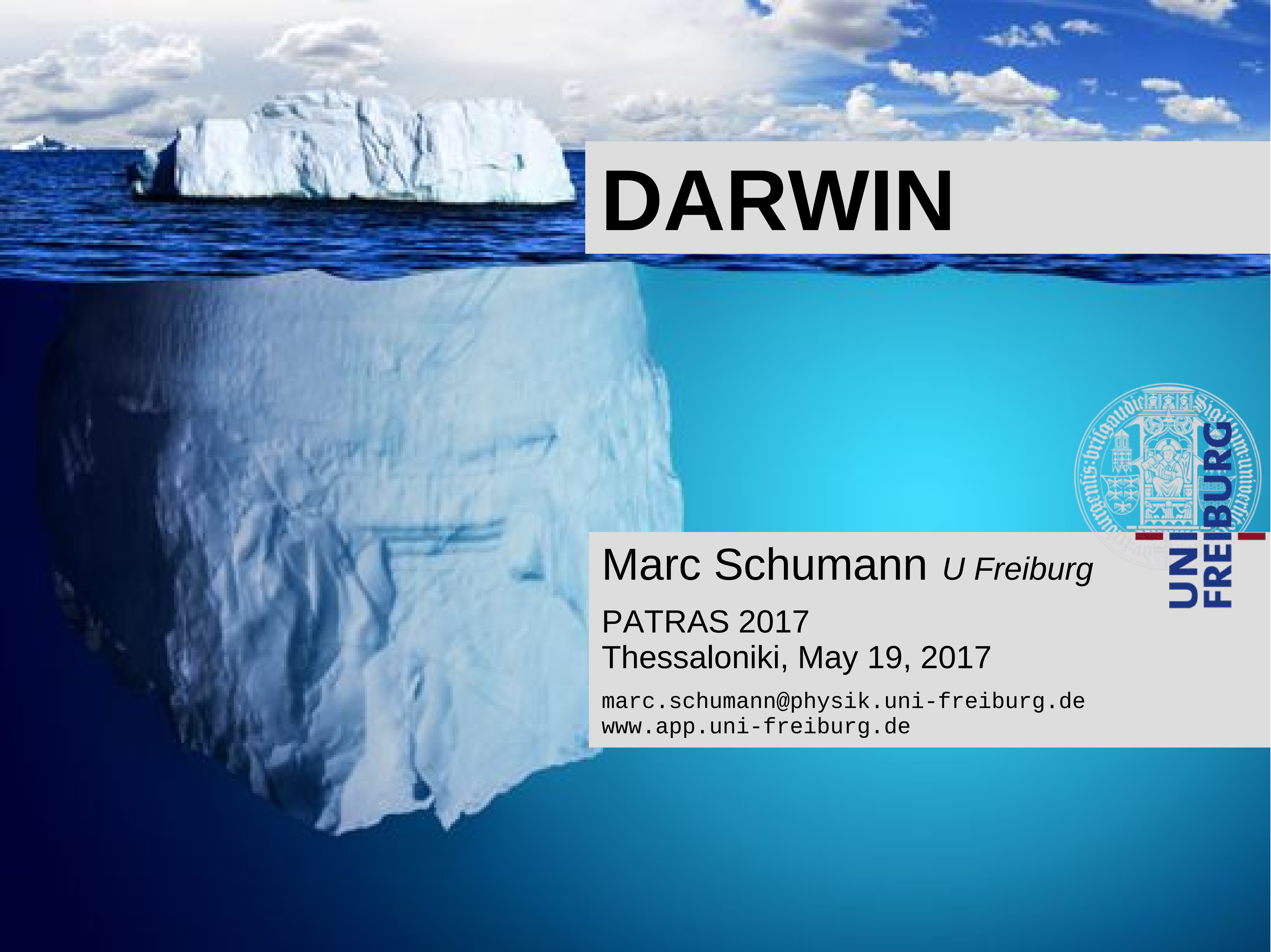


DARWIN

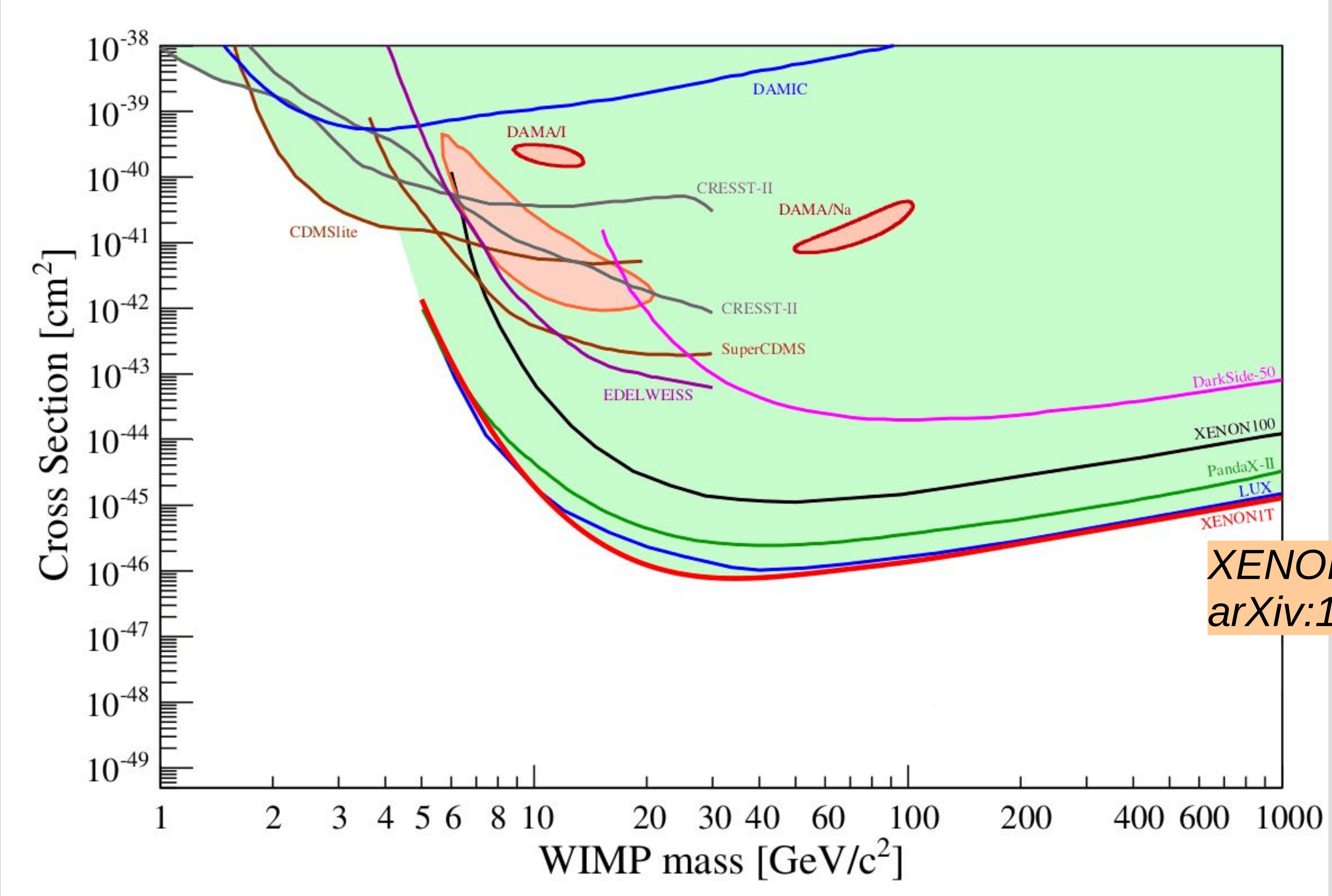
Marc Schumann *U Freiburg*

PATRAS 2017
Thessaloniki, May 19, 2017

marc.schumann@physik.uni-freiburg.de
www.app.uni-freiburg.de

Dark Matter Searches: Status

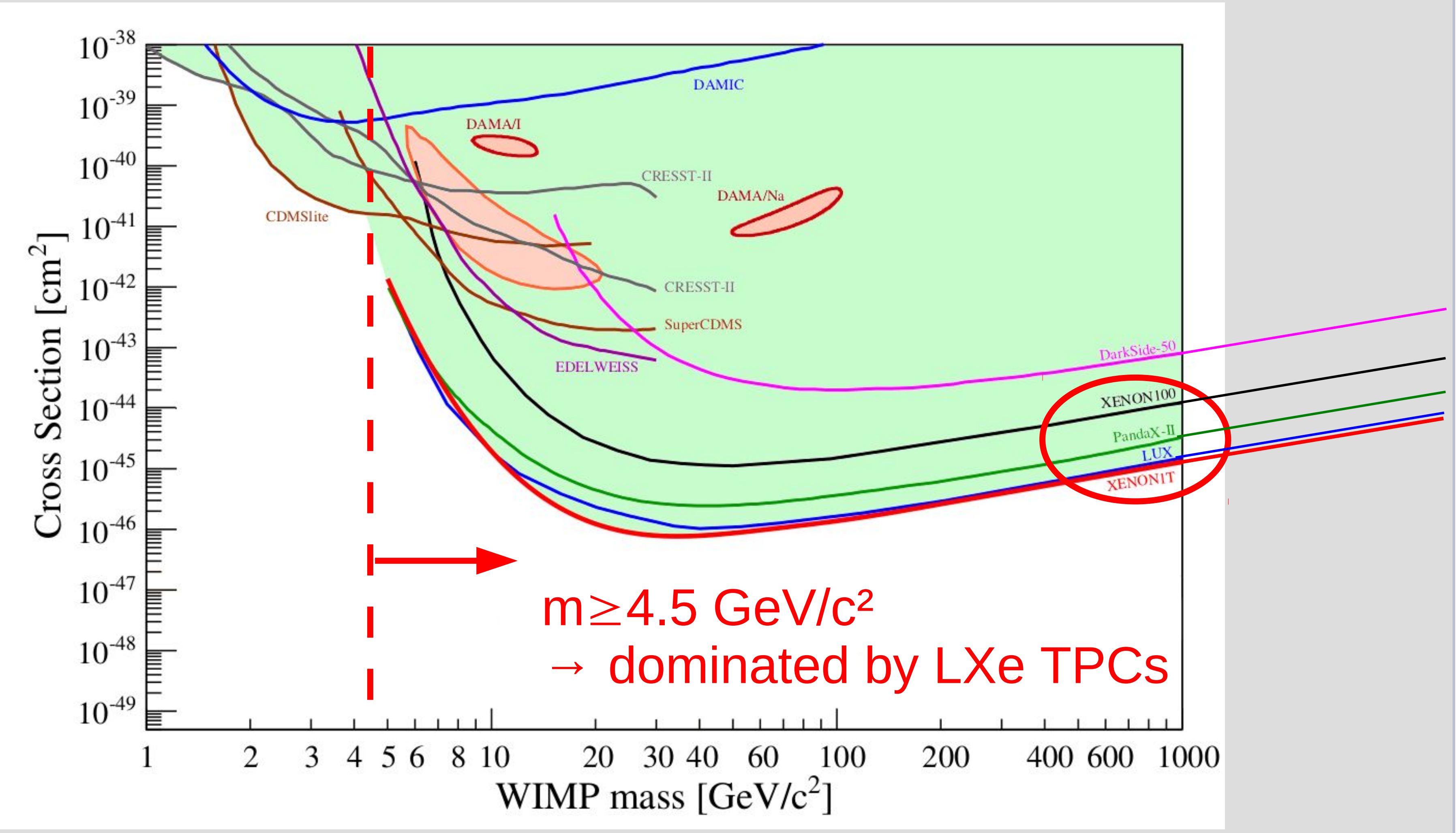
spin-independent WIMP-nucleon interactions



XENON1T
arXiv:1705.06655

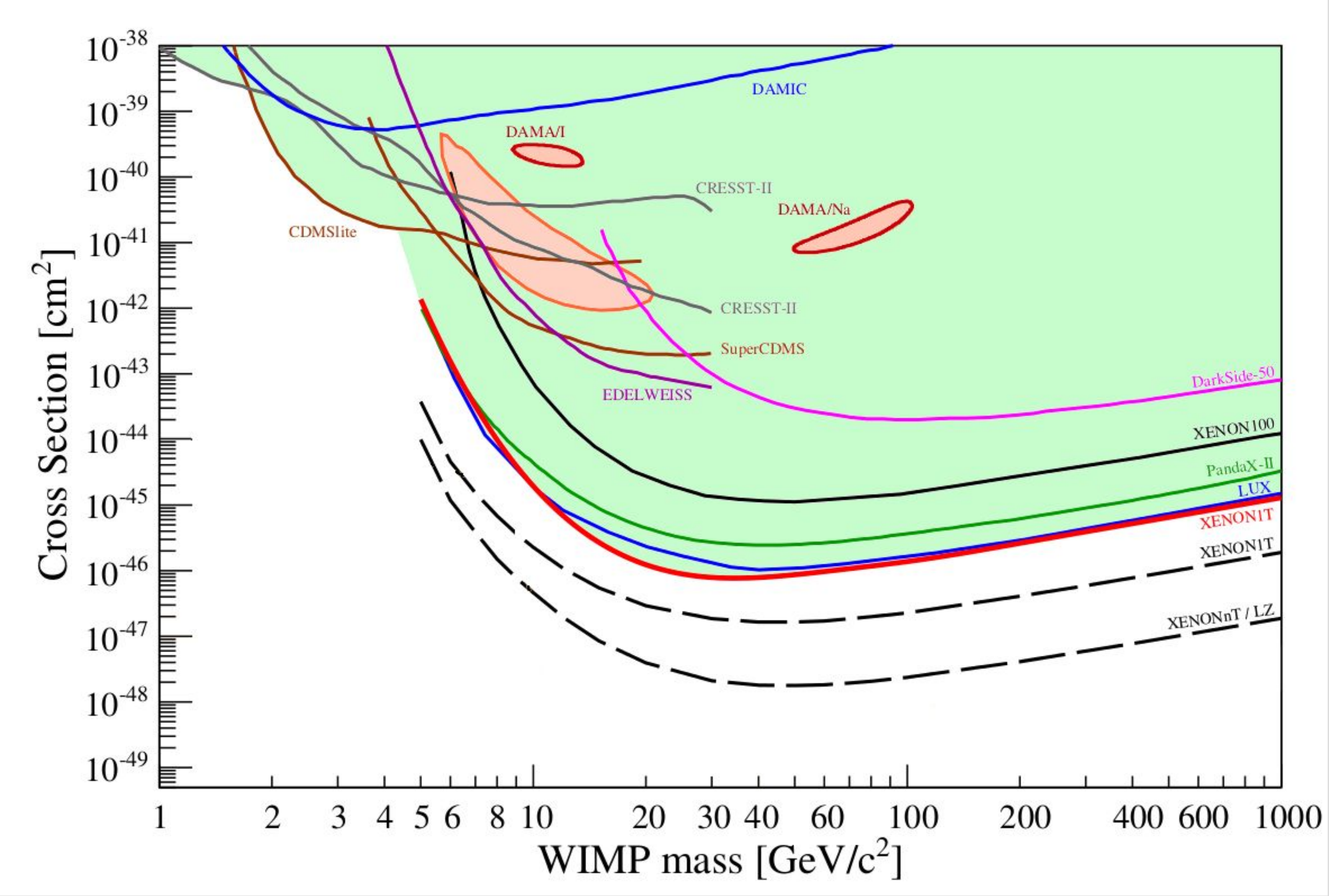
Dark Matter Searches: Status

spin-independent WIMP-nucleon interactions



Dark Matter Searches: The Future

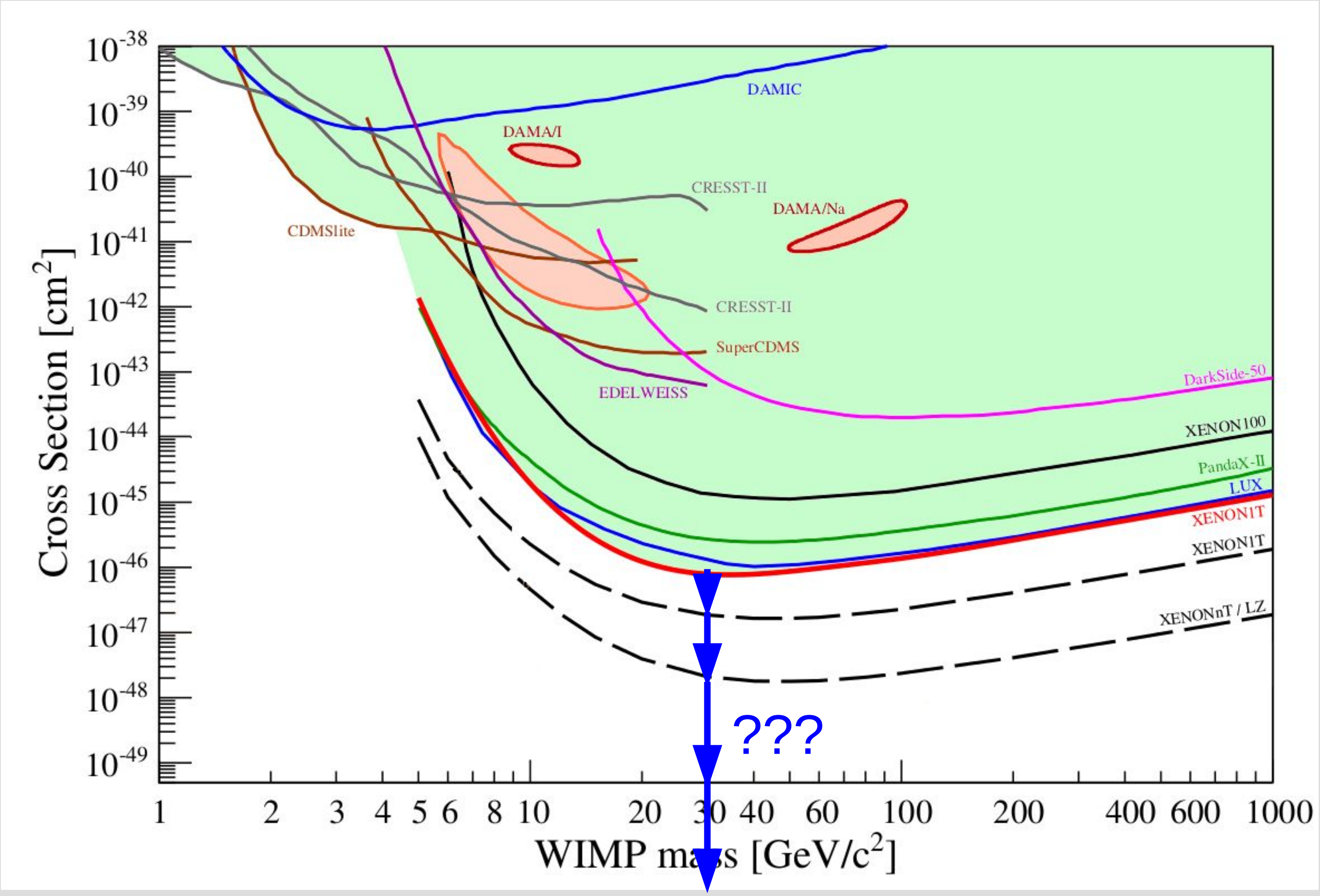
spin-independent WIMP-nucleon interactions



some projects are missing...

Dark Matter Searches: The Future

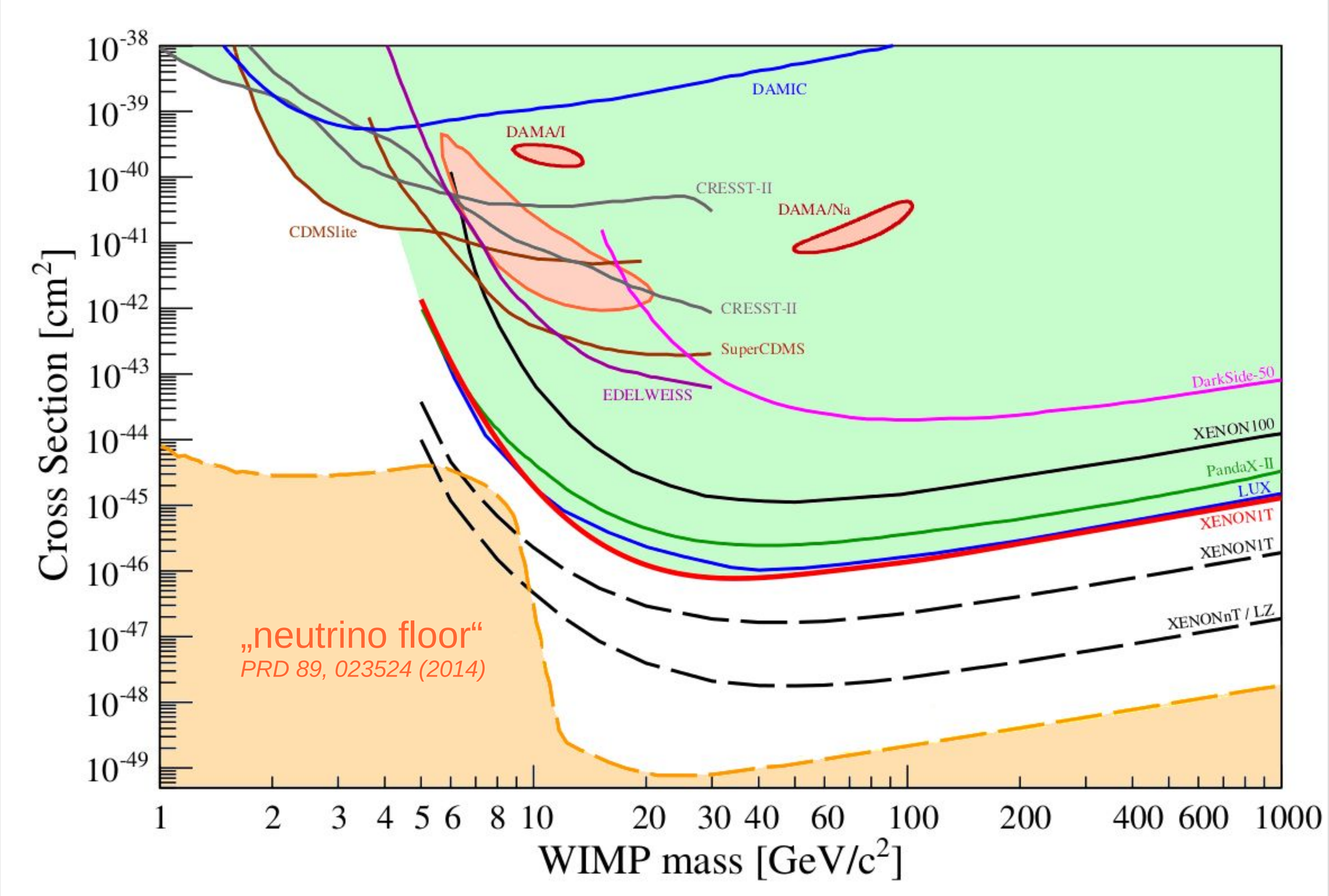
spin-independent WIMP-nucleon interactions



some projects are missing...

