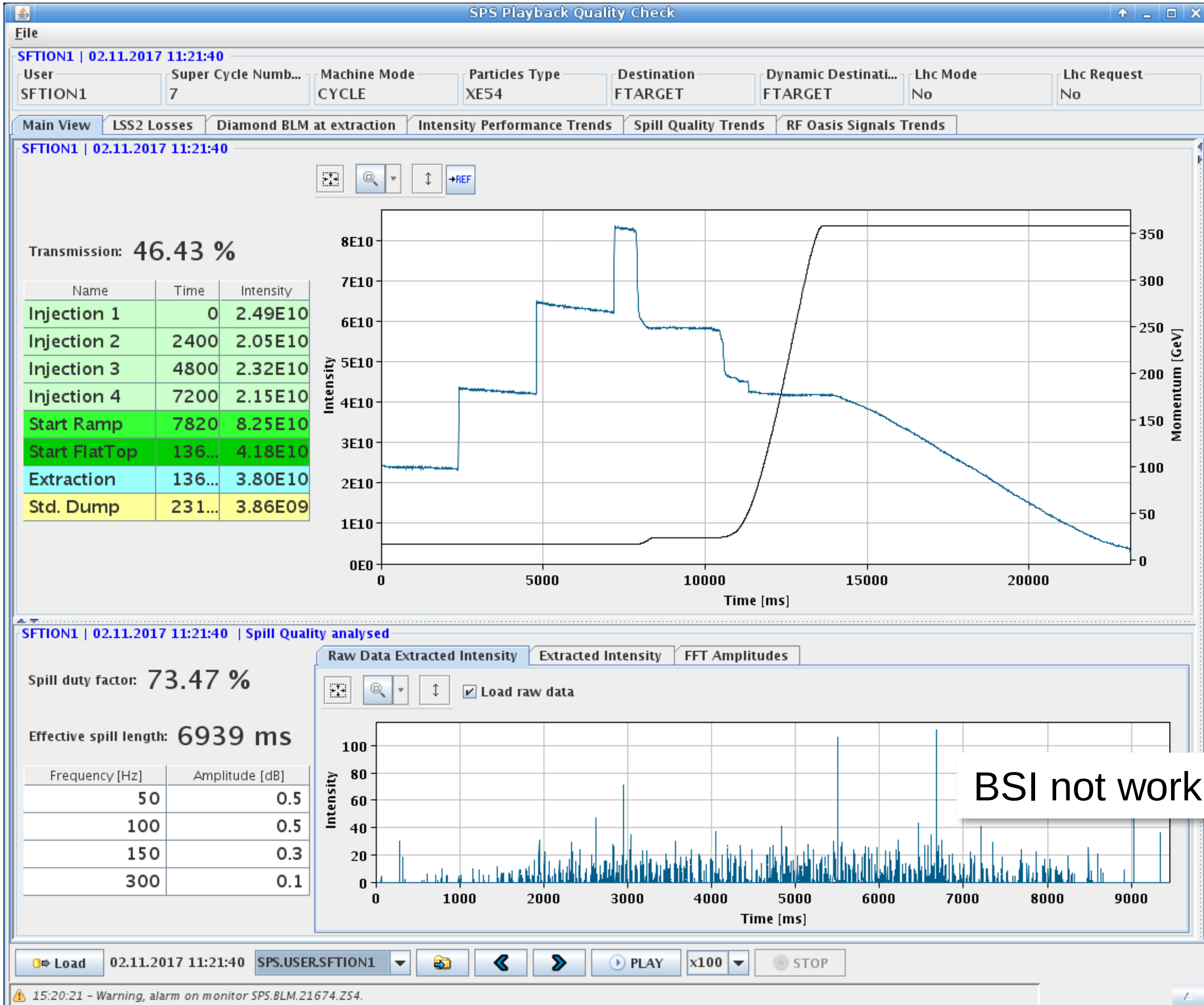


- Unfortunately still significant part of time high 50 Hz amplitude
  - Amplitude and phase drifting

