Cosmic Particles and New Initiatives

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Fermilab Institutional Review
June 6-9, 2011

U.S. DEPARTMENT OF ENERGY

Fermilab

Outline

- Pierre Auger Observatory
- Fermilab Holometer
- QUIET R&D
- Solid Xenon R&D

Pierre Auger Observatory

studying the universe's highest energy particles

Fermilab collaborators:

- Eun-Joo Ahn (postdoc, PPD)
- Henry Glass (TD)
- Carlos Hojvat (PPD)
- Peter Kasper (AD)
- Paul Lebrun (CD)
- Paul Mantsch (Project Manager, TD)
- Peter Mazur (TD, retired)

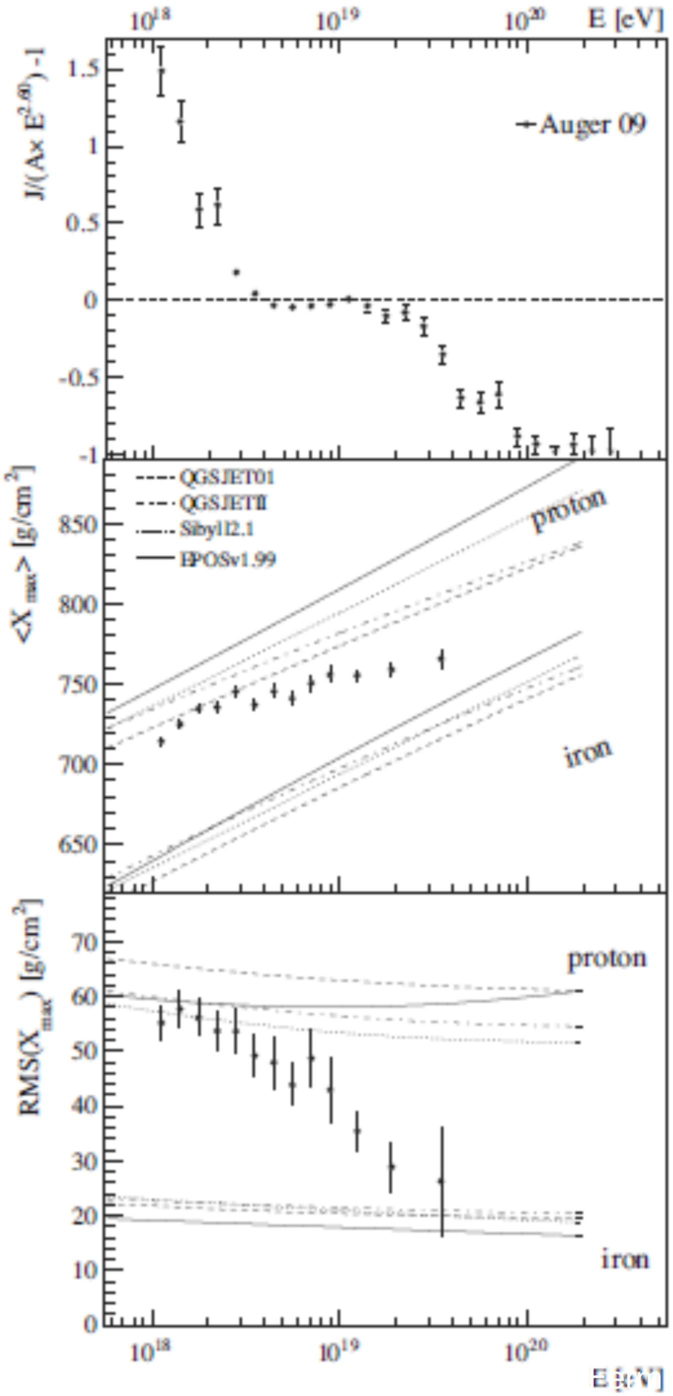
496 authors from 94 institutions in 19 countries.

29 full-author-list papers, 136 PhDs granted

Auger at Fermilab

- **Auger Project Management Office is based at Fermilab**
  TD: Mantsch, Glass, Mazur, McCook (admin)

- Scientific and Technical contributions:
  - Analysis of anisotropy, composition
    - Anisotropy and chemical composition in the direction of Centaurus A (Albuquerque, Kuehn)
    - Catalogue Based Maximum Likelihood Analysis (Kuehn, Kasper, Lebrun)
  - PMT long-term response studies
    - A new study of SD PMT response: Preliminary results (Lebrun, Kuehn)
    - On Systematic uncertainties in the SD energy measurements above 10 EeV (Lebrun)
  - Proton-air cross section studies (Ahn, Kasper)
  - Surface detectors, data acquisition for RDA (Mazur, Kasper)
    - Single PMT SD, low-power consumption electronics, new communications system
  - Participated in design/development/installation of AMIGA underground muon detector array using MINOS scintillators manufactured at FNAL (Mazur)



Energy spectrum and shower development

←Spectrum compared to $E^{-2.6}$

Slope changes at 4 EeV and 20 EeV --

HE suppression consistent with GZK, but could also indicate source acceleration limit

← Depth of shower maximum (X_{max})

Mean (left) and rms (below) both indicate either:

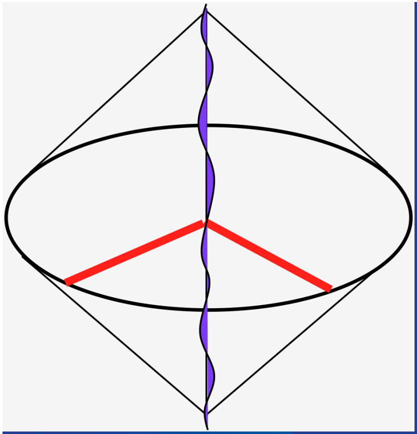
- **transition to higher mass primaries at higher energies in current models, or**
- **new particle interaction dynamics at higher energy**

Pierre Auger Short-term and Long-term Goals

- Understand evolution of X_{max} with energy and related measurements:
  - Determine composition of ultra-high energy cosmic rays.
  - Study the properties of hadronic interactions at center-of-mass energies up to 450 TeV.

