Detector R&D at ORNL

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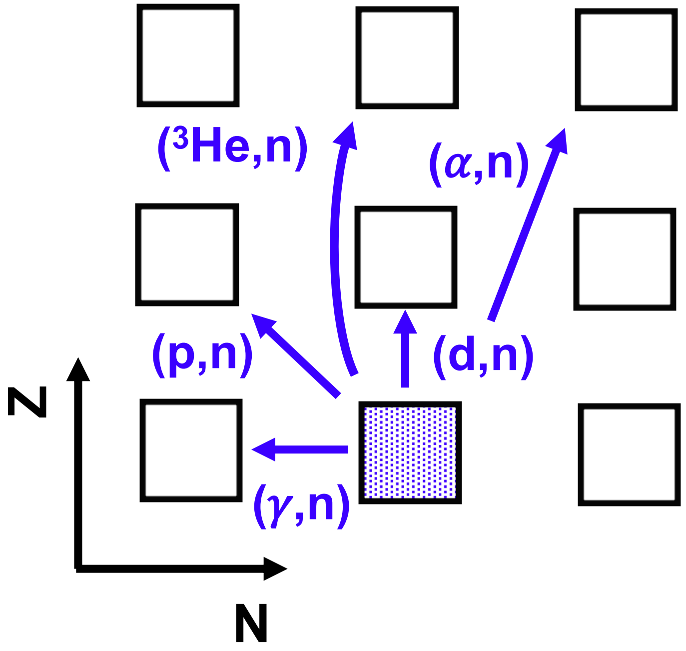
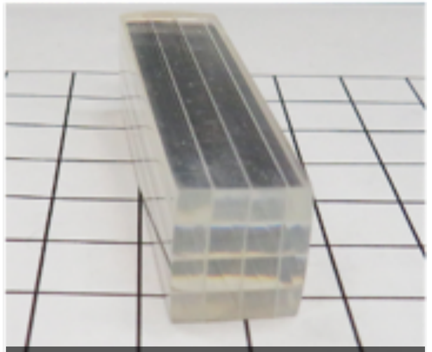
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

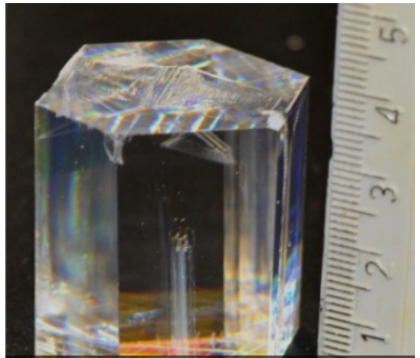
Detectors for Neutron Spectroscopy

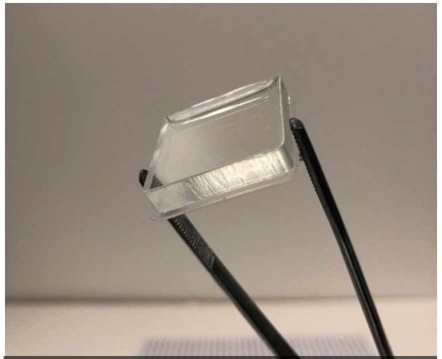
Neutron spectroscopy

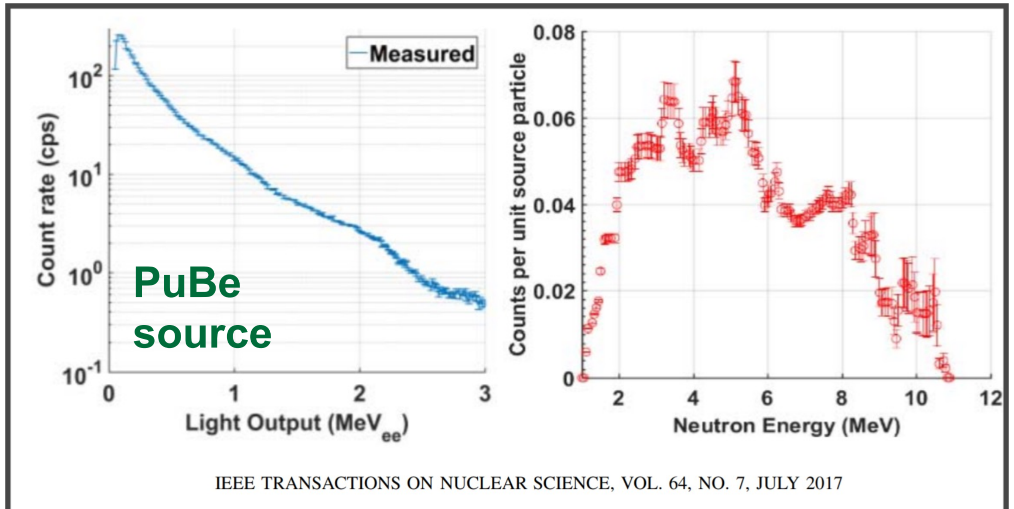
- Neutron-producing reactions impact nuclear astrophysics, applied nuclear science, … *and neutrino physics*!
- Parallel nuclear reaction physics and neutron detector R&D programs
- Synergy between scintillator R&D for neutron detection and neutrino detection (i.e. inverse beta decay)
  - R&D into novel scintillator materials
  - Lithium and boron loaded scintillators




Optically segmented PSD plastic scintillator


Deuterated stilbene (Natalia Zaitseva, LLNL)


PSD – formulation Deuterated polystyrene scintillator



Neutron spectrum unfolding

Neutron spectroscopy with the Oak Ridge Deuterated Spectroscopic Array (ODeSA)

- Has been the workhorse array for the study of neutron-producing reactions experimental efforts
  - ^{11}B(a,n), ^{13}C(a,n), ^{17}O(a,n), ^{18}O(a,n), ^{25}Mg(a,n)
- Many (a,n) reactions have implications for neutrino measurements
  - Example: ^{13}C(a,n) as a background for KamLAND

PHYSICAL REVIEW LETTERS 125, 062501 (2020)

New $^{13}C(\alpha,n)^{16}O$ Cross Section with Implications for Neutrino Mixing and Geoneutrino Measurements

M. Febbraro,[1] R. J. deBoer,[2] S. D. Pain,[1] R. Toomey,[3,4] F. D. Becchetti,[5] A. Boeltzig,[2,*] Y. Chen,[2] K. A. Chipps,[1] M. Couder,[2] K. L. Jones,[6] E. Lamere,[2,†] Q. Liu,[2] S. Lyons,[2,‡] K. T. Macon,[2] L. Morales,[2] W. A. Peters,[1,6] D. Robertson,[2] B. C. Rasco,[6,1] K. Smith,[6,‖] C. Seymour,[2] G. Seymour,[2,§] M. S. Smith,[1] E. Stech,[2] B. Vande Kolk,[2] and M. Wiescher[2]

