Direct WIMP Detection by Noble Liquids: XENON100 and Beyond

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Talk Outline

- **Introduction**
  - Why Noble Liquid?
  - Single Phase vs. Double Phase
  - Xenon – XMASS, LUX, XENON100
  - Argon – DEAP/CLEAN, WARP, DarkSide50

- **G1 : XENON100**
  - New Results

- **Future Directions**
  - G2 : XENON 1 Ton
  - G3 : LZD and MAX (Xenon 10 Ton + Argon 50 Ton)

- **XAX and Neutrino Physics**
  - Solar neutrino
  - Double beta decay
  - Supernova neutrino

6/1/2011

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Introduction
Growth of Direct Detection Community

Dark Matter Direct Detection (Personnel >= Grads)

- Non-US
- US

Scientists (>=Grads)

Year

1997 1999 2001 2003 2005 2007 2009 2011
What is Dark Matter?
Detection Technique

Double Phase
(Zeplin II, III, XENON, WARp, ArDM, LUX, LZ, DarkSide, Max, Panda-X)

Single Phase
(NAIAD, Zeplin I, DAMA/LIBRA, XMASS, DEAP, MiniCLEan, CLEAN)

DRIFT
DMTPC
IGEX

(Ge, CS₂, C₃F₈)

Ionization

~20% of Energy

Heat - Phonons

>100% of Energy

Scintillation

Zeplin II, III, XENON, WARp, ArDM, LUX, LZ, DarkSide, Max, Panda-X

Gamma Ray

CDMS
EDELWEISS
GEODM

Neutron

WIMP

CRESST I, Picasso, COUPP

(CaWO₄, BGO, ZnWO₄, Al₂O₃ ...)

(AI₂O₃, LiF, CF₃I ...)

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# Noble Gases

## Periodic Table of the Elements

- **hydrogen**
- **alkali metals**
- **alkali earth metals**
- **transition metals**
- **poor metals**
- **nonmetals**
- **noble gases**
- **rare earth metals**

---

**Table:**

<table>
<thead>
<tr>
<th>H</th>
<th>He</th>
<th>Ne</th>
<th>Ar</th>
<th>Kr</th>
<th>Xe</th>
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<td>U</td>
<td>Np</td>
<td>Pu</td>
<td>Am</td>
<td>Cm</td>
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## Properties of Noble Liquid

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<tr>
<th></th>
<th>Unit</th>
<th>Neon</th>
<th>Argon</th>
<th>Xenon</th>
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<tr>
<td><strong>Z</strong></td>
<td></td>
<td>10</td>
<td>18</td>
<td>54</td>
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<tr>
<td><strong>A</strong></td>
<td></td>
<td>20</td>
<td>40</td>
<td>~132</td>
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<tr>
<td><strong>Liquid Density</strong></td>
<td>g/cc</td>
<td>1.21</td>
<td>1.4</td>
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<td><strong>Energy Loss (dE/dX)</strong></td>
<td>MeV/cm</td>
<td>1.4</td>
<td>2.1</td>
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<td><strong>Radiation Length</strong></td>
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<td>24</td>
<td>14</td>
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<td><strong>Collision Length</strong></td>
<td>cm</td>
<td>80</td>
<td>80</td>
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<td><strong>Boiling Temperature</strong></td>
<td>°K</td>
<td>27.1</td>
<td>87.3</td>
<td>165</td>
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<td><strong>Scintillation Wavelength</strong></td>
<td>nm</td>
<td>85</td>
<td>125</td>
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<td><strong>Scintillation photon/keV</strong></td>
<td></td>
<td>30</td>
<td>40</td>
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<td><strong>Ionization e-/keV</strong></td>
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<td>46</td>
<td>42</td>
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<td><strong>Decay time (Fast Component)</strong></td>
<td>nsec</td>
<td>19</td>
<td>7</td>
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<tr>
<td><strong>Decay time (Slow Component)</strong></td>
<td>nsec</td>
<td>1500</td>
<td>1600</td>
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<tr>
<td><strong>Isotope</strong></td>
<td></td>
<td></td>
<td>⁴⁰Ar (1 Bq/kg)</td>
<td>¹³⁶Xe</td>
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<tr>
<td><strong>Price $/ton</strong></td>
<td></td>
<td></td>
<td>$90k</td>
<td>~$2k</td>
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</table>

