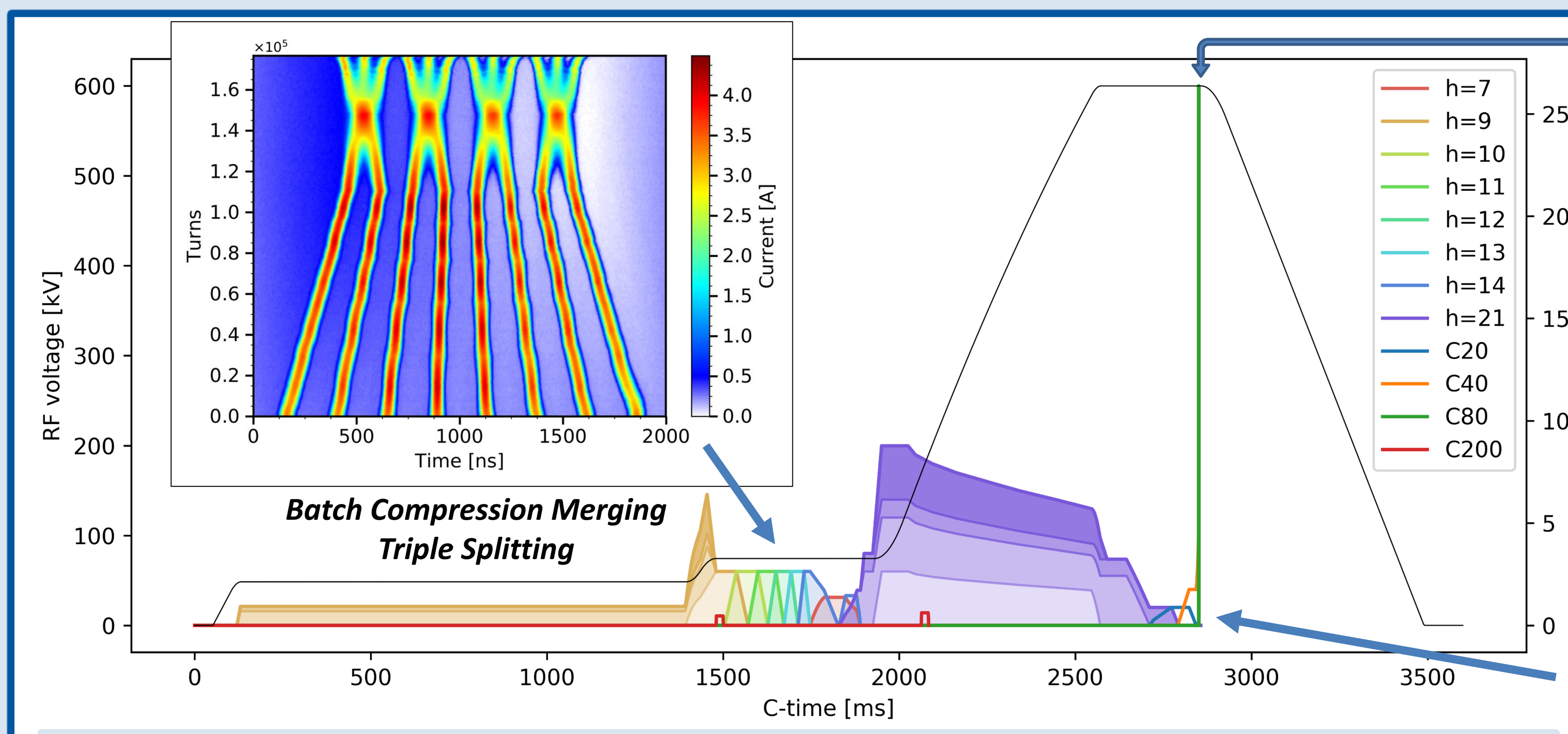
Optimization of the rf manipulations in the CERN PS

