Low Noise Threshold in Ge PPC Detectors

Paul. Barton, LBNL

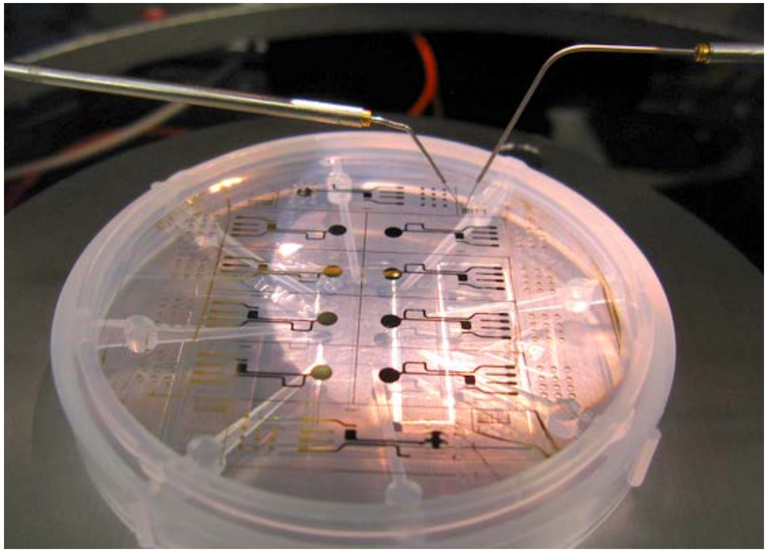
on behalf of the

Ultra-Low Noise Ge Neutrino Detection Collaboration (ULGeN)

CNNS Workshop, Livermore, CA
6-7 December 2012

PPC Detector Electronics at LBNL

1. Mini-PPC / BEGe Performance
2. Low-Mass Front End
3. 0.9 kg PPC Performance
4. Equivalent Noise Charge
5. DAQ Threshold