Proton spill at the end of run 2017 - example

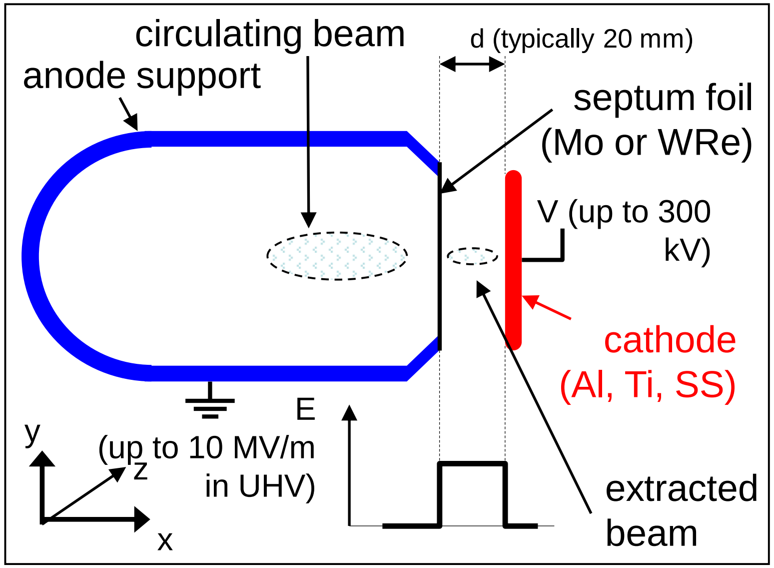


Xe spill at 360 Z GeV/c



BSI not working for ions

Losses



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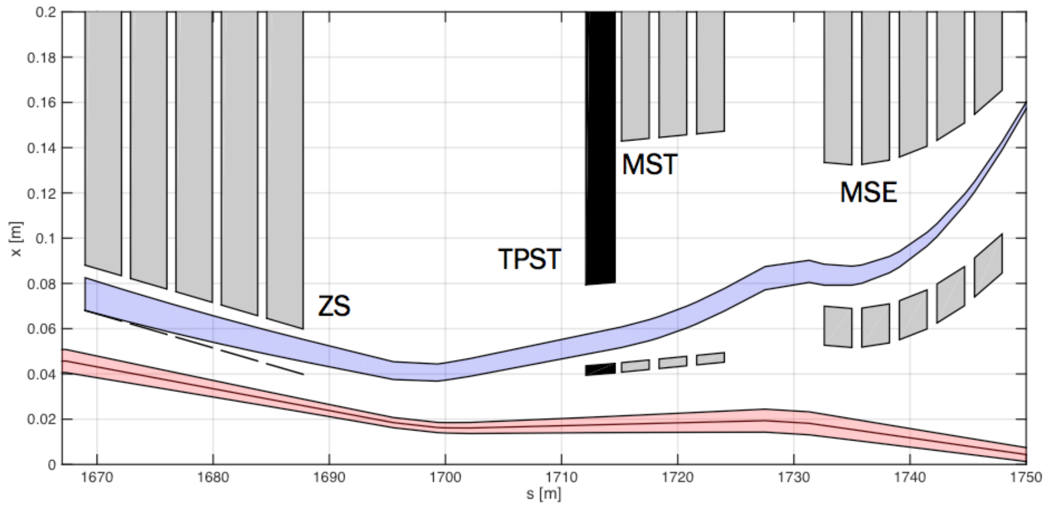
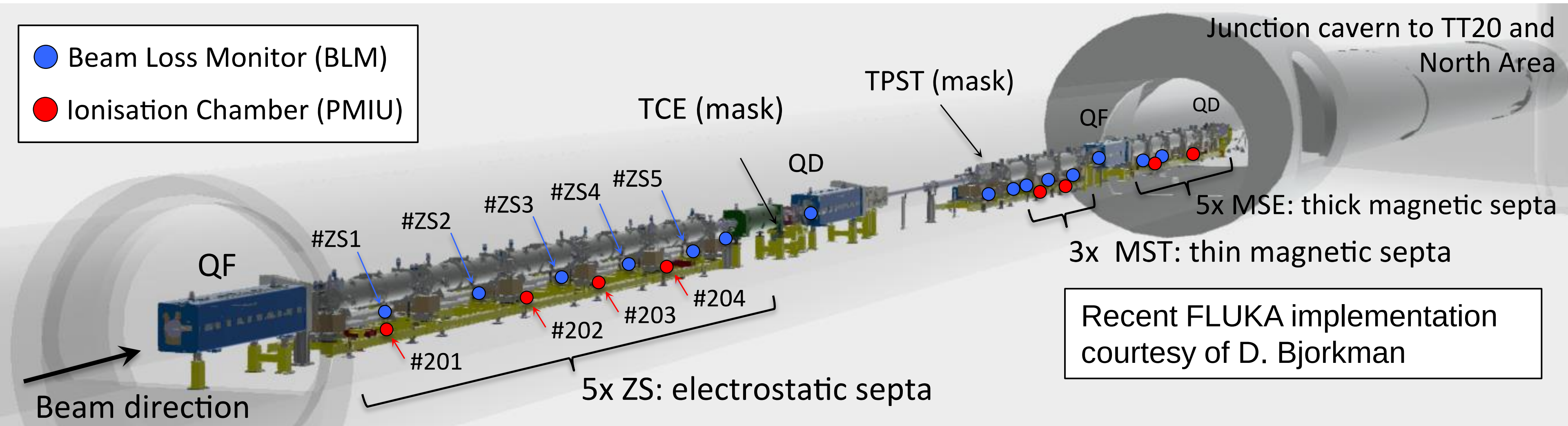
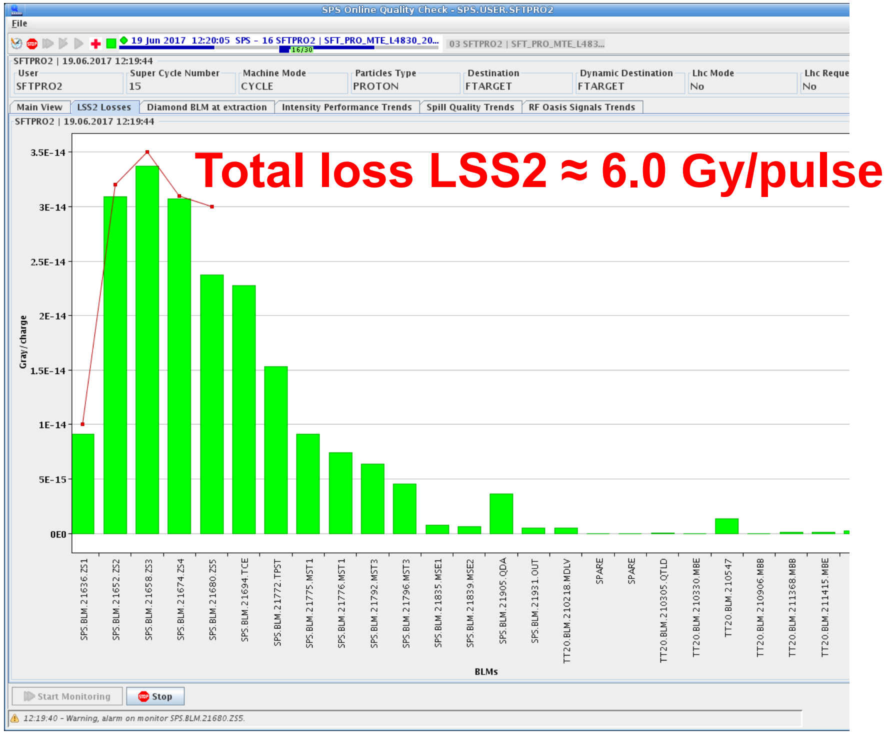




