LHC Injectors Upgrade

Space Charge simulations for LEIR

F. Asvesta, H. Bartosik, D. Garcia Moreno, A. Saa Hernandez

What this presentation is about:

- Pb54+ runs in 2015 and 2016, crash program to deliver higher intensity beams (Alex talk)
- We are now trying to model those measurements. First space charge simulations for LEIR and first presentation on it!
  - Optics overview
  - Simulations parameters and model for SC
  - Comparison simulation vs. measurements
  - Identification of some SC-driven excited resonances
  - Conclusions and next steps
- Xe39+ runs in 2017 , presently taking measurements → not covered in this talk

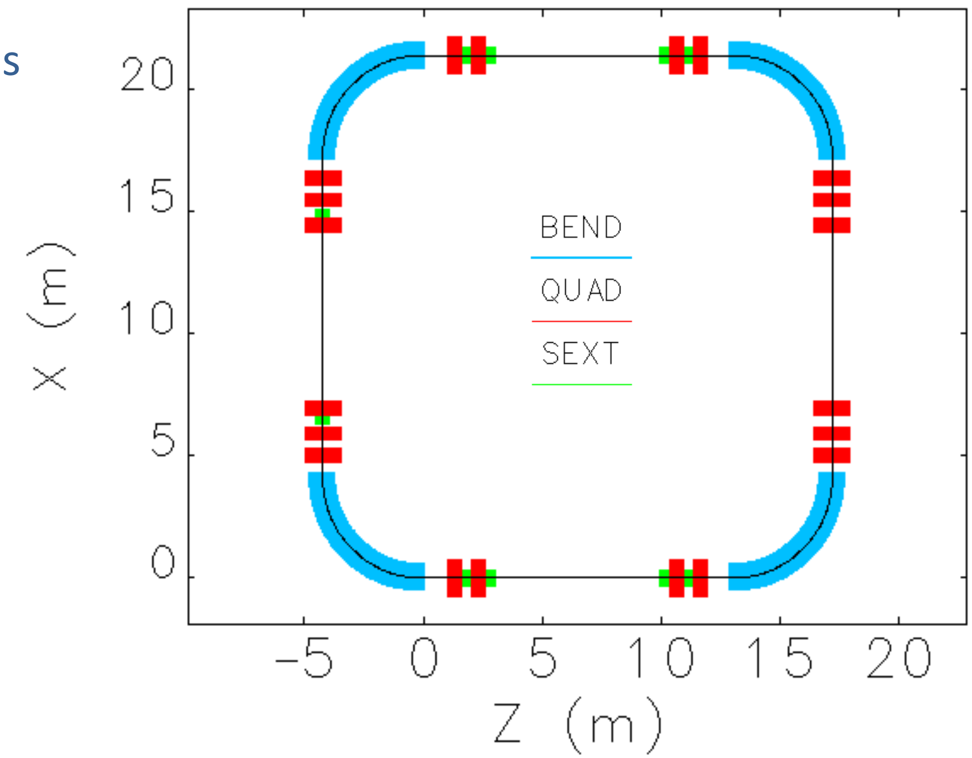
Particle	Pb
Charge state (q)	54^+
Mass	193.7 MeV
Energy	194.57 GeV
γ	1.0045
γ_t	2.8374

An overview of LEIR

Small machine, not only in length but also in number of elements!

- 4 dipoles
- 4 quad doublets + 4 triplets
- 5 H-sextupoles + 5 V-sextupoles

Length (C)	78.54 m
Periodicity	2



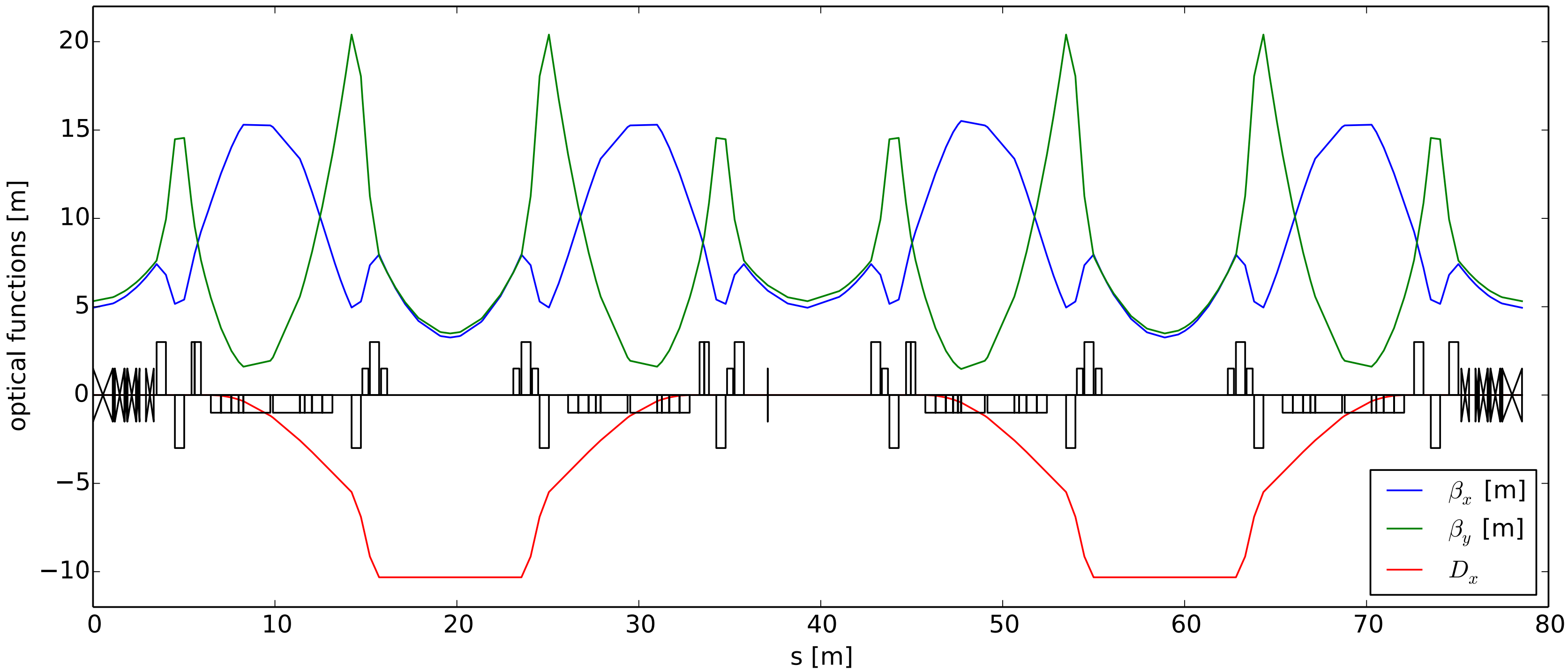
⇢ Large <Dx>
⇢ Small tunes
⇢ Small natural chroma

⇢ Weak sextupole gradients
⇢ Very large DA

LEIR optics …

- Large <Dx>
- Small tunes
- Small natural chroma

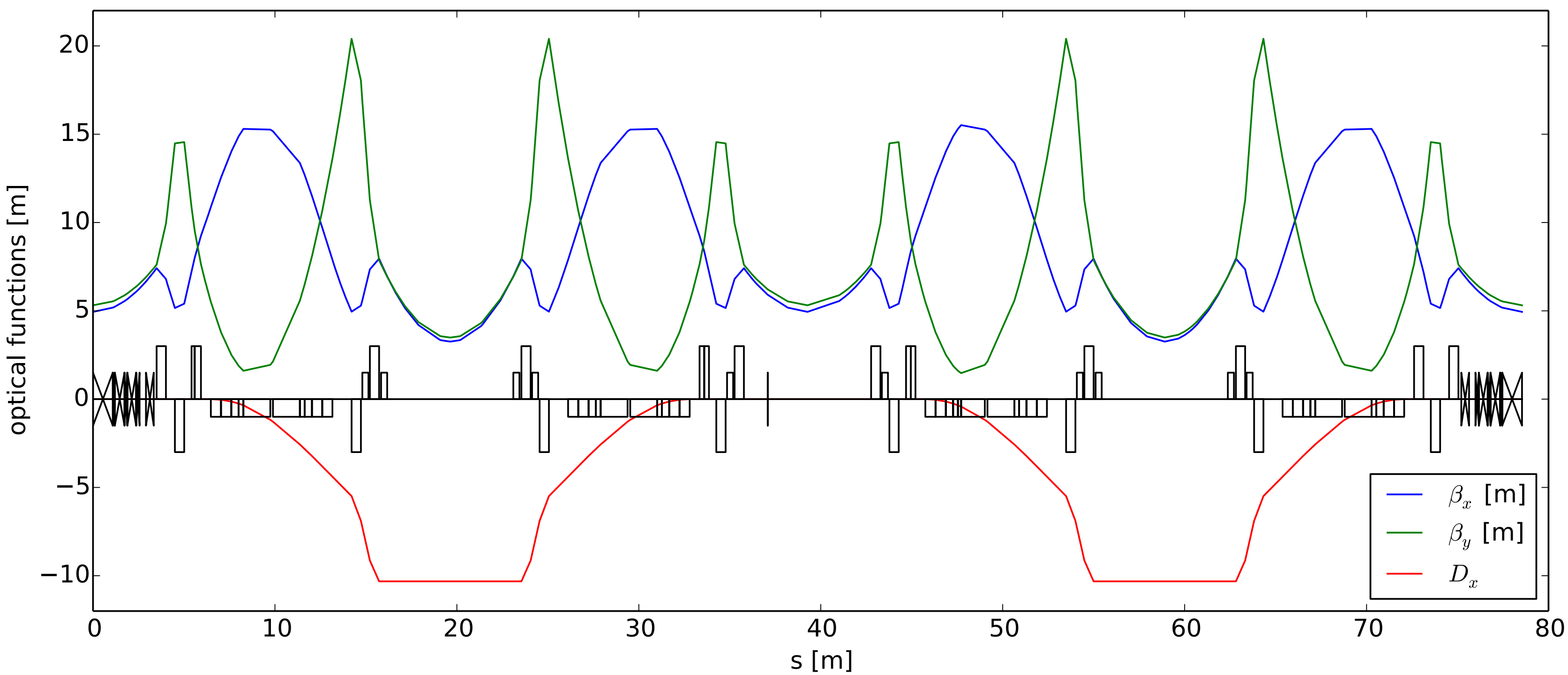
Length (C)	78.54 m
Periodicity	2
Working point (Qx / Qy)	1.82 / 2.72
Natural chroma (ξx / ξy)	-2.19 / -3.74



