Novel Position-Sensitive Particle Tracking Gas Detector

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Other Collaborating Institutions:

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Overall Program Goal

Development of a novel* *<u>ultrathin</u>*, position-sensitive, *micropattern* gas detector for *<u>single particle tracking</u>* of heavy ions with fast timing and with *low* to *at least medium* rate capability.

Plasma Panel Sensor (PPS)

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- **The PPS, conceived as a high-performance, low-cost, particle detector, based on *plasma-TV display* panel technology.**

- **Each pixel operates like an independent *micro-Geiger counter*, activated by *direct* ionization in the gas, or *indirect* ionization via a conversion layer.**

- **Both "*open*-cell" and "*closed*-cell" PPS devices based on *direct* ionization are the primary focus of our research efforts.**

- **Proposed *ultrathin*-PPS is based on a "*grid-support*" structure, which is a *hybrid* between the "*open*" and "*closed*" cell configurations.**

PPS Detector Goals

- ***UltraThin*, ultra-low-mass, long life, inexpensive**
  - proposed: **27 µm Glass** (**6.6 mg/cm^2**) substrates
  - new added goal/task: **8 µm Mica** (**2.2 mg/cm^2**) substrates
- **Design to operate in both *vacuum* & *ambient pressure* environment**
- **Hermetically sealed & rad-hard material structure**
  - no gas flow system & robust *internal* / *external* construction
- **Performance**
  - Pixel efficiency: ≈ **100%**
  - Time resolution: ≈ **1 ns**
  - Position resolution: ≤ **0.5 mm**
  - Response range: ≈ **1 Hz/cm^2** to *at least* **10^5 Hz/cm^2**
  - Internal gas pressure operational range: **≤ 100 Torr**
- **Primary Applications – *Particle Tracking & Active Pixel Beam Monitors***
  - Research: Nuclear physics / high energy physics
  - Medical: Particle beam therapy (NIH-National Cancer Institute)

Sources Successfully Detected

Cosmic-Ray Muons (≈ 4 GeV at sea-level)

Muon Beam: 180 GeV range (at **H8-CERN** for ***high energy physics)***

Beta Particles (max. energy): ^{137}Cs (1.2 MeV), ^{90}Sr (2.3 MeV), ^{106}Ru (3.5 MeV)

Proton Beam: 226 MeV (***proton beam cancer therapy & proton-CT***)

Neutrons: Thermal neutrons (***neutron scattering & homeland security***)

Gamma-Rays: ^{60}Co (1.2 MeV), ^{137}Cs (662 keV), [***can be gamma "blind"***]

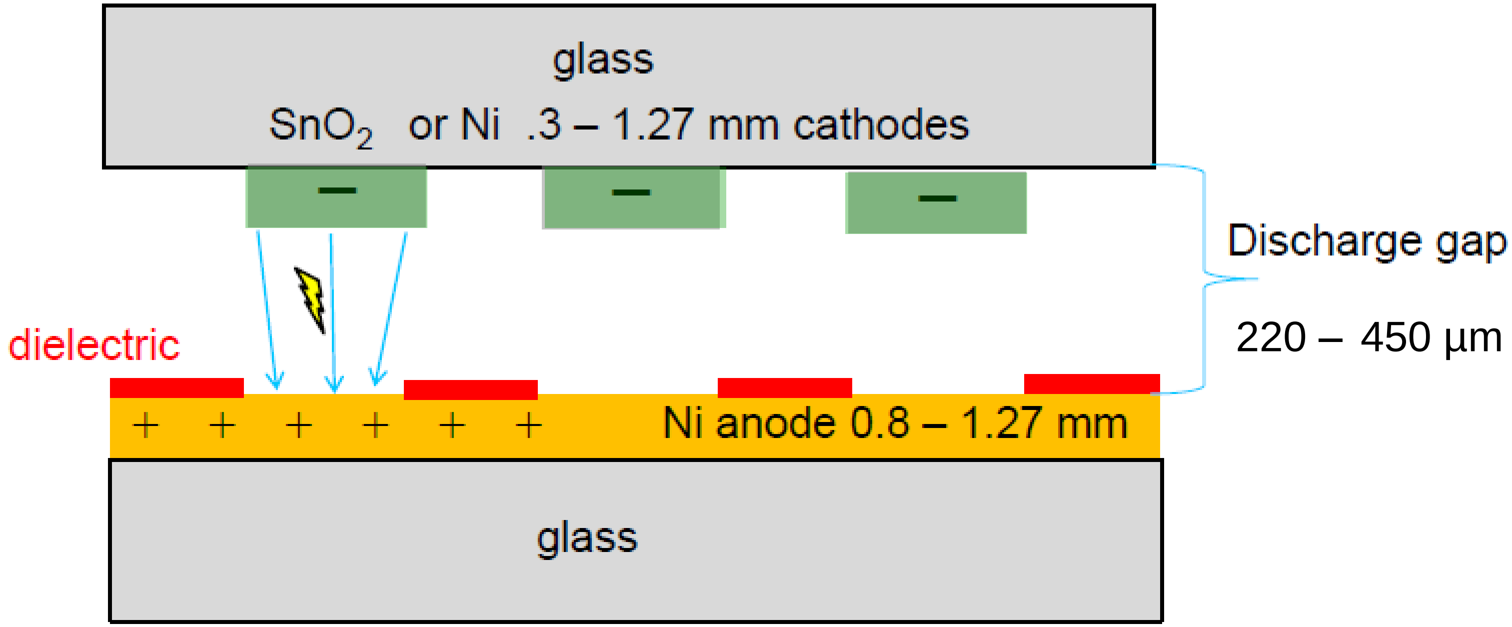
UV-Photons: "Black UV-lamp" with emission at 366 nm

Open-Cell PPS

(DOE-NP & NIH-NCI)

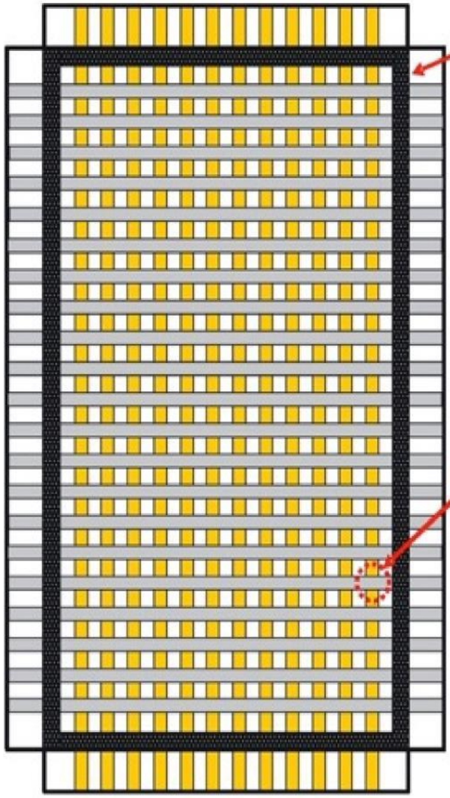
"*Open*-Cell" Commercial Plasma Panel

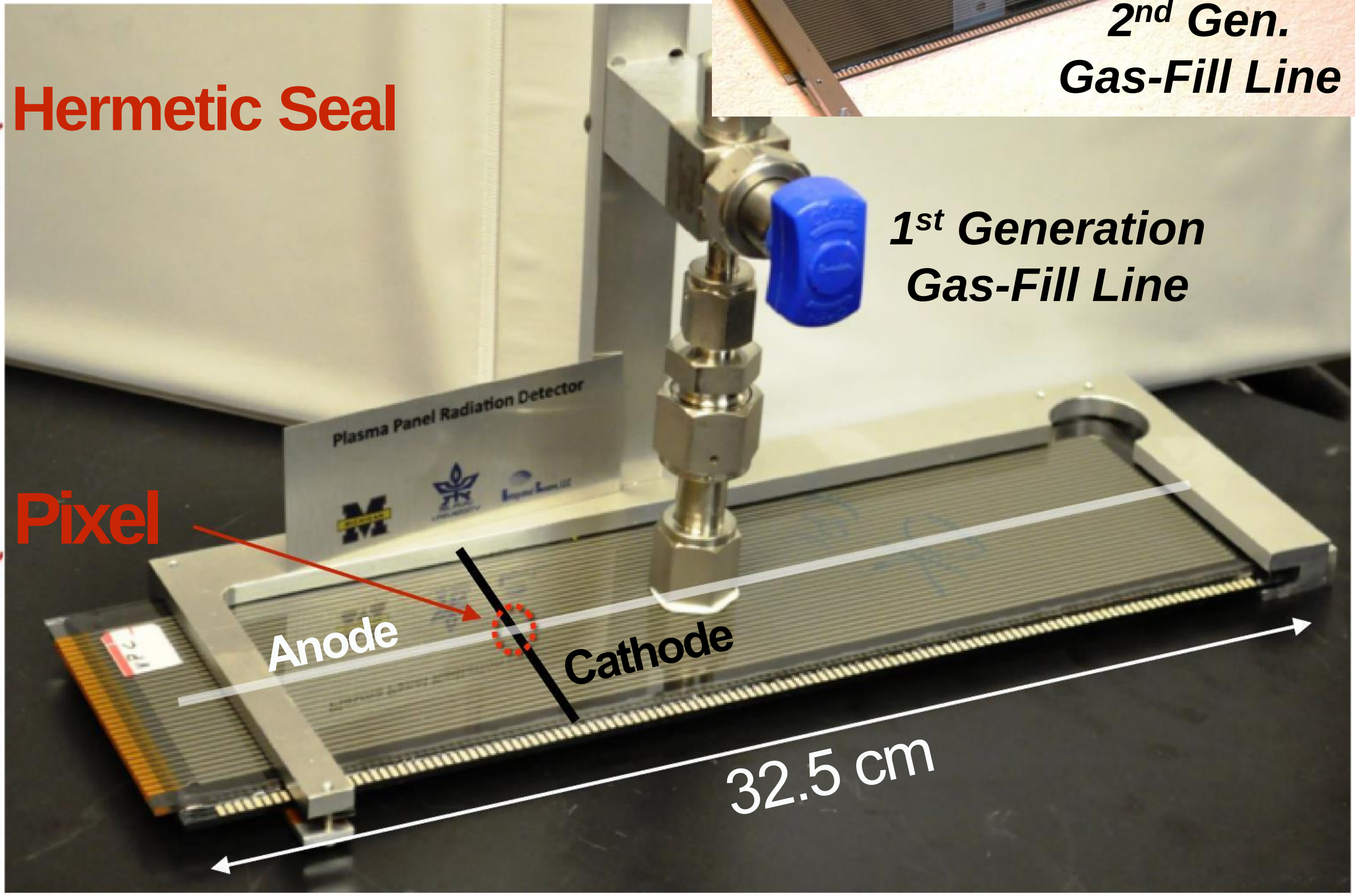
- Columnar Discharge (**CD**) – Pixels at intersections of orthogonal electrode array
- Electrode sizes and pitch vary between different panels

