



Status of Fermilab Detector R&D Program

Petra Merkel – Fermilab Detector R&D Coordinator

Fermilab PAC Meeting

July 30th 2020

Outline

- Program Overview
- New 5-year Strategic Plan
 - New high-priority R&D areas
 - Alignment with BRN for Detectors
 - Program prioritization
- Selected R&D updates
- Connection to community planning and Snowmass

- **Organization:**

- Detector R&D Coordinator: Petra Merkel
- Detector Advisory Group: ~15 experts of different detector technologies across the lab, including 2 external advisors
- Meet bi-weekly to discuss ongoing R&D efforts, new proposals, coordination issues, budget, strategic and tactical investments
- Detector R&D [website](#)

- **Updates since last report:**

- Developed 5-year strategic plan for Detector R&D
- Defined high-priority R&D thrusts aligned with recent DOE BRN for Detectors and with Fermilab's mission, facilities and expertise
- Integrated with annual lab planning (IPPM)
- Initiated call for competitive start-up R&D proposals ("New Initiatives")
- Engaging in quarterly tele-conferences with DOE program manager for detectors and with the other national labs

5-year Strategic Plan for Detector R&D

- A new 5-year strategic plan has been developed
 - well aligned with the four Grand Challenges identified in the recent BRN for Detectors (to be published in July):
 - Advancing HEP detectors to new regimes of sensitivity
 - Using integration to enable scalability for HEP sensors
 - Building next-generation HEP detectors with novel materials and advanced techniques
 - Mastering the challenges of extreme environments and data rates in HEP experiments
- We will strategically boost efforts in the areas of **Picosecond Timing** and **Noble Element Detectors**
- Will increase Blue Sky R&D
- Funding for other Detector R&D has to decrease

New Initiatives

We initiated a new competitive call for proposals, the New Initiatives, with the aim to attract new members and new ideas to the detector R&D community at the lab.

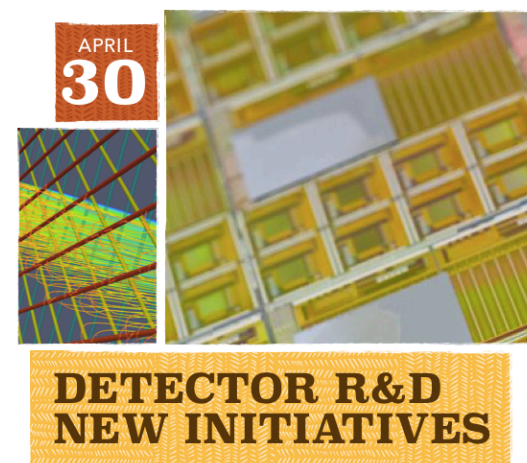
This call is directed towards the newly identified strategic areas. There has been great resonance to this new call, which will enable PIs to perform demonstrator stages of their ideas. This in turn could subsequently enable them to successfully apply for additional funding, such as LDRD, ECA, etc.

New Initiatives

The detector R&D group is seeking proposals for new initiatives in detector R&D. While all Blue Sky ideas are considered, priorities are given for ideas aligned with the strategic directions of the group in Pico Second Timing and Noble Element Based detectors, including light and charge collection.

The magnitude of this seeding support is on the order of \$50k without overhead. It is meant to give an opportunity to test initial ideas before applying for larger supports like the LDRD.

Applications are made in a form of a one page proposal to the Detector Advisory Group by **April 30th, 2020** in an email to petra@fnal.gov. It should include the scientific motivation, R&D goals and plans to be achieved in a year as well as the budget needs. Eligible PIs have to be Fermilab employees.



2020 Winners of New Initiatives

Initial evaluation of electron proportional scintillation in xenon-doped liquid argon using thin wires

PI: Wei Mu (Fermilab)



Wei Mu

This effort aims to achieve charge lead to simplified designs of liquid argon TPCs. Limitations due to the extraction of surface does not need to be cross proportional scintillation process. Ionization scintillation requires a lower electric field. The anode and potential bubbles will lower the energy threshold of low-energy particle physics.