- Observe photons and neutrinos from GZK effect
- Determine astrophysical sources that can produce trans-GZK particles
- Study galactic and intergalactic magnetic fields from deflection patterns of the charged particles across a wide energy range

- New detector subsystems are being installed which will provide additional composition data.
  - AMIGA – underground muon scintillators
  - HEAT -- higher altitude fluorescence detectors
  - AERA, MIDAS, etc. -- detection of radio emission from UHECR

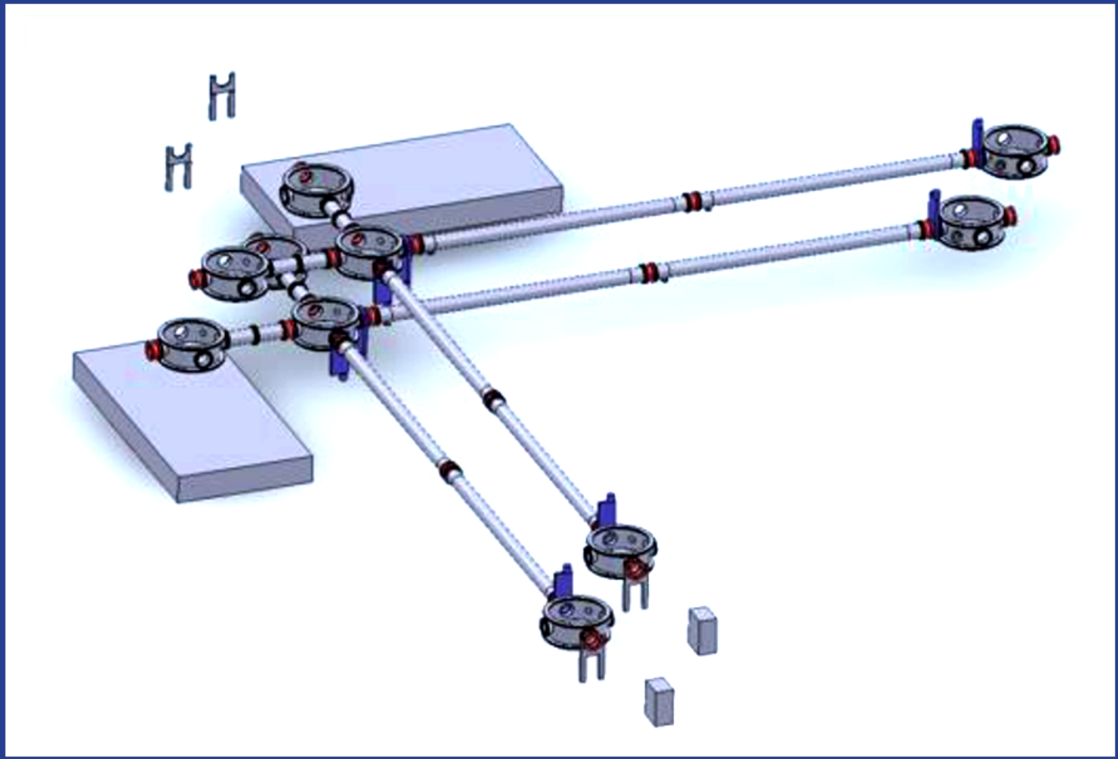


The Fermilab Holometer:

Interferometer probe of the quantum structure of space-time at the Planck scale 10^{19} GeV

5/11: Funding for construction/operation via DOE Early Career grant to A.S. Chou

- Fermilab:
  - A. S. Chou (co-PI, acting project manager), H.Glass, G. Guiterrez, C. Hogan, J. Steffen, C. Stoughton, R. Tomlin, J. Volk, W. Wester. (<2 FTE scientists)
- MIT LIGO:
  - S. Waldman, R. Weiss
- U.Chicago
  - S. Meyer (co-PI), R. Lanza, L. McCuller
- U. Michigan LIGO
  - D. Gustafson



Bekenstein-Hawking black hole entropy suggests that our world is holographic

Susskind, ‘t Hooft

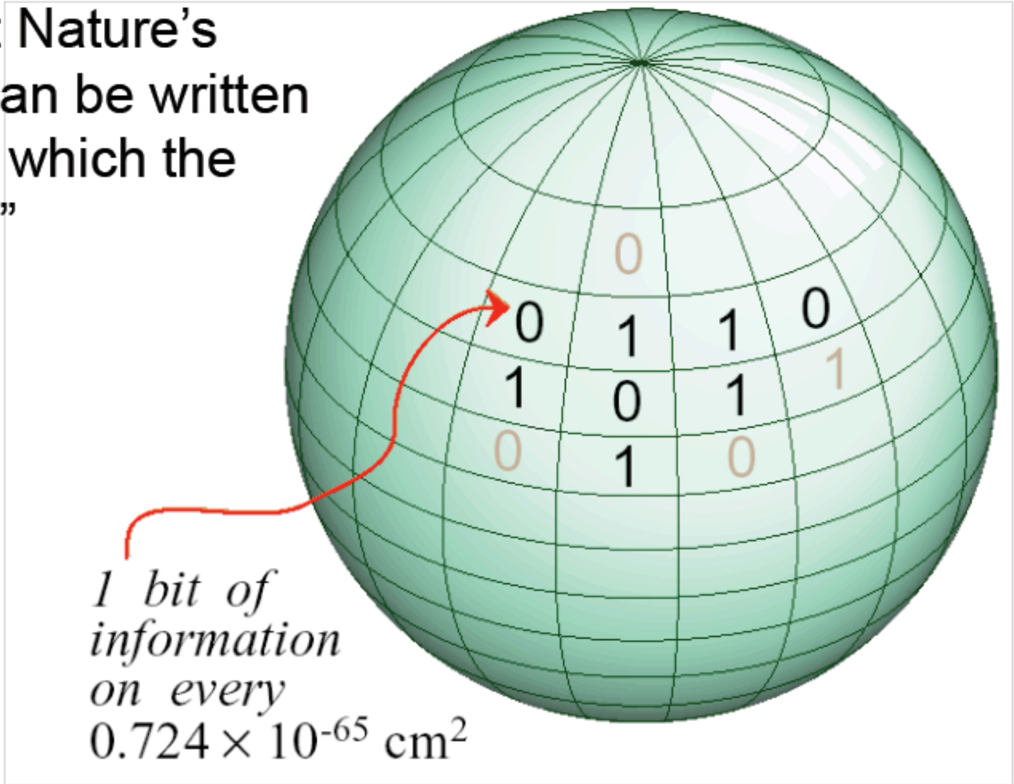
$$S_{BH} = A_{BH} \times (M_{pl}/2)^2 = A_{BH}/(2\,\lambda_{pl})^2$$

“This is what we found out about Nature’s book keeping system: the data can be written onto a surface, and the pen with which the data are written has a finite size.”