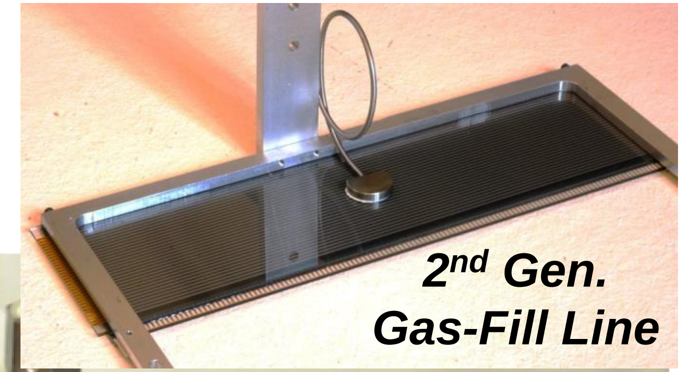


1st Gen. "Open-Cell" PPS Structure

2.54 mm Electrode Pitch



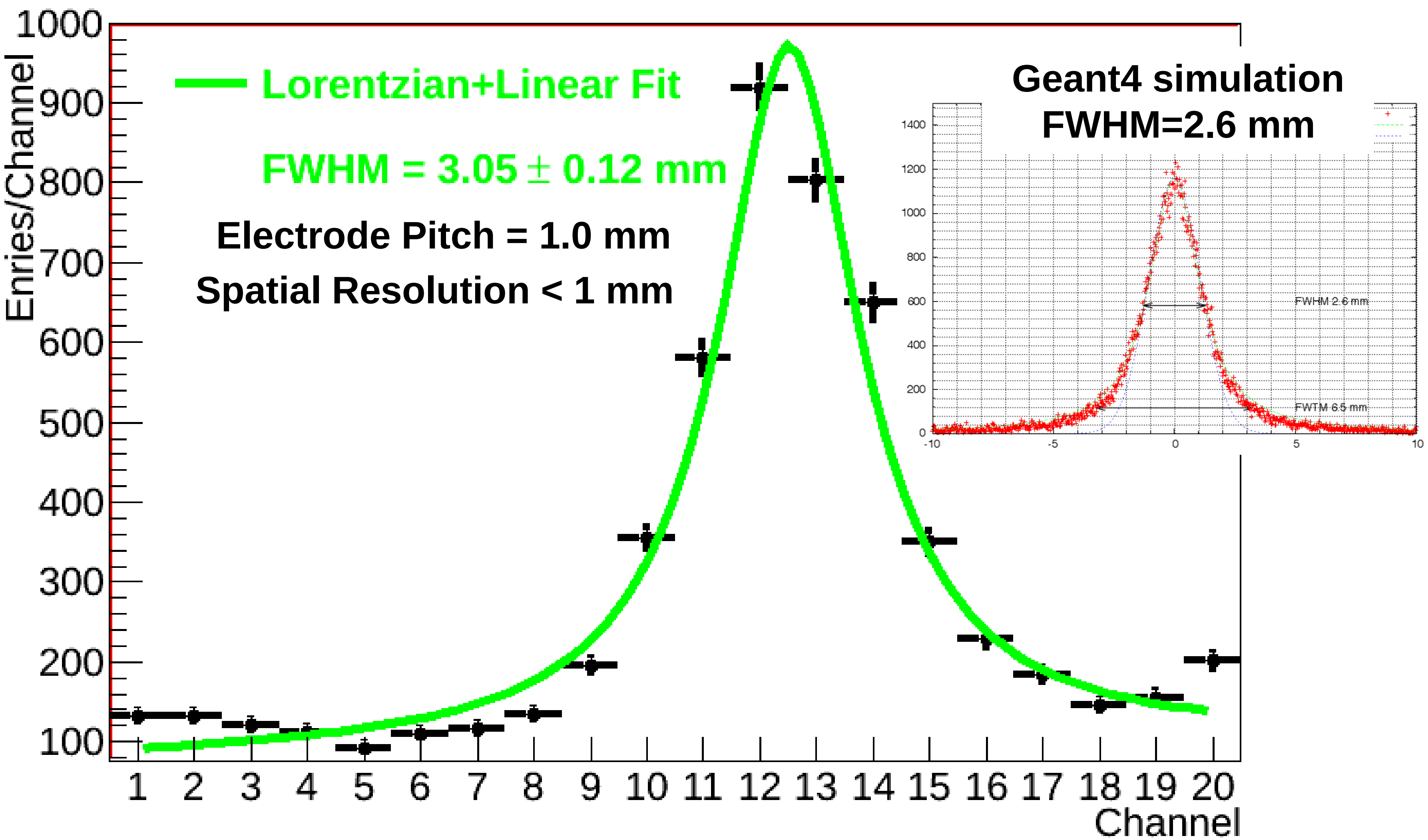




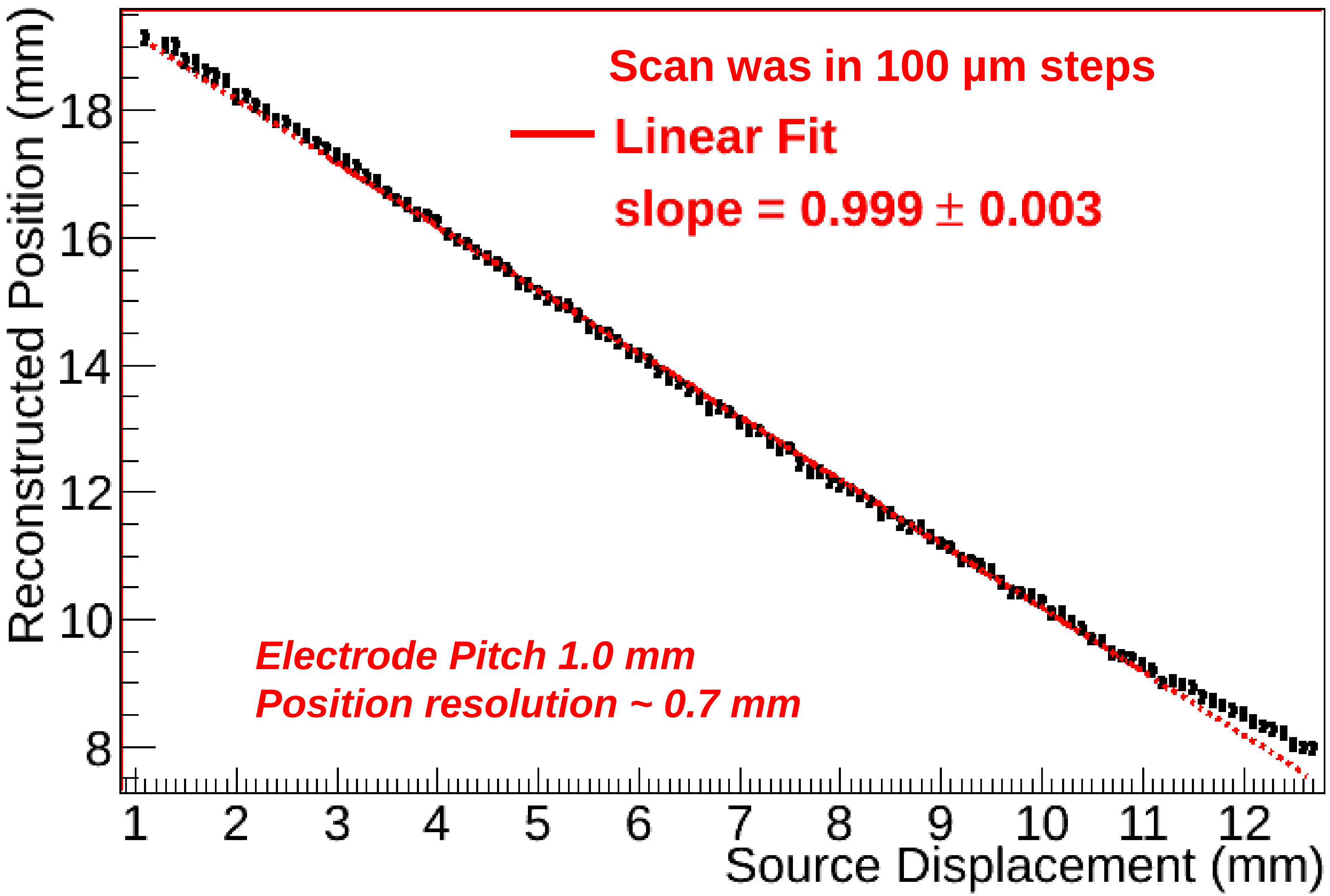
Source Moved in 0.1 mm Increments

(1 mm pitch panel)

Collimated β–Source Measurement (^{106}Ru)

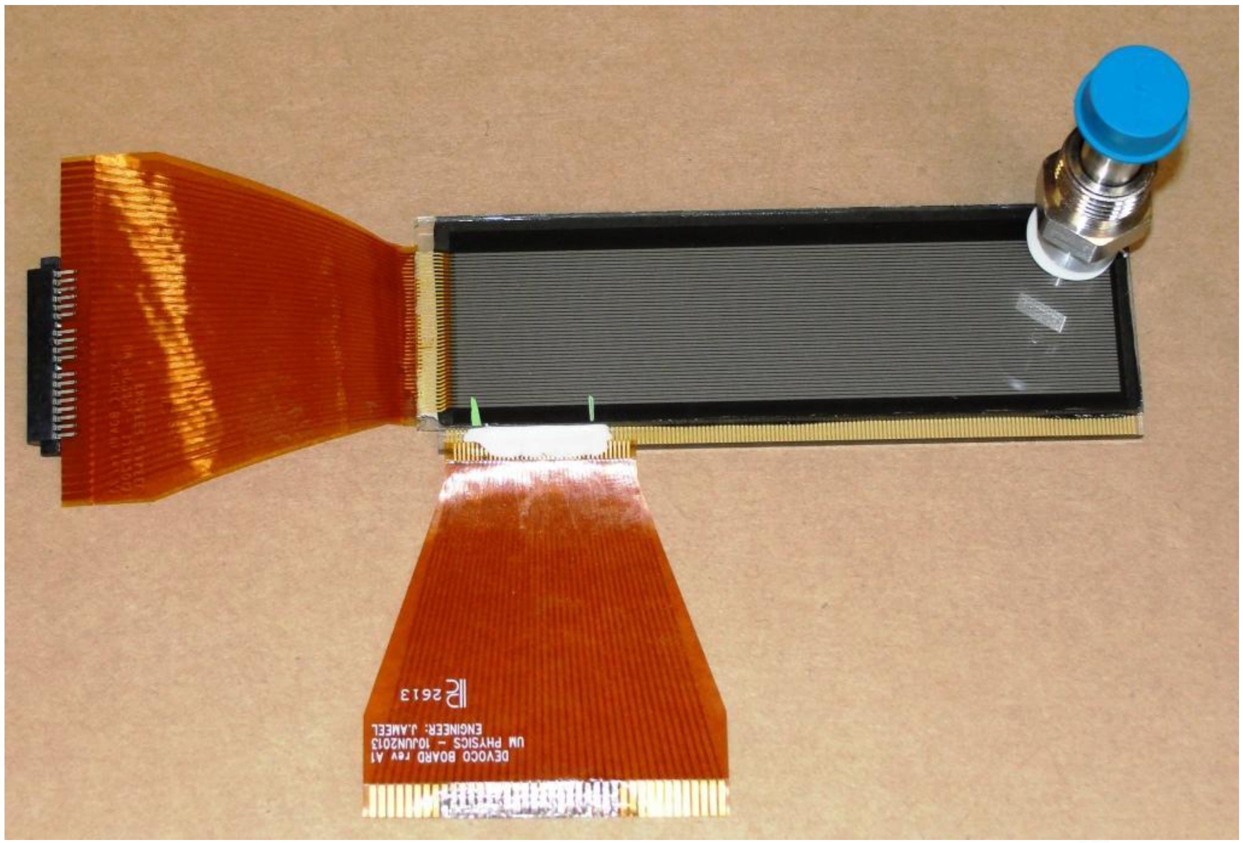


Collimated β–Source Position Scan (^{106}Ru)



