Conceptualization and Analytical Performance of a New ESI-MS Interface for Structures for Lossless Ion Manipulations (SLIM)

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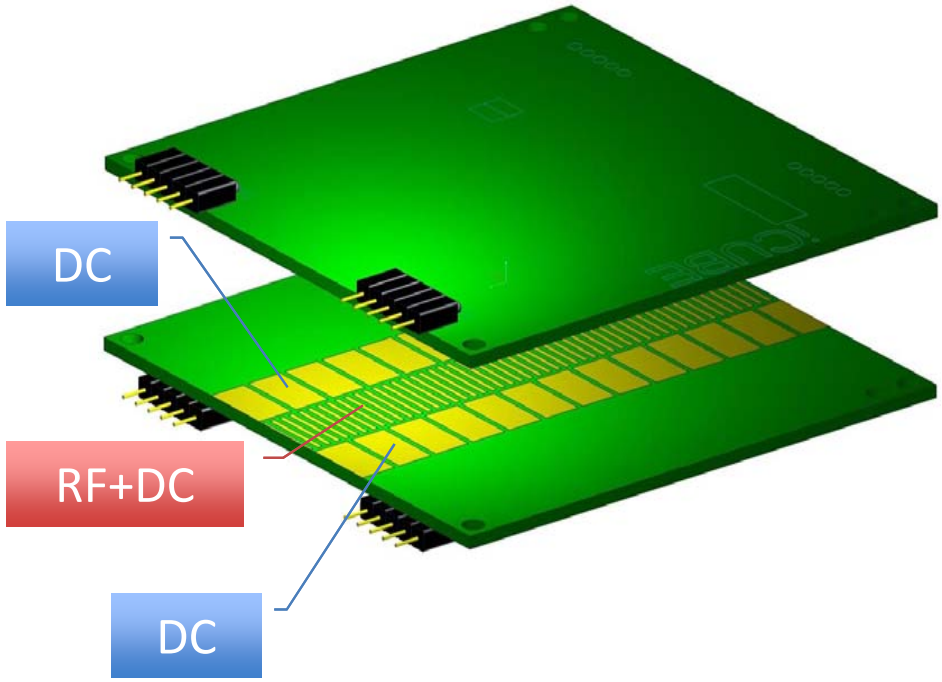
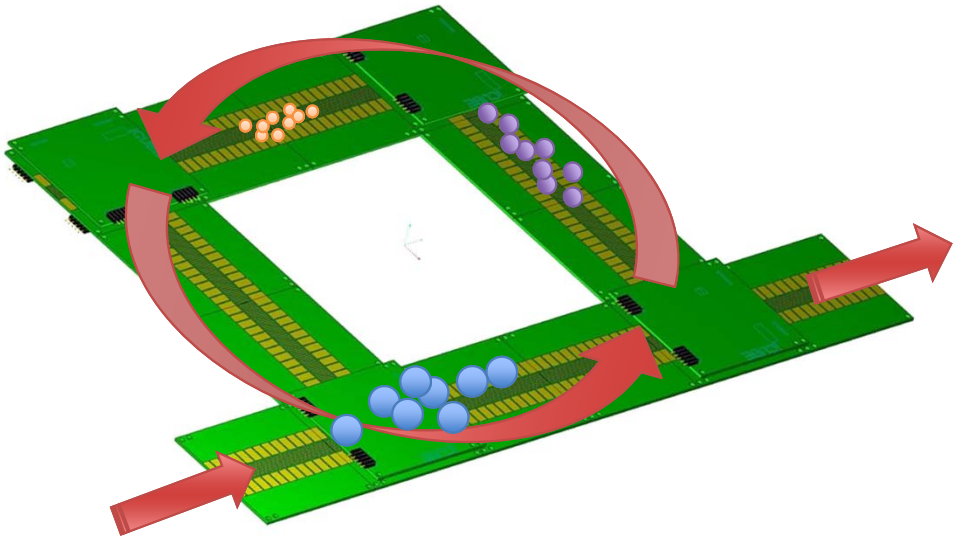
Introduction

- What are **S**tructures for **L**ossless **I**on **M**anipulations (SLIM)?
  - SLIM devices use RF and DC fields to manipulate ions
  - The manipulations include moving forward/backward, turning, switching, mobility separations, etc.
  - The planar surfaces are readily fabricated using printed circuit board (PCB) technologies

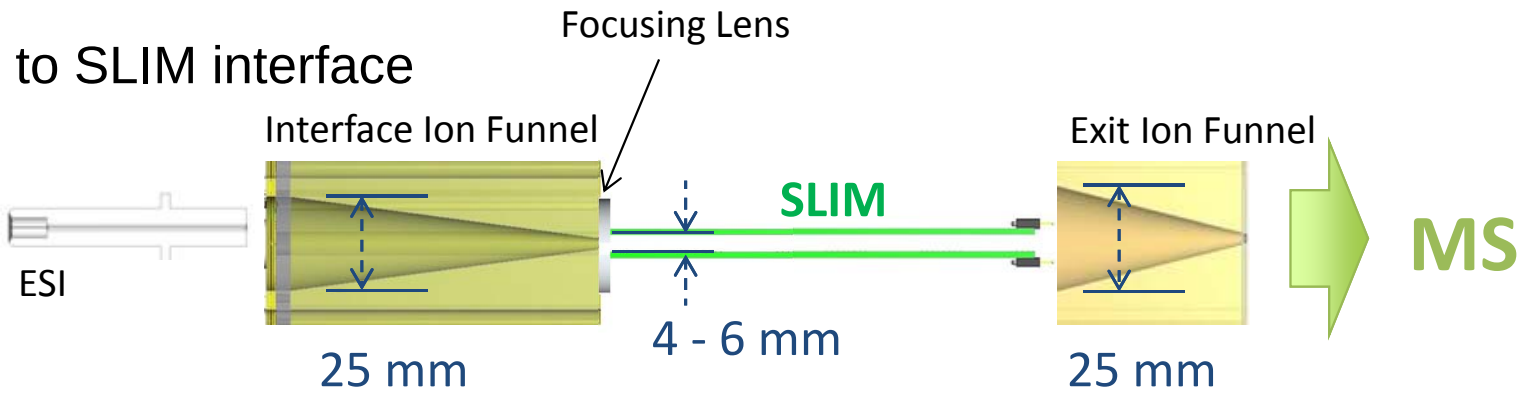


- Applications of SLIM include extended sequences of manipulations, that involve separations, reactions, storage, accumulation, etc.

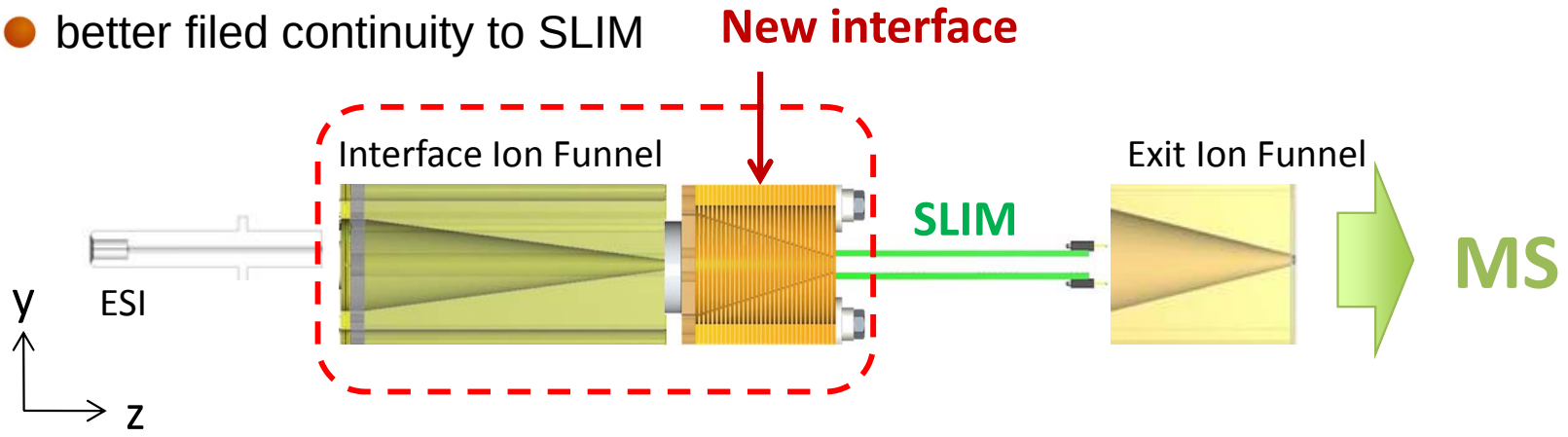


The Need for Efficient transfer of Ions to SLIM

- Need to avoid ion losses upon injection of ions to SLIM devices
  - HPIF to SLIM interface