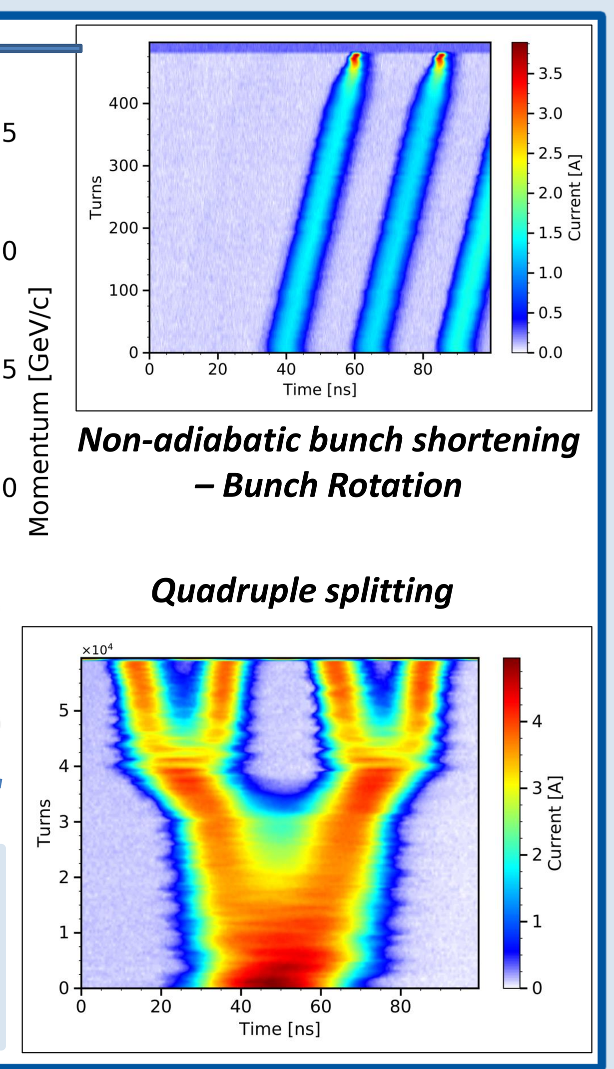
A. Lasheen
CERN, Geneva, Switzerland

Abstract

The Proton Synchrotron (PS) at CERN is part of the injector chain of the Large Hadron Collider (LHC). In the PS, the beam undergoes many rf manipulations including bunch splitting, merging, blow-up, batch compression and bunch shortening. Presently, the settings for the rf manipulations (amplitude and phase) are adjusted manually in order to minimize the bunch-by-bunch variability, with a present performance of +-10% variation in bunch length and intensity along the bunch train at PS extraction. Further decrease of the bunch-by-bunch variability would allow to reduce the losses during beam transfer from the PS to the Super Proton Synchrotron (SPS), the last injector before the LHC, and improve the beam quality in the LHC. To minimize the bunch-by-bunch variability more systematically, up to the limit defined by beam loading effects, possible means of process optimization are under study and are presented in this poster. Eventually, the goal is to progressively include machine learning concepts on top of the optimization tools to minimize the number of iterations necessary to reach the optimum.

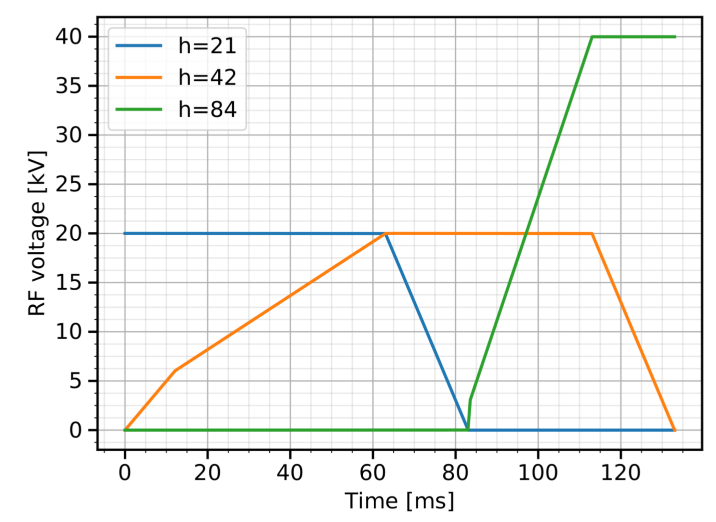
Acceleration ramp and rf manipulations in the CERN PS





- The PS is composed of 6 rf systems, 25 rf cavities, allows many rf manipulations
- The rf voltage/phase is manually adjusted to obtain even bunches at PS extraction
- ➢ Optimization and machine learning can help to systematize and improve the beam quality