LEIR optics …

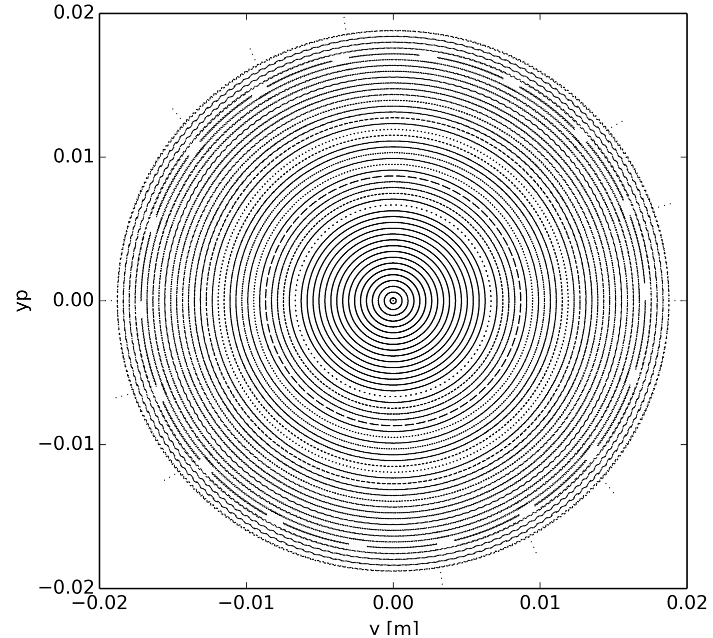
- So far all simulations for an ideal lattice:
  - Electron Cooler OFF (=drift)
  - No magnetic field errors
  - Fringe fields from the quads (short magnets with large aperture)
  - (machine operation with Electron Cooler → periodicity reduced to 1)

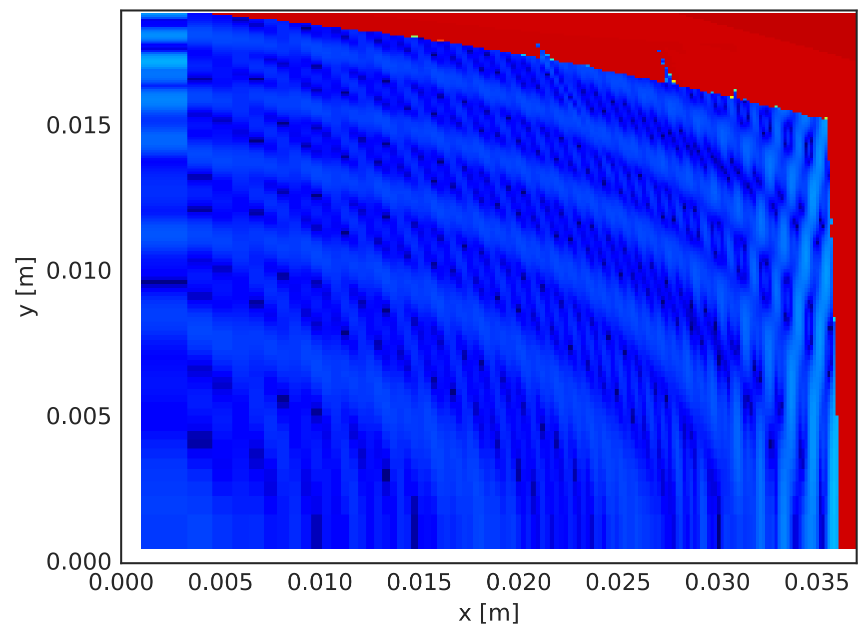
Length (C)	78.54 m
Periodicity	2 (1)
Working point (Qx / Qy)	1.82 / 2.72
Natural chroma (ξx / ξy)	-2.19 / -3.74

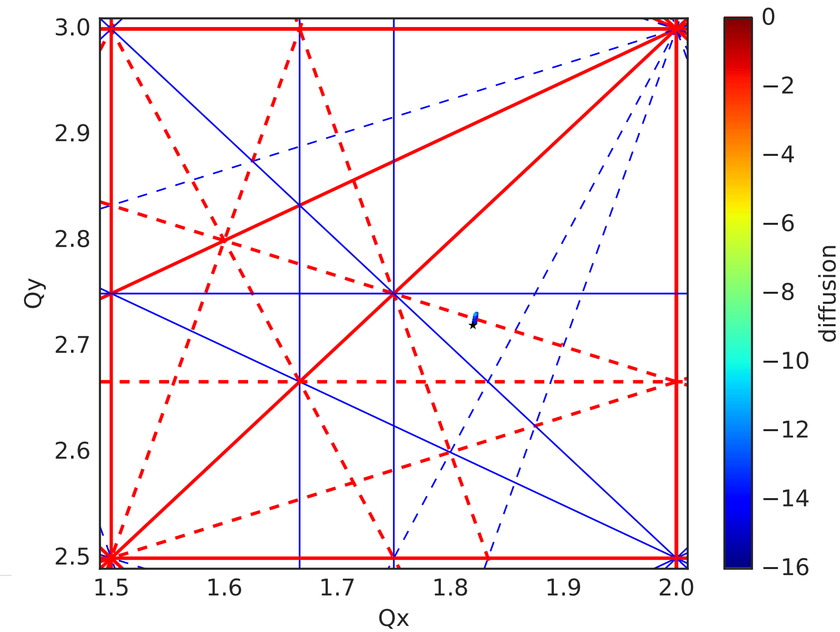


and a first sight into the beam dynamics

- No space charge
- Nominal working point
- Chroma corrected to zero
  - ⇢ Linear phase space
  - ⇢ Almost no amplitude detuning
  - ⇢ Dynamic aperture defined by physical apertures







LEIR beam parameters

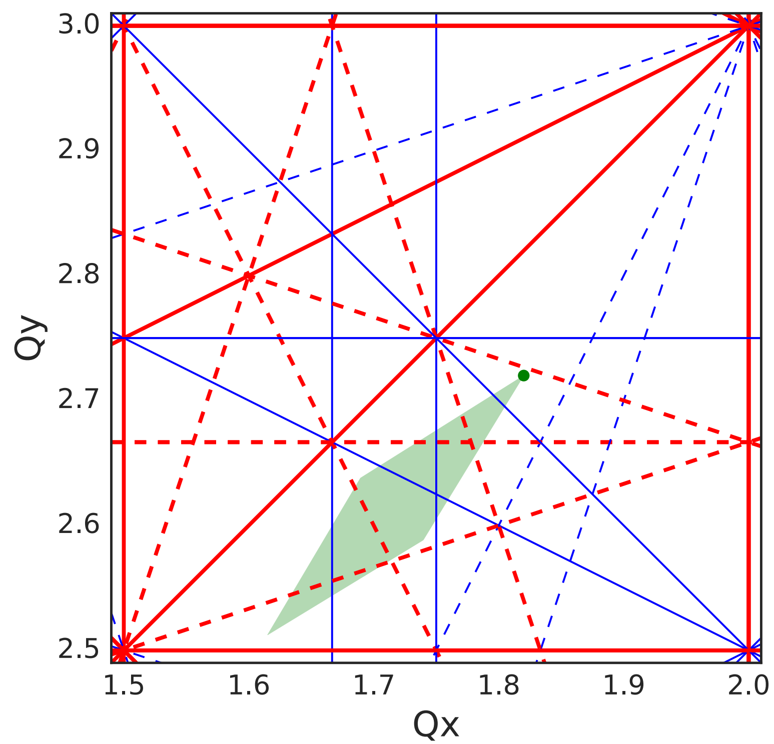
Space Charge (SC) tune spread:
(assuming gaussian profile)

$$\Delta Q_{x,y} = -\frac{r_0 \lambda}{2\pi e \beta^2 \gamma^3} \oint \frac{\beta_{x,y}(s)}{\sigma_{x,y}(s)(\sigma_x(s) + \sigma_y(s))} ds$$

