SPS stability

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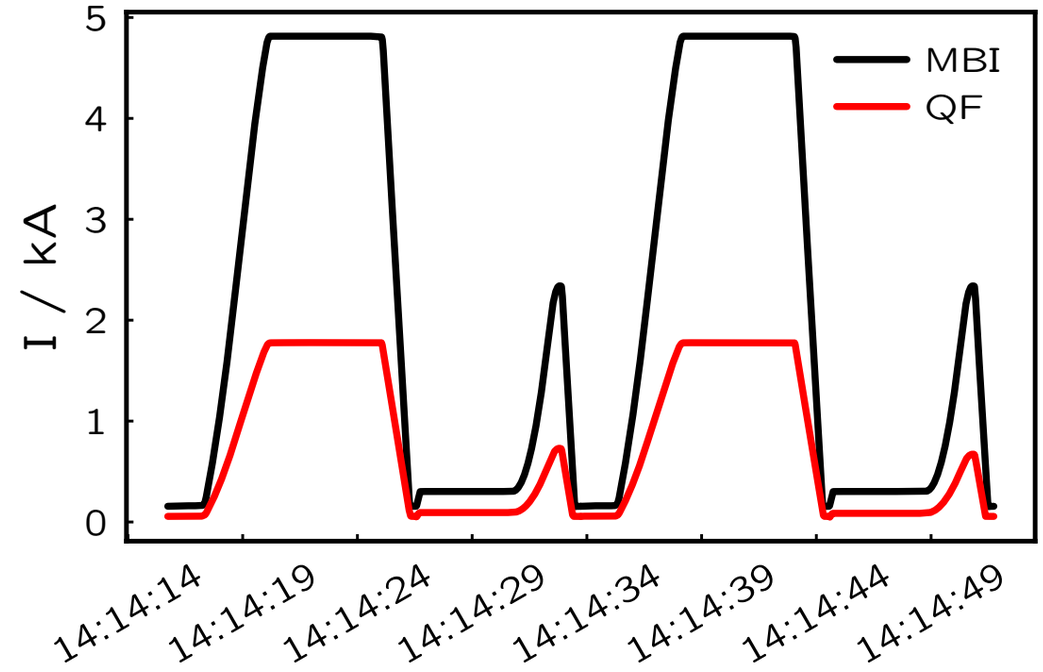
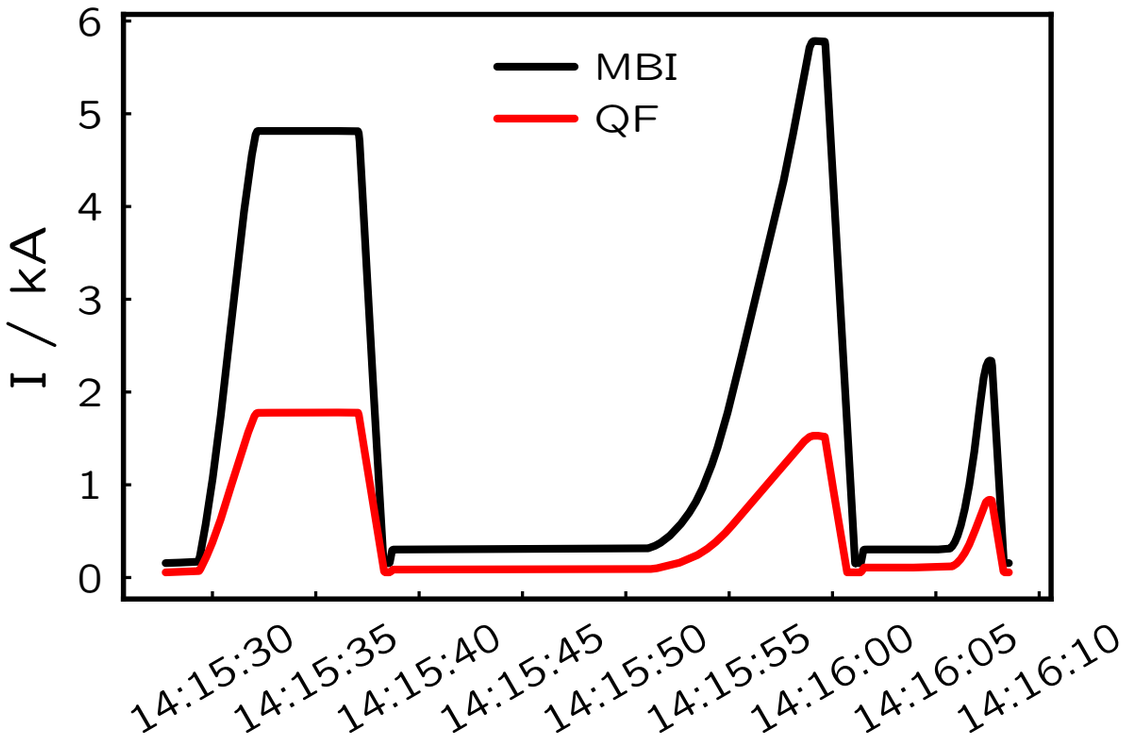
Outline

- Introduction
- Source of non-reproducibility
  - Shot to shot variations
  - Super Cycle changes
  - Long term drifts
- Energy and field stability
- Summary and outlook

Introduction

- Recall:
  - The SPS is a cycled machine
  - Different cycles (i.e. different max and min energy, different optics) compose the SPS Super Cycle (SC)
  - Depending on the users requirements, the SC changes quite often (even up to a few times per day…in bad days)





Introduction

- Three source of non-reproducibility have to be considered:

