Crystal Helioscope

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Fermilab

FCPA Retreat
23 April 2010

PRL Cover and FermiToday

Fermilab Today

Friday, Oct. 30, 2009

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Calendar

Have a safe day!

Friday, Oct. 30
3:30 p.m.
DIRECTOR'S COFFEE BREAK - 2nd Flr X-Over
THERE WILL BE NO JOINT EXPERIMENTAL-THEORETICAL PHYSICS SEMINAR THIS WEEK

Monday, Nov. 2
1:30 p.m.
Research Techniques Seminar - Curia II
Speaker: Juha Kalliopuska, VTT Micro and Nanoelectronics, Finland
Title: Edgeless Detectors for High Energy Physics Applications
2:30 p.m.
Particle Astrophysics Seminar - One West
Speaker: Tyce DeYoung, Pennsylvania State University
Title: Particle Physics and Astrophysics with IceCube
3:30 p.m.
DIRECTOR'S COFFEE BREAK - 2nd Flr X-Over
4 p.m.
All Experimenters' Meeting
Special Topics: ILC Cavity Gradients and Manufacturing; CMS/LHC Report - Curia II

Click here **for NALCAL, a weekly calendar with links to additional information.**

Campaigns

Take Five

Tune IT Up

H1N1 Flu

For information about H1N1, visit Fermilab's flu information site.

Fermilab Special Result of the Week

CDMS looks for finger prints of axions

The finger print that CDMS is looking for: the expected solar axion event rate in a germanium detector depends on the energy of the axions and the position of the sun in the sky. The position of the sun is plotted as time of day.

The theory of strong interactions, known as quantum chromodynamics, predicts that matter and antimatter behave slightly differently, a phenomenon known as CP violation. However, CP violation has never been observed in strong interactions.

In order to save QCD from this dilemma, theorists predict the existence of a particle known as the axion, which barely interacts with matter. While the particle fixes the CP violation problem, experiments have not yet detected any axions.

According to theory, an axion could emerge when a photon traverses a very strong electric or magnetic field. The core of the sun would be a perfect region for the creation of axions. The particles would immediately escape the sun and some of them would travel through Earth.

The Cryogenic Dark Matter Search, which takes place deep underground in the Soudan Underground Laboratory in Minnesota, has searched for axions and set new limits on the properties of these particles. The result made the cover of the Oct. 1 issue of Physical Review Letters.

The primary goal of the CDMS collaboration is the search for weakly interacting massive particles, which are candidates for dark matter particles. But its germanium and silicon detectors, which

Recovery Act Feature

Roll out the wavelength shifter barrel

The first barrels of the chemical powders PPO and bis-MSB began arriving at Fermilab in September. During the next year, Fermilab will receive 8,700 kilograms of the powders.

The first batches of two powdered chemicals, dubbed wavelength shifters, for the future NOvA neutrino project arrived by the barrel at Fermilab recently.

The American Recovery and Reinvestment Act funded the $2.1 million contract for the wavelength shifters, a crucial element for the neutrino project.

Scientists will use the two chemical powders, called PPO and bis-MSB, to change the wavelength of particles of light, called photons, into the required range for the experiment.

During the next year, Fermilab will receive 8,700 kilograms of the wavelength shifters. So far Fermilab has received 3,060 kilograms of the PPO and 120 kilograms of the bis-MSB powders.

"It takes a long time to manufacture this large an amount of the powders," said John Cooper, Fermilab NOvA project manager. Fermilab will receive the wavelength shifters in multiple shipments as they become available, he said.

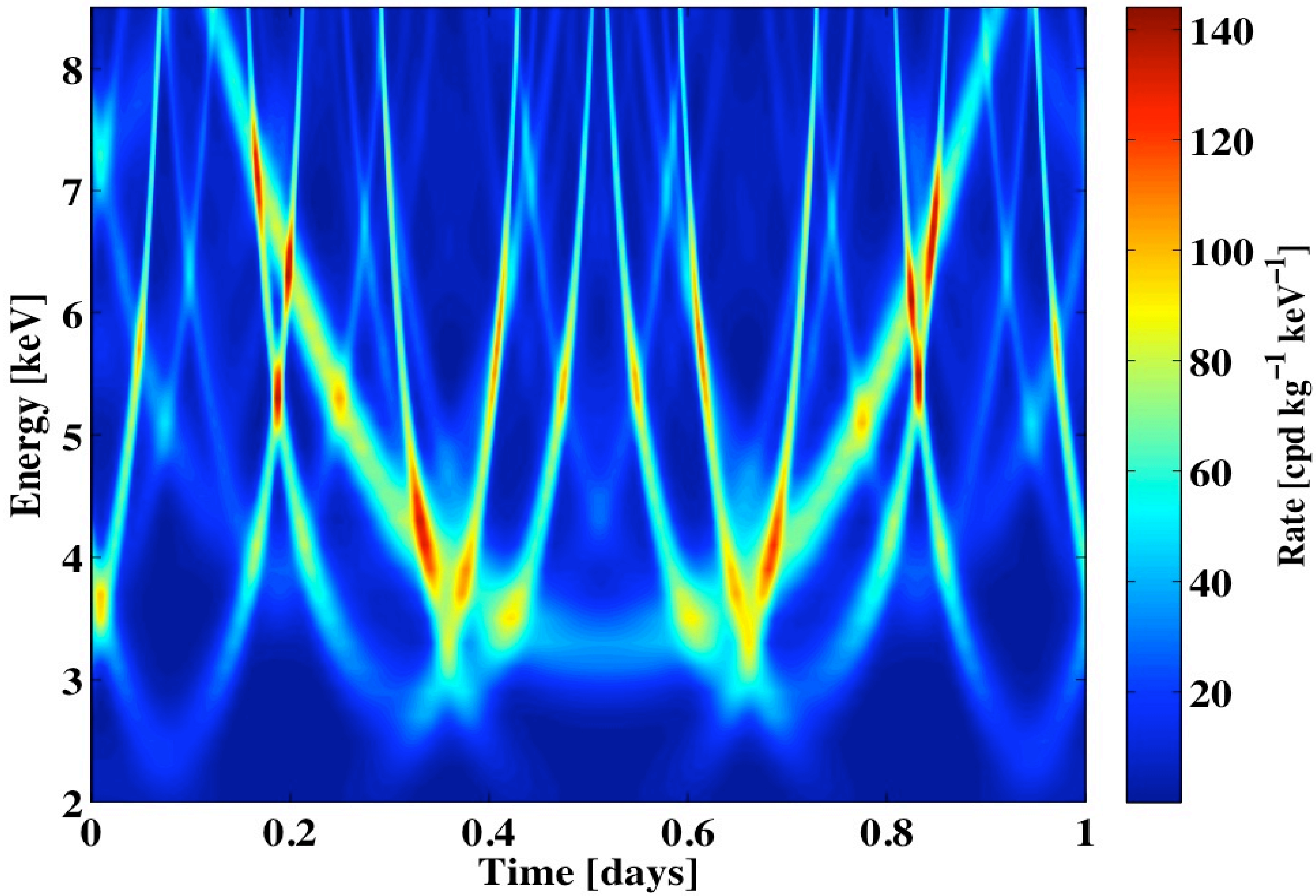
As each shipment arrives, scientists from Fermilab and Northern Illinois University will test the chemical powders for quality control. Using an ultraviolet and visible spectrophotometer, for example, scientists can study the powder's transmittance, which is the area of the light spectrum the material absorbs and transmits.

"These tests tell us about the purity of the powder," said Fermilab chemist Anna Pla-Dalmau. "We requested 99.5 percent purity for NOvA, and we want to make

