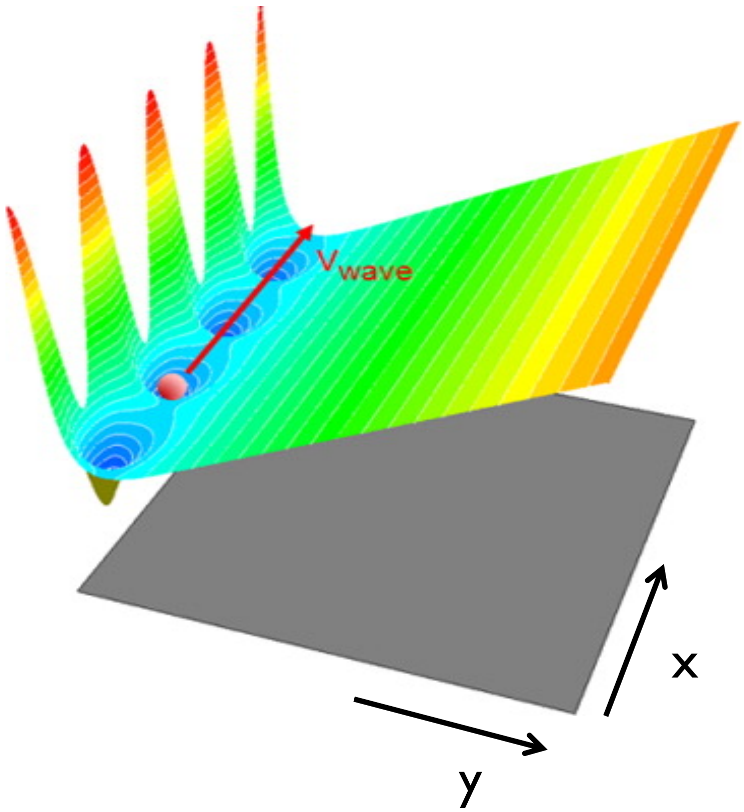
Traveling wave ion transport for the NSCL cyclotron gas stopper



Maxime Brodeur
National Superconducting Cyclotron Laboratory

Ion guiding for the cyclotron gas stopper

Cyclotron gas stopper (cycstopper): reversed operation mode cyclotron (S. Schwarz talk)

- Provide thermal RIB to precision experiments (M. Redshaw talk) and for re-acceleration (D. Leitner talk).
- Some ions of interest will have $T_{1/2}$ < 50 ms and/or produced at low yields.

➡ The efficient and quick transport of the stopped ions is critical.

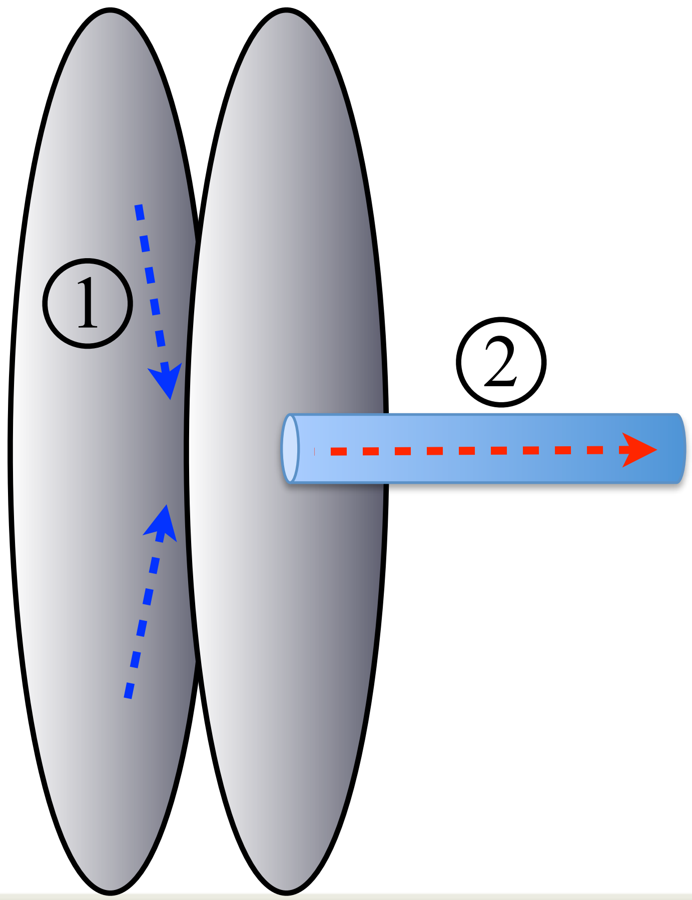
Ion guiding for the cyclotron gas stopper

Cyclotron gas stopper (cycstopper): reversed operation mode cyclotron (S. Schwarz talk)

• Provide thermal RIB to precision experiments (M. Redshaw talk) and for re-acceleration (D. Leitner talk).
• Some ions of interest will have $T_{1/2} < 50$ ms and/or produced at low yields.

The efficient and quick transport of the stopped ions is critical.

Performed detailed R&D of transport methods for the cycstopper.



Outline

1) Transport in stopping region

• Ion surfing method experimental results

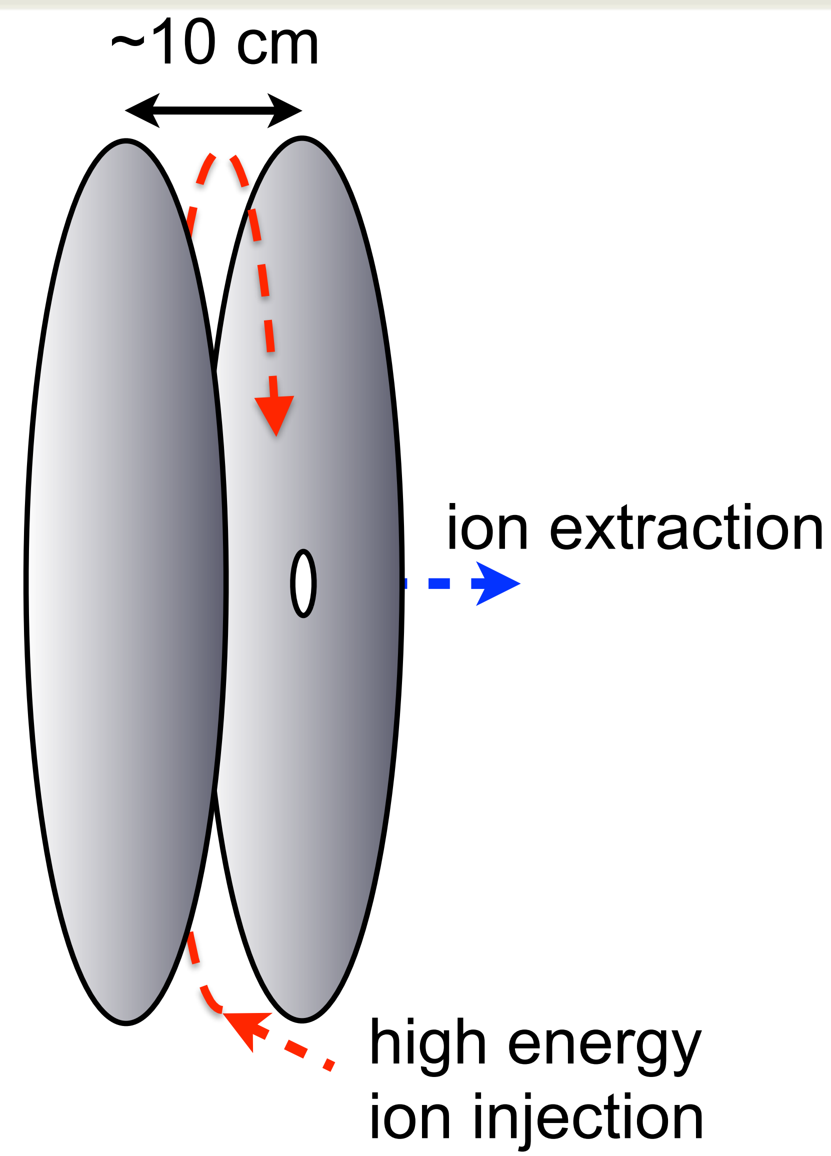
2) Transport in extraction region

• The ion conveyer experimental results

Ion guiding in the stopping region

Ion transport choice guided by:

- Space constrain: set by pole piece separation
- Clearance along the path of energetic ions
- Geometry: cylindrical symmetry
- Required axial extraction of the ions



Maxime Brodeur

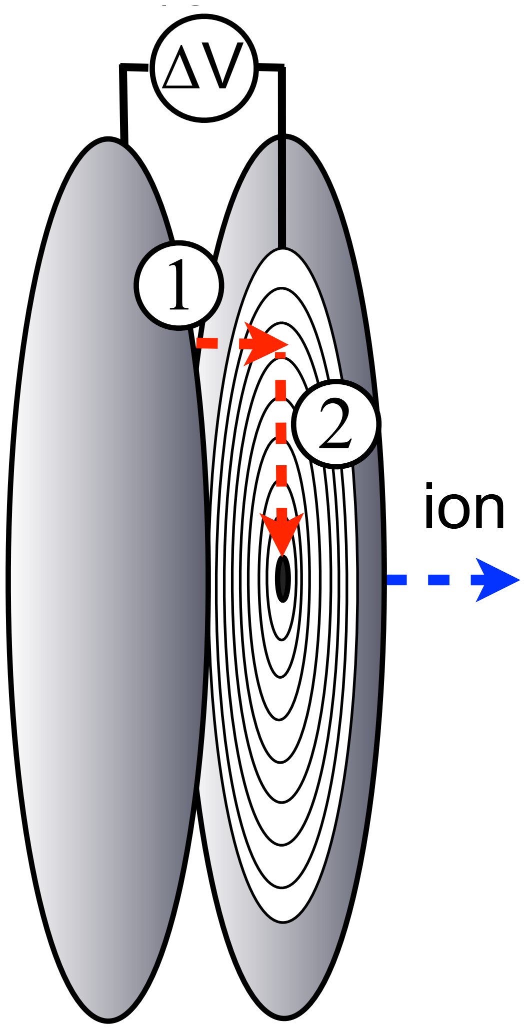
Ion guiding in the stopping region

<u>Ion transport choice guided by:</u>

- Space constrain: set by pole piece separation
- Clearance along the path of energetic ions
- Geometry: cylindrical symmetry
- Required axial extraction of the ions

<u>Easiest choice:</u>

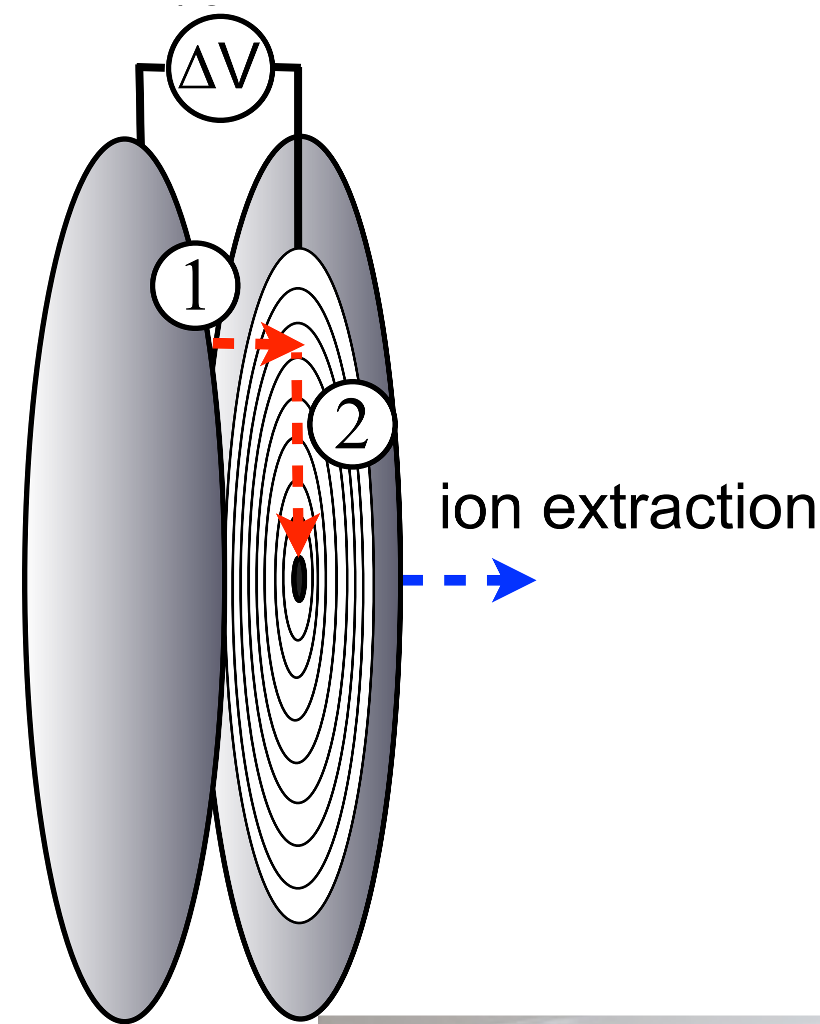
1) Push ions axially (with ΔV)
2) Transport along repelling surface towards orifice



Ion guiding in the stopping region

Ion transport choice guided by:

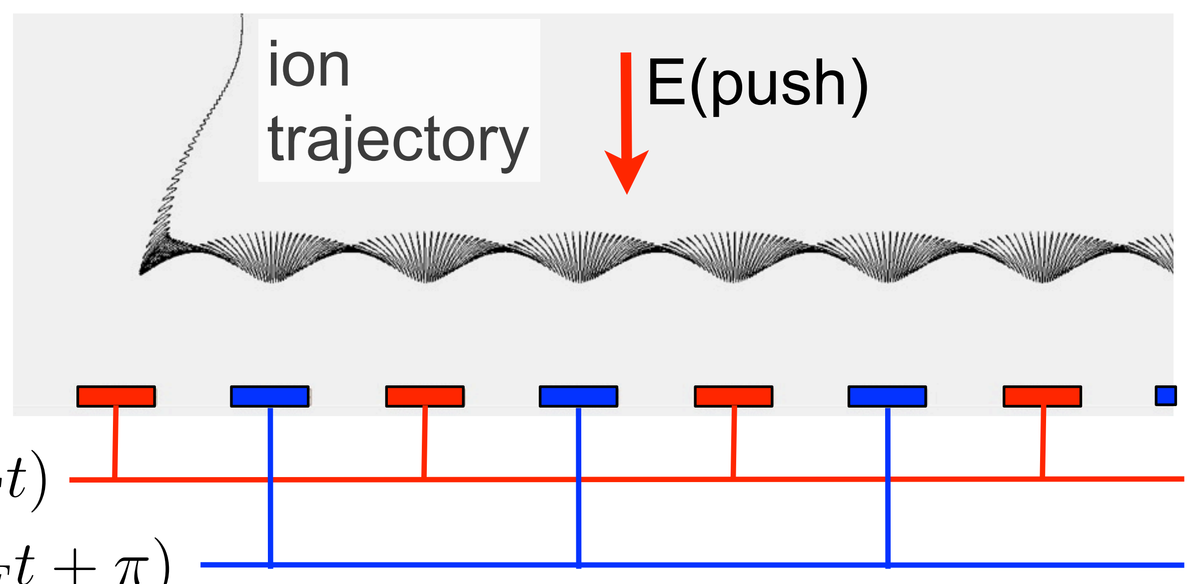
- Space constrain: set by pole piece separation
- Clearance along the path of energetic ions
- Geometry: cylindrical symmetry
- Required axial extraction of the ions



Easiest choice:

1) Push ions axially (with ΔV)
2) Transport along repelling surface towards orifice

RF carpets creates such repelling (Wada-san talk)

