XMASS experiment

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1. Introduction

- Xenon MASSive detector for Solar neutrino (pp/7Be)
- Xenon detector for Weakly Interacting MASSive Particles (Dark Matter search)
- Xenon neutrino MASS detector (double beta decay)

10 ton class Liq. Xe

Scintillation detection by PMTs
Expected spectrum of solar neutrinos

Solar Neutrino

\[ \nu + e \rightarrow \nu + e \]

10t Liq. Xe
5yr

Solar neutrinos
pp: 10ev/day
\(^7\)Be: 5ev/day
(> 50keV)

(Cf. SK-I, ~ 13 events/day)

Quite High statistics

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Precise measurement of oscillation parameters

- 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:
  \[ \sin^2 2\theta = 0.77 \pm 0.03 \text{(stat.+SSM)} \]

KamLAND and pp solar neutrinos will determine precise oscillation parameters
Double beta decay

$^{136}\text{Xe}$ (natural abundance 8.87%), double beta nuclei

It is quite important to investigate whether the origin of the neutrino mass is Majorana type

See-saw mechanism is correct?
$2\nu 2\beta$ background against $0\nu 2\beta$

Resolution by photon statistics

$42000\text{p.e./MeV} \times 2.48\text{MeV} \times 30\%\text{ Q.E.}$

$\Rightarrow 31000\text{ p.e. } \Rightarrow 0.6\%\text{ rms}$

$0\nu 2\beta$ lifetime sensitivity: several $\times 10^{27}\text{ years}$

$m_{\text{Majorana}}$ sensitivity: $0.01 - 0.02\text{ eV}$

$\tau_{1/2\text{ theory}} = 8 \times 10^{21}\text{ y}$

10ton natural, 5 year

Signal region

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Dark matter search

- Expected signal of dark matter

natural Xe 10t
DM 100GeV, $10^{-6}$pb for proton
spin independent ($^{132}$Xe 100%)
quench factor = 0.2

$E_{th} = 20$keV; 30 events/day
$E_{th} = 5$keV; 2000 events/day
Sensitivity of dark matter search

Spin independent

Cross-section [cm$^2$] (normalised to nucleon)

WIMP Mass [GeV]

Seasonal variation

Spectrum only

10 ton Liq. Xe

http://dmtools.berkeley.edu

Gaißkell & Mandic

DATA listed top to bottom on plot
NAIAD 2002 result
Heidelberg Moscow, 1998
EDELWEISS, 4.5 kg-days Ge(320g) June 2001 limit
ZEPLIN 1, 2002 result
CDMS Feb. 2000 vec. sub. to PRL
DAMA 2000 58k kg-days NaI Ann. Mod. 3sigma, w/o DAMA 1996 1
EDELWEISS 2 projection
CDMS, projected at Soudan mine
ZEPLIN 4 projection
Heidelberg - Gemma, projected
Baltz and Gondolo, spin indep. sigma in MSSM, with muon g-2 cosm
XENON 1 ton, projected
Gondolo et al. SUSY (Gungunio-like Models)
Gondolo et al. SUSY (Higgssino-like Models)
Gondolo et al. SUSY (Mixed Models)
Why liquid Xe?

- Large photon yield (∼ 42000 photons/MeV ~ NaI(Tl))
- Self-shield (large Z=54)
- Purification (Distillation, etc) ALWAYS possible
- Scintillation wavelength
  (175nm, possible to detect directly by PMTs)
- Compact detector size (∼ 3g/cm³, 10t=1.5m cubic)
- Relative high temperature
  (∼ 165K, compared with liq. Ne∼ 27K, liq. He∼ 4K)
- No long life isotope (except for $^{136}$Xe ββ)
- Isotope separation
- Well known cross section for solar neutrinos
- Sensitive to dark matter and ββ

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Background rejection

\[ \gamma \text{(U/Th/K/Co/Cs/...)} \]

Self-shield

No long life isotope

\[ \mu \]

H₂O, paraffin

Distillation

\[ \alpha, \beta, \gamma \text{ rays from } ^{85}\text{Kr}, ^{42,39}\text{Ar, U/Th} \]

Self-shield of external gamma rays

Fiducial volume

- 0-3000 keV
- 0-1000 keV
- 0-750 keV
- 0-500 keV
- 0-250 keV

\[ \gamma \text{ rays from } ^{238}\text{U chain} \]

6 orders of magnitude reduction for gamma rays below 500 keV

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2. R&D using 100kg detector

- 54 x 2-inch low BG PMTs
- Copper chamber
- Liq. Xe (31cmx31cmx31cm) ~ 30liter ~ 100kg

Menu of R&D
- Low background setup
- Vertex/energy reconstruction
- Demonstration of self-shielding
- R&D of purification system
- e/gamma separation
- Attenuation length
- Neutron BG study

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Dark matter search
100kg detector

MgF2 window

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Cooling test of 100kg detector

Super-insulation

Vacuum chamber (this time stainless steel)

