Capture

International
MUON Collider
Collaboration

C. T. Rogers
Rutherford Appleton Laboratory

Science & Technology Facilities Council
ISIS

DA and cooling optimisation

- Rectilinear cooling design is approaching a release version
  - Thanks to Ruihu!
  - Ruihu's design now frozen → publication
- Major beam loss at entrance to the cooling system
  - Associated with aperture at 352 MHz
  - Investigate 176 MHz instead
    - Half frequency → double the aperture!
- Can we capture at 176 MHz?
  - Update to the front end…
  - Also of interest to look at few other front end optimisations
- Reminder: challenge is to improve muon production by x2

THE RABBIT HOLE

Urban Dictionary:

Rabbit Hole. Metaphor for the conceptual path which is thought to lead to the true nature of reality. Infinitesimally deep and complex, venturing too far down is probably not that great of an idea.

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Studies

- Various optimisations/studies:
  - Taper length at target
  - Time structure of beam
  - Energy acceptance of longitudinal capture system
  - General optimisation of longitudinal capture system
- Simulations in Geant4v11.1.1
  - Probably sub-optimal, but convenient
  - Using a modified version of G4BL
- Optimisation is incomplete
  - This is a status update
- See also

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **17,** 070102 (2014)

Optimized capture section for a muon accelerator front end

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Brookhaven National Laboratory, Upton, New York 11973, USA
(Received 24 April 2014; published 28 July 2014)

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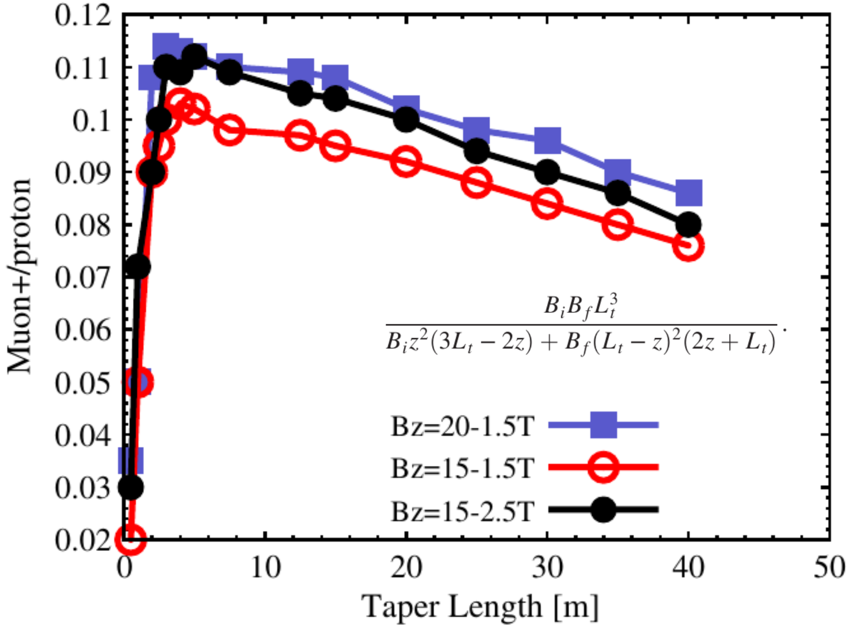
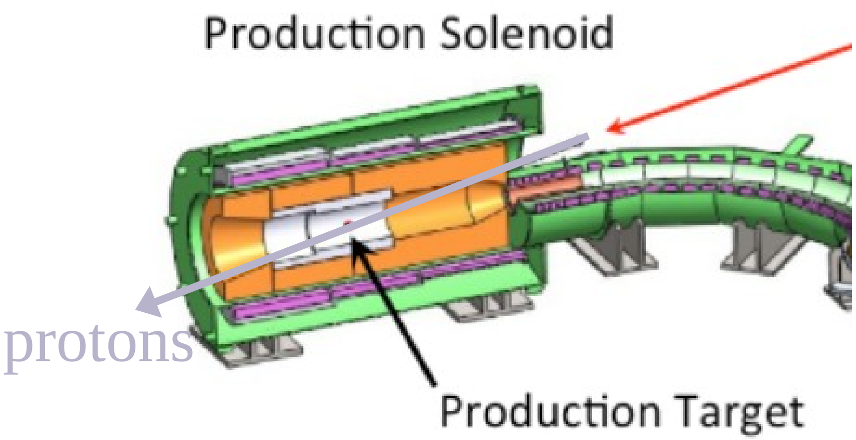
Taper Length



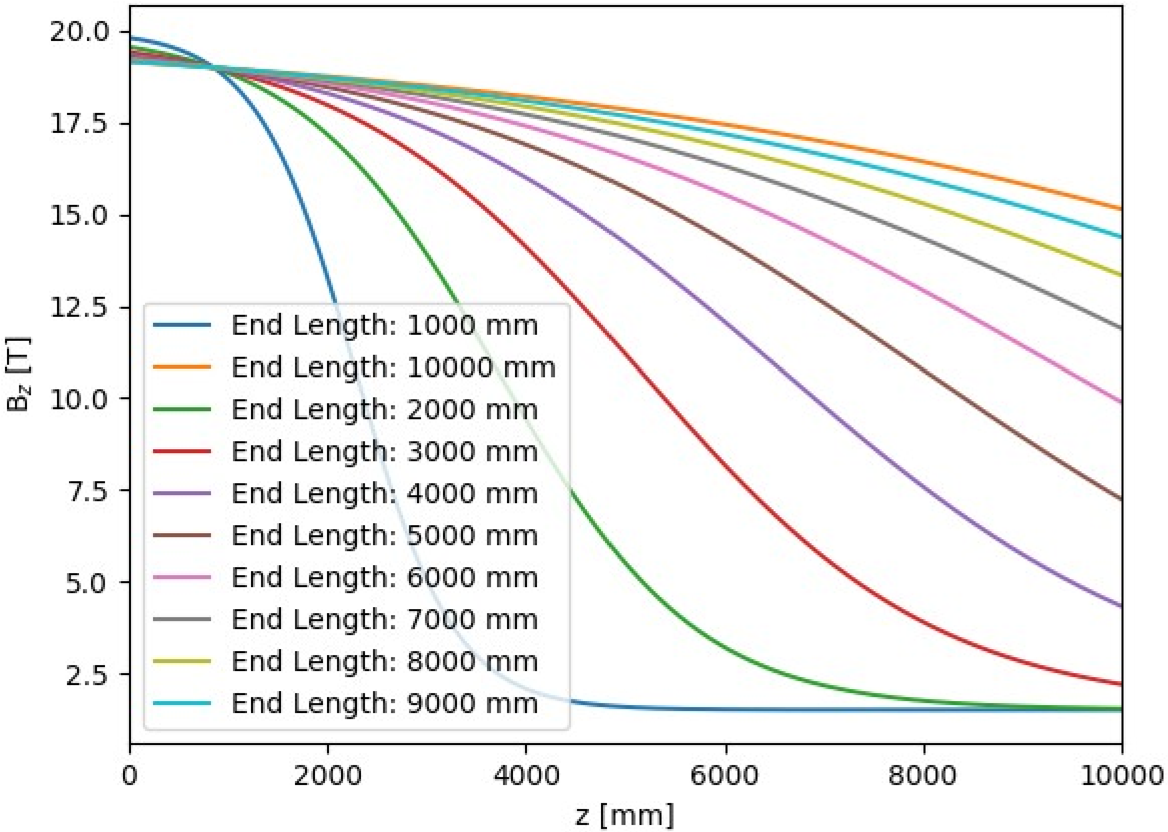


- Shorter taper
  - Makes the target solenoid simpler
    - More reliable, cheaper
  - Probably helps with extraction of the spent proton beam
  - What about pion yield?
- Sayed & Berg suggest taper of 5-6 metres is good
- IMCC baseline has much longer taper

Taper Model

- Use a different model for the taper
  - Set B_0 = 20 T
  - Vary L
  - Set x_0 so that B = 19 T at end of the target (80 cm)

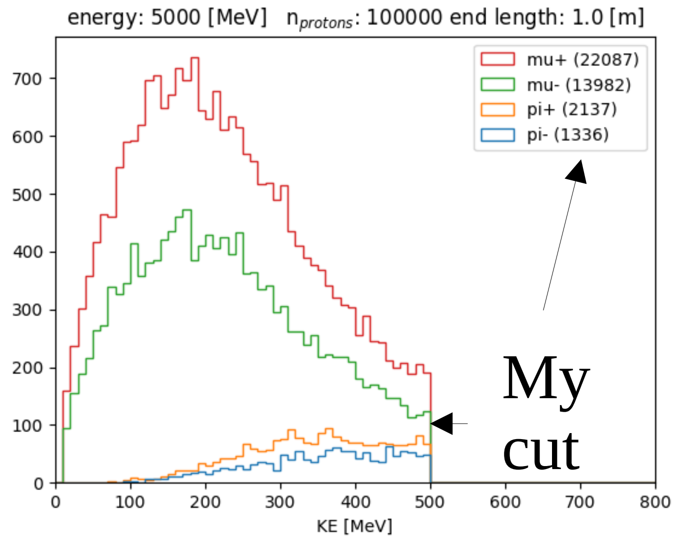
$$\frac{b_0\left(1-\tanh\left(\frac{(x-x_0)}{L}\right)\right)}{2}$$

