IPAC23, Venezia, 9 May 2023

Experimental confirmation of the impedance reduction campaign in the CERN SPS

T. Argyropoulos, G. Papotti,
H. Damerau, A. Lasheen, I. Karpov
CERN, Geneva, Switzerland

Acknowledgements: J. Varela, C. Völlinger, A. Farricker, J. Perez Espinos, C. Pasquino, T. Bohl, E. Shaposhnikova

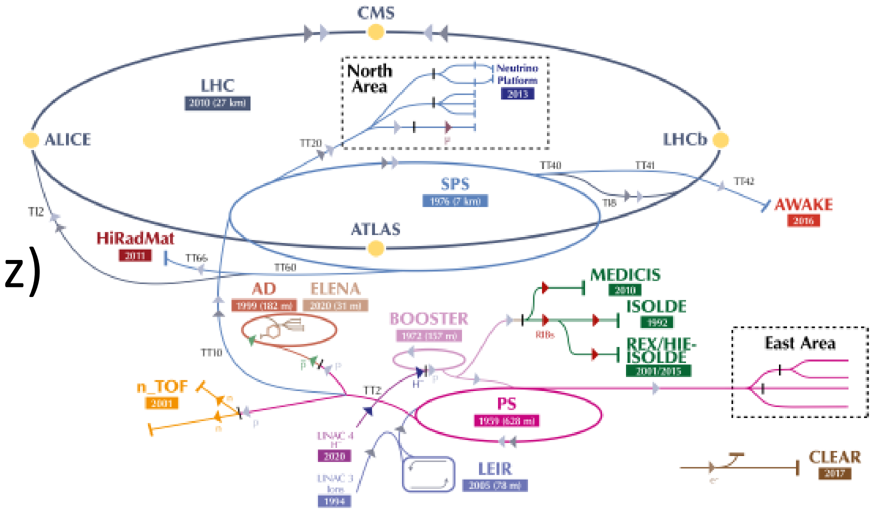
introduction

- Super Proton Synchrotron (SPS) is the second largest CERN accelerator
  - LHC injector, fixed target program in North Area, AWAKE, HiRadMat
- LHC Injector Upgrade (LIU) project to provide high brightness beams to LHC upgrade (High Luminosity LHC project)

M. Meddahi, MOXD1

O. Brüning, TUYG1

- LIU-SPS had limitations by total RF power and longitudinal instabilities, so project included:
  - reorganisation of main accelerating structures (200 MHz)
  - RF power upgrade: added 2x 1.6 MW
  - new digital LLRF
  - impedance reduction campaign

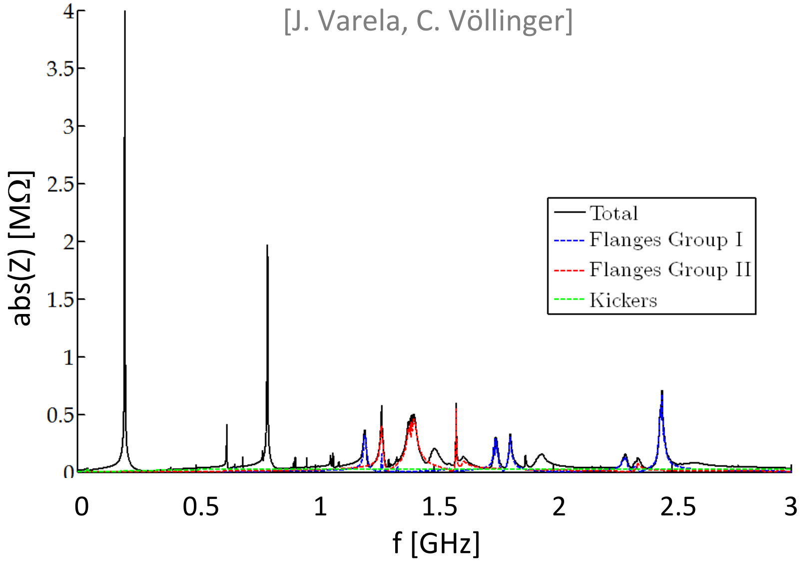


impedance reduction campaign

- 1.4 GHz resonance from vacuum flanges identified as main driver of longitudinal instability
  - microwave instability observed in 2012
    - in fact, mode coupling instability
  - impedance identification in 2012-2013
    - searched for elements that could cause that resonance
- 97 locations shielded during Long Shutdown (2019-2020)
  - shielding of vacuum flanges next to main bends, and attached bellows

