RFQ Status

Mathew Smith: UBC/TRIUMF
TITAN Collaboration meeting June 10th 2005

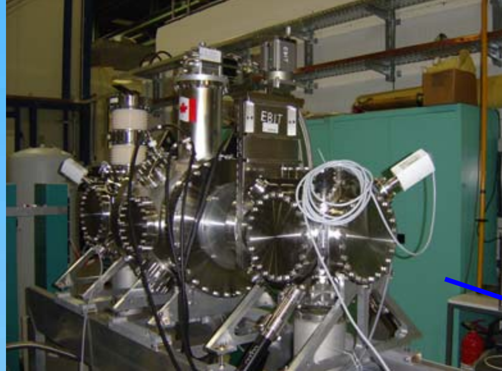
RFQ Status & Testing of the RFQ

Mathew Smith: UBC/TRIUMF
TITAN Collaboration meeting June 10th 2005

Overview

- TITAN
- Background
- Status of Simulations
- Status of RF Generator
- Status of Experimental Setup and Tests
- Summary

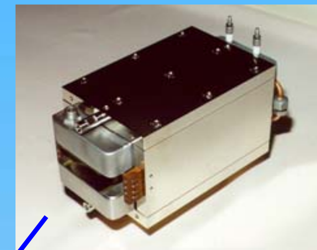
Max-Planck-Institut für Kernphysik

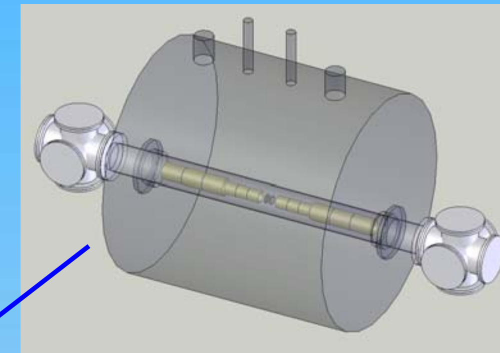


EBIT under testing at MPI-HD.
to TRIUMF Oct. 2005.

McGill

Wien filter
(R=500)

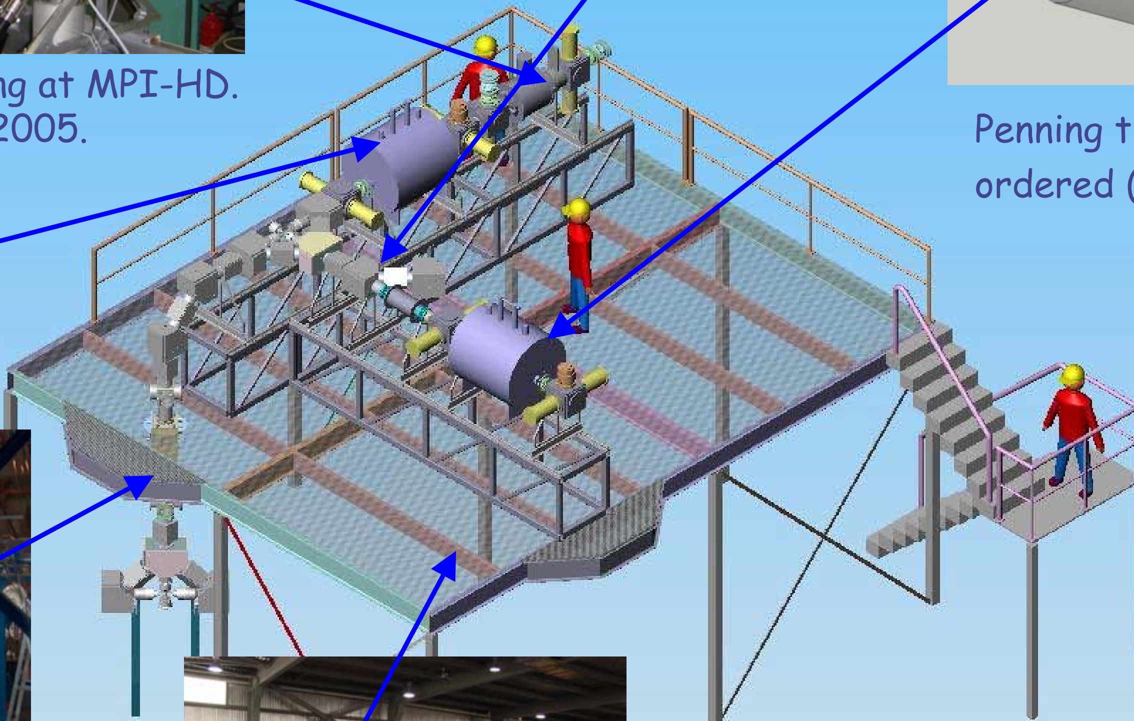


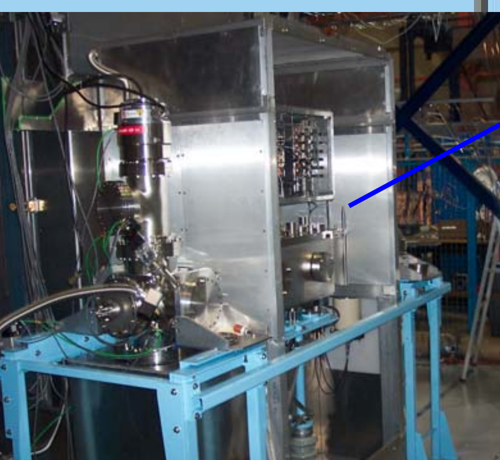


Penning trap magnet
ordered (del. Oct. 2005)

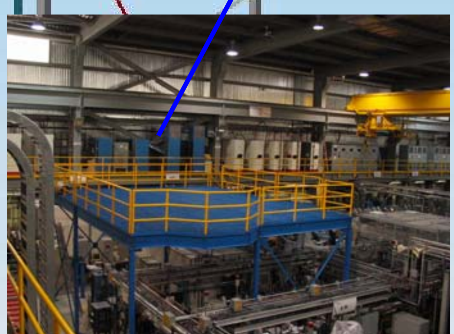
Cooler trap for HCI
(to be built in Manitoba,
CFI grant received)

university of manitoba





RFQ Subject of today's presentation

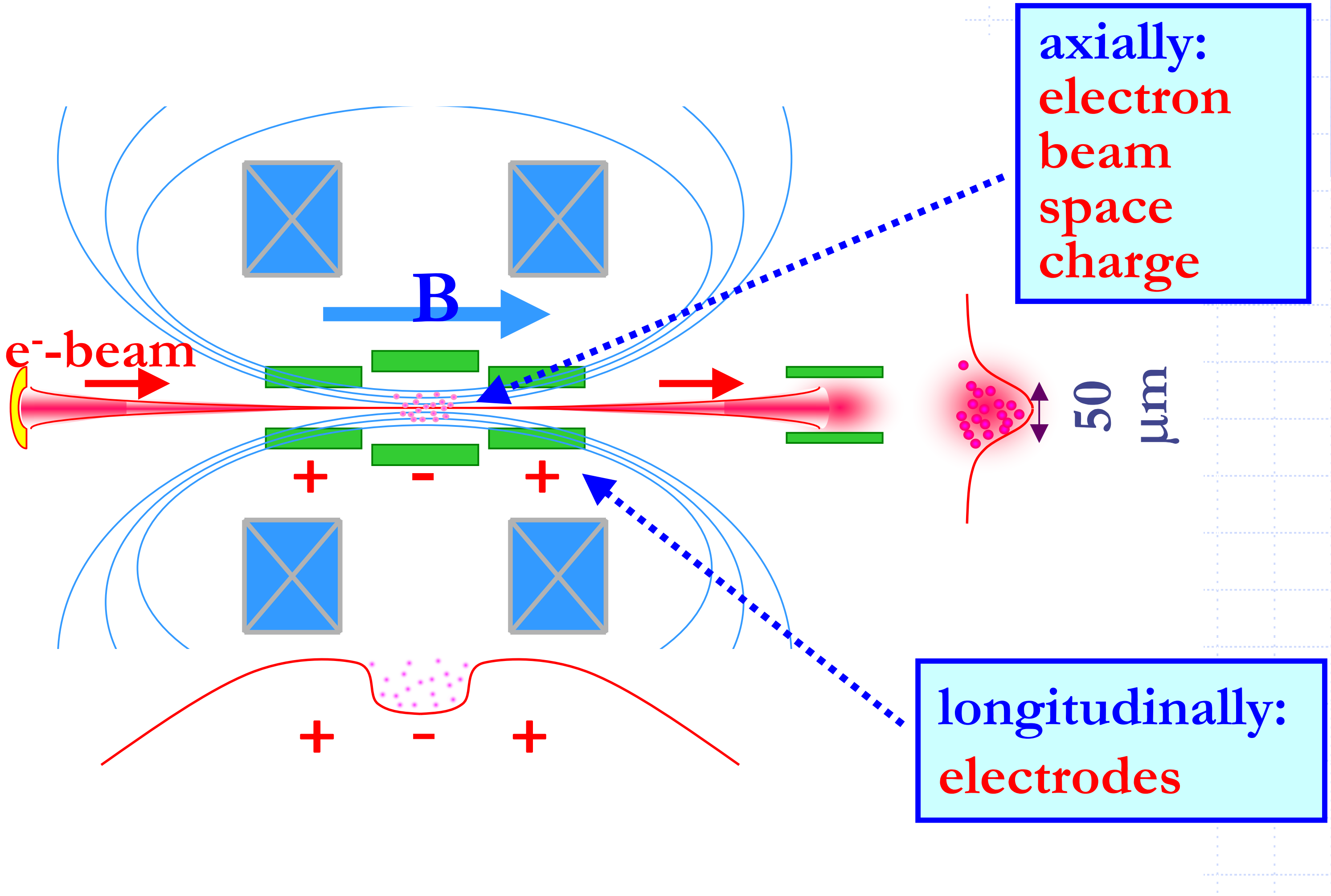


TITAN platform finished at ISAC

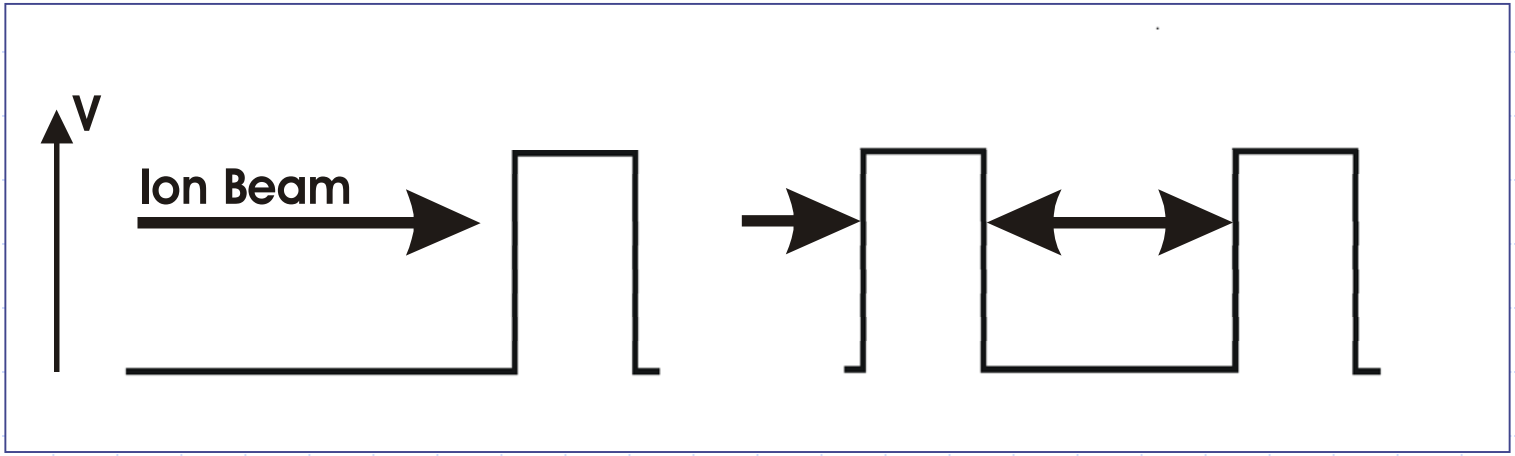
The TITAN system is under construction and will be operational for mass measurements at ISAC/TRIUMF in 2006.
Isotopes with $T_{1/2} \approx 10$ ms
$\delta m/m < 1 \cdot 10^{-8}$

TRIUMF ISAC

Why do we need a cooler and buncher?



