Additive Manufacturing of Z-Channel Detectors for Heavy Ion Accelerator Diagnostics
(DE-SC0019535)

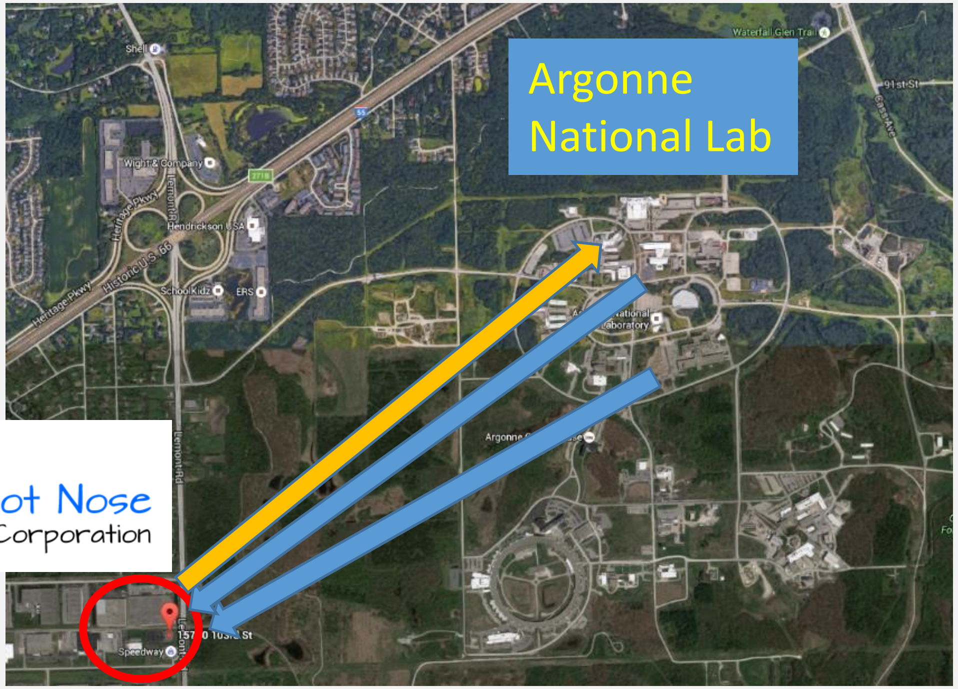
SBIR/STTR Exchange Meeting 2021

Jerome F. Moore, President

Robot Nose is pre-commercial, pre-investment

Core mission: Bridging the cost-complexity gap between chemical sensors and laboratory instruments

We need faster, cheaper, and better ion detectors!



Robot Nose Corporation

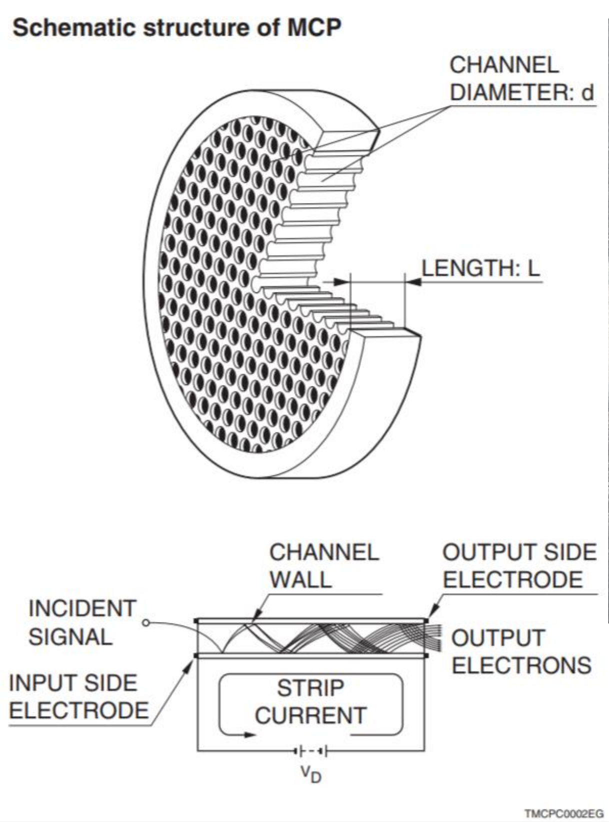
- Technology initiated in MSD, HEP and AMD divisions at Argonne, extended and fed back to PHY (ATLAS). Argonne extensive collaborators on this project.

- SBIR funds have been crucial to taking LDRD work to this next level – BES and HEP funding directed elsewhere.

Background:

Microchannel plates (MCPs) are high-gain detector structures.

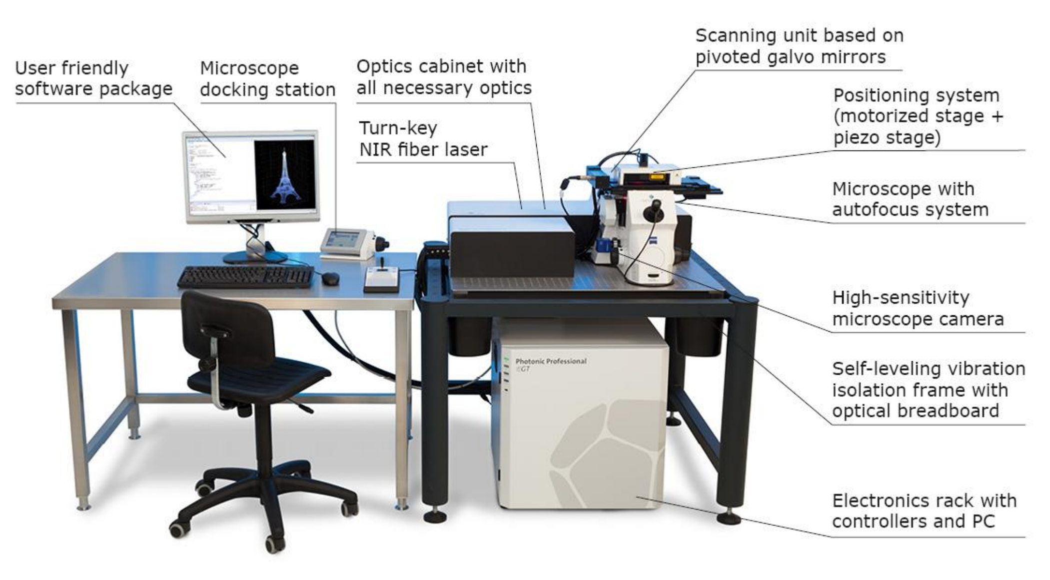
- Traditionally, MCPs are made by fusing and drawing leaded glass capillaries and “drawing” them to shrink the diameter, then slicing into wafers and processing for resistivity and secondary emission.
- Principal driver for this technology for 50 years has been Night Vision (gen 2 and later Image Intensifier Tube) – not scientific applications.
- Timing has been an interesting property of MCPs since they were invented – the planar geometry and generally <ns response makes them useful. But minimal improvements in 50 years (smaller channels, higher bias).

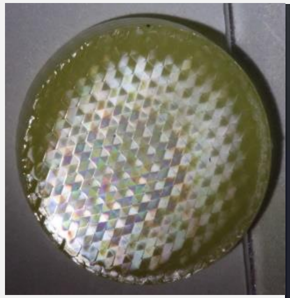


From: Hamamatsu

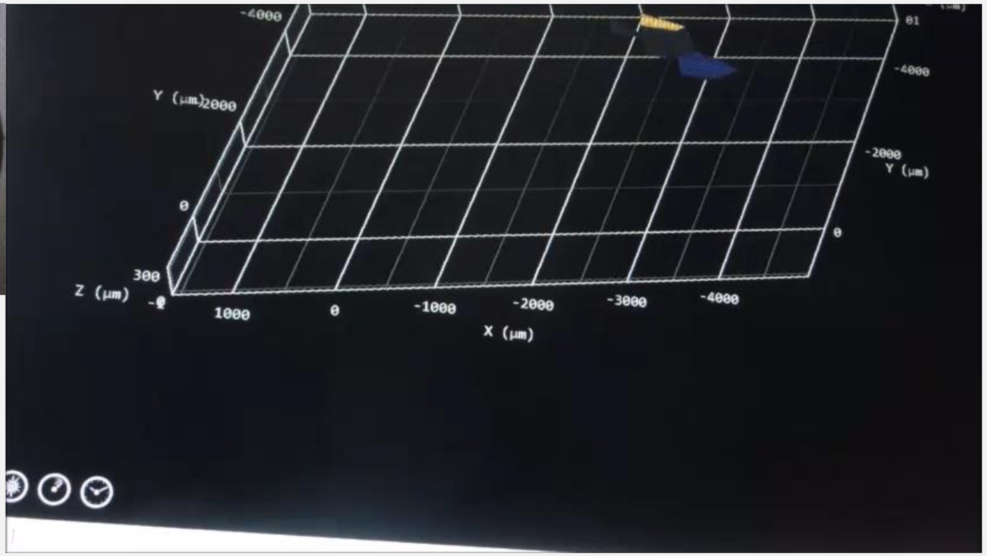
Reference MCP
- 40:1 12° 18mm area
- US$500 each x 2
- Storage in vacuum!

