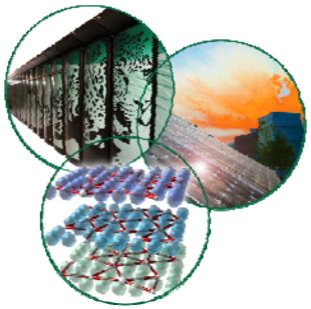
Development of Plasma Panel Sensors

hribf
Holifield Radioactive Ion Beam Facility



U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

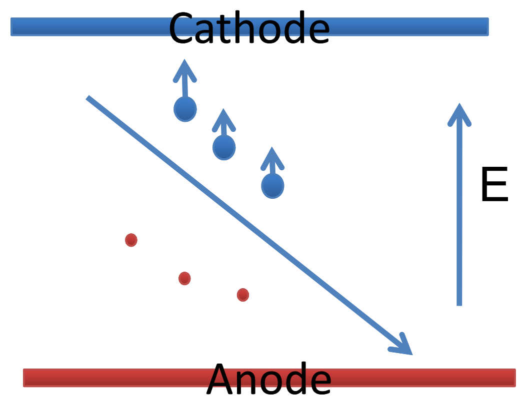
Development of Plasma Panel Sensors

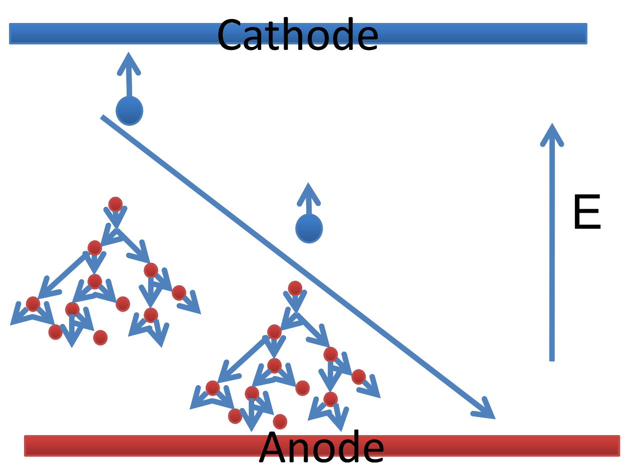
- The Idea – using plasma TV's as detectors
- The Collaboration – international in scope
- The Technology – Why might this work?
- Where are we now?
- Where are we going?

Gas Ionization Detectors

Fast charged particles produce ionization in a gas

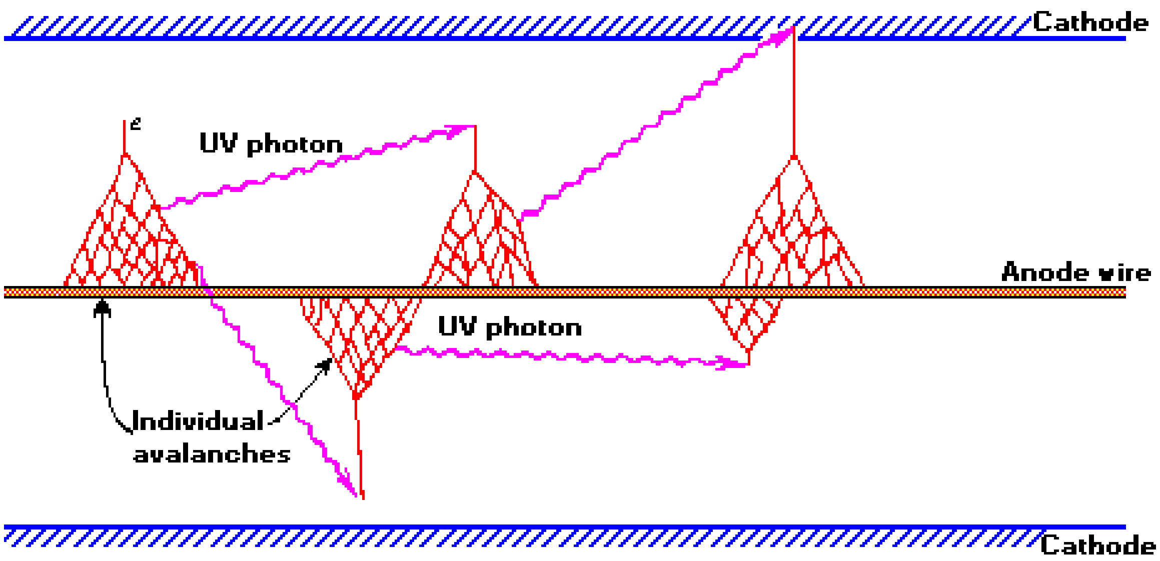
- Ionization counter
  - Low electric field
  - Low gas pressure
  - Ions collected on planes
- Proportional counter
  - High electric field
  - Higher gas pressure
  - Electron multiplication near anode - Avalanche
  - Avalanche spreading minimized





Gas Ionization Detectors

- Avalanche counter
  - High electric field near anode
  - High gas pressure
  - Multiplication and avalanche spreading



Proportional counters

- Multiwire Proportional Counter (Charpak, 1968)
  - Wire space 1 to 2 mm
  - Cathode-anode space 10 mm
  - Localization 0.02 mm
  - Many gas mixtures available
  to optimize performance

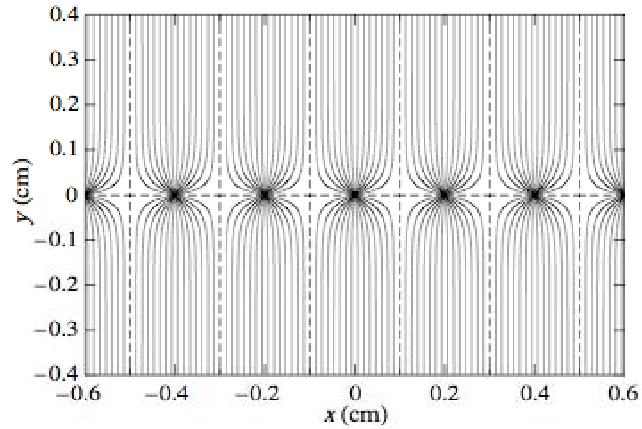


Figure 28.3: Electric field lines in a (MWPC) with an anode pitch of 2 mm as calculated with GARFIELD program [83].

Micropattern detectors

- Use techniques of IC production to make proportional counters
  - Micro Strip Gas Counter (Oed, 1988)
    - Pitch of 0.2mm, anode of 0.02mm
    - Small electrodes damaged easily

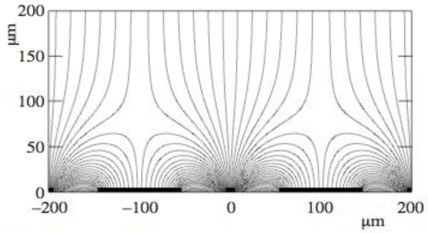


Figure 28.4: Electron drift lines in a micro-strip gas chamber with a pitch of 200 μm.

  - Gas Electron Multiplier (Sauli, 1996)
    - Multiplication happens in the holes
    - More rugged, similar dimensions to MSGC
  - MicroDot, CAT, ...

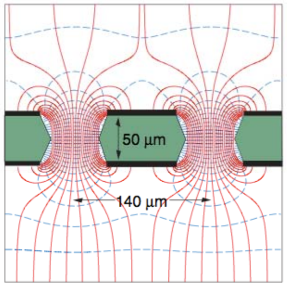


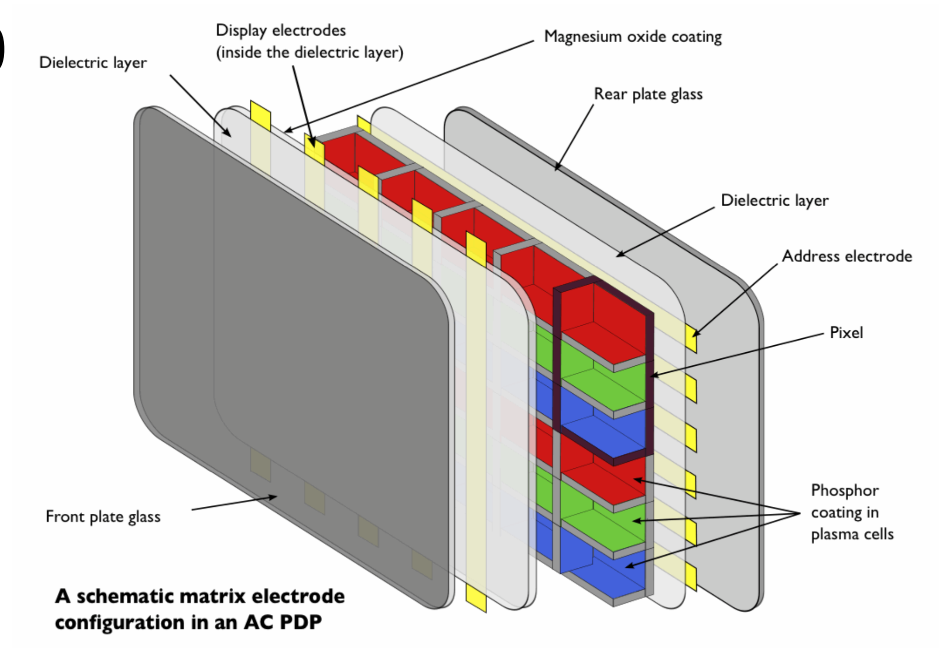
Figure 28.10: Schematic view and typical dimensions of the hole structure in the GEM amplification cell. Electric field lines (solid) and equipotentials (dashed) are shown.

Plasma Display Panel

Widely used commercial product

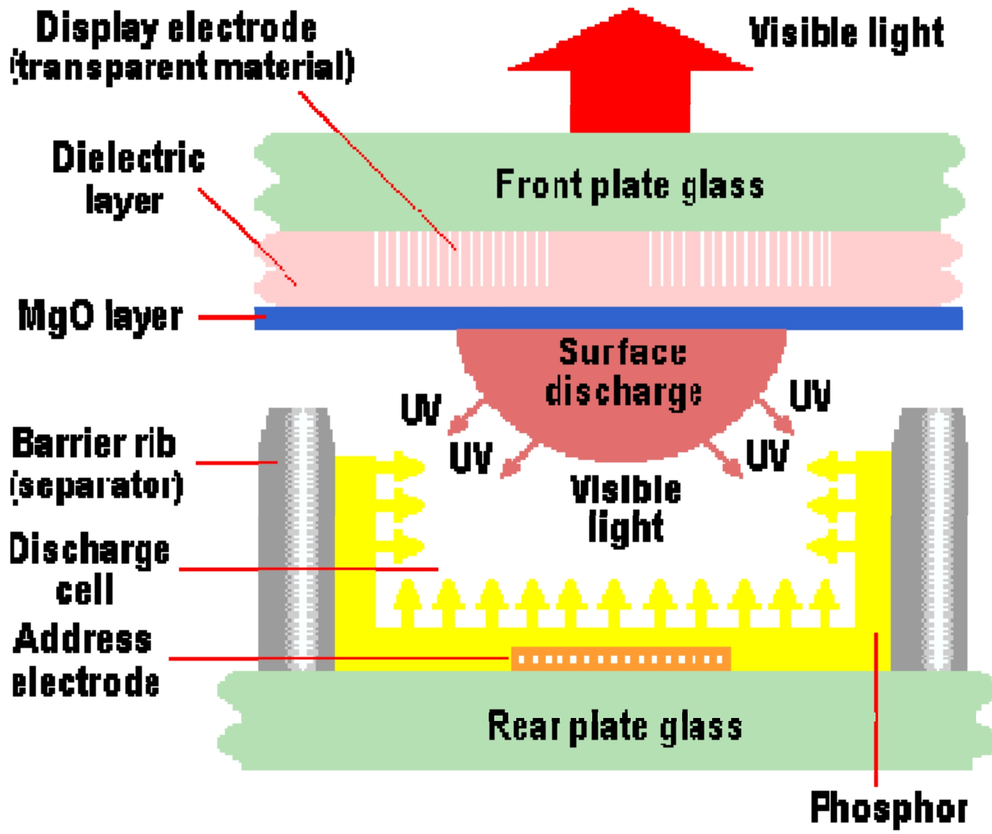
Apply sufficiently high electric field in a cell generates a plasma – UV emitted from the plasma excites the phosphor

- Invented in 1964
- 10^7-10^8 units manufactured 2010
- $1 / sq inch
- 100,000 hour lifetime



Plasma Display Panel

- Two classes of panels
  - AC
    - Dielectric insulation of electrodes
    - Low power, long life
    - Most PDPTVs
  - DC
    - Resistive connection to the discharge cell
    - Brighter, Faster than AC



From displays to detectors

- Investigate plasma display panels for inexpensive, large area arrays of micro-avalanche cells for detection of MIP's and heavily ionizing particles.

