DARWIN

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LAUNCH 17
Heidelberg, September 15, 2017

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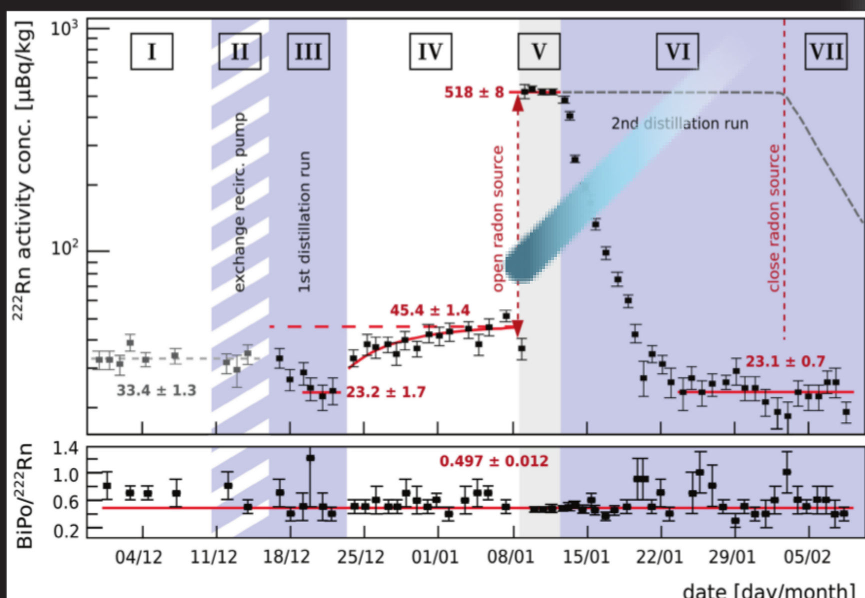
DARWIN



Top panel: Evolution of the ^{222}Rn activity concentration in the XENON100 detector during the purification of xenon from traces of the radioactive noble gas radon using a cryogenic distillation column. The seven different phases (*roman numerals*) show different operational modes of the detector. The *gray dashed line* shows the expected ^{222}Rn concentration in the absence of the radon removal system. *Bottom panel*: Comparison of the ^{222}Rn activity as determined

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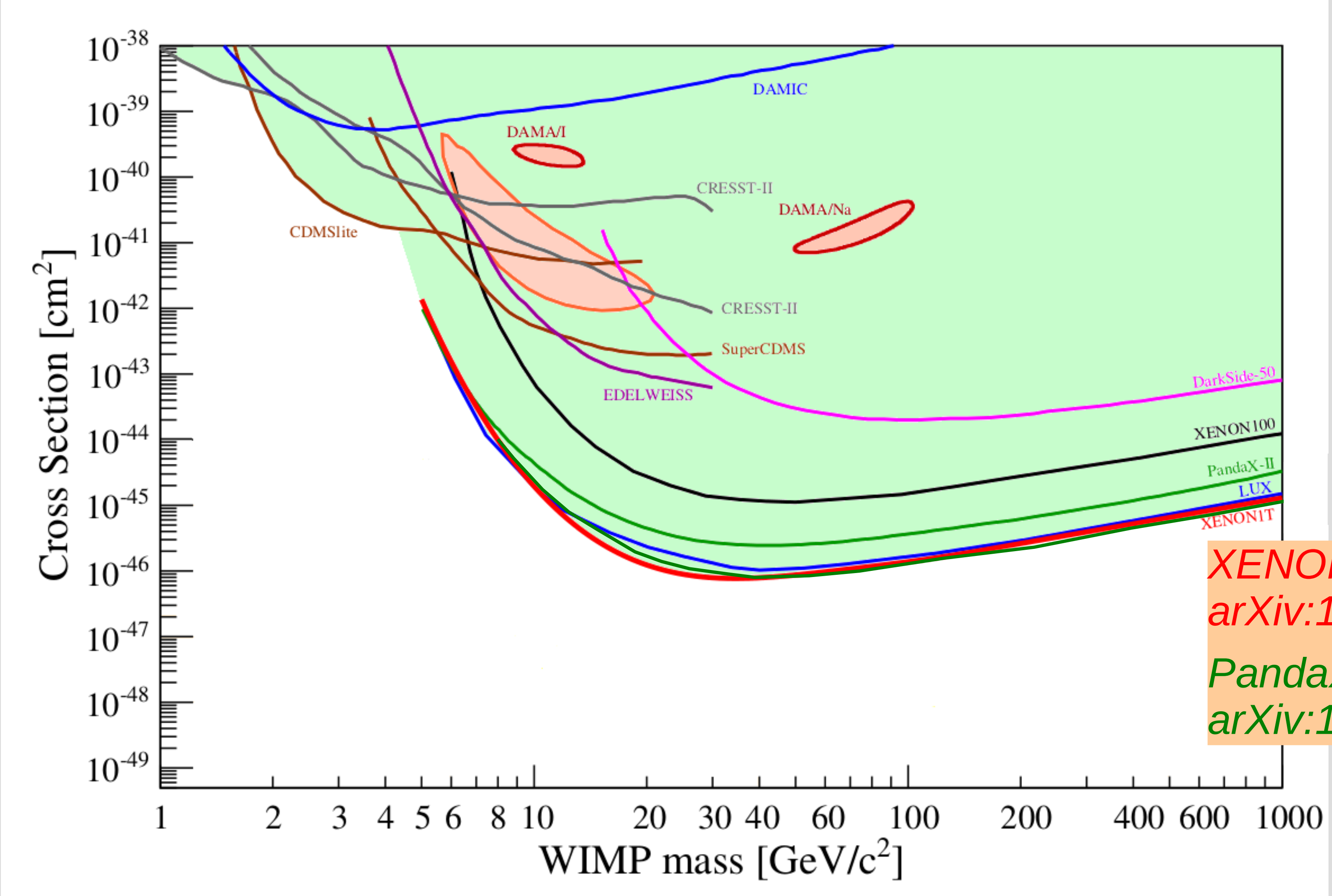
Dark Matter Searches: Status

spin-independent WIMP-nucleon interactions

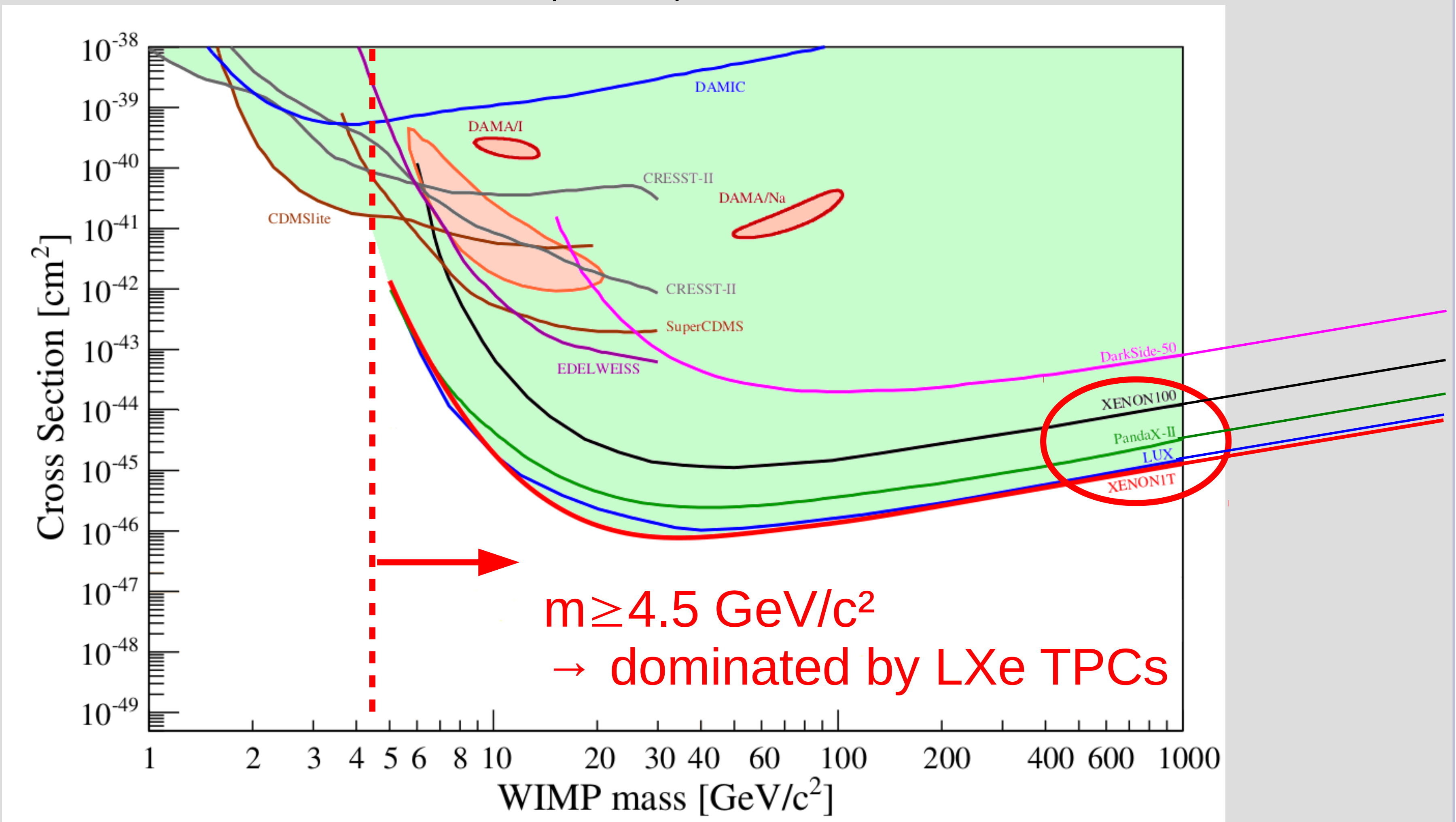


XENON1T arXiv:1705.06655

PandaX-II arXiv:1708.06917

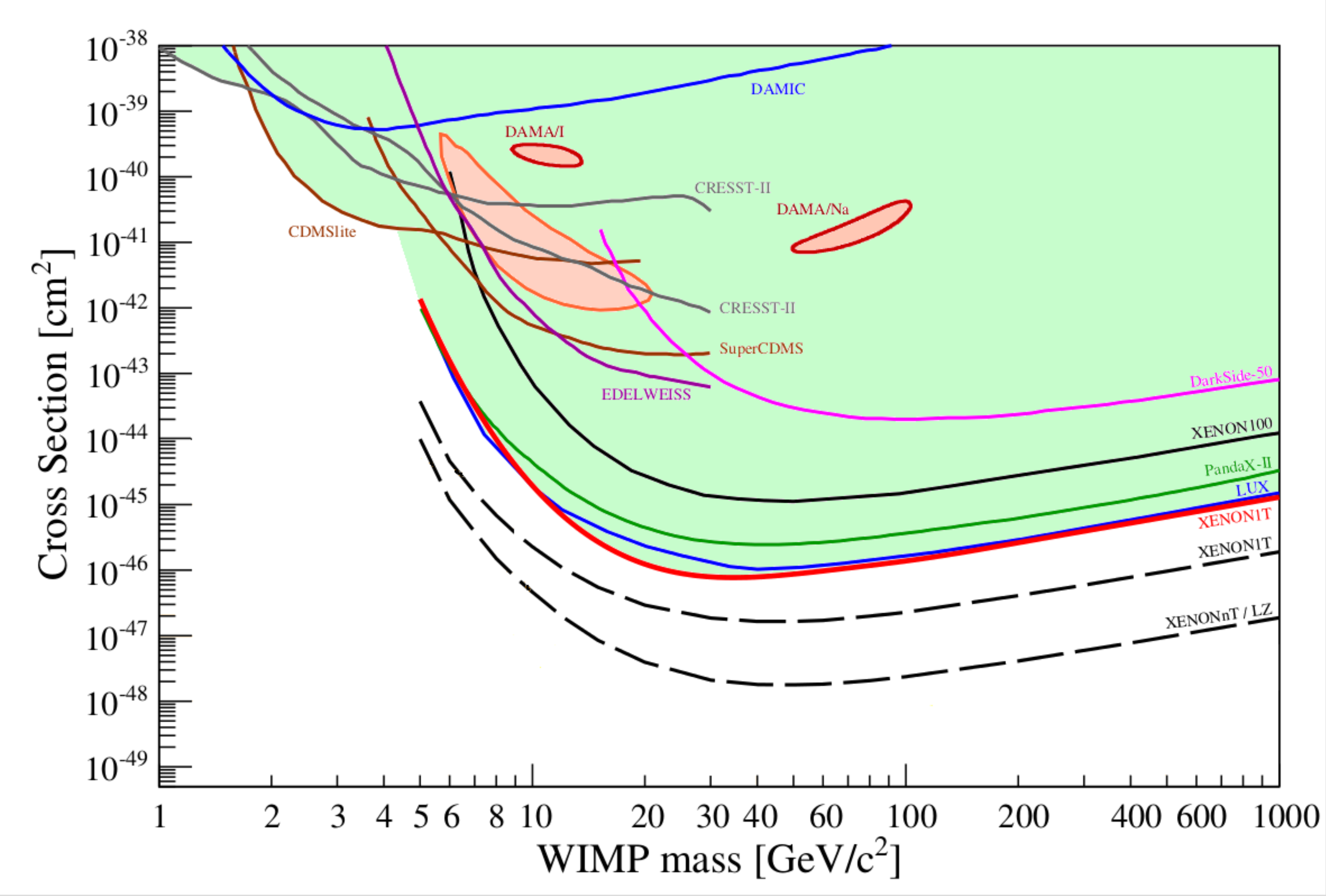
Dark Matter Searches: Status

spin-independent WIMP-nucleon interactions



Dark Matter Searches: The Future

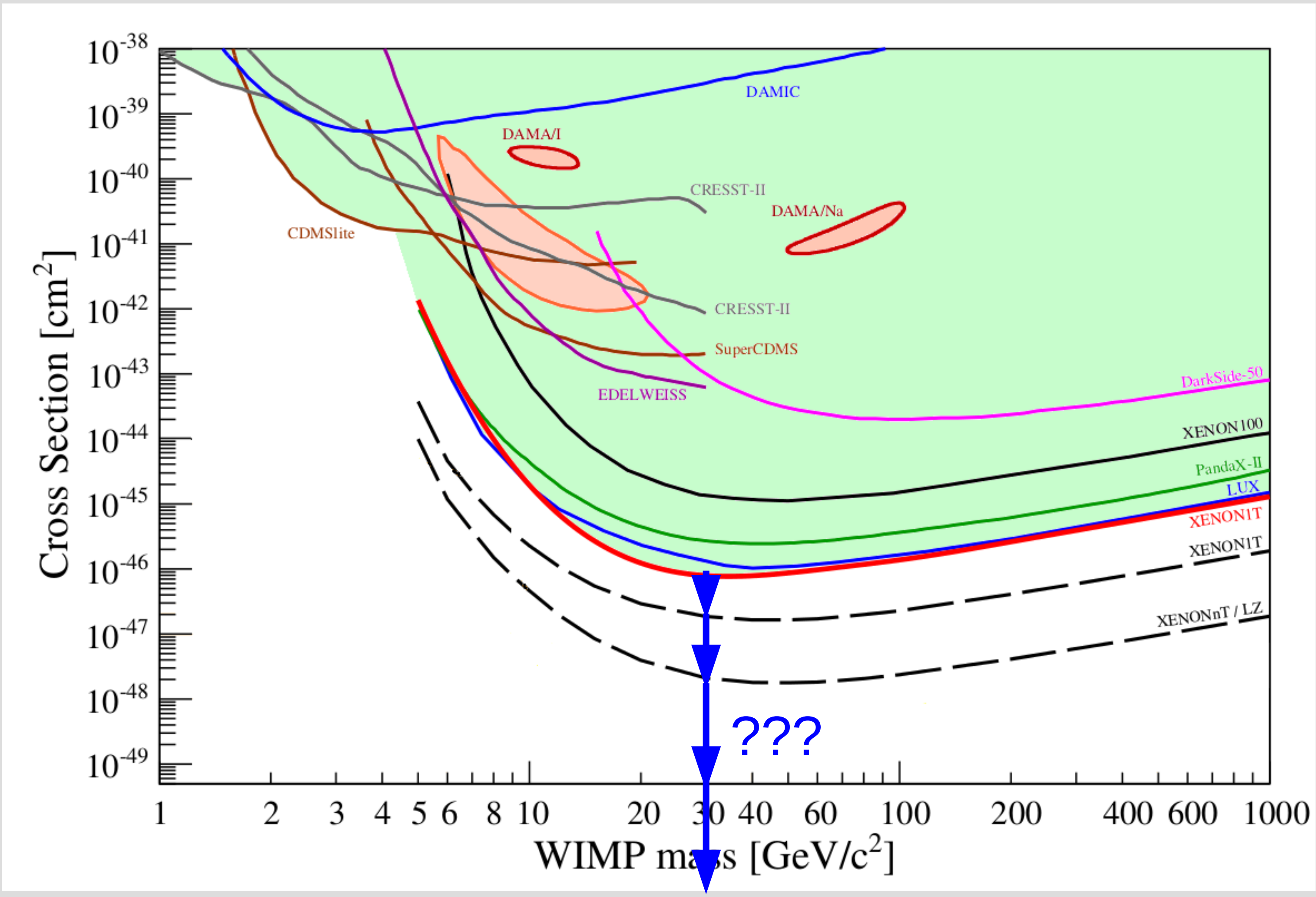
spin-independent WIMP-nucleon interactions



some projects are missing...

