The XENON100 experiment: recent results from 100 d data

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Outline

1. Introduction
2. The XENON100 experiment
3. Detector calibration
4. XENON100 results
5. R&D activities and XENON1T

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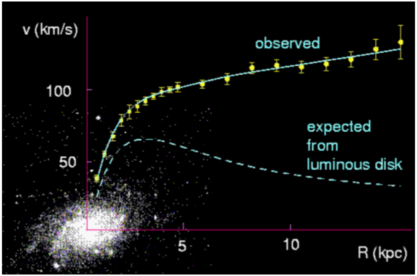
Indications from astronomy

Star rotation curves

- Measurement: 21 cm H-line
- Dark matter halo explanation



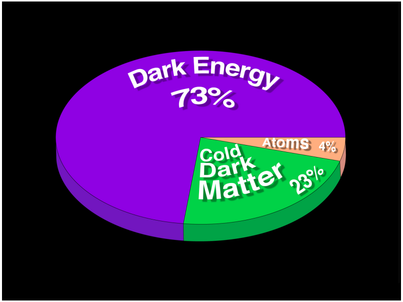
Gravitational lensing

- Light rays bend in around massive objects
- Distorsion geometry
  → total mass

+ large scale structures, WMAP data, collision of galaxy clusters ...

What is dark matter?

23% of the Universe is made of Dark Matter

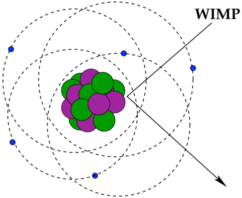


BUT what is its nature?

Well motivated theoretical approach:

WIMP

(**W**eak **I**nteracting **M**assive **P**article)



Example: SUSY particles

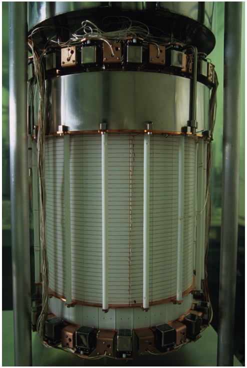
- Neutralino χ
- CMSSM predictions around $10^{-44\pm2}$ cm^{-2}

WIMP search

- Indirect detection

$\chi\chi \rightarrow e^+e^-, p\bar{p}$

- Direct detection

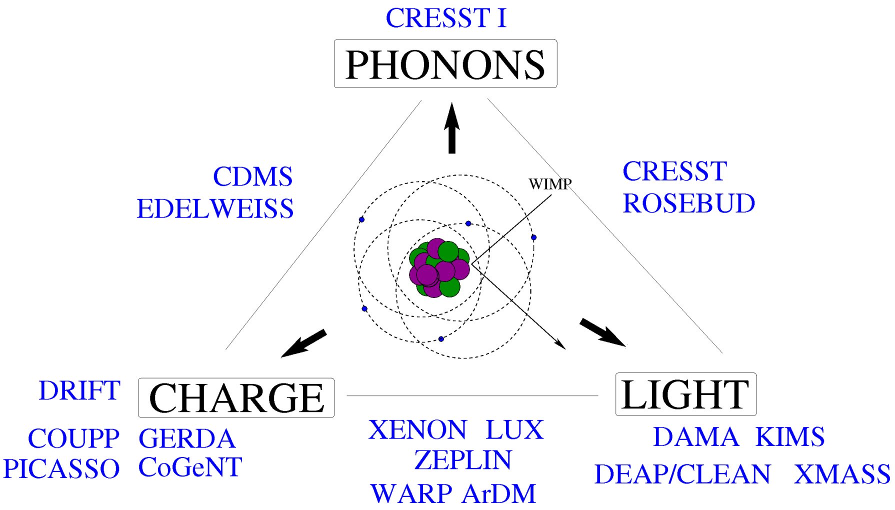


$\chi\,\mathrm{N} \rightarrow \chi\,\mathrm{N}$

- Production at LHC

$\mathrm{p} + \mathrm{p} \rightarrow \chi + \mathrm{a\ lot}$

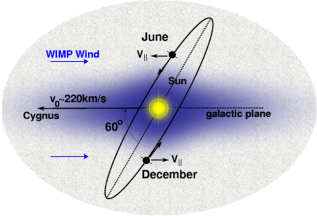
Direct detection experiments

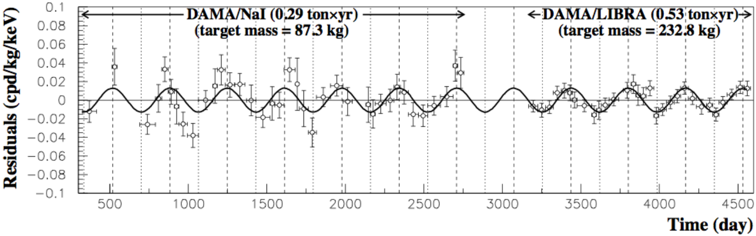


DAMA annual modulation

- Experiment at LNGS underground lab
- Looks for oscillations in background rate of NaI crystals induced due to Earth motion around the Sun

