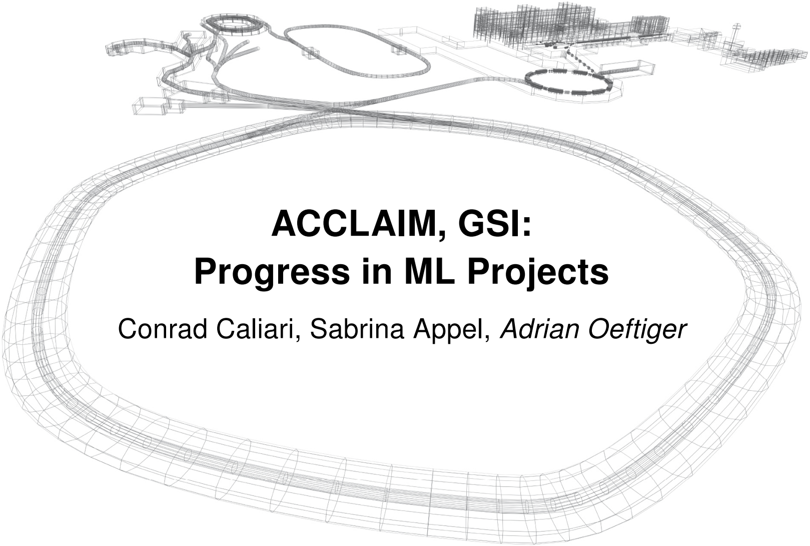


ACCLAIM, GSI:
Progress in ML Projects

Conrad Caliari, Sabrina Appel, *Adrian Oeftiger*

Beam loss prediction for FAIR SIS100 heavy-ion synchrotron

- currently with detailed 3D beam dynamics simulations in `SixTrackLib` and `PyHEADTAIL`
  - thin-lens symplectic tracking
  - using GPUs: self-consistent (2 days) + frozen space charge (2min)
  - magnet error model based on cold bench measurements

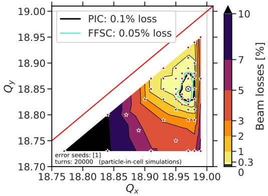


Figure: PIC + magnet errors sims. (natural chroma)

- chromaticity correction in SIS100: limited dynamic aperture
  - reason: only few sextupole magnets (24+18)
  - classical 2-family correction approach problematic
  - ⟶ strong losses in case of heavy-ion beams

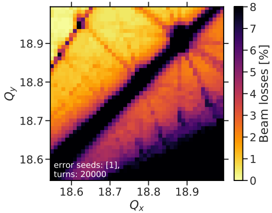
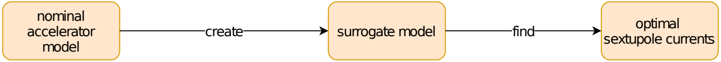


Figure: Corrected chroma sims. (no SC, no errors)

Goals

Goals of ML studies:

- establish ML trained surrogate model for beam loss simulations
- optimise chromaticity correction with more than 2 sextupole families
  - $\Longrightarrow$ minimise beam loss / maximise dynamic aperture
- exploit physics-inspired NN (PINN) to improve error model:
  - set up lattice with expected magnet error model (bench measurements)
  - use beam-based measurements (BPM data) to train PINN
  - extract improved magnet error model from trained PINN
  - $\leadsto$ later include space charge into approach



(Figure taken from thesis proposal talk by Conrad Caliari)

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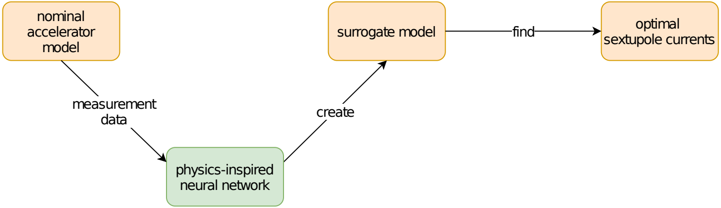
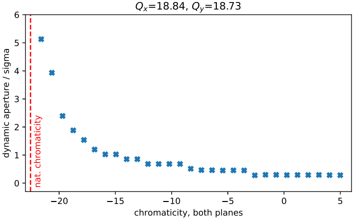
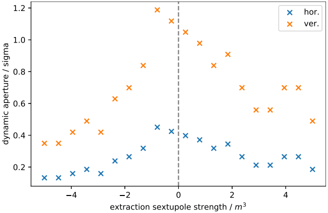


(Figure taken from thesis proposal talk by Conrad Caliari)

Chromaticity Correction

- correct chromaticity, avoid small dynamic aperture





- divide sextupoles into N families
- approximate dynamic aperture : $\mathbb{R}^{N-2} \to \mathbb{R}$ via surrogate model

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(Slide taken from thesis proposal talk by Conrad Caliari)

PINN: First Results

Progress in PINN:

- extended Taylor map approach by IA20[1] to 6D treatment
- implemented alternative PINN structure: intrinsically symplectic approach with Lie maps based on separable Hamiltonian

  $\Longrightarrow$ quadrupole errors can be learned with Lie approach PINN, success!

  - currently working on sextupole errors, in line with goal of chromaticity correction

[1] A. Ivanov, I. Agapov, PRAB 2020

PINN: Quadrupole Error Learning

Thin-Lens Model

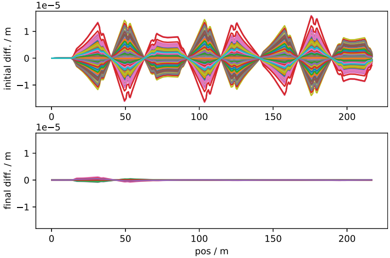

Figure: Difference in predicted and actual particle positions.

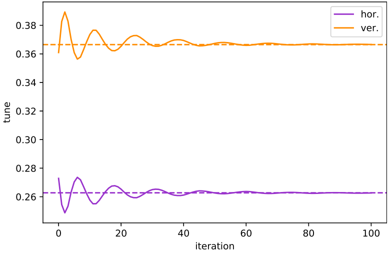

Figure: Tune evolution during training.

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(Slide taken from thesis proposal talk by Conrad Caliari)