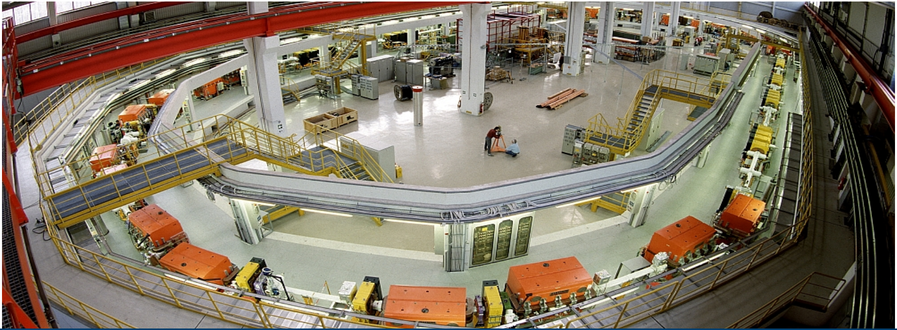


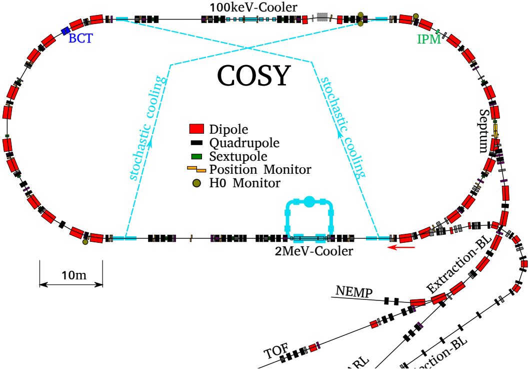
COSY MODEL-MACHINE OPTIMIZATION

For IPAC’21

26.05.2021 | I. Bekman, J. Hetzel | IKP-4, Forschungszentrum Jülich GmbH, Jülich, Germany

Model: COSY in MAD-X

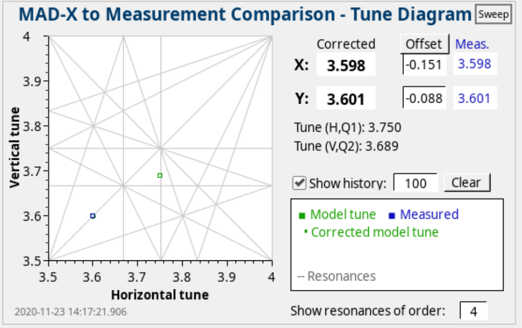
- COoler SYnchrotron (COSY)
- (un-/) polarized p+ and deuterons
- MAD-X lattice from Accelerator_DB [2] [5] [6]
- About 1500 parameters:
  - (6x) * (BPMs+Viewer)
  - + (8x) * (Steerer + Quads + Sexts)
  - + (8x) * Dipoles
  - + Dipole kicks



- Use parametrization to-the-best-knowledge - from surveys, BBA, etc.

Motivation: Model vs. Machine

- Model prediction of the machine is imperfect
- Reliable for relative changes
- Discrepancy (offsets) for absolute values



- Improved Model would allow easier operation and might in turn indicate issues with the physical Machine, which are difficult to assess otherwise (element displacements, rotations)

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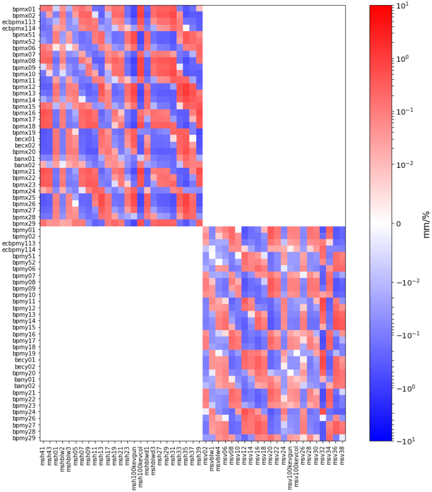
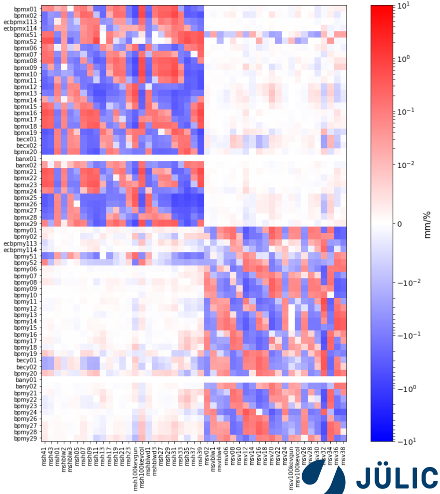
Motivation: Model vs. Machine - ORM

