Optimising the NLK Injection using Reinforcement Learning

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Introduction: 4 Kicker bump

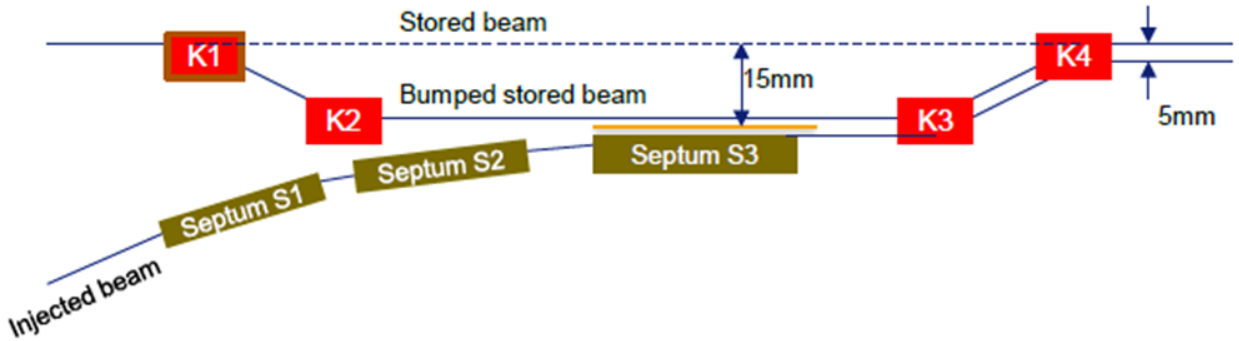

Figure 1: 4 Kicker bump, by [5]

Disadvantages:

- affects stored beam
- might cause the loss of stored electrons

Introduction: Non-linear Kicker Injection

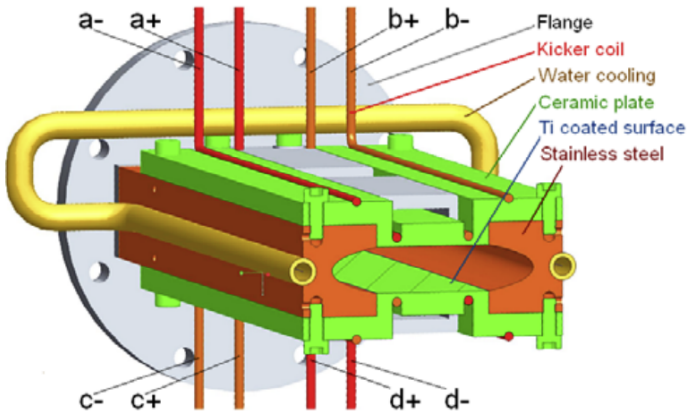

Figure 2: Kicker magnet structure by [3].

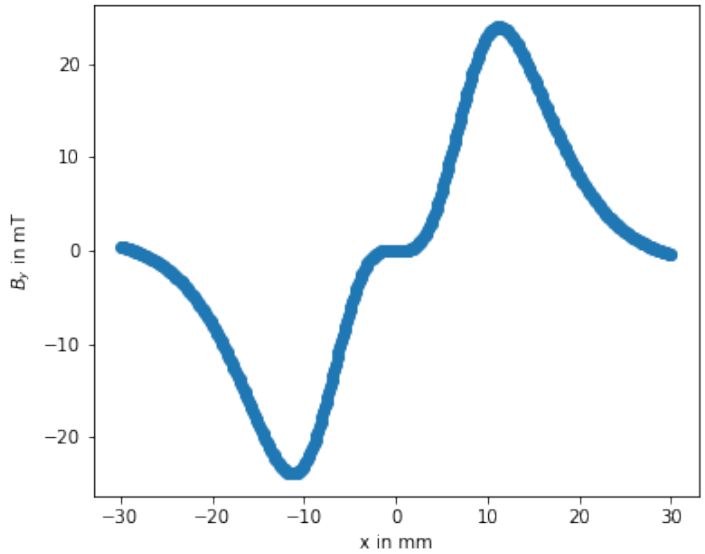

Figure 3: Kicker field strength plot.

- Advantages:
  - Only small effects on stored beam
- installed, but not used device (currently lower efficient)

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Problem Description

- Task: Find optimal NLK settings
- Goal:
  - Improve injection efficiency
- Steps:
  - Choose activation round and strength of NLK

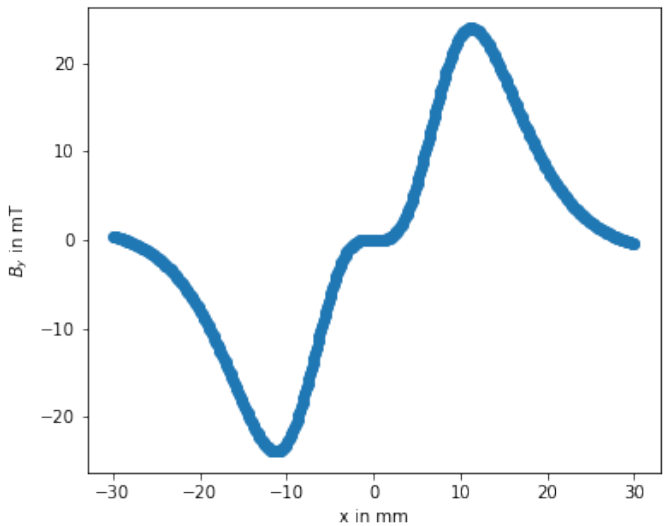


Figure 4: Kicker field strength plot.