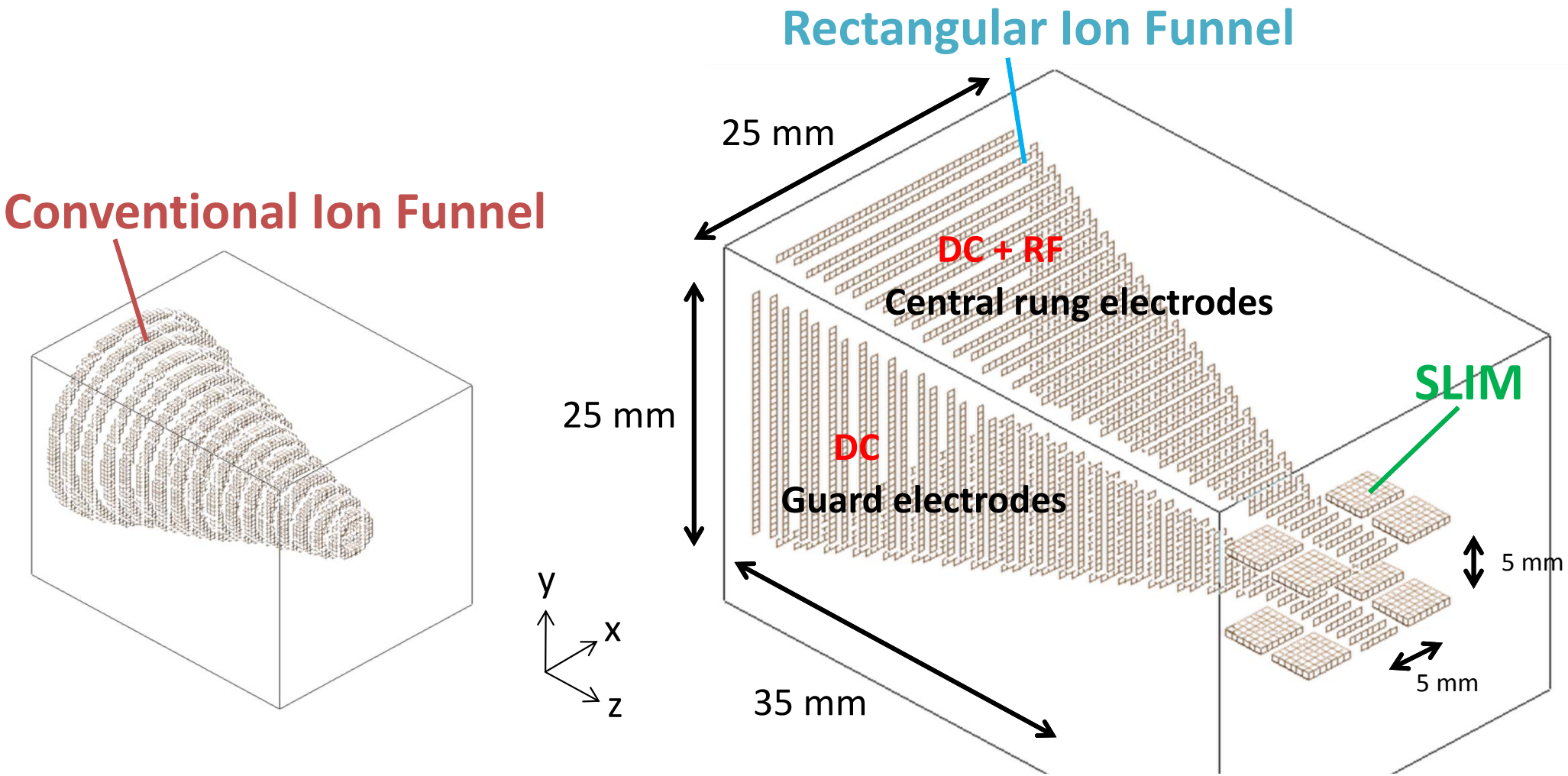


  - HPIF/IF to SLIM interface
    - for larger reception area and
    - better filed continuity to SLIM



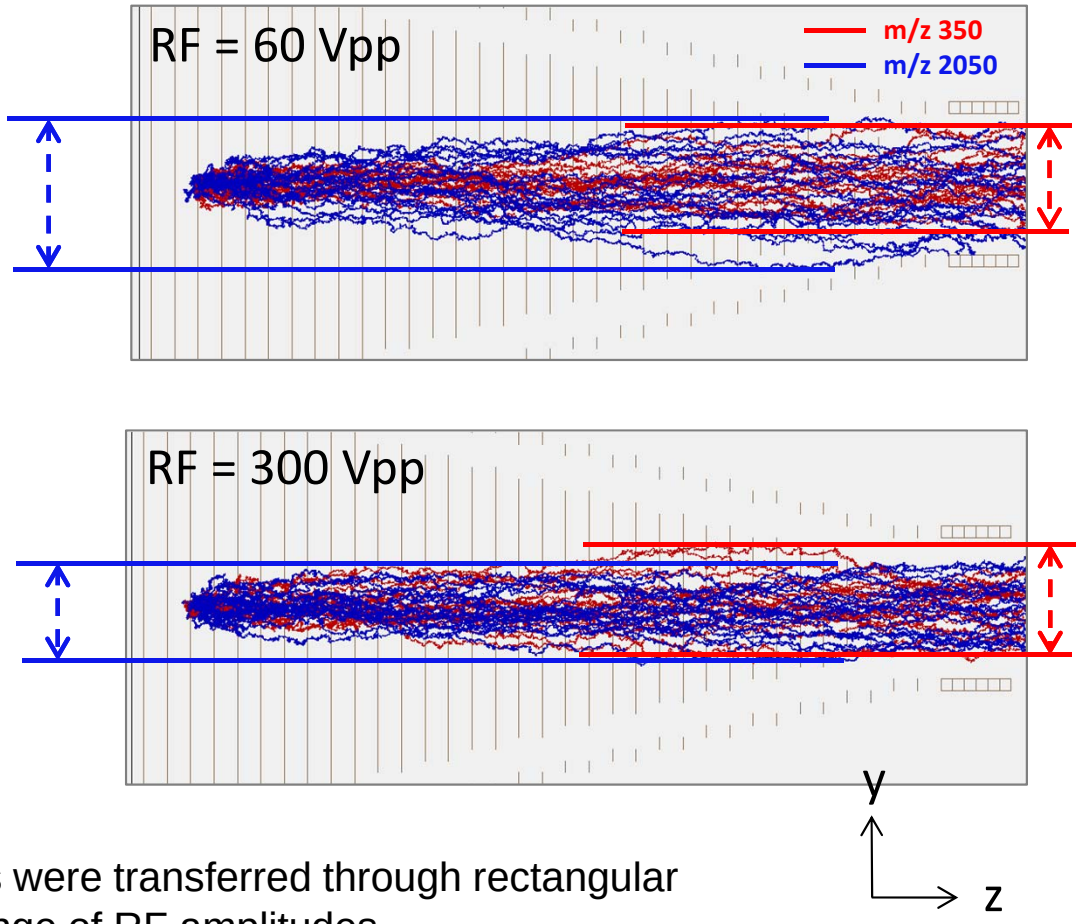
SLIM interface design and simulation

- General conditions for RIF simulation (SIMION):
  - Pressure: 4 torr N_2 (Statistical Diffusion Simulation Model)
  - Charged particle mass: m/z 50-2000



Simulations

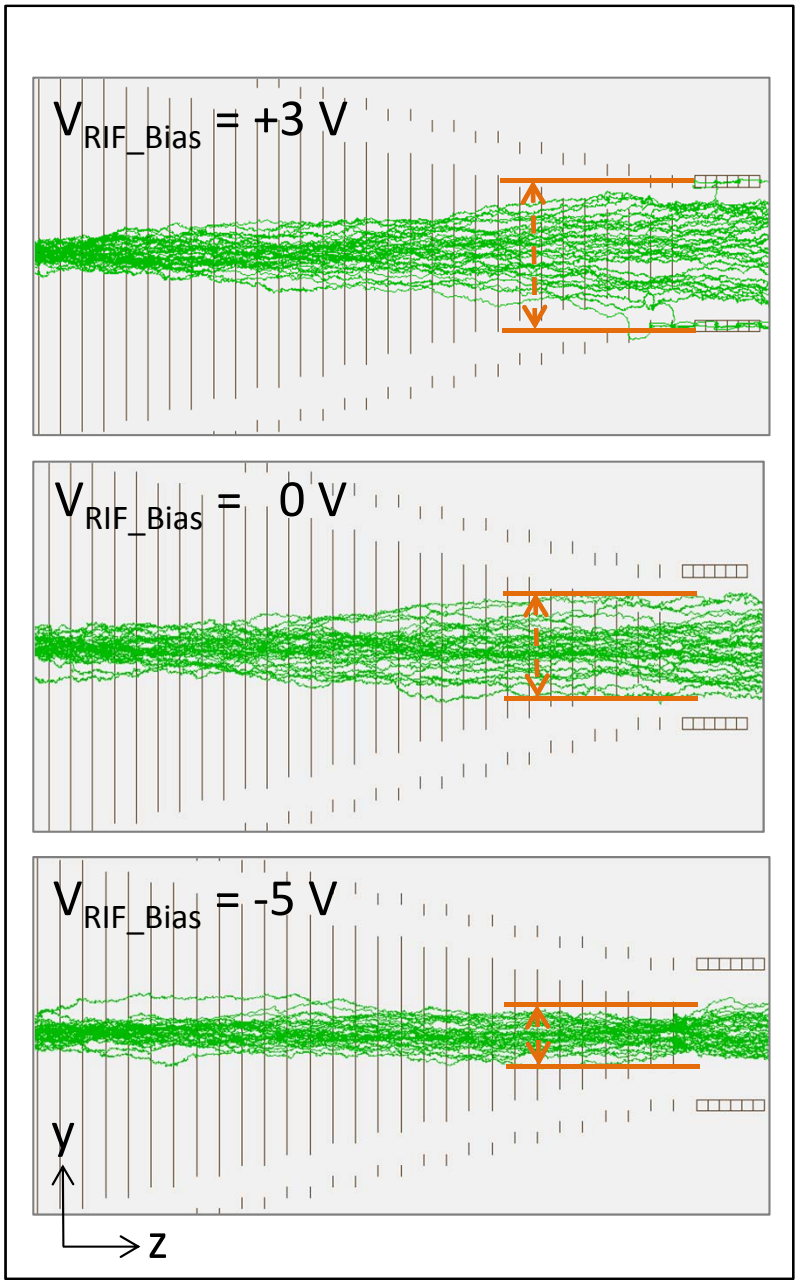
- RF confinement
  - Conditions:
    - RF frequency:
      750 kHz
    - RF amplitude:
      varied from 60 to 300 Vpp
    - Guard DC bias :
      4 V for SLIM
      0 V for RIF
    - DC gradient at central electrodes:
      20 V/cm

