Development of Plasma Panel Particle Detectors

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Collaborators

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Outline

- **Motivation**
- **Plasma display panel (PDP) operational principles**
- **Plasma panel sensor (PPS) description**
- **Simulations**
- **Lab results**
- **Next generation design**
- **Summary**

Motivations

- **Hermetically sealed**
  - no gas flow
  - no expensive and cumbersome gas system

- **Over 40 years of plasma panel manufacturing** & cost reductions ($0.03/cm^2 for plasma panel TVs)

- **Potential for scalable dimensions, low mass profile, long life**
  - meter size with thin substrate capability

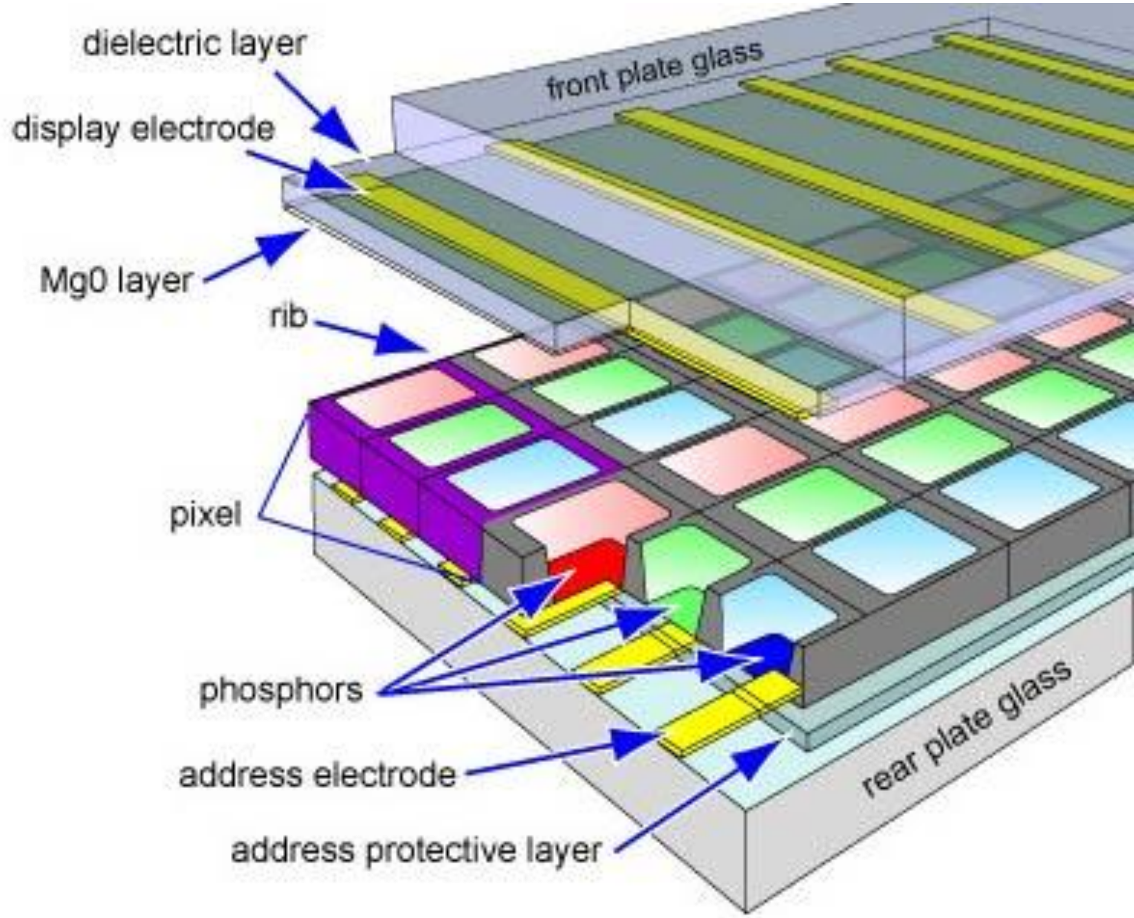
- **Potential to achieve contemporary performance benchmarks**
  - Timing resolution → approx 1 ns
  - Granularity (cell pitch) → 50-200 μm
  - Spatial resolution → tens of μm

- **Potential applications in**
  - Nuclear and high energy physics, medical imaging, homeland security, etc

TV Plasma Panel Structure

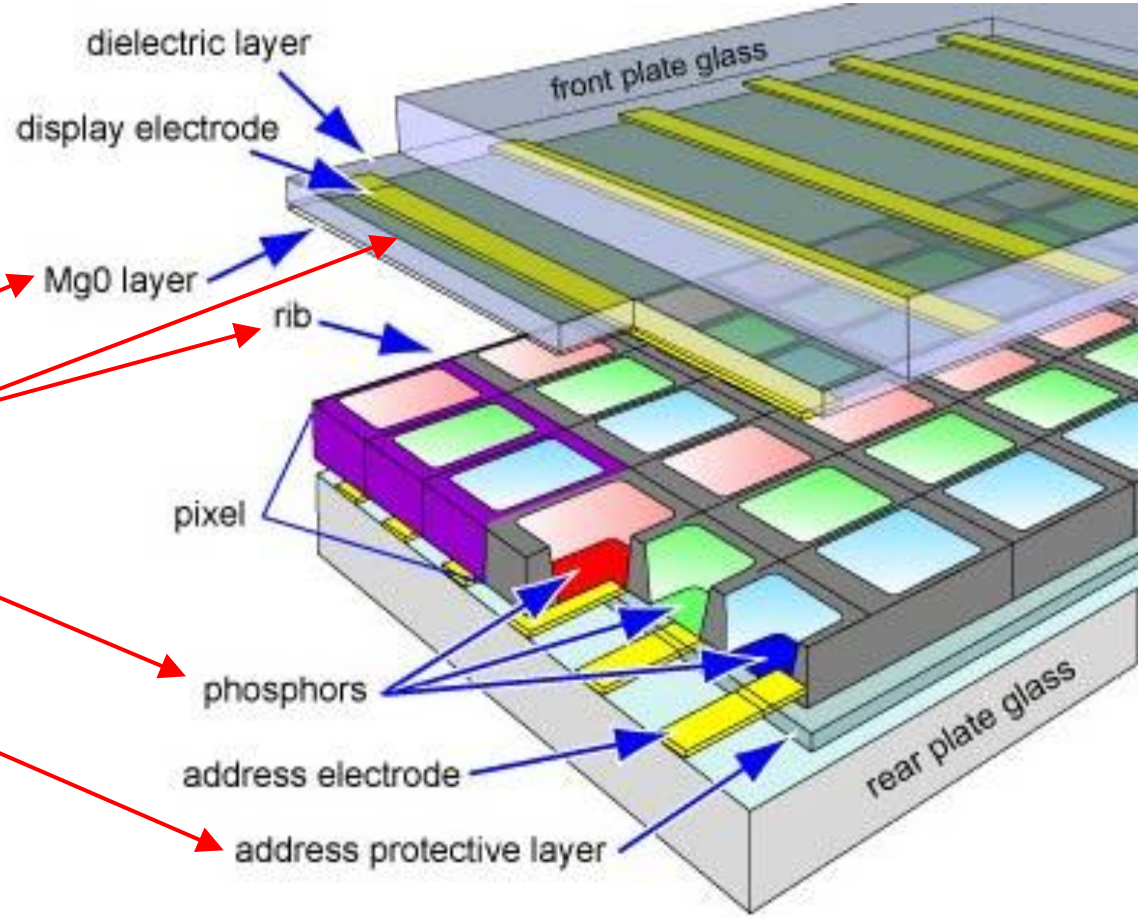
A Display panel is complicated structure with

- MgO layer
- dielectrics/rib
- phosphors
- protective layer



TV Plasma Panel Structure

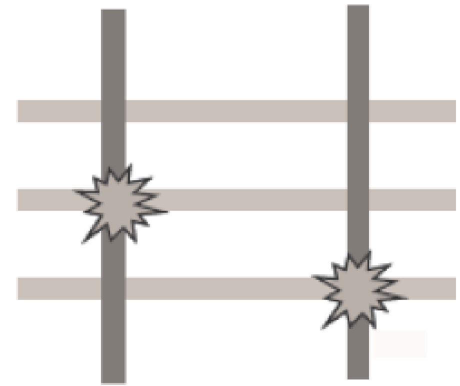
- *For* ***detector****, a simplified version with readout & quench resistor*
  - **No** MgO layer
  - **No** dielectric/rib
  - **No** phosphors
  - **No** protective layer



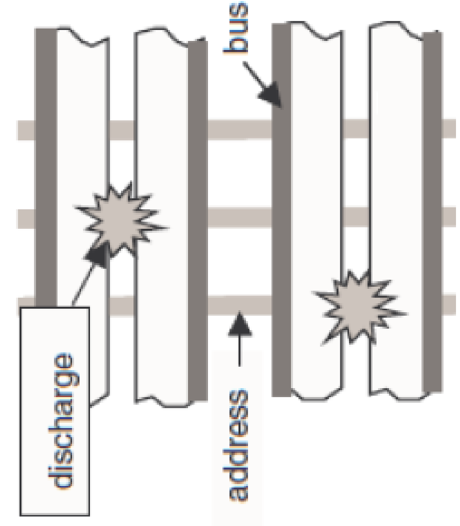
Commercial Panel Designs

- Two basic configurations for the electrodes: **CD** and **SD**
- Discharge dimensions ≈ 100 μm
- Gas pressure ≈ 400-600 Torr (usually Ne, Xe, Ar, Kr, He)
- Applied voltage typically hundreds of volts

Columnar Discharge (CD)



Surface Discharge (SD)



Commercial Panel Designs

- Two operational modes:
  - **AC → televisions, monitors**

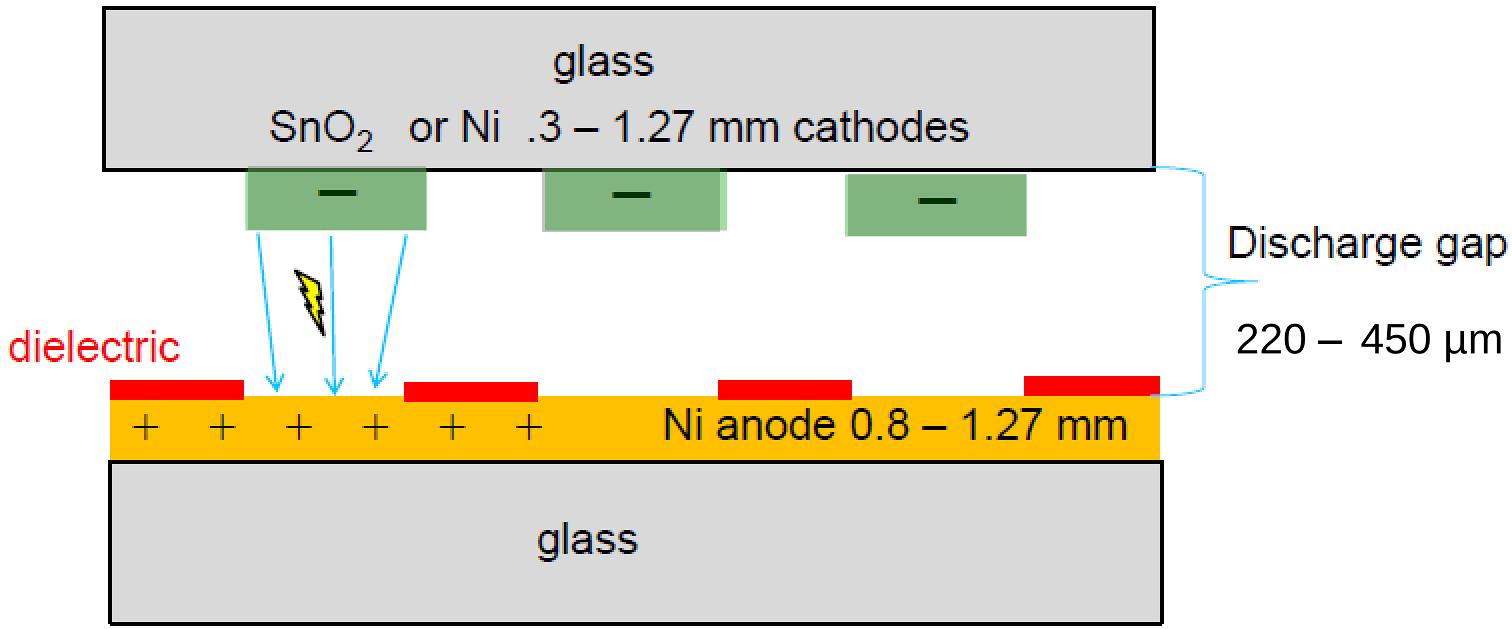
    employ dielectric layers on electrodes

  - **DC → dot-matrix displays**

    use directly facing metalized anodes & cathodes

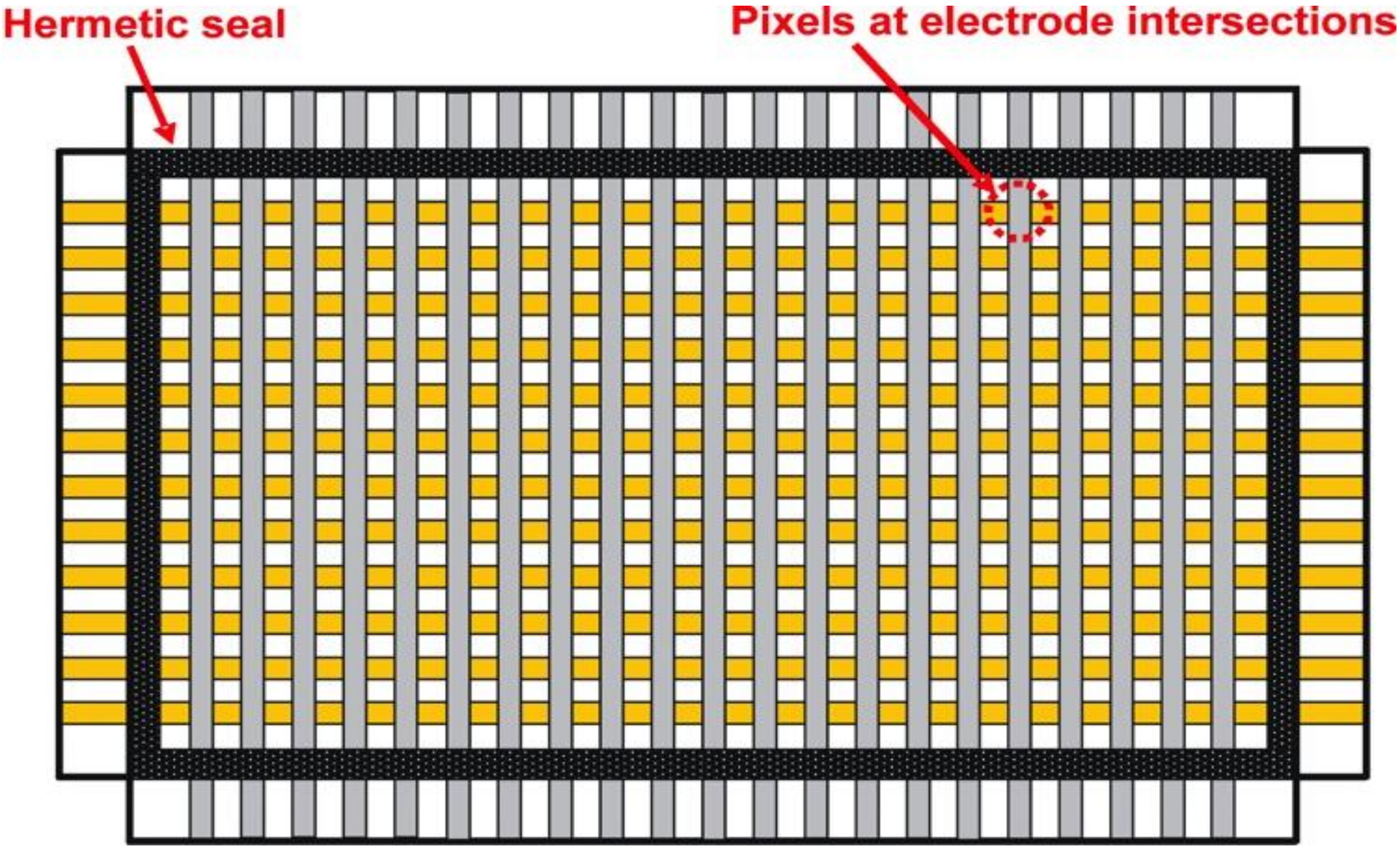
Commercial Plasma Panel

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



PPS with CD-Electrode Structure

(≈ 20-25% active cell/pixel fill-factor)



PDP → PPS

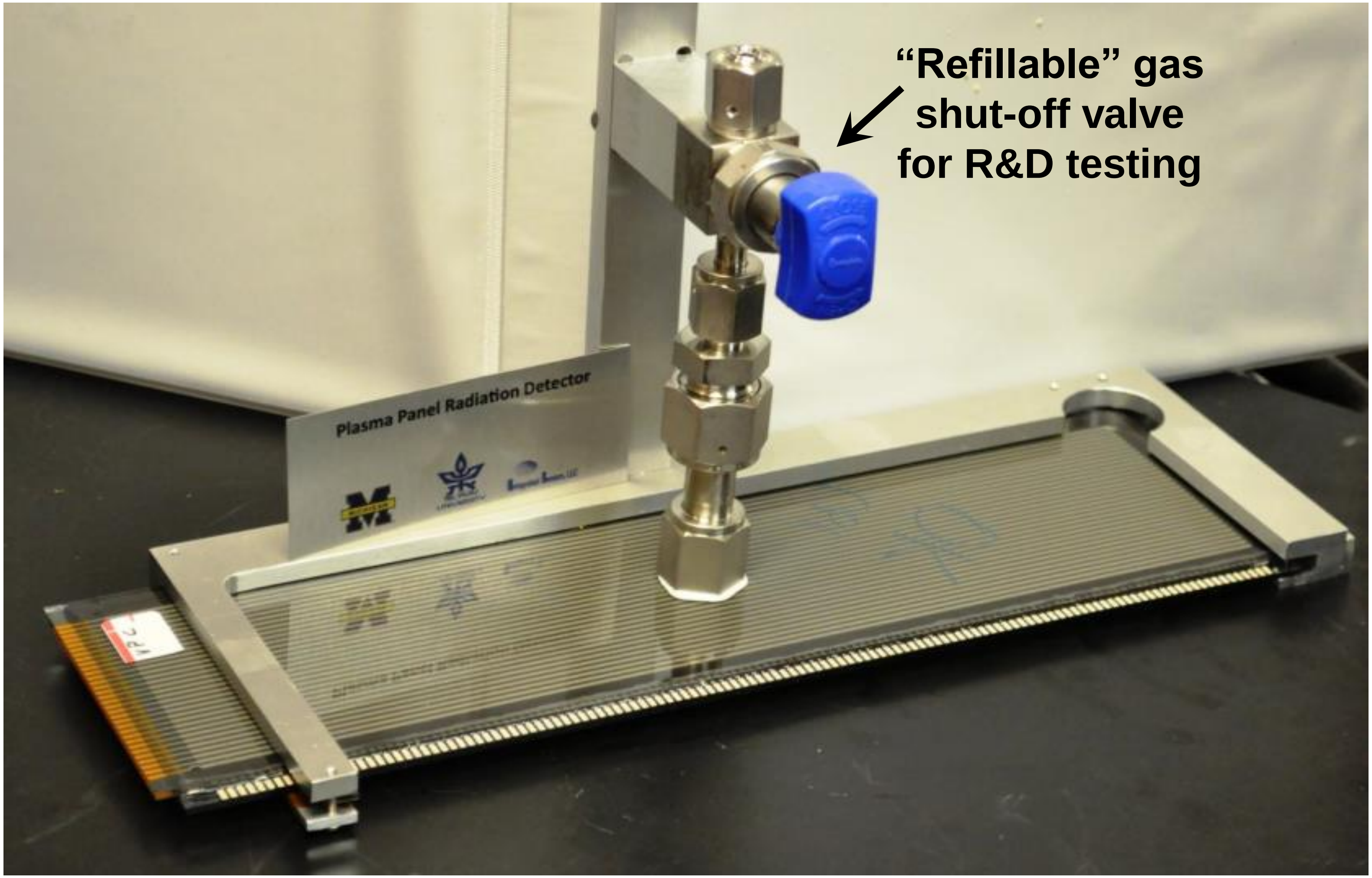
1. Remove or procure without gas
2. Alter manufacturer's electrode material (replace SnO_2 with Ni)
3. Add a custom gas port and high quality VCR valve
4. Subject panel to extended pump down, bake-out
5. Fill with commercial or in-house gas mixture
6. Close valve, mount panel for exposure to source or CR trigger
7. Configure with HV feed, quench resistors, signal readout & DAQ