Intuition

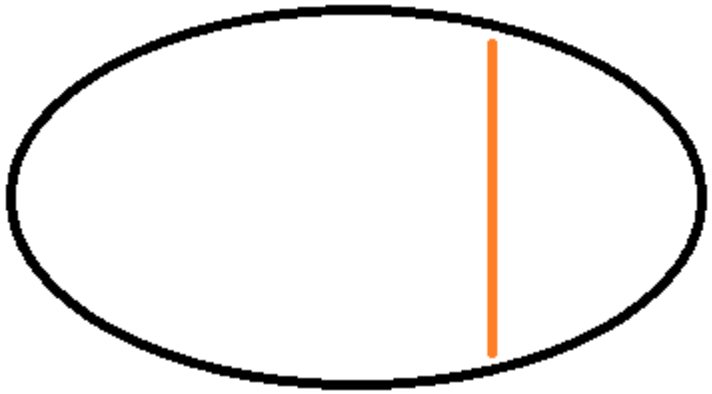


Figure 5: Figure showing the septum sheet at 15mm.

- Injected electrons survive multiple rounds without a kick
- But eventually crash into the septum sheet

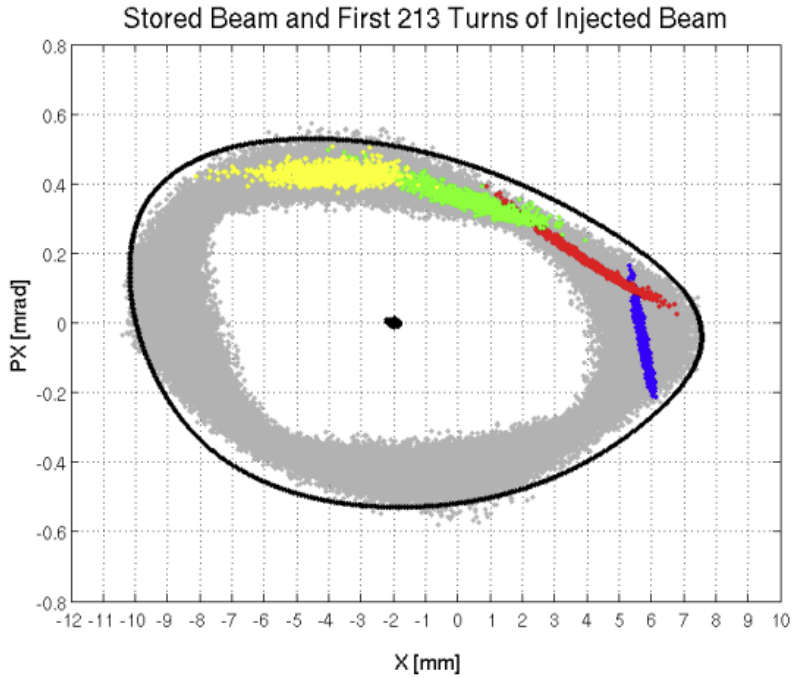


Figure 6: Example of phase space. Blue first round, red second, green third and yellow fourth round. Modified from Lin Liu et al. [4]. Image was mirrored.