PHYSICAL REVIEW C 101, 025808 (2020)

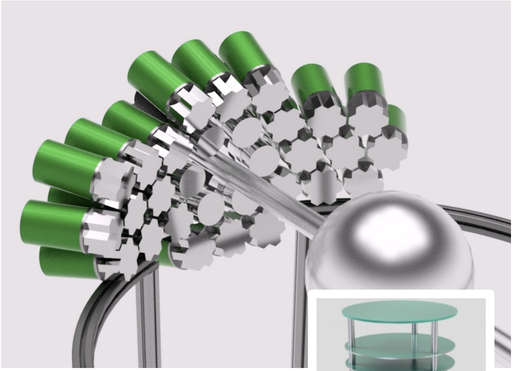
Low-energy cross-section measurement of the $^{10}B(\alpha,n)^{13}N$ reaction and its impact on neutron production in first-generation stars

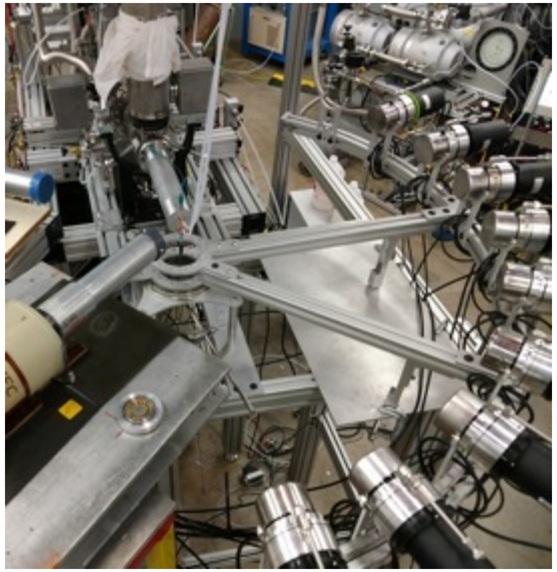
Q. Liu,[1] M. Febbraro,[2] R. J. deBoer,[1] S. Aguilar,[1] A. Boeltzig,[1,*] Y. Chen,[1] M. Couder,[1] J. Görres,[1] E. Lamere,[1,†] S. Lyons,[1,‡] K. T. Macon,[1,3] K. Manukyan,[1] L. Morales,[1] S. Pain,[2] W. A. Peters,[2] C. Seymour,[1] G. Seymour,[1,§] R. Toomey,[4] B. Vande Kolk,[1] J. Weaver,[5] and M. Wiescher[1]

PHYSICAL REVIEW C 100, 034601 (2019)

Measurement of the $^{10}B(\alpha,n_0)\,^{13}N$ cross section for $2.2 < E_\alpha < 4.9$ MeV and its application as a diagnostic at the National Ignition Facility

Q. Liu,[1] M. Febbraro,[2] R. J. deBoer,[1] A. Boeltzig,[1,*] Y. Chen,[1] C. Cerjan,[3] M. Couder,[1] B. Frentz,[1] J. Görres,[1] E. A. Henry,[3] E. Lamere,[1,†] K. T. Macon,[1,4] K. V. Manukyan,[1] L. Morales,[1] P. D. O'Malley,[1] S. D. Pain,[2] W. A. Peters,[2] D. Schneider,[3] C. Seymour,[1] G. Seymour,[1,‡] E. Temanson,[2] R. Toomey,[5] B. Vande Kolk,[1] J. Weaver,[6] and M. Wiescher[1]



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Performance of neutron spectrum unfolding using deuterated liquid scintillator

M. Febbraro[a,*], B. Becker[b], R.J. deBoer[c,d], K. Brandenburg[e], C. Brune[e], K.A. Chipps[a], T. Danley[e], A. Di Fulvio[f], Y. Jones-Alberty[e], K.T. Macon[c,d], Z. Meisel[e], T.N. Massey[e], R.J. Newby[a], S.D. Pain[a], S. Paneru[e], S. Shahina[c,d], M.S. Smith[a], D. Soltesz[e], S.K. Subedi[e], I. Sultana[e], R. Toomey[g]

Nuclear Inst. and Methods in Physics Research, A 946 (2019) 162668
Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/nima
ELSEVIER

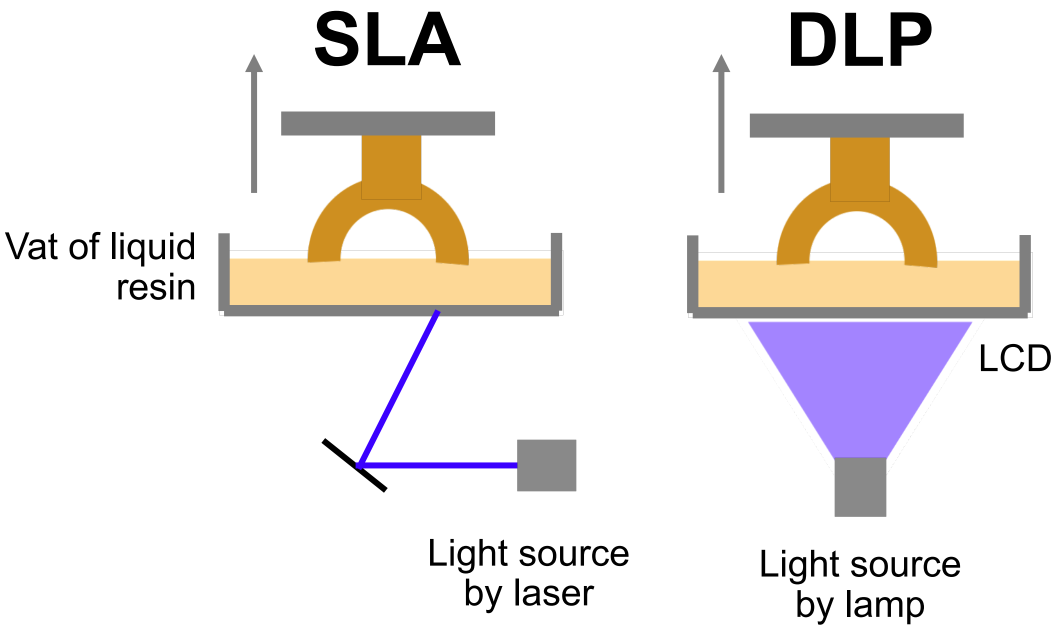
The ORNL Deuterated Spectroscopic Array — ODeSA