Why do we need a cooler and buncher?



- EBIT cannot accept a continuous beam
- Low emittance needed in order to traverse magnetic field efficiently
- Therefore, we need to cool and bunch the ISAC beam

Why do we need an RFQ?

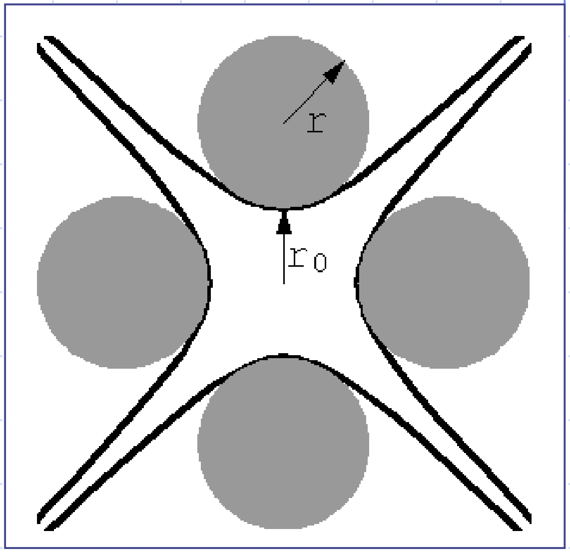
- Thermalization in three dimensions stops the ions in the gas
- Ions will disperse radially due to scattering of forward momentum
- Use RFQ ion trap to provide a force to counteract the dispersion
- Segmenting the RFQ allows for the application of a longitudinal field

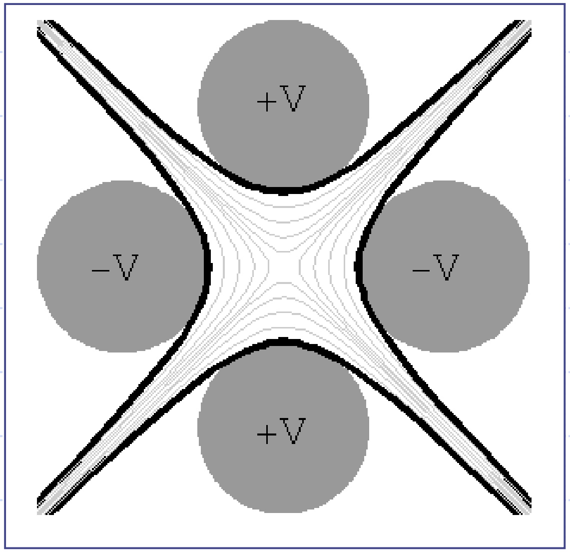
How does the RFQ work?

- Standard quadrupolar geometry focuses in one direction and defocuses in the other

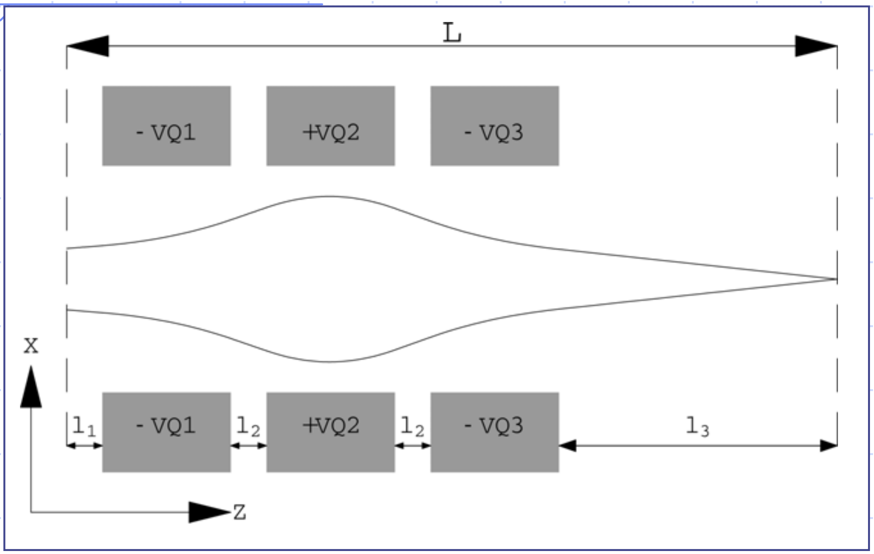
$$\phi = V\frac{(x^2 - y^2)}{r_0^2}$$

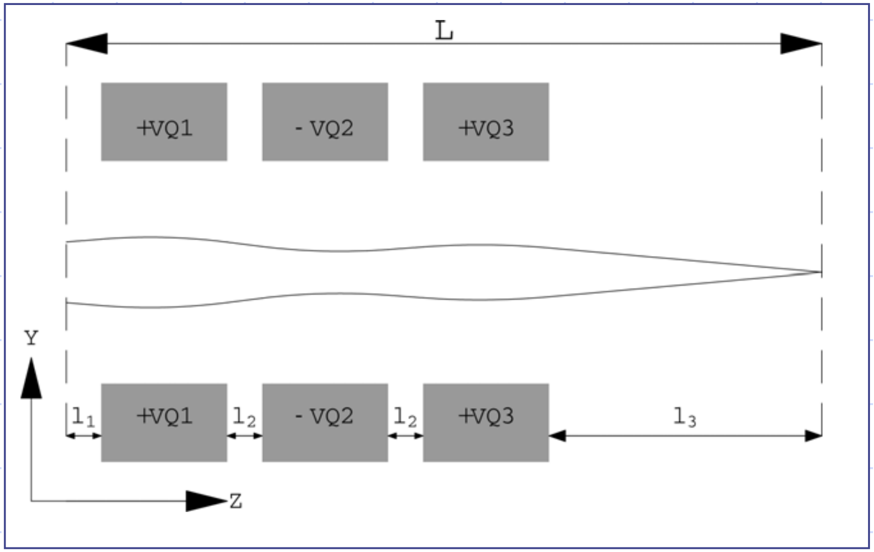
$$E_x = -\frac{2V}{r_0^2}x, \; E_y = \frac{2V}{r_0^2}y$$





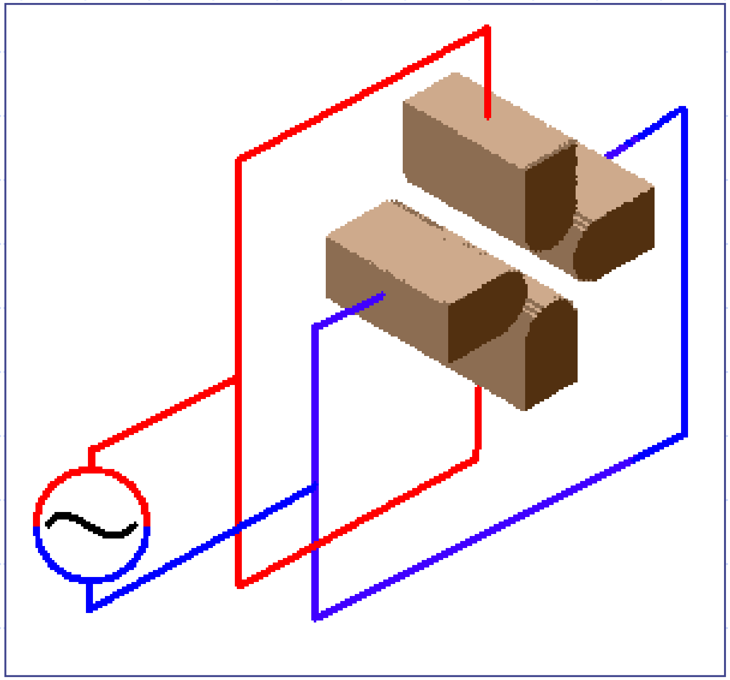
How does the RFQ work?





- However, it has long been known that by placing a series of quadrupoles together a net focusing force can be obtained e.g. in a quad triplet

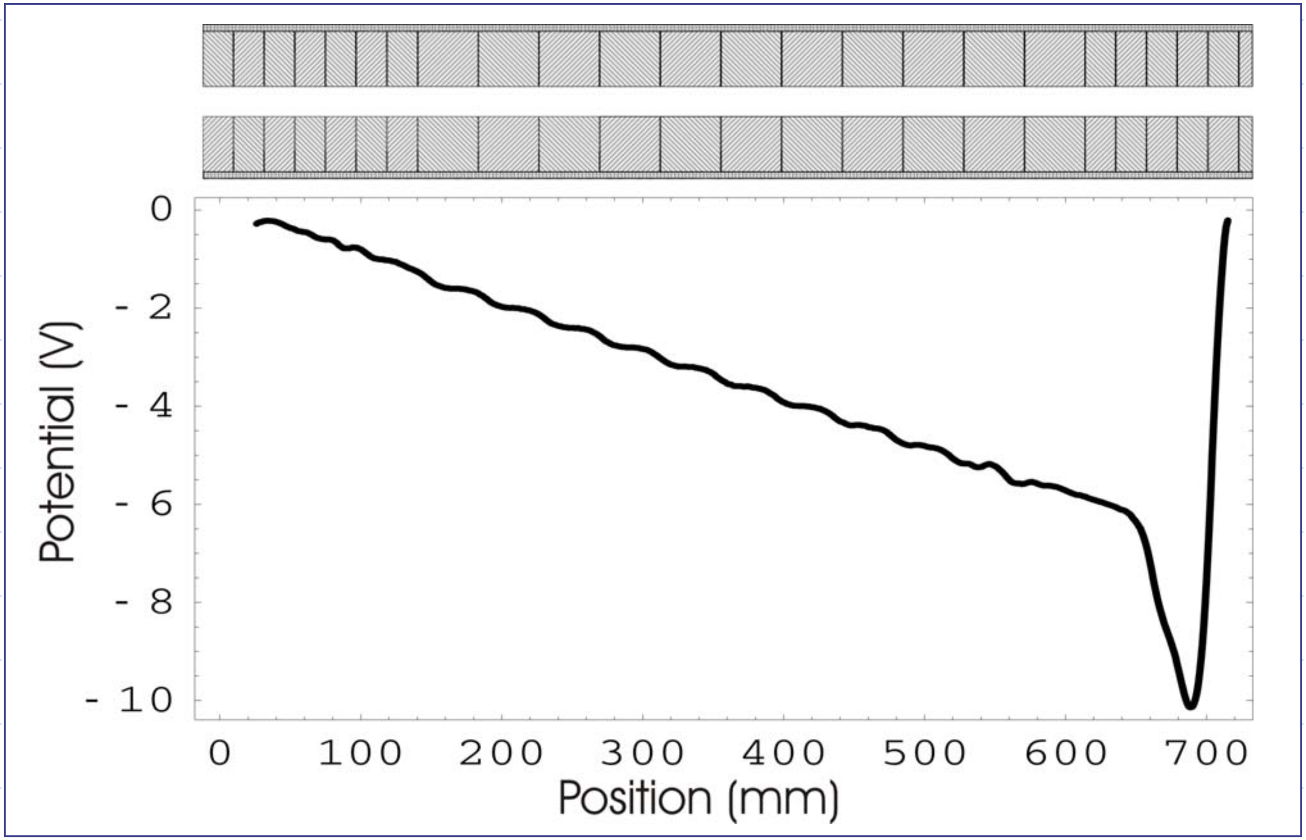
How does the RFQ work?