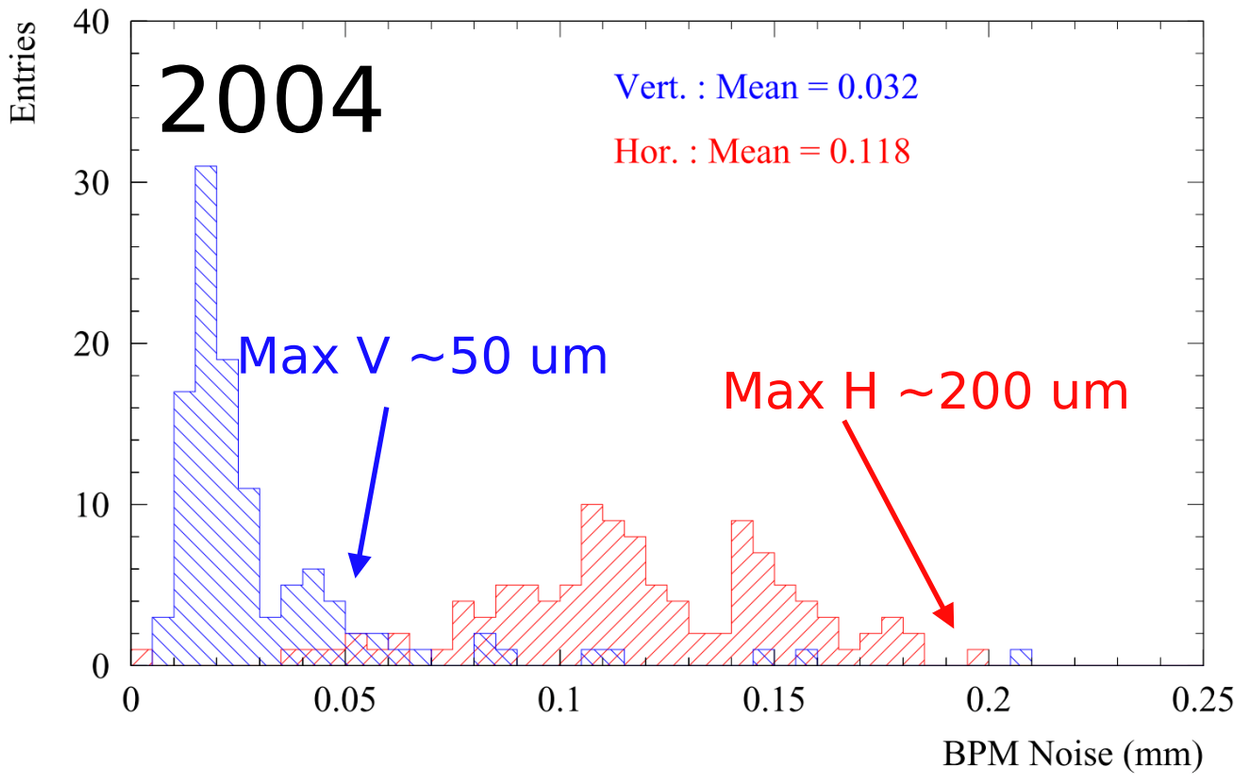
  - **Shot-to-shot variations** => originated by the intrinsic non-reproducibility of machine configuration (main magnets, instrumentation, PC, upstream machines…)

  - **SC changes** => different magnetic history in main magnets and currently no automatised way to compensate for that (work is ongoing on this front!)

  - **Long term drifts** => mainly observed on LHC beams (but no reasons why this should be a single characteristics of LHC beams…expected also on other cycles)

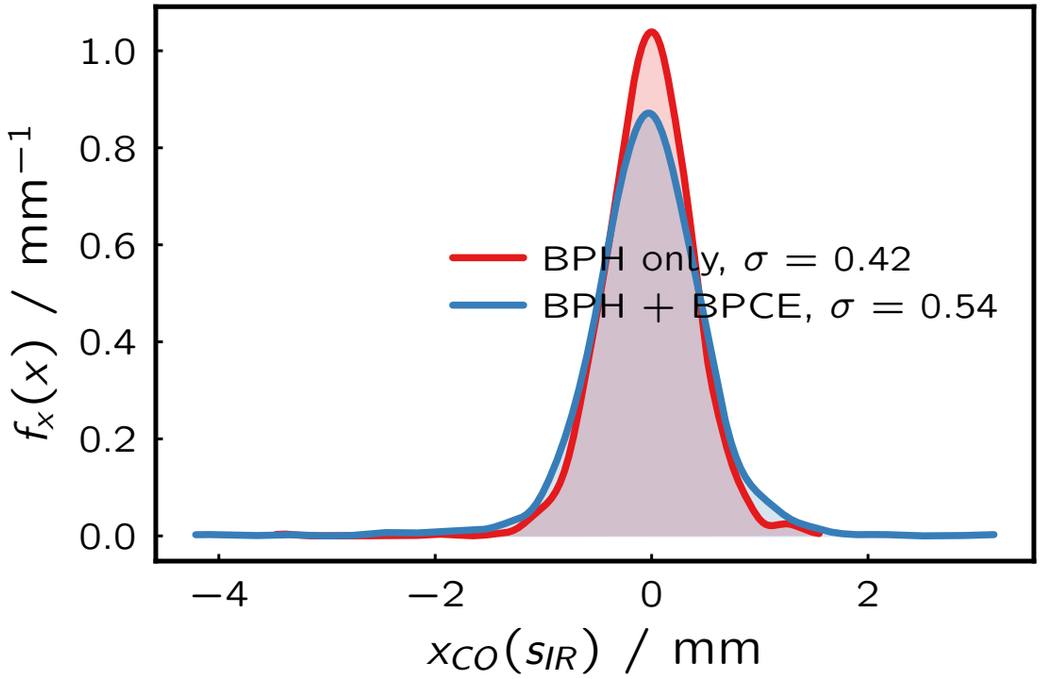
Shot-to-shot variations

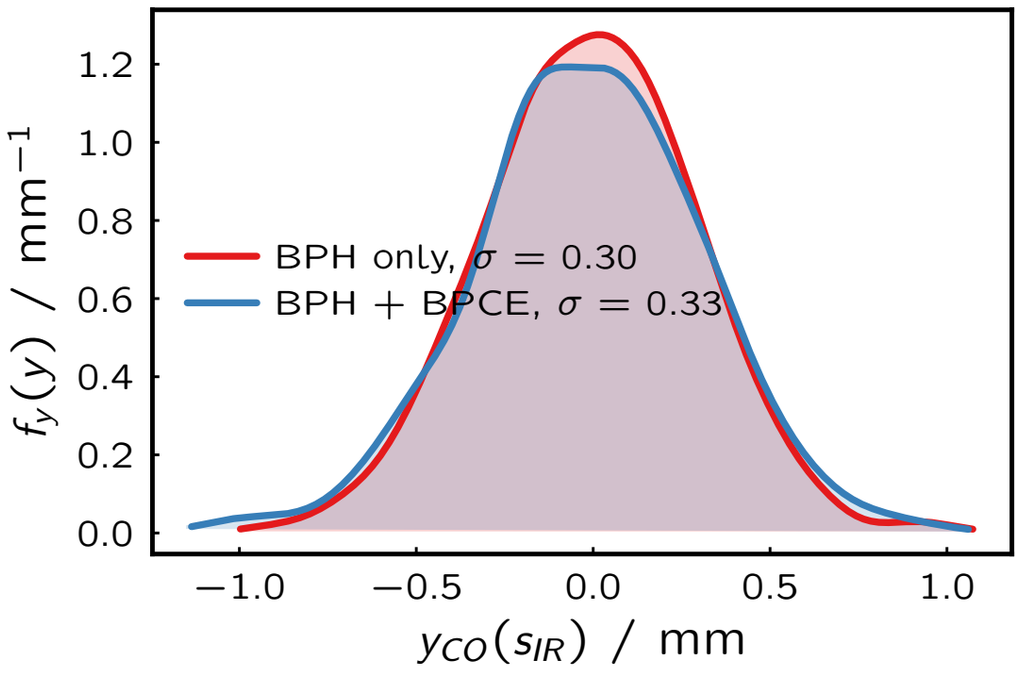
- From old measurements (2004), the SPS CO reproducibility, one cycle after the other, was observed (at max beta) to be ~200 um in H and ~50 um in V
- Beta-beating was estimated to be ~25% in H and ~10% in V
- Error in dispersion was measured to be about 10 cm (rms) wrt the model
  - **<u>At the IR this is in H = 160 um and in V = 34 um</u>**



