Dark matter search with the XENON100 experiment

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Outline

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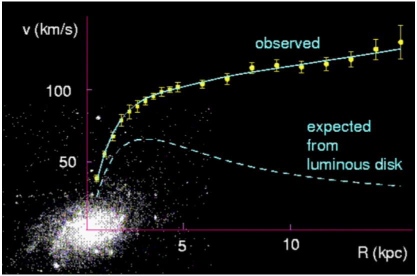
Indications from astronomy

Star rotation curves

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

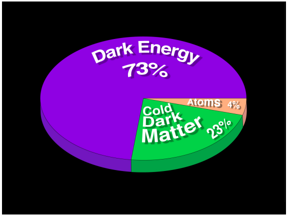


Bullet cluster

- Indirect dark matter evidence
- Baryonic matter in red (X-rays)
- Matter distribution in blue (gravitational lensing)

+ large scale structures, WMAP data...

Dark matter theoretical predictions



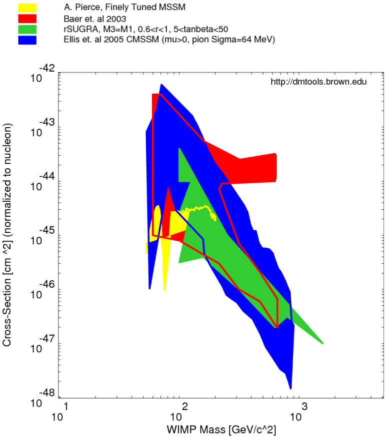
DM particle candidates:

- Sterile neutrinos
- Axions
- Kaluza-Klein states
- SUSY particles
  - Neutralino χ
- Little Higgs ...