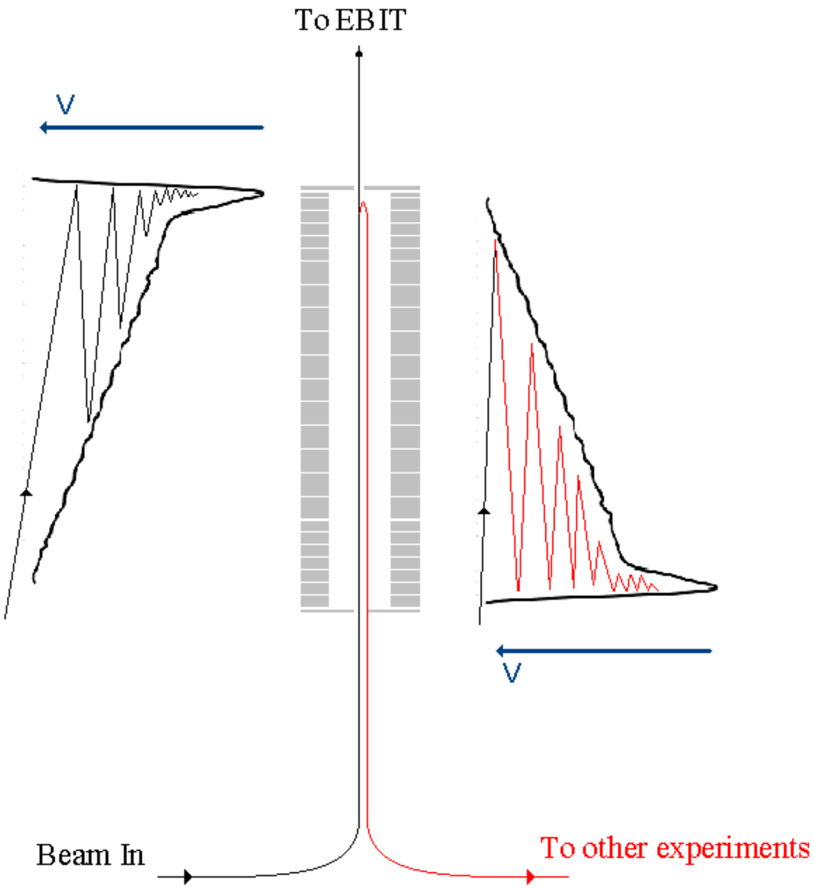
- Can use RF- potential to alternate the orientation of the focusing and defocusing directions
- Net focusing force is then independent of ions longitudinal velocity
- Form of periodic potential somewhat arbitrary, see: J. A. Richards et al., Int. J. Mass Spectrom. and Ion Phys. 12, 339 (1973).

How are beam bunches formed?

- By segmenting the structure we can also apply a longitudinal field and hence create bunches

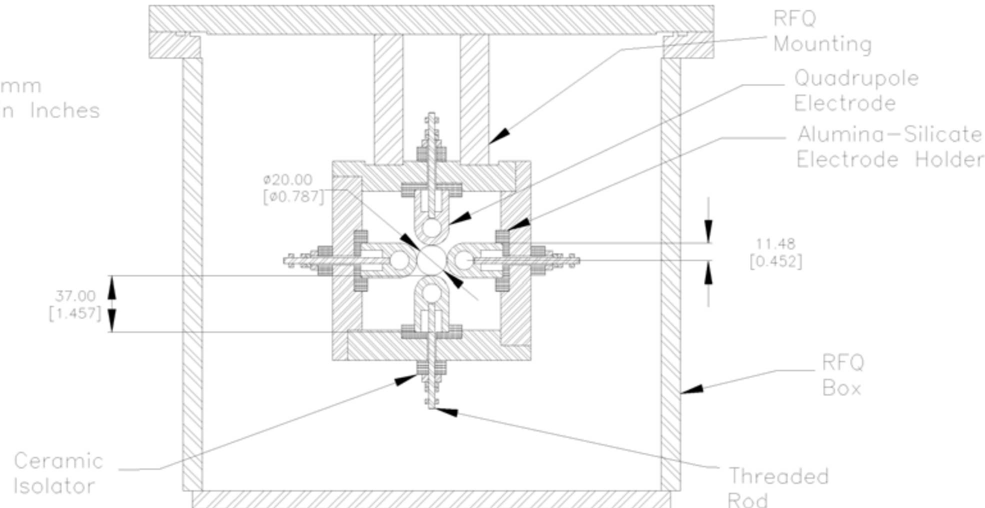


Concept



- Simple rod structure
- Square-wave-driven
- Extraction from both ends
- Separate DC offsets for each electrode

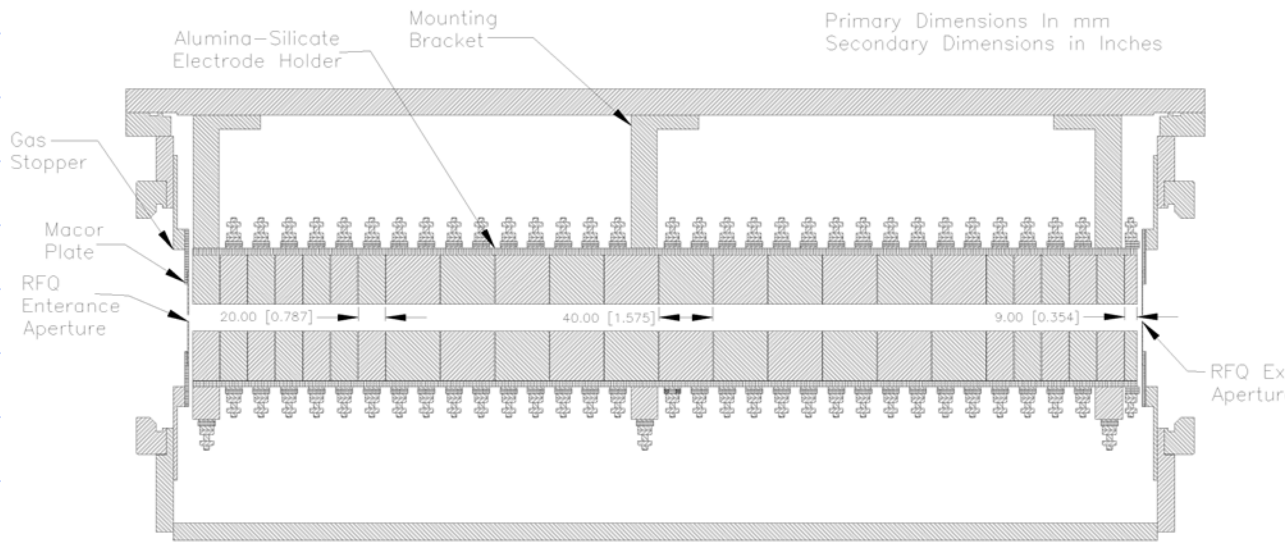
The RFQ Design



$L = 700$ mm

$r_0 = 10$mm

24 segments



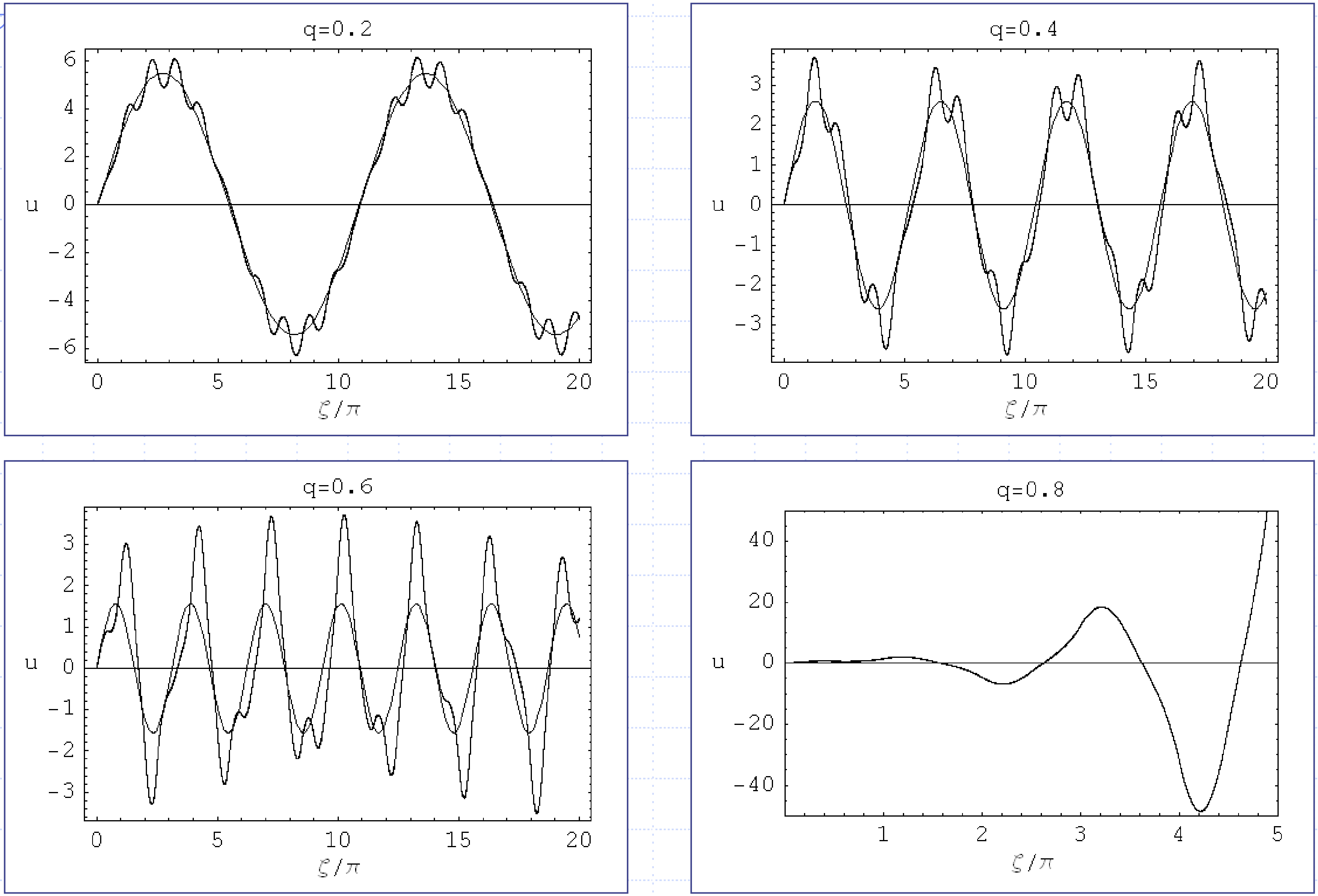
Properties of the RFQ from First Order Model

- Meissner equations determine ions motion in square-wave-driven trap:

$$\frac{\partial^2 x}{\partial \varsigma^2} - 2qx = 0, \quad \frac{\partial^2 y}{\partial \varsigma^2} + 2qy = 0, \quad \varsigma = \frac{\omega t}{2}.$$