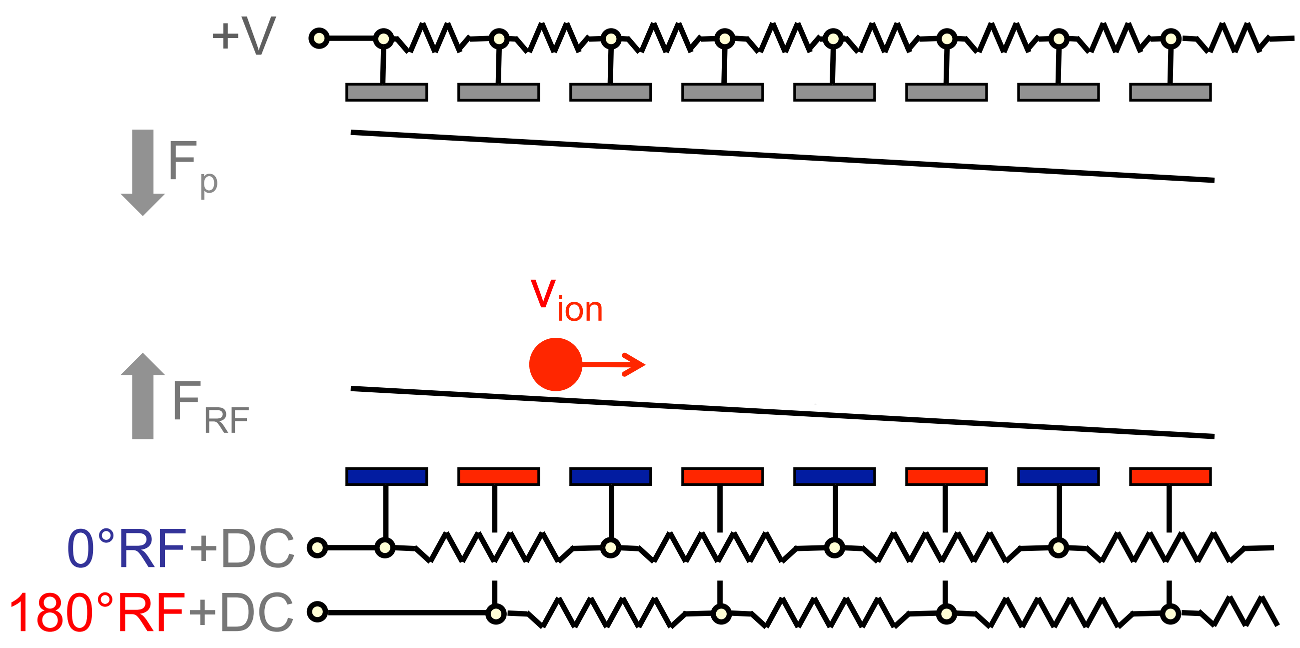


$V_{RF}\sin(2\pi f_{RF}t)$

$V_{RF}\sin(2\pi f_{RF}t+\pi)$

Transport methods using RF carpets

Potential gradient



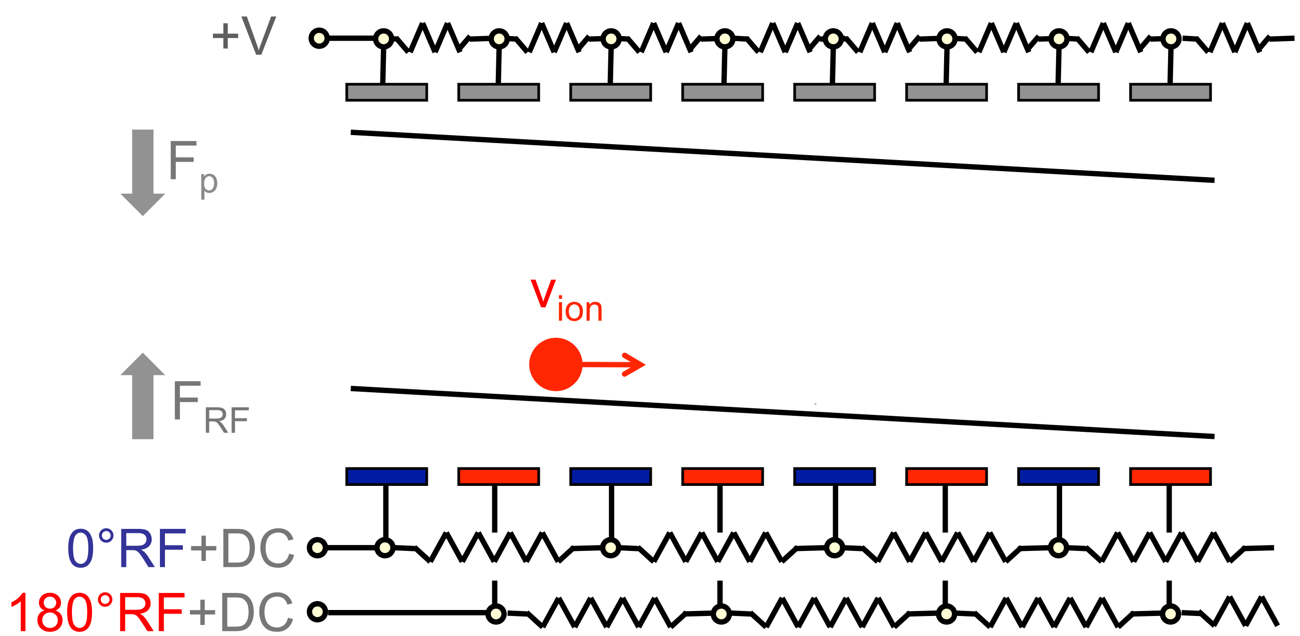
- *Traditional* approach [1-4]
- Transport using potential gradient
- Complicated circuitry with large C
- Drag field discharge-limited

(limit on $T_{1/2}$ that can be extracted)

[1] G. Savard *et al.*, NIM B **204**, 583 (2003).
[2] M. Wada *et al.*, NIM A **204**, 570 (2003).
[3] S. Eliseev *et al.*, NIM B **266**, 4475 (2008).
[4] M. Ranjan *et al.*, EPL **96**, 52001 (2011).

Transport methods using RF carpets

Potential gradient

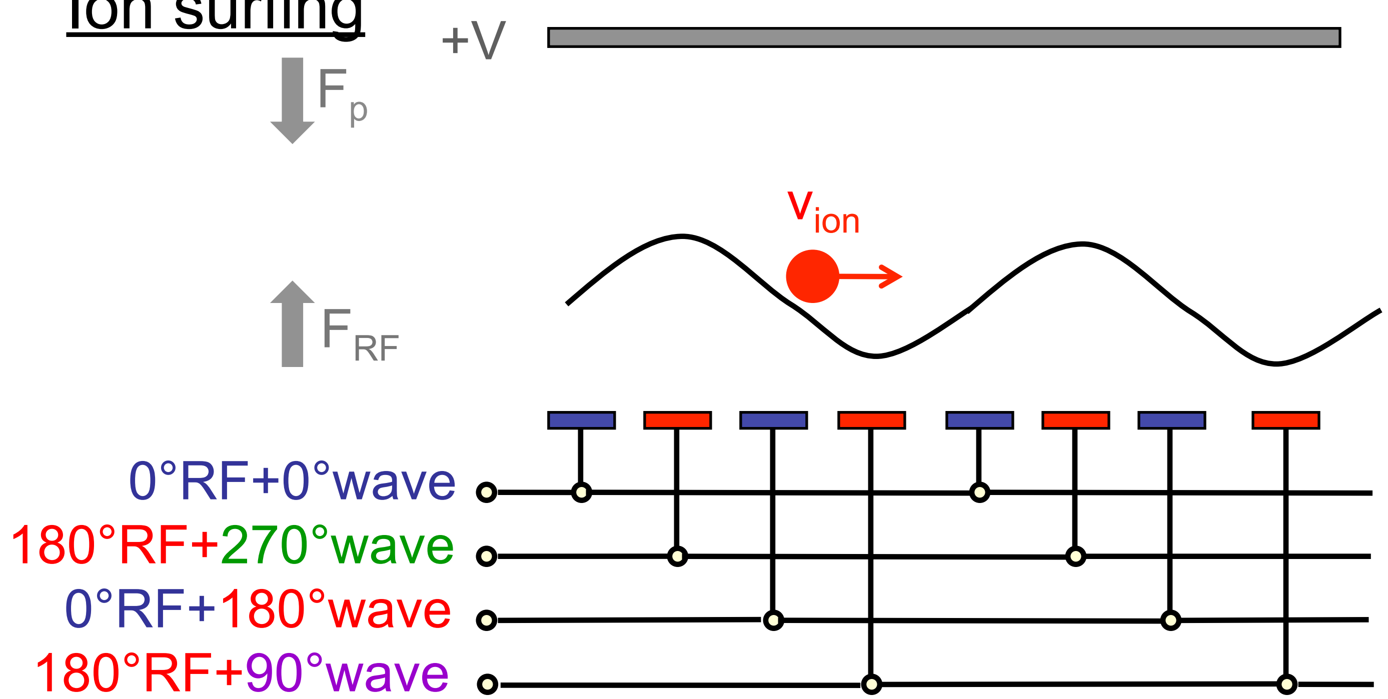


- *Traditional* approach [1-4]
- Transport using potential gradient
- Complicated circuitry with large C
- Drag field discharge-limited

(limit on $T_{1/2}$ that can be extracted)

[1] G. Savard *et al.*, NIM B **204**, 583 (2003).
[2] M. Wada *et al.*, NIM A **204**, 570 (2003).
[3] S. Eliseev *et al.*, NIM B **266**, 4475 (2008).
[4] M. Ranjan *et al.*, EPL **96**, 52001 (2011).

Ion surfing



- *Novel* approach (for RIB) [5]
- Transport using travelling wave
- Simpler circuitry and lower C
- Ion speed not discharge-limited

(can extract shorter-lived isotopes)

[5] G. Bollen, IJMS **299**, 131 (2011)

Maxime Brodeur
EMIS 2012 conference
December 4th, 2012

Ion surfing R&D goals

Require efficient transport of light (A ~ 20) short-lived nuclei (< 50ms) for the cycstopper.

→ Test experimentally the limitations of the ion surfing method.

(should ultimately achieve faster transport than conventional method)

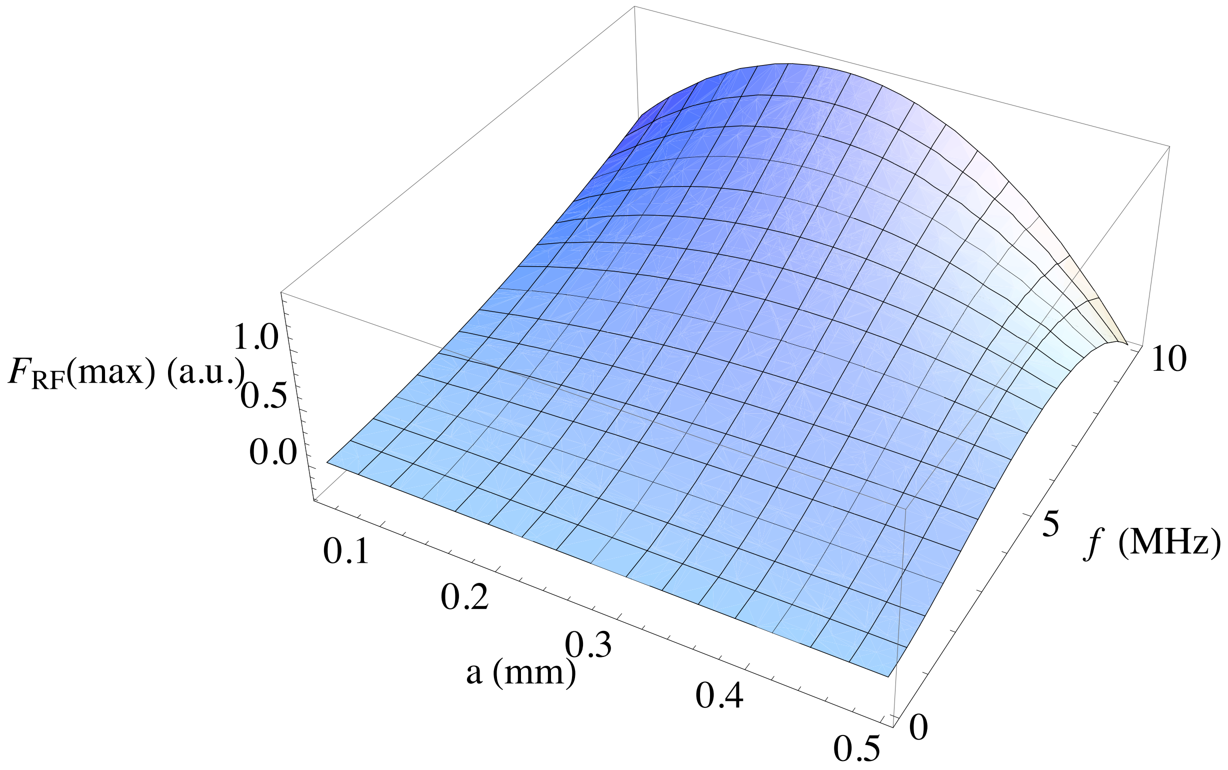
→ Gauge used: the maximum transport speed for efficient transport vs.:

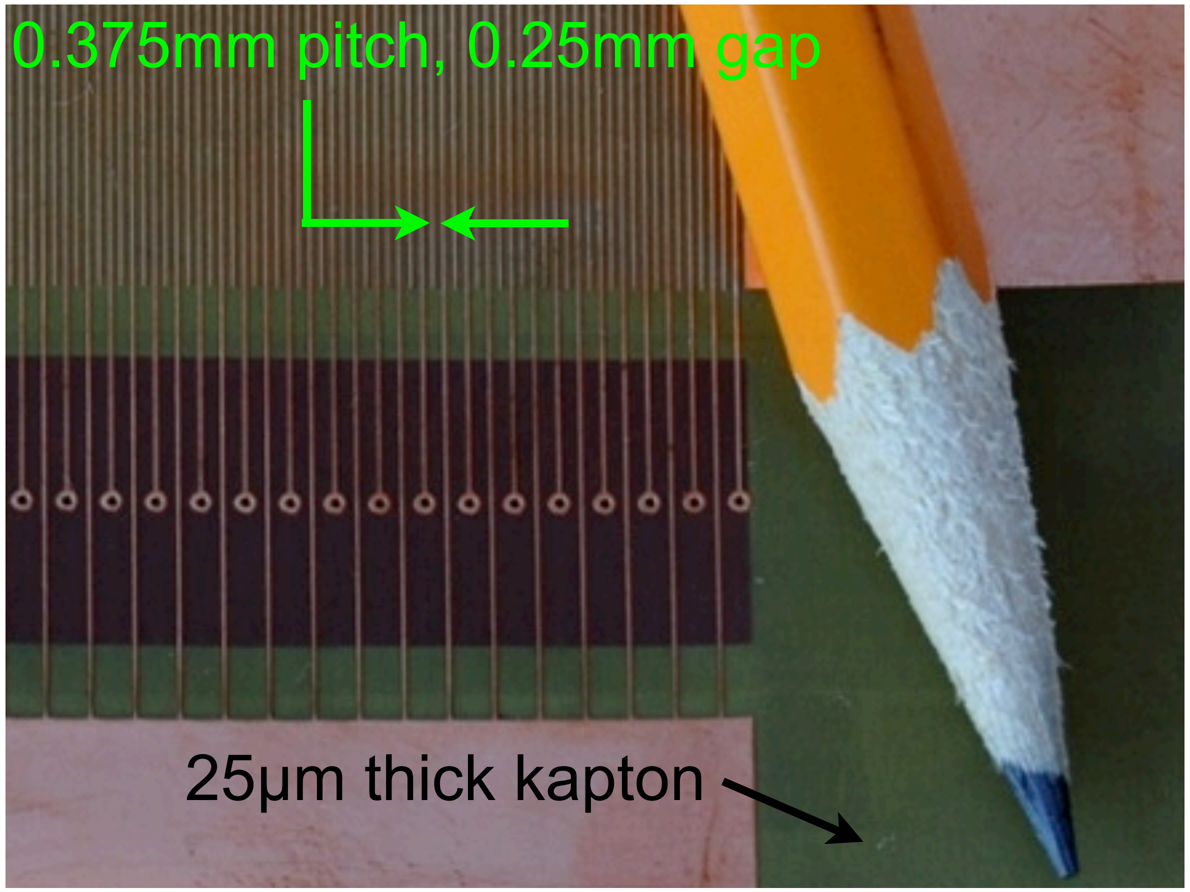
- Pressure (increased pressure gives higher stopping efficiency)
- Push field (larger beam rates, more ionization results larger push towards carpet)
- Ion mass (aim at A ~ 20 and possibly lower)

Ion surfing carpet design

Designed carpet with maximized repelling F_{RF}.

