Micro-pattern detectors based on plasma display panels: Past, present, and future developments

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The Collaboration

- **University of Michigan, Department of Physics**
  - J. W. Chapman, Claudio Ferretti, Dan Levin, Curtis Weaverdyck, Robert Ball, Bing Zhou, Michael Ausilio

- **Tel Aviv University, School of Physics & Astronomy**
  - Meny Ben Moshe, Yan Benhammou, Rivka Ben Simon, Merlin Davies, Erez Etzion

- **Oak Ridge National Laboratory, Physics Division**
  - Robert Varner

- **Integrated Sensors, LLC (Toledo, OH)**
  - Peter Friedman

Motivation : Plasma Panel Sensor (PPS)

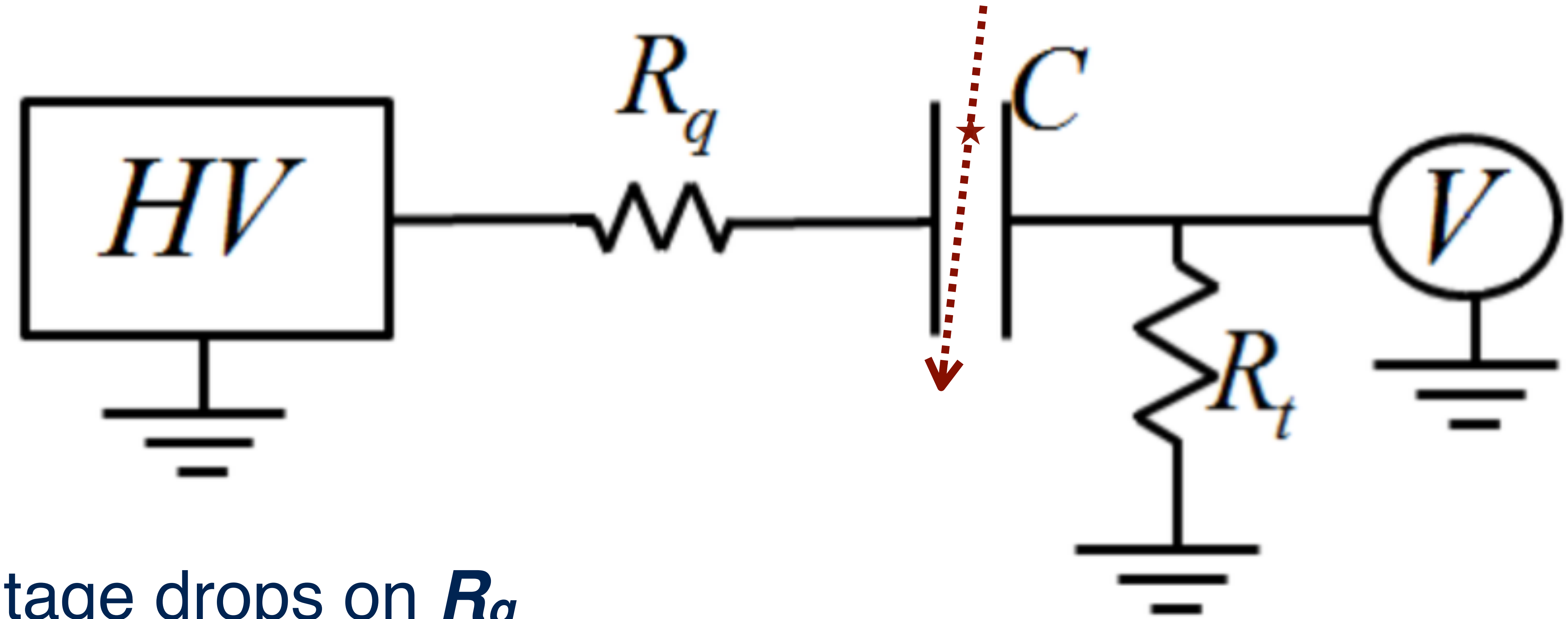
Plasma Display Panel (PDP)
Pixel Array

- **Easily scalable**
- **Long life**

- Use each pixel as **independent Geiger-Mueller Counters**
- Potentially high
  - **Spatial and time resolution**
  - **Detection Efficiency**

The Basics

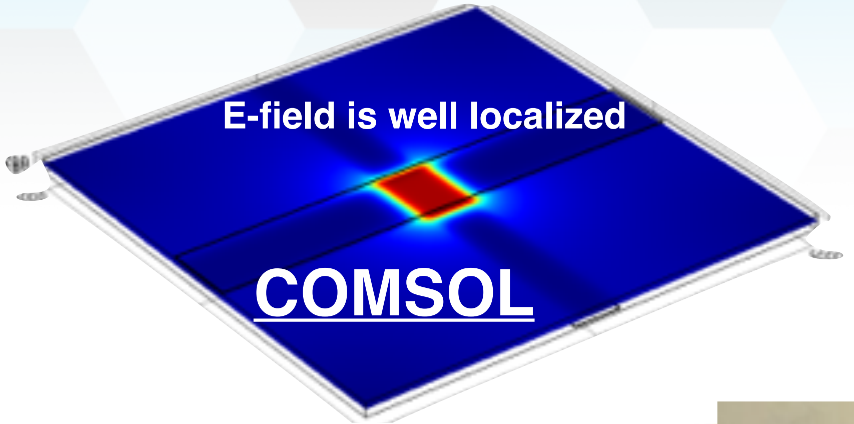
- Apply a **High E-field** on a Penning gas mixture
- **Incident ionizing particles** produce streamers in a cell leading to gas breakdown



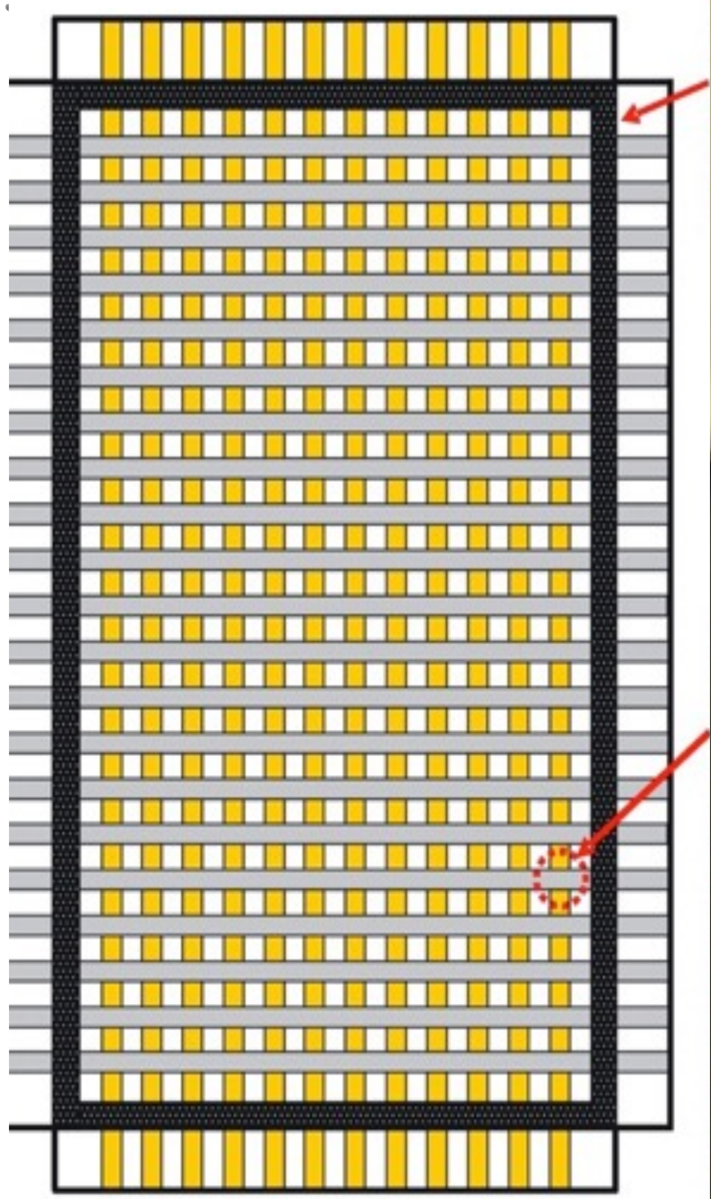
- Voltage drops on R_q
- Measure signal pulse on R_t
- Cell recharges in time: R_qC
  - R_q is large enough to ***quench*** a continuous gas breakdown

