Westfälische Wilhelms-Universität Münster

Direct Dark Matter Search with XENON100 and XENON1T

Xe XENON Dark Matter Project

25th International Workshop on Weak Interactions and Neutrinos (WIN2015)

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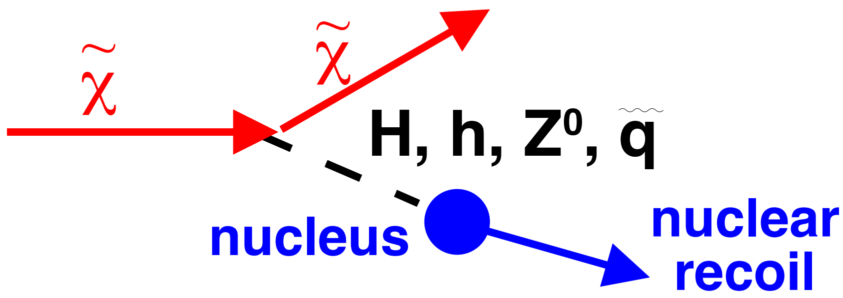
- **Direct dark matter search with XENON100**
- **Recent results from XENON100**
- **Progress and status of XENON1T**
- **Conclusions**

Direct search for WIMPs



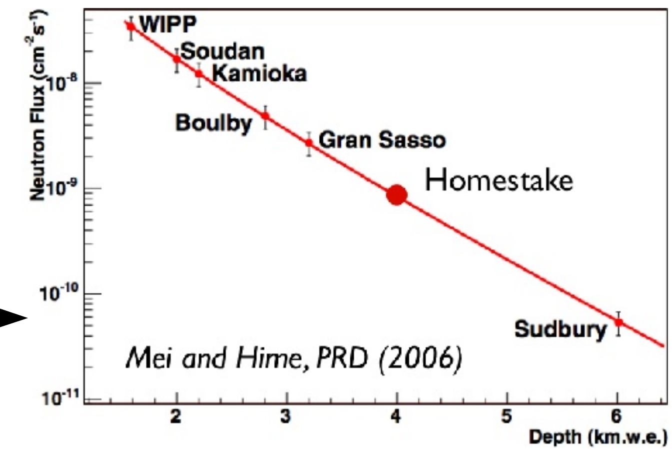
⇒ **exponential recoil energy spectrum:**

$$\frac{dR}{dE_r} = \frac{\rho_0 \cdot \sigma_0 \cdot F^2(q^2)}{2 \cdot m_{\tilde{\chi}} \cdot {\mu_r}^2} \cdot \langle \frac{1}{v} \rangle = \frac{\rho_0 \cdot \sigma_0 \cdot F^2(q^2)}{\sqrt{\pi} \cdot m_{\tilde{\chi}} \cdot {\mu_r}^2 \cdot v_0} \cdot e^{-\frac{E_r \cdot m_A}{2 \cdot \mu_r^2 \cdot v_0^2}}$$

but very low rate & very low recoil energy

⇒ **go underground to reduce μ`s and μ-induced n`s**

& shielding, very clean materials, ..



⇒ **special techniques to suppress γ, e, α background**

a) large detector mass to see annual modulation (DAMA/LIBRA)

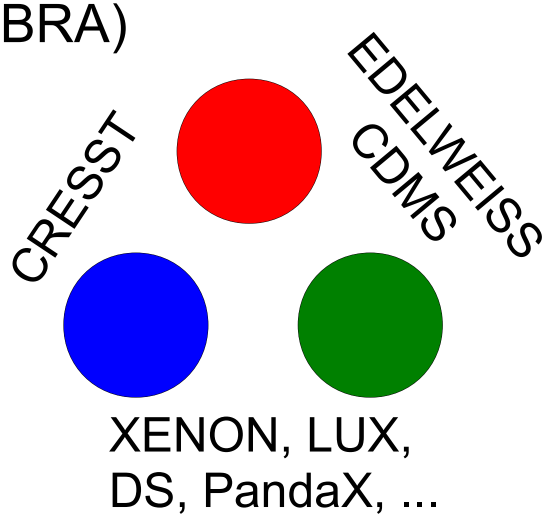
b) double read-out to distinguish nuclear recoil from others

- cryobolometers:

  heat + ionsiation or heat + light

- liquid noble gas detectors:

  light + ionisation

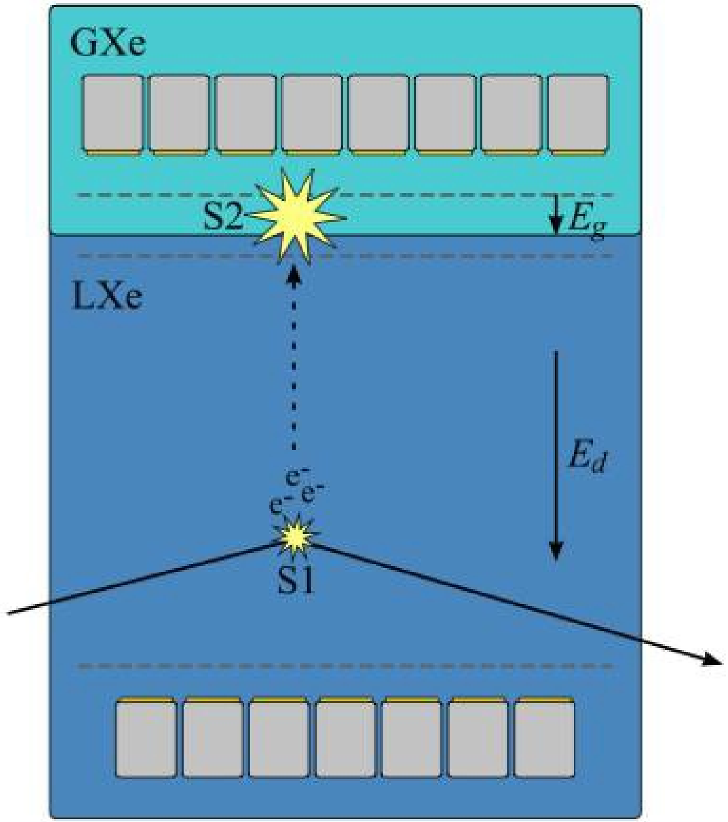


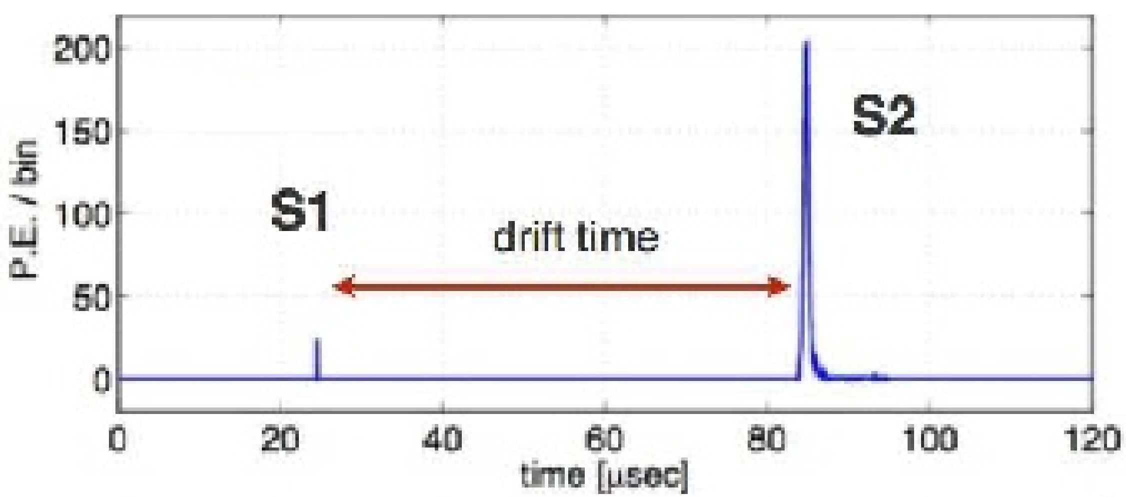
c) directional (but not enough target mass)

Dual phase liquid noble gas detectors eg. XENON 100: basic principle

Detector: liquid xenon time projection chamber (-91 °C)
in passive shield (γ and neutron shield)

WIMP interaction
- ⇒ prompt scintillating light S1
  electrons are drifted into gas phase
  by drift field in LXe (0.5-1 kV/cm)
- ⇒ proportional light (S2) by electro-luminescense
  in GXe (10kV/cm)