WIMP

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

"Enhancement" of predictions around $10^{-45\pm2}$ cm^2

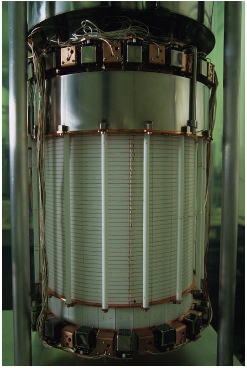


WIMP search

- Indirect detection

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

- Direct detection

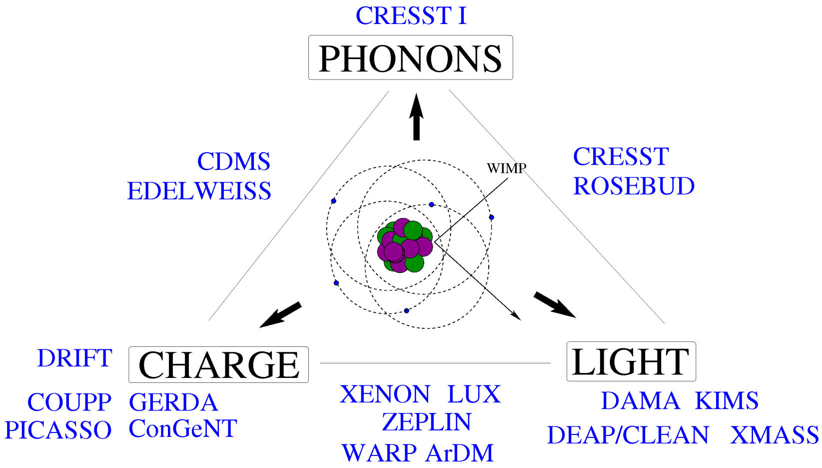


$\chi\,\mathrm{N} \rightarrow \chi\,\mathrm{N}$

- Production at LHC

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

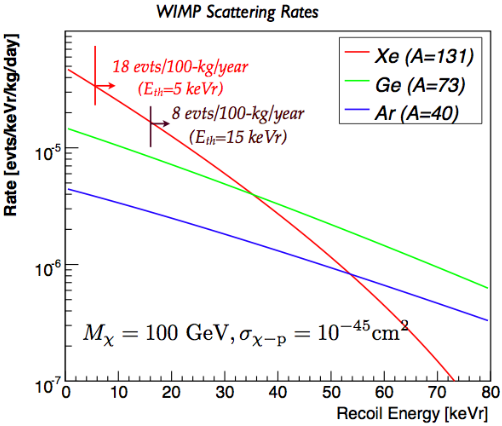
Direct detection experiments



Outline

Xenon as detection medium

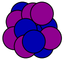
Detection via scatter off nuclei



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

Xenon scintillation

Nuclear recoil



Excitation: N^*

$$N^* + N \rightarrow N_2^*$$

$$N_2^* \rightarrow 2N + h\nu$$

singlet
3 ns

triplet
25 ns

Ionization: N^+ and e^-'s

$$N^+ + N \rightarrow N_2^+$$

$$N_2^+ + e^- \rightarrow N^{**} + N$$

$$N^{**} \rightarrow N^* + \textbf{heat}$$

$$N_2^+ + e^- \rightarrow N_2^*$$

$$N_2^* \rightarrow 2N + h\nu$$

singlet
3 ns

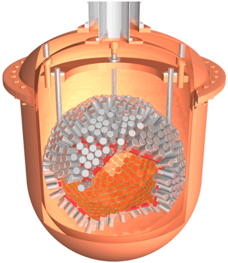
triplet
25 ns

XMASS experiment

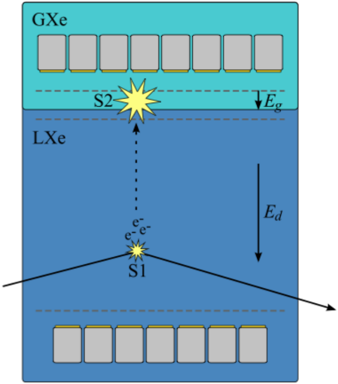
- → Search for dark matter
- → Solar neutrinos
- → Double beta decay

→ Picture from February 2010

- 800 kg of LXe (one phase)
- Copper structure
- $\sim$800 ton water shield
- In construction in the Kamioka mine



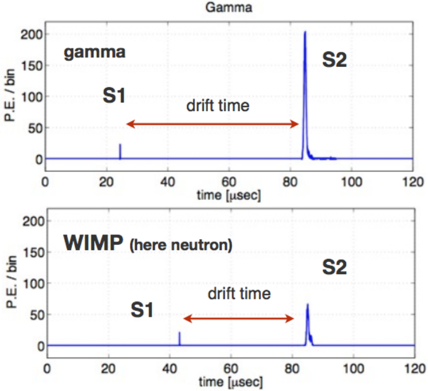
Two phase noble gas TPC



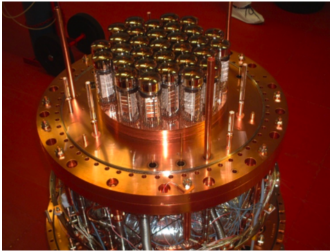
Electron recombination is stronger for nuclear recoils

→ Electron- / nuclear recoil discrimination

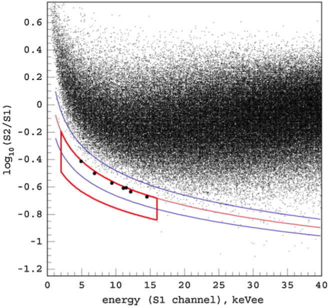
- Scintillation signal (S1)
- Charges drift to the liquid-gas surface
- Proportional signal (S2)

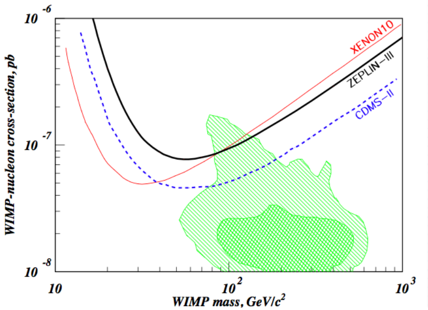


Zeplin III



- $\sim$ 30 cm $\varnothing$
- 31 $\times$ 2 inch PMTs
- 12 kg target mass
- 3.5 cm drift depth $\rightarrow$ high E-field
  3.9 kV per cm
- 0.5 cm electroluminescent gap





