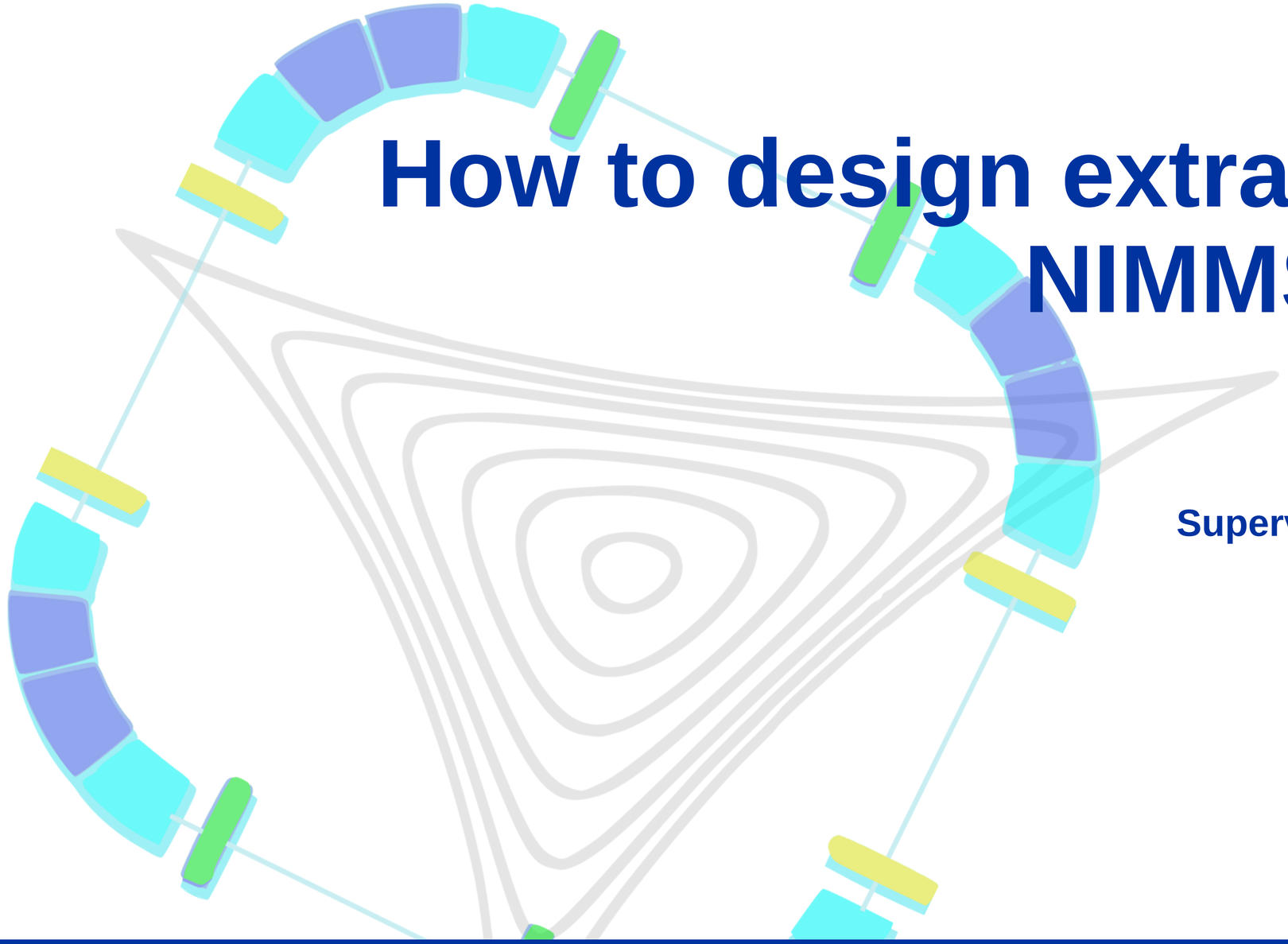

How to design extraction from the NIMMS synchrotron

Rebecca Taylor

PhD student since March 2021

Supervised by M. Vretenar & E. Benedetto

6th October 2021

Why Extraction?

Extraction is critical as it defines the **quality** of the beam.

It has to be designed to meets medical requirements.

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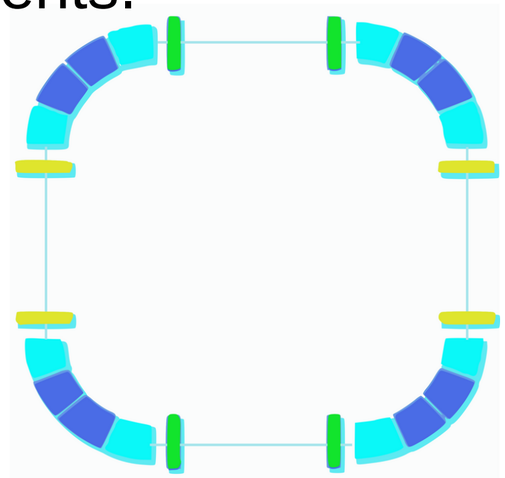
Extraction is critical as it defines the **quality** of the beam.
It has to be designed to meets medical requirements.

- CERN uses a range of extraction techniques in its accelerator transfer lines.
  - **Accelerator expertise** is required to meet these requirements.
- The extraction constraints will affect the **design of the synchrotron lattice**.
- Novel extraction techniques required for the challenges of a **compact, superconducting** accelerator.



Specifications for ion therapy

Beam quality closely depends on extraction:

Beam from
1 - 30 seconds

Stable intensity beam

Rapid changes in energy

Specifications for ion therapy

Beam quality closely depends on extraction:

Active & passive scanning over minutes

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Varying treatment energy to change dose depth

Types of Extraction

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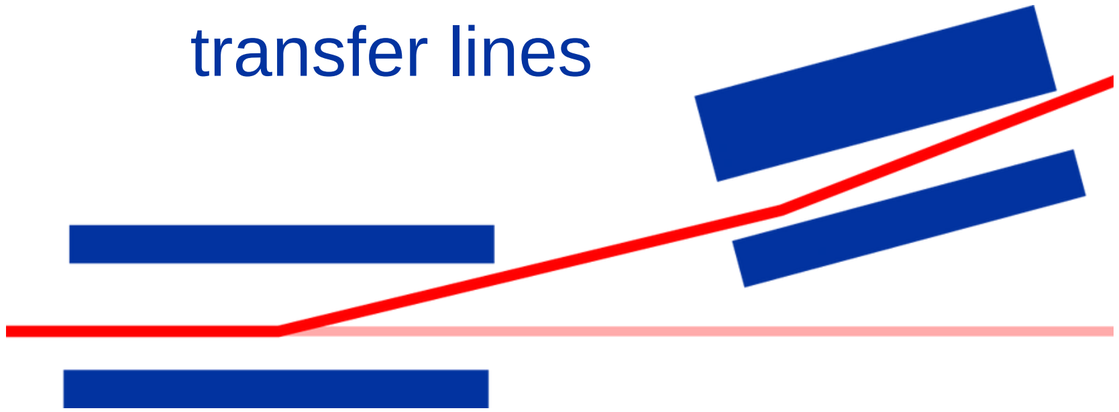
Extracting Fast

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



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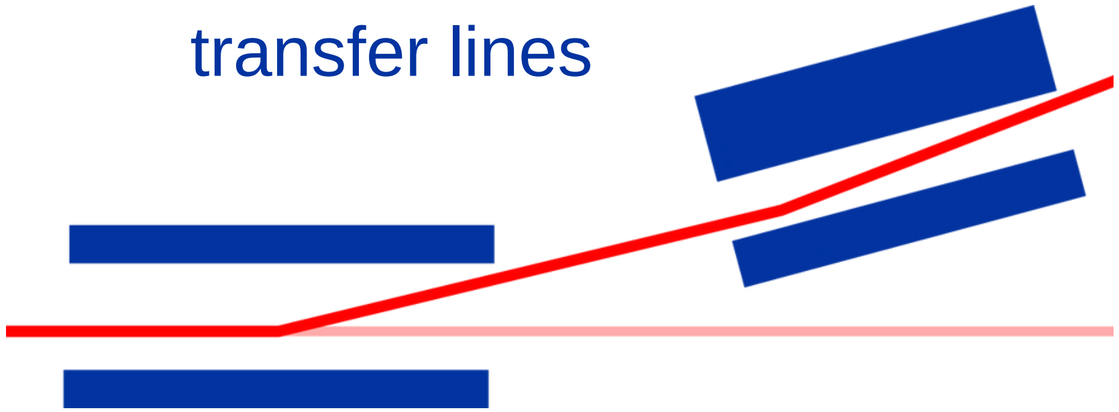

