
CERN

Loss Reduction Techniques for Slow Extraction and Beam Delivery from Synchrotrons

Simulations and Recent Measurements at MedAustron

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JAI Fest, 6th December 2019

Outline

- Introduction: From synchrotron to user
- Loss reduction at Extraction
  - MedAustron Collaboration
  - Simulations
  - Measurements
- Conclusion and Next Steps

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Introduction: From synchrotron to user

- 3rd integer slow extraction -> long (~1-10s) uniform (small intensity variation) spills
- E.g. fixed target experiments, medical ion therapy
- The beam is ...

accelerated → extracted by resonance → transported to user

Introduction: From synchrotron to user

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- E.g. fixed target experiments, medical ion therapy
- The beam is ...

accelerated → extracted by resonance → SPLIT! → transported to user

Introduction: From synchrotron to user

- Goal: reduce overall losses in extraction, splitting and transport in general.

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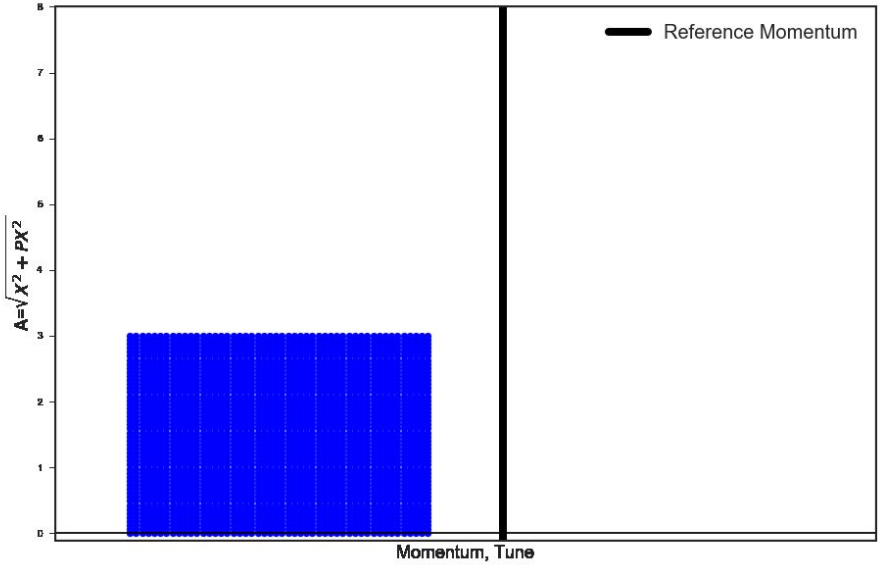
Extracting: Crash Course

Procedure

1. Particles have different momenta, therefore different tune (Q' not 0)
2. A sextupole is used to create a resonance at Q=n ± 1/3
3. Particles are pushed into the resonant region and will gain amplitude exponentially
4. A septum is used to catch them and extracted them

