Challenges for the SPS and SPS-to-LHC Transfer for 2016 Run

Lessons learned in 2015

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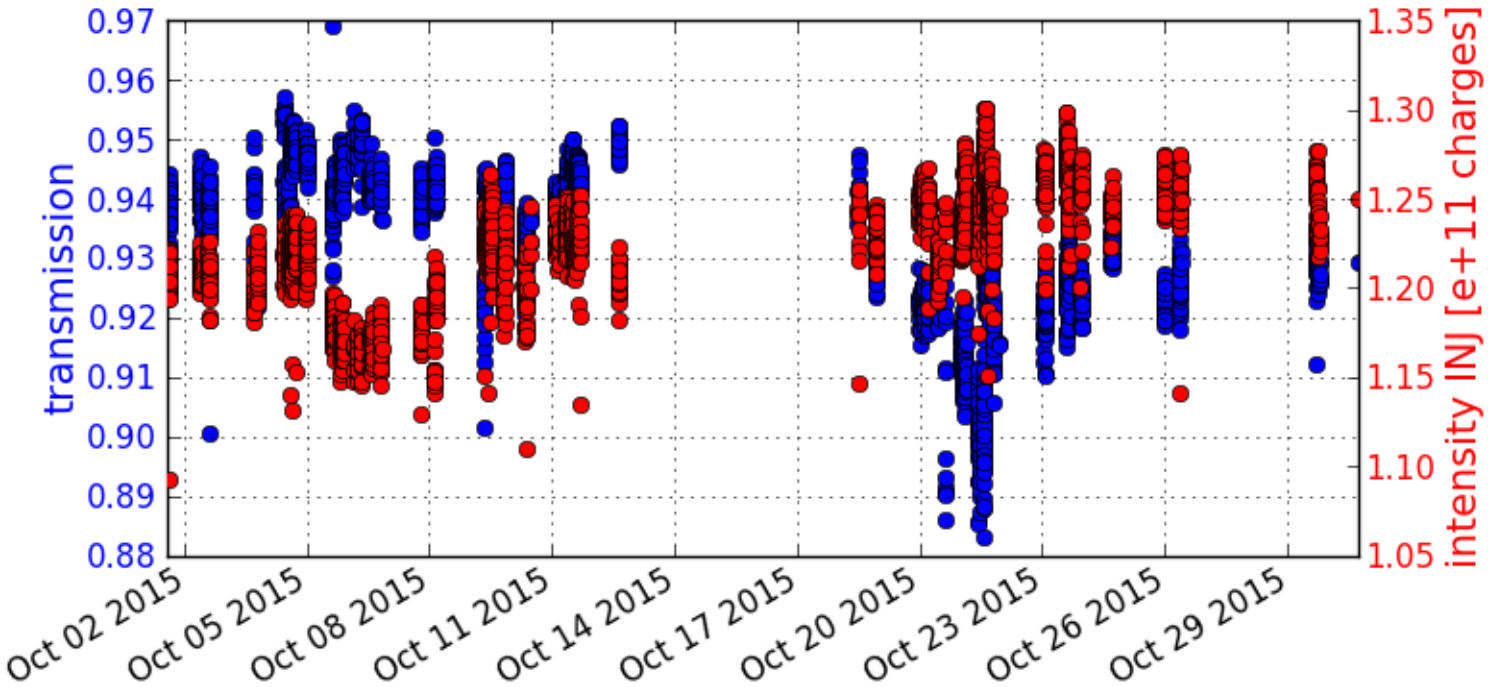
Transmission versus bunch intensity – operational beams

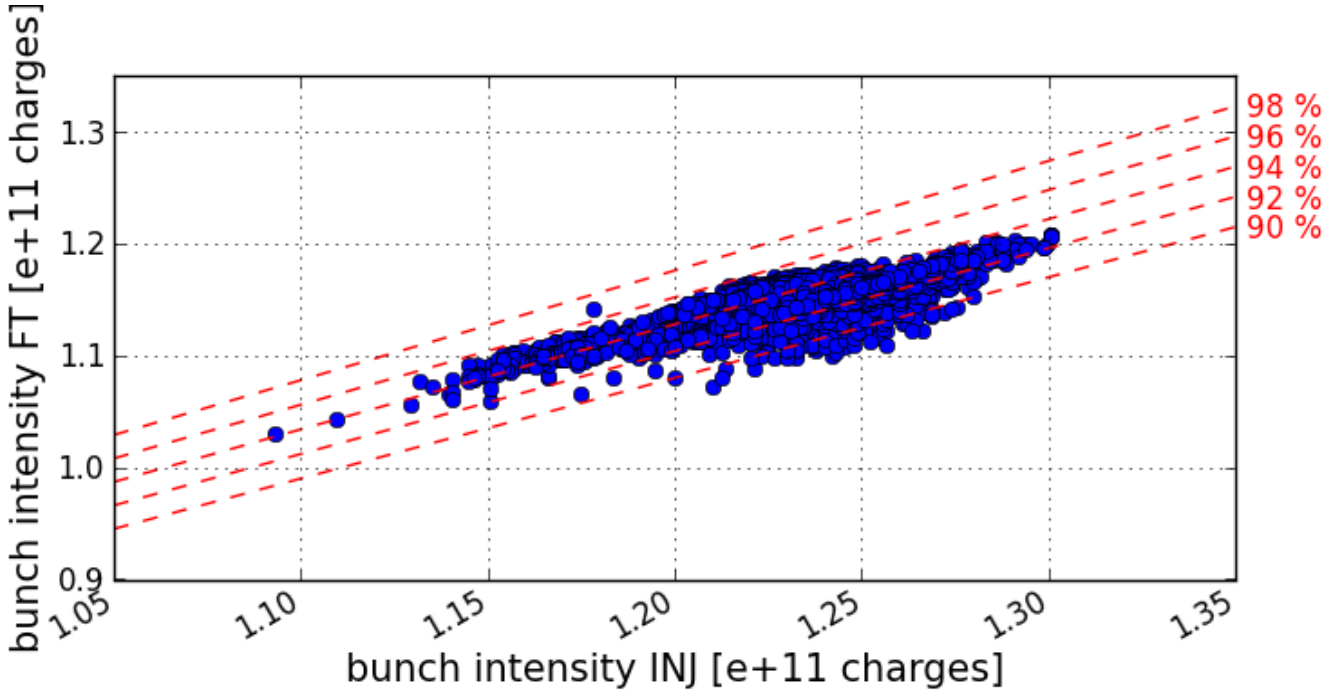
- LHC operational 25 ns beams : max. 144 bunches
  - SPS injected intensity between 1.15 – 1.3 × 10^{11} ppb
- **Transmission reduced systematically with higher bunch intensity**