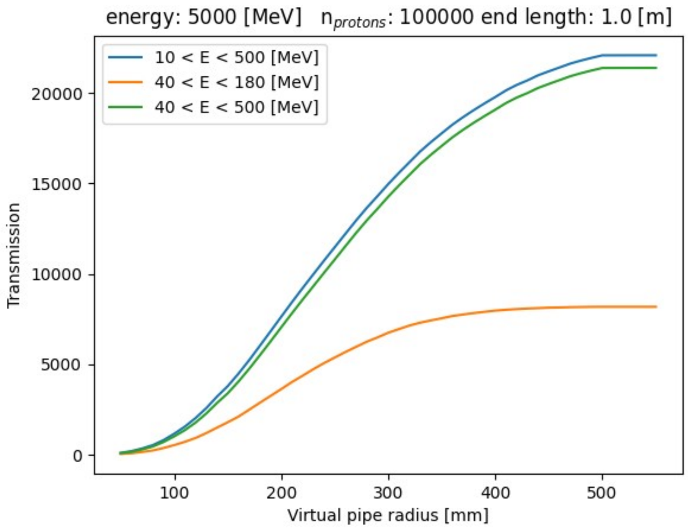


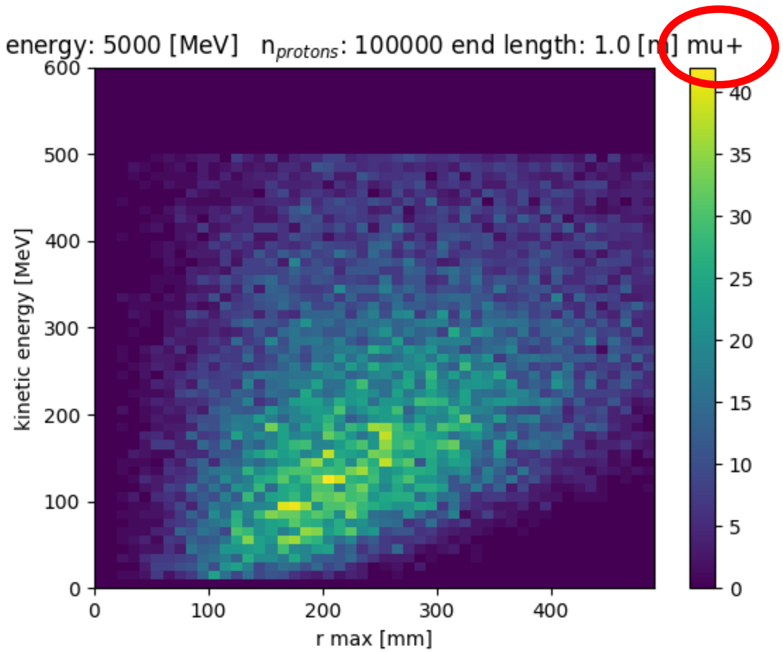
Other things

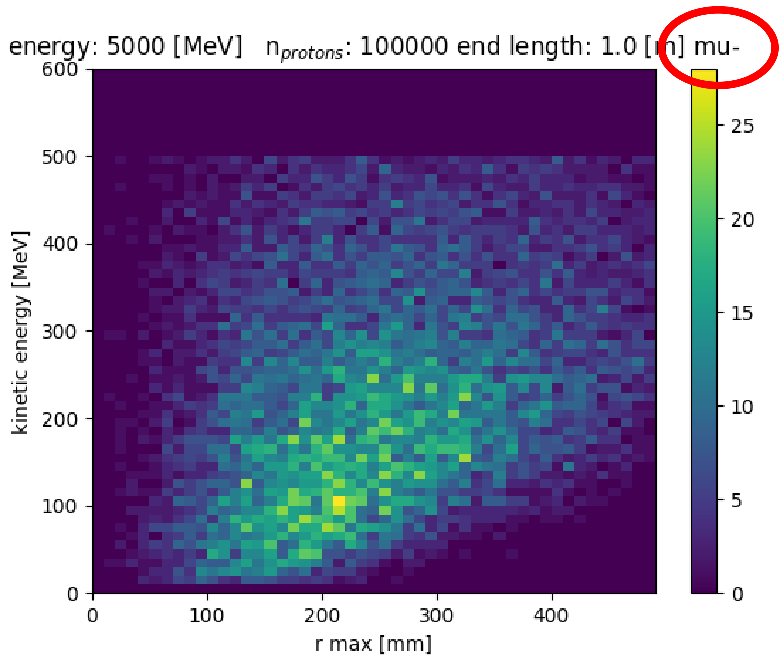
- Other notes
  - Only apertures are a beam pipe aperture at 500 mm
  - No magnet shielding, etc
  - Implement “virtual beam pipe” AKA “r max”
    - Cut on maximum radius of trajectory in uniform B_z
    - Scan beam pipe radius without rerunning tracking simulation
  - Assume target shielding inner radius can be sorted out later
  - Analysis is done at z = 50 m from the target
  - No chicane/proton absorber is included
- In part, I am thinking about the question discussed in the target meeting – what is the correct acceptance cut for the target optimisations

L = 1.0 m, E = 5 GeV


energy: 5000 [MeV] $n_{protons}$: 100000 end length: 1.0 [m]
mu+ (22087)
mu- (13982)
pi+ (2137)
pi- (1336)
KE [MeV]
My cut


energy: 5000 [MeV] $n_{protons}$: 100000 end length: 1.0 [m]
10 < E < 500 [MeV]
40 < E < 180 [MeV]
40 < E < 500 [MeV]
Transmission
Virtual pipe radius [mm]


energy: 5000 [MeV] $n_{protons}$: 100000 end length: 1.0 [m] mu+
kinetic energy [MeV]
r max [mm]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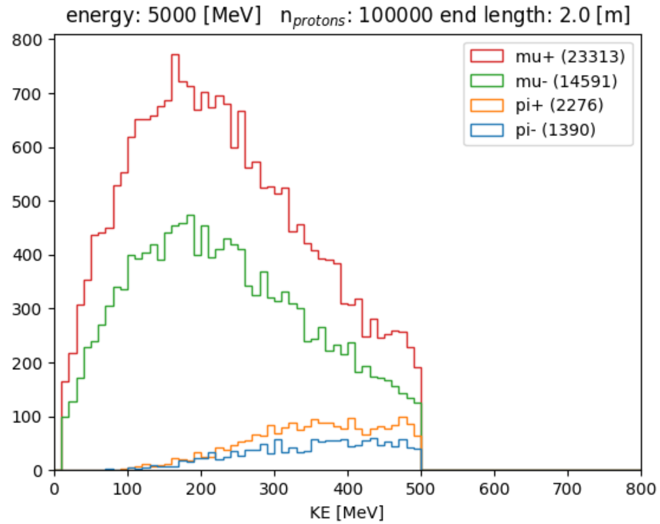
kinetic energy [MeV]
r max [mm]

L = 2.0 m, E = 5 GeV



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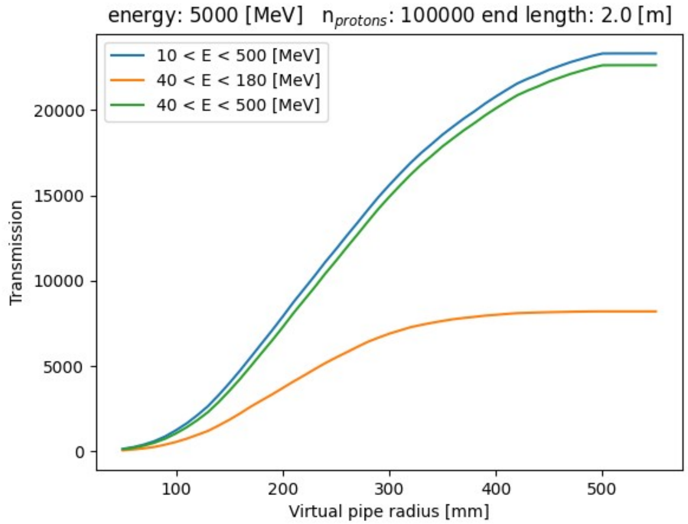
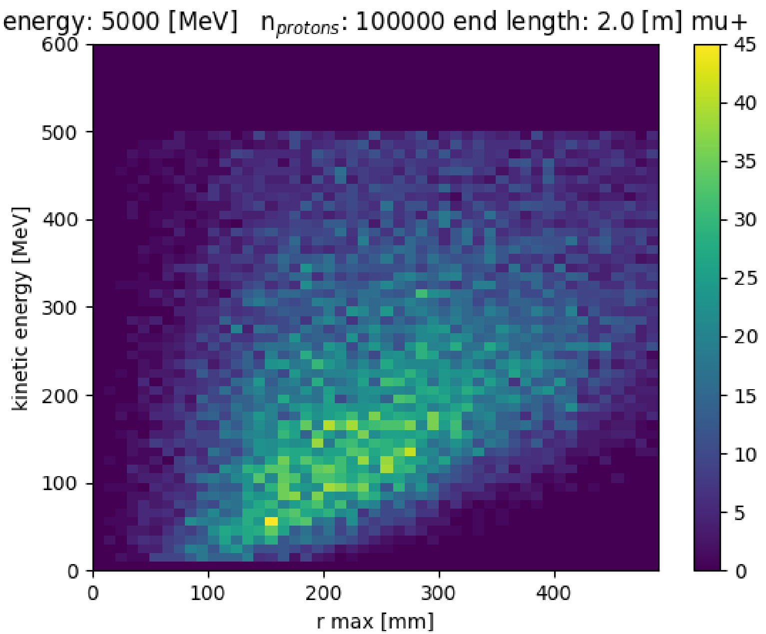
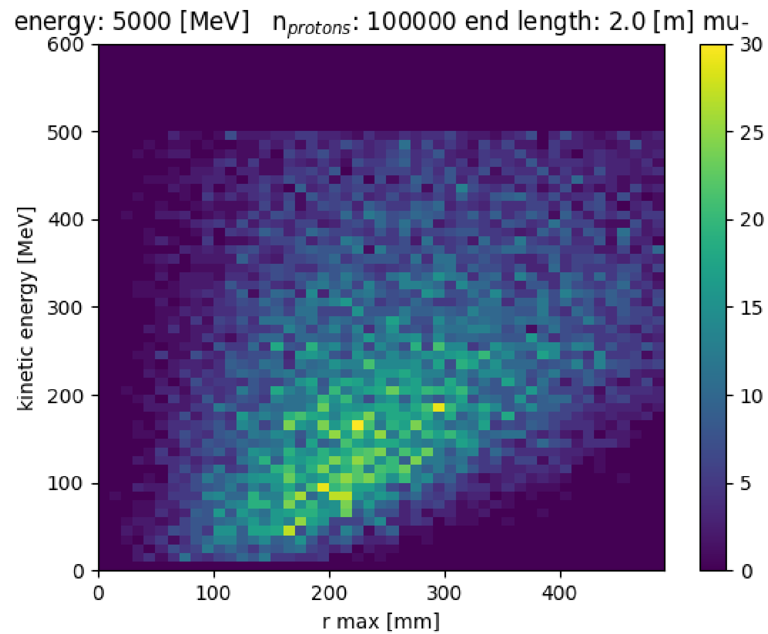
mu+ (23313)
mu- (14591)
pi+ (2276)
pi- (1390)
KE [MeV]



energy: 5000 [MeV] $n_{protons}$: 100000 end length: 2.0 [m]
10 < E < 500 [MeV]
40 < E < 180 [MeV]
40 < E < 500 [MeV]
Transmission
Virtual pipe radius [mm]

