Direct Dark Matter Detection with Noble Liquids, including LUX and MiniCLEAN

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December 16, 2009

KITP Workshop: Direct, Indirect and Collider Signals of Dark Matter

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The Noble Liquid Revolution

Noble liquids are relatively inexpensive, easy to obtain, and dense.

Easily purified
  - low reactivity
  - impurities freeze out
  - low surface binding
  - purification easiest for lighter noble liquids

Ionization electrons may be drifted through the heavier noble liquids

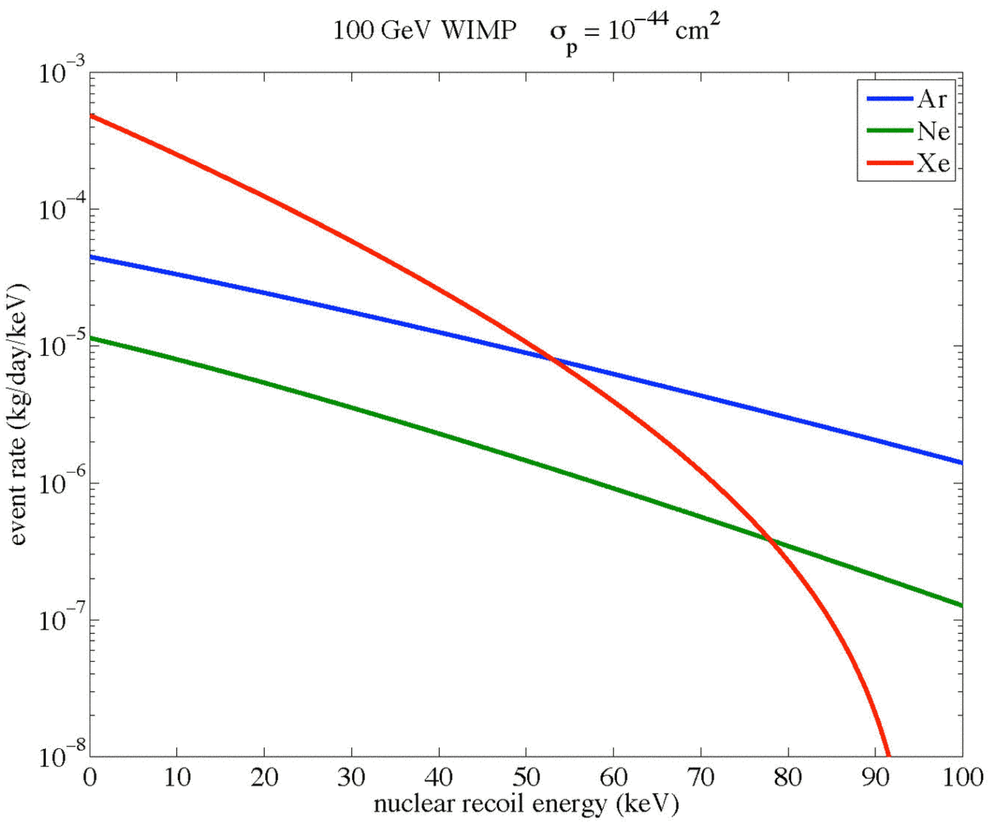
Very high scintillation yields
  - noble liquids do not absorb their own scintillation
  - 30,000 to 40,000 photons/MeV
  - modest quenching factors for nuclear recoils

Easy construction of large, homogeneous detectors

Liquified Noble Gases: Basic Properties

Dense and homogeneous
Do not attach electrons, heavier noble gases give high electron mobility
Easy to purify (especially lighter noble gases)
Inert, not flammable, very good dielectrics
Bright scintillators

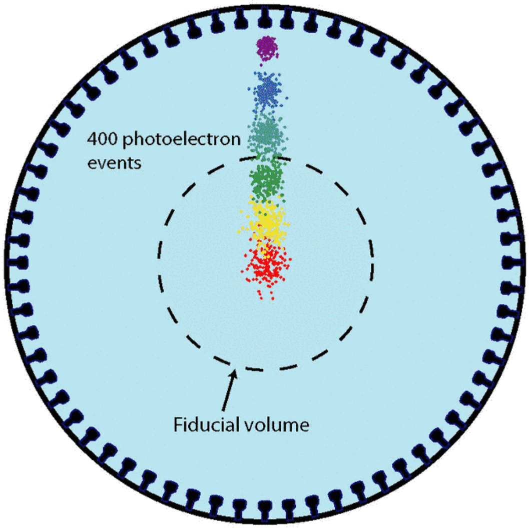
	Liquid density (g/cc)	Boiling point at 1 bar (K)	Electron mobility (cm^2/Vs)	Scintillation wavelength (nm)	Scintillation yield (photons/MeV)	Long-lived radioactive isotopes	Triplet molecule lifetime (μs)
LHe	0.145	4.2	low	80	19,000	none	13,000,000
LNe	1.2	27.1	low	78	30,000	none	15
LAr	1.4	87.3	400	125	40,000	^{39}Ar, ^{42}Ar	1.6
LKr	2.4	120	1200	150	25,000	^{81}Kr, ^{85}Kr	0.09
LXe	3.0	165	2200	175	42,000	^{136}Xe	0.03

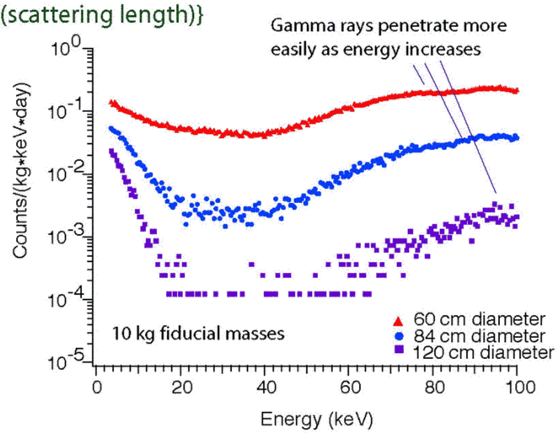


Background reduction through self-shielding and position resolution

There is an energy mismatch between penetrating gamma rays (~MeV) and low energy events of interest. High energy gammas must penetrate fiducial volume, scatter, and escape without depositing too much energy, in order to mimic a WIMP.

Background scales as exp{-(detector diameter)/(scattering length)}





Based on PMT hit pattern
Maximum likelihood algorithm
Incorporates scattering, wavelength shifter

K.J. Coakley and D.N. McKinsey, Astroparticle Physics 22, 355 (2005).

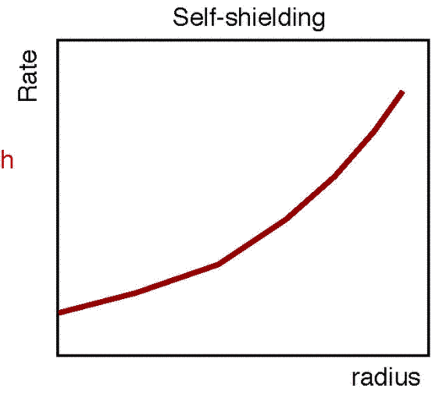
Strategies for Electronic Recoil Background Reduction in Scintillation Experiments

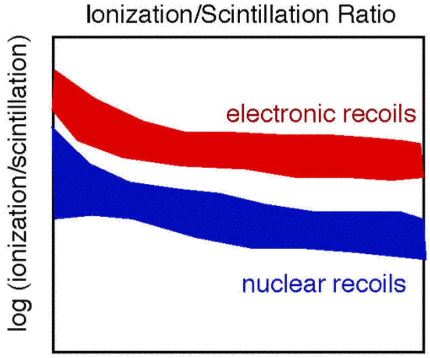
Require < 1 event in signal band during WIMP search

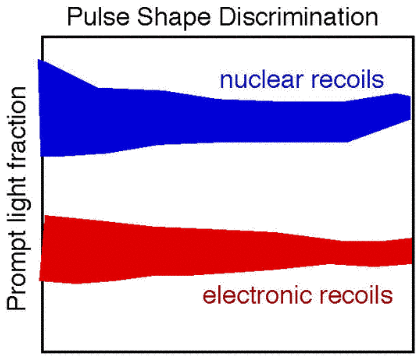
LXe: Self-shielding, Ionization/Scintillation ratio best

LAr: Pulse shape, Ionization/Scintillation ratio best

LNe: Pulse shape, Self-shielding best







Other Backgrounds

(currently subdominant, but a concern fo future experiments)

Fast neutrons:

Can elastically scatter from nuclei; these events look just like WIMPs
Come from surrounding rock, muon spallation, detector materials
Need depth to mitigate muon-produced neutrons
Hydrogenous material (polyethylene or water) to moderate fast neutrons
Large detectors can look for multiple scattering, or shield out the fast neutrons

Radon daughters:

Can decay on the detector surfaces
Produce nuclear recoils that can mimic the WIMP signal
Mitigate using careful surface preparation, radon control,
Can also reduce using position resolution
Active tagging of radon daughters, if the detector surfaces are active

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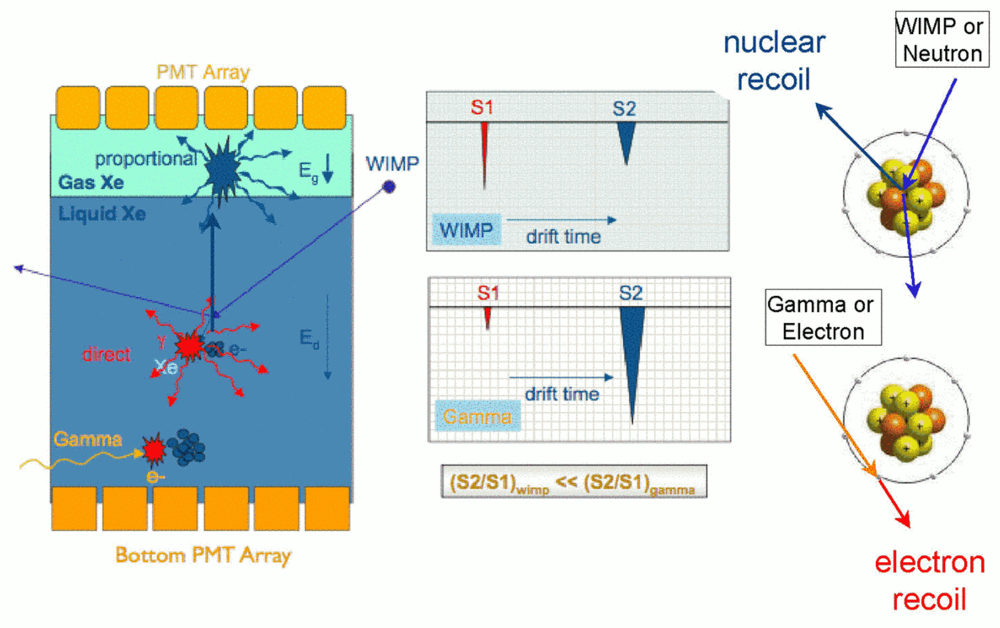
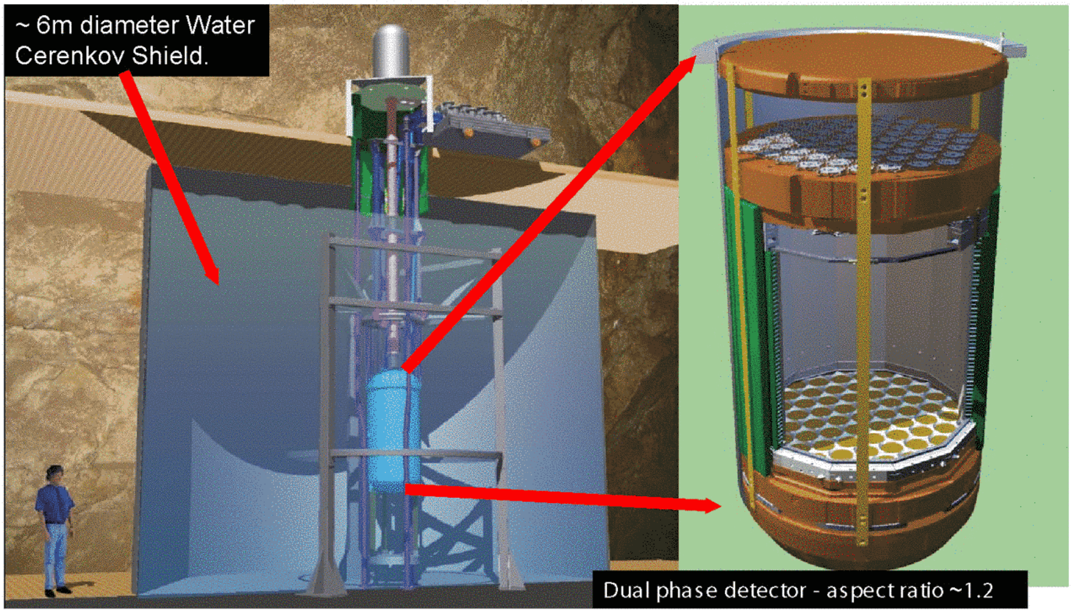
Two-phase xenon detectors



The LUX Detector



350 kg Dual Phase Liquid Xenon Time Projection Chamber, fully funded by NSF and DOE
2 kV/cm drift field in liquid, 5 kV/cm for extraction, and 10 kV/cm in gas phase.
122 PMTs (Hamamatsu R8778) in two arrays
3D imaging via TPC eliminates surface events, defines 100 kg fiducial mass

The LUX-350 Collaboration

Brown University: Richard Gaitskell, Simon Fiorucci, Carlos Hernandez Faham, Jeremy Chapman, David Malling, Luiz de Viveiros

Case Western Reserve University: Dan Akerib, Adam Bradley, Ken Clark, Mike Dragowsky, Patrick Phelps, Thomas Shutt

Harvard University: Masahiro Morii

Lawrence Berkeley National Laboratory: Kevin Lesko, Yuen-Dat Chan, Brian Fujikawa

Lawrence Livermore National Laboratory: Adam Bernstein, Steven Dazeley, Peter Sorensen, Kareem Kazkaz

Moscow Engineering Physics Institute: Alexander Bolozdynya

South Dakota School of Mining and Technology: Xinhua Bai

Texas A&M: Rachel Mannino, Tyana Stiegler, Robert Webb, James White

UC Davis: Tim Classen, Britt Holbrook, Richard Lander, Jeremy Mock, Robert Svoboda, Melinda Sweany, John Thomson, Mani Tripathi, Nick Walsh, Michael Woods

University of Maryland: Carter Hall, Douglas Leonard

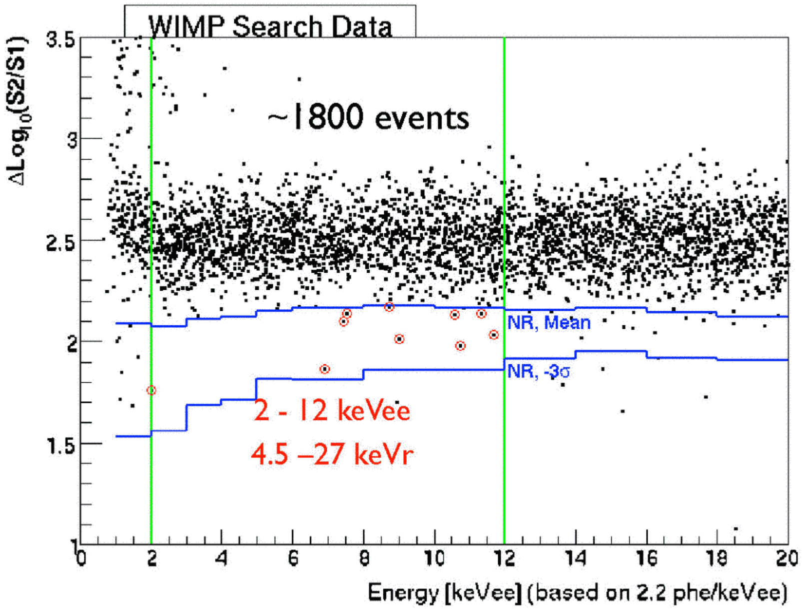
University of Rochester: Eryk Druszkiewicz, Udo Schroeder, Wojtek Skulski, Jan Toke, Frank Wolfs

University of South Dakota: Dongming Mei

Yale University: Susie Bedikian, Sidney Cahn,Alessandro Curioni, Louis Kastens, Alexey Lyashenko, Daniel McKinsey, James Nikkel

XENON10 WIMP Search Data

136 kg-days Exposure= 58.6 live days x 5.4 kg x 0.86 (ε) x 0.50 (50% NR)



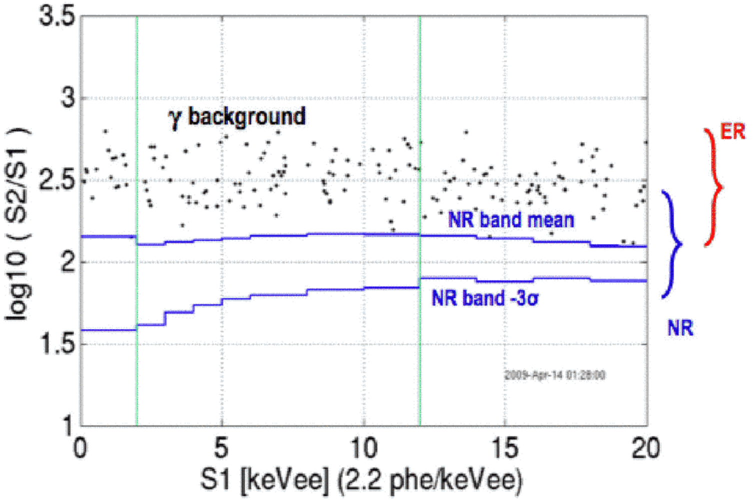
- WIMP "Box" defined at ~50% acceptance of Nuclear Recoils (blue lines): [Mean, -3σ]
- 10 events in the "box" after all cuts in Primary Analysis
- 6.9 statistical leakage events expected from ER band
- NR energy scale based on 19% constant QF

LUX-350 is a background-free experiment

Self-shielding drastically reduces gamma-ray background in the fiducial volume
By defining a fiducial volume, gamma ray backgrounds drop enormously, scaling as exp[-L/Ls], where L is the size of the active volume, and Ls is the gamma ray scattering length. Electron recoil background ~2.6x10^{-4} events/keVee/kg/day (from simulations)

300 days acquisition

100 kg fiducial mass



$L_{eff} = 0.19$

Using same
ER and NR bands
as XENON10

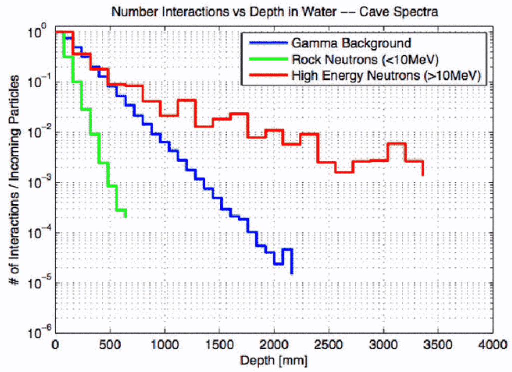
Water Shield

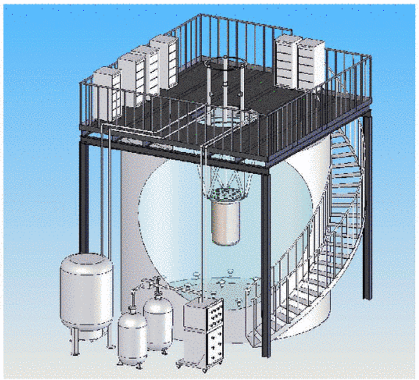
2.5 meters of instrumented water shielding

Gamma rays from rock contribute < 2% of total electronic recoil background.

Fast neutrons from rock are moderated and captured extremely efficiently => negligible.

Muon-induced neutrons in rock: < 0.01 events/year in detector.





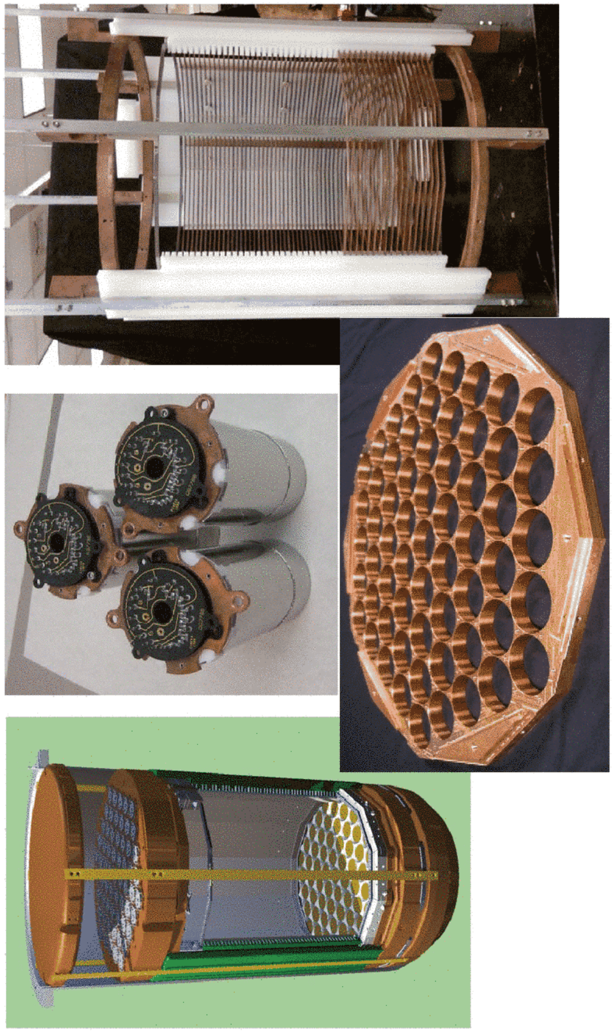
Internal Backgrounds

Kr-85:	Beta decay, 687 keV endpoint. Normally at ppm in commercial Xe, though can purchase at 5 ppb LUX requirement is 5 parts per trillion Achieved by charcoal column separation (< 2 ppt demonstrated at Case)
^{14}C, T, U,Th:	Removed efficiently by getter
Radon:	Pb-210 daughter removed by getter. Surface daughter backgrounds removed by fiducial cut. Pb-214 makes a "naked" beta, which sets the LUX requirement = 16 mBq, compared to XENON10 measured rate of 1.6 mBq.
pp ν's:	Elastic scattering of neutrinos from electrons gives background of 6E-8 events/keVee/kg/day, after discrimination.
Xe-136:	Double beta decay background of 1.5E-8 events/keVee/kg/day, assuming $\tau_{1/2}$ = 0.8 x 10^{22} years (current lower limit).

