# Mini-review Direct Dark Matter Detection and recent XENON100 results

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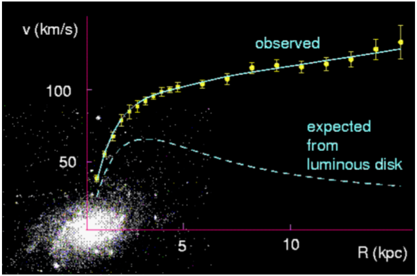
EPS, Grenoble, 21/07/2011


### Star rotation curves

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



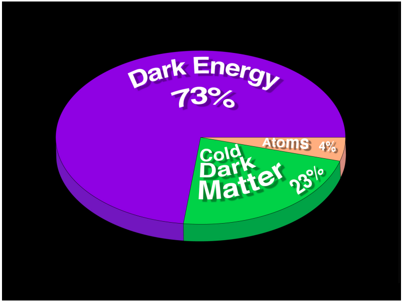

### Gravitational lensing

- Light rays bend around massive objects
- Distorsion geometry $\longrightarrow$ 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**eakly **I**nteracting **M**assive **P**article)

- Theories beyond the standard model of particle physics predict new heavy particles

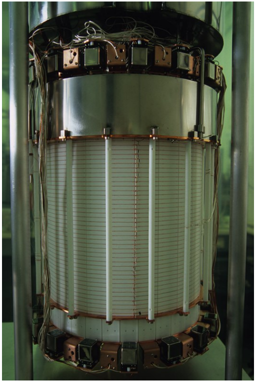
→ Example: the neutralino in SUSY

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

→ BUT many other theories predict the lightest new particle to be neutral and weakly interacting

# WIMP search

- Indirect detection
- Direct detection
- Production at LHC



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

$\longrightarrow$ Talks in next session

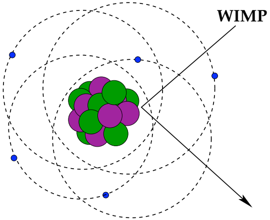
$\chi\,\mathrm{N} \rightarrow \chi\,\mathrm{N}$

$\longrightarrow$ Talk by Y. Suzuki (Tu)

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

$\longrightarrow$ Talk by A. Baroncelli

# Principle of direct detection experiments




$E_{\mathrm{R}} \sim \mathcal{O}(10\,\mathrm{keV})$

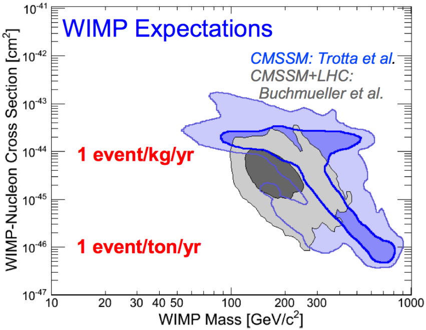
- Recoil energy of the nucleus:

$$E_{\mathrm{R}} = \frac{|\vec{q}|^2}{2m_{\mathrm{N}}} = \frac{\mu^2 v^2}{m_{\mathrm{N}}}(1 - \cos\theta)$$

  - $|\vec{q}|$ = momentum transfer
  - $\mu$ = reduced mass $\quad \mu = \frac{m_{\mathrm{N}} \cdot m_\chi}{m_{\mathrm{N}} + m_\chi}$
  - $v$ = mean WIMP velocity relative to the target
  - $\theta$ = scattering angle in the center of mass

- Expected interaction rates in a detector: $R \propto N \cdot \frac{\rho_\chi}{m_\chi} \cdot \sigma_{\chi N} \cdot \langle v \rangle$
  - $\rho_\chi$, $\langle v \rangle$= astrophysical parameters
  - $m_\chi$, $\sigma_{\chi N}$ = particle physics parameters

