Fermilab Detector R&D

Petra Merkel

50th Fermilab Users Meeting

8 June 2017

Fermilab Assets for Detector R&D

- Access to facilities is available through the Detector Advisory Group, which coordinates detector R&D at the lab
  - Contact: petra@fnal.gov
  - Overview: http://detectors.fnal.gov/index.html
  - New proposals: http://programplanning.fnal.gov/tsw_orc/
- Research Facilities:
  - Silicon Detector Facility (SiDet)
  - Precision Metrology
  - Scintillation Detector Development Facility
  - Thin Film Facility
  - Noble Liquid Detector Development
  - Rapid Prototyping and Special Materials
  - Fermilab Test Beam Facility (FTBF)
  - ASIC Development Group
- Experienced engineering and technical staff:
  - ASIC development, Cryogenics, Data Acquisition, Mechanical and Electrical Engineering
- These facilities promote and benefit from partnership with universities and other national labs.

Recent R&D for CMS HL-LHC Upgrades

HGCal

Fast Timing

Scintillators

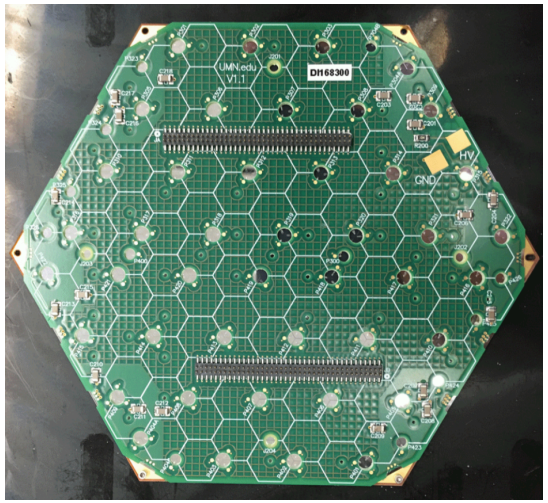
Outer Tracker

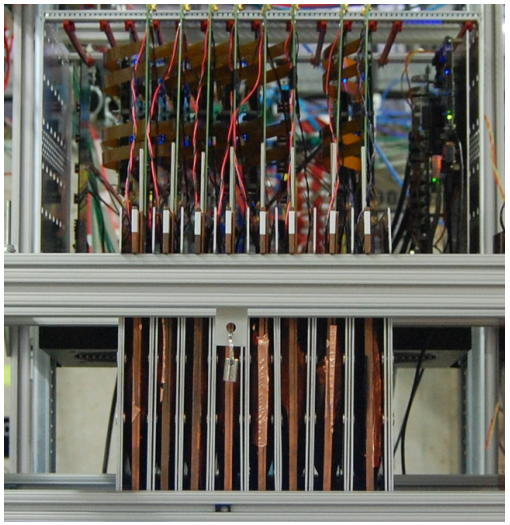
Sensors

HGCal Prototype Construction and Testing

Z. Gecse

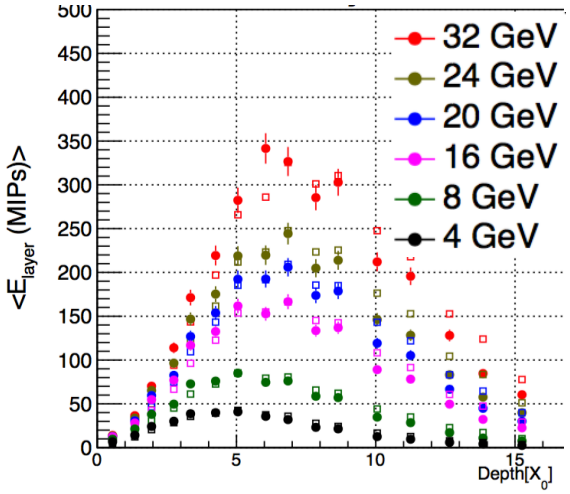
Full wafer silicon sensor
128 channels of 1cm^2
Built into modules
Will be exposed to 150MRad

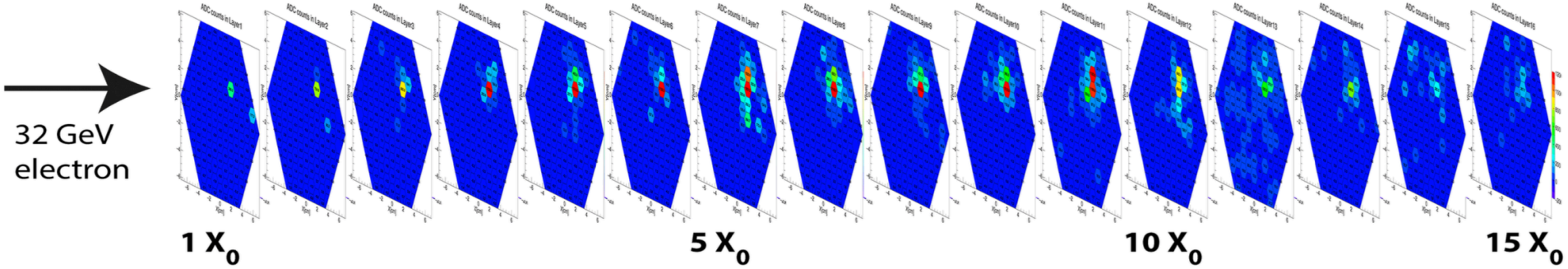




Prototype EM calorimeter:
16 layers of silicon detector
15 X_0 of Tungsten absorber
Final EM will have 28 layers

Events provide "X-ray" picture of shower development
Important for pile-up mitigation
Expect 25ps EM shower timing resolution



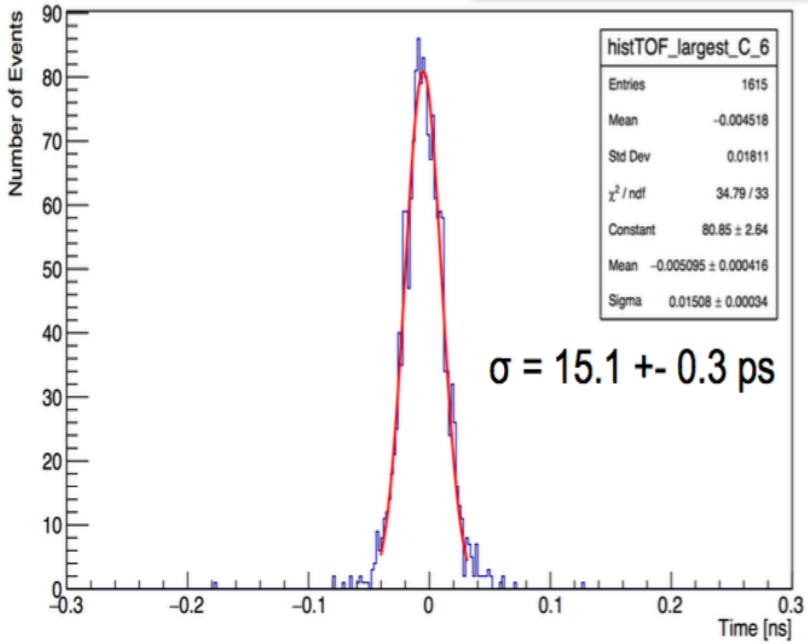


Calorimetry and Photodetection: Fast Timing

A. Apresyan

Fast Timing Studies using Silicon wafers

- The Fermilab Fast Timing Group (in collaboration with Caltech) used a 6 inch silicon wafer produced for the HGCal prototype.
- It was instrumented with FNAL-designed custom amplifiers and DRS4 readout.
- The device was tested in the Fermilab testbeam using the mechanical structure of the HGCal prototype.
- 15ps timing resolution for a single layer measurement for electrons at shower max was measured, demonstrating that silicon calorimetry has the potential for extremely precise timing measurements.