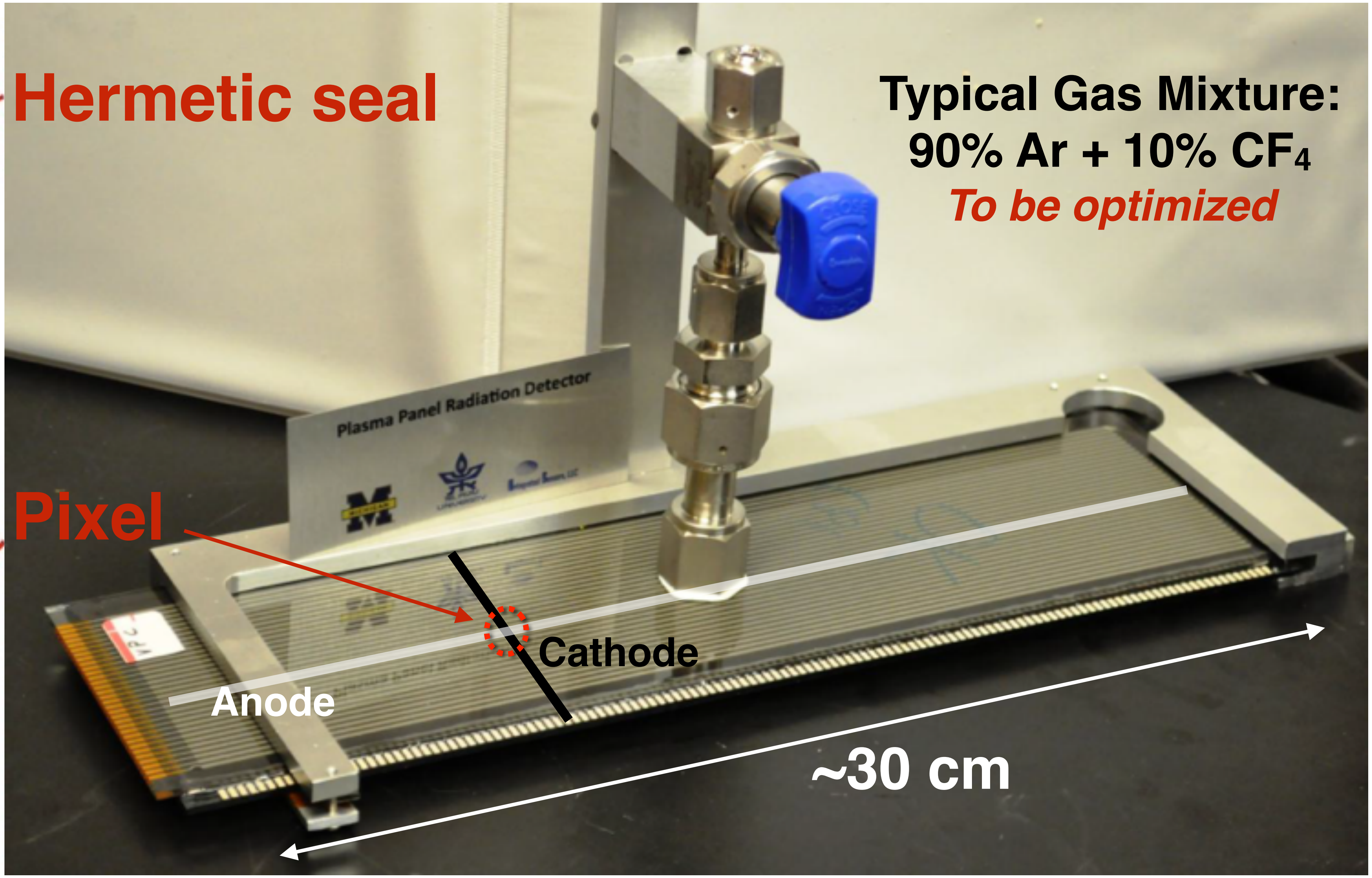
Single Cell Mode Of Operation

PPS Design : First Prototype



- **Open cell prototype**
  - **modified commercial PDP**





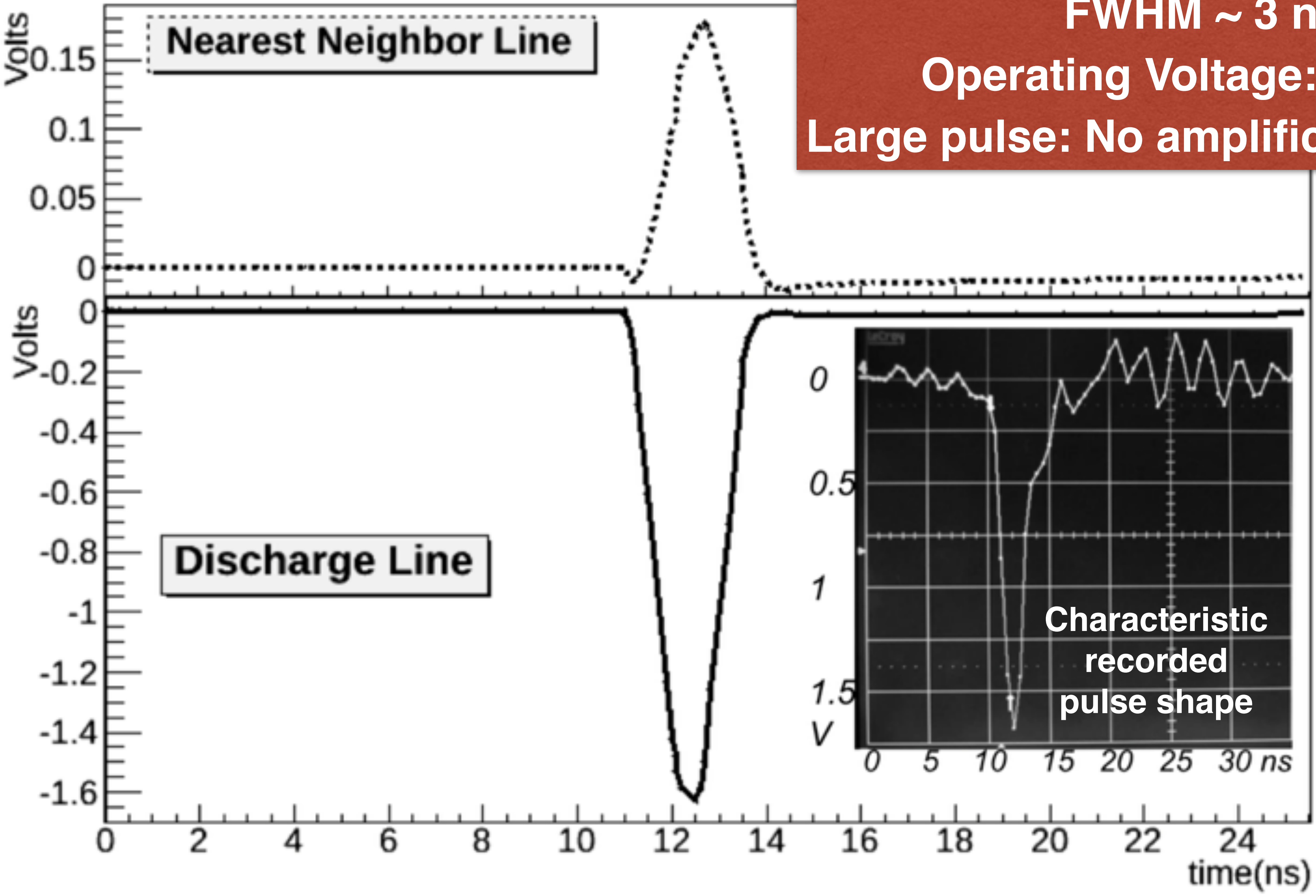
Typical Gas Mixture:
90% Ar + 10% CF_4
To be optimized

PPS : Typical Pulse

- **Excellent Signal/Noise ratio**
- **Uniform shape throughout the panel**
- **Panel sealed 7 years prior**

Rise time ~ 1-2 ns
FWHM ~ 3 ns
Operating Voltage: O(1) kV
Large pulse: No amplification needed