- Panels operable for several months (even 1 year) after gas-filling *without* hermetic seal (i.e. only with "closed" shut-off valve)

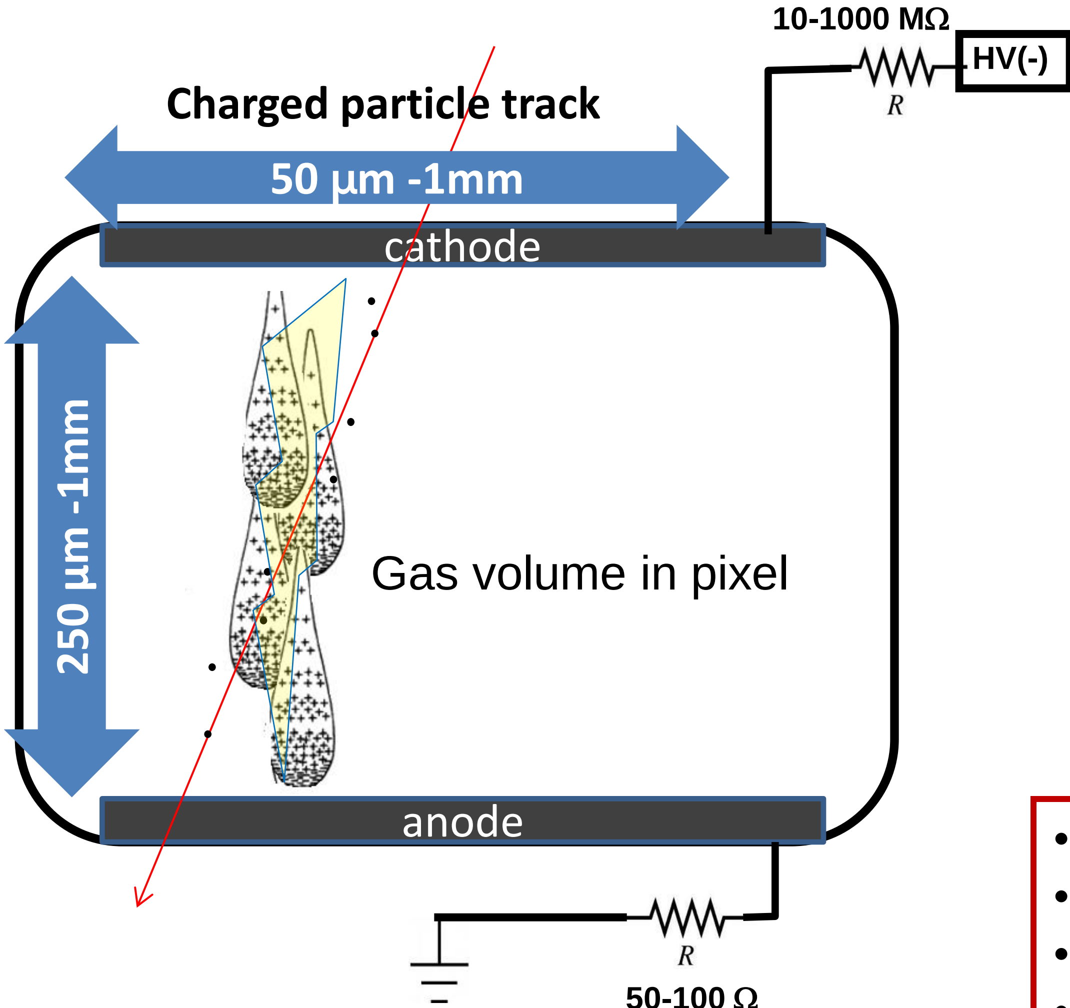
- Investigate the behavior for different conditions
  - Gas composition, pressure, HV, termination, Electrode materials
  - Sources and Configurations
    - β, CR & test beam muons, beam protons, neutrons, gammas
    - Triggered, untriggered, collimated, uncollimated

Modified Commercial Panel

(fill-factor 23.5%, cell pitch 2.5 mm)



Principles of Operation

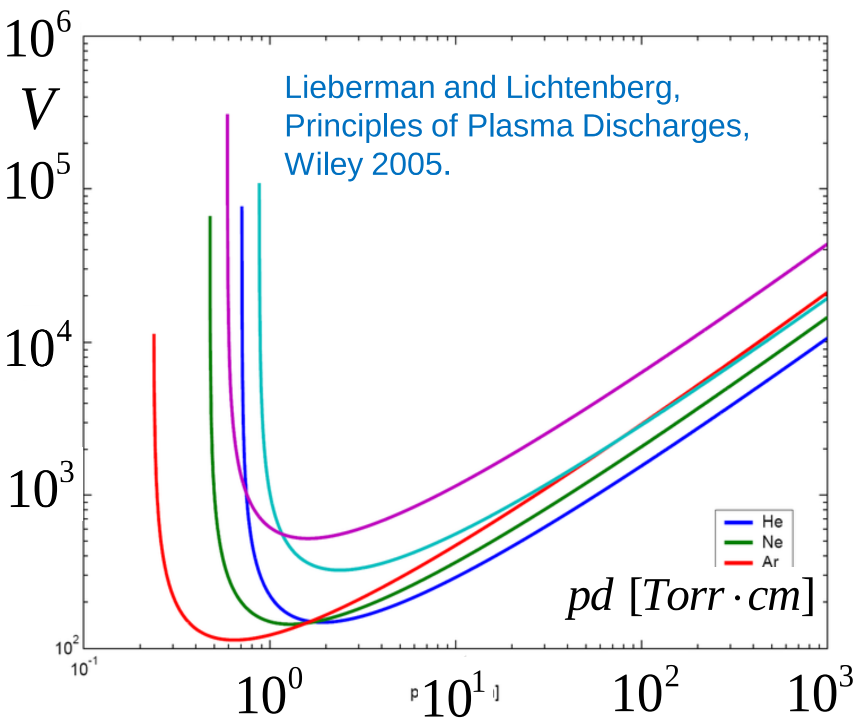


- Accelerated electrons begin avalanche
- Large electric field leads to streamers
- Streamers lead to breakdown - roughly follows Paschen's law.

"A Theory of Spark Discharge",
J. M. Meek, Phys. Rev. 57, 1940

- Gas gap becomes conductive
- Voltage drops on quench resistor
- E-field inside the pixel drops
- Discharge terminates

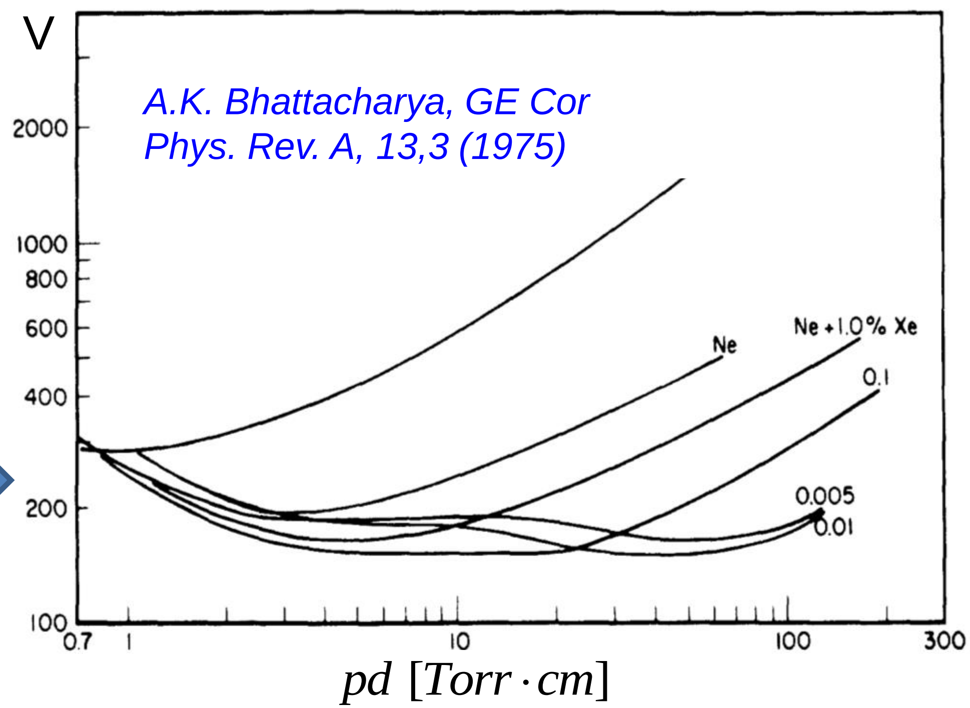
Paschen discharge potential



$$V = \frac{a\,x}{\ln(x/x_0) + b}$$

x = pressure * gap x_0 = 1 Torr cm

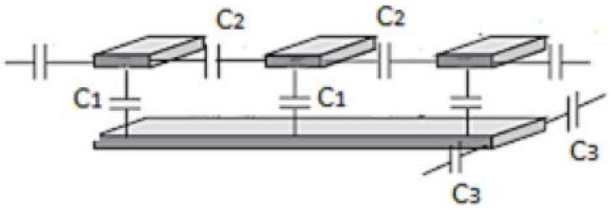
a, b = gas specific parameters



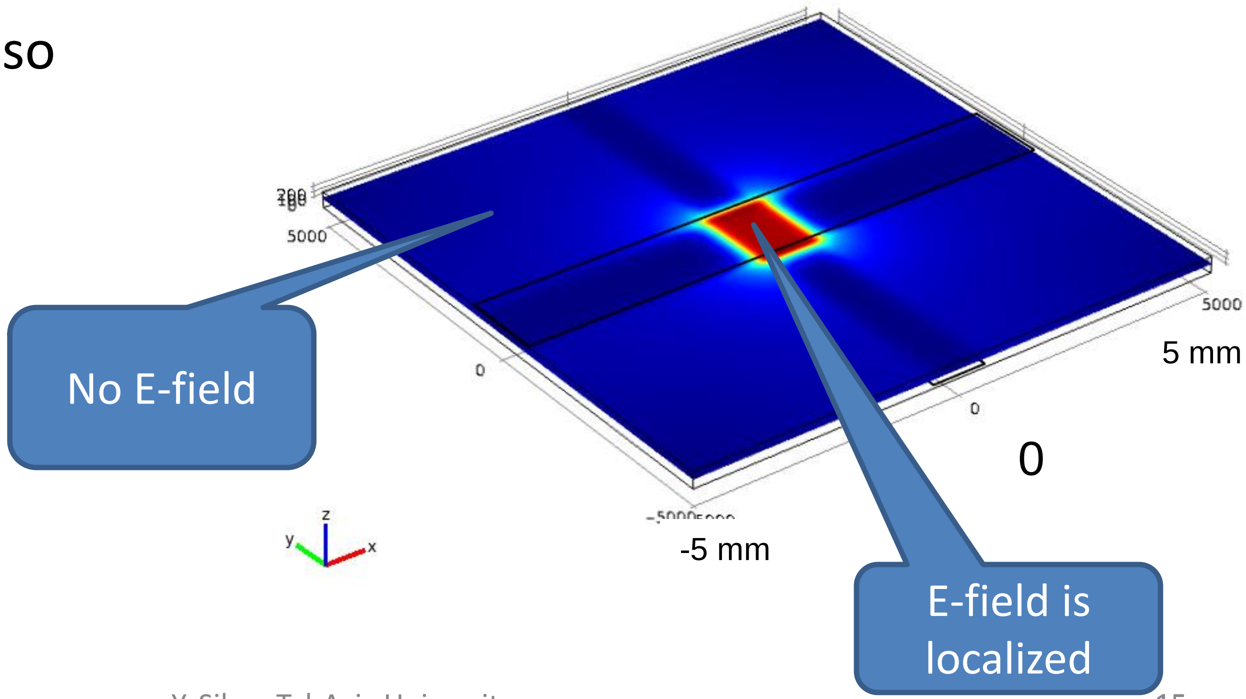
Small variations in Penning mixtures dramatically affect breakdown voltage

Electromagnetic Field Model

- Each cell is modeled as a capacitor
- COMSOL model for the electric field inside the cell
- Capacitances and inductances are also calculated

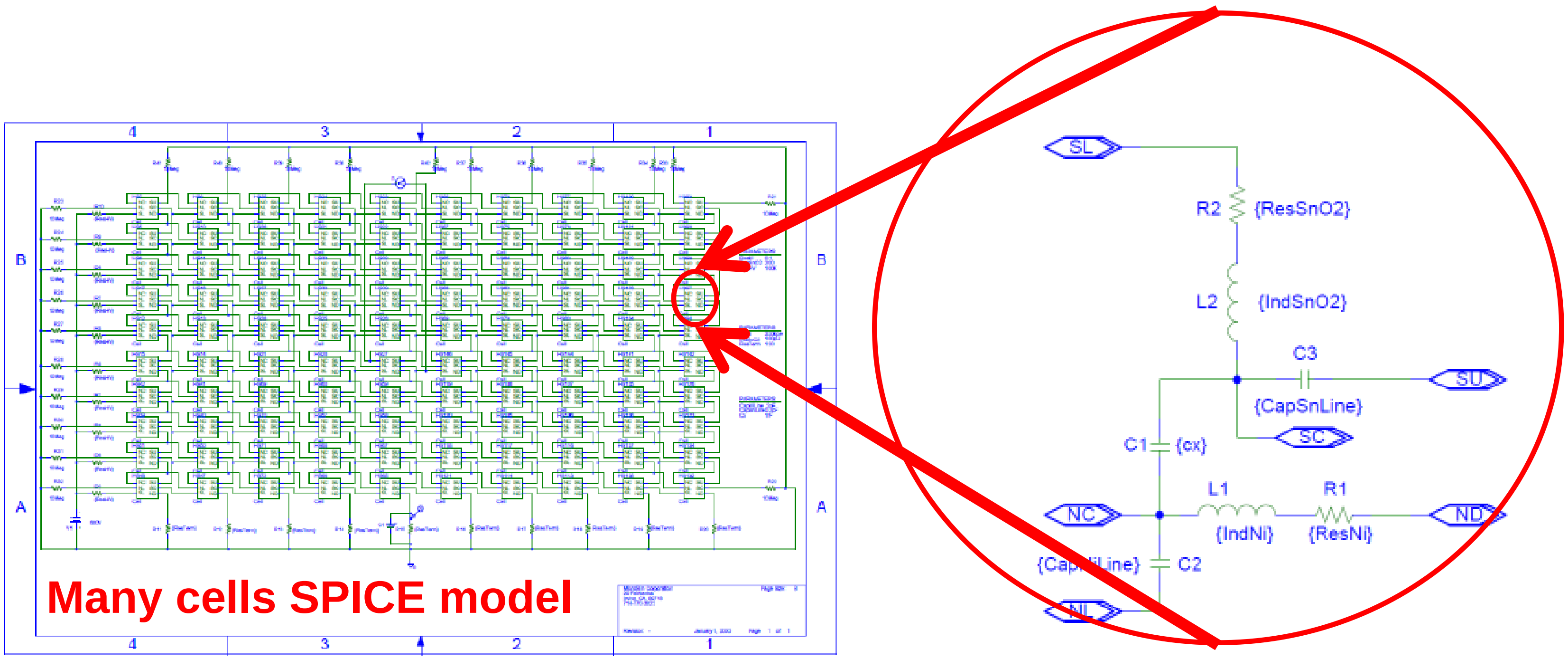


E-field in the PDP pixels

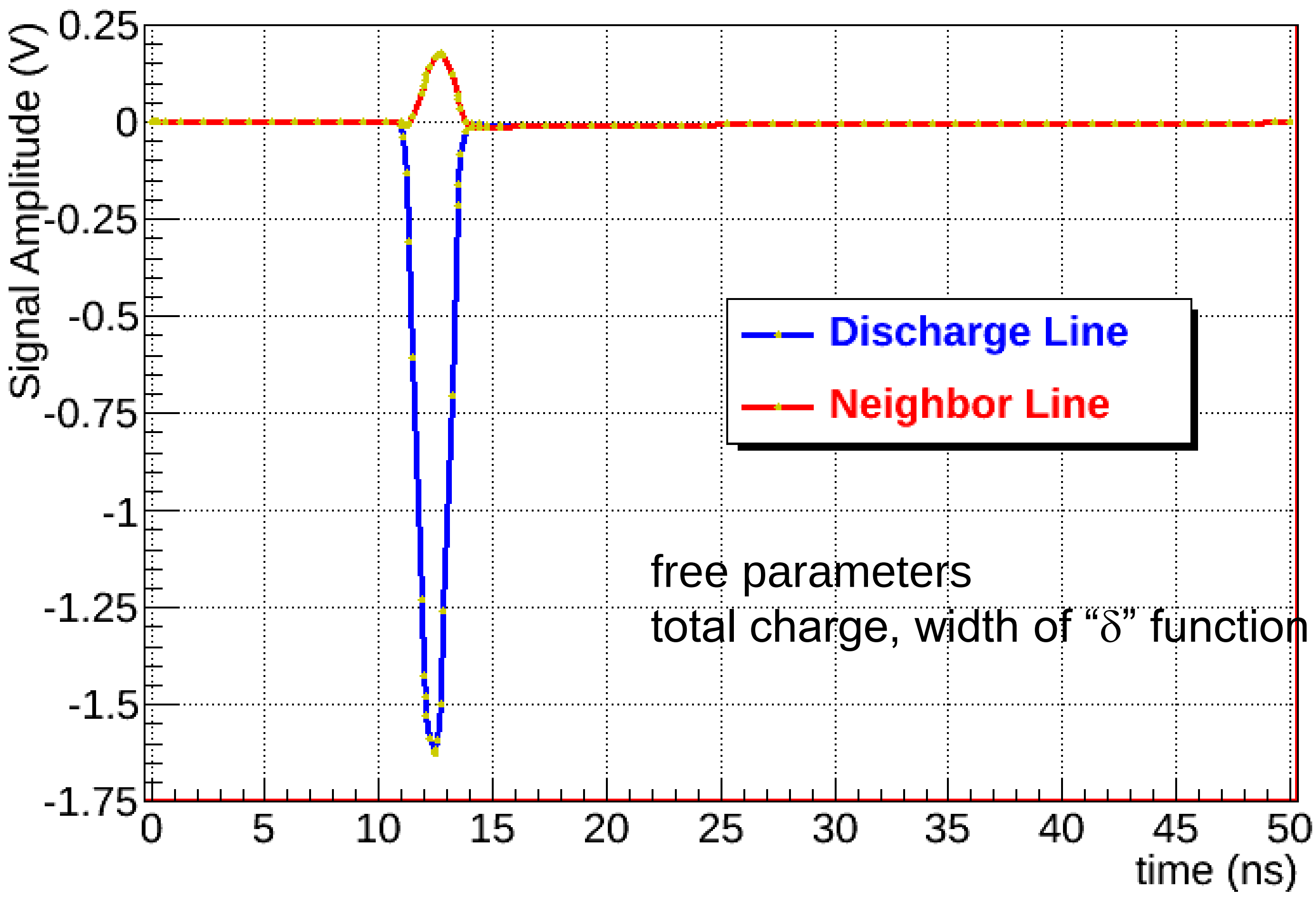


Equivalent Circuit Simulations

- SPICE simulation incorporates the inductances and capacitances calculated with COMSOL
- Electrical pulse is injected into the cell and the output signal is simulated