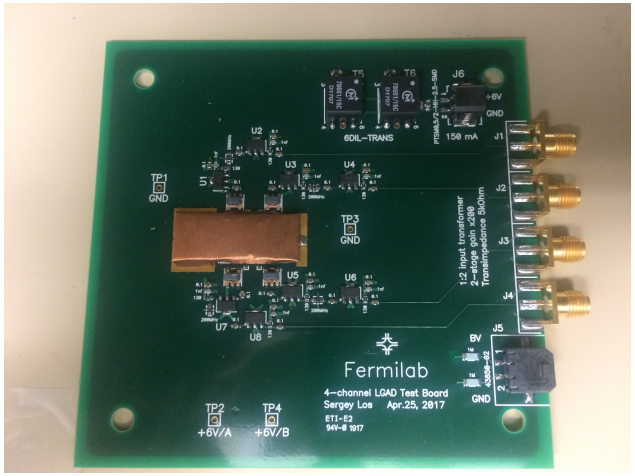


Time resolution for 32 GeV electrons at $6X_0$

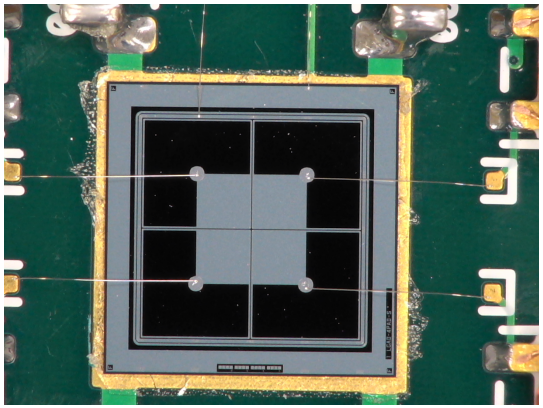
A. Apresyan

Fast Timing Endcap Layer

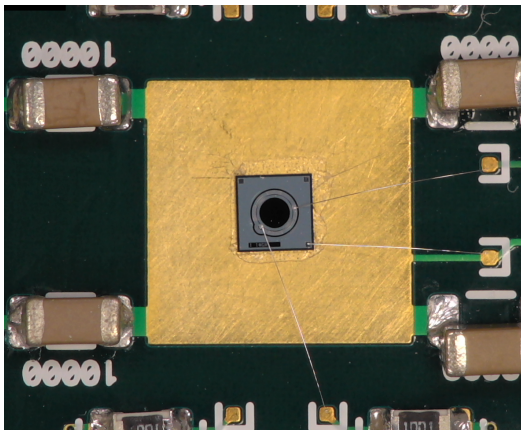
- Collaborative effort with CMS & ATLAS institutes:
  - Caltech, FNAL, Univ. of Kansas, Univ. of Torino, UC Santa Cruz
  - Close collaboration with Hamamatsu, CNM, FBK
- Characterization of newest LGAD sensors: irradiated & unirradiated
  - FNAL was critical for the success of this campaign: Fermilab Test Beam Facility, SiDet, technicians and engineers
- Large number of sensors, and readout designs tested: very promising results



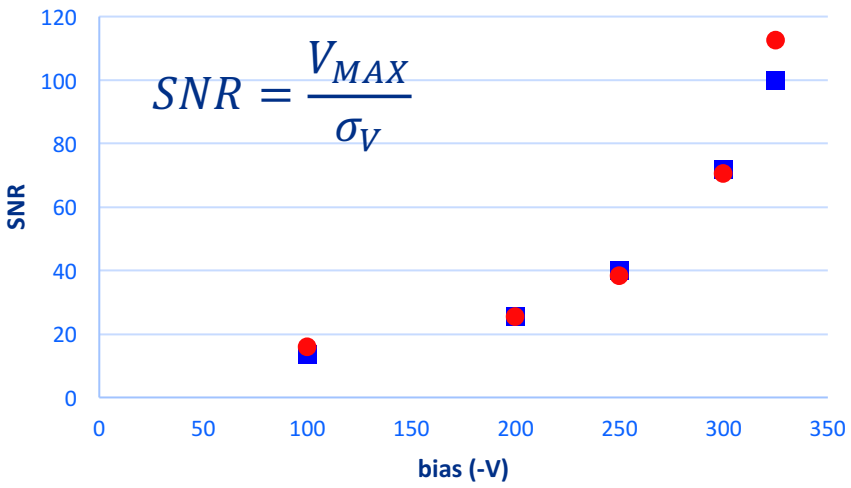
FNAL board: 4 channels



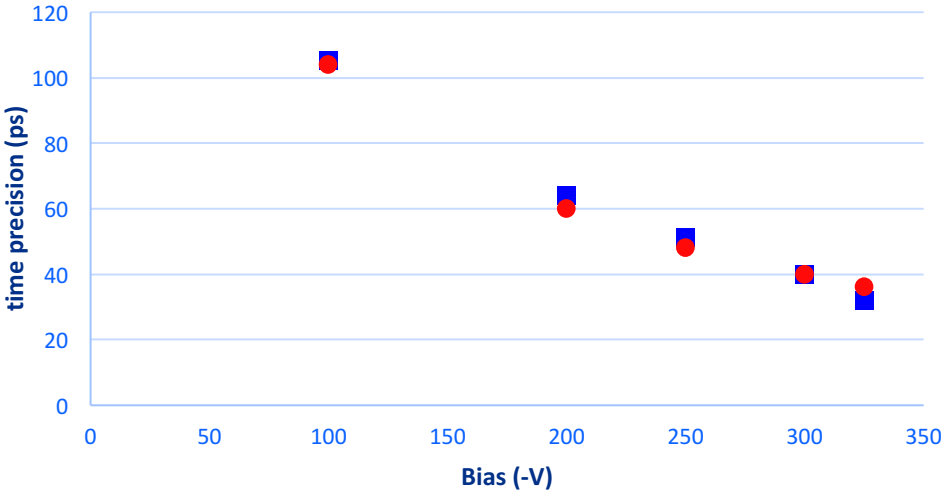
Hamamatsu 2x2 LGAD array
3x3 mm2 pixels



Hamamatsu single channel
1 mm diameter



Signal to noise ratio vs BV for 50 µm HPK sensor

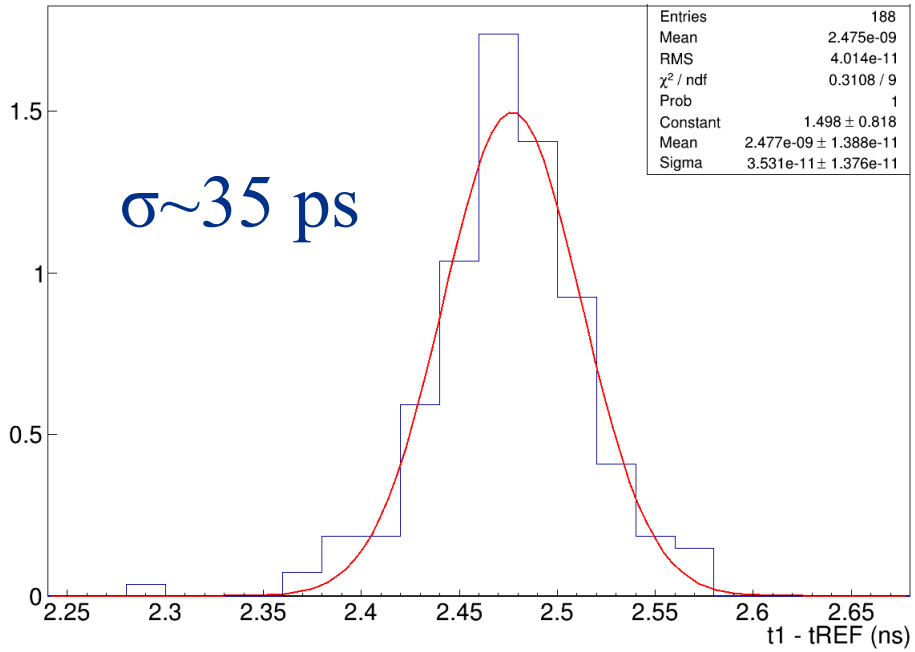


Time resolution vs BV for 50 µm HPK sensor

Irradiated sensors: the gain layer of the LGAD sensors starts to fade

- The gain is maintained by increasing the bias voltage, resulting in excellent timing performance

