www.darwin-observatory.org

DARWIN: Dark Matter (and more) with a multi ton-scale Xenon Detector

Marc Schumann *AEC, Universität Bern*

TAUP 2015, Torino, September 2015

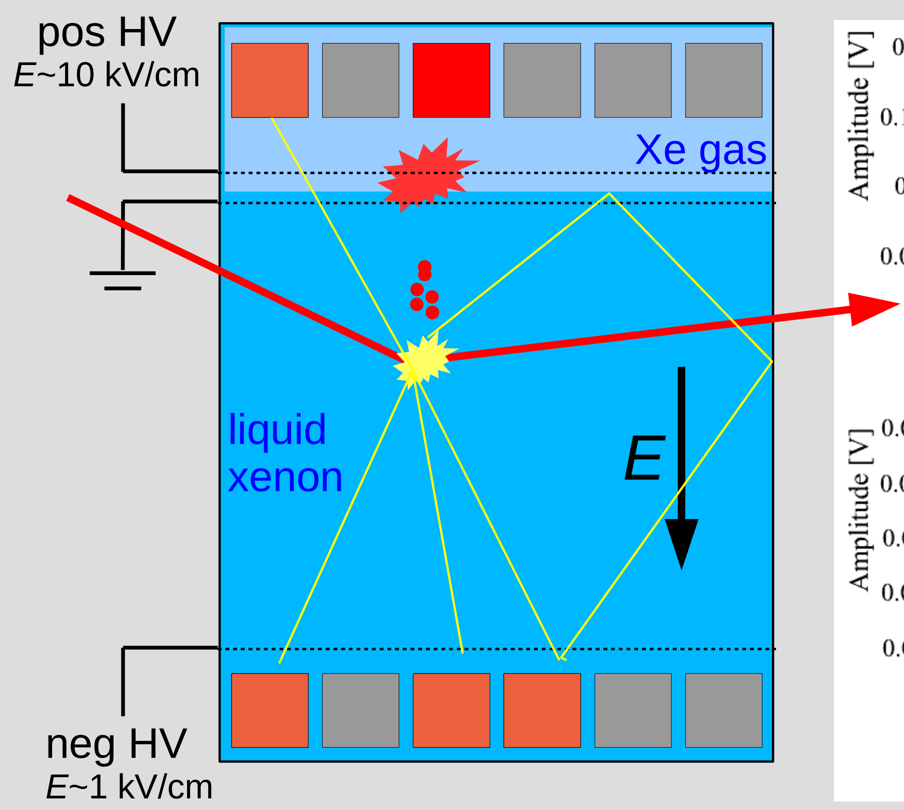
marc.schumann@lhep.unibe.ch
www.lhep.unibe.ch/darkmatter

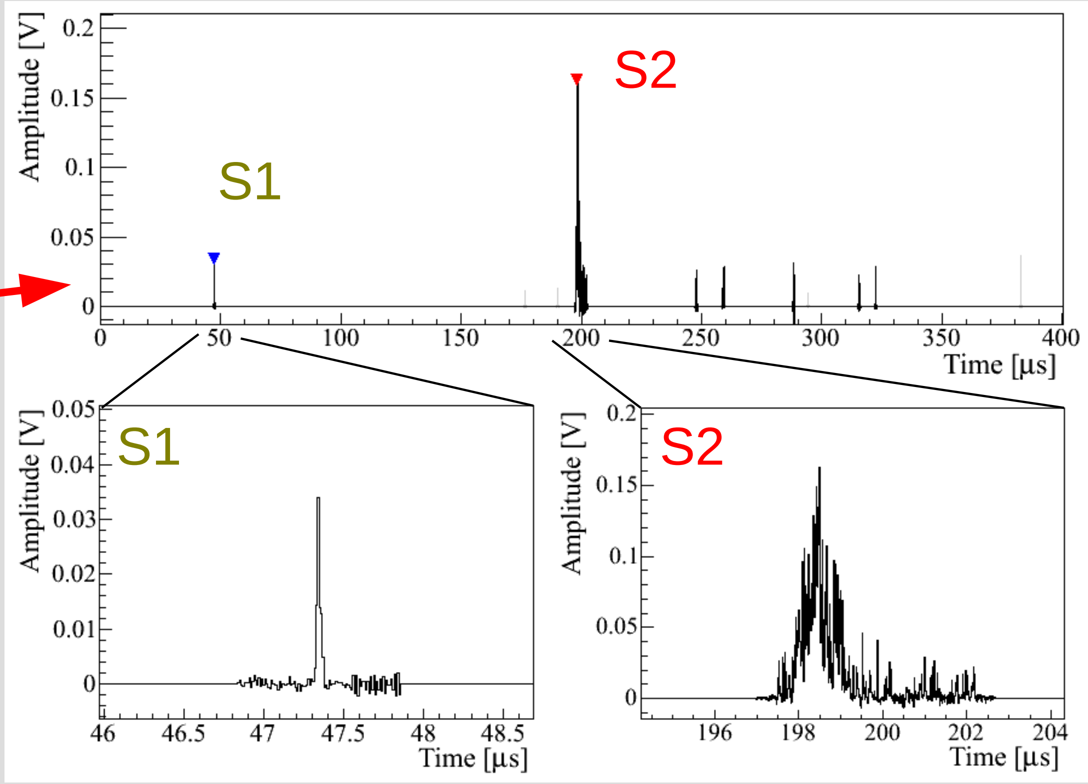
UNIVERSITÄT BERN
AEC
ALBERT EINSTEIN CENTER FOR FUNDAMENTAL PHYSICS

Dual Phase TPC

Dolgoshein, Lebedenko, Rodionov, JETP Lett. 11, 513 (1970)

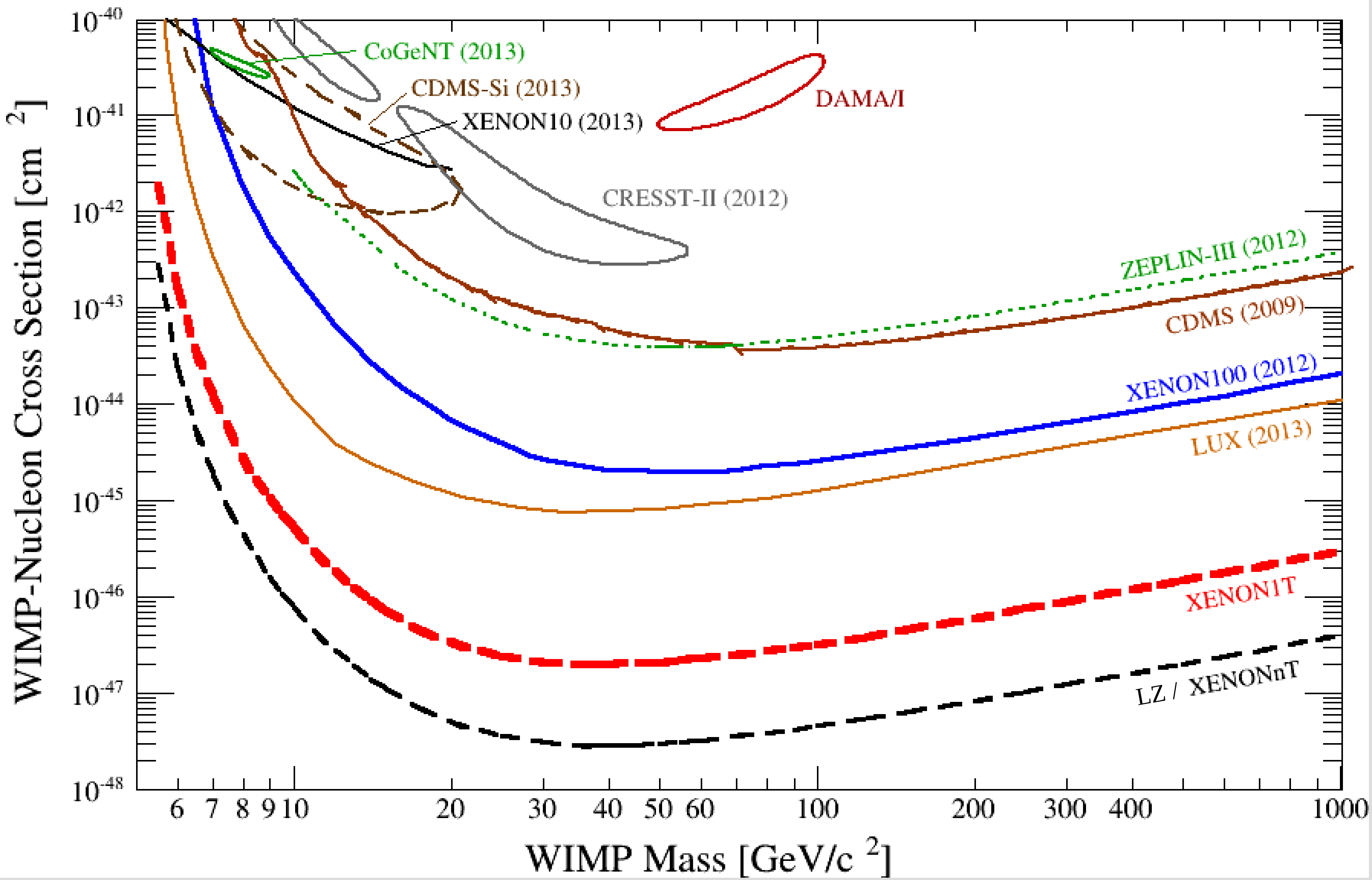
TPC = time projection chamber



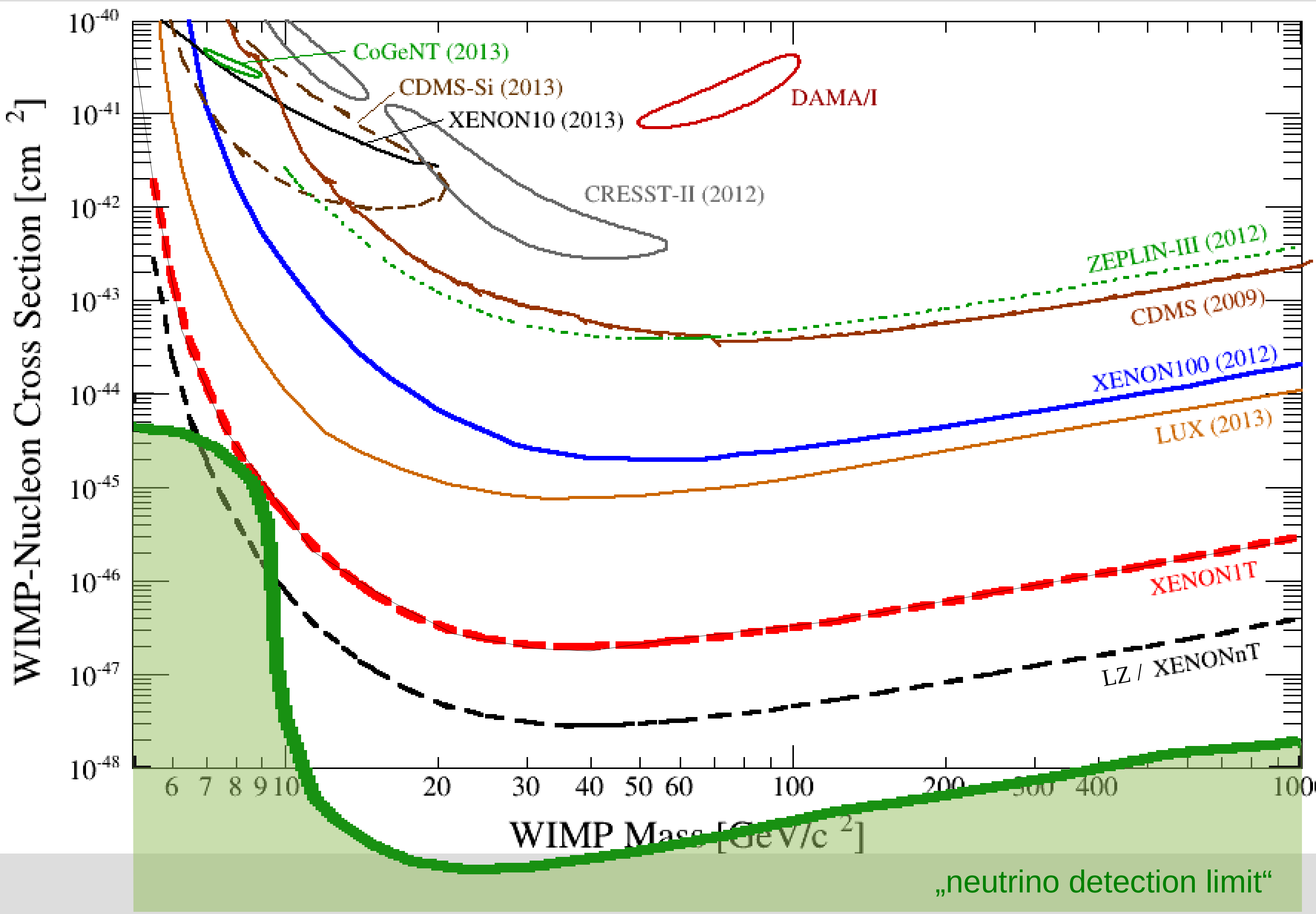


→ 3d vertex reconstruction
→ multi-scatter rejection (WIMPs scatter only once!)
→ S2/S1 ratio: background rejection ~99.5% @ 50% NR acceptance

