A Compact FFAG for Radioisotope Production

D. Bruton

R. Barlow, R. Edgecock, and C.J. Johnstone

David.Bruton@hud.ac.uk

Contents

- Therapeutic Radioisotopes
- What is an FFAG?
- Overview of the design
- Machine characterisation
- Space charge studies
- Extraction and Target

Therapeutic Radioisotopes

- Majority of UK medicinal radioisotopes are produced abroad
- Produced by reactors
- Supply has been disrupted in the past
- Many potentially useful isotopes can not be produced by reactors
  - ^{211}At, ^{67}Cu, ^{47}Sc, ^{161}Tb all need α's for production

Current cyclotron produced isotopes	
Isotope	Use
^{11}C, ^{13}N, ^{15}O, ^{18}F	PET
^{57}Co	Marker
^{67}Cu	Therapy (Beta)
^{67}Ga/^{68}Ga	Tumour imaging/PET
^{111}In	Tracer
^{123}I	Thyroid imaging
^{81m}Kr	Pulmonary imaging
^{201}Ti	Cardio imaging

David.Bruton@hud.ac.uk

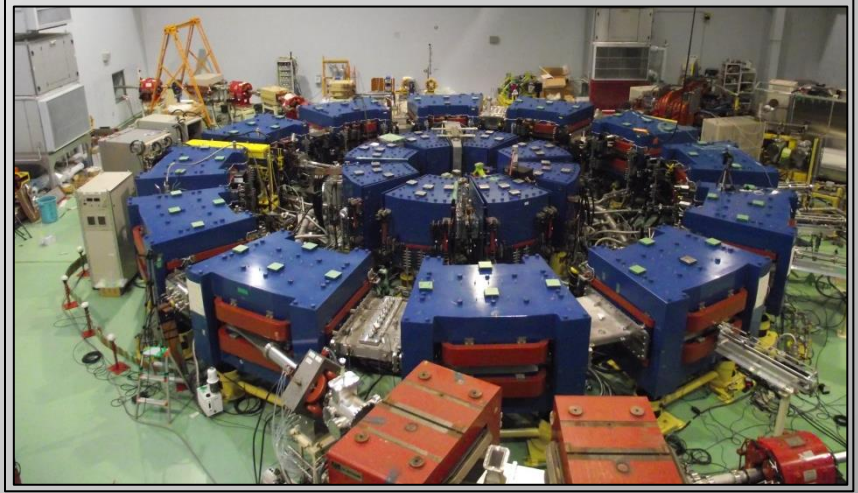
What is an FFAG?

- Fixed fields, like a cyclotron.
- Alternating gradient focusing, like a synchrotron.
- Scaling: Beam dynamics identical at all energies, Pulsed with variable RF.
- Non-Scaling: Continuous wave with fixed RF, Beam dynamics vary across energy range, tune crossing.

Some Examples

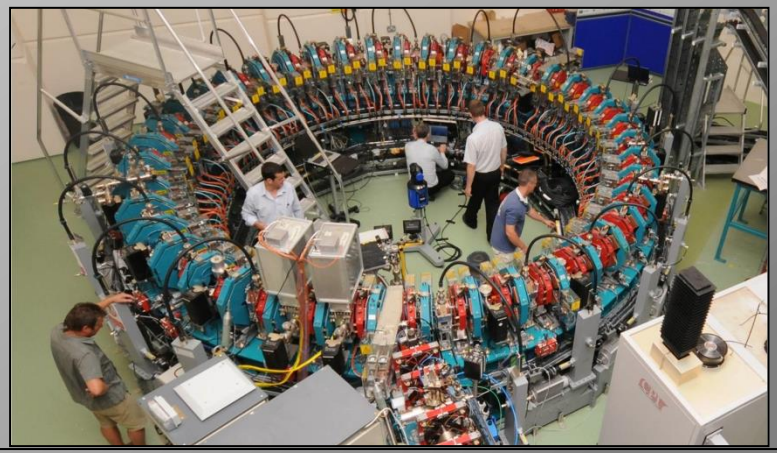
Scaling

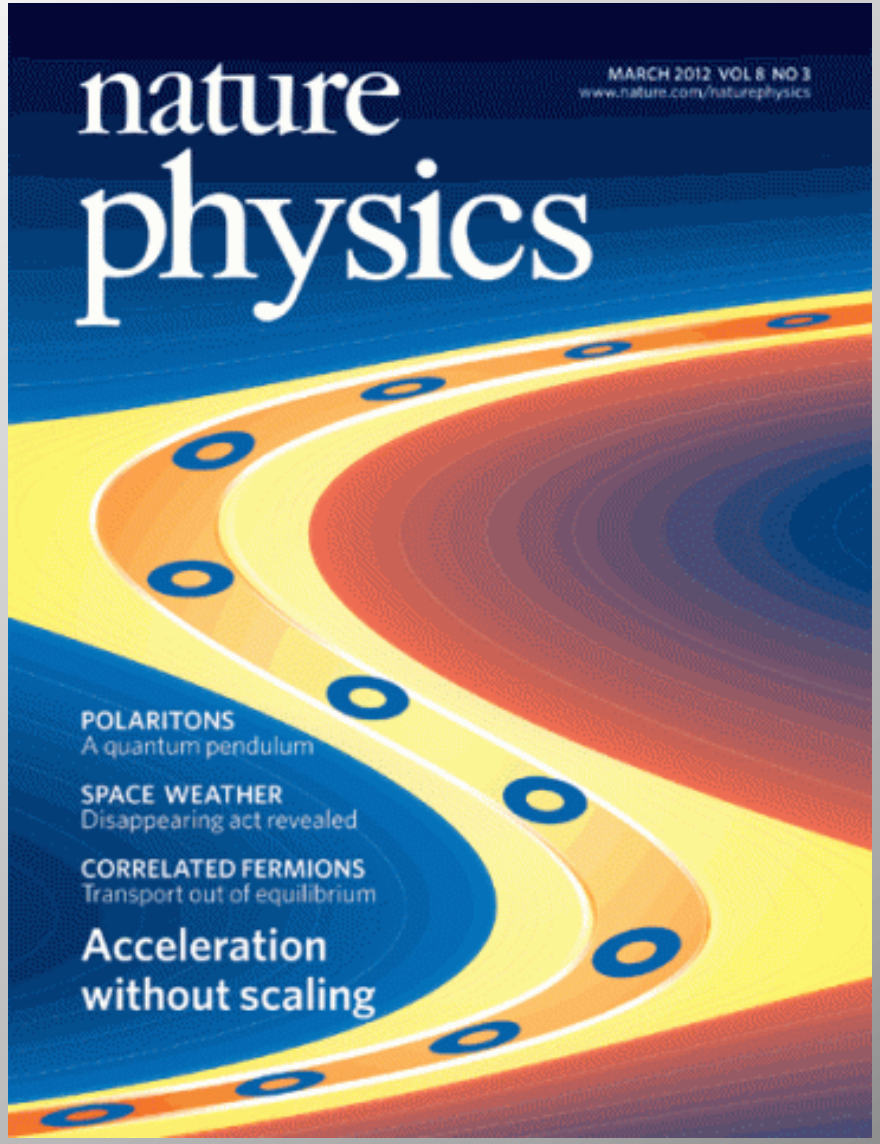
- KURRI main ring
- Protons
- 11-150 MeV
- For ADSR research



Non-Scaling

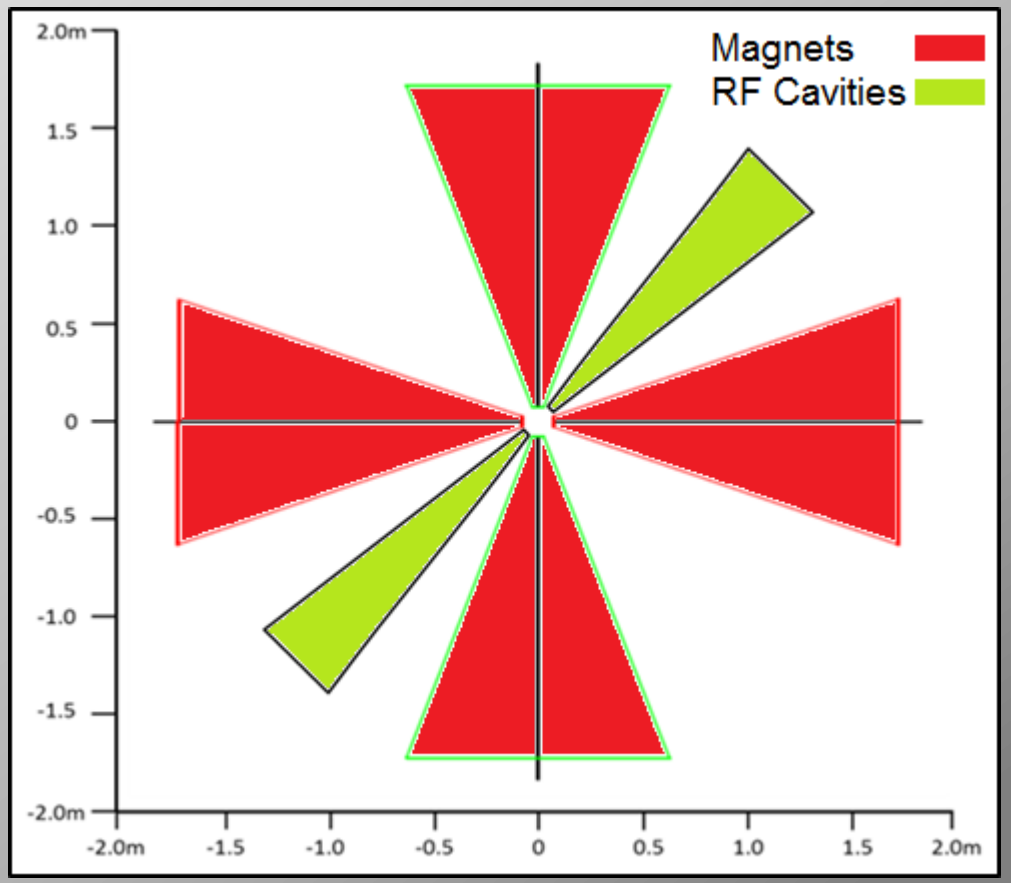
- EMMA
- Electrons
- 10-20 MeV
- Proof-of-principle for NS-FFAGs




nature physics
MARCH 2012 VOL 8 NO 3
www.nature.com/naturephysics
POLARITONS
A quantum pendulum
SPACE WEATHER
Disappearing act revealed
CORRELATED FERMIONS
Transport out of equilibrium
Acceleration without scaling