-Gerard ‘t Hooft

Everything is written on 2D surfaces moving at the speed of light

R. Bousso

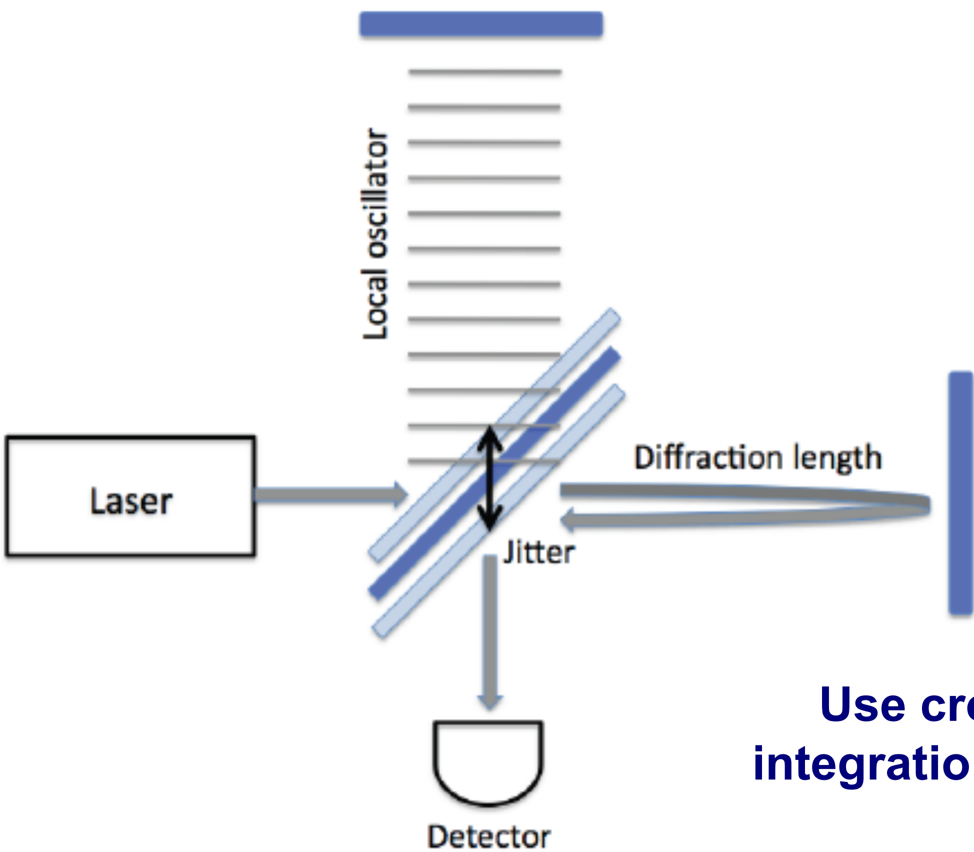


The shocking thing is not holography, but rather the bandwidth limit….

Use lots of photons to make precise position measurements, search for holographic jitter in beamsplitter position in a Michelson interferometer

Each Nd:YAG photon has position resolution 1064 nm.

Measuring with N photons gives resolution: $\frac{1064\,nm}{\sqrt{N}}$

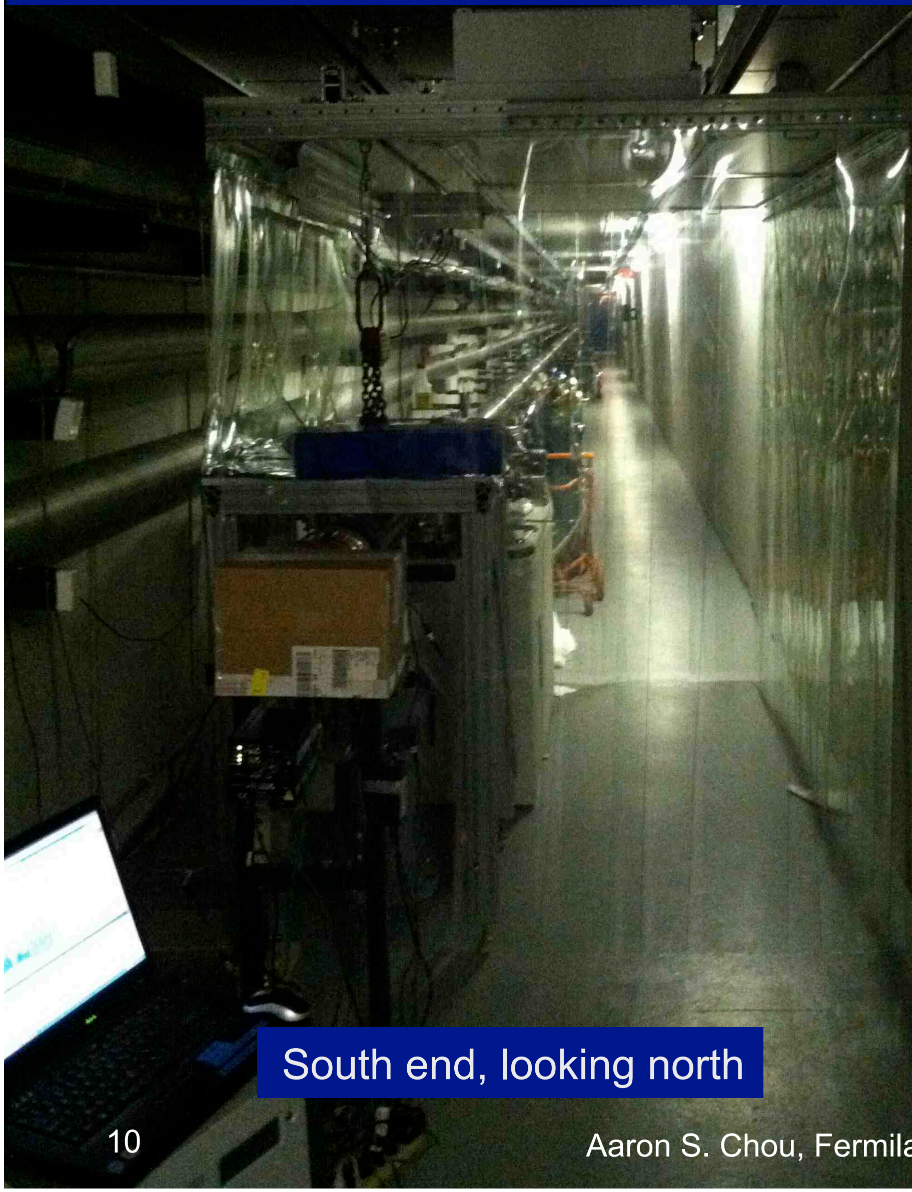


C. Hogan: Measure intrinsic blurriness of beamsplitter position due to Planck-scale quantization of space-time

$$\Delta x = \sqrt{\frac{L}{2\pi / \lambda_{pl}}} = \sqrt{\frac{L}{2\pi M_{pl}}}$$

