Very Long Path Length Ion Mobility Separations using Structures Lossless Ion Manipulations

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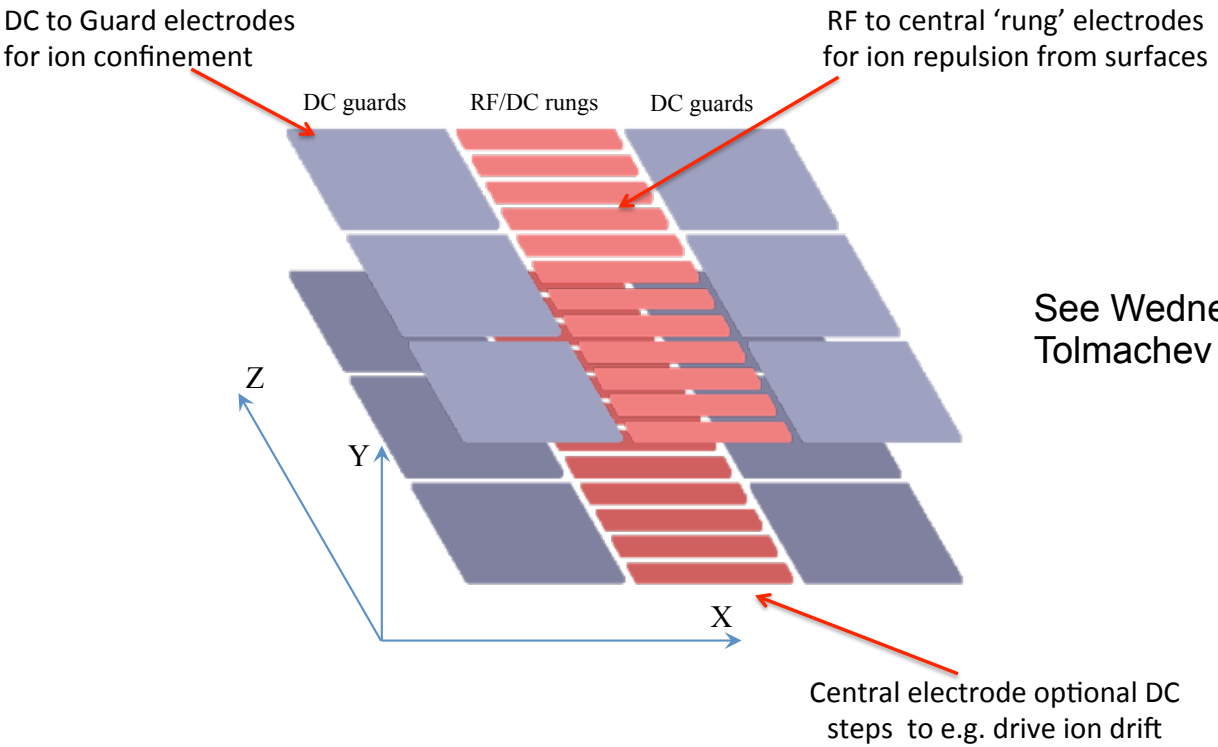
Some approaches for potentially achieving very high resolution ion mobility separations

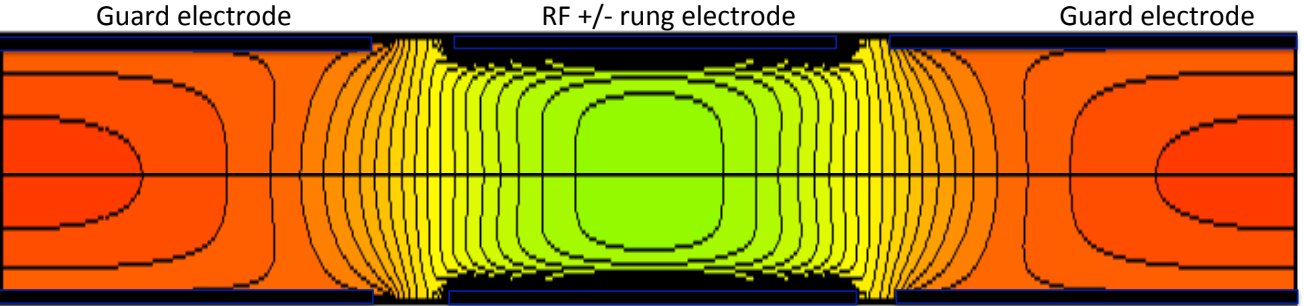
- Separation over long path in dense gas/fluid; challenges: large voltage drop required, difficulty in combining with MS
- Separation in very low temperature fluid; challenges: design complexity, maintaining uniform temperature over useful volume
- Extended residence time Differential Mobility separations (e.g. FAIMS); challenges: large ion losses, slow scan speed
- Separation in flowing (or expanding gas); challenges: maintaining highly stable gas flow, limited separation space and dynamic range
- Separation in cyclic path devices; challenge: limited separation space
- **Separation over very long path lengths; challenges: space and cost needed for long path device, large voltage drop required**

Structures for Lossless Ion Manipulations (SLIM)

One of many SLIM electrode arrangements……



See Wednesday Poster by Tolmachev et al., WP 485



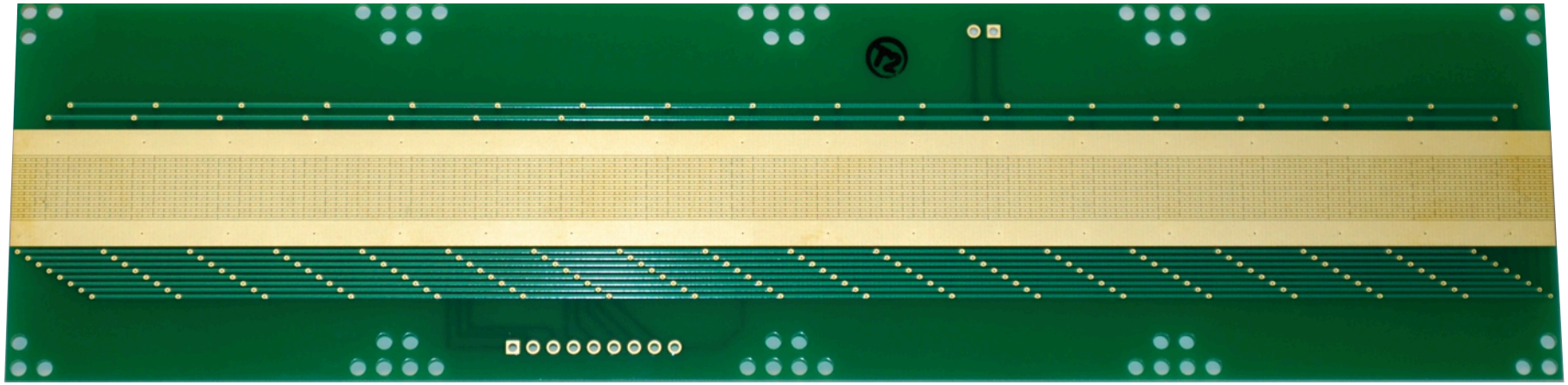
Garimella et al., JASMS, *25*, 1890 (2014)

A traveling wave SLIM IMS variation

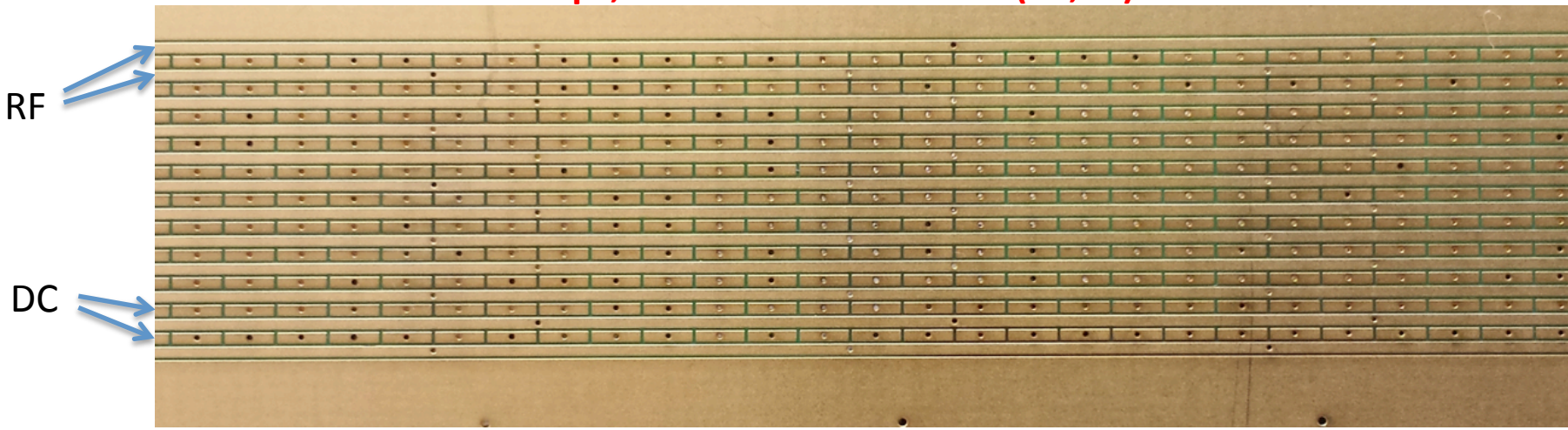
- Existing data shows IMS performance can approach drift tube designs, and theory suggests Resolution $\propto$ (drift path length)$^{0.5}$ with good separations achievable over significant mobility range*
- Attraction: voltages applied independent of drift path length
- Question: can a SLIM implementation provide good resolution?
- 2nd question: can the SLIM implementation be simplified?
- 3rd question: can the design be made compact?
- 4th question: …….

