Development of Plasma-Panel Radiation Detectors for Nuclear and High Energy Physics, Medical Imaging and Homeland Security

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SBIR/STTR Exchange Meeting, Washington, DC Area (September 14, 2010)

Integrated Sensors, LLC

- Integrated Sensors is a privately-held, Toledo, Ohio company, formed in 2004 for the development and commercialization of plasma panel based radiation detectors.

- Working on No-Cost Extension (Phase-II ended Aug 2010)

- Holds the *core IP* (i.e. 5 patents and a dozen pending patents) on Plasma Panel Radiation Detector technology.

- Fostering collaborative partnerships for technology development:
  - University of Michigan
  - Tel Aviv University
  - Oak Ridge National Laboratory
  - Brookhaven National Laboratory

Overview

- What is a Plasma Panel Sensor?
- Phase-II: Goals & Accomplishments
- How does it work?
- Experiments & Simulations
- Applications
- Phase-III: Commercial Interest

Three Plasma Panel Detectors

- **PPS:** ***Plasma Panel Sensor***
  - The most basic plasma panel radiation detector.
  - Each pixel operates like an independent *micro-Geiger counter* and is activated either by direct ionization of the gas, or ionization in a conversion layer with a subsequent charged species emitted into the gas and activating a localized gas discharge at a pixel site.
  - A high resolution pixel discharge counter for ionizing particles, *not* a proportional counter.

- **PPPS:** ***Plasma Panel Photosensor*** – a PPS with the addition of an internal photocathode.

- **PPSD:** ***Plasma Panel Scintillation Detector*** – a PPPS that has been optically coupled to a scintillator.

Primary Project Goals in Phase-II

Demonstrate “Proof-of-Concept” via testing of PPS and PPPS devices.

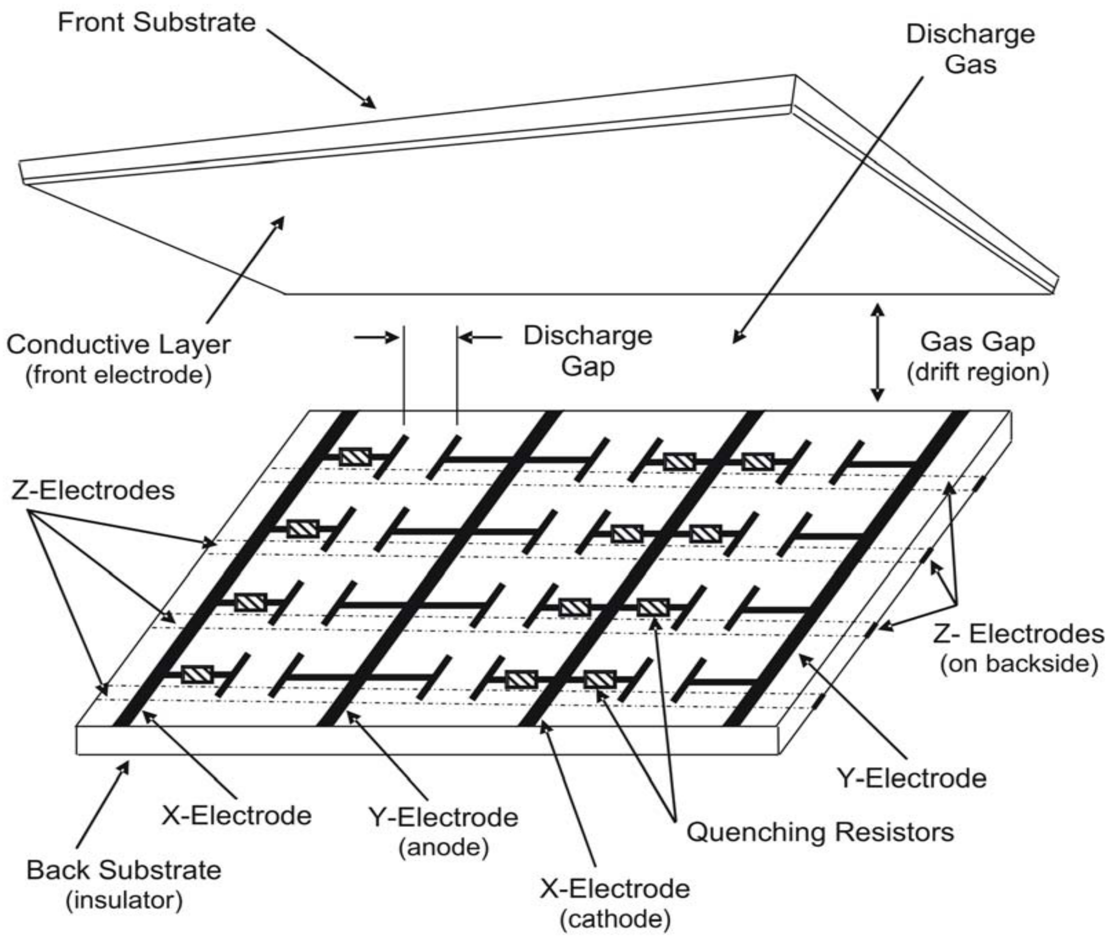
Develop 4” Vacuum Test Chamber for 3.1” diagonal PPS / PPPS devices with *pre-mixed* gases. Measure critical performance parameters, initiate device modeling and simulation program, demonstrate low cost fabrication capability, and path to Phase-III commercialization.

Project Accomplishments in Phase-II

- Demonstrated "Proof-of-Concept" with hermetically sealed 6" diagonal PPS and PPPS devices.
- Developed 8" Vacuum - ***Pressure*** Test Chamber for ***larger*** 6.4" diagonal PPS / PPPS devices with motorized Z-stage and integrated multi-component gas mixing system.
- Initiated PPS device modeling and simulation programs with University of Michigan and Tel Aviv University.
- First fabricated devices (11.4 x 11.4 cm) at cost of ~ **$15 / cm^2** of active area (in quantities of about a dozen units), and at about **$1 / cm^2** in 1000 unit quantities.
- Phase-III commercialization interest expressed by major flat panel display TV-set manufacturers.

4-Electrode Cell Structure*

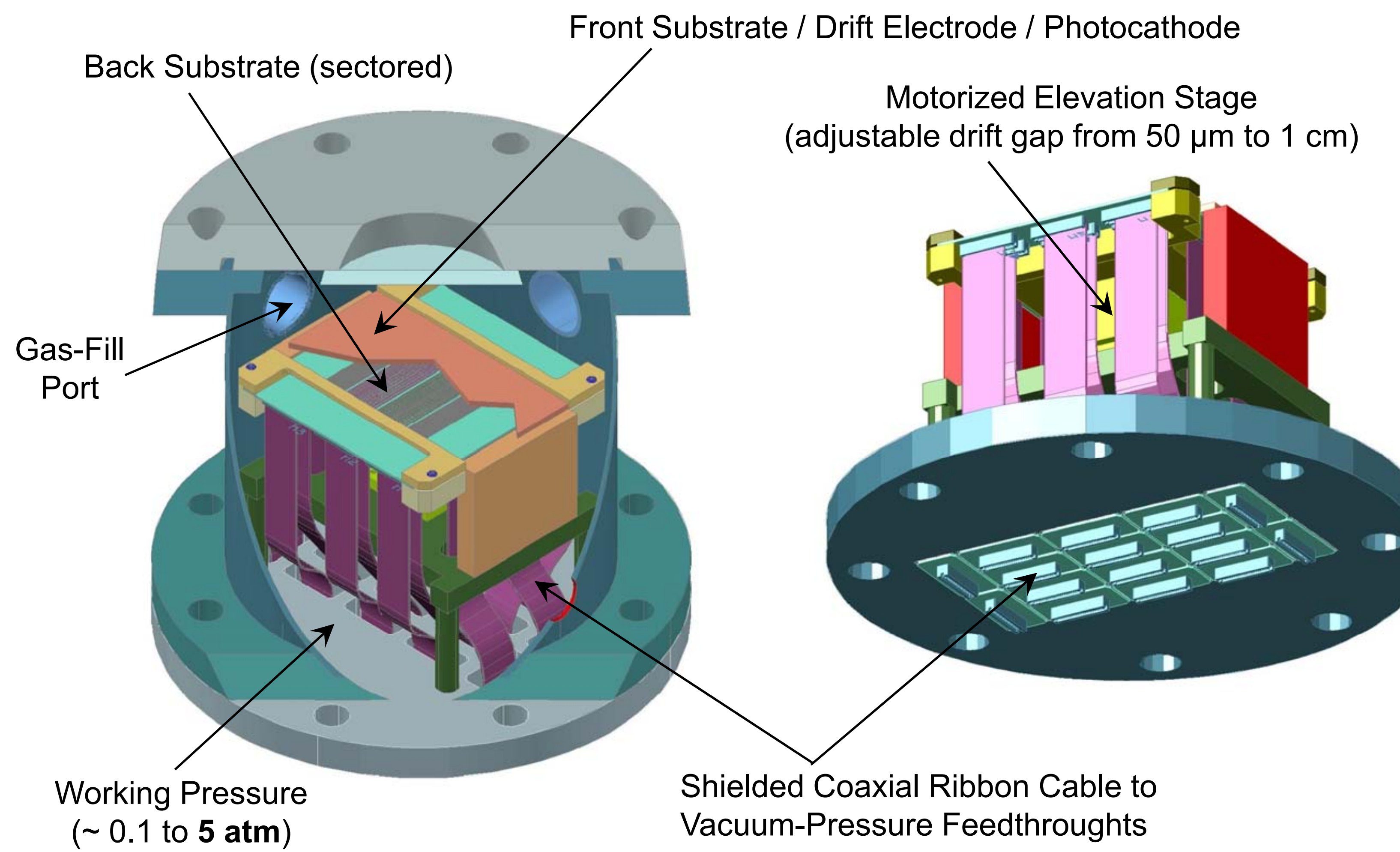
*Conceptual Drawing *(not actual cell configuration)*



