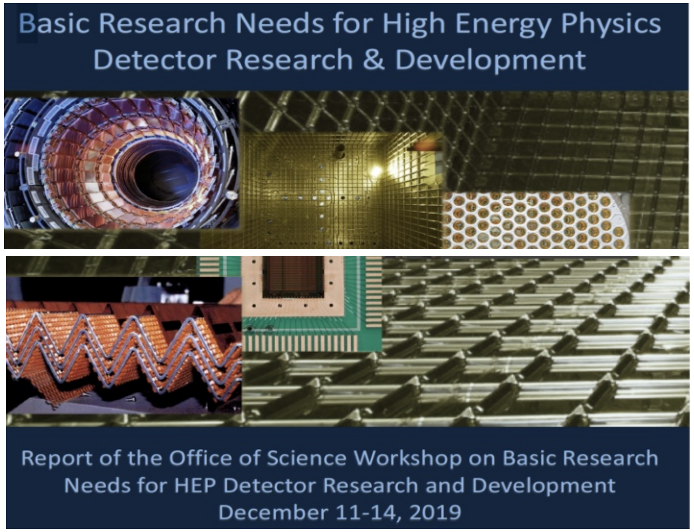
Multidisciplinary development in high energy physics

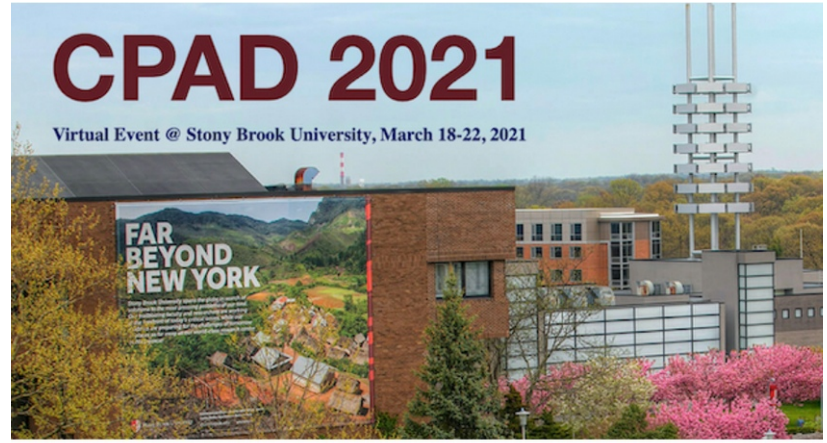
APS April Meeting

20 April 2021

M. Garcia-Sciveres, LBNL
on behalf of the Snowmass Instrumentation cross-cutting working group

Introduction





CPAD Instrumentation Frontier Workshop 2021

Instrumentation Development Ecosystem

Key to the success in this tool revolution are **people**, **facilities and resources**, and **connections and collaborations**

1. Advanced workforce
2. Unique capabilities and facilities
3. Connections to other programs, other offices, other agencies, private foundations, commercial partners, global collaborations

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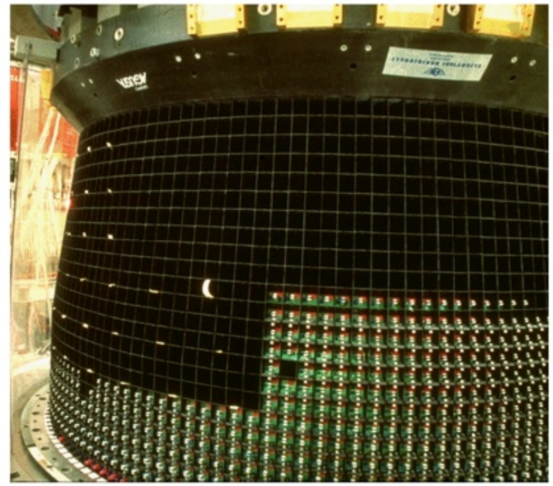
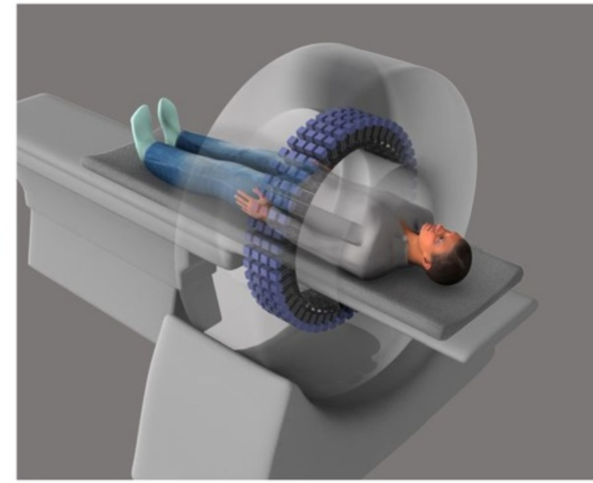
Introduction (2/3)

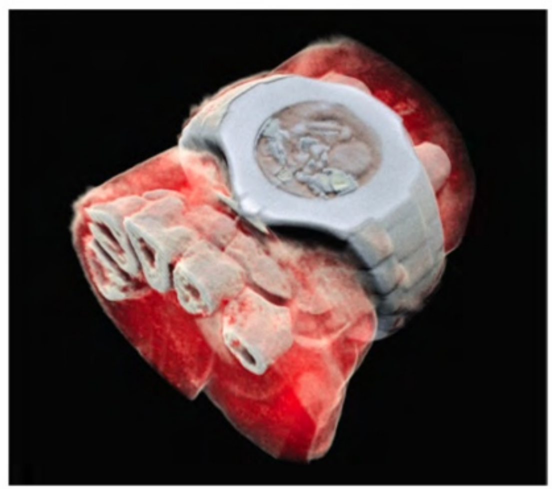
Connections to other disciplines: Benefits to Society

The development of the manufacturing process of BGO crystals for the calorimeter of the L3 experiment at the LEP collider at CERN (left) has contributed significantly to the advancement of Positron Emission Tomography (PET) scanners





(photo credit: CERN and S.R. Cherry/U.C. Davis)



The development of large-area hybrid pixel detectors for high energy physics experiments led to the realization of the potential of this new technology to provide noise-hit-free single-photon counting impactful for development of sophisticated integrated circuits with timing. The circuit is being used in medical imaging, X-ray science, materials analysis, space dosimetry and climate studies among others

The instrumentation plan described in this report will lead to the development of new technologies that hold the promise to be as broadly applicable and equally transformative.

