



# Cooling Simulation Update

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Science & Technology Facilities Council

ISIS Neutron and Muon Source

C. T. Rogers

ISIS

Rutherford Appleton Laboratory

# Sad News



## More Muon Cooling, Higher Luminosity

Don Summers, Lucien Cremaldi, Terry Hart  
University of Mississippi - Oxford  
Alex Bogacz (JLAB), Rebecca Taylor (Imperial)



12 Nov 2020: Muon Capture and Cooling Working Group

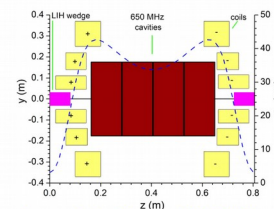
Thursday, 12 November 2020  
Muon Capture and Cooling Working Group

CERN (page 1)

Don Summers  
U. of Mississippi-Oxford

## Rectilinear Cooling Channel Status

- Channel is 969 m long with 826 cells. 6D cooling of 108 000  
Diktys Stratakis and Bob Palmer, PRSTAB 18 (2015) 031003  
Witte, Stratakis, Berg, Palmer, Borgnolutti, IPAC14-WEPR1103



Rectilinear cell at the end in Stage B8 (14T maximum field coil)

- Final xyz emittance equals (280, 280, 1570) microns  
Luminosity is proportional to the square root of 6D emittance  
16x lower 6D emittance would lead to 4x higher luminosity  
Optimal high energy collider: (25, 25, 72000) microns
- Is more cooling/reverse emittance possible?

Thursday, 12 November 2020  
Muon Capture and Cooling Working Group

CERN (page 4)

Don Summers  
U. of Mississippi-Oxford

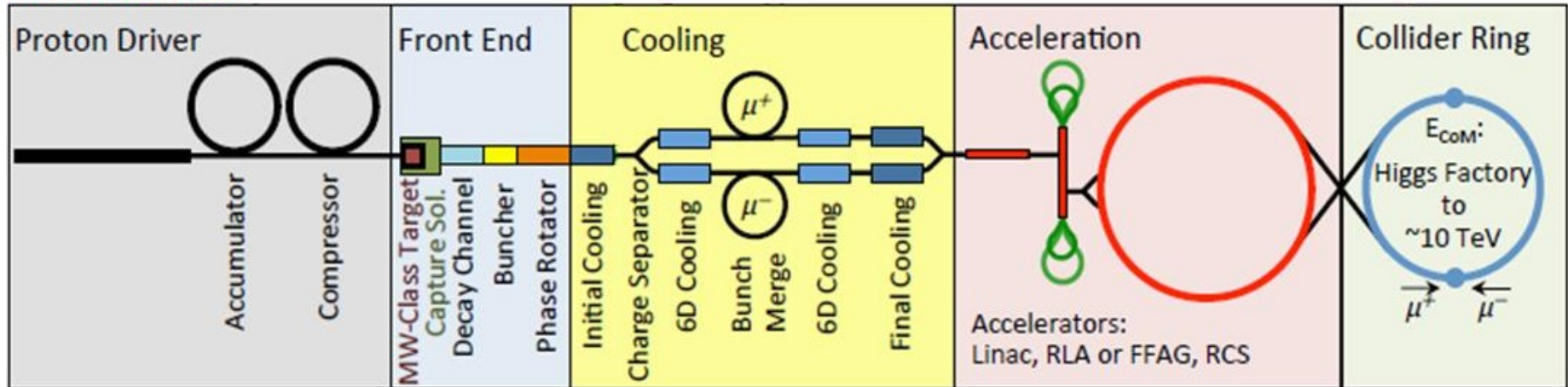


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ISIS Neutron and Muon Source

# Muon Collider Facility

## Muon Collider



- Reminder – muon collider facility (proton-based)
    - Protons on target in high-field solenoid → pions, muons et al.
    - **Clean up beam impurities**
    - **Capture muons longitudinally**
    - **Transverse and longitudinal cooling**
    - Acceleration
    - Collider ring
- } Capture and cooling Working group

# Job List

- Get hold of lattices
- Check they run and we can reproduce results
- Establish where lattices are missing or incomplete
- Develop and maintain hardware requirements
  - Liaise with magnet and RF teams as required
- Work on improving performance
  - Especially final cooling
- Identify technical issues/risks
- Work on mitigating risk
  - What experimental data/demonstrations do we need?
  - (MICE Results)
- Cost optimisation
  - E.g. rings
- **Please let me know if you would like to help!**