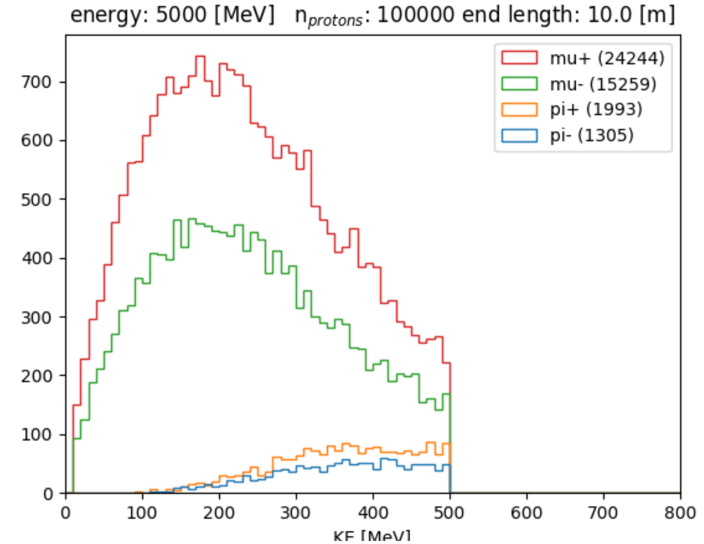


energy: 5000 [MeV] $n_{protons}$: 100000 end length: 2.0 [m] mu+
kinetic energy [MeV]
r max [mm]

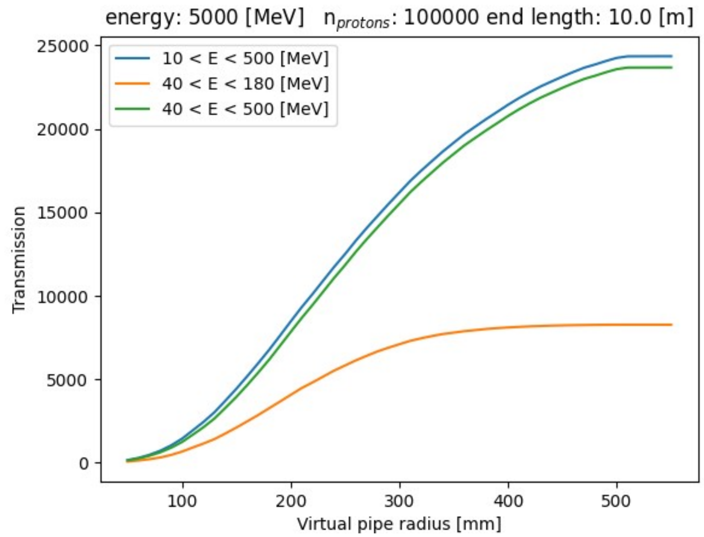


energy: 5000 [MeV] $n_{protons}$: 100000 end length: 2.0 [m] mu-
kinetic energy [MeV]
r max [mm]

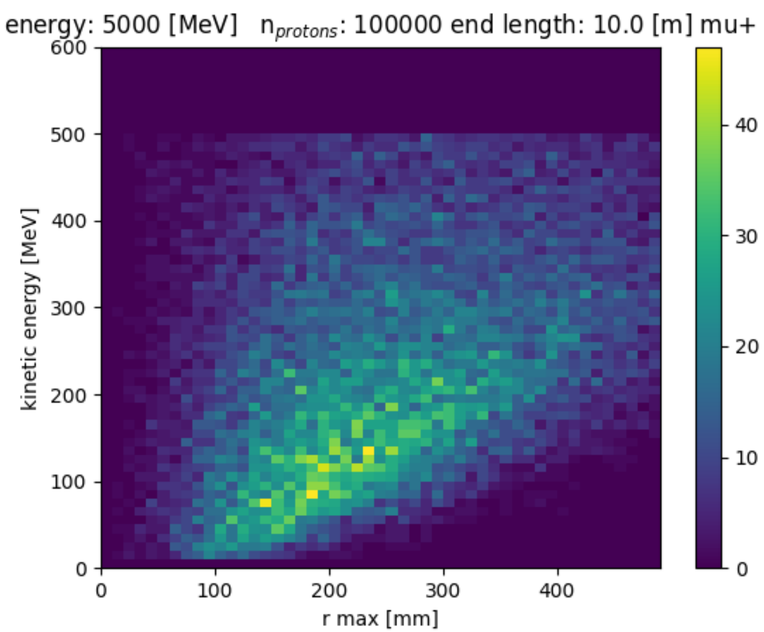
L = 10.0 m, E = 5 GeV



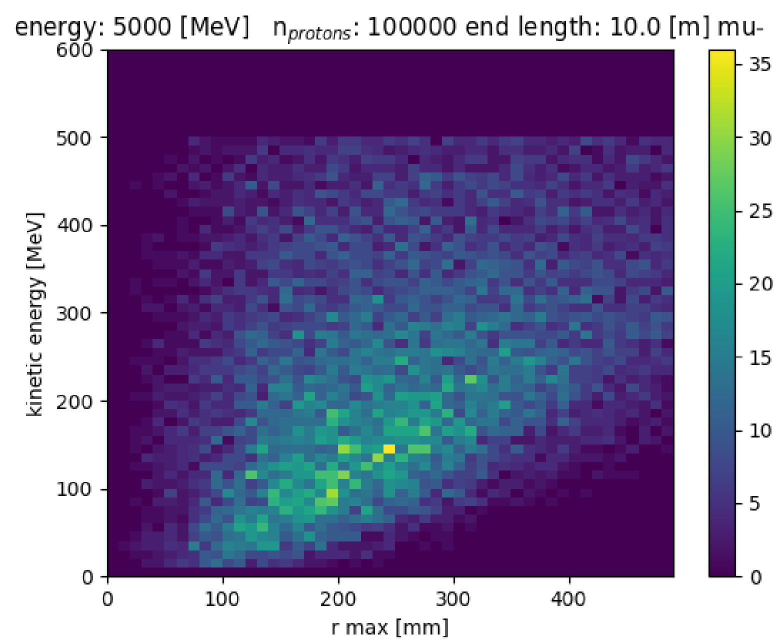
energy: 5000 [MeV] n$_{protons}$: 100000 end length: 10.0 [m]
mu+ (24244)
mu- (15259)
pi+ (1993)
pi- (1305)
0
100
200
300
400
500
600
700
800
KE [MeV]



energy: 5000 [MeV] n$_{protons}$: 100000 end length: 10.0 [m]
10 < E < 500 [MeV]
40 < E < 180 [MeV]
40 < E < 500 [MeV]
Transmission
0
5000
10000
15000
20000
25000
100
200
300
400
500
Virtual pipe radius [mm]

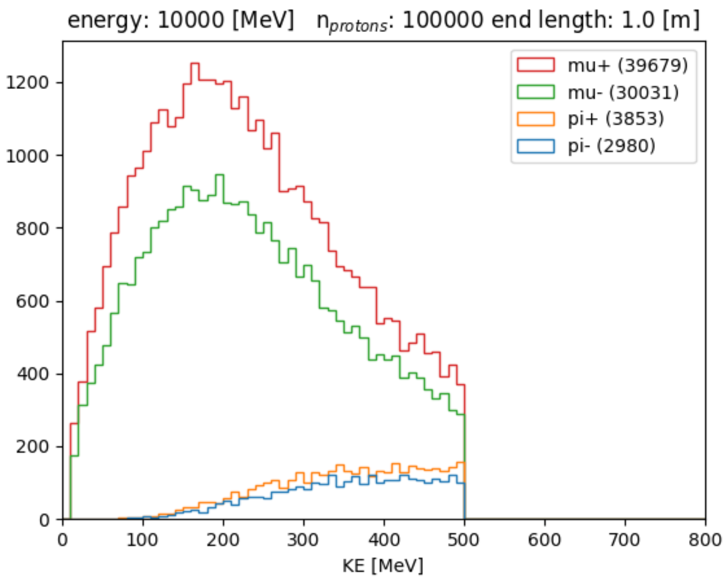


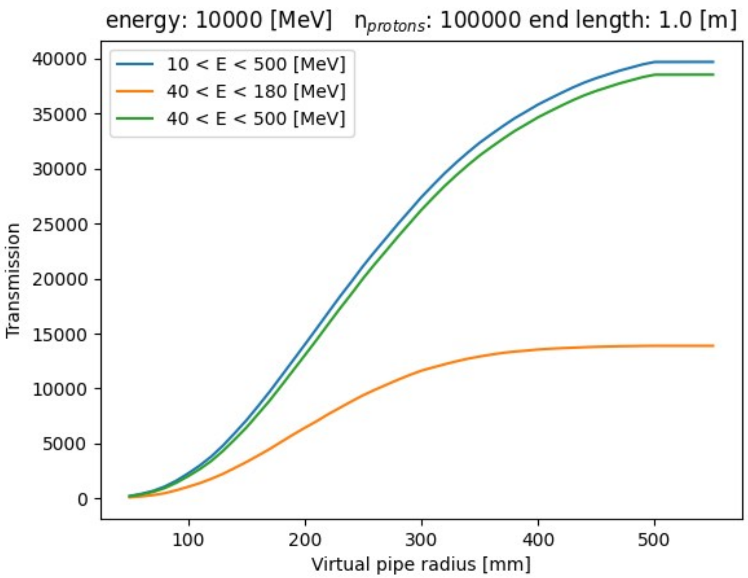
energy: 5000 [MeV] n$_{protons}$: 100000 end length: 10.0 [m] mu+
kinetic energy [MeV]
r max [mm]
0
100
200
300
400
500
600
10
20
30
40



energy: 5000 [MeV] n$_{protons}$: 100000 end length: 10.0 [m] mu-
kinetic energy [MeV]
r max [mm]
0
100
200
300
400
500
600
5
10
15
20
25
30
35