Outline

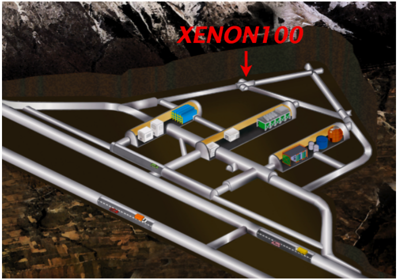
XENON experiment

- Laboratori Nazionali del Gran Sasso (Italy)
- 3 500 m.w.e. shielding

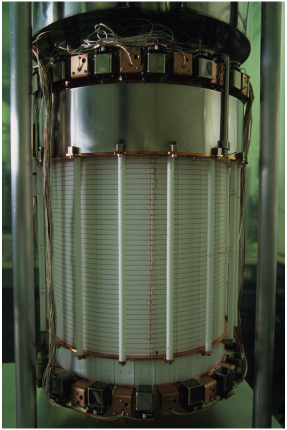
- XENON10: 15 kg active volume
  - Finished: No evidence for DM

J. Angle *et al.*, Phys. Rev. Lett. 100, 021303 (2008)
J. Angle *et al.*, Phys. Rev. Lett. 101, 091301 (2008)
J. Angle *et al.*, Phys. Rev. D80, 115005 (2009)

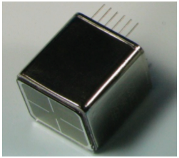
- XENON100: 62 kg active volume
  - Currently taking science data



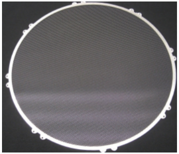
XENON100 detector



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



1 inch PMTs



30 cm ∅ meshes

XENON100 detector

- 30 cm drift length and 30 cm ∅
- 161 kg total (30-50 kg fiducial volume)
- ~ 100x less background than XENON10
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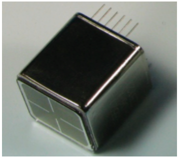
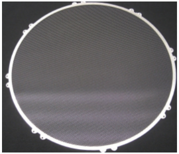
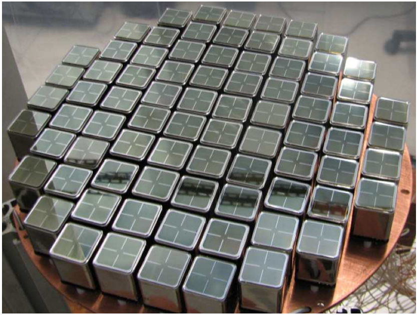


1 inch PMTs



30 cm ∅ meshes

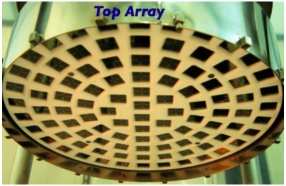
Light and charge read out



gamma event localized

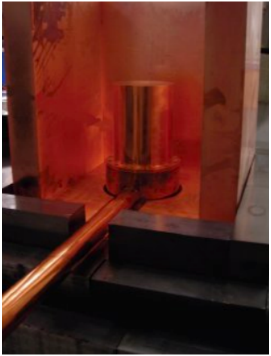
Top PMT array

- High quantum efficiency PMTs in the bottom array (>32% @178 nm)
- 3 Dim. position reconstruction
  - XY from light pattern in the PMTs
  - Z from the drift time
- 3 mm resolution in XY and 2 mm in Z

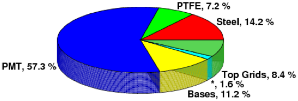


Background prediction

Material screening underground with a 2.2 kg HP Ge detector



- Gamma background expected:
  - $5{\cdot}10^{-3}$ evts/kg/keV/d (before discrimination cuts)

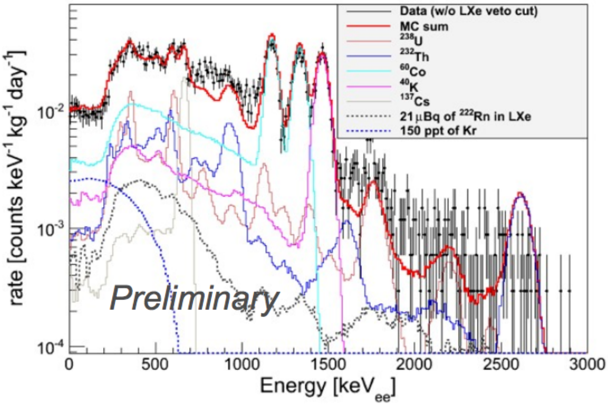


- Neutron bg from simulations:
  - $<$ 1 event/year
  - 2/3 from radioactivity and 1/3 muon-induced

- Removal of ^{85}Kr: distillation column
  - Kr/Xe $\sim$ ppm-ppb commercially available
  - Measurement in XENON100 after purification:

  $\longrightarrow$ currently $\sim$ 140 ppt via delayed gamma-beta coincidence

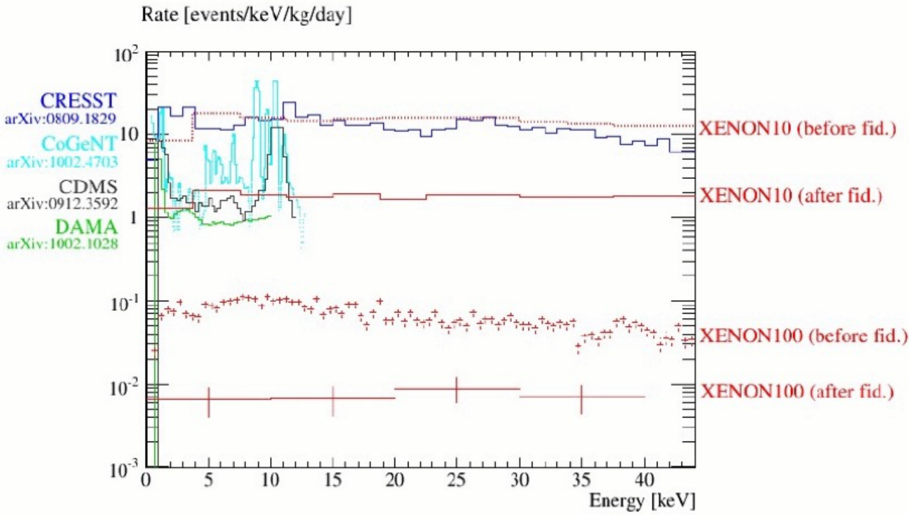
Measured background spectrum



- Background at the level of predictions
- No tuning of the Monte Carlo
- The measured single scatter rate below 100 keVee is 10^{-2} evts/kg/keV/d without veto cut
- Factor 100 less than in XENON10 achieved!!

→ currently optimizing the data/MC comparison

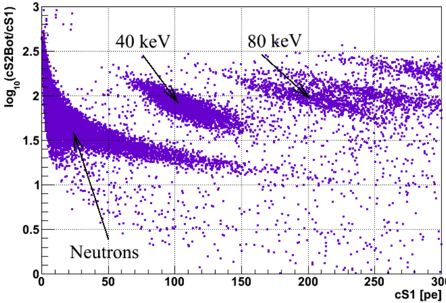
Background in the low energy range

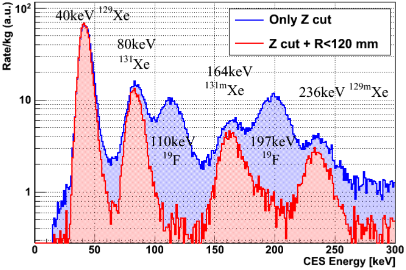


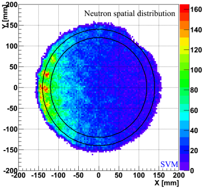
→ Lowest ever measured background rate in a dark matter experiment

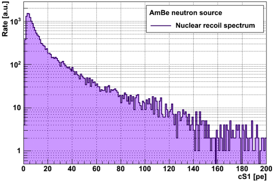
Outline

Neutron calibration



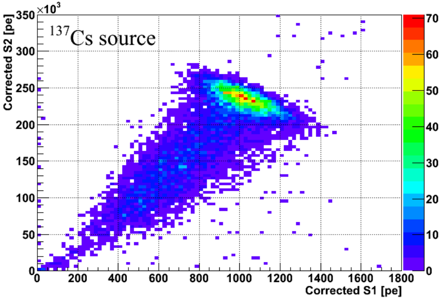


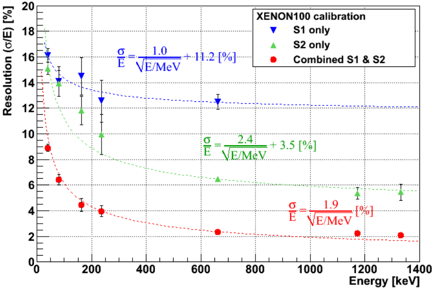


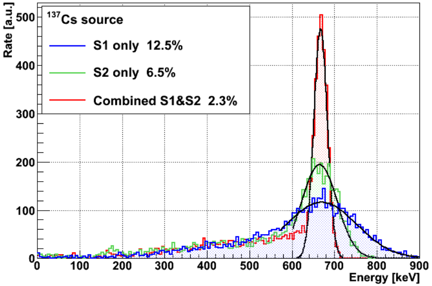


- Source: AmBe with 220n/s
- Determination of nuclear recoil band
- Further lines from inelastic recoils in xenon