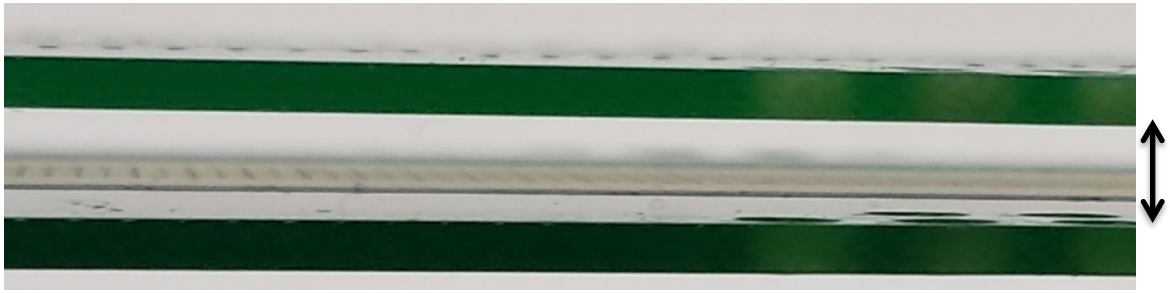
* Shvartsburg and Smith, Anal. Chem., *80*, 9689 (2008)

Initial traveling wave IMS SLIM electrode design evaluated

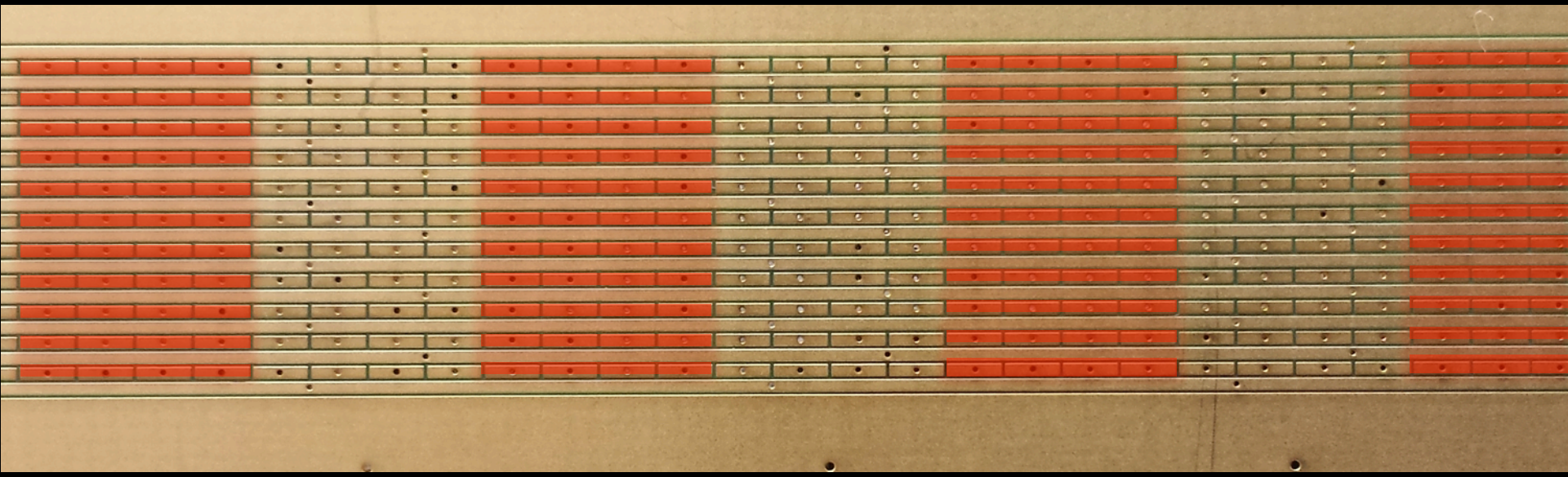


#RF strips, #rows DC electrodes (12,11)



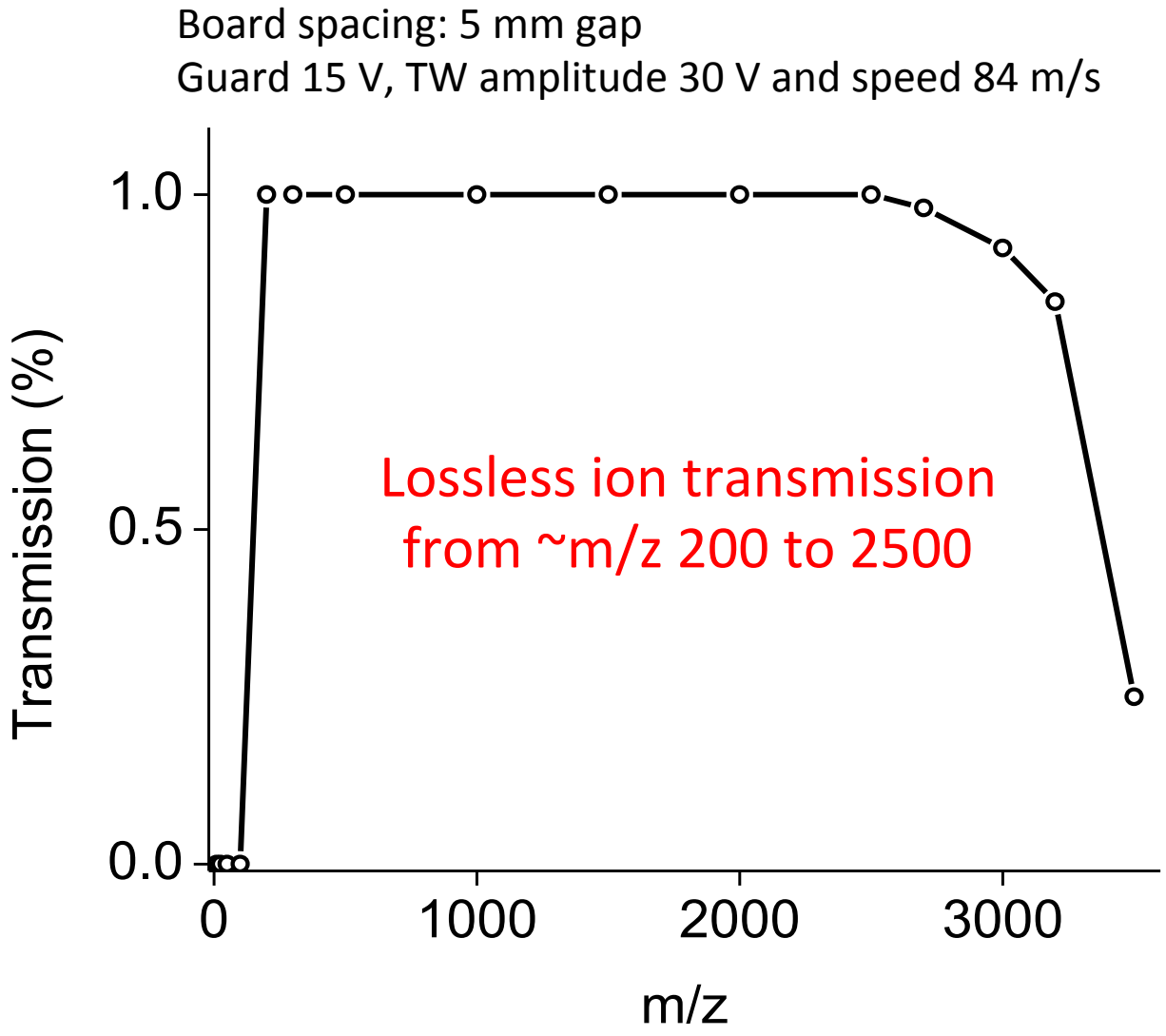


Elevated DC to 4 of every 8 electrodes in each of 11 rows incremented in single electrode steps



Sequence = 11110000

Ion transmission efficiency by trajectory simulations



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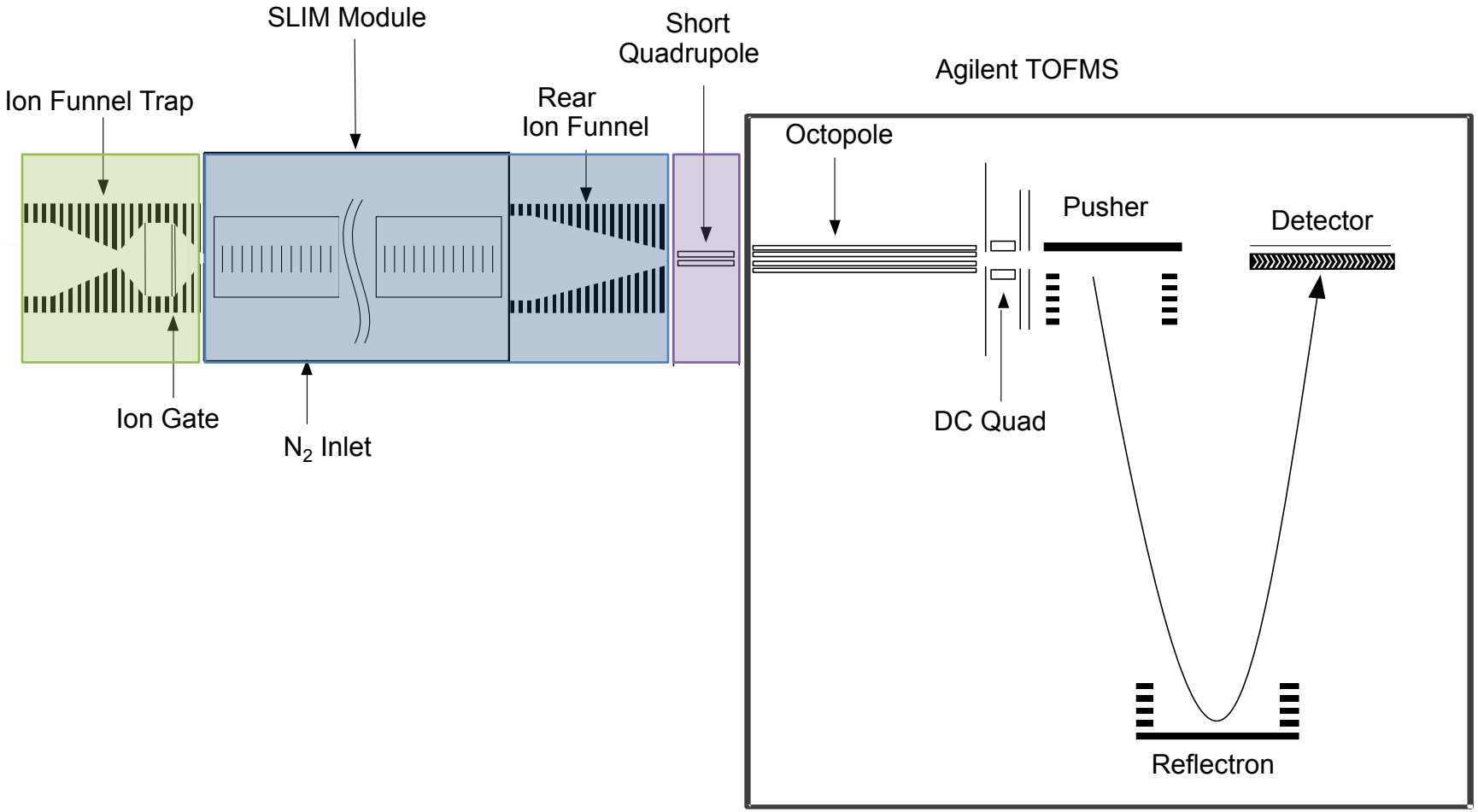
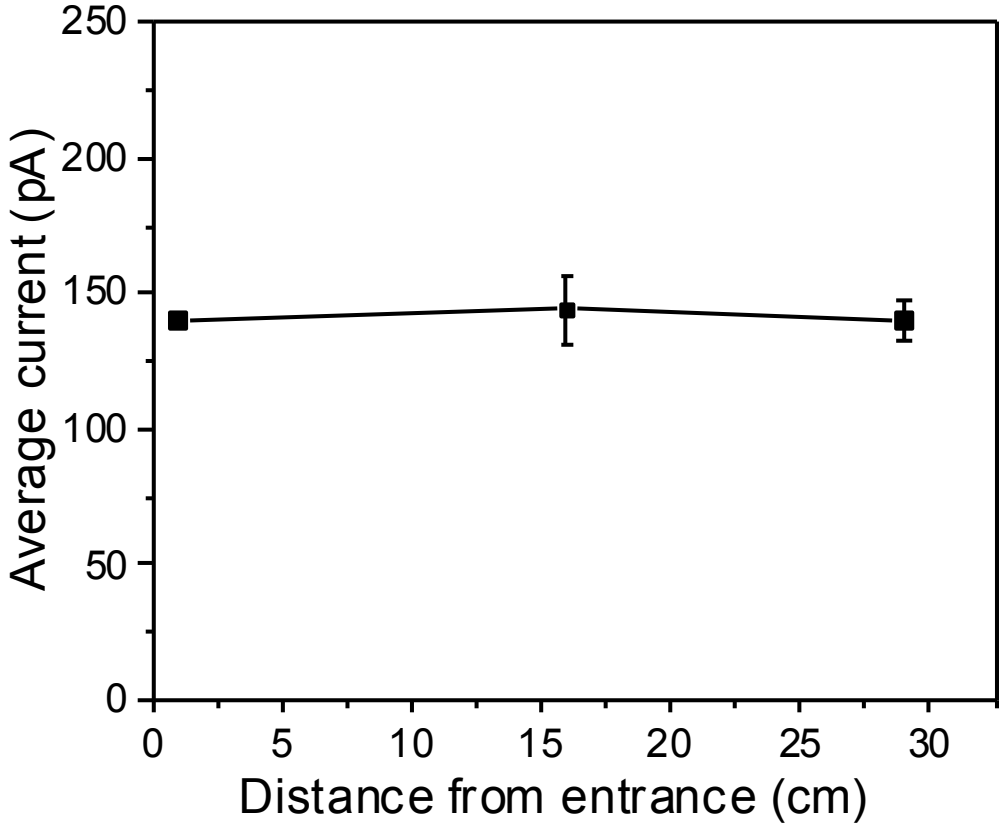
Experimental arrangement



