Microhexcavity Plasma Panel Detectors

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Integrated Sensors
transforming radiation detection

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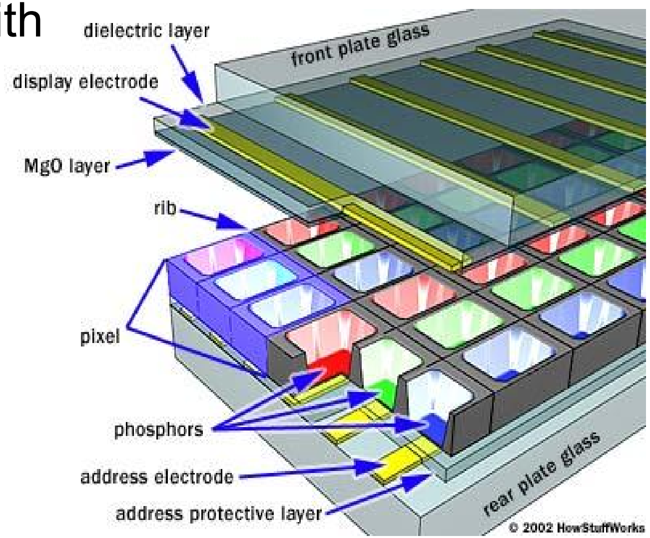
Plasma Panel Detector Collaboration

- University of Michigan- Department of Physics
  - J. W. Chapman, Claudio Ferretti, Dan Levin, Nick Ristow, Curtis Weaverdyck, Michael Ausilio, Ralf Bejko
- Integrated Sensors, LLC
  - Peter Friedman (Toledo, OH)
- Tel Aviv University- School of Physics and Astronomy
  - Achintya Das, Menu Ben Moshe, Yan Benhammou, Erez Etzion
- UC Santa Cruz, Loma Linda University Medical Center

Detector Concept

- Gaseous ionizing radiation detectors with closed cell architecture
- Motivated by flat panel pixelated AC television screens
  - Long lasting
  - Hermetically sealed
  - Lightweight
  - Established industrial fabrication

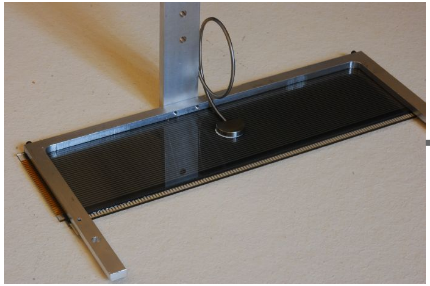


http://s.hswstatic.com/gif/plasma-display-wide.jpg

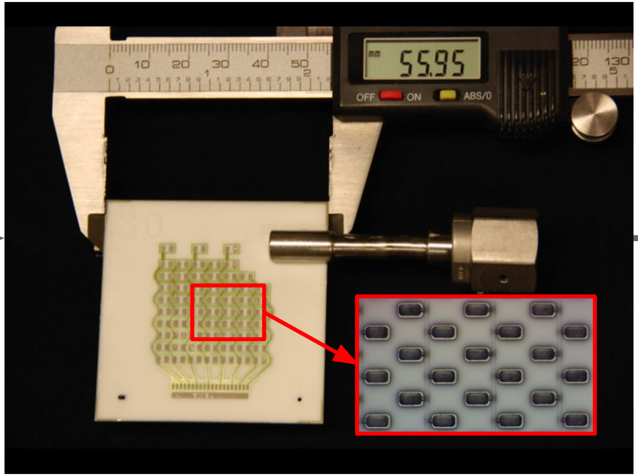
Plasma display panel schematic

Detector Design Progression

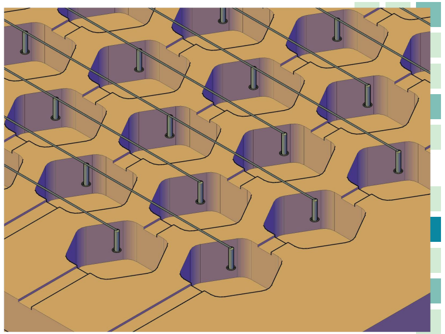
- Modified PDP -> 1st Gen Microcavity -> 2nd Gen: μHexcavity



Modified DC commercial PDP



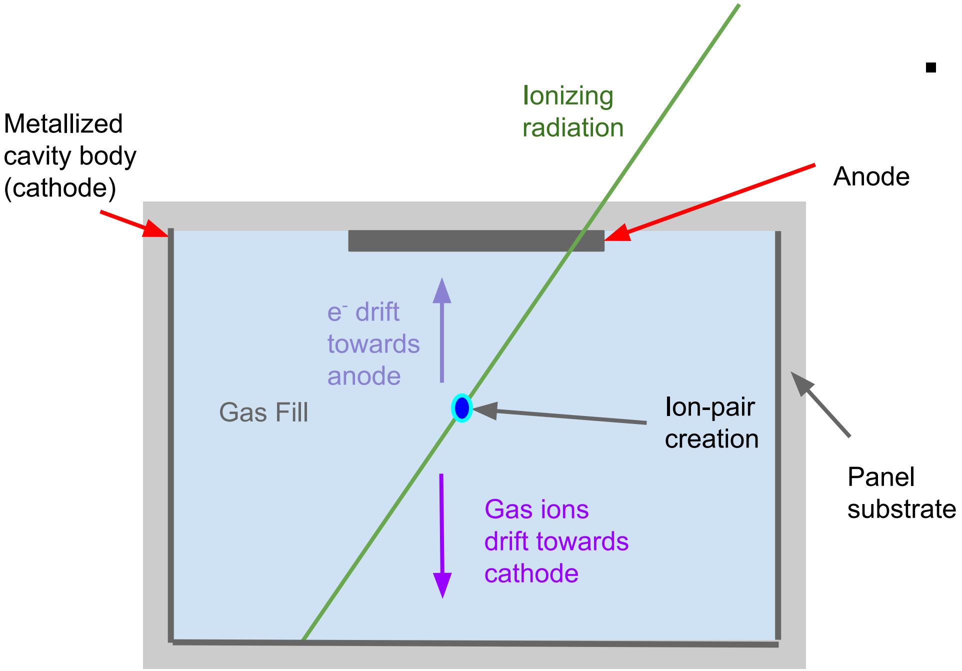
1st generation microcavity detector



3D pixel layout- μHexcavity

- Microcavity -> first independently fabricated detector from Macor & alumina
- <u>**Each cell acts as an independent detector**</u>