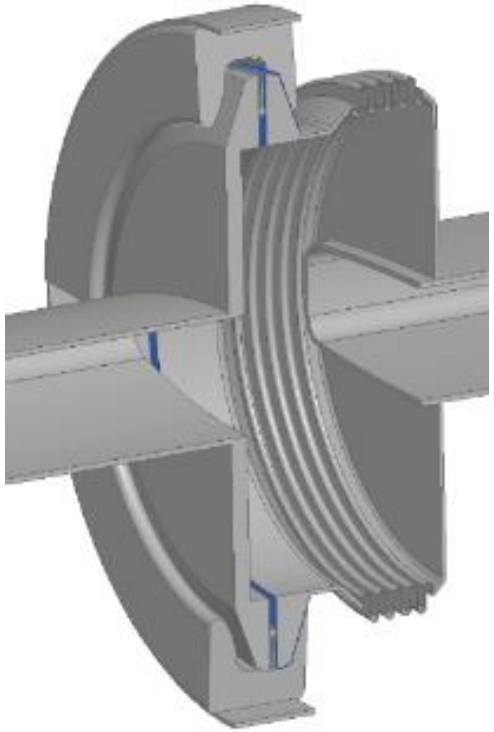
SPS impedance model until 2018

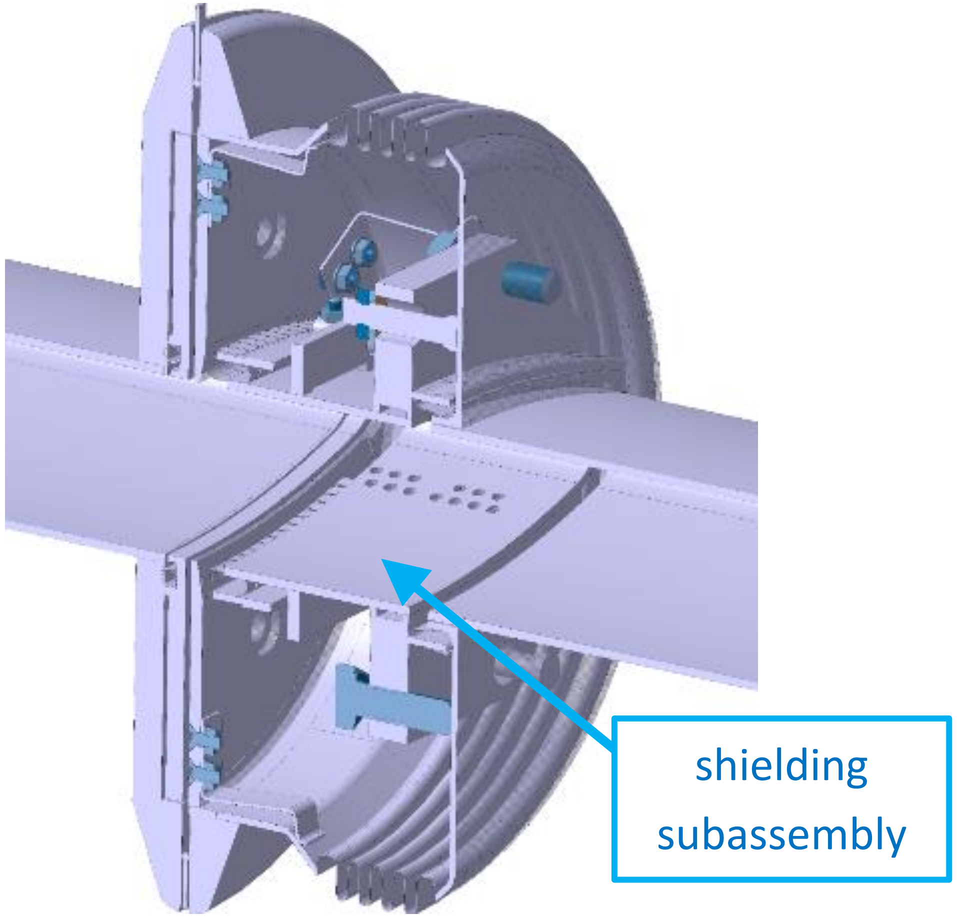
[J. Varela, C. Völlinger]