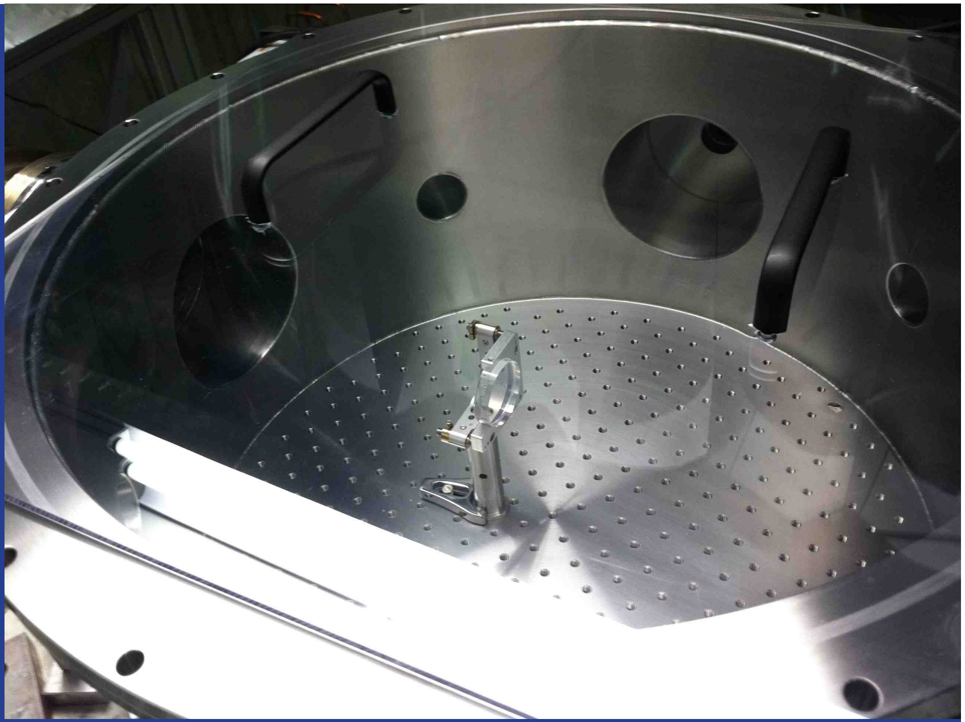
Use cross-correlation technique and extended integration time to reach the predicted signal at a tiny distance scale 10^{-20} m/rtHz

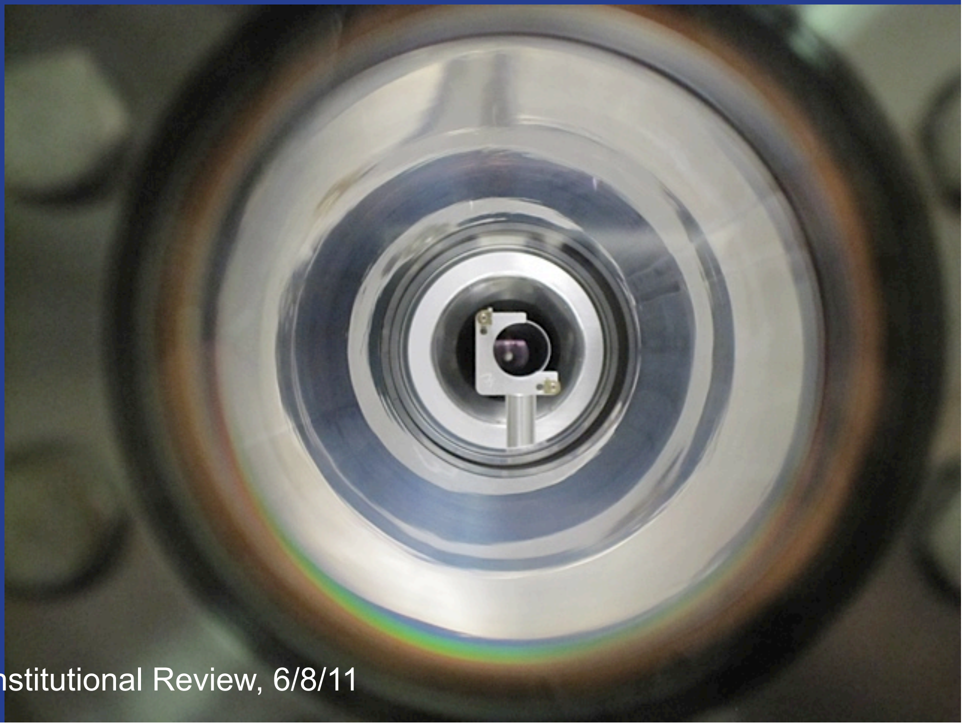
T-1007: Optical Cavity Test Bench
40 meter vacuum system inside laser-interlocked meson beamline.
Develop high power, recycled photon beam for Holometer, axion search.



End station vacuum vessels hold custom optical cavity mirrors and eventually beamsplitters

