A Users Perspective on Research and Development

Sarah Demers

53rd Users Meeting

August 11, 2020

Outline

Where we Stand

Being prepared for transformational R&D opportunities

Coordinating Panel for Advanced Detectors
Basic Research Needs Study

Ongoing R&D at FNAL

Lab Directed Research and Development (LDRD)

Planning ahead

Snowmass

Our Challenges

Use the Higgs boson as a tool for discovery

Pursue the physics associated with neutrino mass

Identify the new physics of dark matter

Understand cosmic acceleration: dark energy and inflation

Explore the unknown: new particles, interactions and physical principles

Picosecond timing

Massless tracking

Better calorimetry resolution

Single photon counters

New radiation Hard Materials

Use the Higgs boson as a tool for discovery

Pursue the physics associated with neutrino mass

Identify the new physics of dark matter

Understand cosmic acceleration: dark energy and inflation

Explore the unknown: new particles, interactions and physical principles

Quantum sensors for HEP

Photosensors for extreme environments

Next Generation Superconductors

ASICs in extreme environments

Autonomous Detector Systems

Deep Learning Algorithm Development

Realtime data processing

Ingredients for a healthy future

- Dedicated funding streams for R&D
- User access to facilities
- Support of detector & accelerator development
- Coordination among labs and universities
- Partnerships with industry
- Training and Education programs
- Culture that encourages innovation supports a diversity of new ideas, and learns from roadblocks
- Healthy cross-pollination with other fields
- and more …

Coordinating Panel for Advanced Detectors (CPAD)

Supporting **evolutionary** and **transformative** R&D coordinated across the national labs and universities

Petra Merkle, FNAL

Karsten Heeger, Yale

The creation of an APS DPF Award for Excellence in Instrumentation Research and Development
Graham Smith, Gabriella Sciolla

Input to the yearly SBIR/STTR proposal calls
Clarence Chang, Maurice Garcia-Sciveres, Wesley Smith, Rick van Berg

Creation of a National Instrumentation Fellowship program for both post docs and graduate students
Matt Wetstein, Gabriella Sciolla, Maurice Garcia-Sciveres, Ulrich Heintz, Juan Estrada

Establish an improved model of an equipment pool that could be used for instrumentation development at U.S. universities and labs
Erik Ramberg, Maurice Garcia-Sciveres

Coordination of instrumentation resources at National Labs for the HEP community
Graham Smith, David McFarlane, Erik Ramberg

A program to further develop instrumentation schools and education
Bob Wagner, Rick van Berg, Marina Artuso, Erik Ramberg, Juan Estrada

Develop a plan to establish and maintain a repository of examples of migration of technologies and instrumentation into high-energy physics and new developments that might benefit HEP
Ron Lipton, Clarence Chang

Continuation and organization of an, at least, annual national instrumentation workshop for HEP & enhancement of interdisciplinary aspects of instrumentation
Ulrich Heintz, Ron Lipton, Bob Wagner, Matt Wetstein, Rick van Berg

https://www.anl.gov/hep/coordinating-panel-for-advanced-detectors

The DOE OHEP BRN Study on HEP Detector Research and Development

At the DPF meeting in Boston in August, 2019 the DOE Office of High Energy Physics (HEP) announced a Basic Research Needs (BRN) Study on HEP Detector Research and Development (R&D).

The Chairs of the BRN Study:
Bonnie Fleming (Yale), Ian Shipsey (Oxford)

The DOE BRN Study liaisons:
Glen Crawford (DOE), Helmut Marsiske (DOE)

Thanks to Bonnie and Ian for the following few slides from their presentation to HEPAP

Four Grand Challenges encompass this Instrumentation revolution

Advancing HEP detectors to new regimes of sensitivity: *To make the unmeasurable measurable will require the development of sensors with exquisite sensitivity with the ability to distinguish signal from noise…. Research will be needed to develop these sensors with maximal coupling to the quanta to be sensed and push their sensitivities to ultimate limits.*

Using Integration to enable scalability for HEP sensors: *Future HEP detectors for certain classes of experiments will require massive increases in scalability to search for and study rare phenomena ... A key enabler of scalability is integration of many functions on, and extraction of multidimensional information from, these innovative sensors.*

