Low-energy event excess in SuperCDMS HVeV detectors

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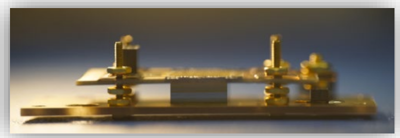
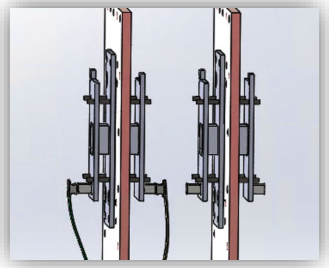
Outline

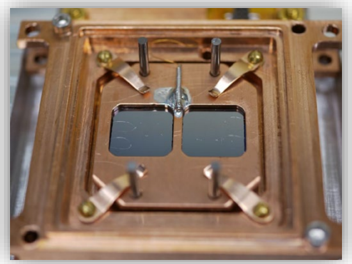
- SuperCDMS HVeV detector description
- Comparison between 0V and HV background with HVeV R2 data
- A coincidence measurement with HVeV R3 data
- Detector holder improvement for HVeV R4



HVeV R2

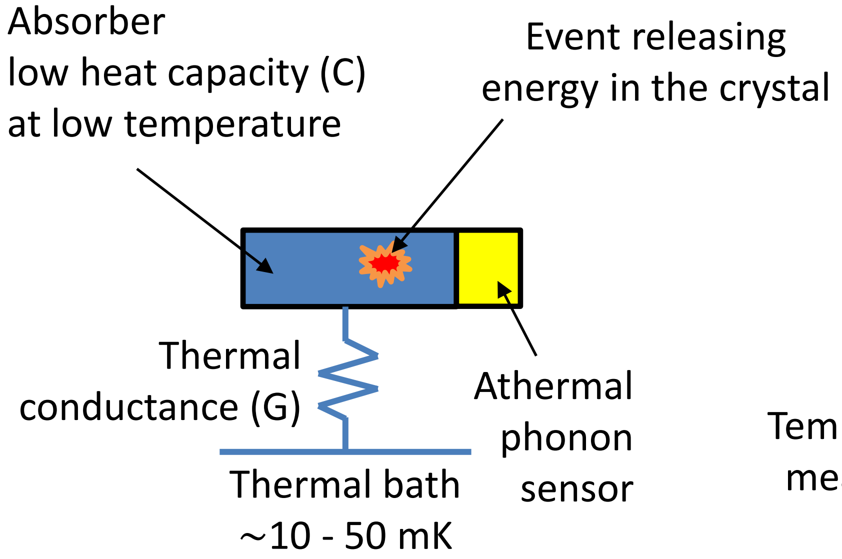


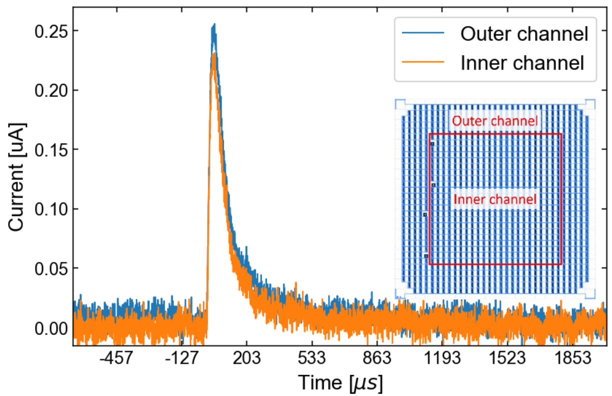
HVeV R3



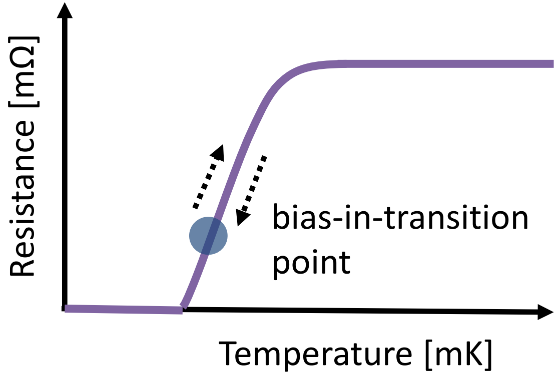
HVeV R4

Calorimetric technique





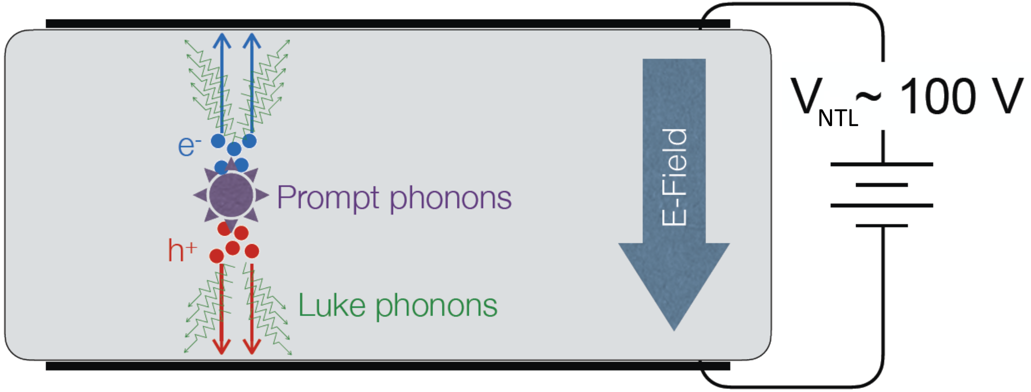
Temperature variations are measured with transition-edge sensors (TES)



Neganov-Trofimov-Luke effect

Charge signals are amplified with an electric field across the crystal

$$E_{total} = E_{recoil}\left(1 + \frac{e \cdot Y \cdot V_{NTL}}{\varepsilon_{eh}}\right)$$

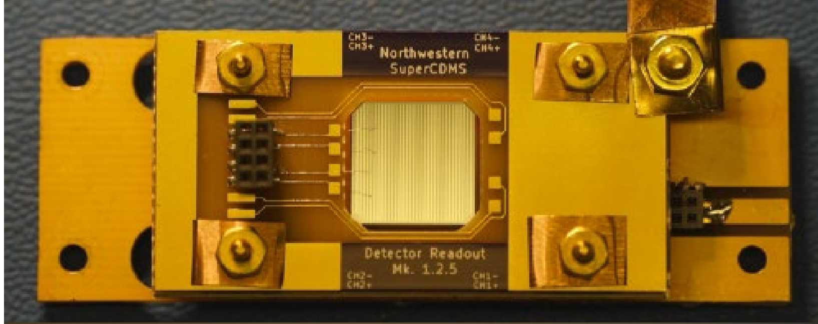


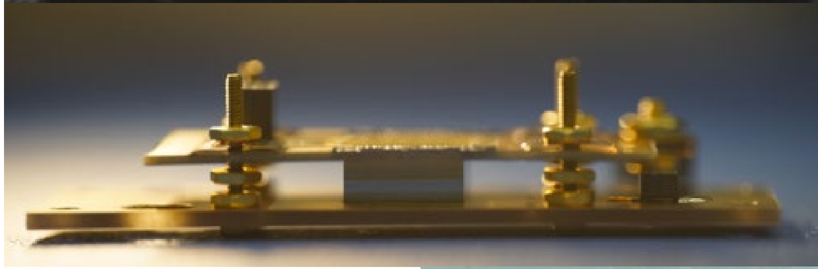
B. S. Neganov and V. N. Trofimov, Otkryt. Izobret., 146, 215 (1985)
P. N. Luke, J. Applied Phys. 64,6858 (1988)

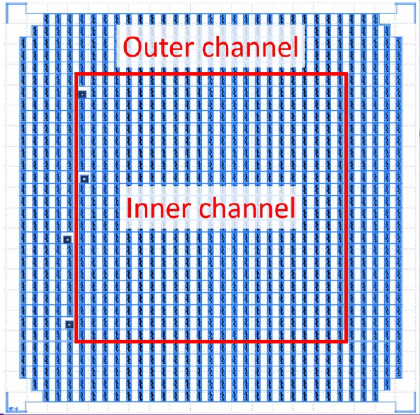
HVeV detectors

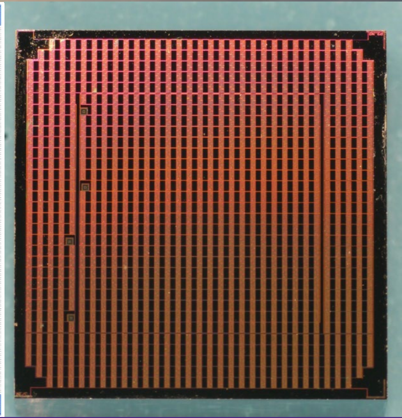
- 0.93 g silicon crystal
- 2 channels of TES-arrays
  - Inner and outer channel
  - Same sensor area – same gain
- Aluminium grid on the back of the detector to apply the NTL bias

- Crystal clamped between two PCB boards
  - Provides electrical and thermal connection
  - 4 spring mechanisms with ~10-70 grams each

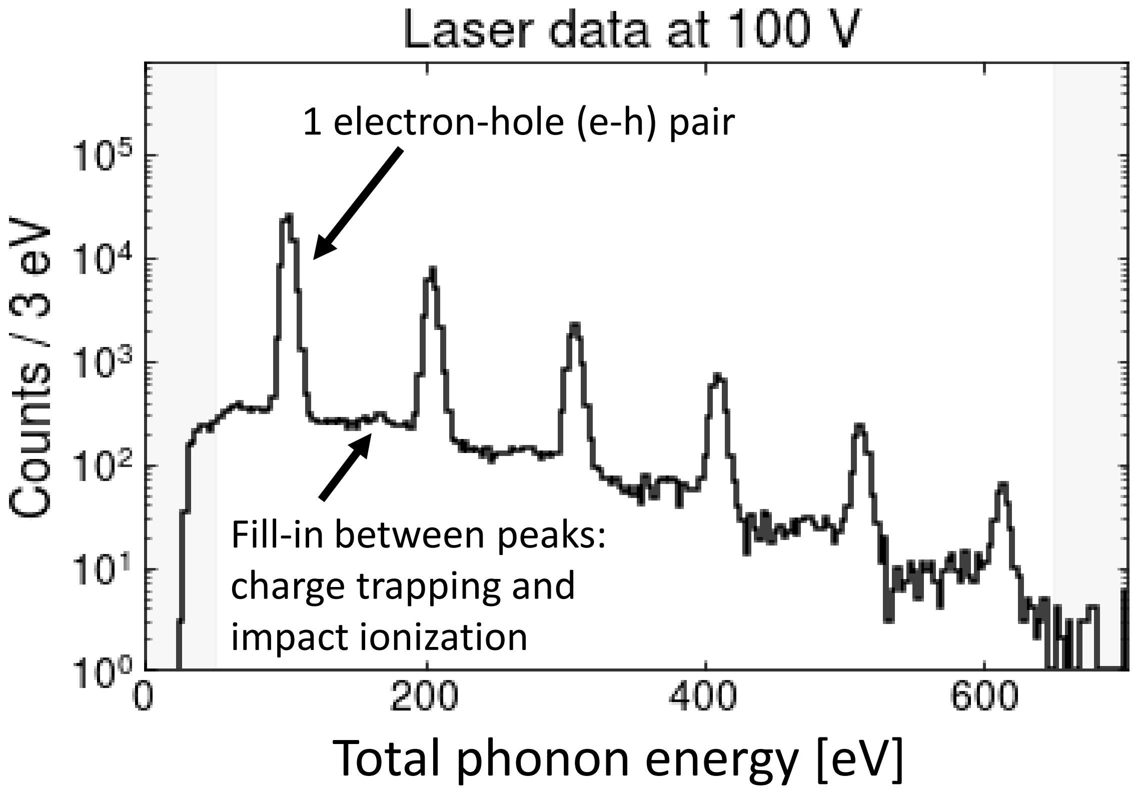






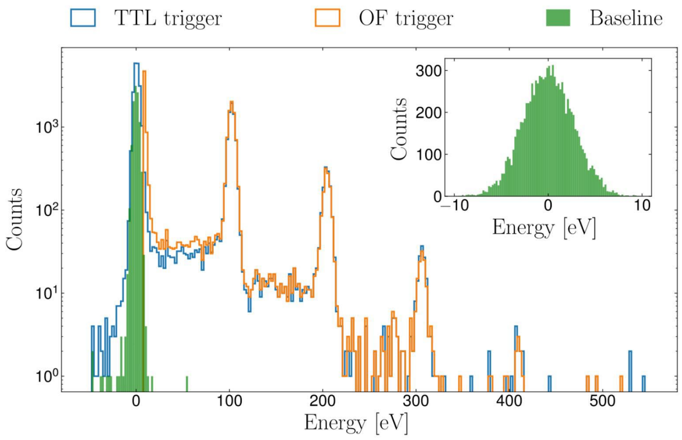


Single electron-hole pair sensitivity



D. W. Amaral *et al.*, Phys. Rev. D 102, 091101(R), 2020
F. Ponce, et al., Phys. Rev. D 101, 031101(R), 2020

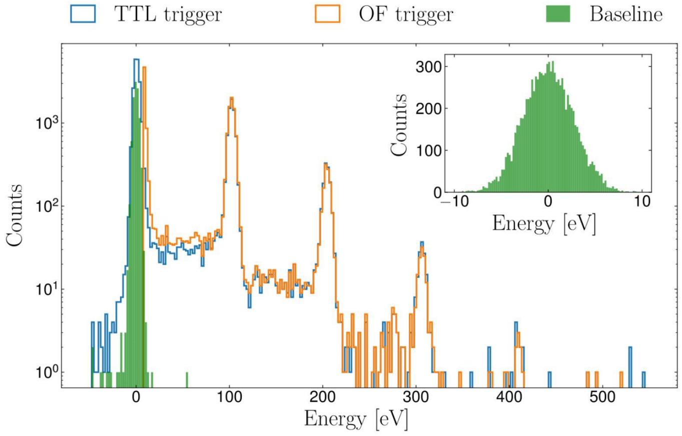
HVeV detectors

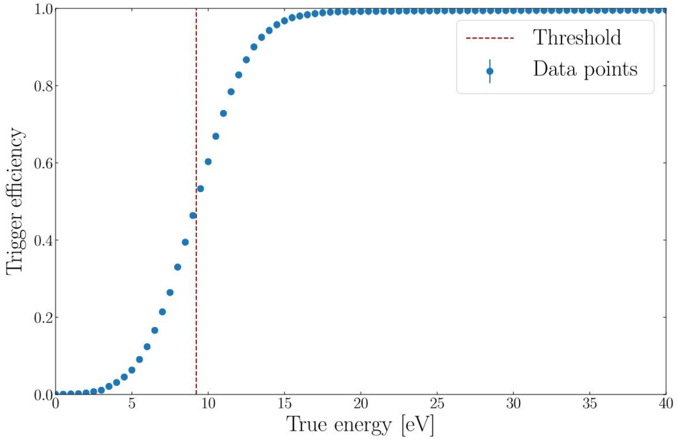


- 2.7 eV baseline resolution

R. Ren *et al.*, Phys. Rev. D 104, 032010, 2021

HVeV detectors

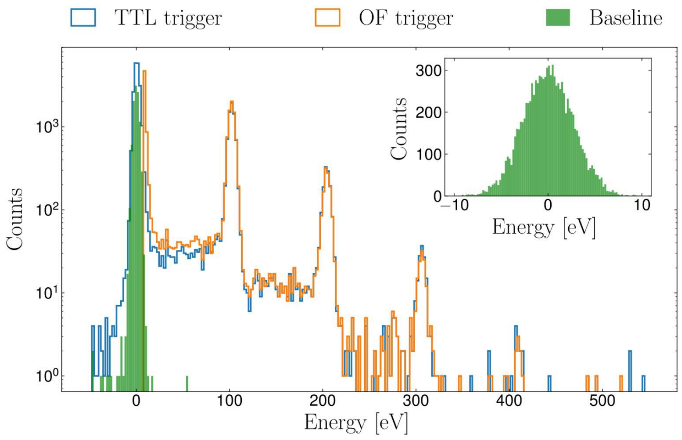




- 2.7 eV baseline resolution
- 9.2 eV threshold

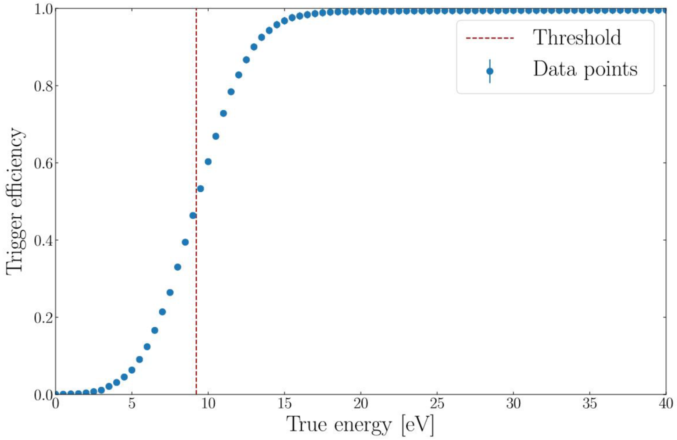
R. Ren *et al.*, Phys. Rev. D 104, 032010, 2021

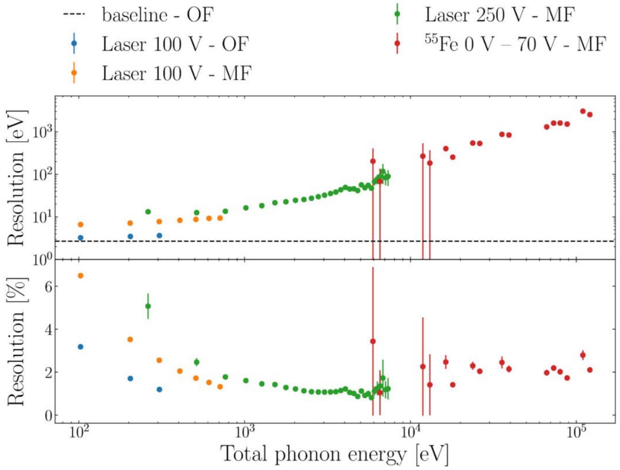
HVeV detectors



- 2.7 eV baseline resolution
- 9.2 eV threshold
- First eV-scale detector reaching up to hundreds of keV (4 order of magnitude)
- Energy resolution < 5 % over the full energy range

best in class!

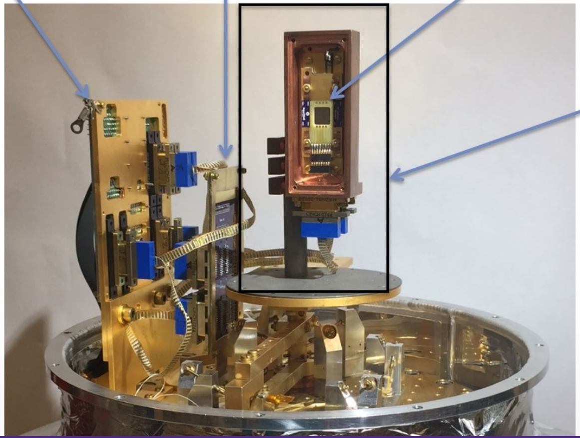




R. Ren *et al.*, Phys. Rev. D 104, 032010, 2021

Run 2 - Northwestern laboratory

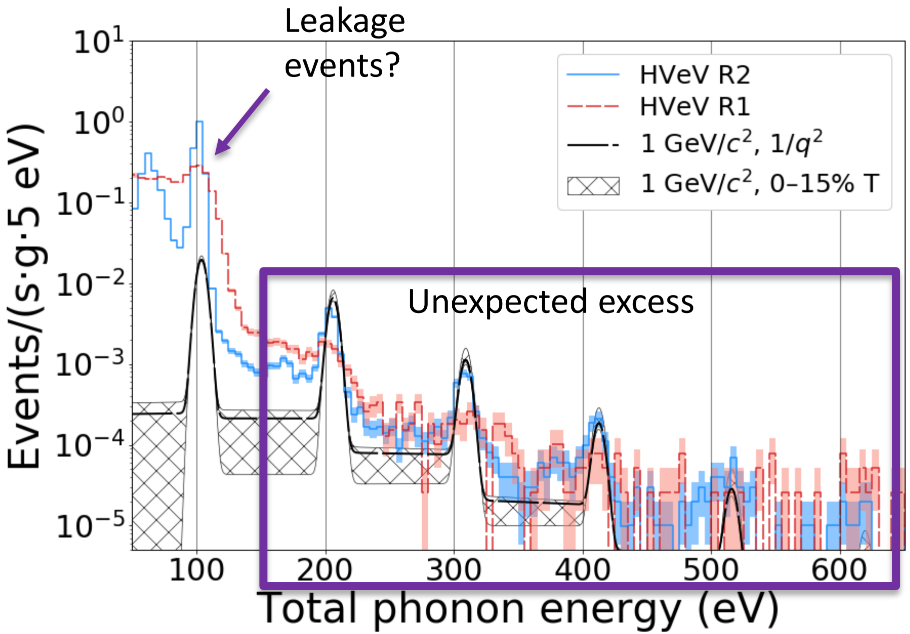
- Surface laboratory at Northwestern University (Evanston, IL)
- No passive or active shielding
- Detector operated at 50 - 52 mK in an Adiabatic Demagnetization Refrigerator (ADR)



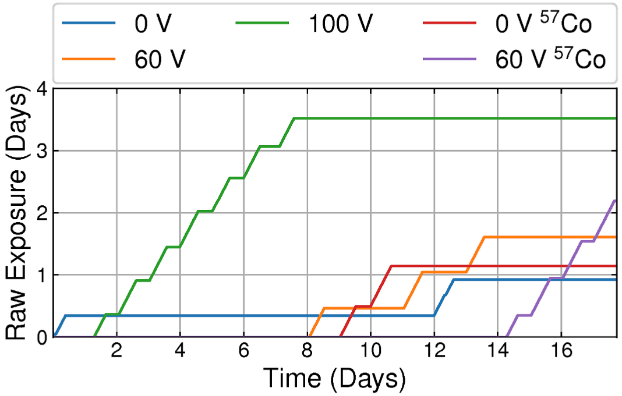
Z. Hong *et al.*, NIMA, 963, 163757, 2020
D. W. Amaral *et al.*, Phys. Rev. D 102, 091101(R), 2020

Run 2 – data

Data taken at 0 V, 60 V and 100 V



D. W. Amaral *et al.,* Phys. Rev. D 102, 091101(R), 2020

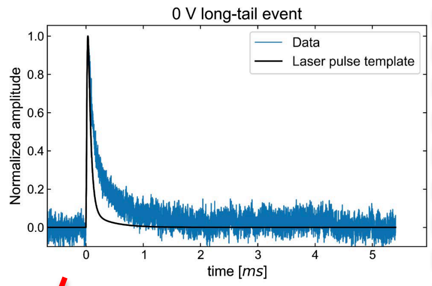


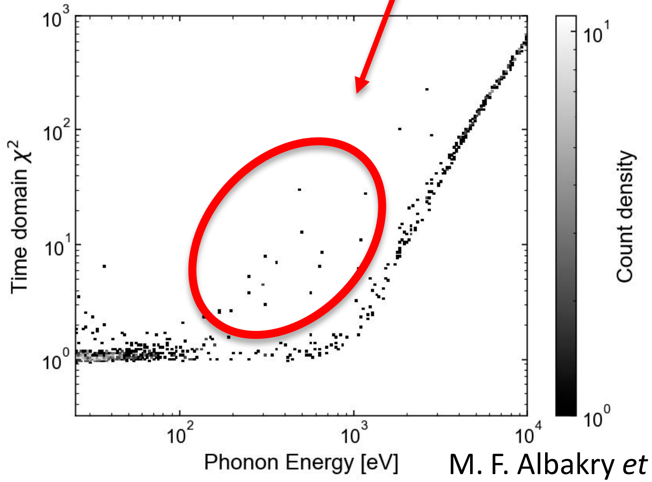
Compatible background between HVeV R1 and R2

→ dedicated comparison between 0V and HV data

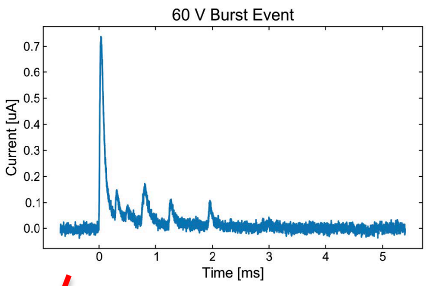
Run 2 – 0V-HV comparison

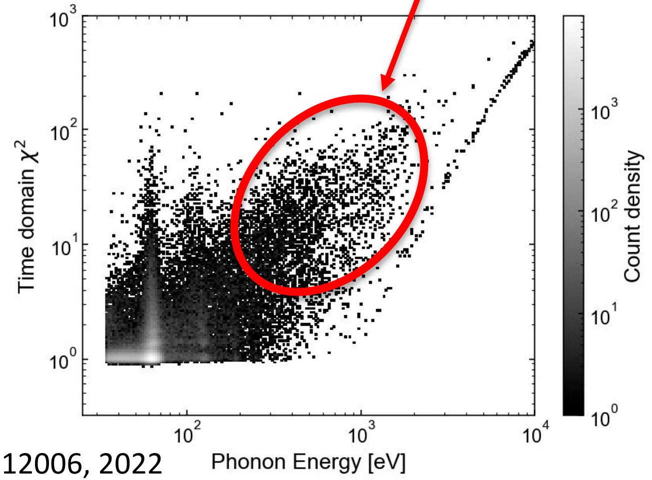
Long-decay-time events in the 0 V data: longer tail than laser-events





Burst events in the high voltage (HV) data: Primary event followed by single-photon secondary events





M. F. Albakry *et al.,* Phys. Rev. D 105, 112006, 2022

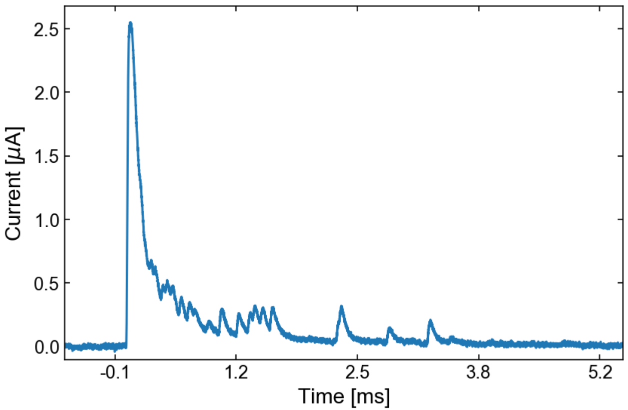
Run 2 – 0V-HV comparison

Neganov-Trofimov-Luke voltage

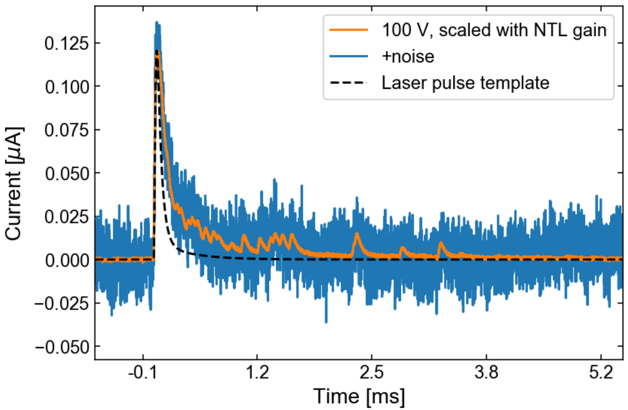
$$E_{total} = E_{recoil}\left(1 + \frac{e}{\epsilon_{eff}} V_{NTL}\right) = E_{recoil}\, G_{NTL}$$

energy to create an electron-hole pair (ϵ_{eh}) divided by the ionization yield (Y)

Neganov-Trofimov-Luke gain



÷ NTL gain + Noise of 0 V data =



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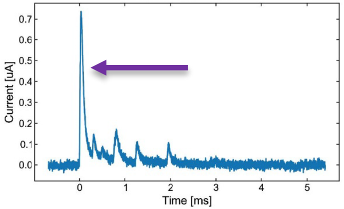
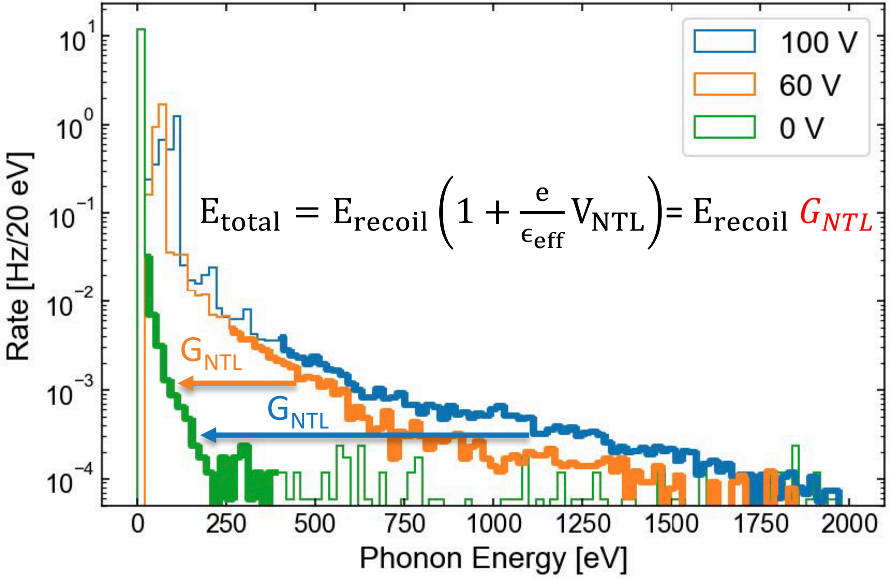
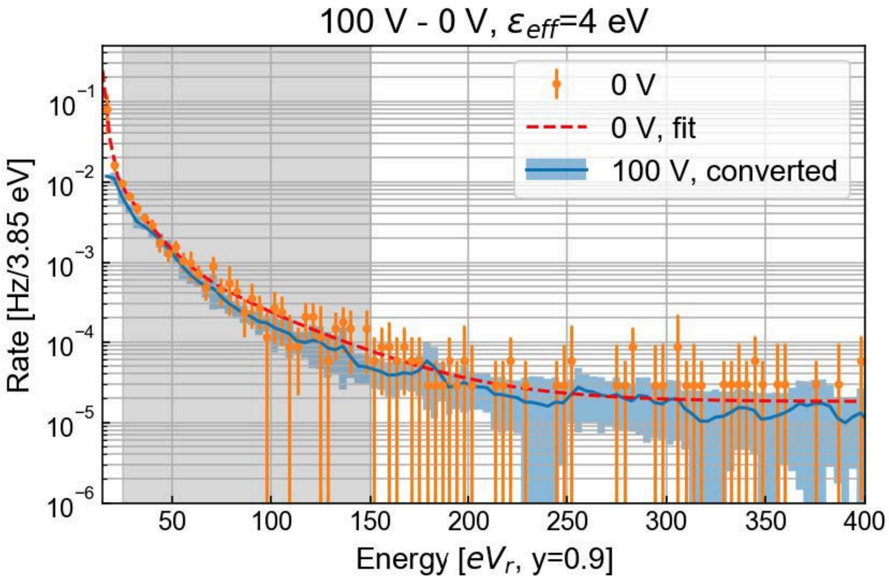
Run 2 – primary events





$$E_{total} = E_{recoil}\left(1 + \frac{e}{\epsilon_{eff}} V_{NTL}\right) = E_{recoil}\, G_{NTL}$$



There is compatibility between the primary events in HV and 0V mode assuming $\epsilon_{eff} \sim$ 4-5 eV

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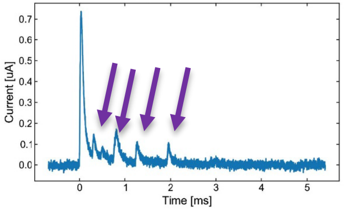
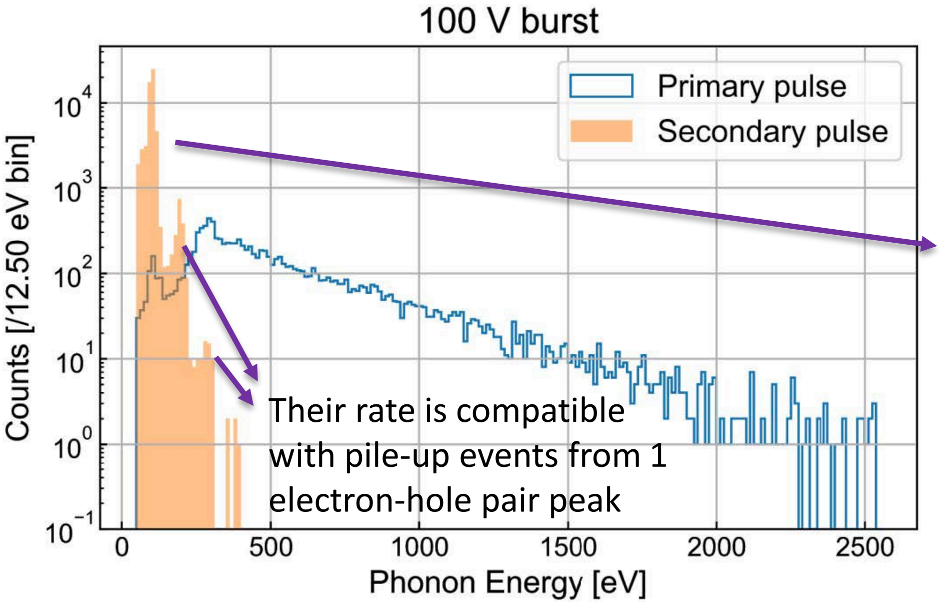
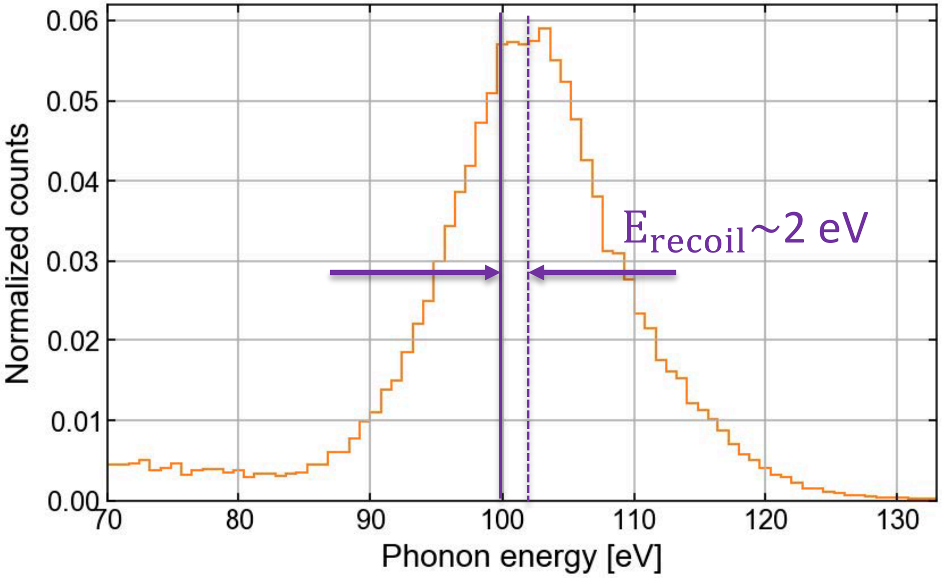
Run 2 – secondary events







Secondary events have an energy of ~2 eV

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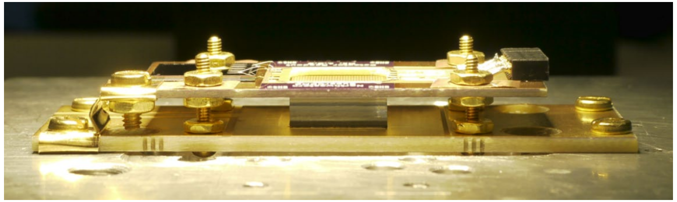
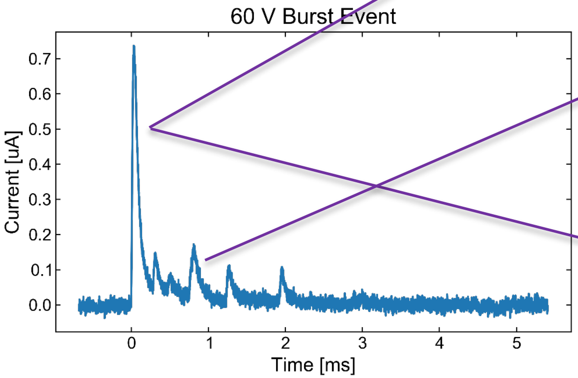
Run 2 – 0V comparison

Burst events and luminescence from the SiO_2 present in PCB have:

- Compatible energies
- Compatible relaxation time





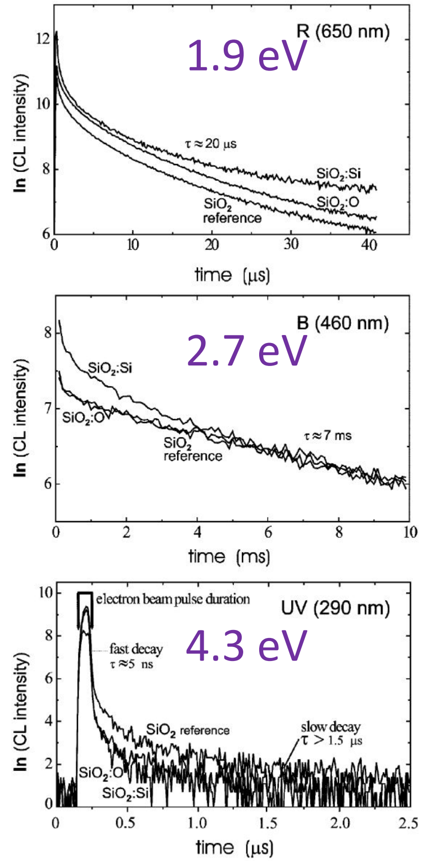


Fig. 3. Decay kinetics of the red R, blue B and UV luminescence in thin SiO_2 films partially doped with Si^+ and O^+ ions and excited by a pulsed electron beam at liquid nitrogen temperature (LNT).

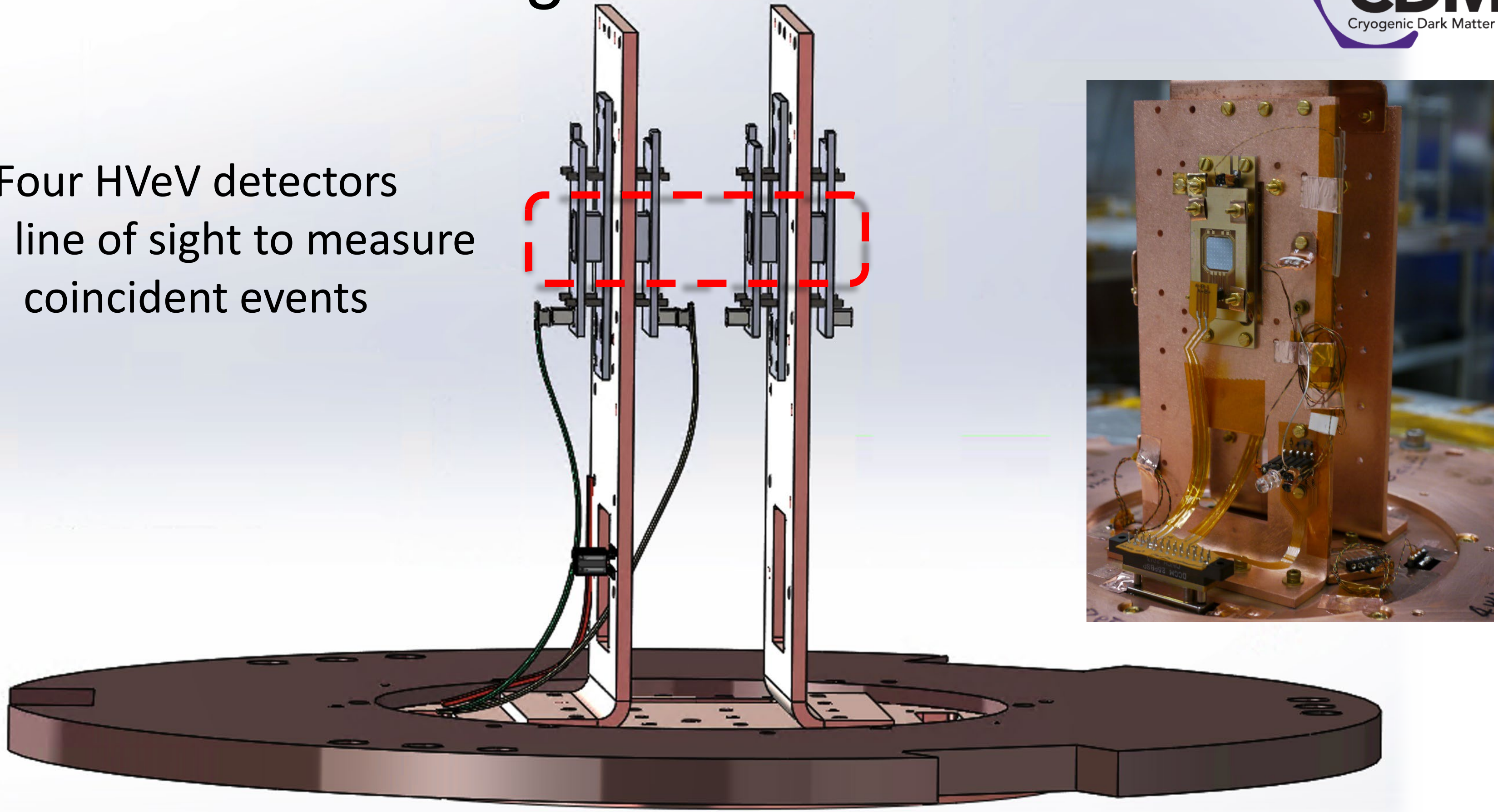
The PCB holder provides both:

- detector thermalization
- electrical contacts

M. F. Albakry *et al.,* Phys. Rev. D 105, 112006, 2022
A.N. Trukhin et al., J. Non Cryst. Solids 331 (2003) 91

Run 3 – detector configuration

Four HVeV detectors
with line of sight to measure
coincident events



Run 3 – new measurement at the NEXUS facility

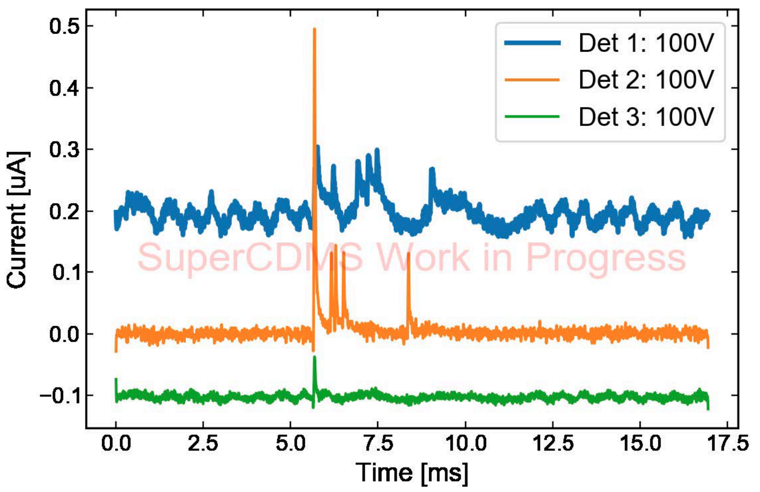
Northwestern EXperimental Underground Site (NEXUS) facility at Fermilab (Batavia, IL)

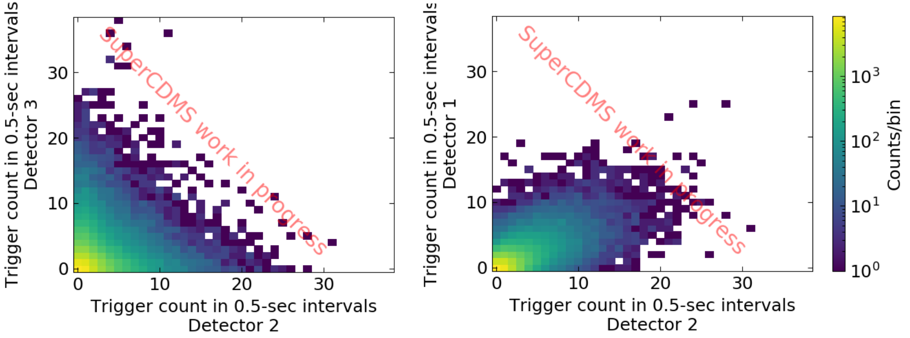
Dry dilution refrigerator from Cryoconcept:

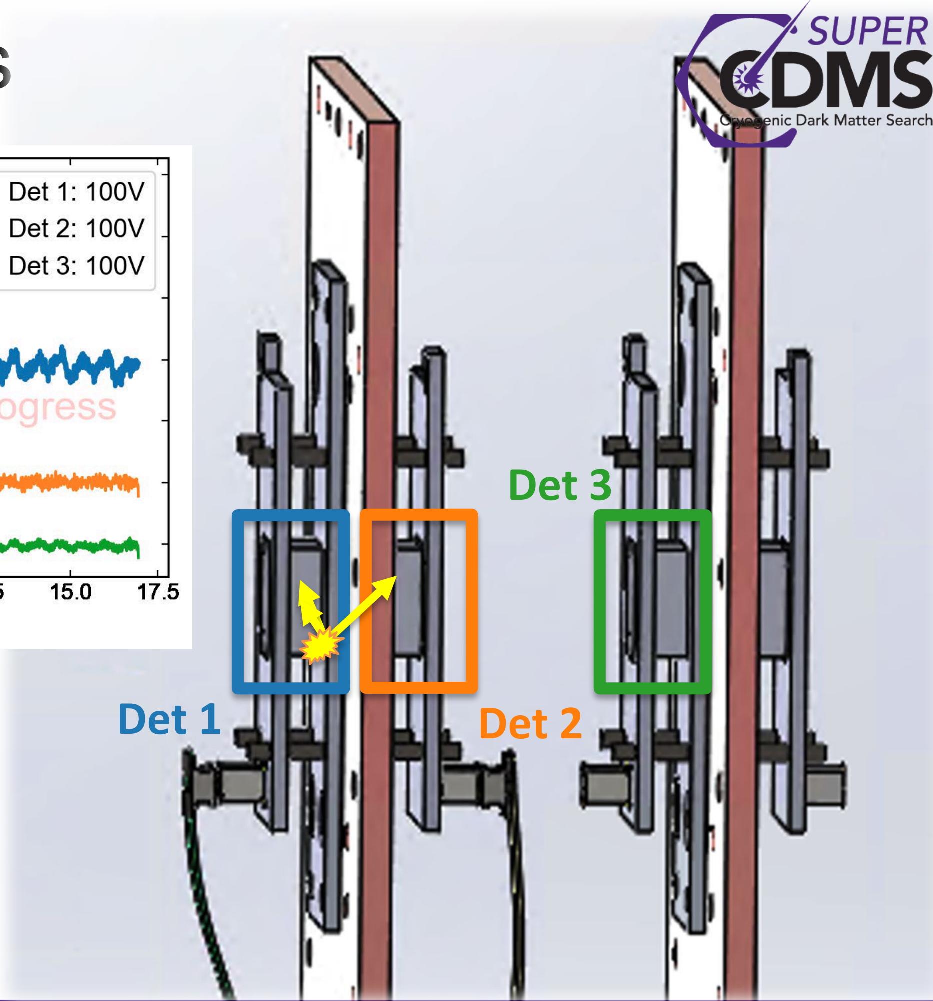
- base temperature ~9 mK
- located in the MINOS hall
  - 107 m underground (~300 mwe)
- Internal lead shield + movable external lead castle
- Vibration reduction via pulse-tube decoupling

Run 3 – coincidence events

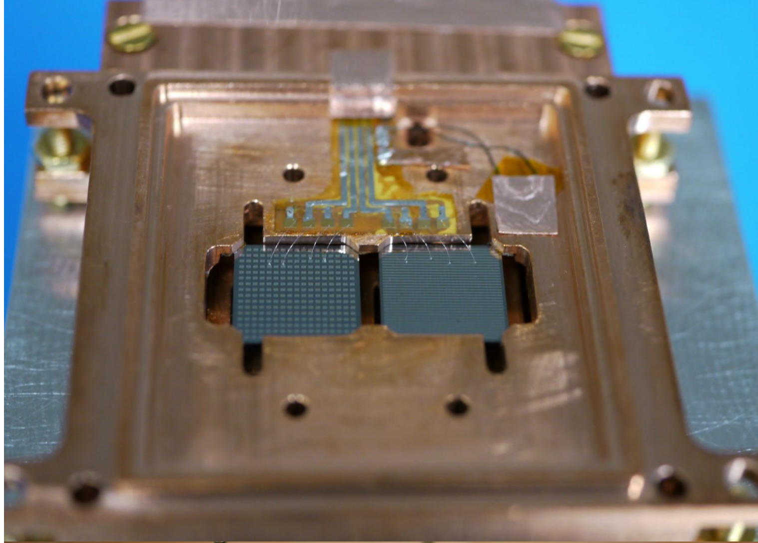
Confirmed external origin of the burst events

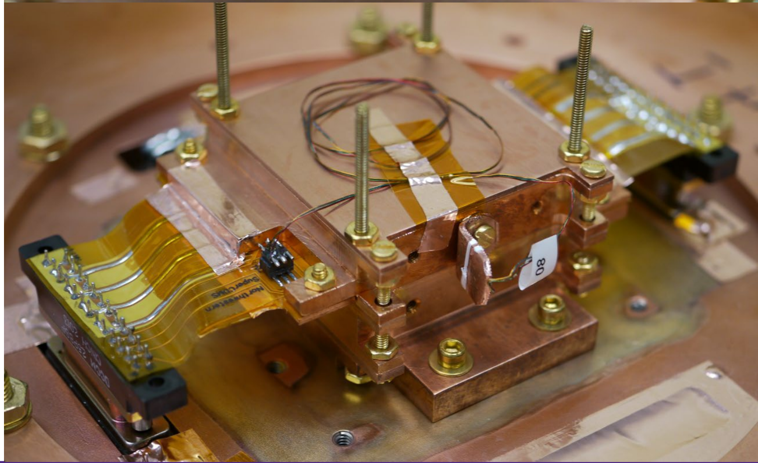




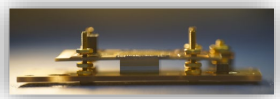


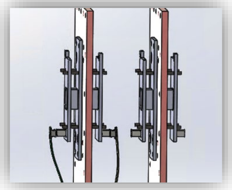
Run 4 – new detector holder

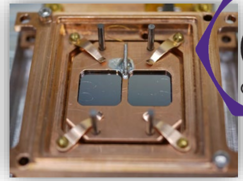




- the PCB was replaced by a copper holder in a light-tight copper box
- a tinned flex cable is used for electrical contact
- 4 closely-packed HVeV detectors to veto coincident events
- 4 spring mechanisms applying ~125 grams each





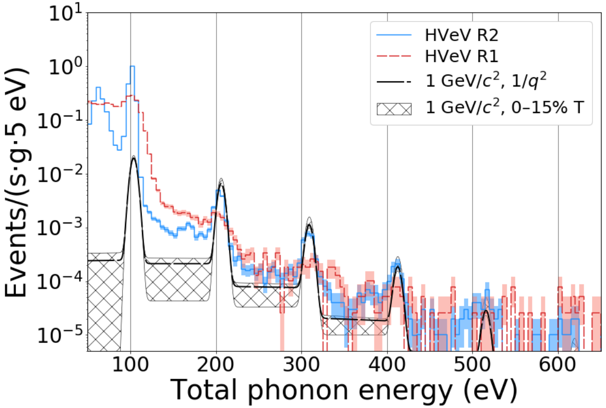


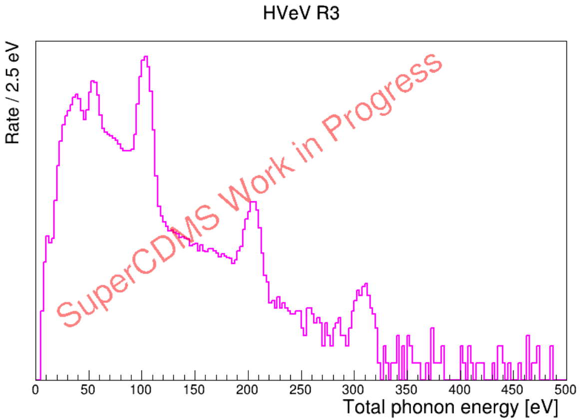
- Burst events detection and study
- Hypothesis: originated by SiO_2 in the detector holder (PCB)

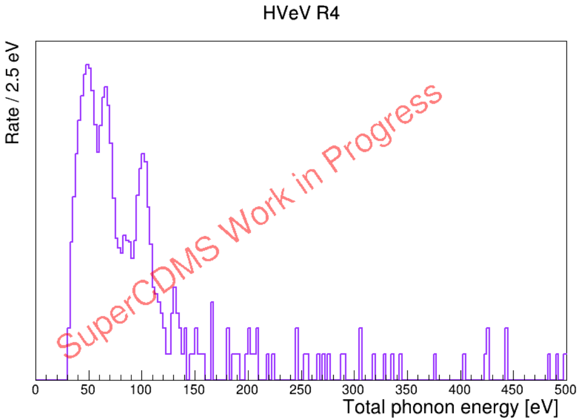
- Coincidence measurement
- Confirmed external origin of this background and its reduction with coincidence cut

- Removed PCB from the detector holder
- Elimination of the quantized background above 1 eh peak

HVeV R2 HVeV R3 HVeV R4

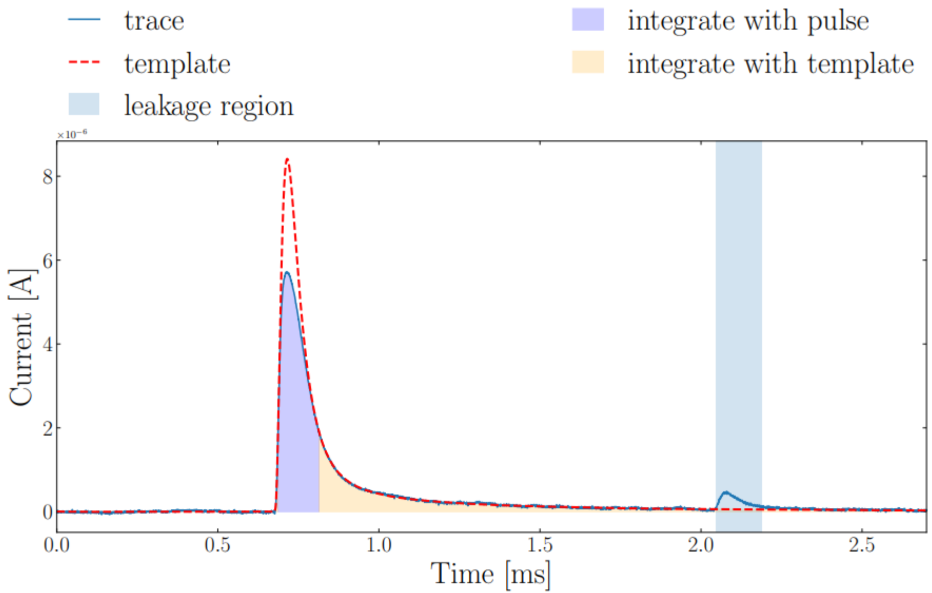


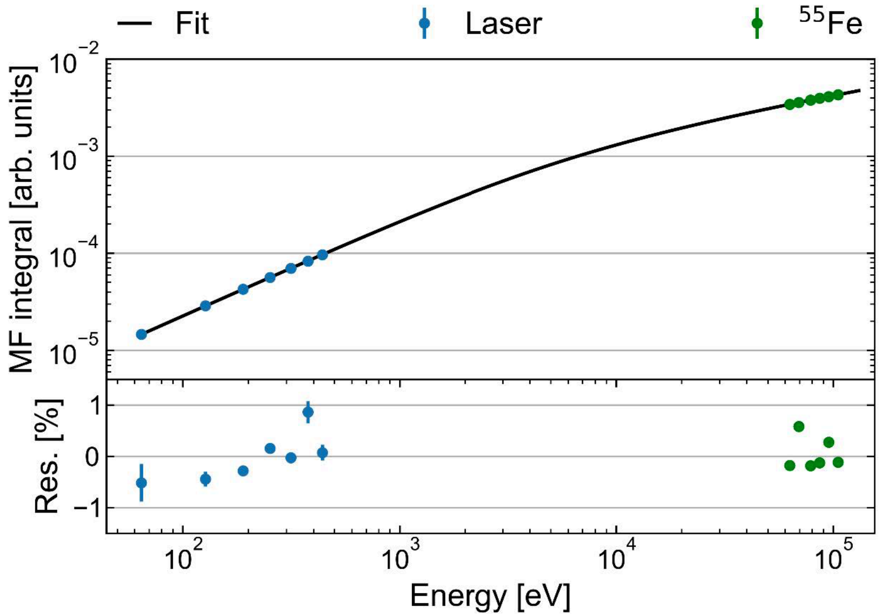




Extra …

0VeV energy reconstruction/calibration





$$E = \begin{cases} E_{OF}, & E_{OF} < 600\ eV \\ (1-k)E_{OF} + kE_{MF}, & 600\ eV \leq E_{OF} \leq 800\ eV \\ & k = \frac{E_{OF}-600}{200} \\ E_{MF}, & 800\ eV < E_{OF}. \end{cases}$$

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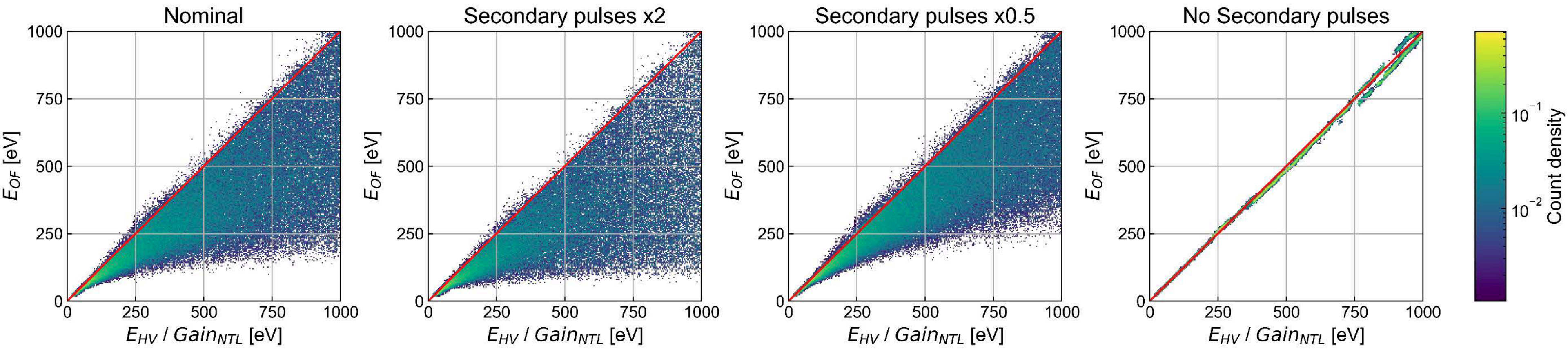
M. F. Albakry *et al.,* Phys. Rev. D 105, 112006, 2022

OF-MF response matrices



M. F. Albakry *et al.,* Phys. Rev. D 105, 112006, 2022

Calorimetric technique