2nd Gen. "Open-Cell" PPS Structure

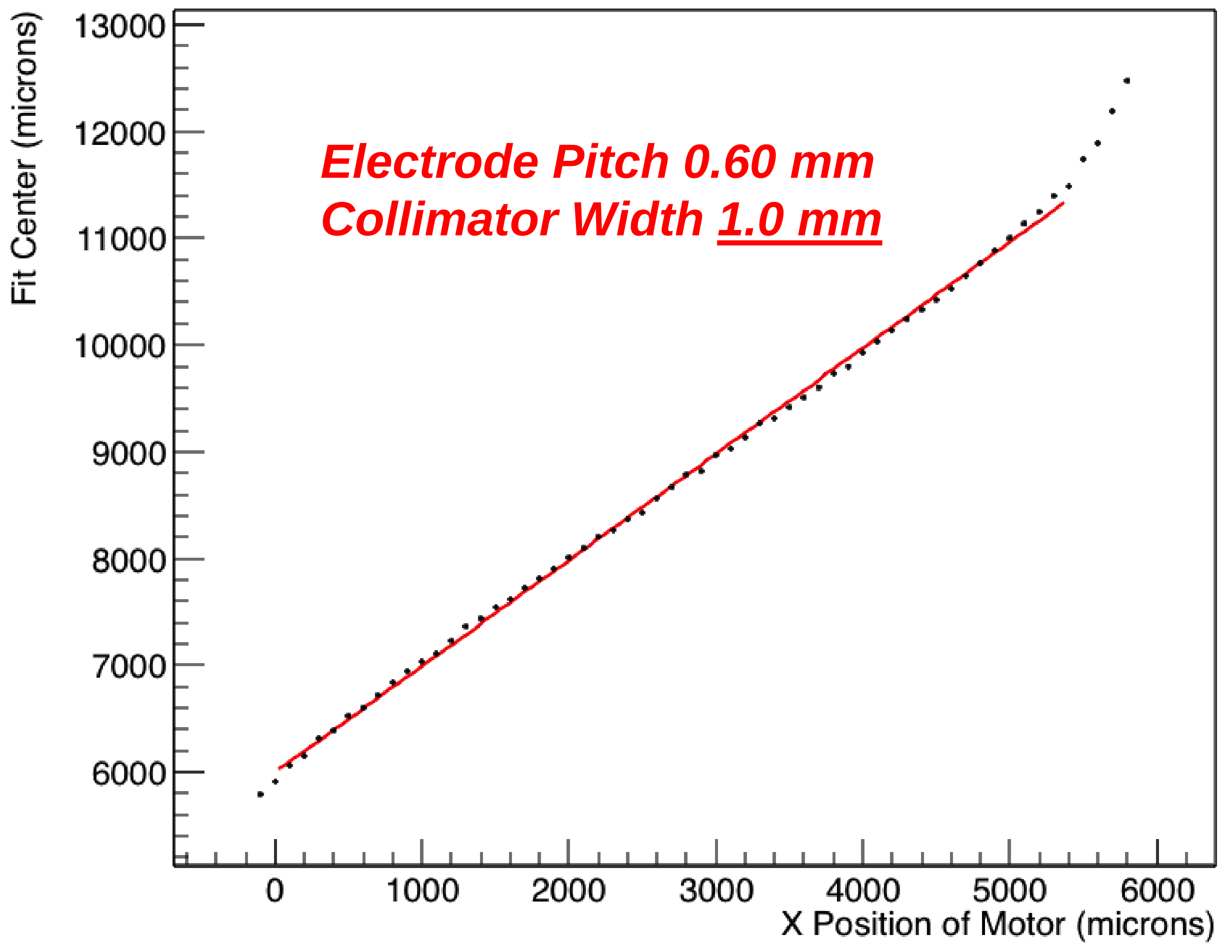
0.60 mm Electrode Pitch



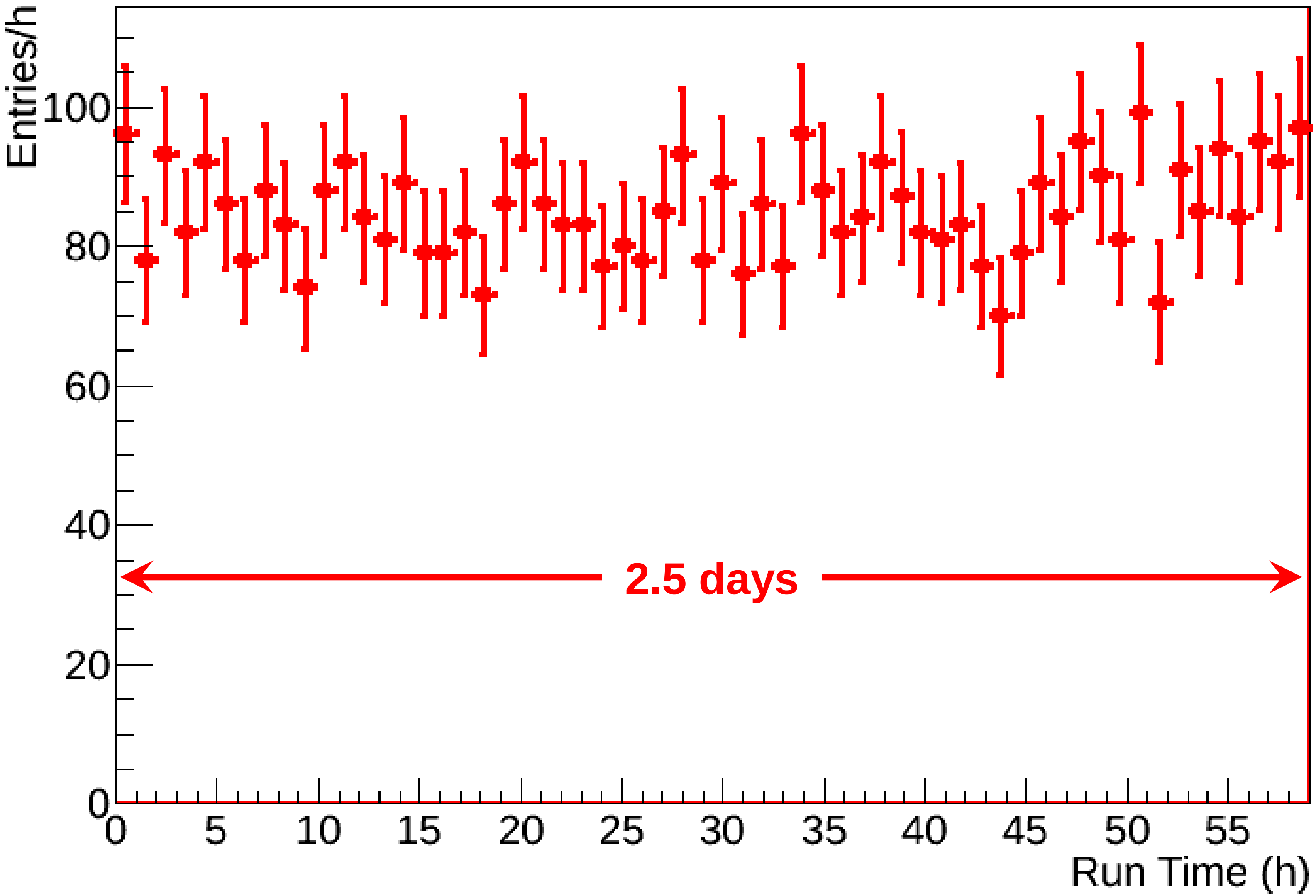
Modified commercial PDP with 1.7 mm thick glass substrates as PPS test panel, 3.9" diagonal, 40 x 160 electrode matrix

Collimated β–Source Position Scan (^{90}Sr)

*Scan of the **0.60 mm electrode pitch** panel in **100 μm steps**. Each point is the Gaussian mean of the hit distribution. The slope is consistent with unity.*



Stability – Response to Cosmic Muons

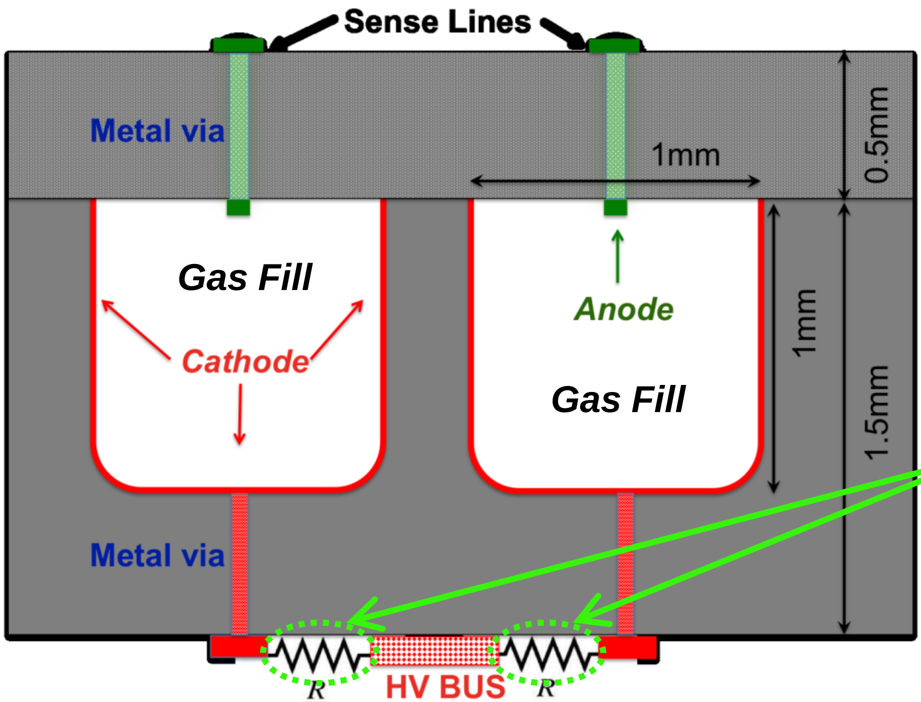


Closed-Cell PPS

(DOE-NP, DOE-HEP, NSF & BSF*)

***United States – Israel* Binational Science Foundation**

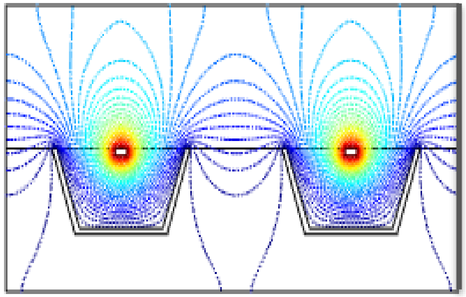
"Closed Cell" Microcavity Concept



1.0 x 1.0 x 2.0 mm
Metallized
Rectangular Cavities

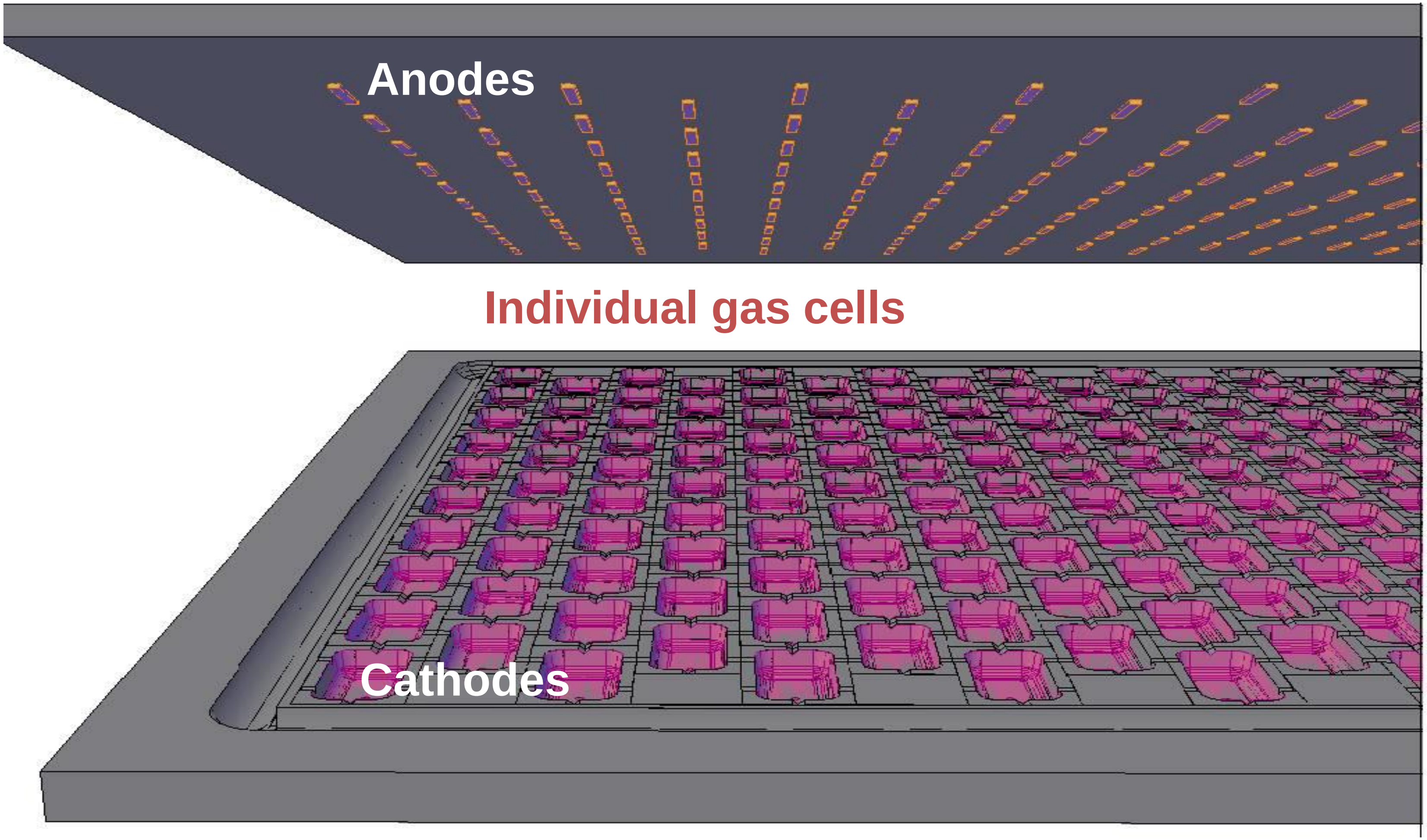
Closed gas cell individually quenched by an external resistor