Building next-generation HEP detectors with novel materials & advanced techniques: *Future HEP detectors will have requirements beyond what is possible with the materials and techniques which we know. This requires identifying novel materials … that provide new properties or capabilities and adapting them & exploiting advanced techniques for design & manufacturing.*

Mastering extreme environments and data rates in HEP experiments: *Future HEP detectors will involve extreme environments and exponential increases in data rates to explore elusive phenomena. ... To do so requires the intimate integration of intelligent computing with sensor technology.*

Charge, audience and goals

- Survey the present state of the HEP technology landscape.
- Identify key capabilities & performance requirements.
- Identify technologies to provide or enhance such capabilities.
- Articulate PRDs to push well beyond the current state of the art, potentially leading to transformative technological advances with broad-ranging applicability.
- Flesh out required R&D efforts with deliverables with notional timelines & key technical milestones. Elucidate the technical infrastructure required to support these efforts.
- Formulate a small set of instrumentation Grand Challenges that could result in game-changing experimental capabilities.

10 Basic Research Needs Study Charge

Department of Energy
Office of Science
Washington, DC 20585

10 July 2019

DRAFT

MEMORANDUM FOR HELMUT MARSISKE

FROM: GLEN CRAWFORD
DIRECTOR, RESEARCH AND TEC[illegible]NOLOGY DIVISION
OFFICE OF HIGH ENERGY PHY[illegible]ICS (HEP)

SUBJECT: Basic Research Needs Study o[illegible] Detector Re[illegible]arch and Development

I request that you organize and carry out a Basic Research Needs (BR[illegible] [illegible]udy to assess the present status of the HEP technology land[illegible]e, and to identify strategic [illegible]nology areas, aligned with the strengths of the US comm[illegible] future long-term resea[illegible]d development (R&D) efforts should focus on in pursuit of [illegible]he HE[illegible]nce drivers identifie[illegible] in the P5 report. For each of these areas, the study should artic[illegible]late and ju[illegible] set of Priority Research Directions (PRDs) to push the technology well beyond [illegible] curr[illegible] of the art, potentially leading to transformative advances with broad-r[illegible]ngin[illegible] applicability [illegible] HEP and beyond. Furthermore, the study should identify a small set [illegible] high-impact instrumentation "Grand Challenges" where te[illegible] breakthroughs co[illegible]ld lead to game-changing experimental capabilities in pur[illegible]it of HEP s[illegible]nce goals.

You should [illegible] co-chairs to le[illegible]d the study and wor[illegible] with them to select the core group of working group le[illegible] to carry i[illegible] out. T[illegible]udy enc[illegible]mpasses responses to the specific charge elements elucidated [illegible] and is expecte[illegible] take several months to complete. A focal point of the study should inclu[illegible] workshop, with attendance beyond the core group, expected to be held in [illegible] 2019 time fr[illegible] in the Washington, DC area. The study participants are to serve by invitation o[illegible]

The HEP Detector [illegible]&D program [illegible]ims to develop cutting-edge, novel instrumentation to enable scientific leadership [illegible] a worldwide experimental program that is broadening into new research areas with ever increa[illegible]ng demands in sensitivity, scale, and cost. To meet this challenge, HEP [illegible]ms to execute a pro[illegible]am appropriately balanced between incremental, near-term, low-risk d[illegible]tor R&D and tr[illegible]sformative, long-term, high-risk detector R&D.

With t[illegible] [illegible]ear-te[illegible] technical challenges of current high-priority P5 projects subsiding, the HEP Detector [illegible] program aims to shift more emphasis towards building a long-term, high-risk high-rewar[illegible] ("Blue Sky") R&D portfolio that holds the promise of transformative advances with broad-ranging applications across HEP as well as other fields of science, medicine, and national security. Crucially, the program must take full advantage of the major advances happening in