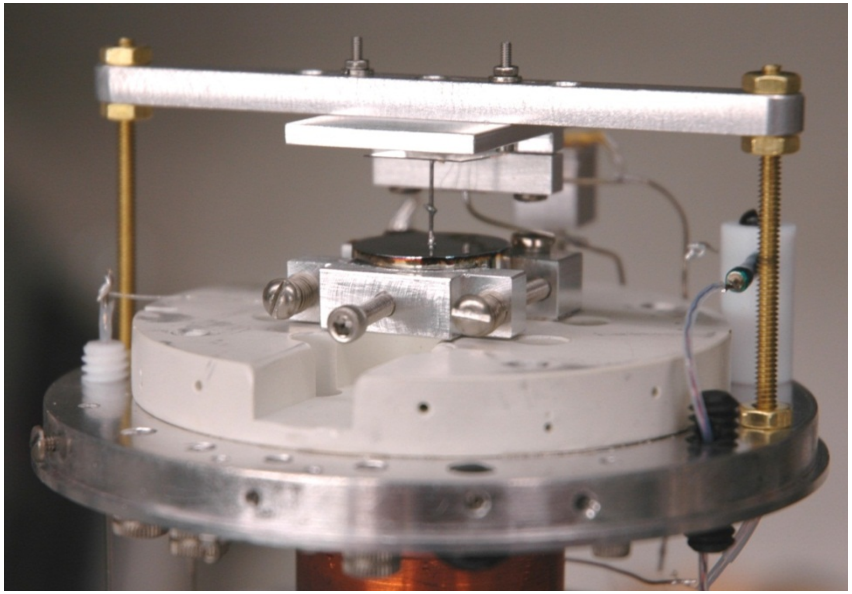


Mini-PPC Performance

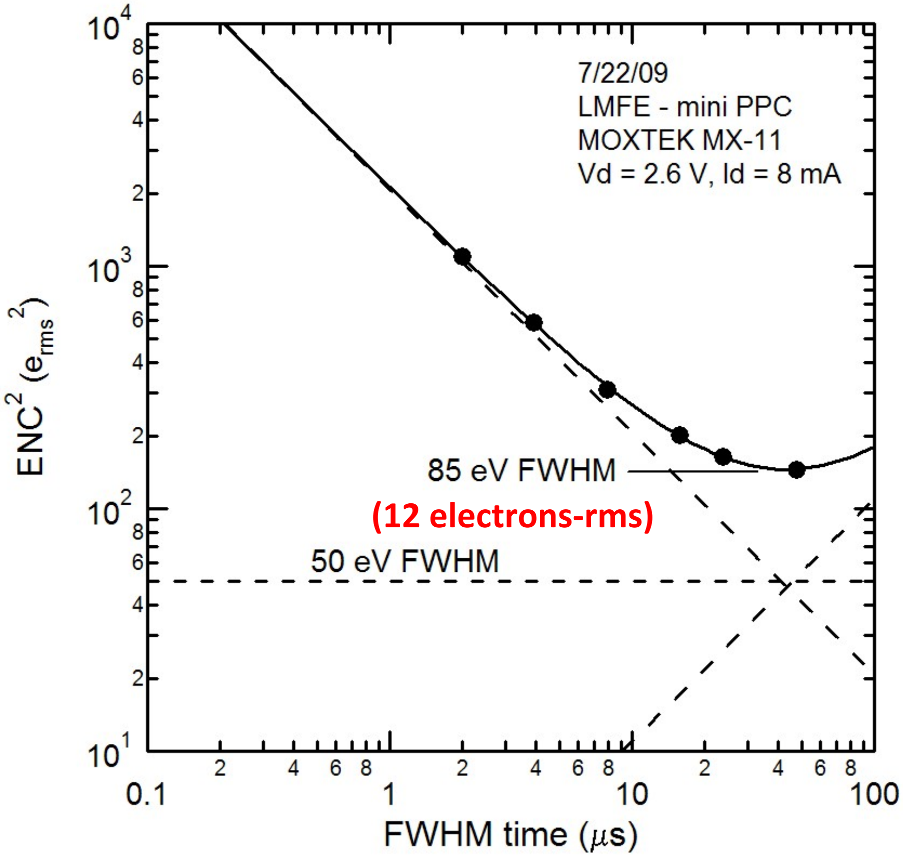
2.96 eV / electron-hole

2.355 rms = FWHM

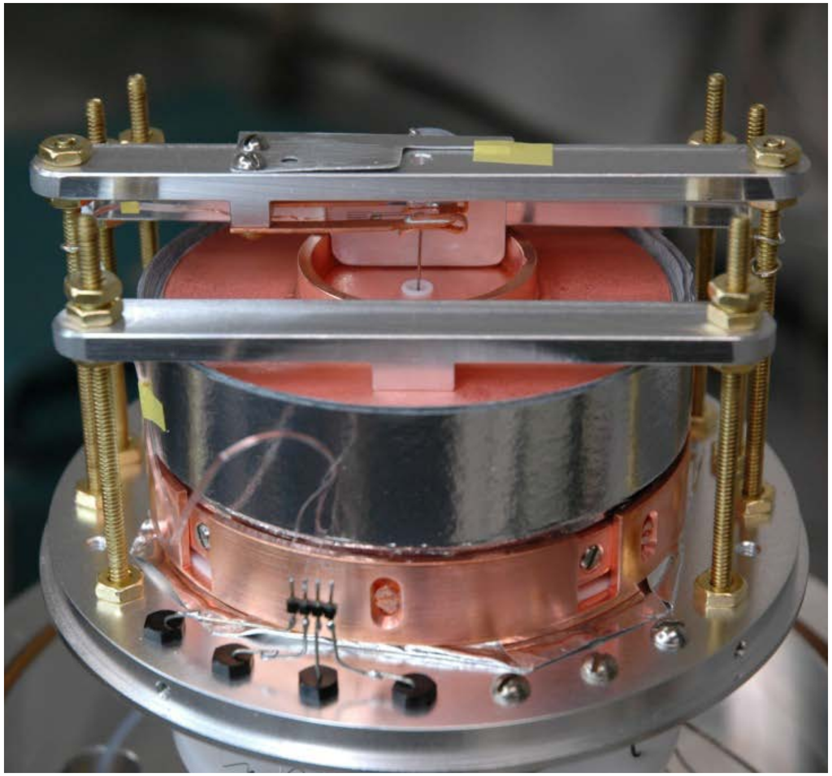
7.0 electrons-rms = eV-FWHM

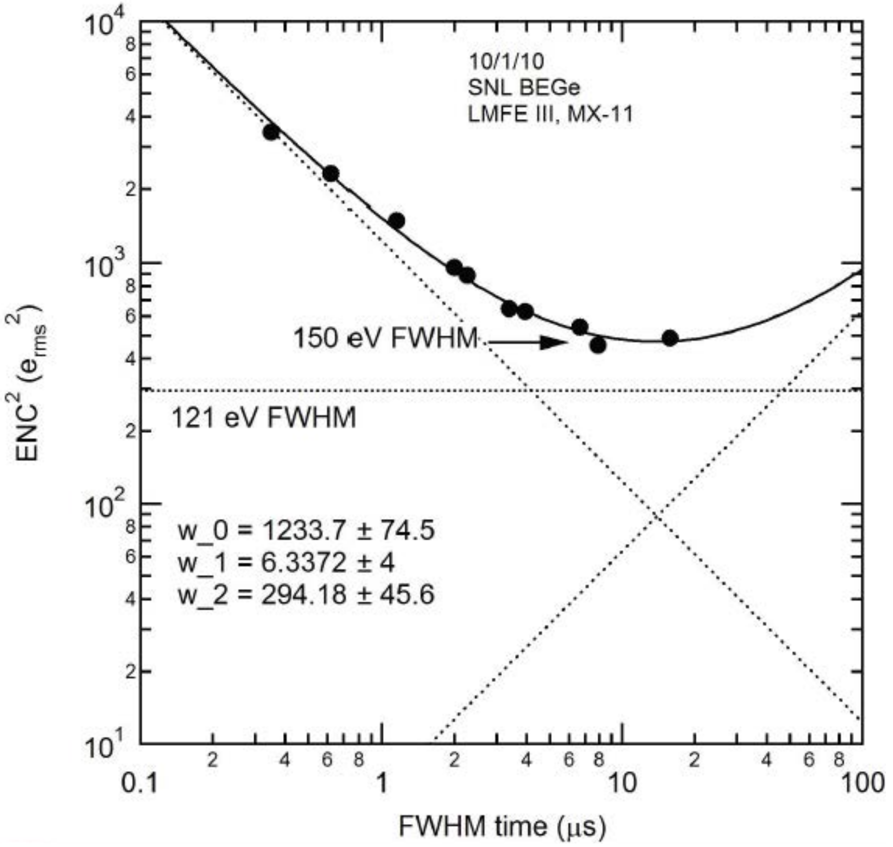


55 eV-FWHM minimum without detector

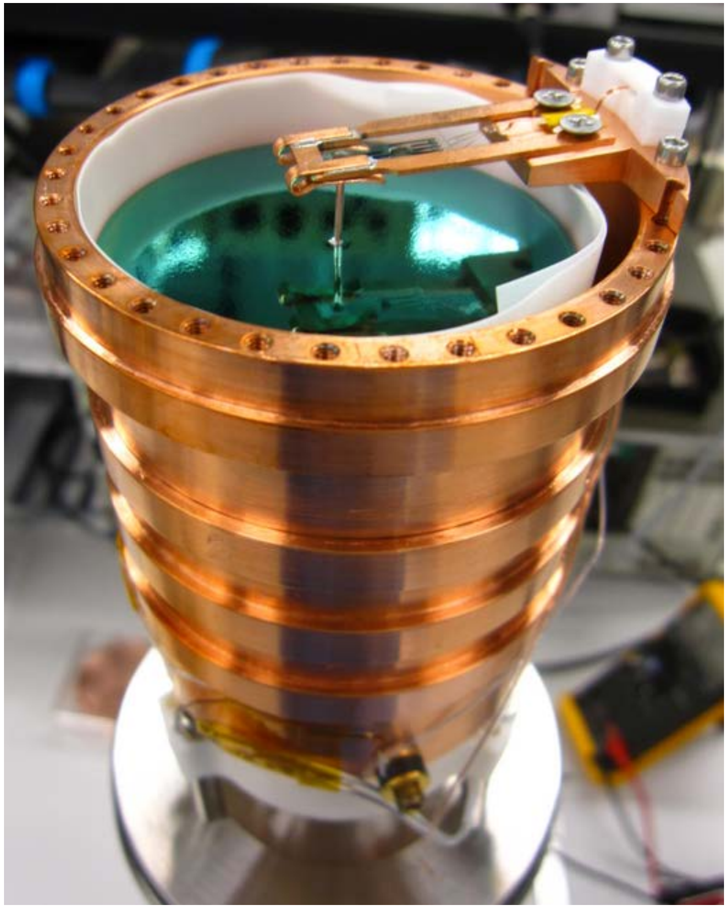


SNL BEGe in LBNL Cryostat

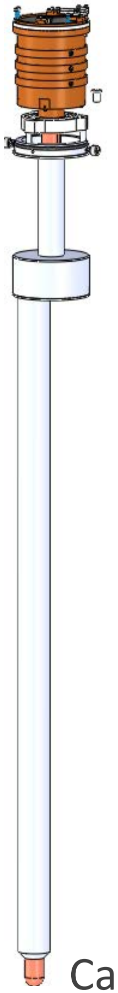




LBNL PPC Readout Electronics