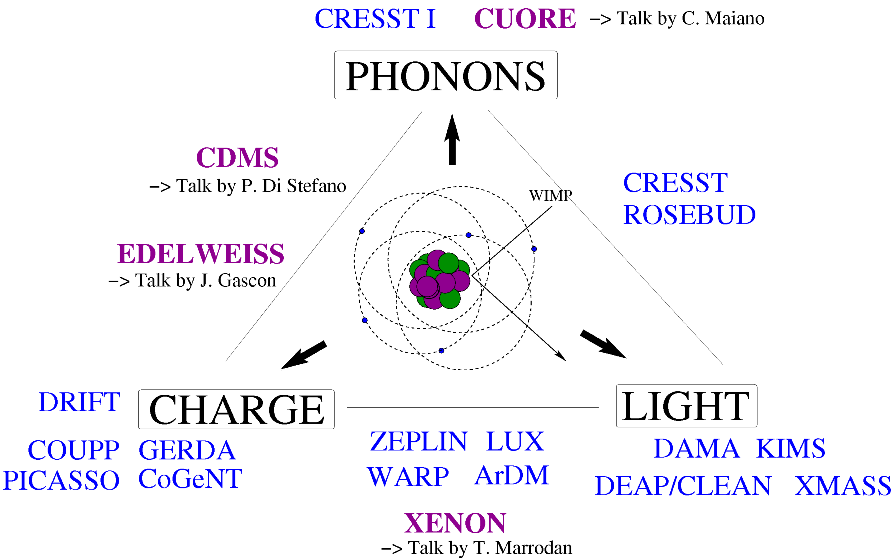
# Detector requirements




Spin independent scattering

- Signatures of dark matter signals
  - Nuclear recoil, single scatter
  - Spectral shape: exponential
  - Dependance on material
  - Annual modulation flux
  - Directional dependance
- A dark matter detector
  - Large mass
  - Low energy threshold
  - Very low background
  - good background discrimination

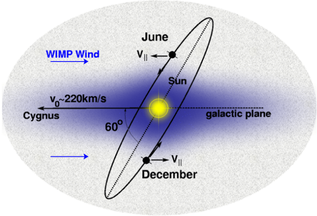
# Direct detection experiments

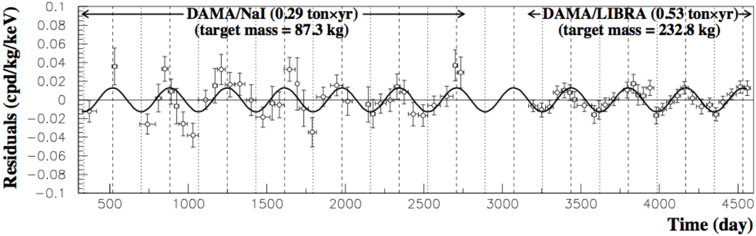


# DAMA annual modulation

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

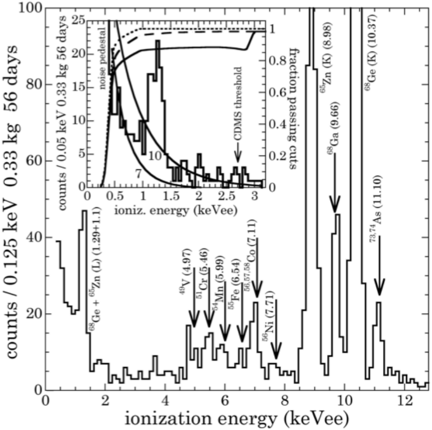
R. Bernabei *et al.*, Eur. Phys. J. C67, 39 (2010)

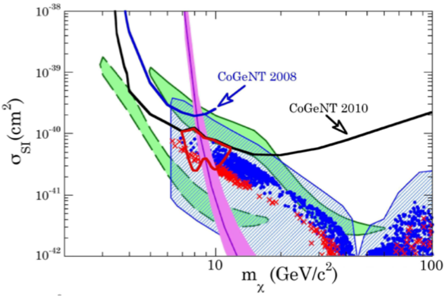



- Significant ($8\,\sigma$) seasonal oscillation in the 2-6 keV energy bin
- Is the DAMA oscillation due to Dark Matter?