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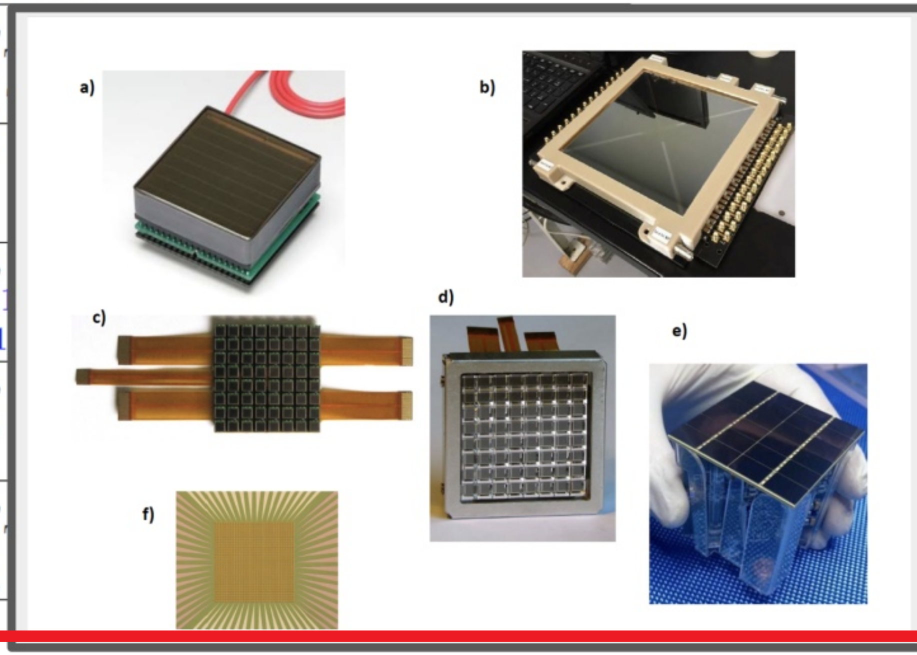
Introduction (3/3)

"Connections outside HEP" given for every technology

Photodetectors

Priority Research Direction	Technical Requirements
PRD 7: Extend wavelength range and develop new single-photon counters to enhance photodetector sensitivity	TR 1.3, TR 1.4, TR 2.8, TR 2.9, TR 3.6, TR 4.1,
PRD 8: Advance high-density spectroscopy and polarimetry to extract all photon properties	TR 4.1, TR 4.2
PRD 9: Adapt photodetectors for extreme environments	TR 1.4, TR 2.3, TR 2.9, TR 2. TR 5.10, TR 5.1
PRD 10: Design new devices and architectures to enable picosecond timing and event separation	TR 1.3, TR 1.4, TR 2.7, TR 4.3,
PRD 11: Develop new optical coupling paradigms for enhanced or dynamic light collection	TR 1.3, TR 1.4, TR 2.7, TR 2.8, TR 3.5, TR 3.6,



Connections outside of HEP

- **physics experiments and detectors at the light sources and in Astronomy**
- **Time-Of-Flight (TOF) PET medical imaging, biology, quantum computers, national security**

Facilities and Capabilities

- **close connections to industry for fabrication of devices and the procurement of materials.**
- **new infrastructure through upgrades at existing DOE facilities or partnerships with other federal facilities and industry. (eg: Ge CCD R&D, development of readout and ASICs**

Lindley Winslow Peter Krivzan (Leads) Graham Giovanetti Adriana Lita Felix Sefkow

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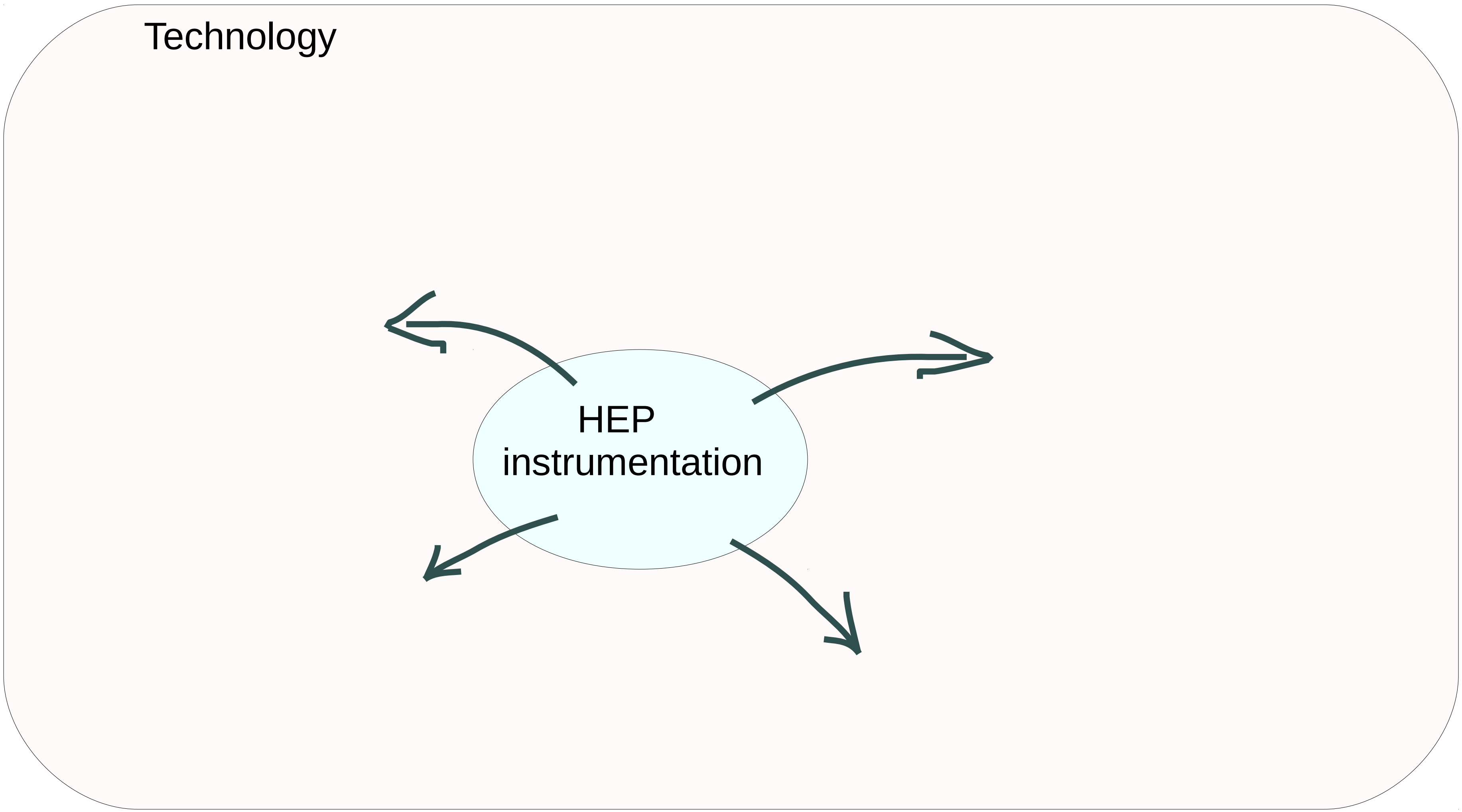
Direction of connections

