IMPLEMENTING TRAPPED-ION ARCHITECTURES FOR ANALYSIS OF DATA

Experimental:
Craig R. Clark, Matthew Blain, Todd Barrick, Paul Parazzoli

Theory:
Robin Blume-Kohout , Jonathan Moussa, and Kevin Young

Manager:
John Aidun

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Milestones & Deliverables

Date	Milestone/deliverable
8/13	Redesign three-ion Triangle trap (not stated in SOW)
9/13	Fabricate the three-ion triangle trap mounted on the high-optical-access platform.
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1/14 (4/14)	Begin: Fabricate the initial design of a 4-ion star and a 7-ion hexagon surface trap
3/14 (5/14)	Deliver triangle trap to experimental groups at Sandia and NIST/Boulder.
4/14	Trap ions at room temp in the triangle trap for initial testing.
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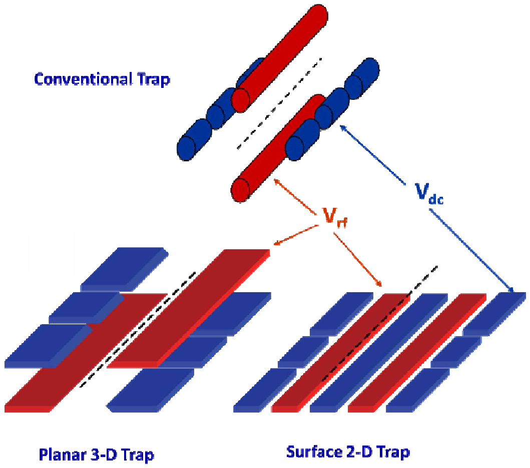
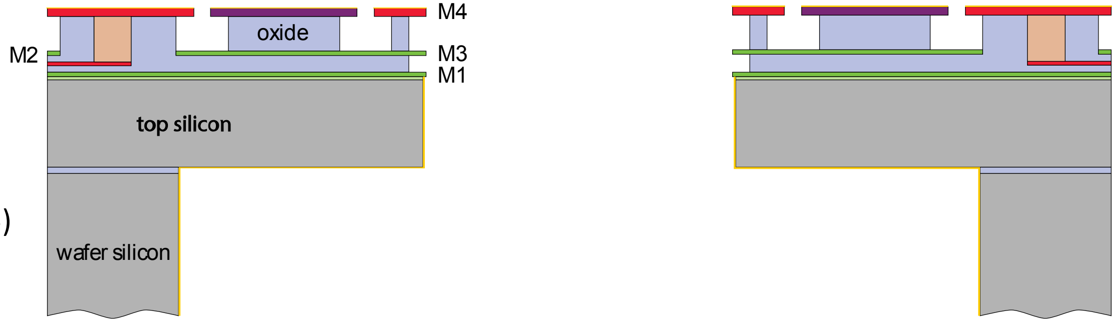
Surface Electrode Ion Trap Fabrication

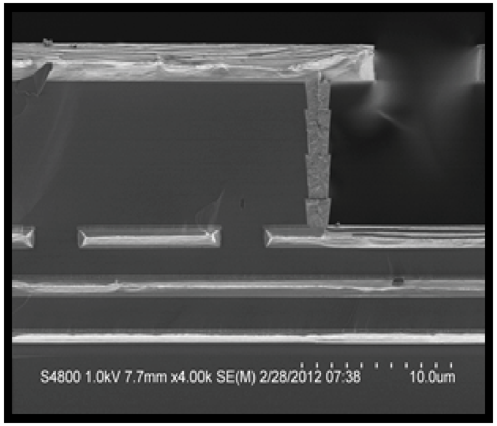
4-metal-layer process modified from Sandia 0.35 µm Al/SiO_2 CMOS Process



J. Chiaverini, *et al.,* Quant. Inf. Comp. 5, 419 (2005)



- **1.2/2.5 µm Al 4LM technology**
- **Trap flow: ~300 ops, 11 mask levels used 17x**
- **Interposer flow: ~320 ops, 15 mask levels used 21x**
- **10 µm oxide separating RF(M4), ground (M3)**
- **Precision Chip thru-holes**
- **Release singulation**
- **Precisely recessed oxide**
- **Routing on M2**
- **Gold coating from front and back side**



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Possible geometries

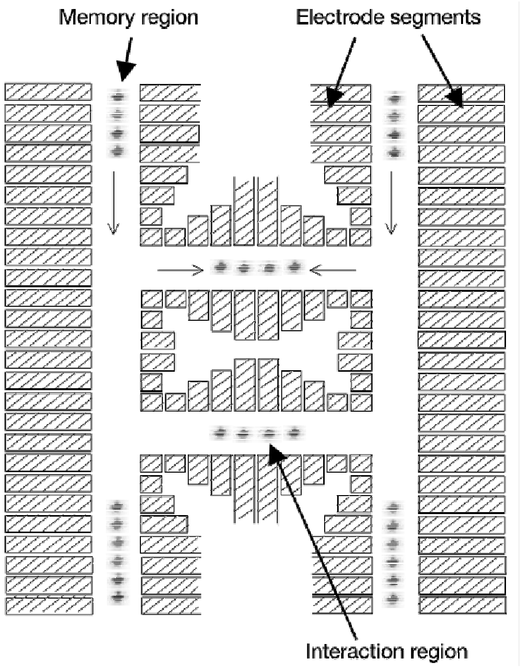
multi-layer technology advantages

Reminder

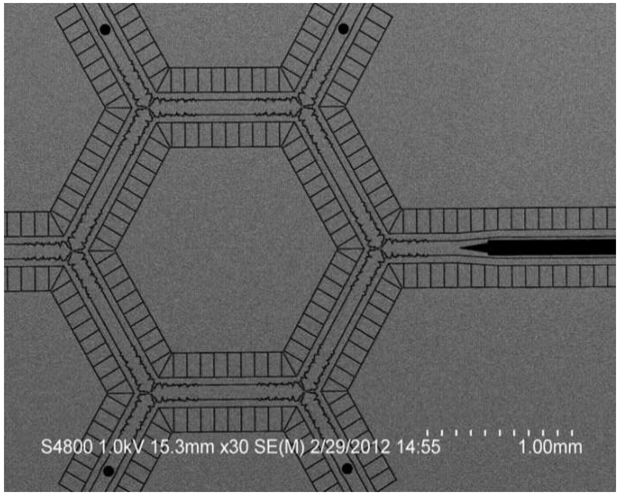
4-level-metal devices allow for:

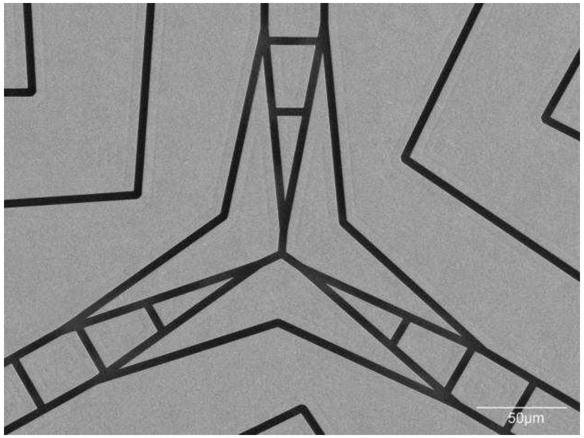
- No exposed routing
- Islanded electrodes
- New topologies
- 5th layer for dense routing

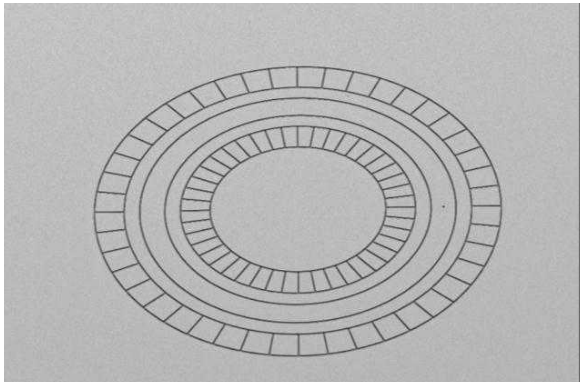
Arbitrary trap geometries
can be realized



D. Kielpinski, *et al.* Nature 417, 209 (2002).



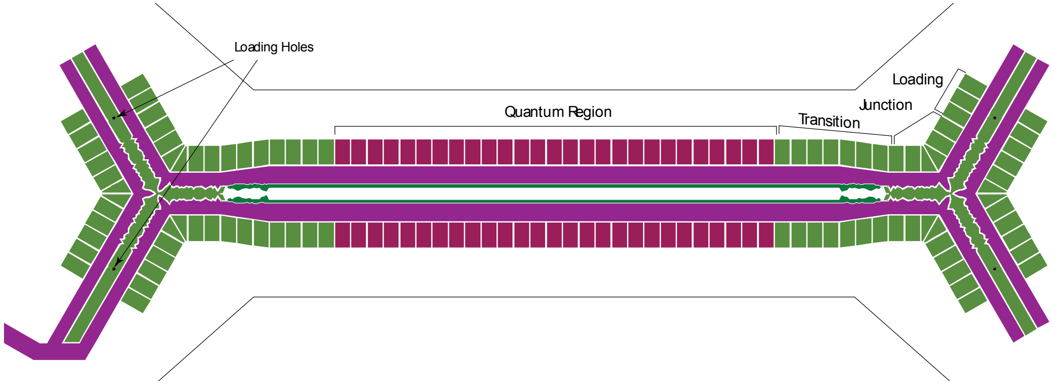


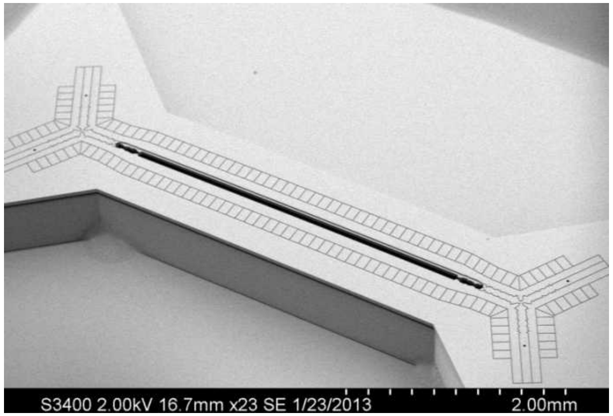


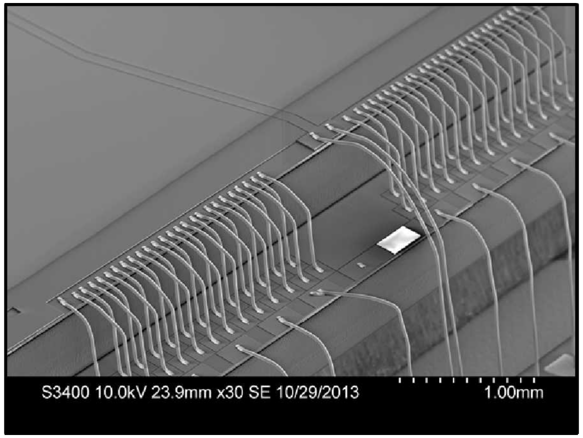
HOA trap platform: *high optical access trap*

