MEMS Based Ion Beam Drivers for Magnetized Target Fusion

Thomas Schenkel, Berkeley Lab

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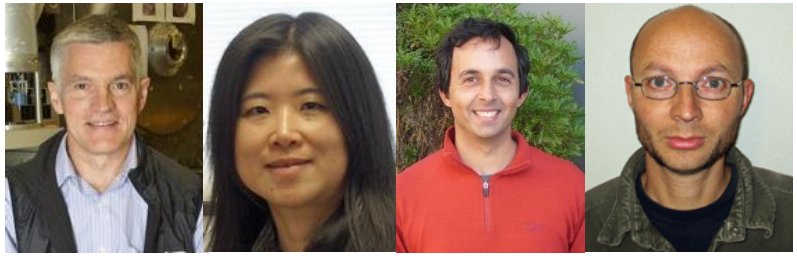
Cornell University

MEMS Based Ion Beam Drivers for Magnetized Target Fusion

LBNL:



Peter Seidl, Qing Ji, Arun Persaud, Will Waldron

- Accelerator physics, Ion sources and beam transport, RF, … http://atap.lbl.gov/

Cornell:

Cornell University

Amit Lal (Co-PI), Serhan Ardanuc, Joseph Miller, Vinaya Kumar

- MEMS fabrication, Chip-scale particle accelerators, … http://www.sonicmems.ece.cornell.edu/

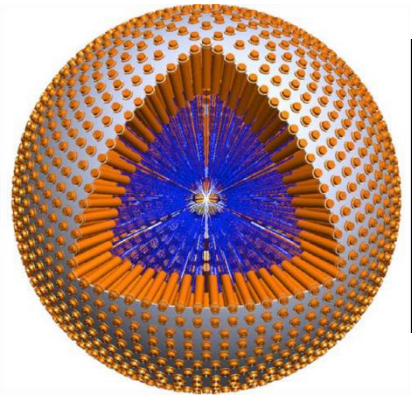
MEMS Based Ion Beam Drivers for Magnetized Target Fusion - Summary

- What are you trying to do ?
  - Our goal is to proof the concept of MEMS based ion accelerators that can be scaled to very high beam energy (>1 MJ in ~1 μs) for compression of magnetized fusion targets at low cost (<$0.05/MJ)
- Why is this important ?
  - Ion beams are very attractive drivers for MTF, but delivering the required beam energy at low enough cost is very challenging
- Why now?
  - MEMS technology and solid state RF have matured significantly and we see an exciting opportunity to implement multi-beamlet accelerator concepts from the 1980s now with low cost fabrication and scalability
- Why is this hard?
  - ion beam transport in arrays of sub-mm beamlets is challenging due to beam emittance and space charge forces
  - alignment of beamlets is critical for efficient transport
  - ion acceleration in RF driven high voltage gaps has to be balanced with breakdown limits
  - …

Our motivation is to develop low cost, scalable ion beam drivers for fusion

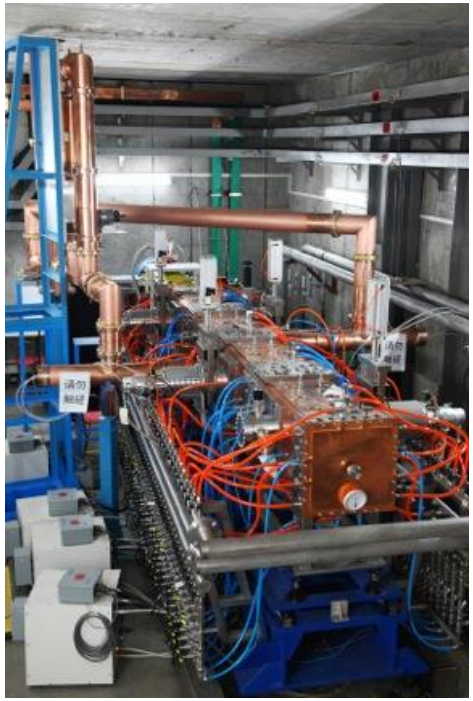
- Ion beam drivers for fusion
  - driver energy = E_{kin} * I_{peak} * pulse length → 1 to 10 MJ
  - Heavy ion fusion (HIF): ~GeV, 0.1 MA, in ns
  - Magnetized target fusion (MTF): ~0.1–1 MeV, MA, in μs

  → we need efficient and low cost drivers (<$0.05/MJ)

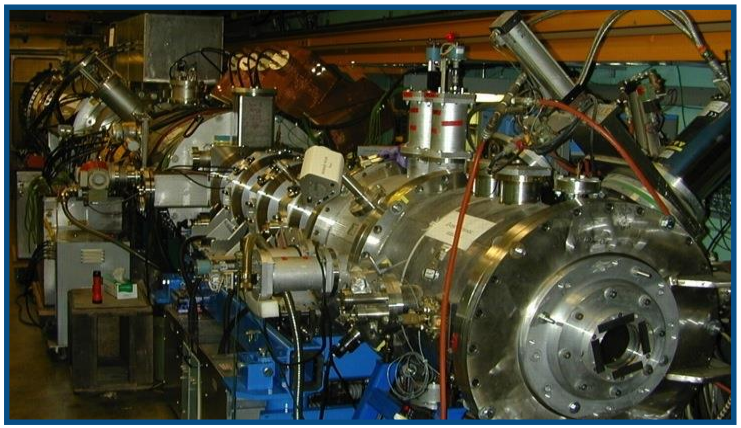


Ion beam driver technology for MTF

- pulsed induction linac (12 m)
- 1 MeV, 2 ns, mm, ≥0.8 A peak
- 200x drift compression
- P. S. Seidl et al. NIM A (2015)



- Radio frequency quadrupole (RFQ)
- 2 MeV, 0.01 A, cw
- 4 m long, 0.4 m cross section
- Z. Zouhli, D. Li et al. IPAC2014