Overview of SPS injected bunch intensity and transmission: October 2015



Transmission versus bunch intensity – operational beams

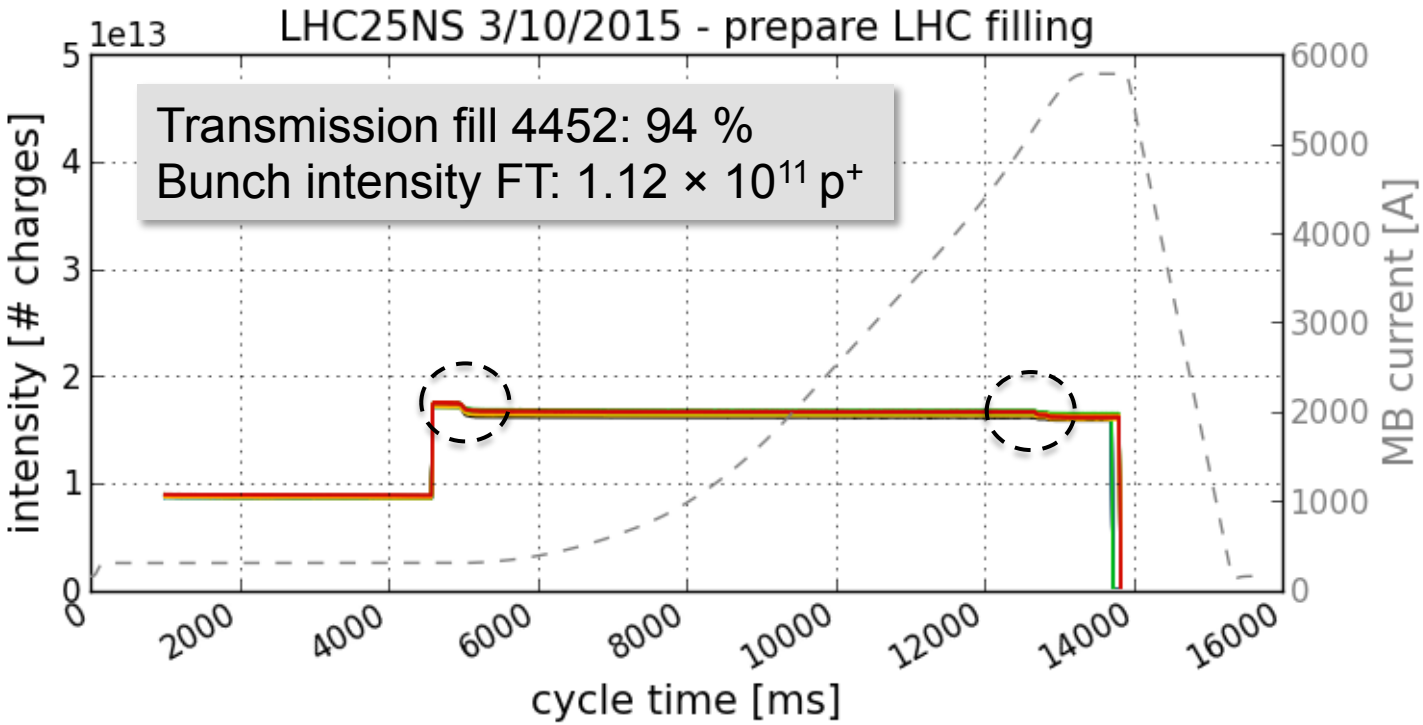
- LHC operational 25 ns beams October 2015: 144 bunches
- For largest bunch intensity injected (1.3×10^{11}ppb): transmission 92 %



- Large spread of obtained transmission for giving bunch intensity
  - ➔ Continuous tuning required
- Intensity out of SPS “not” limited yet, but increased activation of the SPS