Dark Matter Searches: The Future

spin-independent WIMP-nucleon interactions



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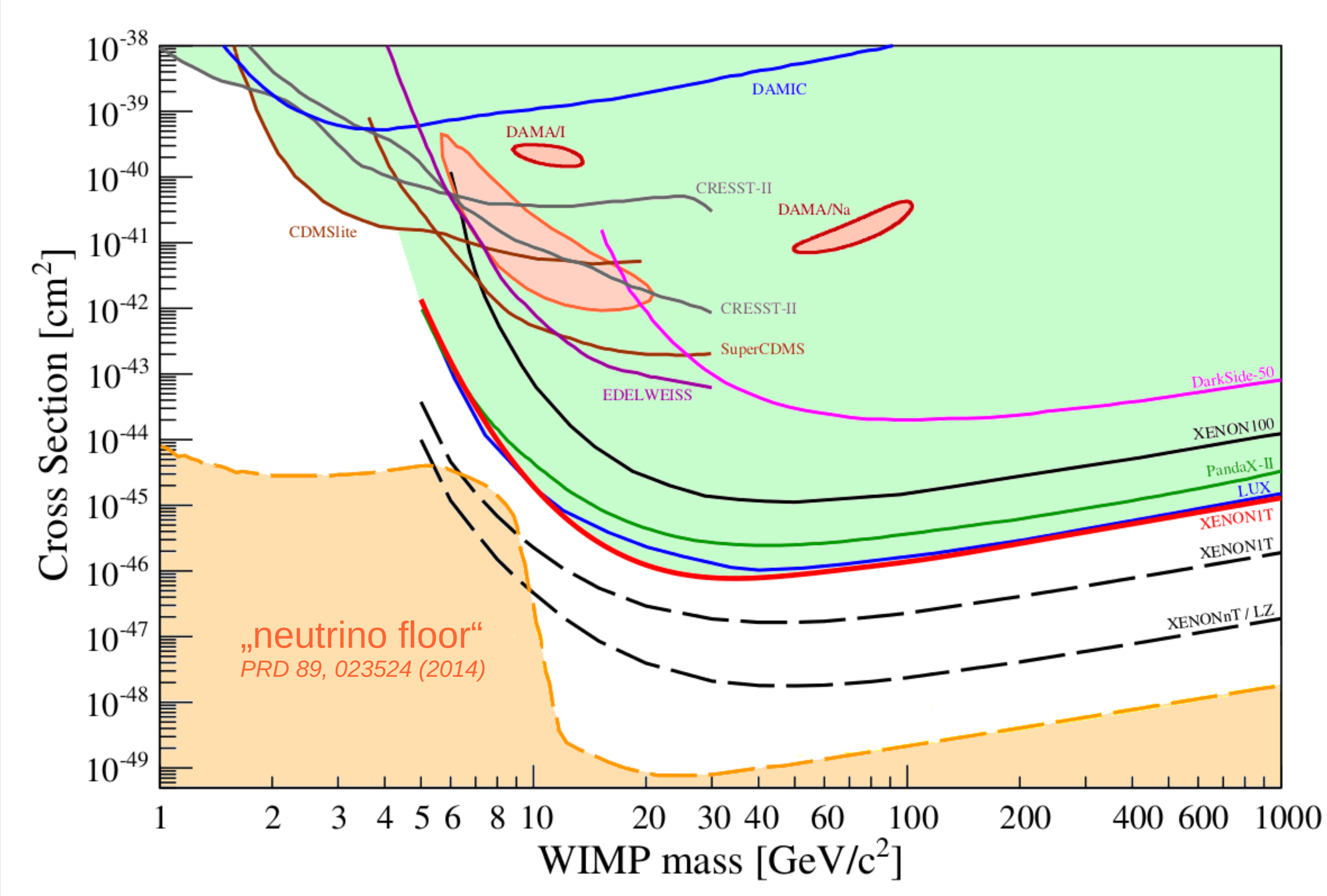
Dark Matter Searches: The Limit

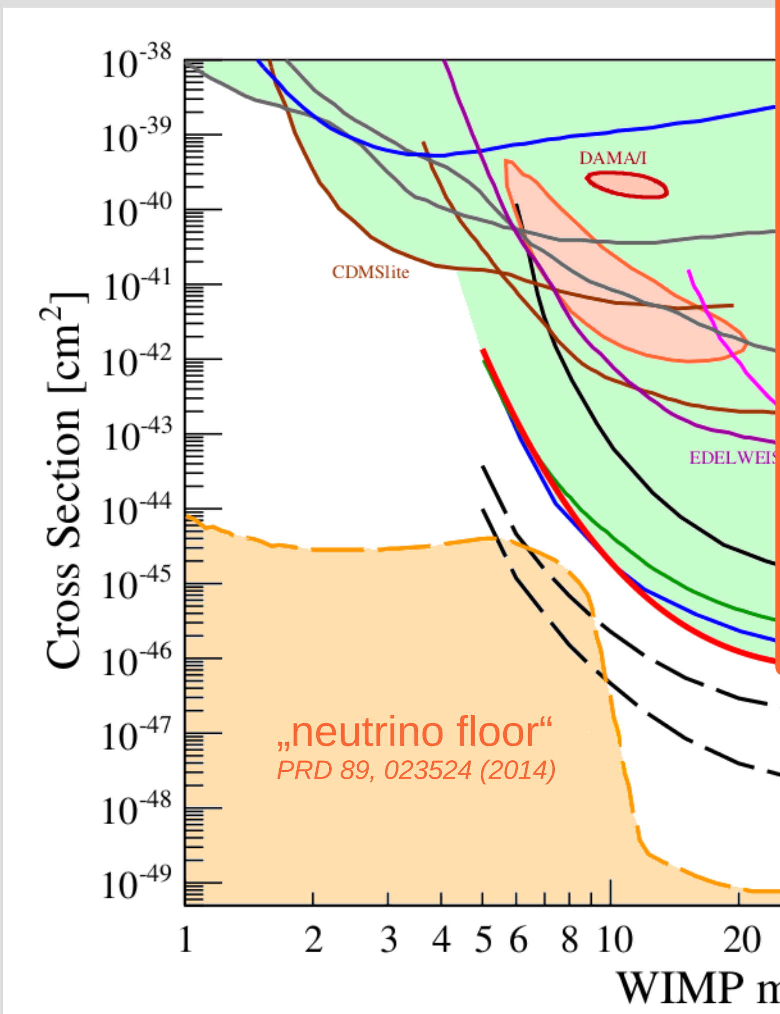
spin-independent WIMP-nucleon interactions

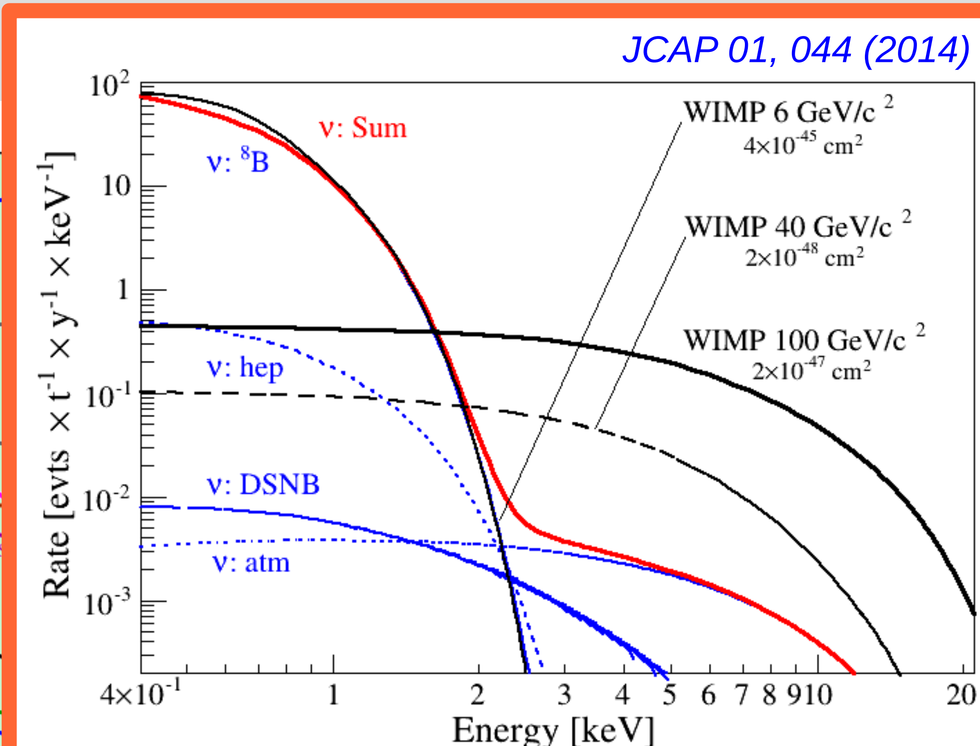


some projects are missing...

Dark Matter Searches: The Limit

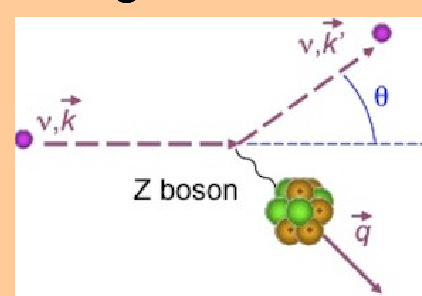
spin-i



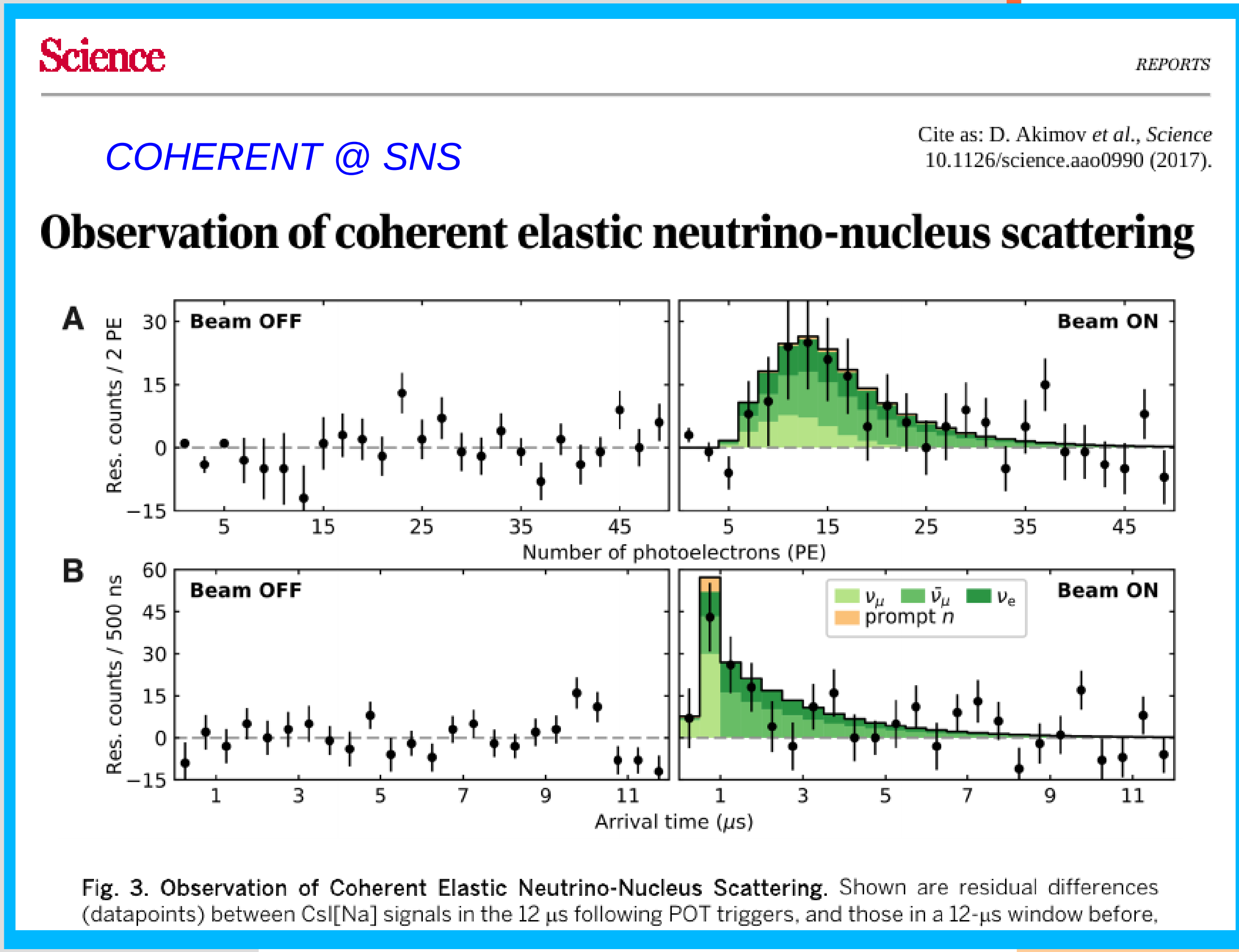


Interactions from coherent neutrino-nucleus scattering (CNNS) will dominate

→ **ultimate background** for direct detection

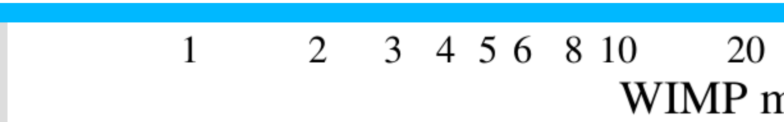


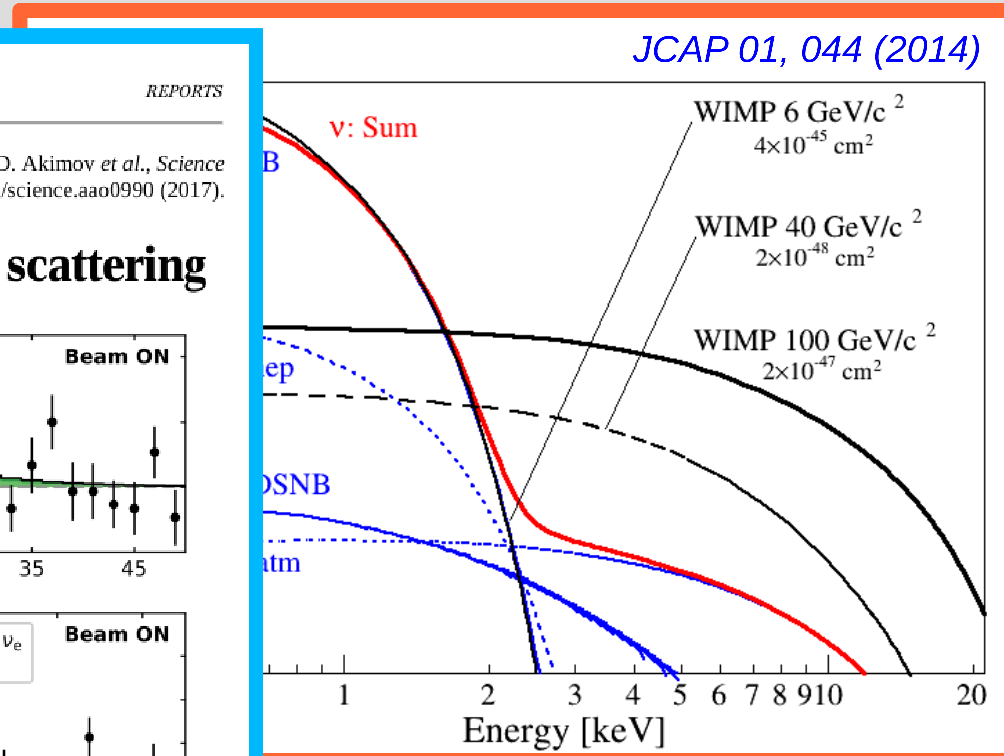
Dark Matter Searches: The Limit



Observation of coherent elastic neutrino-nucleus scattering

Fig. 3. Observation of Coherent Elastic Neutrino-Nucleus Scattering. Shown are residual differences (datapoints) between CsI[Na] signals in the 12 μs following POT triggers, and those in a 12-μs window before,





