Massless septum for slow extraction loss reduction

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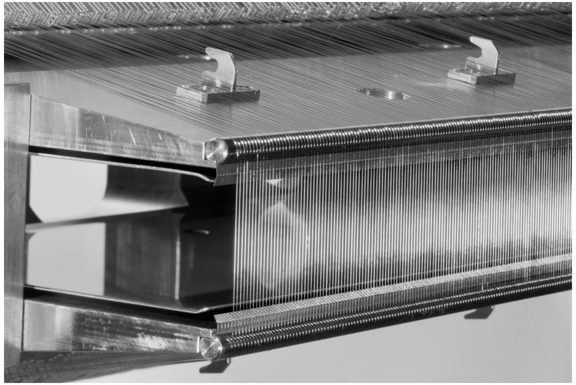
Overview of resonant slow extraction at SPS

- Since SPS slow extraction works at high energy the limiting factor is the activation of the electrostatic septum wires
- This talk is aimed to discuss the possibility of using massless septum to reduce beam loss

- This is a preliminary study whether the method could work or not
- This is a general study, but all parameters (energy, ß, ES parameters) used are taken from SPS



Concept of using massless septa

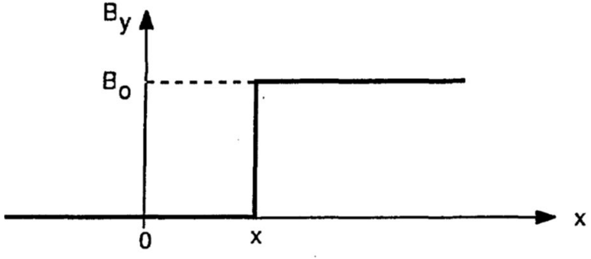
- There are many ways of trying to increase the efficiency of slow extraction (e.g., crystals, multipoles)
- The goal is always to decrease the number of particles hitting the wires, while increasing, or not changing the number of extracted particles
- 3 possibilities using massless septa: [5]
  - To use one massless septum to stretch the resonance arm, so that the density of particles hitting the wires is reduced
  - To use two massless septa, one before one after the extraction point, to “redo” the effect of the first one, so it doesn’t interfere with the circulating beam
  - Or to use one massless septum to “fold back” the particles in the phase space, so we can increase the “effective extraction space”

Massless septum

- The massless septum is a device that has a high field and a zero field region without a physical separator between them
- Ideally the transition is a jump, but realistically there is a continuous change of magnetic field inside the **fringe field**

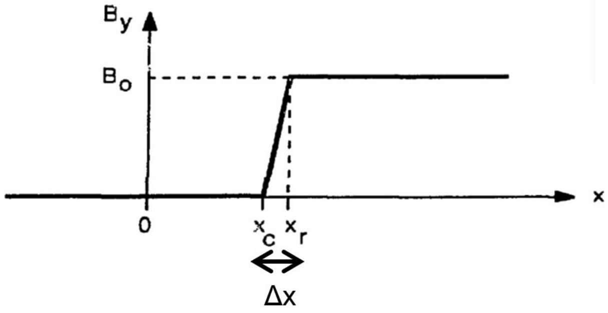
Examples:

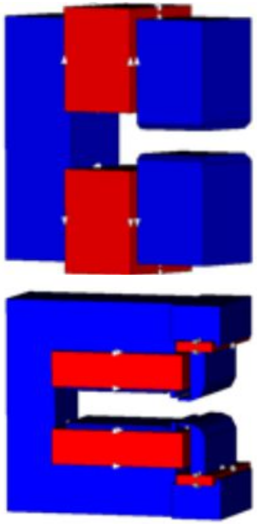
Ideal massless septum



[3]

Real massless septum

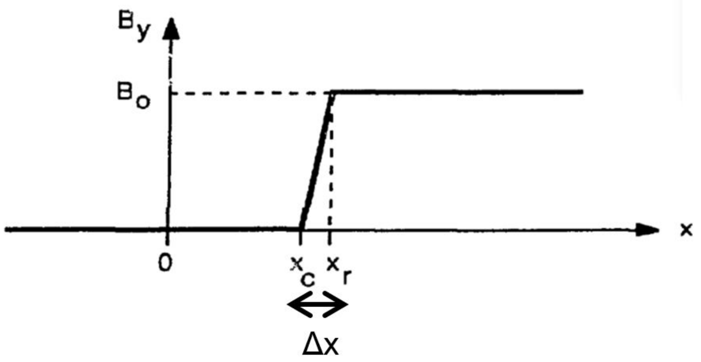




[2]