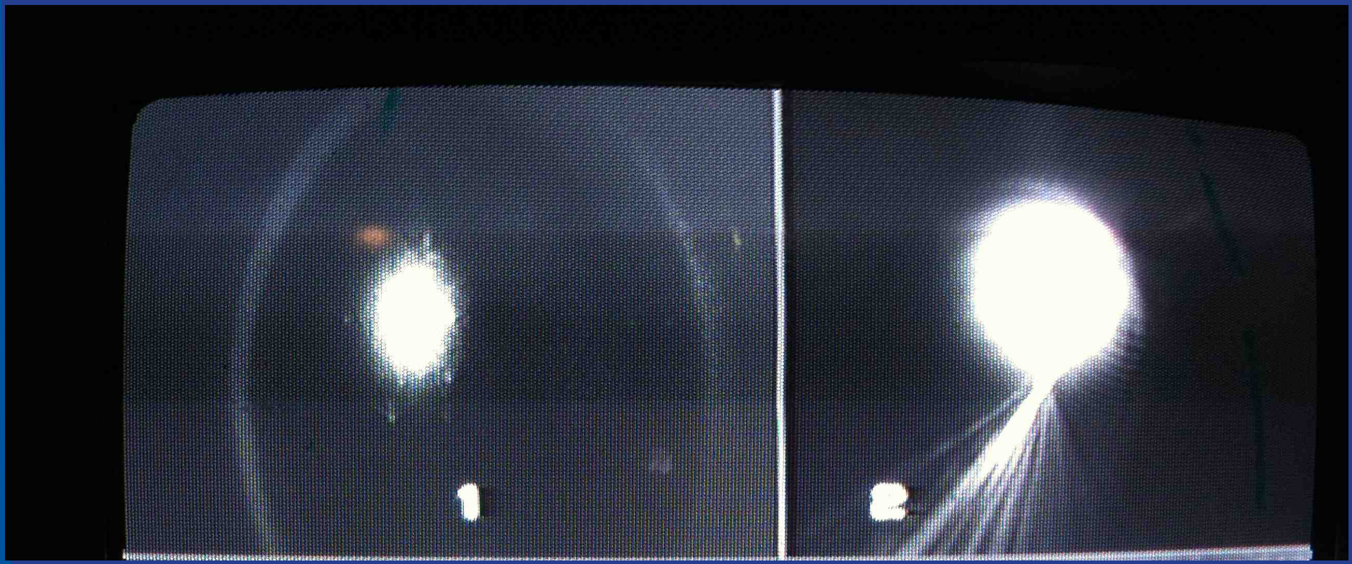
U.Chicago graduate students
R.Lanza, L.McCuller





R&D cavity locked on Gaussian fundamental mode.

Spot on input mirror



Spot on end mirror

A 40m long standing wave with 8×10^7 nodes!

Initial optics recycle the beam 20 times before dumping it.

Custom optics procurements are underway to improve power recycling to 1 kW power.

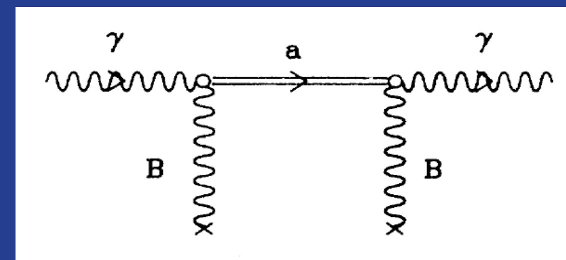
Holometer: progress and plans

- 9/2009: Physics Advisory Committee proposal
- 9/2010: Presented at DOE KA13 review
- 4/2011: First light in 40 meter R&D cavity
  - Constructed in available beamline with help of FNAL vacuum group
  - R&D funded by DOE OJI grant, DOE KA15, SCI grants, NASA grant
- 5/2011: Funding for holometer from Early Career grant

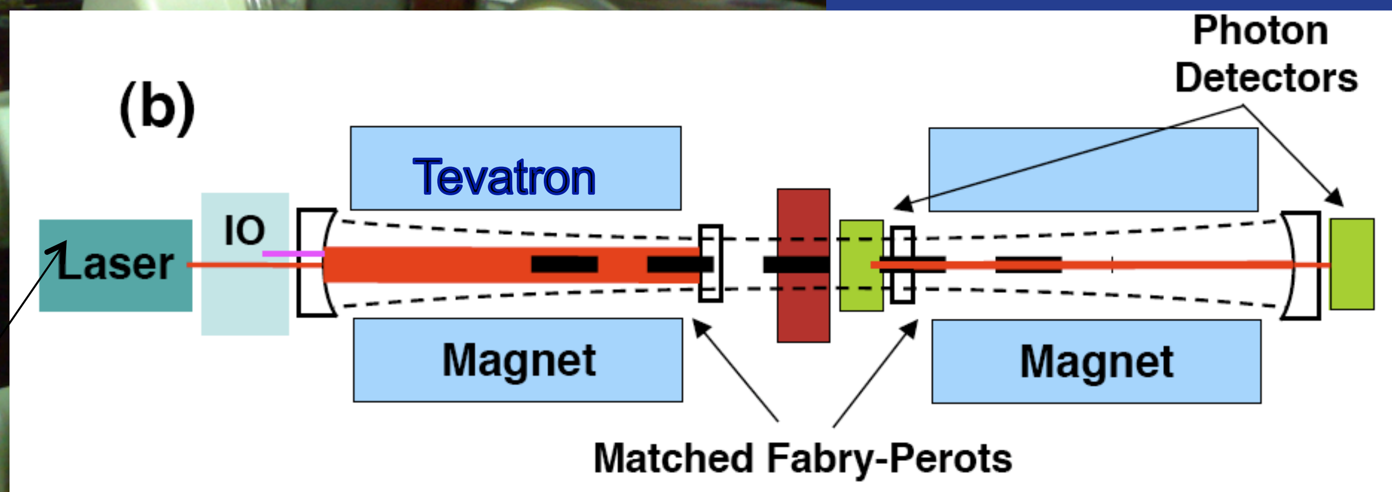
- Remainder of 2011:
  - Installation and commissioning of 1st interferometer at FNAL
  - Commission control and data acquisition hardware/software

- 2012: Installation of 2^{nd} interferometer
  - Look for correlated holographic noise
  - Study correlated RF backgrounds which could mimic holographic noise. (None found so far)

Another application: Use intense photon beam + existing Tevatron magnets to search for rare photon-photon scattering processes mediated by axion-like or Higgs-like particles



$$P_{\text{regen}} \approx \left(\frac{1}{4} g^2 B^2 L^2\right)^2$$



Increase photon flux from 10^{19} to 10^{24} γ/s, increase L from 6 to 40m, resonantly detect
→ improve laser axion sensitivity by 4 orders of magnitude.

Status of QUIET at Fermilab (H. Nguyen, F. DeJongh)

