LHC Injectors Upgrade

Tune Diagram Measurements in the PS

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F. Asvesta, H. Bartosik, M. Giovannozzi, PSB and PS OP team

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CERN

Outline

- Introduction

- Tune diagram measurements
  - Measurements performed in 2012
  - Measurements performed in 2018

- Conclusions and Outlook

Introduction

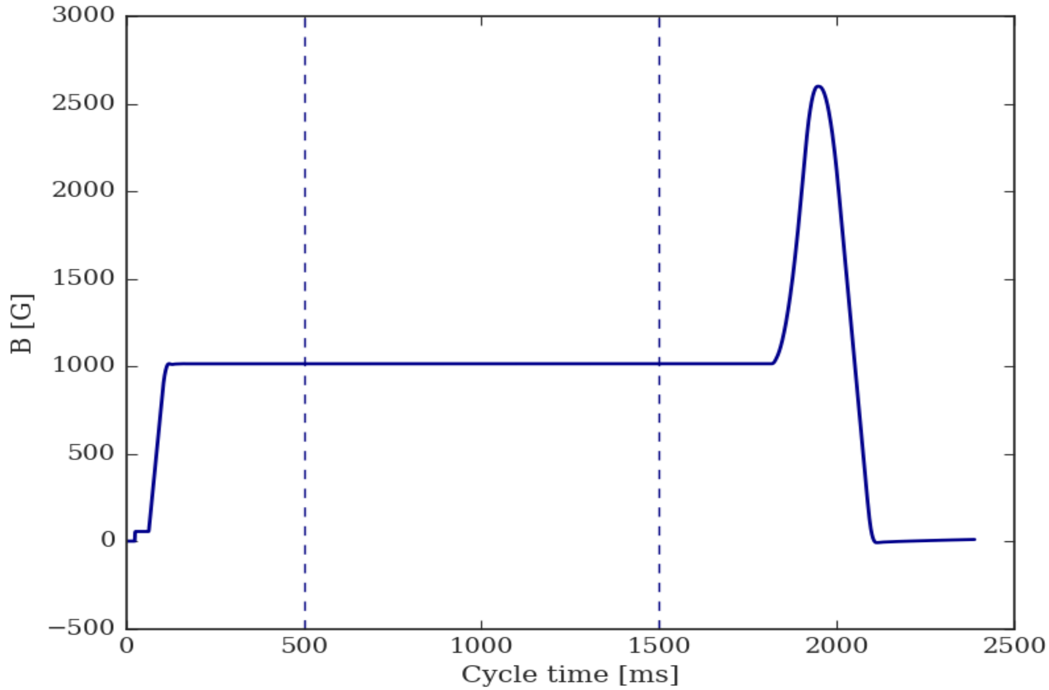
- **Loss map measurements are conducted to investigate resonances**

  - Comparison of measurements from 2012 and 2018
  - Investigate the magnetic stability of the machine
  - Investigation of remnant magnetic effects of sextupoles, octupoles and PFW
  - Furthermore, we will investigate the impact of changing the resonance crossing speed on the results

- **To do this we perform tune scans, varying the tune of a large transverse emittance beam in the PS dynamically, and observing the loss rate**

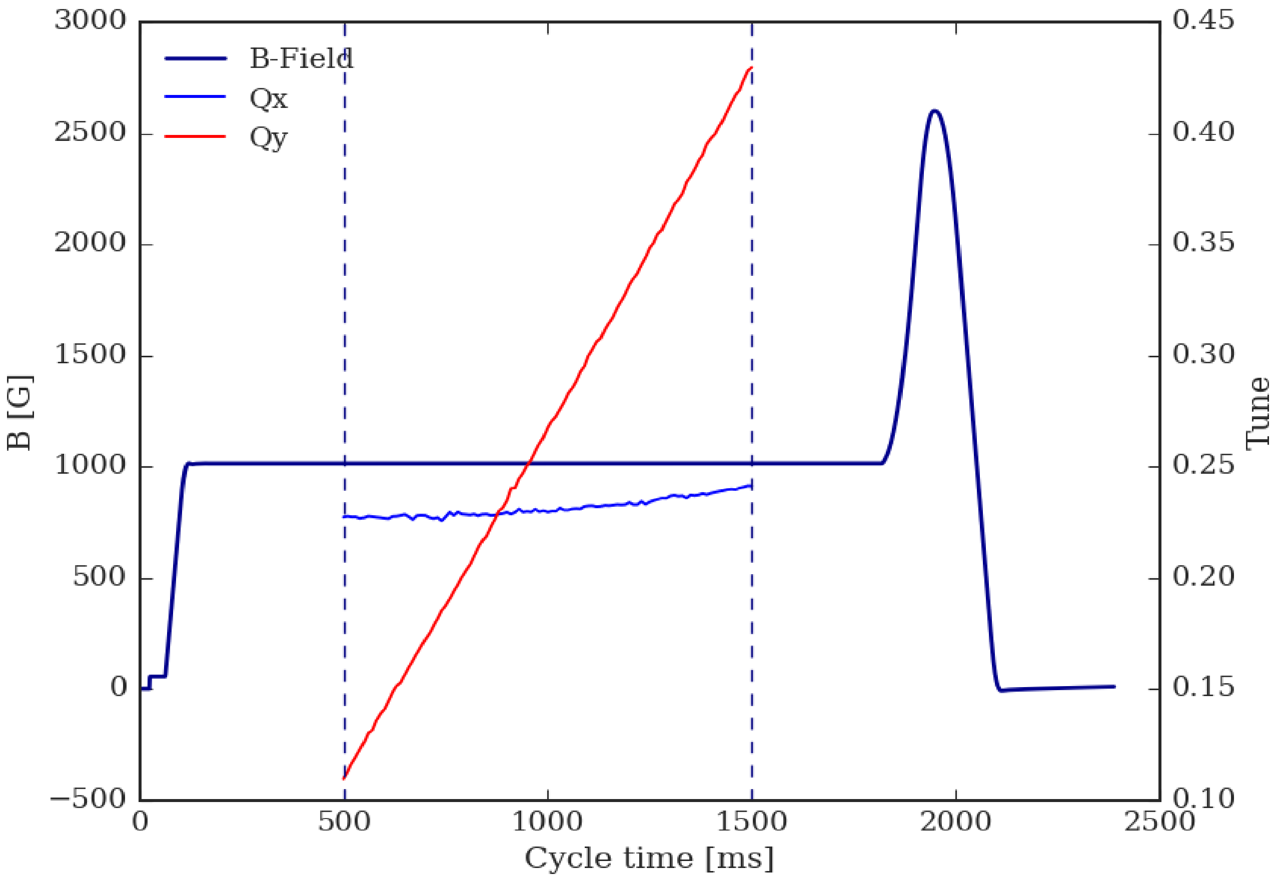
Measurement principle

- **Inject a bunch with large transverse emittances from PSB to:**
  - Reduce the direct space charge tune spread
  - Fill the vacuum chamber and be sensitive to losses during resonance crossing
- **Keep the bunch on a flat bottom (1.4 GeV) between 500 and 1500 [ms] (duration 1 s)**