R. Bernabei *et al.*, Eur. Phys. J. C67, 39 (2010)

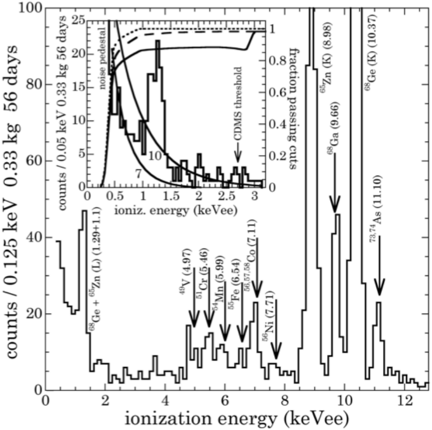


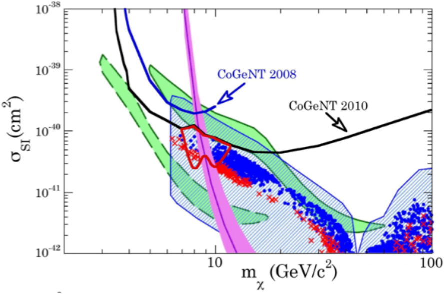


- Significant (8 σ) seasonal oscillation in the 2-6 keV energy bin
- Is the DAMA oscillation due to Dark Matter?

CoGeNT experiment

- Germanium detector with a very low threshold
  - Rate increase below 2 keV$_{ee}$ (in addition to noise)





- Explanation as ligth WIMPs $\sim$ 10 GeV/c^2
- CoGeNT Coll. PRL 106, 131301 (2011)

$\longrightarrow$ Recent news from APS conference: also a modulation in the rate?

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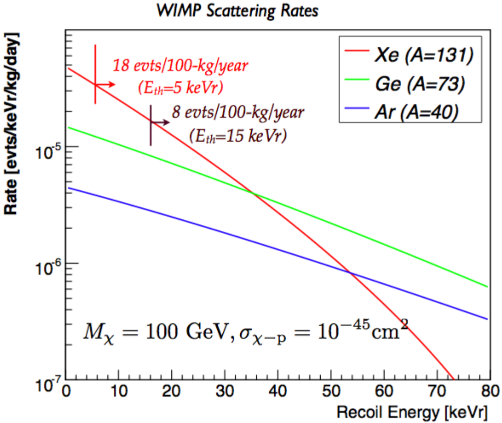
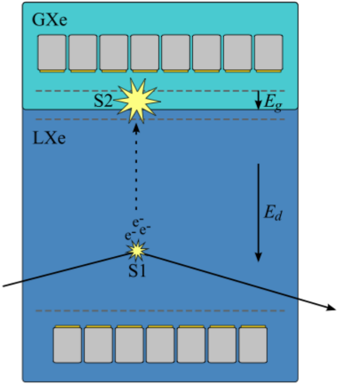
Xenon as detection medium



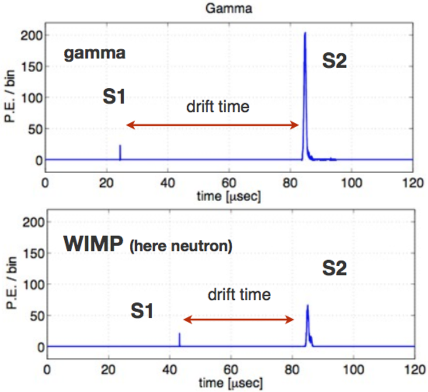
Detection via scatter off nuclei

- Self-shielding
  → High stopping power
- 178 nm UV photons
  → No wavelength-shifter
- Simple cryogenics
  ∼ 180 K = - 93°
- High atomic mass A ∼ 131
  → spin-indep. interactions
- ^{129}Xe and ^{131}Xe
  → spin-dep. interactions

Two phase noble gas TPC



- Scintillation signal (S1)
- Charges drift to the liquid-gas surface
- Proportional signal (S2)



Electron recombination is stronger for nuclear recoils

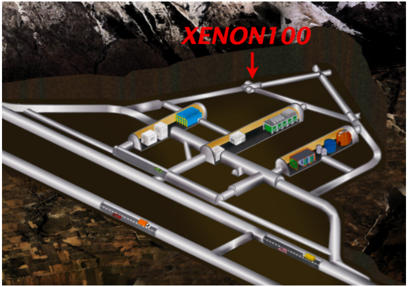
→ Electronic/nuclear recoil discrimination

XENON experiment

- Laboratori Nazionali del Gran Sasso (Italy)
- $\sim$ 3 650 m.w.e. shielding

- XENON10: 15 kg active volume
  - Finished: No evidence for DM
- XENON100: 62 kg active volume

  E. Aprile *et al.*, Phys. Rev. Lett. 105, 131302 (2010)
  E. Aprile *et al.*, arXiv:1103.0303 (2011)
  E. Aprile *et al.*, arXiv:1104.2549 (2011)
  - Currently running