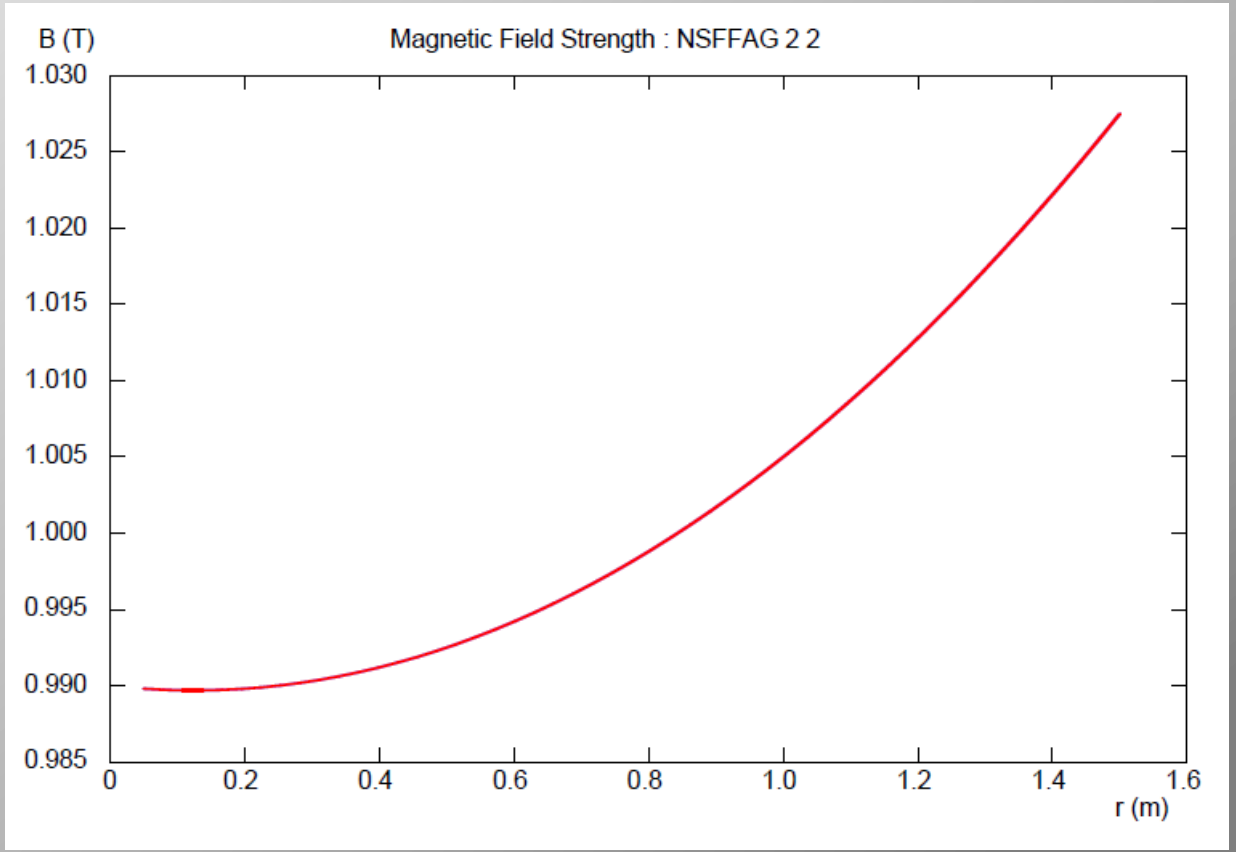
Machine Overview

- Small cyclotron type proton FFAG
- Non-Scaling and non-linear
- 4 Separate sector magnets
- 2 RF Cavities



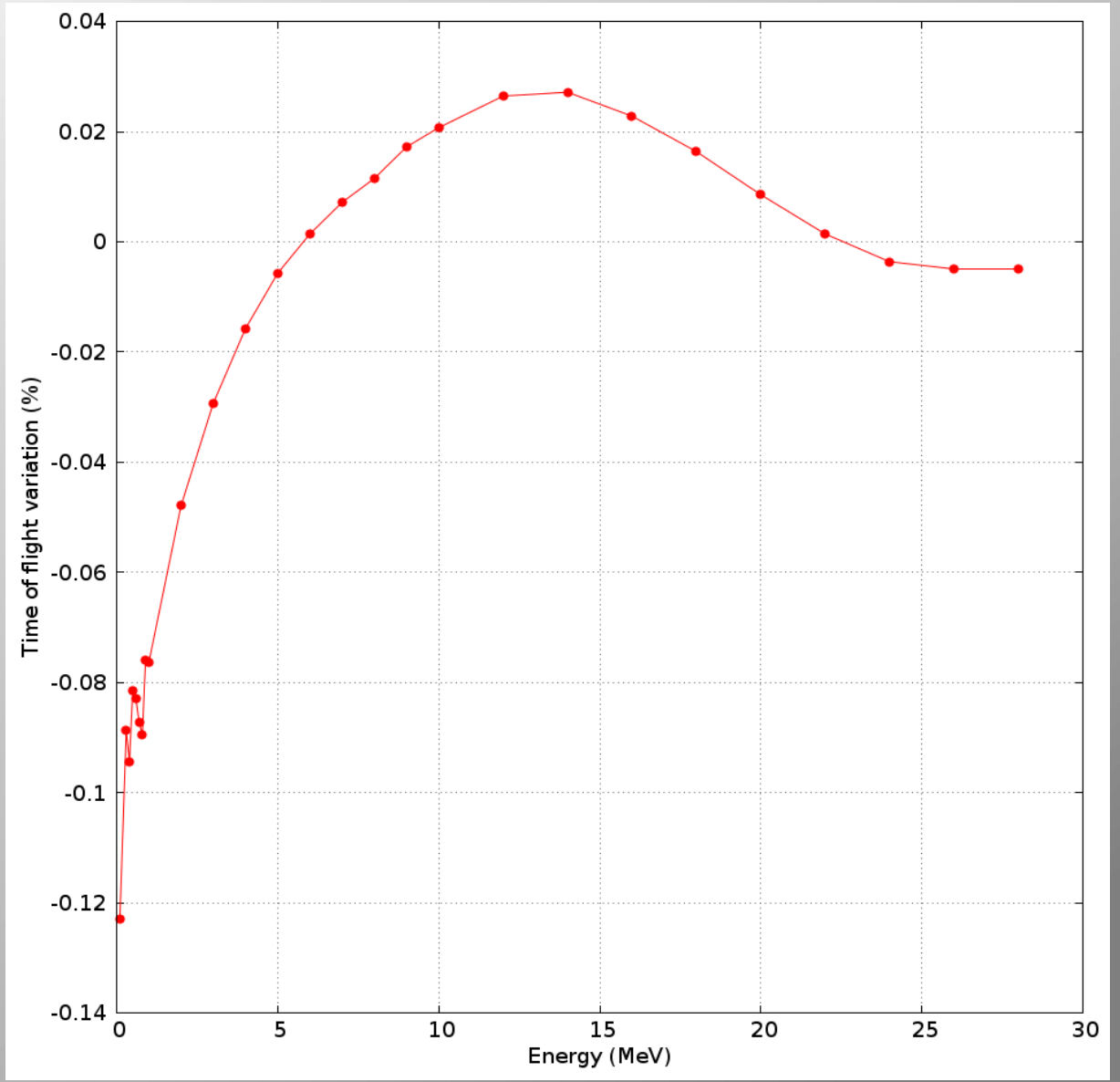
- Three sources of beam focusing:
  - Gradient Focusing
  - Weak Focusing
  - Edge Focusing