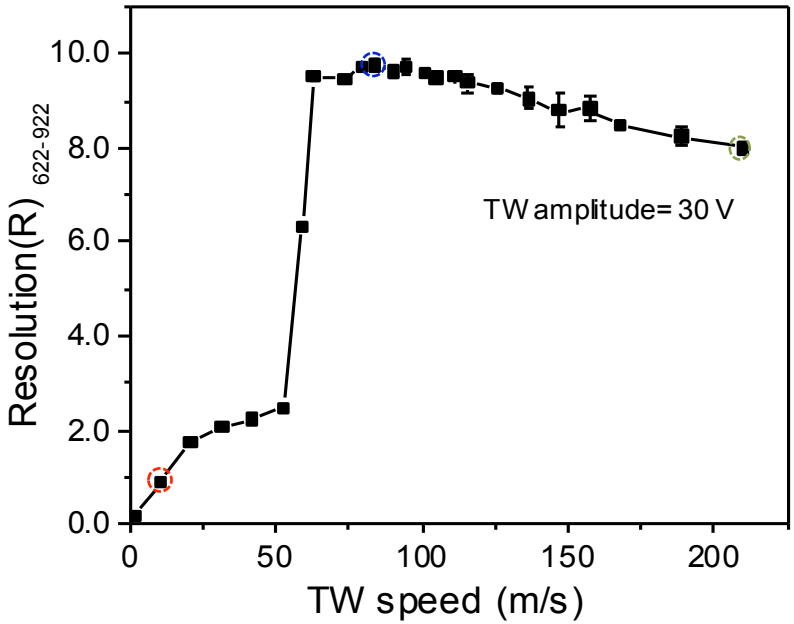
Direct measurement of ion current in SLIM IMS module

Board spacing: 5 mm
Guard 15V, TW amplitude 30 V and speed 84 m/s



See Monday Poster by Hamid et al.; MP 137

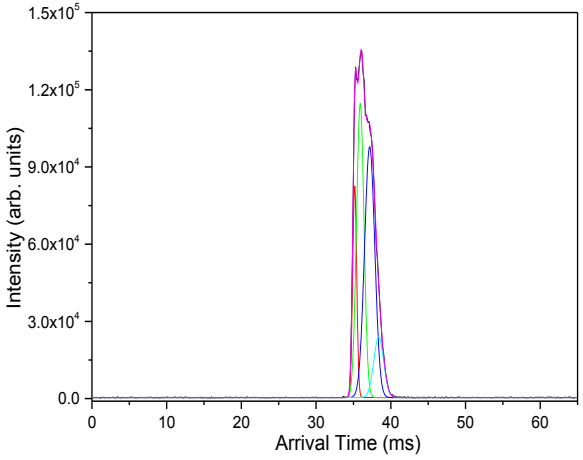
TW speed effect on IMS resolution



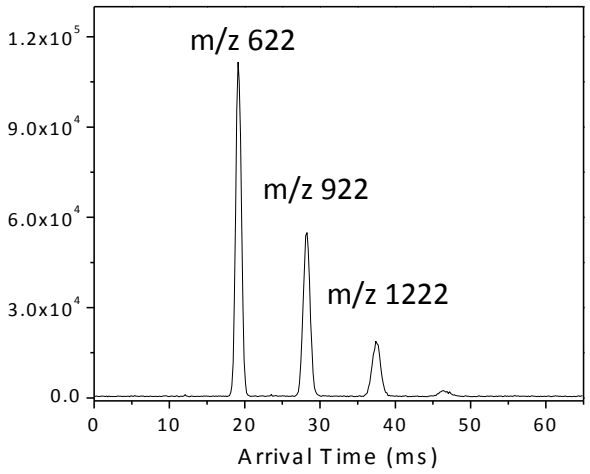
Sequence = 11110000

Resolving power ~35

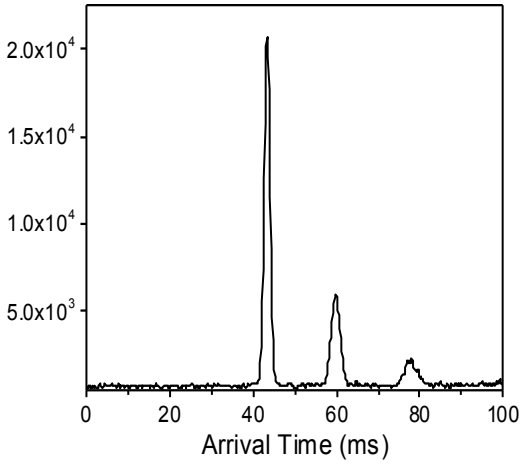
10.5 m/s



84 m/s

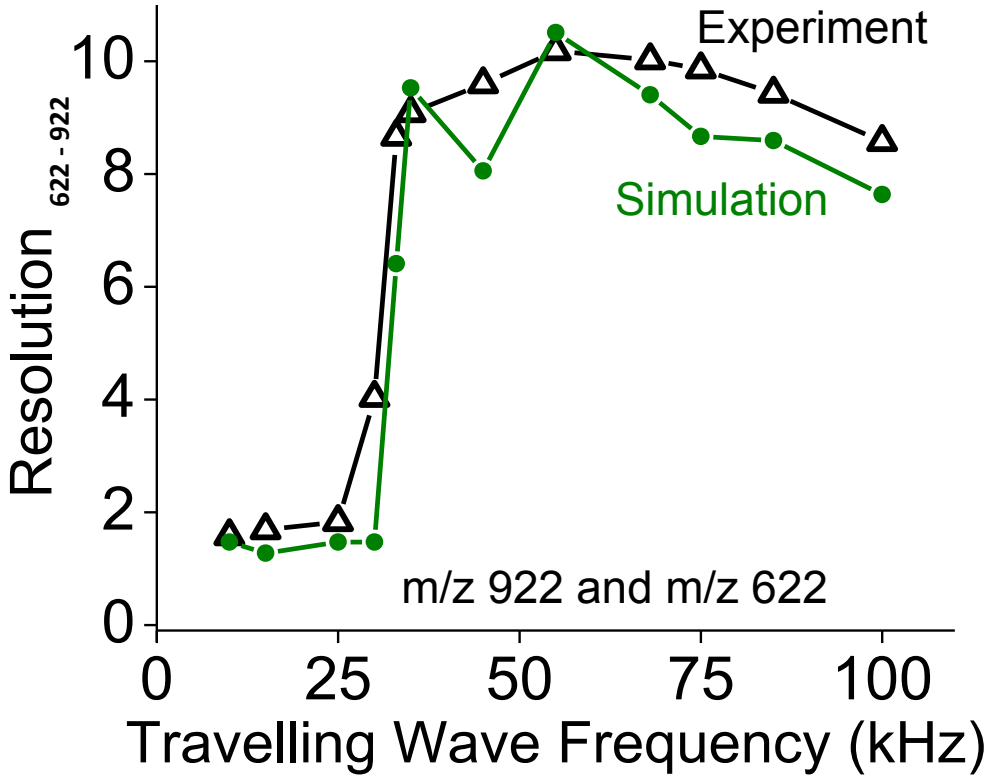


210 m/s



See Monday Poster by Hamid et al.; MP 137

Good agreement between experiment and simulation



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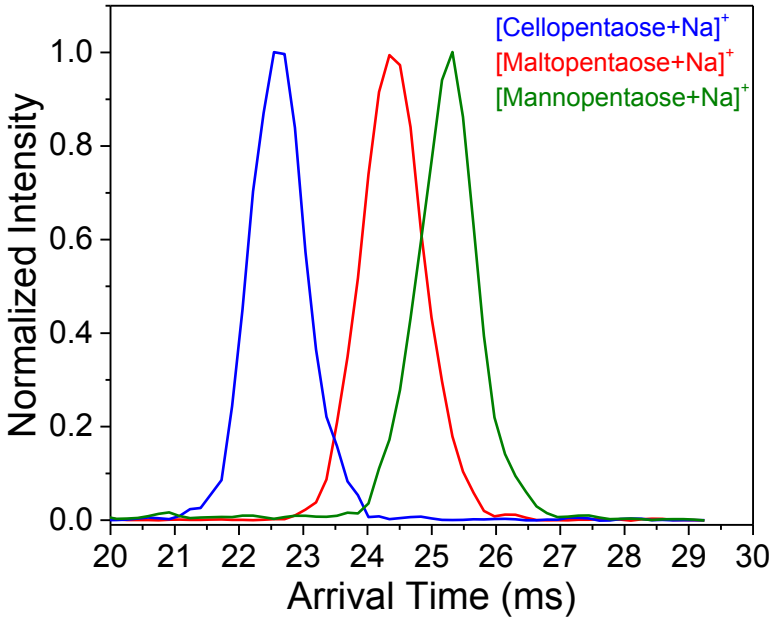
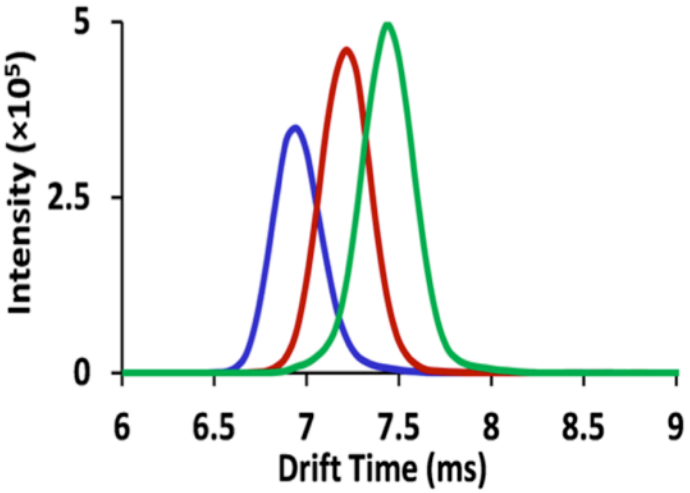
Comparison of 30 cm TW SLIM with conventional TW IMS

TW SLIM (30 cm)



- P = 4.0 Torr N_2
- TW speed = 89 m/s
- TW amp. = 30 V

Synapt G2-TWIMS* (25 cm)