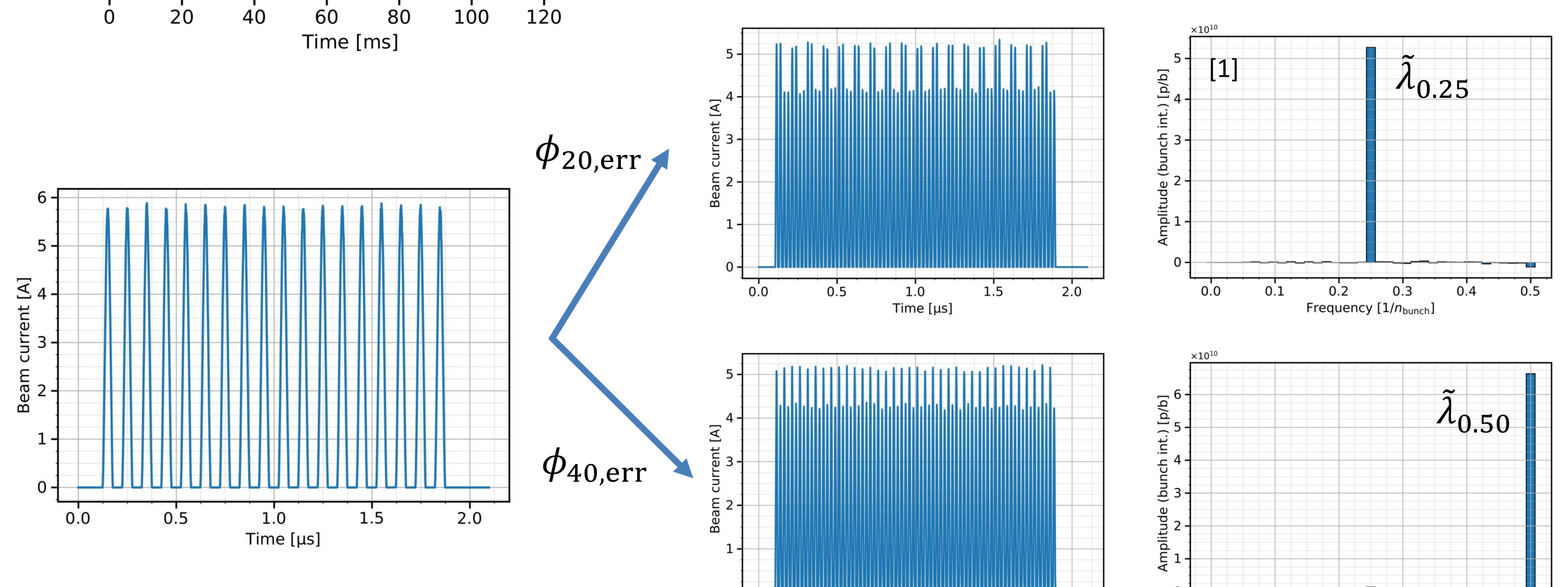
Optimization of quadruple splitting



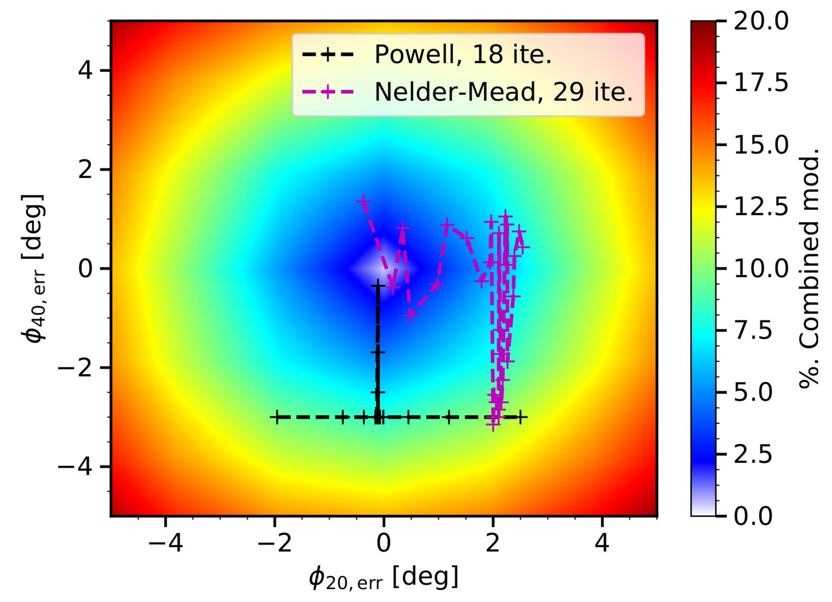
- The parameters to optimize are the phases at h=42 (20 MHz) and h=84 (40 MHz), the two are defined and linked as

$$\phi_{20} = \phi_{20,\mathrm{err}}$$
$$\phi_{40} = 2\phi_{20} + \phi_{40,\mathrm{err}}$$