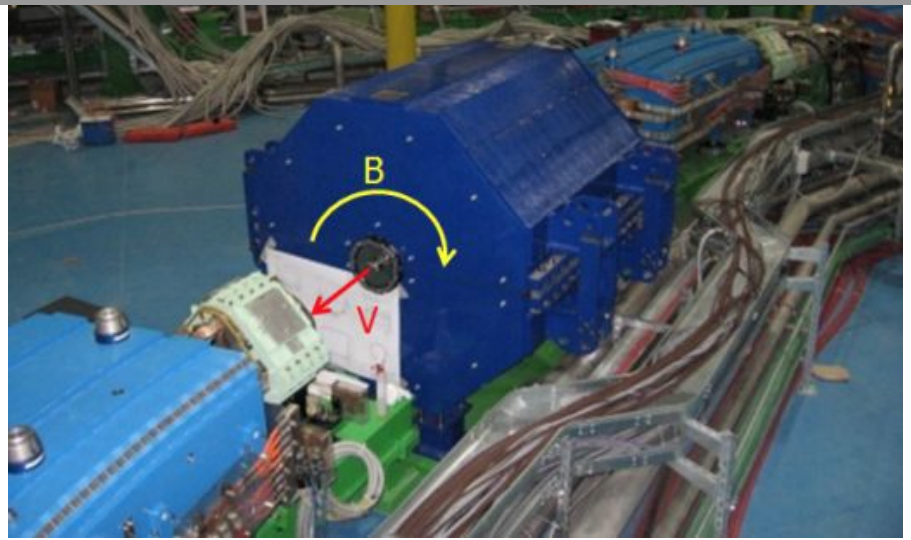
The Steinbach diagram



Extracting: Crash Course

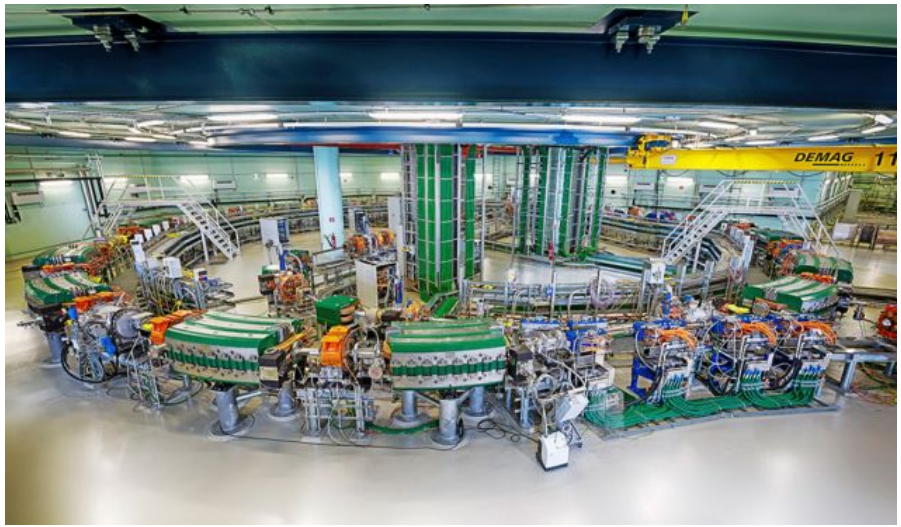
3. **Particles are pushed into the resonant region** and will gain amplitude exponentially

Betatron core: Toroidal Magnet. Variable current -> Variable B-field flux -> Accelerating DC Voltage



Extracting: MedAustron Collab

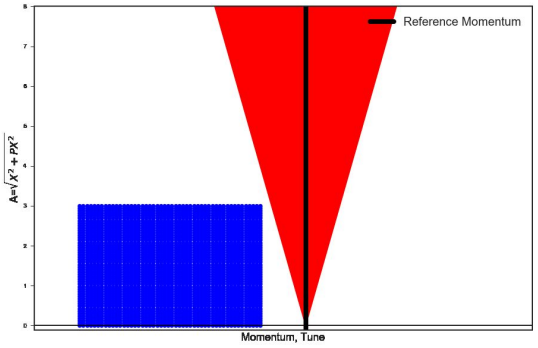
- Ion beam therapy center in Wiener Neustadt Austria



- **Problem:** extraction by sweeping the tune with good beam quality
- **Solution:** apply Constant Optics Slow Extraction (COSE) developed at SPS

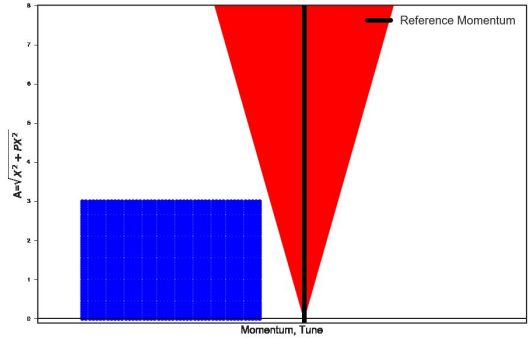
Extracting: MedAustron Collab

Quad-Sweep



-Quad-Sweep extraction scheme ramps the quadrupoles of the machine
-The reference tune changes and the resonance region ‘moves’ through the stack
-**Problem:** different particles see different optics at extraction!

COSE



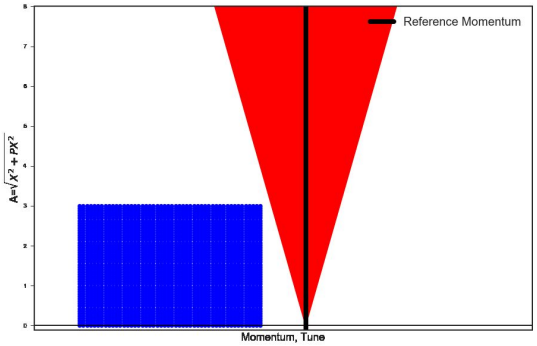
-COSE ramps every magnet, which causes the reference momentum to move in synch with the resonant region.
-Every particle sees the same normalized strengths!

Extracting: MedAustron Collab

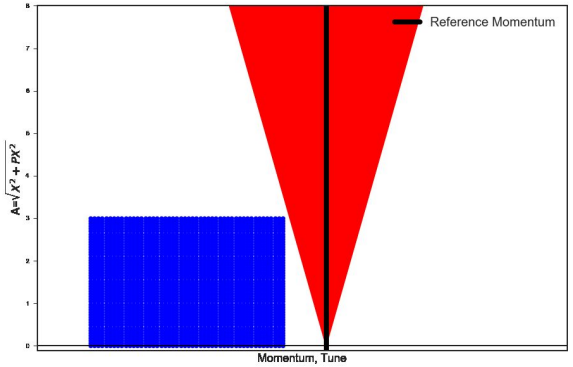
MedAustron is a great testing candidate because…

+ Machine behaviour is very reproducible
+ Large dispersion (~4m) at ES -> Large dispersive steering for Quad-sweep
+ COSE beam profile should be identical to nominal betatron core profile