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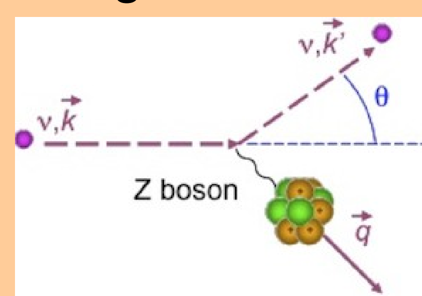
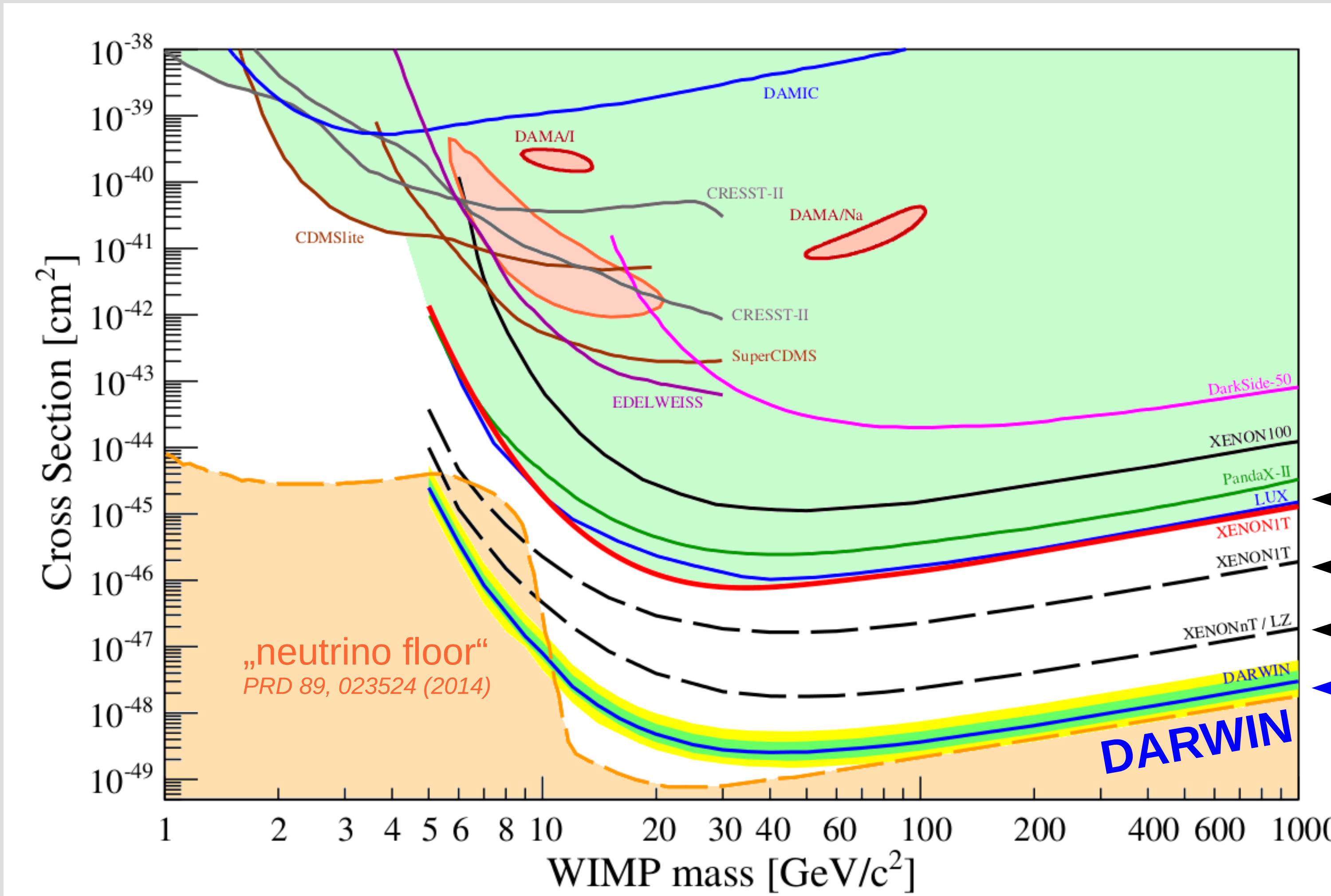


DARWIN The **ultimate** WIMP Detector

spin-independent WIMP-nucleon interactions



Exposure

0.1 t×y

2 t×y

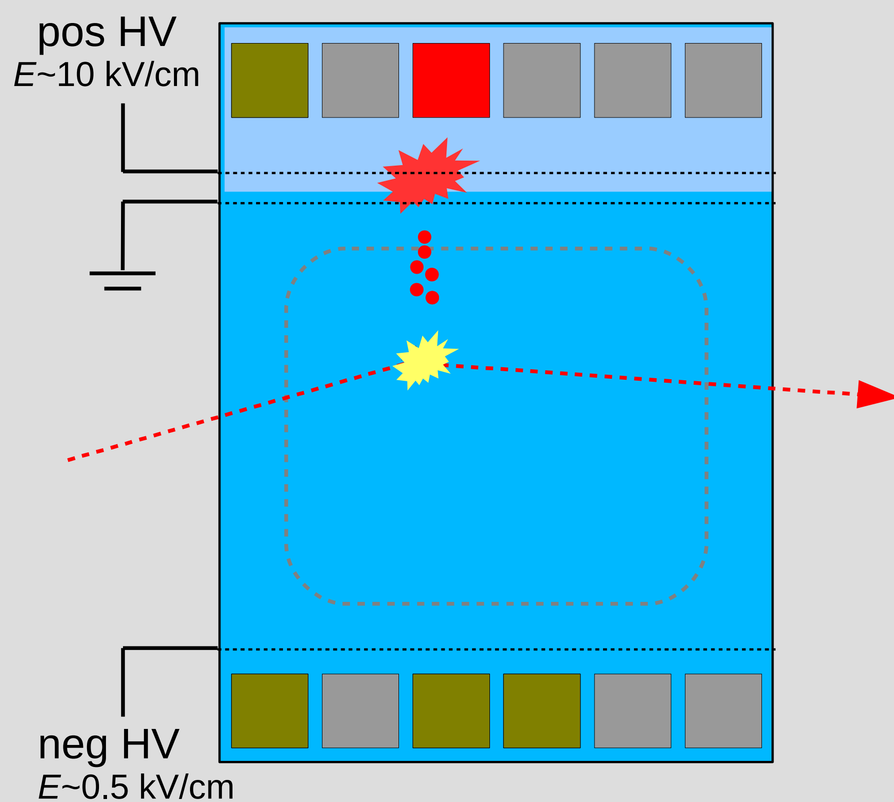
20 t×y

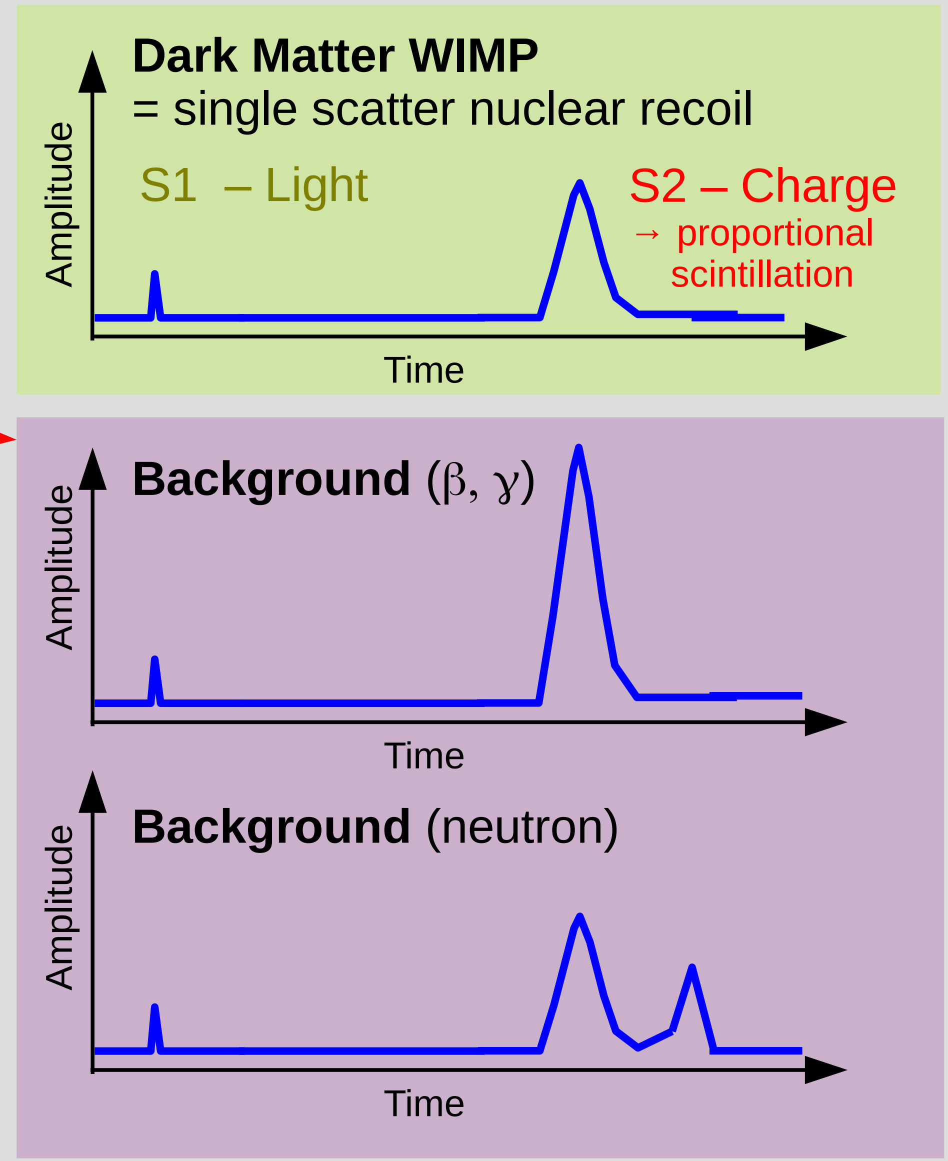
200 t×y

some projects are missing...