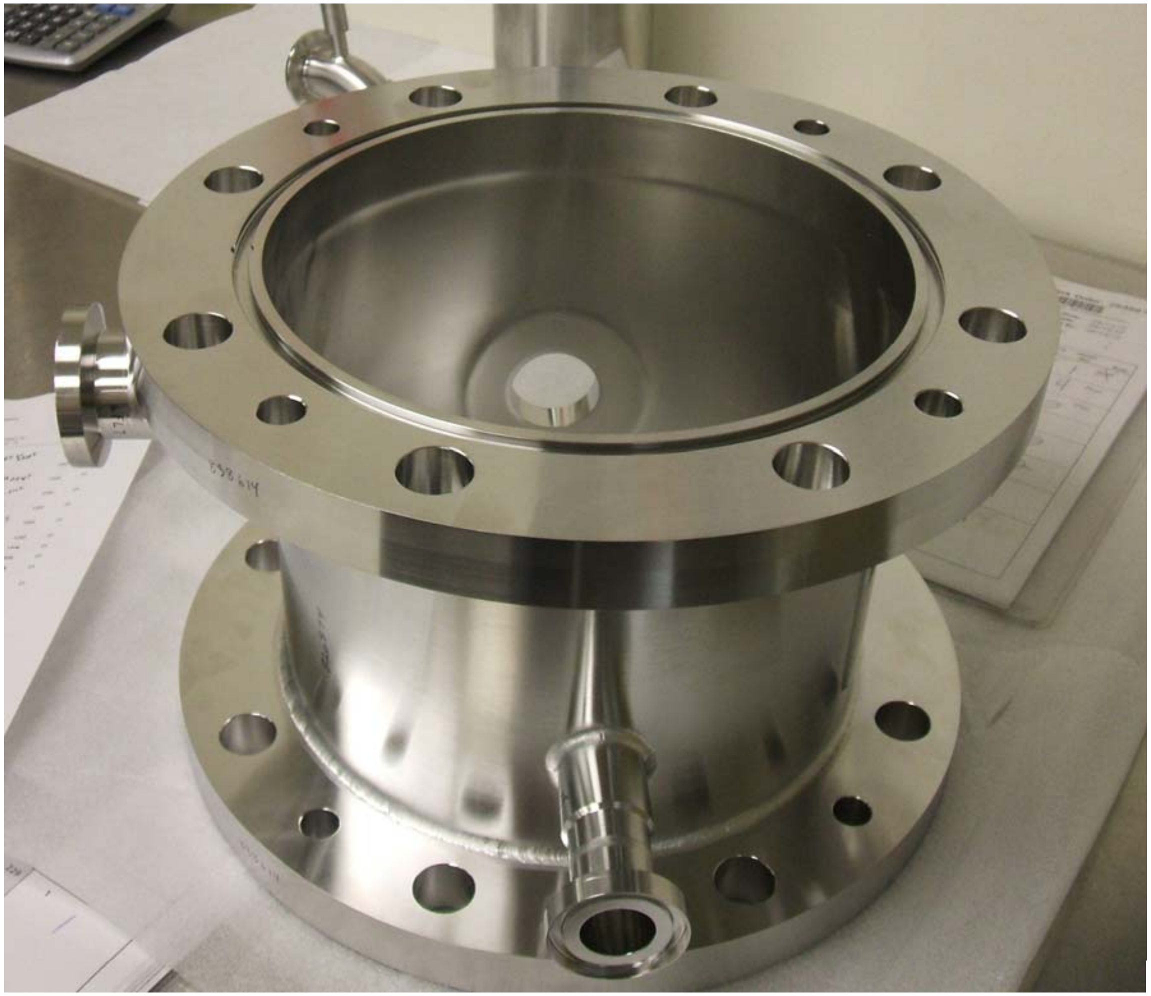
Technology Overview / Projections

- Inherently digital, particle/photon counting devices
- Avalanche initiated by “free-electrons” created by incident radiation
- Pixels/cells act as independent, parallel collectors (~10^3 – 10^5 cells/cm^2)
- Targeted cell size of about 35 - 350 μm, with internal gain ~ 10^6
- Cell response / rise-time (structure dependent) < 1 ns, to ~ 10 ps (?)
- Estimated fall time (1/e) ~ 250 ps to 1 ns (depending upon structure)
- Saturation limit ~ 10^{12} cps/cm^2 (max. for *areal* recovery time of 10 ns)
- Low energy consumption ~ 50 pJ/discharge (for 0.1 mm pitch, 50 fF cell)
  or 1 μW/cm^2 at 20 kHz/cm^2 (i.e. 4X Super-LHC)
- Detector size unconstrained & scalable, with thickness ~ 0.3 - 5 mm
- Detection range: ~ 10 keV to TeV (i.e. X-rays to colliders), plus UV-VIS
- Radiation damage resistant and unaffected by magnetic fields