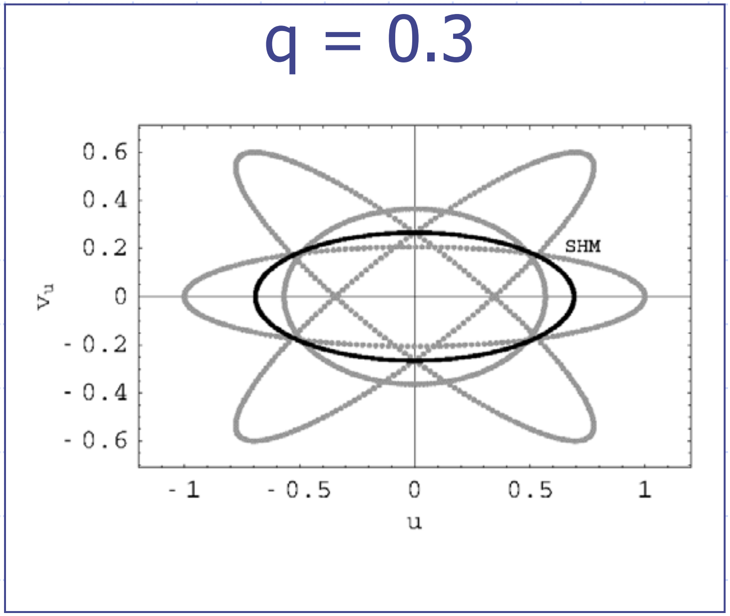
- Analytic solution shows a simple harmonic macro-motion perturbed by a coherent micro-motion
- As q increases so does the amplitude of the micro-motion until at q = 0.712 the motion becomes unbound

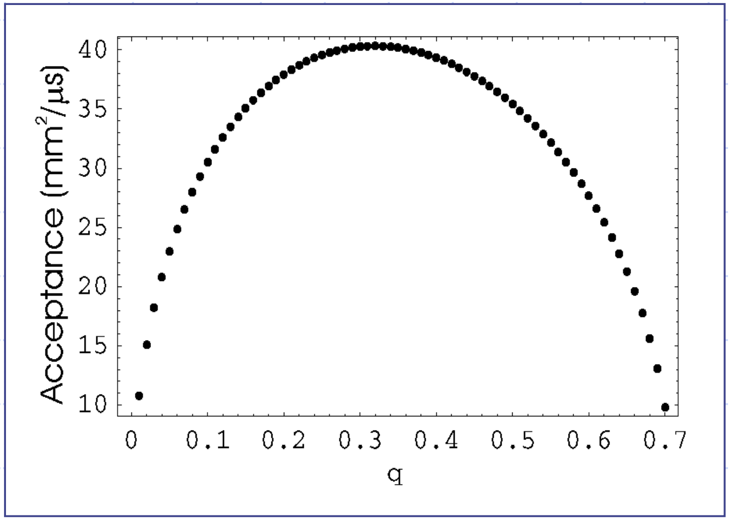
Properties of the RFQ from First Order Model



In Phase Space

- Micro-motion distorts ideal harmonic ellipse
- Acceptance defined as area of harmonic ellipse whose maximum distorted amplitude = r_0
- Acceptance varies as a function of q with a maximum at $q \approx 0.3$



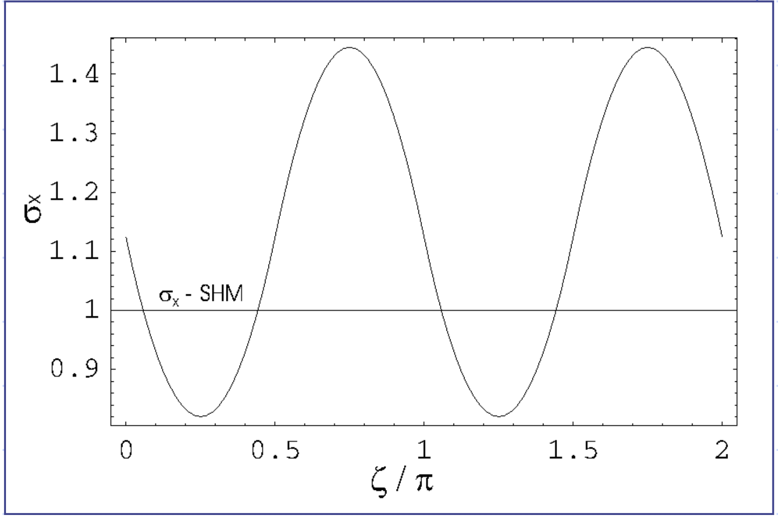


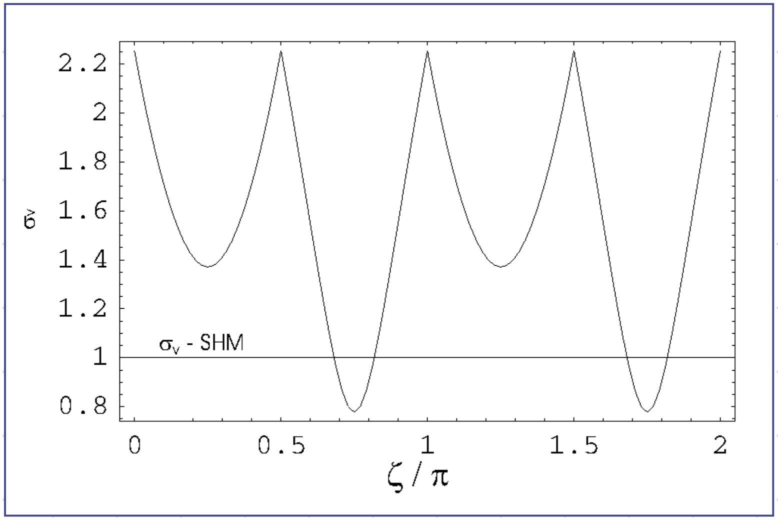
Temperature

- Micro-motion is coherent and therefore doesn't contribute to the temperature of the ions in the trap
- Temperature of an ion cloud in a harmonic potential can be defined in terms of the standard deviation in position and momentum space:

$$\sigma_u = \frac{1}{\omega_s}\sqrt{\frac{kT}{m}}, \quad \sigma_v = \sqrt{mkT}.$$

- Can use information from ellipses to convert from σ_x and σ_v as a function of phase/time to σ_x-SHM and σ_v-SHM and hence define temperature





Space-Charge Limit

- Can use amplitude of harmonic motion combined with secular frequency to define the depth of the psuedopotential
- Use simple model for the beam to get an idea of the space charge limit
- In continuous mode consider beam to be an infinitely long cylinder
- In bunched mode consider bunch to be a perfect sphere

$$E_{ps} = -\frac{m}{ze}\omega_s^2 r_{\max}$$

For Cylinder:

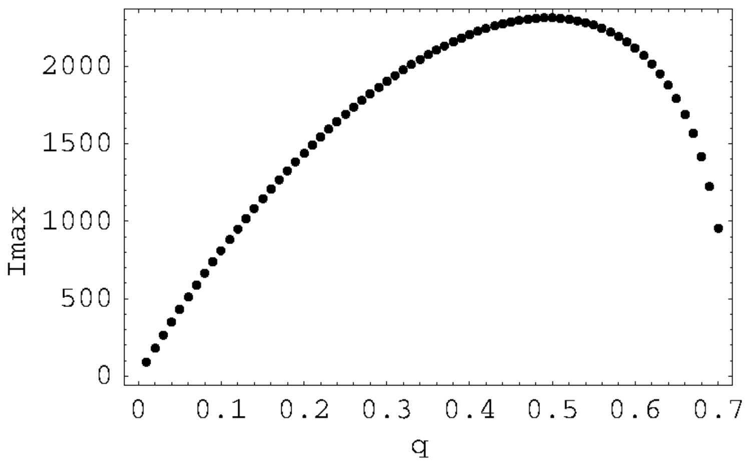
$$E_{sc} = \frac{\lambda}{2\pi\varepsilon_0 r}, \lambda = \frac{I}{V_d}$$

For Sphere:

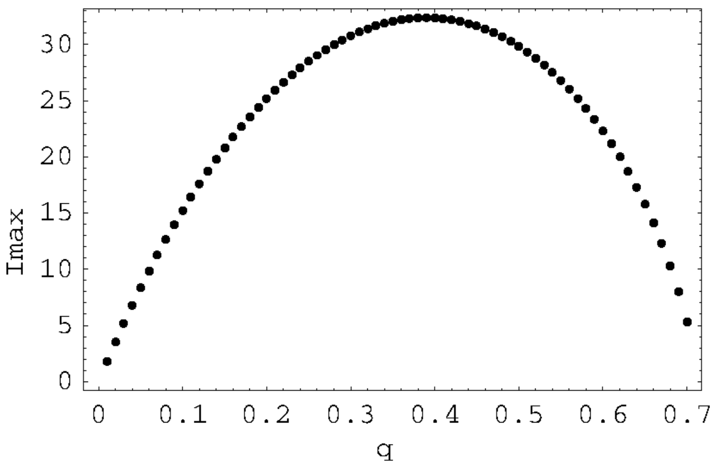
$$E_{sc} = \frac{Q}{4\pi\varepsilon_0 R^2}$$

Space Charge Limit

Continuous, Vd = 1000 m/s



Bunched, t = 1 ms



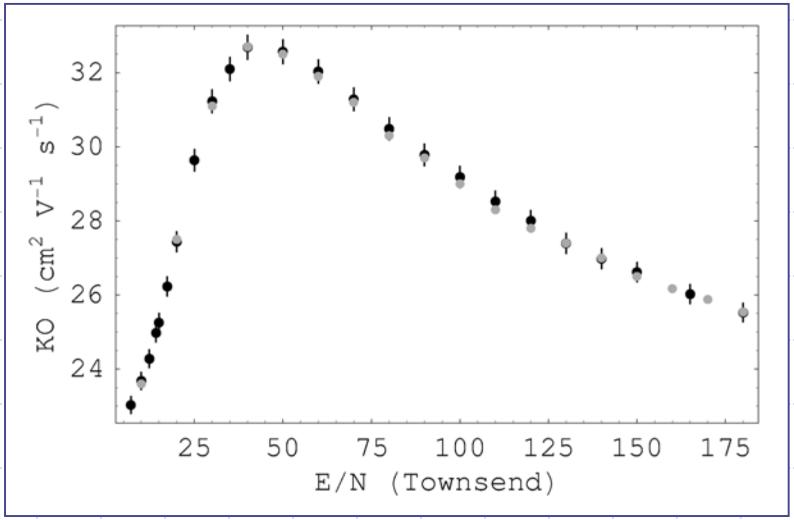
- In continuous mode I_{max} ≈ 2.3 μA, @ q = 0.49
- In bunched mode Q_{max} ≈ 3.2 pC, @ q = 0.39

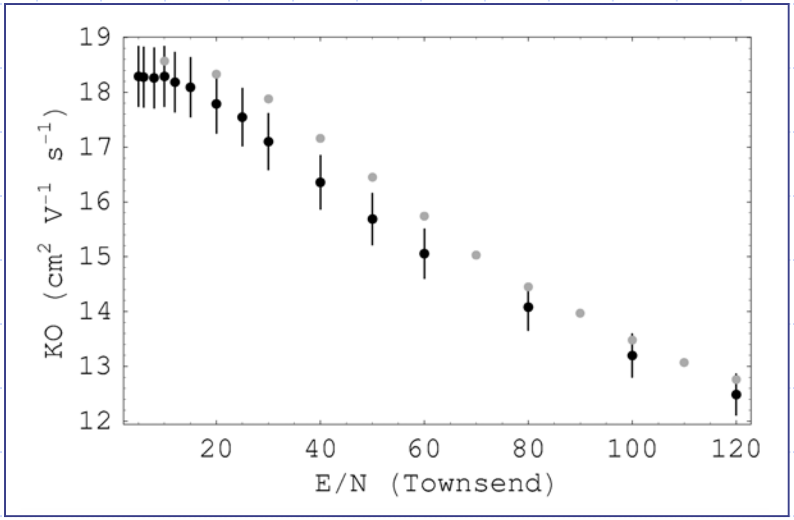
Status of Simulations

- Used SIMION to define geometry and simulate electric fields
- Initially used viscous drag model to simulate ion ranges & cooling times
- User program developed that contains a Monte Carlo algorithm to simulate the ion interaction with the buffer gas
- Uses realistic ion-atom interaction potentials
- Runs in SIMION or separately in C
- Tested by using to recreate experimental results for the mobility of ions in the gas