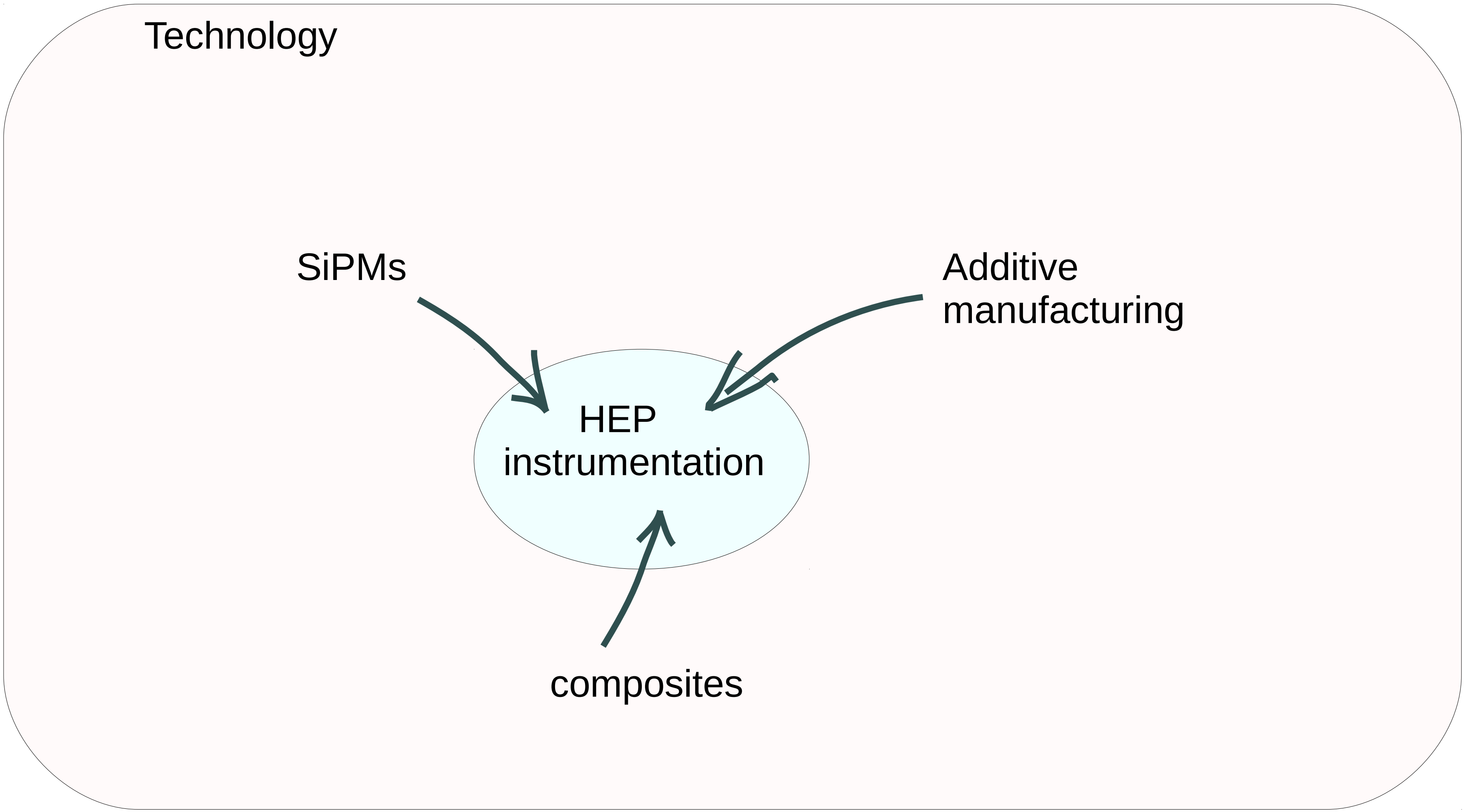
Examples from previous slides. We often hear about this.



Session K08: Physics in Medicine: Imaging and Radiation
Session E06: Advanced Physics for Medical Imaging and Therapy

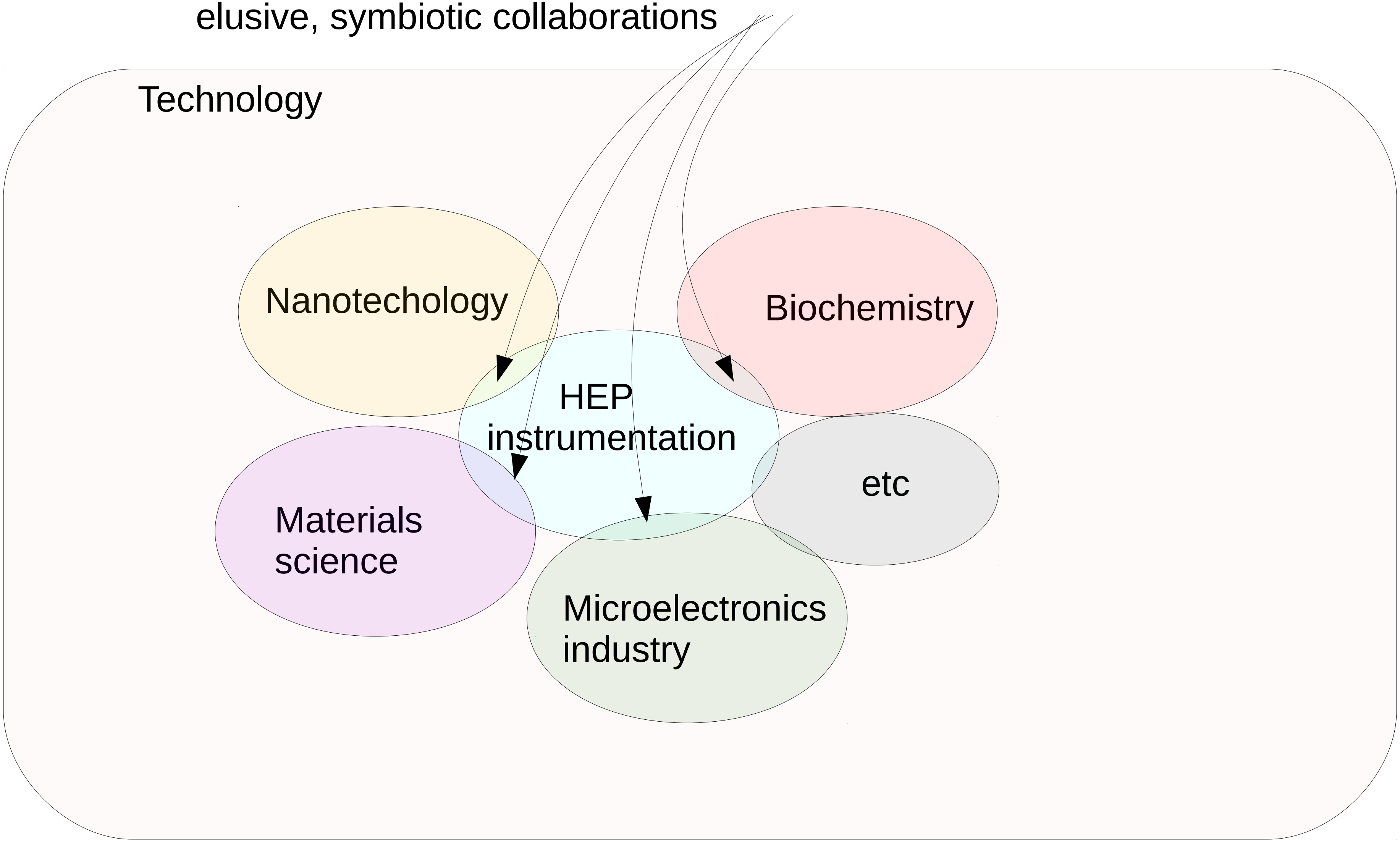
Direction of connections

Also easy to point to examples of new technology adopted ”DIY”



Direction of connections

In “MultiHEP2020” workshop decided to look into the more elusive, symbiotic collaborations