- ➢ The effect on the beam (bunch length and intensity variation) can be evaluated from Fourier harmonics



[1] *LHC Beams in the PS: Reliability and Reproducibility issues, S. Hancock, LHC Performance Workshop, Chamonix (2003)*

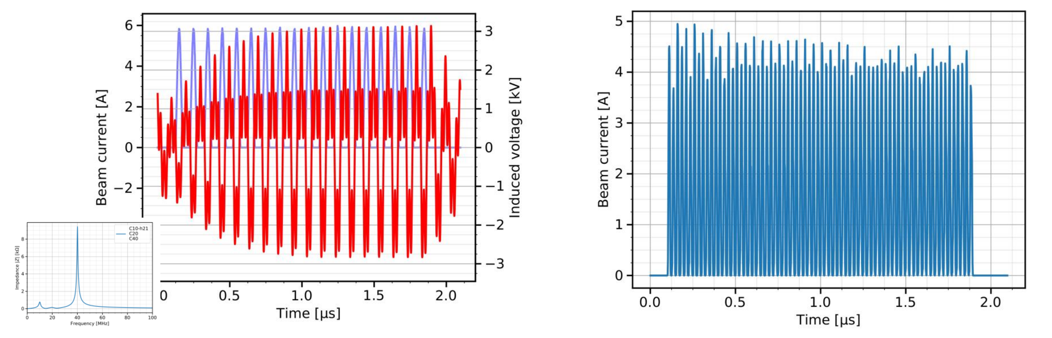


- The Fourier harmonics can be combined to optimize both steps of the splitting at the same time by minimizing

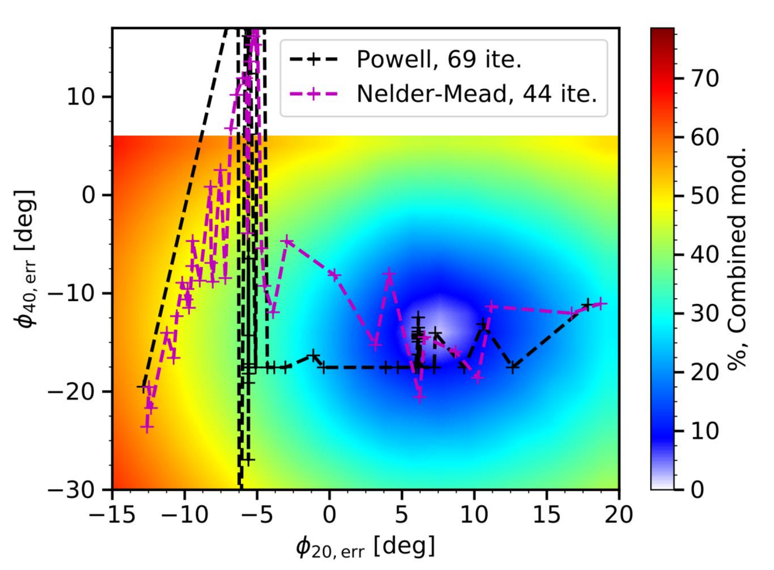
$$\tilde{\lambda}_c^2 = \tilde{\lambda}_{0.25}^2 + \tilde{\lambda}_{0.50}^2$$

(same result for bunch length or intensity)