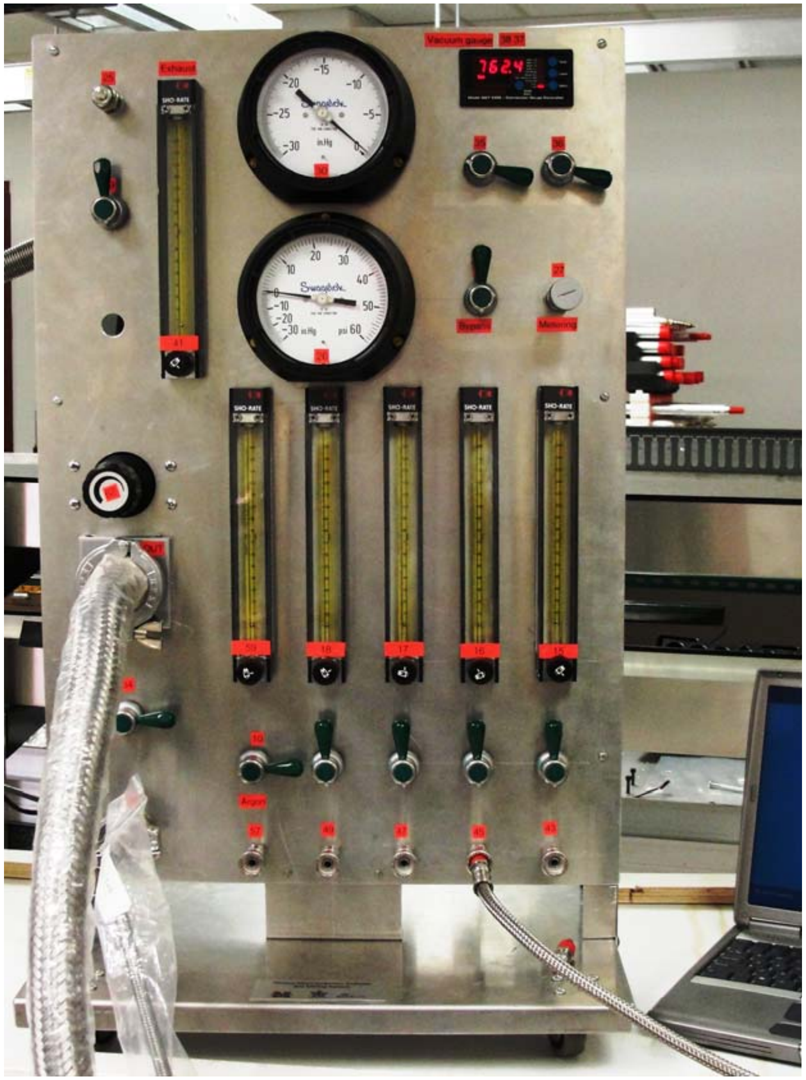
PPS / PPPS Experimental Test Chamber



PPS / PPPS Experimental Test Chamber



PPS / PPPS Chamber Gas Mixing System



Design Summary

4 – Mass Flow Controllers

Pressure Range: 0 to 5 atm

Up to 4 Component Mixtures

PPS / PPPS / PPSD Simulation Program

- Electron drift and avalanche properties simulated using **Garfield**, including field convergence to Sense electrodes and signal jitter due to random distribution of initial charge formation in drift field.

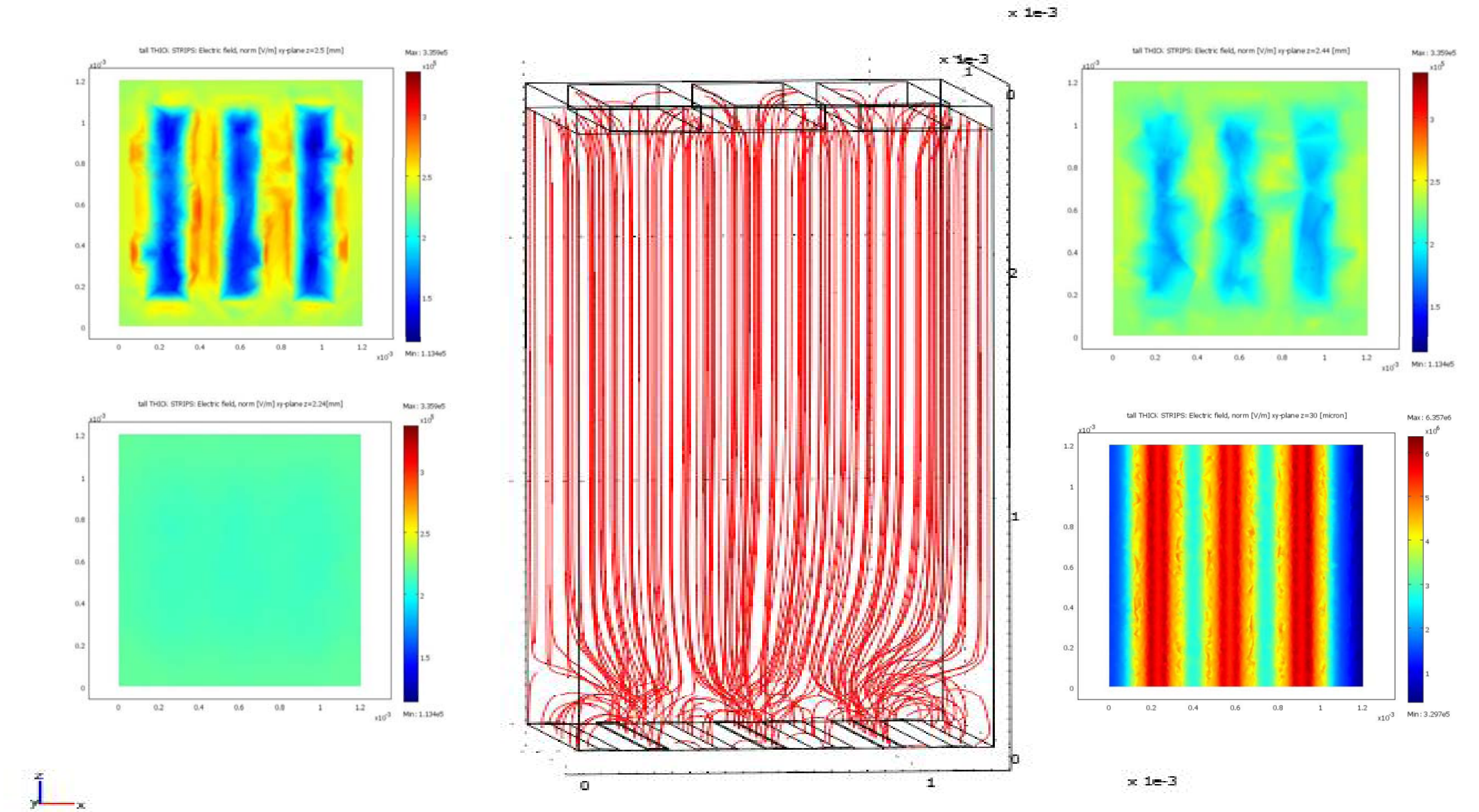
- Signal & voltage distributions, circuit analysis computed with **SPICE**.

- Electrostatics modeled with **Maxwell-2D**, and **COMSOL-3D**, which is also being used for modeling gas avalanche formation.

- Particle/photon-media interaction, conversion, absorption, scattering and emitted secondary particles are calculated using **GEANT**.

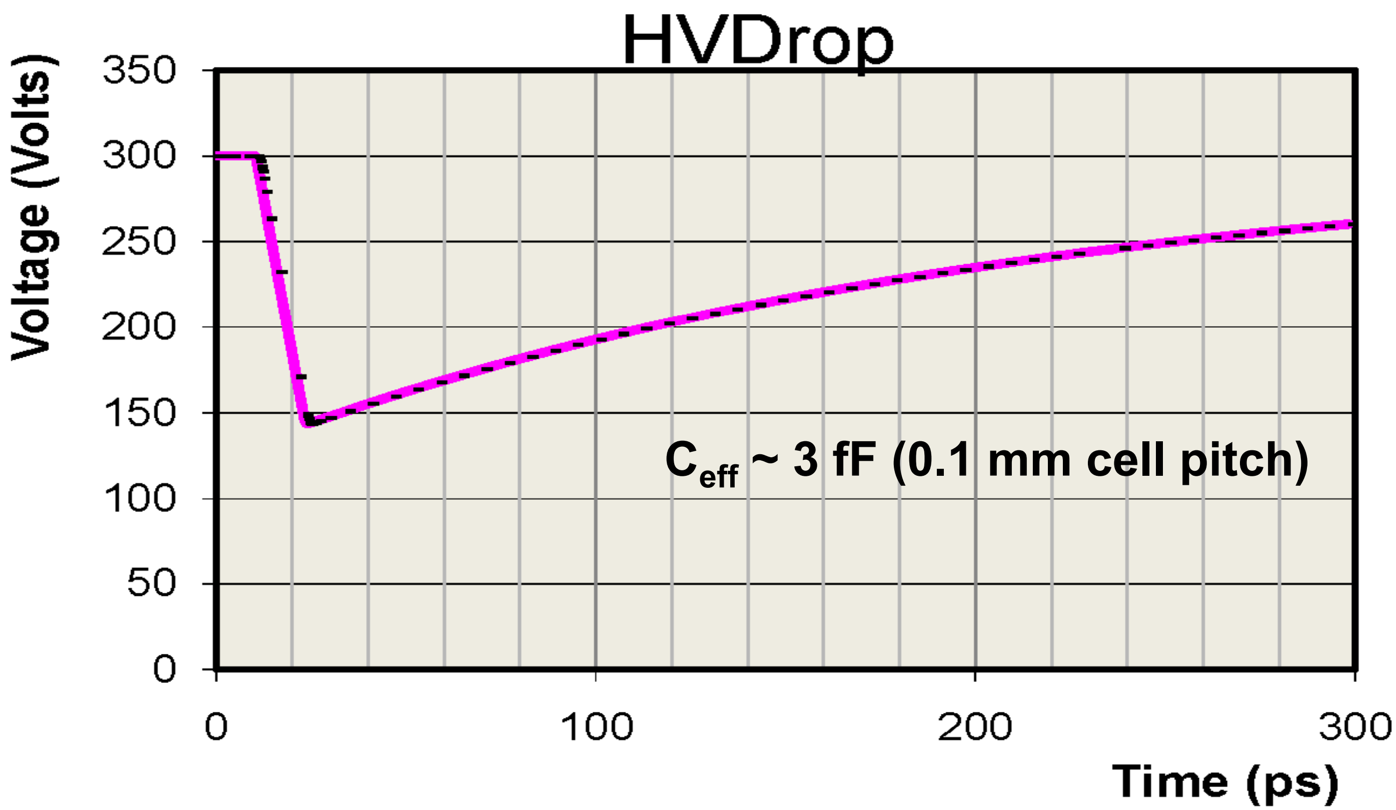
- Modeling and simulation efforts centered at University of Michigan, Tel Aviv University, and ORNL.