Shot-to-shot variations

- On top of that, we should also consider that the machine is “moving” and ageing:
  - Relative alignment between BPM and quads => estimated to be 0.45 mm rms also in agreement with 2004 data
  - Quadrupoles are moved as the SPS orbit at high energy cannot be corrected with CODs => beam based quad alignment done during re-commissioning every year
  - BPM electronics is ageing, hence different gains almost every year => impact on the best CO correction
- Considering these sources of error when correcting for a “normal” SPS CO (rms ~2 mm) we get the following results:



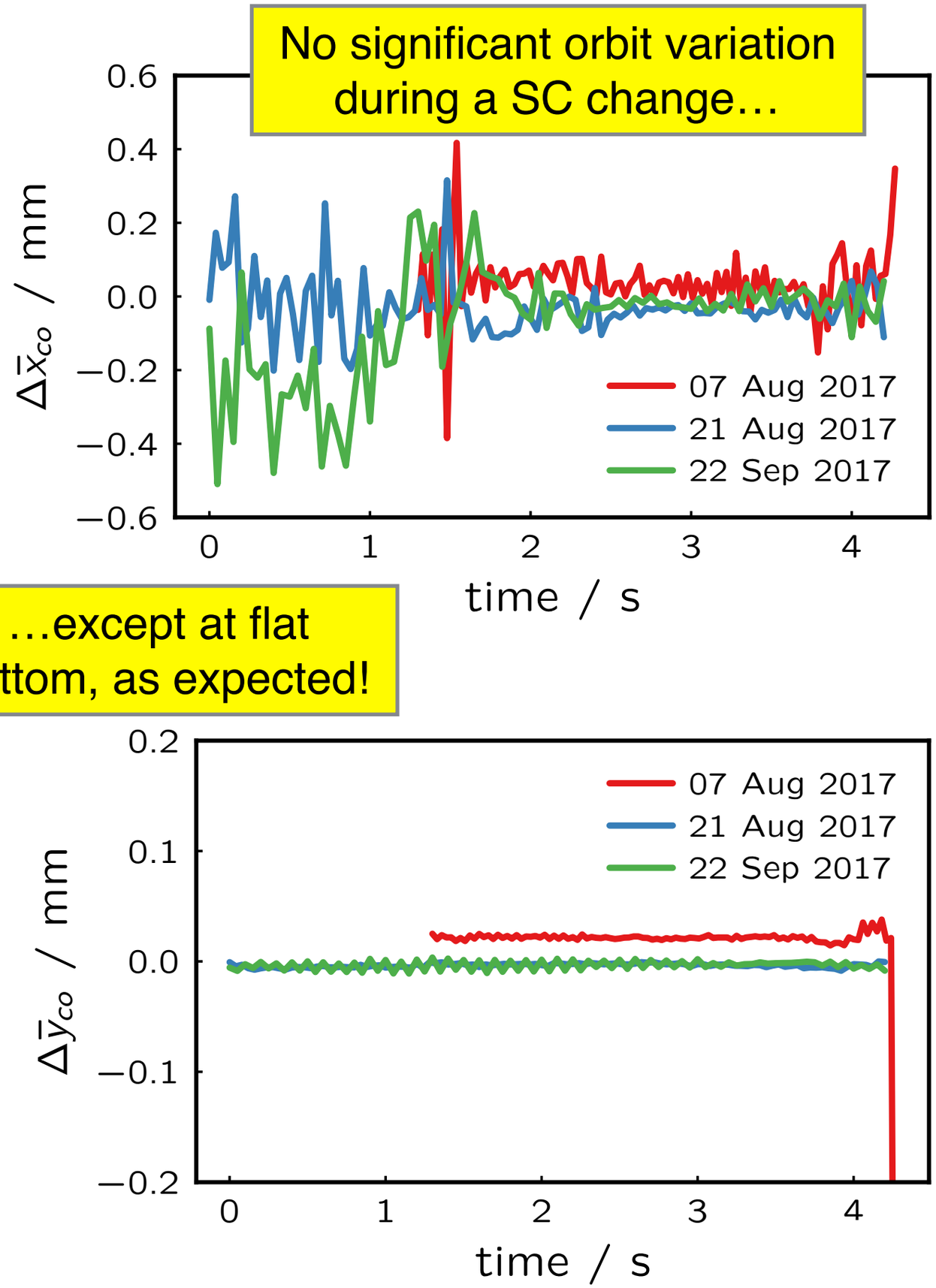


- Combining these and the previous data of CO stability, we get to => **CO_X = 0.45 mm, CO_Y = 0.30 mm**

Super cycle changes effect on SFTPRO (400 GeV)

- One of the most recurrent SC change is from Fixed Target (FT) production SC (=> 2 FT cycle and 2 MD cycles) to LHC filling SC (=> 1 FT + LHC + 1 MD)

- Tune and orbit all along the FT cycle have been measured before and after the SC changes
  - No significant orbit changes as radial loop on…