M. Febbraro[a,*], R. Toomey[b], S.D. Pain[a], K.A. Chipps[a], B. Becker[c], R.J. Newby[a], Z. Meisel[d], T.N. Massey[d], C.R. Brune[d], Q. Liu[e], R.J. deBoer[e], K.T. Macon[e], A. Boeltzig[e], J. O'Neill[a,f], M.S. Smith[a], M. Wiescher[e], D. Soltesz[d], I. Sultana[d], K. Brandenburg[d], S. Subedi[d], S. Paneru[d], T. Danley[d], Y. Alberty-Jones[d]

Additive Manufacturing of Radiation Detectors

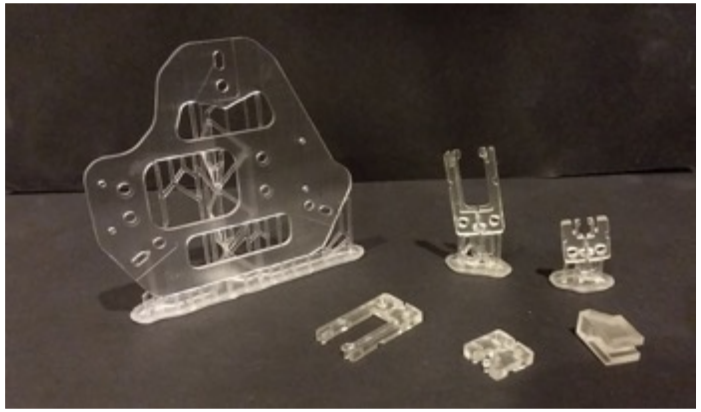
3D printing with *light*

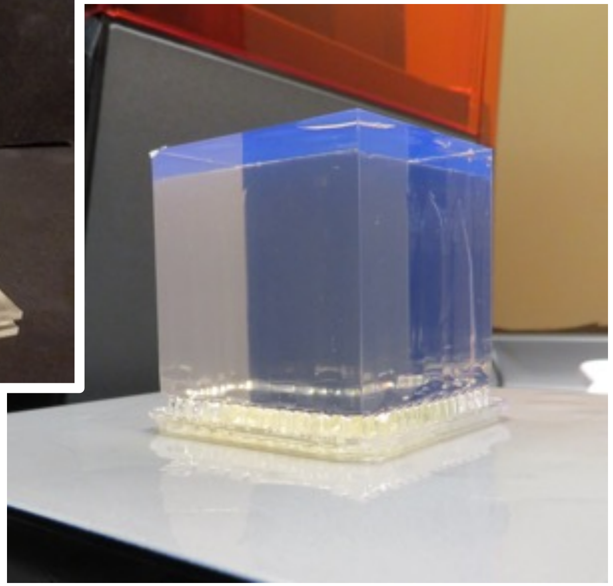
- Light-based 3D printing techniques
  - Stereolithography (SLA)
  - Digital Light Processing (DLP)
- Part is produced layer-by-layer from a liquid resin vat using just ***light***
  - Near ***<u>contactless</u>*** manufacturing!
- Significantly better optical properties than FDM 3D printing



https://www.forbes.com/sites/bernardmarr/2020/07/24/what-can-3d-printing-be-used-for-here-are-10-amazing-examples/?sh=41c994c54d69

https://formlabs.com/

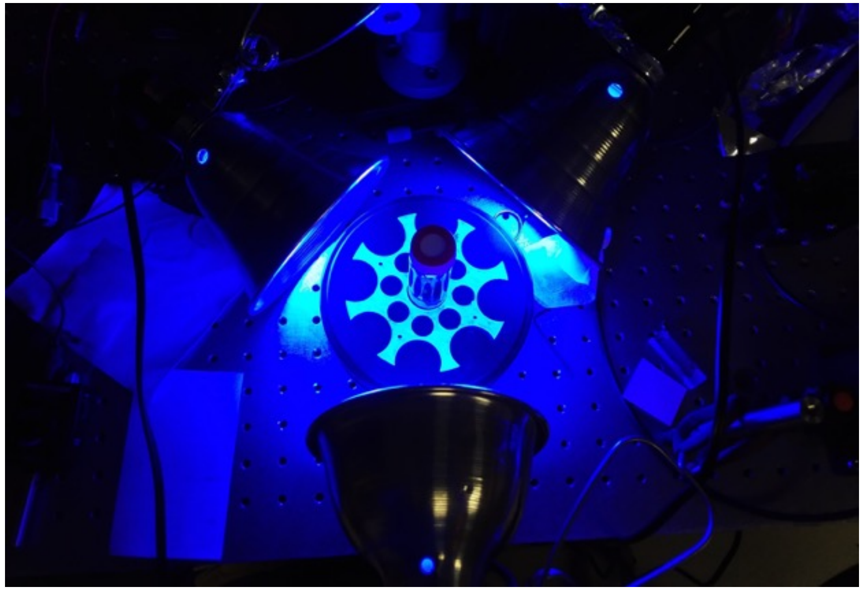


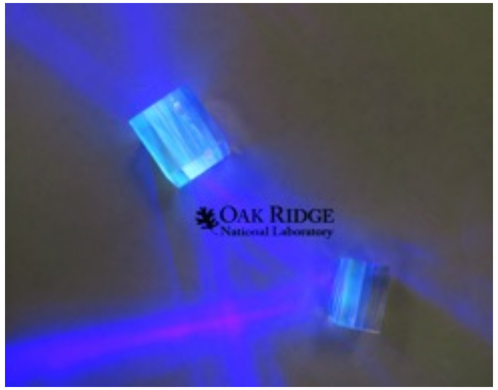


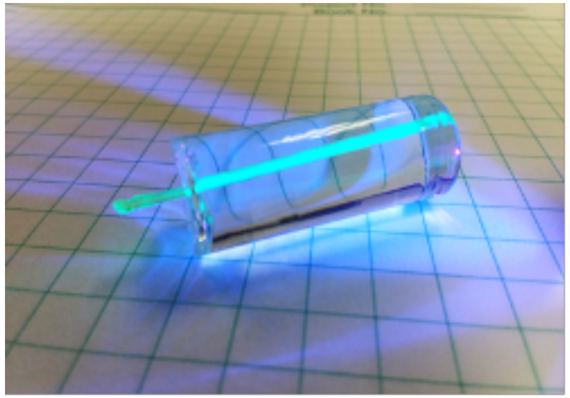
Various SLA printed components (top) and an SLA printed (2 in)^3 (right)