XENON100 Collaboration

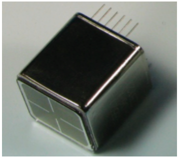
Columbia | Rice | UCLA | Zürich | Coimbra | LNGS | SJTU

Mainz | Bologna | Subatech | Münster | Nikhef | Heidelberg | Weizman

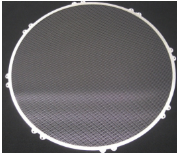
US, Switzerland, Portugal, Italy, China, Germany, Holland, France and Israel

XENON100 detector

- 30 cm drift length and 30 cm ∅
- 161 kg total (30-50 kg fiducial volume)
- Improved shielding
- Material screening and selection
- Cooling (PTR) outside the shield
- Active liquid xenon veto
- ∼ 100x less background than XENON10



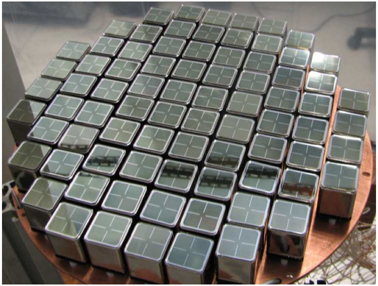
1 inch PMTs



30 cm ∅ meshes

Light and charge read out

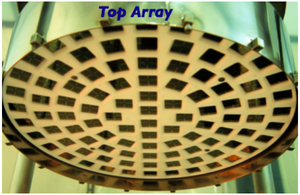
- Bottom PMTs: high quantum efficiency (on average >30% @178 nm)



- 3 Dim. position reconstruction
  - XY from light pattern in the PMTs
  - Z from the drift time
- 3 mm resolution in XY and in Z

gamma event localized

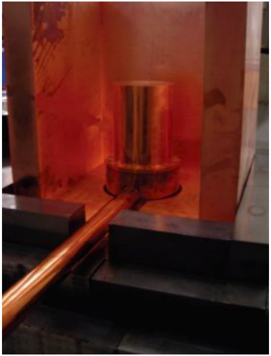
Top PMT array



Gator screening facility operated by UZH

Material screening underground with a 2.2 kg HP Ge detector LNGS

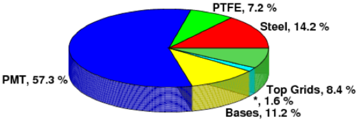
L.Baudis *et al.*, arXiv:1103.2125



→ All XENON100 construction materials were screened and selected

- XENON100, arXiv:1103.5831

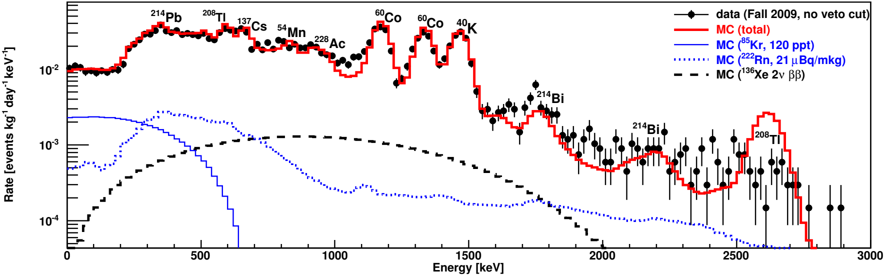
- Gamma background from materials in ROI:



- Removal of ^{85}Kr: distillation column
- Kr/Xe $\sim$ ppm-ppb commercially available

→ After purification: $\sim$ 150 ppt via $\gamma\beta$ delayed coincidence

Measured background spectrum



- Background at the level of the predictions
- The measured single scatter rate below 100 keV is $5{\cdot}10^{-3}$ evts/kg/keV/d after applying the veto cut
- Factor 100 less than in XENON10 achieved!!

→ XENON100 Collaboration, PRD 83, 082001 (2011), arXiv: 1101.3866

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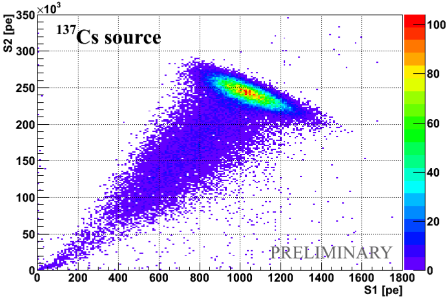
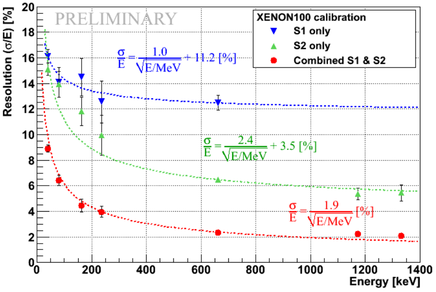
Calibration with gamma sources