Chemically active cosmogenic activation products removed by getter.

Xe-131m, Xe-129m decay away with ~ 10 days half-lives.

LUX Internals Assembly



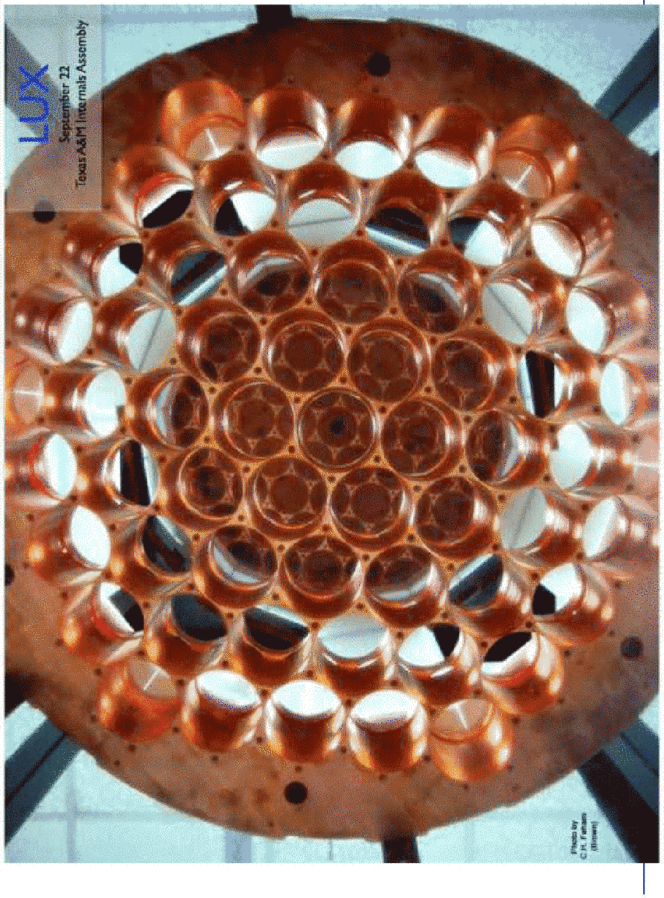
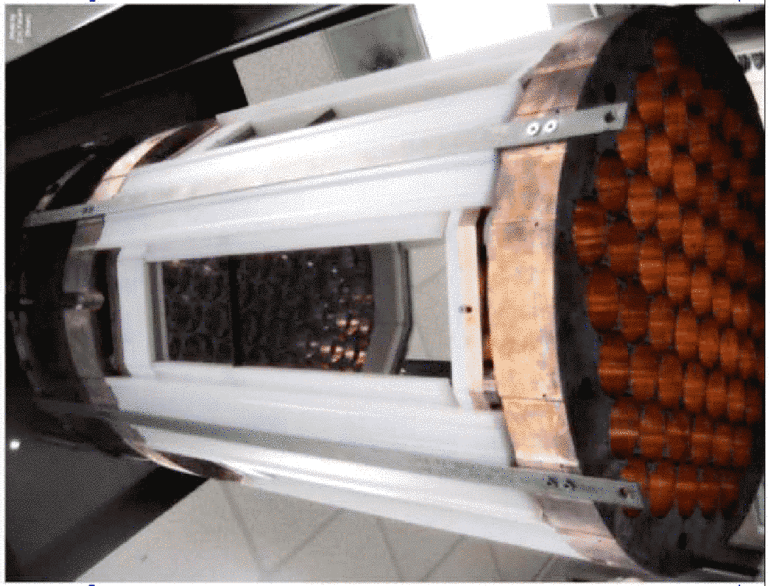
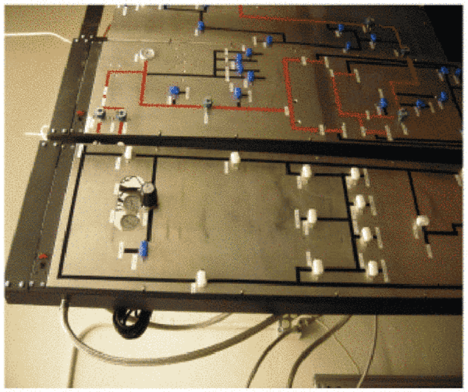


Photo by
C.H. Faham
(Brown)

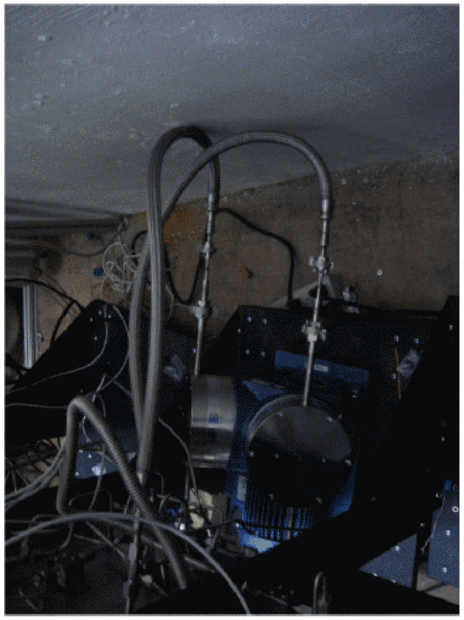


Circulation and Purification System

Gas-phase purification using SAES getter
Demonstrated flow rate of 50 standard liters per minute

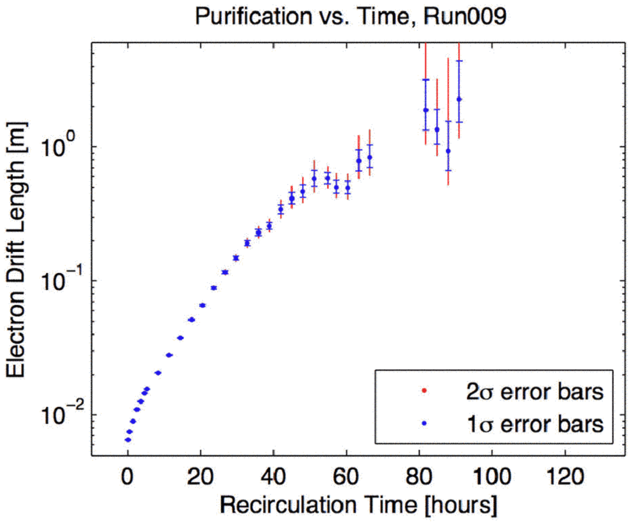


Gas panels



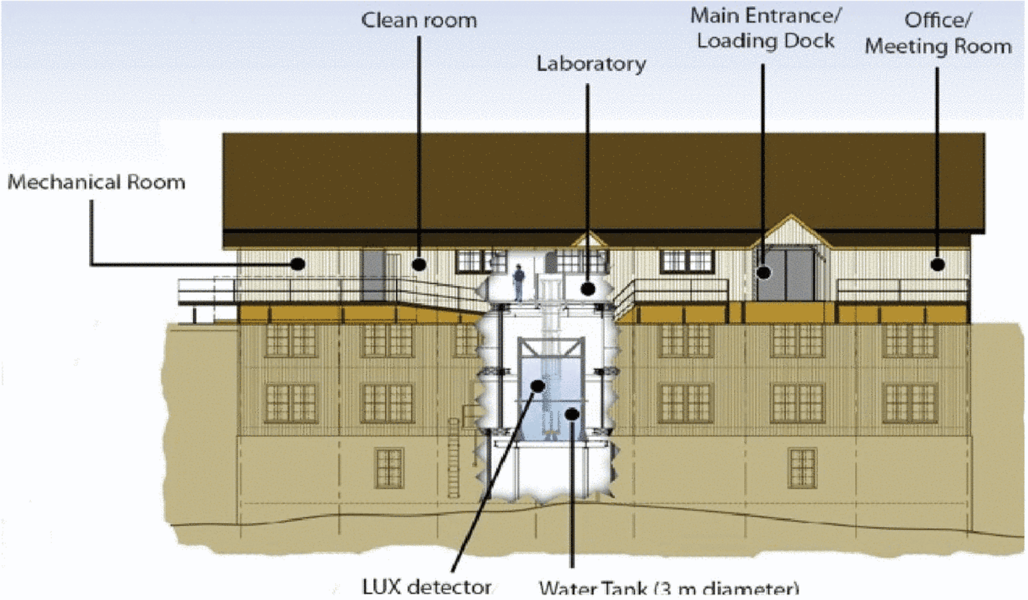
Circulation pump

LXe purification tests in LUX 0.1



- ~9 hr purification time constant
- > 2 m electron drift length
- This is an order of magnitude faster recirculation than achieved before

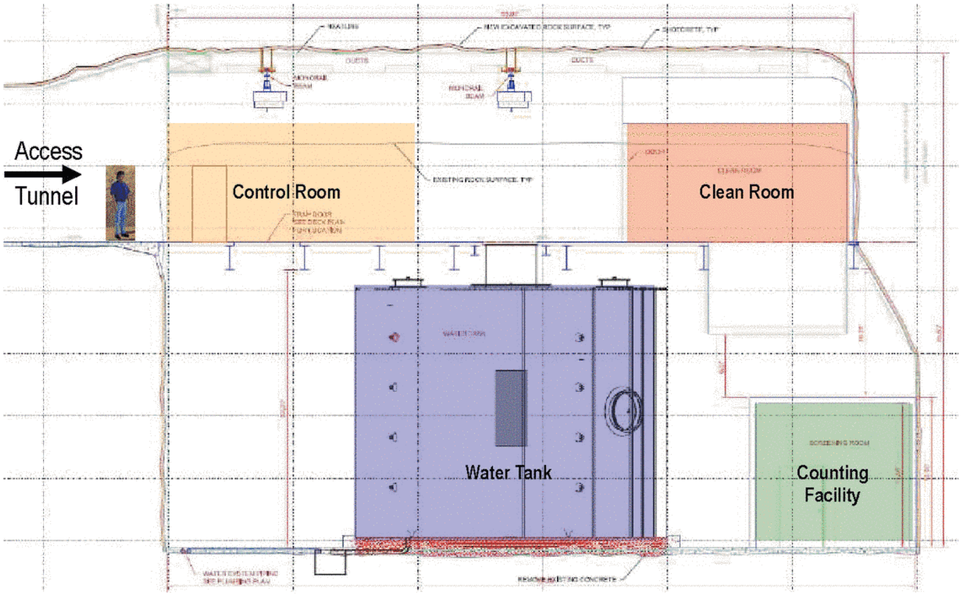
Surface Facility at Homestake



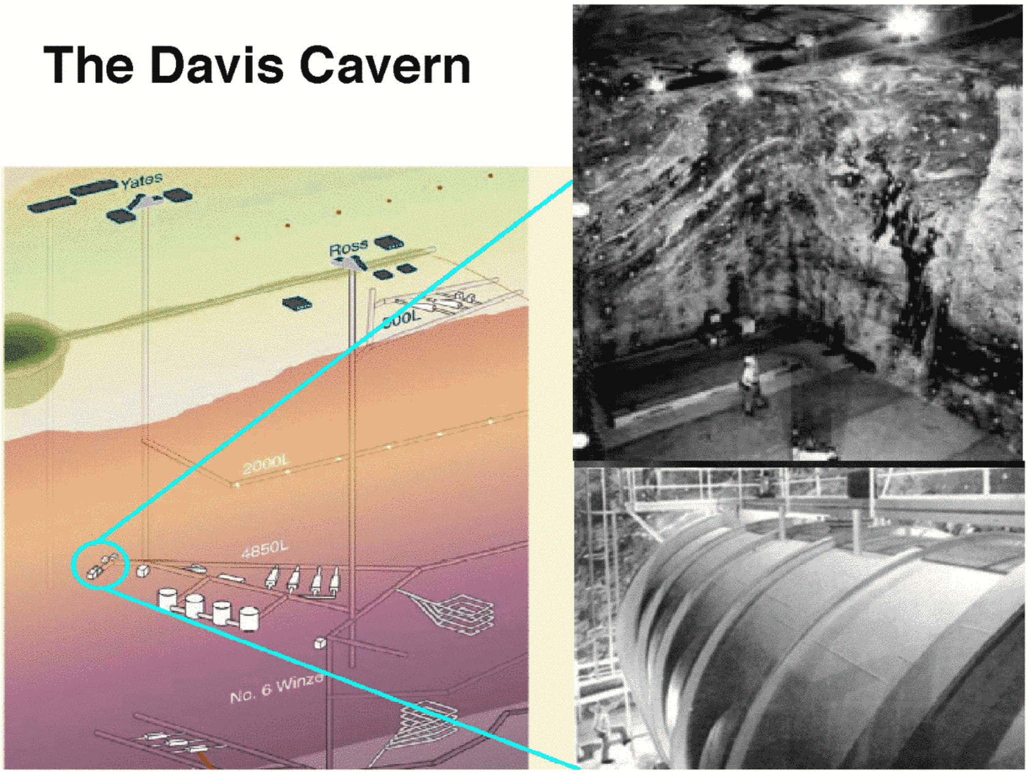
The LUX Surface Facility at Homestake

Rick Gaitskell
+
S. Dakota Gov. Rounds

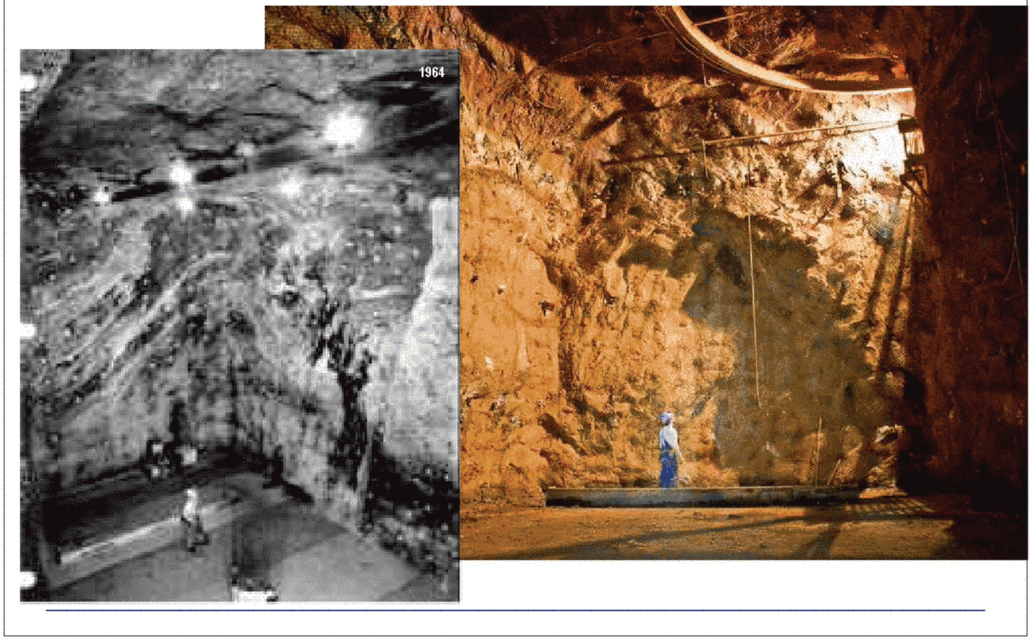
Sanford Lab – Davis Laboratory Layout (Side View)



The Davis Cavern



1964 / 2009 “They want to fill the cavern with what ?*?”



The Future Beyond LUX-350

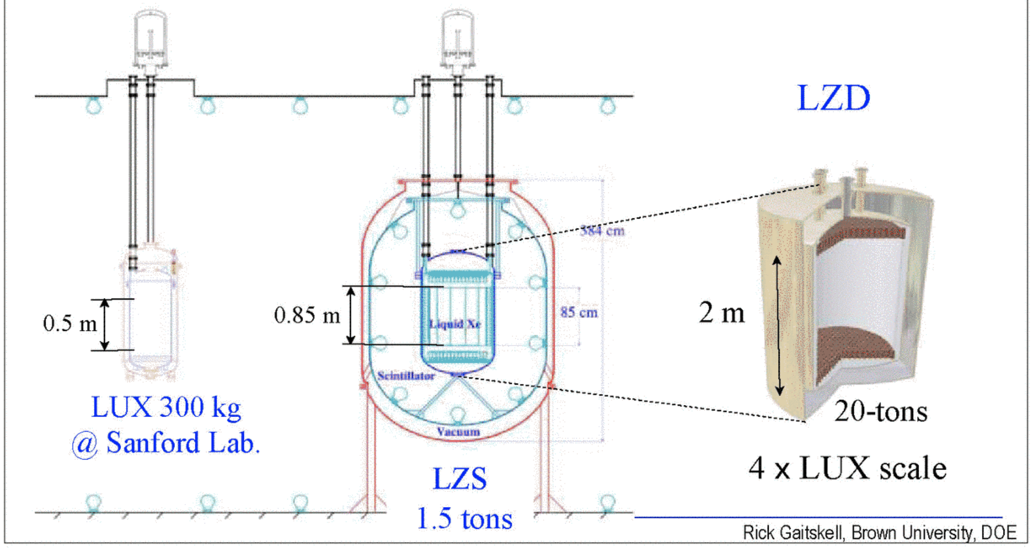
Proposed 1.5 ton instrument, LZ-S, to be installed in the same water tank at SUSEL, replacing LUX-350

Design study for 20 ton instrument, LZ-D,to be built at DUSEL, funded by DUSEL S4 grant. Can address topics in neutrino physics (neutrinoless double beta decay in Xe-136, pp-solar neutrinos), in addition to WIMP dark matter.

New institutions: ZEPLIN-III collaboration (Imperial, RAL, Edinburch, LIP-Coimbra, ITEP) plus new US institutions (Caltech, UC Berkeley, UC Santa Barbara),

The LZ program

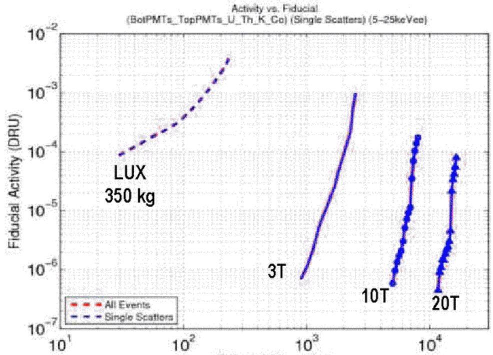
- LZ: LUX + ZEPLIN III + new US and European groups
- LZS (Sanford): 1.5 ton instrument for Sanford Lab, just proposed.
- LZD (DUSEL): Scale based on technically feasibility, cost.

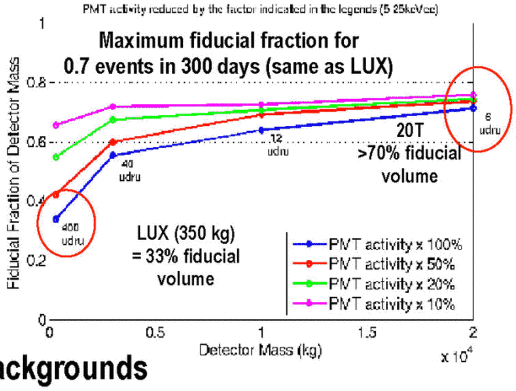


Rick Gaitskell, Brown University, DOE

Larger Detectors – Gamma Backgrounds

- Evolution of fiducial volume: more mass → more self-shielding
  - **Larger total mass leads to larger fraction available for fiducial volume**
- PMT radioactivity reduction subdominant for large detectors
  - **PMT radioactivity (per area) is important for ≤ 1T detectors**
    - x1/10 reduction in PMT activity in LUX => x2.5 increase in fiducial volume
  - **Improvement due to reduction of PMT radioactivity (per area) is subdominant for larger detectors (≥10T)**
    - **x1/10 reduction in PMT activity in 20T => 10% increase in fiducial volume**



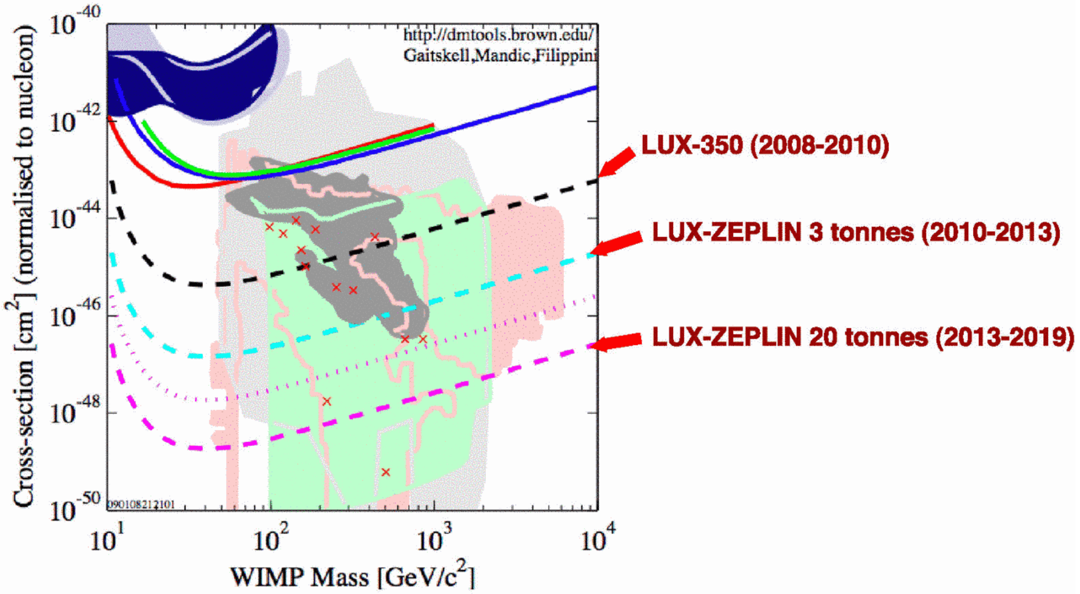


Gamma backgrounds

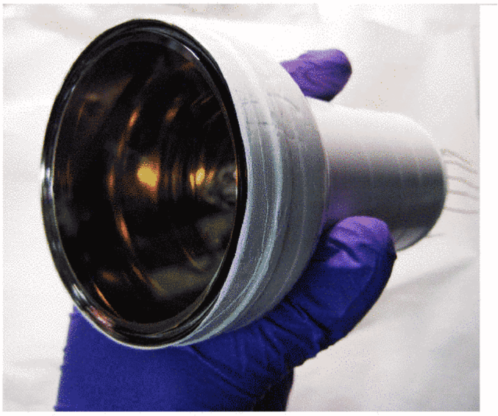
de Viveiros - Brown University

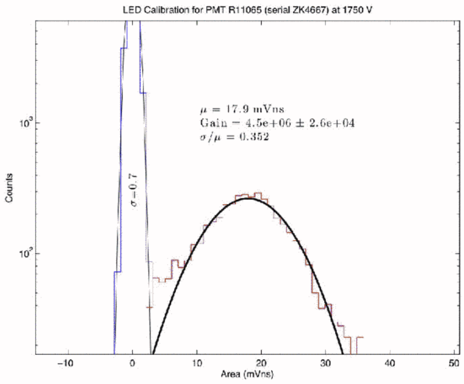
November 2009 v04 <>

Long Term Program



Photomultiplier R&D





New 3" PMTs -- Hamamatsu R11065

With 2x collection area of R8778

Background target: U/Th of 1/1 mBq

Single photoelectron resolution obtained from first articles of Hamamatsu.