### Single Phase Experiments
- CLEAN
- DEAP/CLEAN
- XMASS

### Double Phase Experiments
- WARP, ArDM, DarkSide, MAX
- ZEPLIN, XENON, MAX LUX, LZD

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Target Mass Dependence of WIMP Cross Section

Cross section $10^{-44}$ cm$^2$, WIMP mass 100 GeV

- Xe-132
- Ge-73
- Ar-40
- Si-28
- Ne-20

$dru / $kg/day/keV vs. $E_r$ (keV)

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XMASS (Single Phase Xe)

100kg Prototype (FV:30kg, 30cm)

800kg Detector (FV:100kg, 80cm)

20ton Detector (FV:10ton, 2.5m)

R&D completed

Dark Matter 2011 ~

Solar neutrino Dark Matter Future

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DEAP/CLEAN (Single Phase Ar/Ne)

360 kg Mini-CLEAN

3.6 ton DEAP/CLEAN

Central volume: 165 cm diameter
2,600 litres

217 20 cm PMTs

Sealed acrylic inner vessel

30 cm acrylic light guides
Double-Phase Noble Liquids

Sensitive volume

WIMP

Phototubes

Anode

Grid

Cathode

S1

Electron drift

S2

$E_{\text{gas}}$

$E_{\text{drift}}$

Drift Time

Nuclear Recoil (WIMP)

Electronic Recoil ($\gamma$, $\beta$)

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XENON100 (Double phase Xenon)

161 kg (48 kg)
LUX 350 kg (Double phase Xenon)

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60 cm

350 kg

(100 kg)
WARP 140 kg (Double Phase Argon)
Pulse Shaping Discrimination by Ar
(First WARP Results)

(a) Neutron induced ion recoils

(b) WIMP Exposure of 96.5 kg • day

Gamma
Neutron

Gamma from $^{39}$Ar
DarkSide 50 kg (Double phase Argon)

CTF Water Tank

Liquid Scintillator

Depleted Ar (50 kg)

3” QUPID
(19 top + 19 bottom)
<table>
<thead>
<tr>
<th>Experiment Name</th>
<th>Location</th>
<th>Mass</th>
<th>Photon Detector</th>
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## Single Phase vs. Double Phase

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<tr>
<td><strong>HV for electron drift</strong></td>
<td><strong>Not required</strong></td>
<td><strong>Required (~1 kV/cm)</strong></td>
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<td><strong>$O_2 / H_2O$ impurity</strong></td>
<td><strong>Not critical</strong></td>
<td><strong>Critical</strong></td>
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<tr>
<td><strong>Energy threshold</strong></td>
<td>20 PE</td>
<td>4 PE</td>
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<tr>
<td><strong>Sensitivity for low mass WIMP</strong></td>
<td>&gt; 20 GeV</td>
<td>&gt; 5 GeV</td>
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<tr>
<td><strong>Position resolution</strong></td>
<td>~ 10 cm</td>
<td>~ 2 mm</td>
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<tr>
<td><strong>Gamma rejection by S2/S1</strong></td>
<td>No</td>
<td>Yes (&gt; 99.5%)</td>
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<tr>
<td><strong>Neutron rejection by Multi-hit cut</strong></td>
<td>No</td>
<td>Yes</td>
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Xenon vs. Argon

Xenon
- 5 times more sensitive (per unit mass)
  - due to $A^2$ dependence.
- Expensive
  - ~$1M / ton
- Limited by pp-chain solar neutrino
  - ~0.2 event /ton/year
- Ideal for mass range of 10 – 100 GeV
  - Spectrum is independent from mass