Using MicroBooNE to uniquely study doping large liquid-argon TPCs

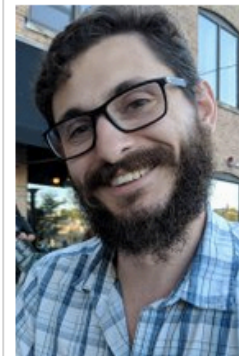
PIs: Andy Mastbaum (Rutgers University), Matthew Touns (Fermilab), Joseph Zennaro, (Fermilab)



Andrew Mastbaum



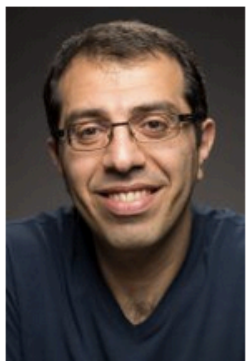
Matthew Touns



Joseph Zennaro

Advanced silicon timing sensors for future trackers

PIs: Artur Apresyan, Karri DiPetrillo, Ryan Heller (all Fermilab)



Artur Apresyan



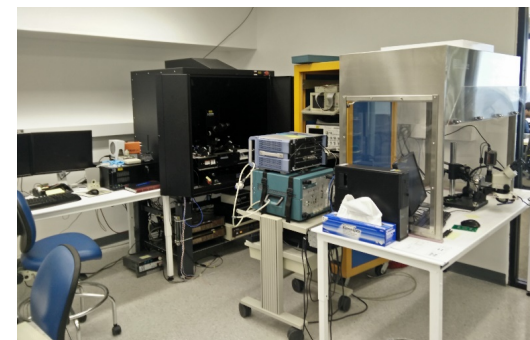
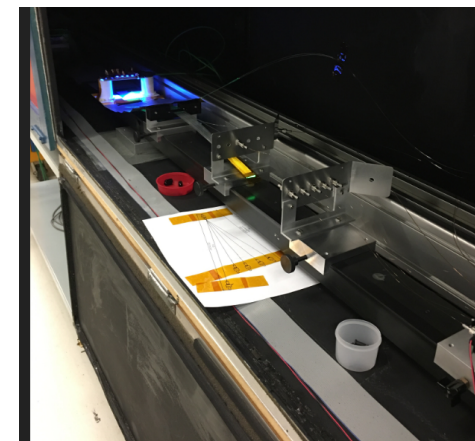
Karri DiPetrillo



Ryan Heller

Detector Facilities and Infrastructure

- Common Detector Test Facility Systems
 - Silicon Detector Facility
 - Precision Metrology
 - Scintillation Detector Development Facility
 - Thin Film Facility
 - Noble Liquid Detector Development
 - Rapid Prototyping and Special Materials
- ASIC Development Facility
- Fermilab Test Beam Facility (FTBF)
- Irradiation Test Area (ITA)



Promote and benefit from partnership with universities and other national laboratories. Previous construction projects at Fermilab either created or contributed to these facilities enabling subsequent Projects and research efforts to capitalize on these investments. Current projects and laboratory operations co-fund these facilities.

Selected R&D Updates: ASIC Group

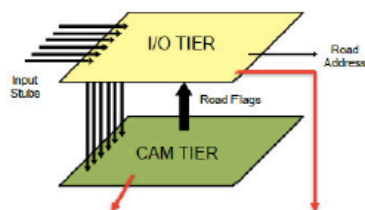
VIPRAM L1CMS Bump Bonding

• Research Goal:

- Development of High-Density Wafer-to-Wafer Interconnects for 3D Circuits
- Technology required for next-generation of on-detector pattern recognition for high-rate experiments → **Critical Technology Development**

• VIPRAM (Vertically Integrated Pattern Recognition Associative Memory)

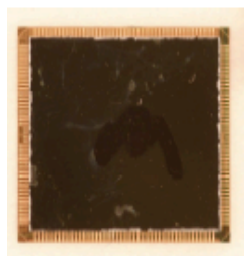
- Develop 3D vertical integration technology to build faster and denser Associative Memory devices
- Goal: 3D bond CAM (Content Addressable Memory) chip to I/O tier
- Original intent: use wafer-to-wafer DBI through Tezzaron, but were not successful
- Back-up plan: Dice wafer, and bond together face-to-face using bump bonding → **Done**



VIPRAM Dies



VIPRAM Concept



Bump Bonded VIPRAM with PRAM on top



• Status:

- Wafers have been fabricated → **Done**
- Attempts to do DBI wafer-to-wafer bonding through Tezzaron failed
- Have contracted with CVInc to dice chips and bond face-to-face → **Done**
 - Produced 9 bonded dies
 - Sent for packaging → **Done**
 - Have produced test board → **Done**
 - Testing at Fermilab is imminent
 - Several pairs remaining to be completed at CVInc

• Outlook

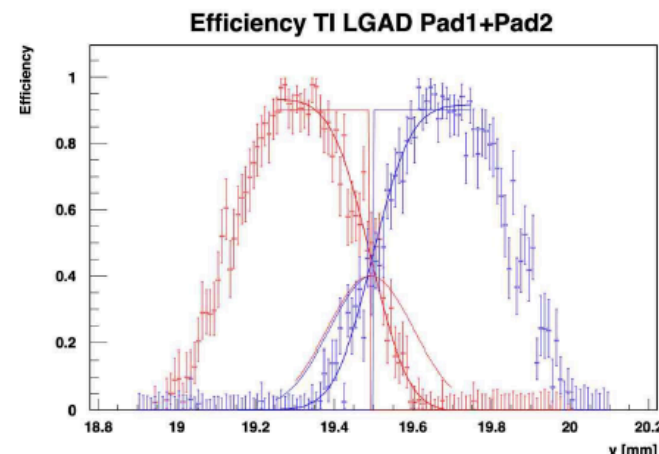
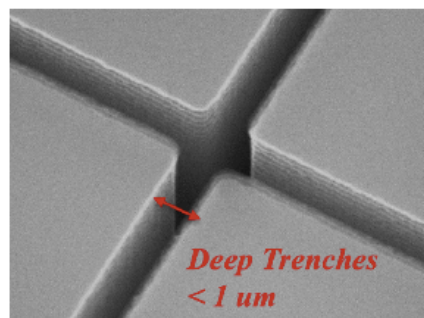
- Chips in hand
- Test board built; software & firmware complete
- ~2-3 person-months of effort
- Goal is to try to complete in FY20

Selected R&D updates: LGADs

- Picosecond Timing sensors for future collider detectors
 - Current challenges: rad hardness, fill factor/pixel size

Trench LGADs

- Another approach to reduce the dead space on LGADs
 - New LGAD technology proposed by FBK:
 - trenches as isolation structures between LGAD pixels
 - Trench isolation already successfully used in FBK HD/UHD SiPMs
- Nominal inter-pixel gain-loss region could be few μm :

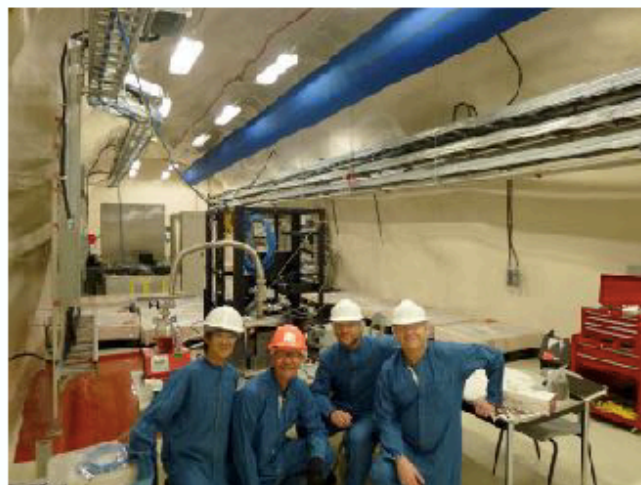
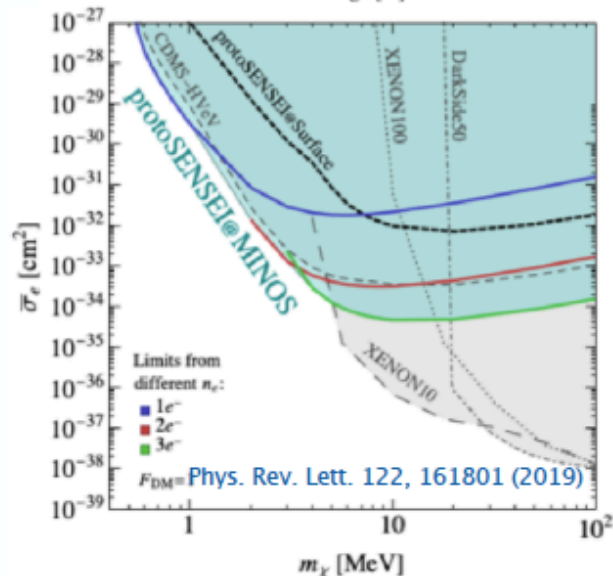
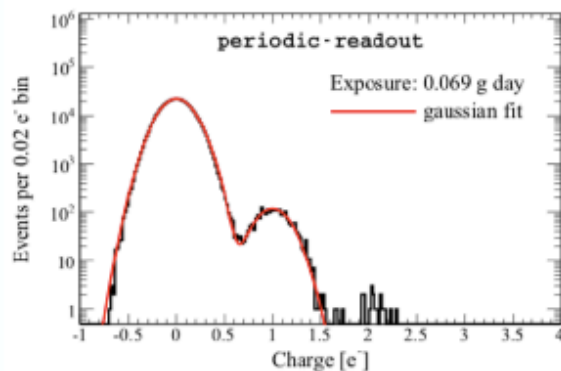