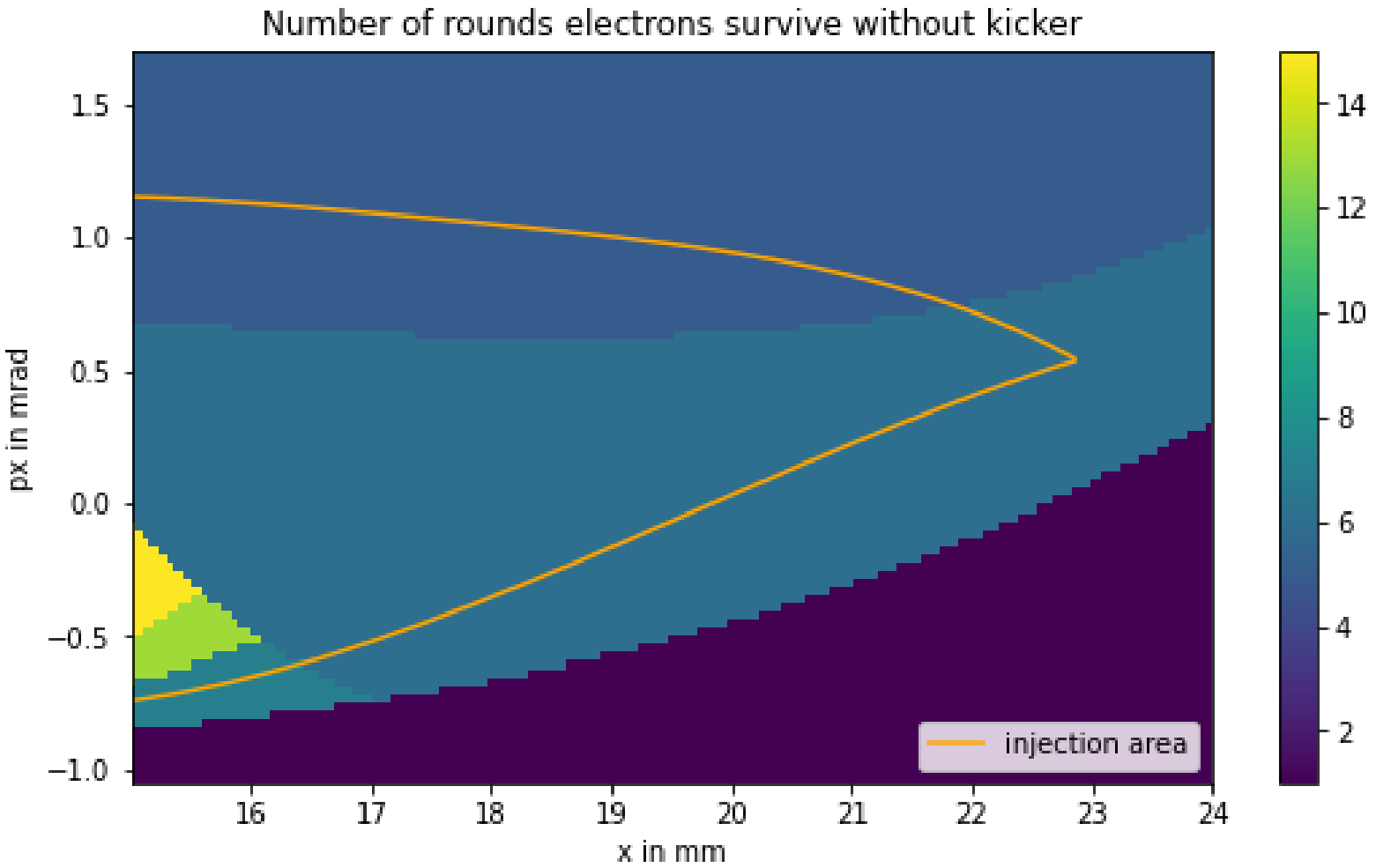


Figure 7: Plot that shows the amount of rounds newly injected electrons survive without kick.

Model setting

- In each round from $0, \ldots, 1000$:
  - Input: $x, \mathrm{p}x$ information of 1000 electrons
  - Choose if we want to activate NLK
  - Choose strength of NLK
- NLK can only be activated once
- Goal: Maximise number of electrons that survive 1000 rounds
- When is an electron lost?
  - If it hits the septum sheet, that lies at 15mm
- Fulfil setting of a Markov Decision Process

What have we done?

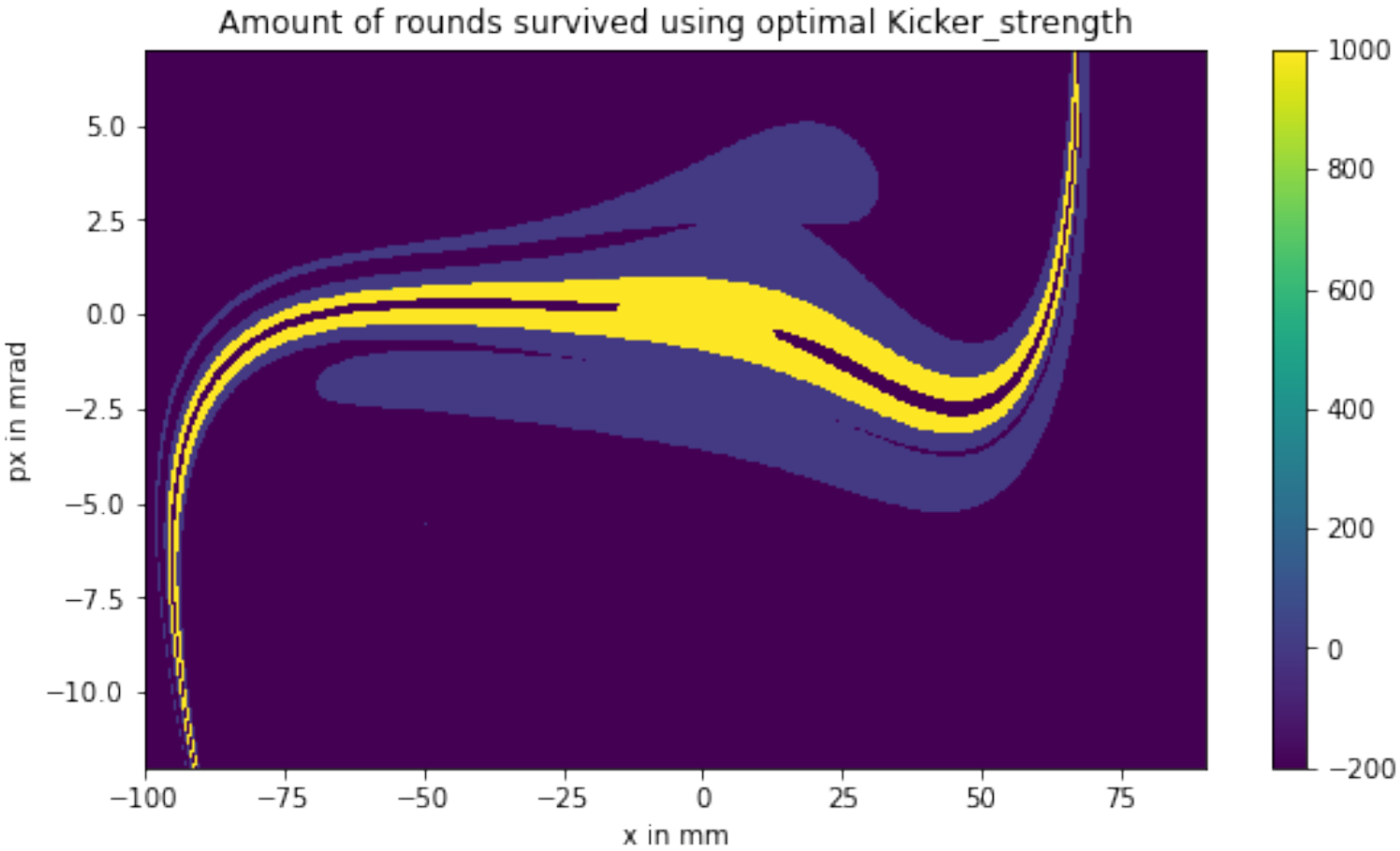
Given a deterministic simulation (Thor SCSI): We have

- Understood how the NLK works
- Created own stochastic simulation (250.000 times faster)
- Applied reinforcement learning algorithms (TD3) to find the optimal actions

