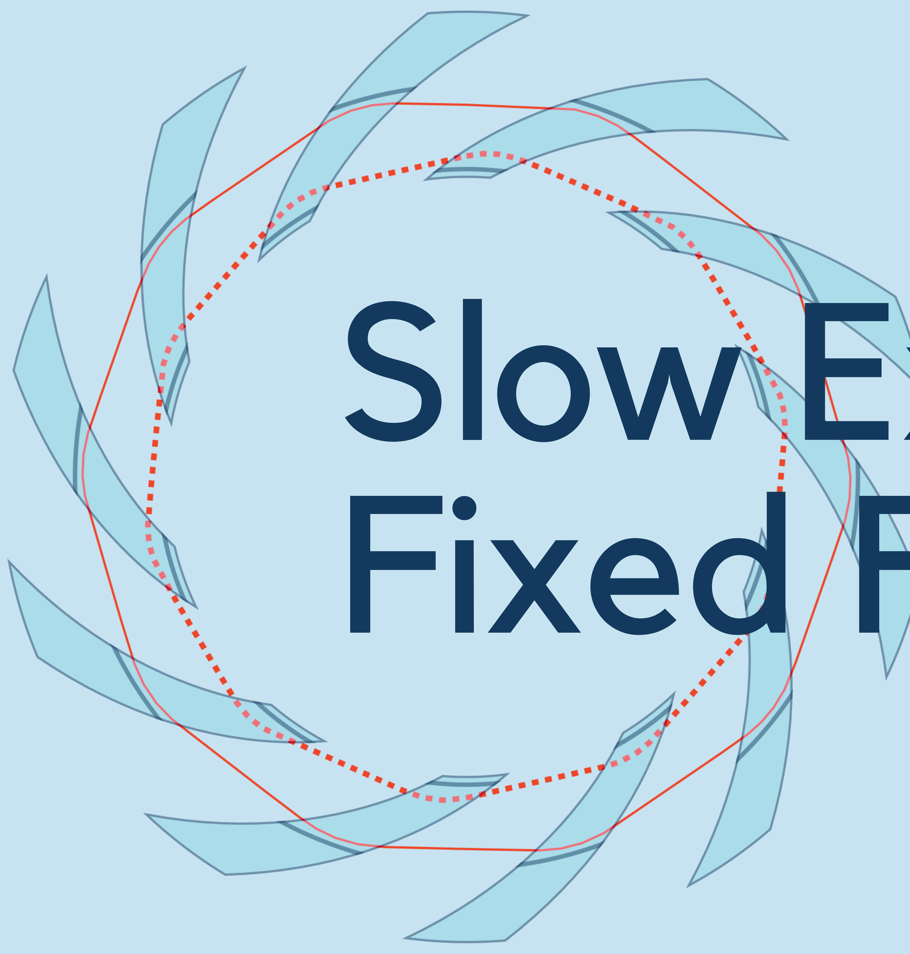

Slow Extraction Techniques from Fixed Field Accelerators

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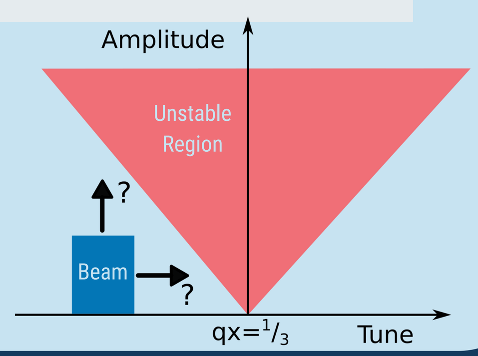
Fixed Field Accelerators (FFAs) are often proposed for **hadron therapy** facilities. Clinical beams require second-long timescales, which requires **slow resonant extraction**. The feasibility of this for FFAs has not been studied before.

Slow extraction ingredients:

1. *Horizontal Tune*: Qx near 1/3 resonance
2. *Strong Sextupole*: To drive resonance
3. *RF-KO Exciter*: To move particles into resonance with time
4. *Electrostatic Septa (ES)*: To kick high-amplitude particles
5. *Magnetic Septa (MS)*: To remove particles from the machine

