Marc Schumann (Freiburg U) on behalf of the Collaboration

LNGS Open Session, 03.04.2017
The XENON Collaboration

22 institutions
10 countries
3 continents
135 scientists
New science results published:

**Search for two-neutrino double electron capture of $^{124}\text{Xe}$ with XENON100**

Two-neutrino double electron capture is a rare nuclear decay where two electrons are simultaneously captured from the atomic shell. For $^{124}\text{Xe}$ this process has not yet been observed and its detection would provide a new reference for nuclear matrix element calculations. We have conducted a search for two-neutrino double electron capture from the $K$ shell of $^{124}\text{Xe}$ using 7036 kg d of data from the XENON100 dark matter detector. Using a Bayesian analysis we observed no significant excess above background, leading to a lower 90% credibility limit on the half-life $T_{1/2} > 6.5 \times 10^{20}$ yr. We have also evaluated the sensitivity of the XENON1IT experiment, which is currently being commissioned, and found a sensitivity of $T_{1/2} > 6.1 \times 10^{22}$ yr after an exposure of 2 yr.

**XENON100 dark matter results from a combination of 477 live days**

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We report on WIMP search results of the XENON100 experiment, combining three runs summing up to 477 live days from January 2010 to January 2014. Data from the first two runs were already published. A blind analysis was applied to the last run recorded between April 2013 and January 2014 prior to combining the results. The ultralow electromagnetic background of the experiment, $\sim 5 \times 10^{-4}$ events/(keV$_{ee}$×kg×day) before electronic recoil rejection, together with the increased exposure of 48 kg × yr, improves the sensitivity. A profile likelihood analysis using an energy range of (6.6–43.3) keV$_{ee}$ sets a limit on the elastic, spin-independent WIMP-nucleon scattering cross section for WIMP masses above 8 GeV/c$^2$, with a minimum of $1.1 \times 10^{-45}$ cm$^2$ at 50 GeV/c$^2$ and 90% confidence level. We also report updated constraints on the elastic, spin-dependent WIMP-nucleon cross sections obtained with the same data. We set upper limits on the WIMP-neutron (proton) cross section with a minimum of $2.0 \times 10^{-40}$ cm$^2$ ($52 \times 10^{-40}$ cm$^2$) at a WIMP mass of 50 GeV/c$^2$, at 90% confidence level.

DOI: 10.1103/PhysRevD.94.122001

Several studies are currently being prepared for submission...
Highlight: Annual Modulation 2.0

Data acquired over 4 years: Jan 2010 – Jan 2014 → longest LXe TPC operation ever
Highlight: Annual Modulation 2.0

PRL 118, 101101 (2017)

Detector
Pressure [bar]

Temperature [K]

Analysis
Cut Acceptance

Rate
Multiples (=background)
Singles (=signal)
Highlight: Annual Modulation 2.0

- additional data improves upon previous analysis *PRL 115, 091302 (2015)*
- no significant modulation observed
- Dark matter explanation of DAMA/LIBRA signal excluded @ 5.7σ
XENON100: R&D for XENON1T

1. Demonstration of online $^{222}\text{Rn}$-removal by cryogenic distillation

- Integration of XENON1T distillation column into XENON100 system
- $^{222}\text{Rn}$ activity inside XENON100 monitored by $\alpha$-tagging
- $^{222}\text{Rn}$ concentration artificially increased
- measured reduction factor of >27 (@ 95% CL)
2. Demonstration of low-E bulk calibration with $^{220}\text{Rn}$ source

$^{228}\text{Th}$ source emanates $^{220}\text{Rn}$

use $\beta$-decay of $^{212}\text{Bi}$ to calibrate low energy region

time distribution of later chain determined by $^{212}\text{Pb}$
$\rightarrow$ back to background level after $\sim 6.5$ days

uniform distribution in TPC
Successfully used in **XENON1T**
XENON1T

largest LXe TPC ever built
- cylinder: 96 × 97 cm
- active LXe target: 2.0t (3.2t total)
- 248 PMTs (Hamamatsu R11410-21)
XENON1T: all systems running

Kr Removal

Purification

Storage/Recovery

Cryogenics

TPC + PMTs

Calibration

DAQ + Computing

Slow Control

Water Shield

Muon Veto

ReStoX

Distillation

M. Schumann (Freiburg) – XENON
XENON1T: Data Taking

commissioning completed!
XENON1T operates stably
Data Taking: Neutrons

- Light: ~8 PE
- Charge: ~240 PE
- A WIMP would look similar

Earthquakes!!!