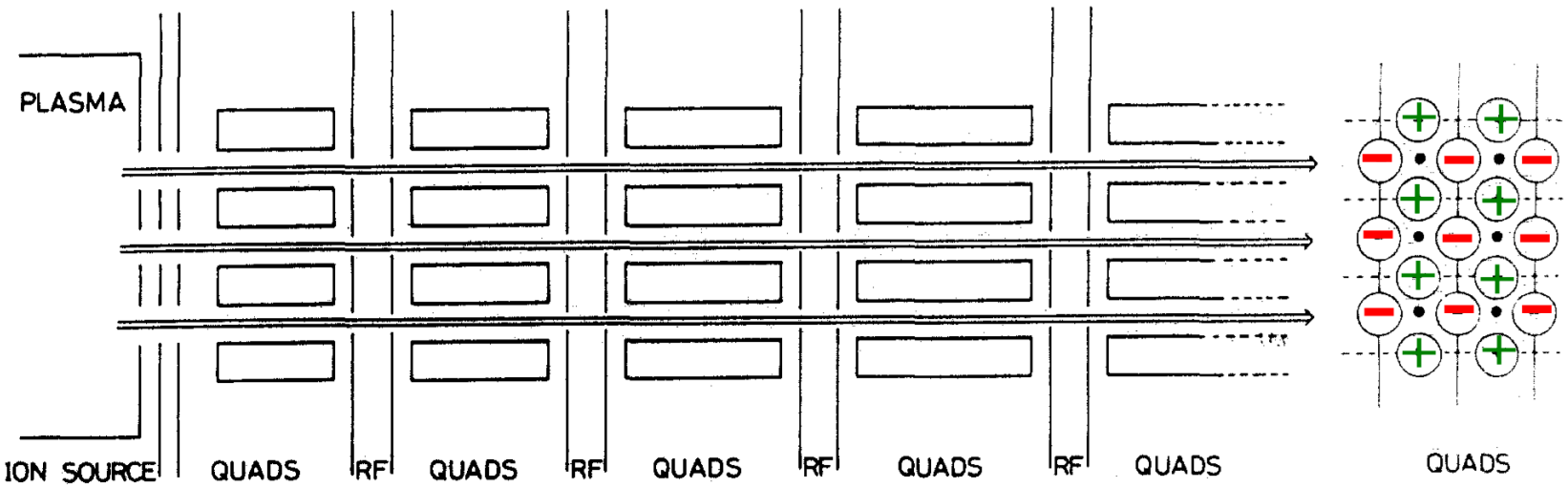


- High Current Experiment (~12 m)
- injection, matching and transport at HIF driver scale
- 1 MeV, 0.2 A, 5 μs, ~12 m
- 0.4 m cross section
- M. Kireeff-Covo, et al., PRL (2006)

how can we scale ion beam drivers to >1 MJ in μs pulses at low enough cost for MTF ?

MEQALAC concept from 1980s

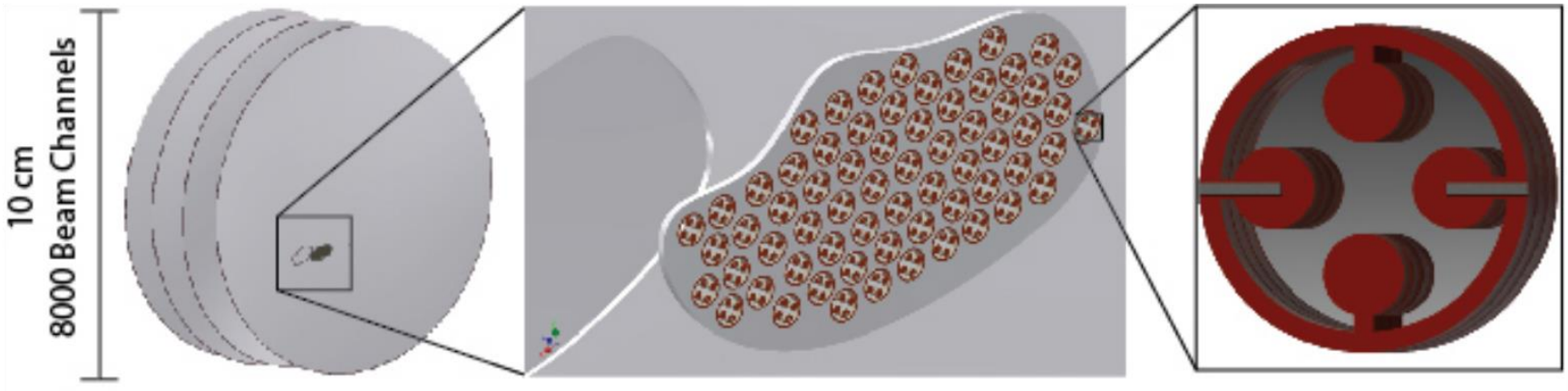
Multiple-Electrostatic-Quadrupole-Array Linear Accelerator



1980 Dimensions: ~ 1 cm beam aperture, ESQ length : ~few cm

- Thomae *et al.*, Mat. Science & Eng., B2, 231 (1989)
- Al Maschke et al., early 1980s

Last year we were talking about arrays of electrostatic quadrupoles that could be produced with unit cells of the order of 1 mm