SPICE Simulated Signal



Design & Operating Parameters

- Cell Design: fill-factor
  - open vs. closed architecture
  - columnar vs. surface discharge
- Electrodes: pitch, width, material
- Cell capacitance
- Operating voltage
- Quench resistance
- Gas mixture & pressure
- Substrate material (e.g. thickness, density)
- Dielectric surfaces

Performance Issues

(some of which we have begun to address)

- After pulsing & discharge spreading
- Gas hermeticity & decomposition
- Response in magnetic field
- Electrode degradation
- Radiation hardness
- High rate response
- Spatial uniformity
- Spatial response
- Time response
- Efficiency
- Readout
- Cost

Experimental Results

All results reported here obtained with prototype detectors adapted from:

glass sealed,

open architecture,

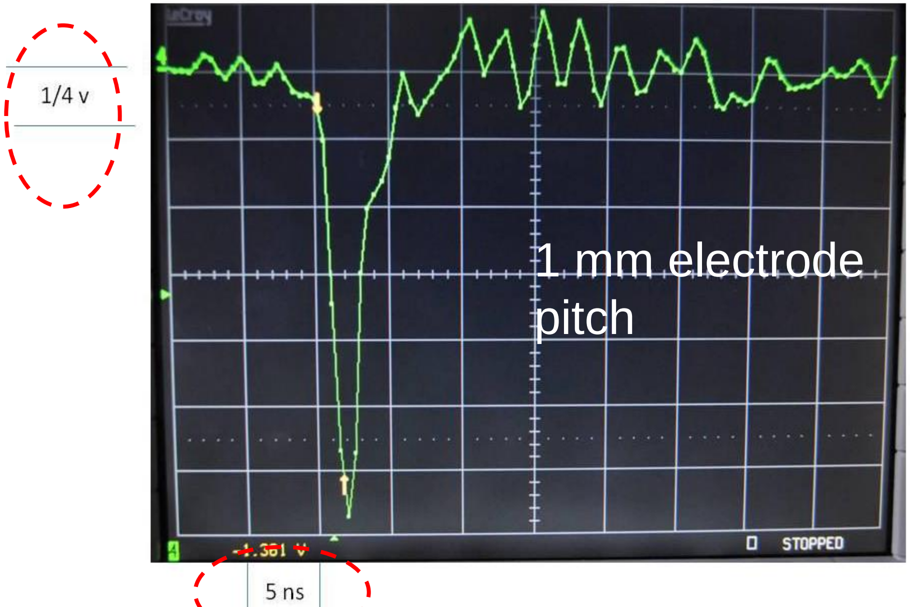
columnar discharge,

monochromatic,

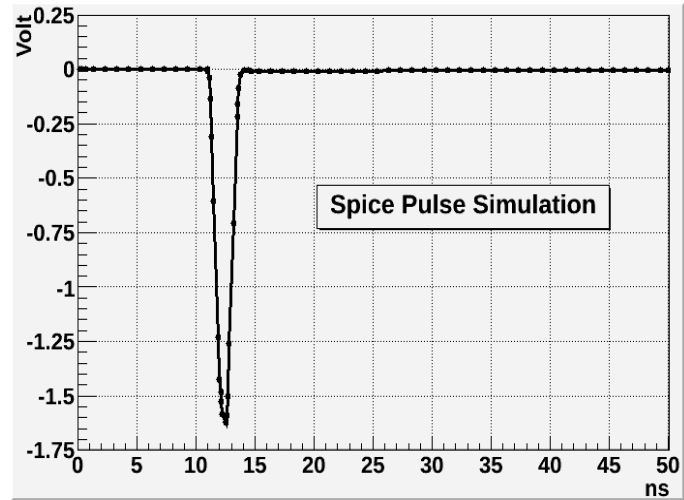
DC display panels

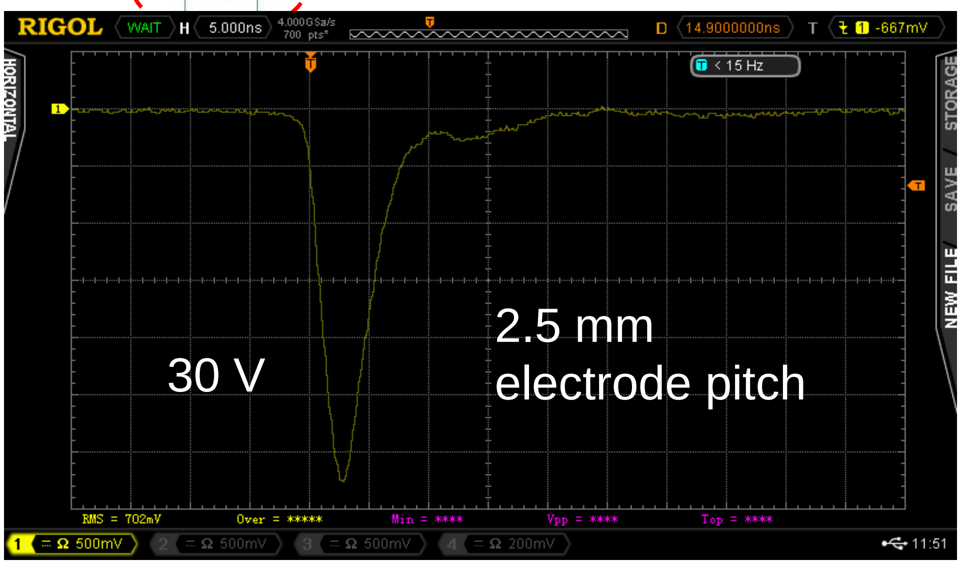
shut-off valve “seal”

Signals from Panel



← pulse from Xe fill 2003, tested 2010

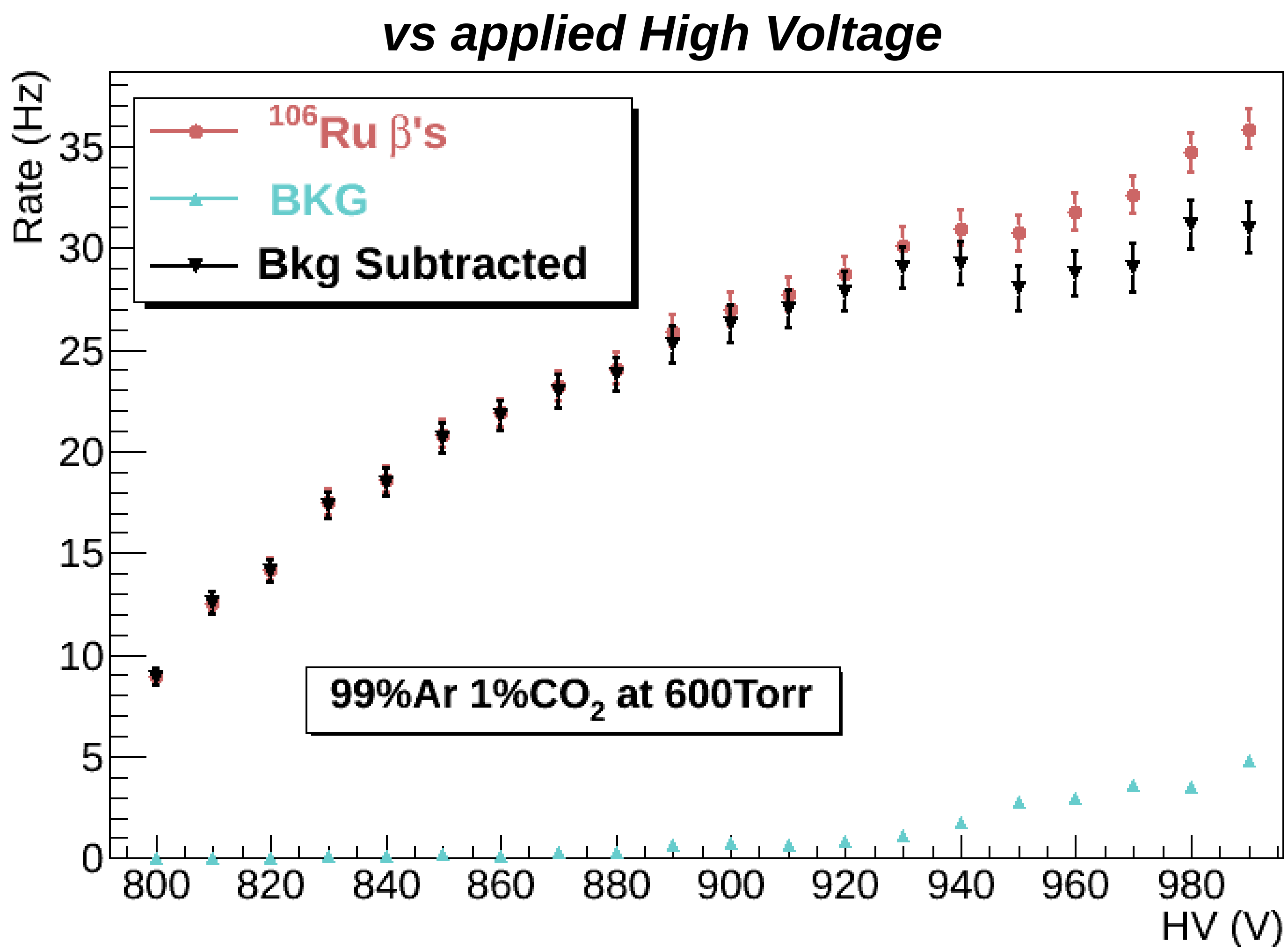




← panel sealed & tested in 2013, pulse from neutron source & ^3He fill

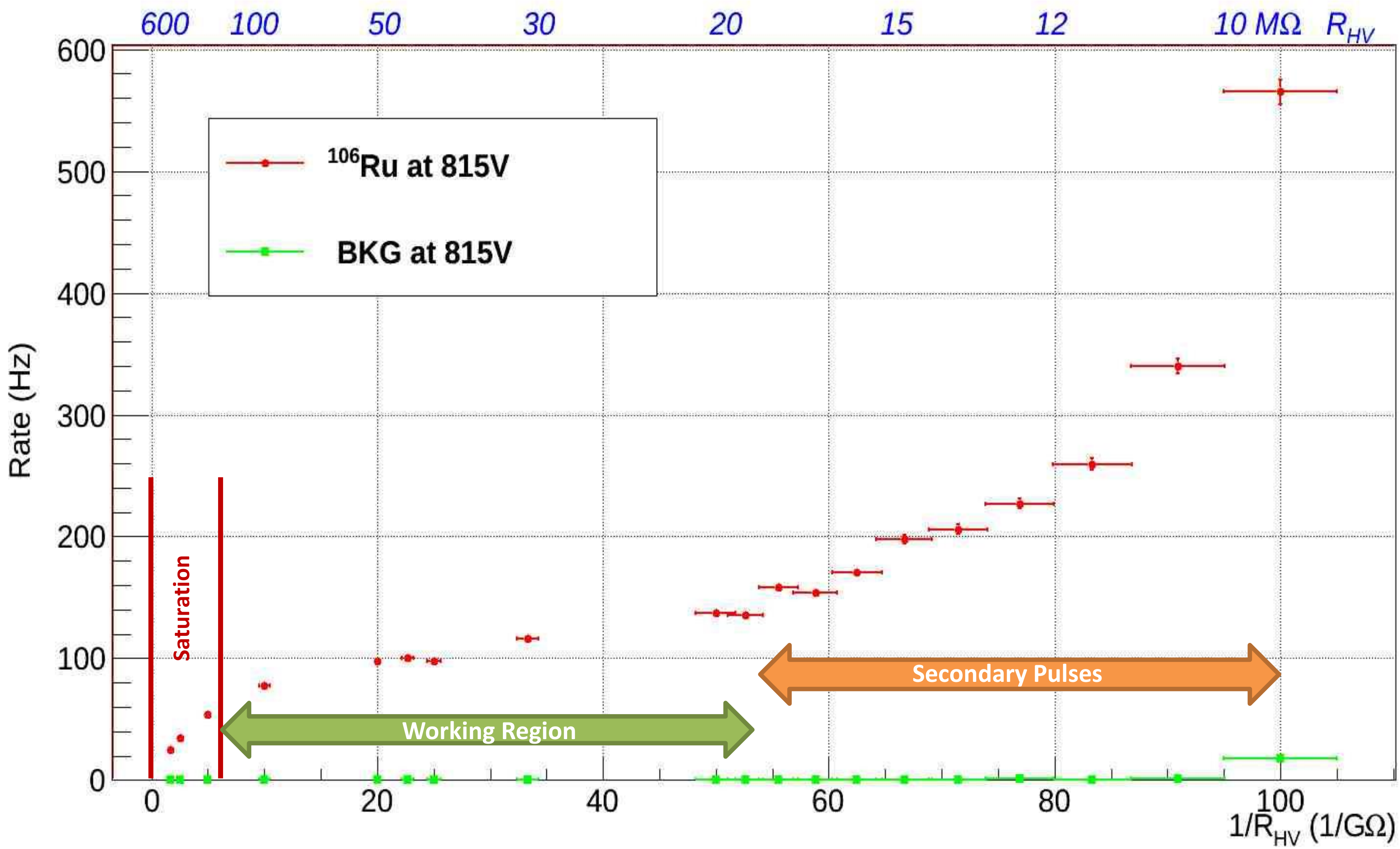
1. Signals amplitudes: volts
2. Good signal to noise ratios.
3. Fast rise times O(ns)
4. Pulse shape uniform for a given panel design

Response to β Source



Quench Resistance Dependence

(Characteristic Response Curve)



Position Sensitivity Proton Test beam & Lab

PPS Proton Test Beam

March 2012

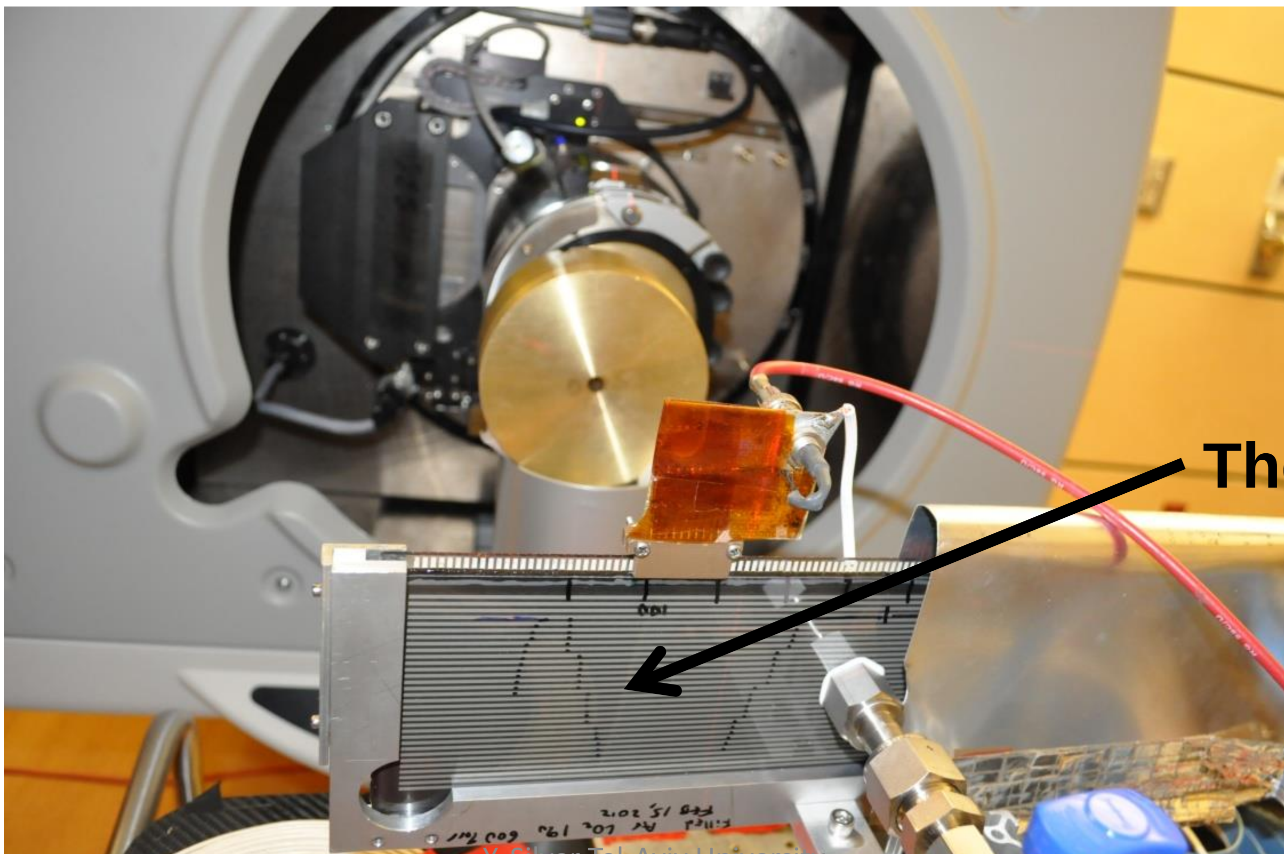
IBA ProCure Facility - Chicago

IBA Proton Beam Test

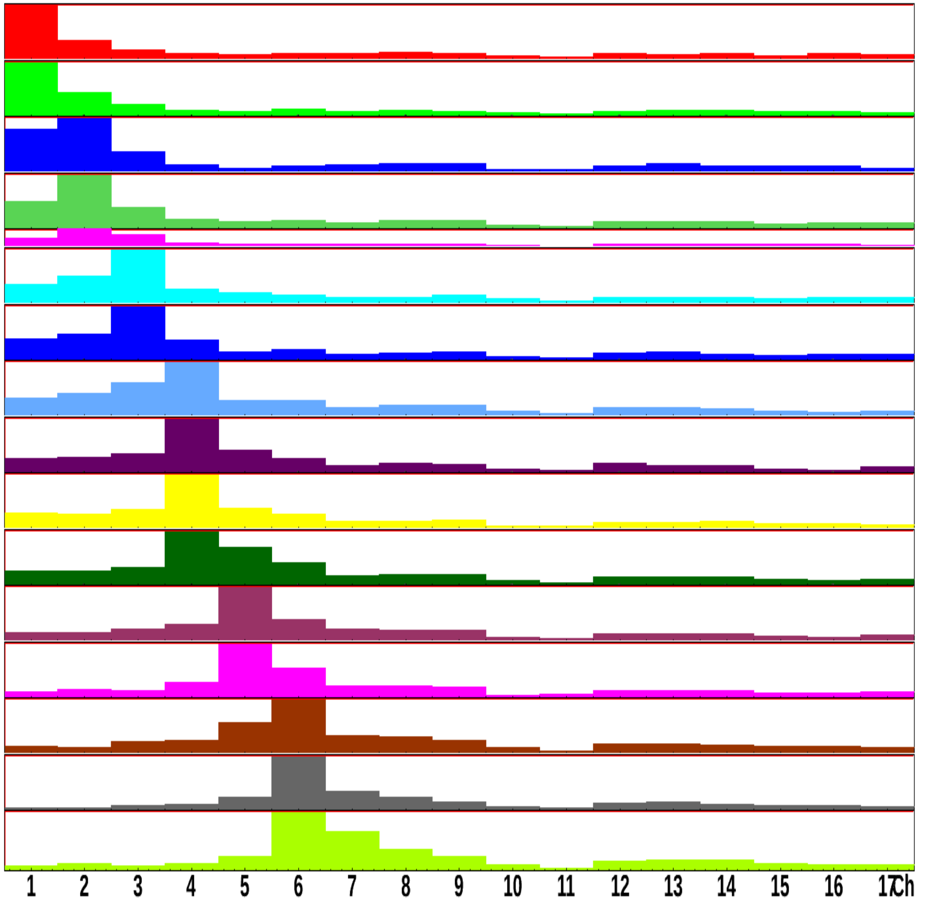
- Beam energy 226 MeV, Gaussian distributed with 0.5 cm width
- Proton rate was larger than 1 GHz on the entire spread of the beam