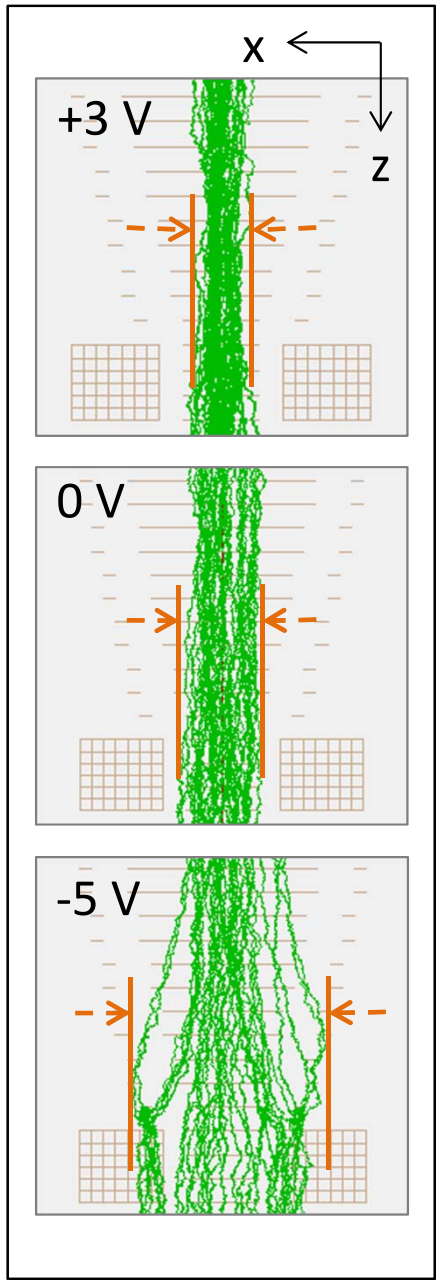


  - Observations
    - Simulation result shows most ions were transferred through rectangular electrodes to SLIM with a wide range of RF amplitudes.
    - High RF amplitude results in better radial confinement essentially focusing high m/z ions.

Simulations

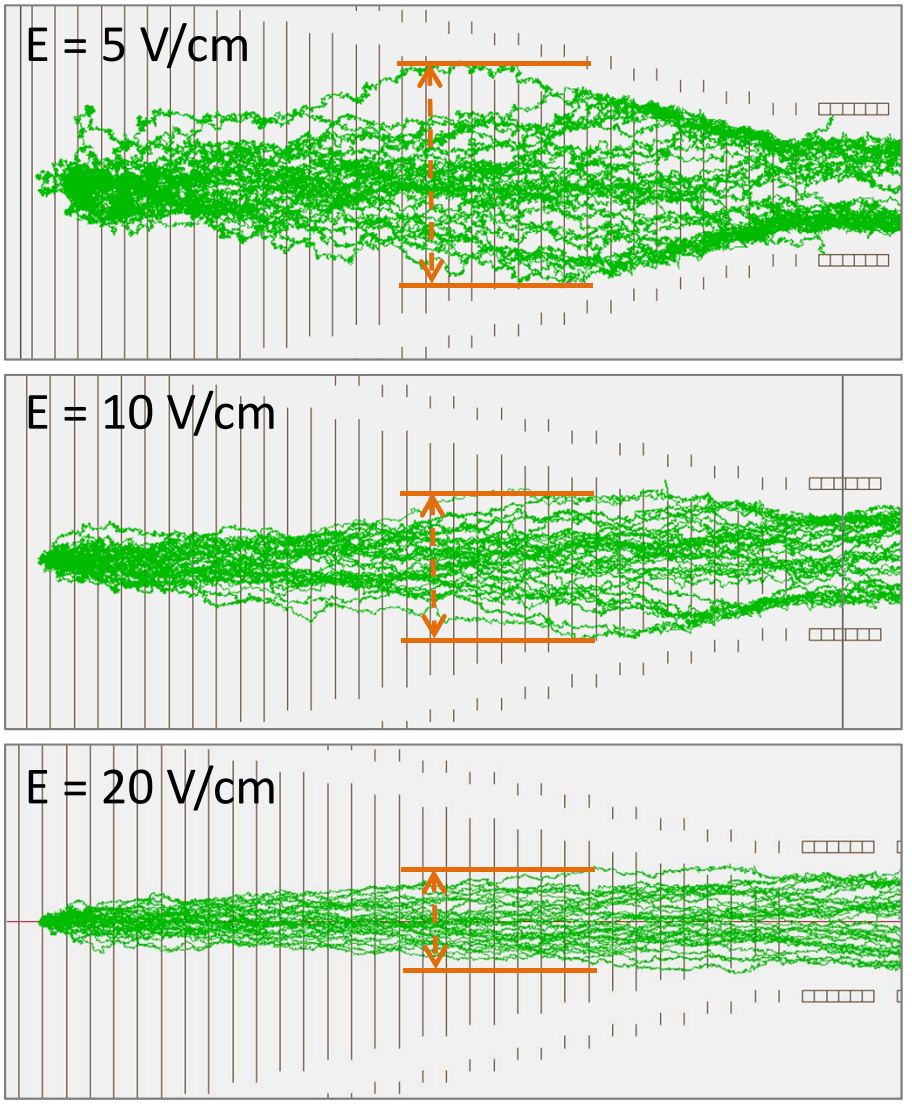
- Guard DC bias
  - Conditions:
    - DC gradient: 20 V/cm
    - RF: 750 kHz, 61.5 Vpp
    - Guard DC bias:
      SLIM: 5 V
      RIF: varied
  - Observations
    - High guard DC bias leads ions dispersed in y direction
    - Low guard DC bias leads ions dispersed in x direction





Simulations

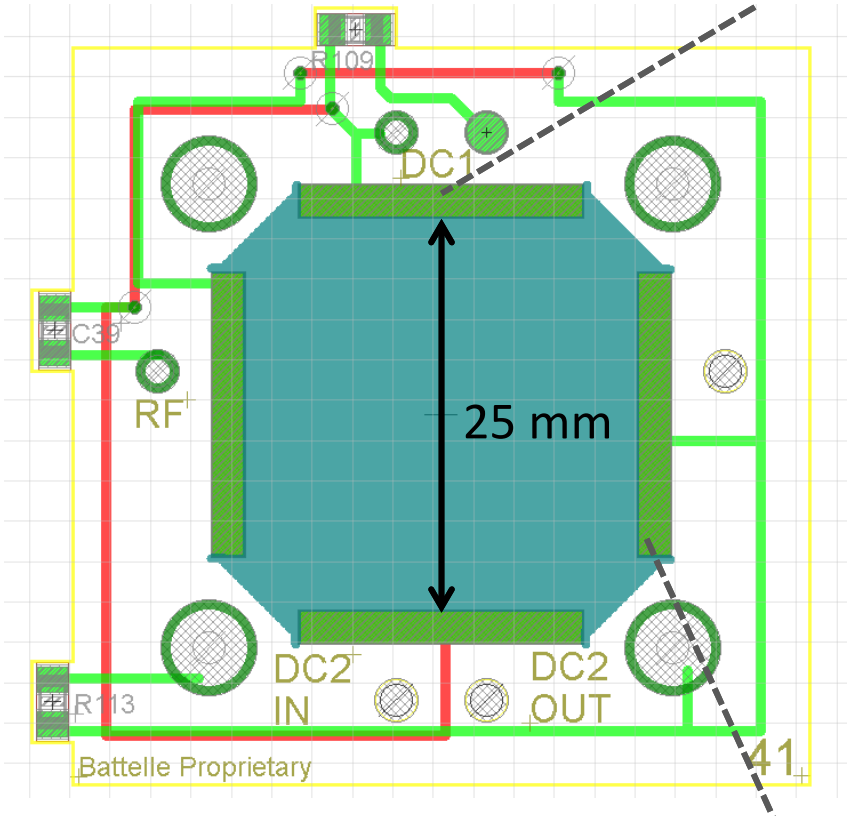
- DC gradient along central rung electrodes
  - Conditions:
    - RF: 750 kHz, 120 Vpp
    - Guard DC bias:
      5 V for SLIM
      1 V for RIF
    - DC gradient: varied
  - Observation:
    - Less ion diffusion in radial direction was found with higher DC gradient along the RIF central electrodes.