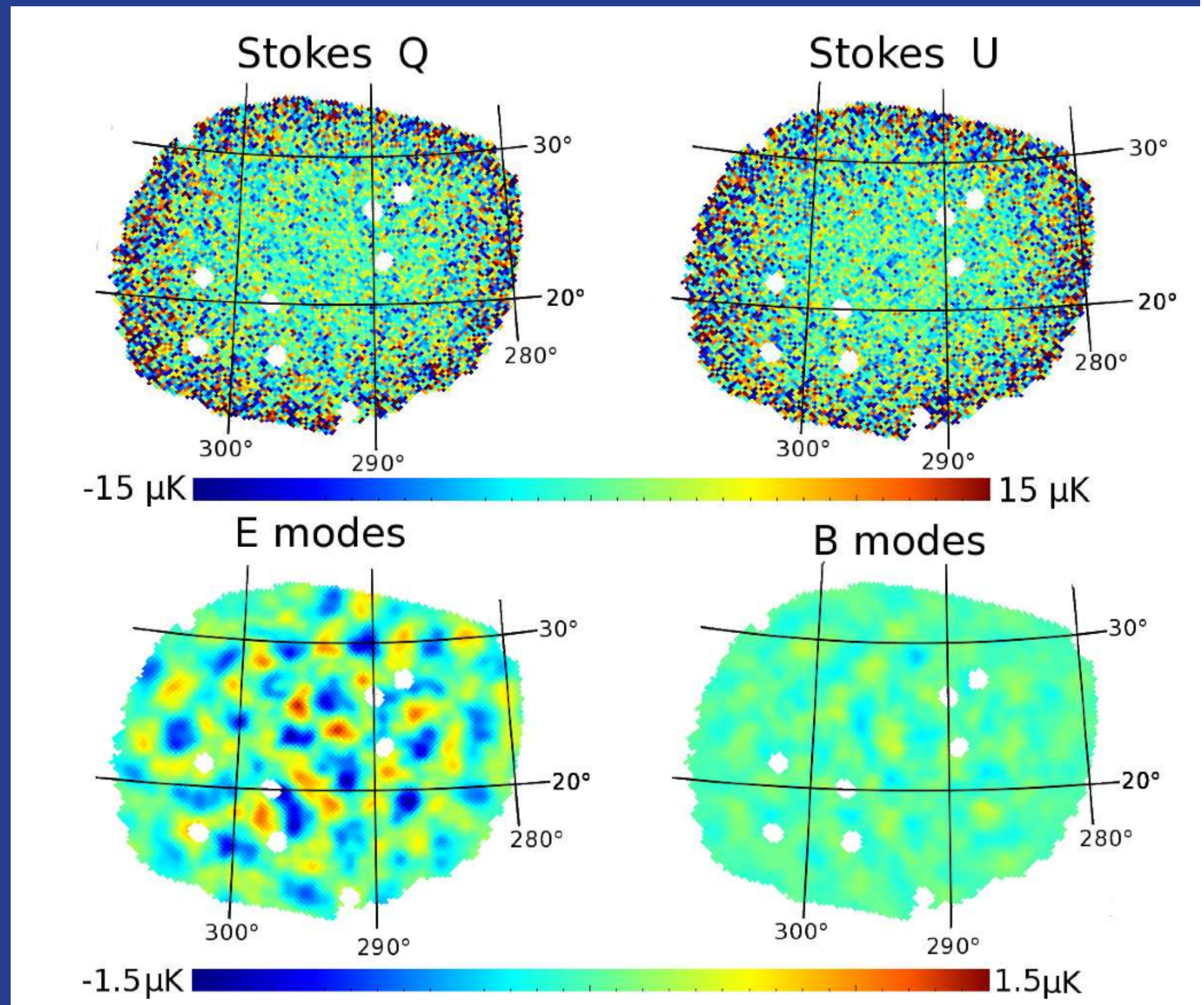
Announcement of Q-band (40 GHz) Result (Fermilab Wine & Cheese in March 2011)

6 sigma detection
of EE peak at 1.2 degree
angular scale.

See 3σ evidence of
Synchroton Foreground
in a supposedly clean
patch of sky

Limit on B mode ($r < 2.2$)
Lowest published systematics
($r_{sys} \sim 0.1$)

Analysis of W-band (90 GHz) Underway

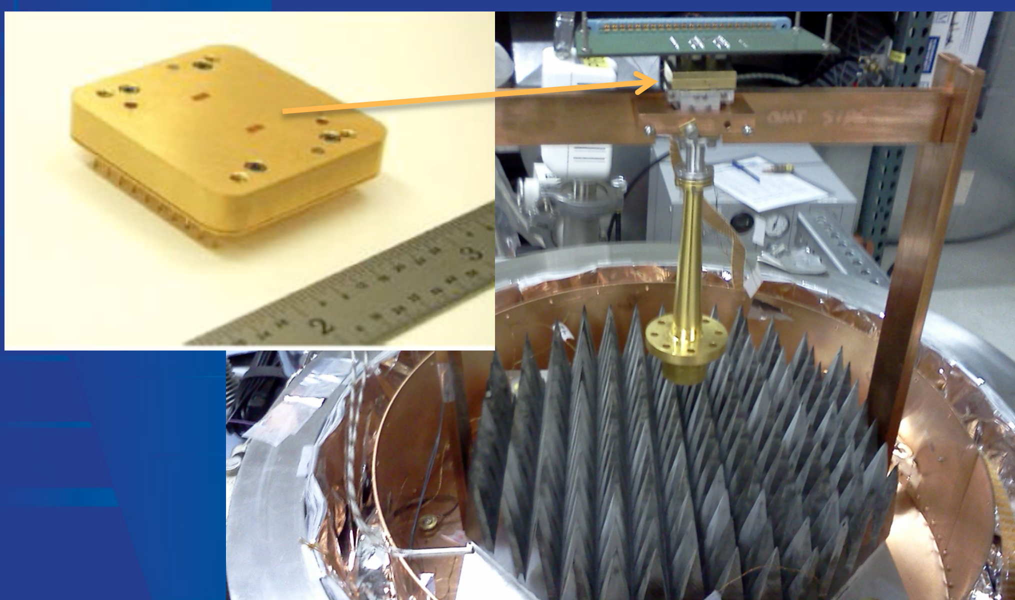


Fermilab contributions to QUIET detector R&D

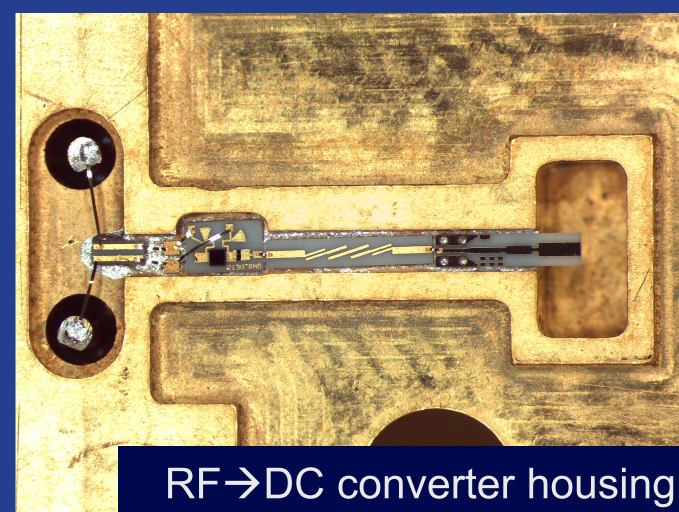
FNAL is playing a key role in detector R&D: electronics, test cryostat, blackbody calibrator. These efforts have leveraged capabilities of FNAL's Silicon Detector facility, which could also serve as the detector assembly facility for the project.

