Status of Direct Dark Matter Search with XENON100 and XENON1T

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On behalf of the XENON collaboration

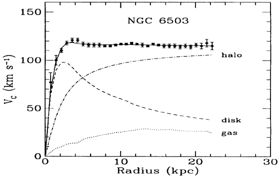
XENON Dark Matter Project

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

18.03.2016

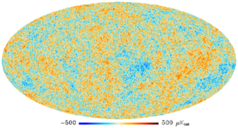
- Galactic Rotation Curves
- Gravitational Lensing
- Bullet Cluster
- Cosmic Microwave Background (CMB)
- Structure Formation
- etc.

Weakly interacting massive particles (WIMPs) are a favoured model for dark matter!



arXiv:0812.4005 [astro-ph]

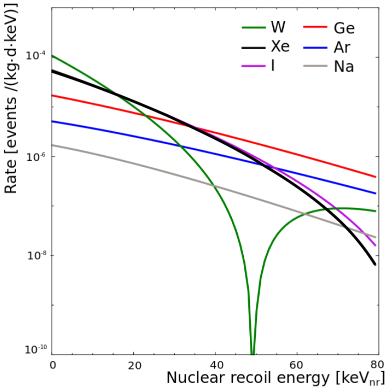
Bullet Cluster, Gravitational Lensing
NASA, Chandra x-ray observatory



CMB, *arXiv:1303.5062*

Why using Xenon for Direct Detection?

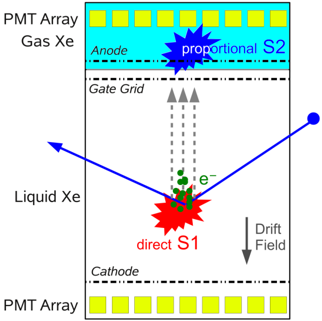
- high mass number: A $\sim$ 131
- high stopping power: $\rho \simeq 3$ g$\cdot$cm^{-3}
- low intrinsic radioactivity
- ^{129}Xe and ^{131}Xe have non-zero nuclear spin ➔ sensitive to spin-dependent interactions
- possible to produce in large quantities

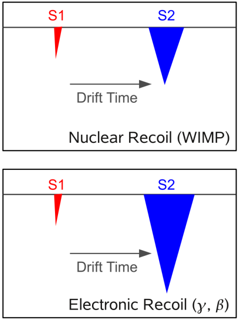


J.Phys. G43 (2016) 1, 013001

$$\frac{\mathrm{d}R_\mathrm{A}}{\mathrm{d}E_\mathrm{nr}} = A^2 \cdot F_\mathrm{A}^2(E) \cdot \frac{\sigma_\mathrm{p} \cdot \rho_\chi}{2 \cdot m_\chi \cdot \mu_\mathrm{p}^2} \cdot \int_{v \geq v_{min}} \mathrm{d}^3 v \frac{f(\mathbf{v}, t)}{v}$$

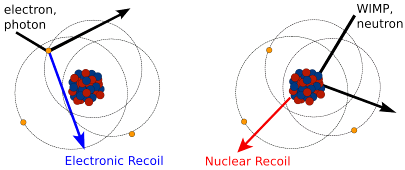
The Detection Principle

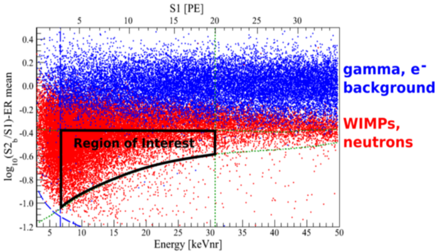




Astropart.Phys. 35 (2012) 573-590

- two phase TPC (time projection chamber)
- light from prompt scintillation (S1) and ionization (S2)
- only innermost xenon volume used for WIMP search

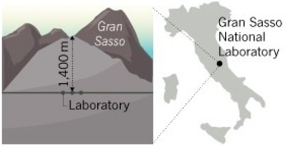


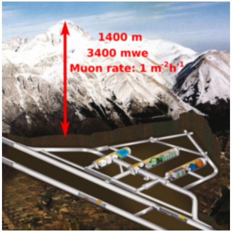


The XENON Experiment

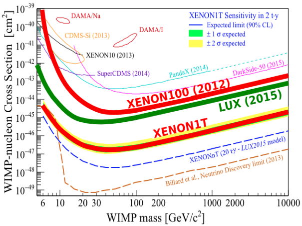
Collaboration of 21 institutes in 10 countries