We can additively manufacture MCPs



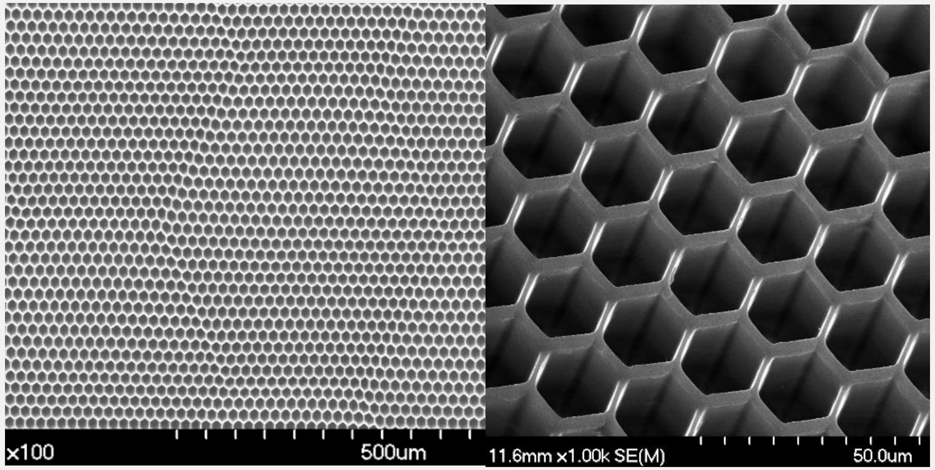


cm size
additive MCP



Argonne LDRD supported (2015-2018)
Two photon additive technique / sterolithography

- better material control (^{10}B for neutron)
- microstructure control (open area ratio)
- macrostructure control (spherical focus…)



Scanning electron microscopy (SEM) of additively manufactured MCPs from Argonne, showing (right) uniformity of channels created over a large area.

GOAL: Improving ATLAS bunch timing

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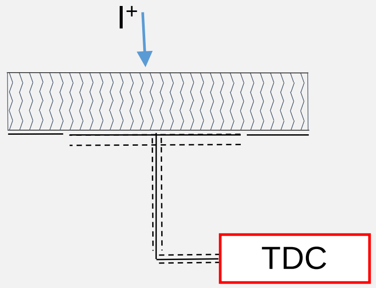
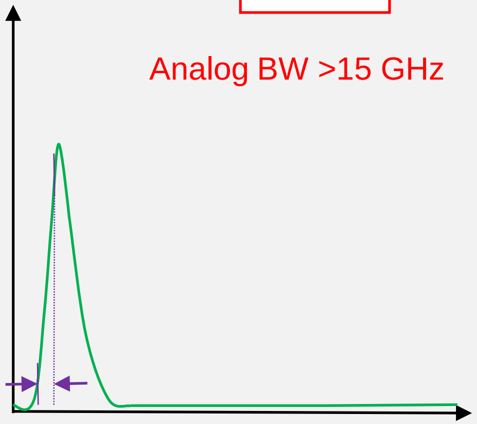
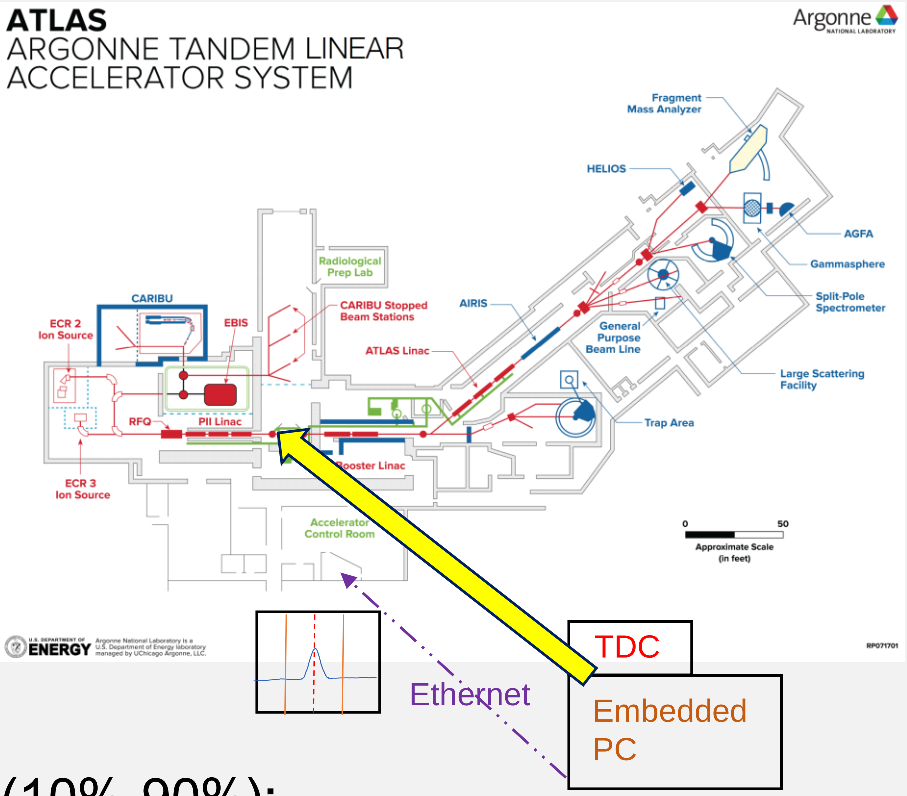
Proposed 3dMCP Detector

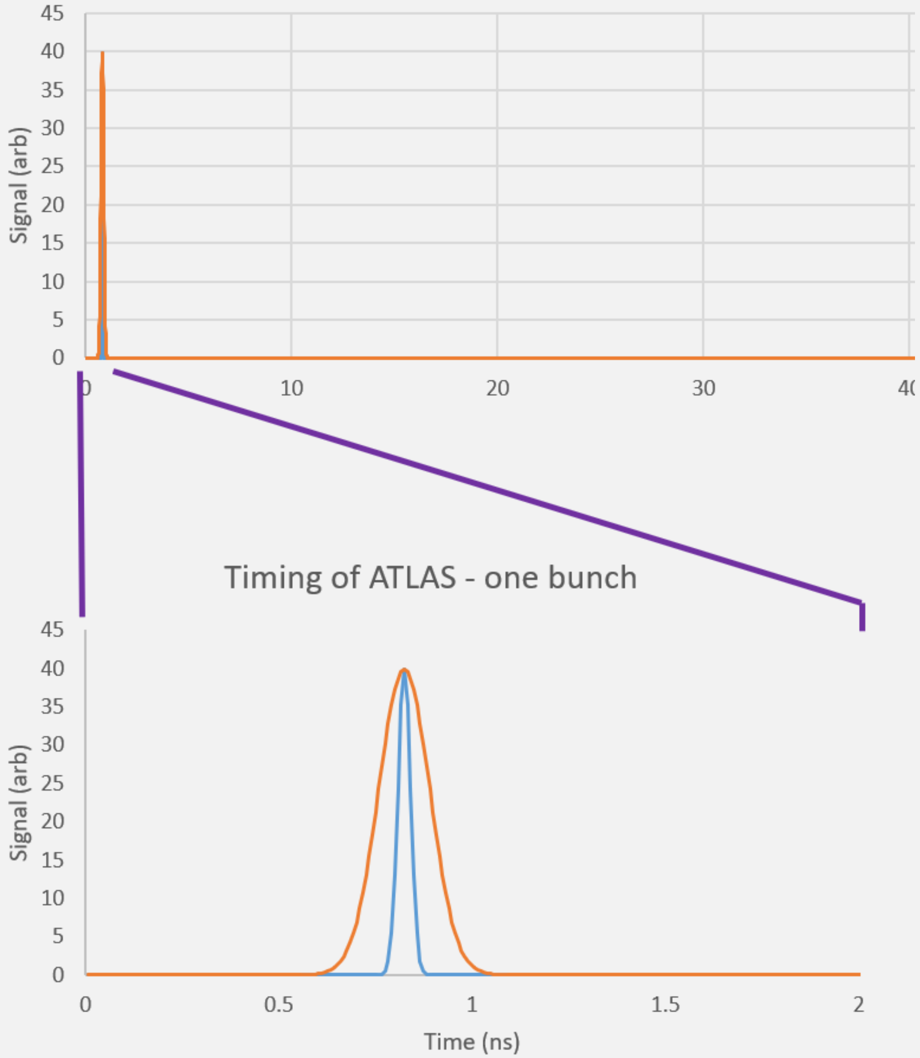


Analog BW >15 GHz



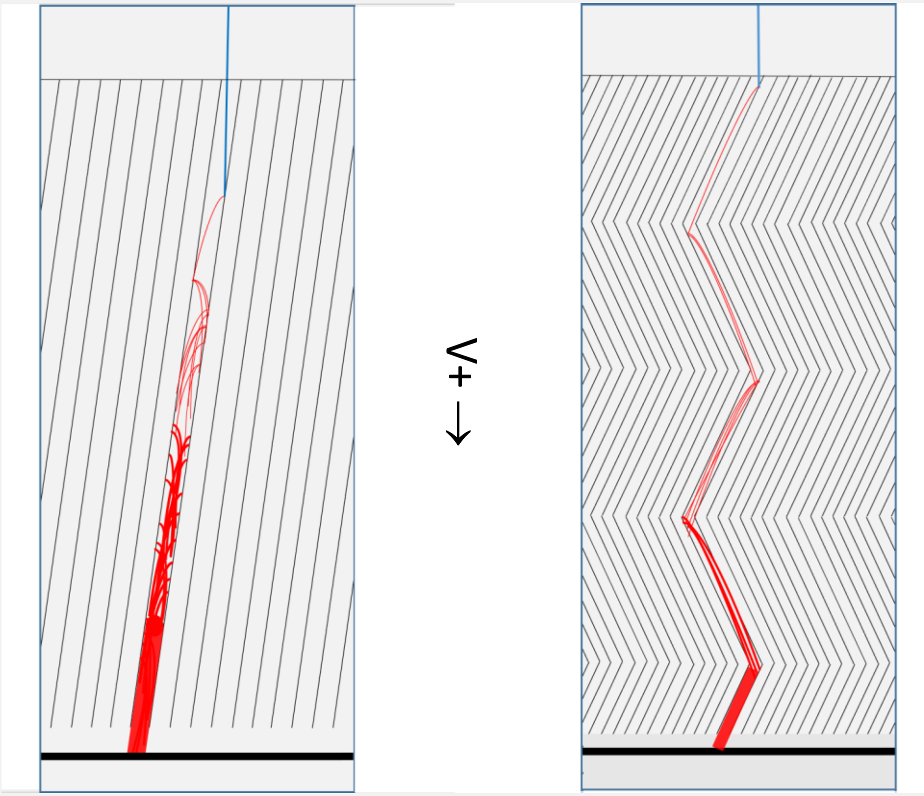
<100 ps rising edge (10%-90%);
<12 ps timing resolution





Z-channels concept

By controlling the landing points and allowing for refocusing, the transit time spread (TTS) can be reduced and the pulse-height distribution narrowed.