Dark Matter Searches: The Limit

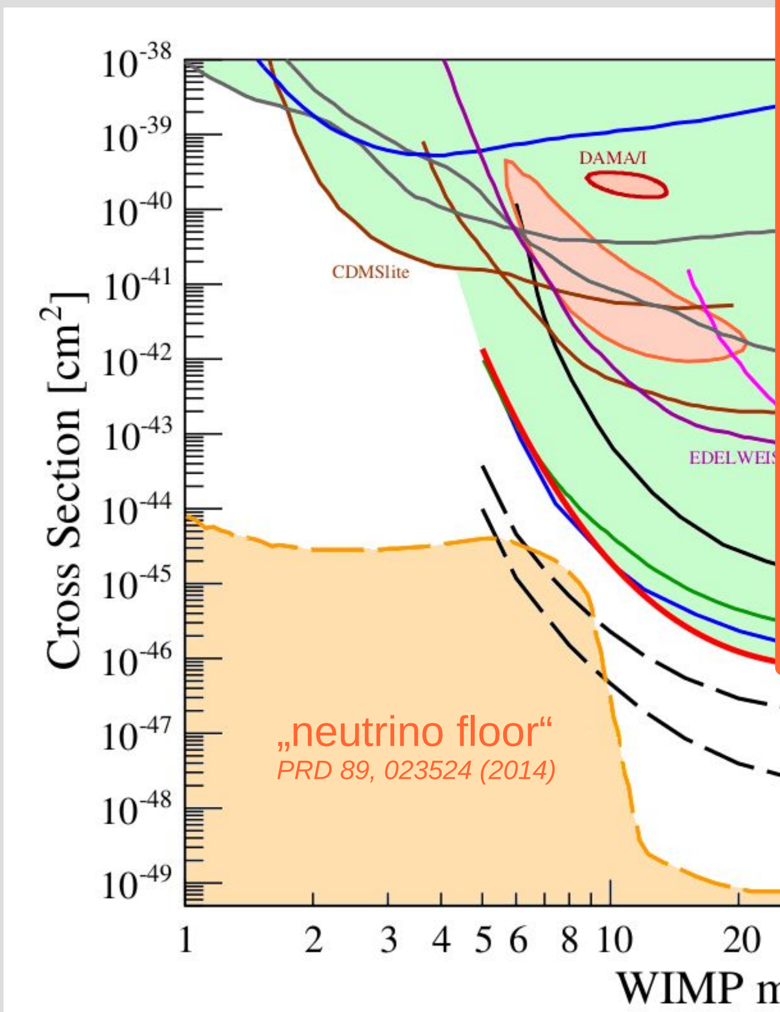
spin-independent WIMP-nucleon interactions

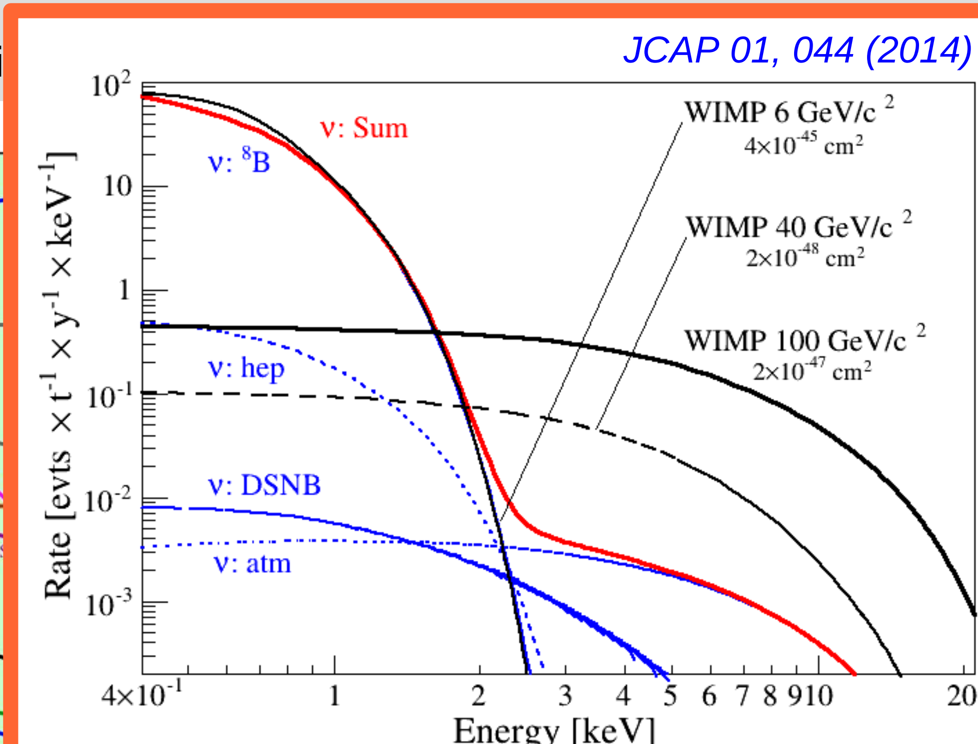


some projects are missing...

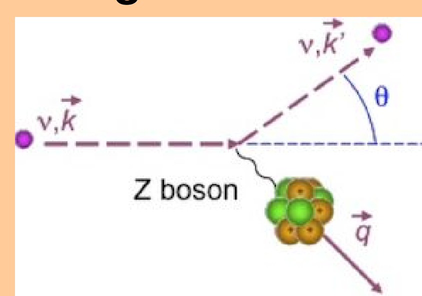
Dark Matter Searches: The Limit

spin-i





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



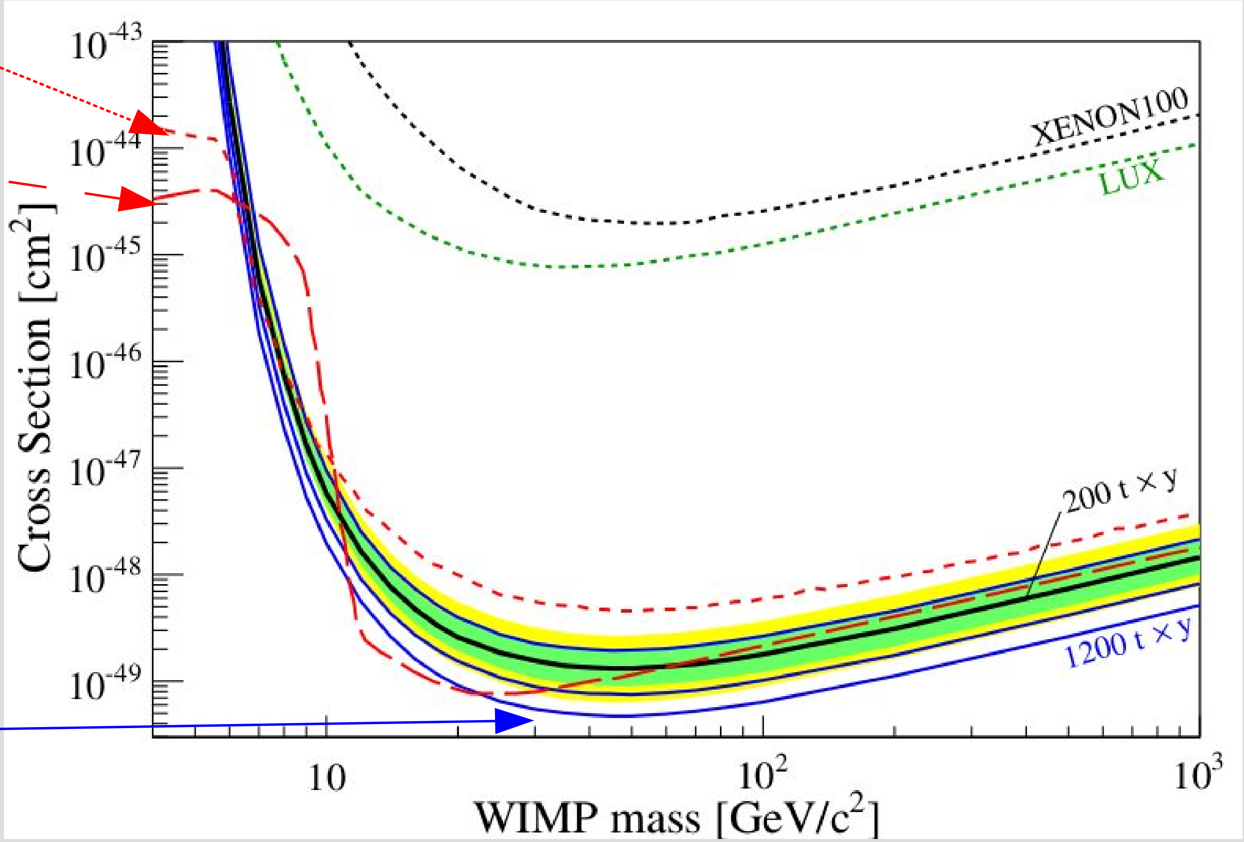
The „Neutrino Floor“

There are different definitions on the market...

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

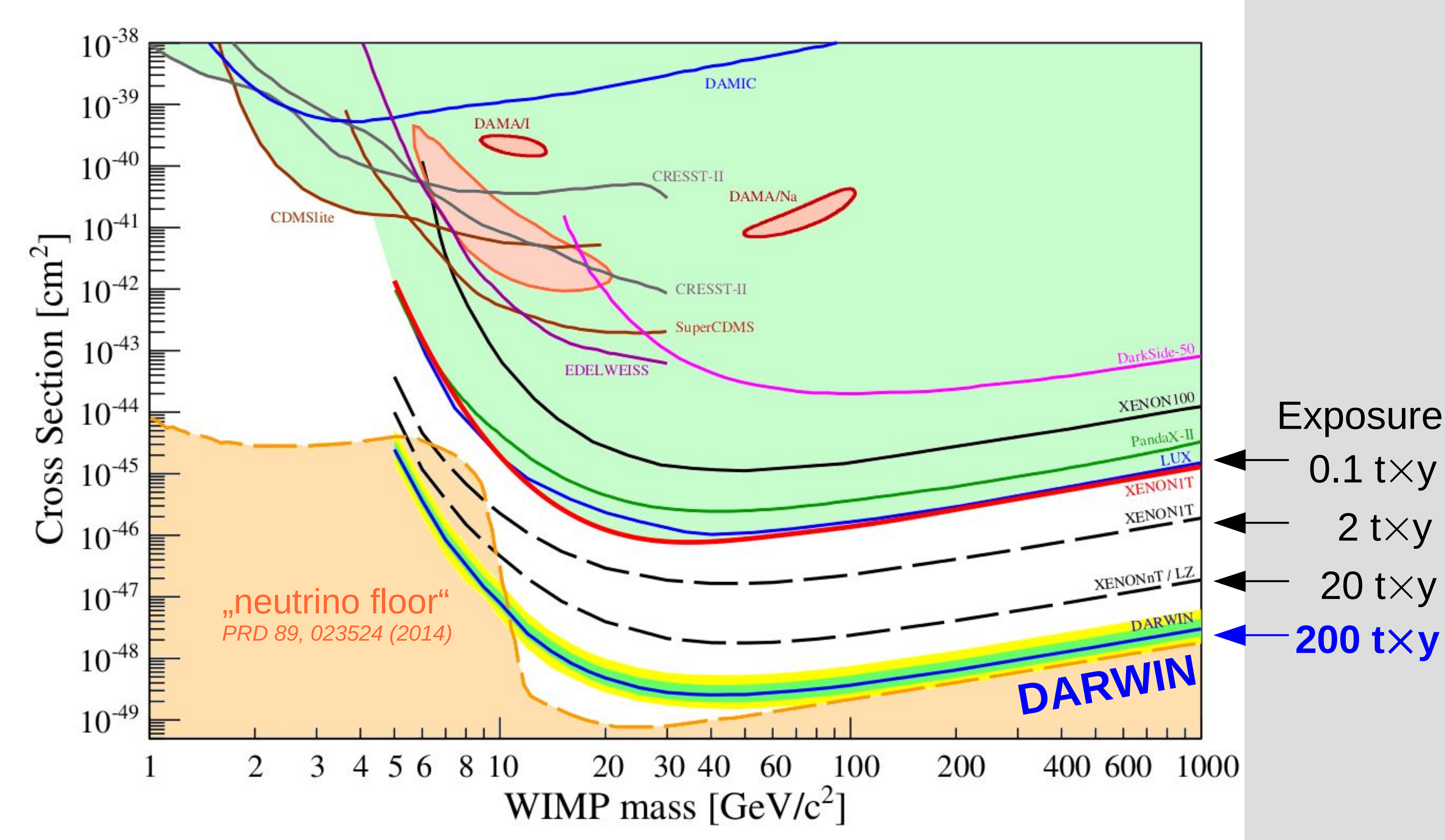
Billard et al. *PRD 89 (2014) 023524*
„WIMP discovery limit“
= detect a WIMP at 3σ on top of **500 CNNS events** above a LXe threshold of 4 keVnr (infinite E resolution)
→ assuming an unrealistic 100% NR acceptance, a **5300 t × y exposure** is required to reach this (4-35 keVnr window)

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



DARWIN The **ultimate** WIMP Detector

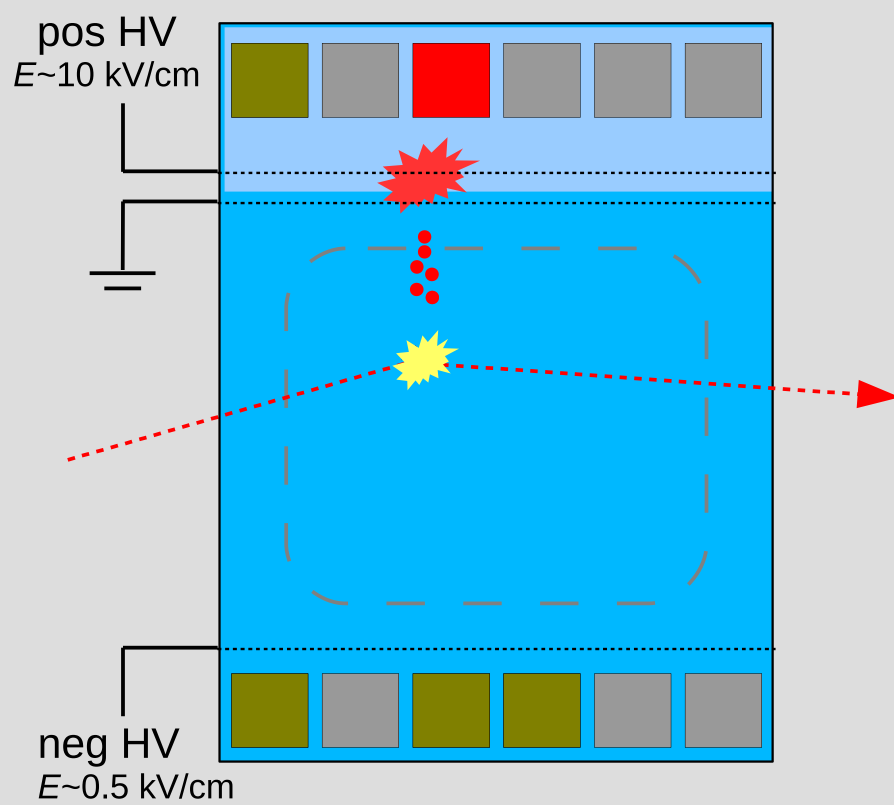
spin-independent WIMP-nucleon interactions

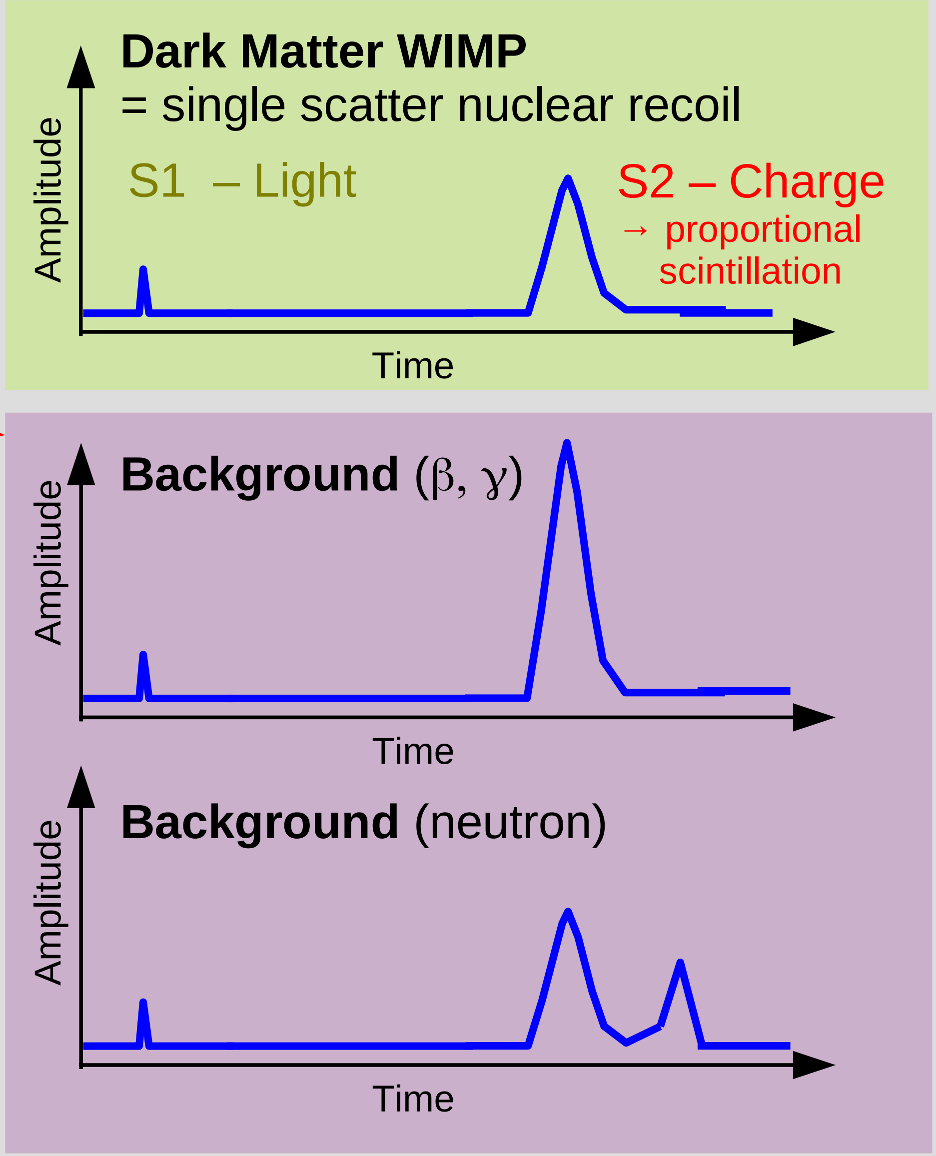


some projects are missing...