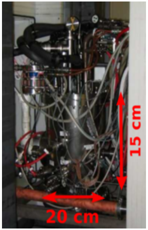
Hosted by the **Laboratori Nazionali del Gran Sasso** (LNGS)

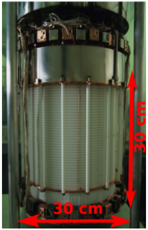




History of the XENON Experiment





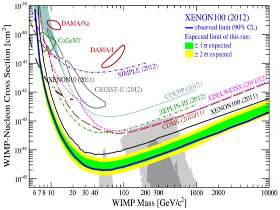


	XENON10	XENON100	XENON1T
Total xenon mass:	25 kg	161 kg	3.5 t
Target mass:	15 kg	61 kg	2.0 t
Runtime:	2005-2007	2008-201x	2016-201x
Exclusion limit: (σ_{SI})	$8.8 \cdot 10^{-44}$ cm^2 @ 100 GeV (2007) *PRL 100 021303*	$2.0 \cdot 10^{-45}$ cm^2 @ 55 GeV (2012) *PRL 109 181301*	$1.6 \cdot 10^{-47}$ cm^2 @ 50 GeV (expected in 2018) *arXiv:1512.07501*

XENON100 Results

Limits on WIMP-nucleon interactions

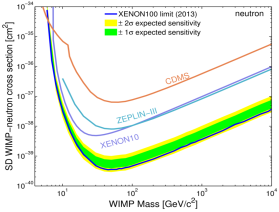
Spin-independent

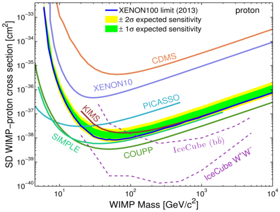


WIMP-nucleon cross-section

Phys.Rev.Lett. 109 (2012) 181301

Spin-dependent



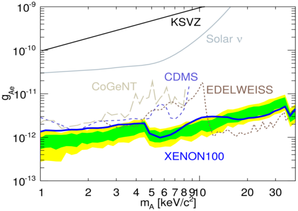


WIMP-neutron cross-section

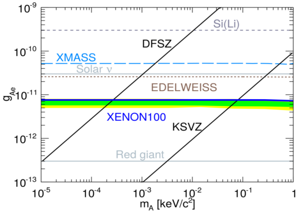
WIMP-proton cross-section

Phys.Rev.Lett. 111 (2013) no.2, 021301

Limits on axion-electron interactions



Axion like particles

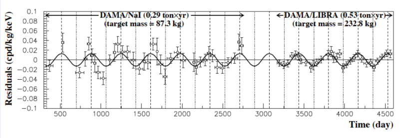


Solar axions

Phys.Rev. D90 (2014) no.6, 062009

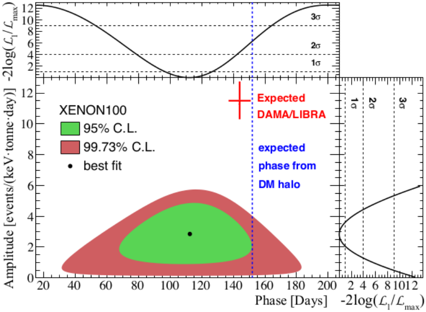
Recent XENON100 Results: Exclusion of Event Rate Modulation in ER

DAMA Signal, 9.3σ *Eur.Phys.J. C73 (2013)*



Eur.Phys.J. C56 (2008) 333

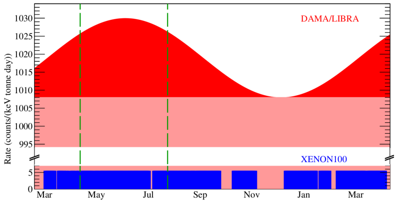
- phase: (144 ± 7) days, period: (0.998 ± 0.002) year
- modulation seen in energy interval $(2 - 6)$ keV$_{ee}$



