Development of a Gas Stopper for Fusion-Evaporation Products

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Outline

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Introduction

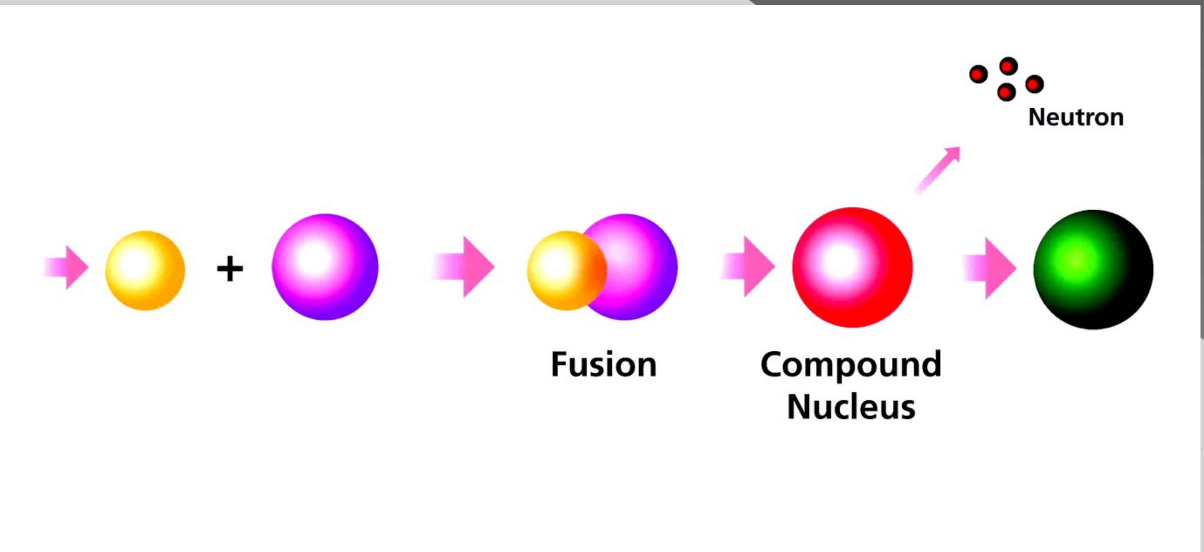
- My research focuses on ^{158}Hf, which is a homolog of ^{257}Rf
- Why do we care about Rf?

hydrogen 1 H 1.0079																		helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122												boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305												aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 * *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

*Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
**Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

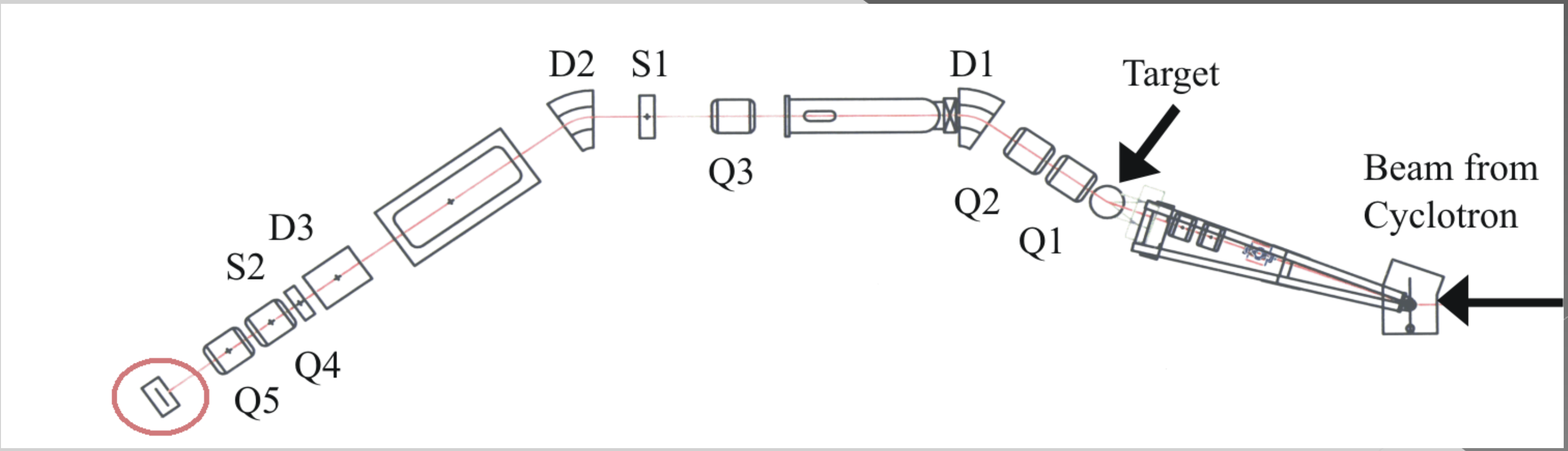
Creation of Fusion-Evaporation Products

- Projectile + Target → Compound Nucleus → Evaporated Residue + Ejectile
  - $^{50}Ti + ^{112}Sn \rightarrow ^{162}Hf^{*} \rightarrow ^{158}Hf + 4n$
- These nuclear reactions have a low probability ($<10^{-8}$ %)