Detector? – Dual Phase Xenon TPC

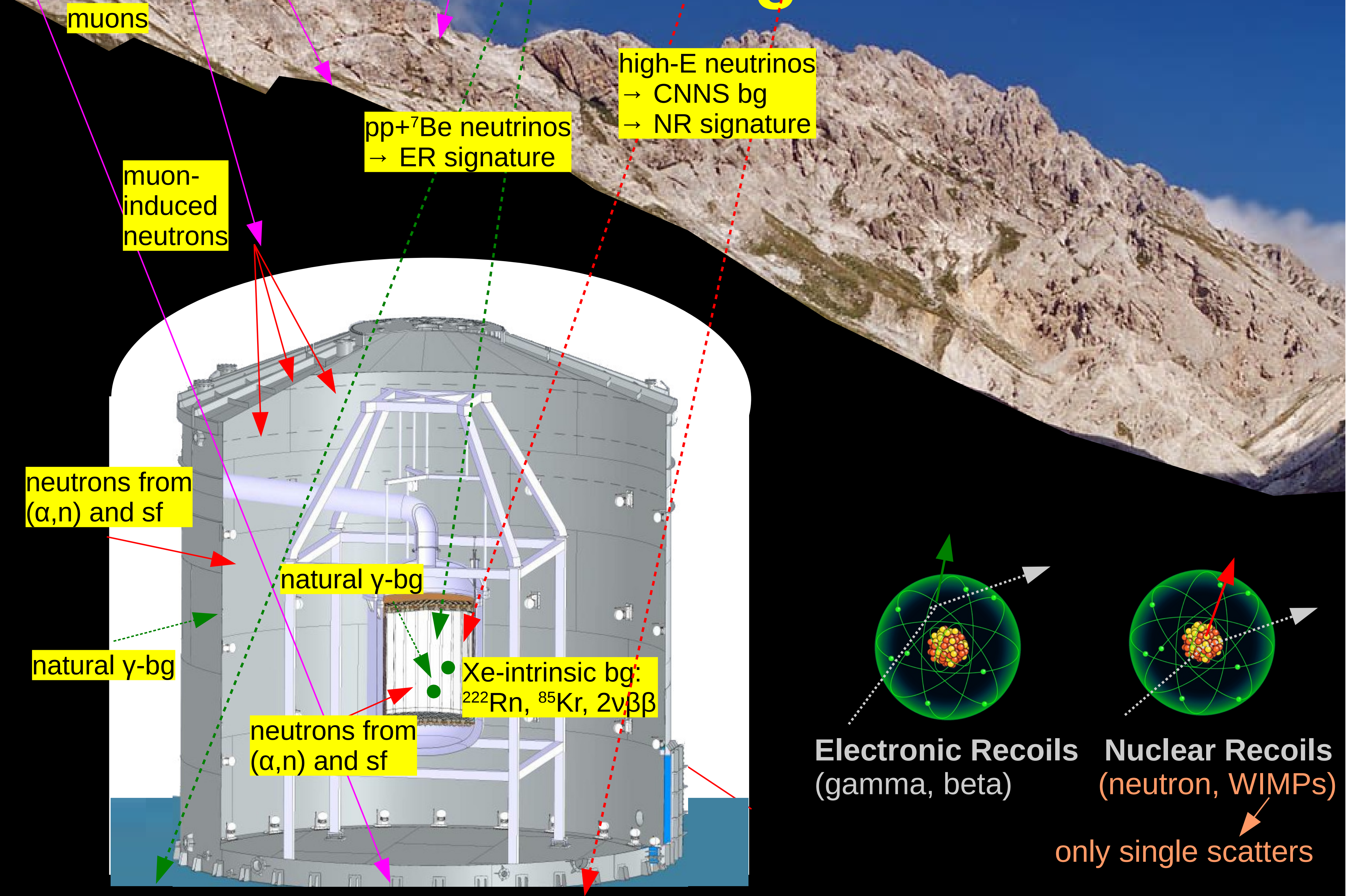
TPC = Time Projection Chamber



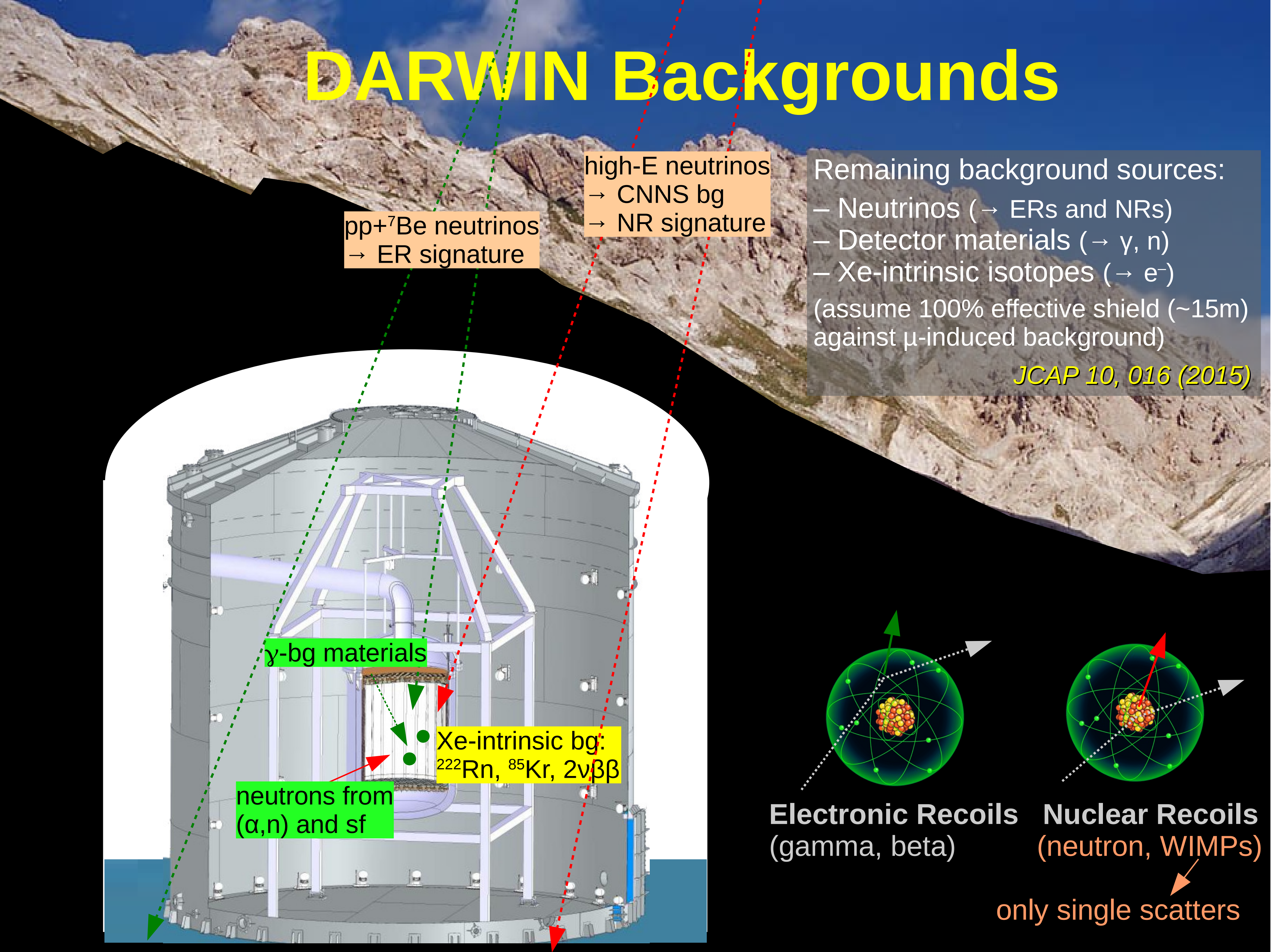


- 3d position reconstruction
  → target fiducialization
- background rejection

Background Sources



DARWIN Backgrounds



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

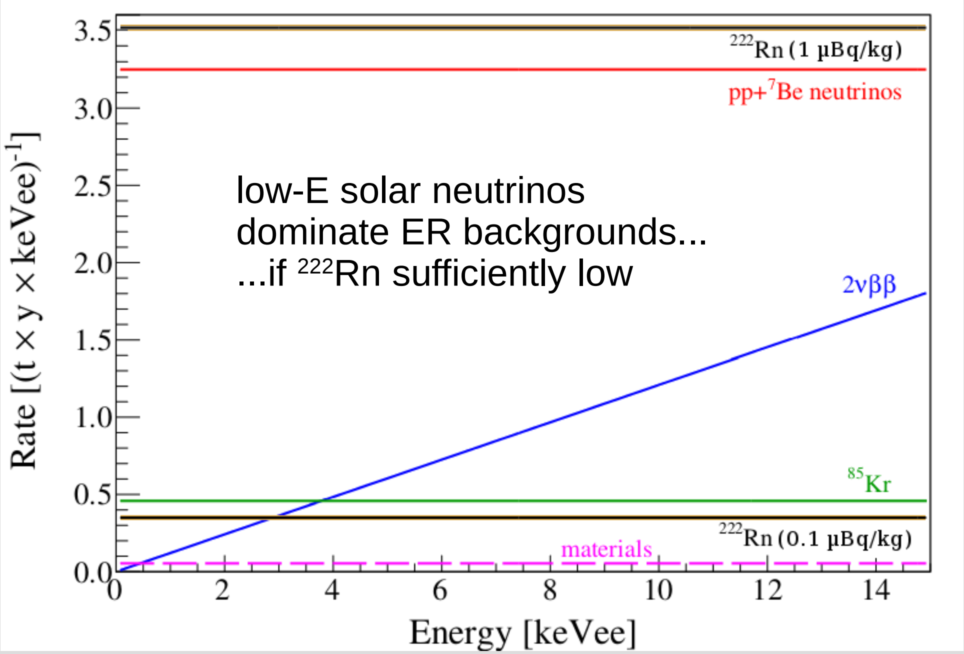
MC simulation of detector made of main components (PTFE, CU, PMTs): subdominant after ~15 cm fiducial cut

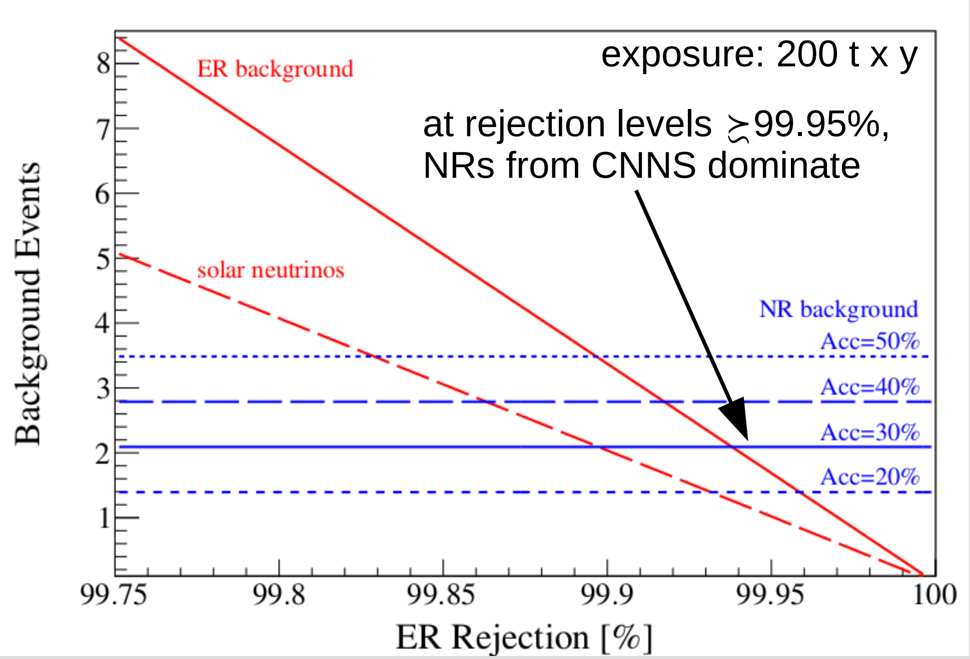
^{85}Kr: 2x below XENON1T design
(0.03 ppt achieved: *EPJ C 74 (2014) 2746*)

^{222}Rn: 100x below XENON1T design

^{136}Xe: assume natural xenon

consider all relevant neutrinos





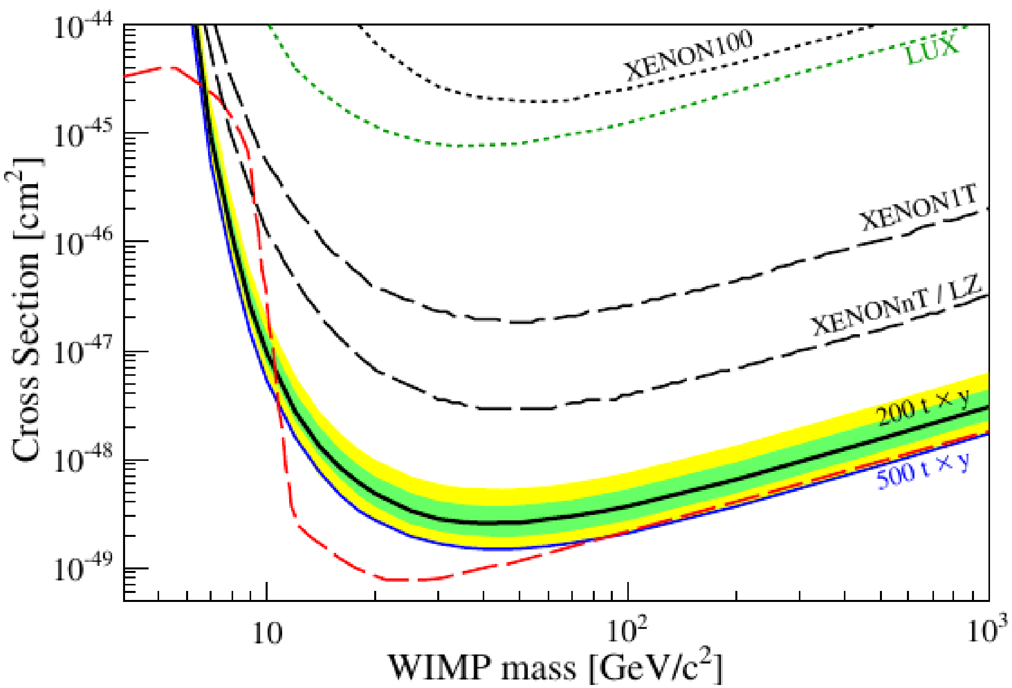
DARWIN WIMP Sensitivity

DARWIN

JCAP 10, 016 (2015)

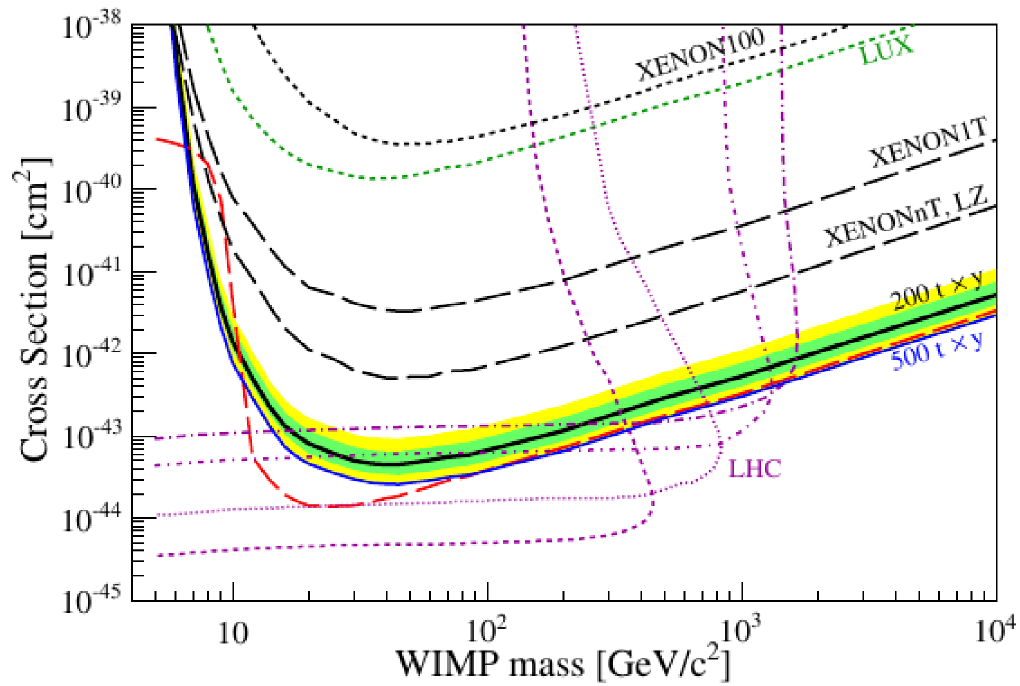
- exposure: 200 t × y; **all backgrounds included**
- likelihood analysis
- 99.98% ER rejection @ 30% NR acceptance,
  S1+S2 combined energy scale, LY=8 PE/keV, 5-35 keV_{nr} energy window

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).

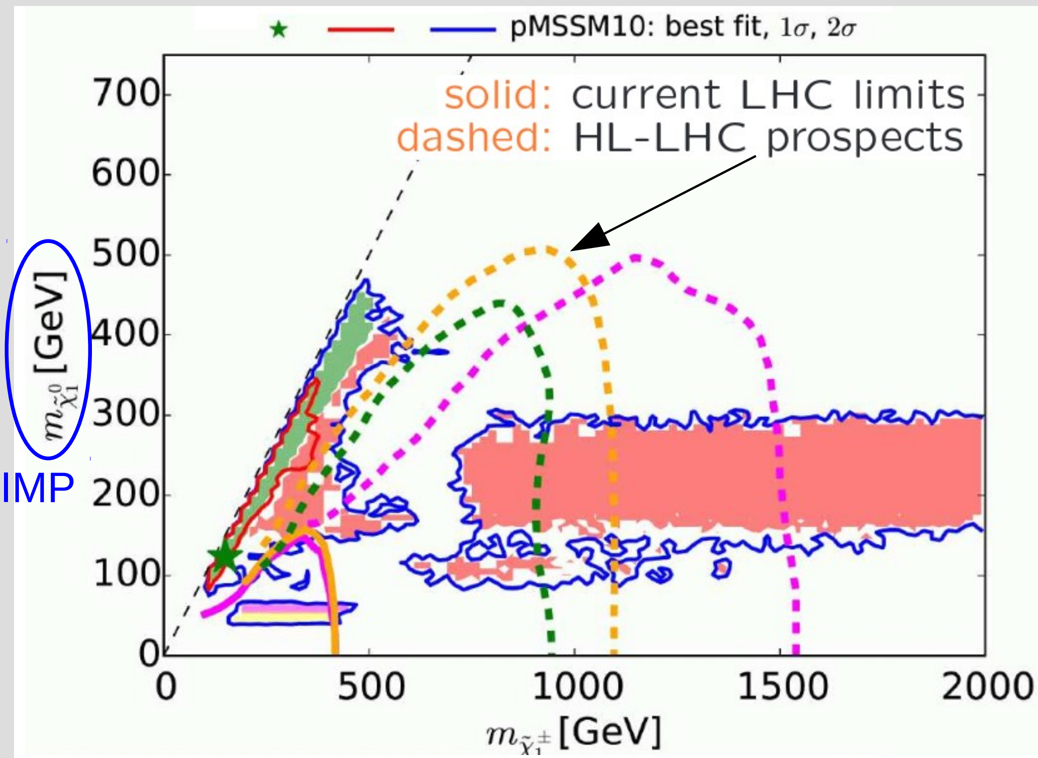
SUSY Dark Matter

plots: Sven Heinemeyer (MasterCode 2015)

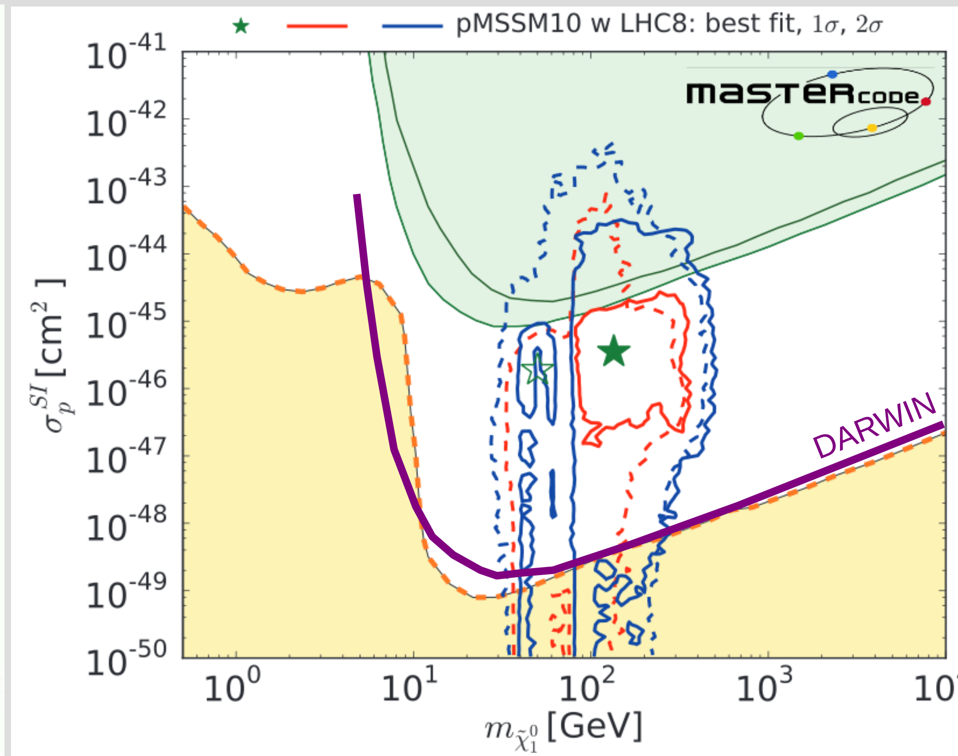
SUSY under pressure because not found at LHC?
→ true for some very constraint models (CMSSM etc.) but looks different when more parameters are left unconstrained