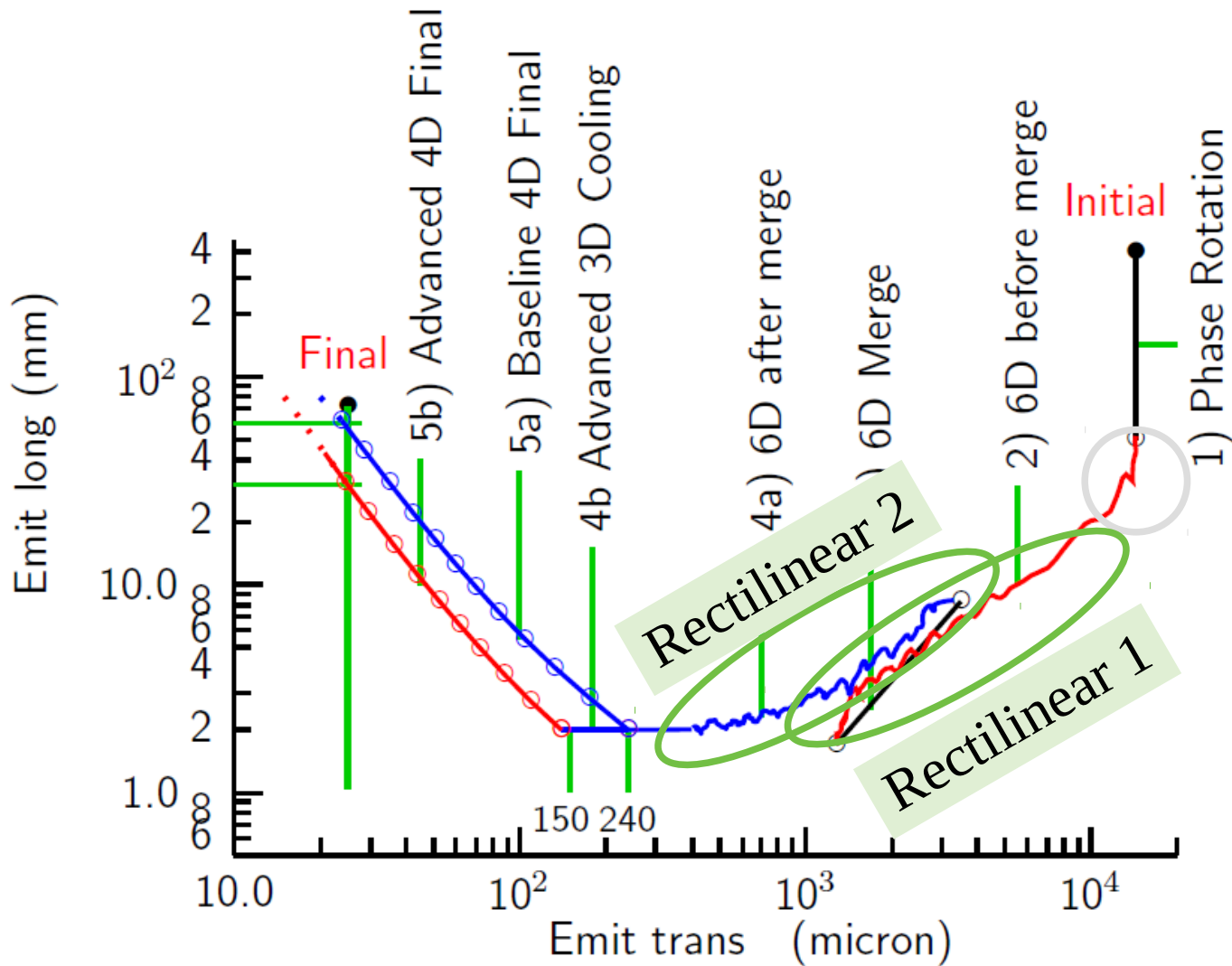


# Lattices, etc

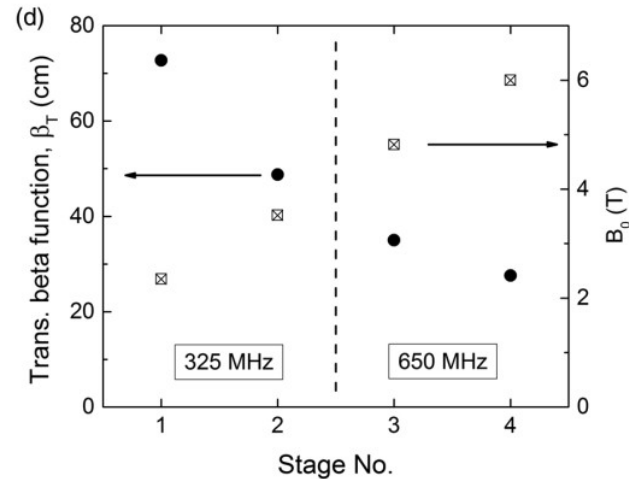
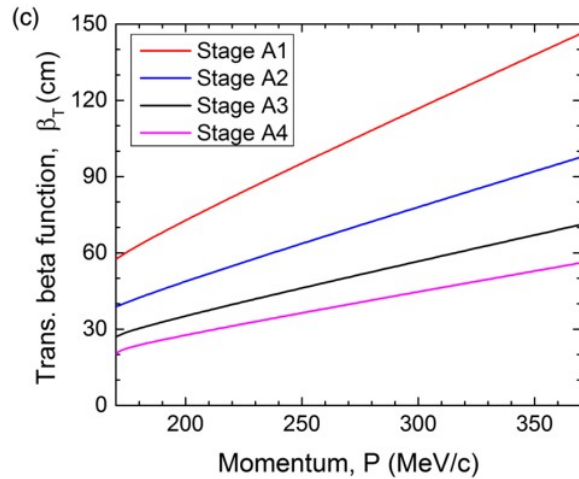
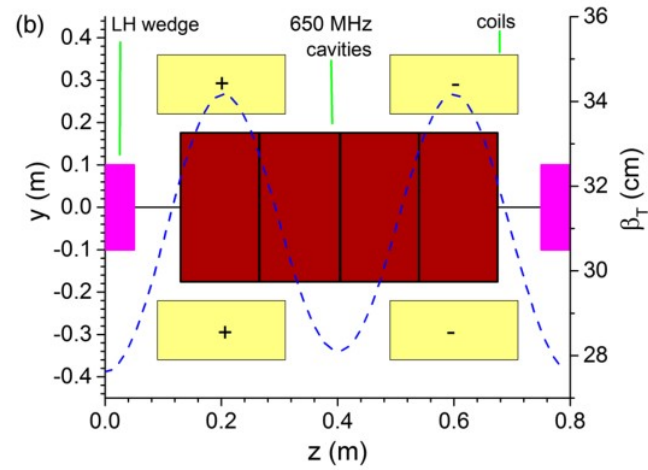
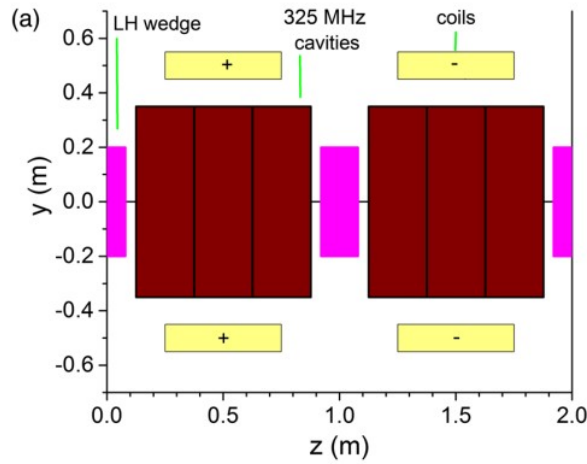
Subsection	Designer	Reference	Lattice Files
<b>Capture</b>			
Particle Selection	Scott Berg	Proc. IPAC2014 TUPME022	With Rogers – checked
Buncher	Dave Neuffer?	<a href="https://map-docdb.fnal.gov/cgi-bin/ShowDocument?docid=4355">https://map-docdb.fnal.gov/cgi-bin/ShowDocument?docid=4355</a>	?
Phase Rotator	Dave Neuffer?	<a href="https://map-docdb.fnal.gov/cgi-bin/ShowDocument?docid=4355">https://map-docdb.fnal.gov/cgi-bin/ShowDocument?docid=4355</a>	?
<b>Initial Cooling</b>			
HfoFo – gas filled	Yuri Alexahin	<a href="https://map-docdb.fnal.gov/cgi-bin/ShowDocument?docid=4377">https://map-docdb.fnal.gov/cgi-bin/ShowDocument?docid=4377</a>	With Rogers – checked
HfoFo – vacuum	Yuri Alexahin	<a href="https://map-docdb.fnal.gov/cgi-bin/ShowDocument?docid=4377">https://map-docdb.fnal.gov/cgi-bin/ShowDocument?docid=4377</a>	?
<b>Charge Separation</b>			
Charge Separation	Cary Yoshikawa	<a href="https://www.osti.gov/biblio/1113648">https://www.osti.gov/biblio/1113648</a>	?
<b>6D Cooling</b>			
Rectilinear	Diktys Stratakis	<a href="https://journals.aps.org/prab/abstract/10.1103/PhysRevSTAB.18.031003">https://journals.aps.org/prab/abstract/10.1103/PhysRevSTAB.18.031003</a>	With Rogers – not run
Helical snake	Katsuya Yonehara	<a href="https://iopscience.iop.org/article/10.1088/1748-0221/13/09/P09003">https://iopscience.iop.org/article/10.1088/1748-0221/13/09/P09003</a>	With Katsuya
<b>Bunch Merge</b>			
Phase Rotator and trombone	Yu Bao	<a href="https://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.19.031001">https://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.19.031001</a>	?
<b>6D Cooling</b>			
Rectilinear	Diktys Stratakis	<a href="https://journals.aps.org/prab/abstract/10.1103/PhysRevSTAB.18.031003">https://journals.aps.org/prab/abstract/10.1103/PhysRevSTAB.18.031003</a>	With Rogers – not run
Helical snake	Katsuya Yonehara	<a href="https://iopscience.iop.org/article/10.1088/1748-0221/13/09/P09003">https://iopscience.iop.org/article/10.1088/1748-0221/13/09/P09003</a>	With Katsuya
<b>Final Cooling</b>			
Linear Cooling	Hisham Sayed	<a href="https://journals.aps.org/prab/abstract/10.1103/PhysRevSTAB.18.091001">https://journals.aps.org/prab/abstract/10.1103/PhysRevSTAB.18.091001</a>	?
PIC	James Maloney?	<a href="https://arxiv.org/pdf/1401.8256.pdf">https://arxiv.org/pdf/1401.8256.pdf</a>	?
Potato slicer	Don Summers?	<a href="https://map-docdb.fnal.gov/cgi-bin/ShowDocument?docid=4403">https://map-docdb.fnal.gov/cgi-bin/ShowDocument?docid=4403</a>	