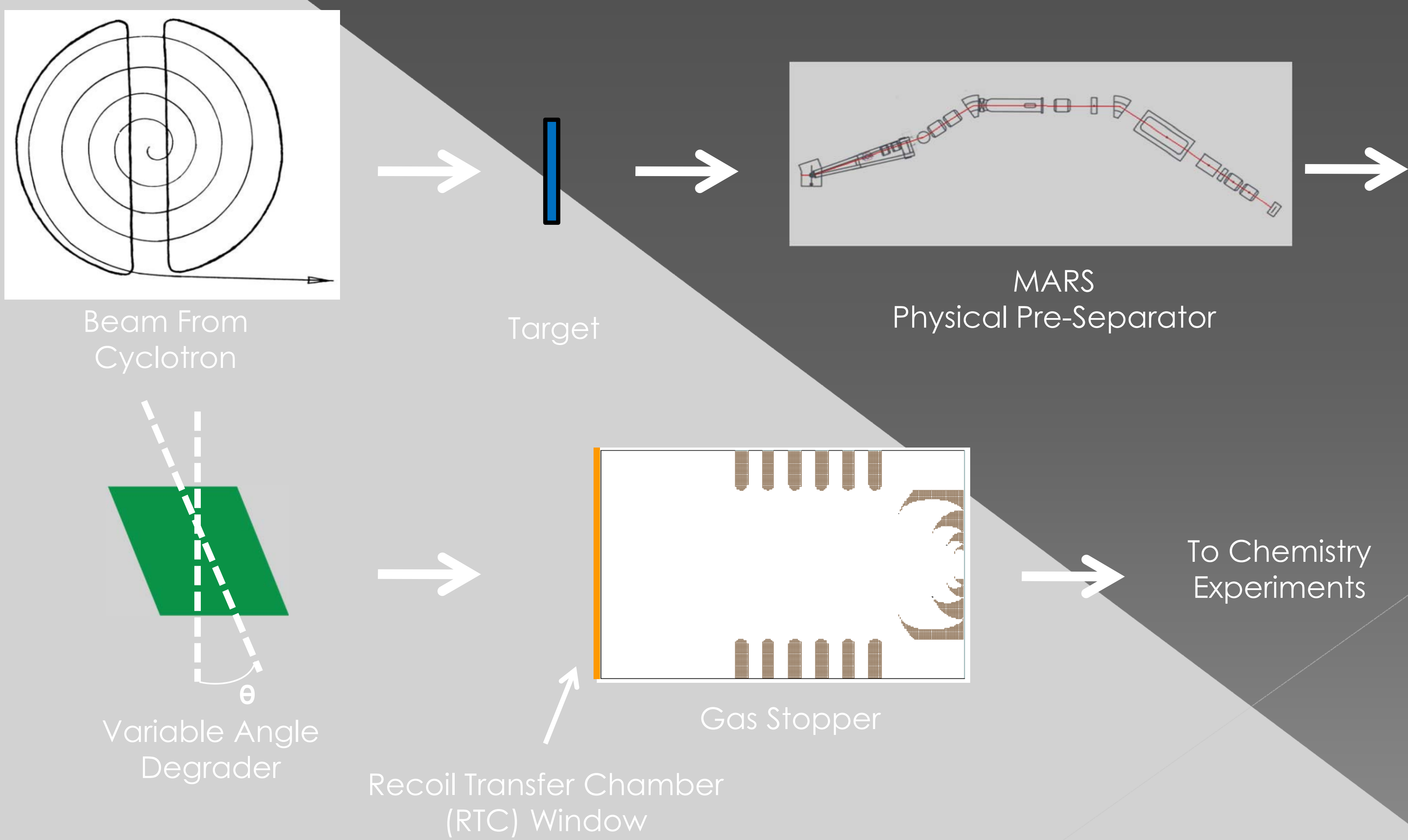


Physical Pre-separation

- Momentum Achromat Recoil Separator (MARS) will filter out unwanted products and beam
- Main components of my simulations: variable angle degrader, Reaction Transfer Chamber (RTC) window, & helium gas cell

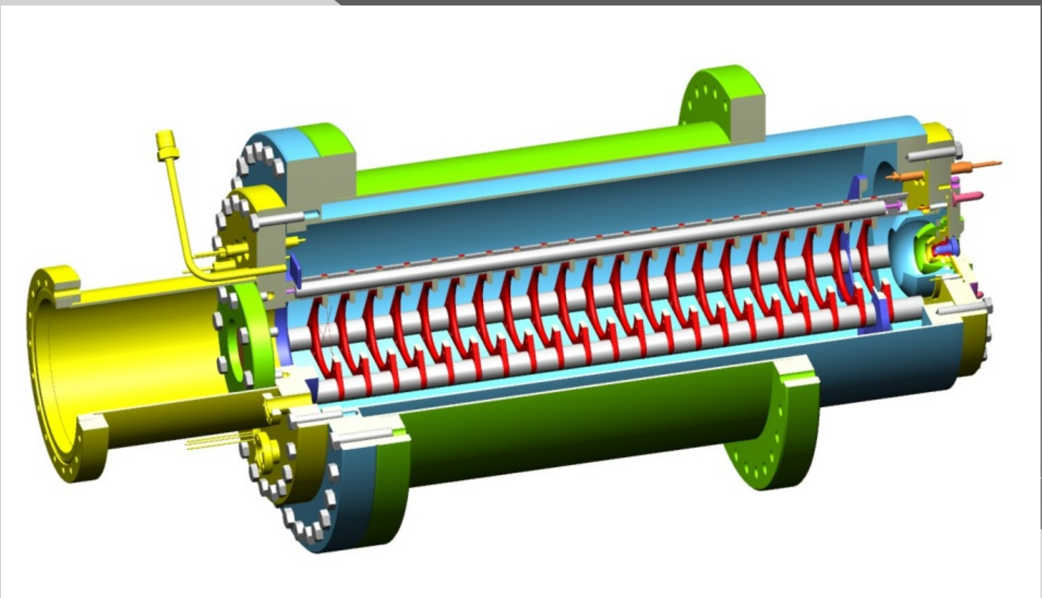


Proposed Experimental Set-up



MSU Gas Stopper

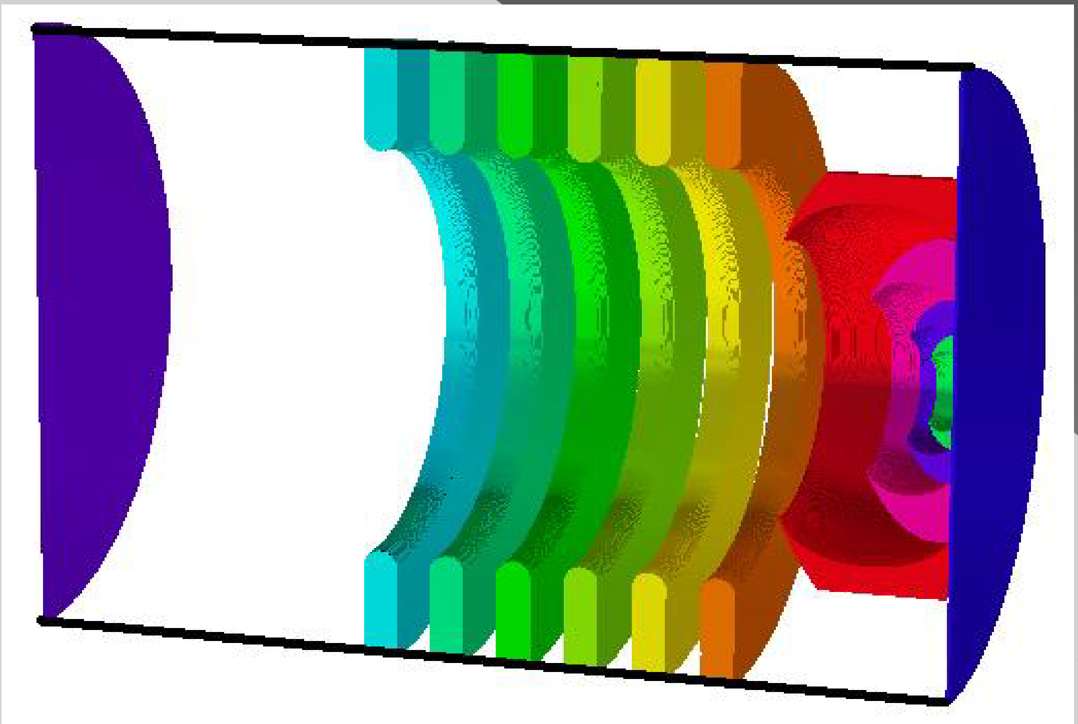
- Thermalize ions
- Original design from MSU: 50 cm in length
- Designed for lighter, faster ions
- 4 concentric spherical electrodes (flower petals)