- Radially varying magnetic field provides focusing in the horizontal plane

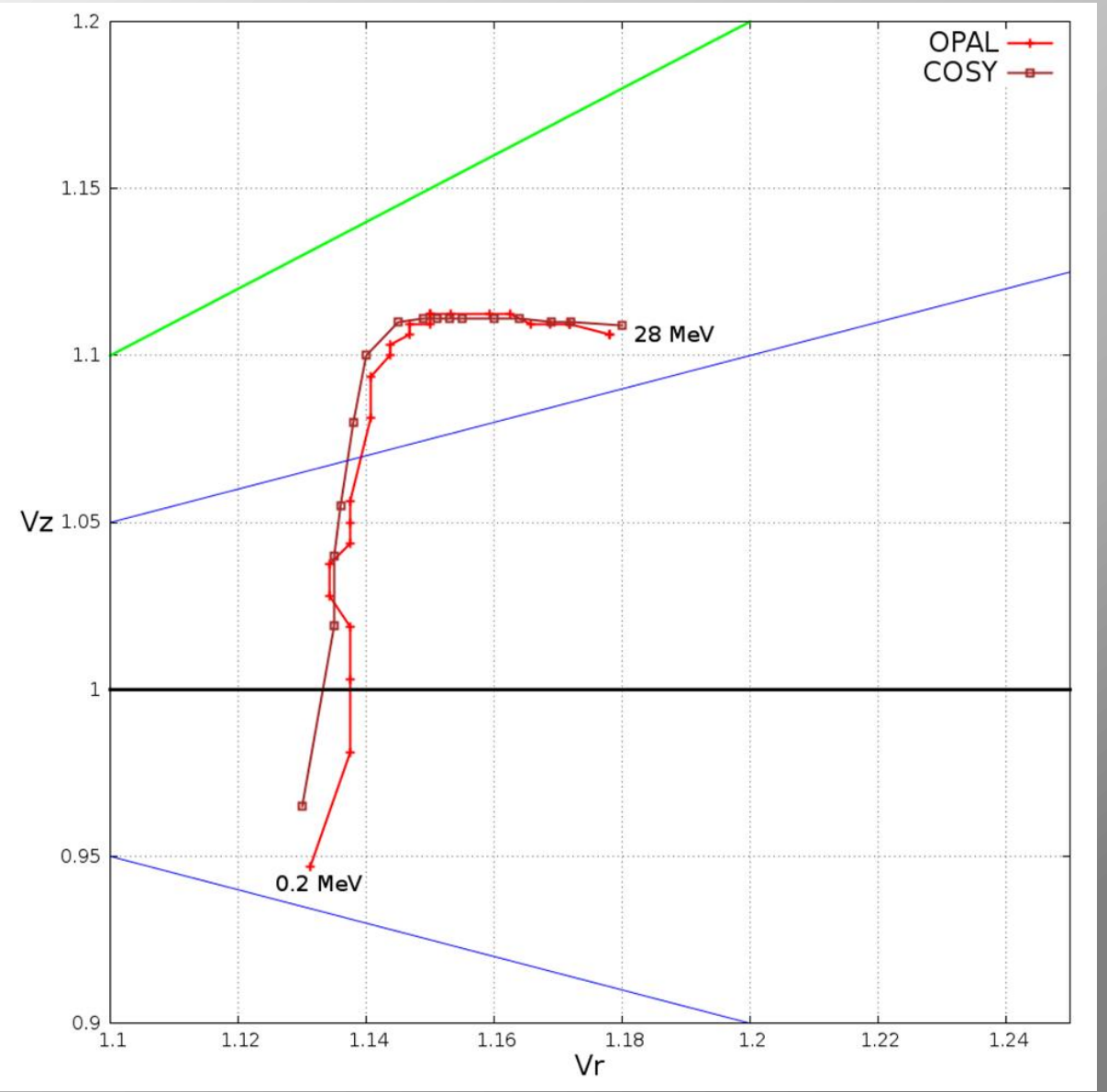


Magnet geometry optimised with field gradient to create isochronous machine

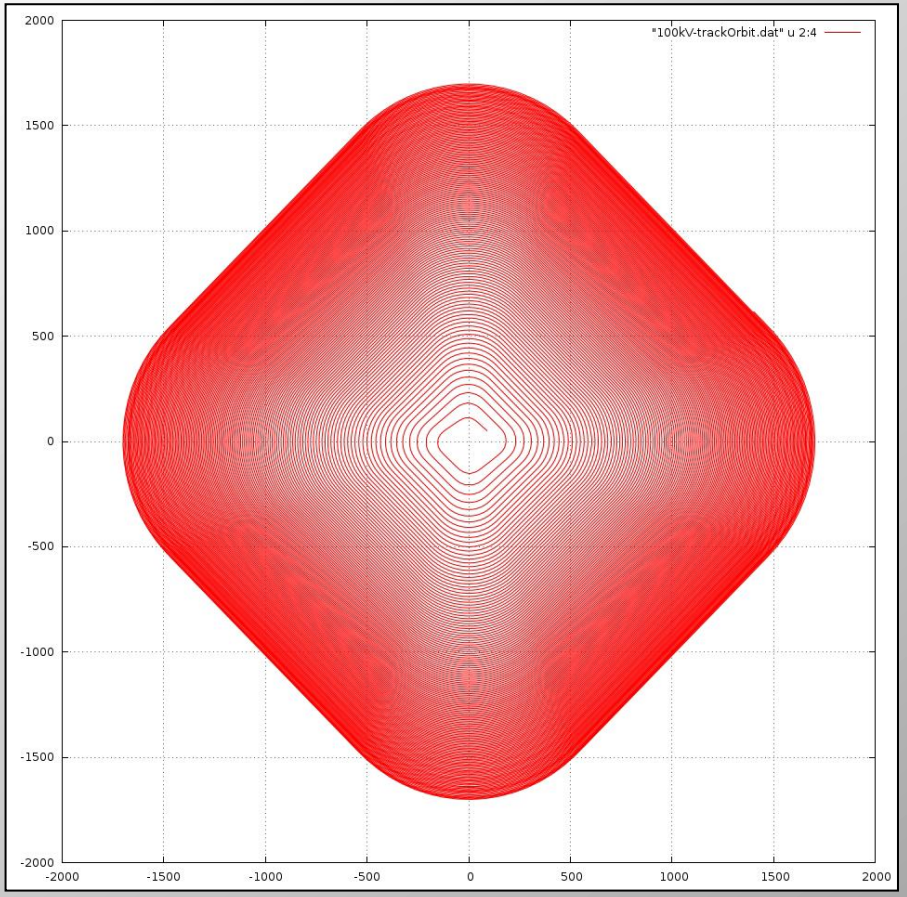
Time of flight variation less than 0.2%

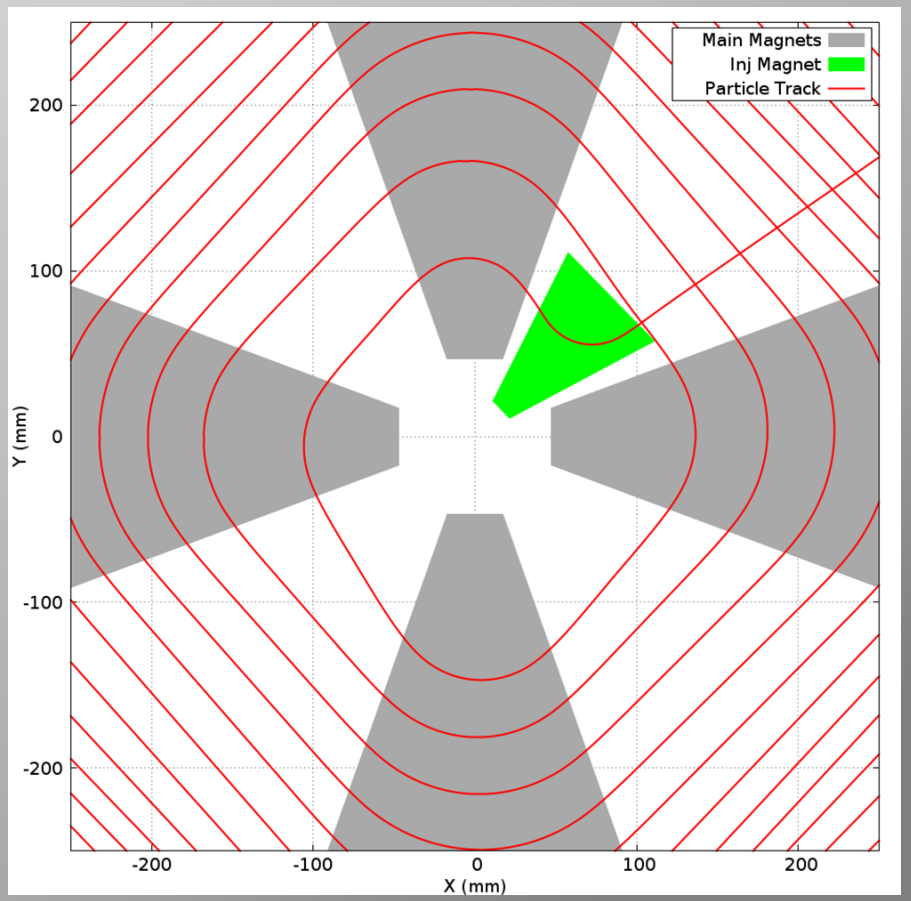


- Injection at 75keV, r=100mm
- Extraction at 28MeV, r=1692mm
- Vertical Tune crosses resonances at low energy



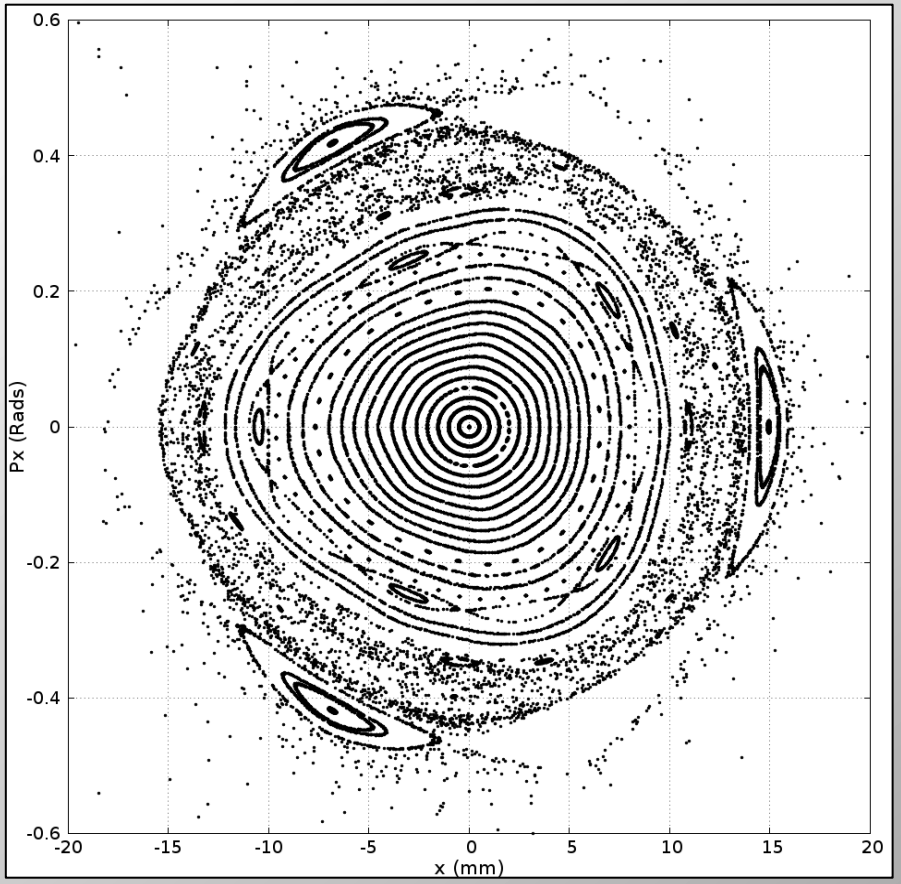
- 144 turns to reach 28MeV with 200kV per turn
- Injection by spiral inflector, Or perhaps radially?