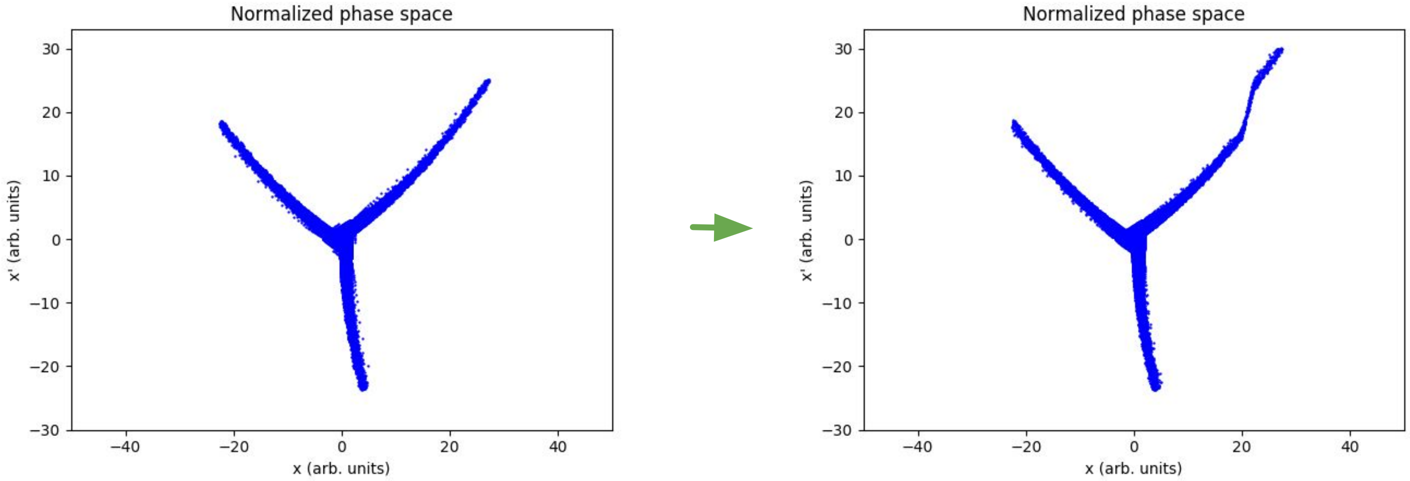
Assumptions and approximations

- Code was developed in python to simulate the particles in the normalized phase space
- The sextupole magnet and the septa are implemented as thin lens (changes only the angle of the particles)
- The phase difference between the sextupole magnets and the massless septum is 0
- Beta does not change “inside” the electrostatic septum (important to determine the acceptance)
- The massless septum field (and also the force acting on the particles) is constant-linear-constant



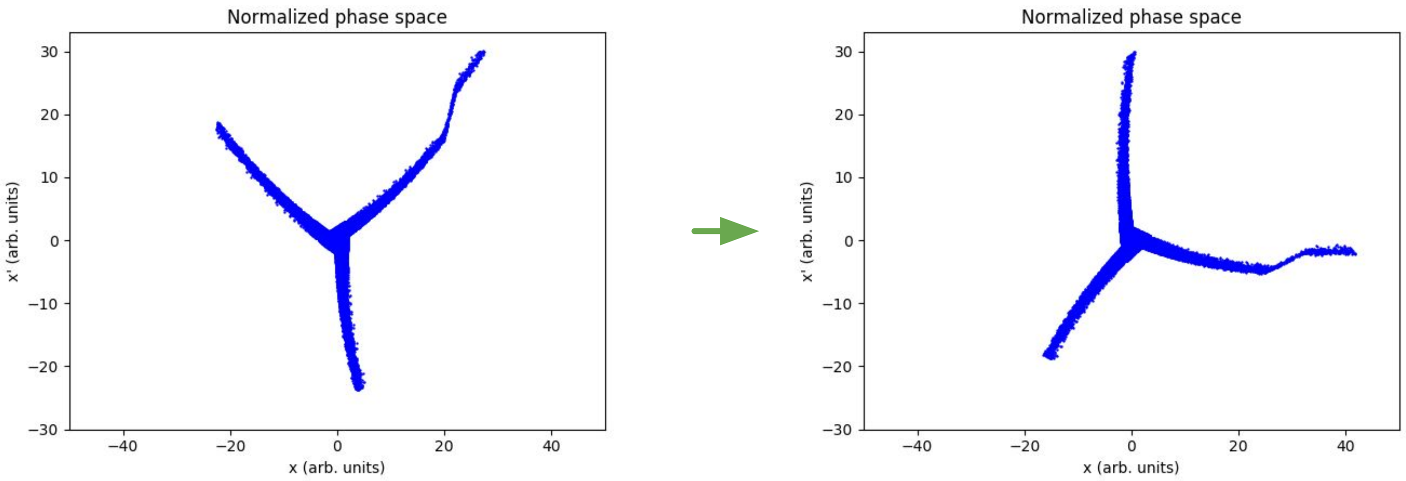
1, 2: Beam stretching with massless septa

- This is how the phase space looks like after a massless septum kick with a linear fringe field is applied to the particles in a third order resonance:



1, 2: Beam stretching with massless septa

- This is how the phase space looks like after a massless septum kick with a linear fringe field is applied to the particles in a third order resonance:
- After some drift (rotation in normalized phase space) the momentum difference becomes spatial separation:

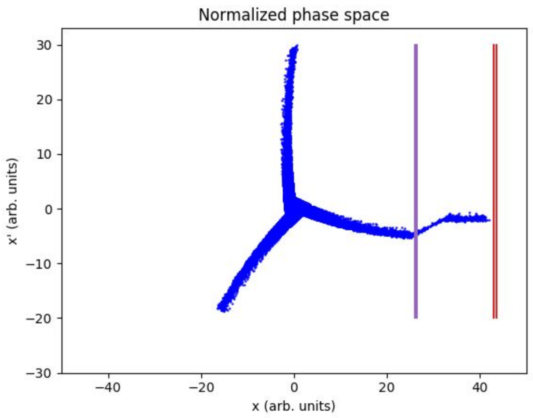


1: Beam stretching with one massless septum

- If the setup is aligned so that the ZS wires position is inside the “low density” area than the number of lost particles decreases

- If the cut is at the closer end of the stretched part then we decrease the density of the extracted particles also

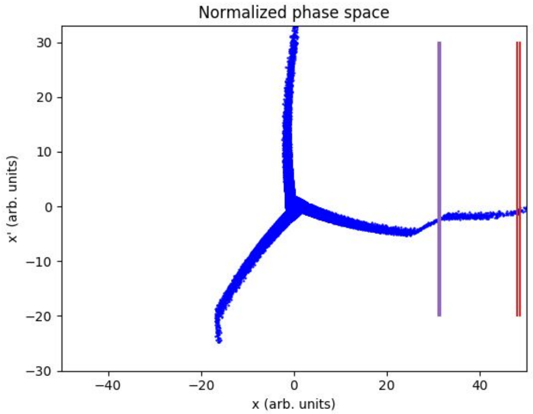
- In this case the limiting factor is the massless septum fringe field length
- It is challenging to reduce
- But in the ideal case it would increase the efficiency to 100% [2]
- See: [3] H. S. Butler/H. A. Thiessen, Proc. of the Advanced Hadron Facility Accelerator Design Workshop, 1988



1: Beam stretching with one massless septum

- However, if the wires are further out then the still circulating “stretched” particles are stretched once more 3 turns later
- A lot of these particles are lost on the cathode
- In the end the efficiency goes down by this effect

- Something has to be done with the circulating, but affected particles



2: Beam stretching with one massless septum, then "push-back"

- The solution to this problem can be to have another massless septum after the extraction with opposite field, that pushes the stretched density back to normal
- This solution was studied at the POP FFAG