MultiHEP 2020

AM

9 Nov 2020

- **08:00 Welcome and Introduction** (until 08:15) ()
- **08:15 Bio/MS/Chem showcase presentations** - Petra Merkel (Fermilab) (until 10:15) ()
- 08:15 Chemistry for barium tagging - Ben Jones (UTA) ()
- 08:45 Novel room temperature photon detectors using carbon nanotubes - Francois Leonard (Sandia NL) ()
- 09:05 Quantum Materials for Axion Searches - Alexander Millar (Stockholm U.) ()
- 09:35 Superconducting Sensors for Coherent Neutrino Scattering - Patrick Harrington (MIT Lincoln Labs) ()
- 09:55 Ultra-low background at PNNL – Materials to measurements and the environment - James Moran (PNNL) ()
- 10:15 --- Break ---
- **10:45 Bio/MS/Chem panel** - Kimberly Palladino Petra Merkel (Fermilab) (until 12:45) ()
- 10:45 Panel Discussion - Will Oliver (Lincoln Labs) Patrick Harrington (Lincoln Labs) Ben Jones (UTA) Sinead Griffin Francois Leonard (Sandia NL) Hiranya Peiris (Stockholm U.) () Submit-a-question

10 Nov 2020

- **08:00 Panel 1: LAPPD experience** - Maurice Garcia-Sciveres Karen Byrum (ANL) (until 10:00) ()
- 08:00 Panel Discussion - Michael Minot (Incom) Henry Frisch (U. Chicago) Simona Malace (JLAB) Mike Pellin (ANL/Chicago) Amanda Weinstein (Iowa State U.) Bob Wagner (ANL) Howard Nicholson (Mt. Holyoke Coll.) Jim Buckley (Washington U. St. Louis) () Submit-a-question
- 10:00 --- Break ---
- **10:30 Panel 2: Low background copper and related technologies** - Jim Fast Jeter Hall (SNOLab) (until 12:30) ()
- 10:30 Panel Discussion - Cabot-Ann Christofferson (S. Dakota School of Mines and Tech.) Frank Avignone (U. of South Carolina) Eric Hoppe (PNNL) Susana Cebrián (Universidad de Zaragoza) () Submit-a-question

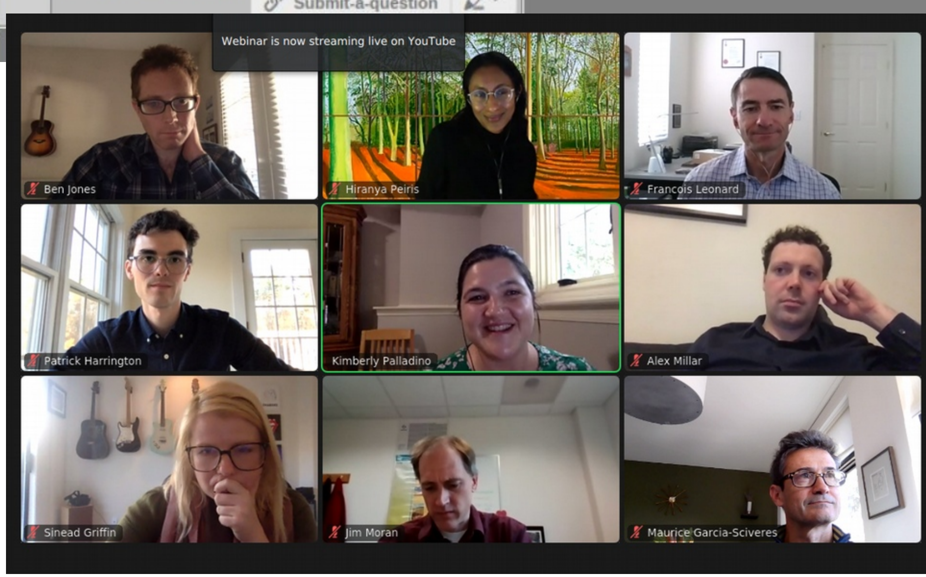
11 Nov 2020

- 08:00 --- Veteran's Day Holiday ---

12 Nov 2020

- **08:00 HEP-Industry partnership talks** - Ian Shipsey (Oxford U.) (until 10:10) ()
- 08:00 Fully depleted scientific CCDs - Stephen Holland ()
- 08:30 Superconducting fab for CMB - Aritoki Suzuki ()
- 08:50 Low-gain Avalanche Detectors (LGAD) for combined temporal and spatial precision - Hartmut Sadrozinki (UCSC) ()
- 09:10 National and DOE SBIR Overview & DOE Office of Science SBIRs for Detectors for HEP and Accelerators - Ken Marken (DOE HEP Accelerator R&D) ()
- 09:40 DOE Office of Science SBIRs for Nuclear Physics - Michelle Shinn (DOE NP Industrial Concepts) ()
- 10:10 --- Break ---
- **10:30 HEP-industry partnerships panel** - Gabriella Carini (BNL) (until 12:30) ()
- 10:30 Panel Discussion - Hartmut Sadrozinki (UCSC) Ken Marken (DOE HEP Accelerator R&D) Juan Estrada (Fermilab) Michelle Shinn (DOE NP Industrial Concepts) Aritoki Suzuki Stephen Holland () Submit-a-question