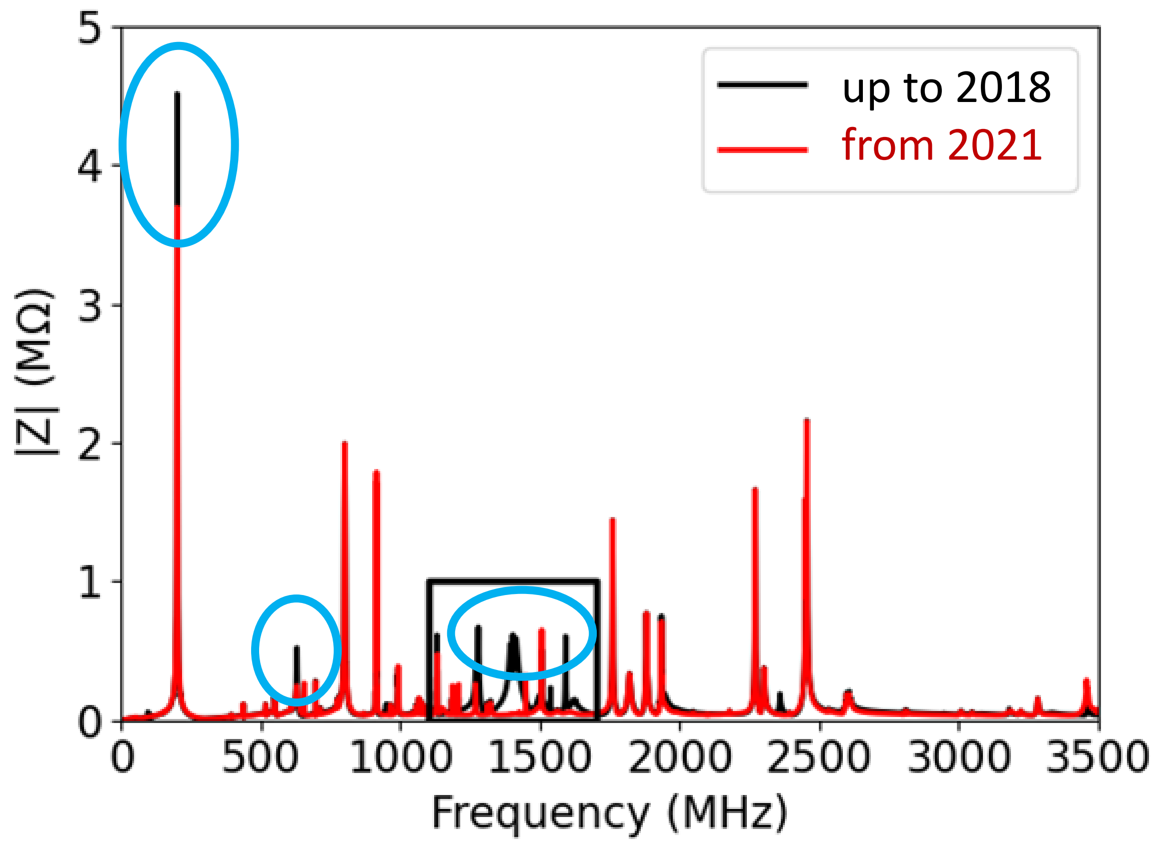
- note: latest leg of impedance reduction campaigns
  - e.g. 800 inter-magnet pumping ports shielded in 2000-2001