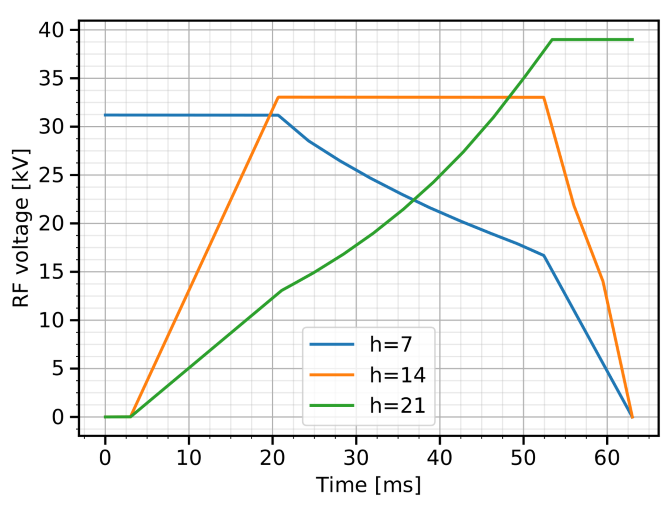
- ➢ Powell and Nelder-Mead optimizers were successfully applied. The number of iterations is however large (usual operation: <5 ite.)
- ➢ Reinforcement learning could allow to minimize the number of iterations



- Beam loading shifts the optimum phases and reduces the best achievable beam quality
- ➢ Machine learning should account for possible shot to shot variations and machine imperfections