with $\lambda = \lambda_z\,(0) = \frac{N_b q}{\sqrt{2\pi}\sigma_z}$

$\Delta Q_x, \Delta Q_y = 0.2049, 0.2075$

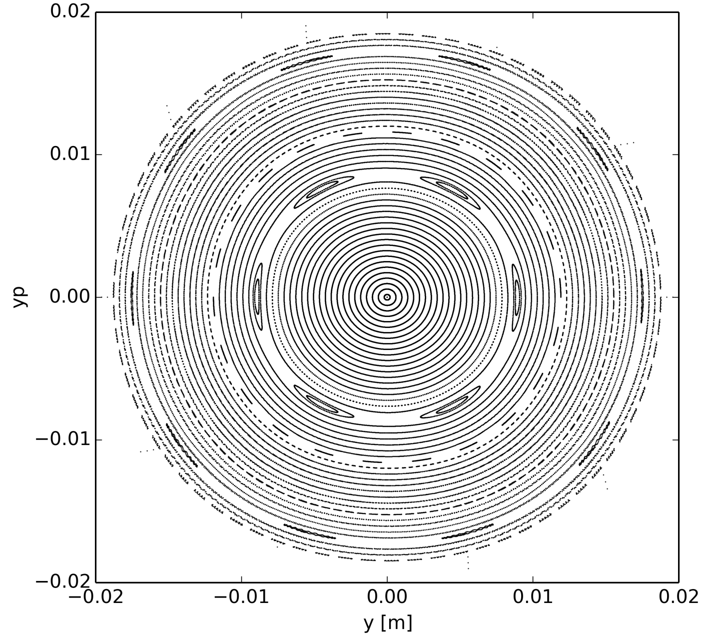
Intensity (N_b)	6e+8
$\varepsilon^n{}_x$	0.2e-6 m·rad
$\varepsilon^n{}_y$	0.2e-6 m·rad
$\Delta p/p$	1.6e-3
Bunch length ($1\sigma_z$)	5.95 m



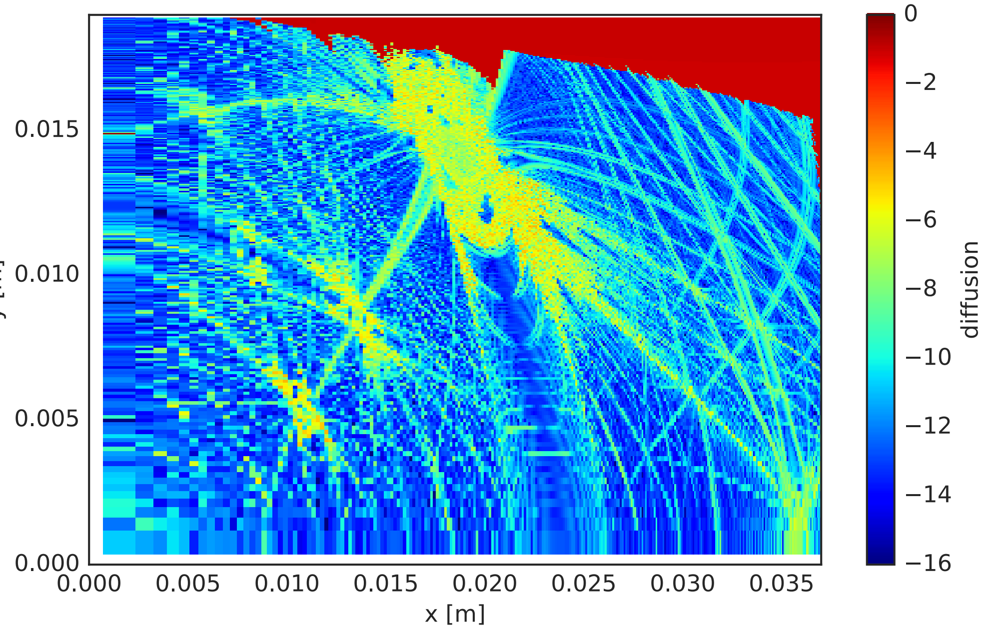
Space charge modelling

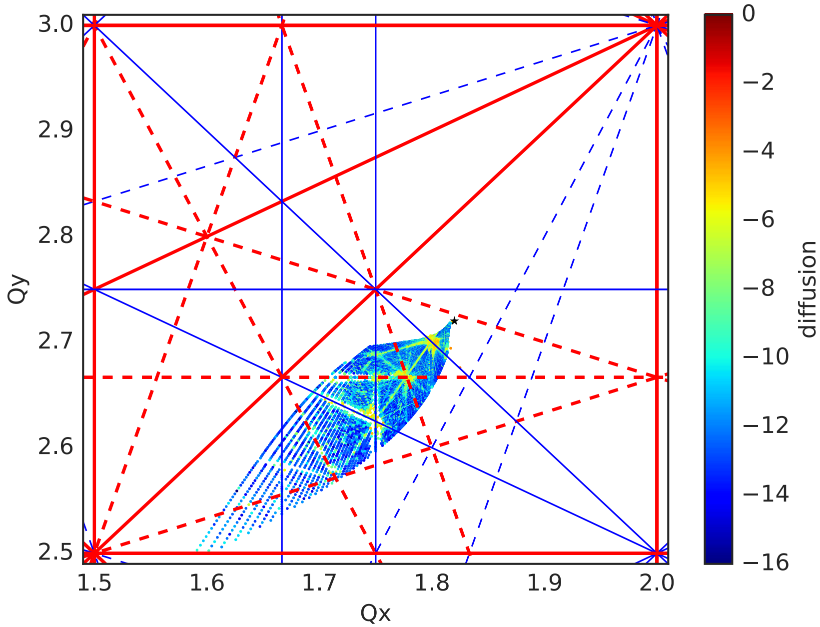
- Tracking simulations including SC in pyORBIT
- SC solver using adaptive frozen potential
- Update SC every n turns (typically: n=1e3 when tracking 2e5 total turns)
- 141 knobs along the lattice (approx. 17 per β wavelength)
  - Test with 1282 SC knobs → same results (but much slower!)
- 5000 macroparticles

A more detailed sight into the beam dynamics:

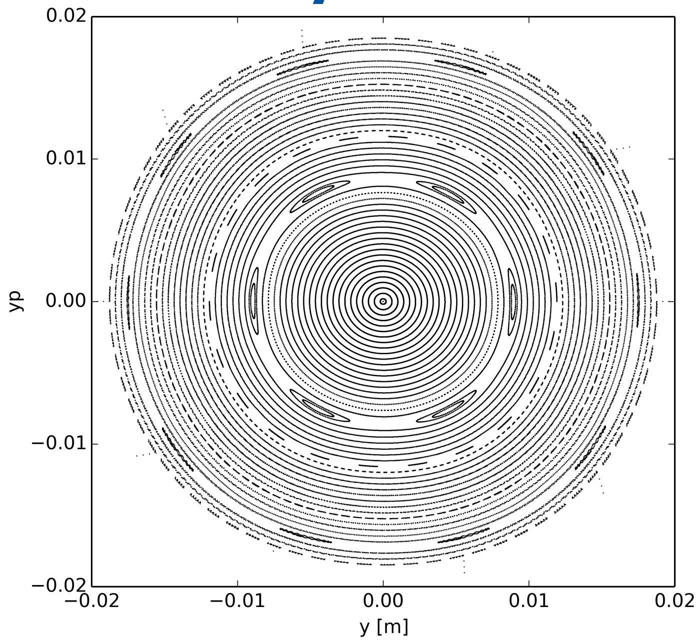


- Including space charge
- Nominal working point
- Chroma corrected to zero
  - ⇢ large tune spread as predicted
  - ⇢ many high-order resonances excited