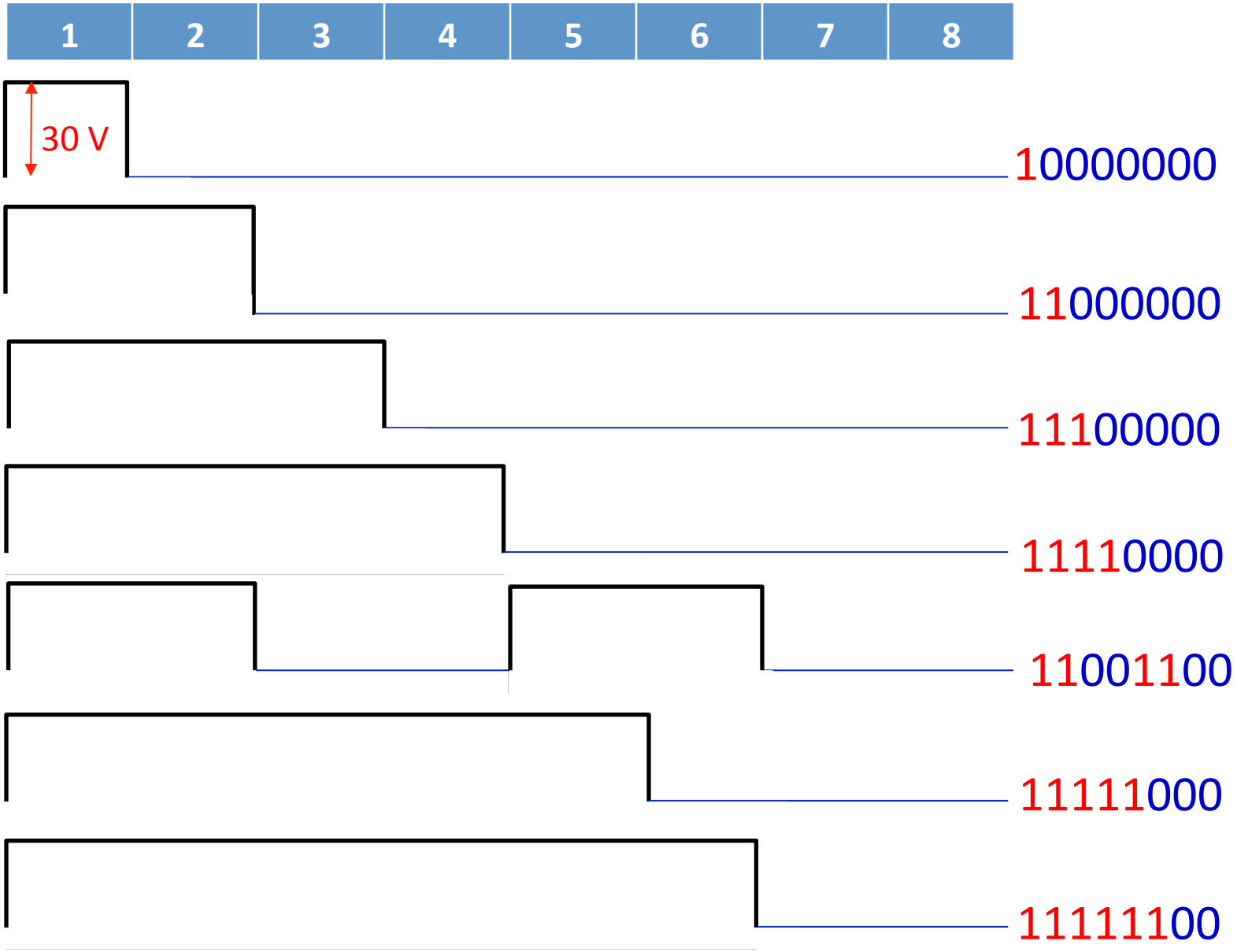


- P = 2.6 Torr N_2
- TW speed = 650 m/s
- TW amp. = 40 V

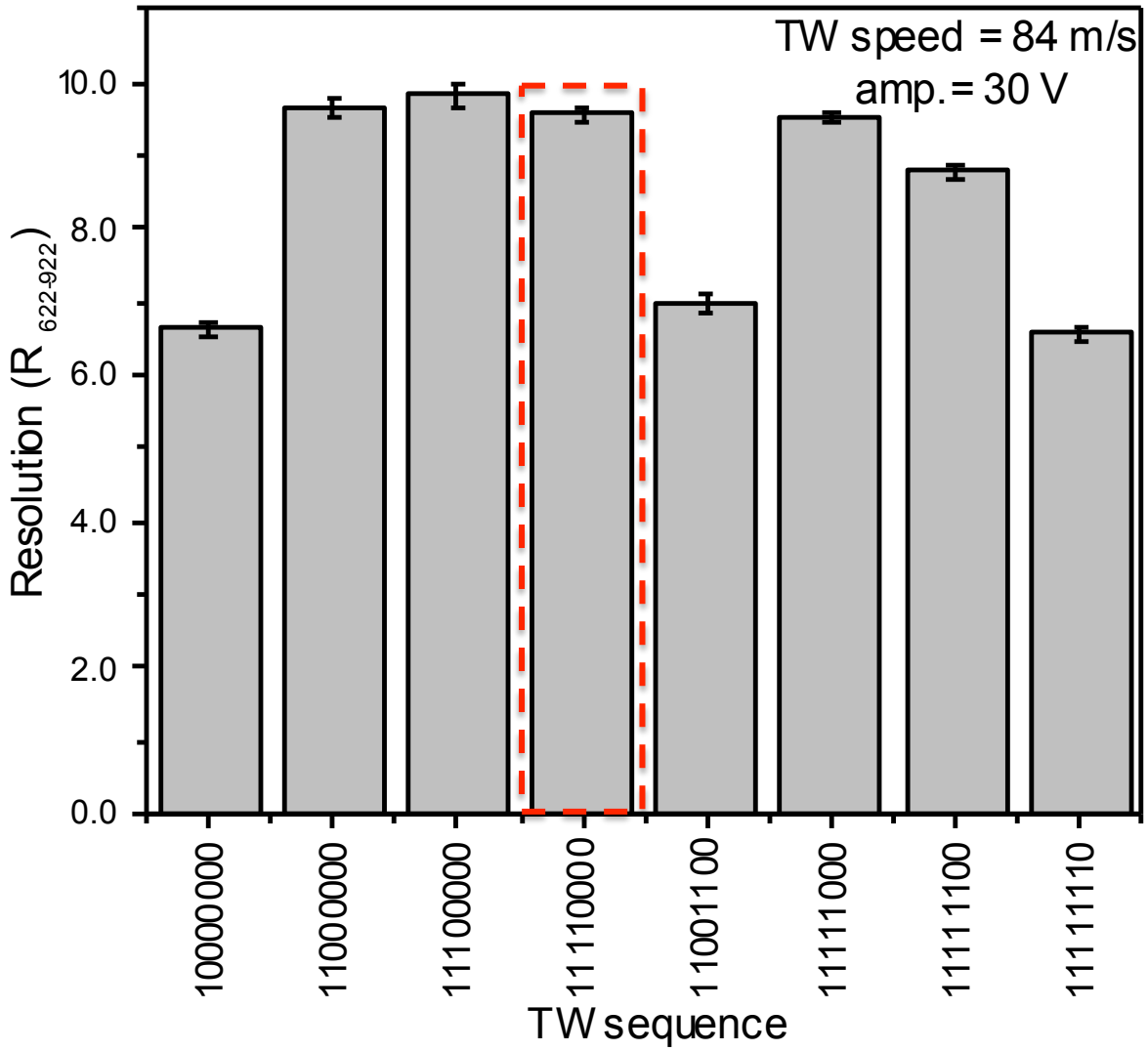
Liulin Deng

*Li, H.; Bendiak, B.; Siems, W. F.; Gang, D. R.; Hill Jr, H. H. Anal. Chem., *85*, 2760 (2013)

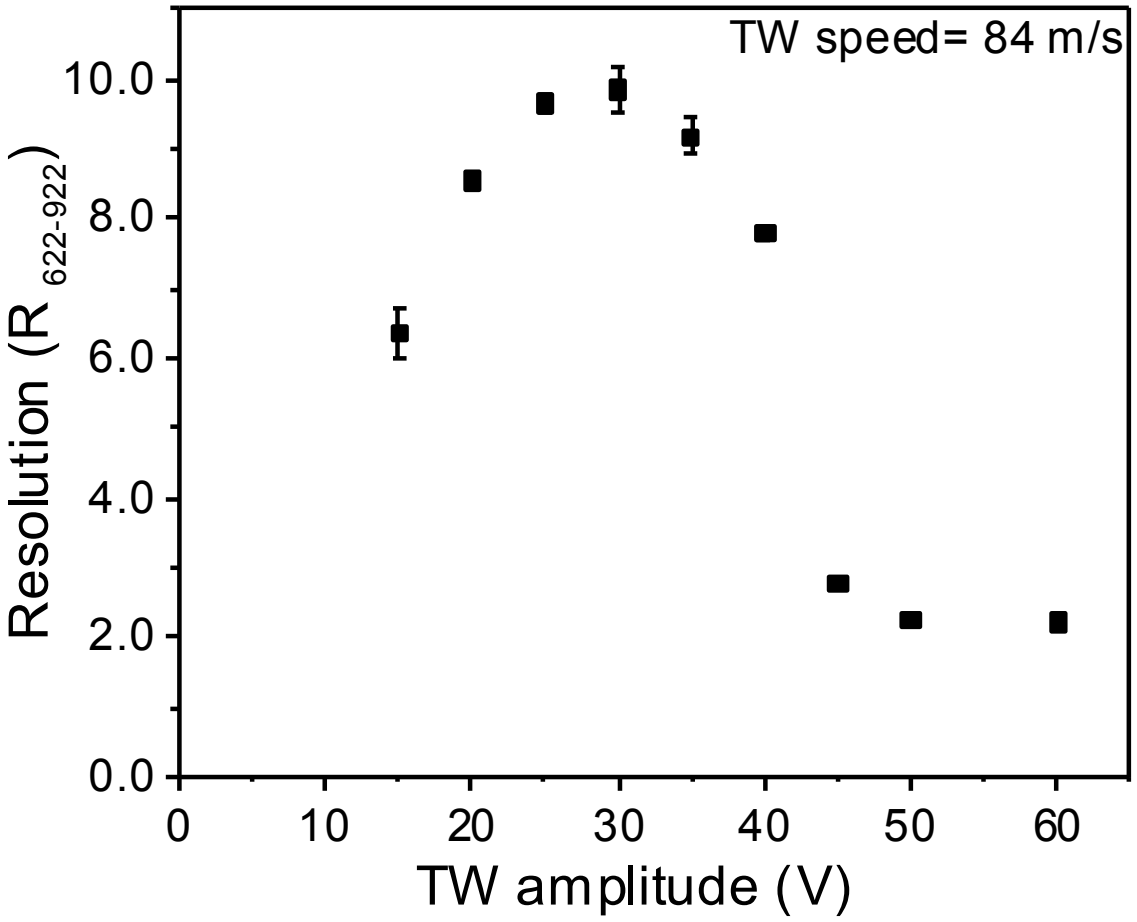
A few of the TW sequences examined in SLIM modules