HPK 6 x 10^{14} n.eq/cm^2 at 600V BV

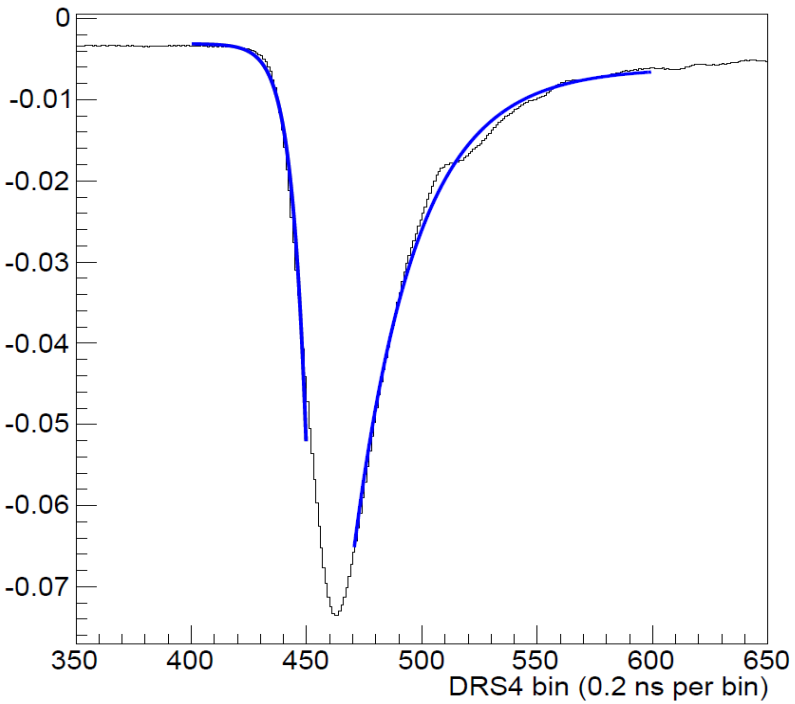


J. Freeman

Calorimetry and Photodetection: Cold Scintillators

Performance and Radiation Hardness of Scintillators at Reduced Temperatures

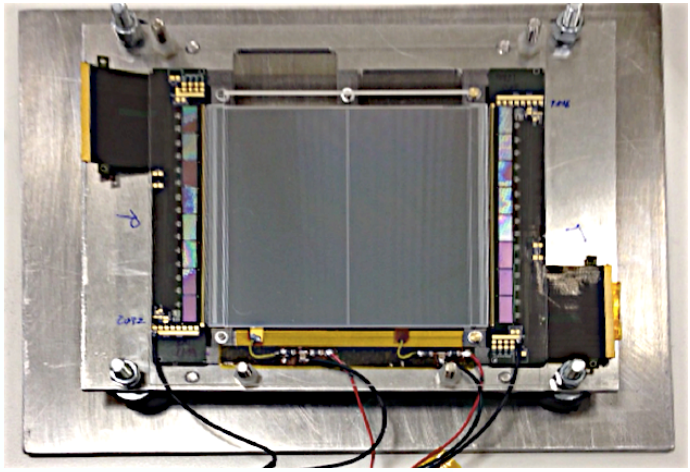
- Fermilab together with UMaryland, UMinn TTU, FSU
- Used photospectrometer instrumented with a cryogenic optical dewar to study scintillation emission and absorption properties at temperatures down to -40C and below.



Average pulse shape for scintillator EJ260 2X2P excited by Bi-207 source. The scintillator was at -40C. The readout is through a PMT into the DRS4 system.

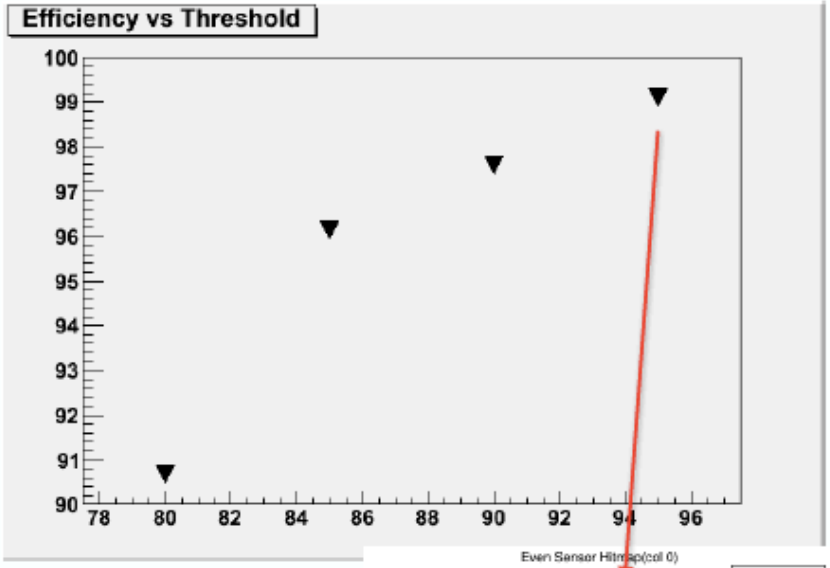
Outer Tracker Module in Test Beam

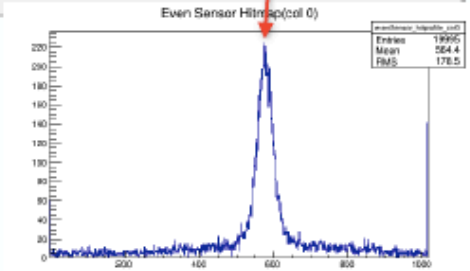
L. Uplegger



Cluster efficiency vs Vcth

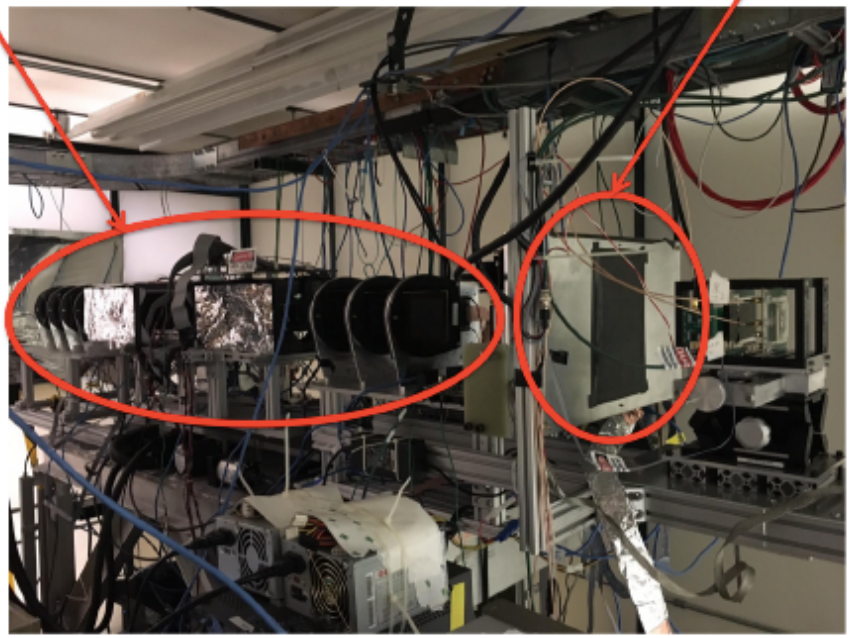
- **Preliminary efficiency around 99%** before the module become too noisy