L = 1.0 m, E = 10 GeV


energy: 10000 [MeV] $n_{protons}$: 100000 end length: 1.0 [m]
mu+ (39679)
mu- (30031)
pi+ (3853)
pi- (2980)
KE [MeV]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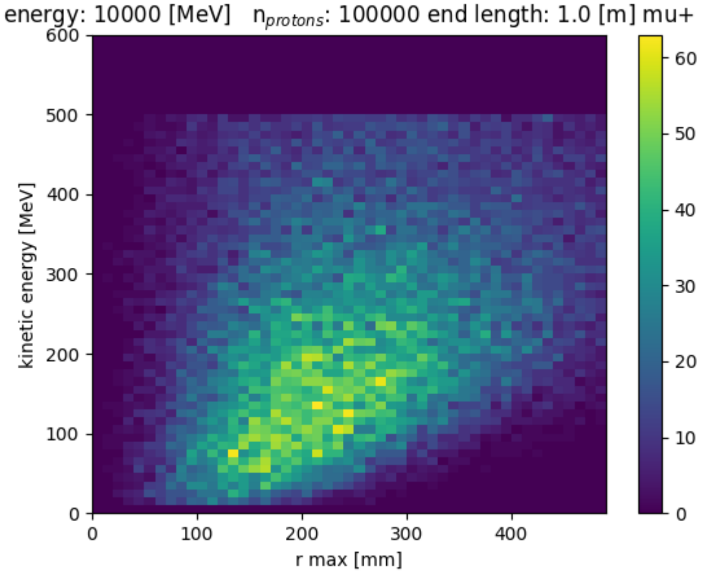
40 < E < 500 [MeV]
Transmission
Virtual pipe radius [mm]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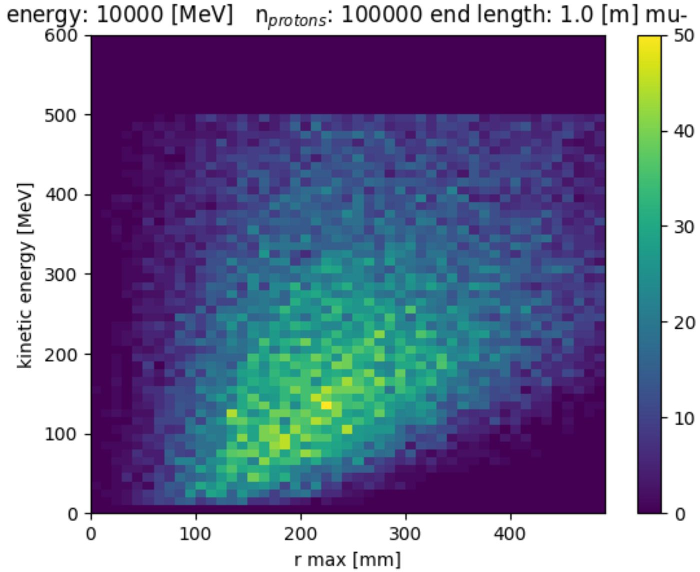
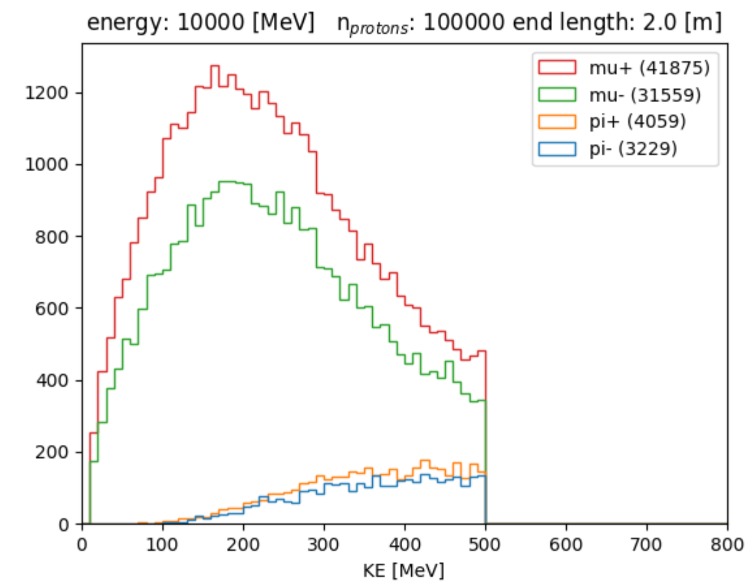
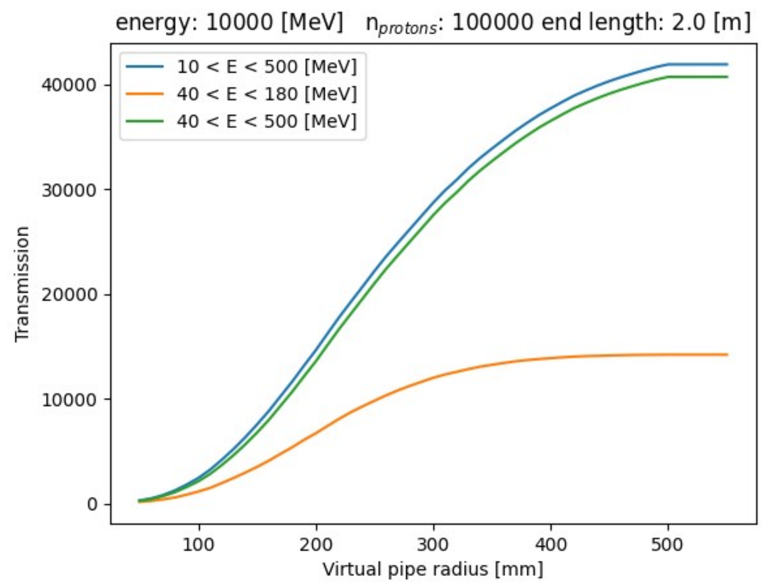
kinetic energy [MeV]
r max [mm]


energy: 10000 [MeV] $n_{protons}$: 100000 end length: 1.0 [m] mu-
kinetic energy [MeV]
r max [mm]

L = 2.0 m, E = 10 GeV



energy: 10000 [MeV] $n_{protons}$: 100000 end length: 2.0 [m]
mu+ (41875)
mu- (31559)
pi+ (4059)
pi- (3229)
KE [MeV]



energy: 10000 [MeV] $n_{protons}$: 100000 end length: 2.0 [m]
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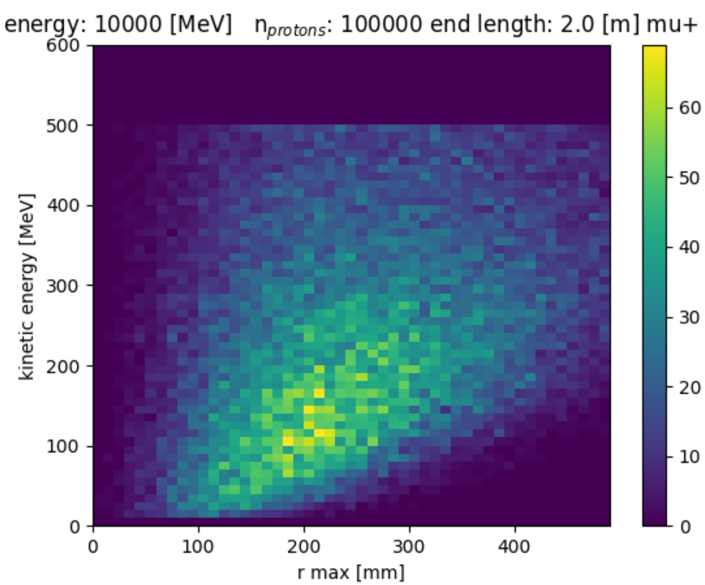
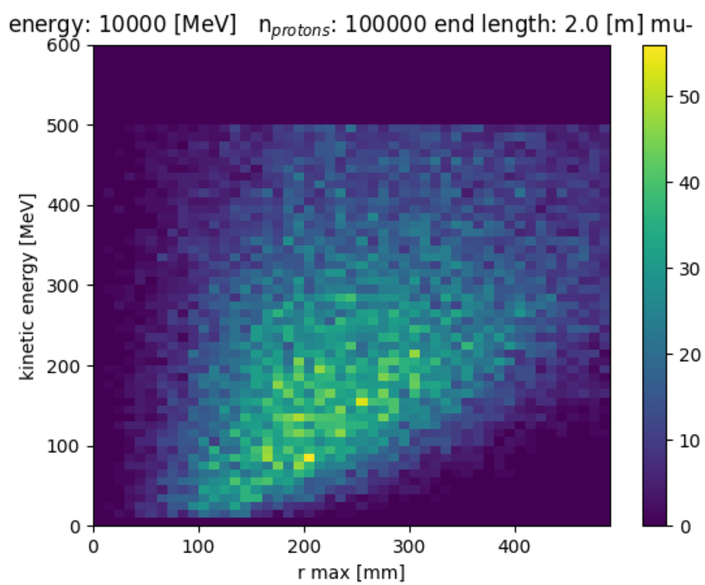
40 < E < 180 [MeV]
40 < E < 500 [MeV]
Transmission
Virtual pipe radius [mm]



energy: 10000 [MeV] $n_{protons}$: 100000 end length: 2.0 [m] mu+
kinetic energy [MeV]
r max [mm]



energy: 10000 [MeV] $n_{protons}$: 100000 end length: 2.0 [m] mu-
kinetic energy [MeV]
r max [mm]