Measurement principle

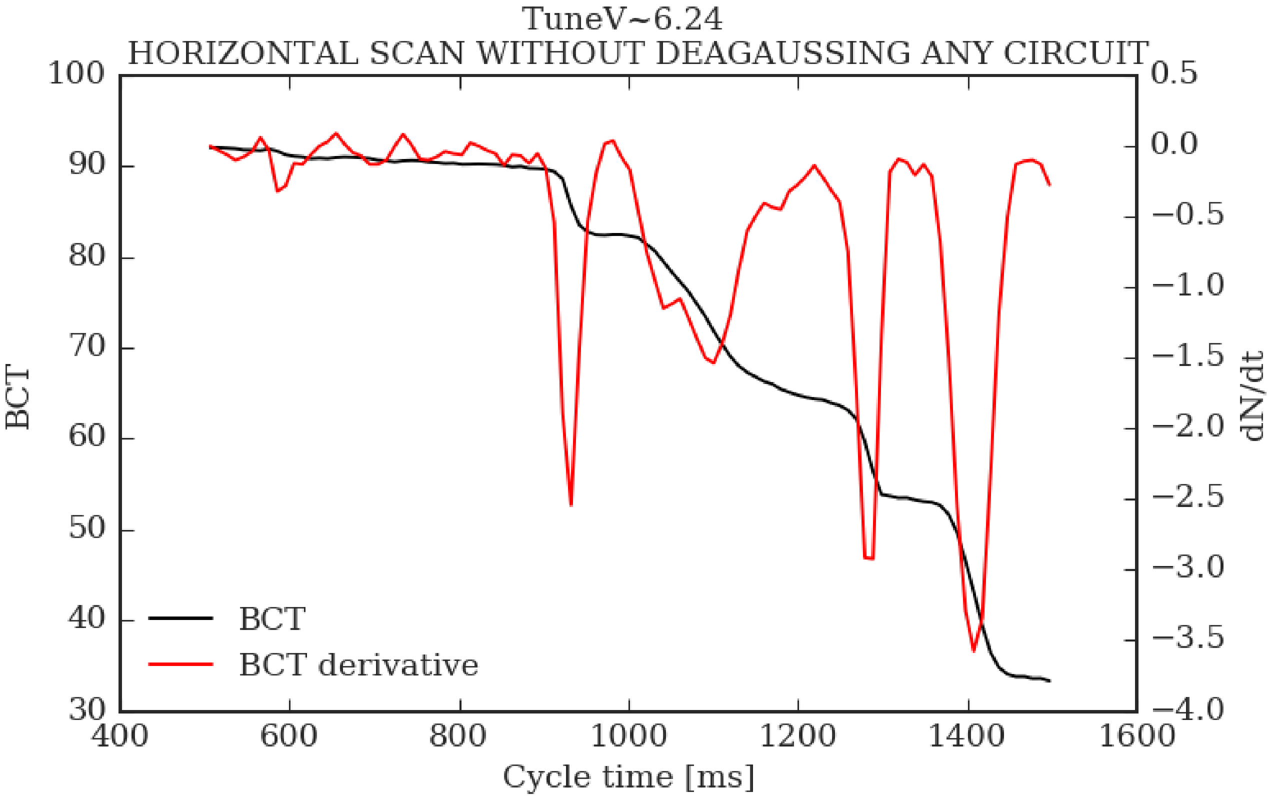
- Keep tune constant in one plane while dynamically changing it in the other during the cycle



Measurement principle

•Qh, Qv are excited and measured on separate cycles while the BCT (intensity) is recorded only when the tune is not excited

•Information about resonances comes from the derivative of the BCT signal



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Measurements performed in 2012

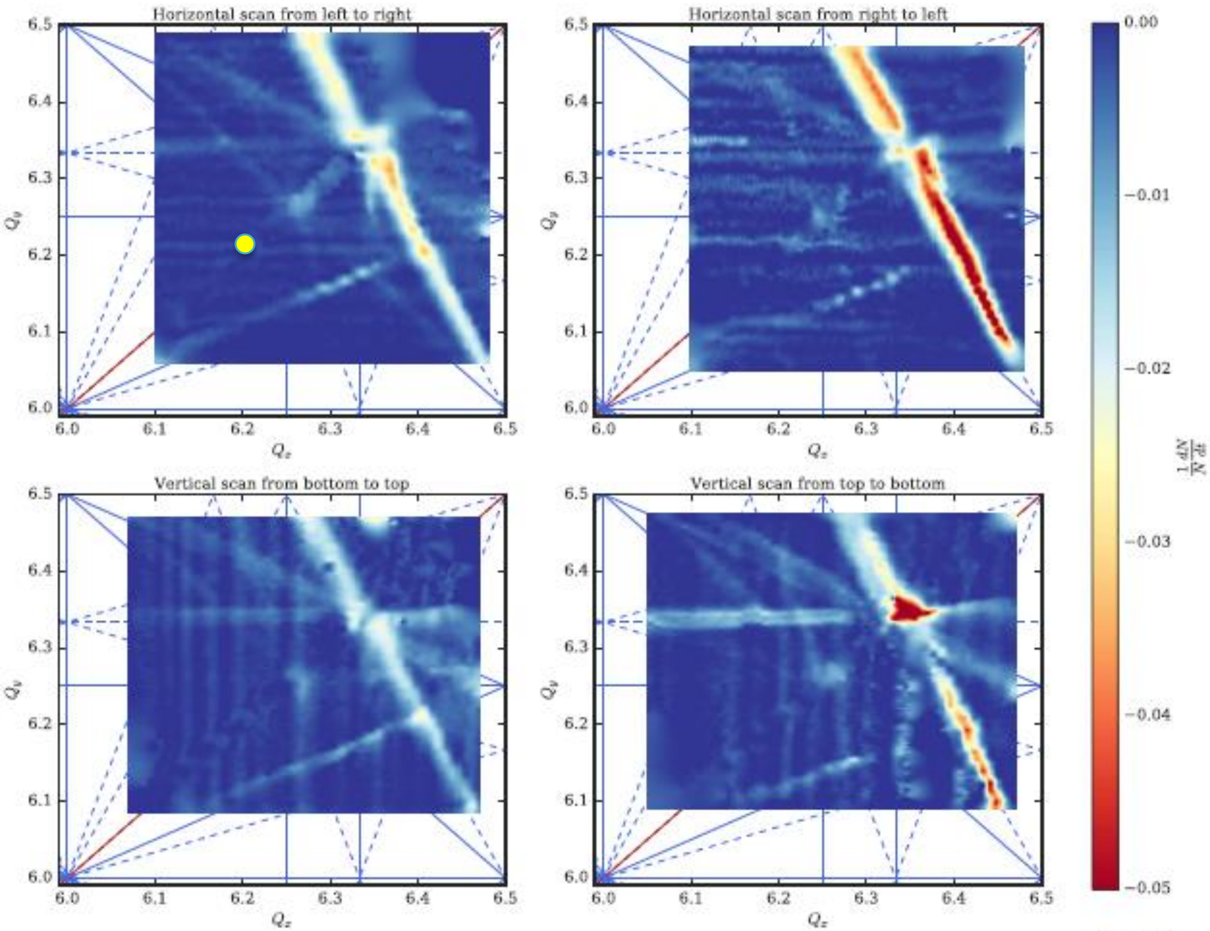
- The main focus was on measurements at the LIU injection energy at 2 GeV
- To perform the measurements at 2 GeV the PFW were used due to insufficient strength in the LEQ

