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Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Detector R&D in Astrophysics

Juan Estrada

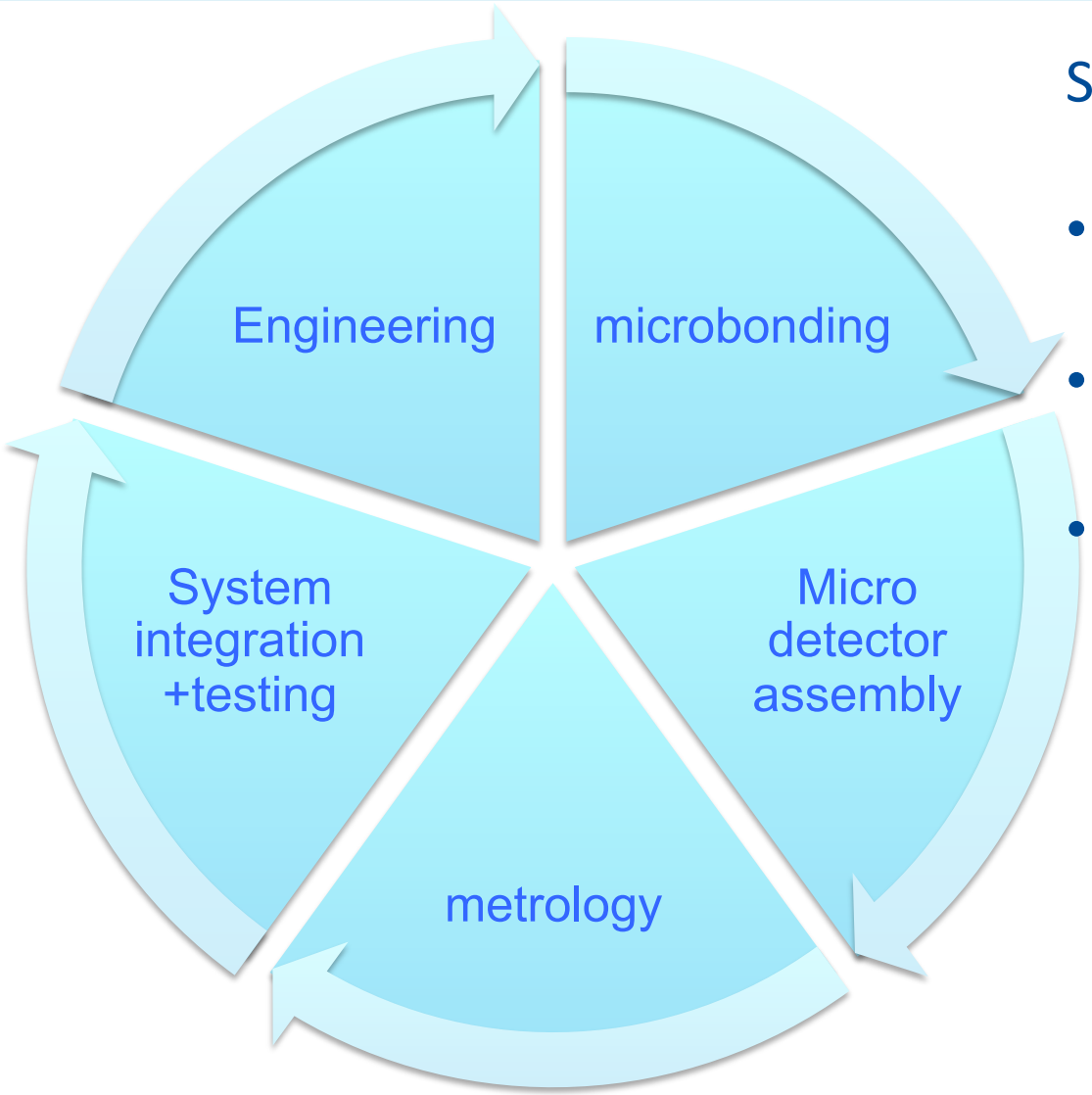
Institutional Review

Feb. 11, 2015

Current Lines of Research

- Charge Coupled Devices (CCDs):
  - Low threshold experiments (DAMIC-CONNIE)
  - Detector packaging and testing for DESI
- Microwave Kinetic Inductance Detectors (MKIDs):
  - DAQ development for large arrays
  - R&D instrument for SOAR
- Adiabatic Demagnetization Refrigerator (ADR) facility
  - Supporting CDMS,STJ,SPT-3G,MKIDs
- Cosmic Microwave Background (CMB)
  - SPT-3g
  - Stage-4
- Noble Gases
  - Liquid Argon
  - Xenon studies