SPICE

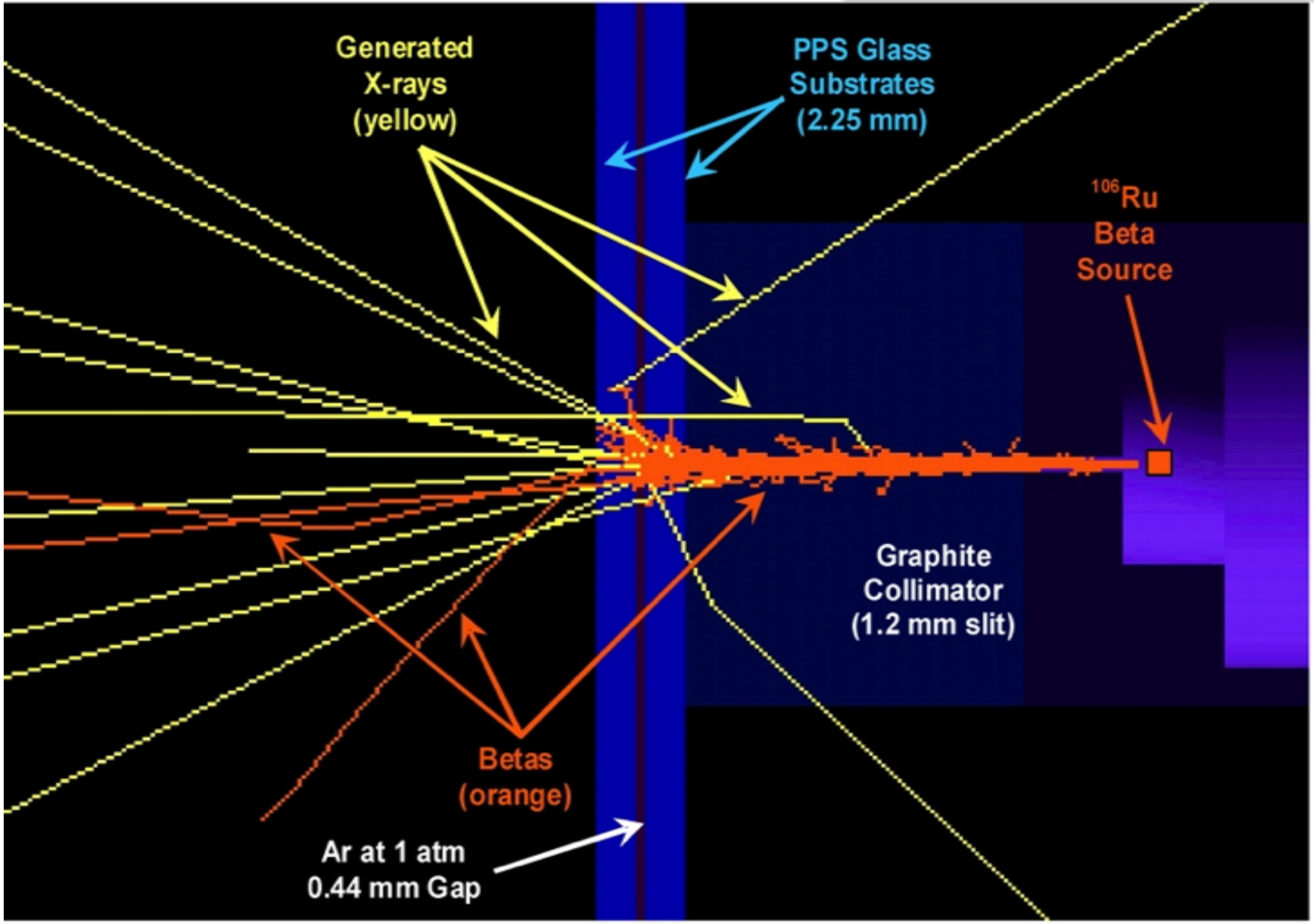


Characteristic recorded pulse shape

PPS : Spatial Resolution

- **Source:** ^{106}Ru **β** (3.54 MeV end-point)
- Electrode Pitch = **1.0 mm**

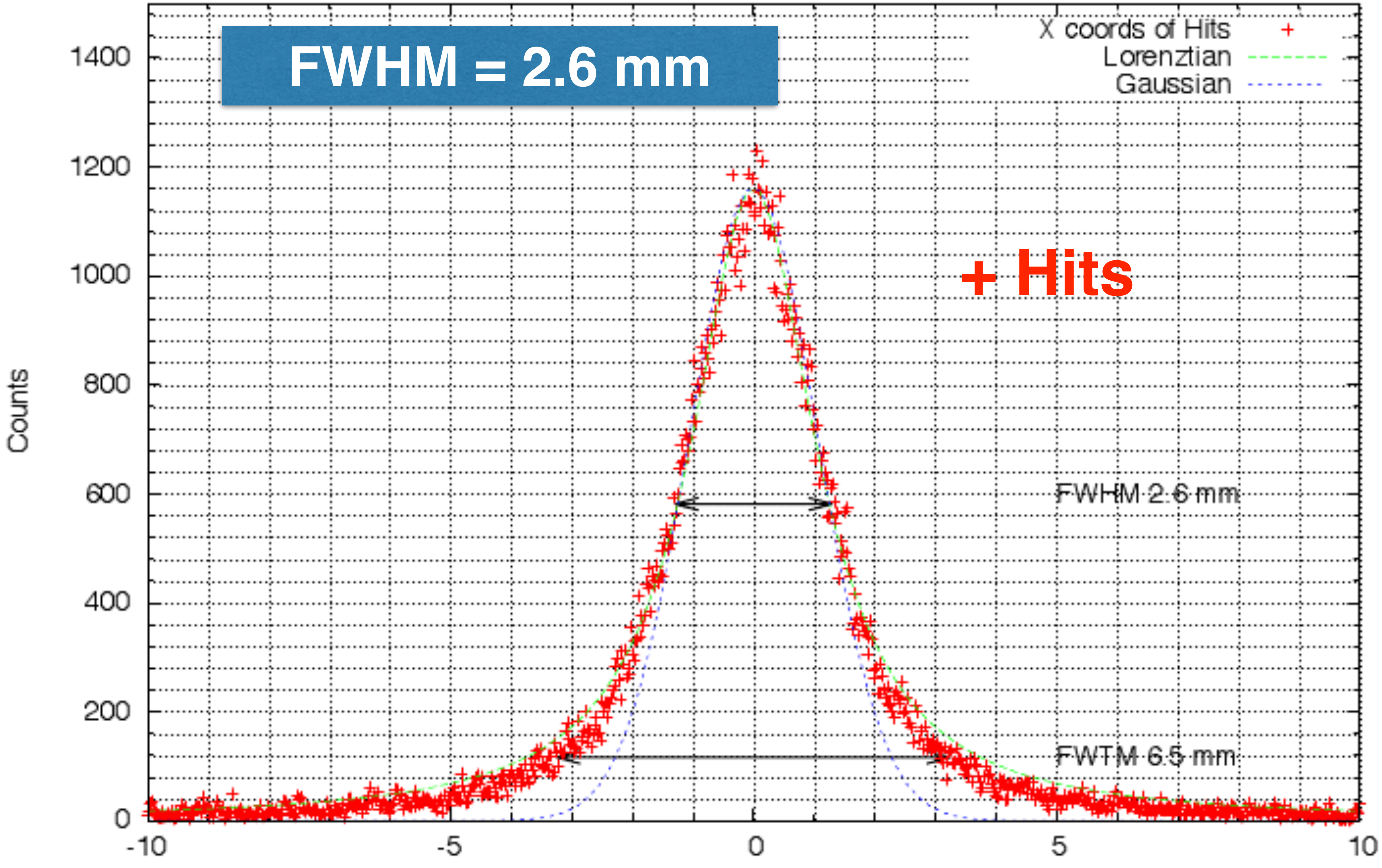
Geant4 Simulation



PPS : Spatial Resolution

Hit Variance

Geant4 Simulation

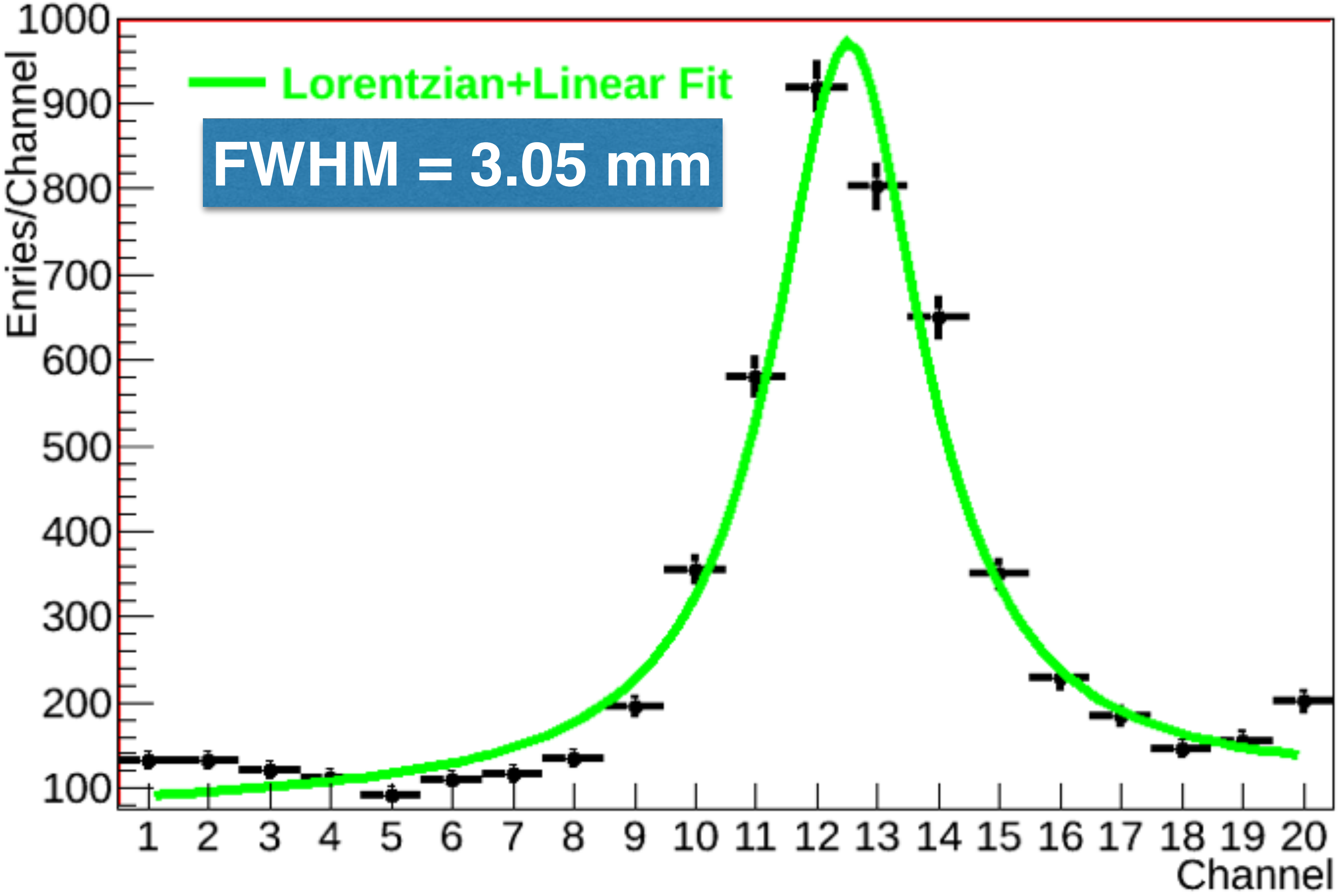


X-position (mm)

PPS : Spatial Resolution

- **Source:**^{106}Ru **β** (3.54 MeV end-point)
- Electrode Pitch = 1.0 mm

Data

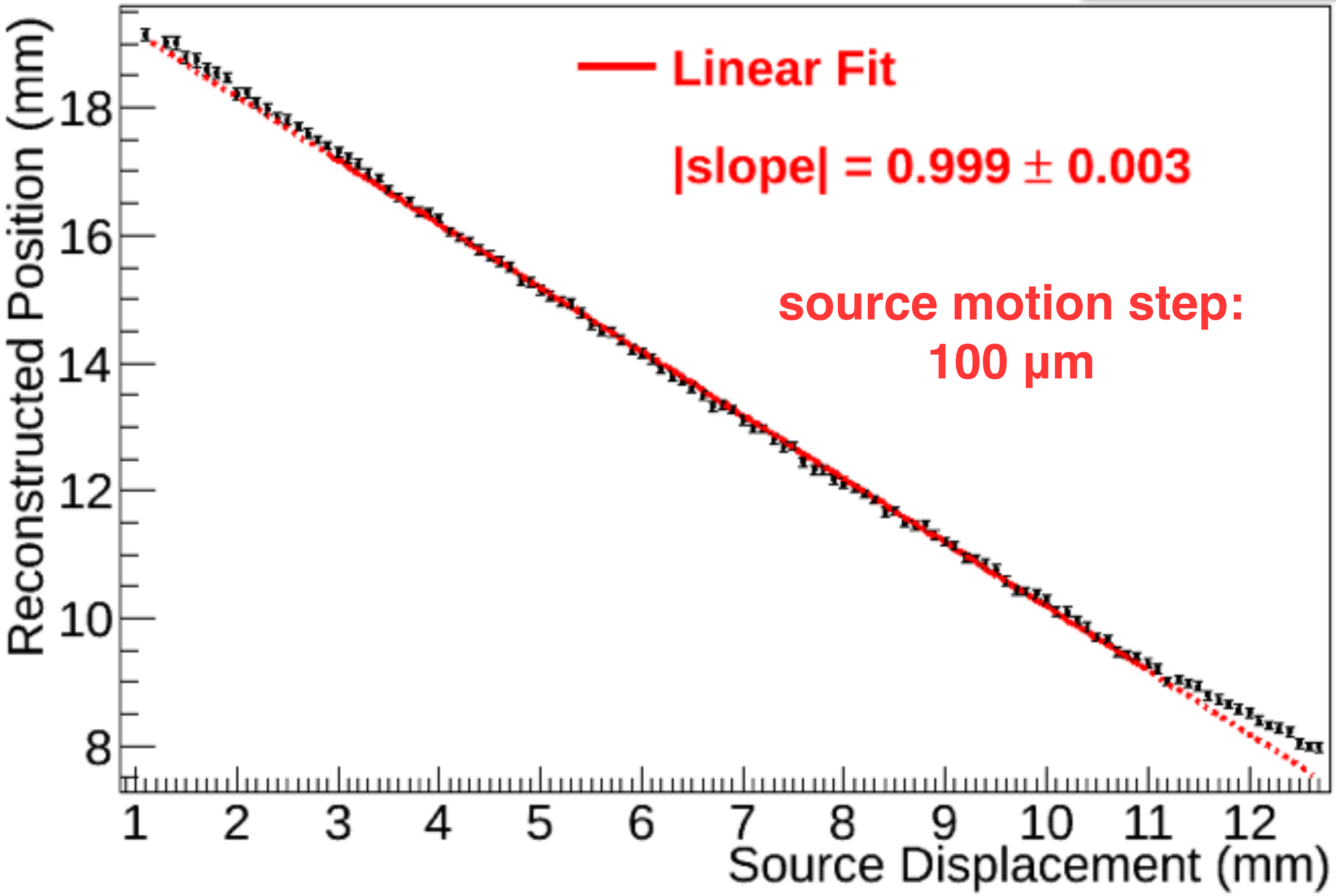


Resolution : < 1 mm

PPS : Spatial Resolution

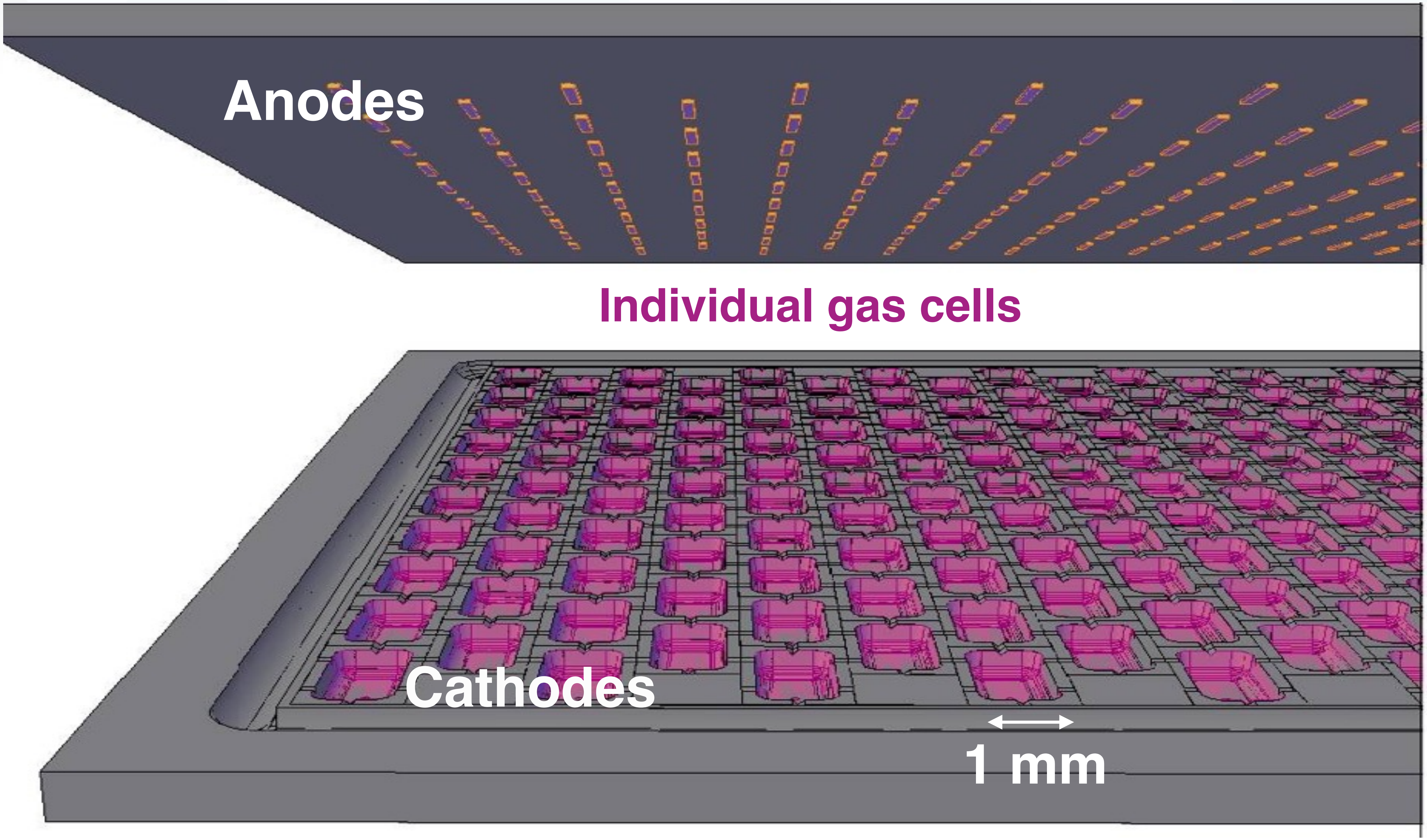
- Moving the source across the panel

Data



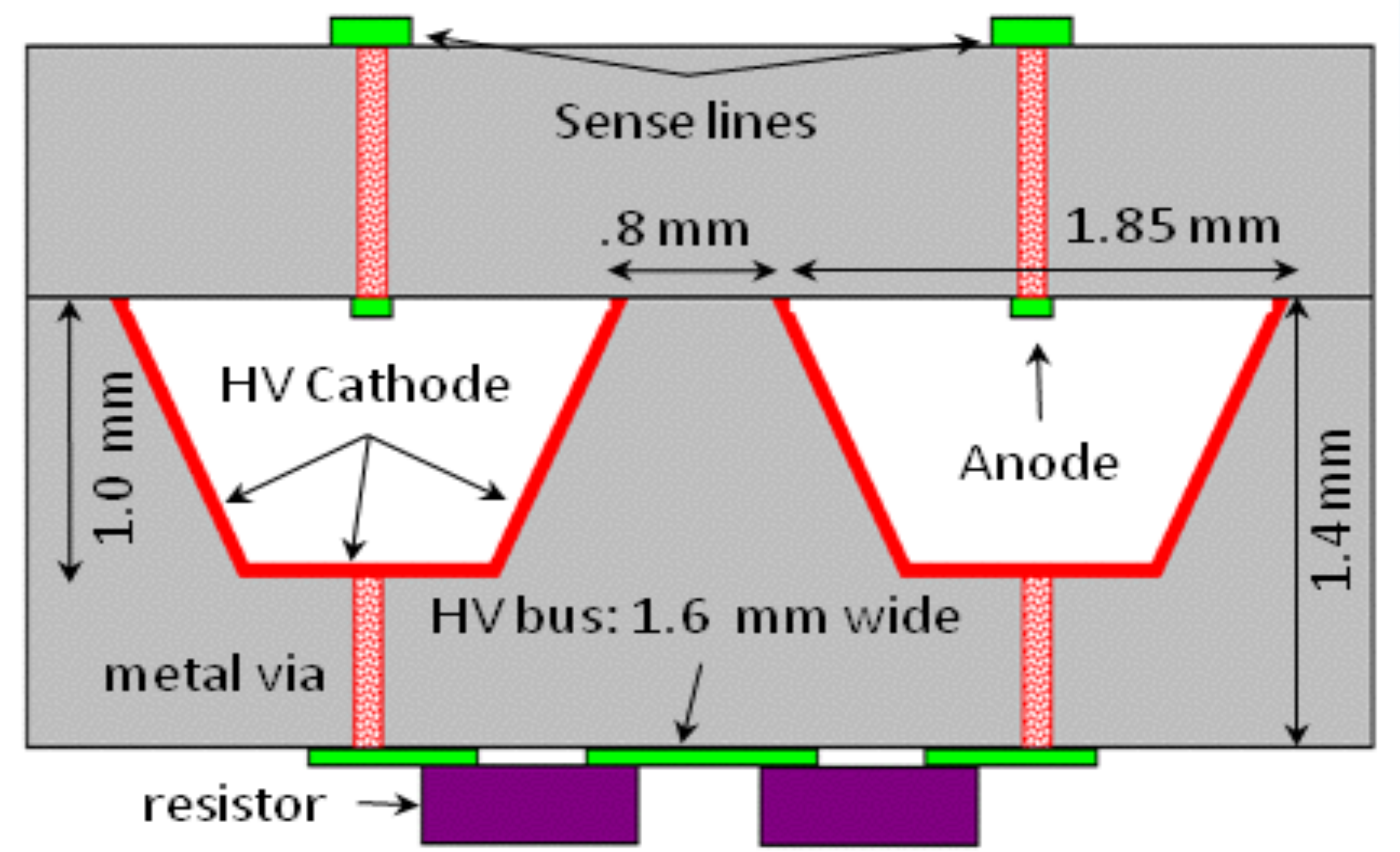
Able to reconstruct the position of the source in steps 10 times smaller than the electrode pitch