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

WIMP



$m_{neutralino} \approx m_{chargino}$



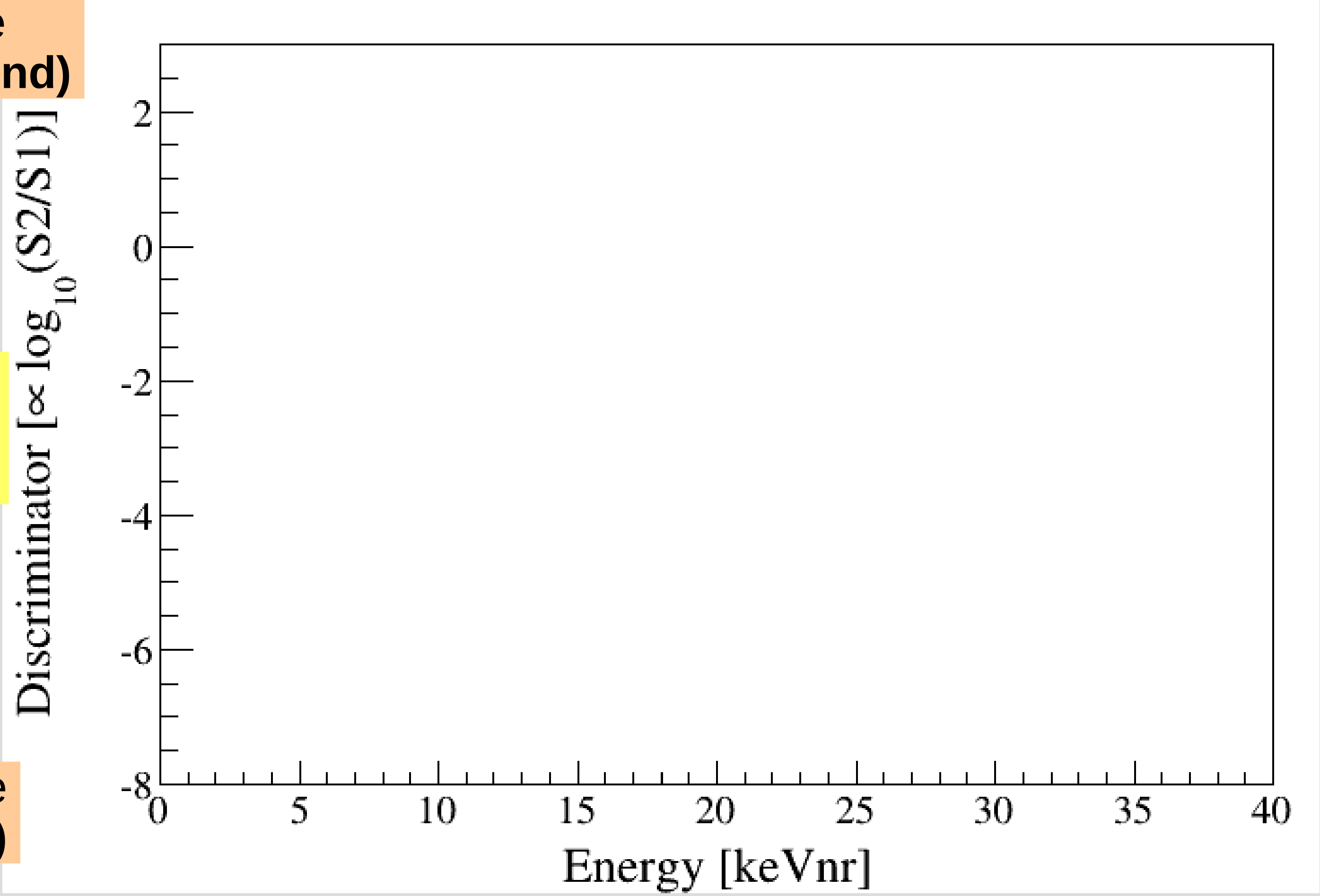
WIMP out of reach of HL-LHC (best-fit regions not covered), but accessible by DARWIN

WIMP Detection

ER-like
(background)

discrimination variable;
based on S2/S1

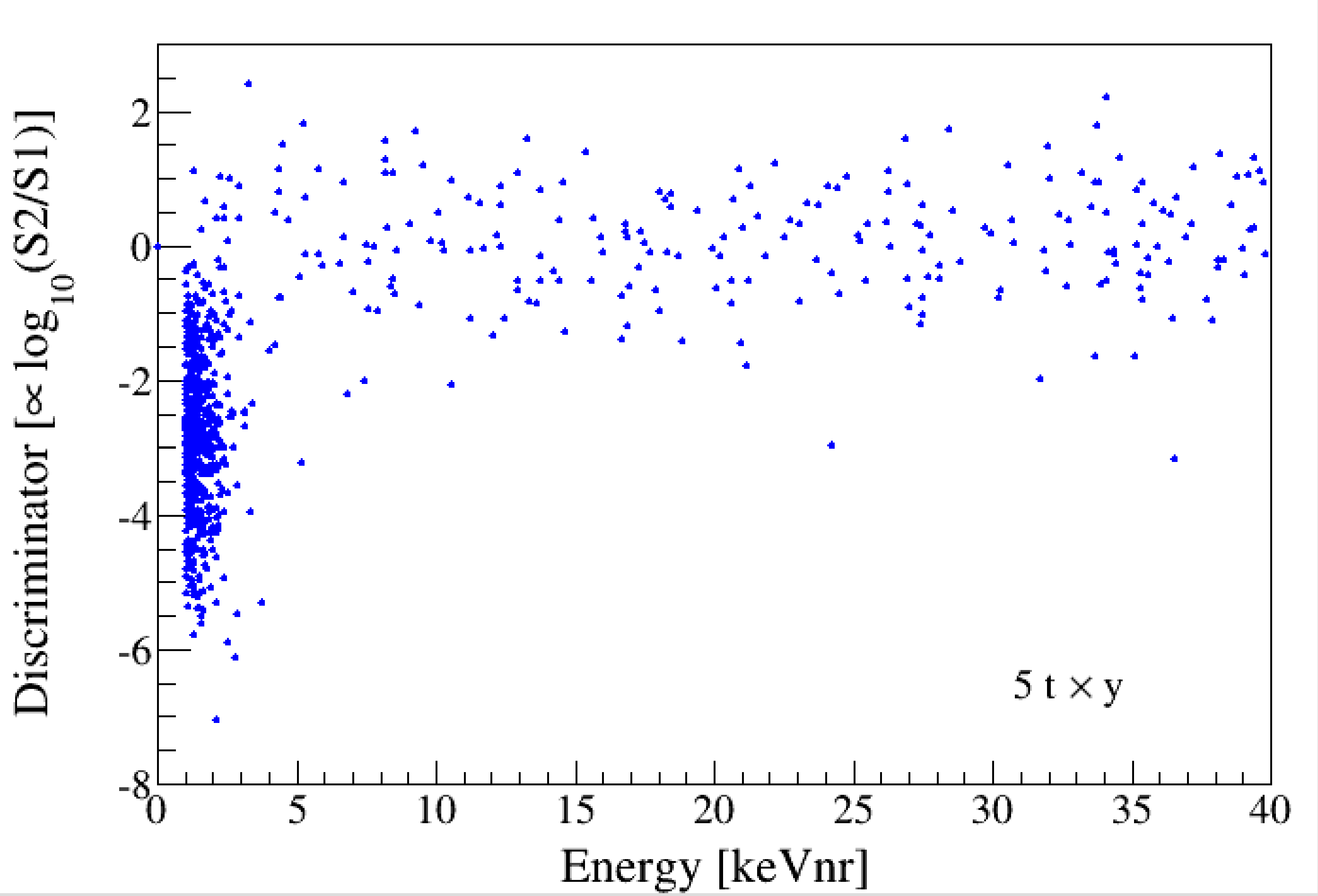
NR-like
(signal)