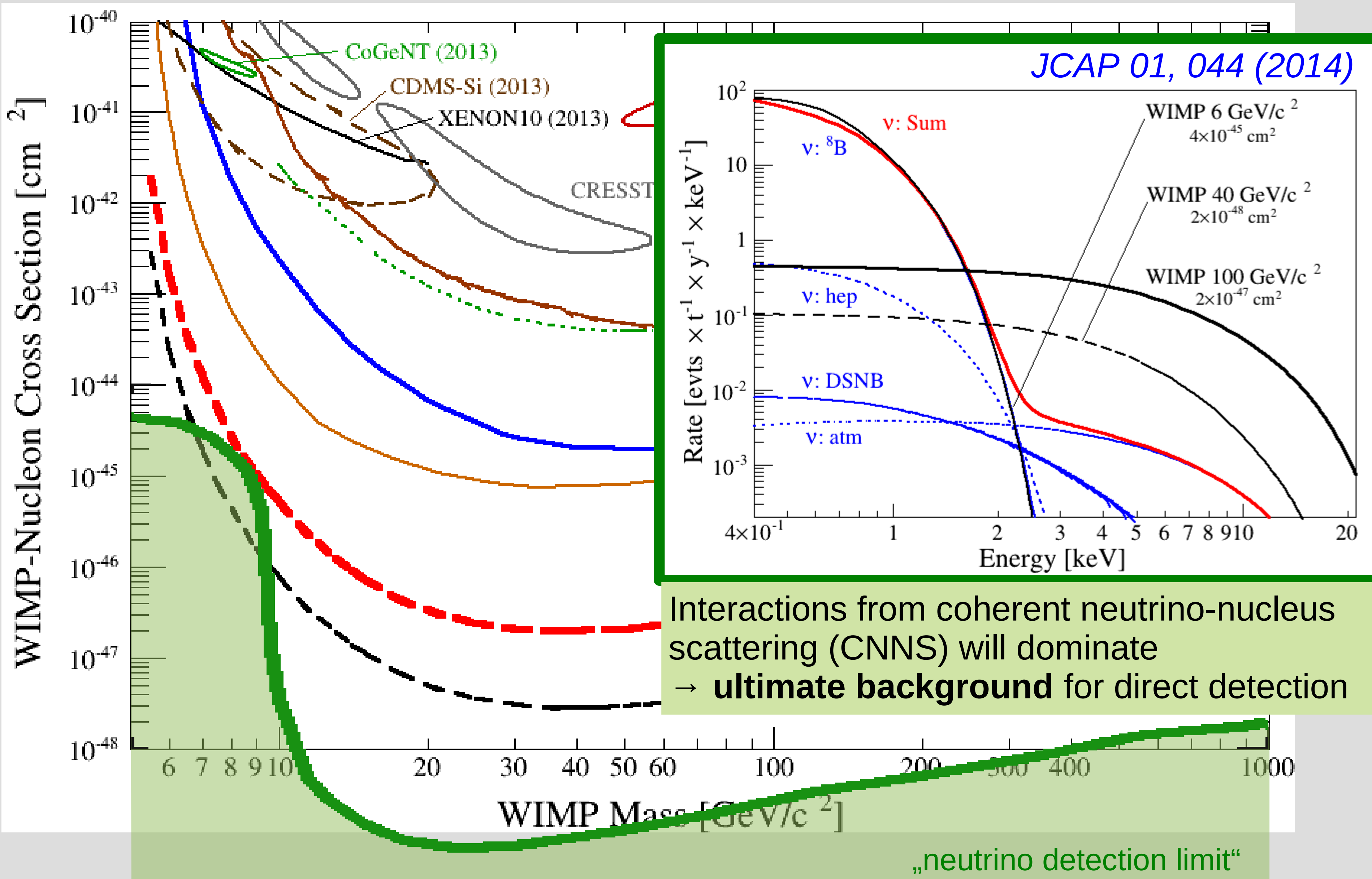
The XENON Future



The XENON Future

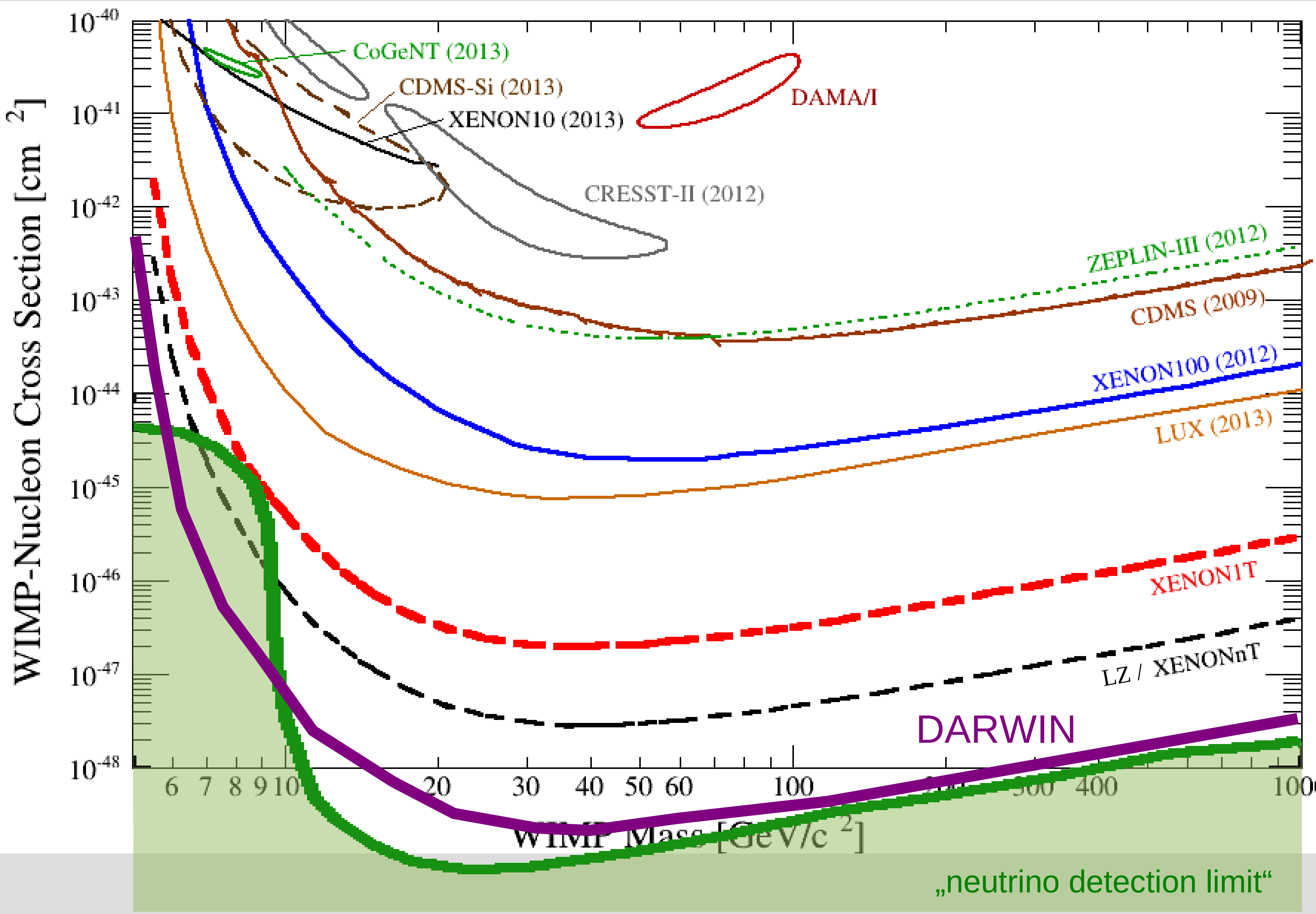


The XENON Future



Interactions from coherent neutrino-nucleus scattering (CNNS) will dominate
→ **ultimate background** for direct detection

The DARWIN goal



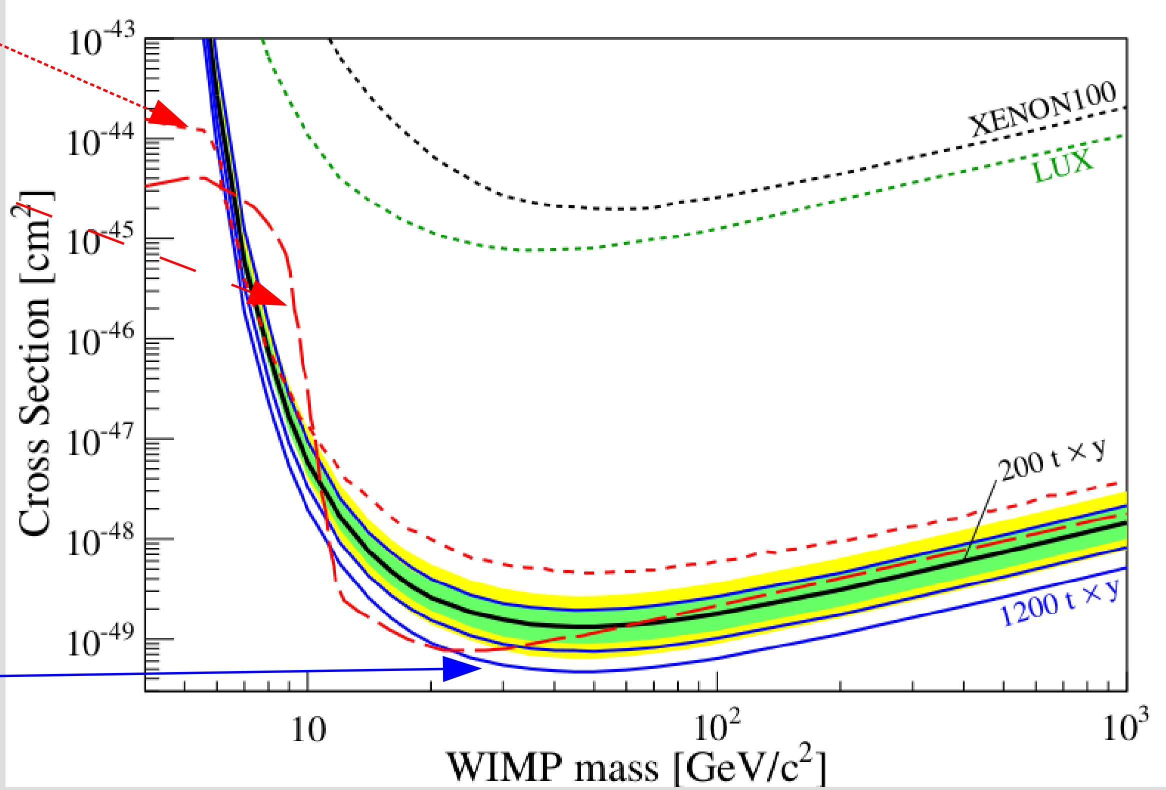
The „Neutrino Floor“

There are different definitions on the market...

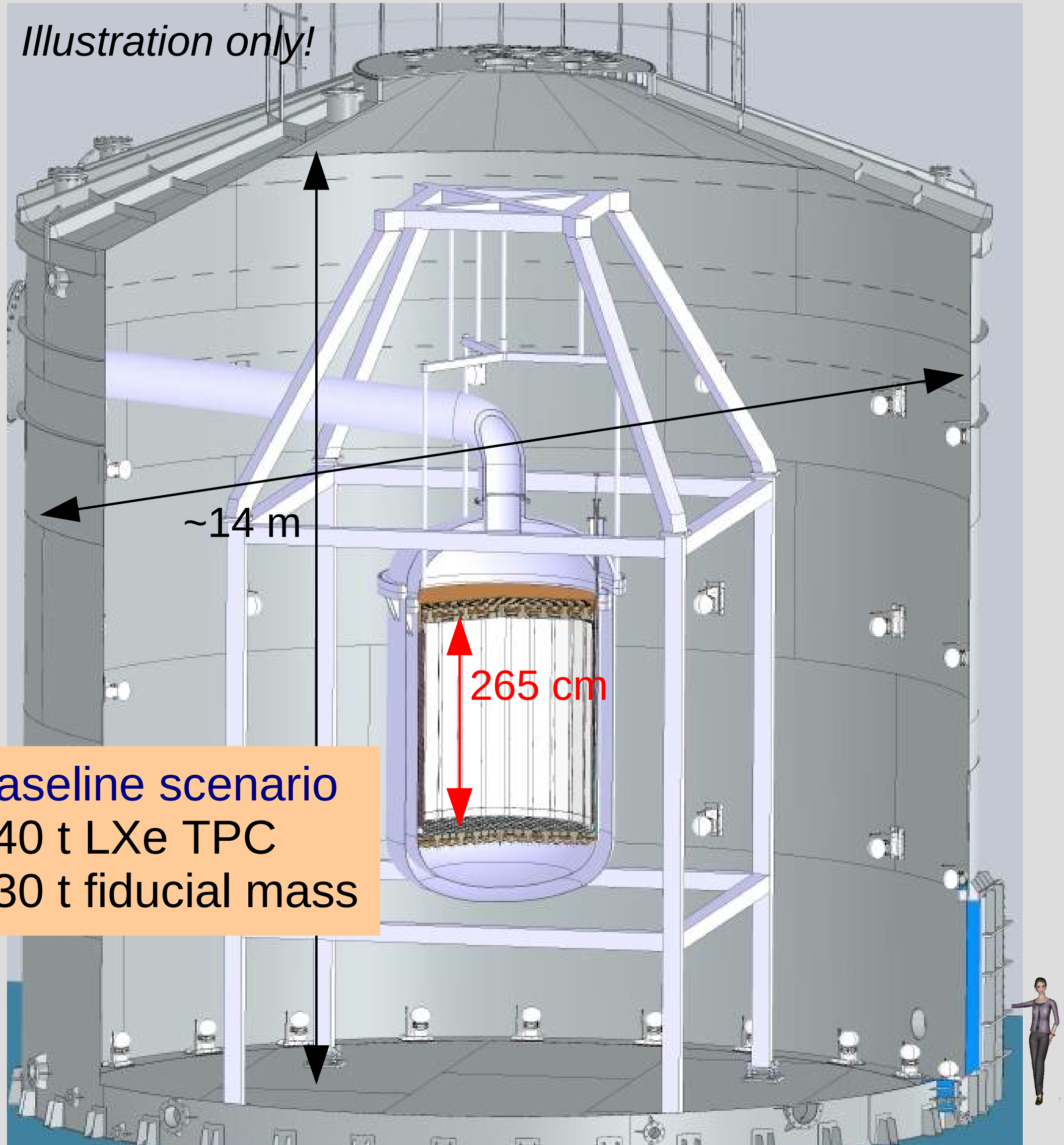
Billard et al. *PRD 89 (2014) 023524*
„1-CNNS event line“

Billard et al. *PRD 89 (2014) 023524*
„WIMP discovery limit“
= detect a WIMP at 3σ on top of 500 CNNS events above a LXe threshold of 4 keVnr (infinite E resolution)
→ assuming an unrealistic 100% NR acceptance, a **5300 t × y exposure** is required to reach this (4-35 keVnr window)

Another possibility
Expected 90% CL exclusion limit
- only CNNS background
- unrealistic 100% NR acceptance