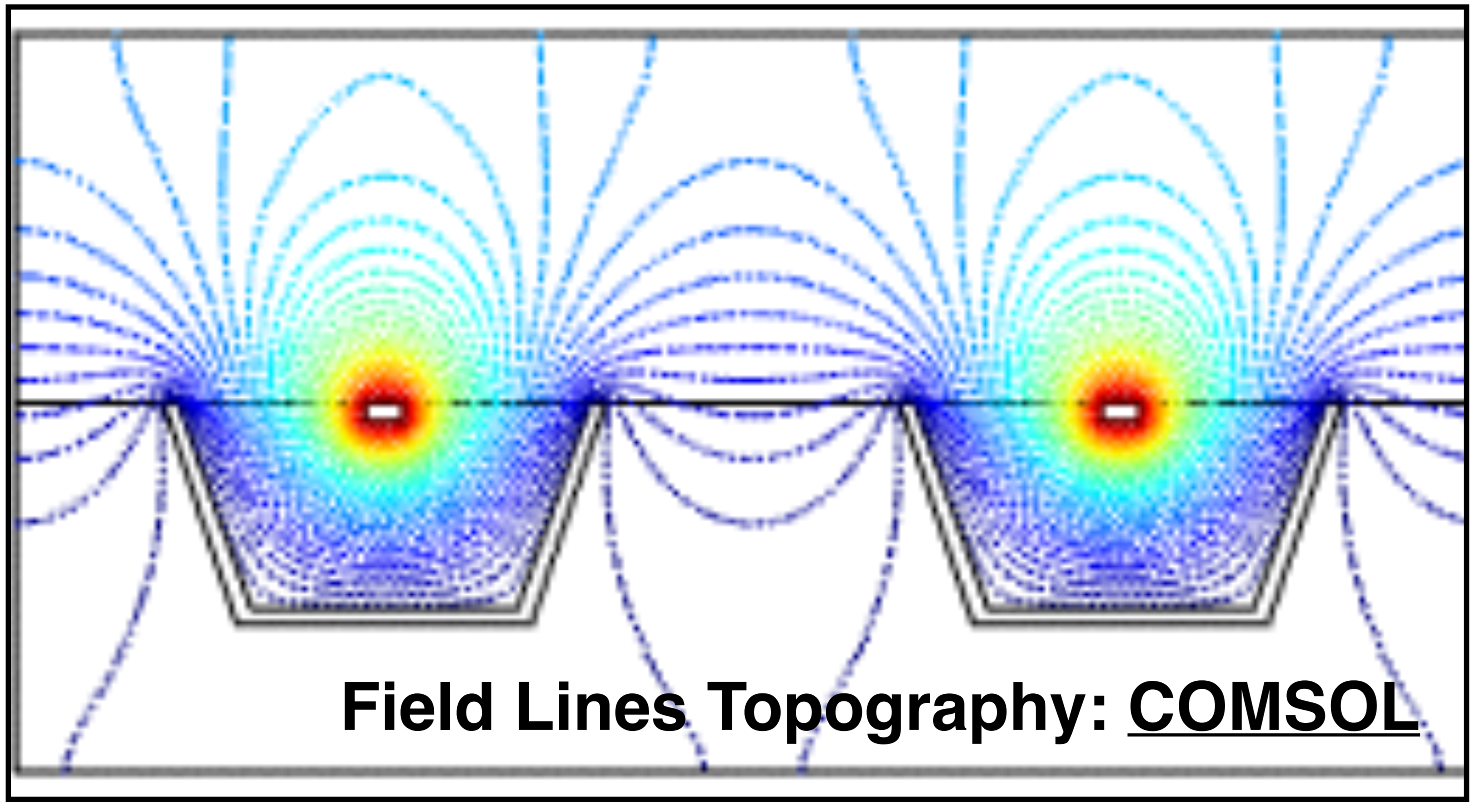
The Micro-Cavity (MiC) : Conceptual Design



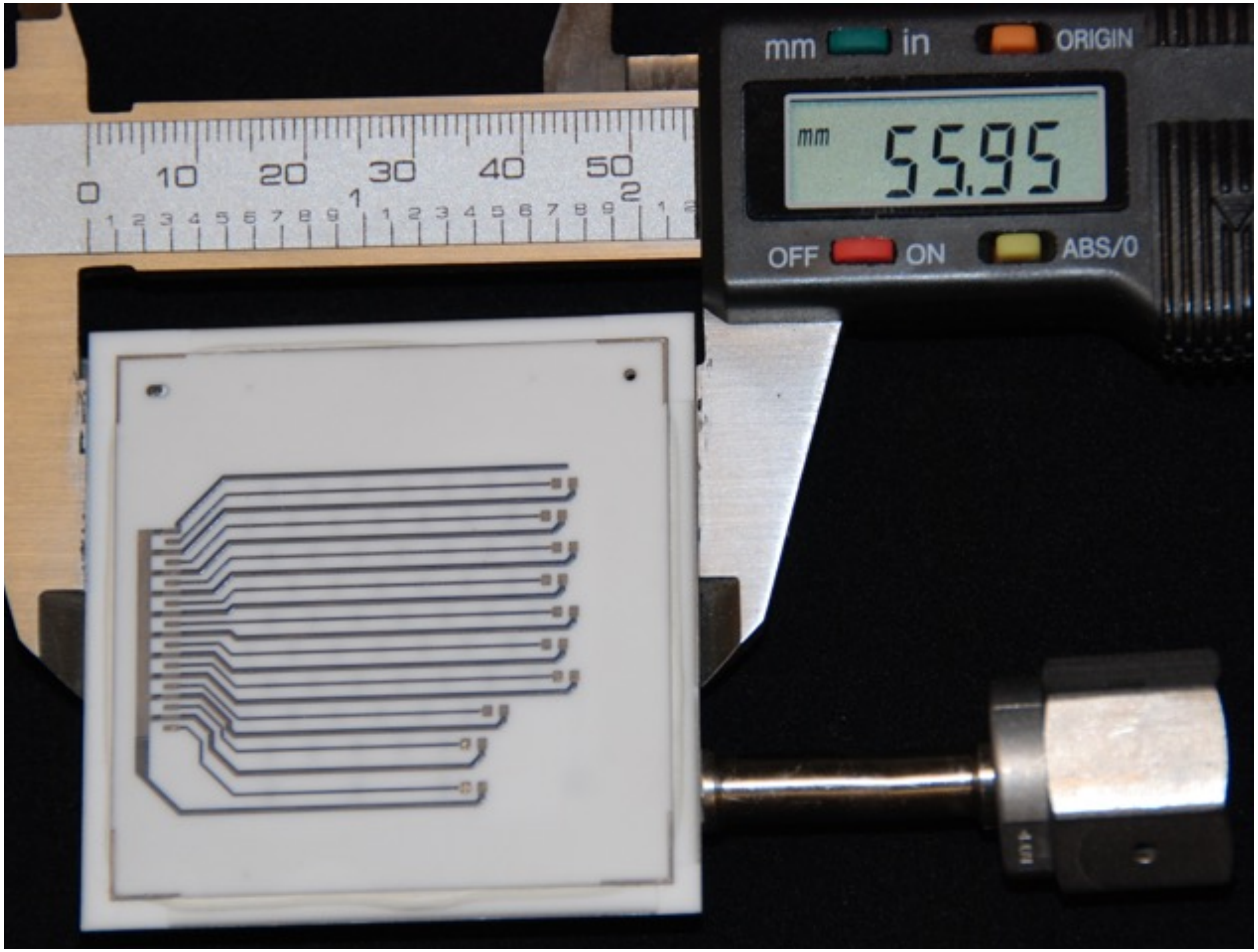
MiC : Cell Geometry

- Has ***1x1x2* mm closed** gas cells
- **Individually quenched** by an external 1 GΩ resistor
- Electric field of a few MV/m

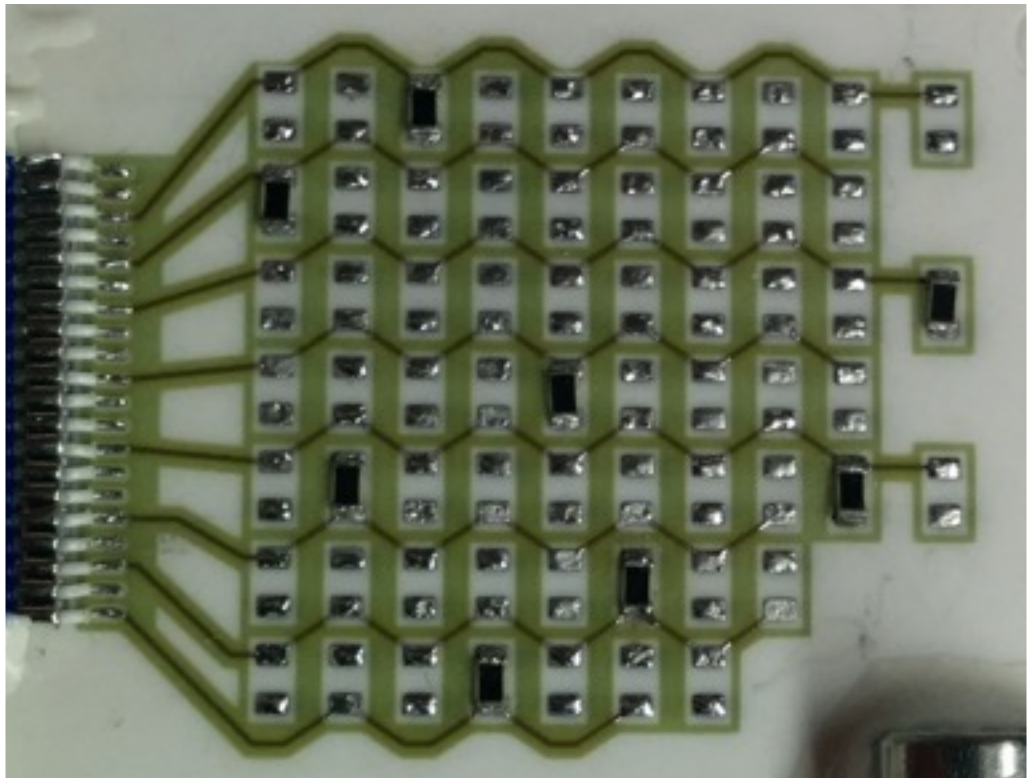




The Micro-Cavity (MiC)