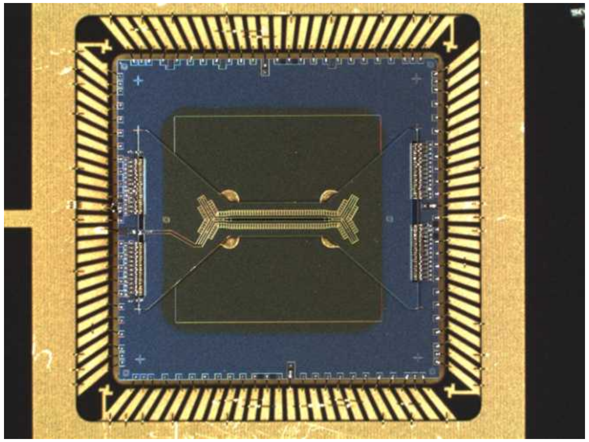
Optimized surface electrode ion trap platform

- **Release singulation allows for arbitrary chip shapes**
- **Greatly improved optical access:**
  - **Larger trap depth**
  - **Higher trap frequencies**
  - **Less optical scatter**



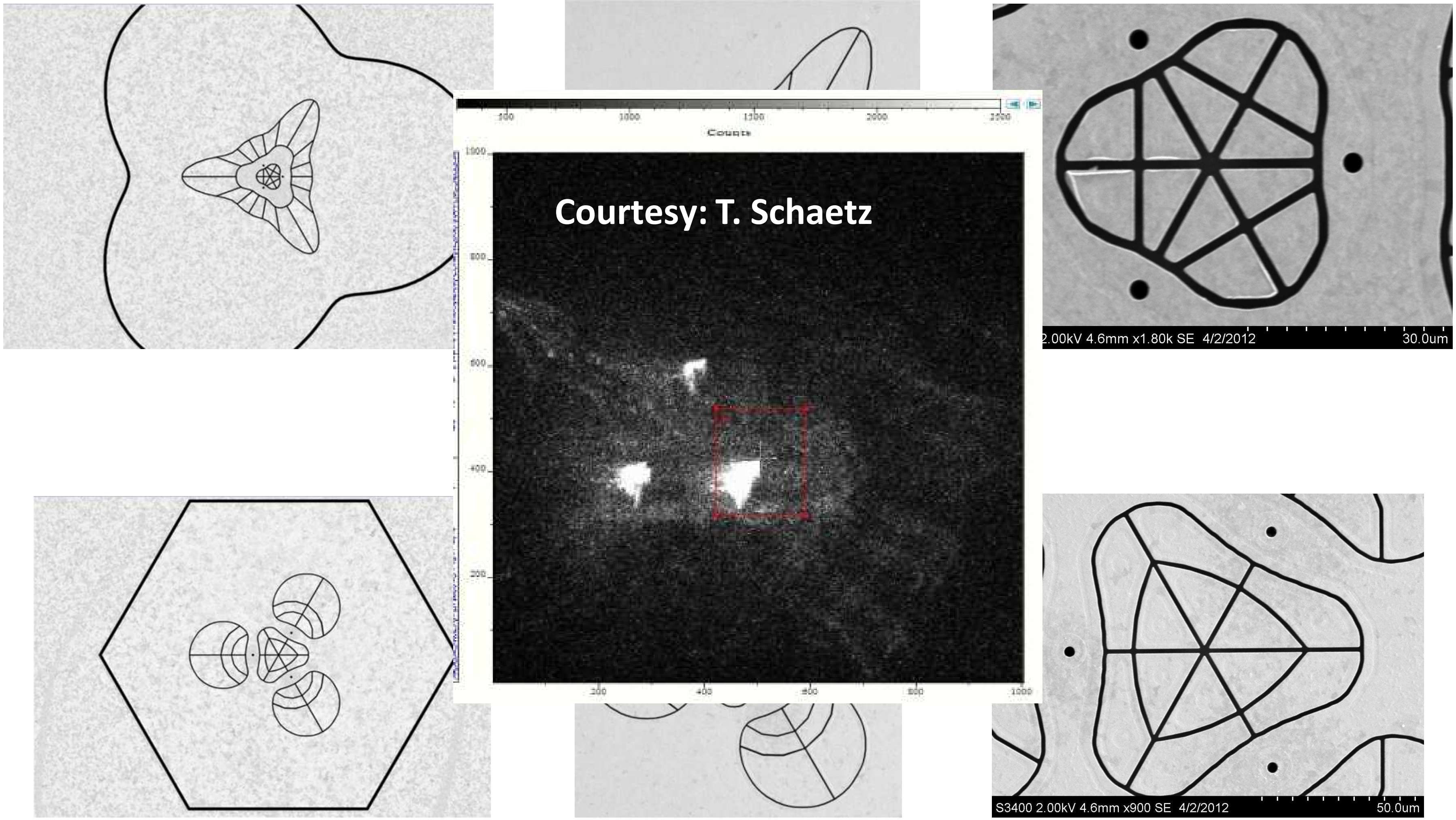






Original Triangle Trap (Rev 0) – 80 μm, 40 μm triangles

40 μm triangles

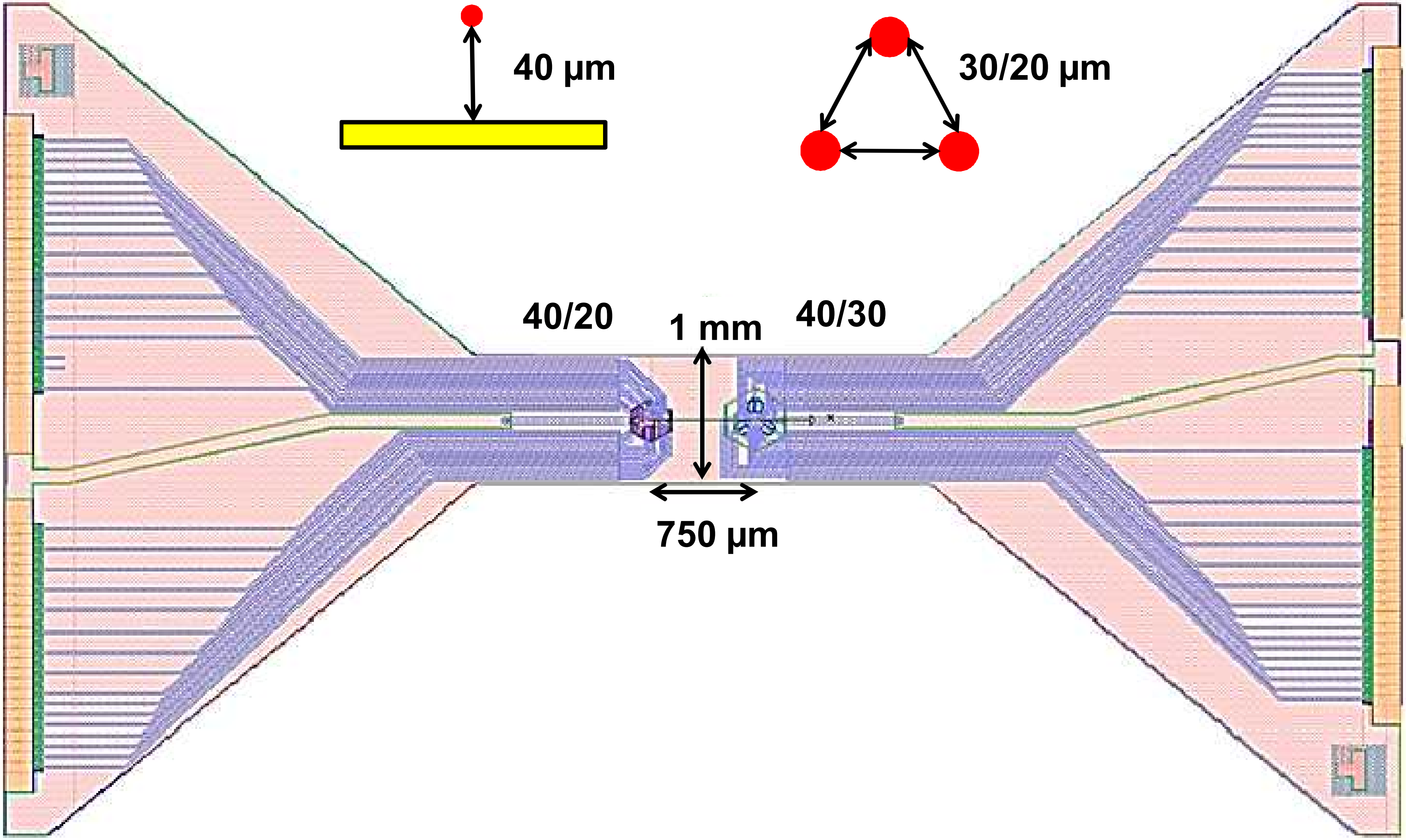