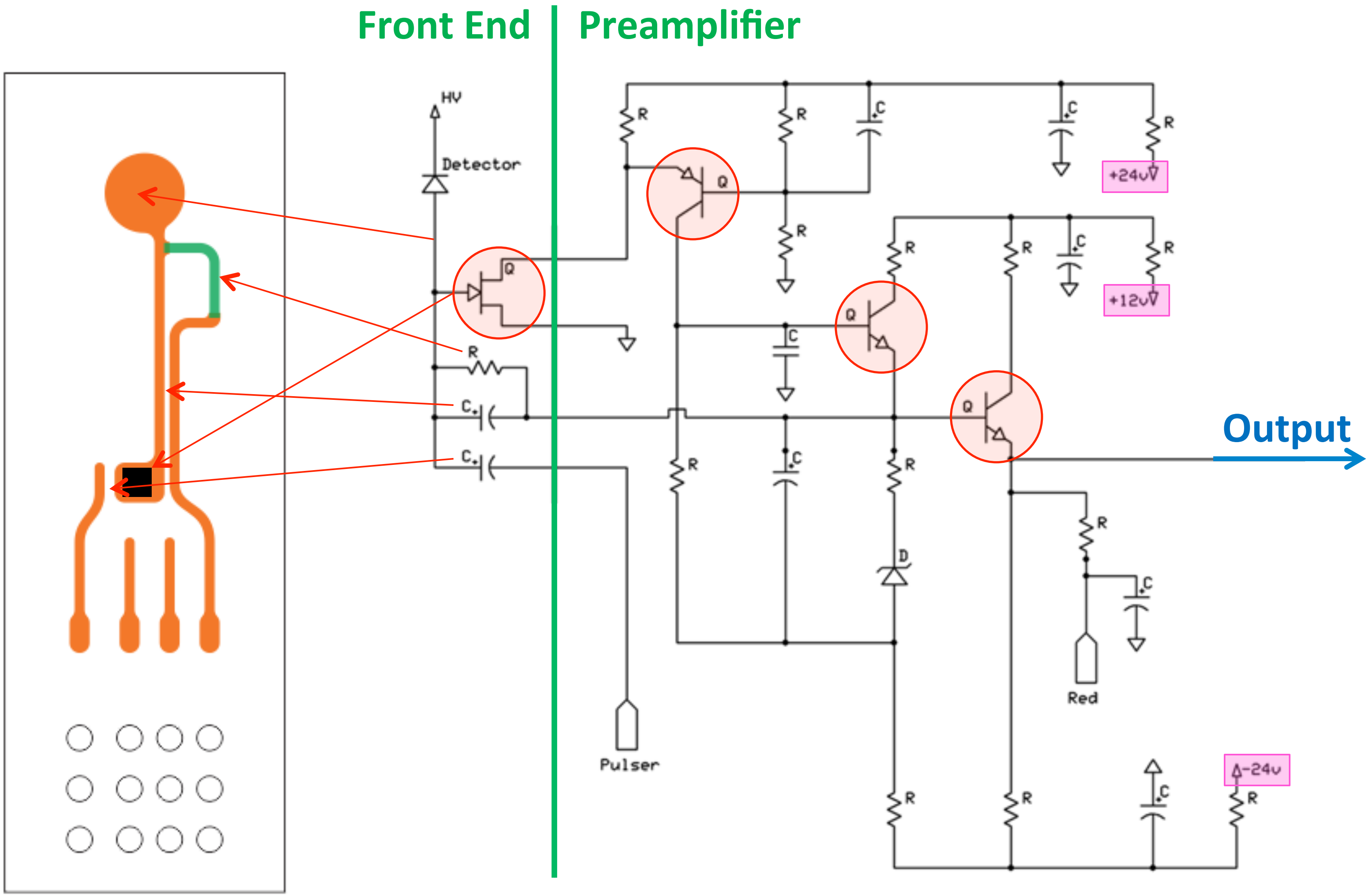
903 g PPC with MJ-LMFE



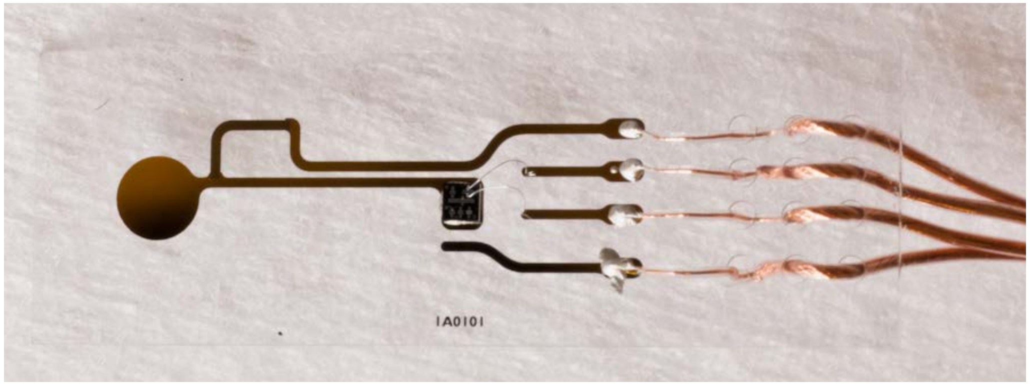
Canberra Low-BG Cryostat

High-Resolution Preamplifier (ca. 1967)

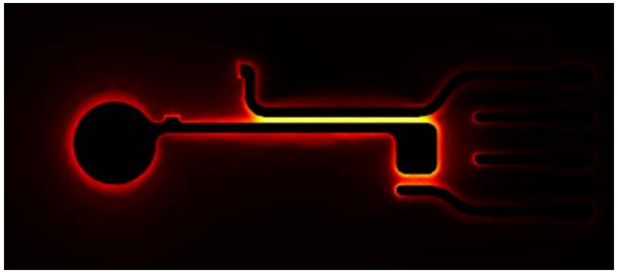
Preamplifier (F. Goulding Design)



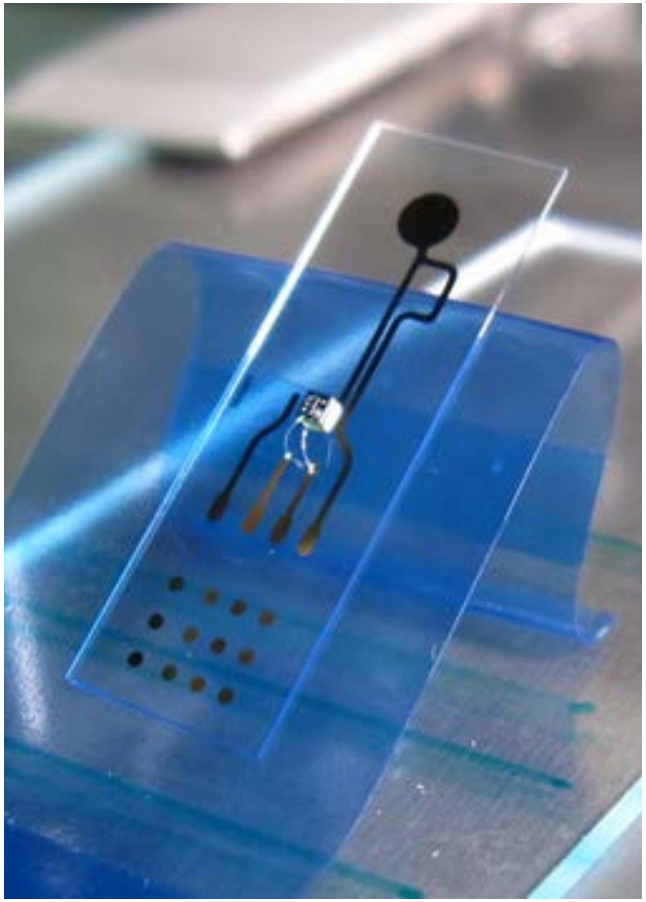
Low-Mass Front End



Majorana LMFE with strain relief

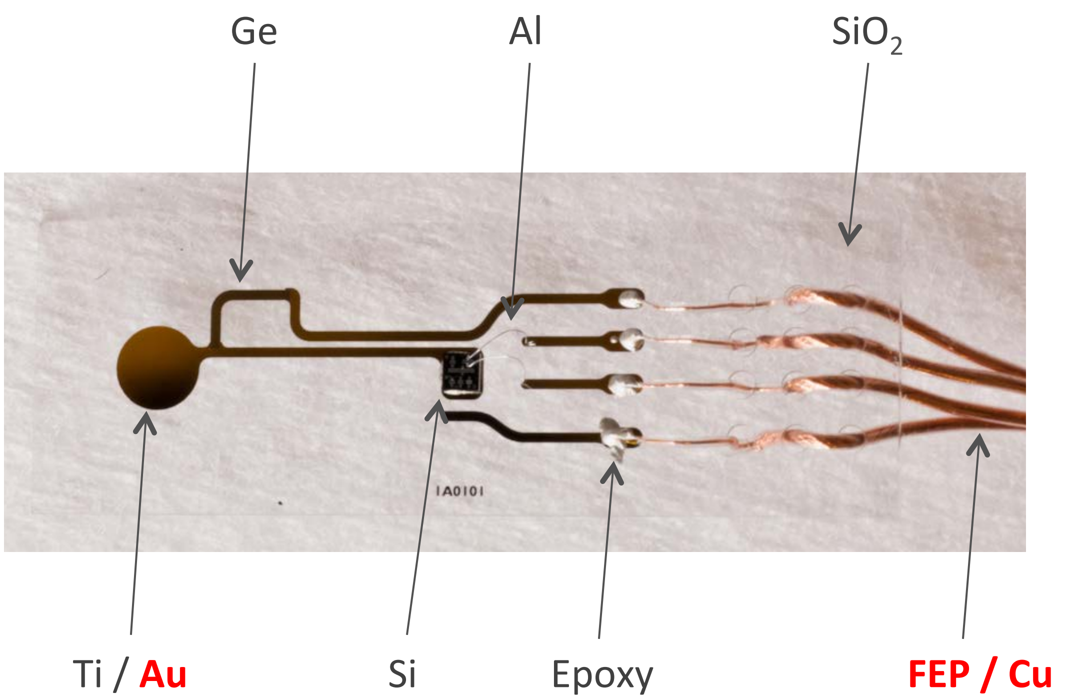


Electric Field



Low-Mass Front End

(Low-Background)



