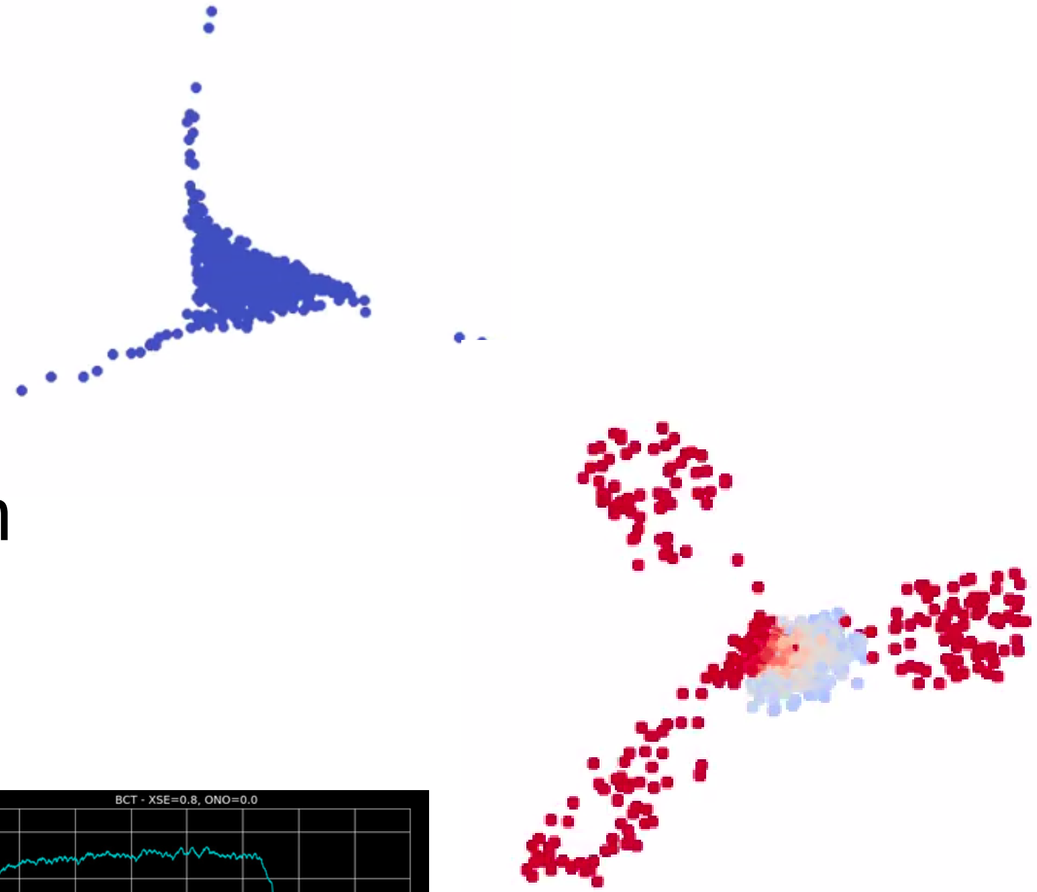
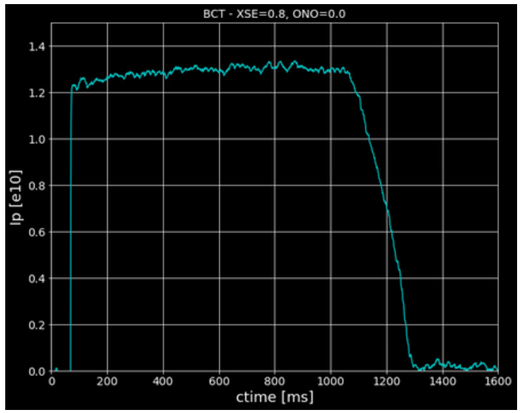
Octupoles applied to slow extraction in the PS

R. Taylor, M. Fraser, P. Arrutia

Contents

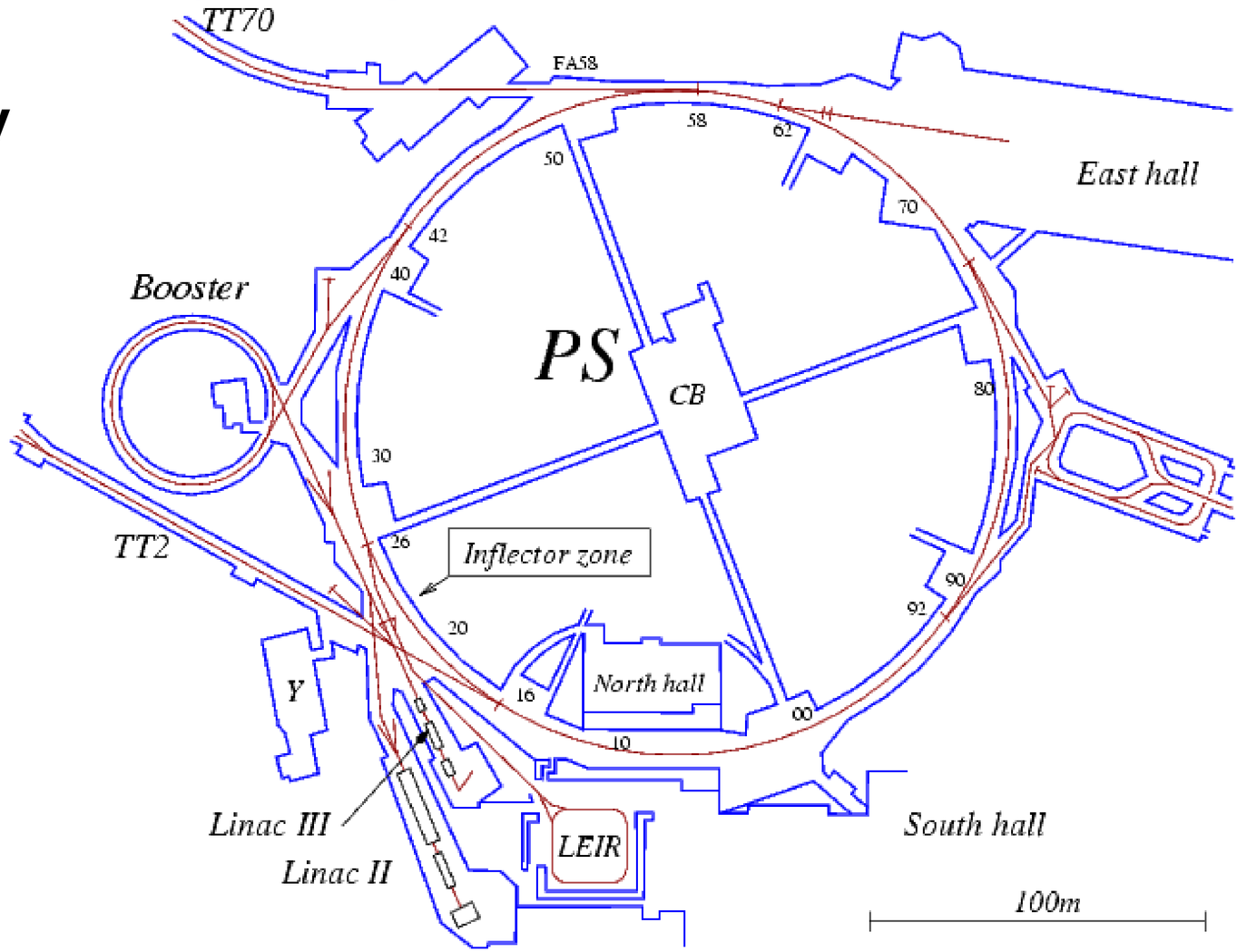
- **What is Slow Extraction?**
  - Proton Synchrotron
  - Simulations of Slow Extraction
- **Why use octupoles?**
  - Simulations with octupoles
- **Beam Operations in the PS**
  - PS Results
  - Simulation Results





Slow Extraction in the PS

- Aim of slow extraction is to **gradually extract beams** from the proton synchrotron to the East Area
  - Used to irradiate electronics at CHARM



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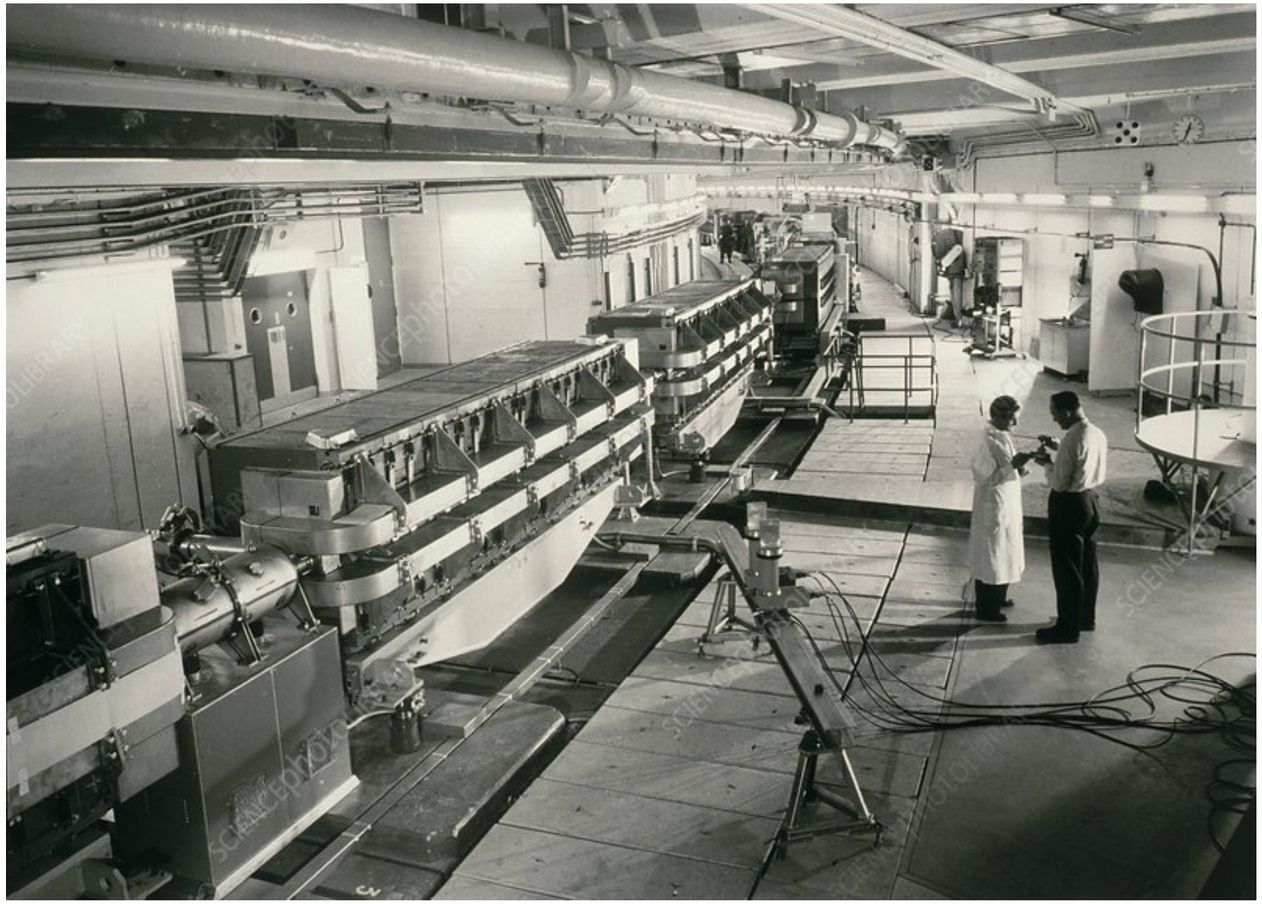
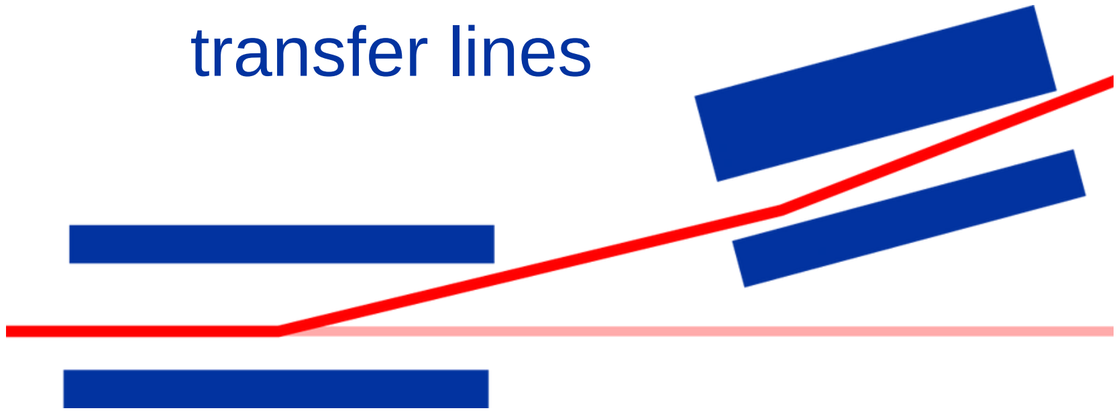


Types of Extraction

Extracting Fast

- Beam out in 1 turn (μs)
- Entire beam deflected
- Used in LHC accelerator transfer lines



Extracting Slow

- Thousands to millions of turns
- Beam gradually shaved
- Used in the PS, SPS for target experiments.
- Required in medical machines.

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Make the beam **unstable**, and **shape** the beam loss towards the extraction regions.

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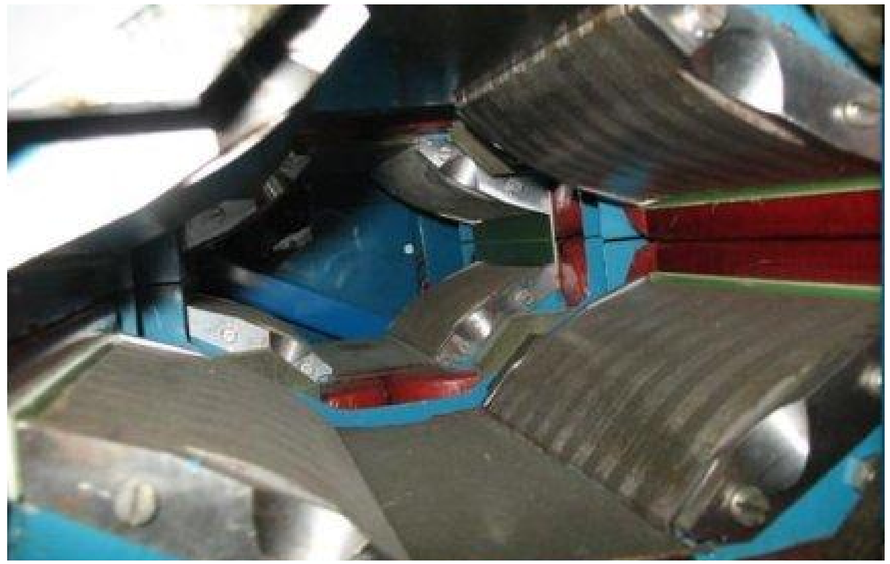

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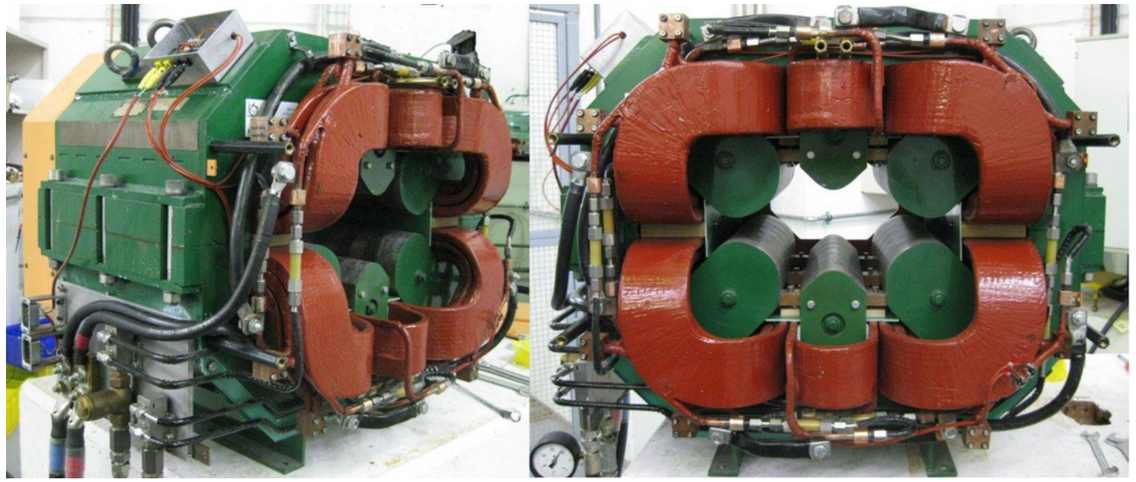

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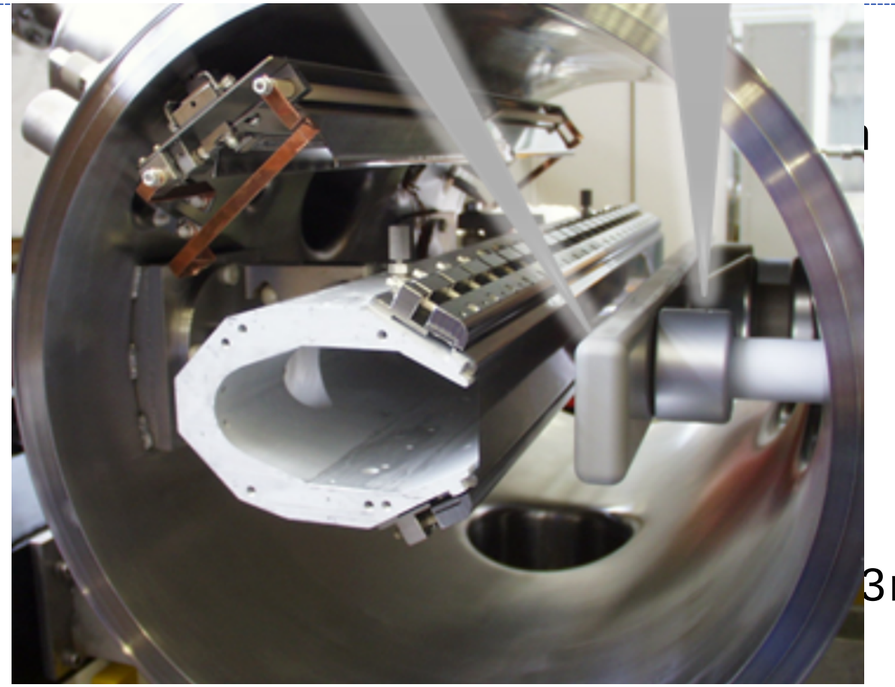