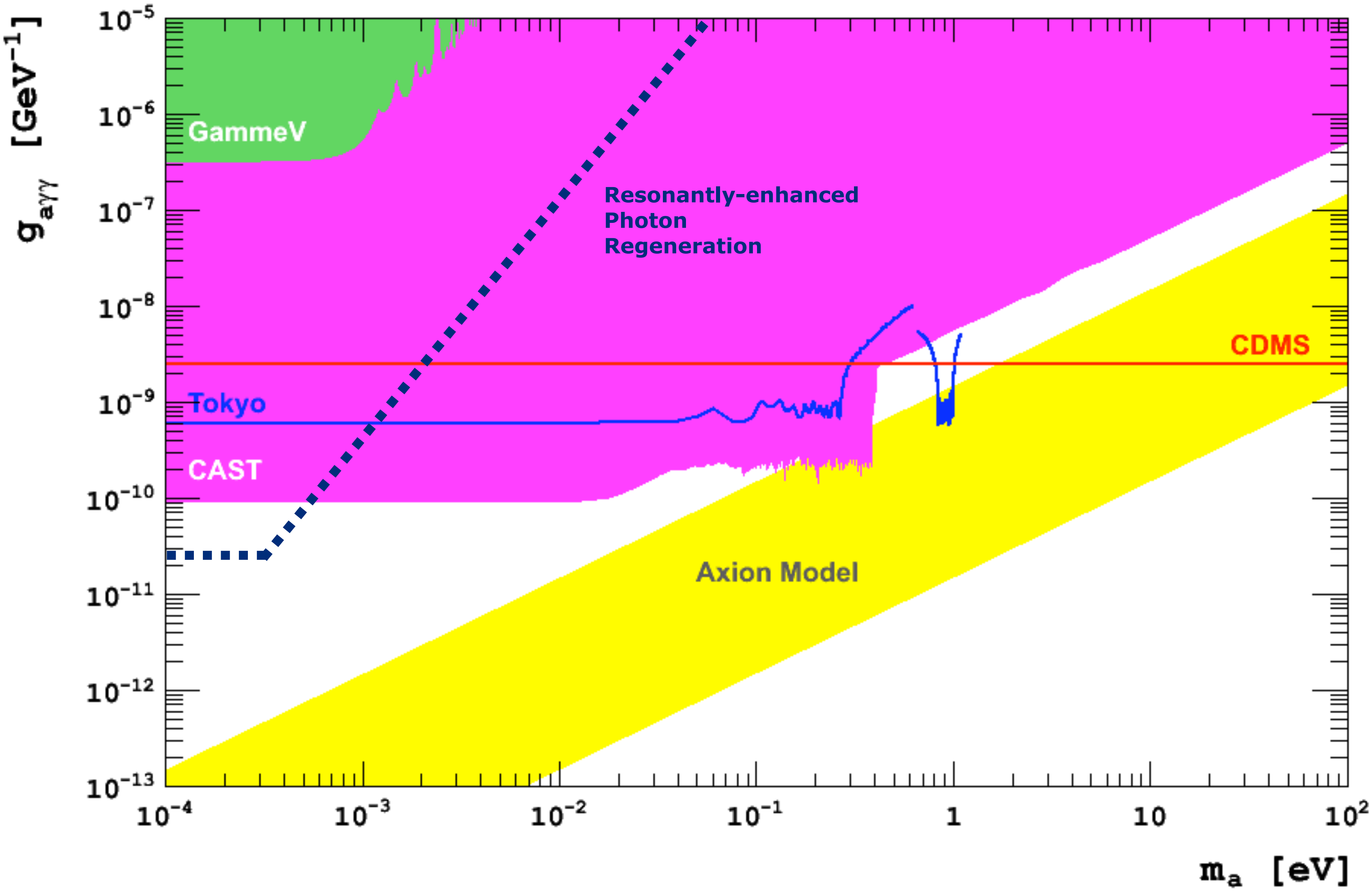
APS2010 Calendar

Finger Print of the Solar Axions

Expected event rate of the solar axions in a CDMS detector



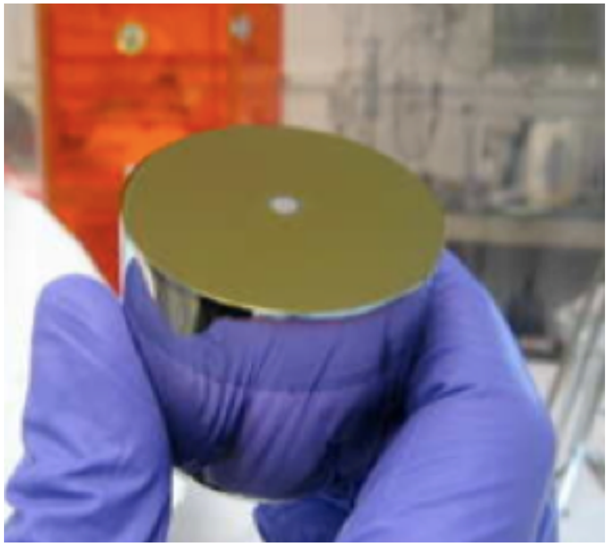
Results



$g_{a\gamma\gamma}$ [GeV^{-1}]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
GammeV
Resonantly-enhanced
Photon
Regeneration
CDMS
Tokyo
CAST
Axion Model
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}
m_a [eV]

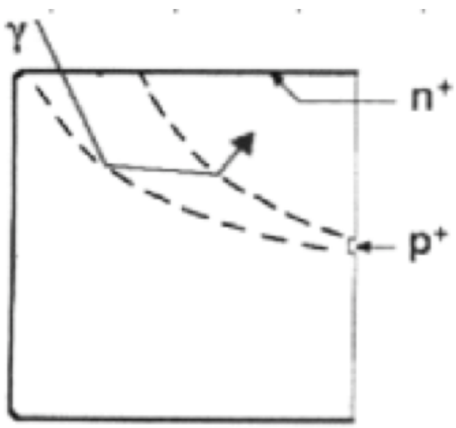
Fine Tune the Existing Technology?

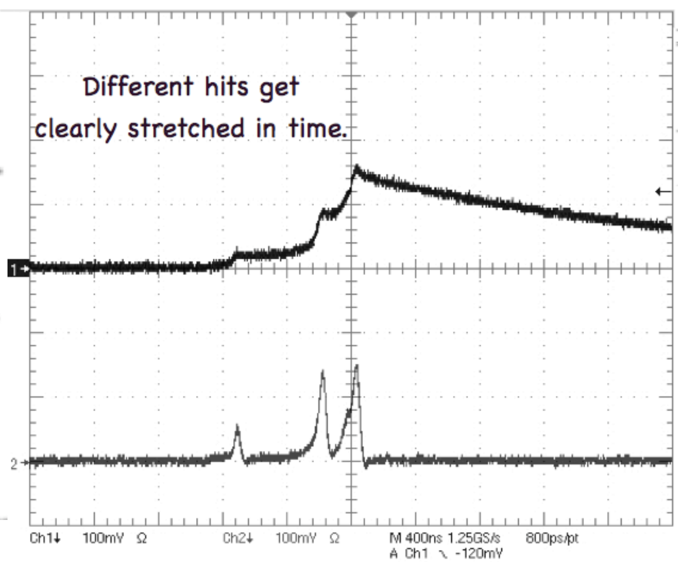
P-type Point Contact (PPC) Germanium Detector

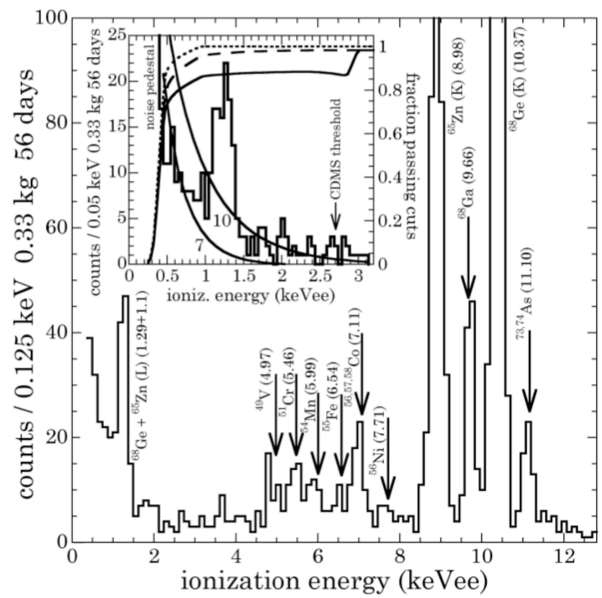


- ***Easy*** **operation (LN temperature)**
- Marginal gamma background (~1 cpd/kg/keV)
- **Good energy resolution (σ/E)**
  ~10%@1keV, 1.3%@10keV
- Commercially available $60K/500g (CANBERRA)
  10kg = ~$1.2M (price negotiable)
- **Directions of the crystal are easy to tag**
- **No further R&D issues for solar axion search**
  (if ~1dru of background level is OK)