Courtesy: T. Schaetz

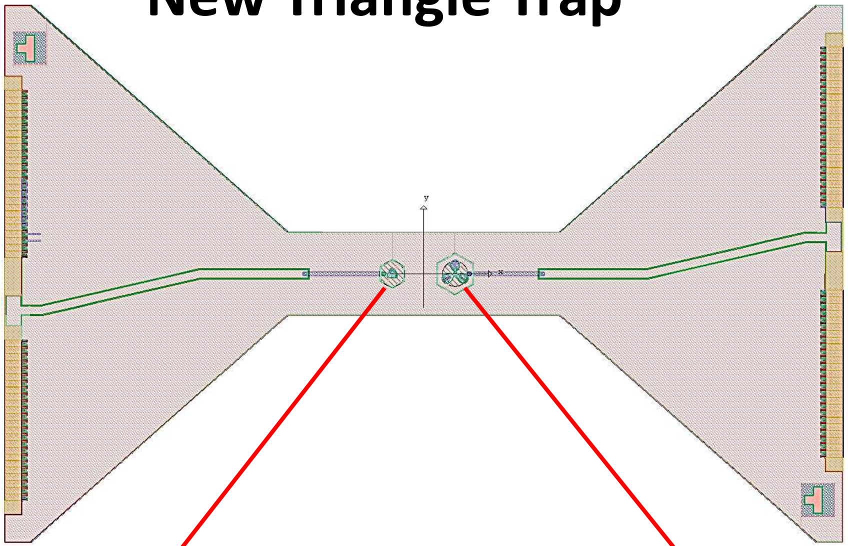
New Triangle Trap

ion height fixed

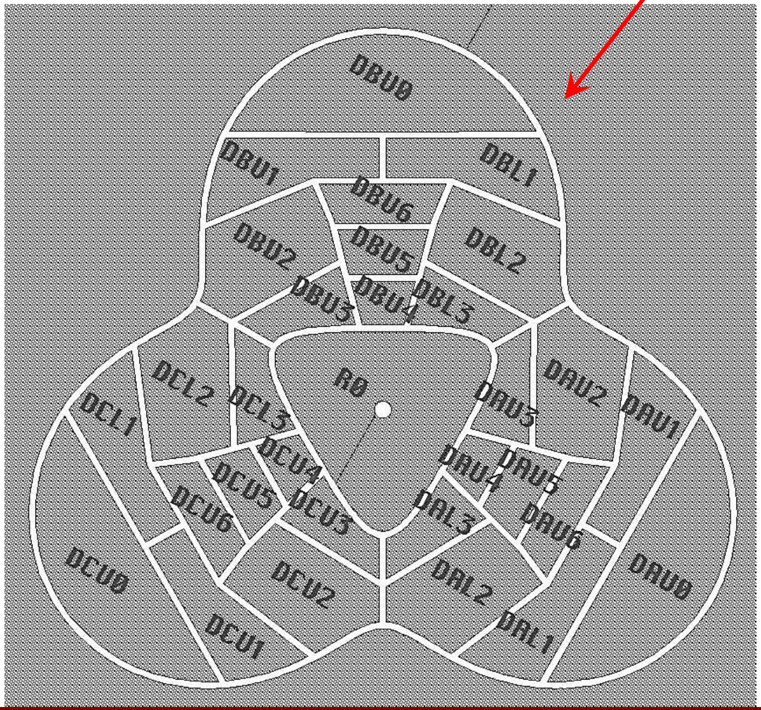
ion-ion distance reduced



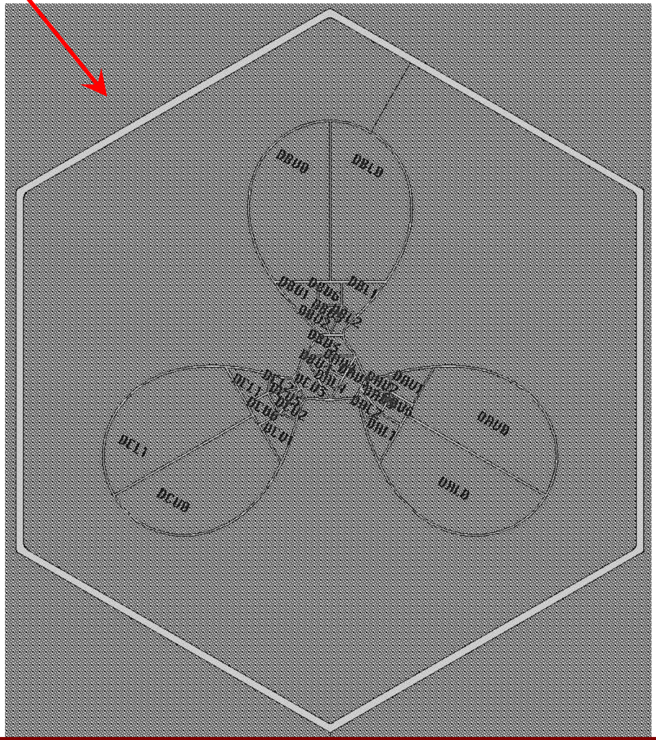
New Triangle Trap



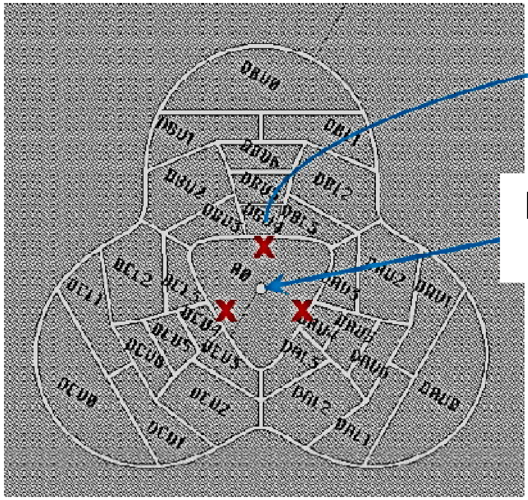
40/20



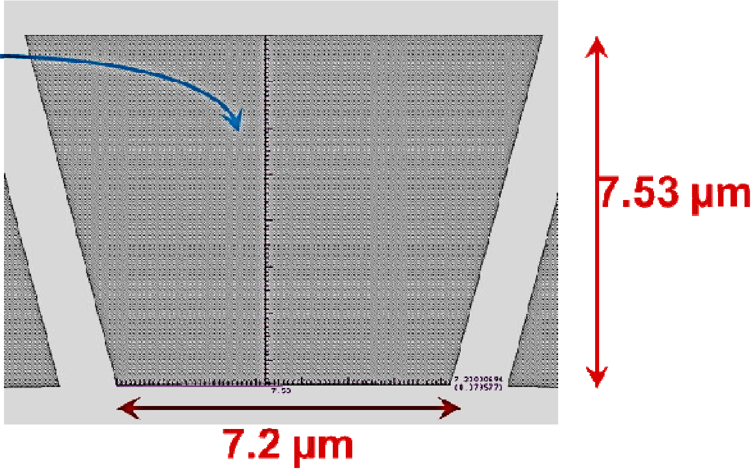
40/30



New Triangle Trap – Smallest Surface Trap

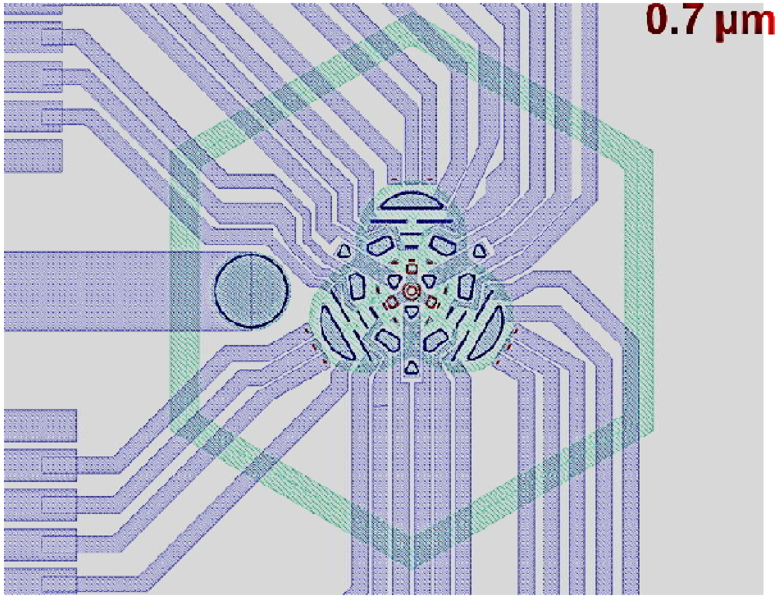


Ion spacing: 20 µm
Ion height: 40 µm