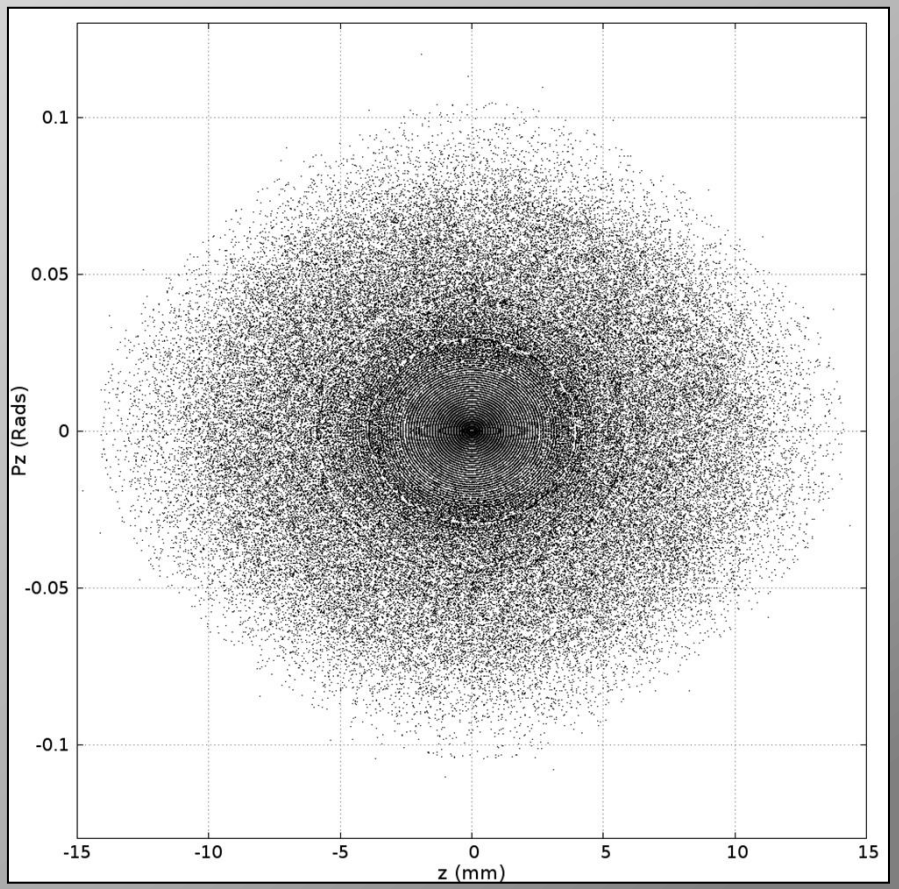




Dynamic Aperture

0.075 MeV



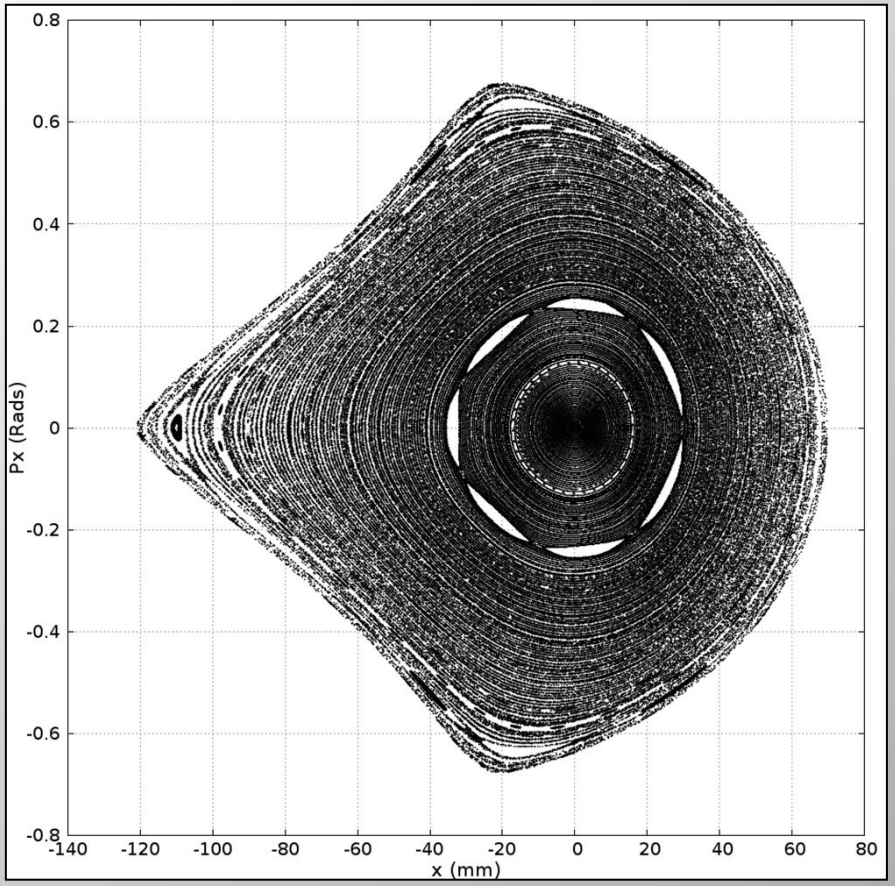


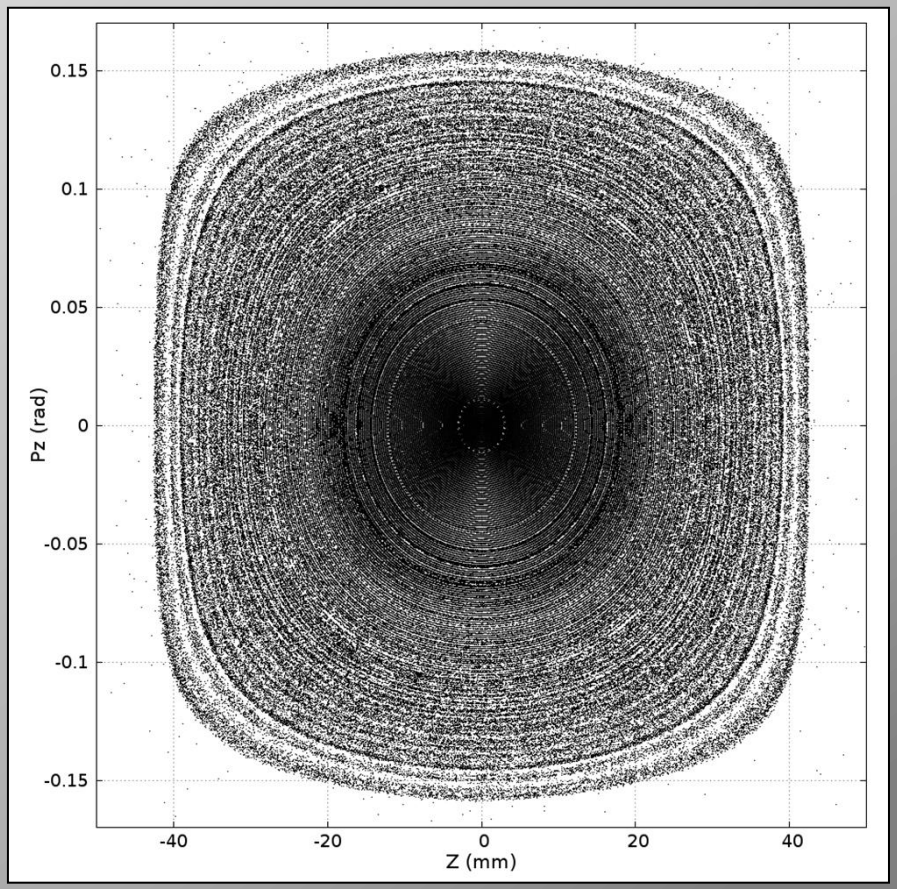
Horizontal 6.3 π*m*mrad

Vertical 1.4 π*m*mrad

Dynamic Aperture

1 MeV

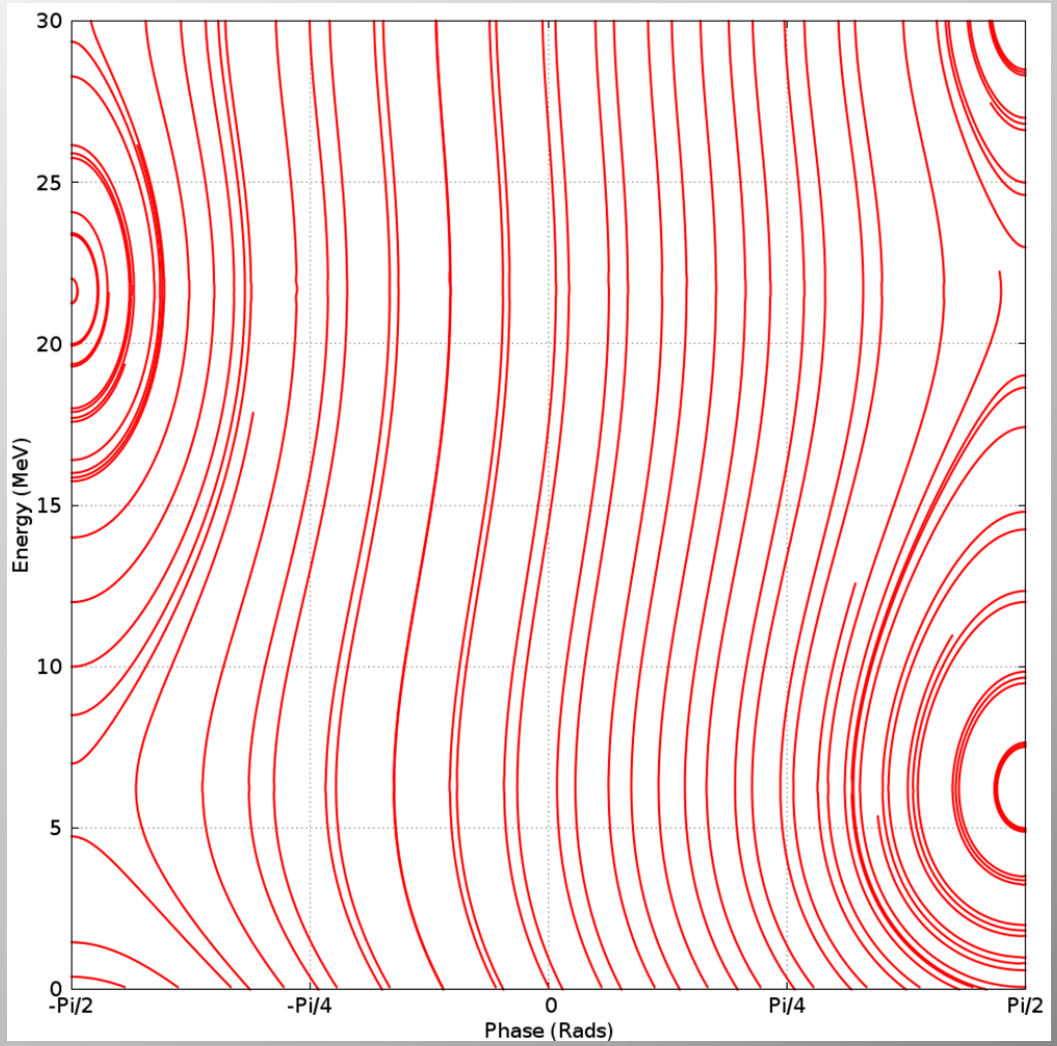


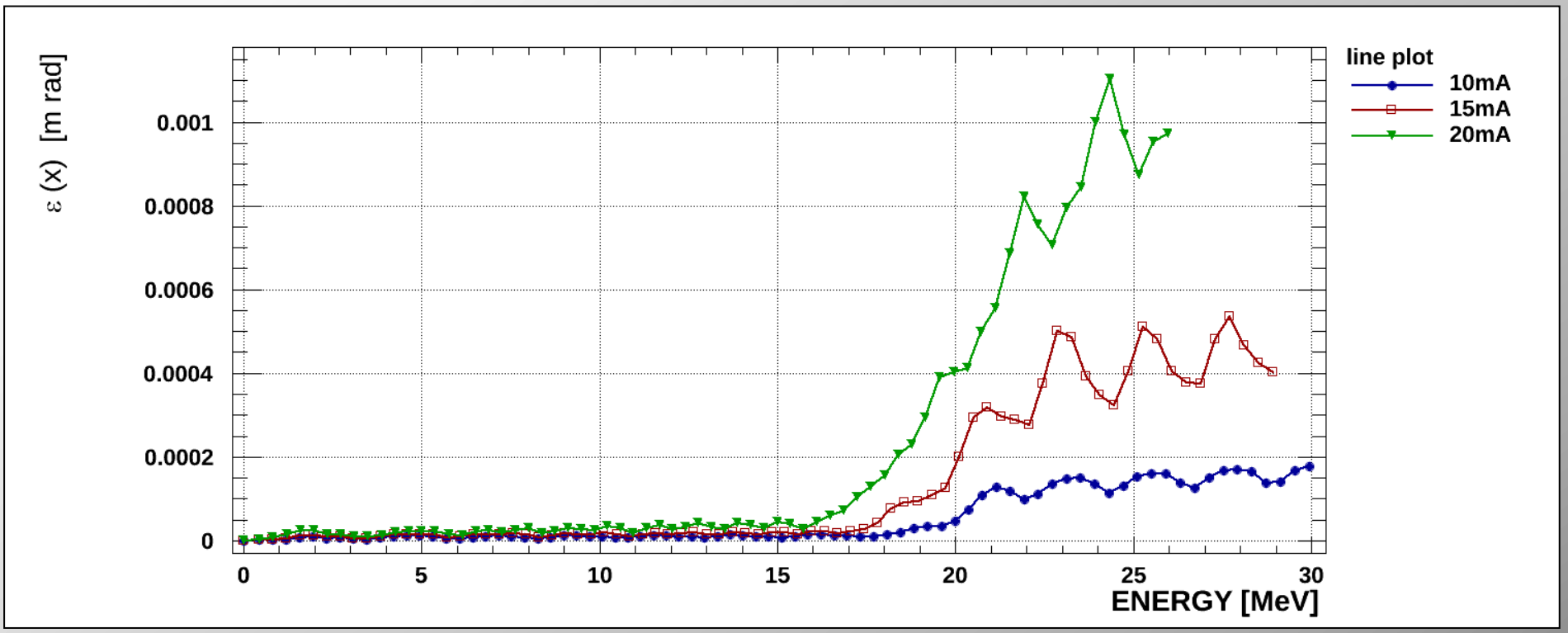


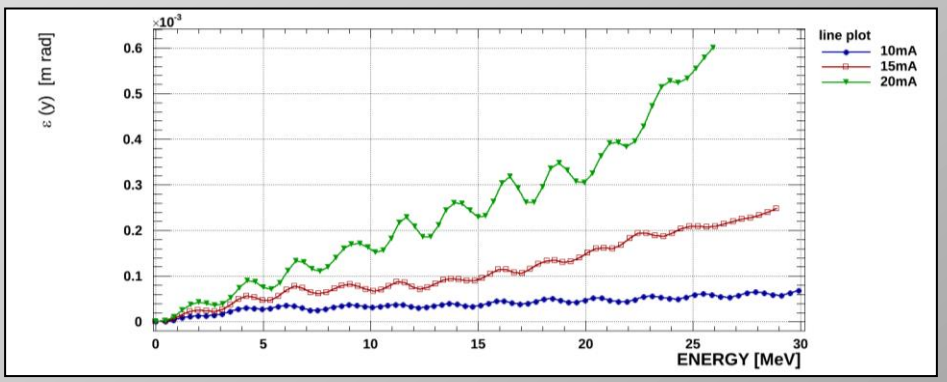
Horizontal 42.7 π*m*mrad