3rd

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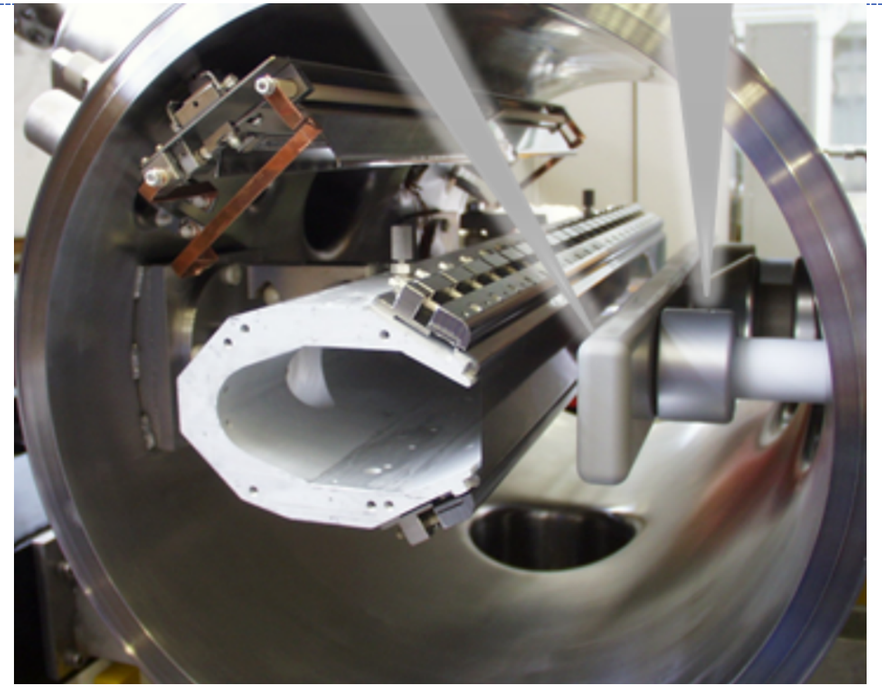

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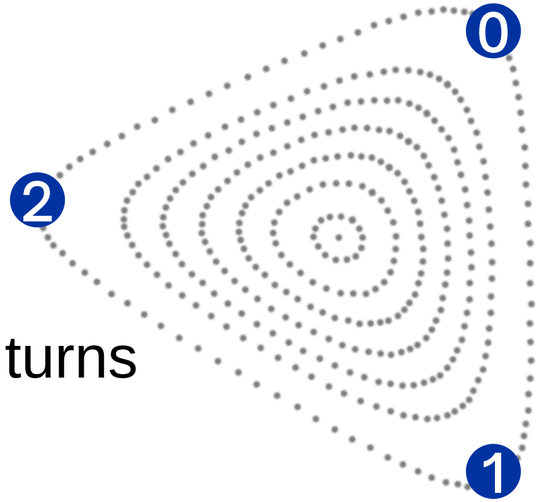
  - A thin wire separating an electric field and non-field region
- **1 good quality spill**
  - The slowly extracted beam

Recipe for extracting slowly



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  - Particles in phase-space return to their original position every 3 turns

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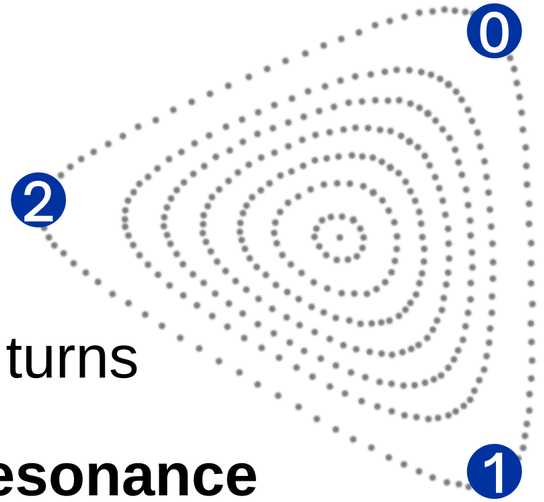

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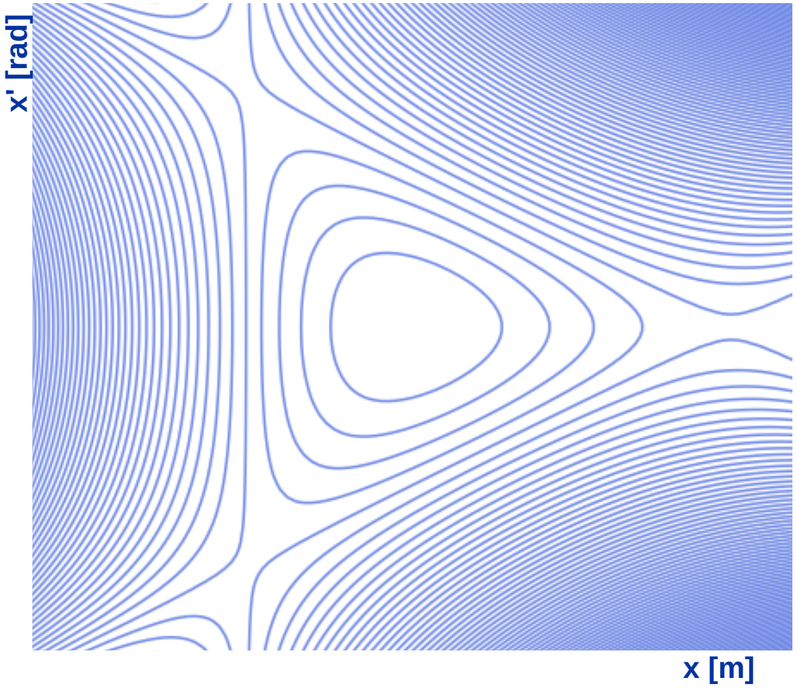

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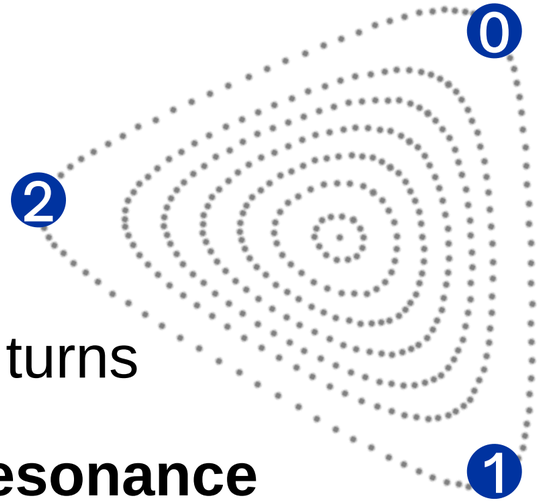

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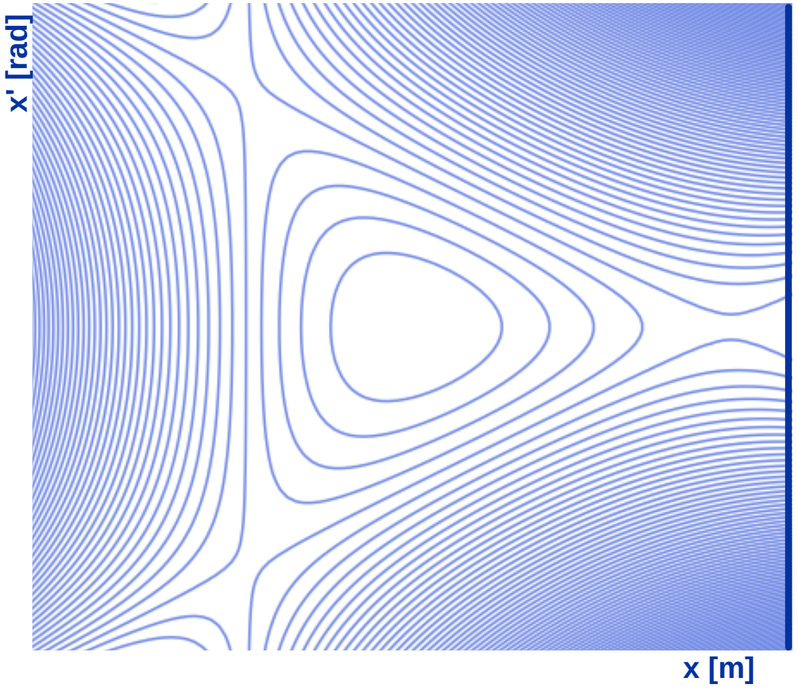

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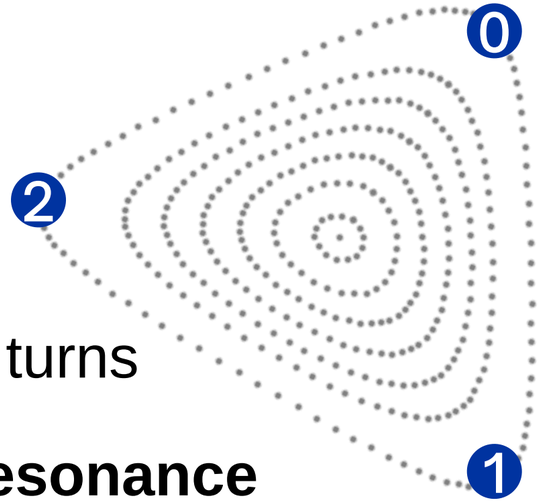

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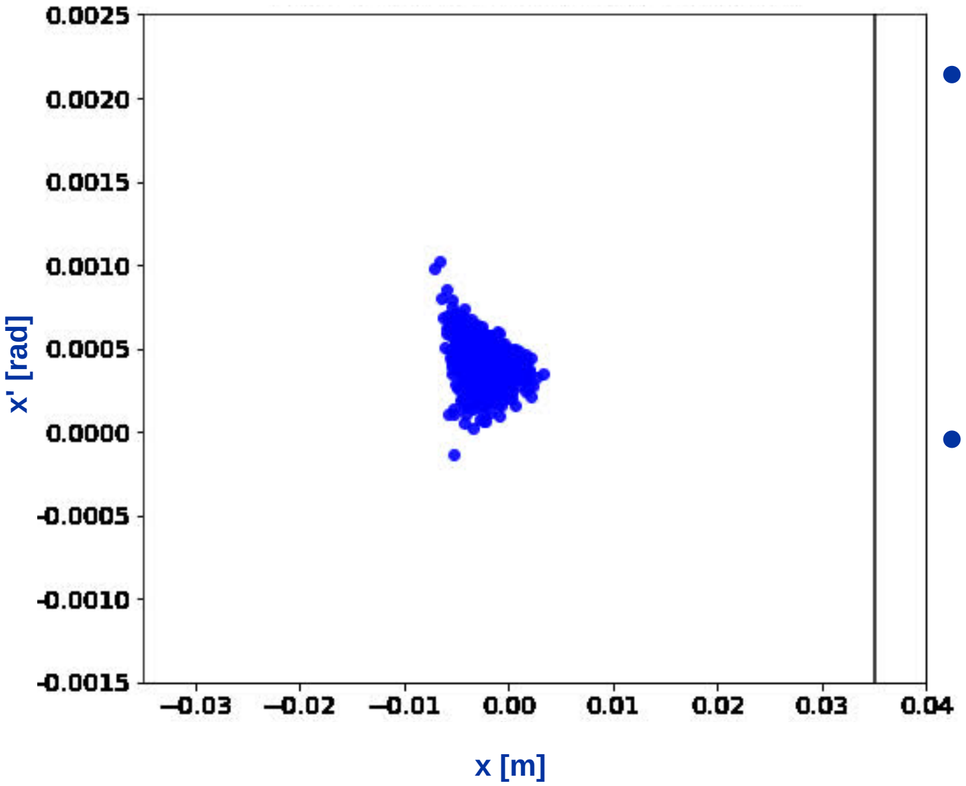

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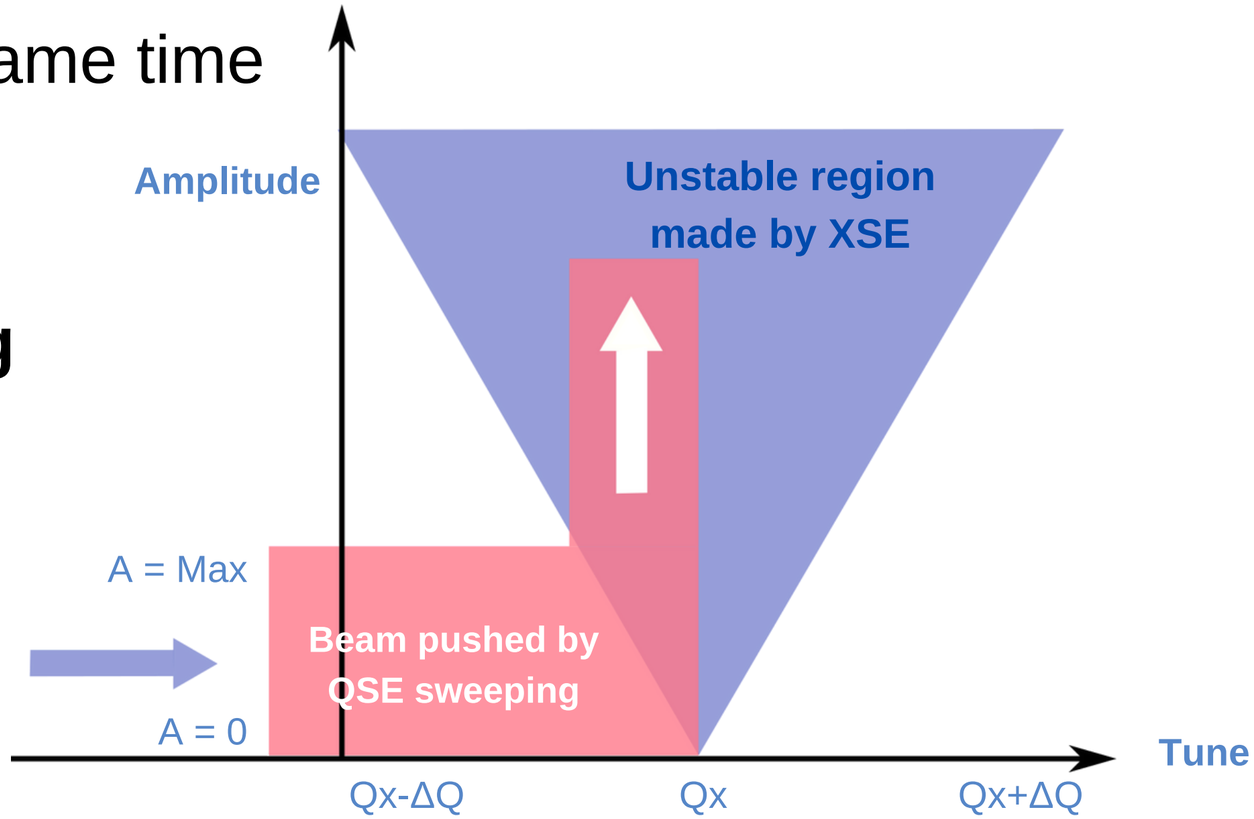
Exciting through the resonance

- Not all particles have the same tune / momentum
- Cannot all be extracted at the same time

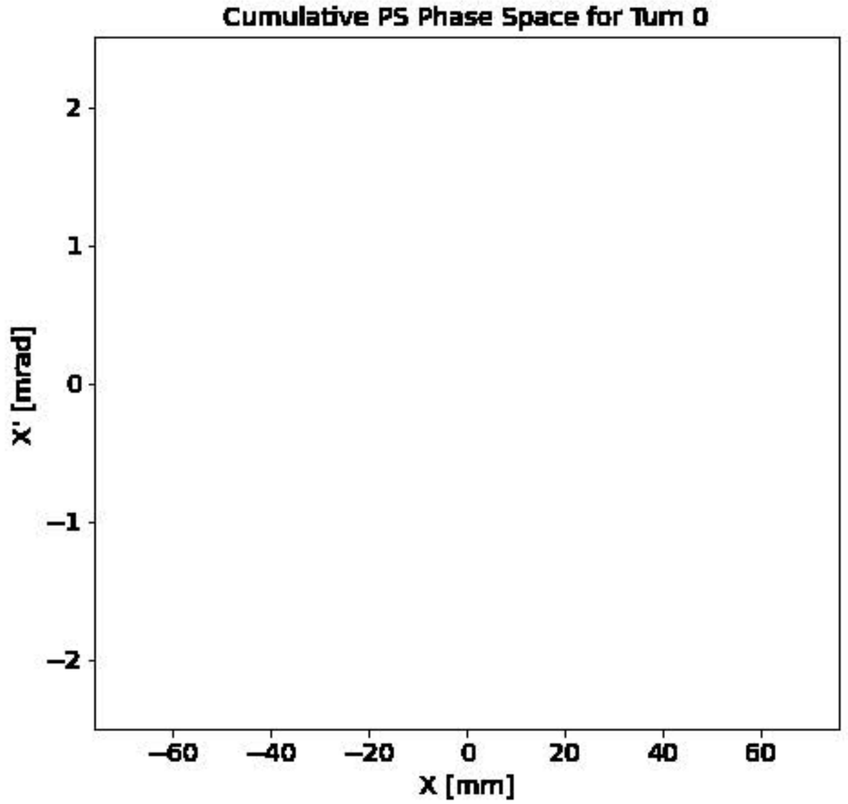
- PS uses **quadrupole sweeping**
  - Moves optics of the beam