Tested immersed in LXe, including Xe primary scintillation detection

Energy Calibration: determine the energy of nuclear recoils

energy of nuclear recoils (NRs)

measured signal in # of pe

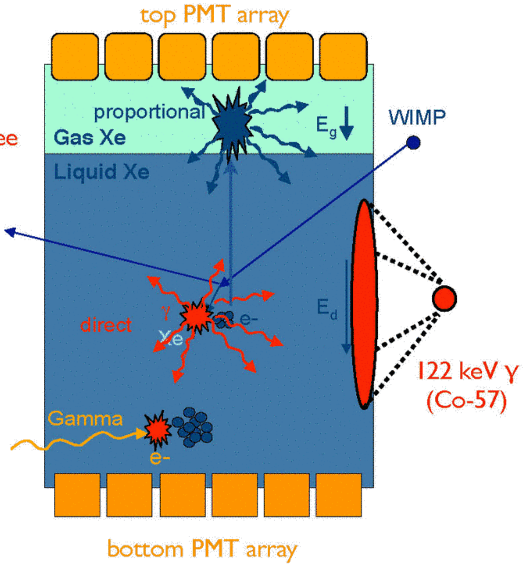
light yield for 122 keV γ in pe/keVee

$$E_{nr} = S1/L_y/\mathcal{L}_{eff} \cdot S_{er}/S_{nr}$$

relative scintillation efficiency of NRs to 122 keV γ's at zero field

quenching of scintillation yield for 122 keV γ's due to drift field

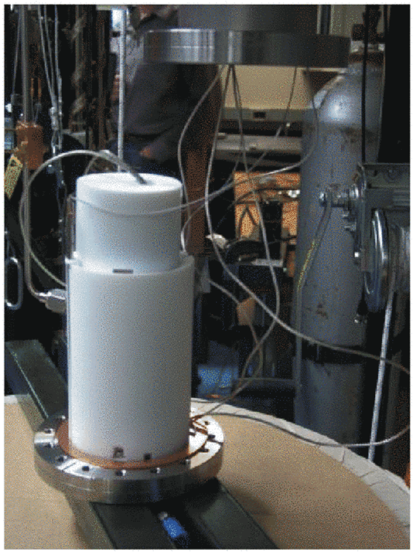
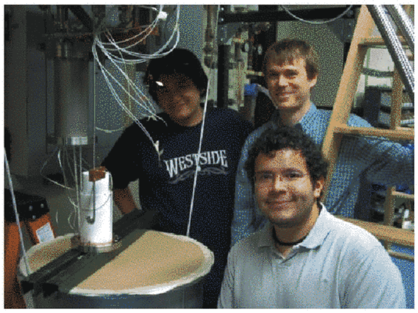
quenching of scintillation yield for NRs due to drift field



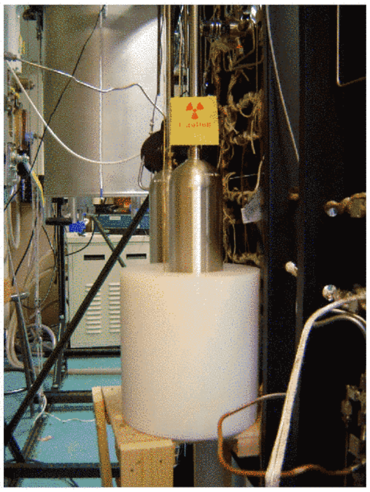
LXe cell at Yale

used for level meter development, LXe scintillation for nuclear recoils, PMT testing in LXe, GEM testing



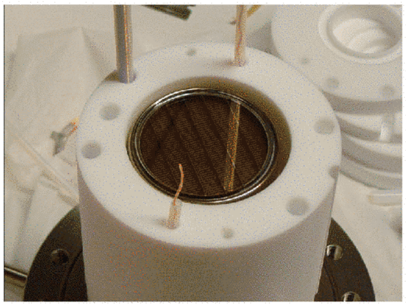
Xenon Activation with Cf-252 at Yale



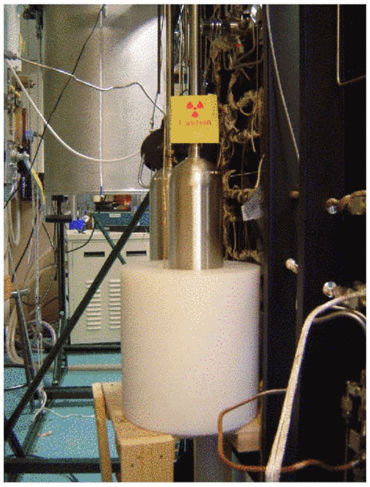
continuous activating Xe
gas with a 5x10^5 n/sec
Cf-252 source for 12 days

→

measure the scintillation light in
a liquid Xenon cell

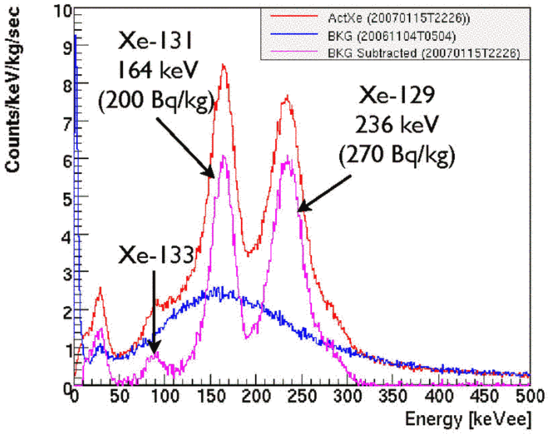


Xenon Activation with Cf-252



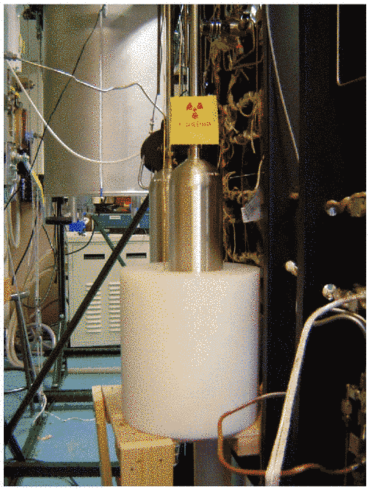
continuous activating Xe
gas with a 5x10^5 n/sec
Cf-252 source for 12 days

after 12-days of activation ...



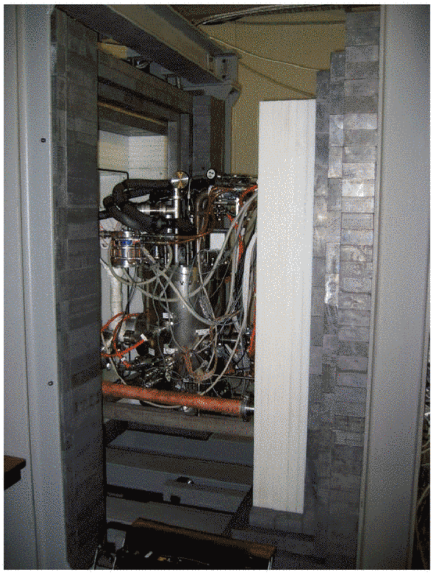
K. Ni, R. Hasty, T. Wongjirad, L. Kastens, A. Manzur, and D. N. McKinsey, Nucl. Inst. and Meth. A 583, 569 (2009).

Xenon Activation with Cf-252



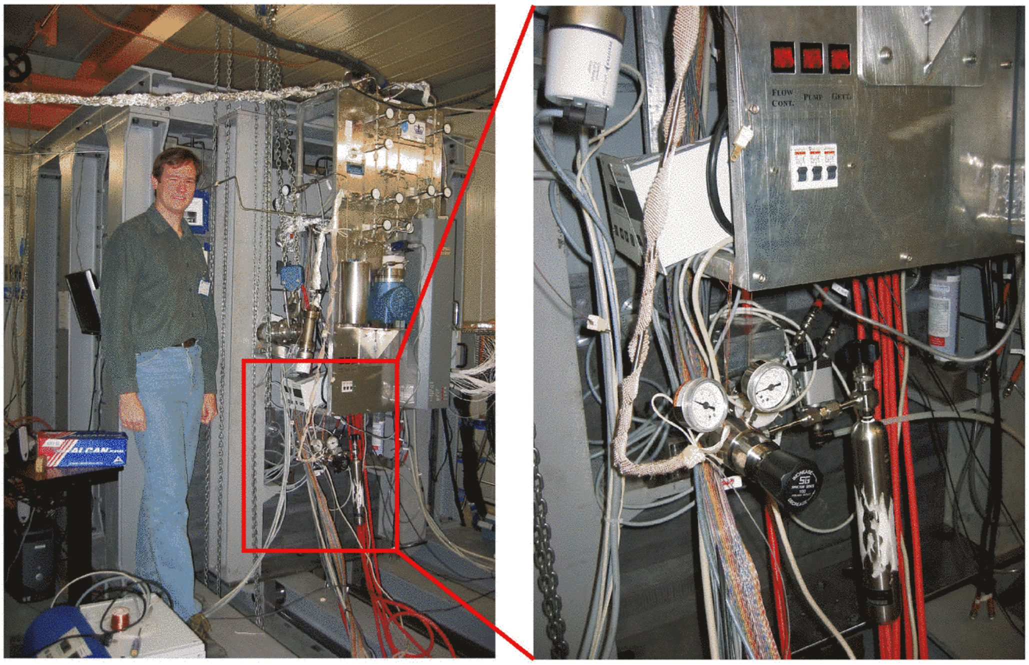
Yale (USA)

~ 1 week

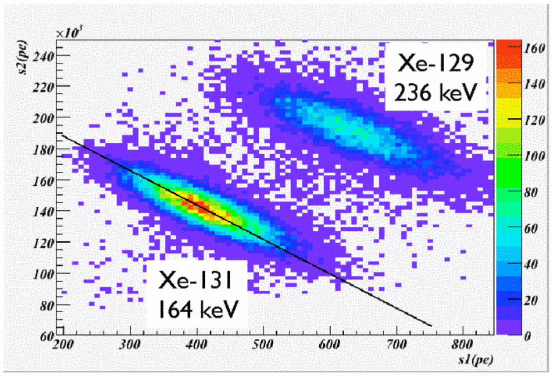


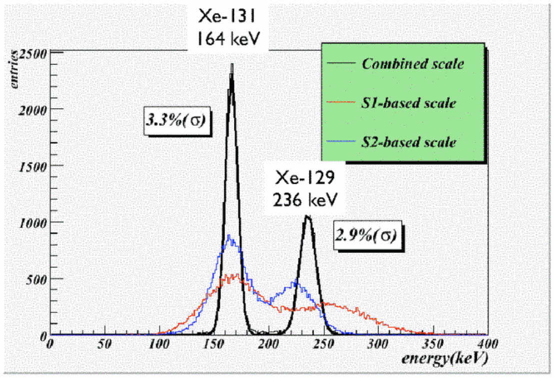
XENON10
Gran Sasso (Italy)

Neutron-activated xenon added to XENON10

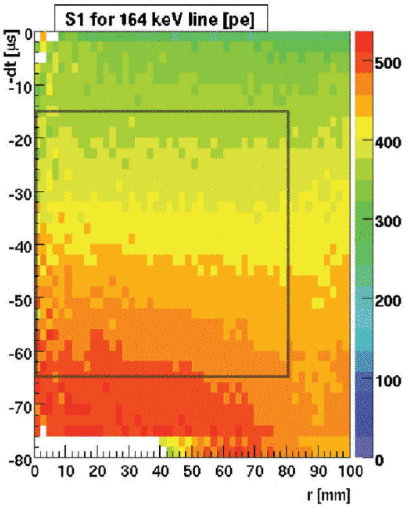


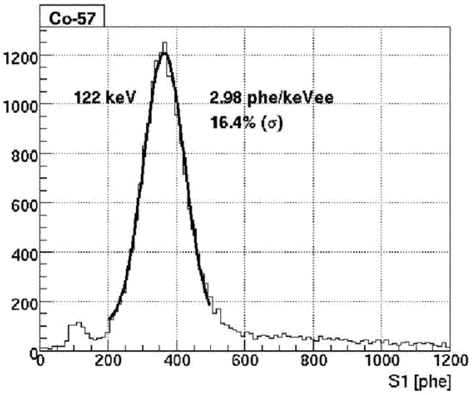
Activated Xenon Lines in XENON10





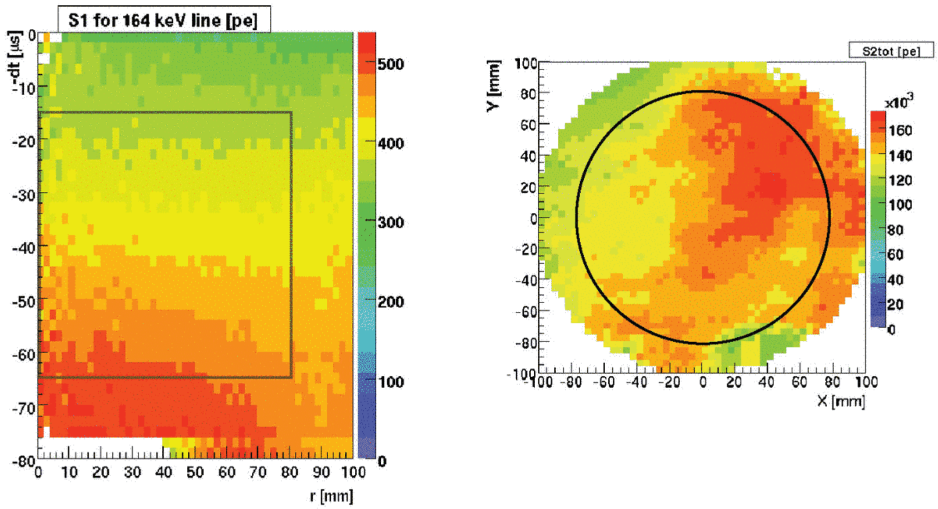
Position dependence of S1 signals in XENON10





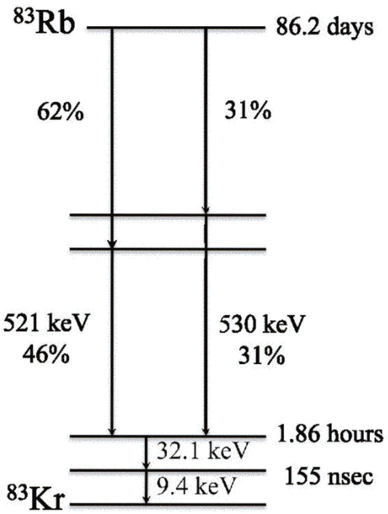
after position-dependent corrections

Position dependence of S1 and S2 signals

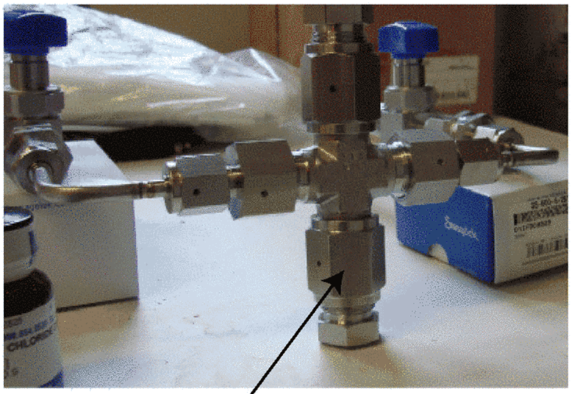


The XENON10 results are from position-dependent corrected signals by using these maps obtained from activated-Xe calibration

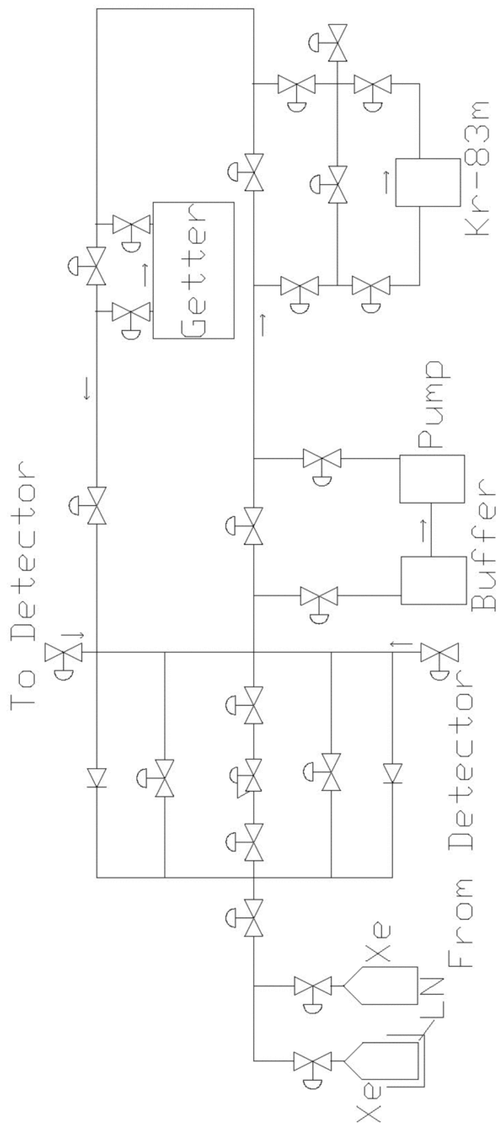
Kr-83m calibration source development at Yale



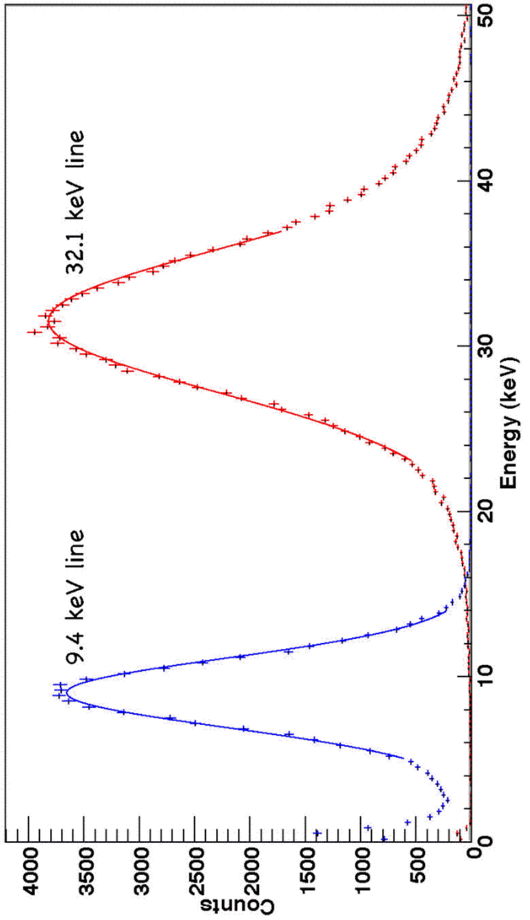
Rb-83 purchased in aqueous solution, then coated on zeolite. Continually emits Kr-83m, which can then be used to calibrate the liquid xenon detector response.



Rb-83 adsorbed on zeolite beads, in vacuum plumbing

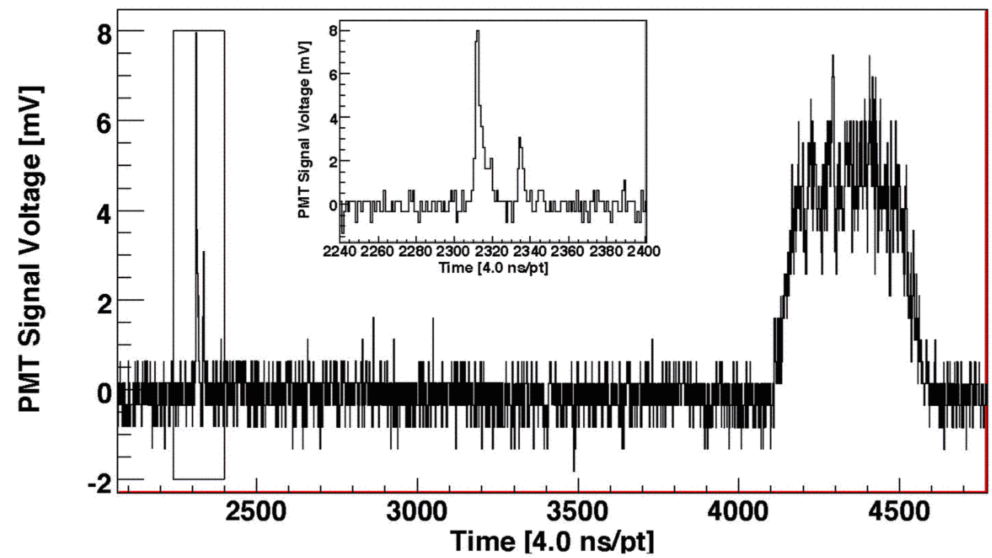


LXe scintillation data from Kr-83m dissolved into LXe



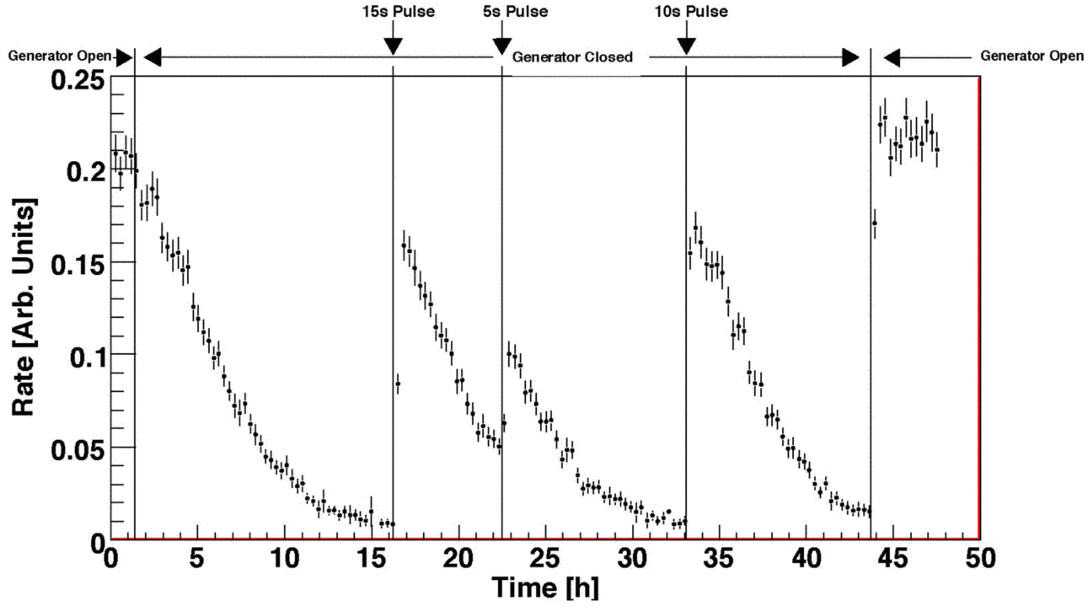
L. Kastens *et al*, Physical Review C **80**, 045809 (2009).