- As a particle detector the cell is biased to:
  - operate at plasma discharge voltage, near Geiger mode
  - pixels activated by:
    - direct gas ionization
    - ionization in a conversion layer – emitting electrons into gas (e.g. photocathode)

PPS aims to inherit Plasma Display Panel features:

- Hermetically sealed volume → no gas flow
- Inherently digital → Avalanche response with large signal
- Targeted cell size of about 50-200 µm → excellent spatial resolution
- Fast cell response → rise-time ~ 1 ns
- Low power → 50 pJ/discharge (100 um cell) or 1 $\mu W/cm^2$ at 20 kHz/cm^2
- Scalable panel size → Up to meter size with thickness ~ 0.3 - 5 mm

PPS aims to inherit Plasma Display Panel features:

- Amorphous and non-reactive materials ➔ radiation damage resistant
- Small drift regions and gas gaps ➔ unaffected by magnetic fields
- Low production costs ➔ projected on order of ~ $1 per sq. inch
- Long lifetimes ➔ 10^5 hours common for PDPs

Plasma Panel Sensor

- First described by P. S. Friedman, *IEEE Nuclear Science Symposium and Medical Imaging Conf., Puerto Rico, NSS/MIC: Paper J03-7, Oct. 26, 2005*
- SBIR Phase I FY2007 topic 26A – Integrated Sensors, LLC.
- SBIR Phase II FY2008

Applications of PPS

- Many of same applications of gas ionization counters
- We are considering:
  - very low mass beam position monitors
    - industrial interest from proton therapy makers
    - HRIBF facility has been interested
  - neutron detectors
    - "Gadolinium Thin Foils in a Plasma PanelSensor as an Alternative to ^{3}He", R. Varner, et al, IEEE NSS-MIC 2010, N41-174.
  - muon counters for SuperLHC
    - motivation of the University of Michigan group
  - Photon counters for scintillators
    - "Simulation of a scintillator-based Compton telescope with micropattern readout", R. Varner, et al., IEEE NSS-MIC 2007.

Original ANS&T Proposal

- Applications of Nuclear Science and Technology – 2009
  - "Micropattern Optical Sensors for Scintillation Counters"
    - Development of Photocathode
    - Simulation and testing of utility of PPS device in photon counting readout of scintillators

ANS&T Recommendation - 2010

- "It is recommended that at this stage basic studies of discharge mechanism and feedback mechanisms should be considered first."

- "...but needs much more R&D to show feasibility"
- "A lot of technical problems need to be overcome, and success is not guaranteed in the short run."
- $650k – three years

Modified Research Plan

- Demonstrate and characterize the ionized radiation detection properties of PPS
  - investigate plasma panel sensor pulses
    - propagation of the pulses
    - sensitivity to radiation
    - effects of electrode patterns and gas mixtures on the pulses
  - Simulation-based models
  - Investigations using a test fixture with PPS electrodes
  - Small, commercially produced PPS modules
- Produce a prototype with 0.1mm pixel spacing

International Collaboration

- Oak Ridge National Laboratory
  - Robert Varner*
- Integrated Sensors, LLC. – P. S. Friedman*
- University of Michigan, Department of Physics
  - Dan Levin*, Claudio Ferretti*, J. Chapman*, Curtis Weaverdyck, Robert Ball
- Tel Aviv University, Department of Physics
  - Yan Benhammou, Meny Ben Moshe, Erez Etion, Yiftah Silver

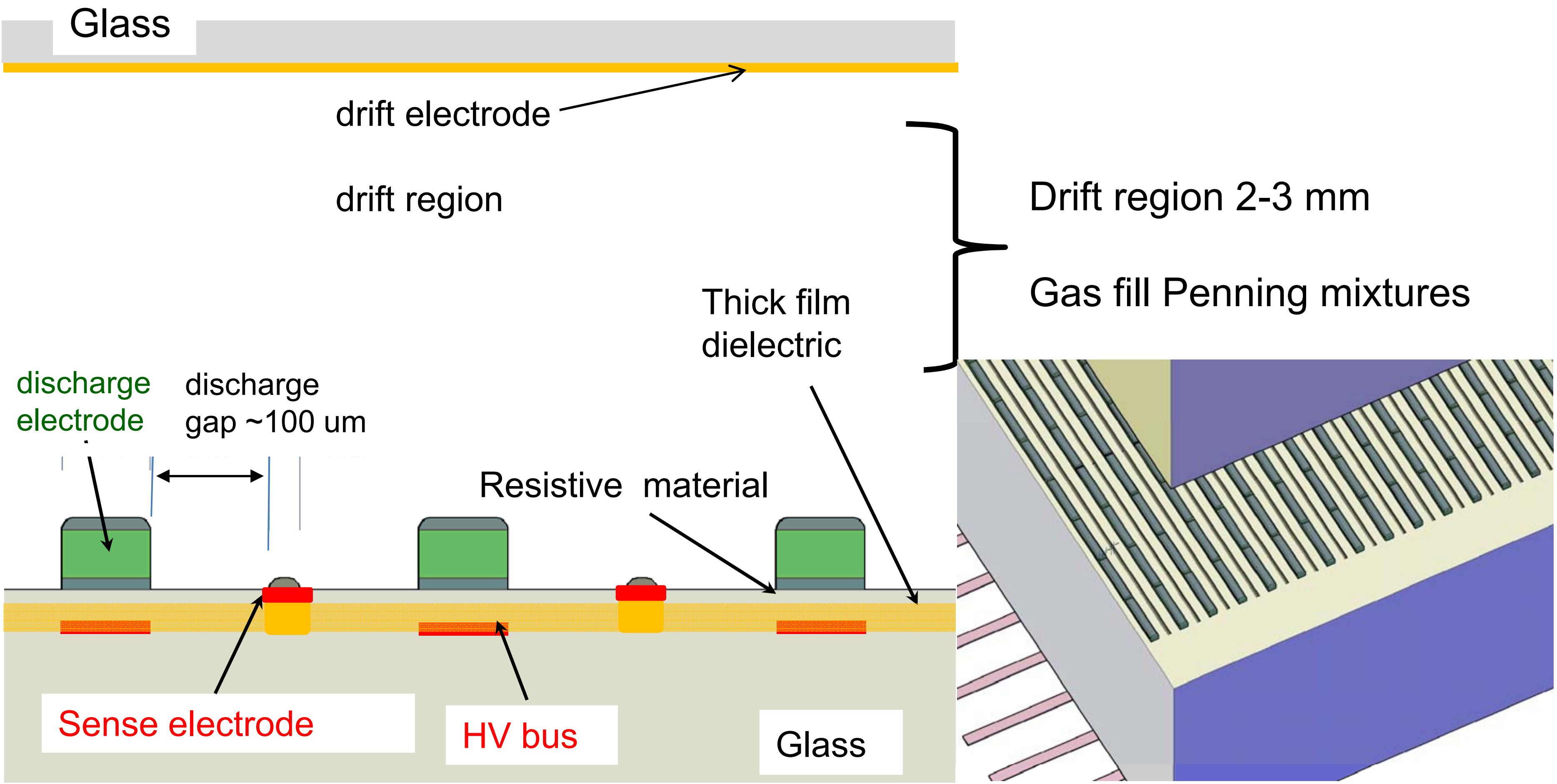
*funded by ANS&T

Current progress in PPS investigation

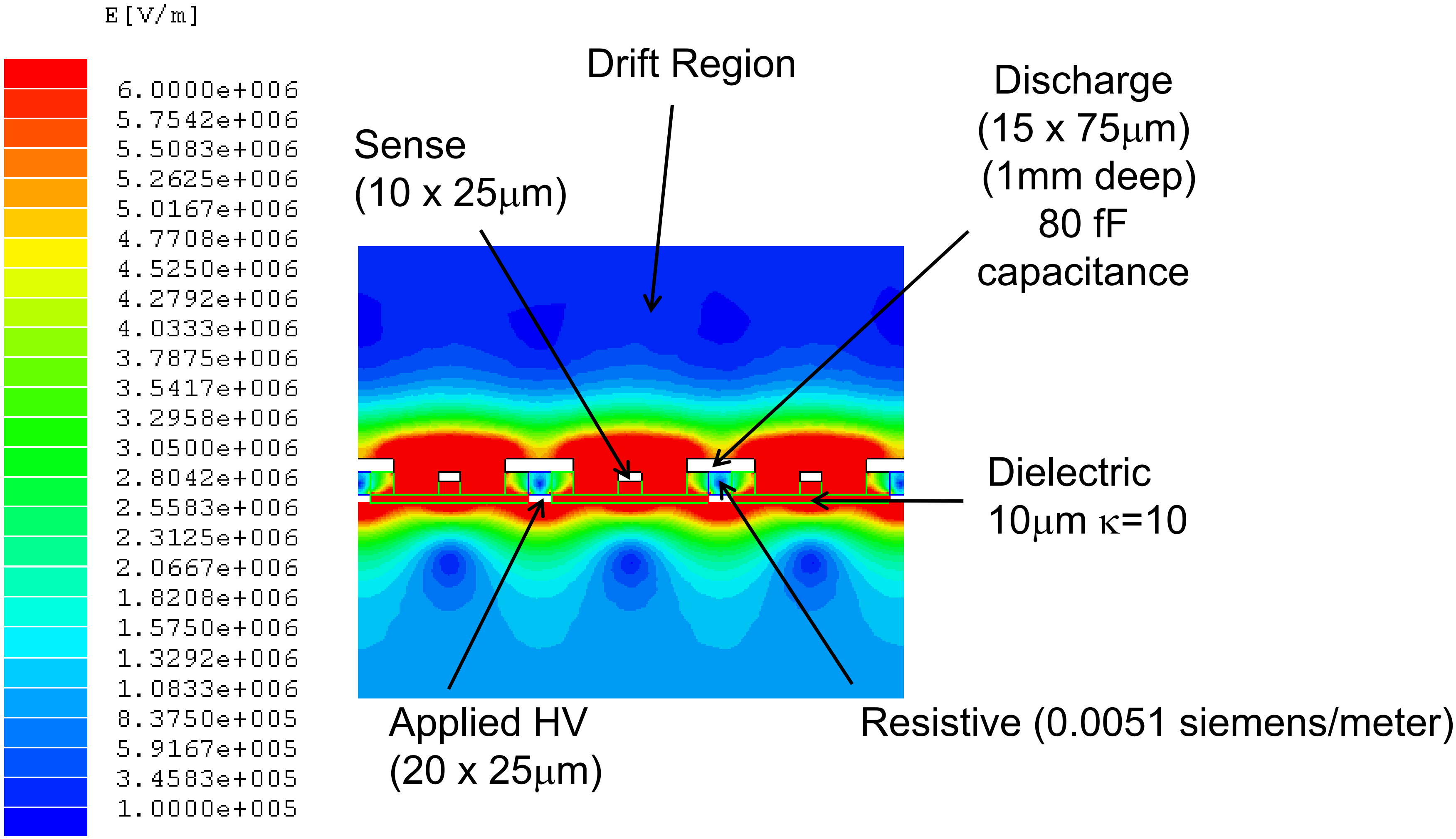
- Modeling
  - COMSOL: electric field and charge motion – Estimate capacitance of cells
  - SPICE: electrical characteristics of PPS cells
- Commercial PDP
  - Starting with Vishay PD128G032-1, DC-PDP (volume discharge)
    - Gas mixtures and pressures
    - Pulse timing – rise time, recovery time
    - Pulse spreading, dark current
- Test Chamber
  - Surface discharge electrode studies
  - Gas mixture, pressure studies