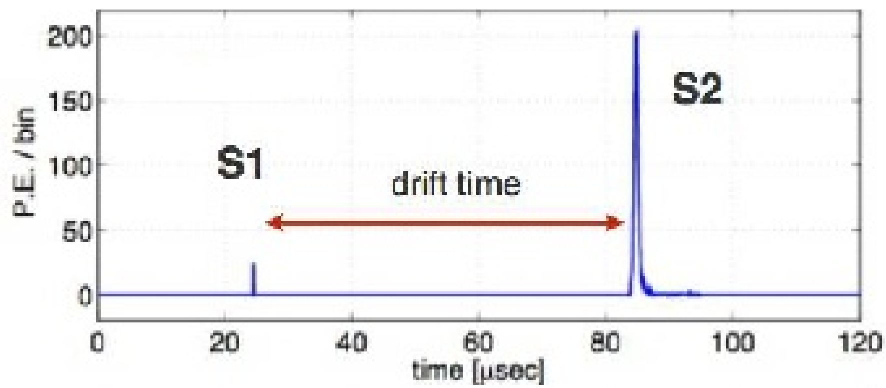


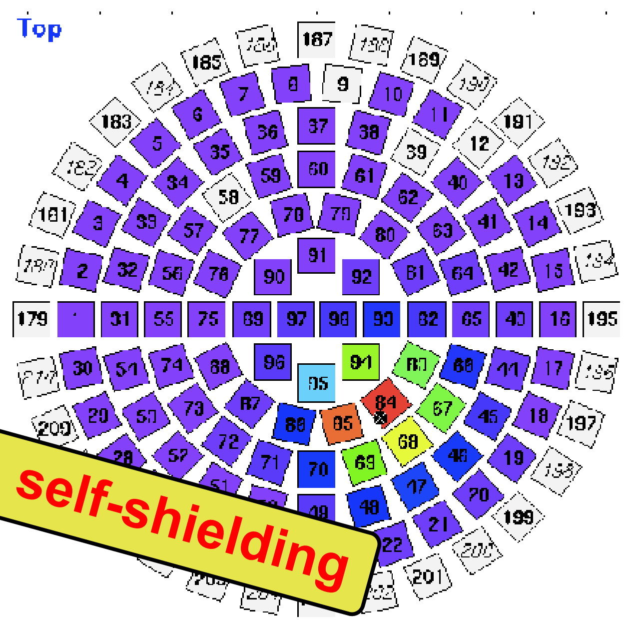
Dual phase liquid noble gas detectors eg. XENON 100: position reconstruction

Drift time of charge to liquid / gas interface = Dt(S1-S2):

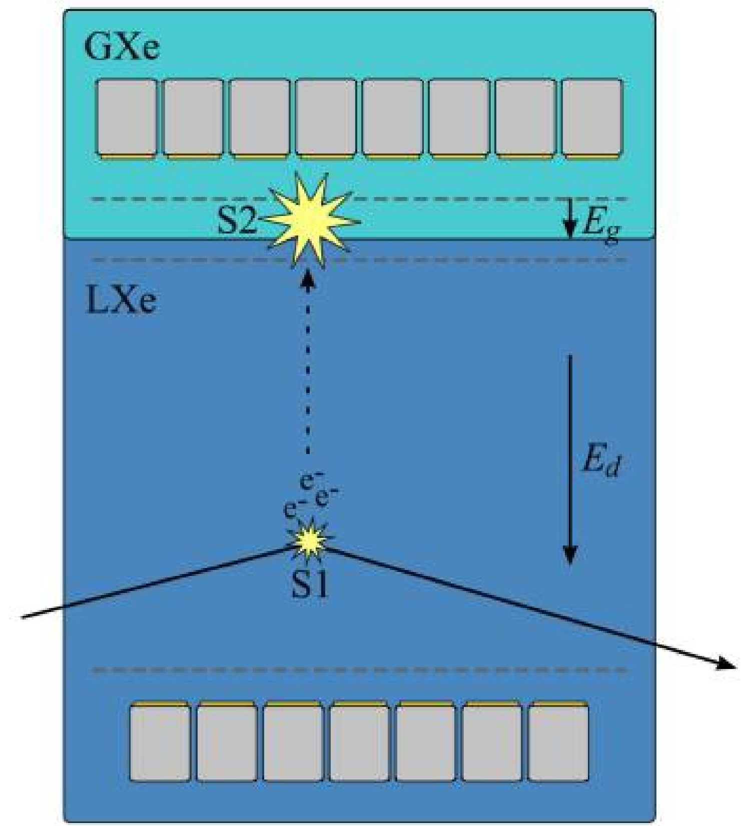
in LXe: 0.53 kV/cm: v_d = 1.7 mm/μs

→ vertical position precision: Δz = 0.3 mm





⇒ fiducialisation & self-shielding

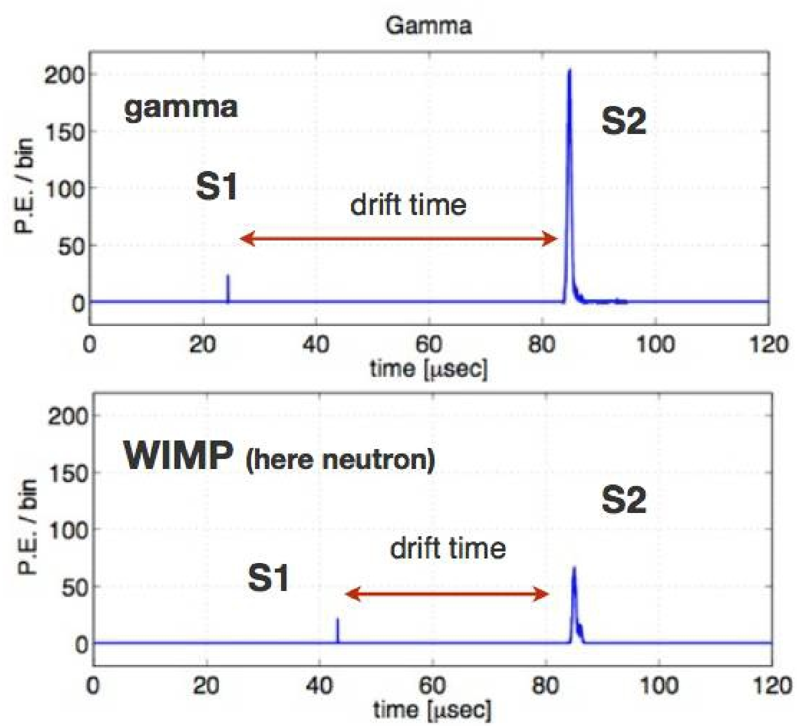


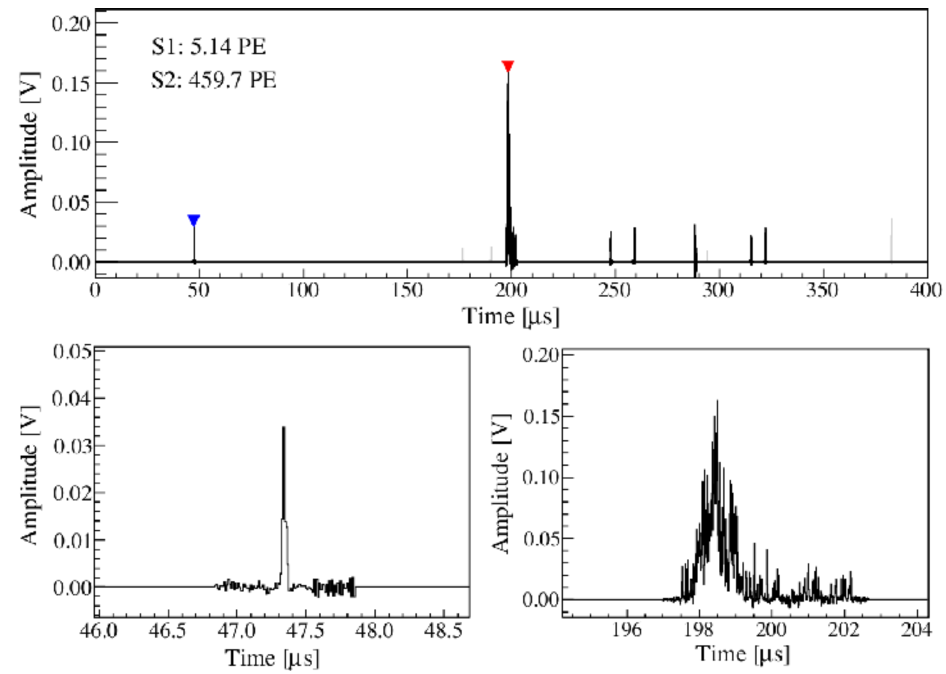
Electroluminescence in GXe

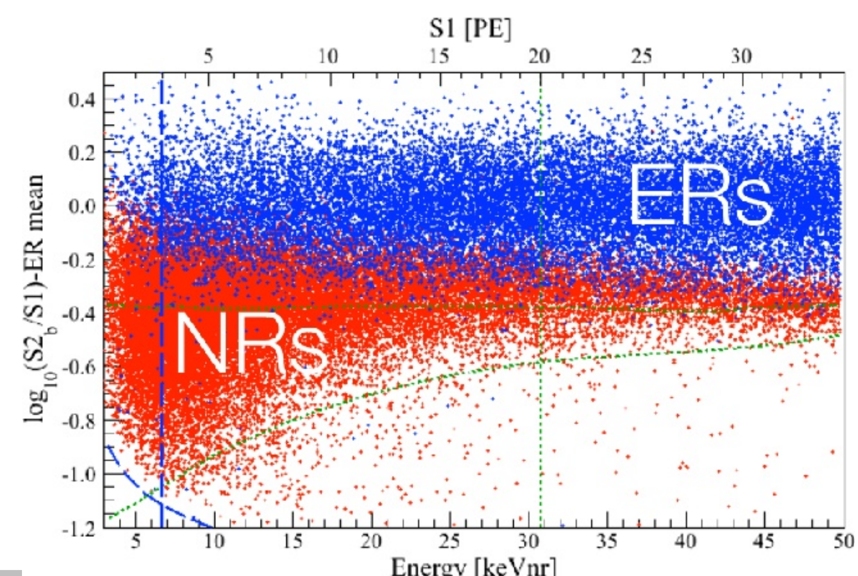
→ light pattern on top PMT array provides horizontal position with Δx = 3 mm = Δy precision