Argon
- Free from gamma background
  - > $10^6$ rejection by pulse shaping
- Inexpensive
- Ideal for mass range of 20 – 200 GeV
  - Insensitive to low mass < 10 GeV
XENON100
XENON100 Detector

161 kg (48 kg)
PMT Arrays

242 Hamamatsu R8520 PMTs

1"x1", optimized for response @ Xe scintillation light (178 nm)
Low radioactivity ( ~ <1 mBq/PMT)

Top Array
98 PMTs
~23% QE

Bottom Array
80 PMTs
~33% QE

Active Veto
64 PMTs
~23% QE
XENON100 Detector
Pb (20cm)  
Poly (20cm)  
Cu (5cm)  
Poly (20cm)  
Cu (5cm)  
Pb (20cm)
Energy Spectrum of Real Data vs. MC

Surface Backgrounds

PMT, 62.6 %
Steel, 15.6 %
Bases, 12.2 %
Teflon, 7.9 %

arXiv:1101.3866

MC Total

data (Fall 2009, no veto cut)
MC (total)
MC (\(^{85}\text{Kr}, 120\text{ ppt}\))
MC (\(^{222}\text{Rn}, 21\text{ Bq/mkg}\))
MC (\(^{136}\text{Xe}\ 2\nu\beta\beta\))

\(^{214}\text{Pb}\), \(^{208}\text{Tl}\), \(^{137}\text{Cs}\), \(^{54}\text{Mn}\), \(^{228}\text{Ac}\), \(^{60}\text{Co}\), \(^{60}\text{Co}\), \(^{40}\text{K}\)

\(^{85}\text{Kr}\), \(^{222}\text{Rn}\)

\(^{136}\text{Xe}\) Double Beta Decay

Rate [events kg\(^{-1}\) day\(^{-1}\) keV\(^{-1}\)]

Energy [keV]

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Level of Backgrounds (before S2/S1 cut)

![Graph showing the level of backgrounds for different experiments like CRESST, CoGeNT, CDMS, XENON10, DAMA, and XENON100 before and after fiducial cut. The graph plots rate [events/keV/kg/day] against energy [keV], with different experiments marked by color and symbols.]
**New $L_{\text{eff}}$ vs. Energy**

**$L_{\text{eff}}$: Relative scintillation efficiency for nuclear recoils to 122 keV gamma rays**
(at zero electric field)

[Graph showing the relative scintillation efficiency for nuclear recoils to 122 keV gamma rays across different energy levels, with data points from various studies labeled.]
Log(S2/S1) vs. Energy

100.9 days, 48 kg

3 events
(1.8 ± 0.6 expected)

99.75% rejection for γ

Neutron band
(Acceptance 30 – 40%)

8.4 keV_{nr}

-3 σ

44.6 keV_{nr}

S2 = 300 PE

S1 = 4 PE

S1 = 30 PE

arXiv:1104.2549
Event distribution in \( z \) vs. \( R^2 \)

100.9 days, 8.4 – 44.6 keV_{nr}

Radius [cm]

\[
\begin{array}{cccc}
2 & 4 & 6 & 8 \\
10 & 12 & 14 & 15.3
\end{array}
\]

Radius^2 [cm^2]

\[
\begin{array}{cccc}
0 & 50 & 100 & 150 \\
150 & 200 & 250
\end{array}
\]

\[
\begin{array}{cccc}
-30 & -25 & -20 & -15 \\
-10 & -5 & 0
\end{array}
\]

\[
\begin{array}{cccc}
0 & 4 & 6 & 8 \\
10 & 12 & 14 & 15.3
\end{array}
\]

3 events

(1.8 ± 0.6 expected)
Single Scatter Nuclear Recoil Event Candidate

11 keV<sub>nr</sub>
90% CL Limits of SI Cross Section (April, 2011)

WIMP-Nucleon Cross Section [cm²]

WIMP Mass [GeV/c²]

DAMA/Na
CoGeNT
CDMS
EDELWEISS
XENON100 (2010)
XENON100 (2011)
CMSSM
Buchmueller et al.

arXiv:1104.2549
Inelastic Dark Matter

\[ \delta = 120 \text{ keV} \]
Summary of XENON100

Purity of Xenon has achieved the design goal.