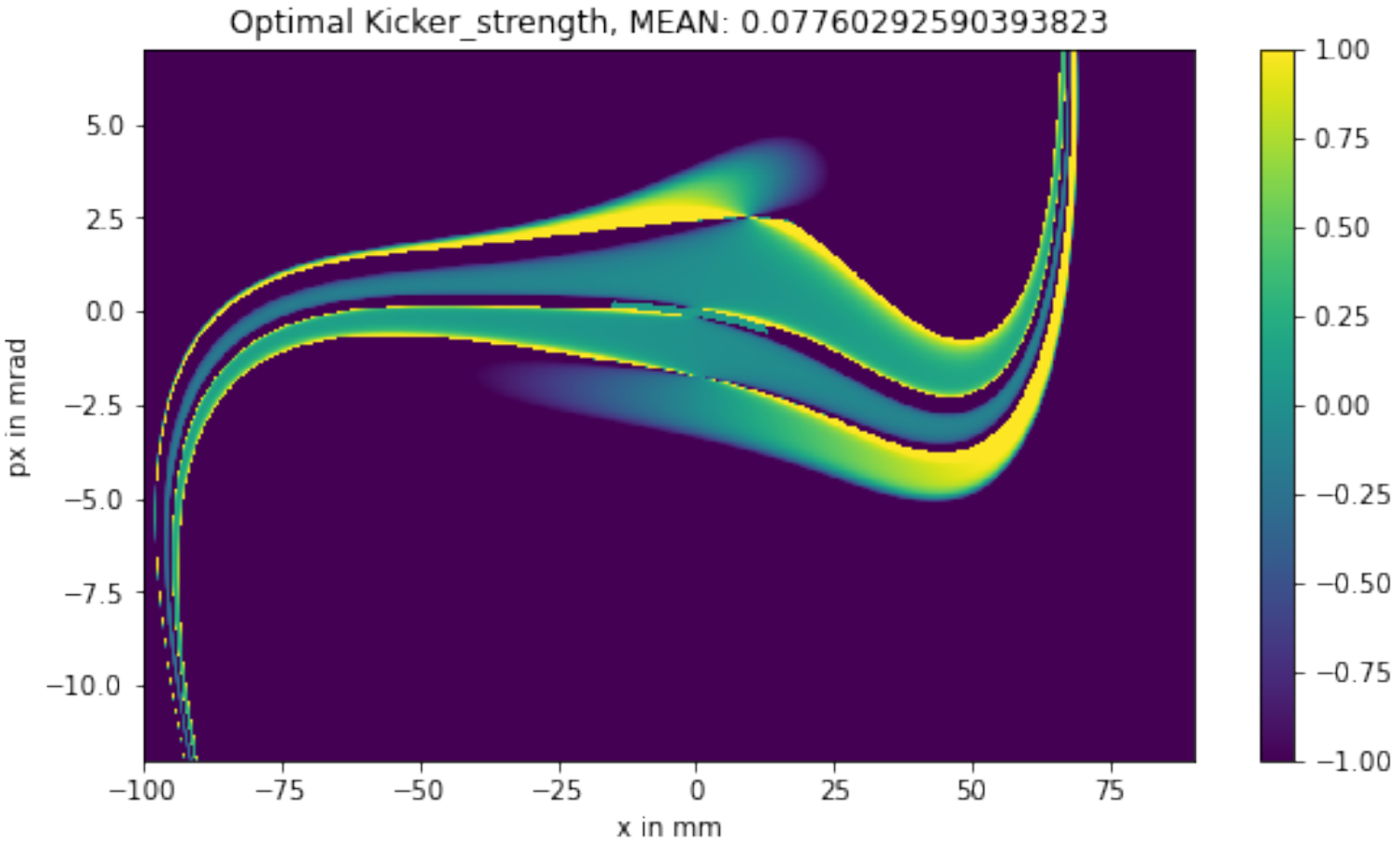
Steps needed for own simulation:

- Round-to-round behaviour
  - Interpolation
- NLK influence
  - More complicated...