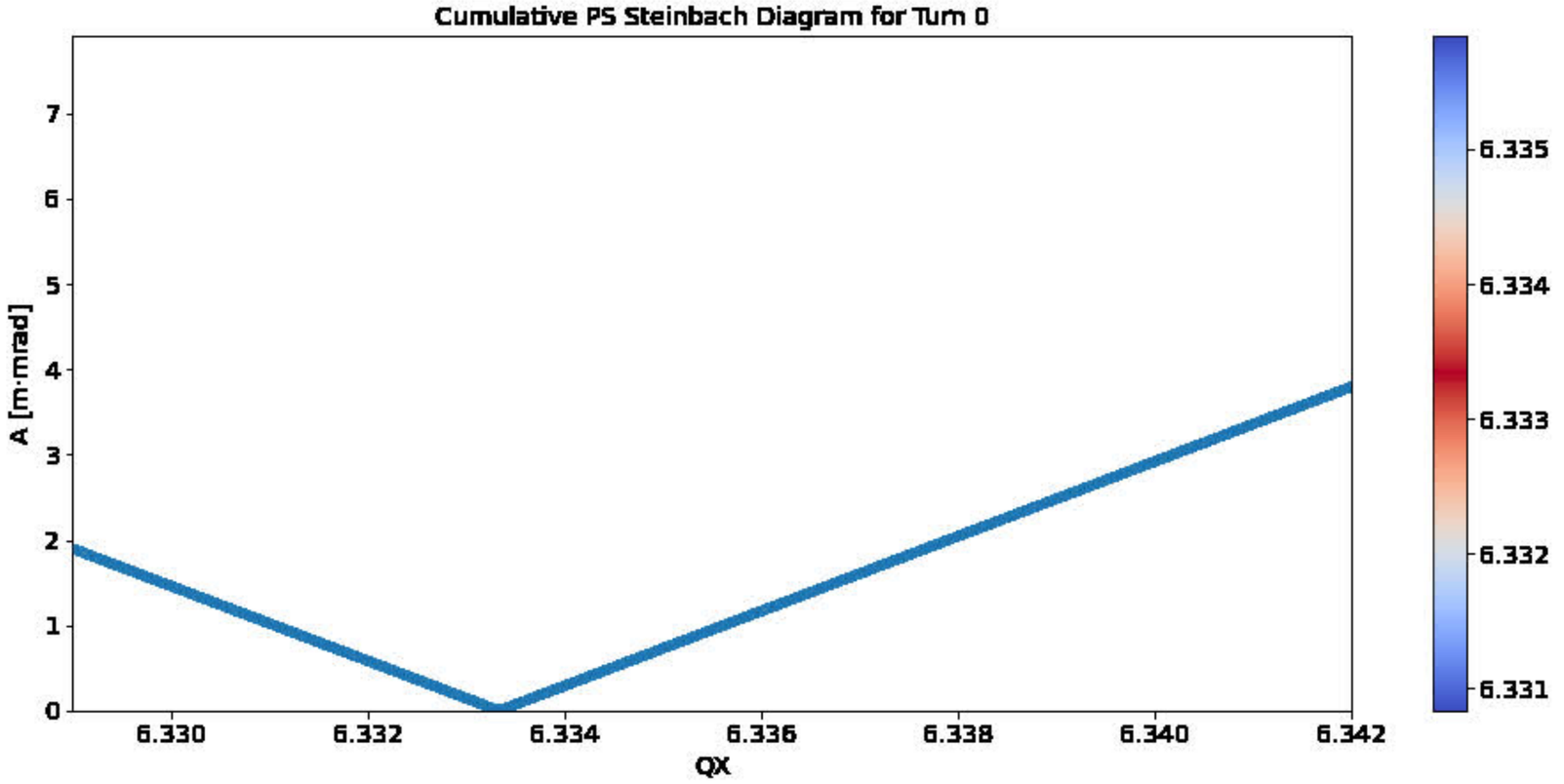


Steinbach Diagram of beam (red) and resonance (blue)

Putting all this into a MADX simulation of the PS...

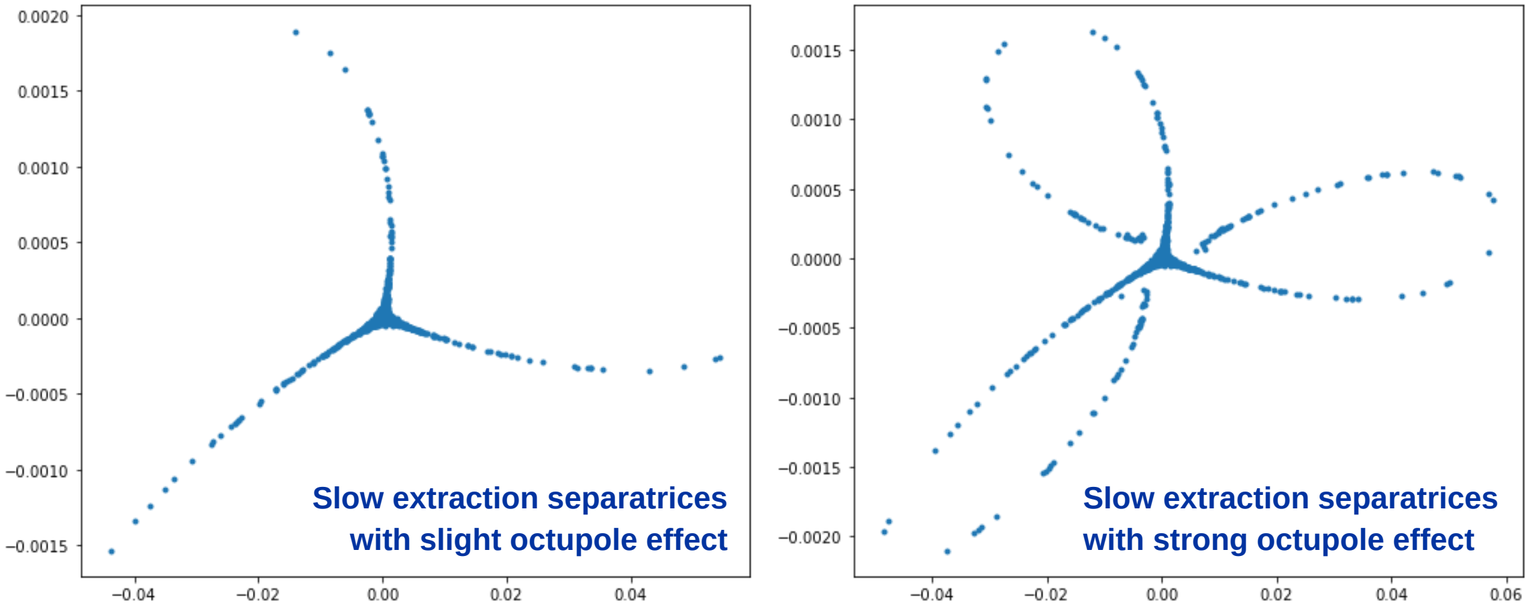
Slow Extraction Simulation





Why Octupoles?

- Octupoles can alter the trajectories of the separatrices during slow extraction.
  - Possible to bend into the septum to reduce losses
- Demonstrated at the SPS & reduced losses up to 40%
  - ***M. Fraser*** Demonstration of slow extraction loss reduction with the application of octupoles at the CERN Super Proton Synchrotron *(2019)*



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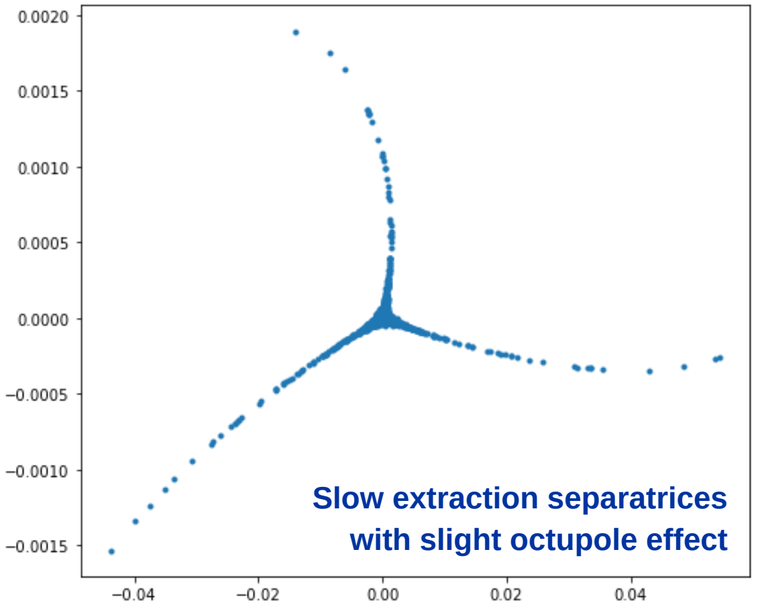

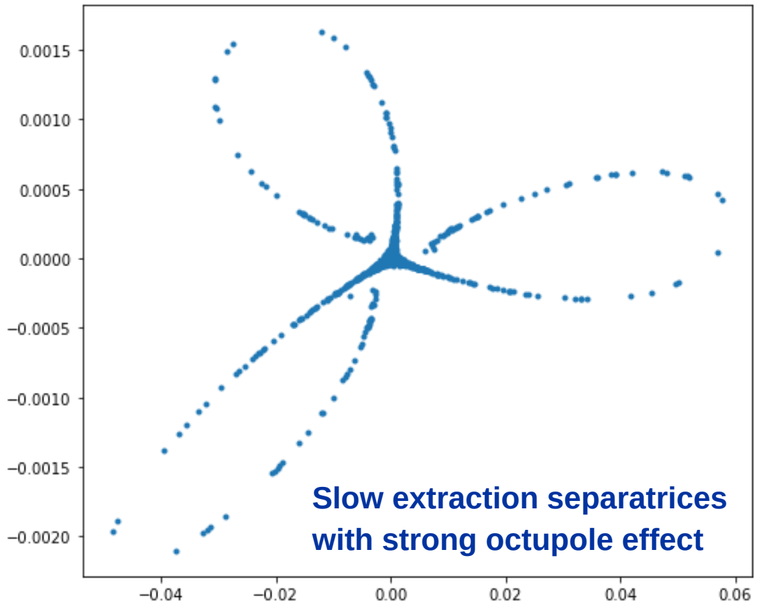

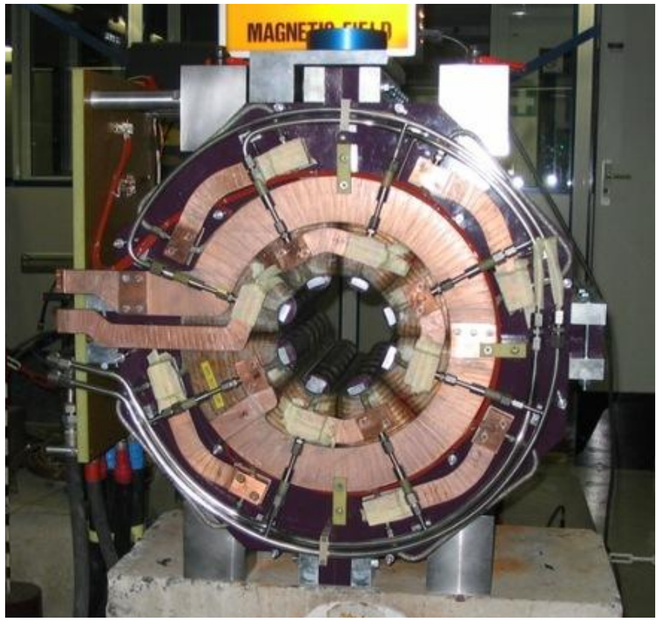

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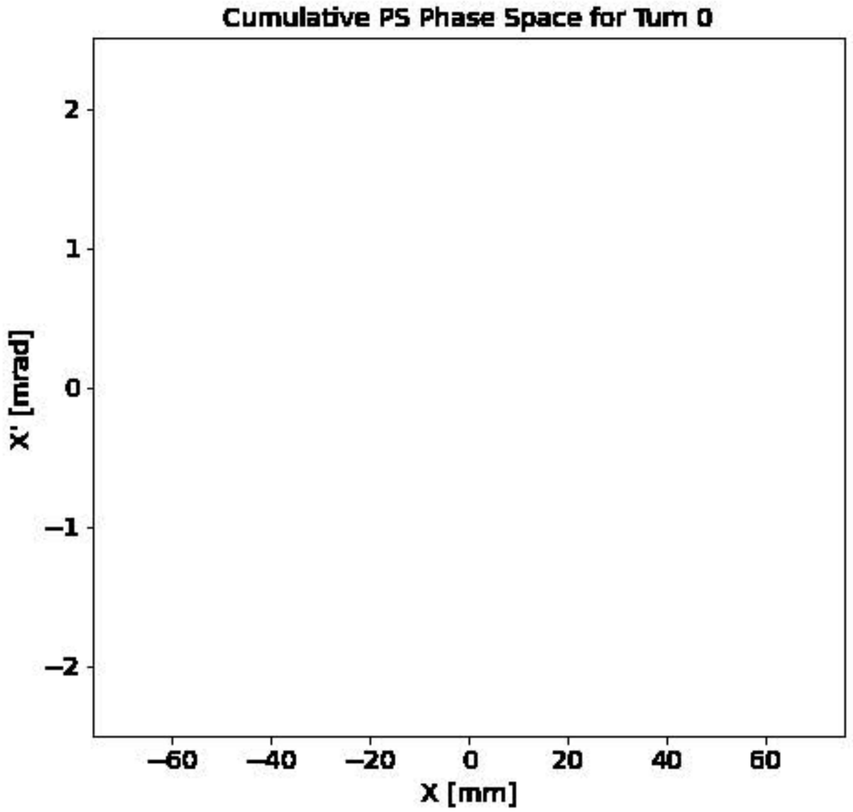
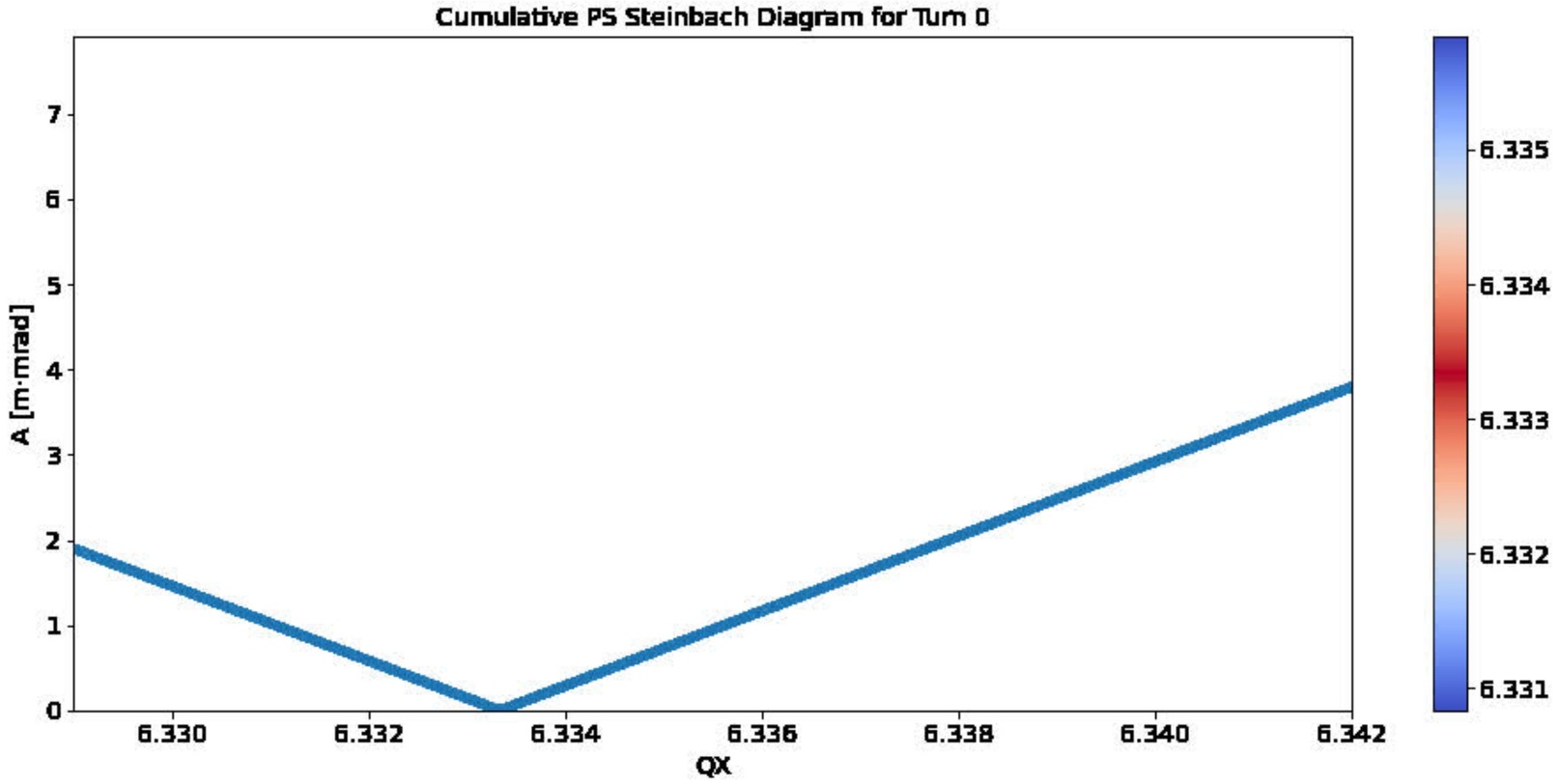
- Before applying octupoles for loss reduction, first need to understand behaviour of beam under different multipole strengths in the machine, compared to simulations.
  - **Octupole trapping** gives a clear indication of beam behaviour