- **Light Yield:** 2.2 > 2 pe/keVee
- **Electron Drift Time:** 400 > 300 µs
- **Krypton 85:** 80 < 100 ppt
- **Radon:** 1.1 < 2 Bq/m³

100 days of data published.

- 3 event observed (1.8 +- 0.6 events expected)
  - Contaminated by $^{85}$Kr at ~ 700 ppt $\rightarrow$ 1.1 events
- < 7 x $10^{-45}$ cm² at 50 GeV [arXiv:1104.2549]
- Low mass (7-10 GeV) WIMP unlikely.
- Inelastic DM excluded. [arXiv:1104.3121]

Data taking continues.

- $^{85}$Kr reduced to < 80 ppt
- < 2 x $10^{-45}$ cm² by the end of 2011 expected.
XENON100 data taking in 2011

March
April
May

Live Days

Dark Matter

232Th

60Co

AmBe

Date in 2011 [Day/Month]

17/02 02/03 16/03 30/03 13/04 27/04 11/05 25/05
Future Directions
DUSEL started in 2007 (~$1B project by NSF)

DUSEL Deep Underground Science and Engineering Laboratory at Homestake, SD
XAX: A multi-ton, multi-target detection system for dark matter, double beta decay and pp solar neutrinos


Department of Physics and Astronomy, University of California, Los Angeles, CA 90024, USA

Abstract

A multi-target detection system XAX, comprising concentric 10 ton targets of $^{136}$Xe and $^{129/131}$Xe, together with a geometrically similar or larger target of liquid Ar, is described. Each is configured as a two-phase scintillation/ionization TPC detector, enhanced by a full 4π array of ultra-low radioactivity quartz photon intensifying detectors (QUPIDs) replacing the conventional photomultipliers for detection of scintillation light. It is shown that background levels in XAX can be reduced to the level required for dark matter particle (WIMP) mass measurement at a $10^{-30}$ pb WIMP-nucleon cross-section, with single-event sensitivity below $10^{-11}$ pb. The use of multiple target elements allows for confirmation of the $A^2$ dependence of a coherent cross-section, and the different Xe isotopes provide information on the spin-dependence of the dark matter interaction. The event rates observed by Xe and Ar would modulate annually with opposite phases from each other for WIMP mass $\sim 100$ GeV/c$^2$. The large target mass of $^{136}$Xe and high degree of background reduction allow neutrinoless double beta decay to be observed with lifetimes of $10^{27}$–$10^{28}$ years, corresponding to the Majorana neutrino mass range 0.01–0.1 eV, the most likely range from observed neutrino mass differences. The use of a $^{136}$Xe-depleted $^{129/131}$Xe target will also allow measurement of the pp solar neutrino spectrum to a precision of 1–2%.

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XAX (Xenon-Argon-Xenon)

- **WIMP (Spin even)**
  - Double Beta Decay
  - Solar Neutrino

- **WIMP (Spin odd)**

- **Water Tank Veto**
  - 12 m

- **Xe**
  - $^{129/131}$Xe
  - 12 ton (6 ton)
  - $^{136}$Xe
  - 7 ton (4 ton)

- **Ar**
  - $^{40}$Ar
  - 70 ton (50 ton)

- **Dimensions**
  - 14 m
  - 12 m
  - 1.2 m
  - 2 m
  - 4 m

6/1/2011

Katsushi Arisaka, UCLA
Report of the HEPAP Particle Astrophysics Scientific Assessment Group (PASAG)