Charge, audience and goals

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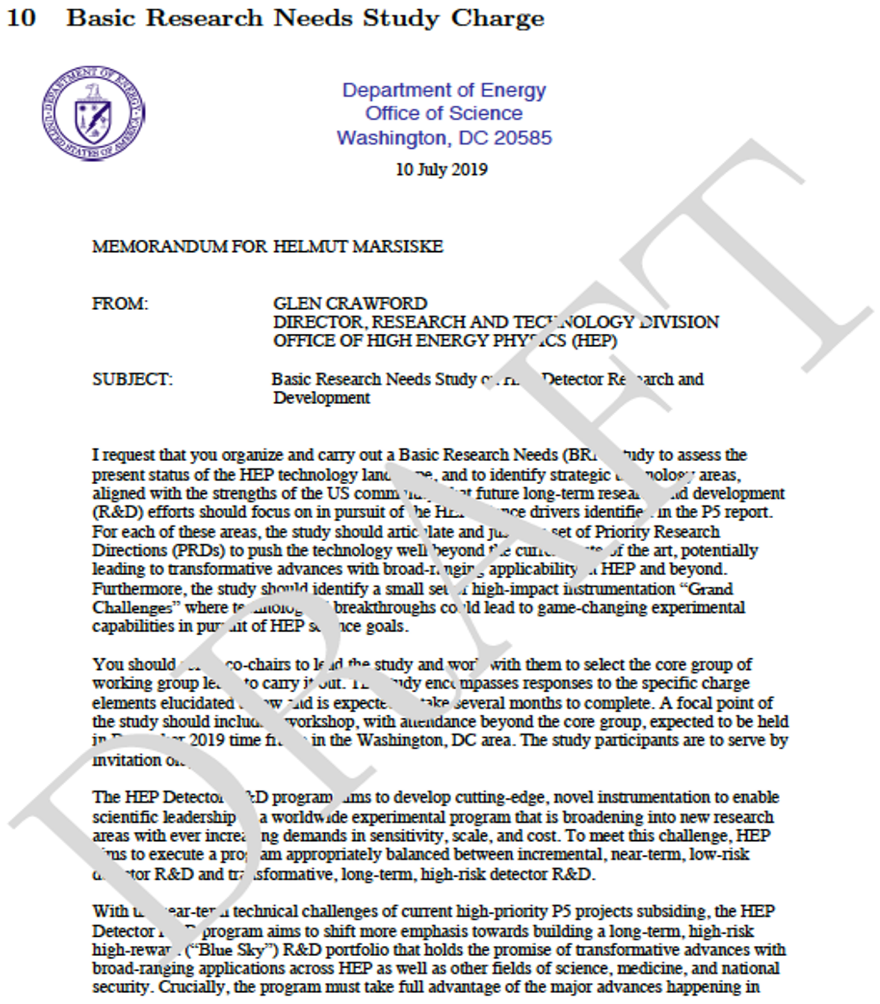
detector R&D

Along with the five science drivers, the 2014 P5 report identifies the importance of Instrumentation R&D in one of its highest level recommendations where it calls for a “balanced mix of short term and long-term R&D" in the current era.



10 Basic Research Needs Study Charge

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The BRN does:
•Describe SCIENCE OPPORTUNITIES
& TECHNOLOGIES
TO REALIZE THEM

(The BRN does not:
•Rank PRD opportunities)

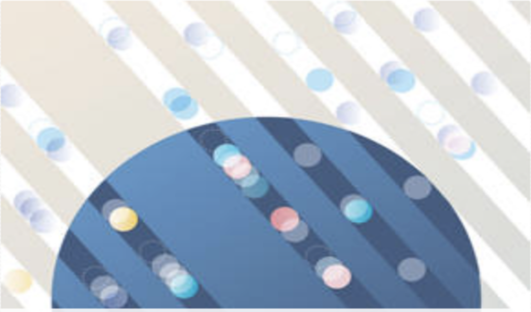
Report should speak to the scientific community, the public, and decision makers

Science opportunities drive the next generation of experiments.