Test Chamber electrode design

<u>A *4-electrode* layout with lateral discharge gap</u>



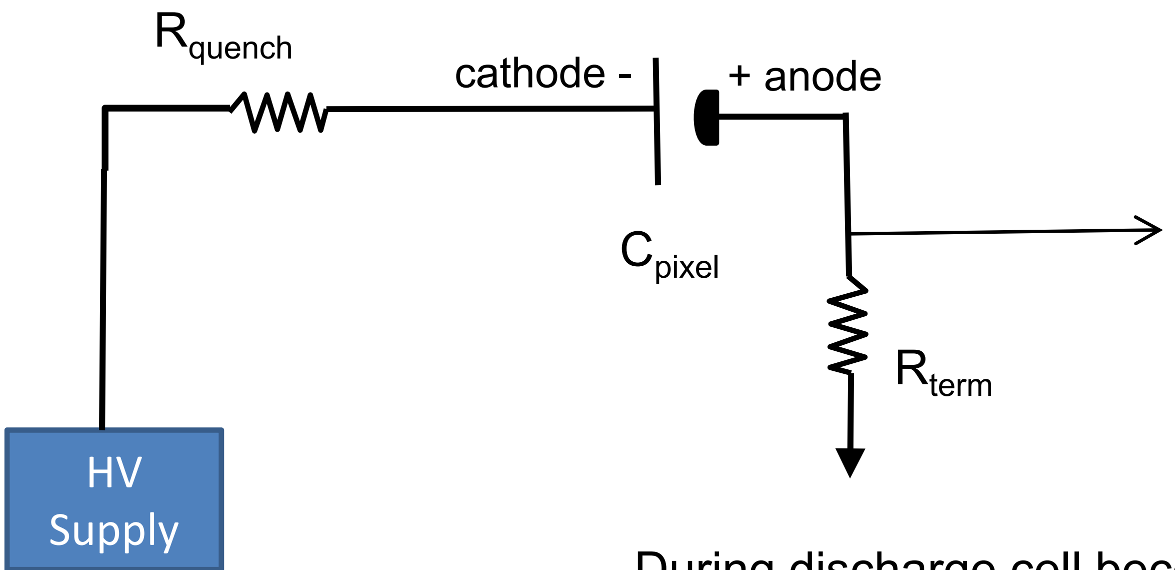
Electric Field Map



Models of PPS

Modeling in SPICE: start with

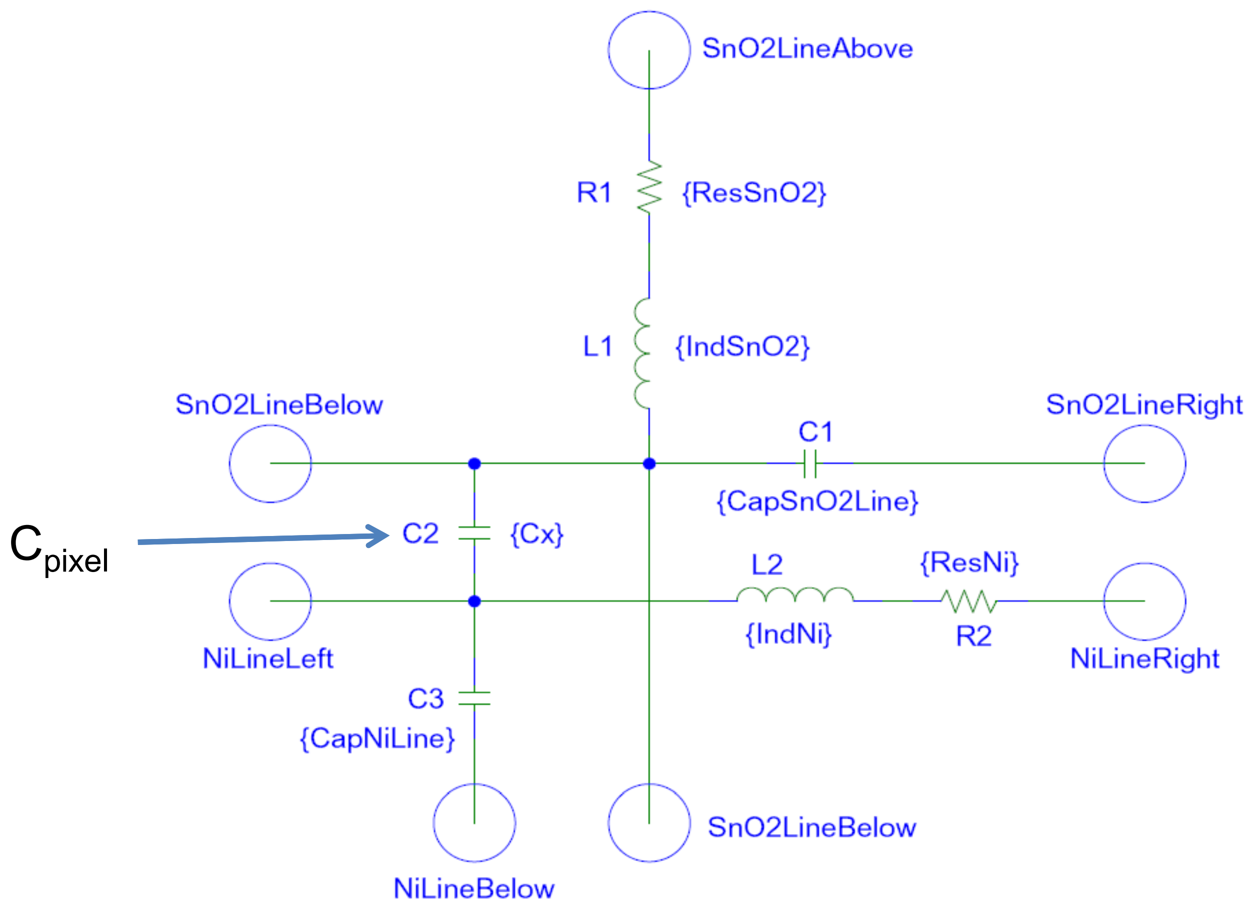
simplified schematic of single PPS discharge cell



During discharge cell becomes conductive,
Voltage drops ➔ E field drops
Discharge self-terminates

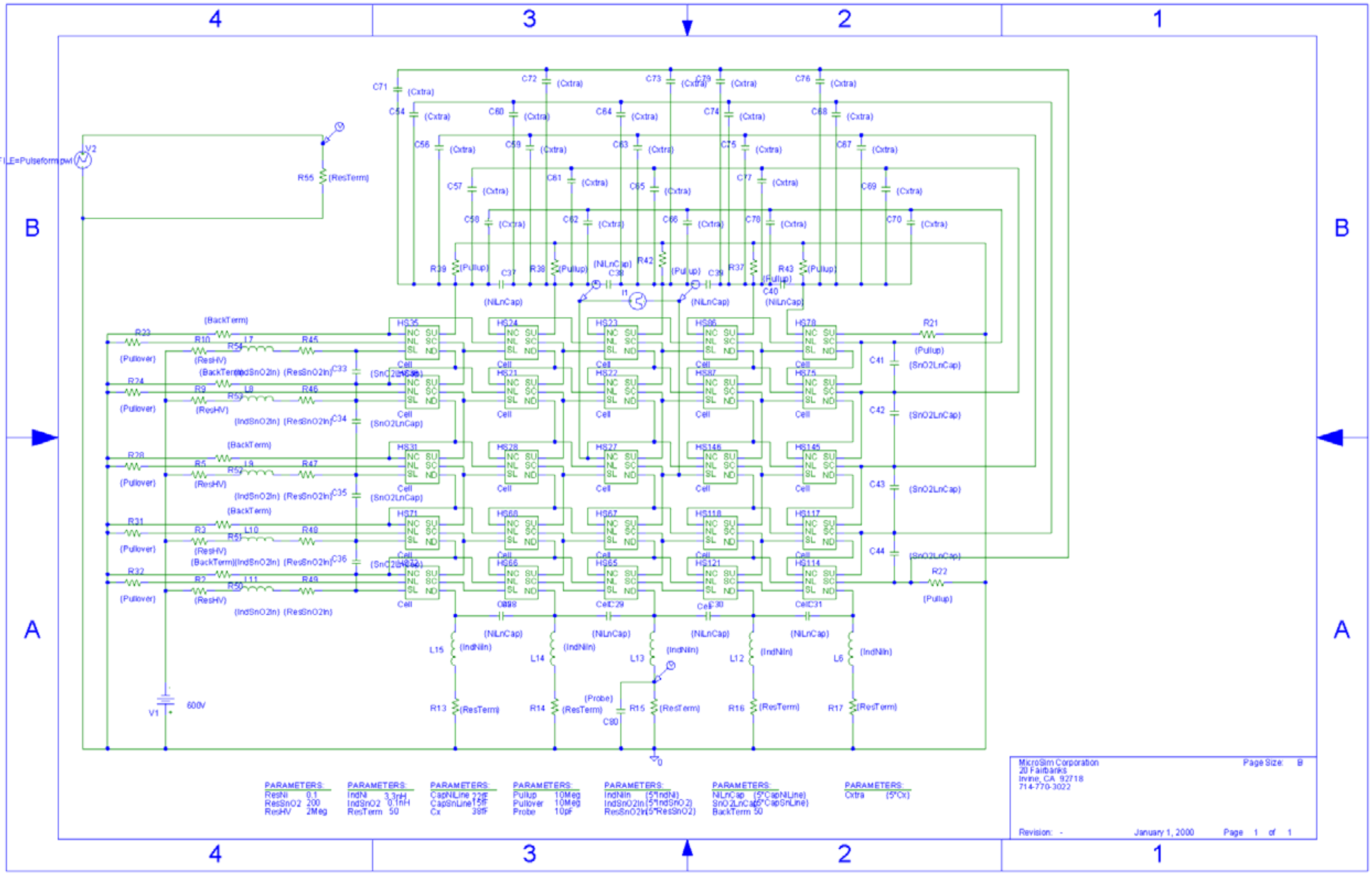
Modeling the PPS

More realistic cell schematic of discharge cell:
includes stray capacitances, line resistance, self inductance
Parameters determined from COMSOL electrostatic model