- 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 paper showing an annual modulation [arXiv:1106.0650]

’Recent results of the XENON100 experiment’

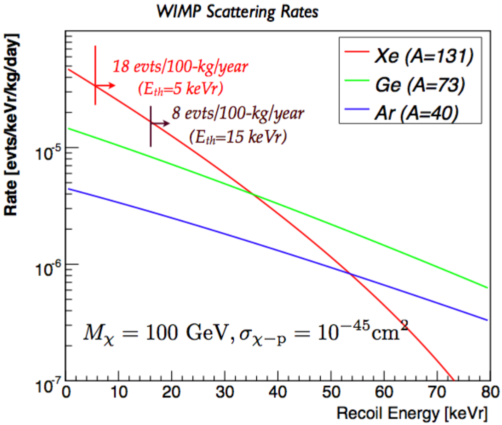
on behalf of the XENON100 Collaboration

# XENON100 Collaboration

Columbia Rice UCLA Zürich Coimbra LNGS SJTU

Mainz Bologna Subatech Münster Nikhef Heidelberg Weizman

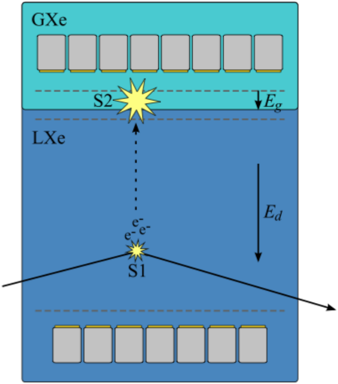
# Xenon as detection medium



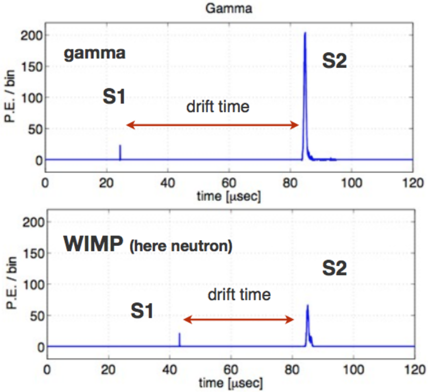

Detection via scatter off nuclei


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

# Two phase noble gas TPC




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



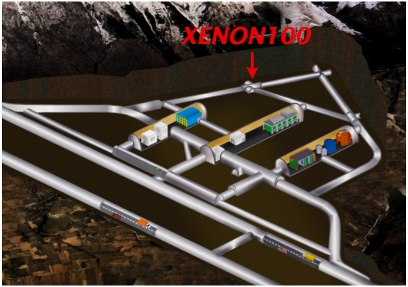

Electron recombination is stronger for nuclear recoils

$\longrightarrow$ Electronic/nuclear recoil discrimination

# XENON experiment

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

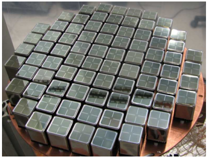
  E. Aprile *et al.*, Phys. Rev. Lett. 105, 131302 (2010)
  E. Aprile *et al.*, arXiv:1103.0303 (2011)
  E. Aprile *et al.*, arXiv:1104.2549 (2011)
  - Currently running



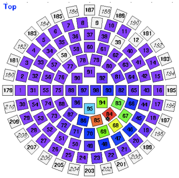

- Laboratori Nazionali del Gran Sasso (Italy)
- $\sim 3\,650$ m w e shielding

# XENON100 detector

- 30 cm drift length and 30 cm ∅
- 161 kg total (30-50 kg fiducial volume)
- Material screening and selection
- Active liquid xenon veto
- ∼100x less background than XENON10
- Bottom PMTs: high quantum efficiency (on average >30% @178 nm)



Bottom PMTs




Top array

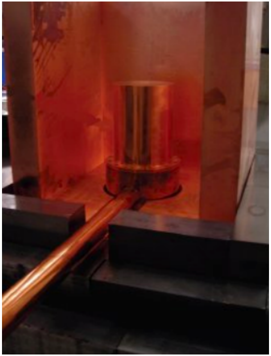
- 3 mm resolution in XY and in Z

- Instrument paper:
  arXiv:1107.2155 (2011)