COSE
->

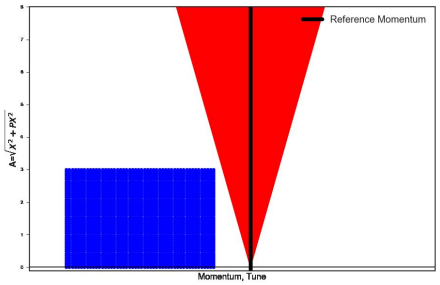


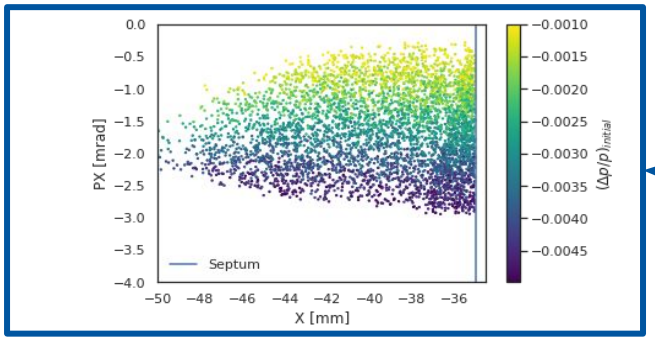
Nominal
(Betatron)
->

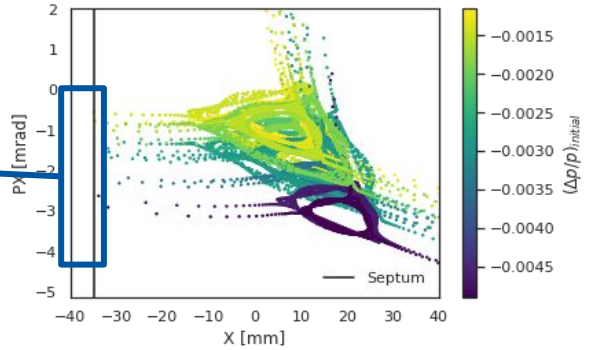


Extracting: Simulations

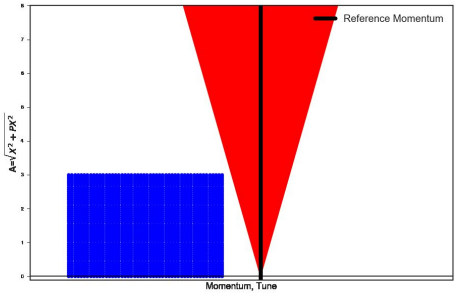
Quad - Sweep

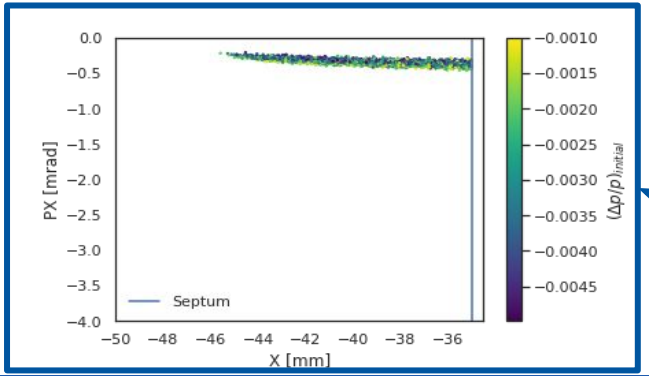


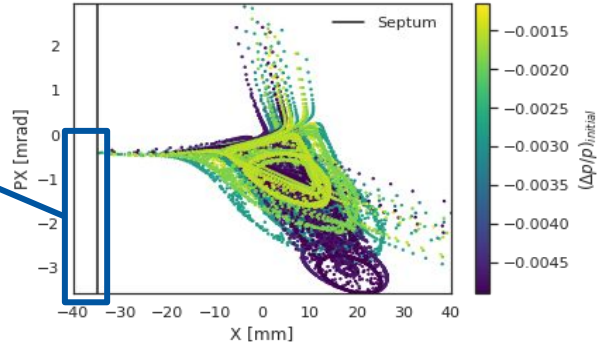




COSE



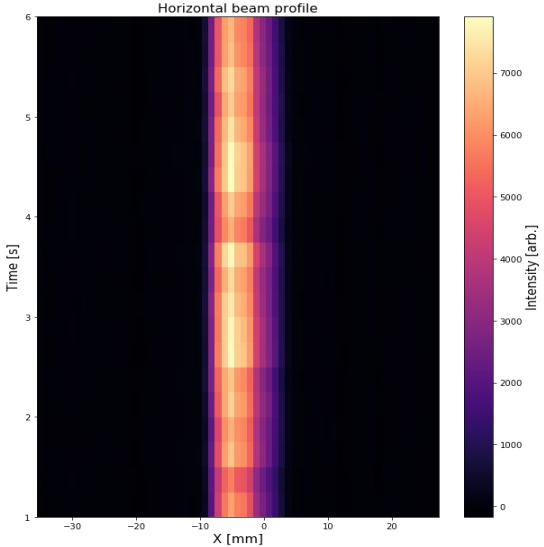