GM refrigerator (100W @170K)

Cooling and liq.Xe supply, recovery test in February using only 6 PMTs

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cooling test

Temperature monitor

- no problem for Xe supply/recovery
- PMTs worked well even at -90°C
Shield of 100kg detector

- OFC vacuum chamber, OFC (5cm thick), Lead (15cm), Boron (5cm), Polyethylene (15 cm)
- Radon shield (EVOH sheet)
Installation of shield

Door, bottom shield, and outer chamber were installed (May and June, 2003)

Full shield will be installed by the end of July, 2003
Vertex/energy reconstruction (MC simulation)

- Make PMT hitmaps
  \[ F(x, y, z; i) : \text{acceptance of scintillation light for i-th PMT from (x, y, z)}. \]
  \[ \text{GEANT based simulation gives } F(x, y, z, i) \]
  \[ \text{on a grid with 2.5cm spacing.} \]
  \[ F(x, y, z, i) \text{ is linearly interpolated by using } F(x, y, z, i). \]

- Maximize the likelihood:

\[
\log(L) = \sum_{PMT} \log\left( \exp(-\mu) \frac{\mu^n}{n!} \right)
\]

L: likelihood
\( \mu : F(x, y, z) \times \)  
\( \text{(total p.e./total acceptance)} \)
\( n : \text{observed number of p.e.} \)

100kg XMASS detector

Red: true vertex
Green: reconstructed

Typical 1MeV alpha ray

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Vertex/Energy reconstruction (MC)

Uniformly distributed source in the fv (20cm cube)

1MeV

\[ \sigma = 62\text{keV} \quad \text{(gauss fit)} \]

0.88cm (68%)

300keV

\[ \sigma = 33\text{keV} \quad \text{(gauss fit)} \]

1.40cm (68%)

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Source driving mechanism

We can control the source position

Attachment
Motor & encoder
RI source
Wire
100kg detector: background level
(expectation by simulation)

- Gamma rays from $^{238}\text{U}$, $^{232}\text{Th}$, and $^{40}\text{K}$ outside the chamber. $^{238}\text{U}$: 2.4Bq, $^{232}\text{Th}$: 1.4Bq, $^{40}\text{K}$: 0.86Bq, determined by a HPGe.
- Events were reconstructed by a reconstruction tool.

100kg all volume estimated

100kg 20cm cube, ½ PMT cut

Efficiency: 60% @ 100keV
2.4% @ 10keV

2 phase detector (S. Suzuki et al.)

$^{85}\text{Kr}$ ~ 0.01ppm

0.1ppm $^{85}\text{Kr}$
Purification system (mainly for Kr rejection)

- Prototype of distillation tower
  Theoretically, 1/1000 reduction
  Process power: 0.6kg/hr

Boiling point: Xe=165K, Kr=120K, Ar=87K

Test operation will be done on June, 2003

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100kg detector improvement for dark matter search

- Improve p.e. yield in fiducial volume
- Reject miss-reconstructed events in fiducial volume

Separate fv with UV mirror, or wavelength shifter and mirror

Detailed study has been started
3. Next 800 kg detector

- 800 kg liquid Xe
- 642 2-in PMTs
- 77% photo-coverage
- ~ 5 p.e./keV

Very low energy threshold

80 cm diameter

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External background in 800kg detector

- Dominant contribution is from PMT
- Assuming further 1/10 reduction of PMTs BG

![Graph showing event rate vs. energy for external gamma rays and dark matter.

- External gamma ray (60cm, 346kg)
- External gamma ray (40cm, 100kg)
- 2ν2β, $8 \times 10^{21}$ yr
- $^7$Be
- pp

Dark matter ($10^{-8}$ pb, 50GeV, 100 GeV)

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Sensitivity of the 800kg detector for Dark Matter

Spin Independent

Spin dependent

Annual Modulation 3σ discovery

Cross section for nucleon [cm²]

Requirements in other background

**External**

Environmental γ rays: 15cm Pb + 5cm OFHC or water shield
Neutron recoil at 10 keV : < 1/10000 of environment
Thermal neutron absorption: < 1/400 of environment

**Internal**

$^{85}$Kr: 0.35 ppt of Kr (by distillation)
$^{42}$Ar, $^{39}$Ar: 0.1 ppm Ar (by distillation)
Radon: < 1microBq/m$^3$
U/Th in Liq.Xe: $< 10^{-14}$ g/g

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4. Summary

• XMASS experiment:
  extremely low BG experiment for pp/\(^7\)Be solar \(\nu\),
  DM and \(\beta\beta\) with liq. Xe

• Key technology:
  self shielding of liq. Xe / event reconstruction /
  continuous purification

• R&D is going on using 100kg detector,
  and we will demonstrate above ideas with the detector

• Next 800kg detector is suitable for DM search,
  and has 4 orders of magnitude better sensitivity than
  current experiments

• Final goal of the XMASS project is 10 ton class detector
  for multi-purpose astro-particle physics.