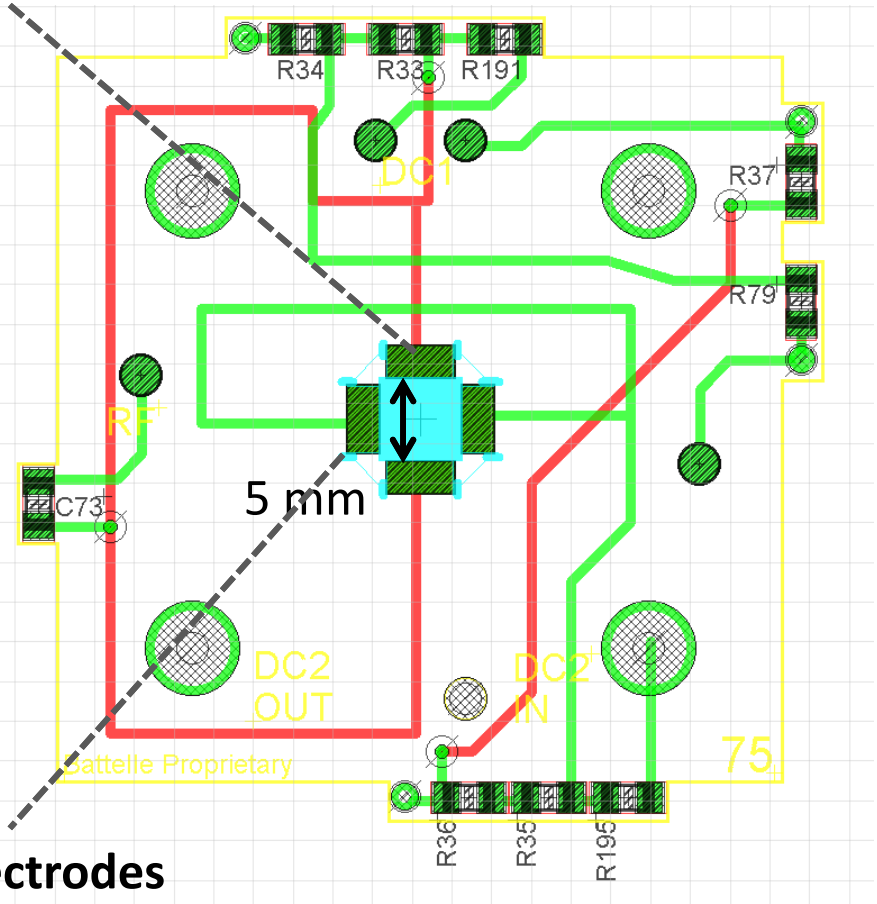


Design and Fabrication

- PCB-based RIF electrode design
  - Central (y) electrodes - RF + DC gradient
  - Guard (x) electrodes - DC bias + DC gradient

Central rung (y) electrodes

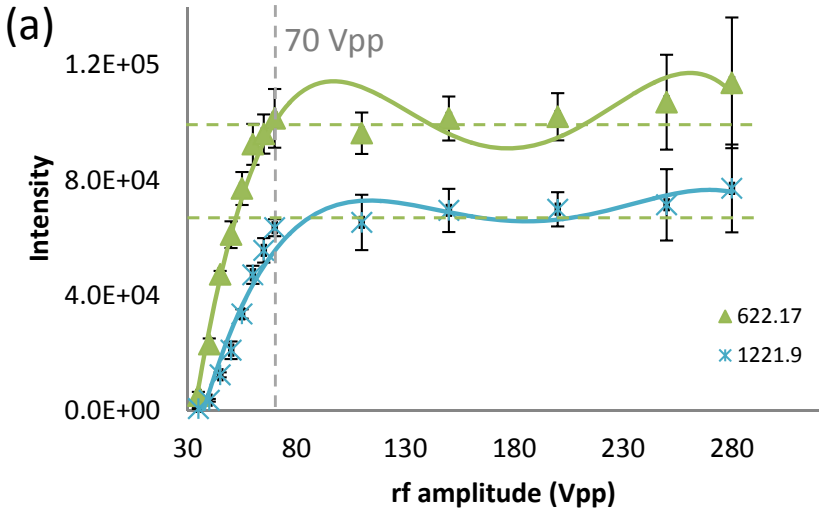


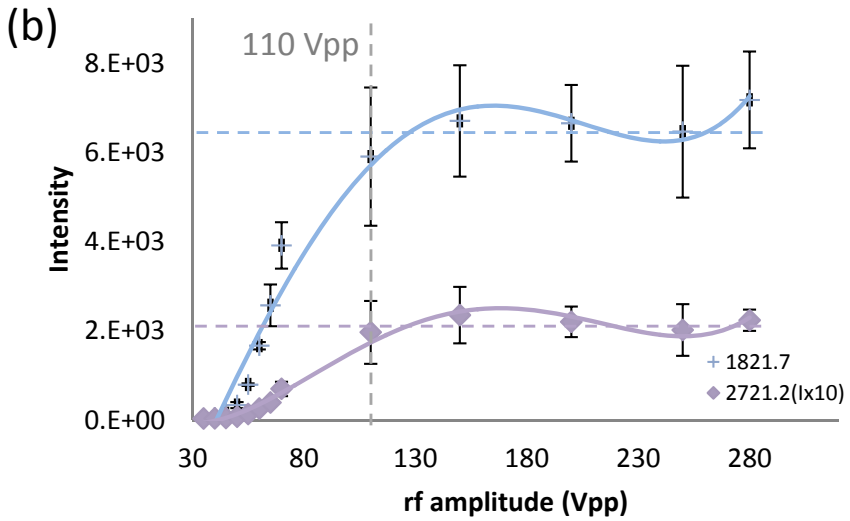


Guard (x) electrodes

Initial RIF Characterization

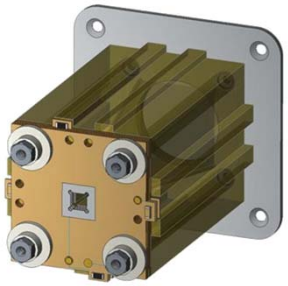
- RF confinement
  - Experimental conditions
    - Pressure : 4 torr
    - RF Freq.: 810 kHz
    - RF Amplitude: varied
    - Guard DC bias:
      - RIF In: 3.2 V
      - RIF Out: 1.9 V
    - RIF DC gradient: 9 V/cm
  - Observations:
    - m/z discrimination was observed for low RF amplitude between 60 and 110 Vpp on RIF
    - Optimal RF amplitude >110 Vpp is suggested for RIF

