Direct Dark Matter Search with XENON

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➔ **Results of XENON100 and status of XENON1T**

on behalf of the XENON Collaboration

Windows on the Universe, Qui Nhon, Vietnam, Aug. 12-17, 2013

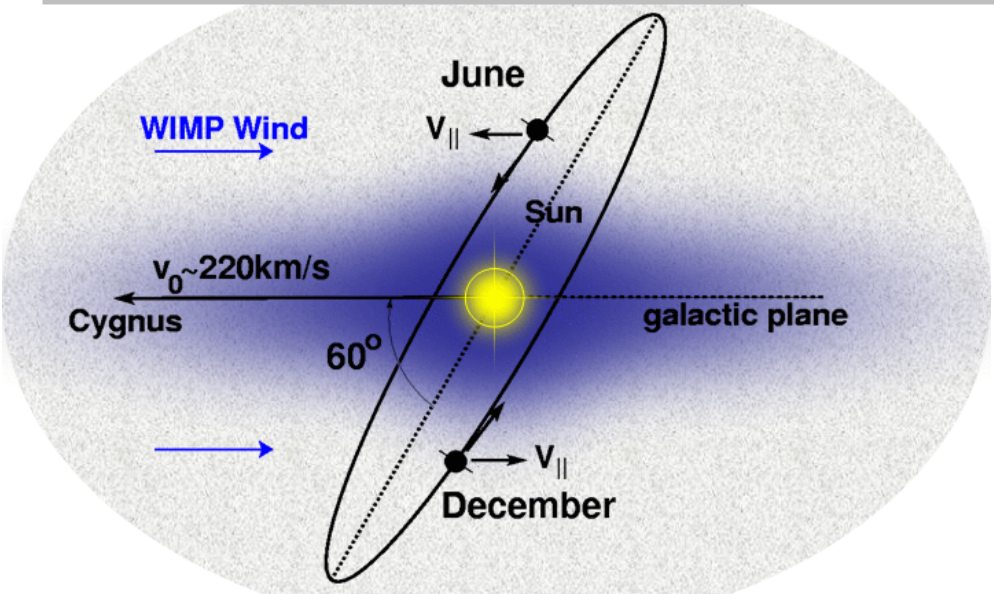
The XENON Collaboration

Xe
XENON
Dark Matter Project

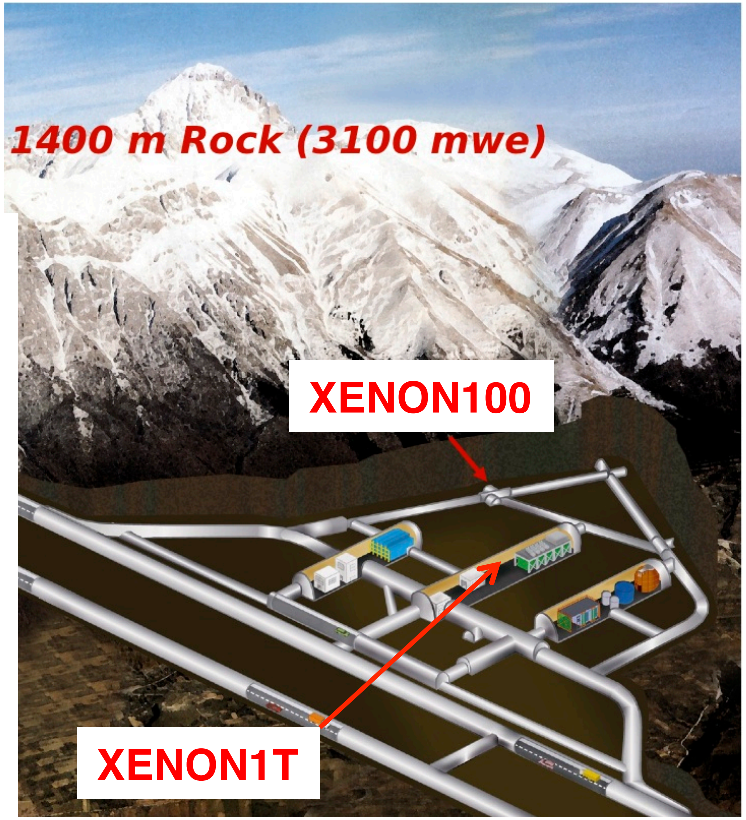
15 institutes
O(100) people

University of California Los Angeles
Universität Bern
Rice University Houston
Purdue University
Columbia University New York
Universidade de Coimbra
Subatech Nantes
NIKHEF Amsterdam
Willhelms Universität Münster
J. Gutenberg-Universität Mainz
Max-Planck-Institut Heidelberg
Universität Zürich
Laboratori Nazionali del Gran Sasso
INFN e Università di Bologna
Weizman Institute Rehovot

Source and Detector Location



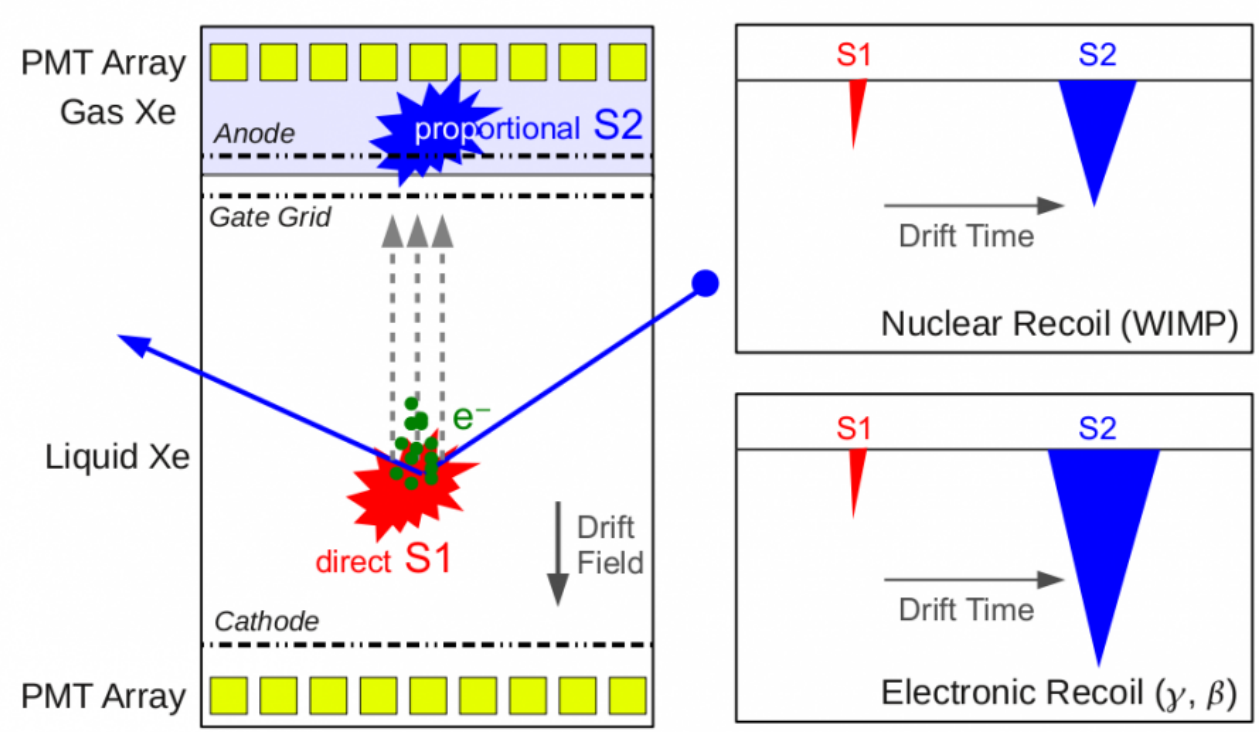
Gran Sasso underground lab
➔ shielding

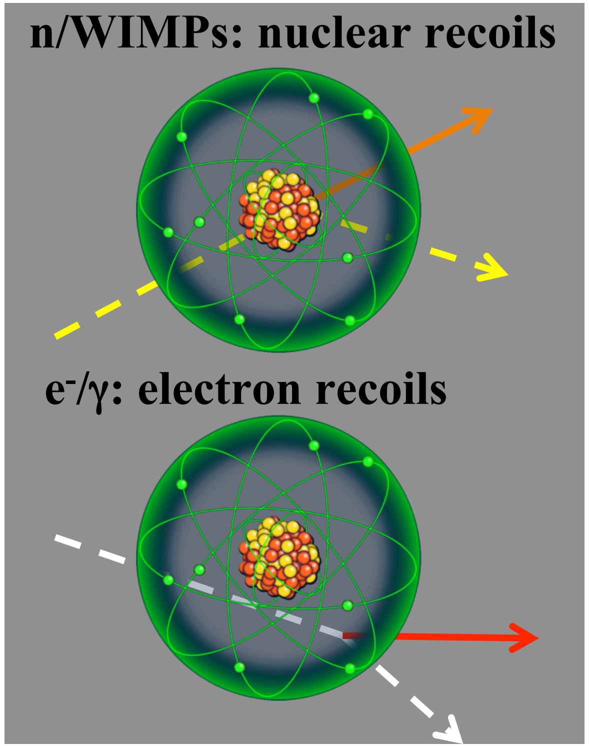


- solar system ~8.5kpc from the GC…
- …moving towards Cygnus
  ➔ "WIMP wind" <v> ~ 220 km/s
  ➔ flux (dispersion, modulation, …)
- tiny x-sections ➔ very rare events