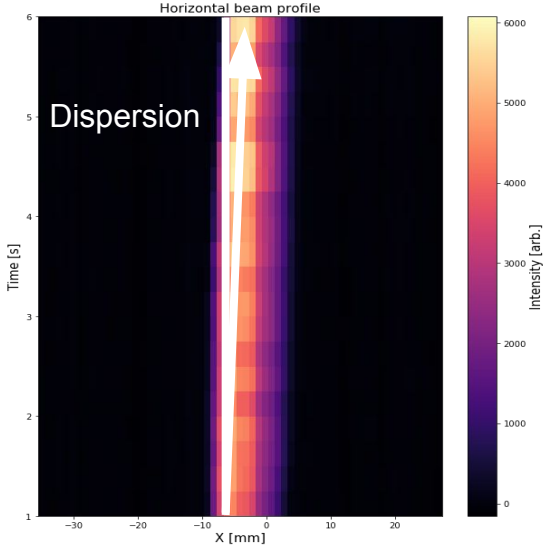
Extracting: Measurements

Transfer line Beam Profile Monitor

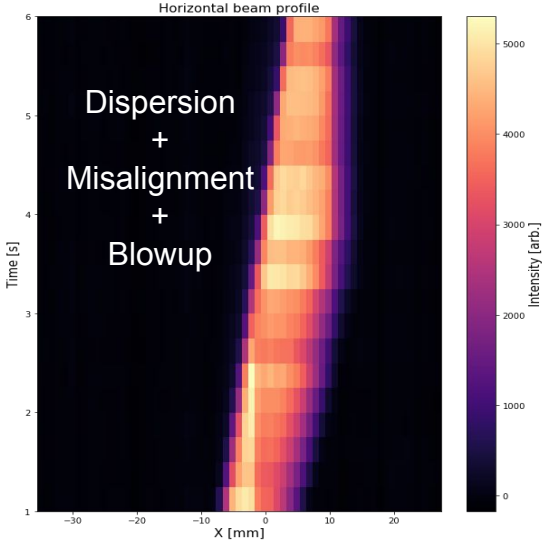
Nominal



COSE

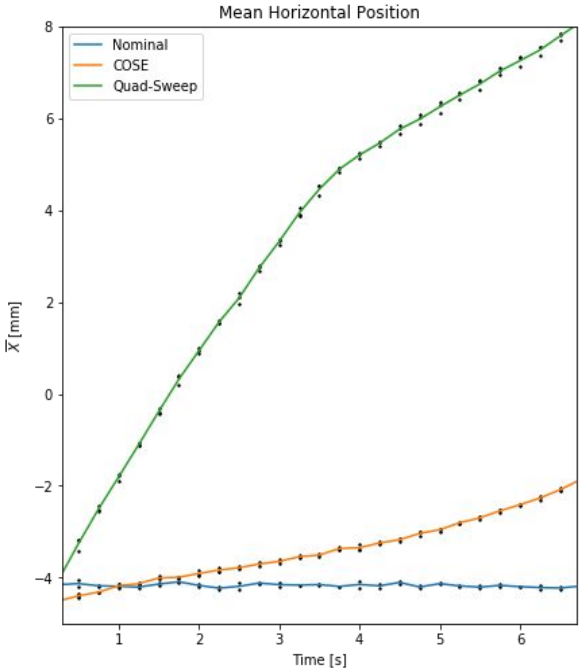


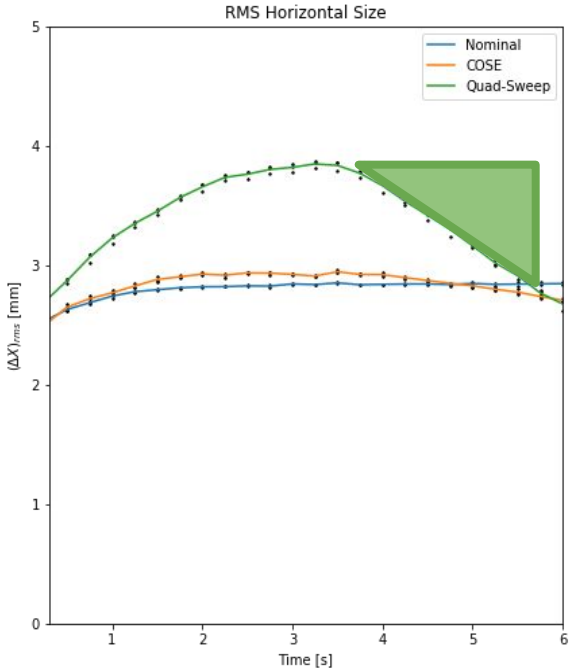
Quad-Sweep



*Extraction transfer line magnets are not scalable (for now) -> Small dispersive effects at BPM