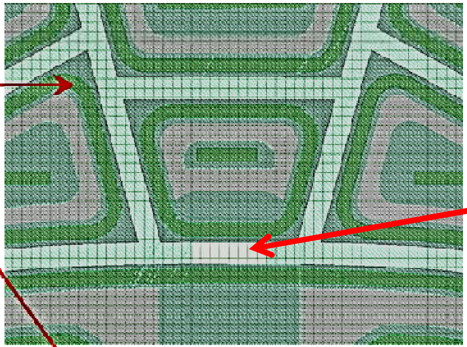


7.53 µm

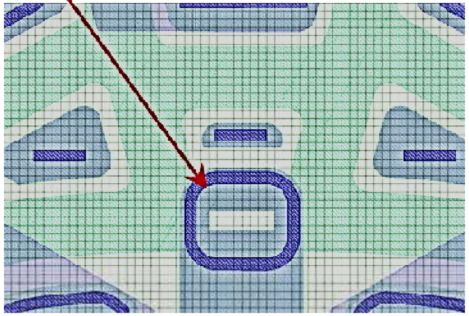
7.2 µm



0.7 µm vias

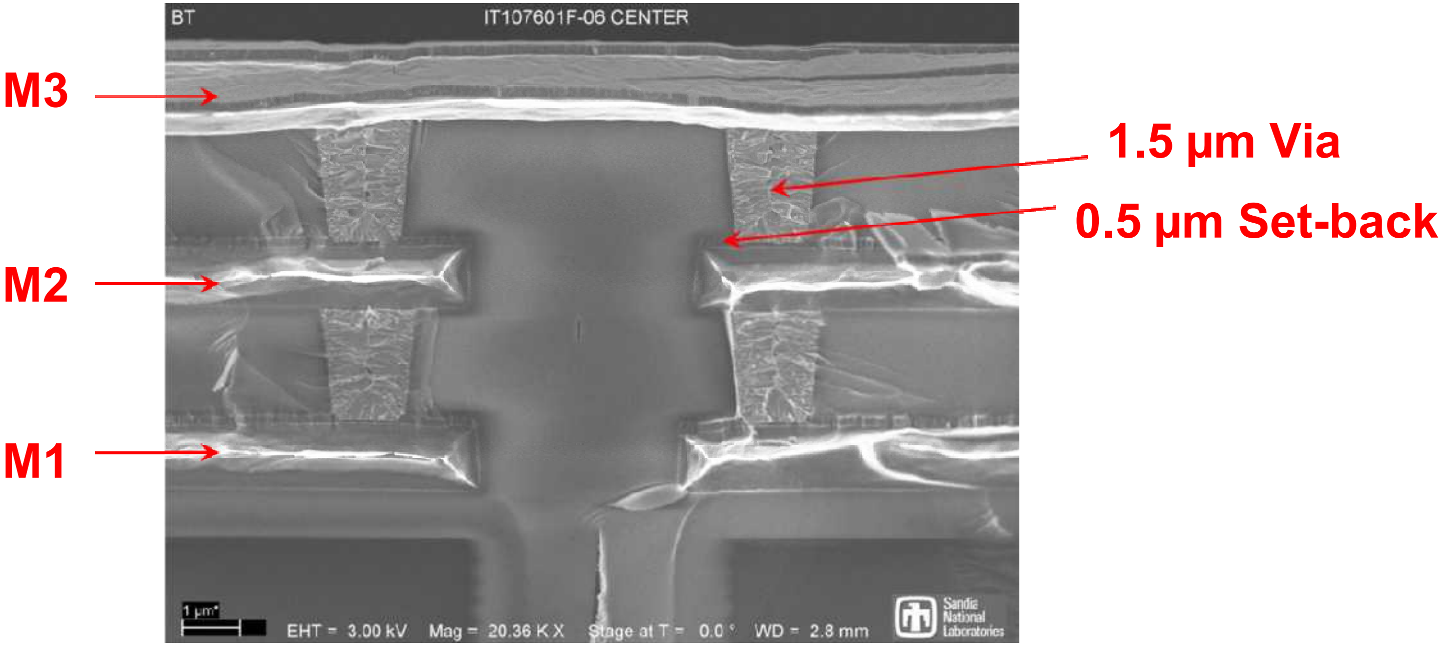


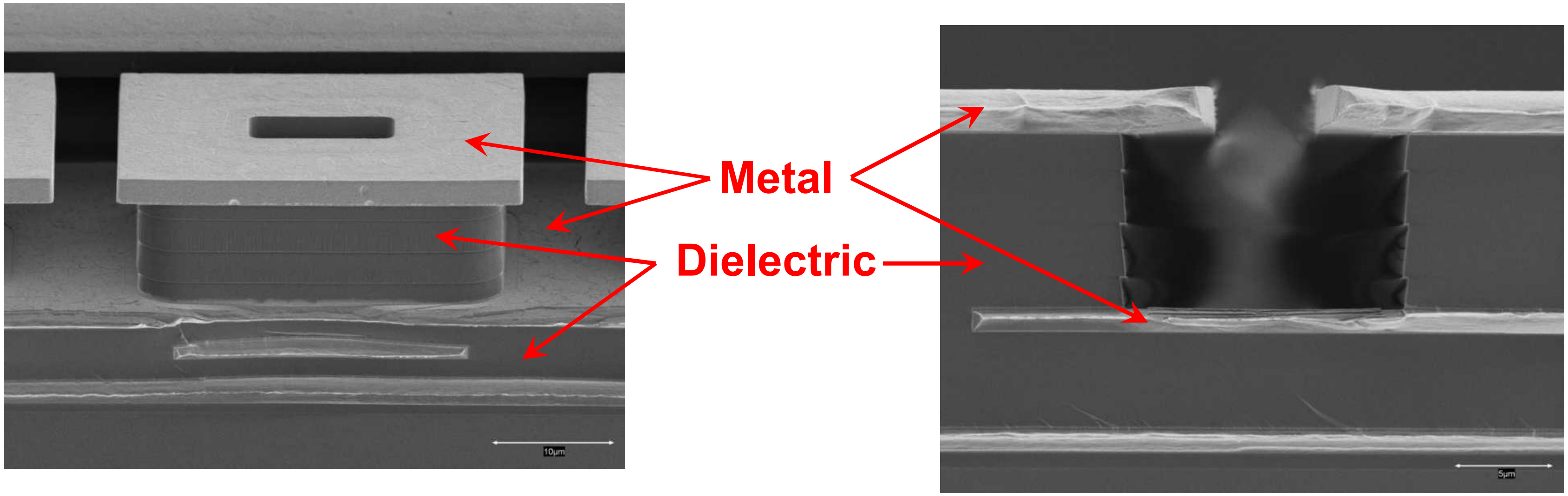
1.2x2.5 μm^2
Loading slot



Loading thru gap in M4 electrodes; loading hole in M3

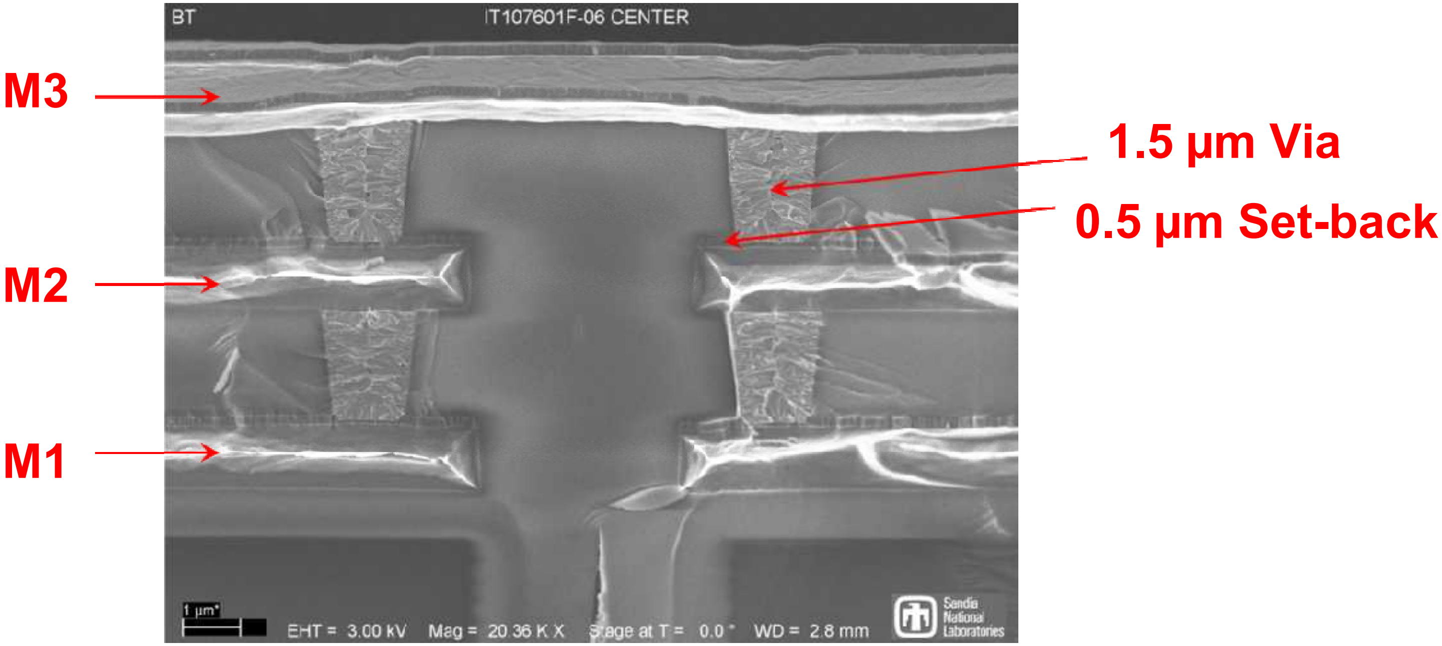
The importance of vias





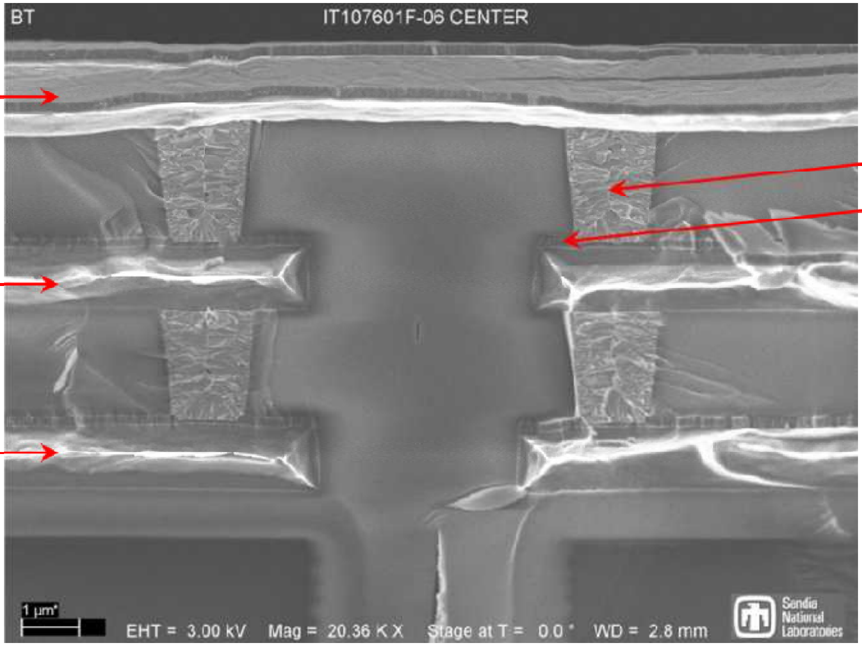
Ion Trap Minimum Electric Rules – 1.5 µm Vias