Pixel+Strip telescope

2S Module



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A. Prosser

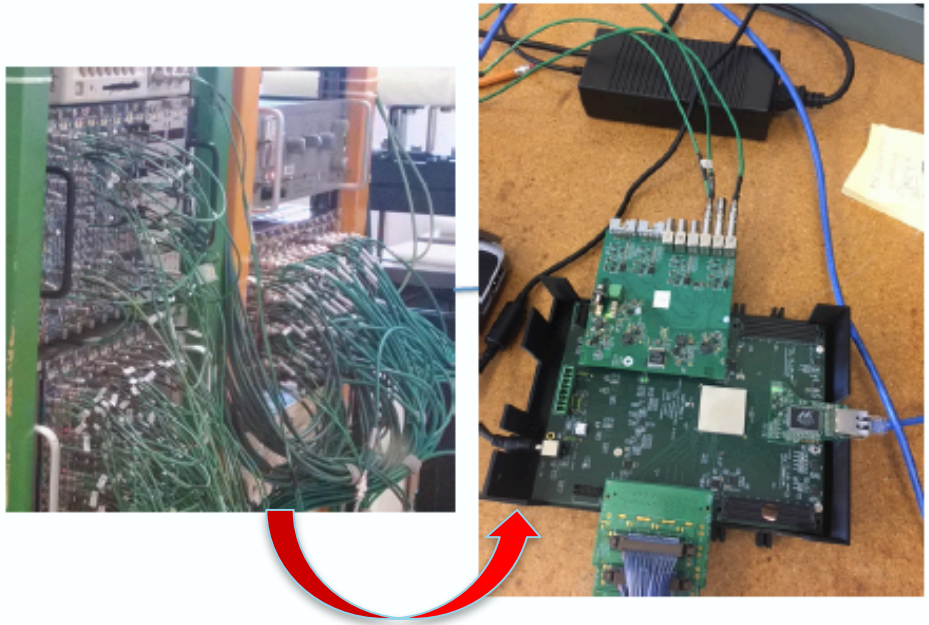
DAQ System R&D: NIM+

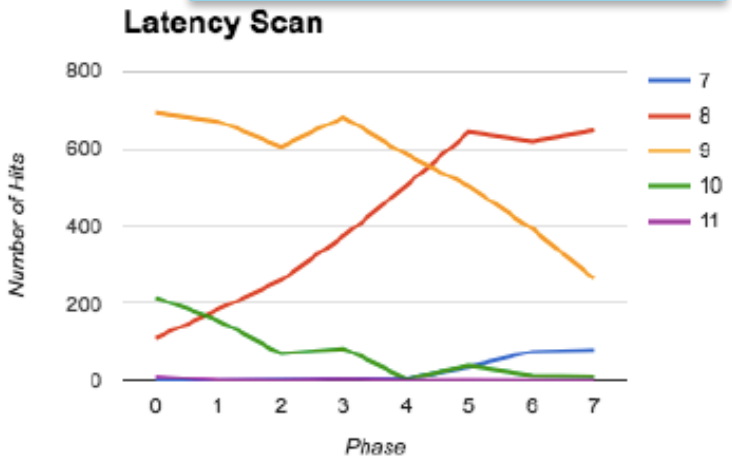
NIM Upgrades

- New card being commissioned that will substitute tens of NIM modules with just one FPGA to provide scintillator coincidences
  - will be used at any upcoming TB
  - allow users to develop their specific firmware according to their needs

- For our specific application, allows TTC 40 MHz clock scan in 3ns steps

From recent CMS Outer Tracker test beam campaign:





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Silicon Sensors: Sensors on 8” Wafers

R. Lipton

Experiments continue to move to larger area silicon-based tracking and calorimetry systems:

- CMS, ATLAS HL-LHC tracking ~ 200 m^2
- CMS HGC ~ 600 m^2

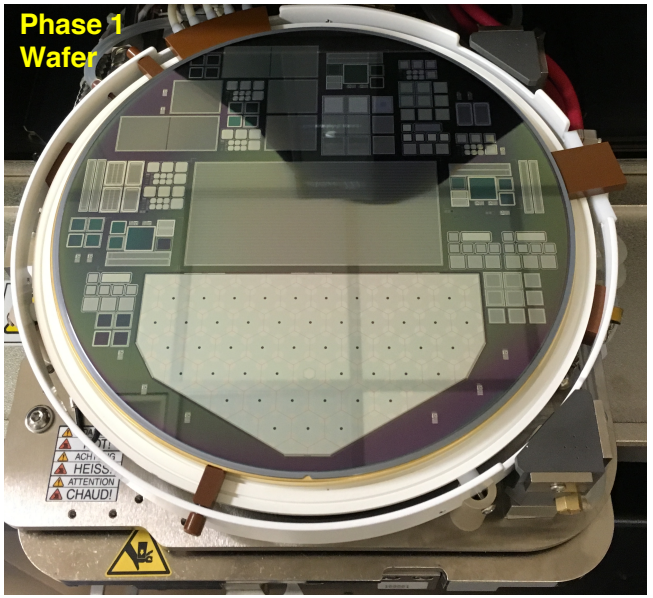
At the same time we still require low mass in the tracking and extreme radiation hardness in the sensors and readout (>10^{16} n/cm^2). A move to 8” *could* reduce costs and will reduce the number of components needed to tile a detector.

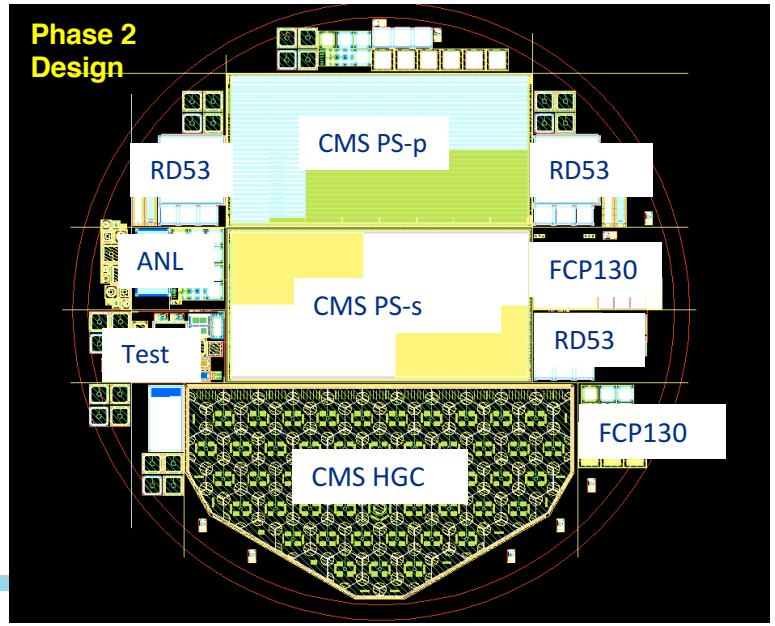
- 8” wafers are ~750 microns thick and specialized equipment or techniques are needed to thin and handle wafer of smaller physical thickness

8” Sensor Development with Novati

- 500 float zone run
- SOI/FZ run Phase 1 SBIR
- Current – Phase 2 SOI run with coupling capacitors and polysilicon resistors

Collaboration with Novati, Argonne, SLAC, LBNL, Brown, Rochester, Northern Illinois