Prototype

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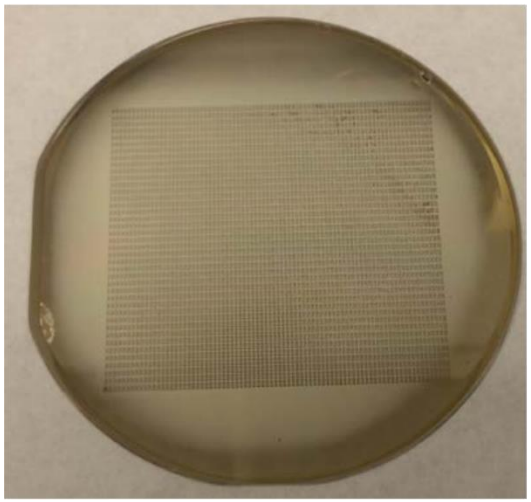
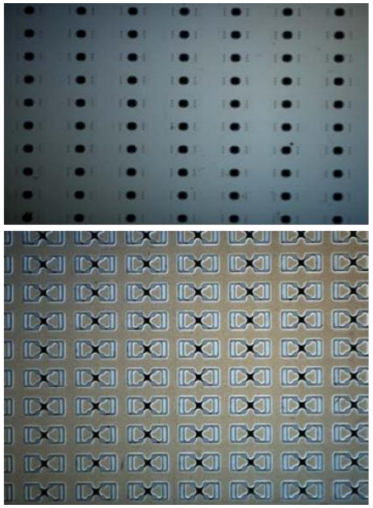
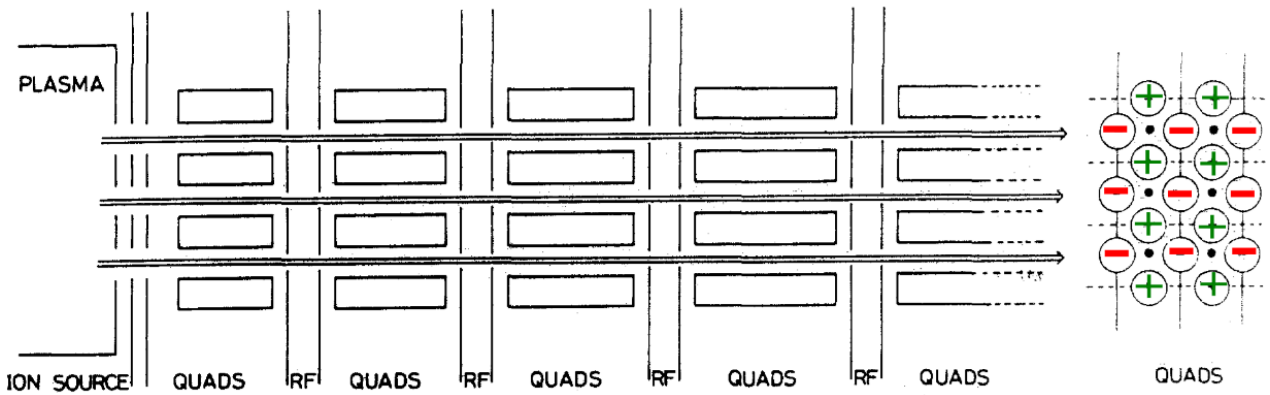


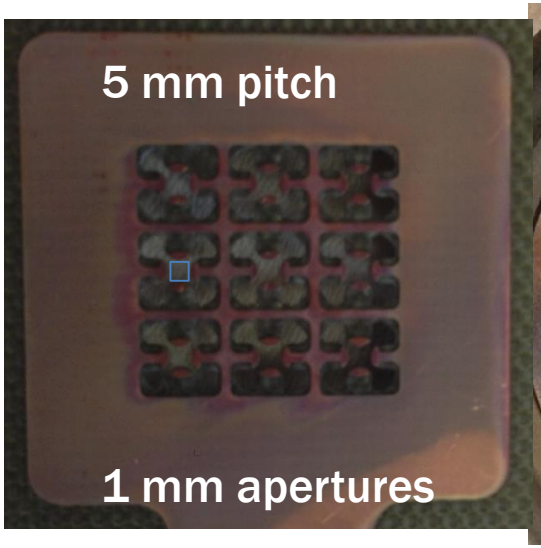


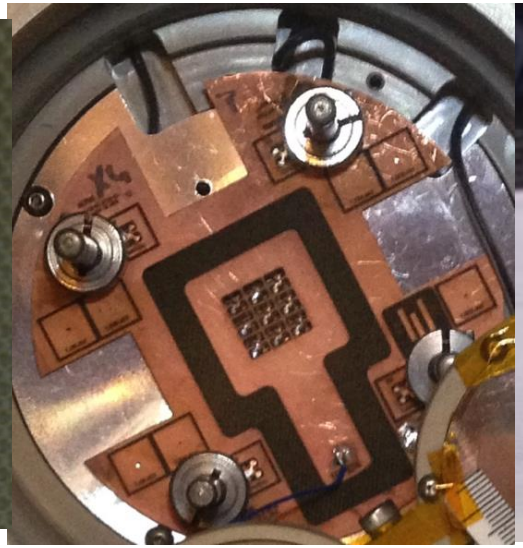
Bottom View

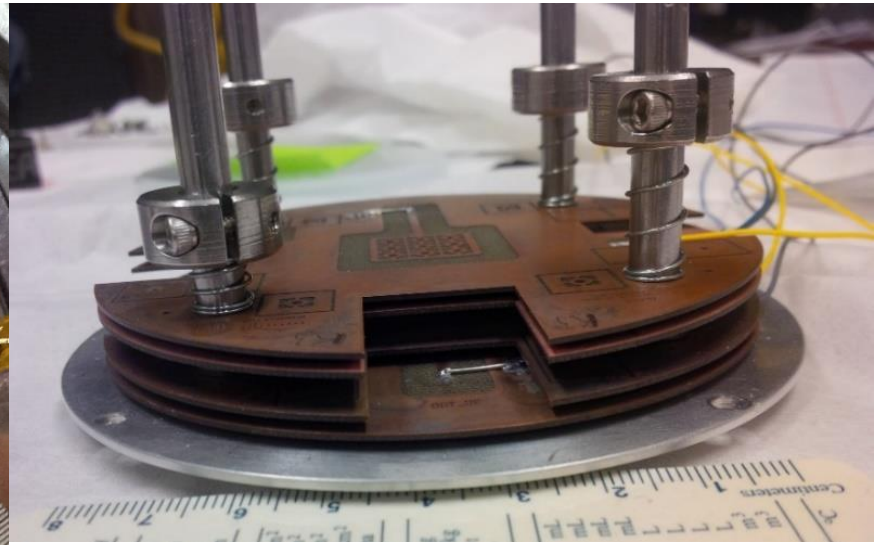
Top View

We have now demonstrated the building blocks of a MEMS based multi-beamlet accelerator