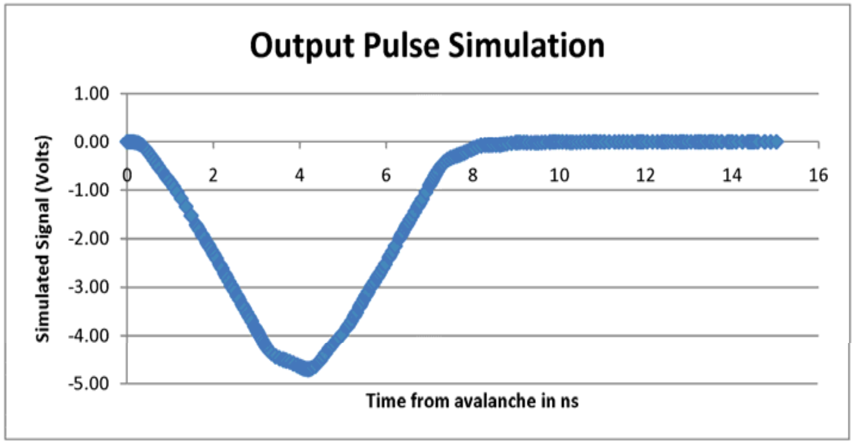


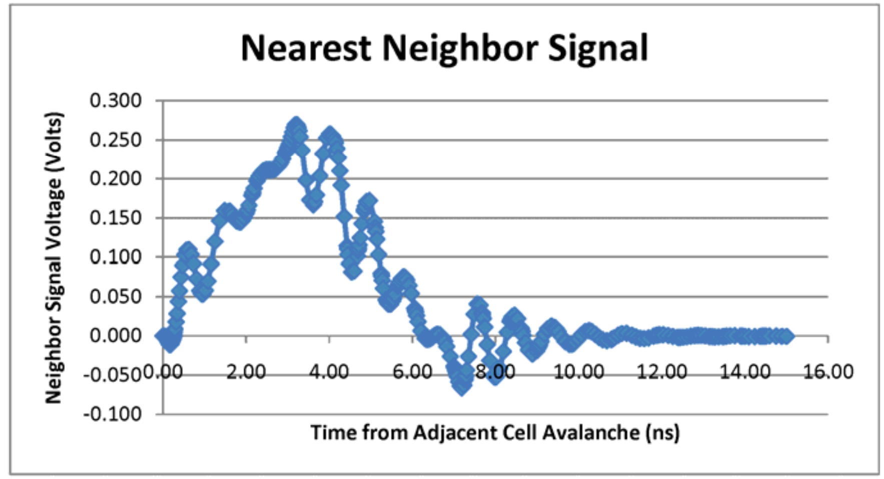
Modeling the PPS

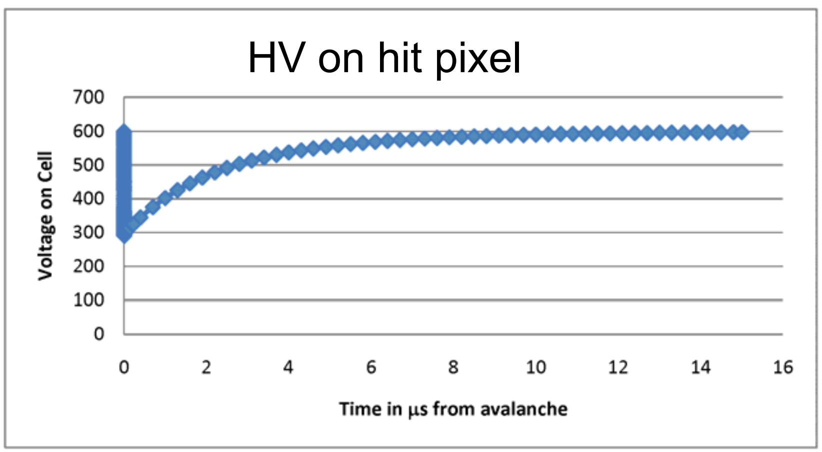
Finally, add in neighboring cells to form a larger cell array…