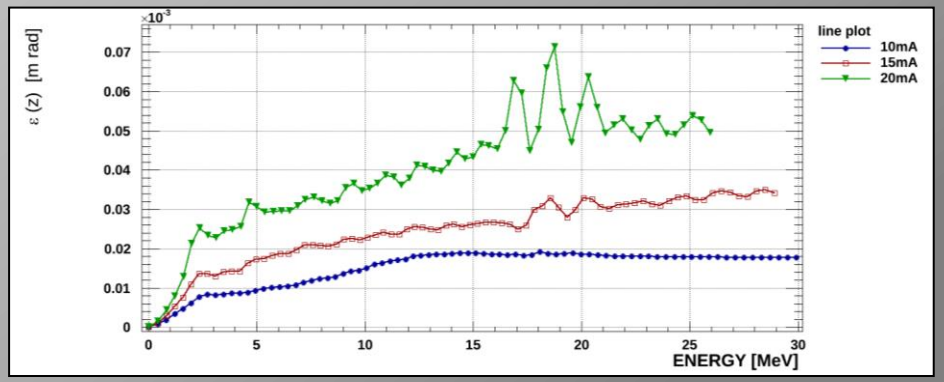
Vertical 1.5 π*m*mrad

RF Phase

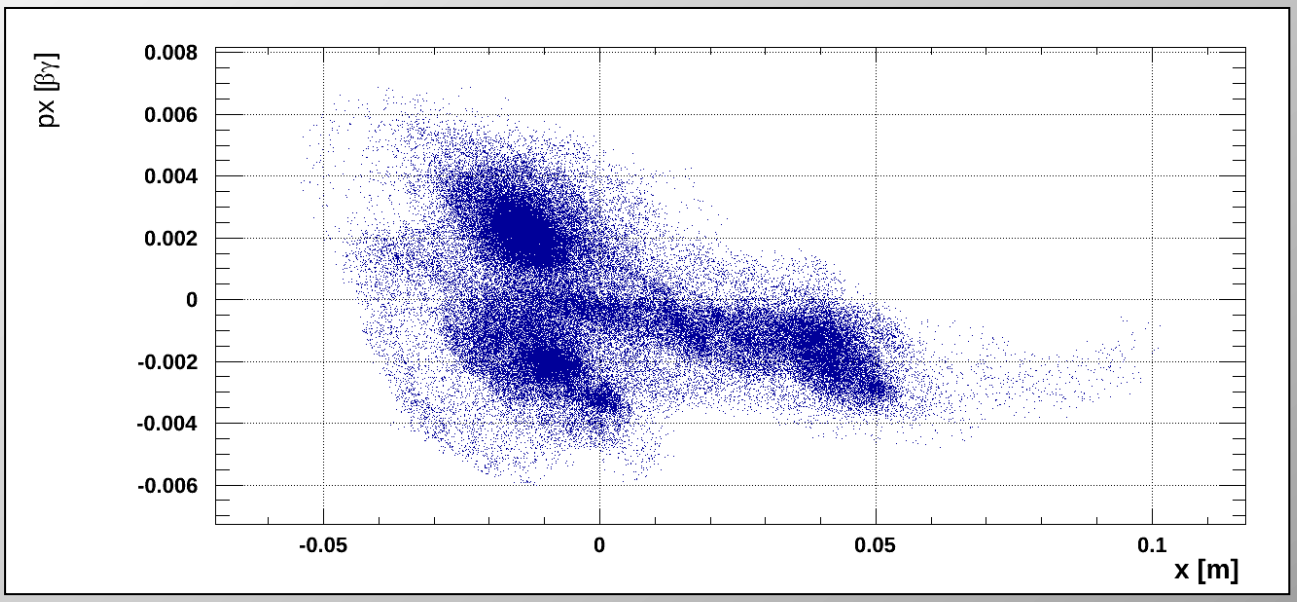



ε (x) [m rad]
0.001
0.0008
0.0006
0.0004
0.0002
0
0
5
10
15
20
25
30
ENERGY [MeV]
line plot
10mA
15mA
20mA

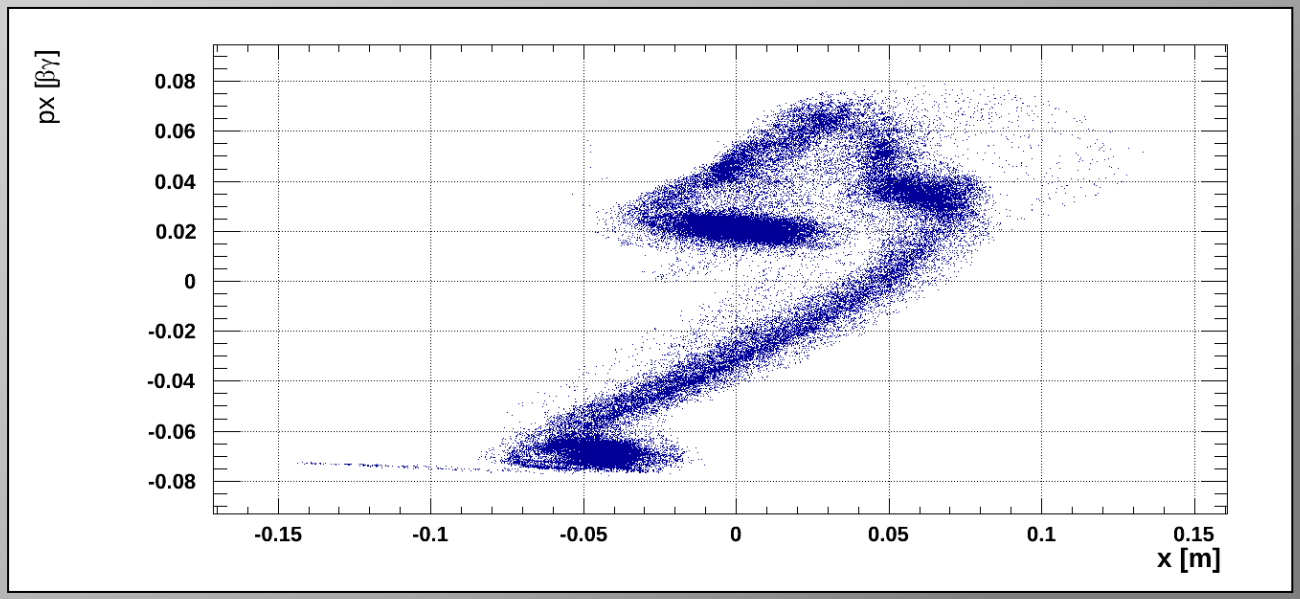

ε (y) [m rad]
×10⁻³
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
ENERGY [MeV]
line plot
10mA
15mA
20mA