What causes the beam loss? Operational beams

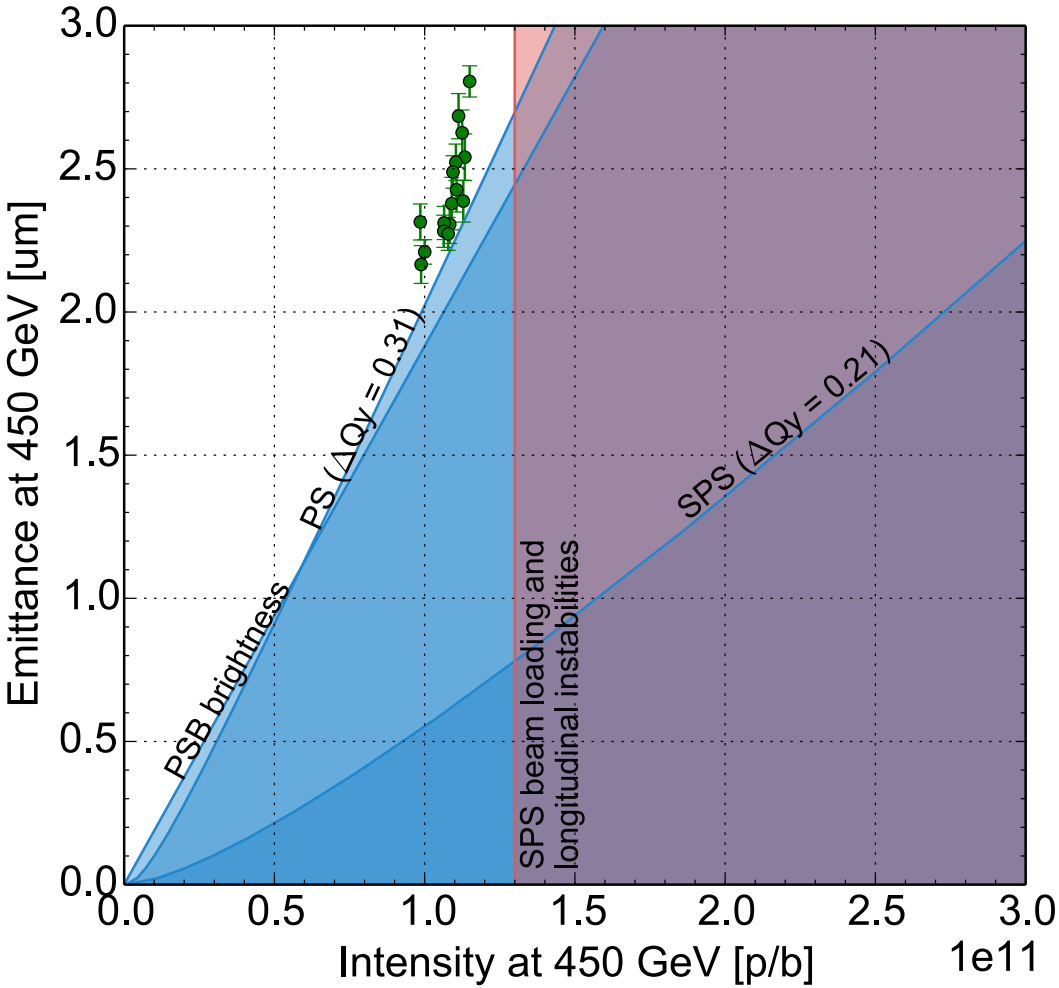
LHC25NS, preparation of fill 4452



Losses: uncaptured beam, scraping

Brightness 2015 LHC25NS

- Emittances and intensities measured in the LHC at injection wrt to performance limitations in the injectors



Achieved brightness consistent with assumptions in injectors.

But not systematically achieved, large spread

➔ Continuous optimization and tuning needed

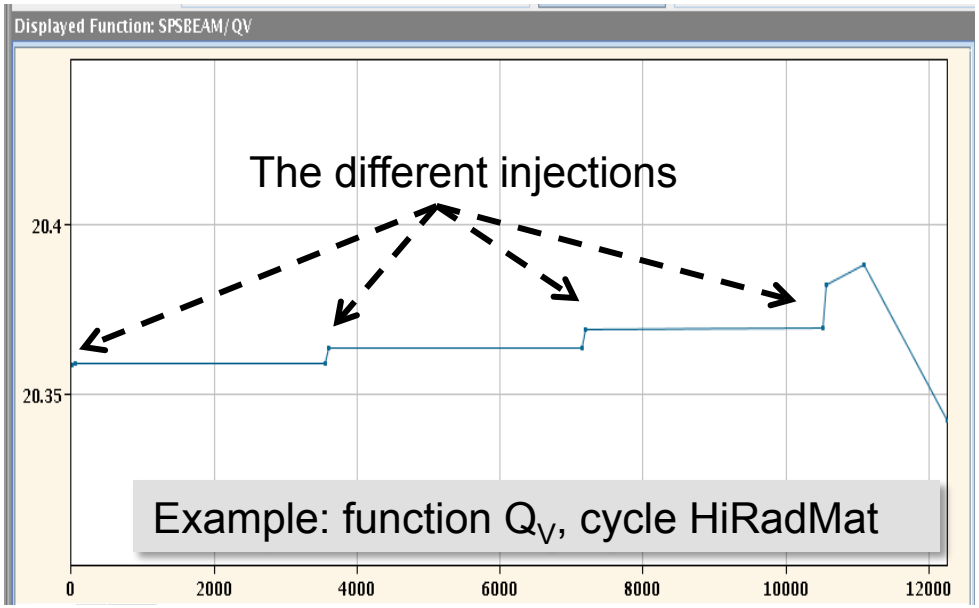
More tools: Automatic tune shift depending on intensity

- Tune shift with intensity not taken into account for dynamic requests of 1 – 4 batches currently
  - The settings of the LHC cycles in the SPS are strictly adequate for one intensity only.
  - Further complication from transverse damper sensitivity with tune error

Prepared proposal with EPC:

FGCs of main quadrupoles will apply preset ΔI at injection.

Might not be available at start-up.



More tuning required, but setting up limitations

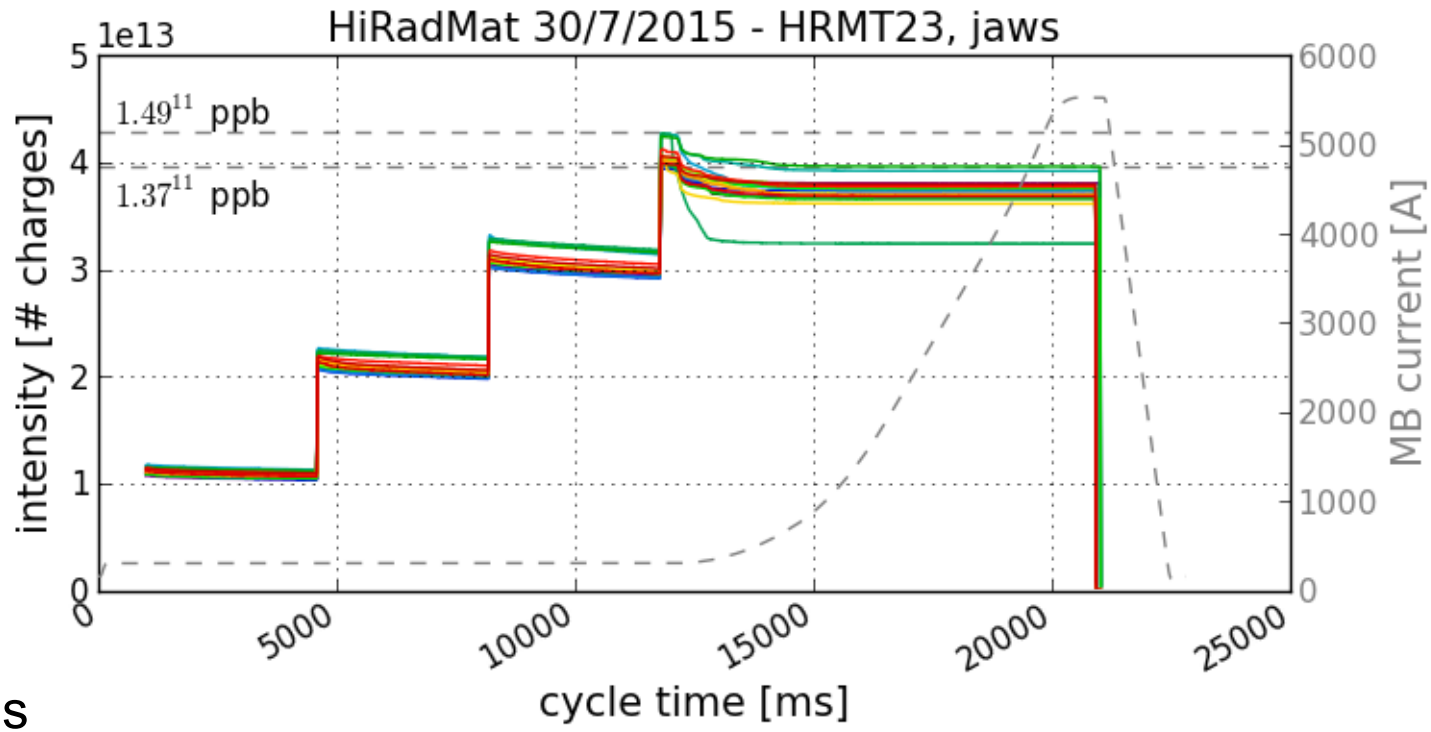
- Power limit on internal beam dump TIDVG will remain
  - Limit is 3.66×10^{13} p+ in 36 s.