Effect of TW sequence on IMS resolution for 6,5 arrangement with 5 mm board gap



TW amplitude effect on IMS resolution



Sequence = 11110000

Some other SLIM electrode arrangements explored

#RF,#DC

5,6

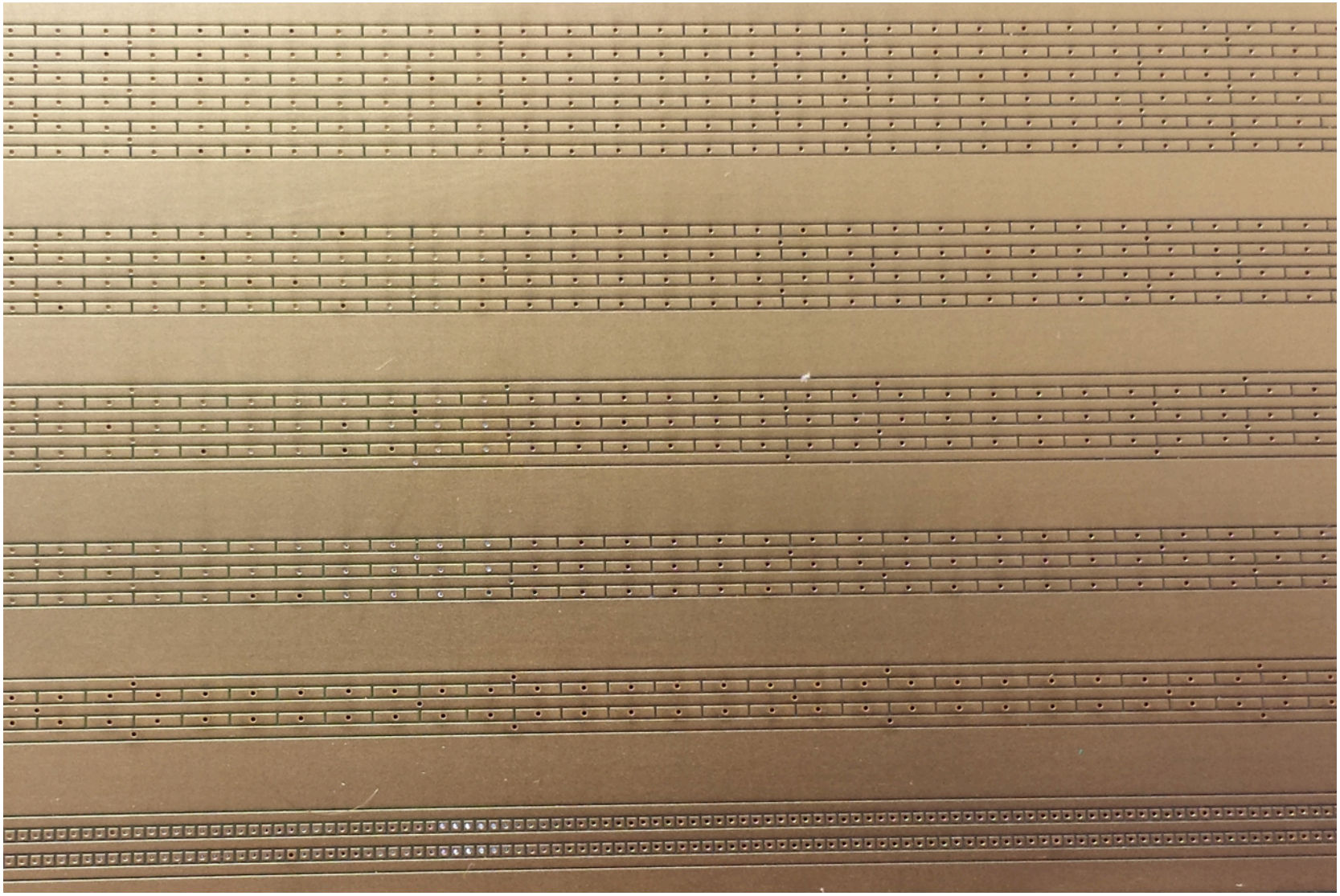
3,4

4,3

2,3

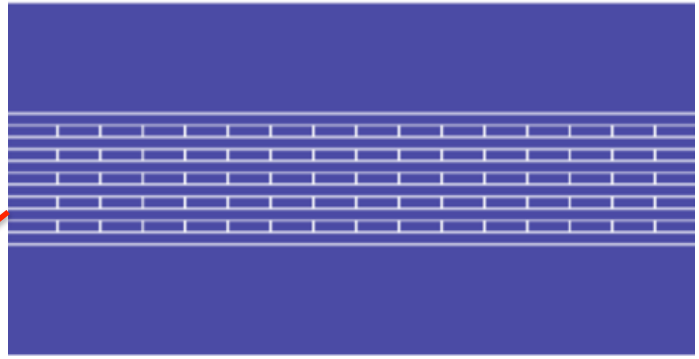
3,2

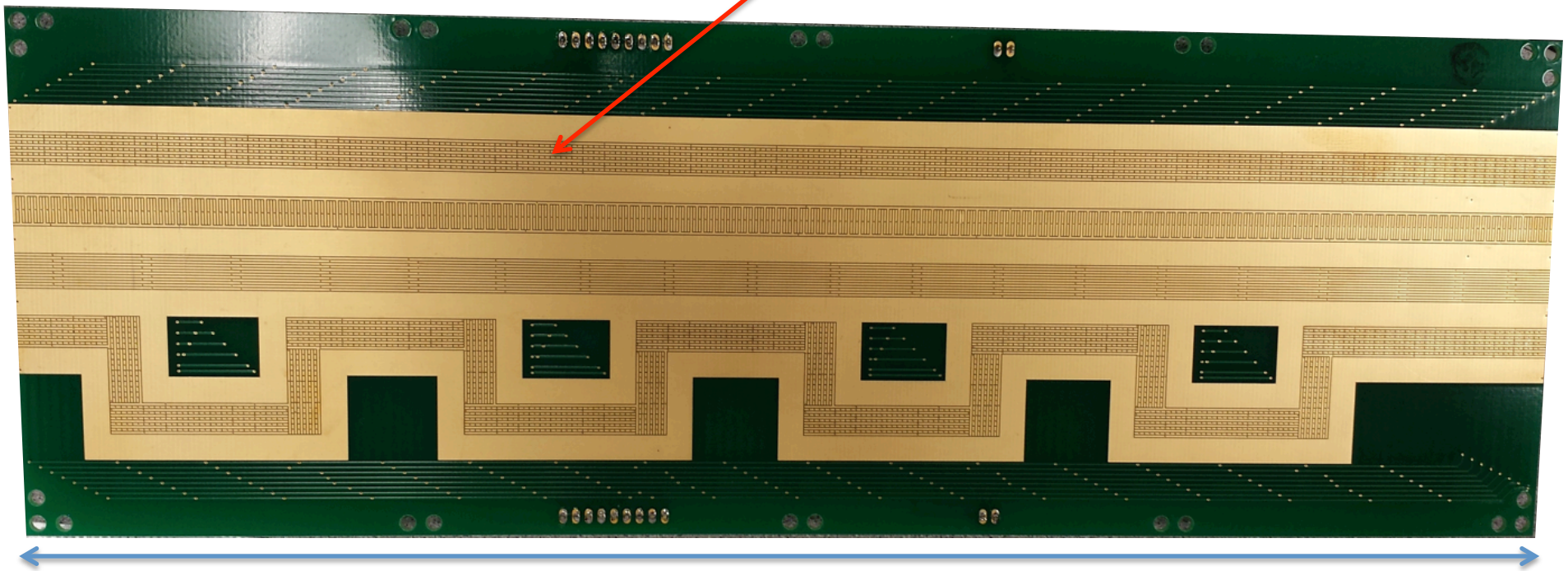
3,2



IMS performance for a 6,5 electrode arrangement

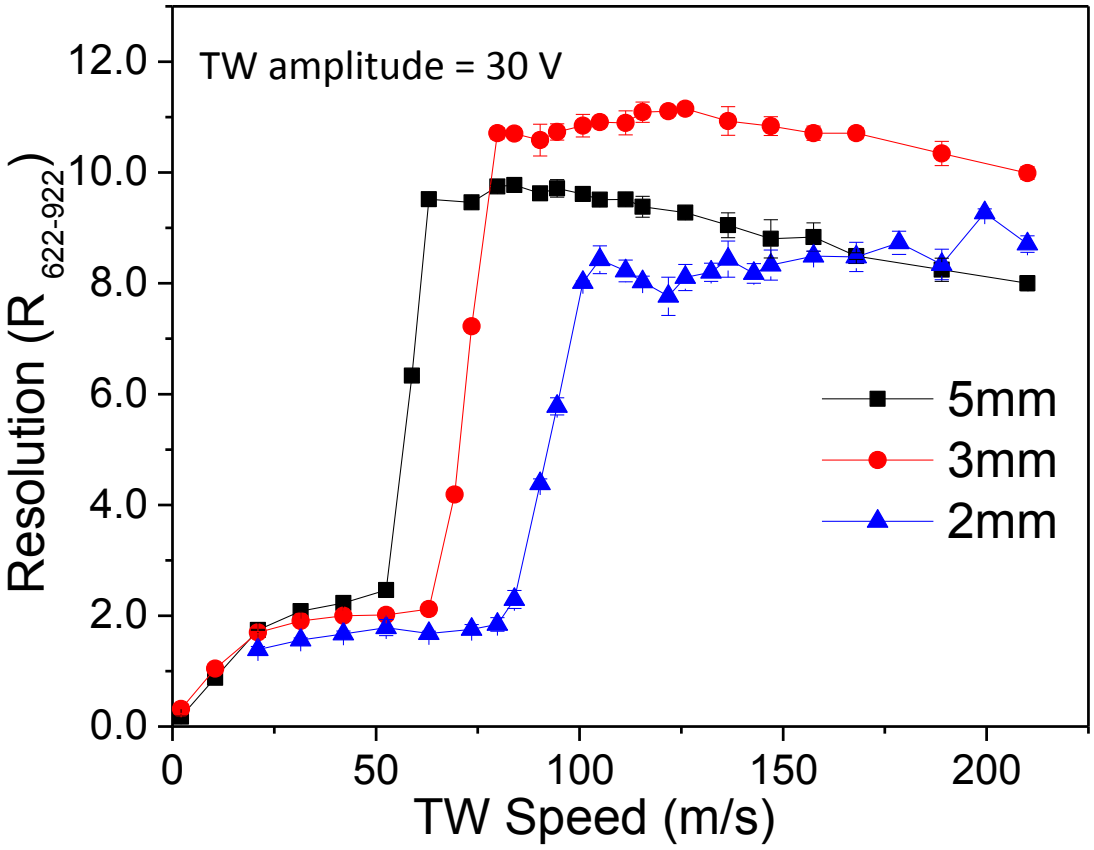
#RF strips, #rows DC electrodes (6,5)