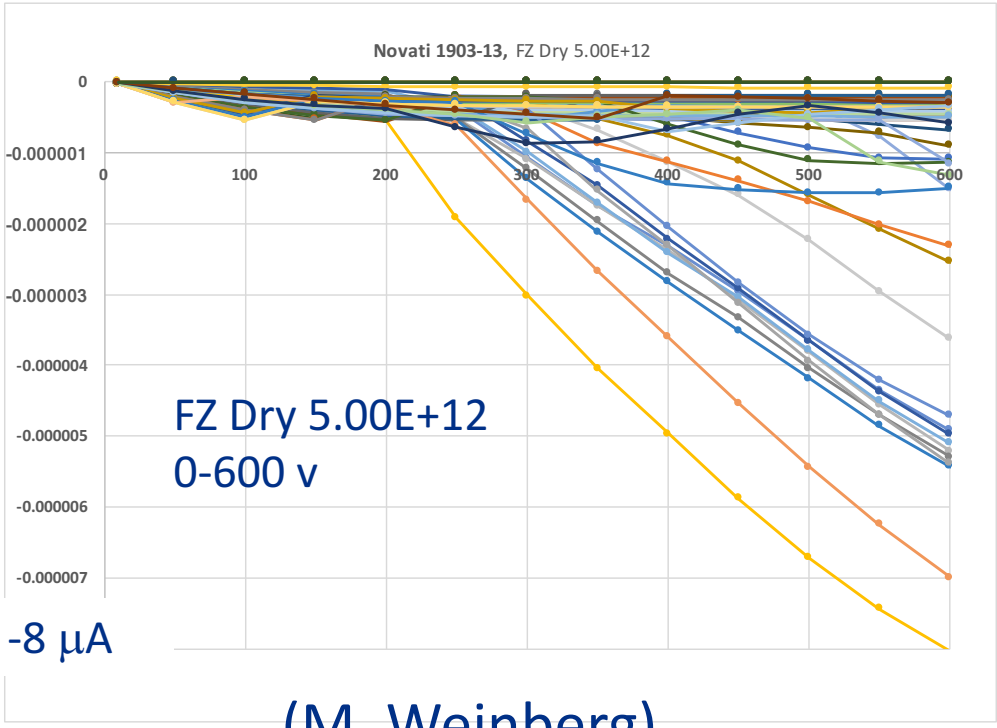




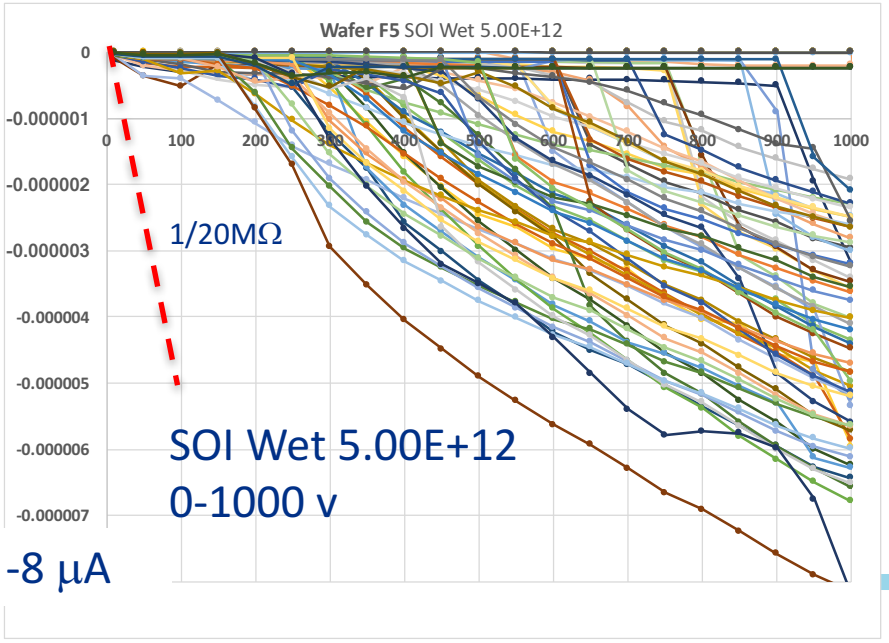
Novati Phase 1 HGCal

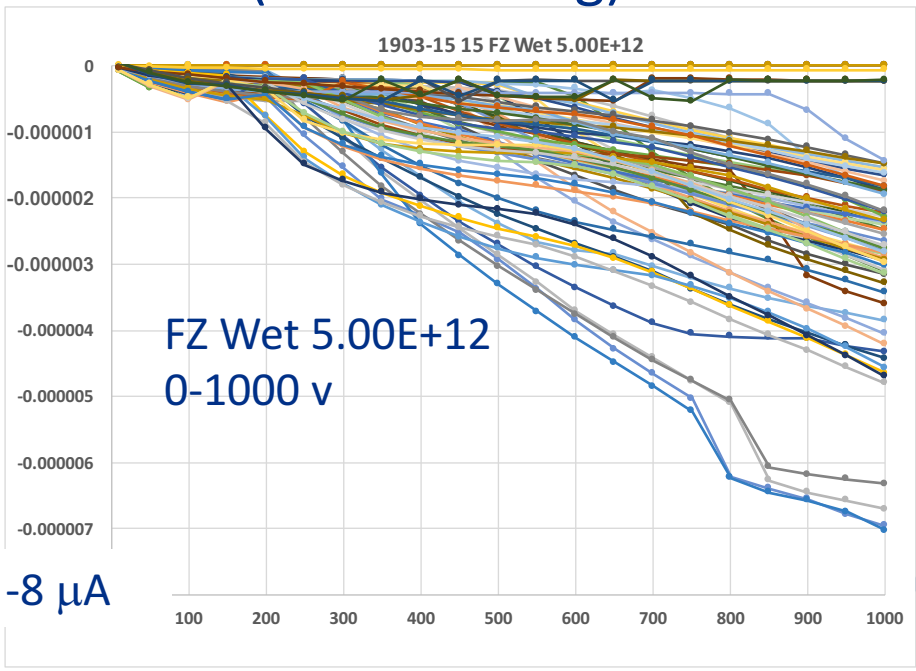
Looked at data from earlier measurements of run 2 HGC sensors:

- Breakdown is typically soft (22M series resistor provides feedback that limits dI/dV)
- Wet oxide appears to have more channels breakdown, but “softly”
- 200 μm SOI device has earlier breakdown than 500 μm FZ



(M. Weinberg)





Recent & Future R&D for Cosmic Instrumentation

Skipper CCDs

CMB-S4

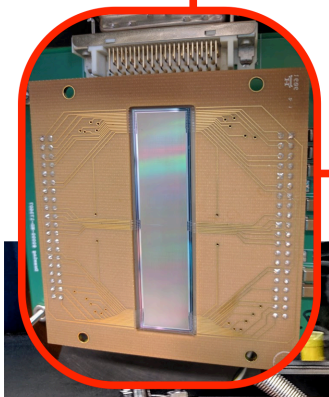
Qubits

…

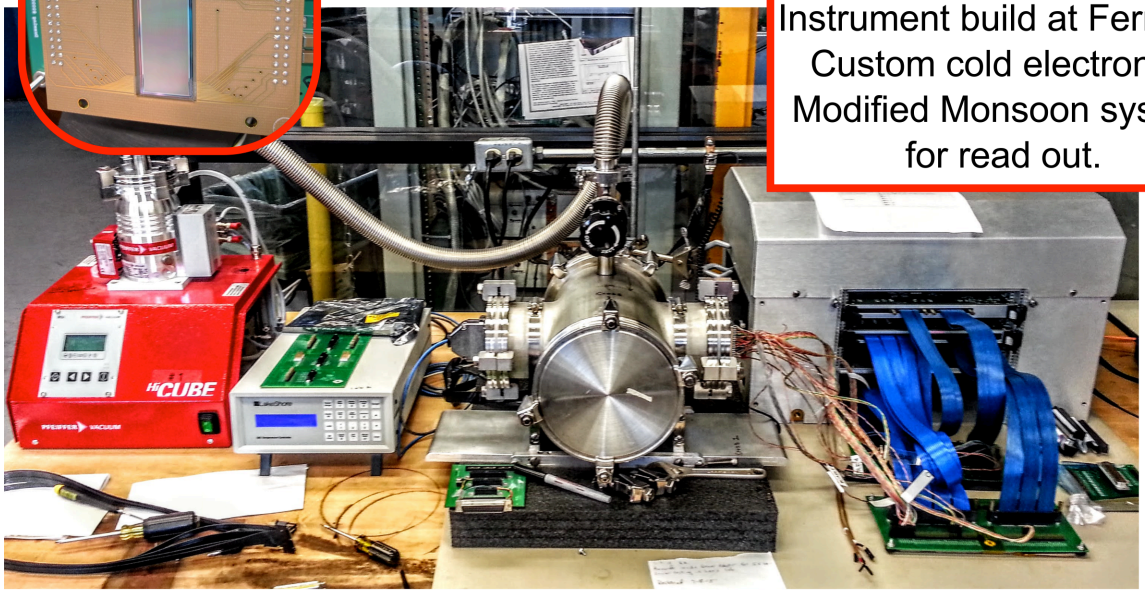
Skipper CCDs

J. Estrada, J. Tiffenberg

Skipper-CCD prototype designed by LBL MicroSystems Lab
200 um thick
15 um pixel size
~ 4k x 1k pixels
parisitic run

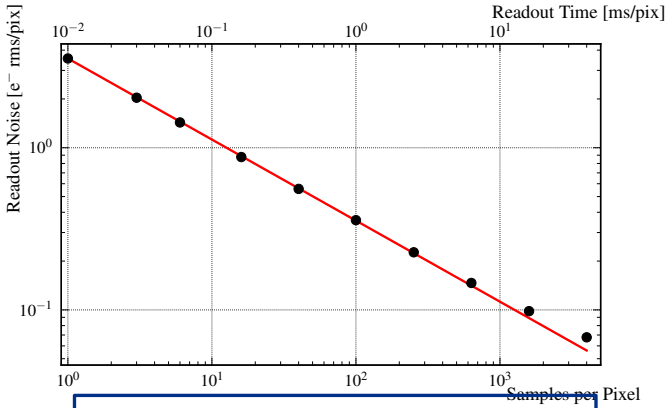


Collaboration with: LBNL, Stony Brook, Stanford, CERN, Tel Aviv



Instrument build at Fermilab
Custom cold electronics
Modified Monsoon system for read out.

- SENSEI is the ultimate silicon ionization detector
- Unmatched performance for electron recoil channels
- Probe DM masses at the MeV scale through electron recoil.
- Probe axion and hidden-photon DM with masses down to 1 eV.
- Probe DM masses as low as 0.1 GeV through nuclear recoil.