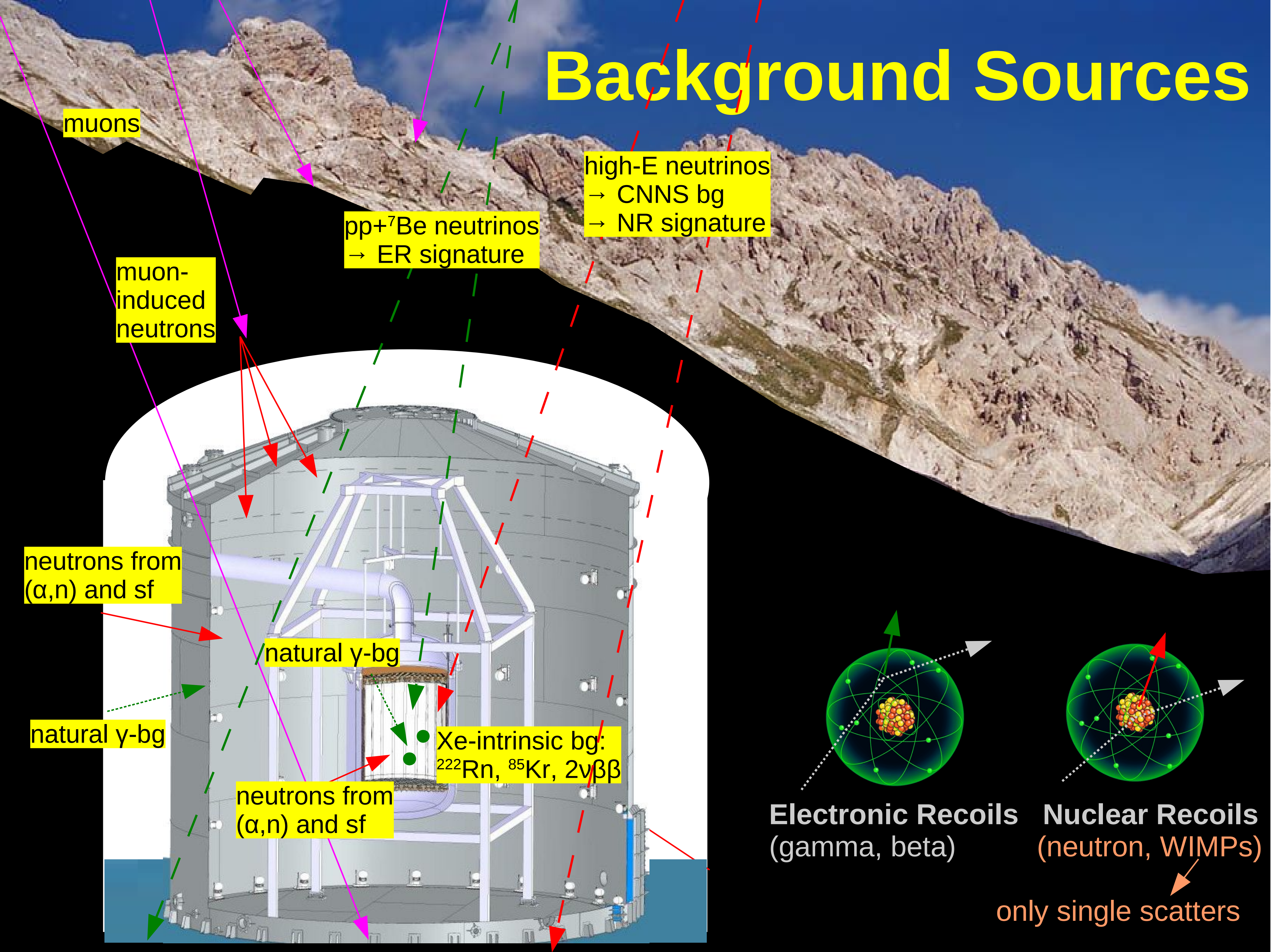
Detector? – Dual Phase Xenon TPC

TPC = Time Projection Chamber





- 3d position reconstruction → target fiducialization
- background rejection


Background Sources
muons
muon-induced neutrons
pp+⁷Be neutrinos → ER signature
high-E neutrinos → CNNS bg → NR signature
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

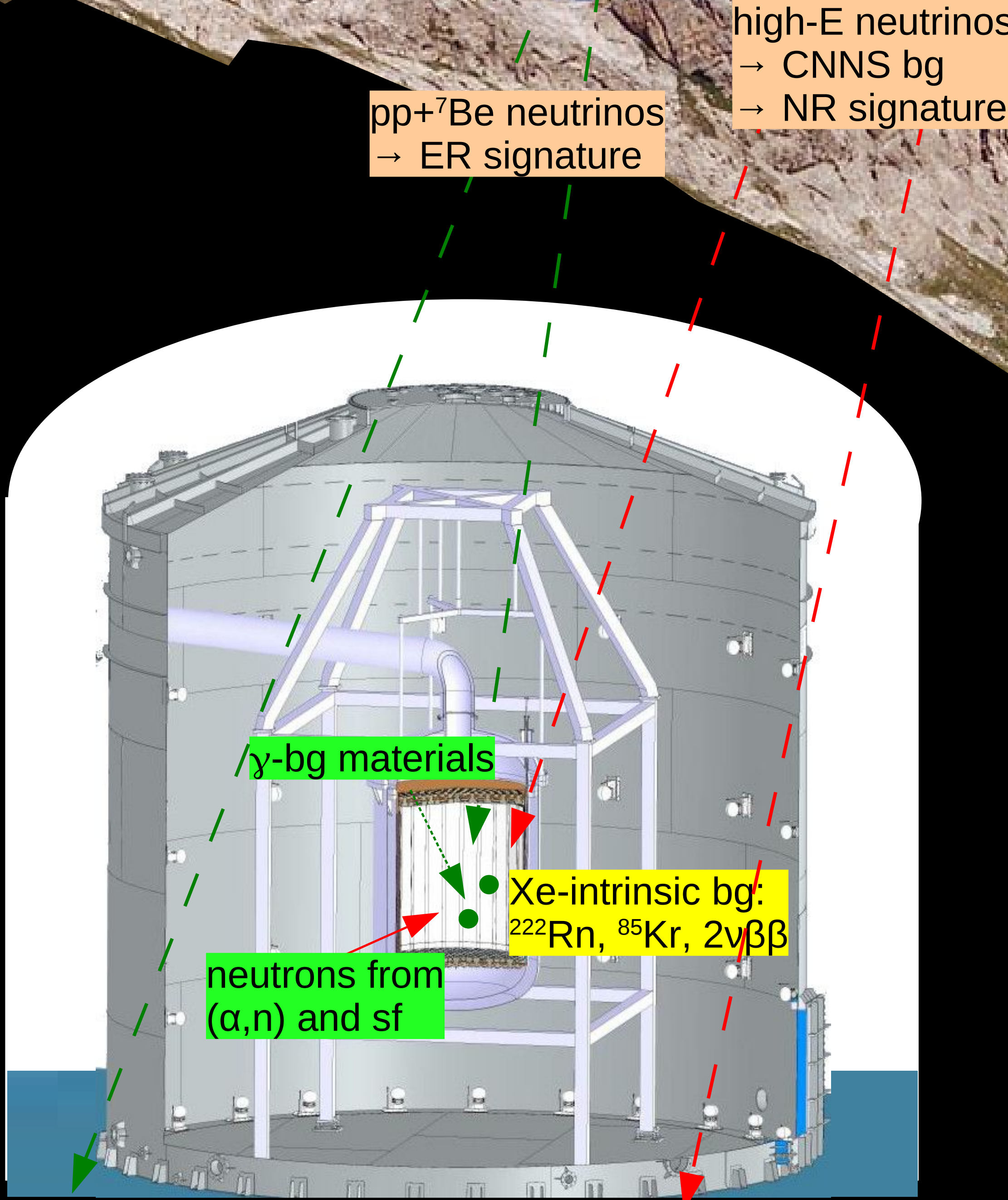
DARWIN Backgrounds

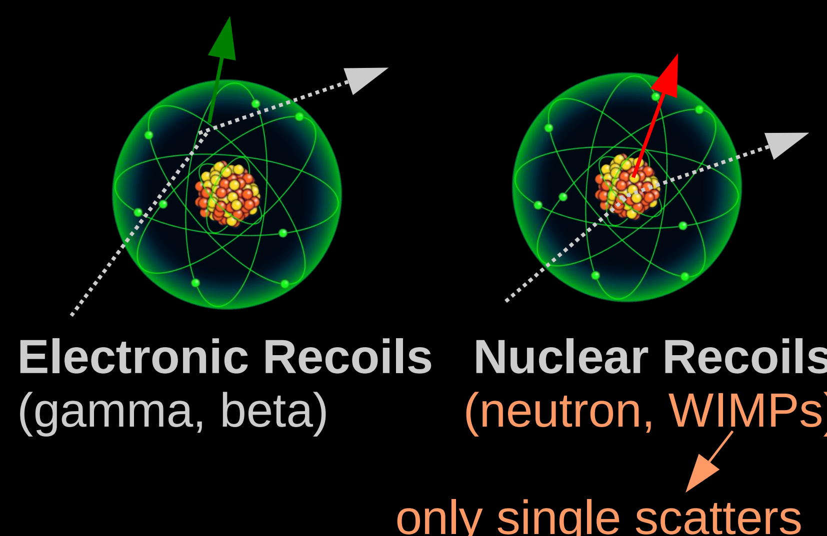
Remaining background sources:

– Neutrinos (→ ERs and NRs)
– Detector materials (→ γ, n)
– Xe-intrinsic isotopes (→ e^-)

(assume 100% effective shield (~15m) against μ-induced background)

JCAP 10, 016 (2015)





Backgrounds

JCAP 10, 016 (2015)

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

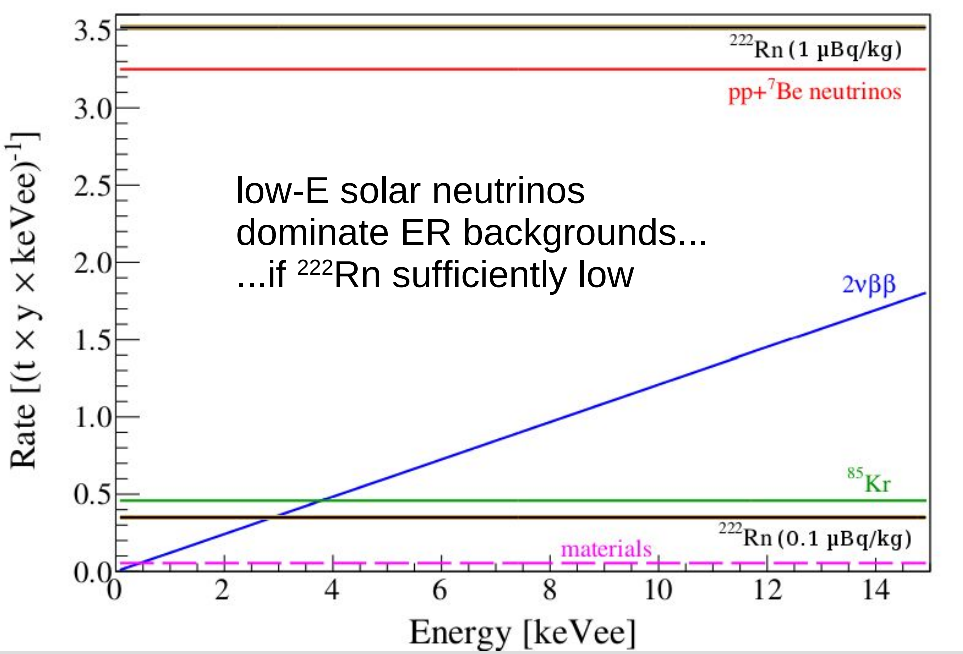
MC simulation of detector made of main components (PTFE, CU, PMTs): subdominant after ~15 cm fiducial cut

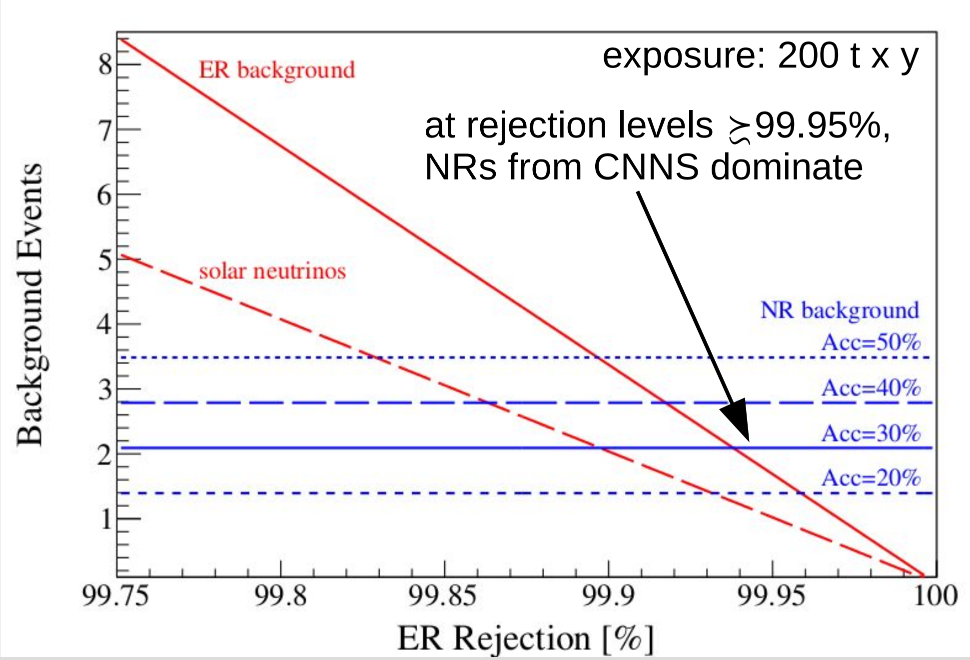
^{85}Kr: 2x below XENON1T design
(0.03 ppt achieved: *EPJ C 74 (2014) 2746*)

^{222}Rn: 100x below XENON1T design

^{136}Xe: assume natural xenon

consider all relevant neutrinos



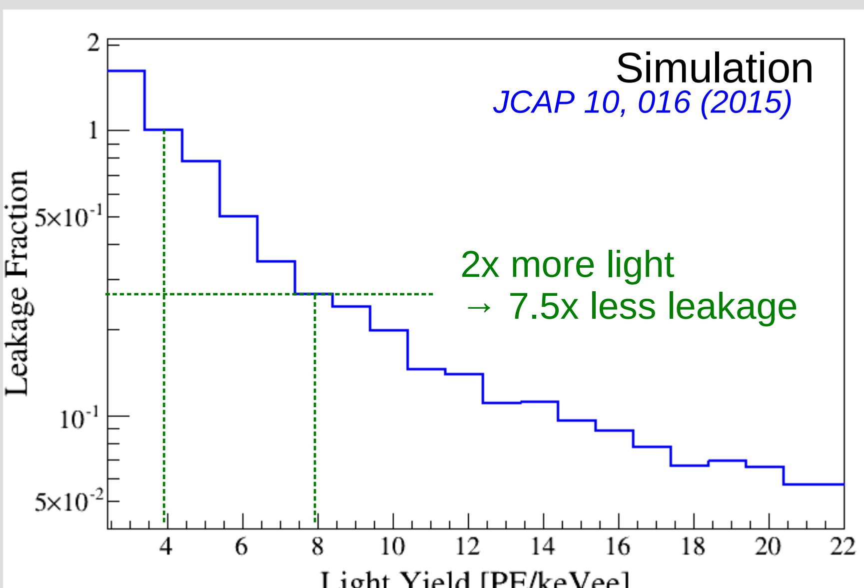


Background Rejection

ER rejection factors ~99.98% required (@ 30% NR acc)

Experimental achievements:

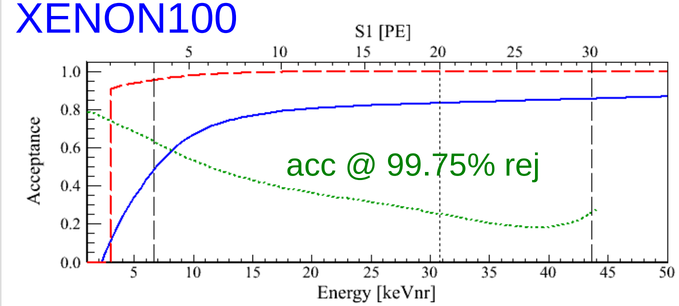
	E_{drift} [kV/cm]	LY @ 122 keV [PE/keV]	NR acc [%]	ER rej [%]
XENON100	0.53	3.8	40	99.75
XENON100	0.53	3.8	30	99.90
LUX	0.18	8.8	50	99.0-99.9
ZEPLIN-III	3.4	4.2	50	**99.987**
K. Ni *APP14*	0.2-0.7	10	50	**>99.999**



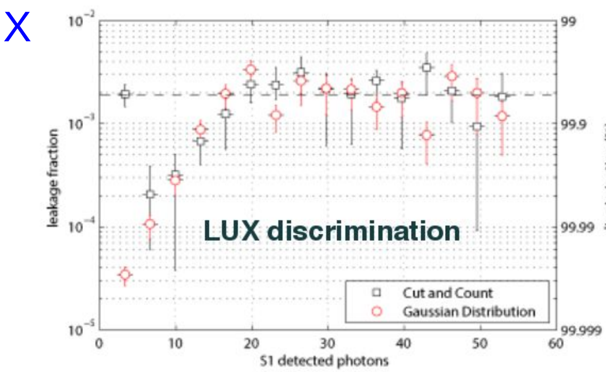
higher light yield improves signal resolution
→ better band separation at given mean values

acceptance improves at lower *E*

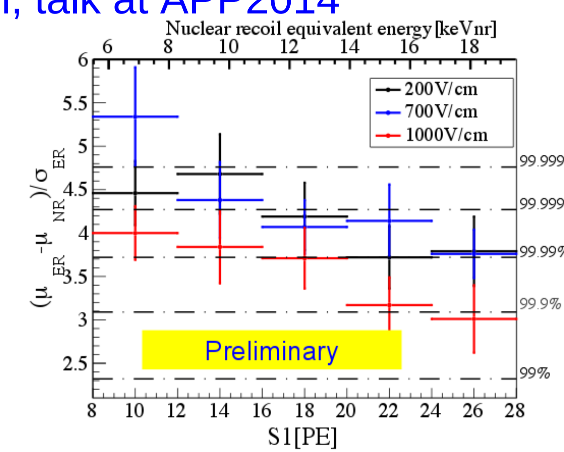
XENON100



LUX



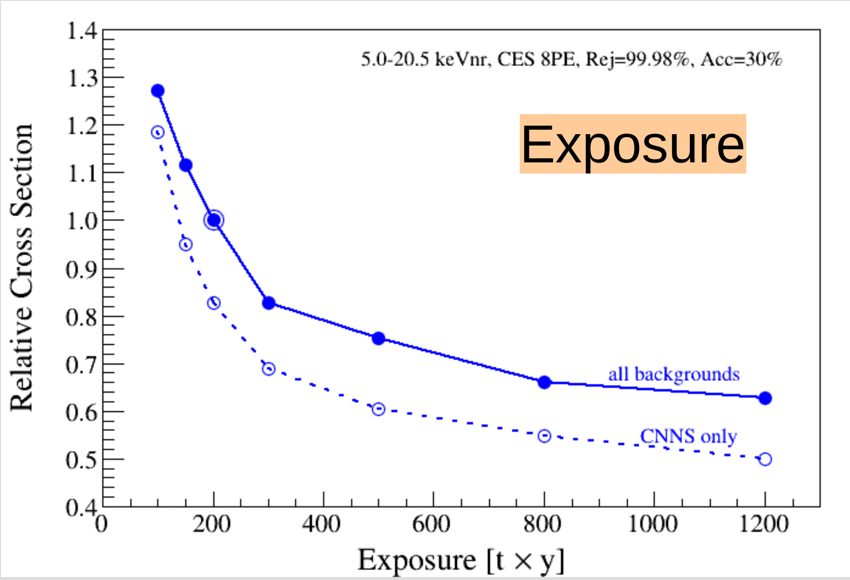
K. Ni, talk at APP2014

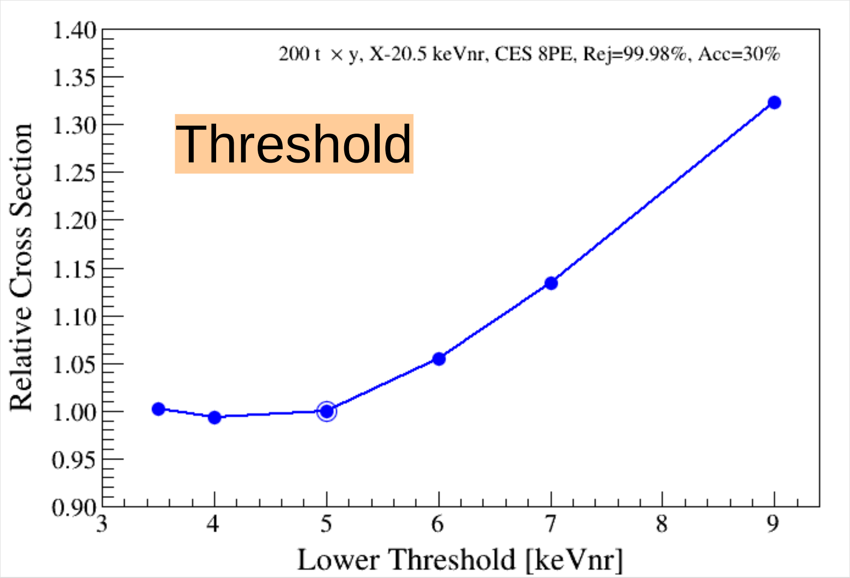


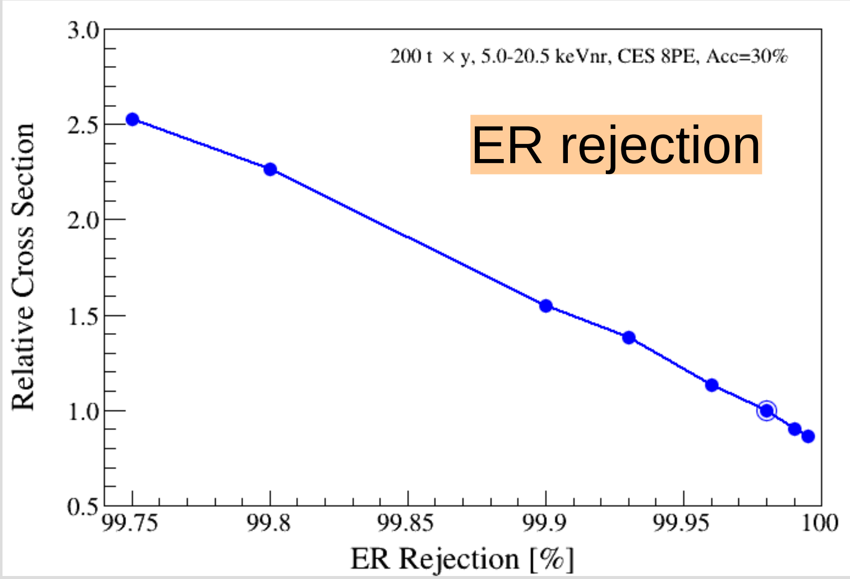
DARWIN WIMP Sensitivity

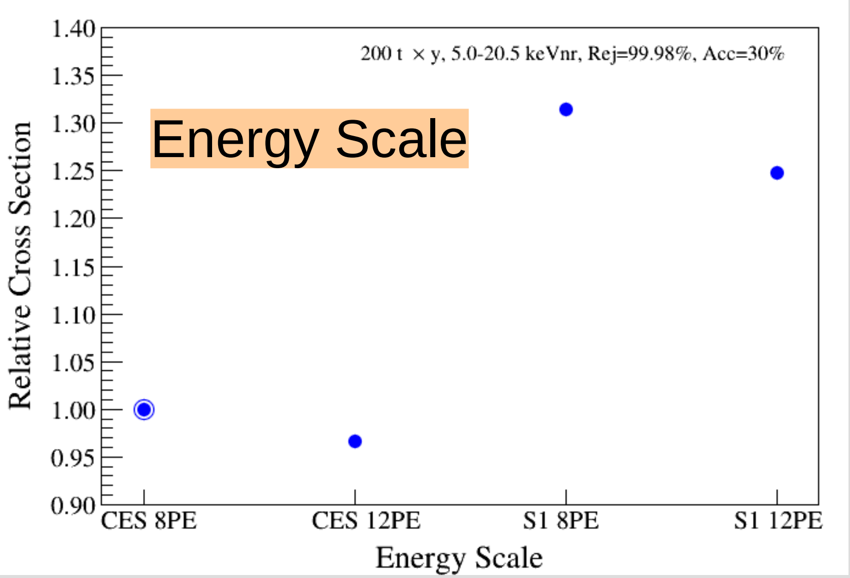
Reference WIMP mass = 40 GeV/c²

JCAP 10, 016 (2015)