L.Weissman, et al. *Nucl. Instr. and Meth. A.* **540** (2005) 245-258.

Our Proposed Gas Stopper

- Our design, adapted from MSU: 13.5 cm in length
- Optimized for heavier, slower ions
- 4 flower petals like original design
- Voltage decreases across the gas stopper

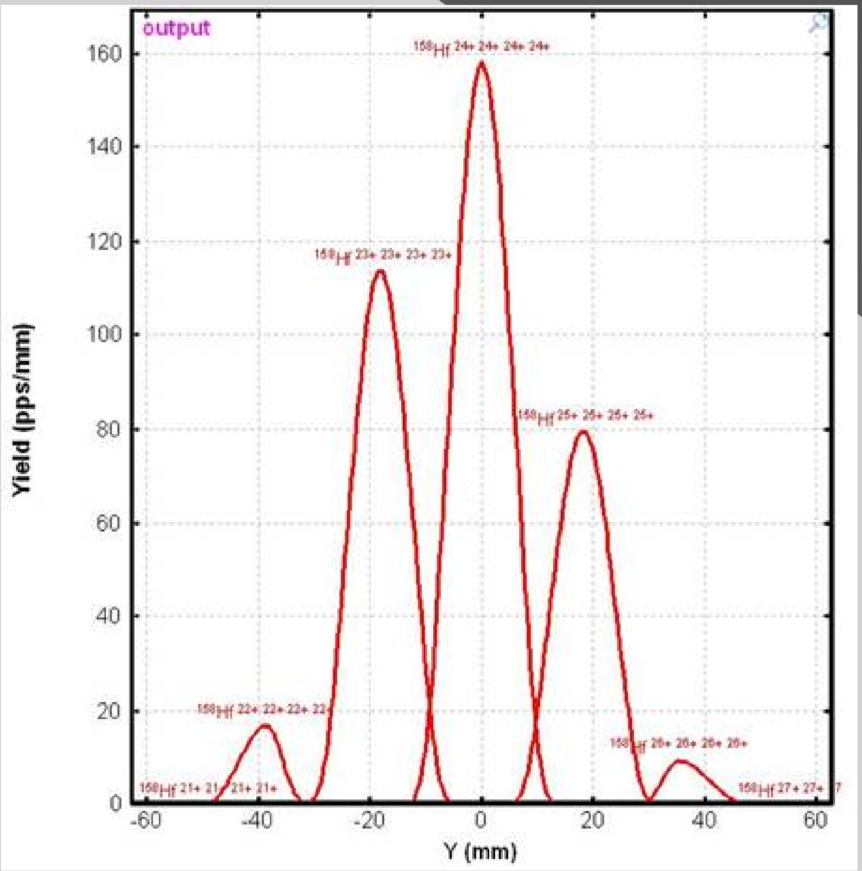


LISE

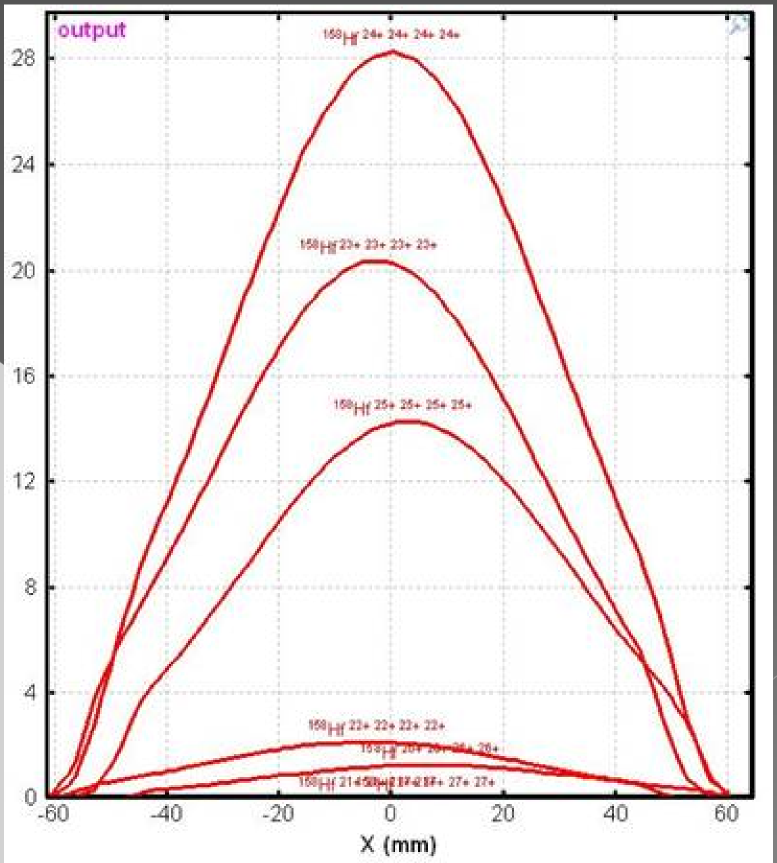
- Simulates motion of ions through separator
- Factors that were optimized:
  - Degrader thickness & angle
  - RTC window thickness
  - Gas cell pressure
- Ion energy and spatial distribution after RTC window