L = 10.0 m, E = 10 GeV

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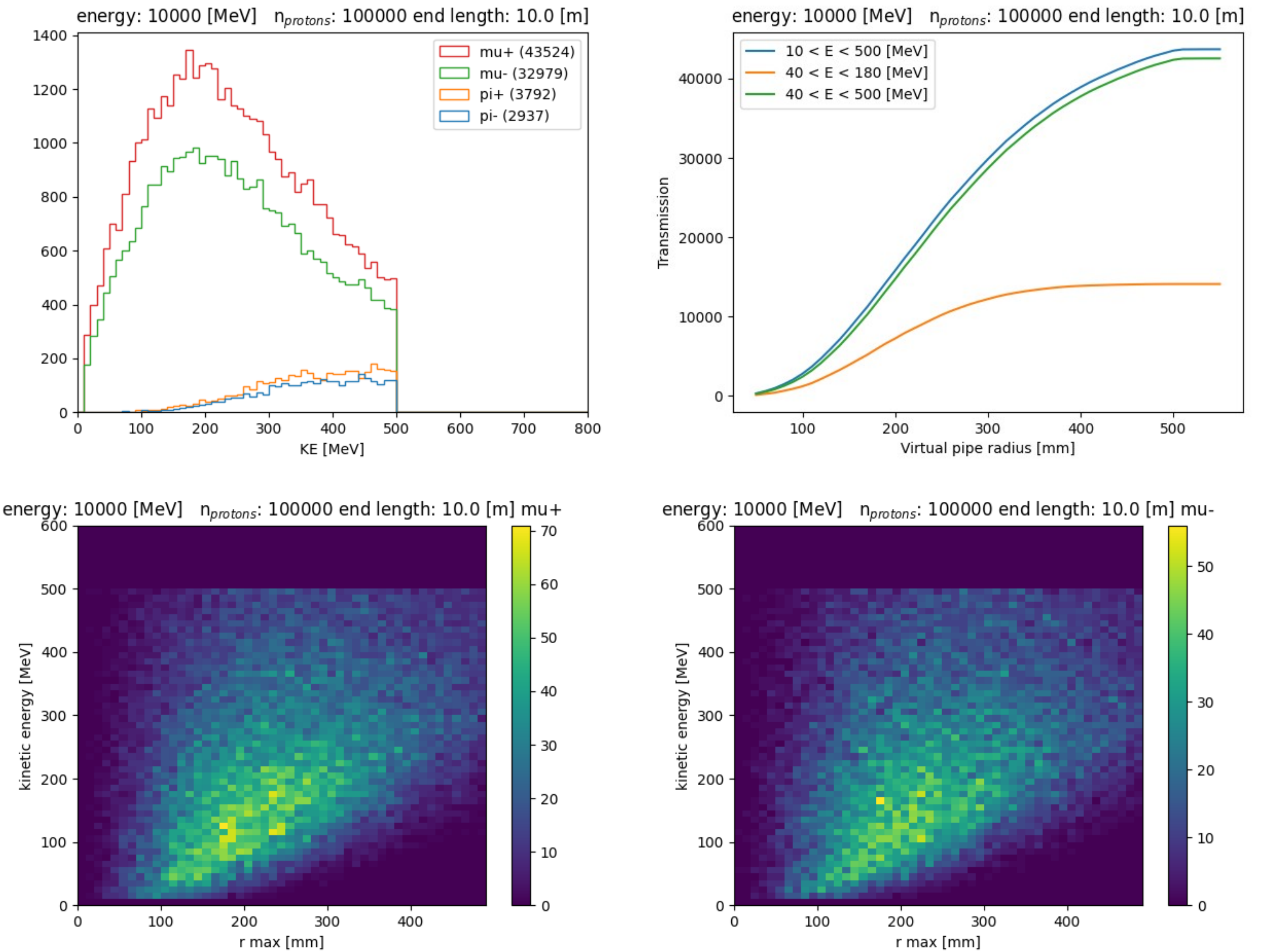
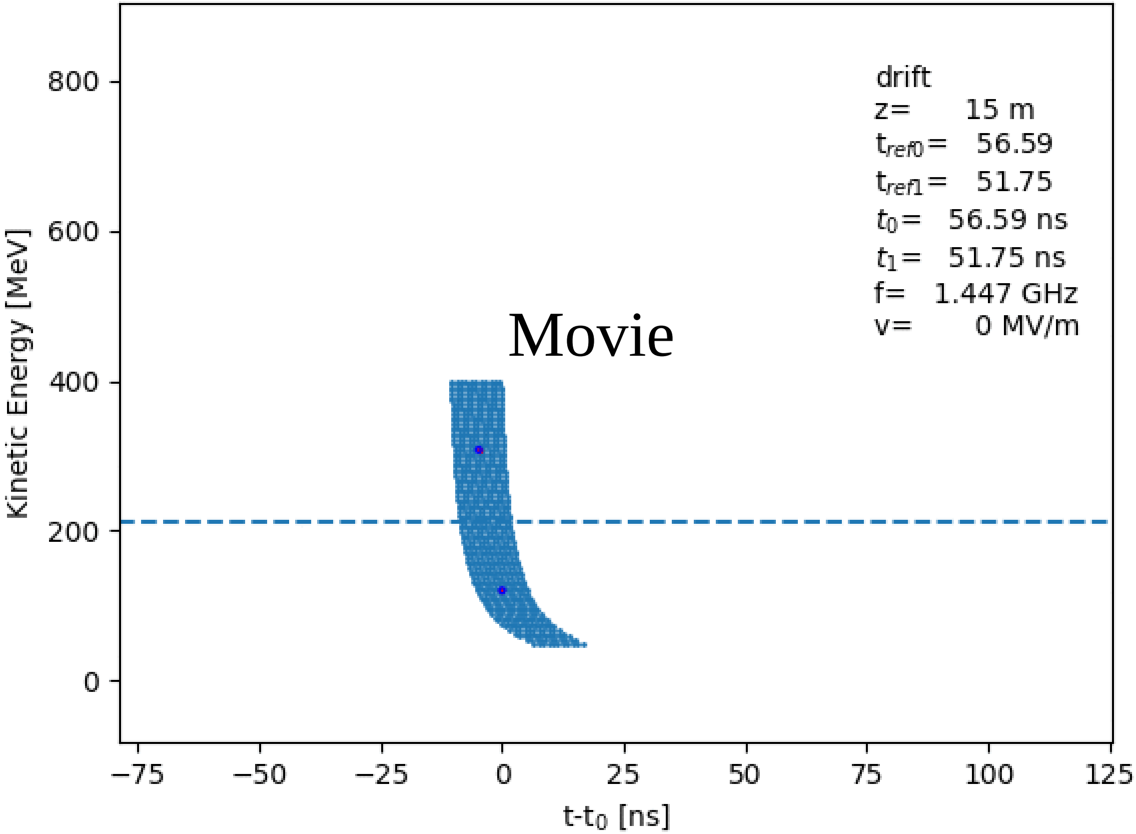
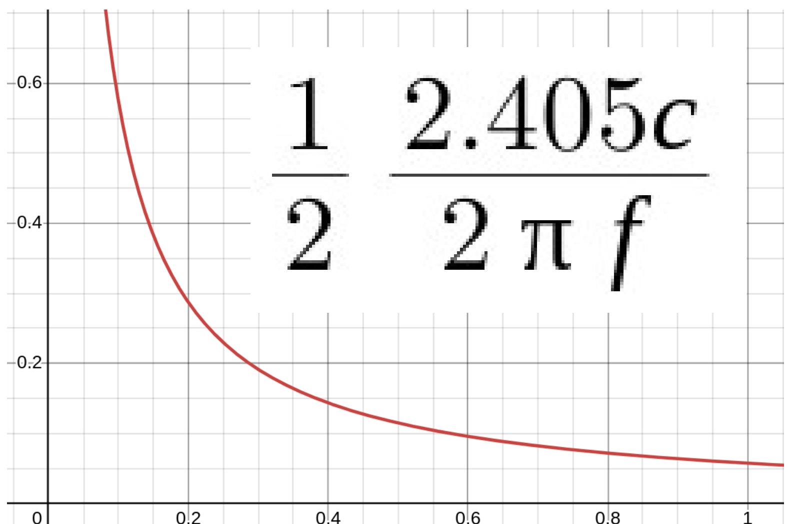


RF capture - reminder



RF capture

- What is the acceptance of the RF capture system?
- Naively there are two different considerations
  - What is the region in time, energy that is accepted (longitudinal)
  - What is the minimum aperture
- Aperture:-
  - Take guidance from Alexej → iris < half the “ideal pillbox radius”
  - Aperture → keep frequency low