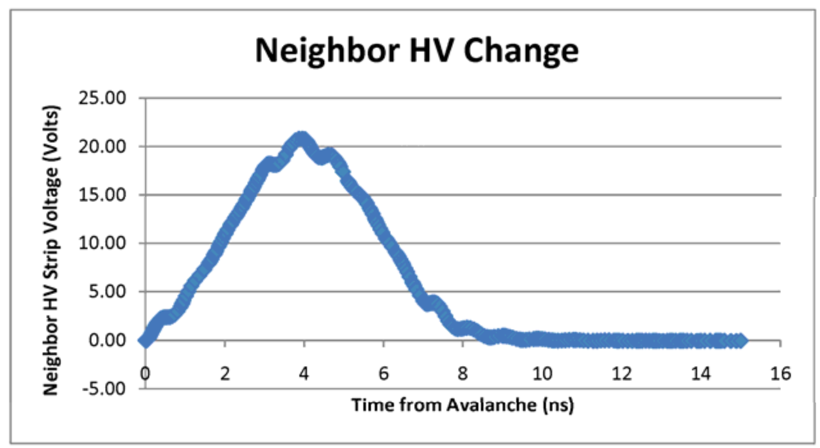


SPICE Output

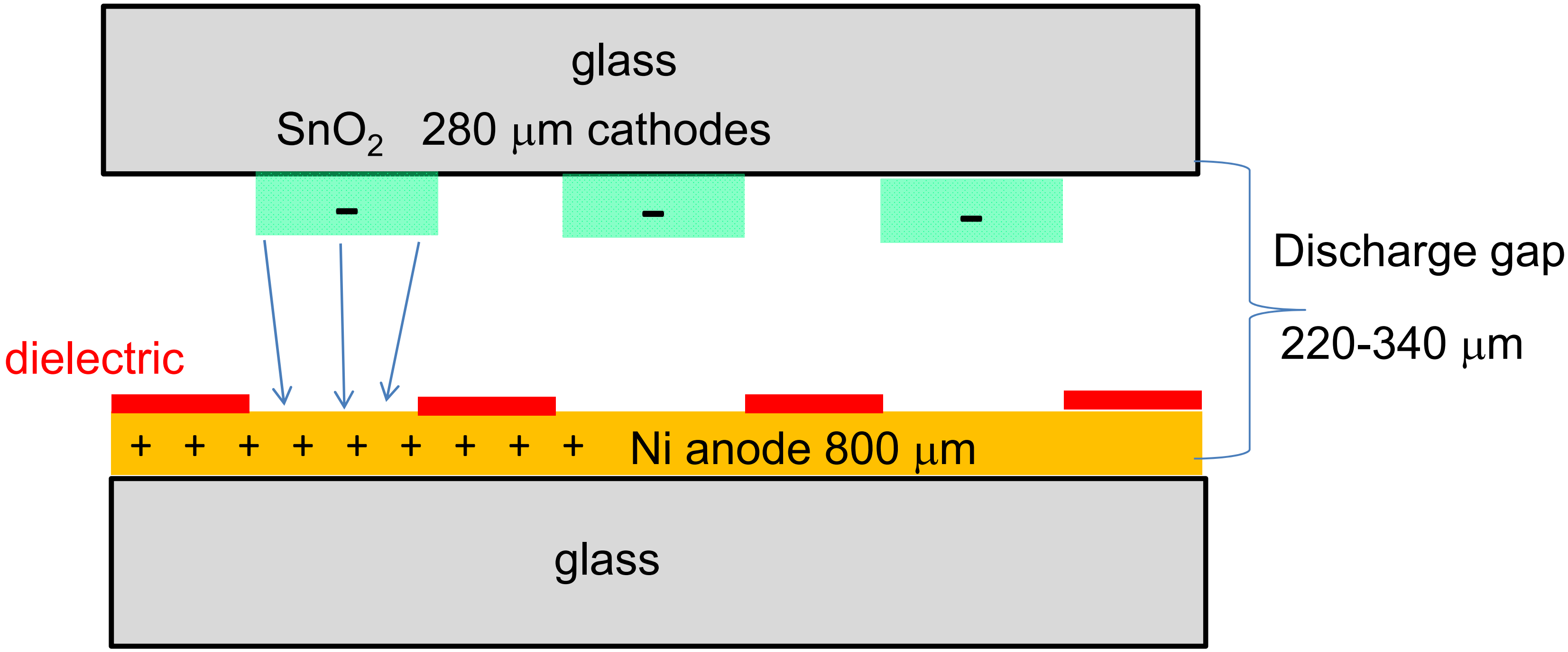








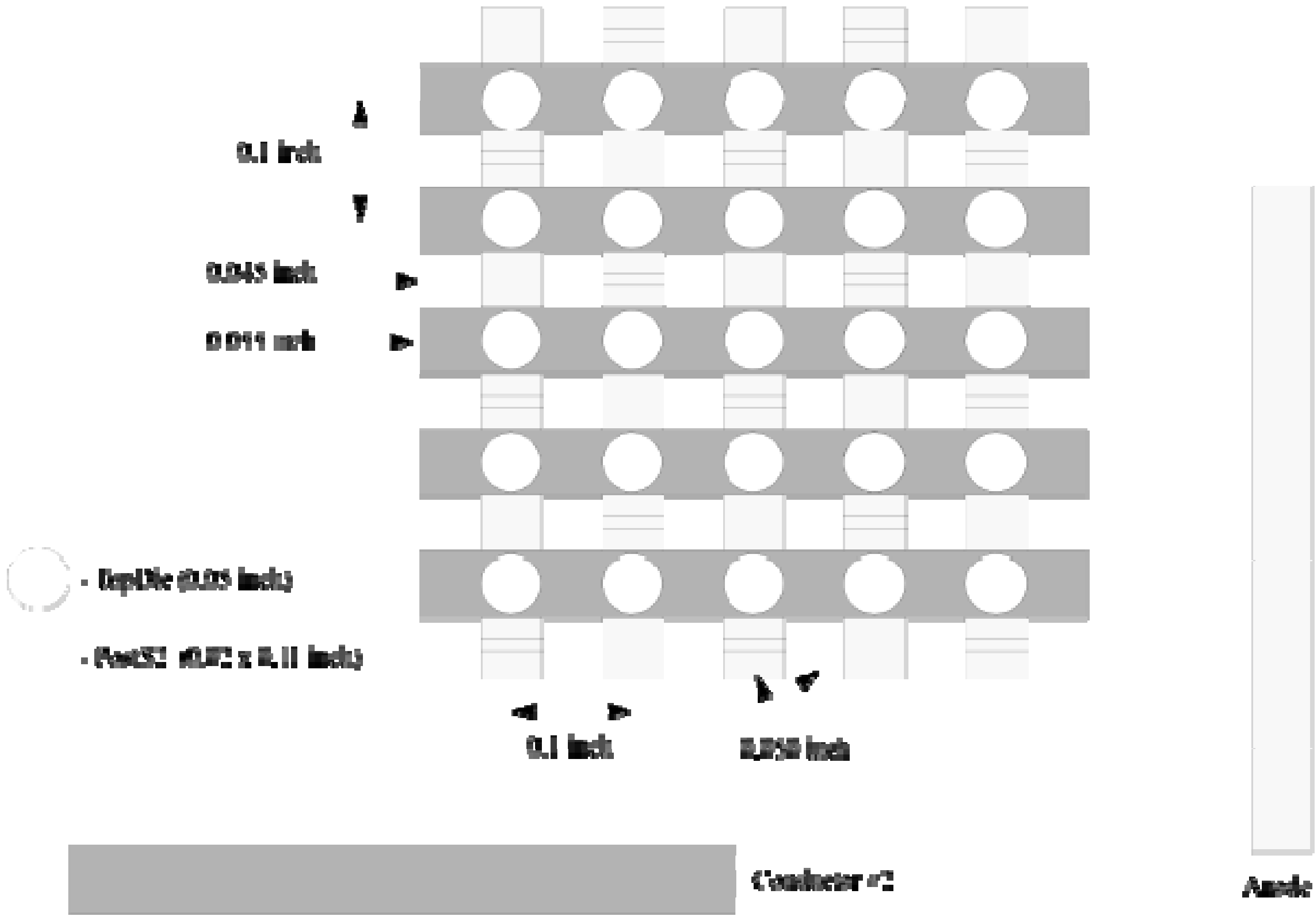
Demonstration using Commercial DC-PDPs

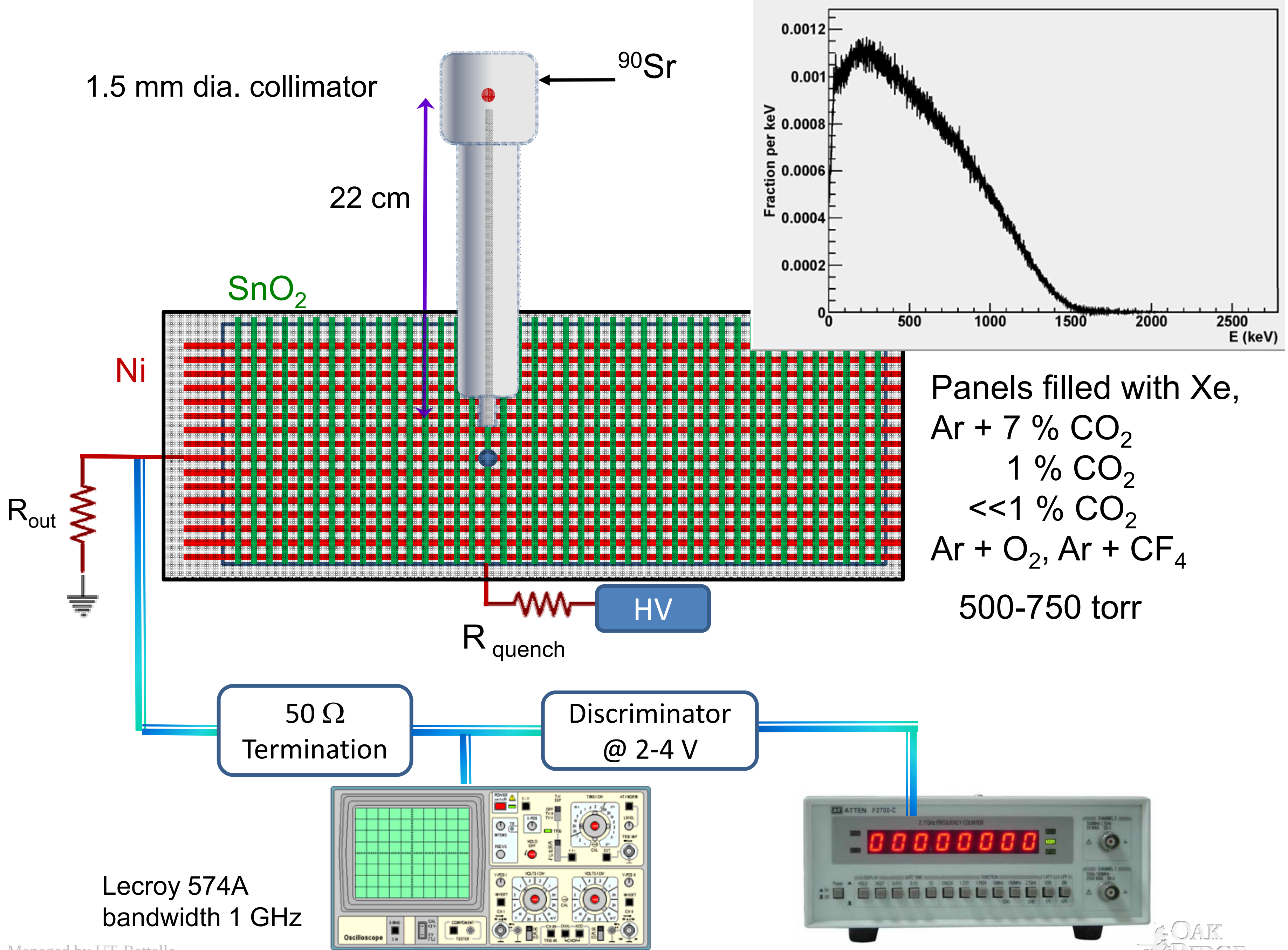


Panel A:
Gas mix: Xe @ 650 torr
Filled: Aug 2003

Panel B:
Gas = Ar + CO_2 (7%, 1%, << 1 %)
also: Ar + O_2, Ar + CF_4

Vishay design





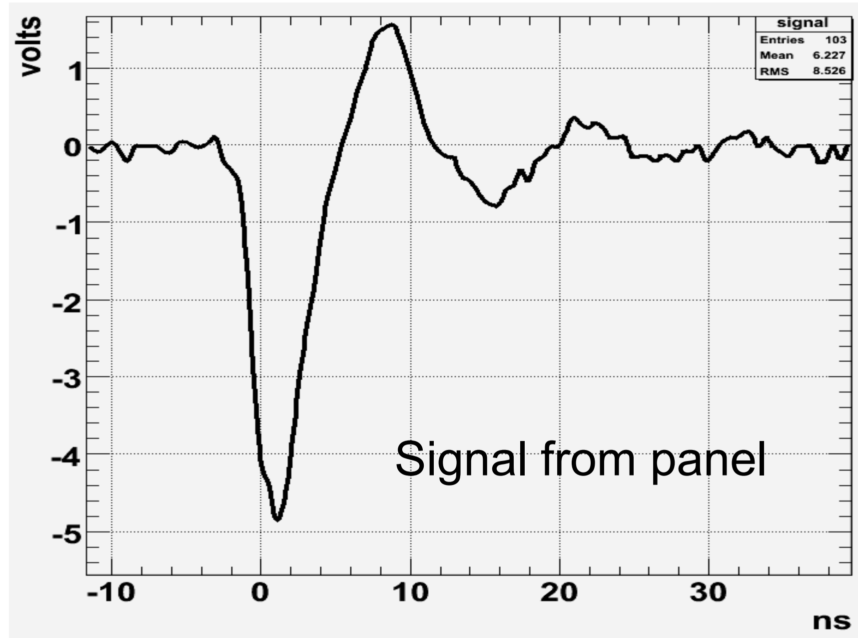
Panels filled with Xe,
Ar + 7 % CO_2
1 % CO_2
<<1 % CO_2
Ar + O_2, Ar + CF_4

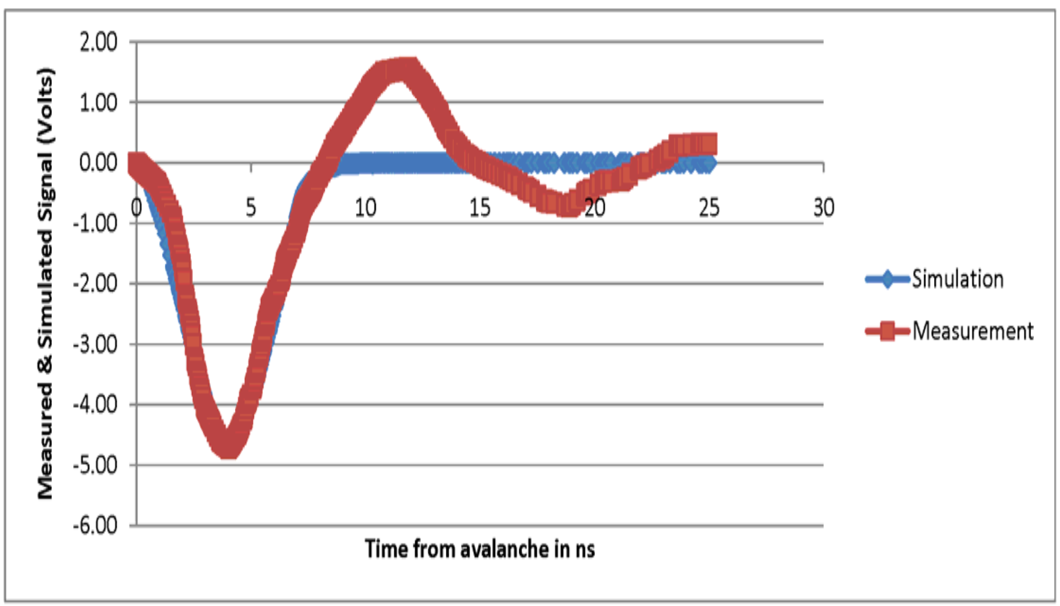
500-750 torr

6" PDP filled to 650 torr of Xe in 2003.
Seven years later…

- single pixel hit → (x,y) position known to (300, 800) μm

- 10%-90% rise time ~ < 2 ns
- FWHM 4 ns
- Scale amplitudes measured in ***Volts***
- Discharges at ~700 V