➔ sufficiently big targets (detectors)
➔ very clean detection environment

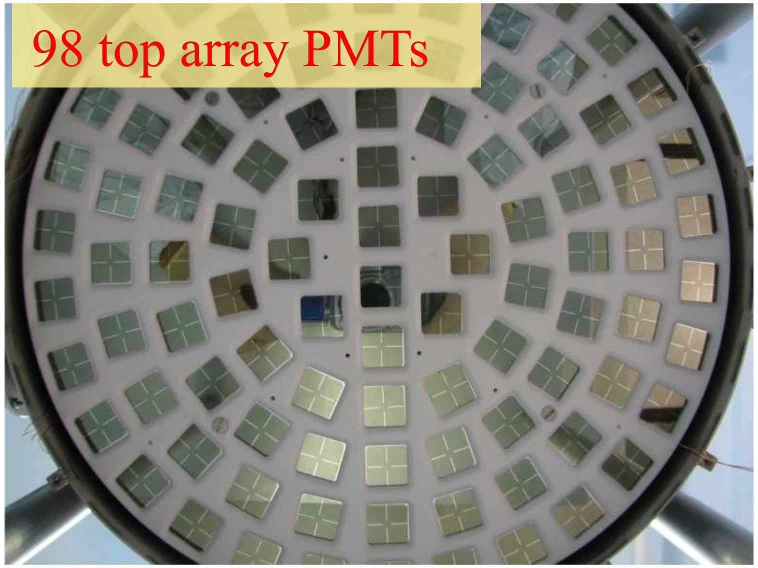
XENON100: A dual Phase TPC

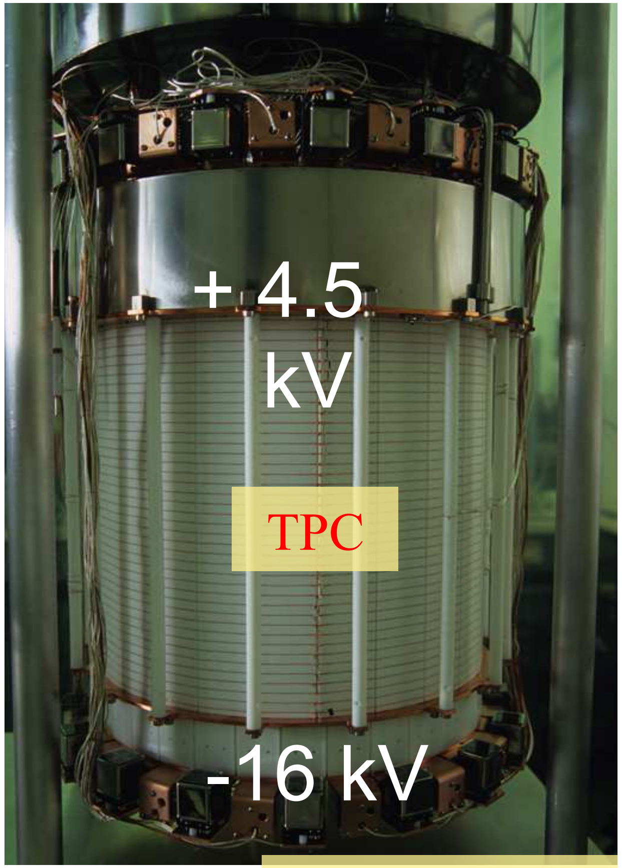


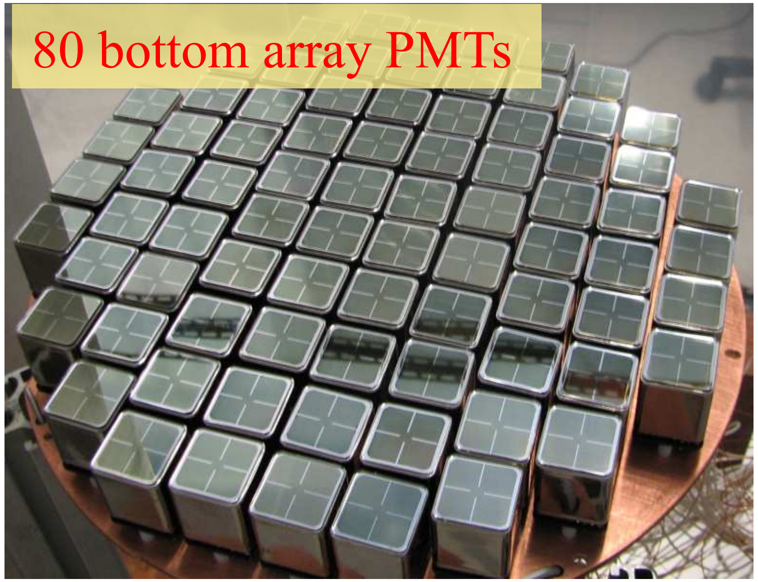


- Discrimination of e^-/γ and nuclear recoils: **$(S2/S1)_{n,WIMP} < (S2/S1)_{e,\gamma}$**
  > 99% ER rejection
- 3D position: drift time → z (<0.3mm); PMT pattern → x,y (<3mm)
  → **precise fiducial inner volume** (avoid BG in outer volume)
- Discrimination of single/multiple scattering
  → **further background reduction**