# Lattices, etc



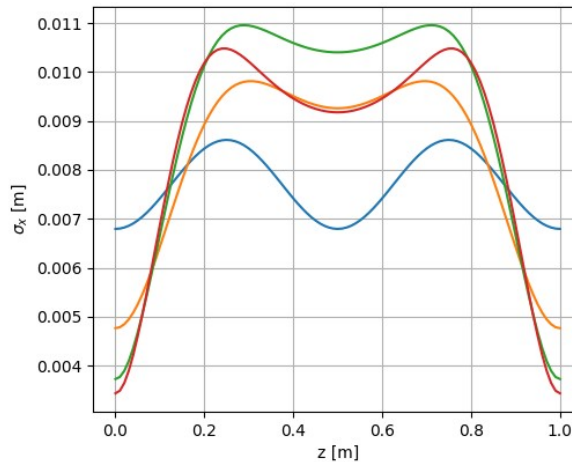
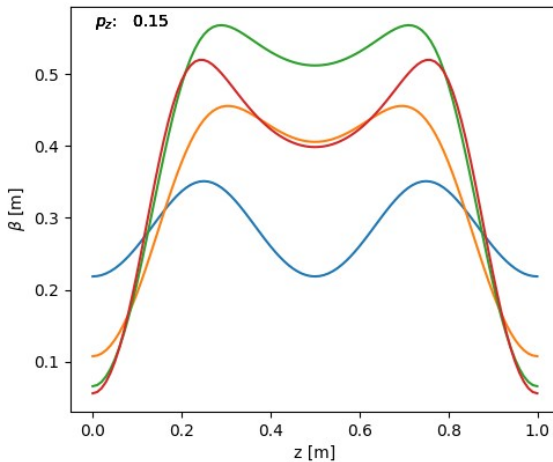
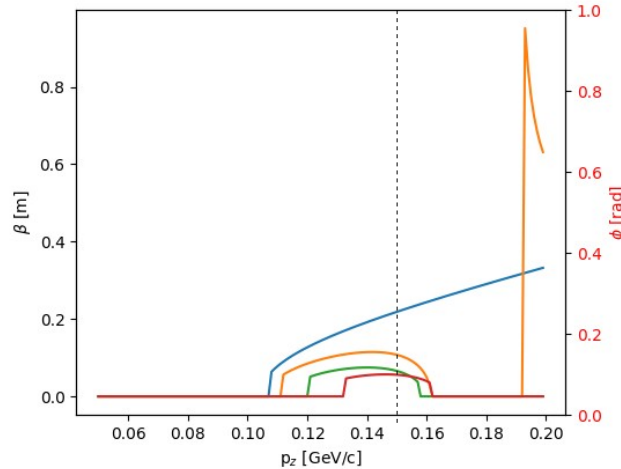
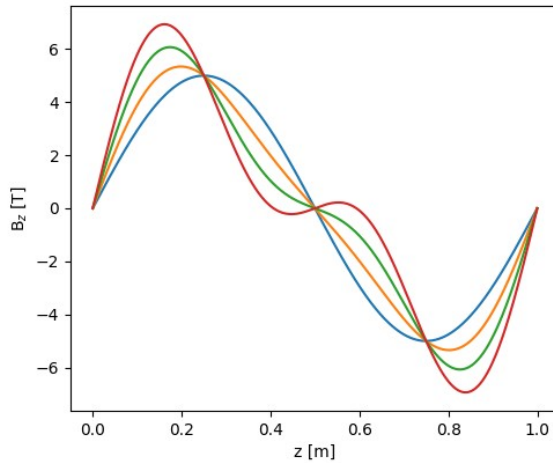
# Rectilinear 1





# Effect of harmonics

$$B_z = B_0 \sin(kz) + B_1 \sin(2kz)$$



Mixing  
different  
harmonics of  $B_z$

Cooling:

$$\varepsilon_{\min} \sim \beta_{\min}$$

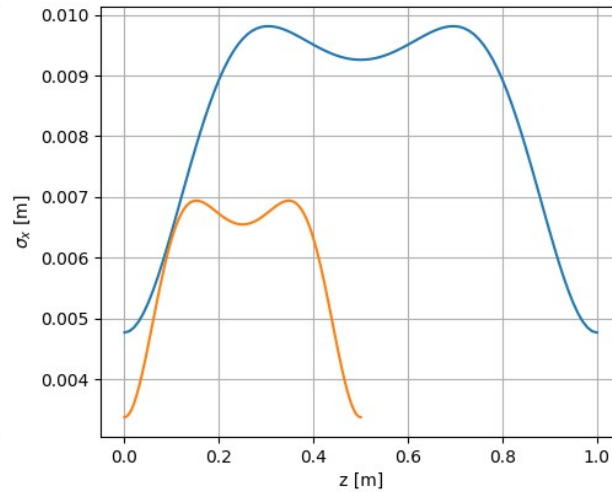
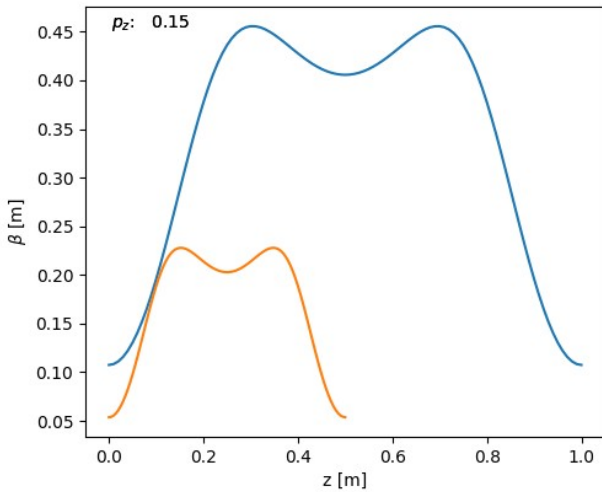
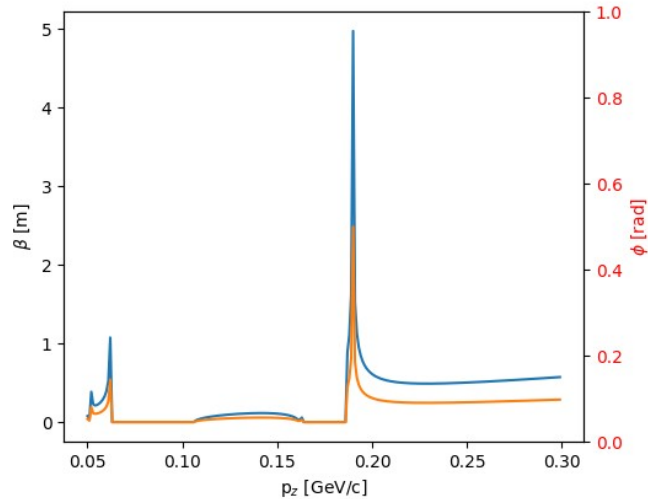
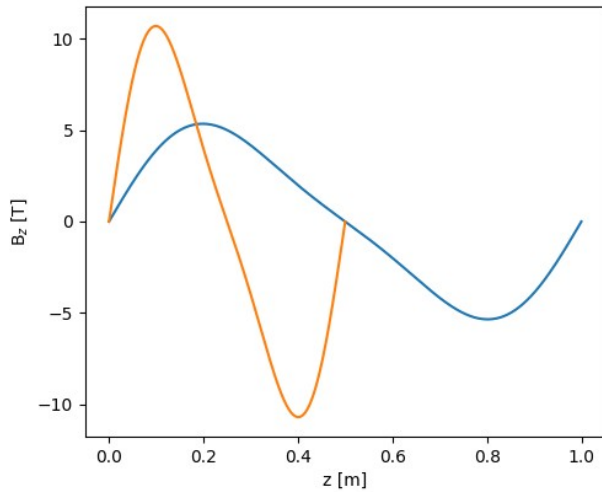
Aperture:

$$\varepsilon_{\max} \sim \beta_{\max}$$



# Scaling

$$B_z = B_0 \sin(kz) + B_1 \sin(2kz)$$



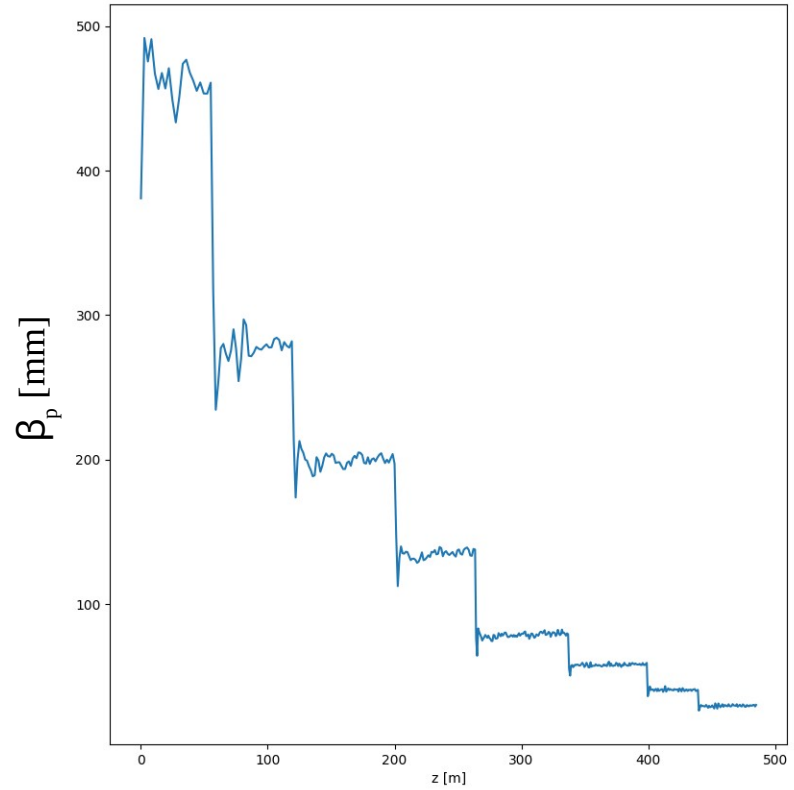
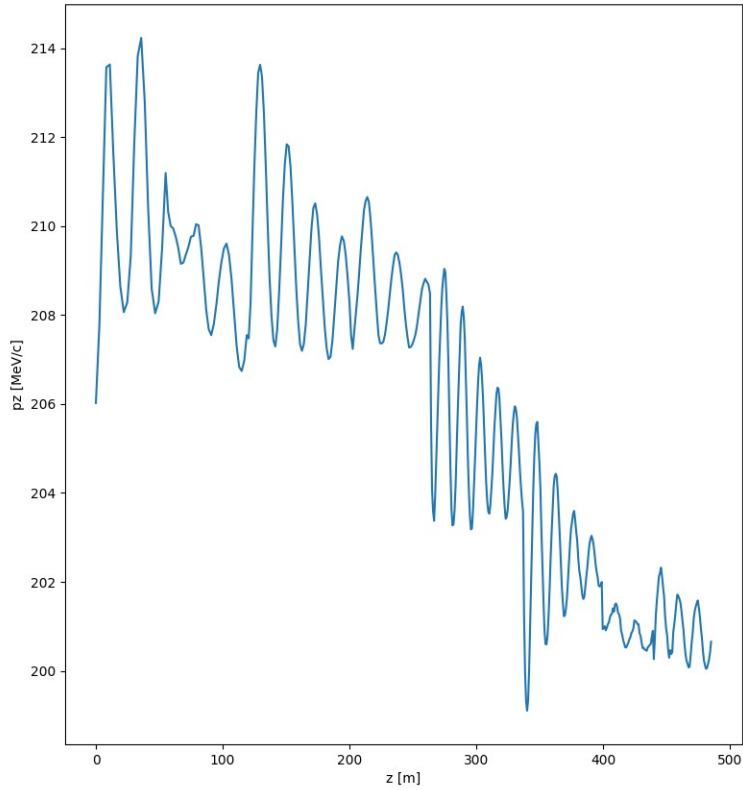
$$B_0 \rightarrow 2B_0$$

$$B_1 \rightarrow 2B_1$$

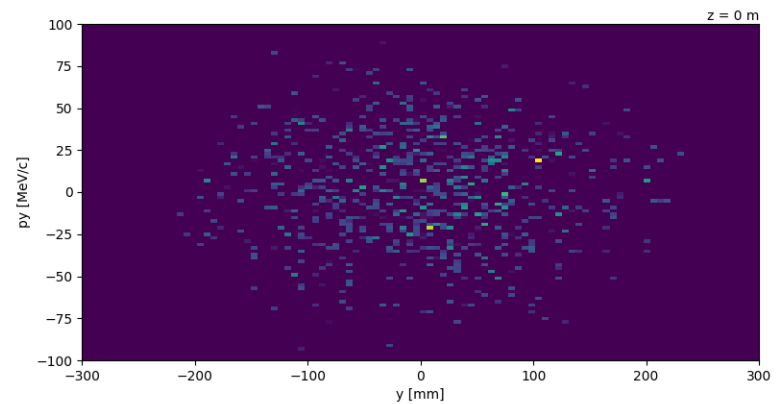
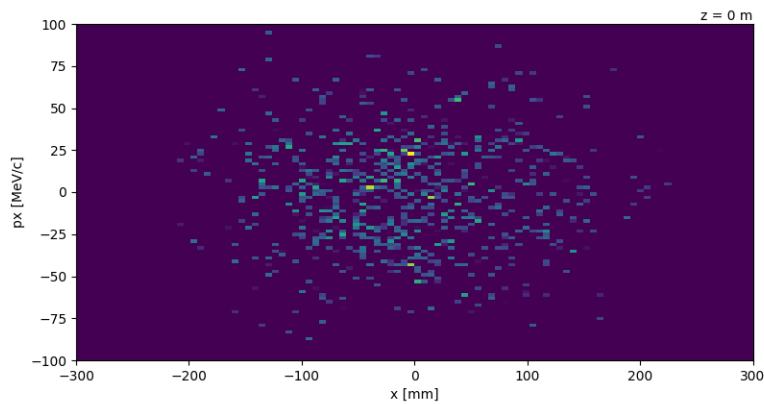
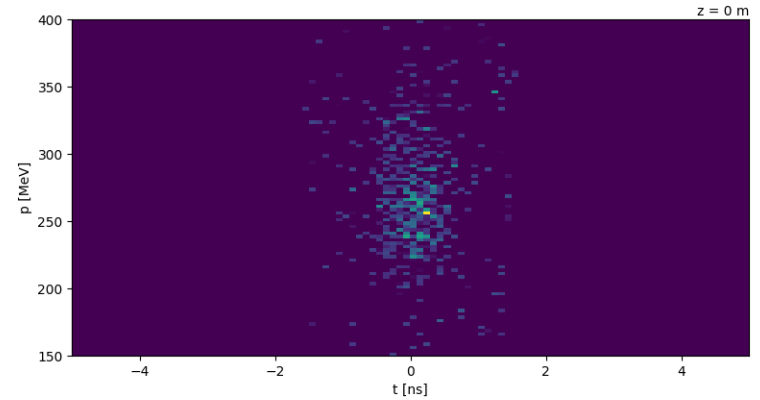
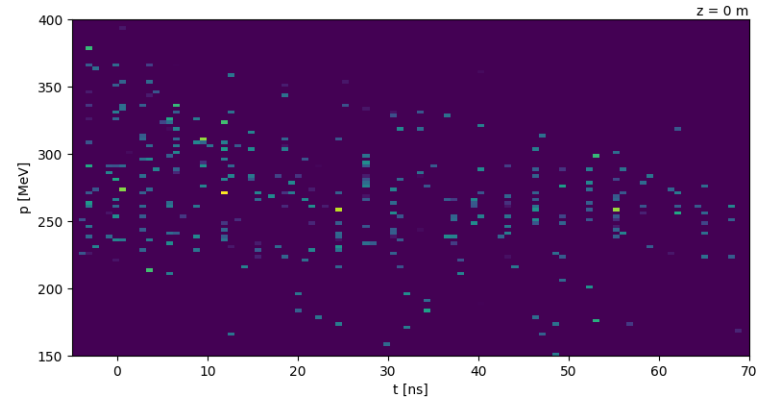
$$k \rightarrow 2k$$