Typical Kr-83m event in 2-phase Xe

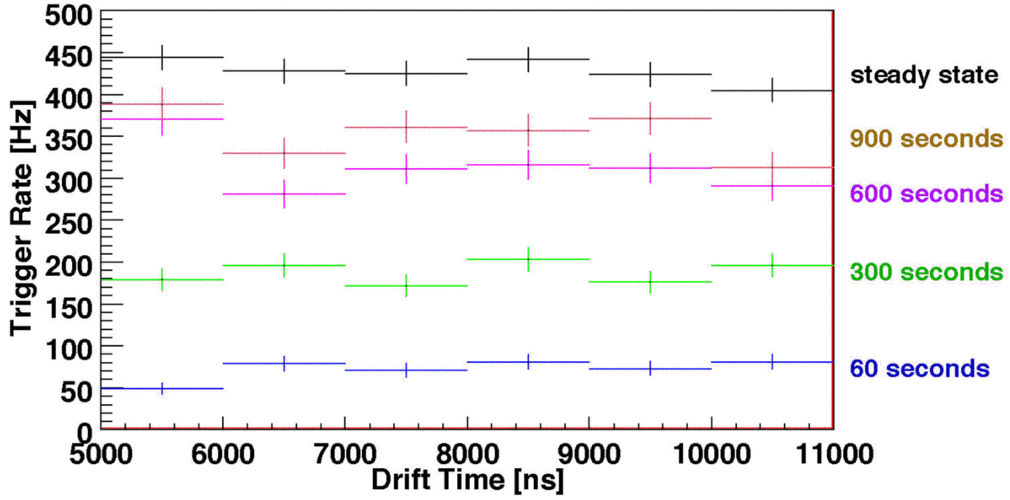


Also see Manalaysay et al, arXiv:0908.0616

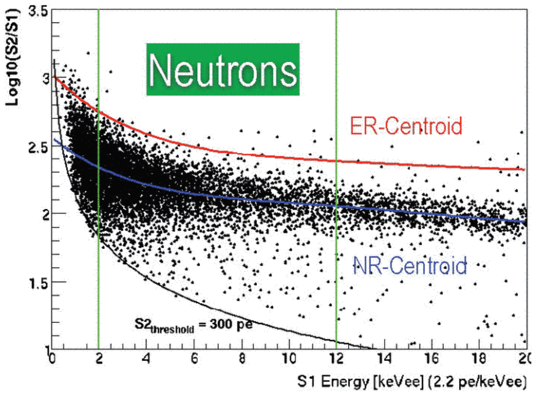
Repeated Kr-83m introduction into 2-phase Xe detector



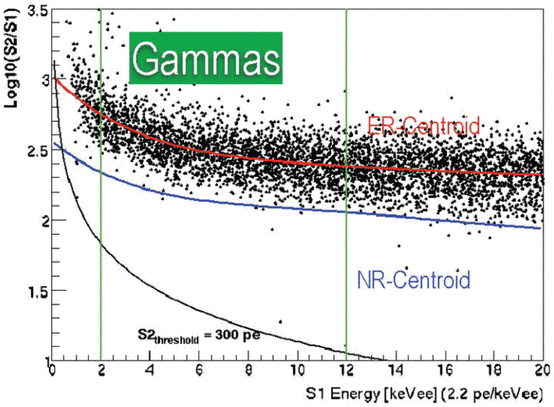
Introduction of Kr-83m into 2-phase detector



XENON10 Gamma/Neutron calibration

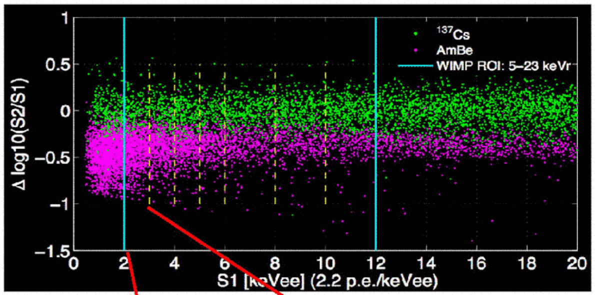


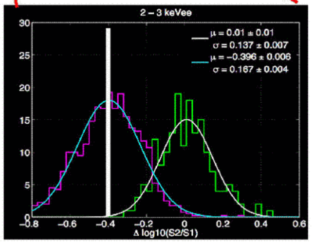
AmBe Neutron Calibration (NR-band)

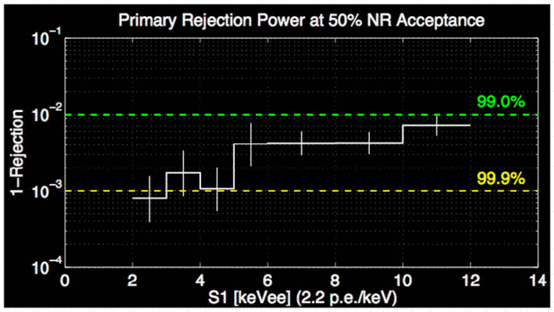


Cs-137 Gamma Calibration (ER-band)

XENON10 measured discrimination power





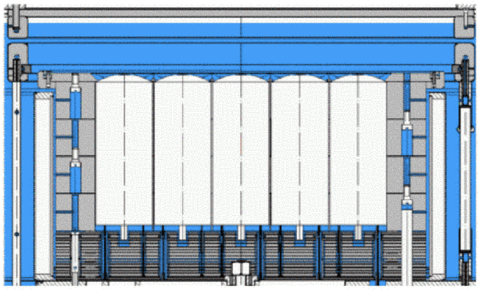


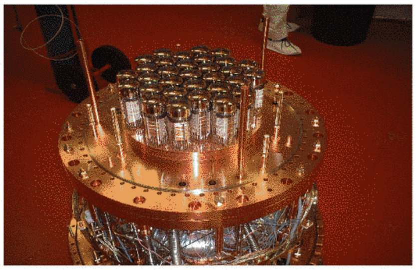
~ 99.5% electron recoil rejection
(improves to 99.9% at low energy
(50% nuclear recoil acceptance).

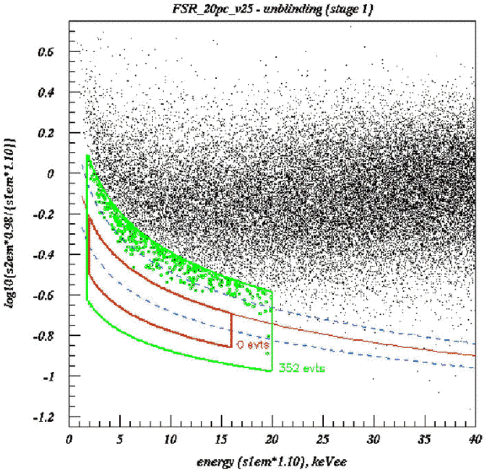
ZEPLIN-III

35 mm fiducial LXe depth;
3.8 kV/cm

31 x 2" PMTs







Better discrimination at 4 kV/cm?

$$L_{eff} = \frac{\text{scintillation per unit energy for nuclear recoils}}{\text{scintillation per unit energy for electron recoils}}$$

In practice, we define the denominator based on 122 keV photoabsorption events from Co-57

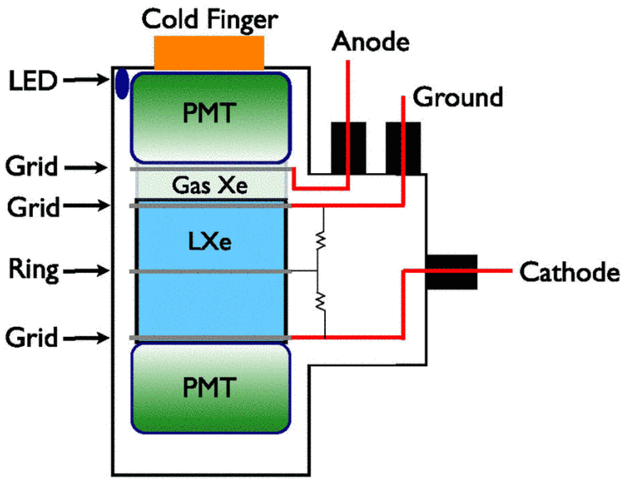
In the XENON10 analysis, we assumed an energy-independent Leff of 0.19 for the WIMP search analysis, and for determining our cross-section limits.

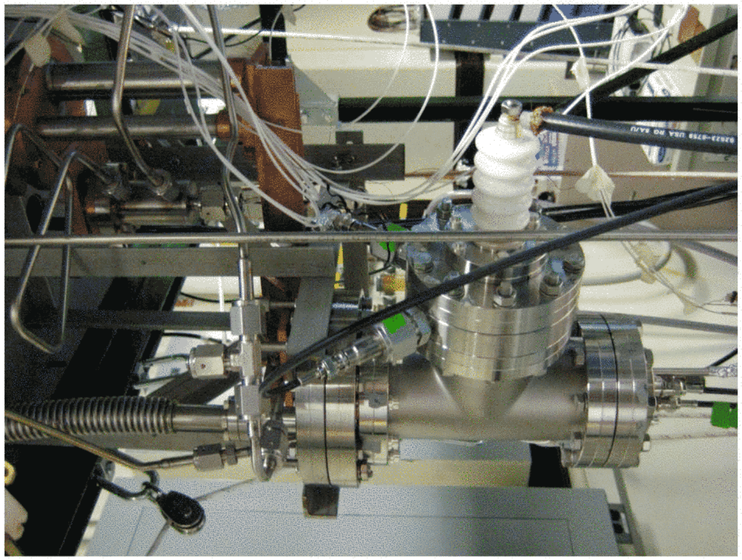
Uncertainty in Leff was the main source of systematic uncertainty in determining the cross-section limits.

New measurement of Leff: A. Manzur et al., arXiv:0909.1063

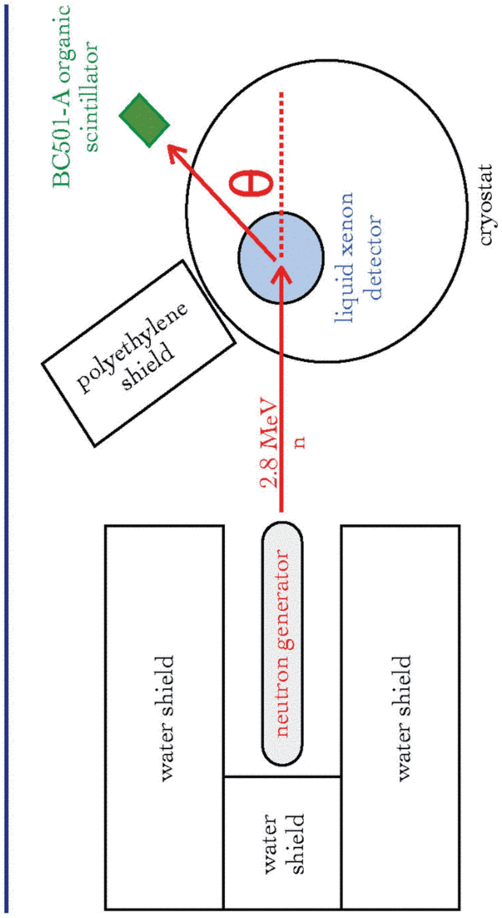
Two-phase LXe detector at Yale (MAXe)

Variable drift field (1-4 kV/cm)
Variable extraction & proportional scintillation field (6-10 kV/cm)
11 pe/keV at zero field
PMTs have ~35% quantum efficiency





Experimental setup

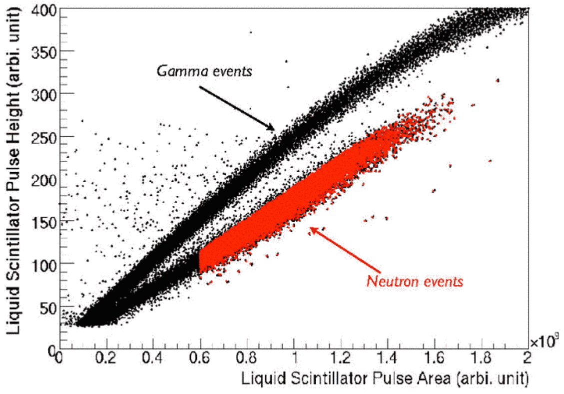


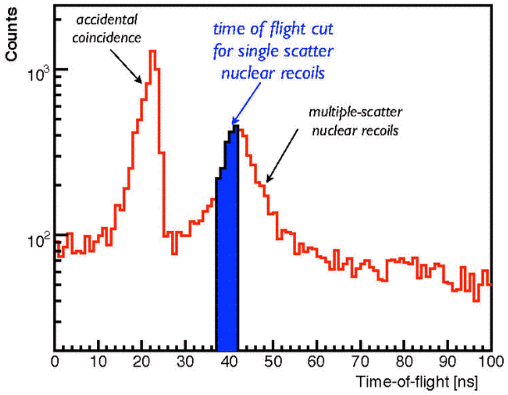
$$E_R = E_n \frac{2 m_n M_{Xe}}{(m_n + M_{Xe})^2}(1 - \cos\theta)$$

Energies: 4 - 66 keVr

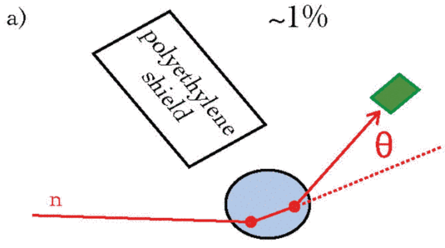
Selecting single nuclear recoils

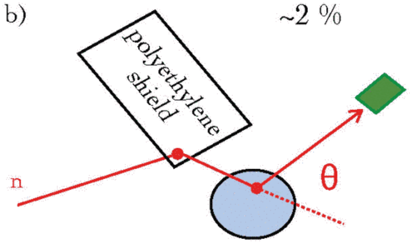
- Quality cuts Q0: remove noise event, high energy events, S1 asymmetry
- Select neutrons using PSD and time of flight (TOF)

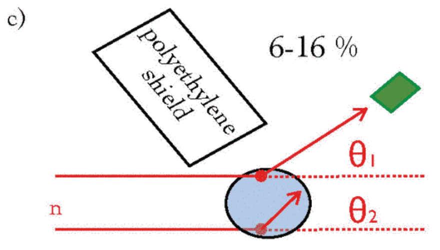




Systematic error

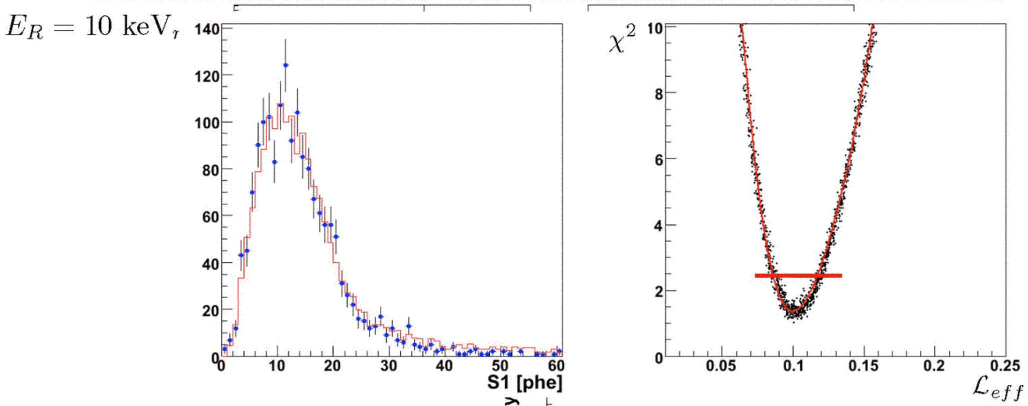






- a) Multiple elastic scatters
- b) Outside scatters
- c) Size and position
- d) Cross-section database ~2 - 4%

Comparing data & Monte Carlo

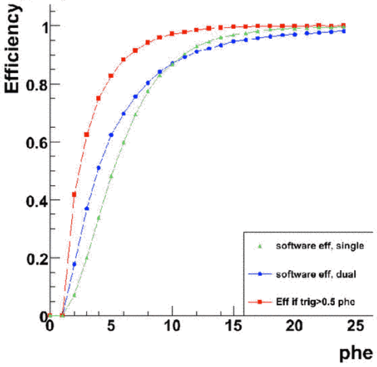


To compare MC & data:

1 $E_R \rightarrow E_e$

2 $\sigma = 3.2\sqrt{N_{phe}}$

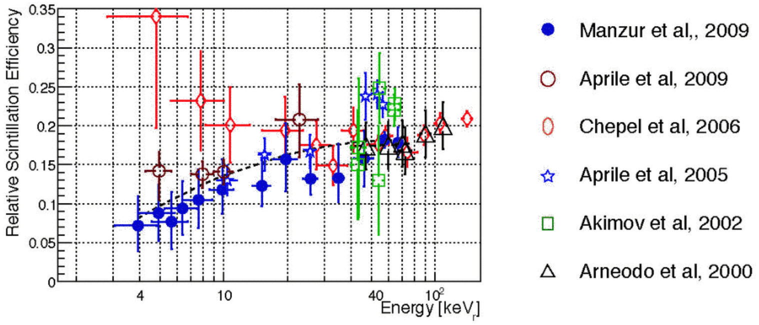
3 software + trigger efficiency

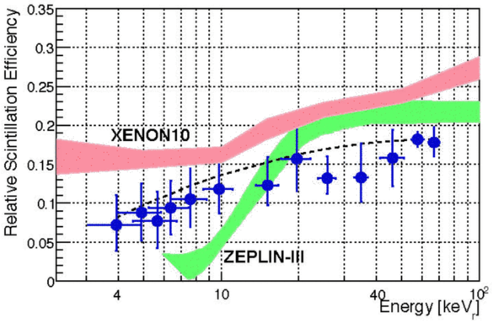


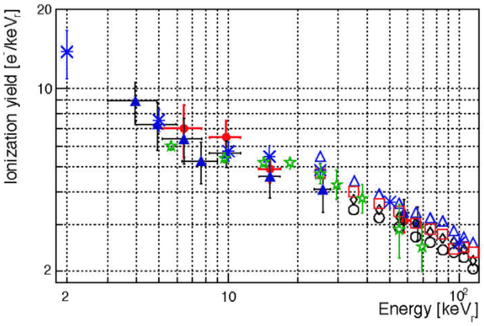
Angel Manzur

May 12, 2009

Leff results







$\mathcal{L}_{eff}$ model

$$\mathcal{L}_{eff} = q_{ncl} \times q_{el} \times q_{esc}$$

- q_{ncl} nuclear quenching (Lindhard factor), energy goes into heat.
- q_{el} electronic quenching. Bi-excitonic collisions

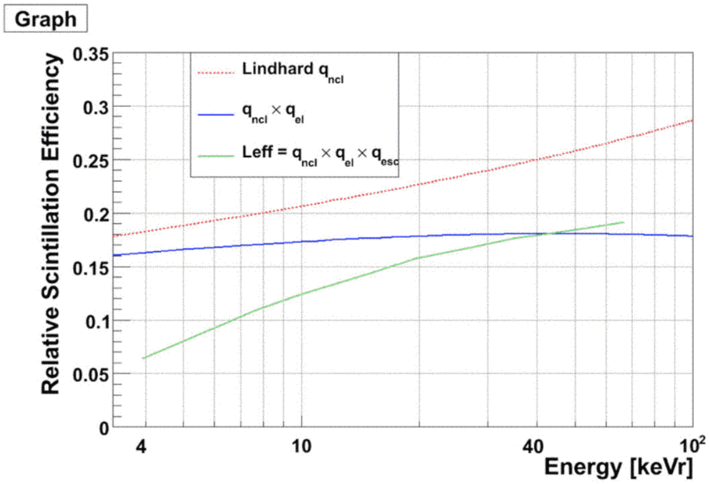
$$\mathrm{Xe}^* + \mathrm{Xe}^* \rightarrow \mathrm{Xe} + \mathrm{Xe}^+ + e^-$$

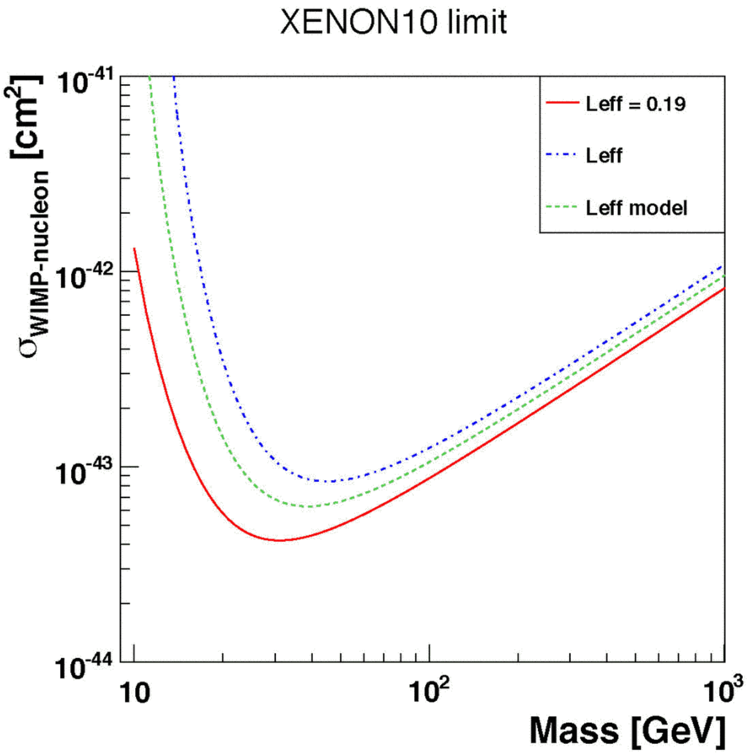
$$q_{el} = \frac{1}{1 + k\frac{dE}{dx}}$$