Electrostatic simulations in COMSOL



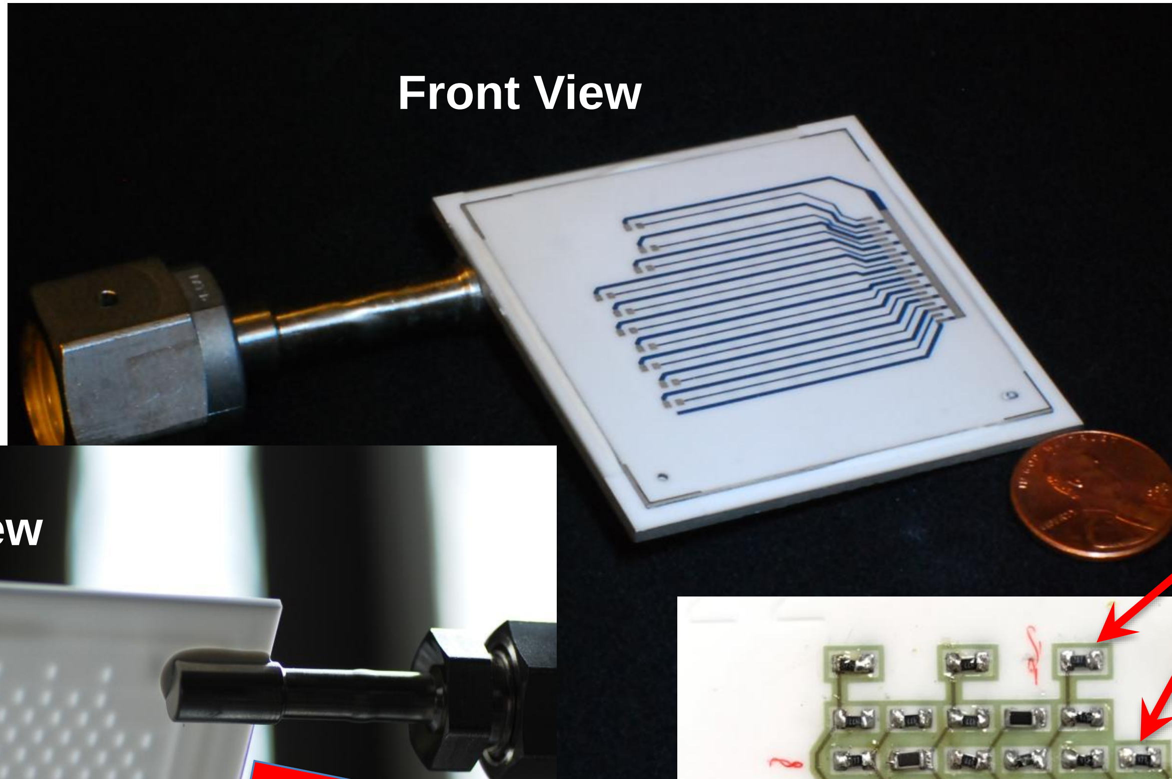
Electric field a few MV/m
→ gas breakdown

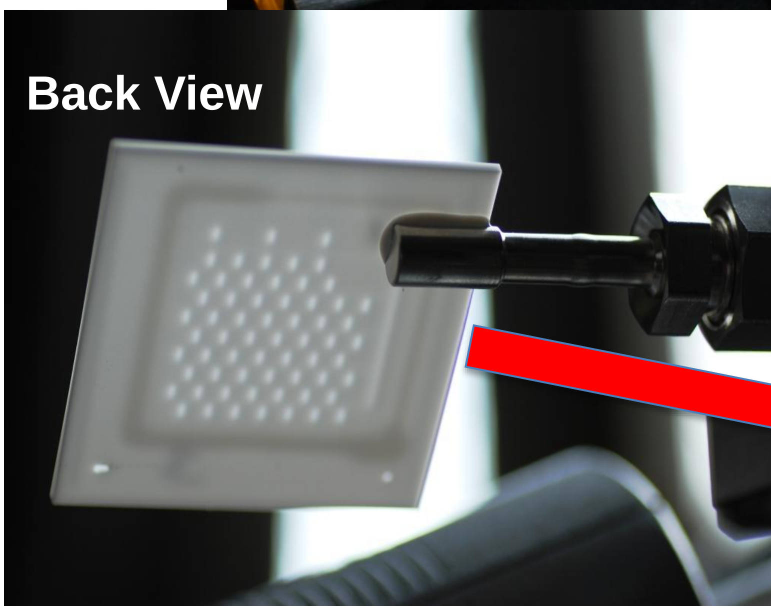
"*Closed* - Cell" Microcavity Concept



Perspective view of a pixel array with gas channels. Metallized cathode cavities on bottom plate with *vias* to HV bus. Anodes on top plate.

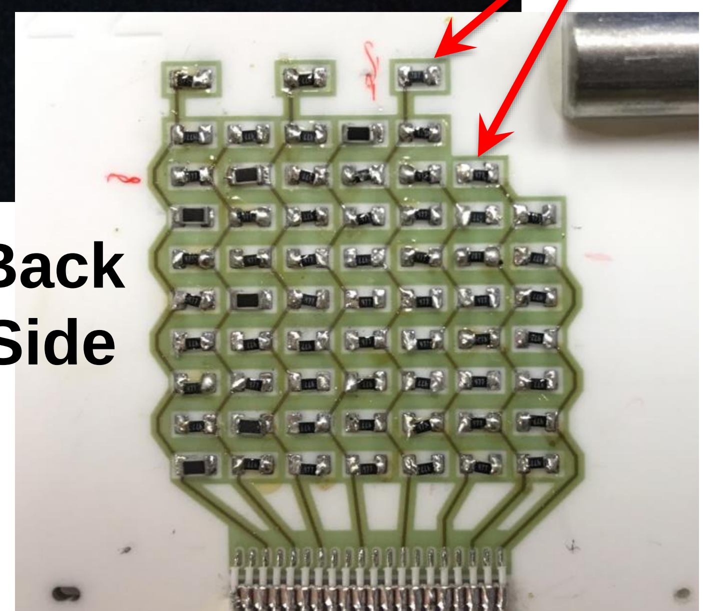
1st Gen. Microcavity-PPS Panel





Back Side

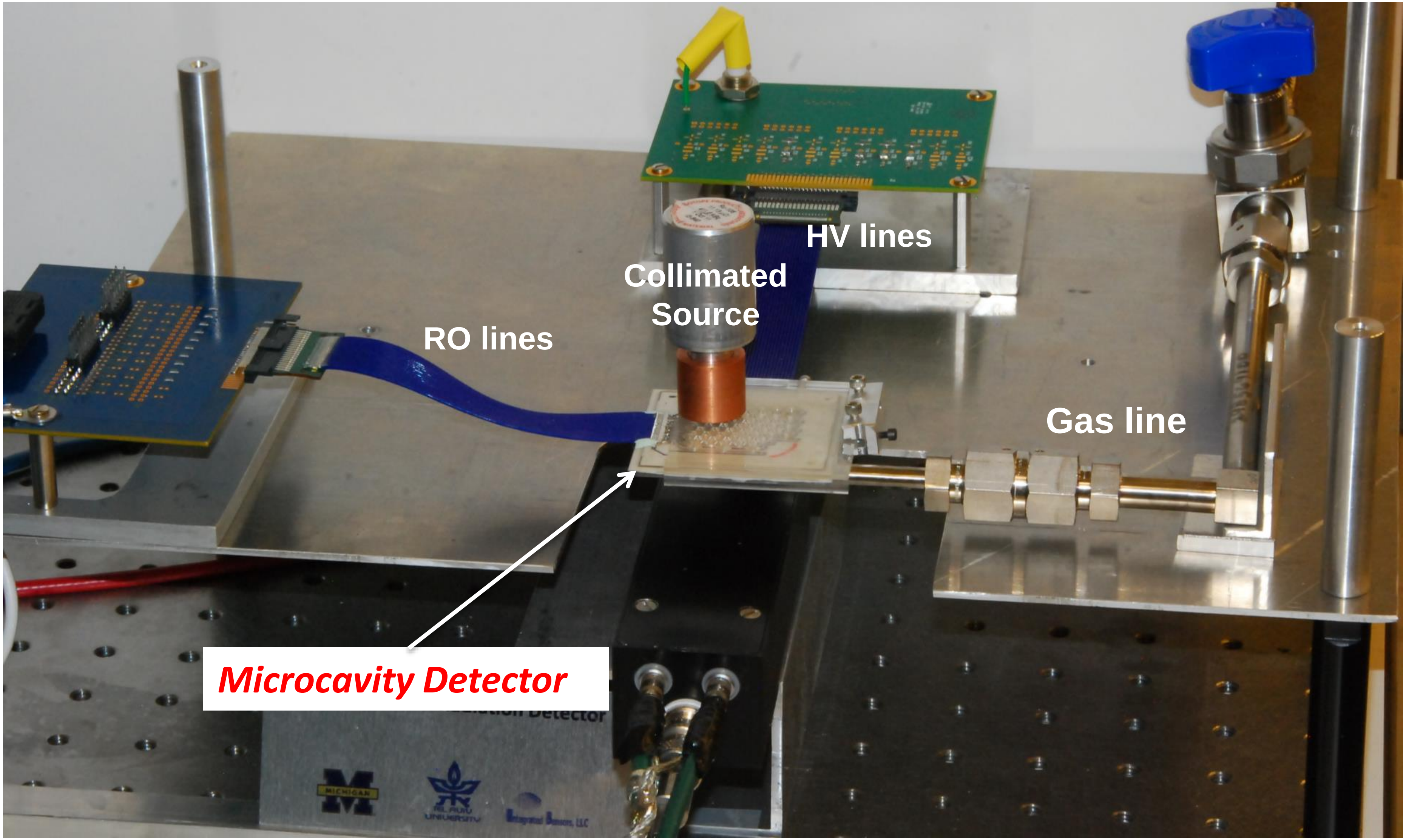
Surface mount quench resistors on each cell



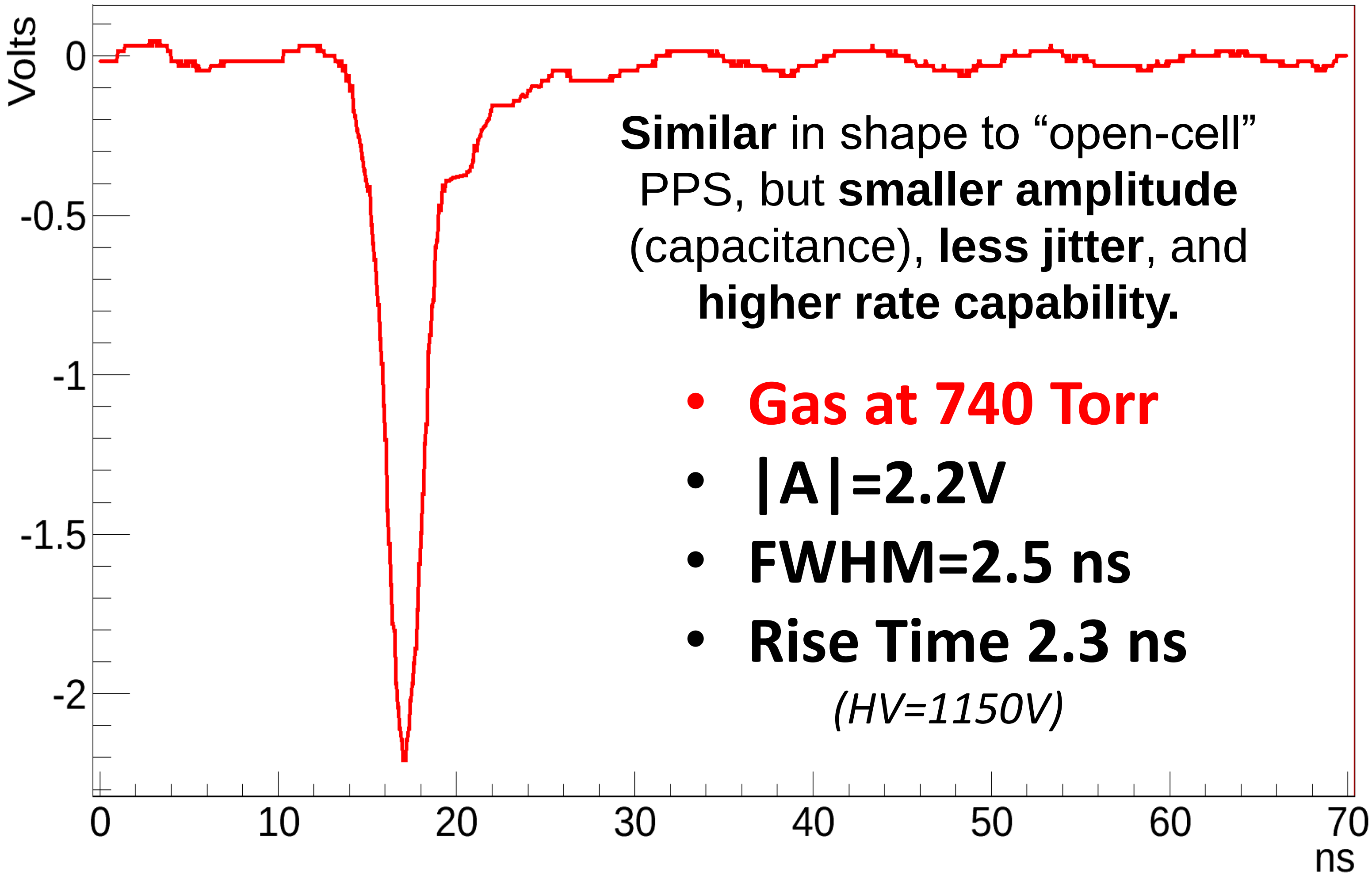
Fill-Factor of 18% in 1st Generation Microcavity Design (*ceramic cover*)