Question: How short can we make the cells?  
How high field?

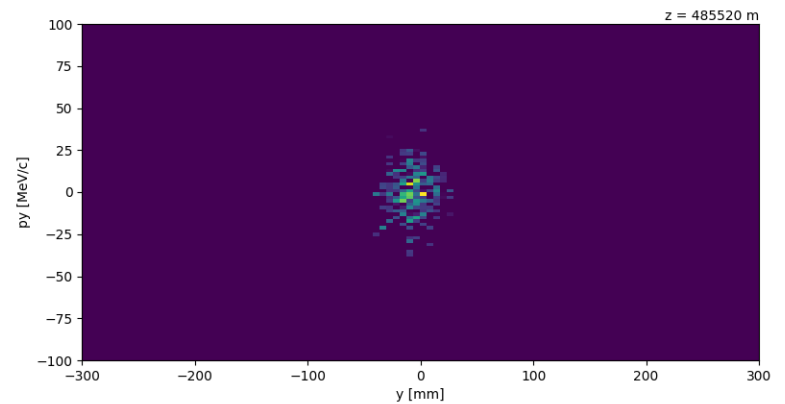
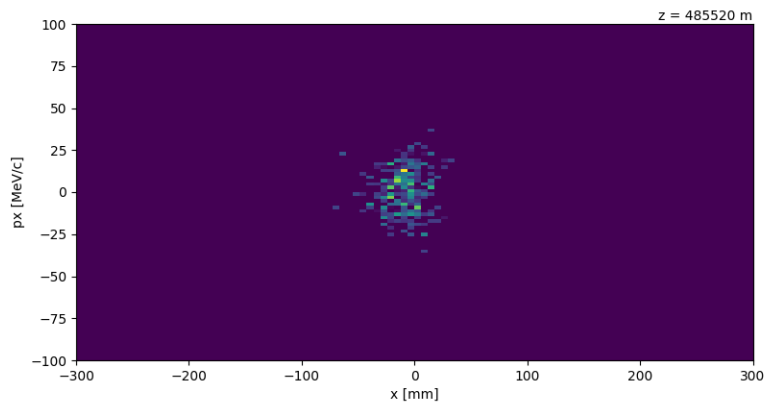
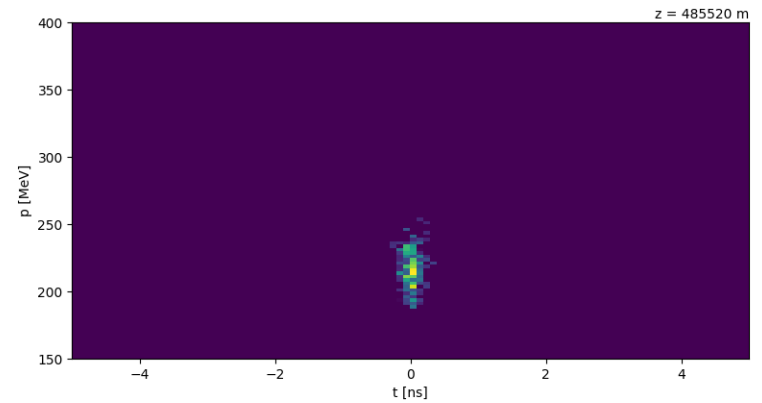
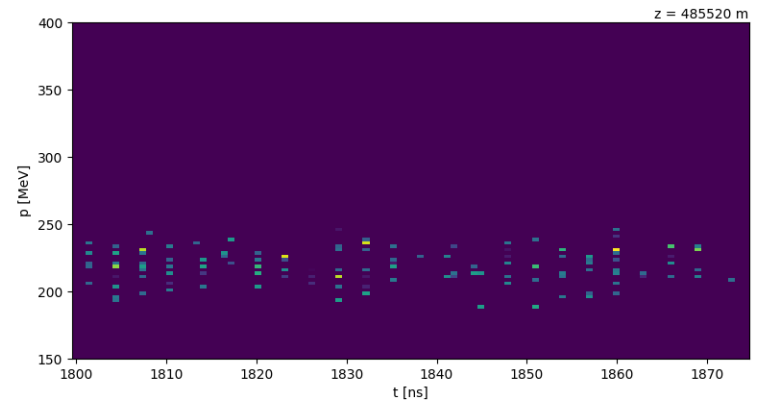
# Rectilinear 1