Position Scan

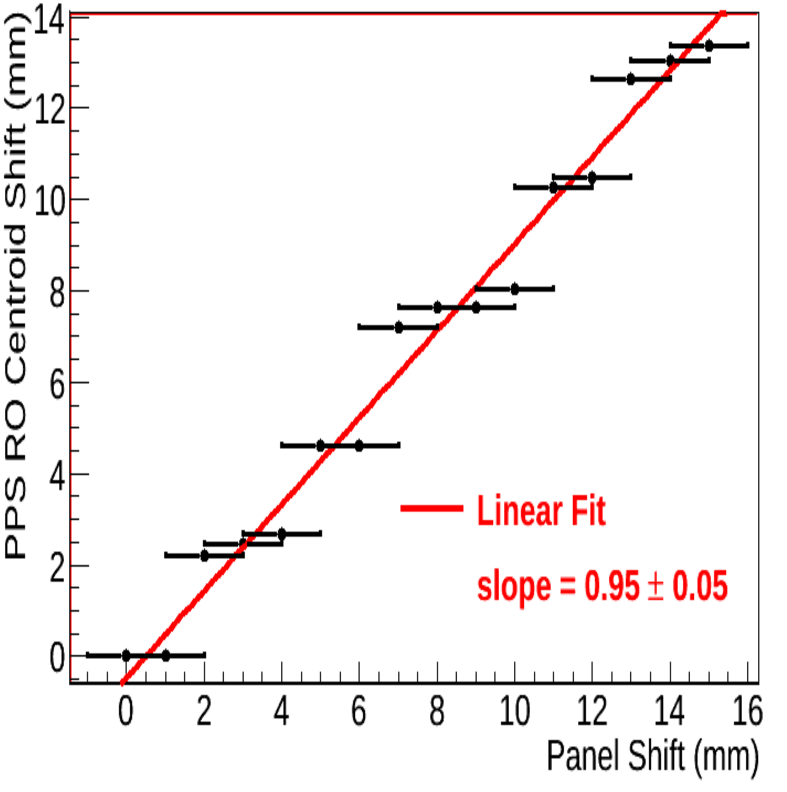
- Two position scans (panel filled with 1% CO_2 in Ar at 600 Torr)
  - ***1 cm steps*** - using brass collimator with **1 cm hole**, 2.5 cm from beam center
  - ***1 mm steps*** with **1 mm hole** directly in beam center
- Rate of protons through 1 mm hole in center of beam was **measured at 2 MHz**



1 mm Scan



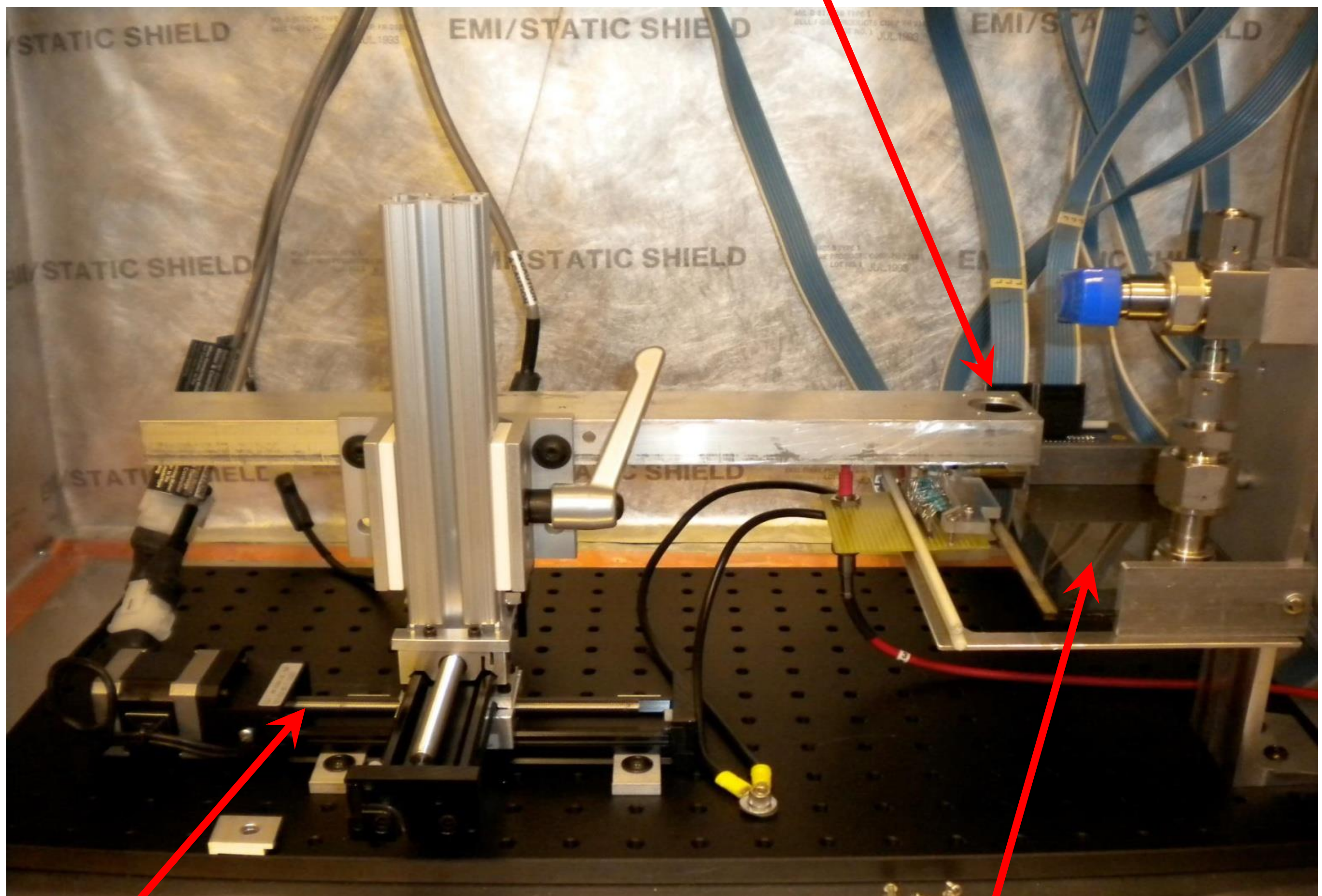
Number of hits per channel



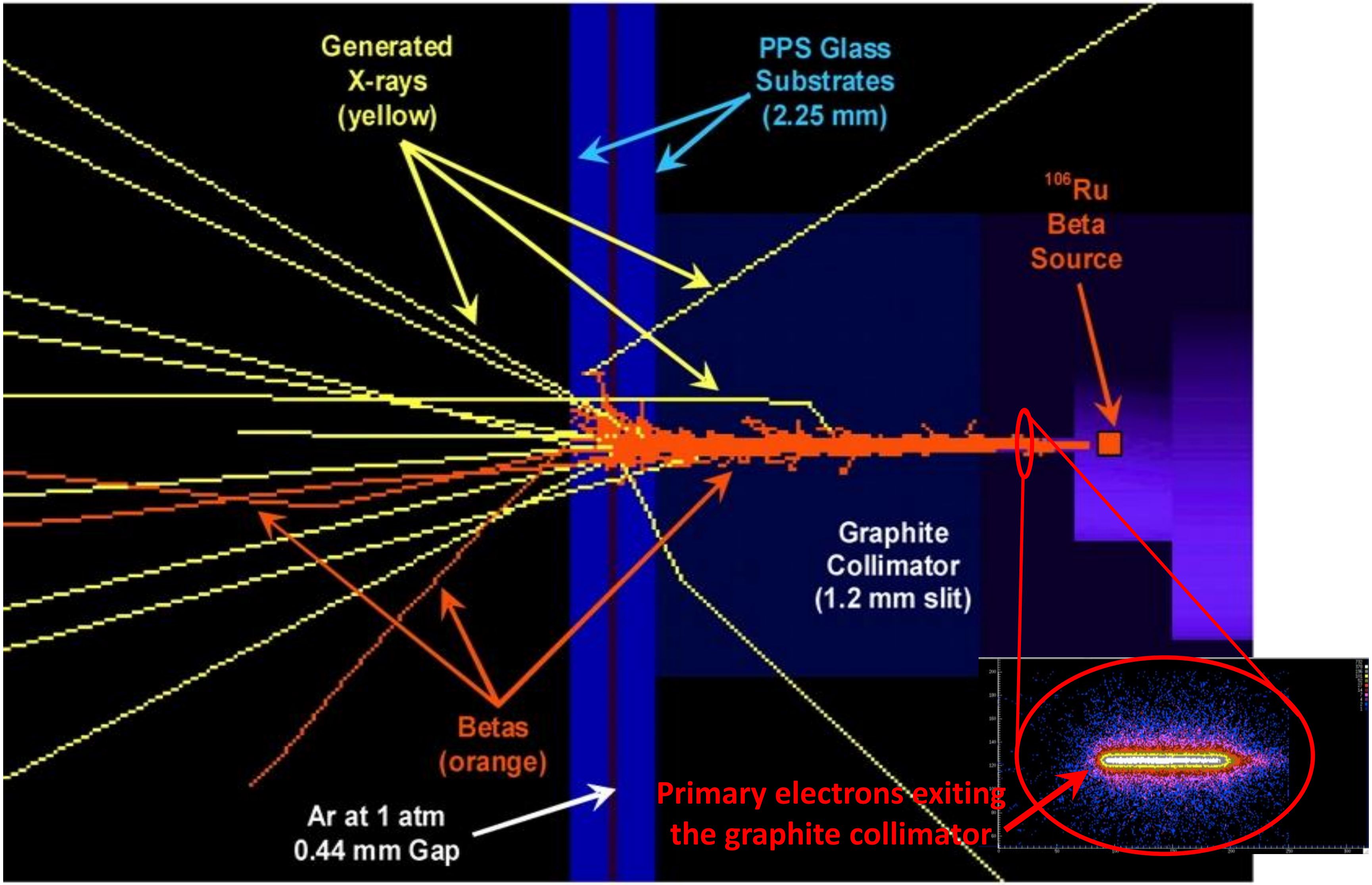
Reconstructed centroid of hit map vs. PDP relative displacement with respect to the panel's initial position

Collimated Source Position Scan

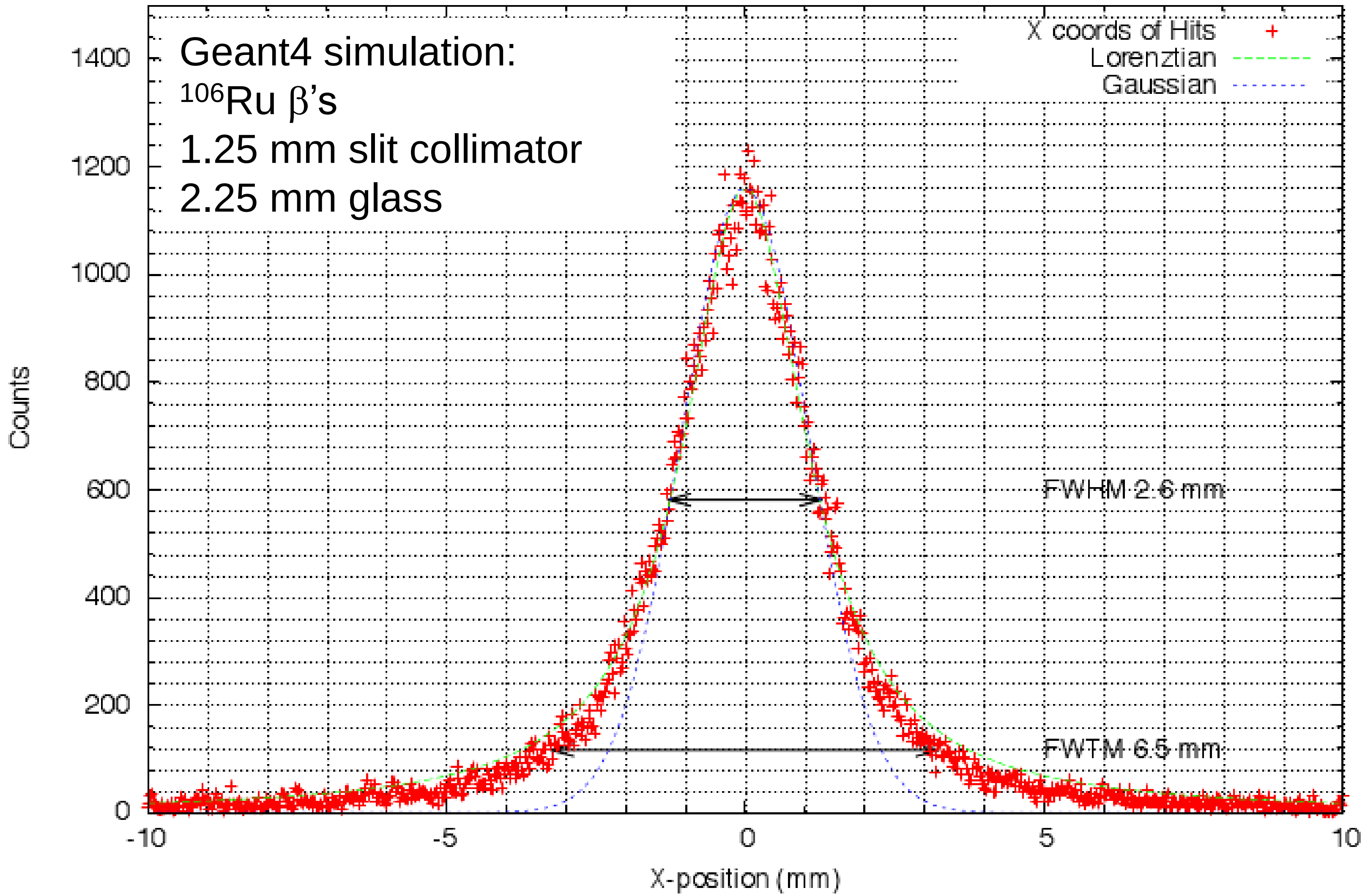
- Light-tight , RF shielded box
- 1 mm pitch panel
- 20 readout lines
- 1.25 mm wide graphite collimator



Collimated β-Source Simulation



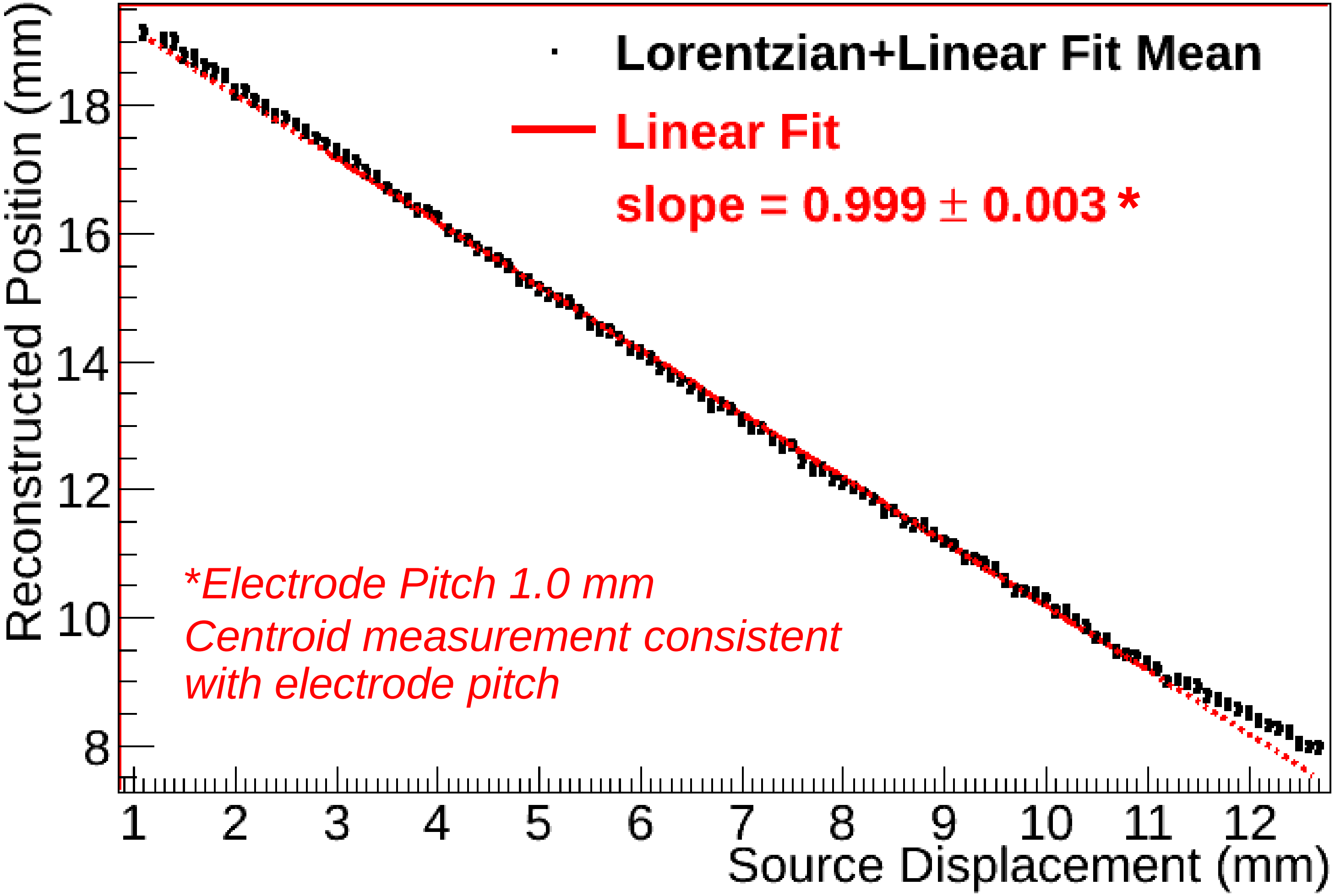
Dispersion of β-Particles in Panel (simulation)



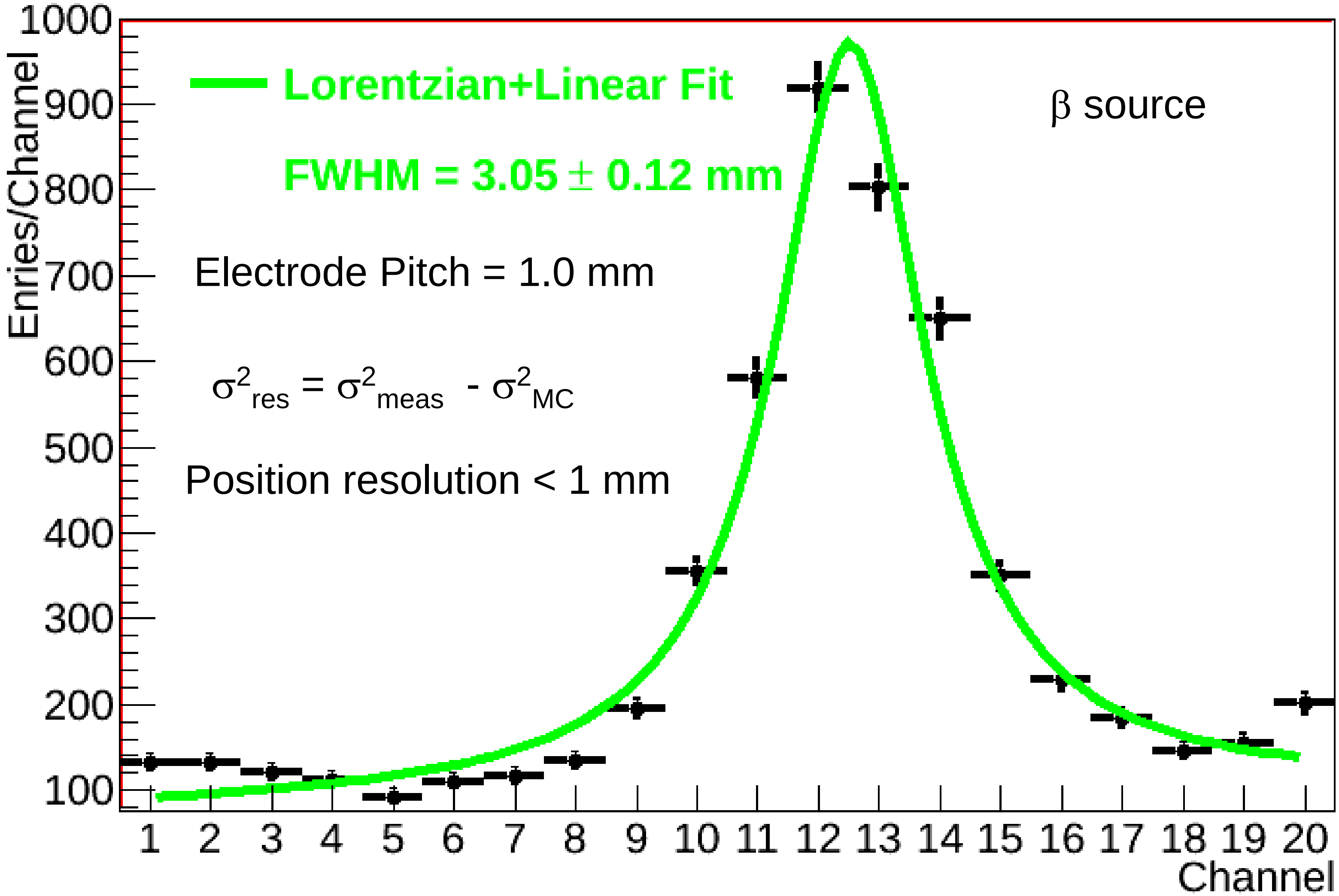
Source Moved in 0.1 mm Increments
(1 mm pitch panel)