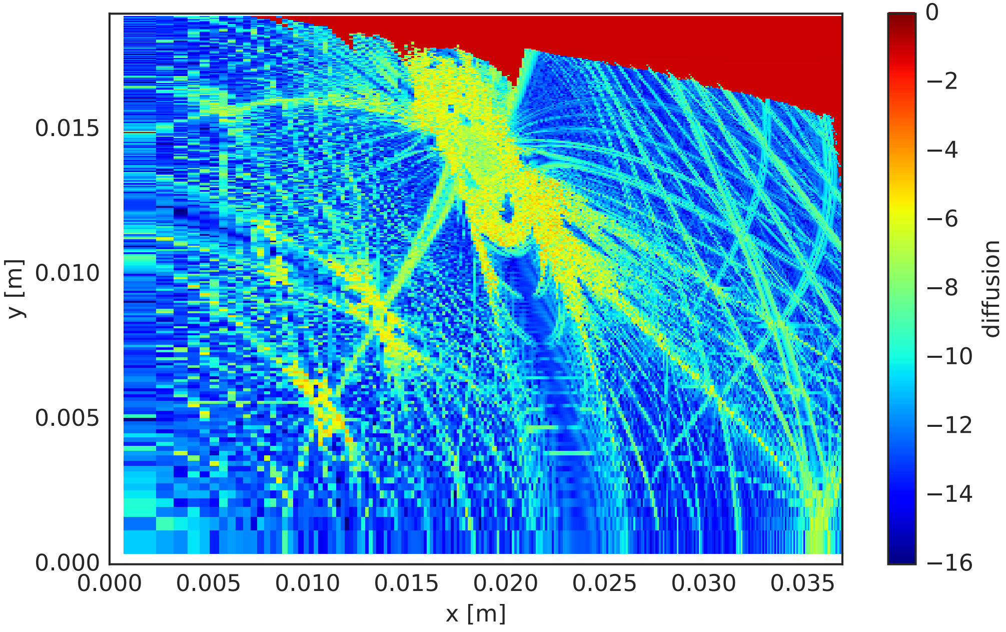


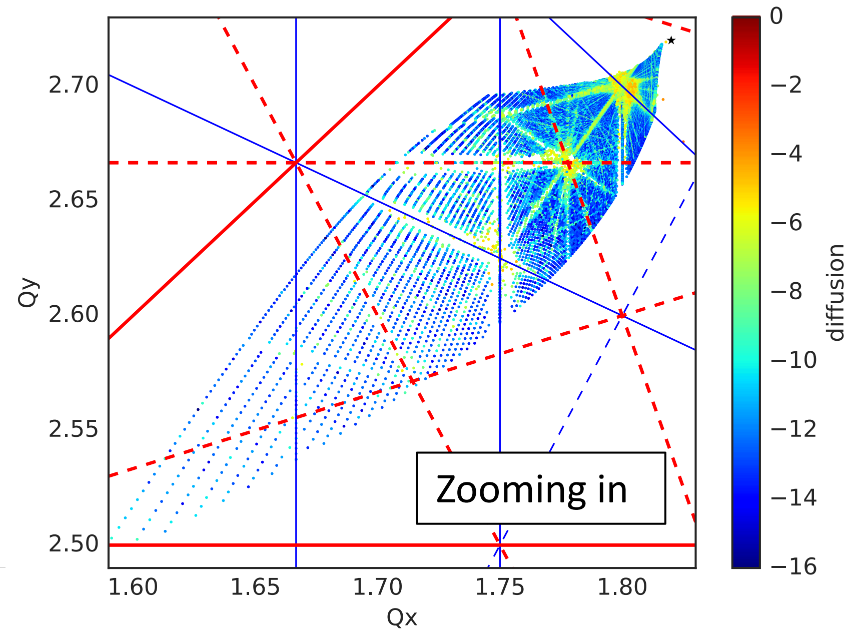


A more detailed sight into the beam dynamics:

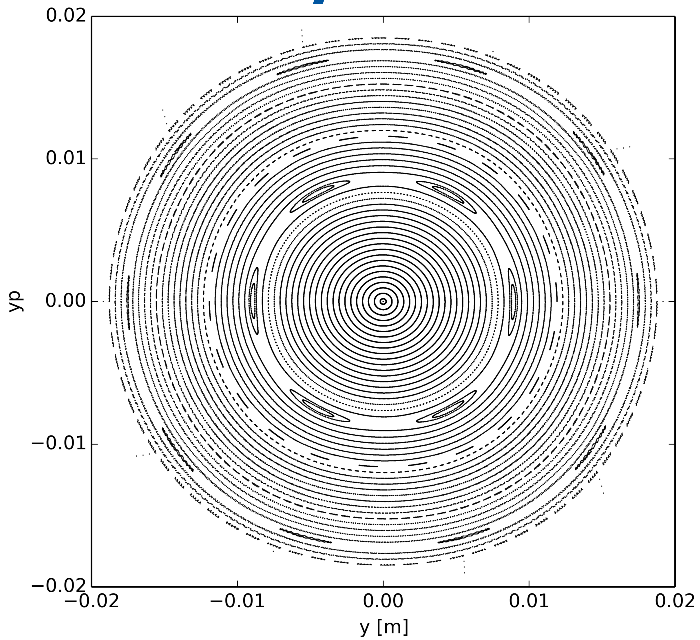


- Including space charge
- Nominal working point
- Chroma corrected to zero
  - ⇢ large tune spread as predicted
  - ⇢ many high-order resonances excited

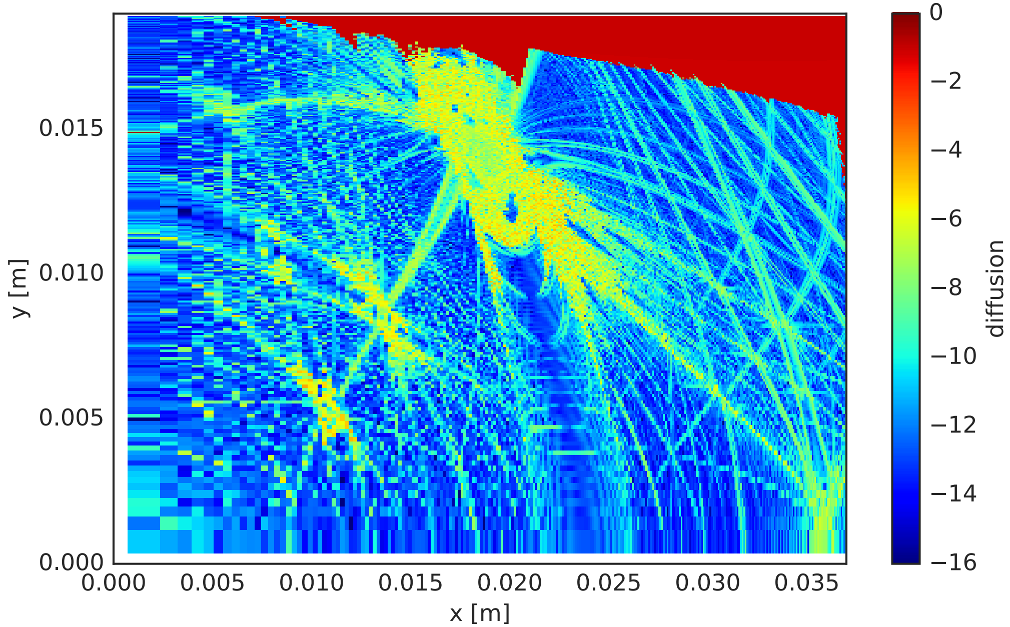


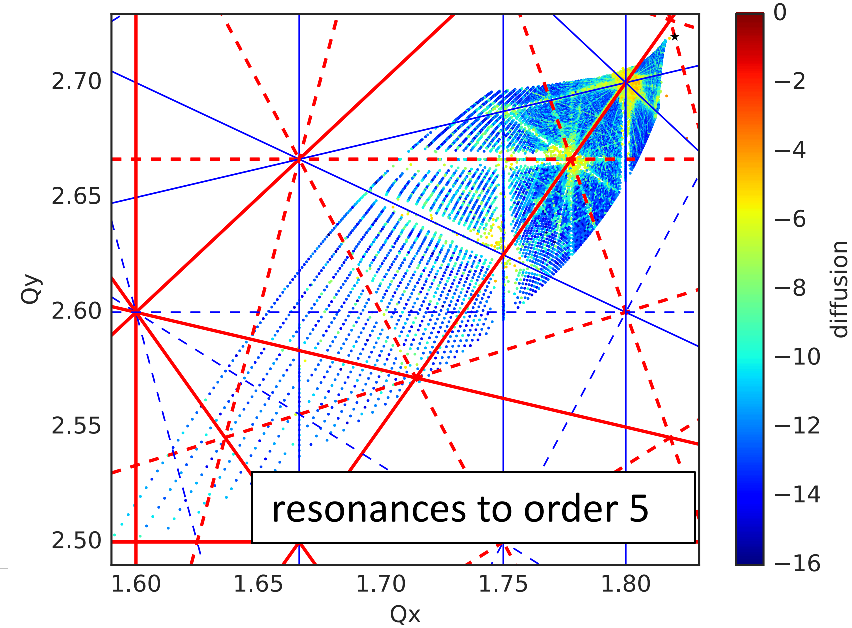


A more detailed sight into the beam dynamics:



- Including space charge
- Nominal working point
- Chroma corrected to zero
  - ⇢ large tune spread as predicted
  - ⇢ many high-order resonances excited