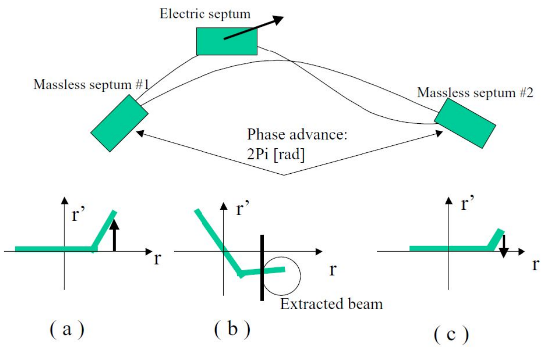


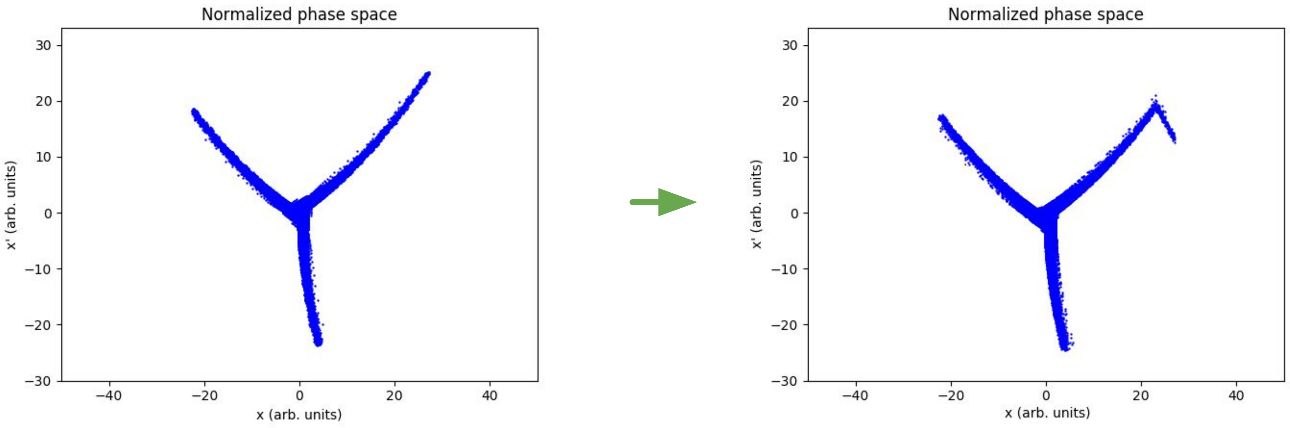
Figure 1: Extraction scheme with massless septum magnet (a) beam tail is developed (b) beam is extracted with an electric septum (c) beam tail returned to the closed orbit

[4] Y. Yonemura et al., Beam Extraction of the POP FFAG with a massless septum, IPAC'03

3: Phase space folding

- The third approach is to use the fringe field of a massless septum to “fold back” the arm of the third order resonance

Without massless septum — With massless septum

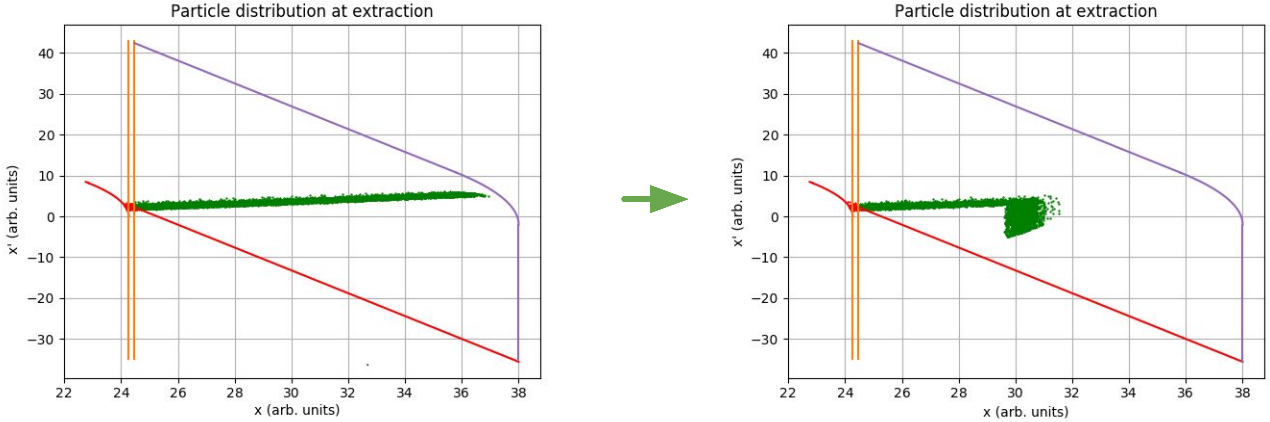


3: Phase space folding

- The third approach is to use the fringe field of a massless septum to “fold back” the arm of the third order resonance
- The sextupole strength (and the spiral step) can be increased without the need of larger extraction space. This would reduce the particle density at the wires, this way reducing the losses.