Minimum Electric Rule (µm)	RS (Release Seam)	MO (Marks Only)	M1 (Metal 1)	V1 (Via 1)	M2 (Metal 2)	V2 (Via 2)	M3 (Metal 3)
Min Width	4	N/A	5	1.5	5	1.5	5
Min Space (preferred)	5*	N/A	3	3	3	3	3
Min Space (Acceptable)	3*	N/A	2.5	2	2.5	2	2.5



Ion Trap Minimum Electric Rules – 1.5 µm Vias

Minimum Electric Rule (µm)	V3 (Via 3)	V3-2 (Via 3-2nd level)	V3-3 (Via 3-3rd level)	V3-4 (Via 3-4th level)	M4 (Metal 4)	HS (Head start)	BS (Backside)
Min Width	1.5	1.5	1.5	1.5	5	3	50
Min Space (preferred)	3	3	3	3	5	N/A	50
Min Space (Acceptable)	2	2	2	2	2.5	N/A	50



M3

M2

M1

1.5 µm Via

0.5 µm Set-back

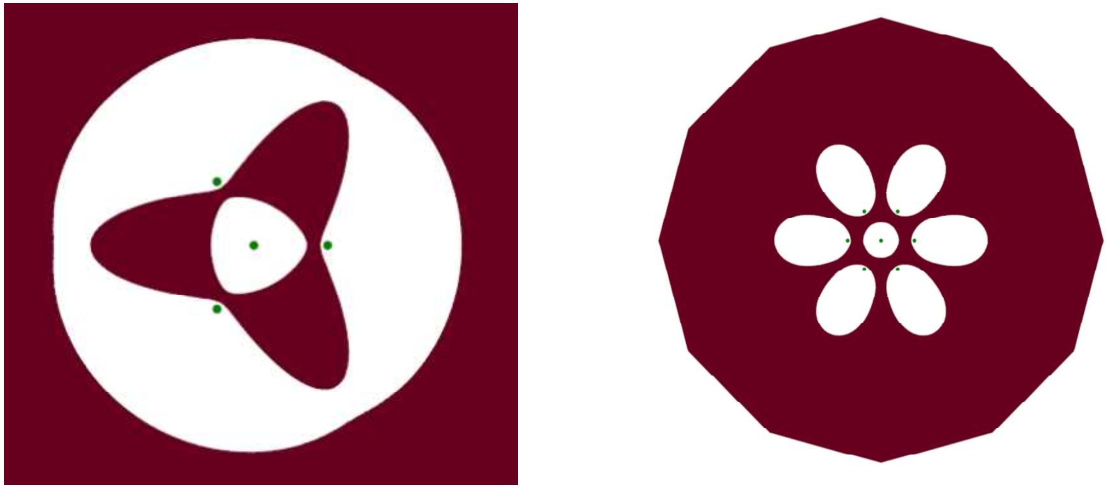
Trap Status

New Triangle Trap

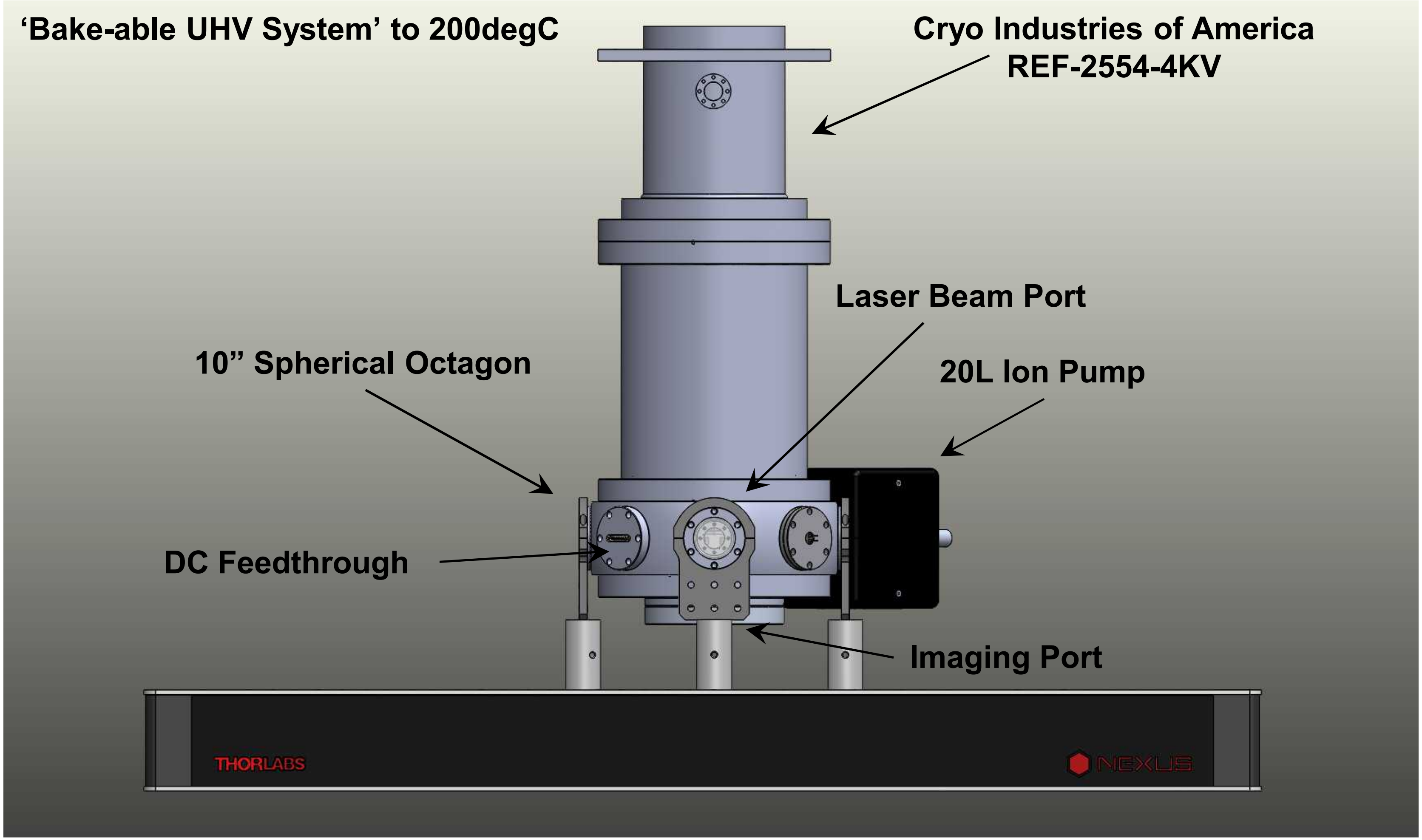
- Two new triangle designs (20 µm/30 µm) simulated by NIST (Robert)
- 1st two photomask levels ordered, lot started November 2013
- Short loop diagnostics mask completed
- Initial short loop experiments for making very small electrodes completed
- Photomask routing/layout for remaining 9 levels in progress, completion projected 1/2014
- Device fabrication/packaging of triangle traps completion projected 4/2014

Hex+Center Trap

- Initial design of 3+1 and 6+1 4LM surface electrode trap received from NIST
- Photomask routing/layout completion projected 2/2014, pending final design



Cryogenic Ion Trap System



‘Bake-able UHV System’ to 200degC

Cryo Industries of America
REF-2554-4KV

Laser Beam Port

10” Spherical Octagon

20L Ion Pump

DC Feedthrough

Imaging Port

Cryogenic Industries of America

Sandia National Laboratories

http://www.cryoindustries.com/pdf/CF_Low_Vibration.pdf

Gifford McMahon Cryo-Cooler
~1Hz Cycle

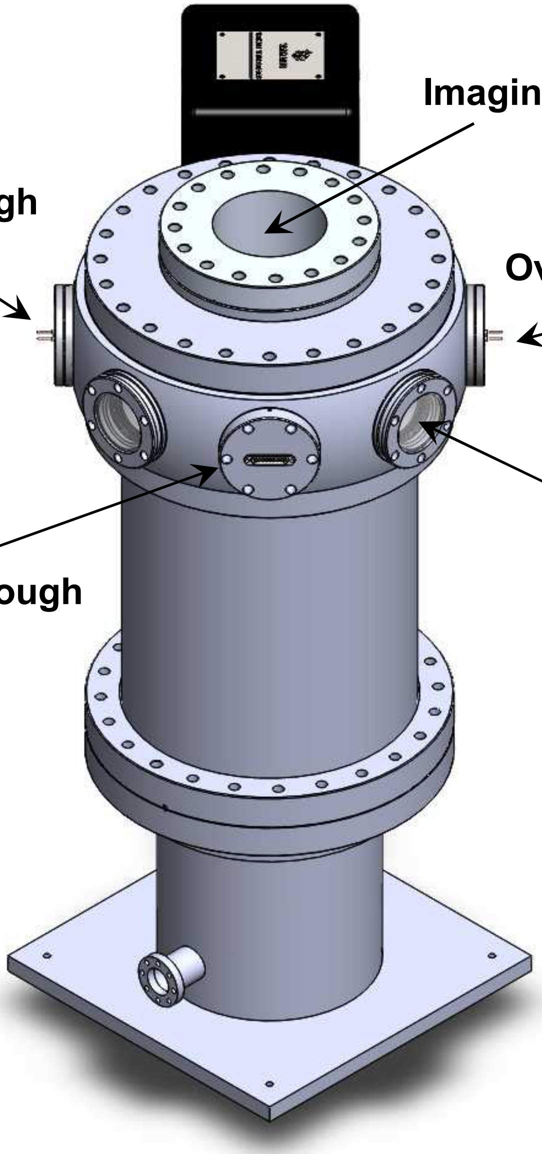
Isolation Bellows

UHV Chamber

Cryo Industries of America

- **1.0 Watt @ 4K – Cooling Power**
- **34.0 Watt @ 40K – Cooling Power**
- **Gifford McMahon (GM) – Closed Cycle**
- **Bellows Vibration Isolated Coldfinger**
    - **Exchange Gas Cooled**