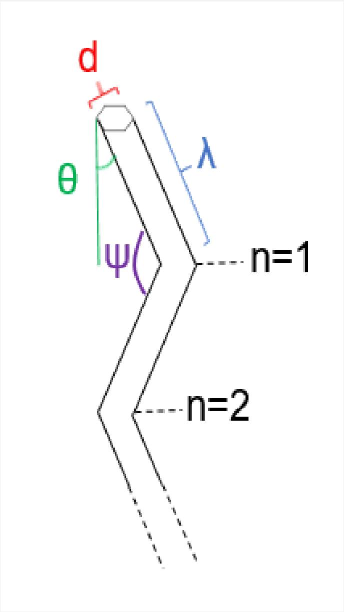


Traditional MCP

~400 ps risetime

Z-channel MCP

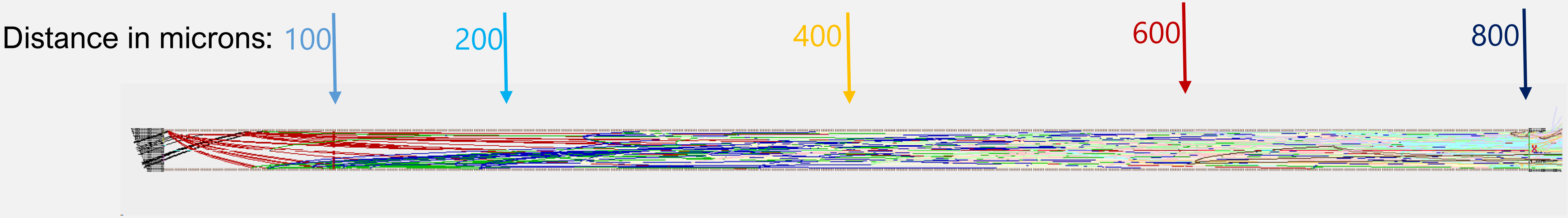
~100 ps risetime

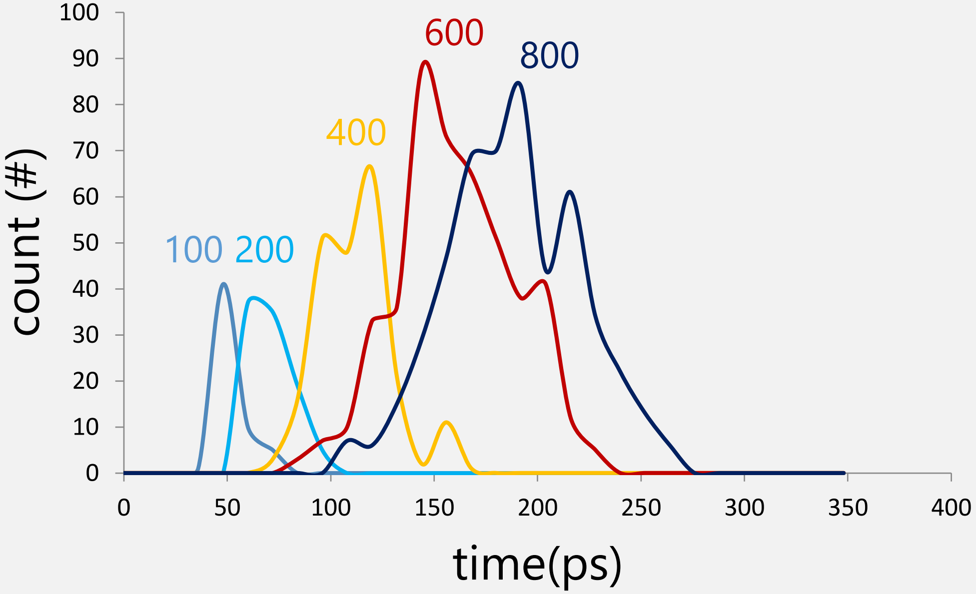


Geometry

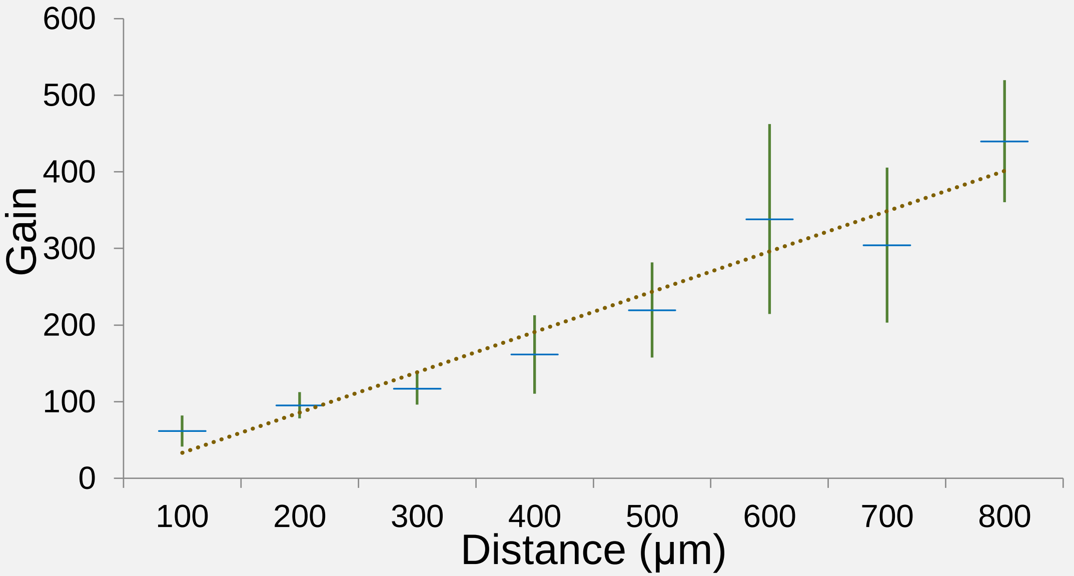
SIMION – commercial nonrelativistic Poisson EM field solver. We built a model for MCPs:

Evolving e- cloud propagating through one channel





Time spread increasing in straight channel as expected



Gain is developing linearly with pore length (not saturated)

- 22.5 degree ok for 'sweet spot' voltage 200 V/stage

Additive MCP parameters requiring control or accounting:

Structural:
- Pore size (d)
- Pore spacing / wall thickness
- Pore shape (square, circular, hex)
- Bias angle(s) (θ)
- Box (tile) shape
- MCP shape
- MCP size
- Number of layers (n)
- Length of a layer (λ)

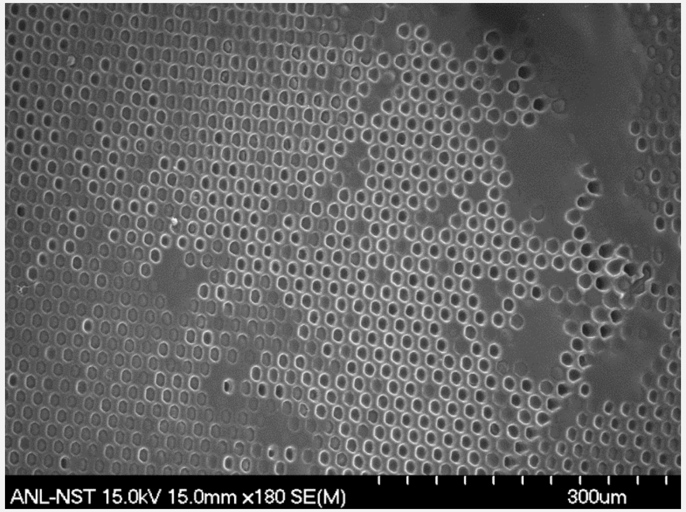
Photoresist:
- Polymer base
- Photoinitator concentration
- Quencher concentration
- Ormocer concentration

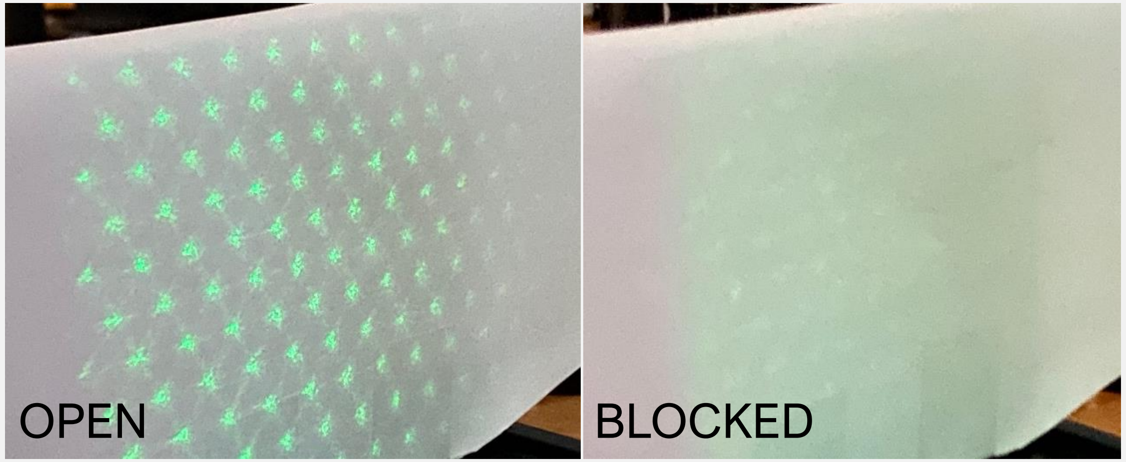
Handling:
- Time in developer
- Time in solvent
- Mechanical separation from slide
- Time in Cure
- Intensity of Cure
- Heating temperature
- Heating atmosphere
- Heating pressure
- Heating time
- Unusual events