- Impedance of injection kicker MKP4: heating up with 25 ns beam and outgassing due to heating.

- Emittance measurement limitation at 450 GeV:
  - not possible with WS and 288 bunches
  - BSRT H at high dispersion location and not operational
  - No operational Beam Gas Ionization monitor BGI

2016: 288 bunches = operational LHC beam

- Example of the highest intensity accelerated in 2015
  - Injected up to 1.49 × 10^{11} ppb, 288 bunches; no scraping
  - Achieved 1.37 × 10^{11} ppb at FT. **~ 1.3 × 10^{11} ppb seems to be limit**

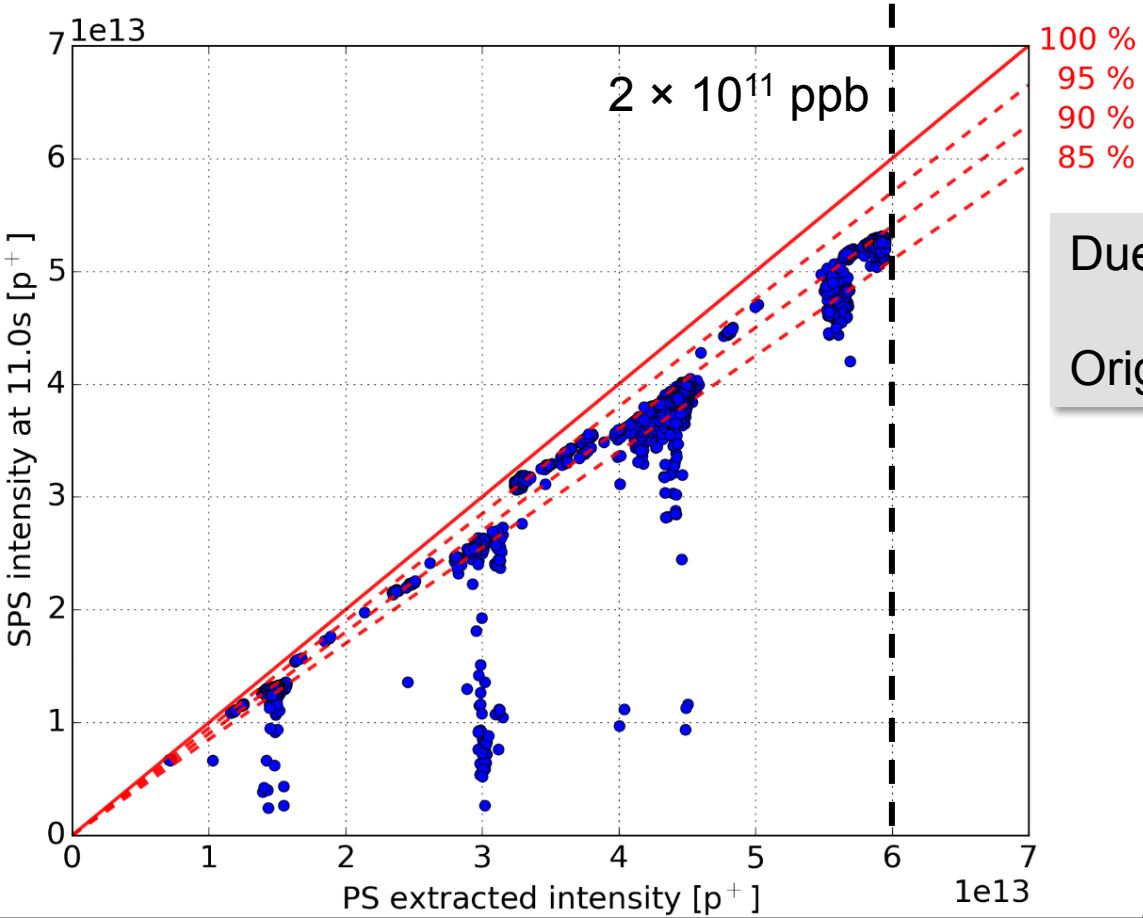


- Losses
  - Uncaptured beam every injection, low lifetime at flat bottom
  - Beginning of ramp: Uncaptured beam, dependence of tune on intensity, beam loading

Significant losses also at flat bottom

Experience from SPS scrubbing run: beam not accelerated

- The higher the intensity, the lower the transmission
  - Lost up to 10 % due to generation of uncaptured beam (kicked out at subsequent injection) and incoherent losses