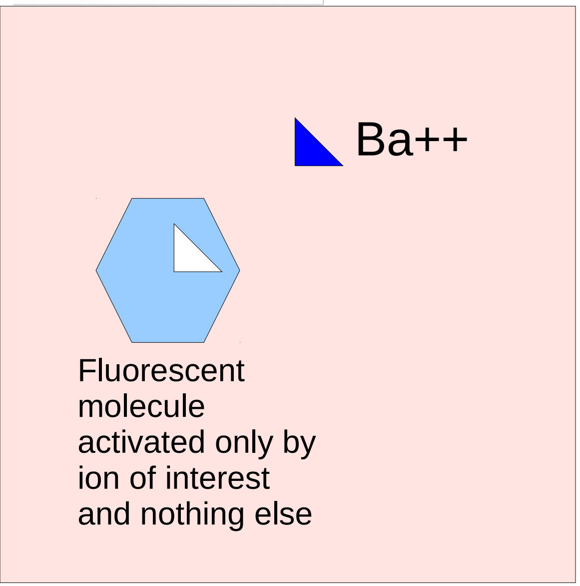
PM

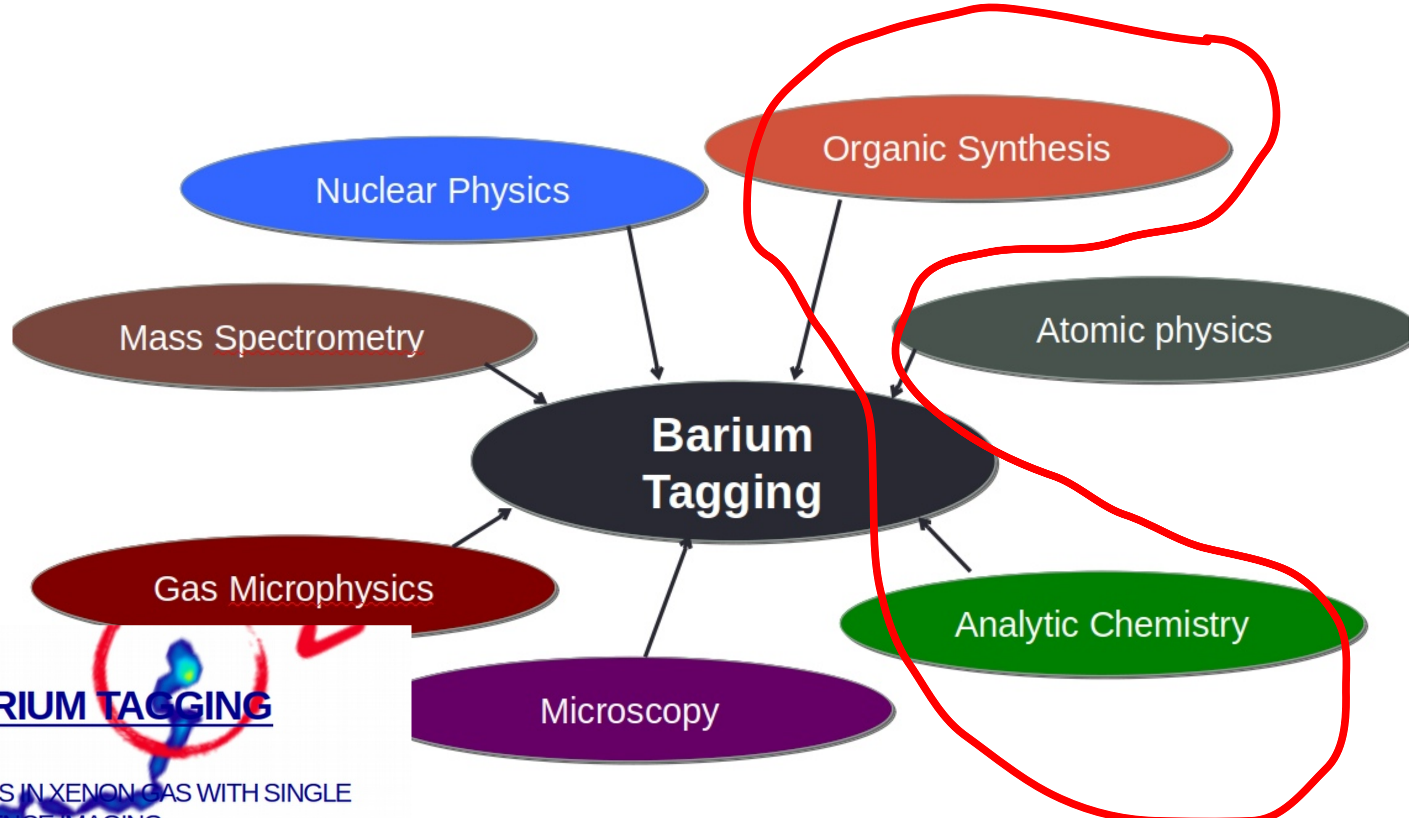


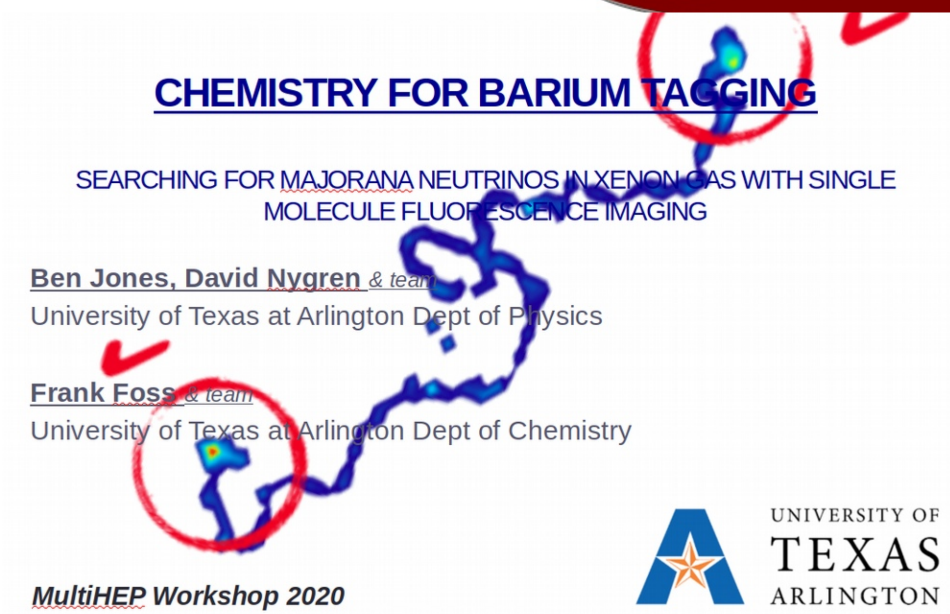
Examples also in this Conference

- Barium Tagging
  - D13.00009 Barium Tagging for NEXT Search for Neutrinoless Double Beta Decay
- LAPPD
  - E11.00006 Results from a recent beam test of a Cherenkov prototype for SoLID
  - L14.00006 Event Classification in ANNIE
  - L14.00008 ANNIE Makes Progress Towards First Neutron Multiplicity Measurement
  - SP01.00062 Early test of photosensors in high rate environment for gas Cherenkov
- Fully depleted CCDs
  - D19.00005 Status of the DAMIC-M Dark Matter Search Experiment
  - H10.00001 Dark Matter Search Results from DAMIC at SNOLAB
  - K18.00005 Measurement of Compton scattering on silicon atomic shell electrons with Skipper CCDs
  - Y06.00002 Dark Energy Survey: Year 3 cosmology from large-scale structure
  - Z08.00004 The Dark Energy Spectroscopic Instrument (DESI)
- Low background materials for underground experiments
  - Too many to list

Development of Barium Tagging







Requires close collaboration with chemists interested in particle physics

Took multiple attempts to find the right match.
People already working on fluorescent imaging less interested.

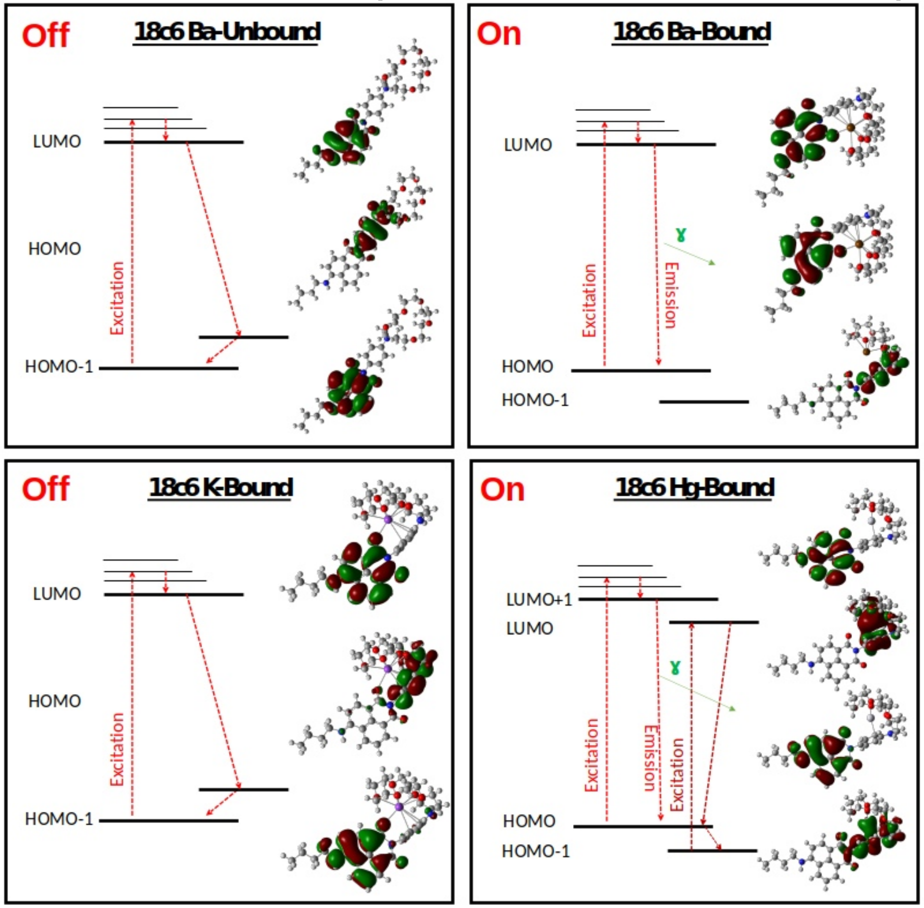
Ba-tagging (cont)