Measurements in FTBF: Trench interpad about 6 μm

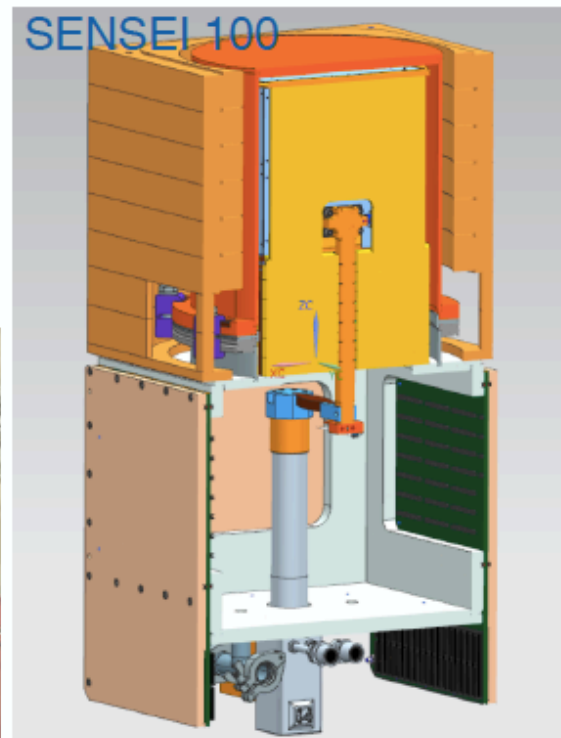
Selected R&D updates: Skipper-CCDs



SENSEI prototype is running in MINOS and producing science results. Leading limits on e-recoil dark matter.



During December we installed the first skipper-CCD at SNOLAB. Results coming soon! (2.5 g active mass)



Design for the 100g experiment is done, and order for parts are placed.



Multi skipper-CCD modules for SENSEI-100 currently being tested at SiDet, with great success.

Selected R&D updates: QPIX

Pixelated Lar Detector Readout (QPIX)

• Opportunity

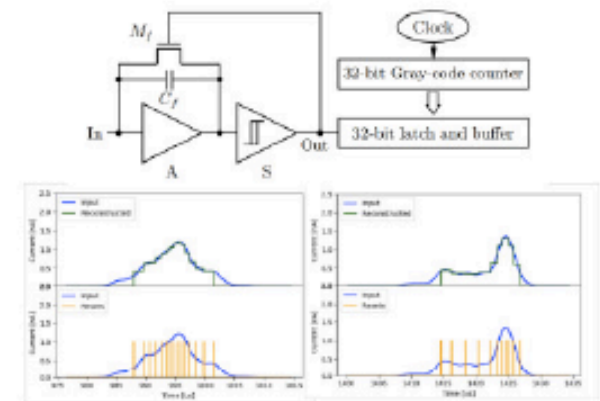
- Work is in progress to define a 4th detector for DUNE → “Module of Opportunity”
- Highly pixelated TPC is being proposed
- Requires a readout ASIC → QPIX
- Requirements a good match for FNAL ASIC design