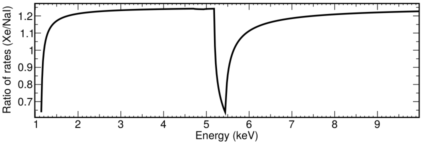
Phys.Rev.Lett. 115 (2015) 9, 091302

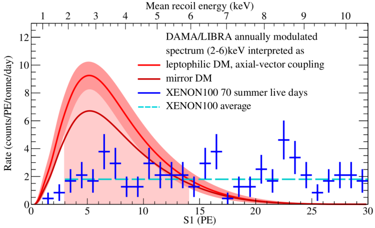
- no particular period favoured at any significant level!
- fixing period to 1 year $\Rightarrow$ best fit for phase: 112 ± 15 days
  - phase of standard DM halo disfavoured **@** 2.5σ
  - phase and amplitude of DAMA disfavoured **@** 4.8σ

Recent XENON100 Results: Exclusion of Leptophillic Dark Matter Models



- DAMA Bkg: 1019 $(\text{keV}\cdot\text{t}\cdot\text{d})^{-1}$
  XENON100 Bkg: 5.3 $(\text{keV}\cdot\text{t}\cdot\text{d})^{-1}$
- DAMA modulation: (11.2 ± 1.2) $(\text{keV}\cdot\text{t}\cdot\text{d})^{-1}$
- assuming full modulation of DAMA to be caused by DM $\Rightarrow$ transfering DAMA spectrum into XENON100 spectrum





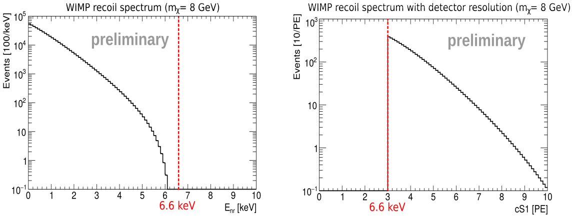
Science 349 (2015) 6250, 851-854

- excluding leptophillic DM @ 4.5σ
- excluding mirror DM @ 3.6σ

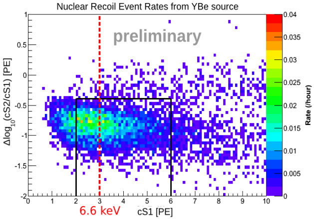
Current XENON100 Activites

Using a uniquely understood device for:

- tests of radon removal techniques for XENON1T
- tests of new calibration sources for XENON1T: ^{220}Rn, ^{83m}Kr, Tritium
- proof of principle: NR below detector threshold ($6.6\,\mathrm{keV}_{nr}$) contribute to event rate due to Poisson fluctuations!
  - YBe source: $^{9}\mathrm{Be}(\gamma,\mathrm{n})^{8}\mathrm{Be}$
  - $E_{\mathrm{nr}}^{\mathrm{max}} = 4.5\,\mathrm{keV}_{nr}$



Simulation

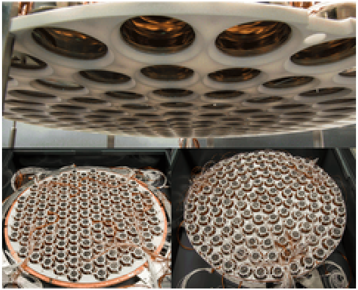


YBe source measurement

⇒ justifies limits for WIMP masses with recoil energies below detector threshold

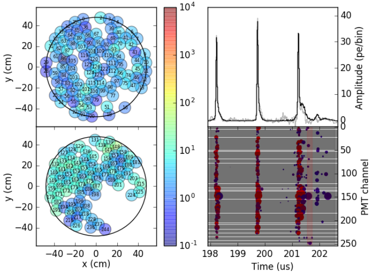
XENON1T - The next Generation

- 3.5 t xenon ⇒ 2.0 t target mass
- TPC with ∼ 1 m drift length, ∼ 1 kV/cm drift field
- 248 PMTs (Hamamatsu R11410-21) *Eur.Phys.J. C75 (2015) 11, 546*
- 10 m water tank for neutron shielding & active muon veto *JINST 9 (2014) 11006*
- background after 99.75% ER rejection: 2.08 events/(t·y) (in S1 range (3,70) PE) *arXiv:1512.07501, submitted to JCAP*



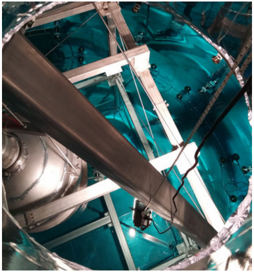
XENON1T - Commissioning

- full inventory of 3.5 tons in LXe storage vessel
- TPC assembled and installed
- muon veto systems tested (water tank filled)
- currently DAQ commissioning and PMT calibration



First LED Light!