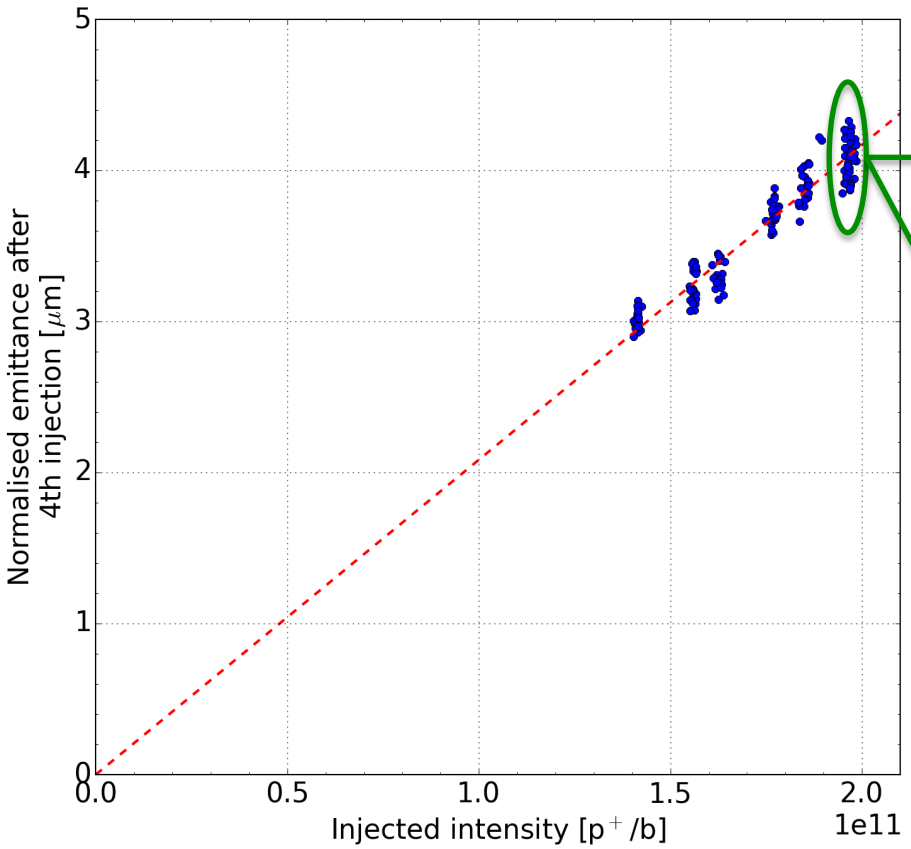


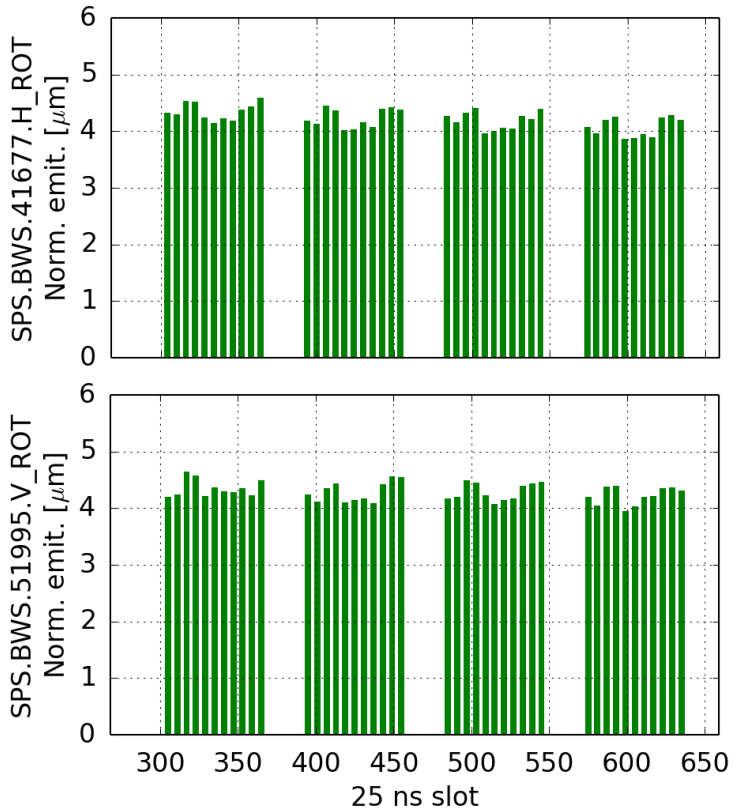
Due to e-cloud?

Origin to be understood

Emittances with288 bunches – from the scrubbing run

- Linear dependence of emittance on bunch intensity as provided from pre-injectors – measurements at injection
  - No measurements of 288 bunches possible with wire scanners in the SPS @ 450 GeV
  - **Need BSRT in 2016**

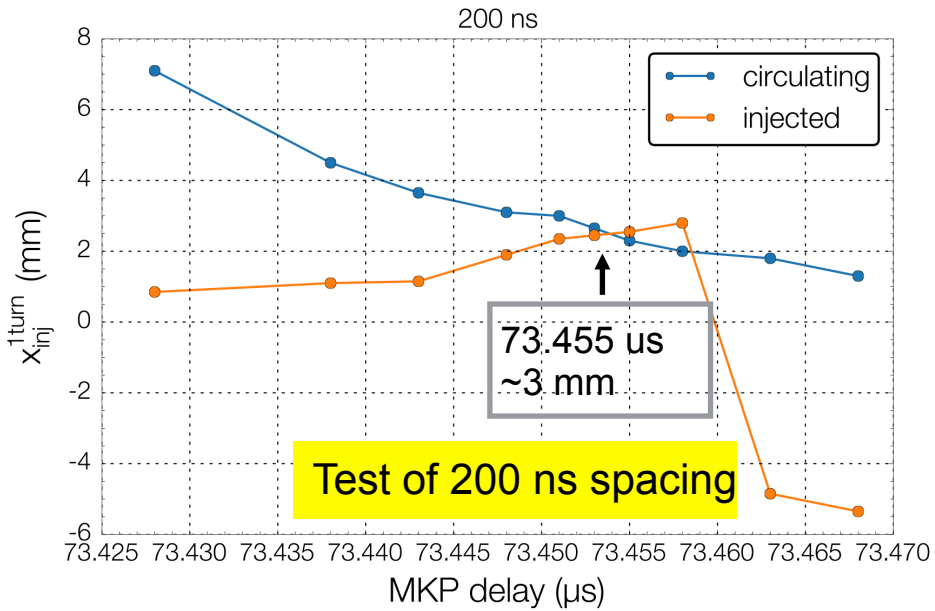




Required improvements for 2016 (1) – batch spacing

- Batch spacing in 2015 was limited to 250 ns due to achievable rise time of SPS injection kickers MKP
  - Design 225 ns!
- Significant progress made during Pb run 2015
  - Hardware issue found: timing jitter of 30 ns
  - 225 ns batch spacing will be OK for 2016!!