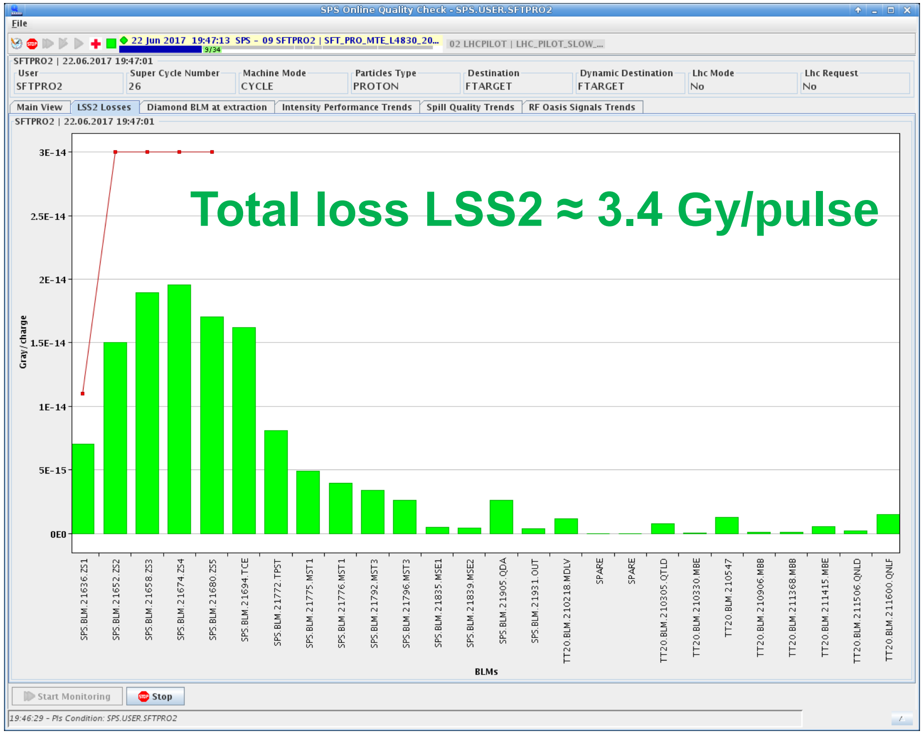
Recent FLUKA implementation courtesy of D. Bjorkman