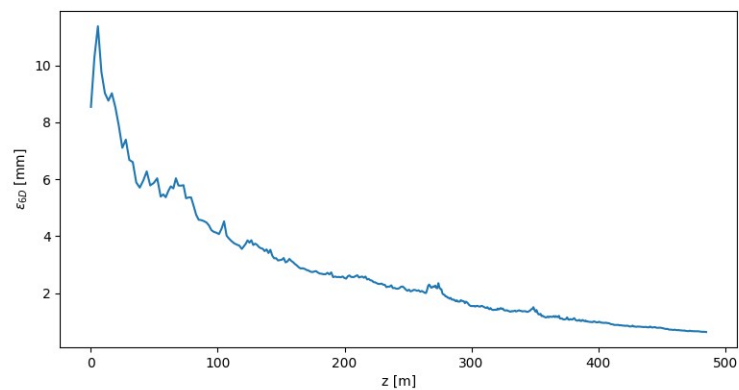
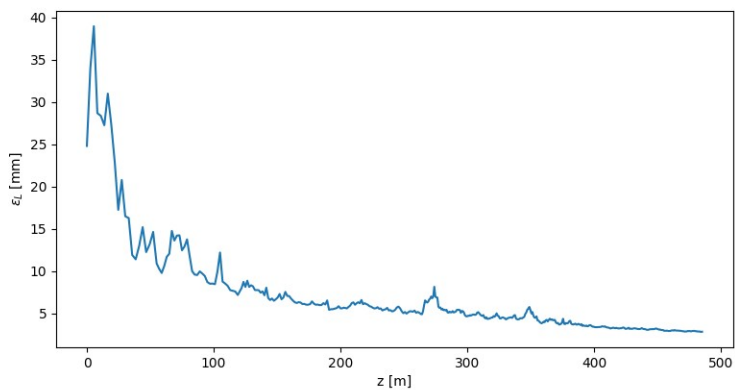
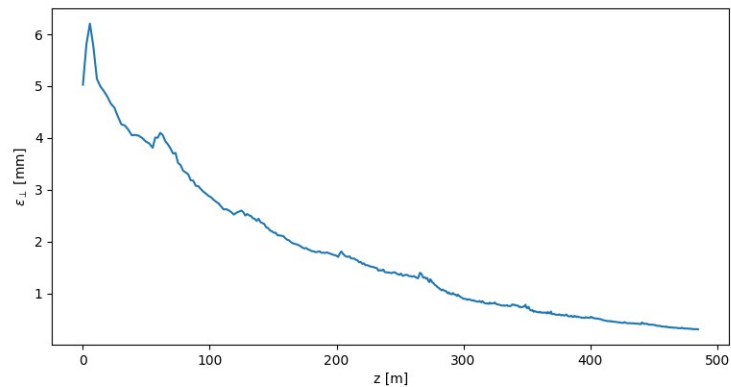
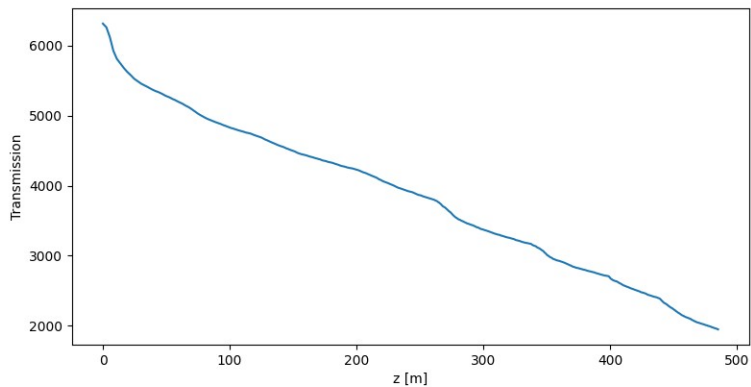
# Rectilinear 1