Extracting Slow

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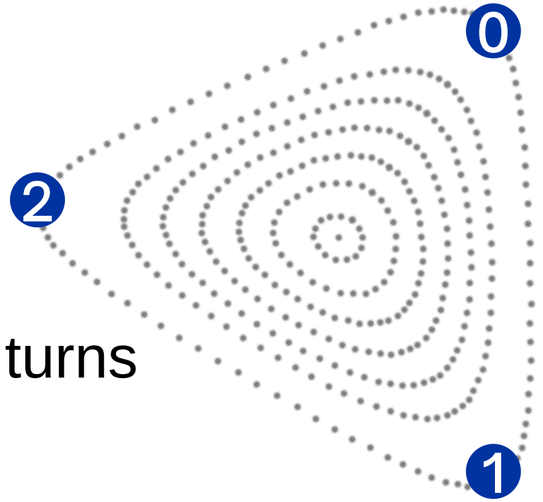
  - A thin wire separating an electric field and non-field region
- **1 good quality spill**
  - The slowly extracted beam

Recipe for extracting slowly



- Put the beam near the third-integer **tune**
  - Particles in phase-space return to their original position every 3 turns

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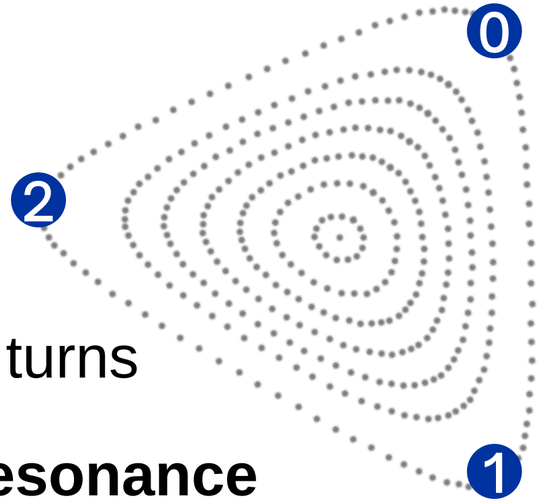

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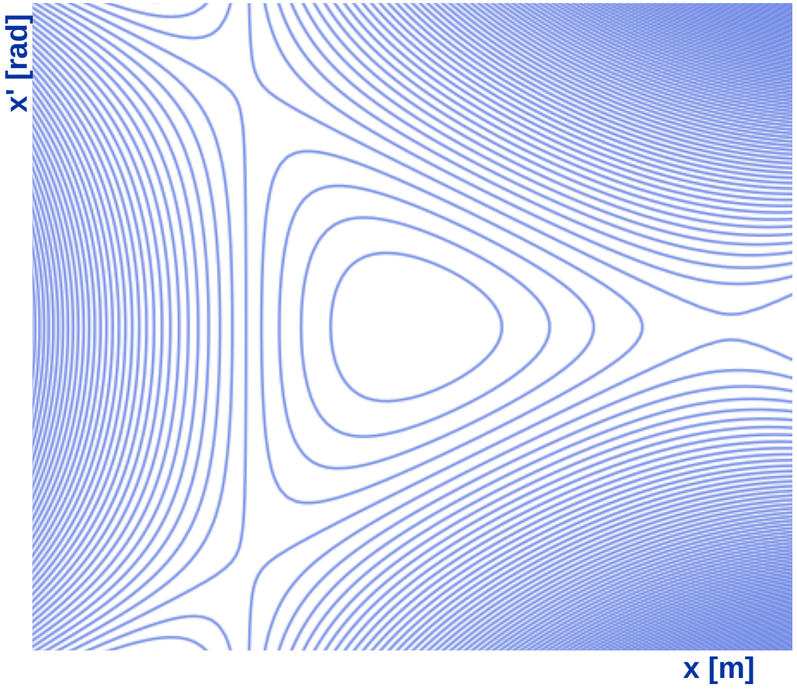

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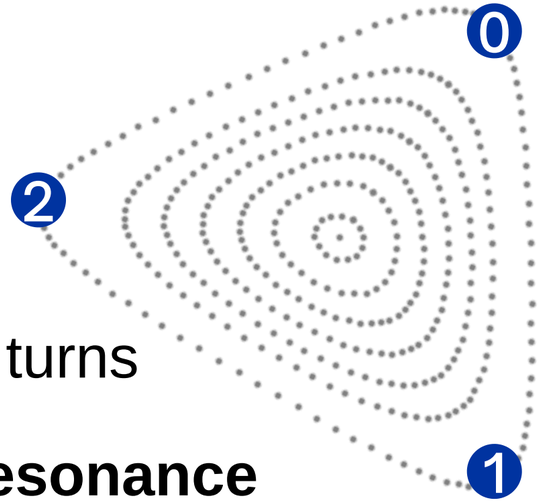

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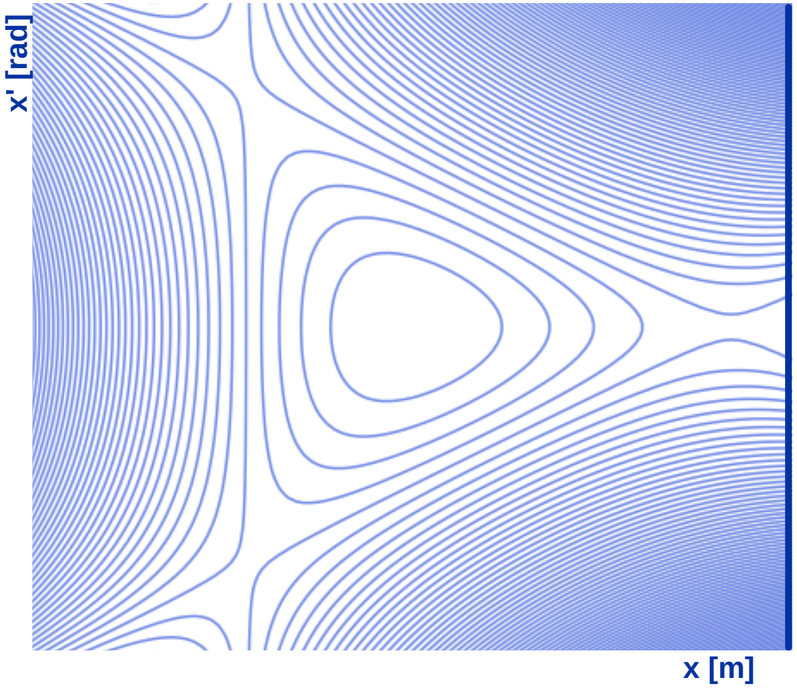

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  - These particles form the **spill** which goes to the extraction line & the gantry.

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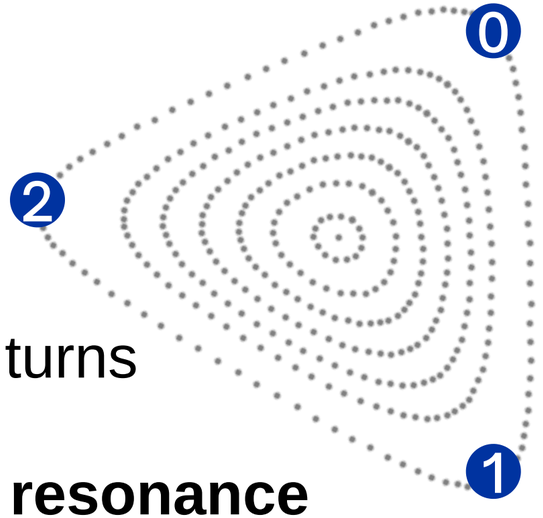