ε (z) [m rad]
×10⁻³
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
5
10
15
20
25
30
ENERGY [MeV]
line plot
10mA
15mA
20mA

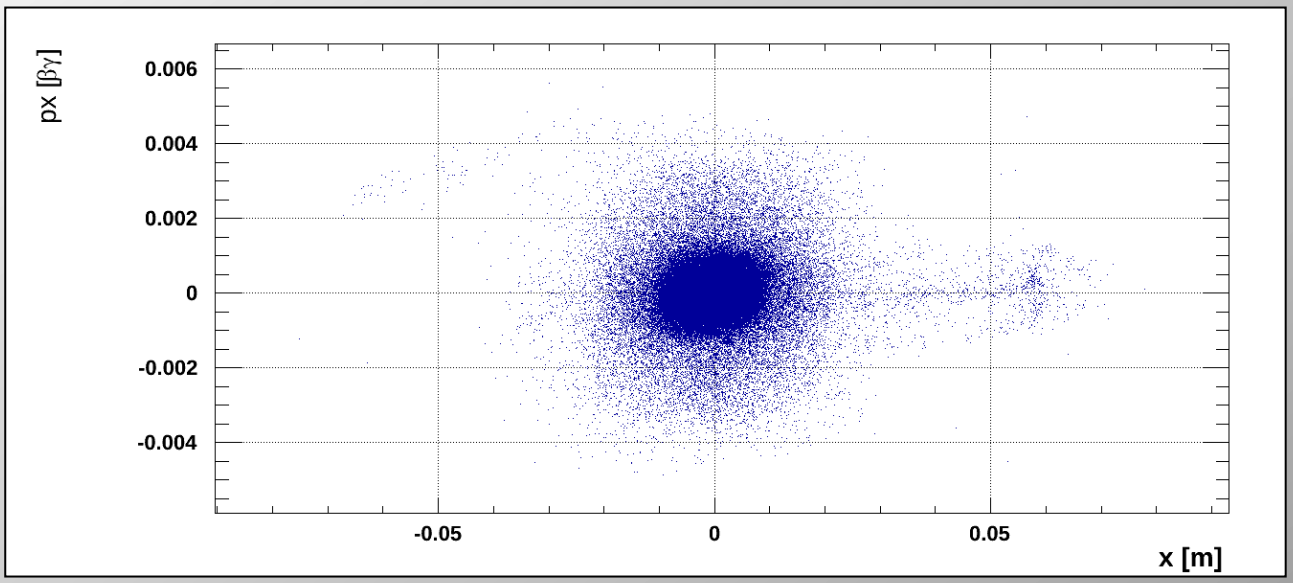
14MeV


px [βγ]
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.05
0
0.05
0.1
x [m]

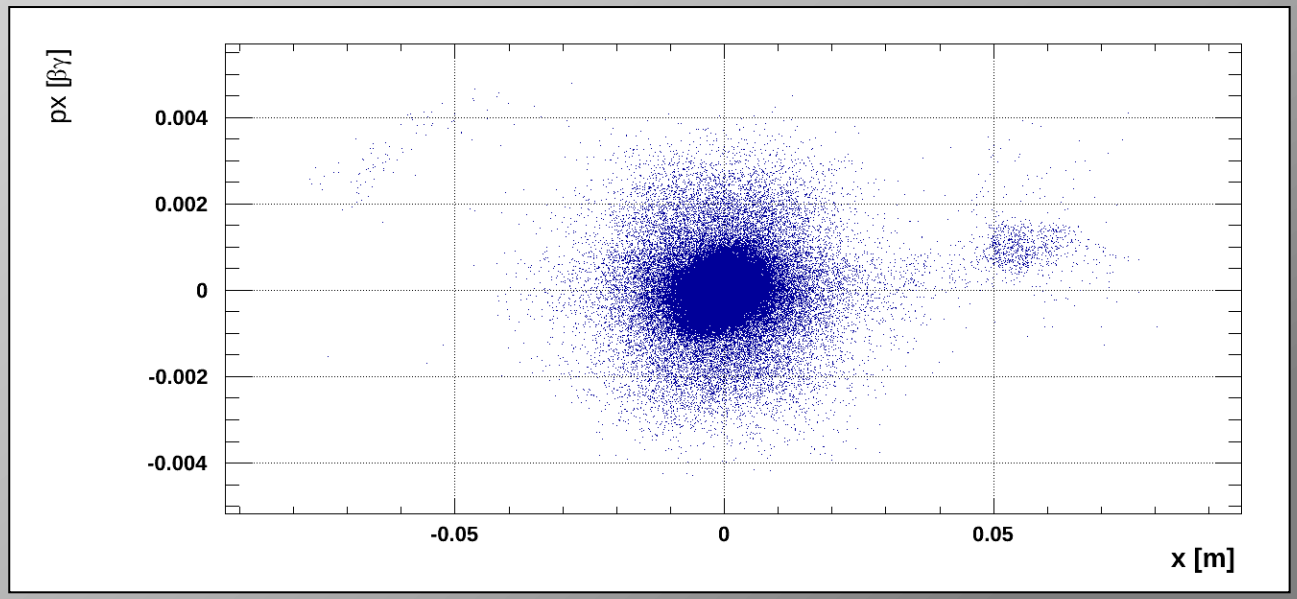
24MeV

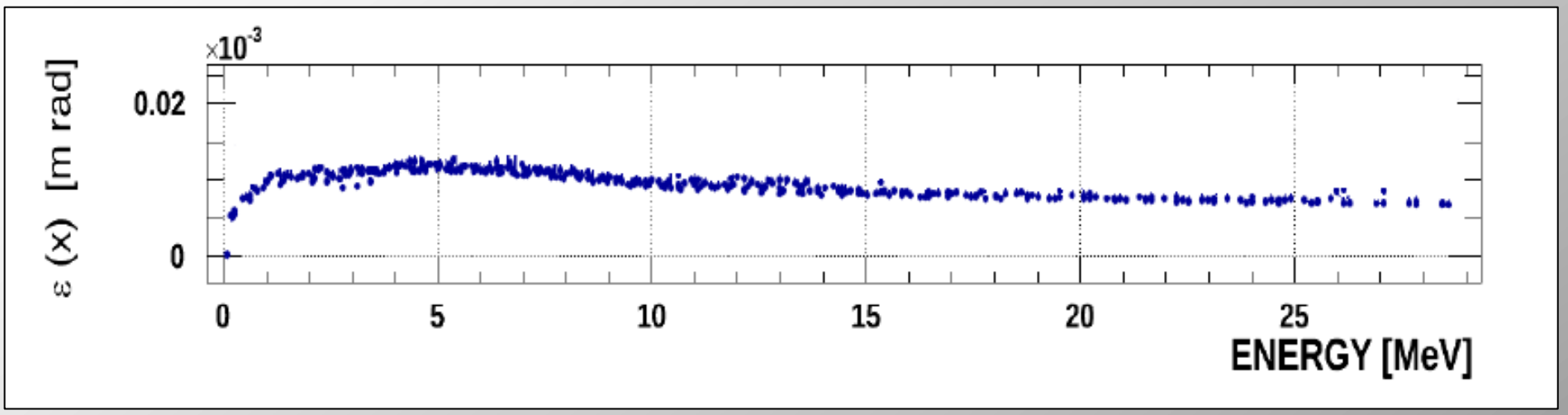

px [βγ]
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
x [m]

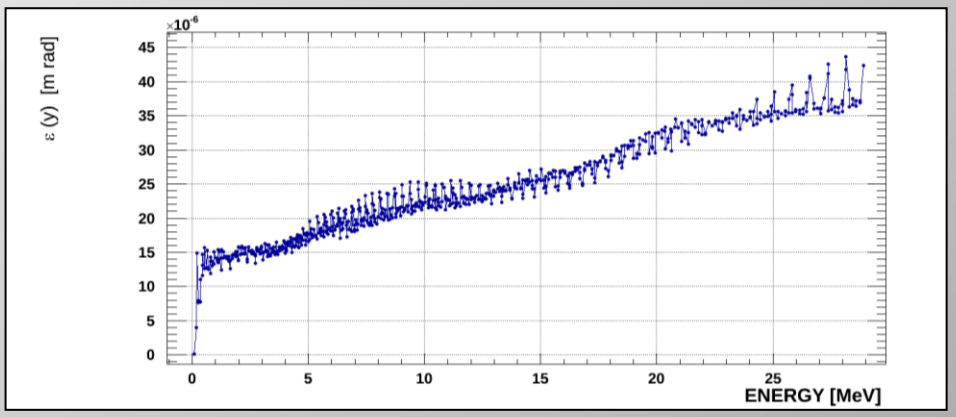
14MeV

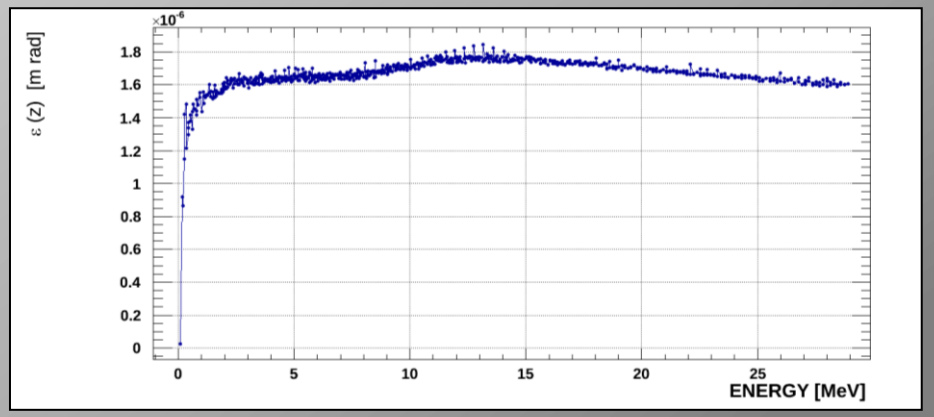

px [βγ]
0.006
0.004
0.002
0
-0.002
-0.004
-0.05
0
0.05
x [m]