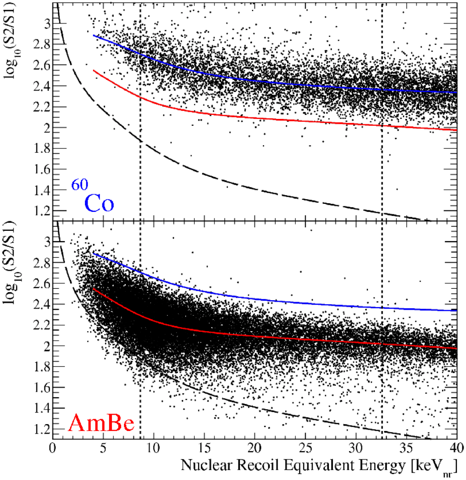




- Energy dependence of resolution for light (S1), charge (S2) and CES signals
- CES: combined energy scale

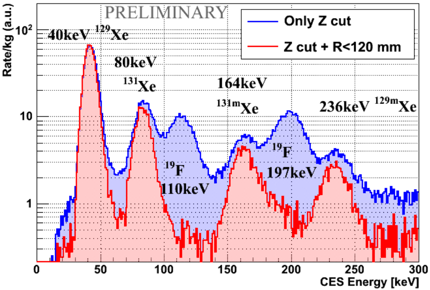
→ using anticorrelation between S1 and S2 signals

Electronic and nuclear recoil bands



- Electronic recoil band: defined with ^{60}Co source
- Nuclear recoil band: defined with AmBe neutron source

→ ER lines during n-calibration:



Calibration of the nuclear recoil energy scale

- Nuclear recoil energy (E_{nr}):

$$E_{nr} = \frac{S1}{L_y L_{eff}} \times \frac{S_e}{S_r}$$

$S1$: measured signal in p.e.

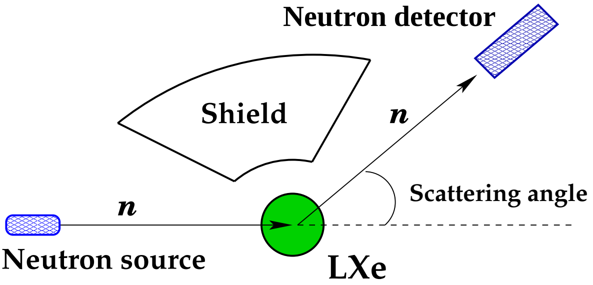
L_y: LY for 122 keV γ in p.e./keV

S_e/S_r: quenching for 122 keV γ/NR due to drift field

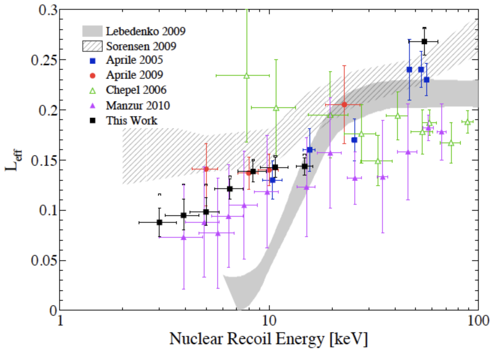
- Relative scintillation efficiency of NR to 122 keV γ at 0-field

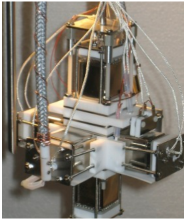
$$L_{eff} = q_{nucl} \times q_{el} \times q_{esc}$$

  - q_{nucl}: Linhard quenching
  - q_{el}: Electronic quenching
  - q_{esc}: Escape e$^-$'s at 0-field



Measuring the nuclear recoil scale





- Recent measurement at U. Columbia
- Lowest Measurement at 3 keV$_{nr}$

G. Plante *et al.*, arXiv:1104.2587 (2011)

- New measurement planned at U. Zürich

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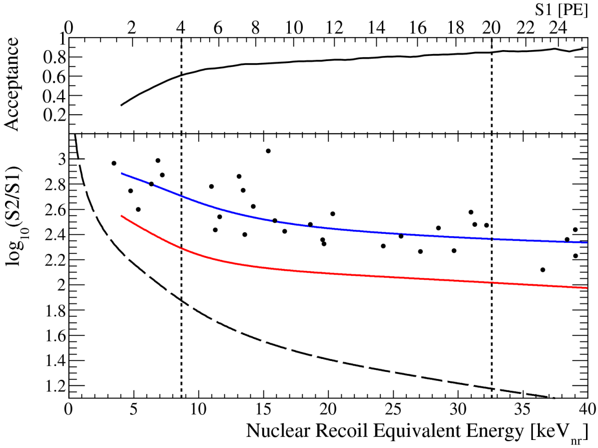
Overview XENON100 data

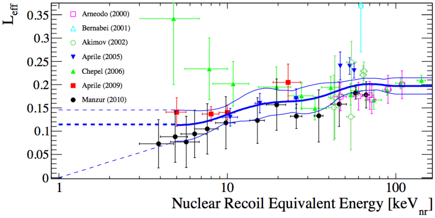
- RUN07:
  - October/November 2009
  - 11.2 days of data used for first results
- RUN08:
  - January to June 2010
  - 100.9 days lead to recent results
- RUN10:
  - Started in February 2011 and on-going