5 Science Panels

The Higgs as a tool for discovery

Conveners:
Jim Hirschauer (FNAL)
Gabriella Sciolla (Brandeis)

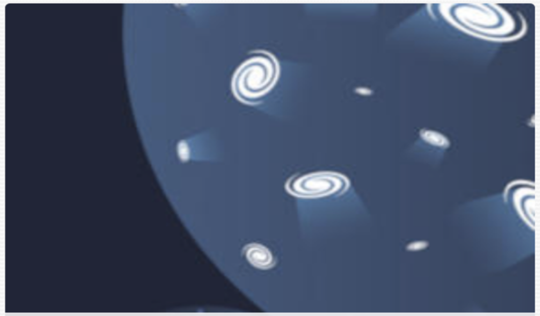


The physics of neutrino mass

Conveners:
Ornella Palamara (FNAL)
Kate Scholberg (Duke)

The new physics of dark matter

Conveners:
Jodi Cooley (SMU)
Dan McKinsey (Berkeley)



Cosmic acceleration: inflation and dark energy

Conveners:
Clarence Chang (ANL)
Brenna Flaugher (FNAL)

Exploring the unknown: new particles, new interactions and physical principles

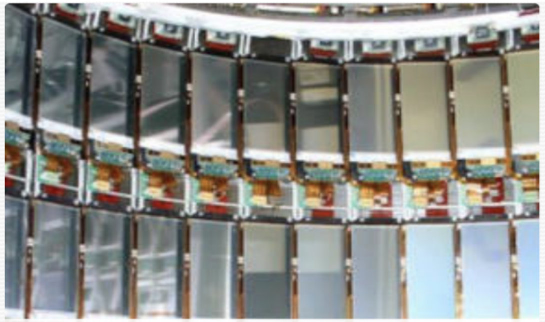
Conveners:
Sarah Demers (Yale)
Monica Pepe-Altarelli (CERN)

An instrumentation revolution is critical to future discoveries

7 Technology

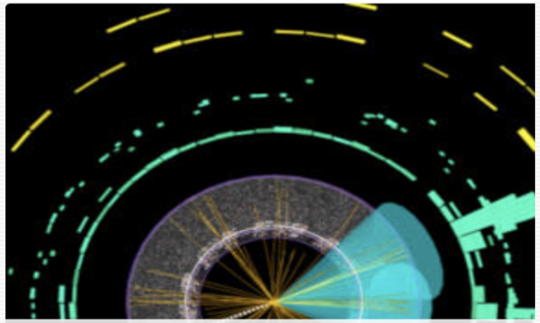
Quantum Sensors

Conveners:
Andy Geraci (Northwestern)
Kent Irwin (Stanford)



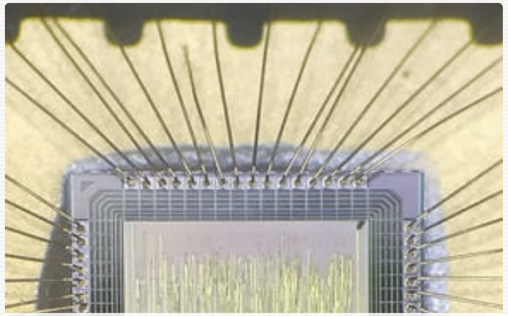
Solid State (including vertexing and tracking)

Conveners:
Marina Artuso (Syracuse)
Carl Haber (LBNL)



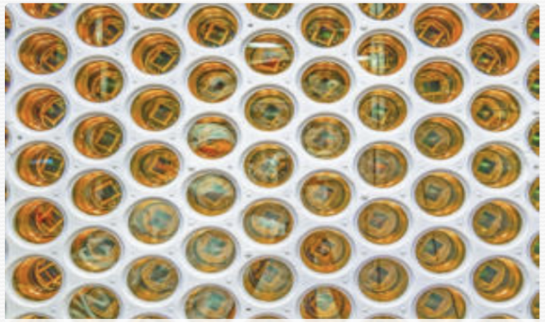
Calorimetry

Conveners:
Francesco Lanni (BNL)
Roger Rusack (Minnesota)