Calibration of signal region
Data Taking: $^{83m}\text{Kr}$

- Calibration of detector response: energy, positions

- PMT
- Gas
- Liquid target
- Pos HV
- Neg HV

S2 corrections

- Top
- Bottom

- Preliminary

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Data Taking: $^{83m}\text{Kr}$

Calibration of detector response: energy, positions

- 8.0 PE/keV @ 122 V/cm for 41.5 keV
- $\sim$8.9 PE/keV @ zero-field
- $2\times$ higher than XENON100
Data Taking: **Dark Matter**

- **Start taking blinded dark matter data**
- **Early $^{220}$Rn data**
- Blinded in DM data

**Graph Details:**
- X-axis: log10(cS2/cS1)
- Y-axis: Total runtime (days)
- Data points from Oct 26, 2016, to Mar 1, 2017
- Blinded data at specific points

**Background Sources:**
- Background
- Kr83m
- Rn220
- AmBe
- LED/Other

**Notes:**
- Preliminary data presented
- M. Schumann (Freiburg) – XENON
Data Taking: $^{220}\text{Rn}$

calibrate ER background in bulk LXe
Data Taking: **LED**

Gains were chosen to optimize individual single photoelectron response while avoiding exceedingly high bias voltages.

**PMT Gain Stability**

**Regular PMT calibrations**
Data Taking: **Dark Matter**

![Graph showing data taking timeline and backgrounds](image)

- **Background**
- **Kr83m**
- **Rn220**
- **AmBe**
- **LED/Other**

**dark matter data**
Jan 18: Earthquake again...

up to 5.5 mag, epicenter ~20 km away

we clearly see earthquakes in our LXe level sensors and detector tiltmeters
→ January 18 earthquake caused high voltage trips
Use „natural break“ to define **science run 0 (SR0)** adds up to ~35 live days

check integrity of detector
Continue Data Taking

data taking ongoing; data quality good, NR region blinded

regular calibrations
SR0: Detector Stability

all detector parameters continuously monitored by slow control system → excellent stability
SR0: Backgrounds

WIMP ROI: 1–12 keV interval

Electronic Recoils
Nuclear Recoils

materials
solar ν
\(^{85}\)Kr
\(^{136}\)Xe

Total
\(^{222}\)Rn

JCAP 04, 027 (2016)

ER Rate \([\text{kg} \cdot \text{day} \cdot \text{keV}^{-1}]\)

Fiducial Mass [kg]

600 800 1000 1200 1400 1600 1800

10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3}

final goals intrinsic:

\(^{222}\)Rn: 10 µBq/kg

\text{nat}\text{Kr}: 0.2 ppt

negligible for SR0 exposure

M. Schumann (Freiburg) – XENON
SR0: Backgrounds

WIMP ROI: 1–12 keV interval

Electronic Recoils
Nuclear Recoils

\( ^{136}\text{Xe} \)
\( ^{85}\text{Kr} \)

negligible for SR0 exposure

Natural Kr: 0.2 ppt

Measured \(^{222}\text{Rn}\) emanation

250 mm cryo-pipe (9.2 ± 1.0) mBq
100mm pipe + tubes (2.7 ± 0.2) mBq
paracrine (2.1 ± 0.3) mBq
cryo system (2.4 ± 0.3) mBq

TPC+Cryostat
TPC (4.5 ± 2.1) mBq
cryostat (inner vessel) (1.9 ± 0.3) mBq
getters (1.6 ± 0.1) mBq

Purification System
3 QDrive pumps ~13 mBq

Expected background: \((11±2)\) µBq/kg prelim.

agrees with preliminary value from \(\alpha\)-counting

\(^{222}\text{Rn}: 10\) µBq/kg

JCAP 04, 027 (2016)
SR0: Backgrounds

WIMP ROI: 1–12 keV interval

Electronic Recoils
Nuclear Recoils

\( (\gamma, \beta) \)

\( (\text{neutron}) \)

negligible for SR0 exposure

\( ^{222}\text{Rn} \) materials

\( ^{85}\text{Kr} \)

final goals intrinsic:

\( ^{222}\text{Rn}: 10 \mu\text{Bq/kg} \) ✓

\( \text{natKr}: 0.2 \) ppt

new: online Kr-Removal

- 3.5 slpm from Xe-gas phase are passed through distillation column
- return to TPC via PUR system
  → online removal of \( \text{natKr} \) while detector acquired science data

\( \text{natKr}/\text{Xe} = (0.6 \pm 0.1) \) ppt achieved
  → lowest value in LXe experiments ever
  → sufficient for SR0 ✓
SR0: Status

- intense „analysis bootcamp“ completed
- analysis is being finalized
- expect result soon
XENON1T: Full Sensitivity

assumptions: energy interval: 4 – 50 keV, ER rejection as XENON100: 99.5% @ 50% NR acc.
XENON1T → XENONnT

XENON1T
- 2t active LXe target
- operating in DM mode
- first results soon

XENONnT
- 6t active target
- projected to start science in 2019

Already existing/operational:
- Muon Veto
- Cryostat Support
- Outer Cryostat
- in-LXe Cabling
- LXe storage system
- Cryogenic system
- Purification system
- Kr removal
- DAQ
- 95% of Electronics
- Calibration System
- 260 PMTs
- >8t of LXe
  (was 4.5t one year ago!)
- Screening facilities
- dedicated nT funding

Already started:
- 230 new PMTs ordered
- TPC/Cryostat design
- first material orders
- Screening campaign
- Neutron veto studies
- 2nd storage vessel ordered
- Rn reduction system design
- purification improvements
- etc.
The XENON Future

some projects are missing...

www.xenon1t.org