Dual phase liquid noble gas detectors, e.g. XENON 100: nuclear recoil and e-/γ separation

Distinguish nuclear recoil
(WIMP, n → charge quenching)
from electronic recoil (background)
using S2/S1 ratio







⇒ 99.5% background rejection @ 50% nuclear recoil acceptance

Arguments for a xenon detector

Heavy nucleus (A~131):
→ good for spin-independent interaction
(coherent scattering off all nucleons)
SD sensitivity too (~50% odd isotopes)

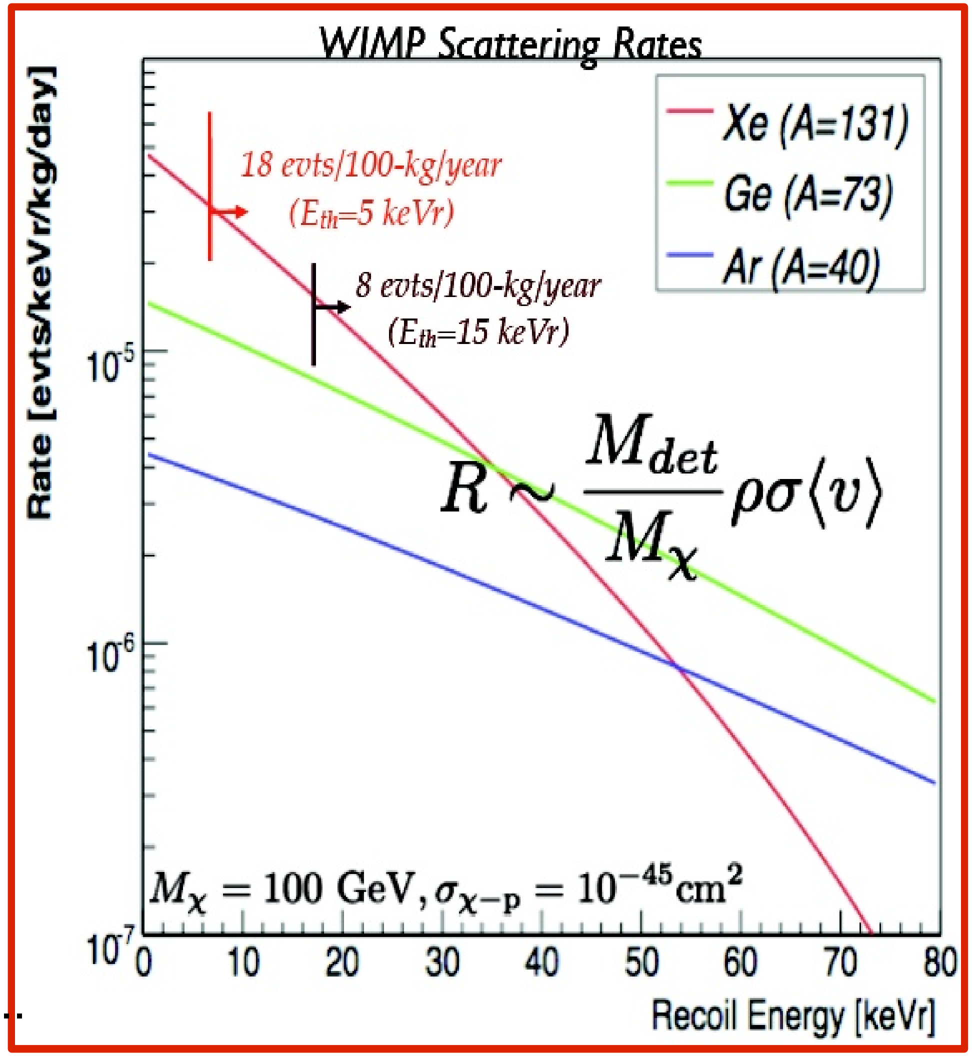
High nuclear charge (Z=54)
→ very good self-shielding

Ultraclean material
liquid noble gases are among the most clean materials
no long-lived isotope except
^{136}Xe: $t_{1/2}$ = 2 10^{21} yr, 8.9% nat. abundance

Very high charge & light yield:
42,000 γ / MeV at 178nm (PMTs exist)

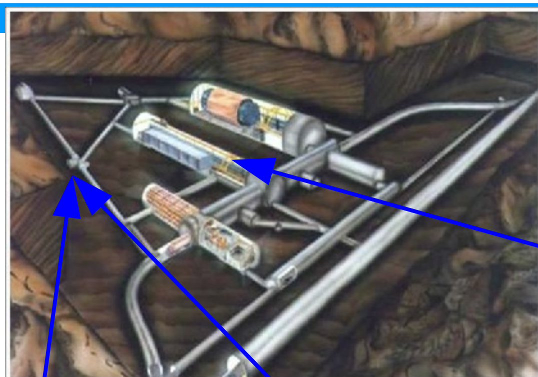
Proven XENON technology with
high efficiency & low energy threshold,
background rejection methods, fiducialisation, ...

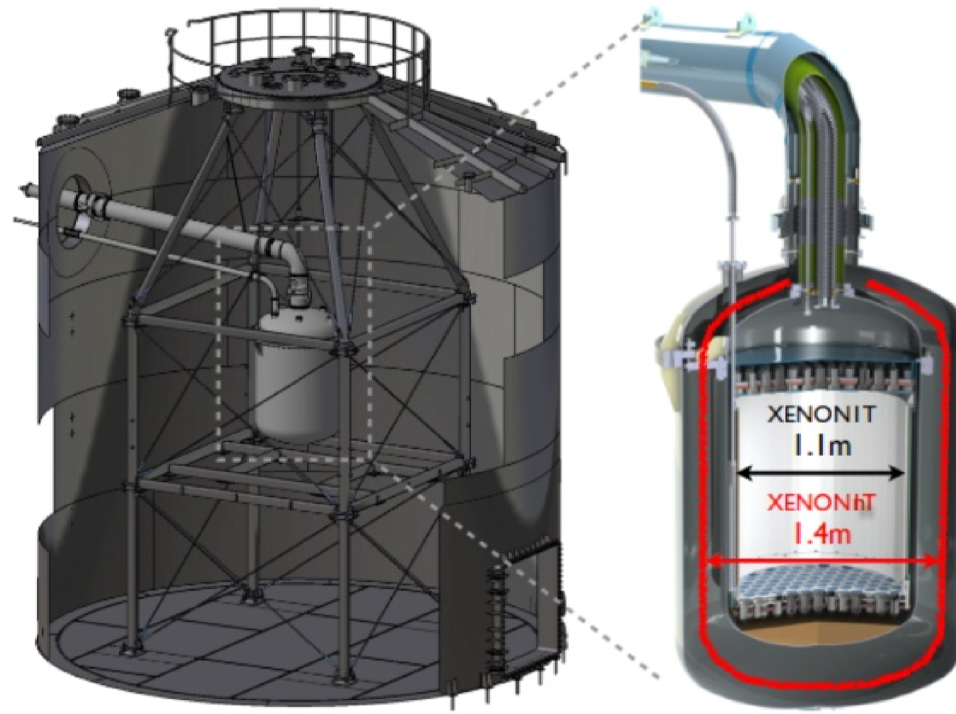
Moderate cost (<2k$/kg),
effort scales with surface not volume



(for details see E. Aprile, T. Doke, Rev. Mod. Phys. 82 (2010) 2053)

XENON: staged WIMP search @LNGS





XENON10
2005 - 2007
15 cm drift TPC
25 kg xenon
$\sigma_{SI} < 8.8 \cdot 10^{-44}$ cm^2

XENON100
2008 - 2015
30 cm drift TPC
161 kg xenon
$\sigma_{SI} < 2.0 \cdot 10^{-45}$ cm^2

XENON1T (XENONnT)
2012 -
1000 cm drift TPC
3300 (7000) kg xenon
$\sigma_{SI} < 1.2 \cdot 10^{-47}$ cm^2 (< $2 \cdot 10^{-48}$ cm^2)

The XENON collaboration
about 120 scientists from 19 institutions

Columbia RPI Nikhef Mainz Stockholm Muenster

Chicago MPIK

UCLA Bern

Rice Zurich

Purdue Coimbra Subatech Bologna LNGS Torino Weizmann NYUAD

XENON100 TPC

161 kg dual phase GXe & LXe TPC

TPC: 30.5 cm diameter
30.6 cm height
→ 62 kg active target
99 kg LXe veto (> 4 cm)