PPS Position Scan

Mean fit for β-source moved in **0.1 mm** increments

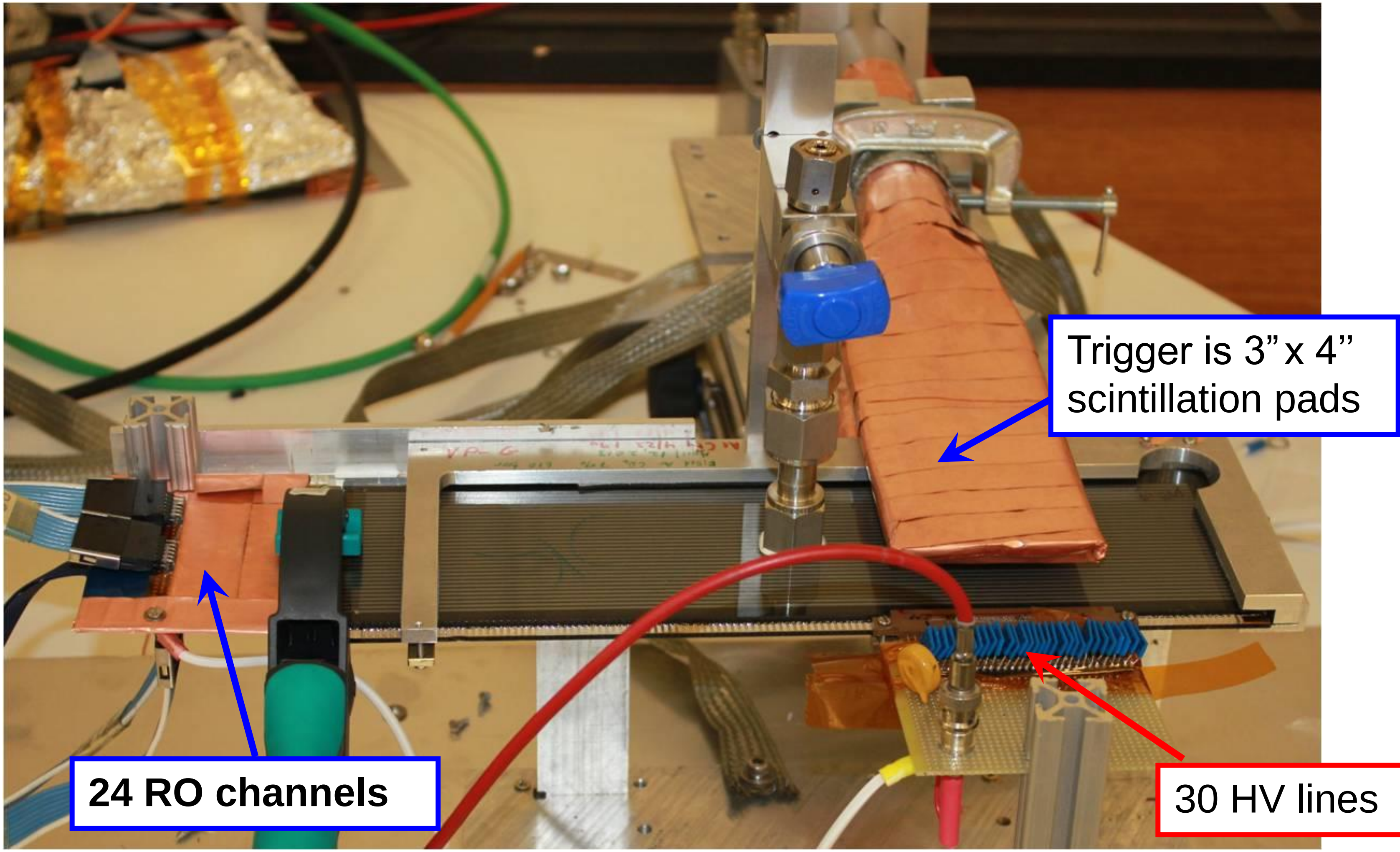


Position Resolution/Dispersion

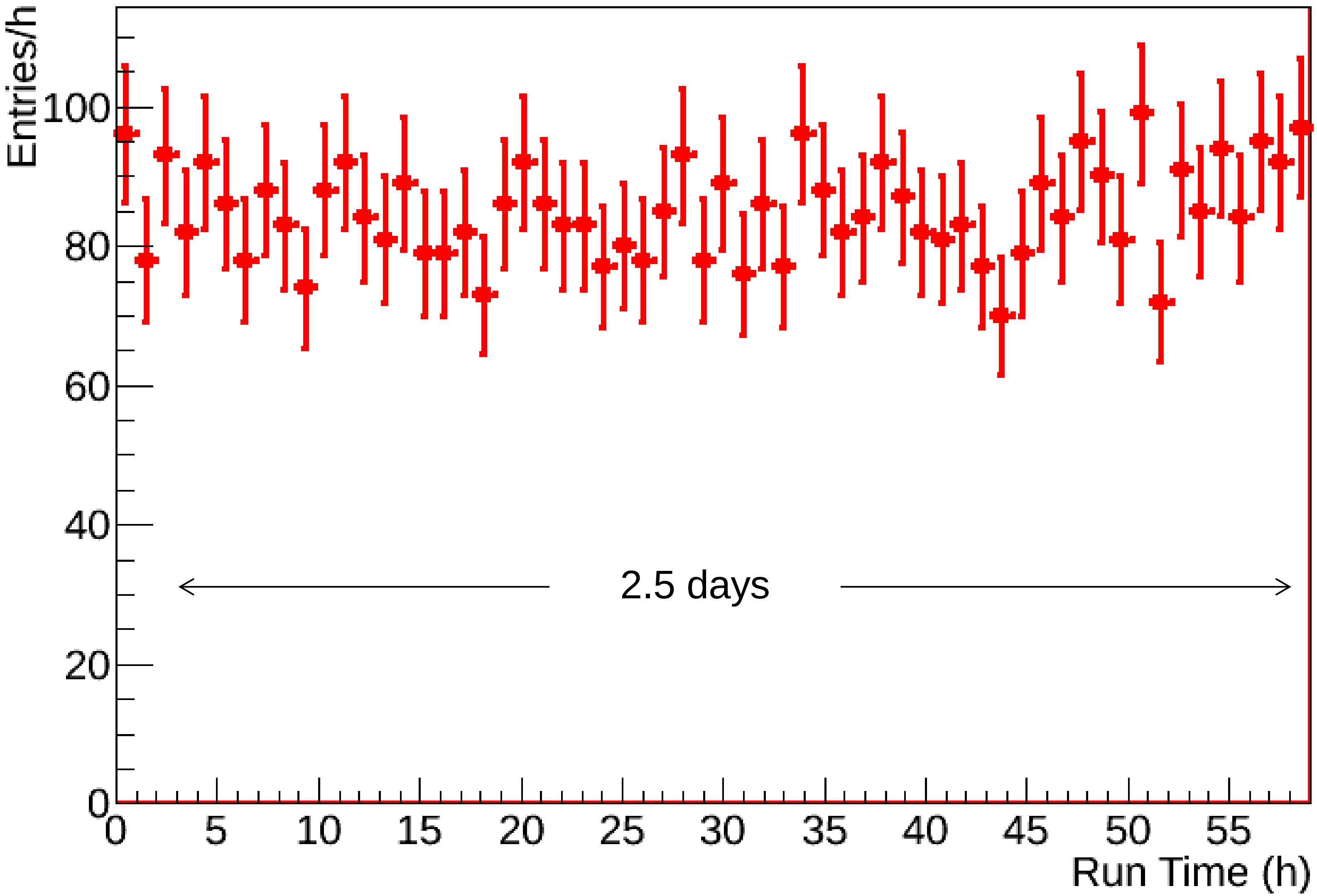


PPS Cosmic-Ray Muon Results

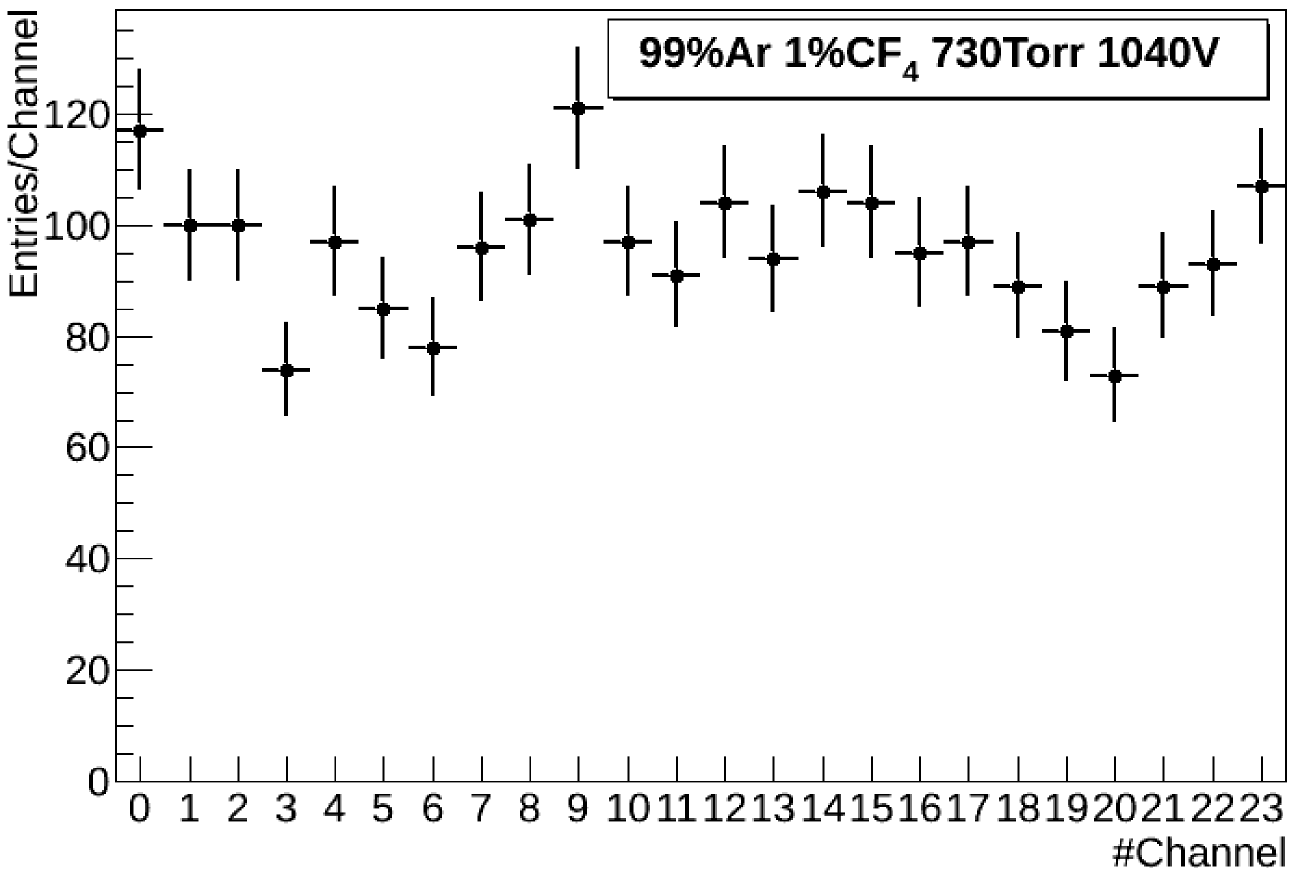
Cosmic Muon Measurement Setup



CR Muon Response



Response over active region



All channels active

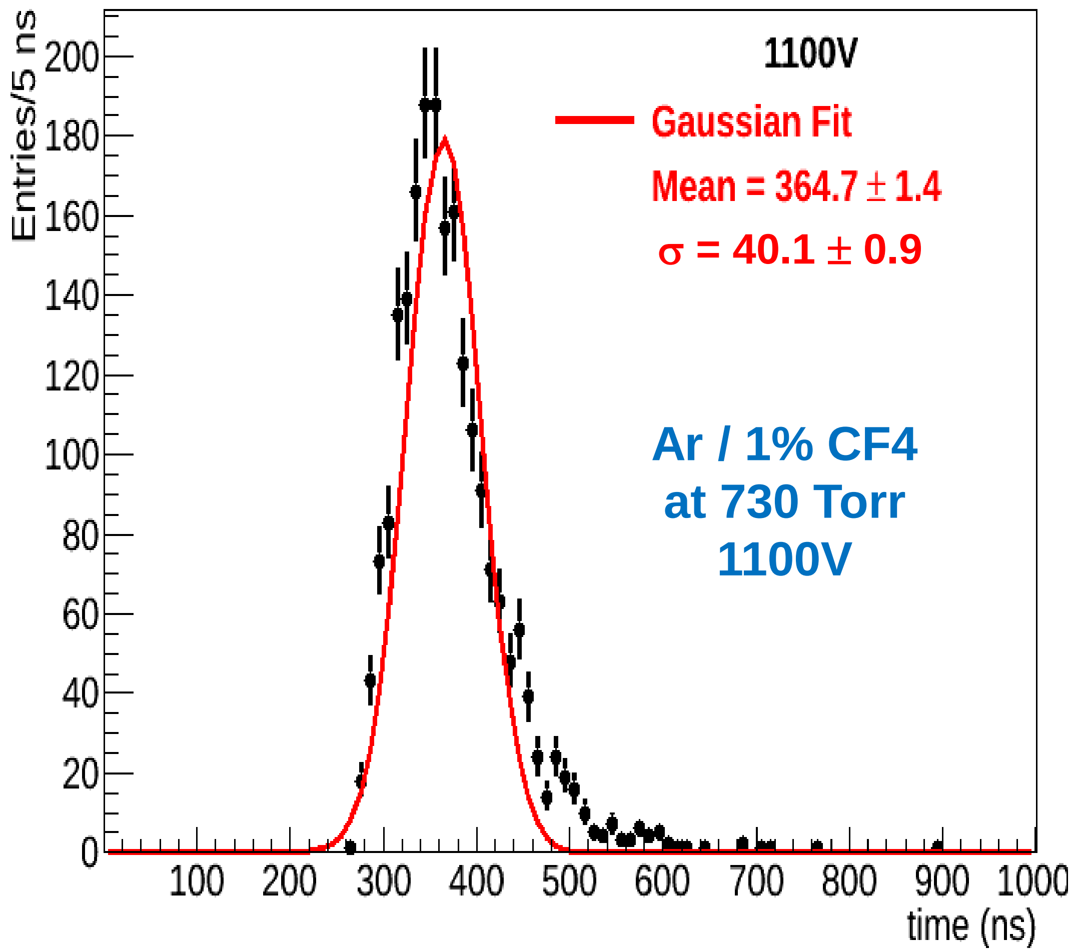
exhibit similar levels of activity

Time Spectrum

- Pulse "arrival" time
(includes arbitrary trigger offset)

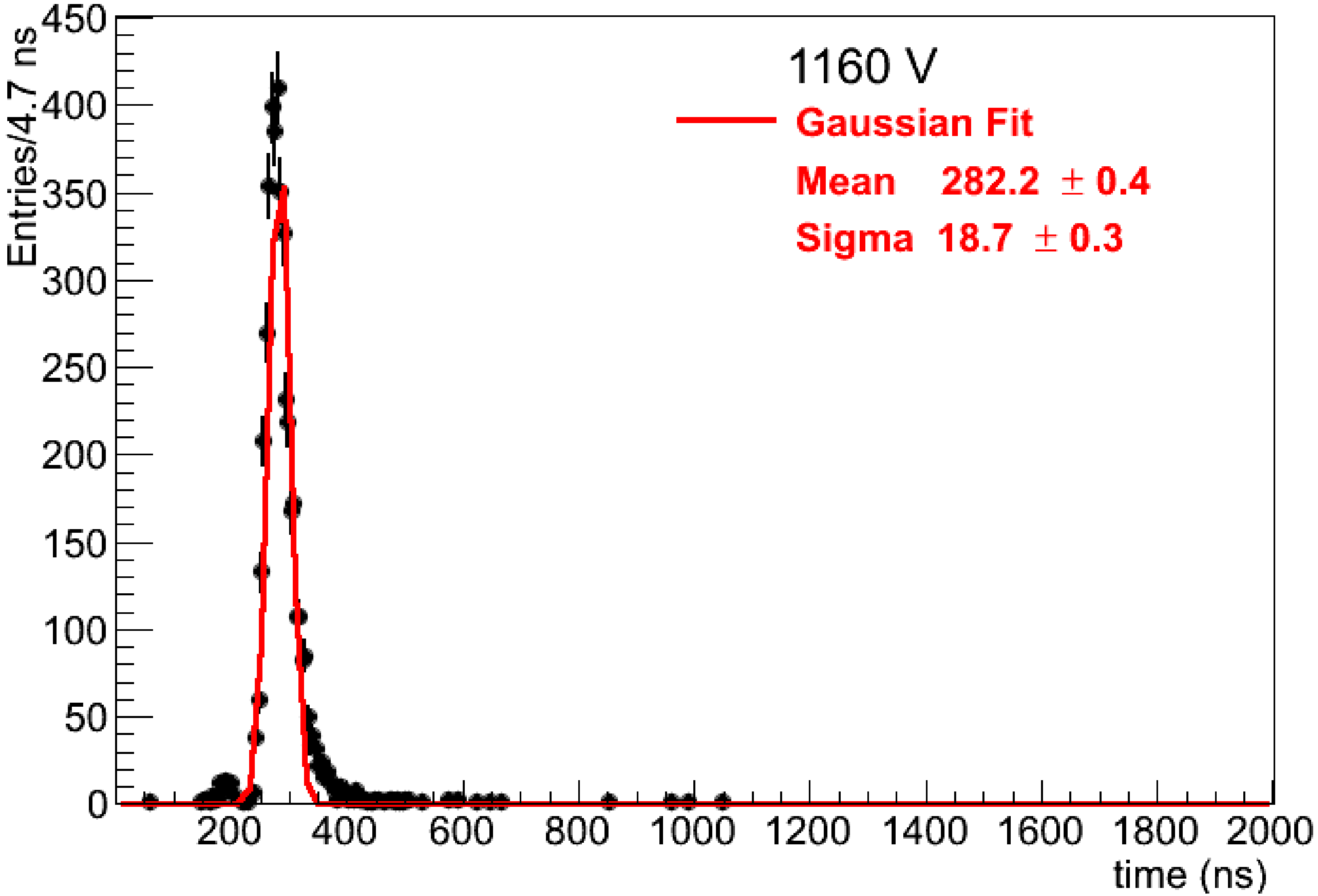
- σ = timing resolution (jitter) of the detector