Pixel Discharge

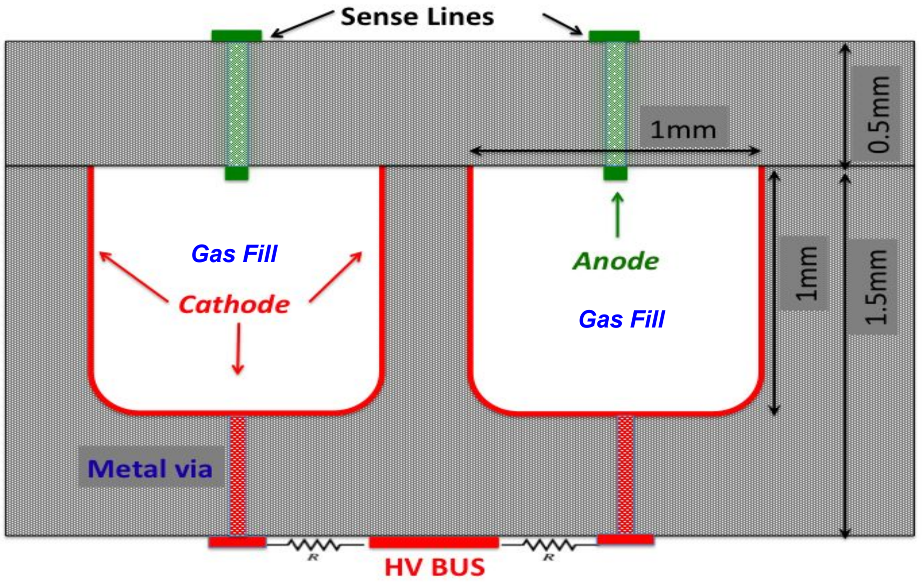


- **Plasma discharge initiated by incident ionizing radiation**
- **Self quenching**
- Design objectives:
  - Thin materials (low mass device)
  - Rates exceeding 100 KHz/cm^2
  - O(ns) time resolution
  - High packing fraction/detection over large areas
  - < 300 micron spatial resolution
  - No amplification
  - Hermetically sealed, no gas flow system

1st Generation Microcavity Detector

1.2 mm long rectangular anode

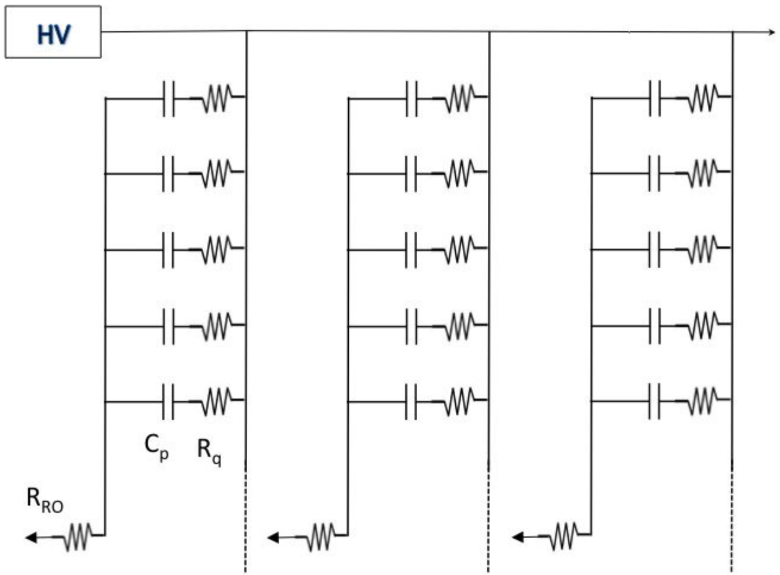
1 x 1 x 2 mm metallized cavities



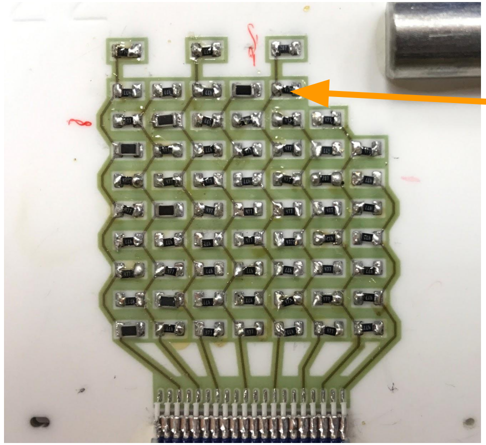
- High voltage applied to cavity body through metal via
- Orthogonal RO and HV lines
- 63 far apart, individually sealed pixels

Electronics and Read Out

Schematic of detector



- Each pixel has < 1pF capacitance
- High valued quench resistors (200 MΩ - 1 GΩ)
- RO to TDC or scalar



