Direct Dark Matter Search with XENON100 and XENON1T

- Direct dark matter search with XENON100
- Recent results from XENON100
- Progress and status of XENON1T
- Conclusions
Direct search for WIMPs

⇒ exponential recoil energy spectrum:

\[
\frac{dR}{dE_r} = \frac{\rho_0 \cdot \sigma_0 \cdot F^2(q^2)}{2 \cdot m_{\tilde{\chi}} \cdot \mu_r^2} \cdot \left(\frac{1}{v}\right) = \frac{\rho_0 \cdot \sigma_0 \cdot F^2(q^2)}{\sqrt{\pi} \cdot m_{\tilde{\chi}} \cdot \mu_r^2 \cdot v_0} \cdot e^{-\frac{E_r - m_{\tilde{\chi}}}{2 \cdot \mu_r^2 \cdot v_0}}
\]

\[\tilde{\chi}, \tilde{\chi}, H, h, Z^0, q\]

nucleus \hspace{1cm} nuclear recoil

⇒ go underground to reduce \(\mu\)\'s and \(\mu\)-induced n\'s & shielding, very clean materials, ..

⇒ special techniques to suppress \(\gamma, e, \alpha\) background

a) large detector mass to see annual modulation (DAMA/LIBRA)
b) double read-out to distinguish nuclear recoil from others

- cryobolometers:
  heat + ionisation or heat + light
- liquid noble gas detectors:
  light + ionisation
c) directional (but not enough target mass)
Dual phase liquid noble gas detectors
eg. XENON 100: basic principle

Detector: liquid xenon time projection chamber (-91 °C) in passive shield (γ and neutron shield)

WIMP interaction

⇒ prompt scintillating light S1
  - electrons are drifted into gas phase by drift field in LXe (0.5-1 kV/cm)
⇒ proportional light (S2) by electro-luminescence in GXe (10kV/cm)
Drift time of charge to liquid / gas interface = \( \Delta t(S1-S2) \):
- in LXe: 0.53 kV/cm: \( v_d = 1.7 \text{ mm/\mu s} \)
- \( \rightarrow \) vertical position precision: \( \Delta z = 0.3 \text{ mm} \)

Dual phase liquid noble gas detectors
eg. XENON 100: position reconstruction

Electroluminescence in GXe
- \( \rightarrow \) light pattern on top PMT array
- provides horizontal position with \( \Delta x = 3 \text{ mm} = \Delta y \) precision
Distinguish nuclear recoil (WIMP, n → charge quenching) from electronic recoil (background) using S2/S1 ratio.

⇒ 99.5% background rejection @ 50% nuclear recoil acceptance
Arguments for a xenon detector

Heavy nucleus (A~131):
→ good for spin-independent interaction (coherent scattering off all nucleons)
SD sensitivity too (~50% odd isotopes)

High nuclear charge (Z=54)
→ very good self-shielding

Ultraclean material
liquid noble gases are among the most clean materials
no long-lived isotope except
\(^{136}\text{Xe}: t_{1/2} = 2 \times 10^{21} \text{ yr, 8.9\% nat. abundance}\)

Very high charge & light yield:
42,000 \(\gamma / \text{MeV at 178nm (PMTs exist)}\)

Proven XENON technology with
high efficiency & low energy threshold, background rejection methods, fiducialisation, ...

Moderate cost (<2k$/kg),
effort scales with surface not volume

(for details see E. Aprile, T. Doke,
Rev. Mod. Phys. 82 (2010) 2053)
XENON: staged WIMP search @LNGS

XENON10
2005 - 2007
15 cm drift TPC
25 kg xenon
σ_{SI} < 8.8 \cdot 10^{-44} \text{ cm}^2

XENON100
2008 - 2015
30 cm drift TPC
161 kg xenon
σ_{SI} < 2.0 \cdot 10^{-45} \text{ cm}^2

XENON1T (XENONnT)
2012 -
1000 cm drift TPC
3300 (7000) kg xenon
σ_{SI} < 1.2 \cdot 10^{-47} \text{ cm}^2 \left( < 2 \cdot 10^{-48} \text{ cm}^2 \right)
The XENON collaboration
about 120 scientists from 19 institutions
XENON100 TPC

161 kg dual phase GXe & LXe TPC

TPC: 30.5 cm diameter
      30.6 cm height
→ 62 kg active target
      99 kg LXe veto (> 4 cm)

98 + 80 (+64) 1“ x 1“ R8520-AL PMTs

passive shield, screened materials

Xe purified by distillation ≈ 20 ppt Kr (run 10)
   1 ppt (at start of data taking in 2013)

E. Aprile et al., Astropart. Phys. 35 (2012) 573
Run 10: 225 live days in 2011/2012

blind analysis, use 34 kg fiducial mass

- cut-based analysis:
  - expected background: 1 event, measured: 2 events
  - → statistical consistent with no signal
  - → no dark matter found, only upper limit

**Profile Likelihood Analysis:**

- all observed events
- full energy information, no discrimination
- incorporate calibration informations
- include systematic uncertainties \((L_{\text{eff}}, \ldots)\)
- method makes smooth transition between rejection/discovery

→ calculate only one true 90%CL limit

Details of the profile likelihood analysis:

E. Aprile et al.,
Phys. Rev. D 84 (2011) 052003

Exclusion curve, no signal found!
World´s best sensitivity on WIMPs up to LUX results in autumn 2013

disfavours DAMA & CoGeNT (& CRESST) possible signal regions
(also IDM@DAMA ruled out, E. Aprile et al, Phys. Rev. D 84 (2011) 061101)
Some data selection and analysis as 225 days run 10 analysis (PRL 109 (2012) 181301)

Sensitivity to SD interaction by odd isotopes $^{129}$Xe (J=1/2, 26.4%) and $^{131}$Xe (J=3/2, 21.2%)

Single particle cross section limits

$$\frac{d\sigma_{SD}(q)}{dq^2} = \frac{8G_F^2}{(2J + 1)v^2} S_A(q)$$

$$\sigma_{p,n}(q) = \frac{3}{4} \frac{\mu_{p,n}^2}{\mu_A^2} \frac{2J + 1}{\pi} \frac{\sigma_{SD}(q)}{S_A^{\alpha_0=\pm a_1}(q)}$$

XENON100 Dark Matter run 10: electron recoil band: limits on ALPs

Expected galactic dark matter axion signal
\[ g_{Ae} = 4 \cdot 10^{-12} \]

Expected solar axion signal
\[ m_A < 1 \text{ keV} \]
\[ g_{Ae} = 2 \cdot 10^{-11} \]

\[ \sigma_{Ae} = \sigma_{pe} \left( E_A \right) \frac{g_{Ae}^2}{\beta_A} \frac{3E_A^2}{16\pi\alpha_{em}m_e^2} \left( 1 - \frac{\beta_A^2}{3} \right) \]
XENON100 Dark Matter run 10: electron recoil band: limits on ALPs

Expected solar axion signal
\[ m_A < 1\text{keV} \]
\[ g_{Ae} = 2 \cdot 10^{-11} \]

Expected galactic dark matter axion signal
\[ g_{Ae} = 4 \cdot 10^{-12} \]

XENON100 is still running for calibration purposes (YBe, \(^{83}\text{mKr}, \ldots\))

Several analyses ongoing

New data to be unblinded soon: 154 live days from 2013

E. Aprile et al. (XENON100), PRD 90 (2014) 062009
XENON1T@LNGS:
Increasing SI sensitivity down to $10^{-47}$ cm$^2$
**Detector:**
1m-drift dual-phase TPC, 248 PMTs 3'', Hamamatsu R11410-2
liquid xenon mass: 3.3t, 2t target → approx. 1t fiducial

**Background goal:**
100 lower than XENON100:
   - less than 1 bg event per year in one 1 fiducial volume
→ rigorous material screening & selection
→ 10m water tank: neutron shielding, active muon veto
→ cleaning from intrinsic contaminations by radioactive noble gases by cryogenic distillation

**Sensitivity:**
1.2 x 10^{-47} cm^2 after 2 t*y exposure

**Status:**
most components under commissioning, TPC under construction
start of data taking in 2015
**Custom-made cryogenic distillation column for XENON1T(nT)**

**Cryogenic distillation:**

multi-stage separation by different vapor pressure

\[ ^{85}\text{Kr} : \]

\[
2 \cdot 10^{-11} \text{ fraction of } ^{85}\text{Kr in } ^{\text{nat}}\text{Kr }
\]

\[
10^{-8} - 10^{-5} \text{ fraction in commercial xenon gas, but XENON1T requires } < 2 \cdot 10^{-13}
\]

→ need very efficient purification method

up to now published Kr-in-Xe fraction concentrations reached by LUX, PandaX, XENON100, XMASS: 1-3 ppt

cryogenic distillation with custom-made Münster column:

\[
< 0.026 \text{ ppt (RGMS measurement by MPIK), 3 kg/h}
\]

\[ ^{219}\text{Rn}, ^{220}\text{Rn}, ^{222}\text{Rn} : \]

comes from walls, weldings, ..

→ rigorous screening of materials

Rn reduction by continuous cryogenic distillation for XENON1nT
Electron recoil background (before ER/NR discrimination)

requirements:

- $^{85}$Kr: $^{nat}$Kr in Xe < 0.2 ppt
- $^{222}$Rn < 1 $\mu$Bq/kg
- same bg rate from solar $\nu$s and materials

Total background (after ER/NR discrimination with 99.75% @ 40% NR acceptance)

source background (evts/ton/y) in [3, 70] PE

ER (materials + intrinsic + solar n): 0.32
NR from radiogenic neutrons: 0.22
NR from neutrino coherent scattering: 0.21

Total: 0.75
XENON1T@LNGS: Increasing SI sensitivity down to $10^{-47} \text{ cm}^2$
XENON1T@LNGS: water tank, service building, cryostat
XENON1T@LNGS: cryosystem, purification system
XENON1T@LNGS: storage, analytics, cryogenic distillation
Conclusion

**XENON100:**
- many physics results on SI, SD, ALPs, etc.
- several ongoing analyses
- still running, calibration (YBe, $^{83m}$Kr), cryogenic Rn distillation

**XENON1T:**
- first multi-ton direct dark matter experiment, $1.2 \cdot 10^{-47} \text{ cm}^2$ sensitivity for SI
- commissioning of most components at the moment, TPC under construction
- start of data taking planned still for 2015
- allows easy upgrade towards XENONnT (7t), see Hardy Simgen's talk

Will we see WIMPs before reaching the neutrino floor?

arXiv:1310.8327