reconstructed energy,
based on S1 and S2 signal

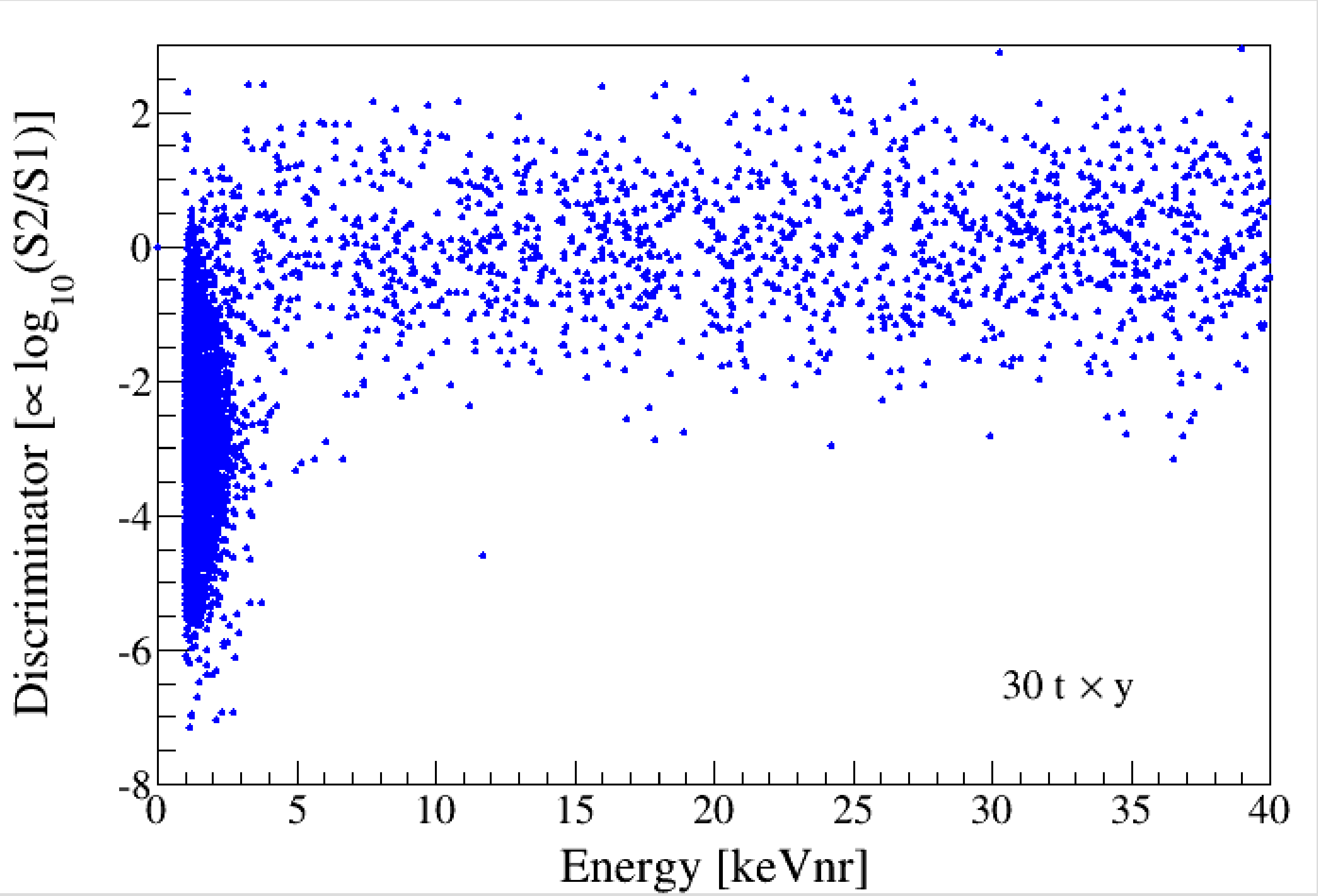
DARWIN with 30t LXe fiducial target

WIMP Detection



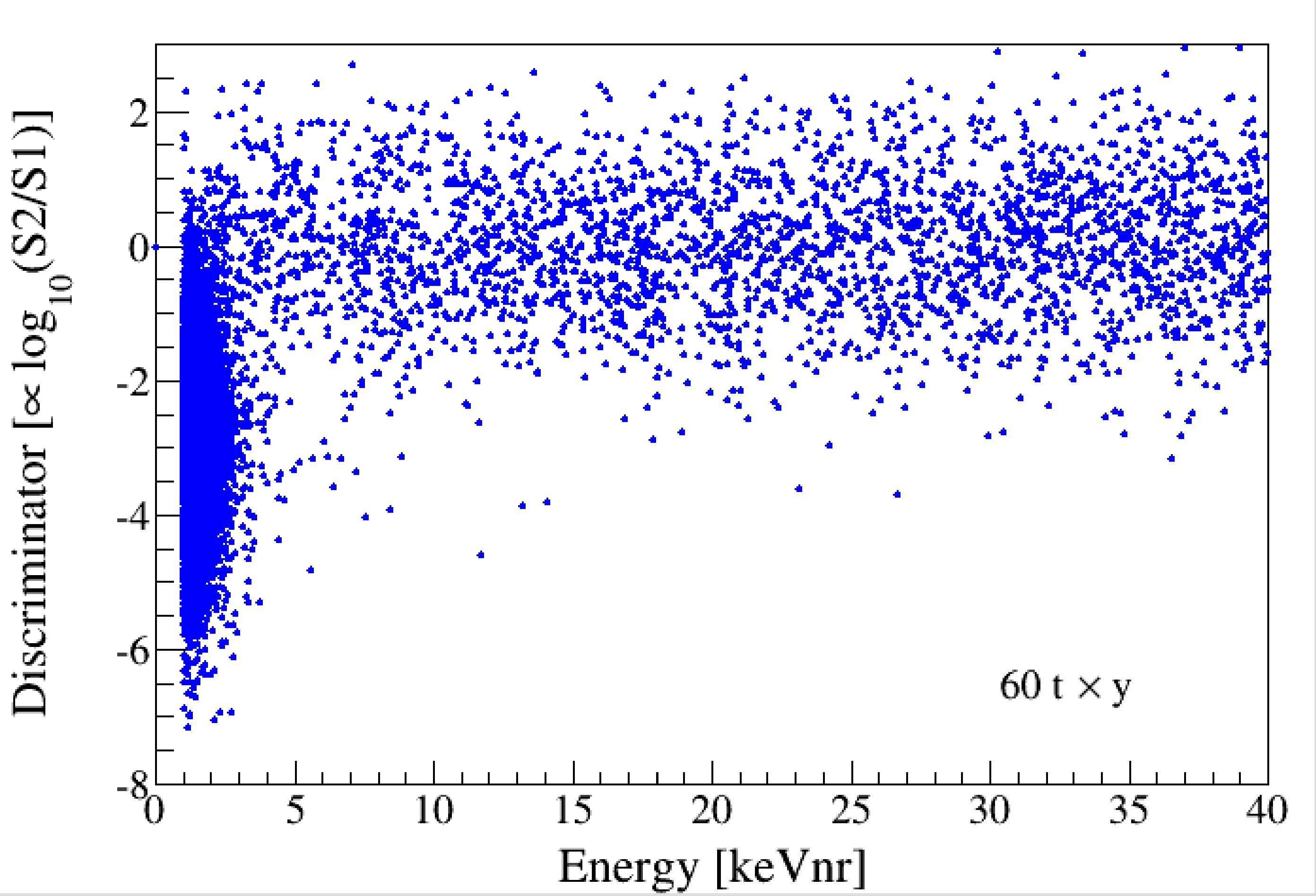
60 days

WIMP Detection



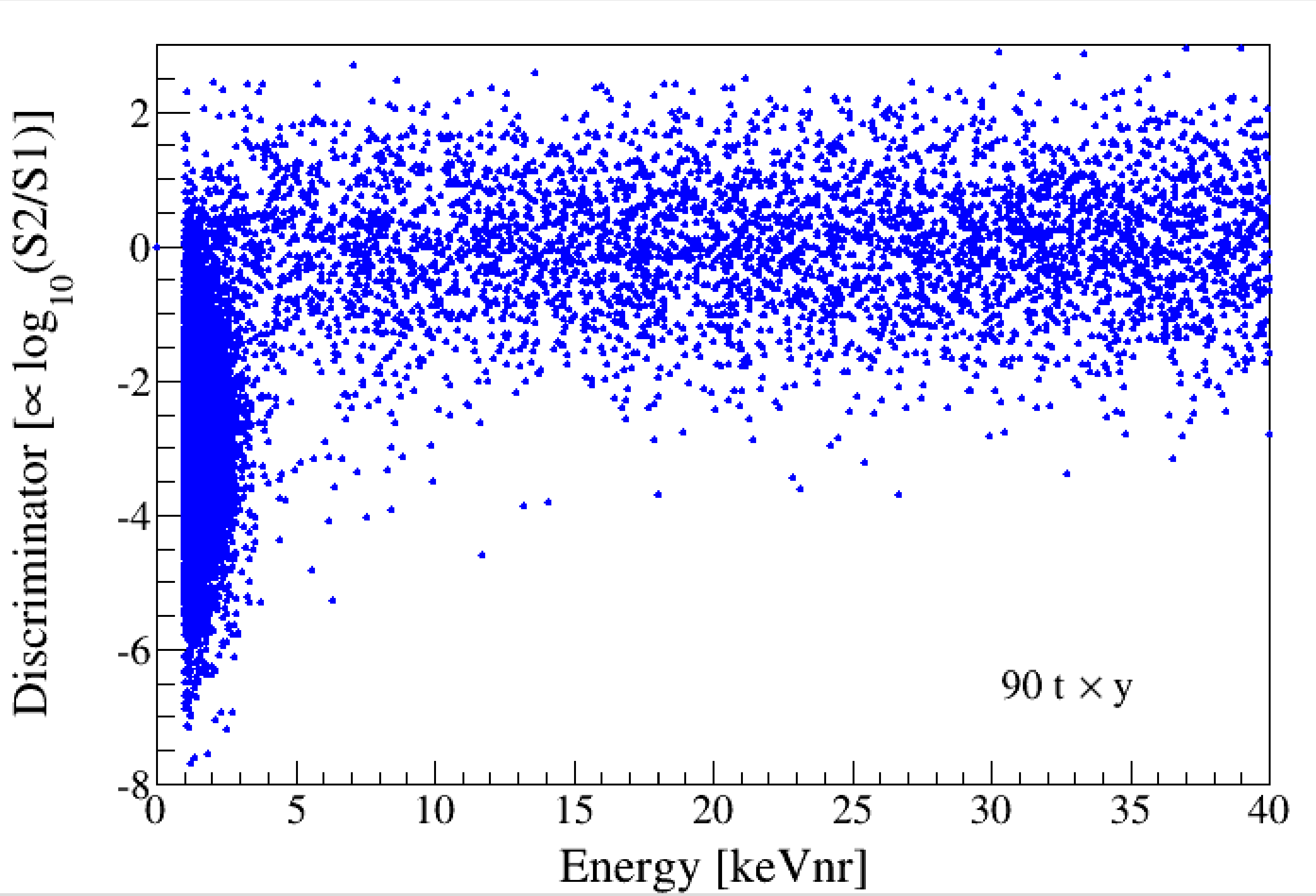
1 year

WIMP Detection



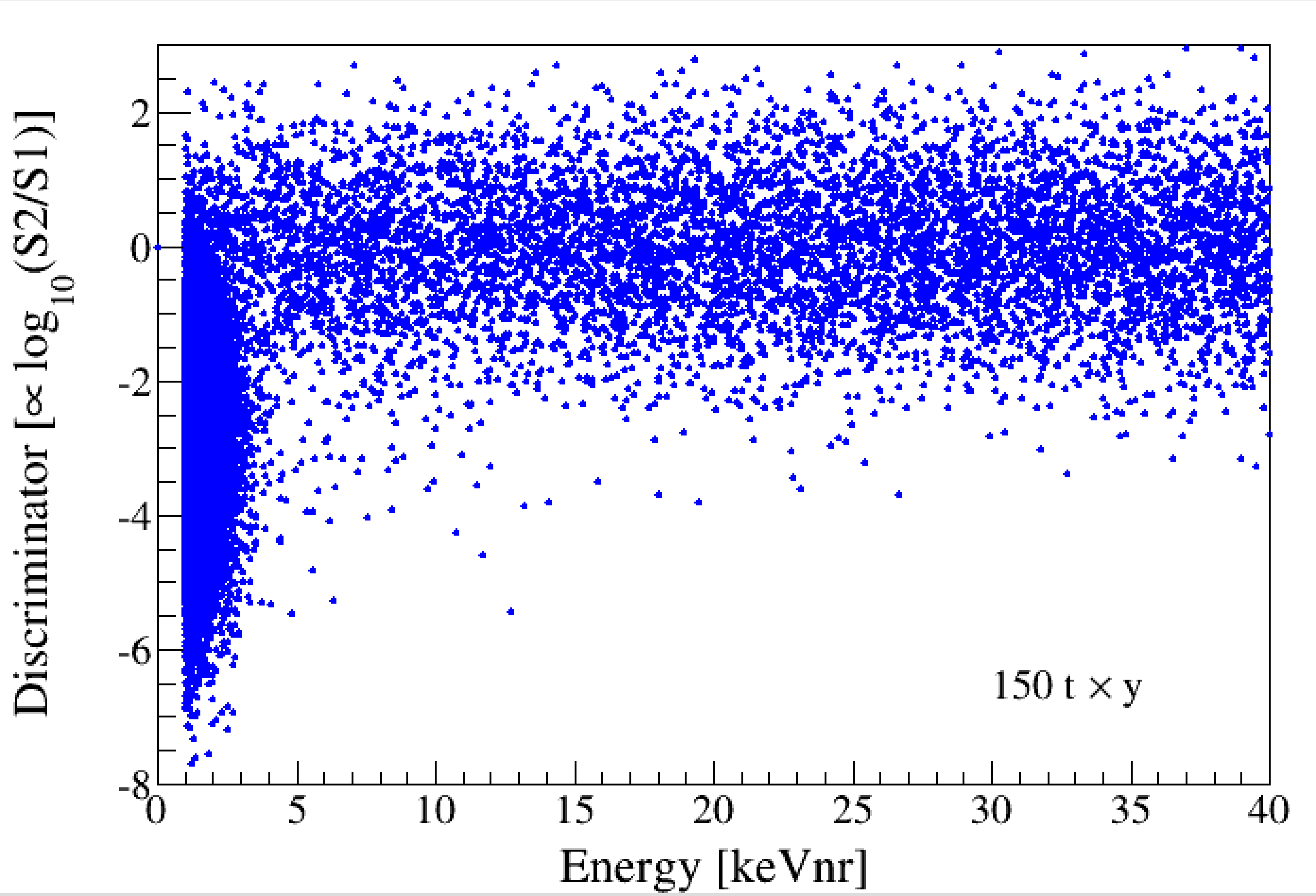
2 years

WIMP Detection



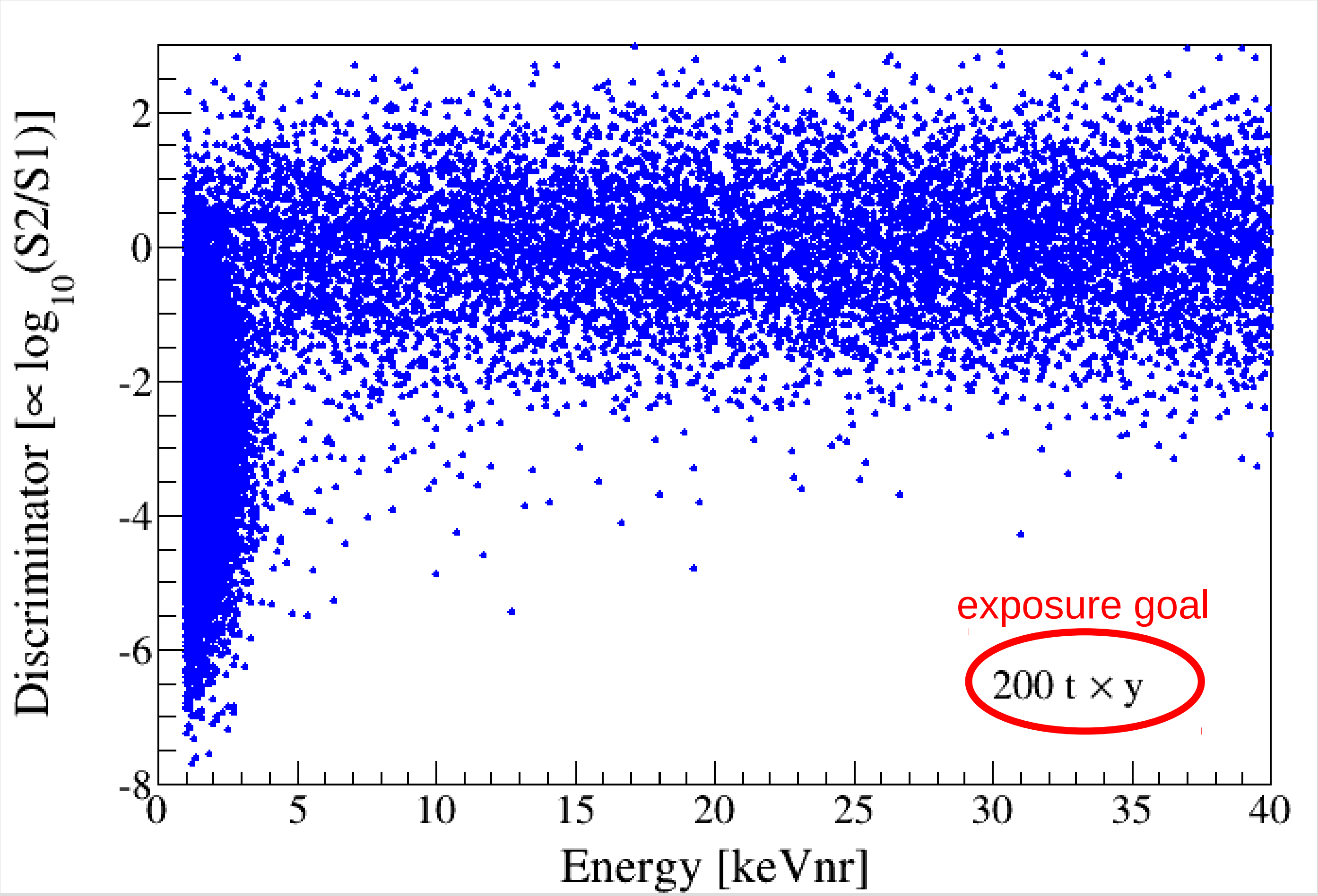
3 years

WIMP Detection



5 years

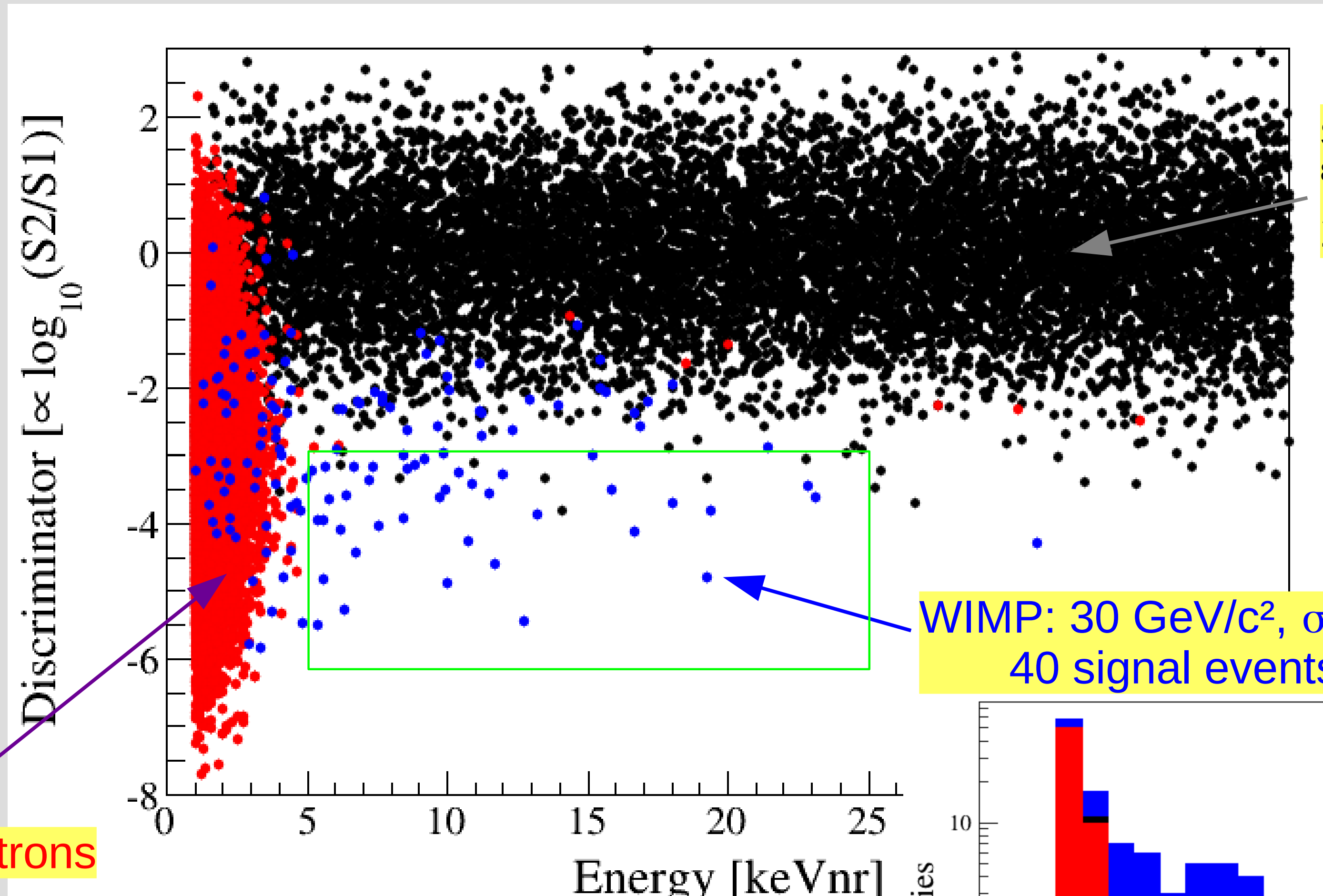
WIMP Detection

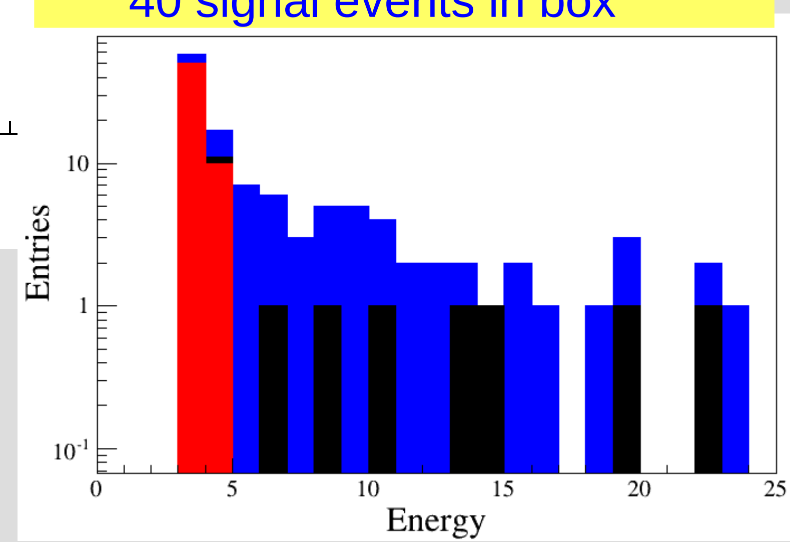


6.7 years

WIMP Detection

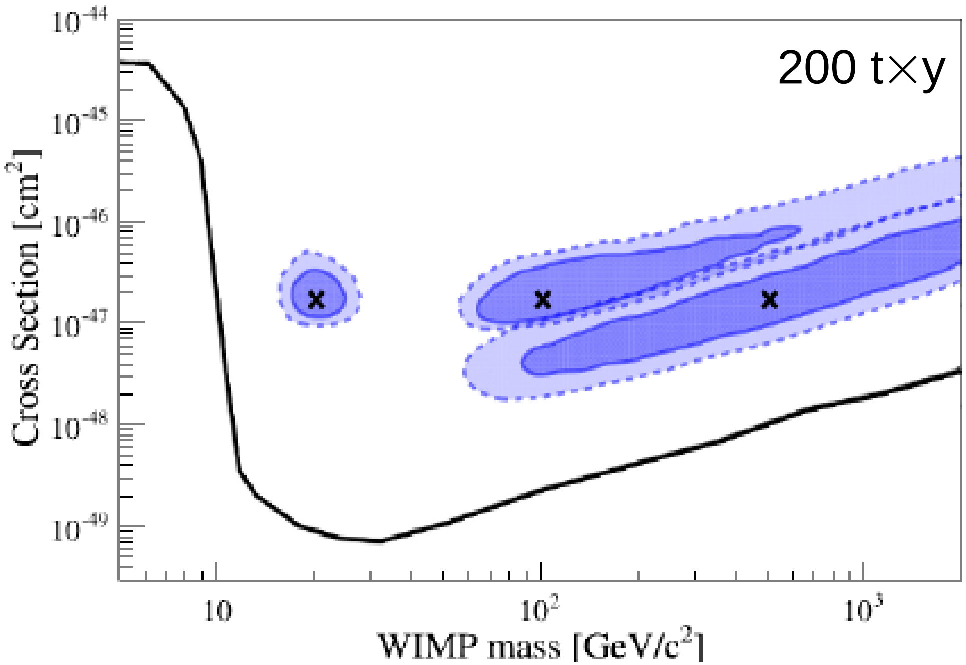