First results from a commissioning run

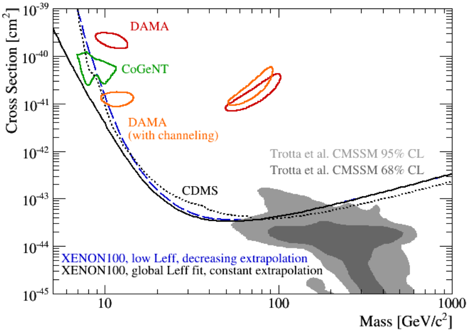


- Data sample: 11.17 days in October/November 2009
- 'Background free' after discrimination

Limit from non-blinded data analysis



- Spin independent limit: for standard halo parameters

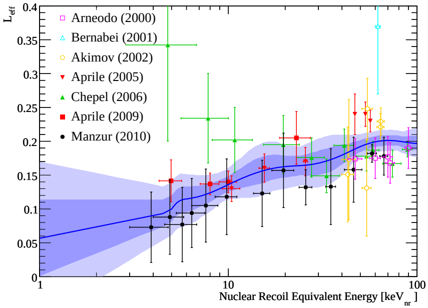


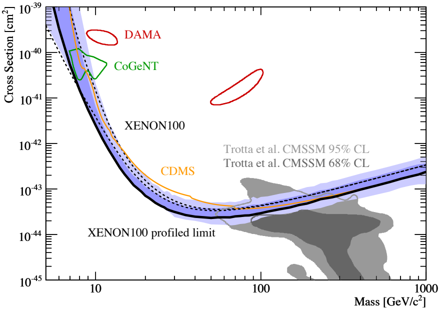
E. Aprile *et al.* (XENON100 Collaboration), Phys. Rev. Lett. 105, 131302 (2010)

- Excellent sensitivity: even with few days of data

→ Sensitivity to low WIMP masses depends on L_{eff}

Introducing the profile Likelihood method



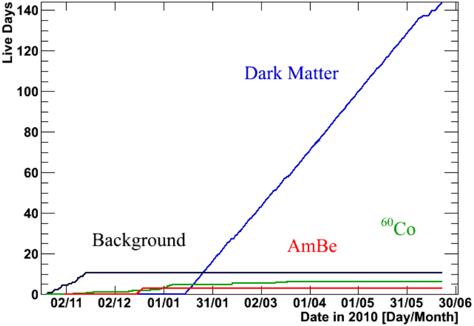


- Uses the whole discrimination parameter space
- Takes uncertainties into account: L_{eff} and galactic escape velocity
- Improvement in the limit for the 11.2 d analysis

  → XENON100 Collaboration, arXiv: 1103.0303

- Tensions between the XENON100 results and the DAMA/CoGeNT evidences

Data taking 2009/2010: Overview



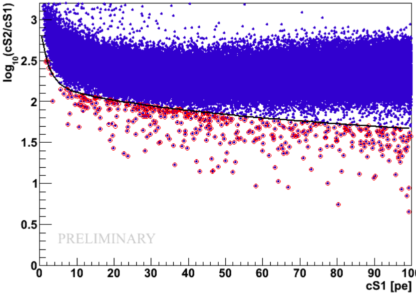
→ 11.2 days of non-blinded data analyzed (commissioning run)

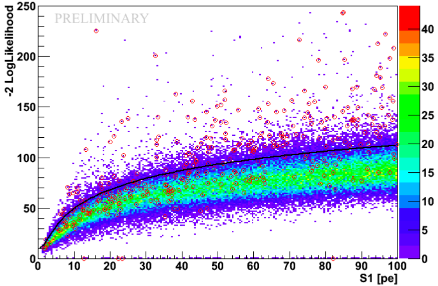
→ New run ∼100 days blinded data

- Improved analysis:
  - New likelihood cut for anomalous S1 patterns
  - New position reconstruction algorithms
  - Improved corrections: XY and Z
  - new MC for background predictions
  - ...

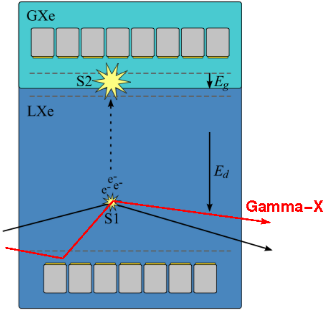
→ Results released this April!