We are currently ramping down a small effort on development of lower-noise RF modules, in support of a lower-cost proposal to NSF.

If NSF decides to proceed with QUIET-II, FNAL will be in a good position to make further important contributions.

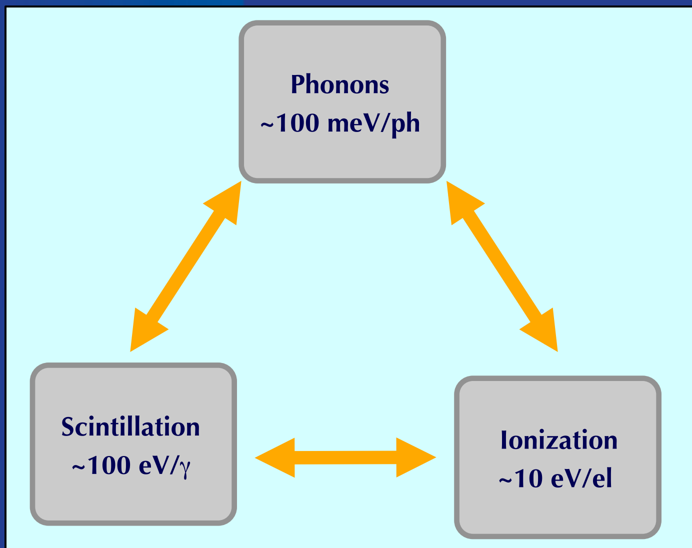


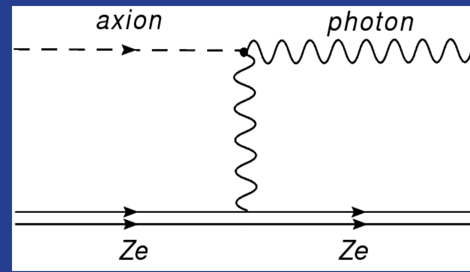
QUIET I Module in Cryostat at Fermilab (PPD Lab 3)

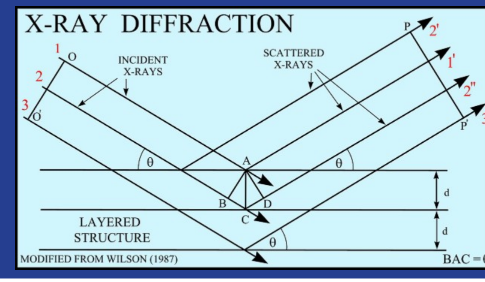


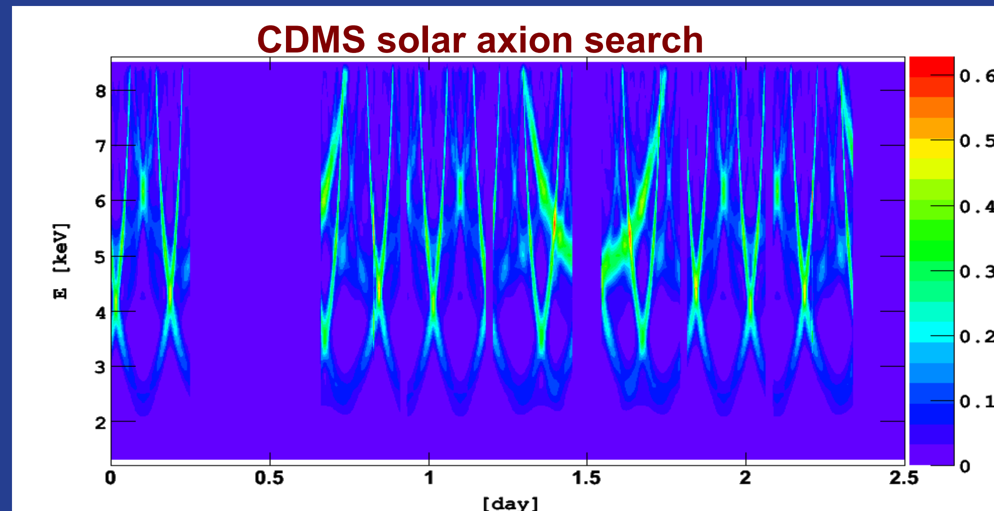
RF→DC converter housing

Solid Xenon for low background detectors (J.Yoo, Wilson Fellow)