98 + 80 (+64) 1“ x 1“ R8520-AL PMTs

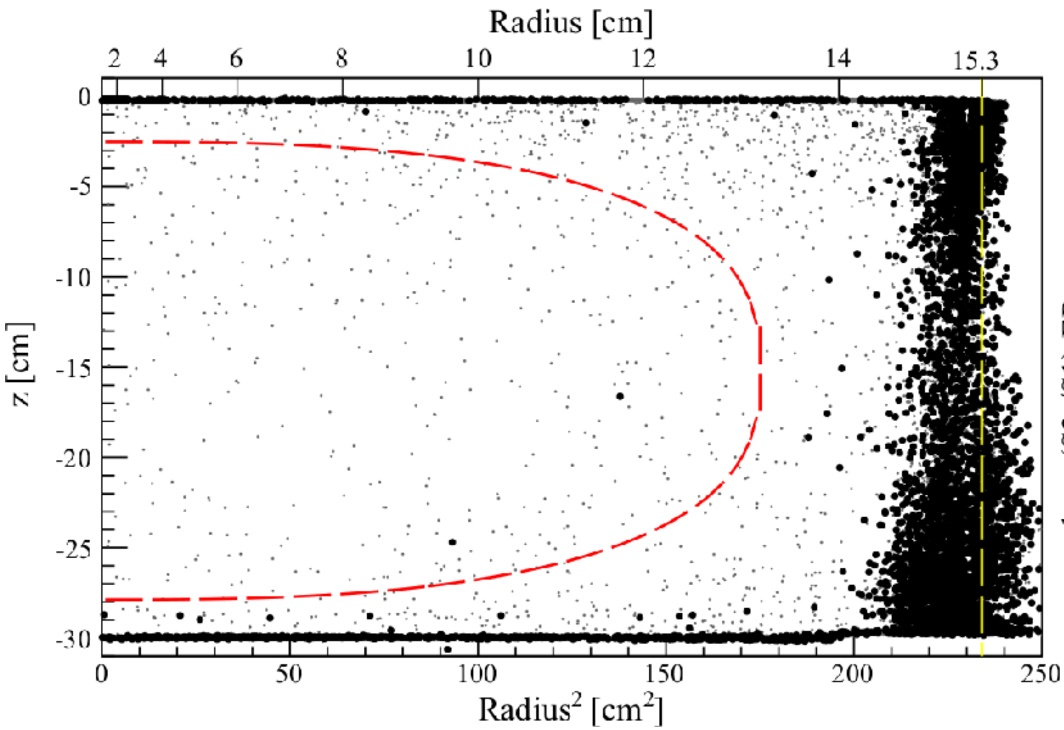
passive shield, screened materials

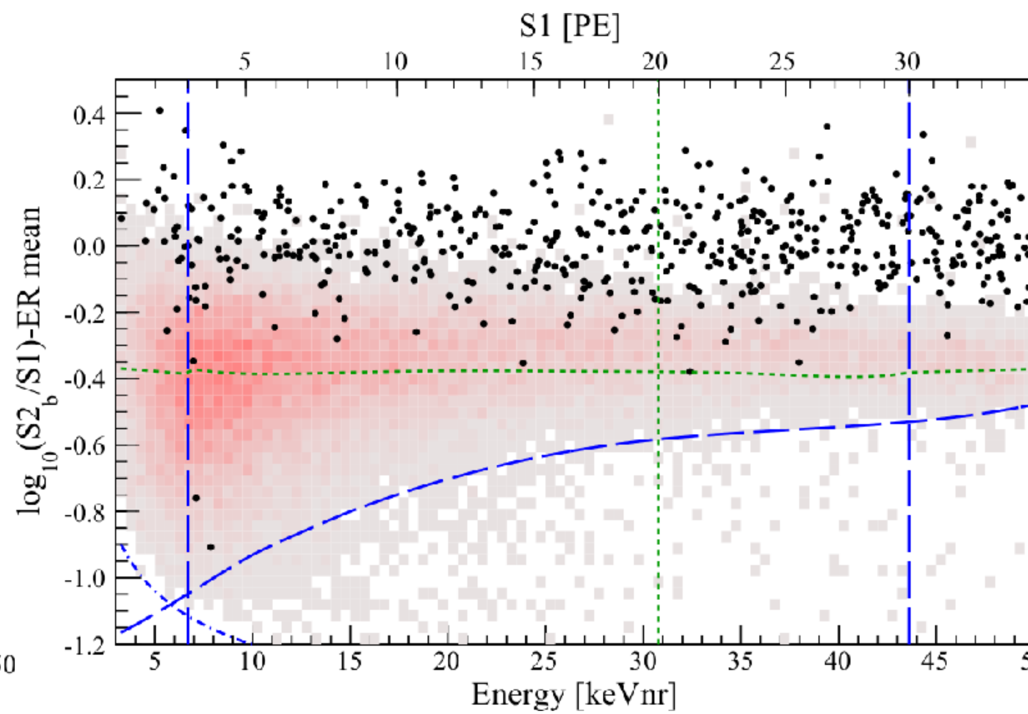
Xe purified by distillation ≈ 20 ppt Kr (run 10)
1 ppt (at start of data taking in 2013)

E. Aprile et al., Astropart. Phys. 35 (2012) 573

Run 10: 225 live days in 2011/2012

E. Aprile et al., Phys. Rev. Lett. 109 (2012) 181301

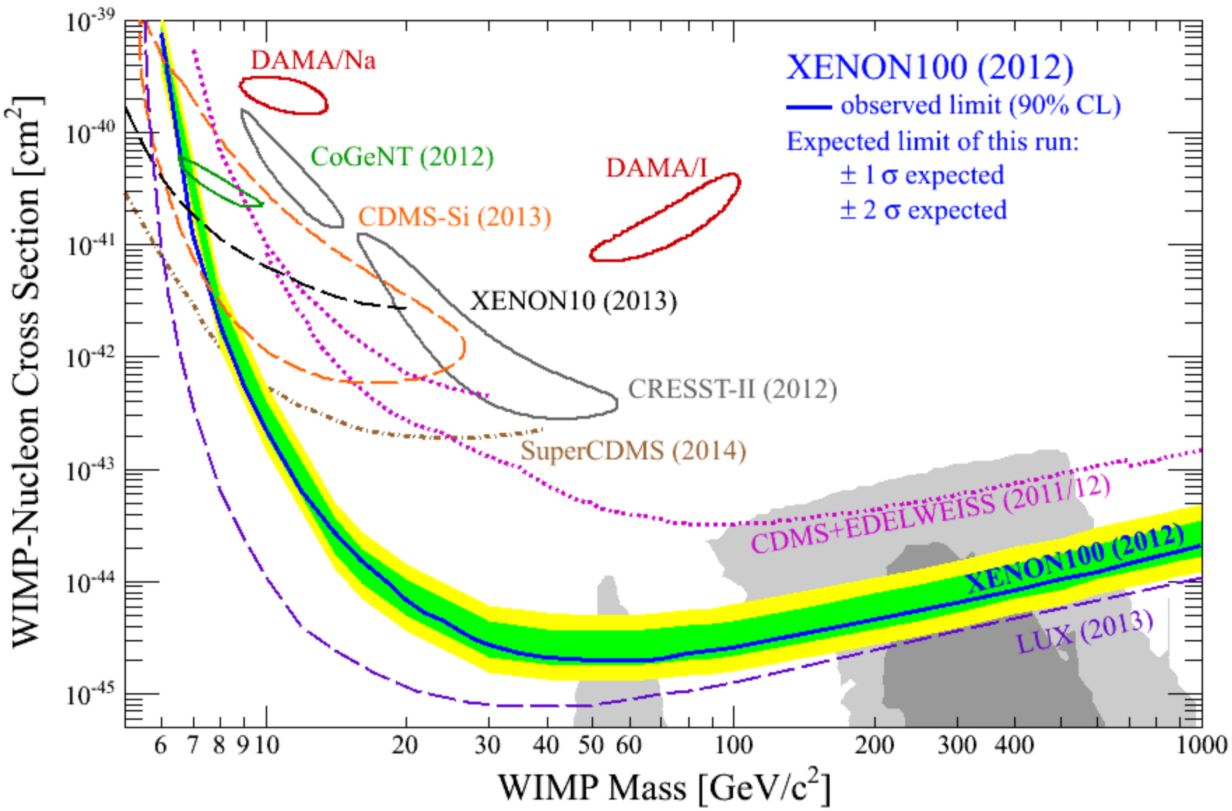




blind analysis, use 34 kg fiducial mass
cut-based analysis:
expected background: 1 event, measured: 2 events
→ statistical consistent with no signal
→ no dark matter found, only upper limit

XENON100 Dark Matter run 10: 225d data of 2011/2012

E. Aprile et al., Phys. Rev. Lett. 109 (2012) 181301



Profile Likelihood Analysis:

- all observed events
- full energy information, no discrimination
- incorporate calibration informations
- include systematic uncertainties (L_{eff}, …)
- method makes smooth transition between rejection/discovery

→ calculate only one true 90%CL limit

Details of the profile likelihood analysis:

E. Aprile et al.,
Phys. Rev. D 84 (2011) 052003

Exclusion curve, no signal found !
World´s best sensitivity on WIMPs up to LUX results in automn 2013

disfavours DAMA & CoGeNT (& CRESST) possible signal regions
(also IDM@DAMA ruled out, E. Aprile et al, Phys. Rev. D 84 (2011) 061101)