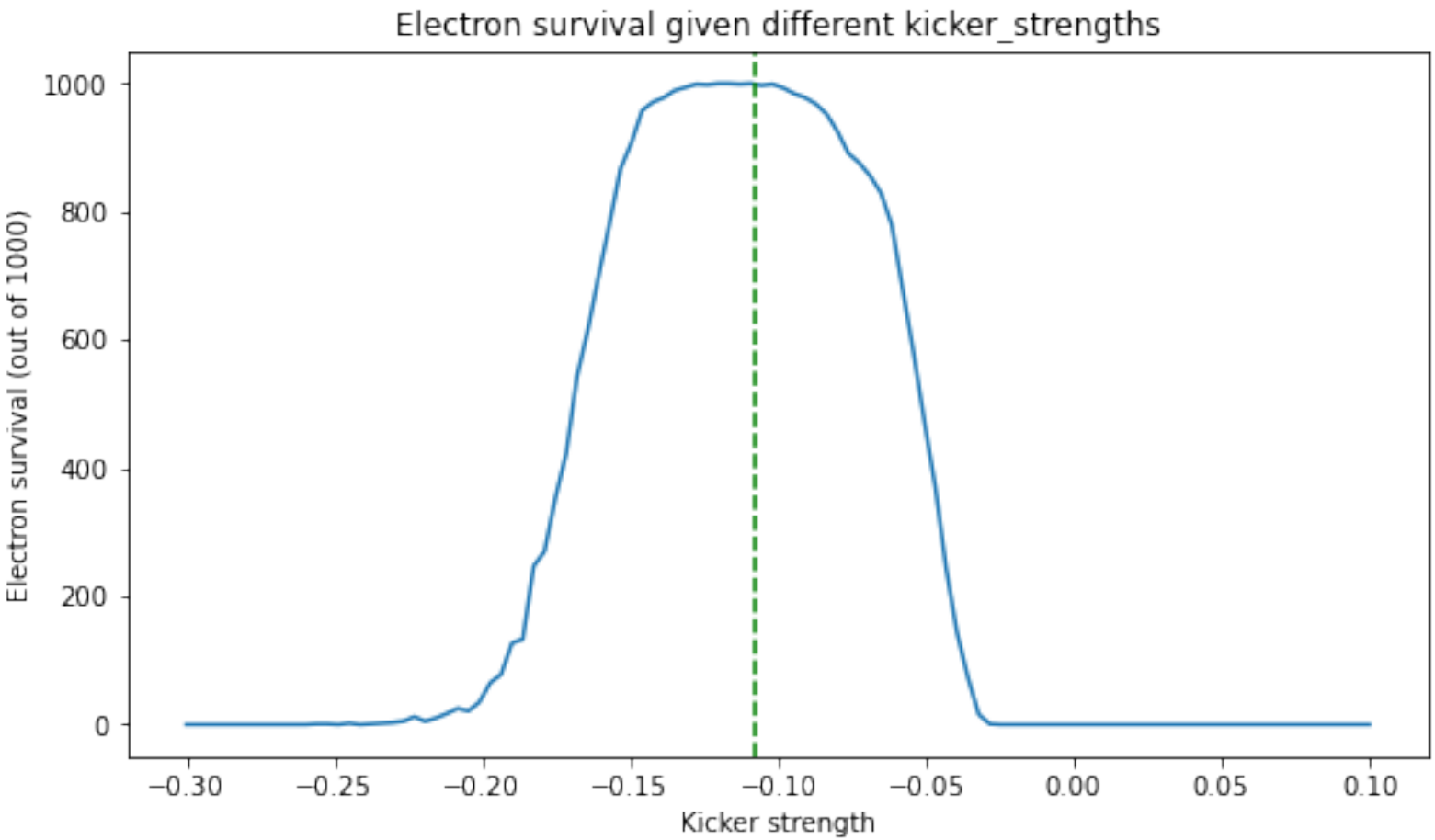
Accepted NLK area



Optimal NLK strength

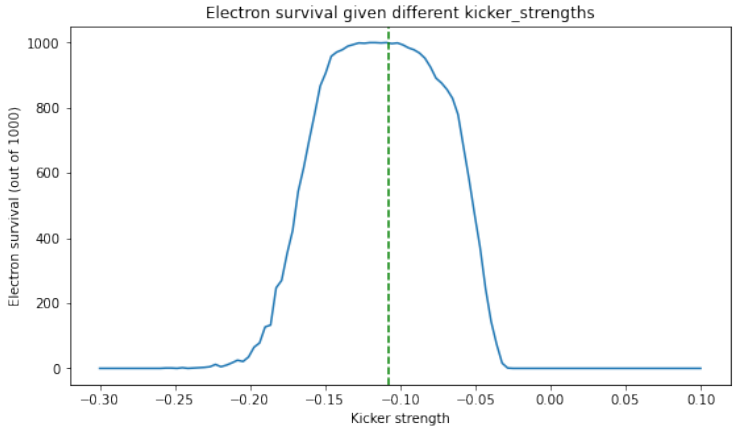


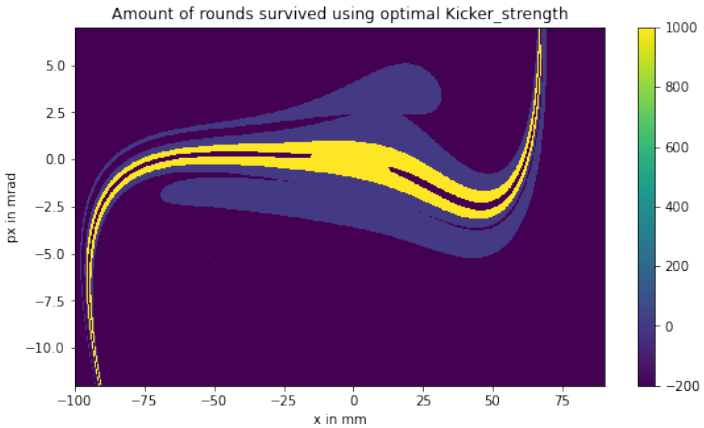
Injection efficiency given kicker strength

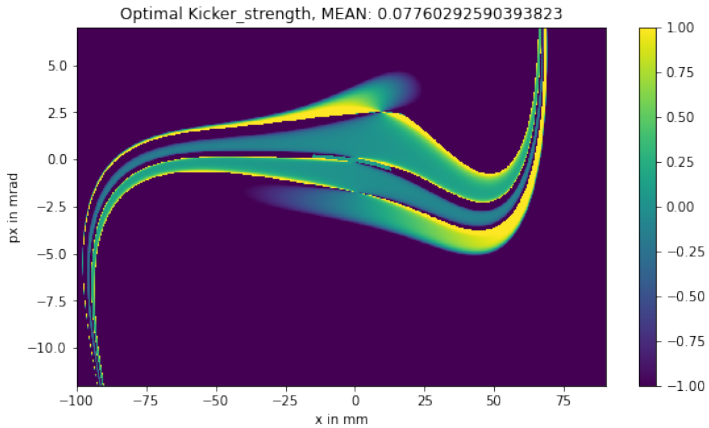


How to model the NLK

- check if electron is in accepted area
- interpolate to get optimal kicker strength
- use approx. for electron survival