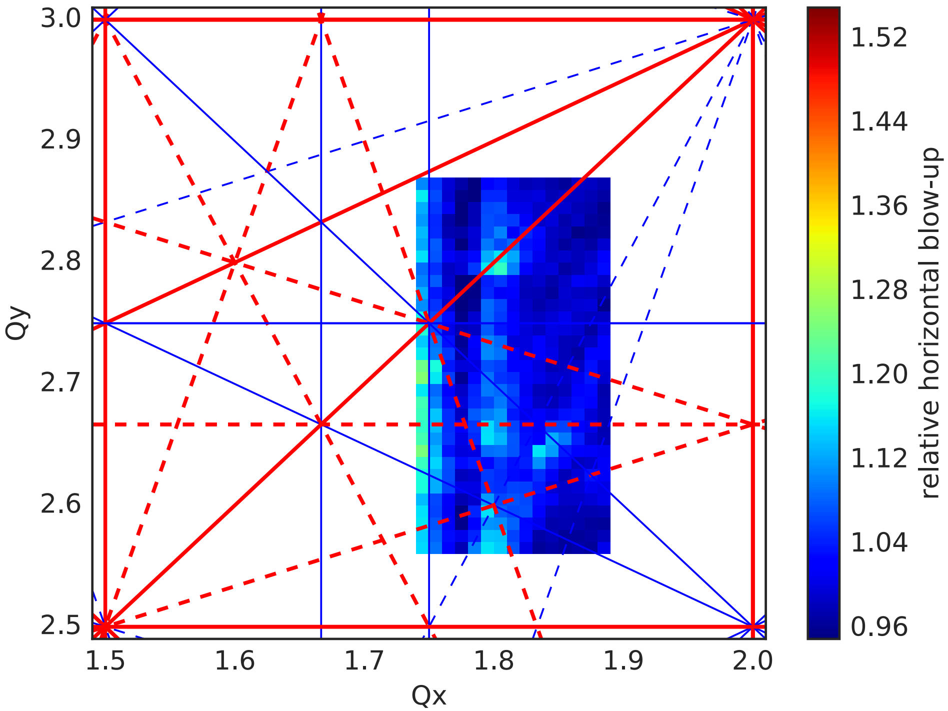


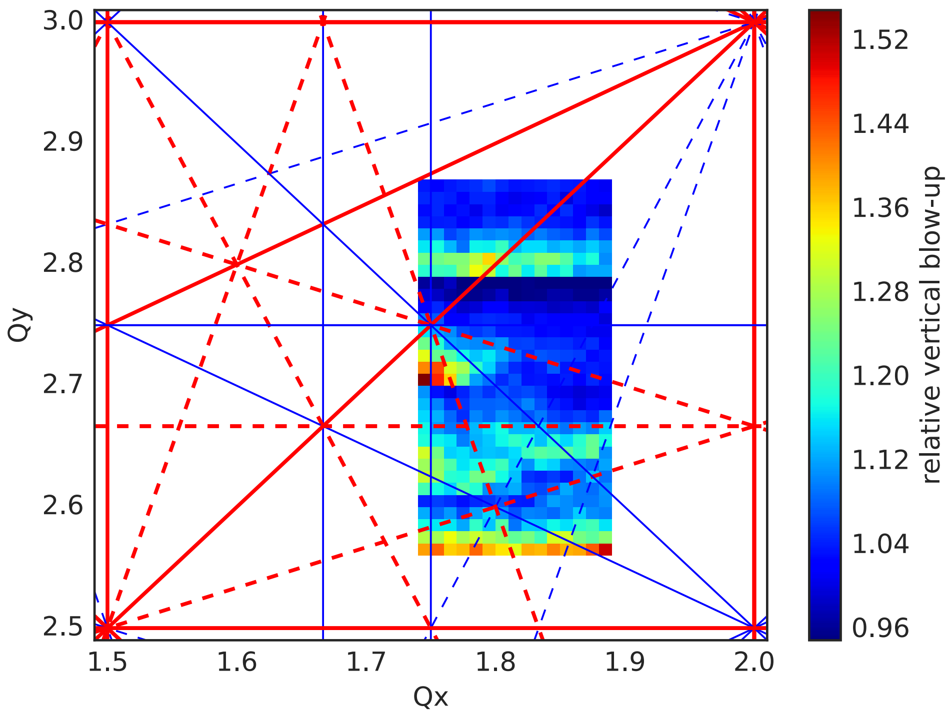


Tune Scan Simulations: emittance blow-up

- Tracking studies for long storage times (2e5 turns = 0.55 s) as typically done during LEIR experiments

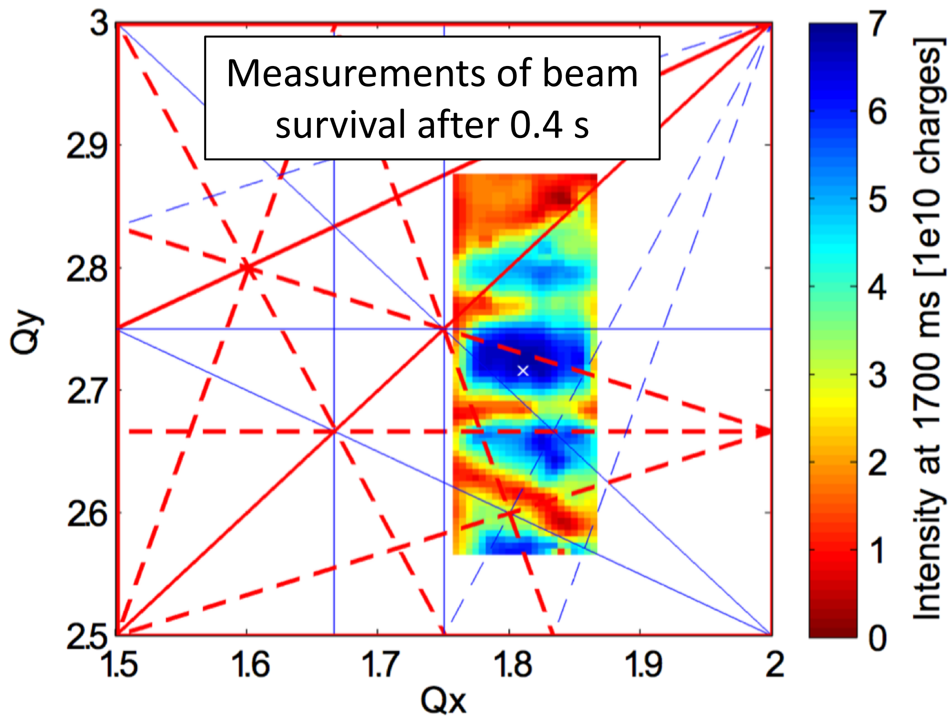
- Horizontal and vertical emittance blow-up observed due to several resonances

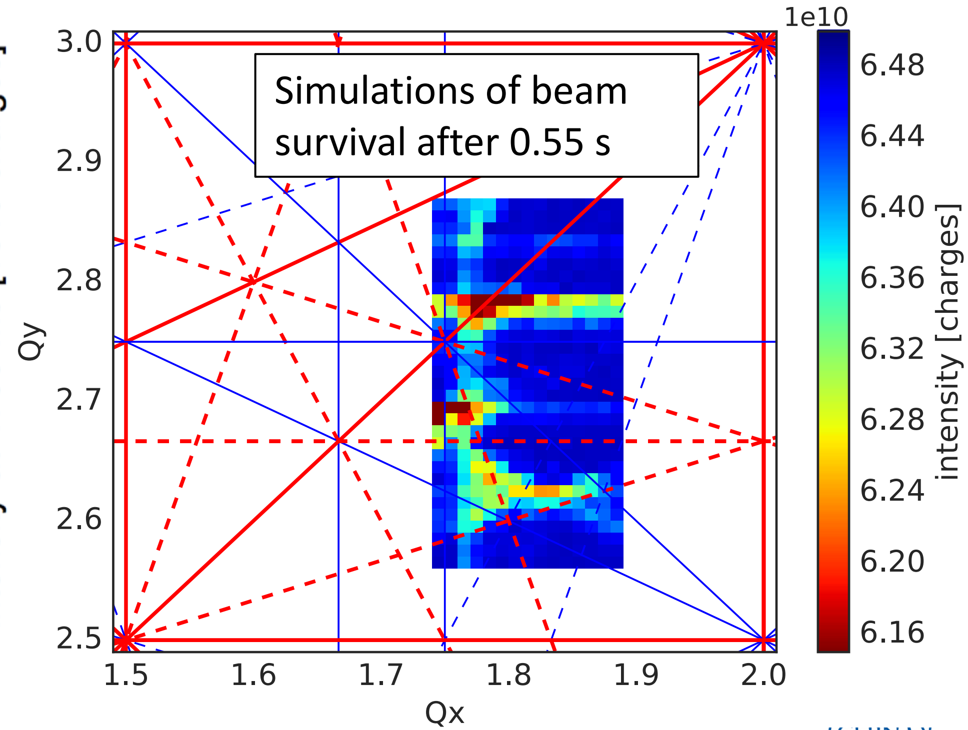




Tune Scan Simulations: intensity

- Tracking studies for long storage times (2e5 turns = 0.55 s) as typically done during LEIR experiments
- Horizontal and vertical emittance blow-up observed due to several resonances
- Losses in qualitative agreement with measurements