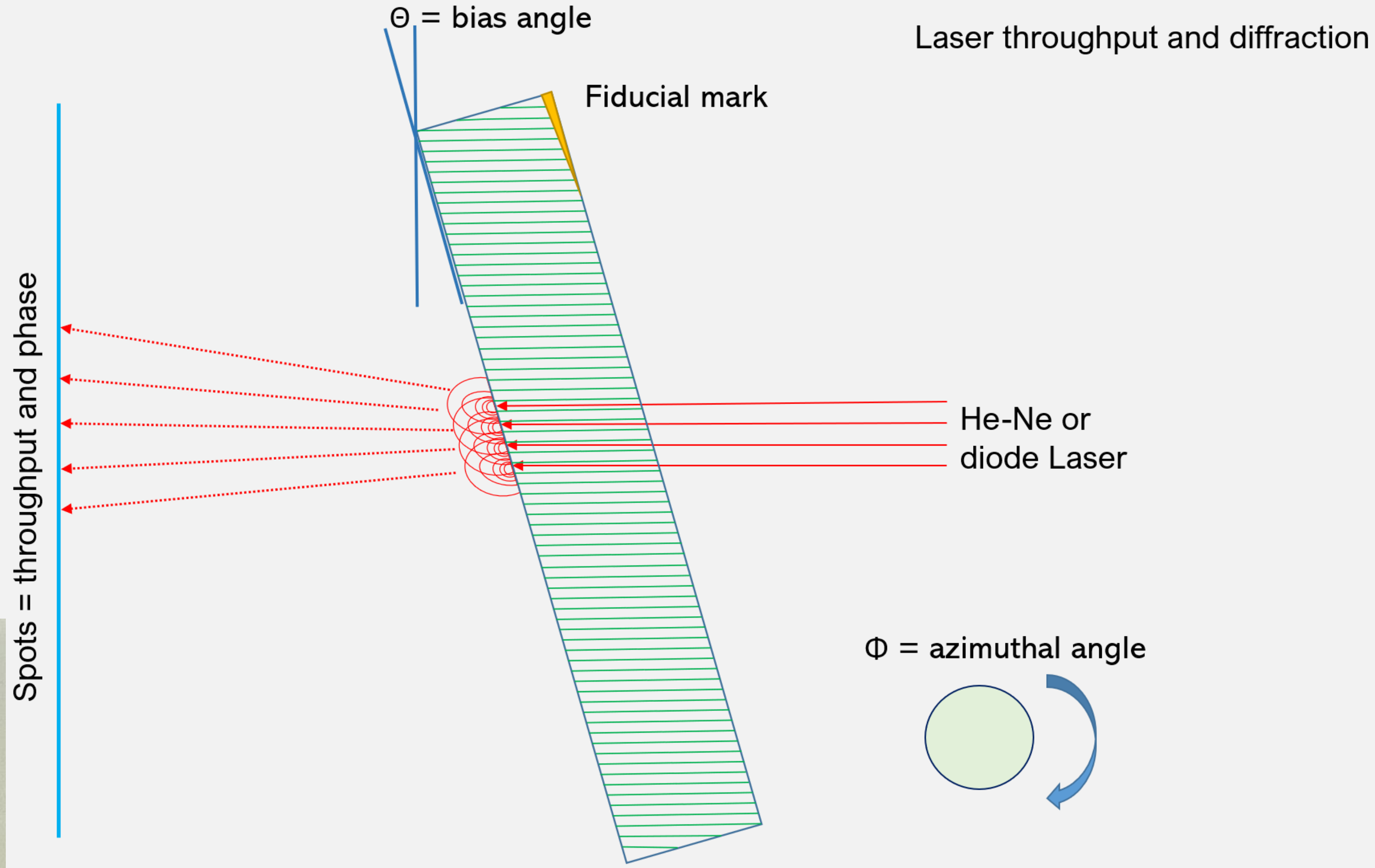
Functionalization:
- Electrode material
- Sputter or evaporation angle
- Vacuum level
- ALD resistive layer composition target
- Deposition conditions
- ALD SEE layer composition target

MANY CHALLENGES!

BLOCKAGE. Can be checked by flow, laser diffraction, SEM and optical microscopy. [we choose to do these things…]





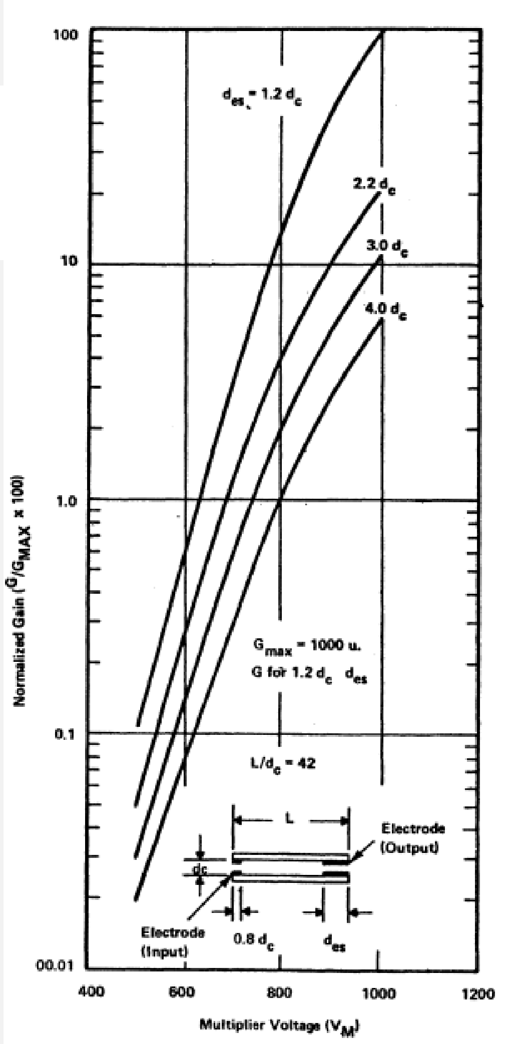


ENDSPOILING: electrodes must be formed at each side of the MCP and can "spoil" the gain if coated too far into the channels. 4 pore diameters = factor of 30 loss.

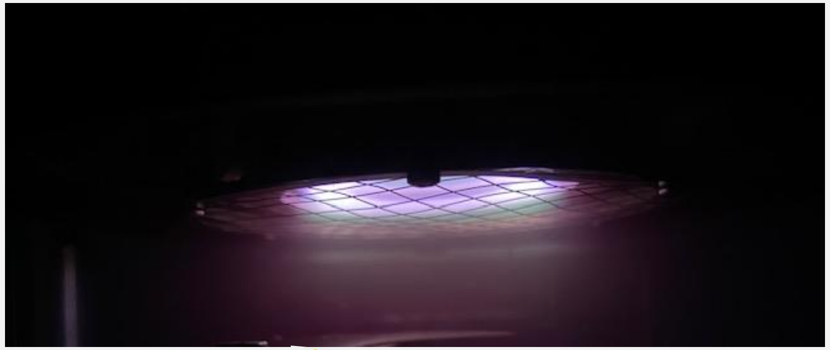
MICROCHANNEL PLATE IMAGING DETECTORS

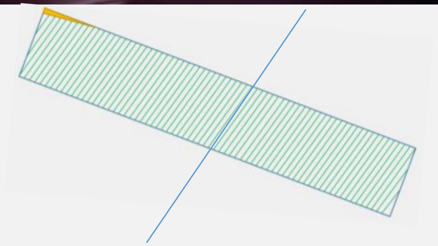
Dominic J. Ruggieri
Microchannel Plate Operation
Varian Associates
Palo Alto, California

IEEE Trans Nucl. Sci. **19** (3) 74-84 1972



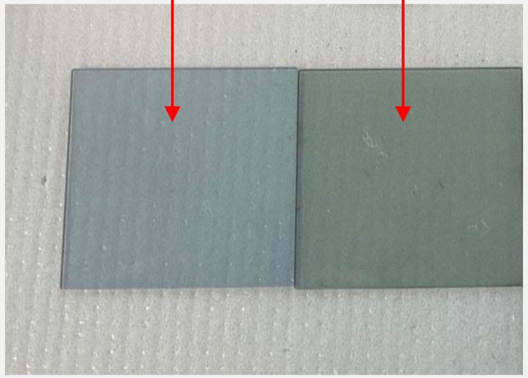
Magnetron sputter deposition of Gold or Nichrome front/back electrodes – tilt angle controls endspoiling





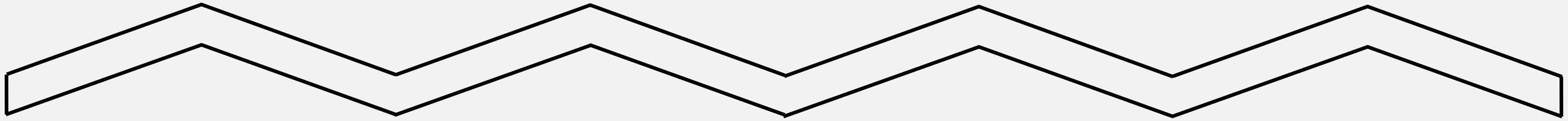
Au 100 sec
@ 20mA
>100MOhm

Au 200 sec
@ 25mA
200kOhm-cm



ALD (atomic layer deposition) builds on successes of AMD team with Chem1 (W/Al_2O_3): binary reaction sequences lead to saturated layer-by-layer growth

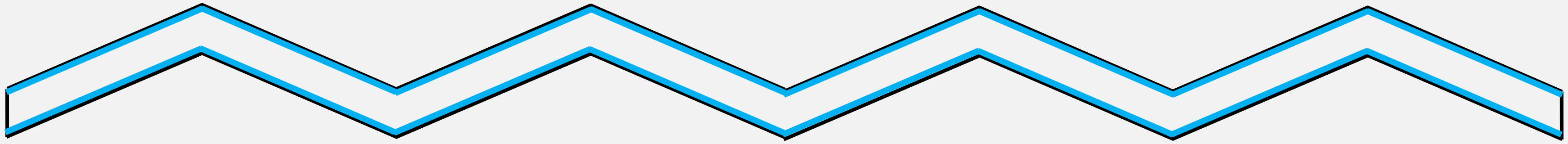
Fine control over layer thickness and composition, outstanding for uniform coverage of high aspect ratio structures for resistance, SEE



A B

$$(CH_3)_3Al_{(g)} + H_2O_{(g)} \rightarrow Al_2O_{3(s)} + CH_{4(g)}$$

Alternate saturating doses of each precursor gas: A – B – A – B – A – B etc.