Choice of moving beam into unstable region either by shifting tune or amplitude



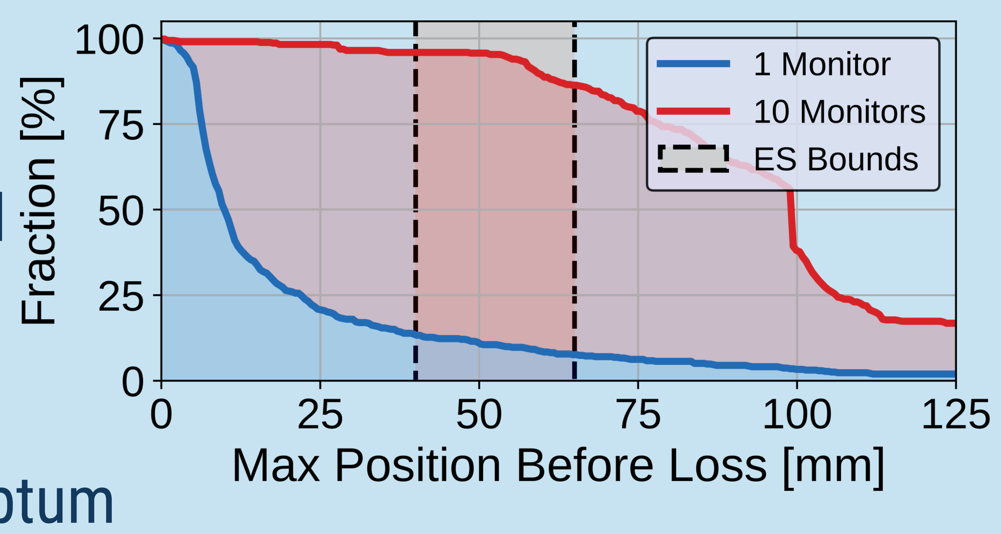
The ideal case: No additional sextupoles.

Zero-dispersive regions impossible, so sextupoles would introduce chromaticity and break the tune-energy relation of the FFA.

Machine Tune: 3.333 ÷ Number of cells: **10** = Tune per cell: **1/3**

Resonance is *too strong*:

- Spiral step increase **per 3 magnets** instead of every 3 turns.
- Particle lost before reaching extraction septum



- Only get 10% efficiency, unless septa placed in all 10 cells.

LhARA Facility

Laser-**h**ybrid **A**ccelerator for **R**adiobiological **A**pplications

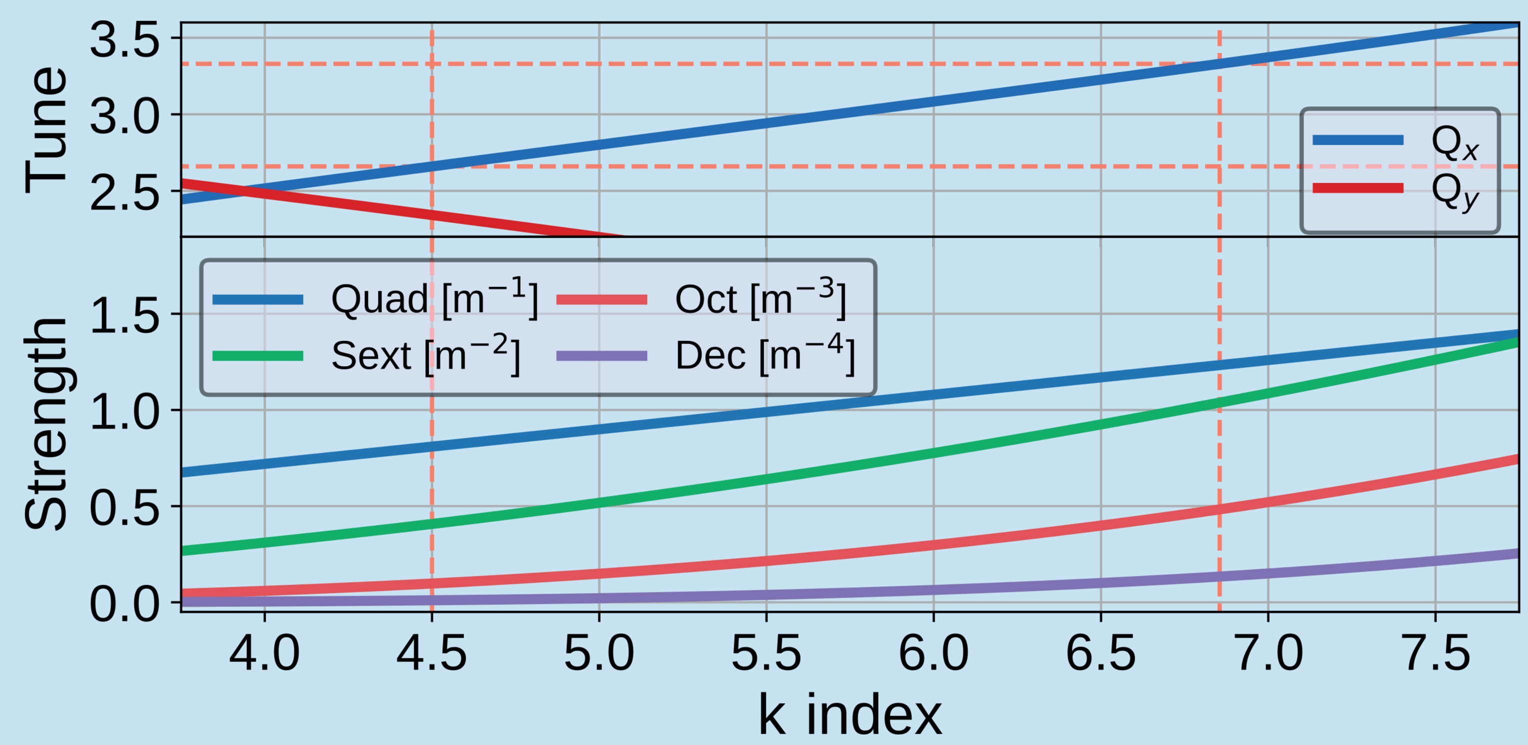
- Proposed design for UK Ion Therapy Research Facility.
- Generates intense laser-driven ion beam at 10 Hz rate.
  - Preserving time-structure of beam with 125 MeV spiral-scaling FFA based on RACCAM design (2006)

Why Fixed Field Accelerators?