Towards 3D printing scintillators with *light*

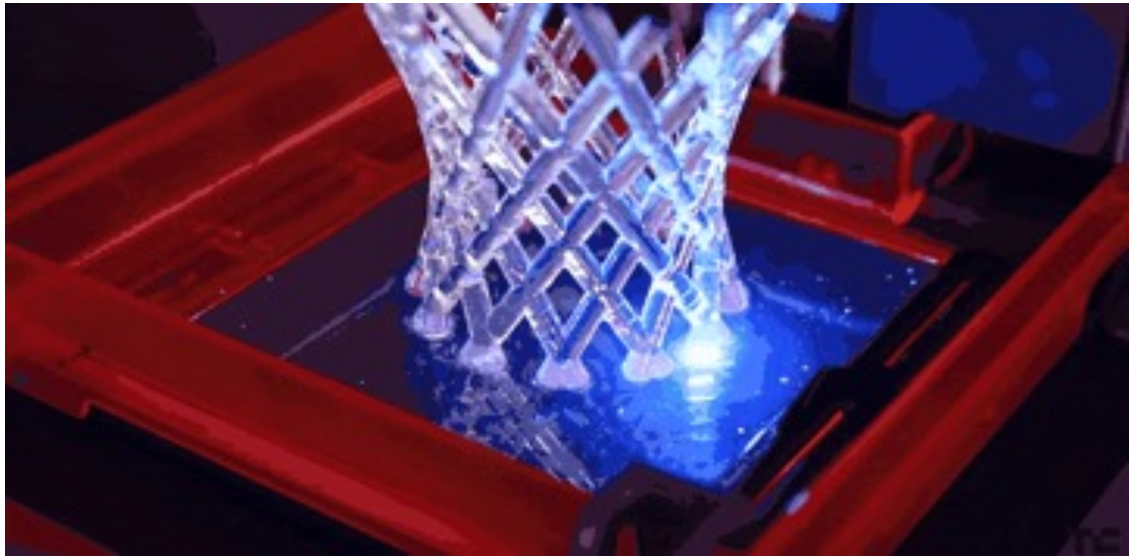
- Photocurable resins allows for preparation of scintillators using UV or visible light
  - Curing time from seconds to hours compared to multiple days for conventional approaches
  - Can be performed at room temperature
  - Resin formulations allows for embedding
- Photocurable resins are a key ingredient towards light-based 3D printing







Examples of embeds – ESR reflectors (left) and WLS fiber (right)

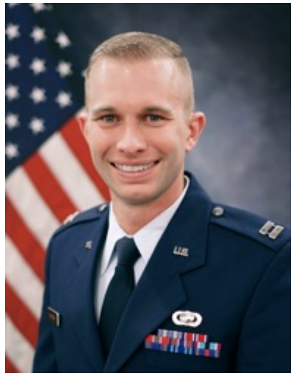


https://all3dp.com/2/dlp-vs-sla-3d-printing-technologies-shootout/

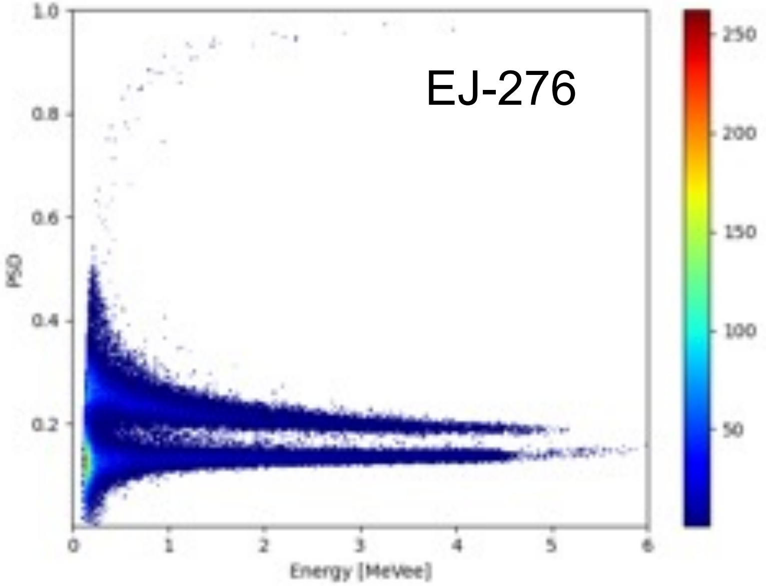
OAK RIDGE National Laboratory

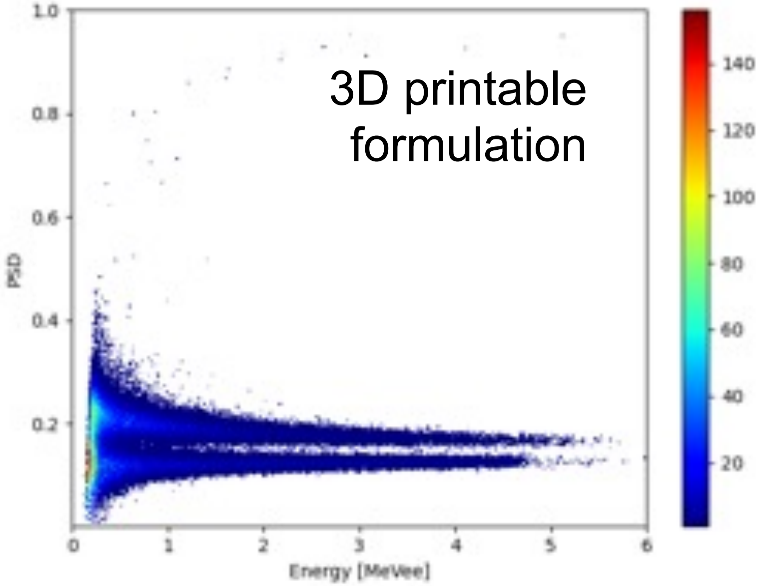
Light yield and PSD results

Capt. Brian Frandsen
Airforce Institute of Technology
PhD student
Advisor: Maj. James Bevins



- Newly developed 3D printable scintillator resin
- Fast cure time
- (< 15 seconds) for light-based 3D printing
- *<u>Light yield **6400 photons / MeVee**</u>*
  - EJ-276 is 8600 photons / MeVee
- Neutron / gamma separation FoM 1.1 @ 500 keVe