# Gator screening facility operated by UZH

Material screening underground with a 2.2 kg HP Ge detector LNGS

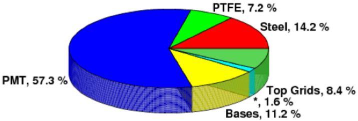
L.Baudis *et al.*, arXiv:1103.2125



→ All XENON100 construction materials were screened and selected

- XENON100, arXiv:1103.5831

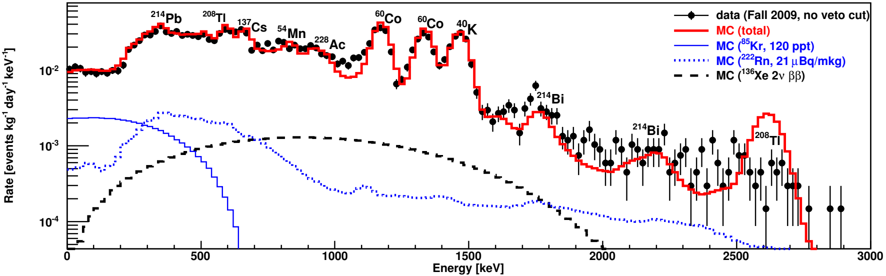
- Gamma background from materials in ROI:




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

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

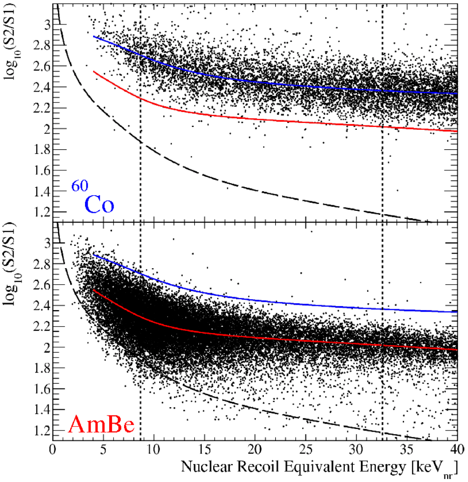
# Measured background spectrum




- 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!!

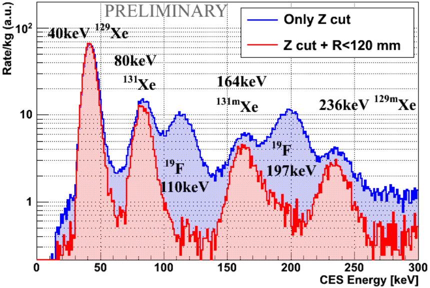
→ XENON100 Collaboration, PRD 83, 082001 (2011), arXiv: 1101.3866

# 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 ($E_{nr}$):

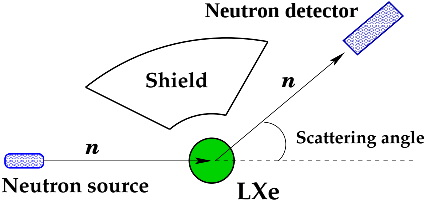
$$E_{nr} = \frac{S1}{L_y L_{eff}} \times \frac{S_e}{S_r}$$

$S1$: measured signal in p.e.

$L_y$: LY for 122 keV $\gamma$ in p.e./keV

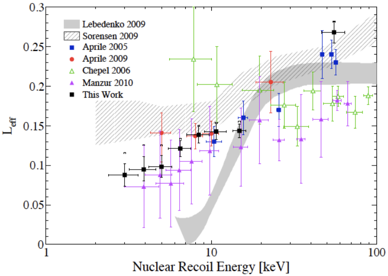
$S_e/S_r$: quenching for 122 keV $\gamma$/NR due to drift field