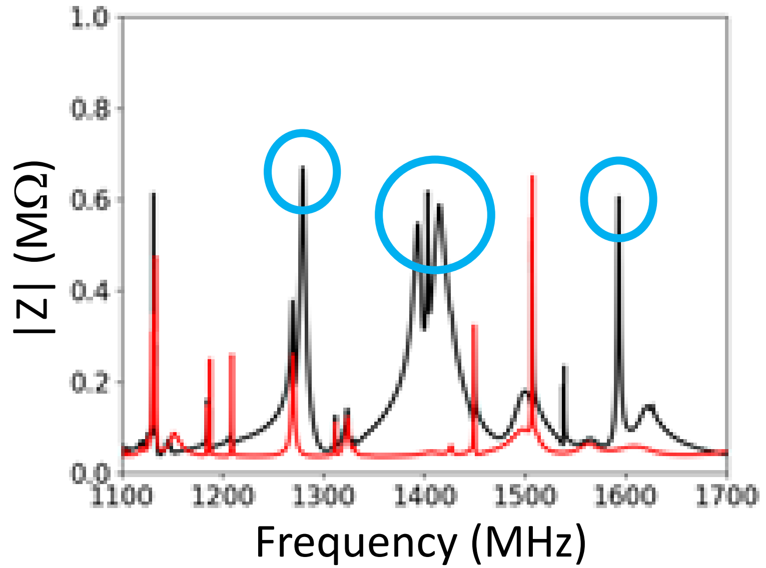
vacuum flanges: before and after





SPS impedance model: before and after





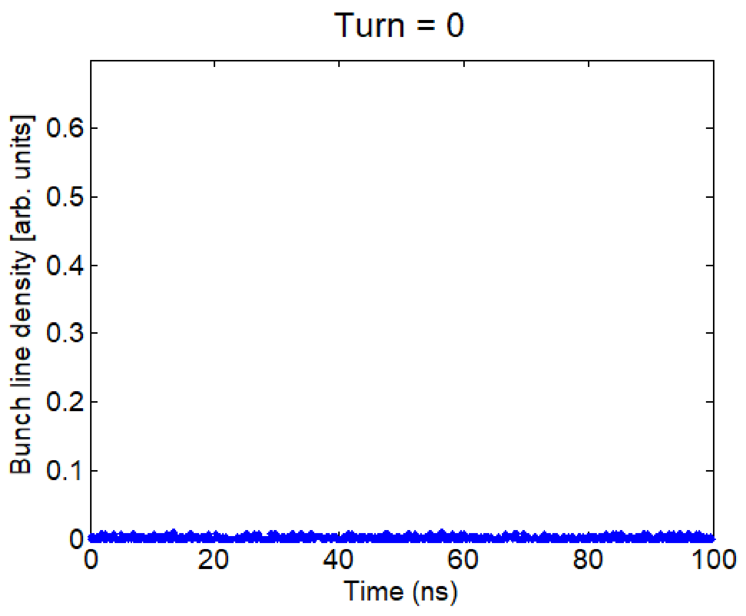
- reduction at 1.4 GHz thanks to shielding of vacuum flanges
- note also
  - decrease of impedance of main 200 MHz travelling wave RF system
  - decrease in 630 MHz High-Order Mode (HOM)

outline

- introduction
  - impedance reduction campaign
- setup of beam measurement
- results of beam measurements
  - before (2012, 2013, 2018), after (2021), and comparisons
- conclusions

measurement setup

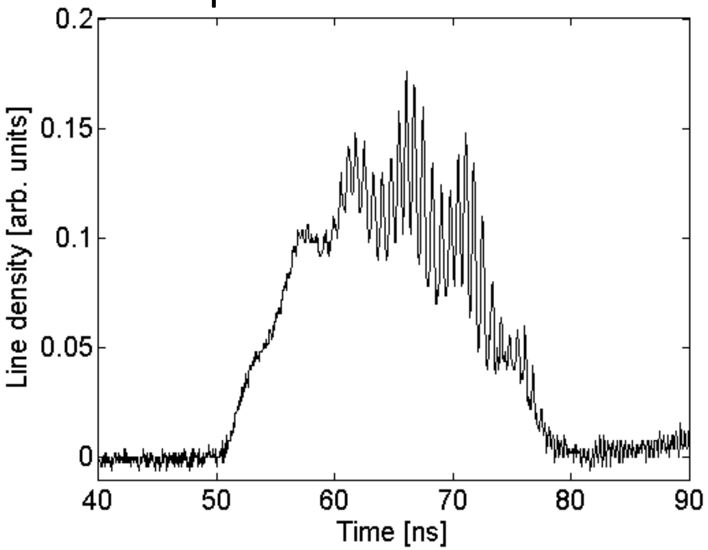
- well established measurement method [5] (1997)
- performed at injection energy (p = 26 GeV/c)
- let the beam slowly debunch with no applied RF voltage
  - particle motion affected by induced voltage only
  - line density modulated by high frequency impedance sources
    - f_{res} > 1 GHz for bunch lengths of the order of ns
- bunch parameters
  - long bunches and small momentum spread dp/p
    - for slow debunching, slow instability, and improved frequency resolution
    - 4σ length: 25-35 ns, to be compared to 5 ns buckets
      - longitudinal emittances of $\varepsilon_l \sim$ 0.23- 0.30 eVs
  - spread of bunch intensities to determine instability threshold
    - $0.5\times10^{11} - 4.5\times10^{11}$ protons
- measurements verified in two optics (SPS Q20 and Q26)
  - different slip factor, different instability threshold