Extracting: Measurements





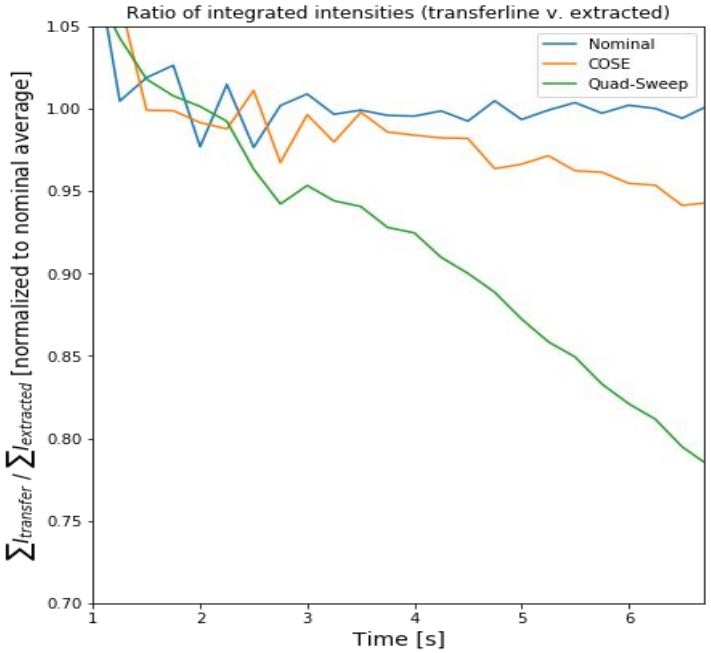
1. If COSE and Nominal are identical:
   a. $(X_{nom.} - X_{COSE})_{end}$ = 2.1 mm .
      Assuming dp/p=.4%
      ->D_x = .53 m .
   b. RMS sizes are consistent

2. We can observe Quad-Sweep...
   a. Misalignment
   b. Blowup
   c. LOSSES?

Extracting: Measurements

Ring Current Transformer + Transfer line Beam Profile Monitor

- There are no beam loss monitors in the extraction region or extraction transfer line
- We use intensity measurements in an attempt to characterize losses
- After the first 2 s, the the nominal extraction stays more or less constant, suggesting very small losses
- Both COSE and specially Quad-Sweep have a decreasing tendency, suggesting losses



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Conclusion & Next Steps

Constant Optics Slow Extraction was implemented at MedAustron to show its loss reduction capabilities vs a quadrupole sweep

- Conclusion: COSE improves performance of a Quad-Sweep extraction scheme
- Next steps: Further loss characterization

On a slightly different note… Plans to look into loss reduction techniques for beam splitting. Some results obtained by Martin Tat (Oxford, Summer Student) can be found in the extra slides

Thank you!

Pablo Arrutia Sota
JAI Fest, 6th December 2019

References

- M. Tat, Beam losses at the TT20 Splitters. CDS
- V. Kain, F. M. Velotti, M. A. Fraser, B. Goddard, J. Prieto, L. S. Stoel, and M. Pari, Resonant slow extraction with constant optics for improved separatrix control at the extraction septum. CDS
- E. Bressi, L. Falbo, C. Priano, S. Foglio, Betatron Core Slow Extraction at CNAO

- https://cerncourier.com/a/austrian-synchrotron-debuts-carbon-ion-cancer-treatment/

Extra slides

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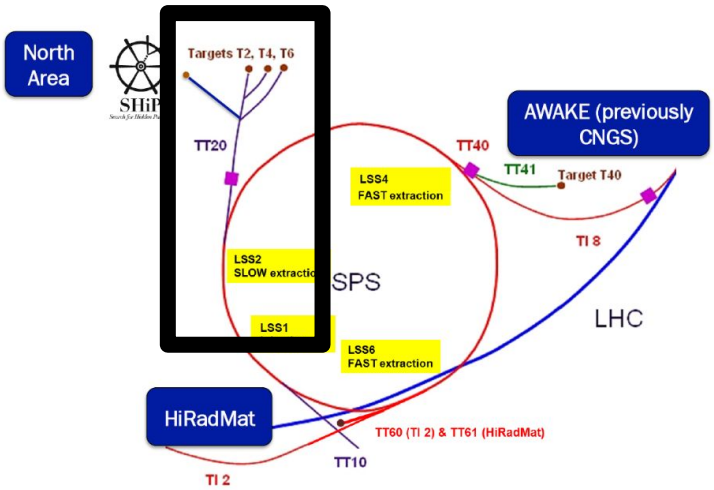
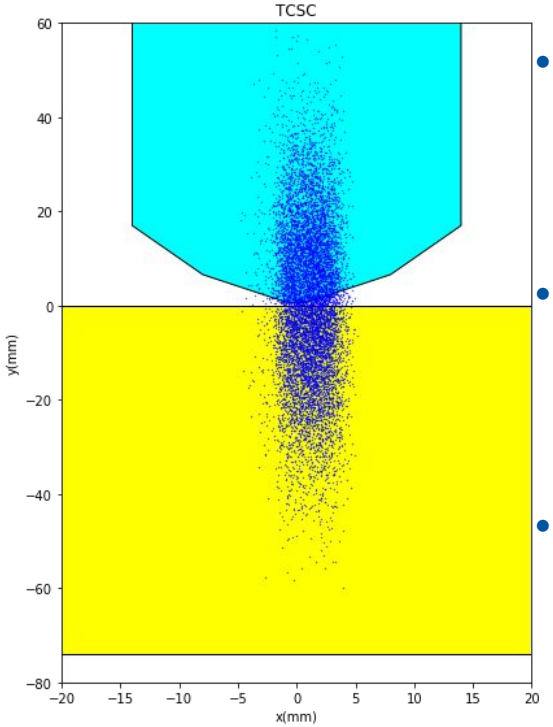
Splitting: CERN TT20 Splitters