Location Distribution after RTC Window

Vertical Distribution



Horizontal Distribution

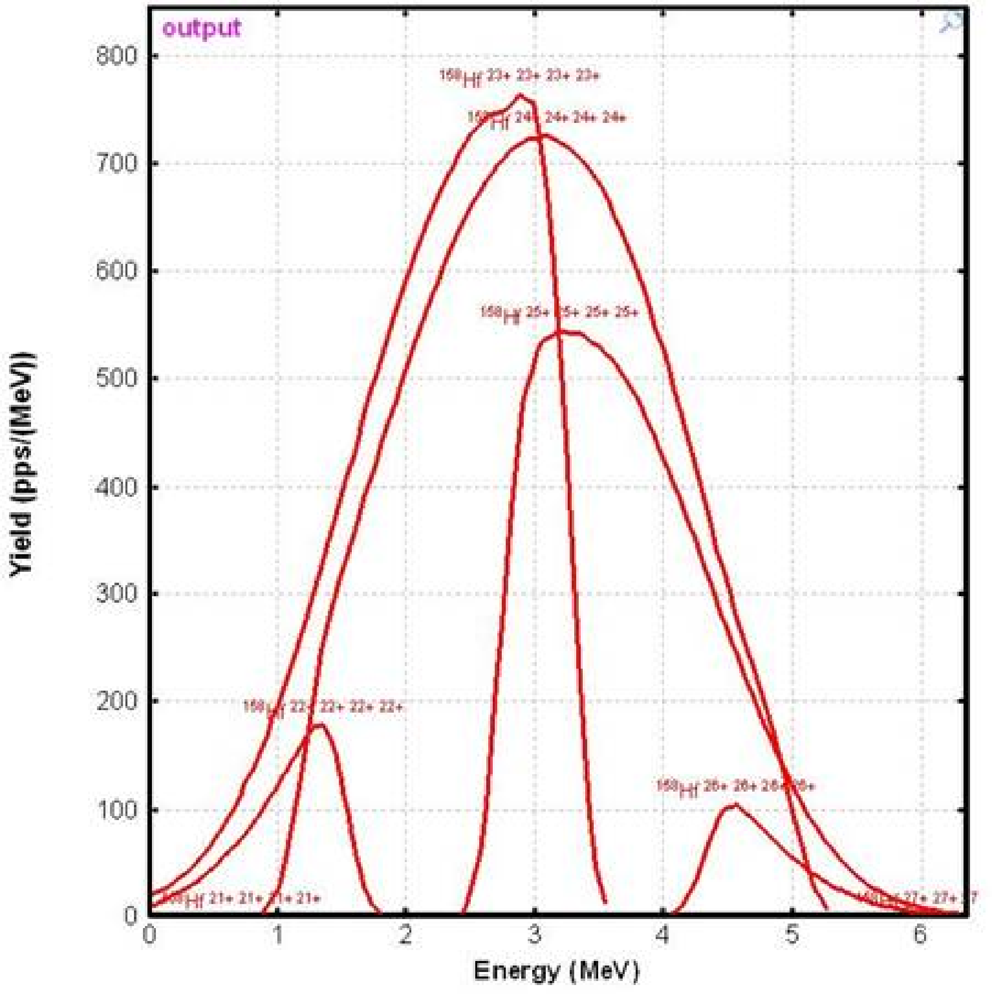


Mean: 0 mm, σ: 17 mm

Mean: 0 mm, σ: 21 mm

Energy Distribution after RTC Window

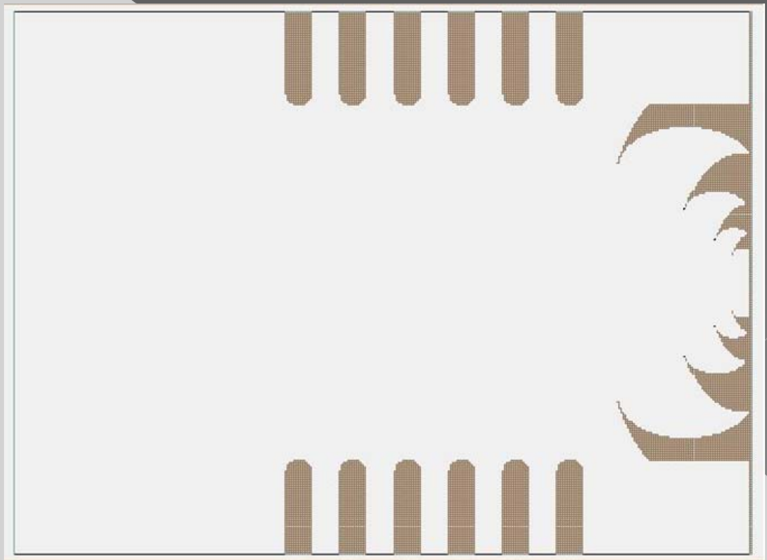
- ^{158}Hf is produced with ~58 MeV of kinetic energy
- 7.75 μm mylar degrader @ 25° effective thickness: 8.5 μm
- 2 μm RTC window