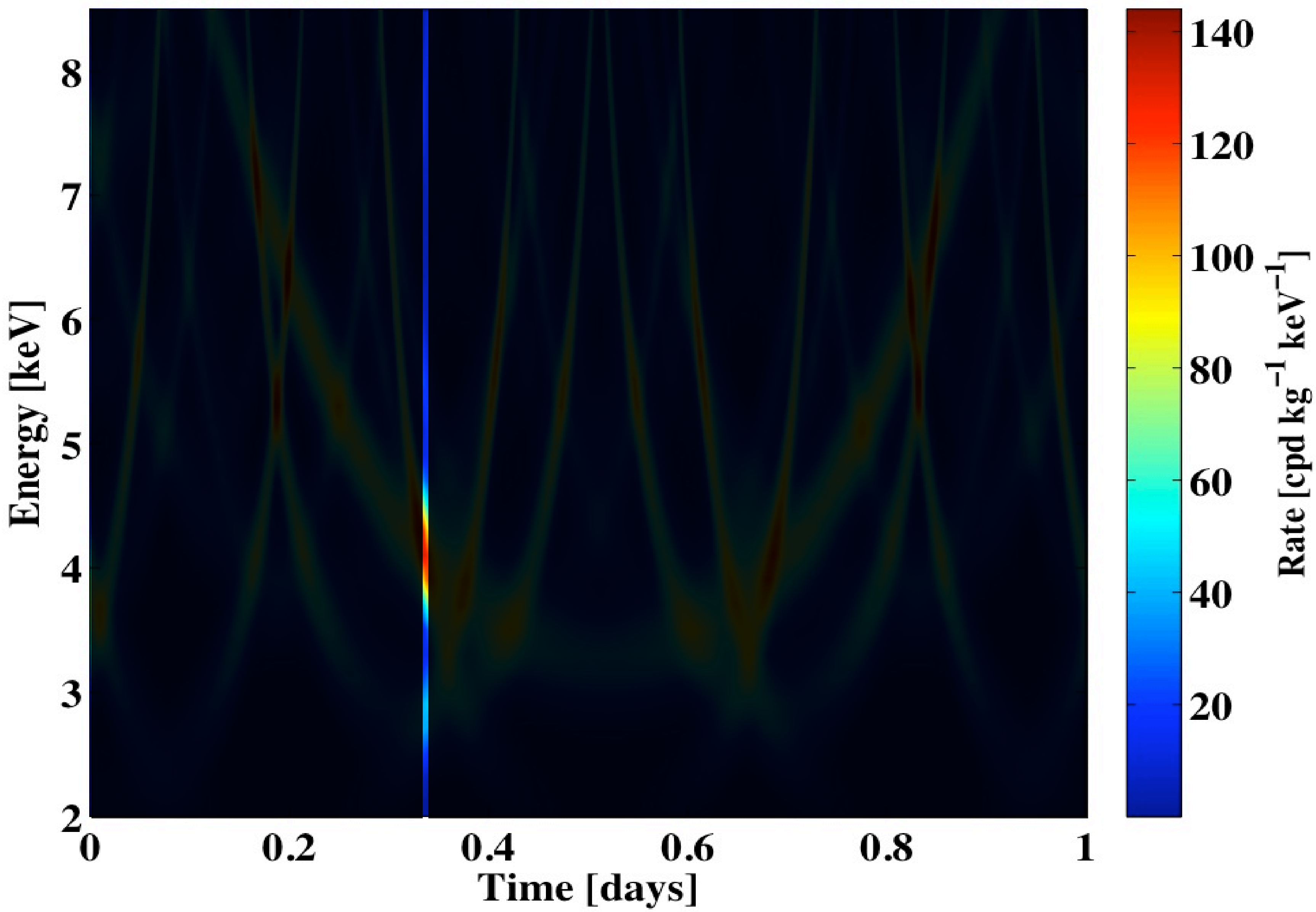
arXiv:1002.4703



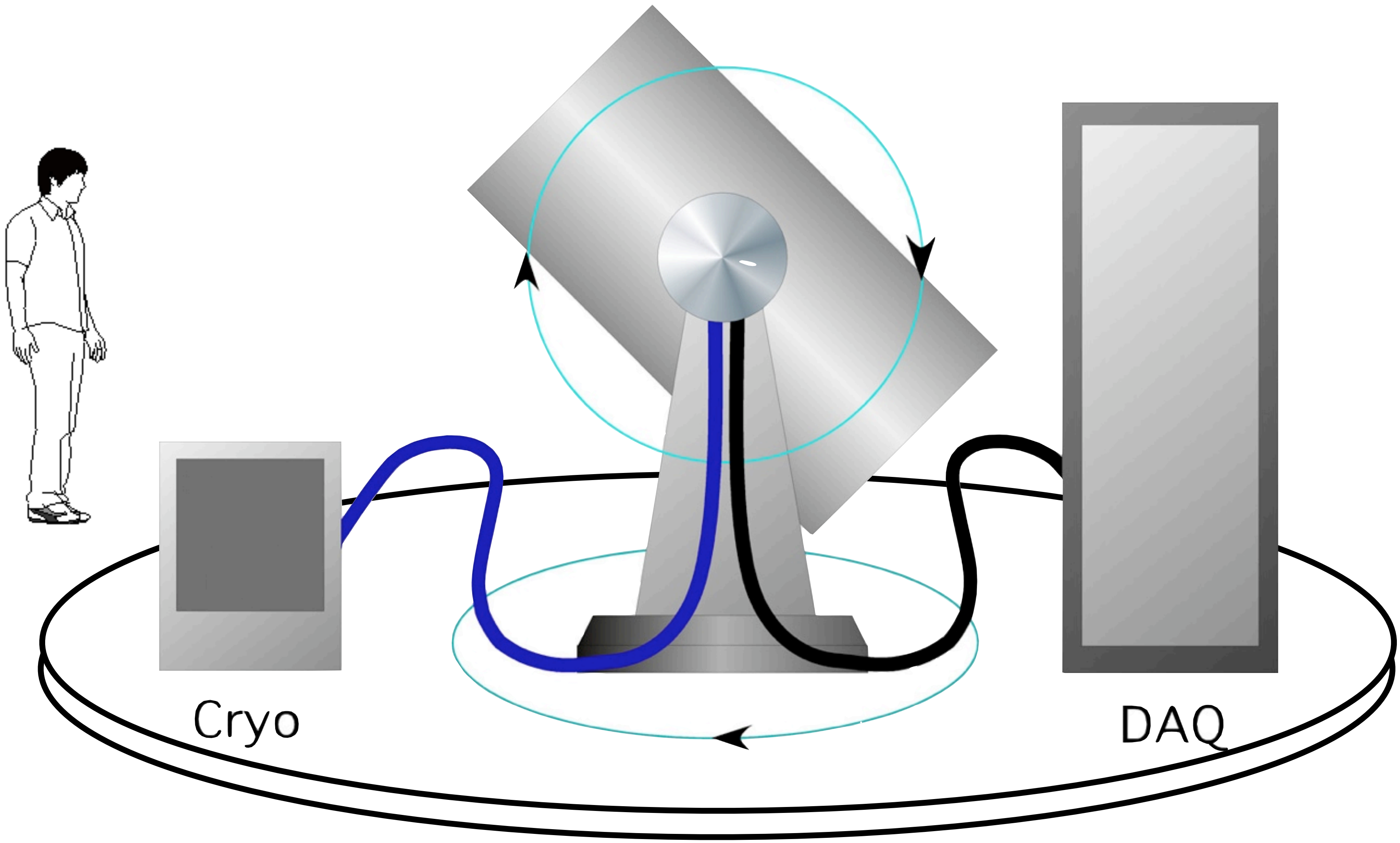




Follow the Sun in the Mine



Crystal Helioscope : x10 more exposure



Yoo & Kendziora

Back of the envelop

Sensitivity of the 10 kg PPC Ge Crystal HelioScope
compared to CDMS axion search results

- **x10** more expected event rate by helioscoping (follow the Sun 24 hours)
- **x5** better energy resolution (current best technology)
- **x3** better angular resolution (can be easily achieved)
- **x30** more exposure (10-kg Ge crystals and 3-years of operation)
- **x1** gamma background level (~1 cpd/kg/keV)

Total 4500 times improved solar axion discovery potential
equivalent to 500kg x 3 year of CDMS style detector operation