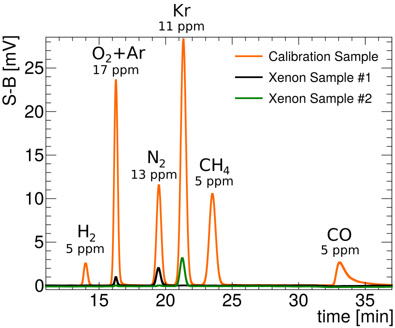
⇒ Data taking soon!



XENON1T - Gas Purity Control

Electronegative impurities (e.g. O_2) can capture electrons
Radioactive impurities (^{85}Kr) contribute to background rate

- gas chomatography used to verify xenon gas purity
- calibration by standard gas mixture $\rightarrow$ peak area proportional to amount of gas
- each xenon bottle measured before filling into storage vessel

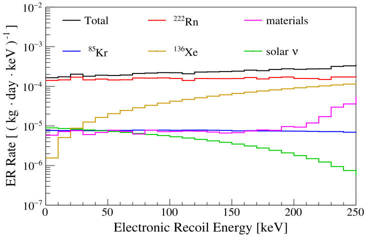


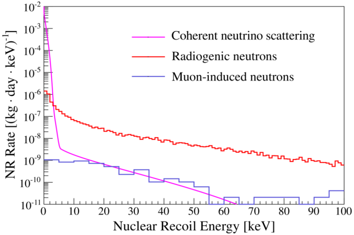
Total impurities of xenon inventory [ppm]

$0.06 <$	**H_2**	< 0.10	$0.003 <$	**Kr**	< 0.025
$0.25 <$	**O_2+Ar**	< 0.55	$0.00 <$	**CH_4**	< 0.02
$0.99 <$	**N_2**	< 1.65	$0.00 <$	**CO**	< 0.21

XENON1T - Background Reduction

Background	Analysis Tools	Reduction/Prediction
radioactivity in materials: γ-rays, neutrons from $(\alpha$,n) reactions, spontaneous fission	screening with germanium detectors, mass spectrometry	material selection: γ-Rate: $(29 \pm 3)\ y^{-1}$ in (1 – 12) keV n-Rate: $(0.6 \pm 0.1)\ y^{-1}$ in (4 – 50) keV
^{222}**Rn** emanating from materials (decay daughters are β-emitters)	emanation measurements	material selection: $10\,\mu$Bq/kg $\rightarrow (620 \pm 60)\ y^{-1}$ in (1 – 12) keV
^{85}**Kr** in xenon (β-emitter)	mass spectrometry	distillation: 0.2 ppt ^{nat}Kr $\rightarrow (31 \pm 6)\ y^{-1}$ in (1 – 12) keV



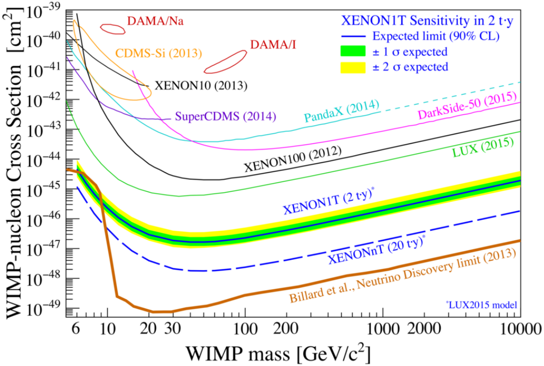


arXiv:1512.07501, submitted to JCAP

Total Background in S1 range (3,70) PE @ 99.75% ER rejection, 40% NR acceptance — ER: 1.62 events y^{-1}, NR: 0.45 events y^{-1}

Summary and Outlook

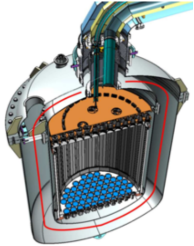
arXiv:1512.07501. submitted to JCAP



- XENON100 excludes DAMA annual modulation and leptophillic DM models and
- XENON100 still in Operation: Tests for XENON1T
- XENON1T commissioning almost completed ⇒ first results this year!