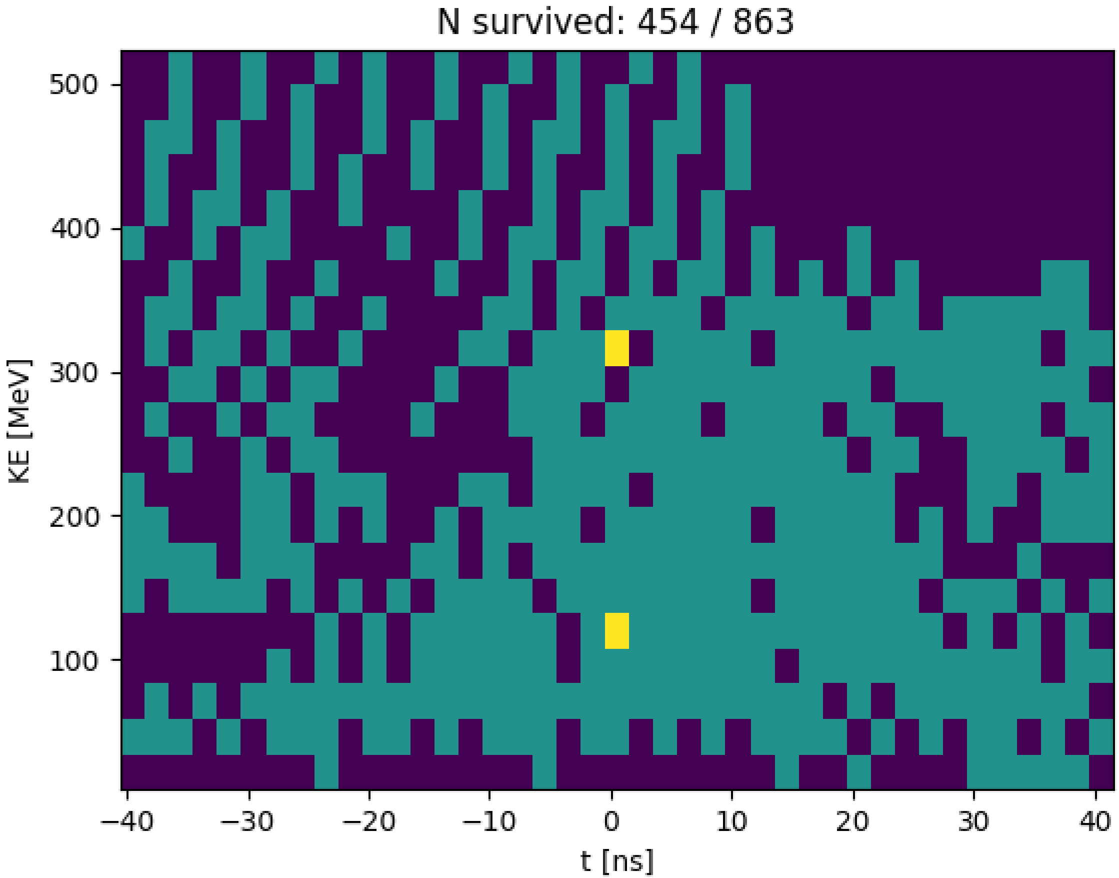


RF capture

- Design
  - RF cavities every 0.25 m each of which is 0.20 m long, ideal TM010 pillbox, no windows
  - Vary cavity frequency and voltage in each cavity independently
  - Buncher:
    - Buncher voltage set to ramp linearly in z from 0 to 12 MV/m
    - Buncher phase → particle @ 200 MeV/c has 0 phase
    - Buncher frequency → particle @ 400 MeV/c has 0 phase
  - Rotator
    - Rotator voltage set to uniform 12 MV/m
    - Rotator phase → particle @ 200 MeV/c is accelerated to 300 MeV/c
    - Rotator frequency → particle @ 400 MeV/c is decelerated to 300 MeV/c
  - Drift
    - Drift length → frequency at the end is 176 MHz
- 12 MV/m → high voltage, but not SOTA
- 200, 400 MeV/c → reasonable range within energy from target
- 300 MeV/c → looks like good acceptance in cooling channel
- Scan buncher length and rotator length

Longitudinal acceptance

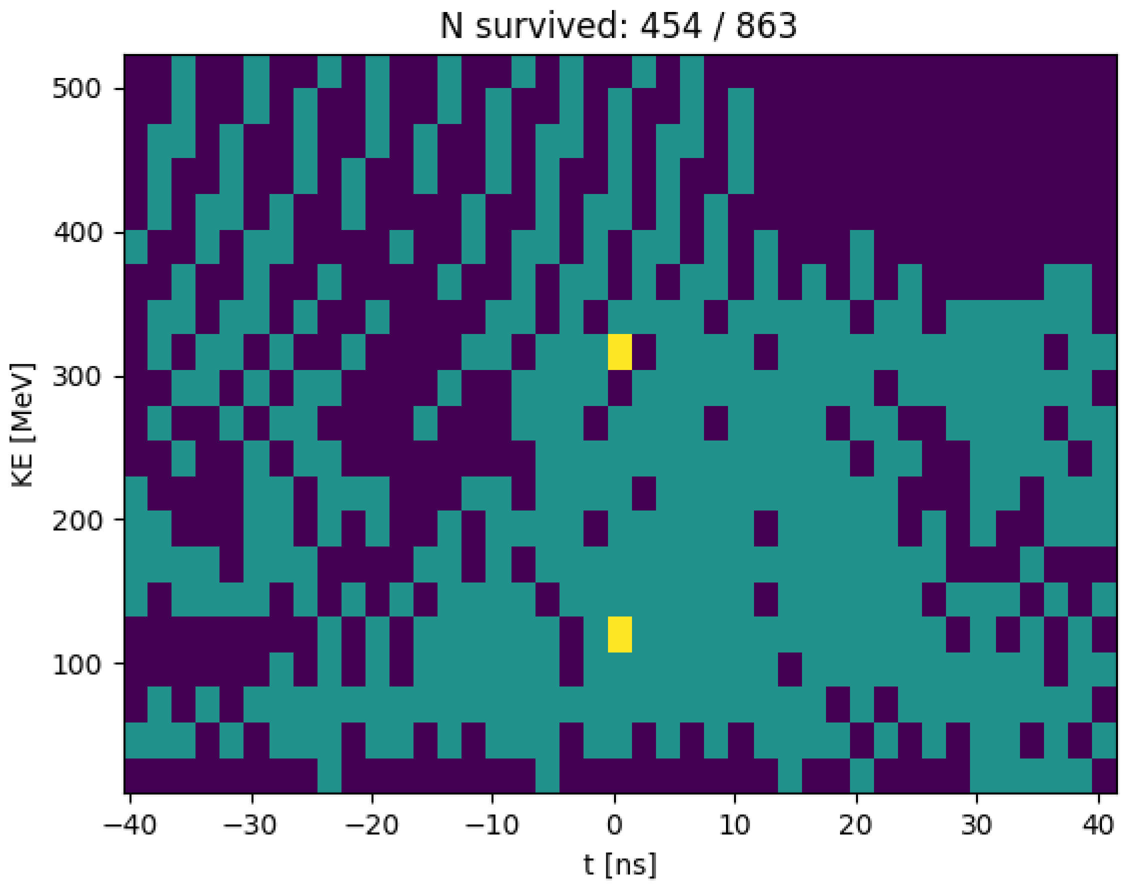
- Longitudinal acceptance criterion
  - Particles are contained in a 176 Mhz/12 MV/m RF bucket