• Chip Requirements

- Amplifier+Discrim+Latch+Counter
- Amplifier is self-resetting – requires very low leakage current, or current-cancelling techniques
- Clock Distribution Counter are complex
- Requires high-reliability, low-power
- Final system will have ~millions of channels
- Must operate at Lar temperatures

⇒ **Good match for FNAL Expertise & Experience**

From DOE Proposal, “QPix: Achieving kiloton scale pixelated readout for Liquid Argon Time Projection Chambers”



Primary Task	Lead Institution	Partner University Group(s)	Partner Lab(s)
Physics Sensitivity Studies	Harvard	UTA, Texas A&M	Oak Ridge, Argonne
Readout and Detector Simulation	Texas A&M	UTA, Penn, Harvard	LBNL
Front End Development	Penn	UTA, Hawaii	Fermilab, LBNL
Oscillator / Network / Readout	Hawaii	Penn	Fermilab
Photon Detection	UTA	Harvard	Argonne, Fermilab, Oak Ridge
Teststands / Mechanics	UTA	Harvard, Penn	Argonne, Fermilab, Oak Ridge

• Outlook

- Simulation work is in progress now by collaborators
- Opportunity now for R&D to develop “proof-of-principle” chip
- Experience with DUNE Cold ASICs, 65 nm, leakage current cancellation, and discriminators could be leveraged to help develop this concept

Publications and Student Involvement

- Fermilab has continued its efforts to collaborate with university partners and other laboratories on various R&D topics. In total about 35 undergraduate and graduate students, as well as summer interns, both domestic and international, have participated in our KA25-funded research over the last year.
- Selected Publications:
 - “Fast timing with induced current detectors”
<https://doi.org/10.1016/j.nima.2019.162423>
 - “SENSEI: Direct-Detection Results on sub-GeV Dark Matter from a New Skipper-CCD” <https://arxiv.org/abs/2004.11378>
 - “Absolute measurement of the Fano factor using a Skipper-CCD”
<https://arxiv.org/abs/2004.11499>
 - “Low Threshold Acquisition controller for Skipper CCDs”
<https://arxiv.org/abs/2004.07599>
 - “Differences in the response of two light guide technologies and two readout technologies after an exchange of liquid argon in the dewar”
<https://arxiv.org/abs/1912.05987>

Role of FNAL within Community

- Aiming to be effective partners in Snowmass/P5 process

- Fermilab Scientific Advisory Council is organizing strategic lab planning process for 2026 and beyond, also for detectors.
- Expecting 30+ white papers on instrumentation out of Fermilab
- P.M. is also Snowmass Instrumentation Group co-convener

- Some of the envisioned contributions:

4D-tracker R&D, Light and charge pixel readout of large LArTPCs, NIR in LAr, Doping in LAr, Stable avalanche gain in LAr, Straw tracker R&D, Magnetizing LAr, Induced current silicon detectors, AC buried layer LGADs, High-speed links, Quantum dot scintillators, HV in LAr, Power over fiber, Silicon sensors for 5D calorimeters, Intelligent on/off-detector real-time electronics using ML, Hydro-X: hydrogen dissolved in LXe, SBC: superheated scintillating argon, New materials for particle detection, Silicon detectors with non-destructive readout for DM and neutrinos, Skipper-CCDs optical and NIR, Axions instrumentation, MKIDs for CMB, MKIDs for optical and NIR astronomy, Readout and control of superconducting detectors, Scintillator extrusion for mega-experiments – MATHUSLA, Injection-molded scintillator for future high-granularity experiments, High-intensity proton irradiation facility

Role of FNAL within Community

- CPAD: Coordinating Panel for Advanced Detectors
 - APS/DPF Panel on instrumentation
 - In existence since last Snowmass process
 - Organizes annual instrumentation workshops and reports, cross-cutting workshops, instrumentation prizes, instrumentation studentships (GIRA), SBIR reviews (small business initiatives), etc.
 - P.M. is newly appointed CPAD co-chair

Summary

- Developed 5-year strategic plan aligned with Detector BRN and Fermilab's mission and technical expertise
- Launched new competitive call for proposals to strengthen R&D program:
New Initiatives
- New and ongoing collaborations with other national labs and universities, including strong student involvement in R&D
- Continued several multi-year R&D efforts, concluded some R&D with new publications, and initiated some new R&D projects
- Several successful transitions from KA25-funded R&D to other funding sources