Readout noise as a function of the number of samples taken

Skipper CCDs: 10x better noise performance

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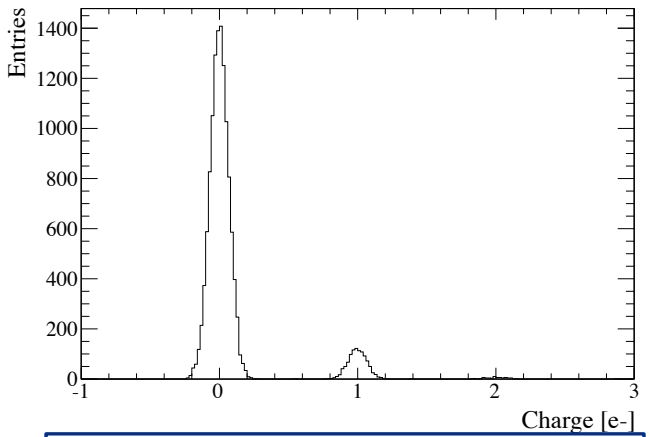
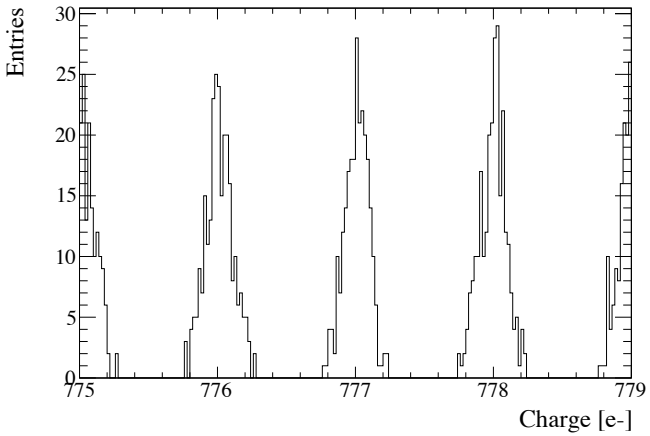
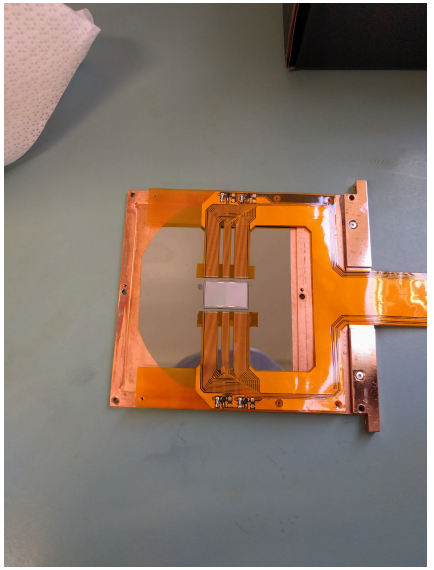
First Results from Setup in MINOS Hall

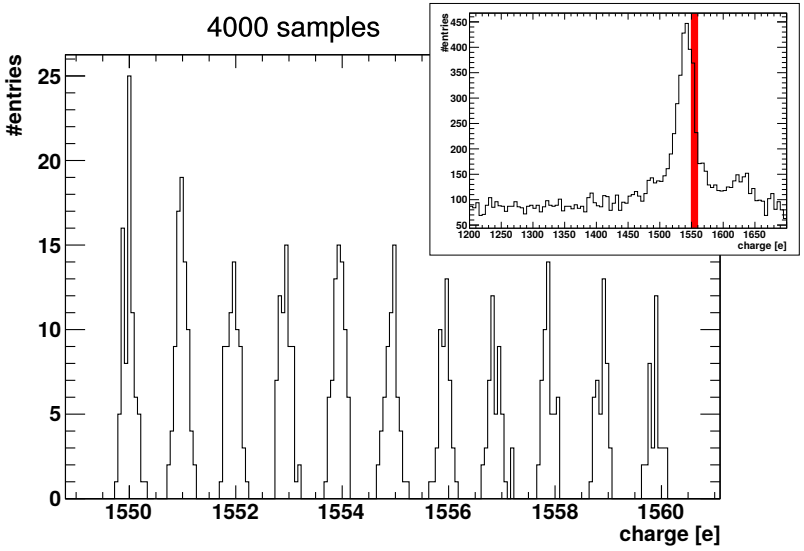


Measured charge in pixels for a dimly illuminated Skipper-CCD



Measured charge in pixels for a strongly illuminated Skipper-CCD

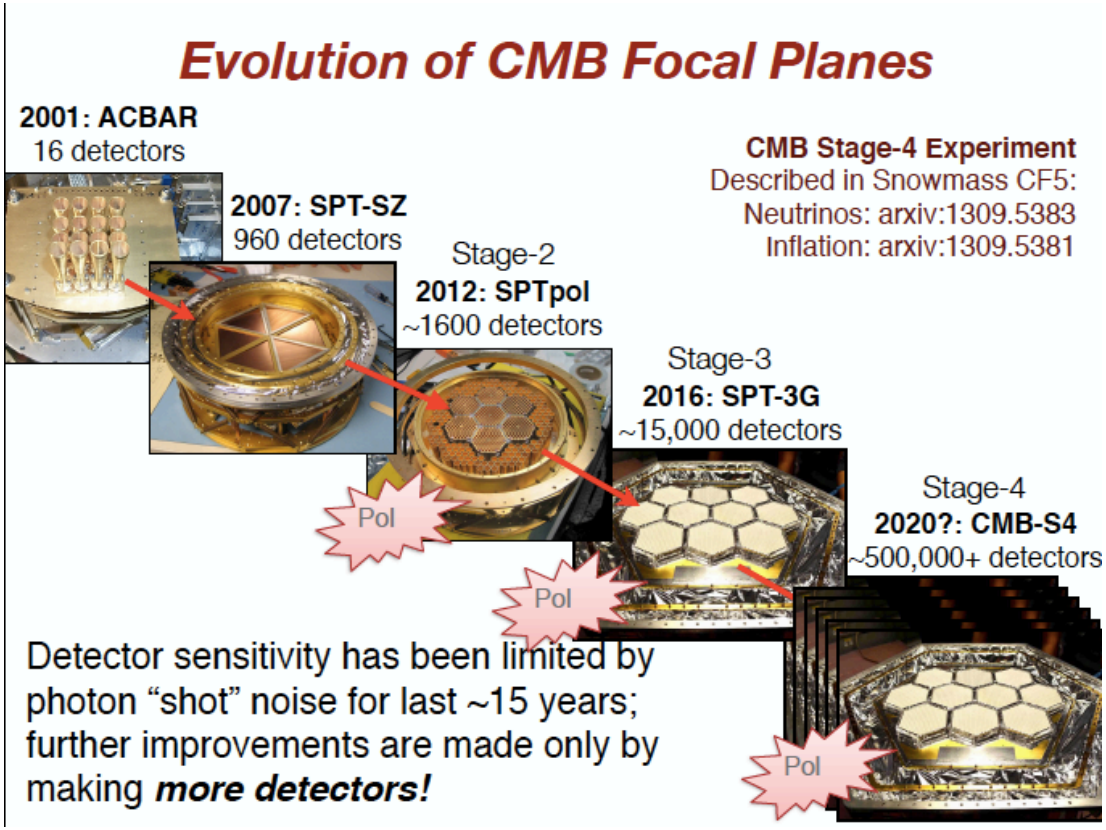




Measured charge in pixels for a Skipper-CCD illuminated by x-rays from an 55Fe source