20 October 2009
## G2 and G3 facilities defined by PASAG (2009)

<table>
<thead>
<tr>
<th></th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensitivity</strong></td>
<td>$&lt; 10^{-44} \text{ cm}^2$</td>
<td>$&lt; 10^{-46} \text{ cm}^2$</td>
<td>$&lt; 10^{-47} \text{ cm}^2$</td>
</tr>
<tr>
<td><strong>Target Mass</strong></td>
<td>10 – 100 kg</td>
<td>~ 1 Ton</td>
<td>~ 10 Ton</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>$1M – 5M$</td>
<td>$10 – 20M$</td>
<td>~ $100M$</td>
</tr>
</tbody>
</table>
Supports on G2 and G3 Detectors

A sequence of U.S. projects, with 2-3 second-generation detectors covering the major technologies (CDMS and cryogenic liquids) and 2 third-generation detectors is optimal. More details for each of the budget scenarios are given below. Experiments should move forward as soon as they demonstrate essential technical requirements. Plausible starting years for construction of second-generation and third-generation detectors are 2013 and 2017, respectively. An essential feature of this program is a sequence of detectors with increasing mass, operating with multiple background rejection tools, and crosschecks. A final configuration of two large G3 detectors with independent targets would assure a clear interpretation of a signal.

The second-generation detectors should have sensitivity for detecting WIMPS with spin-independent cross-sections of $10^{-46}$ cm$^2$ or lower, while the third-generation should surpass $10^{-47}$ cm$^2$ (see Figure 3-1).
Comparison of Xenon Detector Size

G1
- ZEPLIN-II: 31 kg (7.2 kg)
  - 14 cm
  - 30 cm
  - 2007

- XENON10: 14 kg (5.4 kg)
  - 15 cm
  - 20 cm
  - 2007

- XENON100: 161 kg (48 kg)
  - 30 cm
  - 30 cm
  - 2010

G2
- XENON 1ton: 2.4 ton (1 ton)
  - 1 m
  - 1 m
  - 2014

G3
- MAX, LZD, XAX: 20 ton (10 ton)
  - 2 m
  - 2019

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Where backgrounds come from?

Photon detectors are the major source of backgrounds.
QUPID (QUartz Photon Intensifying Detector)
New 3” QUPID (Production Version)
Comparison of Low-radioactive Photon Detectors from Hamamatsu

R8520
1 inch

R8778
2 inch

QUPID
3 inch

XENON10
XENON100

LUX
(XMASS)

DarkSide50
XENON1Ton
MAX, XAX
QE of two types of QUPID

- Xenon type (178 nm)
- Argon + TPB (420 nm)

Quantum Efficiency [%]

Wavelength [nm]
1, 2 and 3 PE Distribution with 2m cable

[Graph showing 1 PE, 2 PE, and 3 PE distributions over time with voltage (mV) on the y-axis and time in ns on the x-axis.]
Expected Backgrounds in XENON 1Ton
(100 Year, Multi-hit Cut)

Gamma Background (1 year, multi-hit cut, no S2/S1 cut, 2-18 keVee)

Neutron Background (100 years, multi-hit cut, 5-45 keVr)

0.07 $\gamma$ / year
1.1 ton

0.1 n / year
1.1 ton

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MAX Detector (G3)

Xe
20 ton (10 ton)

Ar
40
70 ton (50 ton)

2 m
4 m

3” QUPID x 595 (Top)
3” QUPID x 595 (Bottom)

3” QUPID x 2644 (Top)
3” QUPID x 2644 (Bottom)
MAX (G3) Shielding Structure

**Xe**
- 20 ton
- (10 ton)

**40Ar**
- 70 ton
- (50 ton)

Water Tank

Liquid Scinti

Water Tank

- 18 m
- 8 m
MAX at DUSEL

MAX Layout in Homestake 4850ft

Xe
20 ton
(10 ton)

40Ar
70 ton
(50 ton)
US Dark Matter Programs

2010 11 12 13 14 15 16 17 18 19 20

SuperCDMS Soudan
15kg $1.5 \times 10^{-44}$

SuperCDMS SNOLab
100kg

GEODM
1.5T $3 \times 10^{-46}$ $2 \times 10^{-47}$ $93M$

Xenon100 LNGS $2 \times 10^{-45}$

Xenon1t LNGS $2 \times 10^{-47}$ $10 \times 10^{-48}$ $119M$

2.5t-total, 1.5t fid

DarkSide
50kg fid $10^{-45}$

LUX 350 $8 \times 10^{-46}$

LZS 1.6T fid $2 \times 10^{-47}$ $96M$

LZD Xe - 20t $10^{-49}$

G3 = Xe (10T) + Ar (50T)