Beam and machine parameters

Parameters	2012
Kinetic energy [GeV]	2
Harmonic number	8
Number of bunches	1
Number of protons per bunch [10^{10}]	120
Bunch length (4σ) [ns]	117
Relative momentum error (1σ) [10^{-3}]	0.8
Longitudinal emittance (matched area) [eVs]	0.84
Normalized horizontal emittance (1σ) [mm mrad]	10.4
Normalized vertical emittance (1σ) [mm mrad]	7.64
Horizontal direct space charge tune spread	0.05
Vertical direct space charge tune spread	0.06

Tune diagrams with PFW in 2012

- **Tune variation performed with PFW**
- **Regime around operational working point (6.2, 6.24) rather resonance-free**
- **Very strong normal and skew sextupole resonances observed**
    - No resonances above 3rd order observed



Courtesy of A. Huschauer

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Measurements performed in 2018

- Investigation of changes in resonance excitation over time
- Alignments of the main magnets have taken place in previous years, and we have seen that the resonances are affected by the magnet misalignments
- The LEQ have received new power converters, allowing to explore a larger extent of the tune diagram

Beam and machine parameters

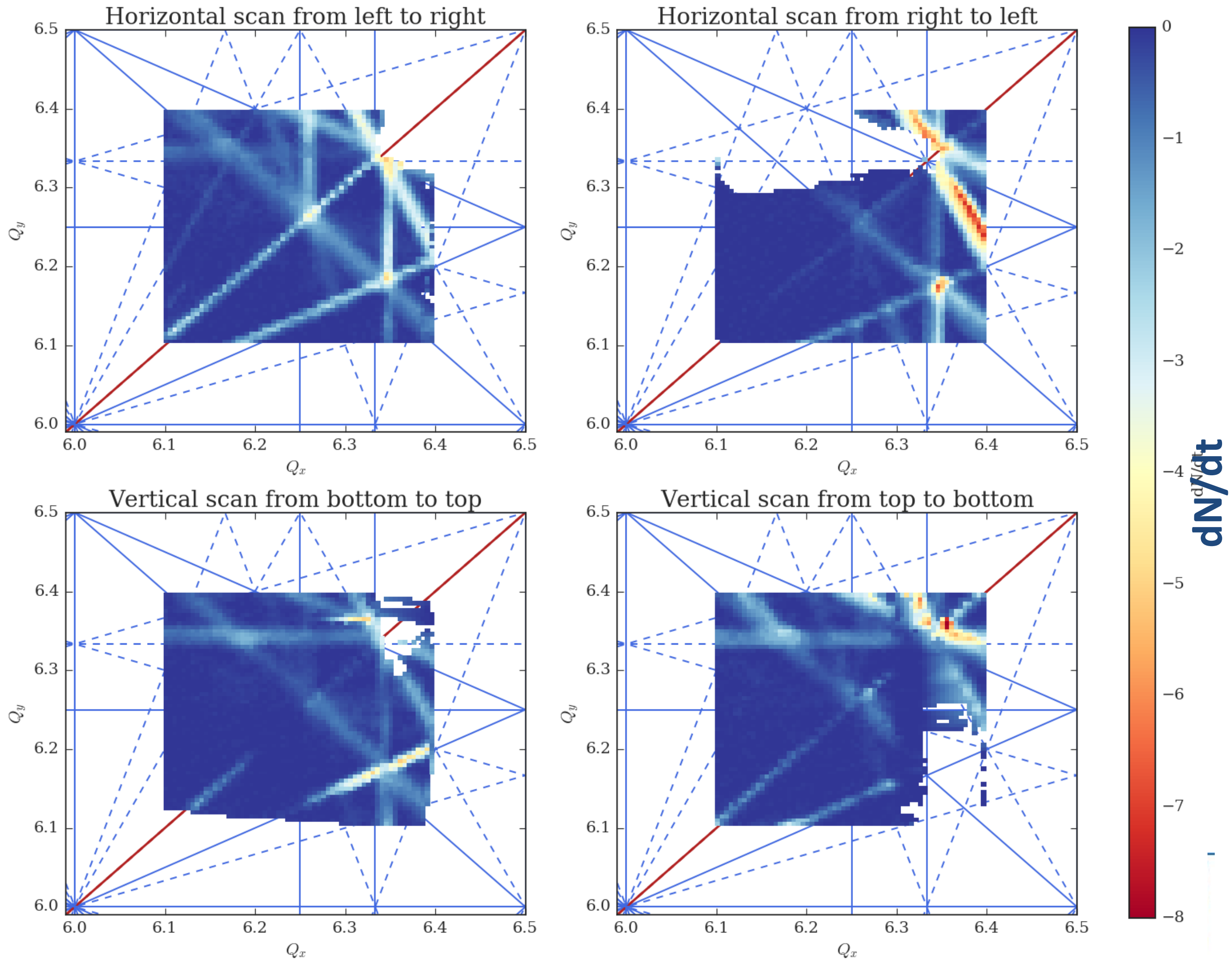
Parameters	2018	2012
Kinetic energy [GeV]	1.4	2
Harmonic number	8	8
Number of bunches	1	1
Number of protons per bunch [10^{10}]	100	120
Bunch length (4σ) [ns]	160	117
Relative momentum error (1σ) [10^{-3}]	0.99	0.80
Longitudinal emittance (matched area) [eVs]	1.24	0.84
Normalized horizontal emittance (1σ) [mm mrad]	11.8	10.4
Normalized vertical emittance (1σ) [mm mrad]	7.14	7.64
Horizontal direct space charge tune spread	0.04	0.05
Vertical direct space charge tune spread	0.06	0.06