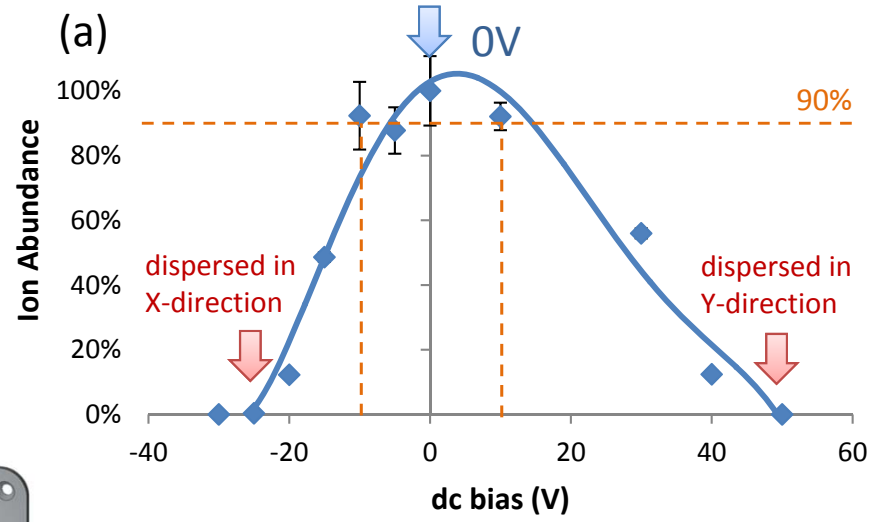


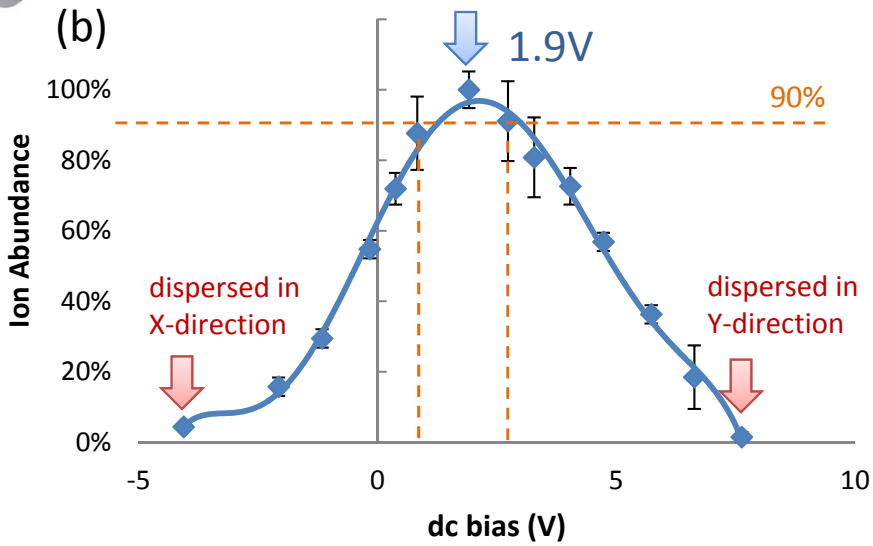


Initial RIF Characterization

- Guard DC bias
  - Experimental conditions
    - RF: 810 kHz, 160 Vpp
    - Pressure: 4 torr
    - Guard DC bias:
      - varied
    - Electrode dimensions
      - Inlet: 25.4 x 25.4 mm
      - Outlet: 5 x 5 mm
    - RIF DC gradient: 9 V/cm
  - Observations:
    - DC bias at inlet is less sensitive to the voltage change than that at outlet due to the different spacing of electrodes
    - Optimal DC bias ranges of -10~+10 V for RIF inlet and +1~+3 V for outlet.

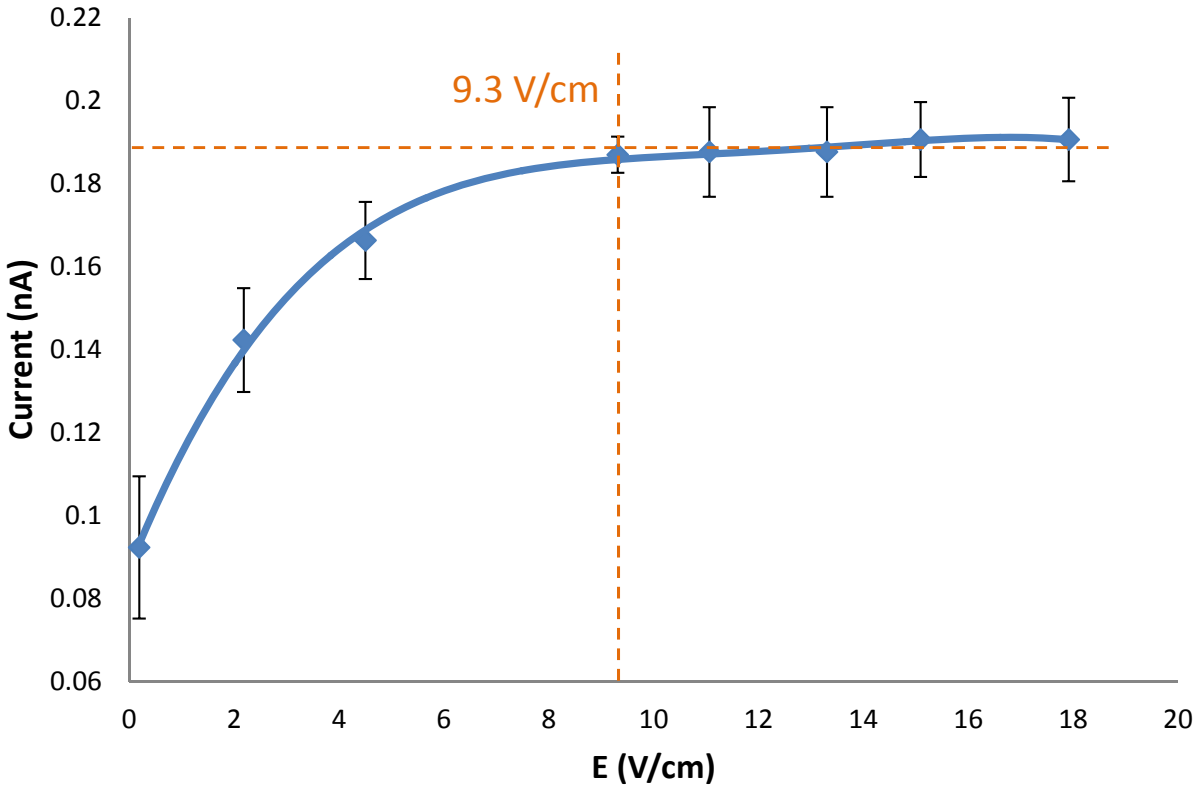






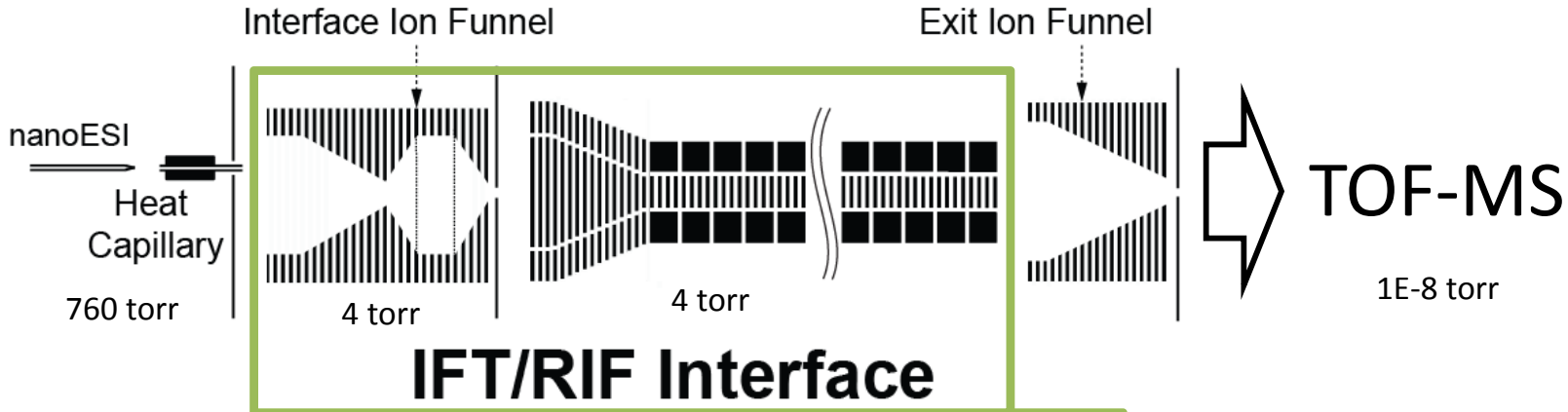
Initial RIF Characterization

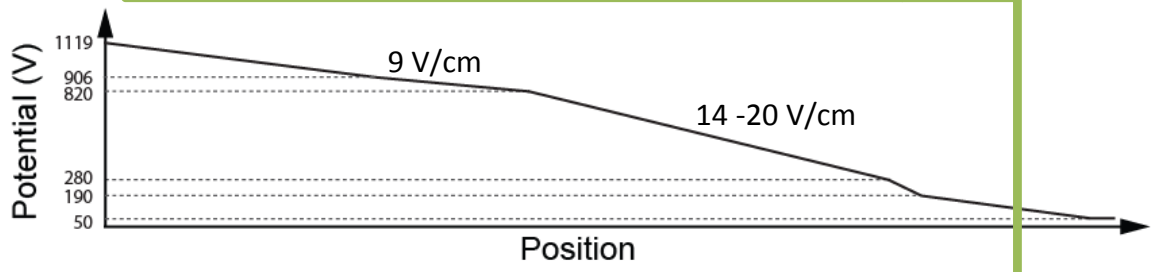
- RIF DC gradient
  - Experimental conditions
    - RF:
      - Freq.: 750 kHz
      - Amp.: 160 Vpp
    - Pressure : 4.1 torr
    - DC gradient: Varied
    - Guard dc bias:
      Optimized based on
      the current measurement
  - Observation
    - RIF DC gradient >10 V/cm for optimal ion transmission for 3” RIF