- Escape electrons

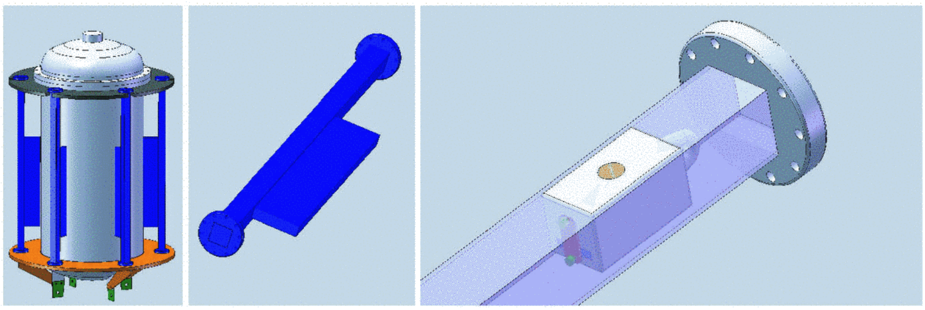
$$q_{esc} = \frac{N_{ex} + N_i - N_{esc}}{N_{ex}^{122} + N_i^{122} - N_{esc}^{122}} = \frac{\alpha + 1 - \beta}{\alpha + 1 - \beta^{122}}$$

$\mathcal{L}_{eff}$ model





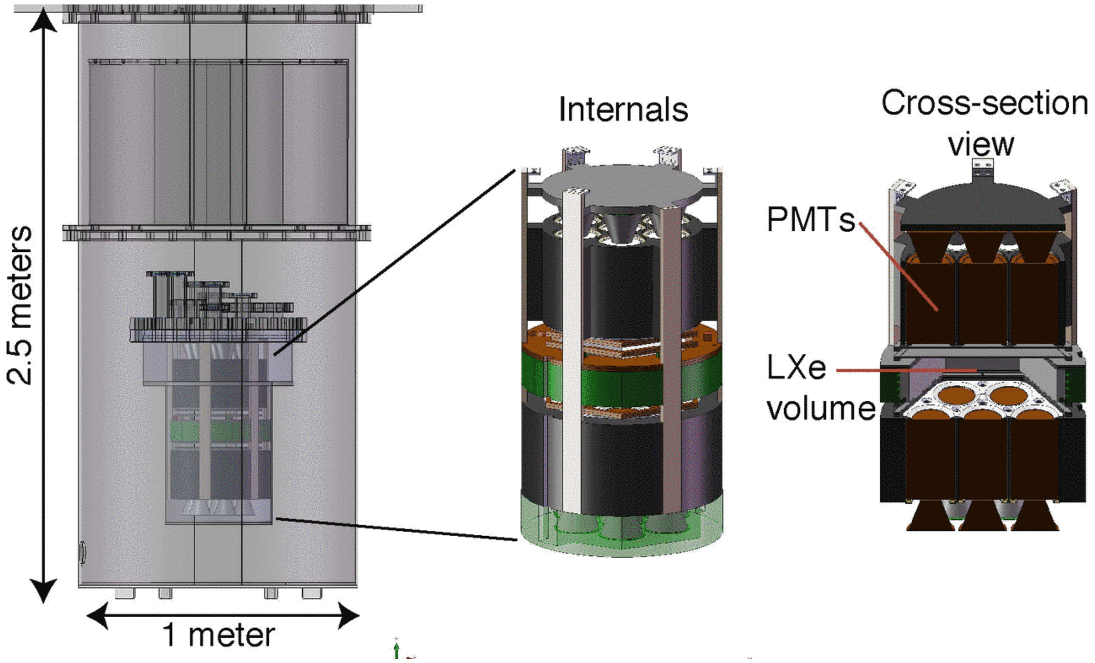
Source tubes for LUX



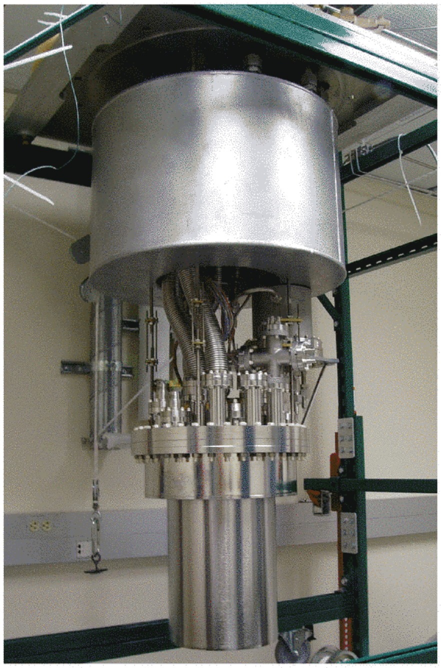
Am-Be neutron source for nuclear recoil calibration
Low energy gamma sources for energy scale calibration
High energy gamma sources for S2/S1 band calibration

Particle Identification in Xe at Yale (PIXeY)

Goals: a) S2/S1 discrimination as a function of drift field
b) Energy resolution studies in 2-phase Xe



PIXeY photos

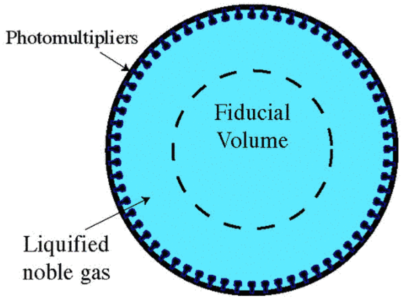


The Mini-CLEAN Approach

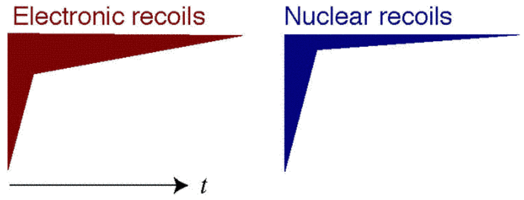
Scaleable technology based on detection of scintillation in liquified noble gases. No E field.
Ultraviolet scintillation light is converted to visible light with a wavelength-shifting film.

Liquid neon and liquid argon are bright scintillators (30,000 - 40,000 photons/MeV).
Do not absorb their own scintillation.
Are inexpensive (Ar: $2k/ton, Ne: $90k/ton).
Are easily purified underground.
Exhibit effective pulse shape discrimination.
Exchange of targets allows direct testing of A^2 dependence of WIMP scattering rate

Self-shielding



Pulse-shape discrimination



Fast component: < 10 ns
Slow component: 1.5 μs (LAr), 15 μs (LNe)
Discriminate based on fraction of light in first 100 ns (Fprompt)

D. N. McKinsey and J. M. Doyle, J. Low Temp. Phys. 118, 153 (2000).
D. N. McKinsey and K. J. Coakley, Astropart. Phys. 22, 355 (2005).
M. Boulay, J. Lidgard, and A. Hime, nucl-ex/0410025
M. Boulay and A. Hime, Astropart. Phys. 25, 179 (2006).

Why single-phase?

Ar-39 background (1 Bq/kg in natural argon) drives design.

Pile-up is a significant issue for two-phase, because of the high Ar-39 rate and the ~ms drift time for a tonne-scale instrument. In a blind analysis, how to match up S1 and S2 signals to achieve good S2/S1 discrimination and position resolution? Depleted Ar therefore needed in two-phase.

In single-phase, event lifetime is set by triplet molecule lifetime of 1.5 μs, allowing detectors with tens of tons of inexpensive readily available natural argon (CLEAN). Depleted argon not needed in single-phase.

Pulse-shape discrimination is the most effective means of rejecting Ar-39 beta-decay background in LAr. At a given energy threshold, PSD efficiency depends exponentially on scintillation signal yield.

In microCLEAN, we see 6 photoelectrons/keVee (see James Nikkel's talk). Based on MicroCLEAN data and detailed optical Monte Carlo data, we project 6-7 photoelectrons/keVee in MiniCLEAN. This will allow superb Ar-39 background rejection at a reasonable energy threshold (~50 keVr)

No need for very high cathode voltages - simplifies design.

The DEAP/CLEAN Collaboration

15 Institutions:

Boston University, Carleton University, Harvard University, Los Alamos, MIT, NIST, Queen's University, SNOLAB, Syracuse University, University of Alberta, University of New Mexico, University of North Carolina, University of South Dakota, University of Texas, Yale University

Expertise in neutrons, neutrinos, low backgrounds, noble liquids, underground operations

DEAP/CLEAN Collaboration

BOSTON UNIVERSITY

HARVARD

Queen's UNIVERSITY

UNIVERSITY OF ALBERTA

THE UNIVERSITY of NEW MEXICO

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

THE UNIVERSITY OF SOUTH DAKOTA 1862

Massachusetts Institute of Technology

LUX ET VERITAS

Penn UNIVERSITY of PENNSYLVANIA

Carleton UNIVERSITY

NIST

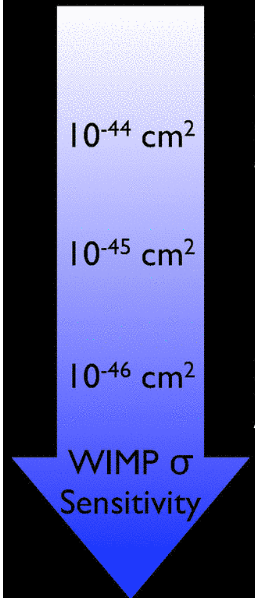
SYRACUSE UNIVERSITY : FOUNDED A.D. 1870

TRIUMF

SNOLAB MINING FOR KNOWLEDGE CREUSER POUR TROUVER... L'EXCELLENCE

Los Alamos NATIONAL LABORATORY EST. 1943

The DEAP and CLEAN Family of Detectors



DEAP-0:
Initial R&D detector

DEAP-1:
7 kg LAr
2 warm PMTs
At SNOLab 2008

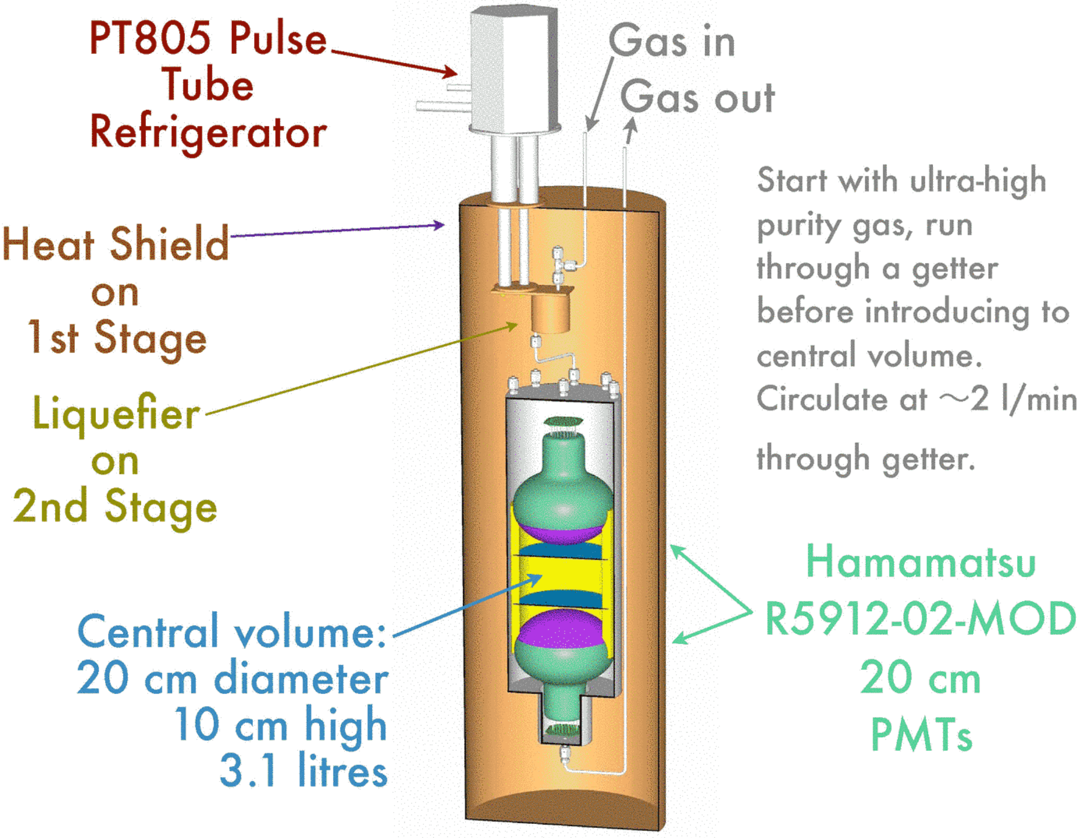
picoCLEAN:
Initial R&D detector

microCLEAN:
4 kg LAr or LNe
2 cold PMTs
surface tests at Yale

MiniCLEAN:
500 kg LAr or LNe (150 kg fiducial mass)
91 cold PMTs
At SNOLAB mid-2010

DEAP-3600:
3600 kg LAr (1000 kg fiducial mass)
266 cold PMTs
At SNOLAB 2011

50-tonne LNe/LAr Detector:
pp-solar ν, supernova ν, dark matter $<10^{-46}$ cm^2
At DUSEL ~2015?



PT805 Pulse Tube Refrigerator

Heat Shield on 1st Stage

Liquefier on 2nd Stage

Central volume:
20 cm diameter
10 cm high
3.1 litres

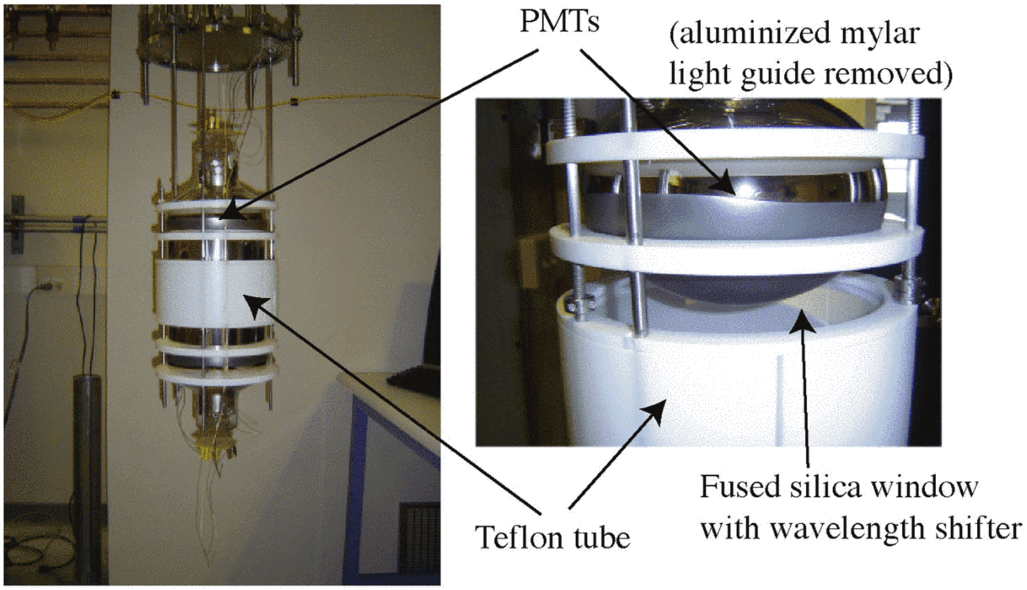
Gas in

Gas out

Start with ultra-high purity gas, run through a getter before introducing to central volume. Circulate at ~2 l/min through getter.

Hamamatsu R5912-02-MOD 20 cm PMTs

Close-up shots of micro-CLEAN



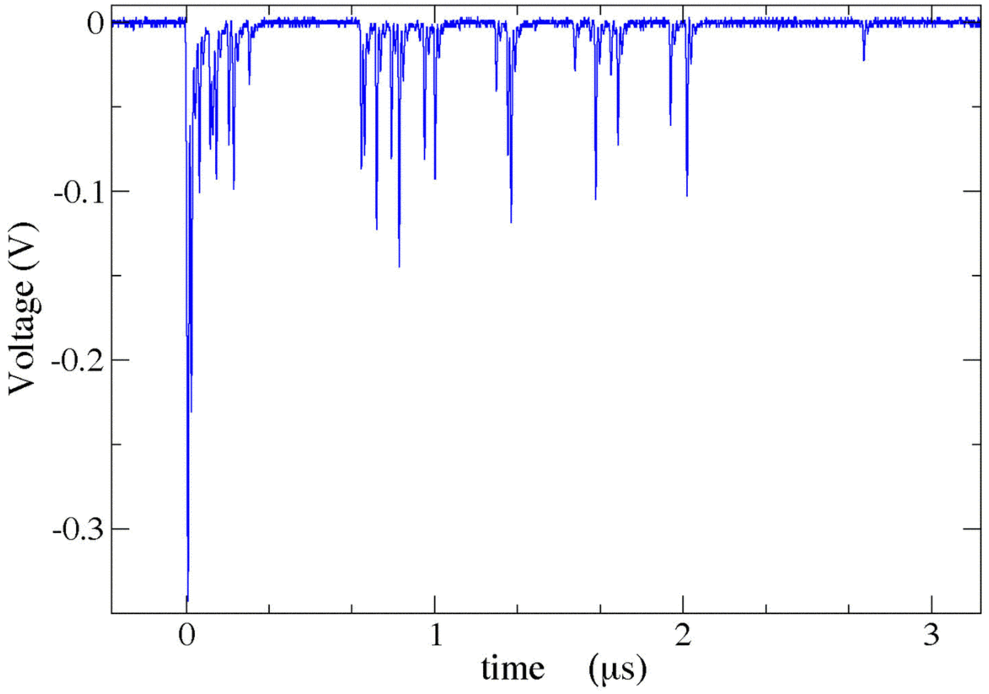
PMTs

(aluminized mylar
light guide removed)

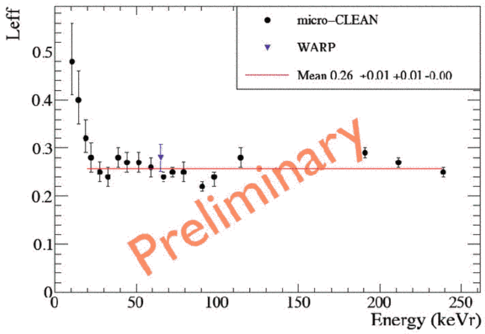
Teflon tube

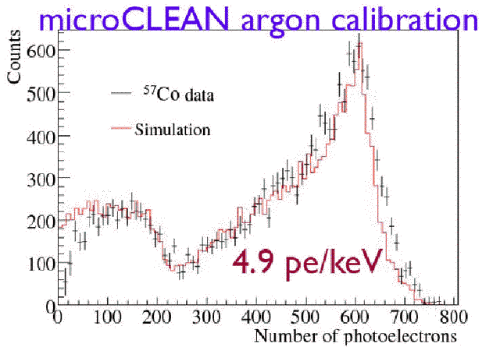
Fused silica window
with wavelength shifter

Sample scintillation pulse (gamma Compton scatter in LAr)



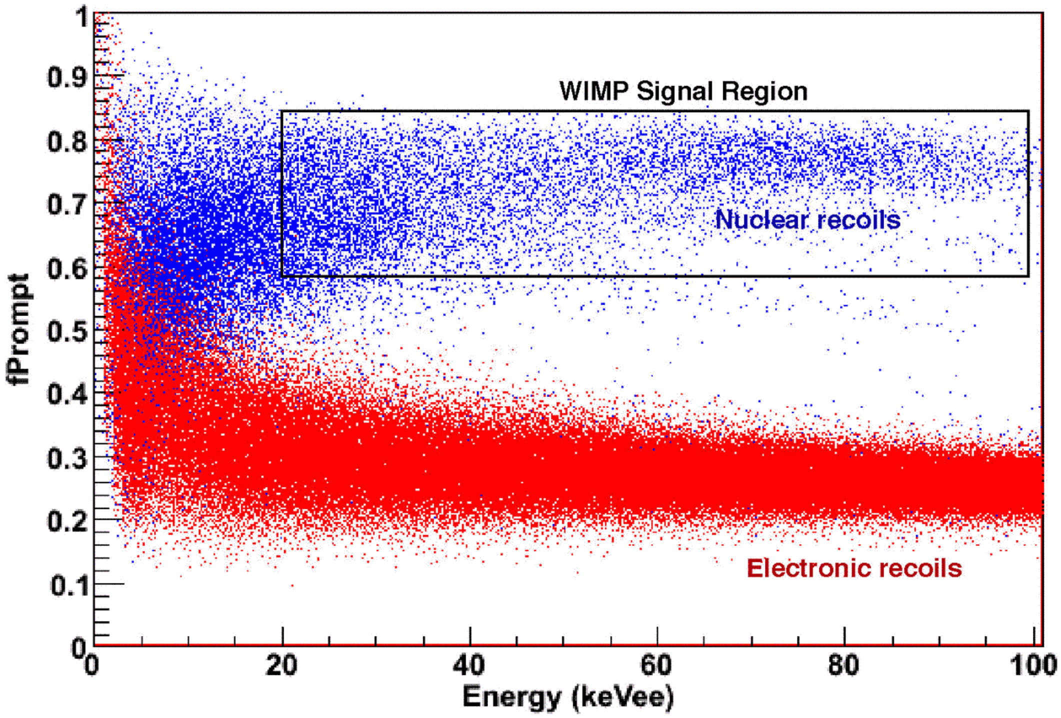
Some LAr R&D results





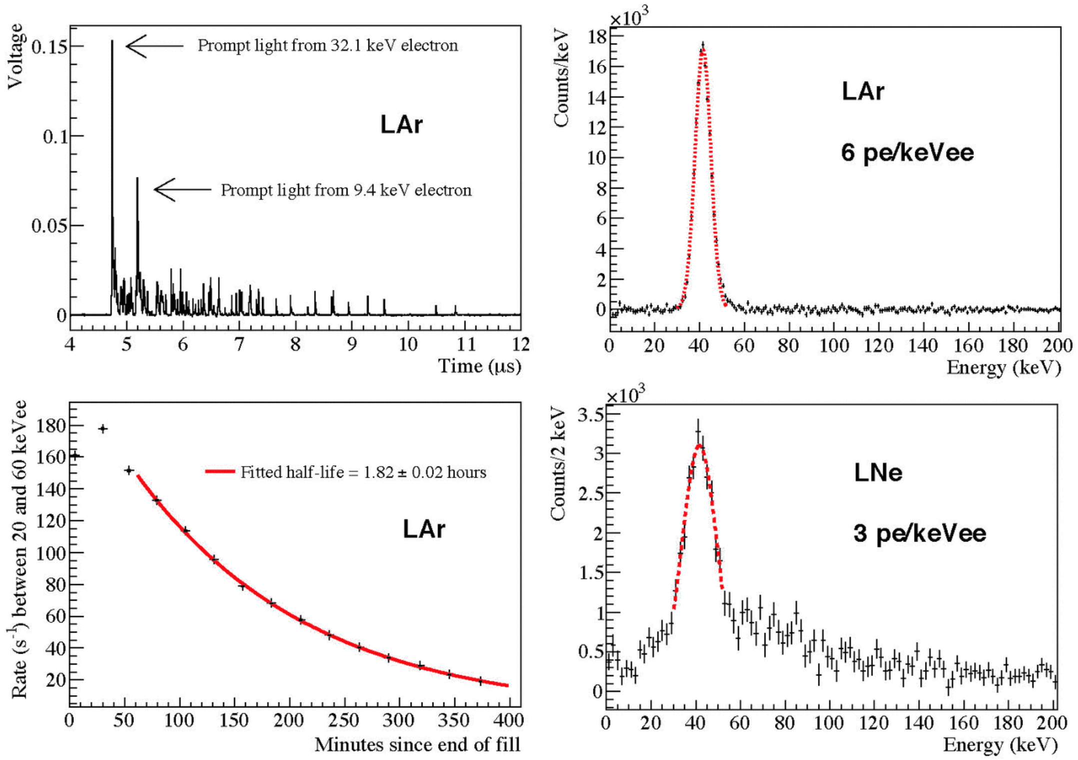
- 4.9 PE/keV experimentally demonstrated
- QF above 20 keV ~0.26