DEAP 3600kg $2 \times 10^{-45}$ $1 \times 10^{-46}$

WARP 140 $5 \times 10^{-45}$

COUPP $4 \times 10^{-38}-10^{-39}$

COUPP 500kg $10^{-46}$

COUPP-16t $66M$

4kg $10^{-38}-10^{-39}$ $60kg$

COUPP-16t $10^{-44}$ $10^{-48}$ $66M$ COUPP $500kg$ $10^{-39}$ $60kg$

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Xe 10 ton Neutron Background (100 Years)

Before Cuts

0.81 n/year

Multi Hit Cut

0.10 n/year

Liquid Scinti. Veto

0.03 n/year

Xenon 10 ton

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Ar 50 ton Neutron Background (100 Years)

Before Cuts

Multi Hit Cut

Liquid Scinti. Veto

42 n / year

2.1 n / year

0.39 n / year
(SI) WIMP Energy Spectrum for LXe
(Cross Section = $10^{-45}$ cm$^2$)

(SI) WIMP Recoil Energy Spectrum for LXe ($\sigma = 10^{-45}$ cm$^2$)

Event rate (kg/day/keVr)

Xenon

8 keVr  45 keVr

$E_r$ (keVr)

M = 20 GeV
50 GeV
100 GeV
200 GeV
500 GeV
1000 GeV

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(SI) WIMP Energy Spectrum for LAr
(Cross Section = $10^{-45}\text{cm}^2$)

(SI) WIMP Recoil Energy Spectrum for LAr ($\sigma = 10^{-45}\text{cm}^2$)

Event rate (kg/day/keVr)

40 keVr (w/ pulse shaping) 200 keVr

M = 20 GeV
50 GeV
100 GeV
200 GeV
500 GeV
1000 GeV

Argon

E_r (keVr)

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$1-\sigma$ Error of WIMP Mass vs SI Cross Section
(10 ton*year Xe and 50 ton*year Ar)

$1-\sigma$ Error of WIMP Mass and SI Cross Section

Cross Section (cm$^2$)

- 10 ton*year Xenon
- 50 ton*year Argon
- 10 ton*year Xe + 50 ton*year Ar

Mass (GeV)$^{10^3}$

- 50 GeV
- 100 GeV
- 200 GeV
- 500 GeV

- Argon
- Xenon

G3

$10^{-45}$ cm$^2$
1-σ Error of WIMP Mass vs SI Cross Section
(10 ton*year Xe and 50 ton*year Ar)

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1-σ Error of WIMP Mass vs SI Cross Section (10 ton*year Xe and 50 ton*year Ar)

1-σ Error of WIMP Mass and SI Cross Section

- 10 ton*year Xenon
- 56 ton*year Argon
- 10 ton*year Xe + 50 ton*year Ar

Xenon (56 events)
Argon (42 events)

- 100 GeV

G3

10^-46 cm^2

Mass (GeV)^{10^3}

10^-47
10
10^2
10^-46
10^-45

Cross Section (cm^2)
$1-\sigma$ Error of WIMP Mass vs SI Cross Section
(10 ton*year Xe and 50 ton*year Ar)

Xenon
(5.6 events)

Argon
(4.2 events)

Cross Section (cm$^2$)

100 GeV

G3

$10^{-46}$

$10^{-47}$

$10^{-48}$

10

10$^2$

10$^3$

Mass (GeV$^3$)
Neutrino Physics
Energy Spectrum (Natural Xe)

Events (keV/day/kg)