Challenge: <200 °C temperatures required (plastic melts)

Plasma ALD system

A. Martinson – Argonne MSD

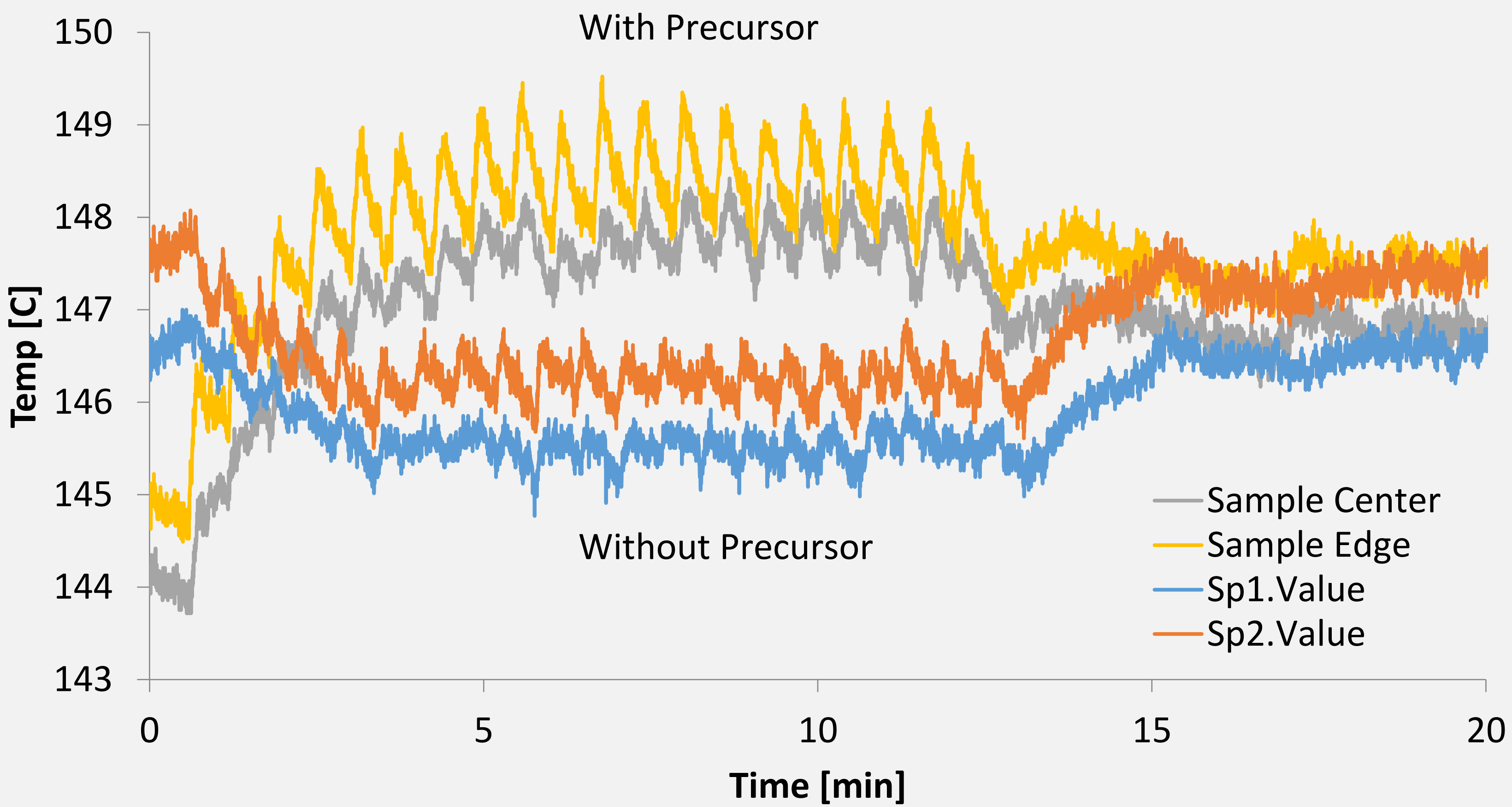
New concept being explored is ultrathin film conductive coating, which has the advantage of simplicity and positive temp coefficient. Plasma ALD approach to TiN and TiAlN etc.

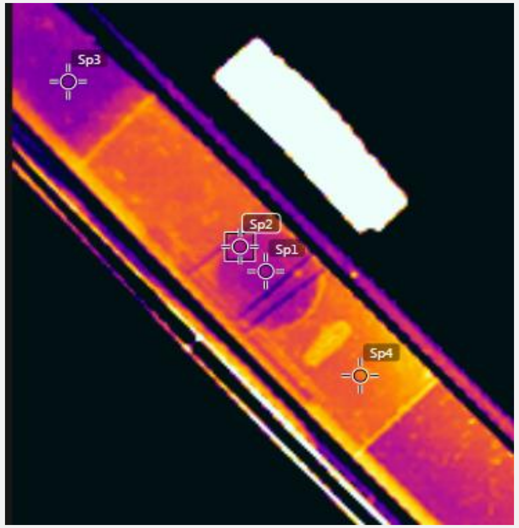
- Positive results so far with <u>both</u> ALD systems – ideal resistivity for MCP 100MΩ (power < R < gain)