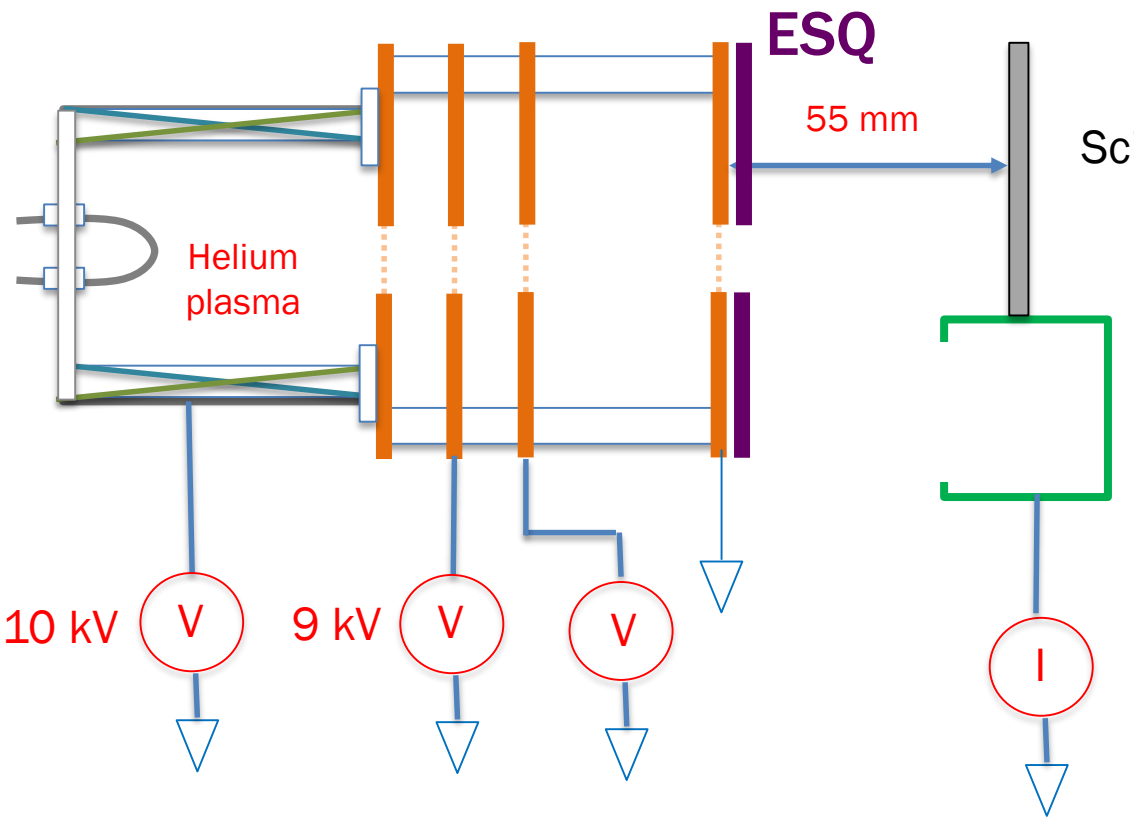


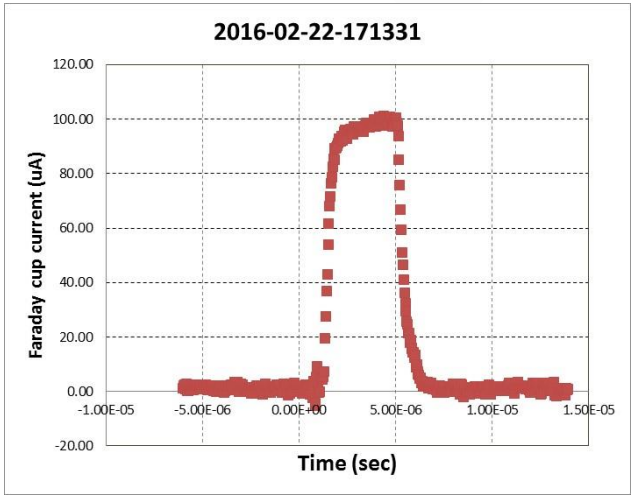




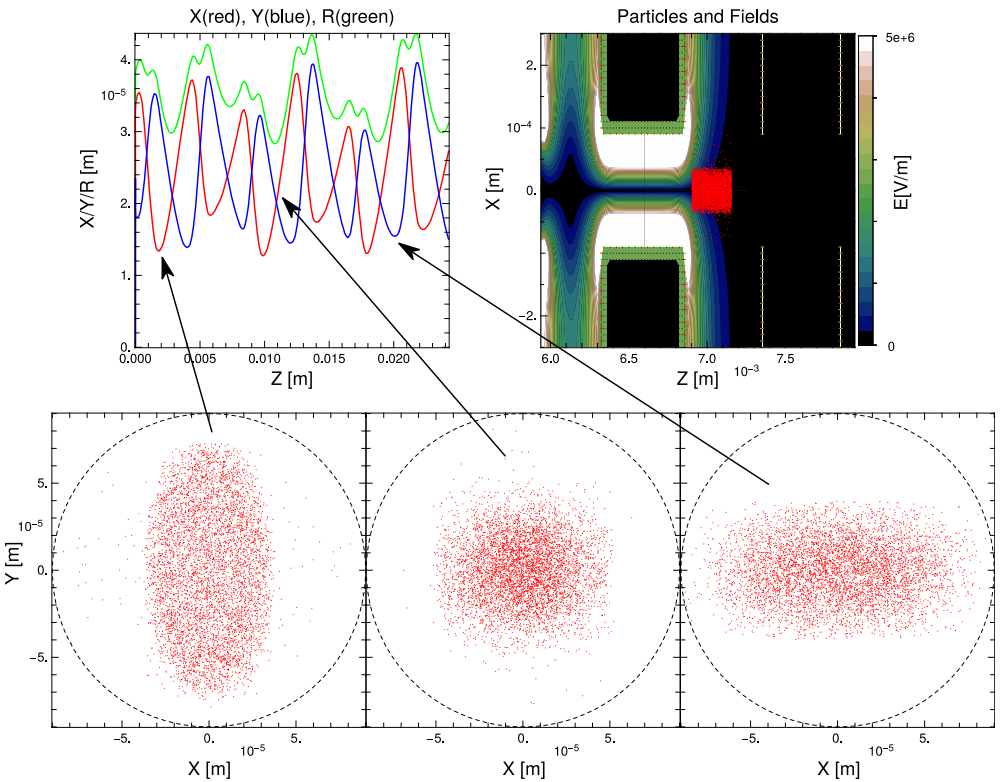


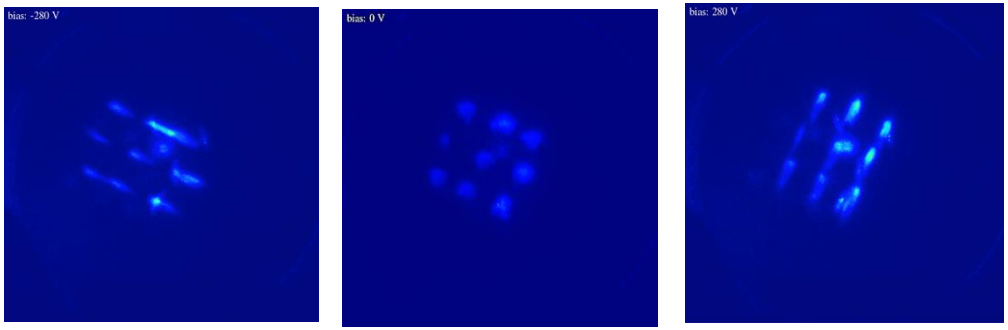
Single-Quad focus/defocus experiment setup