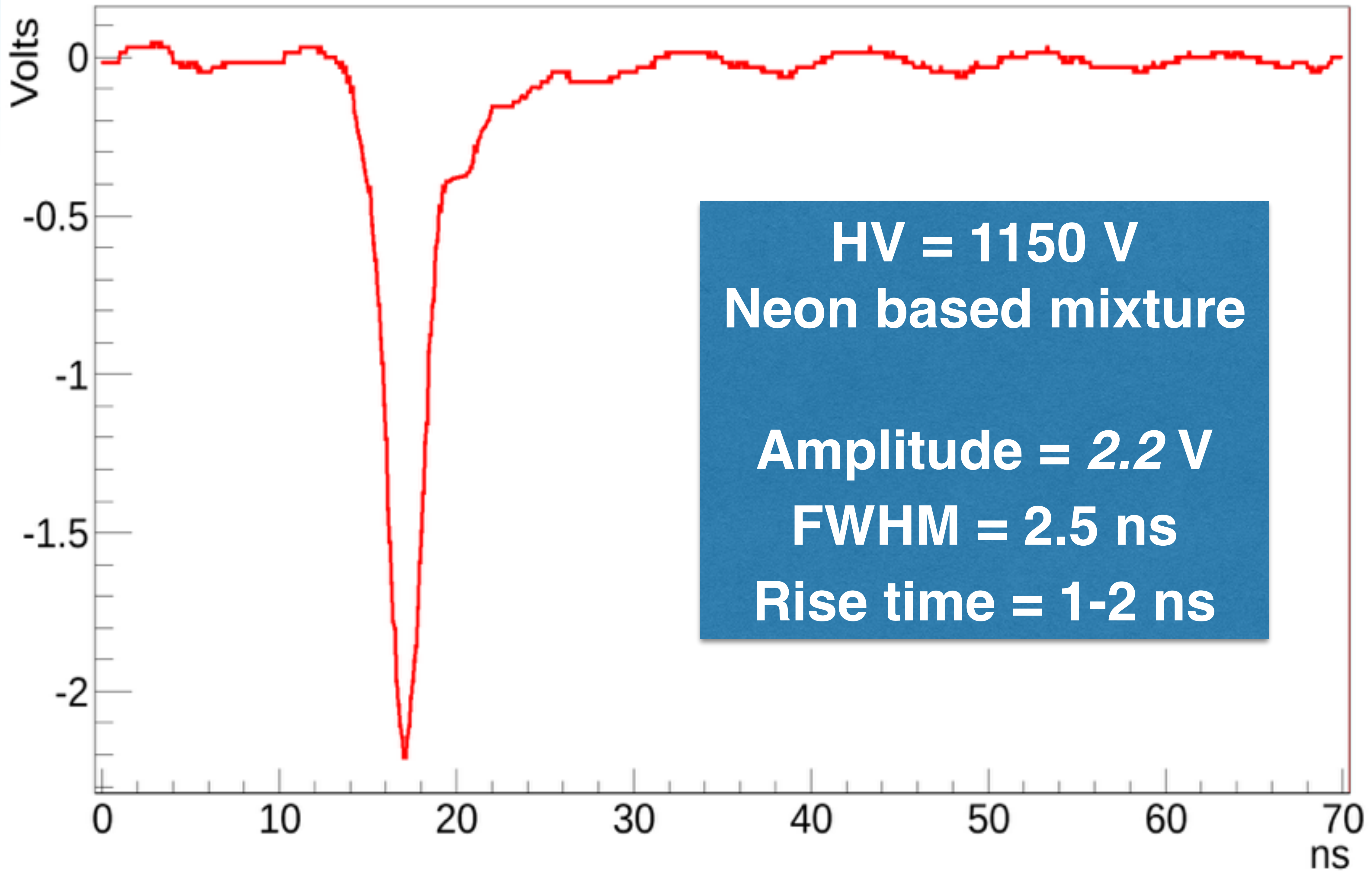


Front



Back

MiC : Pulse Characteristics

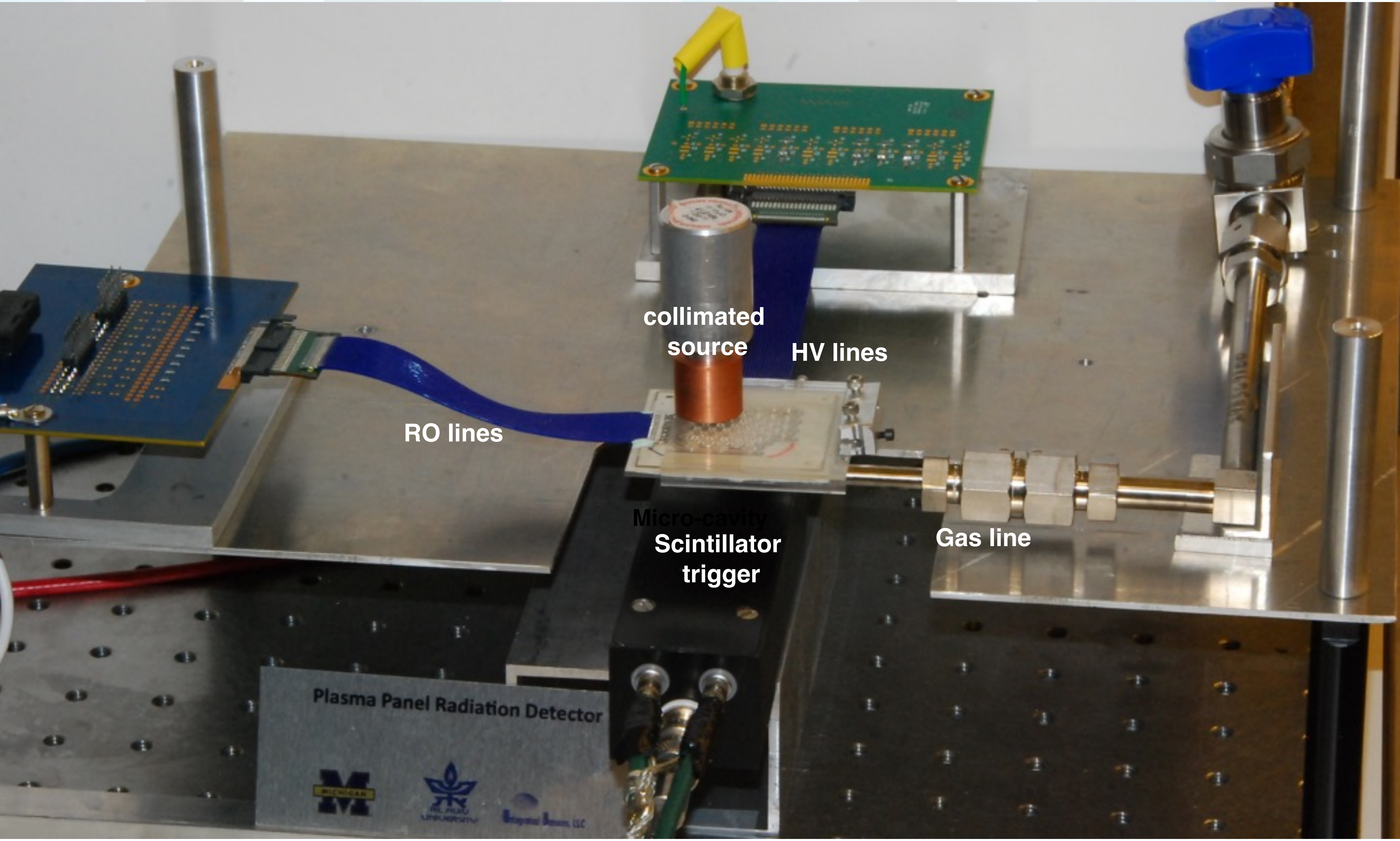


HV = 1150 V
Neon based mixture

Amplitude = *2.2* V
FWHM = 2.5 ns
Rise time = 1-2 ns

- **Clean pulse : no amplification needed**

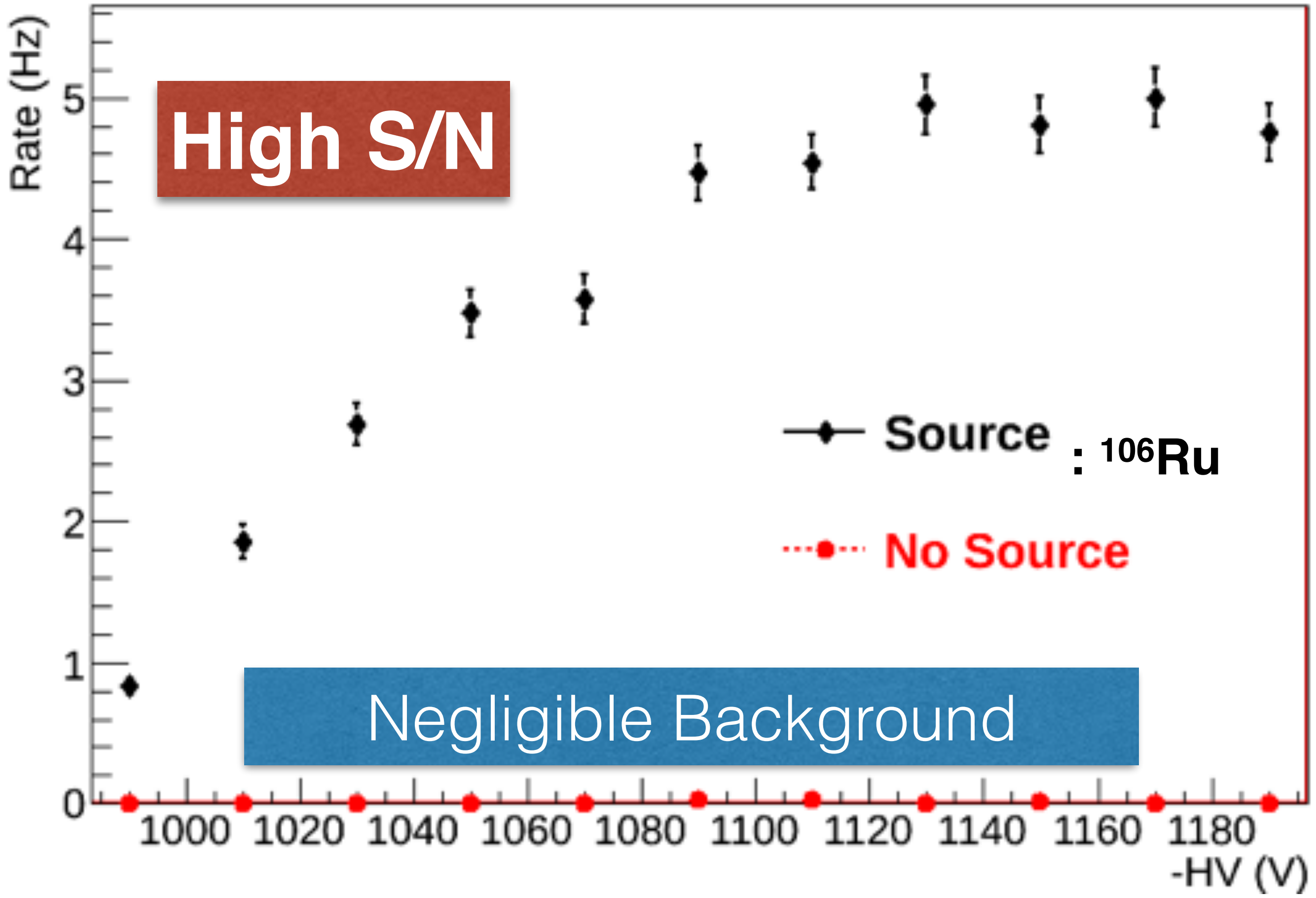
Experimental Setup



MiC : General Performance

- Using a **collimated ^{106}Ru source** placed directly above the micro-cavity
- All cells show very **limited noise** (**10^2 better than the open cell prototype**)
- The measured **rates** of each individual cell are **similar**