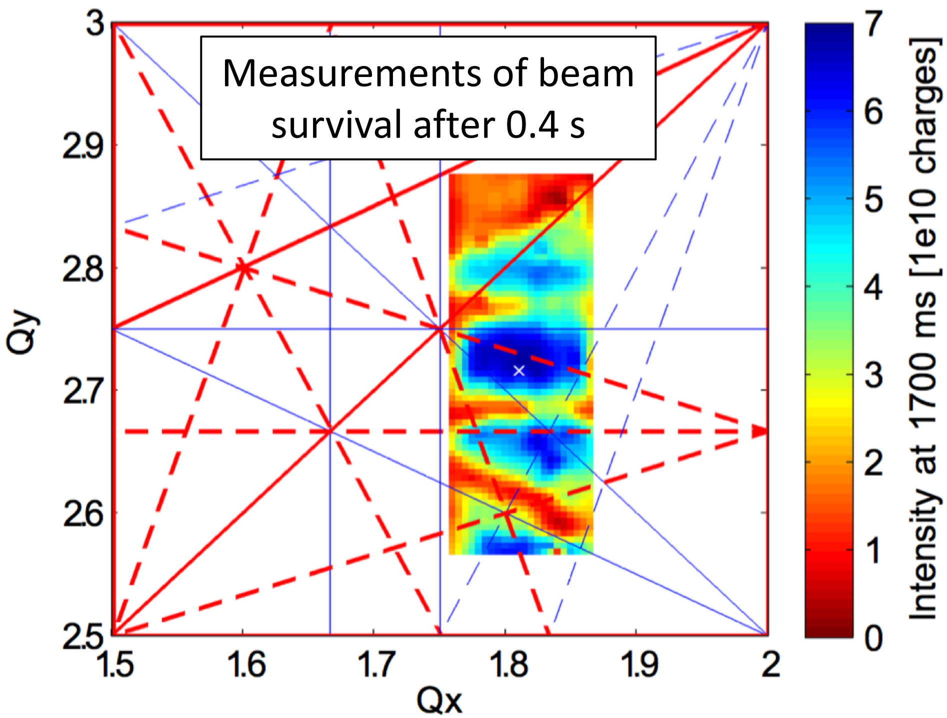


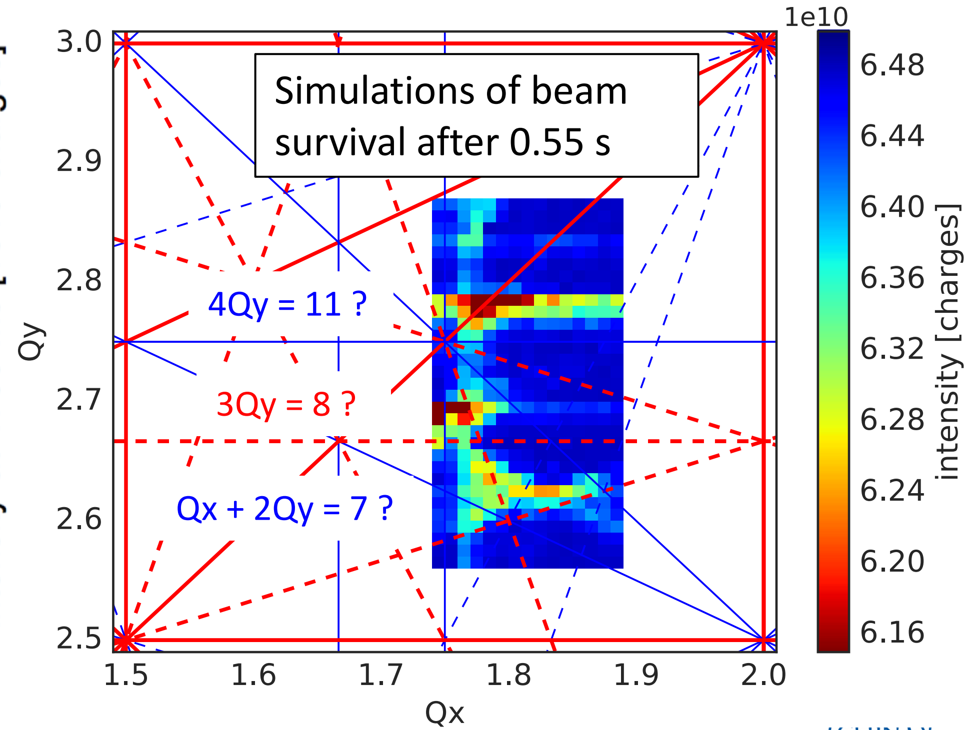


H. Bartosik, S. Hancock, A. Huschauer, V. Kain, CERN, Geneva, Switzerland
Proceedings of HB2016, Malmö, Sweden

Intensity Measurements vs. Simulations

- Tracking studies for long storage times (2e5 turns = 0.55 s) as typically done during LEIR experiments
- Horizontal and vertical emittance blow-up observed due to several resonances
- Losses in qualitative agreement with measurements