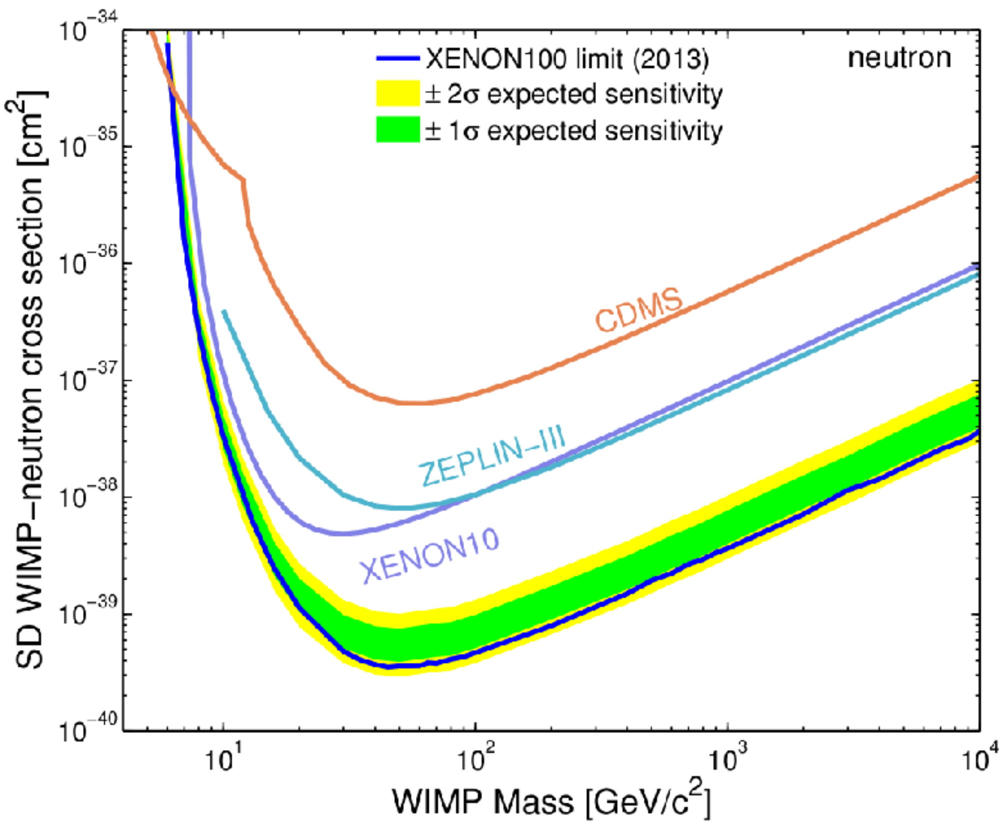
XENON100 Dark Matter run 10: Limits on spin-dependent interaction

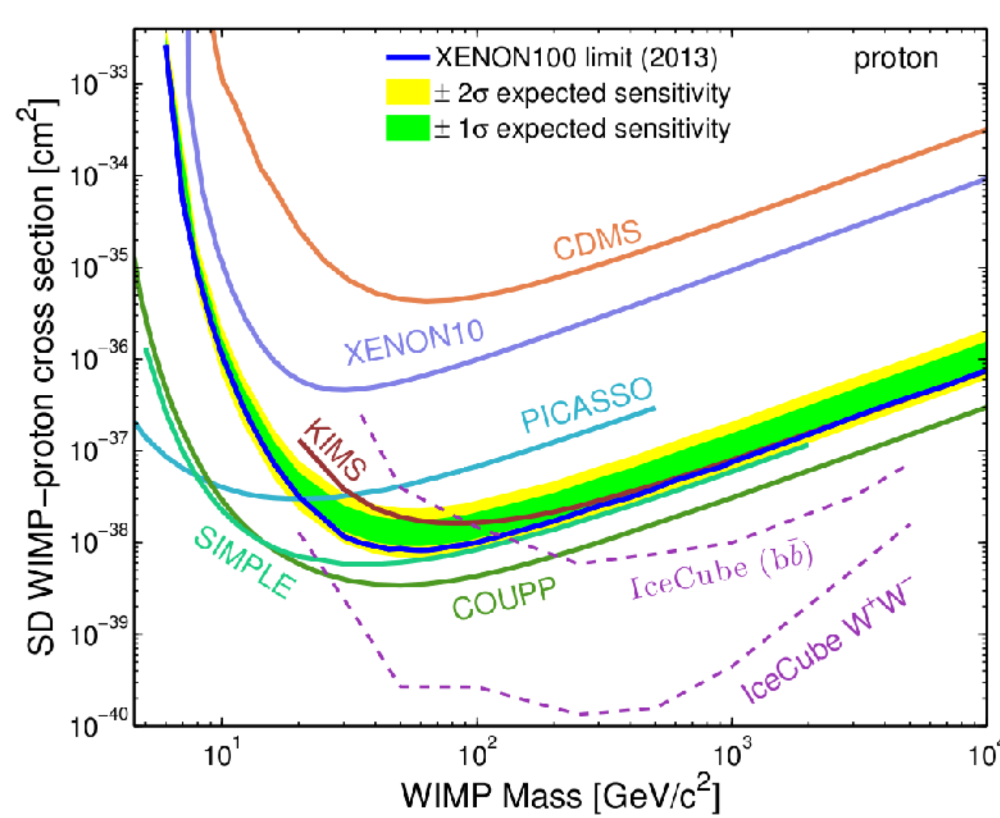
Some data selection and analysis as 225 days run 10 analysis (PRL 109 (2012) 181301)

Sensitivity to SD interaction by odd isotopes ^{129}Xe (J=1/2, 26.4%) and ^{131}Xe (J=3/2, 21.2%)

Single particle cross section limits

$$\frac{d\sigma_{\mathrm{SD}}(q)}{dq^2} = \frac{8G_F^2}{(2J+1)v^2} S_A(q) \qquad \sigma_{p,n}(q) = \frac{3}{4}\frac{\mu_{p,n}^2}{\mu_A^2}\frac{2J+1}{\pi}\frac{\sigma_{\mathrm{SD}}(q)}{S_A^{a_0=\pm a_1}(q)}$$