242 low activity PMTs 1x1" (Hamamatsu R8520, QE>32% @175nm

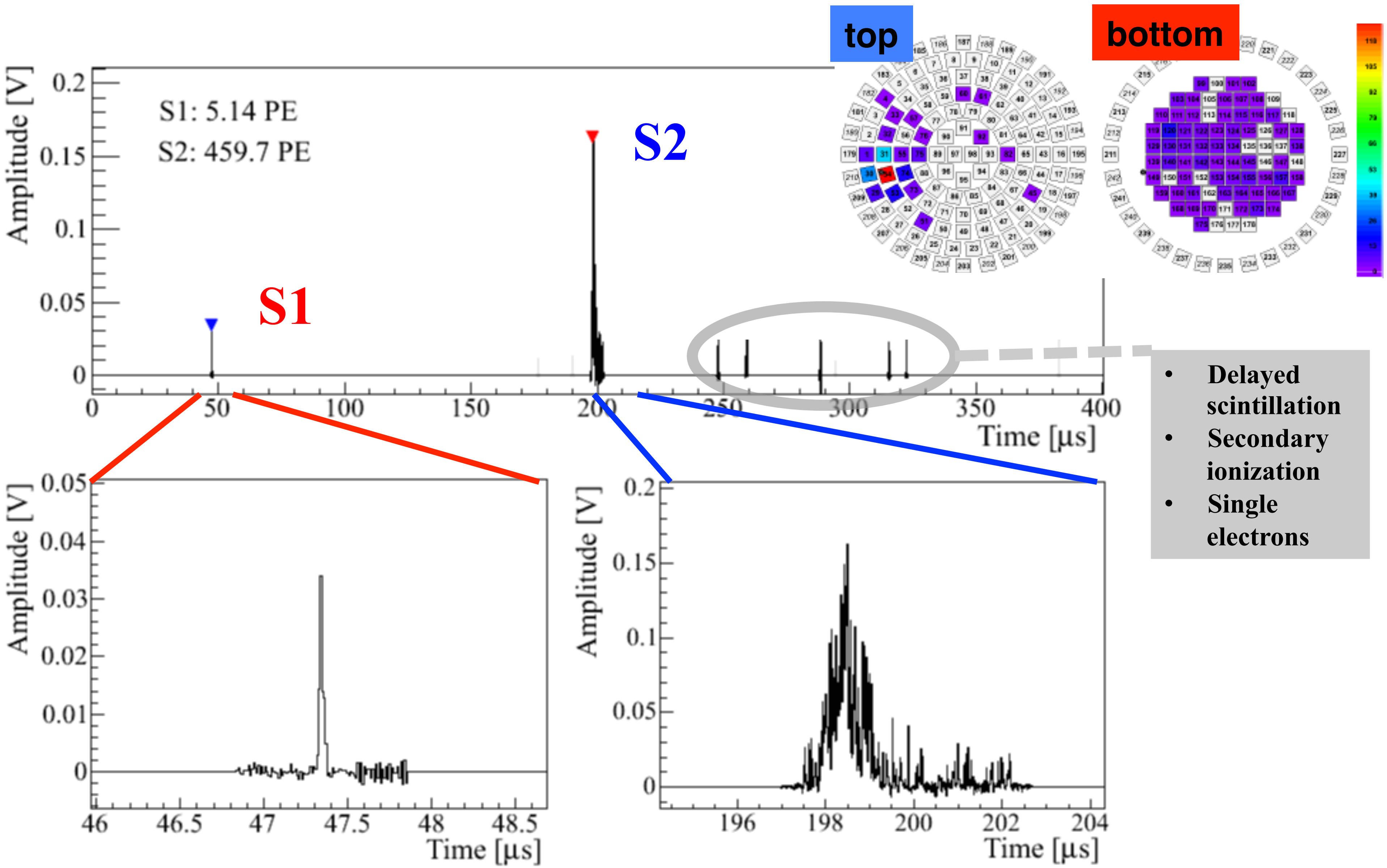






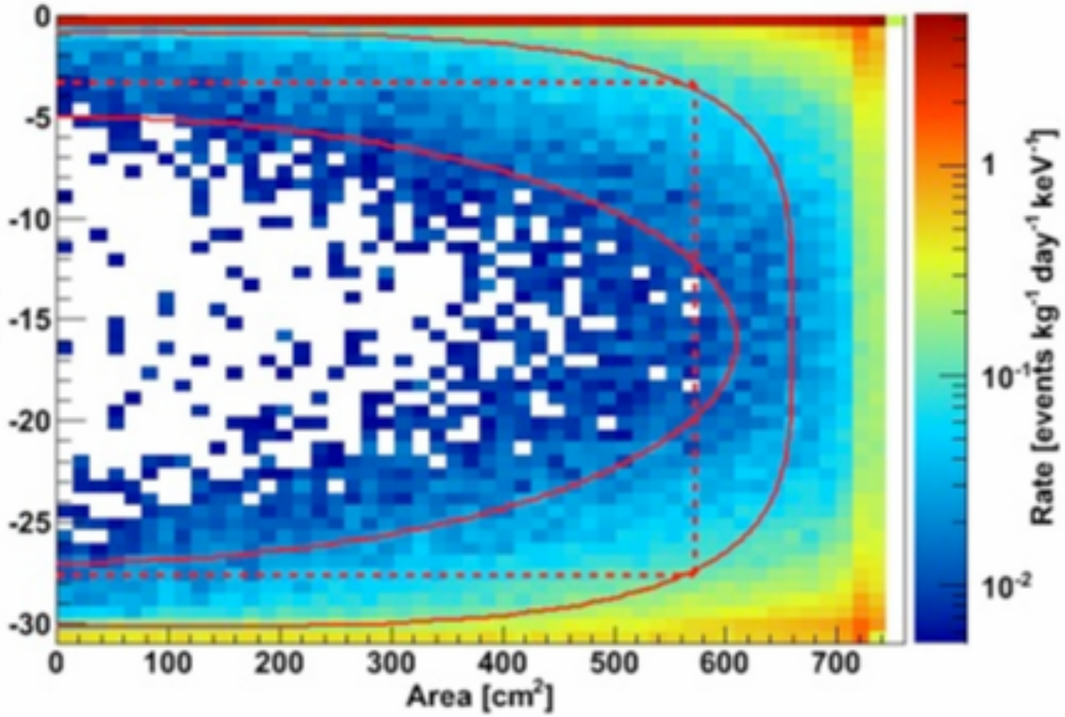
- 161kg Xe, 62kg target
- 30cm drift length
- radio-purity
  → material screening
- ^{85}Kr
  →distillation column
- ^{222}Rn emanation
  → avoid/monitor
- passive shielding:
water, lead, PE, copper

The TPC at Work



- Delayed scintillation
- Secondary ionization
- Single electrons

Fiducialization and BG Reduction



Precise spacial information:

- S2 hit pattern: $\Delta r < 3$ mm
- Drift time: $\Delta z < 0.3$ mm

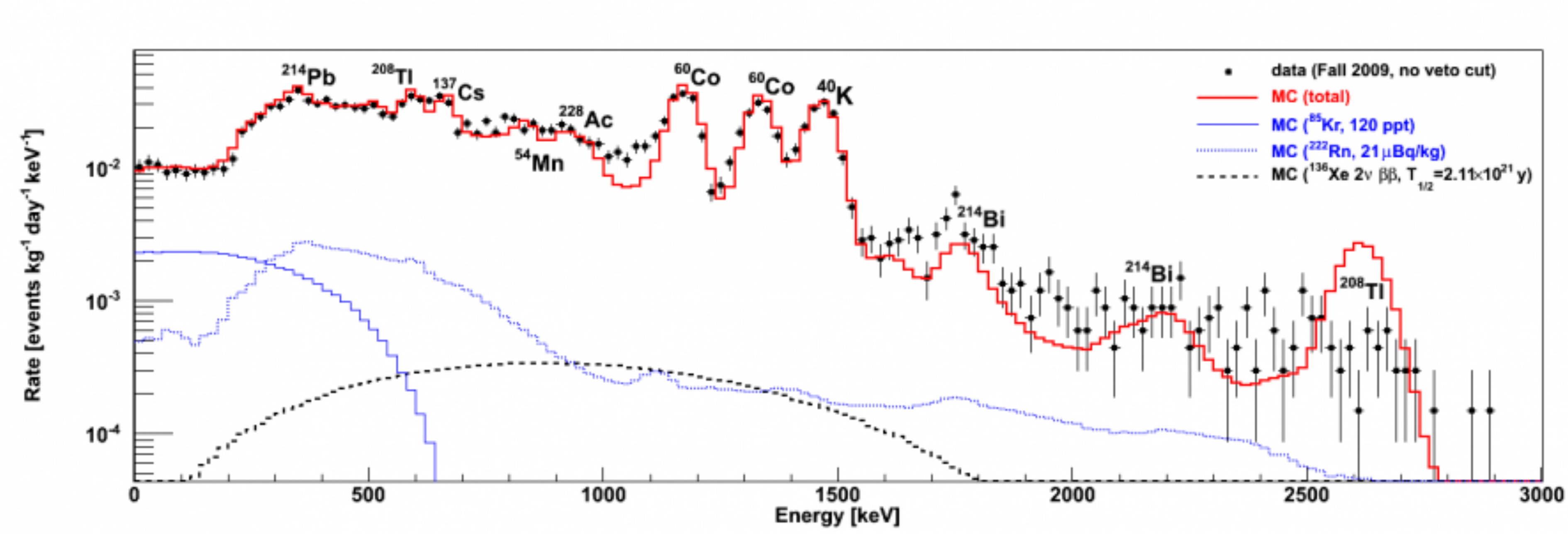
→ avoid 'dirty' surfaces by selection of a fiducial volume

Optimization of fiducial volume with Monte Carlo:

good background rejection efficiency ←→ target mass

Detailed Background Understanding

PRD 83, 082001 (2011)



- MC simulations and background in good agreement
- Background very well understood in full energy range
- $5 \leq 10^{-3}$ evts/kg/keV/d after the veto cut
  → achieved design goal of factor 100 lower than in XENON10!
  (and than any other search…)

ER/NR Calibration

Regular calibrations with LEDs and sources

→ **Position dep. Corrections**

→ **…**

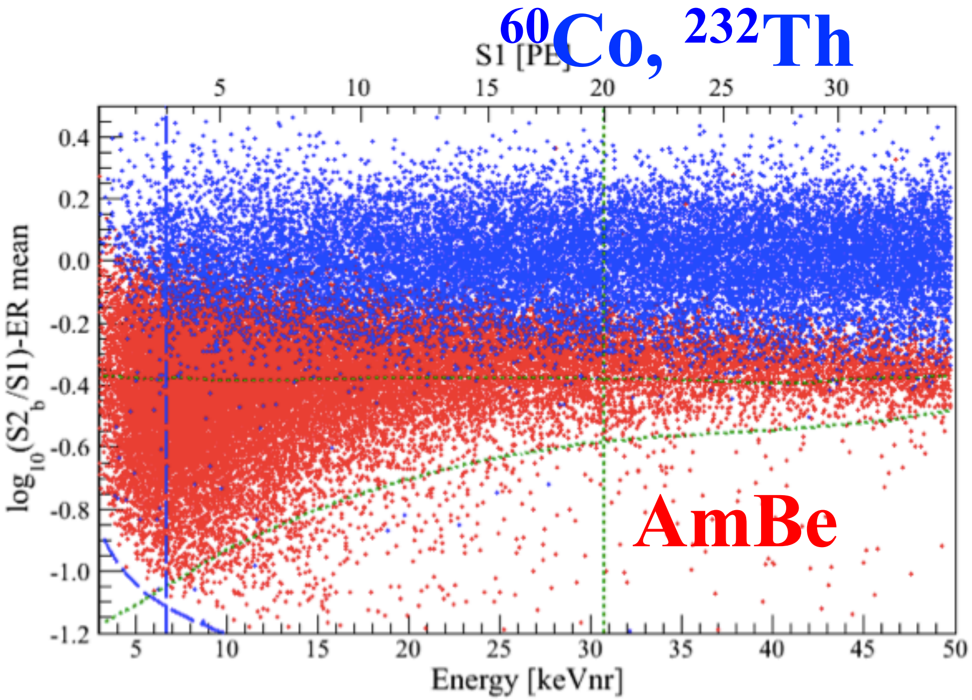
ER calibration: ^{60}Co, ^{232}Th

→ **Electron Recoil Band**

NR: AmBe calibration at beginning and end of run

→ definition of WIMP search region

→ Discrimination power: 99.5% at low energies for 50% acceptance



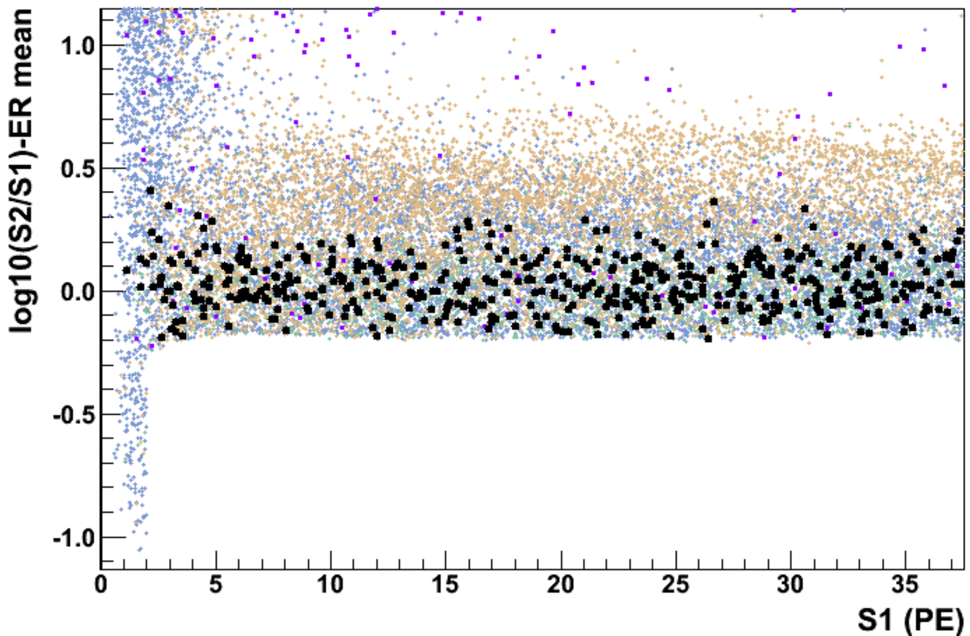
Blind WIMP Analysis

Data below the 10% quantile of the e-recoil band were blinded

➔ cuts: calibration data and background events outside WIMP region

Selection cuts:

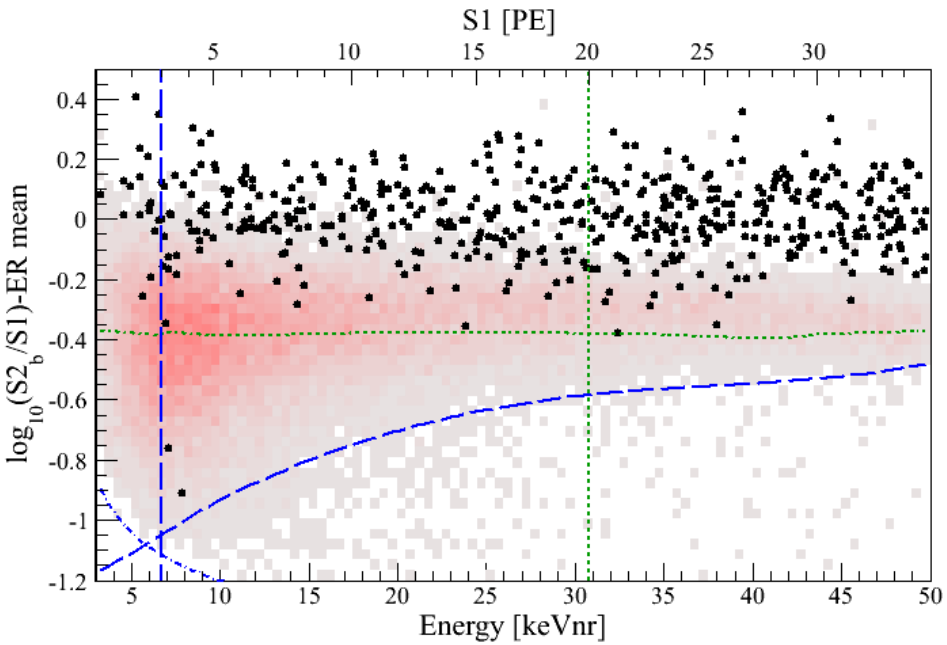
- Data quality
  - only stable detector periods, …
- Energy cuts
- Single event selection
- Consistency
- NR/ER discrimination
- Event inside fiducial volume



Cut based analysis → profile likelihood based on all events:

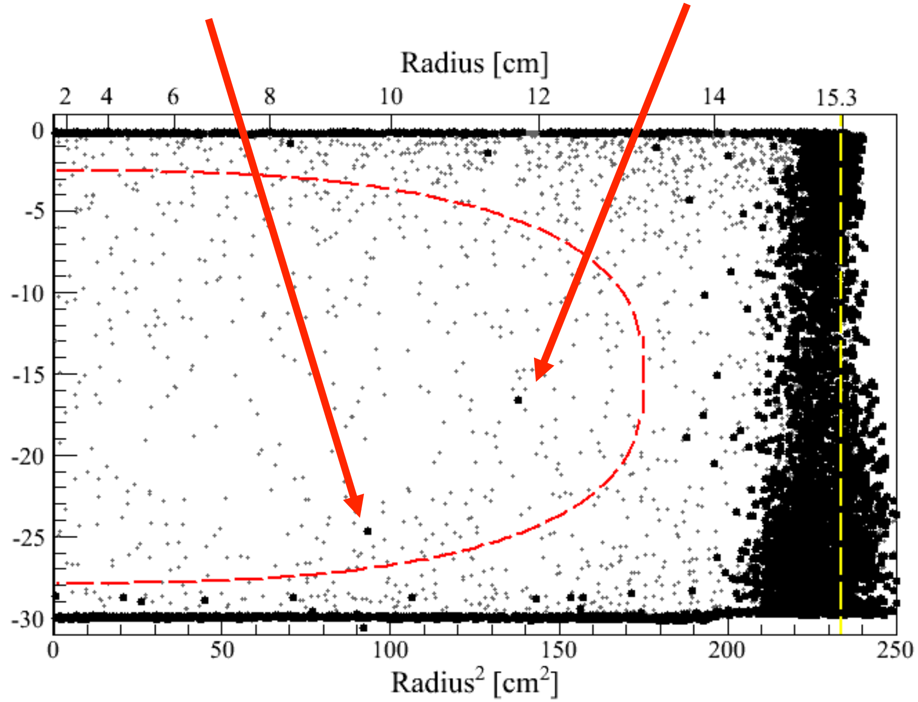
- full energy information, no discrimination
- incorporate calibration information (data, simulation, errors)
- include systematic uncertainties (L_{eff}, …)
- smooth transition between rejection / discovery

Results from 225 Live Days (Run 10)



The two events have good quality by visual inspection

Position of the two events in the fiducial region

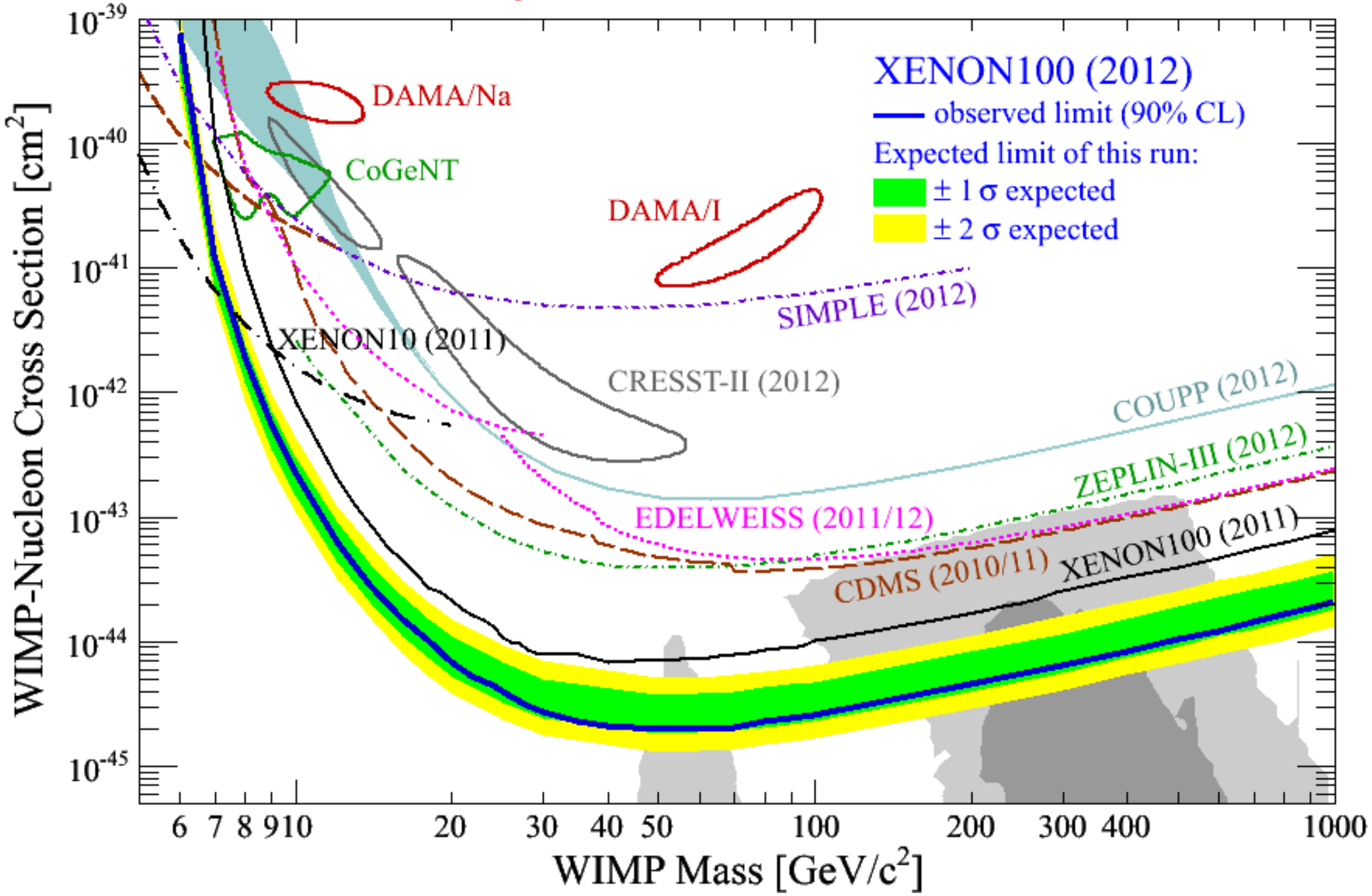


- 2 events in fiducial volume
- expected background 1.0 + 0.2
- probability for a fluctuation from 1 to 2 events: 26.4%
- No significant excess seen