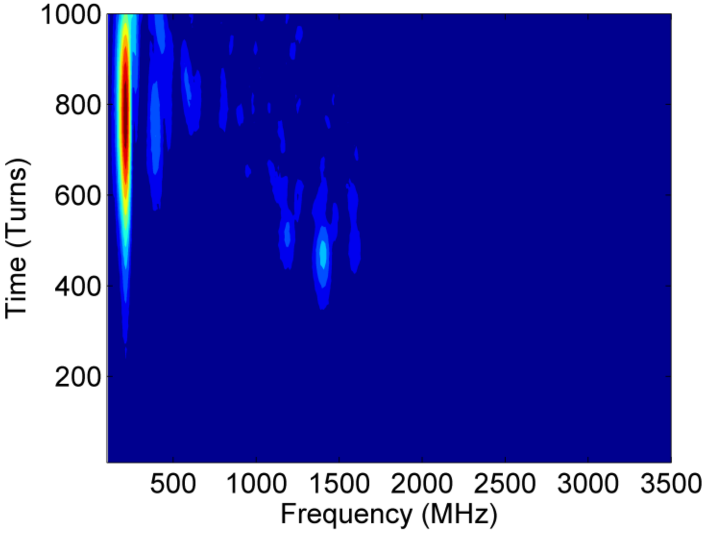
measurement and analysis example

- longitudinal profiles acquired over hundreds of turns
- spectrum calculated to look at frequency content, per turn
- maximum per frequency of all acquired turns to derive “mode amplitude”