30.5 cm

Effect of SLIM board gap on R for 6,5 linear path arrangement



5 mm gap

Resolution = 9.8

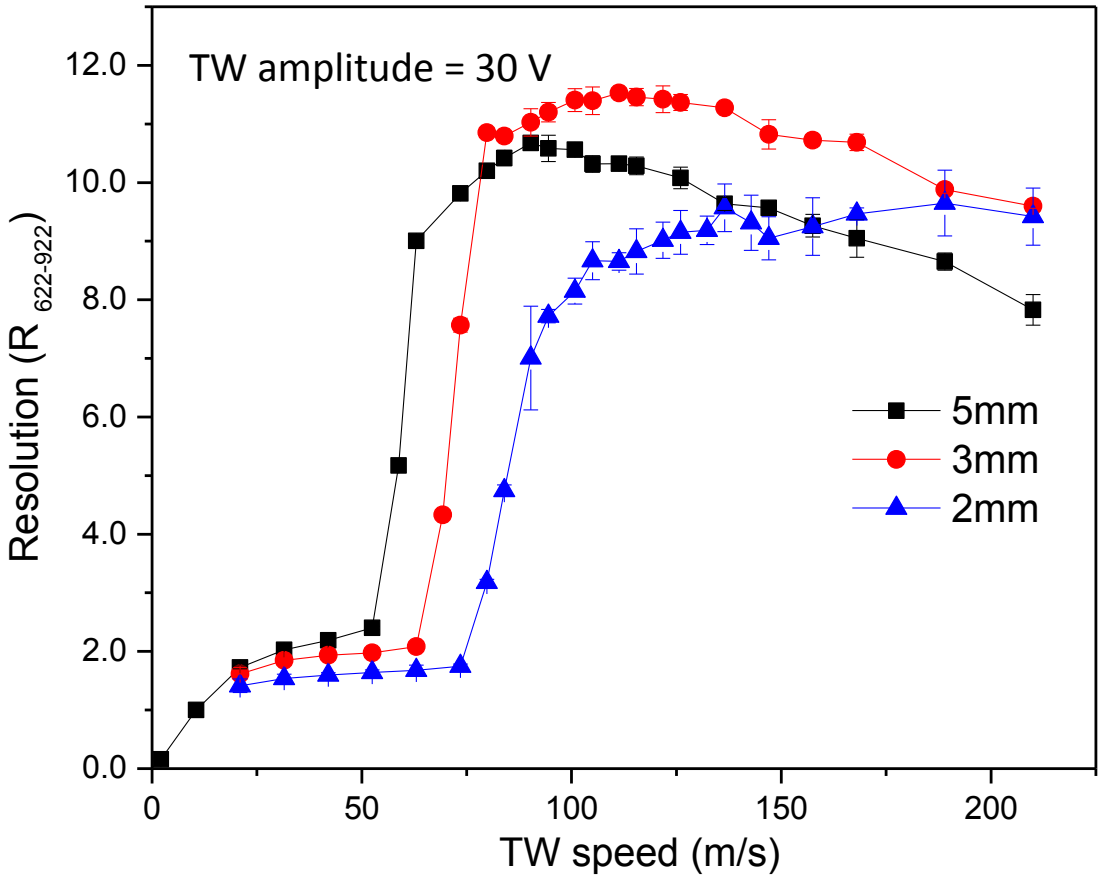
3 mm gap

Resolution = 11.2

2 mm gap

Resolution = 9.3

Effect of SLIM board gap on R for 6,5 multi-turn path arrangement



5 mm gap

Resolution = 10.8

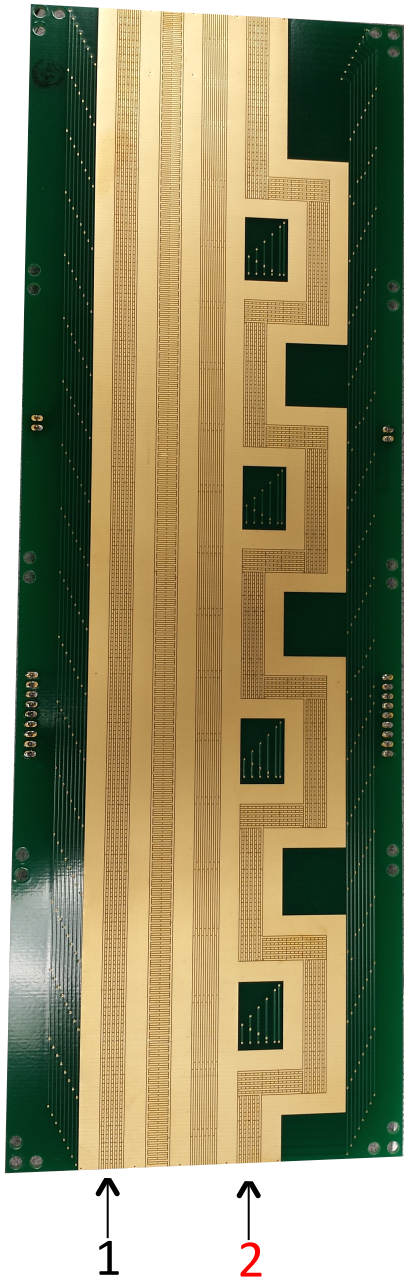
3 mm gap

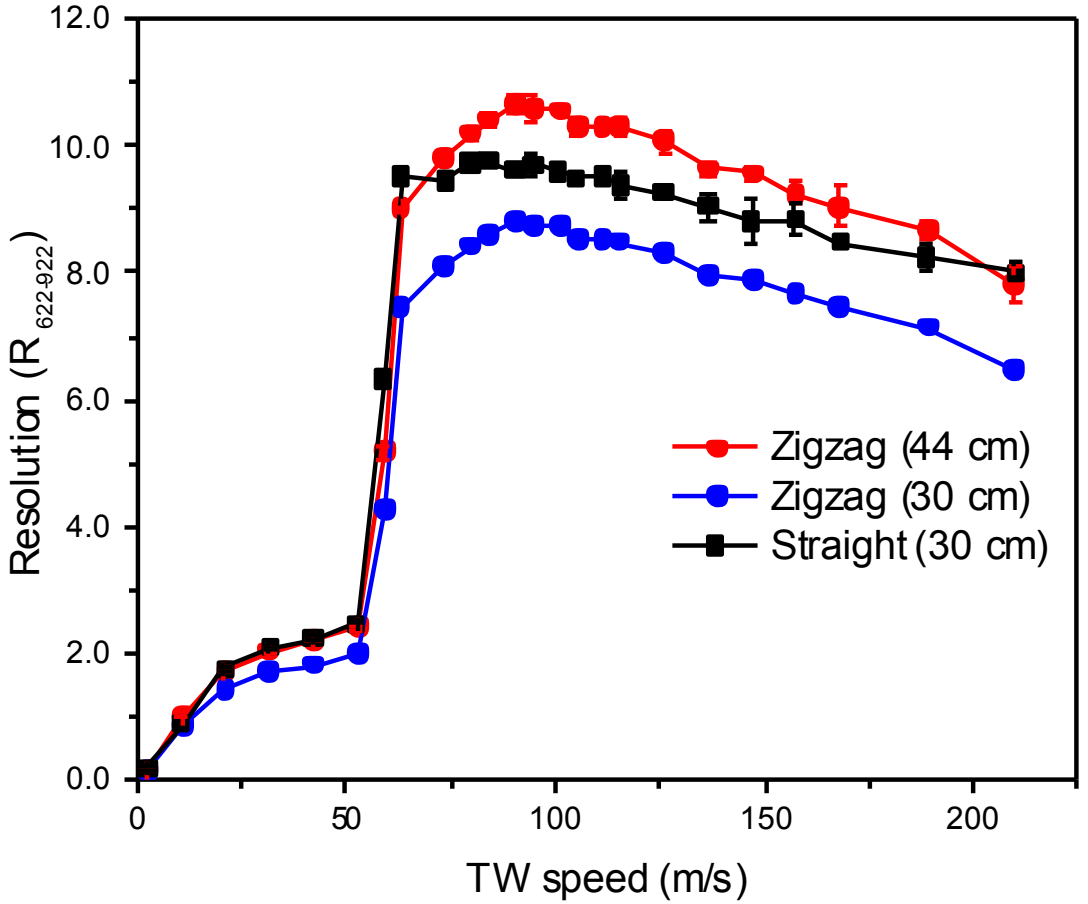
Resolution = 11.6

2 mm gap

Resolution = 9.8

Resolution for straight vs. multi-turn path arrangements