Octupole trapping simulation

Model of PS in Maptrack, ramping with QSE, XSE = 0.6, ONO = 50





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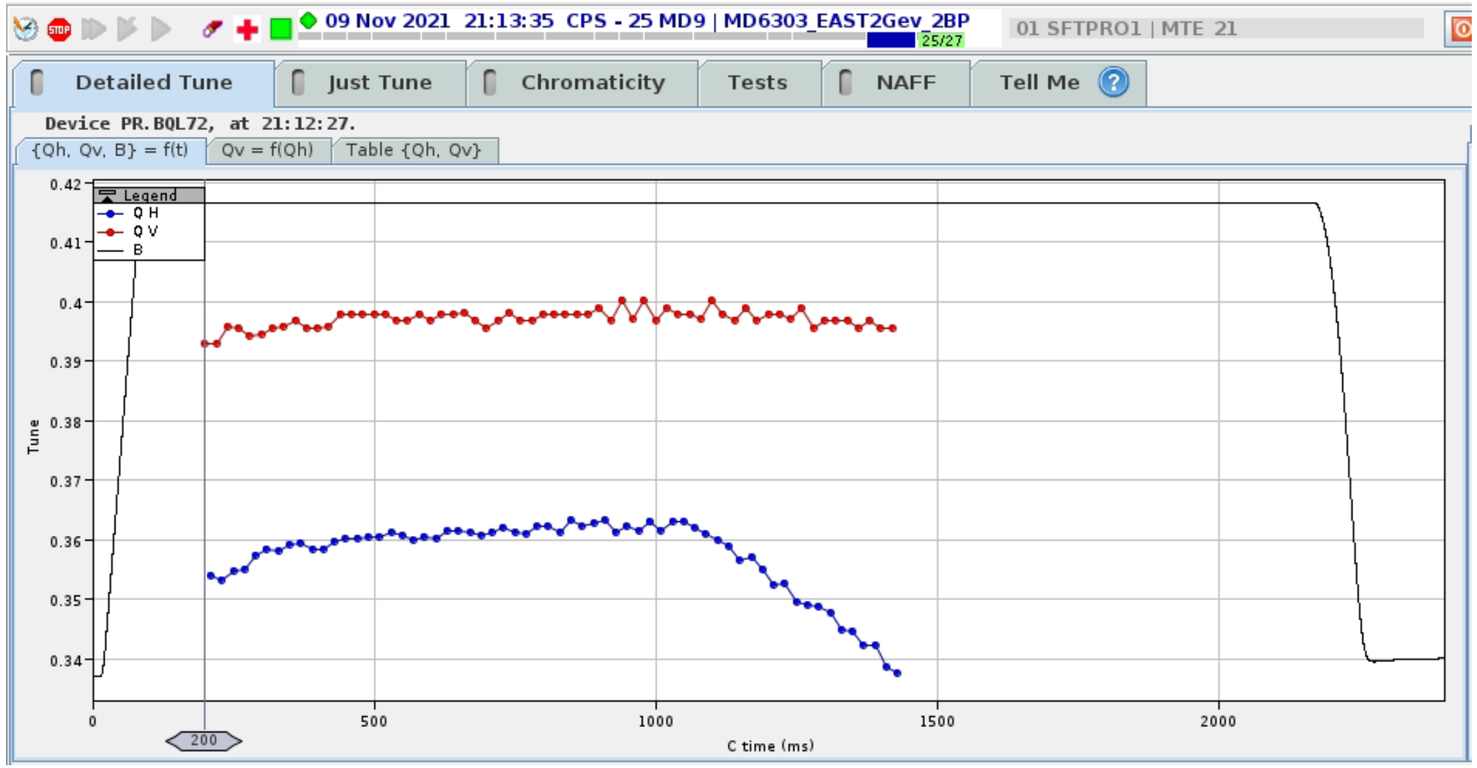
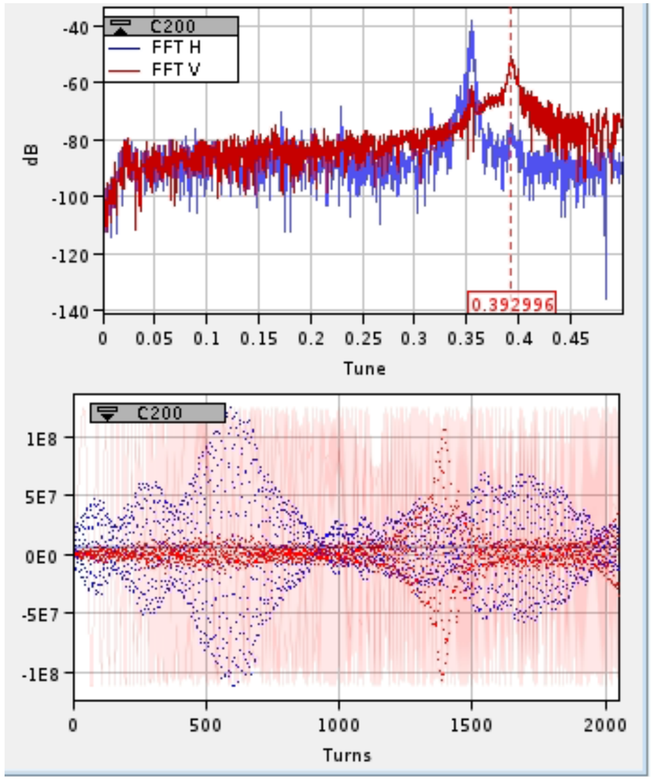
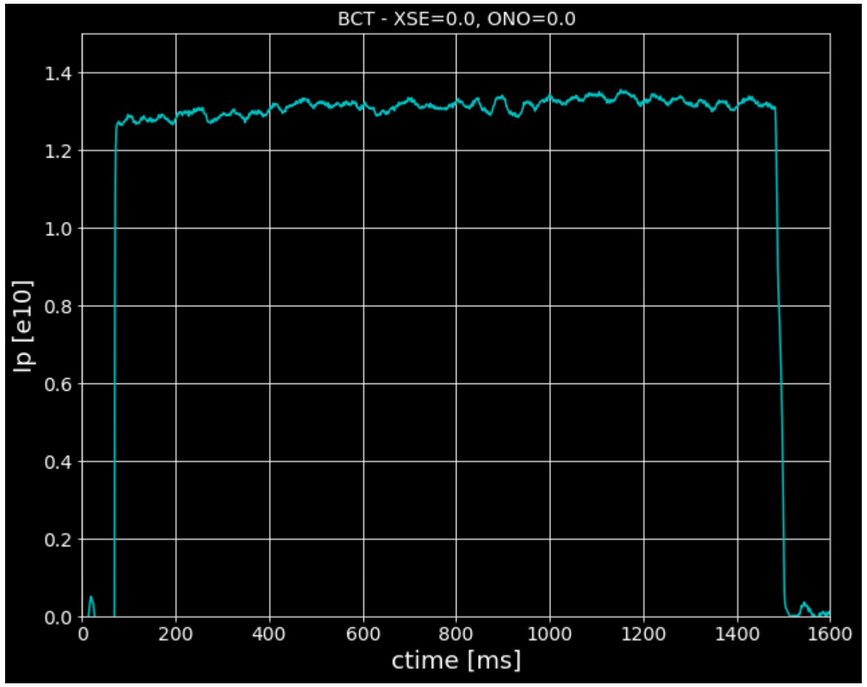




PS Method

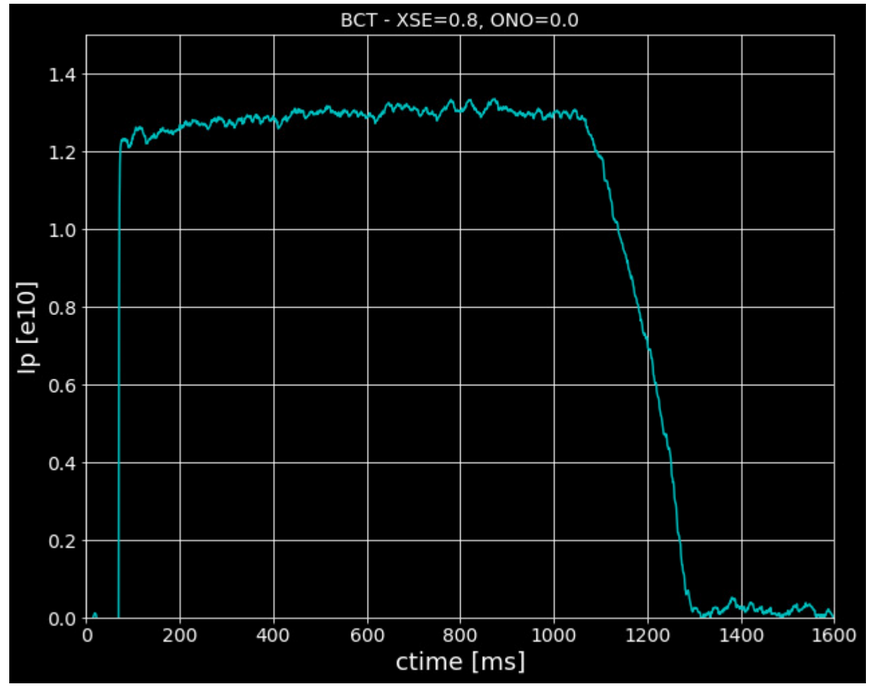
1. Vary strengths / currents of the magnets using LHC Software Architecture (LSA)
2. Ensure tune of beam goes through resonance with QMeter
3. Observe beam intensity as a function of time with the Beam Current Transformer (BCT)



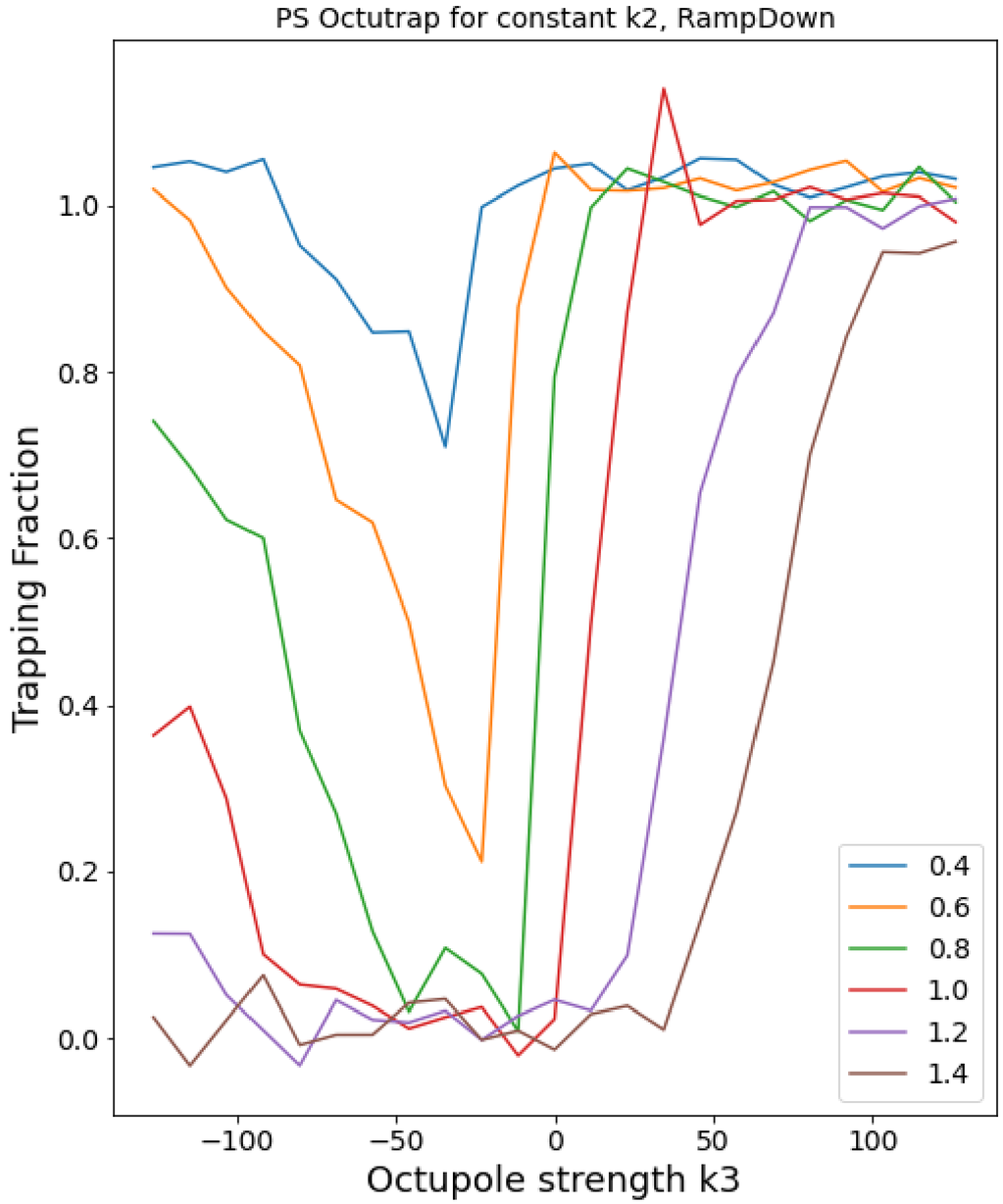
No intensity loss - stable beam or trapped beam

Intensity loss - slow extraction or beam loss

- First set up a good slow extraction, then turn octupoles on.