Status of Simulations

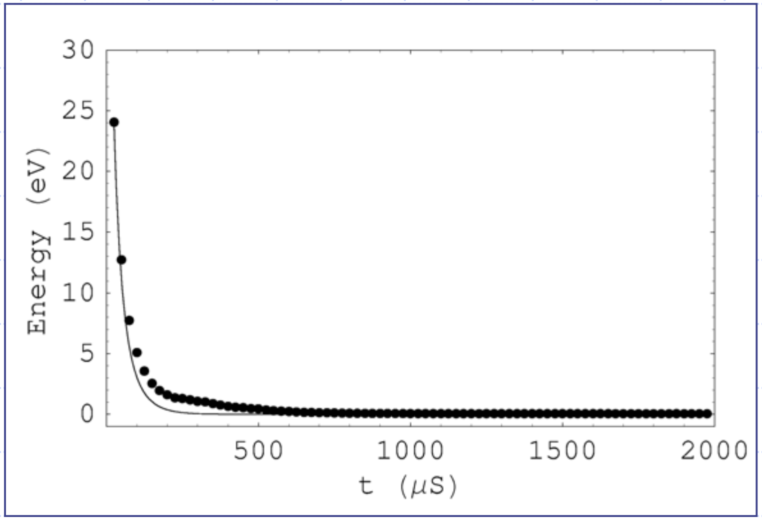
- Lithium in helium perfect agreement
- Cesium in helium some small discrepancies
- Li^+-He interaction potential well known with ab-initio calculations possible
- Cs^+-He simple (8,6,4) potential used. Much disagreement about the proper form in the literature



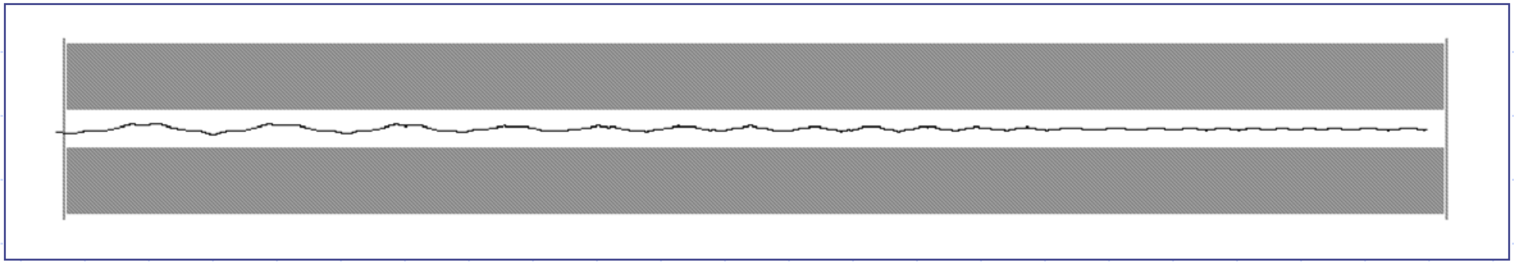


Modeling Buffer-gas Cooling: Monte Carlo

- Simulation of cooling of Cs^+ in 2×10^{-2} mbar of He
- Segmented into 24 pieces with longitudinal potential previously shown
- Transfer of beam with 98% efficiency

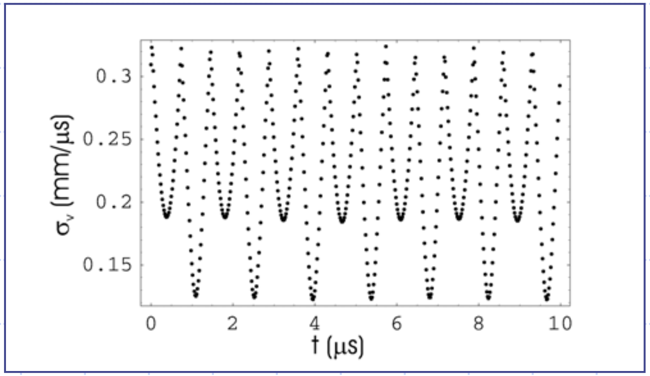


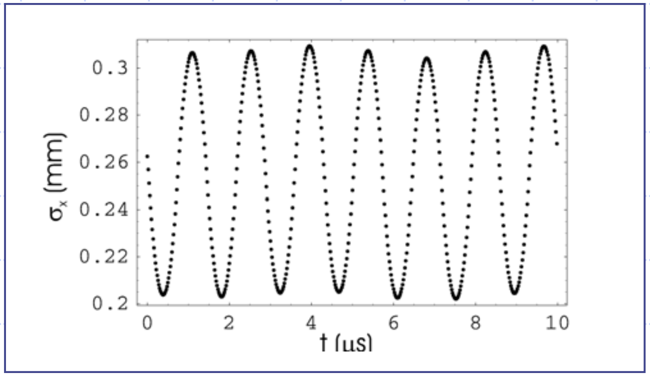
- Cooling time approx. 2 x longer than that from simple drag model

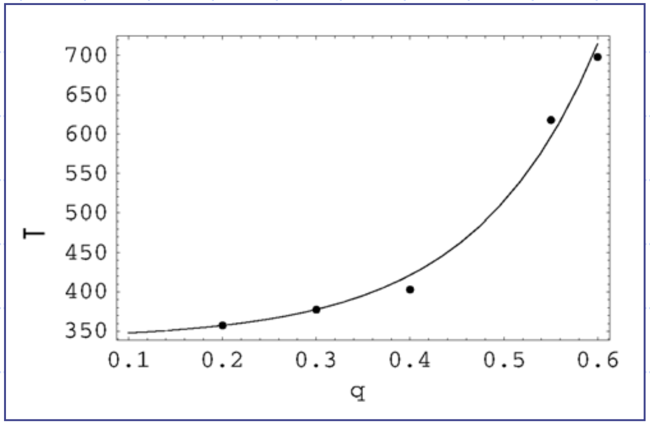


Modeling Buffer-gas Cooling: Monte Carlo

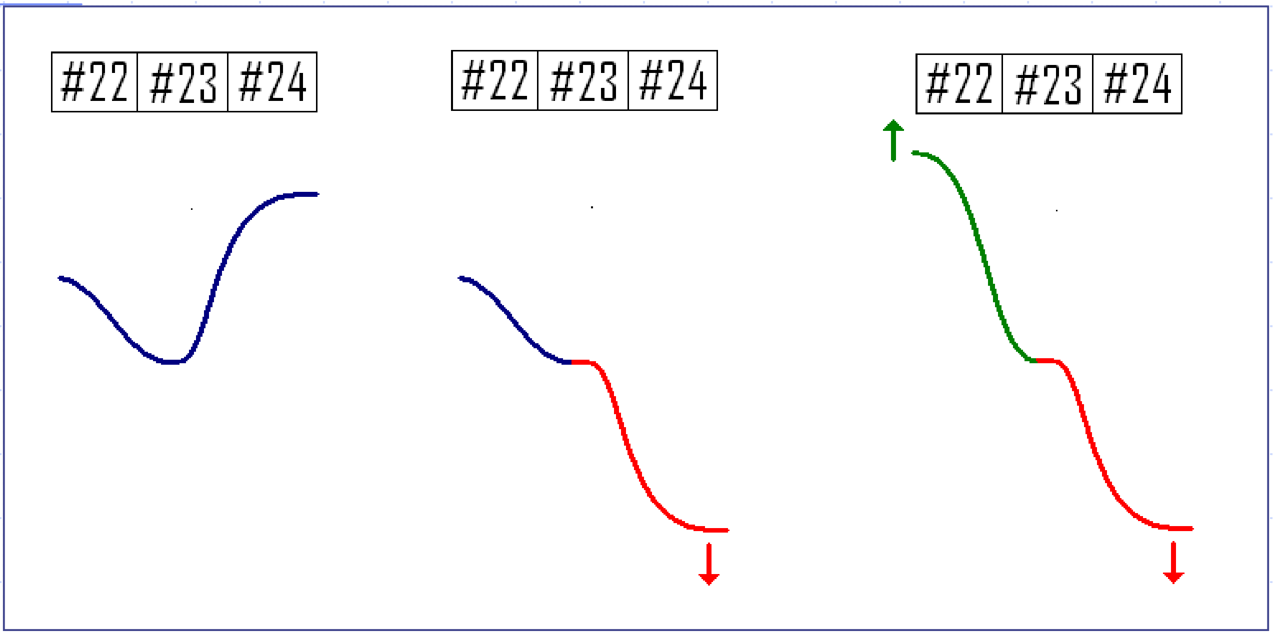
- Ions initialized in trap with T = 800 K
- Cooled for 500 μs and then data recorded in 0.02 μs intervals for 10 μs
- Plot of temperature as a function of q shows the effects of RF-heating
- Space-charge not yet included so represents a minimum possible temperature







Extraction Methods

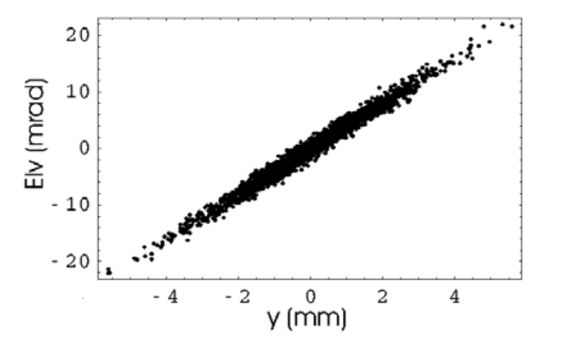


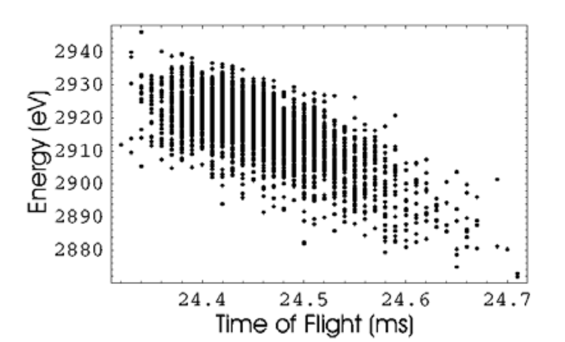
- In absence of buffer-gas expect all bunches to have the same longitudinal and transverse emittances
- First extraction method releases ions with a small energy spread and large time of flight spread
- Second method reduces time of flight spread but increases energy spread

Simulated Beam Properties

ΔV_{22} (V)	ΔV_{24} (V)	$\varepsilon_{t_{rms}}$ (π mm mrad)	$\varepsilon_{l_{rms}}$ (eV/μs)	σ_{ti} (μs)	σ_{en} (eV)
0	-30	3.3±0.3	4.7±0.2	1.13	1.04
0	-60	4.2±0.1	7.4±0.3	0.78	2.42
30	-30	3.8±0.2	1.3±0.1	0.28	1.31
60	-60	3.6±0.1	1.4±0.1	0.15	2.48
500	-500	4.8±0.2	1.8±0.1	0.06	10.20

$$\varepsilon_{rms} = 4\sqrt{\langle x^2\rangle\langle \dot{x}^2\rangle - \langle x\dot{x}\rangle^2}$$