R&D for CMB-S4

B. Benson

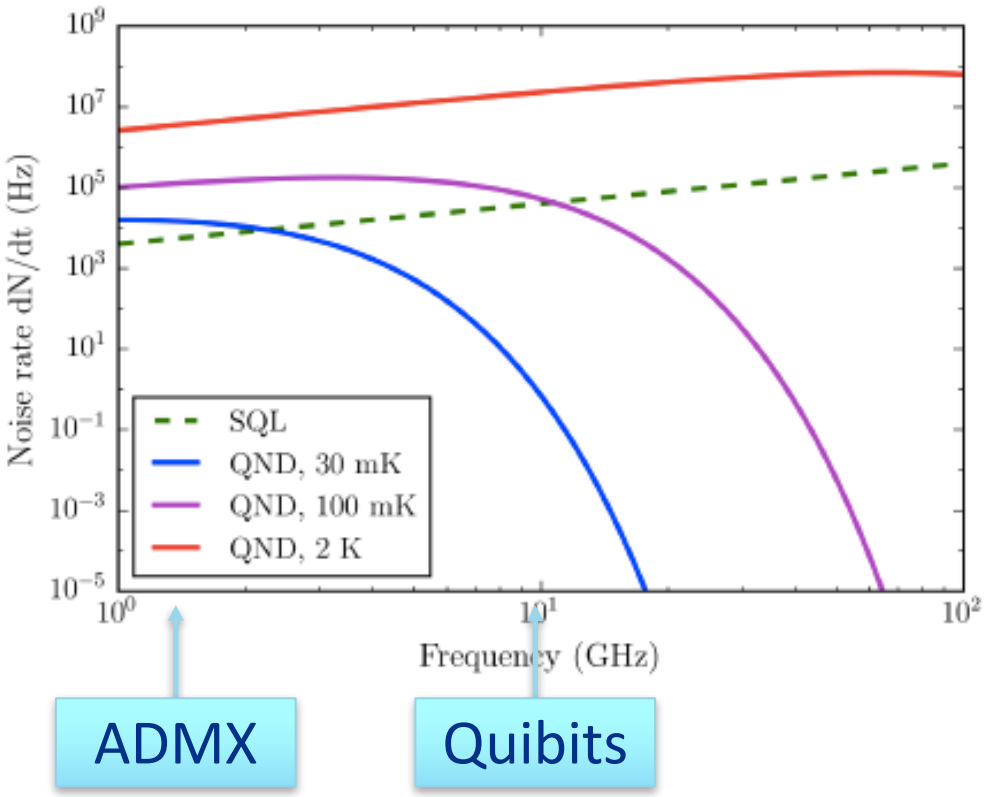


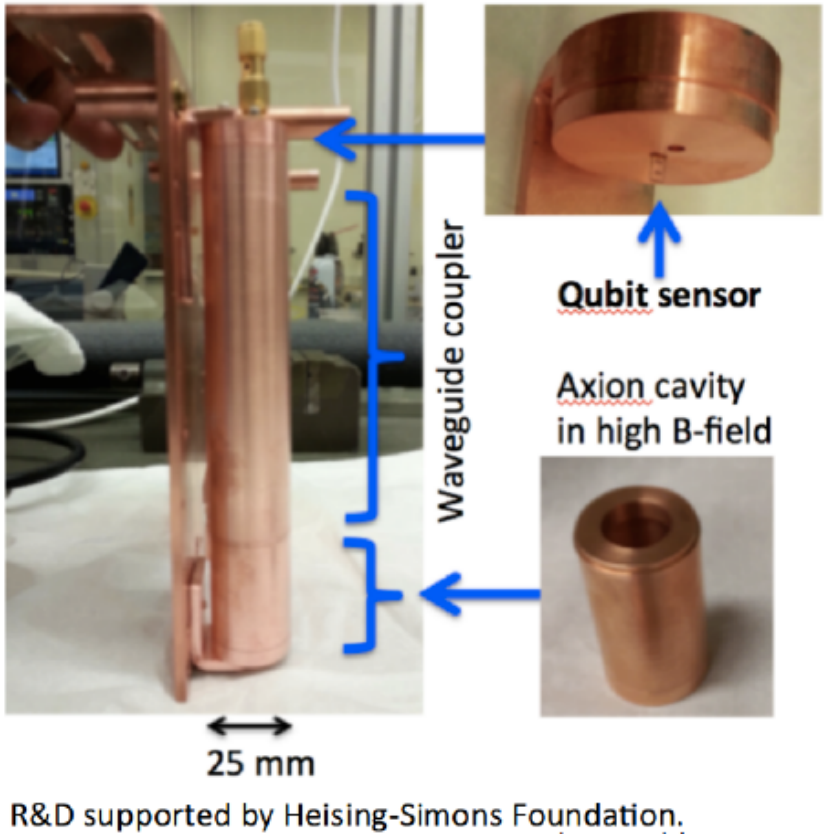
R&D needed in the following areas:

- TES detectors: develop broader range of properties to cover likely CMB-S4 needs
- μm-wave antenna coupling: develop lenslet and horn-coupled technologies
- Microwave simulations
- Microstrip materials: superconducting resonators
- MKIDs: potential alternative to TES detectors
- Readout electronics

Quibits for Axion DM Searches

A. Chou, D. Bowring, A. Sonnenschein





R&D supported by Heising-Simons Foundation.

- Need Quibits to beat single quantum limit (SQL) through quantum non demolition (QND) measurements
- R&D is starting on several fronts (Qubits, cavities)
- Setting up cryogenic test stand now

Recent & Future R&D for Neutrino Experiments

LArIAT

HV in LAr

Light Guides

Beamloss Monitors

…

LAr In A Testbeam: LArIAT

J. Raaf

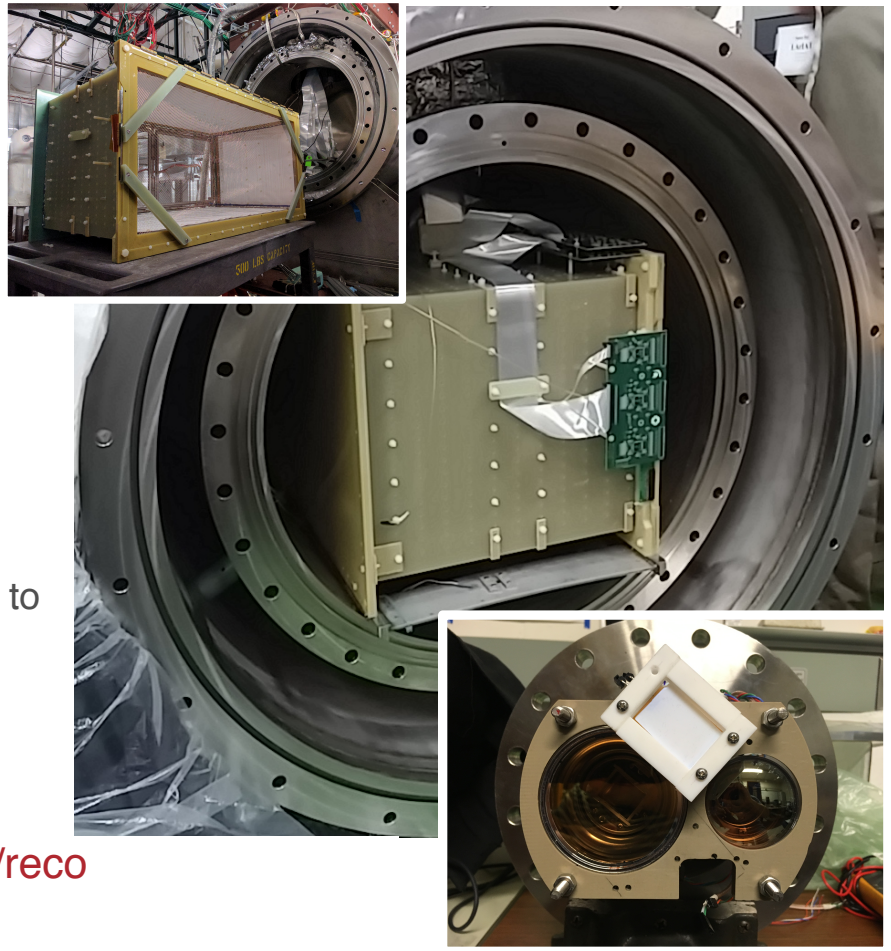
Program for comprehensive characterization of LArTPC performance in energy range relevant to short- & long-baseline neutrino experiments.