- **We repeat this measurement with various gases and voltages**

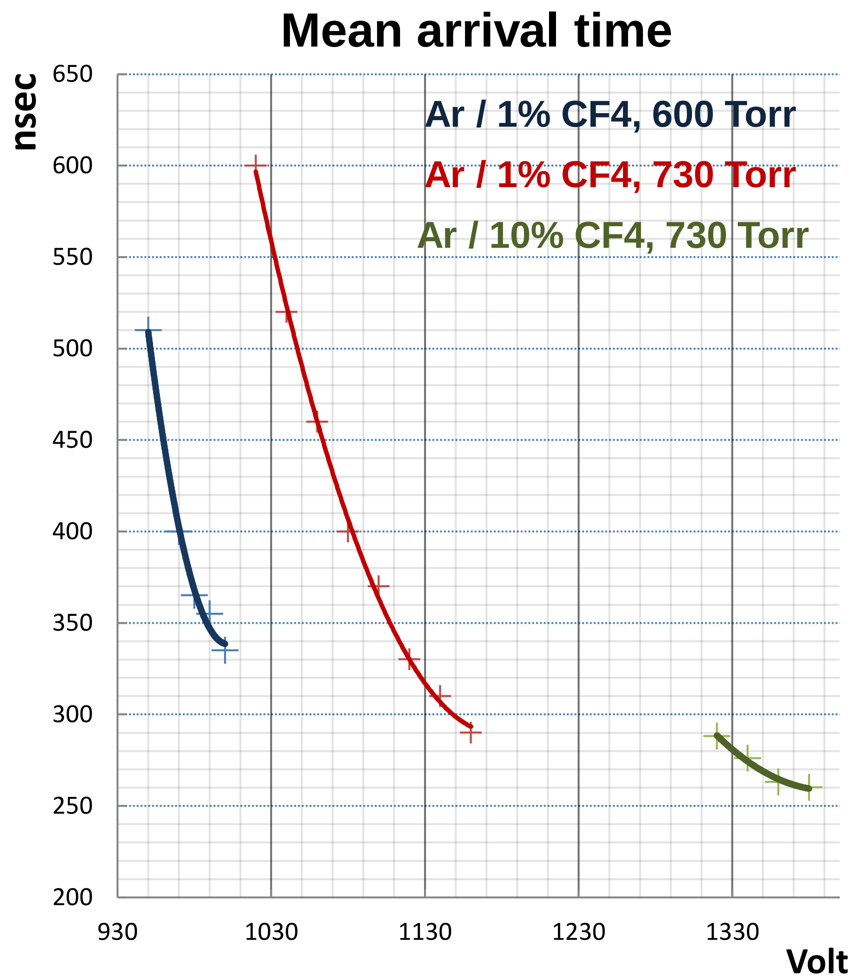


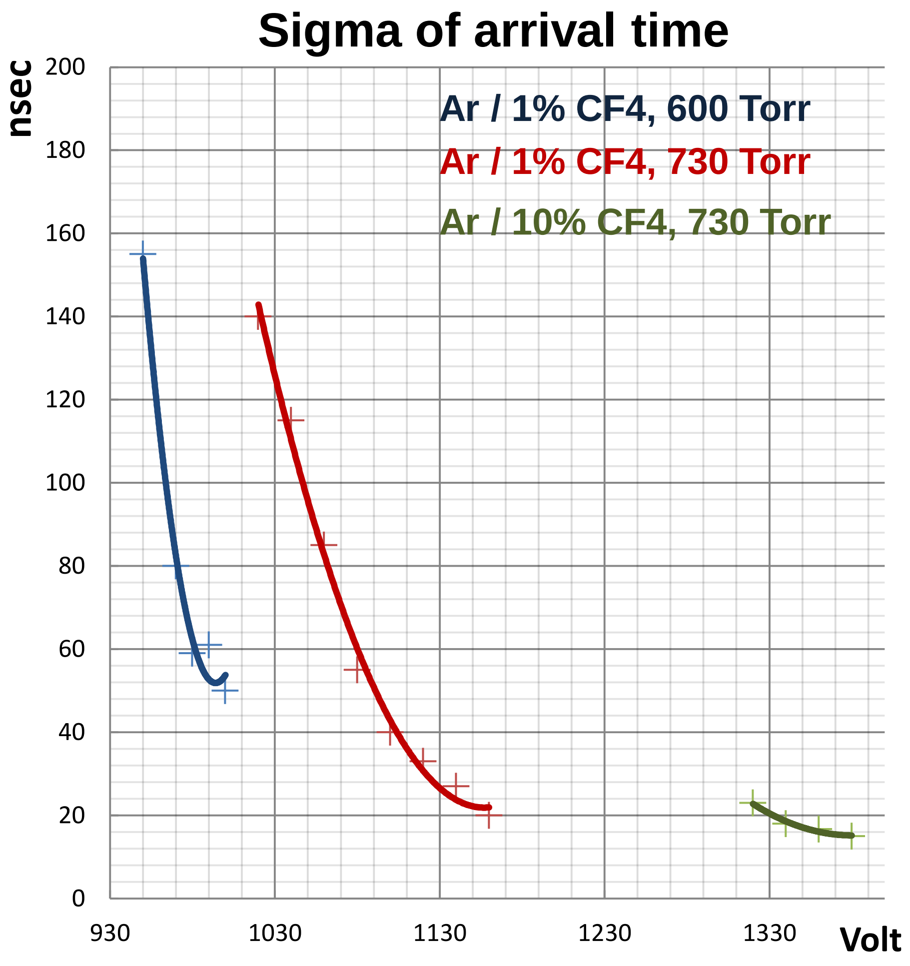
Time Spectrum

Ar / 1% CF_4 at 730 Torr



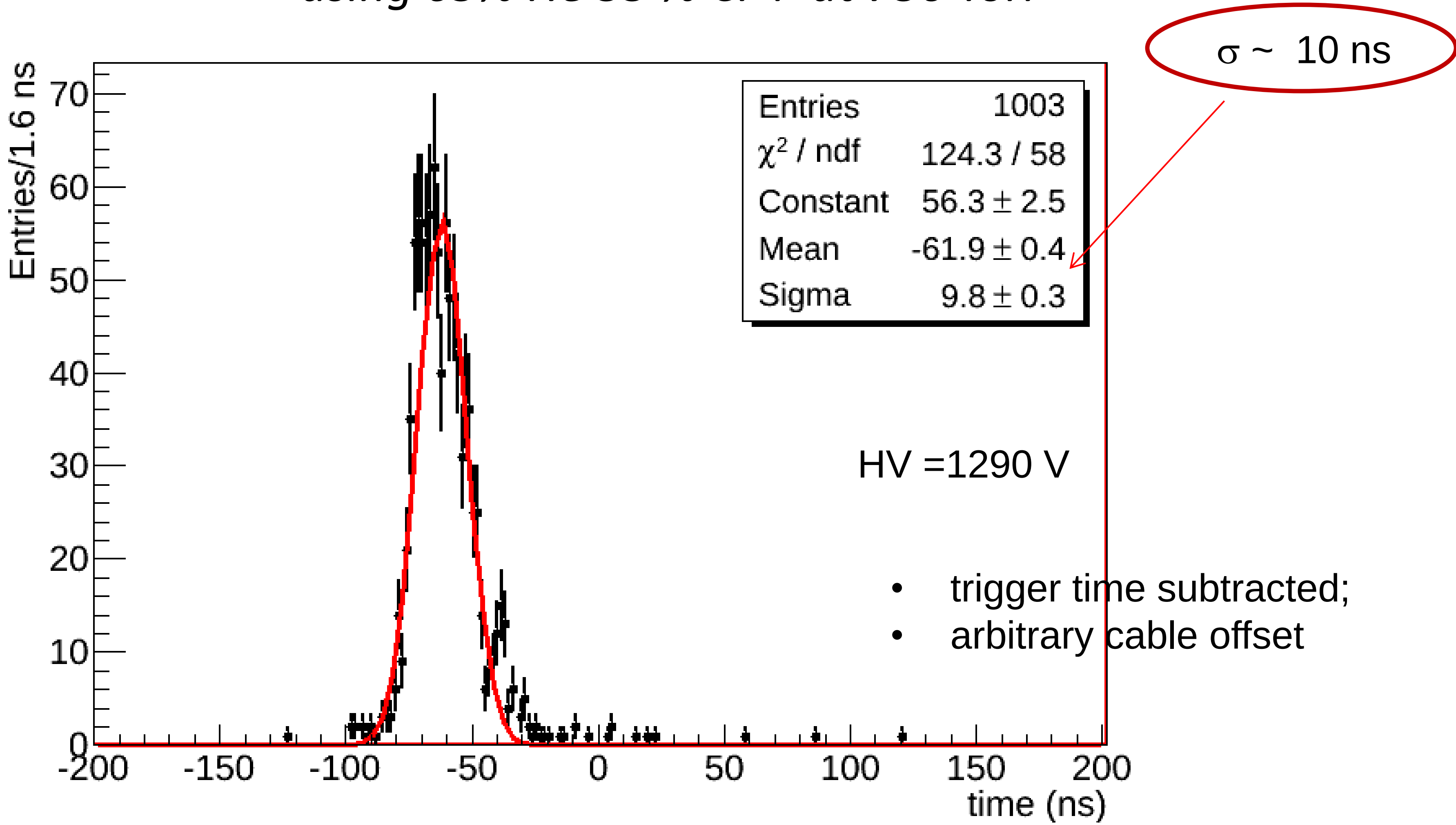
Timing Resolution vs. Applied HV





Timing Resolution

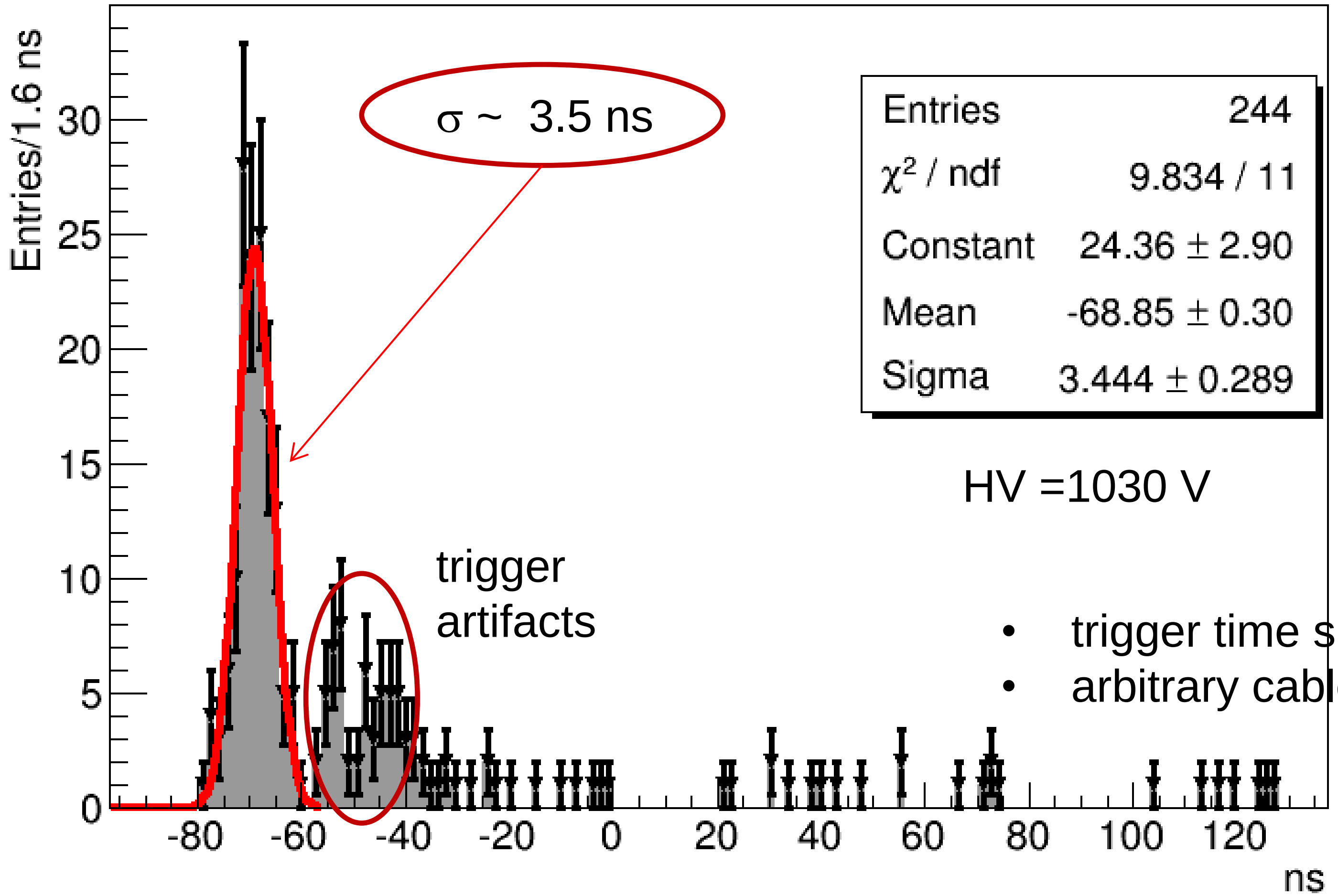
using 65% He 35 % CF4 at 730 Torr



- trigger time subtracted;
- arbitrary cable offset

Timing Resolution

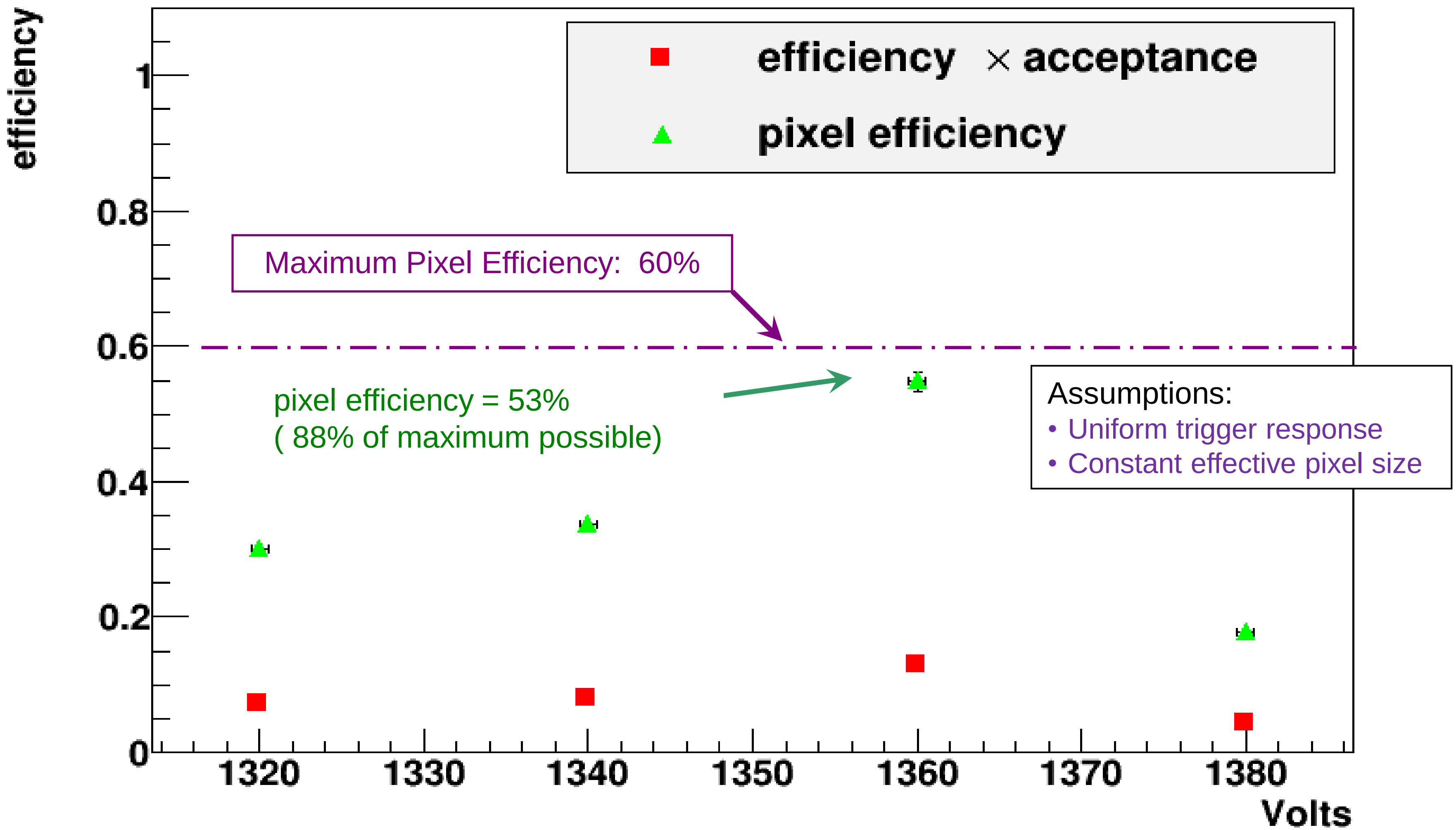
using 80% ^{3}He 20 % CF4 at 730 Torr



- trigger time subtracted;
- arbitrary cable offset

PPS Area Corrected Efficiency

(10% CF_4 in Ar, at 740 Torr, 0.38 mm gas gap)