24MeV

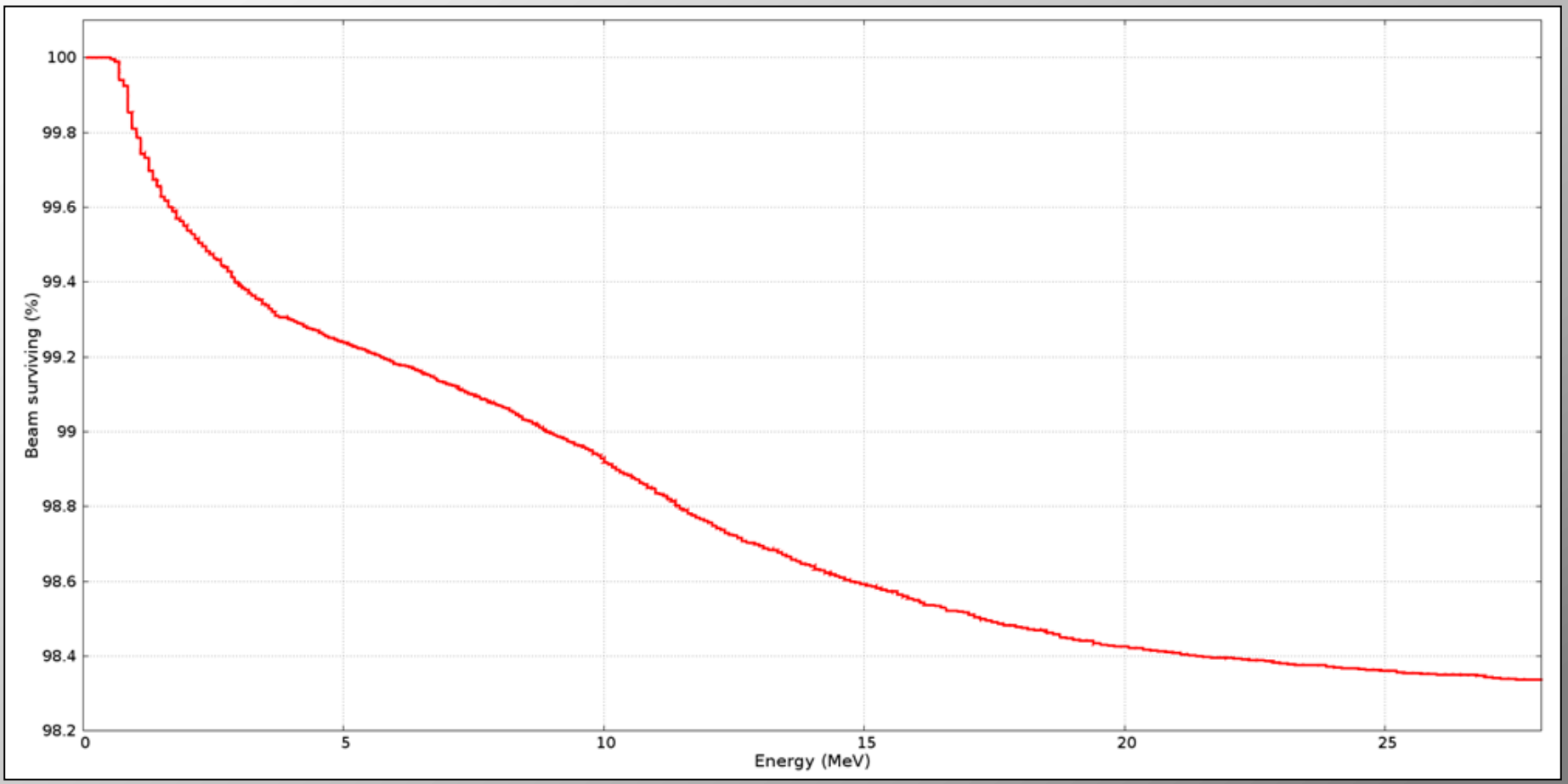

px [βγ]
0.004
0.002
0
-0.002
-0.004
-0.05
0
0.05
x [m]


ε (x) [m rad]
×10^-3
0.02
0
0
5
10
15
20
25
ENERGY [MeV]

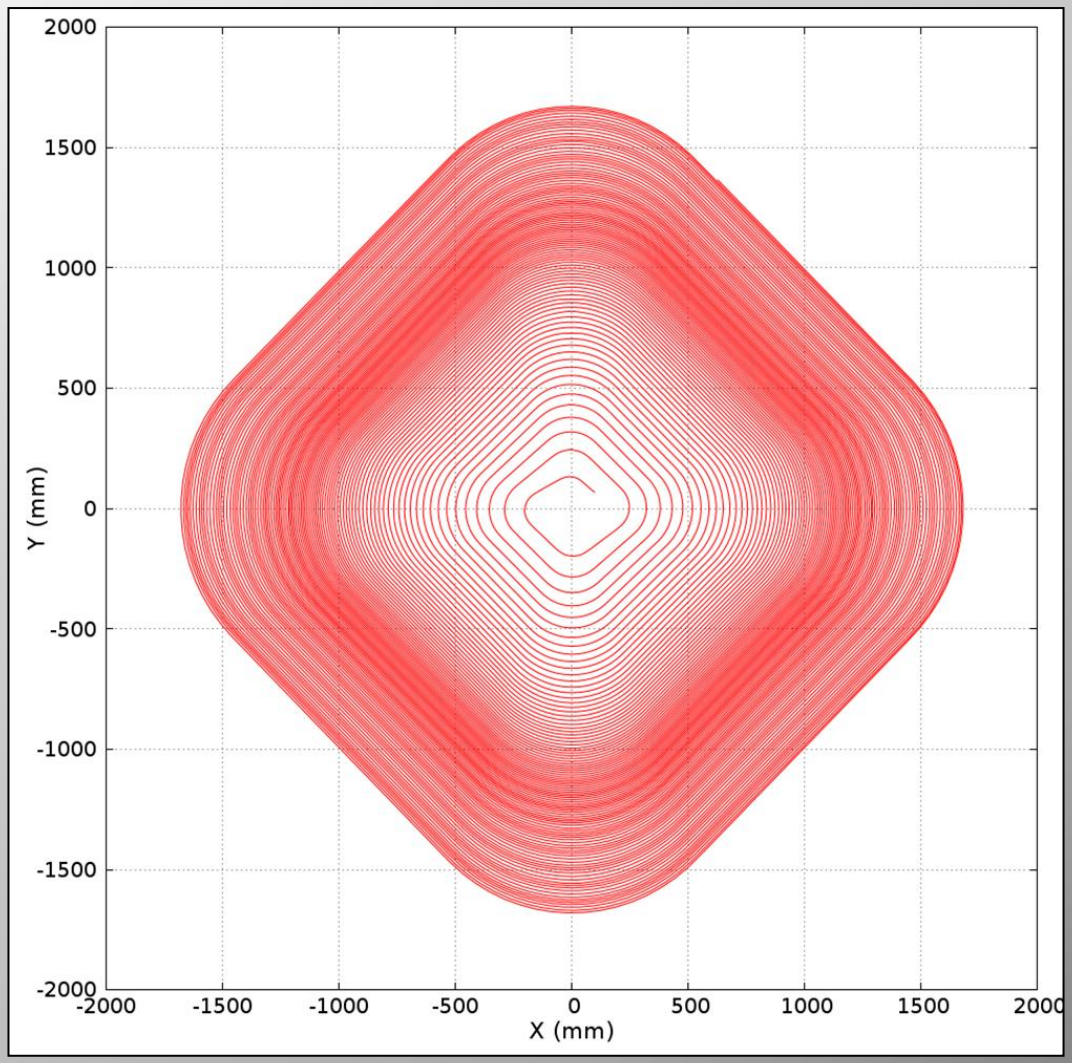

ε (y) [m rad]
×10^-6
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
ENERGY [MeV]


ε (z) [m rad]
×10^-6
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
ENERGY [MeV]

