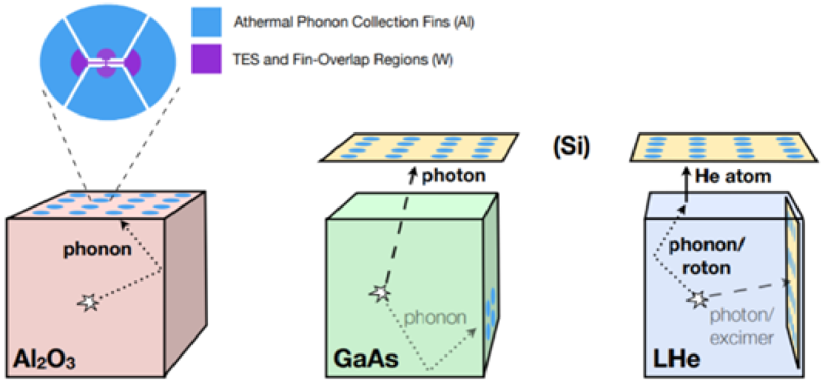
SULI, SUMMER 2022

TES DETECTORS FOR DARK MATTER PARTICLE DETECTION



TATHAGATA BANERJEE
HEP Division, Argonne National Laboratory
University of Illinois Urbana-Champaign

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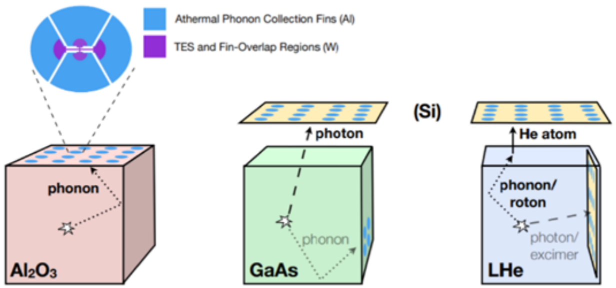
Lemont, IL

INTRODUCTION

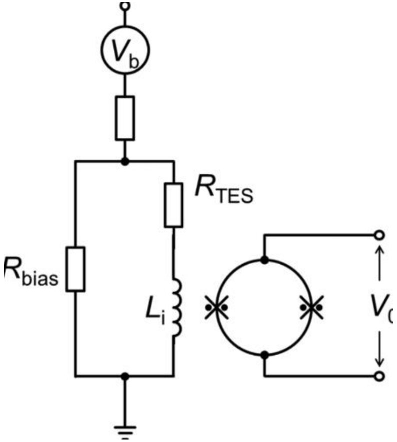
SPICE/HeRALD Project

- The SPICE/HeRALD projects aim to detect sub-GeV dark matter particles, with detector sensitivities in the meV to eV range
- SPICE
  - Uses Sapphire (Al_2O_3) and GaAs crystals as detection targets
  - Optimal for electron recoils which produce phonons and photons
- HeRALD
  - Uses superfluid Helium as target
  - Optimal for nuclear recoils which produce excimers, photons, phonons/rotons, and evaporated He atoms
- Both use TES detectors to detect these particles



TRANSITION-EDGE SENSOR: PRINCIPLES

- TESs are superconductors that have strong temperature-dependent resistance during phase transition
- They generally have low critical temperatures (<1K) for high energy resolution
- Absorption of energy in transition region results in negative electrothermal feedback under a voltage bias
  - Increase in resistance
  - Decrease in TES current
  - Decrease in Joule power
- TES measurements are conducted using ultra-sensitive SQUID amplifiers

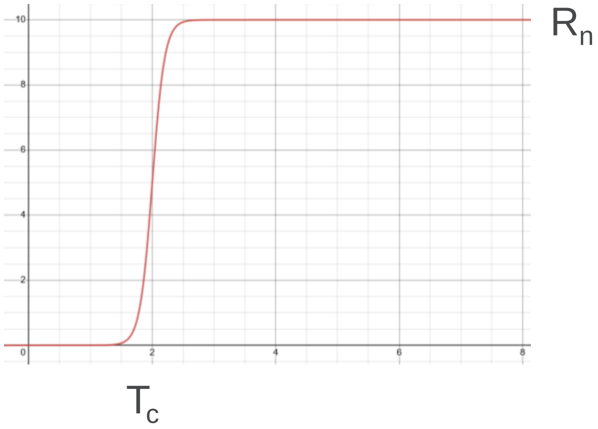


Source

PARAMETERS OF INTEREST

- Critical Temperature (T_c) – Superconducting transition temperature
- Normal Resistance (R_n) – Resistance in non-superconducting regime
- Detector thermal performance, $P = K(T_c^n - T_b^n)$
  - n: exponent, generally ~5
  - K: Thermal coupling strength
- Detector energy resolution,

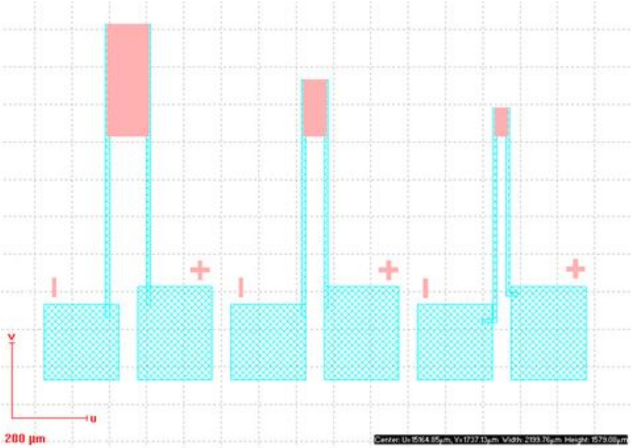
$$\Delta E \approx 2.35 \sqrt{\frac{k_B T_C^2 C}{\alpha} \sqrt{\frac{n}{2}}}, \ \alpha = \frac{T}{R} \frac{dR}{dT} \Big|_{T=T_c}$$

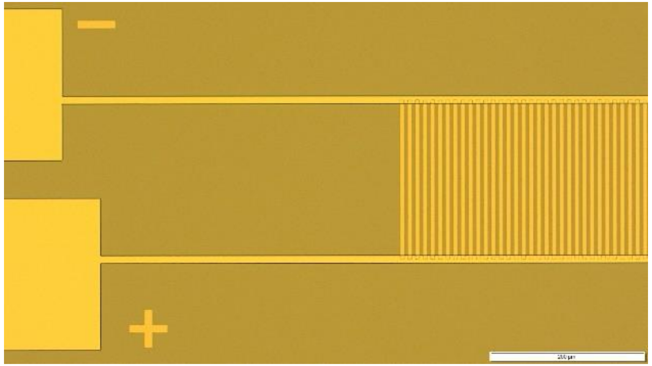


DETECTOR MEASUREMENT AND ANALYSIS

DETECTOR DESIGNS

- 4 detectors with same bilayer recipe: Ir30nm/Pt12nm, with Al leads
- 3 detectors for volume effect: 1:3 ratio, 100 µm, 50 µm and 25 µm lengths
- 1 detector for structure effect: 5 µm stripes with 5 µm gap

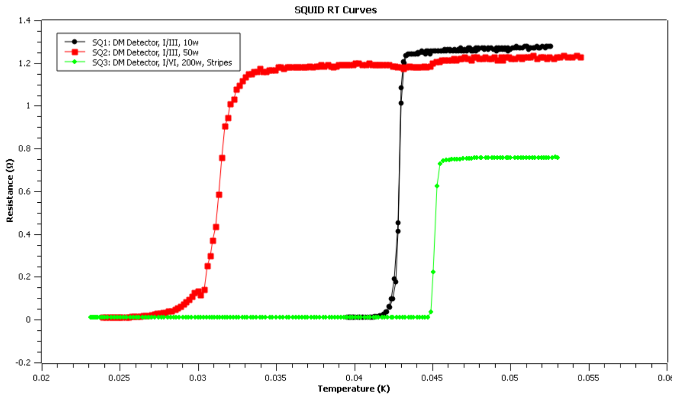




RESISTANCE VS TEMPERATURE CURVES

- 100 µm and striped detector have expected T_c and sharp transition profile
- 50 µm detector has lower T_c and broader transition
- 25 µm detector did not show any transition

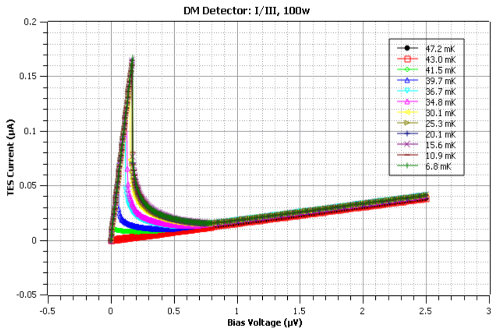
Detector	R_n	T_c
100 µm	1.20 Ω	42.5 mK
50 µm	1.25 Ω	31.0 mK
25 µm	1.30 Ω	-
Striped	0.70 Ω	45.2 mK

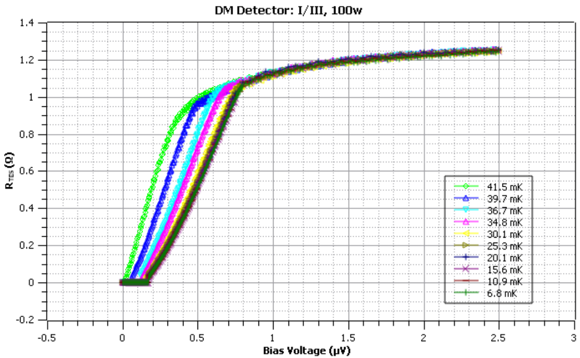


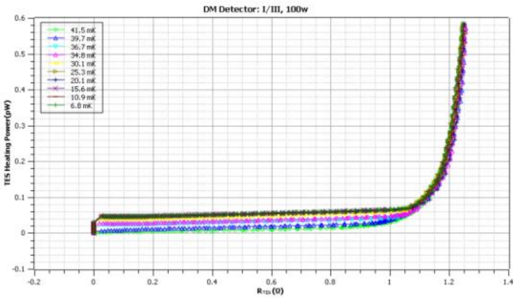
THERMAL PERFORMANCE OF 100 µm DETECTOR

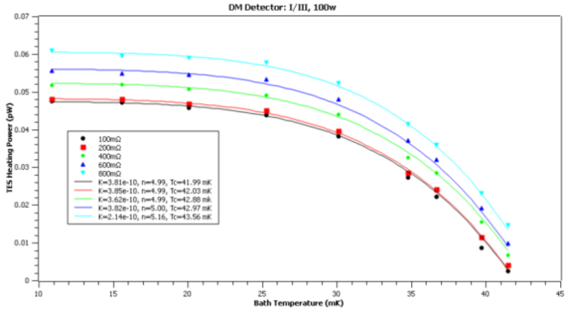
- IV curves were measured to understand thermal performance of TES detector
- Power law fit in PT curve

$$P = K(T_c^n - T_b^n)$$





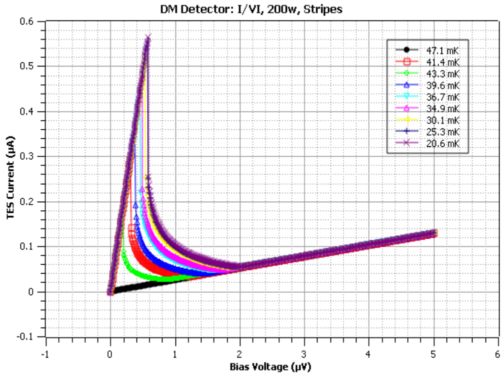


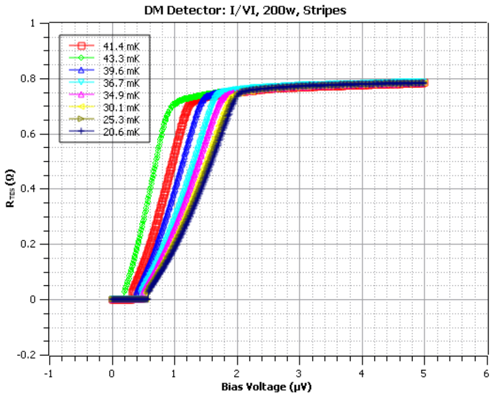


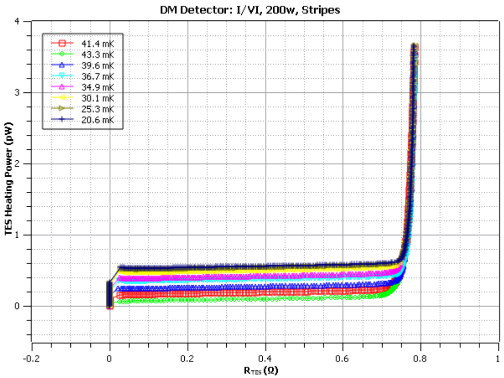
THERMAL PERFORMANCE OF STRIPED DETECTOR

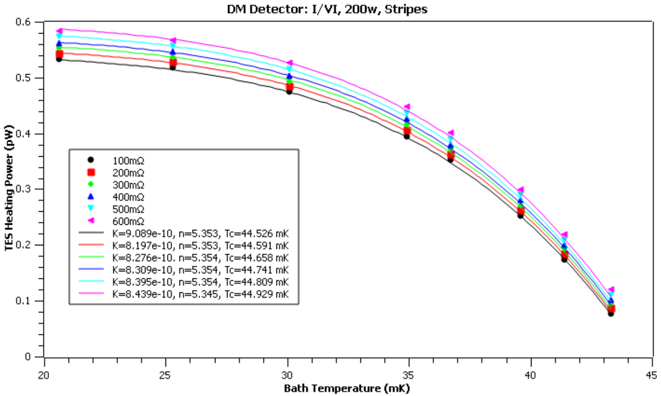
- IV curves were measured to understand thermal performance of TES detector
- Power law fit in PT curve

$$P = K(T_c^n - T_b^n)$$



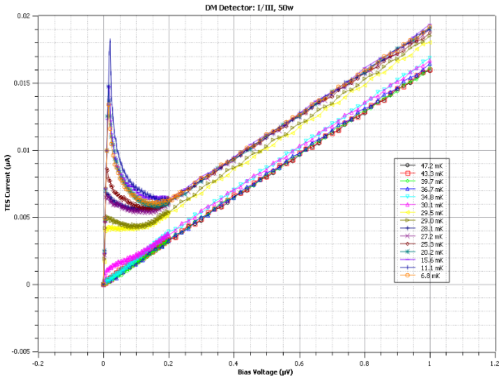


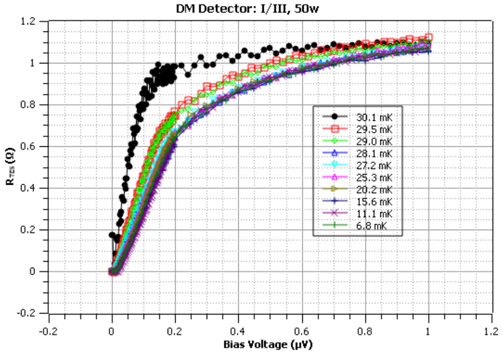


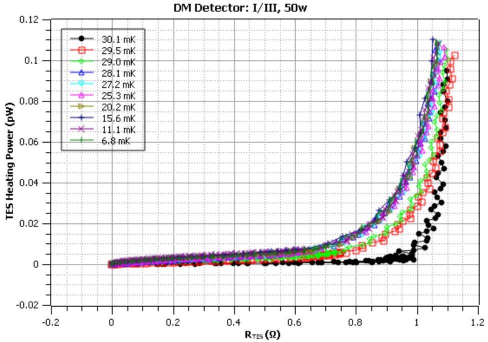


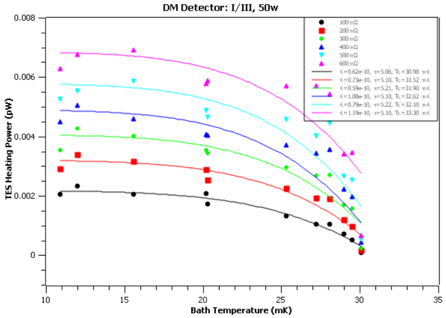
THERMAL PERFORMANCE OF 50 µm DETECTOR

- IV curves were measured to understand thermal performance of TES detector
- Smaller saturation power due to smaller volume of TES
- Joule heating power is non-linear due to broad transition
- Noise in 50 µm PT curve due to channel coupling with environment
  - Not sensitivity of device









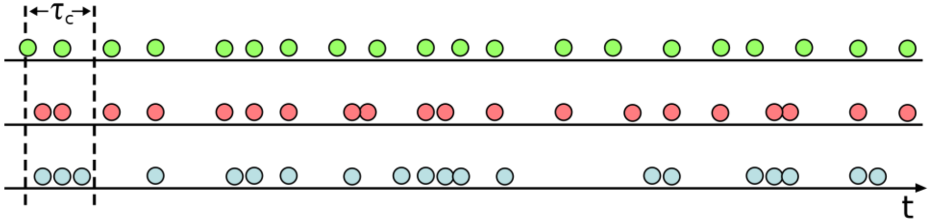
SINGLE PARTICLE DETECTION?

- We have functioning TES detectors
- Single photon source needed to characterize detectors further
  - Detector calibration
  - Detection threshold

- Therefore, setup needs to be enhanced to conduct single photon source measurements

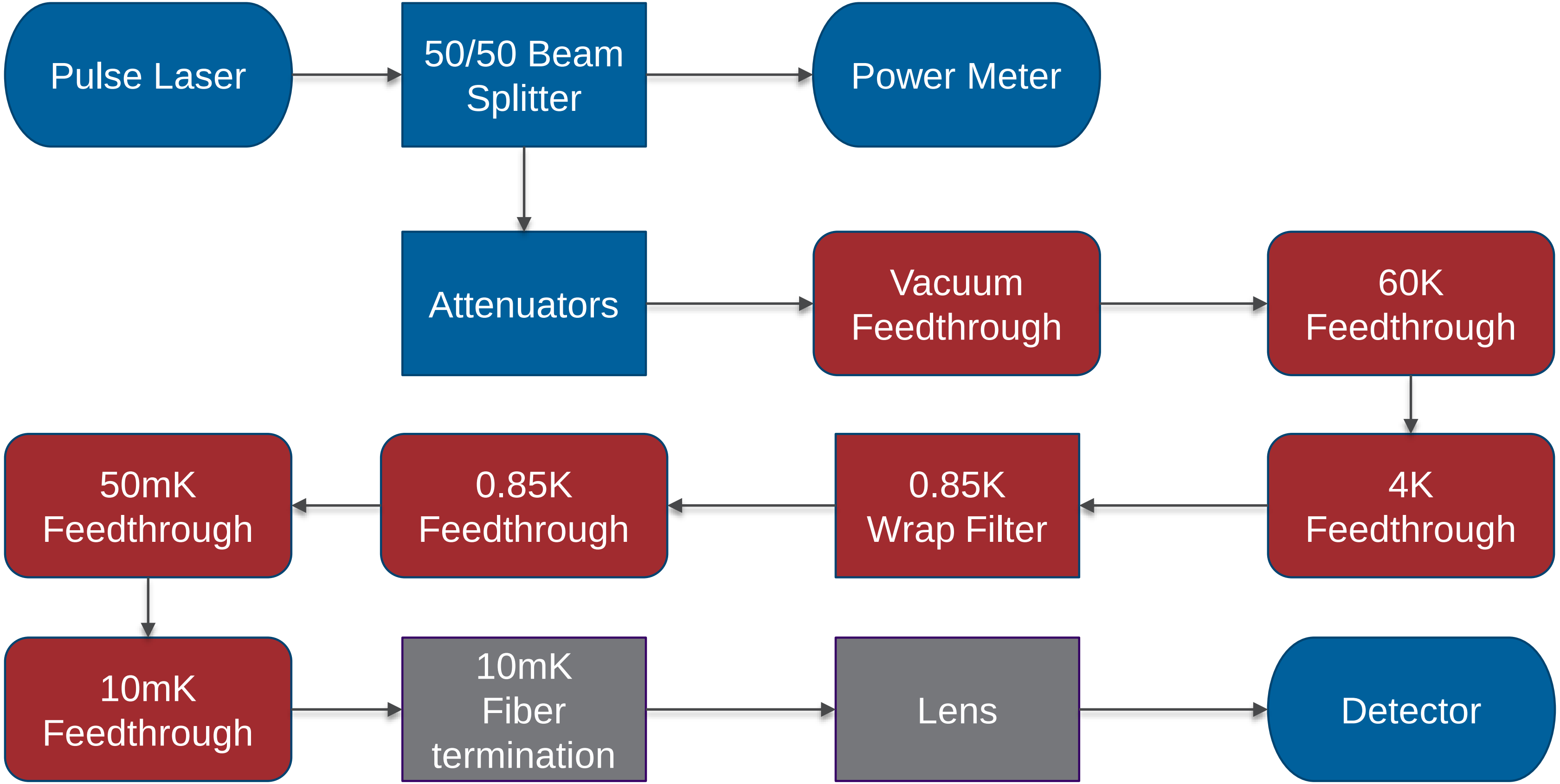
SINGLE PHOTON SOURCE SETUP (SPS)

SPS PRINCIPLE

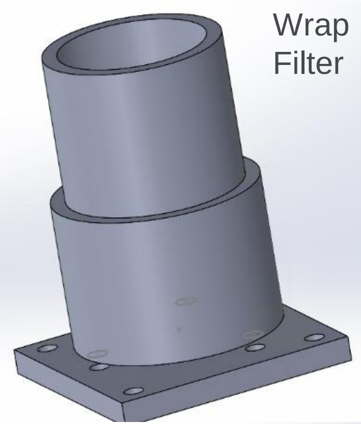


- SPS have antibunched photons
- We use an attenuated laser beam
  - Reduces intensity and photon count per pulse through high attenuation
- Not strictly SPS, finite probability of multiphoton emission
  - Low cost, easily available, easy to set up

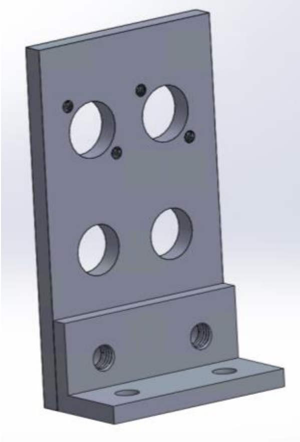
DESIGN FLOWCHART



COMPONENT DESIGNS

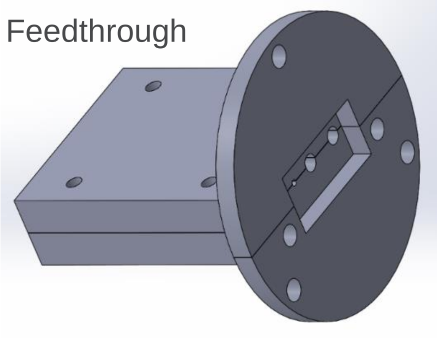


Wrap Filter

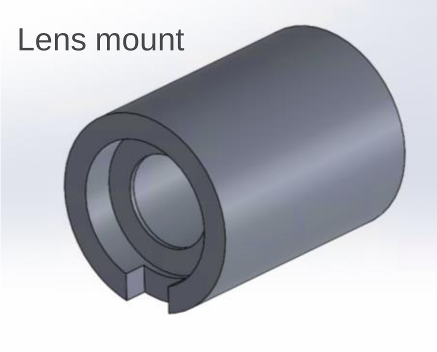


Fiber termination

Feedthrough



Lens mount



Current setup structure

CONCLUSIONS

- Tested a batch of low-T_c TES detectors made of Ir/Pt bilayer
  - RT dependence, transition temperature
  - TES thermal performance
  - Size effect on sensitivity of DM detectors
  - Striped design does not significantly change properties of DM detectors
- Single photon source setup is needed to characterize detectors fully
  - Designed necessary components of the setup
  - Currently developing the new setup to expand measurement capabilities

REFERENCES

- SnowMass2021 Letter of Interest, TESSERACT Dark Matter Project.

https://www.snowmass21.org/docs/files/summaries/CF/SNOWMASS21-CF1_CF2-IF1_IF8-120.pdf

- Irwin, K. D. and Hilton, G. C. Cryogenic Particle Detection (Springer, Berlin, Heidelberg, 2005), pg 63-150

THANK YOU