Synergy with CMS: infrastructure and expertise

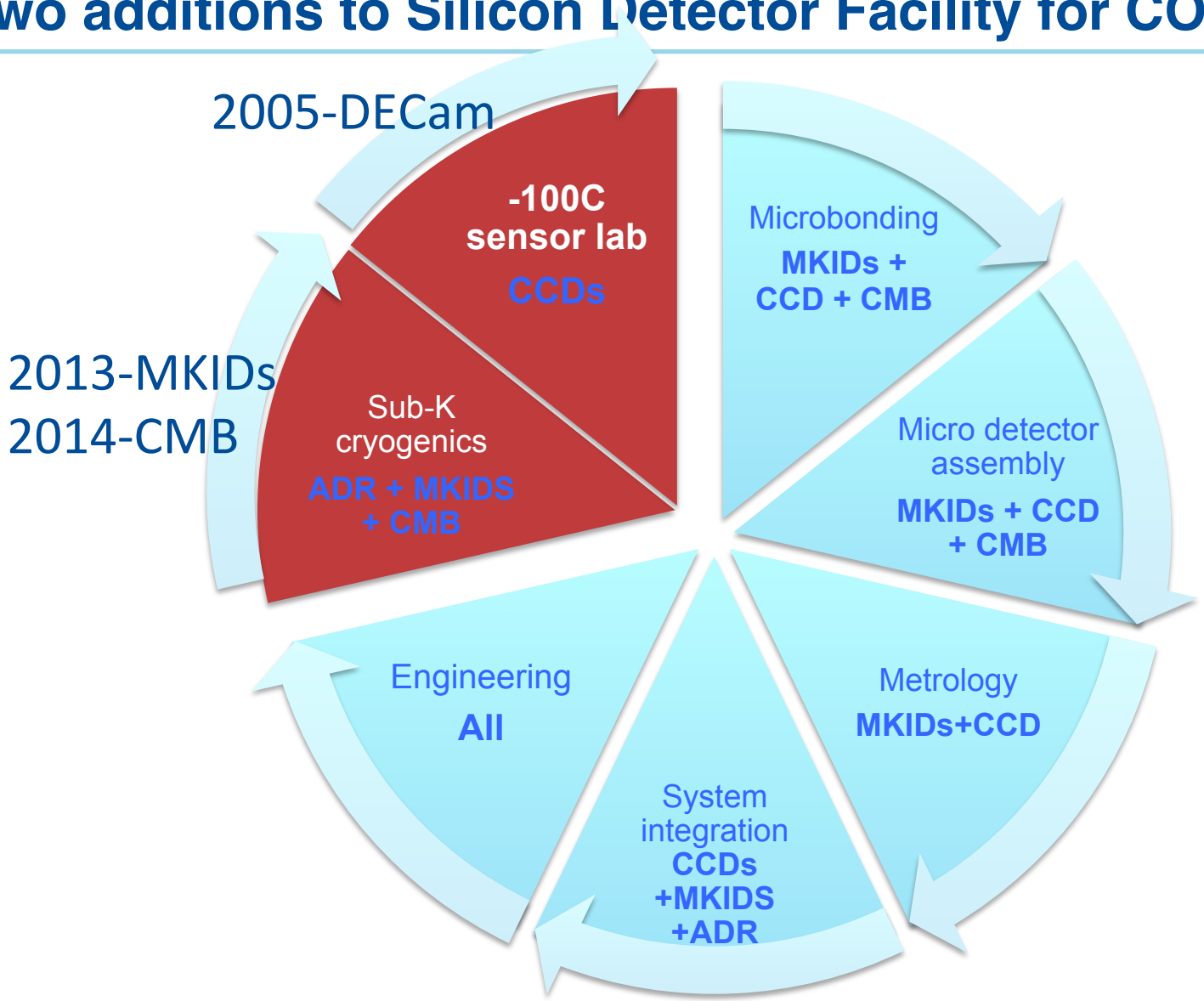


Silicon Detector Facility:

- Developed for CDF and DZero trackers.
- Big role in CMS (past in future).
- These allowed us to build Dark Energy Camera.

Cleanroom, labs space, machines and **experienced technical specialists.**

Two additions to Silicon Detector Facility for COSMIC needs



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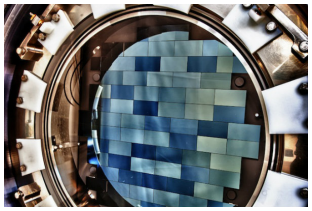
R&D program that enables experiments in astrophysics



DECam needed CCD R&D to produced a focal plane in 2005 .

CCD R&D

Massive detectors with 2e- noise developed at LBNL for astronomy.

DAMIC 2011 demo at NuMI

DAMIC 2012 10 g @ SNOLAB

Best limit at low masses for DM search. Now an international collaboration with funds from several institutions. 15 scientists, 3 postdocs, 10 students.

DAMIC 2014 100g @ SNOLAB

DESI packaging @ FNAL 2013

Detector R&D funds allowed FNAL to develop a facility for the fabrication and testing of 500um silicon packaged for spectrograph. This has now put us in conditions to build the detectors for DESI project.

CONNIE 2014 Installed at ANGRA

Seeded by general R&D program. Attracted collaborations in Europe and South America. With their own funding. FNAL now supporting with LDRD. "First dark" collected 10/16/2014. **Neutrino coherent scattering experiment.**

1e- threshold

Prototypes sensors exist. Would open a new window to MeV dark matter searches.

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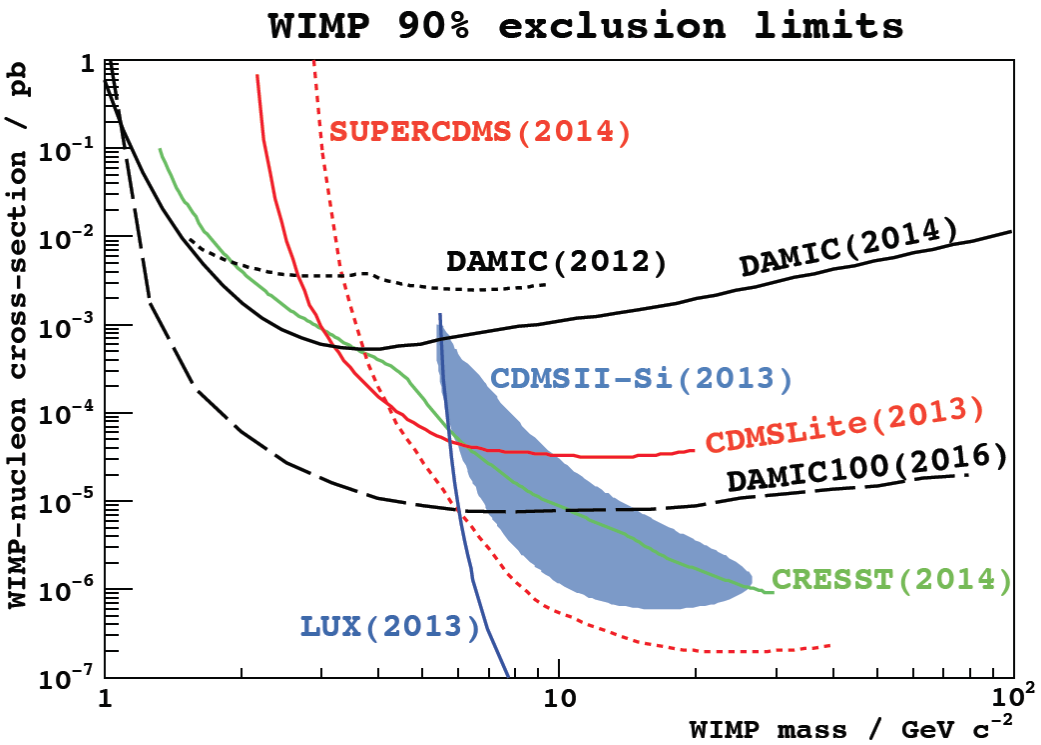
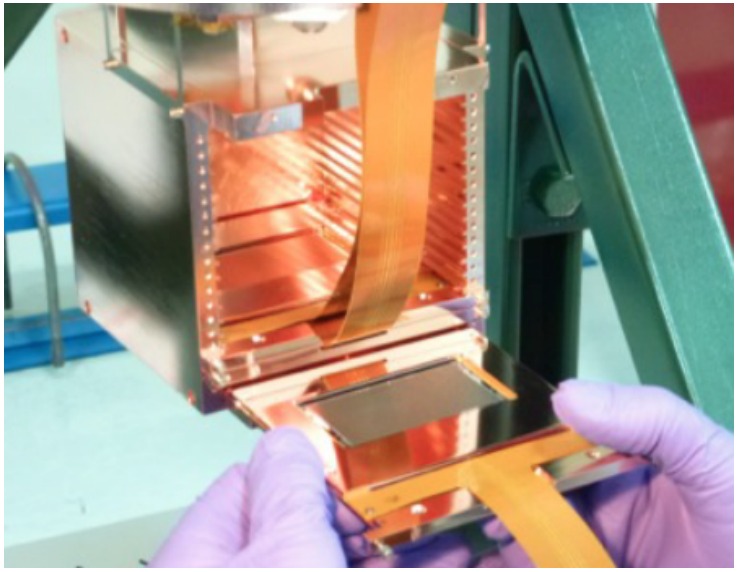
DAMIC: Direct Search for low mass DM with CCDs