Collimated β-Source Test Setup

Ne-based gas mixtures



Typical Microcavity-PPS Signal Pulse

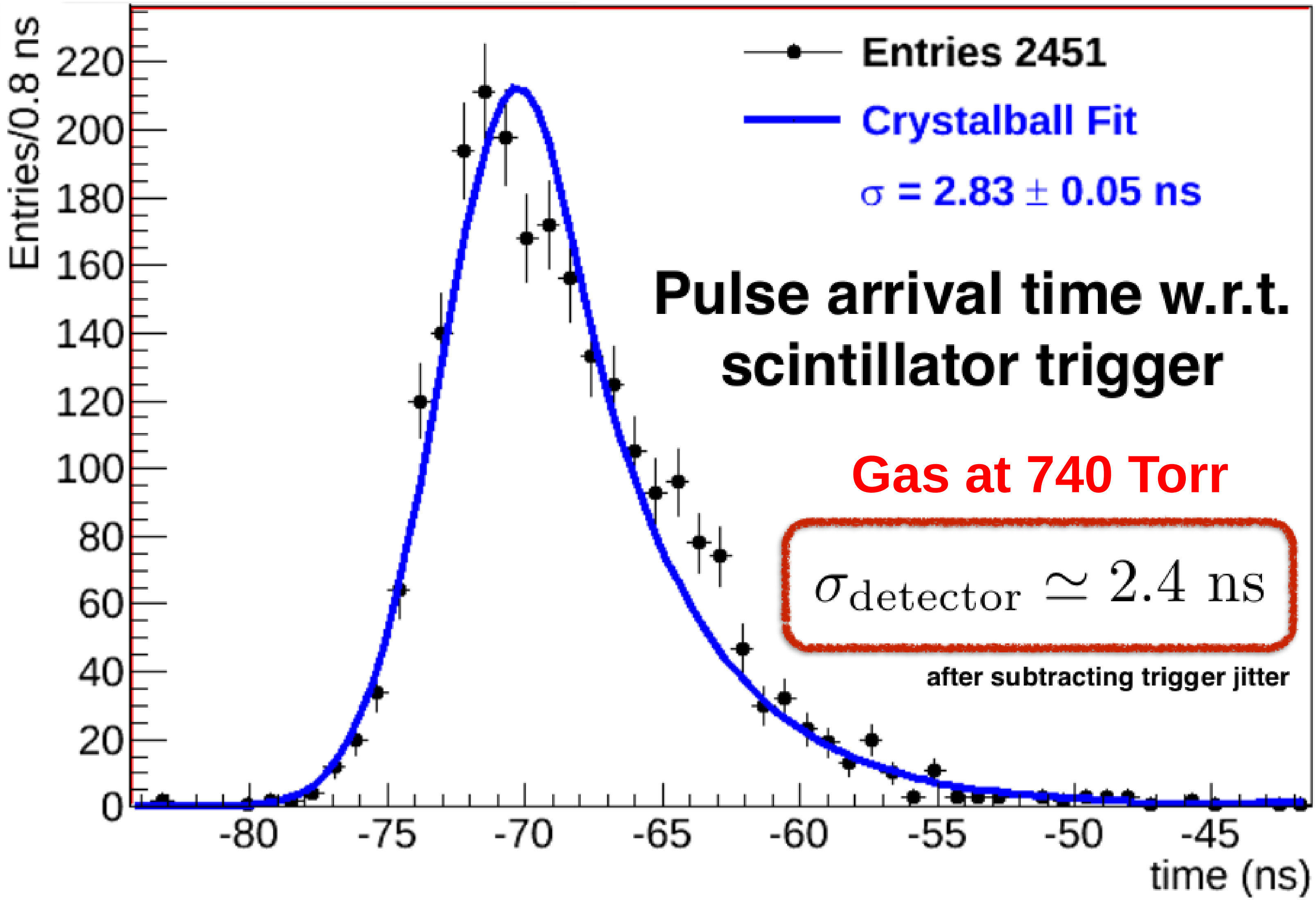


Similar in shape to "open-cell" PPS, but **smaller amplitude** (capacitance), **less jitter**, and **higher rate capability.**

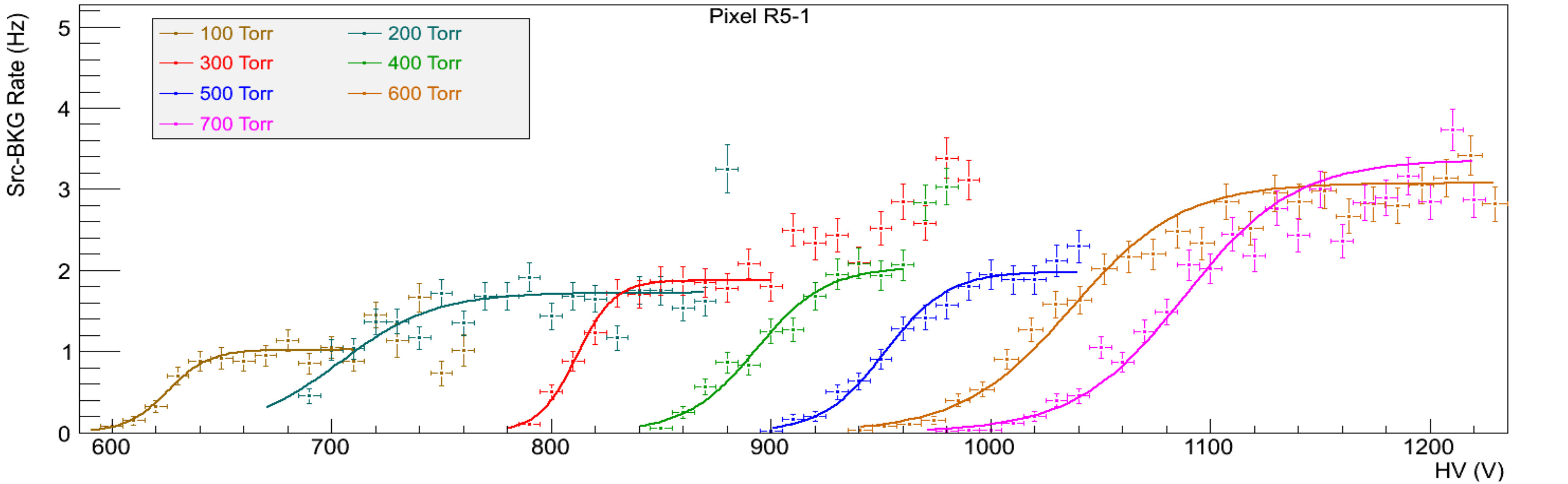
- **Gas at 740 Torr**
- **|A|=2.2V**
- **FWHM=2.5 ns**
- **Rise Time 2.3 ns**

(HV=1150V)

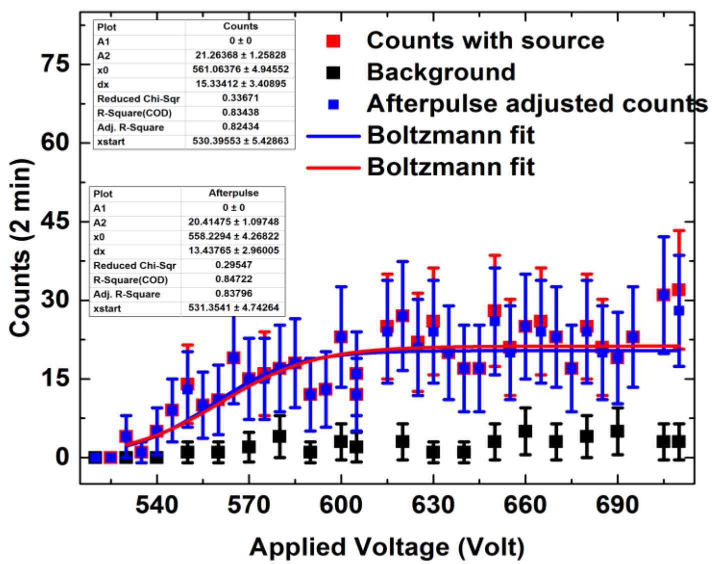
Pixel Time Resolution - Jitter



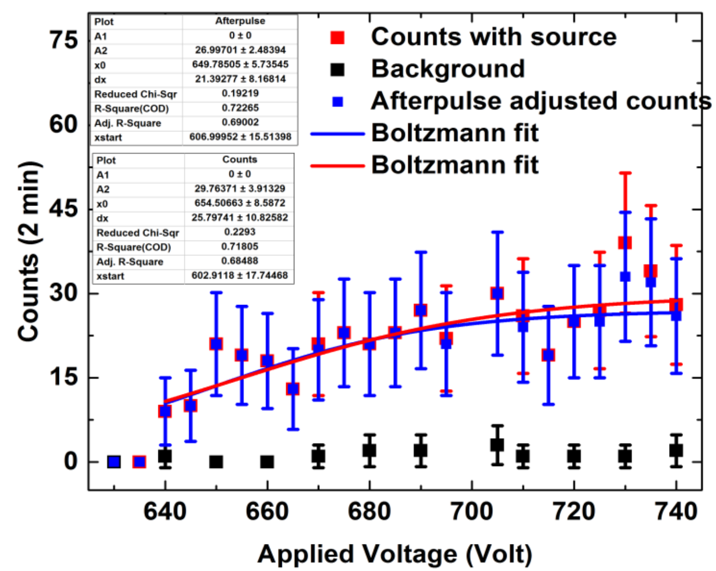
Pixel Response vs. Gas Pressure



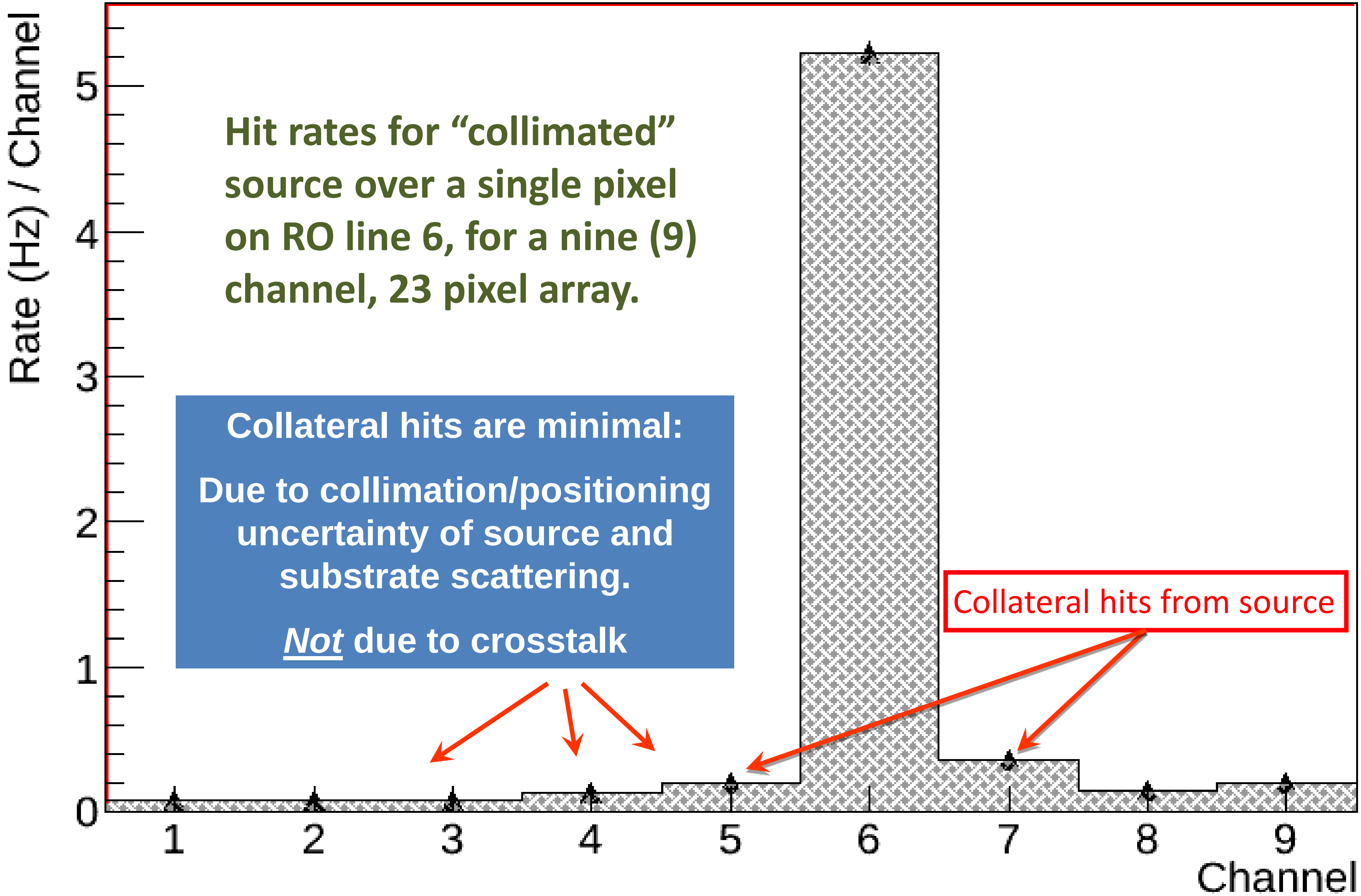
30 Torr (different panel & gas mixture than above)