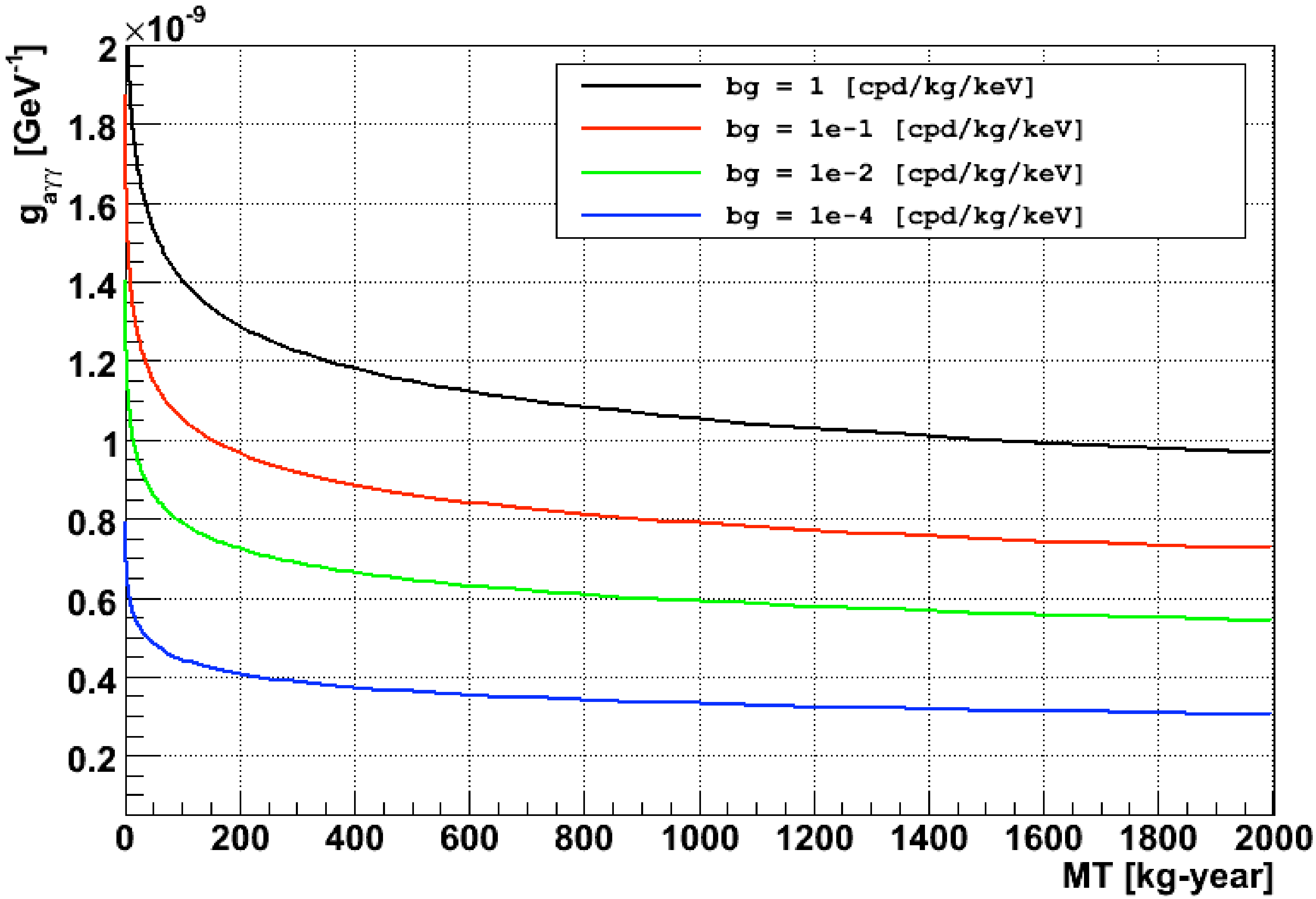
Attractive idea but ...

$$1/g_{a\gamma\gamma} \sim (\text{discovery potential})^{1/8} = (4500)^{1/8} = 2.9$$

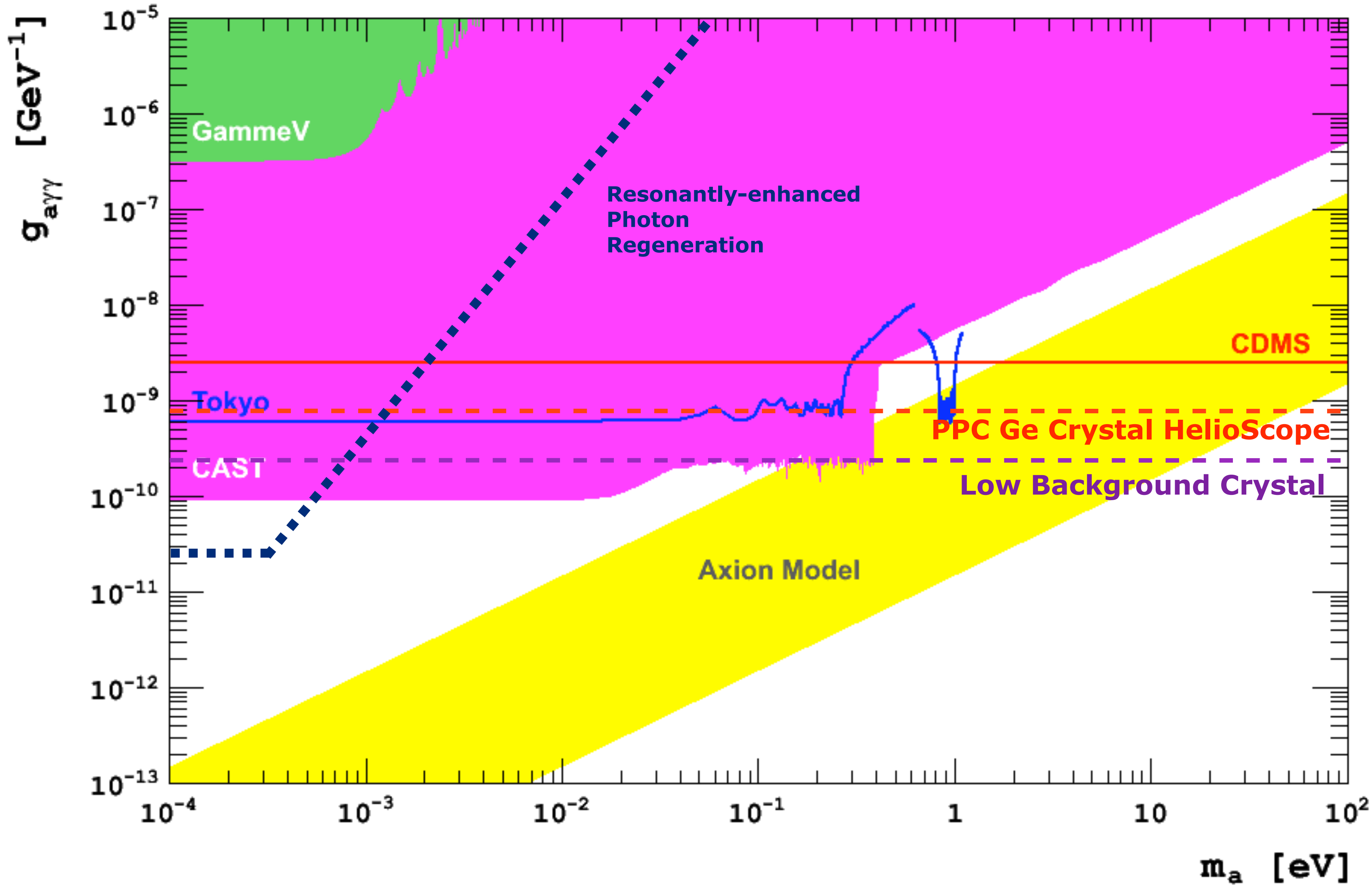
Factor 2.9 improvement in $g_{a\gamma\gamma}$ parameter space

A Fundamental Approach

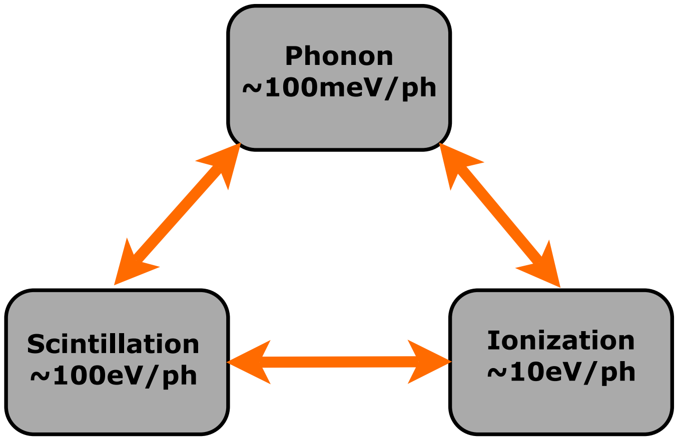
It's not quite about the detector exposure, but more about the background!



Projected Solar Axion Search Sensitivity



Solid Xenon



Why Xenon ?

- No long-lived Xe radio isotope (no intrinsic background)
- High yield of scintillation light
- Scintillation wavelength : 175nm (optically transparent)
- Relatively high melting point : T_m = 161K
- Simple crystal structure : fcc (same as Ge)
- Easy purification (distillation, etc)
- Self shielding : Z=54

Why Solid ?