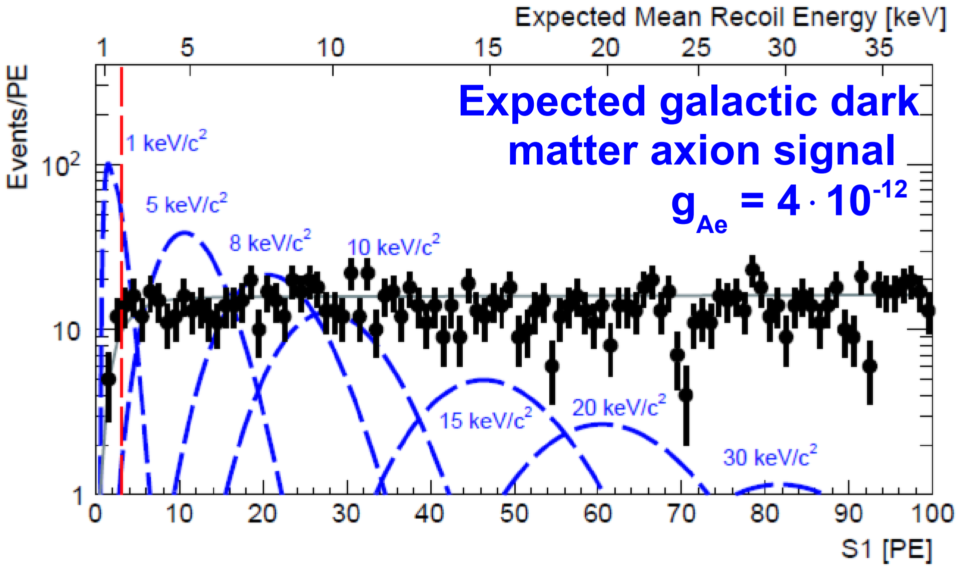


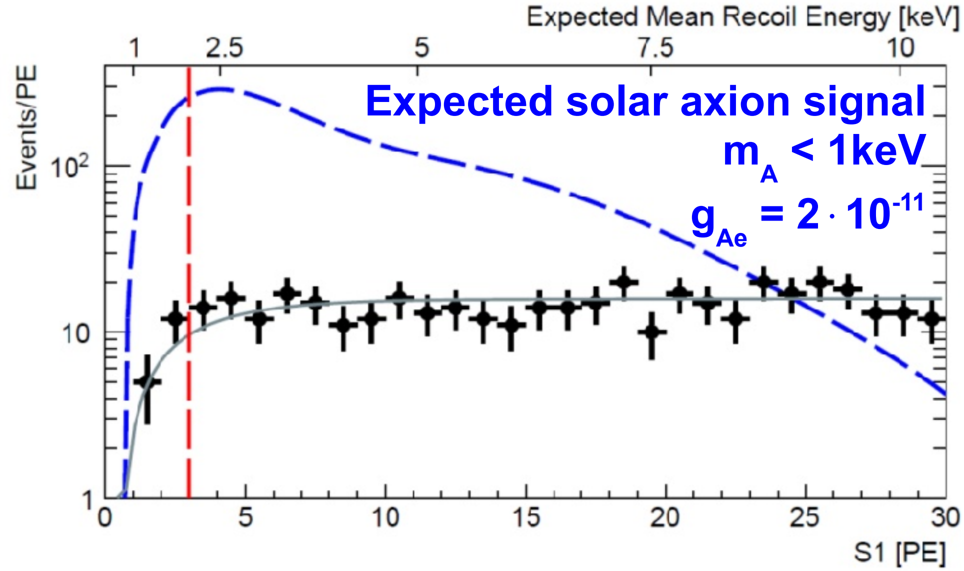


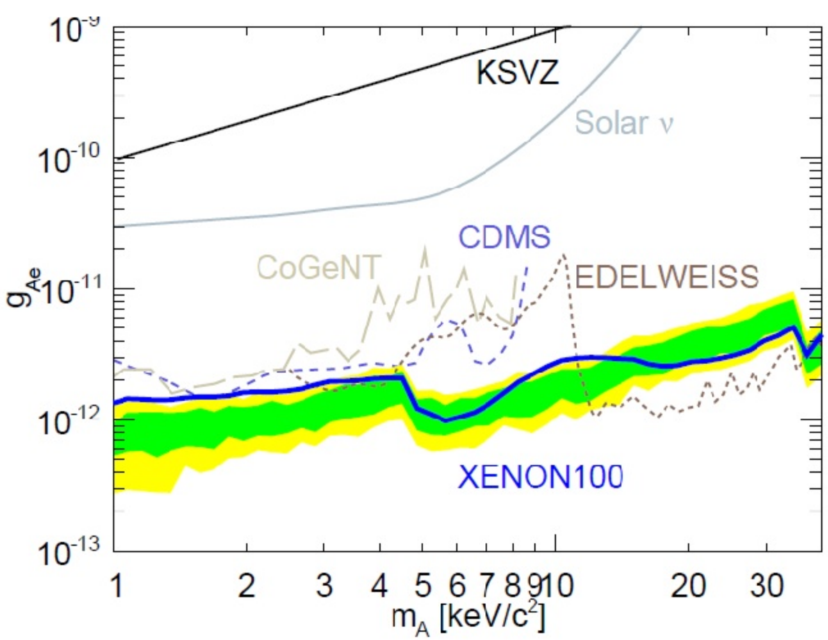
E. Aprile et al., Phys. Rev. Lett. 111 (2013) 021301

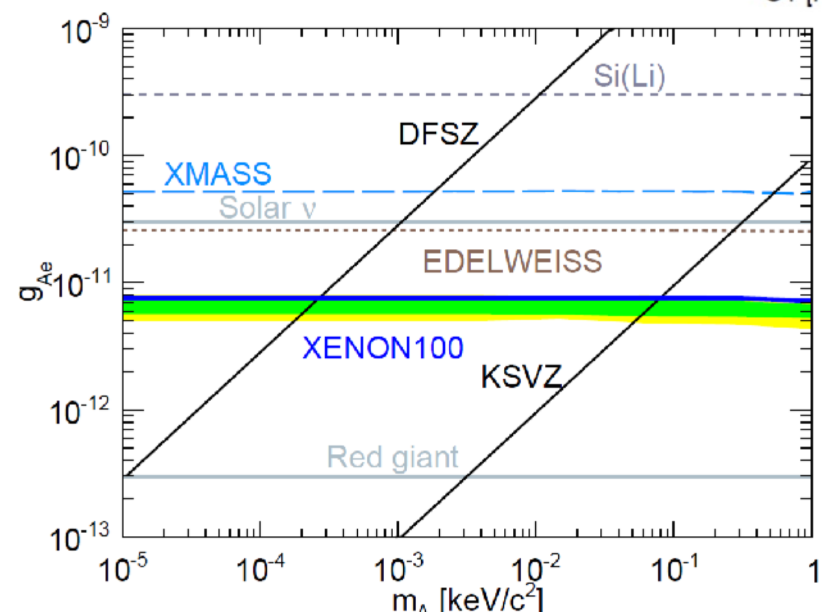
XENON100 Dark Matter run 10: electron recoil band: limits on ALPs

E. Aprile et al. (XENON100), PRD 90 (2014) 062009



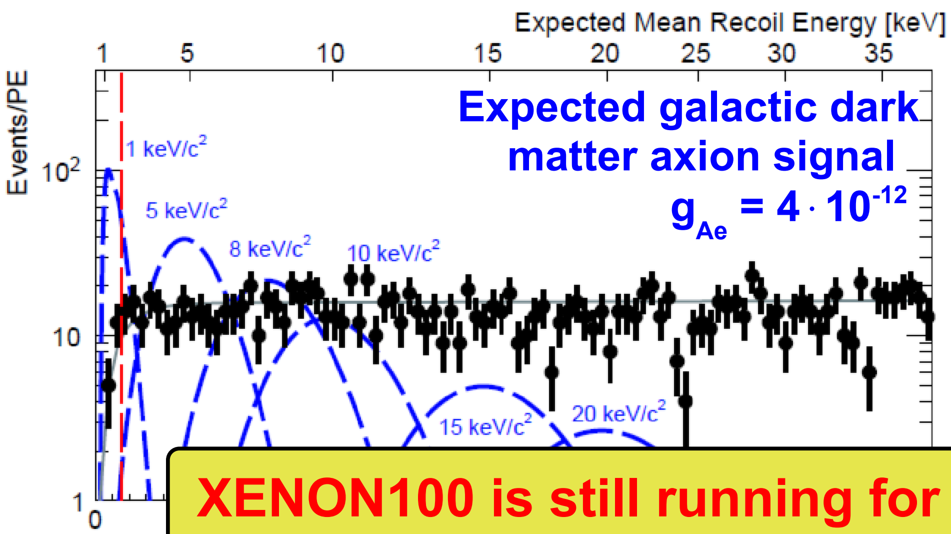


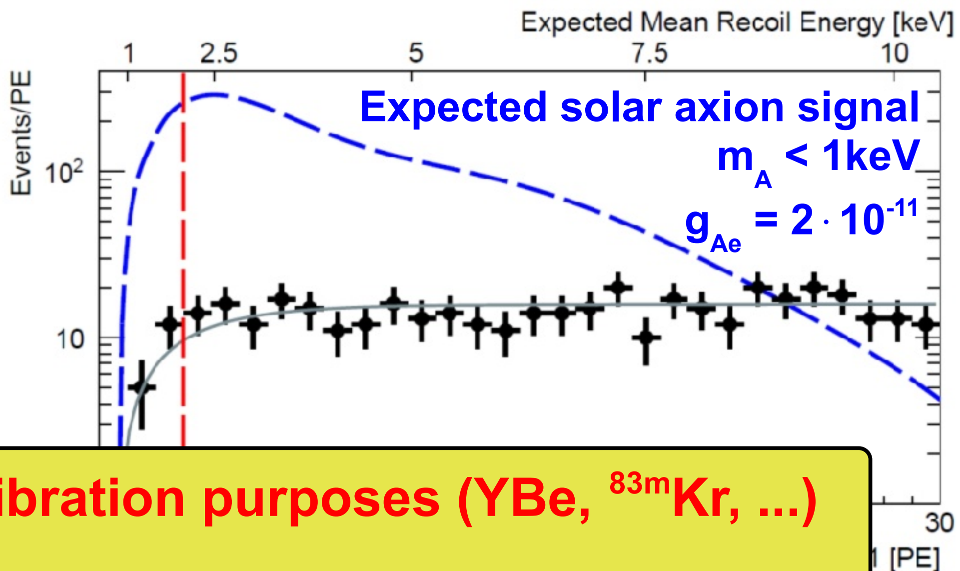




$$\sigma_{Ae} = \sigma_{pe}(E_A)\frac{{g_{Ae}}^2}{\beta_A}\frac{3{E_A}^2}{16\pi\,\alpha_{em}\,{m_e}^2}\left(1-\frac{\beta_A^{2/3}}{3}\right)$$