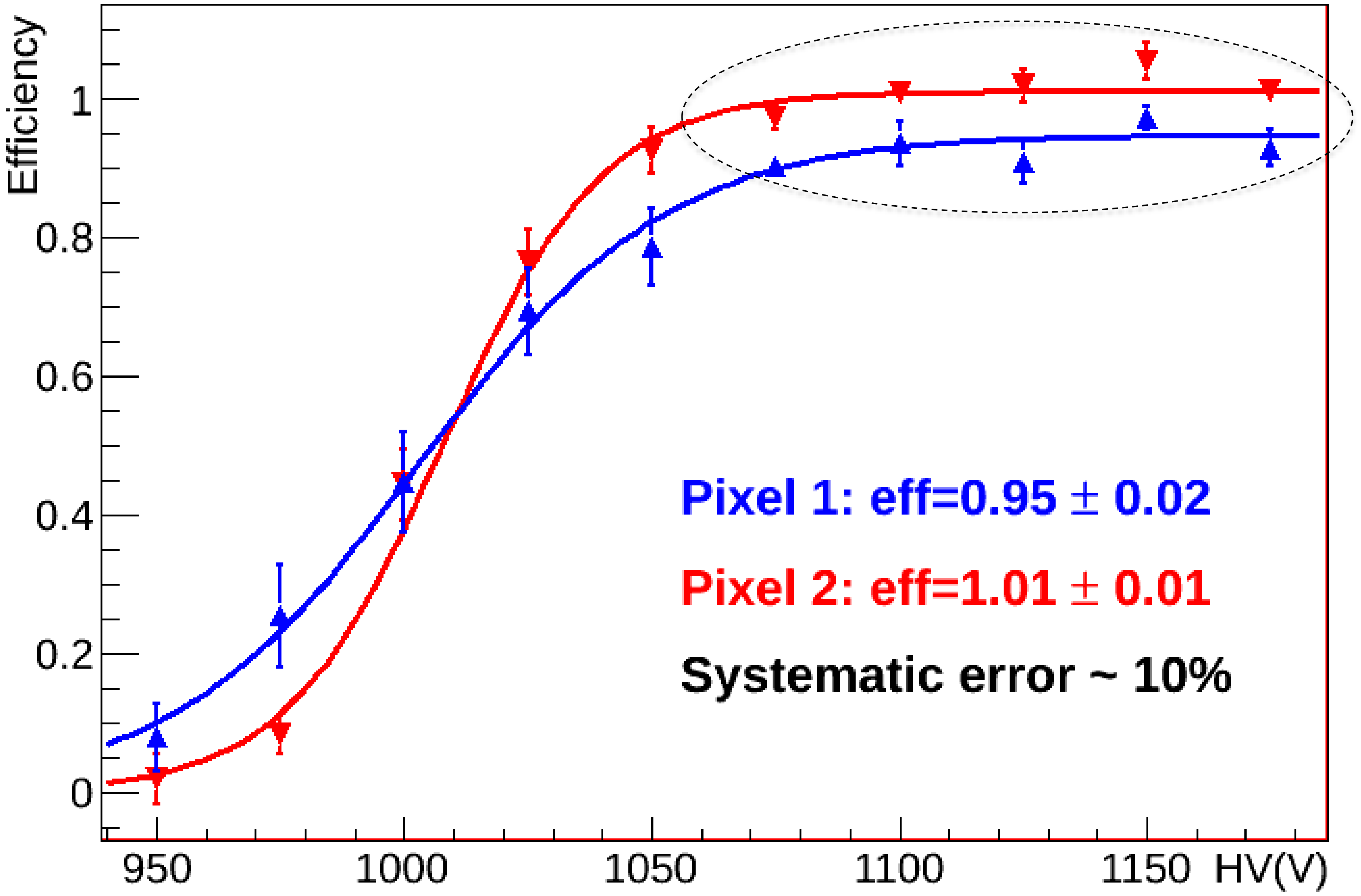
50 Torr (different panel & gas mixture than above)



Pixel Isolation

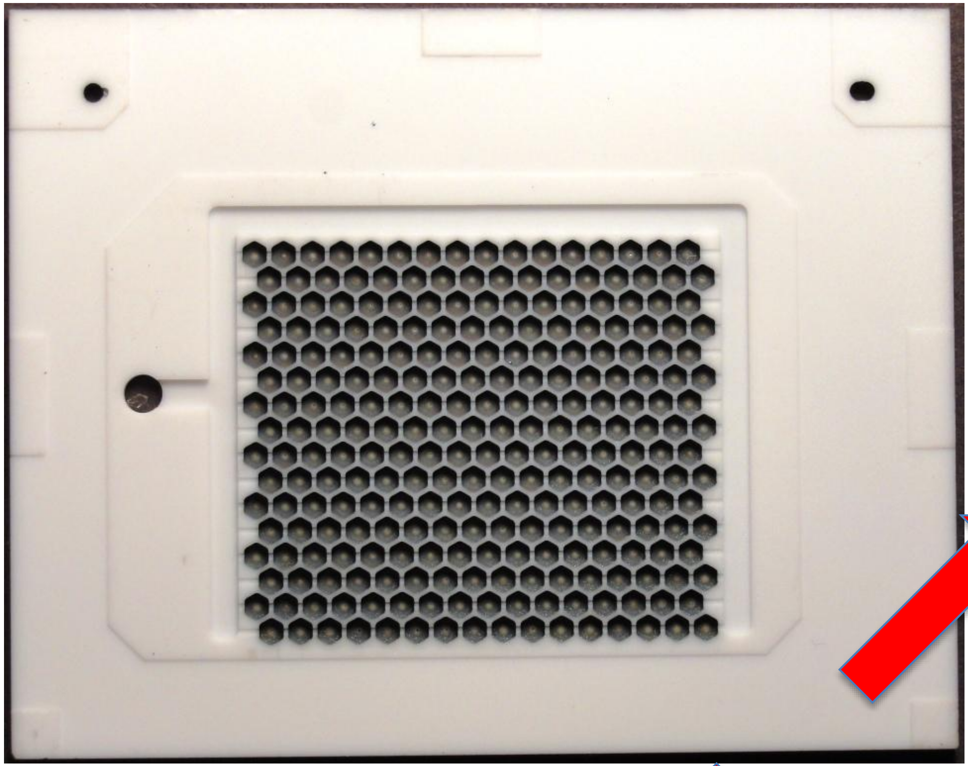


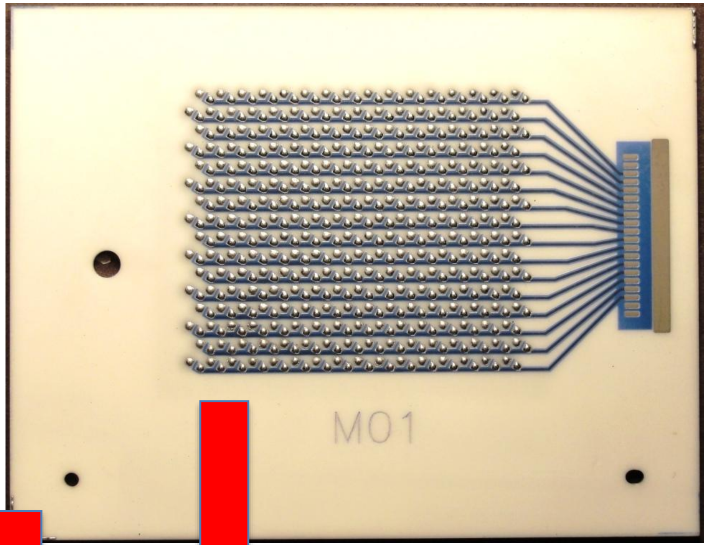
Pixel Efficiency (β-source)



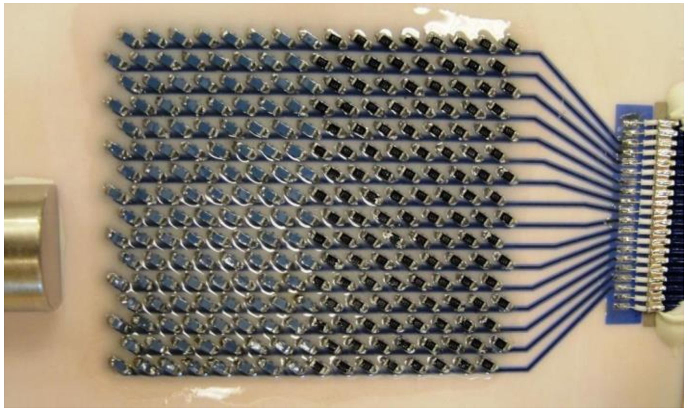
Hexcavity-PPS (2nd Gen. Microcavity)

2.0 mm Hexagon Pixels, 70% Fill-Factor, 256 pixel panel (16 x 16 matrix)





Cavities fully populated:
256 surface mount
quench resistors



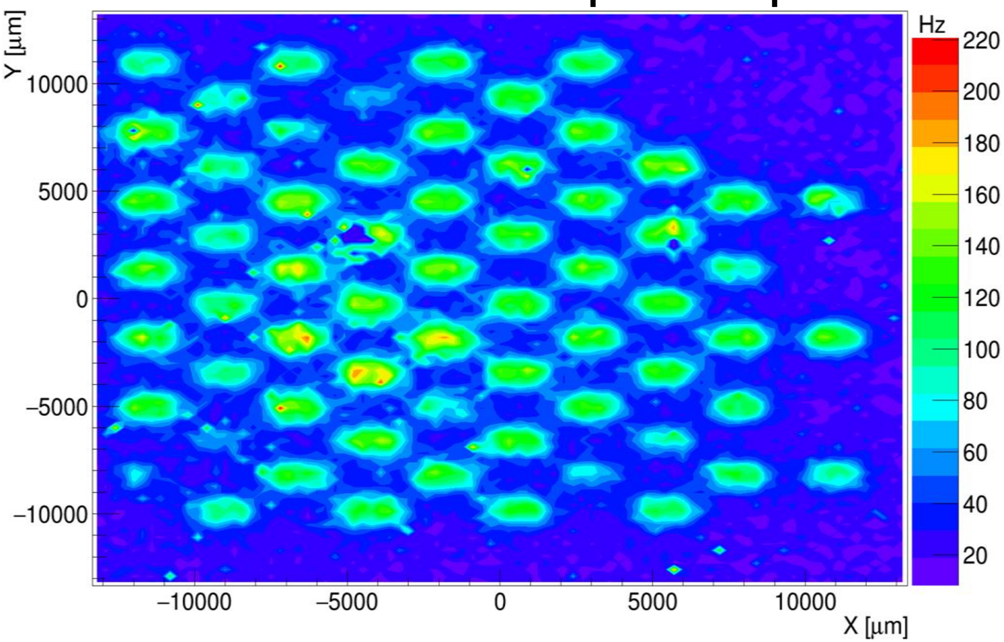
Glass Cover Plate

Ceramic Back Plate
Front with hexagon cavities and conductive vias (dot) to Back side Quench resistors