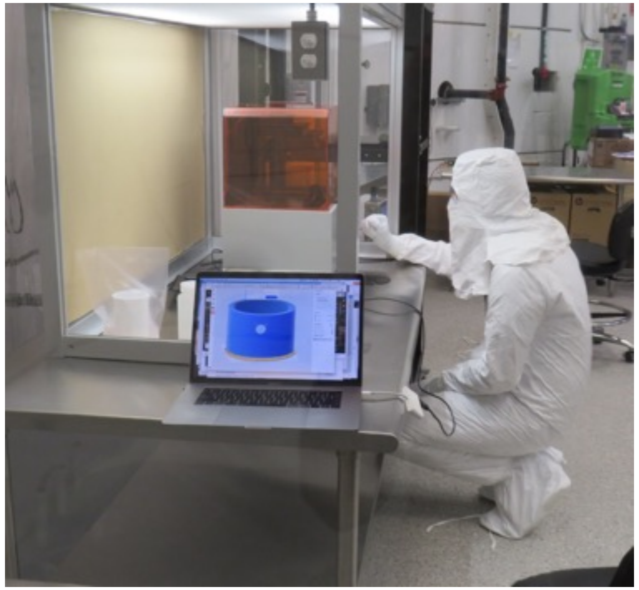


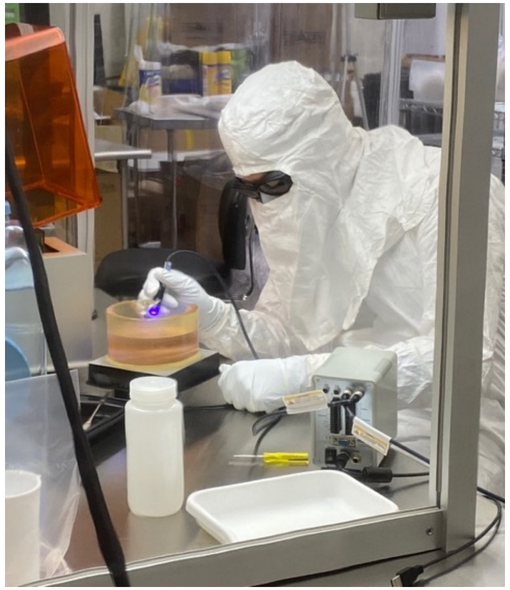
~75% light yield of EJ-276 with only 30% "active ingredients"

(benzene-like compounds)

3D printable Low-background materials

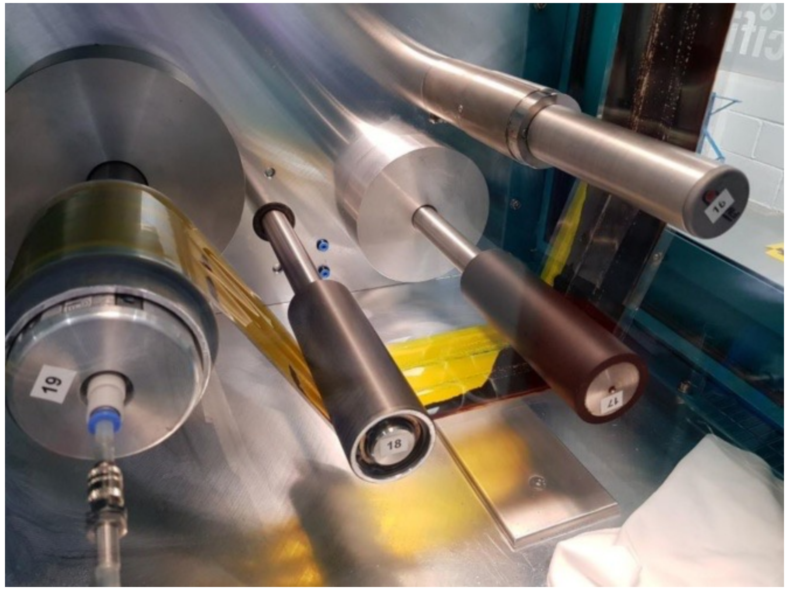
- 3D printing of low background components using light-based techniques
  - Near contactless manufacturing
  - Can be scintillating (active) materials for background rejection
- Working towards fully automated systems
  - Reducing contamination risks due to handling





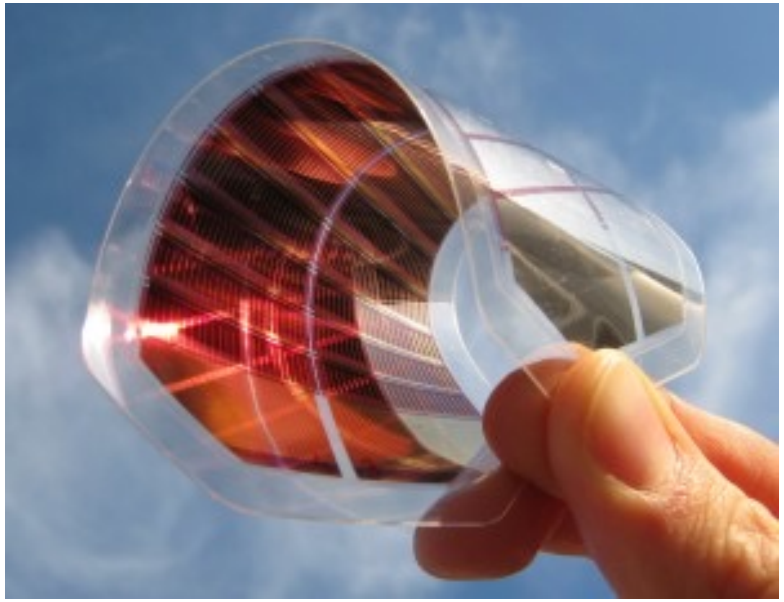
Organic photosensors

Organic semiconductors



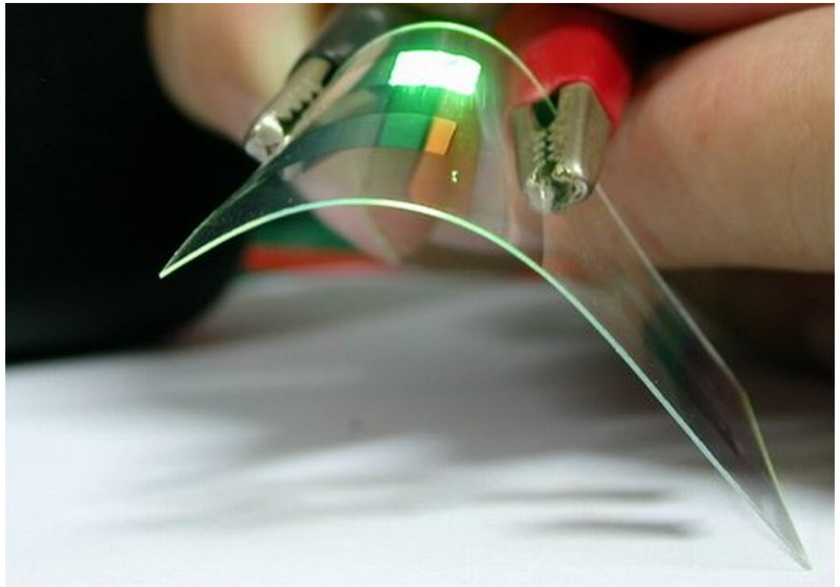
https://www.theengineer.co.uk/printed-perovskite-solar-cells/