Scan Buncher Length

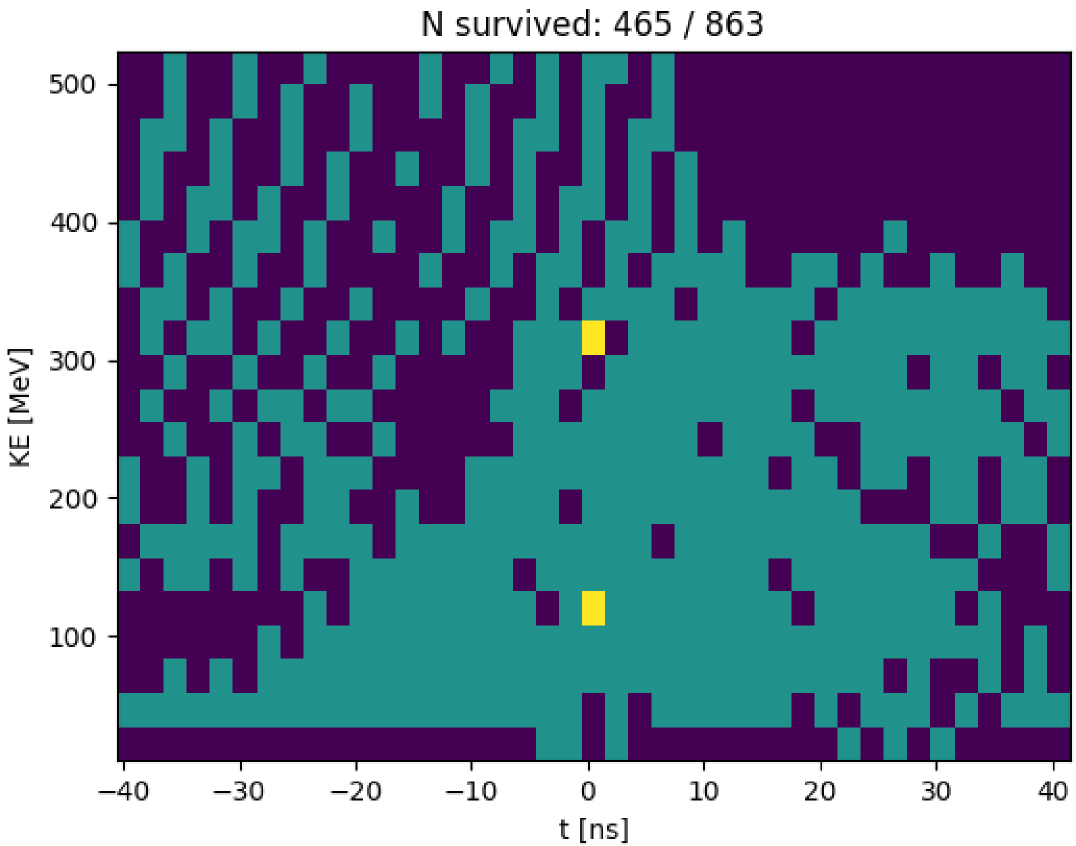
Scan Buncher Length

25 buncher cells, 200 rotator cells



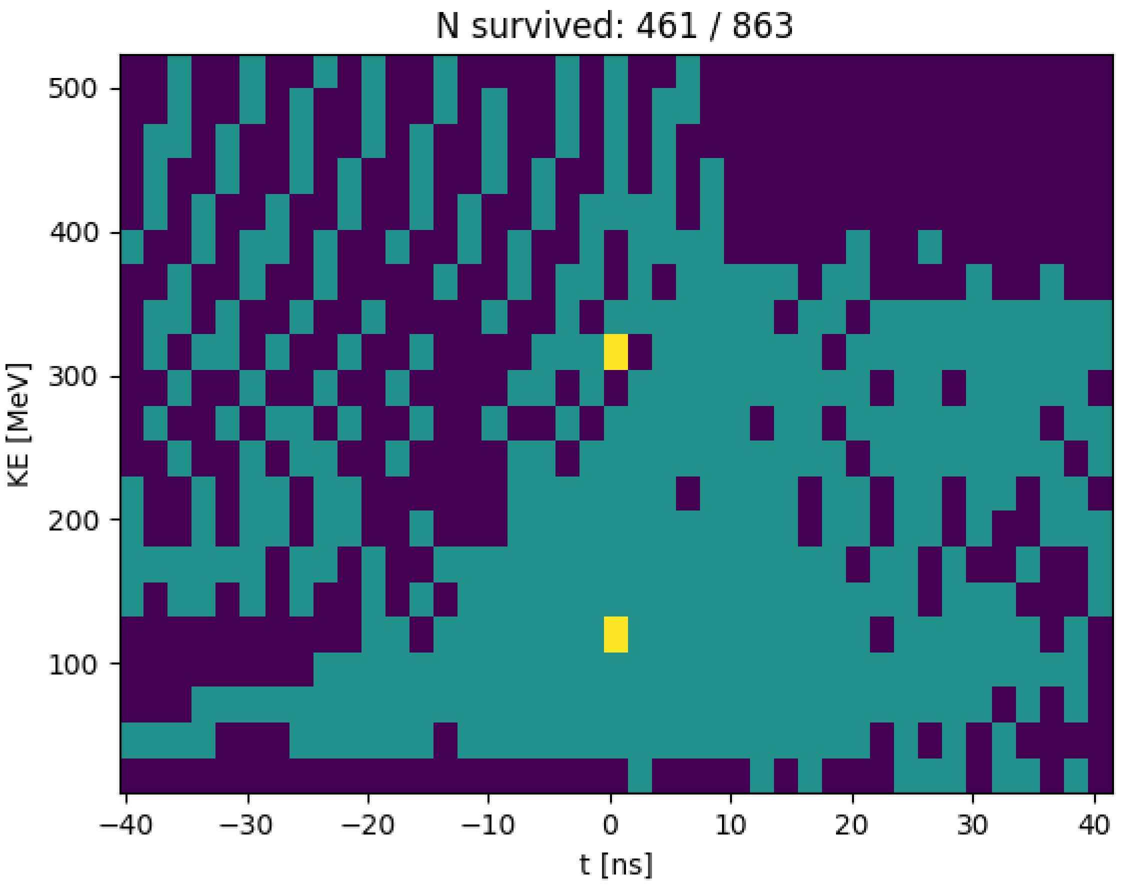
Scan Buncher Length

50 buncher cells, 200 rotator cells



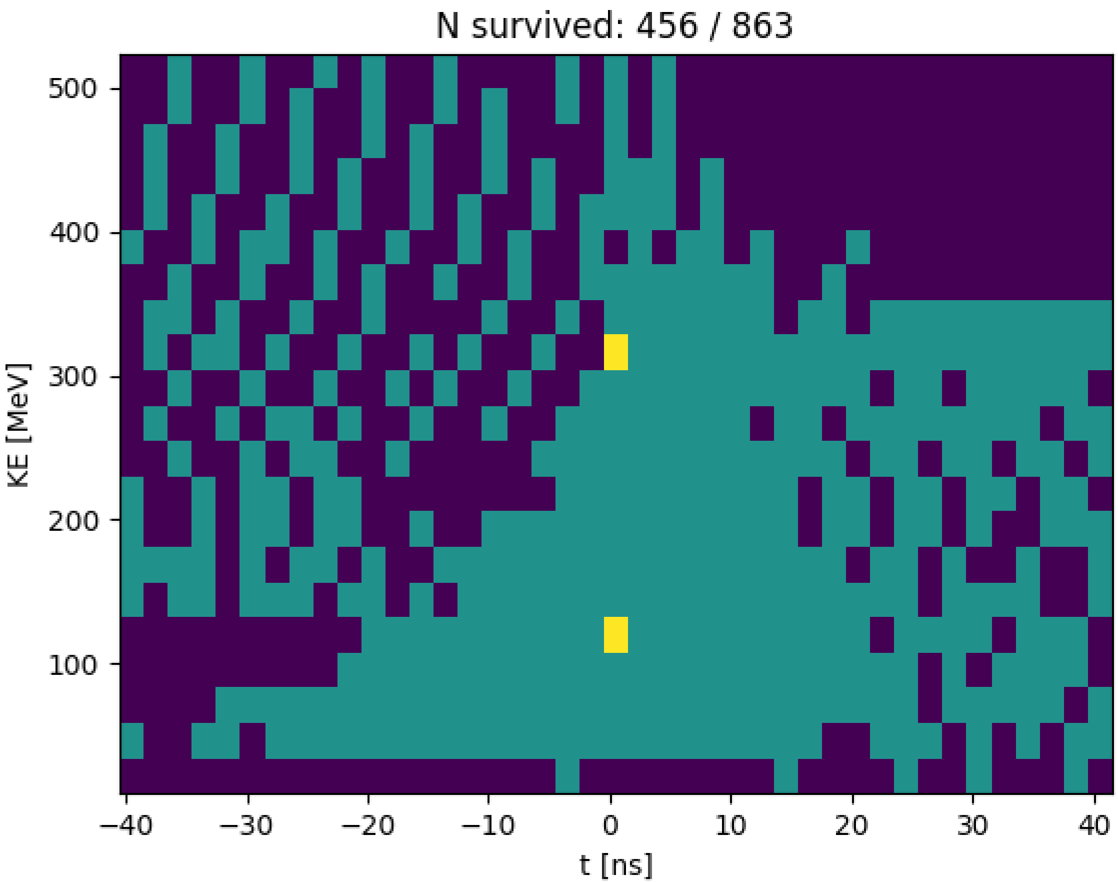
Scan Buncher Length

100 buncher cells, 200 rotator cells



Scan Buncher Length

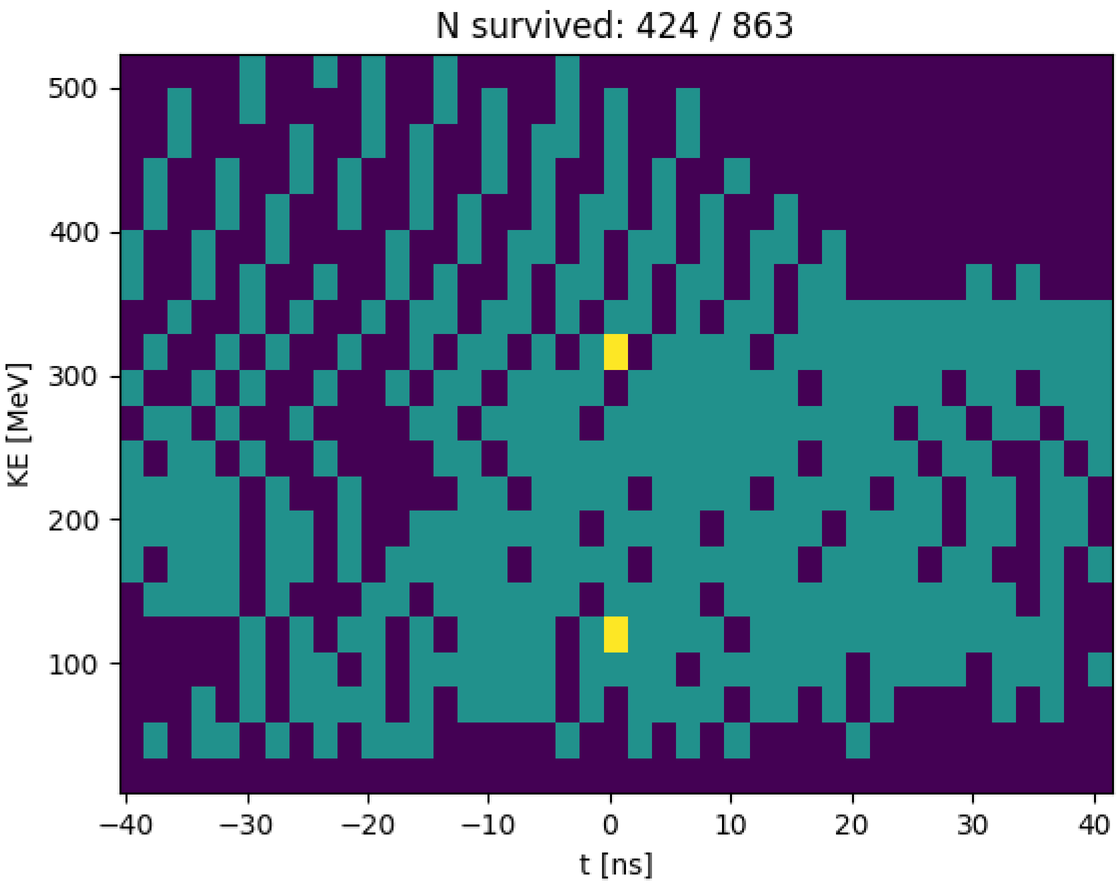
200 buncher cells, 200 rotator cells



Scan Rotator Length

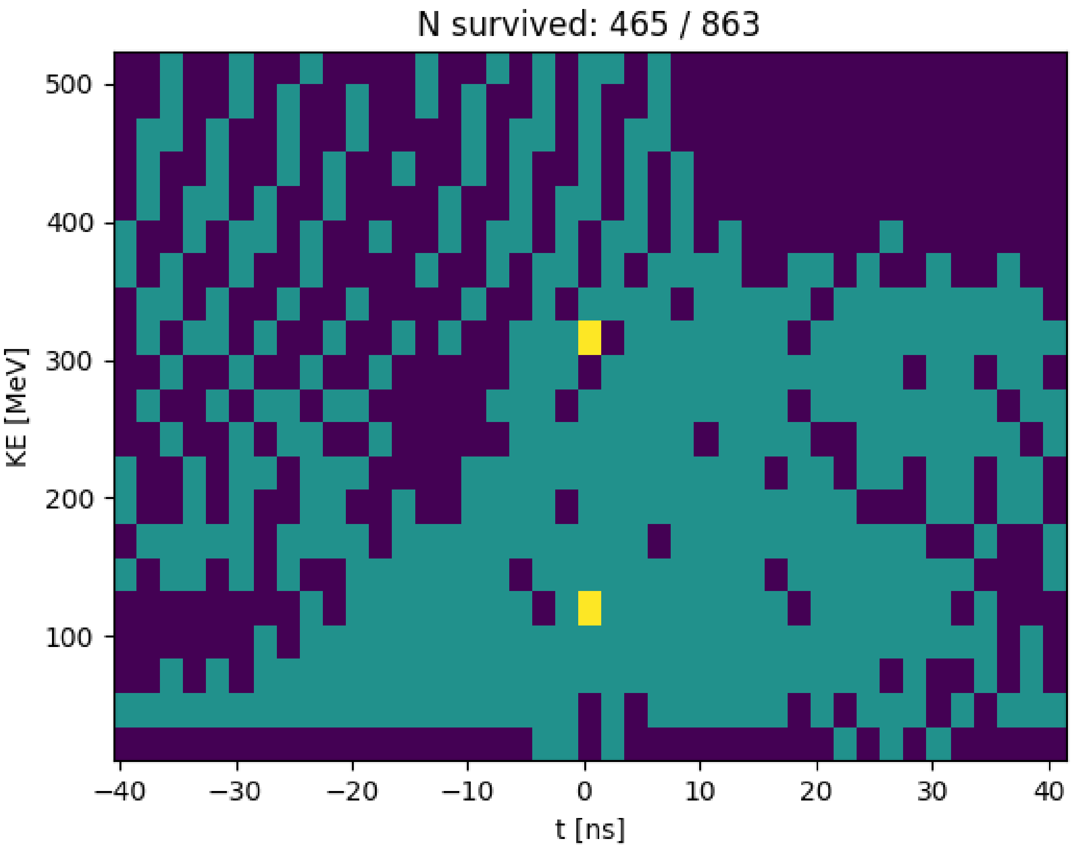
Scan Rotator Length

50 buncher cells,100 rotator cells



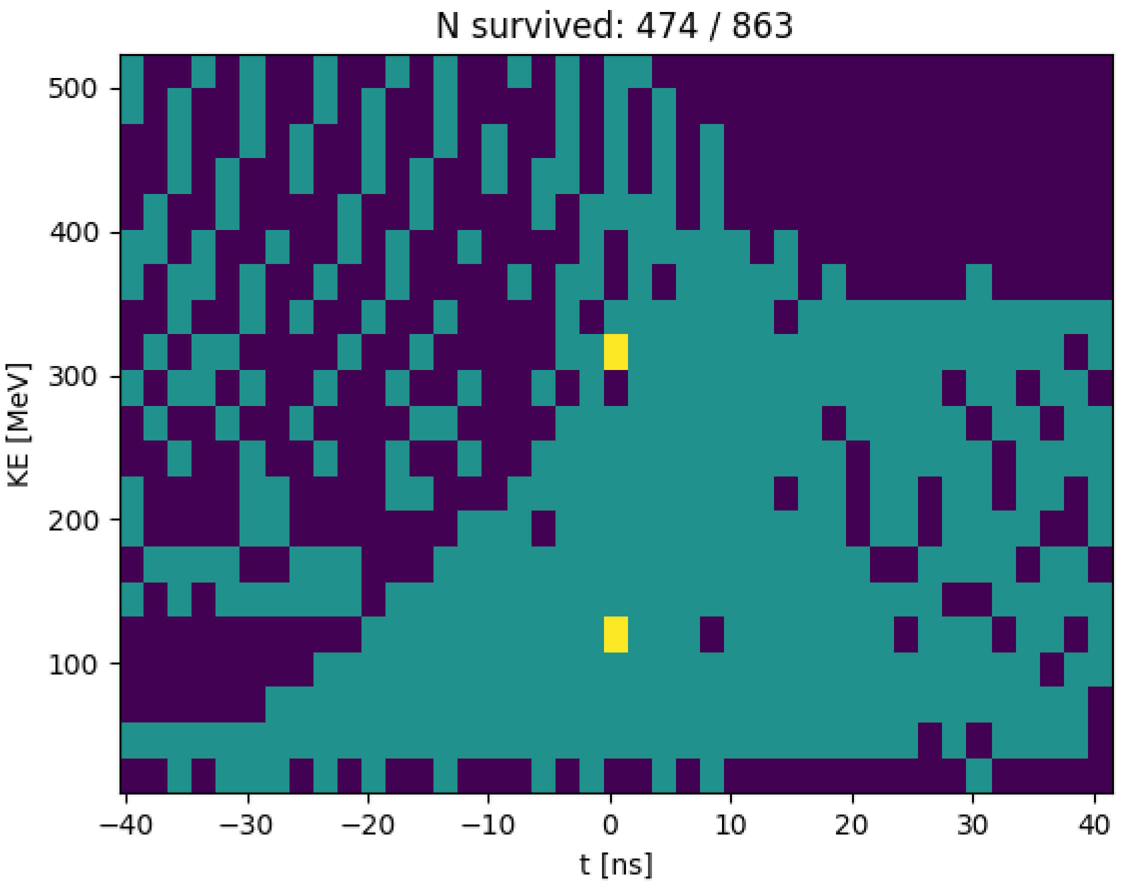
Scan Rotator Length

50 buncher cells, 200 rotator cells



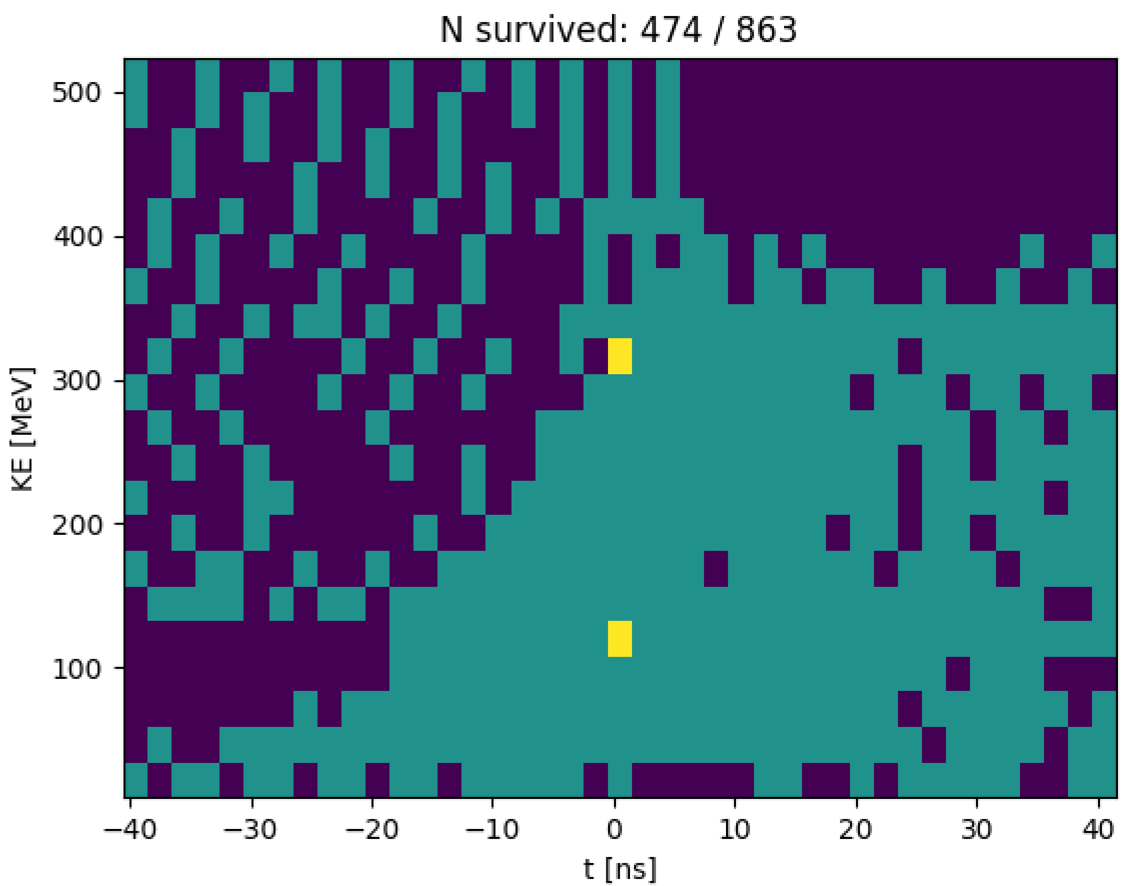
Scan Rotator Length

50 buncher cells,300 rotator cells



Scan Rotator Length

50 buncher cells,400 rotator cells



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Full simulation

- Started looking at full simulation
  - Integrated simulation of beam from target
- Work in progress…

Discussion

- Optimisation is ongoing
- Optimisation parameters - target:
  - Target length (vs proton energy)
  - Target radius (vs proton energy)
  - Target shielding aperture
  - Target field strength

  Done by Daniele
- Optimisation parameters – capture
  - Max voltage
  - Number of rotator cells
  - Number of buncher cells
  - Capture momentum
  - Momentum of reference trajectories
- Chicane
- Charge separation
- Cooling cell integration