Physics

- Hadron-Ar interaction cross sections
- Study of nuclear effects
- Geant4 validation
- Develop criteria for determining particle charge based on topology (decay vs. capture), without magnetic field
- Electron/photon shower ID

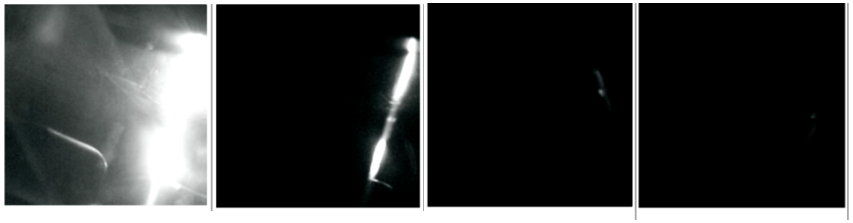
R&D

- Ionization and light production properties
  - Establish relationship between energy deposited to charge and light collected, for stopping tracks of known energy
- Optimization of particle ID methods
  - 2D & 3D event reconstruction
- Impact of 5-mm vs. 3-mm wire spacing on PID/reco
- New transparent (mesh) cathode
  - Test of SBND cathode design
- Test of Arapuca light collection devices



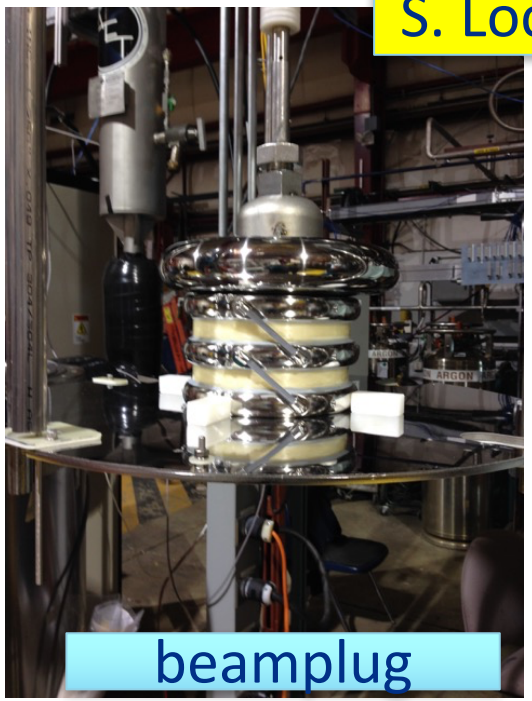
HV in LAr R&D

- High voltage in liquid Argon is still a rich field of study
- Tests performed in the Blanche cryostat at the PAB
- Paper in preparation:
  - plate breakdown tests
  - improved understanding of breakdown conditions for various size effects and LAr purity conditions
- Ongoing tests:
  - Streamer vs. spark test
  - Prototypes have observed elevated current draws without spark



- Performed tests of components for ProtoDUNE in gas and ultra pure liquid

S. Lockwitz



beamplug

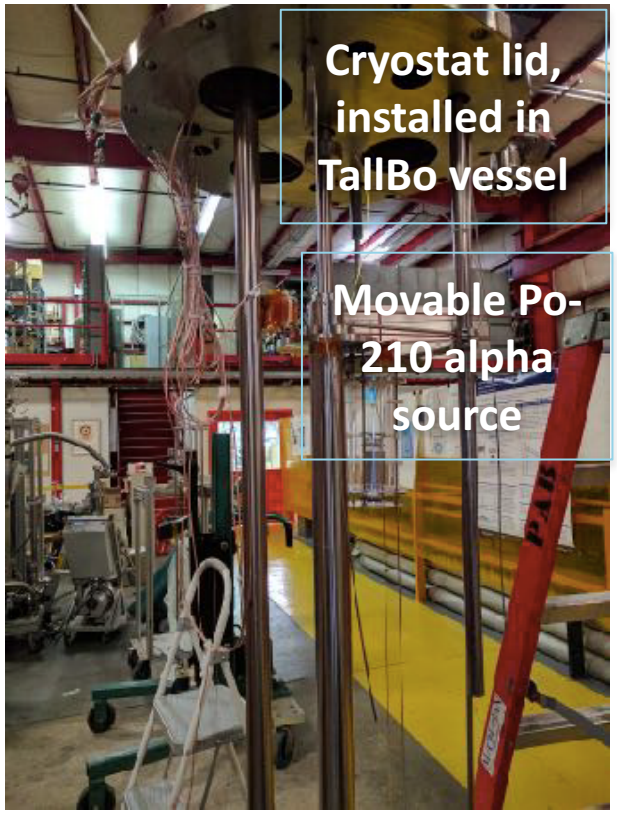
Plate test

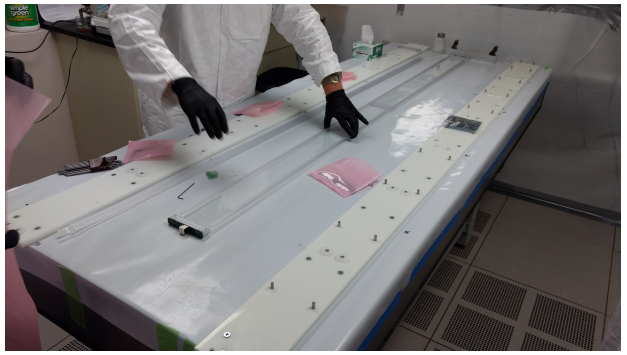
Fermilab

QA testing for TPB coated light guides

E. Niner

- Acrylic light guides coated in tetraphenyl-butadiene (TPB) shift 128 nm light in liquid argon to visible wavelengths
- Performance and attenuation length measured in TallBo dewar at Fermilab, together with MIT group
- Light guides manufactured for ProtoDUNE and SBND
- This past month the first light guides for protoDUNE were annealed and dipped in TPB.





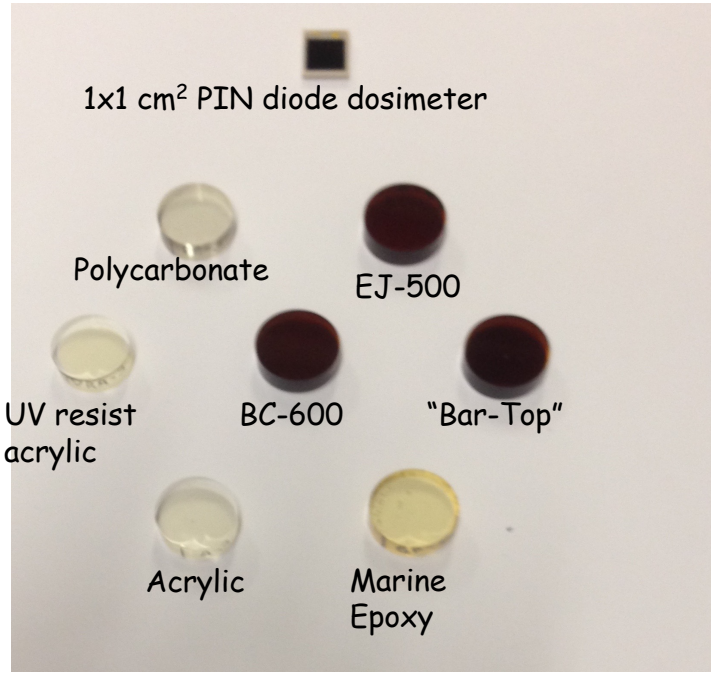
first Fermilab light guide being assembled into a module for protoDUNE

Fermilab

Radiation Damage in Scintillator Materials

R. Tesarek

- Losses in the accelerator complex limit available beam power to neutrino experiments
- Current beam loss monitors (ionization chambers) are slow
- Alternative: fast PMT+scintillator based monitors, but current lifetimes only ~1 year
- R&D into more radiation tolerant materials: light guide materials and optical cements



Charged Particle Fluence ~3×10^{14} MIPs/cm^2
Samples ~ 3.5mm thick

Sample	Refractive Index	Relative Transmission* @420nm (Irradiated/Unirradiated)	Cost
BC-600	1.571	(0.021 +/- 0.006) %	~$300/500 ml
EJ-500	1.574	(0.103 +/- 0.004) %	~$300/500 ml
Bar-Top	1.561	(0.125 +/- 0.004) %	~$30/1000 ml
Marine	1.567	(56.215 +/- 0.016) %	~$30/1000 ml

Summary

- Detector R&D at Fermilab is a very active field of research across the lab, divisions and technologies
- The pursued R&D is strongly driven by P5 and the identified CPAD grand challenges
- A reasonable balance between directed and generic R&D is attempted as the funding profiles allow
- Collaboration with other laboratories and universities is being sought and actively pursued

- Are you a user and want to do detector R&D at the lab? Start here: http://programplanning.fnal.gov/tsw_orc/

  Or contact petra@fnal.gov