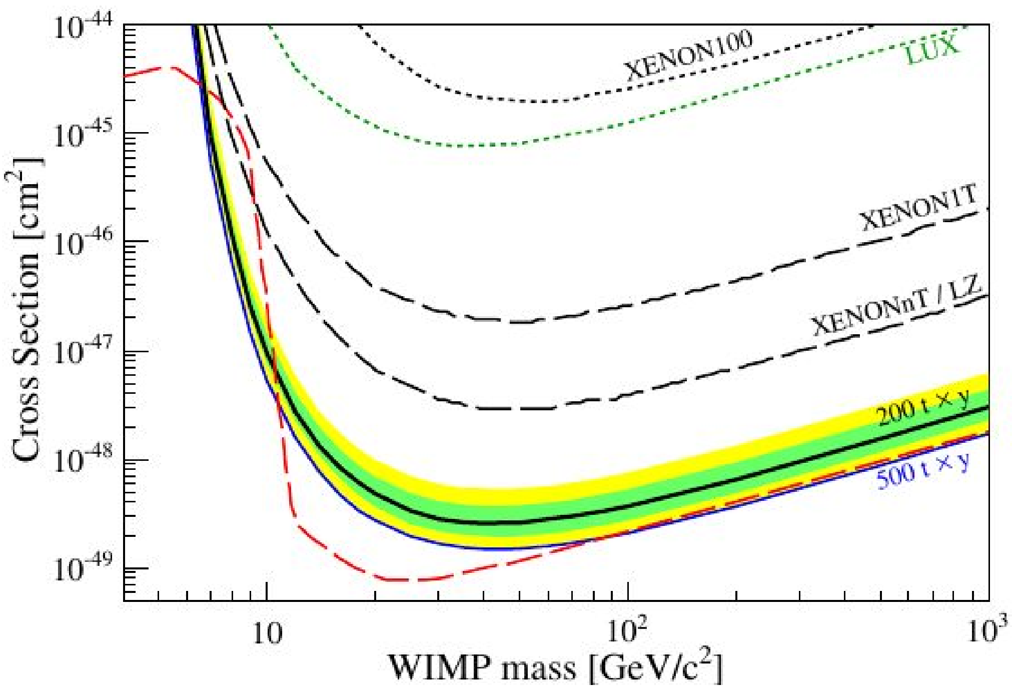


DARWIN WIMP Sensitivity

JCAP 10, 016 (2015)

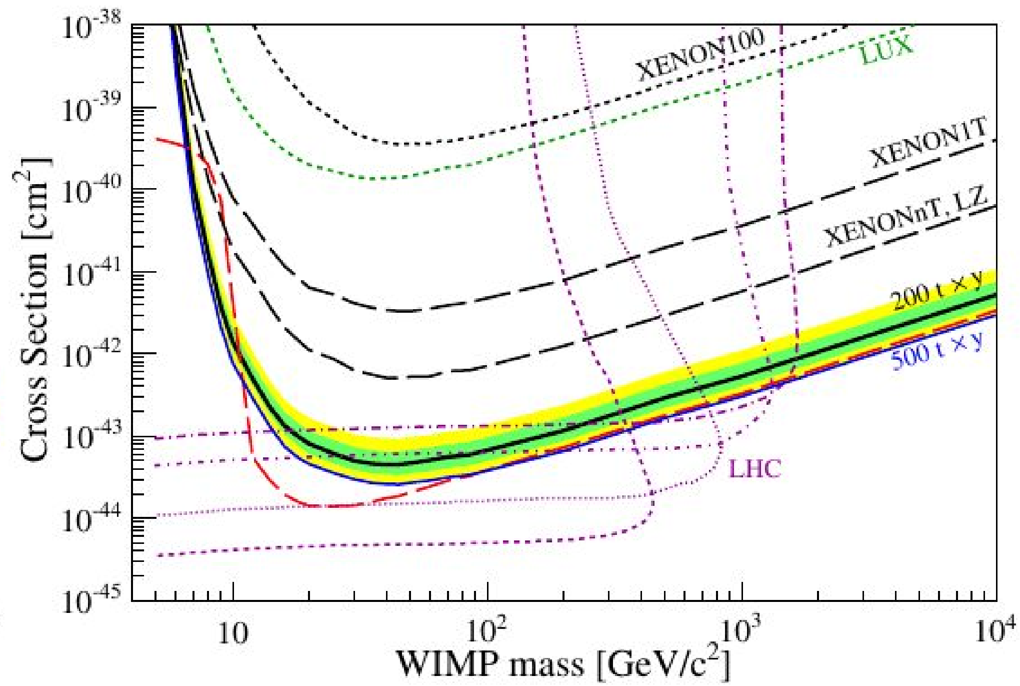
- exposure: 200 t × y; **all backgrounds included**
- likelihood analysis
- 99.98% ER rejection @ 30% NR acceptance,
  S1+S2 combined energy scale, LY=8 PE/keV, 5-35 keV_{nr} energy window

spin-*in*dependent couplings



200 t×y: σ < 2.5 x 10^{-49} cm² @ 40 GeV/c²

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



excellent complementarity to LHC searches

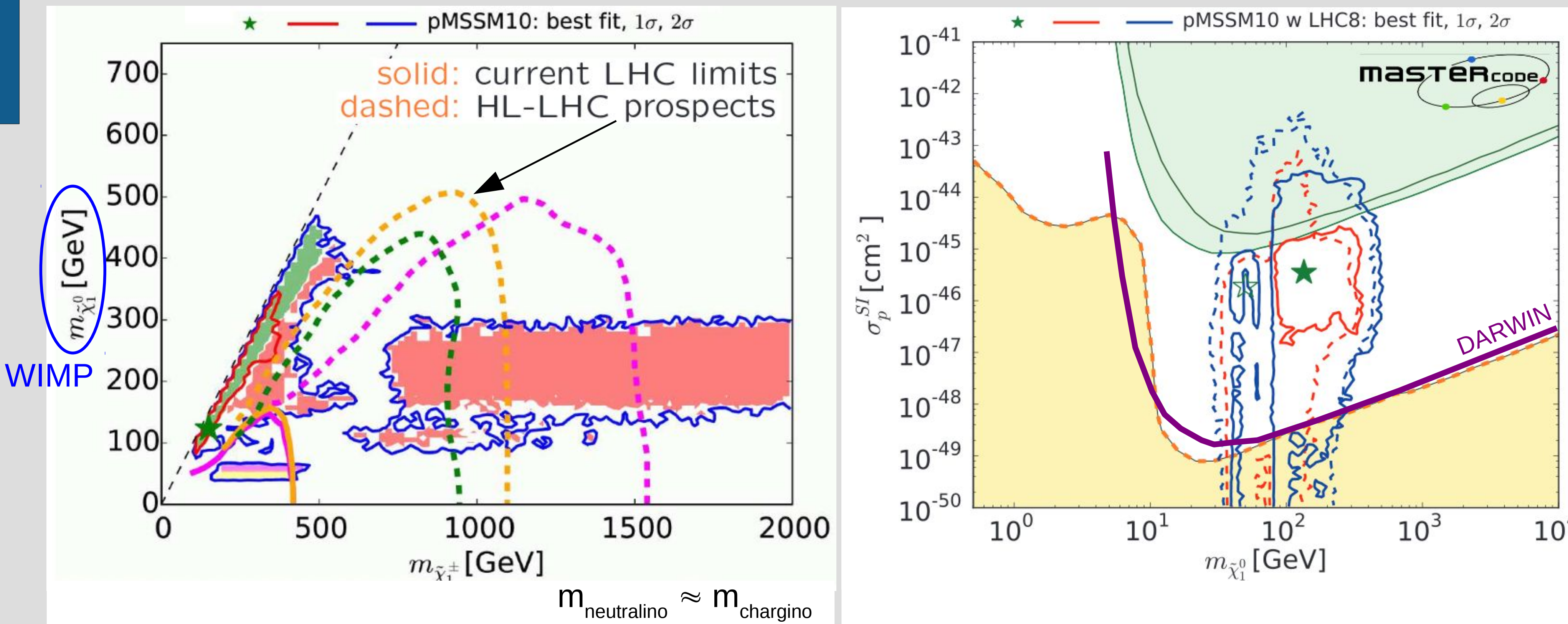
Phys.Dark Univ. 9-10, 51 (2015).

SUSY Dark Matter

plots: Sven Heinemeyer (MasterCode 2015)

SUSY under pressure because not found at LHC?
→ true for some very constraint models (CMSSM etc.) but looks different when more parameters are left unconstrained

Example: pMSSM10 ← 10 SUSY parameters, *e.g. EPJ C75, 422 (2015)*



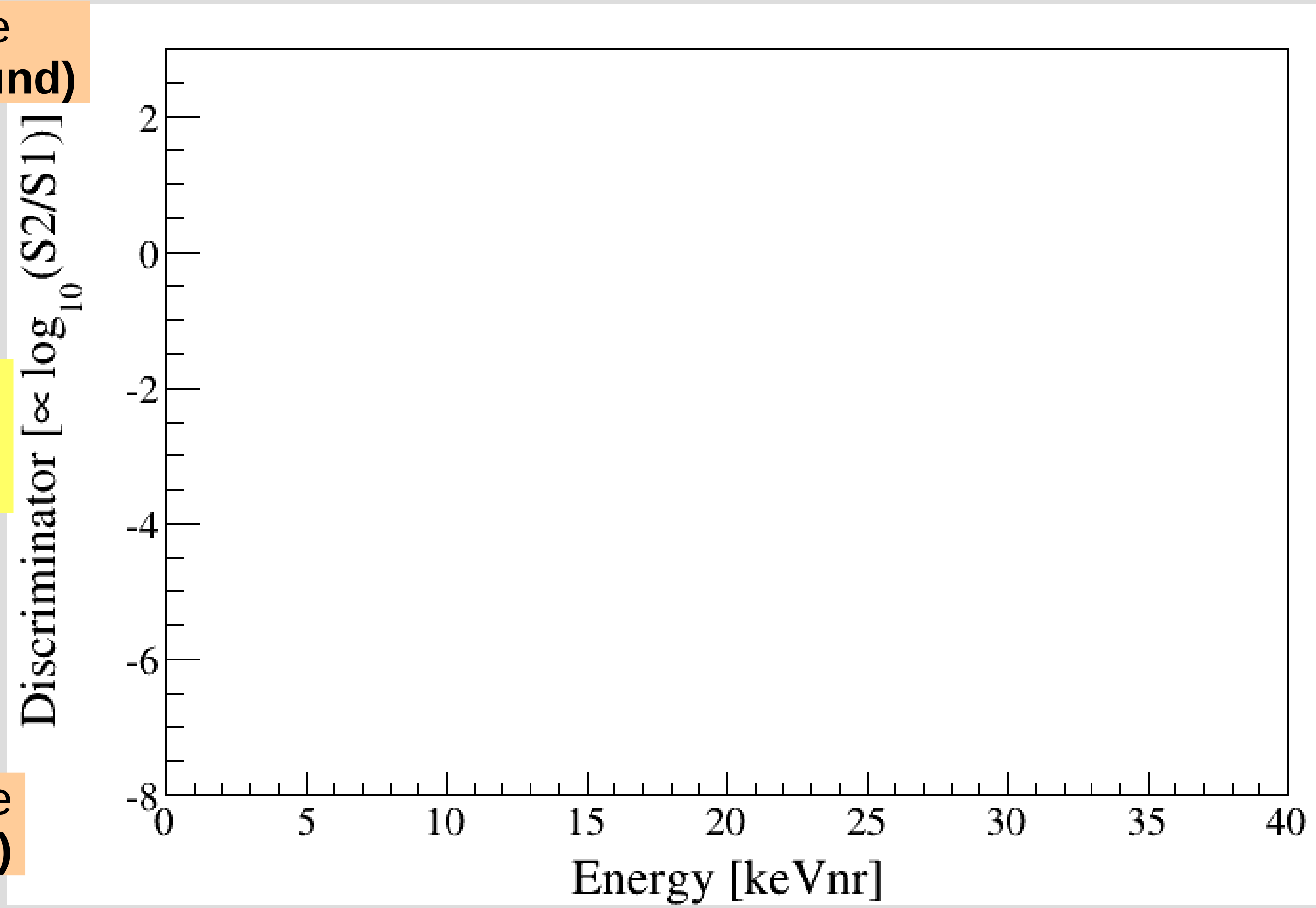
WIMP out of reach of HL-LHC (best-fit regions not covered), but accessible by DARWIN

WIMP Detection

ER-like
(background)

discrimination
variable;
based on S2/S1

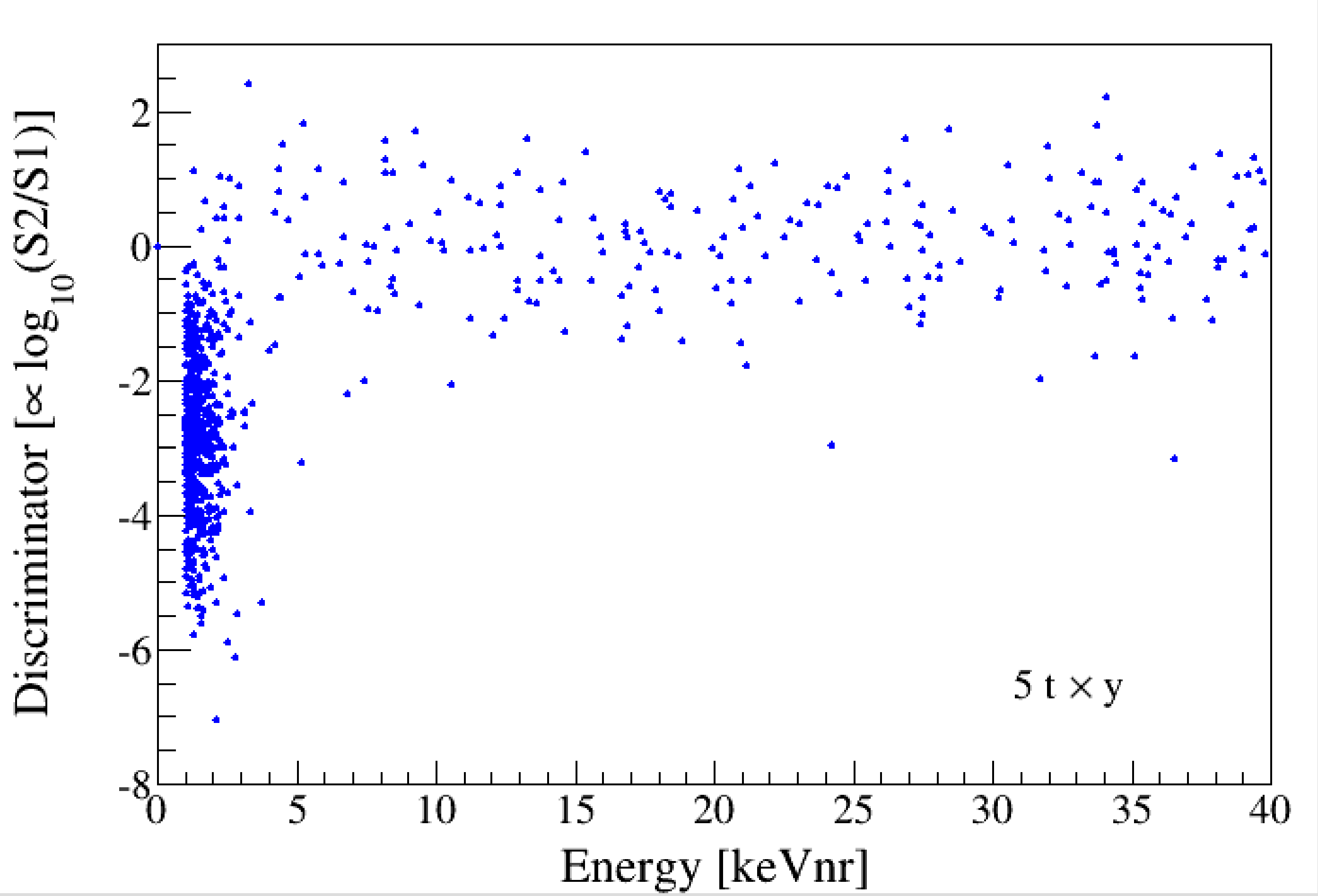
NR-like
(signal)