- Problem: Losses at septum blade. Up to ~6%
- Idea: reduce density at blade by ‘kicking’ upstream
- Studies by Martin Tat, Oxford

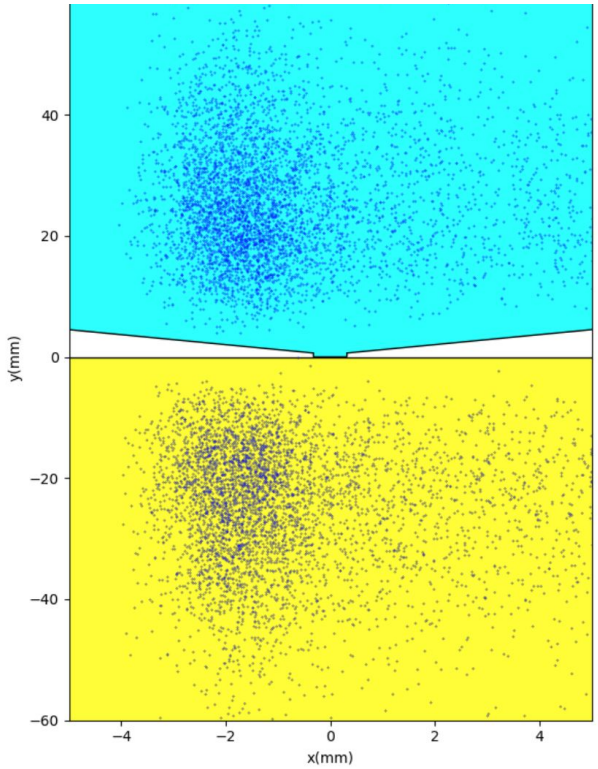
Splitting: Results

- Option 1: Electrostatic septum

Rough specs

- 500m upstream from splitter
- Length: 1.0 m
- Width: 0.1 mm
- Field: 5.0 MV m−1

Up to 18x reduction in losses

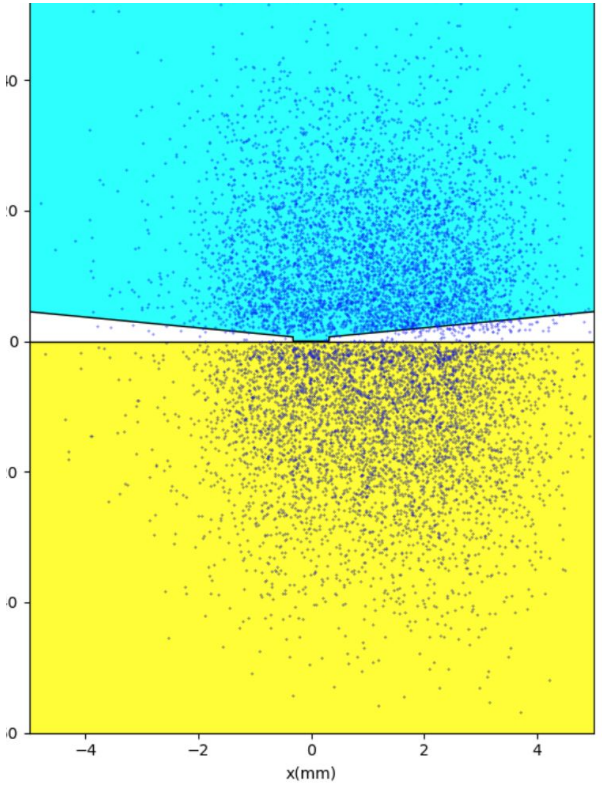


Splitting: Results

- Option 2: Silicon crystal stack

Rough specs

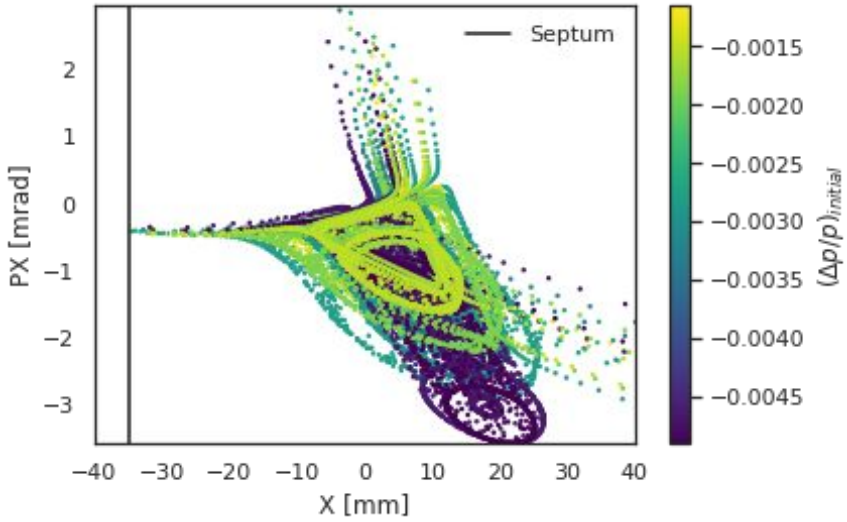
- 30 m upstream of splitter
- Number of crystals: 5
- Width: 0.4 mm