F. Velotti, E. Carlier, B. Goddard



200 ns batch spacing might be within reach

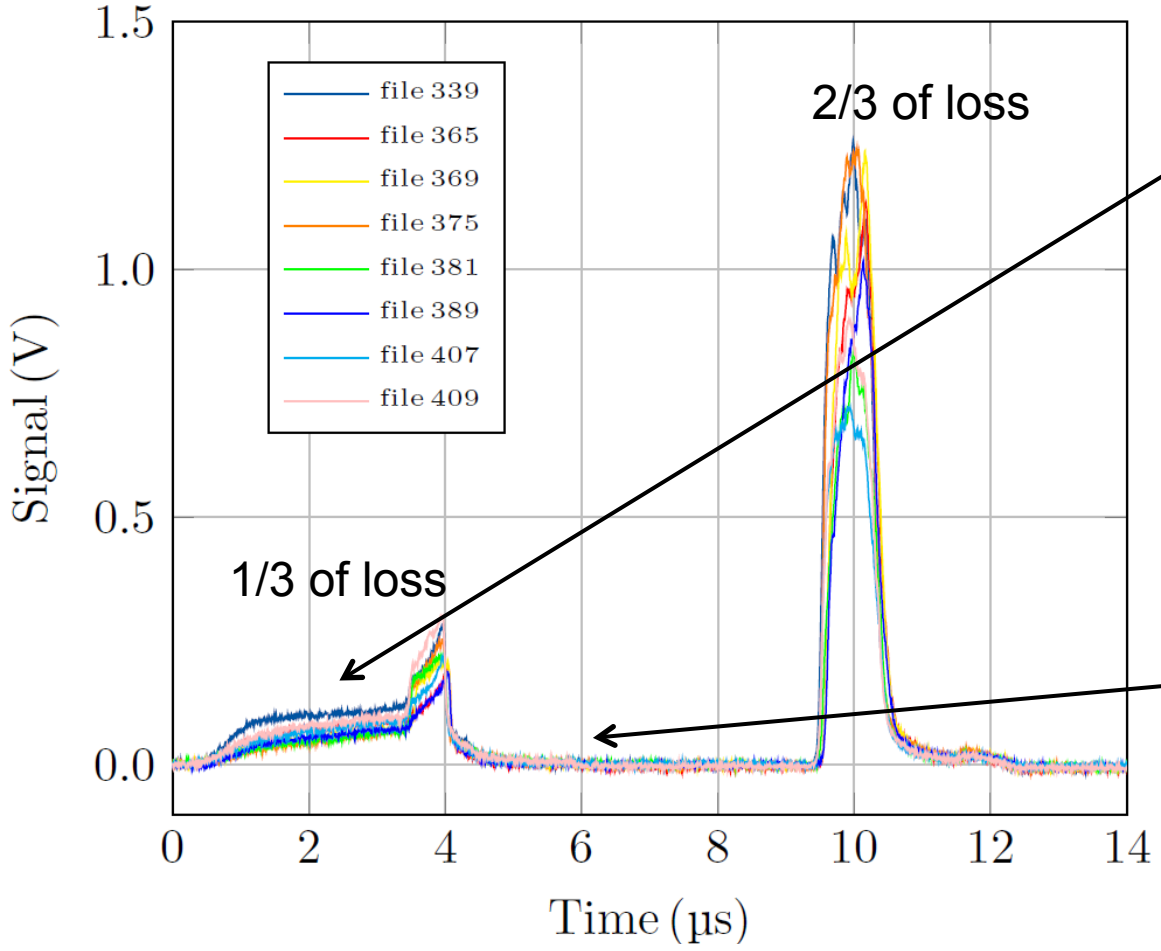
More tests required with injection into LHC to check tails….
Relies on SPS damper

Required improvements in 2016 (2) – re-captured beam

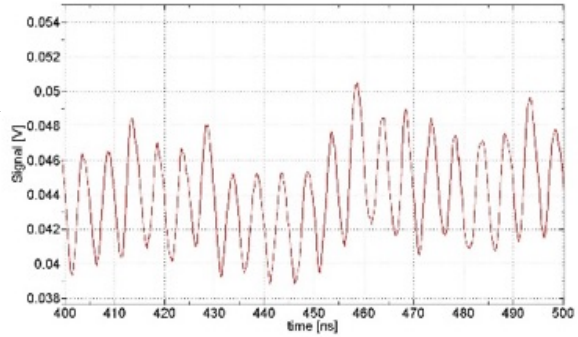
F. Burkart, O. Stein

- High losses on injection stopper TDI in 2015.
  - Up to 93 % of dump threshold with 144 bunches
  - Factor 25 lower losses on TDI with 288 bunches in 2012
- Origin of losses was identified thanks to the diamond BLMs with 5 ns time resolution:
  - Originally uncaptured beam in the SPS is re-captured at the beginning of the ramp
- Possible mitigation:
  - SPS and injectors: reduce as much as possible amount of uncaptured beam, start ramp earlier, further optimize RF voltage program
  - SPS and injectors: use MKQ or transverse damper to clean before ramp
    - MKQ already successfully tested, further optimization required
  - LHC: MKI wave length of nominal length

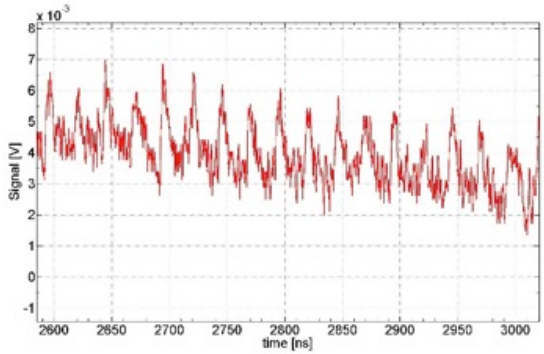
Loss signal on diamond detector at TDI with 144 b in IP2



5 ns – 200 MHz
SPS re-captured beam



25 ns - injected beam



F. Burkart
O. Stein

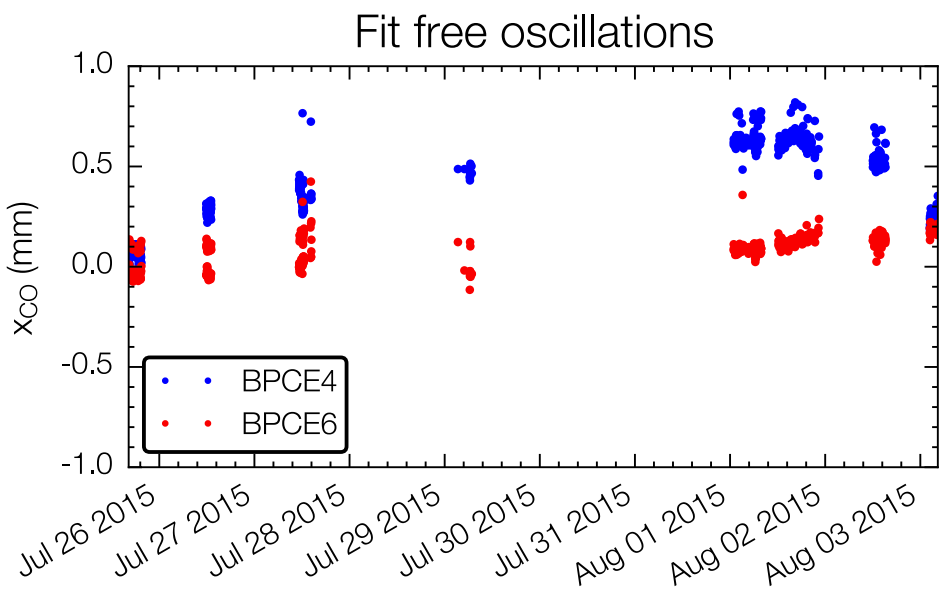
Required improvements in 2016 (3) - transfer line trajectory drifts