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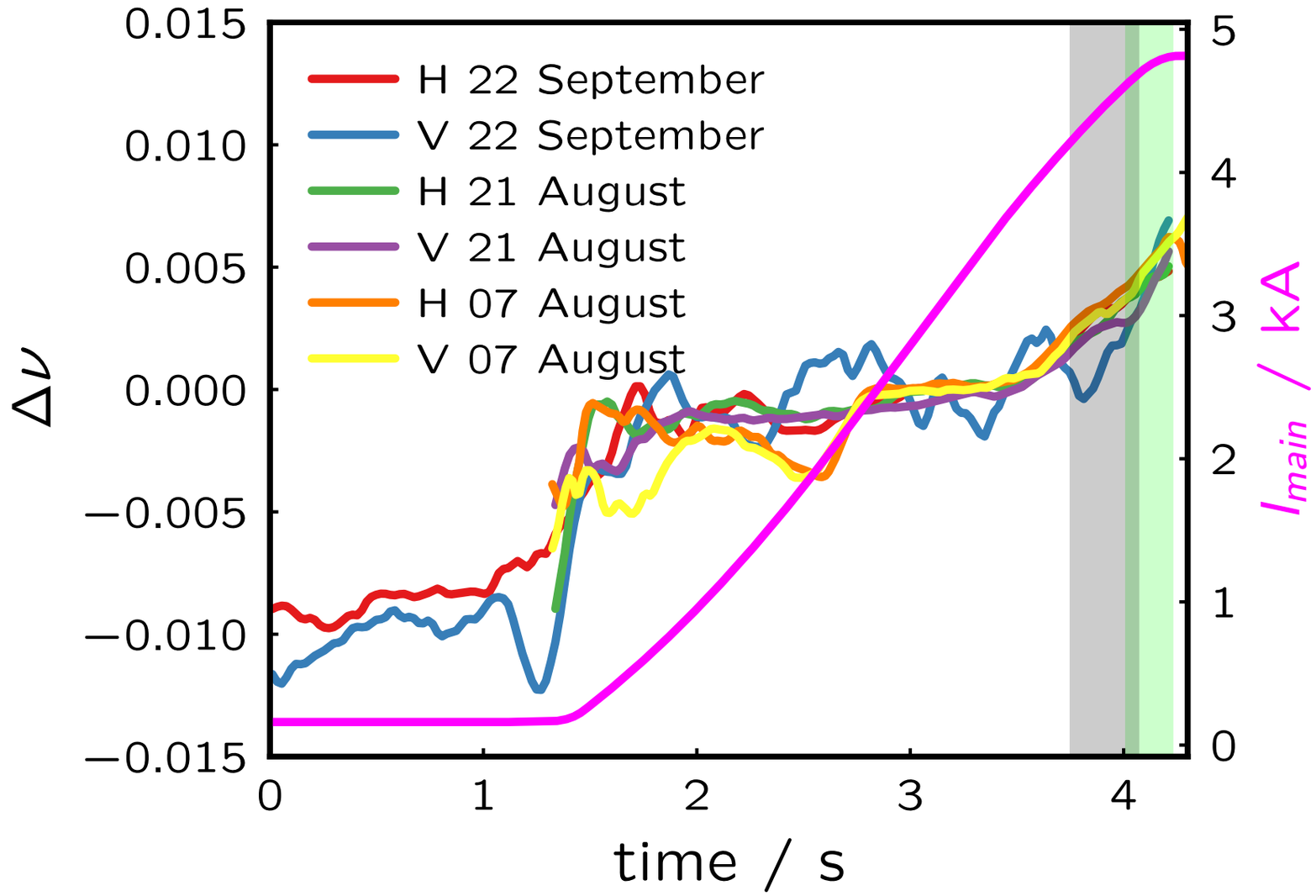
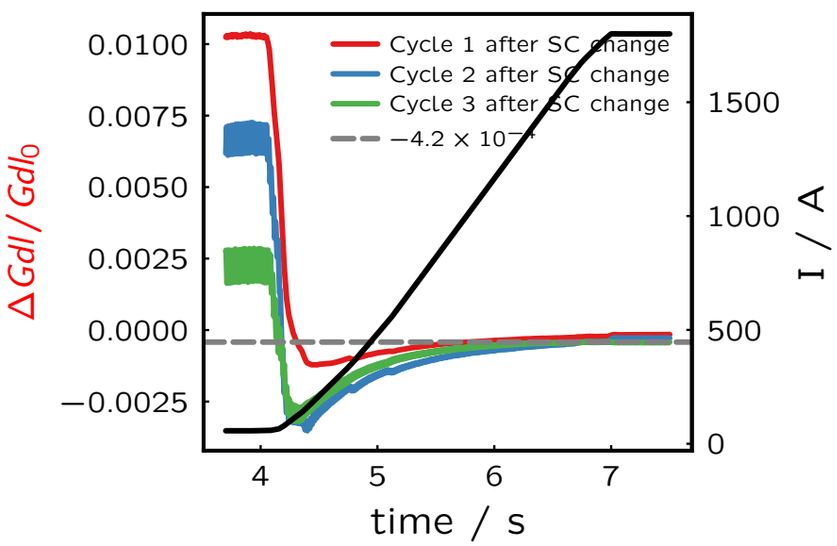


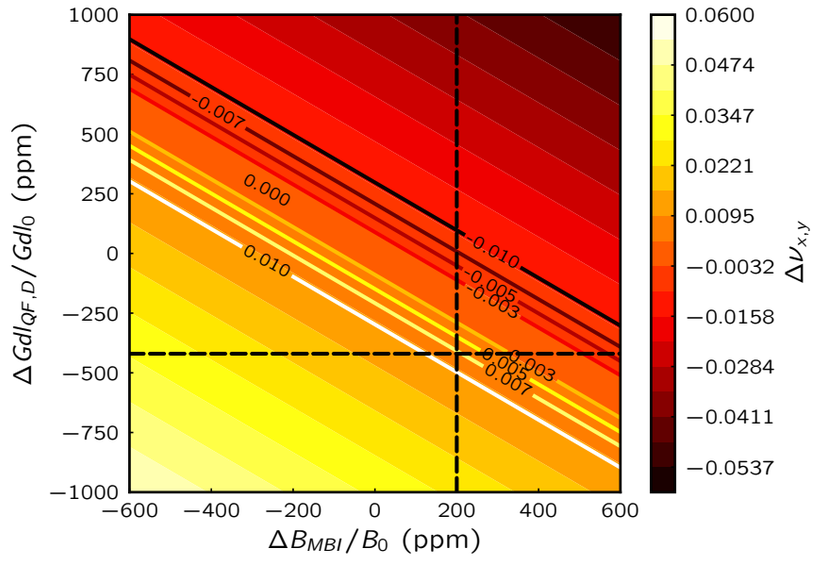
The tune variation observed are basically the same on all 3 days of the measurements, as well as the same variation is observed in both H and V

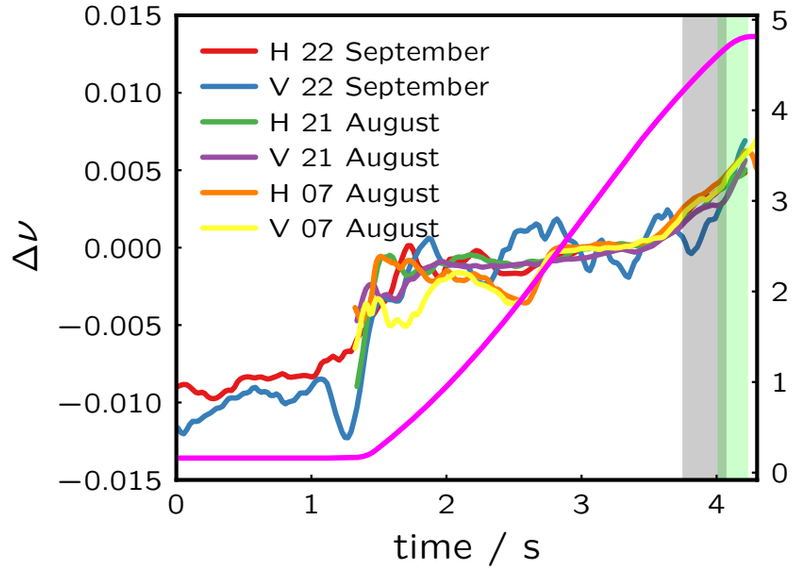
Super cycle changes effect on SFTPRO (400 GeV)