→ Minimize pitch, while maximizing f_{RF}.





1) Maximize resonant f_{RF}

- Minimize carpet C by using thin substrate

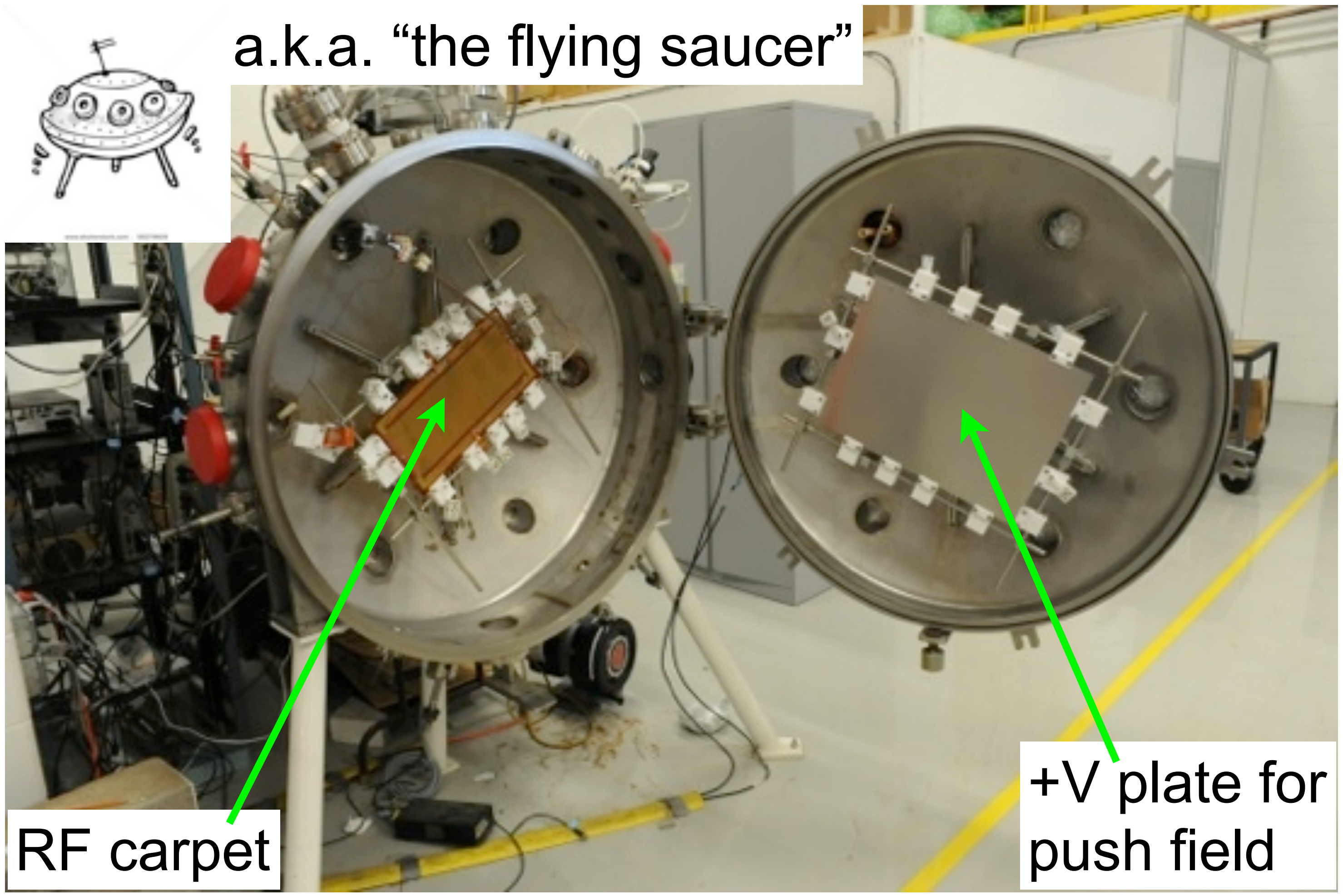
2) Minimize carpet pitch *a*

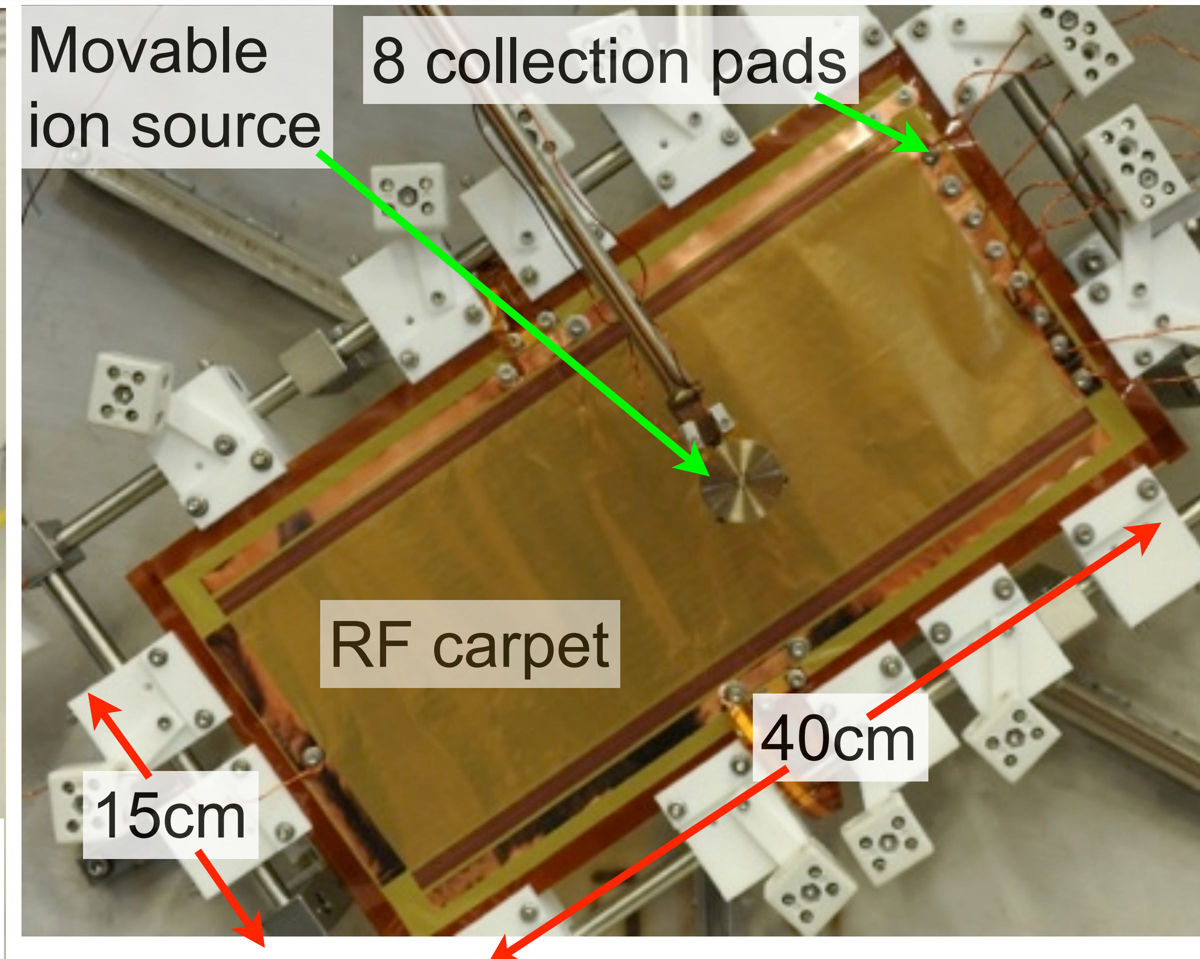
- Min. manufacturing gap & electrode width

Also added C in series with carpet to reduce overall C.

Result: f_{RF} = 6.8 MHz for a = 375µm

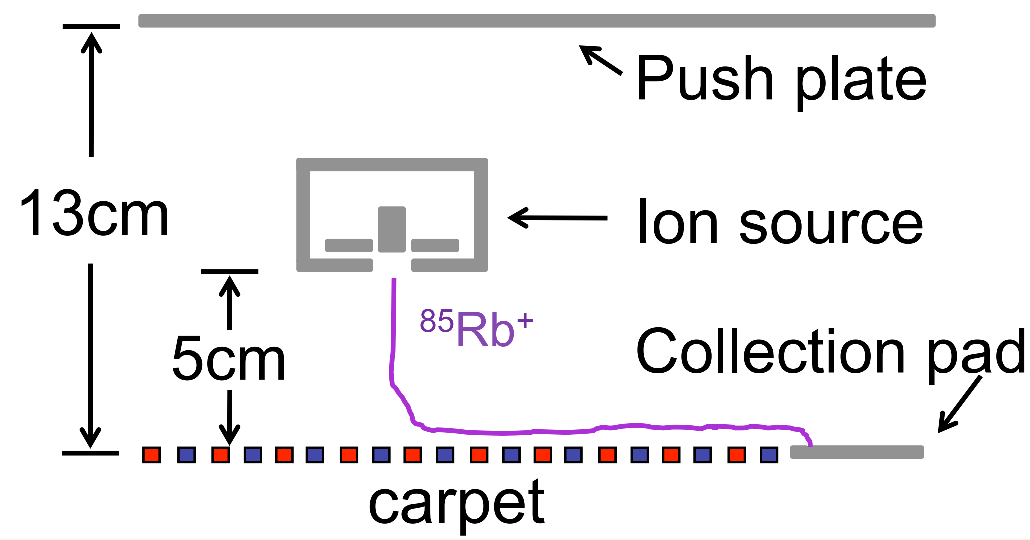
Test setup for RF carpet R&D



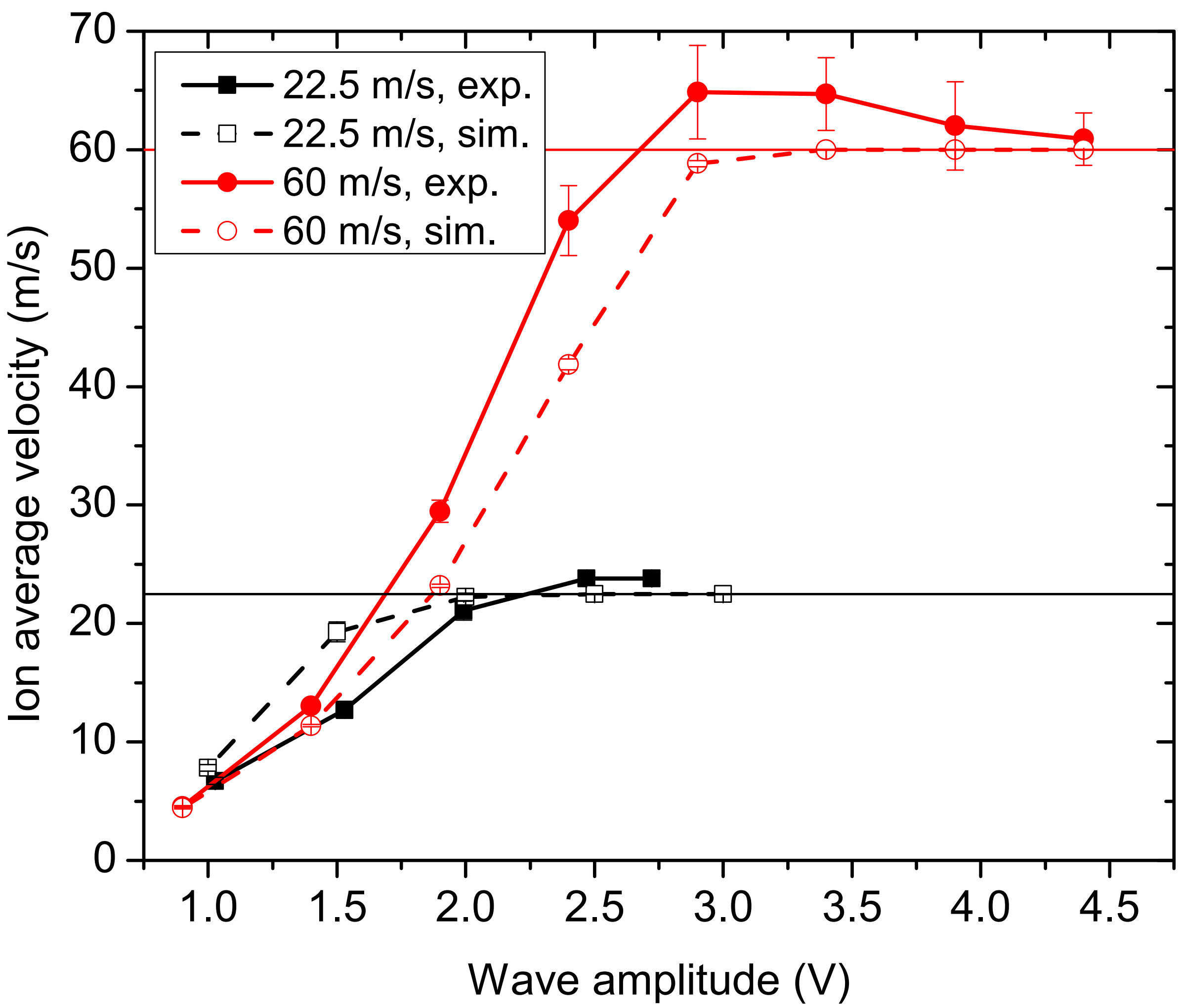


Test setup includes:

- Movable surface ion source
- Push field plate & RF carpet
- RF & traveling wave circuitry
- pA-meters to read transported ion current



Experimental results vs. simulations

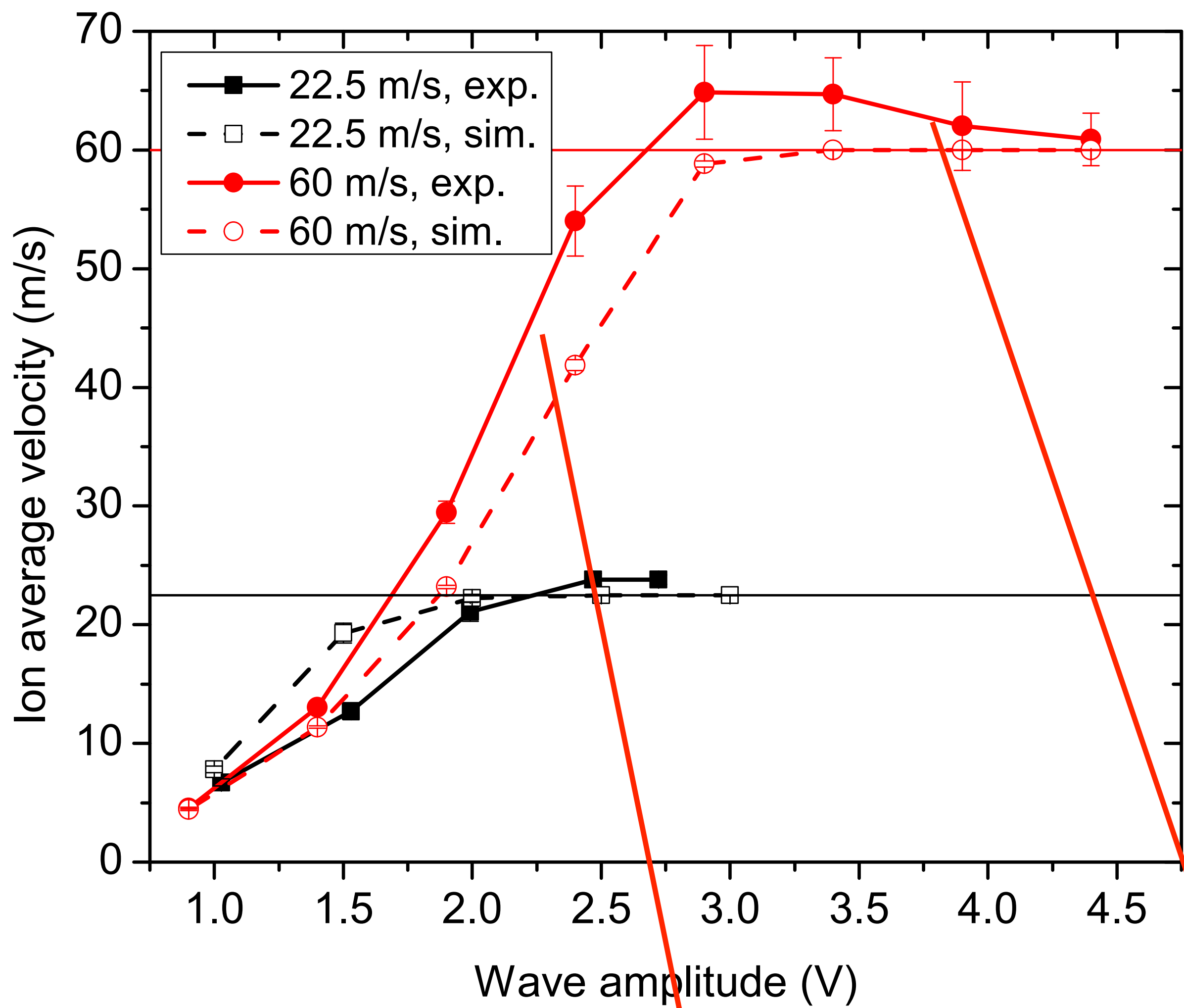


Parameters used:

RF amplitude	75, 51 V
RF frequency	6.6, 6.8 MHz
Push field	45, 30 V/cm
Beam current	1 nA
Pressure	120, 80 mbar
Travel distance	30 cm
Wave speed	60, 22.5 m/s

Good agreement between experimental results and simulations including hard sphere collisions (IonCool code).