Likelihood cut for anomalous S1 patterns





- Example: Gamma-X events, double scatters, one of them in a charge insensitive region



- Likelihood cut removes large fraction of events below NR median while having a high neutron acceptance

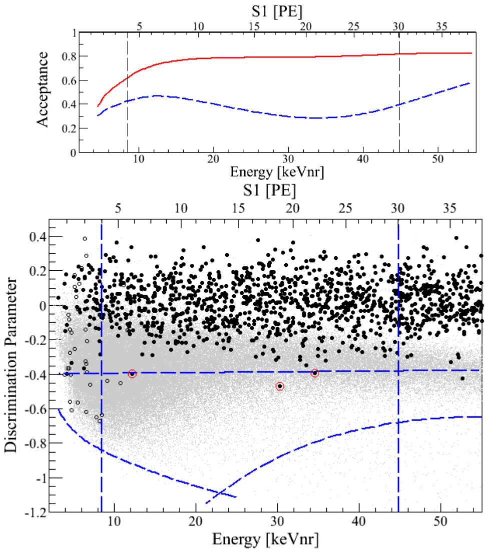
Data analysis:

- Data stability:
  - Selection of periods with stable HV, low radon level, stable thermodynamics of the detector (P, T,...)
- Selection of physical interactions:
  - Noise cuts, stability of PMTs, selection on the width of S2 pulses, S2 pulse above threshold and S1 pulse seen by at least 2 PMTs
- Selection of single scatters:
  - Single S1 and single S2, S1 PMT pattern (rejects gamma-X), cut on position reconstruction, veto cut
- Fiducial volume and WIMP search region:
  - 48 kg superelliptic volume
  - Events between 4 pe and 30 pe and above the 3σ contour of the nuclear recoil distribution

Background prediction

- Statistical leakage from the electronic recoil band
  - (1.14 ± 0.48) events
  - using non blinded ER background data
  - Increased ^{85}Kr level by a factor of 5 due to a leak ($\sim$650 ppt)
- Anomalous leakage events
  - $(0.56^{+0.21}_{-0.27})$ events
  - using data and MC from ^{60}Co and Bg
- Neutron prediction
  - Muon-induced fast neutrons: $(0.08^{+0.08}_{-0.04})$ events
  - $\alpha - n$ reactions and spontaneous fission: (0.032 ± 0.006) events
- TOTAL: (1.8 ± 0.6) events in 100.9 d

Unblinding of the 100 days data

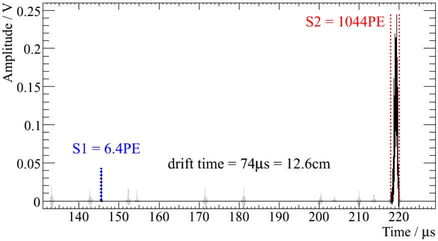


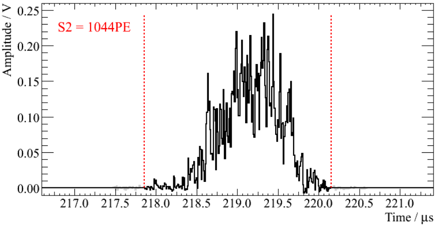
- High cut acceptance
- NR acceptance below 99.75% rejection

- 6 events in search window after unblinding
- 3 events identified as part of a noise population around 4pe

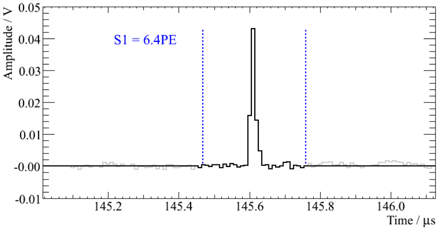
→ 3 WIMP candidates

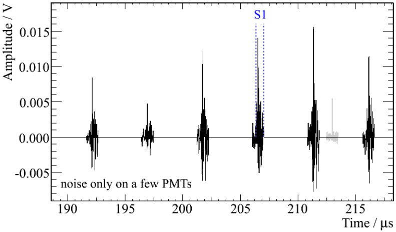
Event waveforms



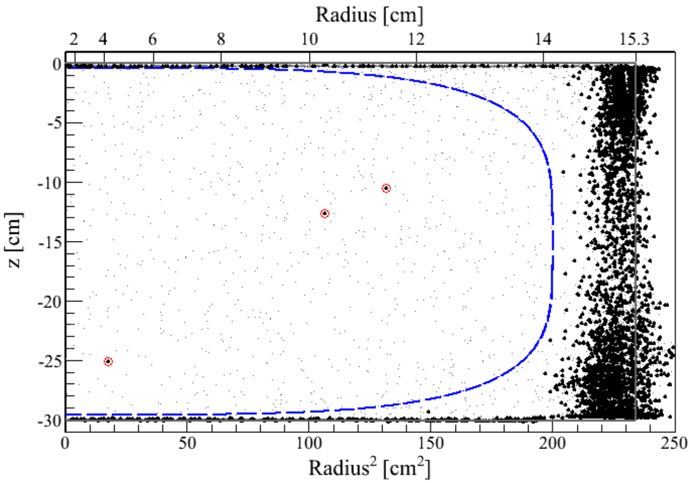


Examples of normal and noisy S1s:





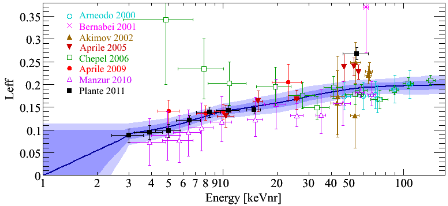
Spatial distribution of the WIMP candidates



- 3 candidates clearly inside the 48 kg fiducial volume
- Background on the ER band mainly due to the homogeneous ^{85}Kr