24 GeV PS Results



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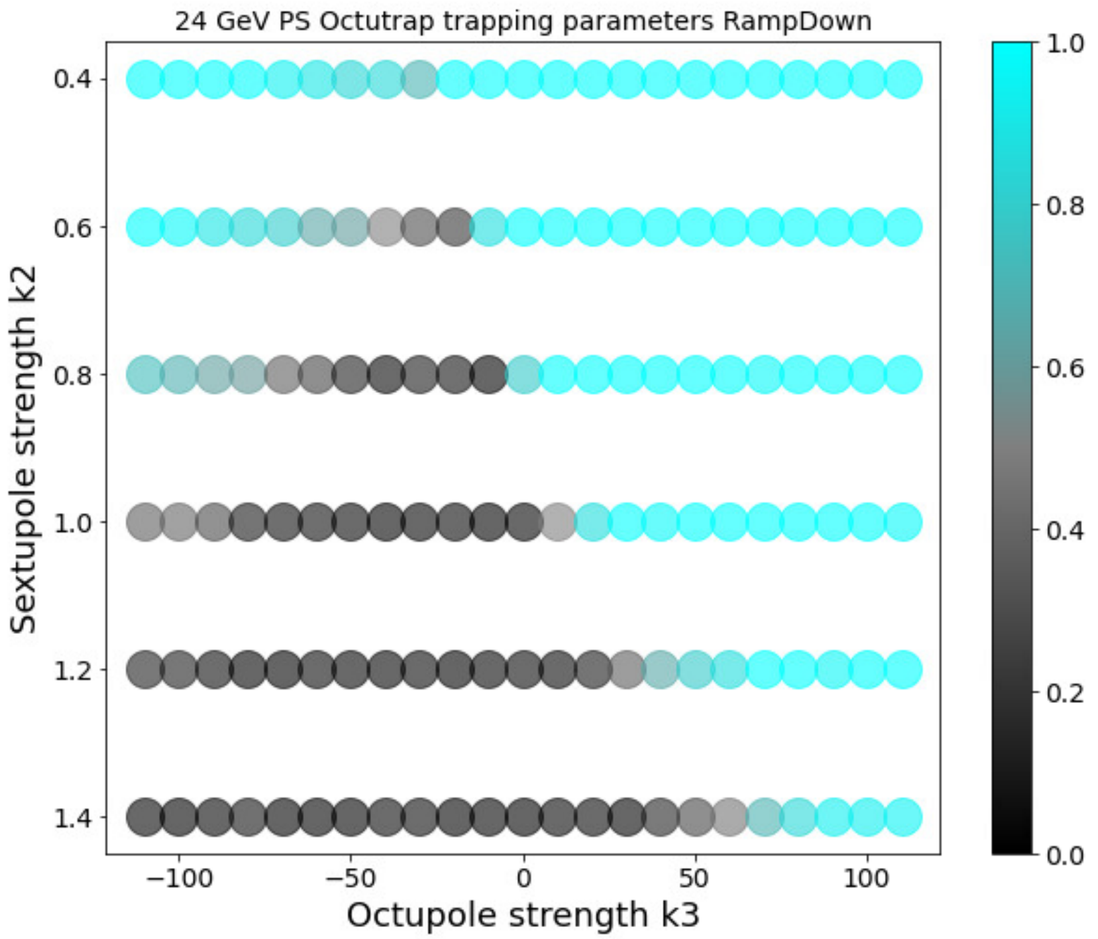
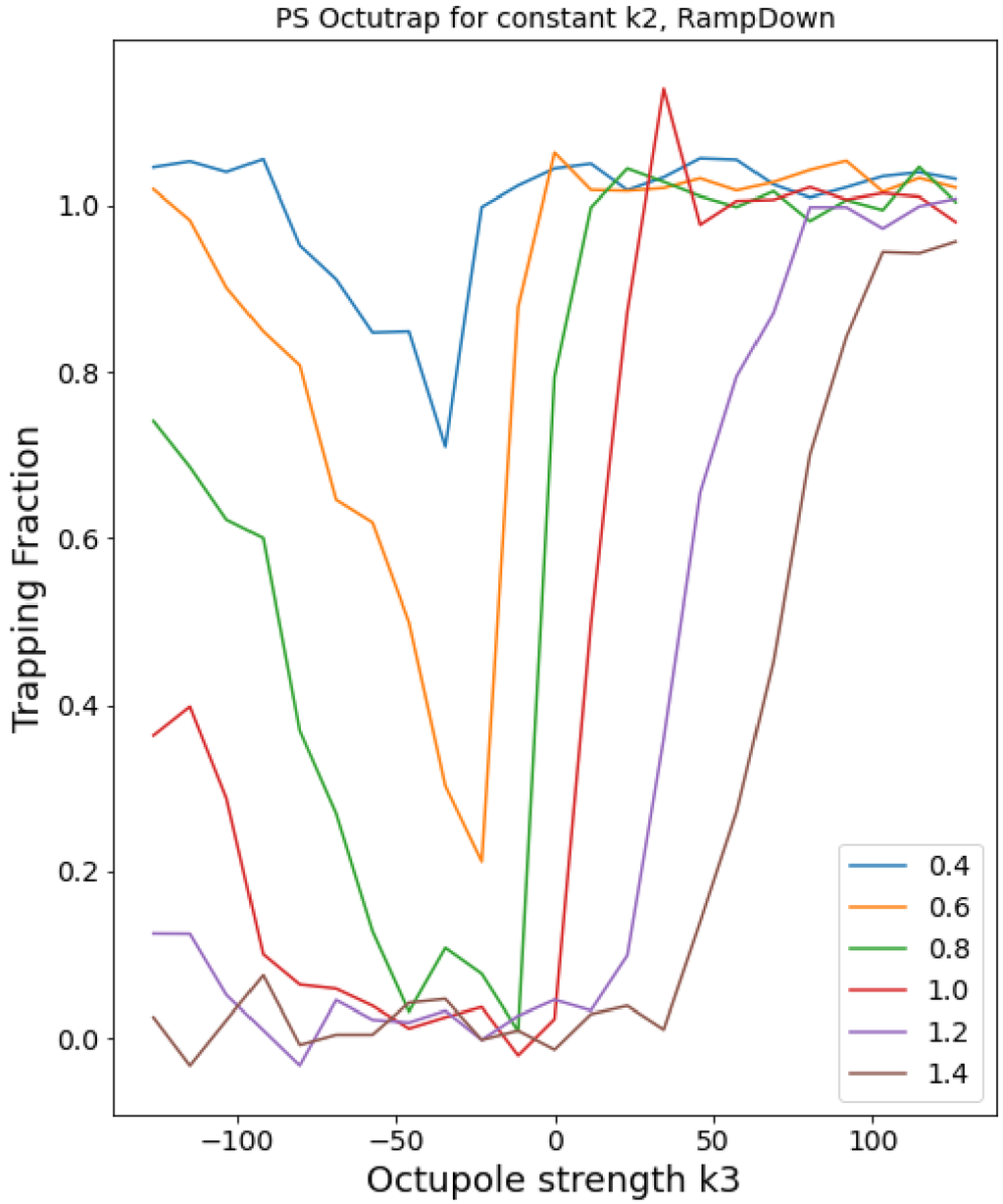
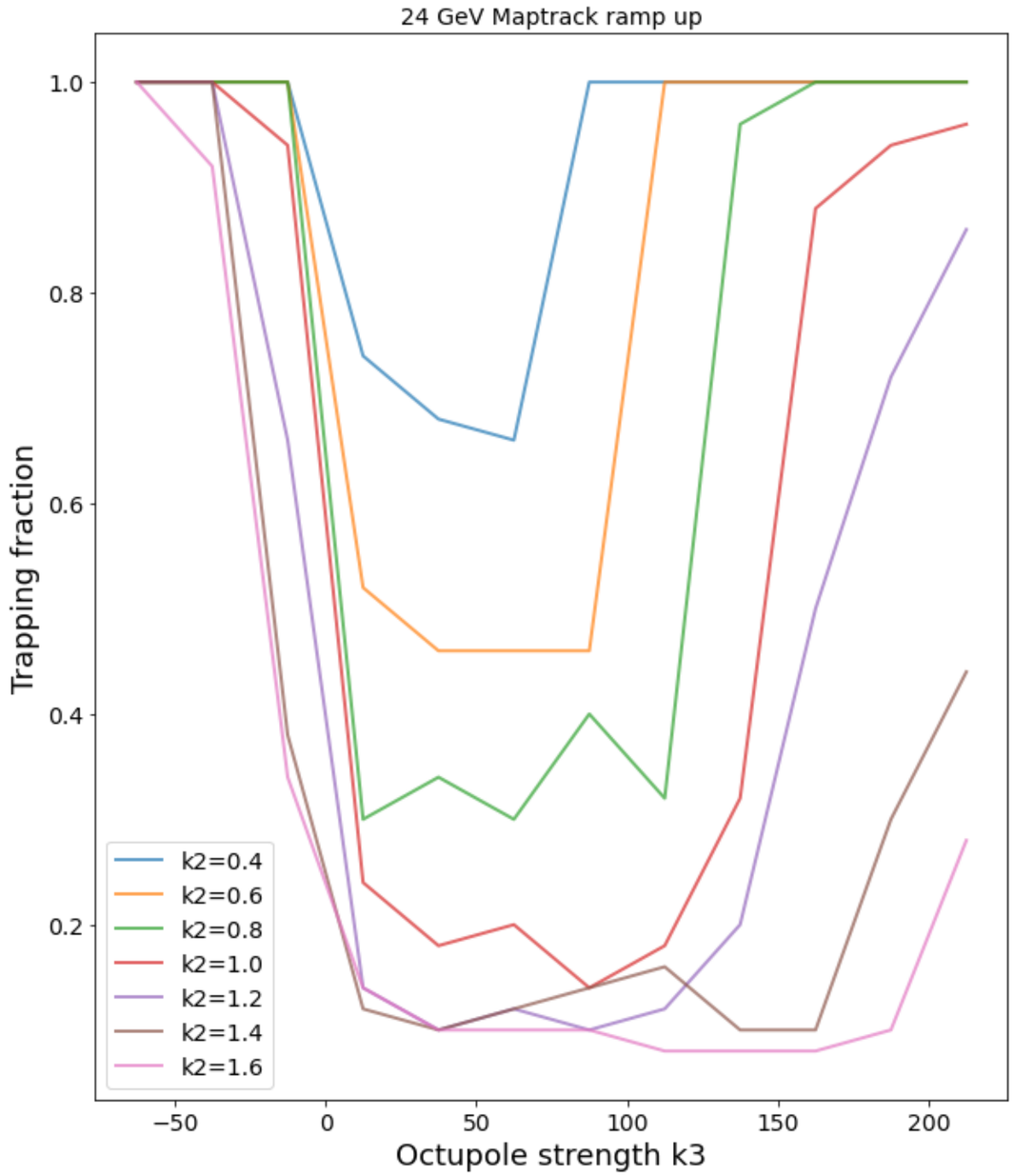




PS Simulations



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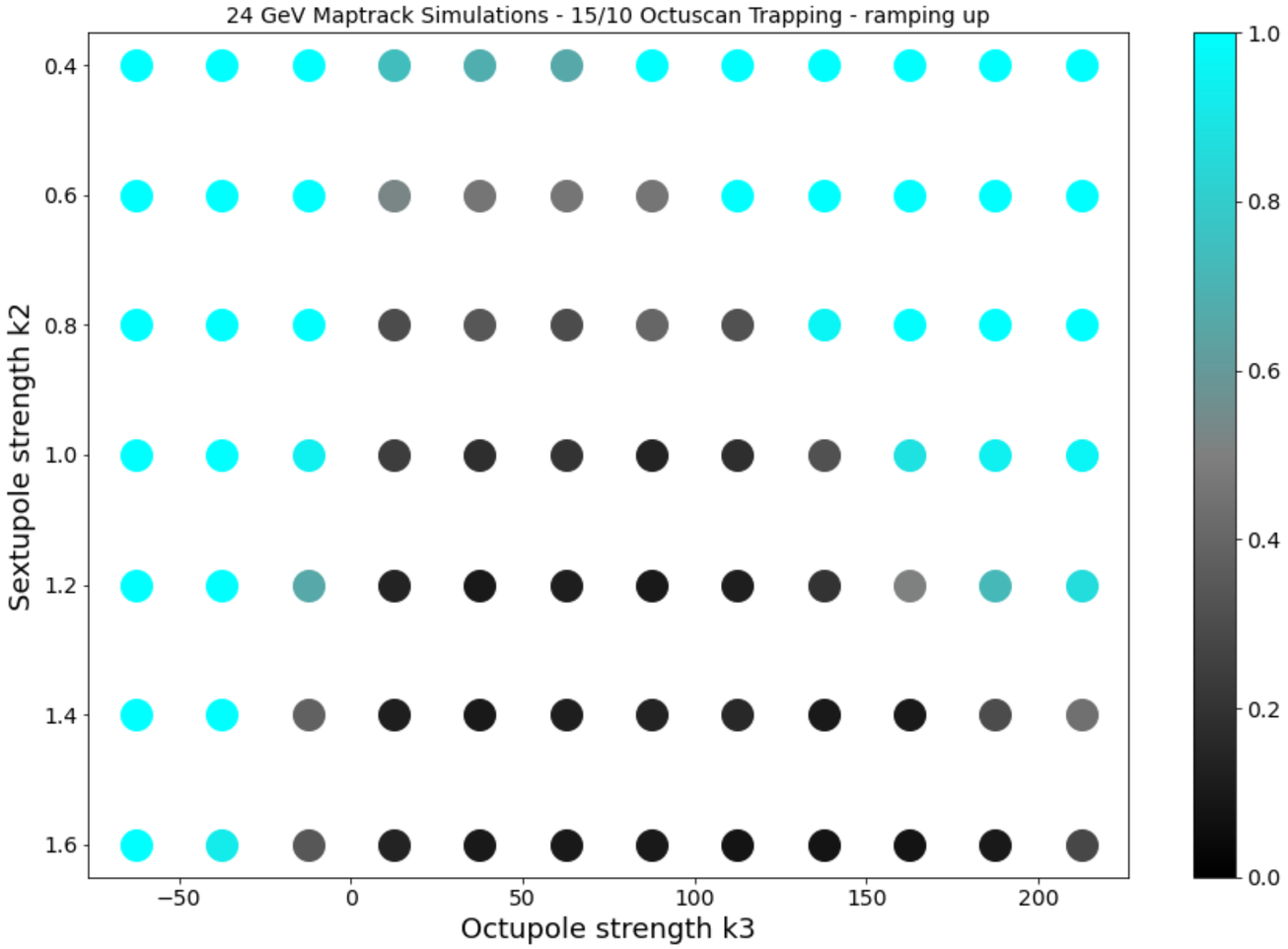
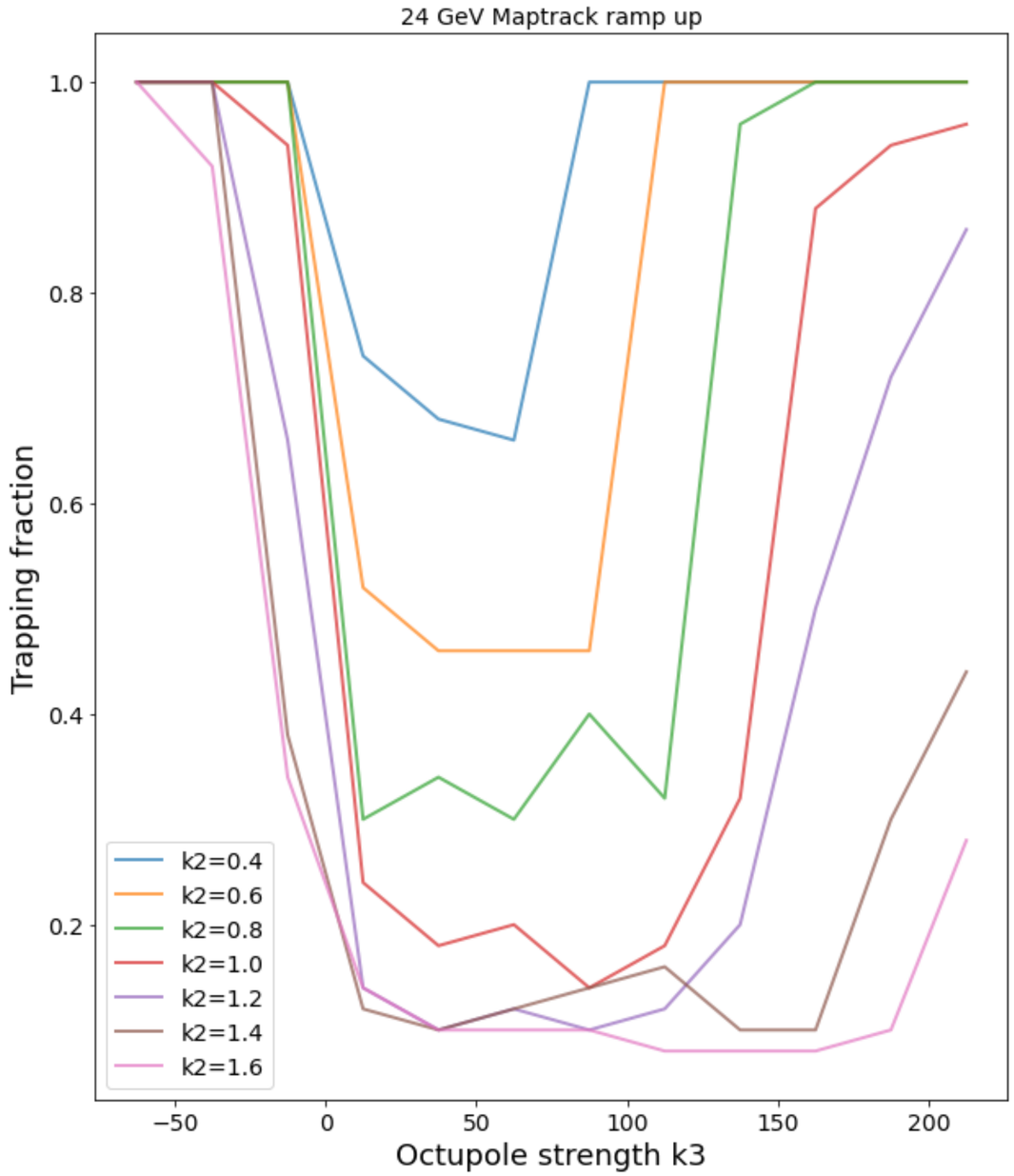
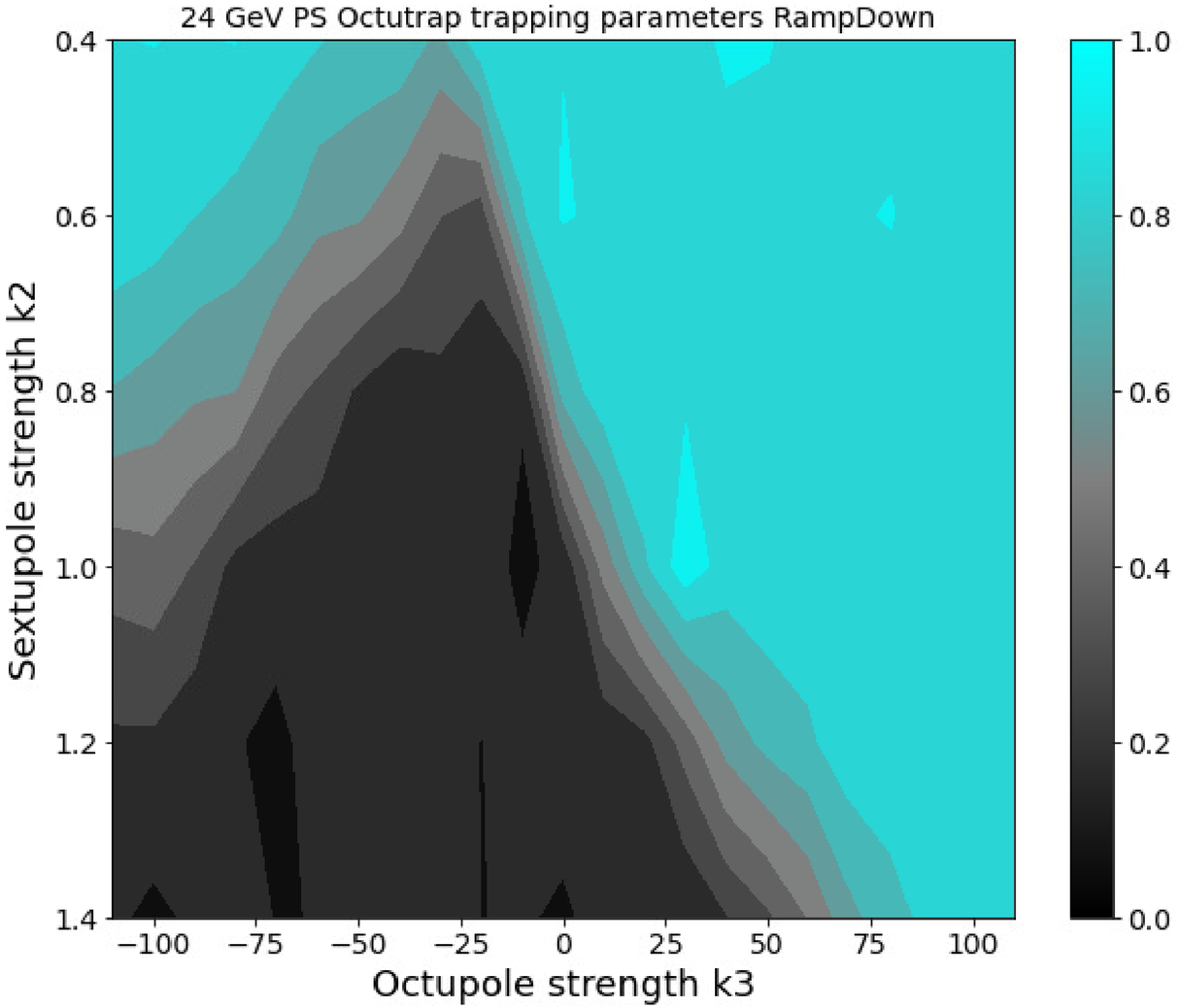
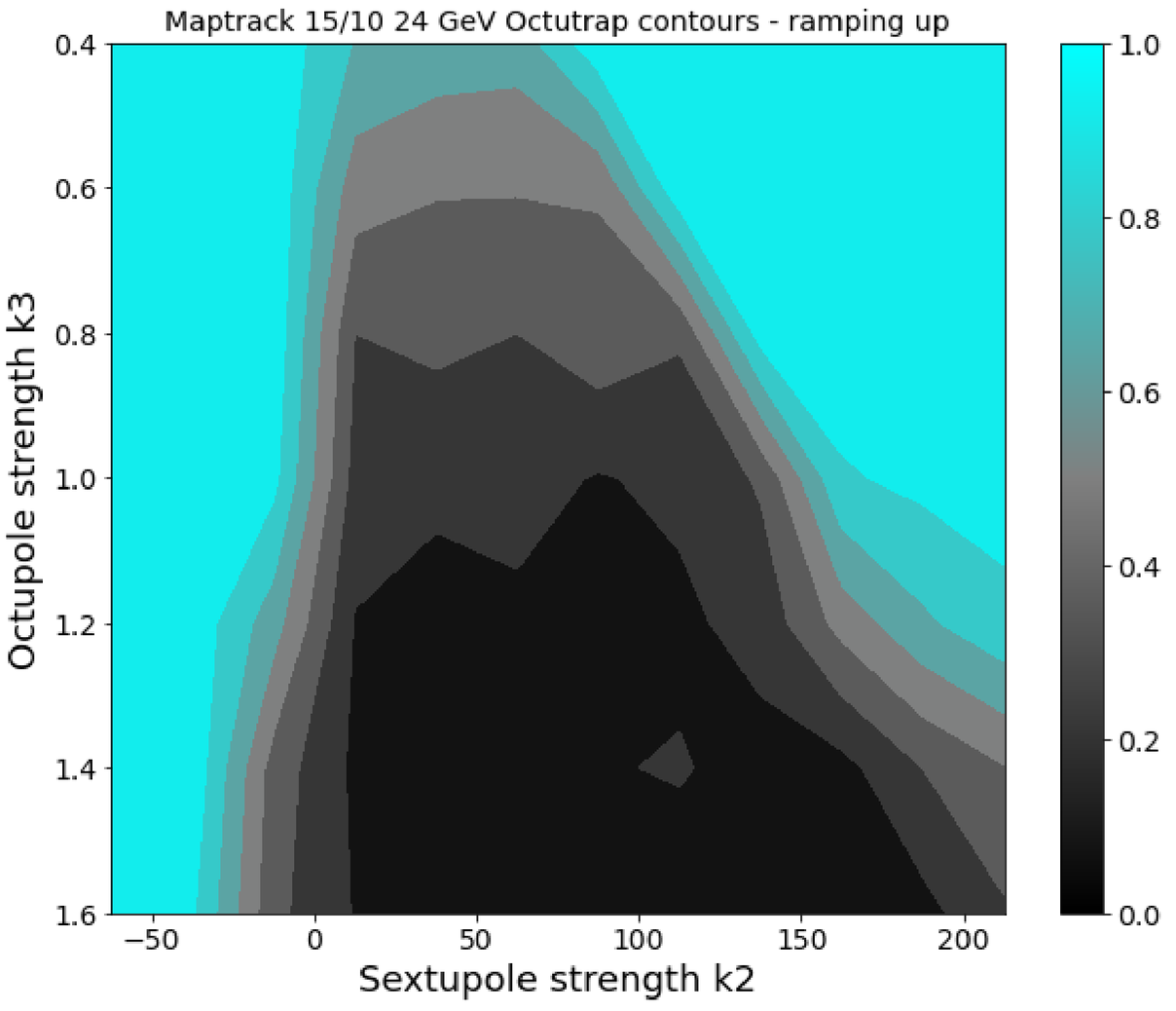