Without massless septum

With massless septum

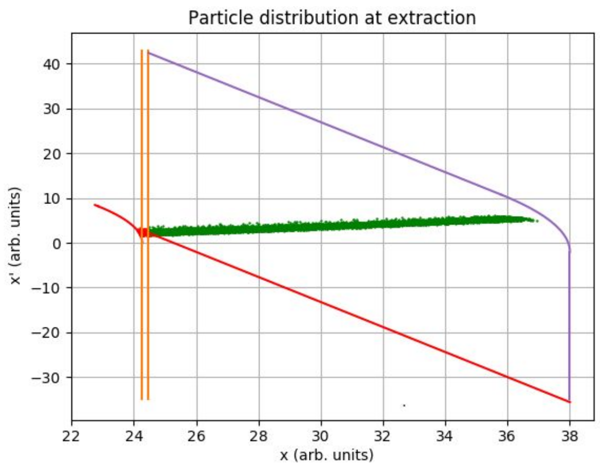


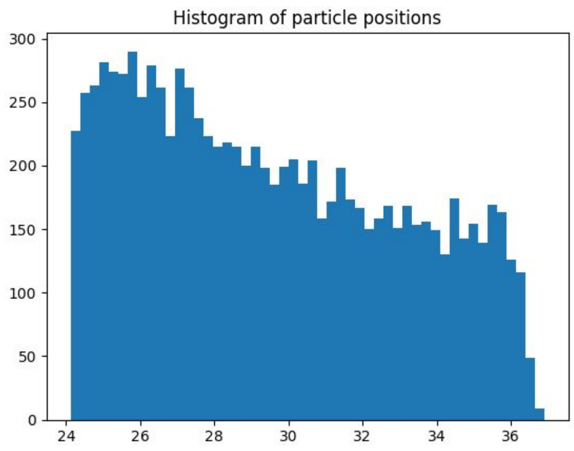
Simulation

- Fixed parameters used for simulations:
  - 2D Gaussian particle distribution in the beginning (in both x and x') with variance 0.4
  - The tune is changed from 0.33 to 0.334 in 10000 steps
  - 10000 particles simulated
  - The extraction geometry is the realistic ZS geometry with effective wire thickness of 200 μm
- The tuneable parameters:
  - Sextupole strength [0.02,0.11]
  - Massless septum position (x), strength, fringe field length
  - Phase difference between massless septum and the extraction
- For each sextupole strength the massless septum parameters were optimized, to increase the efficiency as much as possible.

Examples

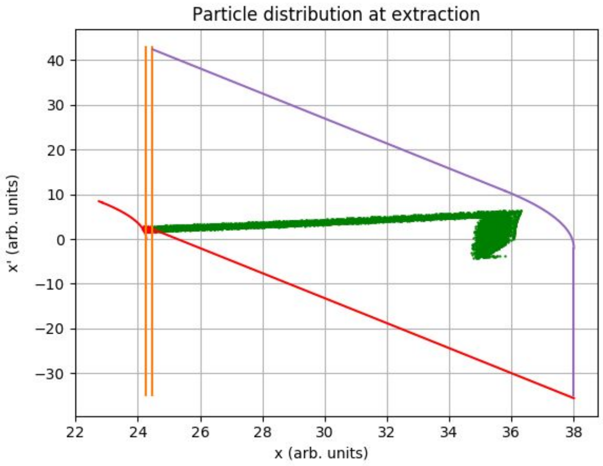
- Sextupole strength: 0.02
  - Particles hitting the wires: 349
  - Extracted particles: 9262

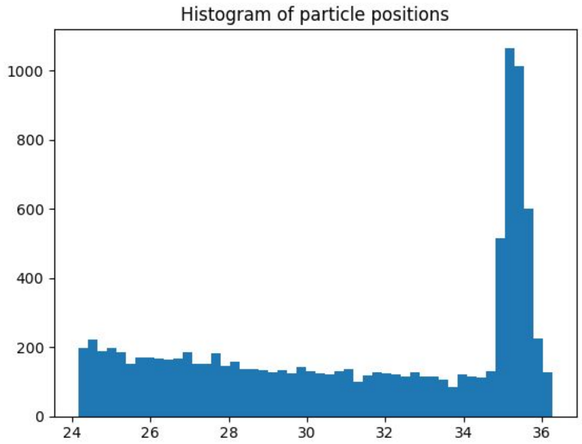




Examples

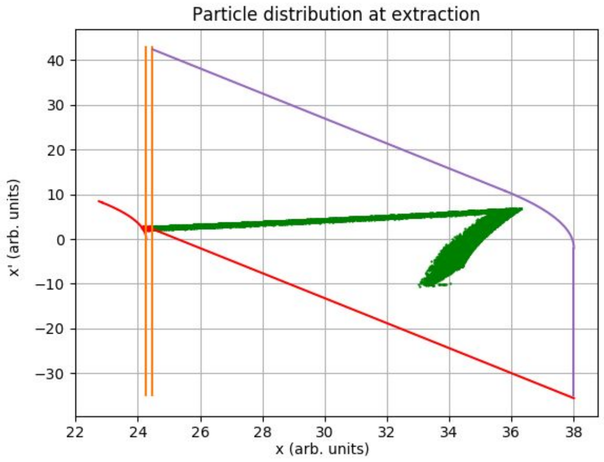
- Sextupole strength: 0.03
  - Particles hitting the wires: 305
  - Extracted particles: 9512

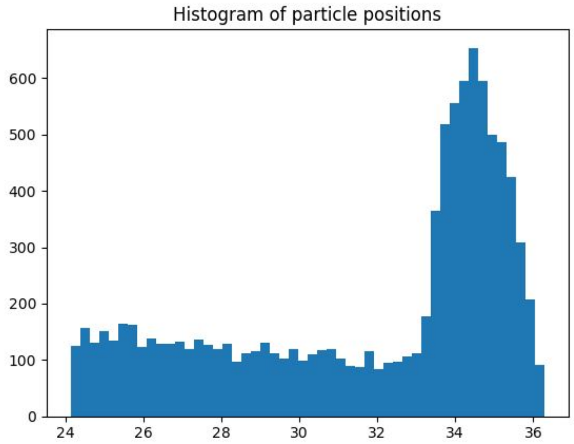




Examples

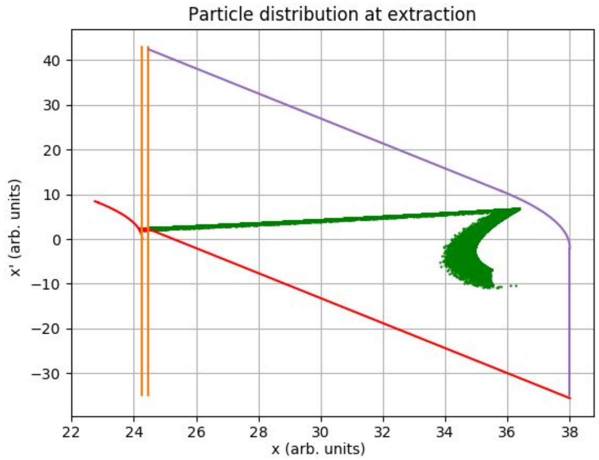
- Sextupole strength: 0.04
  - Particles hitting the wires: 183
  - Extracted particles: 9719