- No negligible effect on main beam parameters from SC changes (didn't show here chroma changes…)
- Work is ongoing to try to automatise the correction => sources seems to be well understood but instrumentation to online correct for it still need to be developed, together with all the SW
- Investigation ongoing to have online available NMR measurements for MBI
  - Investigation ongoing to realise synthetic Q-train (based on ML) => if not working, possibility to install spare magnet for QF/D as done for MBI for field measurements online

Measured quad field change → **Tune change expected** → **Tune change measured**

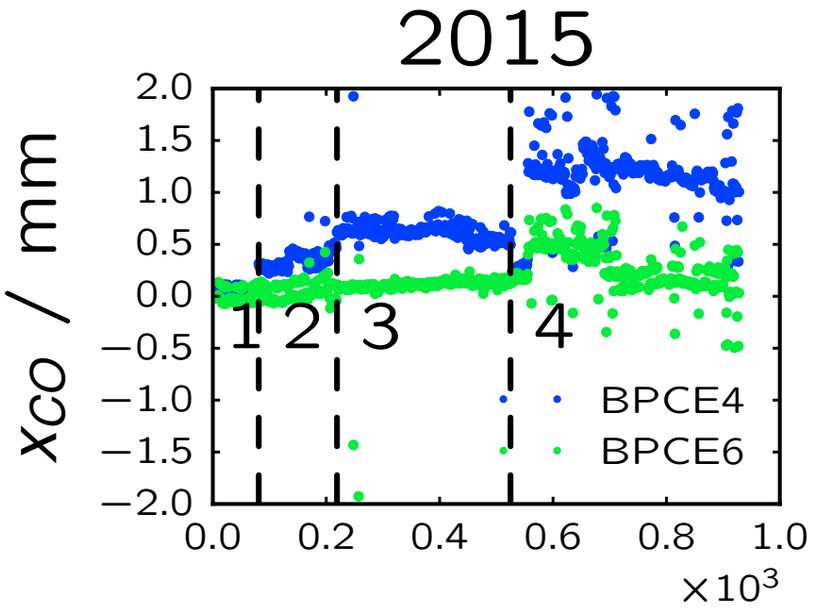


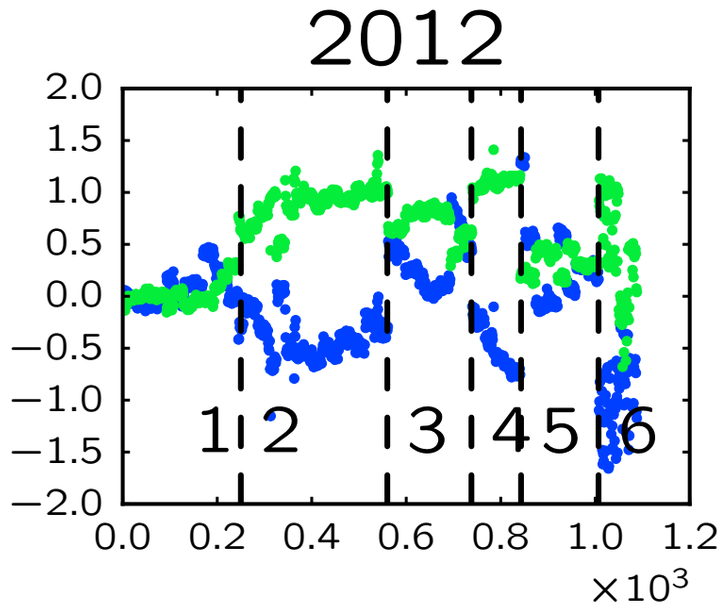


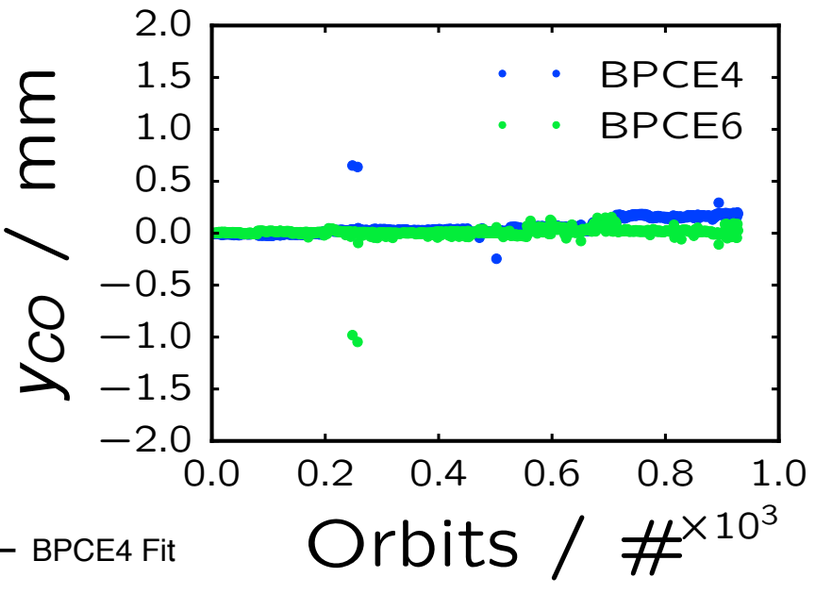


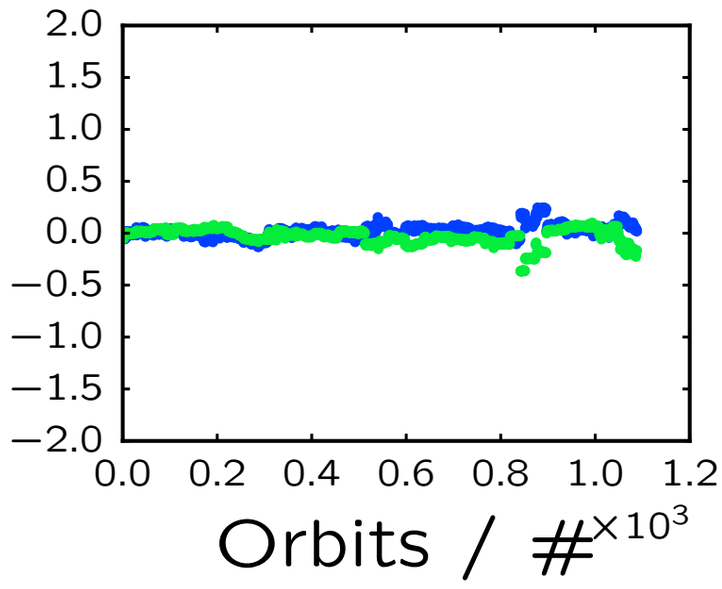
Overview of the orbits

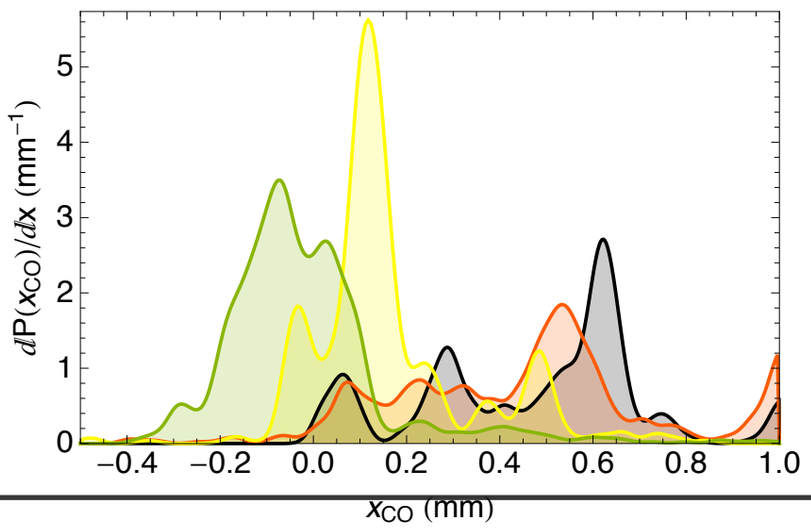
- An horizontal orbit drift, mainly at the BPCE4, can be observed in 2015 set
  - In the 2012 set the drift is about the same in both LSS4 and LSS6
- Basically no change observed on the vertical plane
- <u>The source of these drifts is not fully understood yet</u>