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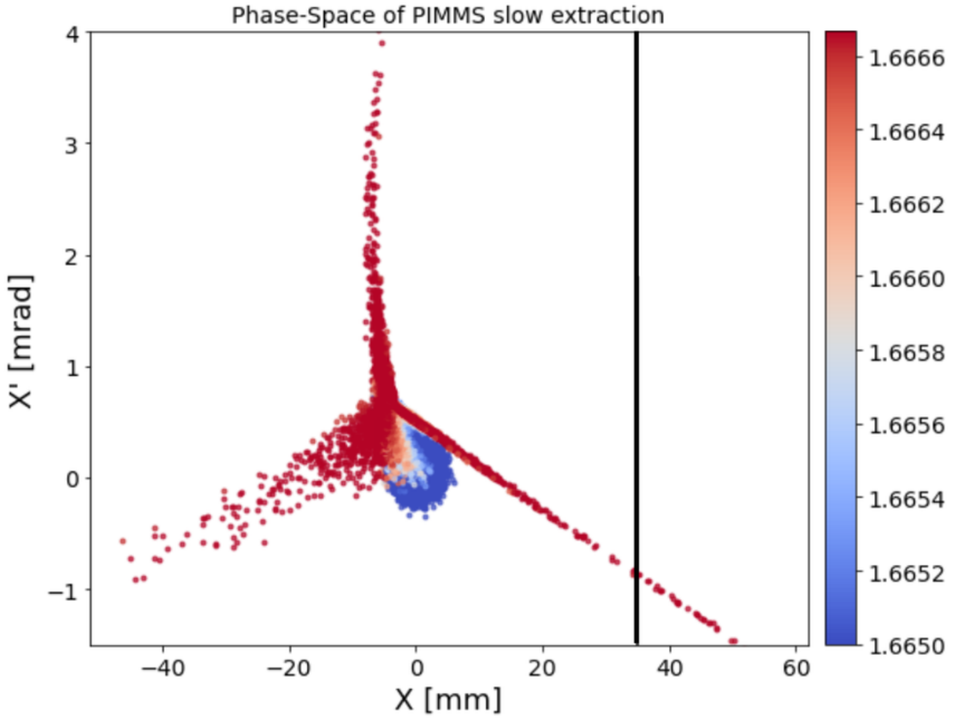

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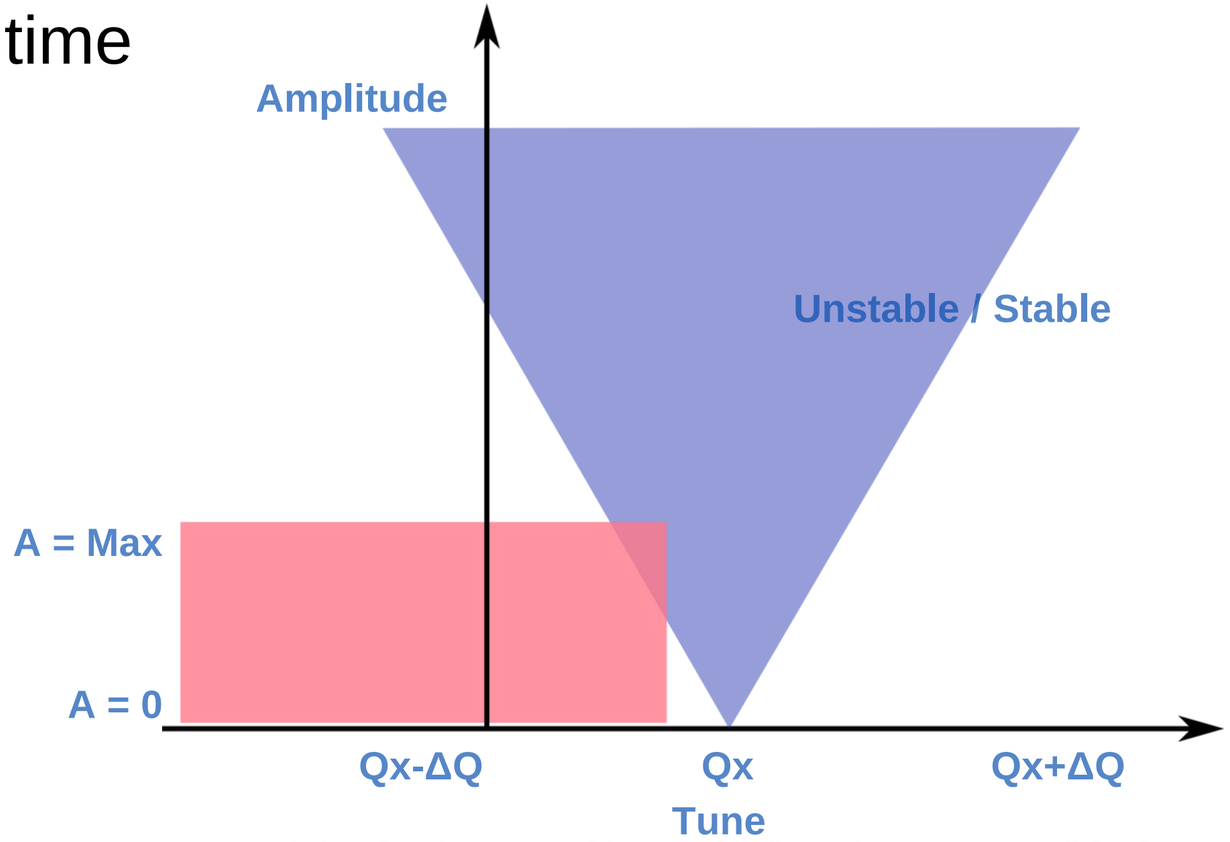
Just one problem!

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

Either:

- Increase the momentum of the particles
- Increase the amplitude of the particles.

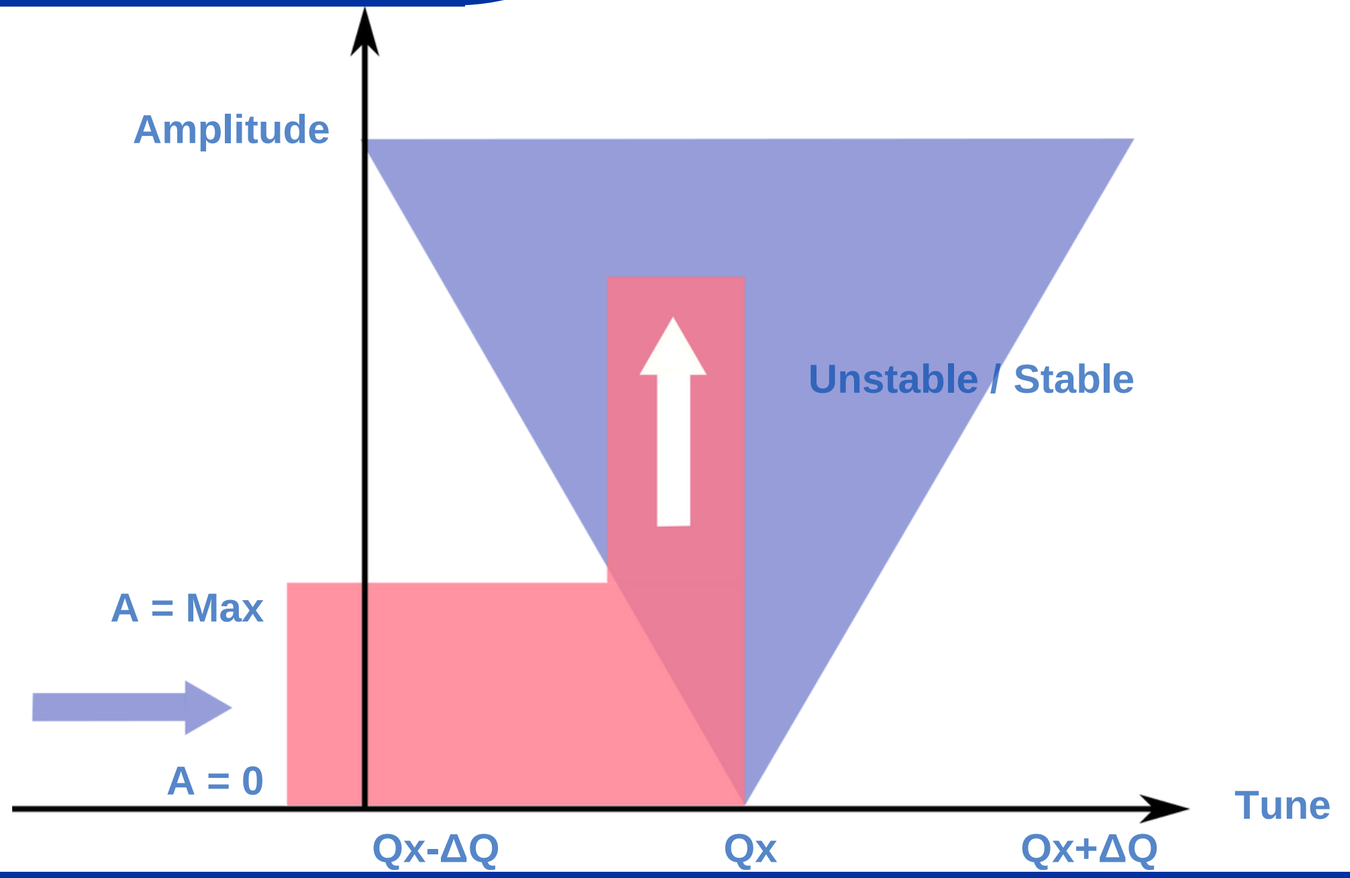


Steinbach Diagram of beam (red) and resonance (blue)