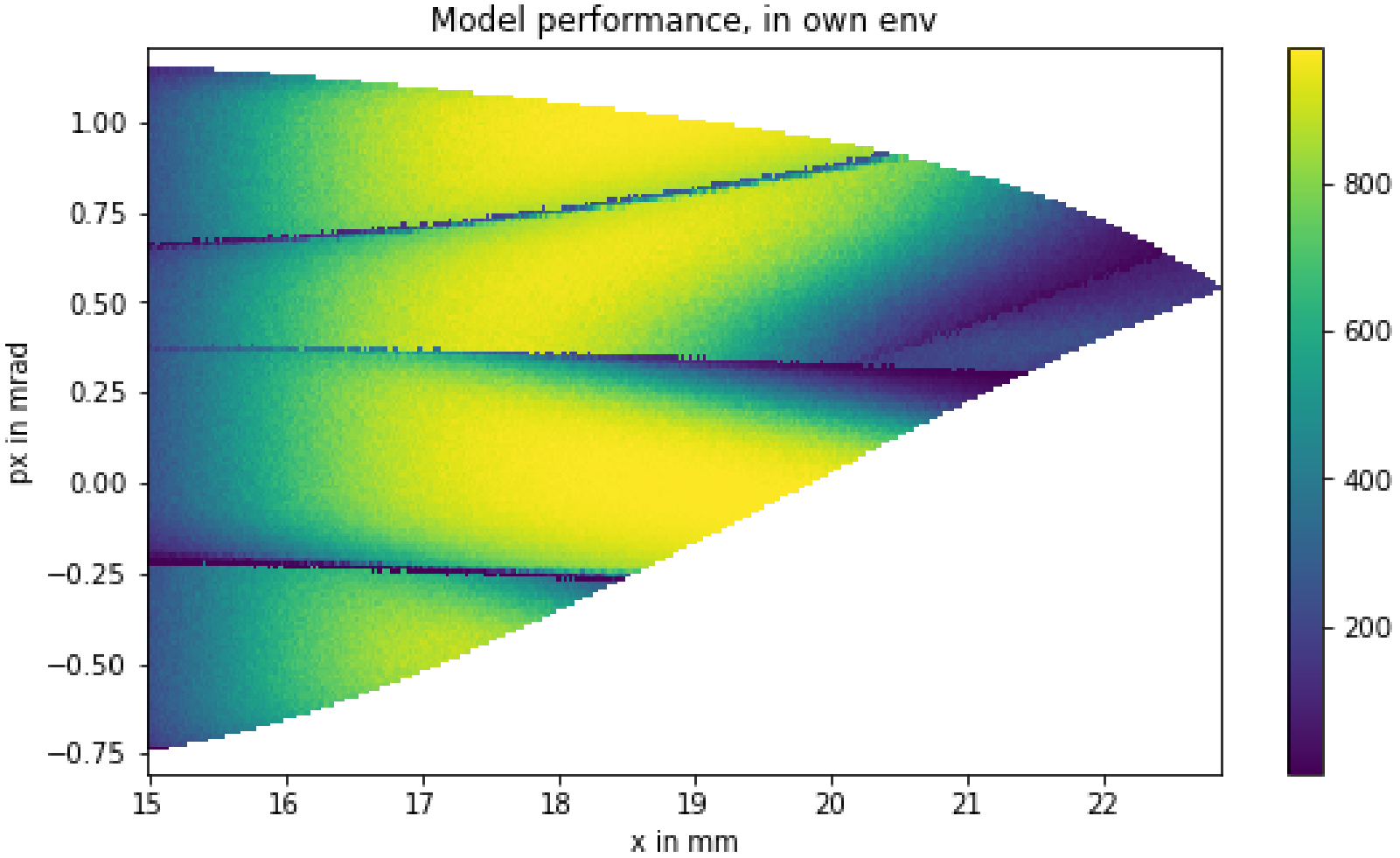


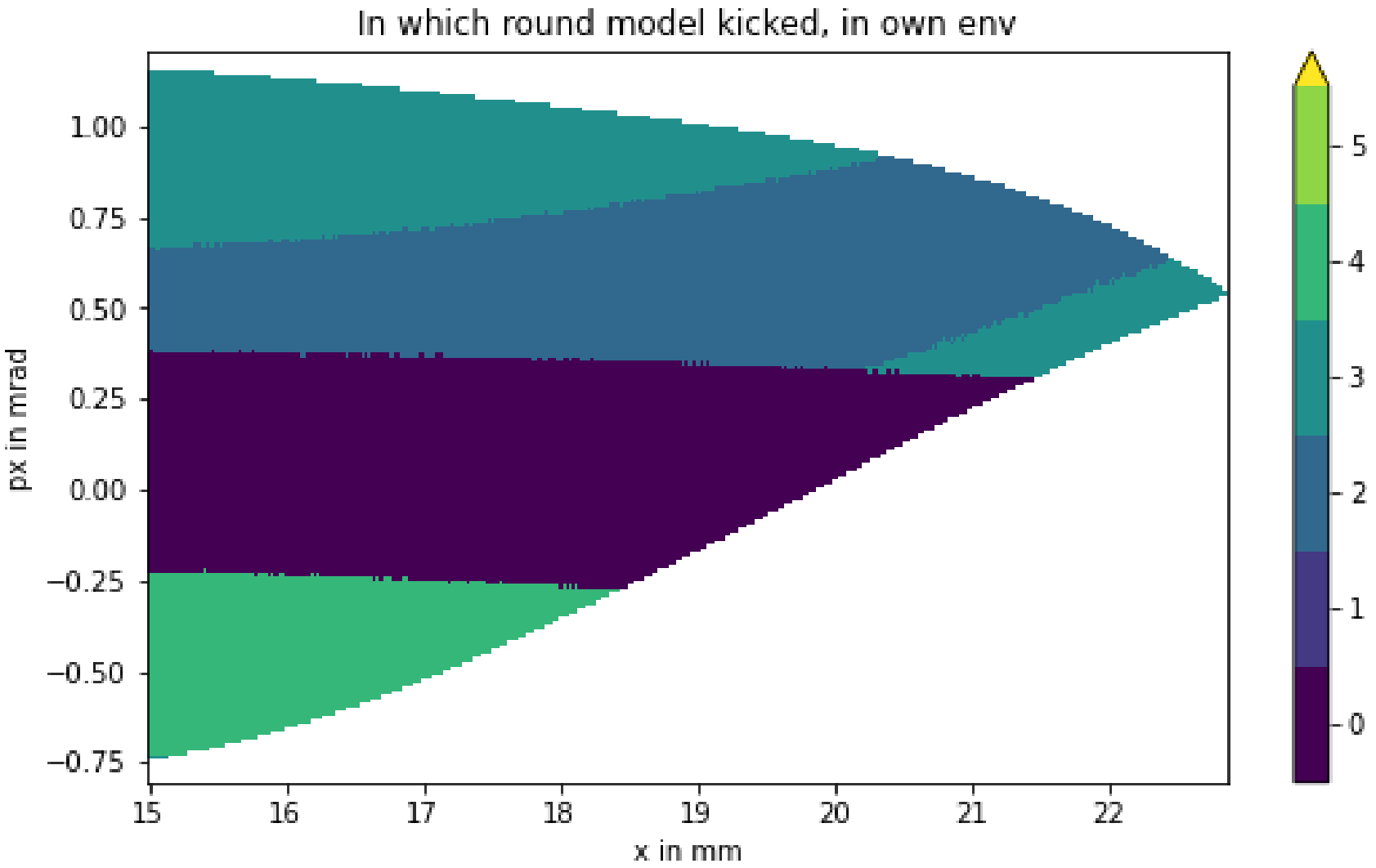
Advantages of this model

- very fast simulation
- round-to-round behaviour very accurate
- can be used to pre-train RL-Agents/ find good hyperparameters

We have trained RL-Agents for 1000-step 1000-electron and 1-step 1000-electron Injection