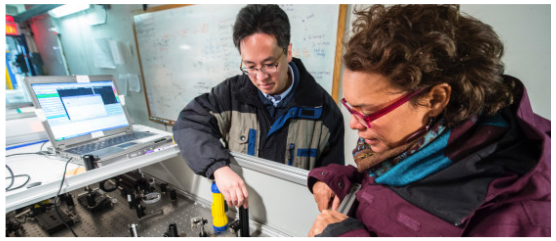
Started as R&D project at FNAL. Currently an international collaboration running the experiment at SNOLAB. Holding the best limit for low mass DM below ~ 3.5GeV, with only a 0.3 kg-day exposure.

R&D program alumni

Freaky Physics Experiment May Prove Our Universe Is A Two-Dimensional Hologram

The Huffington Post | By David Freeman

Posted: 08/29/2014 8:22 am EDT | Updated: 08/29/2014 8:59 am EDT



First Results from the DarkSide-50 Dark Matter Experiment at Laboratori Nazionali del Gran Sasso

P. Agnes[a], T. Alexander[ag], A. Alton[b], K. Arisaka[af], H.O. Back[z], B. Baldin[h], K. Biery[h], G. Bonfini[r], M. Bossa[j], A. Brigatti[t], J. Brodsky[z], F. Budano[aa], L. Cadonati[ag], F. Calaprice[z], N. Canci[af], A. Candela[r], H. Cao[z], M. Cariello[j], P. Cavalcante[r], A. Chavarria[z], A. Chepurnov[u], A.G. Cocco[v], L. Crippa[t], D. D'Angelo[t], M. D'Incecco[r], S. Davini[l], M. De Deo[z], A. Derbin[w], A. Devoto[d], F. Di Eusanio[z], G. Di Pietro[t], E. Edkins[k], A. Empl[l], A. Fan[af], G. Fiorillo[v], K. Fomenko[g], G. Forster[ag], D. Franco[a], F. Gabriele[r], C. Galbiati[z], A. Goretti[z], L. Grandi[e], M. Gromov[u], M.Y. Guan[m], Y. Guardincerri[h], B. Hackett[k], K. Herner[h], E.V. Hungerford[l], Al. Ianni[r], An. Ianni[z], C. Jollet[ac], K. Keeter[f], C. Kendziora[h], S. Kidner[ah,1], V. Kobychev[o], G. Koh[z], D. Korablev[g], G. Korga[l], A. Kurlej[ag], P.X. Li[m], B. Loer[z], P. Lombardi[t], C. Love[ad], L. Ludhova[t], S. Luitz[ab], Y.Q. Ma[m], I. Machulin[p,s], A. Mandarano[j], S. Mari[aa], J. Maricic[k], L. Marini[aa], C.J. Martoff[ad], A. Meregaglia[ac], E. Meroni[t], P.D. Meyers[z,*], R. Milincic[k], D. Montanari[h], A. Monte[ag], M. Montuschi[i], M.E. Monzani[ab], P. Mosteiro[z], B. Mount[f], V. Muratova[w], P. Musico[i], A. Nelson[z], S. Odrowski[r], M. Okounkova[z], M. Orsini[r], F. Ortica[x], L. Pagani[i], M. Pallavicini[i], E. Pantic[af,ae], L. Papp[ah], S. Parmeggiano[t], R. Parsells[z], K. Pelczar[n], N. Pelliccia[x], S. Perasso[a], A. Pocar[ag], S. Pordes[h], D. Pugachev[p], H. Qian[z], K. Randle[ag], G. Ranucci[t], A. Razeto[r], B. Reinhold[k], A. Renshaw[af], A. Romani[x], B. Rossi[z,v], N. Rossi[r], S.D. Rountree[ah], D. Sablone[j], P. Saggese[r], R. Saldanha[e], W. Sands[z], S. Sangiorgio[q], E. Segreto[r], D. Semenov[w], E. Shields[z], M. Skorokhvatov[p,s], O. Smirnov[g], A. Sotnikov[g], C. Stanford[z], Y. Suvorov[af], R. Tartaglia[z], J. Tatarowicz[ad], G. Testera[i], A. Tonazzo[a], E. Unzhakov[w], R.B. Vogelaar[ah], M. Wada[z], S. Walker[v], H. Wang[af], Y. Wang[m], A. Watson[ad], S. Westerdale[z], M. Wojcik[n], A. Wright[z], X. Xiang[z], J. Xu[z], C.G. Yang[m], J. Yoo[h], S. Zavatarelli[i], A. Zec[ag], C. Zhu[z], G. Zuzel[n]

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Preprint submitted to Physics Letters B December 25, 2014

Preprint typeset in JINST style - HYPER VERSION

FERMILAB-PUB-14-402-E

Scalability, scintillation readout and charge drift in a kilogram scale solid xenon particle detector

J. Yoo, H. Cease, W. F. Jaskierny, D. Markley, and R. B. Pahlka

Fermi National Accelerator Laboratory, Kirk and Pine St., Batavia, IL 60510, USA

D. Balakishiyeva and T. Saab

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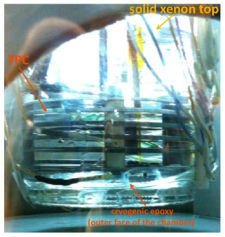
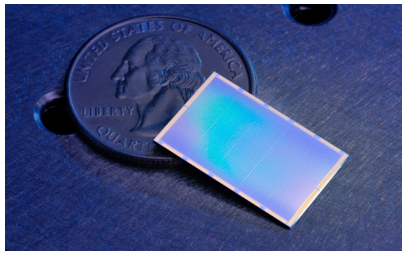


Figure 12. The TPC installed in the xenon glass chamber. The TPC operation, such as pulsed photon emission through the optical fiber to the photo-cathode, can be viewed from the external window. In this particular sample, the amount of solid xenon in the chamber is about ~2 kg. A little opaque area near the surface of the glass bottom edge is cryogenic epoxy. In this particular sample, some birefringence can be seen at the inner glass wall near the grid rings.