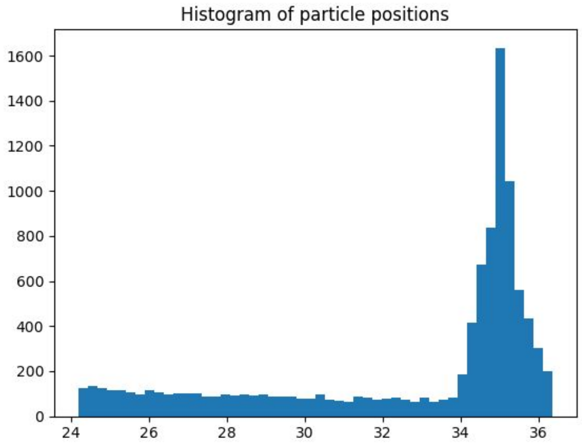




Examples

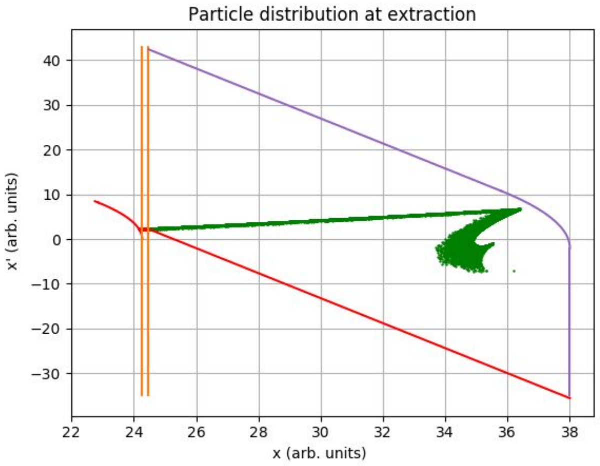
- Sextupole strength: 0.06
  - Particles hitting the wires: 156
  - Extracted particles: 9801

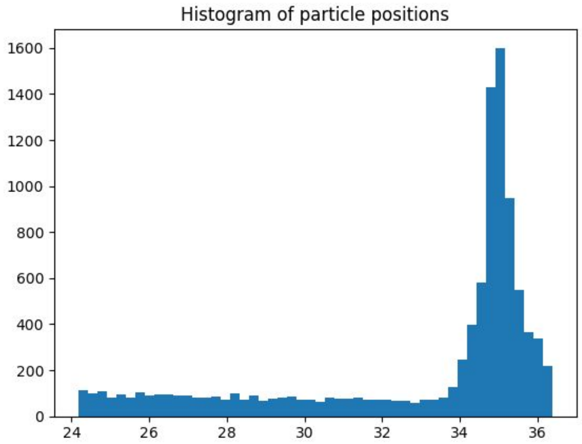




Examples

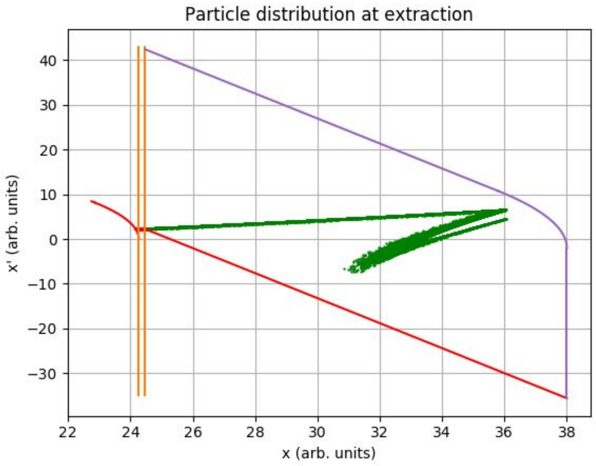
- Sextupole strength: 0.08
  - Particles hitting the wires: 141
  - Extracted particles: 9837

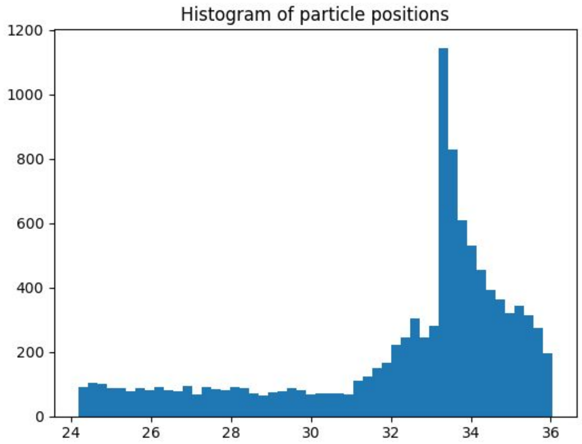




Examples

- Sextupole strength: 0.09
  - Particles hitting the wires: 105
  - Extracted particles: 9868