DARWIN The ultimate WIMP Detector

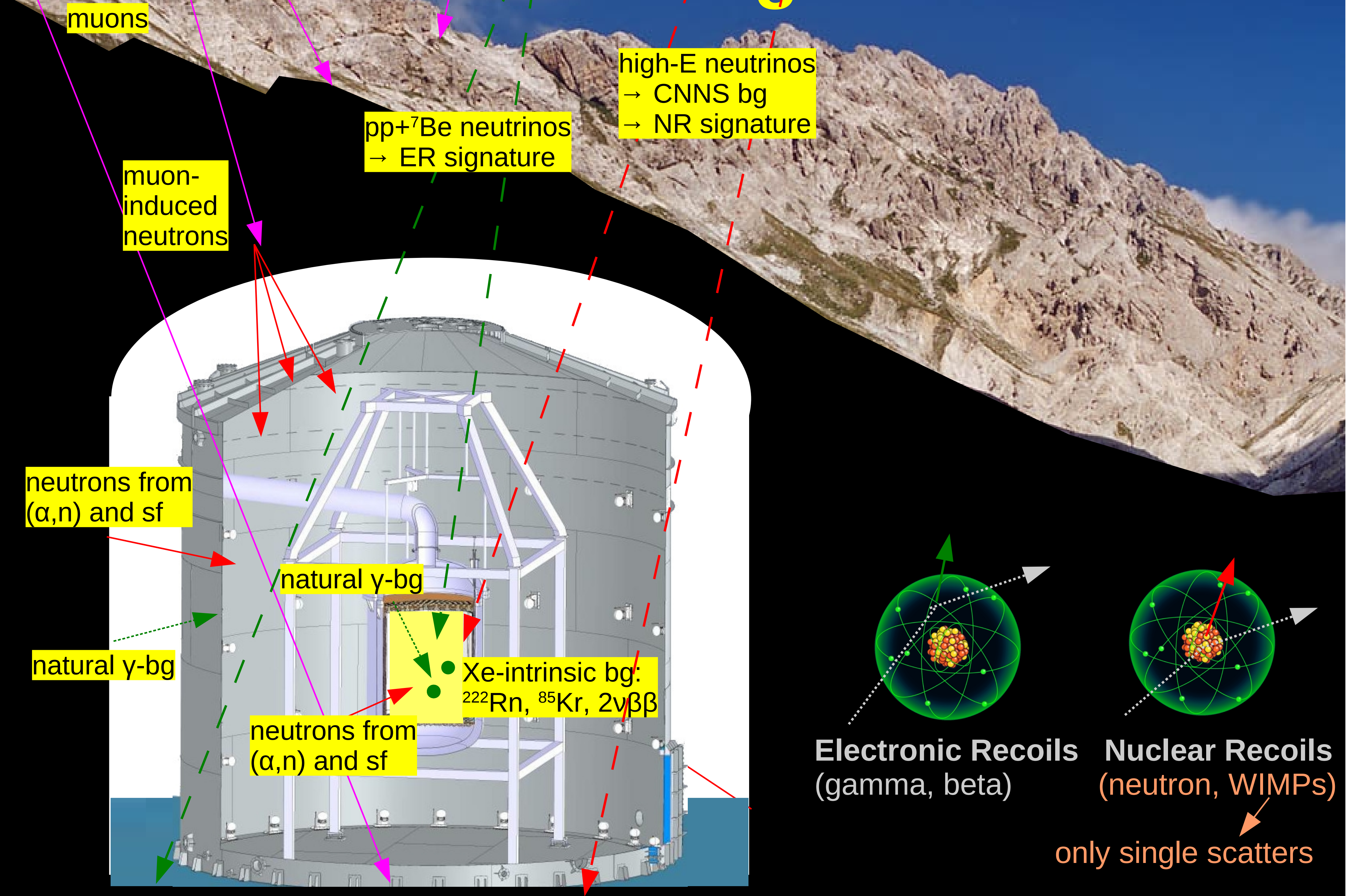


Baseline scenario
~40 t LXe TPC
~30 t fiducial mass

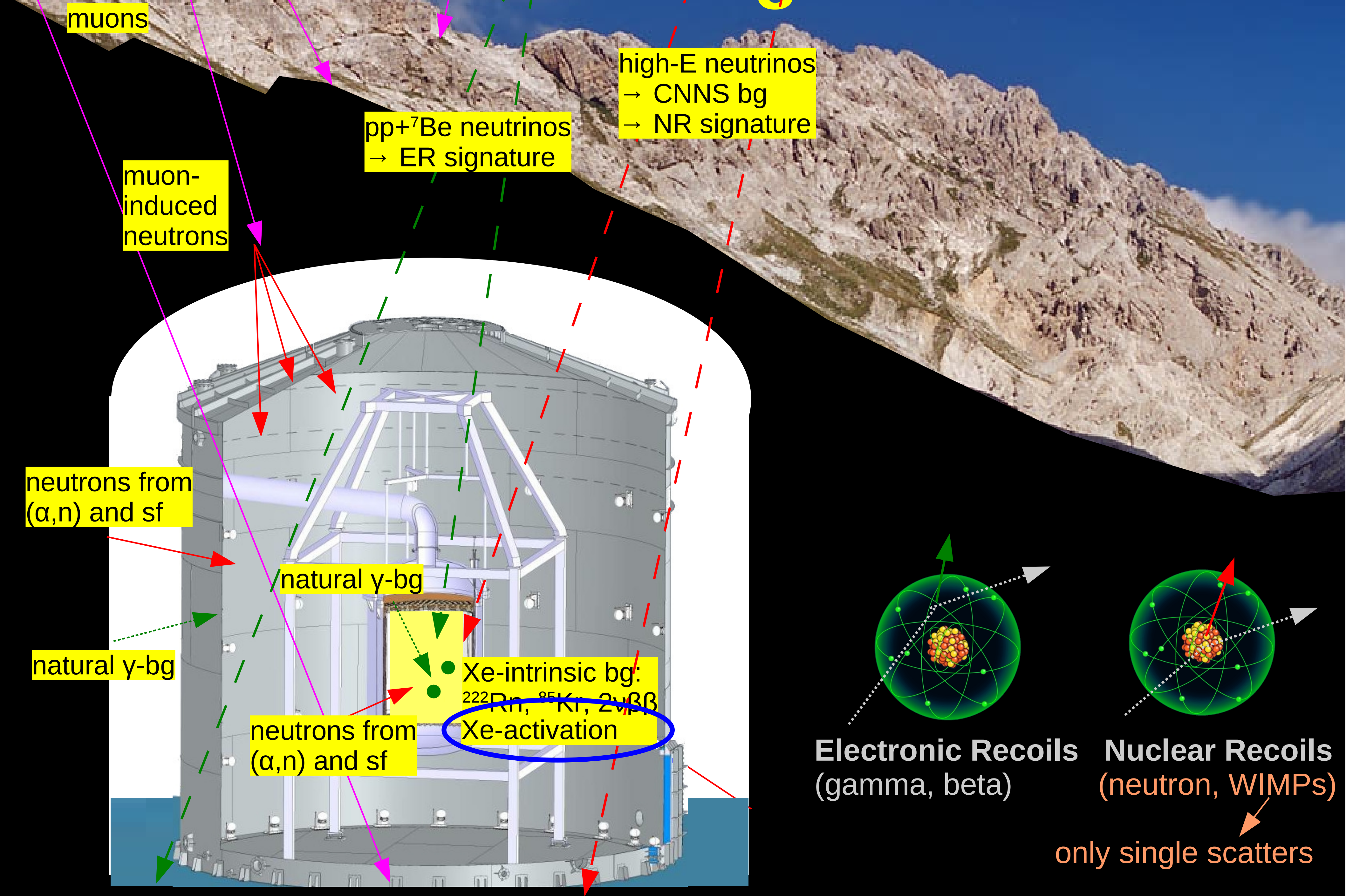
- aim at sensitivity of a few 10^{-49} cm², limited by **irreducible ν-backgrounds**
- international consortium, 21 groups
- R&D ongoing
  - challenges include
    - background rejection
    - HV stability (–150..200 kV)
    - target purity, electron drift
    - intrinsic radiactivity (^{85}Kr, ^{222}Rn)
    - calibration, stability
- DARWIN is on the European astroparticle physics APPEC roadmap and endorsed by the Swiss State Secretariat (SERI)
- Timescale: start after XENONnT

www.darwin-observatory.org

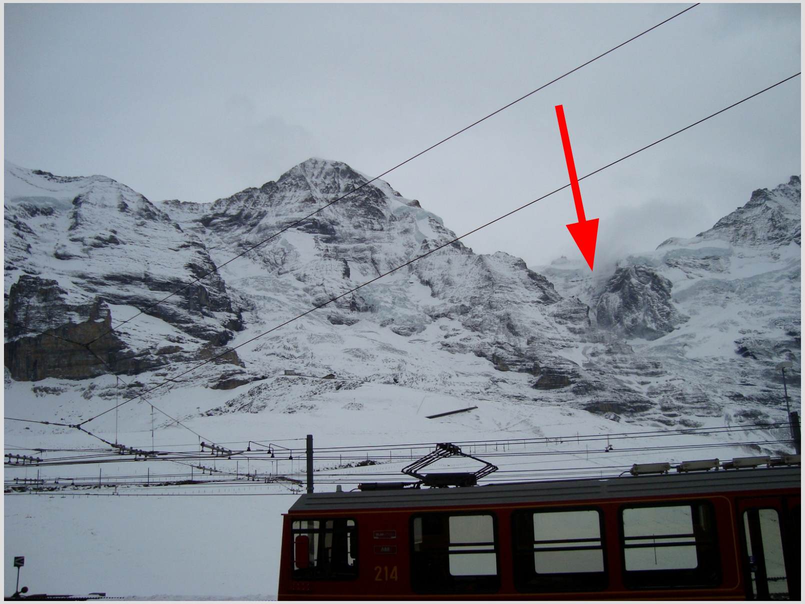
Background Sources



Background Sources



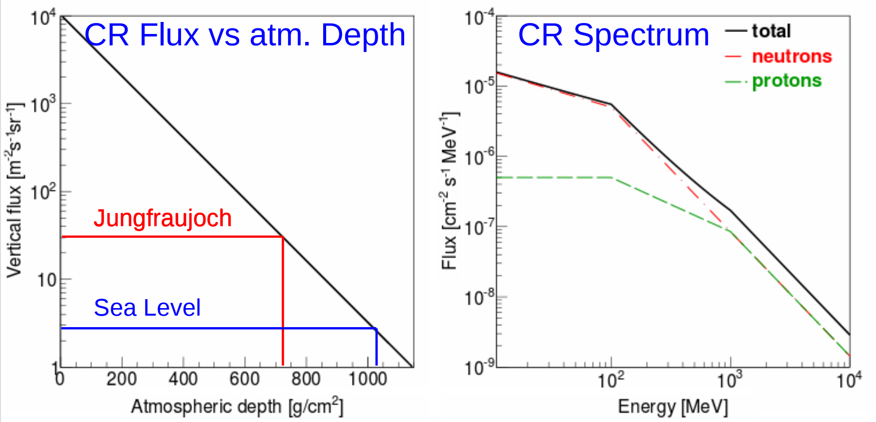
Measuring Xenon Activation



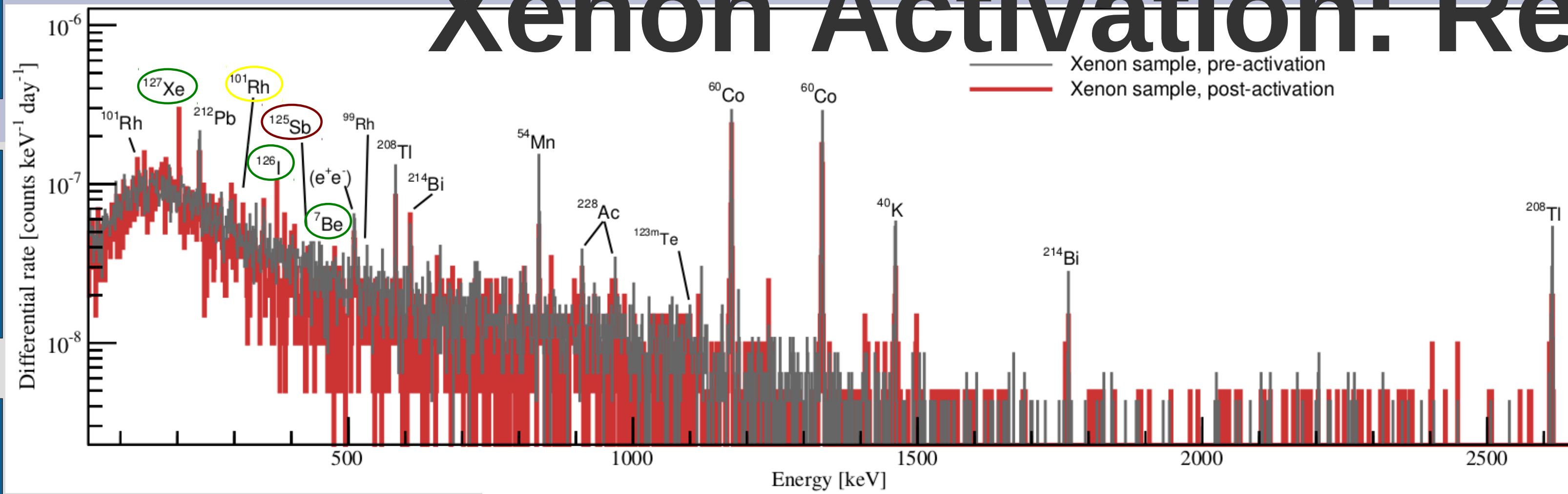
arXiv:1507.03792

- study xenon activation by cosmic rays
- 2.04 kg ultra-pure xenon + 10.35 kg OFHC copper activated at Jungfraujoch for **345 days** `www.ifjungo.ch`
- CR flux @**3470m** 11.2× higher than at sea level
  → corresponds to >10 years sea-level exposure
- transport and cool-down times minimized
- gamma-ray spectra measured before and after activation with Gator HPGe spectrometer @ LNGS

Goals: (i) identification of isotopes from activation
(ii) comparison with activation codes
(Activia, Cosmo, TALYS)
(iii) impact for dark matter searches?



Xenon Activation: Results



arXiv:1507.03792

5 isotopes detected

^{7}Be, ^{126}I and ^{127}Xe are short-lived and therefore uncritical

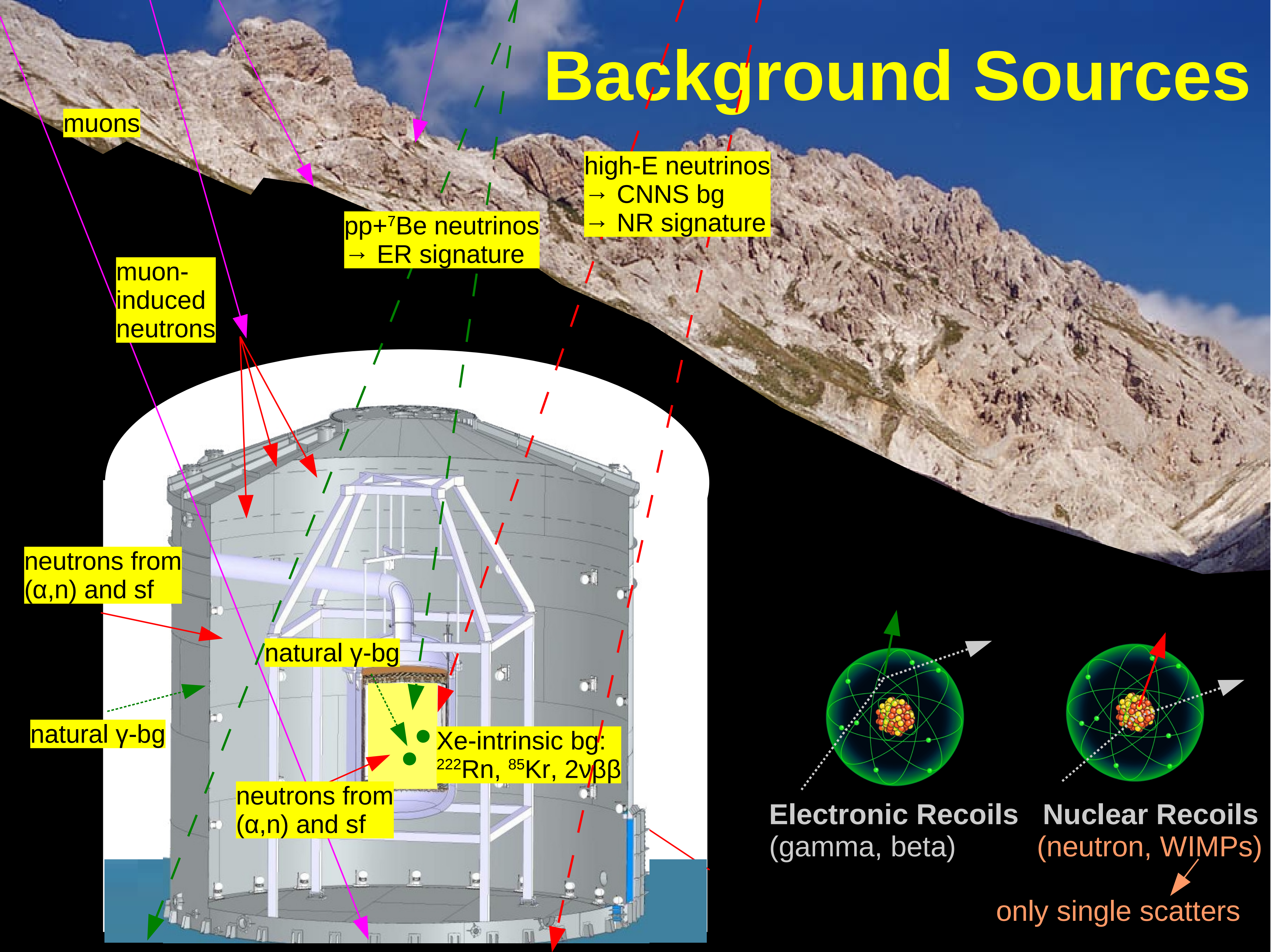
^{101}Rh: no single low-E electrons or γ-rays

^{125}Sb: produces single low-E electrons
→ expected rate too high for LUX background
→ removed by getters?

Isotope	$T_{1/2}$ [days]	Xenon: specific saturation activity at sea level A_{sat} [μBq/kg] — This work: Measurement	This work: Calculations Activia	This work: Calculations Cosmo	Literature values: Measurement LUX [47]	Literature values: Calculation TALYS [42]
^{7}Be	53.3	370^{+240}_{-230}	*6.4*	*6.4*	–	–
^{85}Sr	64.8	< 34	5.3	4.6	–	–
^{88}Zr	83.4	< 52	6.7	4.6	–	–
^{91m}Nb	62.0	< 1200	5.6	5.0	–	
^{99}Rh	15.0	< 120	8.3	8.2		
^{101}Rh	1205.3	1420^{+970}_{-850}	*16.6*	*15.3*	–	*0.5*
^{110m}Ag	252.0	< 49	0.9	0.8	–	–
^{113}Sn	115.0	< 55	51	47	–	–
^{125}Sb	986.0	590^{+260}_{-230}	*0.2*	*13.5*	–	*0.5*
^{121m}Te	154.0	< 1200	299	276	–	135
^{123m}Te	119.7	< 610	14.7	14.4	–	140
^{126}I	13.0	175^{+94}_{-87}	247	247	–	–
^{131}I	8.04	< 190	147	170	–	–
^{127}Xe	36.4	1870^{+290}_{-270}	*415*	*555*	1530 ± 300	–
^{129m}Xe	8.89	$< 8.7 \times 10^3$	238	421	1360 ± 250	
^{131m}Xe	11.77	$< 3.6 \times 10^4$	251	313	1620 ± 370	–
^{133}Xe	5.25	$< 1.2 \times 10^5$	159	196	1140 ± 230	–
^{132}Cs	6.47	< 120	**166**	**164**	–	–

The majority of the calculated predictions are too low (*italic font*); agreement only for ^{126}I