- ORM: Orbit change for each steerer (67x BPMs on Y axis, 47x on X axis)
- e.g. BP#2: Simulated vs. Measured





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Machine: Measurements

The goal of this optimization

Find Model parameters to minimize the difference between observables measured at the **Machine** and simulated from the **Model**

- Measurements of several observables at a few benchmark points
- During beam time 2021KW05 (CBAC A014.3) [4]
  - Pure: minimal setting to achieve stable beam conditions
  - Production: optimized tune, dispersion, orbit correction, beam lifetime

Benchmark Points

- 3000MeV/c pure
- 3000MeV/c prod
- 970MeV/c pure
- 970MeV/c prod
- 600MeV/c prod

Observables

→ for each Benchmark Point

- Tune Q1,Q2 - weight 2
- Orbit Response Matrix (ORM) - weight 1

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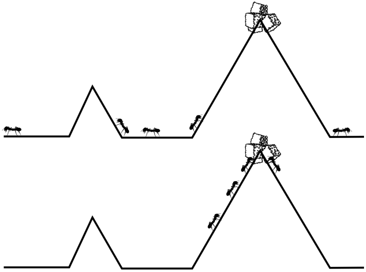
Genetic Algorithm (GA)

- Due to complex correlations and vast phase-space of parameters Genetic algorithm was chosen
- DEAP framework [1] used for it's flexibility and multi-objective capability
- Exploration vs. Exploitation ($\rightarrow$)



multi-candidate solutions to avoid local optima

- Achieved with a set of solutions, applying stochastic Changes, Evaluating new solutions and Choosing a subset of better solution iteratively

GA: Individual and Fitness

- Fittest: minimum difference between simulation and measurement

Individual	Fitness
a set of model variables (see below)	Σ weighted absolute (simulated - measured) $\forall$ observables $\forall$ benchmark points

Type	Correction	Lim.	Unit	Idx.
Dipole	shortening kick	[-3,3]	mrad	0
Quad	roll (S-axis)	[-6,6]	mrad	25
Quad	displacement X	[-1,1]	mm	81
Quad	displacement Y	[-1,1]	mm	137
Quad	displacement S	[-20,20]	mm	193

249 variables $\Rightarrow$ i.e. genes

- Eval. 5x MAD-X sim, and 5x ORM calc $\Rightarrow \mathcal{O}$(1sec wall-time) [3]

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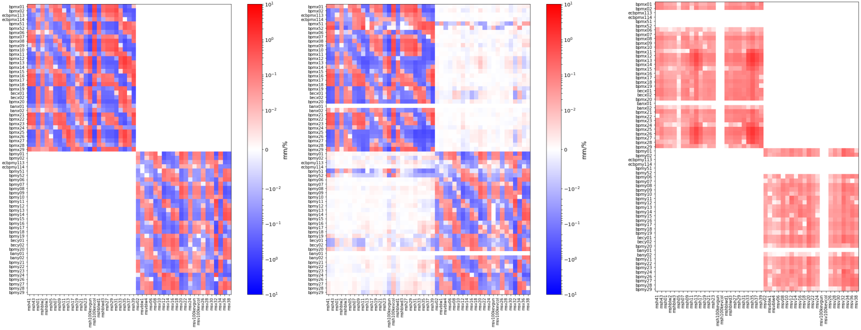
GA: Fitness from ORM