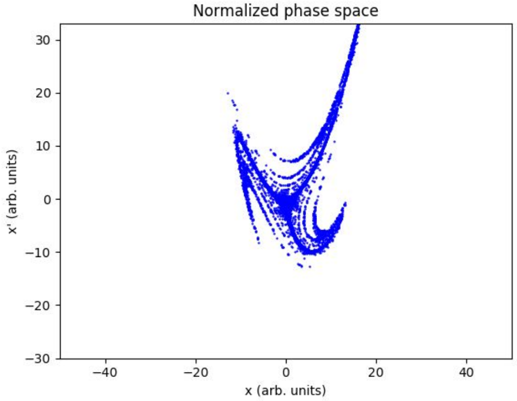




Limitation

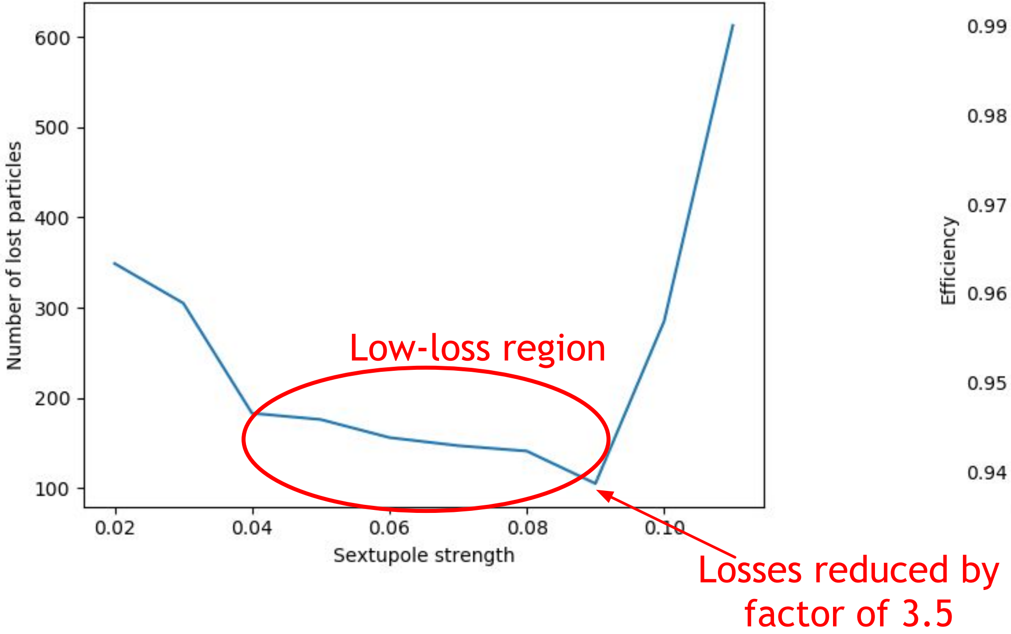
- The sextupole strength has an upper limit
  - If the field is too strong, then the nonlinear effects start to play a role,and the arms “bend back”
  - This increases the thickness of the arm, and in the end the losses on the wires also

Sextupole strength: 0.12

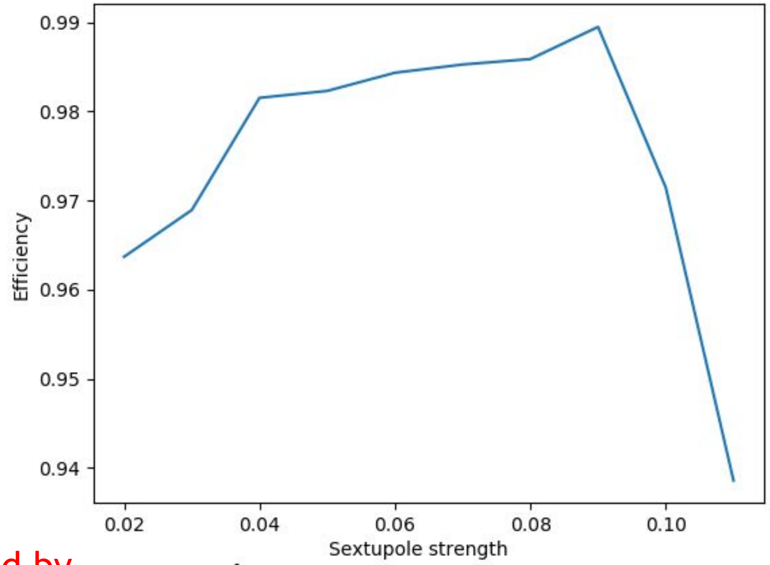


Results

Number of lost particles as a function of sextupole strength



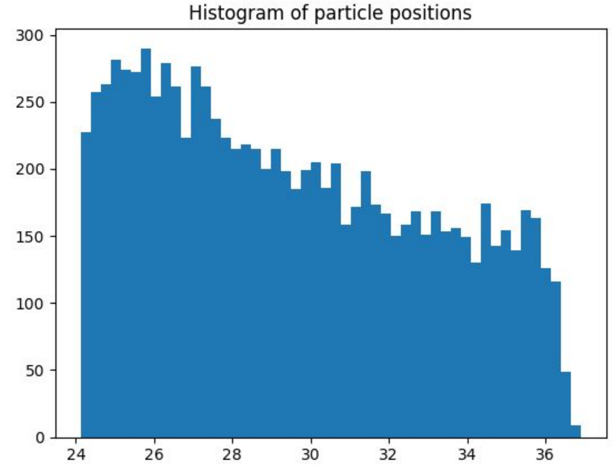
Efficiency as a function of sextupole strength



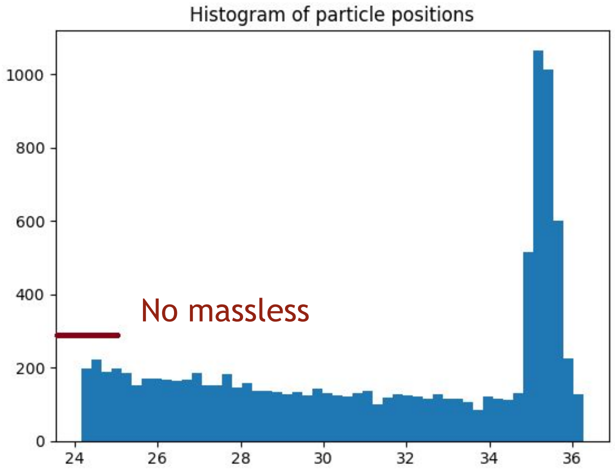
Results

- The particle’s position histogram without and with massless septum:

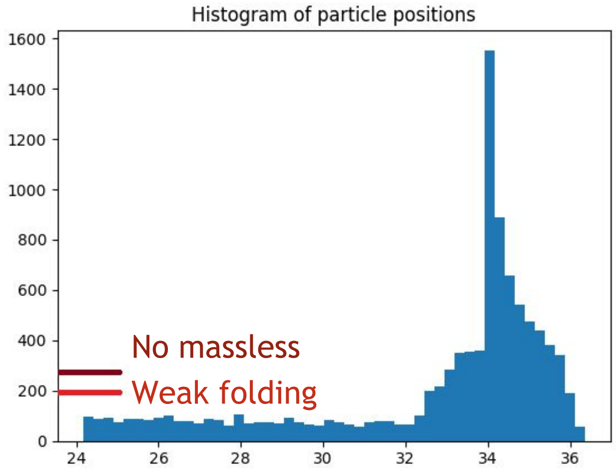
Regular slow extraction



Improved efficiency



Maximum efficiency

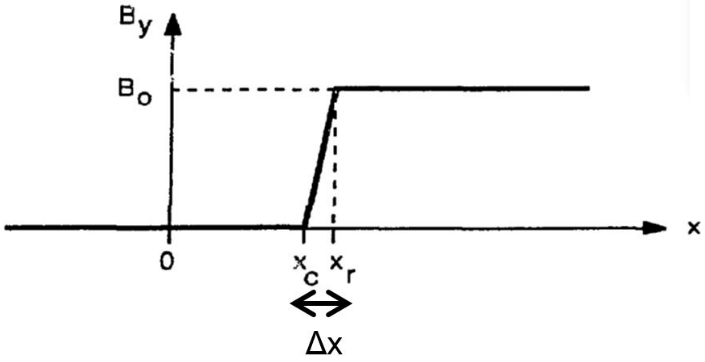


Feasibility?