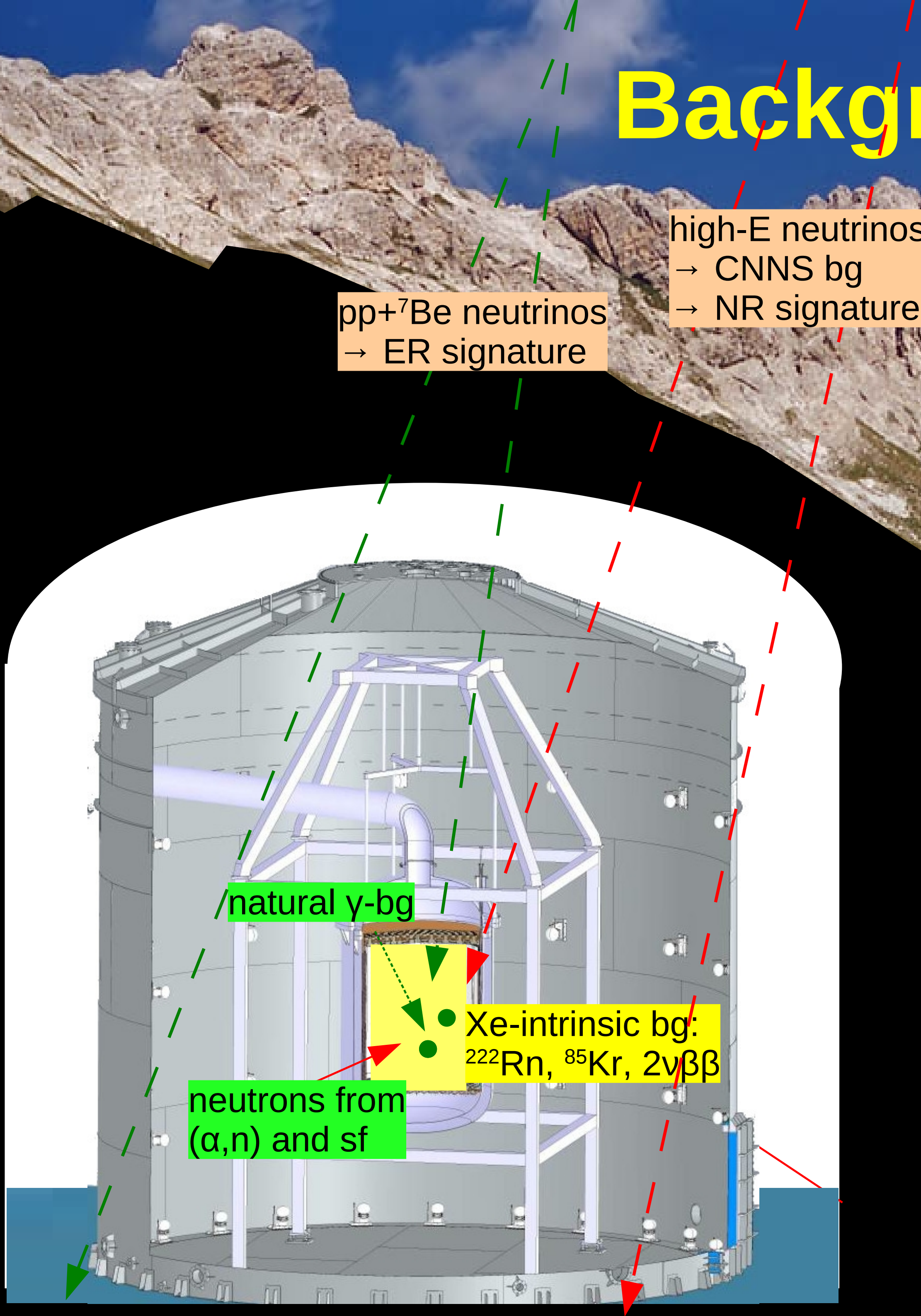
Xe-isotopes: good agreement with LUX


Background Sources
muons
high-E neutrinos
→ CNNS bg
→ NR signature
pp+⁷Be neutrinos
→ ER signature
muon-
induced
neutrons
neutrons from
(α,n) and sf
natural γ-bg
natural γ-bg
Xe-intrinsic bg:
²²²Rn, ⁸⁵Kr, 2νββ
neutrons from
(α,n) and sf
Electronic Recoils
(gamma, beta)
Nuclear Recoils
(neutron, WIMPs)
only single scatters

Background Sources

assume 100% effective shield

(~14m diameter,
10x better than
XENON1T shield)

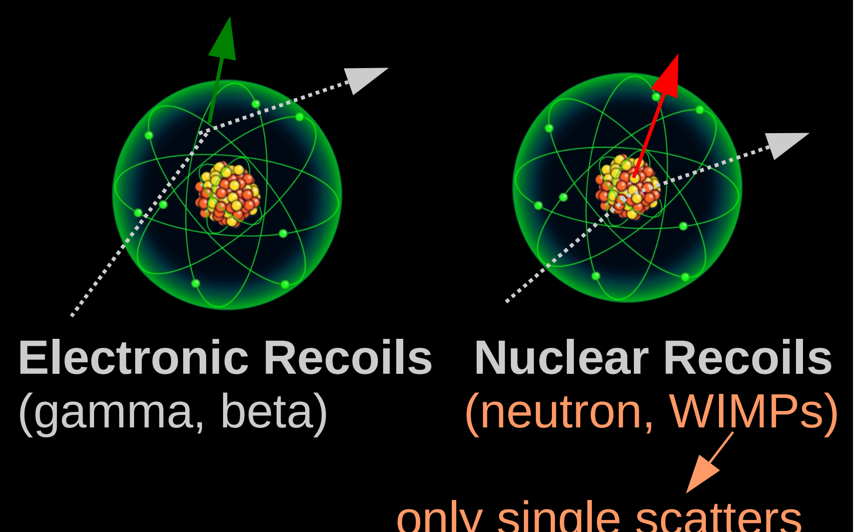


Dark matter sensitivity of multi-ton liquid xenon detectors

Marc Schumann,[a,1] Laura Baudis,[b] Lukas Bütikofer,[a] Alexander Kish,[b] Marco Selvi[c]

[a]Albert Einstein Center for Fundamental Physics, Universität Bern, Switzerland
[b]Physik-Institut, Universität Zürich, Switzerland
[c]INFN Bologna, Italy

arXiv:1506.08309



Backgrounds

arXiv:1506.08309

All relevant backgrounds are considered:

Source	Rate [events/(t·y·keVxx)]	Spectrum	Comment
γ-rays materials	0.054	flat	assumptions as discussed in text
neutrons*	3.8×10^{-5}	exp. decrease	average of [5.0-20.5] keVnr interval
intrinsic ^{85}Kr	1.44	flat	assume 0.1 ppt of ^{nat}Kr
intrinsic ^{222}Rn	0.35	flat	assume 0.1 μBq/kg of ^{222}Rn
$2\nu\beta\beta$ of ^{136}Xe	0.73	linear rise	average of [2-10] keVee interval
pp- and ^{7}Be ν	3.25	flat	details see [19]
CNNS*	0.0022	real	average of [4.0-20.5] keVnr interval

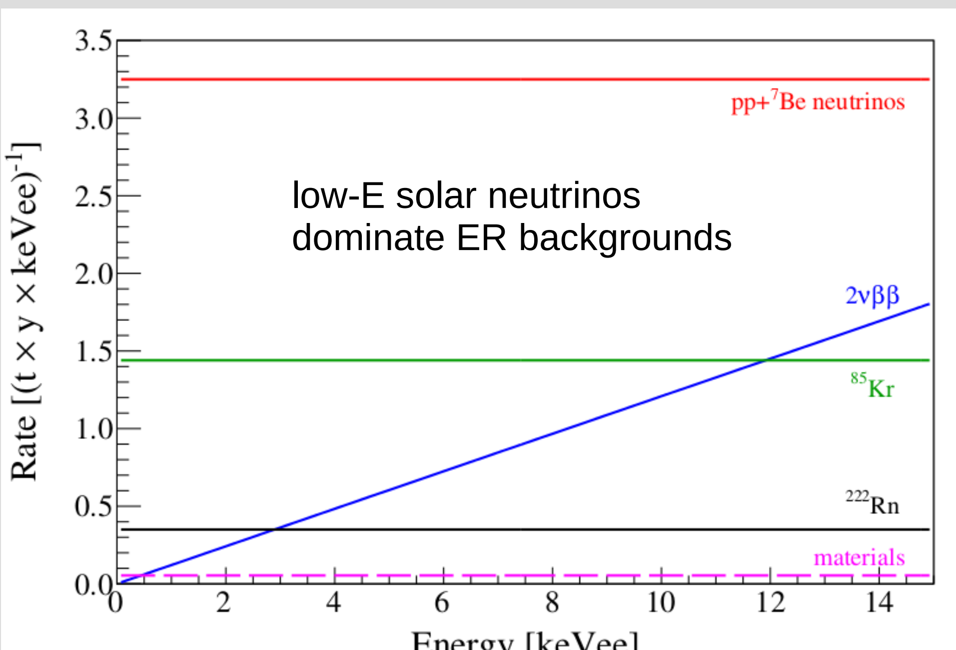
MC simulation of detector made of main components (PTFE, CU, PMTs): subdominant after ~15 cm fiducial cut

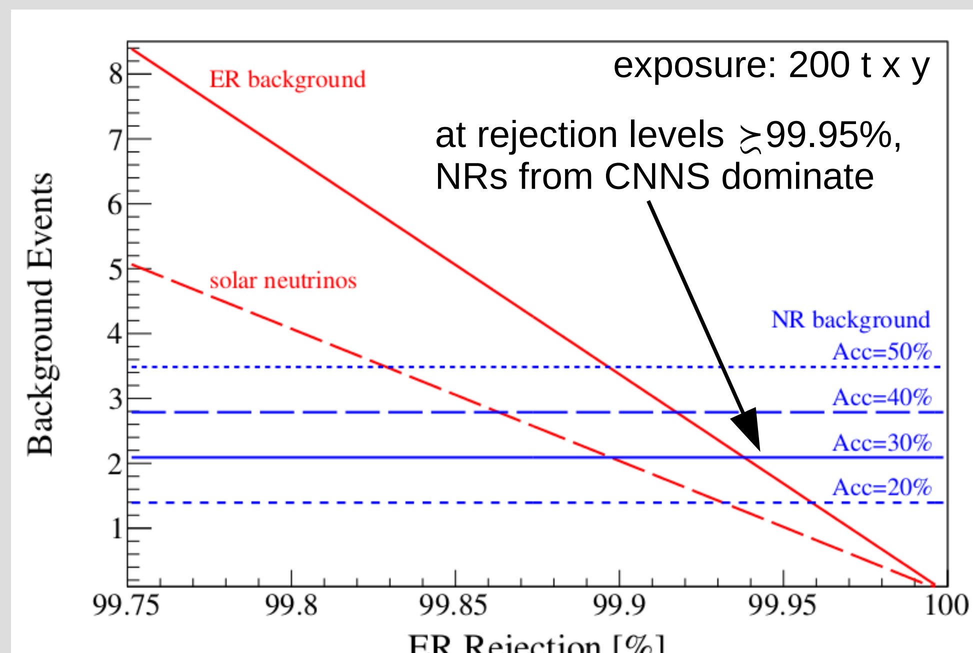
^{85}Kr: 2x below XENON1T design
(0.03 ppt achieved: EPJ C 74 (2014) 2746)

^{222}Rn: 10x below XENON1T design

^{136}Xe: assume natural xenon

consider all relevant neutrinos





Background Rejection

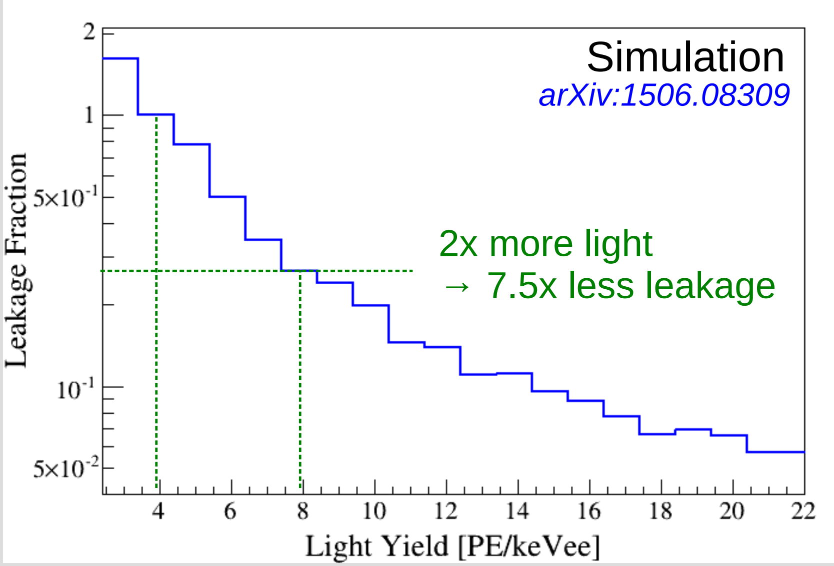
DARWIN

ER rejection factors around 99.98% required

Experimental achievements:

	E_{drift} [kV/cm]	LY @ 122 keV [PE/keV]	NR acc [%]	ER rej [%]
XENON100	0.53	3.8	40	99.75
XENON100	0.53	3.8	30	99.90
LUX	0.18	8.8	50	99.0-99.9
ZEPLIN-III	3.4	4.2	50	**99.987**
K. Ni *APP14*	0.2-0.7	10	50	**>99.999**

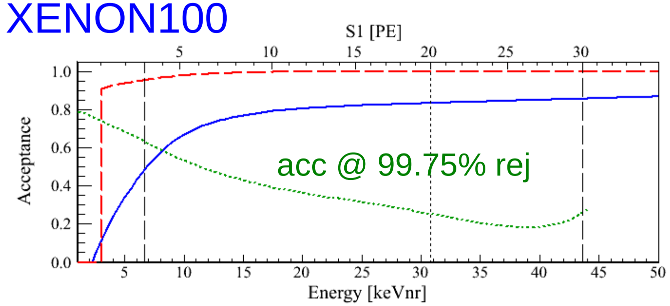
field uniformity is important!



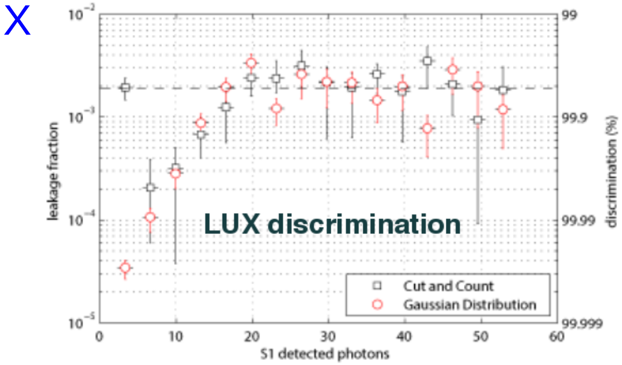
higher light yield improves signal resolution
→ better band separation at given mean values

acceptance improves at lower *E*

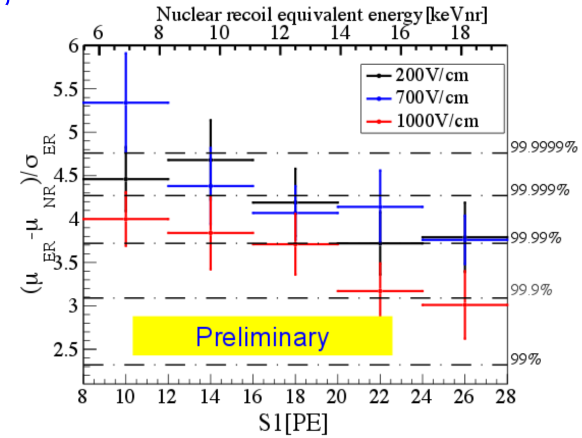
XENON100



LUX



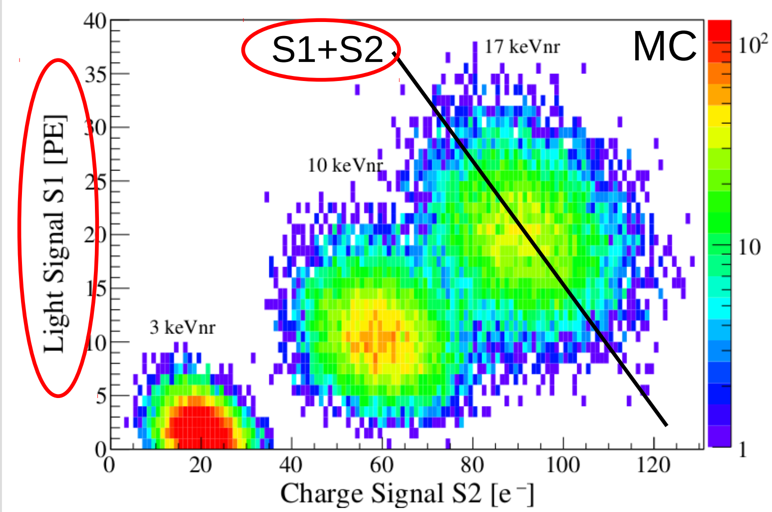
K. Ni, talk at APP2014

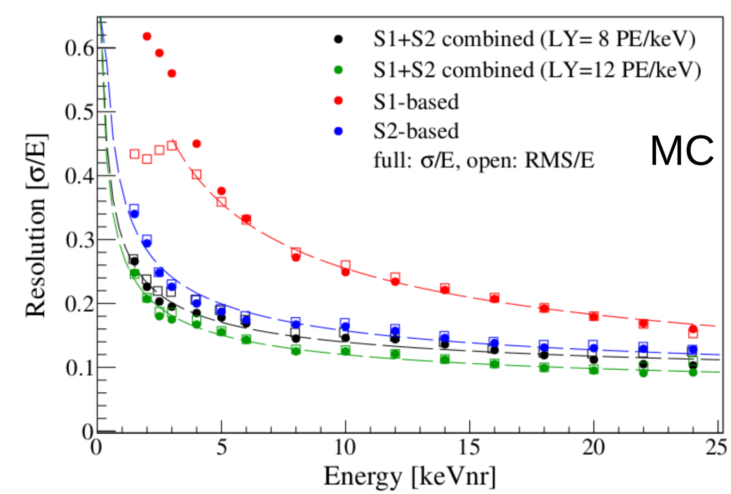


DARWIN WIMP Sensitivity

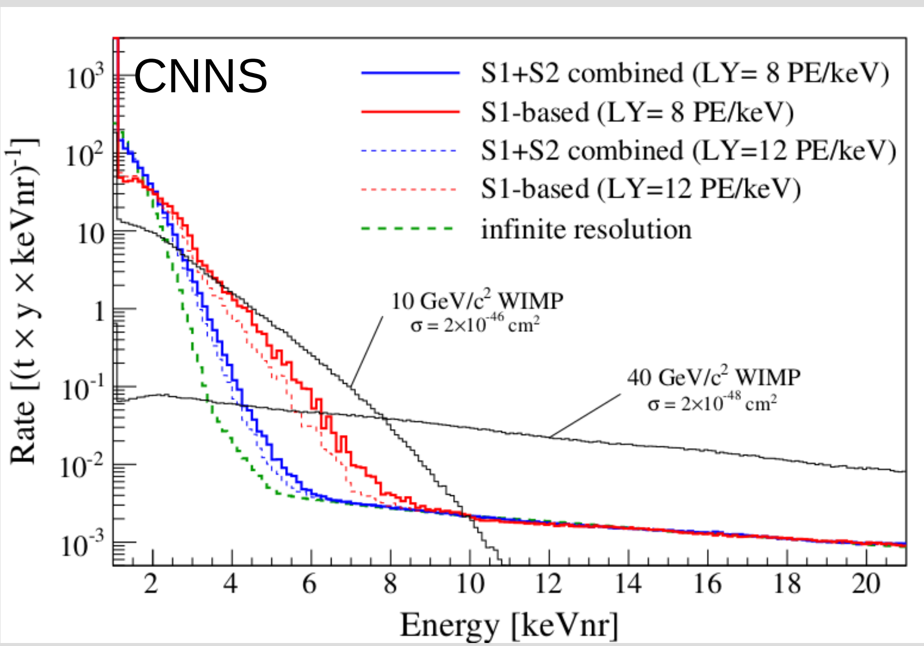
arXiv:1506.08309

- consider all backgrounds:
  - neutrinos (pp+^{7}Be)
  - external (γ, neutrons)
  - intrinsic (0.1 µBq/kg ^{222}Rn, 0.1 ppt Kr)
  - CNNS (mainly ^{8}B at low E)
- study different E-scales (S1, S1+S2, LY)
- study threshold, exposure, ER rejection