Issues with the FLUO family for dry sensing (bio applications use it in solution)

Nature Sci Rep 9, 15097 (2019)

Initiated a program to design and synthesize SMFI molecules at UTA in collaboration with Foss organic chemistry lab

Serious development in a different discipline



From guesswork to precision molecular design

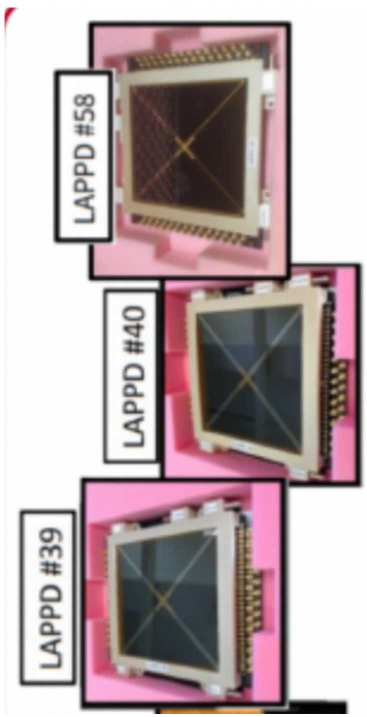
Computations with DFT and TDDFT now allow us to be predictive of which receptor / fluor combinations respond to which ions and why.

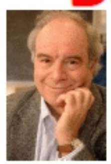
Exploration of a wide space with this tool is ongoing.

arXiv: 2006.09494 (submitted to JACS)

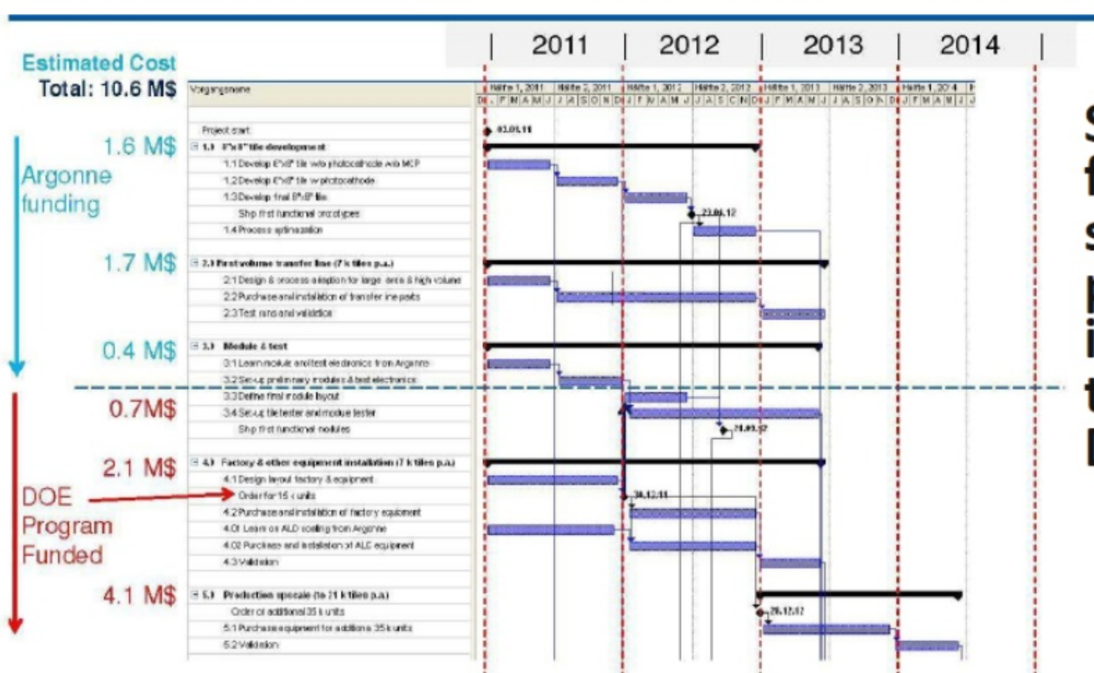
Development of LAPPDs

Large Area Picosecond Photo Detectors
LAPPD project was launched as an R&D project, not small R&D, in 2009, when it was estimated that a 100 kton water Cherenkov detector (LBNE) would need about ~300 $M to buy phototubes





Batch production process/facility development

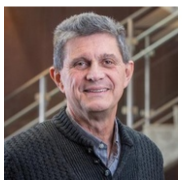


Schedule from a serious proposal by industry at the time of DUSEL

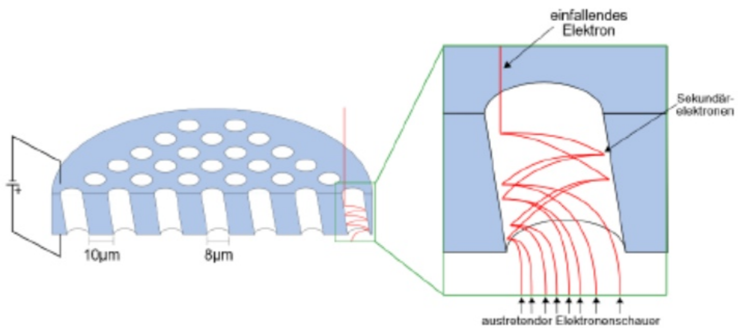
A big flat tile with mm or better position and ps timing resolution for impinging single photons