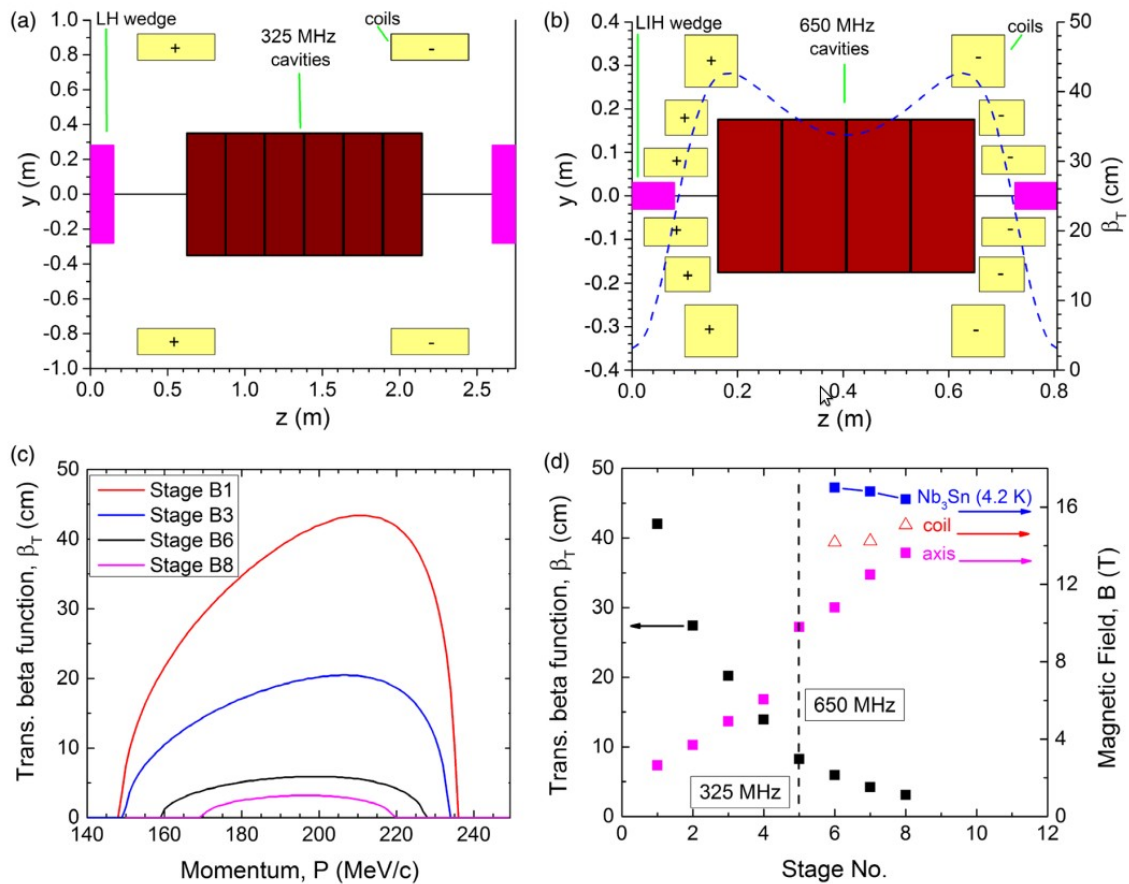
# Rectilinear 1



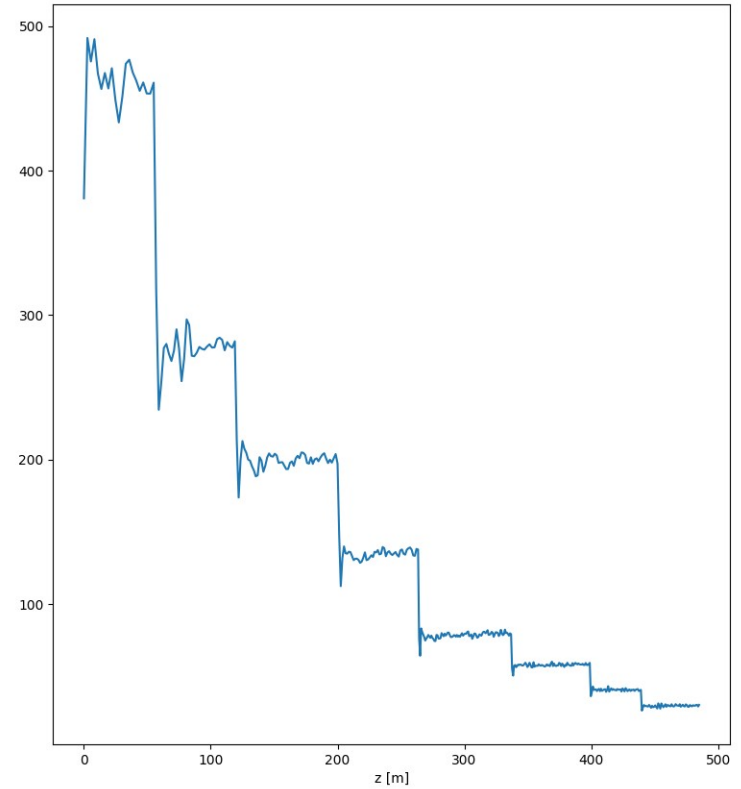
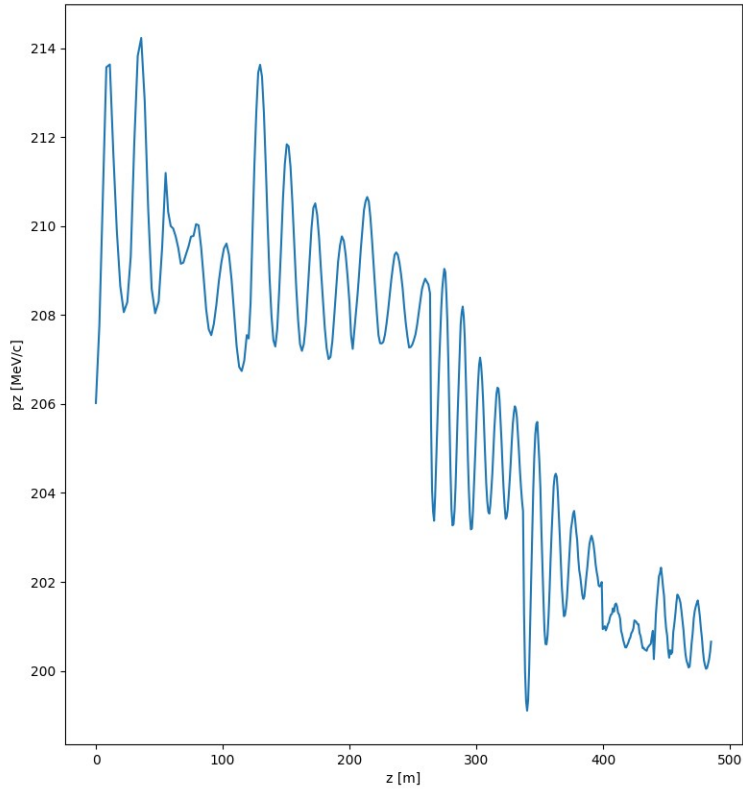
# Rectilinear 1 - performance



# Rectilinear 2

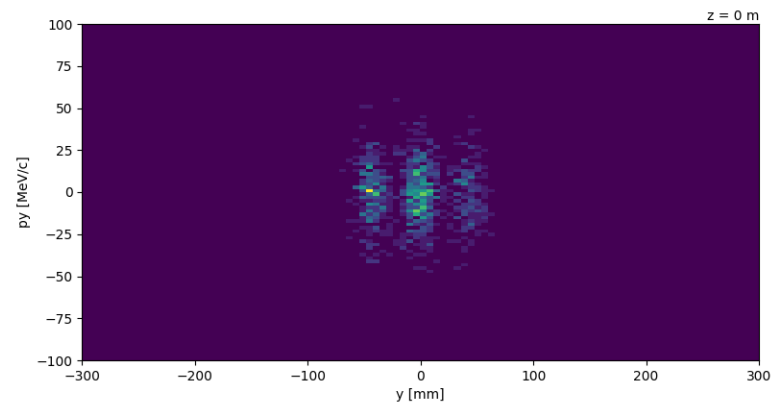
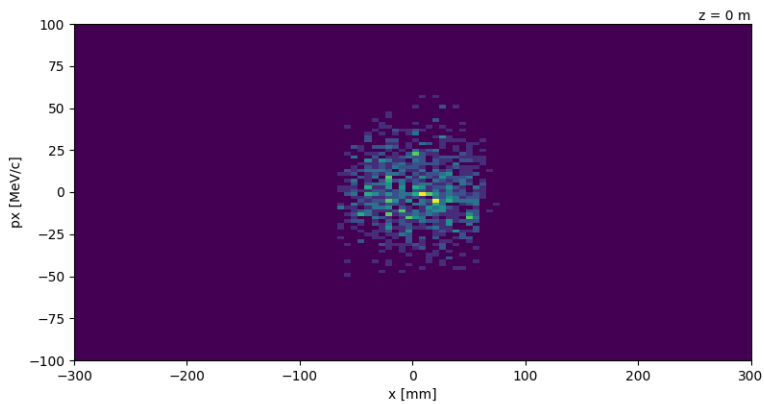
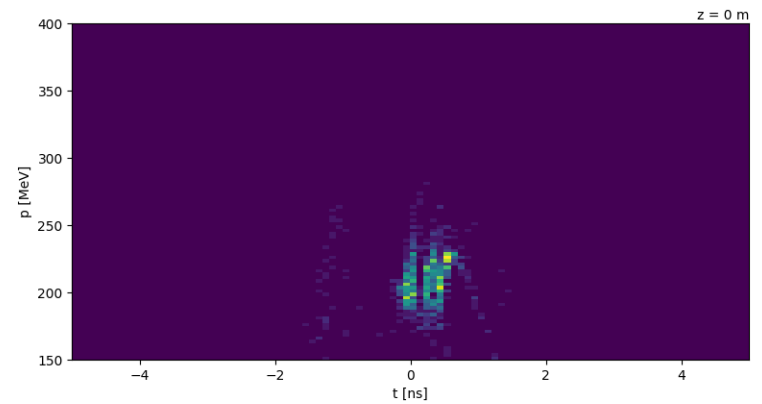
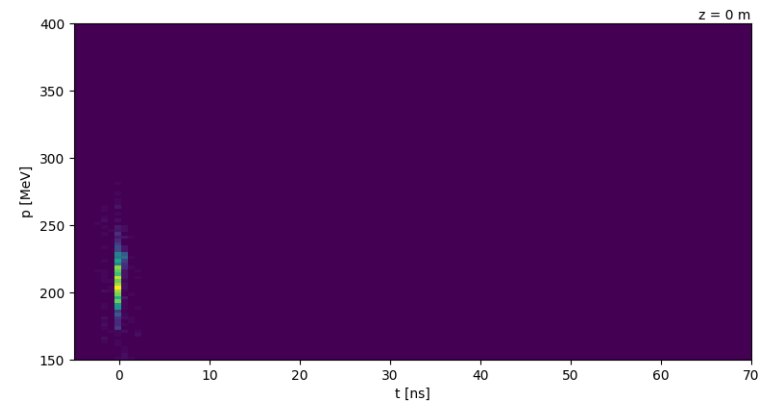