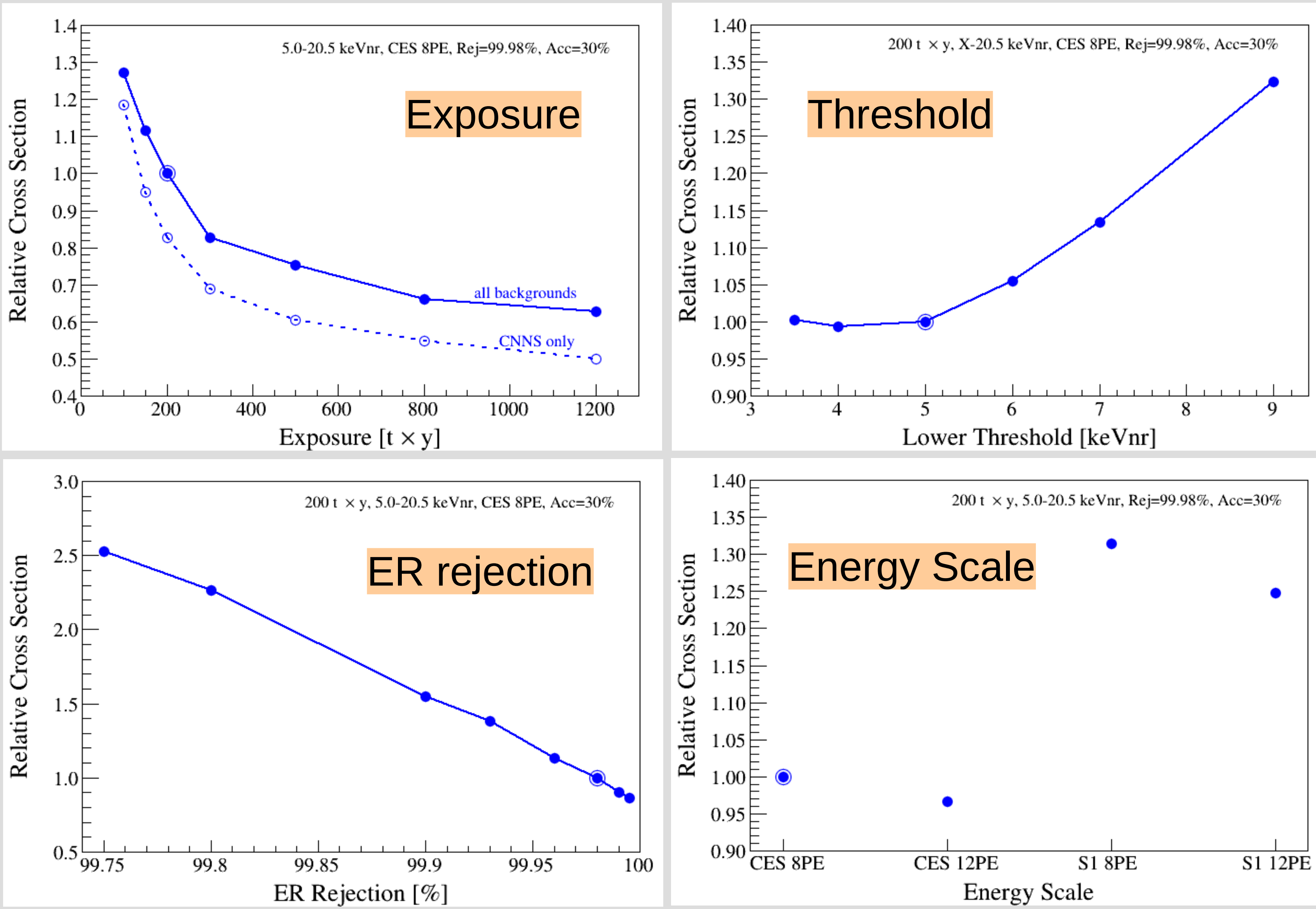
Resolution consideraby improved when using combined S1+S2 scale
→ improvement mainly from S2 signal



DARWIN WIMP Sensitivity

Reference WIMP mass = 40 GeV/c²

arXiv:1506.08309



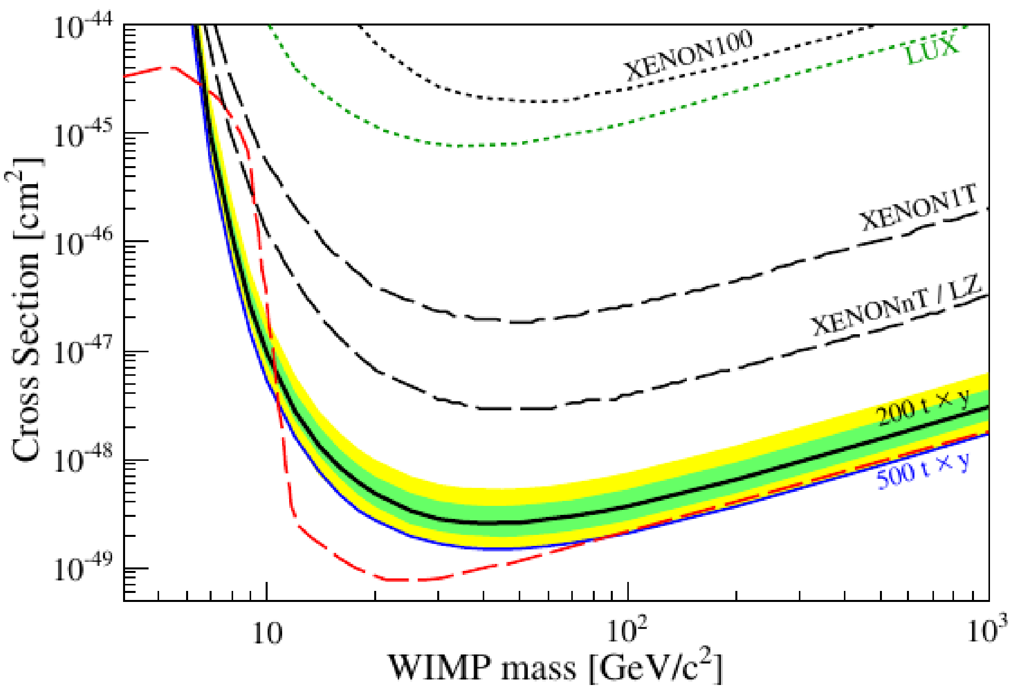
DARWIN WIMP Sensitivity

DARWIN

arXiv:1506.08309

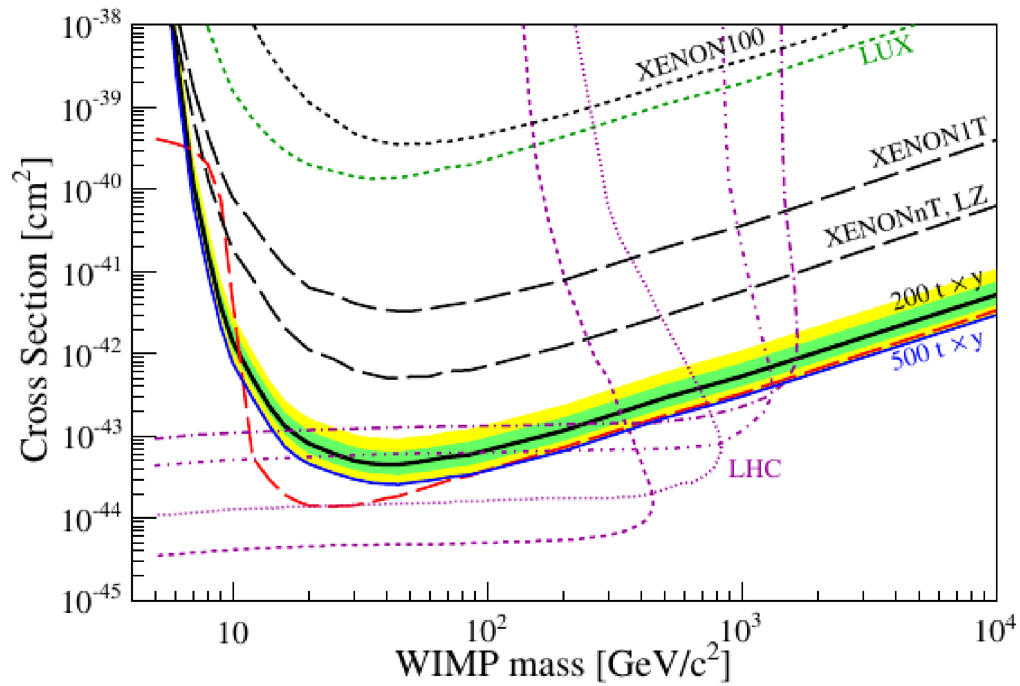
- exposure: 200 t x y; **all backgrounds included**
- likelihood analysis (~99.98% ER rejection @ 30% NR acceptance)
- S1+S2 combined energy scale, LY=8 PE/keV, 5-35 keVnr energy window

spin-*in*dependent couplings



best sensitivity: 2.5 x 10^{-49} cm² @ 40 GeV/c²

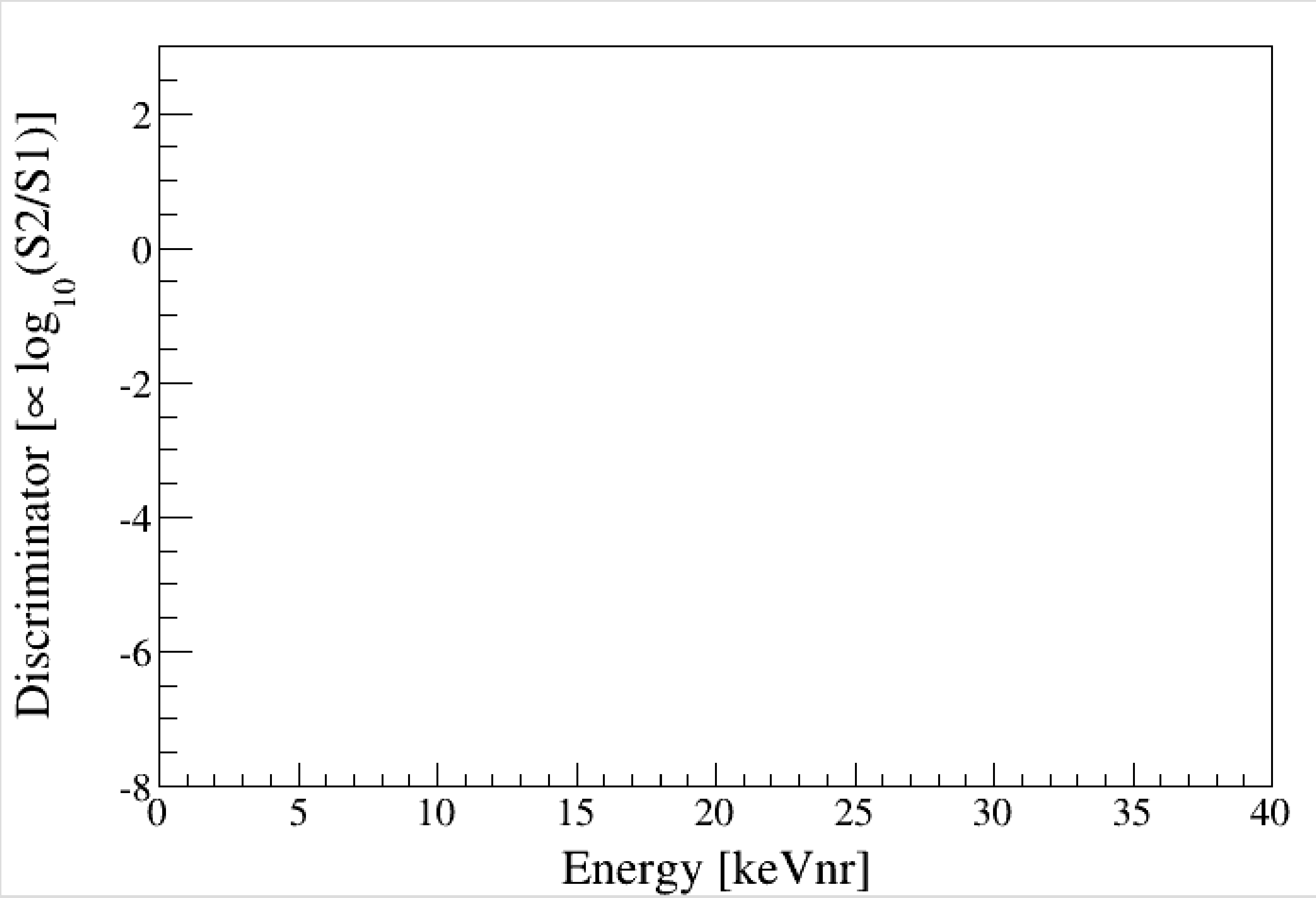
spin-*de*pendent couplings (n-only)



excellent complementarity to LHC searches

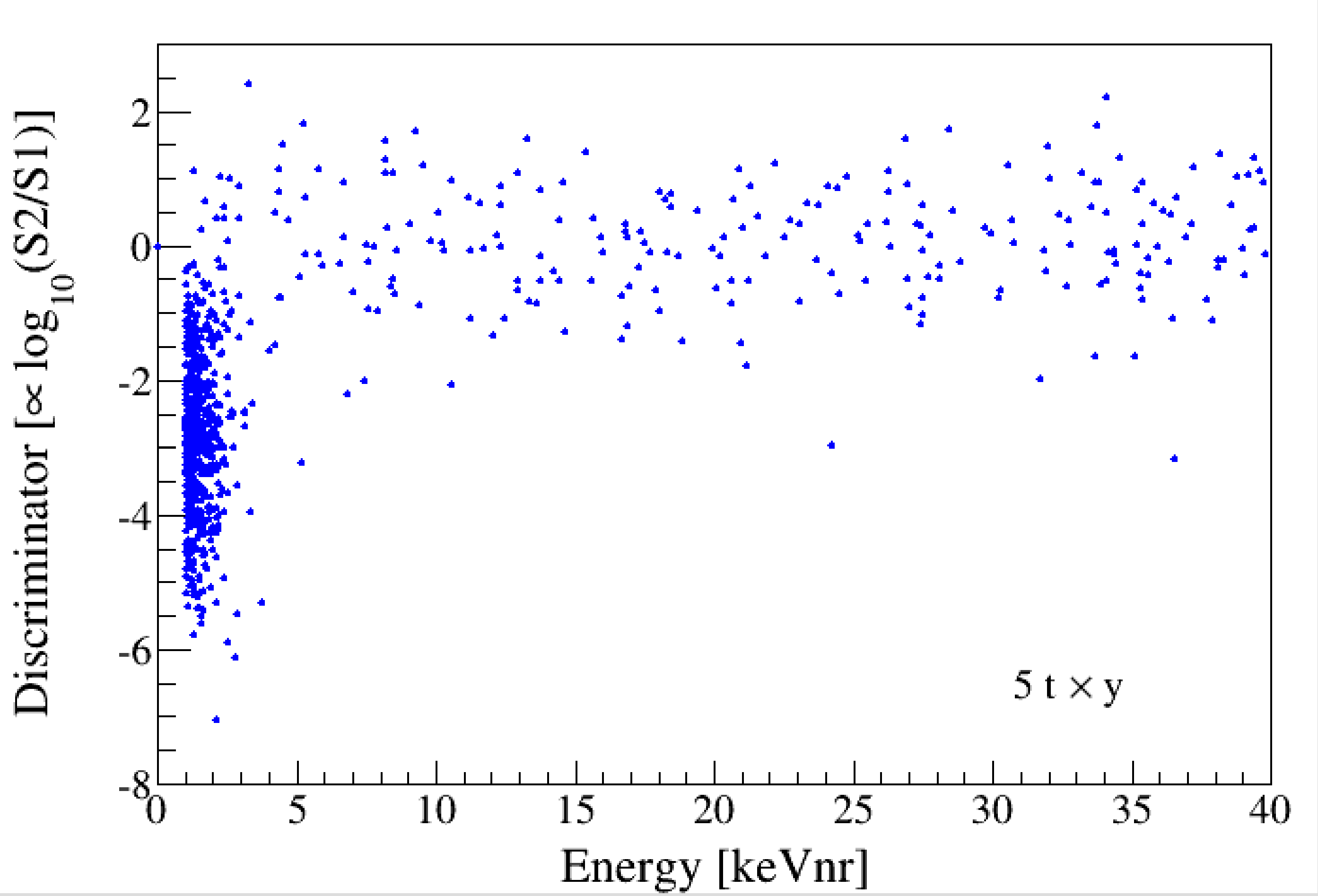
→ also sensitive to inelastic WIMP interactions