Calibration with gamma sources





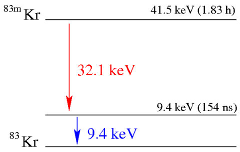


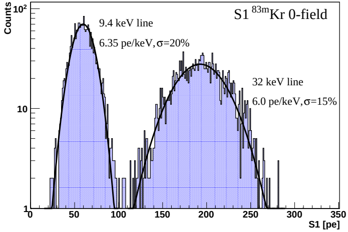
- Energy dependence of resolution in S1, S2 and CES
- CES: combined energy scale

→ anticorrelation between S1 and S2

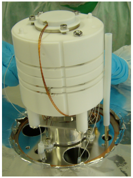
Low energy calibration of xenon detectors

- ^{83m}Kr calibration source:
  - EC decay-product of ^{83}Rb
  - Lines at 9.4 and 32.1 keV
  - Uniform distribution



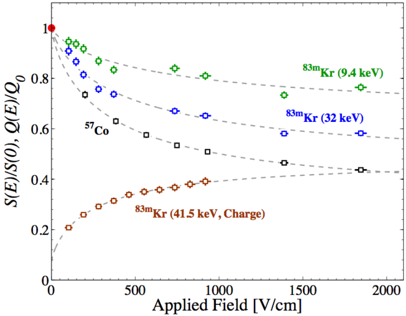


- ^{83m}Kr calibration planned in XENON100



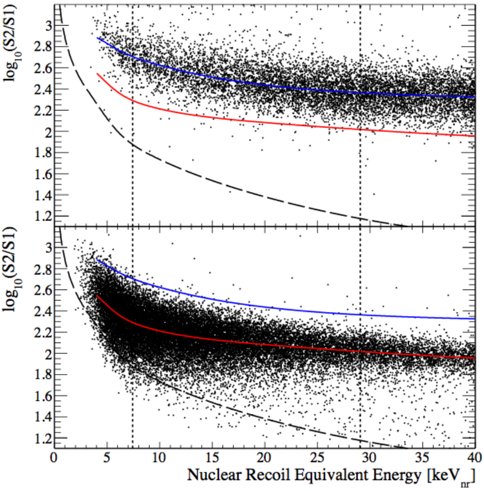
- Target mass: ∼ 0.1 kg Xe
- Volume: 3 cm drift length and 3.5 cm diameter
- Two R9869 PMTs
- 6 pe/keV in double phase

→ at University of Zürich



A. Manalaysay *et al*, accepted at Rev. Sci. Instrum. (2010)

Electronic and nuclear recoil bands



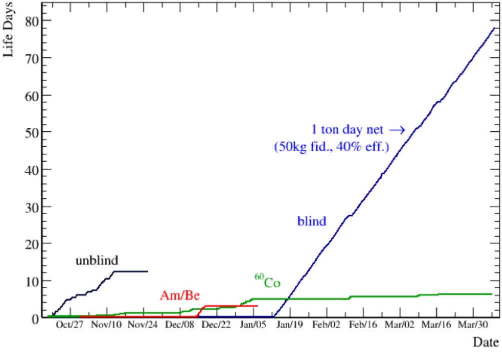
- Electronic recoil band: defined with ^{60}Co source
- Nuclear recoil band: defined with AmBe neutron source

- Discrimination better then 99% @ about 50% NR acceptance

Outline

Data sample

Overview of the data taking:



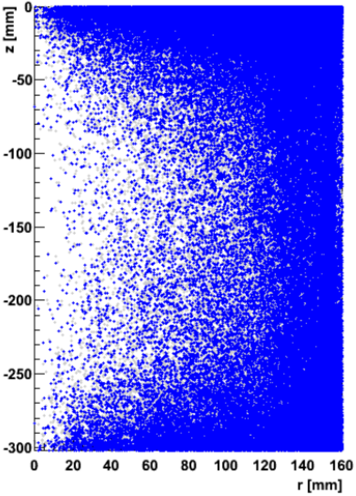
→ Analysis of unblinded data

→ Main data sample (blinded) not yet analyzed!