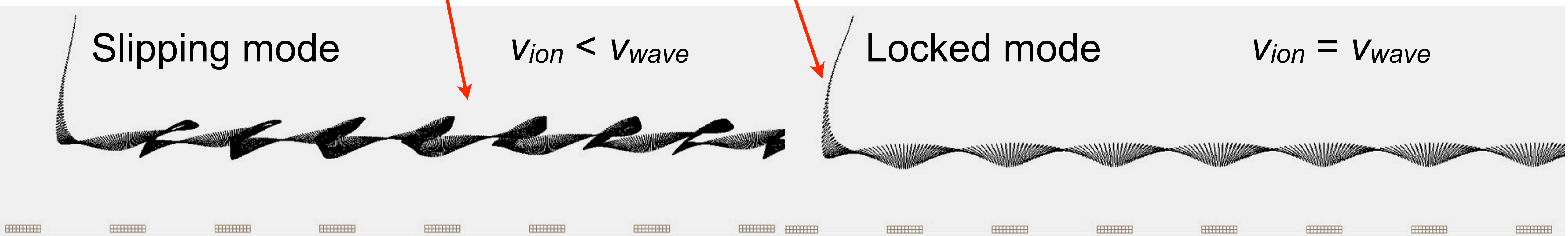
Experimental results vs. simulations



Parameters used:

RF amplitude	75, 51 V
RF frequency	6.6, 6.8 MHz
Push field	45, 30 V/cm
Beam current	1 nA
Pressure	120, 80 mbar
Travel distance	30 cm
Wave speed	60, 22.5 m/s

Good agreement between experimental results and simulations including hard sphere collisions (IonCool code).



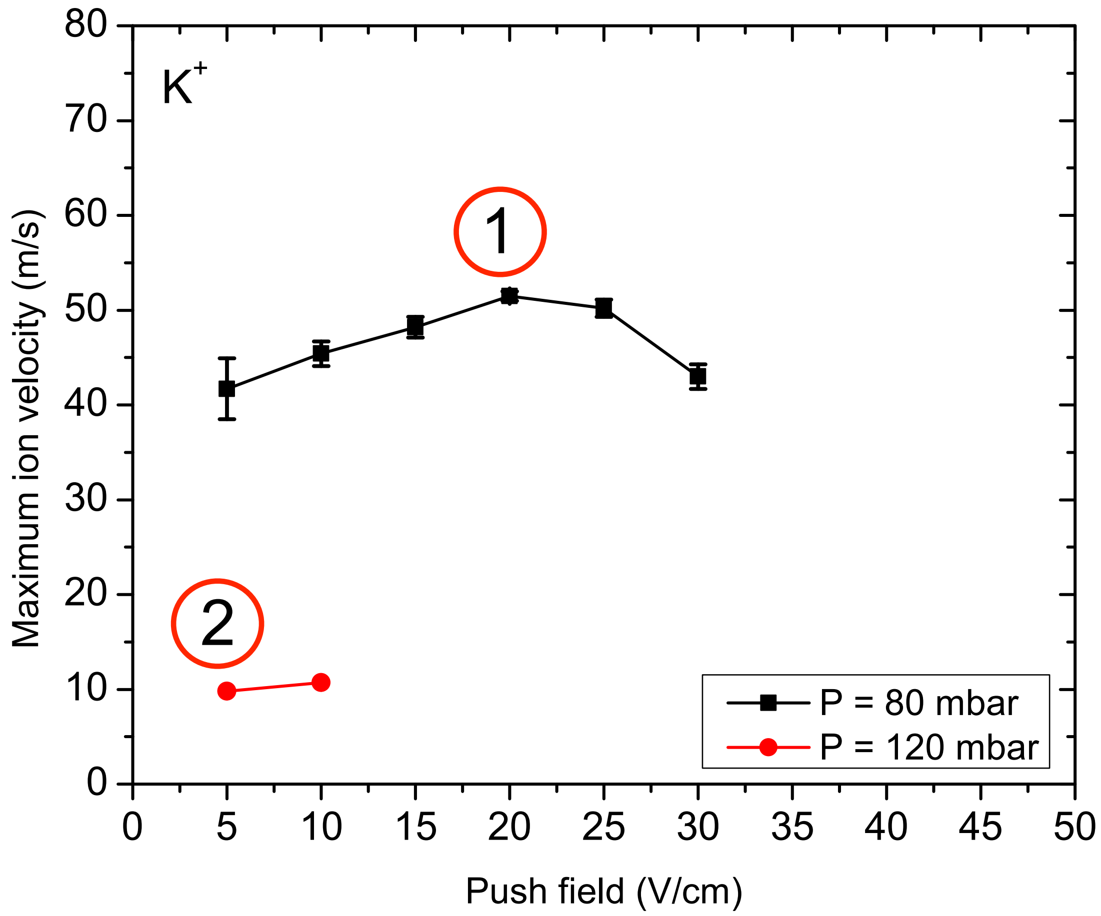
National Science Foundation
Michigan State University
NSCL

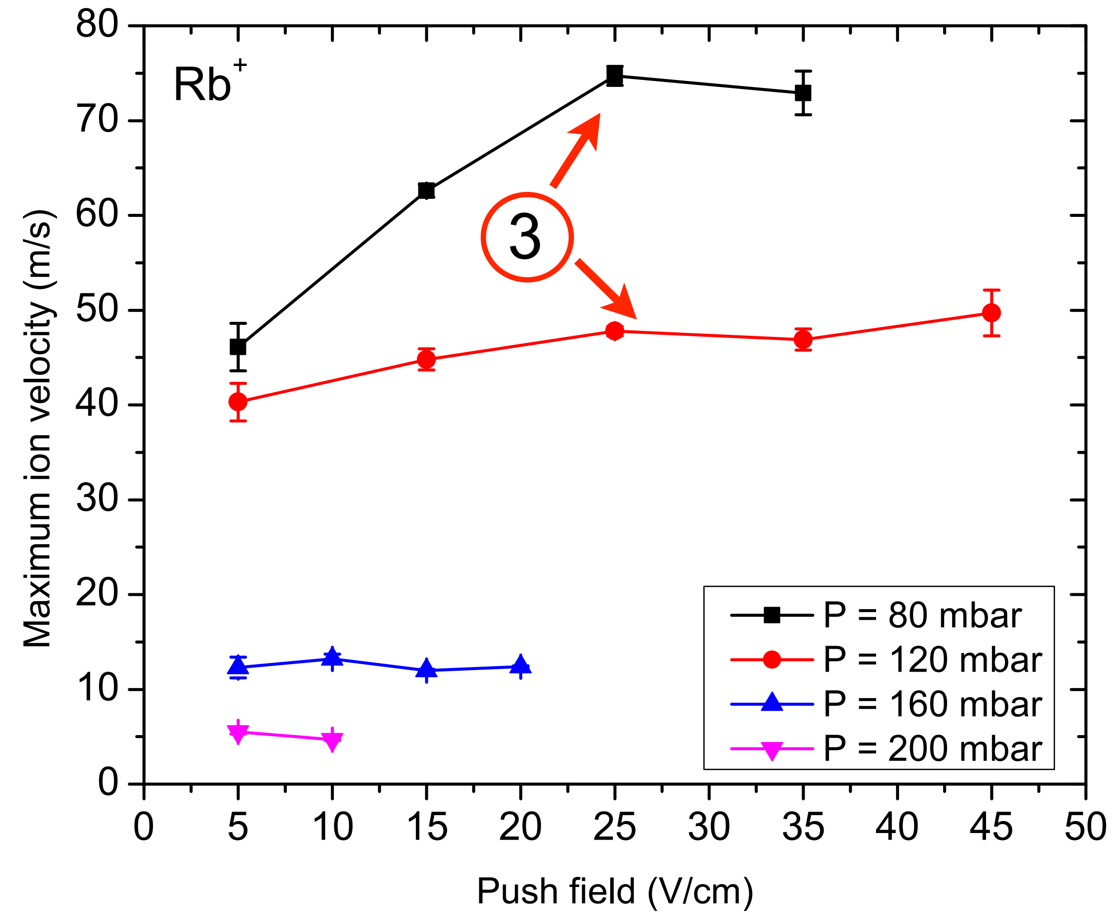
Maxime Brodeur
EMIS 2012 conference
December 4th, 2012

Maximum transport speed

Maximum speed $v_{ion,max}$ for efficient ion transport (90% over 10cm).

→ Varied V_{RF}, wave amplitude and speed for different P, push field & A





1) K: peak speed of ~50 m/s
2) Increased P: tolerate lower push and wave amplitude → lower speeds
3) Rb at P = 80, 120 mbar: could go faster, limited by circuitry used

$$F_{RF}(\max) = m \cdot 4\pi a f^2 \left(1 - 1.09 \sqrt{\frac{a^2 f}{2V K_0} \frac{p/p_0}{T/T_0} \frac{1}{\mathrm{sinc}(\pi\gamma/2)}}\right)$$

National Science Foundation
Michigan State University

Ion transport in extraction region

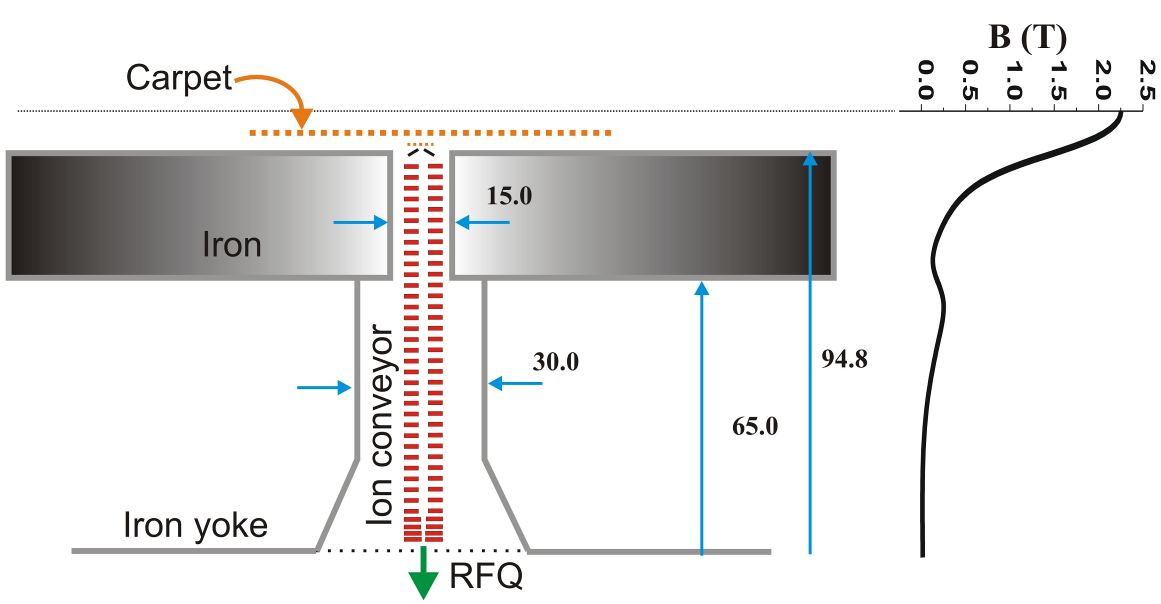
After leaving stopping region, need quick & efficient transport through magnet yoke.

<u>"Traditional" transport methods</u>:

- RFQ ion guide →
- RF funnel →

<u>Issues for the cycstopper</u>:

- Magnetic field gradient requires high RF frequencies
- Pressure in region: 2 to 30 mbar limits DC gradient, resulting in slow extraction.



Maxime Brodeur
EMIS 2012 conference
December 4th, 2012

Ion transport in extraction region

After leaving stopping region, need quick & efficient transport through magnet yoke.

"Traditional" transport methods:

- RFQ ion guide → Magnetic field gradient requires high RF frequencies
- RF funnel → Pressure in region: 2 to 30 mbar limits DC gradient, resulting in slow extraction.

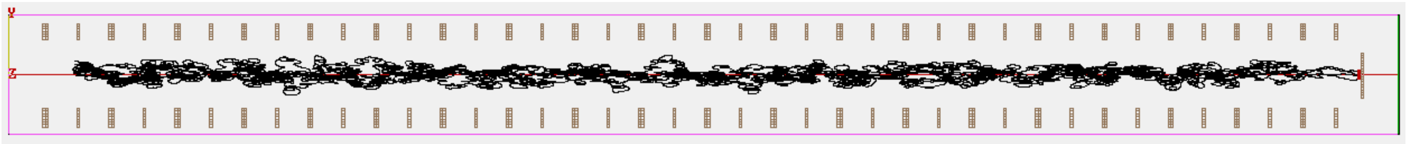
Issues for the cycstopper:

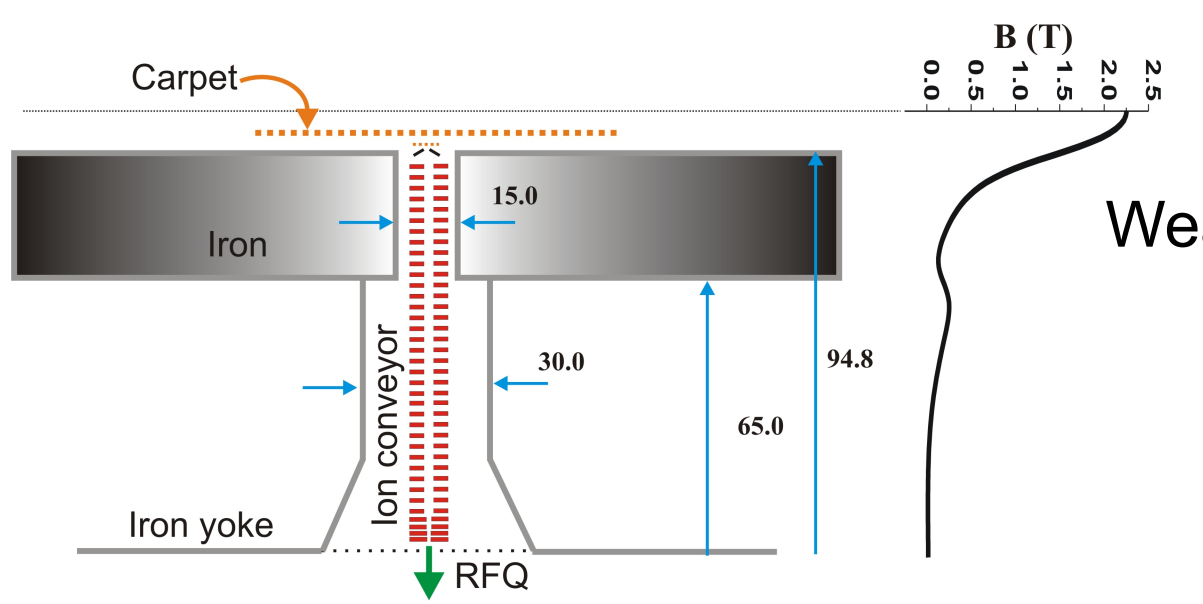
- Magnetic field gradient requires high RF frequencies
- Pressure in region: 2 to 30 mbar limits DC gradient, resulting in slow extraction.