L. Drosdal, G. Le Godec

- Much improved shot-by-shot stability
  - Losses due to large transverse excursions almost gone in 2015
  - A lot more margin for drifts
  - Thanks to the effort from EPC on the power converter of the extraction septa shot-by-shot trajectory variations improved by factor 2

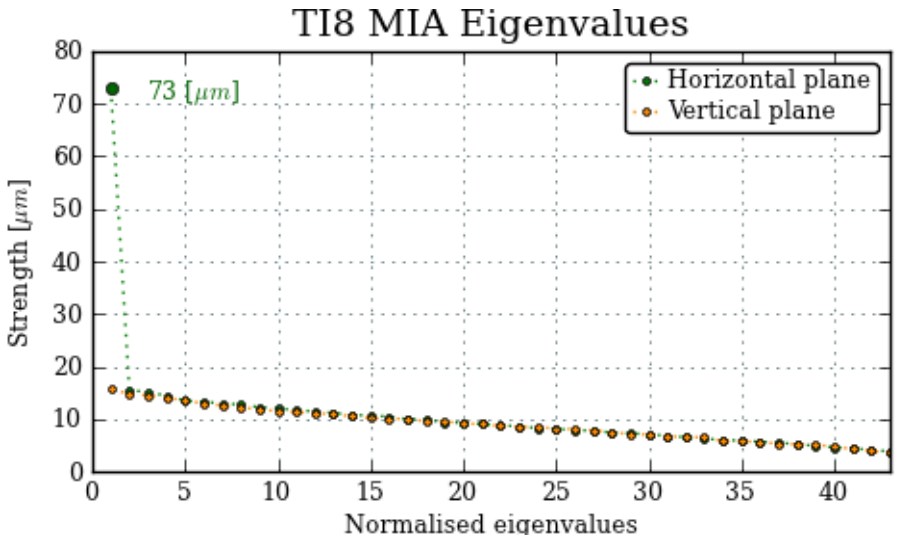
- Still SPS orbit drifts
  - ~ 0.5-1 mm in 3 - 5 days
  - Study to be continued

- Test of orbit correction with extraction bumpers

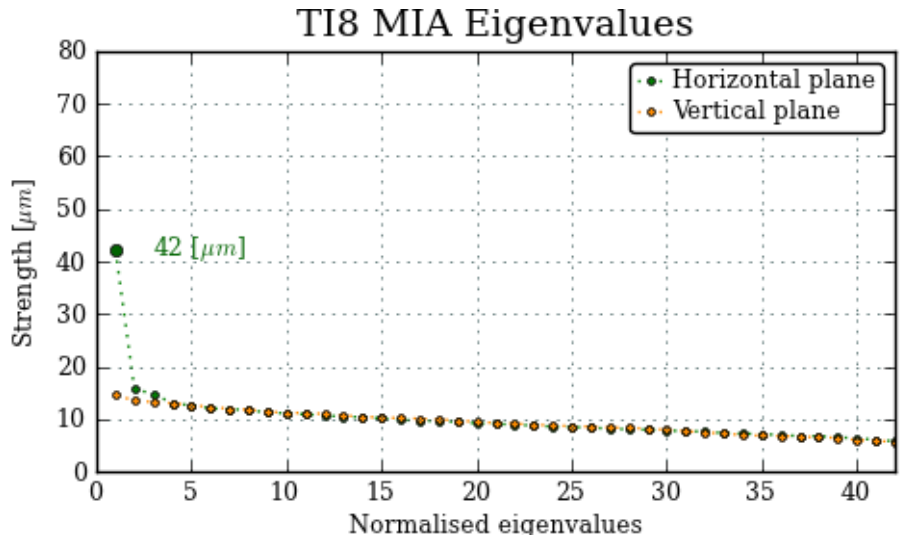


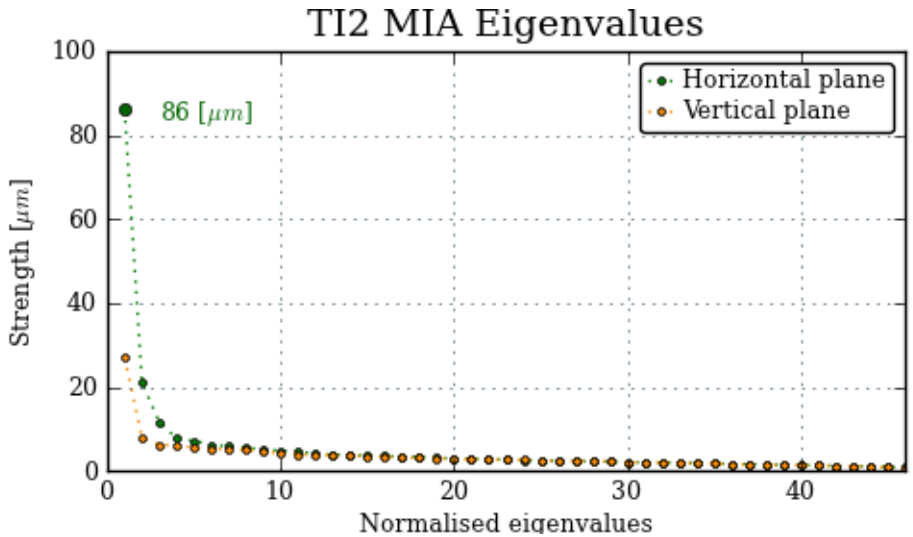
Reduction of shot-by-shot trajectory jitter