WIMP Detection



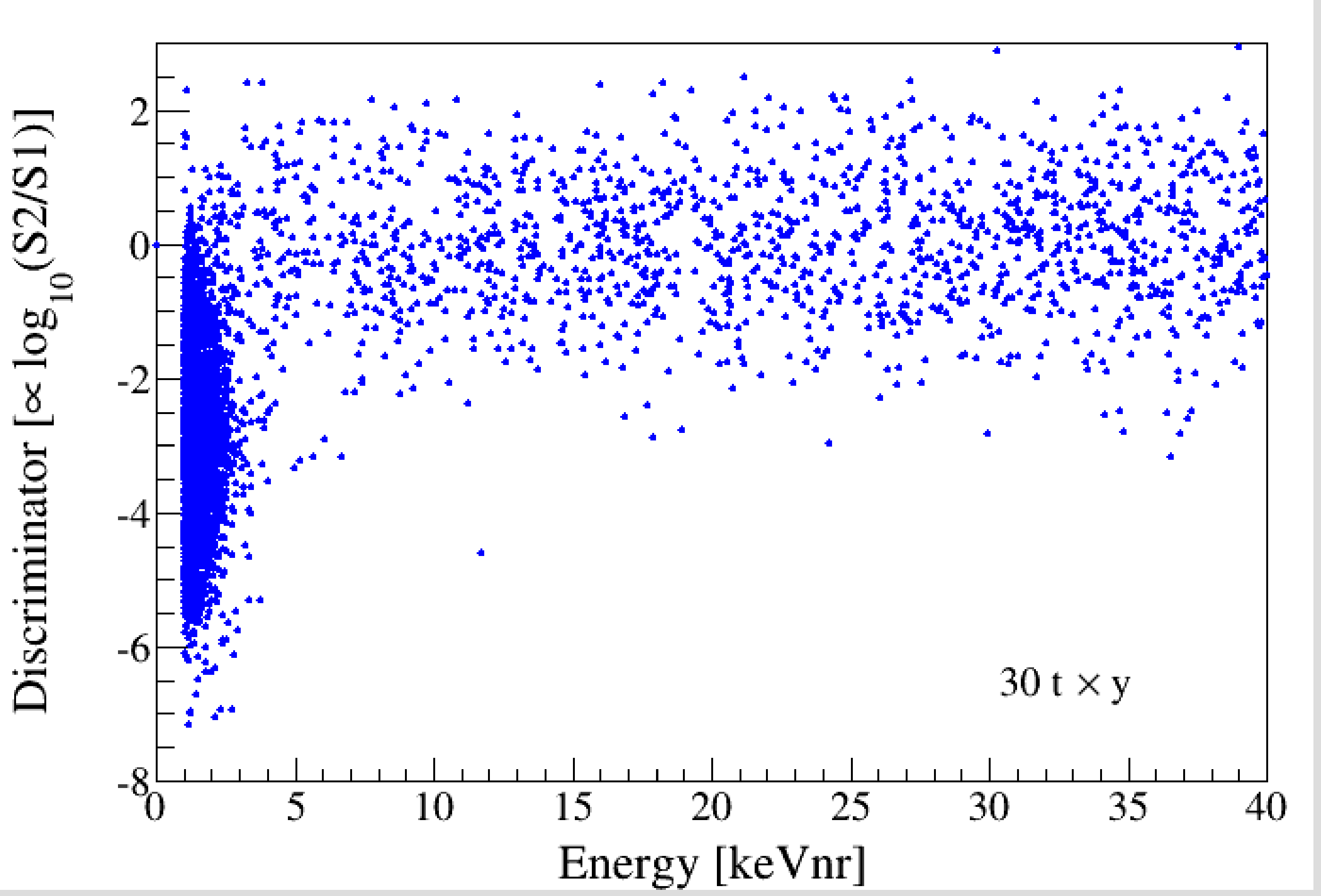
DARWIN with 30t LXe fiducial target

WIMP Detection



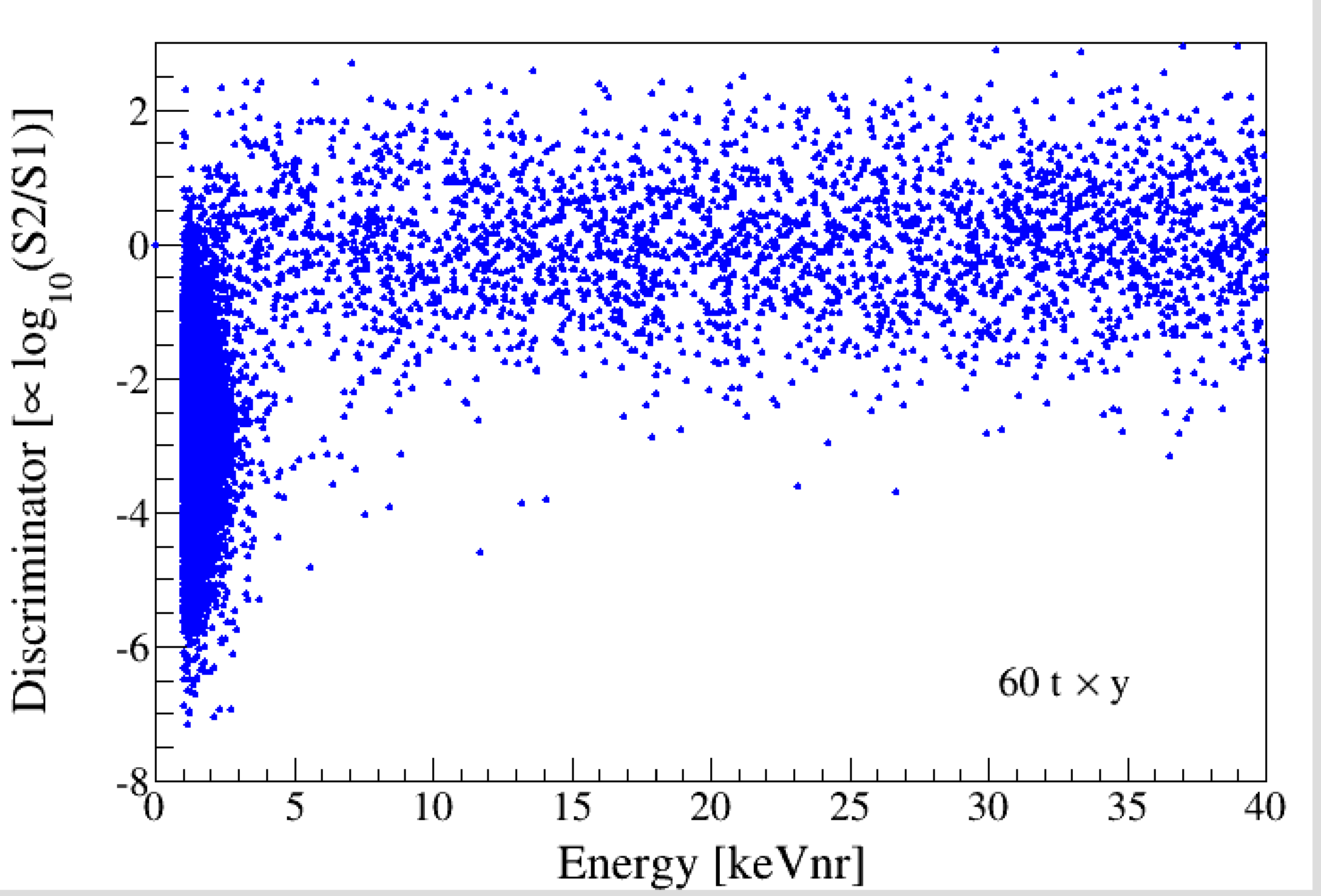
60 days

WIMP Detection



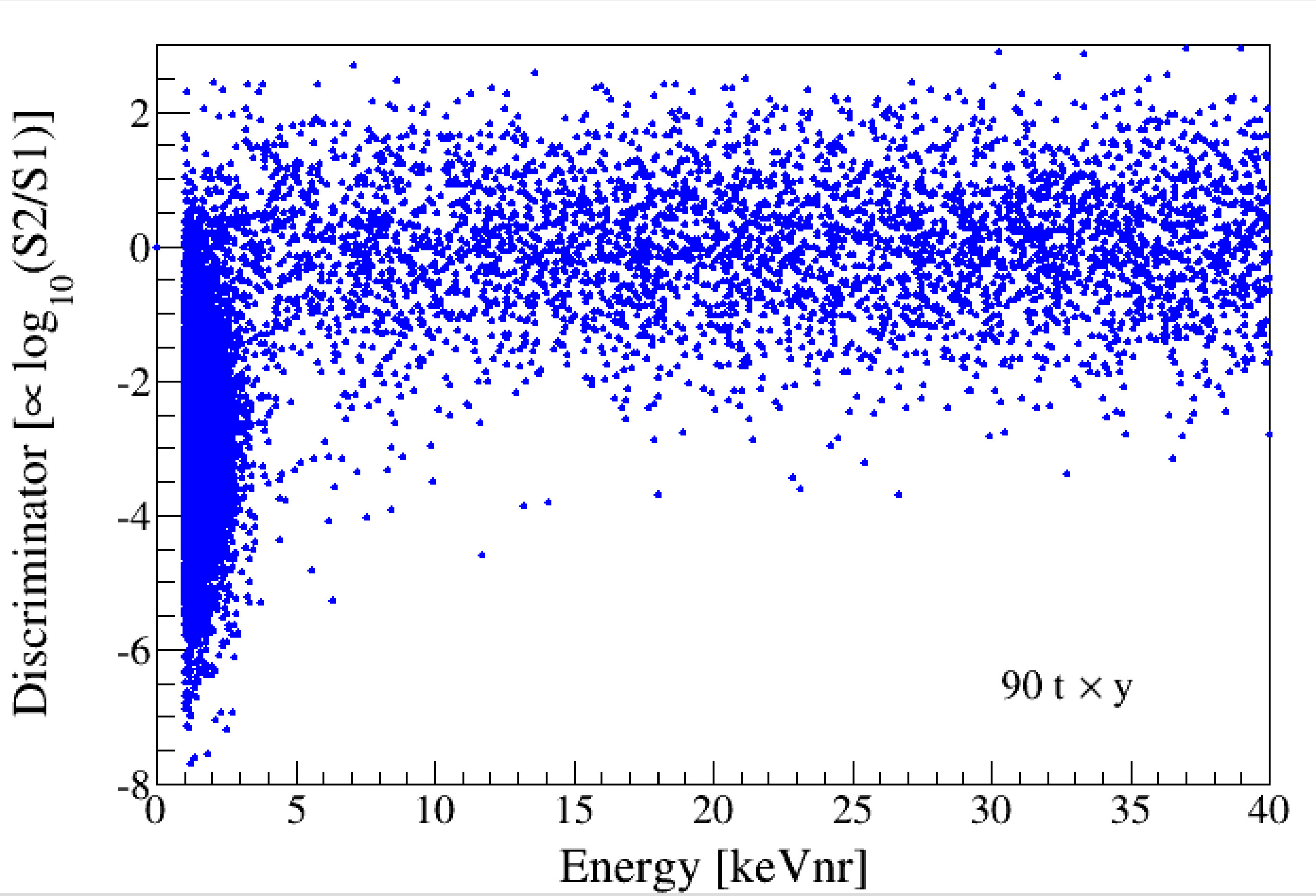
1 year

WIMP Detection



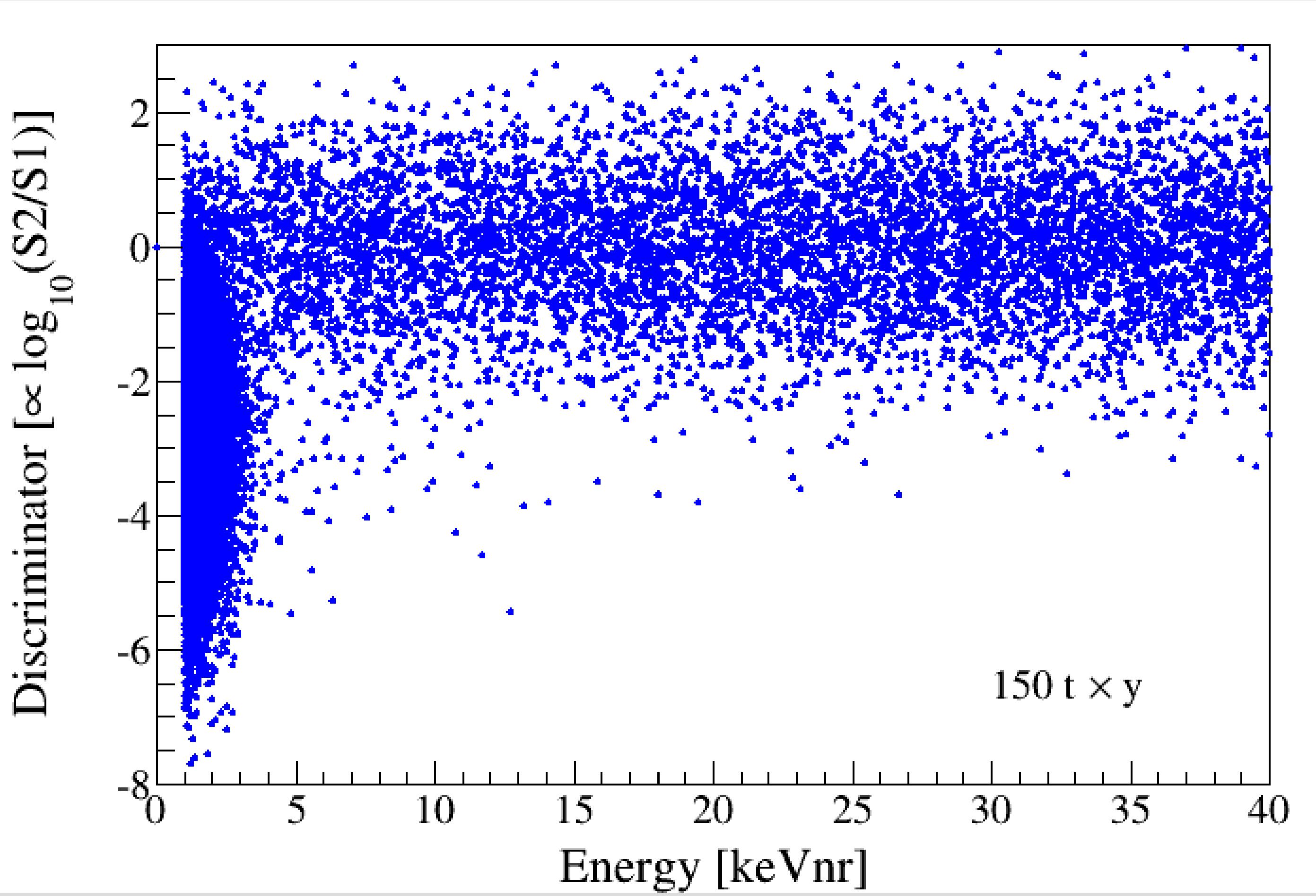
2 years

WIMP Detection



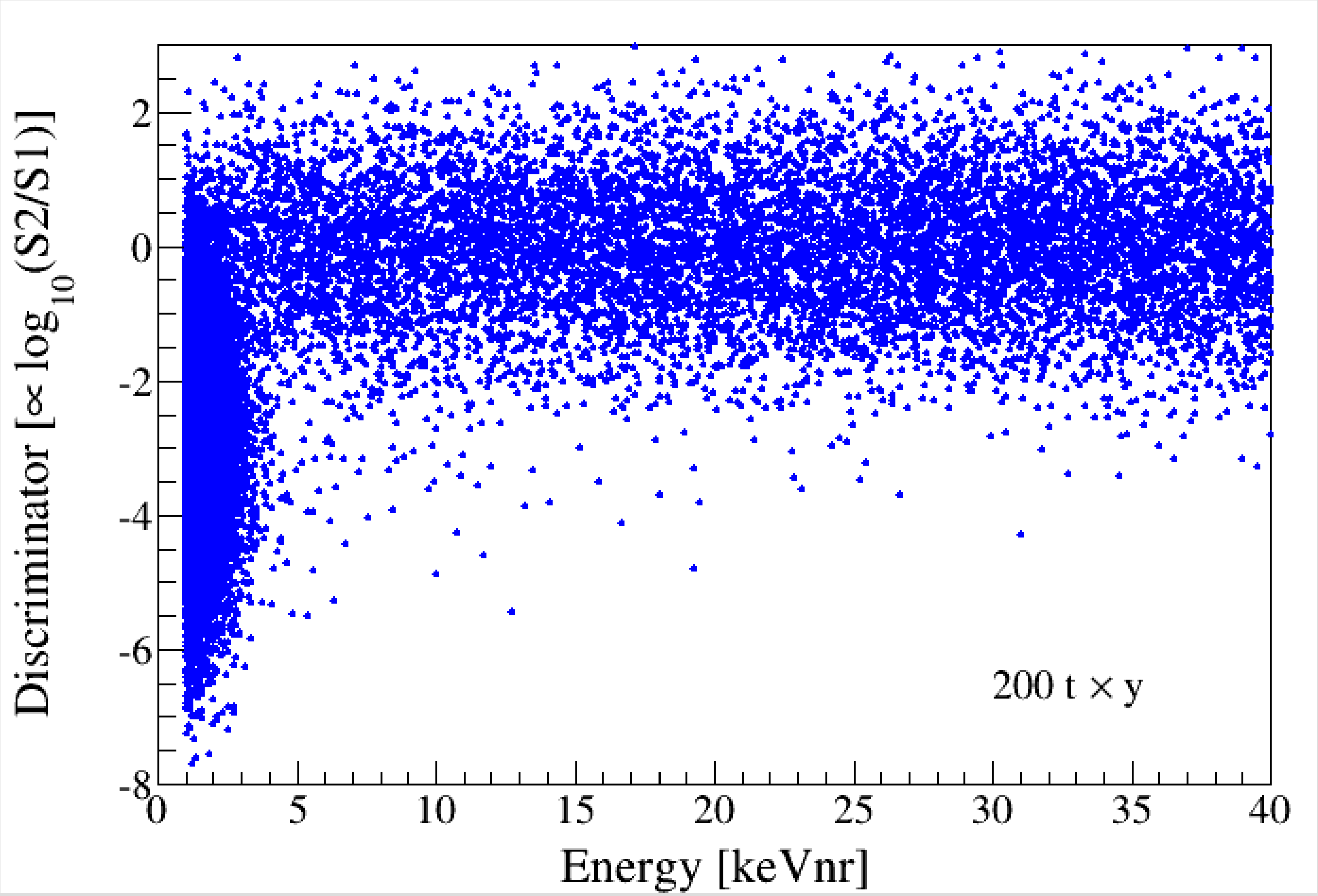
3 years

WIMP Detection



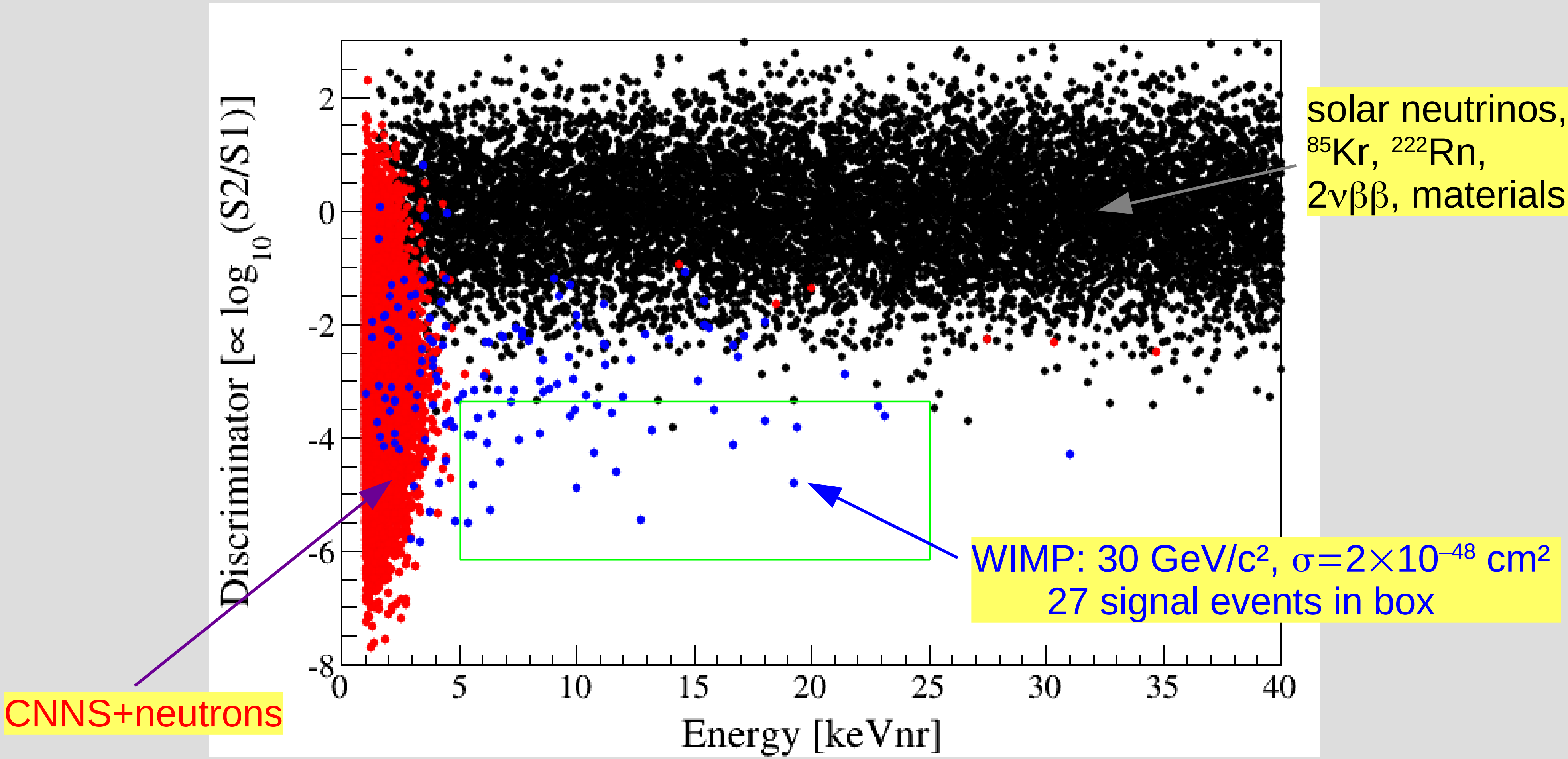
5 years

WIMP Detection



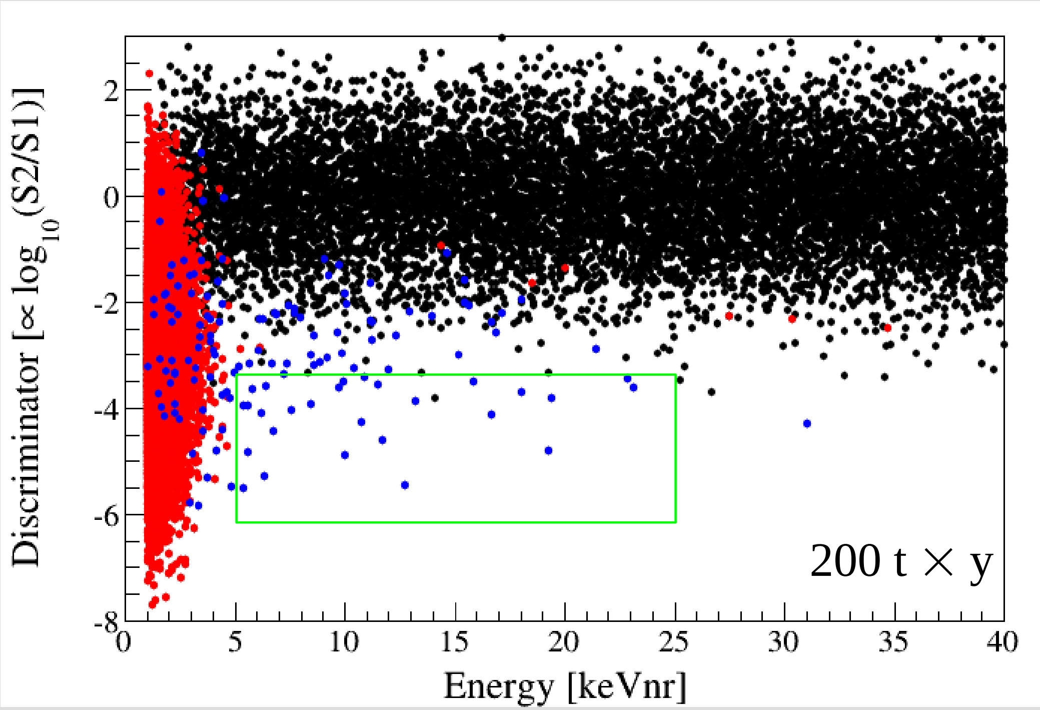
6.7 years

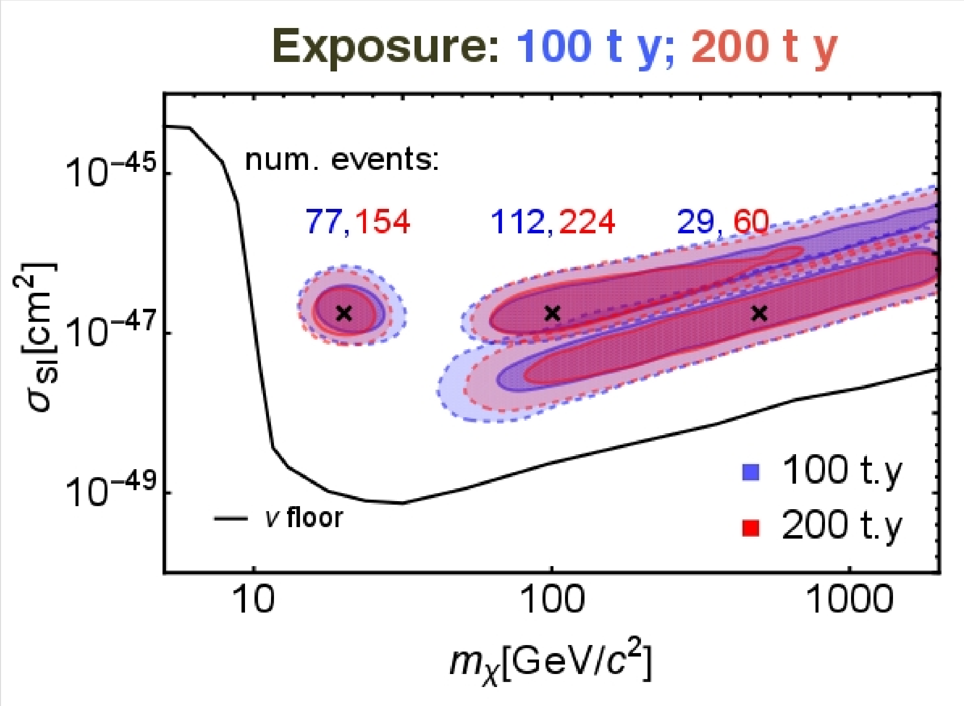
WIMP Detection



WIMP Spectroscopy

2×10⁻⁴⁸ cm² | 2×10⁻⁴⁷ cm²





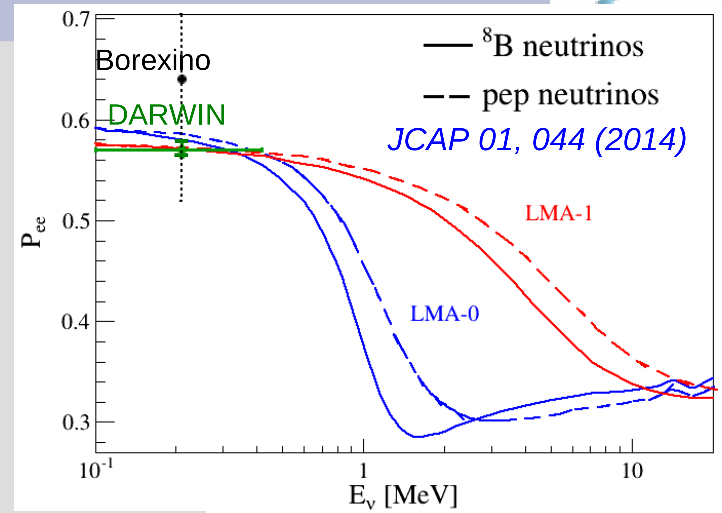
Update of Newstead et al., PRD 8, 076011 (2013)

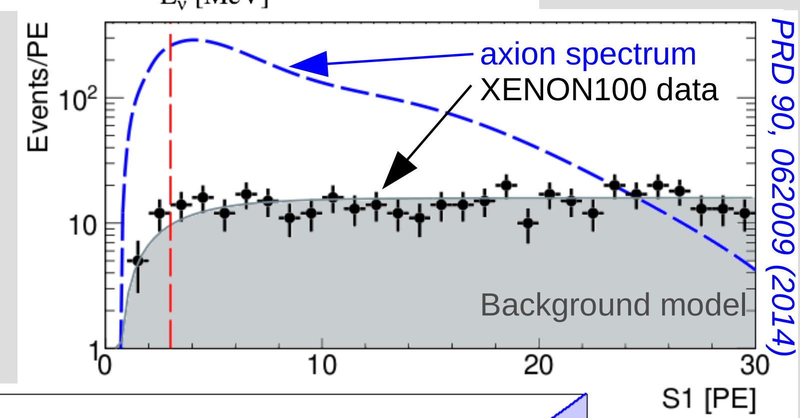
Capability to reconstruct WIMP parameters

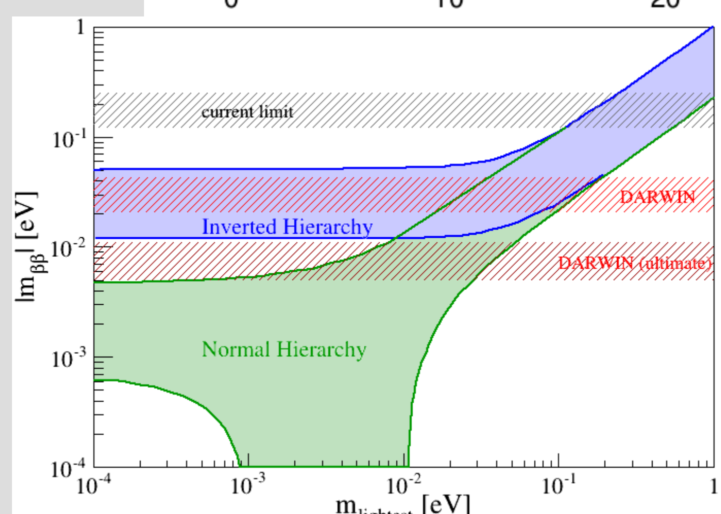
- m_χ=20, 100, 500 GeV/c²
- 1σ/2σ CI, marginalized over astrophysical parameters