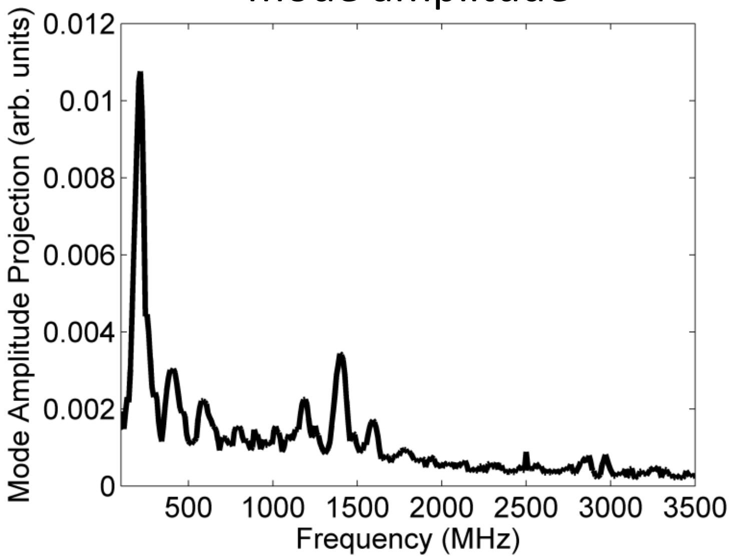
profile at turn 460



spectrum per turn

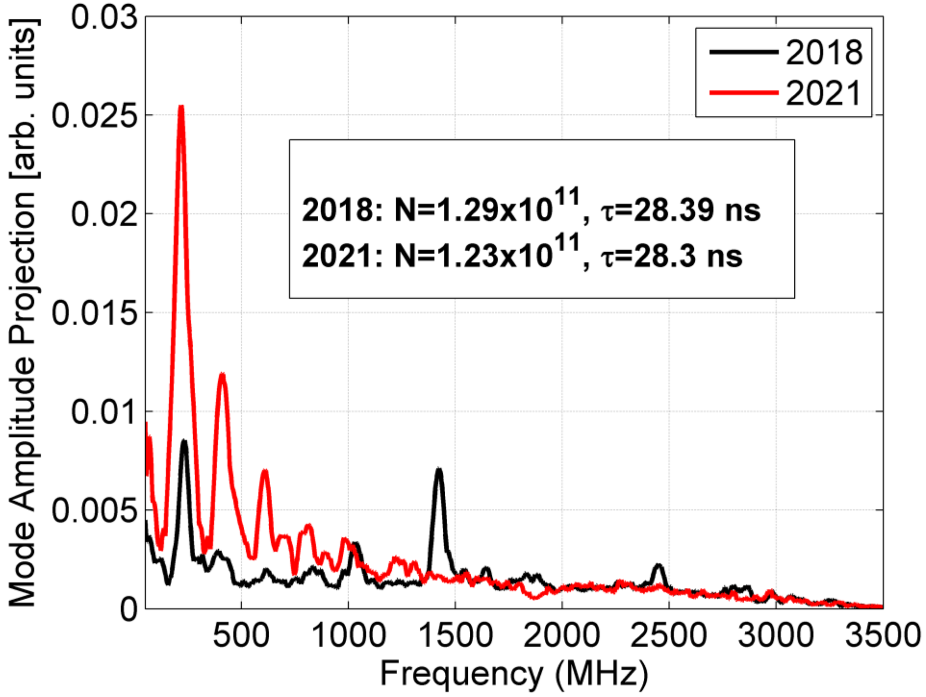


mode amplitude



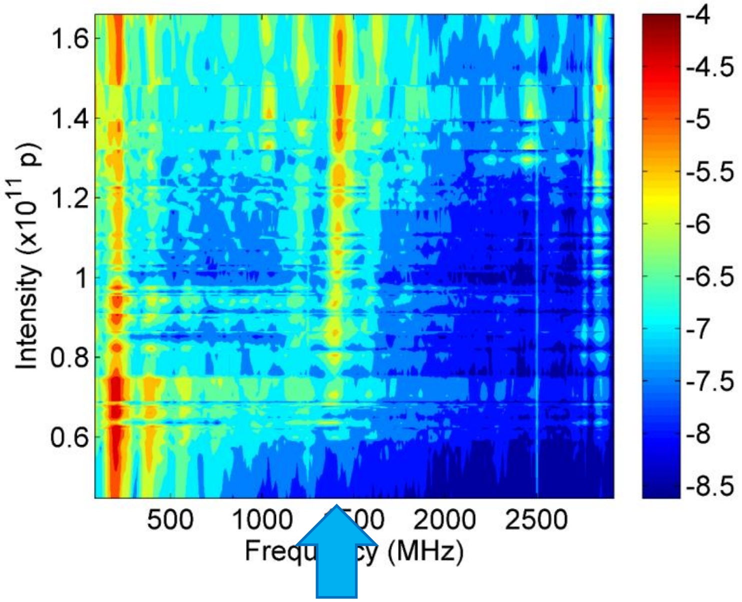
measurement before and after shielding

- similar beam parameters
  - 2018 before shielding
  - 2021 after shielding
- suppression of the 1.4 GHz peak in 2021
- bunch mainly modulated by the 200 MHz impedance
  - 200 MHz impedance reduced by shortening and reconfiguring accelerating structures