COMSOL-3D Electrostatic Simulation



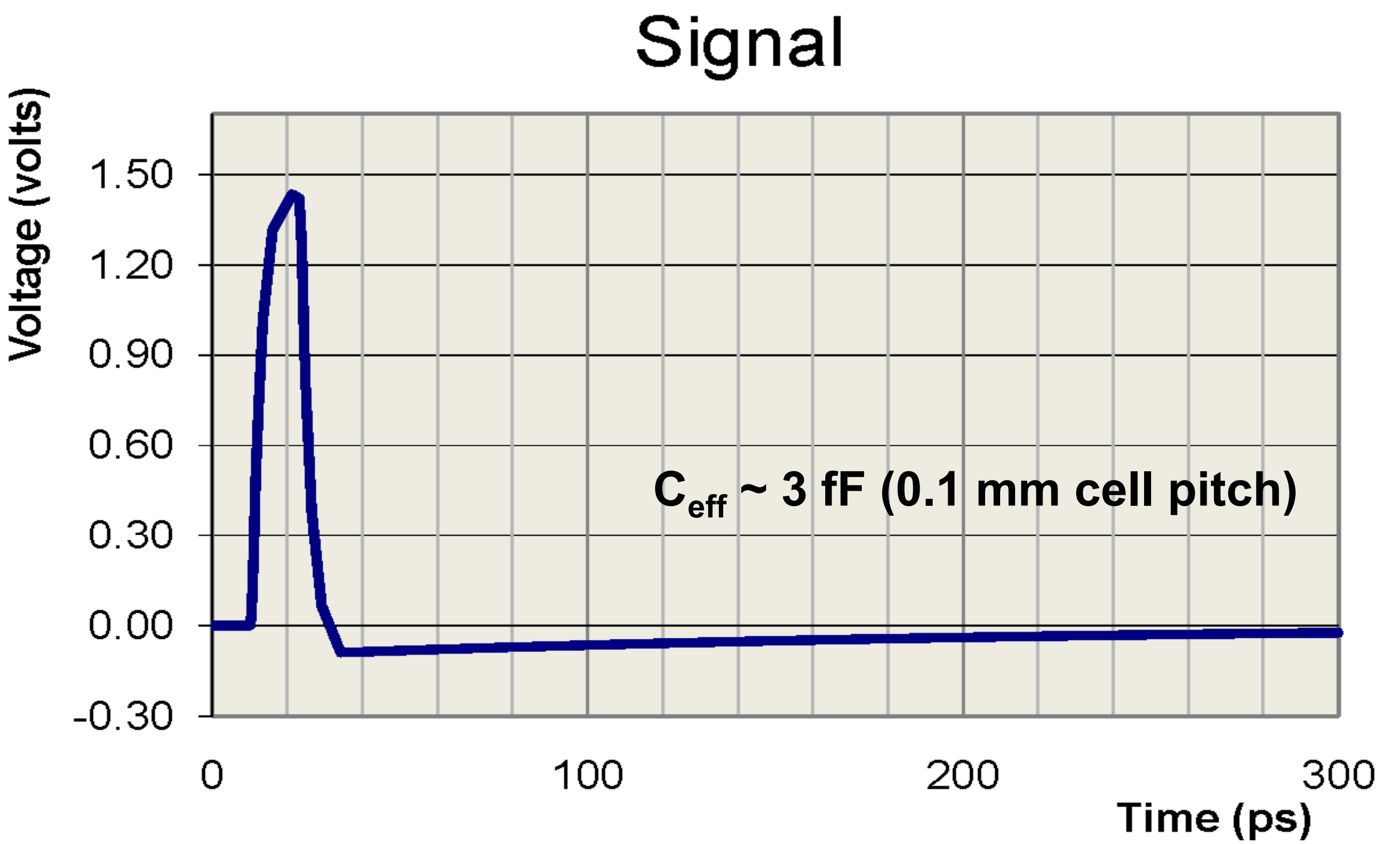
Uniformity of field beneath a drift mesh electrode having 200 x 1200µm openings with 65µm wire. Top Left 40µm from mesh. Top Right 100µm from mesh. Bottom Left 300µm from mesh. Bottom Right shows convergence of electric field lines near the electrodes ~ 3mm from mesh (3000 µm).

Discharge Electrode (cathode) HV Drop



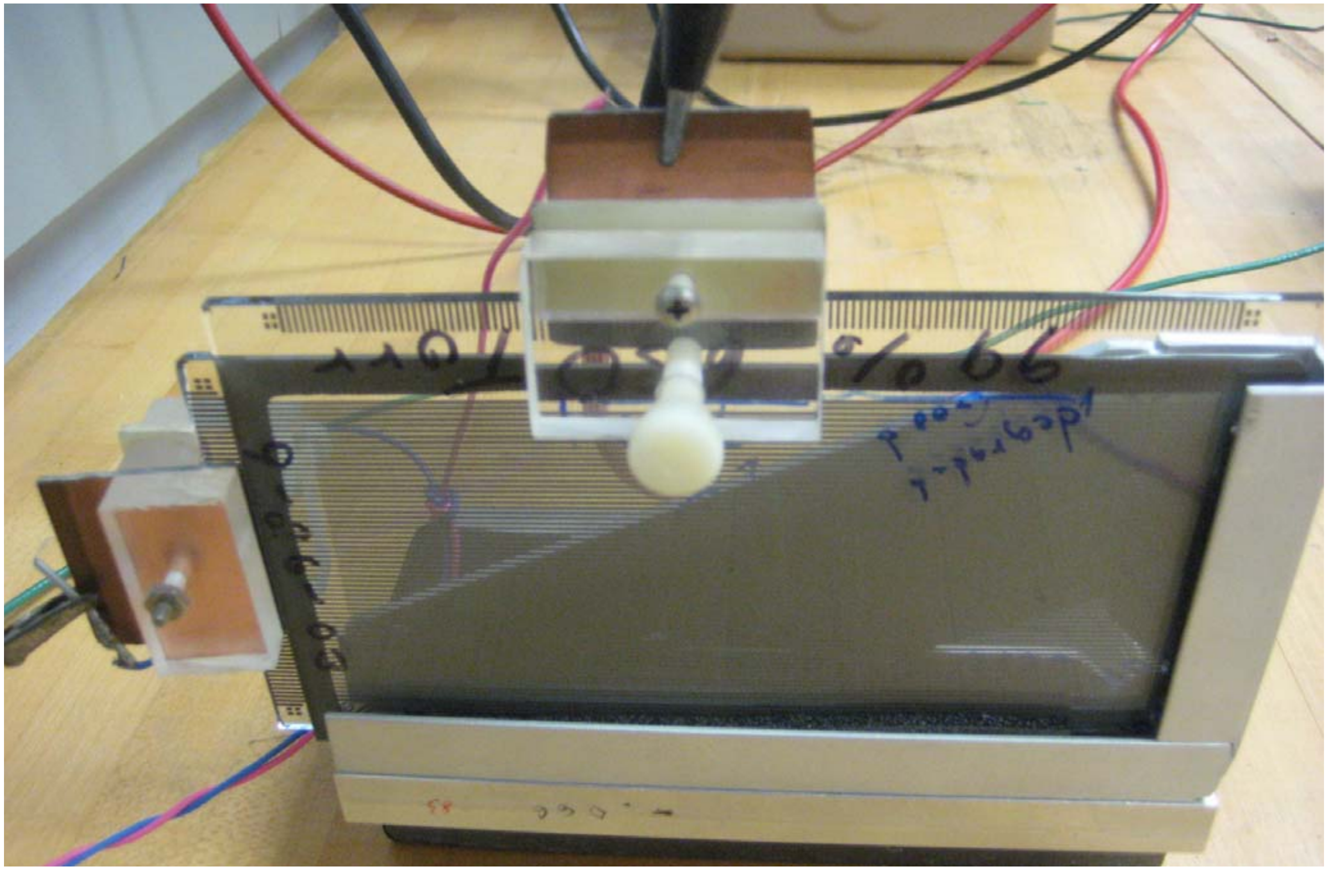
High voltage drop across the "hit" cell in 13-cell chain. The rise and fall times reflect the cell capacitances and resistances. The fall time (1/e return to baseline) is ~ 250 ps. The HV-drop across *adjacent cells* remains essentially unchanged at 300V, indicating a localized discharge.