- For solar axion search, being a crystal is crucial (Bragg scattering)
- Even more scintillation light in solid (61γ/keV) than liquid (42γ/keV)
- Drifting electrons faster in the crystal
- Superb low-noise superconducting sensors are running at low temperature (K~mK)
- No further background contamination through circulation loop (no convection mix)
- Optimal detector design for low background experiment
  - Possible container free design
  - No outgassing issue
- Phonon readout: largest number of quanta (~10,000 phonons/keV)
  - In principle, the best energy resolution can be achieved in phonon channel
  - Luke-phonon effect may provide ionization energy and position information

Science Potential

(1) Solar axion search (crystal)
- scintillation / (ionization)

(2) Dark Matter search
- scintillation / ionization / (phonon)

(3) Neutrinoless double beta decay (0v2β)
- phonon

(4) pp-Solar neutrino measurement : ^{136}Xe depleted
- neutrino oscillation / pp-Solar ν flux measure

(5) Supernova detection

(6) Neutrino coherent scattering

(7) Medical usage (MRI/NMR) : Hyperpolarized ^{131}Xe

Full of science topics

- Strong motivation to initiate R&D project
- But it does not necessarily mean we can initiate real science experiment
- We need proven technology in order to achieve immediate science goal

Skepticism

- Many people do NOT believe that large scale xenon crystal can really grow (mostly high energy physicists)

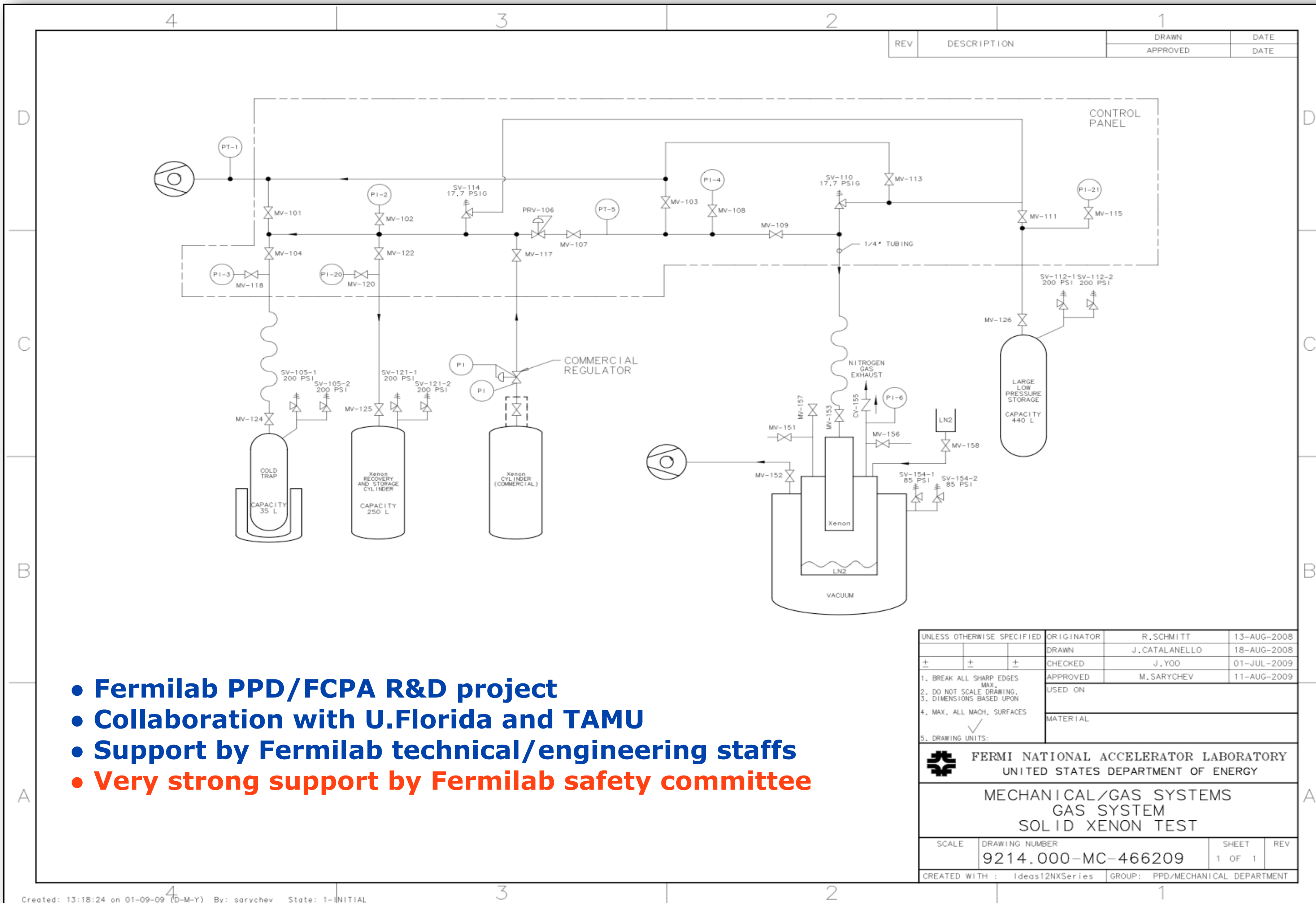
- Some crystallography scientist stop responding to me as soon as I mentioned “dark matter” (dark matter physicists still need to do better job for the public)

- Some medical scientist told me that it’s hard to believe that one can readout UV scintillation light even from liquid xenon

- Some people thought solid xenon is something similar to semi-conductor, because they could drift electrons in the solid xenon, but did not see scintillation light from it (?)

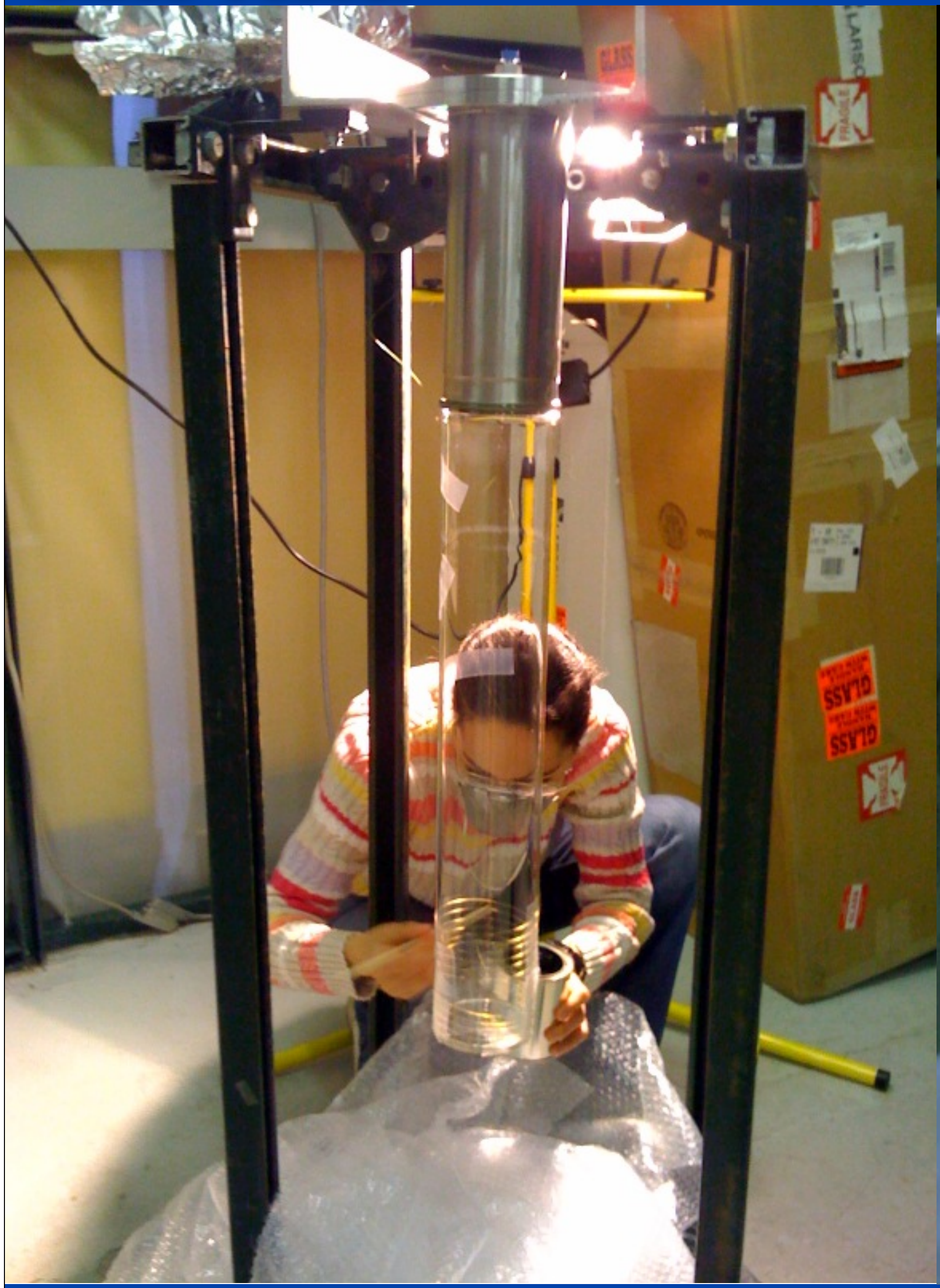
- **“I don’t like Solid Xenon!” - Pier**