EXOTHERMIC reactions, and maximum temperature for the thermoplastic is 200 °C

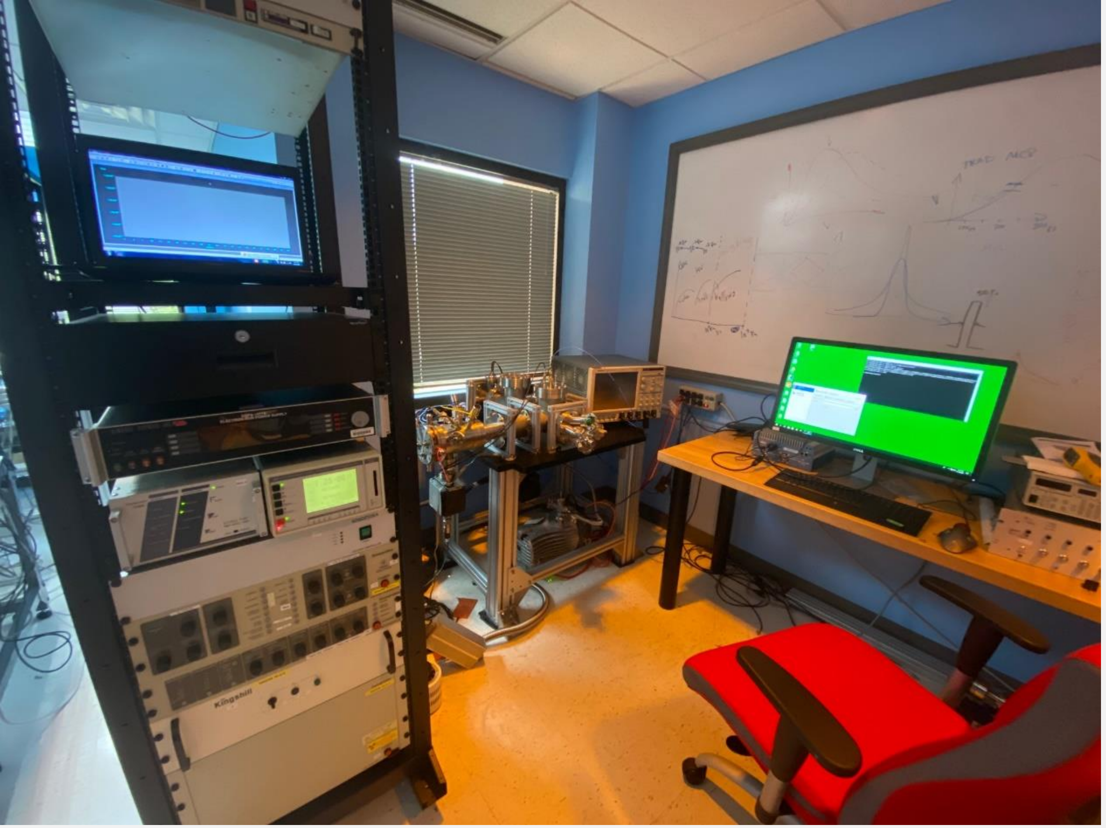
IR probe experiment

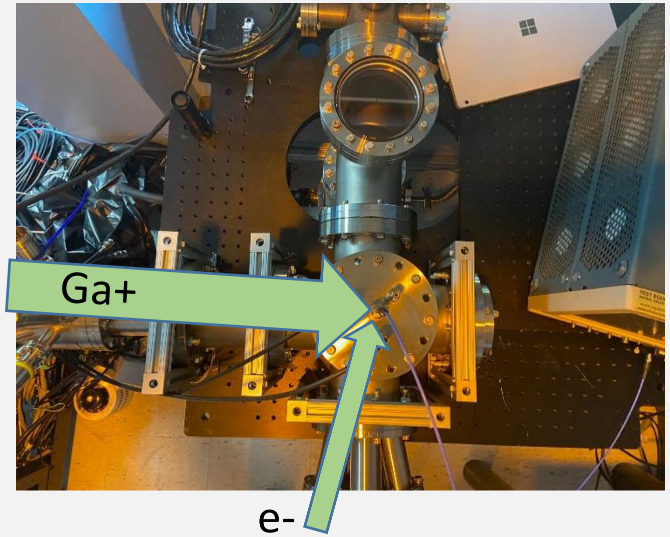
A. Bielinski, Argonne MSD





- Temperature rise is manageable





BIJOU test stand

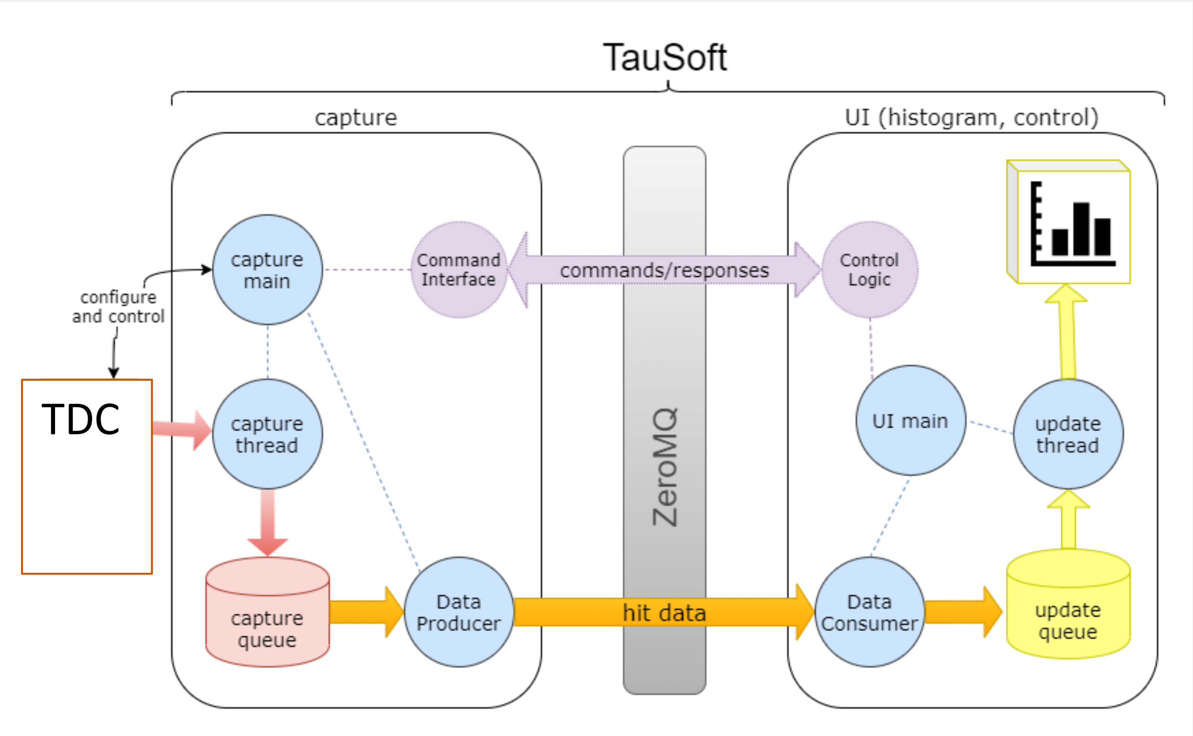
(**b**eam **i**nstrument for **j**itter **o**bservation at **u**ltrafast scales)

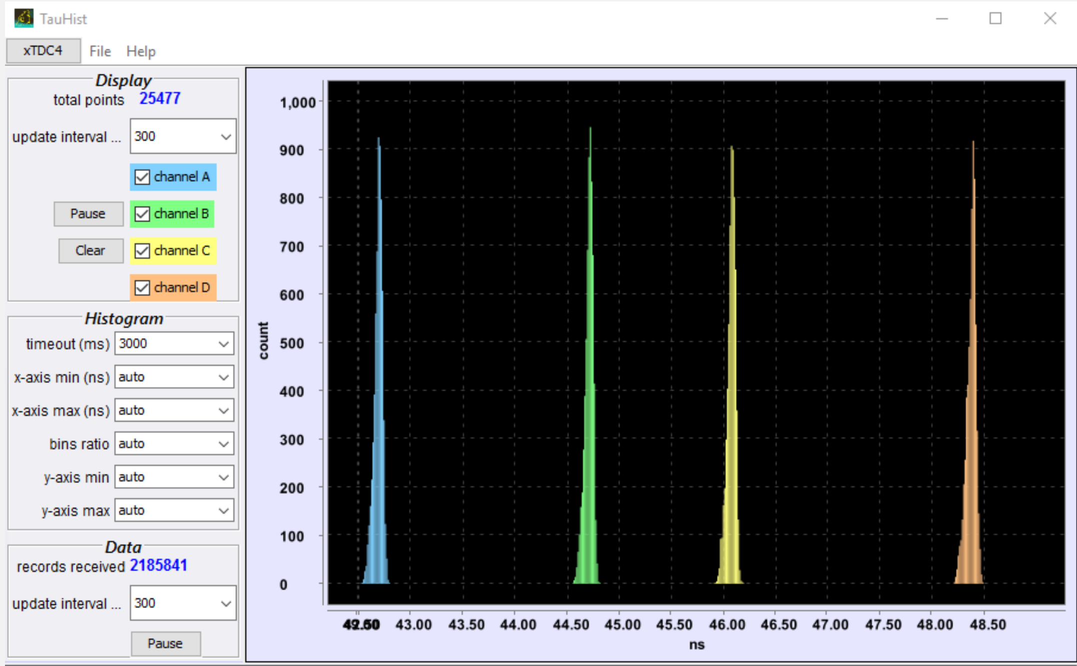
- Dry scroll, maglev turbo, ion pumped UHV system with RGA – can determine outgassing of additive MCPs (negligible so far).
- 5 keV e^- and 25 keV Ga^+ guns for primary particle beams
- Dedicated port for MCP detectors
- Several swappable MCP mounts and coupled feedthroughs
- Separate MCP storage "library"
- Vibration stabilized to <0.5μm
- High speed low noise electronics suite – 4 Gs/s 8 bit ADC for pulse height analysis, high BW oscilloscope, quiet HV power supplies etc.
- Hosts tests of MCPs, detector assemblies and Tauboxes prior to deployment to ATLAS.

Embedded computers (Tauboxes) use TDCs and custom software.

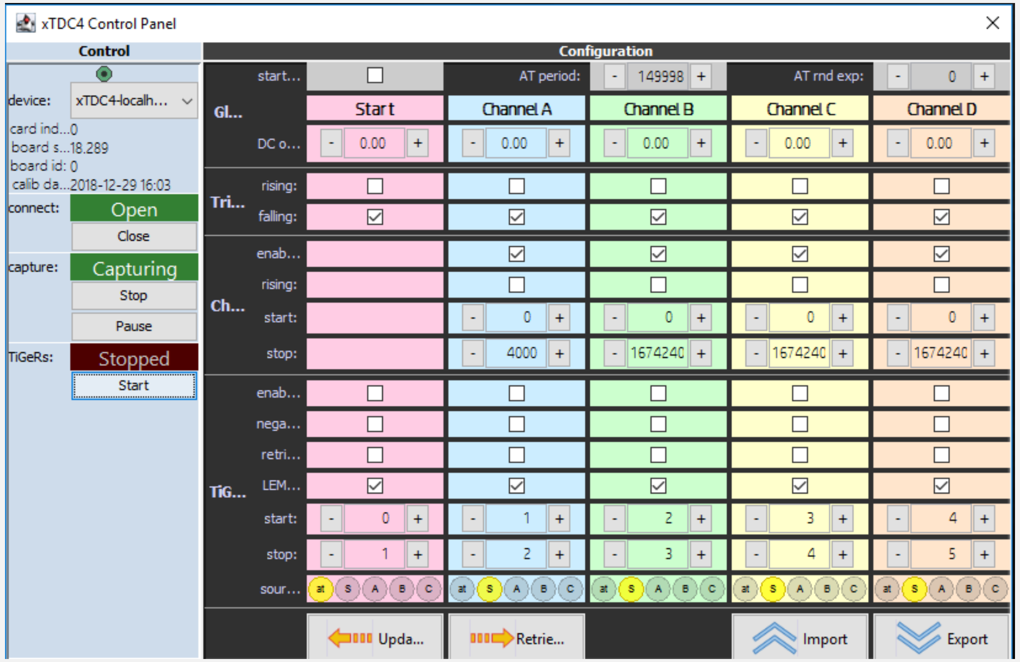
- distance from detector to electronics minimized
- local processing of MHz countrates to displayed histograms
- remote interface via ethernet – real time updates
- rack mountable, low vibration, rugged, flexible power source
- can be paired for particle ID, vernier measurements on bunch trains, etc.
- Windows 10 LTSC

Software has been engineered carefully to be flexible extendable and useful to machine operators





A. Moore – Robot Nose



TauSoft data flow:

Capture (9,836 lines of C++ code) takes TDC data to ZeroMQ messaging queue.

UI (10,931 lines of Java code) retrieves this data and updates a histogram of timing data in near real-time; user control and configuration of the TDC remotely.

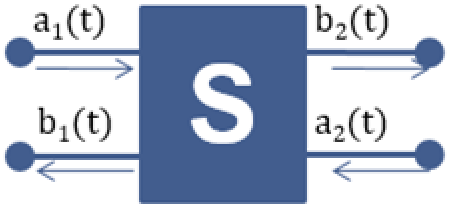
Fast pulses from the Z-MCP must be preserved:

connectors and cables must be chosen carefully for

>15 GHz performance.