➔ improved WIMP limits

XENON100 Spin Independent Exclusion Limit

Phys. Rev. Lett. 109 (2012) 181301



➔ profile likelihood:
PRD 84, 052003, 2011

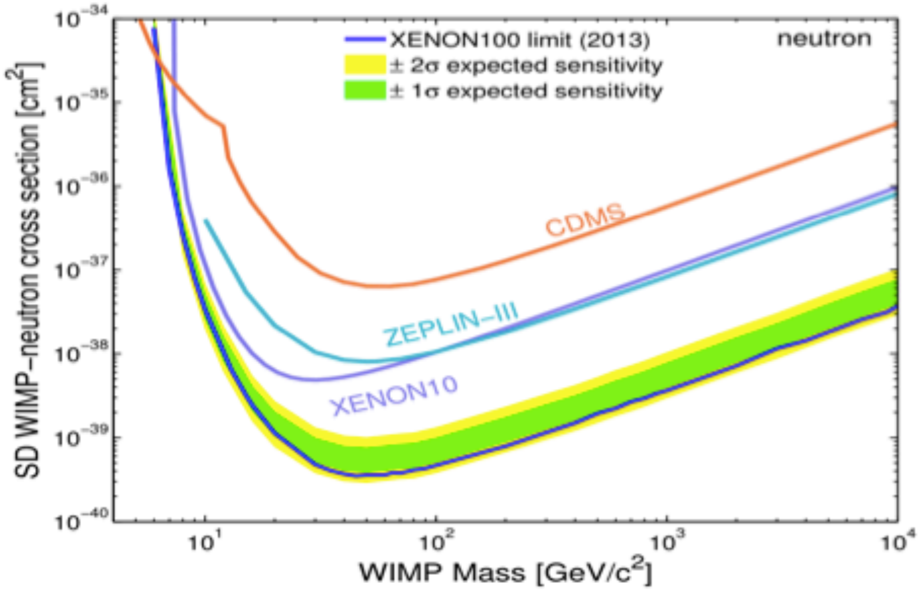
➔ new L_{eff}:
PRC 84.045805

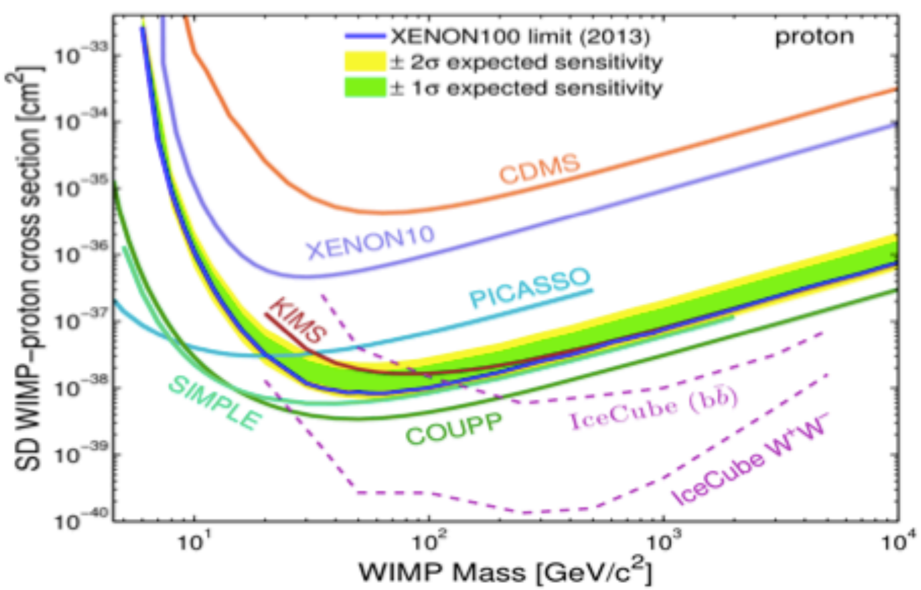
➔ WIMP velocity:
v_0 = 220 km/s
v_{esc}= 544 km/s

- **best spin independent DM limit: 2 x 10^{-45}cm² at 50 GeV/c²**
- **excludes part of the predicted region for SUSY candidates**
- **excludes other WIMP evidences**

XENON100 Spin Dependent Exclusion Limits

Phys. Rev. Lett. 111, 021301 (2013)

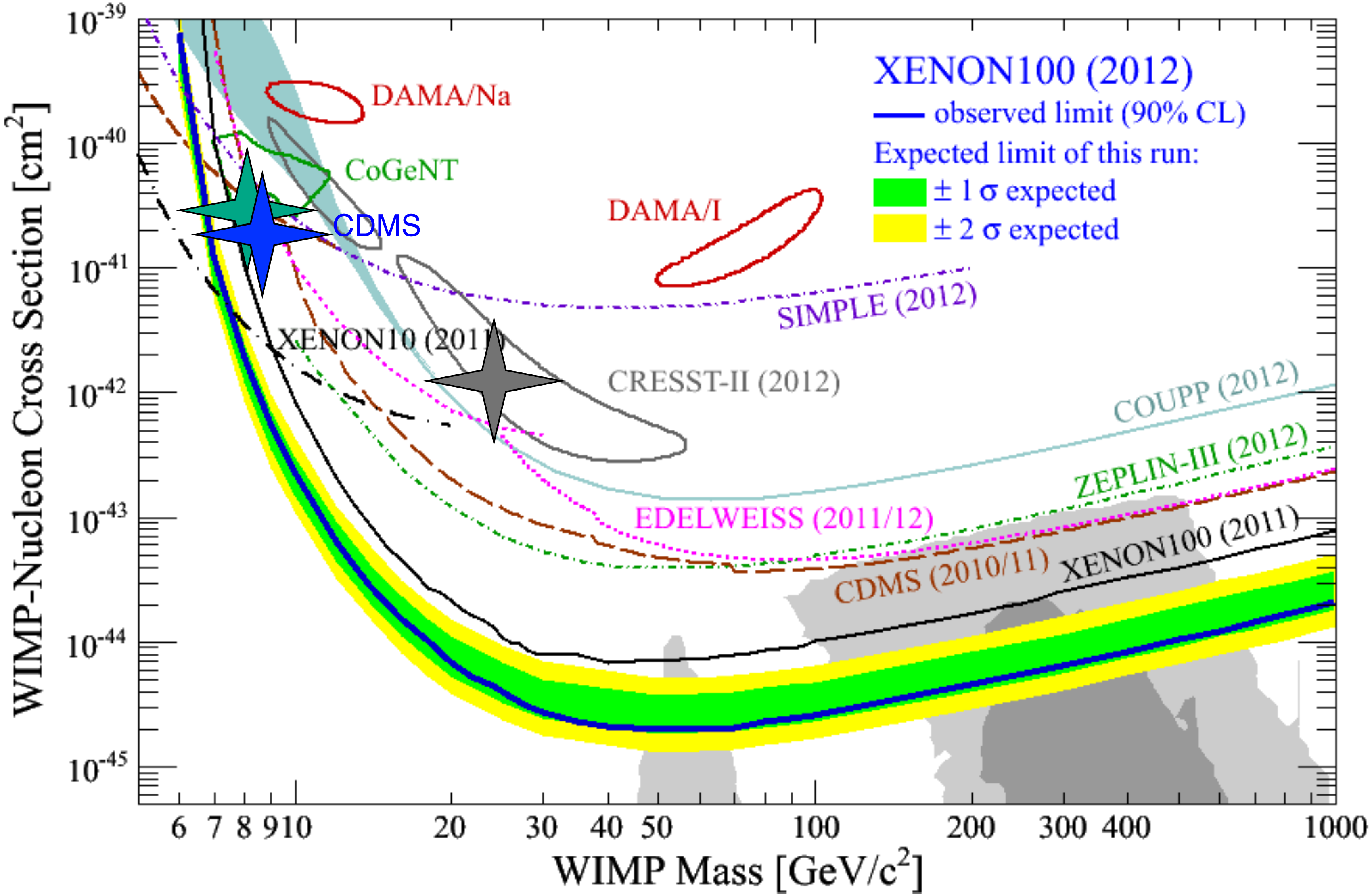




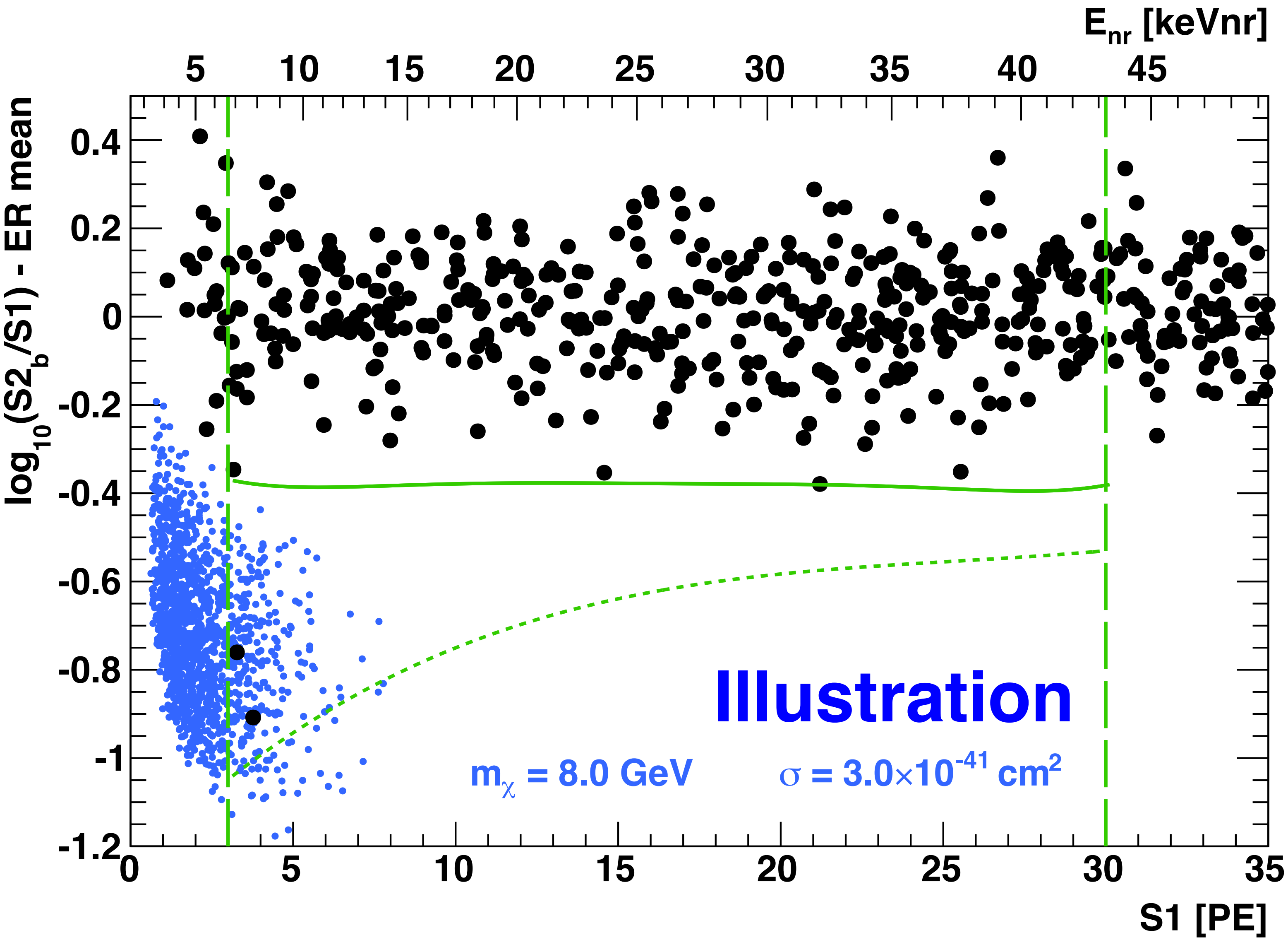
- 2 isotopes with nonzero spin: ^{129}Xe (26.2%) and ^{131}Xe (21.8 %)
- nuclear model (Menendez et al. *Phys.Rev.D86, 103511, 2012)*
- $\sigma = 3.5 \times 10^{-40} cm^2$ for a 45 GeV WIMP mass and neutron coupling at 90% CL