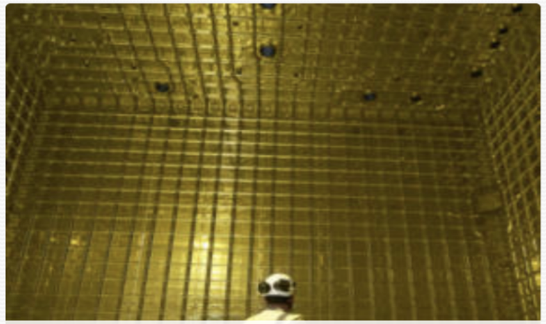
Readout & ASICs

Conveners:
Gabriella Carini (BNL)
Mitch Newcomer (Penn)



Photodetectors

Conveners:
Lindley Winslow (MIT)
Peter Krizan (Jožef Stefan Institute)



Noble Liquids

Conveners:
Roxanne Guenette (Harvard)
Jocelyn Monroe (RHUL)

TDAQ (including Machine Learning)

Conveners:
Darin Acosta (Florida)
Tulika Bose (Wisconsin)

There is also a cross-cutting group.

Cross Cut

Conveners:
Marcel Demarteau (ORNL)
Abe Seiden (UCSC)

Study Process and timeline

Summer 2019: DOE charged co-Chairs. Conveners, panel members and additional members identified.

Fall 2019: Regular telecons began to conduct the ground work leading up to December BRN workshop.

Interim report laid the foundations of the panel's work and informed interactions at CPAD

December 11-14, 2019: BRN Workshop in the Washington D.C. area. The workshop was attended by all BRN Study members and a number of observers: DOE Program Managers from HEP and related programs, and from NSF. The plenary talks on the first day were live-streamed to the community.

July 2020: Presentation to HEPAP

Study hallmarks

- Close interaction between physics and technology groups.
- Cross cutting group across all areas to identify foundational issues and synergies
- Community input through CPAD, community surveys, town hall meetings, small targeted workshops

Report will be available within the next few days!

Lab Directed Research and Development (LDRD)

Fermilab has instituted a Laboratory Directed Research and Development program as outlined by DOE Order O413.2C in order to support employee initiated proposals that are novel, cutting edge, and explore forefront areas of science and technology. The program will enhance the Laboratory's ability to carry out the mission of DOE and the Laboratory in areas that are outside current programmatic activities but are well-aligned with the strategic goals of the Laboratory.

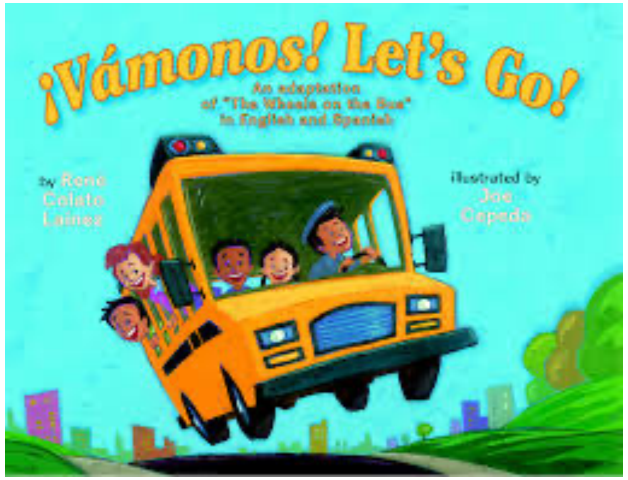
- **What LDRD can be used to support**
  - Advanced study of hypotheses, concepts, and innovative approaches to scientific, technical, or computational problems
  - Experiments, theoretical studies, simulations, and analyses directed toward "proof of principle" or early determination of the utility of new scientific ideas, technical concepts, and devices or research tools
  - Concept creation and preliminary technical analyses of advanced, novel experimental facilities and devices or of facilities for computational science.
- **What LDRD is unable to support**
  - R&D that is already part of programmatic activity / existing project
  - R&D that requires non-LDRD funds to complete