- 11.17 life days
- Data selection based on stable conditions:
  - no activation
  - no HV problems
  - no radon
- Period:

  October-November 2009
- Cuts defined on calibration data: AmBe and ^{60}Co

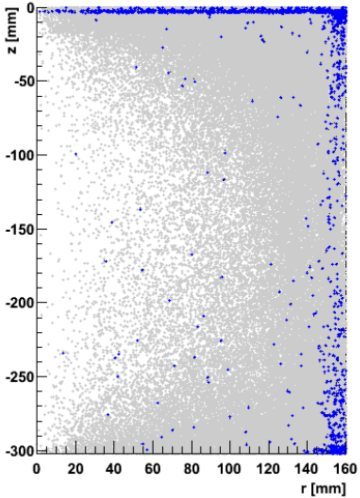
Basic cuts



→ Spatial distribution of the events after:

- Signal/noise ratio cut
- Single S1 peak: remove accidental coincidences
- Single S2 peak: select single scatter events
- Remove events in gas phase
- Apply active veto cut

Energy cut



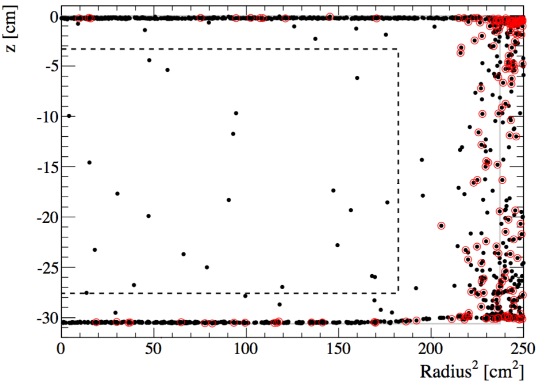
- Energy cut: Select events with energies lower than 28 keVnr (keV nuclear recoil equivalent)

→ defined region of interest for elastic scattering of WIMPs in xenon

- Self-shielding: Most of the low energy events are located close to the edges of the detector

→ remaining events mostly intrinsic contamination

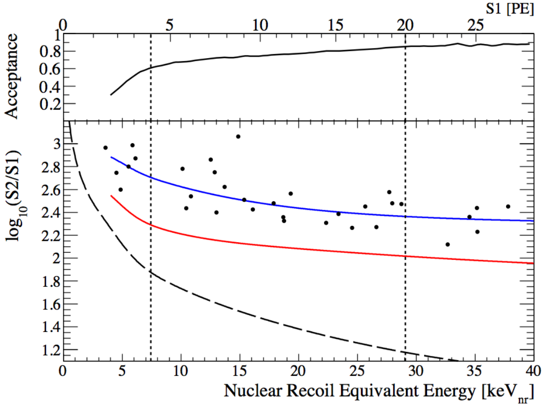
Fiducial volume



- 3-D position reconstruction:
  allows the selection of the inner part of the detector
- Current fiducial volume: cylindrical shape with 40 kg mass

$\longrightarrow$ will be further optimized

Particle discrimination



- 'Background free': in the 11.17 days after discrimination
- Comparison to XENON10: for approximately the same exposure

→ much cleaner detector

Converting pe into keVnr

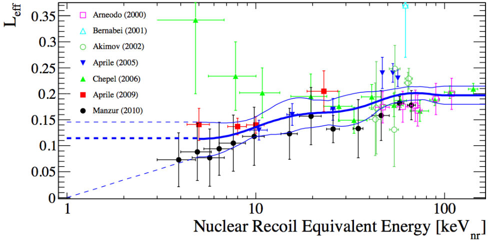
- Nuclear recoil energy (E_{nr}):

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

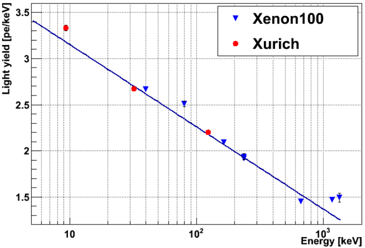
$S1$: measured signal in p.e.