24 GeV Comparison





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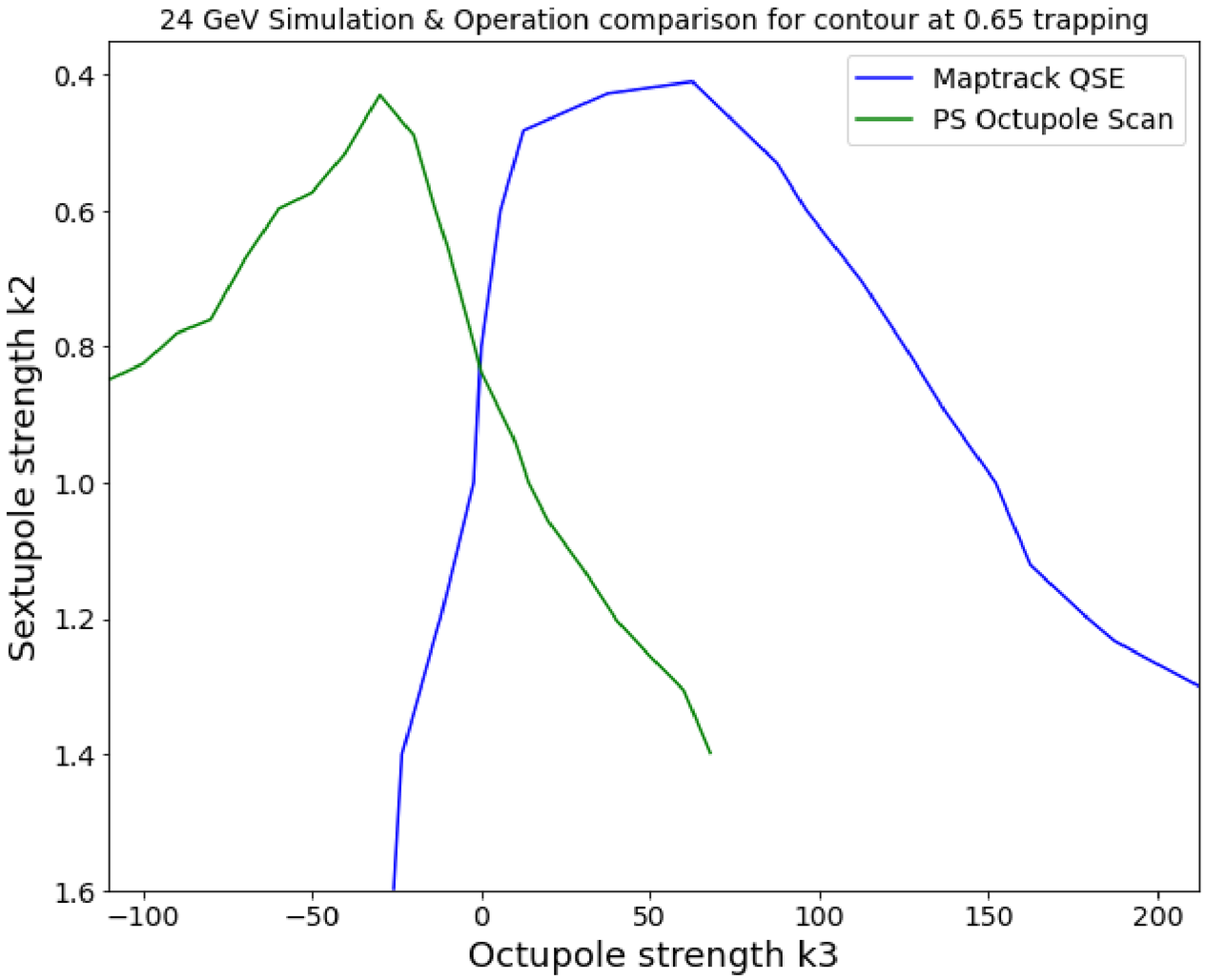

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- Polarity difference in octupoles between simulation and PS

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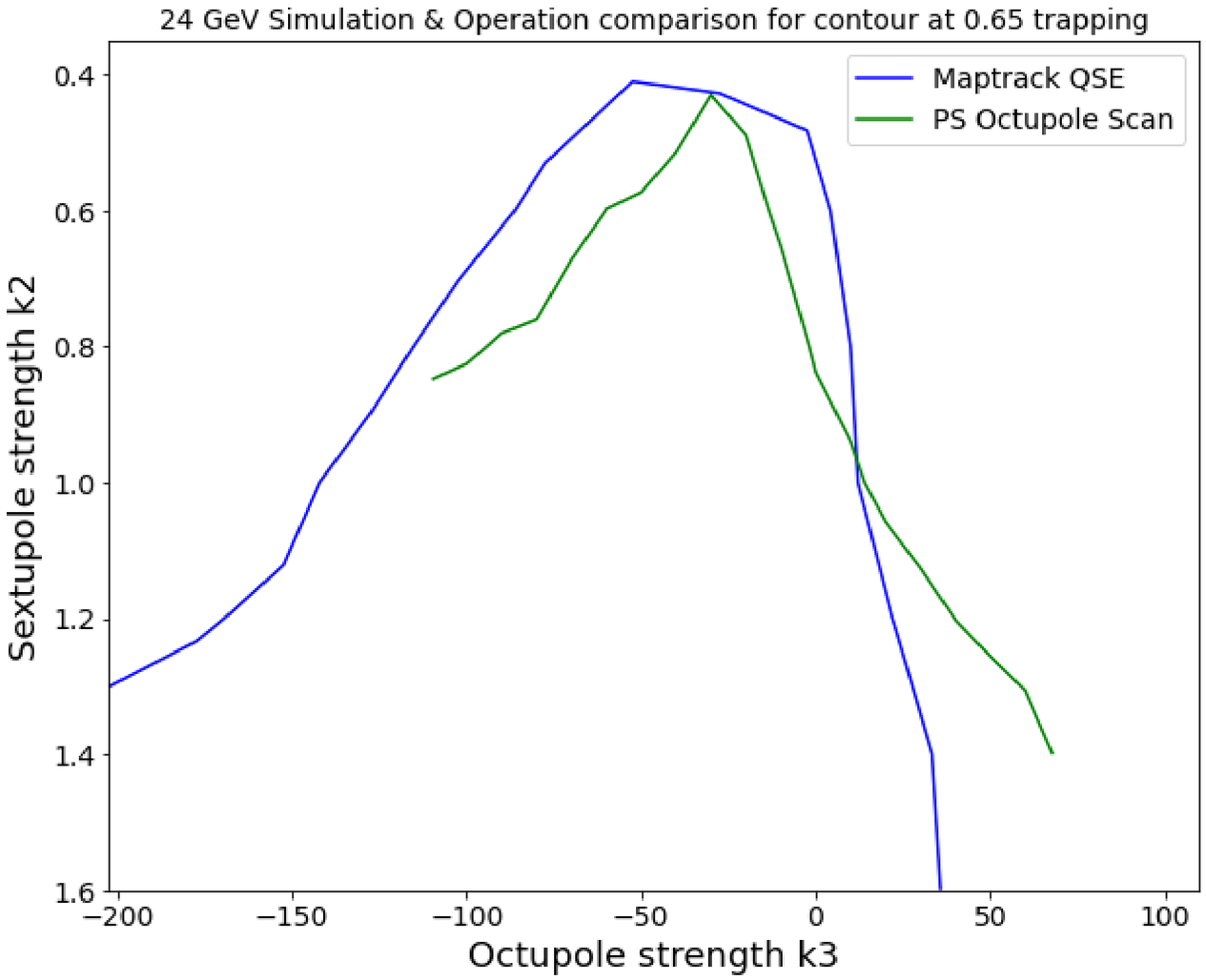

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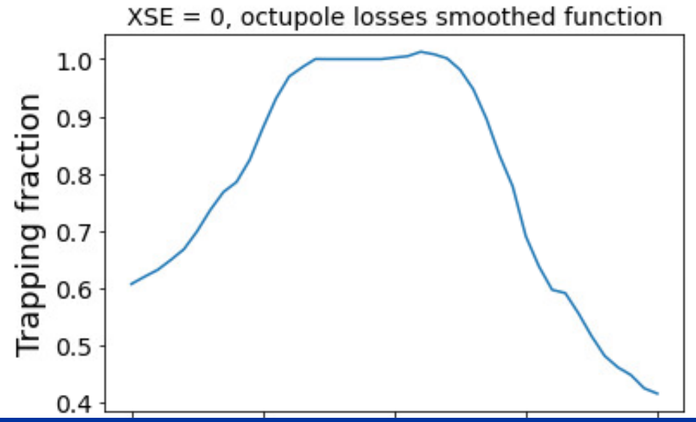
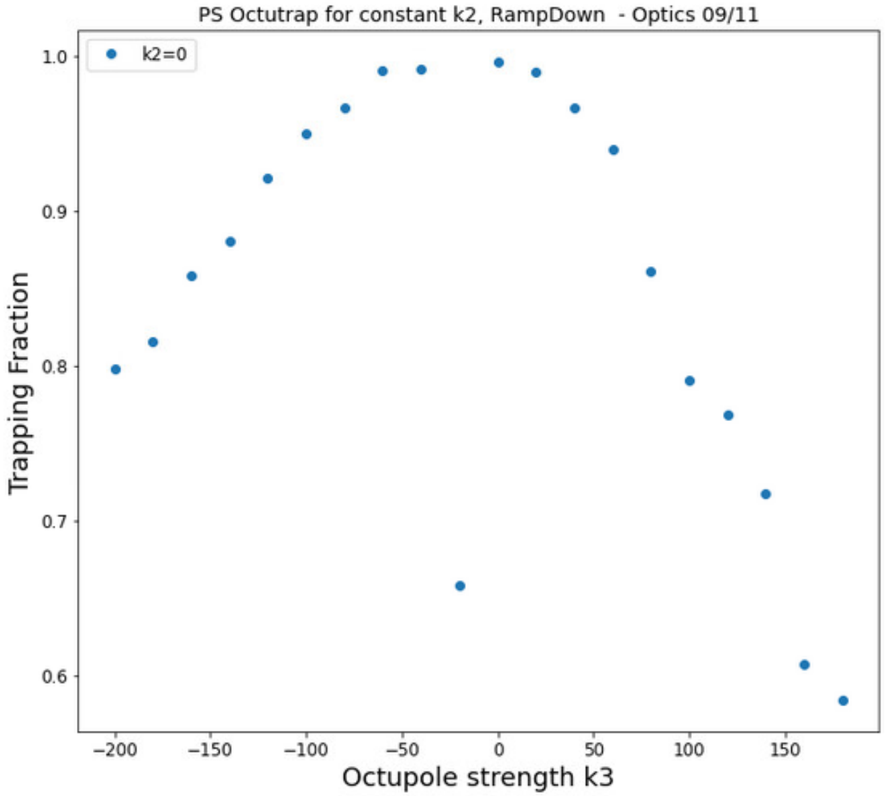
2 GeV in PS

- Octupole **strength** in the PS **limited** by maximum current.
  - Lower energy and **lower beam rigidity** gives larger range of magnet strength.
- Verifying slow extraction & octupole loss validity at **injection energy** (2 GeV) to benefit the East Area preparations.
- Requires different settings in the PS, e.g. no accelerating RF, no PFWs, use of Low Energy Quadrupoles (LEQ).

2 GeV in PS

- Issue found: when octupoles were turned on, the beam would get lost.
  - Higher octupole strength gave higher losses
- Currently quantifying these losses
  - Chaotic regime, high space charge etc.
- In the mean time, counteracted the losses by adding a smoothed function to results.