Position Scans

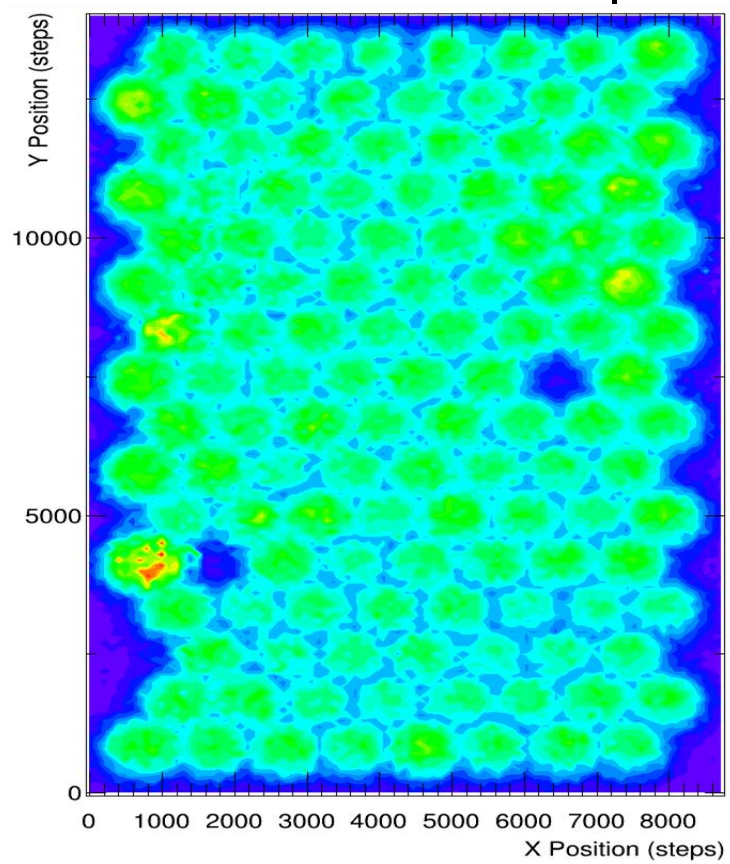
1st Gen Microcavity – 18% Fill Factor

Position scan over *total* panel - 63 pixels



2nd Gen Microcavity – 70% Fill Factor

Position scan over *one-half* of panel*

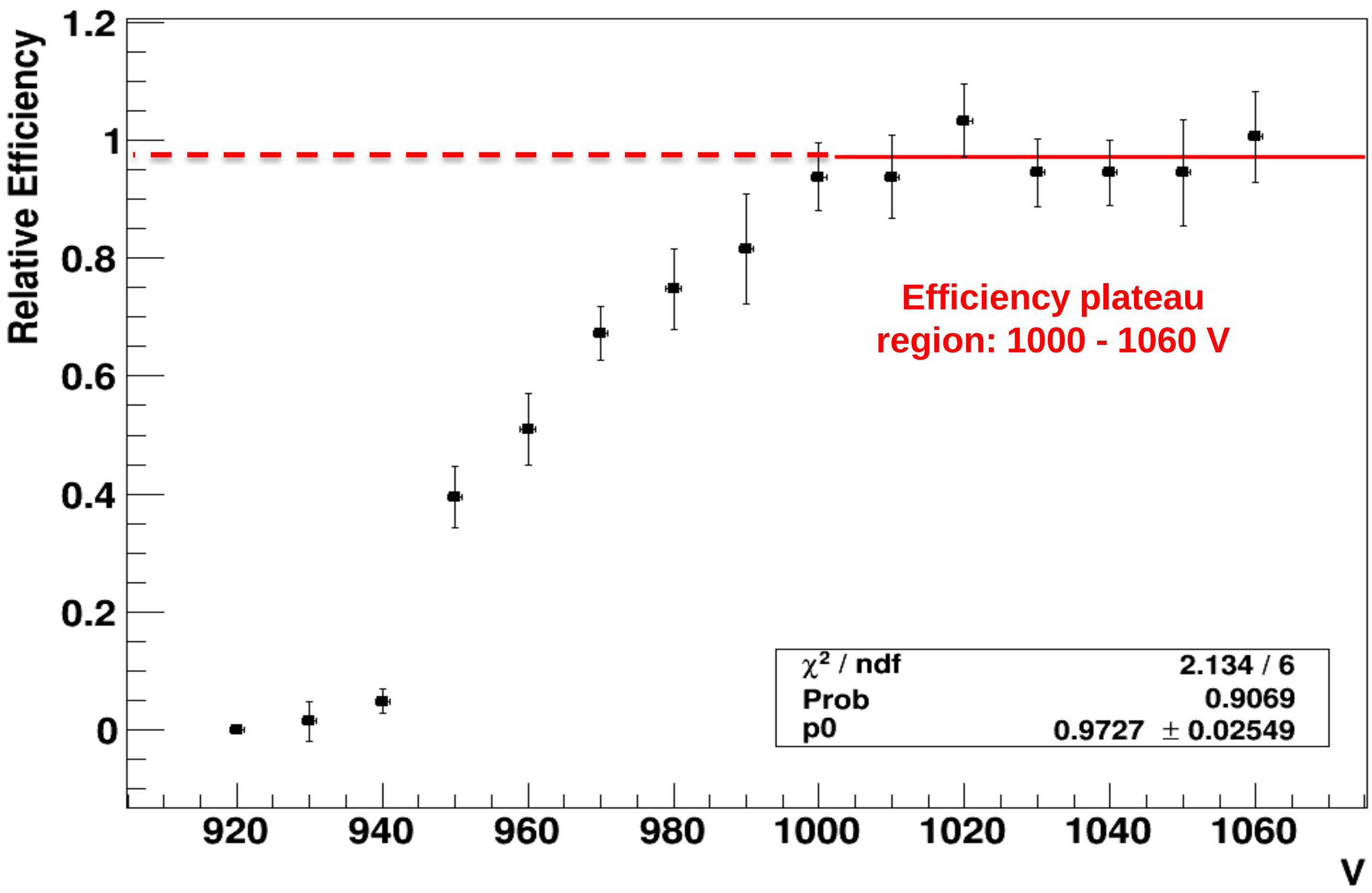


***125 Instrumented pixels**
(3 disconnected)

Fill-Factor increased from 18% to 70% from 1st to 2nd Gen. Microcavity-PPS design

- **^{90}Sr beta-source with 1.0 mm collimator**
- **Each pixel responds only when irradiated**
- **No discharge spreading**

Hexcavity Efficiency w.r.t. Cosmic Muons

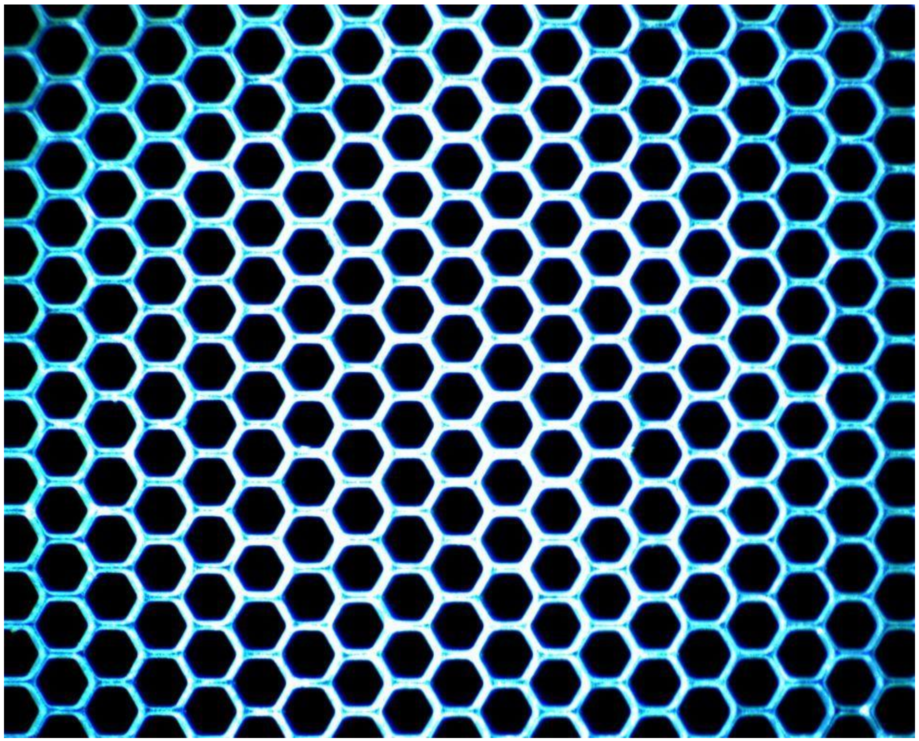


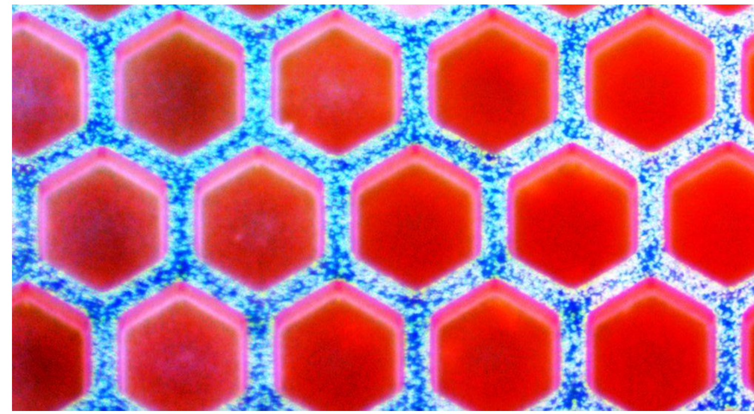
Relative efficiency (ϵ) of Hexcavity-PPS detector w.r.t. cosmic ray muons ***after*** allowing for ion-pair formation: **ϵ = 97.3% ± 2.5%**

“High-Res” Fab Capability

Fabricated Structure: 0.27 mm Hexagon Pixels, 73% Fill-Factor

14,400 pixel structure (120 x 120 matrix)





Hexcavity Structure

Grid-Support Structure

(Left) – Photo of small segment of high-resolution fabricated ceramic SPACER plate with 0.05 mm width-wall structure between adjacent hexagon HOLES. Hexagon hole pitch of 0.32 mm (i.e. 120-row x 120-column matrix, with 14,400 pixels). Note the excellent hole & wall uniformity with “zero” defects for 14,400 holes!

(Right) – Photo of small segment of high-resolution fabricated ceramic HEXCAVITY plate with same 0.05 mm width-wall structure and same cavity pitch of 0.32 mm (i.e. 120-row x 120-column matrix). Note off-angle lighting shows reflection of cavity hexagon walls on cavity bottom.

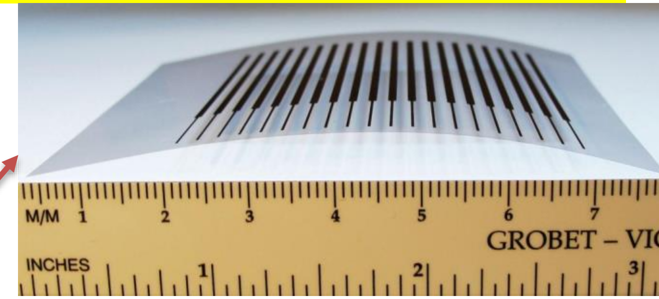
Grid-Support *UltraThin*-PPS

(Hybrid of “*open*” & “*closed*” cell structures)

Electrodes on *UltraThin* Mica & Glass

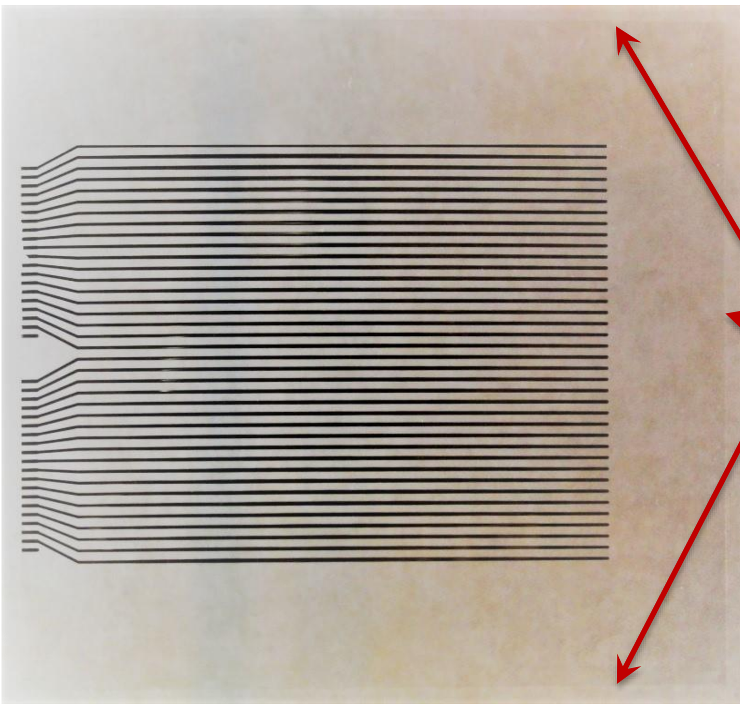
Substrate Size: 3.00” x 3.15”