Sense Electrode (anode) Signal



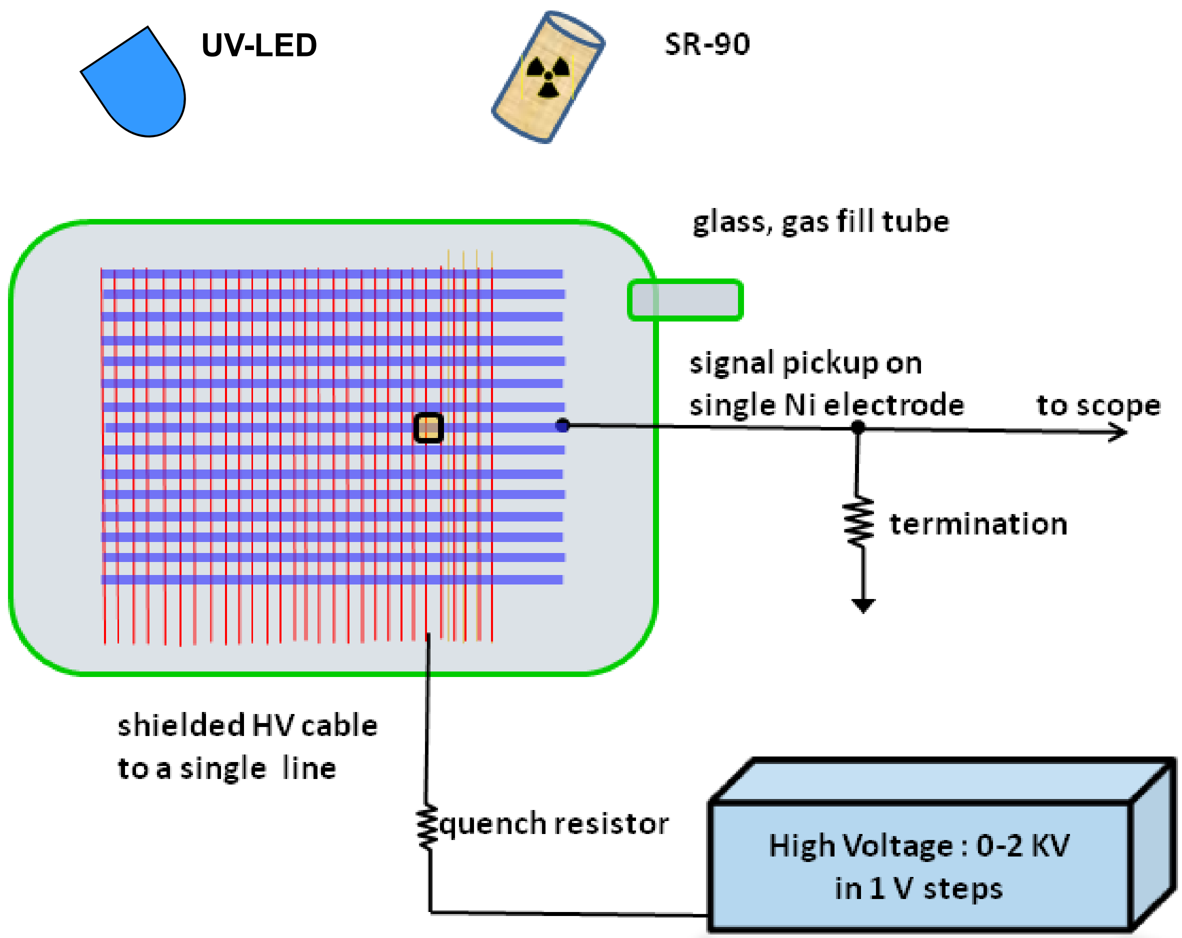
Time profile of Sense line signal produced by "hit" cell in the 13-cell chain shown for SPICE simulation. The drop to ½ the cell potential occurs with a (10-90%) rise time of ~8 ps, assuming a delta function. The signal appears across a 120Ω output impedance.

2-Electrode Columnar PPS



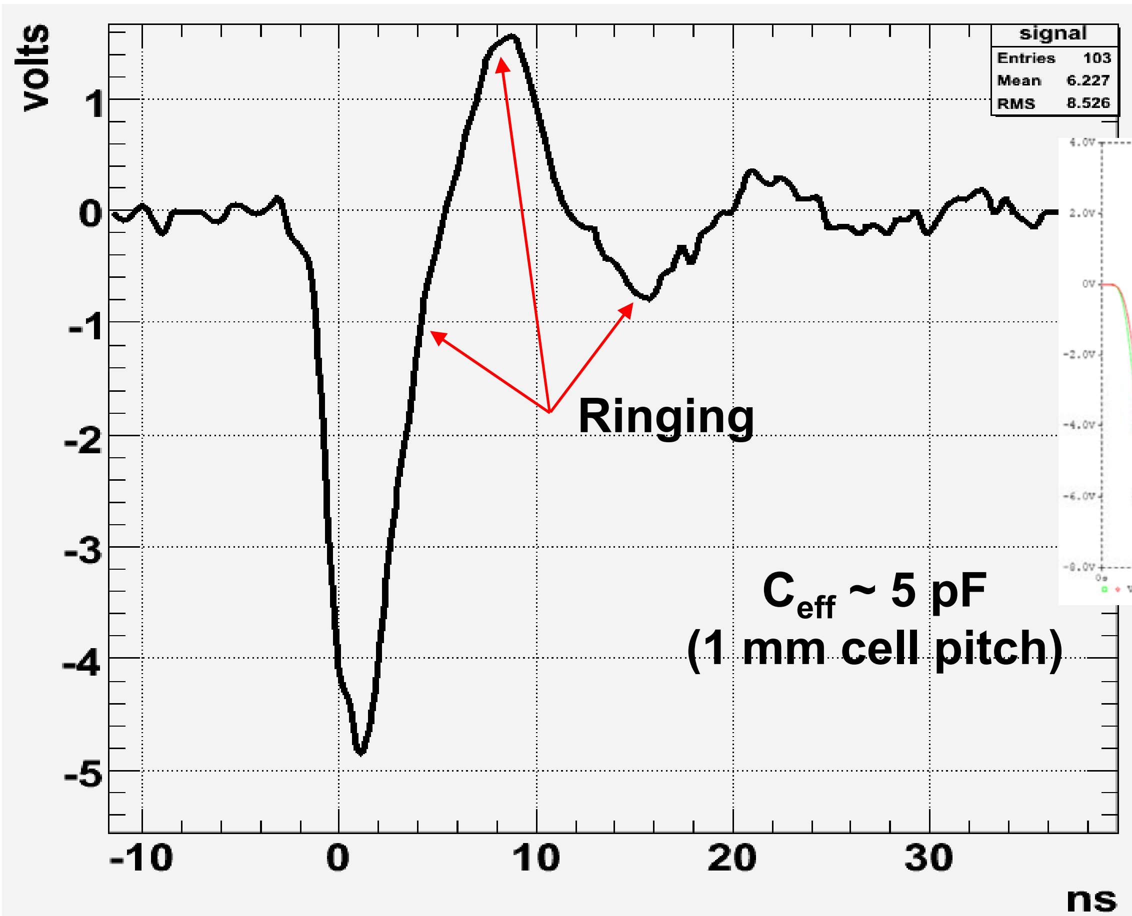
PPS active area of 6.4 x 12.8 cm, with pixel pitch of 1 mm.

