Prospects for WIMP Dark Matter Direct Searches with XENON1T and DARWIN

8th Patras Workshop on Axions, WIMPs, and WISPs
Chicago, 21-July-2012
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http://xenon.physik.uni-mainz.de

NASA/WMAP
Status in WIMP DM Sensitivities (2012)

Spin-dependent, n-coupling

Spin-dependent, p-coupling

Spin-independent

Annual modulation – DM?

XENON100 (2012)
observed limit (90% CL)
Expected limit of this run:
\( \pm 1 \sigma \) expected
\( \pm 2 \sigma \) expected
The Future of Direct Dark Matter Searches (next ~5 years)

Spin-independent sensitivity

![Spin-independent sensitivity graph]

- DAMA/Na
- CoGeNT
- CDMS (2011)
- CDMS (2010)
- CRESST (2011)
- EDELWEISS (2011)
- XENON100 (2010)
- ZEPLIN-III
- XENON100 (2011)
- XENON100 (2012)
- Buchmueller et al.
- XENON1T (2017)
- Trotta et al.

update with new limit
… but we hope for a detection

For a WIMP with $10^{-45}$ cm$^2$
$\sim$100 events
Liquid Xenon for Dark Matter Search

- Large atomic number $A \sim 131$ best for SI interactions ($\sigma \sim A^2$).
  Need low threshold.

- $\sim 50\%$ odd isotopes: SD interactions
  If DM detected: probe physics with the same detector using isotopically enriched media.

- No $^\#$ long-lived Xe isotopes.
  But control Kr-85, Rn-222. $^\#$Xe-136 $2\nu\beta\beta$

- High $Z$ (54) and density:
  compact & self-shielding

- Scalability to large mass.

- “Easy” cryogenics (-100°C).

- Efficient and fast scintillator.

- Good ionization medium, long drift.

- Background discrimination in TPC.
  $\rightarrow$ Ionization/Scintillation
  $\rightarrow$ 3D imaging of TPC
The Liquid Xenon Dual Phase TPC
Ionization + Scintillation

- WIMP recoil on Xe nucleus in dense liquid (2.9 g/cm³) → Ionization + UV Scintillation
- Detection of primary scintillation light (S1) with PMTs.
- Charge drift towards liquid/gas interface.
- Charge extraction liquid/gas at high field between ground mesh (liquid) and anode (gas)
- Charge produces proportional scintillation signal (S2) in the gas phase (12 kV/cm)

- **3D position measurement**
  - X/Y from S2 signal. Resolution few mm.
  - Z from electron drift time (~0.3 mm).
Background Discrimination in Dual Phase Liquid Xenon TPC's

Ionization / Scintillation Ratio S2/S1

3D Position Resolution: fiducial cut, singles/multiples

Gamma-rays ($^{60}$Co)

Neutrons (AmBe)

XENON100
The XENON Program

GOAL: Explore WIMP Dark Matter with a sensitivity of $\sigma_{\text{SI}} \sim 10^{-47}$ cm$^2$.

→ Requires ton-scale fiducial volume with extremely low background.

CONCEPT:
- Target LXe: excellent for DM WIMPs scattering.
  → Sensitive to both axial and scalar coupling.
- Detector: two-phase LXeTPC: 3D position sensitive, self-shielding.
- Background discrimination: simultaneous charge & light detection.
- PMT readout with >3 pe/keV.
  Low energy threshold for nuclear recoils (∼6-8 keV).

PHASES:

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- Proof of concept.
  Total mass: 14 kg
  15 cm drift.
  Best limit in '07:
  $\sigma_{\text{SI}} \sim 10^{-43}$ cm$^2$

- Ongoing DM search.
  Total mass: 170 kg
  30 cm drift.
  Best limit in '11, '12:
  2012: $\sigma_{\text{SI}} \sim 2 \times 10^{-45}$ cm$^2$

- Technical design studies.
  Total mass: ∼ 3 t
  1 m drift.
  Goal:
  $\sigma_{\text{SI}} \sim 2 \times 10^{-47}$ cm$^2$
The XENON Collaboration

USA, Switzerland, Portugal, Italy, France, Germany, Israel, Netherlands, China (XENON100)

Columbia
Rice
UCLA
Zürich
Coimbra
LNGS
Purdue

Mainz
Bologna
Subatech
Münster
Nikhef
MPI-K
Weizman
**XENON1T**
*(2011-2015)*

- Liquid xenon TPC to explore $\sigma \sim 2 \times 10^{-47} \text{ cm}^2$
- Detector size:
  $\sim 1 \text{ m}^3$, $\sim 3 \text{ t LXe}$, $\sim 1 \text{ t fiducial mass}$
- Water Cherenkov Muon Veto
- Approved by INFN.
- Funded.
- Construction start: fall 2012.
Yes, it's faked.
See real photo at the next Patras meeting!
Water Cherenkov Muon Veto

**Concept:**
- Water tank: ~10 m high and 9.6 m in diameter
- 84 high QE 8” PMTs Hamamatsu R5912 with water-tight base
- Specular Reflector: foil DF2000MA by 3M

**Trigger requirements:**
- single photoelectron
- 4 fold coincidence
- time window: 300 ns

**Trigger efficiency**
- > 99.5% for neutrons with muons in WT
- ~ 78% for neutrons with μ's outside WT

**μ-induced neutron background**
- 0.01 per year
- ≪ WIMP signal

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**Image:** Muon-induced neutrons from the rock

- **Graph:**
  - Single scatter, whole volume (2.43 t)
  - Single scatter, FDV (1.27 t)
  - 100 GeV, $10^{-7}$ cm$^2$ WIMPs
Cryostat

