The XENON Dark Matter Project Roadmap

past
(2005 - 2007)

XENON10
Achieved (2007) $\sigma_{SI}=8.8 \times 10^{-44}$ cm$^2$

current
(2008-2010)

XENON100
Projected (2010) $\sigma_{SI}\sim2\times10^{-45}$ cm$^2$

future
(2011-2015)

XENON1T
Goal: $\sigma_{SI} < 10^{-46}$ cm$^2$
Spin-IndependentProjected Sensitivity

SI XENON1T Sensitivity

Cross Section (cm²)

XENON10 Limits (Maximum Gap Method)
XENON10 Limits (New Quenching Factor)
CDMS Limits (2009)
CDMS Limits (Combined)
ZEPLIN III
Edelweiss II
XENON100 (6000 kg*days, BG Free)
XENON1T (1ton x year) E_m = 8 keVr, BG free

Mass (GeV)³
Constraints on WIMP Mass

<table>
<thead>
<tr>
<th>Number of events</th>
<th>Mass (GeV)</th>
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<tbody>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Cross Section</td>
<td>230</td>
</tr>
<tr>
<td>$10^{-44}$ cm$^2$</td>
<td>23</td>
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<tr>
<td>$10^{-45}$ cm$^2$</td>
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XENON1T Collaboration

USA, Switzerland, Portugal, Italy, Germany, France, China, Netherlands

COLUMBIA  RICE  UCLA  ZURICH  COIMBRA

LNGS  INFN  MPIK  Bologna  SJTU

MÜENSTER  SUBATECH  NIKHEF
XENON100 is working very well. It is the largest mass and lowest background DM experiment accumulating statistics. The fiducialization allowed by the 3D TPC, the active LXe veto and the S2/S1 discrimination allow for a background free target of many tens of Kg mass.

Within 2010 XENON100 will a) either see a signal or b) will significantly constraint WIMP models for both SI and SD cross-section compared to current situation. Continued improvement in sensitivity with several targets will be essential for the field.

Based on our understanding and progress achieved with critical technologies a Xe two-phase detector at the ton scale is feasible and can be realized within a few years. The risks and the costs are fully understood.

With a strong international collaboration, with continued support from the National Science Foundation, with 50 - 50 share of resources between US and foreign groups, the goal is an experiment working before the middle of 2010.

Three key factors have accelerated our roadmap towards XENON1T: 1) cost of Xe material; 2) QUPID development; 3) foreign collaborators with guaranteed funding.
XENON1T is in line with PASAG recommendation of a vigorous pre-DUSEL program of G2 experiments to push technologies while achieving great science.

**Generation 2 and 3: PASAG definition**

- G2 $\approx 10^{-46}$ cm$^2$ or lower, construction and operation cost $15M-20M$, $\approx 2013$
- G3 $\approx 10^{-47}$ cm$^2$ or better, construction and operation cost $50M$, $\approx 2017$

Note: slight disagreement between PASAG figure and text. Here the figure has been corrected.

Scenario A: FY10 $84M$, 3.5%/yr, $266M$ FY10-FY20 runout in FY10 dollars
Scenario B: FY10 $94M$, 3.5%/yr, $389M$
Scenario C: FY10 $96M$, 6.5%/yr, $640M$
XENON1T Cryostat and Detector

- Design follows closely the approach tested with XENON10 and XENON100, with improvements in several areas:
  - Cryostat and Detector Vessels: Lower radioactivity
  - PMTs & Cabling: Lower radioactivity QUPIDs (see Arisakas’ talk)
  - Cryogenics: Cryocooler with Heat Exchanger (see next slide)
  - Xe storage and filling: Liquid Phase (MEG experience)
- Efficient background reduction based on:
  - 3D event imaging of a TPC
  - Self-shielding of the dense LXe
  - Charge & Light discrimination
- Technical proposal in preparation with full costing and risk assessment, especially for the water shield option
- Capital cost ~8 M$ shared 50-50 between US and foreign
XENON1T Cryogenics and Purification System

- Baseline design based on single 200 W Pulse Tube Refrigerator (as in XENON100 and in the MEG experiments)