MD cycles used for the measurements

•Parameters	•Description
•PSB user: MD3105_XL_EMIT	•Single bunch from ring 3
•PS user: MD3105_Tunediagram	•Cycle length : 2400

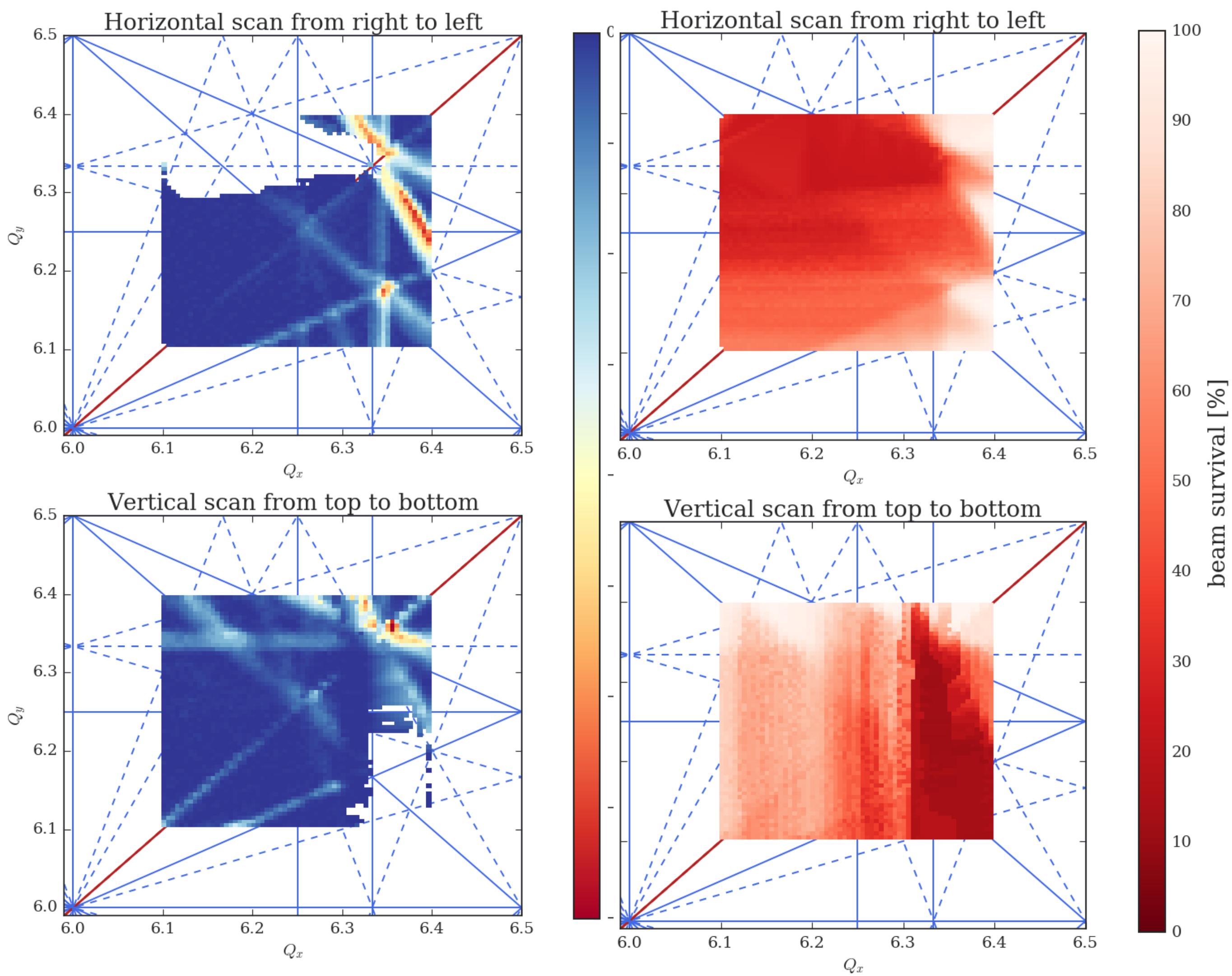
First measurement results

- Loss maps obtained from scans in four different directions
- Measurements of a specific area (both Qx , Qy varies from 6.1-6.4)
- Tune variation controlled only with LEQ
- Observation of resonances with order > 3



First measurement results

- White areas correspond to missing data due to very low beam intensity
- In red diagrams BCT data are interpolated
- Normalized intensity is calculated and then plotted