- Preliminary SPS parameters were considered
- Sextupole strength used in the simulation is similar to the total strength of the four SPS extraction sextupoles
- In the case of highest efficiency the sextupole strength is increased by a factor of 4.5
  - But a factor of 2 would already increase the efficiency significantly
- There could be a problem with the growth of the beam due to the resonance
  - If there is only one massless septum, but multiple sextupoles, the beam has to travel through the whole ring (growing at all sextupoles) before being folded back
  - Transfer line acceptance have to be taken into account

Feasibility?

- Required maximum kick from the massless-septum is 500 µrad
- This means that the massless septum's maximum integrated field is 0.66 Tm
- The smallest fringe field used in the simulations was ~10 mm
- Notice that since we only used the fringe field, the real important parameter is the field gradient, so if the magnet is twice as strong, the fringe field can be twice as wide



Outlook

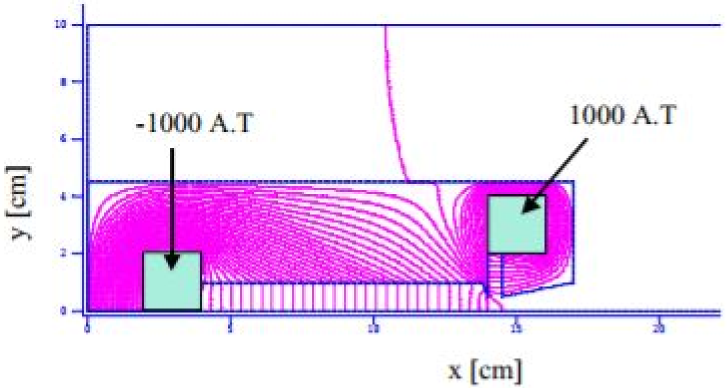
- Still a lot of open questions…
- A more realistic massless septum fringe field (nonlinear) has to be implemented
- The effect of using more than one sextupole magnet (in the SPS there are 4)
- Study different phase advances between sextupole magnets and massless septum
- Check for realistic SPS beam parameters (beta, alpha, …), location
- Acceptance of transfer line, and the growth of circulating beam
- Effect of different density distribution and momentum spread

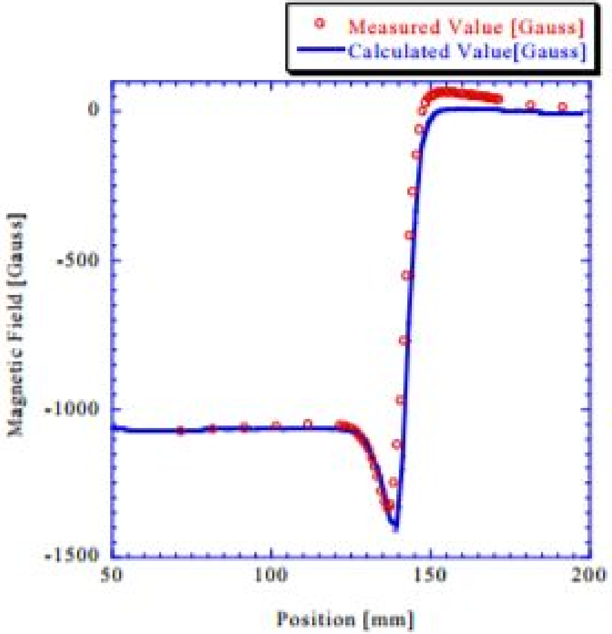
Thank you for your attention!

References:

1) Matthew Fraser, CAS Budapest 2016
2) Christoph Wiesner, R&D Meeting, 08/11/2016
3) H. S. Butler/H. A. Thiessen, Proc. of the Advanced Hadron Facility Accelerator Design Workshop, 1988
4) Y. Yonemura et al., Beam Extraction of the POP FFAG with a massless septum, IPAC'03
5) Christoph Wiesner, SLAWG meeting 01/09/2016