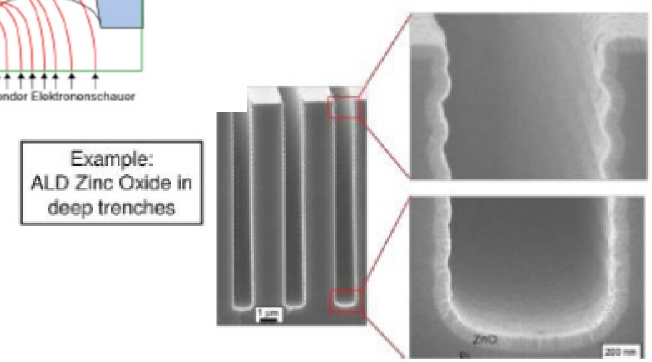
LAPPD from MS to HEP

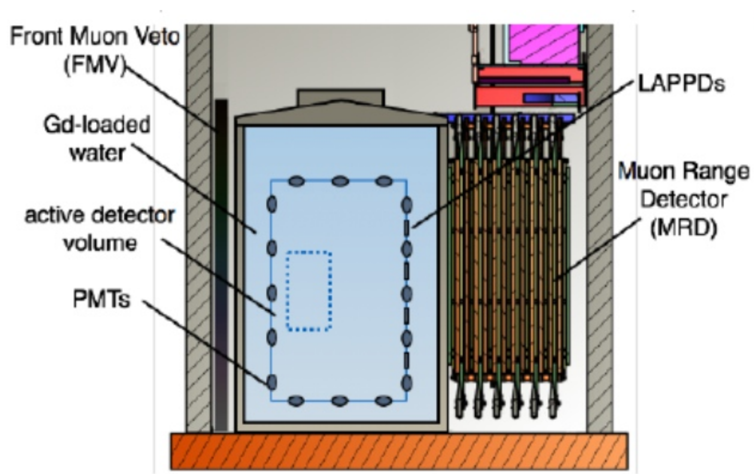
The LAPPD Project succeeded only by the ability to draw on expertise of scientists in a wide range of disciplines and thanks fo DOE-OHEP willingness to fund work across these disciplines



Materials Science Division was responsible for many fundamental discoveries related to energetic particle interactions with surfaces





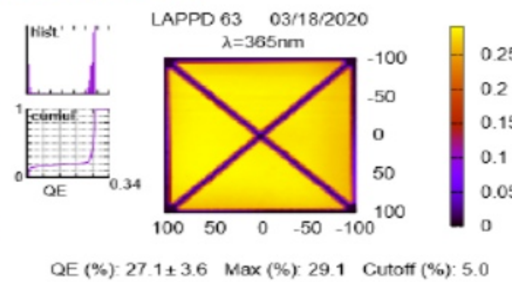


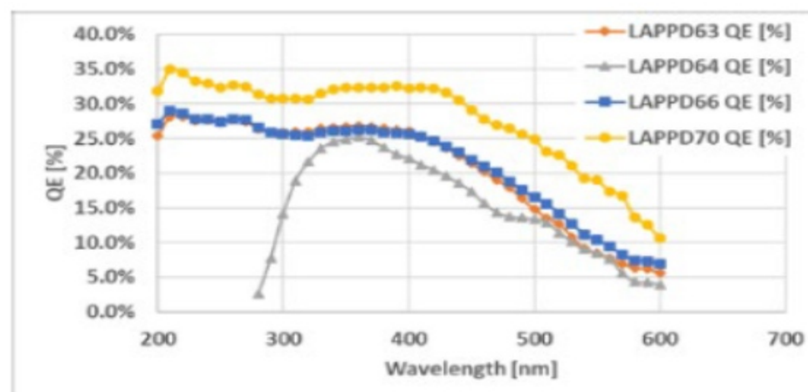
LAPPD Production

Michael Minot, Incom, Inc

LAPPD Attributes & Performance Overview

1. Large active area
   a) 350 cm^2, 92% open area
   b) Planar Design
2. High Gain: mid-10^6 to 10^7 for single PE
3. K_2NaSb PC QE ≈20-30 ⟶ 35% at 365 nm
4. Position resolution: ≤3 mm
5. Time resolution: ≈5.4 - 80 pS, depends on operating point
6. Low Projected Cost / cm^2 - \$58/cm^2 to 79/cm^2.
   a) Hollow-core base-glass MCP Strategy
   b) Braze free, pin free design
   c) Low cost glass body
   d) Labor same for 400 cm^2 device vs. 28 cm^2 device.
   e) Flat low aspect ratio planar design,
   f) On-board read-out electronics





11/10/2020 MultiHEP 2020 Workshop - LAPPD Sensors for HEP NP and PET - Minot, Incom Inc. 1

The biggest challenge is still ahead: achieving economy of scale.
Requires large (by HEP standards) orders from early adopters.