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



- Light yield with energy



- 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

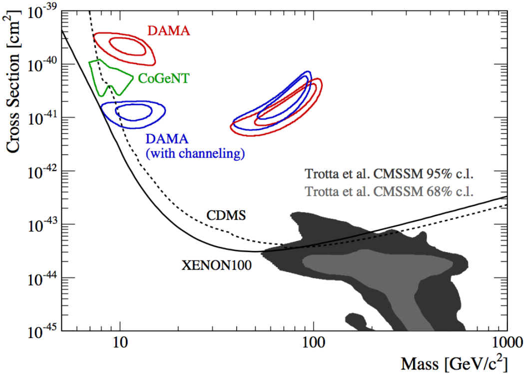
Limit from unblinded data

- Spin independent limit: for standard halo parameters

→ using the energy region $(7.4 - 29.1)$ keVnr

- Excellent sensitivity: even for few days of data

→ arXiv:1005.0380v1

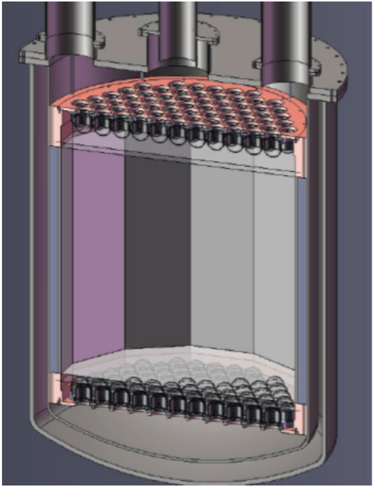


- New result questions light WIMP explanation of DAMA and CoGeNT signals

- Much more data recorded in blind mode

+ analysis in the high nuclear-recoil energy region

Future: XENON1t



- 1 ton fiducial mass (total of 2.2 ton LXe)
- Drift length = $\sim$90 cm
- 100x background reduction
- Muon veto
- Copper/titanium cryostat
- New photo-detectors?

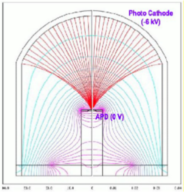
$\rightarrow$ Schedule: 2010 - 2015 ?

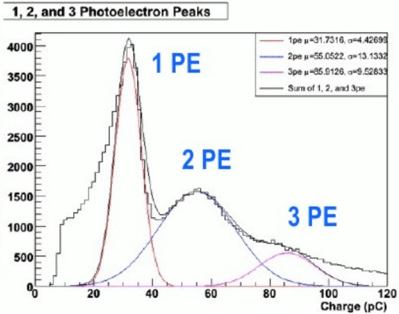
New collaborators

Currently working on MC simulations and design +secure funding

Photosensors

- **QUPIDS** for light readout
  (**QU**artz **P**hoton **I**ntensifying **D**etector)
  - Ultra-low radioactivity
    ($\sim$ 0.1 mBq)
  - High QE and high SPE resolution
  - Development UCLA &
    Hamamatsu

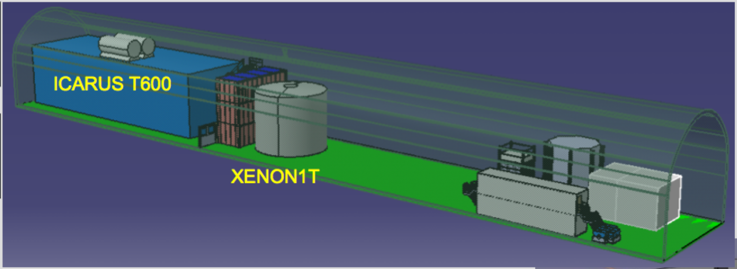




- First test at UCLA
- QUPID working in liquid xenon!

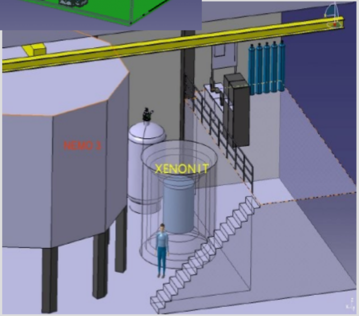
$\rightarrow$ single electron response

Location under discussion ...