XENON100 Dark Matter run 10: electron recoil band: limits on ALPs

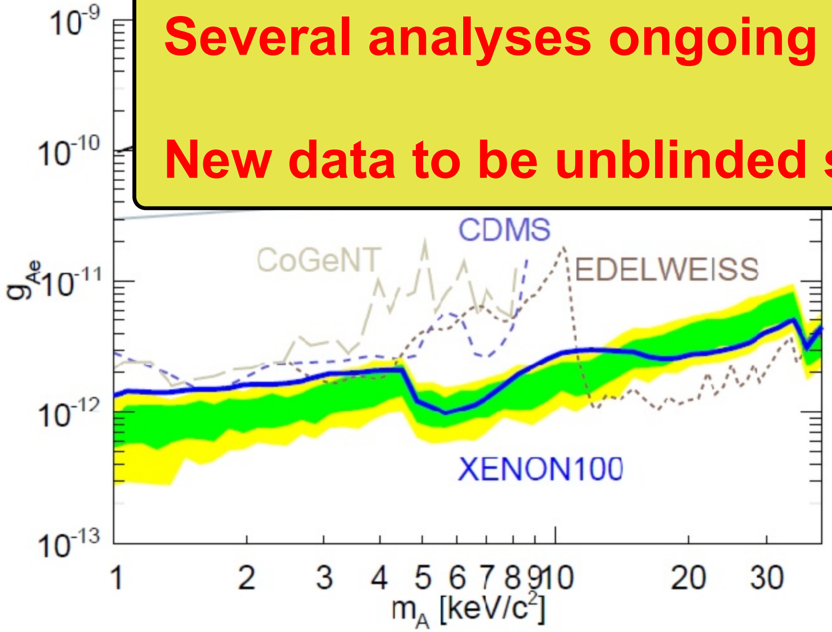


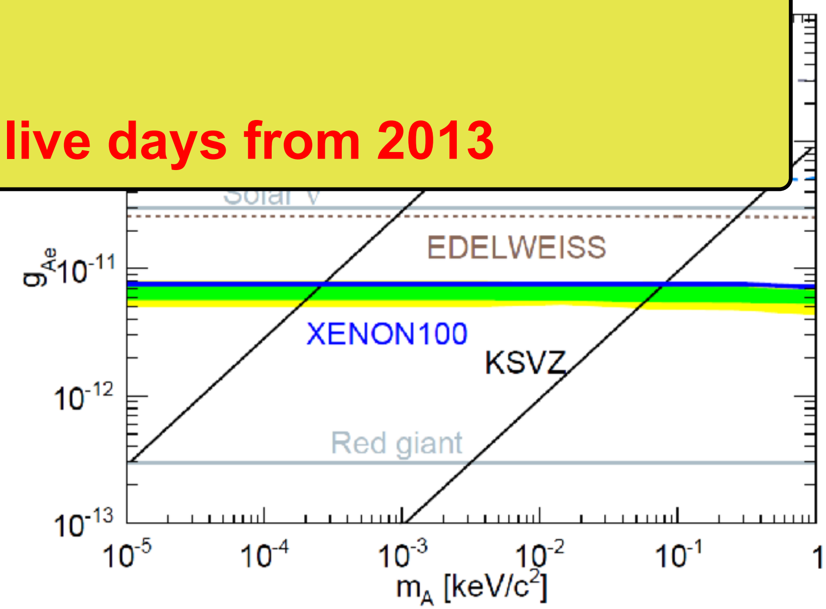


XENON100 is still running for calibration purposes (YBe, ^{83m}Kr, ...)

Several analyses ongoing

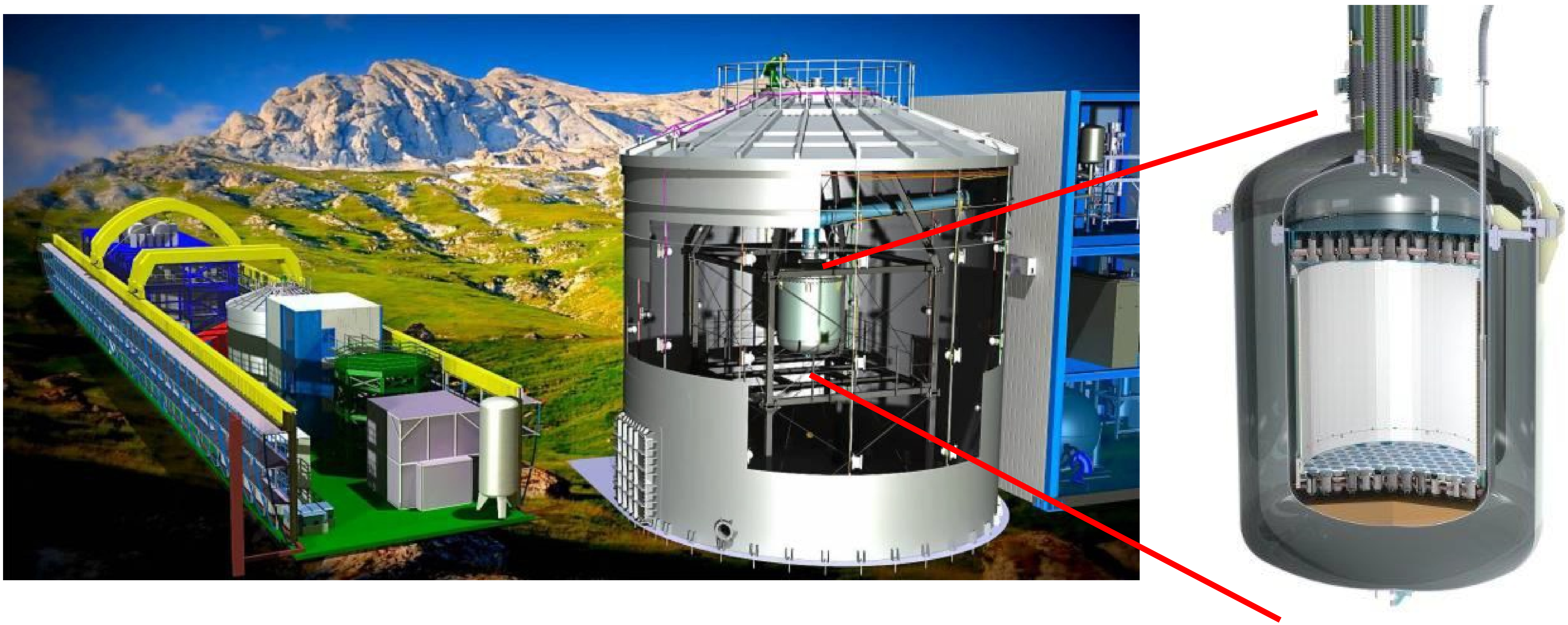
New data to be unblinded soon: 154 live days from 2013





E. Aprile et al. (XENON100), PRD 90 (2014) 062009

XENON1T@LNGS: increasing SI sensitivity down to 10^{-47} cm^2



LNGS hall B

10m water tank with muon veto

cryostat with XENON1T detector

XENON1T@LNGS: increasing SI sensitivity down to 10^{-47} cm^2

Detector:

1m-drift dual-phase TPC, 248 PMTs 3", Hamamatsu R11410-2

liquid xenon mass: 3.3t, 2t target → approx. 1t fiducial

Background goal:

100 lower than XENON100:

less than 1 bg event per year in one 1 fiducial volume

→ rigorous material screening & selection

→ 10m water tank: neutron shielding, active muon veto

→ cleaning from intrinsic contaminations by radioactive noble gases by cryogenic distillation

Sensitivity:

1.2 x 10^{-47} cm^2 after 2 t*y exposure

Status:

most components under commissioning, TPC under construction

start of data taking in 2015

Custom-made cryogenic distillation column for XENON1T(nT)

Cryogenic distillation:

multi-stage separation by different vapor pressure

^{85}Kr:

$2 \cdot 10^{-11}$ fraction of ^{85}Kr in ^{nat}Kr

10^{-8} - 10^{-5} fraction in commercial xenon gas,
but XENON1T requires $< 2 \cdot 10^{-13}$

→ need very efficient purification method

up to now published Kr-in-Xe fraction concentrations reached by
LUX, PandaX, XENON100, XMASS: 1-3 ppt

cryogenic distillation with custom-made Münster column:
< 0.026 ppt (RGMS measurement by MPIK), 3 kg/h

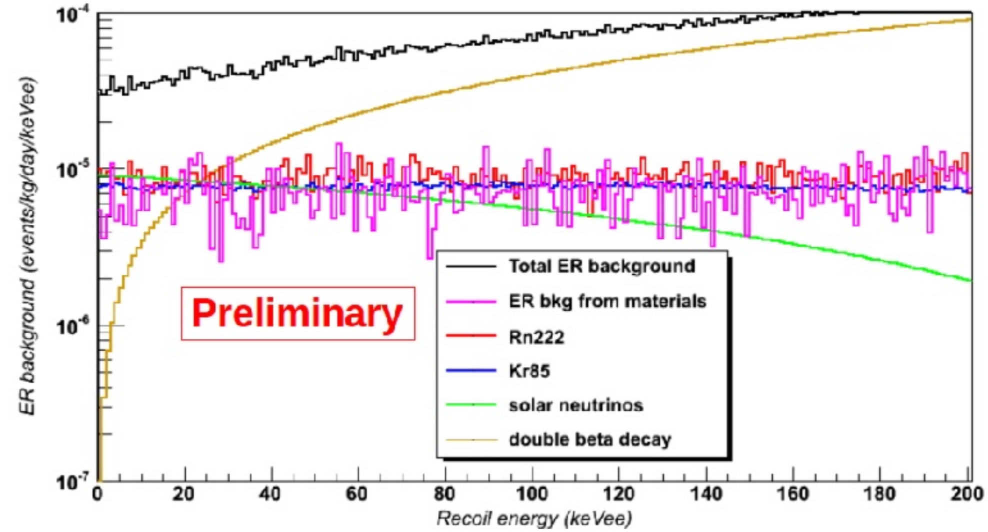
^{219}Rn, ^{220}Rn, ^{222}Rn:

comes from walls, weldings, ..
→ rigorous screening of materials
Rn reduction by continuous cryogenic distillation for XENONnT