Cryogenic Ion Trap System



Imaging Port

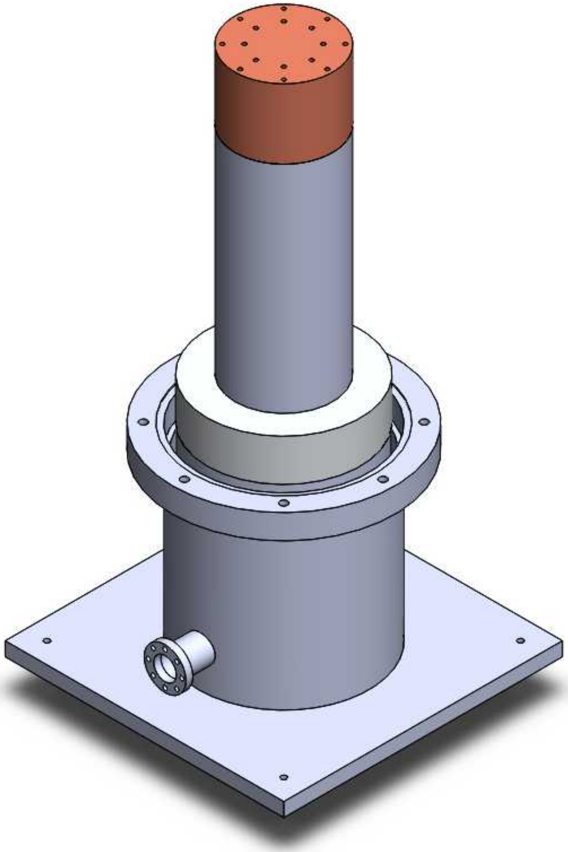
RF Feedthrough

Oven Feedthrough

Laser Port

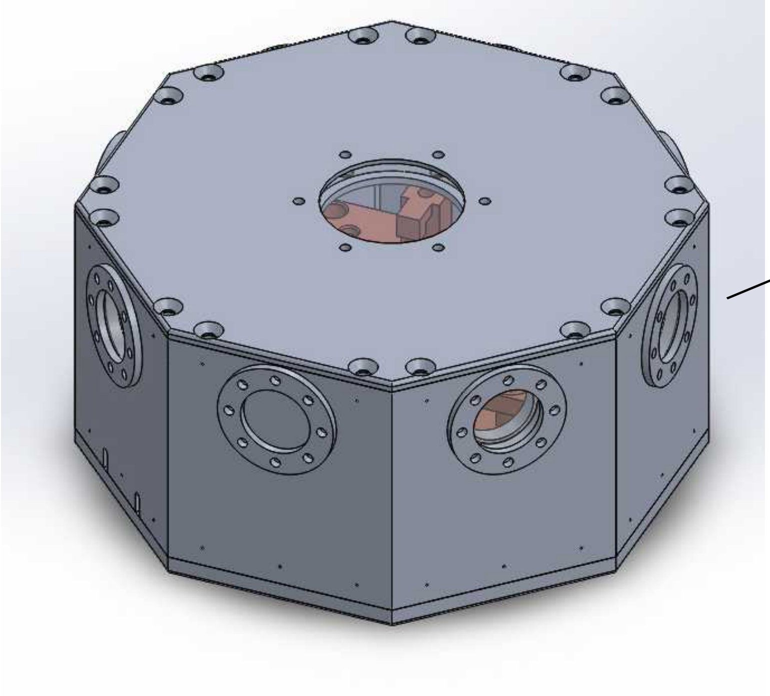
DC Feedthrough

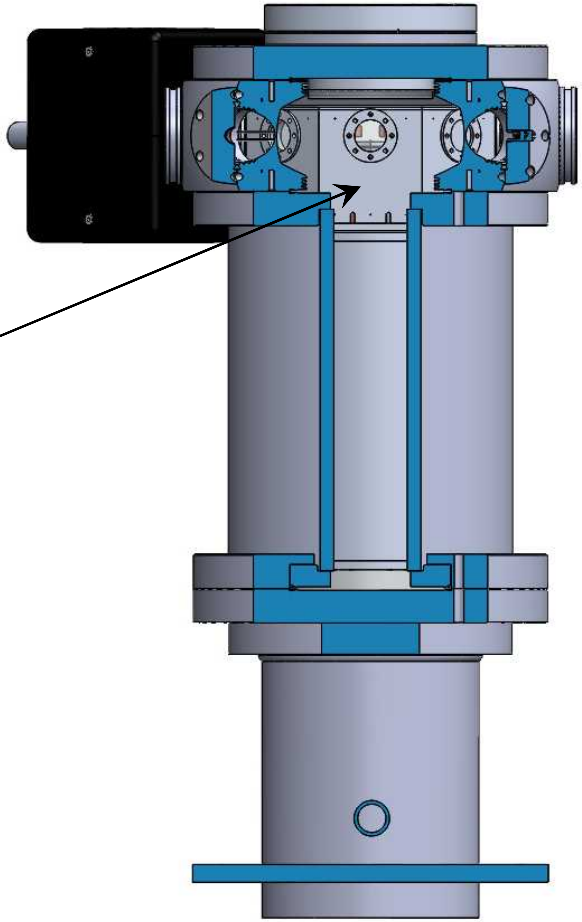
Vibration Isolated Coldfinger



Cryo-system: What's Inside?

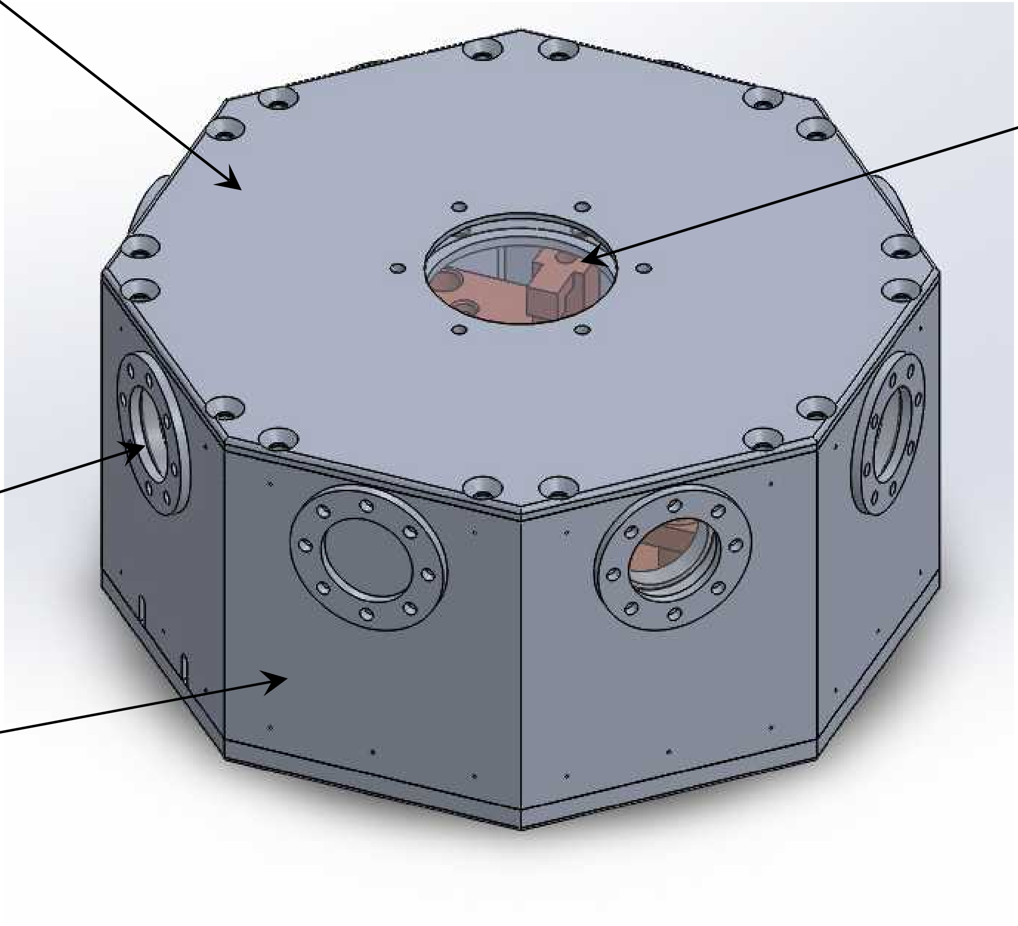
Experimental Carriage





Modular Experimental Carriage – Allows system to be assembled independent of cryostat

Cryo-system: What's Inside?