- XY-quadrants not simulated, likewise some BPMs without signal during measurement, thus not considered in fitness.
- e.g. BP#2: Simulated vs. Measured, abs(Difference)



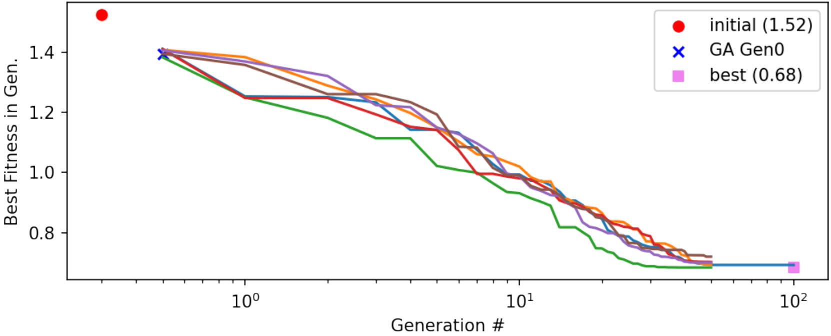
sim_{init} $meas$ $|meas - sim_{init}|$

- Normalize ORM part of the fitness by the number of entries

GA: Execution

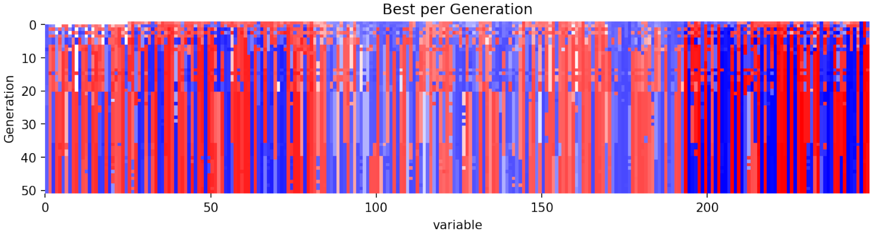
- # Generations = 20..100
- # Individuals = 100..1000
  - pre-Mutate initial Population
- Selection Tournament
  over 5% of population

- Crossover (uniform)
  0.5 p./indi., 0.9 p/gene
- Mutation (custom)
  0.4 p./indi.,0.5 p./gene
  - Gaussian within gene limits
    (3 sigma)

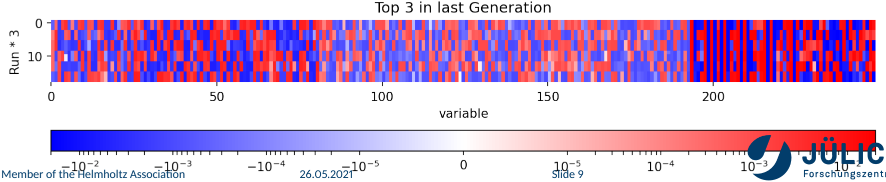


GA: Results

- GA for all variables - visualization of best setting in each generation



- Comparison of top 3 settings for 6 runs
- Similar fitness reachable with many different configurations
- Displacement in S (variable idx.$>=$ 193) is comparable across runs

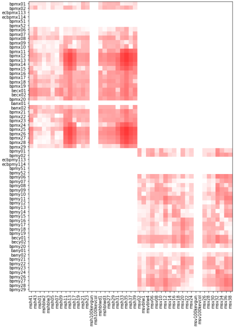


GA: Results - Improvement of ORM

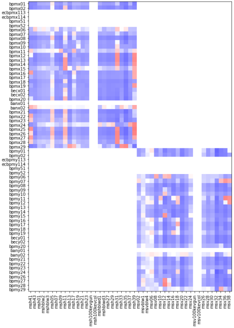
- e.g. BP#2: Initial discrepancy vs. Post-GA discrepancy, improvement

  (blue/white is better)