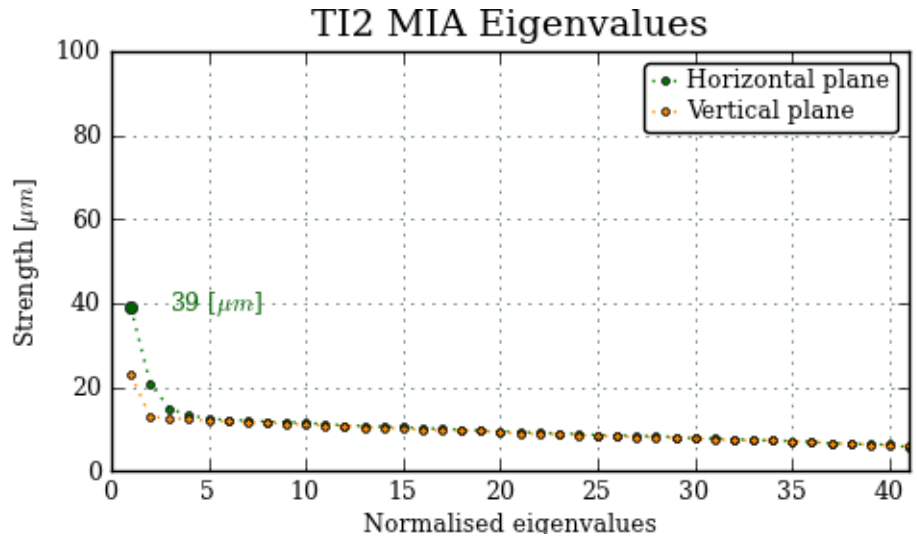
APRIL 2012



NOVEMBER 2014







A propos LHC dedicated filling

- Technically possible
  - No limitation from quality checks or other control system features
  - Need to add 1 BP after LHC cycle in the SPS (interleaved)

- Need to keep in mind:
  - Not only the time of filling; also time of setting up (30 minutes to 1 h)
  - Setting up and filling need to be done under the same conditions: SPS impact on beam parameters of magnetic history in super cycle
  - Dump TIDVG power limitation during setting up

- Should test it though!!
  - But: will not have an impact on 6-7 h most probable LHC turn-around time
  - Setting up time for LHC beams probably independent of duty cycle
    - Only filling might be faster
- Short-time NA experiments and parallel MDs will be heavily impacted.
  - Discussion needs to take place

Summary & Conclusion

- LHC 25ns operational beam 2015
  - 144 bunches, ~ 1.15×10^{11} p^+ per bunch, $\varepsilon \sim 2.5$ μm
  - Transmission up to 96 %
- 2016: 288 bunches: will be more challenging
  - Realistically aiming at ~ 1.2×10^{11} p^+ per bunch, $\varepsilon \sim 2.6$ μm

- Good transmission and brightness not reliably achieved or lower than expected: to be improved
  - Dynamic modification of SPS settings depending on intensity required
  - Reduced amount of un-captured beam, transverse tails
  - Improved damper performance
  - Tools, tools, tools (online beam quality tracking, SPS Quality Check (SPS QC))

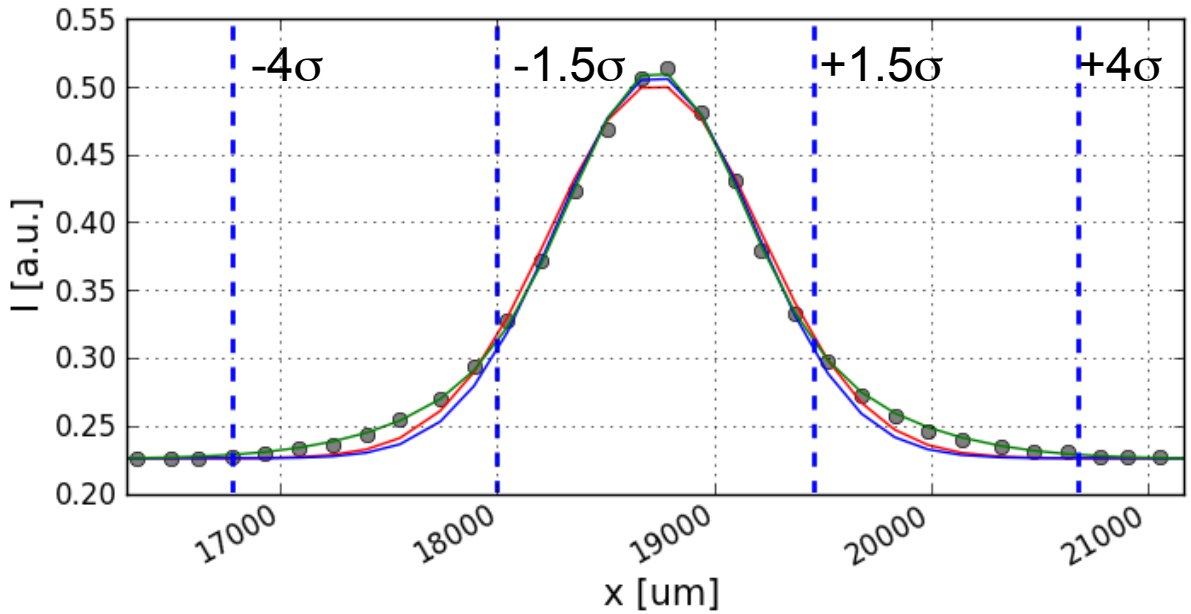
- Reliable performance relies on continuous tuning and setting up
  - Measurement possibilities with 288 bunches more and more limited

EXTRA SLIDES

Tail population nominal 25 ns: Results from MD on 23rd of September

- Measured population can be fitted with Double Gauss (green line)
- It is compared to Gauss fit of the core of the distribution (blue line)
- Tail population:

$$\frac{\int_{-4\sigma}^{-1.5\sigma}(\phi_{2Gauss}-\phi_{Gauss})+\int_{+1.5\sigma}^{+4\sigma}(\phi_{2Gauss}-\phi_{Gauss})}{\int_{-4\sigma}^{+4\sigma}\phi_{2Gauss}}$$



Why scraping? Results from MD on 23rd of September – Tail population vertical plane; no scraping

- Vertical plane: 4 to 6 % of beam in non-Gaussian tails
  - Not growing through cycle
- Consistent with measurements in the PS at flattop
  - Tails exist already in the PS
- Origin still to be understood
- Similar tails in H