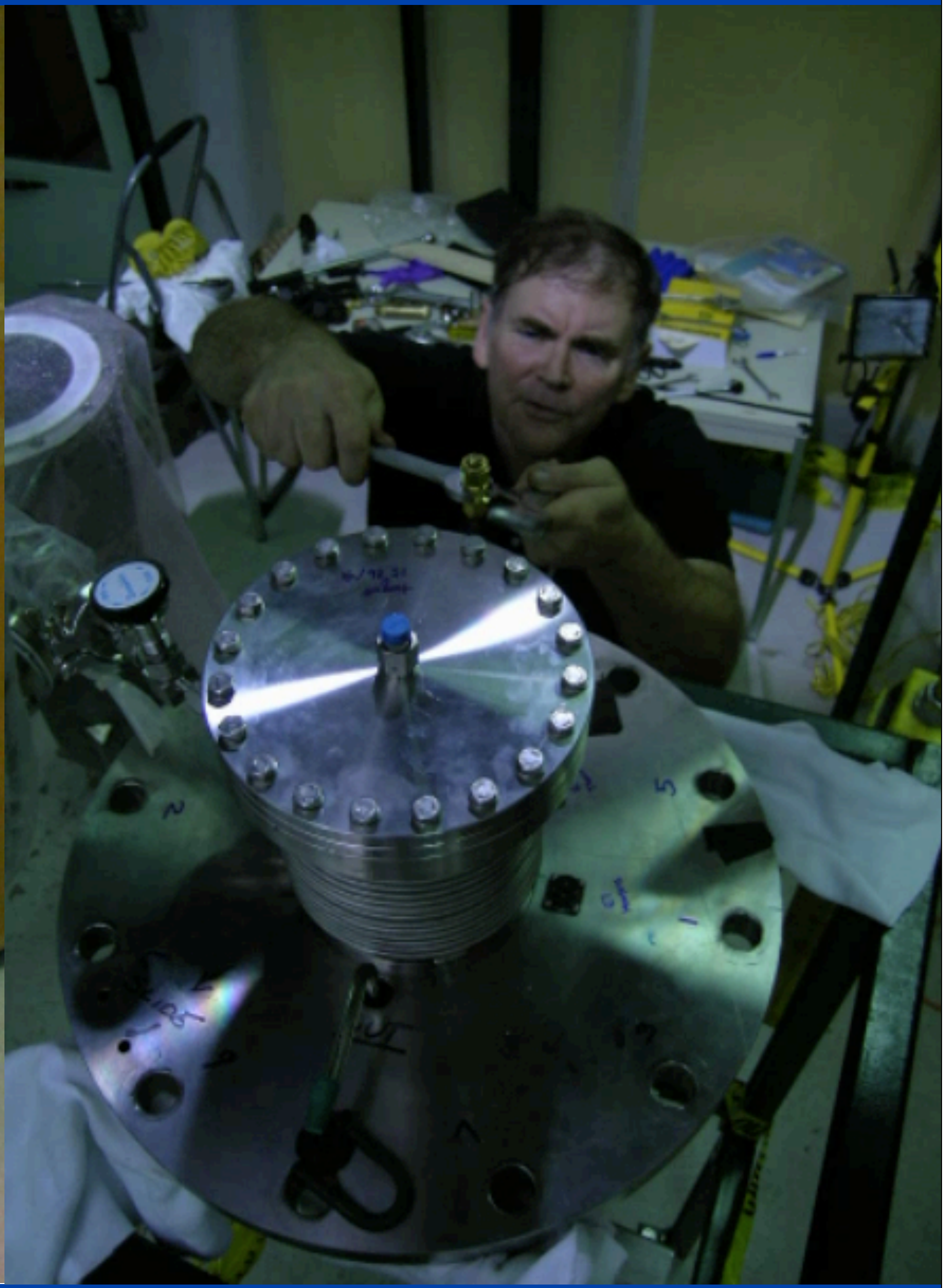
Solid Xenon R&D Phase-1 : Grow Solid Xenon



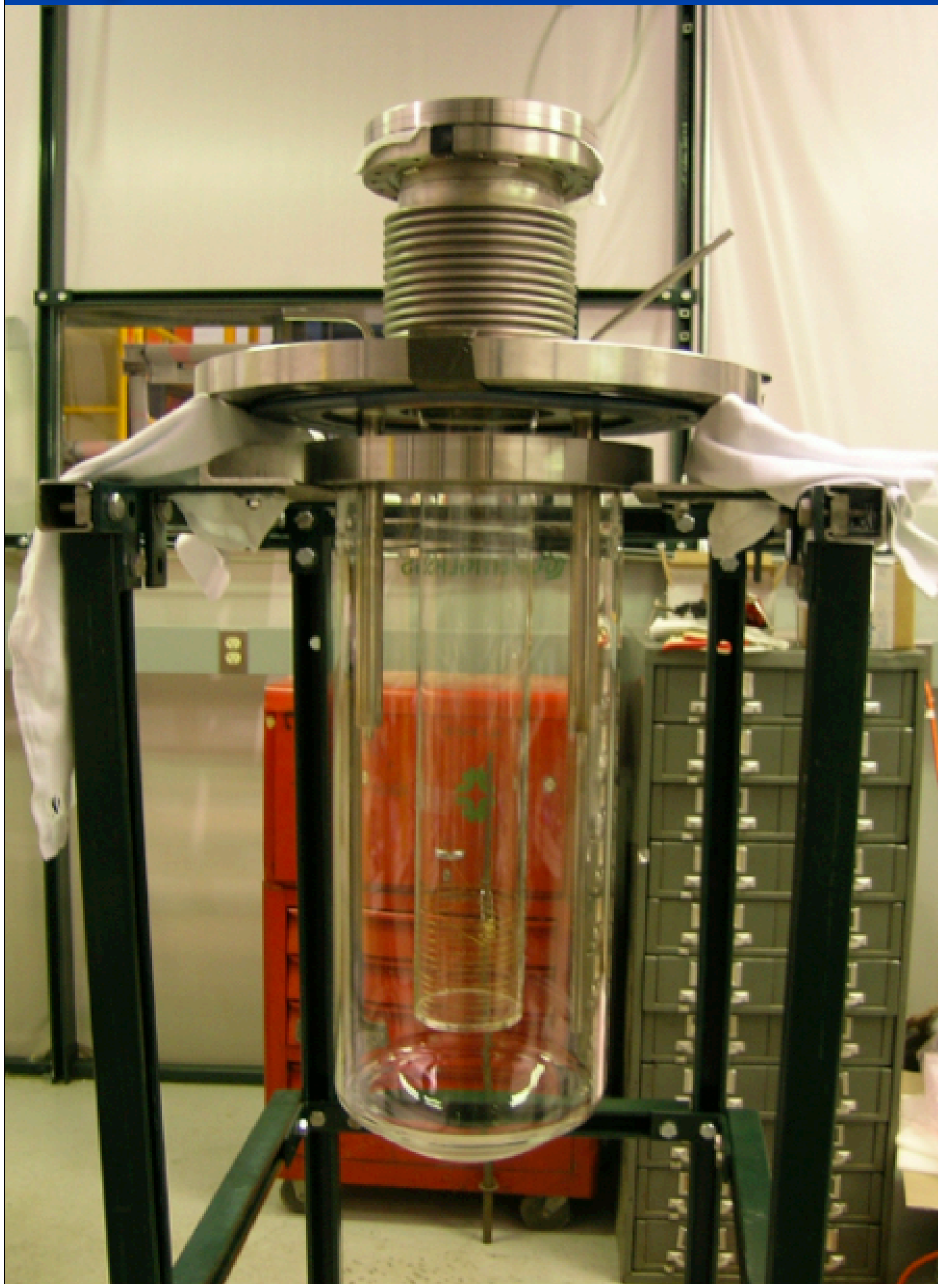
- **Fermilab PPD/FCPA R&D project**
- **Collaboration with U.Florida and TAMU**
- **Support by Fermilab technical/engineering staffs**
- **Very strong support by Fermilab safety committee**

