LUX: A Large Underground Xenon detector

WIMP Search

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INPAC Meeting
Berkeley, May 5, 2007
New Collaboration

Groups formerly in XENON10: 
Case Western, Brown, Livermore Natl. Lab 
(major fraction of the US contingent in XENON10)

Groups from ZEPLIN II: 
UCLA, Texas A&M, Rochester 
(entire US contingent in ZEPLIN-II)

New Entrants: 
UCDavis, LBNL 
(background in neutrinos/nuclear/HEP)

INPAC is a large fraction of this effort.
Direct Detection Techniques

Ge, CS$_2$, C$_3$F$_8$

DRIFT
IGEX
COUPP

Xe, Ar, Ne

Ionization

Scintillation

Heat - Phonons

NaI, Xe, Ar, Ne

ZEPLIN II, III
XENON
LUX
WARP
ArDM
SIGN

NAIAD
ZEPLIN I
DAMA
XMASS
DEAP
Mini-CLEAN

CRESST II
ROSEBUD
CaWO$_4$, BGO
ZnWO$_4$, Al$_2$O$_3$ ...

CDMS
EDELWEISS

Xe, Ar, Ne

Ge, Si

Al$_2$O$_3$, LiF

Fig. courtesy H. Sobel

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Noble Liquids as Target

WIMP flux on earth:
\[ \nu \sim \frac{c}{1000}, \]
\[ m_c \sim 100 \text{ m}_{\text{proton}} \]
\[ \text{flux} \sim 10^5 \text{/(cm}^2 \text{ s)} \]

Scatter on nuclei:
For Xe, useful range is
5 KeV < Recoil Energy < 50 KeV

Scatter coherently from whole nucleus:
\[ \sigma = \sigma_{\text{proton}} \mu^2 A^2 \]
(\(\mu = \text{reduced mass}\))
Liquid Xenon has come out with results in 2007

\[ \sigma < 6.6 \times 10^{-43} \text{ cm}^2 \]
@ m = 65 GeV

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Dramatic Improvement in DM Sensitivity

XENON10
April 2007

10 kg fiducial dual phase xenon detector with only 60 days data

DATA listed top to bottom on plot
- Edelweiss, 32 kg-days Ge 2000+2002+2003 limit
- WARP 2.3L, 96.5 kg-days 55 keV threshold
- ZEPLIN II (Jan 2007) result
- CDMS (Soudan) 2004 + 2005 Ge (7 keV threshold)
- XENON10 2007 (Net 136 kg-d)
- XENON10 2007 (Net 136 kg-d, BG Subtract)
- Ruiz de Austri/Trotta/Roszkowski 2006, CMSSM Markov Chain Monte Carlos: 9
- Ellis et. al Theory region post-LEP benchmark points
- Baltz and Gondolo, 2004, Markov Chain Monte Carlos

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Two Signal Technique

PMT Array
(not all tubes shown)

Time

Secondary
~1 μs width
0–150 μs depending on depth

Primary
~40 ns width

Light Signal
UV ~175 nm photons

Anode
Liq. Surface
Grid

E_{AG} > E_{GC}

Electron Drift
~2 mm/μs

Cathode

Interaction (WIMP or Electron)

~40 ns width

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Xenon Facts

Ionization in liquid:
- About one electron-ion pair /15 eV of deposited energy

175 nm Scintillation:
- About one photon/20 eV of deposited energy

- Ionization/Scintillation ratio changes with interaction type

Ion pairs more likely to recombine in the dense tracks generated by nuclear interactions

- A strong anti-correlation between ionization and scintillation

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Ionization/Scintillation Response

**Nuclear recoil:**
Electrons recombine in the liquid due to higher ionization density
- fewer primary electrons

Also overall **quenching** of scintillation relative to electron recoil

**Gamma recoil:**
Less recombination in the liquid due to lower ionization density
more primary electrons

\[(S_2/S_1)_{\text{wimp}} \ll (S_2/S_1)_{\text{gamma}}\]
Realization of Two Signal Technique

Example from XENON10:

Plot $\log (S2/S1)$ versus total recoil energy.

Neutron recoils: WIMPs would appear here

Electromagnetic recoils
~ 6m diameter Water Cerenkov shield (low cost)

Tall dual phase detector

Aspect ratio = 1.5

100 kg

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LUX Parameters

• 300 kg Dual Phase liquid Xe TPC with 100 kg fiducial
  – >99% ER background rejection for 50% NR acceptance, E>10 keVr
  3D-imaging TPC eliminates surface activity, defines fiducial

• Backgrounds:
  – Internal: strong self-shielding of PMT activity
    • $\gamma/\beta < 7 \times 10^{-4}$ /keVee/kg/day, from PMTs (Hamamatsu R8778 or R8520).
    • Neutrons ($\alpha,n$) & fission subdominant
  – External: large water shield with muon veto.
    • Very effective for cavern $\gamma+n$, and HE n from muons
    • Very low gamma backgrounds with readily achievable <10^{-11} g/g purity.

• DM reach: $2 \times 10^{-45}$ cm$^2$ in 4 months
  – Possible $\sim 5 \times 10^{-46}$ cm$^2$ reach with recent PMT activity reductions, longer running.
Active Water Shield and Veto

Veto on incoming muons via Cherenkov light signal.

Tag thermalized neutrons generated within the detector

- Gd (0.2%) in water gives a capture efficiency of > 90% for thermal neutrons, followed by an 8 MeV gamma cascade

Studies for SuperK have shown compatibility with standard detector materials (Bob Svoboda et al)

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Lux dark matter goal

Lux - Sensitivity curve at $2 \times 10^{-45}$ cm$^2$ (100 GeV)

- Exposure: Gross Xe Mass 300 kg
  Limit set with 120 days running x 100 kg fiducial mass x 50% NR acceptance

~1 background event during exposure assuming most conservative assumptions of
ER $7 \times 10^{-4}$ /keVee/kg/day and 99% ER rejection

- ER bg assumed is dominated by guaranteed Hamamatsu PMT background. Improvements in PMT bg (and rejection power) will extend background free running period, and DM sensitivity

Comparison -- SuperCDMS Goal @ SNOLab: Gross Ge Mass 25 kg
(x 50% fid mass+cut acceptance)
Limit set for 1000 days running x 7 SuperTowers

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Status

Proposal Under review by NSF/DoE.

Meanwhile, **LUXCore**

The collaboration is fully active – Technical VideoCons every Week … Construction activity in full swing at all institutions using Univ resources, startup seed funds etc.

Construction finished late Summer 07 -- operations at Case: Fall 2007.
LUX program: exploit scalability

• LUXcore: Final engineering for large-scale detector
  – Cryostat, >100 kV feedthrough, charge drift, light collection over large distance
  – Full system integration, including ~1m water shield
  – 40 kg narrow “core”, 14 PMTs, 20 cm Ø x 40 cm tall.
• Radial scale-up requires full-funding.

Very good match to early-implementation DUSEL SNOLAB LOI
System scalable to very large mass.

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Cryostat Being Installed At Case.