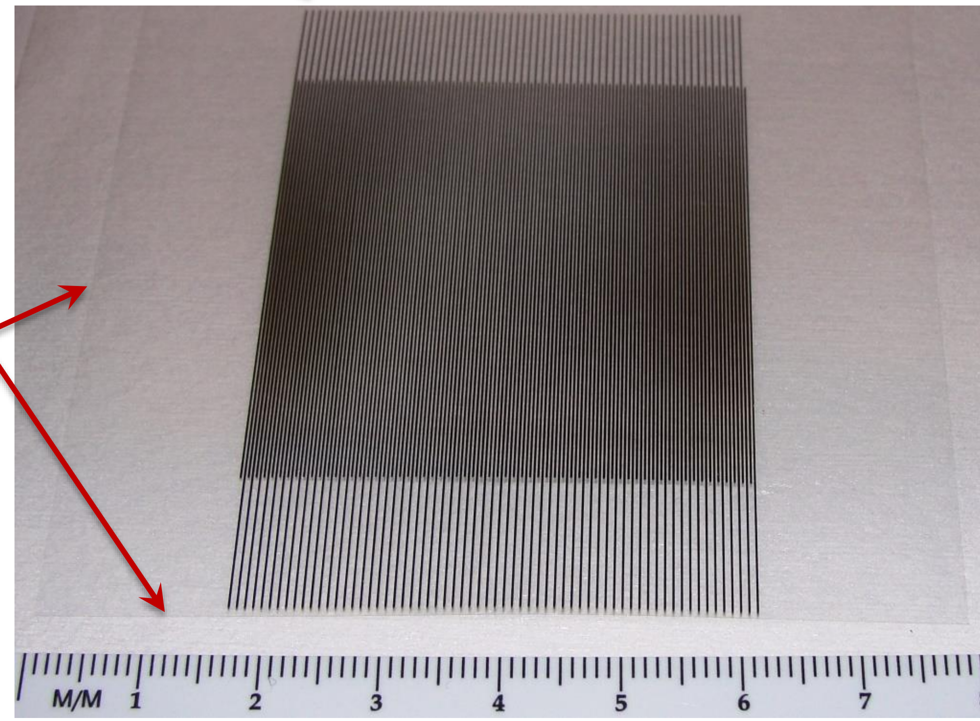
Areal Density / Mass Thickness = 2.2 mg/cm^2 (Mica) vs. 6.6 mg/cm^2 (Glass)
(substrate “curling” shown in top right photo has been fixed as seen in bottom right photo)



8 µm Mica

27 µm Glass





Left: 8 µm thick Mica substrate with electrode pitch of 1.00 mm. **Right:** 27 µm thick Glass substrate with electrode pitch in active area (center) of ***0.35 mm***. Narrow electrode width & spacing on the very slightly bowed Glass created the Lissajou type interference pattern, which is an optical artifact of image magnification and viewing angle. The actual electrode pattern is very uniform as seen at top & bottom. Metallization systems (20) evaluated include: **Al, Au, Cu, Cr, Mo, Pt, Ru, Ta, Ti, W, Zr**. The chosen system is compatible with both ***soldering*** and ***wire-bonding*** (pull strength >11 grams) for pad connections.

Beam Energy Loss* in *UltraThin* Glass vs. Mica

Energy Loss in 25 µm *thick Glass* cover PPS for selected Ion Beams

(gas is 1.0 mm of Ar at 100 Torr; *no nuclei get through the glass at 1 MeV/A*)

Energy (MeV)/A	Ion Energy (MeV)	Energy *loss in Glass* (MeV)	Energy *loss in Gas* MeV (# ion pairs)
3.0 (Ni-64)	192	190	0.13 (4,700)
3.0 (Sn-124)	372	348	0.57 (21,000)
3.0 (U-238)	**714**	**570**	1.52 (58,000)

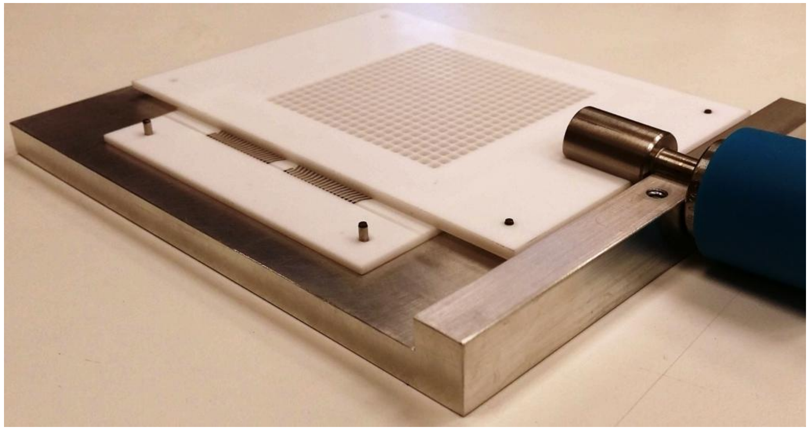
Energy Loss in 8 µm *thick Mica* cover PPS for selected Ion Beams

(gas is 1.0 mm of Ar at 100 Torr ; *all nuclei get through 2 panels at 12 MeV/A*)

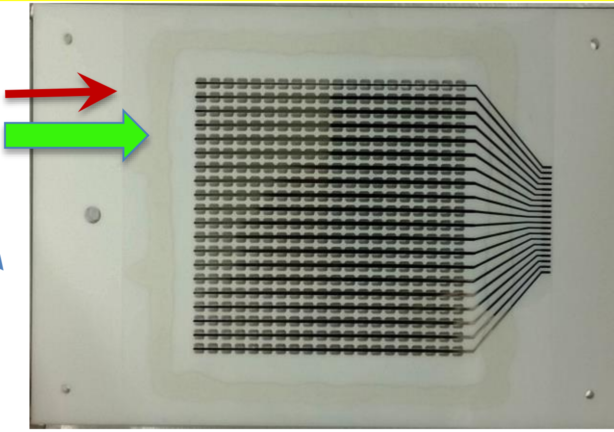
Energy (MeV)/A	Ion Energy (MeV)	Energy *loss in Mica* (MeV)	Energy *loss in Gas* MeV (# ion pairs)
1.0 (H-1)	1	0.5	0.006 (210)
1.0 (He-4)	4	2	0.02 (810)
1.0 (C-12)	12	12	0.04 (1,400)
1.0 (Ni-64)	64	62	0.14 (5,400)
1.0 (Sn-124)	124	107	0.53 (20,000)
1.0 (U-238)	**238**	**143**	1.20 (47,000)

*****
Energy Loss calculated using Geant4. A value of 26 eV was used for the effective Ar ionization energy and came from the tabulation in "Average Energy Required to Produce an Ion Pair", ICRU Report #31.

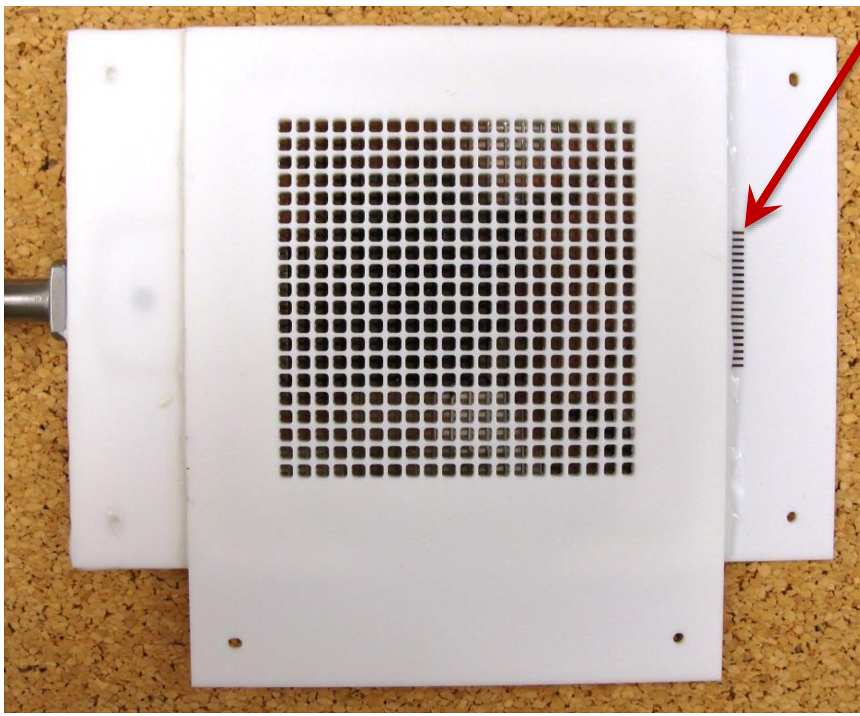
UltraThin-PPS Assembled Panel (64% Fill-Factor)



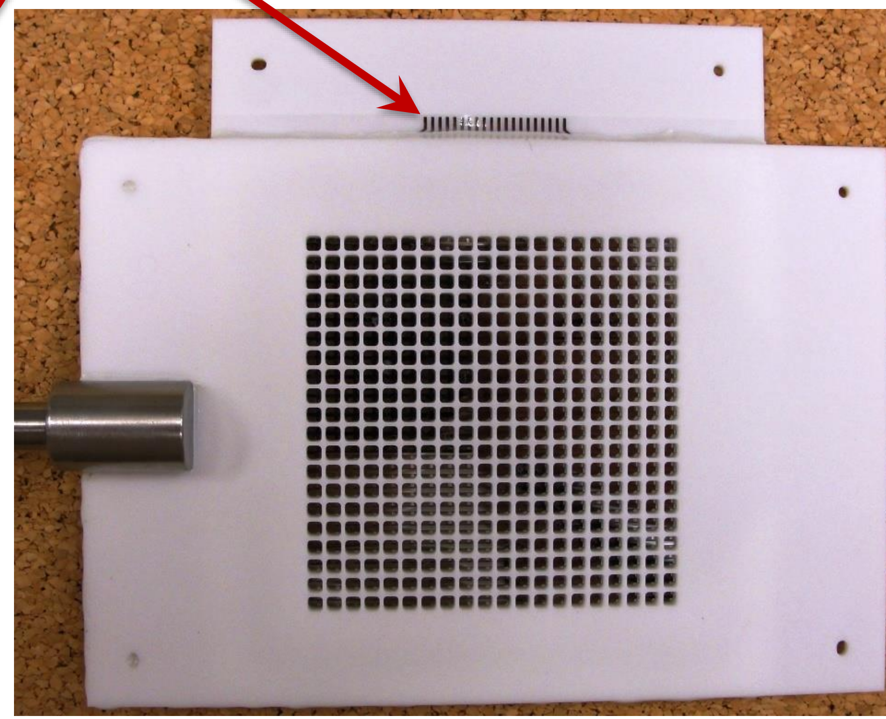
Assembled Front plate (glass seal)



27 µm Glass substrate, 1.00 mm electrode pitch



View from panel FRONT side



View from panel BACK side

Summary

- **PPS detectors have *demonstrated: submillimeter* position-resolution, good pixel-to-pixel uniformity, pixel response isolation, time resolutions of *~ 2 ns at 740 Torr* internal gas pressure, excellent S/N, high gain, and *relative efficiencies of essentially unity (i.e., ~ 100%) over a 60-100 volt* range for beta and cosmic muon sources. We expect *< 0.5 ns* timing at < 100 Torr pressure. Similar efficiencies have been demonstrated for protons & neutrons.**

- **Each pixel responds as an individual detector. Spatial fill-factors have increased from 18% to 70%, with future designs expected to achieve *fill-factors ≥ 90%*. PPS devices have demonstrated successful operation over a wide voltage range (~ 100 volts) to beta-sources at internal gas pressures of *30 Torr*, which is much better than expected and bodes well for *ultrathin* panels that must operate in a vacuum environment.**

- **The proposed "*ultrathin*" grid-support PPS design is a "hybrid" structure between "open" and "closed" cell PPS structures.**

- **Two *ultrathin* PPS device substrates are under development: 27 µm thick Glass and 8 µm thick Mica. We have *demonstrated* both substrates capable of holding a vacuum, but the *much thicker Glass substrates seem to be more fragile than the Mica*. Avoiding substrate breakage during final panel assembly has been a challenge (now on 3rd Gen. fixtures).**

- **Problems associated with electrode patterning on *ultrathin* Glass & Mica have been solved, including: high-resolution electrode patterning, substrate breakage during electrode deposition, elimination of substrate flexing/curling, poor electrode adhesion to substrate, and electrode degradation upon exposure to high intensity plasma discharges/streamers.**

Question for NP Community

We are interesting in other applications that could benefit by being able to fabricate devices with electrode circuitry on 8-27 µm *ultrathin* inorganic substrates.