https://fermipoint.fnal.gov/project/LDRD/SitePages/Home.aspx

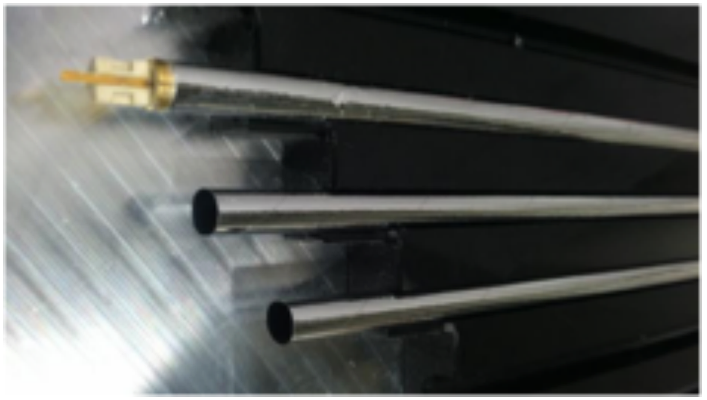
A few examples of some LDRD-funded work

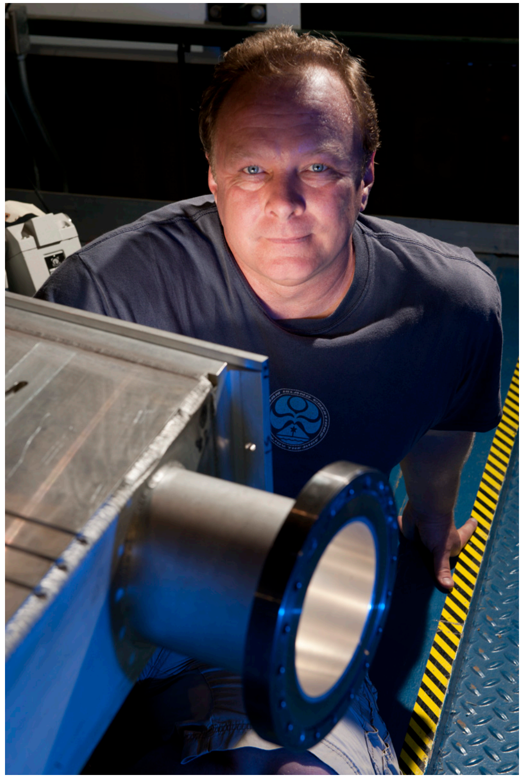
- We only have time for a few examples of the ongoing R&D work at FNAL, which is a good sign!
  - Apologies if I do not mention your favorite project

- The LDRD program is only one component of the lab infrastructure that enables research
  - Also critical are the test-beam facilities, computing infrastructure, scientist & engineering & technical support, partnerships with other labs and universities, URA visiting fellows programs, DOE graduate student support programs at labs, URA awards…



Project ID: FNAL-LDRD-2020-037
Project title: Development of straws for an ultra-low mass tracker in preparation for Snowmass 2021
Principal investigator: Brendan Casey

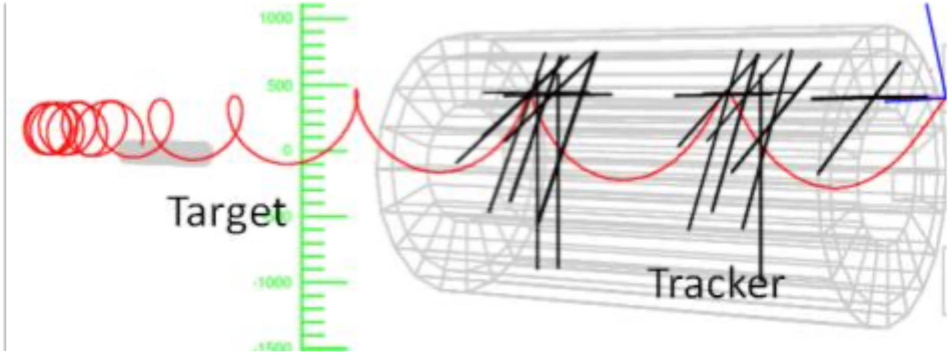




Experiments like Mu2e that search for new physics via rare processes with large backgrounds may rely on precision measurements of particle trajectories to separate signals from backgrounds.

Multiple scattering and **energy loss** in the tracking detector are the enemy.

Reducing tracker material is a critical step toward next-generation experiments.