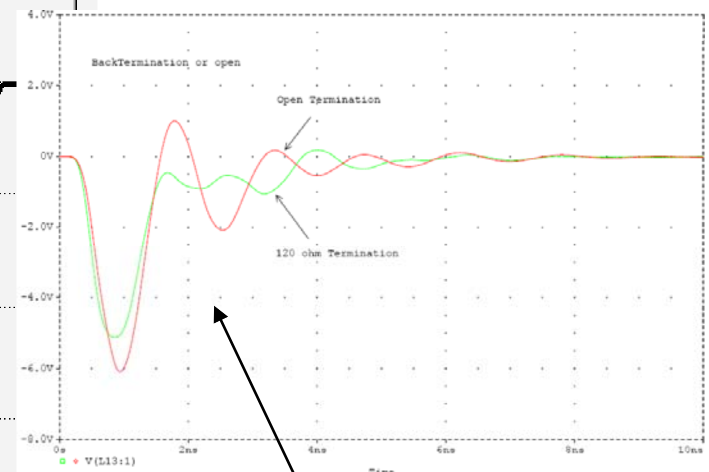
DC-PPS Electrical Configuration



Quench Resistor: ~ 100 KΩ – 2 MΩ , Termination Resistor: ~ 50 – 100 Ω

Sense Signal from 2-Electrode Columnar PPS





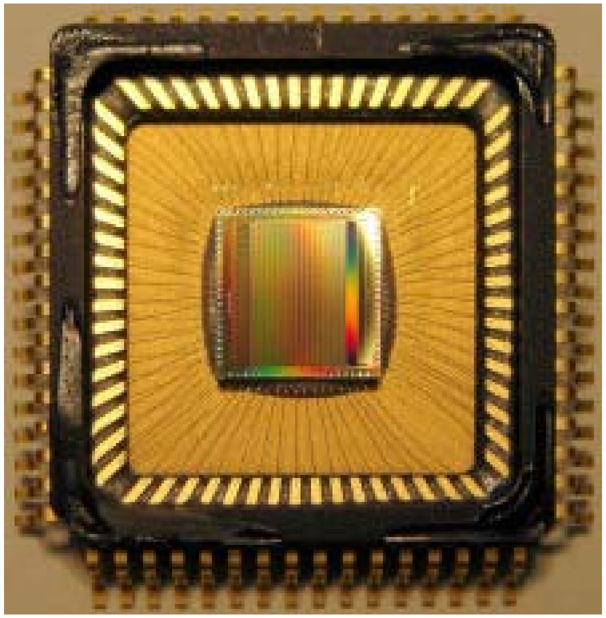
SPICE Simulated Signal

Capacitive & Inductive coupling

(ferromagnetic Ni-electrodes)

Oscilloscope trace of Sense electrode cell discharge with ~ 1 ns rise time (20% - 80%) and ~ 4 ns pulse width (FWHM) initiated by incident β-electron "hit" from ^{90}Sr source. Observed residual ringing has broadened the "true" discharge pulse which is believed to be significantly narrower. Estimated effective capacitance ~ 5 pF.

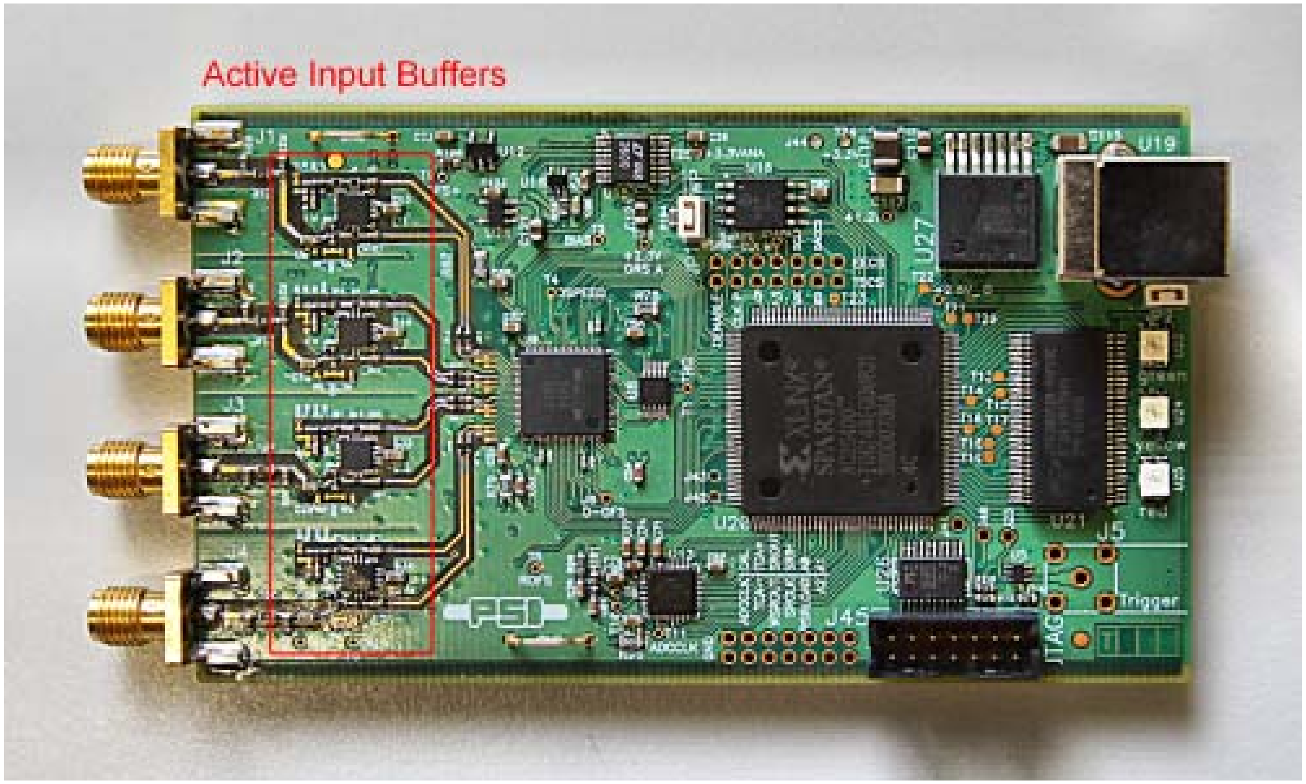
Signal Readout Diagnostics



The DRS4 chip is radiation hard, has 6 GHz, 1024 sampling cells per channel, 9 channels per chip, 11.5 bit vertical resolution, with nominal *3 ps timing resolution*. Resolution of ***1.6 ps*** ***measured*** at BNL (July 2010).