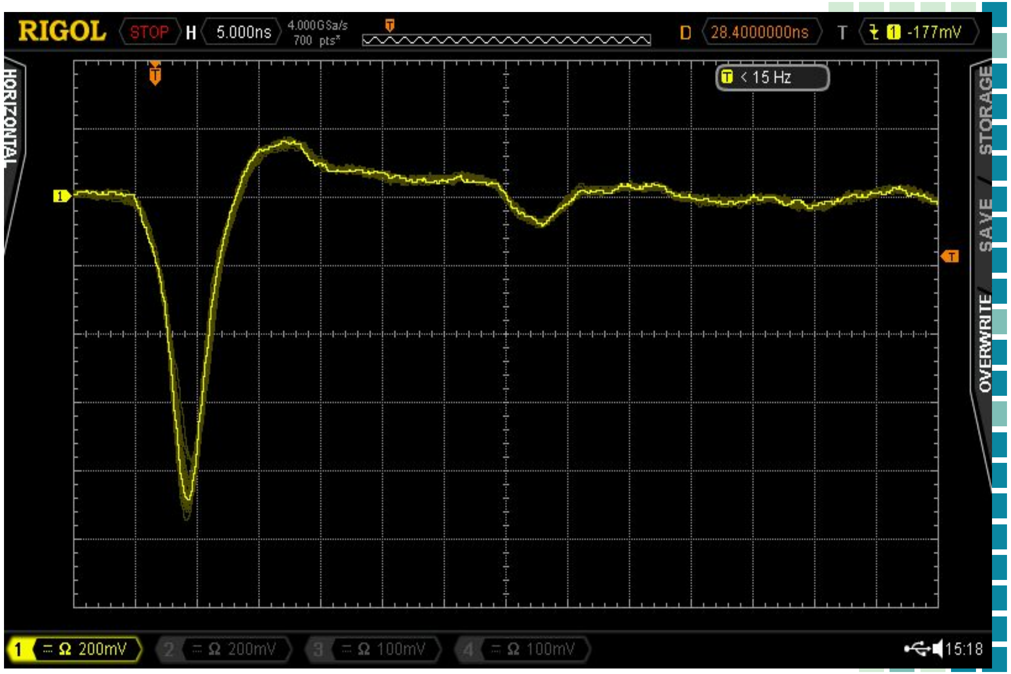
Surface mount quench resistors on each cell

Detector Operational Principles

- Individual cells biased for gas discharge when ion pair is created by incident ionizing radiation
- Metallized cell walls act as cathode, anode positioned at top center
- Operated in Geiger region of gaseous detectors
- Three-component Penning gas mixture fill
  - Neon based, atmospheric pressure or below
- Individually quenched by external high-valued resistor

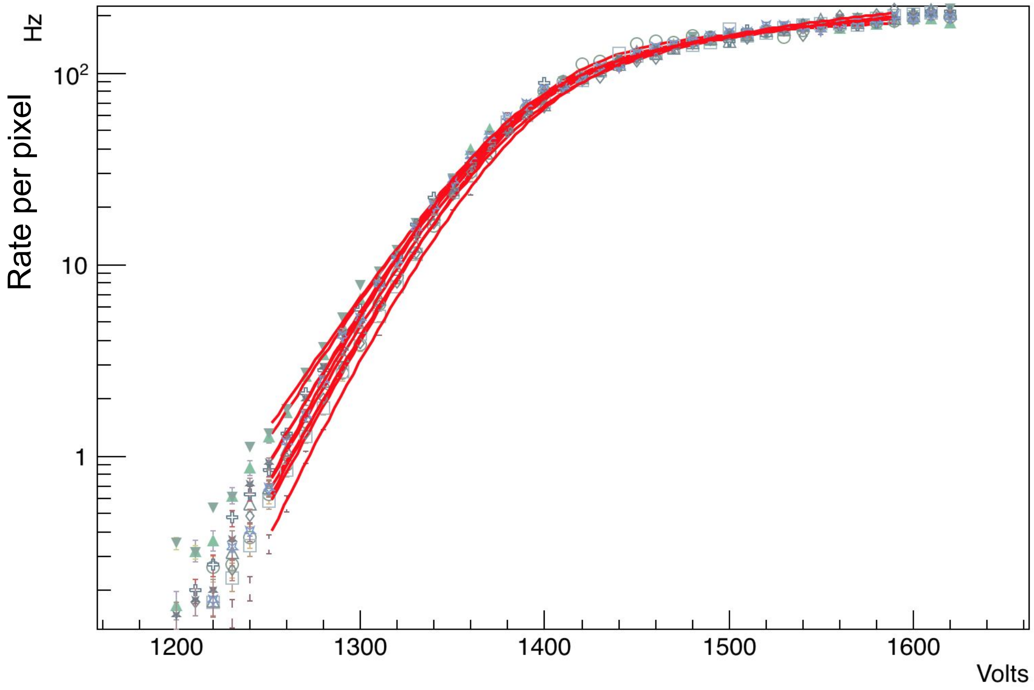
First Data and Results

- Typical pulse characteristics:
  - Pulse shape uniform across panel
  - Pulse width at half max: 3 ns
  - Rise time ~3 ns
  - Pulse height: 1 V
- Operating voltage is gas dependent
  - Varies between between 900 V and 2000 V
- **<u>Volt-level pulses</u>**