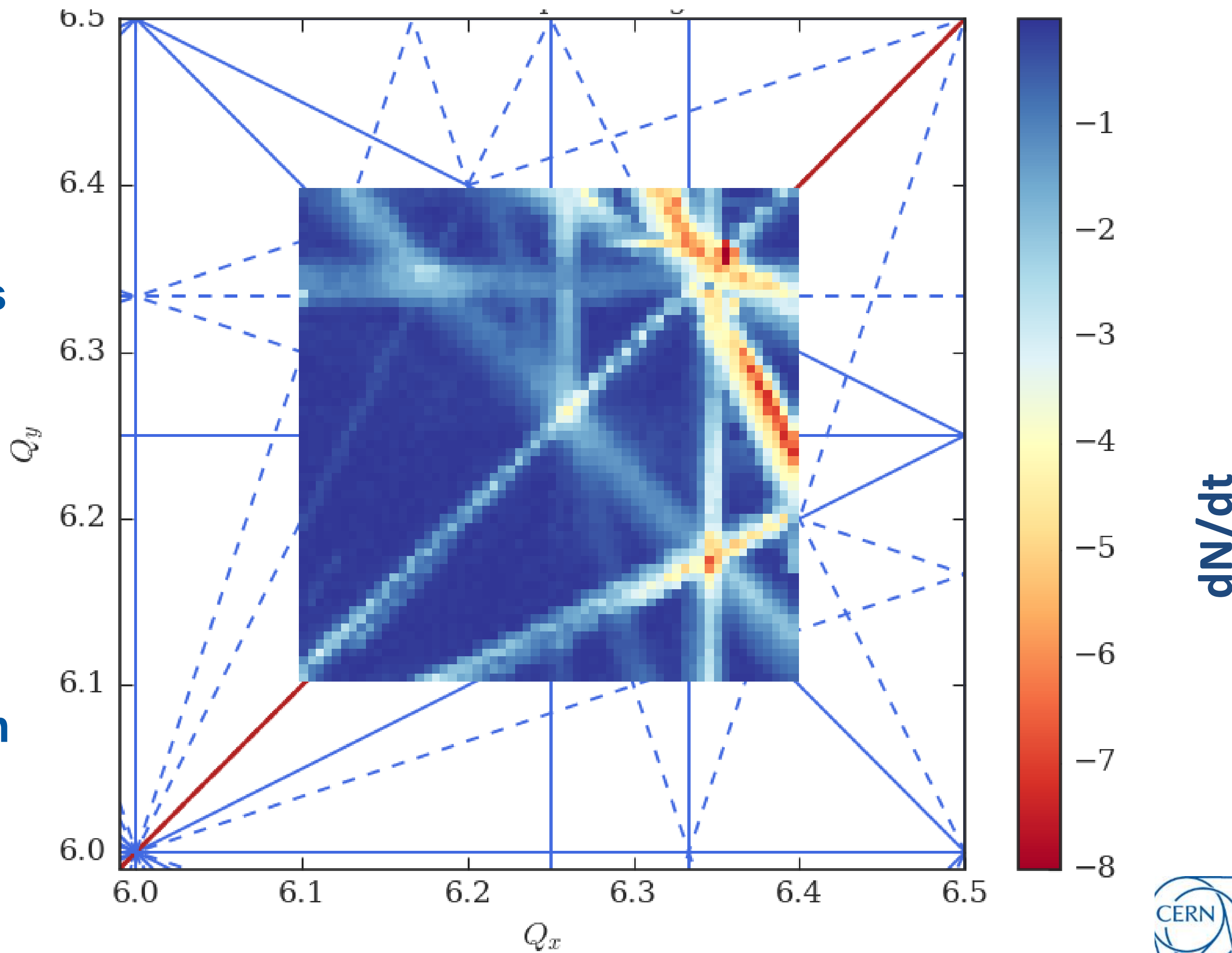


First measurement results

- Plotting maximum values derived from scans in all directions to combine measurement results

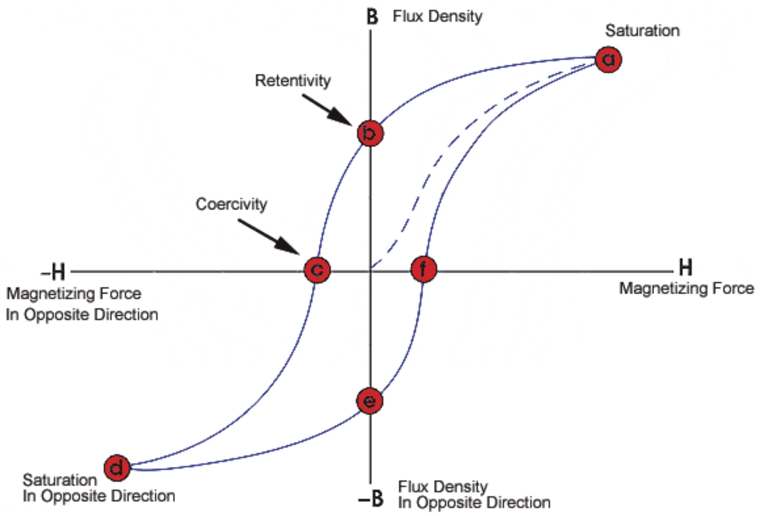
- 3rd and 4th order resonances observed very clearly compared to the past

- Could possibly stem from non-linear fields used for MTE (since 2015)



Dealing with remnant fields

- The magnetic hysteresis loop, shows the behaviour of a ferromagnetic core (like magnets of PS) graphically
- The relationship between the induced magnetic flux density (B) and the magnetizing force (H) is non-linear



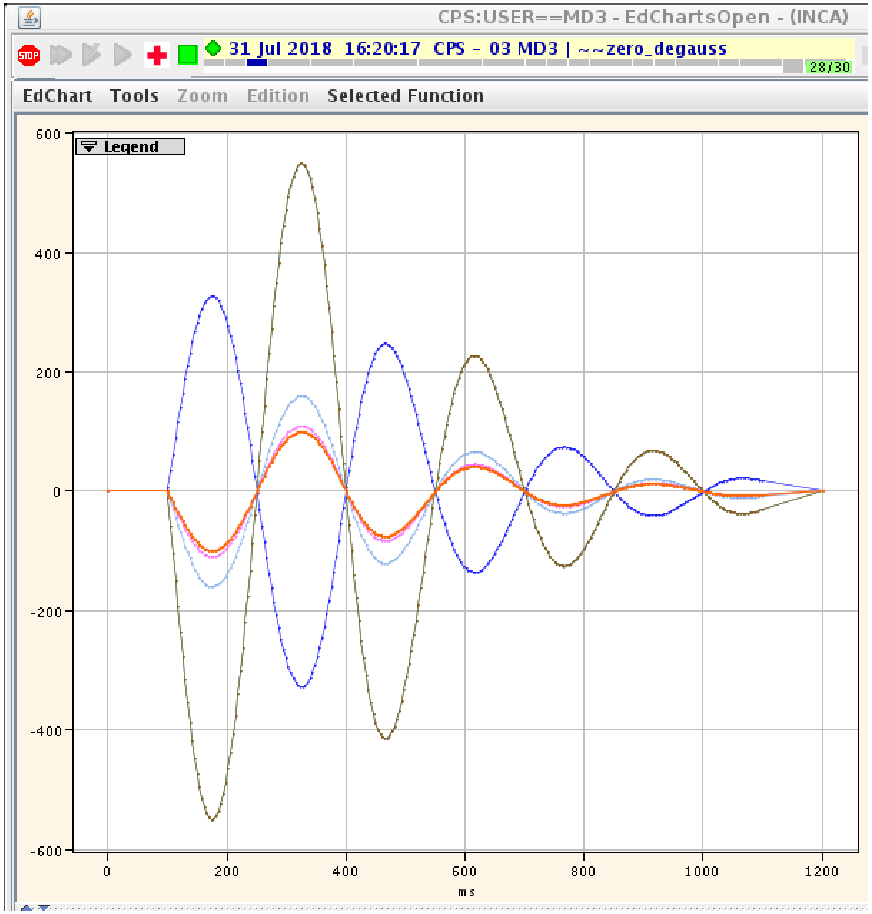
- In order to degauss the circuits, we excite them with plus/minus the operationally used maximum current followed by an amplitude decay