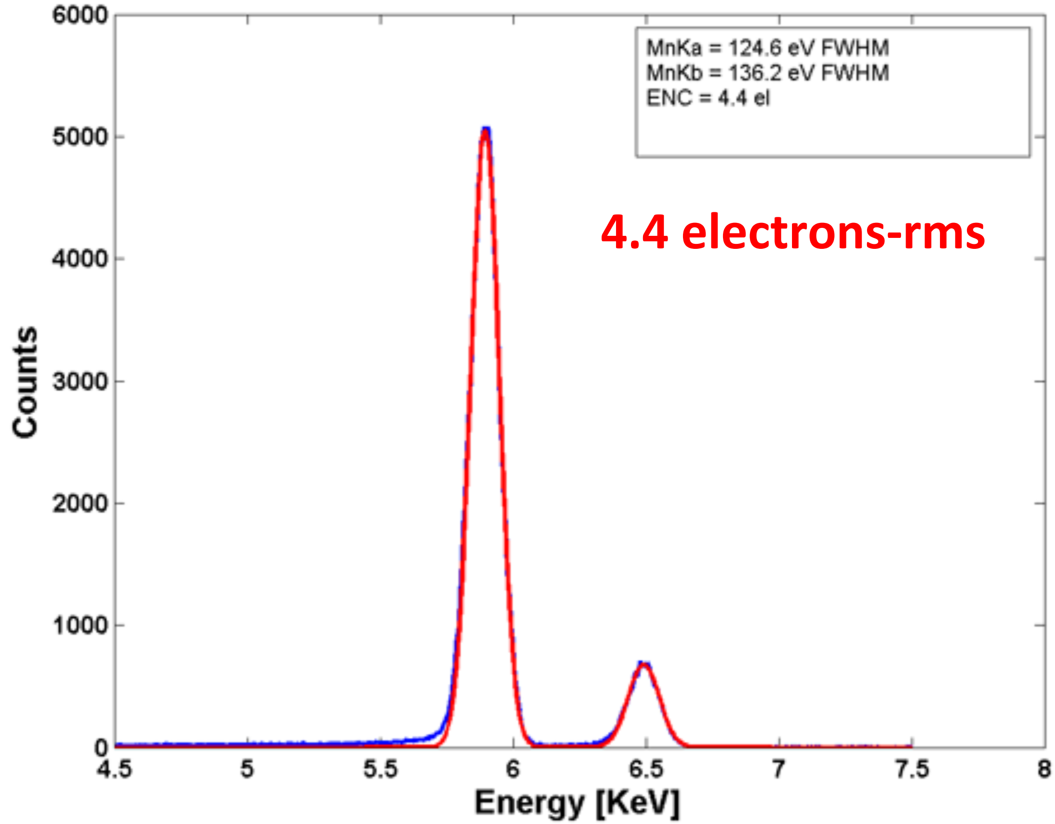
(Legacy) Majorana Prediction: < 702 nBq / board (Th + U)

MOSFET Alternative to JFET

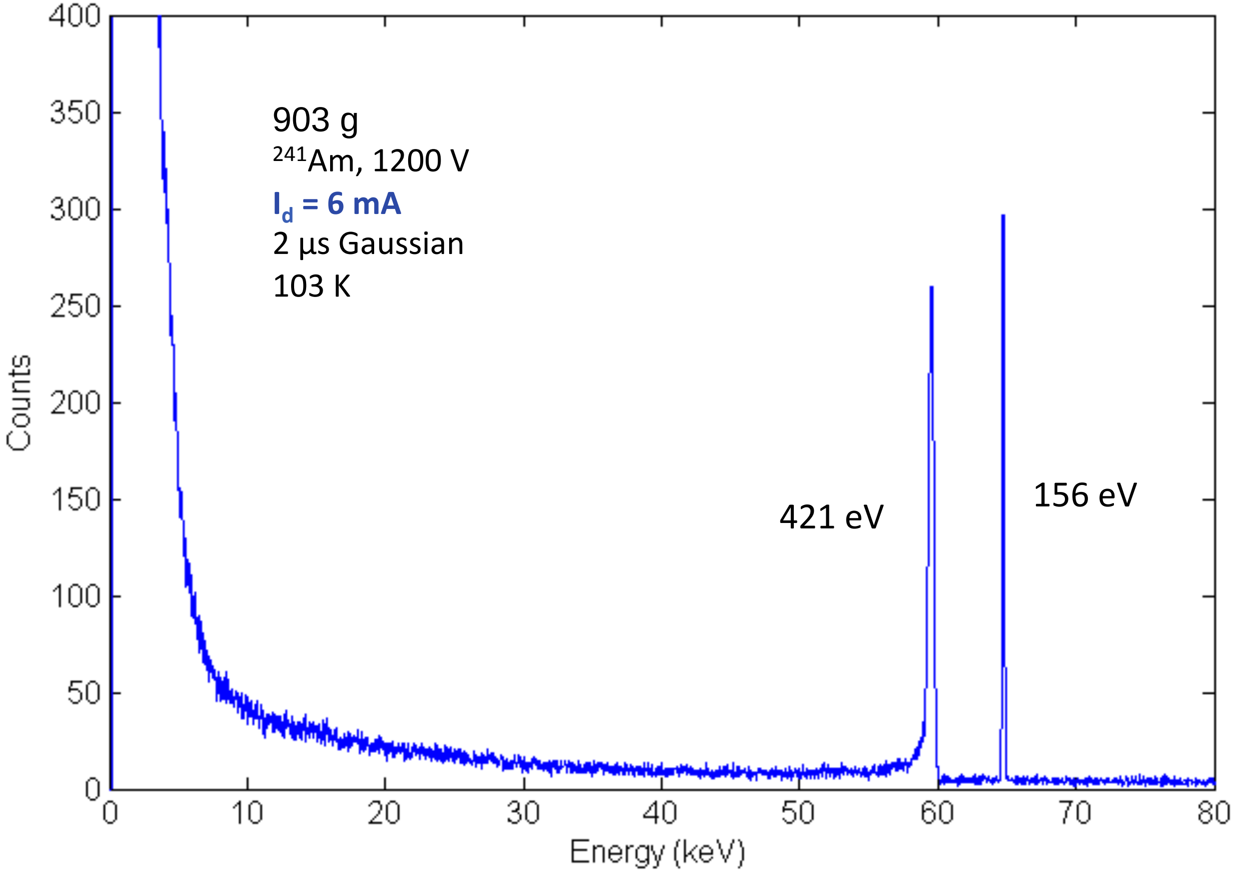
Investigating cold CMOS options:

XGLab CUBE ASIC
Originally for SDD

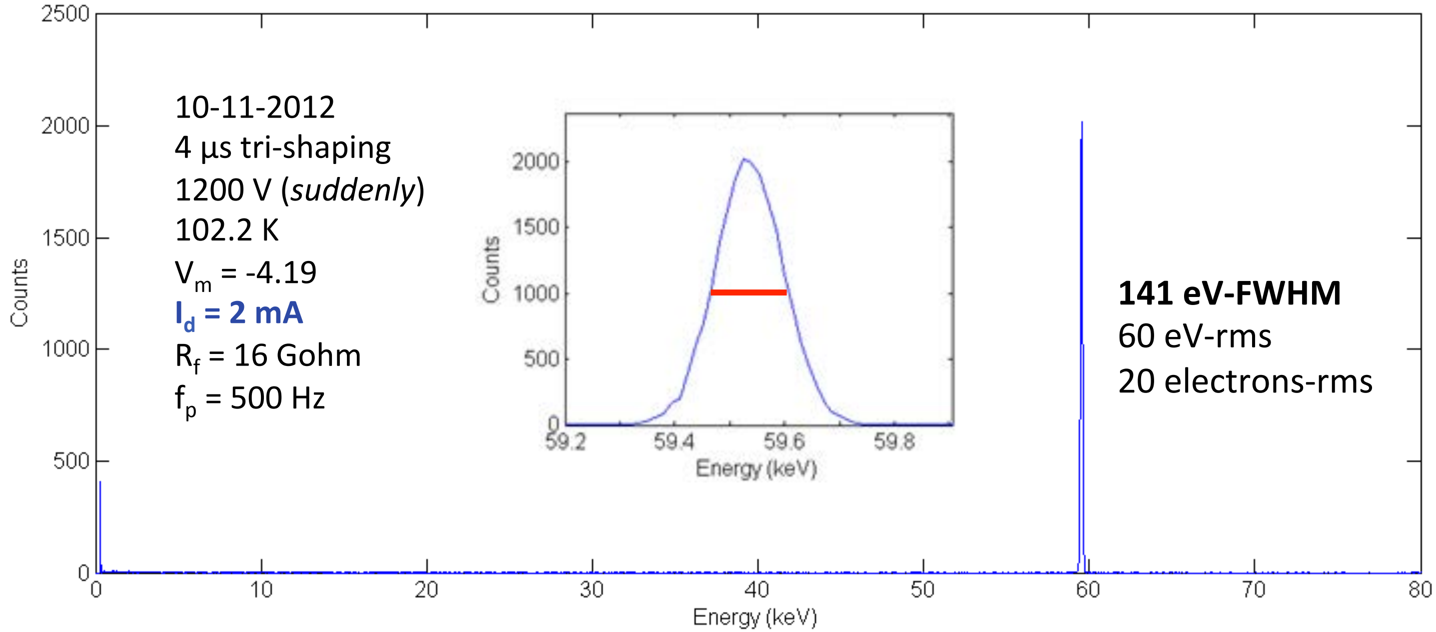
Pulsed-Reset
0.75 x 0.75 mm^2
3.4 el.rms alone

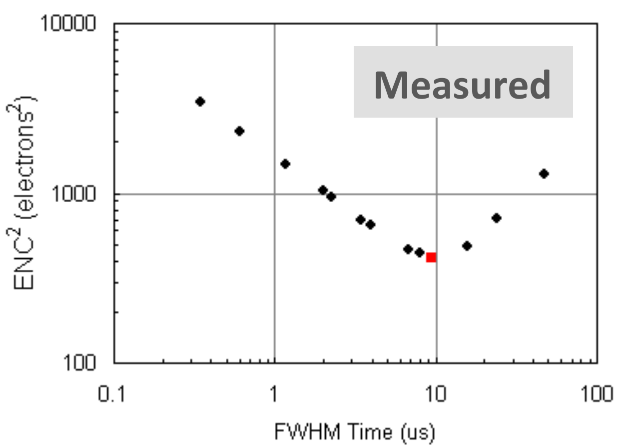


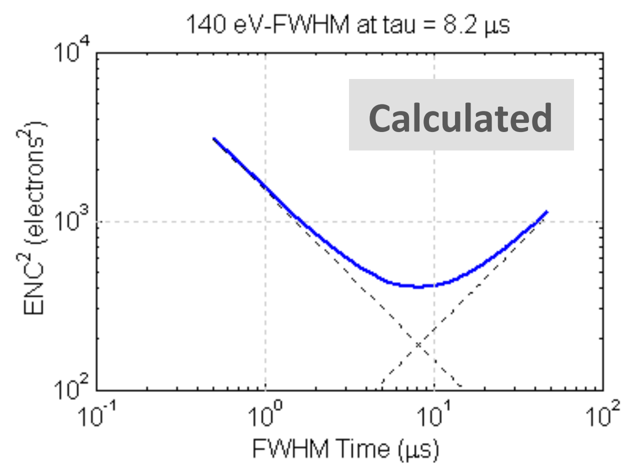
Electronic Noise with 0.9 kg Detector



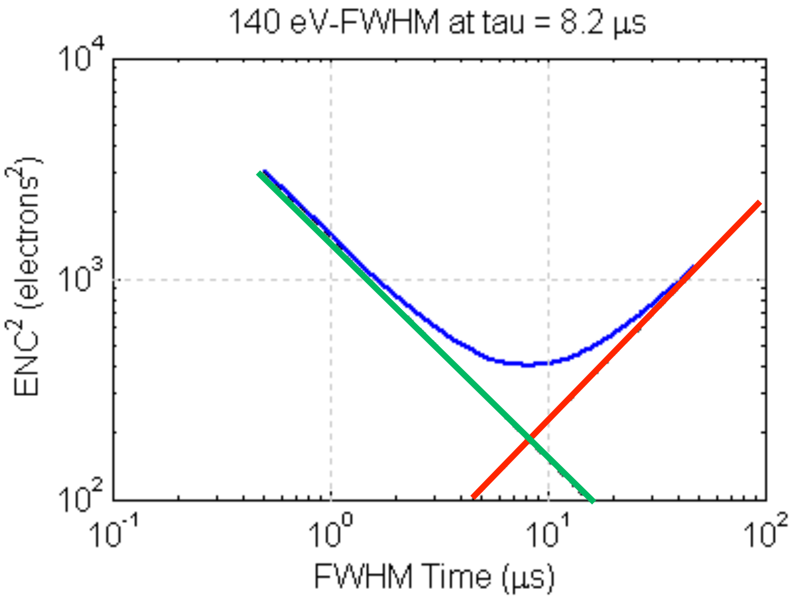
Equivalent Noise Charge







Equivalent Noise Charge

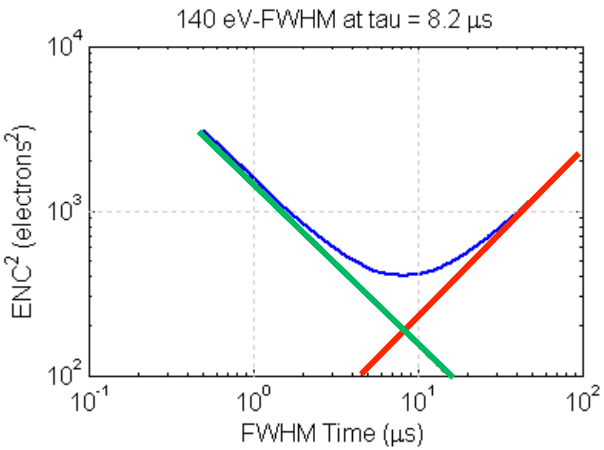


$T = 100{:}140$
$C_d = 1.2\ \text{pF}$
$I_d = 3.0\ \text{pA}$
$R_F = 16\ \text{G}\Omega$

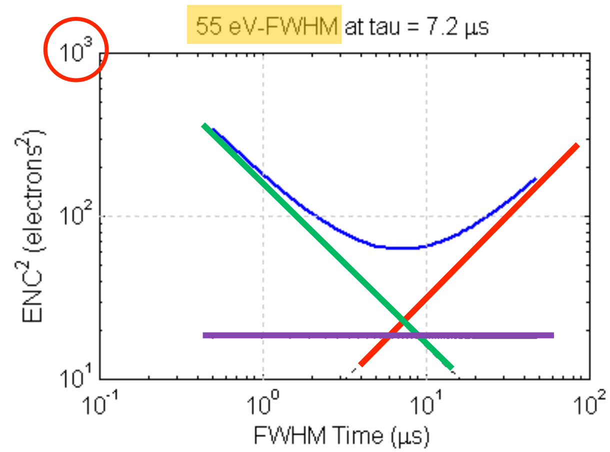
Voltage (series) **1/f** **Current (parallel)**

$$ENC^2 = Q_n^2 = \left(\frac{e^2}{8}\right)\left[\left(\frac{4kT}{g_m} + e_{na}^2\right)\frac{C_d^2}{\tau} + 4A_f C_d^2 + \left(2q_e I_d + \frac{4kT}{R_F} + i_{na}^2\right)\tau\right]$$

ENC Improvement Plan



$T = 100{:}140$
$C_d = 1.2\ \text{pF}$
$I_d = 3.0\ \text{pA}$
$R_F = 18\ \text{G}\Omega$



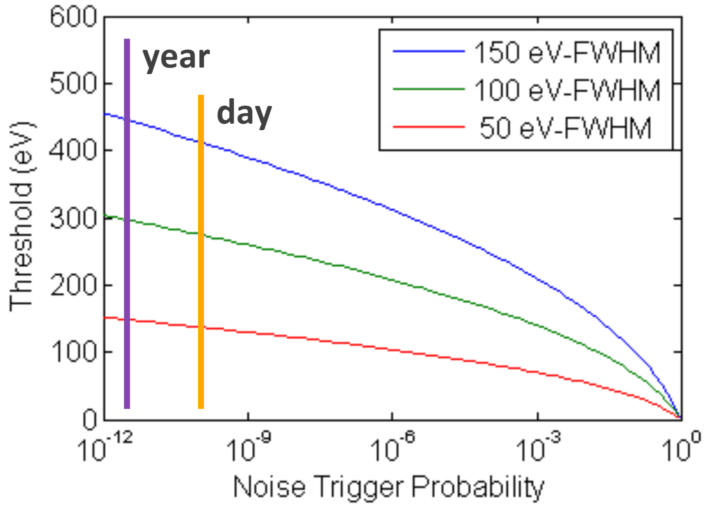
$T = 90{:}130$
$C_d = 0.5\ \text{pF}$
$I_d = 0.1\ \text{pA}$
$R_F = 100\ \text{G}\Omega$

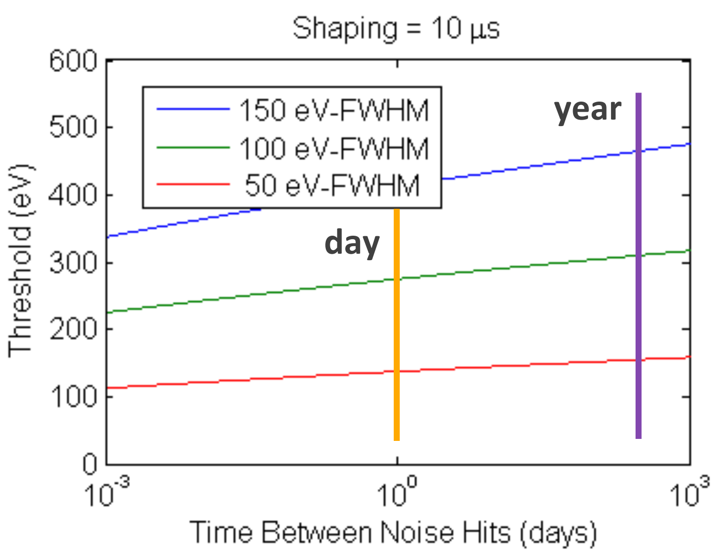
Voltage (series) **1/f** **Current (parallel)**

$$ENC^2 = Q_n^2 = \left(\frac{e^2}{8}\right)\left[\left(\frac{4kT}{g_m} + e_{na}^2\right)\frac{C_d^2}{\tau} + 4A_f C_d^2 + \left(2q_e I_d + \frac{4kT}{R_F} + i_{na}^2\right)\tau\right]$$

$1\ \text{pA} \cong 15\ \text{G}\Omega$

DAQ Threshold & Noise Triggers





Gaussian Probability

$$n_\sigma(p_t) = \sqrt{2} \cdot erf^{-1}(p_t - 1)$$

Probability vs. Frequency

$$p_t = \boxed{10^{-10}} \Rightarrow \frac{1}{f_n} = \boxed{1\text{ day}}$$

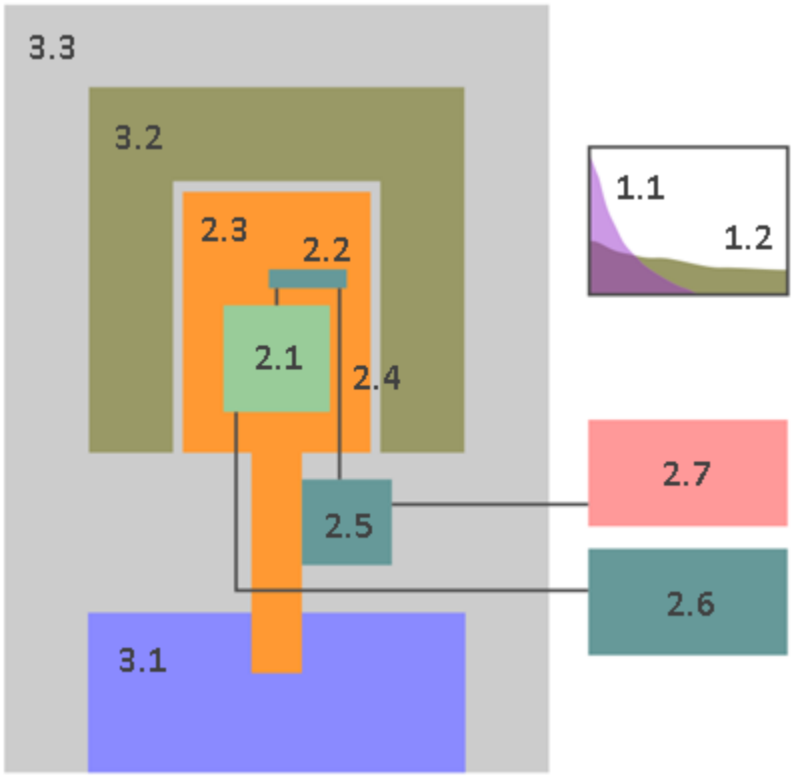
With Pulse Shaping (Low Pass)

$$\frac{E_{Th}}{E_N} = \sqrt{-2\log\left(4\sqrt{3} f_n \tau\right)}$$

$$\therefore E_{Th} \approx 3\Delta E_{\mathrm{FWHM}}$$

Ultra-Low Noise Germanium Neutrino Detection System (ULGeN)

1. **Signal and Backgrounds**
    1. Signal
    2. Backgrounds
2. **Low Noise Detector**
    1. Crystal
    2. Front End
    3. Cryostat
    4. Cables
    5. Preamplifier
    6. High Voltage
    7. DAQ
3. **Deployment**
    1. Cooling
    2. Vetoes
    3. Shielding
    4. Operations
    5. Data Analysis

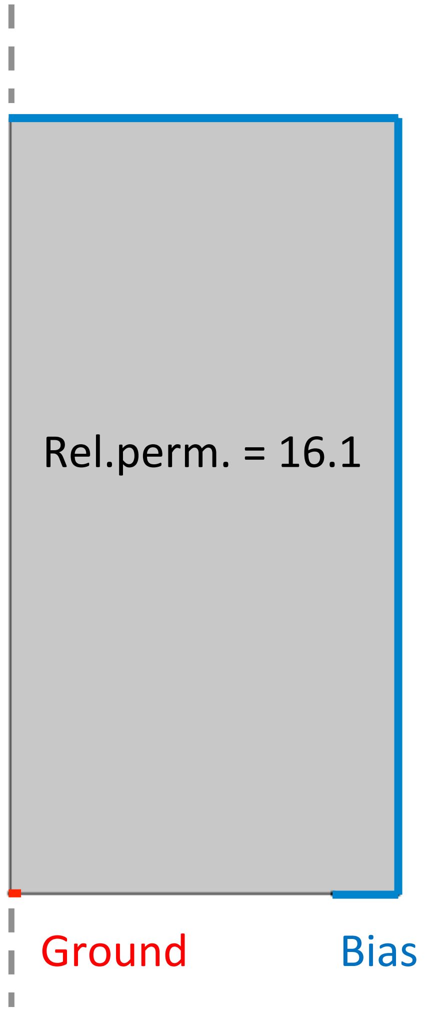


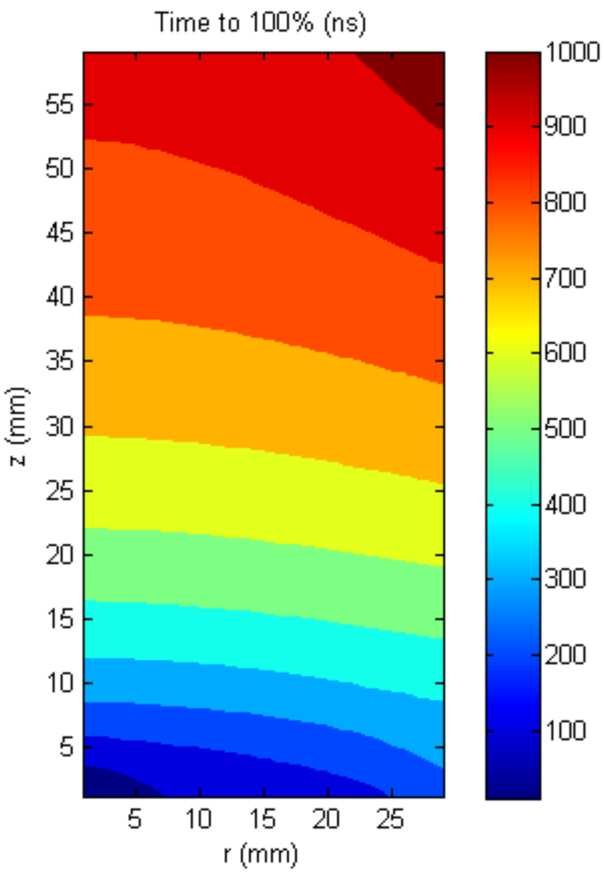
Discussion

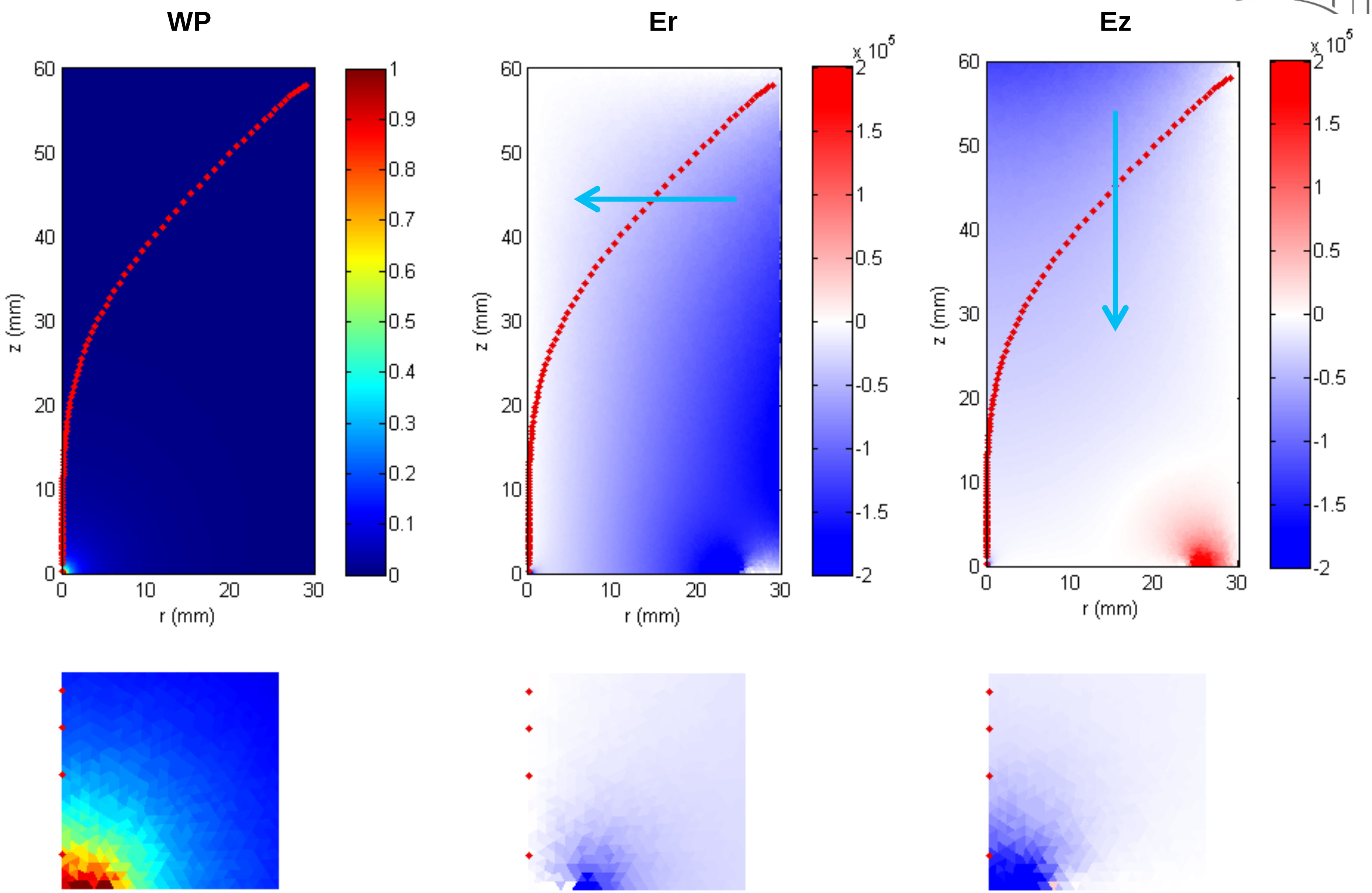
- **CNNS detection:** low threshold / noise, low background, large mass
- **Ge PPC:** large volume, low capacitance, low leakage current
- **Cold JFET:** low capacitance, high transconductance
- **Rare events:** long pulses, waveforms for physics discrimination

Backup Slides

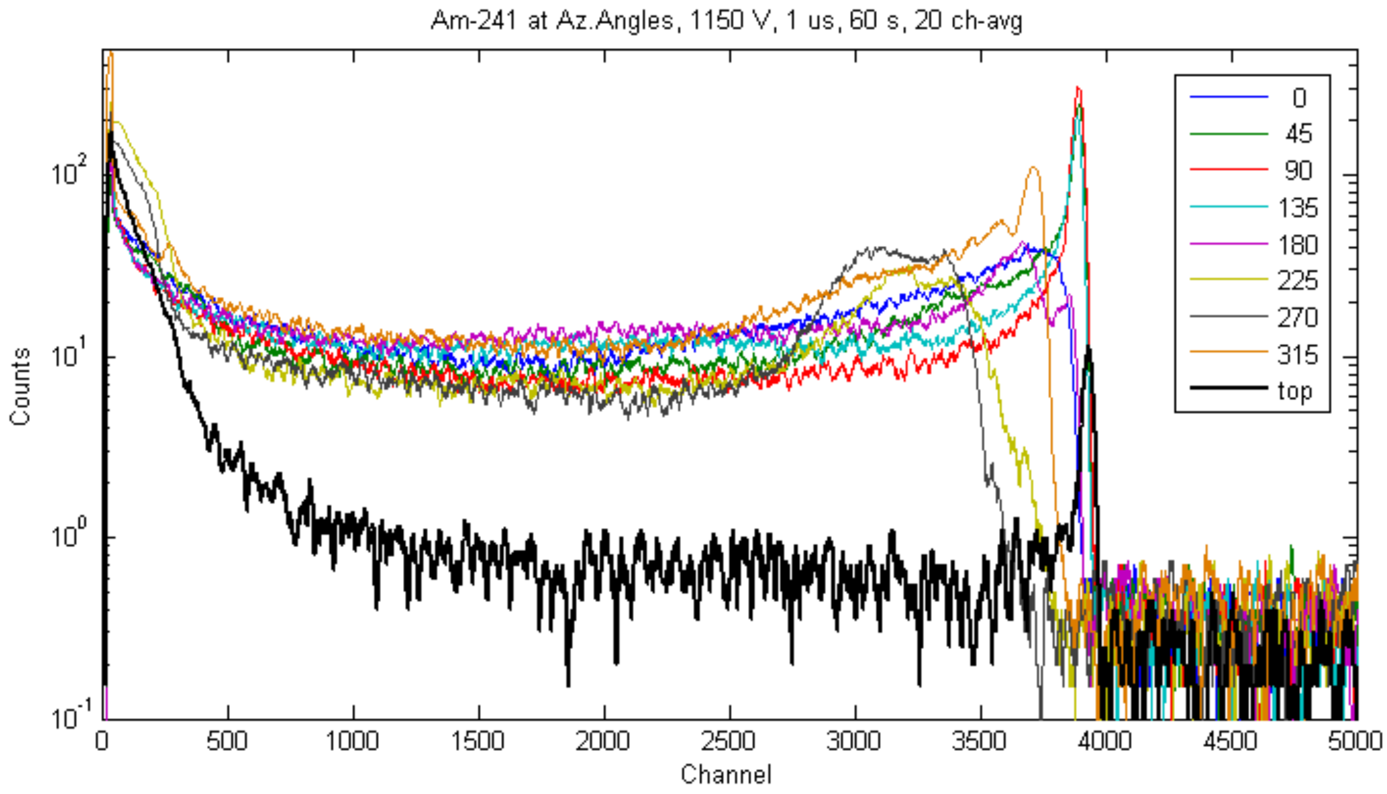
PPC Isochrones (Equal Drift Times)

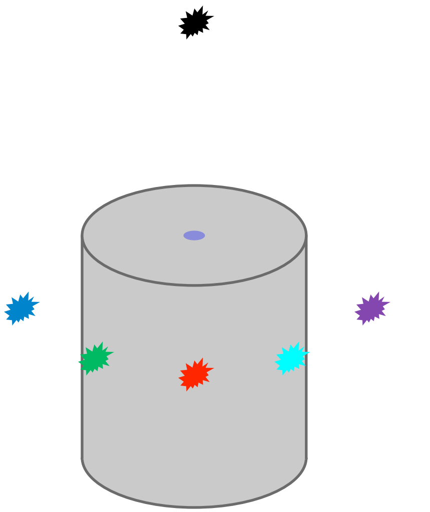




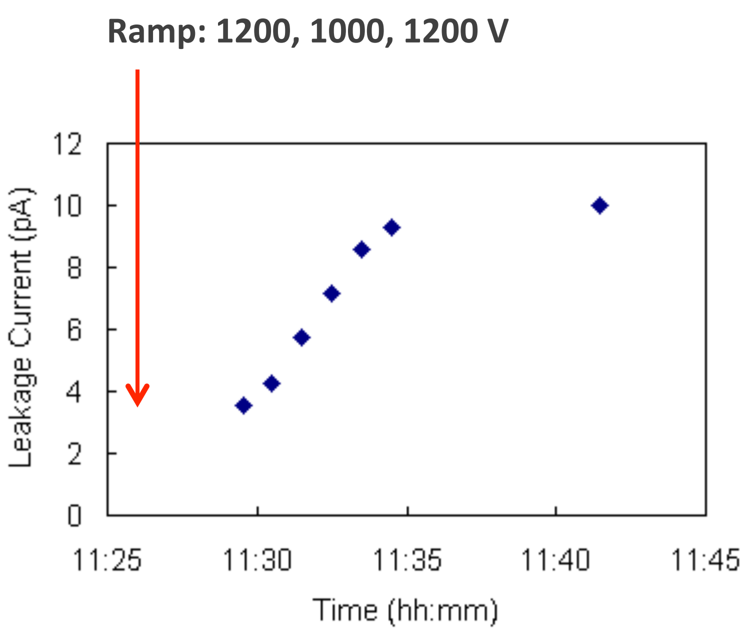

WP
Er
Ez
z (mm)
r (mm)
x 10^5

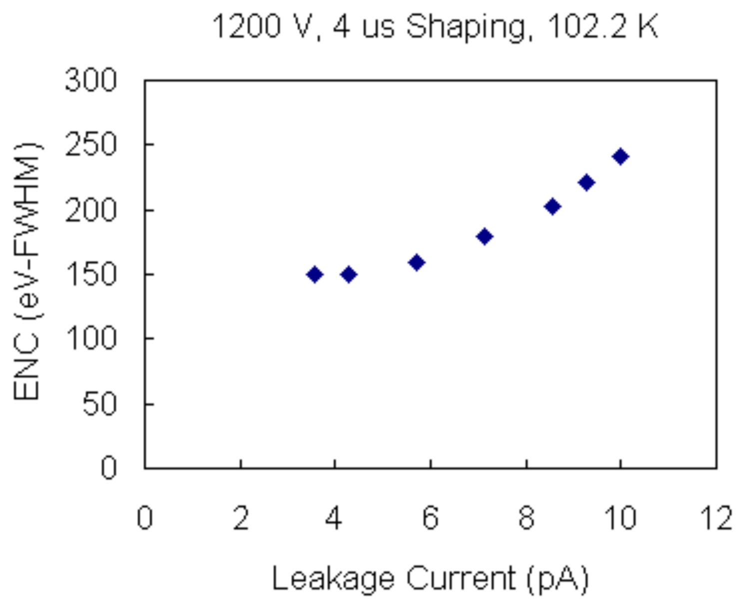
PPC Performance (non-ideal)





Leakage Current Buildup





a-Ge Resistance vs. Temperature