Rate vs HV

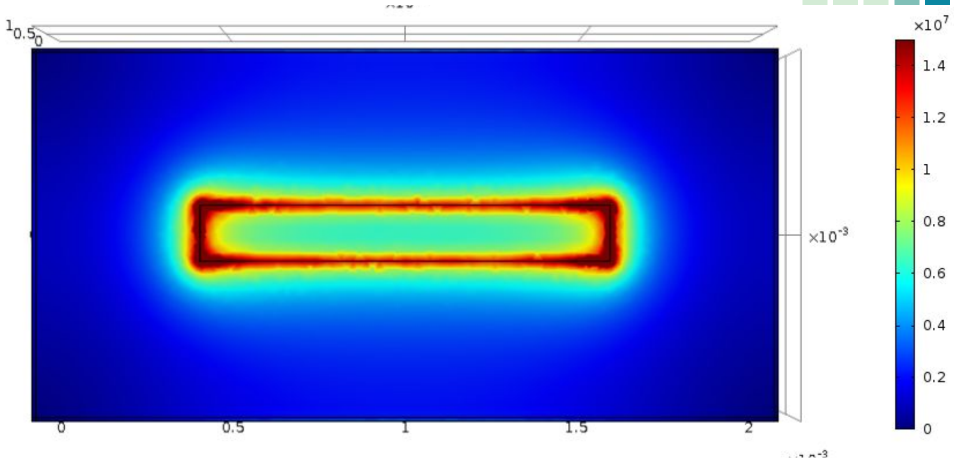
Curves for 10 instrumented pixels on 10 readout lines



- Uniform change in rate as a function of HV across RO lines
- Measured rates from each isolated cell are similar
- < 1Hz/RO line spontaneous discharge rate (background)
- Rate increase flattens around ~1500 V (approaching maximum efficiency)

Microcavity E-Field Simulation

- E-field peaks at edges of anode (microcavity PPD simulated in COMSOL)
- E-field peaks at ~9.7 x 10^6 V/m

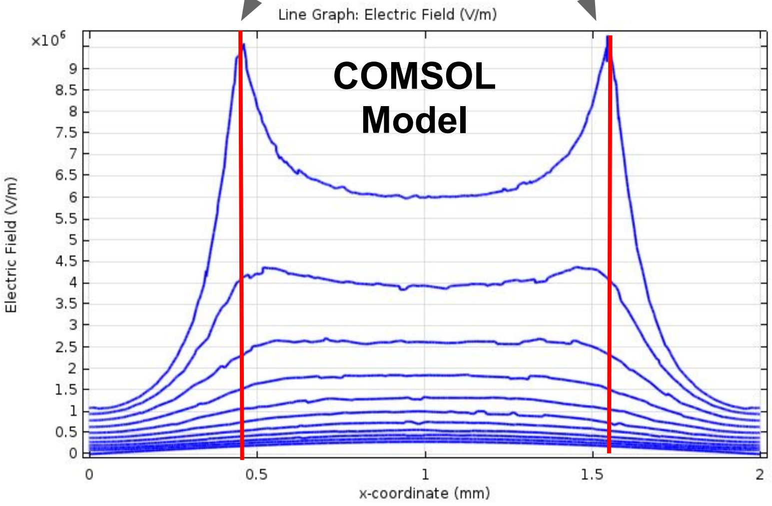


<u>Horizontal cross-section of field under anode</u>

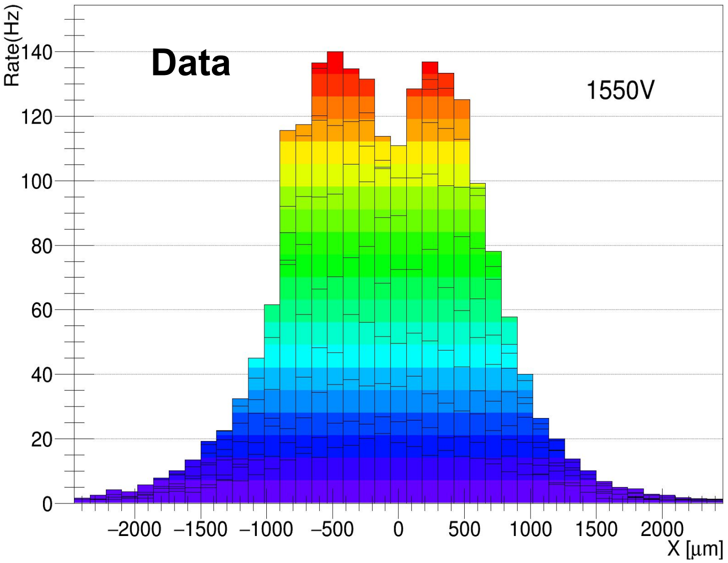
(1550 V potential difference)