mode amplitude projection for all campaigns

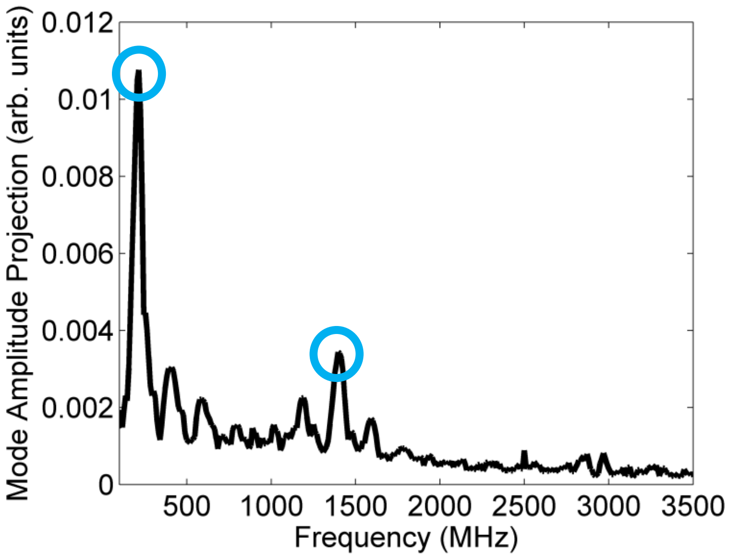
2012

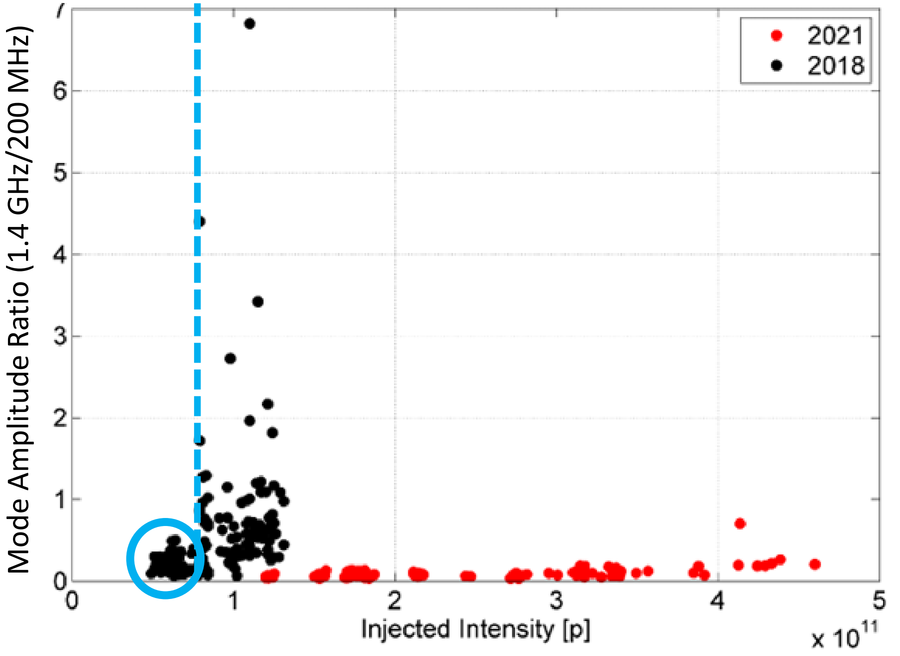


- combine mode amplitude measurements with different bunch intensities into single plot
  - per year
- observe lines at 1.4 GHz:
  - strong peak at 1.4 GHz visible in 2012 and 2018
  - no peak at 1.4 GHz visible in 2021

instability threshold

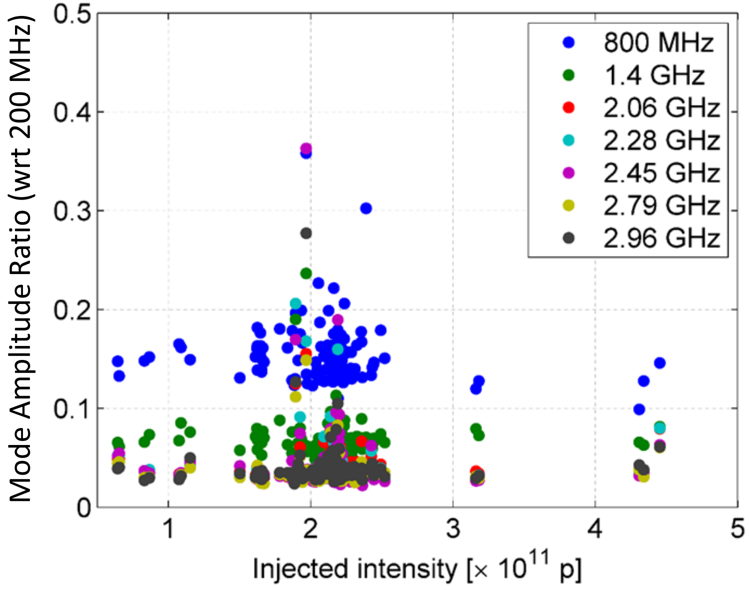
- derive mode amplitude ratio
  - ratio between mode peak at 1.4 GHz and 200 MHz in mode amplitude projection
    - i.e. refer to the 200 MHz, as is well known reference
  - and combine measurements with different intensities
- instability threshold identified by abrupt increase in mode amplitude ratio (ratio of impedance peaks)
  - before (2012 and 2018): threshold = 0.8×10^{11} p (in SPS Q26 optics, 1.5×10^{11} p in Q20)
  - after (2021): no unstable mode at 1.4 GHz observed