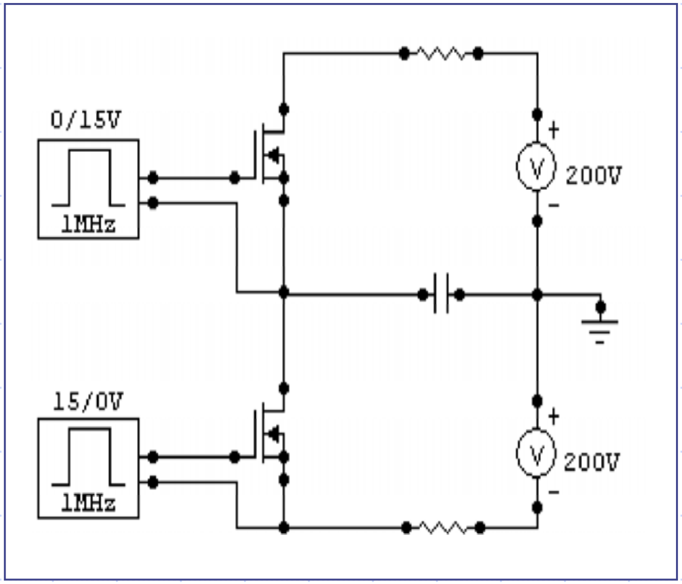
- Cooling times on the order of 1-2 ms
- Buffer-gas heats beam so emittances not constant
- Kicking the ions hard out of the trap reduces time of flight spread and increases energy spread
- ε_{rms} = 3 π mm mrad @ 2.5 kV
- Doesn't include space charge which becomes important for >10^6 ions in the trap

The Square-Wave RF Generator

$$q = \frac{4zeV}{m\omega^2 r_0^2},$$

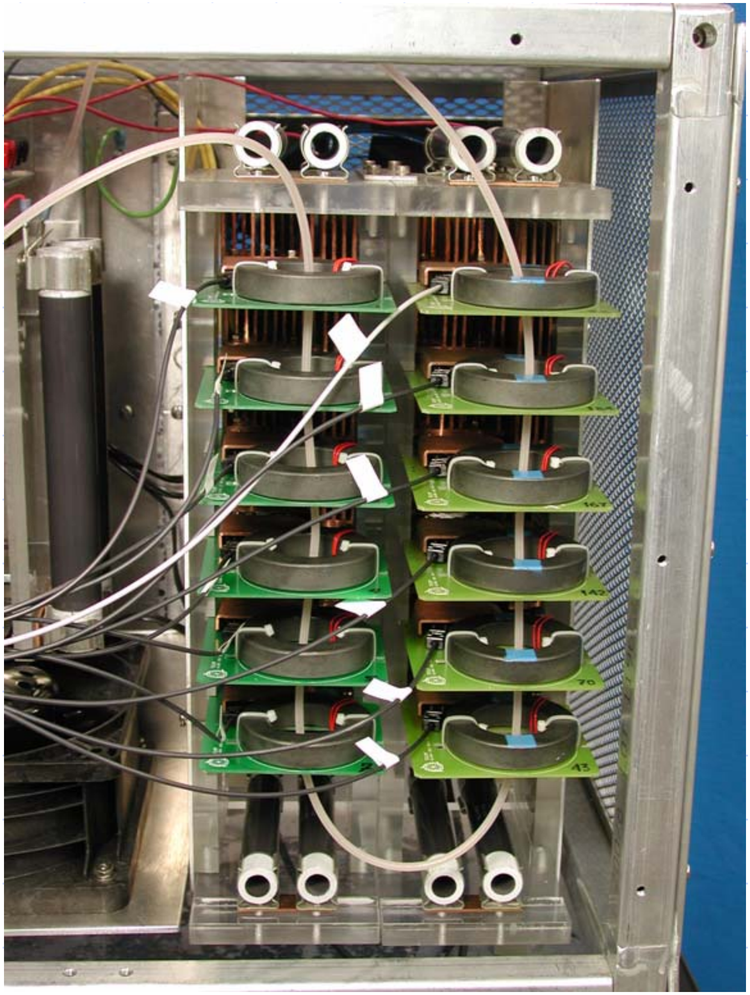
Sine-Wave q<0.908 Stable, q≈0.4 best.

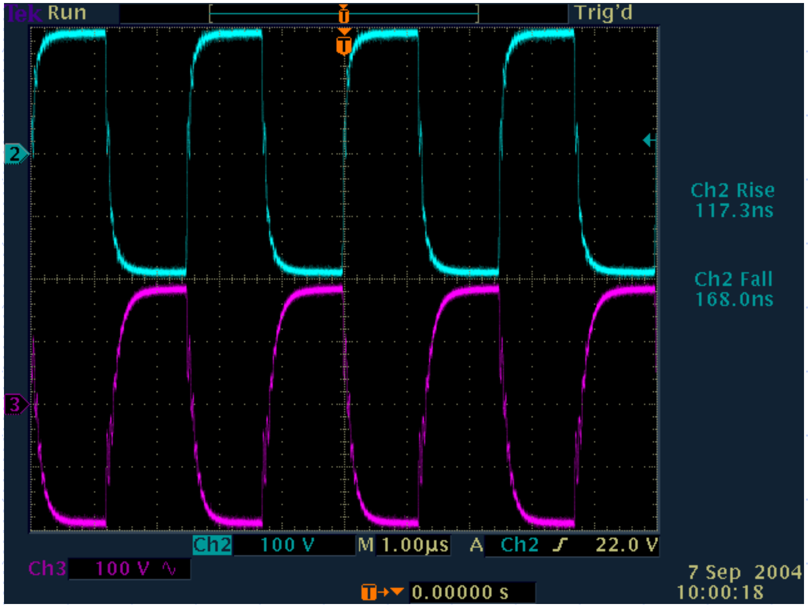
Square-Wave q<0.712 Stable, q≈0.3 best.



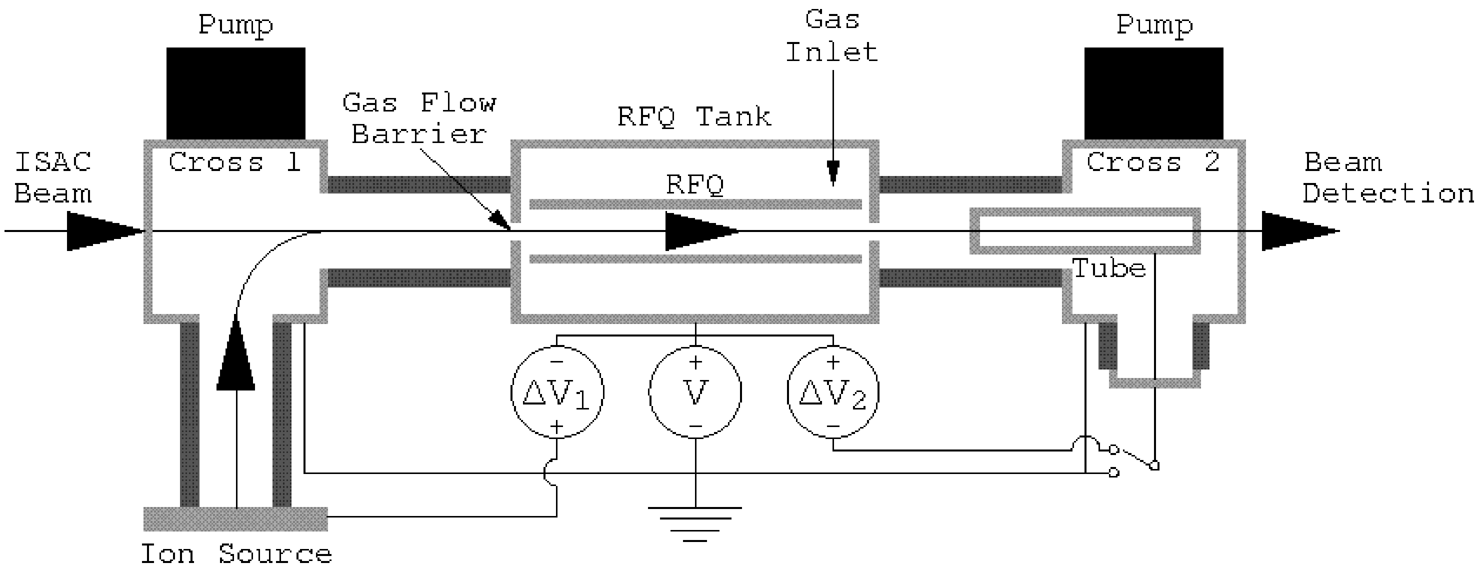
- $7 \le m \le 235$ u, $0.4 \le f \le 3$ MHz @ 400 V_{pp}, r_0 = 10 mm
- First system in use: V_{pp} = 400 V, f = 1 MHz ($m \ge 65$)
- Second version designed and tested: V_{pp} = 600 V, f = 3 MHz