DARWIN





WIMP Spectroscopy

Reconstruction: 2×10⁻⁴⁷ cm²

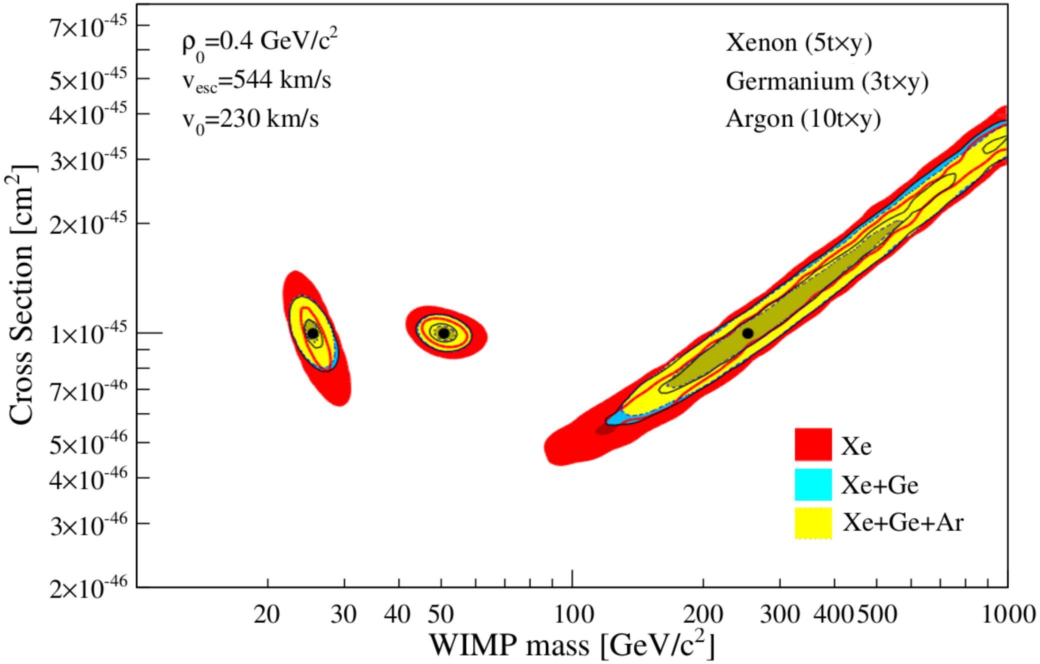


JCAP 11, 017 (2016)

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

Target Complementarity



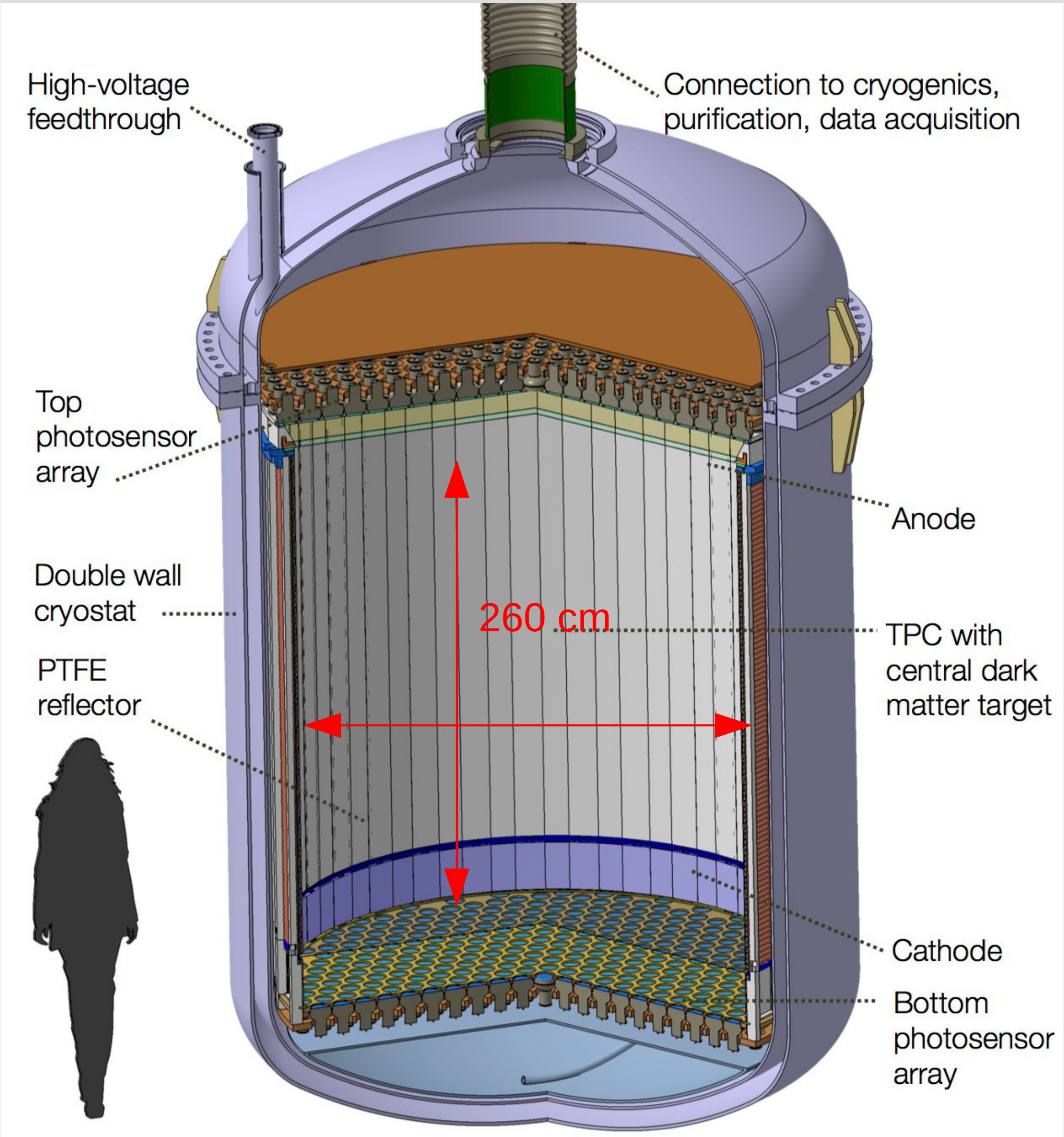
PRD 83, 083505 (2011)

Reconstruction improves considerably by adding Ge-data to Xe.

Only minimal improvement for Ar.

DARWIN The ultimate WIMP Detector

JCAP 11, 017 (2016)



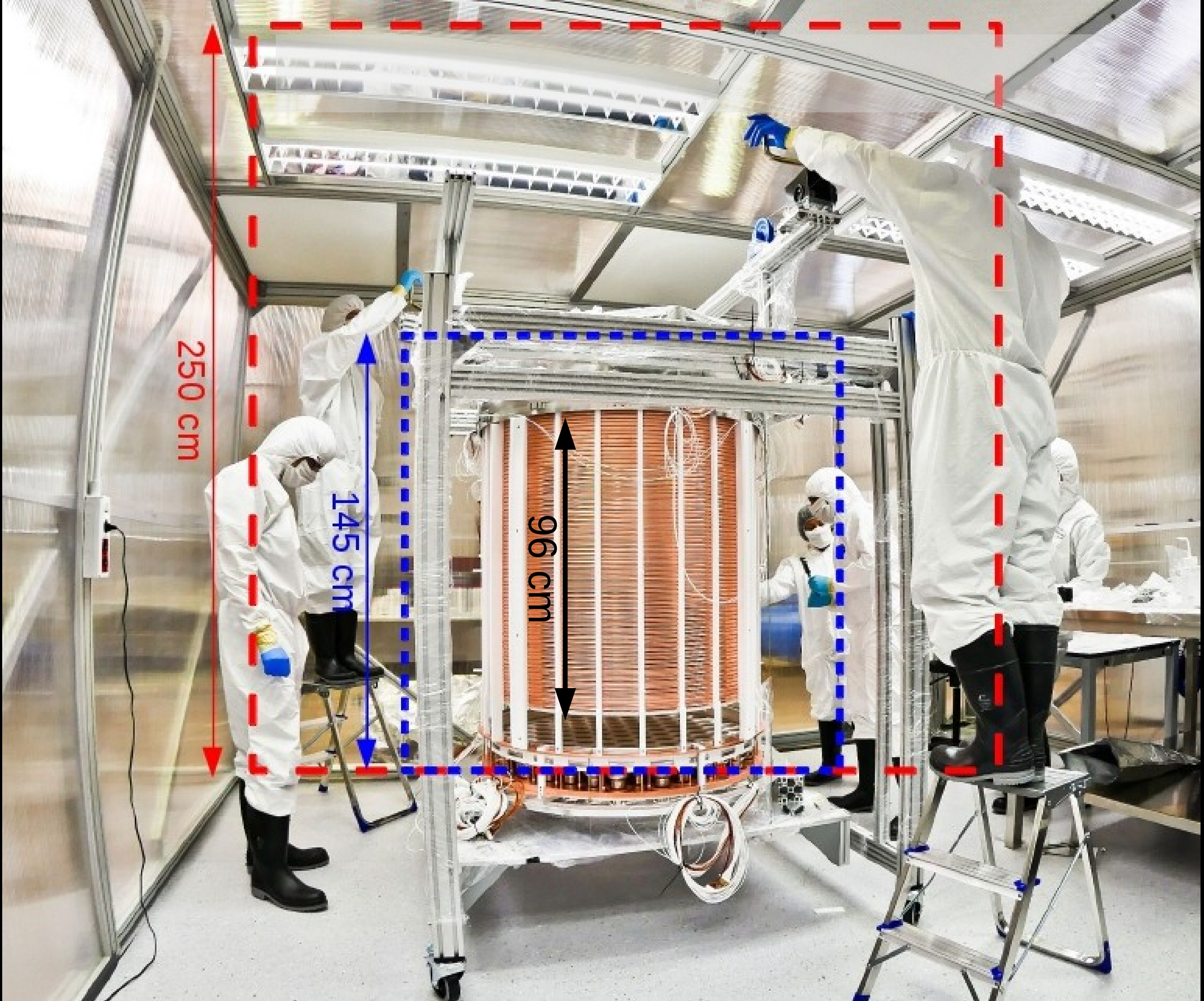
- aim at sensitivity of a few 10^{-49} cm², limited by **irreducible ν-backgrounds**
- international consortium, 24 groups
  → R&D ongoing