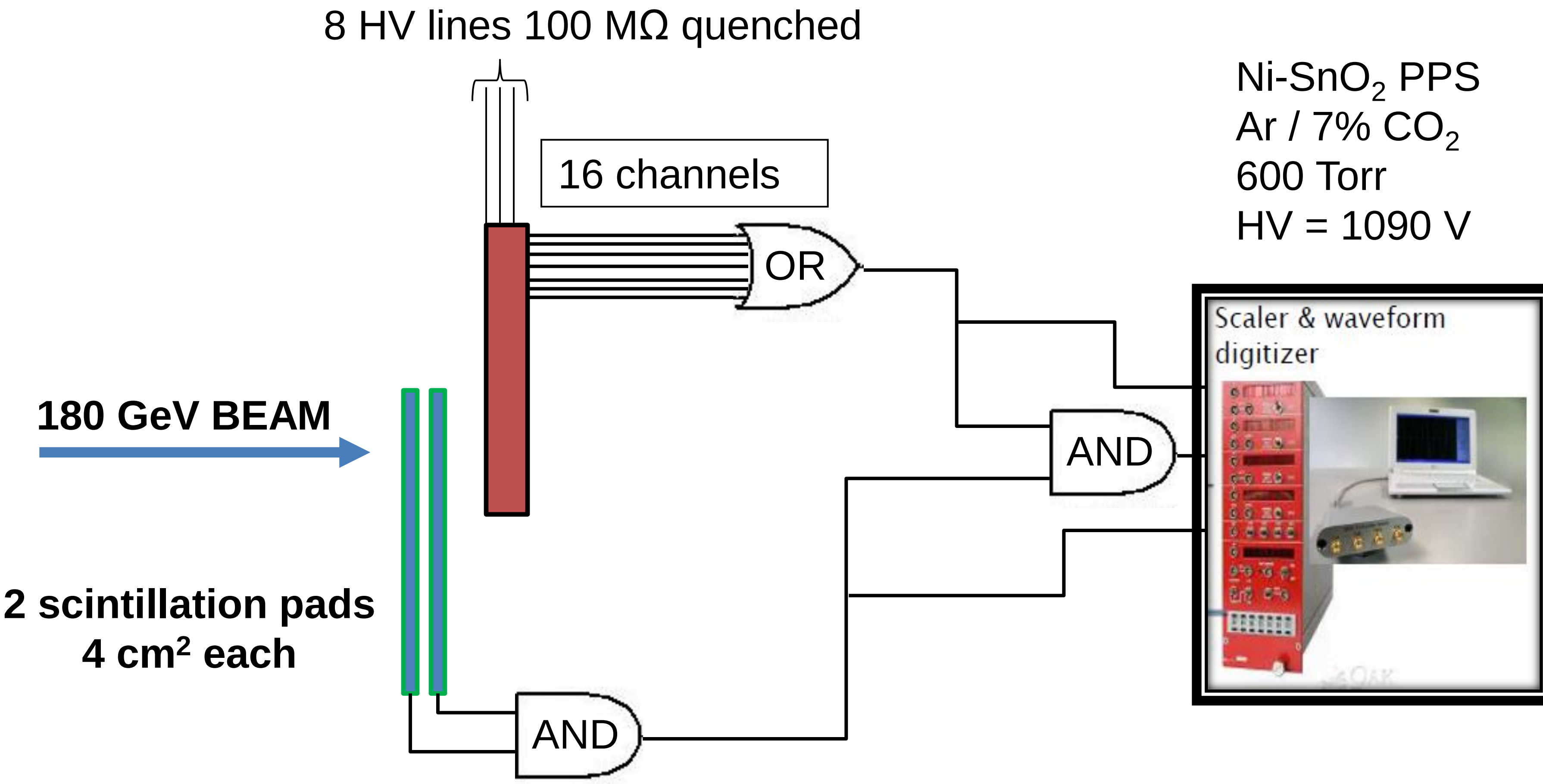


PPS Muon Test Beam

November 2012

H8 at CERN

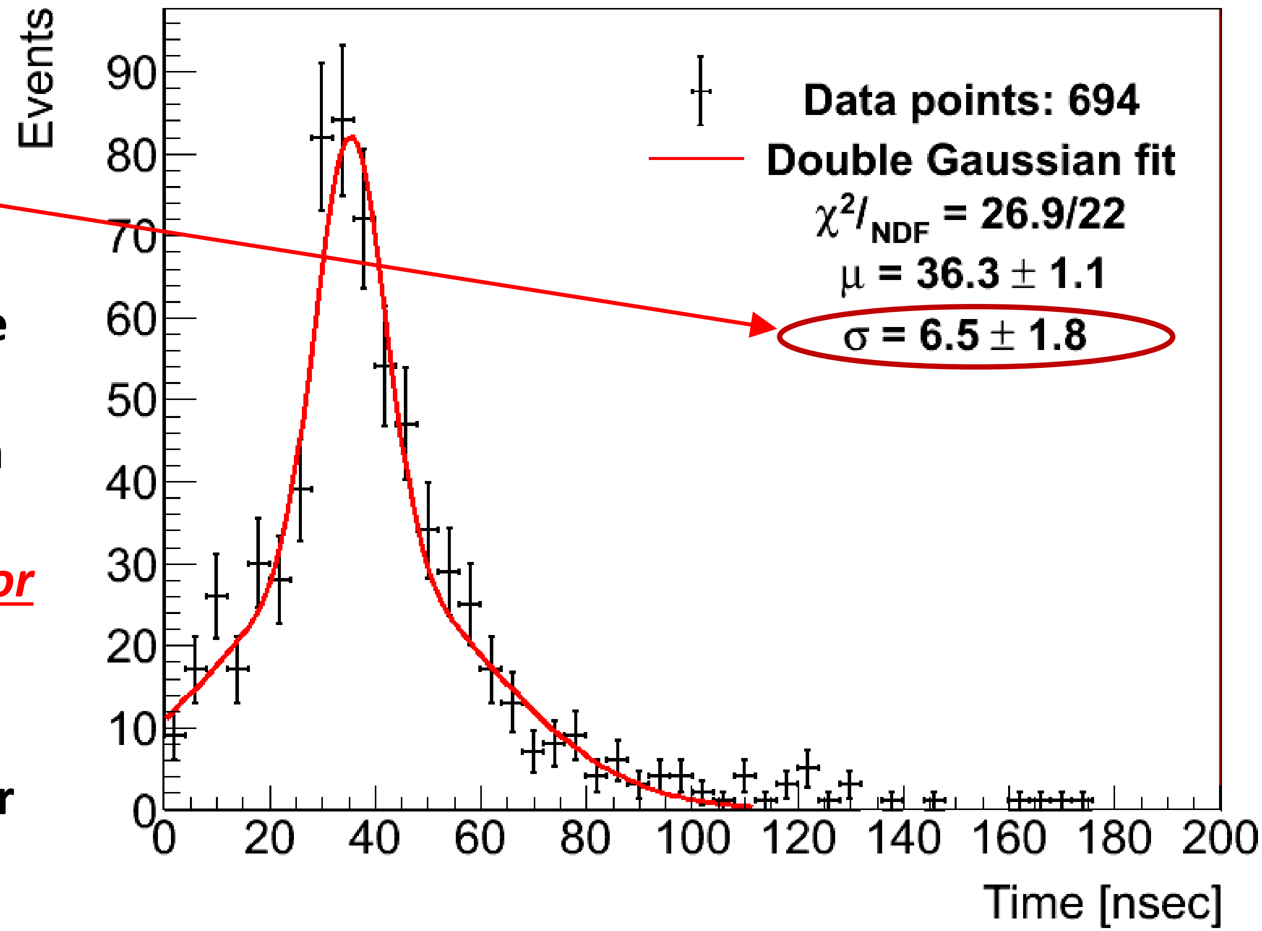
Setup



Panel active area is 2 cm x 4 cm

Time Resolution

- **Timing resolution with $Ar\text{-}CO_2$ better than 10 nsec**
- **Geometrical acceptance times efficiency ≈ 2% (pixel efficiency is much higher).** ***Did not have beam time to optimize or even raise the voltage!***
- **Active area fill-factor for PPS detector is 23.5%**



Neutron Detection

in collaboration with GE, Reuter-Stokes

Objectives: high efficiency neutron detectors with high γ rejection
develop alternate to ^{3}He as neutron interaction medium

This test: explore PPS as a general detector structure for converting neutrons using thin gap ^{3}He gas mixture

Gas fill: 80% ^{3}He + 20% CF_4 at 730 Torr

Panel: 2.5 mm pitch large panel used for CR muons
Instrumented pixels = 600 Area: 6 in^2

Method: irradiate panel with
thermal neutrons from various sources
high activity (10 mrem/hr) gammas
conduct count rates experiment with & w/o neutron mask plates.

Setup

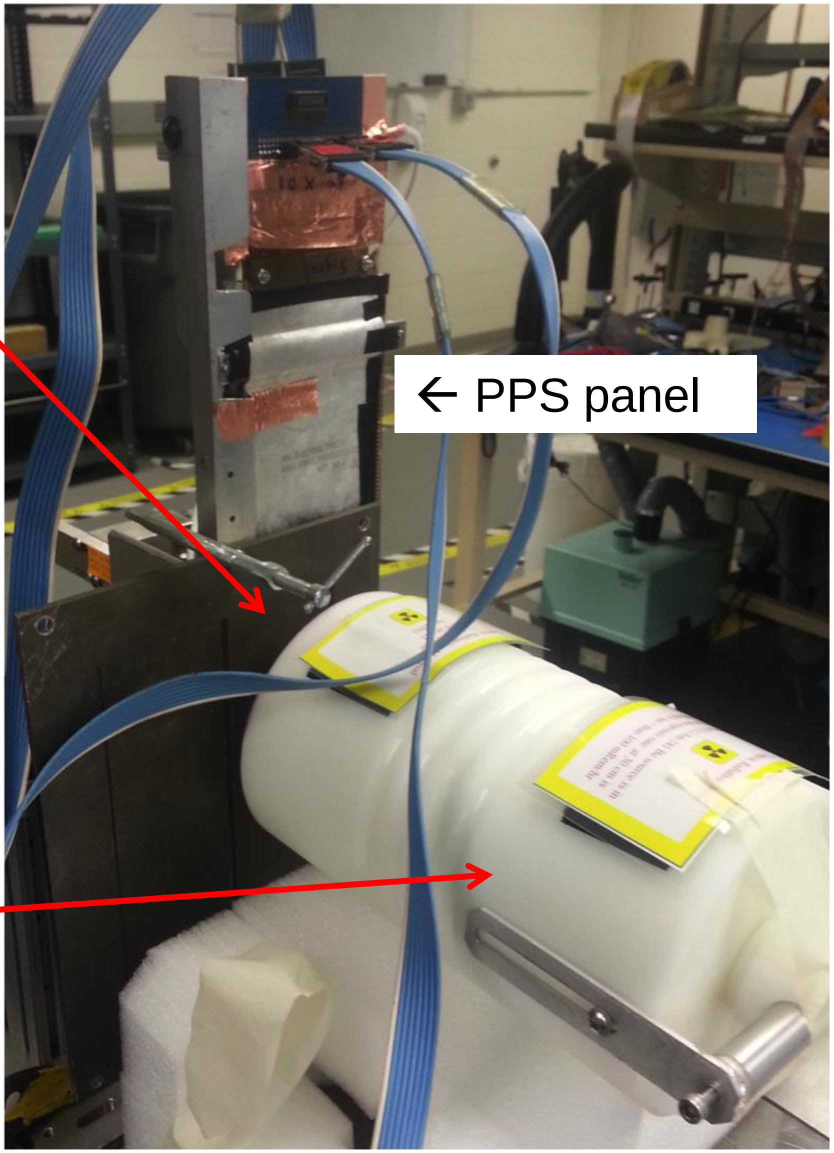
Gamma transparent, neutron blocking plates

(~ 0.1% transmission)

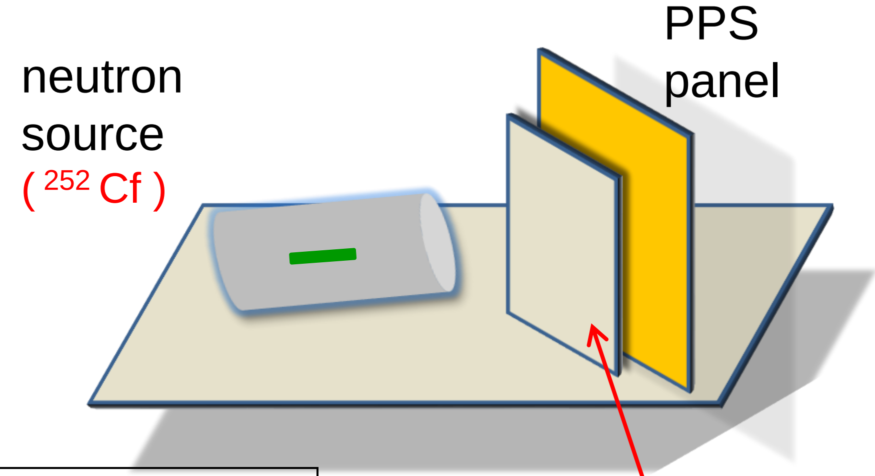
neutron sources

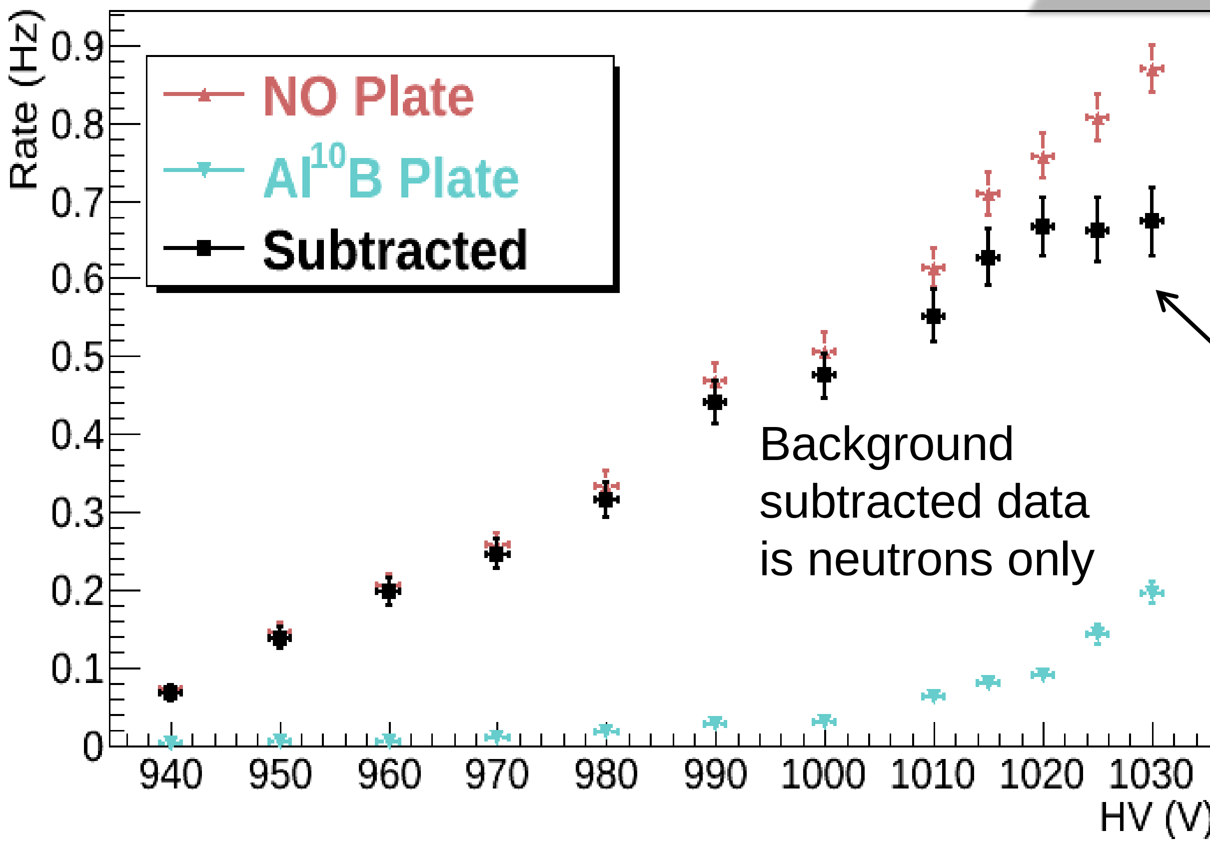
^{252}Cf , ^{241}Am-Be, ^{239}Pu-Be

nested in stainless capsule, Pb cylinder, high density polyethylene (HDPE)



Results



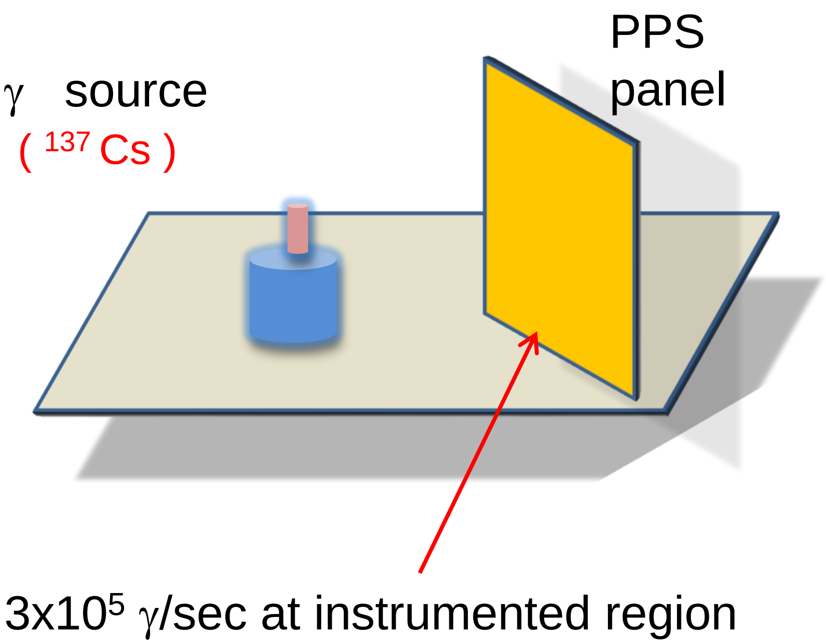


Neutron
blocking
plate

efficiency
plateau

Background:
γ from source

γ Rejection

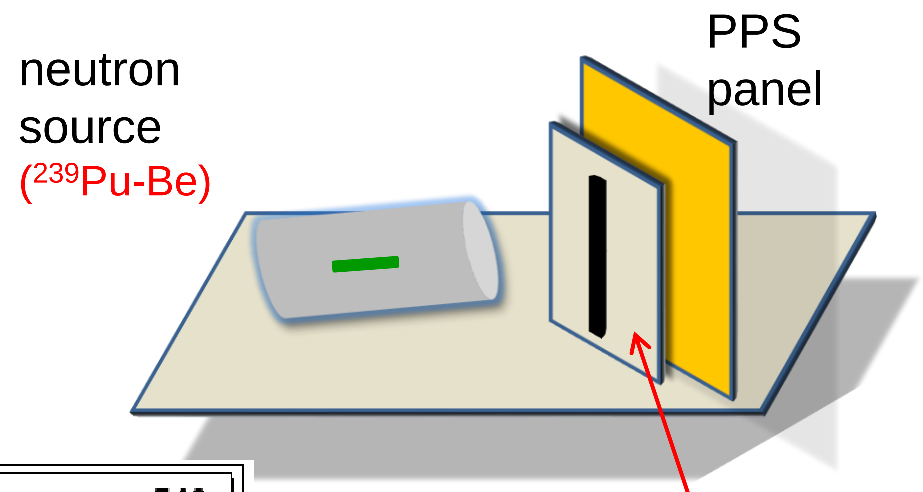


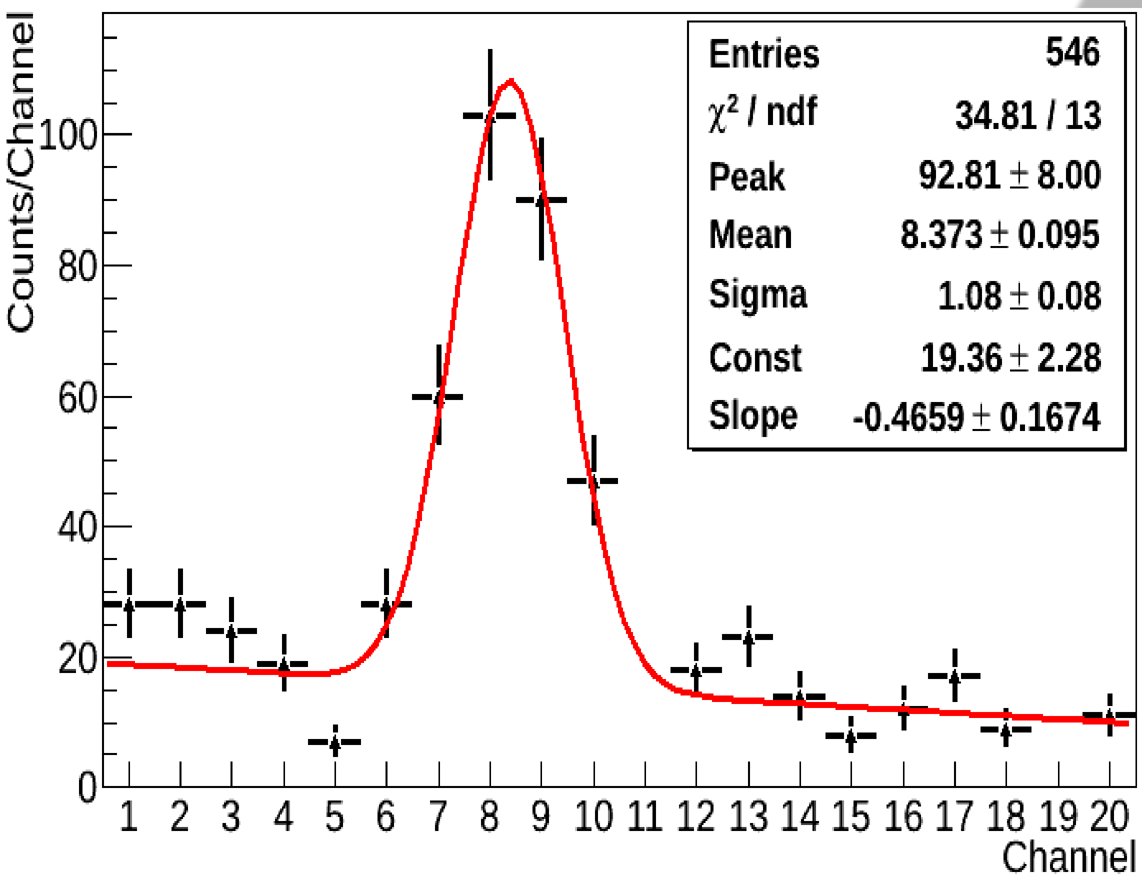
VPE HV (V)	γ detection rate Hz	γ efficiency
970	0.09	***3.0e-07***
1000	1.2	***3.7e-06***
1030	7.9	***2.5e-05***