  - <u>Time scale of days so this should not be a problem for the PoP!</u>





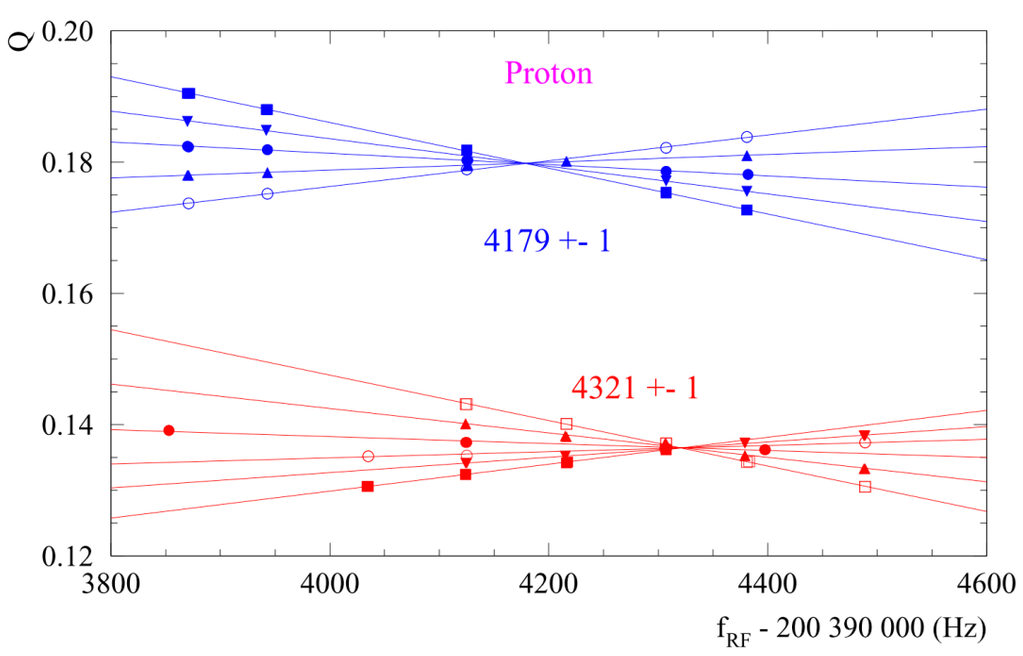


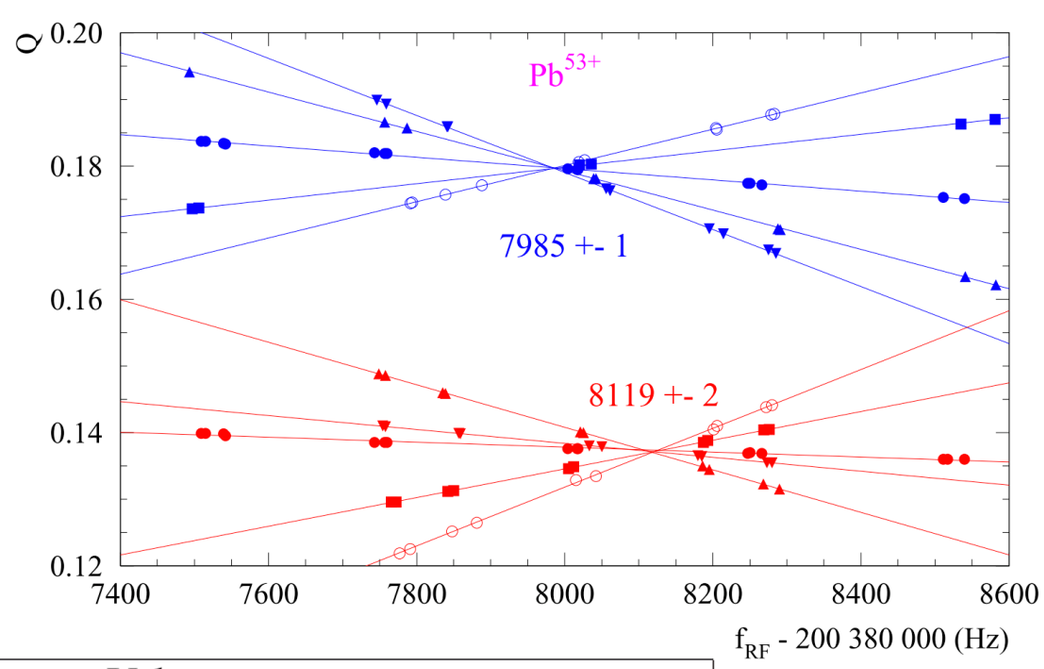




Energy and field stability

- Absolute measurements of beam momentum on synchrotron is not a simple task
  - A way to do this is to use 2 ion species, injected in the same magnetic machine, and measuring the delta in revolution frequency (or RF frequency as h is known), the absolute momentum of the beam can then be computed. Details in [G. Arduini et al.]
- This was done in 2002 [G. Arduini et al.] where Pb53+ and p were used to compute the absolute momentum of the beam to be used for the LHC (450 GeV settings)
  - These measurements relay on two main points:
    - Large difference between the f_{RF} for the two species chosen (that's the reason to use Pb53+ and not fully stripped)
    - Exactly the same machine configuration magnetically - for this also the PS had to be adapted to allow such a measurement as usually different injection energy (proton equivalent) between Pb and p