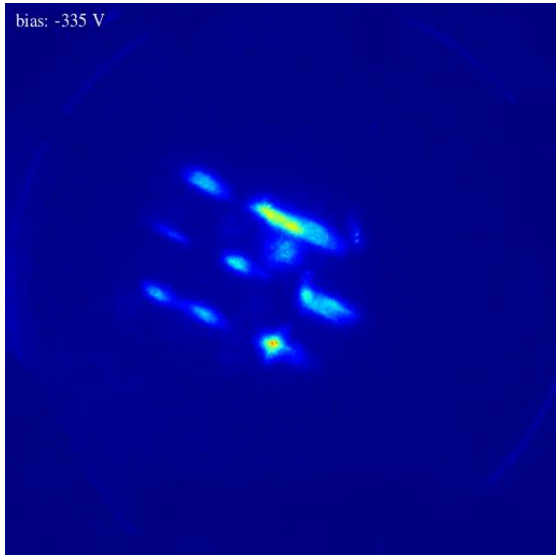




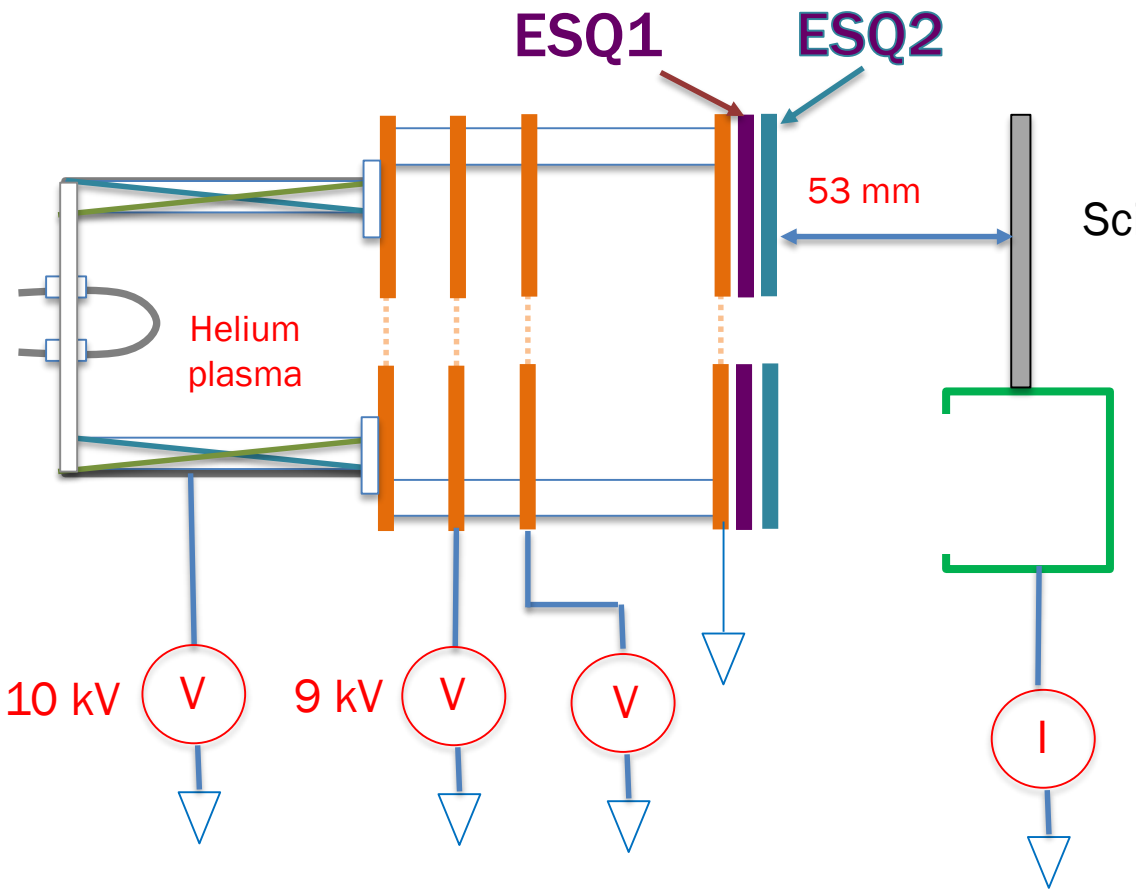
We have demonstrated transport and focusing by ESQs in a 3x3 beamlet structure fabricated on PC boards