We measure an electron recoil contamination of 7.6 x 10^{-7} above 52 keVr

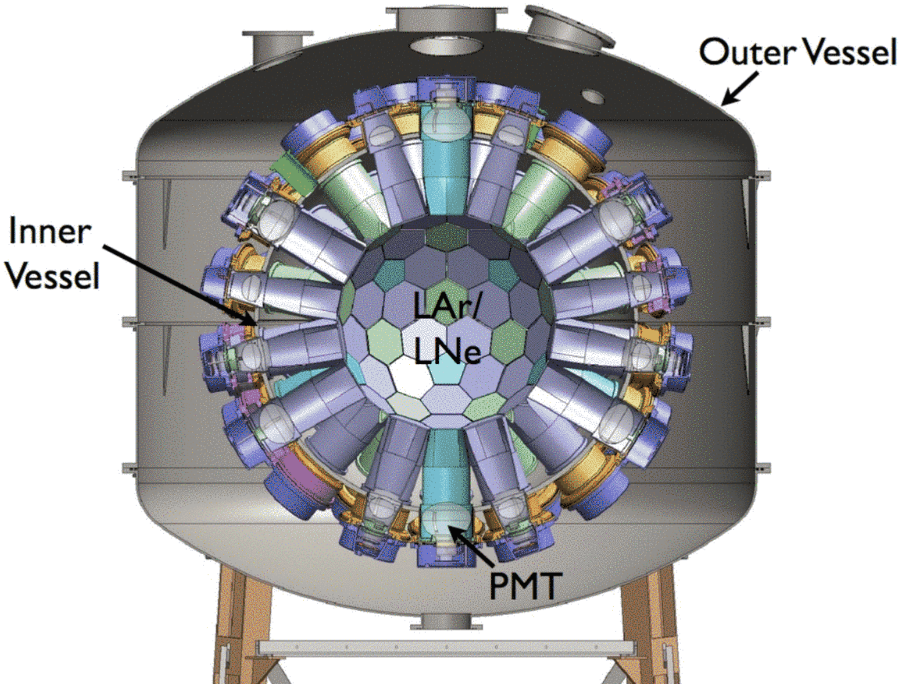


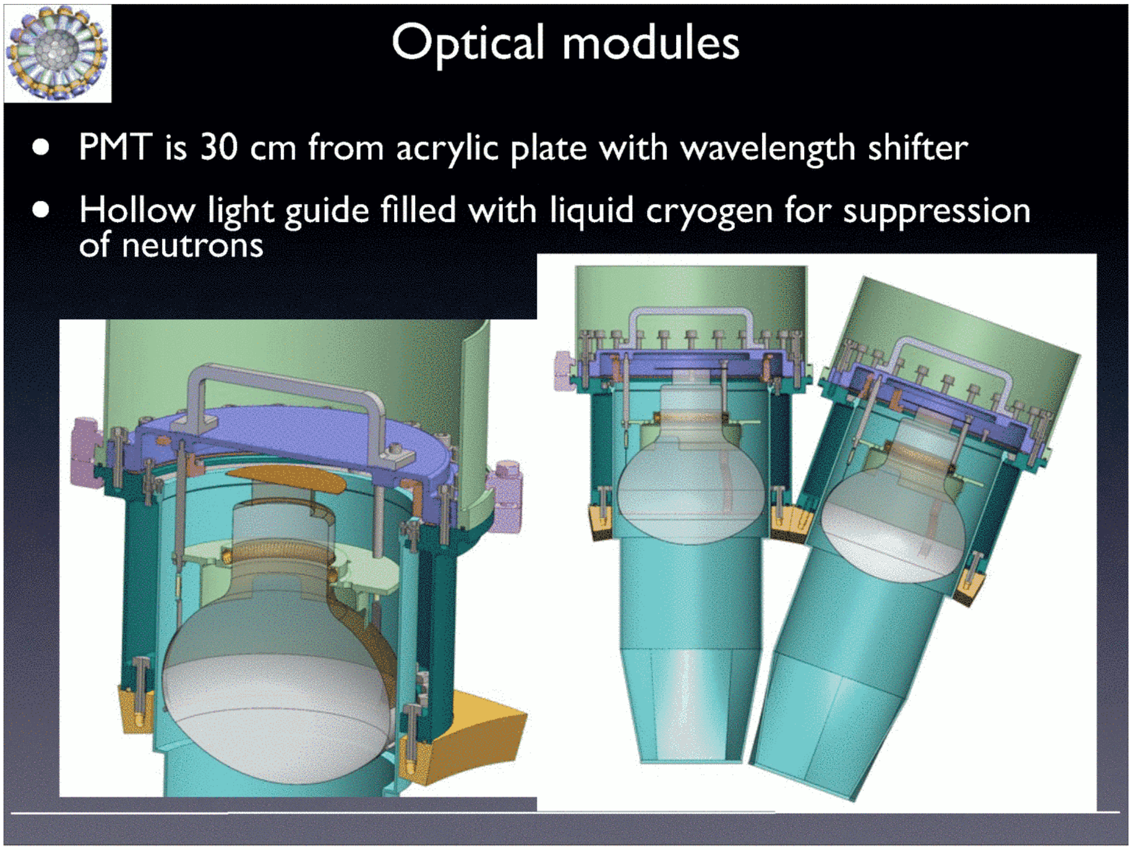
Lippincott et al., Phys. Rev. C 78, 035801 (2008).

Kr-83m in liquid argon and liquid neon



MiniCLEAN detector





Optical modules

- PMT is 30 cm from acrylic plate with wavelength shifter
- Hollow light guide filled with liquid cryogen for suppression of neutrons

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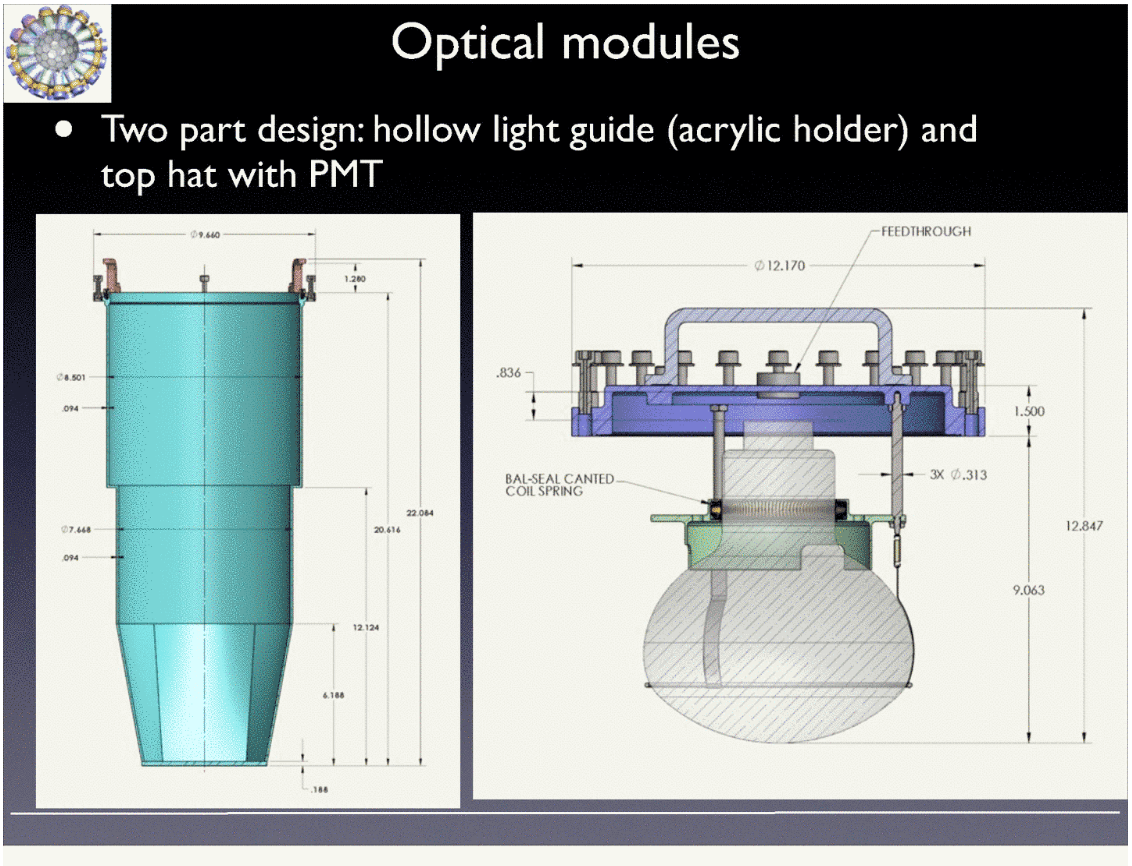

Optical modules

- Two part design: hollow light guide (acrylic holder) and top hat with PMT

MiniCLEAN Detector

- Liquid cryogen can be argon or neon
- ~150 kg fiducial volume
- PMTs - Hamamatsu R5912-02MOD operating in cryogenic liquid
- Cryogen, PMTs and wavelength shifters contained in stainless steel Inner Vessel (IV)
- IV is surrounded by stainless steel Outer Vessel with vacuum insulation and thermal blanket
- PMT and wavelength shifter (TPB) on acrylic plate are part of modular optical cassette
- 91 optical cassettes, plus one port used for calibrations

Goals of MiniCLEAN

- Have capability to set WIMP cross-section limit at 2×10^{-45} cm^2
- Show backgrounds of less than 1 neutron in region of interest
- Demonstrate position reconstruction, neutron tagging
- Demonstrate Pulse Shape Discrimination of 10^{10} for argon
- Demonstrate liquid neon capability for a future detector
- Demonstrate radon daughter background of one alpha per m^2 per day

Backgrounds

- Multiple strategies to reduce backgrounds in region of interest
    - 1.5 meters of water shielding on all sides
    - Experiment sited at SNOLAB Cube Hall, 6000 mwe
    - Materials screened for low radioactivity, PMT glass is hottest
    - PMTs as far as possible from active volume (inside TPB sphere), 43 cm buffer of liquid cryogen to fiducial volume
    - Neutron tagging
    - Position reconstruction
    - Radon daughter deposition: optical cassettes assembled on surface in low radon environment then placed under vacuum for transport, kept in vacuum when put into IV -- goal of one alpha per m^2 per day on the acrylic
    - Muon veto uses 48 spare SNO PMTs to veto muons in shield tank

---

Outer Vessel Progress

- Outer Vessel: being made at PHPK in Columbus, OH (delivery: early Dec. 09)

Outer Vessel Progress

- Outer Vessel: being made at PHPK in Columbus, OH (delivery: early Dec. 09)

Inner Vessel Progress

- Stainless steel hemispheres made by Trinity Heads, Inc in Texas
- Will go for machining next

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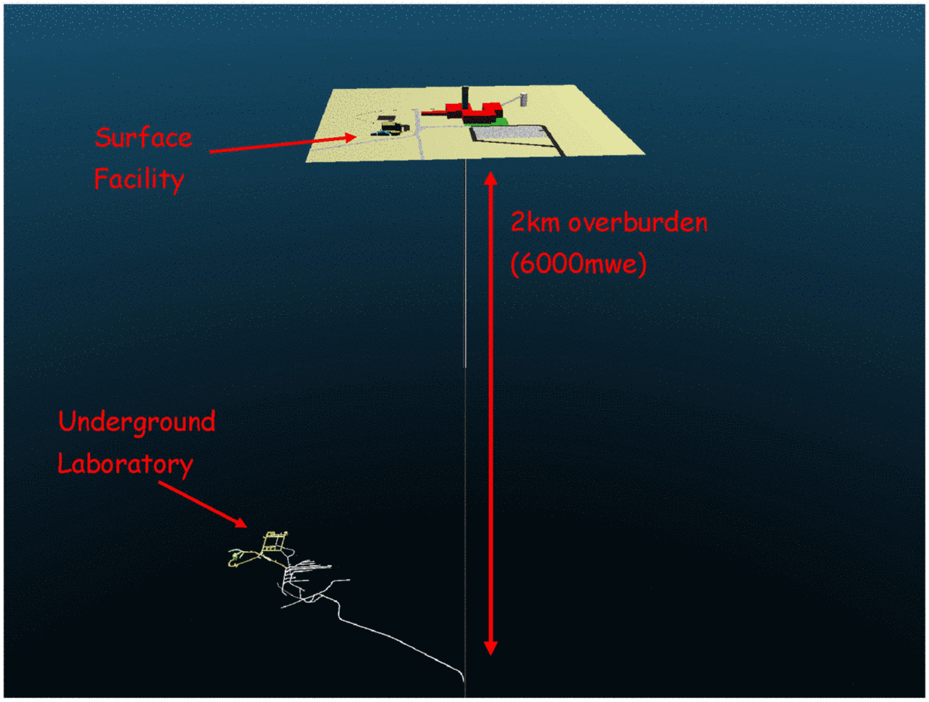
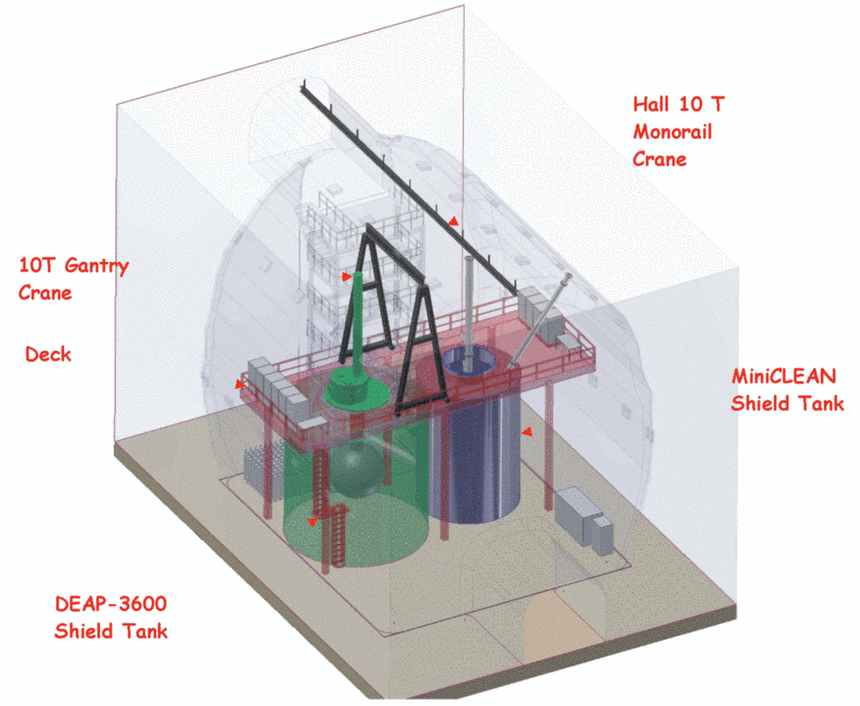
Infrastructure Progress

- MiniCLEAN will be located in the Cube Hall at SNOLAB in Sudbury, Canada at 6800 foot level underground
- Support steel going up, shield tank and crane arrived

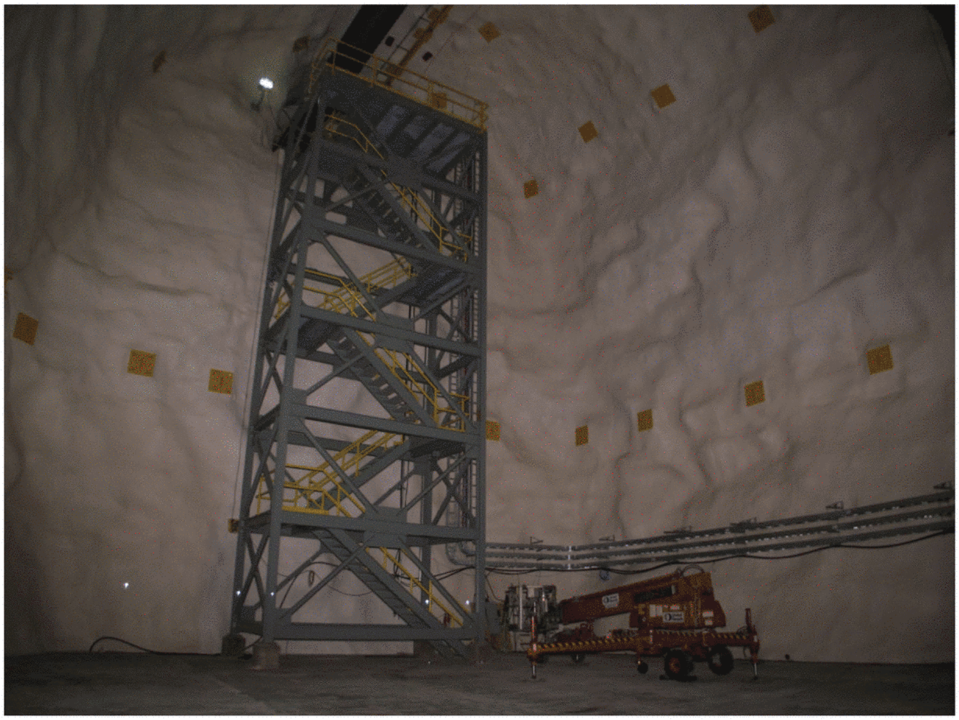


SNOLAB

Infrastructure Progress



Infrastructure Progress



Infrastructure Progress

Infrastructure Progress

Infrastructure Progress

Infrastructure Progress

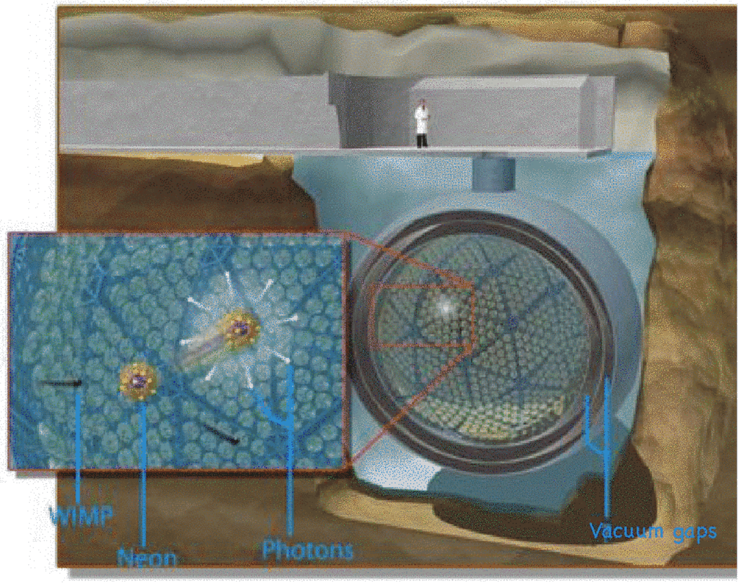
Further Progress

- Electronics chosen (CAEN VX1720), some procured, HV system procured and tested
- 100 PMTs delivered from Hamamatsu
- Acrylic chosen for cassette (Spartech Townsend SUVT)
- Initial radon removal tests complete
- Initial low-mass PMT bases being tested
- Planning for transport of OV and IV complete

Next Steps

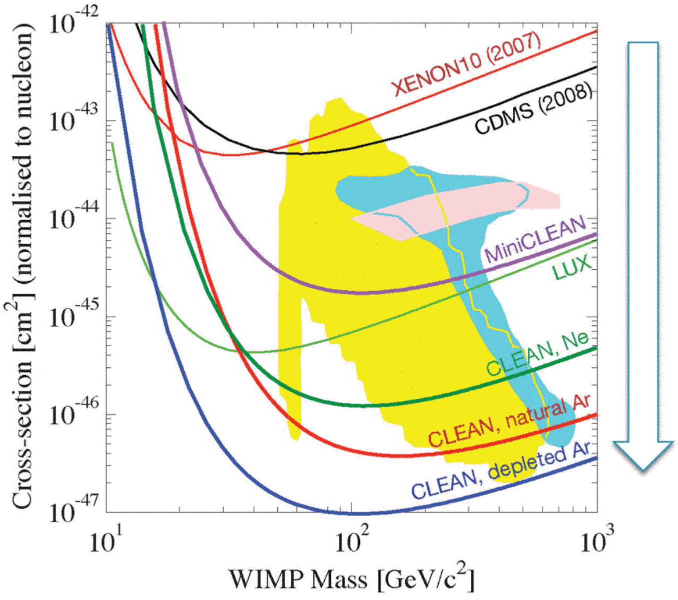
- Main components (IV, OV) are well underway with plans on transport and assembly
- OV will be underground by end of year
- Underground infrastructure (utilities, deck, water tank) ready January 2010
- IV scheduled for completion in March 2010
- Assembly scheduled for Spring 2010
- Commissioning in Summer 2010
- First liquid argon dark matter run Fall 2010