Transmission

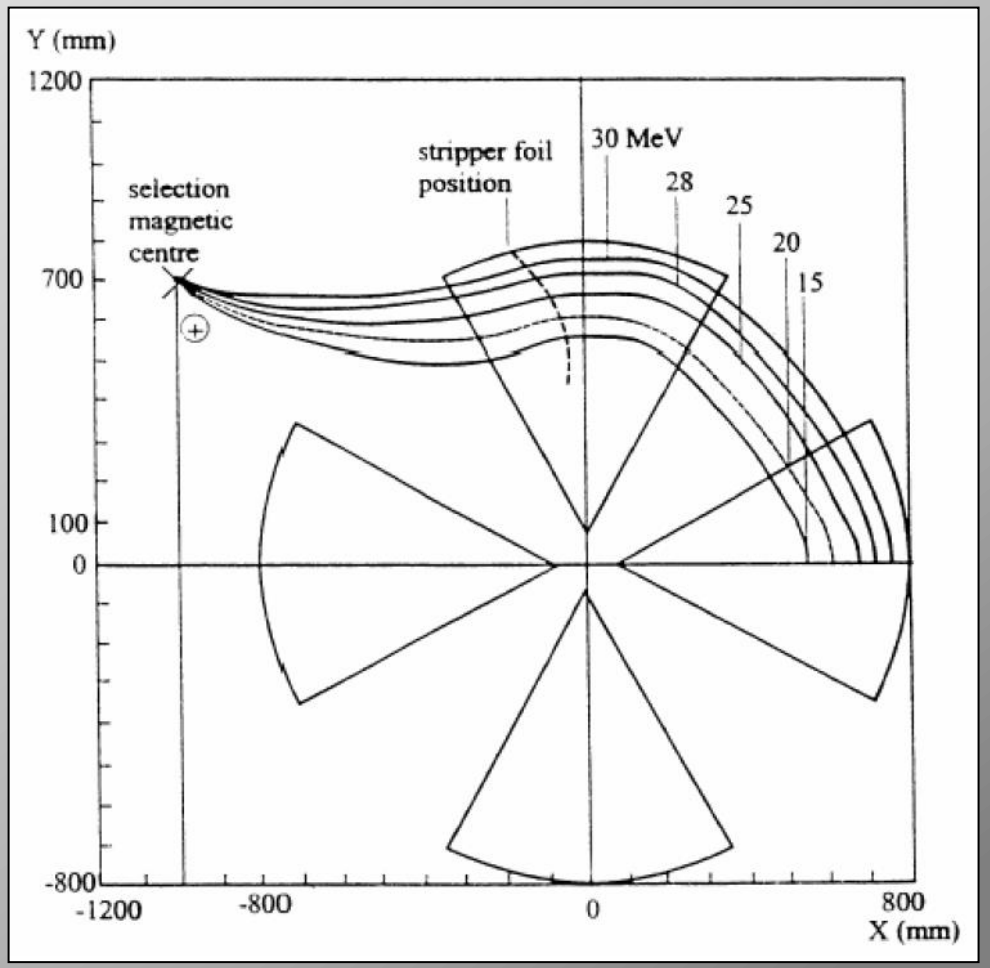


He^{2+} Acceleration



Extraction

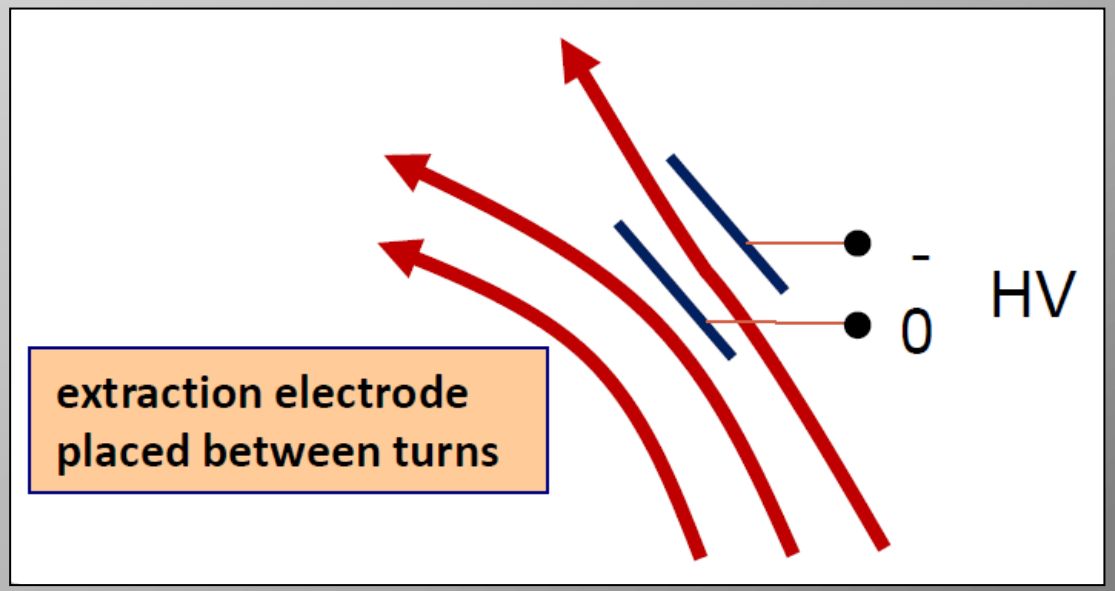
- Charge Exchange
  - Run H^- ions
  - Simple design
  - Variable energy
  - Commonly used in cyclotrons
  - Not possible for He^{2+}



[1] W. Kleeven, Injection and extraction for cyclotrons

Extraction

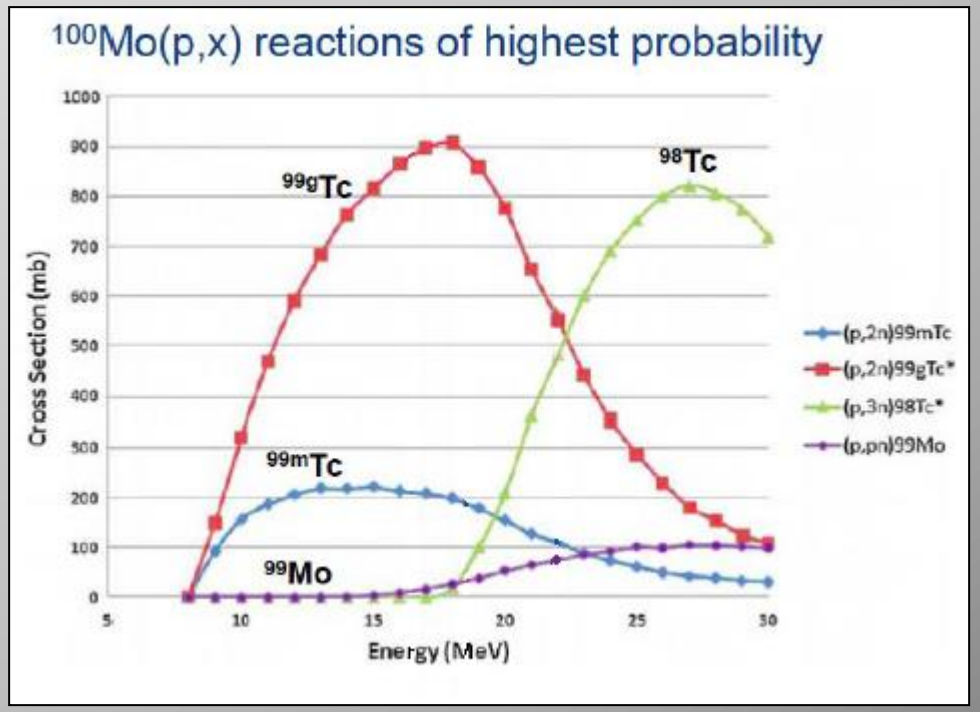
- Electrostatic Deflector
  - Two DC electrodes bend the final orbit out of the machine
  - Needs large orbit separation at
  - extraction
  - Heat loss on septum limiting factor on current

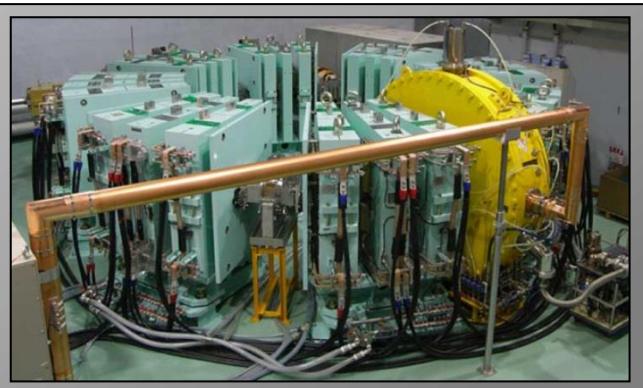


[2] M.Seidel, Cyclotrons for high intensity beams

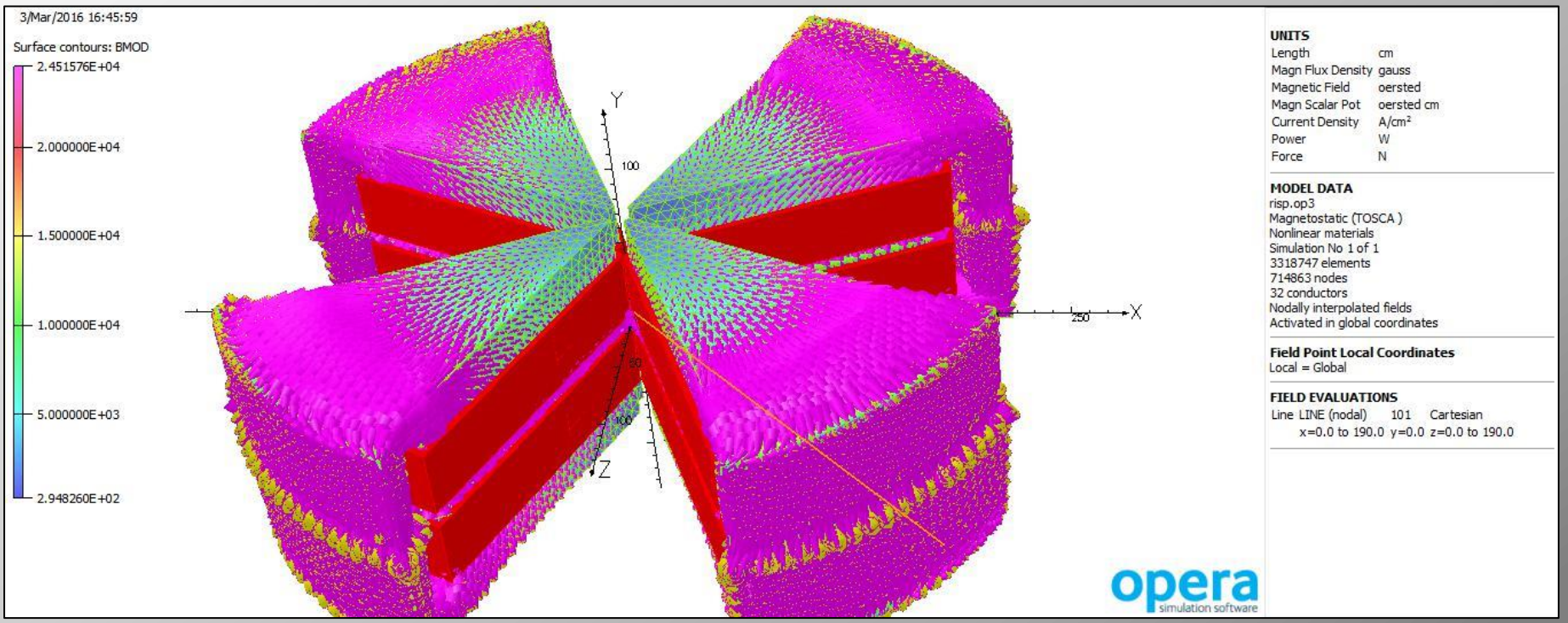
Internal Target

- Reaction cross-sections are energy dependent
- In a thick target many proton wont react before dE/dX moves them away from peak
- To increase efficiency use an internal target and recycle the beam
- Demonstrated by ERIT for neutron production





Magnet Design



Summary

- Non-Scaling proton FFAG for radioisotope production
- Flexible
  - can accelerate protons or He^{2+}
  - Potentially variable energy
- High current (20mA)
- Beam recycling could improve production rates
- We want to build it!