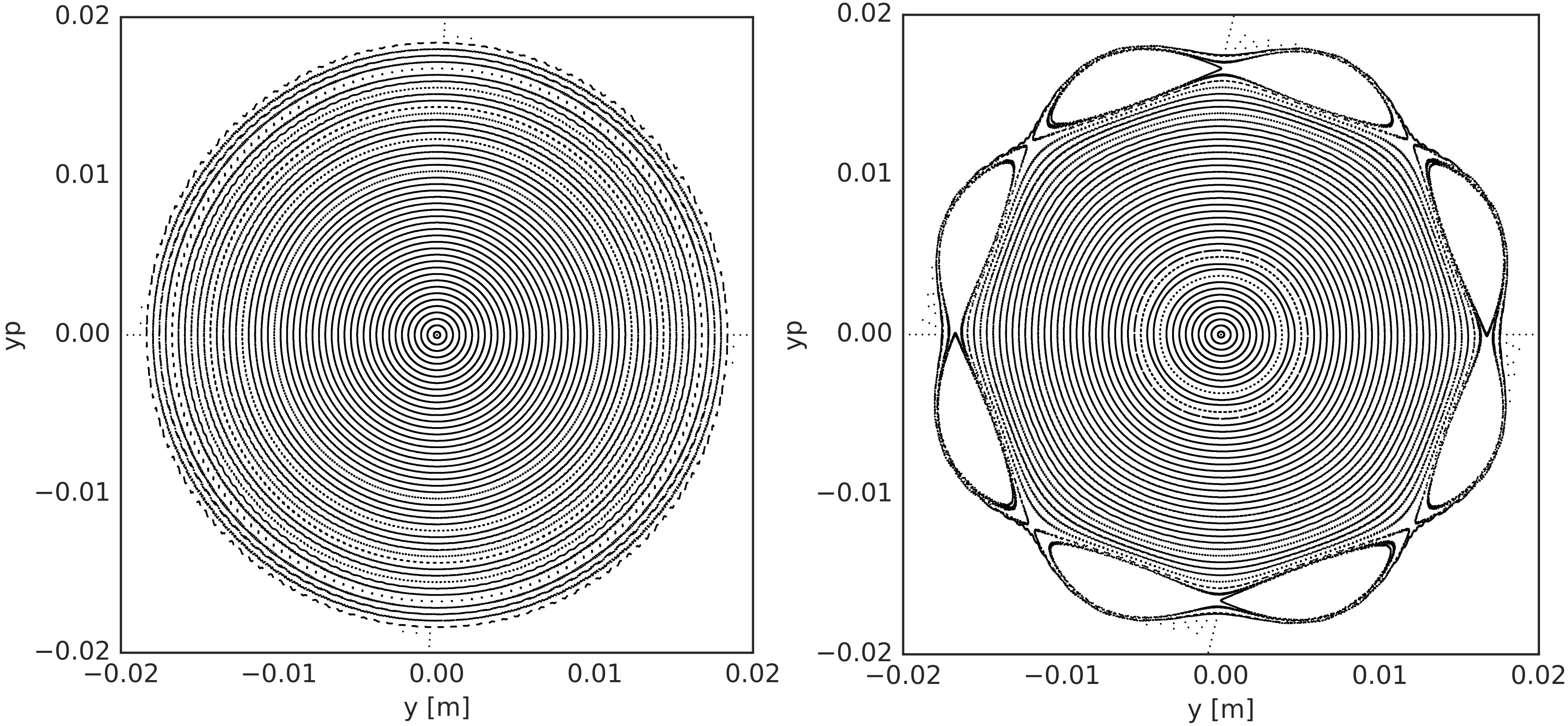




H. Bartosik, S. Hancock, A. Huschauer, V. Kain, CERN, Geneva, Switzerland
Proceedings of HB2016, Malmö, Sweden

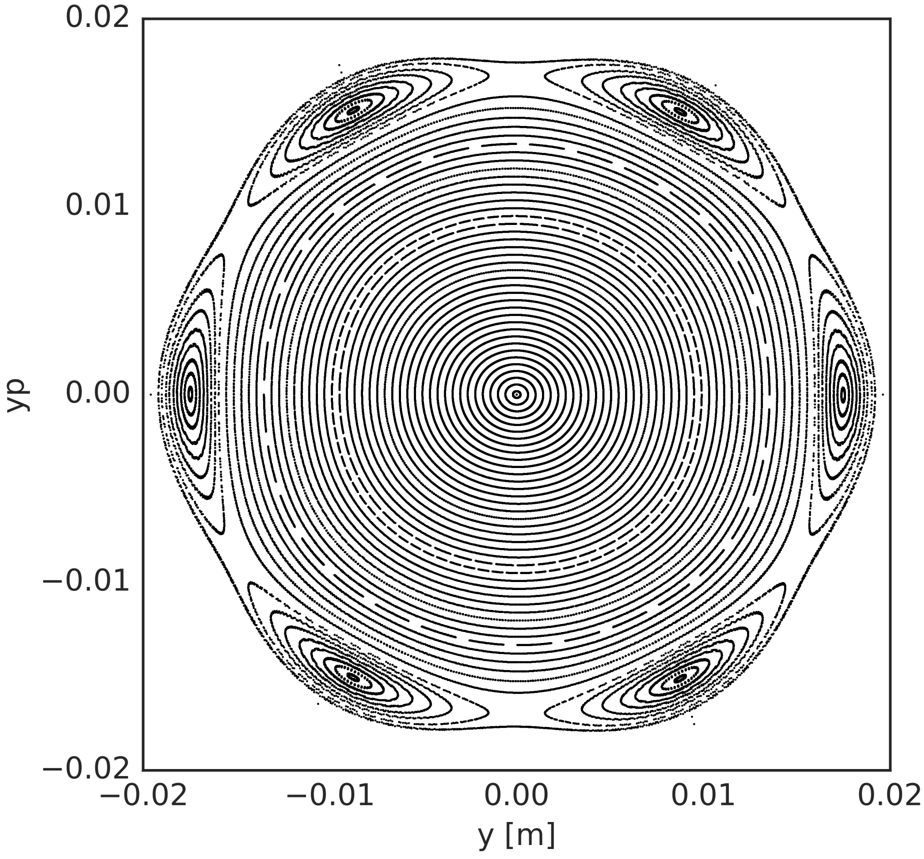
Resonance at Qy = 2.75

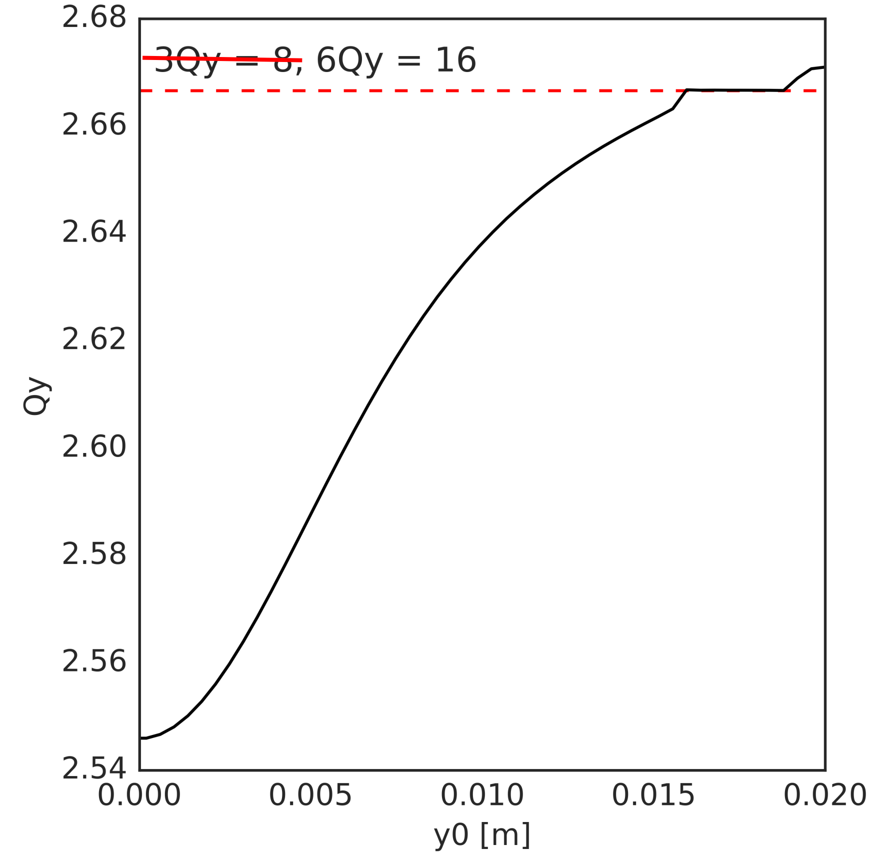
- Fringe fields from quads could excite 4th order but not systematic on periodicity 2
- No sources for excitation of 8th order resonance in the model, except space charge



Resonance at Qy = 2.66

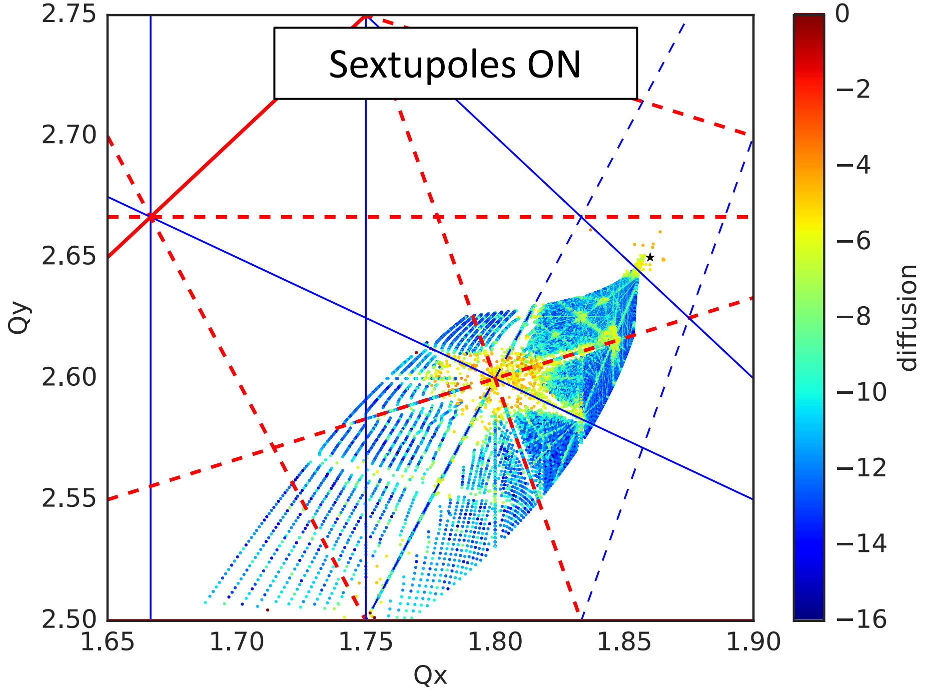
- No sources for excitation of 3rd order skew resonance 3Qy = 8 in the model
- 6th order resonance 6Qy = 16 driven by space charge

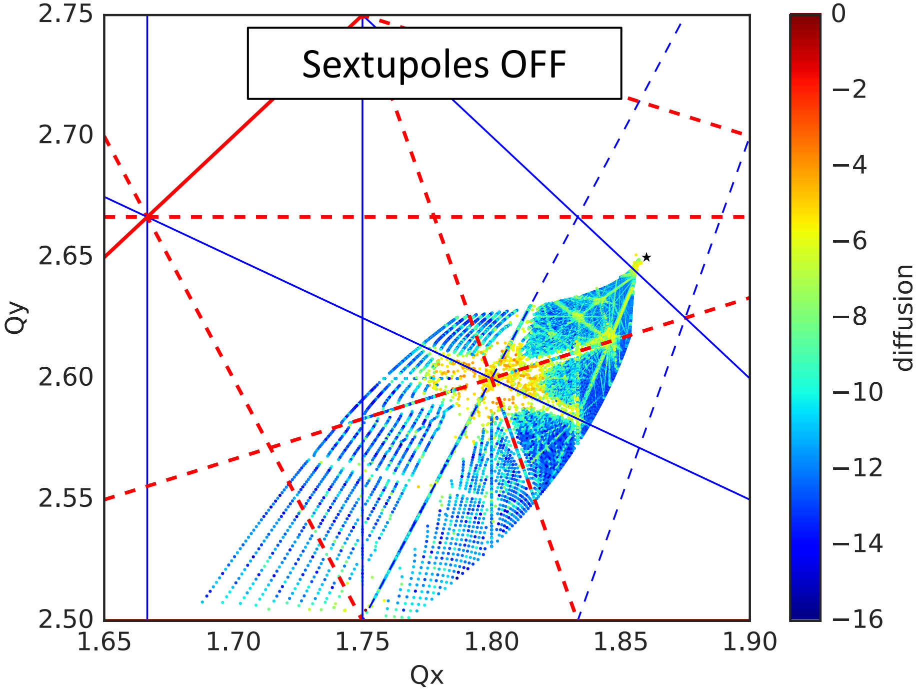




Resonance Qx + 2Qy = 7?

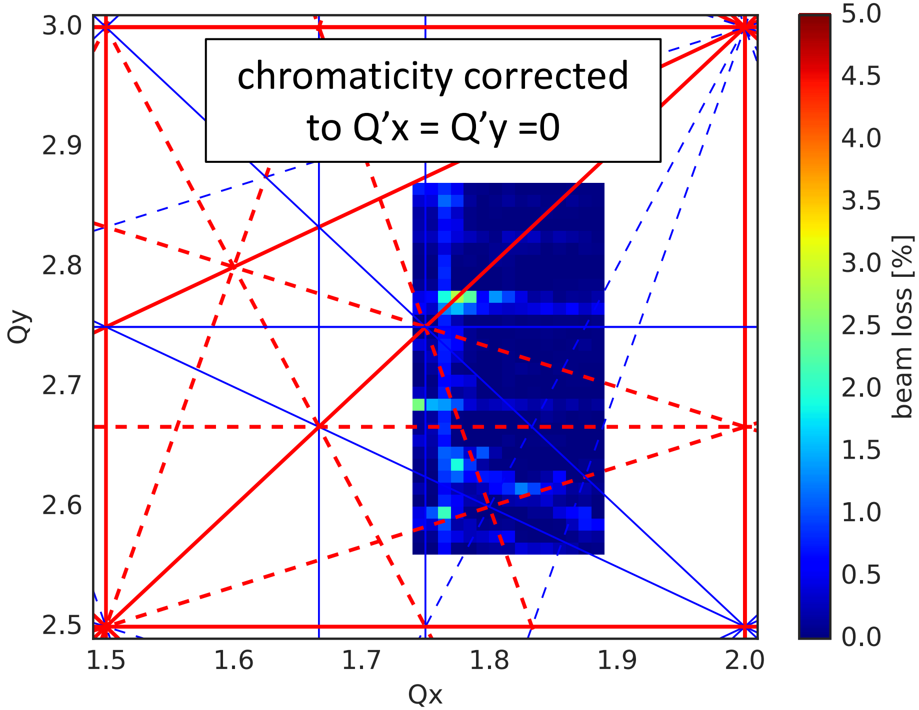
- FMA from tracking a single particle with dp/p =0
- Sextupoles do not change the excitation of this resonance (non-systematic for periodicity = 2), thus we suspect it is actually a 6th order SC-driven resonance: 2Qx + 4Qy = 14. However in machine studies (periodicity 1) could be partially compensated with the use of sextupoles.