Microcavity E-Field Simulation & Data

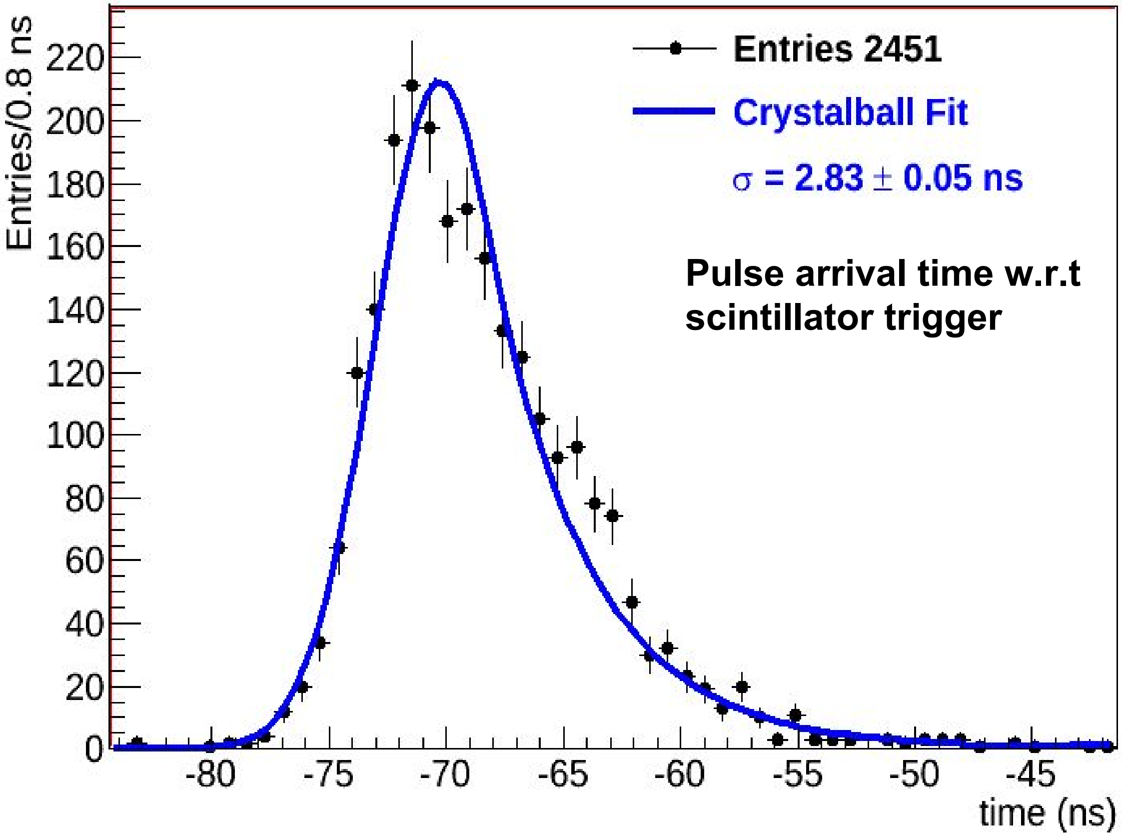
± 600 μm -> edges of anode



Rate vs position for a single pixel



Timing

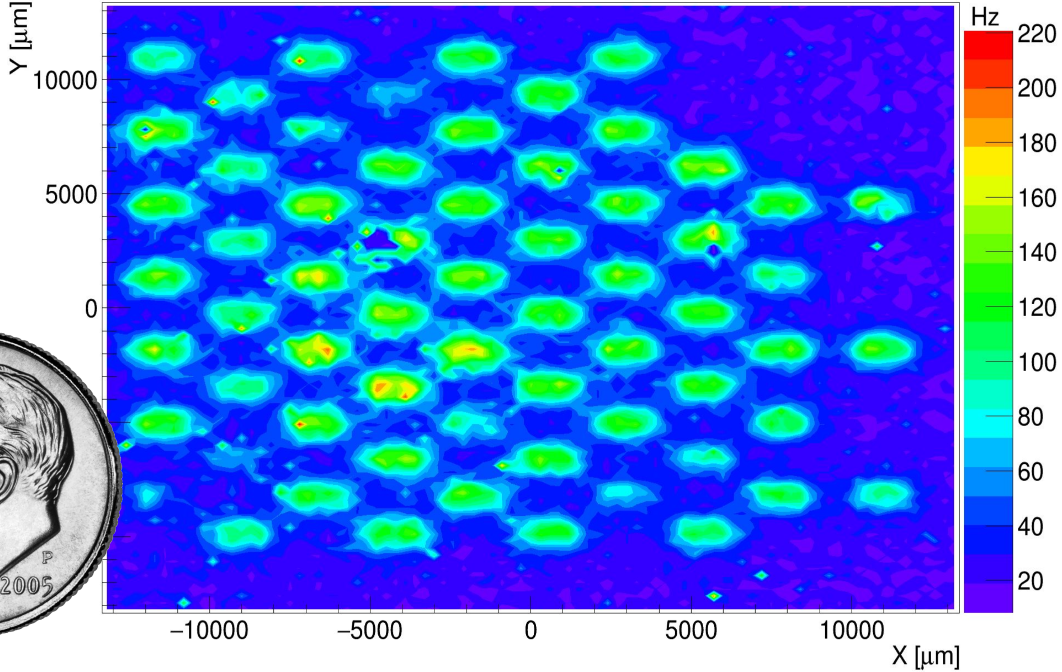


- Ru^{106} collimated source
- Panel above scintillator hodoscope
- Hodoscope hit gives time reference

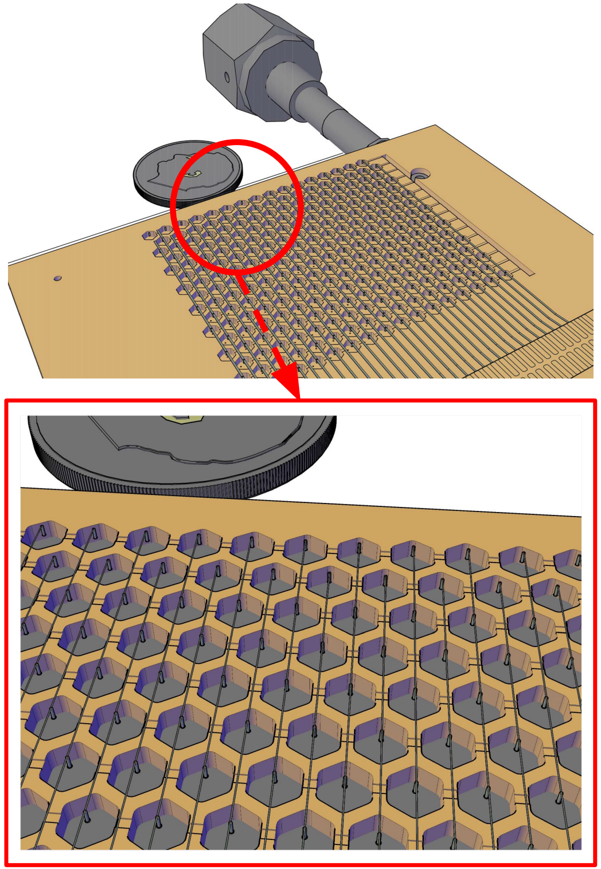
$\sigma_{detector}$ ≅ 2.4 ns (trigger jitter subtracted)