reconstructed energy,
based on S1 and S2 signal

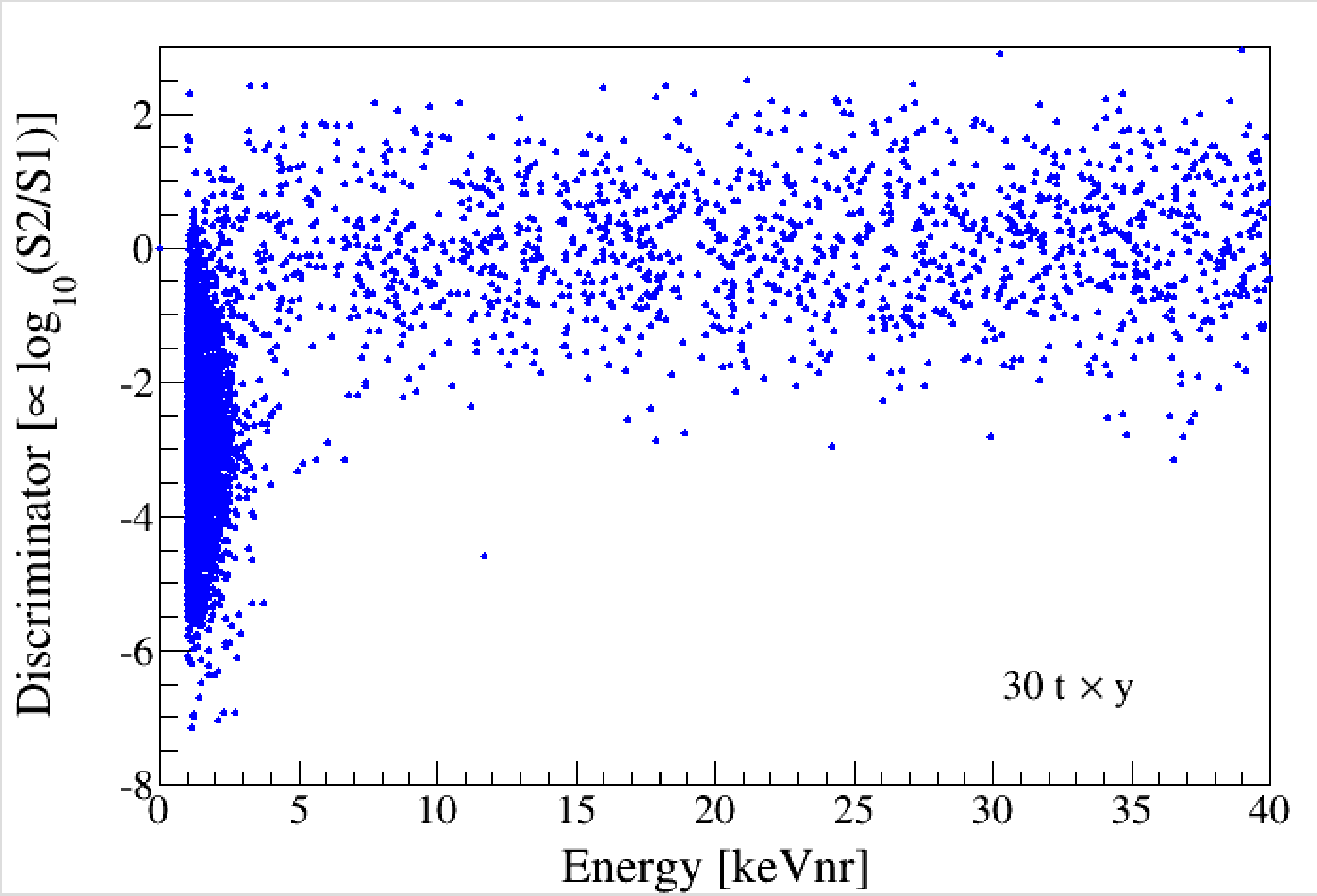
DARWIN with
30t LXe fiducial
target

WIMP Detection



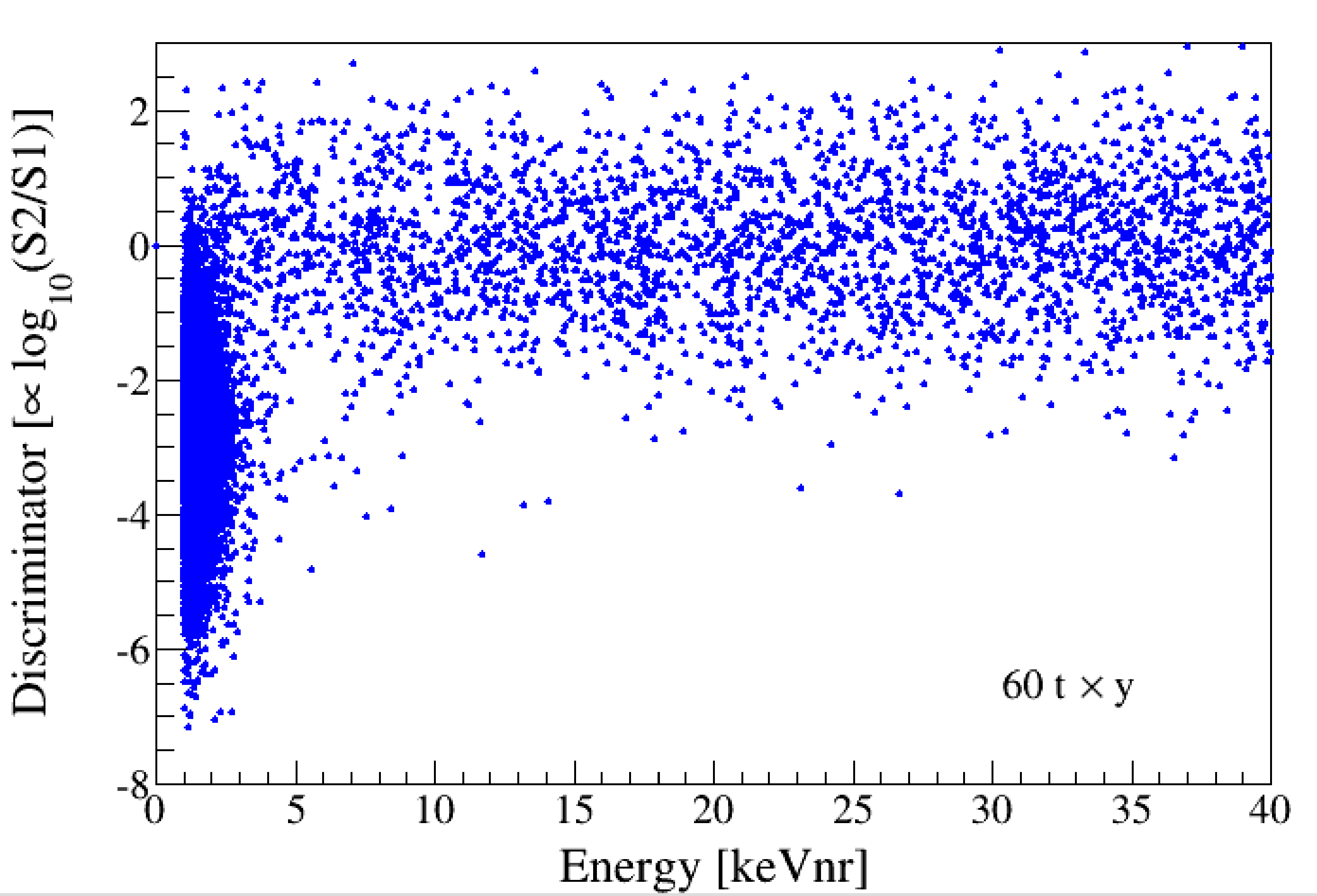
60 days

WIMP Detection



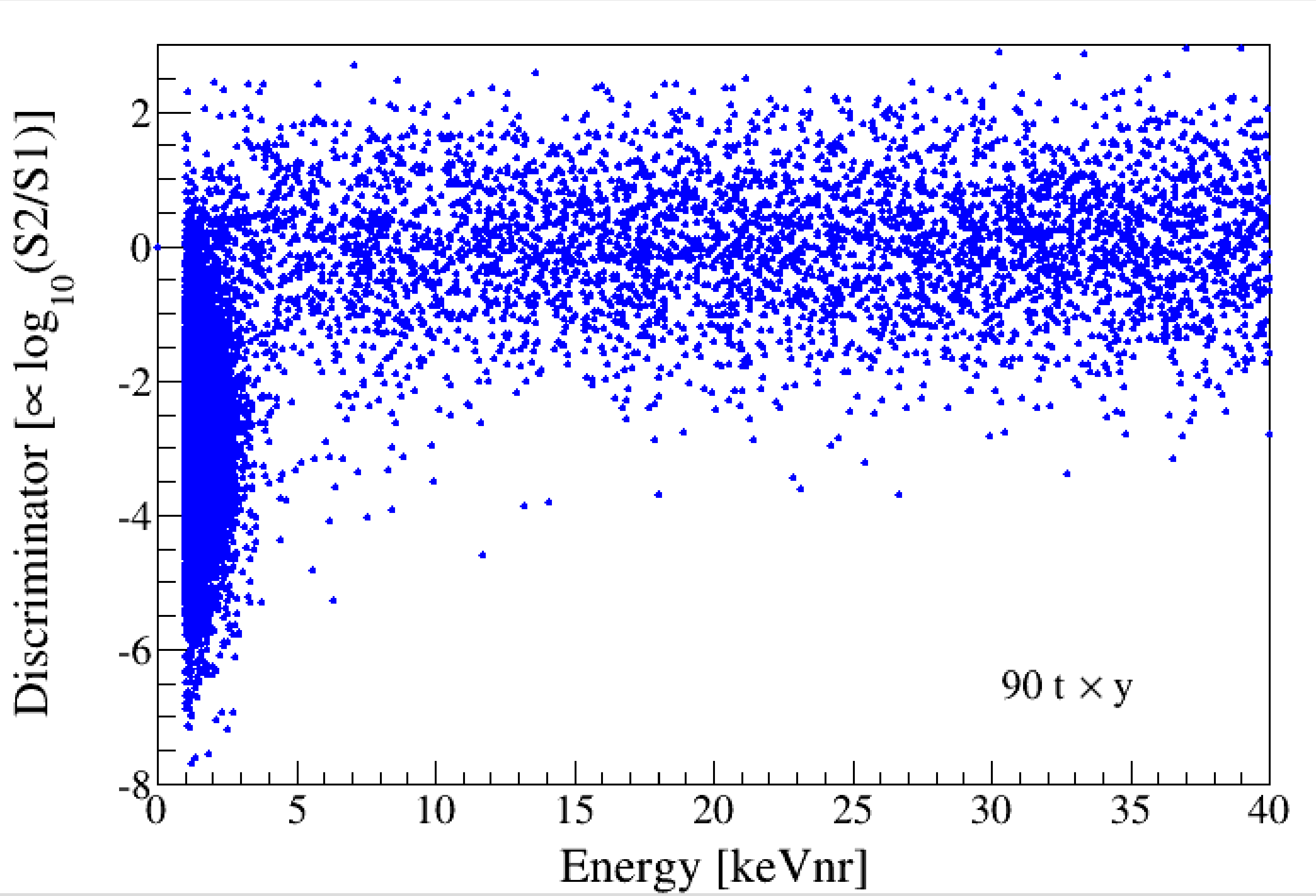
1 year

WIMP Detection



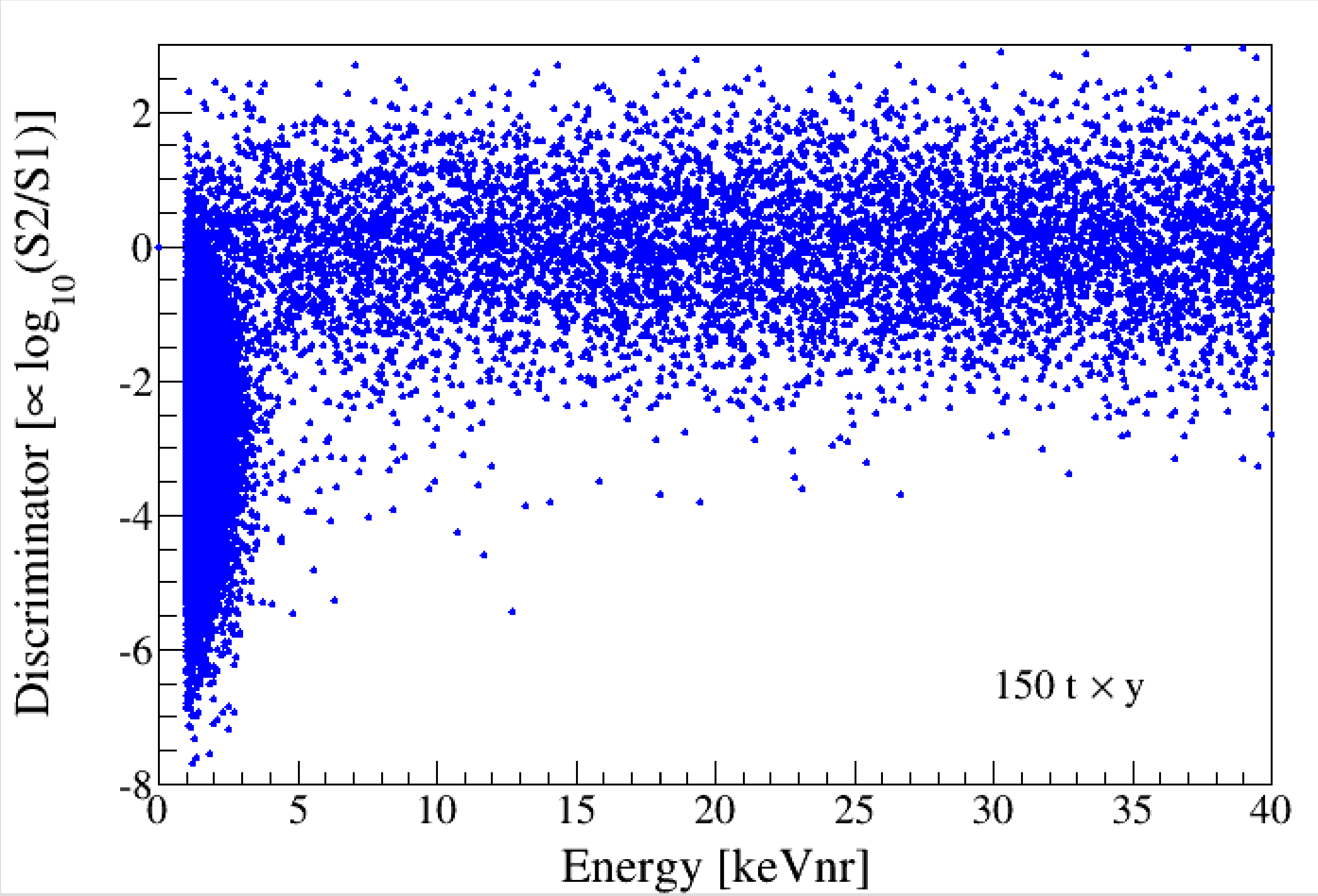
2 years

WIMP Detection



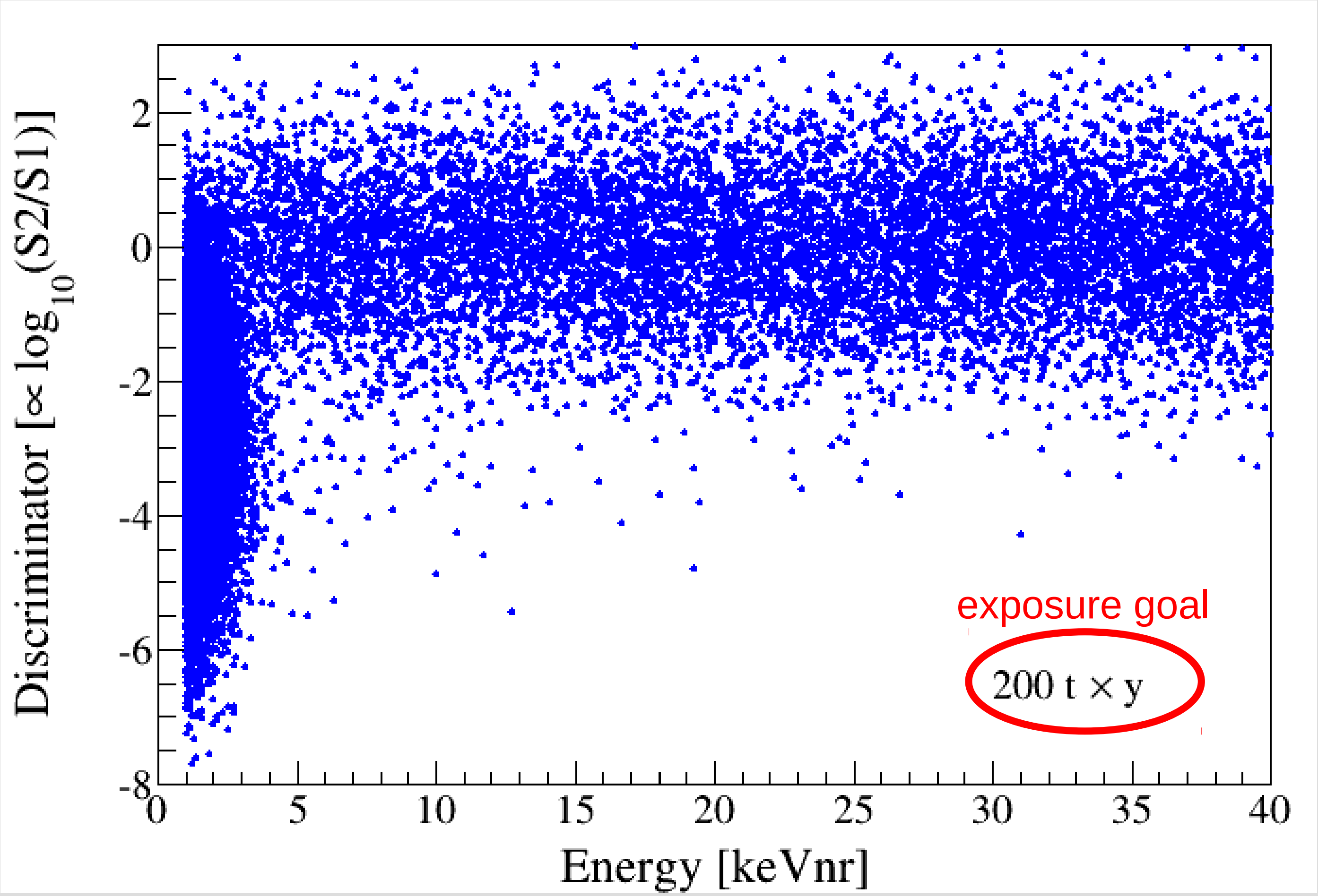
3 years

WIMP Detection



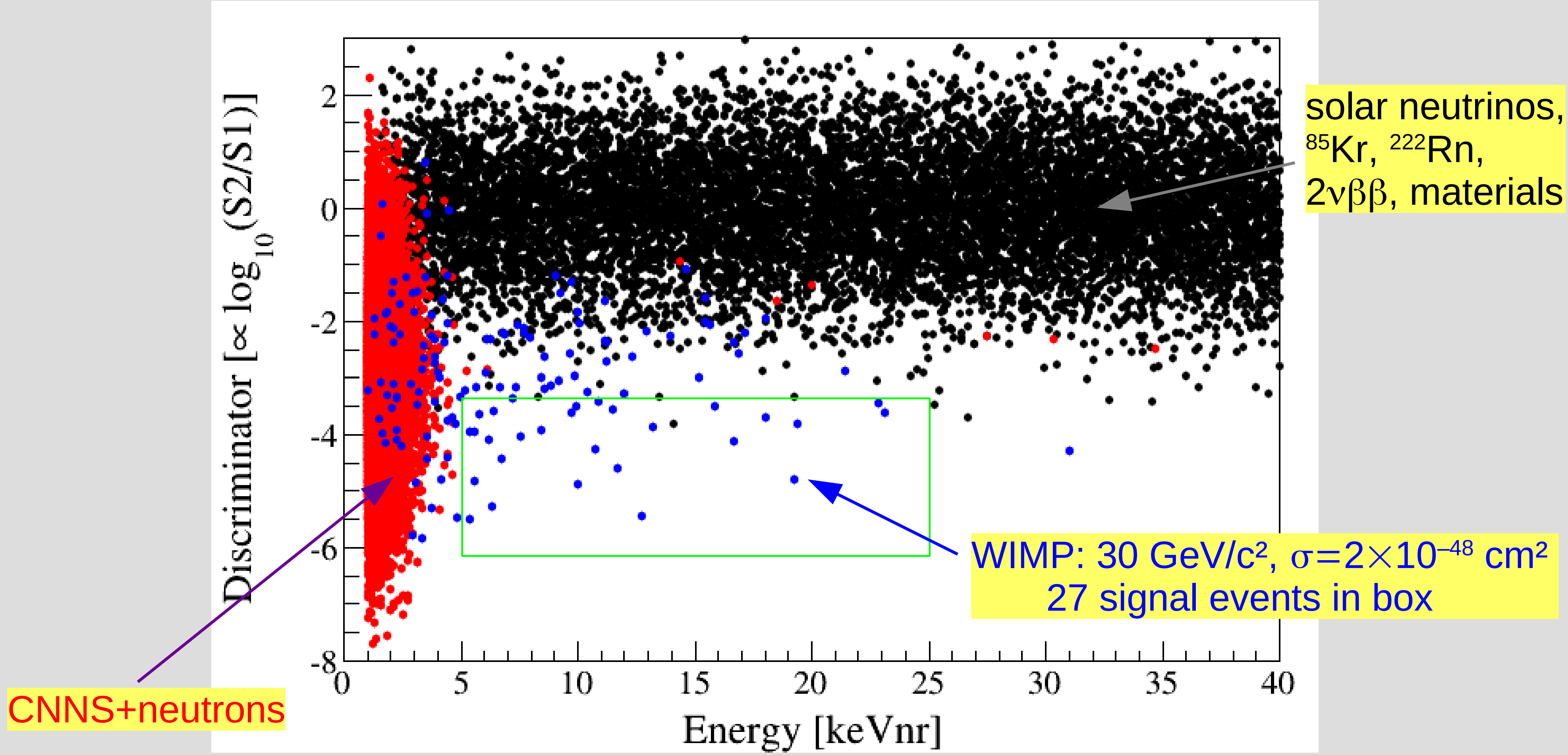
5 years

WIMP Detection



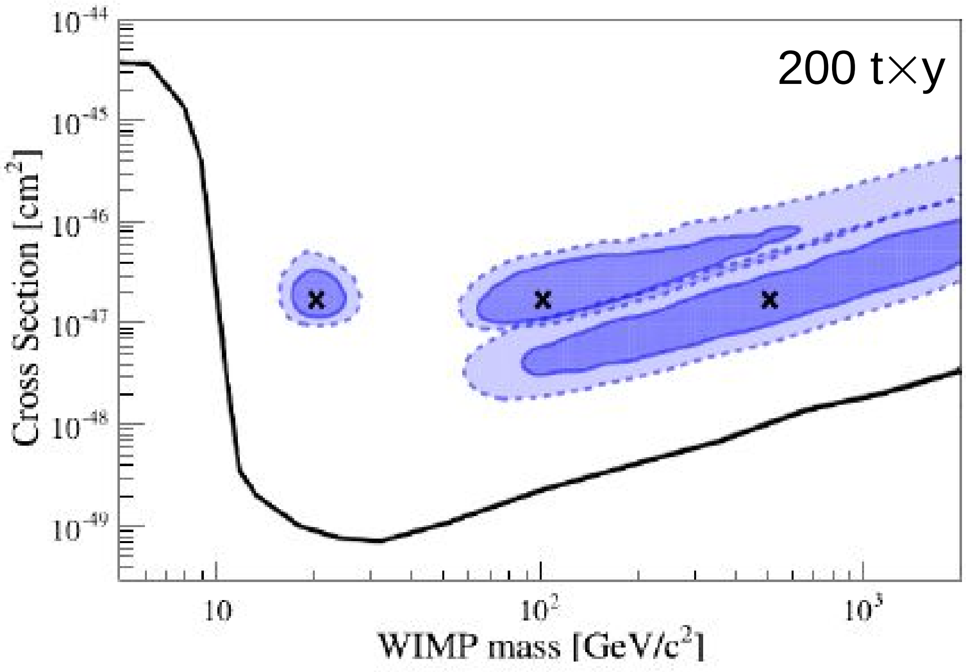
6.7 years

WIMP Detection



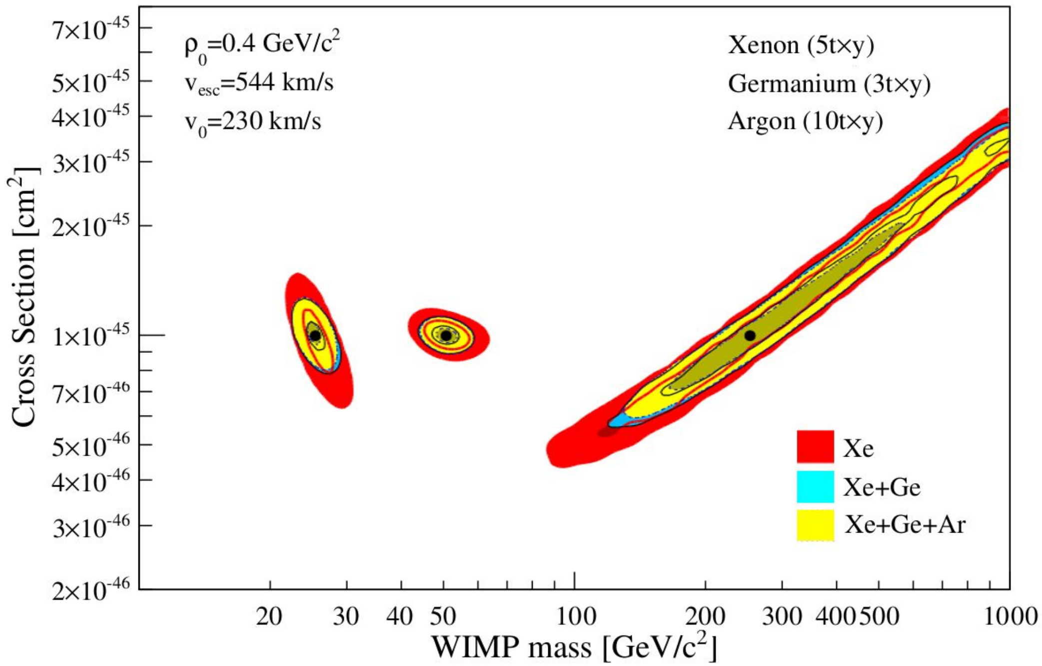
WIMP Spectroscopy

Reconstruction: 2×10^{-47} cm²



JCAP 11, 017 (2016)