Reasonably good γ rejection
before any optimizations offered by:

thin substrates
lower gas pressure
thinner metallization
Improving internal dielectrics around pixels

Spatial Position





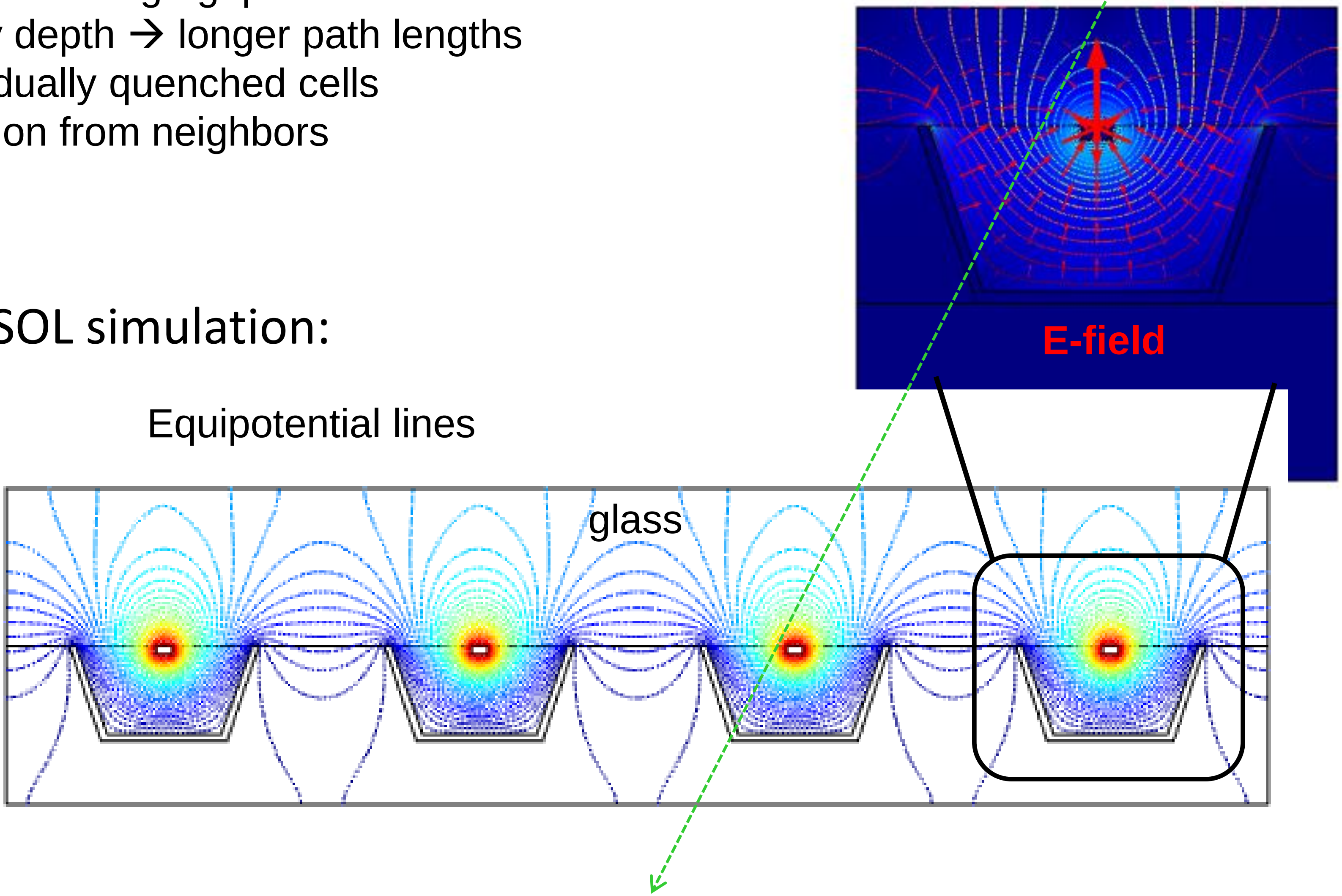
Microcavity-PPS

Microcavity Concept

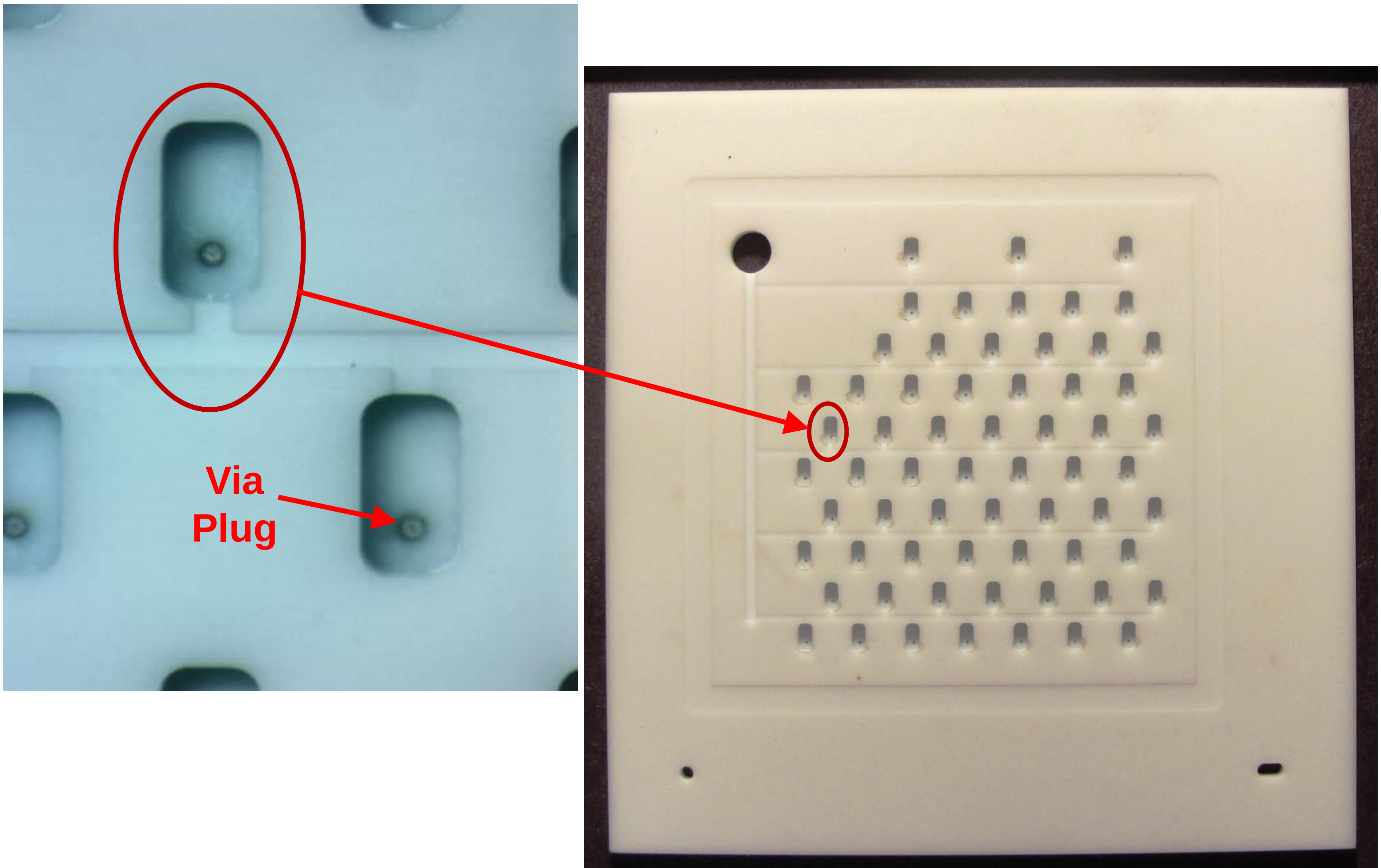
radial discharge gaps
cavity depth → longer path lengths
individually quenched cells
isolation from neighbors

COMSOL simulation:

Equipotential lines

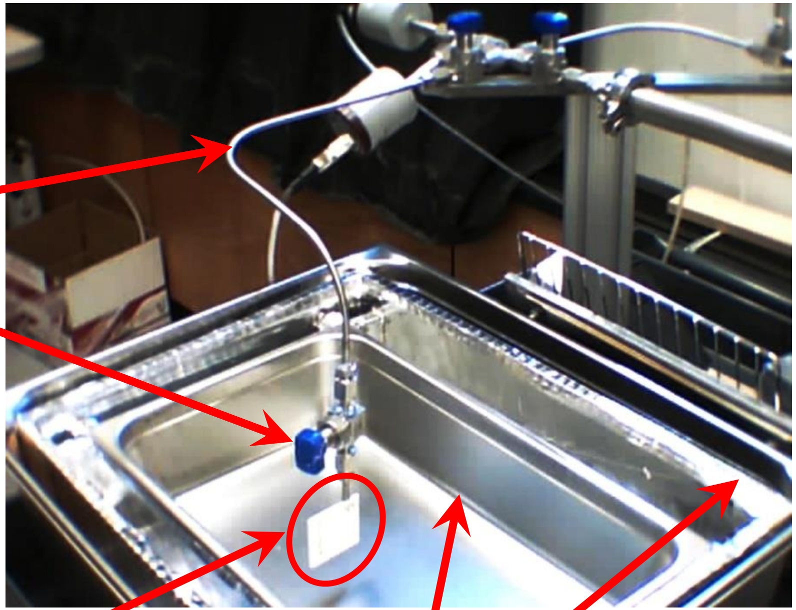


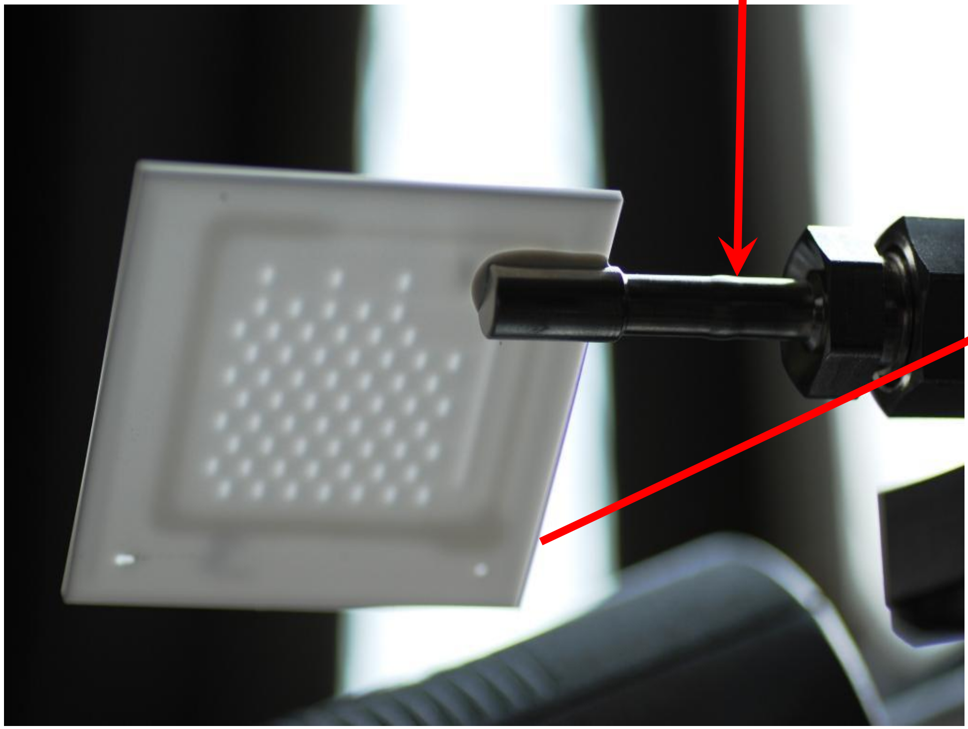
Microcavity Prototype (Back Plate)



Sealed Microcavity-PPS

Microcavity-PPS attached to vacuum-line / gas-fill system





Bottom Half of "*Open*" Bakeout Oven

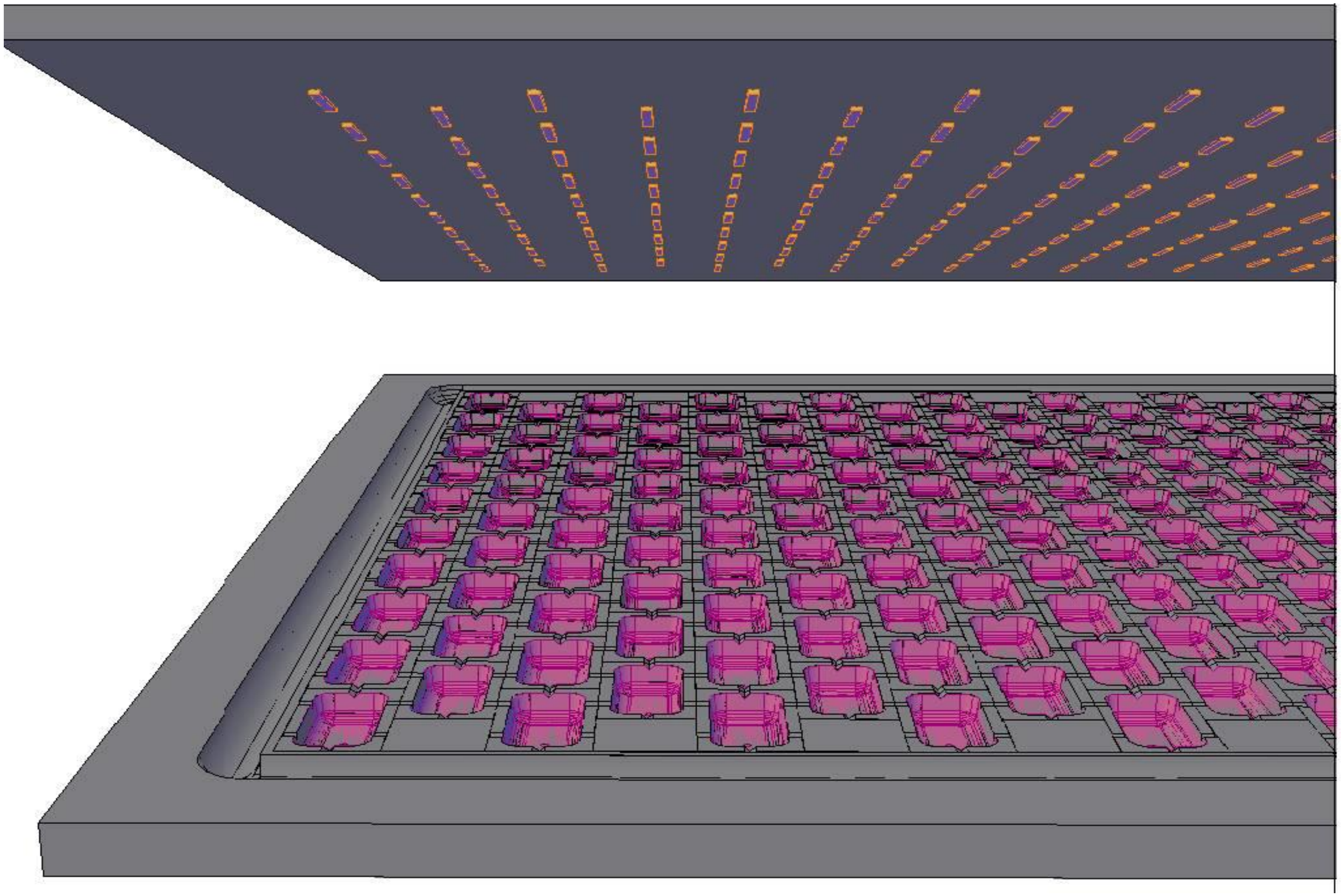
Summary

We have demonstrated functioning of modified plasma displays as highly pixelated arrays of micro-discharge counters

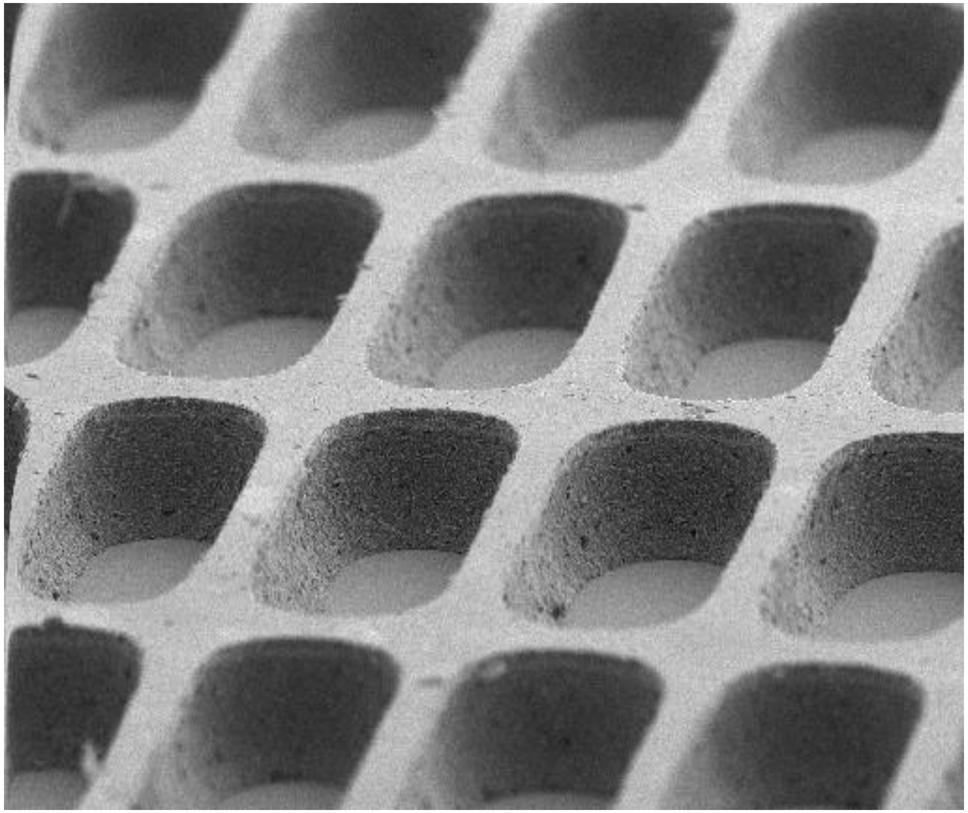
- sensitive to highly ionizing & minimum ionizing charged particles:
  β's, μ's CR and test beam, intense proton beams,
  neutrons [with appropriate conversion (^{3}He)] & high γ rejection
- Panels have operated for up to 1 year (sealed only by valve)
- Timing resolution < 10 ns, approaching 3 ns for some gasses
- Spatial response at level of pixel granularity

Near Term Efforts

- Near term effort
  - microcavity PPS program
    - Final fabrication & initial testing
  - 2D readout
  - Pursue higher resolution panels, faster timing
  - stacked panels for tracking



Cathodes: metalized inner cavity surfaces
connected to HV bus with resistive *via*
Anodes: pads on top plate



Example of microcavity arrays produced by chemical etching processes commonly used in PDP fabrication. Cavity scale is 100 microns.

Yong-Seog Kim, Woong Sik Kim, Yoo-Seong Kim, “Cost Effective Technologies for Barrier Rib Processing of HD PDPs” (Invited Paper), SID 2006 Digest of Technical Papers, Vol. XXXVII (June 2006), 1480-1483.