Position Scans

- Robotic arm increments collimated Sr-90 source over detector
- Rate measured as a function of collimator position
- Panel operated at 1450 V
- **Outline of each cavity visible**
- **Each pixel operating independently**

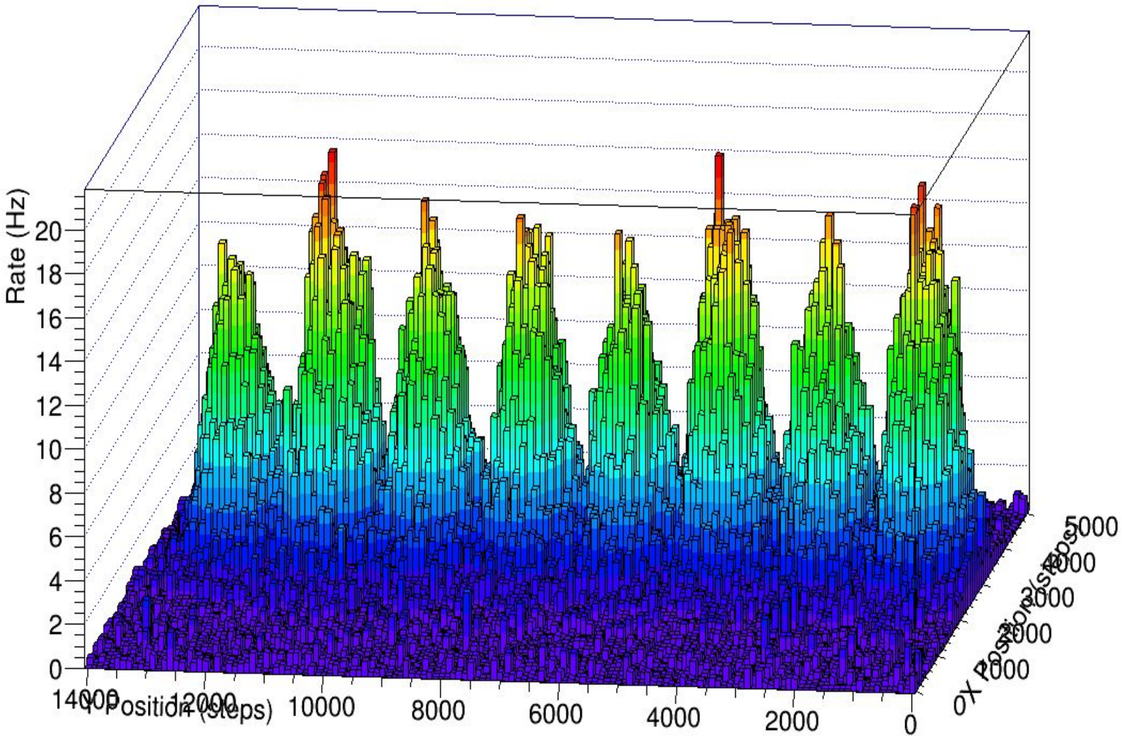


2nd Generation- µHexcavity



- Same HV/RO system as 1st gen
- 2 mm regular hexagonal cavities
- Higher packing fraction/spatial coverage
  - $f_p = (R_{inner}/R_{outer})^2 = 70\%$
- Circular anodes
- Thin (400 micron) cover plate
  - Glass or Macor