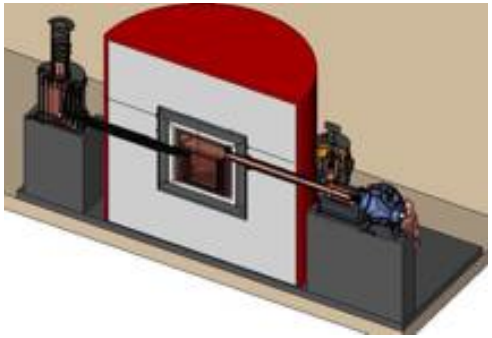
R&D program that enables experiments in astrophysics

MKIDs (Dark Energy)

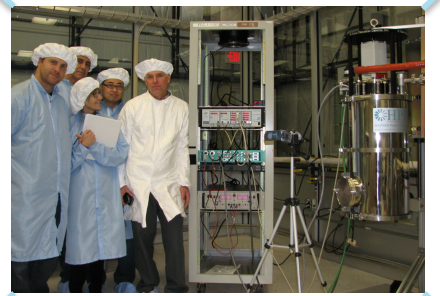
(main driver for the facility)



Super CDMS (Dark Matter)
Materials properties measurements



Adiabatic Demagnetization Refrigerator @ FNAL.



Operations start 2013.

30mK at FNAL for the first time!

STJ (neutrino decay)

Photon detector development with KEK group

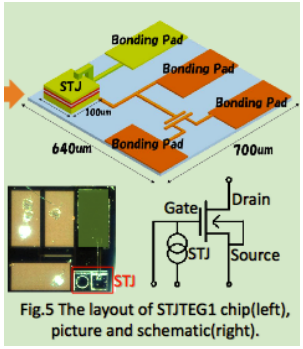


Fig.5 The layout of STJTEG1 chip(left), picture and schematic(right).

SPT-3G (CMB)
Resonator tests

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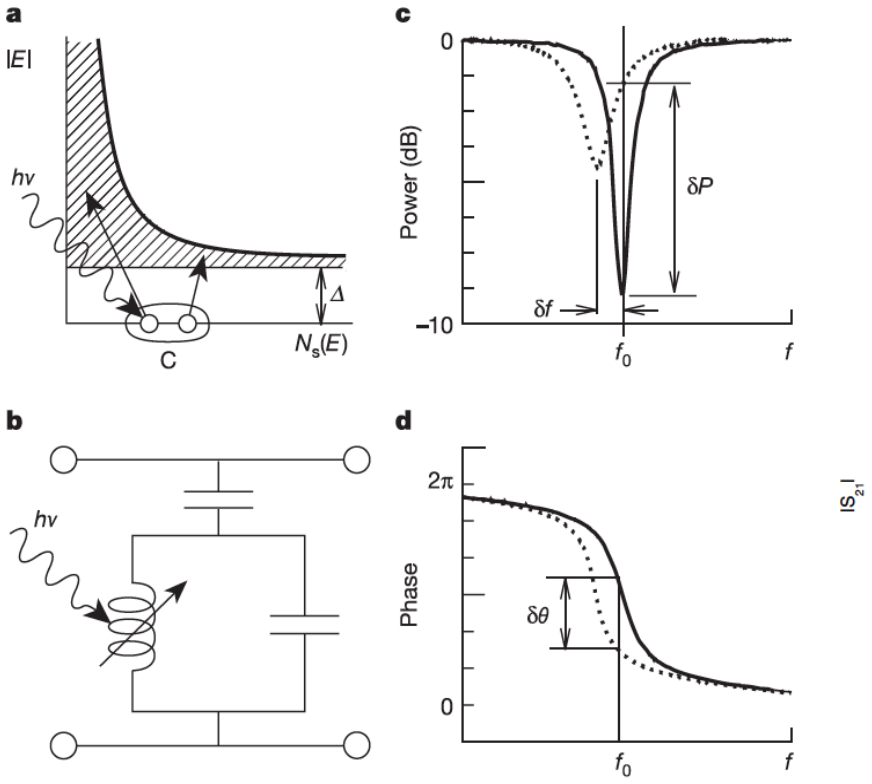
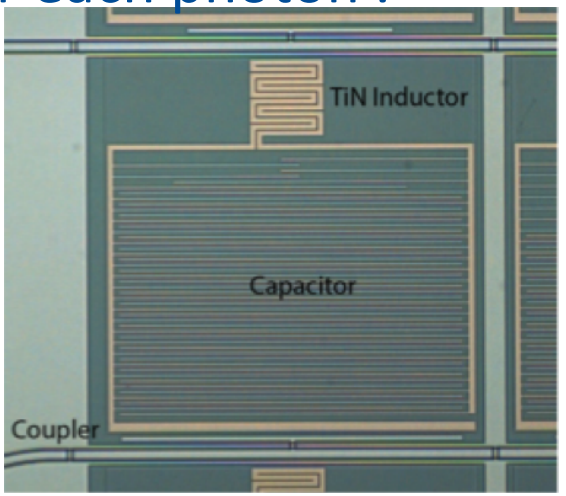
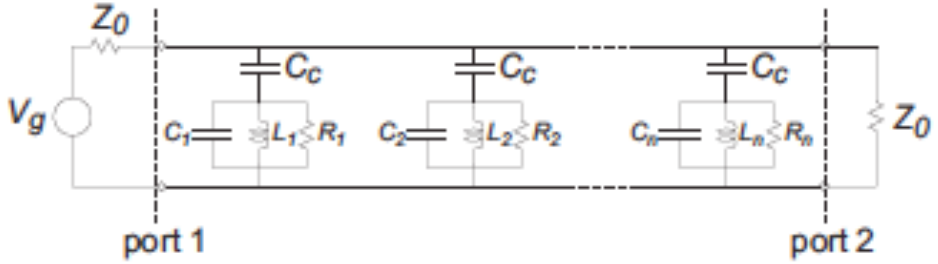
MKID: superconductor detectors for optical-NIR astromomy