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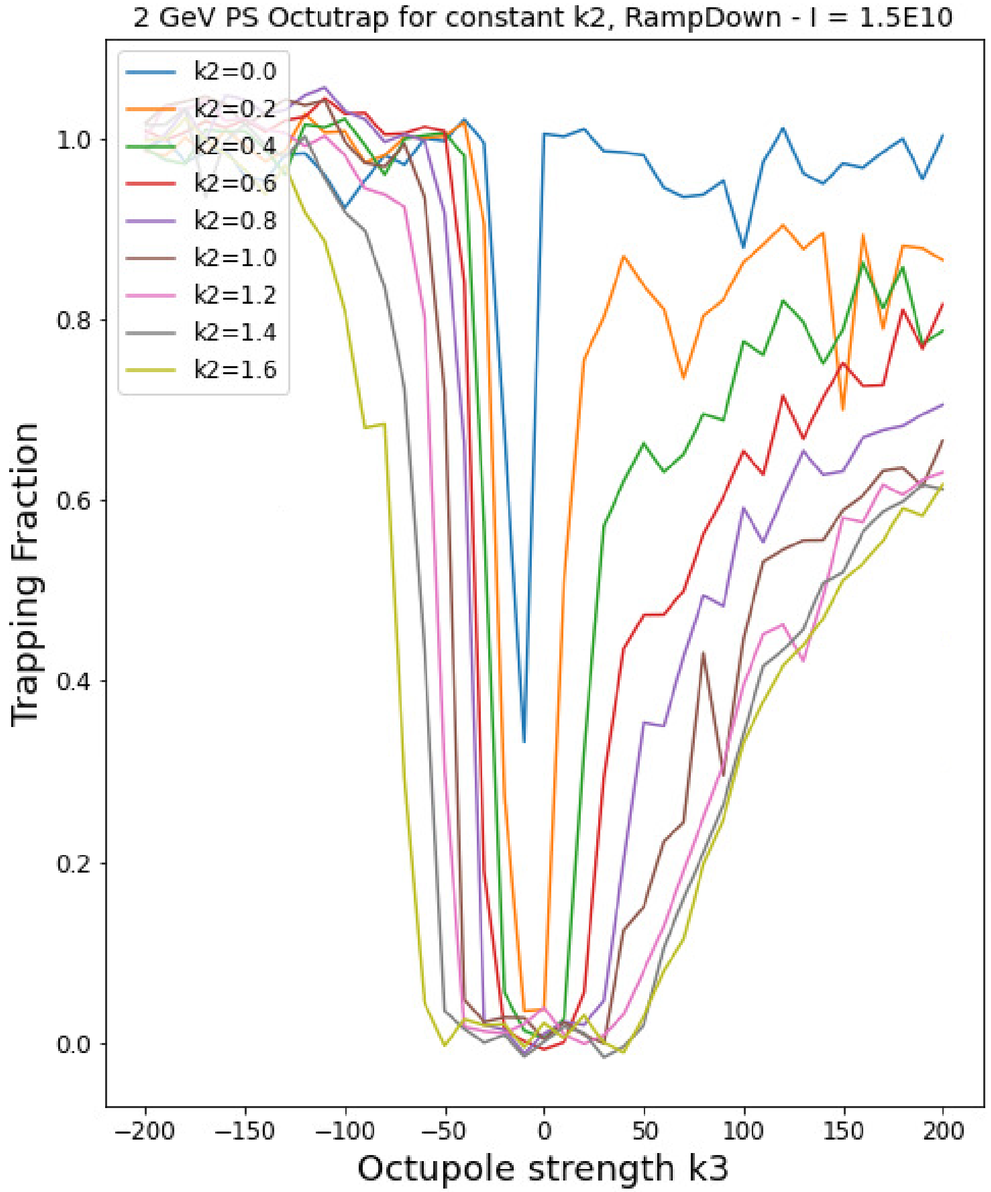
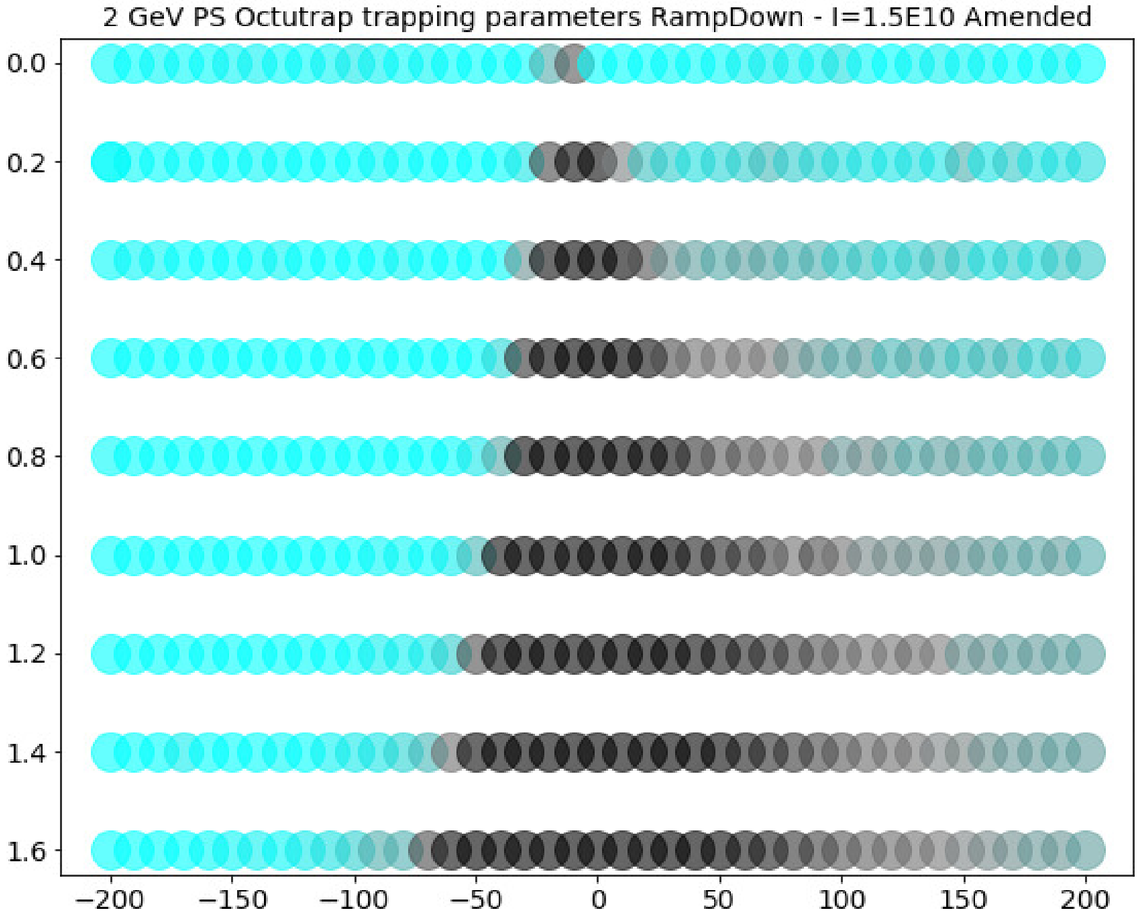
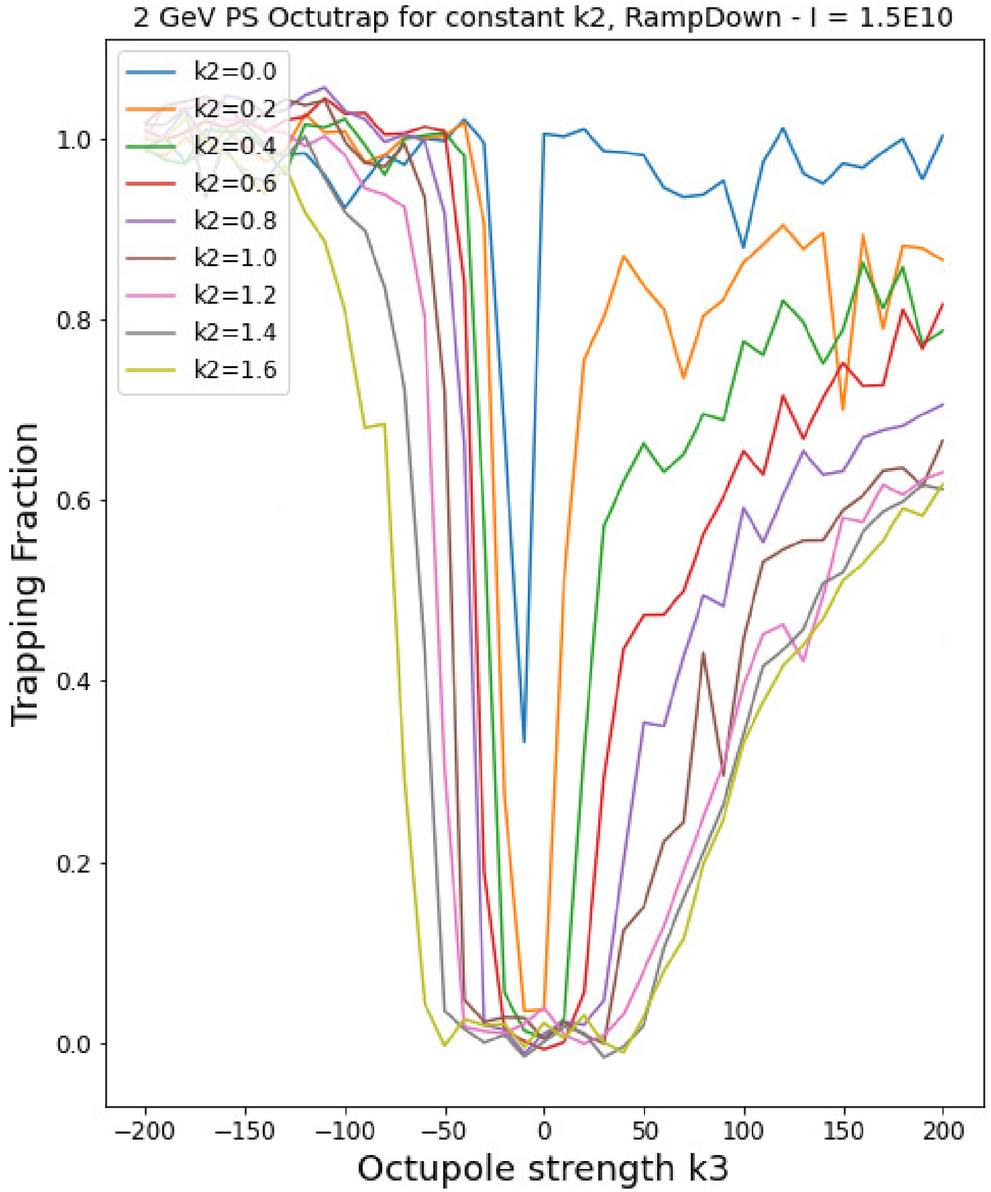
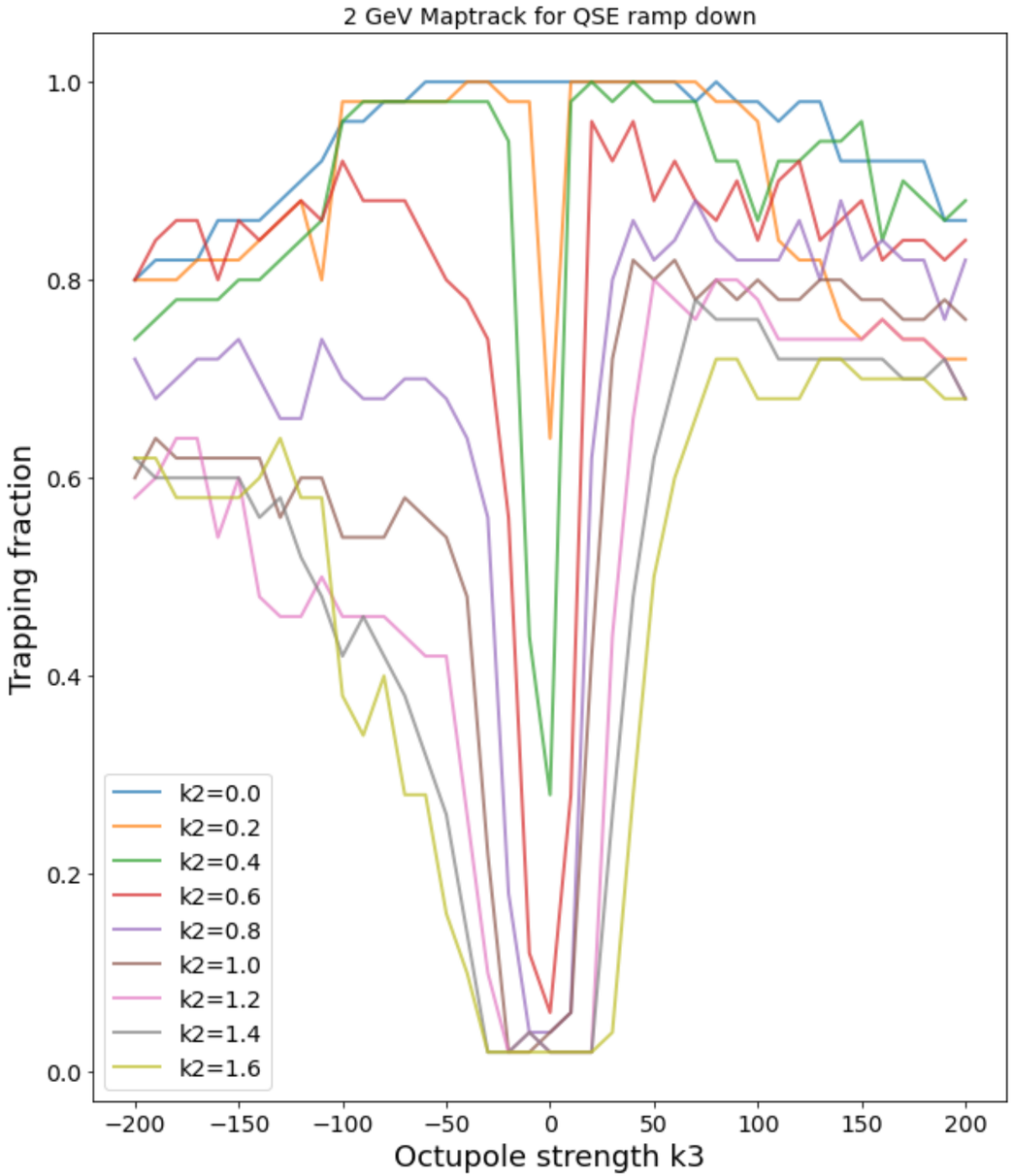