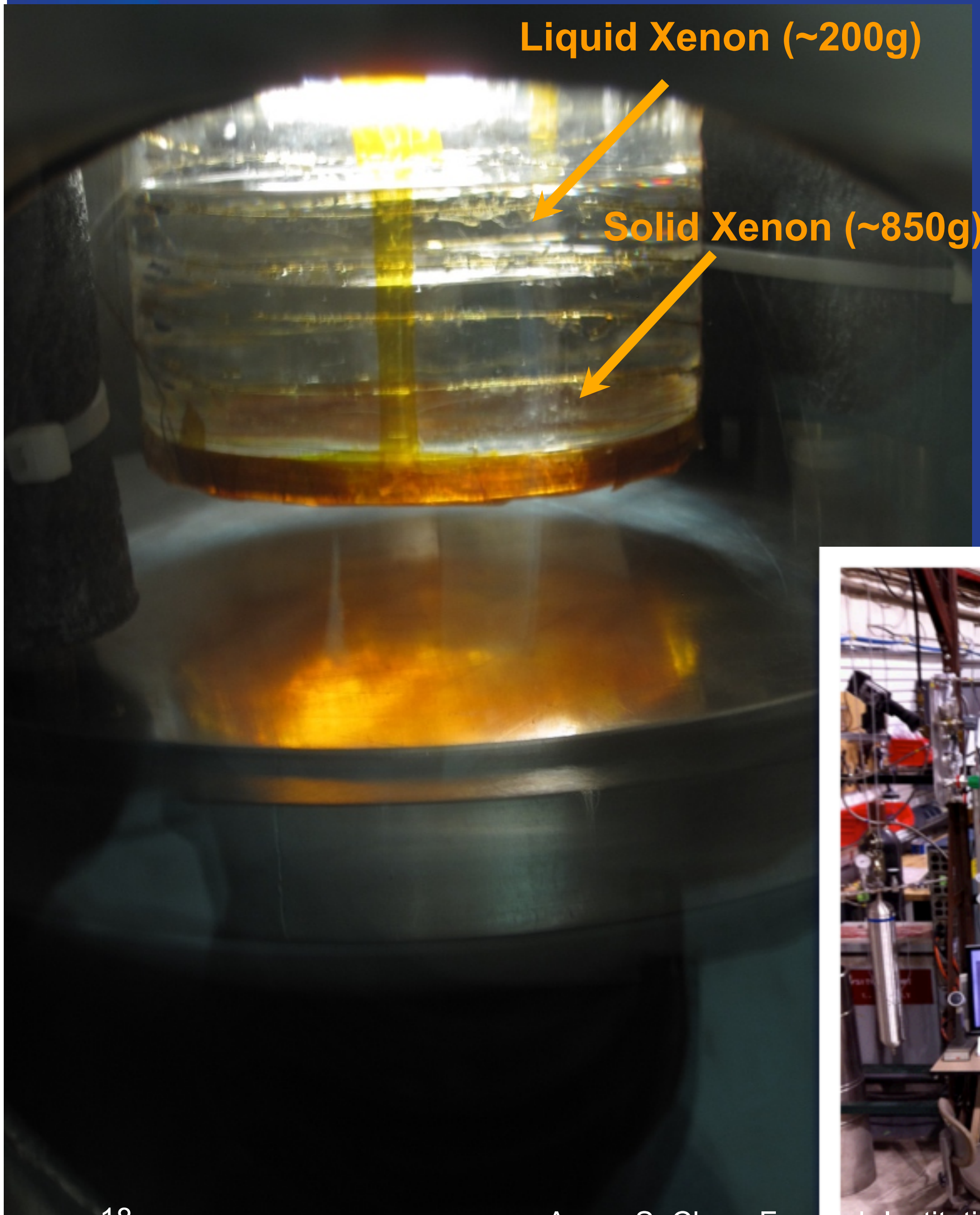




Why Solid Xenon?

- For **solar axion search**, having a crystal is crucial for Bragg scattering enhancement
- Even more scintillation light (61 γ/ keV) than LXe (42 γ/ keV) is reported
- Drifting electrons faster in the crystal– reduced event pile-up in the ionization channel.
- Potentially improved energy resolution in phonon channel → application to **0νββ decay search**
  - Large number of quanta:10,000 phonons / keV
  - Luke-phonon readout will provide ionization energy and position information
- No further background contamination through circulation loop (no convection mix)

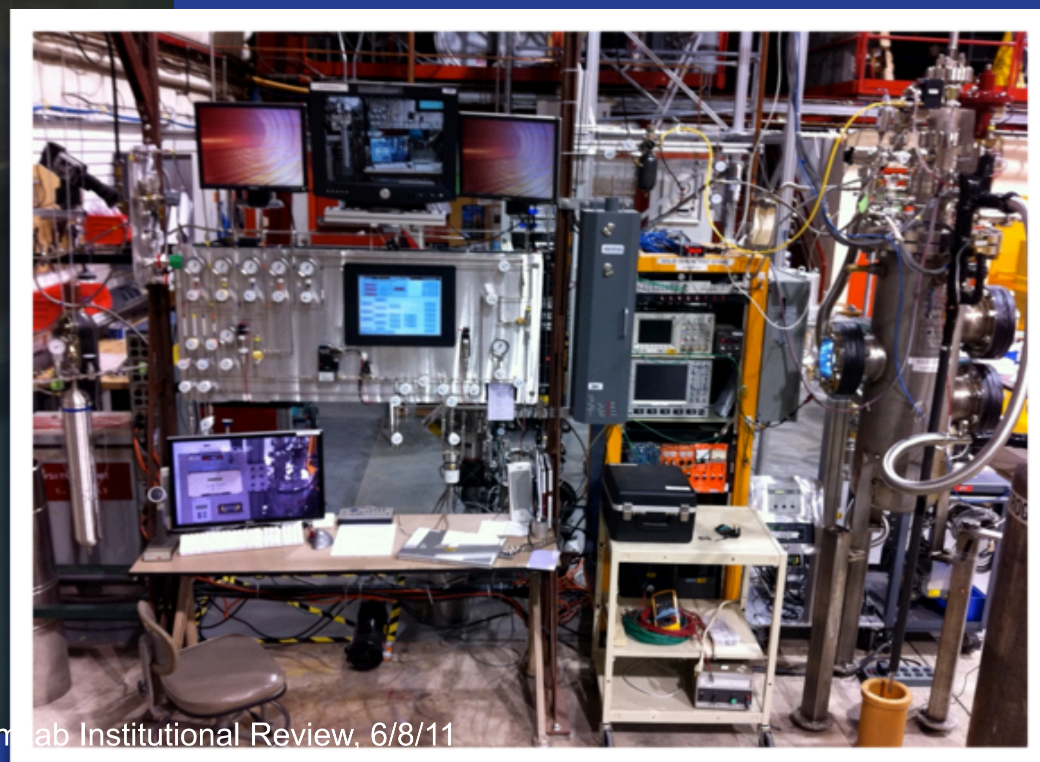
Solid Xenon R&D



Phase-1: ~kg scale crystal clear solid xenon was successfully made (2010)

Phase-2: Automate solid xenon fabrication and readout scintillation light in progress (2011)

Apparatus set up in corner of Fermilab's liquid argon lab, utilizes Fermilab **infrastructure** for liquid Argon R&D, and **expertise** in cryogenic engineering, safe cryo-liquid handling.



Summary

- Auger:
  - FNAL is making large contributions towards managing and operating the observatory, as well as towards production of scientific and technical results.
  - Current research is focused on a mysterious composition/interaction change in UHECR will be probed with higher statistics and new detector subsystems.
- Holometer/axions:
  - FNAL has converted an existing beamline into a laser lab and demonstrated a 40m optical cavity for producing intense photon beams
  - With new funding, plans are now underway to construct the holometer as a low-cost experiment to probe Planck-scale physics.
  - Cavity-recycled photon beams + Tevatron magnets + cryo infrastructure can be used in an improved laser axion search.
- QUIET-II R&D:
  - Utilizing Silicon Detector Facility infrastructure, FNAL has participated in microwave detector R&D, making important hardware contributions
  - Further participation depends on NSF approval of the experiment.
- Solid Xenon R&D
  - Utilizing liquid argon facility and cryo expertise, FNAL has produced optically transparent solid xenon, for possible use in solar axion or $0\nu\beta\beta$ search.