Mean: 3.0 MeV, σ: 0.9 MeV

SIMION

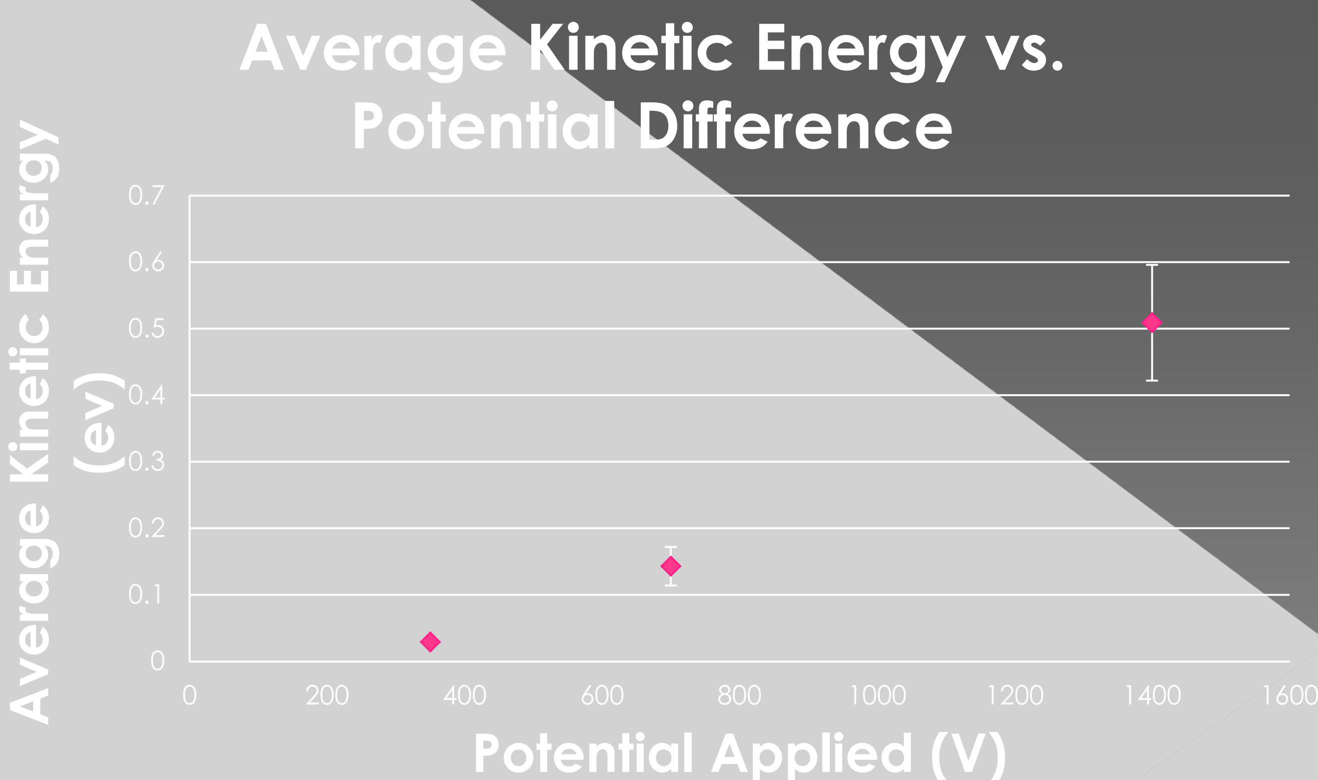
- Ion simulation program that calculates electric fields and trajectories of ions for those electric fields
- Ion energy and spatial distribution determined by LISE
- Mobility: ($17.7\ cm^2\ V^{-1}\ s^{-1}$) [1]
- Gas flow: 11.5 mm/sec in beam direction
- Collisions with He
- SRIM range of ^{158}Hf in 0.3 atm of He



[1] R. Johnsen, *et al. J. Chem. Phys.* **57** (1972) 5292-5295.