Target Complementarity



PRD 83, 083505 (2011)

Capability to reconstruct WIMP parameters

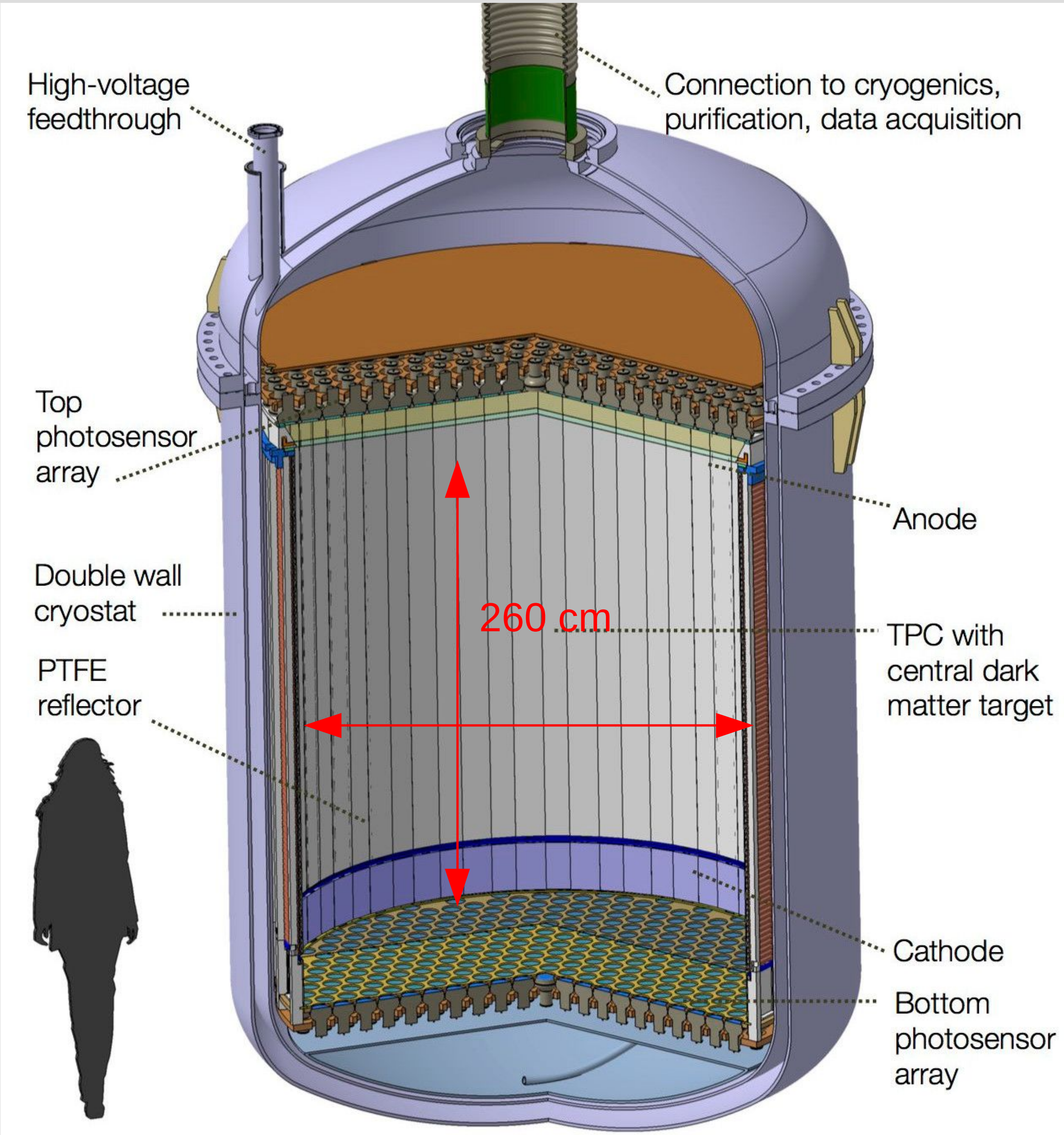
- m_χ=20, 100, 500 GeV/c²
- 1σ/2σ CI, marginalized over astrophysical parameters
- due to flat WIMP spectra, no target can reconstruct masses >500 GeV/c²

Reconstruction improves considerably by adding Ge-data to Xe.

Only minimal improvement for Ar.

DARWIN The ultimate WIMP Detector

JCAP 11, 017 (2016)

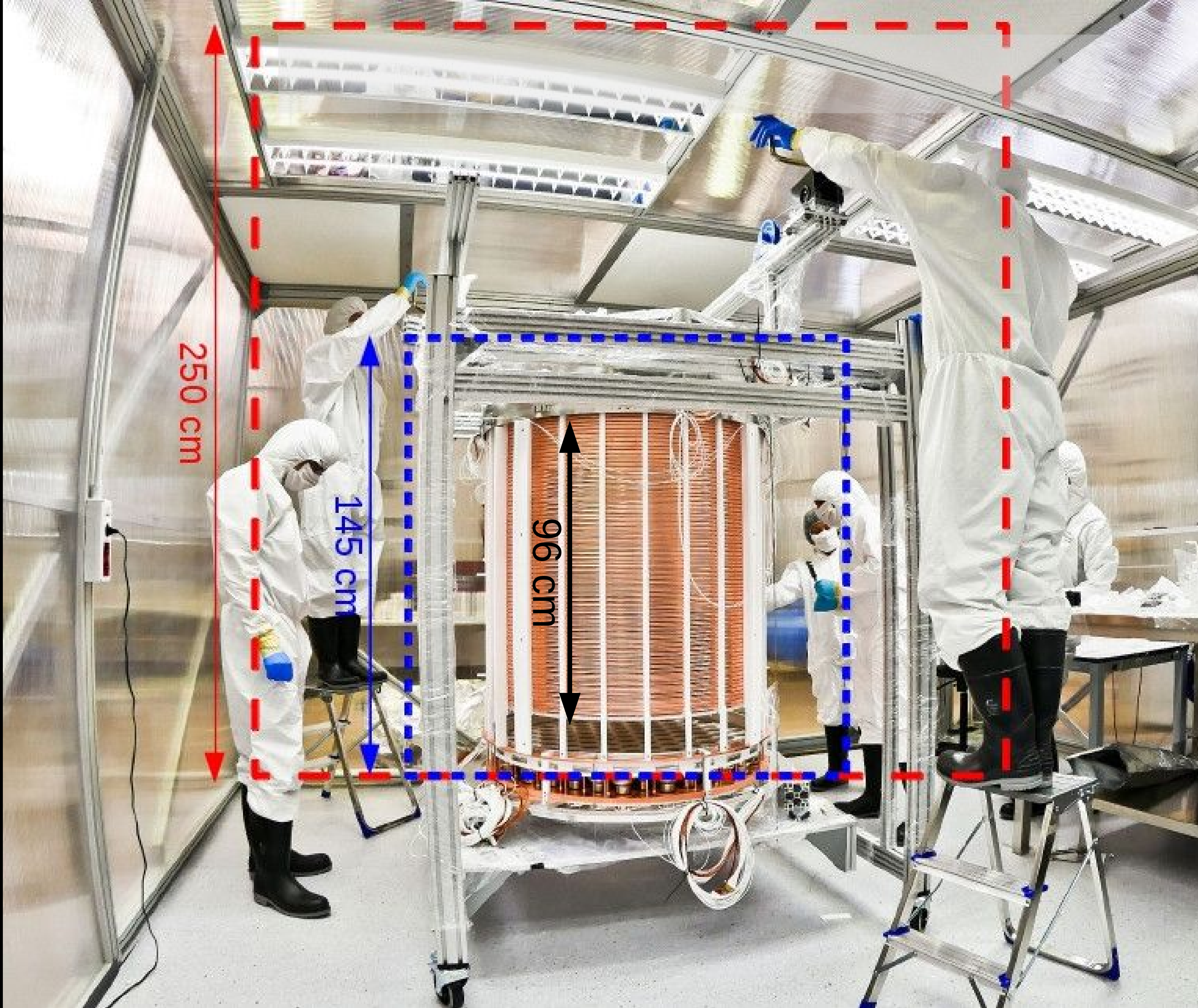


- aim at sensitivity of a few 10^{-49} cm², limited by **irreducible ν-backgrounds**
- international consortium, 21 groups
  → R&D ongoing

Baseline scenario
~50t total LXe mass
~40 t LXe TPC
~30 t fiducial mass

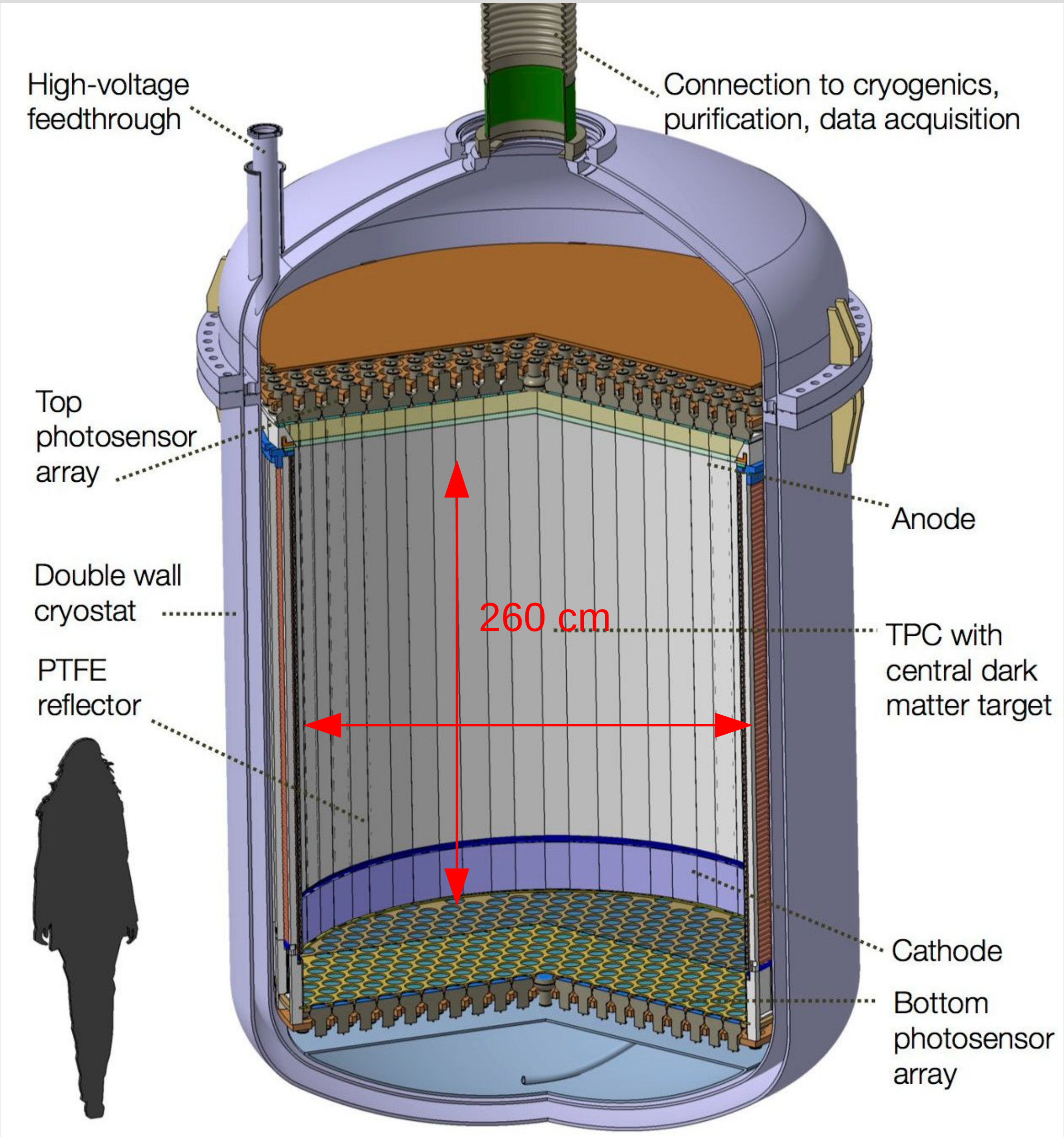
- Timescale: start after XENONnT

www.darwin-observatory.org


250 cm
145 cm
96 cm

DARWIN The ultimate WIMP Detector

JCAP 11, 017 (2016)

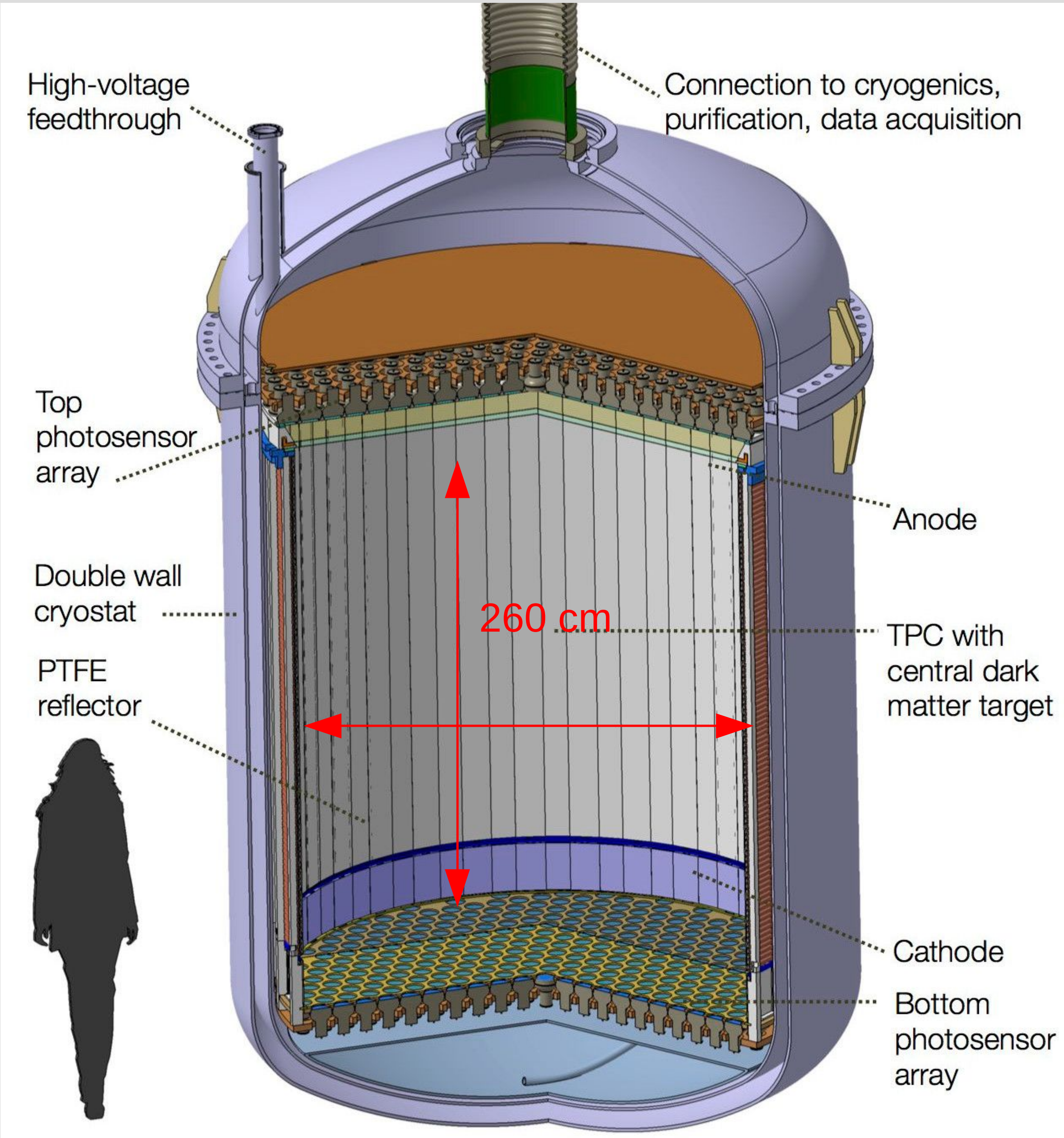


Challenges

- Size
  - → electron drift (HV)
  - → diameter (TPC electrodes)
  - → mass (LXe purification)
  - → dimensions (radioactivity)
  - → detector response (calibration, corrections)
- Backgrounds
  - → ^{222}Rn: factor 100 required
  - → (α,n) neutrons (from PTFE)
- Photosensors
  - → high light yield (QE)
  - → low radioactivity
  - → long-term stability
- etc etc

DARWIN The ultimate WIMP Detector

JCAP 11, 017 (2016)



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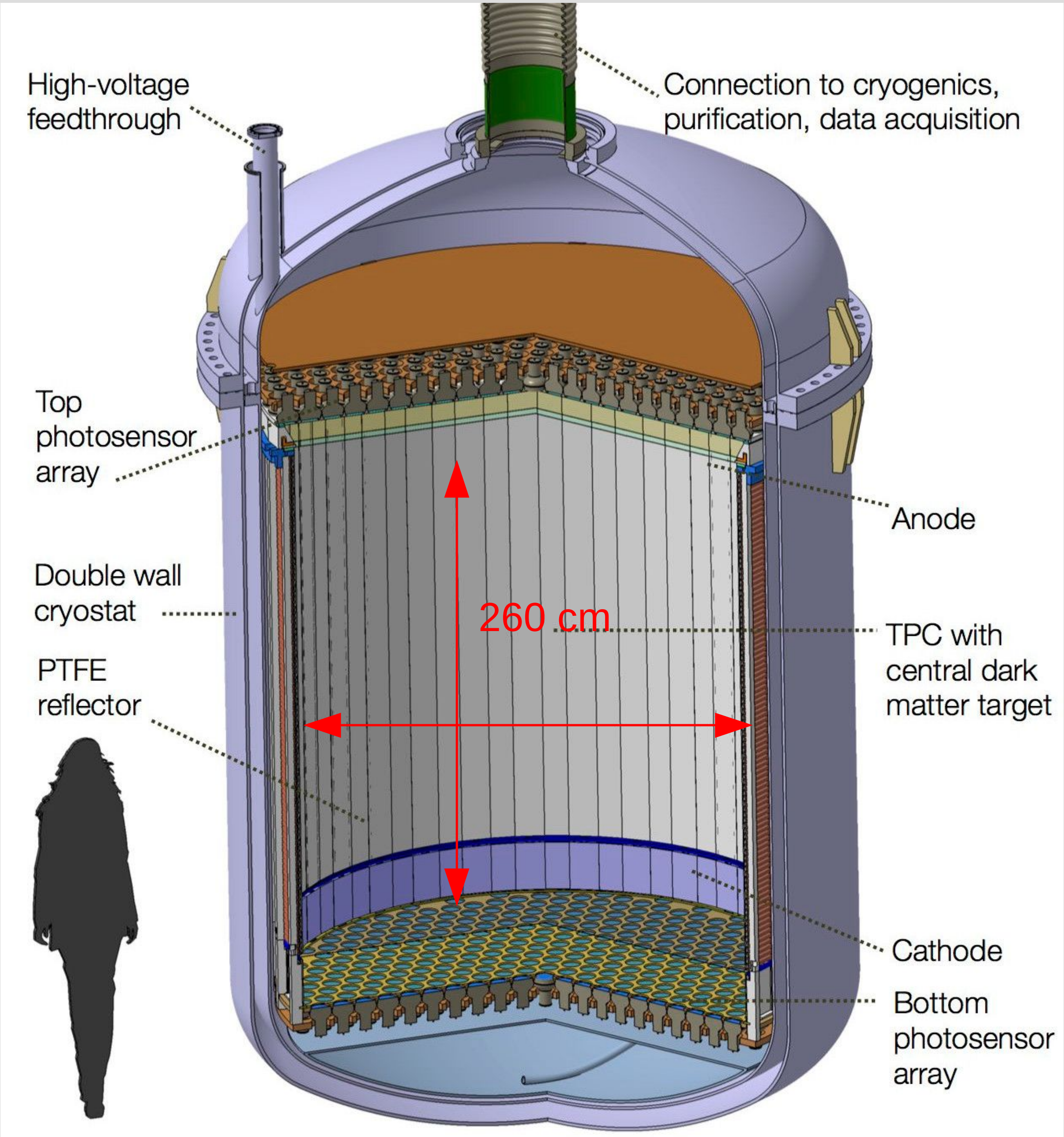
- etc etc

– R&D within XENON collaboration
– **new: two ERC projects**
ULTIMATE (Freiburg)
Xenoscope (Zürich)