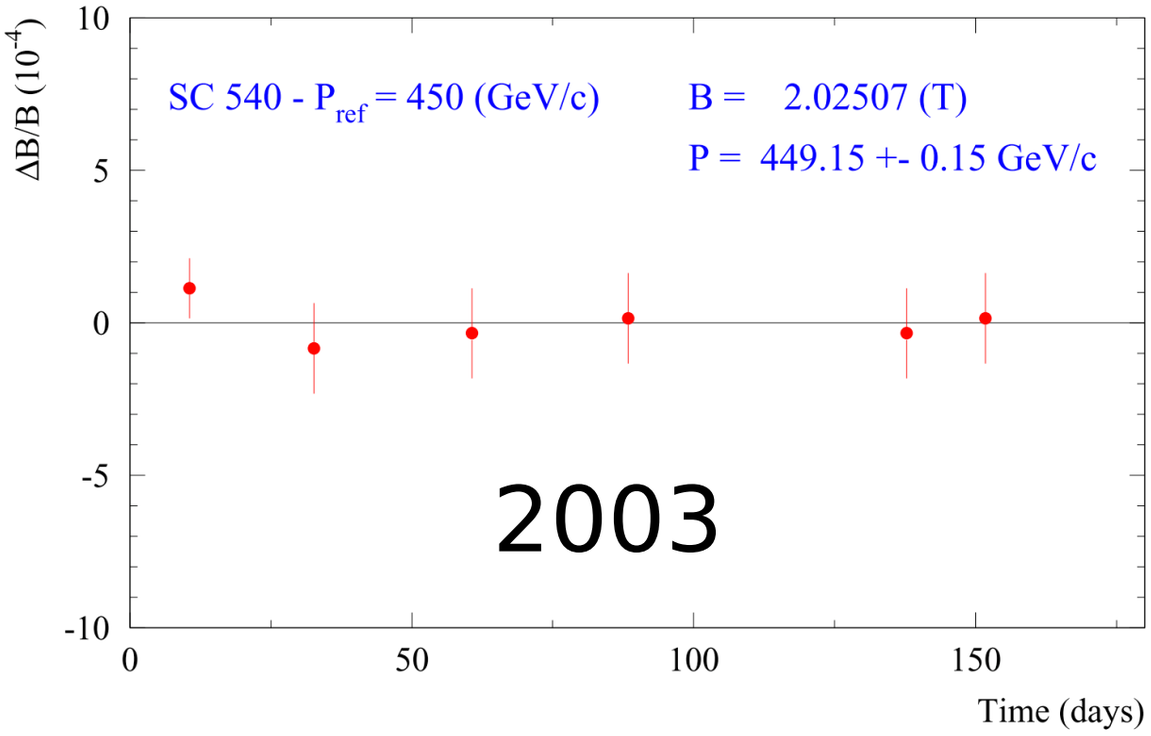


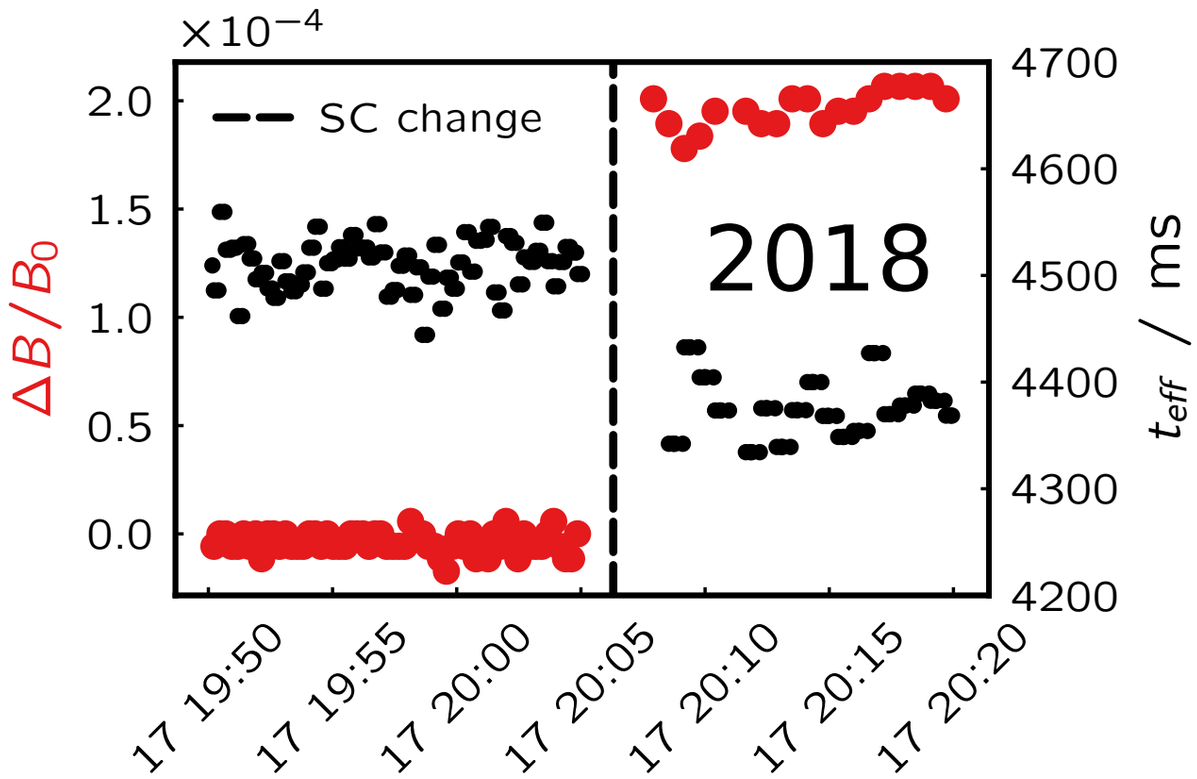


Parameter	Value		
	Horizontal plane	Vertical plane	Difference
Proton momentum P (GeV/c)	449.265 ± 0.057	449.044 ± 0.098	0.221 ± 0.113
Central orbit length C (mm)	$6'911'568.62 \pm 0.04$	$6'911'563.78 \pm 0.04$	4.84 ± 0.05