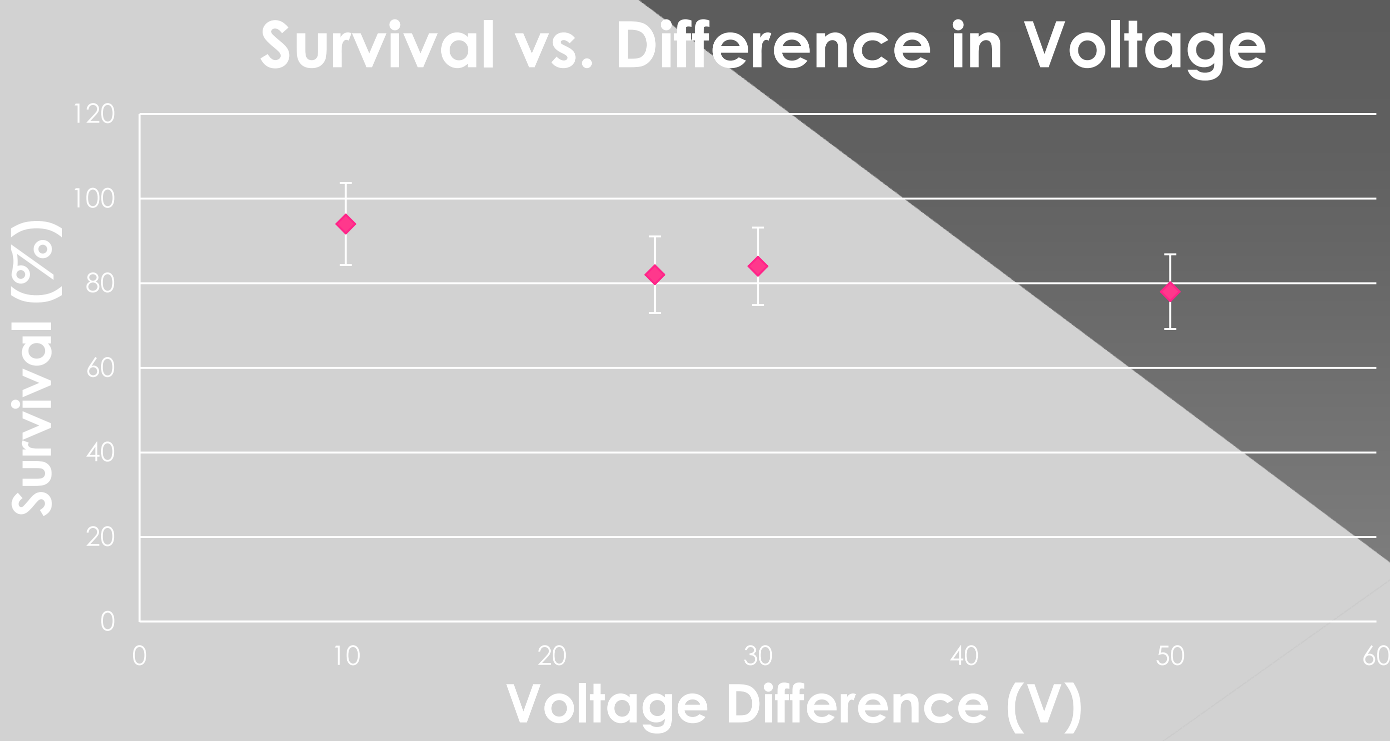
Scaling Electric Potentials

- High survival rate & low kinetic energy is needed
- 3 different simulations



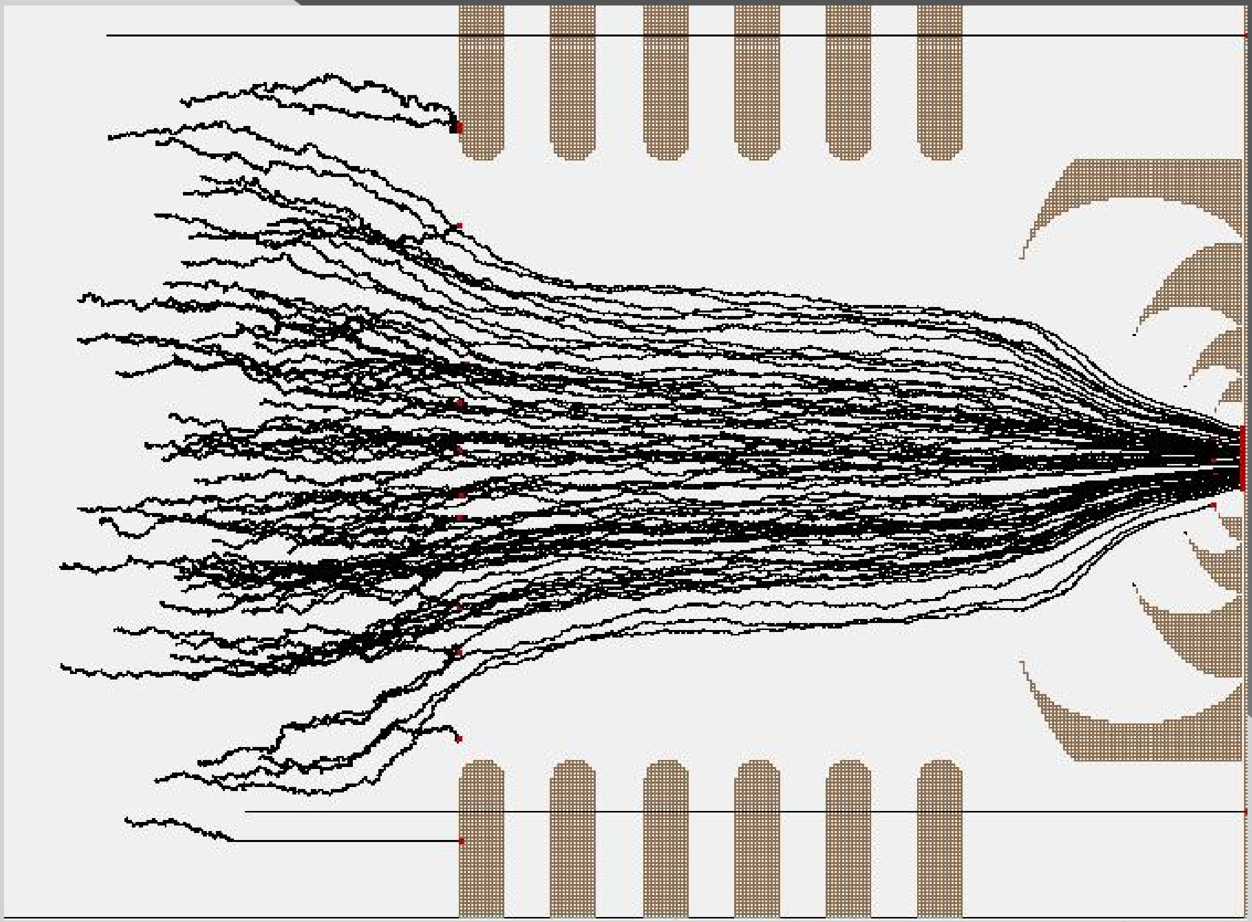
Difference between RTC Window and 1st Ring