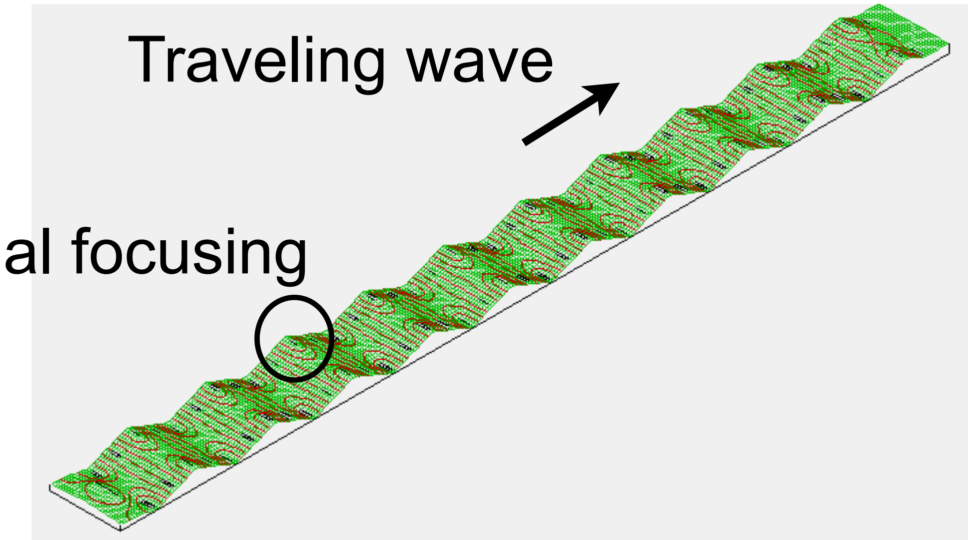
Proposed solution: ion conveyer

- Stacked rings
- Traveling wave pushed ions axially
- Weak radial focusing

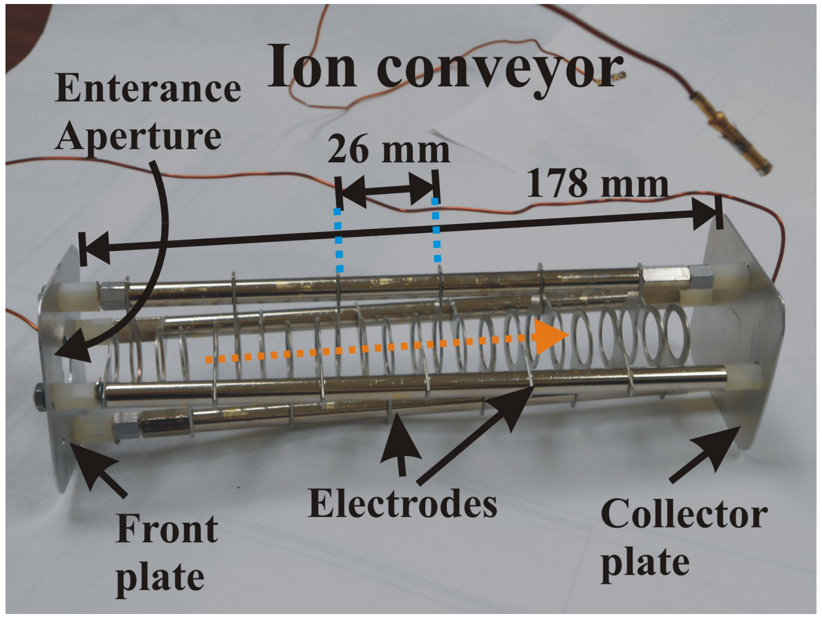
Stacked rings



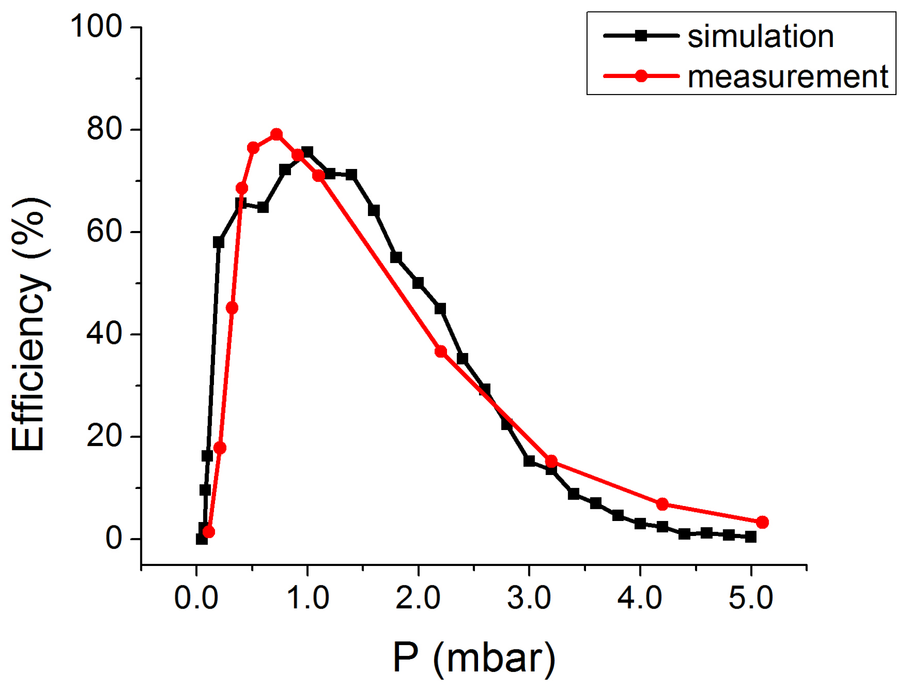


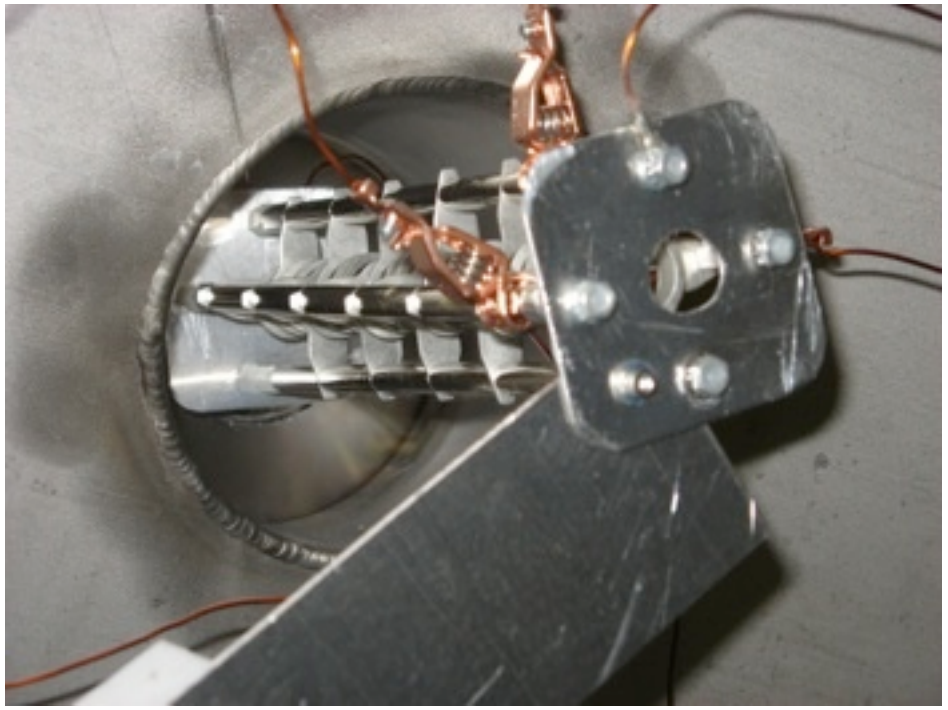


Ion conveyer first prototype



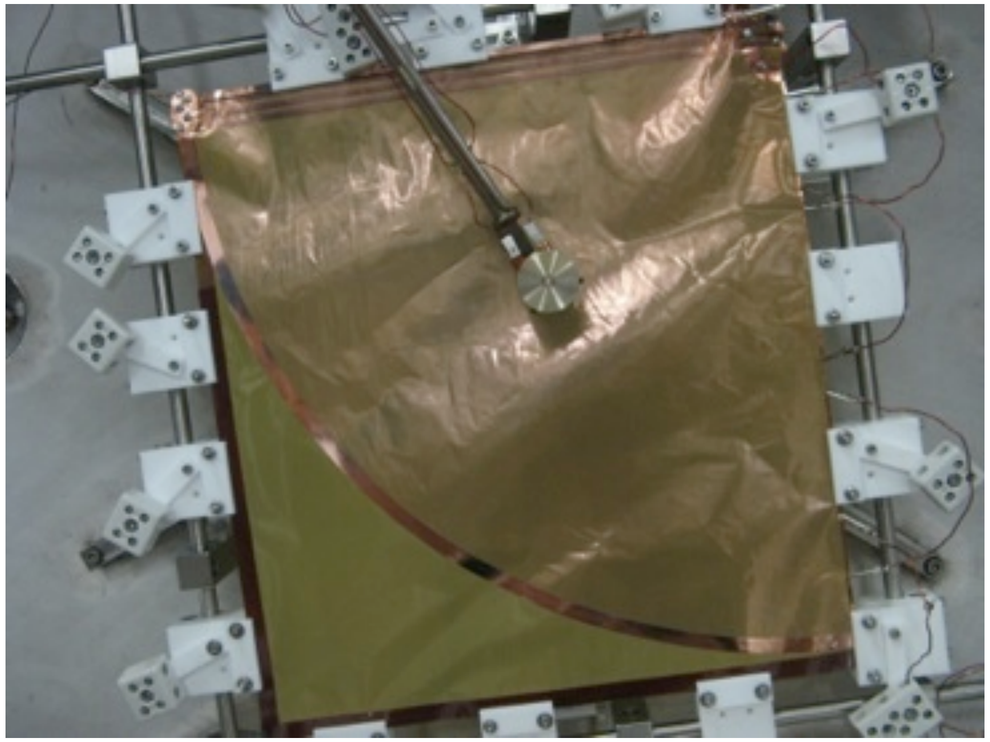
- 4 phases traveling wave, 19V max, up to 500 kHz
- Ring structure made on the fly from stockroom material (that's why it looks crooked)
- Rb^+ ions from surface source





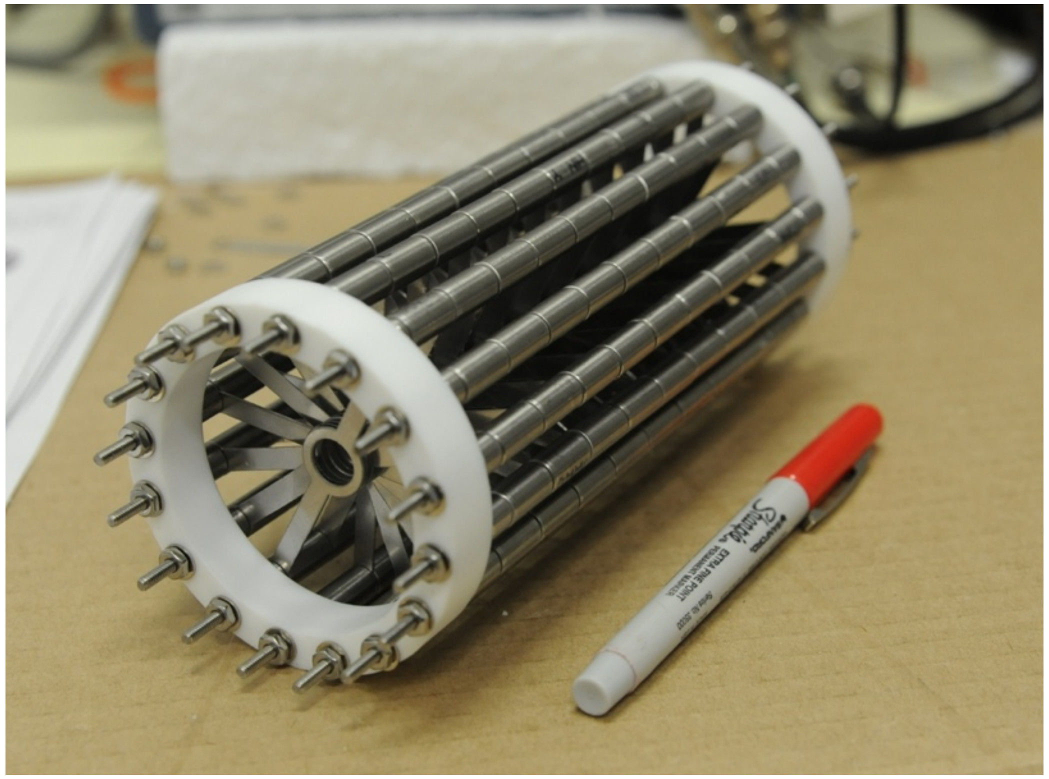
Found good agreement between measured efficiency measurements and simulations including hard sphere collisions (IonCool code)

Current & future testings



- RF carpet with circular stripes
- Improve the RF circuit, f_{RF} = 8.4 MHz
- Reached 75 m/s for K at 80 mbar
- Next: transport of Na

- Cycstopper RF carpet will be formed of 6 pie-shaped circular segments



- Designed ion conveyer
- 8 phases traveling wave
- Prototype have been assembled and ready to test.

Ion transport summary

Ion specie	^{39}K	$^{85,87}Rb$	^{24}O ($t_{1/2}$ =65ms)
Max. ion velocity (80 mbar)	~50 m/s	>75 m/s	~10 m/s *
Transport time on carpet *	5 ms	< 4 ms	28 ms
Transport time on conveyer *	4 ms	3 ms	1 ms
Total transport time	9 ms	< 7 ms	29 ms

* Based from simulation results
** Used stopping distribution centroid: 0.27(12) m

- Extraction time lower then 30 ms down to A = 24.
- The transport methods using traveling wave studied will allow both a quick and efficient extraction of radioactive ions.