DRS4 Chip – V3 (available from Paul Scherrer Institut)

Signal Readout Diagnostics



DRS4 Evaluation Board V3 (four channels) – available Aug 2010

PPS / PPPS Demonstration Sources

- ***Sources demonstrated to date:***

  Gamma-Rays: ^{57}Co (122 keV), ^{99m}Tc (143 keV), ^{137}Cs (662 keV)

  Beta-Rays (high energy electrons): ^{90}Sr radiation source (546 keV)

  UV-Photons: 370 nm output UV-LED (15 nm FWHM, with 10 μs pulse)

- ***Sources to be demonstrated in 2011***

  Proton Beam: 50-200 MeV for *Particle Beam Cancer Therapy*

  Electron Beam: 3 ps pulsed 60-100 MeV at Brookhaven Nat. Lab (DOE)

  Radioactive Ion Beam Nuclides: ~ 1 to 500 MeV at ORNL

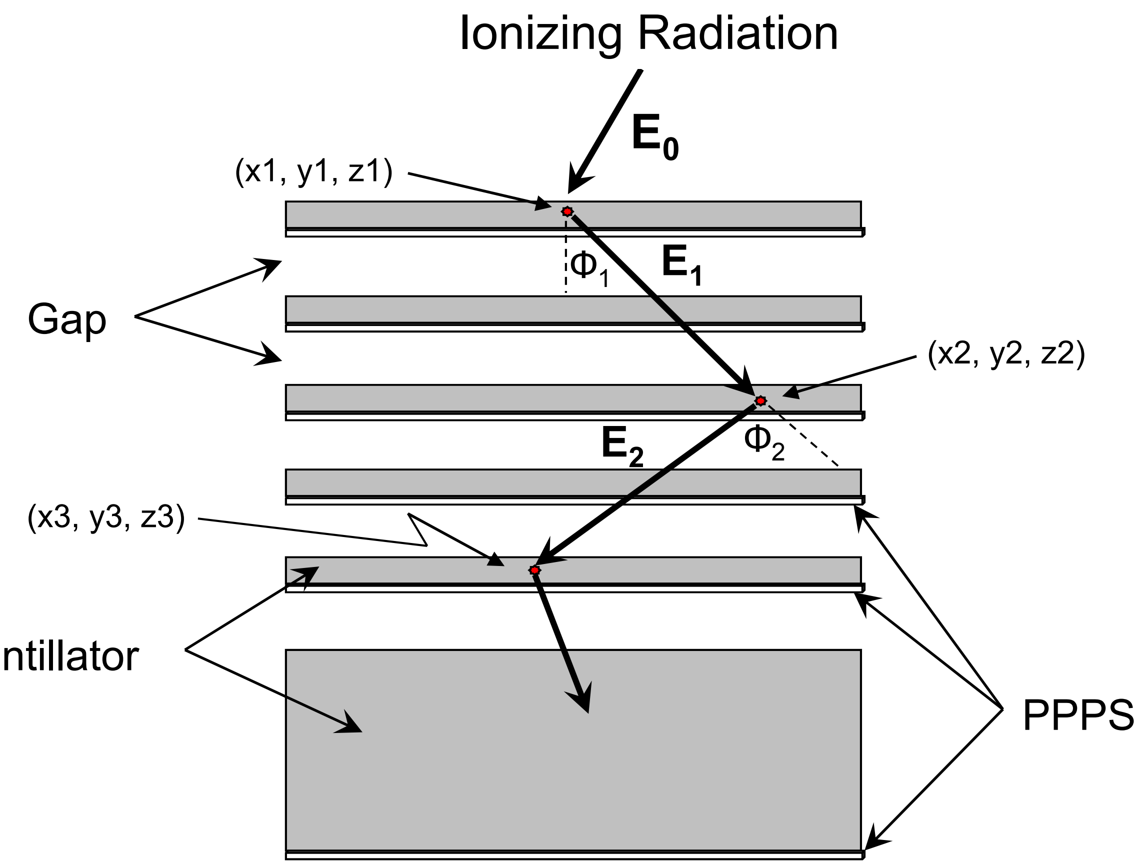
  Neutrons: Thermalized neutrons at ORNL for *Homeland Security*

  Muons (relativistic energies): Muon telescope at Univ. of Michigan

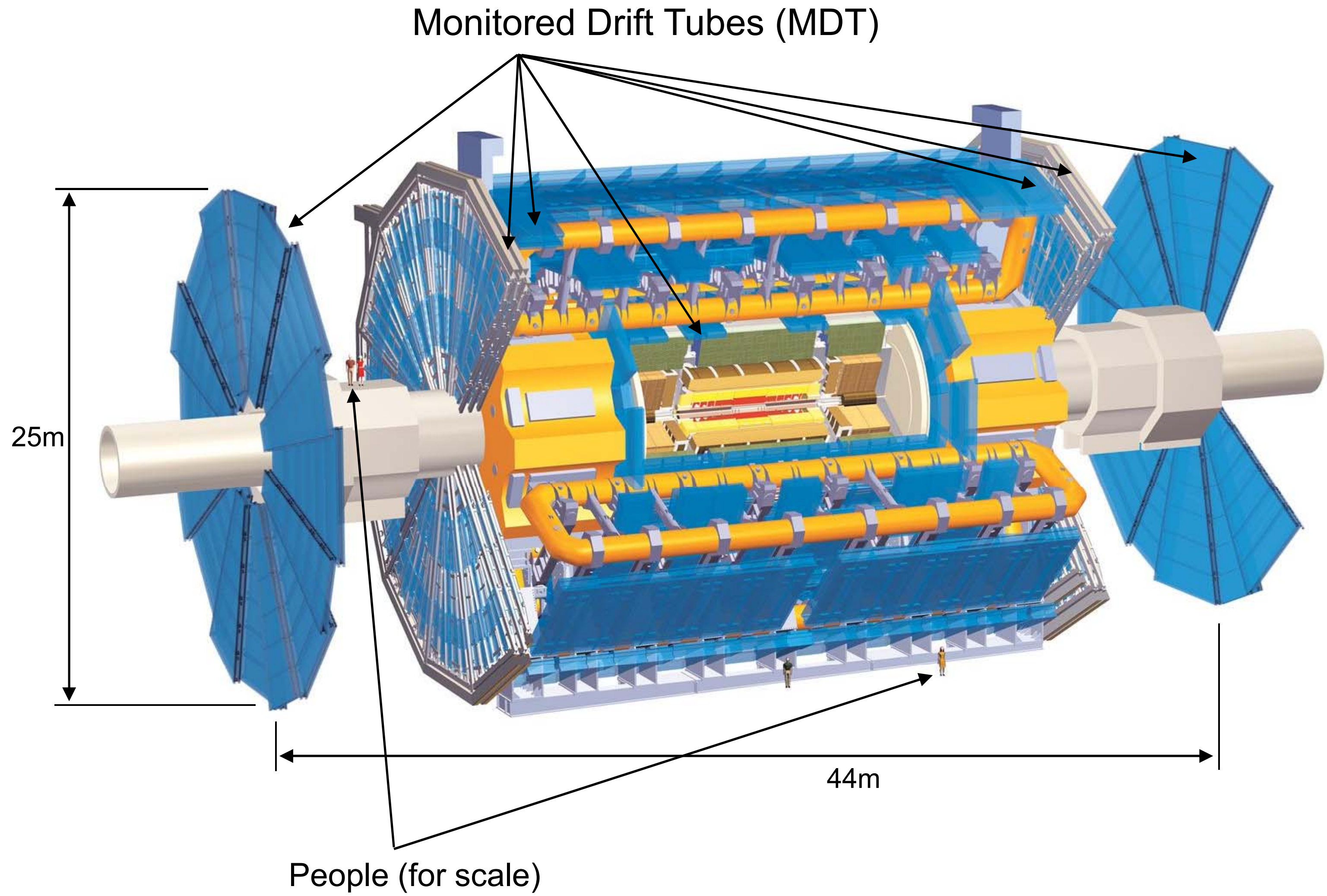
  UV-Photons: 240 - 340 nm UV-LEDs with calibrated output

PPPS-Scintillator Vertical Stack

Compton Telescope arrangement utilizing 3-Compton technique
to determine incident energy and angle ***without collimator***