Betatron Core

- Moving the beam towards the resonance by changing the momentum each turn

- Made of a large coil winding with an iron core.
  - 1.5 meters long
- Sets up a stable extraction
- Can improve spill quality with channelling techniques



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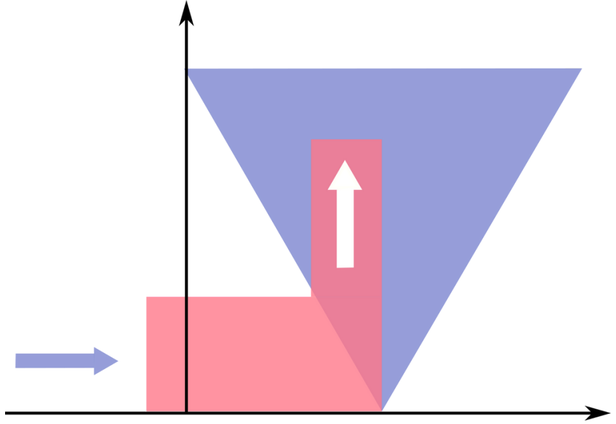
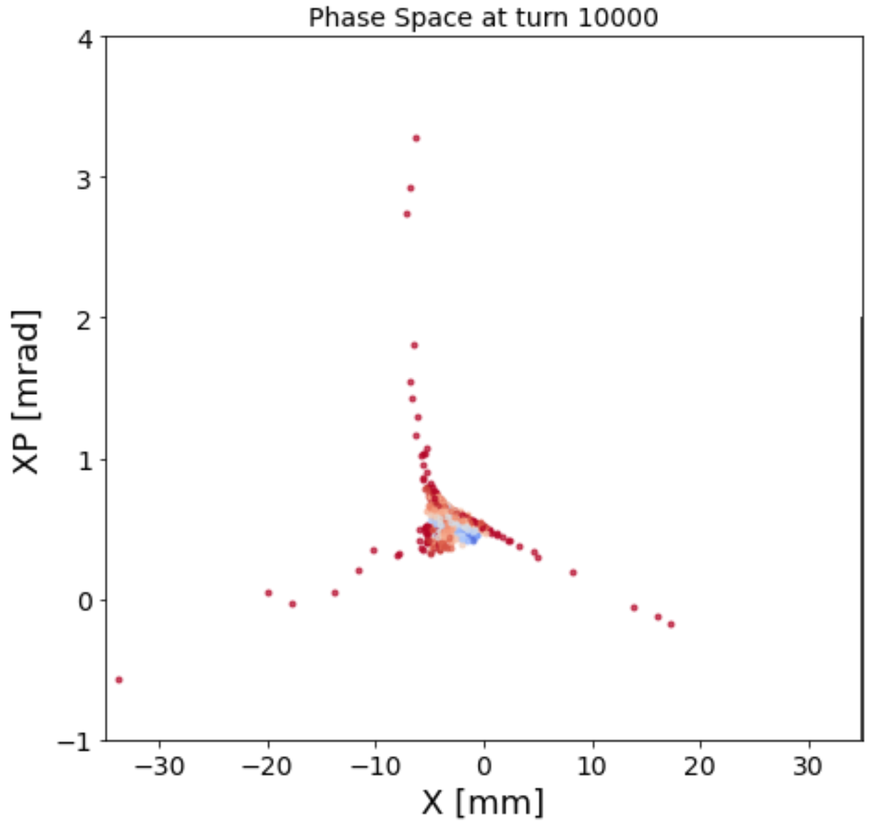
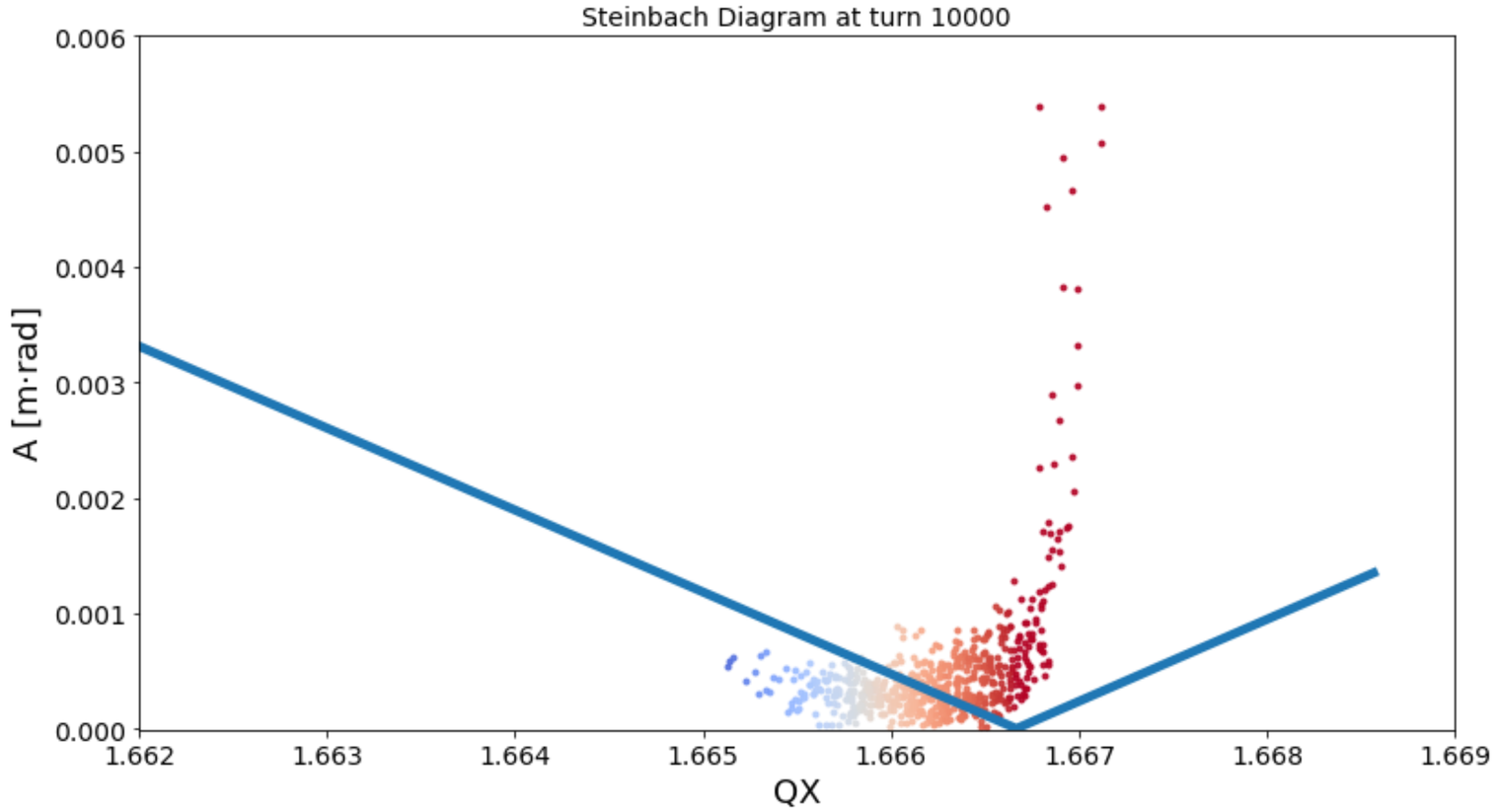
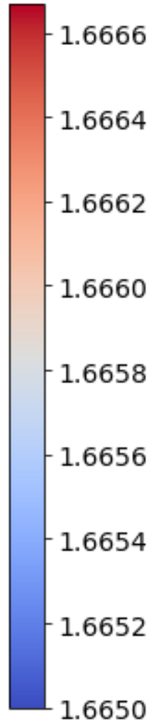