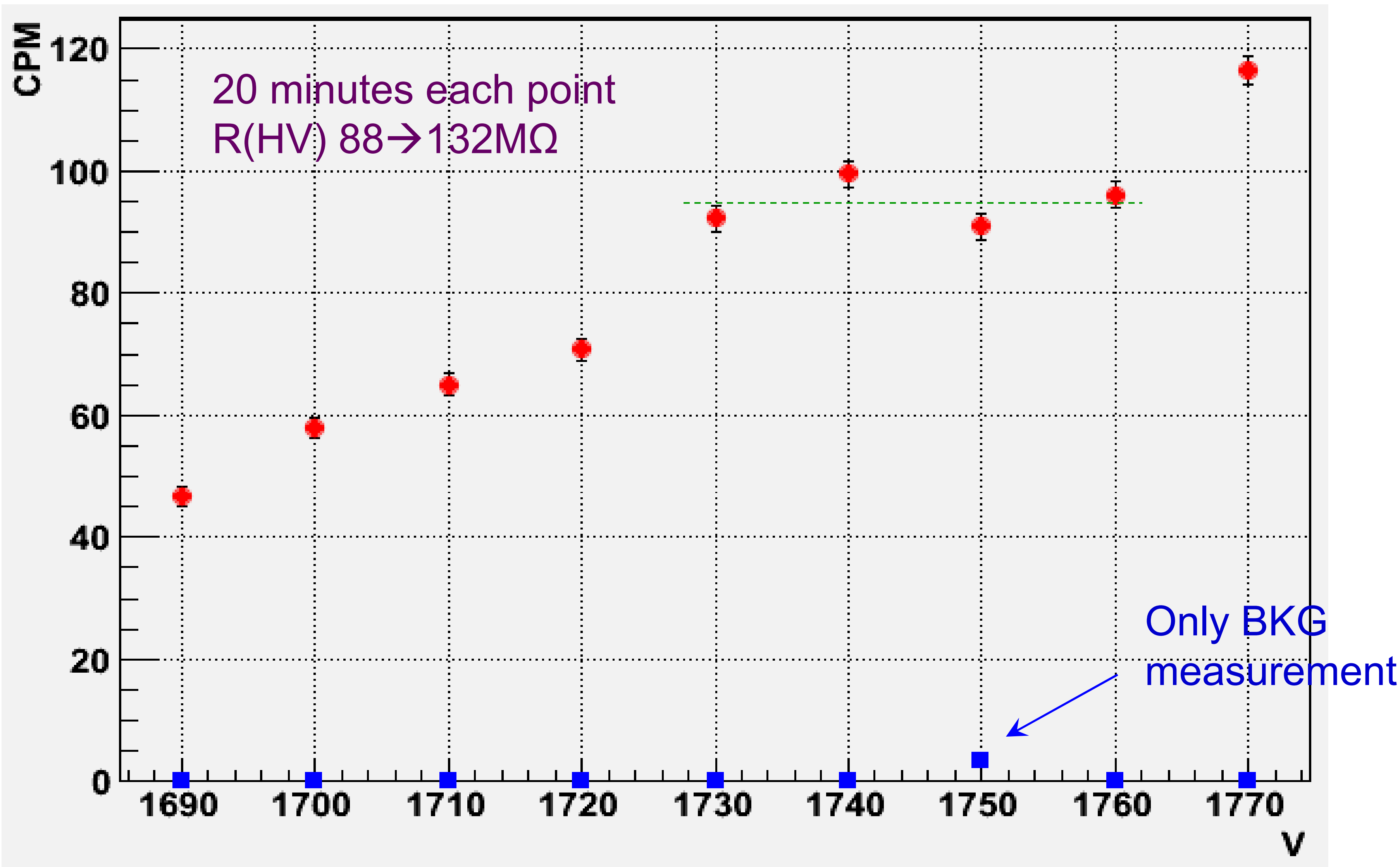


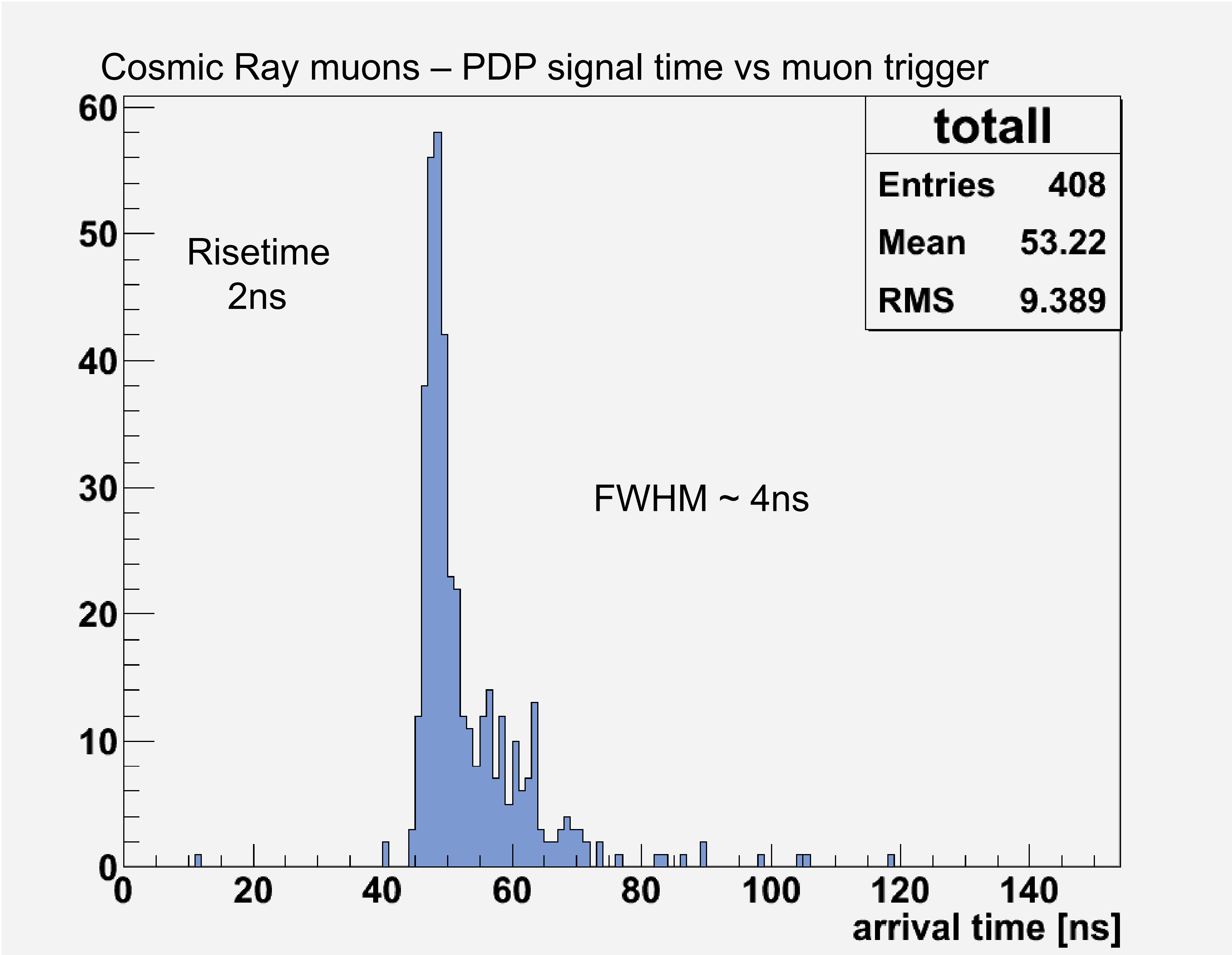
SPICE modeling

parameters from COMSOL

assumes 2 ns discharge

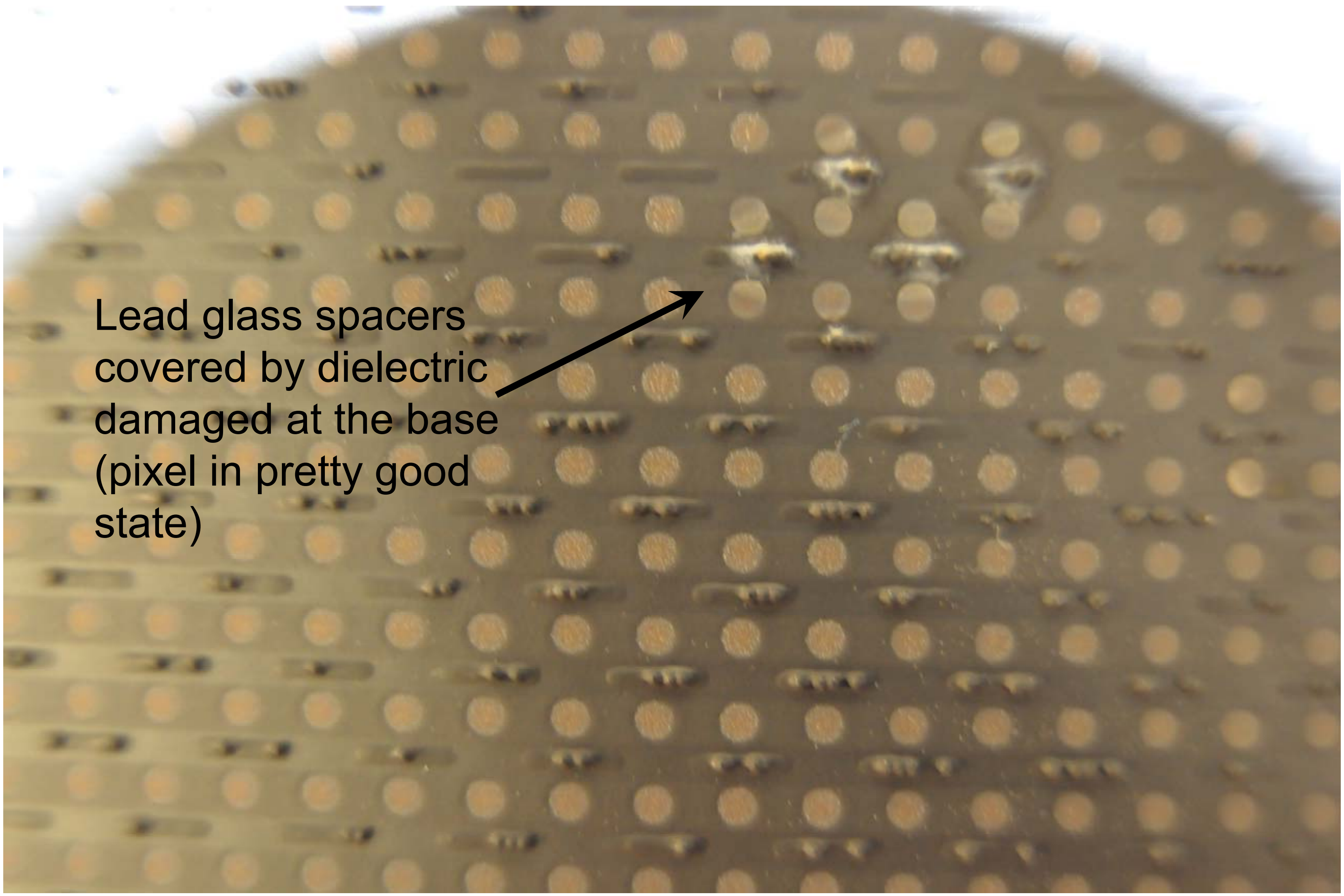
Final Voltage Scan





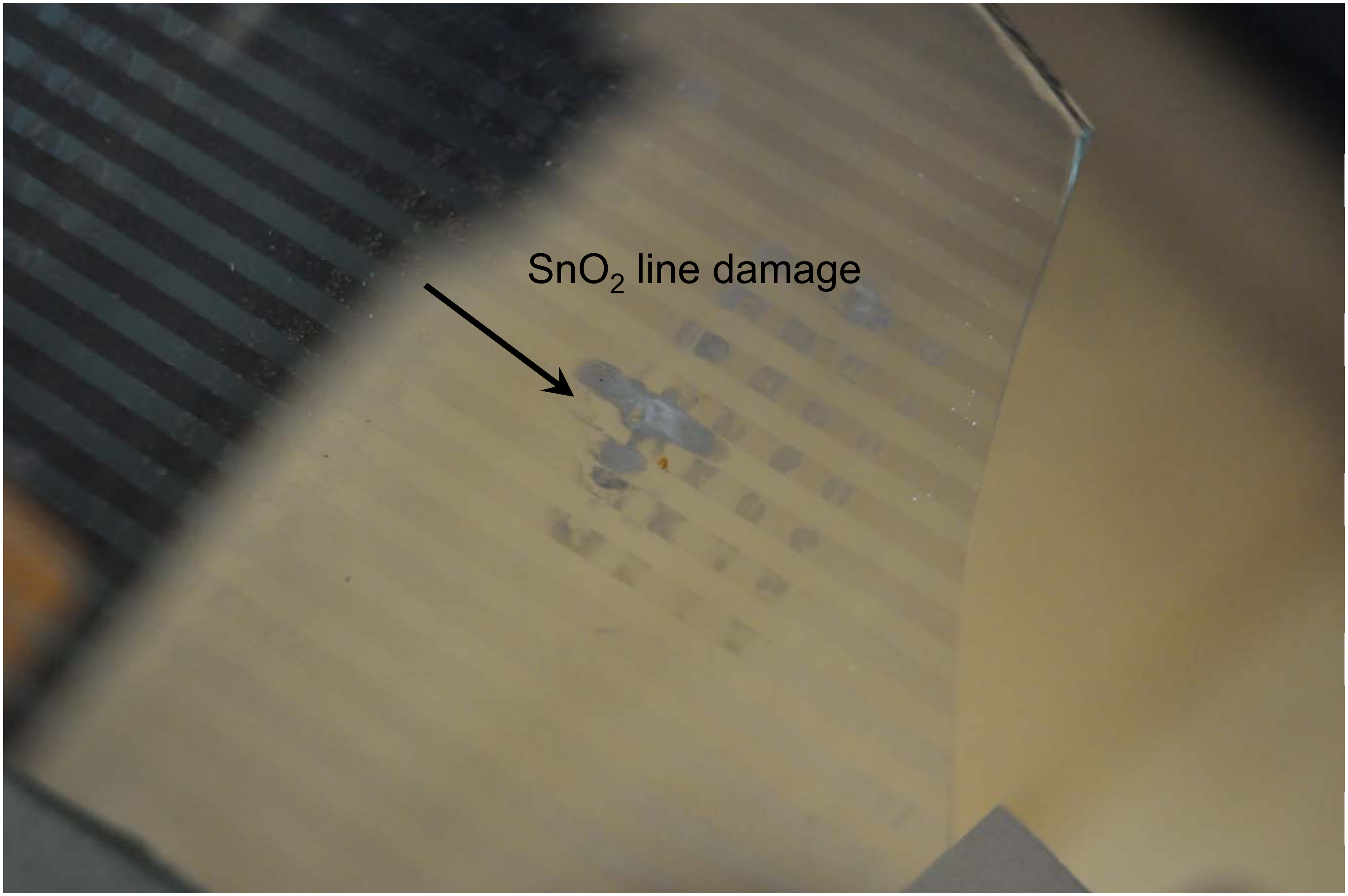
Cosmic Ray muons – PDP signal time vs muon trigger
totall
Entries 408
Mean 53.22
RMS 9.389
Risetime
2ns
FWHM ~ 4ns
0
10
20
30
40
50
60
0
20
40
60
80
100
120
140
arrival time [ns]