$|meas - sim_{init}|$



$|meas - sim_{best}|$

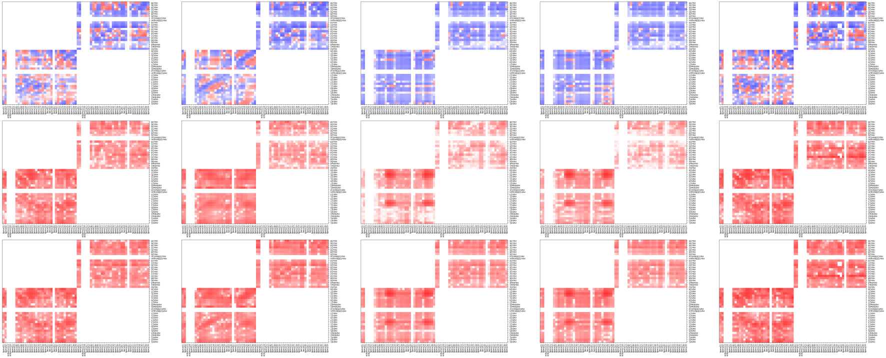


$|meas - sim_{init}| - |meas - sim_{best}|$

- Improvement of correspondence of the Model to the Machine
- Not all parameters were free, unlikely to decimate all discrepancy

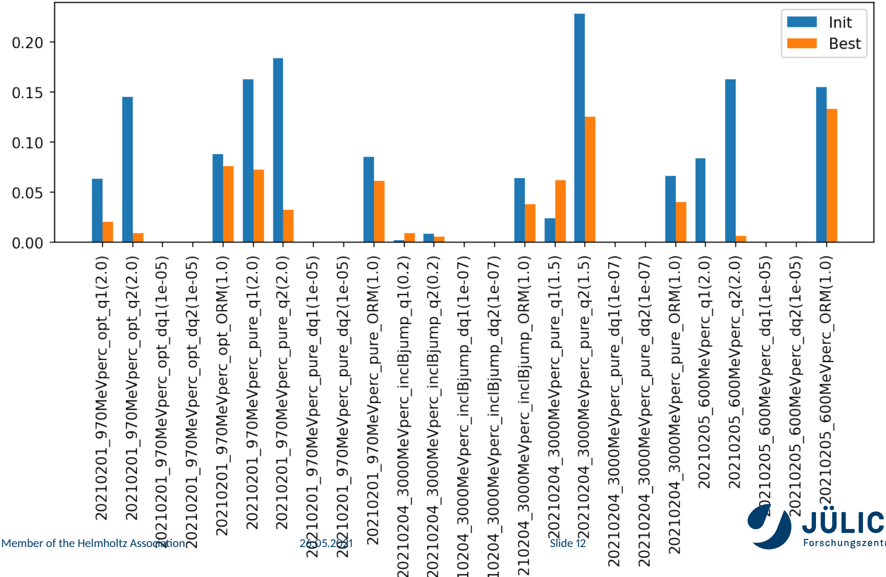
GA: Results - Improvement of ORM

- improvement over all Benchmark Points, some more, some less



GA: Results - Improvement of Model Prediction

- improvement over all Benchmark Points, some more, some less



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Summary and Outlook

- COSY Model and Measurements were used to improve the simulation
- Genetic Algorithm was used for the optimization
- Simultaneous optimization against 5 optics and several observables

Outlook

- Consider more measurement points and observables (Chromaticity, Orbit)
- Use ORM Simulation (vs. calc) to consider full ORMs (XY-quadrants)
- Include more variables, all rotations, effective element lengths, steerer calibration
- Parametrize correlations to reduce over-determination

Backup information

Contact

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References and Further Reading

[1] Fortini F.-A., et al. "DEAP: Evolutionary algorithms made easy.", Journal of Machine Learning Research, 2171–2175(13), Jul. 2012.

[2] Grote H., et al. "The MAD-X program (methodical accelerator design) version 5.05: User's reference manual.", CERN; `http://mad.web.cern.ch/mad`

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[4] Bekman, I., Hetzel, J. (2020). "COSY Orbit Control Studies", 12th Meeting of the COSY Beamtime Advisory Committee, Darmstadt (Germany).

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[6] Bekman, I., Hetzel, J. (2020). "Model-Related Applications", Annual Report 2020, Institut für Kernphysik, COSYJül-4427., Jülich, (Germany).