High Beam Current → Ideal for LhARA Facility ← Novel Treatment Modalities

- Choose the **k-index** value to a qx = 1/3 resonance.
  - Relative multipole strength is fixed.
- Choose spiral angle **ζ** to ensure stability in vertical plane.

$$B = B_0\left(\frac{r}{r_0}\right)^k \mathcal{F}\left(\theta - \tan(\zeta)\ln\frac{r}{r_0}\right)$$

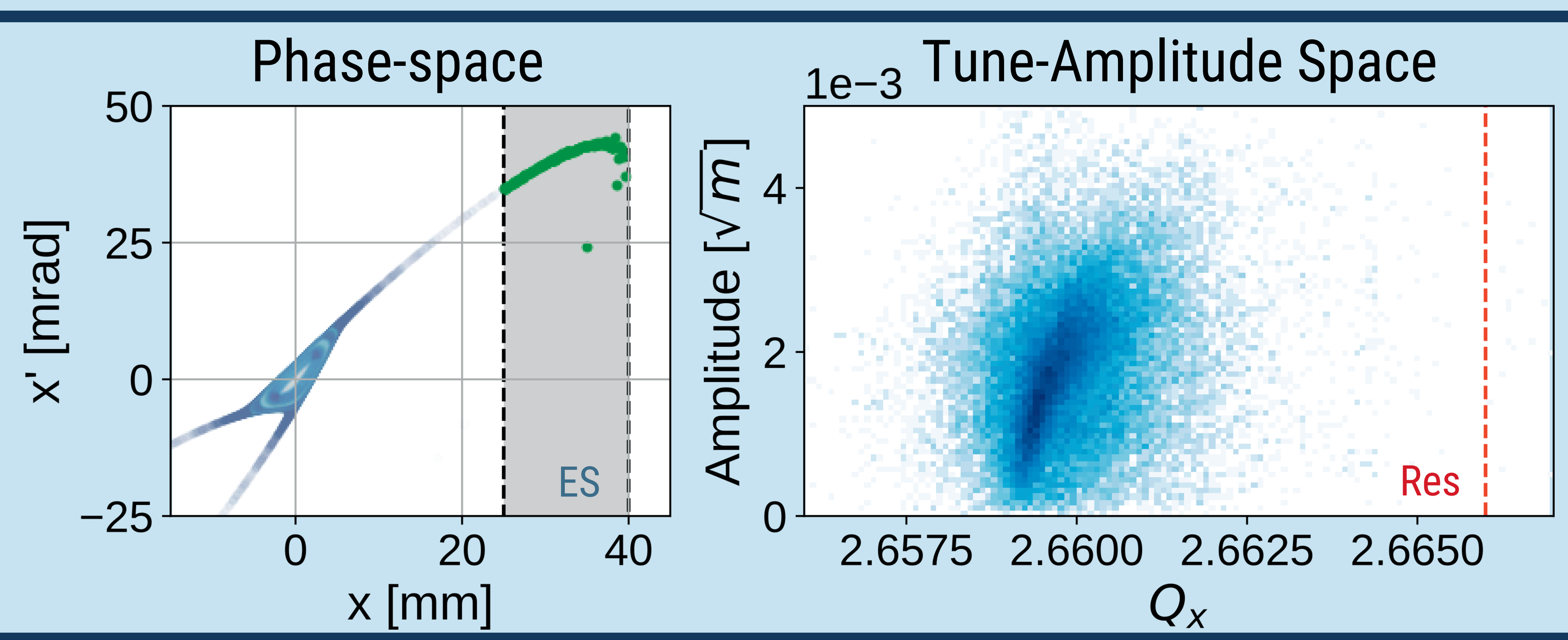


Radiofrequency Knock-Out Results

Machine Tune: Qx = 2.659 | **Additional sextupole required** | **Modelled components with zero-length**

- Adding a sextupole **breaks scaling law** & introduces chromaticity. Should only be activated at **flat-top** of cycle.
- Must get correct **phase-advance** between ES and sextupole.
  - For this optics design, ES only fit when **within a magnet**.

- Gave **sinusoidal** excitation per turn of A = 0.025 mrad, and frequency qx = 0.695, with bandwidth covering tune spread.
- Simulated in Zgoubi for **256 particles over 30,000 turns**.
- Sextupole strength changes **spiral step**. Optimised ES position to get suitable size of extracted beam (in green).



It is **feasible** to to perform slow extraction from **scaling** Fixed Field Accelerators.

RF-KO allows for control of extraction rate with **constant machine tune**.

Compactness of FFAs results in **geometric difficulties** to fit in components for extraction.

Complexity of FFAs means slow extraction **must** be considered concurrently alongside the optical design.

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