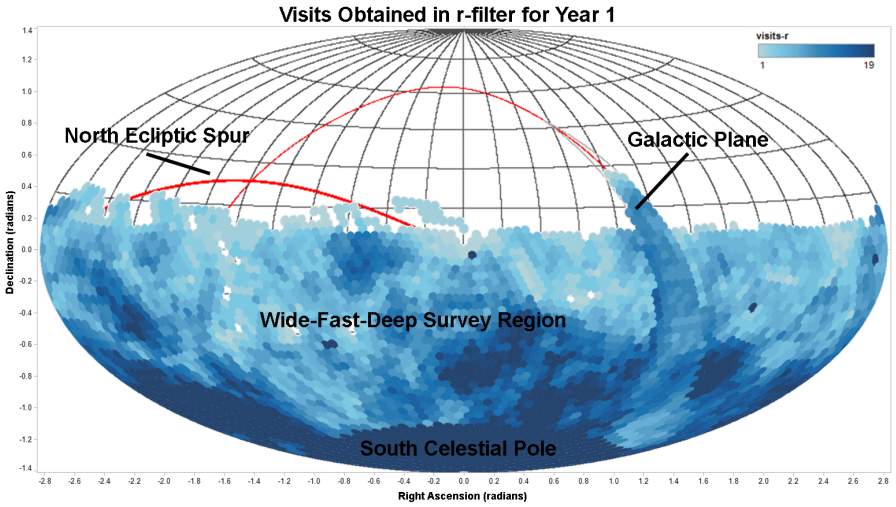
Pixels are SC resonators. Can detect single photons hitting a pixel and measure energy (R~100)and timing (~usec) for each photon .





Highly multiplexed in a RF line. Large focal planes are possible.

MKID for Dark Energy



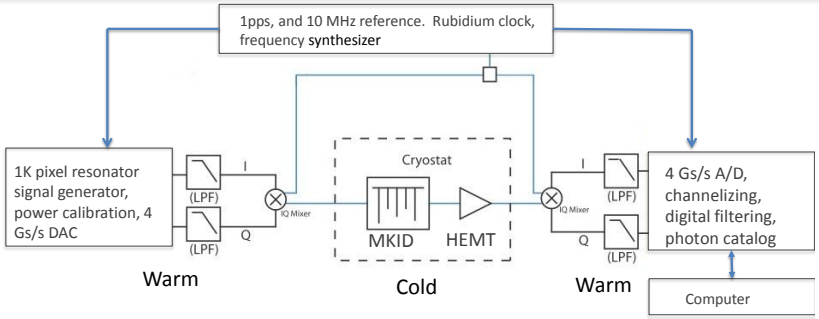
The DES and LSST will produce unprecedented imaging data sets in the coming years, decade. Do we have the technology to address the challenge of spectroscopic follow-up for this data? Are the MKIDs the solution?

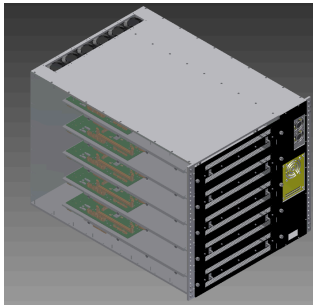
Recognized by P5 as a technology that could dramatically leverage investments.

Candidates for the **Small Projects Portfolio** can dramatically leverage investments in DESI and LSST. With Integral Field Spectrographs, the large samples of both nearby and distant supernovae found by, *e.g.*, DES and LSST can be studied in detail to make supernova-based measurements as precise as the complementary DESI BAO measurements. With focused spectroscopic follow-up of the LSST galaxies, the galaxy-based measurements from LSST can be calibrated much more precisely. Proposals to develop novel Microwave Kinetic Inductance Detectors would allow the billions of galaxies found by LSST to be used for wider field/lower resolution RSD. Novel probes to search for the new force introduced by explanations of acceleration that modify Einstein's theory of gravity were identified at Snowmass.

MKID R&D steps

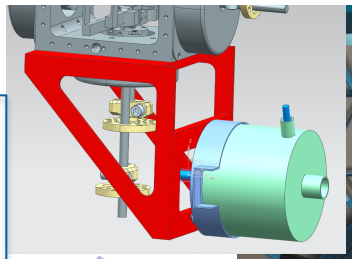
- Close collaboration with UCSB for developing the **next generation of large focal planes** (+10,000 pixels).
- UCSB is the sensor developer (current best R~17, theory limit R~80)
- FNAL is developing the **readout electronics and a prototype imager for SOAR**.

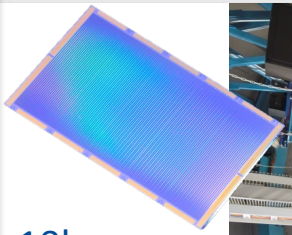




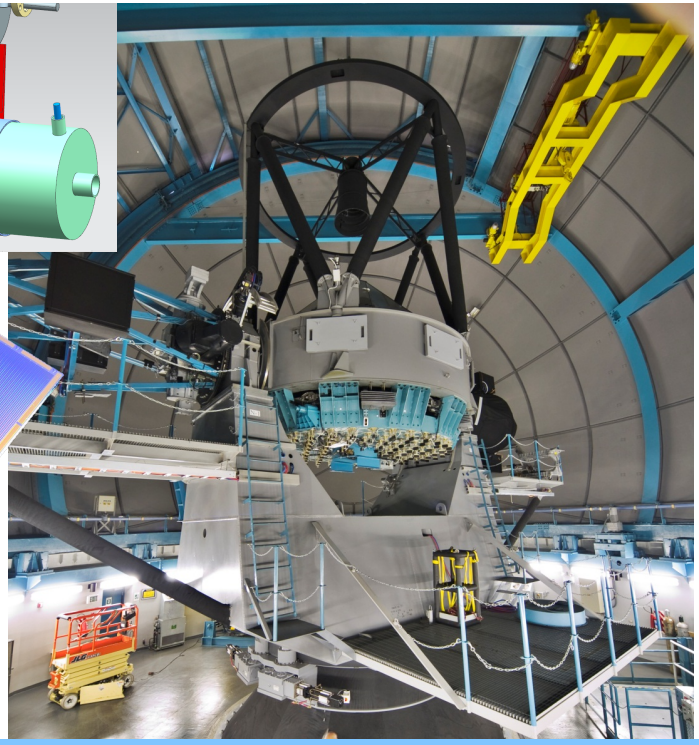
FNAL engineers developing RF multiplexing electronics for reading 10,000 pixels. Solution scalable to larger arrays.