  ➔ best limits for 'neutron' ; competitive limits for 'proton'

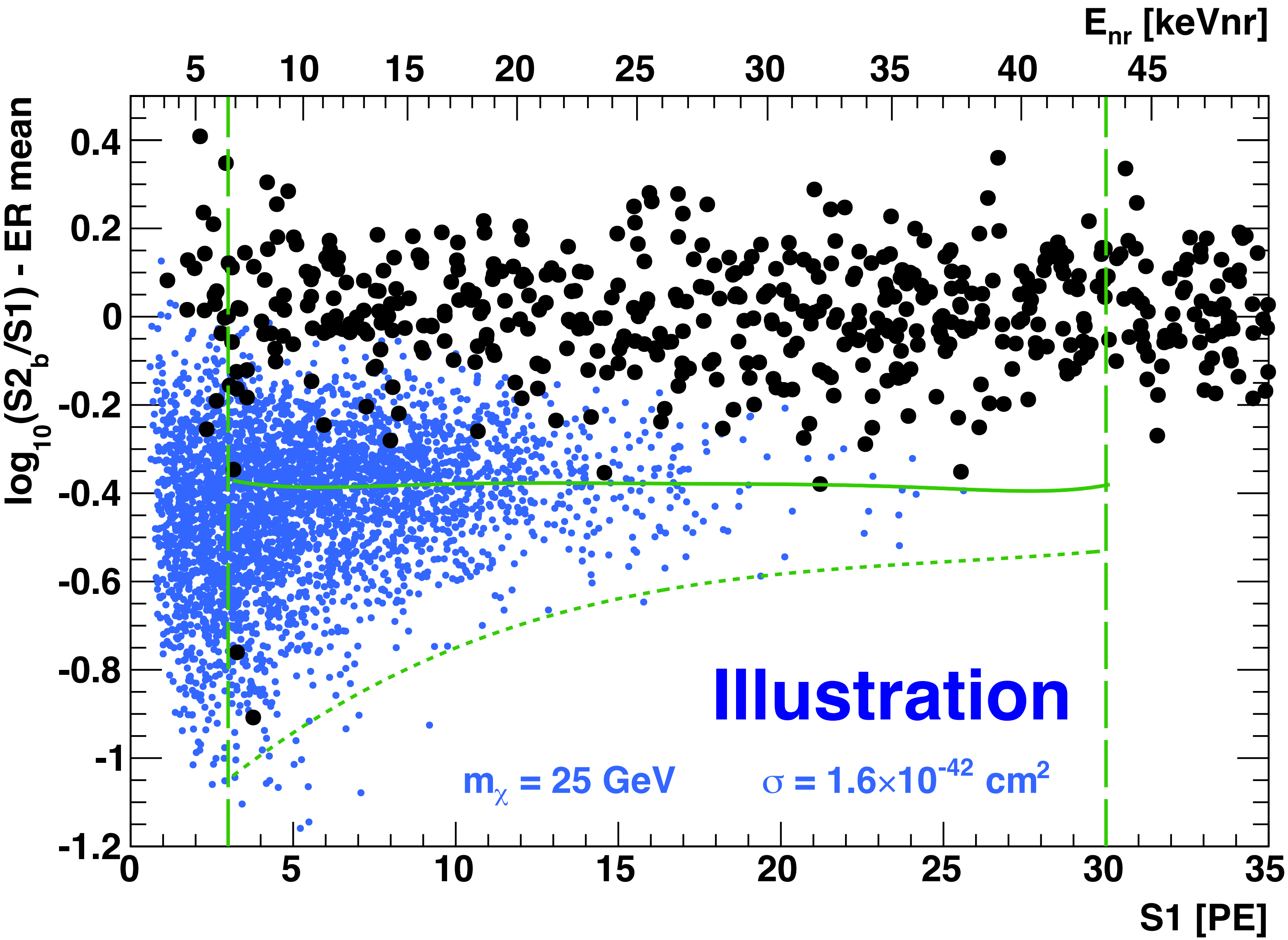
What XENON100 would see if…



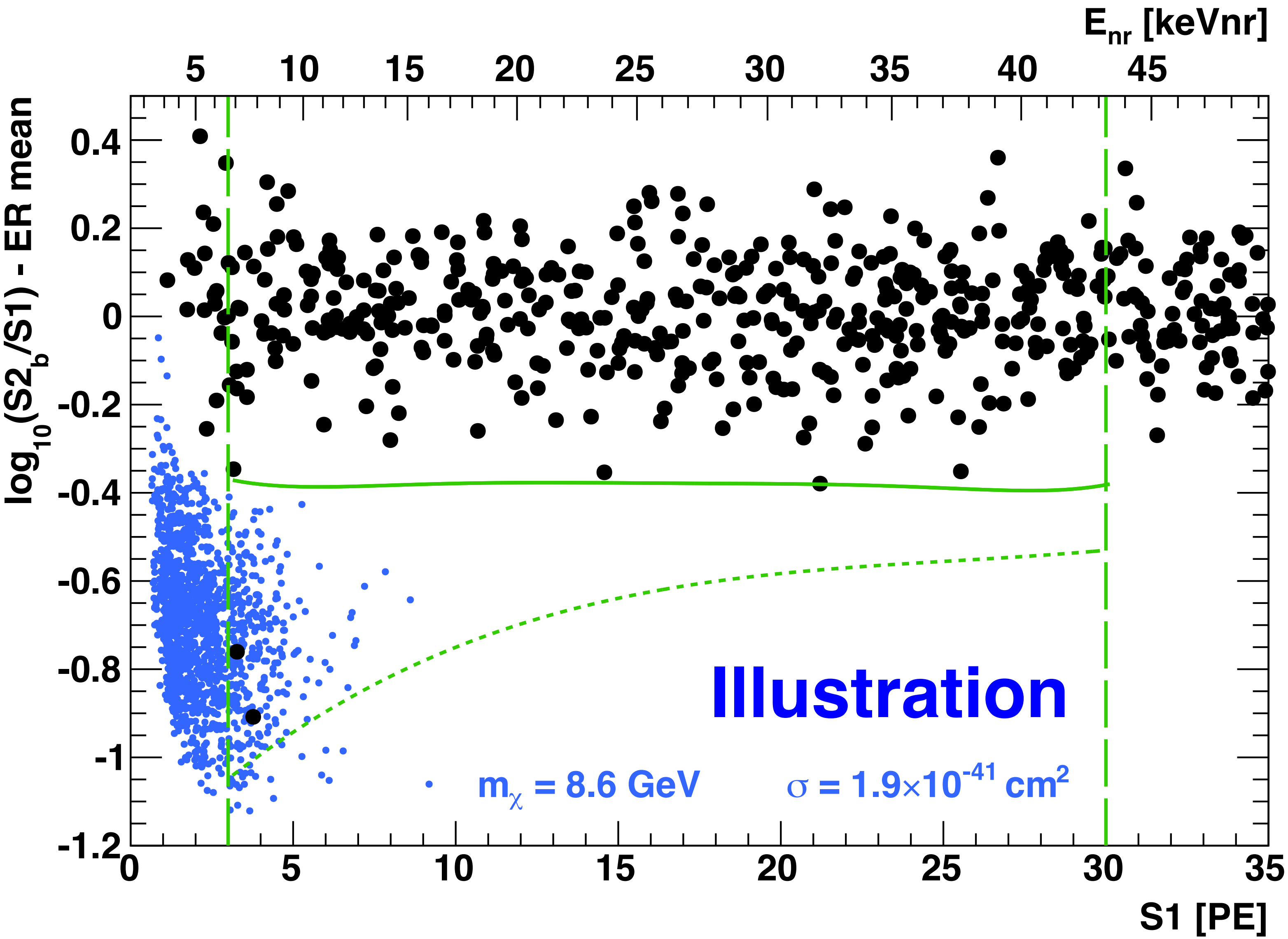
Assume "CoGeNT"



Assume: "CRESST"



Assume “CDMS”