2 GeV PS Results

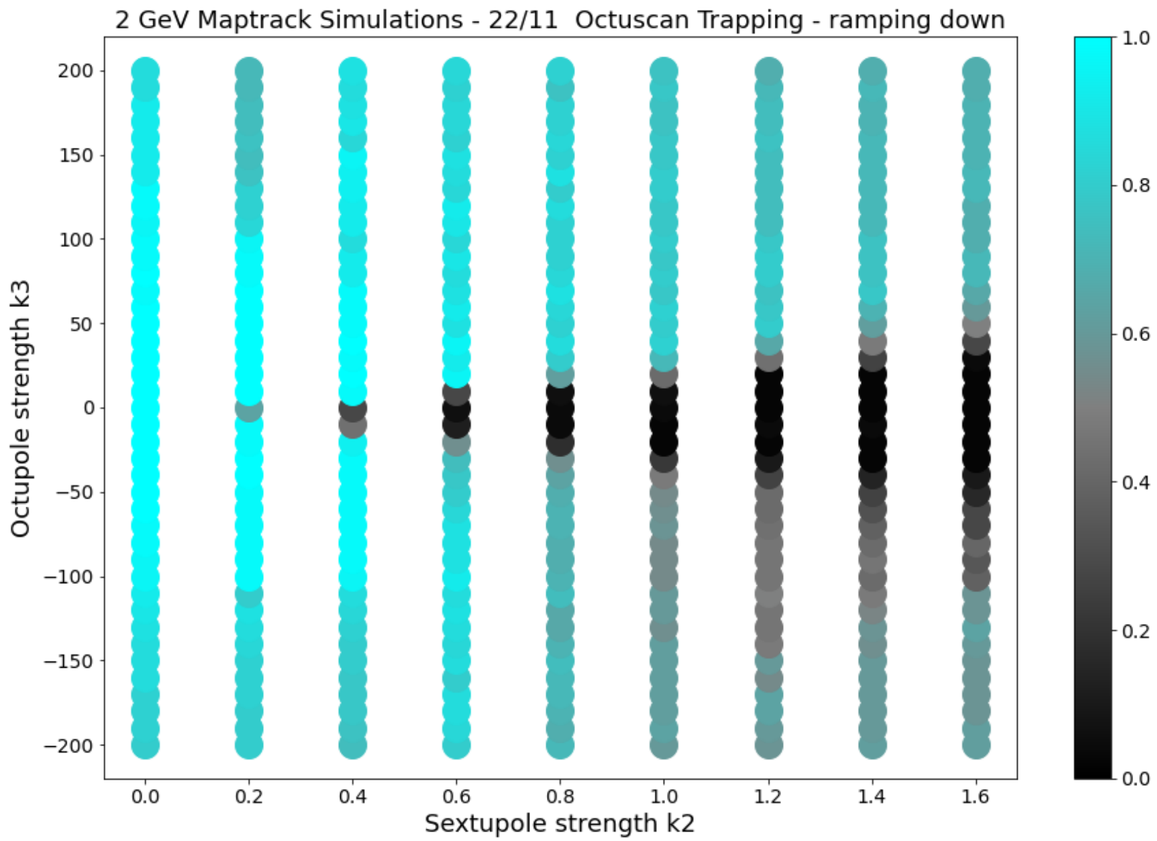


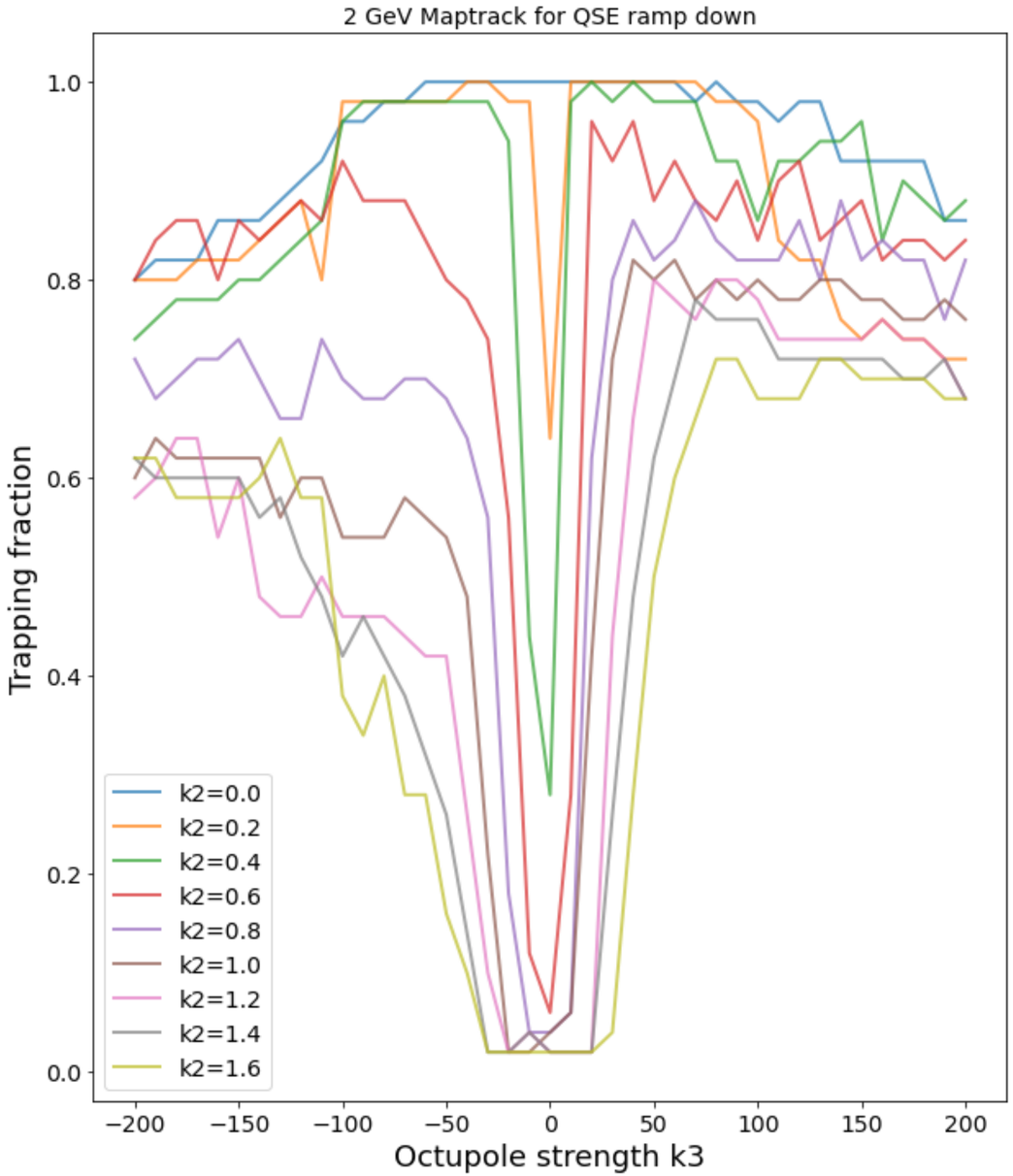


2 GeV Simulations

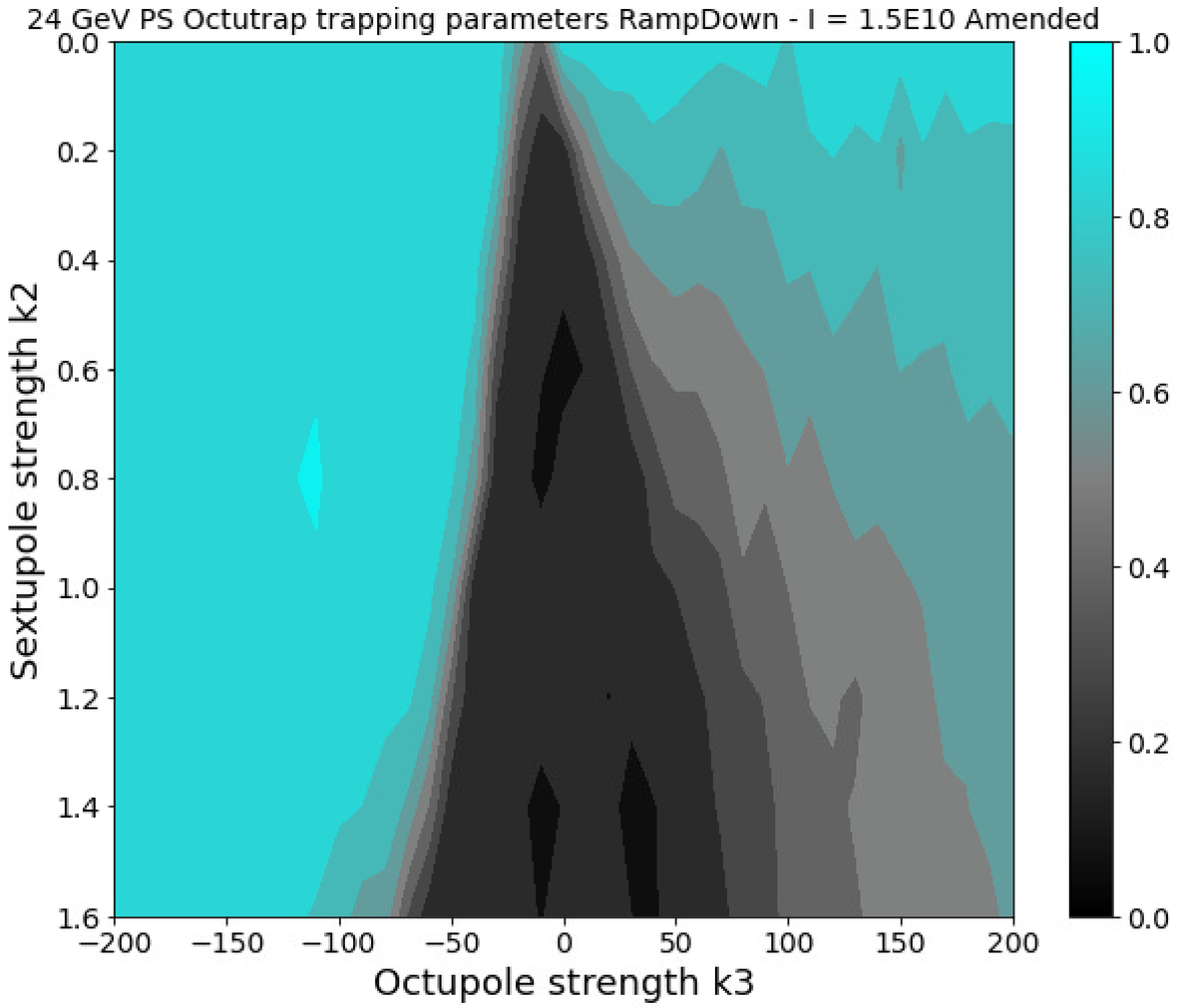


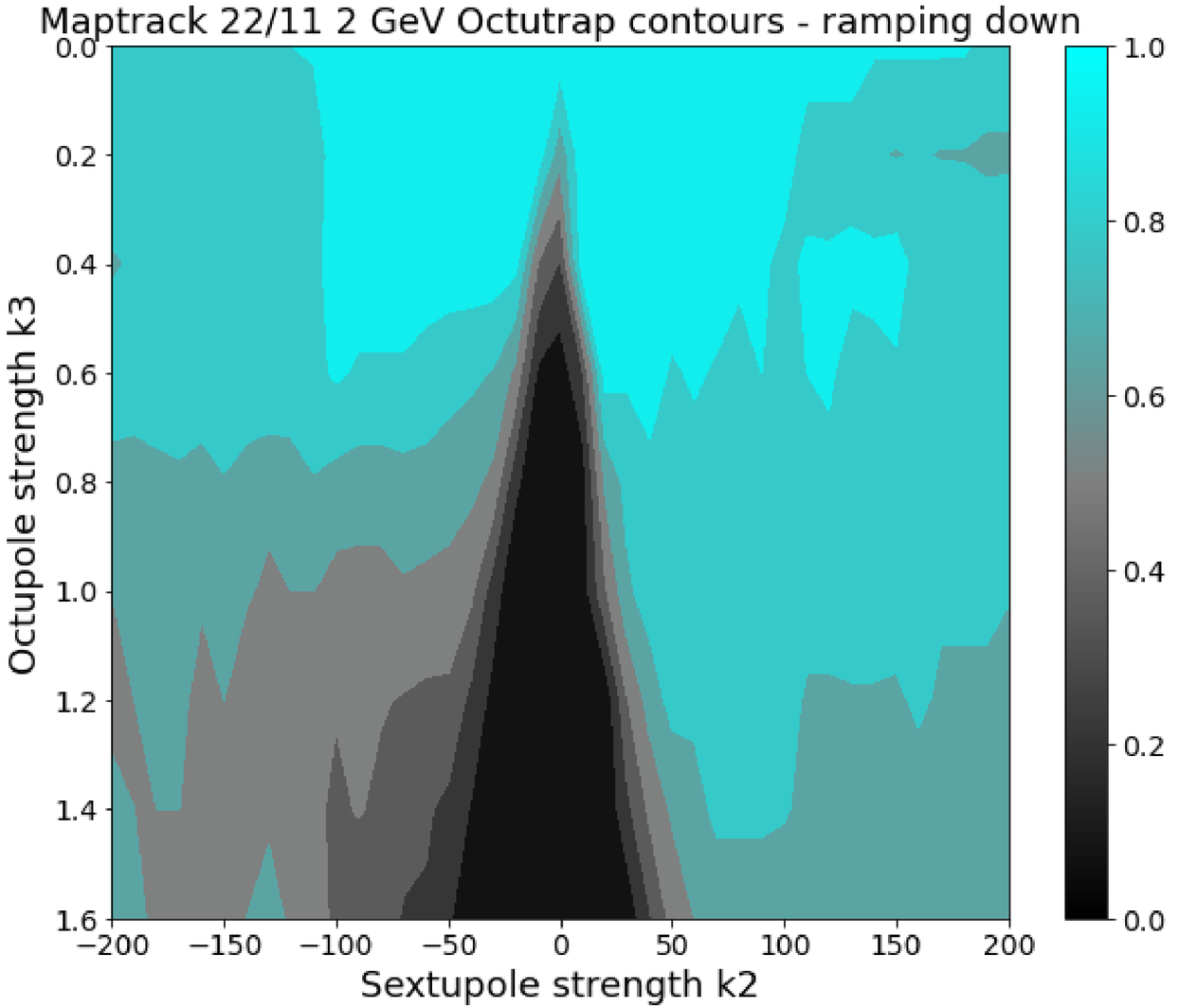
2 GeV Simulations



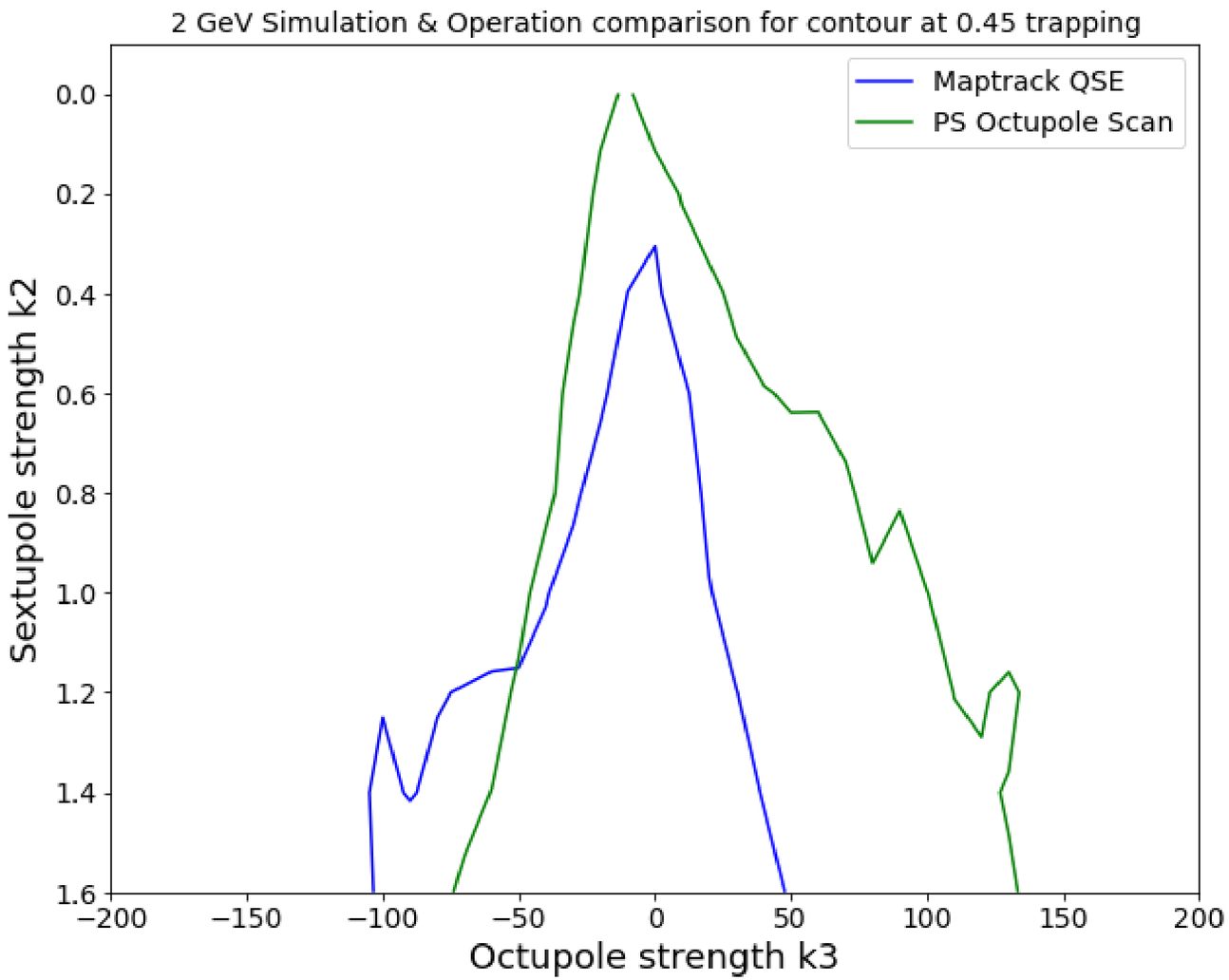


2 GeV Comparison



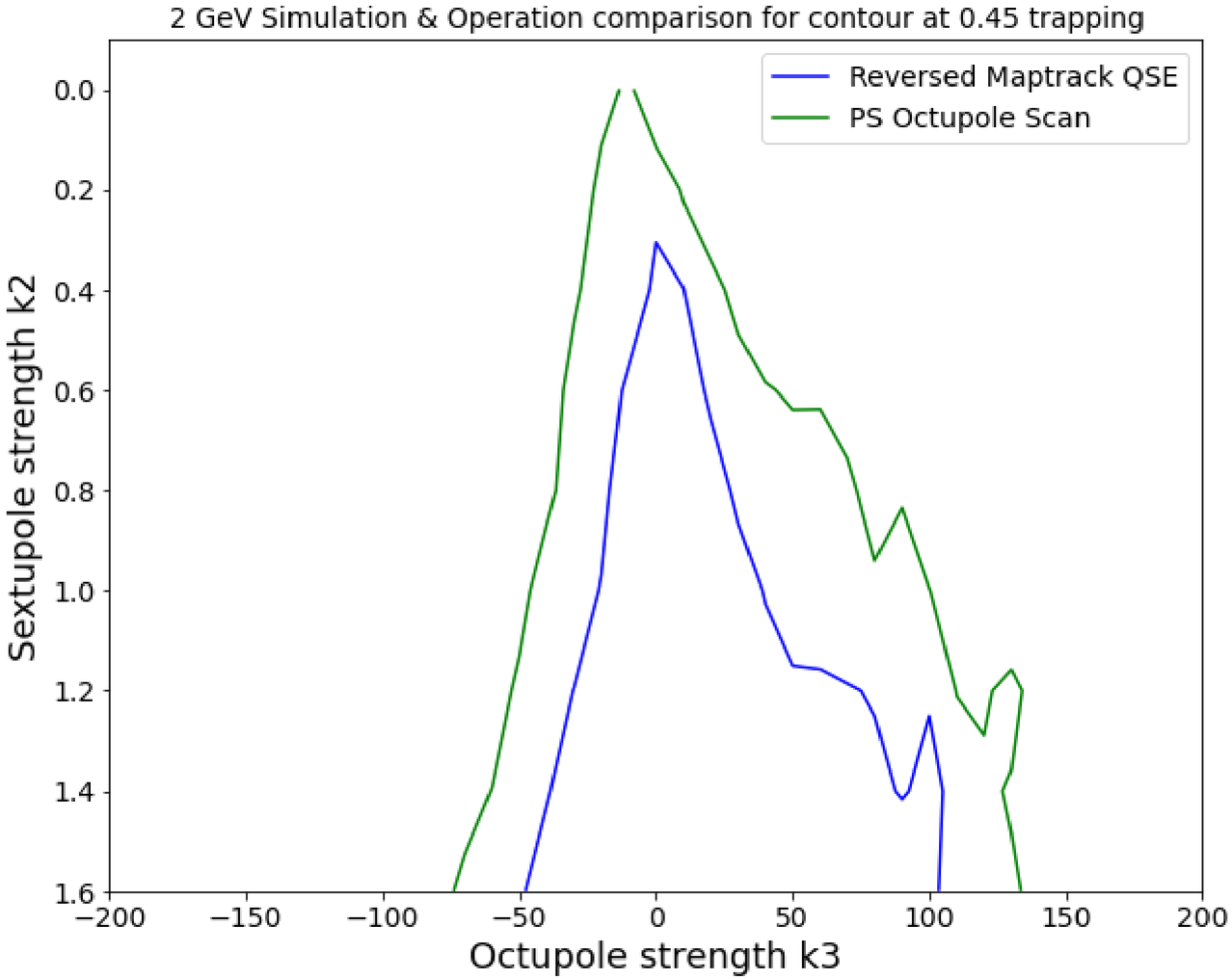


2 GeV Comparison



- No offset as PFWs not used at lower energy

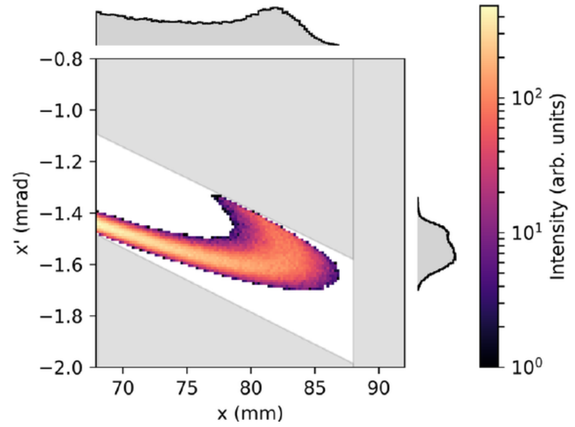
24 GeV Comparison

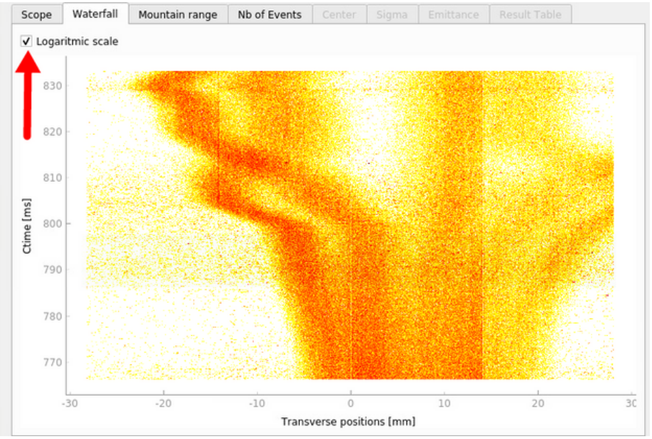


Next Steps

- Now I know where trapping occurs / does not occur
  - Can now fine-tune my octupole strengths to bend the separatrices around the electrostatic septum without hitting the foil, causing losses.
- Would like to observe shape and size of islands using the Beam Gas Ionization chamber.
- Would like to understand why octupole causes losses at 2 GeV and mitigate this.

M. Fraser *Demonstration of slow extraction loss reduction with the application of octupoles at the CERN Super Proton Synchrotron (2019)*





Conclusions

- Obtained invaluable operational experience & enhanced my knowledge of slow extraction by performing it in real life.
  - Benefitted from a theoretically and experimentally challenging topic (non-linear magnets in an old machine).
  - Hope that practical benefits arise from this research topic (beam loss reduction for East area)

Thank you for listening! Any questions?