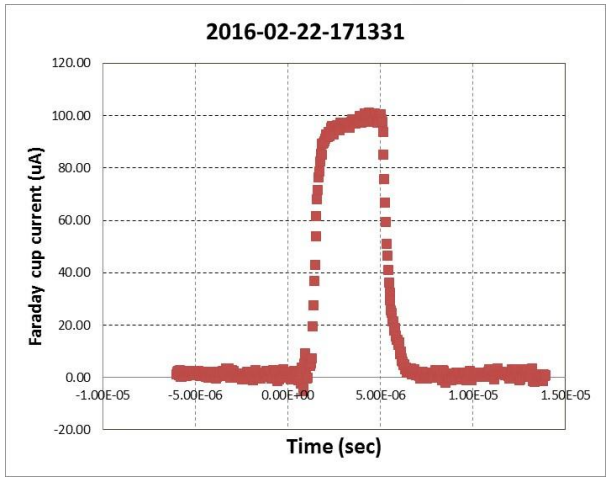






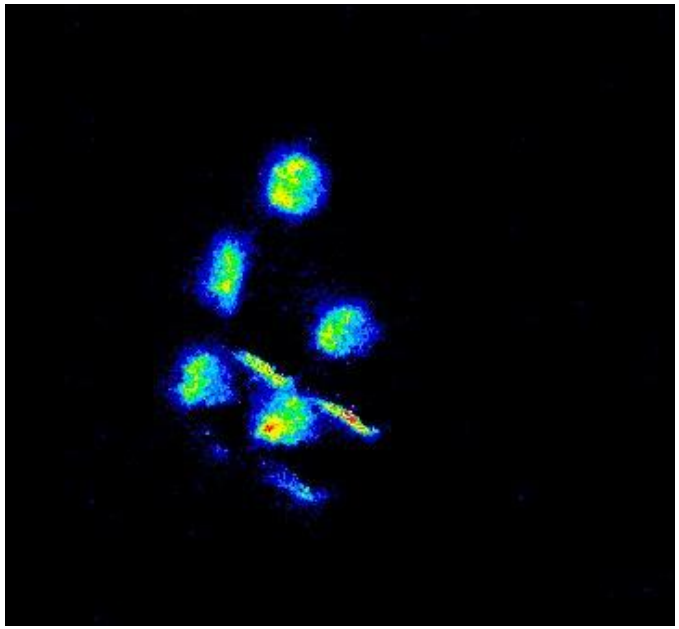
Two-Quad beam transport experiment setup



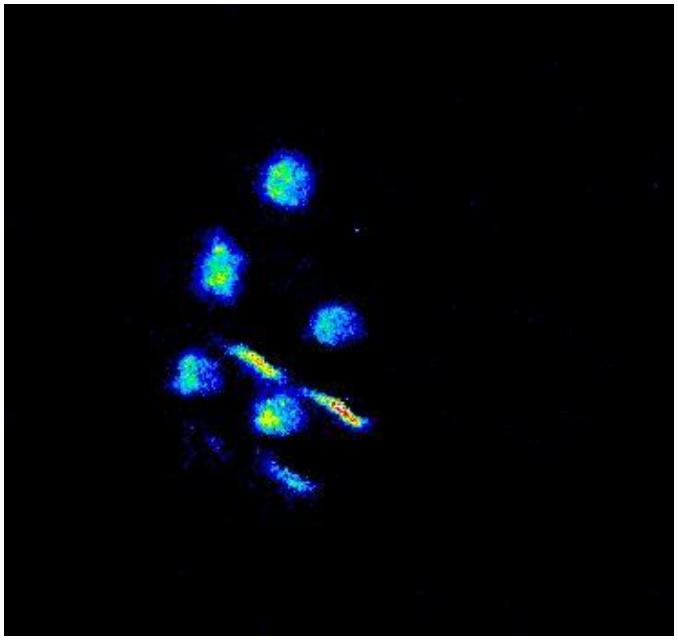


Results with two ESQs in series show refocusing

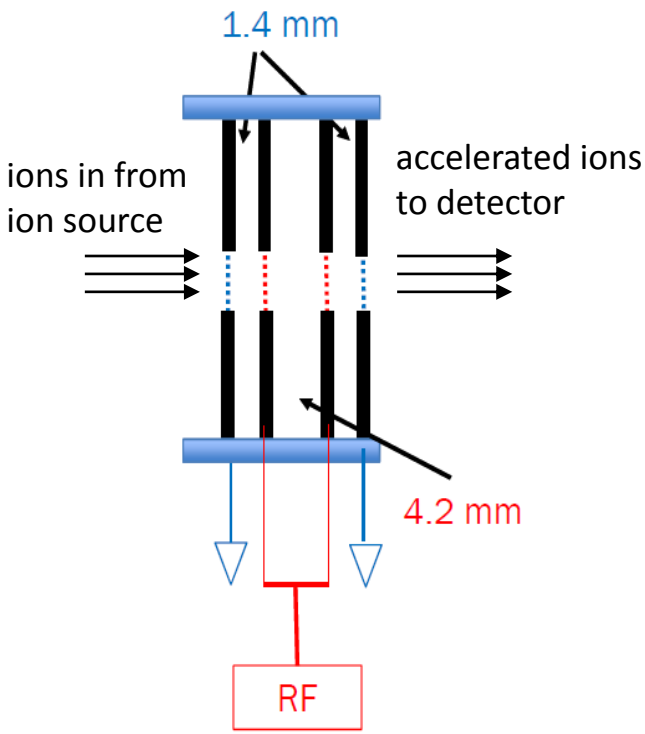
Quad1: V_x=0V, V_y=0V
Quad2: V_x=0V, V_y=0V