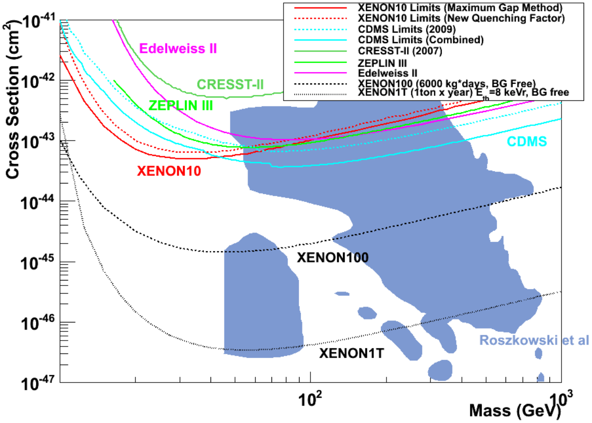


XENON1T @ LNGS (Hall B)
→ 4 m water shield

XENON1T @ LSM
→ solid shield (55cm poly, 20cm Pb, 15cm poly, 2cm ancient Pb, >99% muon veto)



XENON sensitivity



- XENON100 sensitivity for 6 000 kg days (200 d $\times$ 30 kg bg free)
- Capability to detect about 10 events for 100 GeV mass for a WIMP-nucleon cross section of $\sim 10^{-44}$ cm^2 within 2010

Outline

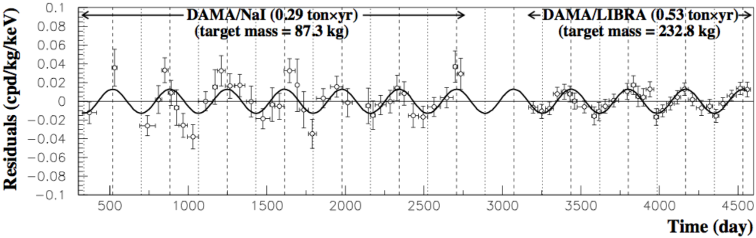
Summary

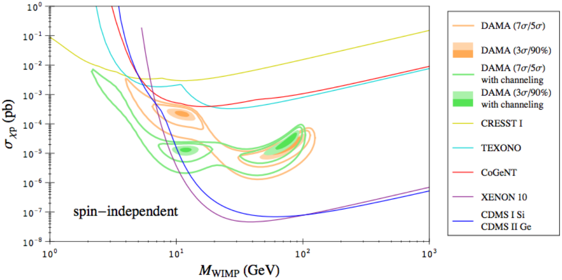
- Liquid xenon is a promising detector material to discover dark matter
  - Large nucleus (A^2 enhancement on σ)
  - Dual-phase: particle discrimination
  - Self-shielding (large detectors)
- XENON100 is taking dark matter data
  - Design background level achieved:

  $\rightarrow$ lowest ever measured!
  - First unblinded data analyzed

  $\rightarrow$ new limit published! arXiv:1005.0380v1
- XENON1t currently under design

DAMA compared to other experiments





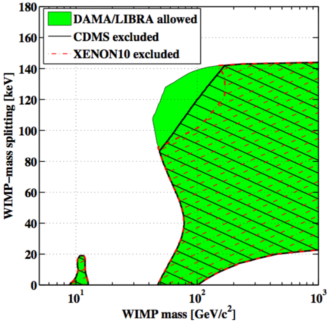
- Significant seasonal oscillation in the 2-6 keV energy bin
- Tension with other DM experiments

→ Plot from C.Savage, G.Gelmini, P.Gondolo and K. Freese (2009)

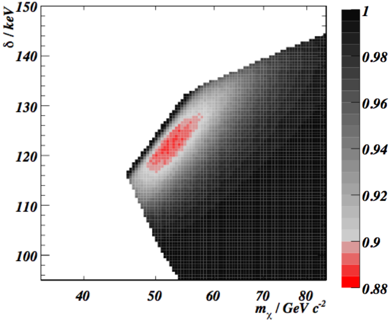
Interpretation of DAMA signal as iDM

- Inelastic dark matter model (D. Tucker-Smith and N. Weiner)
  - WIMP scatter to an excited state
  - Minimum relative speed: $v_{min} = \frac{1}{\sqrt{2m_N E_R}}(\frac{m_N E_R}{\mu_N} + \delta)$

→ Expected WIMP rates for Ge/Xe at higher nuclear recoil energies



CDMS detector: 230 g of germanium
arXiv: 0912.3592 [astrp-ph]



Zeplin: 6.5 kg liquid xenon
Latest result arXiv:1003.5626v2 [hep-ex]

- XENON100 results can check the remaining allowed region