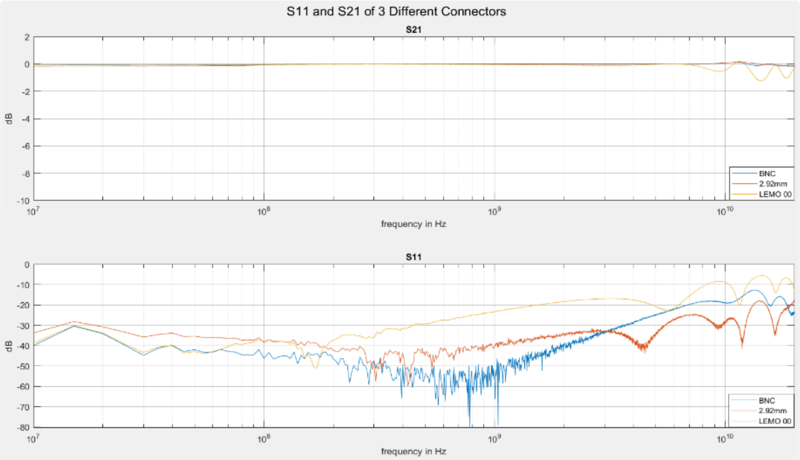
EE intern: M. Alnahhas, U Michigan, NASA Pathways Fellow

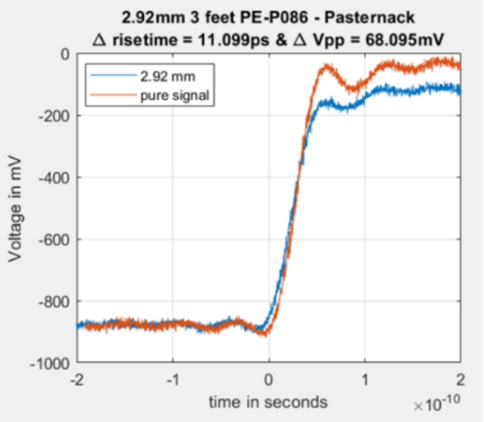
Cable type	Connector type(s)	Length (m)	10%-90% Risetime (ps)
RG316 L00sa-316ds-3 W2021	SMA – LEMO 00	0.92	60.0
4801 Keithley	BNC	1.2	51.1
RG58C/U - Pasternack	SMA	0.92	48.7
PE-P086 - Pasternack	2.92 mm	0.92	36.6
Adaptor only	2.92mm M-M	0.01	32.5

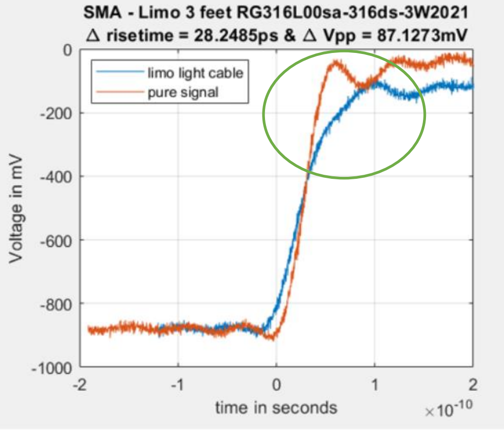


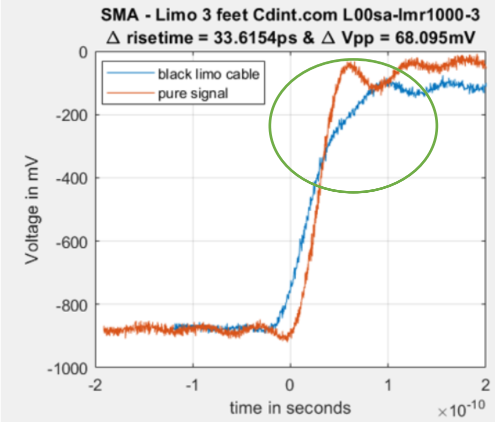
$$b_1(t) = S_{11}a_1(t) + S_{12}a_2(t)$$
$$b_2(t) = S_{21}a_1(t) + S_{22}a_2(t)$$

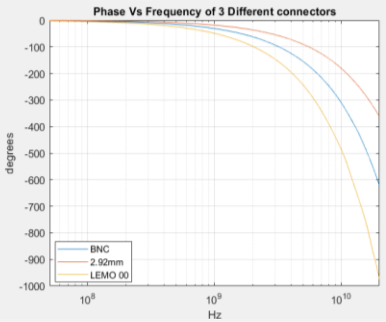
$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