CERN Large Hadron Collider ATLAS Detector



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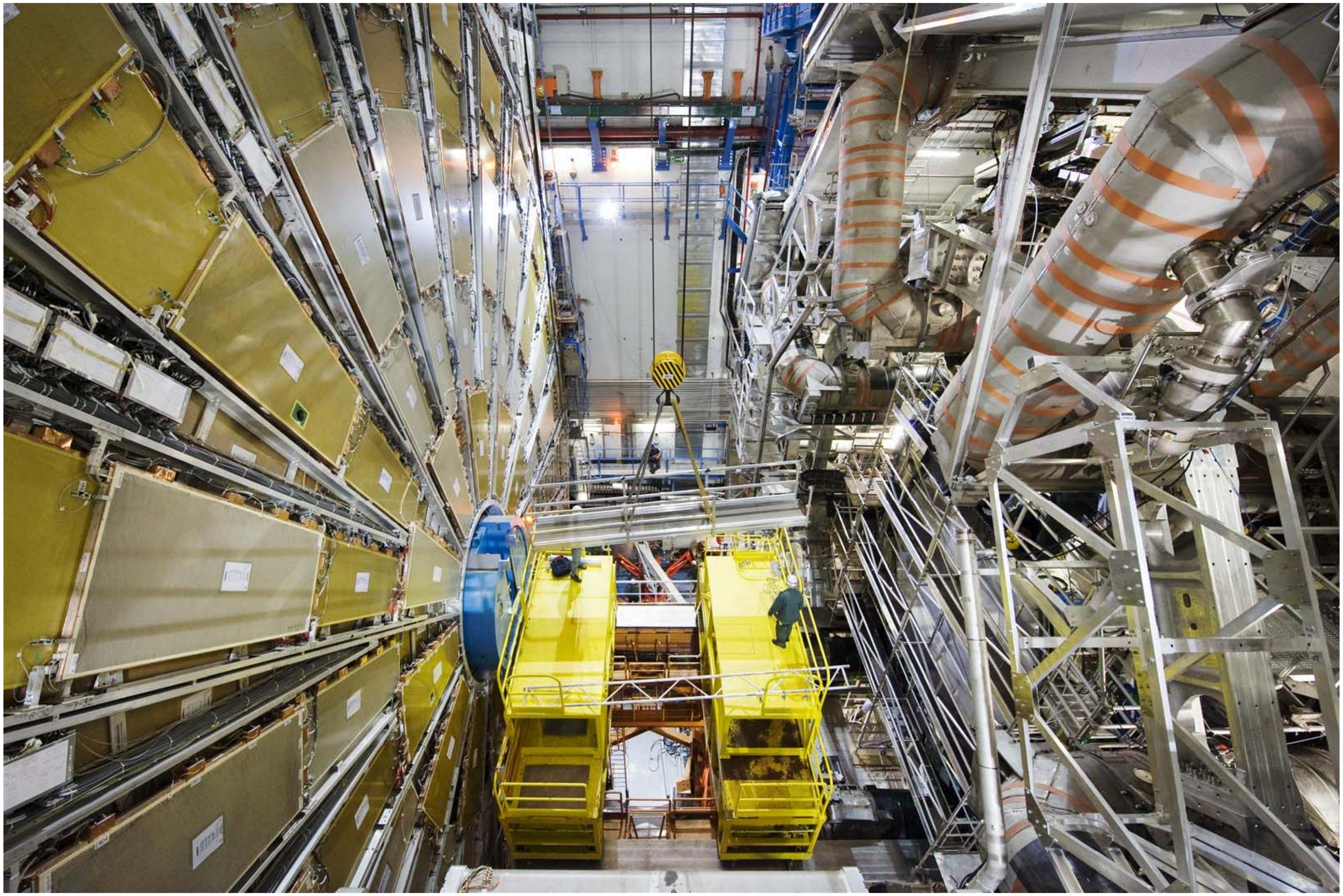

Active Pixel Beam Monitors (PPS-APBM)

- PPS-APBM to provide ***"instantaneous" beam position*** / current / intensity profile monitoring and particle energy for improved beam steering and quality via real-time feedback and optimization of beam power, energy, alignment / position, focus and target steering.

- PPS-APBM is extremely radiation damage resistant and is being designed for in-beam operation either in-vacuum or in-atmosphere.

- PPS-APBM with high sensitivity should be ideal for proton beam therapy in medicine, and radioactive ion beam (RIB) research in nuclear physics.

- Devices being developed for ORNL Holifield RIB facility. First commercial application is ***cancer treatment*** via proton beam therapy with planned *alpha*-testing in 2011 at a major U.S. university medical center.

^{3}He Replacement Detectors & Non-Proliferation

PPS devices offer a low cost, high sensitivity means to detect thermalized neutrons with excellent discrimination for separating prompt neutrons from delayed neutrons, from gamma emission and background radiation. A conceptual design has been completed with simulations for a PPS based device to replace ^{3}He detectors. A design has also been completed for a Xe gas measuring instrument for monitoring underground nuclear explosions. A PPS muon detector can be used for START treaty warhead verification via passive detection of fissile material.

Why Should FPD Manufacturers be Interested?

- A new class of radiation detectors with unique capabilities, potentially offering ***order-of-magnitude higher profit margins*** than *flat panel displays*.

- Older generation *plasma display panel* (i.e. PDP or converted LCD) facilities that are no longer suitable for low cost *"commercial"* products, would be ideal for production of these new radiation detectors.

Order-of-Magnitude Higher Margins

- **PDP's Wholesale Price: < *$0.25 / inch^2*** (i.e. per sq. inch *with electronics*)
- **PMT's**: Photomultiplier tubes are the lowest cost radiation detector and in volume sell for about ~ ***$25 / inch^2***, or **100 times the price of a PDP!**
- **Solid State Radiation Detectors**: Many different types and materials, including: Si, Ge, CdTe, etc., and a variety of configurations; however, an average price is ~ ***$250 / inch^2***, or **1,000 times the price of a PDP!**
- **Multichannel Plate Detectors (MCP's)**: High-end radiation detectors with a price of ~ ***$2,500 / inch^2***, or **10,000 times the price of a PDP!**
- **SUMMARY:** PPS potentially offers *order-of-magnitude* greater profit margins than FPDs – *at least* ***10 times more profit per unit area than for a FPD*!**

Publications under Phase-II

- R. Ball, J. W. Chapman, E. Etzion, P. S. Friedman, D. S. Levin, M. Ben Moshe, C. Weaverdyck and B. Zhou, *"Plasma Panel Detectors for MIP Detection for the SLHC and a Test Chamber Design"*, 2009 IEEE Nucl. Sci. Symp. & Medical Imaging Conf. (Orlando), NSS Conf. Record, Paper N25-33, pp. 1321-1327.
- P. S. Friedman, R. Ball, J. W. Chapman, D. S. Levin, C. Weaverdyck, B. Zhou, Y. Benhammou, E. Etzion, M. Ben Moshe, Y. Silver, J. R. Beene and R. L. Varner Jr., *"Large-Area Plasma-Panel Radiation Detectors for Nuclear Medicine to Homeland Security and the Super Large Hadron Collider"*, SID 2010 Digest of Technical Papers (Seattle, May 2010), pp. 1080-1083.
- D. S. Levin, R. Ball, J. R. Beene, Y. Benhammou, J. W. Chapman, T. Dai, E. Etzion, P. S. Friedman, M. Ben Moshe, Y. Silver, R. L. Varner Jr., C. Weaverdyck, S. White, B. Zhou, *"Development of a Plasma Panel Muon Detector"*, Nuclear Instr. and Methods A, *in press* (2010).
- R. Ball, J. Beene, Y. Benhammou, M. Ben Moshe, J. W. Chapman, T. Dai, E. Etzion, C. Ferretti, P. S. Friedman, D. S. Levin, Y. Silver, R. L. Varner, C. Weaverdyck, S. White, B. Zhou, *"Progress in the Development of Plasma Panel Radiation Detectors"*, 2010 IEEE Nucl. Sci. Symp. & Medical Imaging Conf. (Knoxville, TN), Paper N50-7 (November 3, 2010).
- R. L. Varner, P. S. Friedman, J. R. Beene, *"Gadolinium Thin Foils in a Plasma Panel Sensor as an Alternative to ^{3}He"*, 2010 IEEE Nucl. Sci. Symp. & Medical Imaging Conf. (Knoxville, TN), Paper N41-174 (November 3, 2010).