Baseline design

- Ti grade 1 double-walled cryostat
- UHV compatible, low outgas rate
- Heat load < 50 W
- Immersed in water shield
- Buoyancy load
- LNGS seismic environment
- Safety review currently ongoing
TPC

1.5 m

1.00 m

0.95 m

Columbia-Rice-UCLA-Zurich

HV feed-through
**PMTs**

- 2 × 121 3” PMTs by Hamamatsu
- QE: 30% min., >35% achieved
- Ongoing screening program to further reduce radioactivity

![Prototype PMT mounting](image)

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UCLA – Columbia – MPIK – Zurich

Prototype PMT mounting
Cryogenics

- Cooling towers
- Emergency LN2 cooling
- High flow demonstrated

Diagram:
- Heat exchanger
- Cryostat
- LXe Collection Funnel
- PTR
- Cold Finger
- Umbilical
- Water Tank
- LXe to Cryostat
- LXe from Cryostat
- Signal and HV pipe
- Vacuum Insulated Line
- LXe to/from ReStox Vessel
- Note: HV Port not shown

Columbia
Xenon Purification & Rn-Removal

- ½ inch gas lines, VCR connections
- Orbitally welded
- Pneumatic valves
- SAES PS4-MT50 getter
- QDrive and KNF pumps
- Dedicated monitors for ppb-level impurities (H₂O, O₂, Kr)

Münster (Xe purification) – MPIK (Rn column)
Krypton Removal

- Cryogenic distillation
- Reduce ppb Kr traces in Xe gas to ppt
- proven technique, achieved (19 +- 1) ppt in XENON100

Design Parameters for XENON1T

- through-put: 3 kg/hr
- factor of $10^4$-$10^5$ separation
- final Kr/Xe < 1 ppt

Münster
Krypton Analysis

• Kr measurements with gas chromatography plus Rare Gas Mass Spectroscopy RGMS
  → measurement of $^{nat}$Kr to ppt level
  → extrapolation to $^{85}$Kr from atmospheric abundance
  → gas chromatography: Xe separation
  → demonstrated for XENON100

• $^{84}$Kr measurement with atomic trap ATTA
  → measurement of $^{84}$Kr to ppt level
  → extrapolation to $^{85}$Kr from atmospheric abundance
  → Atom trap operational and efficient for Ar*
  → First Kr/Xe measurements for XENON100 by Fall 2012

MPIK (RGMS) – Columbia (ATTA)
Material Screening

- Gamma-ray screening with sensitivity ~10 μBq/kg with GeMPIs and Gator, located at LNGS
- Gas counting systems, located at LNGS and MPIK, for $^{222}$Rn measurements at few atoms sensitivity
- ICPMS @ LNGS, UCLA
  Inductively coupled plasma mass spectrometry
- Neutron activation analysis @ PSI, Mainz

MPIK – Zurich
Xenon Storage

RESTOX: A Liquid Xenon station
(REcovering and STOrage system of Xenon1T)

Motivations:
- Very compact station
- 3T storage capacity from 20°C to -108°C
- Able to keep high purity all the time
- withstands 65 bar
- can also keep Xe at room temperature

Time schedule:
- Construction will start in summer 2012
- Installation for end of 2013

RESTOX will be easily scalable to larger sizes
XENON1T Demonstrator

- XENON purification and heat exchange at 100 slpm
- Verification of cooling concept
- Cathode HV tests: grid+feed-through goal: -100 kV
- Electron lifetime demonstrated. Next: 1 m drift

Columbia – Rice – UCLA
PMT Stability Tests

- Stable operation in liquid and gaseous Xe over 5 months
  - Blue LED for SPE
  - PMT @ –1 600V
  - T = 171 K
  - P = 1.4 bar

Zurich

Mean gain: $6.04 \times 10^6$
± 4% variation

Single PE response
DARWIN
Dark Matter WIMP Search with Noble Liquids

R&D and design study for a next-generation noble liquid facility in Europe

25 groups from ArDM, DarkSide, WARP, XENON
Europe: UZH, INFN, ETHZ, Subatech, Mainz, MPIK, Münster, Nikhef, KIT, TU Dresden, Israel: WIS, USA: Columbia, Princeton, UCLA, Arizona SU

similar effort in the US: MAX
XENON10:
14 kg (5.4 f d)

XENON100:
161 kg (62 f d)

XENON1t:
2.4 t (1 t f d)

DARWIN:
20 tons LXe/LAr (10 t f d)
(indicative masses*)

WARP:
140 kg

WARP: 2.3 l

DarkSide:
55 kg (33 f d.)

ArDM: 850 kg

20 tons LXe/LAr
~ 10 tons in the
central,
background-free
region

(*optimal masses for LAr/LXe to be
determined in the study;
here MC sketch)
DARWIN physics

- Measurement of dark matter properties
  → ultimate WIMP limit around $10^{-48}$ $\text{cm}^2$
- Measurement of pp-neutrinos
  → with 10 t of LXe about 4000 neutrinos per year
- $^{85}\text{Kr}$ ($^{\text{nat}}\text{Kr} < 0.1$ ppt) and $^{222}\text{Rn} < 0.1$ µBq/kg required

- 2νββ: EXO measurement of $^{136}\text{Xe} T_{1/2}$

Assumptions: 50% NR acceptance, 99.5% ER discrimination, 80% flat cut acceptance.
2νββ background can be reduced by using depleted xenon.
Expected sensitivity

Goal is not exclusion limits, but WIMP detection!

~ 1 event kg\(^{-1}\) year\(^{-1}\)

~ 1 event (10 kg)\(^{-1}\) year\(^{-1}\)

~ 1 event (100 kg)\(^{-1}\) year\(^{-1}\)

~ 1 event ton\(^{-1}\) year\(^{-1}\)
Outlook

Thank you for your attention!

Darwin