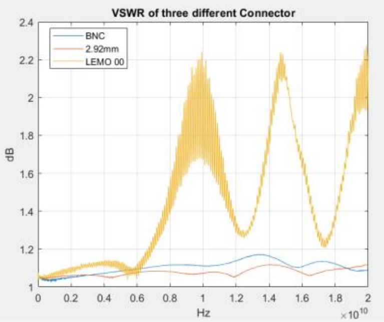


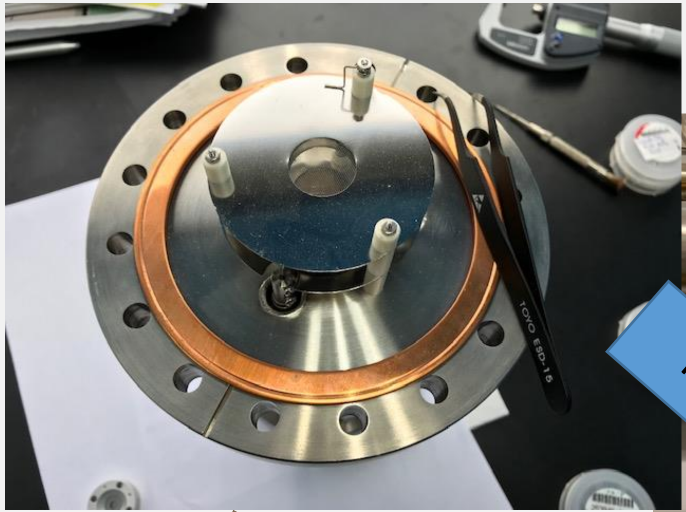


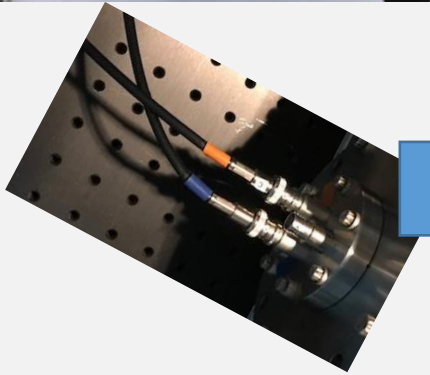


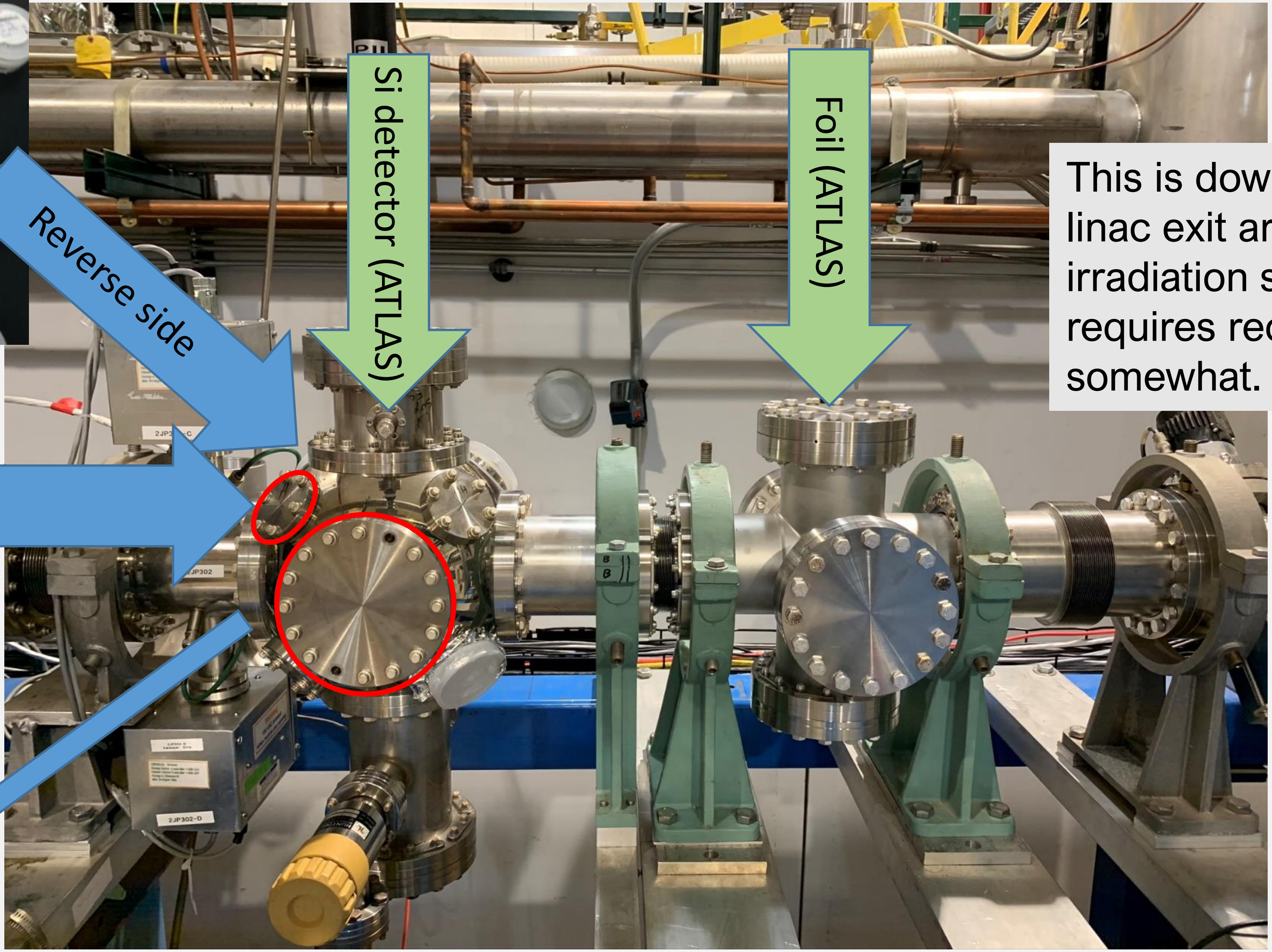












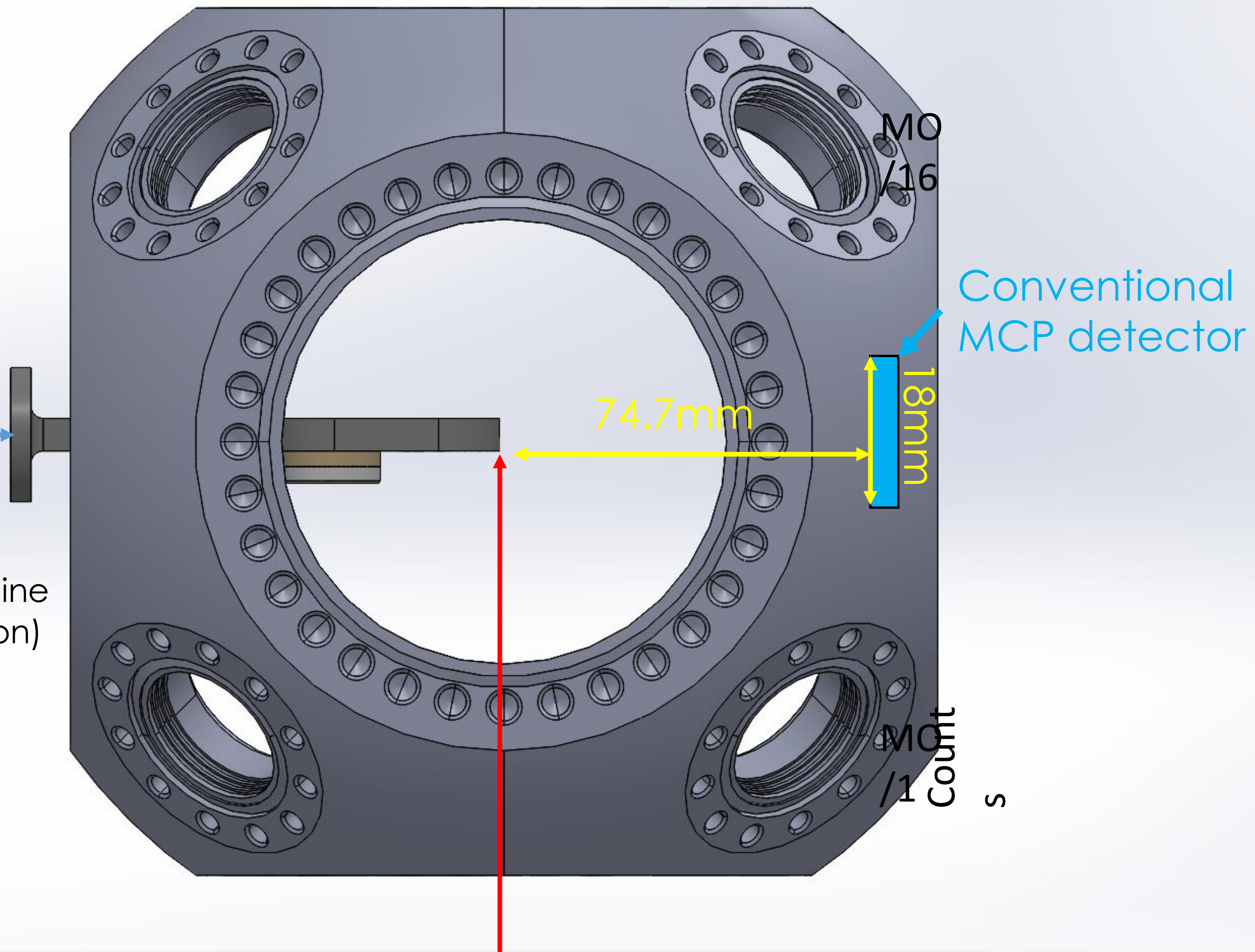
This is downstream of PII linac exit area, new irradiation station requires reconfiguring somewhat.

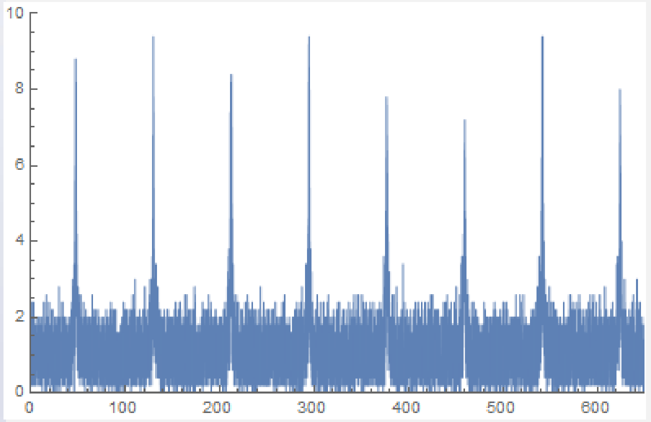
Cabling: bias supplies, timing and PC

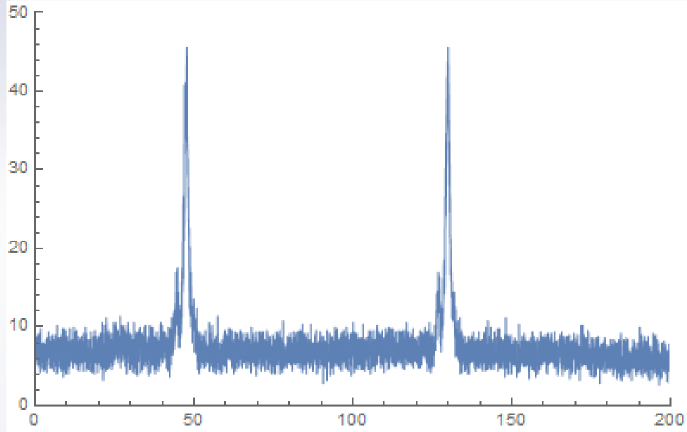
TOP VIEW Geometry Detail

75mm travel

Z-MCP
(Front is Offset 4mm from centerline in upstream direction)







ATLAS beam from PII exit
$^{40}Ar^{8+}$ 5-60 pA current
(0.29,0.79,1.34 MeV/z)

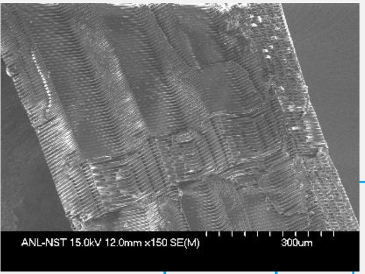
Plan for fall:

- Install 2nd generation test station
- Take opportunistic beam at ATLAS (M. Hendricks “beam du jour”) - compile a suite of wide ranging data (isotope, charge state, weak, etc.)
- Additive MCPs inherently disposable; test to failure or contamination ok

Plan for remainder of Phase II:

- Feedback into modifications if needed for geometry
- Feedback on software esp User Interface
- Paired installation and synchronous measurement

Technology Readiness



		6σ	Silicon valley
	- TRL 1 – Basic principles observed		CONCEPT
	- TRL 2 – Technology concept formulated		
Ph1 →	- TRL 3 – Experimental proof of concept	1	MVP
	- TRL 4 – Technology validated in lab	30%	
Oct →	- TRL 5 – Technology validated in relevant environment	70%	PROTOTYPE
End →	- TRL 6 – Technology demonstrated in relevant environment (handoff)	93%	
	- TRL 7 – System prototype demonstration in an operational environment	99%	DEVELOPMENT
	- TRL 8 – System complete and qualified	99.9%	
	- TRL 9 – Actual system proven in operational environment	99.99%+	PRODUCTION

Coda: small, robust, fast detectors and readouts will lead to smaller, cheaper TOF mass spectrometers.

For given mass resolution needed flight path $\propto \Delta t$;

linear	0.5 m	$\rightarrow$ 10 cm
mass	150kg	$\rightarrow$ 10 kg or less!
cost to manufacture	$$$	$\rightarrow$ $

- startup like ours can punch above our 'weight class' and contribute to NP goals, while finding a broad market

Ionwerks Inc. System 7 Imaging Ion Mobility Mass Spec

IP allowed or in progress on printed MCP + ALD:

```
US 7,709,056 B ALD transparent conducting oxides
US 8,741,386 B ALD quarternary chalcogenides
US 9,139,905 B2; Sept 15, 2015; Micro-channel plate detector; covers ALD to
       functionalize glass
US 2019/0318896 A1; Oct 17, 2019; Any 3D printed plate
US 2020/0103638 A1; Apr 2, 2020; All Reflective Dip Mic Objective
US 10,403,464 B2; Sep 2020 Printed MCP and Use
```

PROJECT TEAM

Additive Manufacturing of Detectors for Heavy Ion Accelerators (DE-SC0019535) SBIR/STTR Exchange Meeting 2021

Robot Nose
- Jerome Moore (Jerome@robotnose.net)
- Maram Alnahhas
- Andy Moore

Argonne:

(HEP) Robert G. Wagner

(MSD) Ashley Bielinski
- Alex Martinson (Technical Point of Contact)
- Prabhjot Menon (also Moriane Valley CC)
- Michael Pellin (also U of Chicago)

(AMD) Jeff Elam
- Anil Mane

(PHY) Jerry Nolen
- Clayton Dickerson
- Richard Pardo
- ATLAS operators and staff

Thanks to the DOE Office of Nuclear Physics for funding!
Michelle Shinn, Manouchehr Farkhondeh

DOE SBIR office: Manny Oliver, Claudia Cantoni, Carl Hebron…

Argonne Site Office (DOE): Walter Strzepka (contract admin)

Argonne Nat'l Lab: Jolene O'Bryan (financial admin)