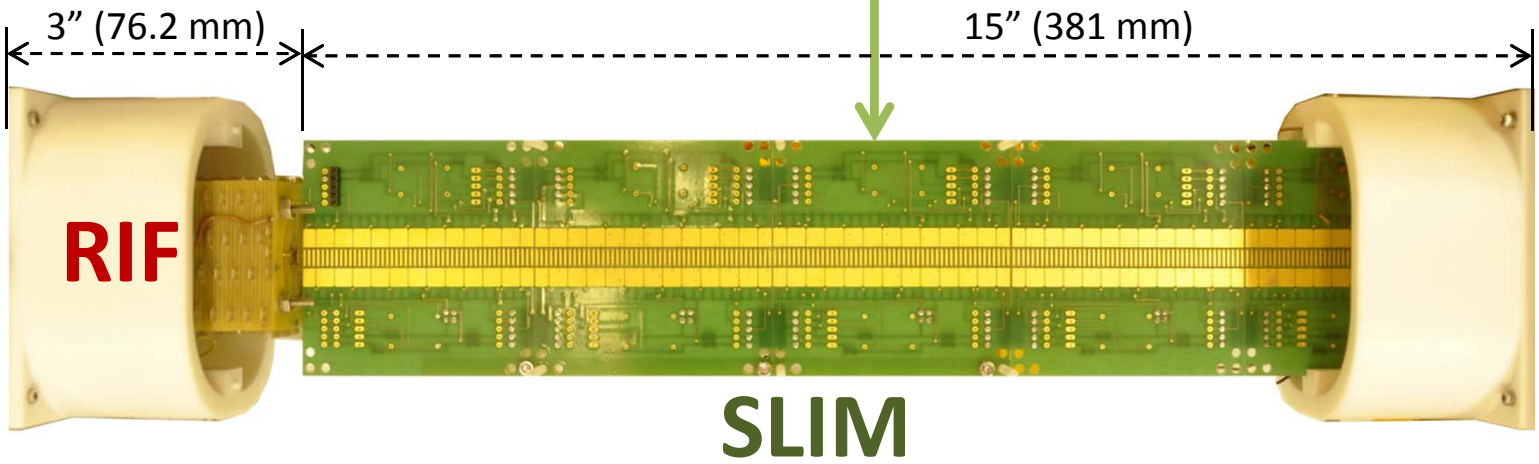


Initial RIF-SLIM Characterization

- Instrumental configuration used & ion optics design

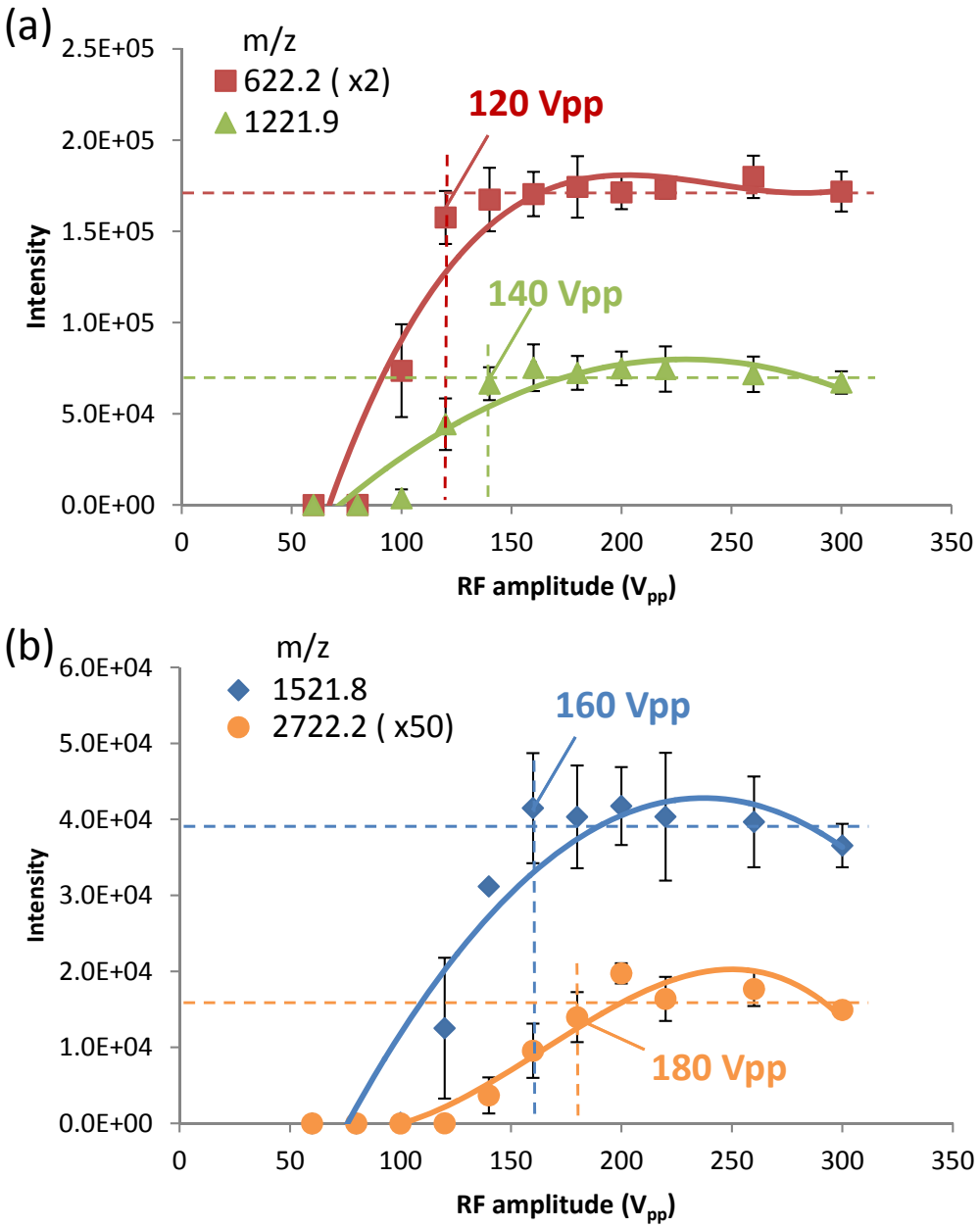






Initial RIF-SLIM Characterization

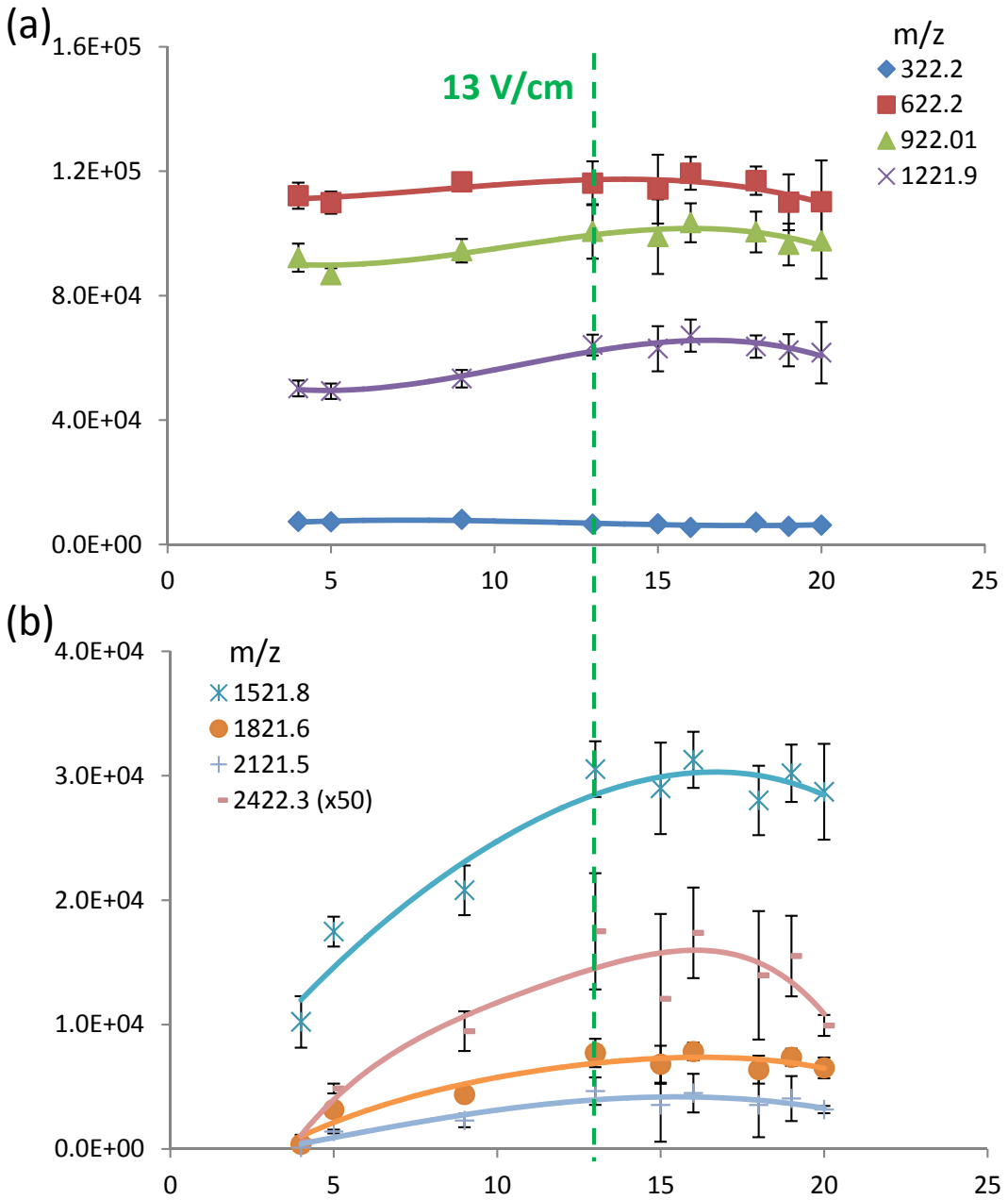
- RF amplitude
  - Conditions:
    - Guard DC bias :
      - SLIM: 15 V for
      - RIF In: 3.2 V
      - RIF Out: 1.9 V
    - Central electrode DC gradient:
      - SLIM: 14 V/cm
      - RIF: 9.3 V/cm
    - RF frequency:
      - RIF&SLIM: 810 kHz
    - RF amplitude:
      - SLIM: varied
      - RIF: 160 Vpp