- due to flat WIMP spectra, no target can reconstruct masses >500 GeV/c²

LXe: Non-WIMP Channels

- **Coherent Neutrino Nucleus Scattering**
  → not observed yet
  → 200 t×y: ~200 evts > 3 keVnr
  ~25 evts > 4 keVnr
- **Low E solar neutrinos: pp, ^{7}Be**
  → test solar model; test neutrino models
  → 1% stat. precision in 100 t x y
- **Solar axions and dark matter ALPs**
  → alternative dark matter candidates
  → couple to electrons via axio-electric effect
- **Supernova Neutrinos**
  → sensitive to all neutrino species (CNNS)
  (→ complementary information to large-scale neutrino detectors)
  → O(10) events for SN @ 10 kpc
- **Neutrinoless Double-Beta Decay**
  → leption number violating process
  → access to neutrino mass, neutrino hierarchy
  → no ^{136}Xe enrichment required





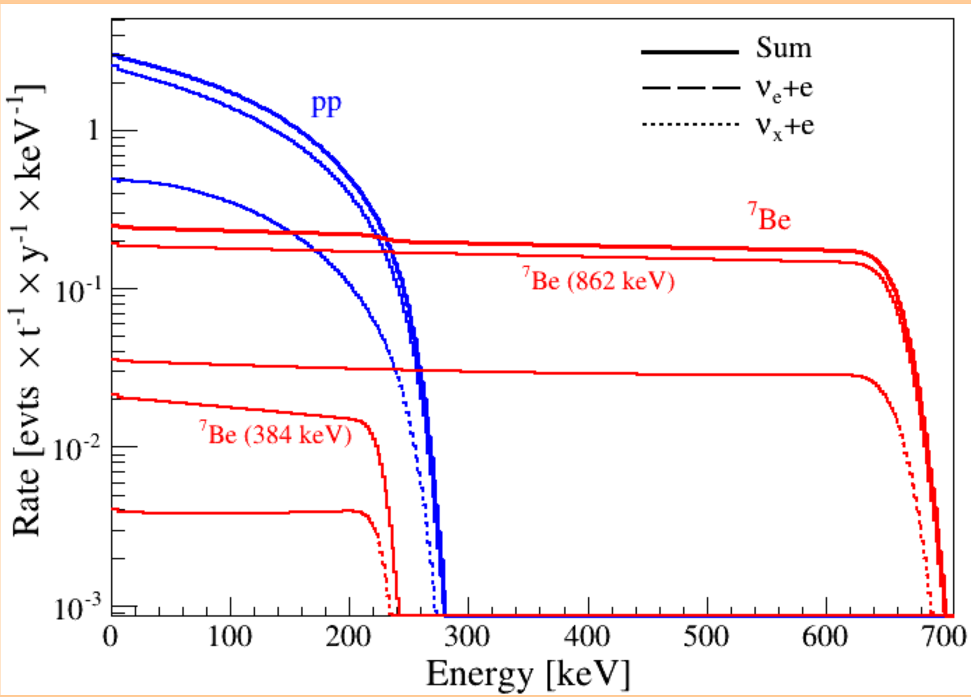


pp-Neutrinos in DARWIN

a new physics channel!