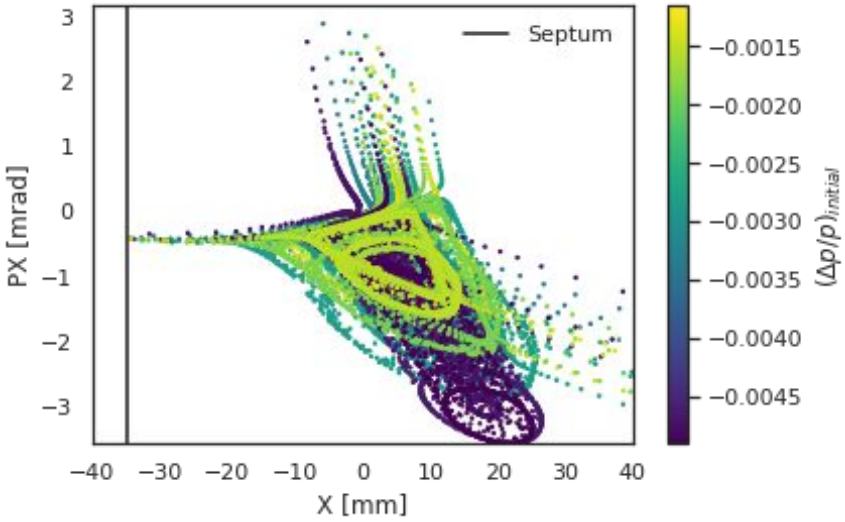
Up to 10x reduction in losses

Extracting: Simulations

COSE



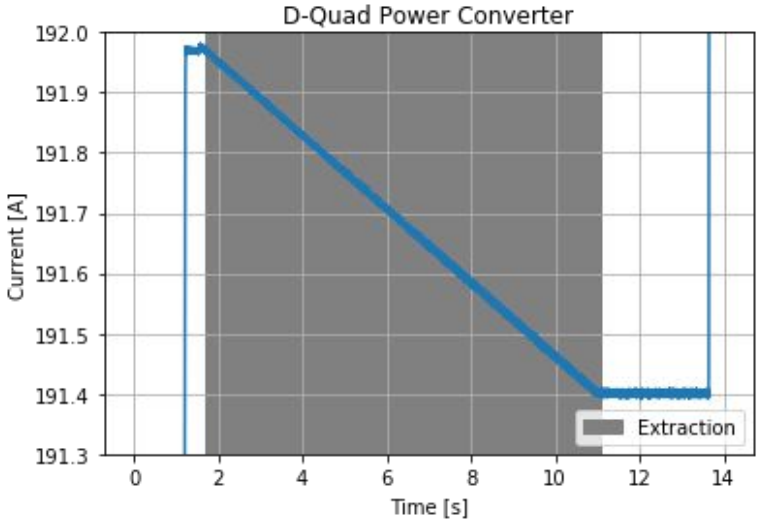
Nominal (betatron core)



Extracting: Measurements

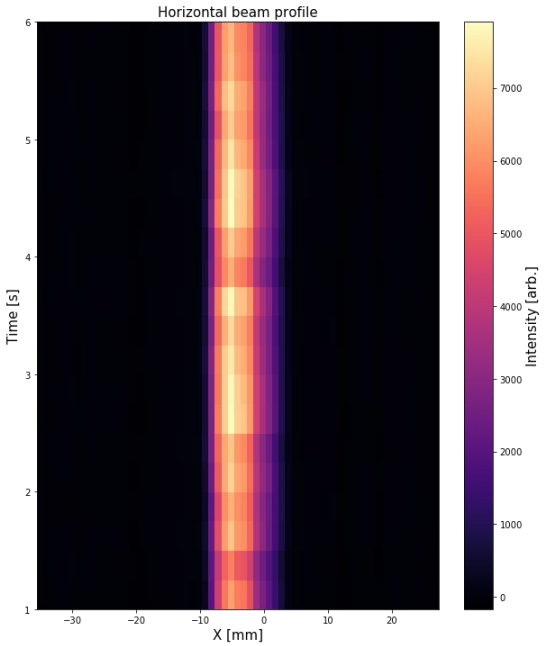
Procedure

1. Ramp Magnets in Main Ring
   a. Only Quads for Quad-Sweep
   b. All magnets for COSE
2. Measure beam profile at transfer line
3. Compare with nominal case