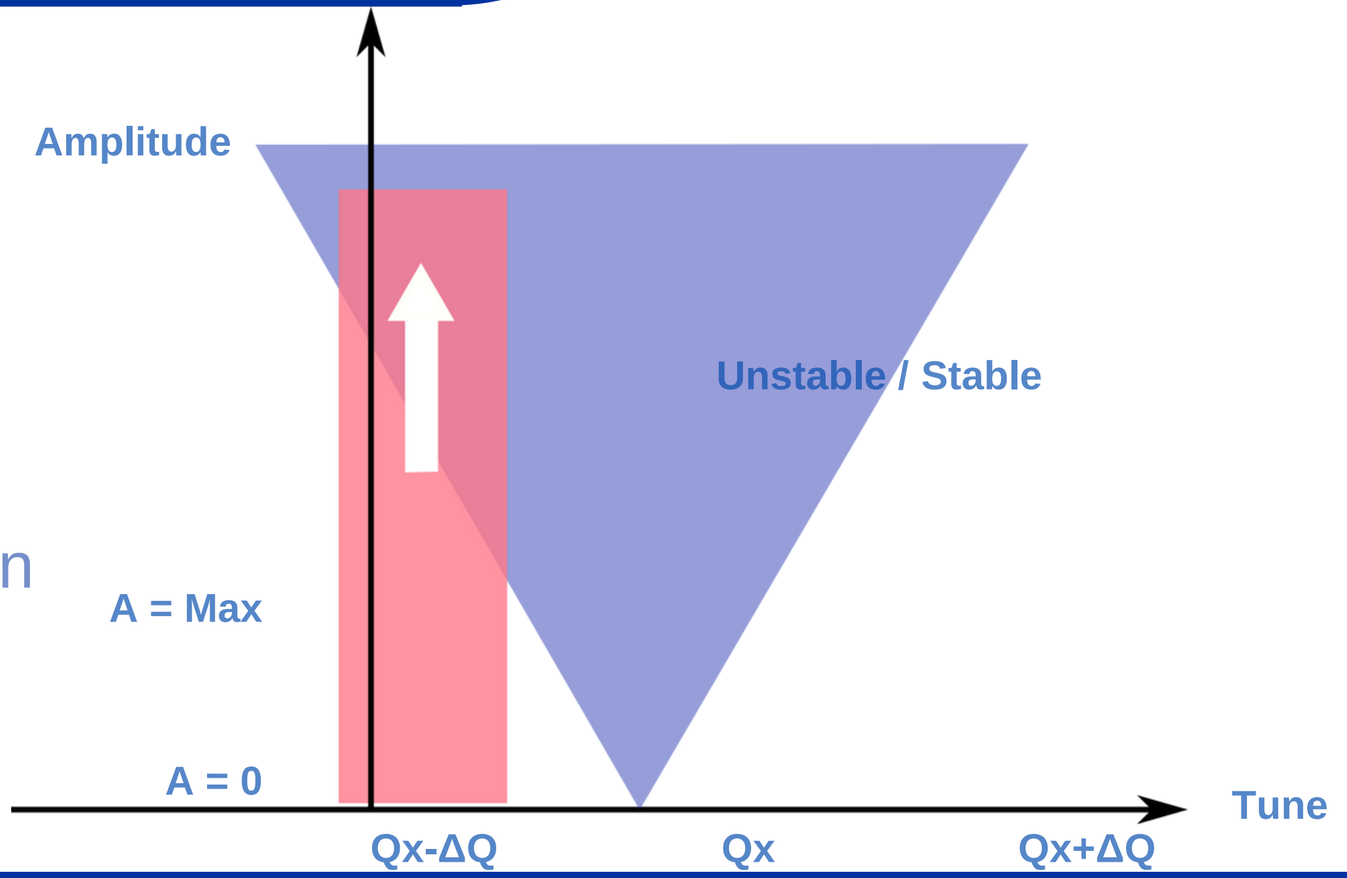




Radio-Frequency Knock-Out

- Moving the beam towards the resonance by giving a kick to the amplitude each turn

- Made of a small horizontal kicker
  - 1 meter in length
- Faster to respond and switch off
  - Can stop the spill
  - Option for multi-energy extraction



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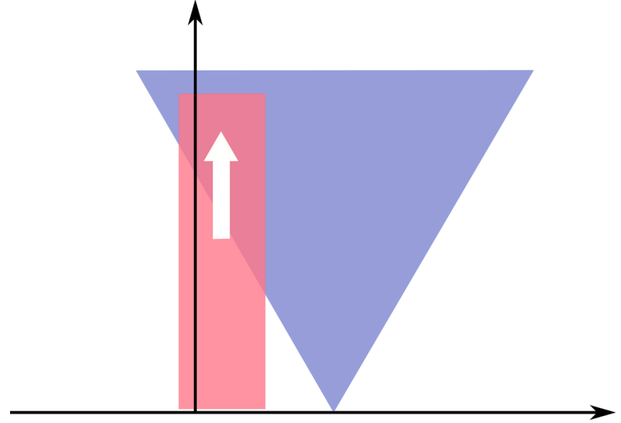
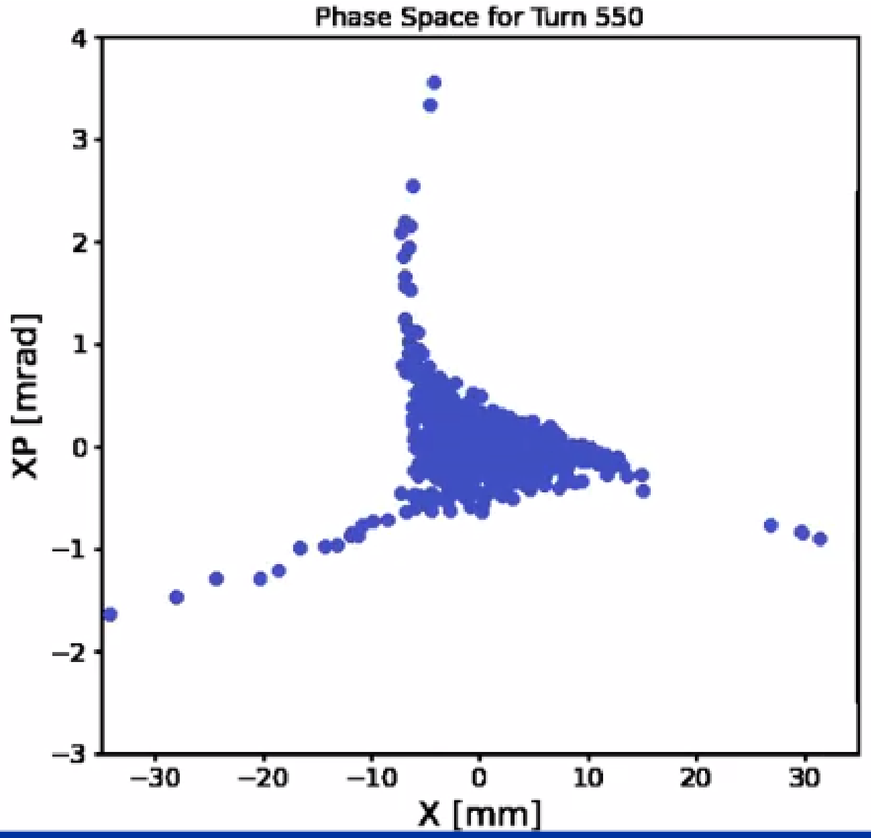
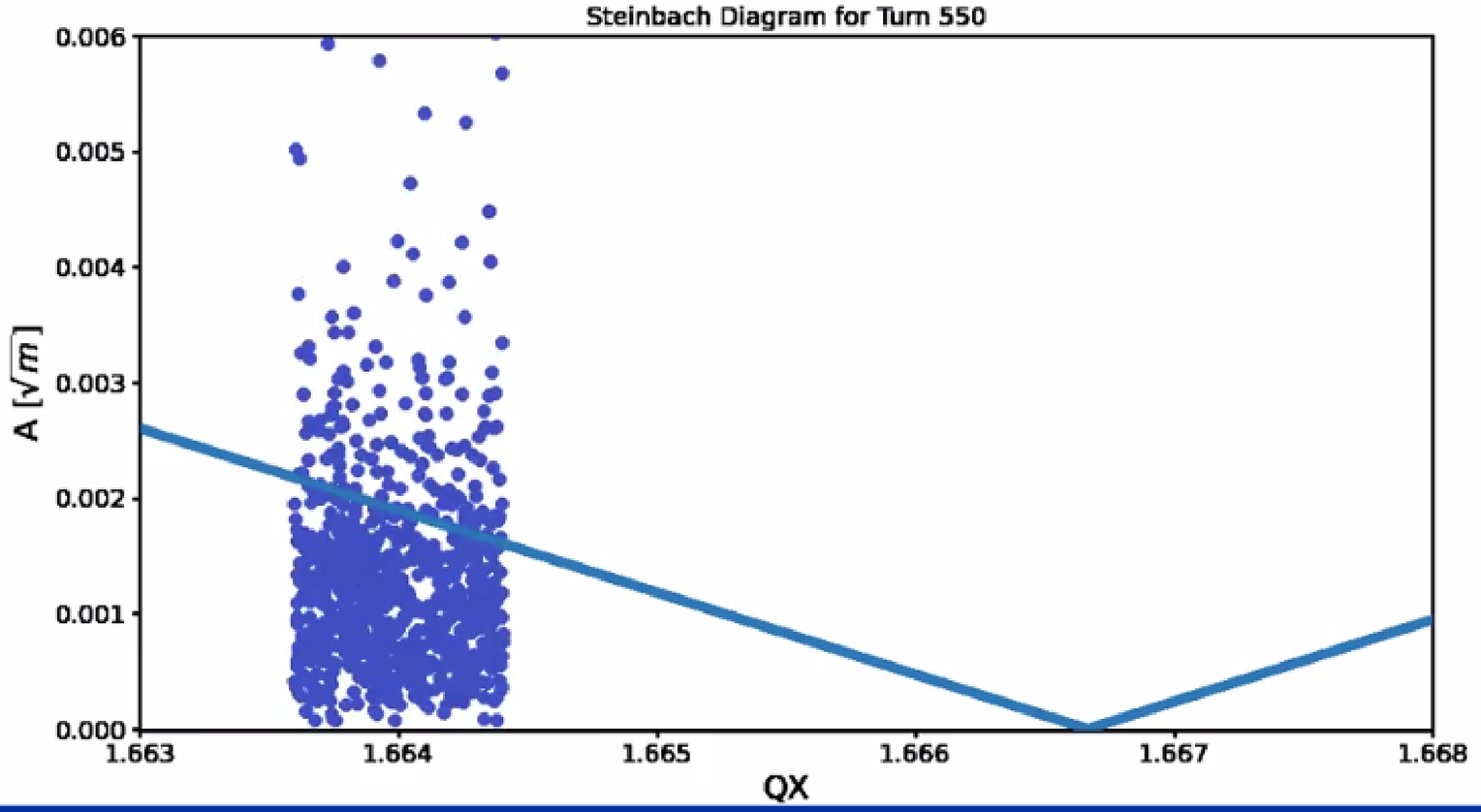
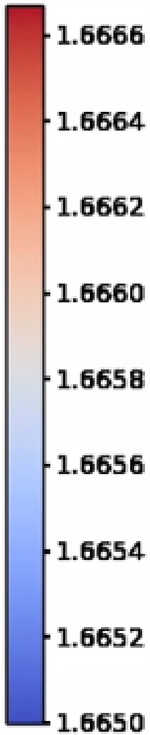