Additive manufacturing (3D printing)



https://3dprint.com/1666/scientists-3d-print-new-solar-panels-which-work-best-when-cloudy/

Solar energy



https://www.evolving-science.com/matter-energy-materials/powering-future-one-step-closer-organic-electronics-our-homes-00165

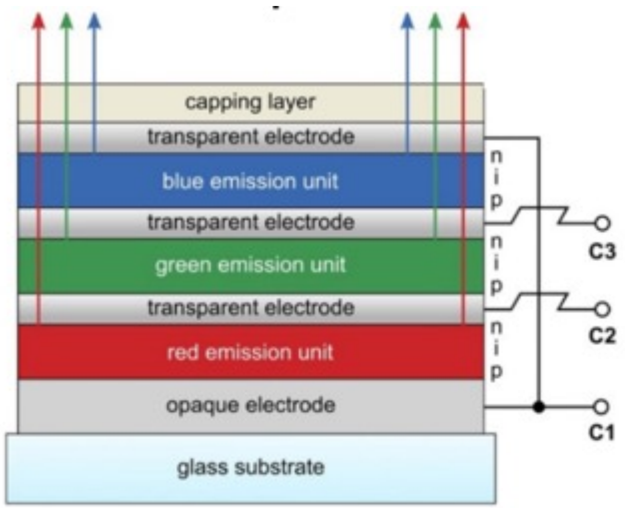
Organic LEDS (OLEDs)

Vast amount of knowledge exists – Can it be adapted for high energy physics experiments?

Interesting opportunities….

- Organic semiconductors
  - Low cost & highly scalable
    - Roll-to-roll printing production > 100 m scale
  - Industry driven technology
    - Cell phones, OLED displays, sensors for medical devices
- Can be made on rigid and flexible substrates
- Stackable geometry for spectroscopic (multicolor) readout
  - No loss of photosensor coverage
  - Cherenkov vs scintillation separation?

https://www.sammobile.com/news/samsungs-new-foldable-and-udc-panels-reveal-an-exciting-future/



https://www.nature.com/articles/s41598-018-27976-z

Stacked OLED

Stacked OPD

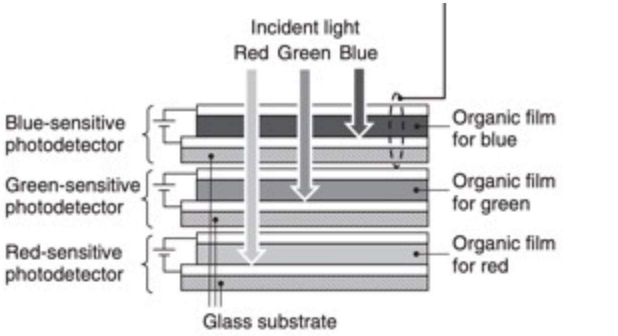
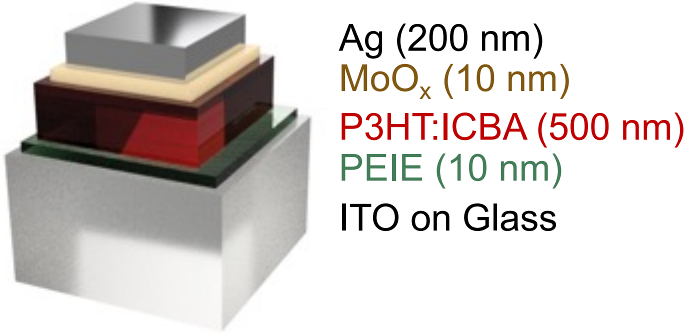
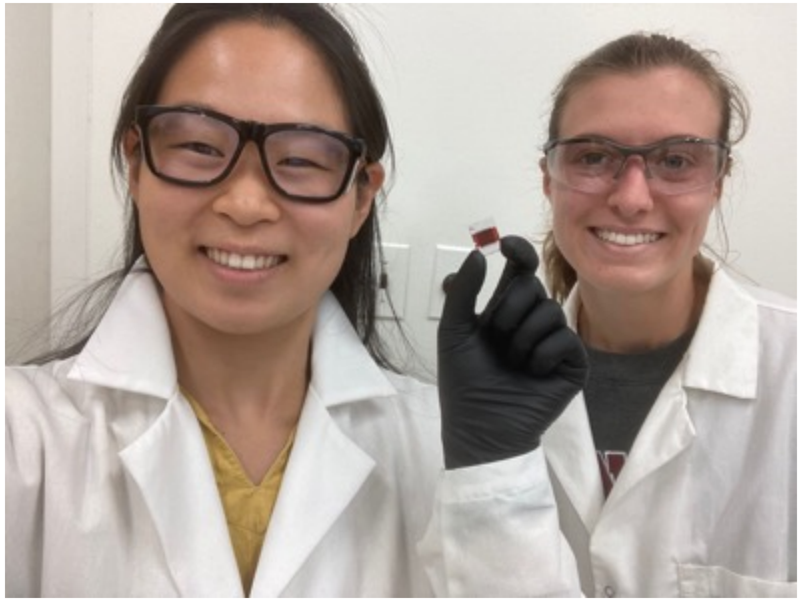


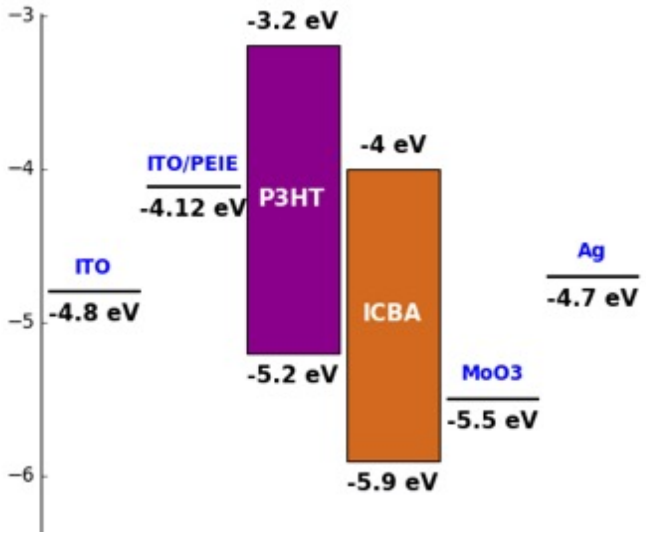
Fig. 1. Schematic diagram of stack structure and cross sectional view of a photodetector.