- Differences:
  - Improved thermal insulation. Keep heat losses below 50 W
  - Filling and Recovery in liquid phase (as in MEG experiment) however gas phase recirculation-purification
  - Use of efficient Heat Exchanger to evaporate and recondense Xe gas for recirculation (Tested at CU)
  - With PC150 PTR, with larger pump and getter, gas flow rate would be \(~300\) SLPM
  - No need for liquid recirculation

Test Set-up at Columbia

Heat Exchanger Performance

- Cryocooler PDC08: 29W
- System Heat Loss: 12.5 W
- 96.6 % Efficiency
XENON1T Gas & Liquid Storage Systems

Gas Storage: 8 Tanks
250 liter each
60 bars
360 kg each

Liquid Storage: 1 Tank
1000 liter
<20 W Thermal Loss
1 PTR (PC150)
Expected Gamma-Background

(1 Year, Multi-hit Cut, no S2/S1 Cut)
WIMP Signal and Gamma Background

Gamma rays: < 0.07 /ton-year
Neutrons: < 0.1 /ton-year
Kr85: < 1 /ton-year for 1ppt Kr/Xe
Irreducible background from pp solar neutrino: < 0.5 event /ton/year
Location for the XENON1T Experiment

Collaboration is studying two options for site and shield

- **LNGS** with a water tank acting as shield and muon veto
- **LSM** with a polyethylene-lead shield and plastic scintillators for muon veto
Muon-induced Neutrons

The neutron flux \( \phi_n \) as a function of depth is shown in Fig. 14 where we have included a fit function of the following form:

\[
\phi_n = P_0 \left( \frac{P_1}{h_0} \right) e^{-h_0/P_1},
\]

where \( h_0 \) is the equivalent vertical depth (in km.w.e.) relative to a flat overburden. The fit parameters are \( P_0 = (4.0 \pm 1.1) \times 10^{-7} \text{ cm}^{-2}\text{s}^{-1} \) and \( P_1 = 0.86 \pm 0.05 \text{ km.w.e.} \).

Energy spectrum from our Geant4 MC simulation of the muon induced neutrons at LNGS, rescaled for the LSM depth. The neutron flux normalizations are taken from Mei and Hime (astro-ph/0512125v2) for \( E_n > 10 \text{ MeV} \).
Water Shield at LNGS

A cylindrical water tank with a minimum buffer of 4-5 m, equipped with PMTs to detect muons through Cherenkov light. External dimensions: diameter 10 m, height 10 m.
Water Shield @ LNGS

- external gamma background (0.13 $\gamma$/cm$^2$/s) requires at least 3m of water (reduction factor 100/m)

- with 3m water, less than 0.0001 evts/keVee/ton/year remain in the fiducial volume after electron recoil discrimination
Water Shield @ LNGS

- neutrons from radioactivity (\(\alpha,n\), fission) negligible (reduction factor \(10^5/m\))
- neutrons induced by muons in the rock require at least 4m of water at LNGS (reduction factor 3/m)
Water Shield @ LNGS

- active muon veto against muon induced background in the shield, assumed efficiency 98%
- neutron background sufficiently low.
- gamma background negligible

![Graph showing single scatter NR, muon-induced n from shield/detector, 4m water, 98% muon veto.

- 2.2 ton FDV
- 1.2 ton FDV

- 100 GeV, $10^{47}$ cm$^2$ WIMPs
- Single NR rate (5.25 keVr): 0.14 evts/year in 1.2 ton]
Solid Shield at LSM

XENON1T @ LSM
Solid Shield @ LSM

- muon veto, 55cm PE, 20cm Pb, 15cm PE, 2cm Pb
- neutrons induced by muons in the rock can be reduced to sufficient level

![Diagram showing single scatter NR, muon-induced n, LSM passive shield with rates in dru for different FDV masses. The graph includes energy [keVr] on the x-axis and rate [dru] on the y-axis. The data points indicate a single NR rate (5-25 keVr) with 0.44 evts/year in 1.2 ton. There is also a note about 100 GeV, $10^{47}$ cm$^2$ WIMPs.]
XENON1T at LNGS

LNGS HALL B

WARP

ICARUS