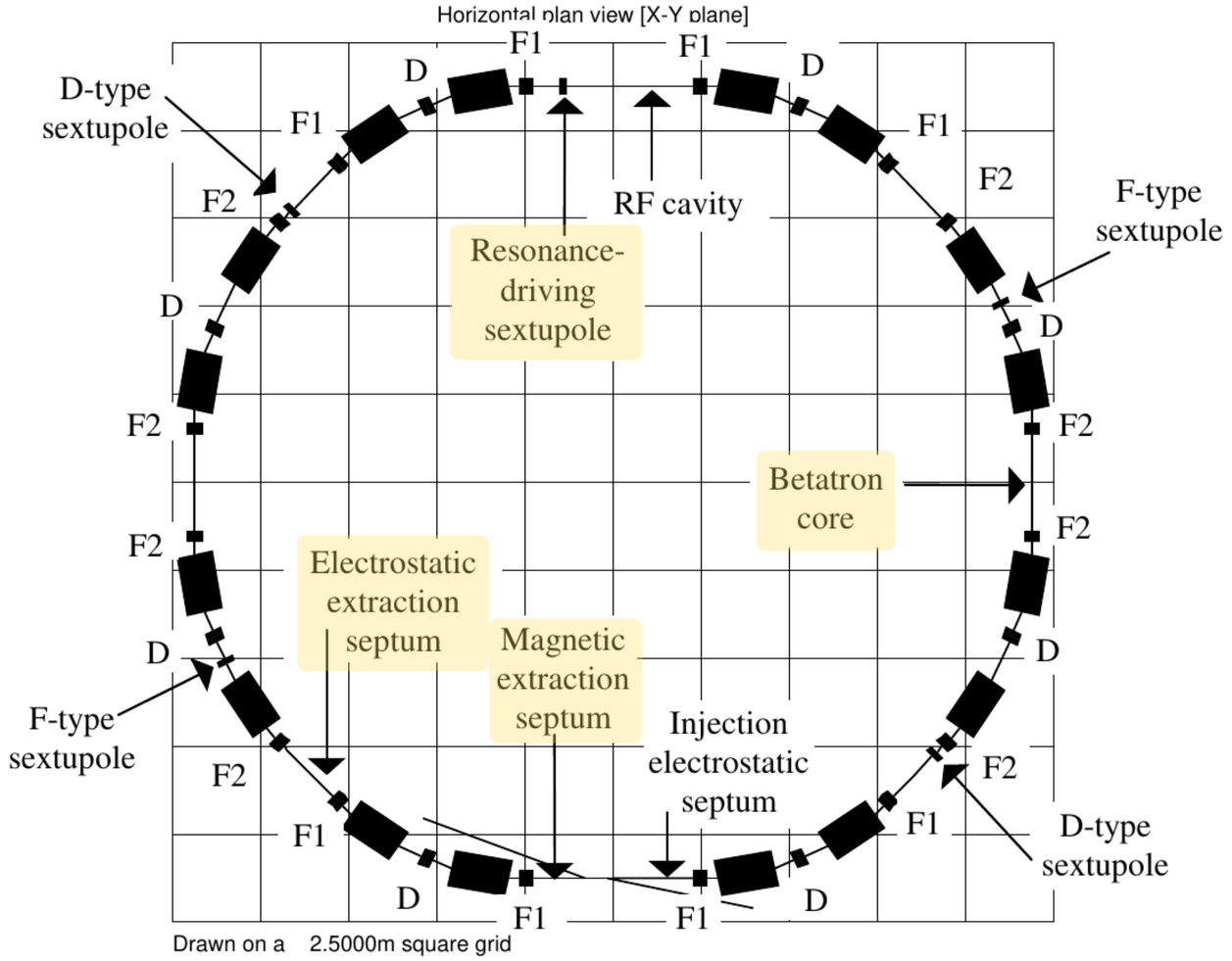






How to model slow extraction

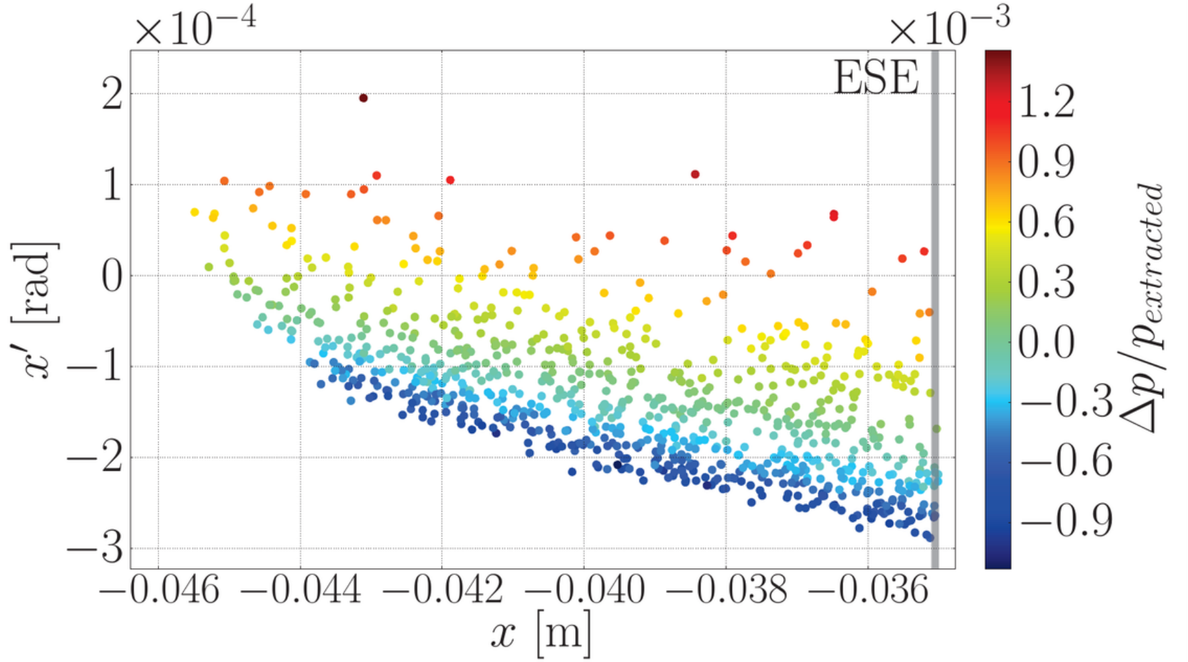
- Created particle tracking maps (**maptrack**) from **MADX** sequence files
- Used normal-conducting synchrotrons as a baseline to benchmark results
  - Proton Ion Medical Machine Study (**PIMMS**) design
- Adjusted the elements highlighted, and observed beam at the electrostatic septum.
- Calculated tune to produce Steinbach diagrams & results