µHexcavity Position Scans



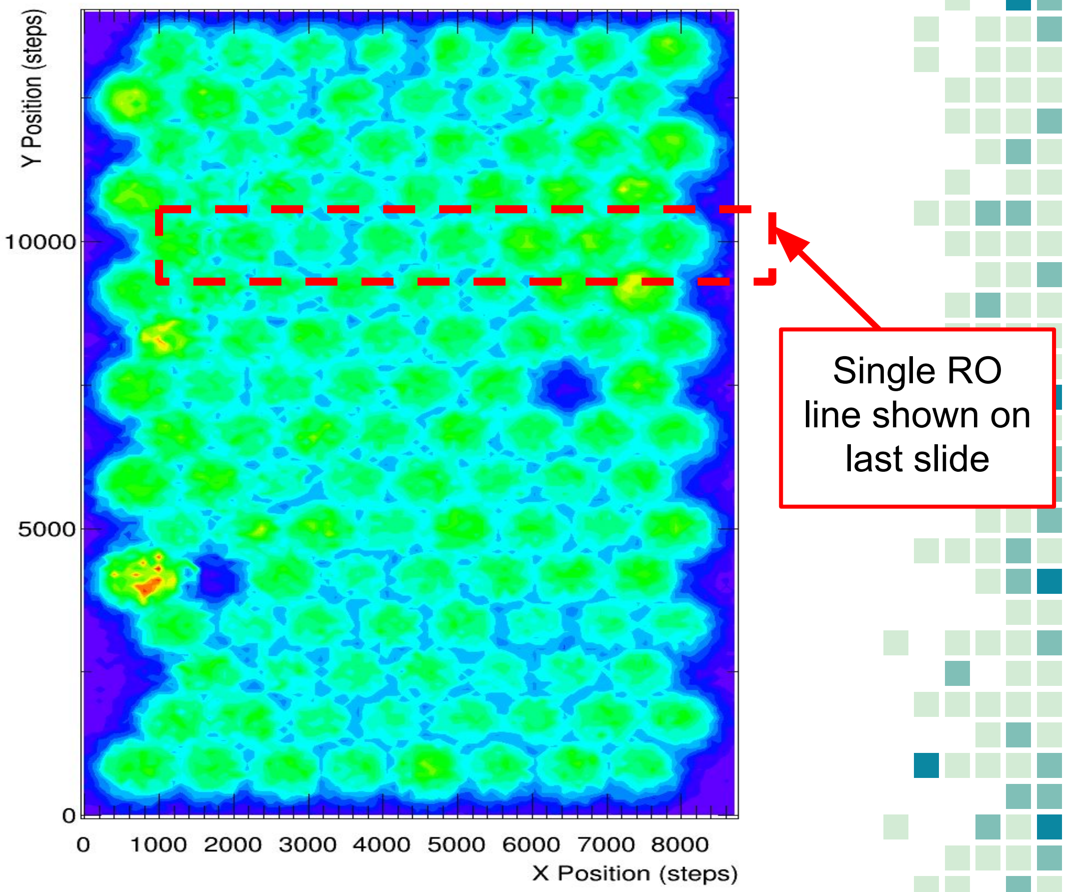
8 pixels, individual RO line

- Sr-90 w/ 1 mm collimator
- Pixels respond when irradiated, quiet otherwise
- Peaks due to higher flux
- No discharge spreading

μHexcavity Position Scans

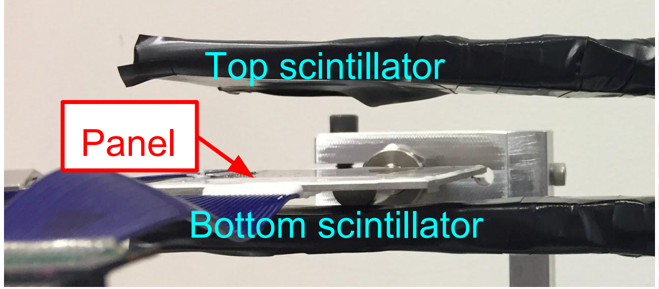
Position scan over entire panel

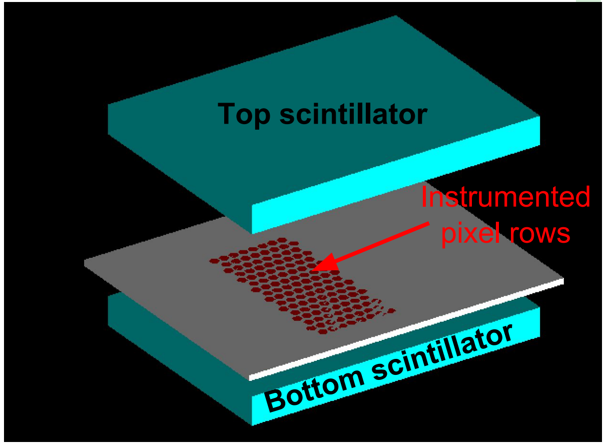
- 125 instrumented pixels (3 disconnected)
- **Each pixel responds individually when irradiated**



µHexcavity Efficiency with Cosmic Ray Muons

- Setup:
  - µHexcavity detector placed between two scintillator paddles
  - 125 instrumented pixels
  - Measured three-fold (scintillator and detector) and two-fold (scintillator) coincidences at different voltages
- Experimental setup recreated in Geant4





Efficiency (ϵ) with Cosmic Ray Muons

N_3 = Threefold coincidence
N_2 = Twofold coincidence

D = Data
MC = Monte Carlo

Cosmic ray muons

Prob. to create ≥ 1 ion-pair

3-fold acceptance

$$\frac{N_3^D}{N_2^D} = \epsilon \frac{\int \frac{dN}{d\Omega} P(n \geq 1) A_3(\theta, \phi) d\Omega}{\int \frac{dN}{d\Omega} A_2(\theta, \phi) d\Omega}$$

$$\frac{dN}{d\Omega} \sim \cos^2(\theta)$$

2-fold acceptance

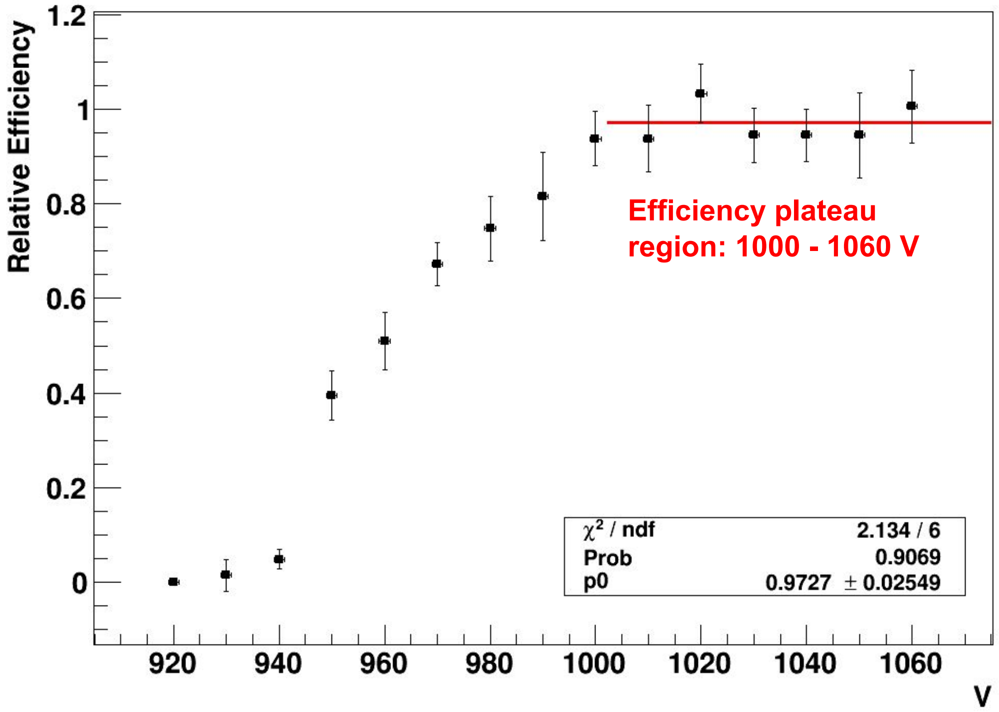
$$\left(\frac{N_3}{N_2}\right)_D = \epsilon \left(\frac{N_3}{N_2}\right)_{MC}$$