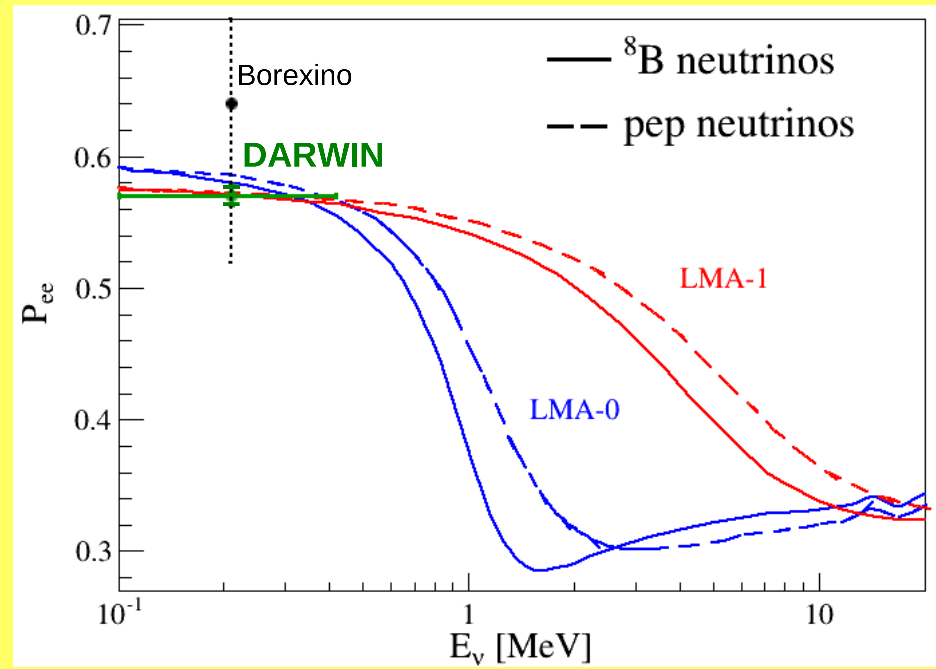
JCAP 01, 044 (2014)

Differential Recoil Spectrum in Xe



- neutrinos interact with Xe electrons
  →electronic recoil signature
- continuous recoil spectrum
  → largest rate at low E
  ~0.26 ν evts/t/d in low-E region (2-30 keV)

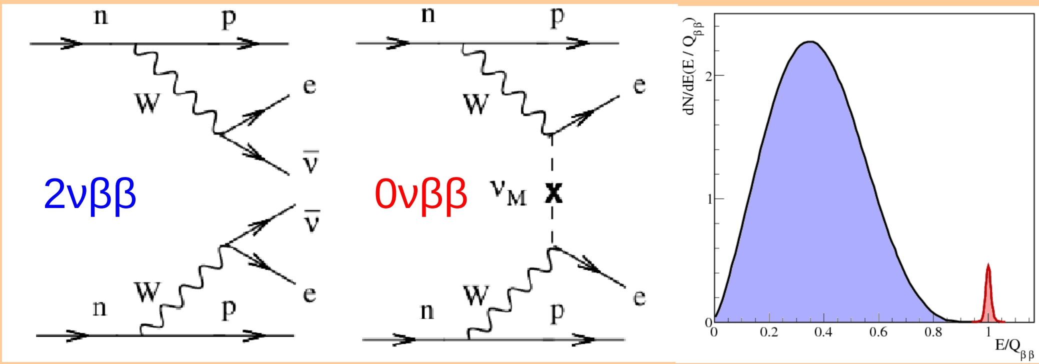
Neutrino interactions



- 30t target mass, 2-30 keV window
  → 2850 neutrinos per year (89% pp)
  → achieve 0.8% statistical precision on pp-flux (→P_{ee}) in 5 years

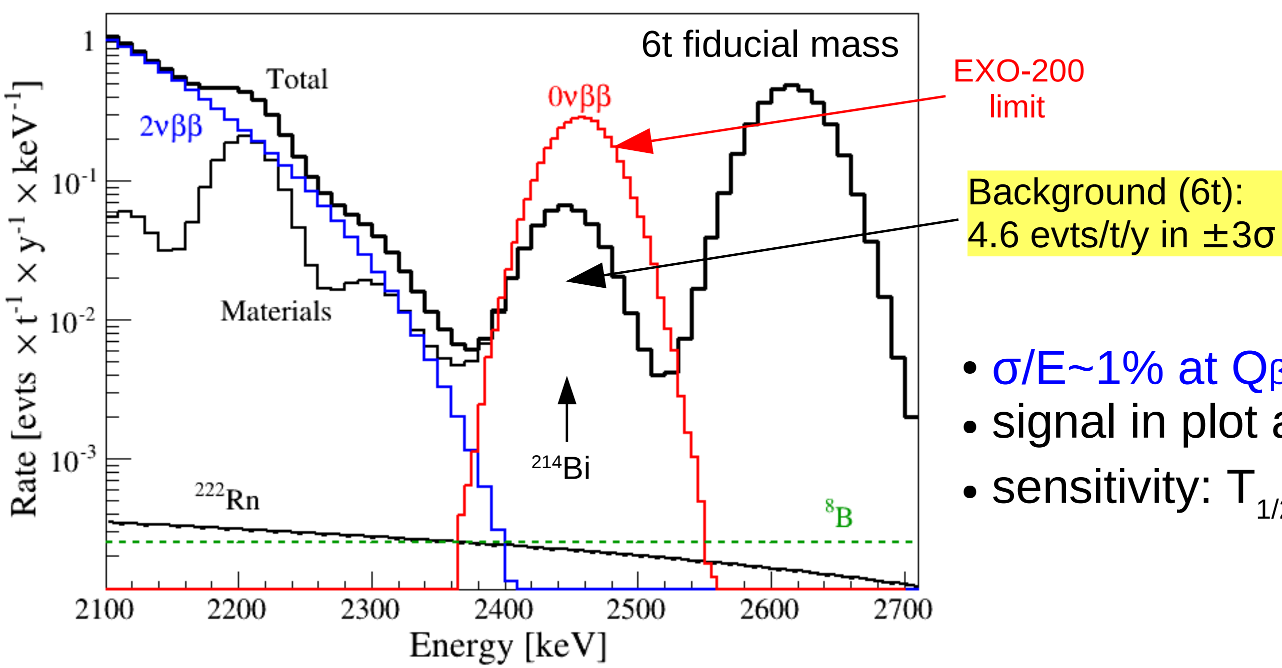
^{136}Xe: 0ν Double-beta Decay

JCAP 01, 044 (2014)



also accessible: ^{134}Xe, ^{126}Xe, ^{124}Xe

N. Barros et al., J. Phys. G 41, 115105 (2014).

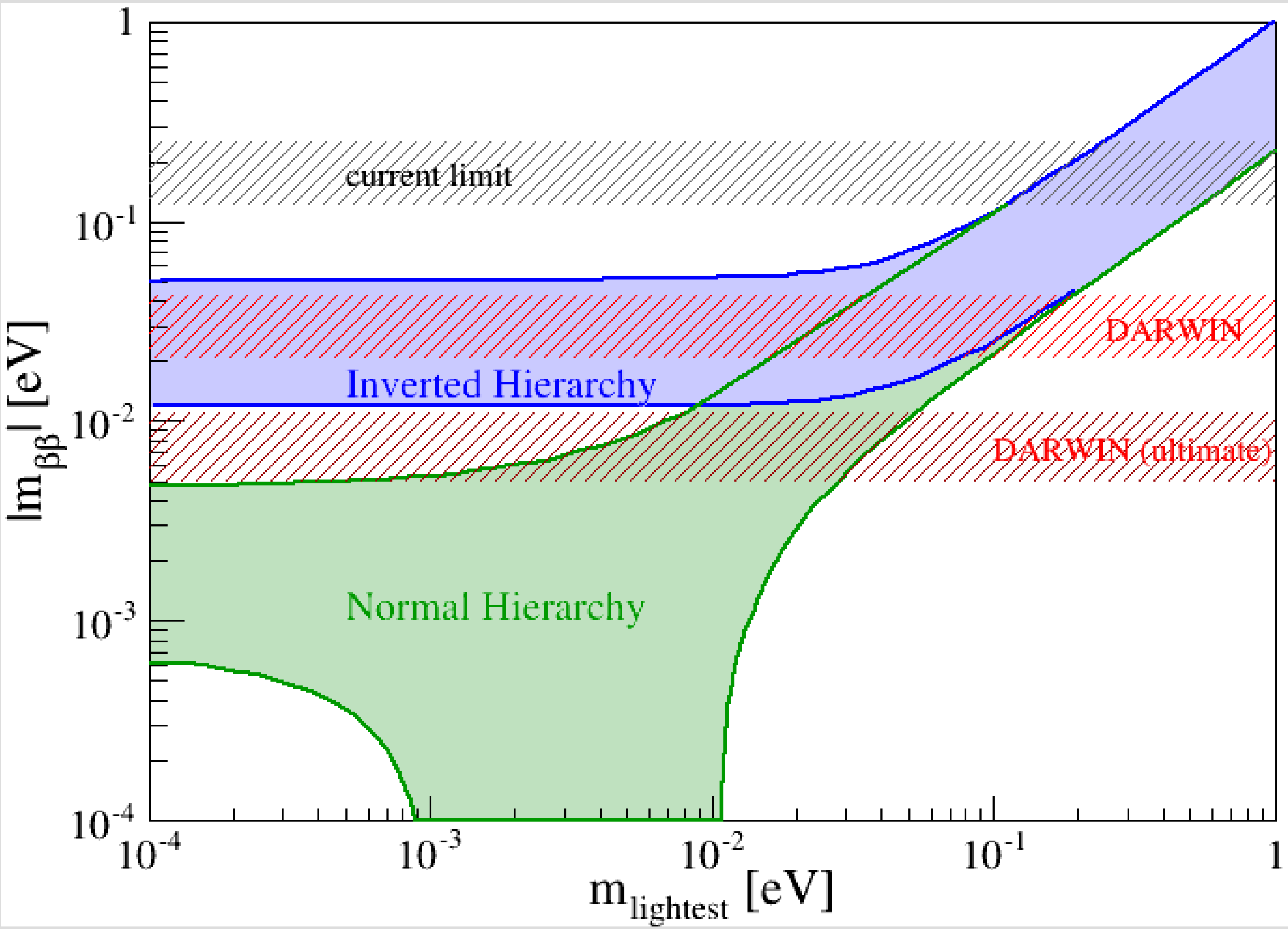


no ^{136}Xe enrichment!

- σ/E~1% at Qββ, combined *E*-scale
- signal in plot assumes $T_{1/2}$=1.6 x 10^{25} y
- sensitivity: $T_{1/2}$=5.6 x 10^{26} y (95% CL, 6t x 5y)

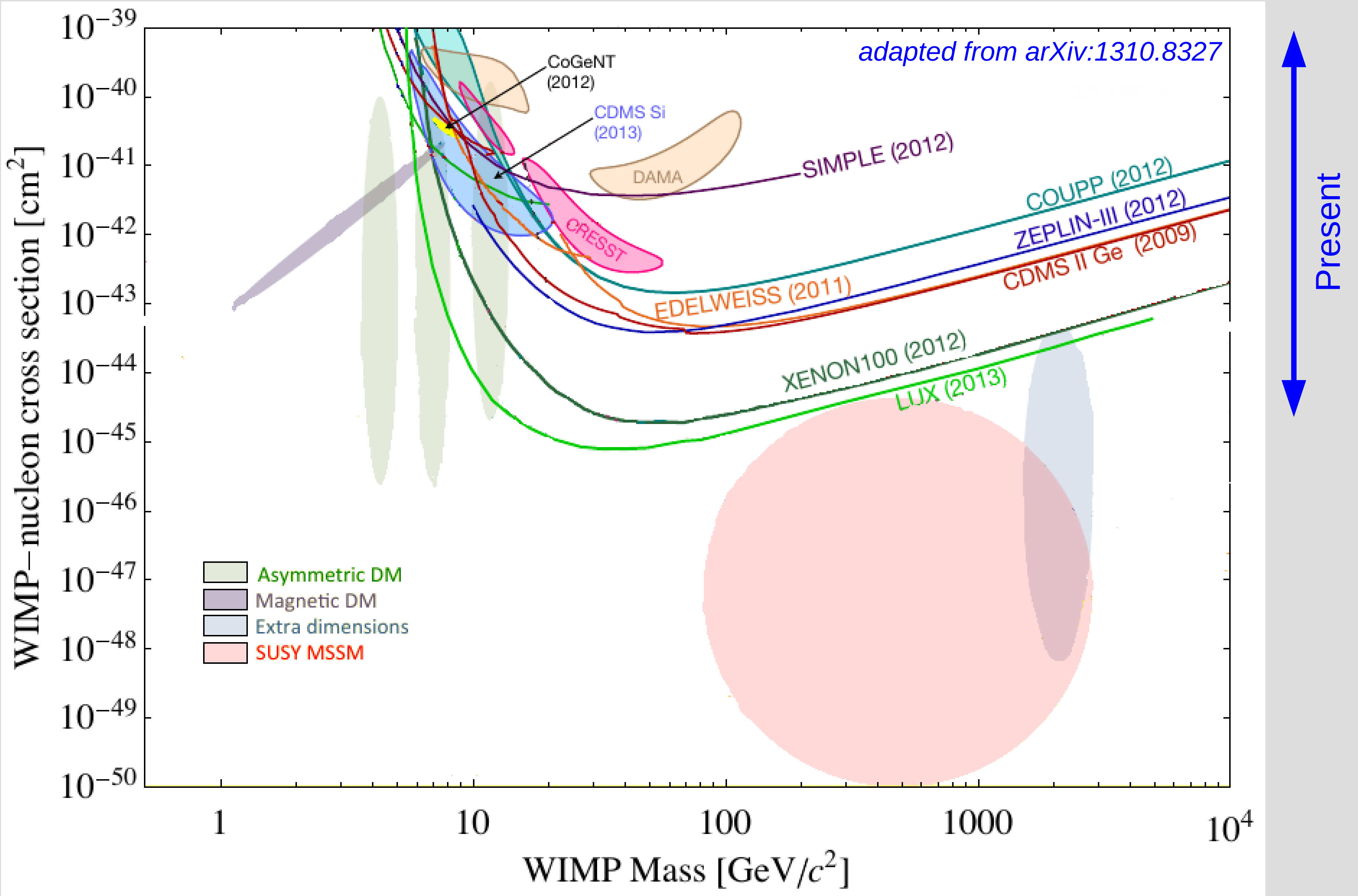
0ν Double-beta Decay

to be published



only neutrino background

The WIMP Landscape today



Exciting times ahead of us

DARWIN