Maptrack supervision from M. Fraser and P. Arruita SY-ABT

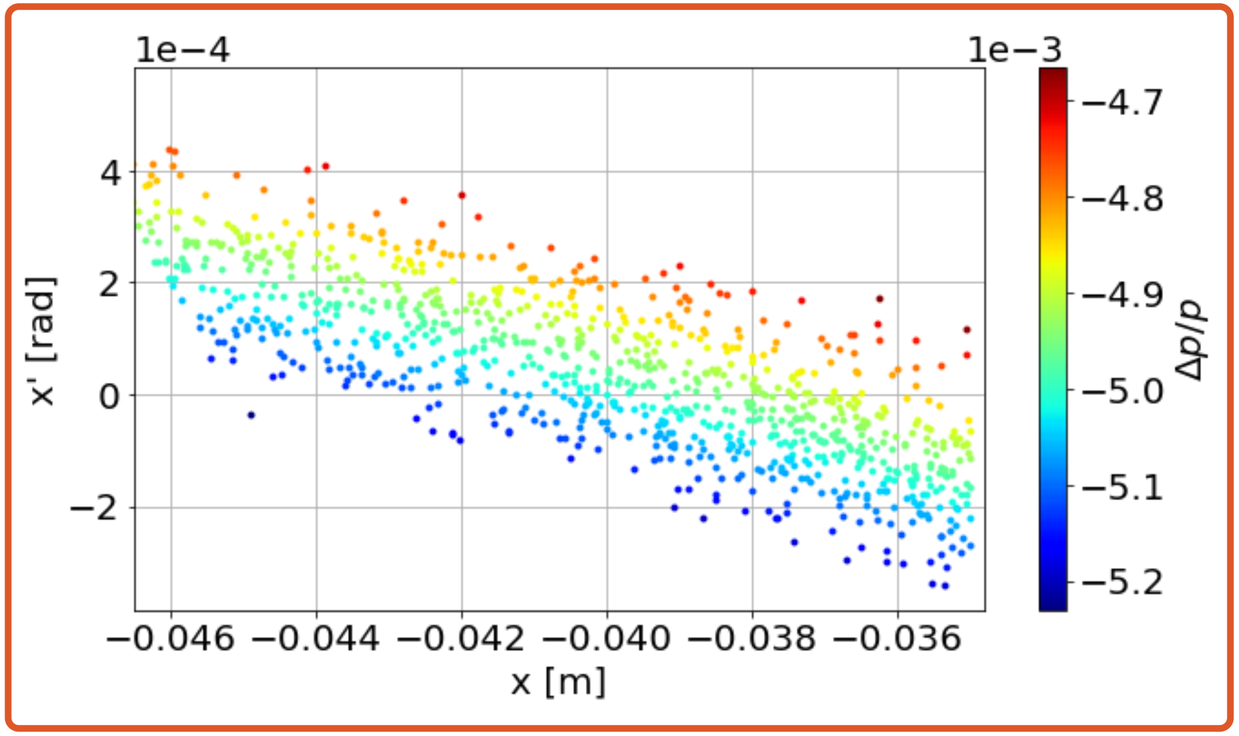
Comparisons to previous studies

Phase-Space of Betatron core extracted particles



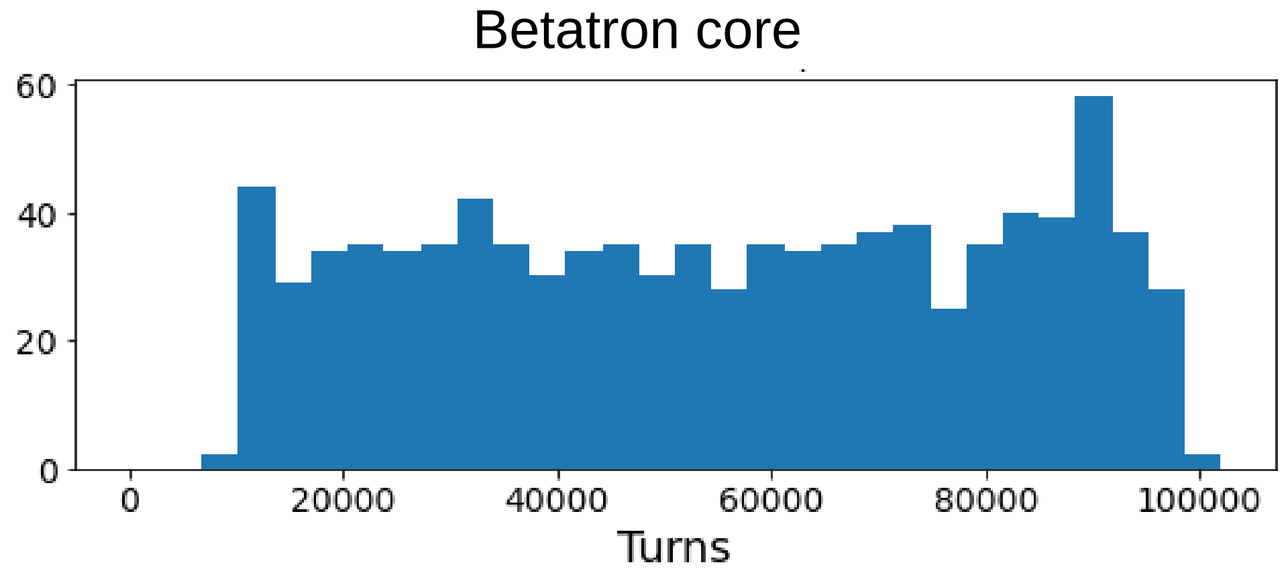
G. Feldbauer *Extraction methods for the MedAustron Synchrotron* pg. 68 (2011)

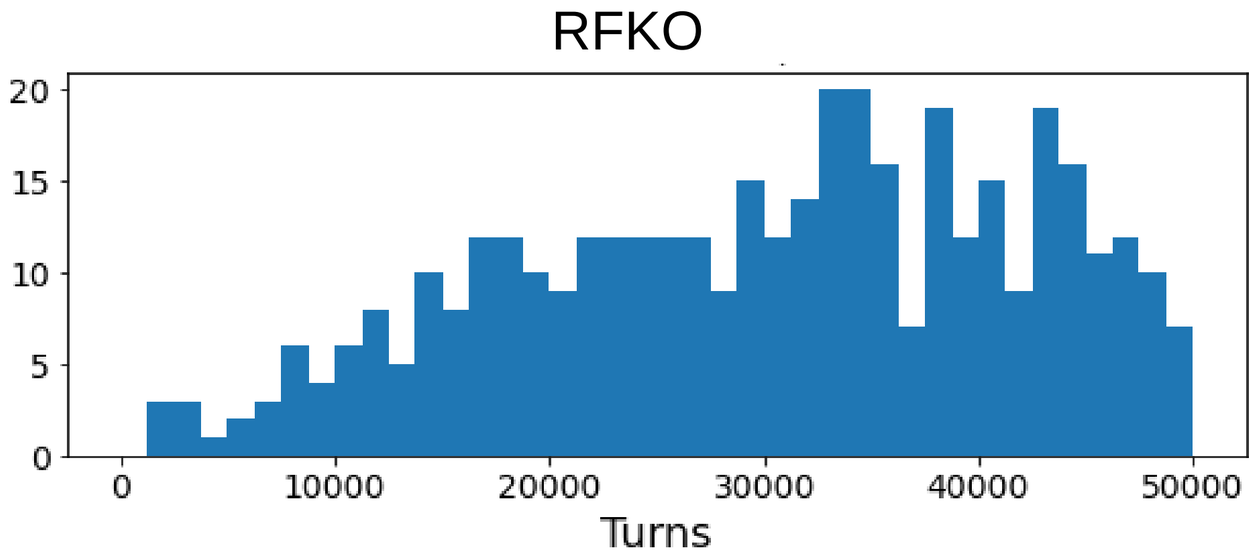
Current simulation results



Beam spill results

- Spill results for 1000 particles are roughly uniformly distributed but with ripples or tails in the structure.
- Optimising slow extraction conditions can improve the distributions.
- Ripple-reducing effects to be investigated and applied.