Existing solution for 2,000 pixels does not scale for large arrays.





10k sensor developed by Prof. B.Mazin (UCSB)

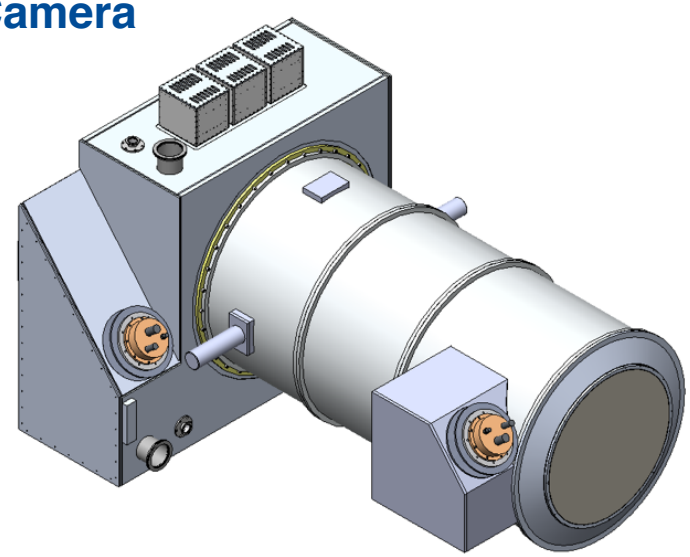


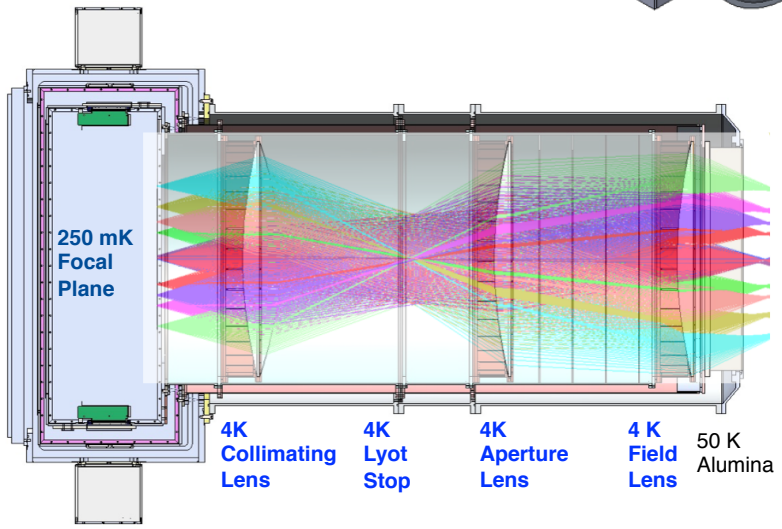
Now building at FNAL a prototype instrument to install at SOAR 4m telescope (Chile) during 2016. Already in discussions with SOAR Science board to do this. Encouragement from SOAR director.

CMB: SPT-3G Camera Design and Assembly

- **SPT-3G Camera:** FNAL is leading the design and fabrication of the camera, and its integration with the detector focal plane.
  - High-bay at Sidet will be used for SPT-3G camera assembly and testing.
- **Personnel:** Brad Benson (Scientist), Hogan Nguyen (Scientist), Sasha Rahlin (Postdoc), Andrew Lathrop (Technician), Donna Kubik (Technician)

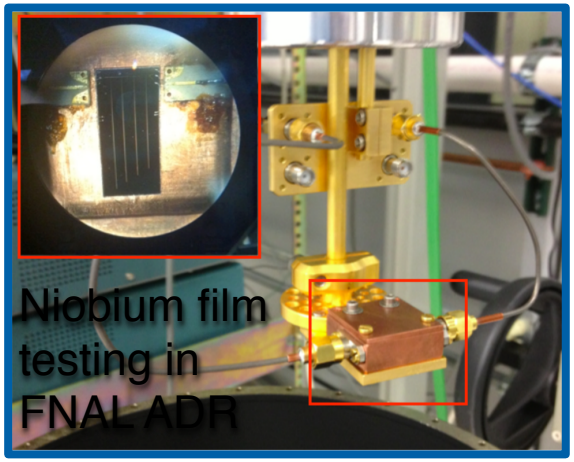
SPT-3G Camera Cryostat
2300 lbs,
8 feet long

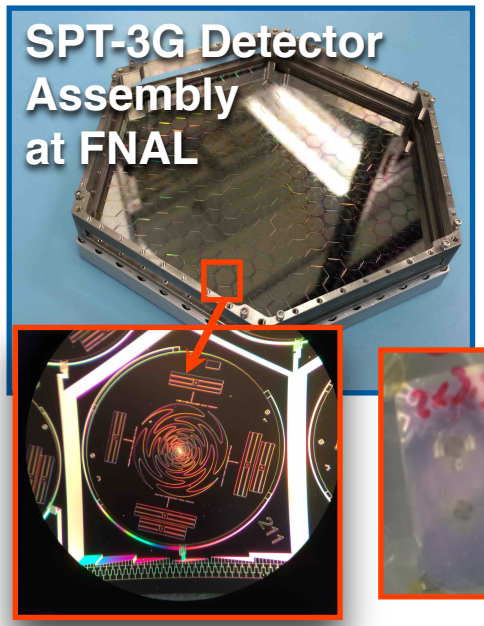


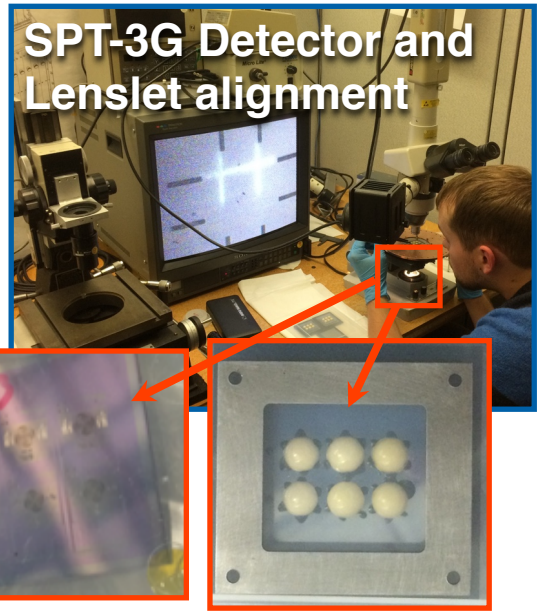


CMB: Detector Simulation, Assembly, Testing

- **Detector Simulation:** RF simulations of coupling, and microstrip filters.
- **Detector Assembly:** Detector module assembly and packaging for SPT-3G (e.g., wire-bonding, wafer alignment).
- **Detector Testing:** Adiabatic de-magnetization and He4/He3/He3 cryostats characterize detectors and superconducting films.
- **LDRD support:** Sims, assembly, and testing to support development of CMB detectors in collaboration with ANL.