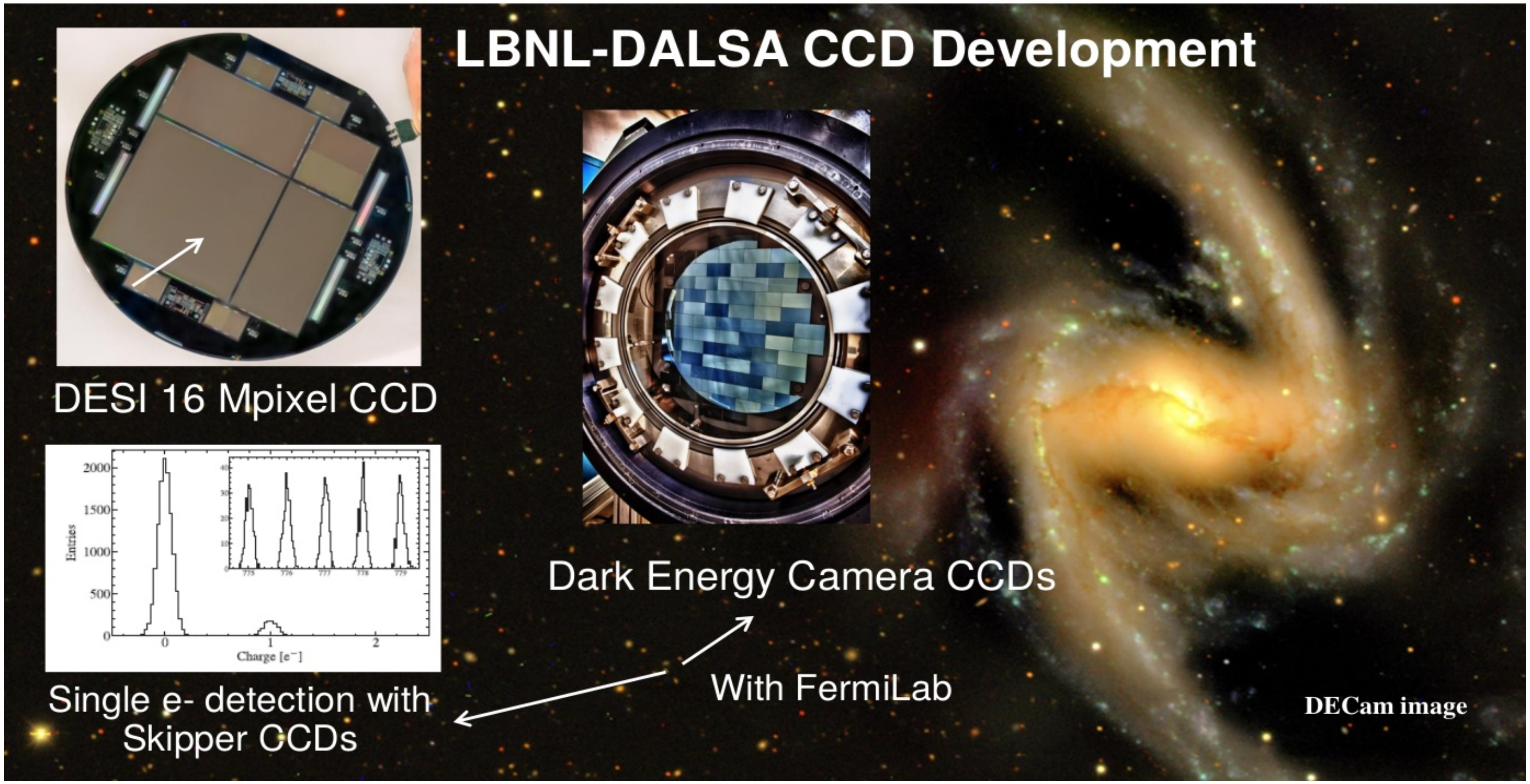
Development of electroformed copper

Copper Type	^{232}Th [pg/g] (*µBq/kg*)	^{238}U [pg/g] (*µBq/kg*)	Source
Best source of C10100 commercial copper found to date	0.46 ± 0.06 (*1.19* ± 0.25)	0.21 ± 0.06 (*2.54* ± 0.74)	Majorana Demonstrator, (PNNL assays) 10.1016/j.nima.2016.04.070
Majorana Electroformed (at PNNL and SURF)	<0.029 (<*0.11*)	<0.008 (<*0.10*)	

Interesting history of how assay and electroforming were developed using equipment and methods from NNSA supported (non-HEP) development.

Fully depleted CCDs

LBNL-DALSA CCDs for DOE projects



- Another great example of HEP-industry partnership
- Following their development at LBNL, the need for industrial production of fully depleted CCDs was recognized early on
- Hut how to identify and interest a company in carrying out the necessary development?

Production of Fully Depleted CCDs

- Jim Janesick had worked with every commercial company willing to attempt to produce CCDs for NASA space missions
  - 1992 paper mentions RCA (later Sarnoff later SRI), Fairchild, Texas Instruments, EG&G Reticon (Gene Weckler), Tektronix (later spun off as SITe / Morley Blouke), Loral (sold several times / Richard Bredthauer)

Astronomical CCD Observing and Reduction Techniques
ASP Conference Series, Vol. 23, 1992
Steve B. Howell, ed.

HISTORY AND ADVANCEMENTS OF
LARGE AREA ARRAY SCIENTIFIC CCD IMAGERS

- Of about 4 choices, only Mitel[1] was a foundry
  - This turned out to be very advantageous
  - Mitel produced 200k wafers per year at that time
    - Production proven technology
  - Mostly process integration of standard process steps
    - High-ρ, float-zone silicon was not standard, though

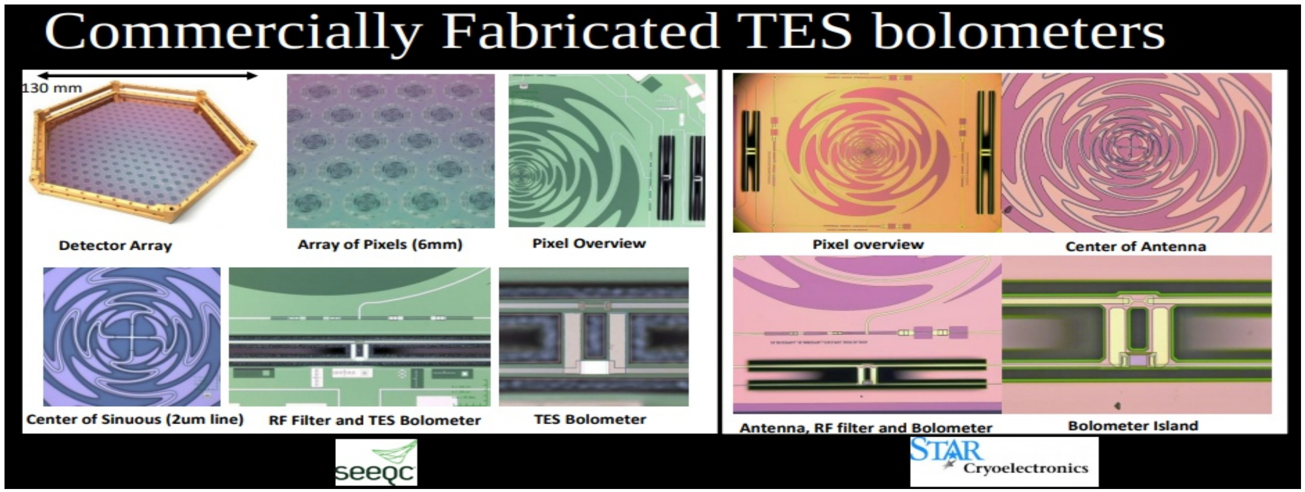
MITEL™ SEMICONDUCTOR   ZARLINK SEMICONDUCTOR

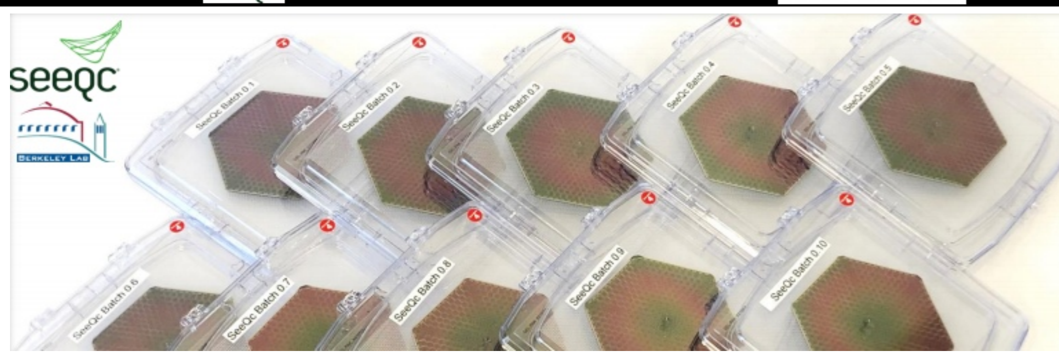
DALSA SEMICONDUCTOR   TELEDYNE DALSA A Teledyne Technologies Company

[1]Mitel became Zarlink became DALSA became Teledyne DALSA

SBIR Program

- Today, finding industrial partners is facilitated by the SBIR program. Which provides funding to companies to work with HEP scientists
- Good example in superconducting device fabrication





- Process: provide input to yearly call for SBIR topics
- If looking for industrial partner to fill a specific need, request to have vendors responding to a topic forwarded to you

Others Points

- Did not cover all examples from the workshop
- Another topic discuss was the multi-disciplinary career path
  - Multidisciplinary development requires people with multidisciplinary skills.
  - But training students and postdocs in 2 disciplines is not without risk:
    - Less competitive than peers in either one of the disciplines
    - Maybe small or zero number of jobs looking for that specific combination
- Research funding coming from one office typically needs to go to people in that area of science. Hard to fund other disciplines from HEP and vice-versa

Conclusion

- Multi-HEP 2020 workshop collected a wealth of information on symbiotic, multidisciplinary collaborations
- True collaborations between scientists from HEP and other disciplines have enabled new HEP instrumentation and experimental techniques
- However, no cookie-cuter formula
  - In all examples, establishing and funding such collaborations took several attempts and perseverance
  - 100% based on matching the right people, with shared interests, and not necessarily the most obvious experts
- Increasing popularity of LDRD program is helping make industrial connections

BACKUP