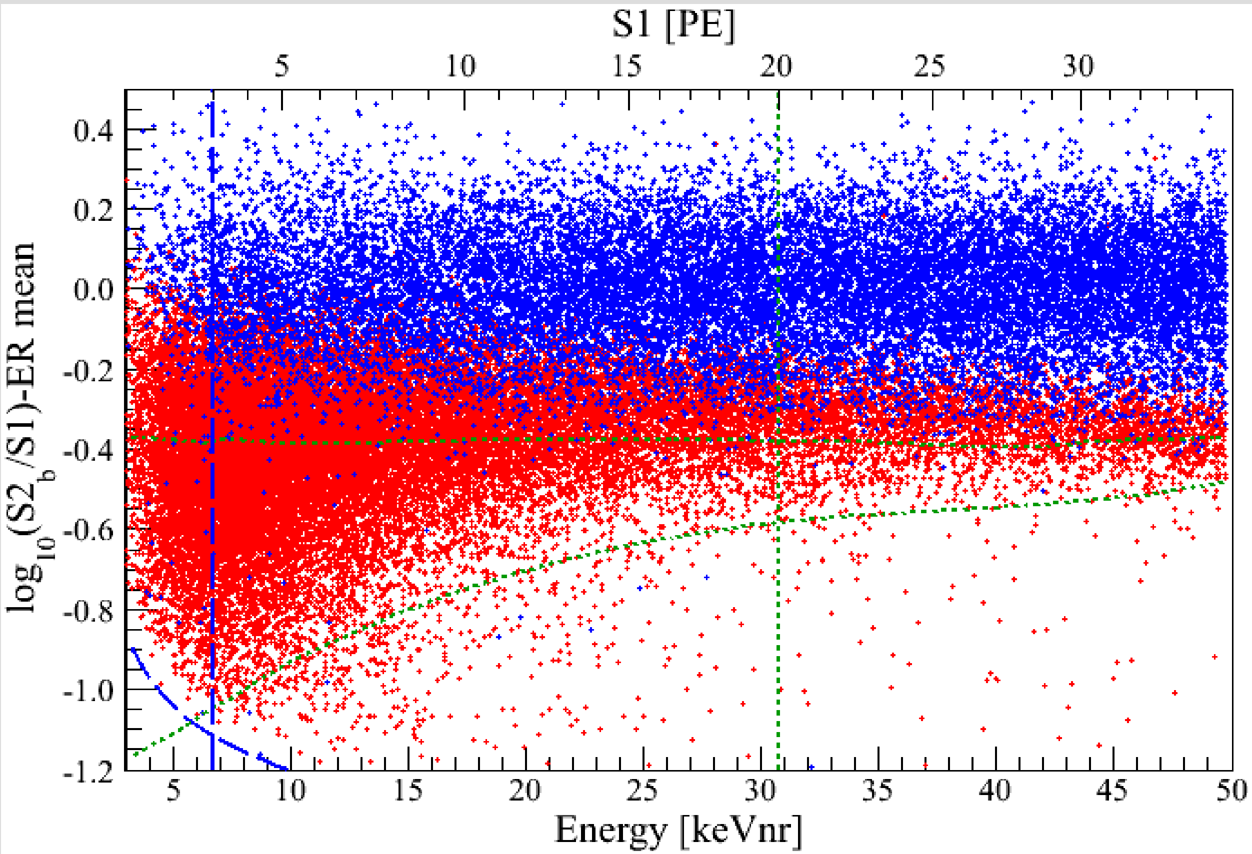
DARWIN The ultimate WIMP Detector



other than WIMPs

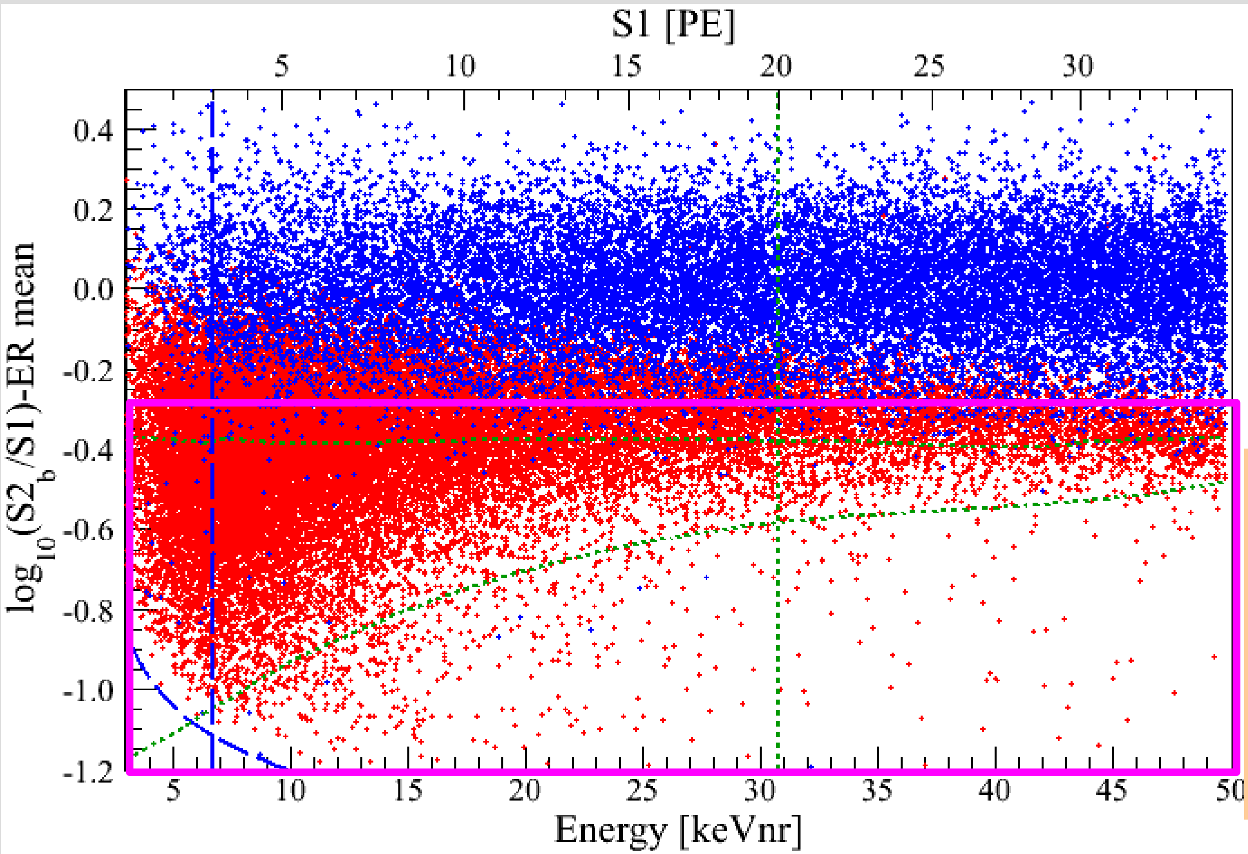
What (else) can we do with these instruments?

Interactions in LXe Detectors



from XENON100

Interactions in LXe Detectors

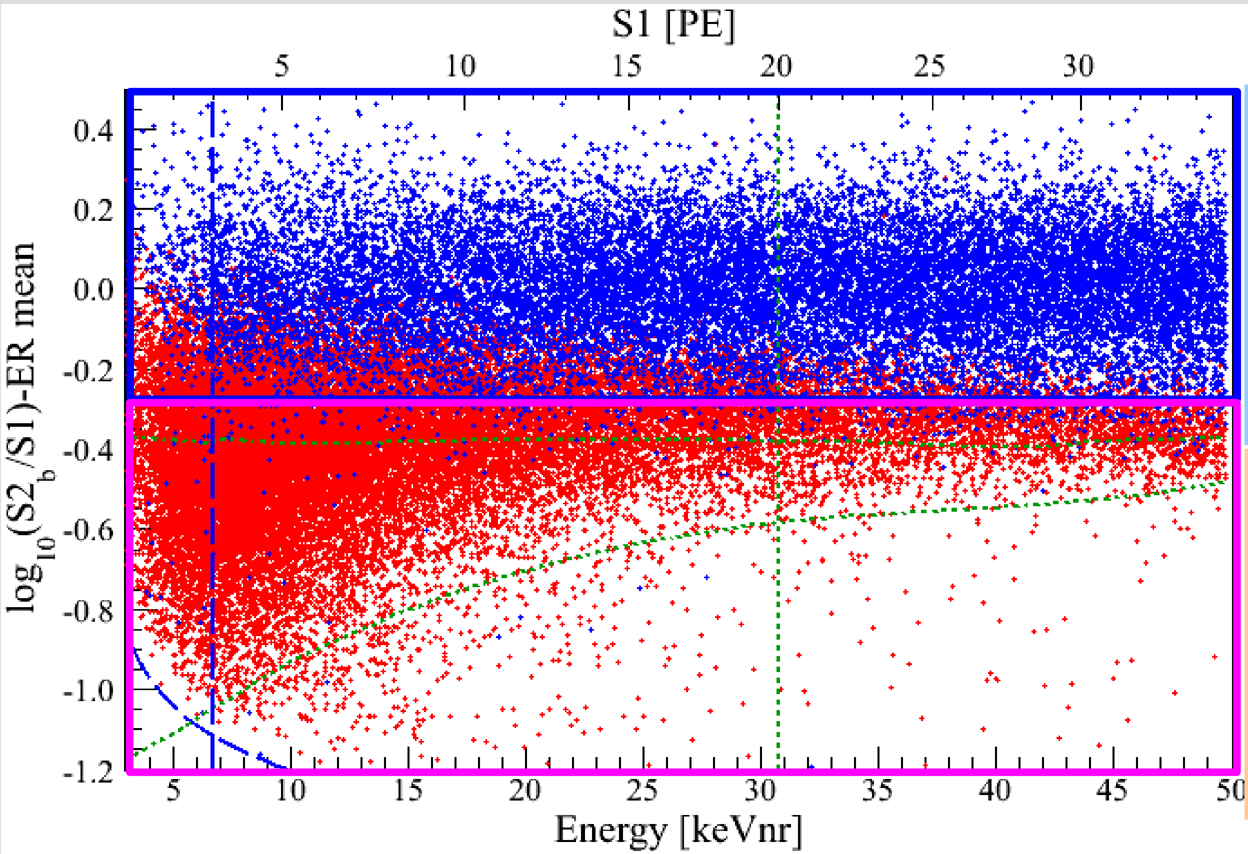


coherent scattering
off xenon nucleus
→ nuclear recoil

- Dark Matter
- CNNS

SM process, not yet measured.
Deviation from expectation
→ new physics?

Interactions in LXe Detectors



scattering off atomic electrons, excitations etc.
→ electronic recoil

- rare processes detectable if ER background is low

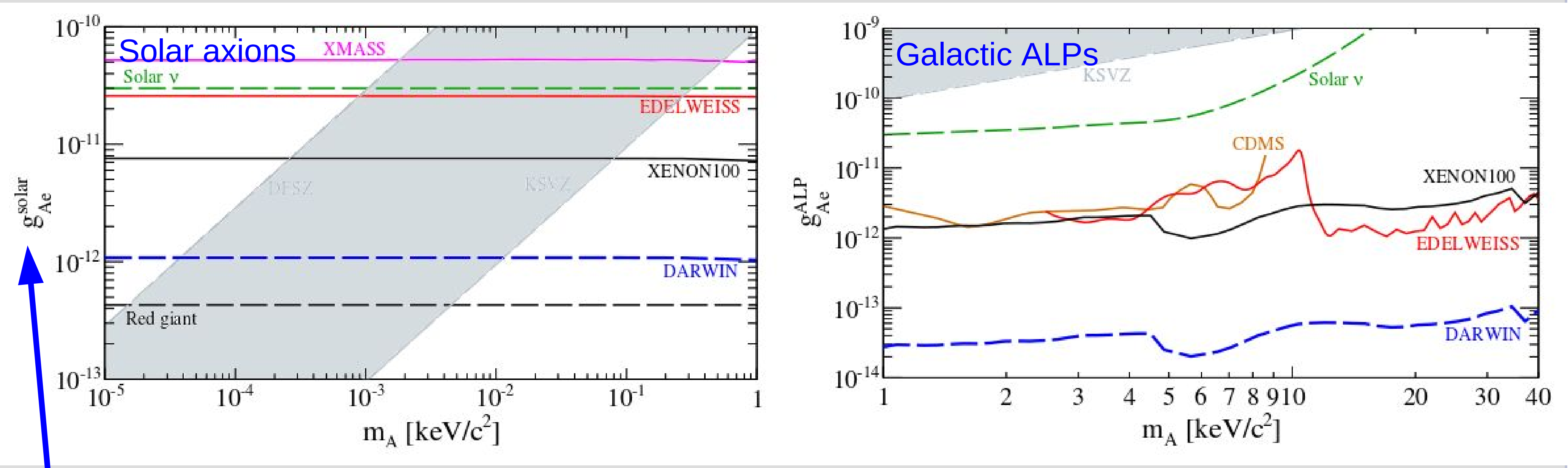
coherent scattering off xenon nucleus
→ nuclear recoil

- Dark Matter
- CNNS

Many **science channels** are accessible with a multi-ton DARWIN detector thanks to its extremly low ER background.

Solar Axions, Dark Matter ALPs

JCAP 11, 017 (2016)



Axions and ALPs couple to xenon via **axio-electric-effect**

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

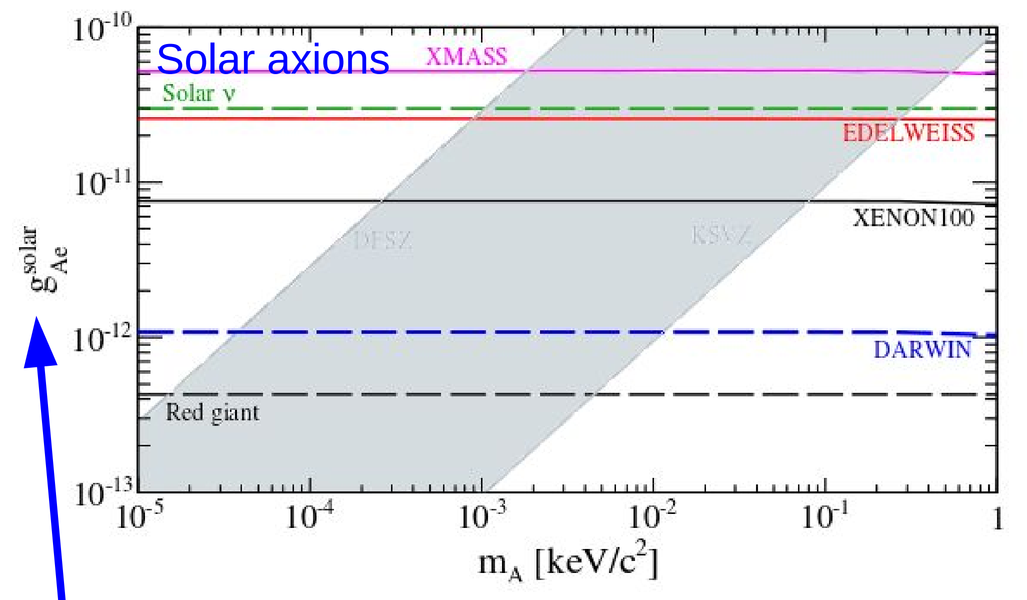
→ axion ionizes a Xe atom

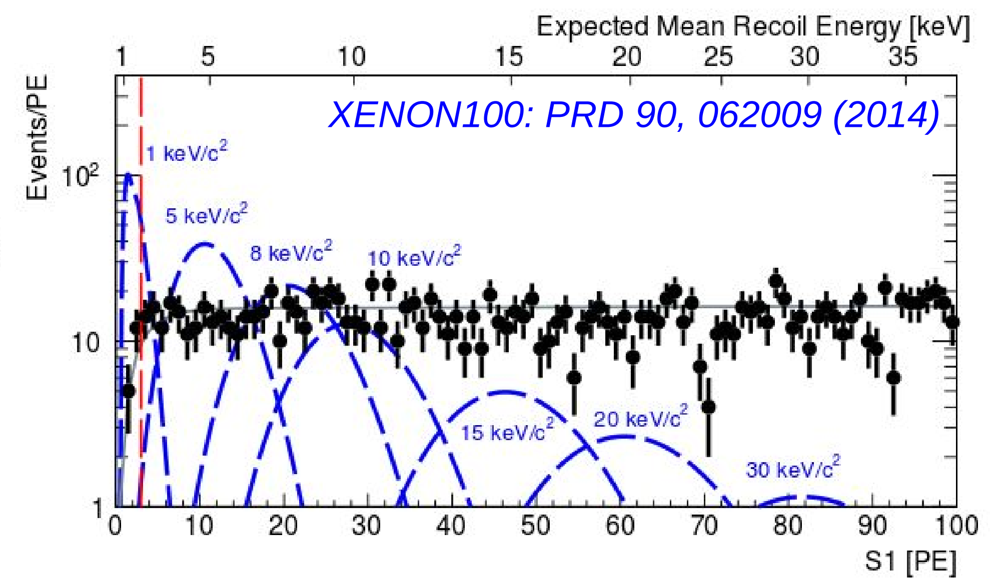
Axion
arises naturally in the Peccei-Quinn solution of the strong CP-problem
→ well-motivated dark matter candidate

Axion-like particle (ALP)
generalization of the axion concept, but without addressing strong CP problem
(ALPs = Nambu-Goldstone bosons from breaking of some global symmetry)

Solar Axions, Dark Matter ALPs

JCAP 11, 017 (2016)





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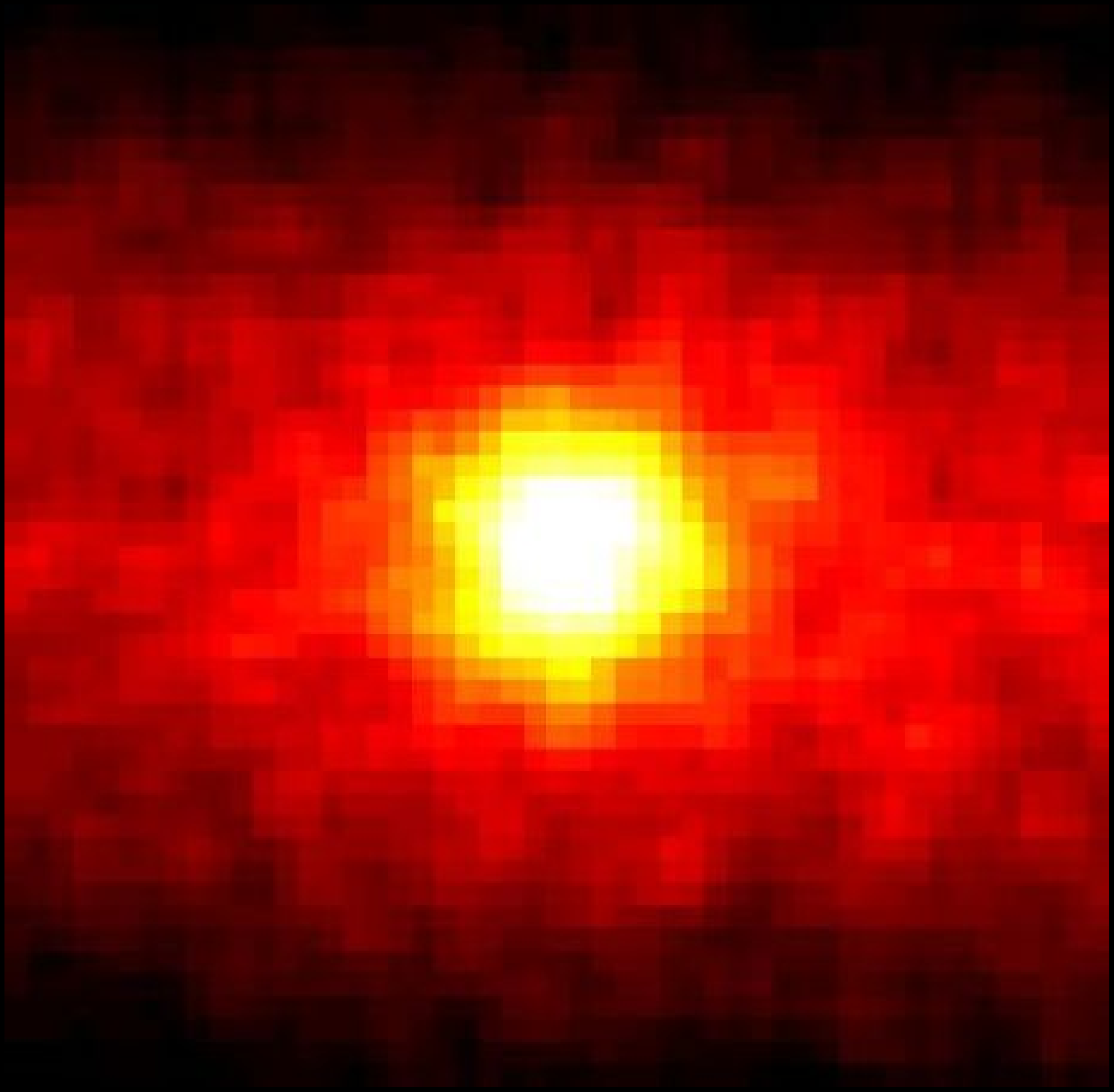
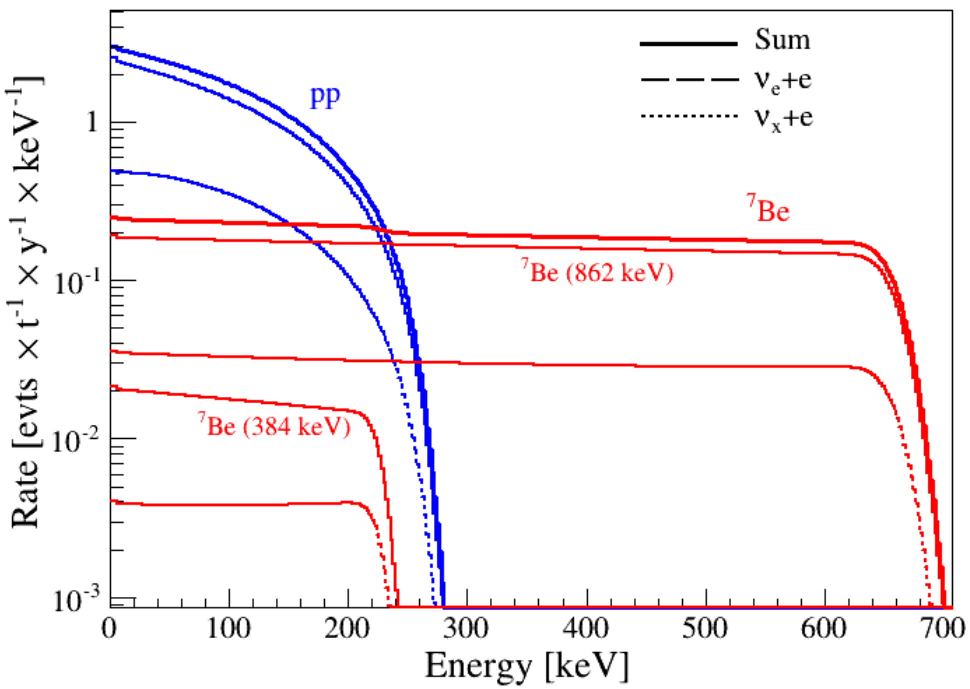
generalization of the axion concept, but without addressing strong CP problem
(ALPs = Nambu-Goldstone bosons from breaking of some global symmetry)



pp-Neutrinos in DARWIN

JCAP 01, 044 (2014)