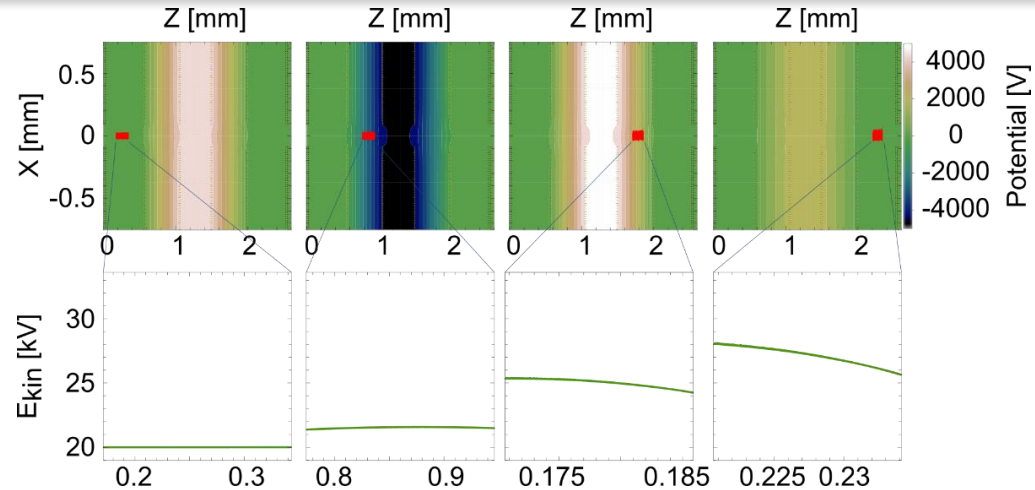


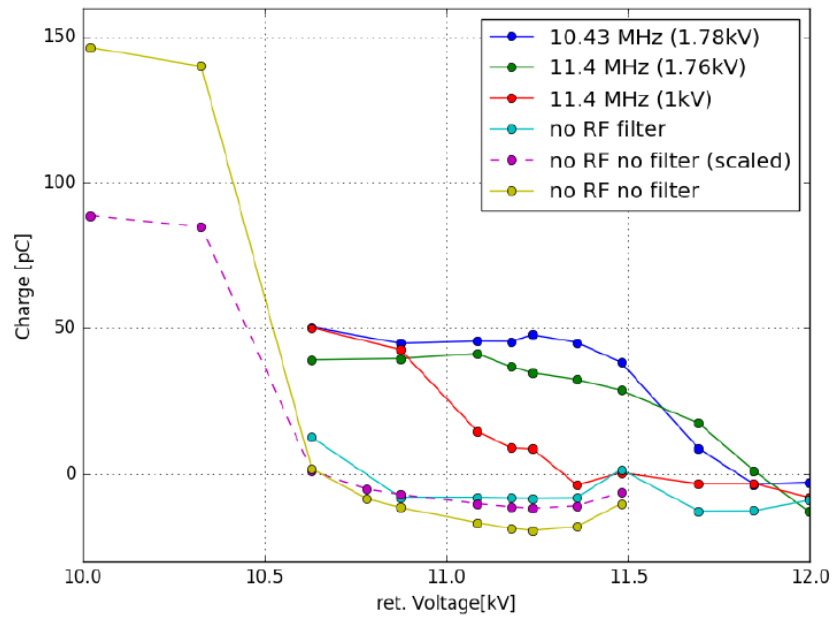
Quad1: V_x=-200V, V_y=+200V
Quad2: V_x=+150V, V_y=-150V



We have demonstrated RF acceleration in a 3x3 beamlet structure fabricated on PC boards

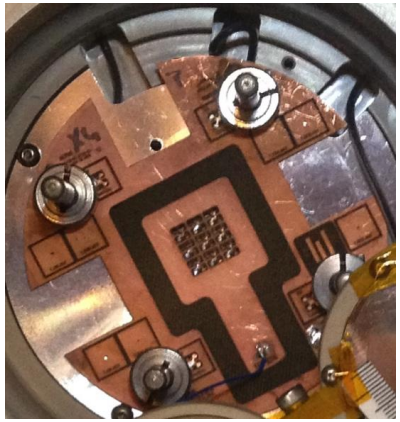


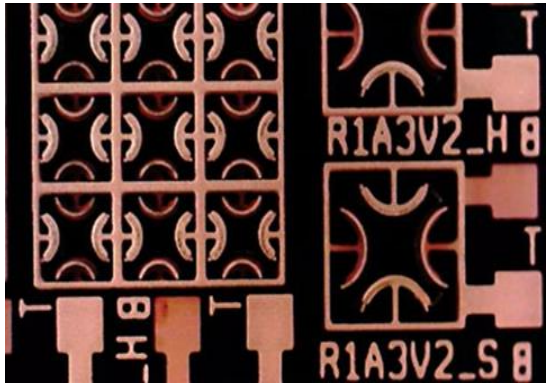


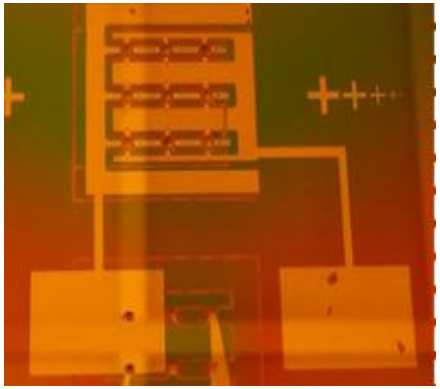


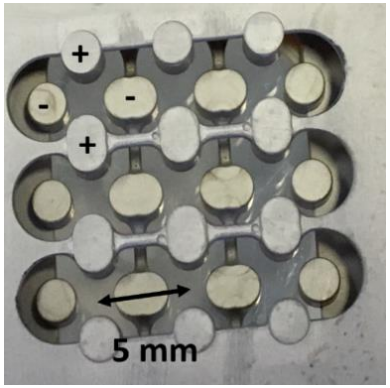
Platforms for focusing

- **ESQ options**
  - PCB
  - Glass/metal
  - Silicon
  - 3D printed
- **Evaluation metrics**
  - Package density
  - Robustness (handling)
  - Beam transmission
  - Scalability
  - Cost