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Xenon Studies (FNAL-Northwestern-Yale-Chicago)

- Doping LXe dual phase TPC (like LUX/LZ) with helium or neon
  - Initially proposed as a potential technical aide to maintaining surface stability
  - Could greatly improve reach of experiment for low mass dark matter

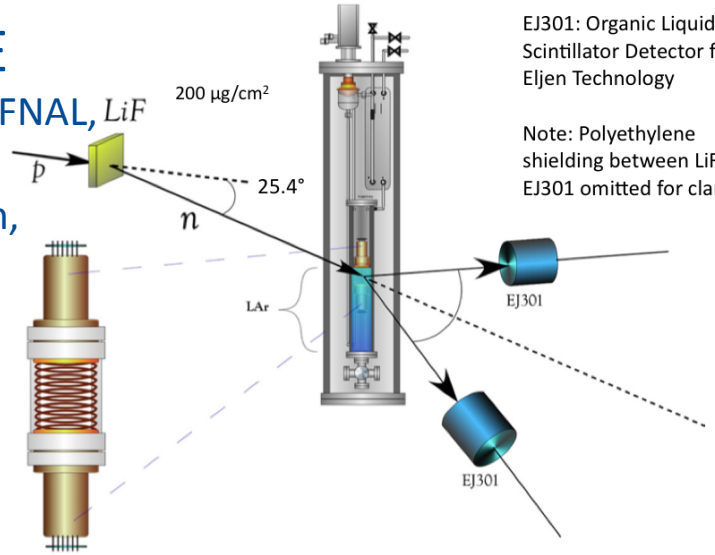
  Shares a lot of infrastructure with previous solid Xe R&D.
- Xe doping in LAr
  - Could shift the light to earlier times (from usec to 10 nsec), easier to collect in a **neutrino LArTPC**.
  - Shift light to 175nm → more efficient detection.
  - Could be interesting for DM (more light).

  Shares a lot of infrastructure with previous LAr R&D.

Nuclear Recoil Calibrations : LAr + CCDs

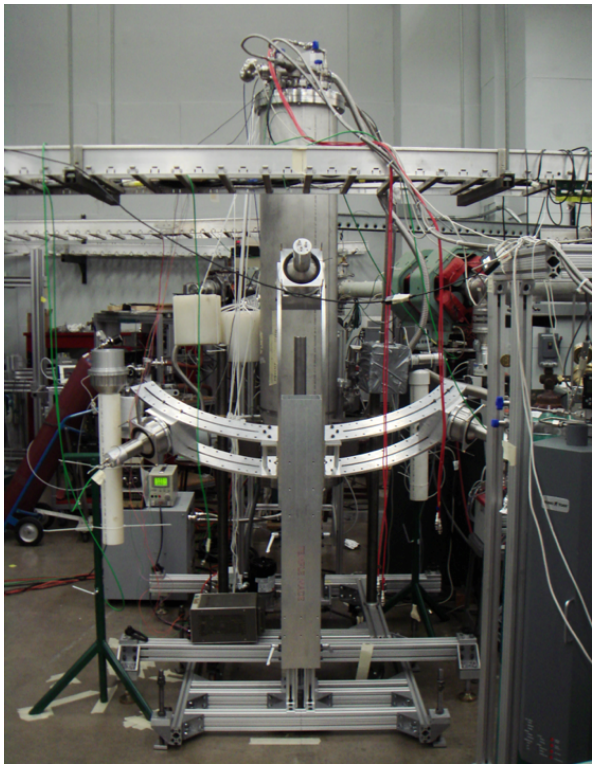
SCENE

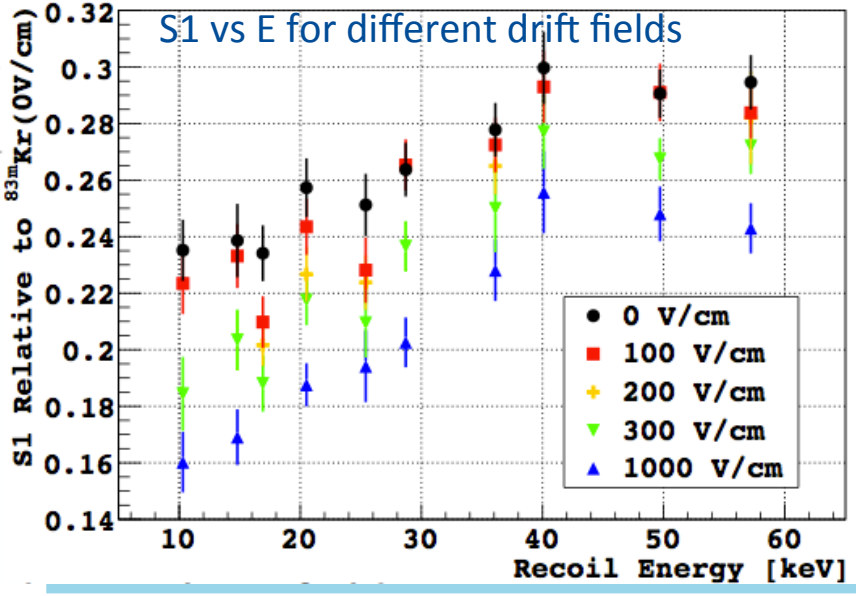
Chicago, FNAL, Naples, Princeton, Temple