The Square-Wave Driver



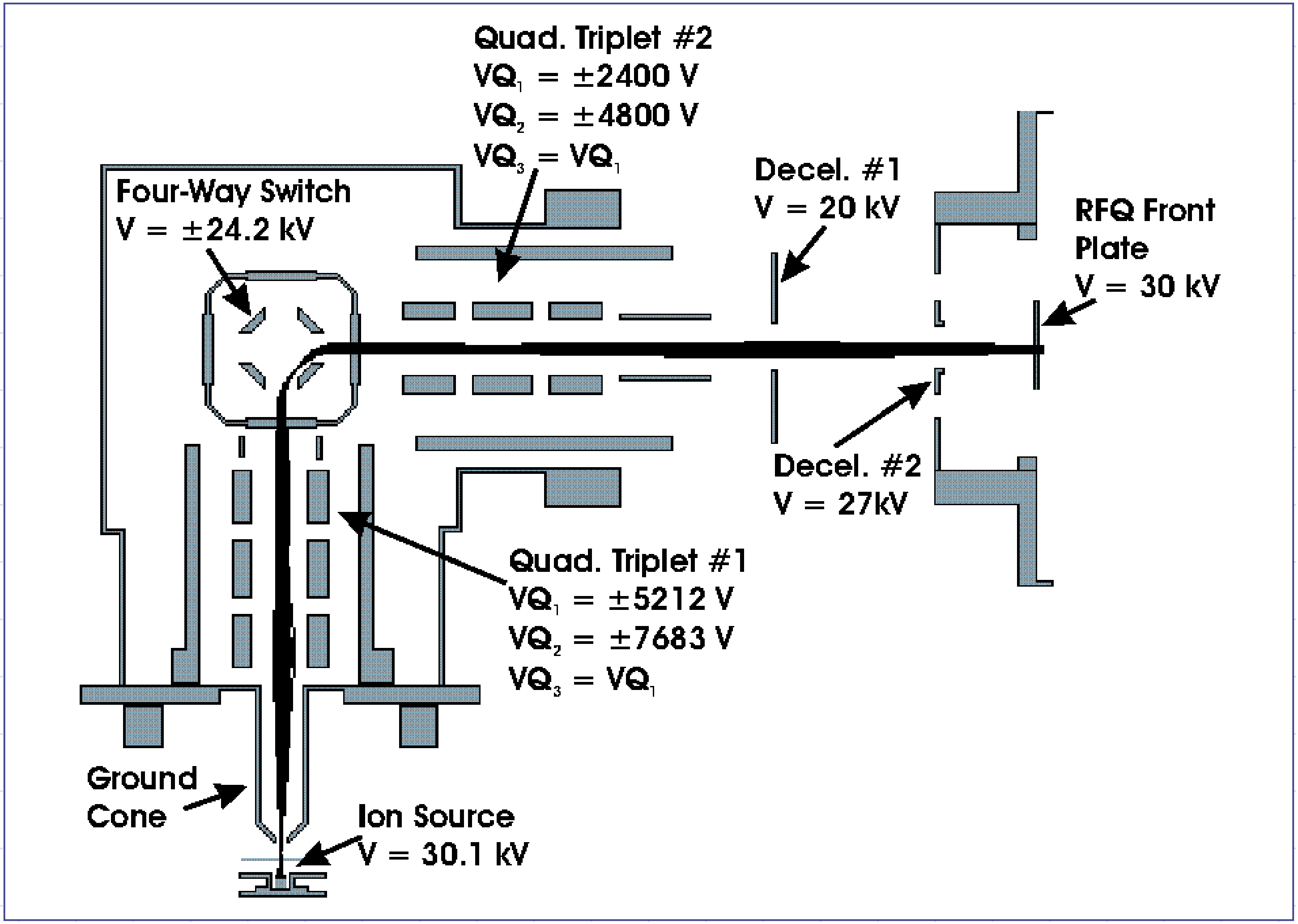


Test Setup

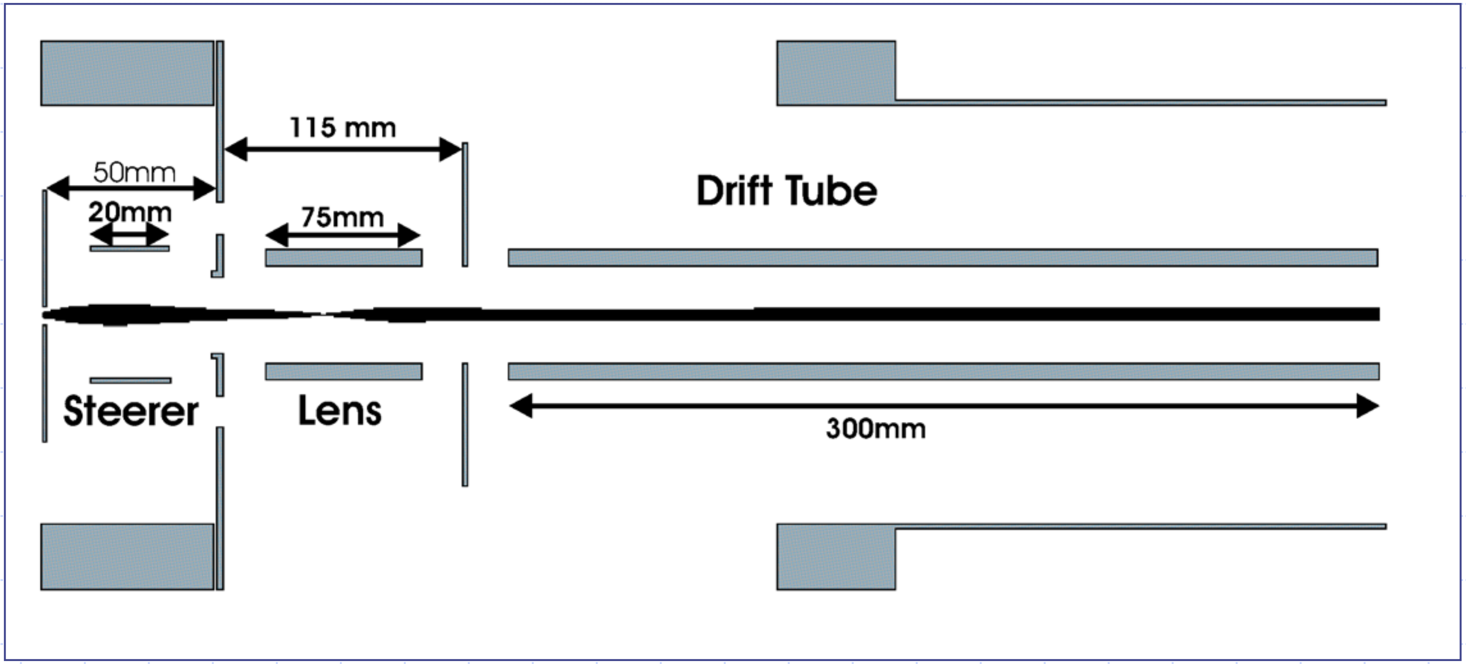


- The purpose of the test setup is to provide a test ion beam with properties similar to the ISAC beam
- Allows us to optimize the RFQ performance before installation at ISAC