Initial RIF-SLIM Characterization

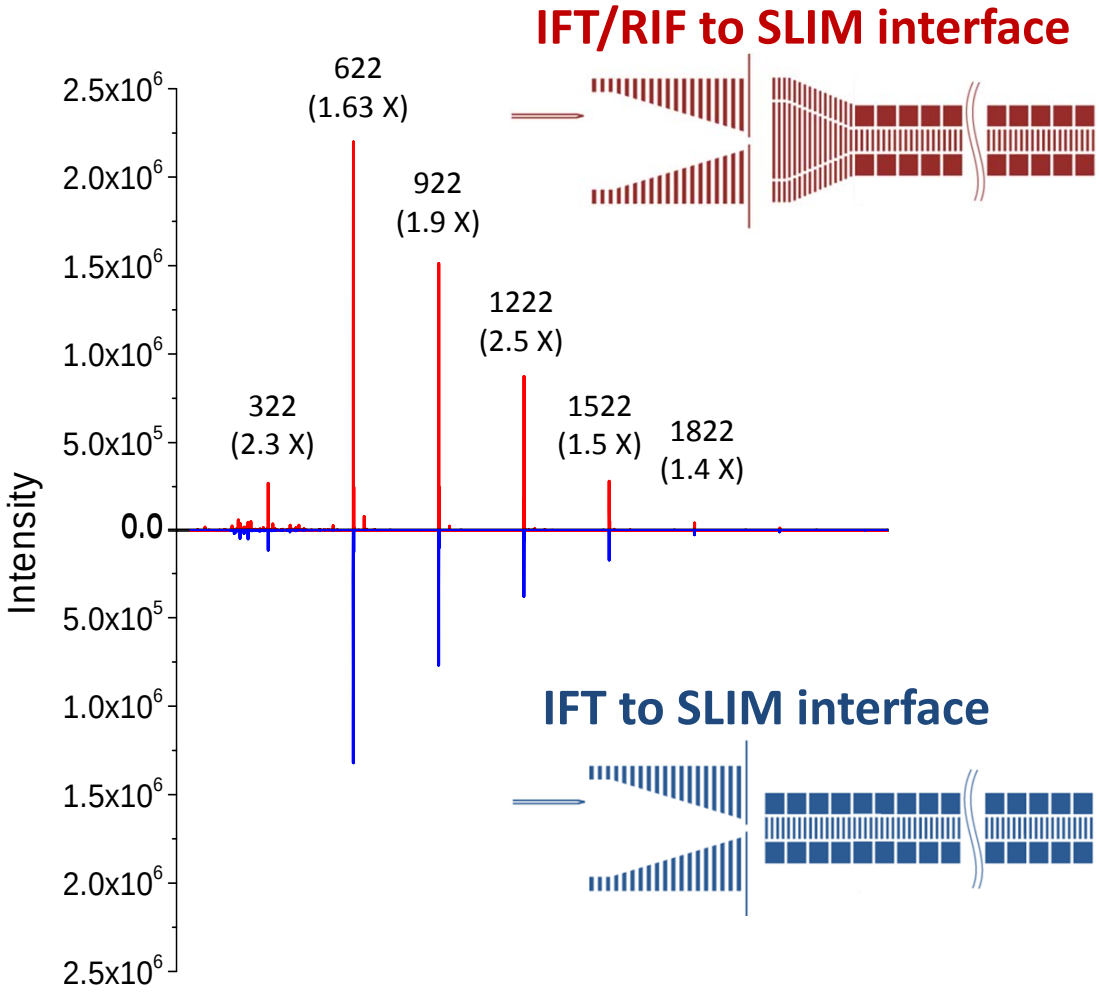
- SLIM DC gradient
  - Exp. Conditions
    - RF:
      - Frequency: 810 kHz
      - RIF amplitude: 160 Vpp
      - SLIM amplitude: 200 Vpp
    - Pressure : 4 torr
    - DC gradient:
      - RIF: 9.3 V/cm
      - SLIM: Varied
    - Guard DC bias:

      Optimized based on the TIC measurement
  - Observation
    - m/z discrimination was found for high m/z ions (1522-2422) with low DC gradient (>13 V/cm) on RIF-SLIM device



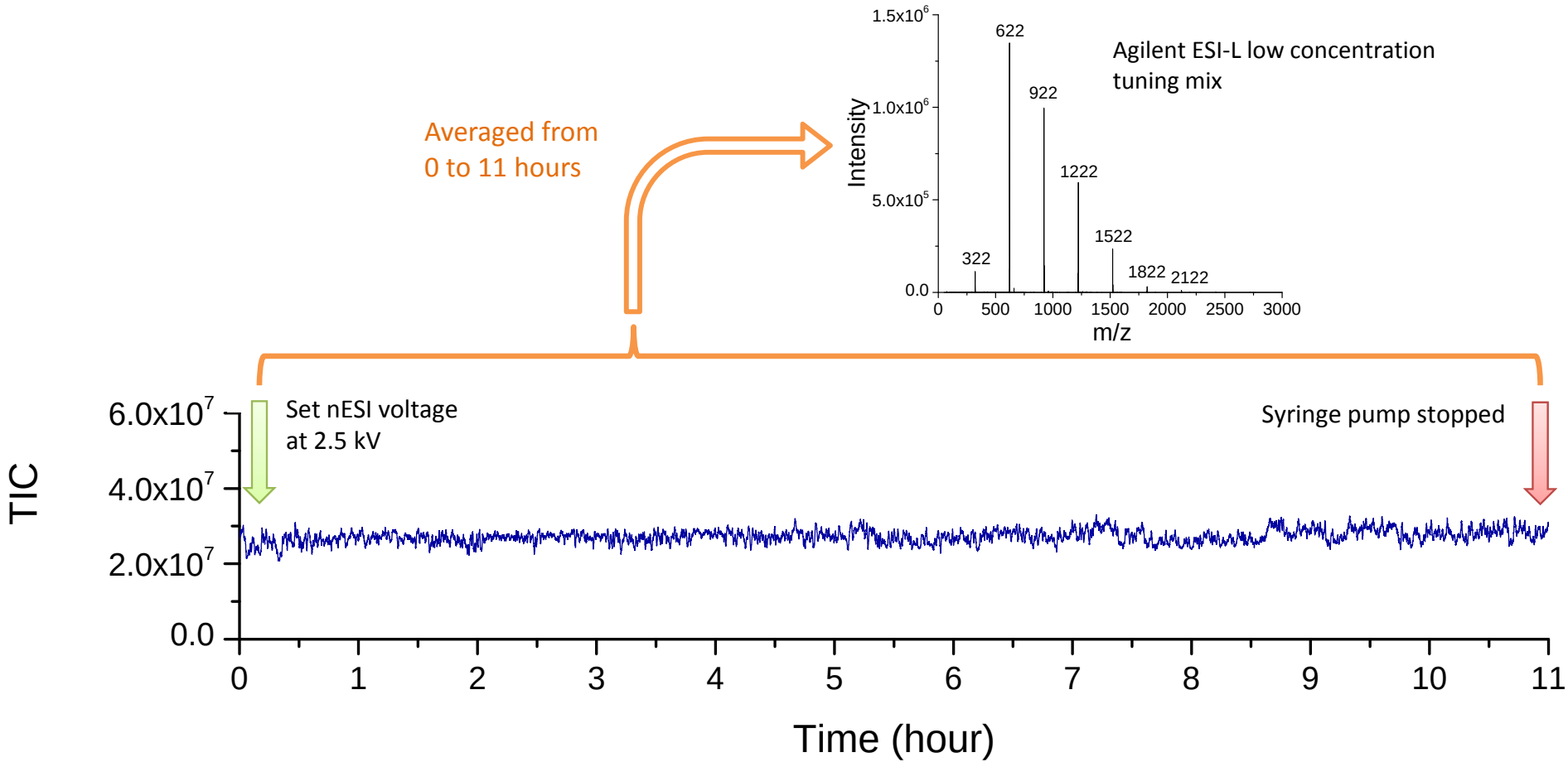
RIF-SLIM Performance

- Sensitivity
  - Exp. Condition
    - Pressure:
      - RIF-SLIM: 4.00 torr
    - Guard DC bias, DC gradient & RF were optimized based on the characterization results.
    - Solution electrosprayed: Agilent ESI-L tune mixture
  - Observation:
    - ~2x intensity increase by RIF-SLIM