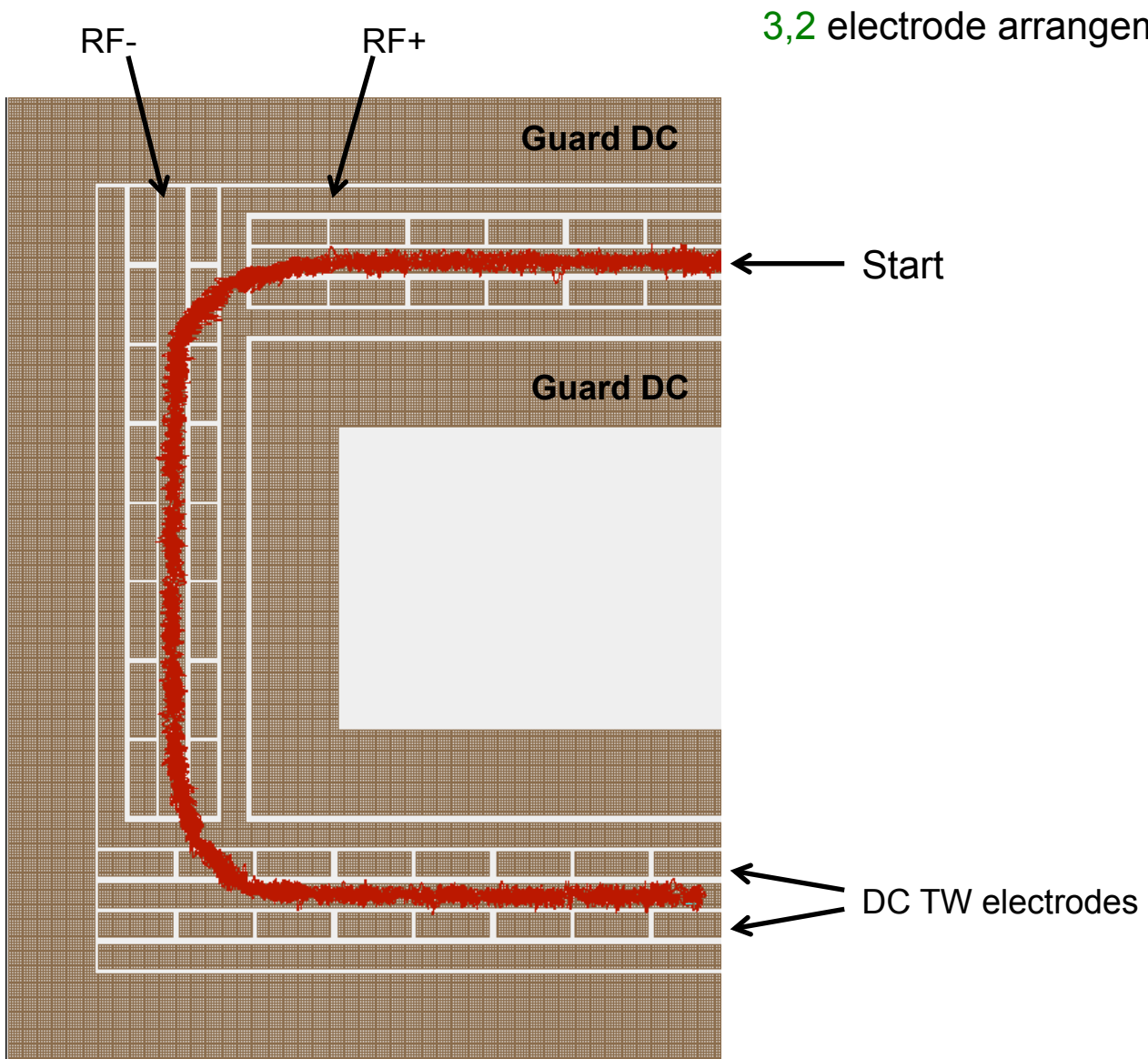




See Monday Poster by Hamid et al.; MP 137

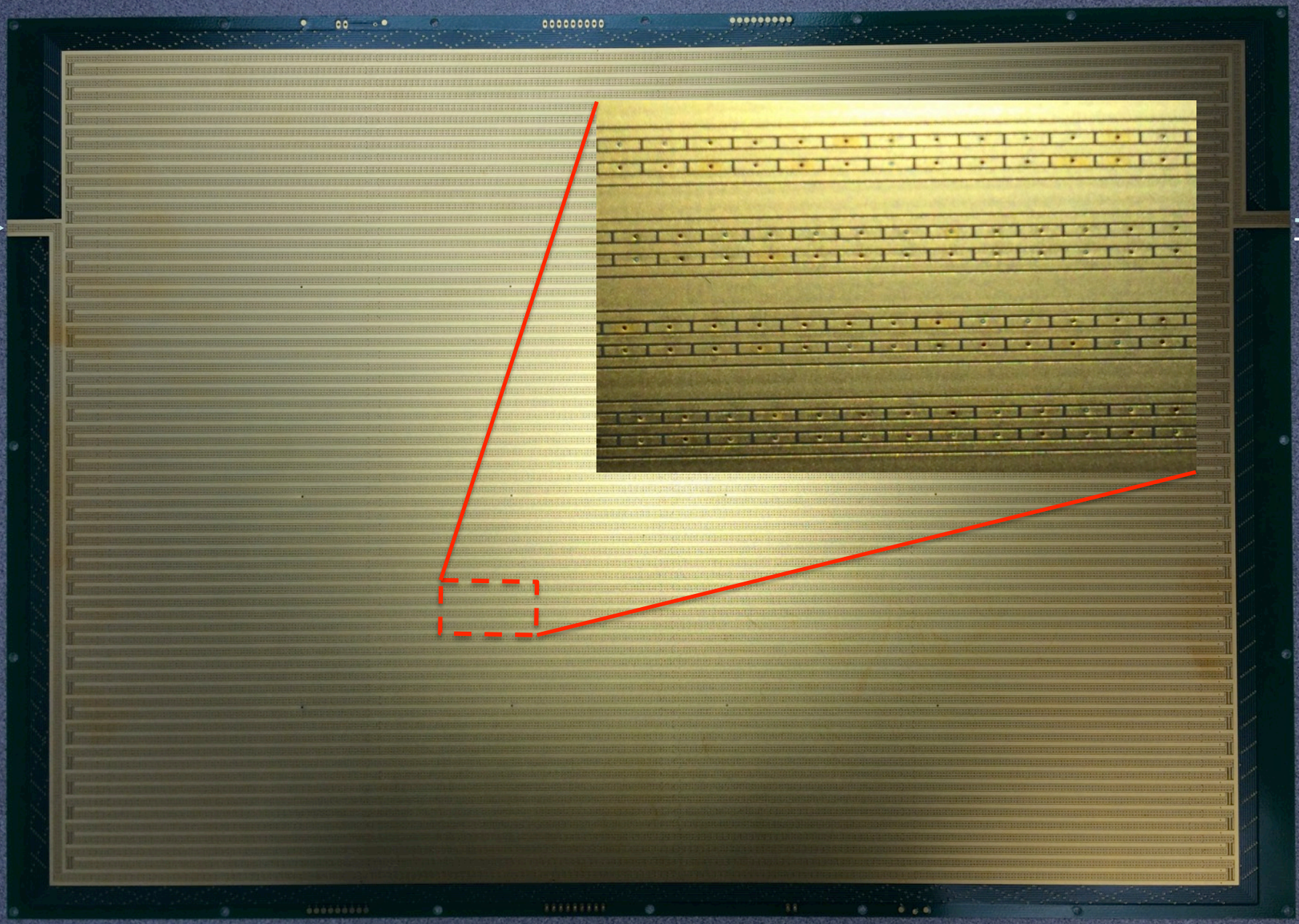
Simple electrode arrangement for turning corners

Ion trajectories calculated for 3 mm gap, TW amplitude = 30 V, speed = 84 m/s



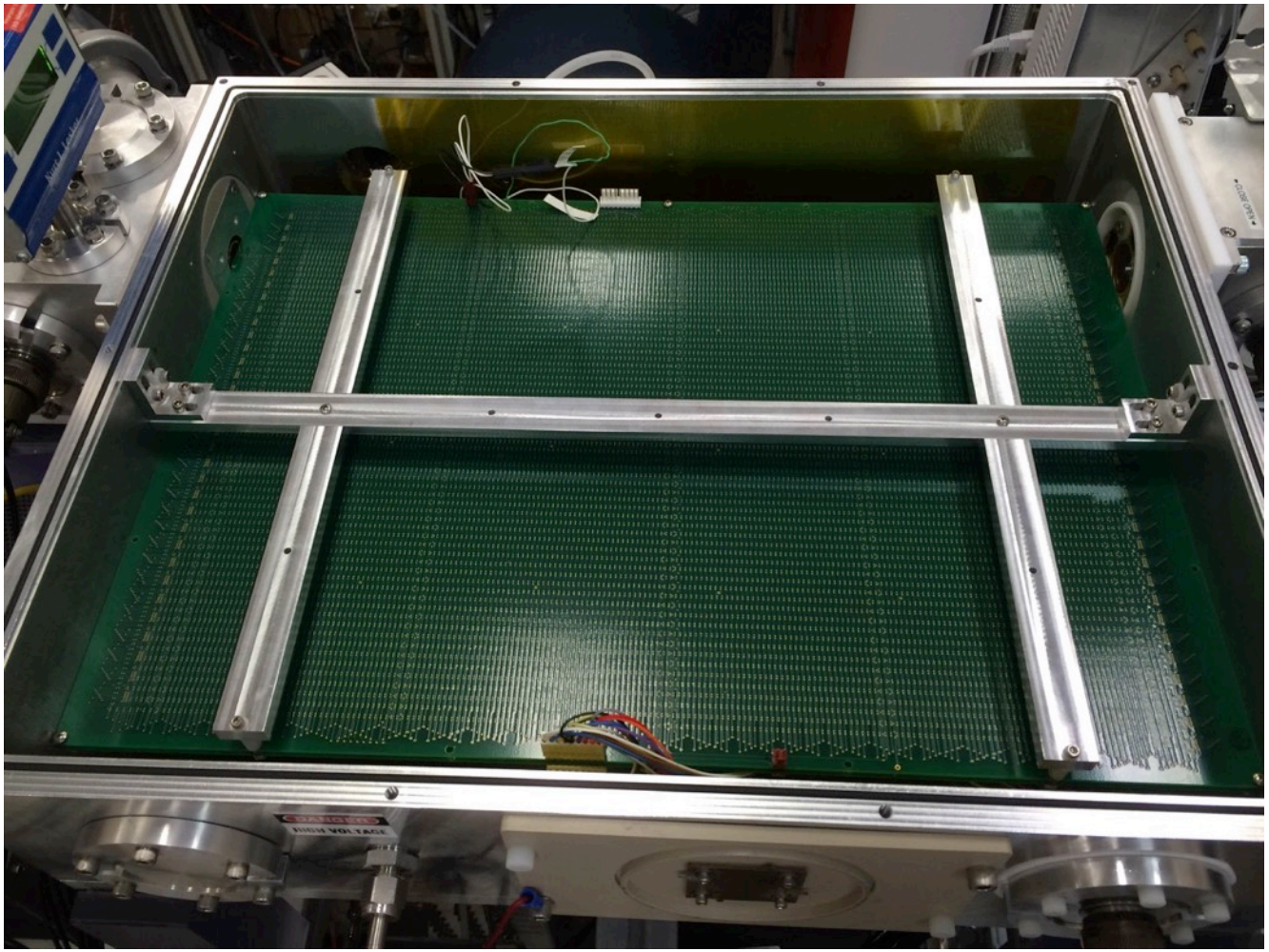
The long or winding roads towards higher resolution

28 M path SLIM IMS module incorporating ~60,000 discrete electrodes



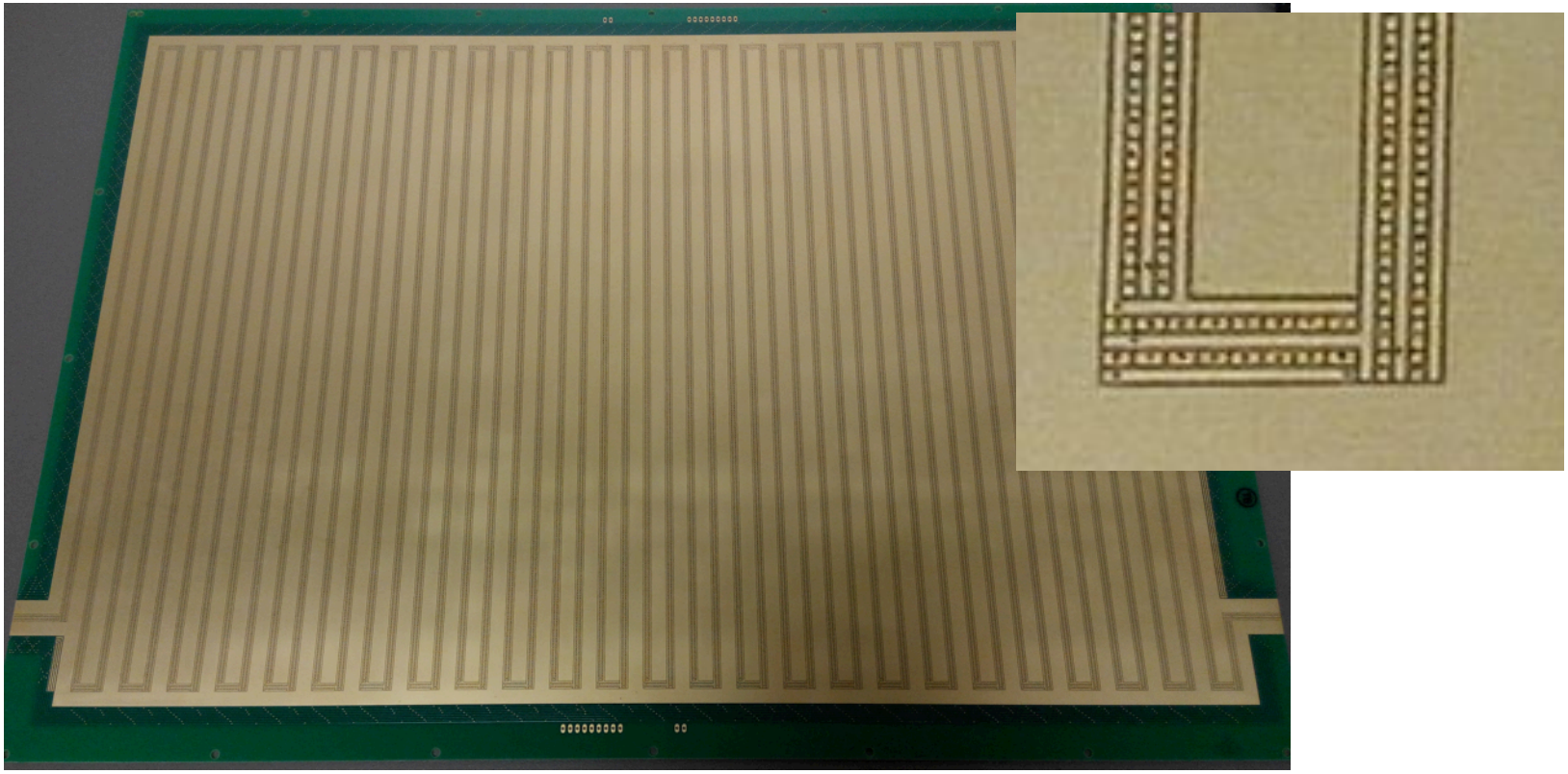
Initial evaluation of long path length SLIM IMS-MS