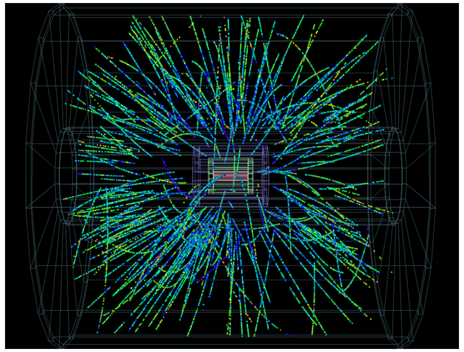


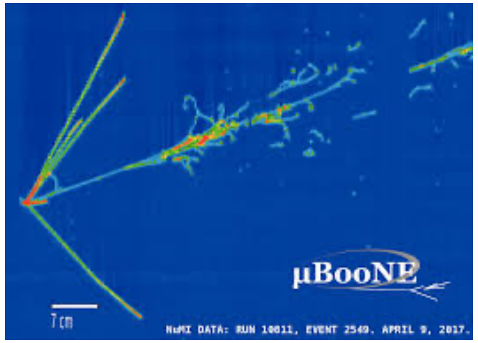
Project ID: FNAL-LDRD-2018-006
Project title: Modeling Physical Systems with Deep Learning Algorithms
Principal investigator: Brian Nord

Fermilab's AI Project

"Cosmology and astrophysics is undergoing yet another phase transition in both the quantity and complexity of data generated from observations and simulations."

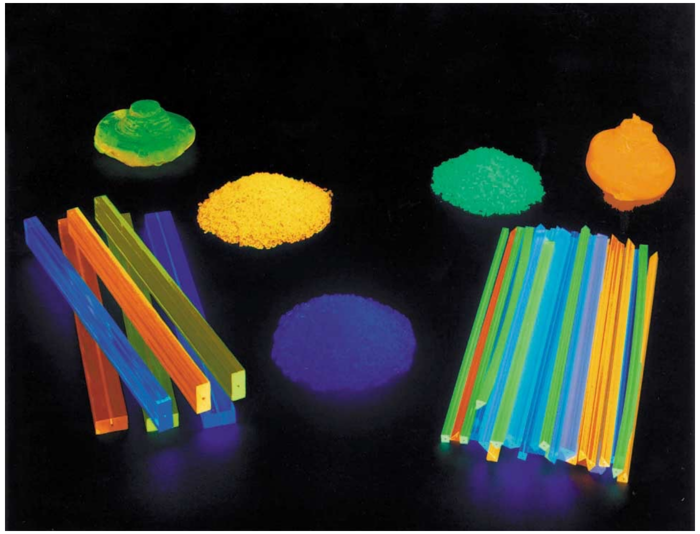
Project aims to use Deep Learning to "extract physical parameters from unprecedently large datasets" with a focus on cosmology. But the pursuit of using ML algorithms is shared across the frontiers explored in HEP, from extracting information from an almost-saturated environment at the CERN's future High-Luminosity Large Hadron Collider to reconstructing events in Liquid Argon Time Projection Chambers at DUNE.

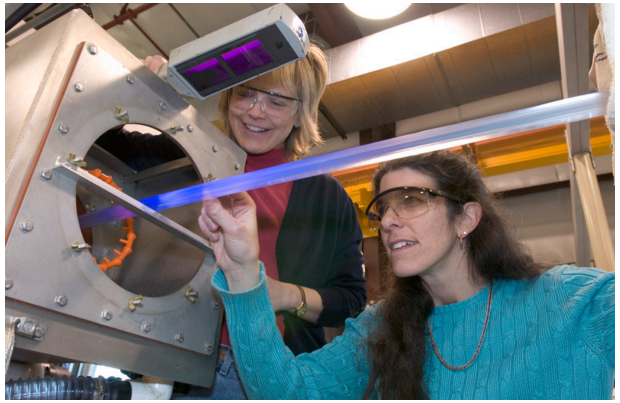




Project ID: FNAL-LDRD-2020-035
Project title: Injection-molded plastic scintillator
Principal investigator: Anna Pla-Dalmau

"This project aims to (i) improve the light yield of injection-molded scintillator and to (ii) develop a manufacturing process to produce large quantities of small plastic scintillator elements with volumes of 1 cm3 to 50 cm3 which could be appropriate for new high-granularity detectors such as the CMS High Granularity Calorimeter and the DUNE Near Detector scintillator tracker."