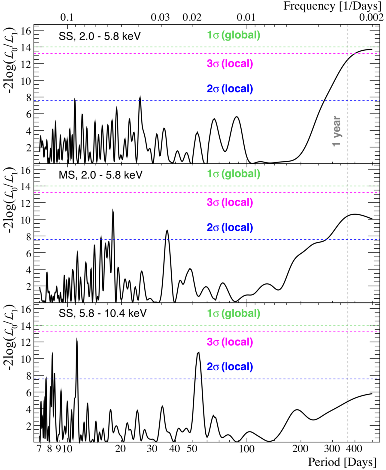
Future: XENONnT Upgrade

- only TPC & inner cryostat have to be exchanged
- $\sim$ 7.5 t total xenon mass
- $\sim$ 200 PMTs additionally required
- sensitivity improves by one order of magnitude!



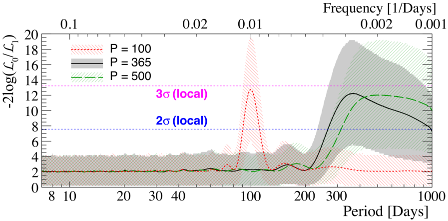
Backup Slides

$$\text{ModulationRate}: f(t) = \epsilon(t)\left(C + Kt + A \cdot cos\left(2\pi\frac{(t-\phi)}{P}\right)\right)$$



Science 349 (2015) 6250, 851-854

K	...	Bkg rate from ^{85}Kr rate from air leak
C	...	constant WIMP rate
$\epsilon(t)$	...	cut acceptance



XENON1T - Background

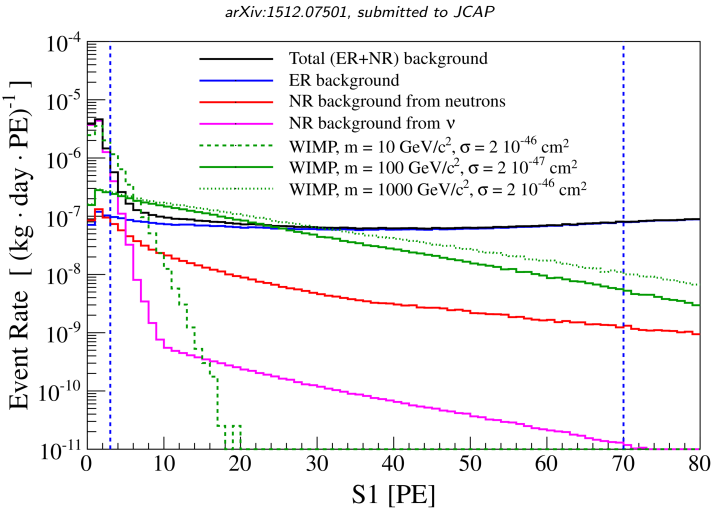
Electronic Recoil Background in (1 – 12) keV

Source	Background [y^{-1}]	Fraction [%]
Materials	29 ± 3	4.1
^{222}Rn	620 ± 60	85.4
^{85}Kr	31 ± 6	4.3
^{136}Xe	9 ± 4	1.4
Solar Neutrinos	36 ± 1	4.9

Nuclear Recoil Background in (4 – 50) keV

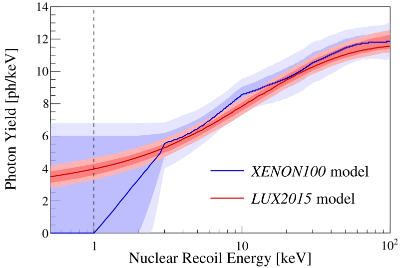
Source	Background [y^{-1}]	Fraction [%]
radiogenic neutrons	0.55	48.2
muon induced neutrons	< 0.01	0
coherent neutrino scattering	0.59	51.8

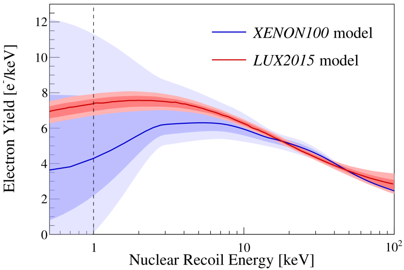
XENON1T - Background



Energy Scales

arXiv:1512.07501, submitted to JCAP





$$E = \frac{S1}{L_y}\frac{1}{\mathcal{L}_{eff}(E)}\frac{S_{ee}}{S_{nr}}$$

$$E = \frac{S2}{L_q}\frac{1}{\mathcal{Q}_y(E)}$$