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

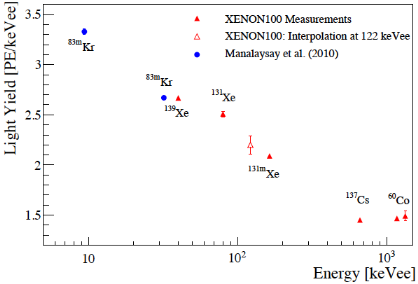


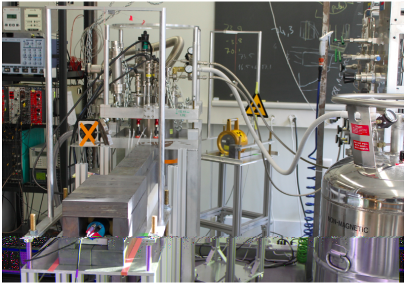

- Recent measurement at U. Columbia
- Lowest Measurement at 3 keV$_{nr}$

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




→ New measurement planned at U. Zürich



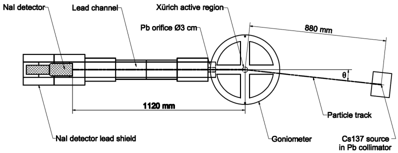
R&D at Universität Zürich:

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

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

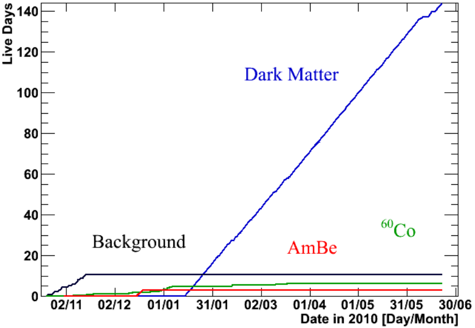
- Further down in energy

$\rightarrow$ Compton measurement




- Goal: determine the xenon LY down to $\sim$ 2 keV

# Data taking 2009/2010: Overview




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

→ New run ∼100 days blinded data

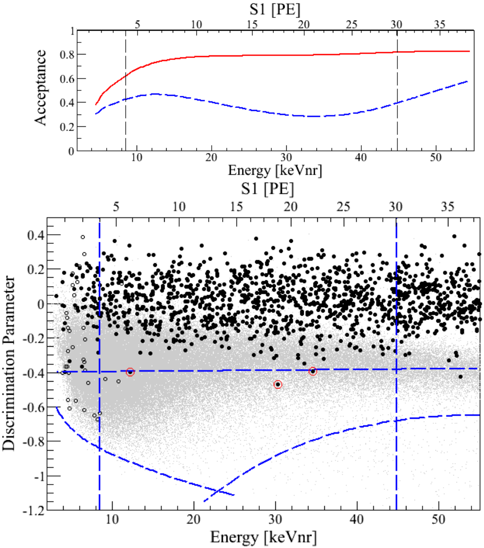
- Improved analysis:
  - New likelihood cut for anomalous S1 patterns
  - New position reconstruction algorithms
  - Improved corrections: XY and Z
  - new MC for background predictions
  - ...

→ Results released this April!

# Background prediction

- Statistical leakage from the electronic recoil band
  - $(1.14 \pm 0.48)$ 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: $(0.032 \pm 0.006)$ events
- TOTAL: $(1.8 \pm 0.6)$ events in 100.9 d

# Unblinding of the 100 days data




– High cut acceptance
– NR acceptance below 99.75% rejection

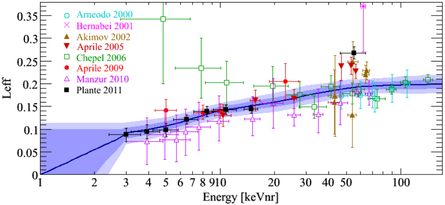
- 6 events in search window after unblinding
- 3 events identified as part of a noise population around 4pe