VP1 ‘spacer’ Damage



Lead glass spacers covered by dielectric damaged at the base (pixel in pretty good state)

VP1 Glass Side



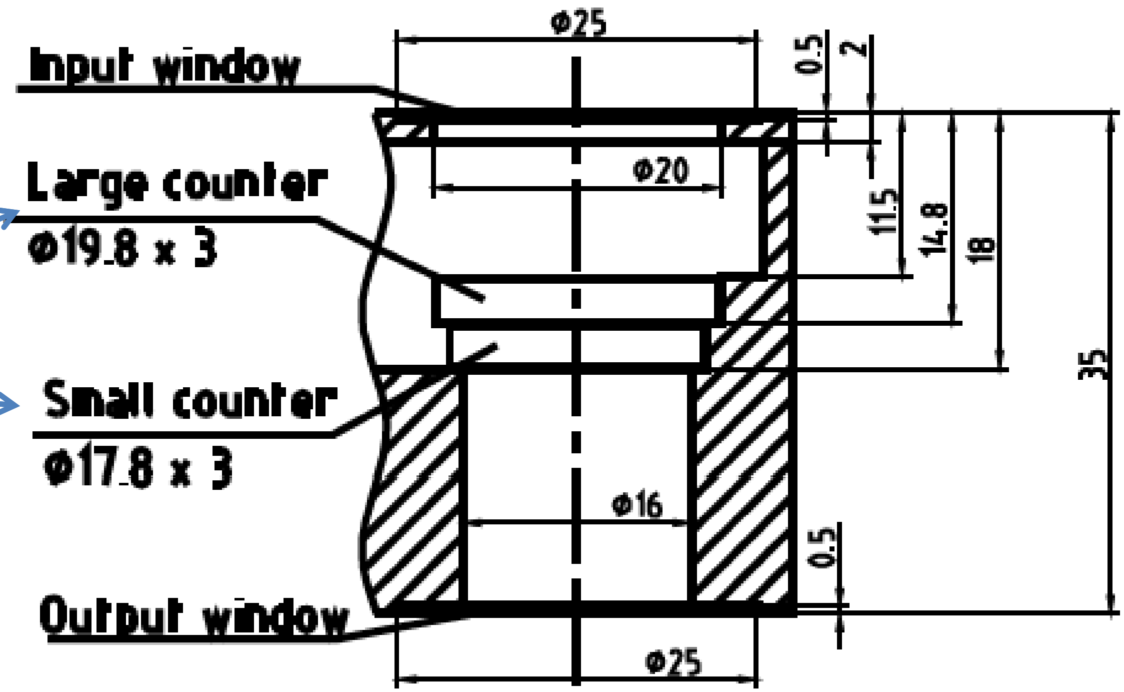
Setup for next set of tests

- Source : Strontium 90, ~3 mCu, not collimated

- Hodoscope :

2 PMTs,

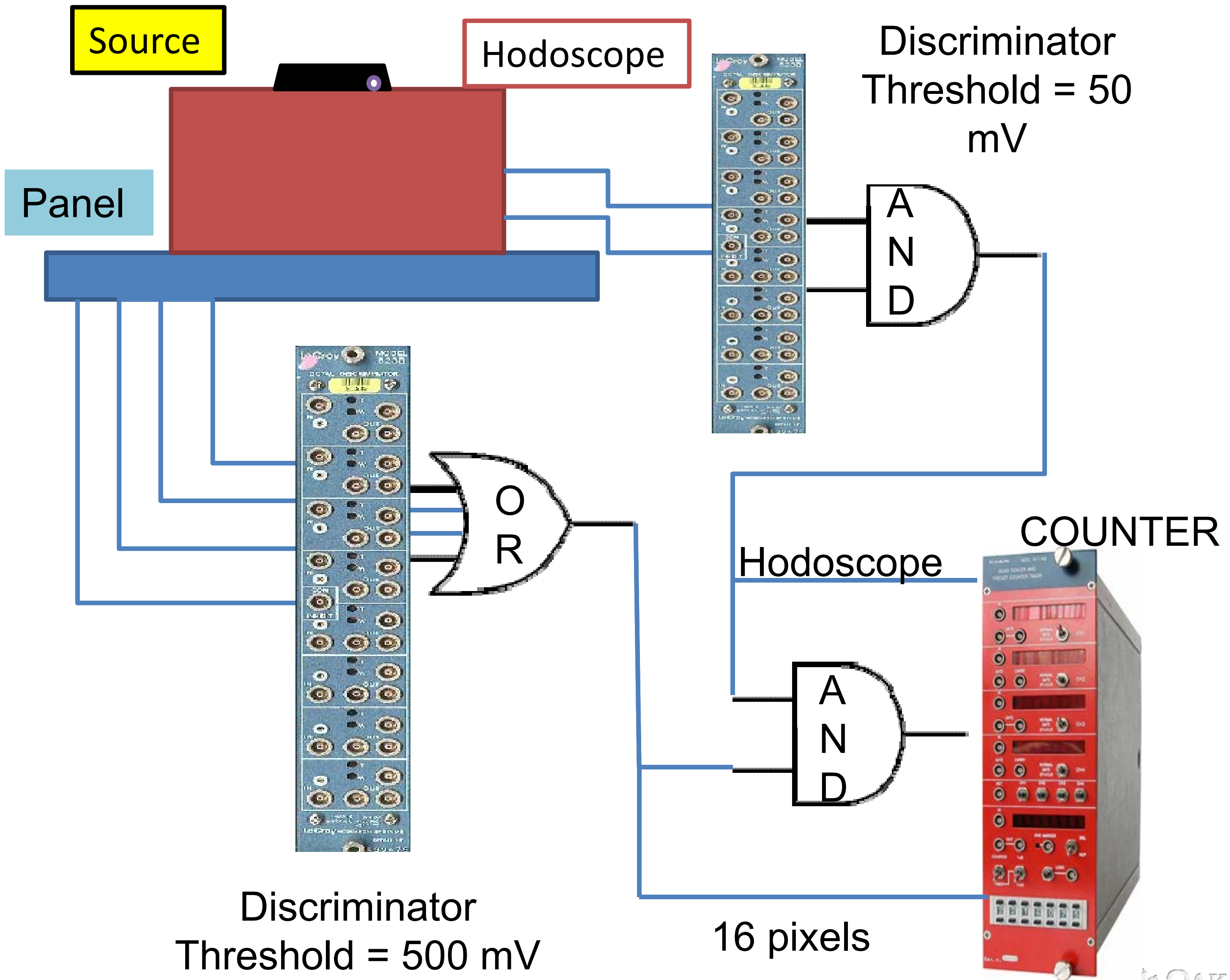
~2.5 cm^2 active area



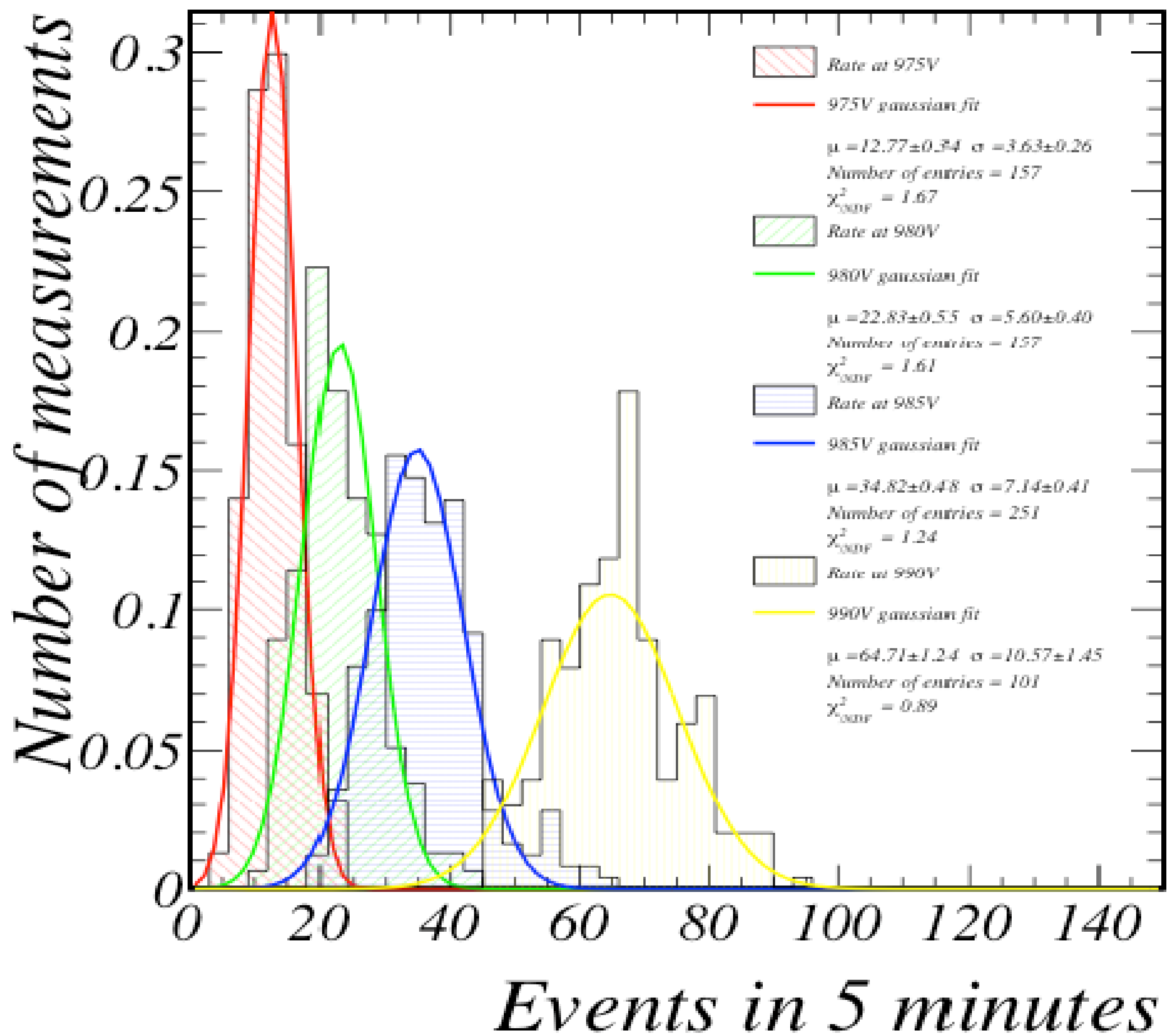
- Panel VP1 : gas Ar-CO2 93%-7% 600 Torr.