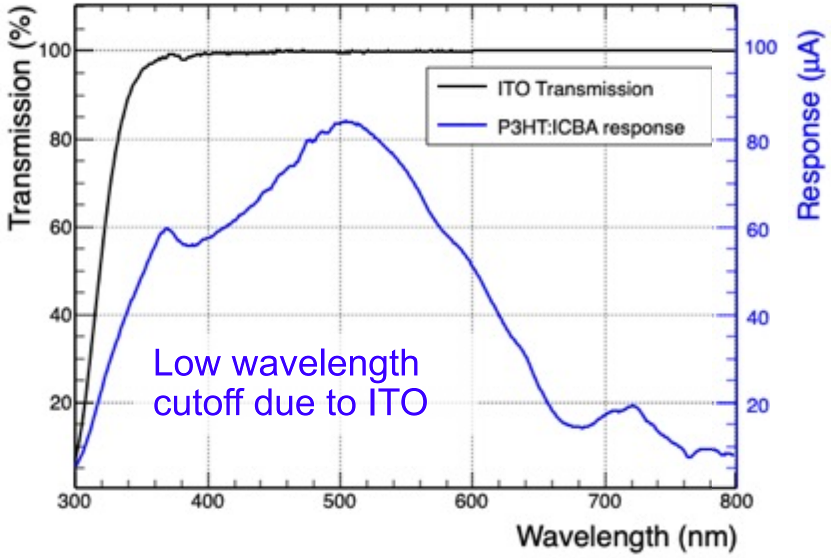
P3HT:ICBA photosensors

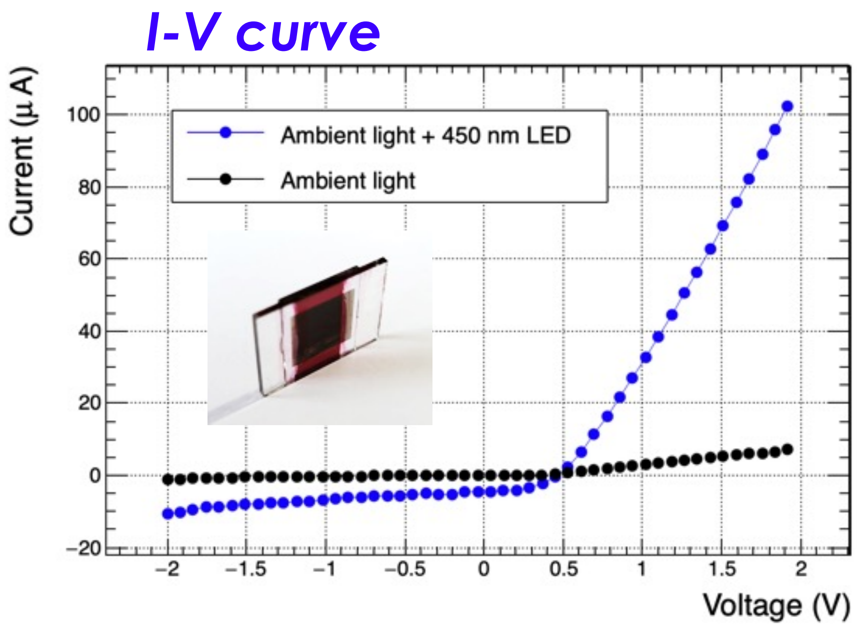
- Functional P3HT:ICBA photosensor on ITO substrates have been fabricated at ORNL
- Sensor evaluation in progress
  - Wavelength (VUV-UV-VIS)
  - Temperature
  - Timing











VUV sensor R&D platform

VUV sensor evaluation platform at ORNL

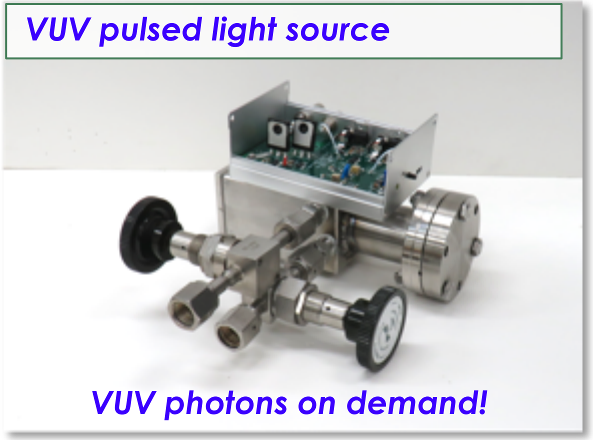
Newly developed state-of-the-art VUV sensor evaluation platform

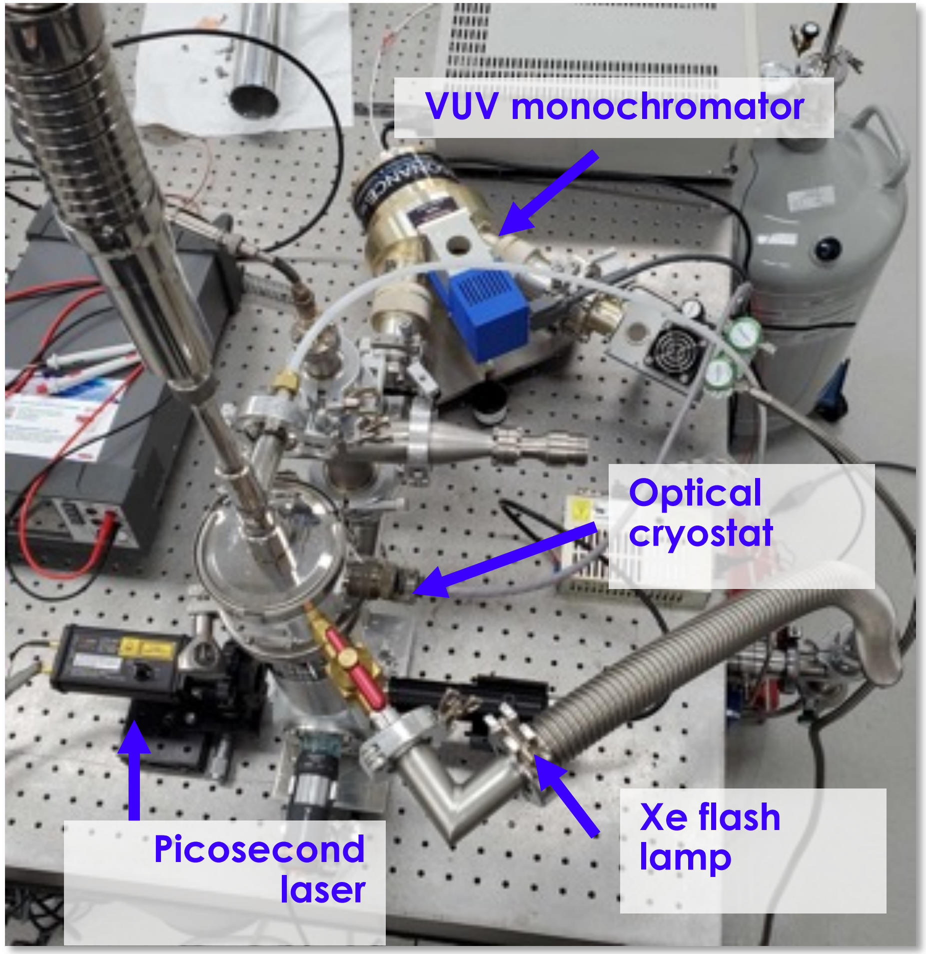
- Wavelength range: 58 – 3200 nm
- Temperature range: 5 – 500 K (50 mK stability)