single pixel rate

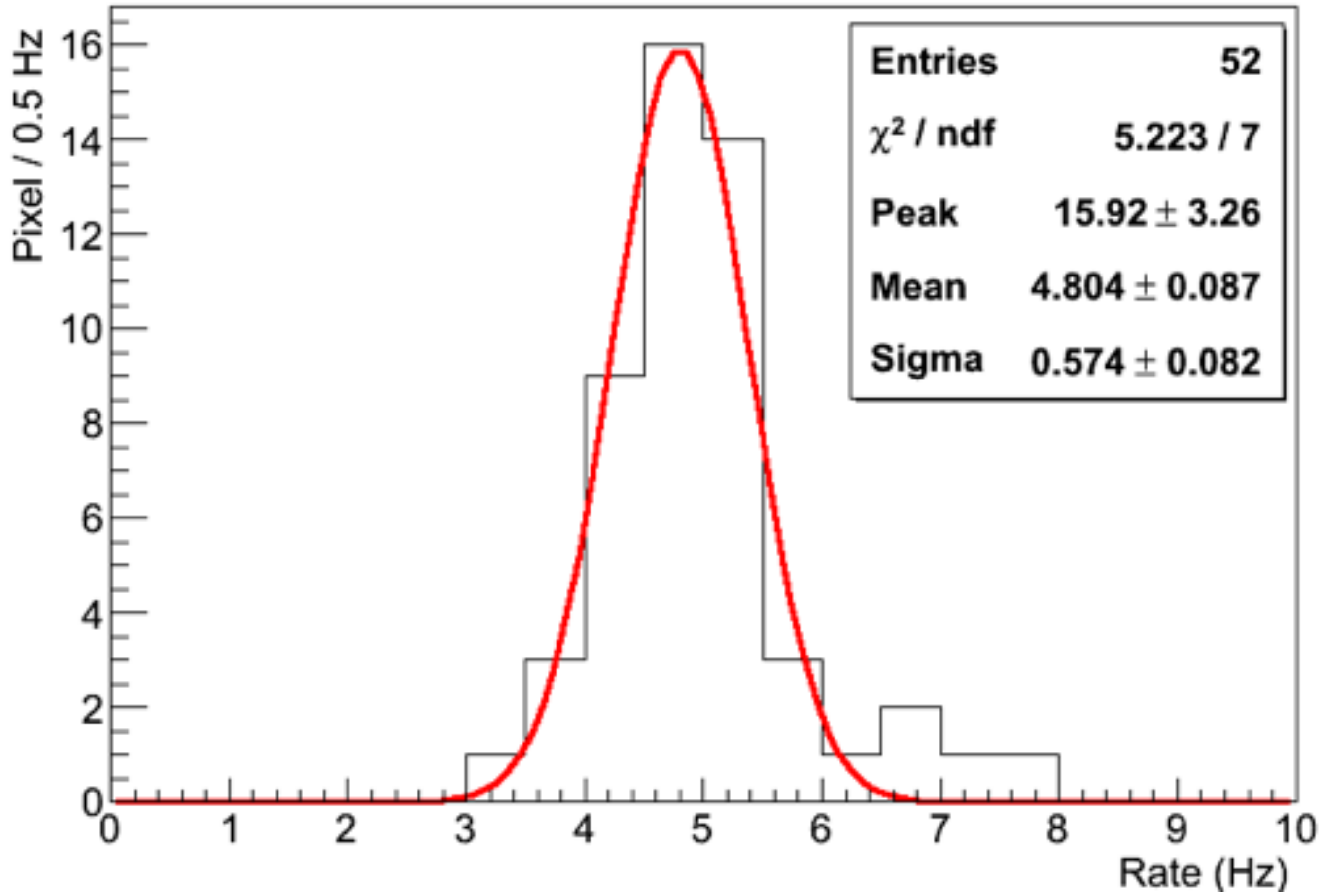


High S/N

Negligible Background

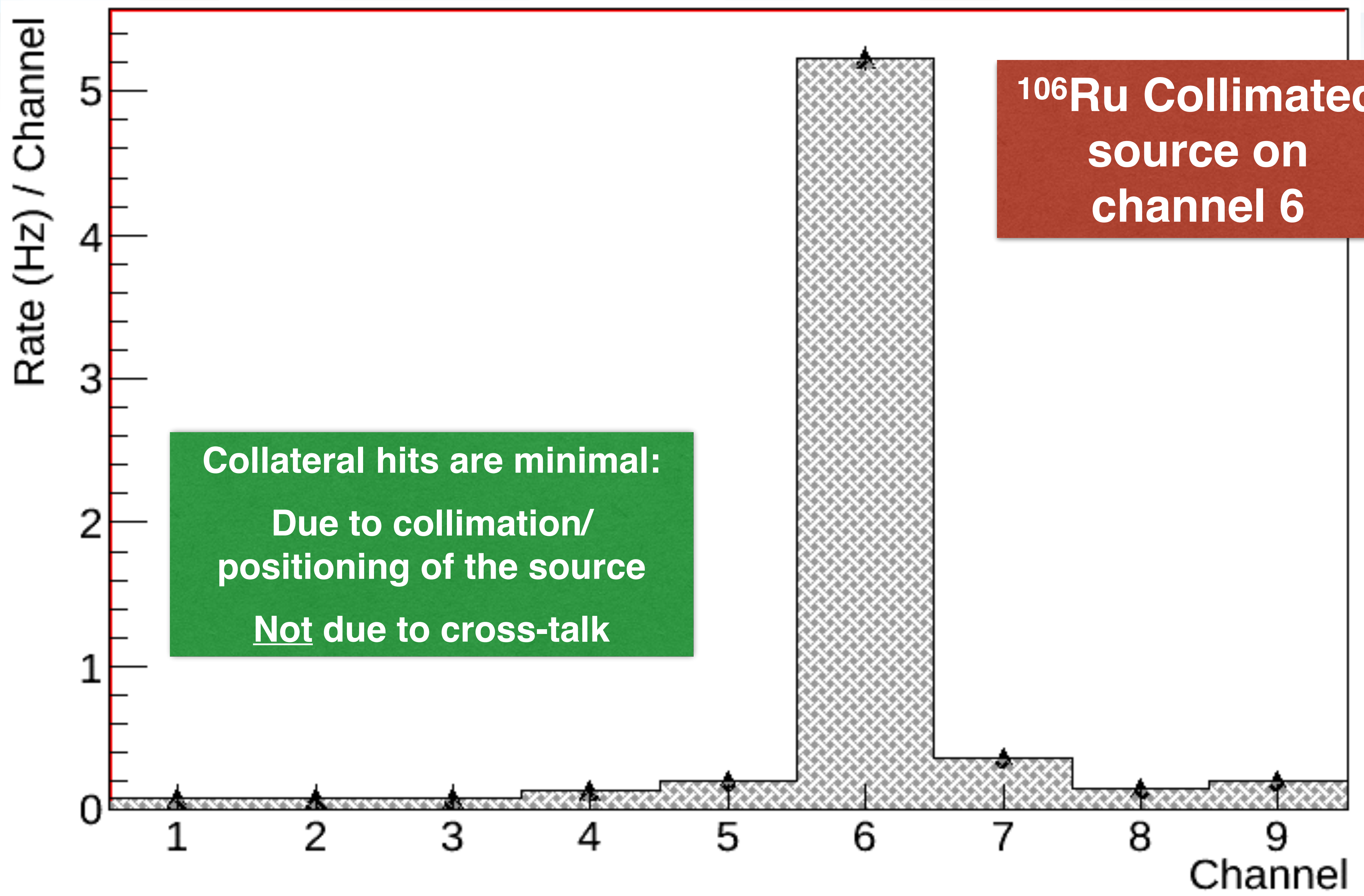
Efficiency constant over a wide range of voltages

average pixel rates



Keep in mind: imprecision in the position/collimation of the source

MiC : Pixel Isolation



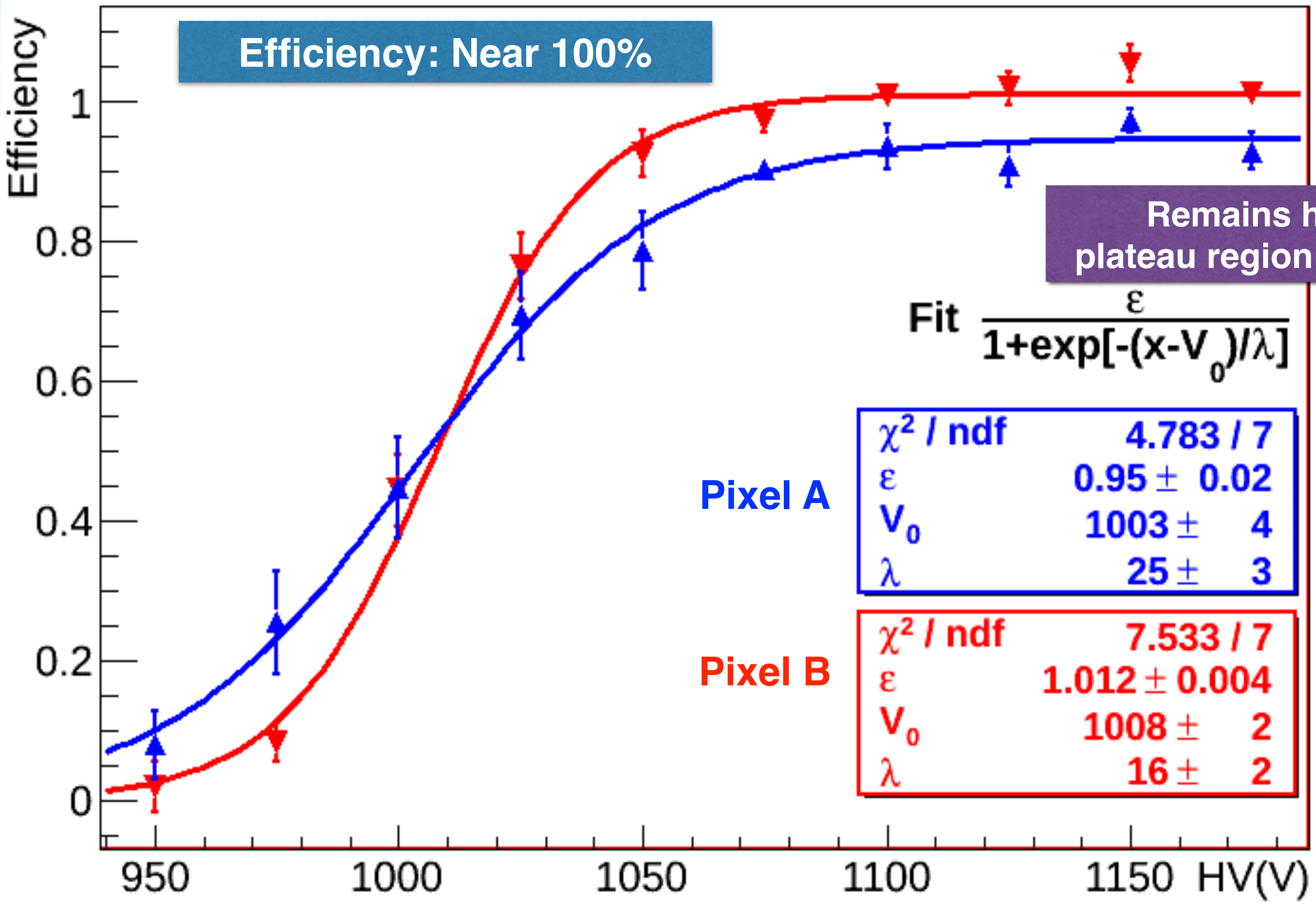
^{106}Ru Collimated source on channel 6

Collateral hits are minimal:

Due to collimation/ positioning of the source

<u>Not</u> due to cross-talk

MiC : Pixel Efficiency



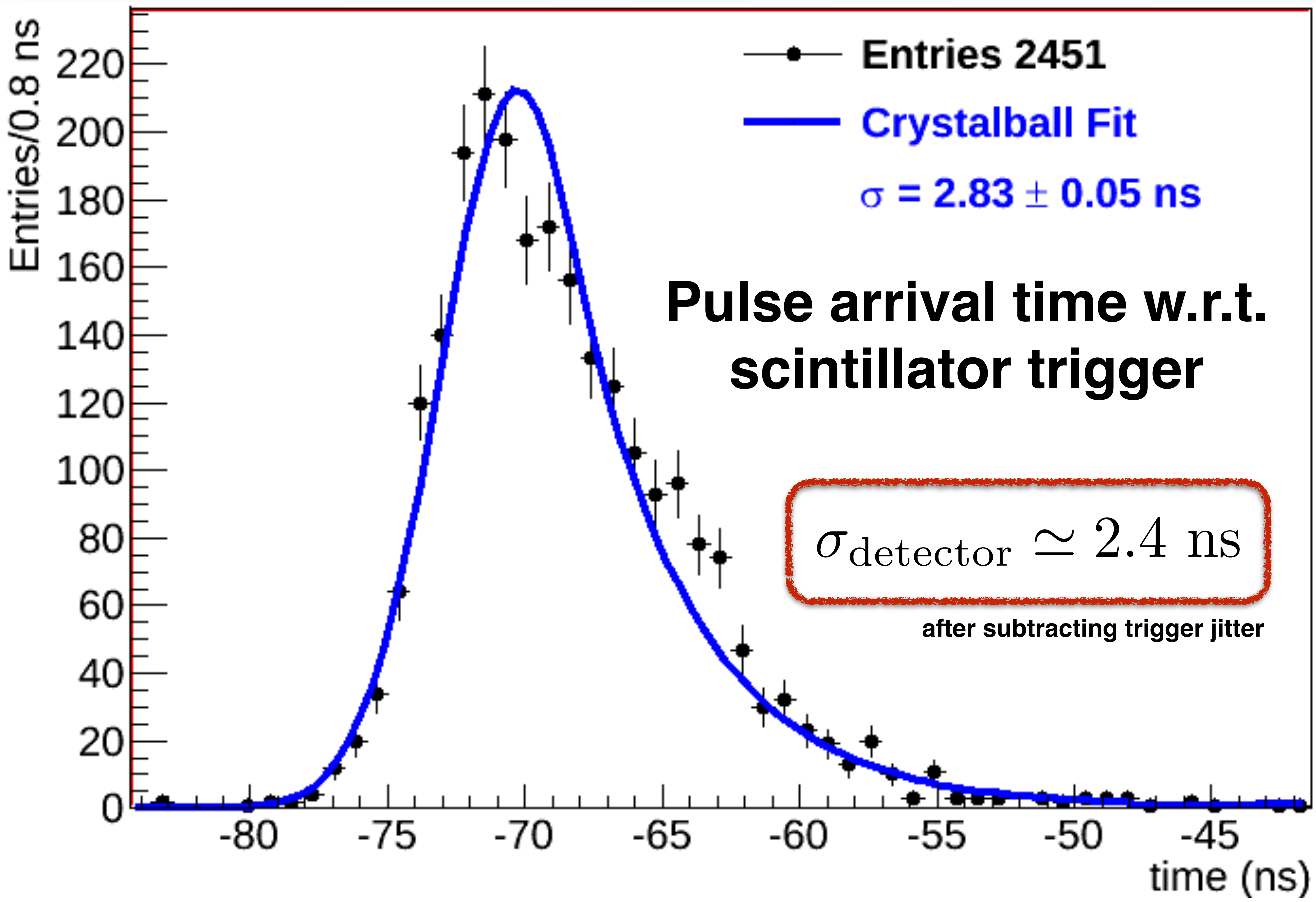
Efficiency: Near 100%

Remains high in the plateau region > 100 V range

Simulation is used to estimate source rate within the cells' geometrical acceptance —> 10% syst. uncertainty