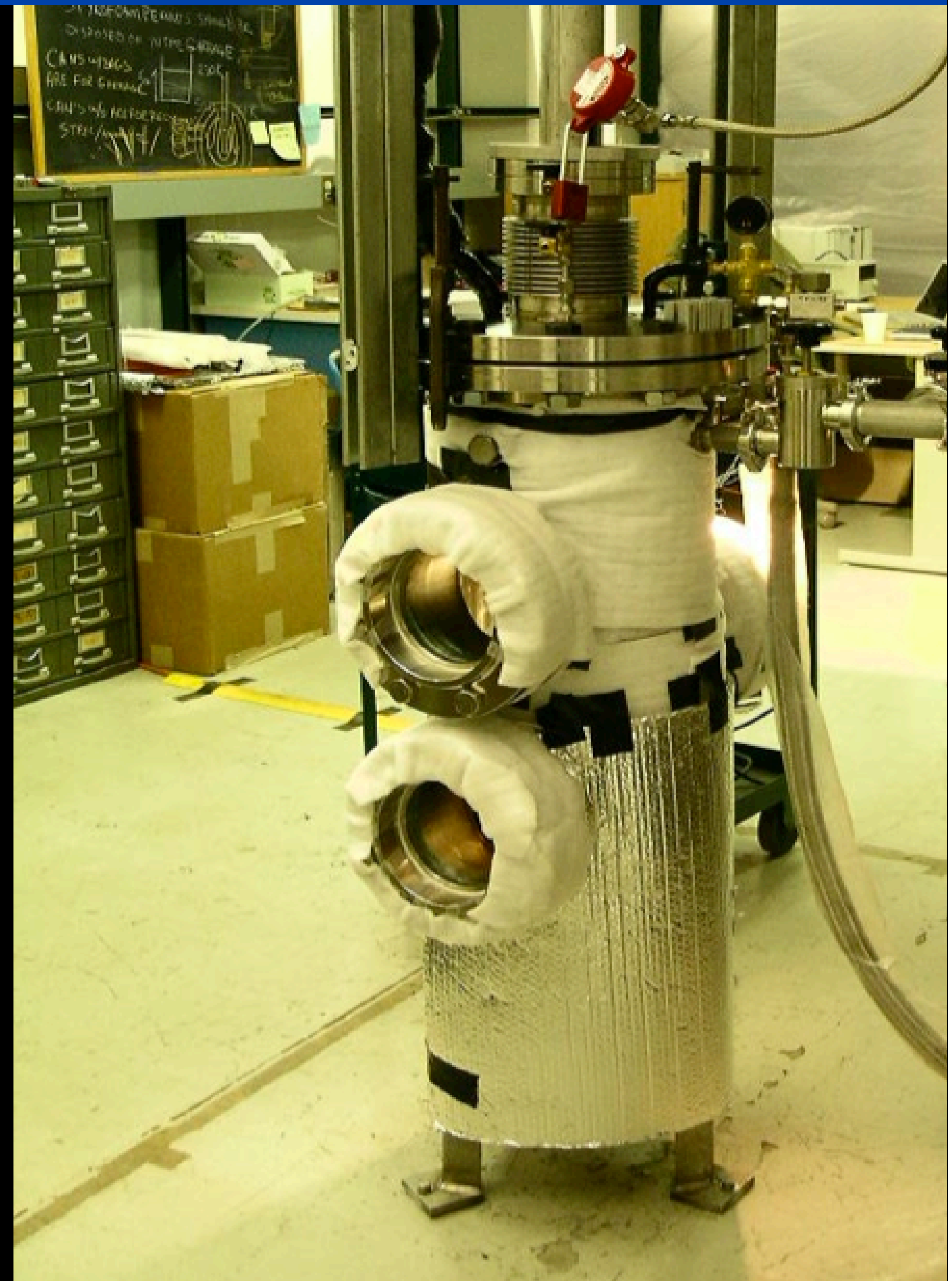
Glass Vessel



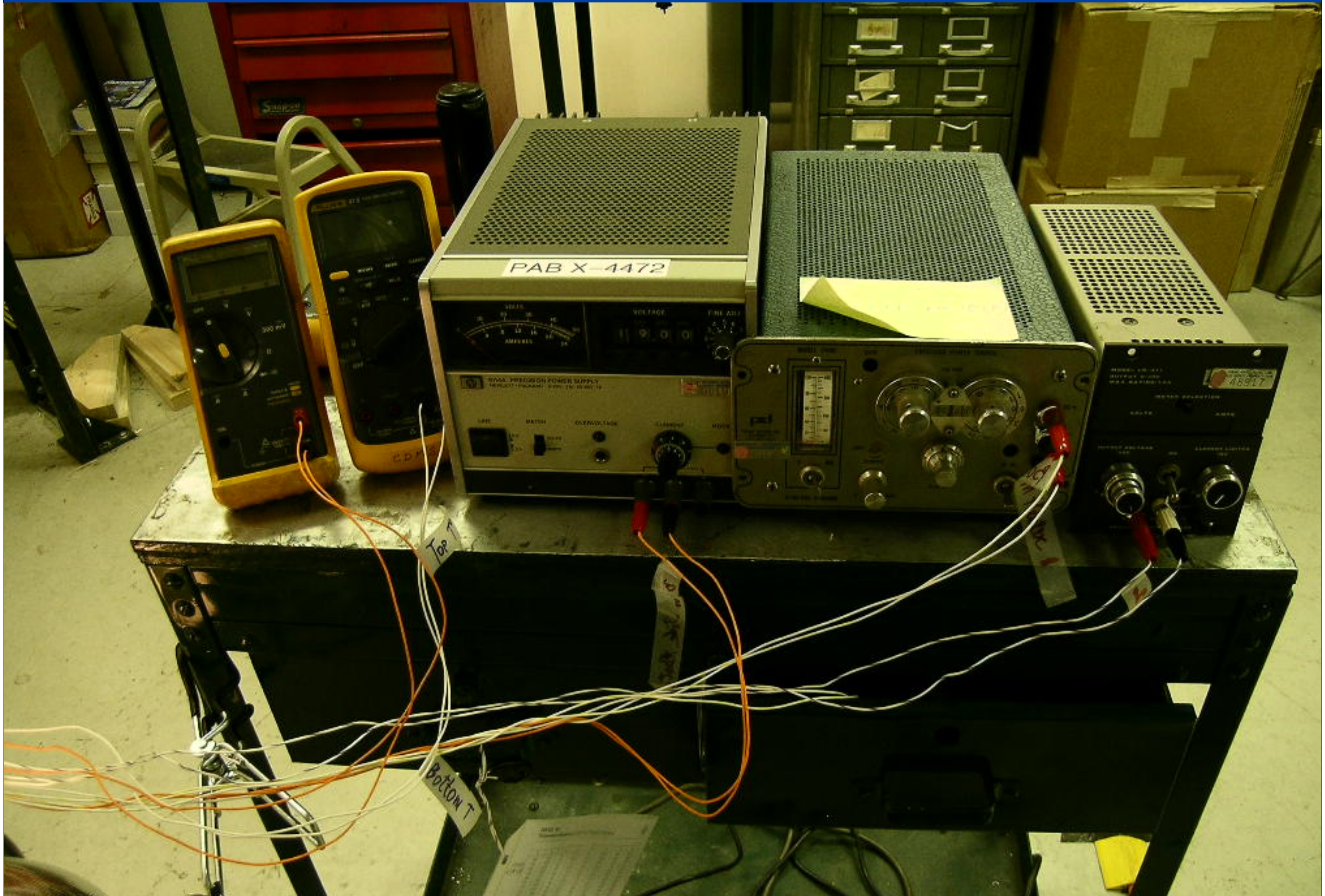


Cryobath and Vacuum Jacket



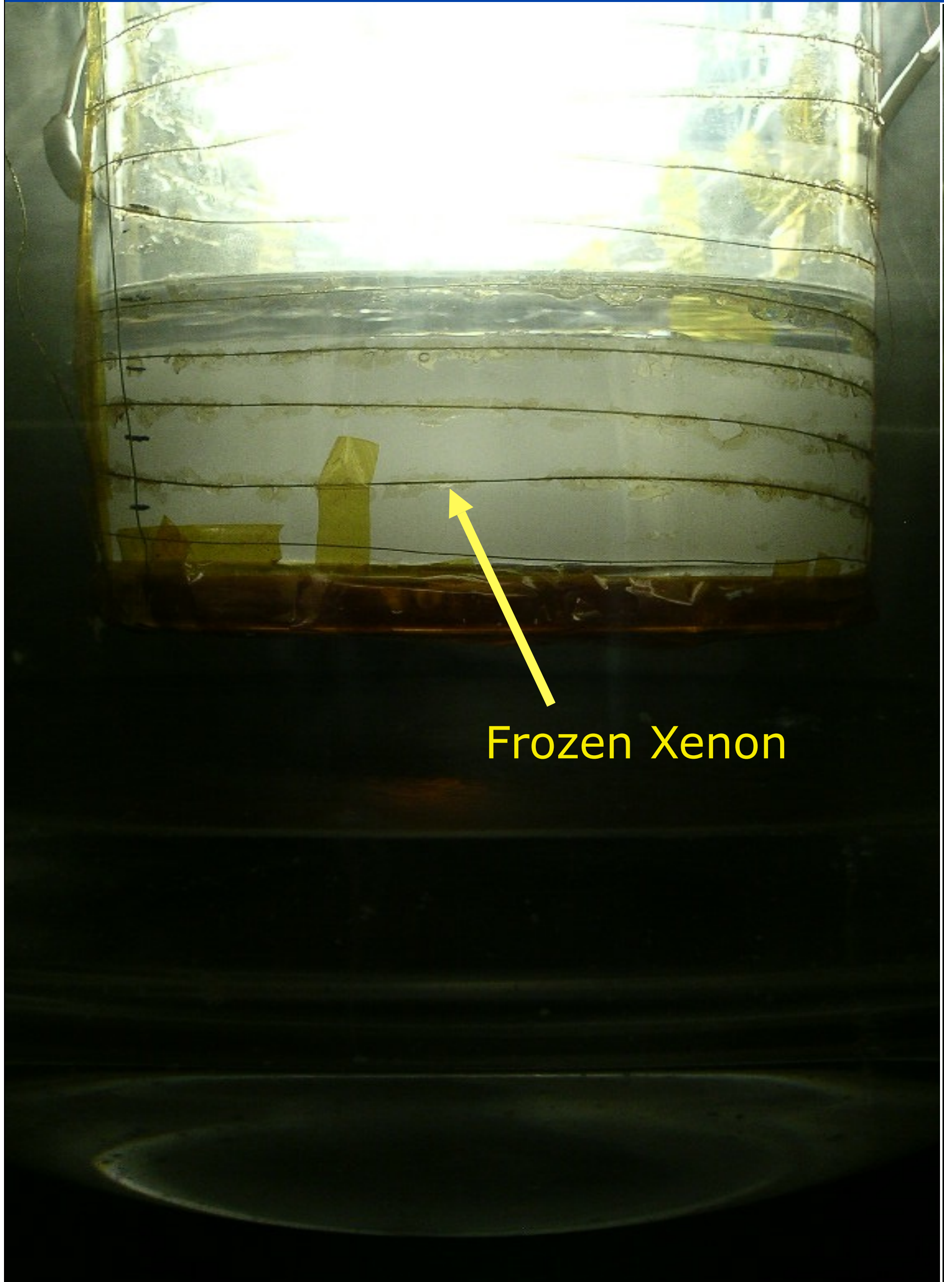


DAQ

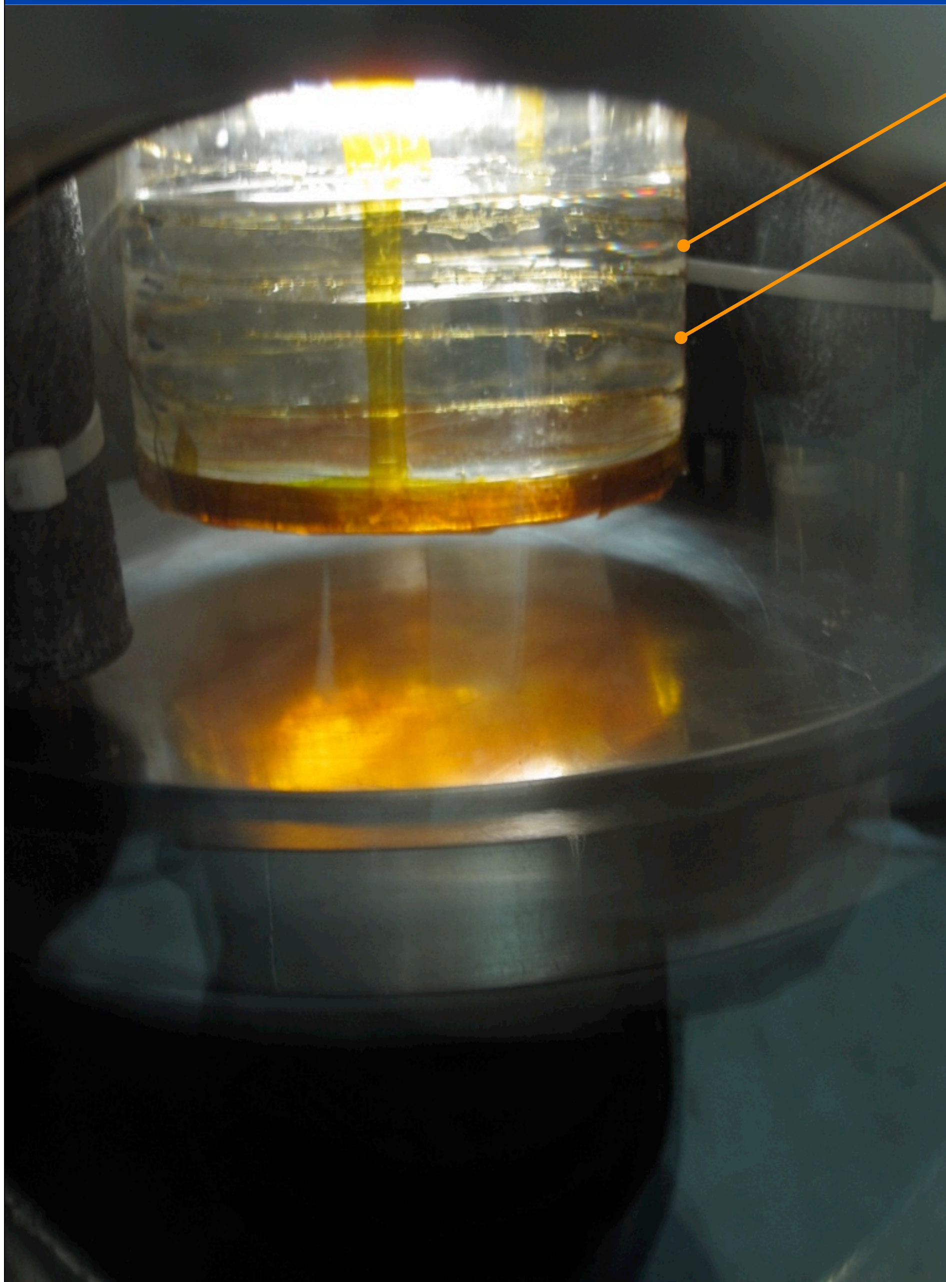


Solid Xenon Setup at Lab-F

Frozen Xenon



Solid Xenon



Liquid Xenon

Solid Xenon (~850g)

<u>Recipe within Fermilab Safety regulation</u>

- **Top T : 160 ± 0.5K**
- **Bottom T : 145 ± 0.5K**
- **Xenon gas pressure : 1.0 ± 0.1 atm**
- **Patience : 3cm growth / 10 hours**

There are many other ways to produce crystals; vapor deposition, flash freezing, cryobath method etc

- Faster growth induces optical defects in the bulk
- Vibration free configuration is necessary
  - Cryocooler may not be a good choice
  - Pulse tube refrigerator is worth to try
- Full automatic control system of temperature and pressure is necessary to grow a larger crystal
- Transparency has to be quantitatively measured using calibrated light source system in the future

Next

Phase 1: Growing Solid Xenon ~kg size

- **Completed (@Lab-F)!**
- Special thanks to: S.Dodelson, D.Bauer & R.Schmitt
- Eng&Tech support: A.Lathrop, D.Pushka, M.Sarychev, J.Voiln, H.Cease & K. Taheri

Phase 2: Scintillation light readout (PPD/FCPA approved : March 2010)

- Solid xenon setup at **PAB**
- Full automatic controller setup for crystal growth
- Xenon purification system and mass spectroscopy