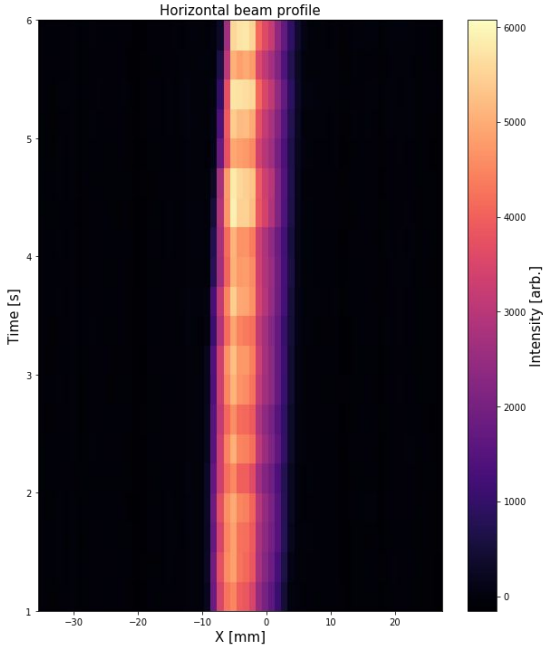


Extracting: Measurements

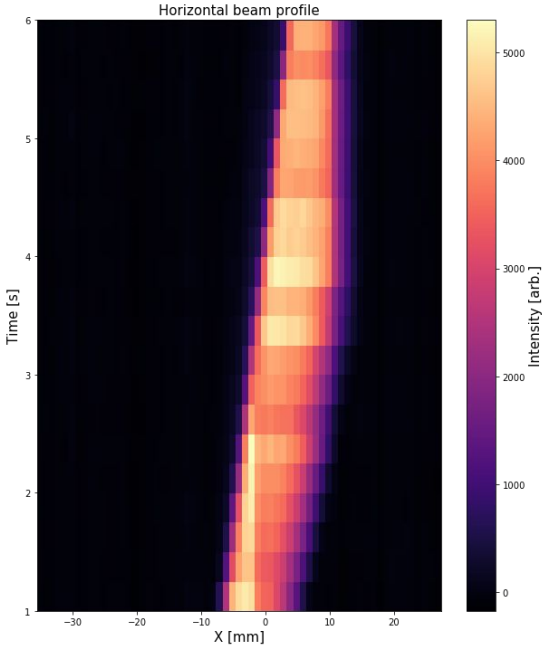
Nominal



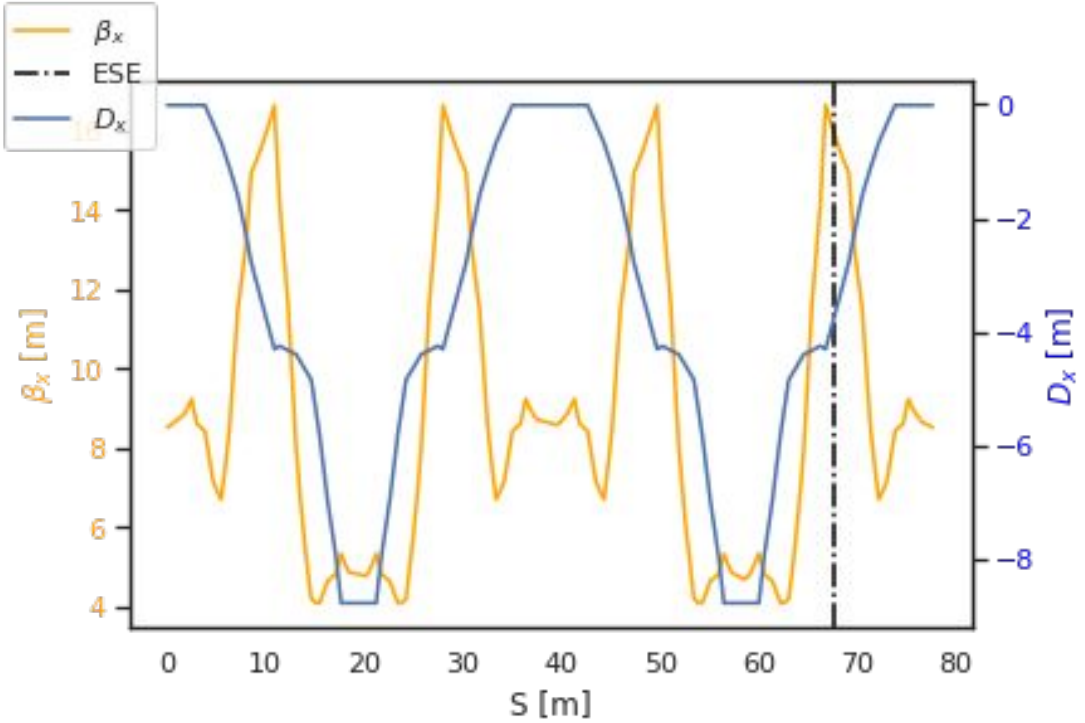
COSE



Quad-Sweep



Optics


β_x
ESE
D_x
β_x [m]
D_x [m]
S [m]
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8
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14
0
−2
−4
−6
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80


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