Light sources

- Windowless plasma lamp
    - Wavelengths down to 58 nm (LHe ~80 nm)
- Picosecond laser (405 nm)

- *Newly developed 128 nm pulsed light source*
    - Adjustable intensity – ~10k to single photon level



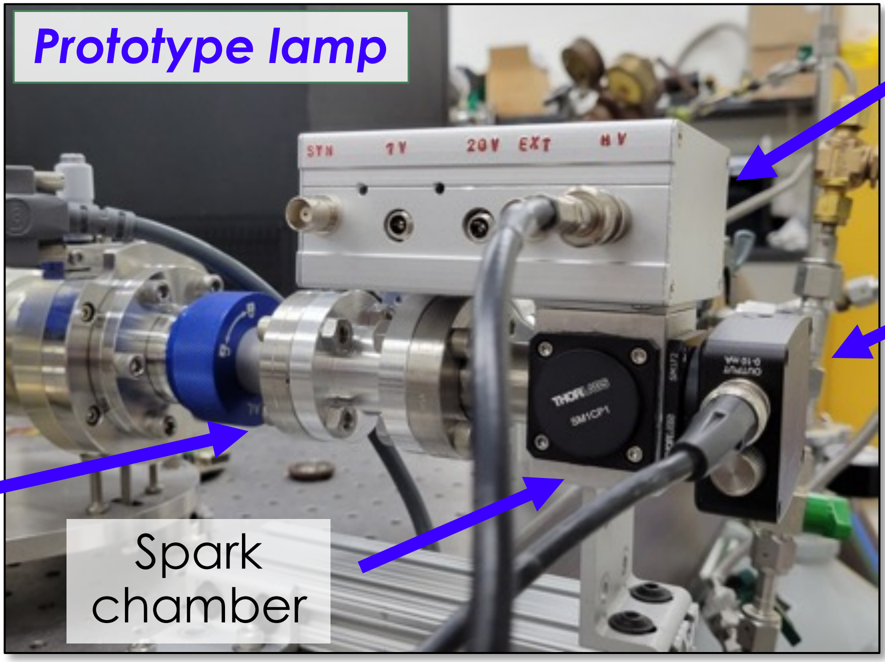


Credit
- Preamp: Lorenzo Fabris
- Design: Austin McDonald

Development of a pulsed VUV light source

To VUV monochromator

Optical attenuator



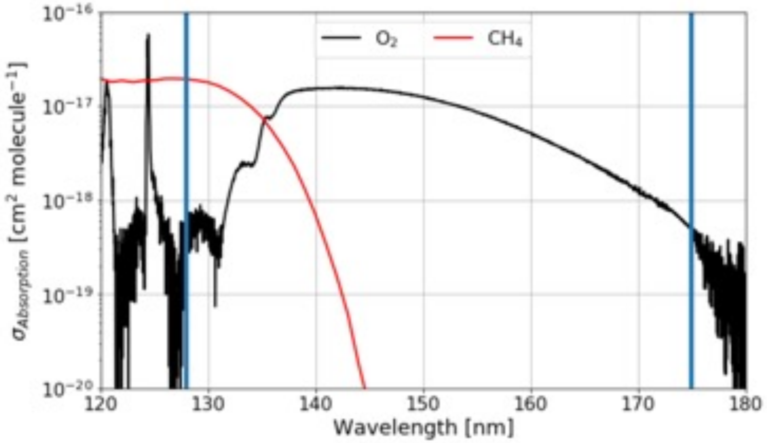
Trigger / discharge circuit

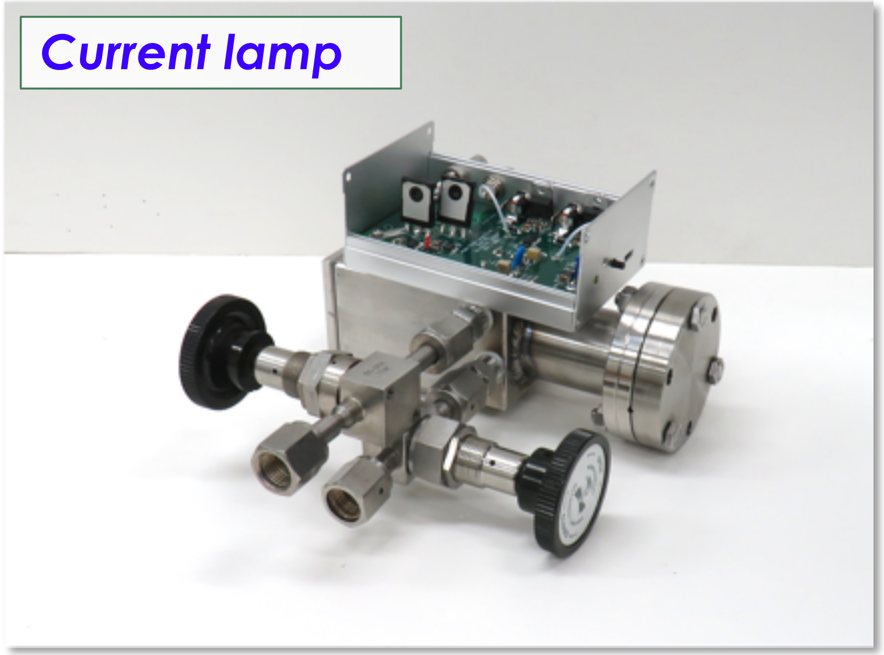
Photodiode

UNIVERSITY OF TEXAS ARLINGTON

Dr. Austin McDonald
University of Texas - Arlington
Postdoctoral researcher
Advisor: J. Asaadi

Optical attenuation using CH_4 absorption
(variable pressure of P10 gas)





Conclusion

- ORNL detector R&D working on a wide range of topics
  - Scintillators & neutron detectors
  - Additive manufacturing and low-background materials
  - Organic photosensors
  - VUV sensor R&D

- Collaborative work welcomed!

Questions ?