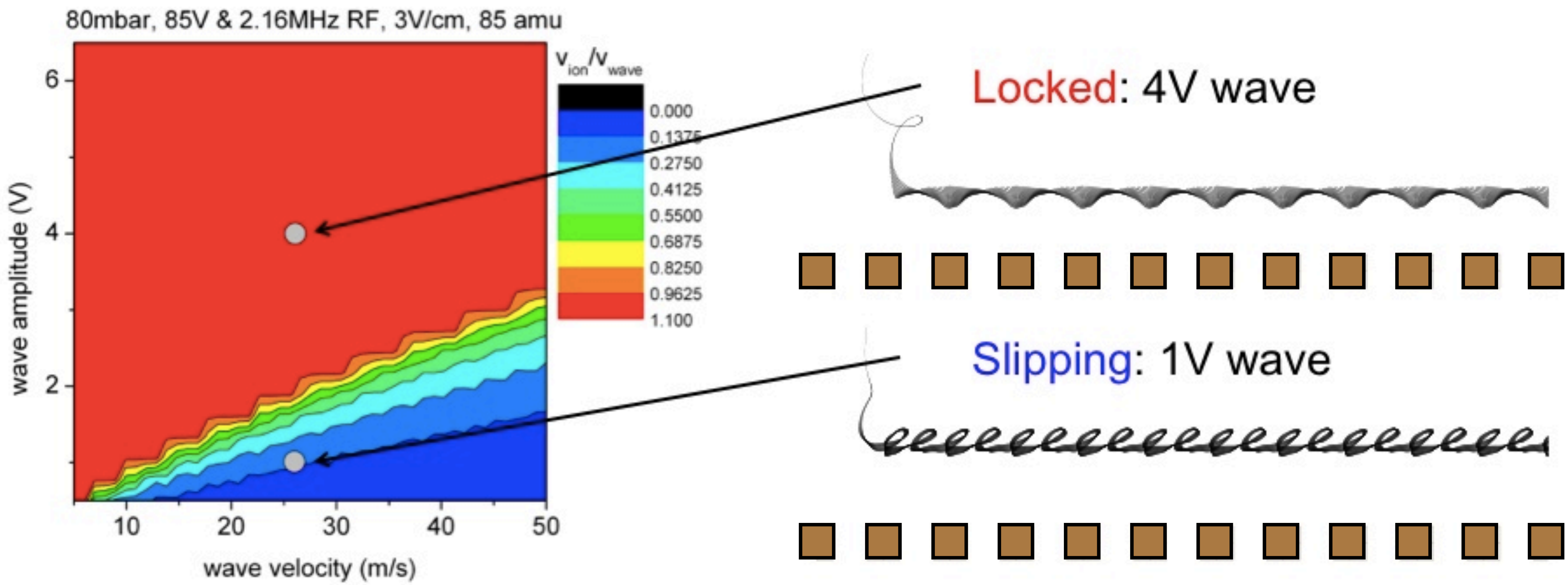
Special thanks to:
A.E. Gehring, G. Bollen, N. Joshi, S. Schwarz and D.J. Morrissey.

Extras

Ion surfing transport regimes

The travelling wave carries the ions along the carpet in two possible regimes:

- Slipping (if $v_{ion} < v_{wave}$)
- Locked (if $v_{ion} = v_{wave}$)



- With increased wave amp., the ions gets deeper in the trough
- When locked-mode is reached, $v_{ion} = v_{wave}$ remains constant
- Until amplitudes gets too large resulting in ion losses

Maxime Brodeur

RF carpet design optimization

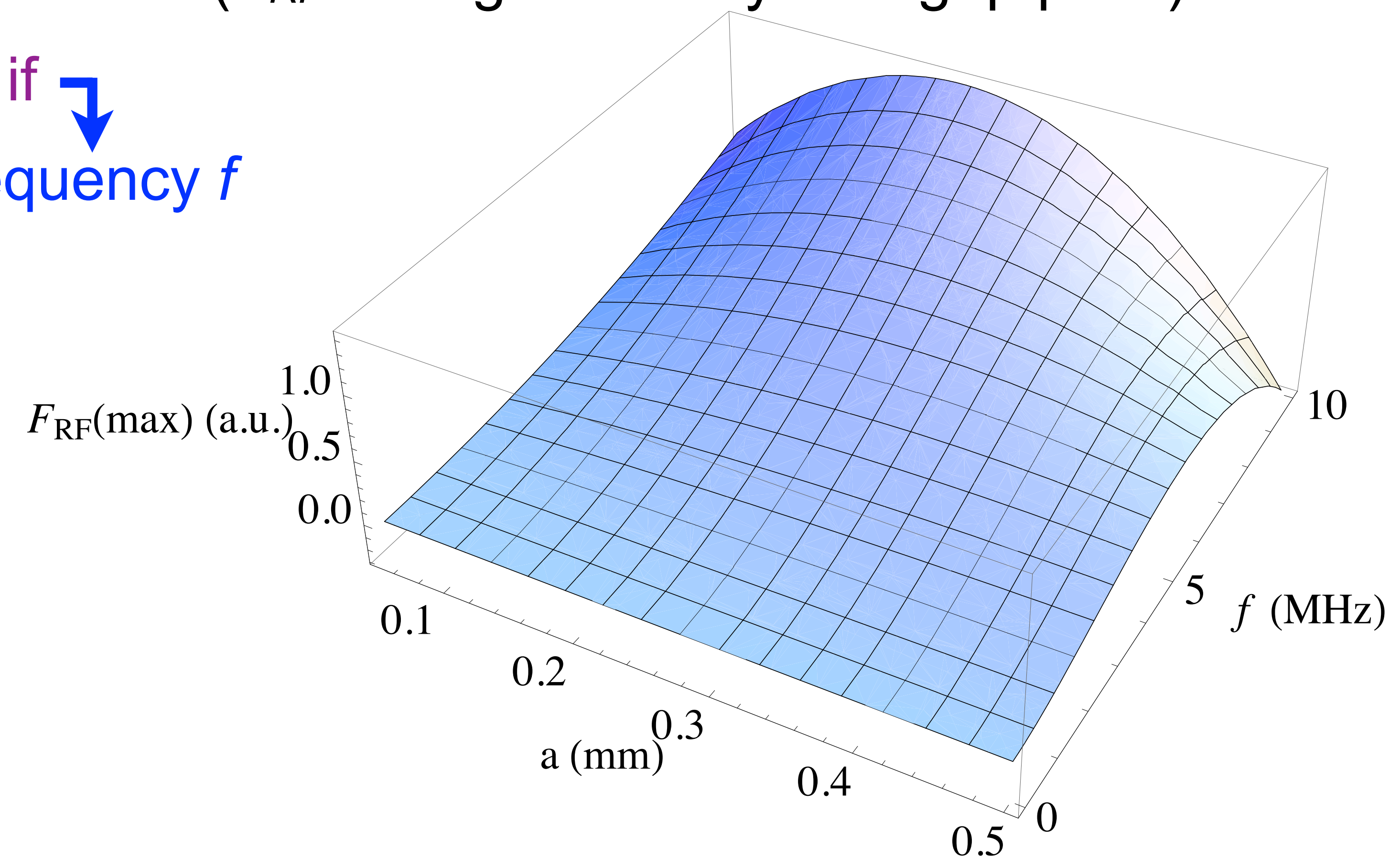
For the cycstopper, want efficient transport of light (A ~ 20) short-lived nuclei (< 50ms).

→ Need a carpet with maximized repelling force (since $F_{RF} \propto A$)

$$F_{RF}(\max) = m \cdot 4\pi a f^2 \left(1 - 1.09 \sqrt{\frac{a^2 f}{2 V K_0} \frac{p/p_0}{T/T_0} \frac{1}{\mathrm{sinc}(\pi\gamma/2)}} \right)$$

Possible actions:
- Increase RF amplitude V (discharge-limited to ~ 75V at 100 mbar)
- Reduce gap/pitch ratio (F_{RF} changes weakly with gap/pitch)
- Reduce pitch a if
- Increase RF frequency f

Need to reduce carpet capacitance

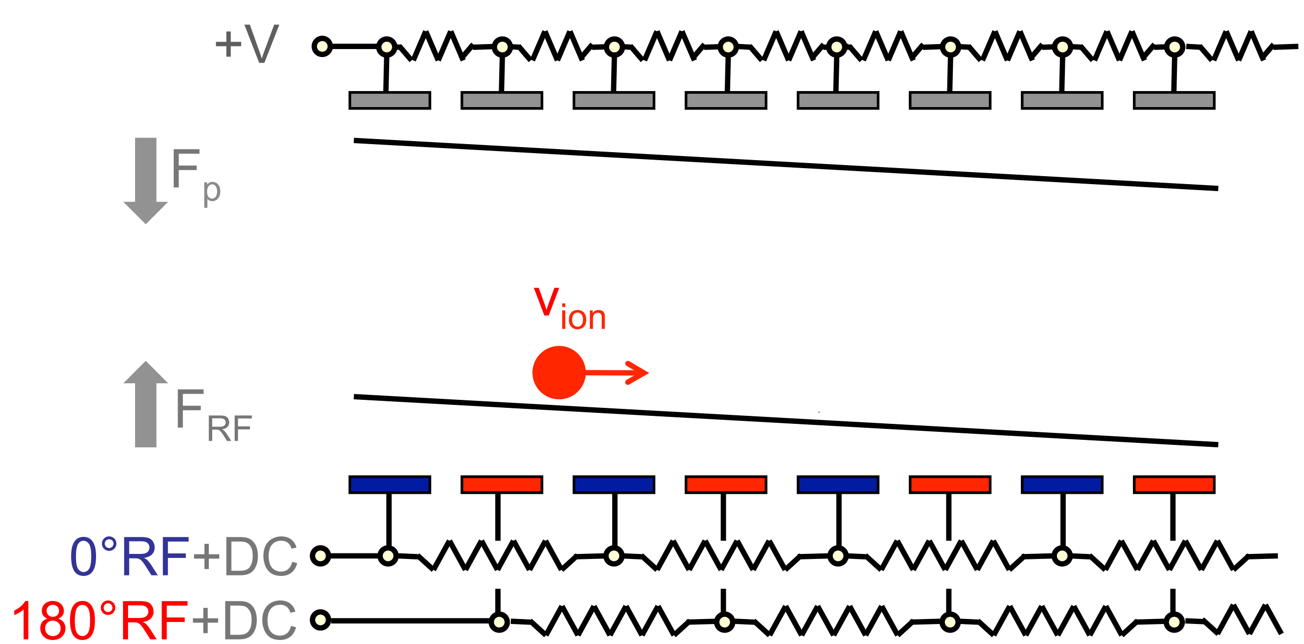


Ion transport using RF & DC gradient

One common transport method makes use of RF carpets *.

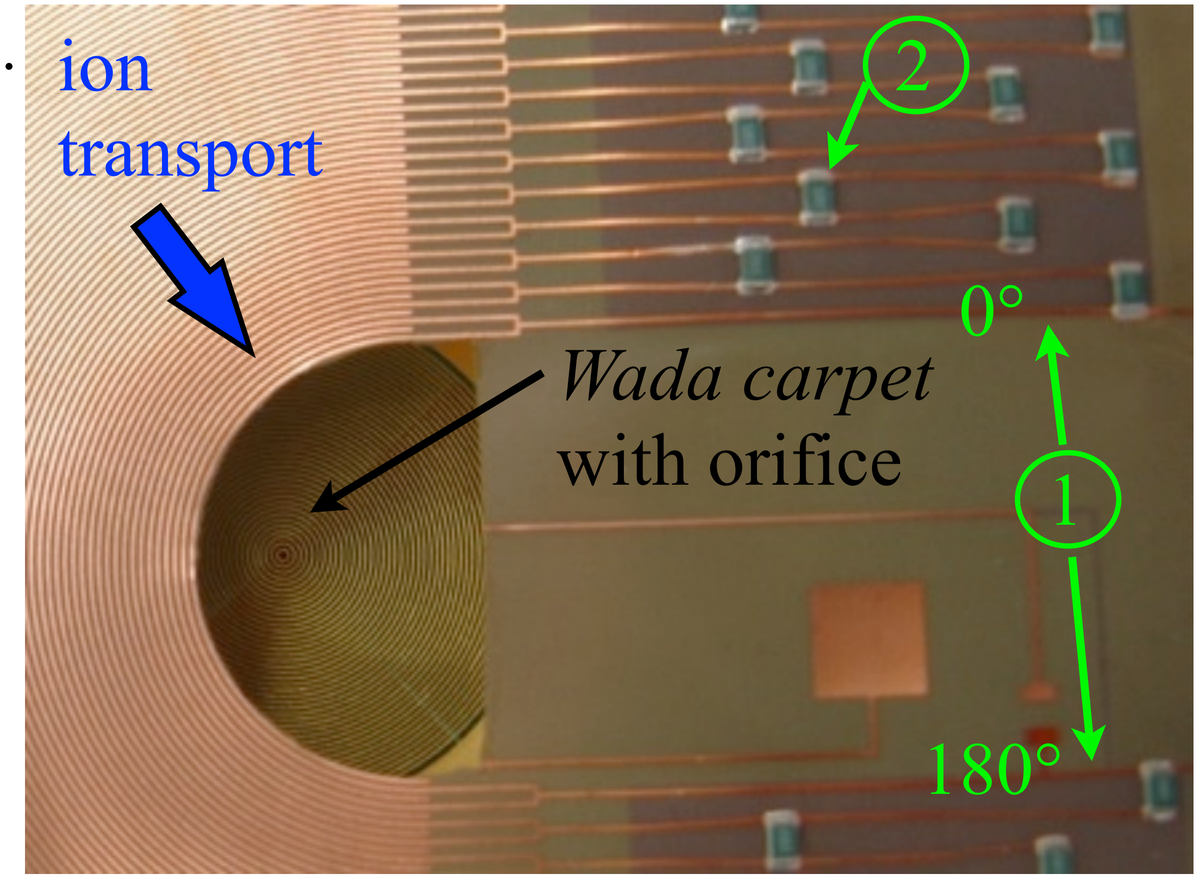
1. Made of electrode stripes on which an alternating RF voltage with reversed polarity on adjacent electrode is applied. Results in repealing pseudo-potential.

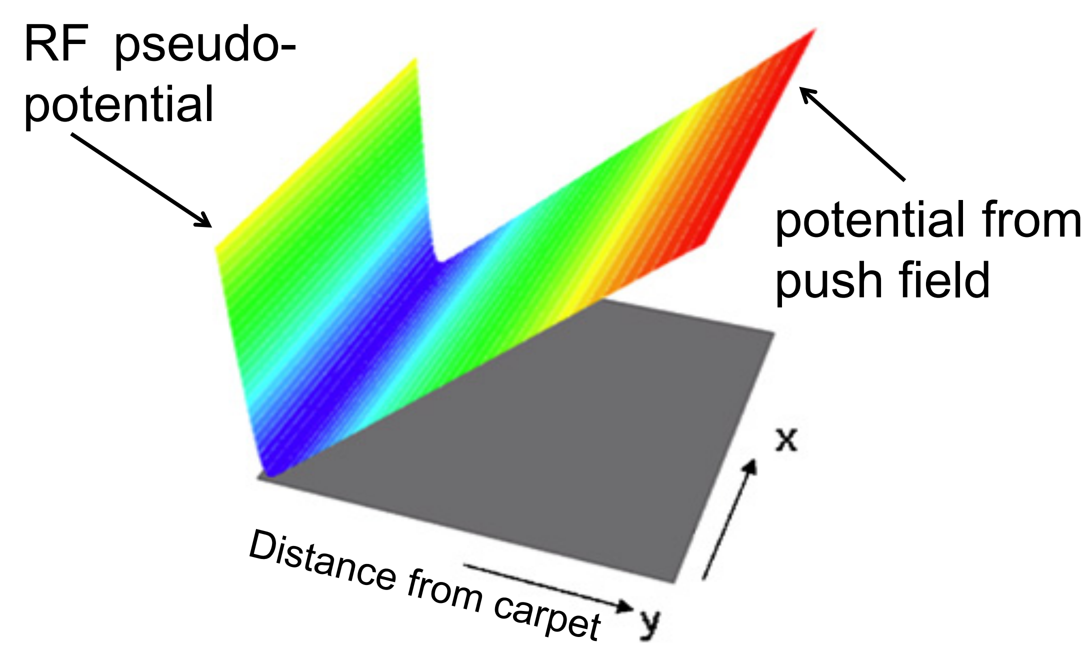
2. Couples a constant voltage gradient to guide the ions to the extraction orifice.