50 ton CLEAN detector, filled with LAr, then LNe



Science: WIMP dark matter, pp neutrinos, supernova neutrinos

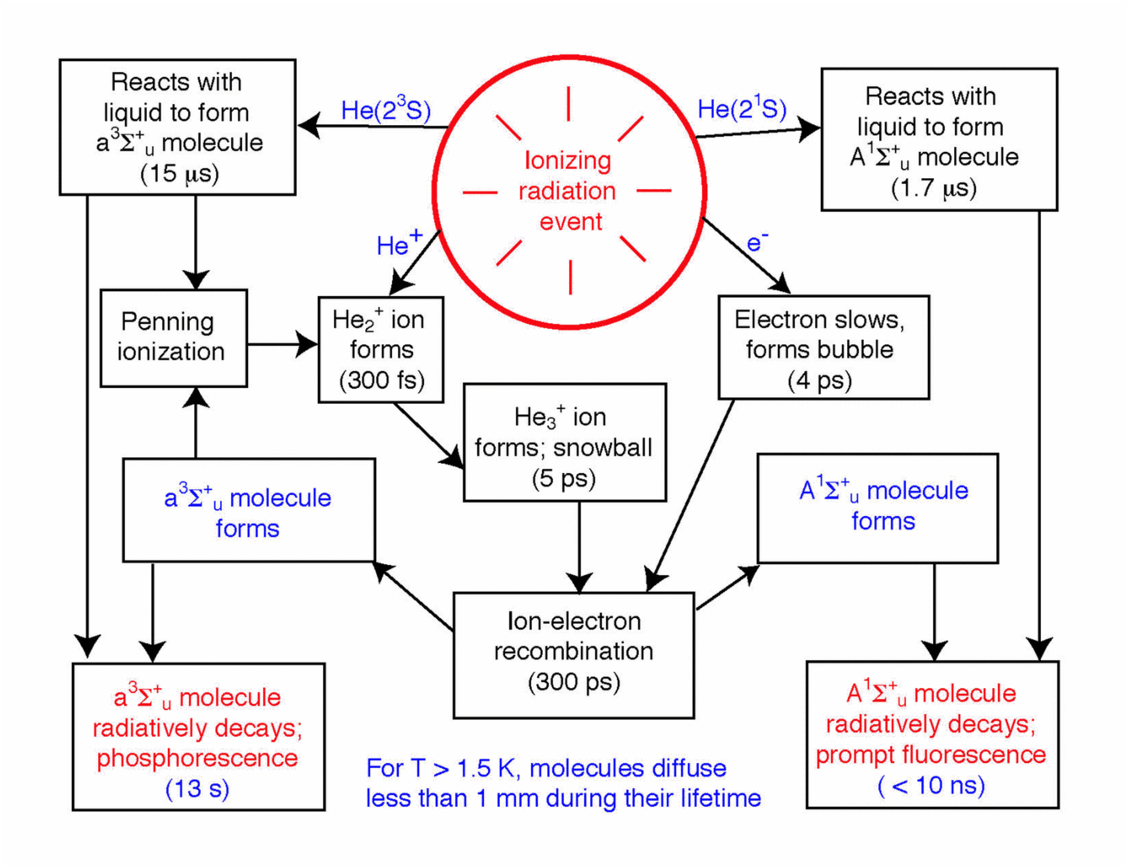
Sensitivity



Events / 10 kg / yr

Events / 100 kg / yr

Events / 1000 kg / yr



Ionizing radiation event

$He(2^3S)$

Reacts with liquid to form $a^3\Sigma^+_u$ molecule (15 μs)

$He(2^1S)$

Reacts with liquid to form $A^1\Sigma^+_u$ molecule (1.7 μs)

He^+

e^-

Penning ionization

He_2^+ ion forms (300 fs)

He_3^+ ion forms; snowball (5 ps)

Electron slows, forms bubble (4 ps)

$a^3\Sigma^+_u$ molecule forms

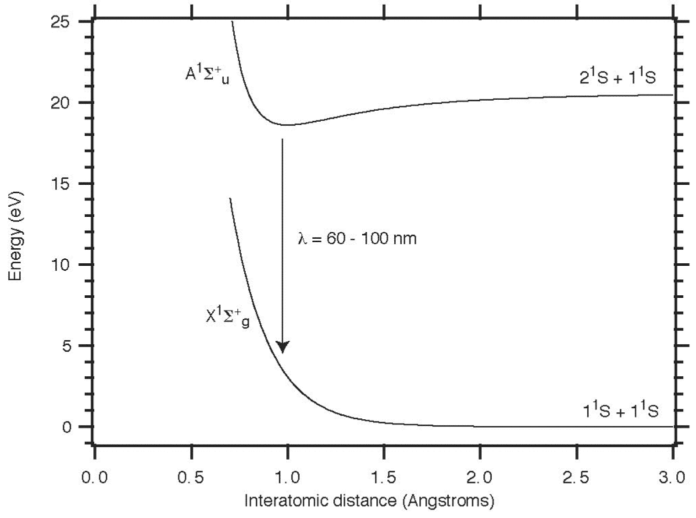
$A^1\Sigma^+_u$ molecule forms

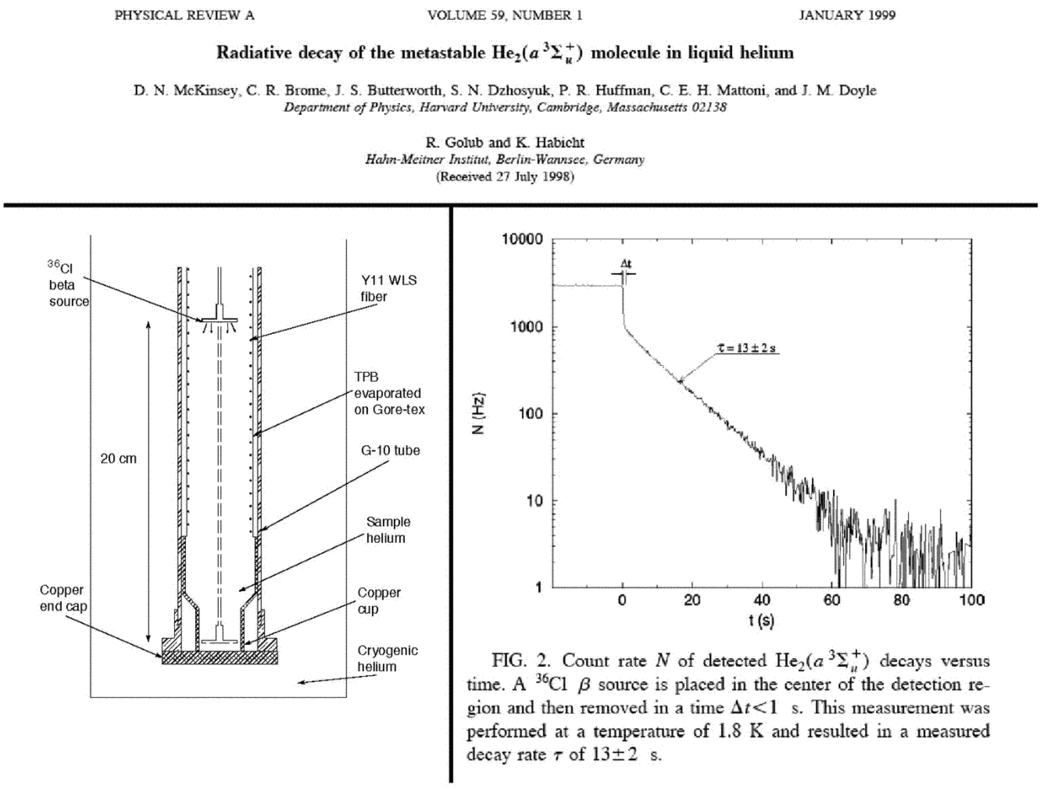
Ion-electron recombination (300 ps)

$a^3\Sigma^+_u$ molecule radiatively decays; phosphorescence (13 s)

$A^1\Sigma^+_u$ molecule radiatively decays; prompt fluorescence (< 10 ns)

For T > 1.5 K, molecules diffuse less than 1 mm during their lifetime





PHYSICAL REVIEW A VOLUME 59, NUMBER 1 JANUARY 1999

Radiative decay of the metastable $He_2(a\,^3\Sigma_u^+)$ molecule in liquid helium

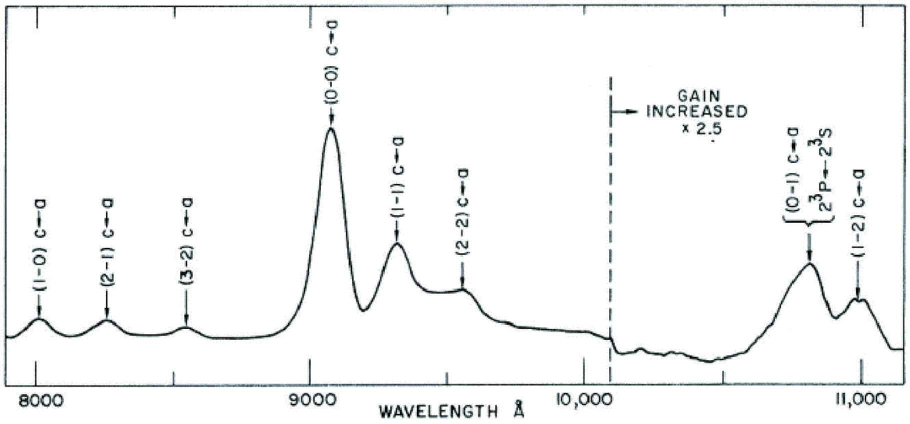
D. N. McKinsey, C. R. Brome, J. S. Butterworth, S. N. Dzhosyuk, P. R. Huffman, C. E. H. Mattoni, and J. M. Doyle
Department of Physics, Harvard University, Cambridge, Massachusetts 02138

R. Golub and K. Habicht
Hahn-Meitner Institut, Berlin-Wannsee, Germany
(Received 27 July 1998)

FIG. 2. Count rate N of detected $He_2(a\,^3\Sigma_u^+)$ decays versus time. A ^{36}Cl β source is placed in the center of the detection region and then removed in a time $\Delta t<1$ s. This measurement was performed at a temperature of 1.8 K and resulted in a measured decay rate τ of 13 ± 2 s.

In the 60's and 70's, spectroscopic studies were done on electron-excited LHe.
(Groups of Reif, Walters, Fitzsimmons, and more recently Parshin)
Lines were visible from a long-lived "neutral excitation", identified as triplet He_2

Absorption spectrum of electron-excited liquid helium:



J. C. Hill et al, Phys. Rev. Lett. 26, 1213 (1971).

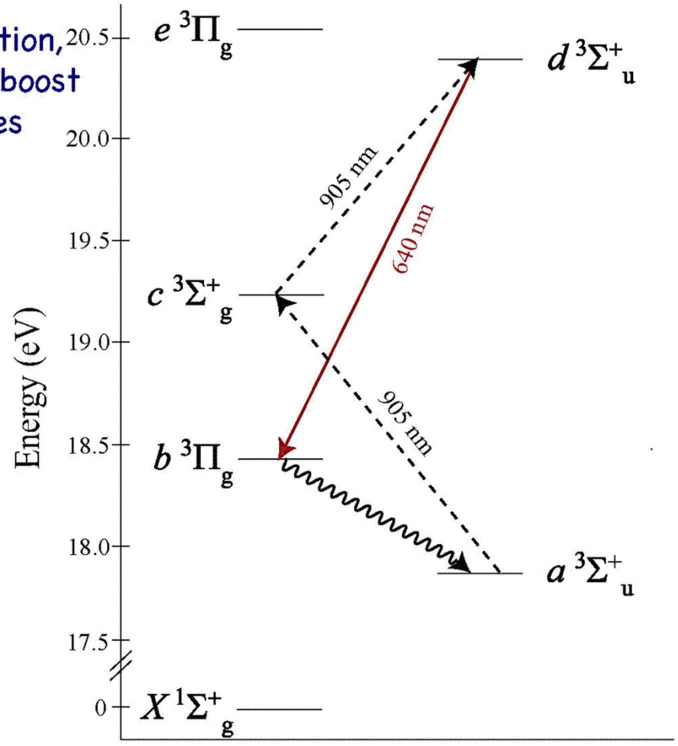
Strong absorption at 910 nm: c-a transition, 0-0 vibrational
Other vibrational transitions visible.
The triplet He_2 molecule exists as a bubble in liquid helium, with radius 0.7 nm.
Density is limited by Penning ionization, with rate constant 2E-10 to 4E-10 cm^3/s

Idea: Use 2-photon excitation, fluorescence detection to boost sensitivity to He_2 molecules (D. N. McKinsey et al, PRL 95, 111101 (2005))

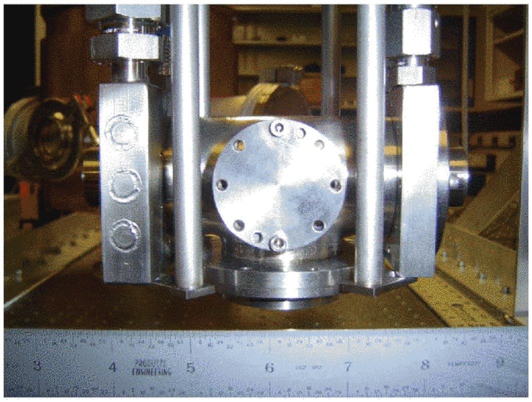
Uses:

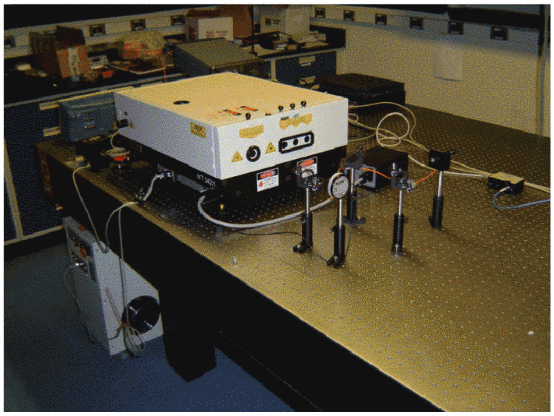
- WIMP detection
- ultracold neutrons
- gamma ray imaging
- Turbulence visualization

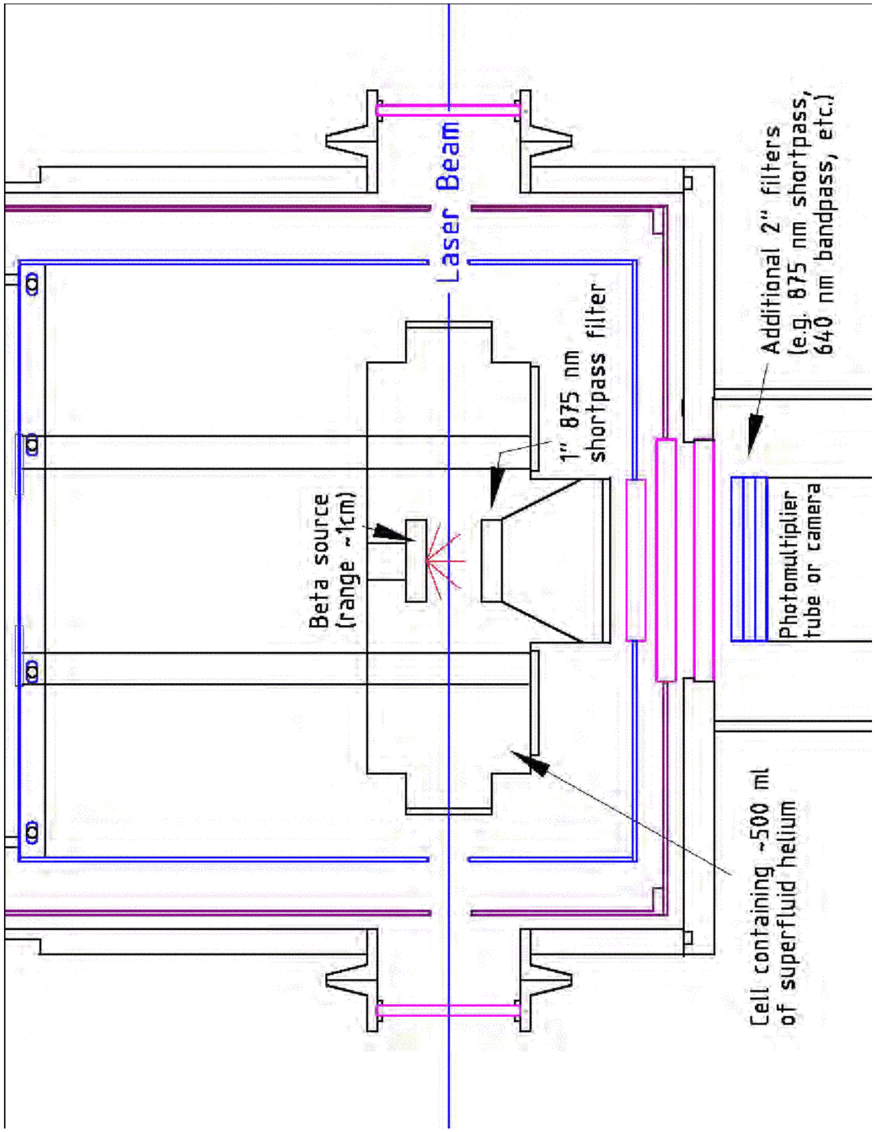
Recent support:
Packard foundation, DTRA

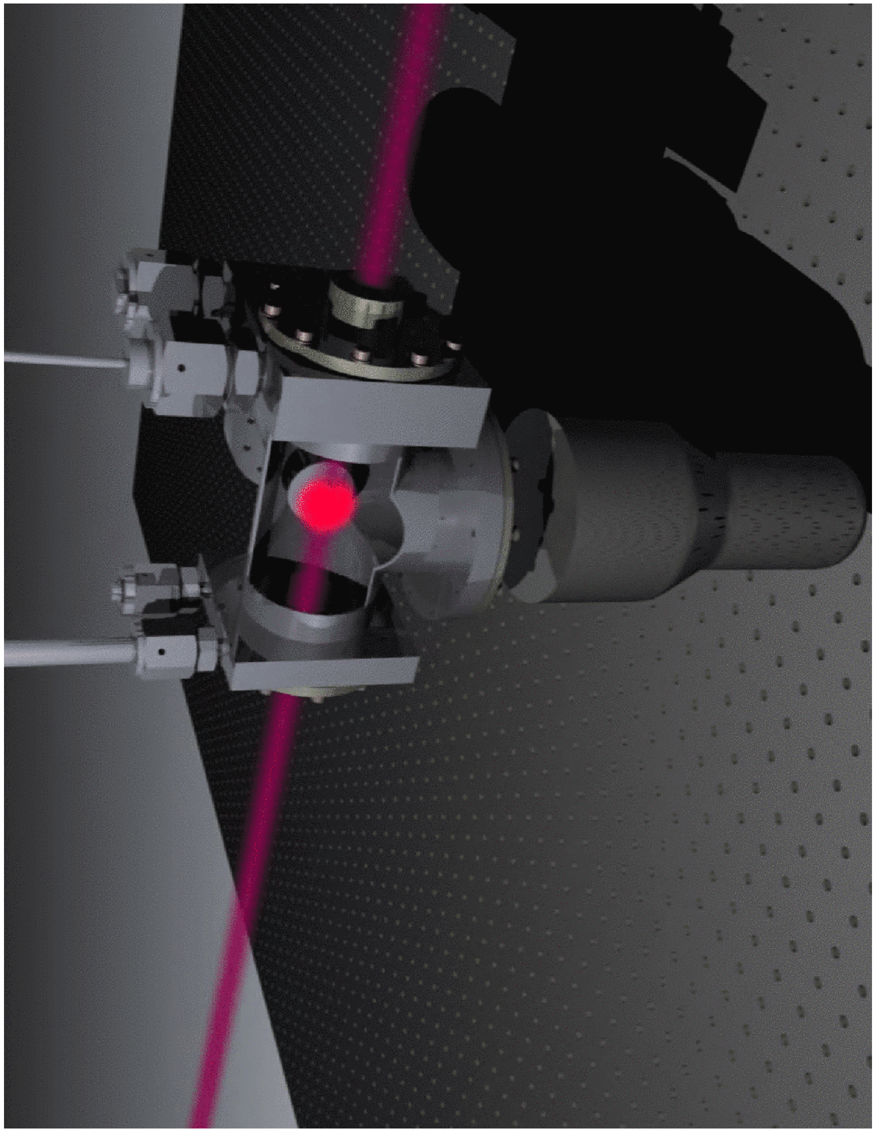


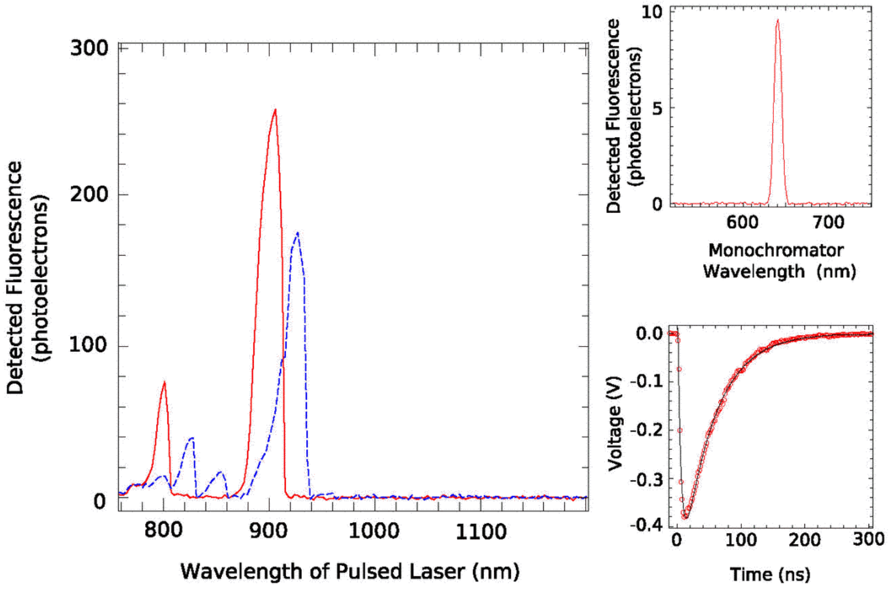
Pumped He-4 system at Yale, with optical access