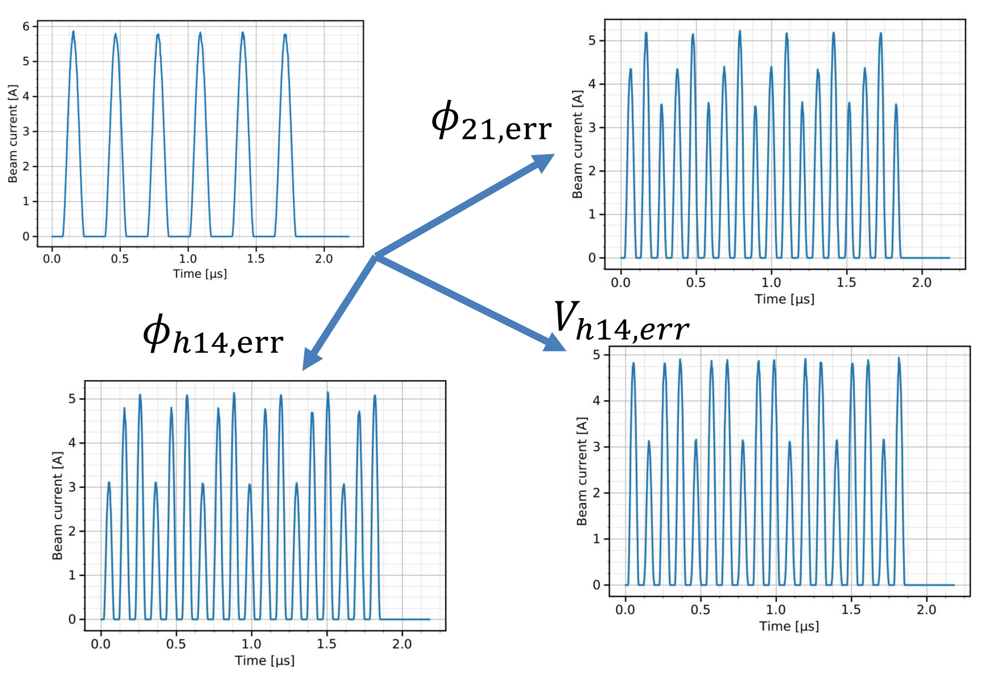


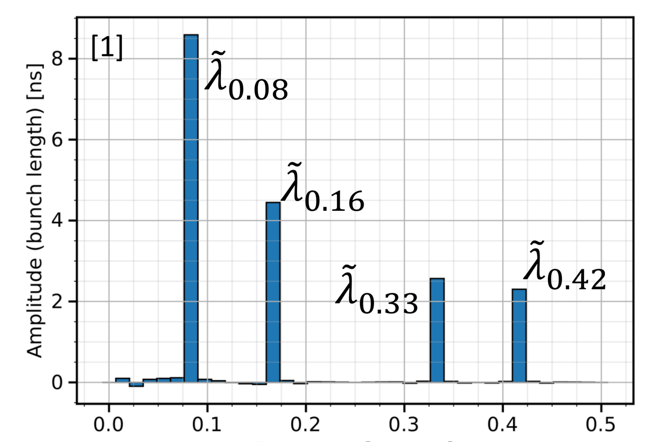
Optimization of triple splitting



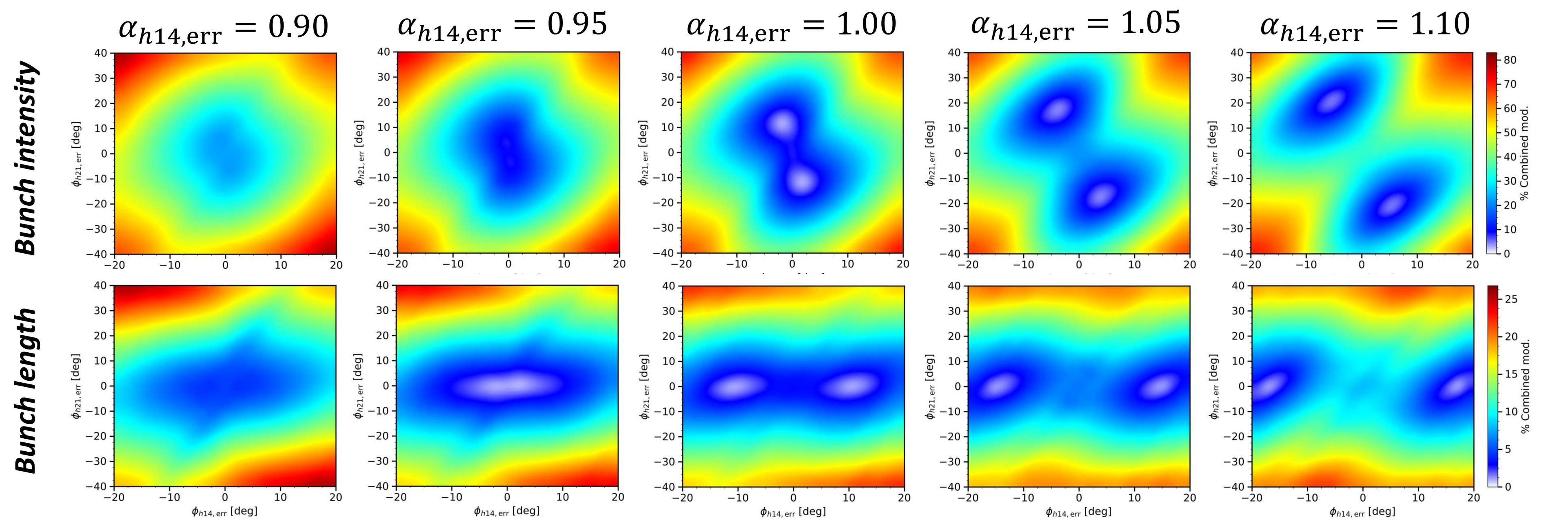
- The parameters to optimize are the phases at h=14, h=21 and the amplitude of the rf voltage of the intermediate step

$$\phi_{h14} = \phi_{h14,\mathrm{err}}$$
$$\phi_{h21} = \phi_{21,\mathrm{err}}$$
$$V_{h14} = \alpha_{h14,\mathrm{err}} \cdot V_{h14,\mathrm{prog}}$$





- Fourier harmonics assuming ideal quadruple splitting at top energy
- ➢ All harmonics are increased by the three parameters, difficult to disentangle



- The Fourier harmonics can be combined to optimize all parameters of the triple splitting at the same time by minimizing

$$\tilde{\lambda}_c^2 = \tilde{\lambda}_{0.08}^2 + \tilde{\lambda}_{0.16}^2 + \tilde{\lambda}_{0.33}^2 + \tilde{\lambda}_{0.42}^2$$

- ➢ Powell and Nelder-Mead optimizers were applied, but the outcome of the optimization depends on the initial condition (finding local minima), and the optimization strategy (intensity, bunch length, or combination of both)
- ➢ Beam loading issues also apply, optimization routines may need better and/or more observables for safe convergence including machine imperfections
- ➢ Would machine learning complement optimization routines to alleviate these issues?

Conclusions and acknowledgements

Optimization routines were successfully applied in particle simulations in the CERN PS to adjust the splittings, and can serve as basis to introduce machine learning routines. Progress in understanding of potential of machine learning could be later applied to more complex rf manipulations like bunch rotation (4-5 parameters) and controlled longitudinal emittance blow-up (non-linear model and more complex definition of optimum). The following people are gratefully acknowledged: Simon Hirlaender for introduction on the methods used in the CERN LEIR, Steve Hancock and Rodolphe Maillet for introduction on the Fourier harmonics analysis and implementation in operation, Heiko Damerau and Elena Shaposhnikova for fruitful discussions.