# Rectilinear 2

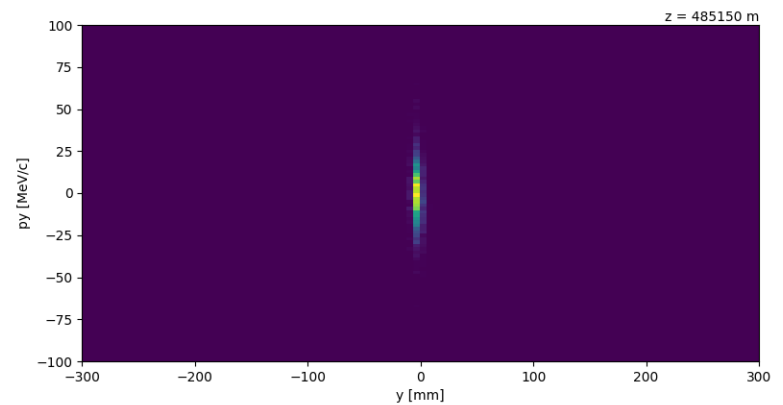
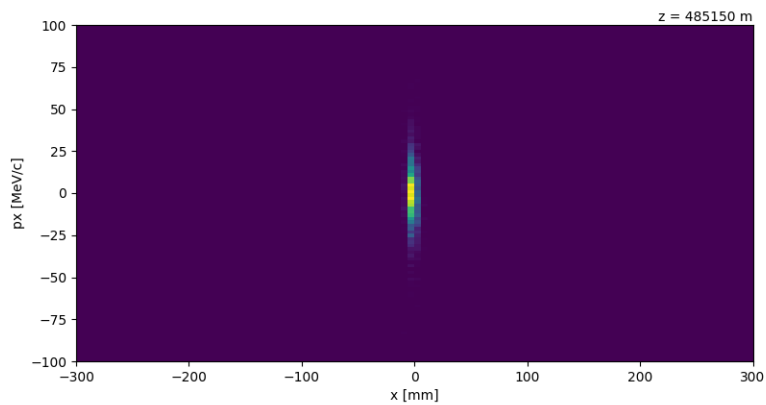
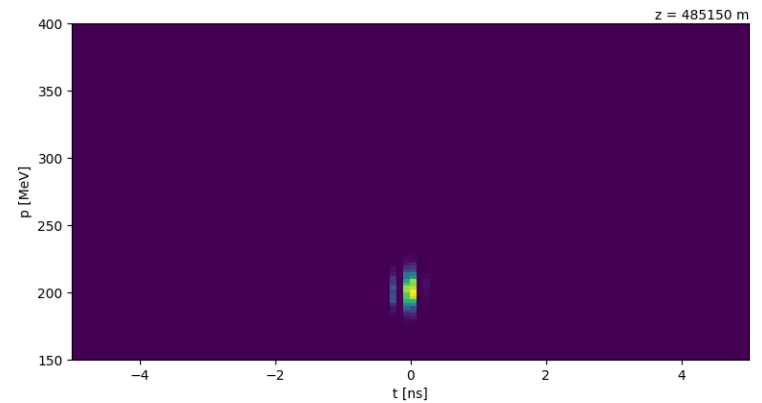
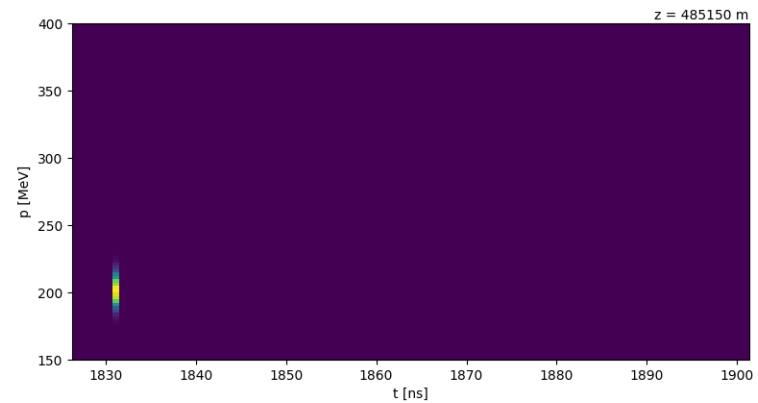




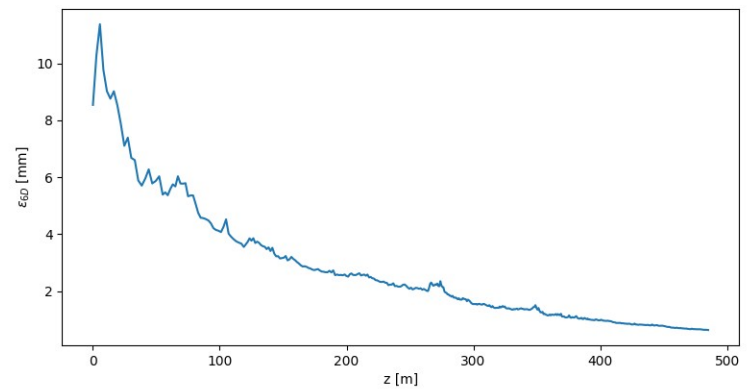
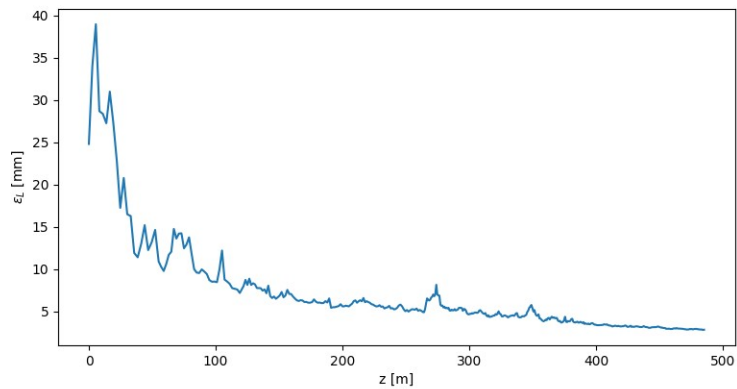
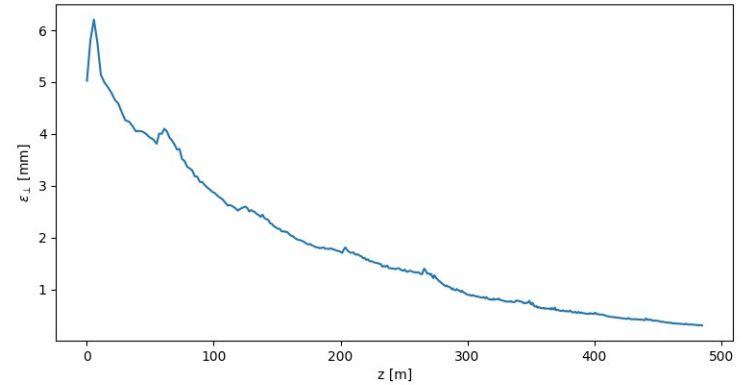
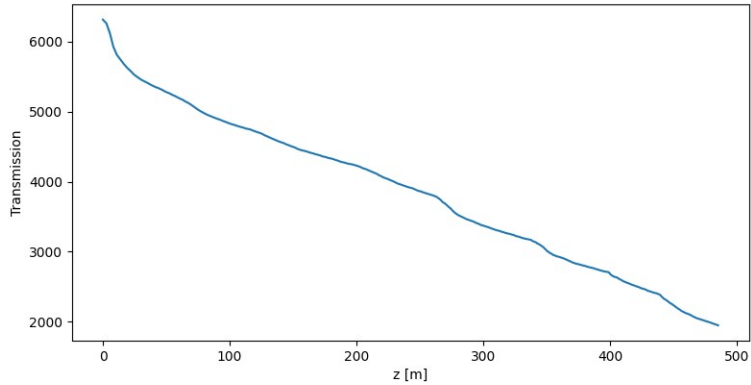
# Rectilinear 2



# Rectilinear 2



# Rectilinear 2



# Comments

- Not clear how the HFoFo fits in with this lattice
  - The PRAB paper mentions the HfoFo and charge selection but appears to assume beam comes straight from phase rotator
- Transmission of rectilinear 1 is low – about 30 %
  - Compared to 50 % in PRAB paper
  - Initial mismatch?
- Transmission of rectilinear 2 is high – about 30 %
  - Compared to 20 % in PRAB paper
- From Diktys:
  - “ the files you are using are an older version of the rectilinear channel.



# Zoom in