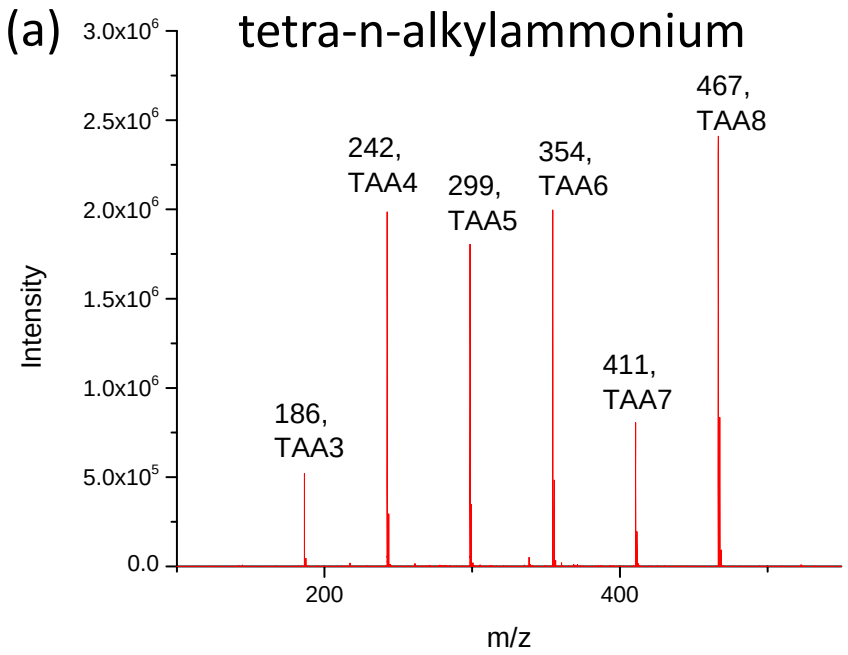


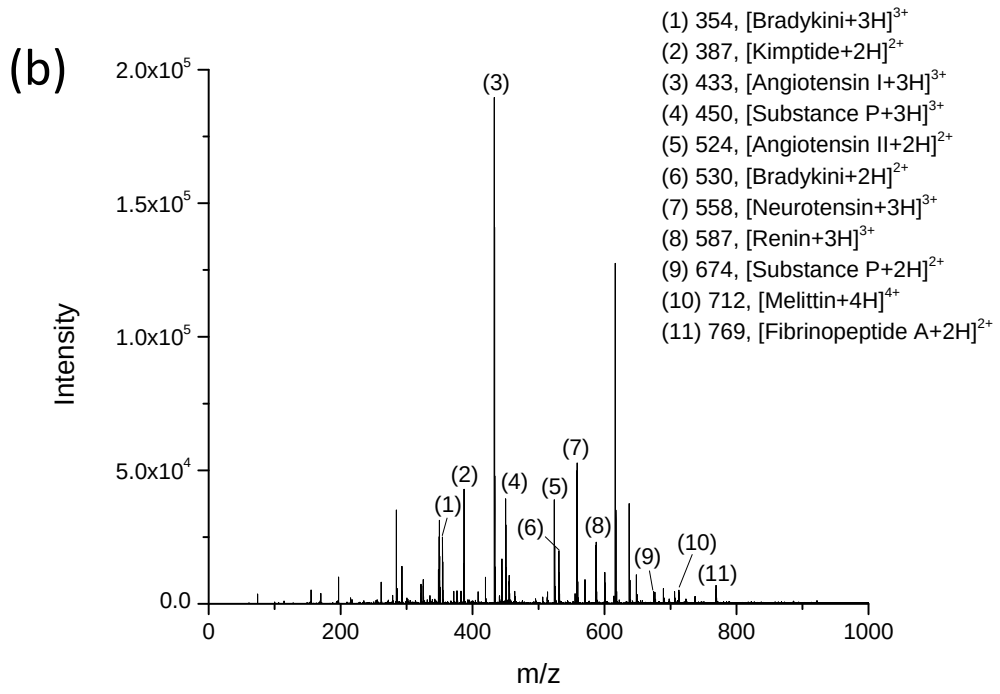
RIF-SLIM Performance

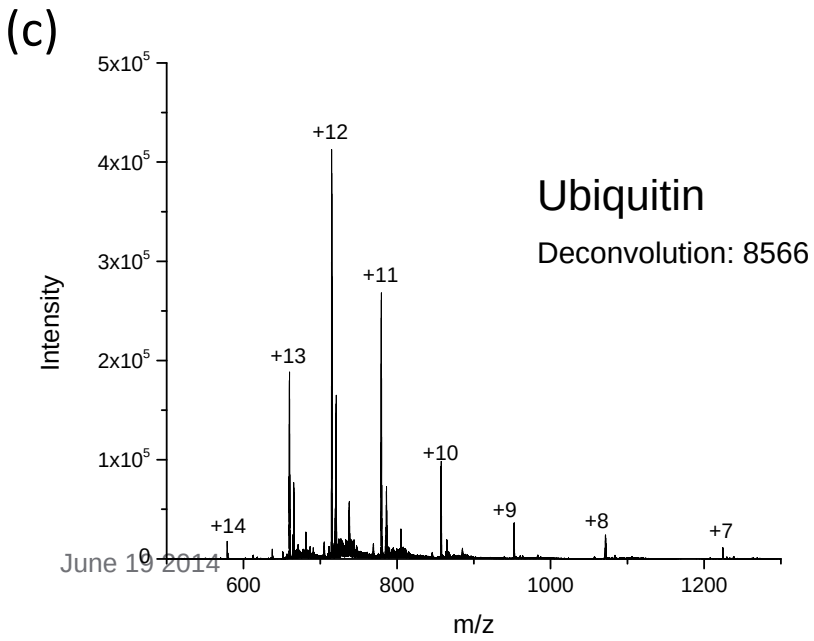
- Stability
  - No observable intensity decrease during the 11-hour stability test

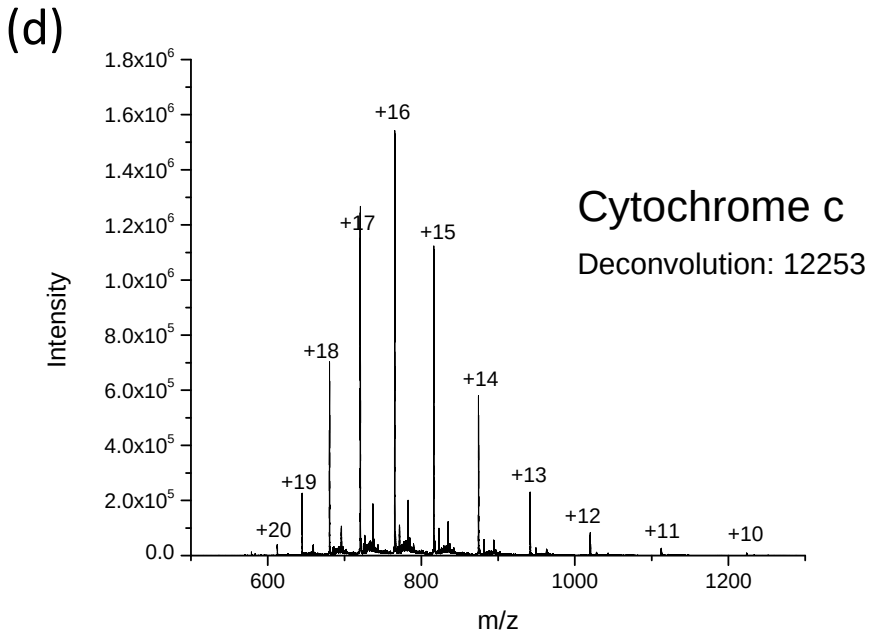


Performance evaluation on RIF-SLIM









Conclusions

- A Rectangular Ion Funnel (RIF) was designed, guided by ion simulations, including PCB-based circuit and electrode designs
- The RIF and its interface with SLIM was characterized to determined the optimal operating parameters, including RF amplitude, Guard DC bias and central rung electrode DC gradients
- The results of performance evaluation on RIF-SLIM indicated ~2x sensitivity increase, and displaying extended operation with high stability and without significant *m/z* discrimination over 300-2700 m/z range

Support

- NIH GMS Biomedical Technology Proteomics Research Resource
- DOE Office of Biological and Environmental Research
- PNNL Laboratory Directed R&D

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