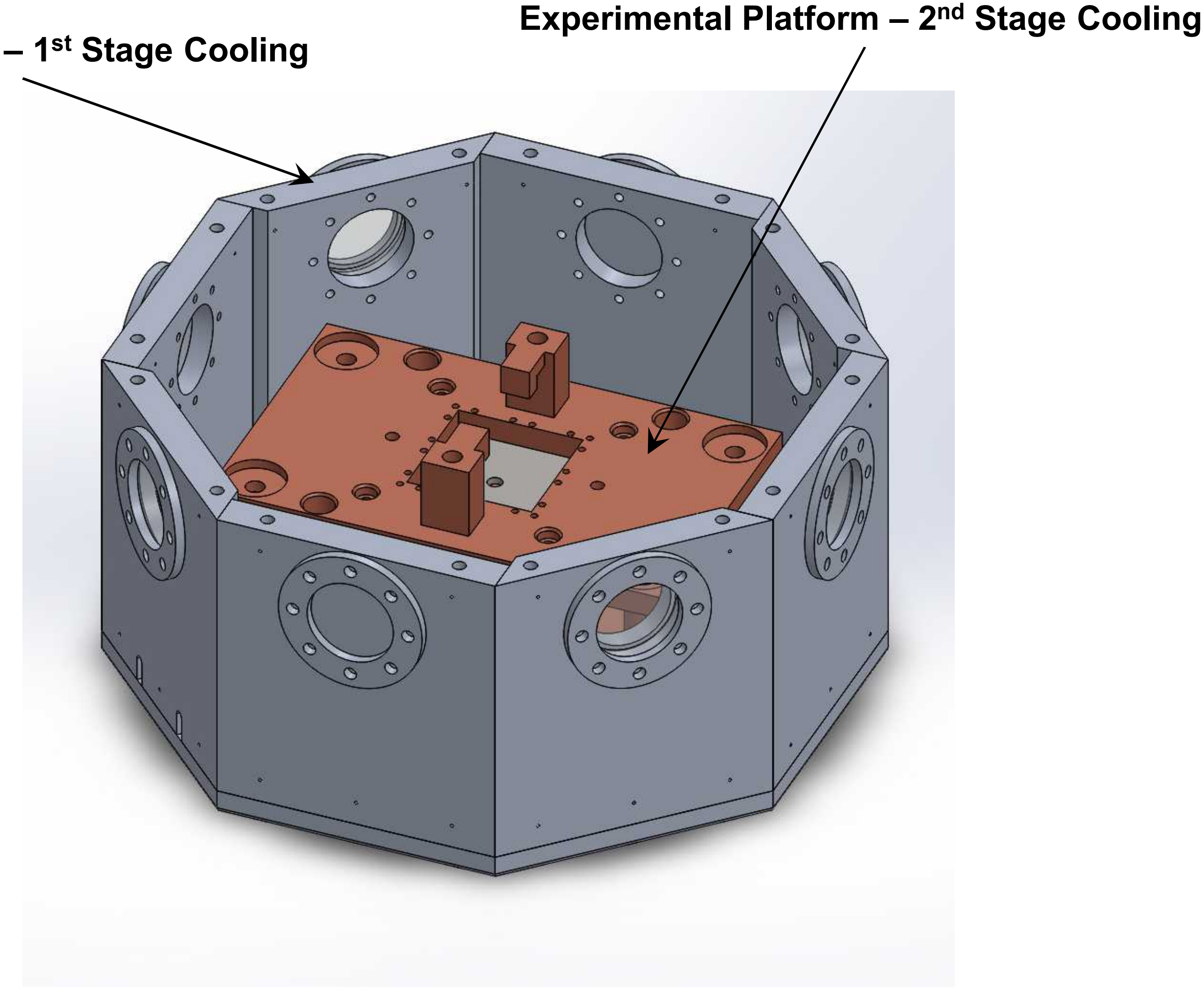
Radiation Shield – tied to first stage cooling

Imaging Port

Laser Port

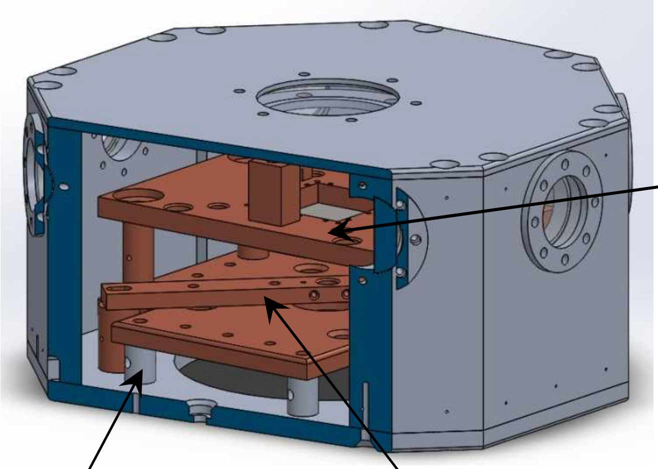
Swappable Walls

Cryo-system: What's Inside?

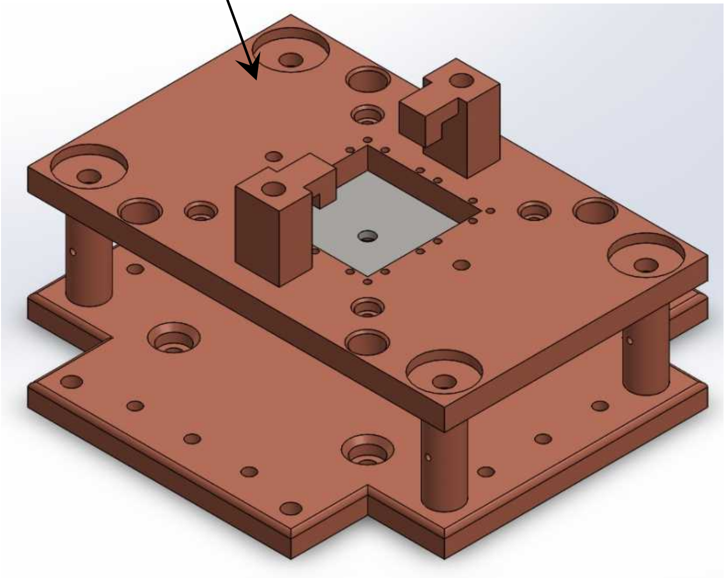


**Radiation Shield and Experimental Platform are independent during operation

Cryo-system: What’s Inside?

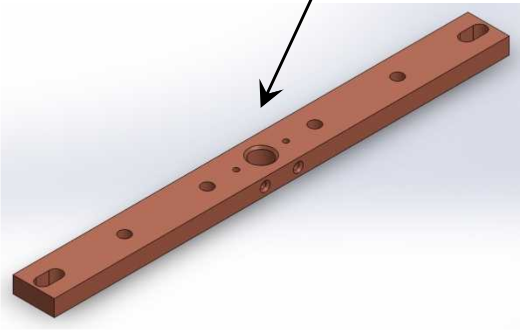


Experimental Platform – 2nd Stage Cooling



Coupling Posts**

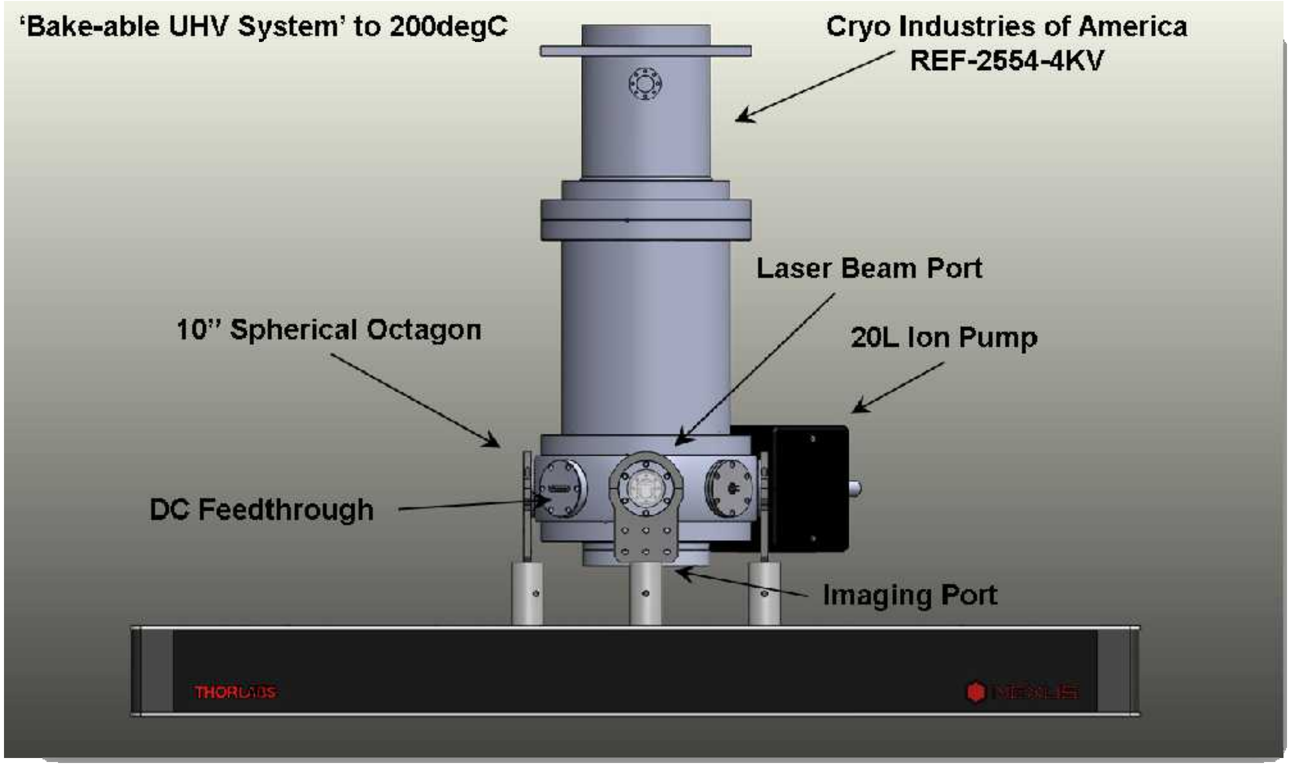
Oven Mount



****Removed After Assembly of System**

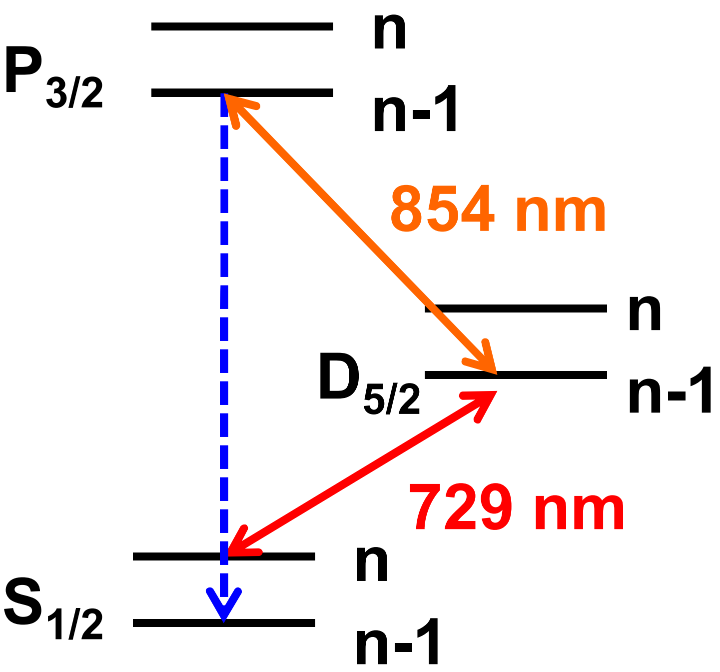
Cryo Status

- Cryostat ordered from Cryo-Industries of America December 2013 (2-3 month lead time)
- Laboratory modification due to start January 2014, completion projected February 2014
- Assembly of cryostat to start upon arrival and be completed in 3-4 months , projected June 2014
- Successfully trap ions in cryostat by August 2014