100 GeV WIMP ($10^{-44}$ cm$^2$)

10$^{-3}$

10$^{-4}$

10$^{-5}$

10$^{-6}$

10$^{-7}$

10$^{-8}$

10$^{-9}$

Energy (keV)

500

1000

1500

2000

2500

3000

2ν DBD ($10^{22}$ yrs)

pp Solar

Be7 Solar

0ν DBD ($10^{27}$ yrs)

B8 Solar

100 GeV WIMP ($10^{-44}$ cm$^2$)

1TeV WIMP ($10^{-44}$ cm$^2$)

10TeV WIMP ($10^{-44}$ cm$^2$)

Solar ν pp chain

Solar ν Be7

Solar ν B8

0ν decay ($\tau = 10^{27}$ yr)

2ν decay ($\tau = 10^{27}$ yr)
Neutrino-less Double Beta Decay
\(^{136}\text{Xe}\) Double Beta Decay and Gamma Background (1 mBq / QUPID, 2m Xenon Detector)
Double Beta Decay Experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Mass (kg)</th>
<th>No. of Backgrounds (/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuoricino</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GERDA I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GERDA II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GERDA III</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Super-NEMO (Se)</td>
<td></td>
<td></td>
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<tr>
<td>XENON1T</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUORE I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUORE II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CUORE III</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXO 1Ton (Ba tag)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXO 1Ton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXO200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEMO3 (Mo)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEMO3 (Se)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CANDLES III</td>
<td></td>
<td></td>
</tr>
<tr>
<td>XAX (Natural)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>XAX (Enriched)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mass (kg) vs. No. of Backgrounds (per year) graph showing various experiments and data points.
Solar Neutrino Detection
**Solar Neutrino (by XMASS group)**

- **Motivation**
  - 99% of solar neutrinos are from pp chain
  - Measurement of $\theta_{12}$ with ~1% precision
  - Confirmation LMA solution

*M. Nakahata*
Sular Neutrino Detection

10pp /5 \(^7\)Be events/day/10ton
SK  13  events/day

10 ton LXe
0  = 50 kton

M. Yamashita
Solar Neutrino Study by XMASS Group

- Expected region using pp neutrinos (90% C.L.):
  - 10 ton Liq. Xe
  - νe scattering
  - 5 years data
  - Statistical error and SSM prediction error (1%)
- Accuracy of mixing angle:
  \[ \sin^22\theta = 0.77 \pm 0.03 \text{(stat.+SSM)} \]

KamLAND and pp solar neutrinos will determine precise oscillation parameters

M. Nakahata

6/1/2011

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Summary
Detection of Cosmic Radiation

- XENON10
- IMB
- Kamiokande
- AMANDA
- Super-K
- HiRes
- AGASA
- XENON1T
- MAX / XAX
- LBNE (Water)
- ICECUBE
- AMANDA
- JEM-EUSO
- Pierre-Auger
- HiRes
- AGASA
- Future
- Cosmic Ray
- Neutrino
- Dark Matter
- Larger Volume
- Lower Threshold
- Past
- Ongoing
- Future

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XAX vs. Super-K

**XAX**
Liquid Xenon  (20 ton)

- Energy Threshold = 5 keV
- 3" QUPID x 4,000

**Super-K**
Pure Water  (50,000 ton)

- Energy Threshold = 5 MeV
- 20" PMT x 11,200

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Conclusions

- **XENON100 new results announced.**
  - 3 event observed ($1.8 \pm 0.6$ events expected)
  - $< 7 \times 10^{-45}$ cm$^2$ (at 50 GeV WIMP mass)
  - $< 2 \times 10^{-45}$ cm$^2$ by the end of 2011 expected

- **Future multi-ton Xe/Ar detectors designed and proposed.**
  - G2 : XENON 1T and DarkSide 50 / 5T at Gran Sasso.
  - G3 : MAX + LZD (Xe 10T + Ar 50T) at DUSEL

- **XAX** is an ultimate general purpose detector with $\sim 5$ keV threshold.
  - Double beta decay
  - Solar (pp-chain) and supernova neutrinos