Differential Recoil Spectrum in Xe



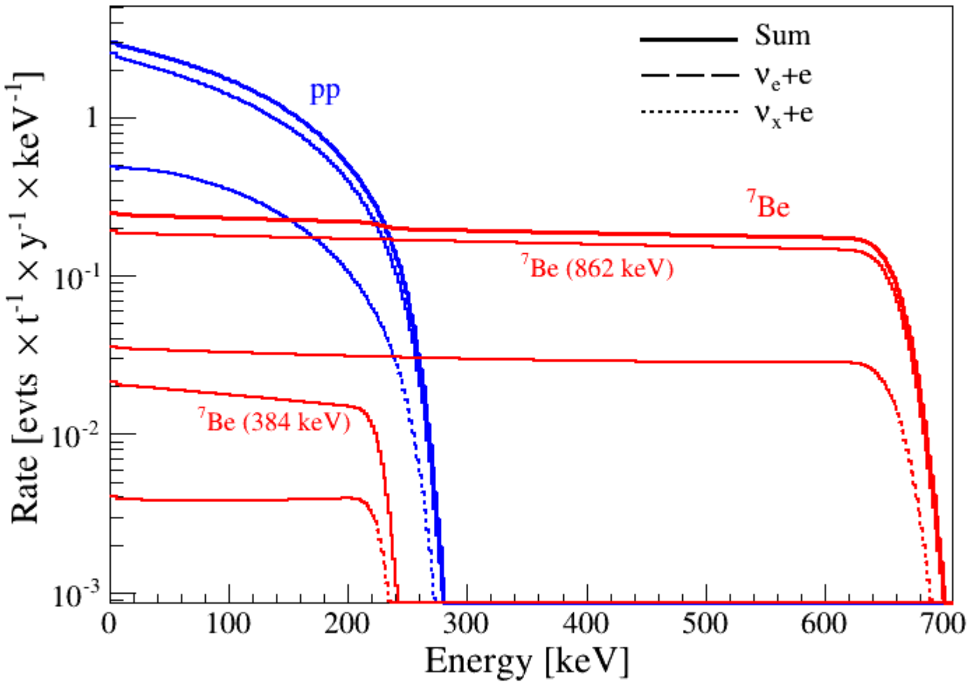
- neutrinos interact with Xe electrons
  → electronic recoil signature
- continuous recoil spectrum
  → largest rate at low E

pp-Neutrinos in DARWIN

a background for the WIMP search

JCAP 11, 017 (2016)

Differential Recoil Spectrum in Xe



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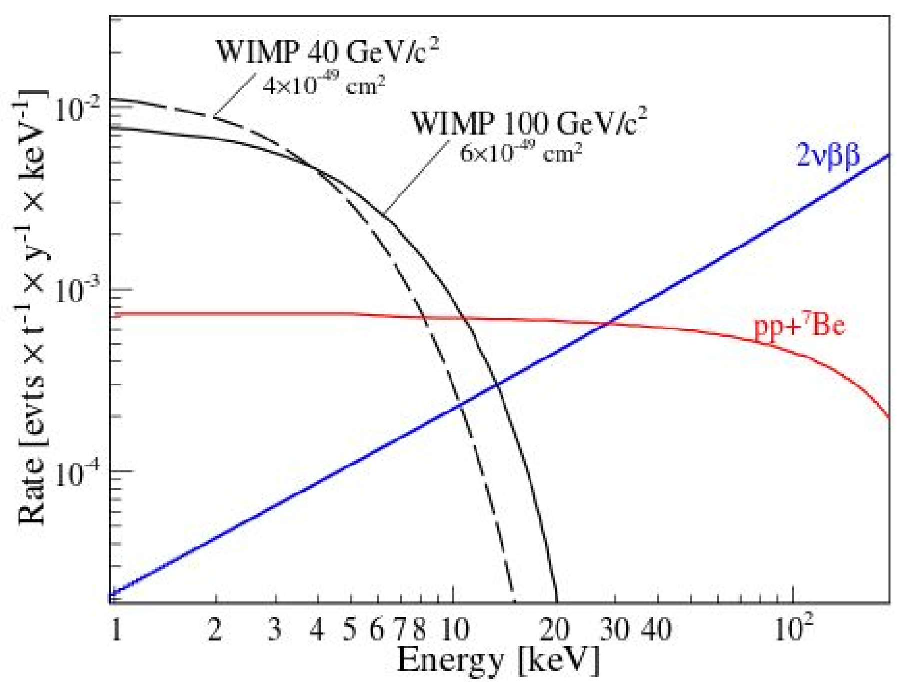
Neutrino interactions



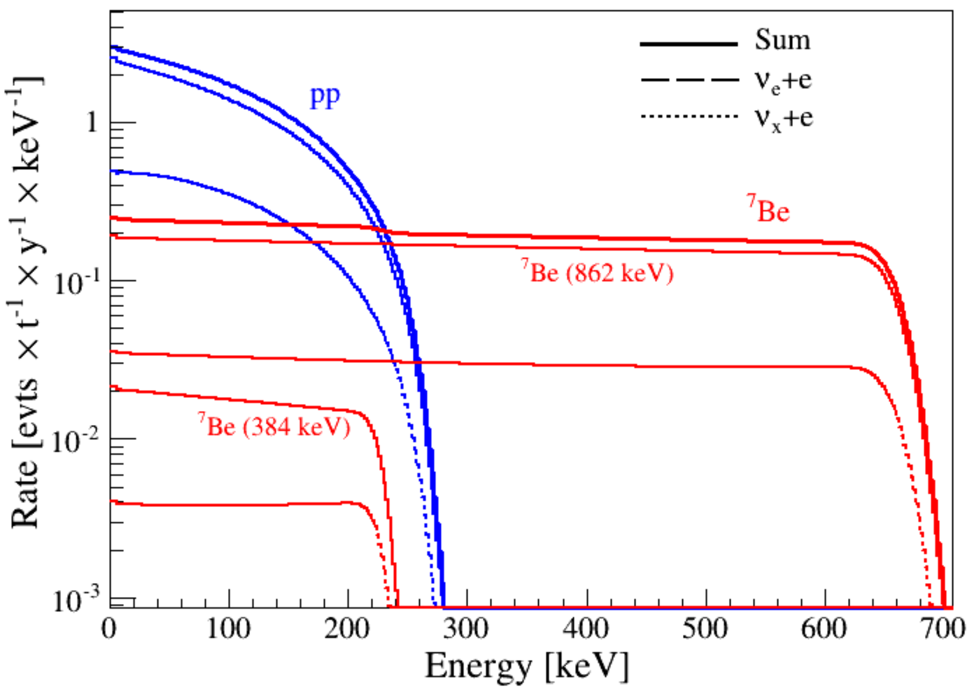
- ER rejection efficiencies ~99.98% at 30% NR efficiency are required to reduce to sub-dominant level

pp-Neutrinos in DARWIN

JCAP 11, 017 (2016)

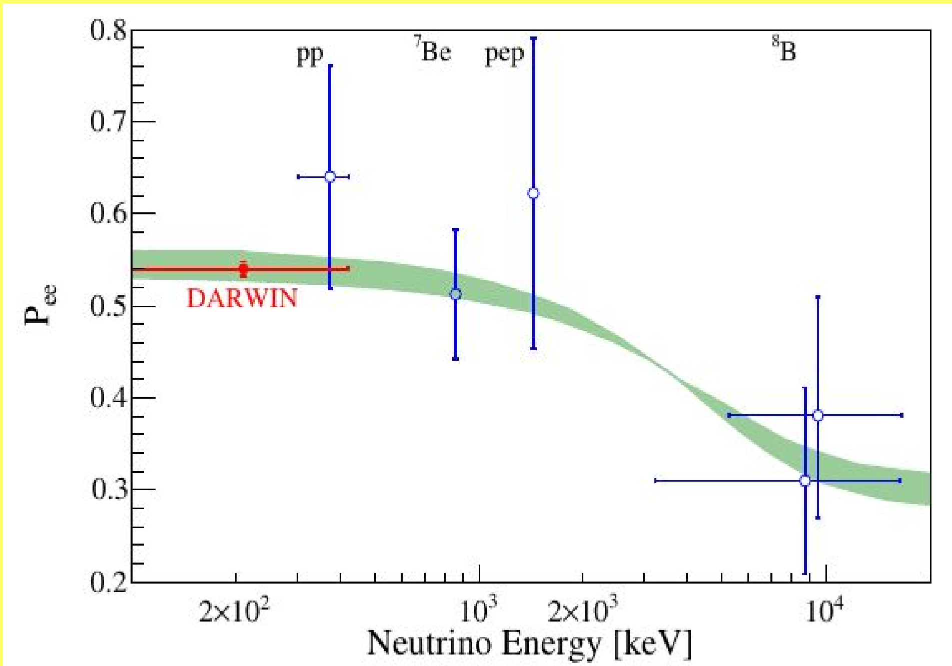
a new physics channel!

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)

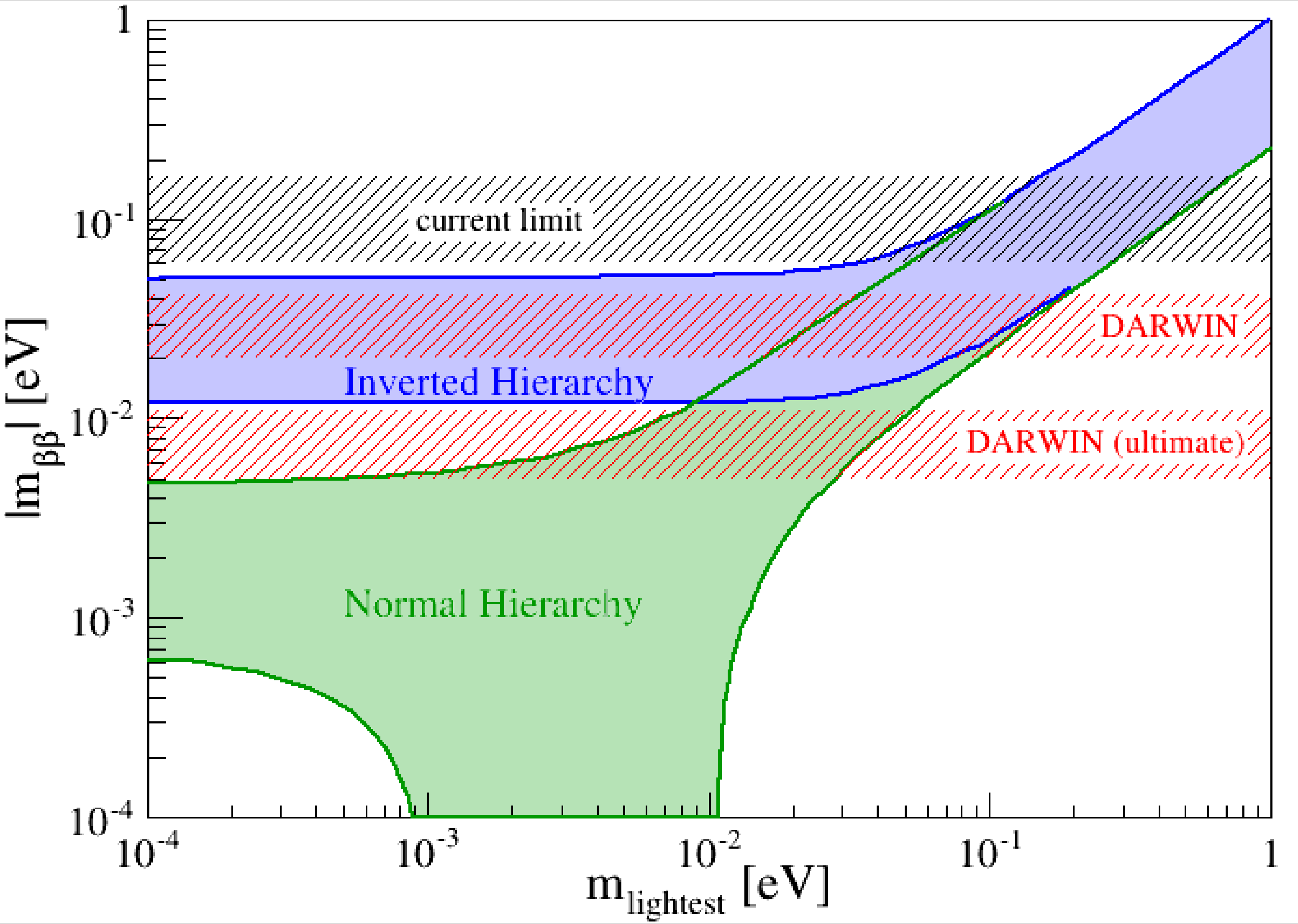
Neutrino interactions



- 30t target mass, 2-30 keV window
  → 2850 neutrinos per year (89% pp)
  → achieve 1% statistical precision on pp-flux (→P_{ee}) with 100 t x y

0ν Double-beta Decay

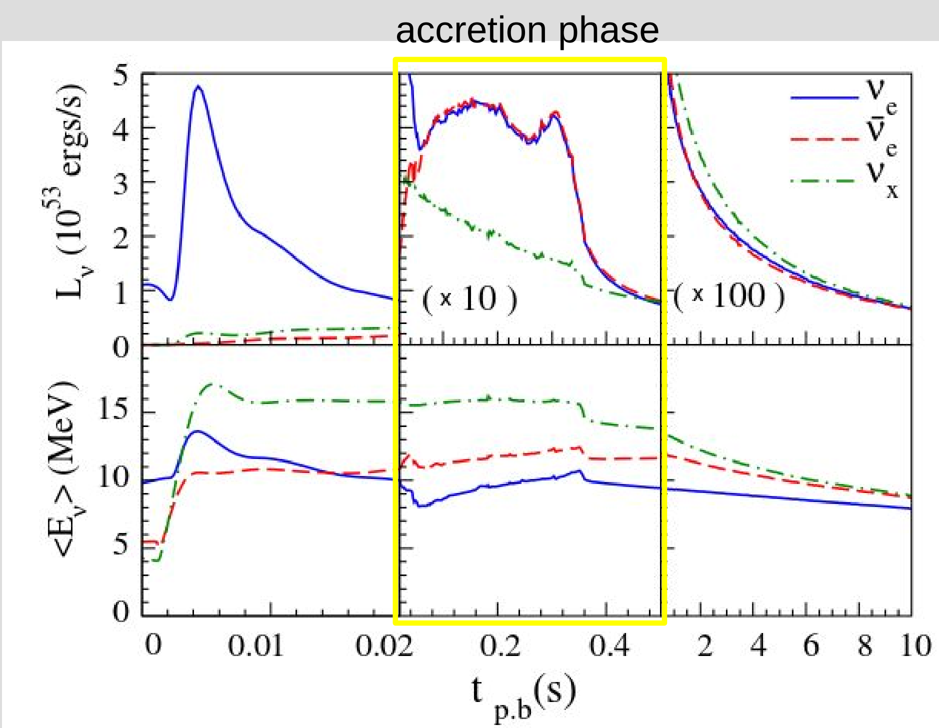
JCAP 11, 017 (2016)

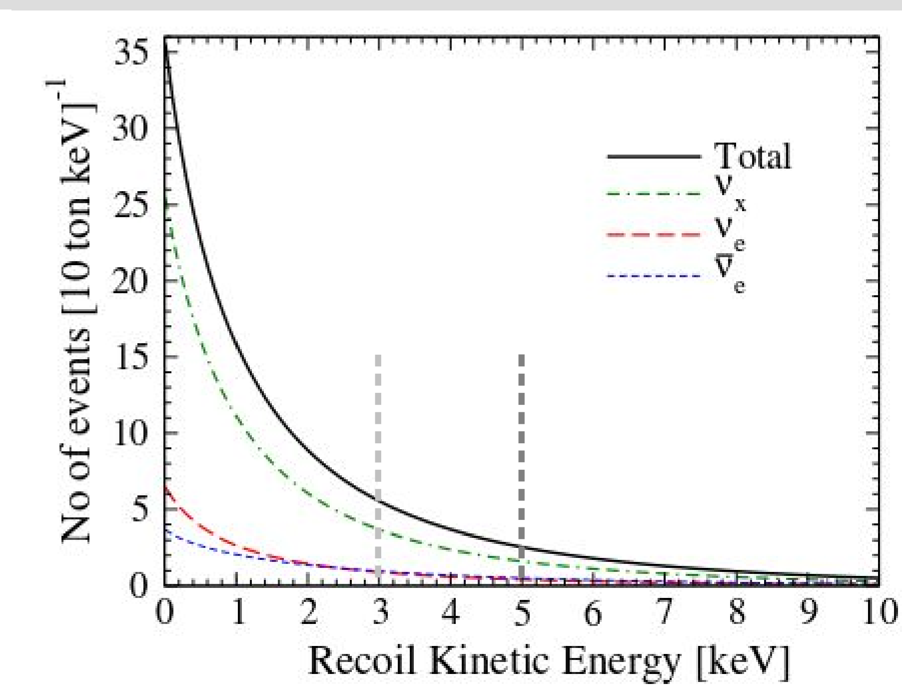


Supernova Neutrinos

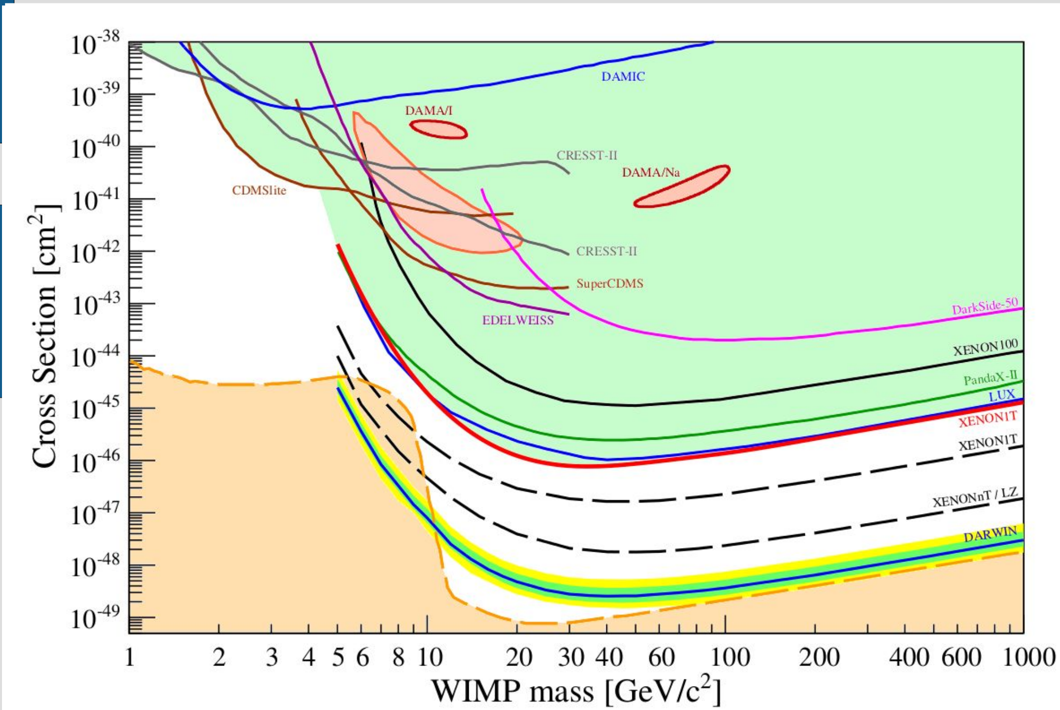
Chakraborty et al., PRD 89, 013011 (2014)
Lang et al., PRD 94, 103009 (2016)

- ν from supernovae could be detected via CNNS as well
- signal fom accretion phase of a ~18 M_{sun} supernova @ 10 kpc is clearly visible in DARWIN
- signal: NRs plus precise time information
- challenge: theshold





DARWIN – exciting prospects



DARWIN

www.darwin-observatory.org

Science with a 40 t LXe TPC

Nuclear Recoil Interactions

WIMP dark matter *JCAP 10, 016 (2015)*

– spin-independent mid/high mass

– spin-dependent

→ complementary with LHC, indirect search

– various inelastic models (χ, n, MiDM, …)

Coherent neutrino-nucleon scattering (CNNS)

– ^{8}B neutrinos (low E), atmospheric (high E)

– supernova neutrinos

PRD 89, 013011 (2014), PRD 94, 103009 (2016)

Electronic Recoil Interactions

Non-WIMP dark matter and neutrino physics

– axions, ALPs *JCAP 1611, 017 (2016)*

– sterile neutrinos

– pp, ^{7}Be: precision flux measurements <1% *JCAP 01, 044 (2014)*

Rare nuclear events

– $0\nu\beta\beta$ (^{136}Xe), $2\nu EC$ (^{134}Xe), ...

JCAP 01, 044 (2014)