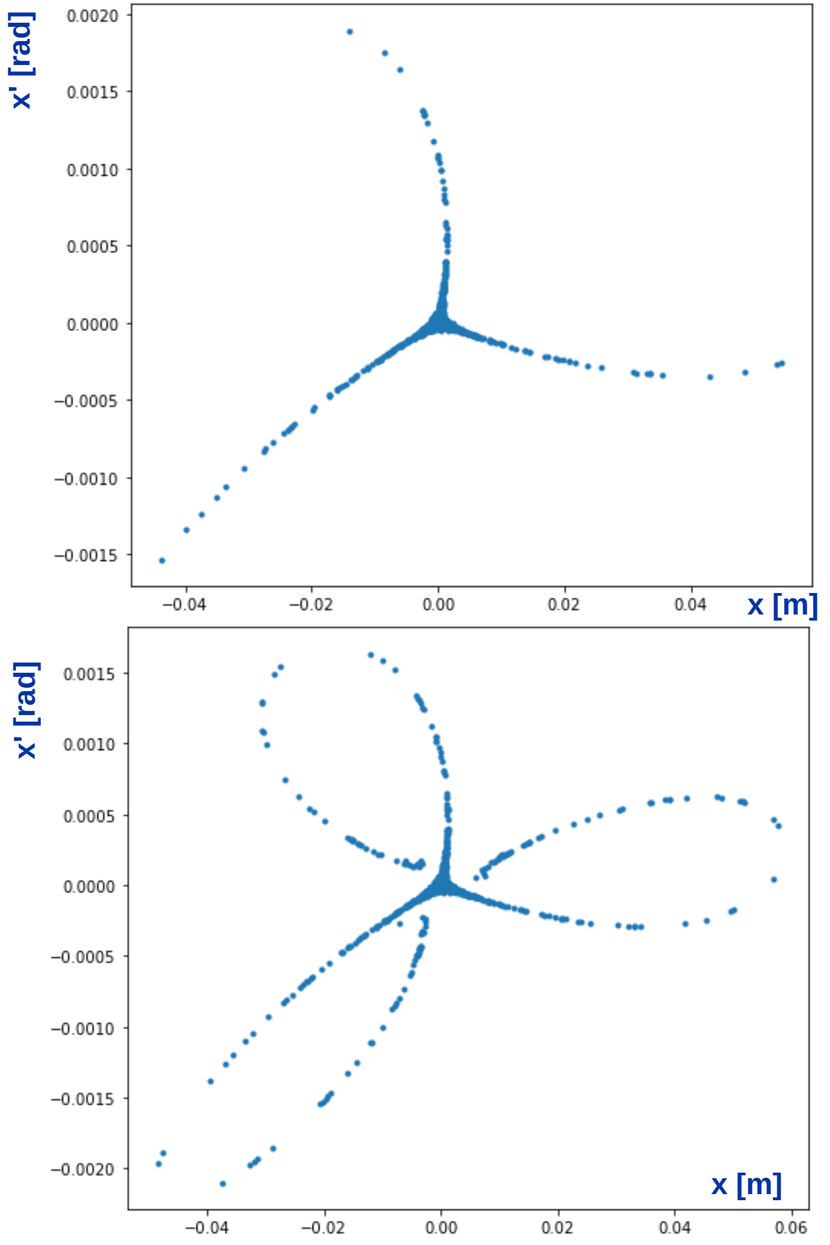


Synergies

- CERN's PS / *SPS* uses slow extraction to deliver beam to the East Area / *North Area*.

- SPS operators **reduced beam loss** by 40% on the electrostatic septum by bending the beam around the foil.
  - Possible to bend separatrices with **octupole** magnets

- Repeating this study for the PS
  - Modelling the machine in MADX
  - Fully bending / trapping the separatrices with octupoles
  - Optimising for best bending to reduce beam loss



Work supervised by M. Fraser and P. Arruita SY-ABT

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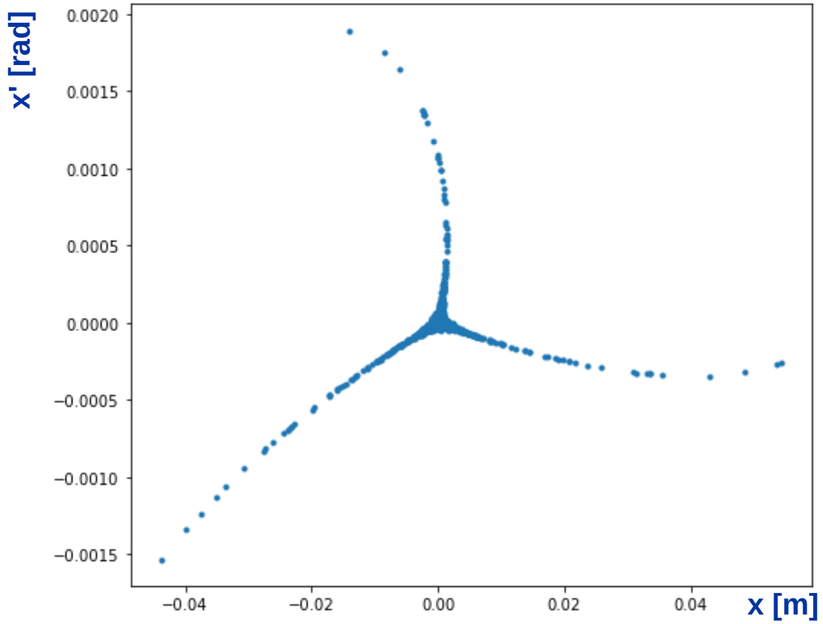

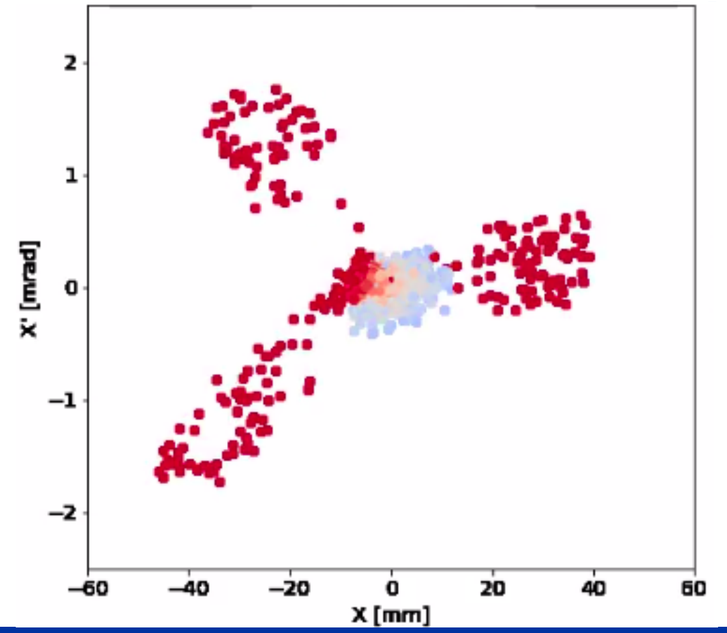

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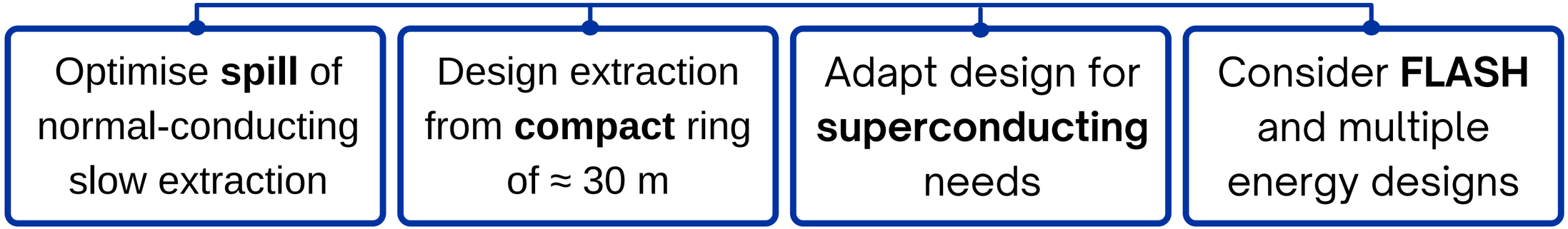
Conclusions

- Currently understanding slow extraction to apply to the design of the NIMMS lattice.
- Developed tools for slow extraction with **betatron core** and **RF-KO** methods.
  - Simulated extraction and compared with existing literature to **benchmark model**.
- Applied simulation models to PS for machine development studies.

Future Investigations



Thank you & I welcome any questions