- Remnant fields in octupoles and sextupoles used for MTE appeared a good candidate to explain the additional horizontal resonances

Dealing with remnant fields

- We use a zero cycle in front of the MD cycle, on which certain circuits are degaussed

Octupoles degaussed
PR.ODN
PR.ONO39
PR.ONO55
Sextupoles degaussed
PR.XNO39
PR.XNO55
PR.XNO

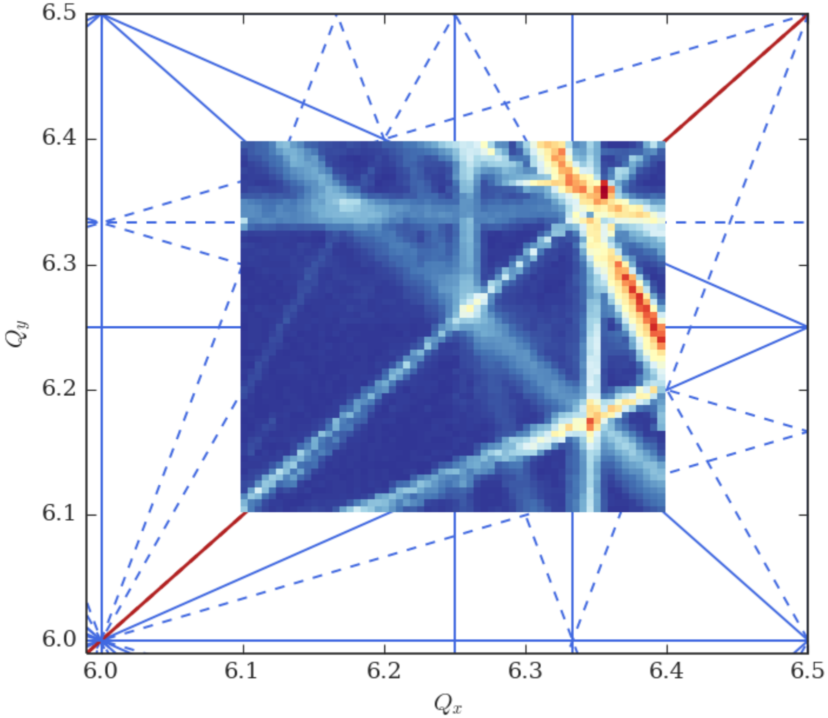


Current [A]

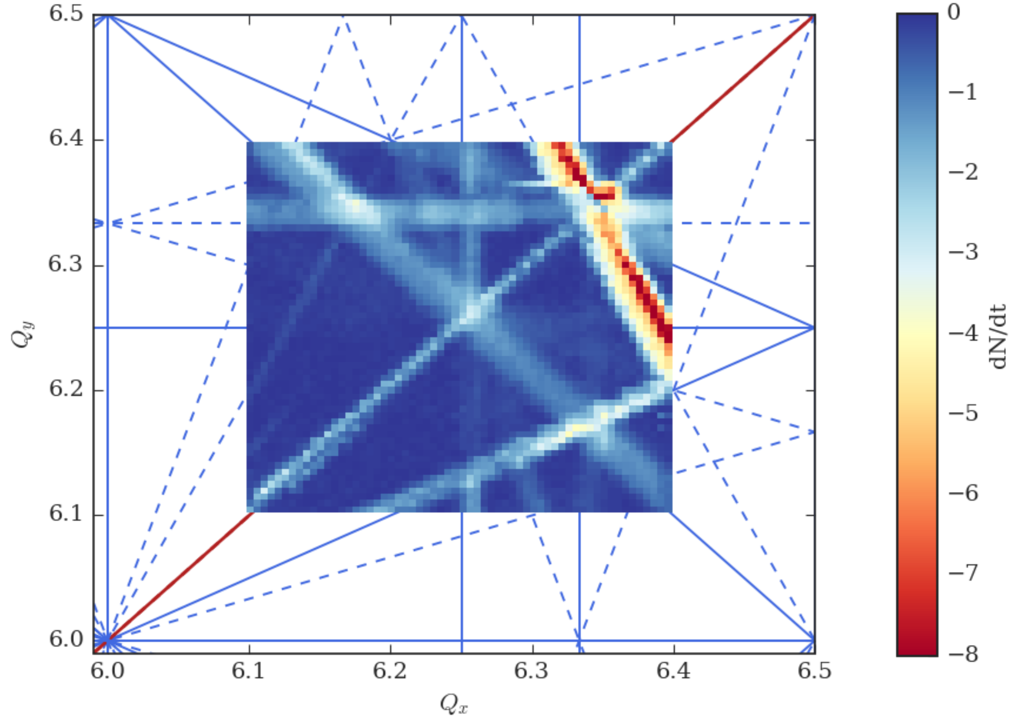
Cycle time [ms]