3. The force from the RF is used to balance a pushing field that drives the ions towards the carpet.

* M. Wada *et al.*, NIM A **204**, 570 (2003)



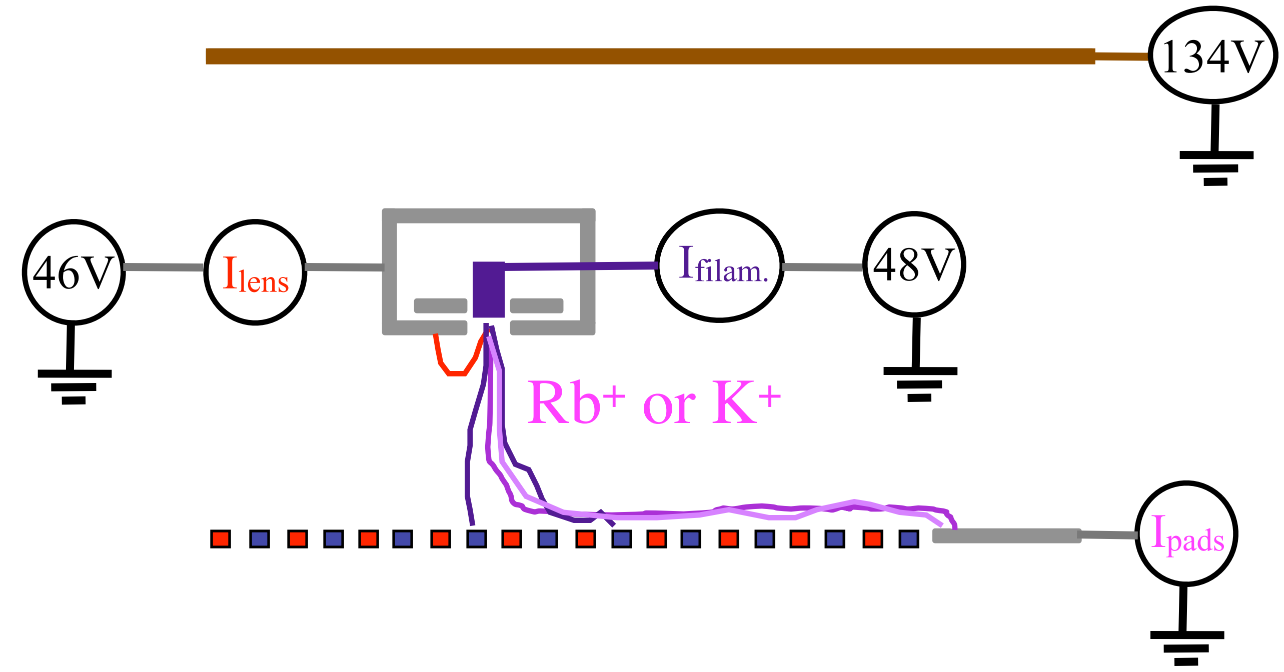


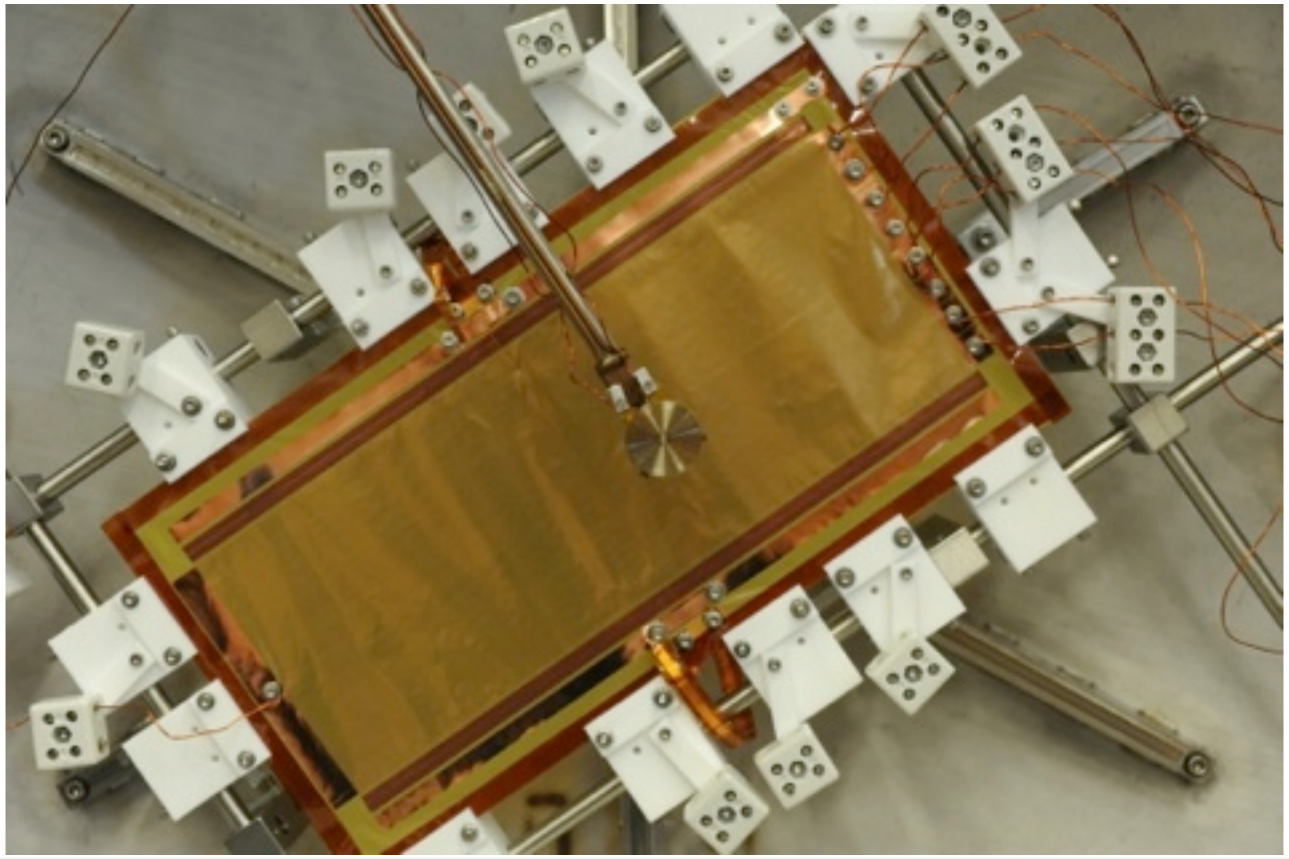
Transport efficiency measurement

Transport efficiency measurement procedure:

1) Collection efficiency: $\epsilon_{coll.} = I_{coll.}/I_{carpet}$

where: $I_{carpet} = I_{filam.} - I_{lens}$



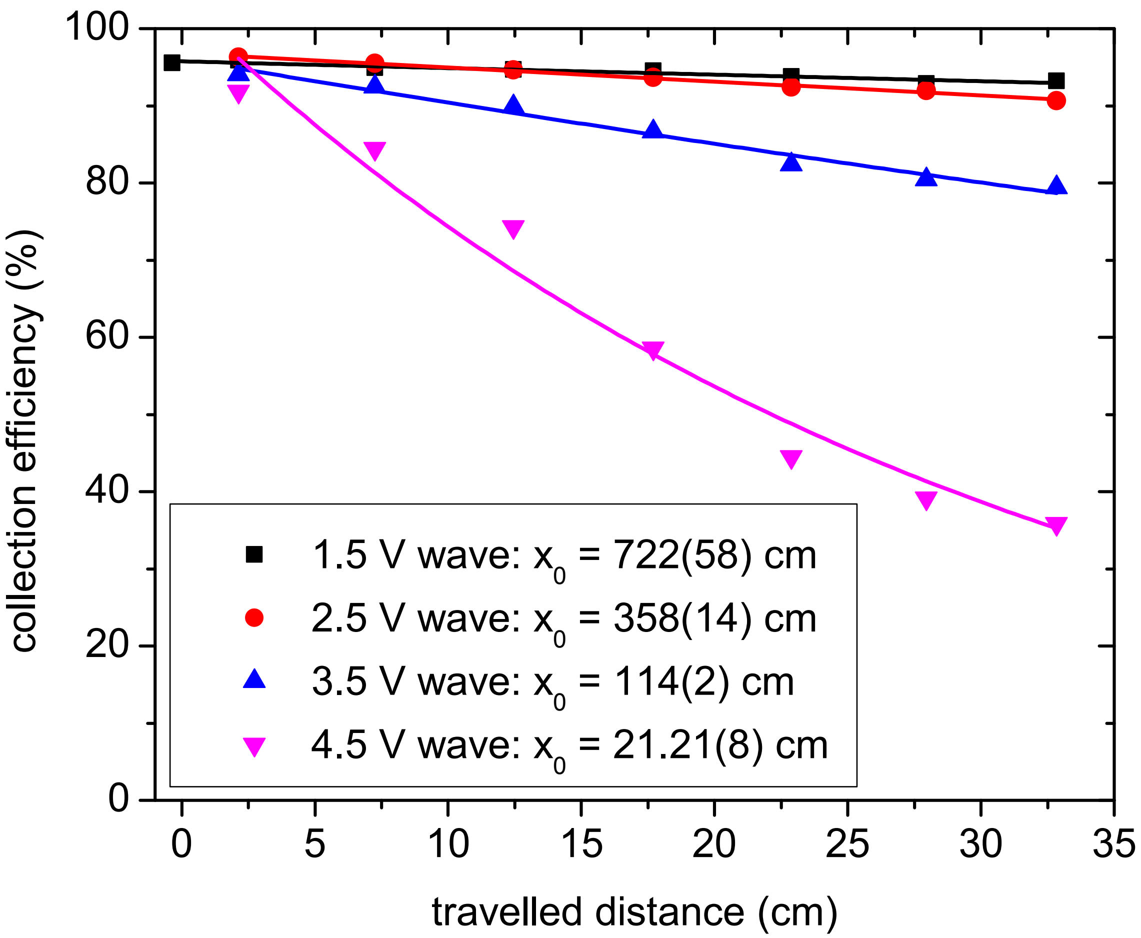


Transport efficiency measurement

Transport efficiency measurement procedure:

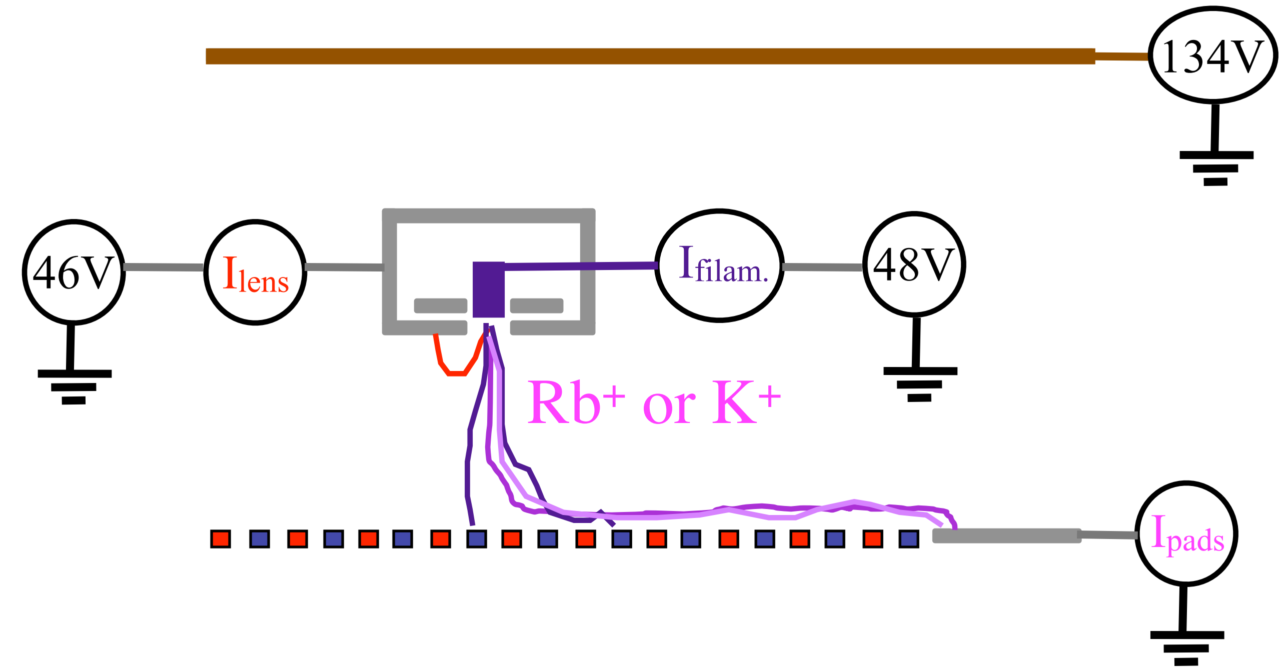
1) Collection efficiency: $\epsilon_{coll.} = I_{coll.}/I_{carpet}$

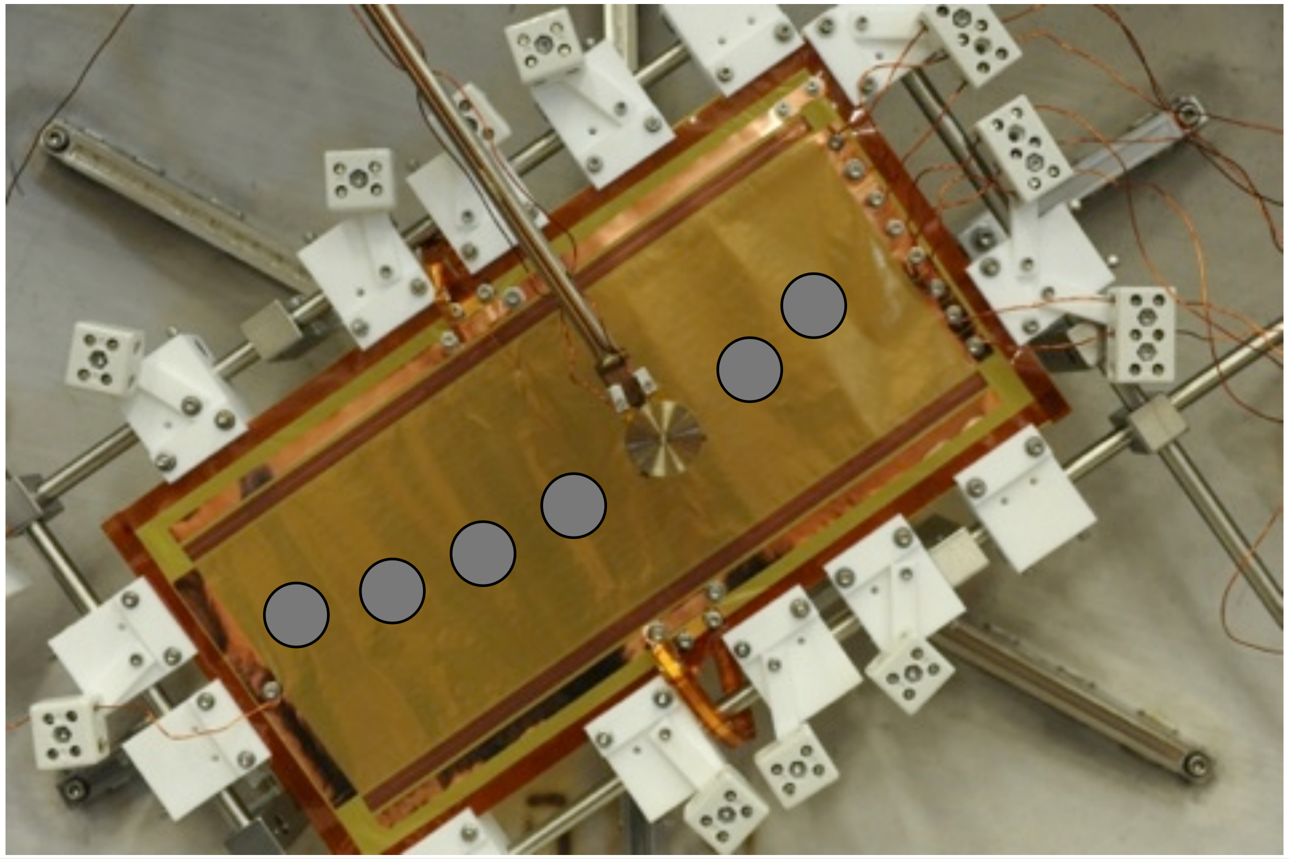
where: $I_{carpet} = I_{filam.} - I_{lens}$