E_{nr} [keVnr]
5
10
15
20
25
30
35
40
45
$\log_{10}(S2_b/S1)$ - ER mean
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
0
5
10
15
20
25
30
35
S1 [PE]
Illustration
m_χ = 8.6 GeV
$\sigma = 1.9\times10^{-41}$ cm^2

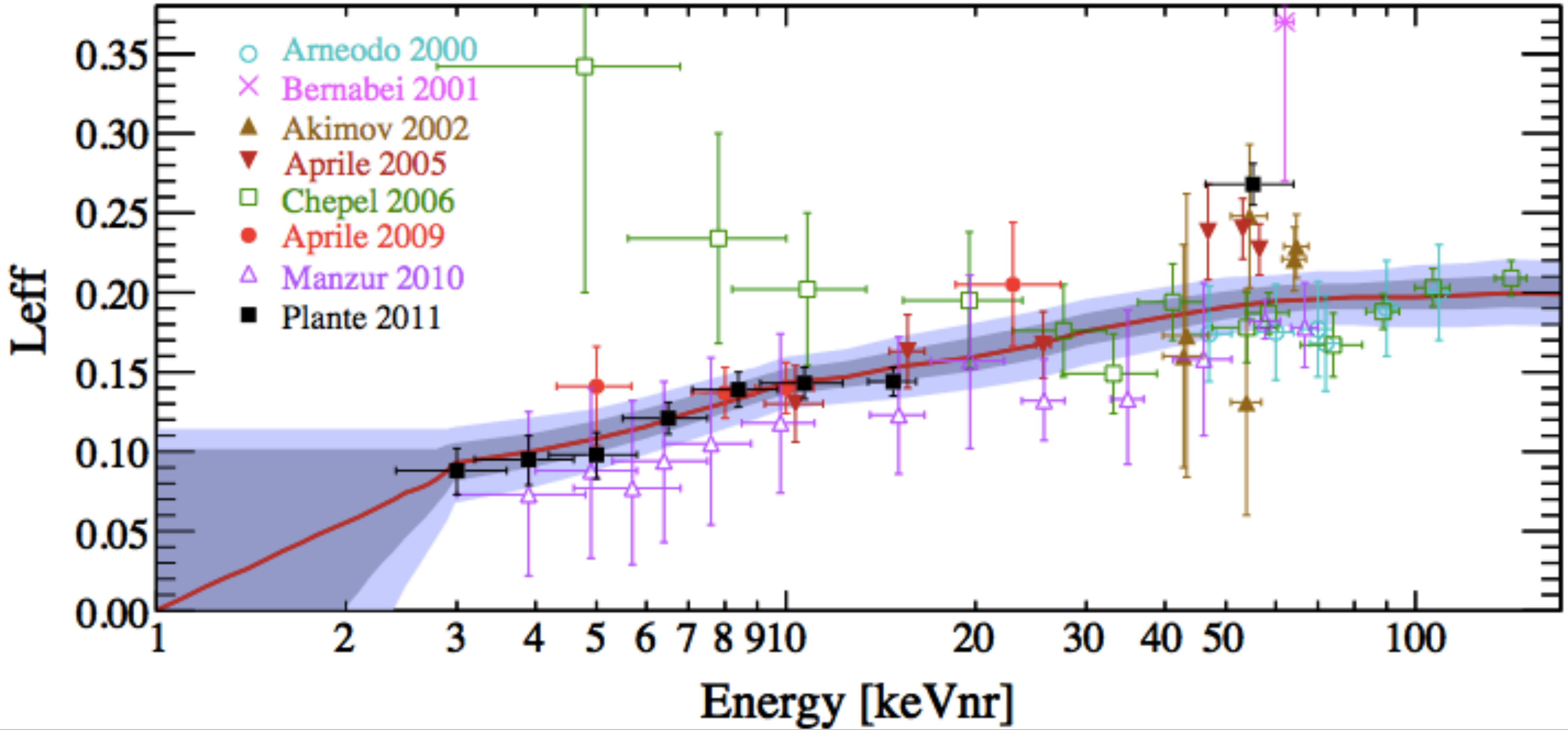
Nuclear Recoil equivalent Energy

S1 ←→ nuclear recoil energy: $E_{NR} = S_1/L_y/L_{eff} \times S_e / S_r$

S_1: 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



Verification of Nuclear Recoil Energy Scale

➔ XENON100 nuclear recoil energy scale including all measurements of direct neutron scattering experiments

Monte Carlo simulation of neutron source: PRD 88, 012006 (2013)

- Input AmBe spectrum (ISO 8529-1 standard). Analysis robust against variations of this spectrum
- Source strength measurement (PTB): (160 ± 4) n/s
- Complete Monte Carlo description of the detector including detector shield (water, lead, polyethylen and copper)
- E_{dep} is converted to S1 and S2 including thresholds, resolutions and acceptances from data

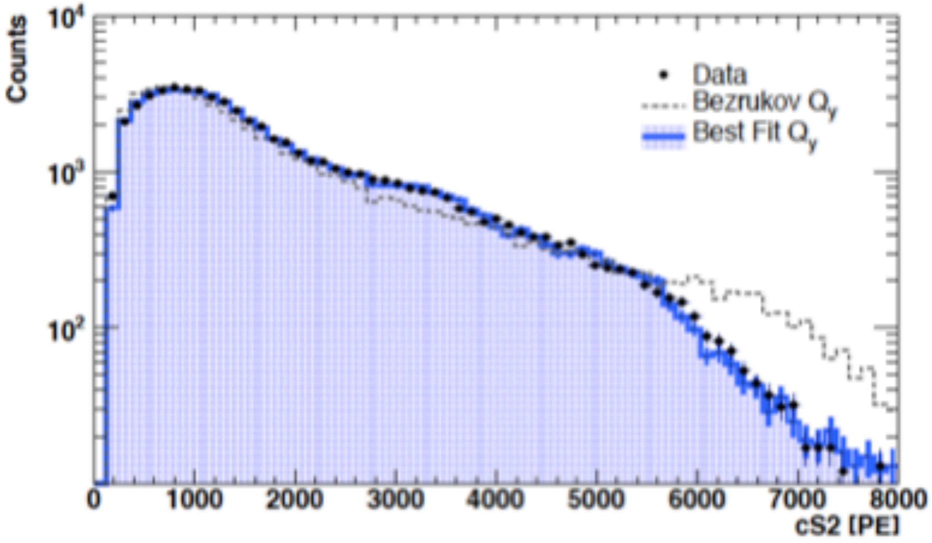
MC Simulation of Neutron Source

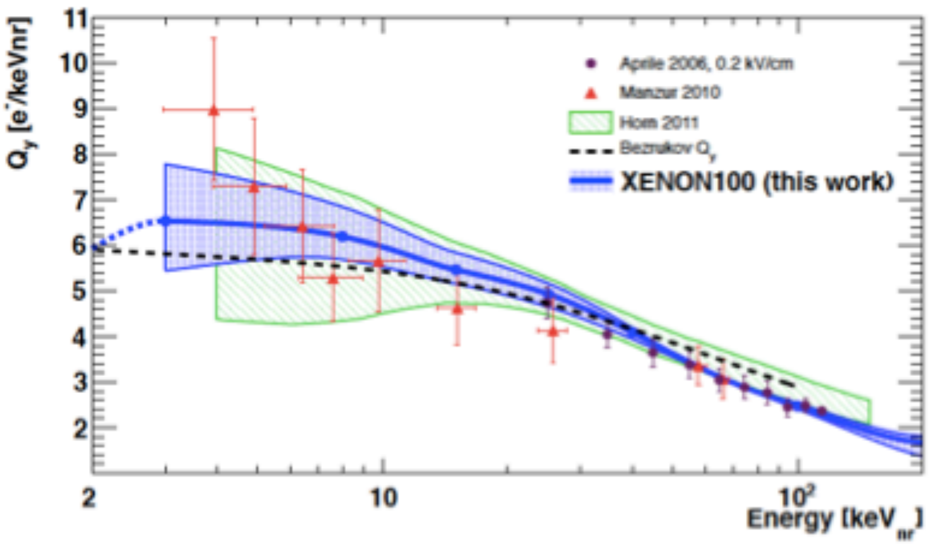
Step 1: Use L_{eff} from direct measurements

→ reproduce S2 spectrum → obtain optimal Q_y

Step 2: Use obtained Qy

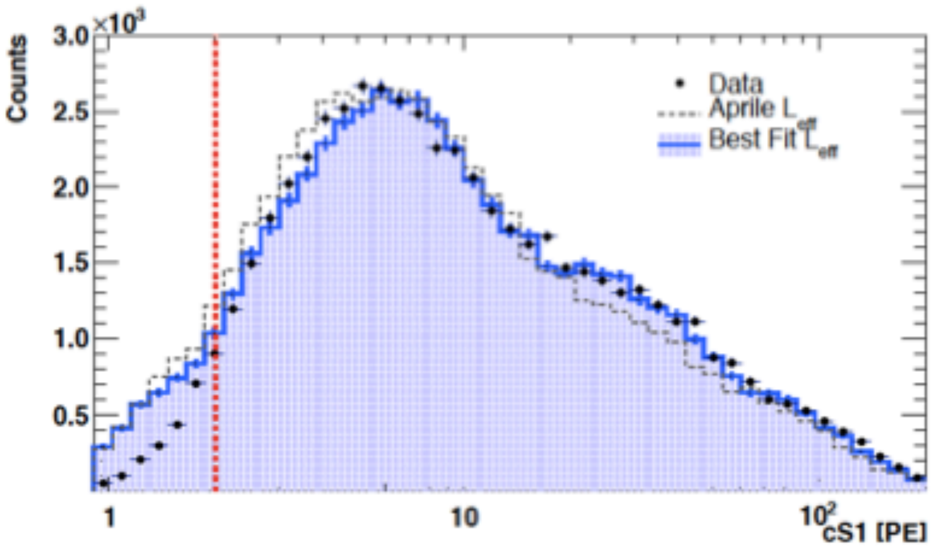
→ reproduce S1 spectrum → obtain a new L_{eff}