4 readout lines and 4 high voltage connected : 16 pixels

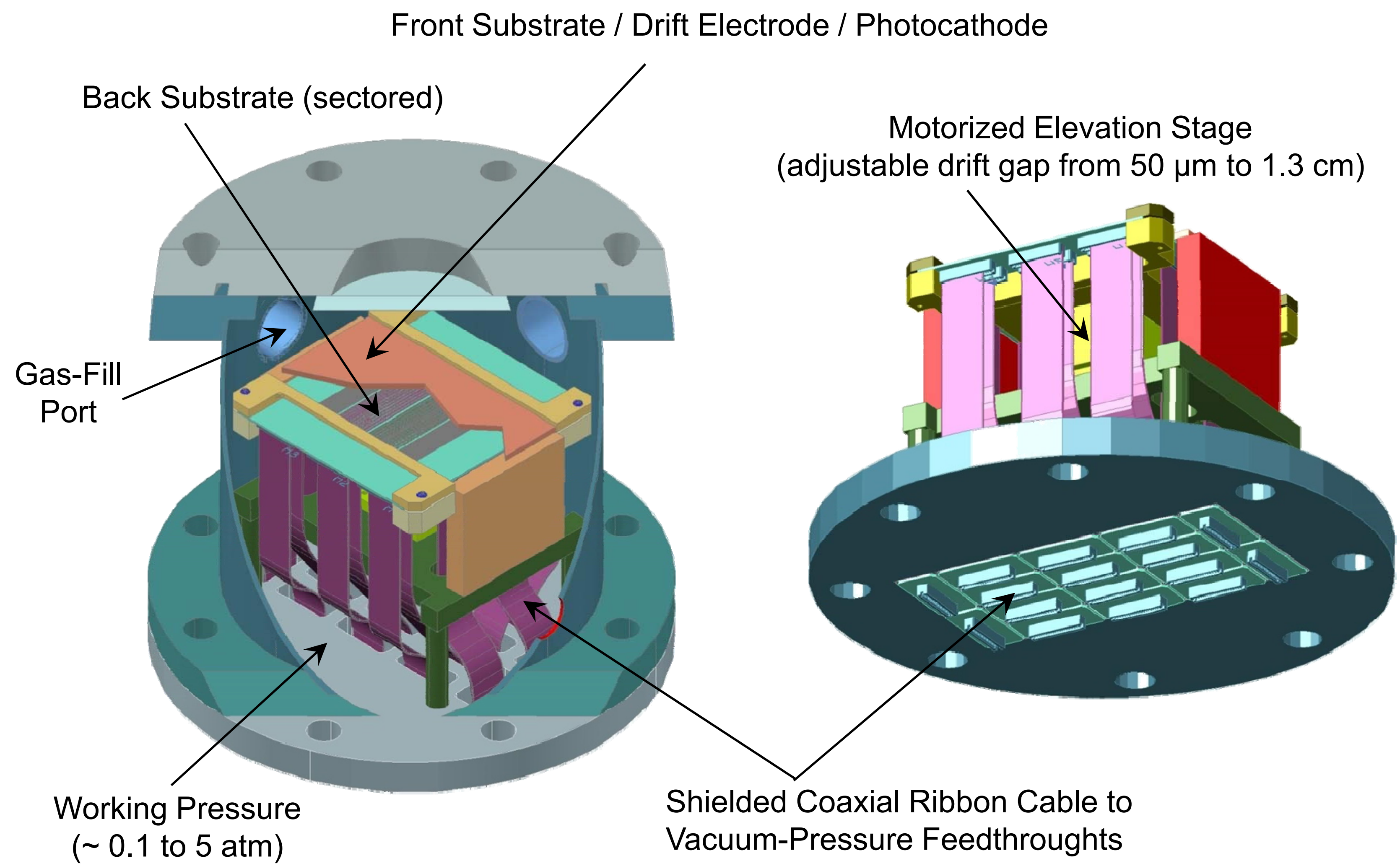
Testing conditioning of the panels



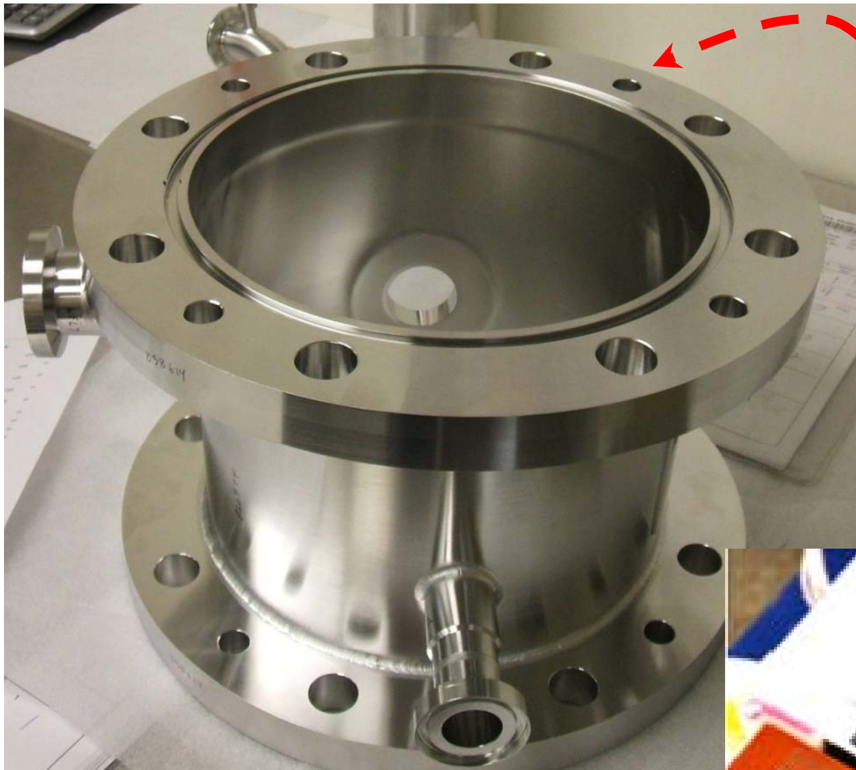
Voltage saturation studies



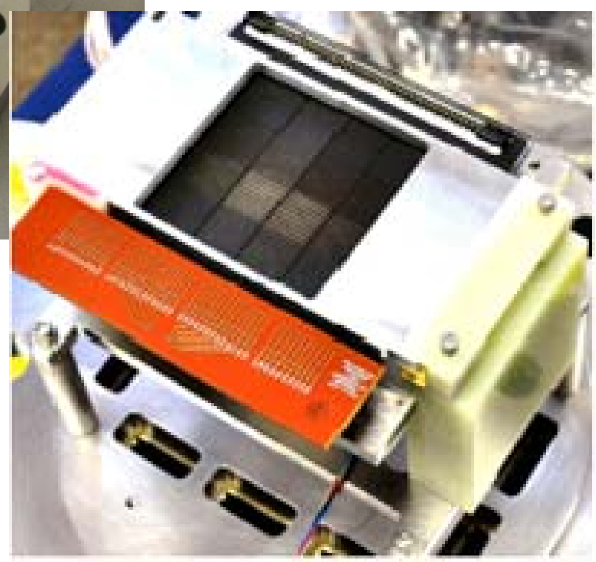
PPS Experimental Test Chamber



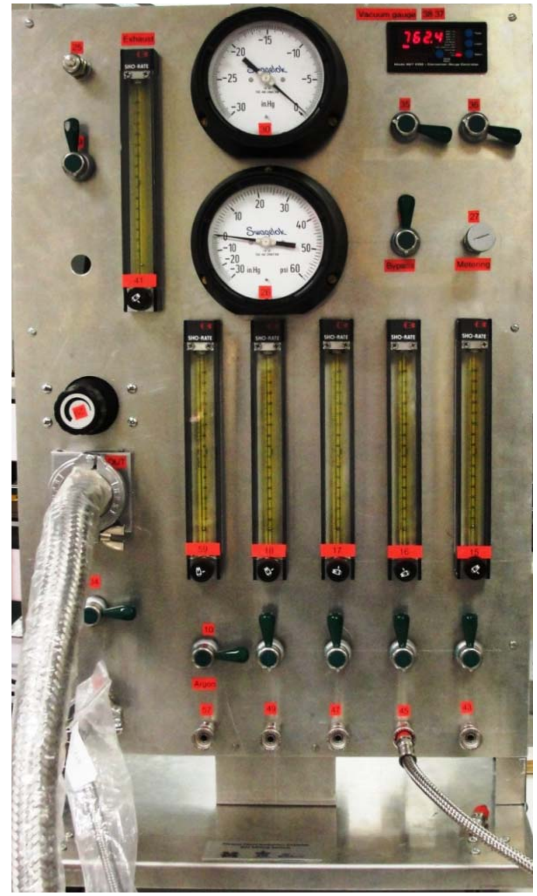
Test chamber construction



PPS Test Chamber



internal substrate and support



PPS Gas Handling and Mixing

Results summary

- Detection of ^{90}Sr radiation and cosmic-ray muons in commercial PDPs
- Investigation of gas mixtures and operating voltages
  - $Ar+CO_2$, $Ar+CH_4$, $Ar+SF_6$(1000V), CF_4(1700V)
- Pulses are fast, 1-2 ns risetime, 4ns FWHM
  - Some crosstalk and pulse spreading
- Cleanliness of gas handling is essential!
- Cleanliness of panel system is essential!
- SnO_2 electrodes may damage easily, may be slightly photoemissive
- Dielectric charge buildup will be a problem on structures

Interesting problems of PDPs

- SnO2 electrodes
  - photoemissive?
  - easily damaged by fluorine
- Ni electrodes
  - some common Ni pastes used in manufacture are magnetic
- Composition of the posts

Research Budget

Total budget: $650k

Total allocated	$650,000
Spent to date:	$ 90,275
Explanation	Postdoc just started in June, 2011

Research direction

- Next steps
  - Use test chamber to investigate surface discharge panels
  - Testing commercial panels with higher energy source – ^{106}Ru (3.54 MeV end point)
  - Replace SnO_2 electrode with Ni for more durability
  - Consider in-beam tests of commercial panels
    - CERN
    - Diagnostic Electron beam facility
    - HRIBF tandem beam
- Longer term
  - Design a 10cm x 10cm panel with 0.1mm pixel spacing
  - Construct and characterize the design

Research Budget

Total budget: $650k

	ORNL:	Integrated Sensors:	University of Michigan: (includes postdoc)
Total allocated	$52,307	$146,440	$451,253
Spent to date:	$ 6,219	$ 53,622	$ 30,434
Explanation			Postdoc start mid-June, 2011

Project Milestones – Year 1

- Q1: Determine what models to pursue, plan initial tests with commercial PDP devices. Done
- Q2: Results from tests with commercial PDP devices Done
- Q3: Modeling effort initial results, compare to PDP tests; test chamber construction complete. Started
- Q4: Test chamber operations with initial surface discharge electrodes.

Project Milestones – Year 2

- Q5: Gas mixture conclusions; PDP and test chamber data reconciled with modeling.
- Q6: Revised test chamber substrate designs complete
- Q7: Initial results from revised test chamber substrates
- Q8: Beam tests with test chamber substrates

Project Milestones – Year 3

- Q9: Prototype sealed panel specification and design
- Q10: Prototype sealed panel fabrication complete
- Q11: Prototype panel laboratory test results
- Q12: Prototype panel beam test results

- Summary evaluation of the outlook for PPS application