other impedances

- mode amplitude ratio of other major SPS impedances with respect to 200 MHz mode amplitude
- 800 MHz (4th harmonic RF system) becomes most prominent
  - ratio remains well below one, indicating that debunching is mainly driven by 200 MHz RF cavity impedance



conclusions

- measurements of long bunches in the SPS with RF off done in 2021 to validate shielding of vacuum flanges
  - strong peak at 1.4 GHz now absent
- large increase on instability threshold for 1.4 GHz impedance
  - increase of instability threshold also observed with single and multi-bunch proton beams as of 2021
- no other dominant peak for measured intensity range was observed
  - debunching mainly from main 200 MHz cavity impedance

- come see also:
  - SPS impedance reduction impacted (negatively) fixed target beams — G. Papotti, TUPA157
  - results of similar measurements at the CERN PS — E. Vinten, WEPA011
  - longitudinal loss of Landau damping at SPS — L. Intelisano, WEPA012-3

references

1. I. Béjar Alonso, O. Bruning, P. Fessia, M. Lamont, L. Rossi, L. Tavian, M. Zerlauth, "High-Luminosity Large Hadron Collider (HL-LHC): Technical design report", CERN, Geneva, Switzerland, 2020.
2. E. Shaposhnikova, "Cures for beam instabilities in the CERN SPS and their limitations", *in Proc. 39th ICFA Advanced Beam Dynamics Workshop on High Intensity High Brightness Hadron Beams (HB2006)*, Tsukuba, Japan, May-June 2006, TUBX05.
3. T. Argyropoulos *et al.*, "Identification of the SPS Impedance at 1.4 GHz", *in Proc. 4th Int. Particle Accelerator Conf. (IPAC'13)*, Shanghai, China, May 2013, TUPWA039.
4. A. S. Lasheen, "Beam measurements of the longitudinal impedance of the CERN Super Proton Synchrotron", Ph.D. thesis, Université Paris Saclay, Paris, 2017.
5. T. Bohl, T. P. R. Linnecar, and E. Shaposhnikova, "Measuring the Resonance Structure of Accelerator Impedance with Single Bunches", *Phys. Rev. Lett*. 78, 3109 (1997).
6. T. Bohl, T. P. R. Linnecar, and E. Shaposhnikova, "Impedance reduction in the CERN SPS as seen from longitudinal beam measurements", *in Proc. 8th European Particle Accelerator Conf. (EPAC'02)*, Paris, France, June 2002,
7. E. Shaposhnikova *et al*., "Identification of high-frequency resonant impedance in the CERN SPS", *in Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, June 2014, TUPME029.
8. J. E. Varela, "Longitudinal impedance characterization of the CERN vacuum flanges", *in Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, MOPJE036.
9. J. Repond, "Possible mitigations of longitudinal intensity limitations for HL-LHC beam in the CERN SPS", Ph.D. thesis, Ecole Politechnique, Lausanne, 2019.
10. A. Lasheen *et al*., "Effect of the various impedances on longitudinal beam stability in the CERN SPS", *in Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, TUPOR008.
11. T. Kaltenbacher, C. Vollinger, "Characterization of Shielding for the CERN-SPS Vacuum Flanges With Respect to Beam Coupling Impedance", in Proc. 8th Int. Particle Accelerator Conf. (IPAC'17), Copenhagen, Denmark, May 2017, WEPIK090
12. J. Coupard *et al*., "LIU Technical Design Report- Volume I: Protons", CERN, Geneva, Switzerland, Rep. CERN- ACC2014-0337, Dec. 2014.
13. CERN SPS Longitudinal Impedance Model, https:// gitlab.cern.ch/longitudinal-impedance/SPS
14. E. Shaposhnikova, E. Ciapala, E. Montesinos, "Upgrade of the 200 MHz RF system in the CERN SPS", *in Proc. 2nd Int. Particle Accelerator Conf. (IPAC'11)* IPAC11, San Sebastian, Spain, Sept. 2011, MOPC058.
15. E. Shaposhnikova *et al*., "Removing known SPS intensity limitations for High Luminosity LHC goals", *in Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, MOPOY058.

spares

similar results in Q20 optics