- Different voltages tested to determine best scenario
- Forward push is needed



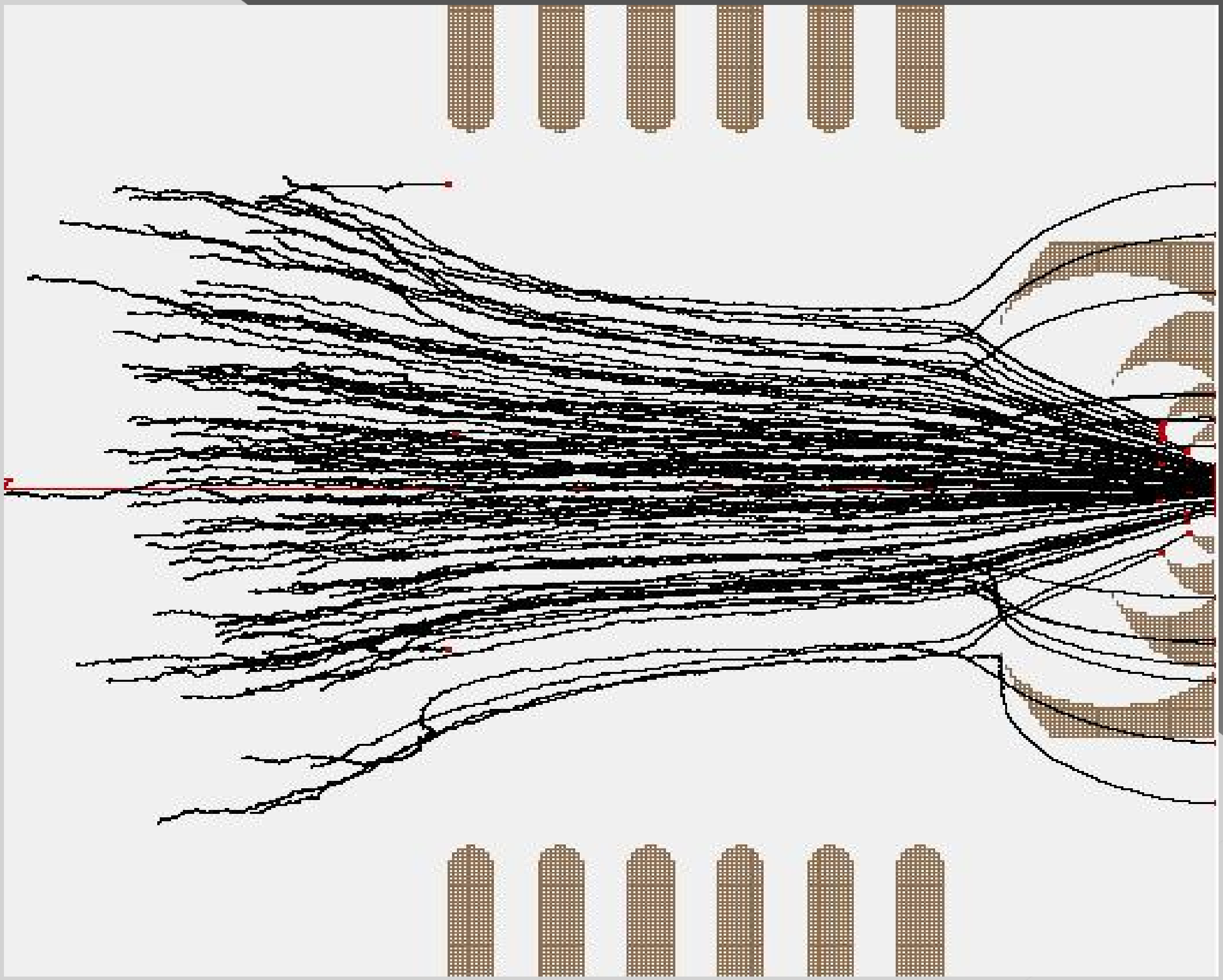
Stopped by 1st Electrode

- Too many ions stopped by 1st electrode

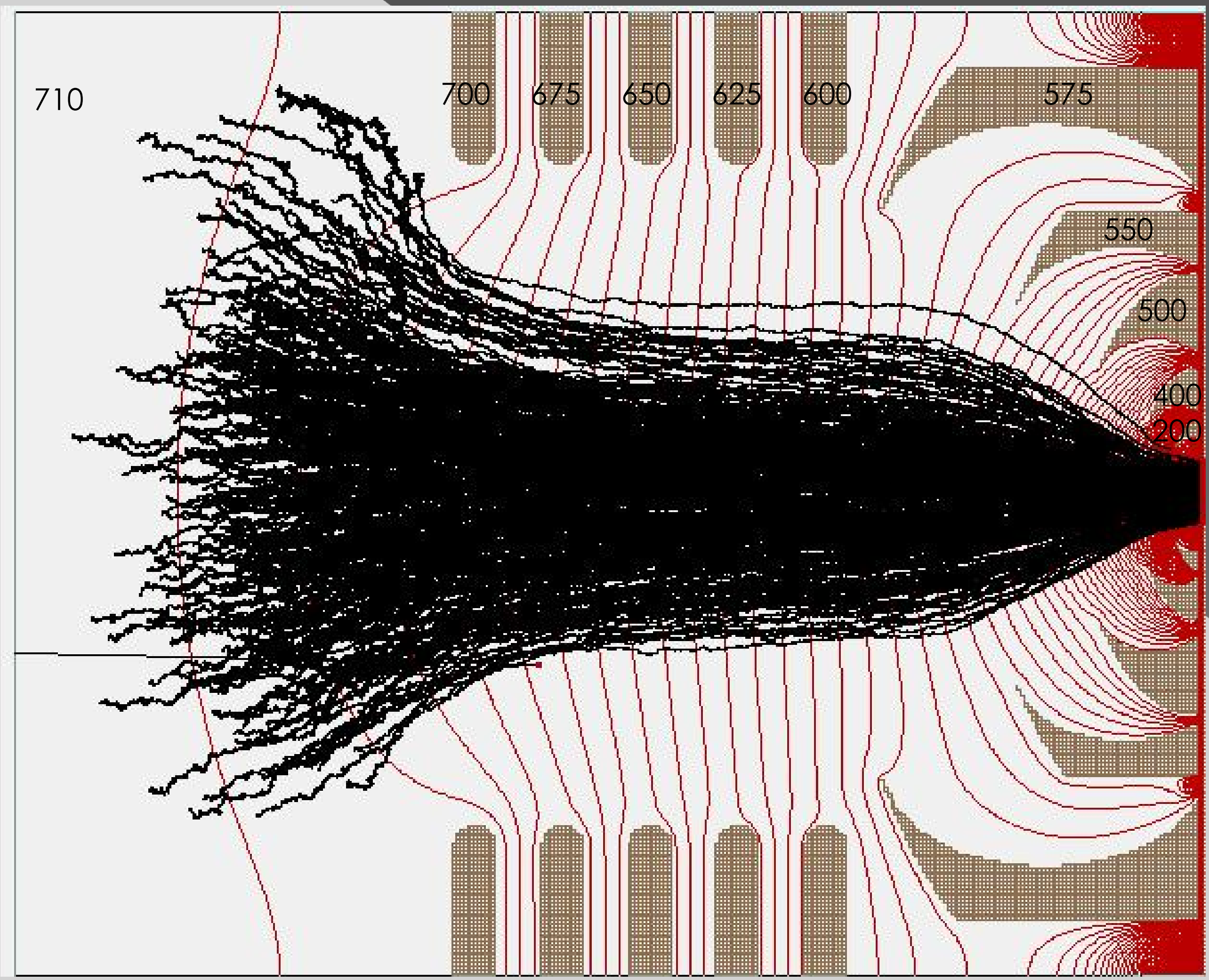


Not Enough Petal Focusing

- Lack of petal focusing



Addition of 5th Petal



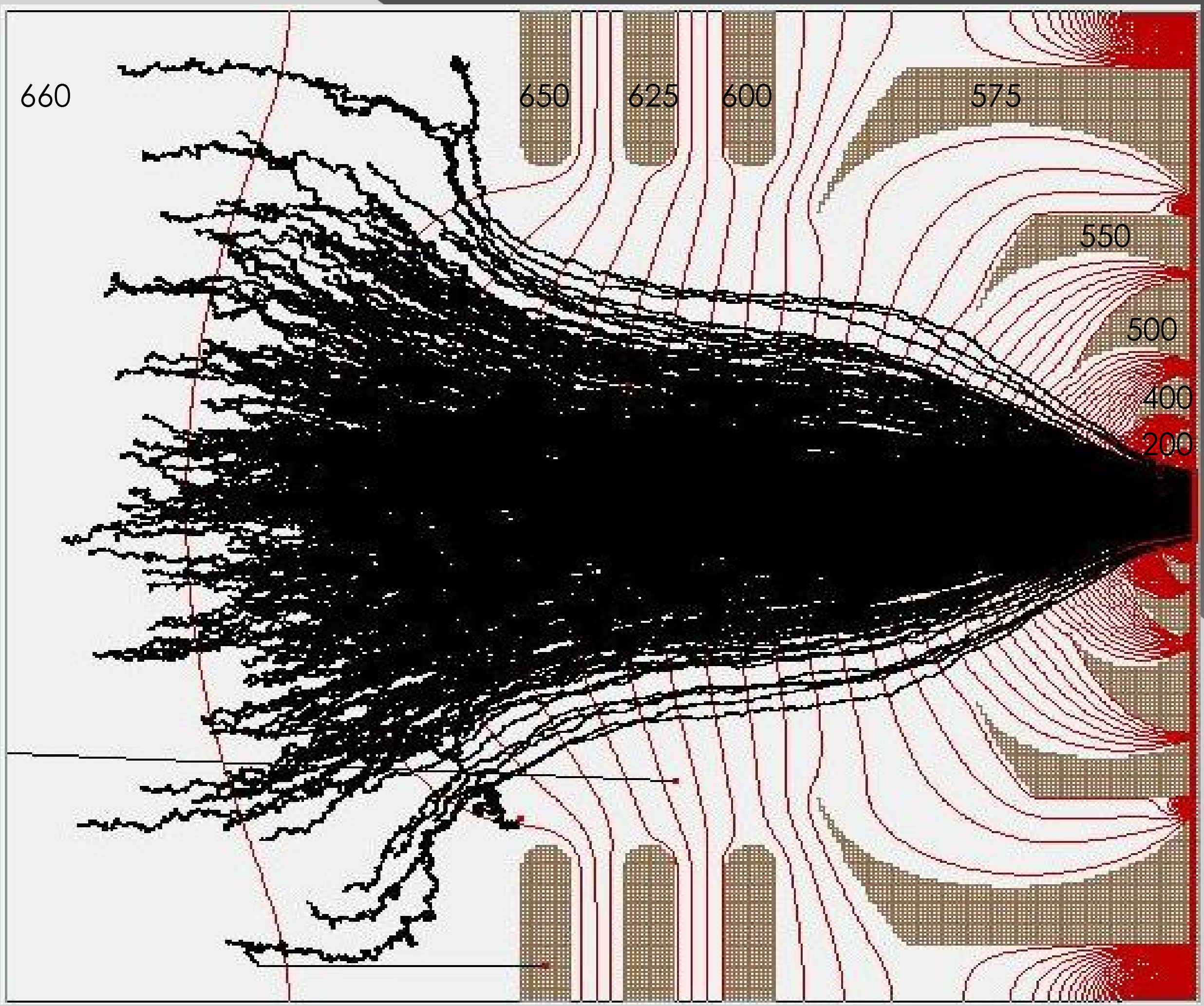
5 Ring

98% Survival

Need for all 5 Rings?

0.143 eV average kinetic energy

Eliminating 2 Rings



3 Ring

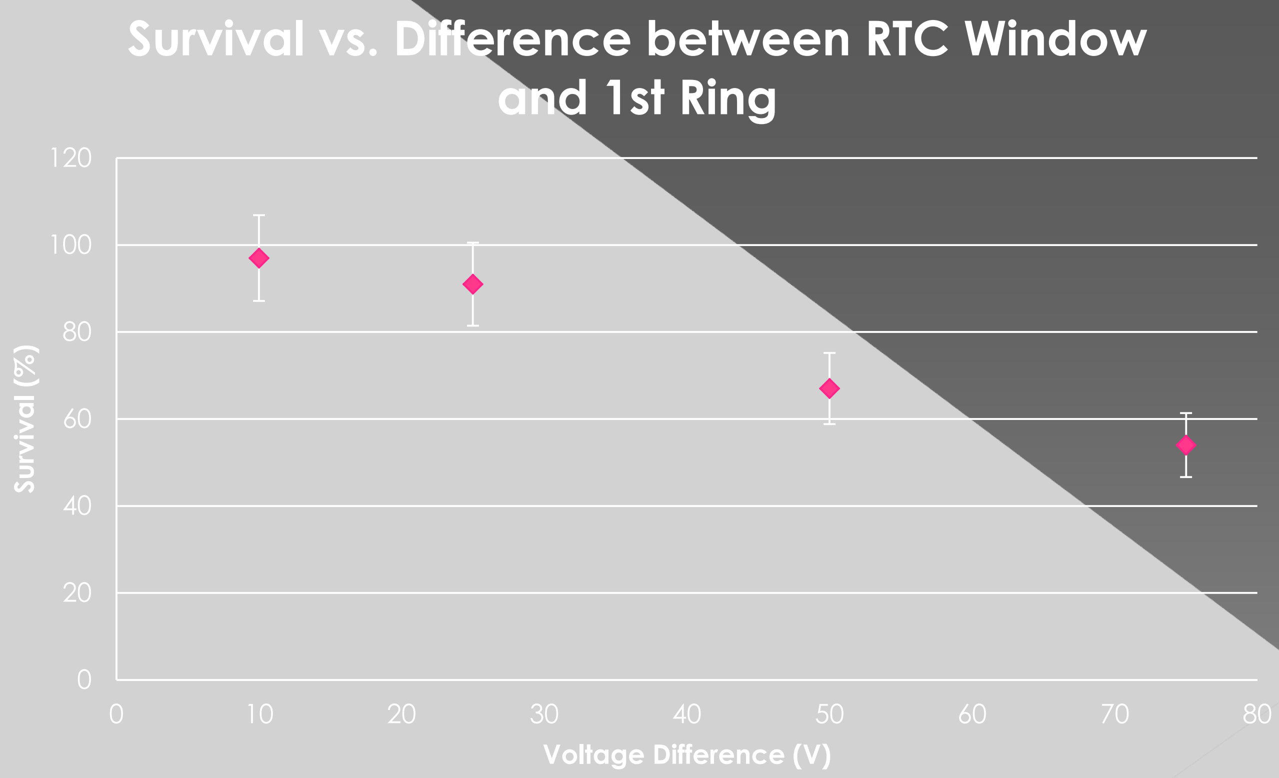
Makes the cell smaller

96% Survival

0.146 eV average kinetic energy

Difference between RTC Window and 1st Electrode

- Like before, less of a difference proves to be better



Conclusions

- An RTC window voltage was optimized at 710 V, then decreased down the length of the stopper
- Can decrease ions from ~3 MeV to ~0.14 eV in just 115.5 mm
- Ion spatial distribution decreased vertically from 17 mm to 1.5 mm and horizontally from 21 mm to 1.8 mm
- 3 ring electrodes is sufficient in steering the ions

Future Work

- Further simulate the gas cell for other similar elements, such as zirconium
- Fabricate and test the gas cell
- More sophisticated gas flow
- Charge exchange

Acknowledgements

- National Science Foundation
- Department of Energy
- Texas A&M Cyclotron Institute
- Dr. Sherry Yennello

- Special thanks to my advisor, Dr. Folden, and my graduate student mentor, Marisa Alfonso

Questions?