Energy and field stability

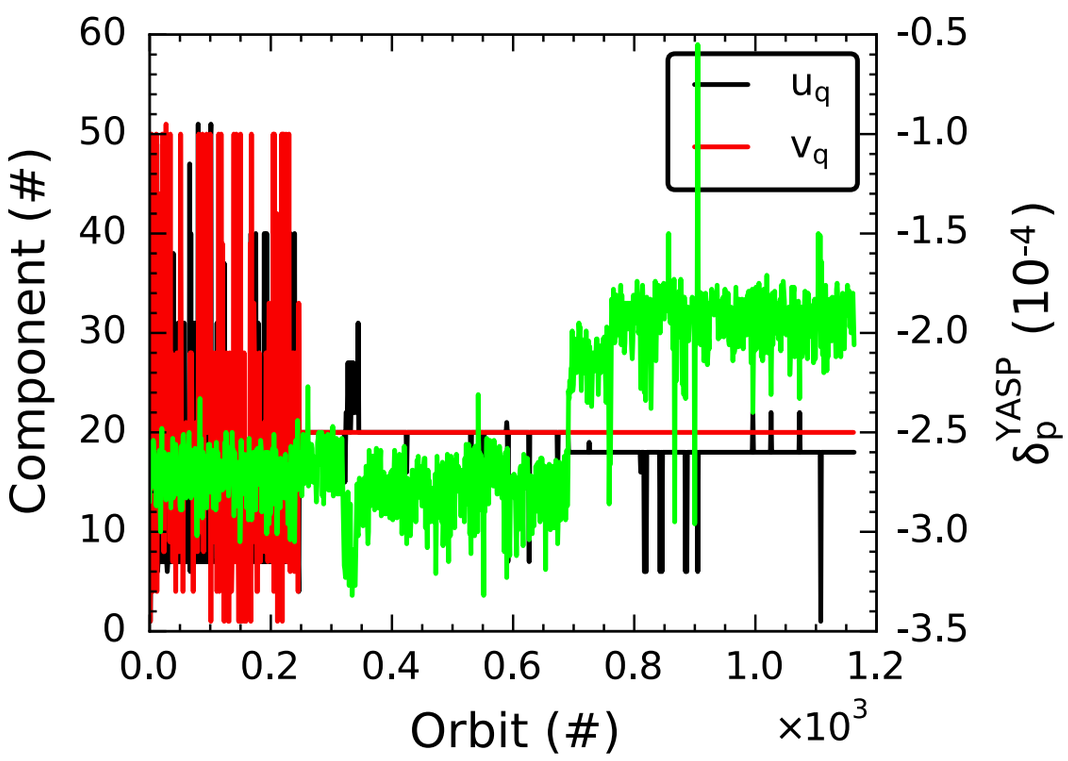
- SPS magnetic stability was measured in 2003 [J. Wenninger] using NMR at 450 GeV
- In 2018, using only the B-train (non-calibrated measurements as no NMR field marker available), ~2e-4 variation was observed following a SC change
  - Jitter shot to shot ~ 1e-5

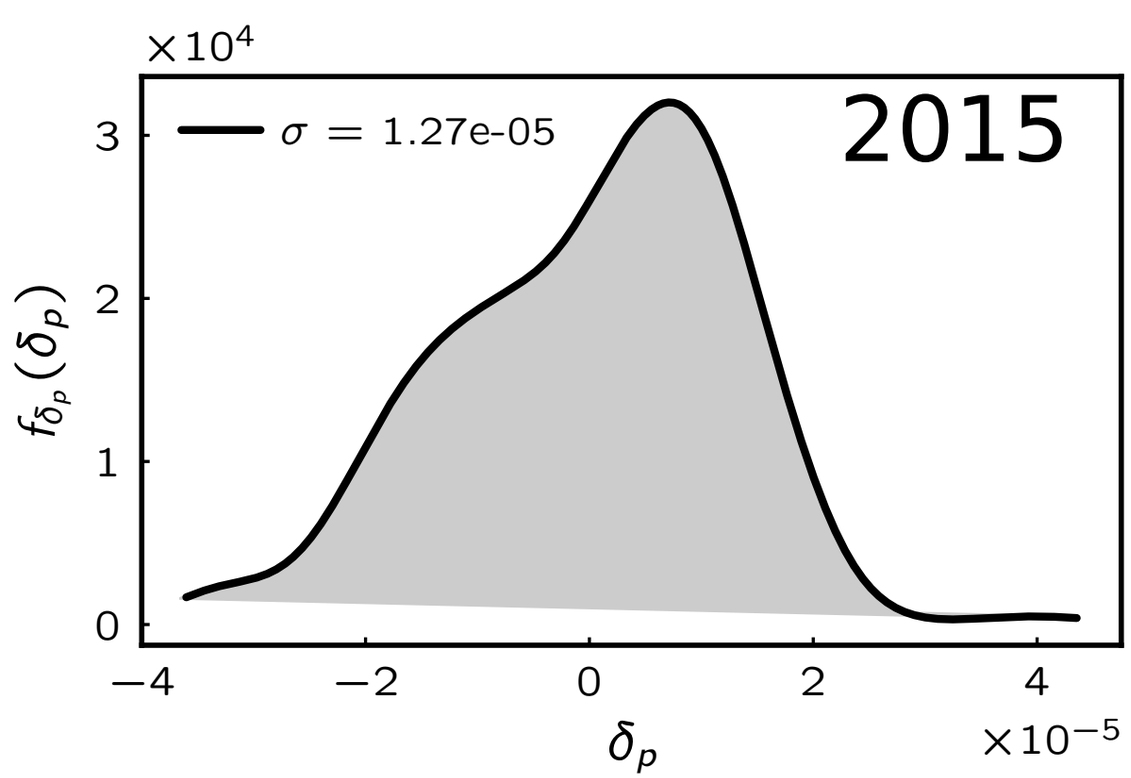




Energy and field stability

- Using the LHC beam at 450 GeV, CO measurements were recorded for long periods to study long term drifts and stability
- Also in this case, the shot-to-shot fluctuation observed is ~1e-5 (rms) in short periods
- Otherwise, including SC changes and other source of drifts, this in the order of 2 x10^{-4}





Summary and outlook

- Many measurements over the years have been performed looking at the SPS stability and reproducibility

- A significant effort is in place to fully understand the sources and propose solutions

  - Mainly looking at LHC and SFTPRO beams as most sensitive to these changes

- For Gamma Factory PoP:

  - Combining the StS variation in CO (betatronic) and the StS in energy (or field, **(d_p = 1.5e-4)**), the position jitter expected at the IR is:

  - **CO_X = sqrt(0.45**2 + 0.37**2) = 0.58 mm, CO_Y = 0.30 mm**

- Studies are ongoing to try to put in place automatic correction for SC changes => aim to start testing corrections at restart in 2021

  - Absolute energy measurements could be attempted again - it needs significant planning as cycle across machines need to be prepared and time needs to be allocated to obtain the required statistics

  - Investigation is ongoing to evaluate the possibility to have absolute field measurements available online with high accuracy => very challenging as for now the NMR used couldn't go below ~1e-4 accuracy!