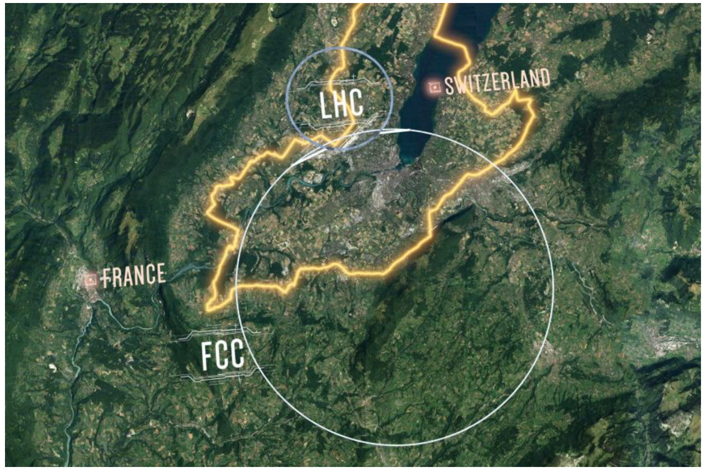


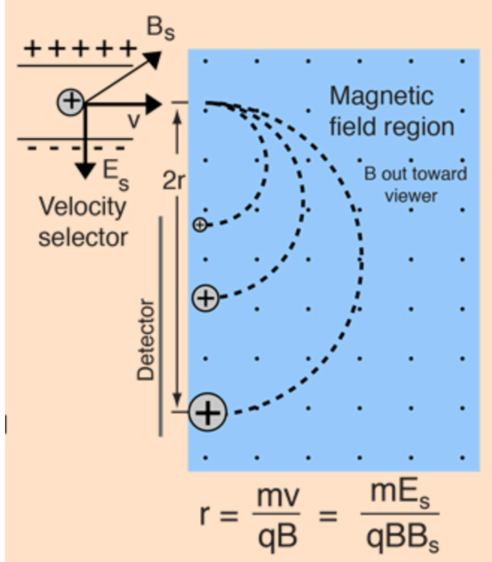
Project ID: FNAL-LDRD-2020-027
Project title: UV Light Detection with Thin Films of Amorphous Semiconductors for Imaging with Liquid Argon Scintillation Light (LILAr)
Principal investigator: Elena Gramellini

"This project will characterize the photoemission of different amorphous semiconductors and dopant cocktails for both visible and VUV light at cryogenic temperatures, finding a suitable material candidate for the detection of scintillation light in liquid Nobel elements…The goal is to obtain a signal compatible with innovative liquid argon pixel readout technologies such as Qpix or LArPix and to develop a first light detection prototype."

Project ID: FNAL-LDRD-2017-020
Project title: Development of next-generation Nb3Sn superconductors for accelerator magnets
Principal investigator: Xingchen Xu

Aims to "develop a new generation of Nb3Sn conductors with significantly enhanced performance for superconducting magnets. Such conductors cannot only increase the achievable field of accelerator magnets (to 16 T and above) and hence boost particle collision energy in search for new physics, but also greatly reduce their costs."





SnowMass2021

Welcome to Snowmass 2021

Snowmass

The US particle physics planning exercise is underway!

The Snowmass Instrumentation Frontier (see tomorrow's panel for more information and to learn how to get involved!) is a critical piece of the planning needed to support R&D for our field's future!

Instrumentation Frontier Groups

IF1: Quantum Sensors

IF2: Photon Detectors

IF3: Solid State Detectors and Tracking

IF4: Trigger and DAQ

IF5: Micro Pattern Gas Detectors (MPGDs)

IF6: Calorimetry

IF7: Electronics/ASICs

IF8: Noble Elements

IF9: Cross Cutting and Systems Integration

A closing question

Do we have the infrastructure that we need --
facilities, processes, incentives, resources, culture
-- to support the R&D that will enable
future discoveries?

A closing challenge

It is up to **all of us** to be good stewards of our current resources/facilities and even better planners if we want to become better acquainted with our Universe!