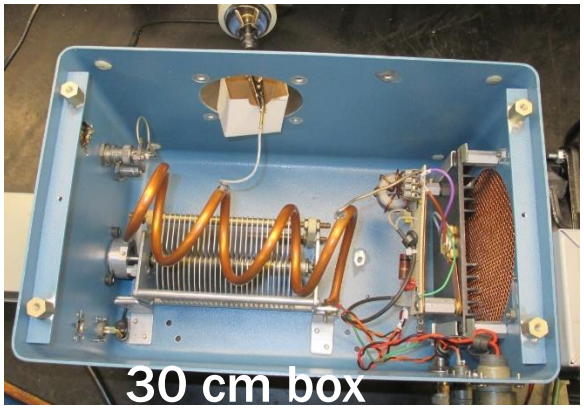


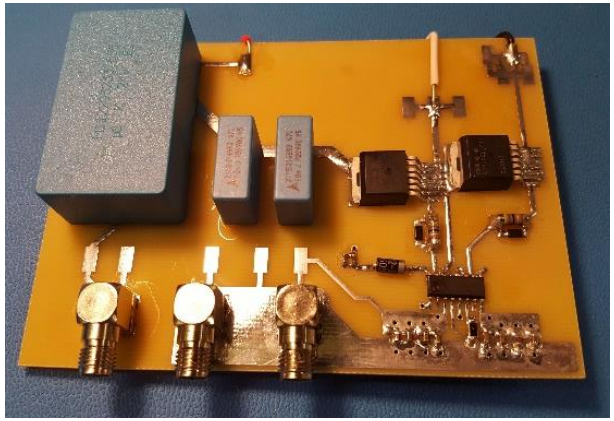


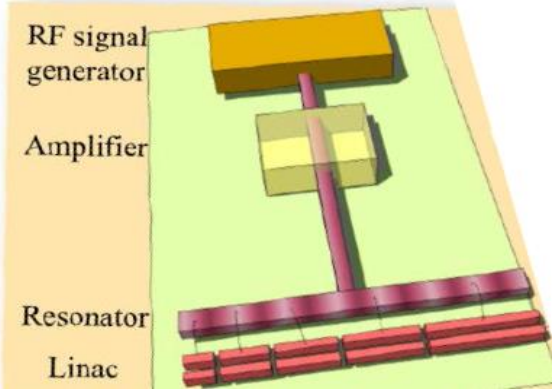
Platforms for acceleration

- **Acceleration options**
  - Off board RF
  - HV pulsers based on MOSFETS
  - RF driven co-planar waveguides

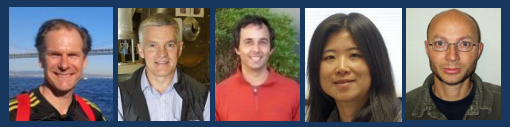
- **Evaluation metrics**
  - Gradient per gap
  - Duty cycle
  - Scalability
  - Compactness
  - Cost

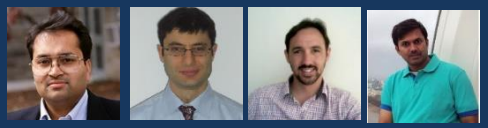






MEMS Based Ion Beams for Fusion


T. Schenkel, P. A. Seidl, A. Persaud, Q. Ji, W. L. Waldron


A. Lal, S. Ardanuc, J. Miller, K.B.Vinayakumar

Sonic MEMS
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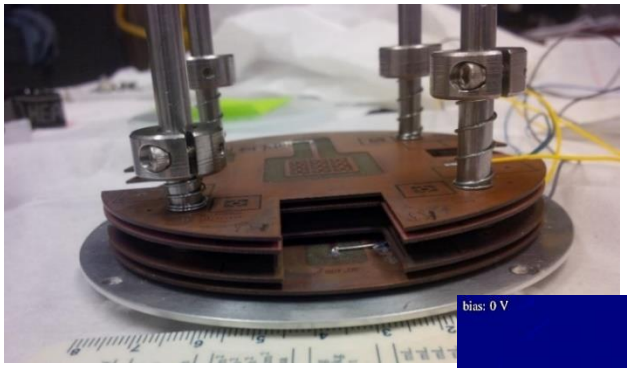

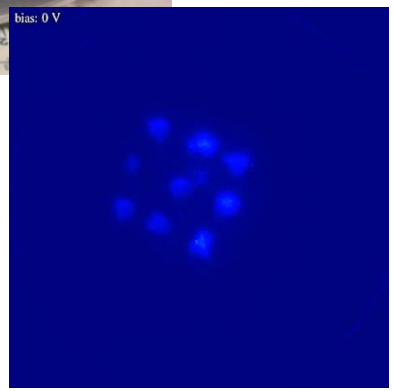

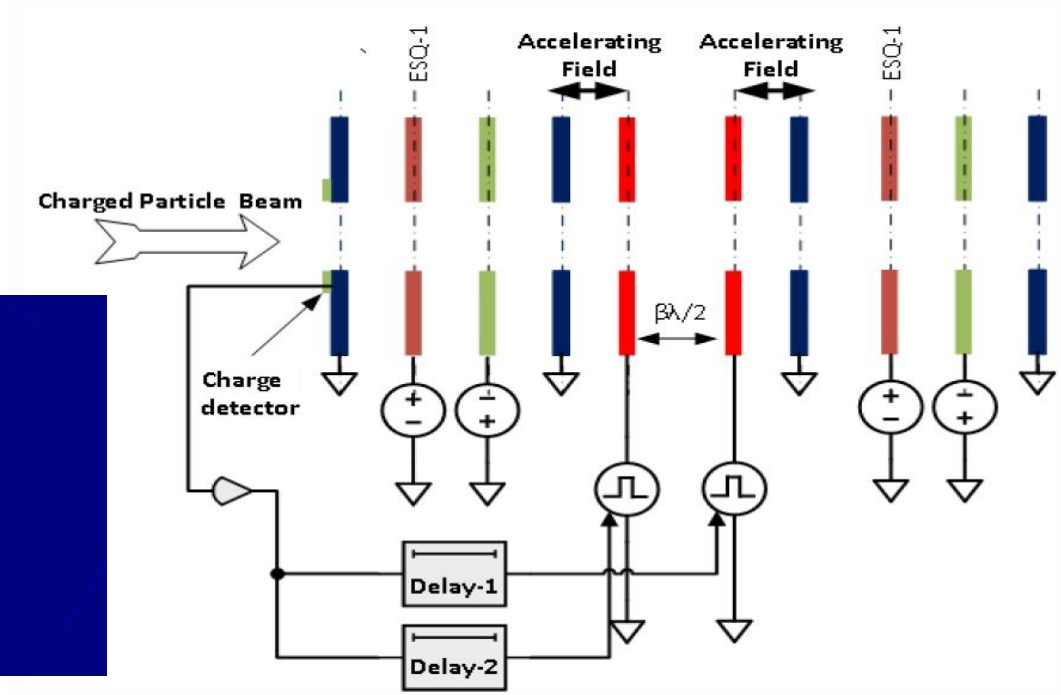

- We have demonstrated RF acceleration and ESQ focusing in a 3x3 beamlet accelerator formed from a stack of printed circuit boards
- In year 2 we will demonstrate an integrated accelerator with a series of stages
- We see intriguing early applications: mass spectrometry, neutron-generators, surface treatment, …