- ~65% efficiency for ion transmission through long path module
- Guard electrode spacing between tracks too narrow; ions jump paths at turns* under conditions needed for separation
- Refined design developed

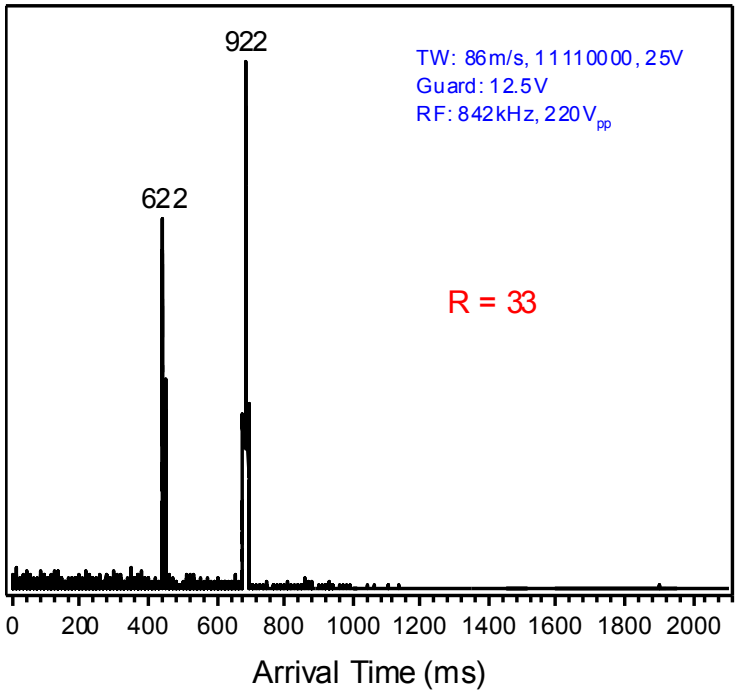


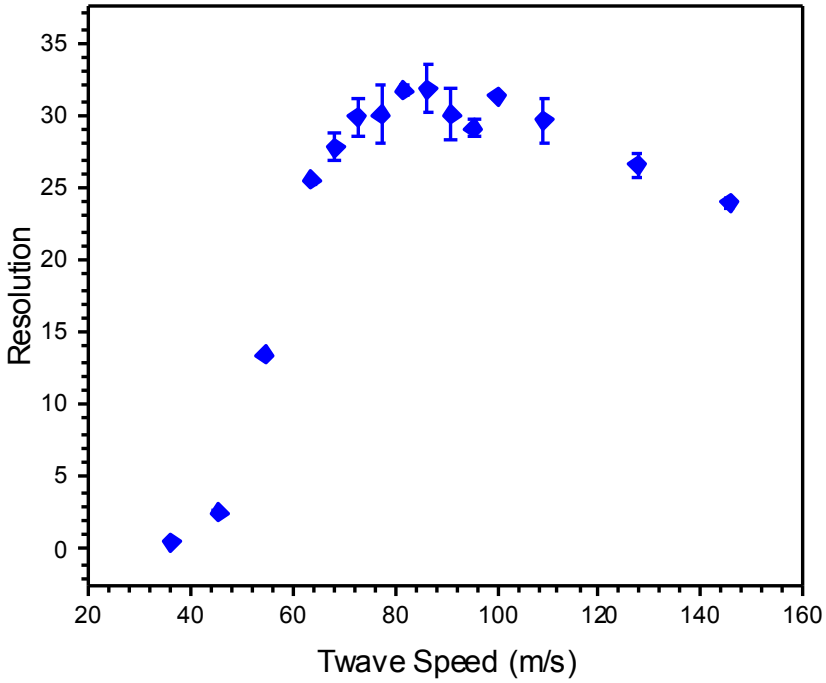
Take 3 long path (14 M) SLIM design

TW Electrode dimensions: 0.43 mm width x 0.91 length; 0.13 electrode gaps



Initial results….much optimization to come





A good separation is often not enough

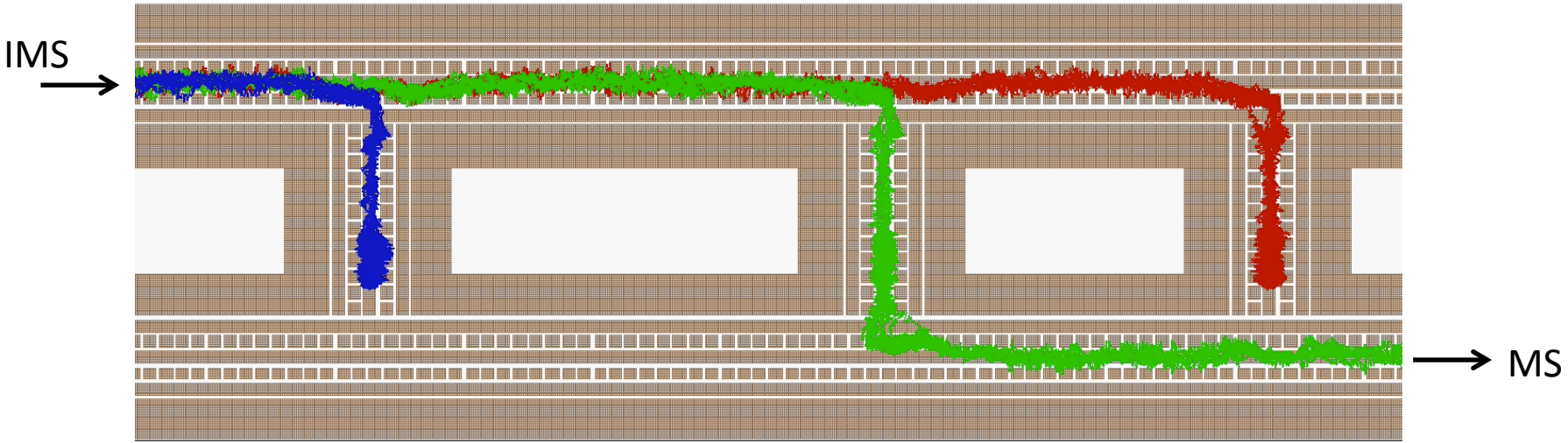
Fast switching of selected ion packets to different path previously demonstrated (Webb at al, Anal. Chem., **86**, 9169; 2014)

Trapping and accumulation of selected packets from multiple separations (see Tuesday Poster by Tsung-Chi Chen et al.; TP 074)

Our plan: Capture entire separations in a large array of traps, with intensity dependent number of accumulation steps for each trap (i.e., AGC) to increase dynamic range

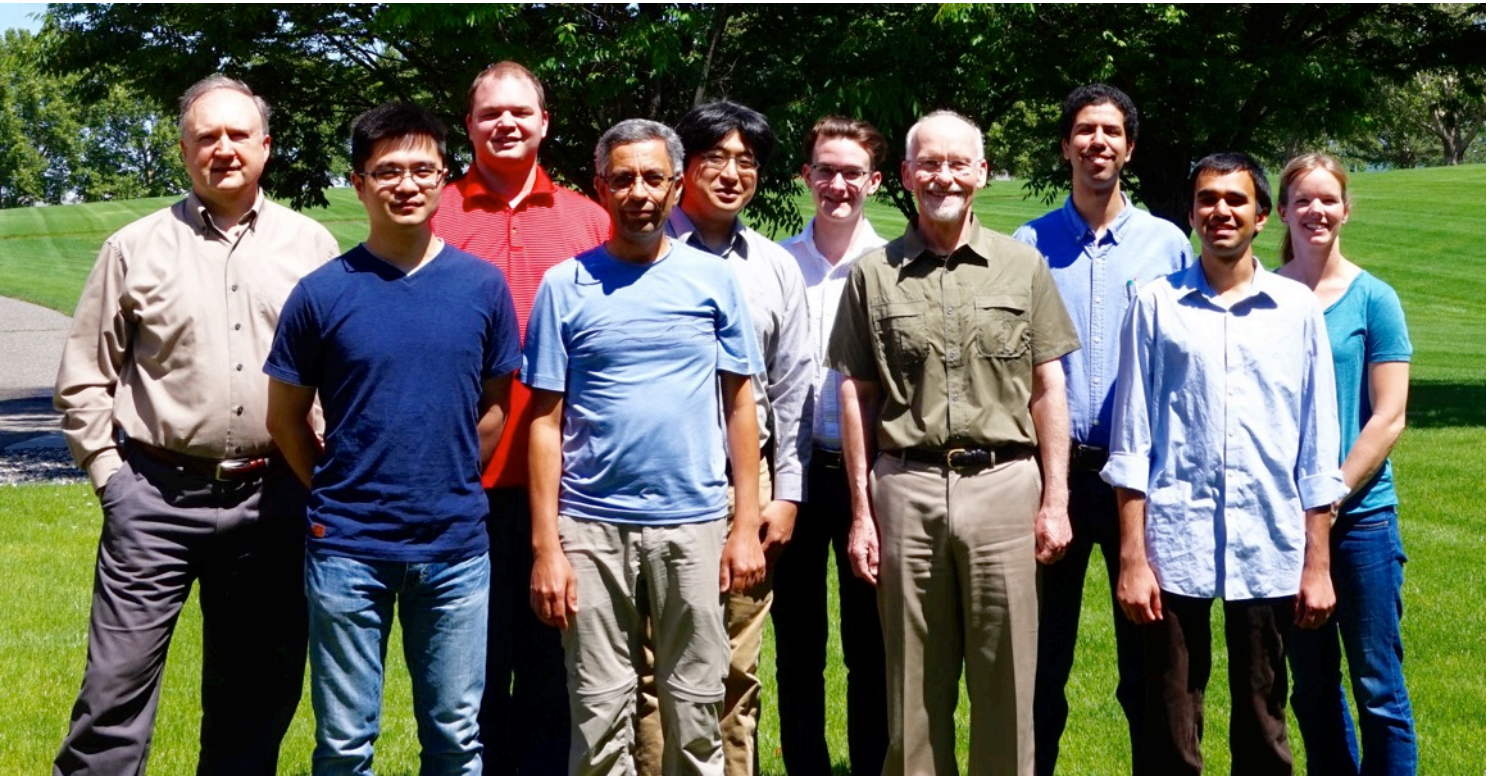
Goal: Enable 'read out' of the entire separation, or ***any*** selected fractions, at ***any*** speed, to ***any*** MS platform type

Screen shot of ion trajectory simulation; ions of three different mobilities first separated and shown fractionated into three different traps, stored, and selected (green) for transfer to MS



Acknowledgements

PNNL SLIM Team



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Jonathan Cox

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