Impact of degaussing on the resonances

Without degaussing any circuit



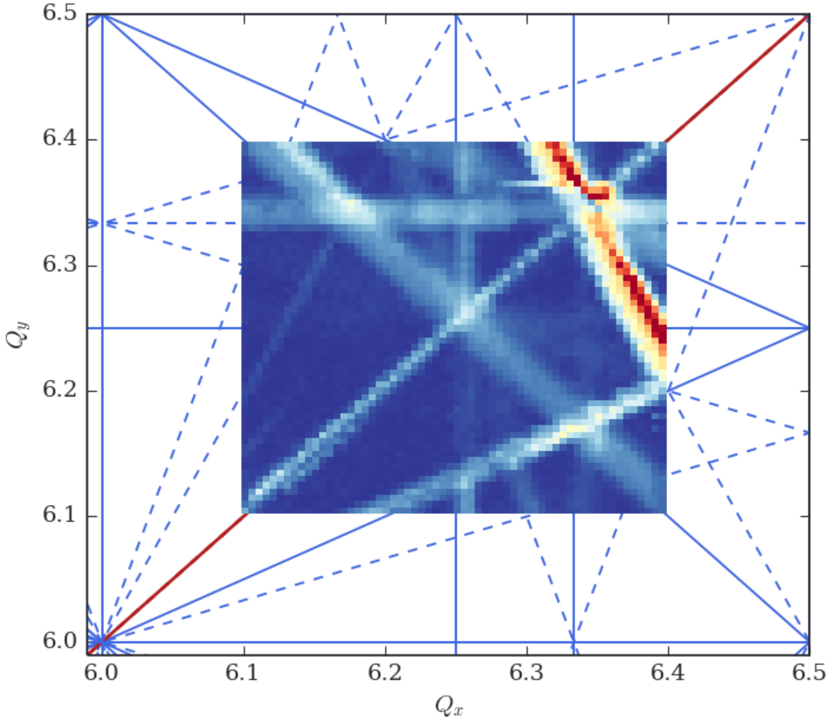
Octupoles degaussed



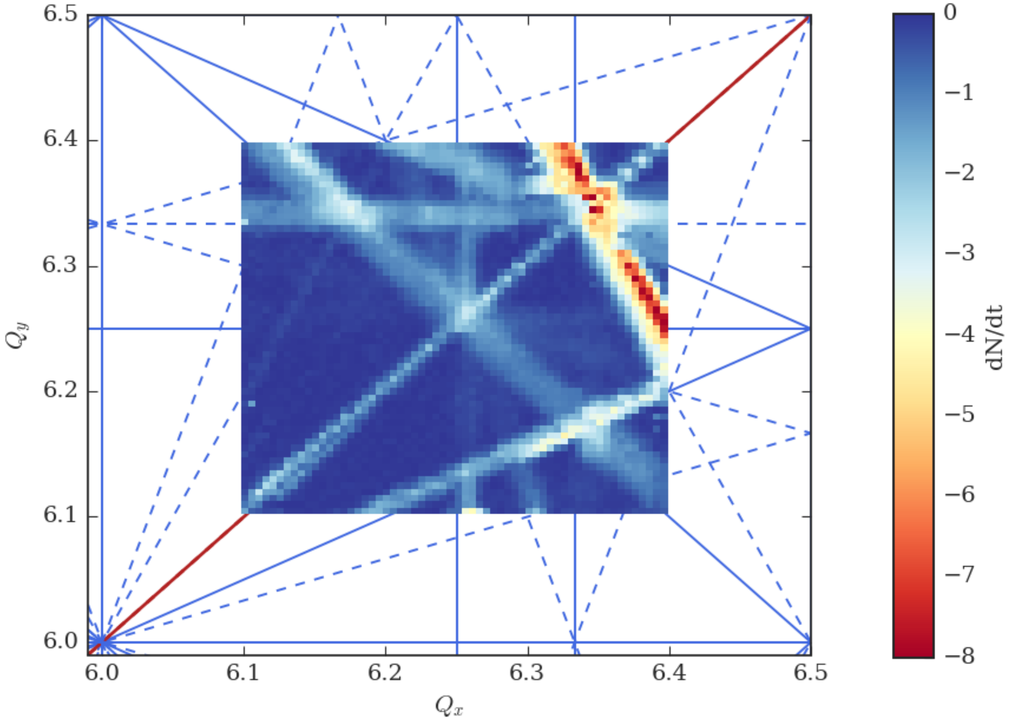
- 3rd order resonance $3Q_x = 19$ clearly disappeared
- 4th order resonances seem to be reduced in strength