2) Fit decay of efficiency: $\epsilon_{coll.}(x) = 2^{-x/x_0}$

to obtain half-distance x_0

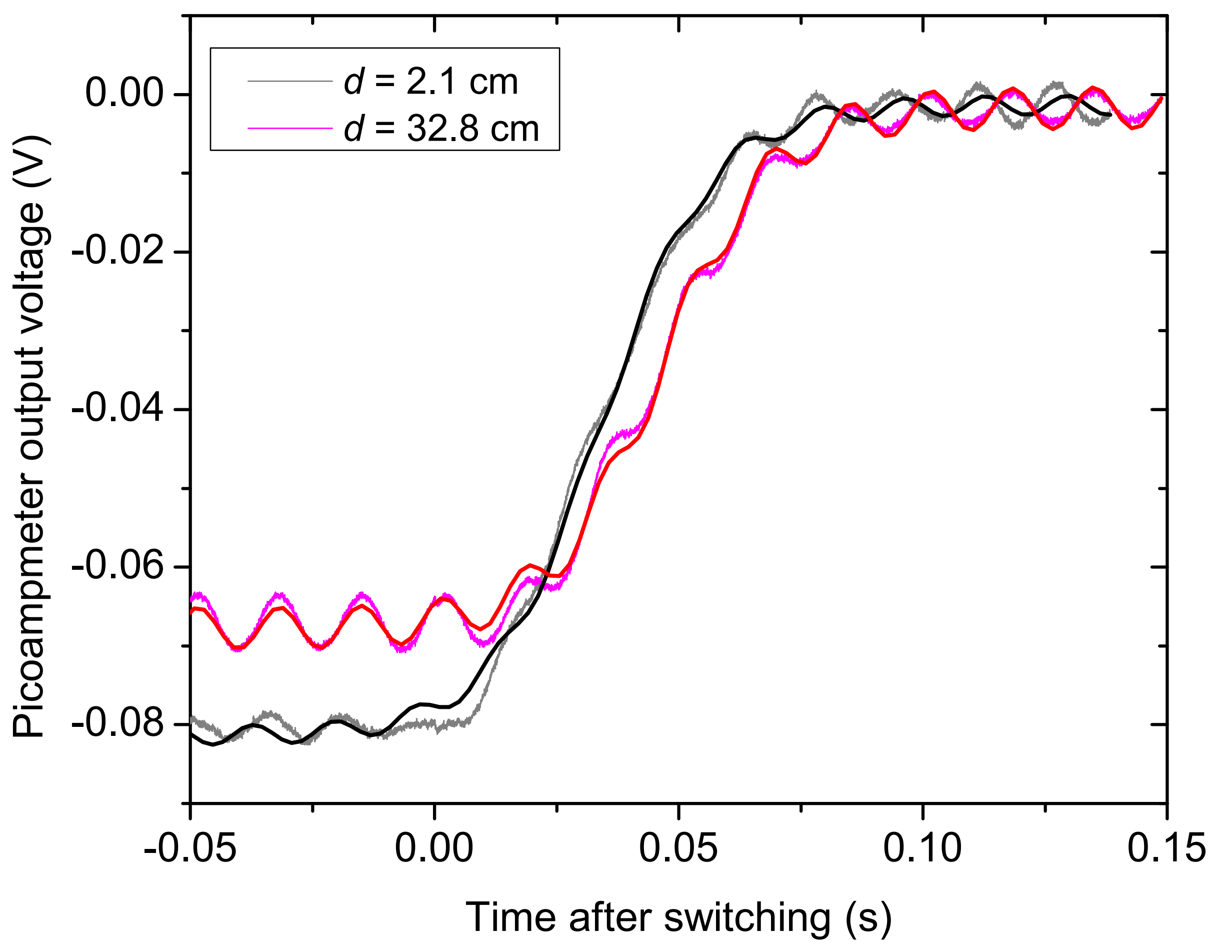


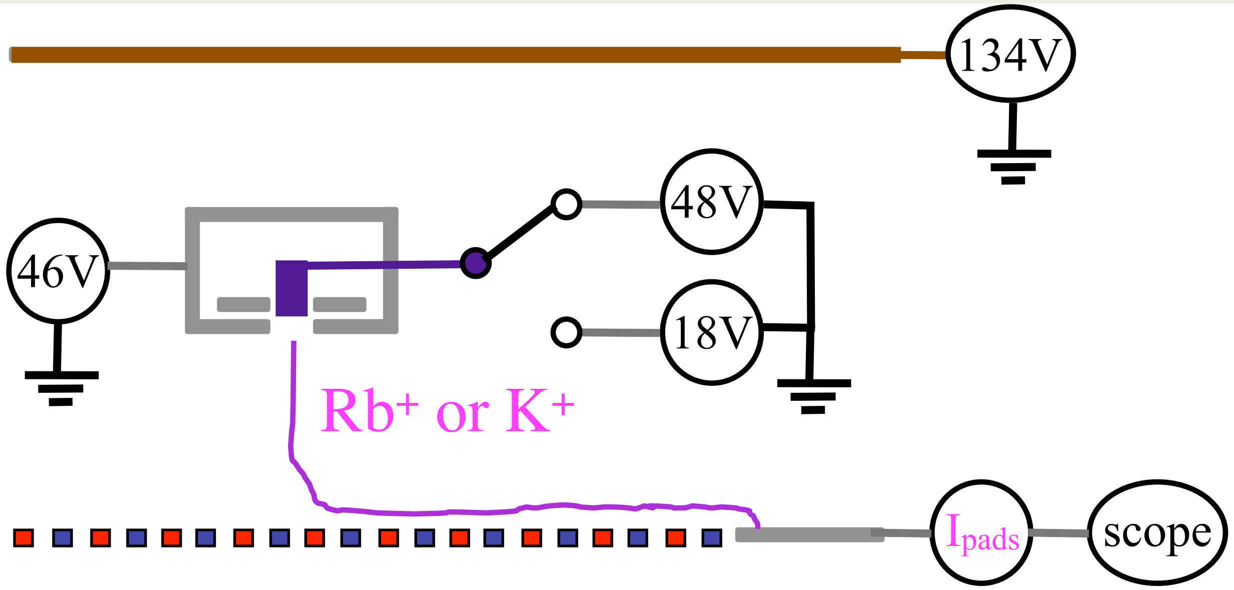


Transport velocity measurement

Transport velocity measurement procedure:

1) Switch down ion source bias (block ions).
2) Results in a drop of I_{pads}
3) Travel time: moment drop occurs
(obtained using a Boltzmann+sine fit function)

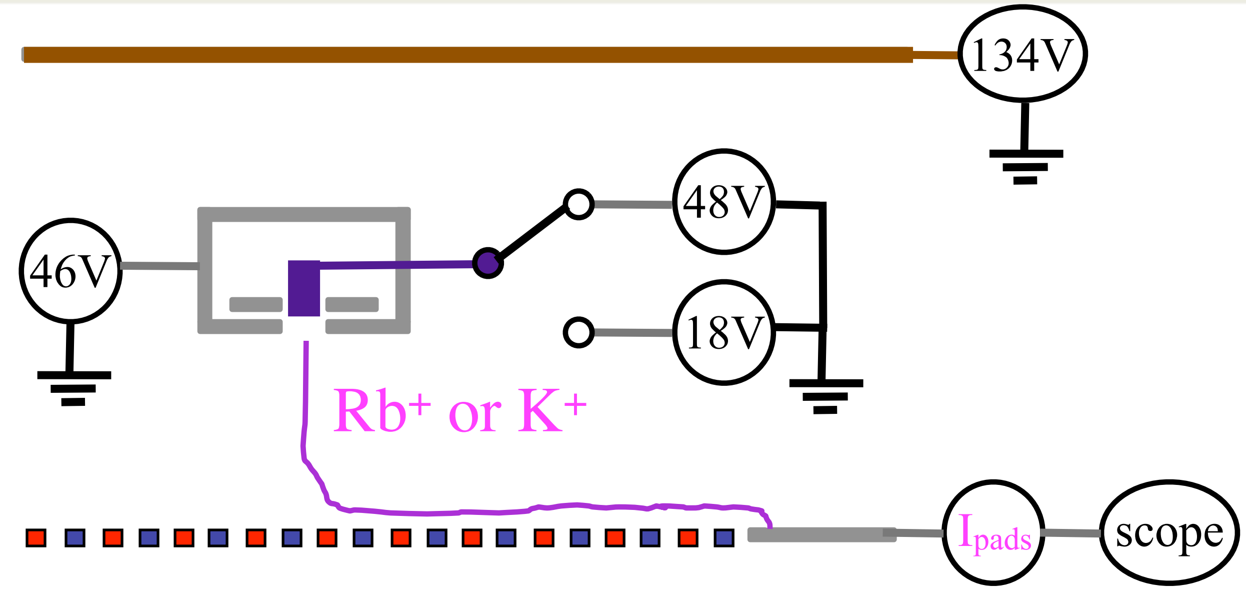


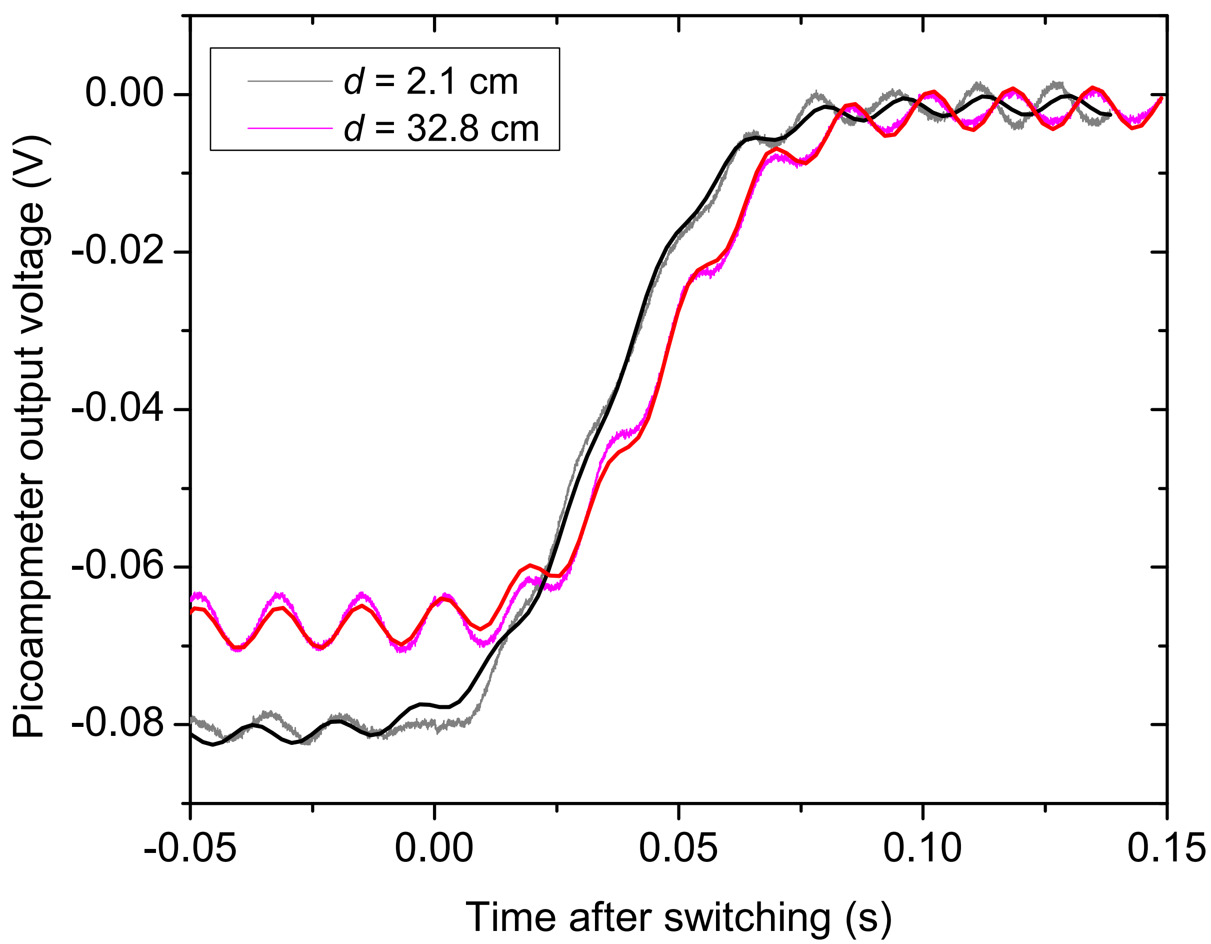


Transport velocity measurement

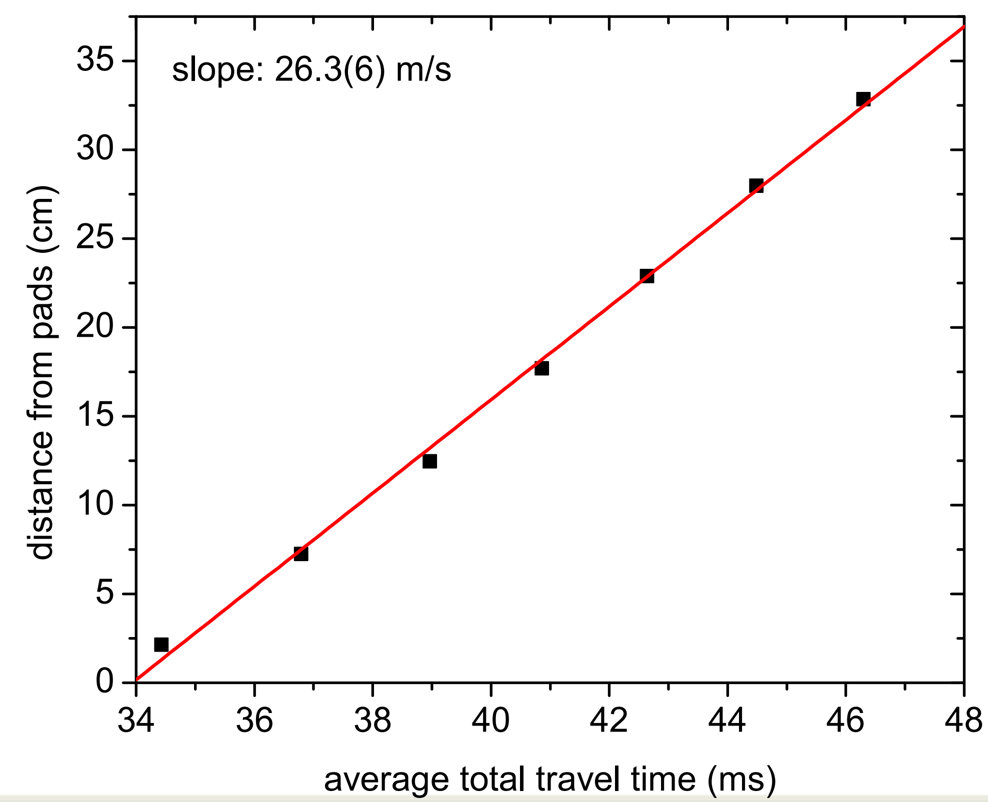
Transport velocity measurement procedure:

1) Switch down ion source bias (block ions).
2) Results in a drop of I_{pads}
3) Travel time: moment drop occurs
(obtained using a Boltzmann+sine fit function)





4) Repeat for different distances d
5) Average ion velocity: $d = \bar{v} \cdot (t - t_{drop})$



Maxime Brodeur
EMIS 2012 conference
December 4th, 2012