EJ301: Organic Liquid Scintillator Detector from Eljen Technology

Note: Polyethylene shielding between LiF and EJ301 omitted for clarity

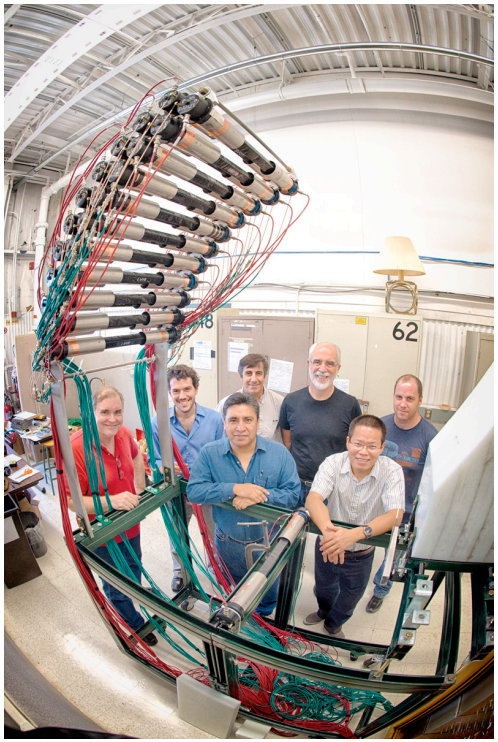


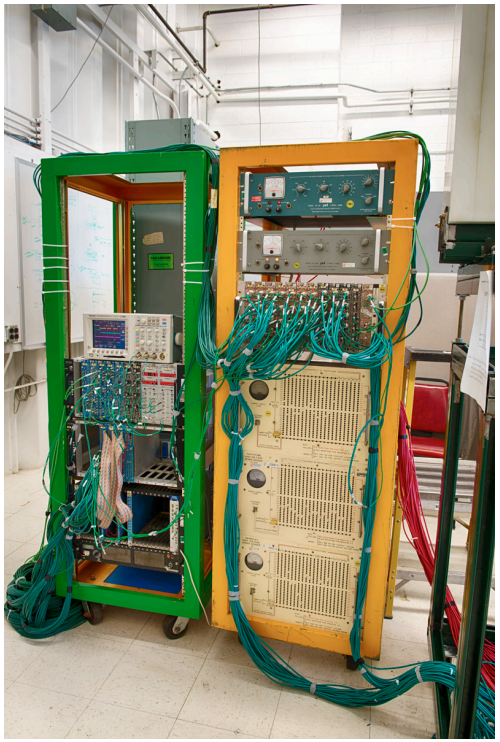


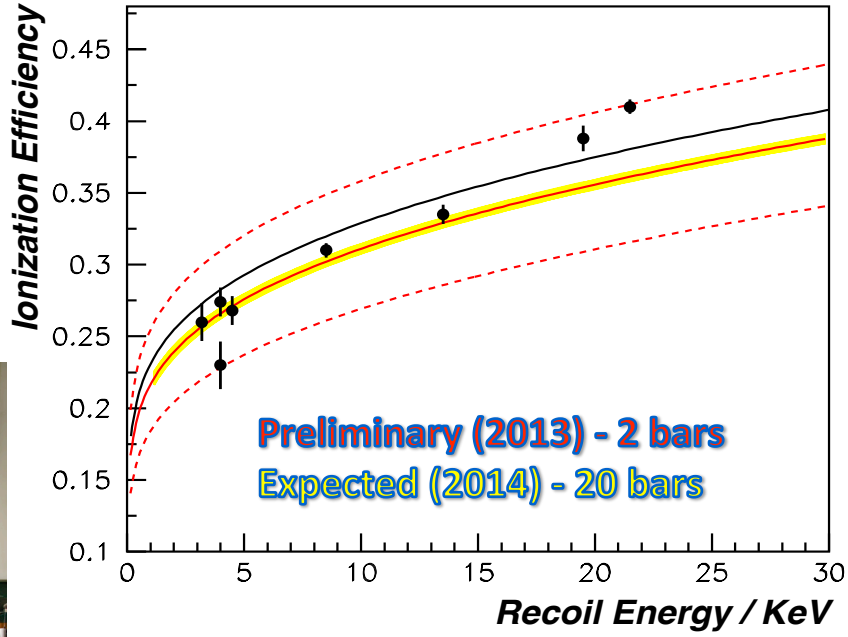
Measured light and ionization yield for nuclear recoils using neutrons at U. of. Notre Dame. Key for LAr dark matter.

Nuclear Recoil Calibrations : LAr + CCDs

For very low energy nuclear recoils detected with Silicon we also need this calibration. Threshold 100eV, existing calibration down to 4keV.







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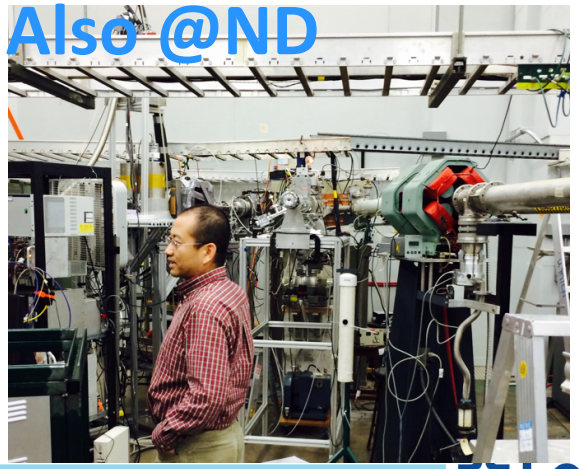

Some of the students visitors for Cosmic detector R&D during 2014

High school
- Max Drimmer (now at Stanford)
- Sebastian Wagner (now at Harvard)
- David Dodelson (now at Durham)
- Steve Kerby (senior)
- Meghan Razimoff (senior)

Undergraduate:
- Eduardo Mejia (Northern Illinois Univ)
- Mikhail Rezazadeh (U. Chicago)
- Emily Macuk (Marquette University)

Graduate:
- Melissa Butner (Northern Illinois Univ)
- Alex Kavner (U. Michigan) ⊙
- Junhui Liao (Zurich) ⊙
- Rafael Ollala (Mexico)
- Guadalupe Moreno (Mexico) ⊙
- Alejandro Castaneda (Mexico)
- Pamela Hernandez (Mexico)
- Federico Izraelevitch (Argentina)
- Guillermo Fernandez (Argentina)
- Conett Huerta (University of Puerto Rico)
- Jing Zhou (U.Chicago) ⊙

⊙ Shared R&D equipment with universities to enable contributions from home institution

Discussion