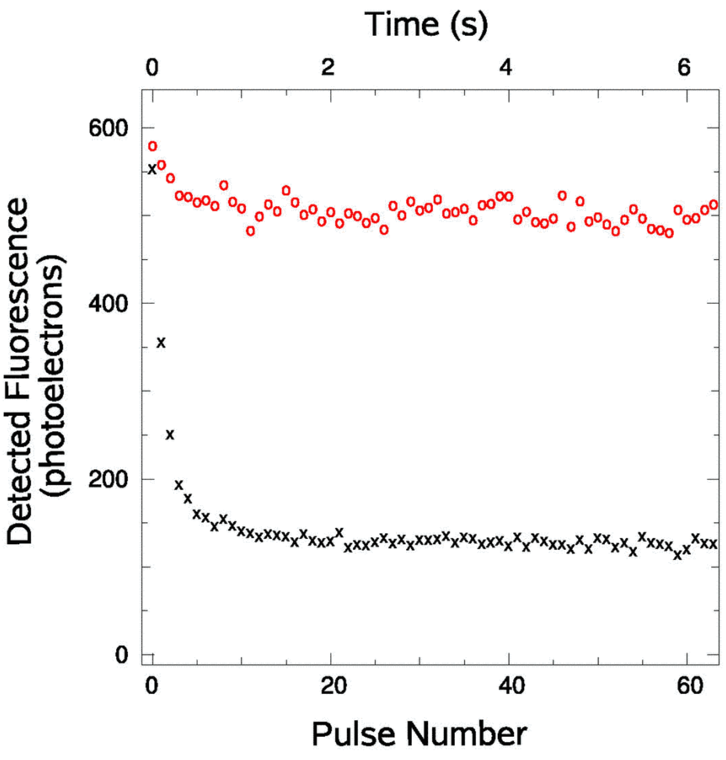



Laser Beam
Additional 2" filters
(e.g. 875 nm shortpass,
640 nm bandpass, etc.)
1" 875 nm
shortpass filter
Beta source
(range ~1cm)
Photomultiplier
tube or camera
Cell containing ~500 ml
of superfluid helium

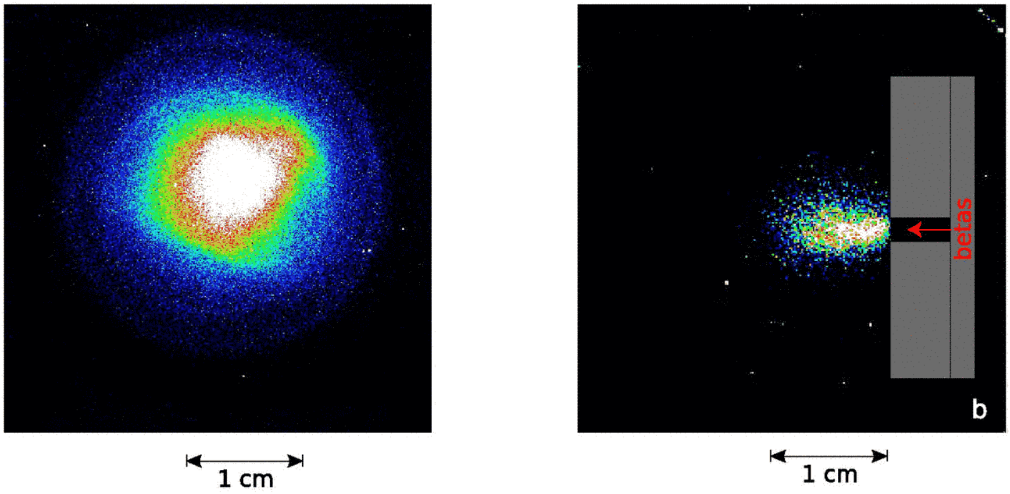




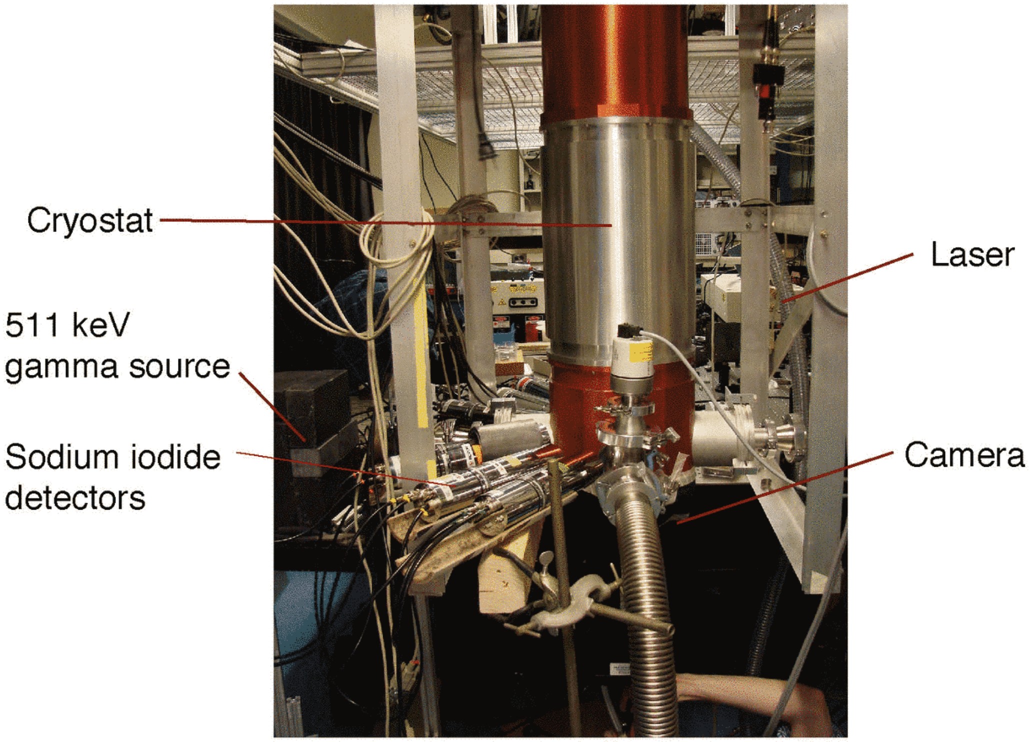
W. G. Rellergert *et al*, Phys. Rev. Lett. **100**, 025301 (2008).

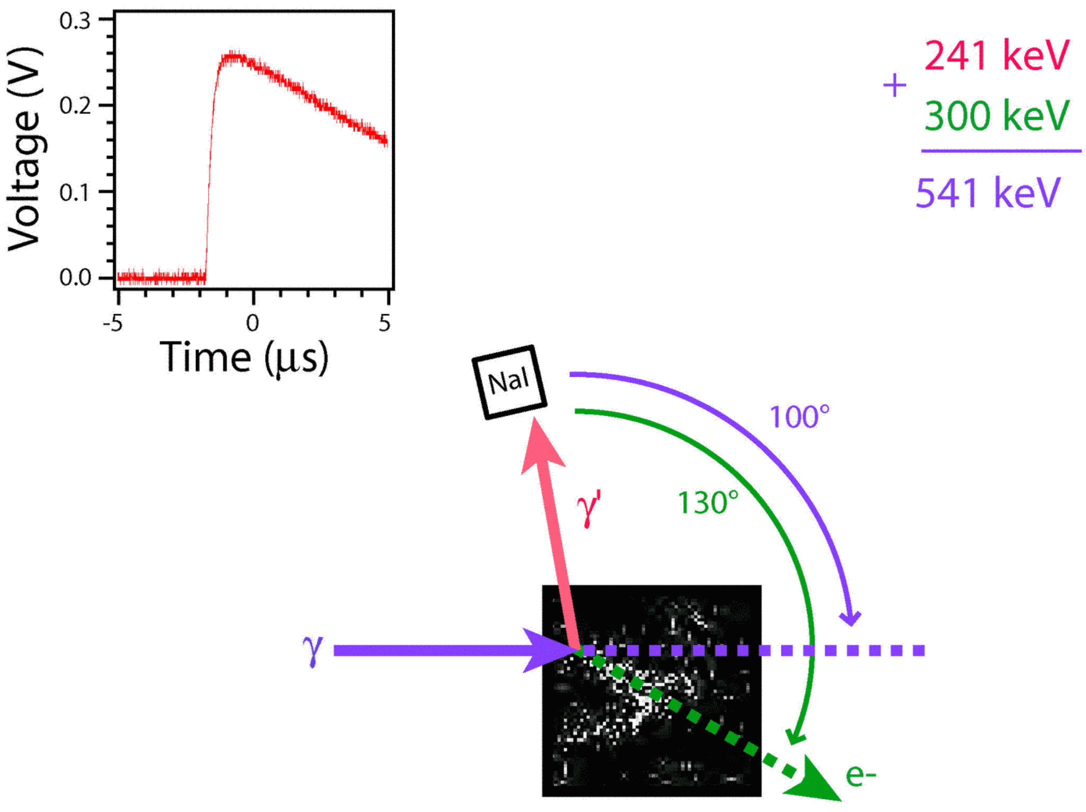


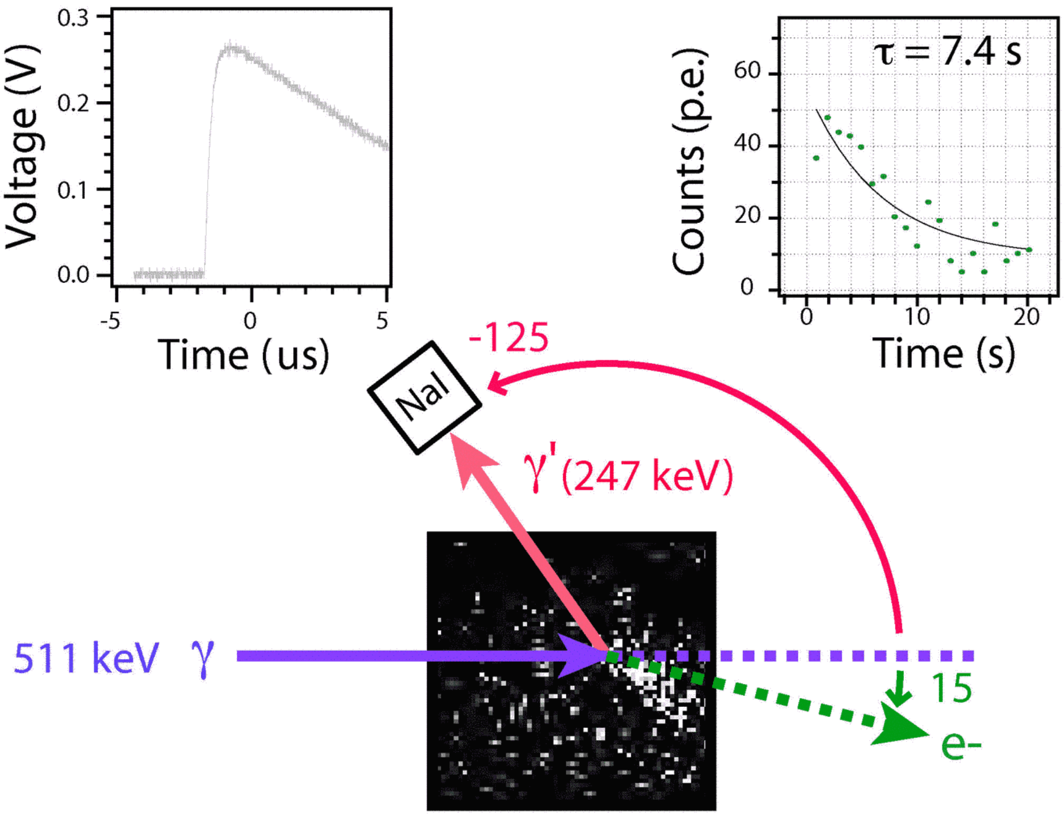
Images of Helium Molecules

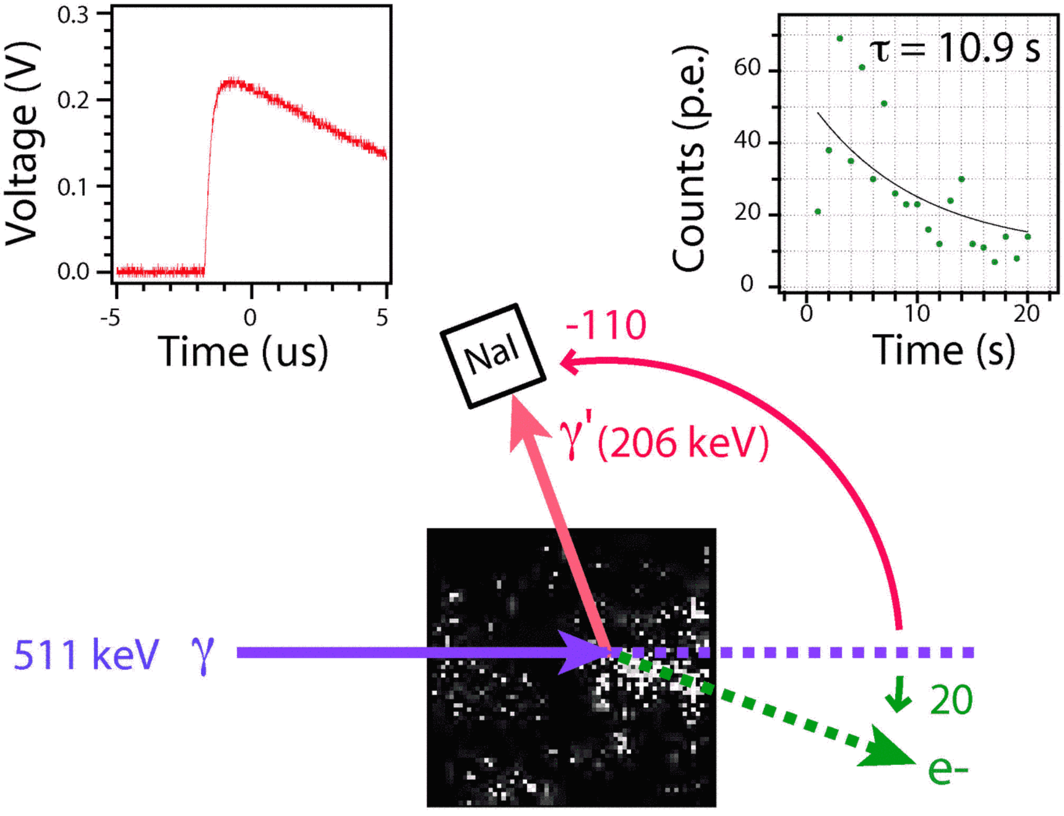


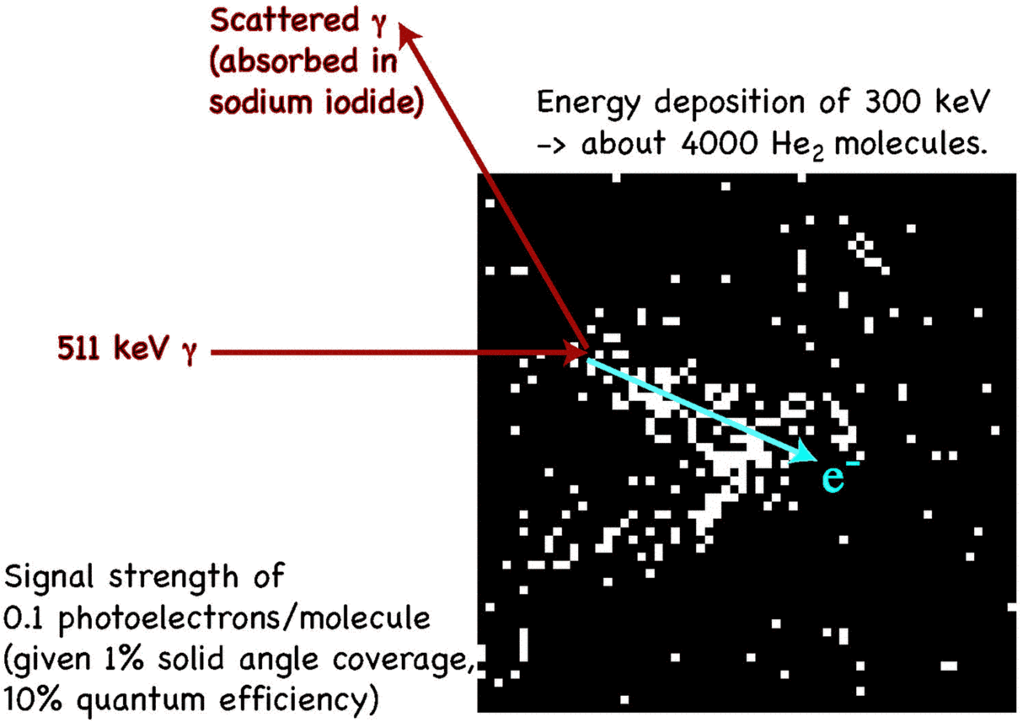
Scattering gamma rays in liquid helium




Voltage (V)
0.3
0.2
0.1
0.0
-5
0
5
Time (μs)
241 keV
+
300 keV
541 keV
NaI
100°
130°
γ'
γ
e-


Voltage (V)
0.3
0.2
0.1
0.0
-5
0
5
Time (us)
Counts (p.e.)
60
40
20
0
0
10
20
Time (s)
τ = 7.4 s
-125
NaI
γ'(247 keV)
511 keV γ
15
e-





Energy deposition of 300 keV
-> about 4000 He_2 molecules.

Signal strength of
0.1 photoelectrons/molecule
(given 1% solid angle coverage,
10% quantum efficiency)

Liquid helium as a dark matter detection material?

Idea: Use a superfluid helium time projection chamber (T ~ 2 K).

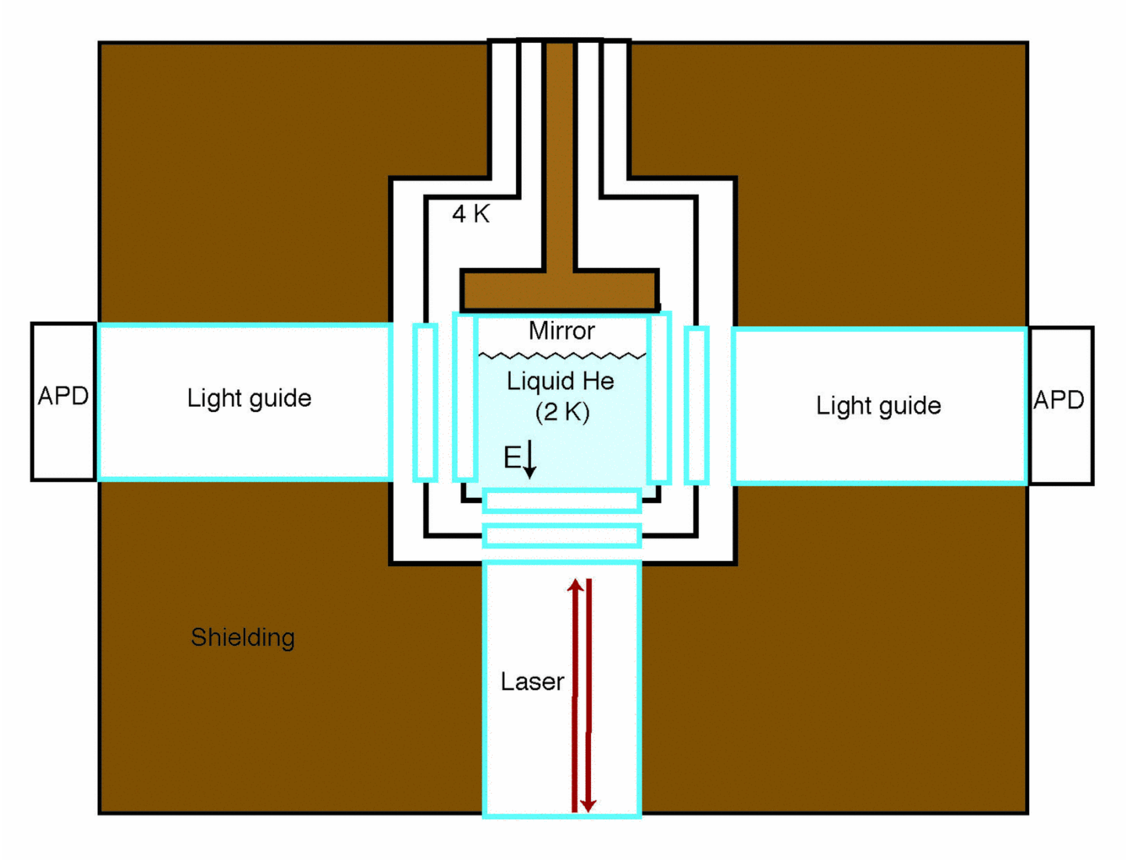
Signals:

Proportional scintillation from drifted ionization
Laser-induced fluorescence from triplet molecule states

Both of these signals can be amplified within the detector, allowing low energy threshold and discrimination power.

Ratio of charge to light should give discrimination against electron recoils.

Goals: Energy threshold of ~ 1 keVr, background of 10^-3 events/keV/kg/day



Laser-induced fluorescence signal strength and background discrimination

From our Compton imaging experiments, we see about 1300 photons/keVee in our intensified CCD camera, given 10% quantum efficiency and 1.5% solid angle.

With avalanche photodiodes (quantum efficiency of 80% at 640 nm) and 25% coverage, this gives a signal strength of 260 photoelectrons/keV, about 50 times higher than in XENON10.

Through individual electron detection (as in XENON10) and large signals from laser-induced fluorescence, one might reasonably expect a 1 keVr threshold and 99 to 99.9% reduction of gamma ray backgrounds through measurement of the charge/light ratio.

Pileup: With a gamma background rate of 10^-3 events/kg/s (not too hard) and a mass of 10 kg, the average time between events is 100 seconds, significantly longer than the triplet molecule lifetime of 13 seconds or the electron drift time of about 1 second.