MiC : Time Resolution

^{106}Ru β collimated source



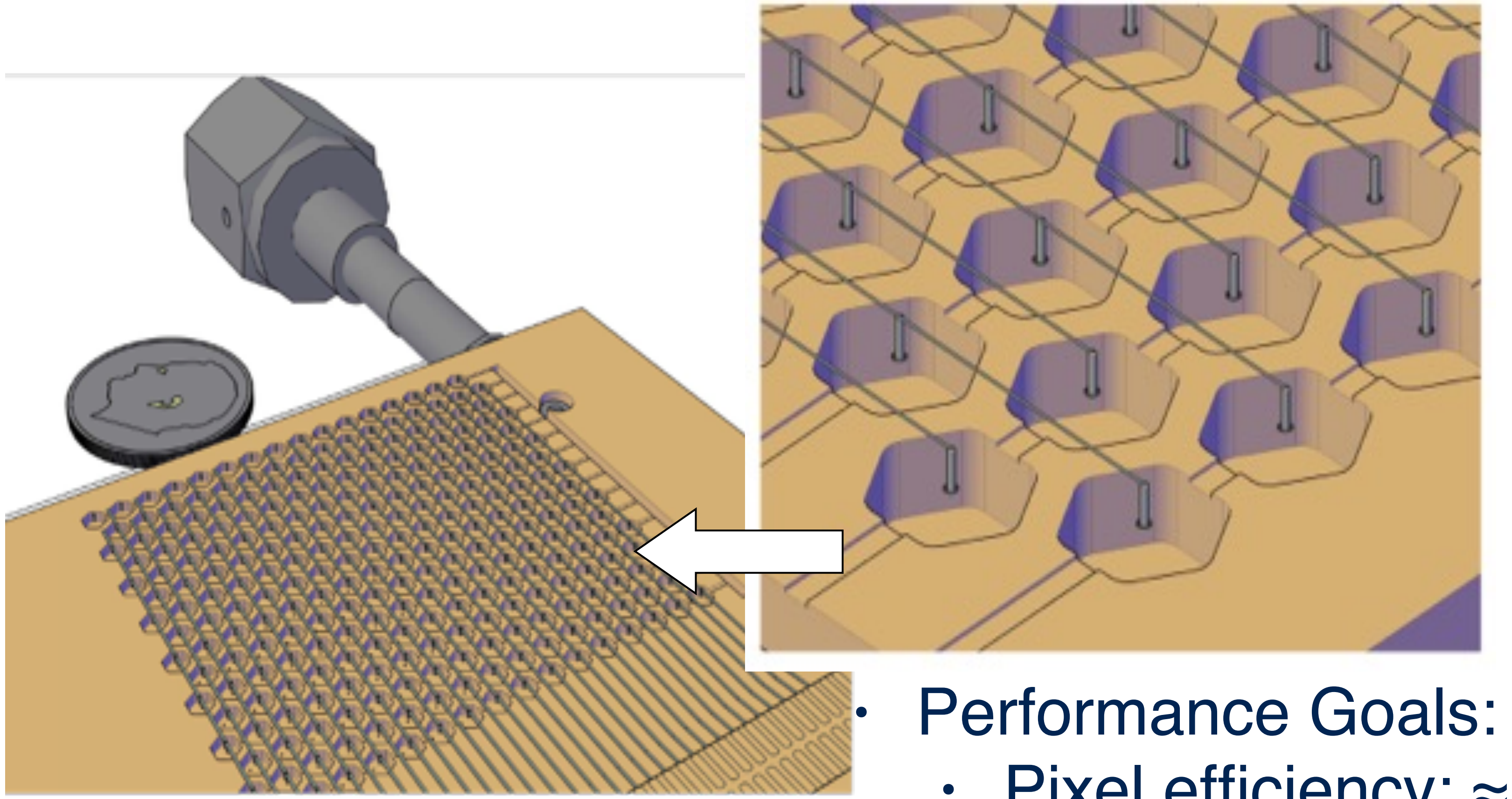
Pulse arrival time w.r.t. scintillator trigger

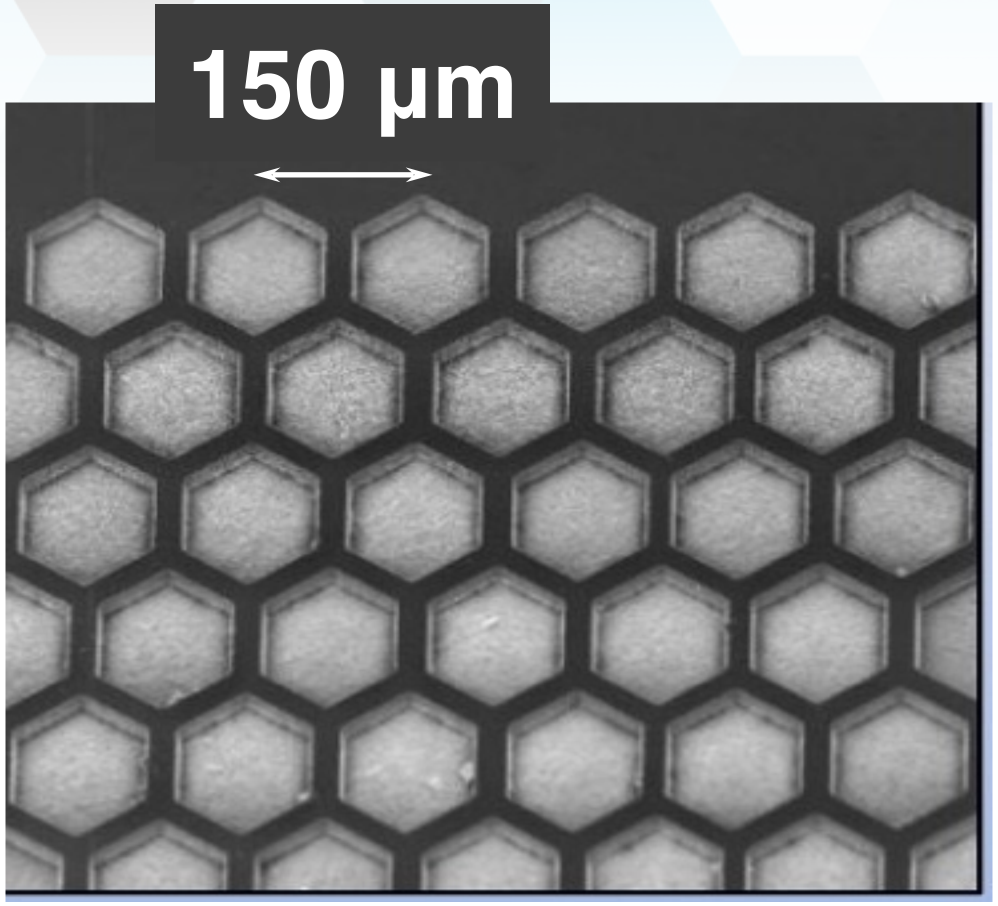
$$\sigma_{\rm detector} \simeq 2.4 \text{ ns}$$

after subtracting trigger jitter

Next Generation

- Developing a **hexagonal design**
  - **Higher spatial coverage**
  - **Higher spatial resolution**





Commercial substrate

- Performance Goals:
  - Pixel efficiency: ≈ 100%
  - Time resolution: ≤ 1 ns
  - Granularity: same level
  - Spatial resolution: < 1 mm
  - Wide response range: ≈ 1 Hz/cm^2 to at least 10^6 Hz/cm^2

Conclusion

- **Both prototypes** show good
    - Spatial/Time resolution
    - Low spontaneous background
    - High efficiency
    - Cell isolation
- **The Micro-Cavity greatly improves upon the PPS** on all of these points
- **Promising results** towards a **high performance particle detector** that is
    - Gas sealed
    - Easily scalable
    - Long life

Thank You!

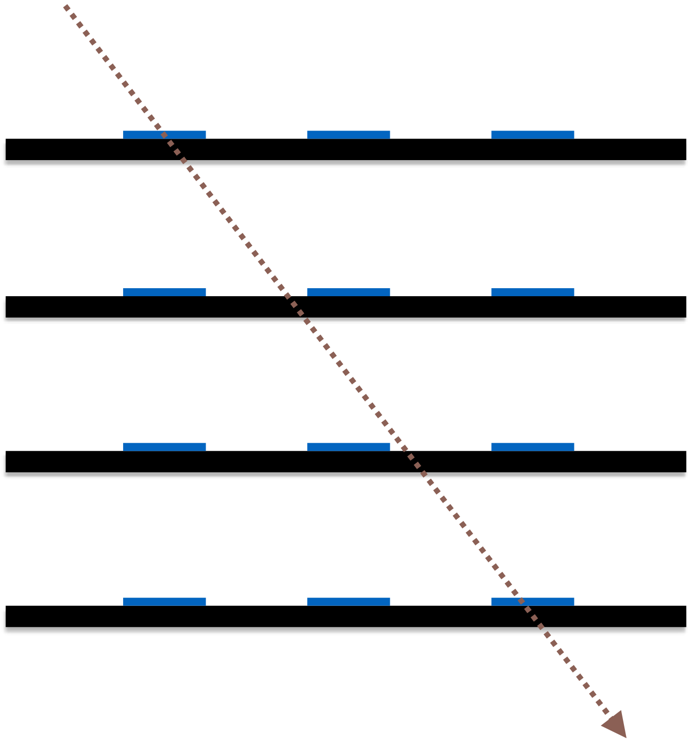
Bonus Slides

PPS : Tracking

Proof of concept

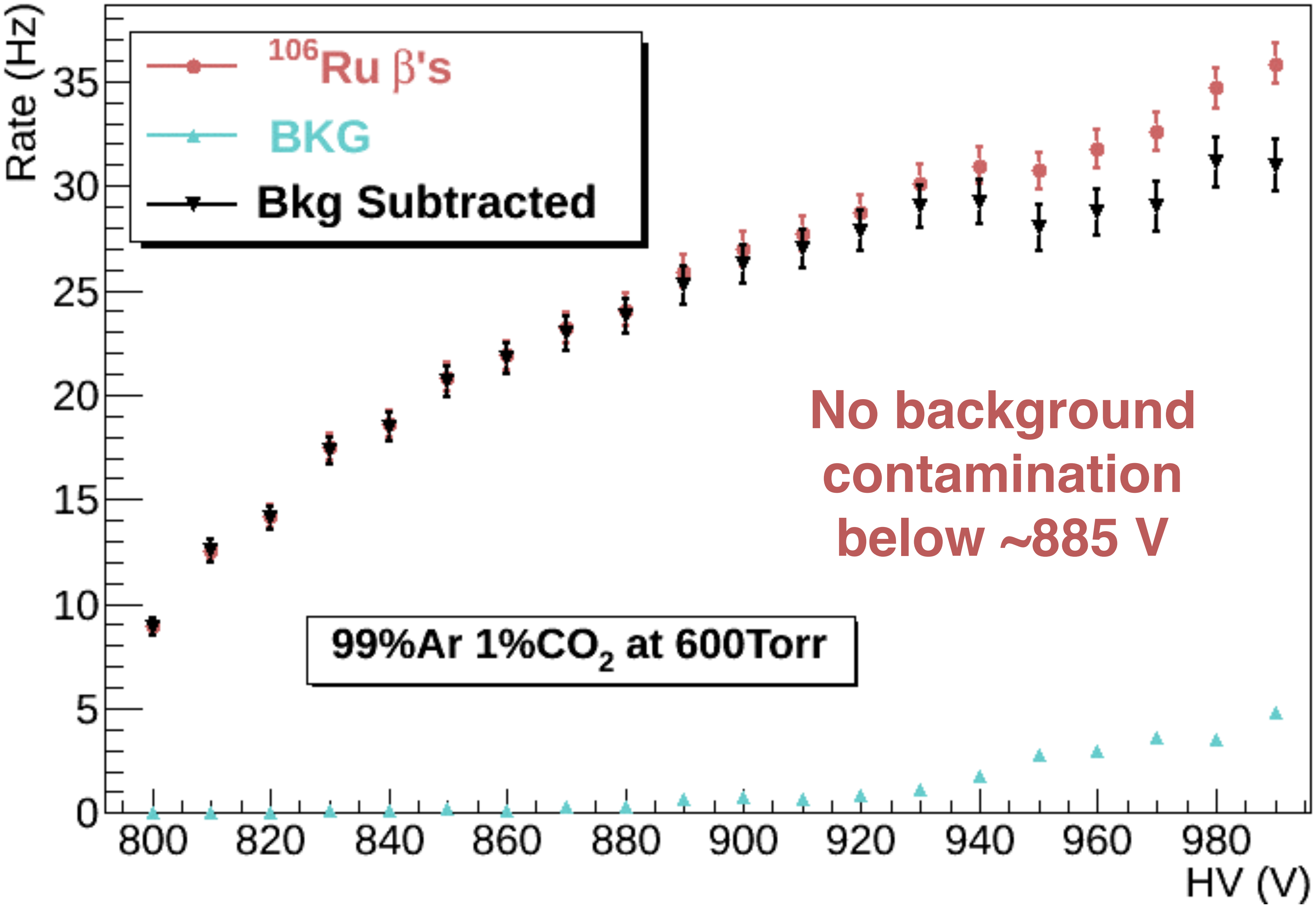
- Building an array of these panels for a *tracker*
- Optimizing gas composition to maximize efficiency
    - The nature of the quenching gas (**CF_4, CO_2,** etc…) and its proportion in the Penning mixture have a **large impact** on the performance of the panel