→ 3 WIMP candidates

# Results from 100 days data

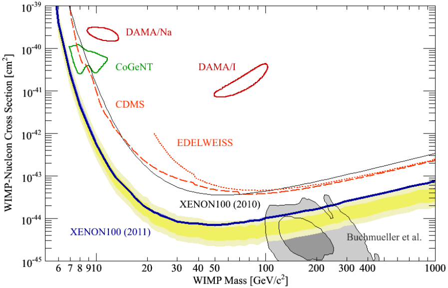
→ Poisson probability of 1.8 events to oscillate to 3 or more: 28%

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)

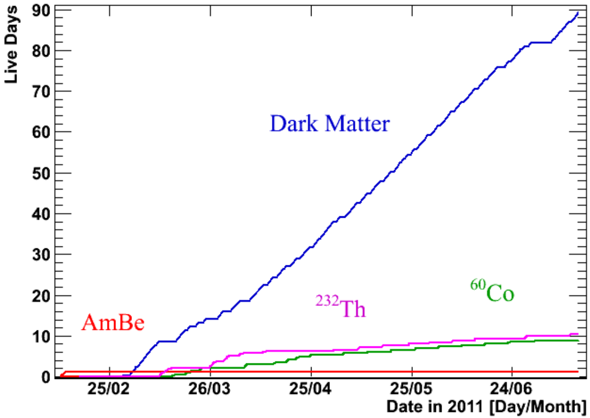
- Likelihood analysis used to extract the limit on WIMP-nucleon cross section
- Sensitivity shown by the yellow band
- Limit is robust against uncertainties



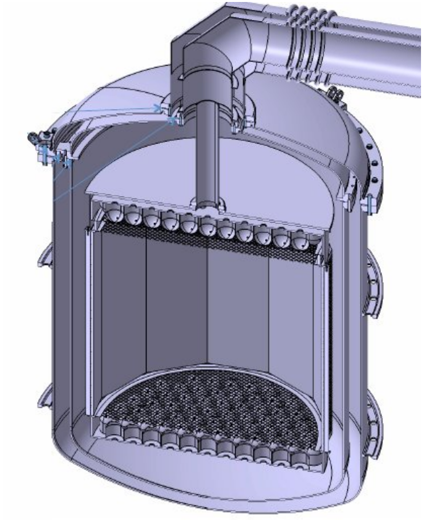

→ XENON100 Collaboration, arXiv:1104.2549

# Current status of the data taking

- New DM run started at the beginning of 2011
- Lower concentration of $^{85}$Kr: factor of 5
- Improved purity and lower trigger threshold