Impact of degaussing on the resonances

Octupoles degaussed

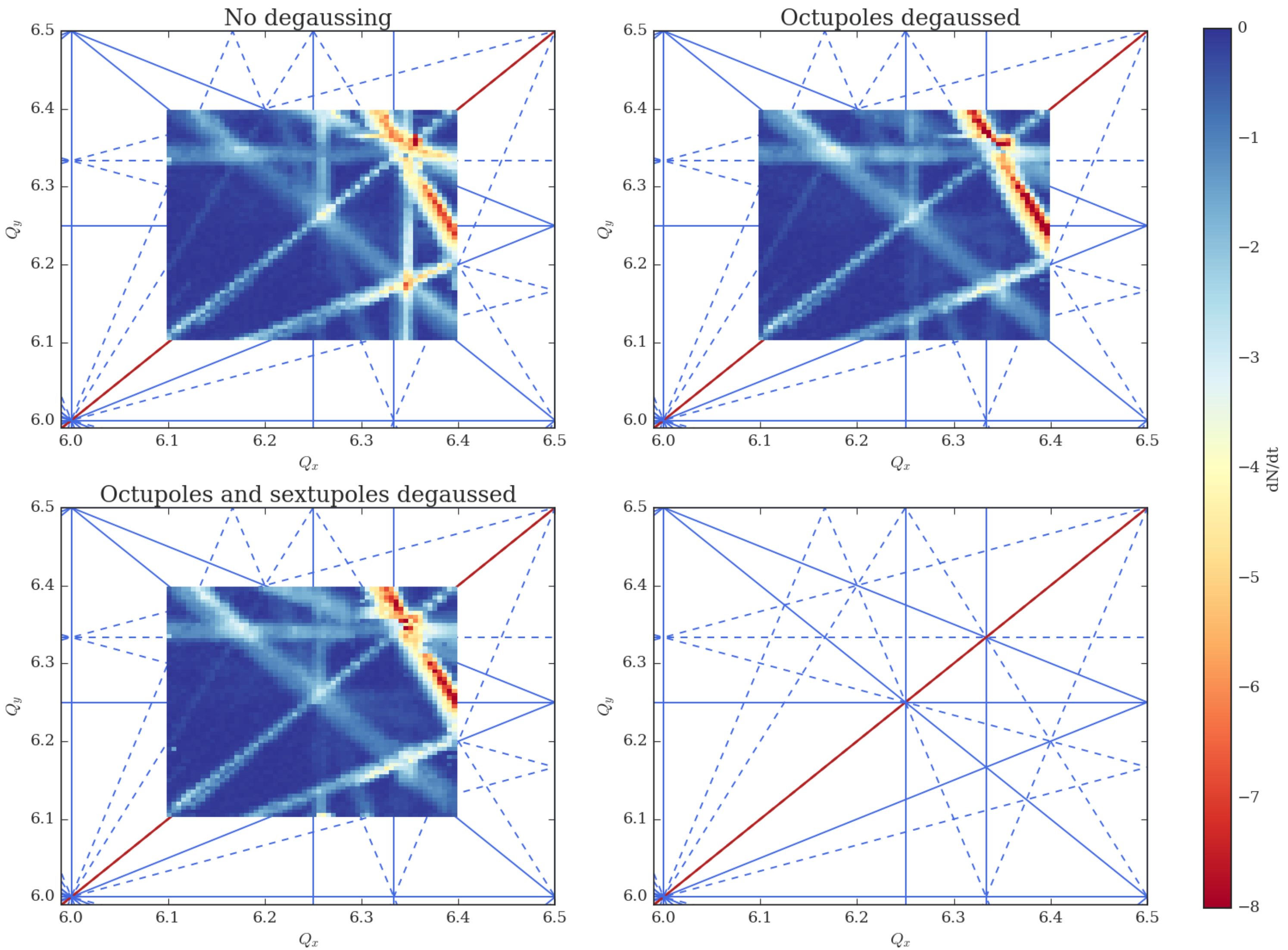


Octupoles and sextupoles degaussed



- No important impact of sextupoles
- Somehow expected, as sextupoles are operated far from saturation regimes

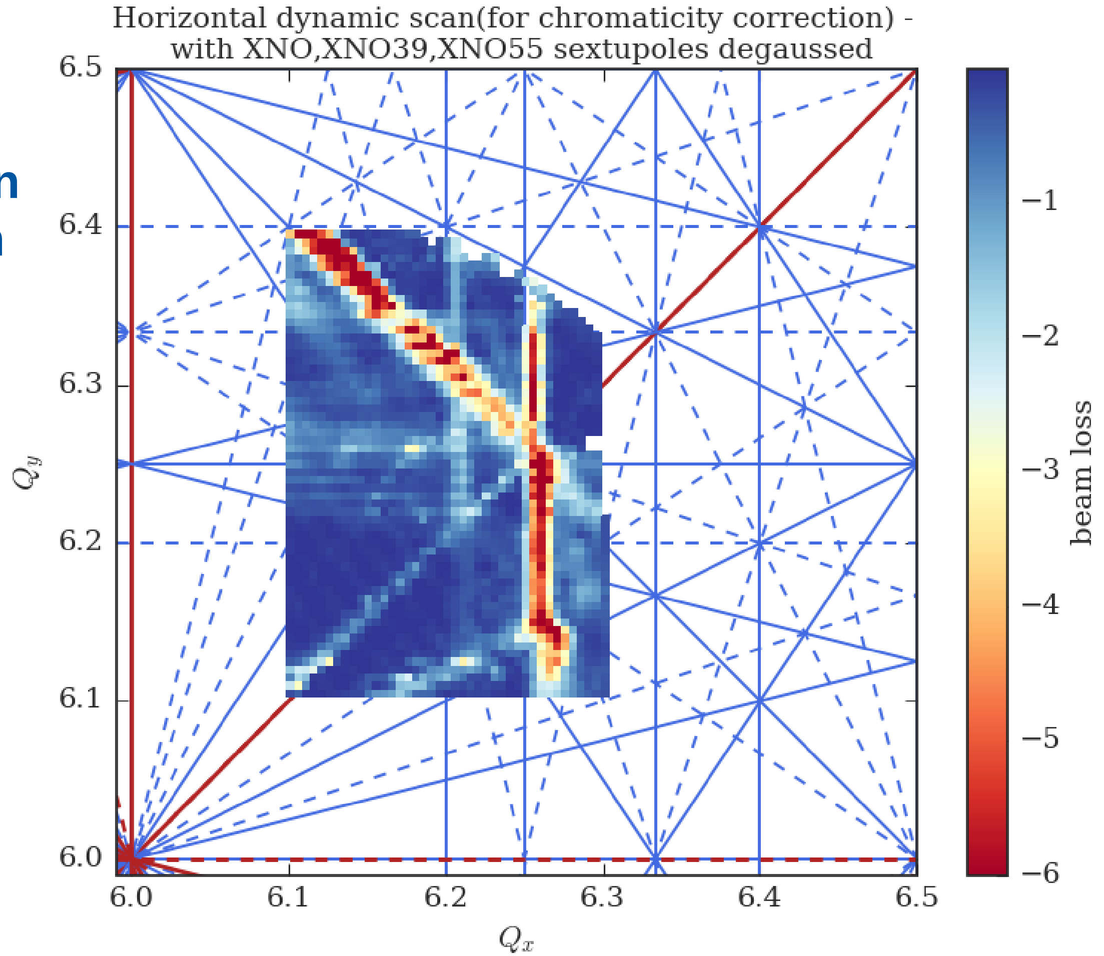
Compare max values of 3 configurations



Chromaticity correction

- In general performed with PFW
- Possibility to use MTE sextupoles and new vertical sextupoles instead
- Impact on resonance excitation investigated with tune diagram measurements

Sextupoles enabled	Current [A]
PR.XNO39	-16
PR.XNO55	-16
PR.XNO	-46



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Conclusions and Outlook

- **Tune diagram measurements revealed very different resonance excitation with respect to 2012**
- **Important effects of remnant fields observed**
  - Octupoles seem to be main contributors
  - Less impact of sextupoles observed
  - Impact of PFW to degauss the main magnets to be investigated
- **Chromaticity correction with dedicated sextupoles instead of PFW strongly excites additional resonances**
- **Further measurements to clearly identify the octupolar circuit with highest remnant field**
  - Amplitude detuning measurements using the TFB as AC dipole
- **Investigating the impact of resonance crossing speed on the resulting tune diagrams**

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THANK YOU FOR YOUR ATTENTION!

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