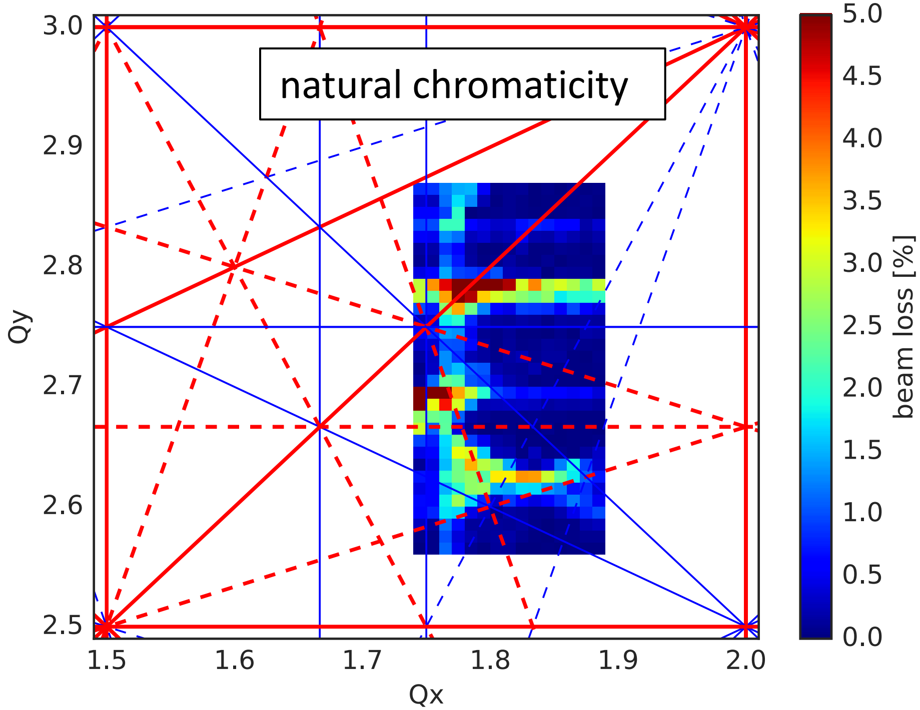




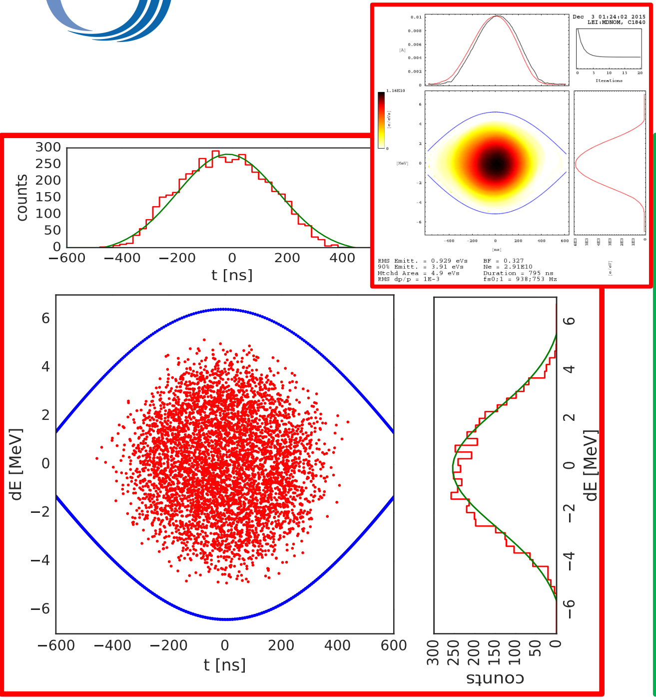
Effect of chromaticity

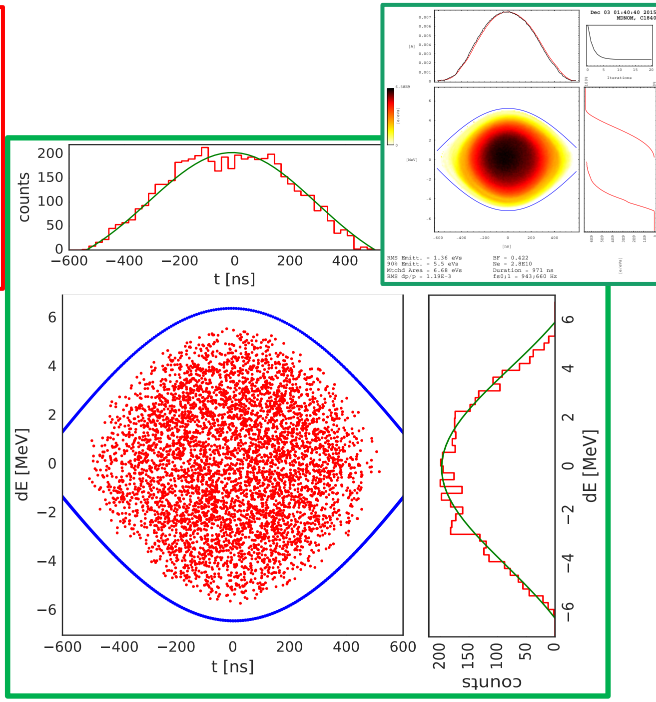
- Higher losses due to additional tune modulation from chromaticity (resonance crossing)

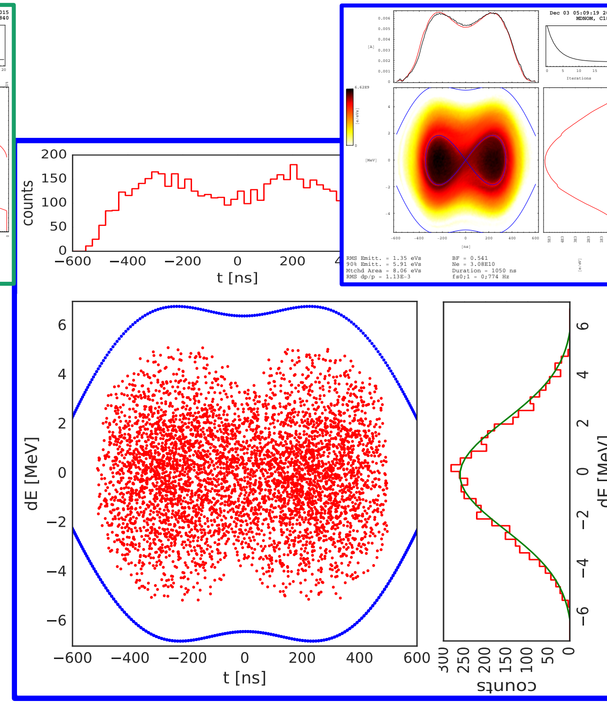




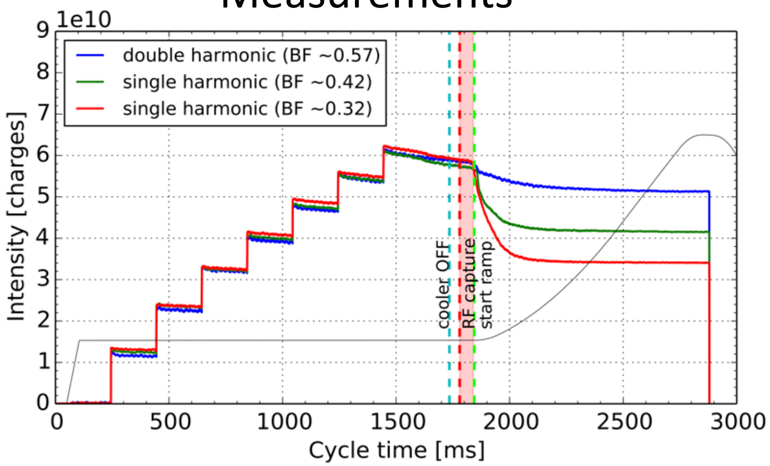
Effect of longitudinal distribution



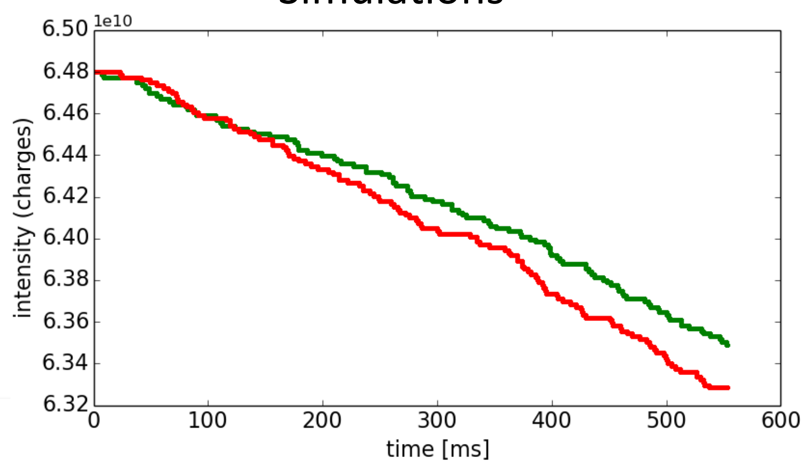




Measurements



Simulations



Conclusions and next steps

- First space charge simulations for LEIR
- Very simple (ideal) lattice model with periodicity 2 and no magnetic field errors
- Almost perfect linear dynamics gets completely messed up (many high-order resonances excited) when space charge is considered
- Simulations with space charge in pretty good qualitative agreement with measurements: we could identify some 6th and 8th order excited resonances driven by space charge, which produce losses
- Similar analysis for the new optics
- Including Electron Cooler perturbation to the lattice
- Careful quantitative comparison of simulations and measurements with the Xe beams

LHC Injectors Upgrade

Thank you for your attention!