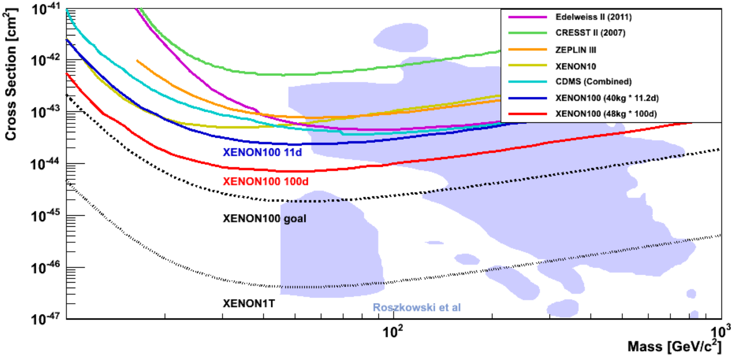
# Future: XENON1T



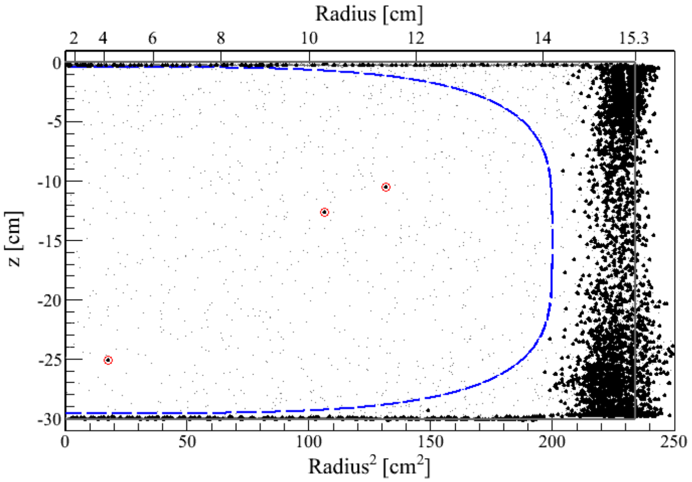
- 1 ton fiducial mass
  (total of 2.4 ton LXe)
- Drift length = $\sim$90 cm
- 100x background reduction compared to XENON100
- Water Cerenkov shielding 5 m around the detector
- Titanium cryostat
- Low radioactivity photosensors
- Timeline: 2011 - 2015
- TDR submitted to LNGS in October 2010: recently approved

# Summary

- Liquid xenon is a promising target material to discover DM
- XENON100 is taking dark matter data
  - Design background level achieved
  - New limit based on ∼100 days of data released in April!
- XENON1T currently under design
  - Plans to start construction at LNGS this year

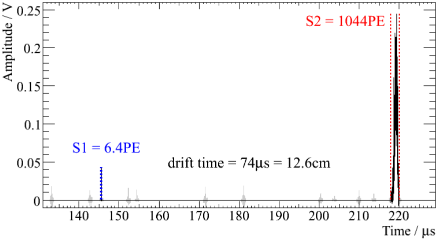


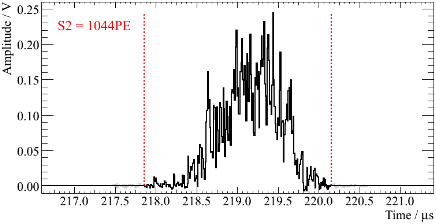
# Spatial distribution of the WIMP candidates



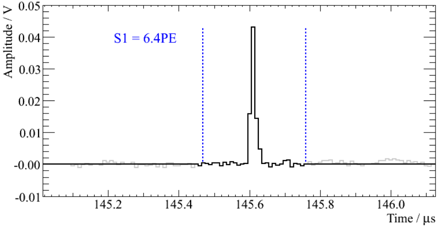

- 3 candidates clearly inside the 48 kg fiducial volume
- Background on the ER band mainly due to the homogeneous $^{85}$Kr

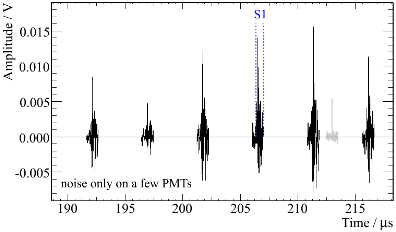
# Event waveforms: 100d data




Examples of normal and noisy S1s:

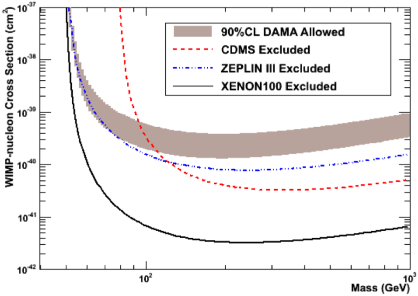


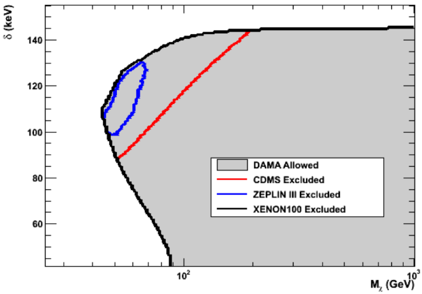



# Interpretation of DAMA signal as being due to iDM

- 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: $v_{min} = \frac{1}{\sqrt{2m_N E_R}}\left(\frac{m_N E_R}{\mu_N} + \delta\right)$

→ XENON100 excludes the interpretation of DAMA as due to iDM




⟶ XENON100 Collaboration, arXiv:1104.3121

# Background rate in Dark Matter experiments