- Scintillation light measurement from the solid xenon (compare with LXe)
- Temperature dependence of scintillation light emission
- Understand Phase-3 (electron drift chamber) design issue

Phase 3: Ionization readout and study crystal characteristics (plan)

Solid Xenon properties (Spectromag - already obtained)

- Transparencies, absorption, index of refraction ...
- Lower temperature characteristics (~4K)

Ionization readout

- Ionization readout by drifting electrons (grid mash)

Demonstrate large solid xenon crystal growth (>10 kg)

Design 10 kg phase prototype detector

Discussions

- **Is the science compelling and within the DOE OHEP mission?**

  PASAG 2009 report highlighted both **dark matter** and **axions** as key scientific elements for future research.

- **Is our experimental program leading the field, or competitive?**
- **Identify the FNAL current and future roles**

  - Fermilab is the inventor of the solid (crystal) xenon particle detector idea.
  - No known competition yet.
  - Universities (U.Florida and TAMU) collaborating with us.
  - Depends on our R&D results; future collaboration with MIT, Columbia and U.Zurich.

- **What are the weaknesses of our program in this area?**

  - We know ~1kg size of transparent solid phase of xenon grows.
  - We do not know how big it will grow without optical defects.
  - Future R&D will address whether we can make a single crystal or not.
  - No obvious show stopper yet.