Injection Optics

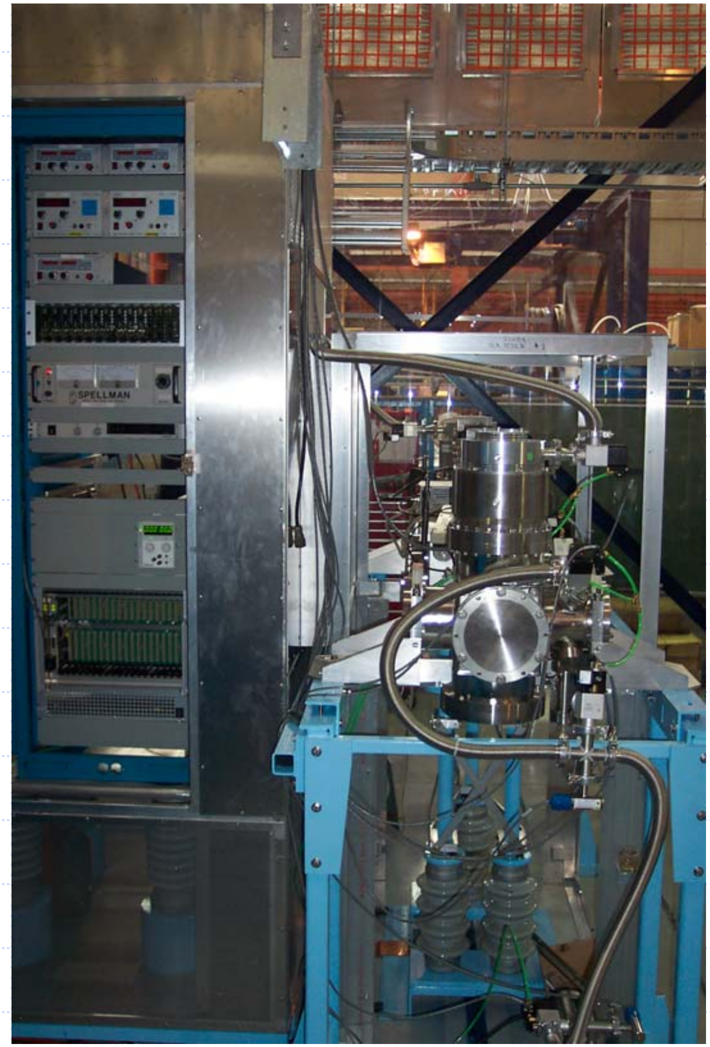


Extraction Optics

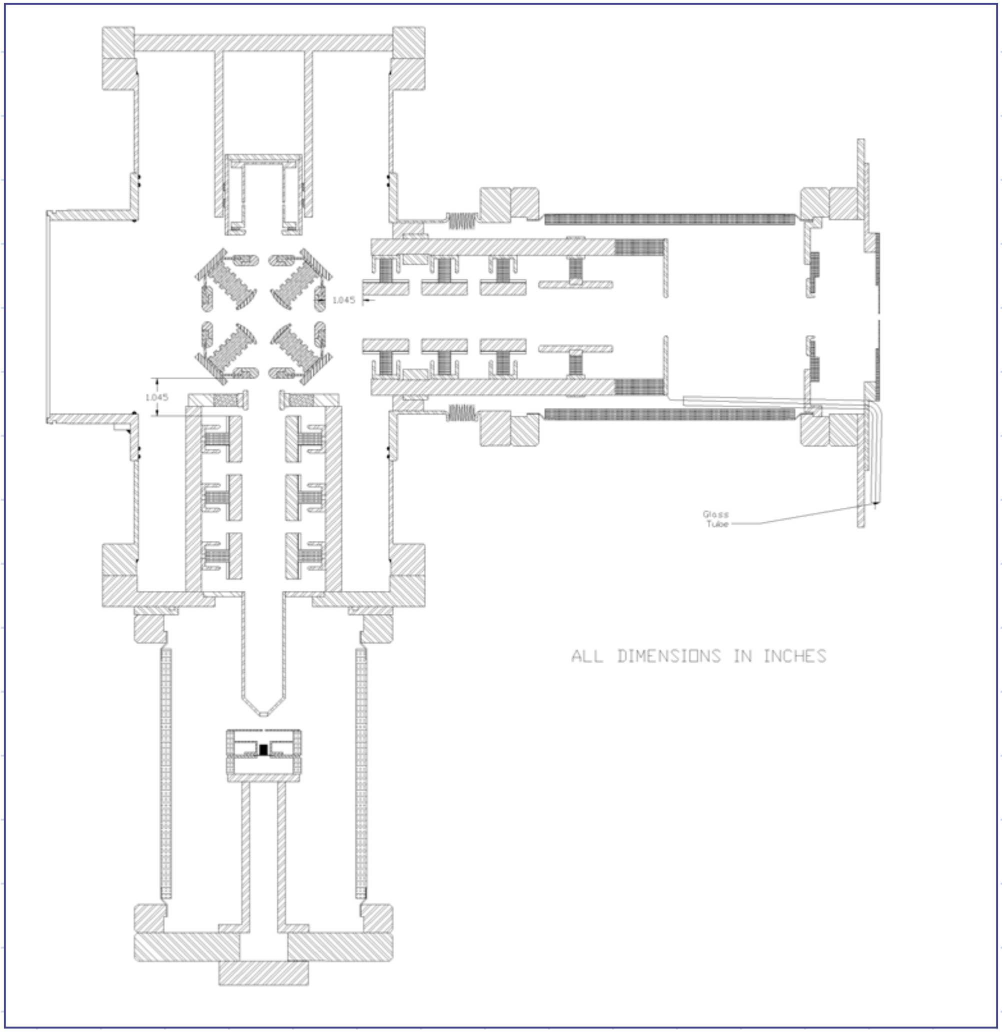


Experimental Setup

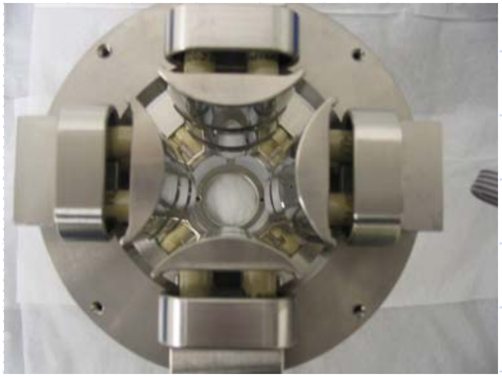
Experimental Setup

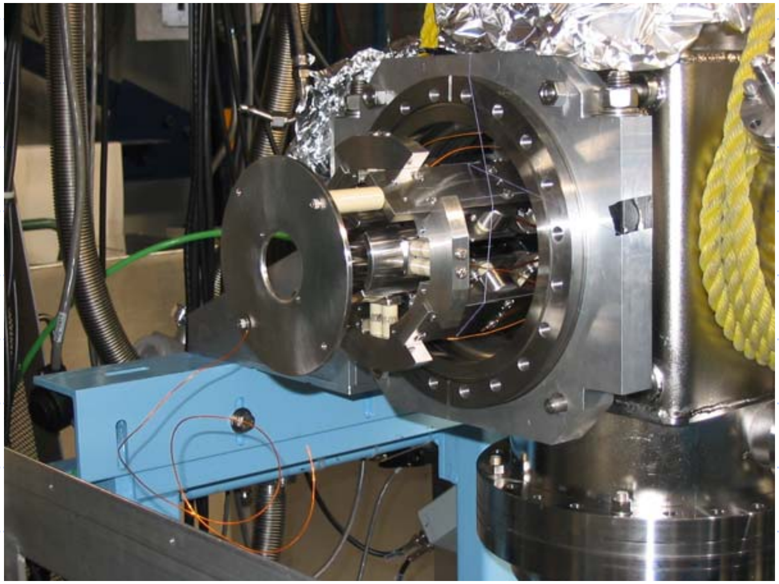


Experimental Setup: Injection



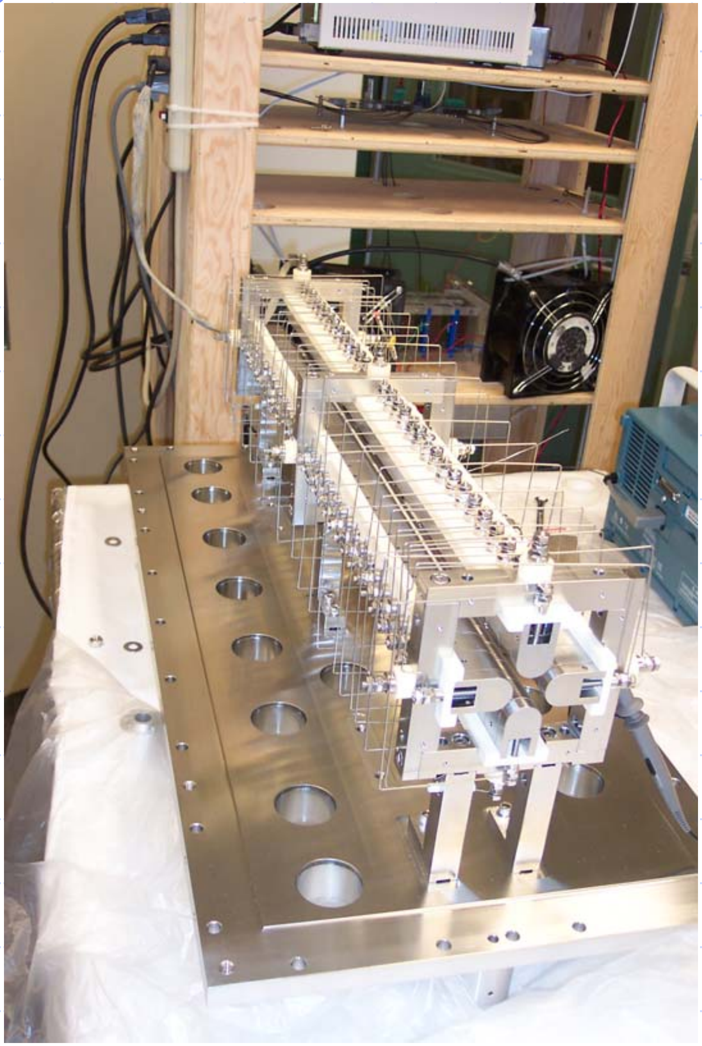
Experimental Setup: Injection

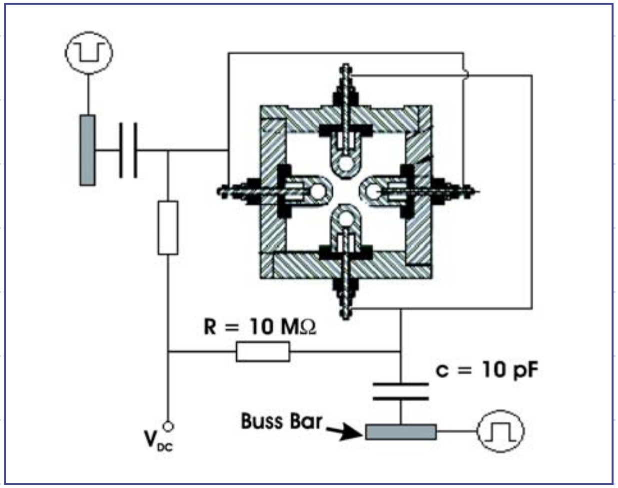




- Beam through four-way switch with approx. 100% efficiency
- Beam into RFQ with approx. 95% efficiency

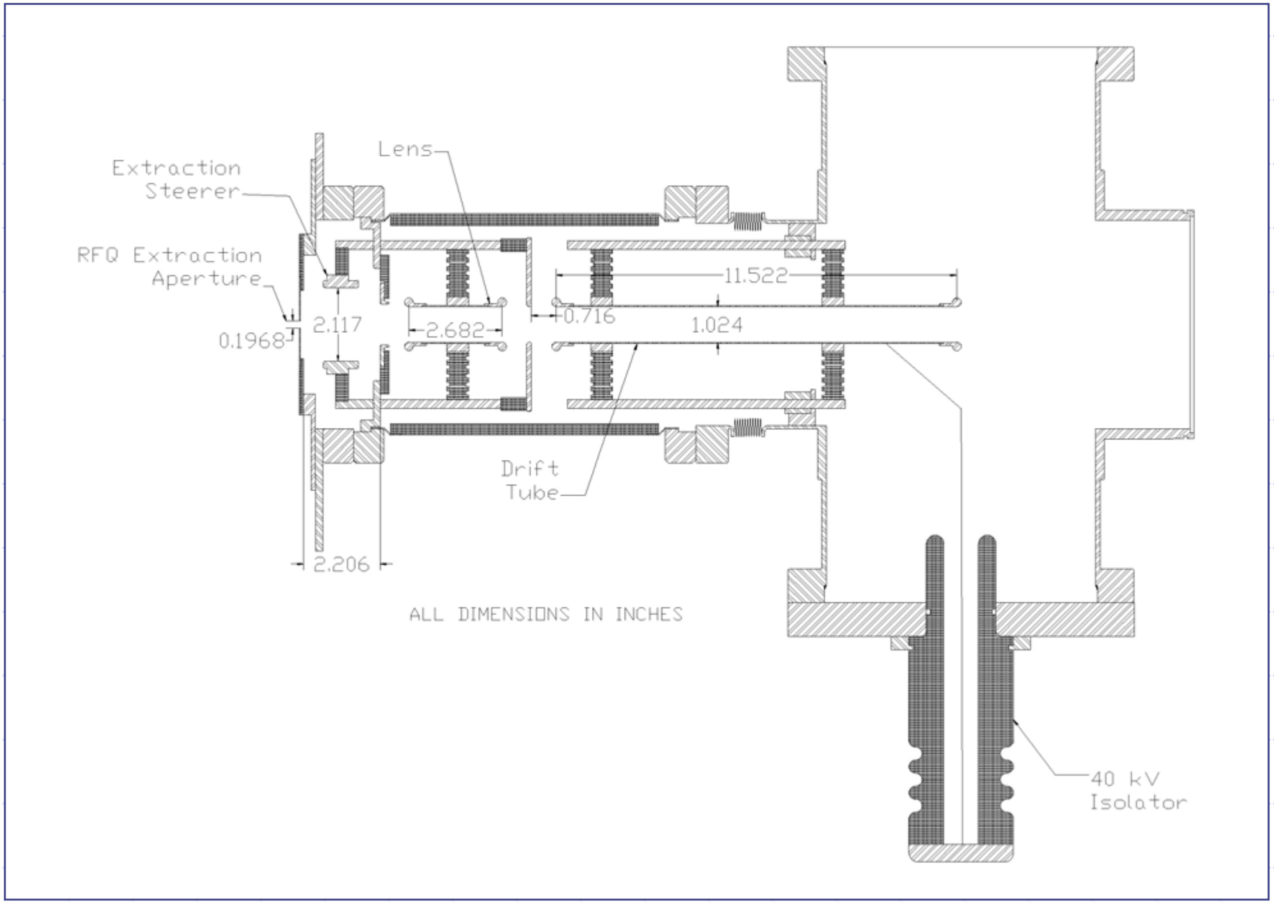
Experimental Setup: RFQ



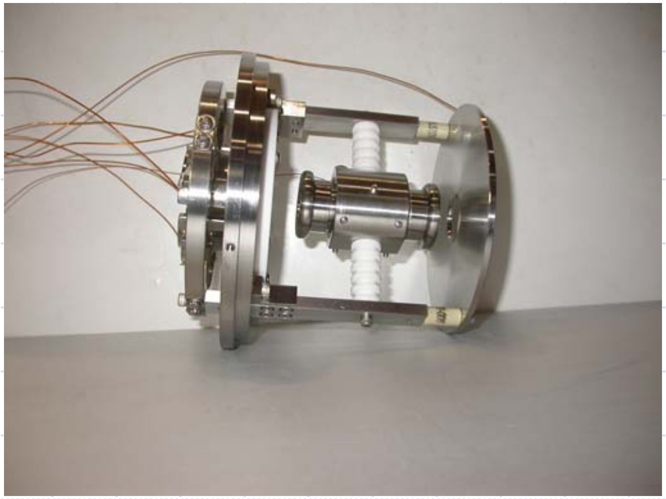


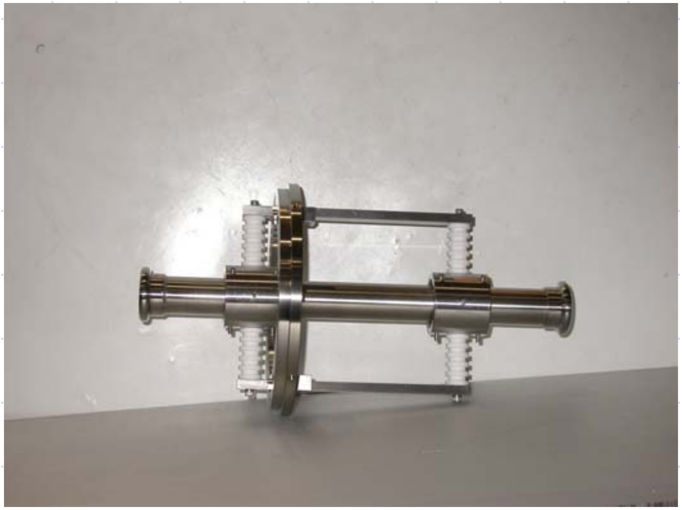
- Installed and Square-Wave successfully applied to the rods
- Beam passed through RFQ and detected at the RFQ exit without gas with 30% efficiency

Experimental Setup: Extraction



Experimental Setup: Extraction





- Extraction optics installed
- MOSFET switch developed at McGill used to switch RFQ dc bias
- Belhke 60 kV switch used to pulse drift tube
- Drift tube pulser underway tested and ready for instalation

Commissioning the RFQ

- Transverse emittance rig has been built and is being tested.
- Time-of-flight information from MCP couple either directly to scope or through MCA
- Longitudinal energy spread?

Summary and Outlook

- Detailed simulations of cooling process in a square-wave driven RFQ carried out
- Based on simulations system designed and built
- Square-wave driver capable of driving large capacitive loads at high voltage and high frequency developed and tested
- Testing of the system underway. Beam has been extracted from the RFQ and detected in DC mode.
- TITAN platform now installed in proton hall
- RFQ will be installed ready for the delivery of the EBIT at the end of the summer

Thanks

Jens Dilling, Joe Vaz, Laura Blomeley and the rest of the TITAN group.

Co-op Students: Robert Cussons, Ori Hadary, Amar Kamdar, George Yuan.

Triumf Support: M. Good, H. Sprenger, M. McDonald, R. Dube, R. Baartman, Controls Group, Design Office, KICKER Group,
Machine Shop, Vacuum Group.

For more information see my thesis at:
www.triumf.ca/titan/group