LSS2: beam loss profile in 2017

18th June 2017
Extracted p^+ flux: 3E13 ppp

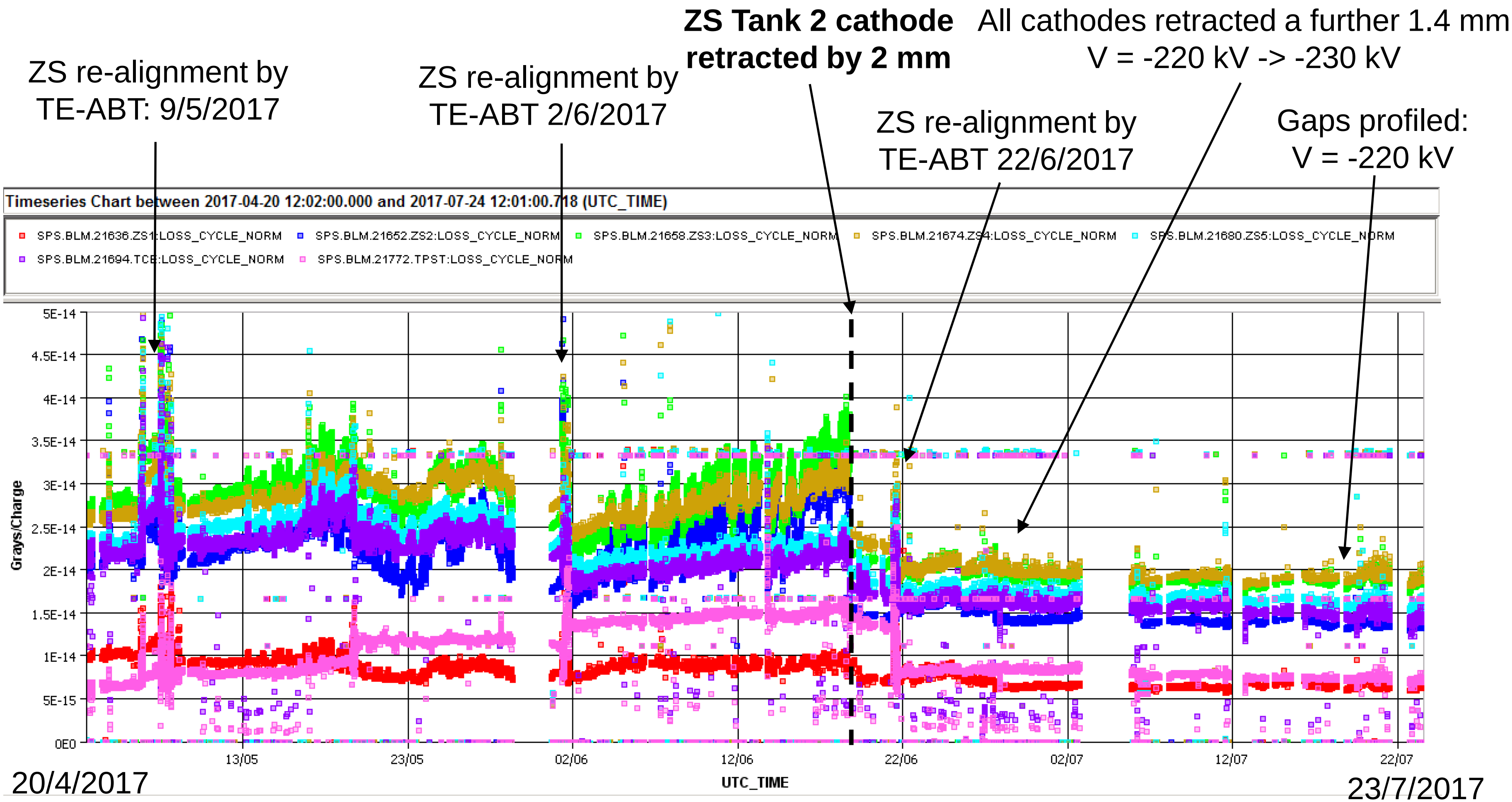


22th June 2017
Extracted p^+ flux: 3E13 ppp



M. Fraser

ZS normalized losses



2E13 ppp and 18 s rep rate: correlated to time structure in Normalised losses

3E13 ppp and 18 s rep rate

Stable (low-loss) operation

M. Fraser

SPS slow extraction challenges – A summary

- Spill quality and stability
  - Hysteresis, power converter ripple
  - See talk by F. Velotti
- Losses in extraction channel and splitters
  - Alignment of ZS anodes and girder
  - Calibration of intensity measurements with BSI
  - See talk by M. Fraser
- Lengthy (and not straight forward) setting up due to beam instrumentation for DC beams
  - Especially steering in TT20 with split foils

- Other challenges are associated with the fixed target beam in the SPS and the production scheme of it in the pre-injectors
  - MTE beam, "large" vertical emittance and limited acceptance, transition crossing,…
  - Transmission > 95 % with > 3e+13 protons is work of many weeks

EXTRA SLIDES

Trajectory stability after introduction of Autospill

- 12 h under similar conditions as plot before