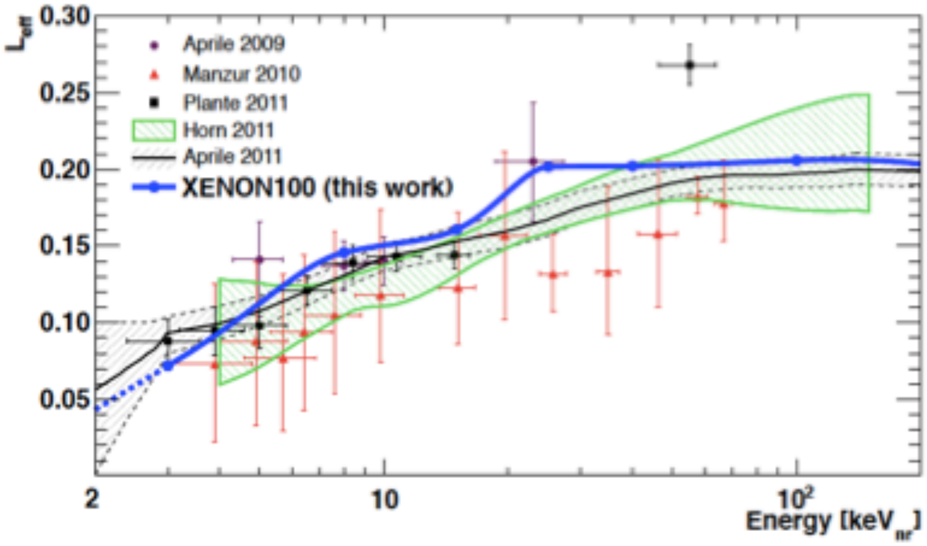




Best fit for source strength: 159 n/s

←→ fits perfectly to PTB source measurement



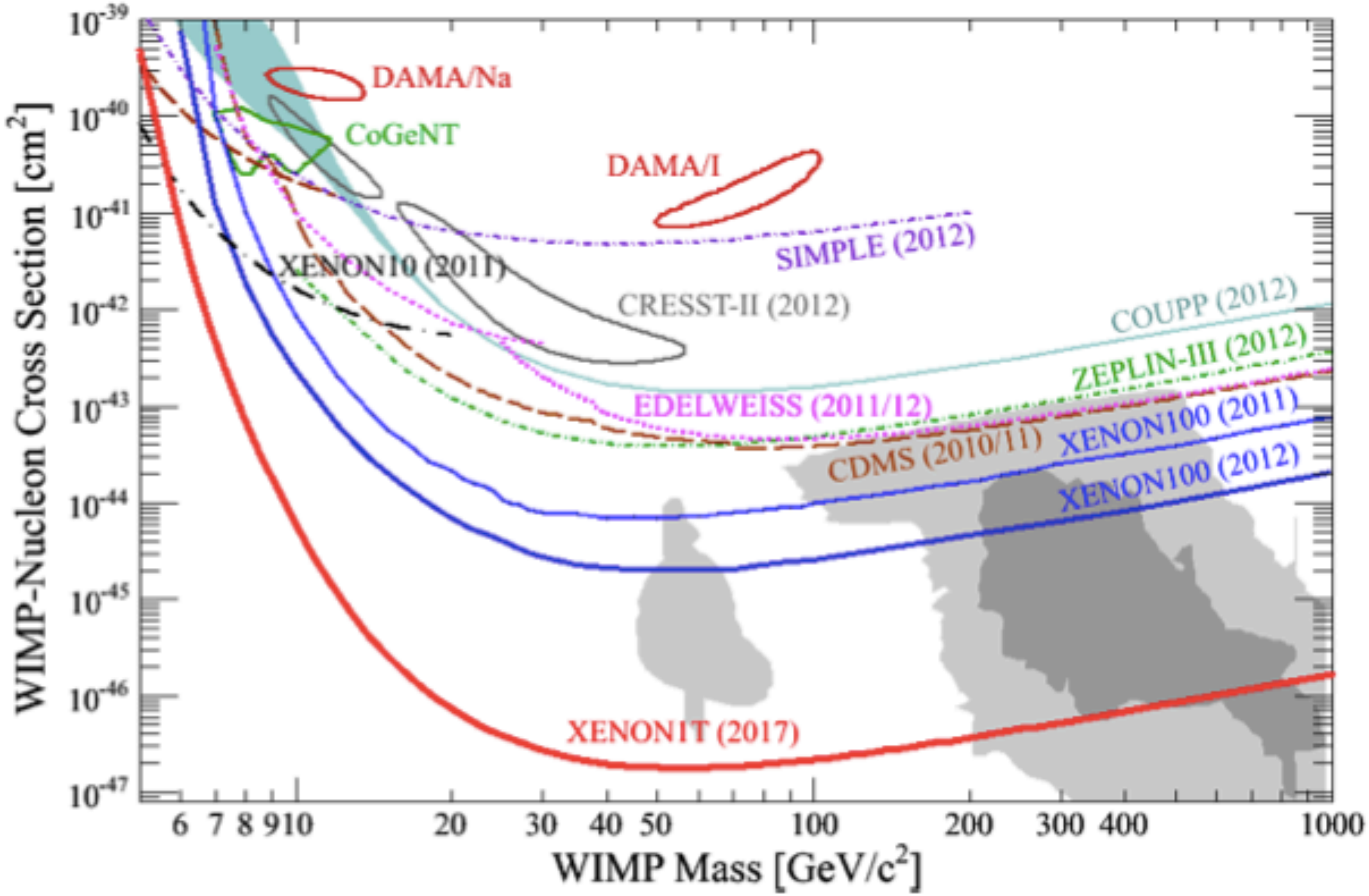


- Poor agreement below 2PE due to unknown efficiencies below threshold
- Best fit L_{eff} matches perfectly to previous measurements and theoretical calculations

➔ Consistency strengthens reliability of analysis

➔ **Limits of XENON100 are confirmed**

The Future: XENON1T



➔ **sensitivity goal: $\sigma < 2 \times 10^{-47}$ cm^2 for M_{WIMP}=50 GeV after 2t*year**

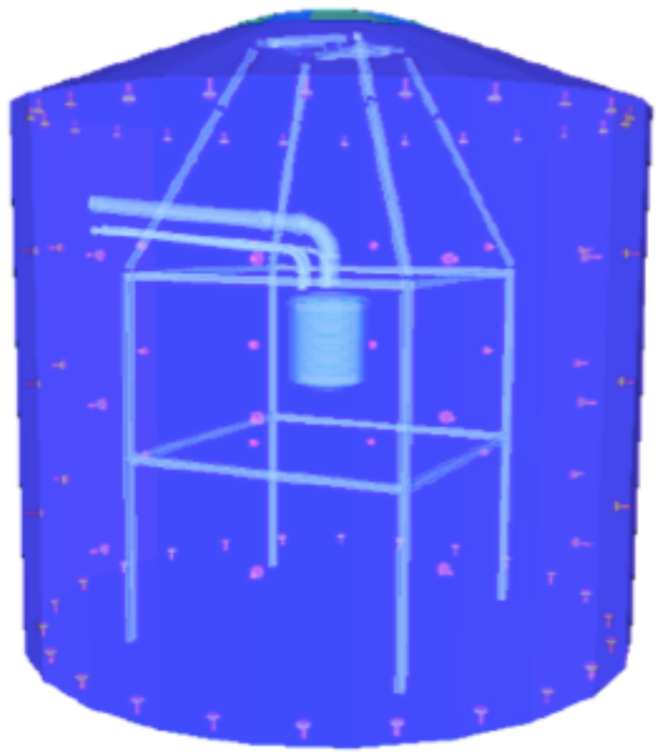
XENON1T Background Suppression

Requirement: < 1 event in the full exposure

- **External γ's:**
  - suppression via self-shielding ($\rho_{LXe} \sim 3 g/cm^3$)
  - material screening and selection
- **Internal BGs (^{222}Rn and ^{85}Kr)**
  - cryogenic distillation column (Kr)
    < 1 ppt nat. Kr achieved in XENON100
  - online Rn removal by Rn tower
- **Neutrons**
  - muon veto and material selection
  - low U and Th contaminations
  → low α and (α,n) production

Example: Development of
low radioactivity PMTs with Hamamatsu
<1mBq/PMT in U and Th

Muon veto design



Background rejection power:
> 99.5% neutrons with a μ
tagged in the veto

XENON1T Status

- funding in place
- Xenon purchased
- construction started in June 2013 @ hall B, LNGS
  - First: support building
  - Next: water tank, …

- in parallel finalizing detector design & construction of components:
  - teflon UV reflector
  - high transparent meshes
  - cooling (pulse tube refrigerators)
  - Purification rate~100s.l.p.m.
  - 1m drift of e- demonstrated
  - 100kV HV demonstrated

Summary

➢ WIMP scattering off nuclei (SI):

- XENON100 excludes the current indications of DM
- Strongest exclusion limits 2 x 10^{-45} cm^2 for 50 GeV
- Nuclear recoil energy scale verified with MC/data comparison of an AmBe neutron source
  → reliable L_{eff} , complete understanding of NR acceptance

➢ Limits on spin dependent (SD) scattering

- Strongest limits for n and competitive for p

➢ XENON1T:

- Construction has started in June 2013
- Sensitivity goal: 2 x $10^{-47}$$cm^2$ for M_{WIMP} = 50 GeV
- Ongoing optimisation of TPC design
- Planned start of science run: early 2015