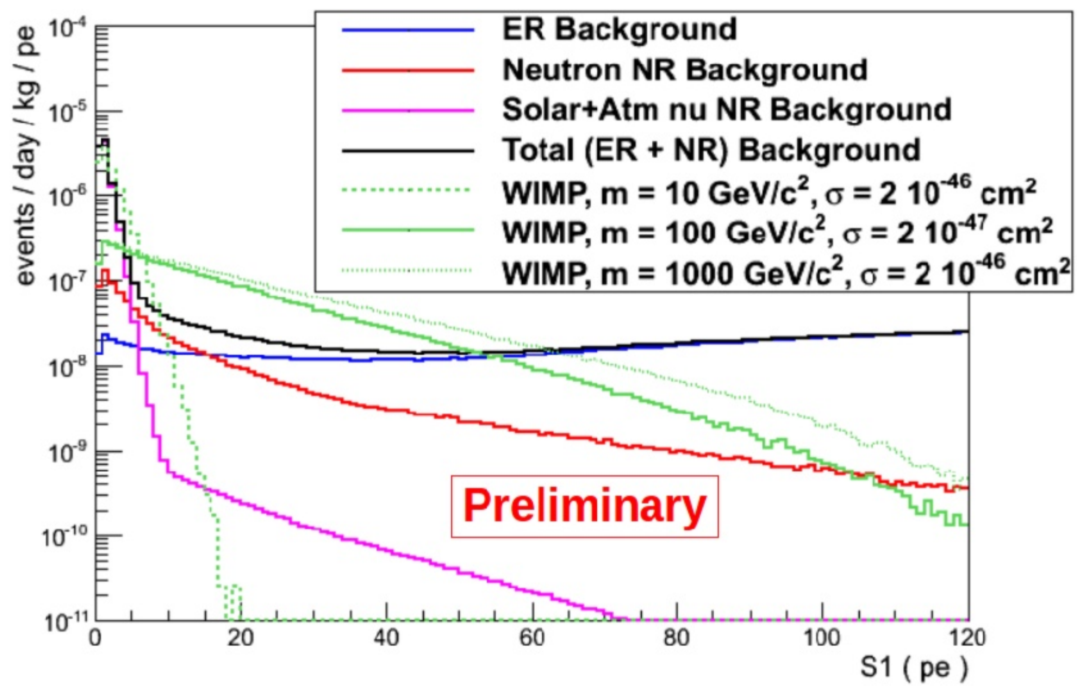
Electron recoil background total background

Electron recoil background
(before ER/NR discrimination)

requirements:
^{85}Kr: ^{nat}Kr in Xe < 0.2 ppt
^{222}Rn < 1 μBq/kg
same bg rate from solar νs and materials



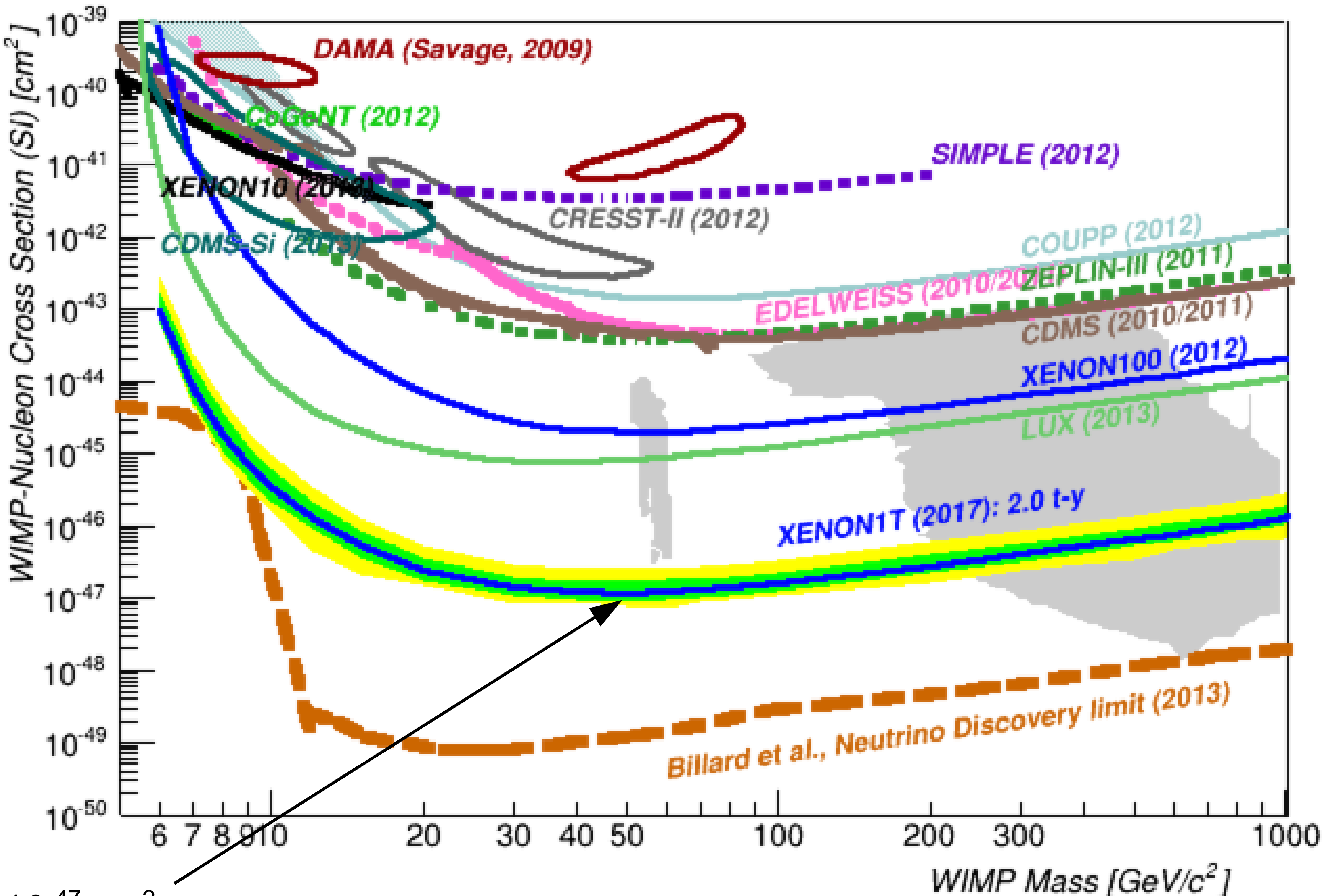
Total Background in XENON1T



Total background
(after ER/NR discrimination with 99,75% @40% NR acceptance)

source	background (evts/ton/y) in [3, 70] PE
ER (materials +intrinsic + solar n):	0.32
NR from radiogenic neutrons:	0.22
NR from neutrino coherent scattering:	0.21
Total:	**0.75**

XENON1T@LNGS: increasing SI sensitivity down to 10^{-47} cm^2



$1.2 \cdot 10^{-47}$ cm^2

XENON1T@LNGS:
water tank, service building, cryostat

XENON1T@LNGS:
cryosystem, purification system

XENON1T@LNGS:
storage, analystics, cryogenic distillation

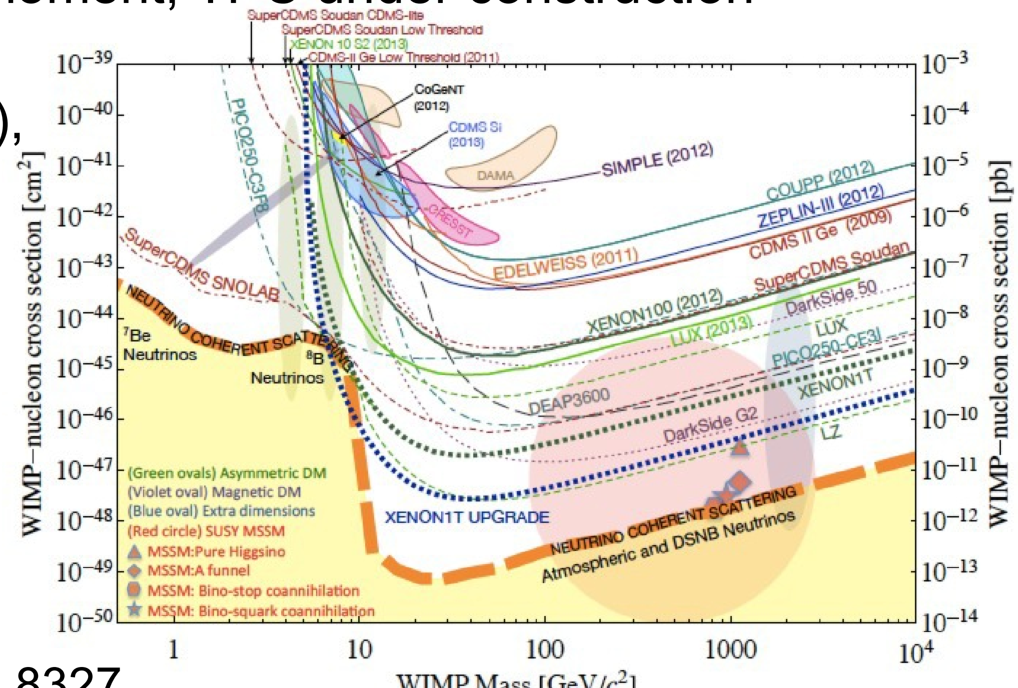
Conclusion

XENON100:

- many physics results on SI, SD, ALPs, etc.
- several ongoing analyses
- still running, calibration (YBe, ^{83m}Kr), cryogenic Rn distillation

XENON1T:

- first multi-ton direct dark matter experiment, $1.2 \cdot 10^{-47}$ cm^2 sensitivity for SI
- commissioning of most components at the moment, TPC under construction
- start of data taking planned still for 2015
- allows easy upgrade towards XENONnT (7t),
  see Hardy Simgen's talk



arXiv:1310.8327

Will we see WIMPs before reaching the neutrino floor?