Best performing 1000-electron 1000-step-RL-agent




In which round model kicked, in own env
px in mrad
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
15
16
17
18
19
20
21
22
x in mm
5
4
3
2
1
0

Performance Analysis

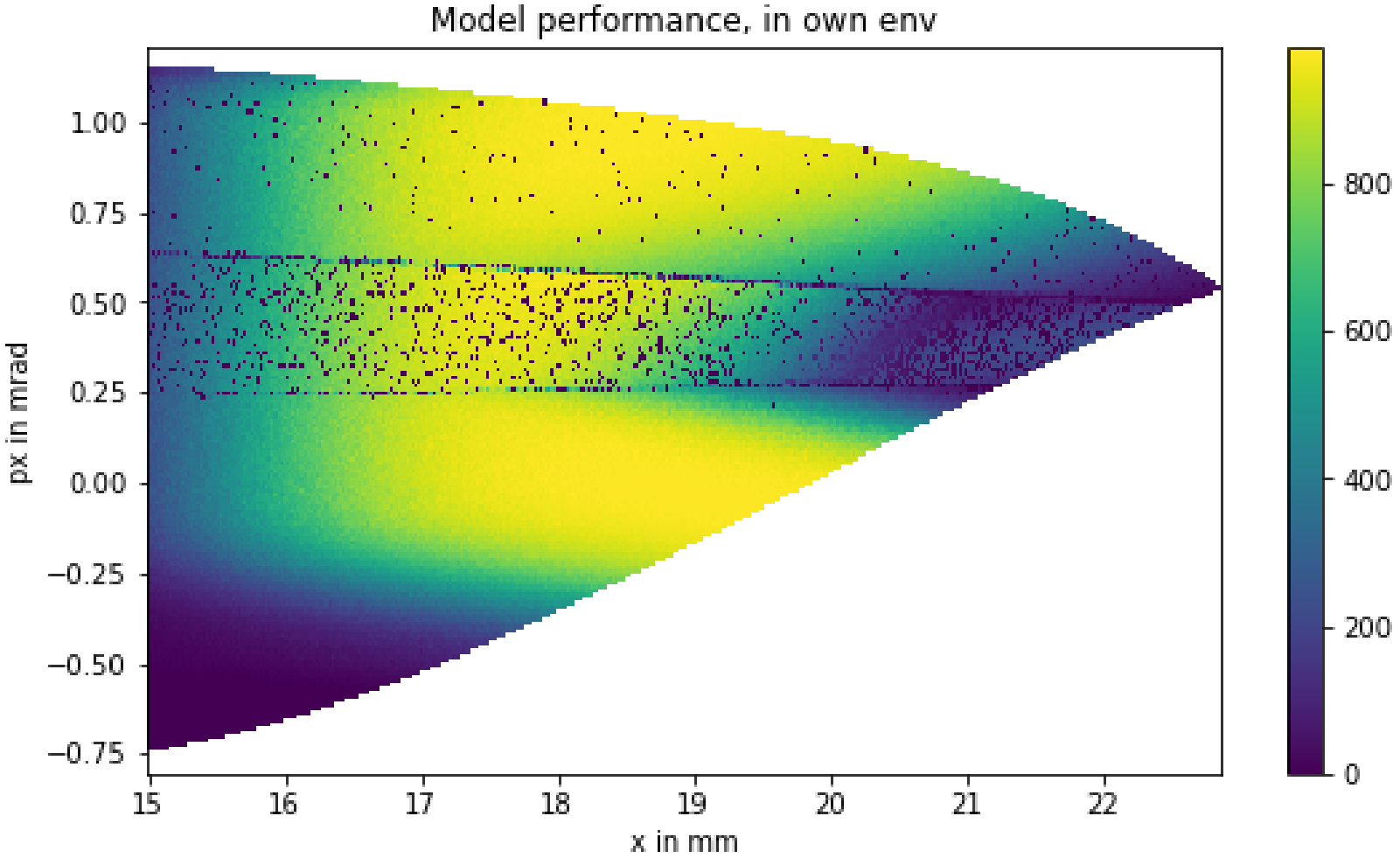
Results:

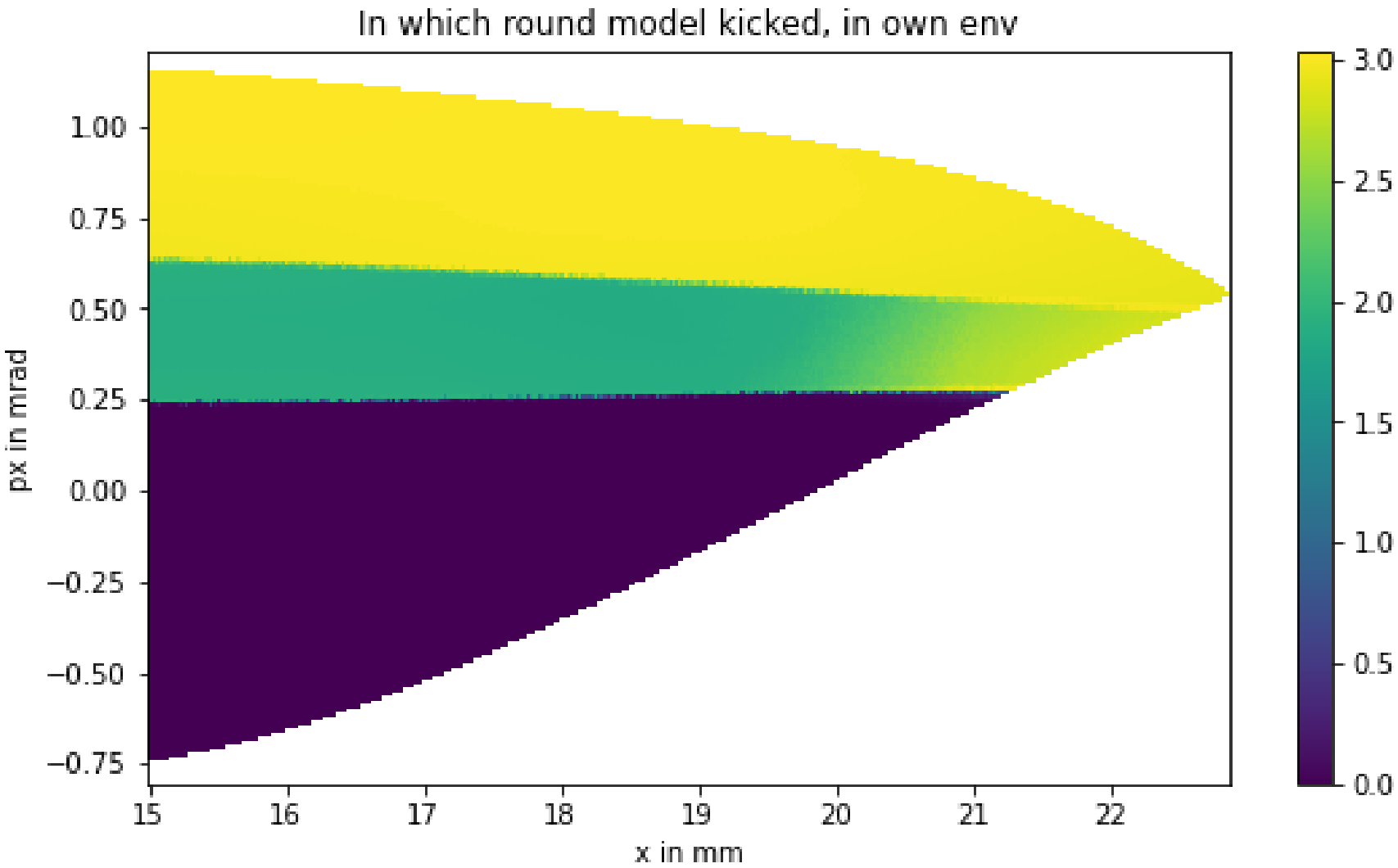
- Only kicking in round 0 is not optimal
- Identified good regions to kick electrons
  $\Rightarrow$ Adjust steerer settings to steer electrons in these regions

How to apply to BESSY II?

- Create an injection-injection model
- Activation round and strength of NLK has to picked immediately
- Only small changes in electrons position/shape from injection-injection

Best performing 1-step 1000-electron RL-agent

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−0.75
15
16
17
18
19
20
21
22
x in mm
3.0
2.5
2.0
1.5
1.0
0.5
0.0

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Summary

What have we seen?

- Advantages using NLK injection
- Creating own environment
- Results in different environments

Left to do?

- Find the optimal steerer settings before the NLK
- Apply to BESSY II

References

[1] P. Schnizer et al. “Progress on Thor SCSI development”. In: *Proc. IPAC'23*. IPAC'23 - 14th International Particle Accelerator Conference 14. May 2023. DOI: 10.18429/JACoW-IPAC2023-WEPL127.

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[3] T Atkinson et al. “Development of a non-linear kicker system to facilitate a new injection scheme for the bessy ii storage ring”. In: (Jan. 2011).

[4] Lin Liu et al. “Injection Dynamics for Sirius Using a Nonlinear Kicker”. In: 2016.

[5] Simon White. *Experience at ESRF*. Presentation given at Topical Workshop on Injection and Injection Systems. Aug. 28, 2017. URL: https://indico.cern.ch/event/635514/contributions/2660458/attachments/1518207/2370454/Berlin_TWIIS.pdf (visited on 01/30/2024).