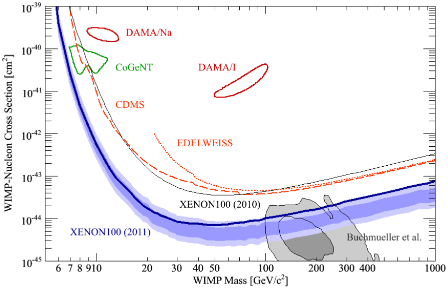
Results from 100 days data

→ Poisson probability of 1.8 events to oscillate to 3 or more: 28%
No evidence of dark matter in the data



- L_{eff} includes new data (uncertainties represented by the blue band)
- Logarithmic extrapolation below 3 keV_{nr} (including large uncertainty)

- Likelihood analysis used to extract the limit on WIMP-nucleon cross section
- Sensitivity shown by the blue band
- Limit ist robust against uncertainties

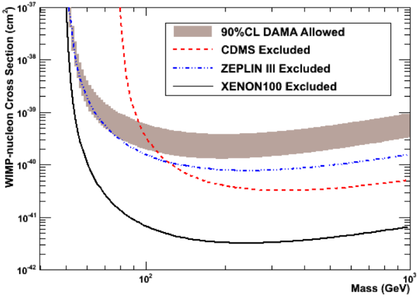


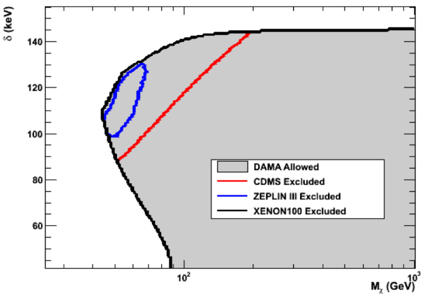
→ XENON100 Collaboration, arXiv:1104.2549

Interpretation of DAMA signal as being due to iDM

- Inelastic dark matter model (Tucker-Smith and Weiner, Phys. Rev. D64, 043502 (2001))
  - WIMP scatter to an excited state $(\chi + N \rightarrow \chi^* + N)$
  - Minimum relative speed: $v_{min} = \frac{1}{\sqrt{2 m_N E_R}} \left(\frac{m_N E_R}{\mu_N} + \delta \right)$

→ XENON100 excludes the interpretation of DAMA as due to iDM

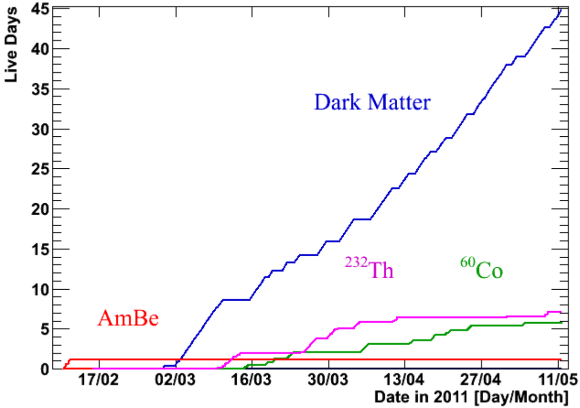




⟶ XENON100 Collaboration, arXiv:1104.3121

RUN10: Current status of the data taking

- New DM run started at the beginning of 2011
- Lower concentration of ^{85}Kr: back to the level of 2009
- Improved purity and lower trigger threshold



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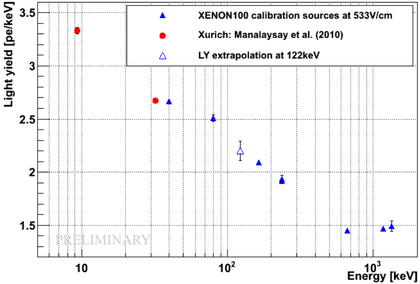
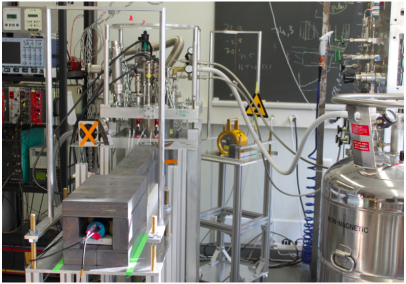
Low energy electron recoils





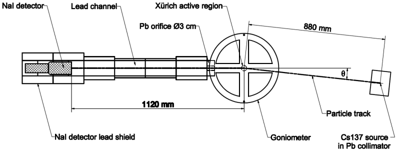
R&D at Universität Zürich:

- ^{83m}Kr provides lines at 9.4 keV and 32.1 keV

  A. Manalaysay *et al*, Rev. Sci. Instrum. **81**, 073303 (2010)

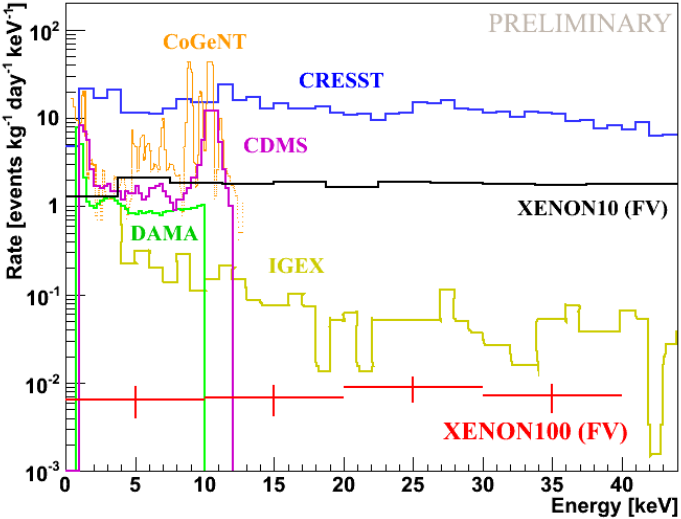
- Further down in energy

→ Compton measurement

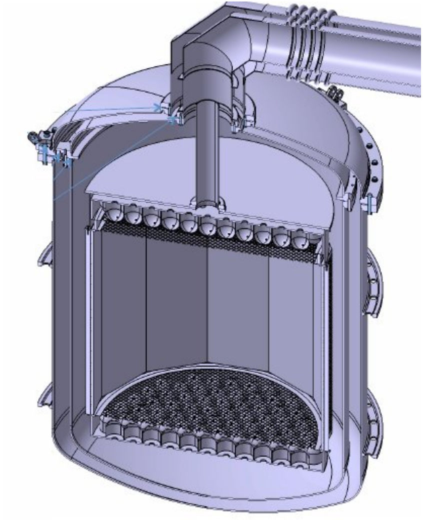


- Goal: determine the xenon LY down to ∼ 2 keV

Background rate in Dark Matter experiments

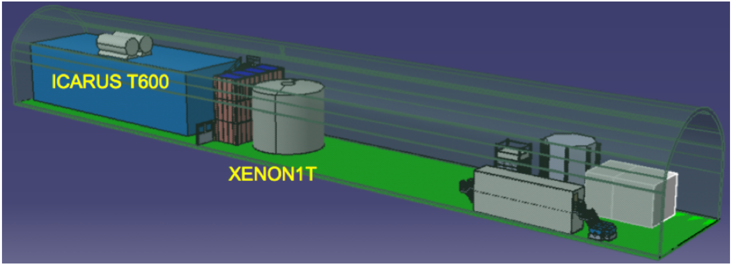


Future: XENON1T



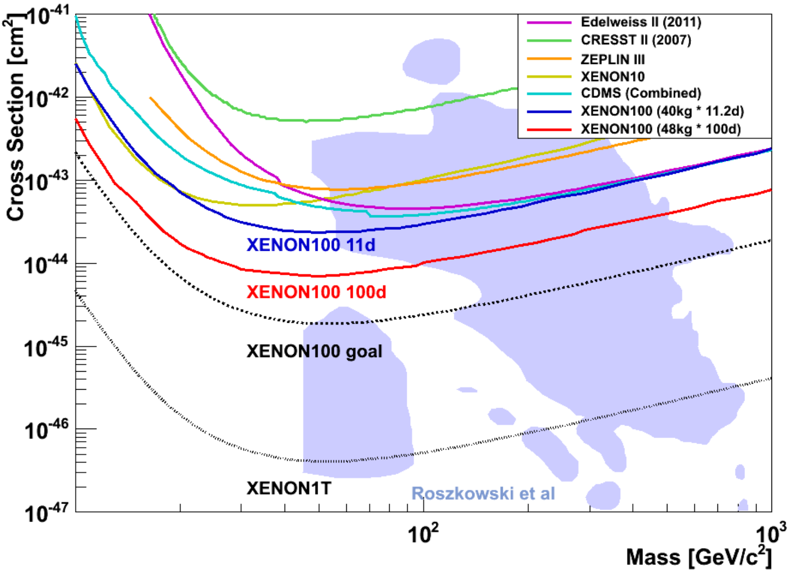
- 1 ton fiducial mass
  (total of 2.4 ton LXe)
- Drift length = $\sim$90 cm
- 100x background reduction compared to XENON100
- Shielding: 5 m water around the detector
- Titanium cryostat
- Low radioactivity photosensors
- Timeline: 2011 - 2015

XENON1T location at LNGS



- TDR submitted to LNGS in October 2010: approved recently
- Activities at UZH:
  - Test low radioactivity PMTs
  - Screening of materials
  - Design inner TPC
  - LED calibration system, DAQ, trigger system

XENON sensitivity



Summary

- Liquid xenon is a promising target material to discover dark matter
  - Large nucleus (A^2 enhancement on σ)
  - Self-shielding (large detectors)
  - Dual-phase: particle discrimination
- XENON100 is taking dark matter data
  - Design background level achieved
  - New limit based on $\sim$100 days of data released in April!
  - More data is currently being acquired under improved conditions
- XENON1T currently under design
  - Plans to start construction at LNGS this year

Additional plots