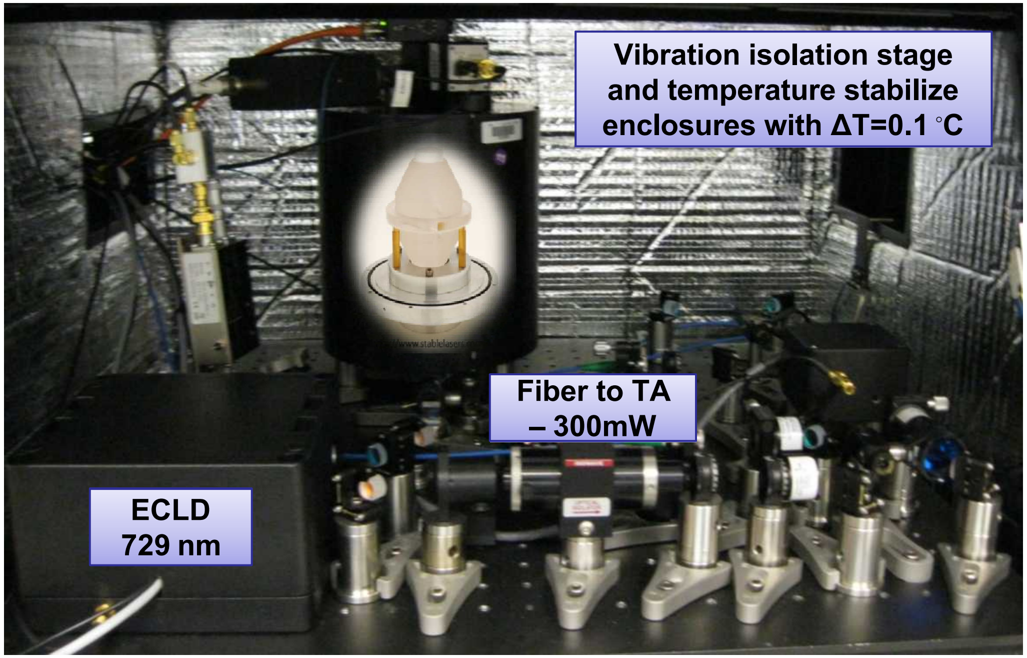
Progress towards Qubit operations

Calcium Optical Quibit



ULE Optical Cavity

Fabry-Perot cavity (ATFilms 6030)



Vibration isolation stage and temperature stabilize enclosures with ΔT=0.1 °C

Fiber to TA – 300mW

ECLD 729 nm

$F = 200000$

$\nu_F = 1.93\ \text{GHz}$

$\delta_\nu = \frac{\nu_F}{F} = 9.65\ \text{kHz}$

$T_c = 24.2\ ^\circ\text{C}$

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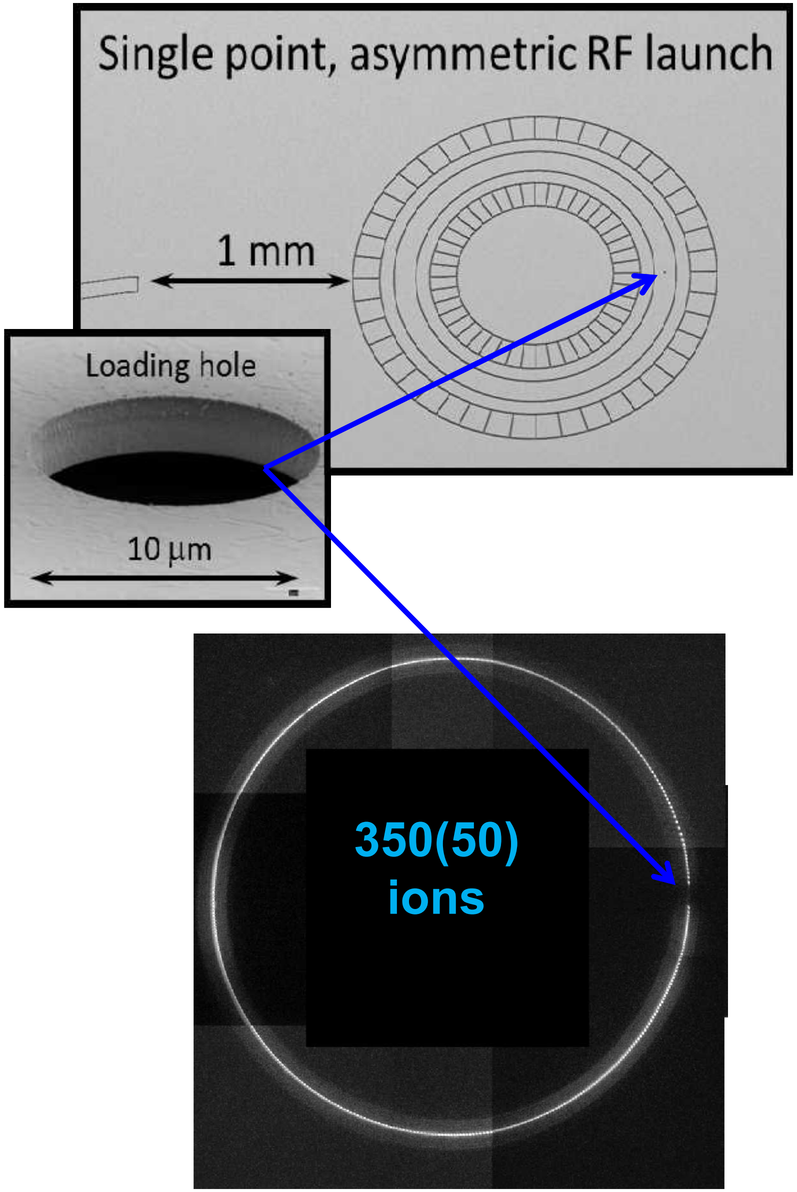
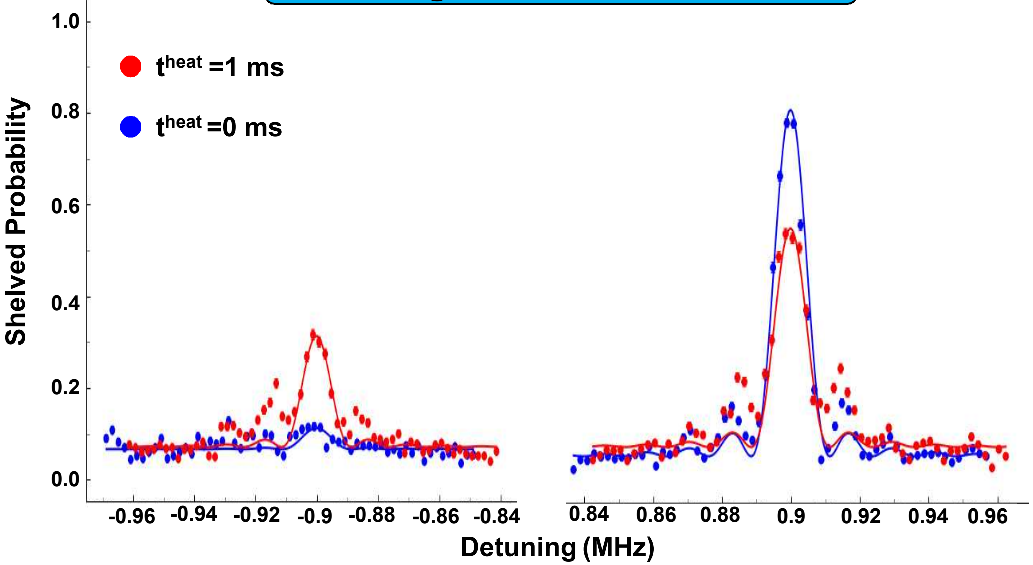
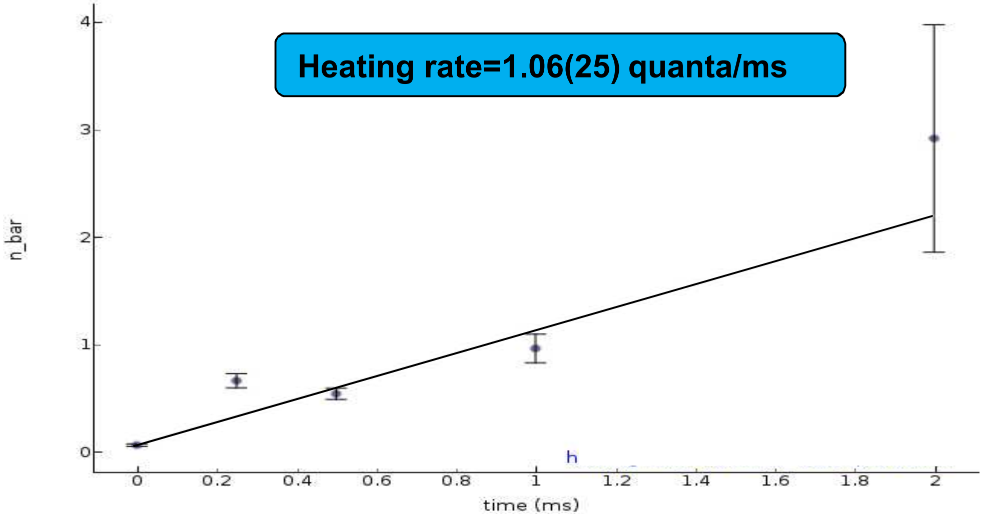


350(50) ions

Heating Rate Measurements





Heating rate=1.06(25) quanta/ms

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