Pixel efficiency given *at least one* ion-pair

$$\epsilon = \frac{\left(\frac{N_3}{N_2}\right)_{MC}}{\left(\frac{N_3}{N_2}\right)_{D\_MAX}}$$

Relative efficiency of plateau region (from data)

Efficiency with Cosmic Ray Muons

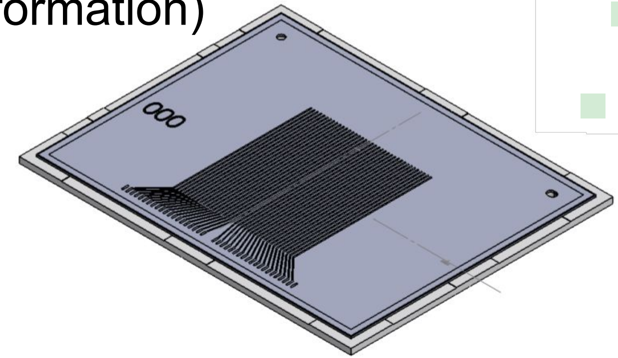


Relative efficiency of detector with cosmic ray muons *after* allowing for ion-pair formation:

$$\epsilon = 97.3 \pm 2.5\%$$

Summary/Next Generation

- Presented a hermetically sealed gaseous ionizing radiation detector
  - Operated for months on single fill
- Each cell responds as an individual detector
- < 3 ns timing resolution
- Spatial coverage increased from 18% to 70% with **µ**Hexcavity design
- Relative efficiency is unity for **µ**Hexcavity with cosmic ray muons & 3-component gas fill (allowing for ion-pair formation)
- <u>Next generation objectives:</u>
  - 100 KHz/cm^2
  - Increase pixel density

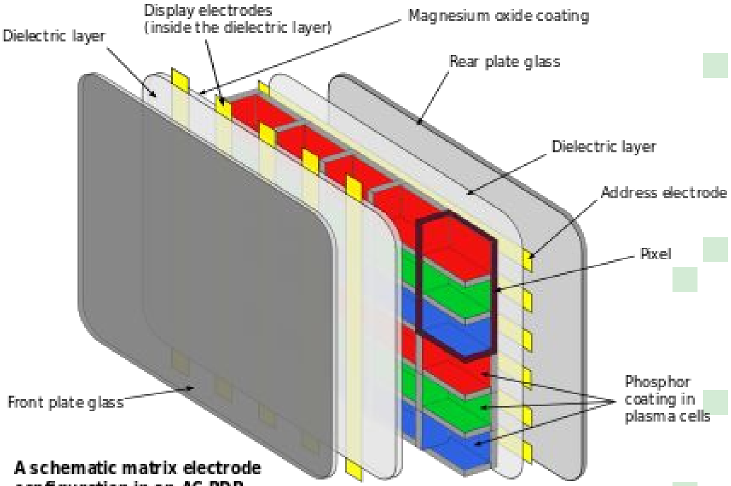


Thank you!

Bonus Slides

Plasma Display Panel Discharge

- Inert gas mixture held in array of cells between glass plates
  - Individually sealed cells
- Anti-parallel rows of address and transparent display electrodes in dielectric material + MgO coating
- Plasma discharge sustained when cell biased above critical potential



A schematic matrix electrode configuration in an AC PDP

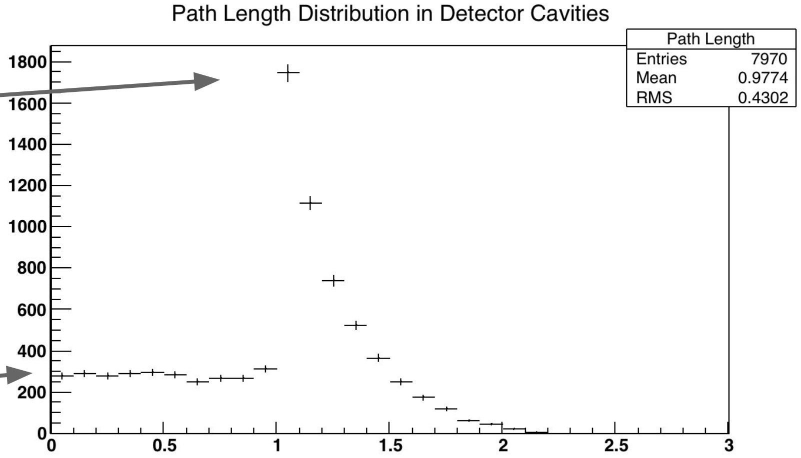
https://upload.wikimedia.org/wikipedia/commons/thumb/5/5d/Plasma-display-composition.svg/440px-Plasma-display-composition.svg.png

Efficiency with Cosmic Ray Muons

- Efficiency for throughgoing muons
  - Path length through pixel: 1 mm
  - Ion-pairs created per path length with chosen gas fill: 14.9 cm/atm
  - Probability to create at least 1 ion pair for a straight track: 1 - e^(-1.49) ≅76% -> Absolute efficiency
- Path length distribution through pixels:

Spike at 1 mm
(height of cavities)

Uniform
distribution
until 1 mm



Afterpulse Measurements