Flattened gas line



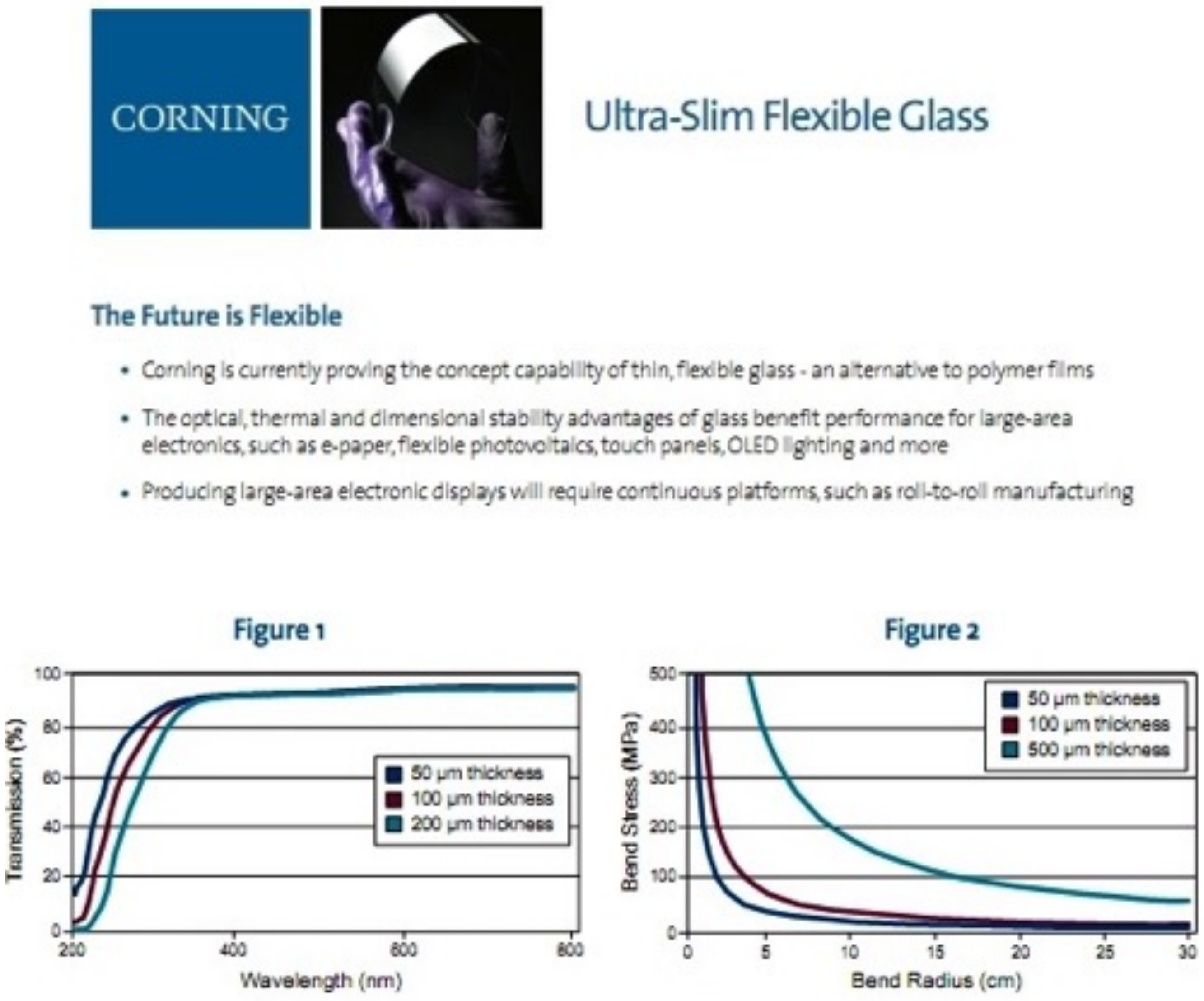
The commercial prototype

- β source sensitivity: ^{106}Ru : 39.4 KeV (Q-value)
- Source placed directly over 4 adjacent cells.



No background contamination below ~885 V

Ultra Thin Glass Properties



CORNING

Ultra-Slim Flexible Glass

The Future is Flexible

- Corning is currently proving the concept capability of thin, flexible glass - an alternative to polymer films
- The optical, thermal and dimensional stability advantages of glass benefit performance for large-area electronics, such as e-paper, flexible photovoltaics, touch panels, OLED lighting and more
- Producing large-area electronic displays will require continuous platforms, such as roll-to-roll manufacturing

Figure 1

Figure 2

Beam Energy Loss in UltraThin Glass vs. Ti-foil

Energy Loss in 25 µm *thick glass* cover PPS for selected Ion Beams
(gas is 1mm of Ar at 760 Torr; *no nuclei get through the glass at 1MeV/A*)

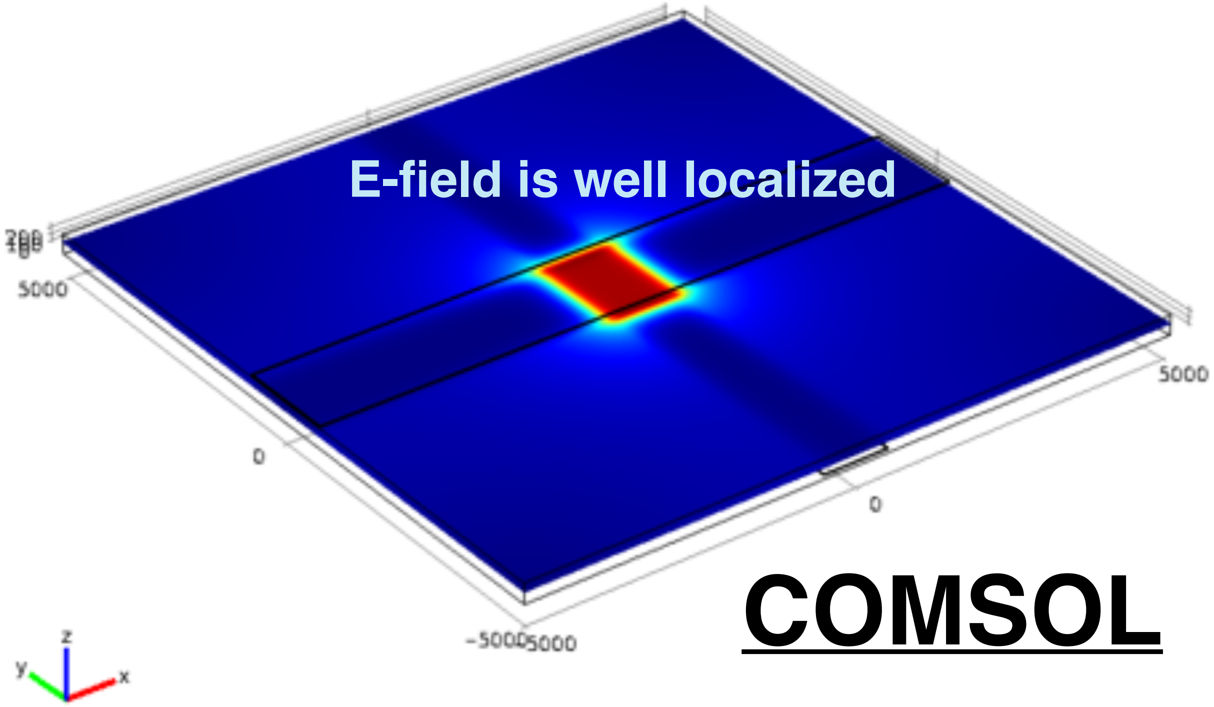
Energy (MeV)/A	**Ion Energy (MeV)**	**Energy *loss in Glass* (MeV)**	**Energy *loss in Gas*** **MeV** (# ion pairs)
3.0 (Ni-64)	192	190	0.95 (36,000)
3.0 (Sn-124)	372	348	4.34 (160,000)
3.0 (U-238)	**714**	**570**	11.60 (440,000)

Energy Loss in 7.6 µm *thick Ti-foil* cover PPS for selected Ion Beams
(gas is 0.25mm of Ar + 10% CO_2 at 600 Torr)

Energy (MeV)/A	**Ion Energy (MeV)**	**Energy *loss in Ti-foil* (MeV)**	**Energy *loss in Gas*** **MeV** (# ion pairs)
1.0 (Ni-64)	64	60.5	0.29 (11,000)
1.0 (Sn-124)	124	111	0.70 (26,000)
1.0 (U-238)	**238**	**199**	1.48 (56,000)
3.0 (Ni-64)	192	81.5	0.93 (35,000)
3.0 (Sn-124)	372	160	1.77 (67,000)
3.0 (U-238)	**714**	**298**	3.21 (120,000)

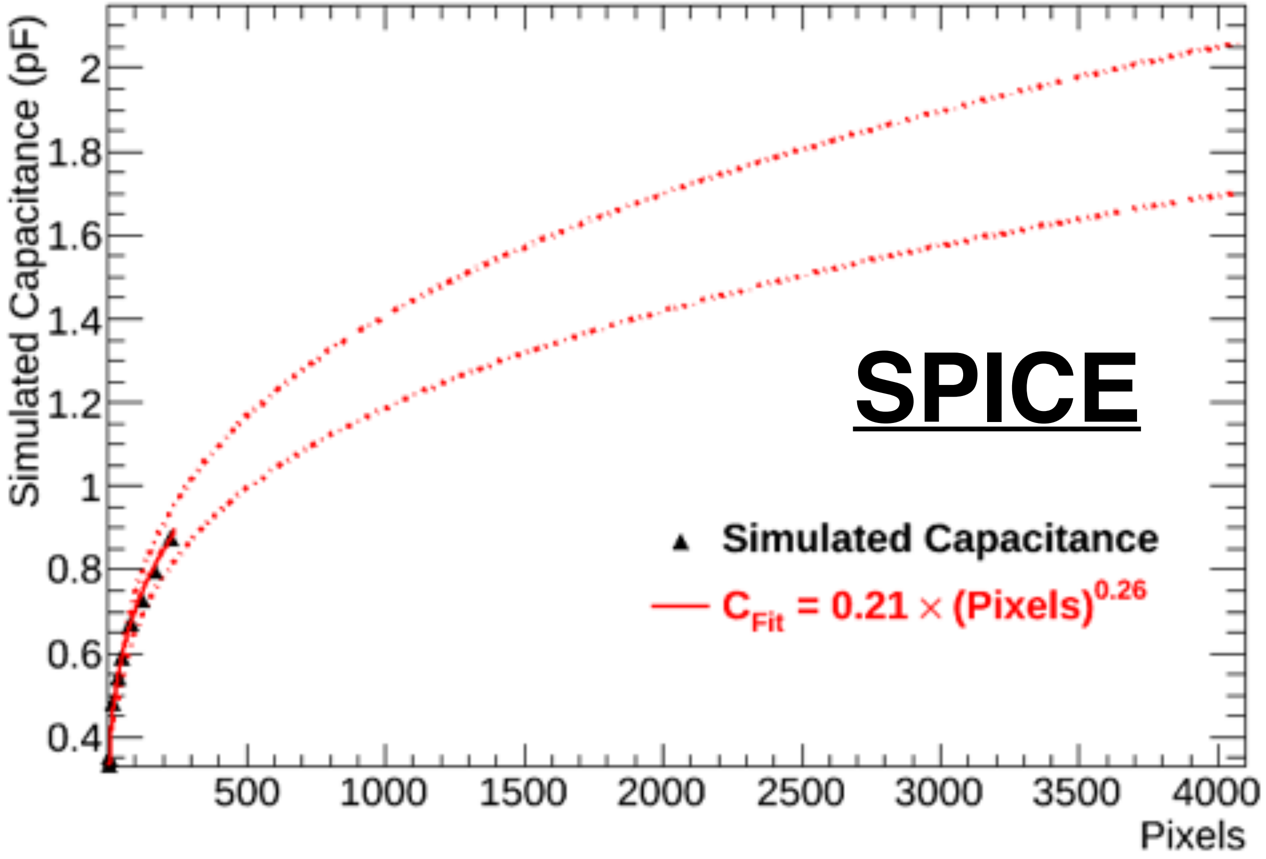
PPS : Simulated Field Properties

- **E-field** produced at the **anode/cathode intersection**



COMSOL

- Simulated **capacitances**
- Stray capacitances – **coupling of all lines included**



SPICE

- Given the single volume gas geometry
  - The **capacitance** depends on the **number of lines**

Origin of the first prototype: