Enabling Low-Cost Radiation Detectors Through Organic Electronic Device Design, Fabrication, and Integration

Oliver Moreno, Youngrak Park, Silja Abraham, Jingwei Yang, Canek Fuentes-Hernandez, and Bernard Kippelen

ETI TA3

Advisor: Bernard Kippelen

omoreno3@gatech.edu

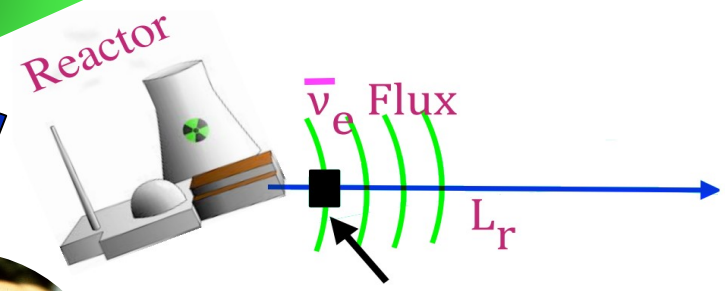
March 29th, 2022

Consortium for Enabling Technologies & Innovation

Introduction

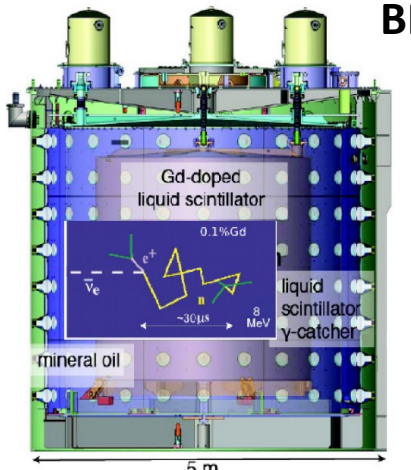
Nuclear nonproliferation

Fuel Cycle

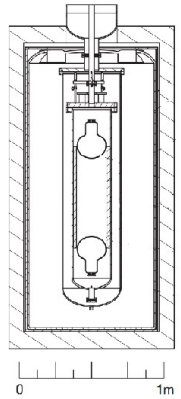


Remote Detection

BNL



WbLS



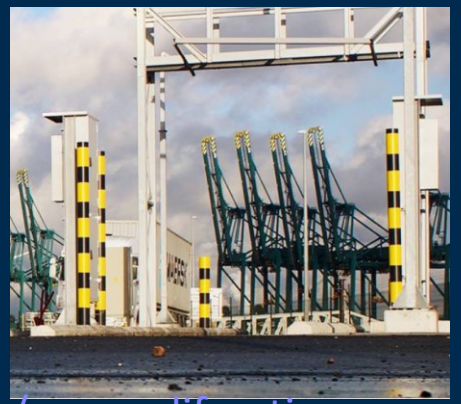
ArLS

High-energy physics

Policy

LLNL

γ Flux



Mid-Range Detection

https://www.energy.gov/nnsa/missions/nonproliferation

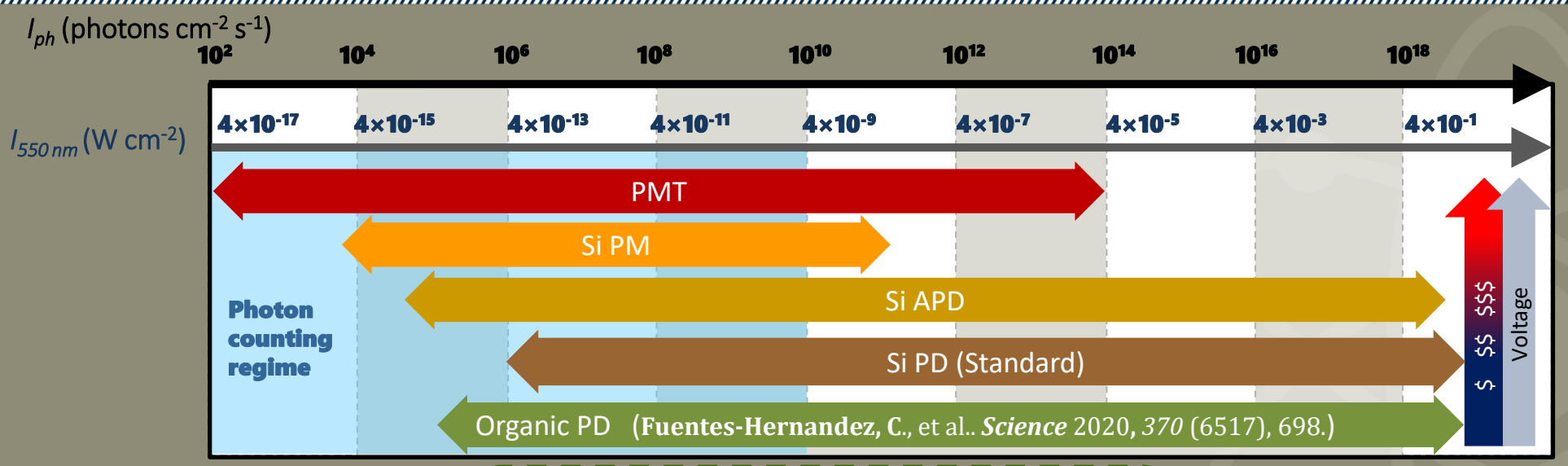
Georgia Tech

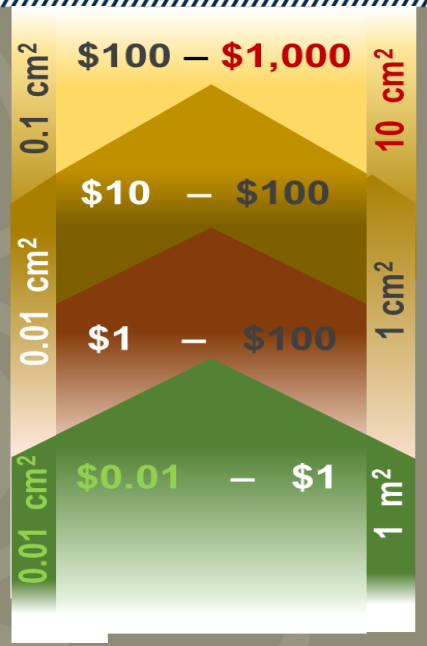
ETI

Motivation

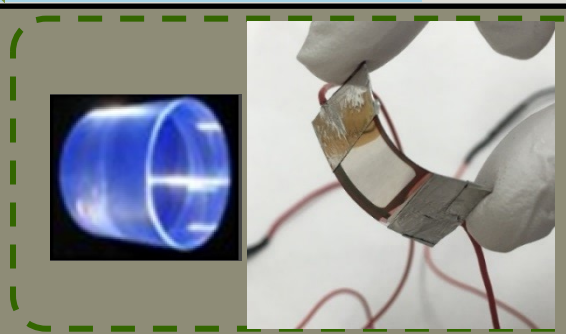
What are applications for current organic photodetectors?

What are necessary advancements to enable novel applications?



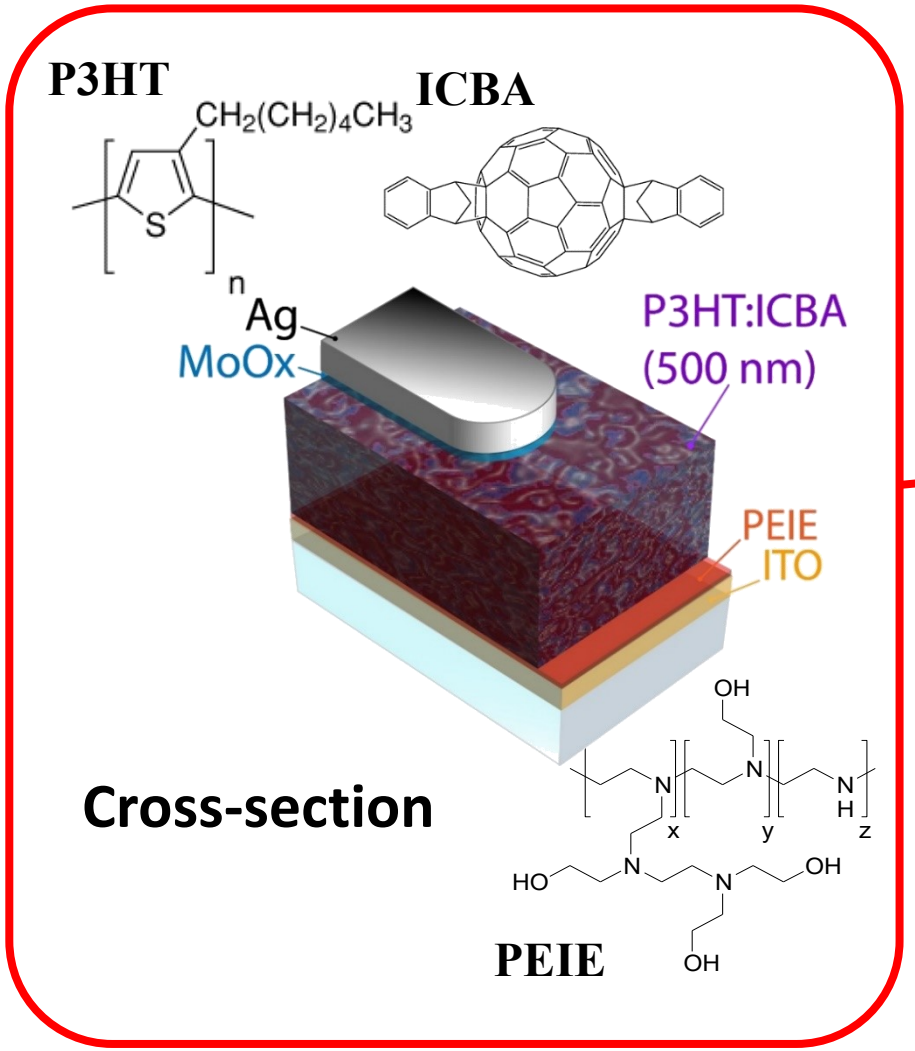


Indirect detection



Organic photodiode (OPD)

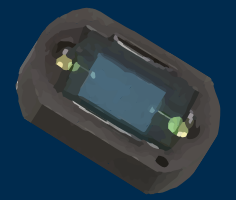
Organic Photodiode: Device Geometry



Active Area
0.11 cm^2

Benchmark

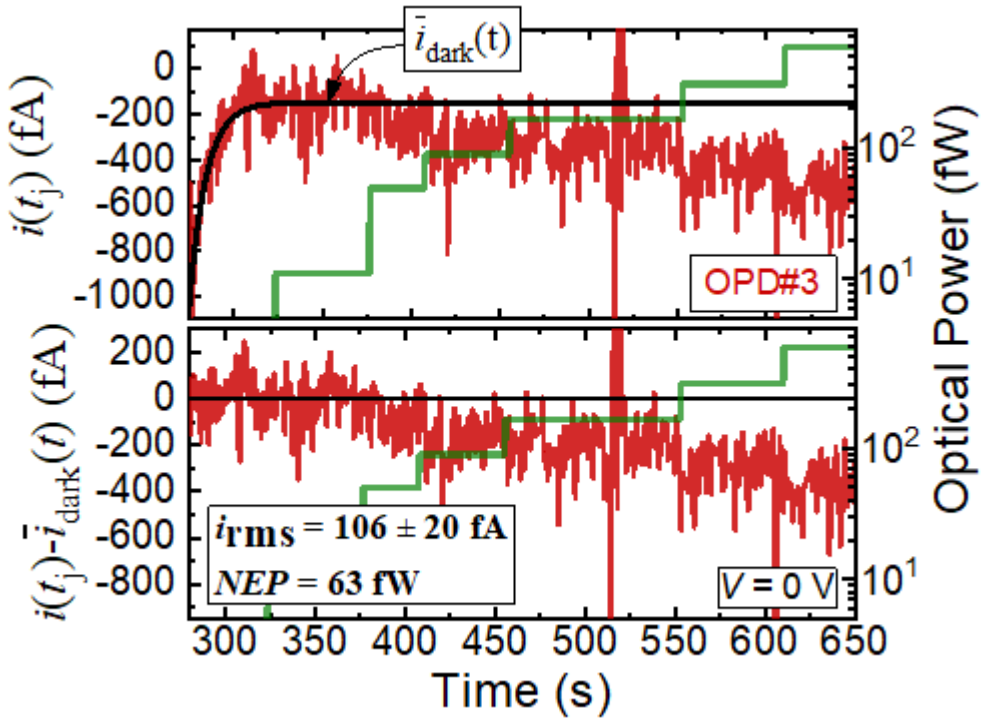
SiPD
(Hamamatsu S1133)

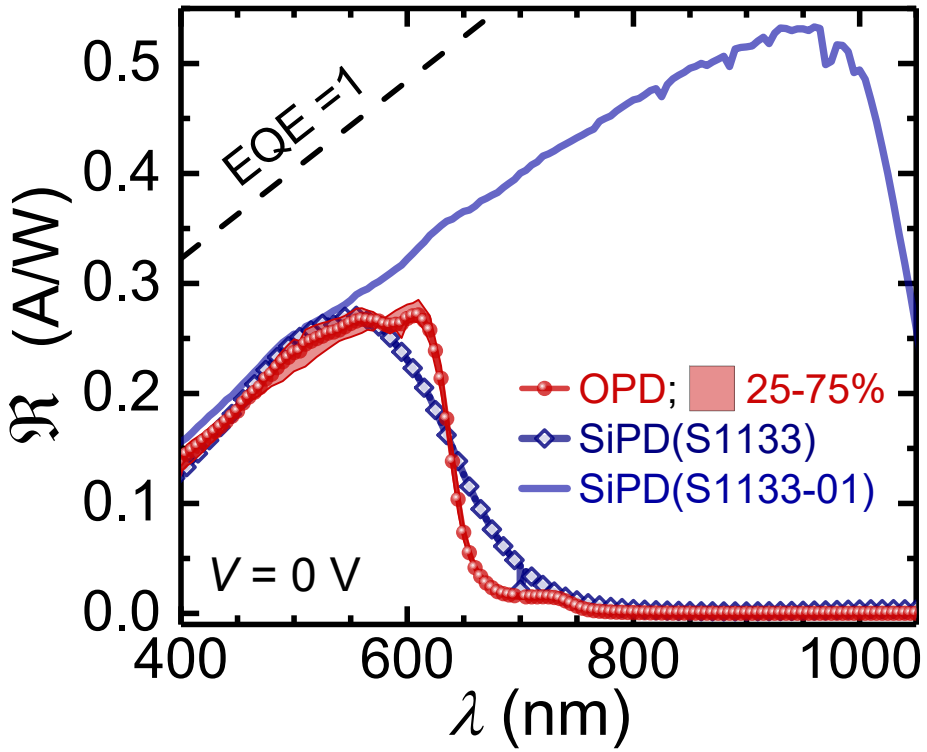


Area
0.07 cm^2

Fuentes-Hernandez, C., et al.. ***Science*** 2020, *370* (6517), 698.

OPD Characterization





$$NEP = \frac{\bar{\phi}_{opt}}{\bar{i}_{photo}\left(\bar{\phi}_{opt}\right)/i_{rms}\Big|_{\bar{i}_{photo}=\bar{i}_{rms}}} = \frac{i_{rms}}{\Re(NEP)}$$

$$\Re(\phi_{opt}) = \frac{\bar{i}_{ill} - \bar{i}_{dark}}{\bar{\phi}_{opt}} = \frac{\bar{i}_{ph}}{\bar{\phi}_{opt}}$$

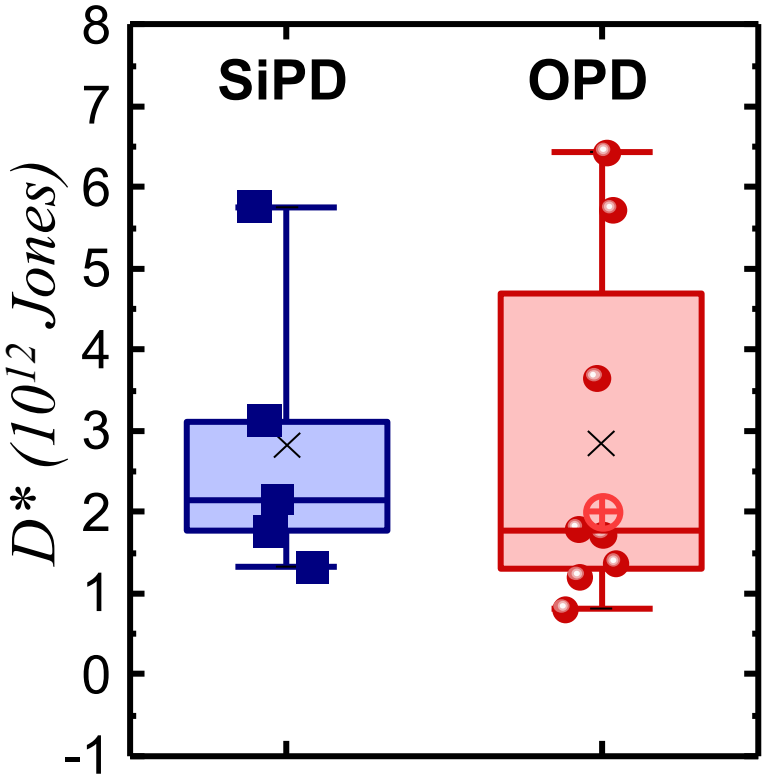
Large Area OPD Benchmarking

$$D^* = \frac{\sqrt{AB}}{NEP}$$

B = 1.5 Hz

A = area

NEP = noise equivalent power



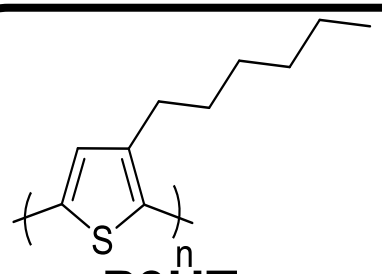
Fuentes-Hernandez, C., et al.. ***Science*** 2020, *370* (6517), 698.

This level of performance is maintained for OPDs with areas up to 0.9 cm^2

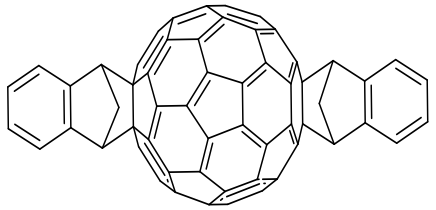
Elastomeric Bulk Heterojunction

BHJ

P3HT:ICBA (1:1 weight ratio)

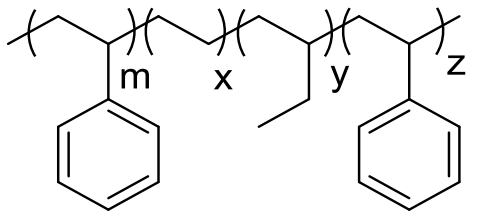


P3HT (Donor)

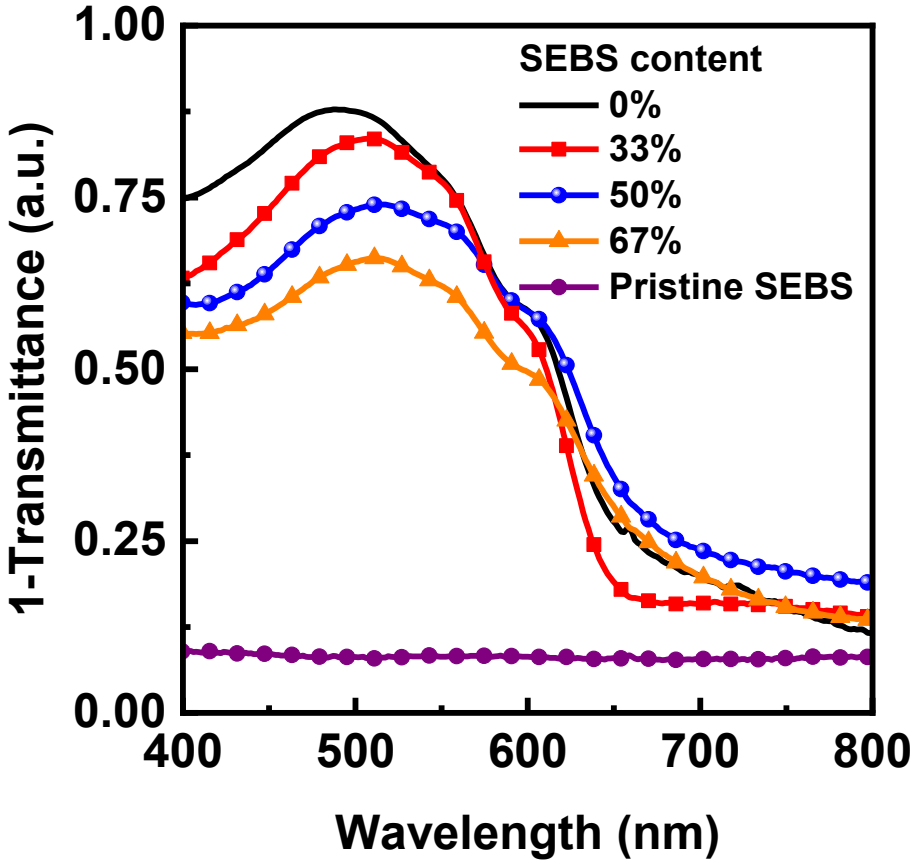


ICBA (Acceptor)

Elastomer



SEBS



- New approach to impart stretchability to organic photoactive layer
  → Use BHJ blended with elastomer SEBS

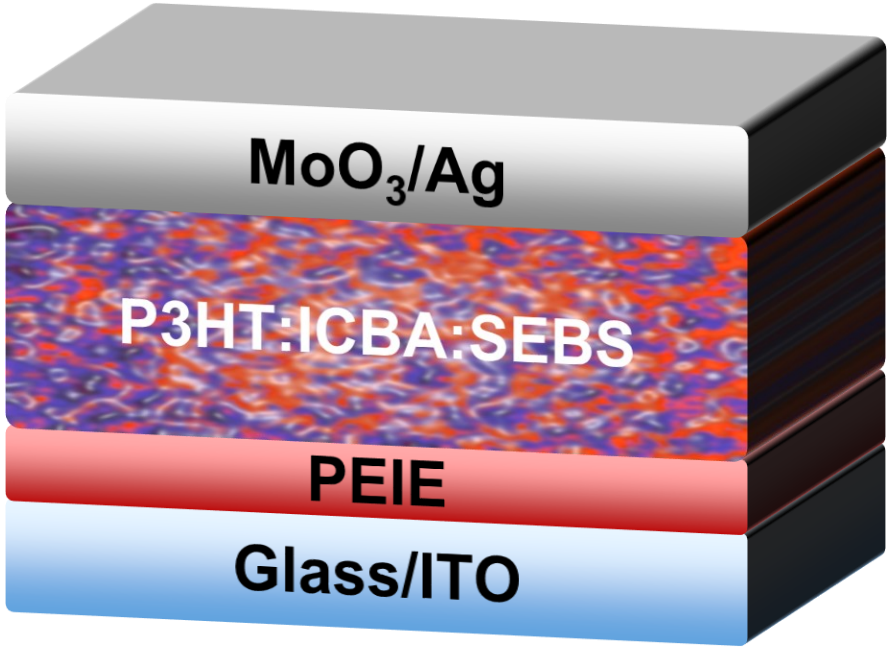
Fabrication of OPD – towards stretchability

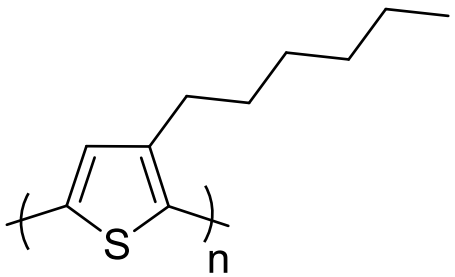
Hole-collecting layer and top electrode →

Photoactive Layer →

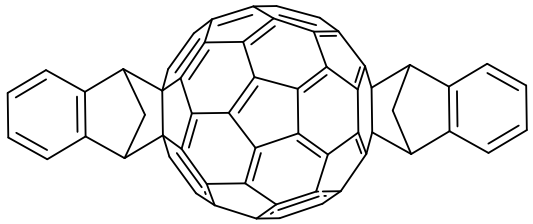
Electron-collecting Layer →

Bottom electrode and substrate →

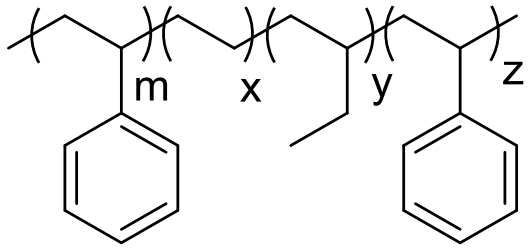




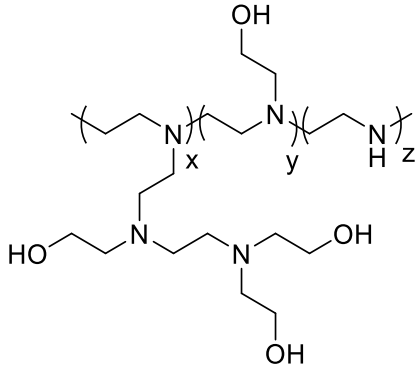
P3HT



ICBA

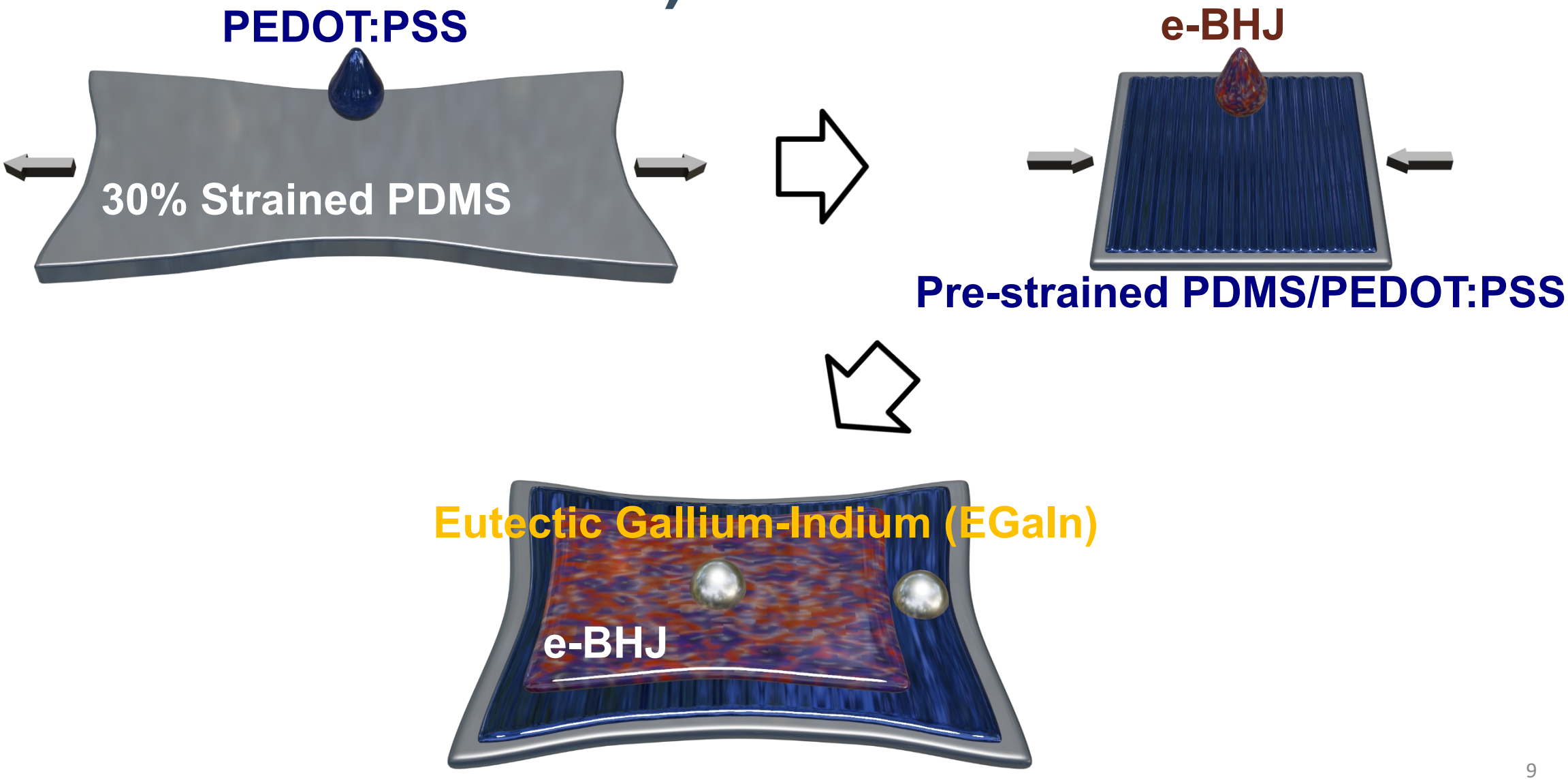


SEBS

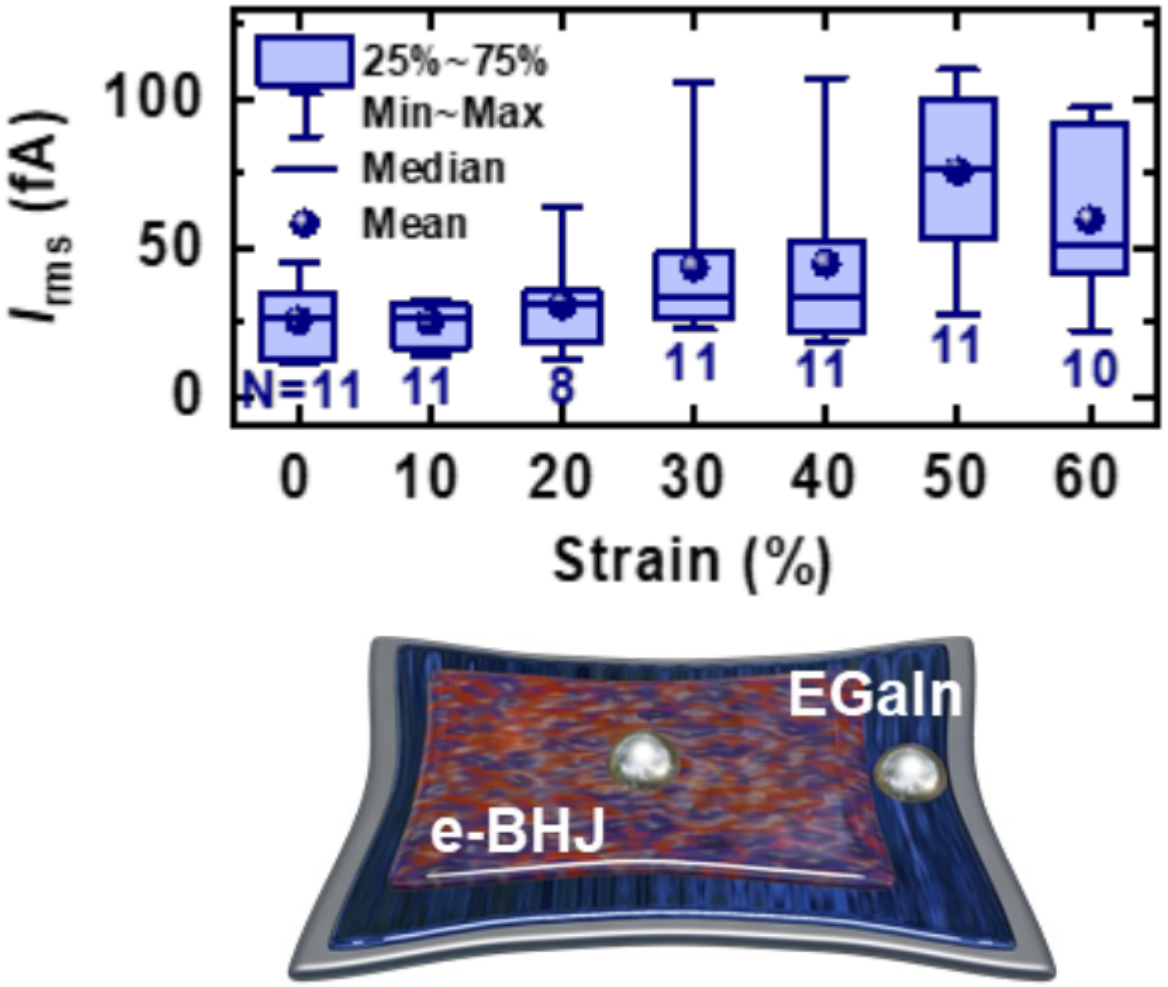


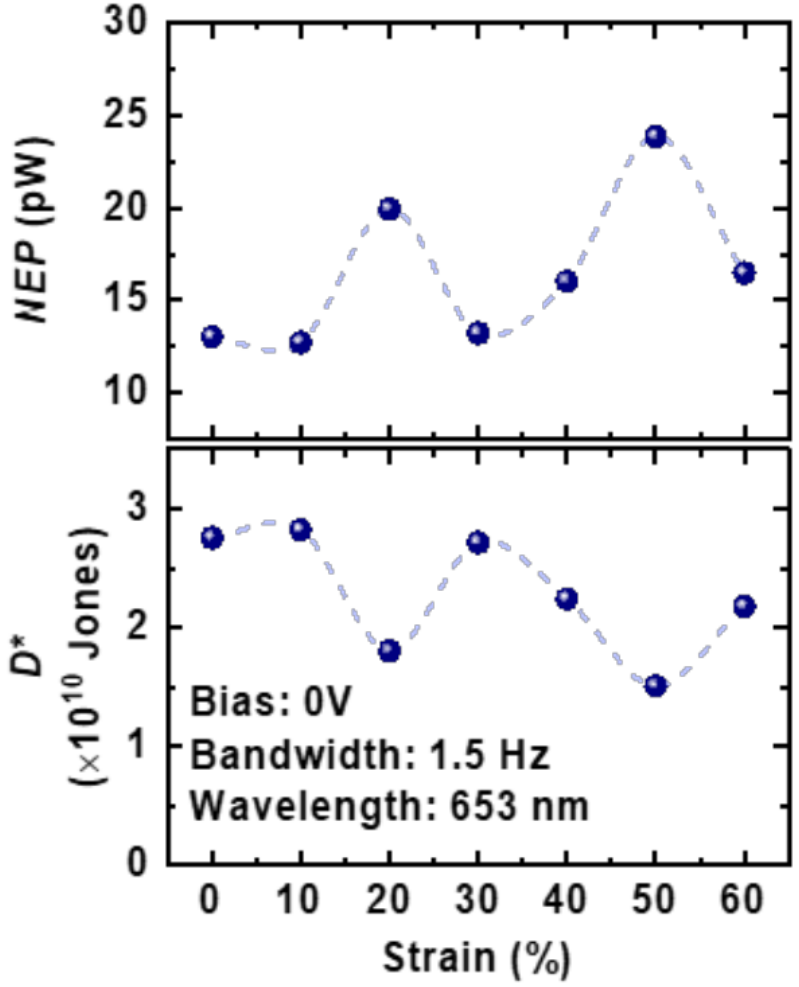
PEIE

Fabrication of e-OPD (Fully stretchable OPD)



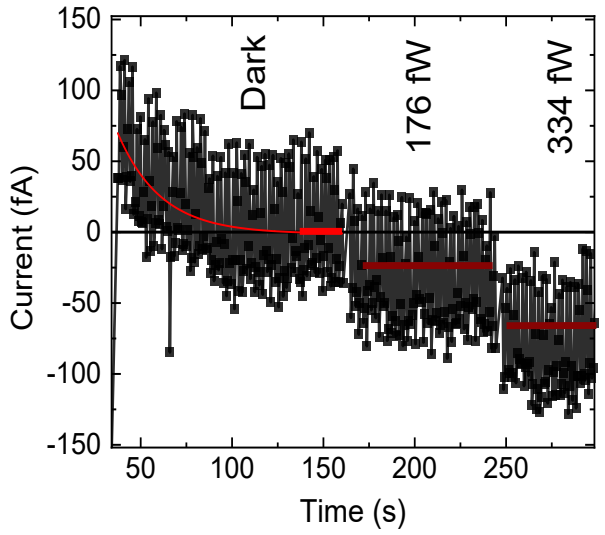
Noise Performance of e-OPD





Park, Y., et al.. ***Science Advances*** 2021, *7, 51* (6565).

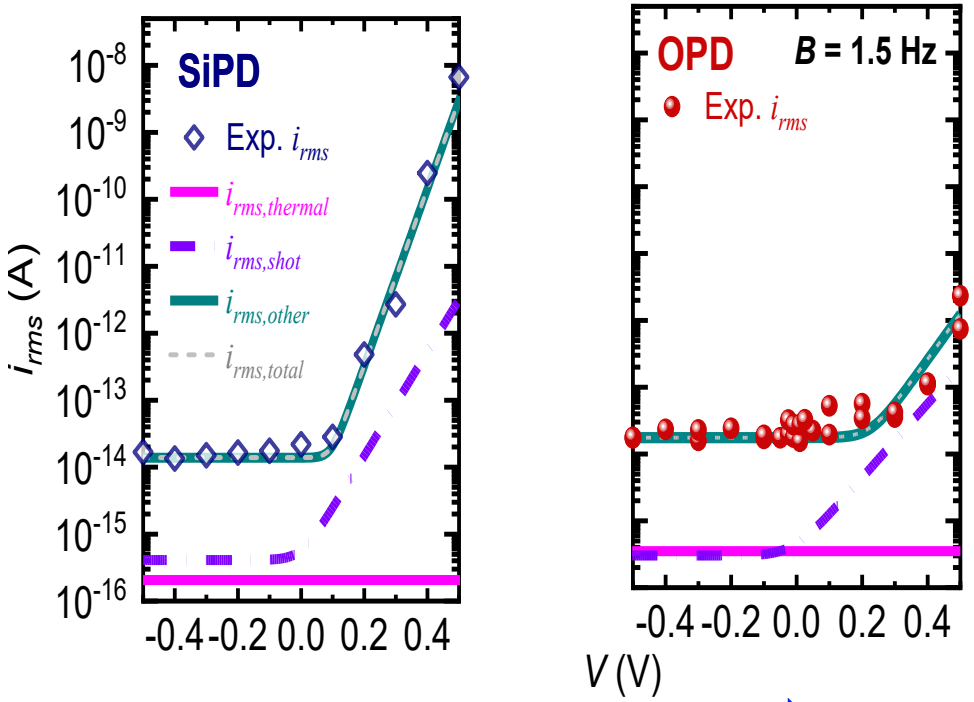
Direct Measurement of Electronic Noise

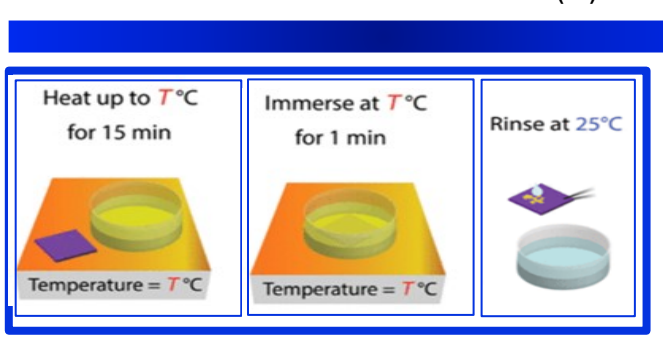


$$\overline{i_{dark}(t_i)} = \overline{i_{dark}(t_j)} \equiv \bar{i}_{dark}$$

$$\overline{i_{ill}(t_i)} = \overline{i_{ill}(t_j)} \equiv \bar{i}_{ill}$$

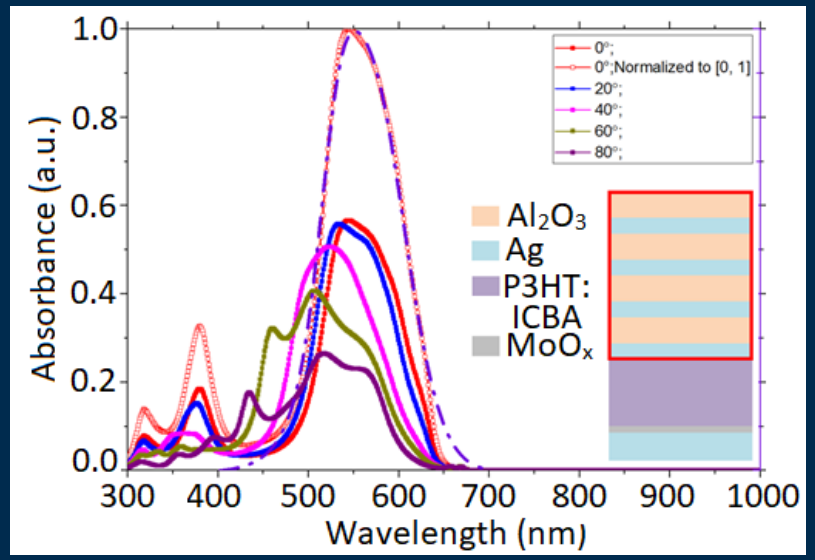
$$i_{rms} = \left(i_{rms,thermal}^2 + i_{rms,shot-noise}^2 + \sum i_{rms,other}^2 \right)^{1/2}$$



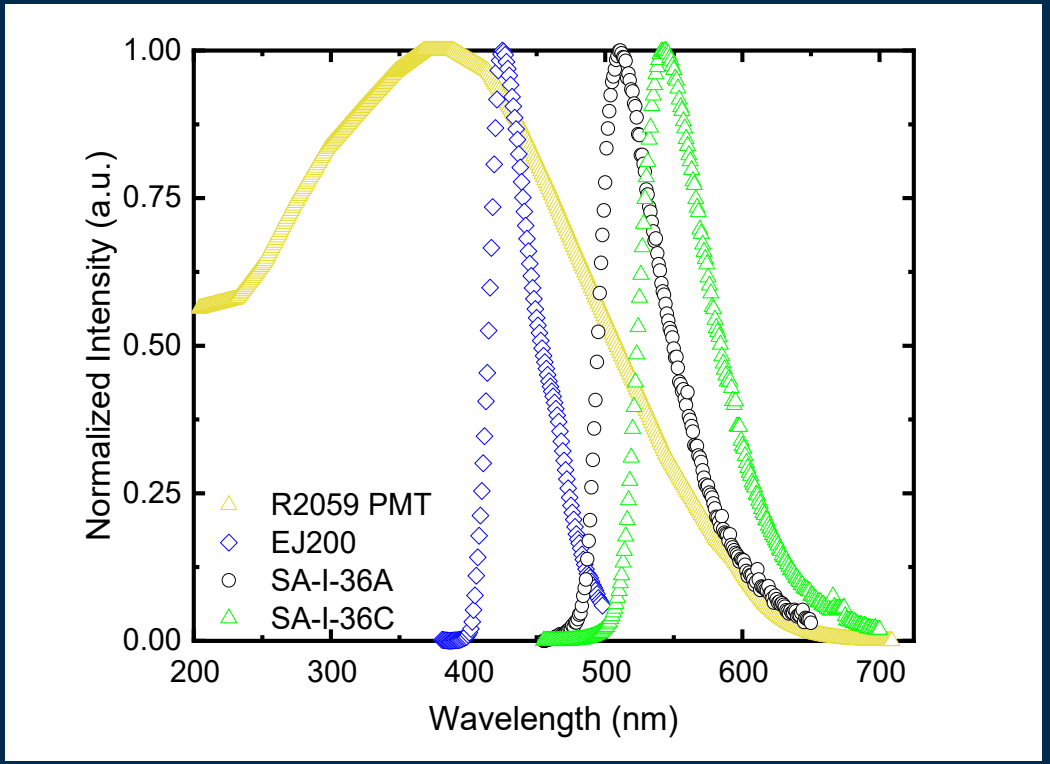


Chemical doping through PMA Strategy for noise reduction

Spectral Overlap for Noise Rejection

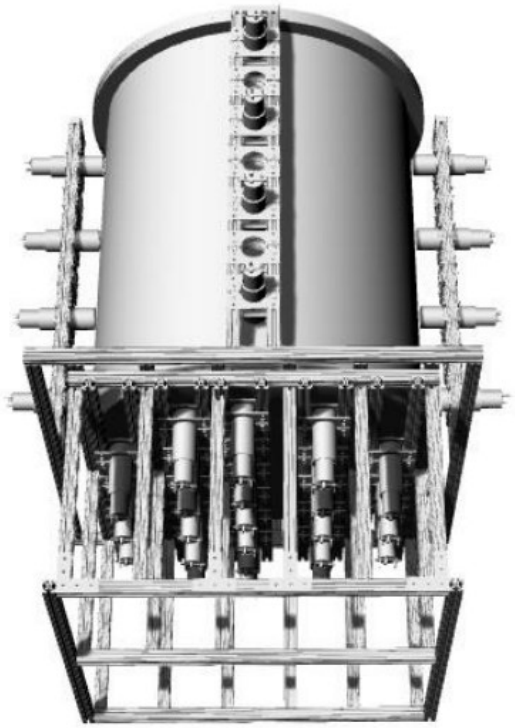


OPD with absorption approximating photopic response of human vision

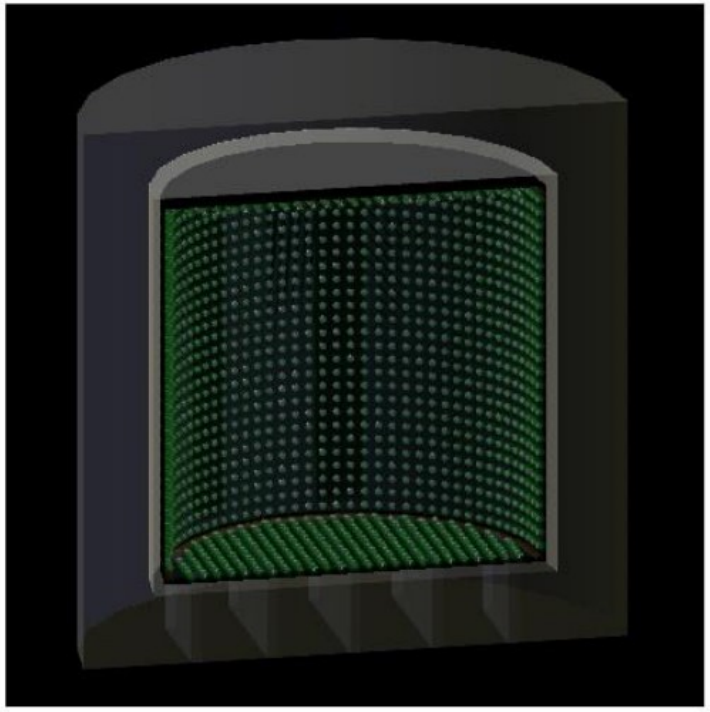


Organic 3D printable scintillators

Collaboration with BNL



1-ton prototype
2” and 3” PMT

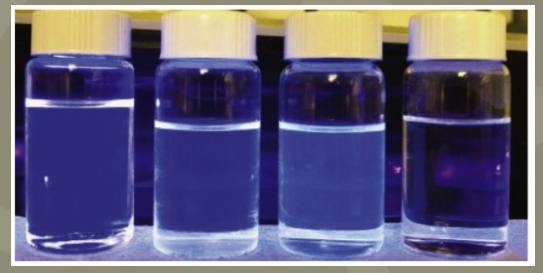


Design and
deployment of
kton detector

1-ton prototype allows for iterative testing

- PMT
- Scintillator choice
- Benchmarking and scaling

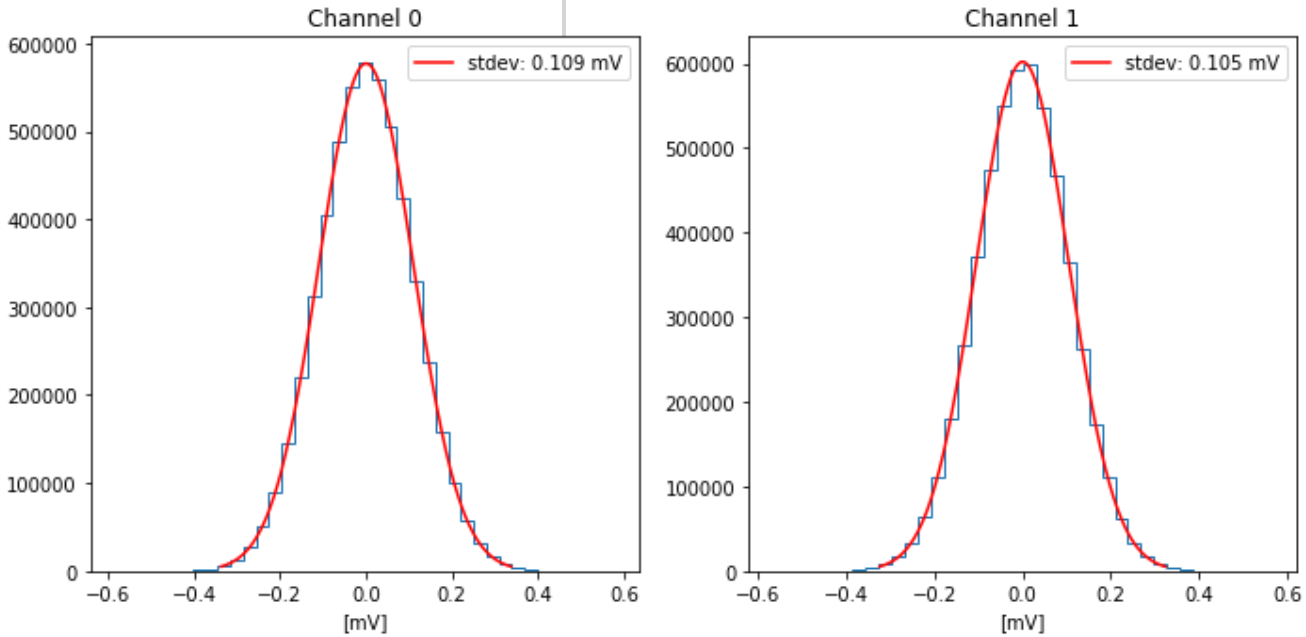
Large scale deployment in 2023 for high-energy physics and nonproliferation



Optimization of
WbLS chemistry

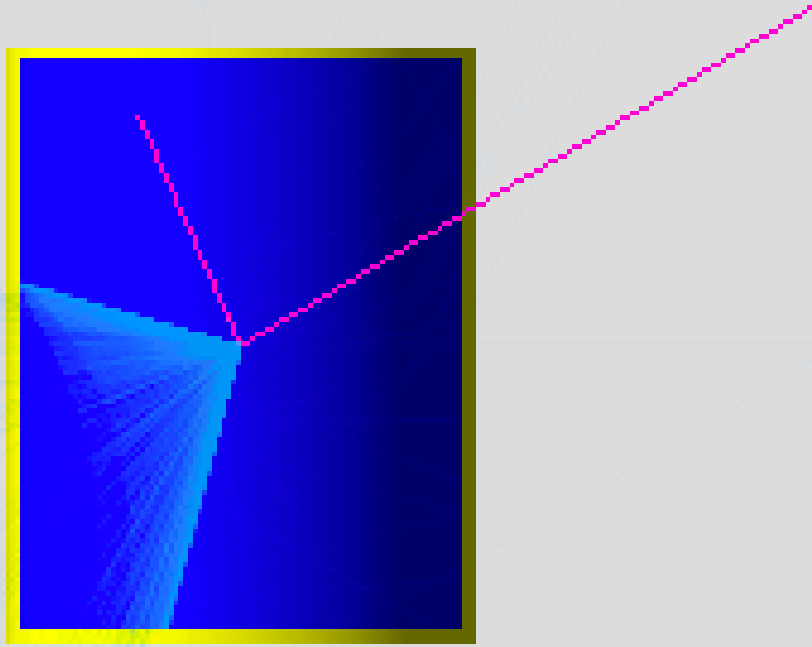
Minfang Yeh, et al., **Nuclear Instruments and Methods**, 2011, 660.

System Design & Characterization



- Channel calibration ongoing on 32 PMT channels total
- Ray traced optics simulations and ionizing radiation interactions
- Geant4-based program RAT-PAC
- Updating model parameters for novel organic scintillators, optical filters, and photocathodes

Data credit: Adam Baldoni, Xin Xiang, and Milind Diwan



1 GeV muon interaction simulation

Summary

- Fully stretchable OPD
  - D* 2x10^{10} J for 653 nm light, 1.5 Hz
  - 60% strain
  - 142 μs response time

Park, Y., et al.. ***Science Advances*** 2021, *7, 51* (6565).

- Ongoing work to design and prototype large-volume detectors with BNL for high-energy physics
  - Study application to nonproliferation

ACKNOWLEDGEMENTS

This material is based upon work supported by the Department of Energy / National Nuclear Security Administration under Award Number(s) DE-NA0003921.