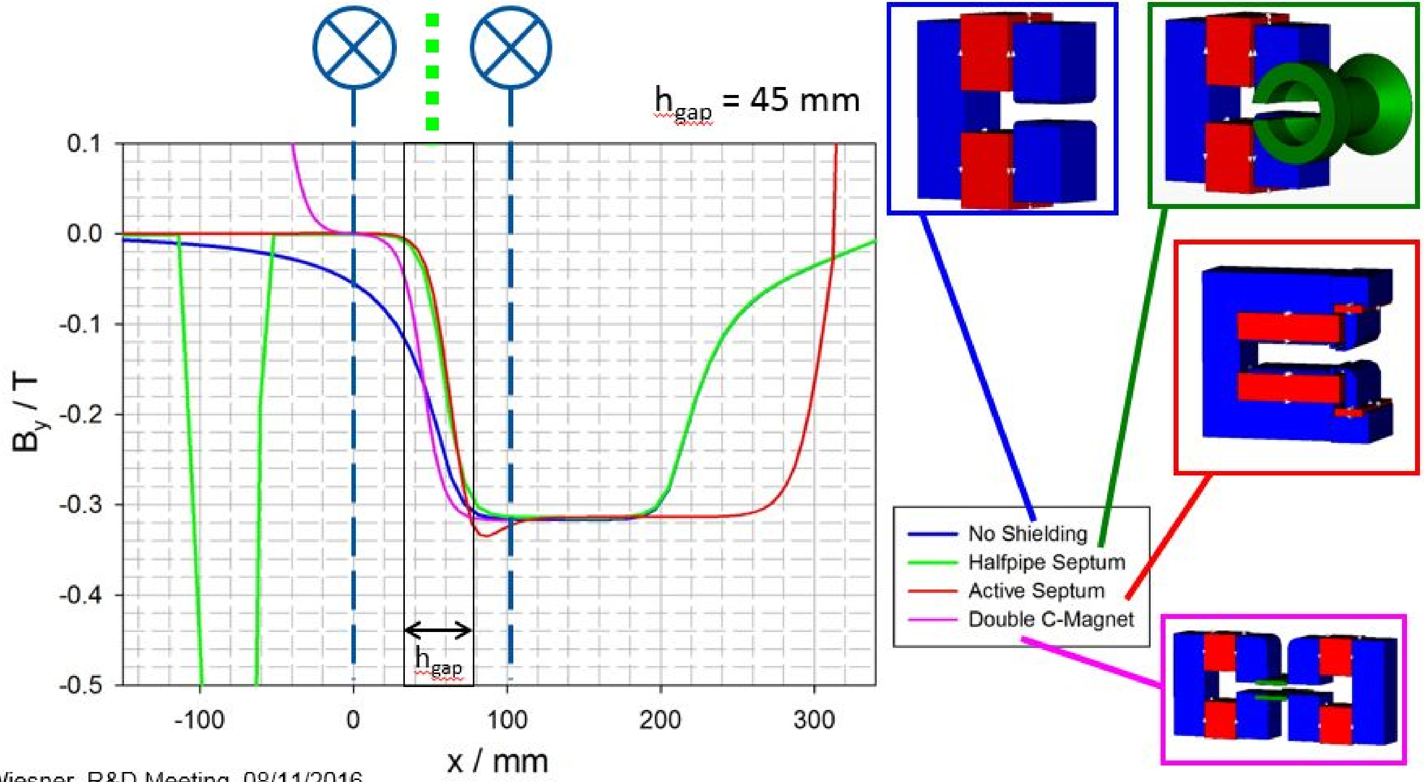
Example massless septum field





[4] Y. Yonemura et al., Beam Extraction of the POP FFAG with a massless septum, IPAC’03

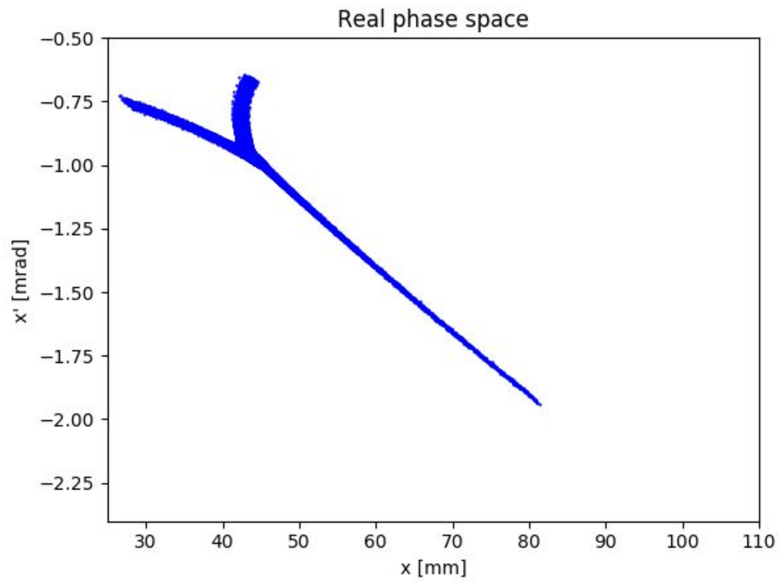
Example massless septum designs



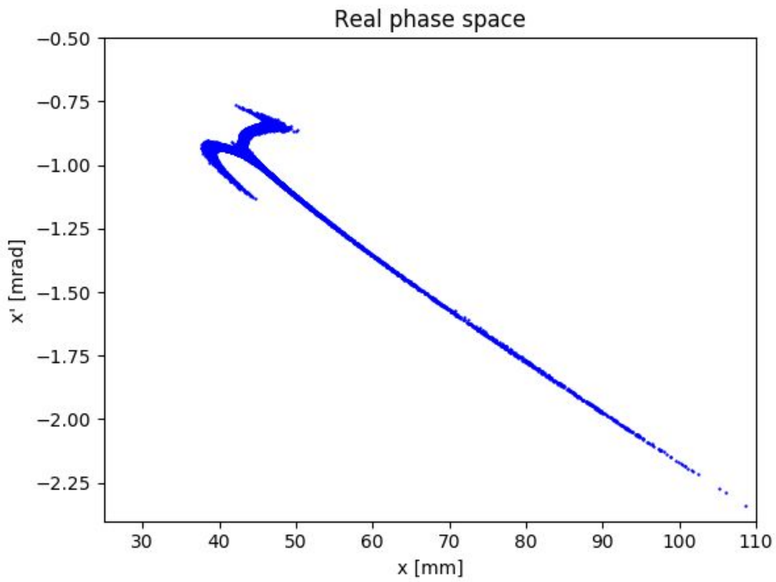
C. Wiesner, R&D Meeting, 08/11/2016

Real space particle distribution at extraction

Strength=0.02



Strength=0.09



Real space particle distribution at extraction

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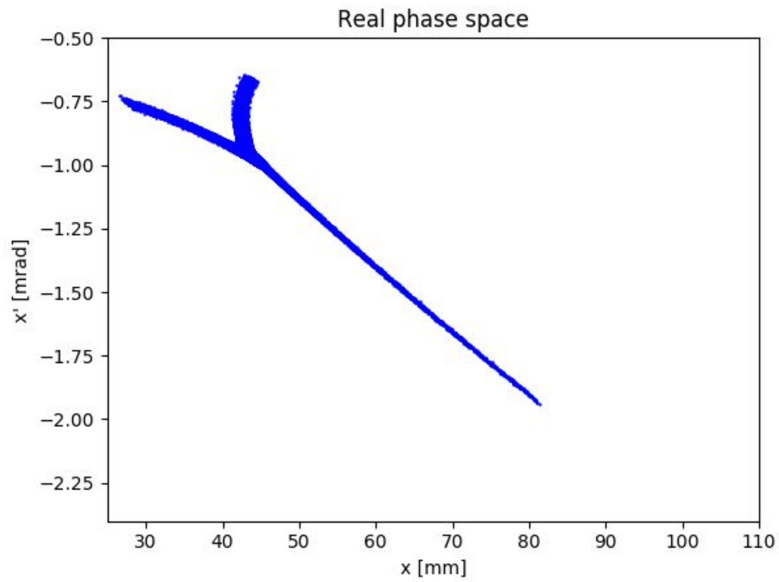

Strength=0.09