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

- Timescale: start after XENONnT

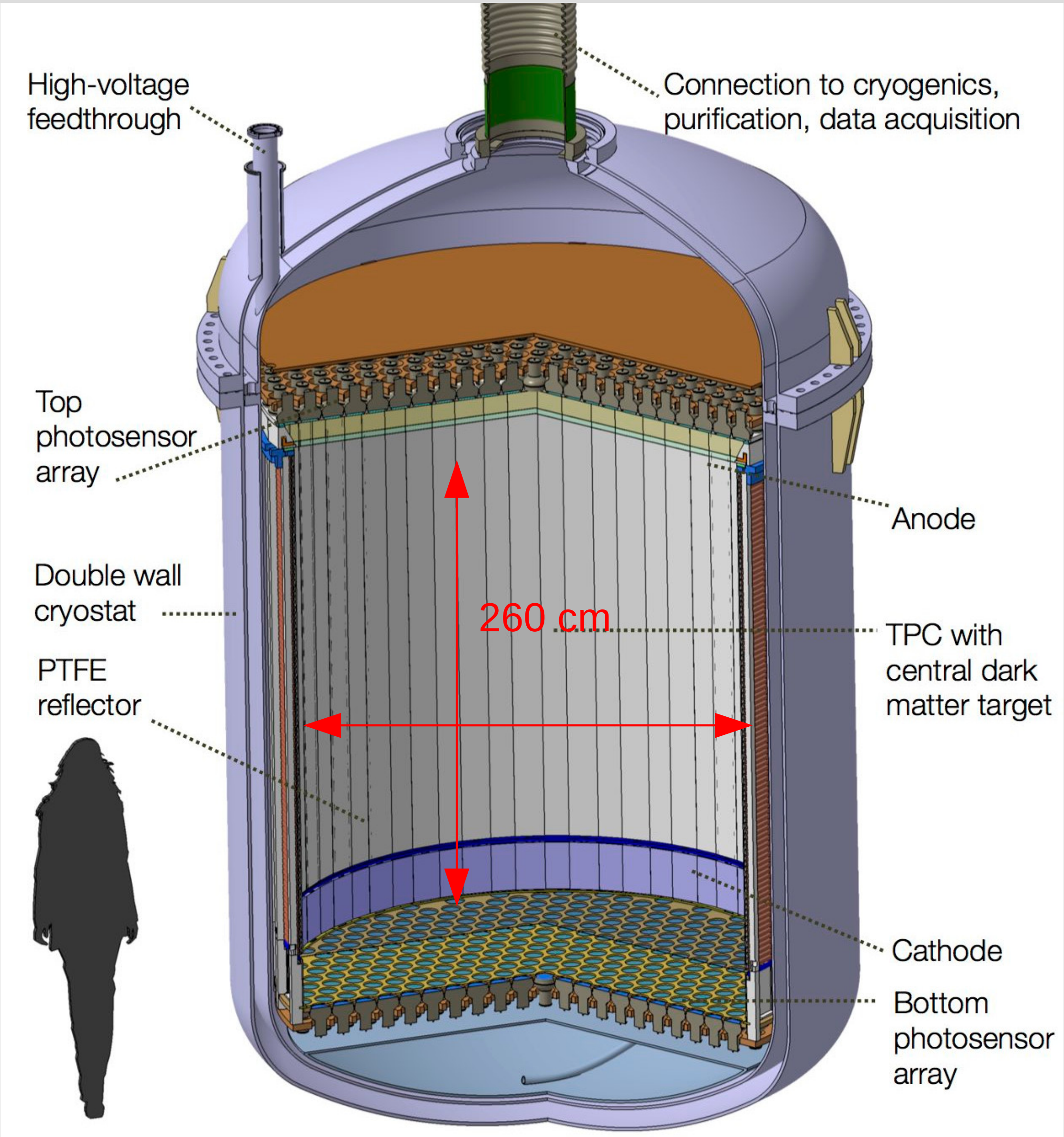
www.darwin-observatory.org

DARWIN Collaboration


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

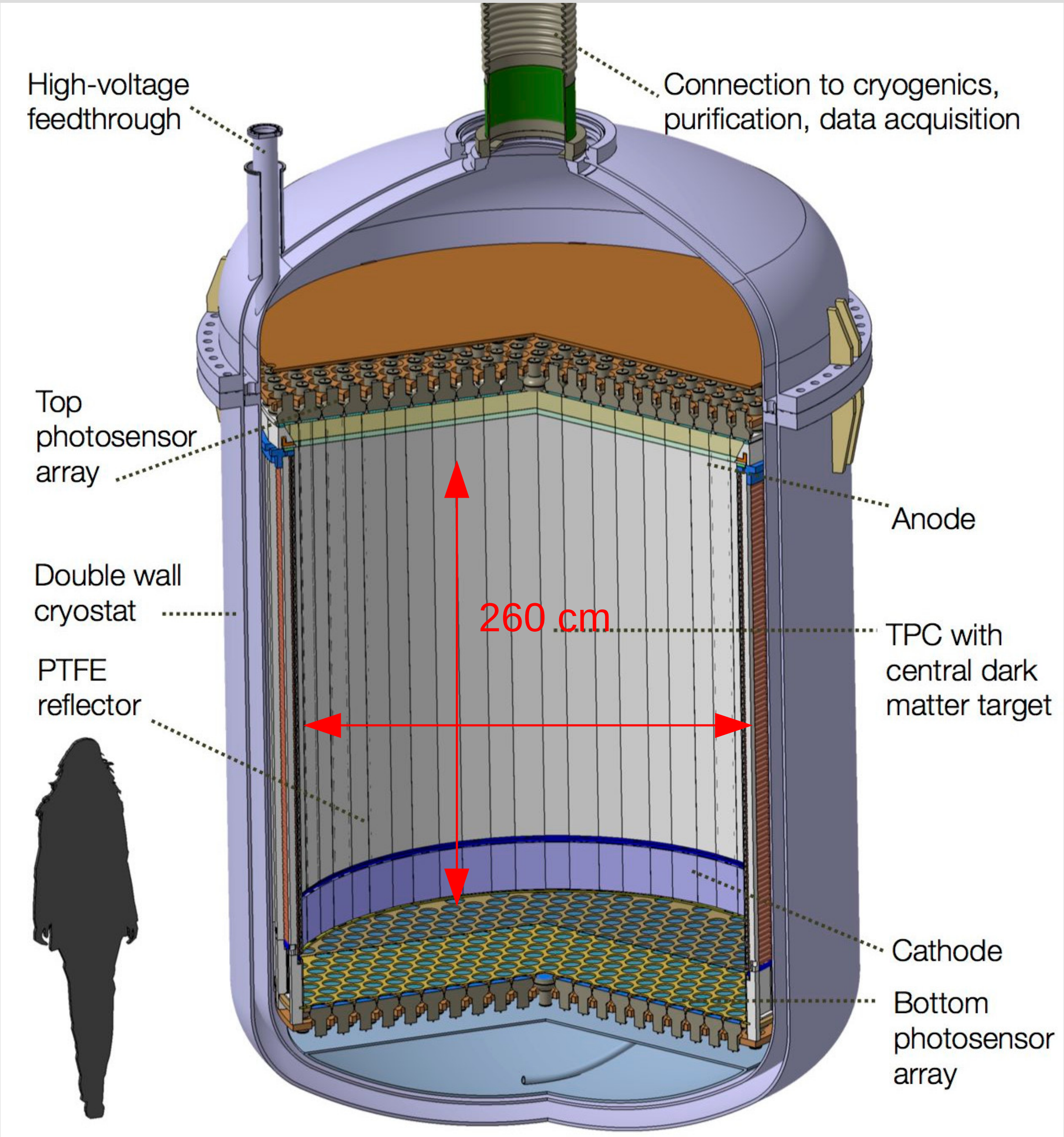
– R&D within XENON collaboration

– **new: two ERC projects**

ULTIMATE (Freiburg)

Xenoscope (Zürich)

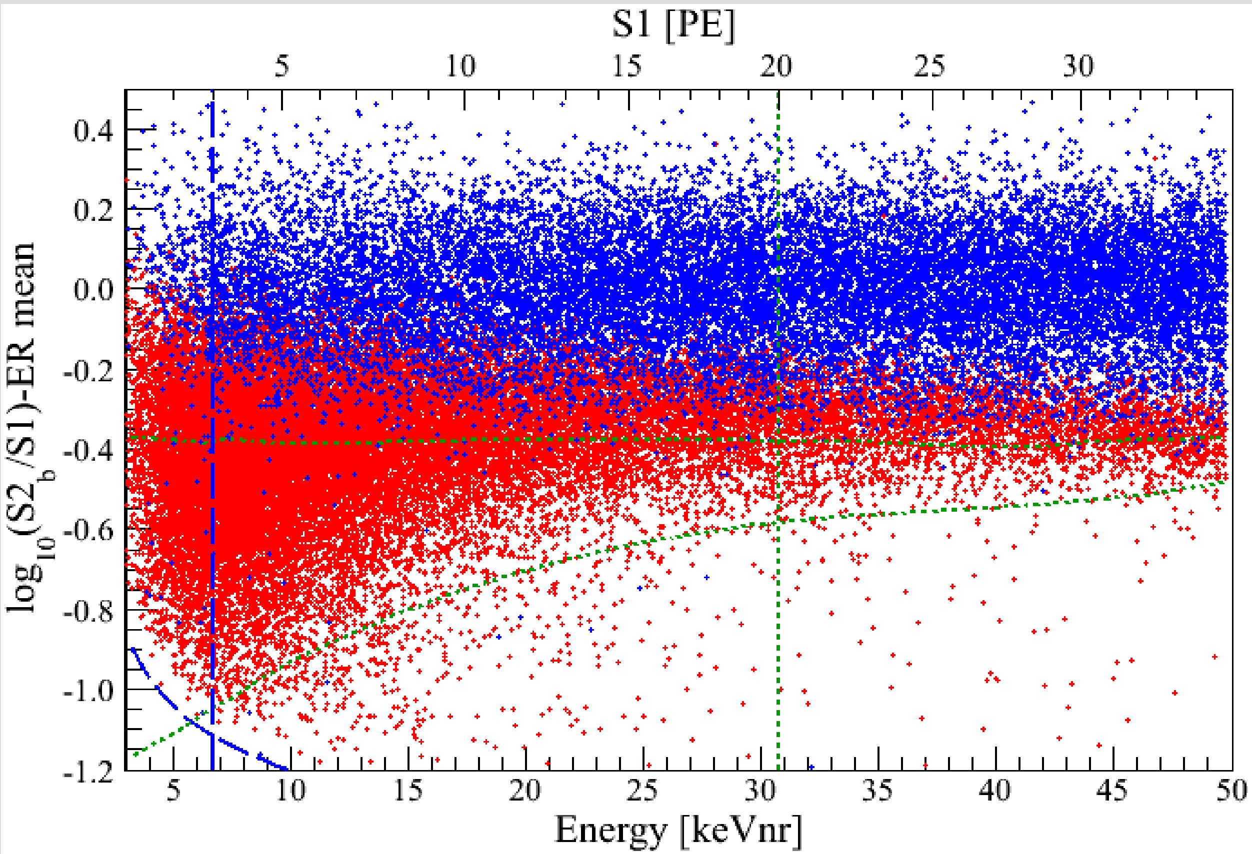
DARWIN The ultimate WIMP Detector



other than WIMPs

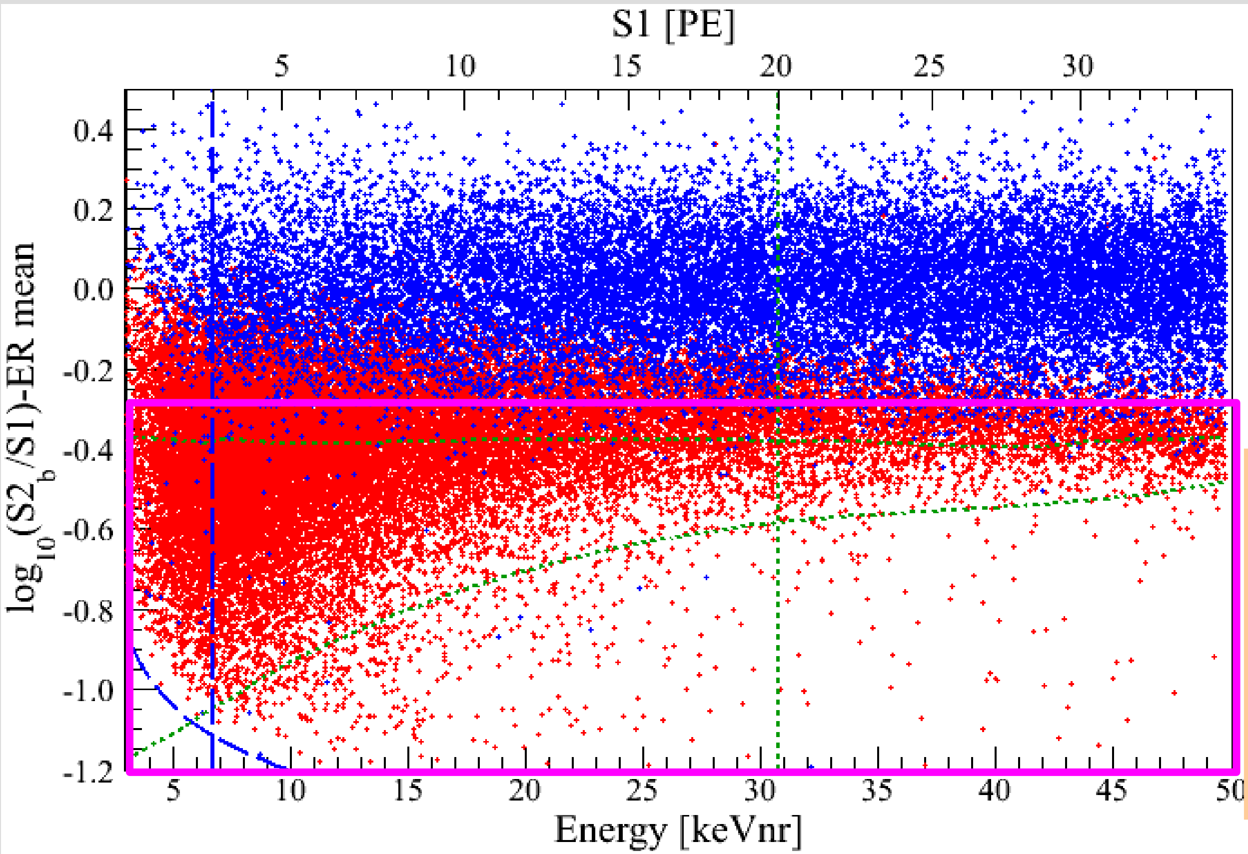
What (else) can we do with these instruments?

Interactions in LXe Detectors



from XENON100

Interactions in LXe Detectors

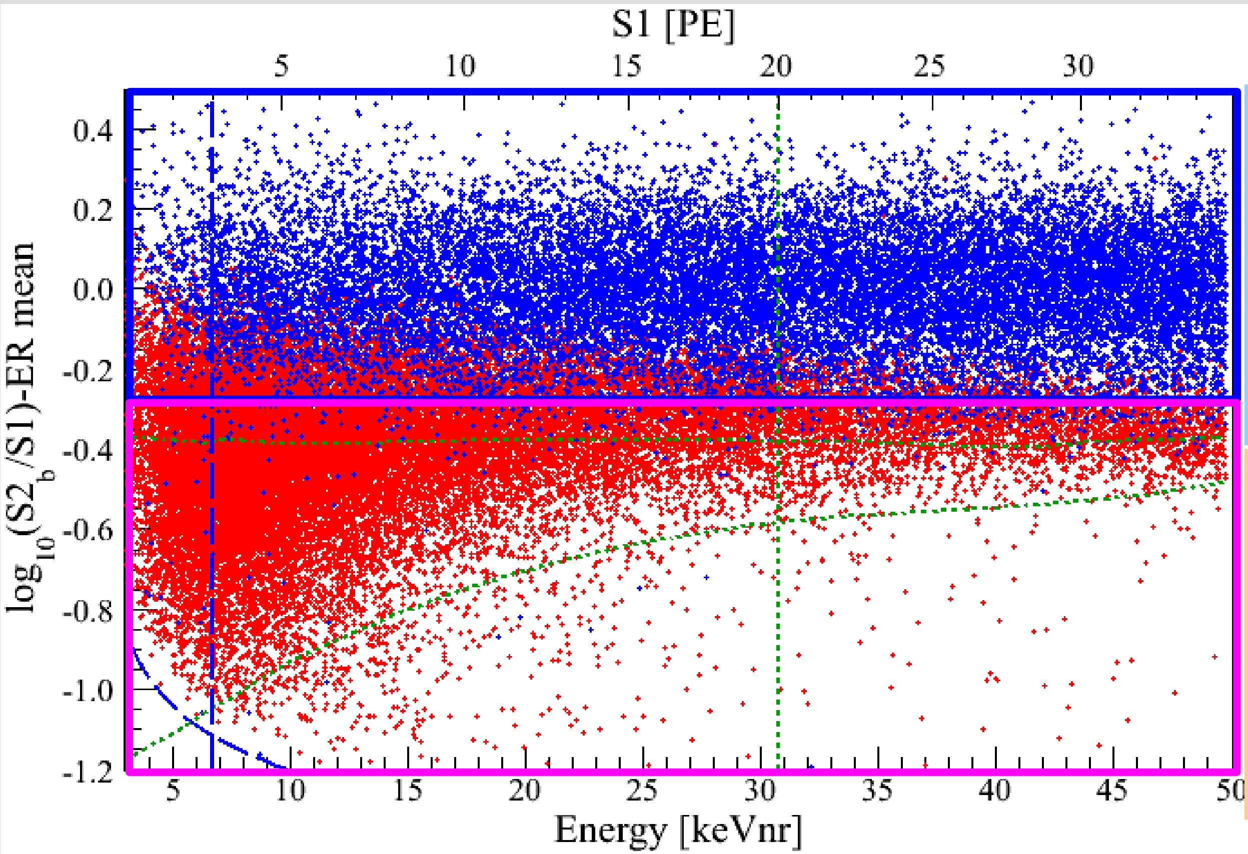


coherent scattering
off xenon nucleus
→ nuclear recoil

- 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

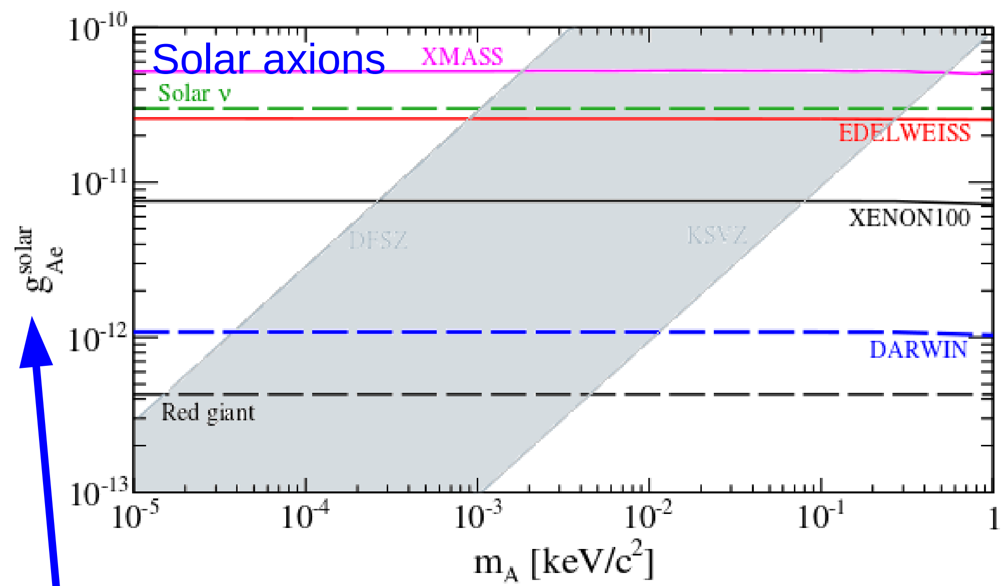
coherent scattering off xenon nucleus
→ nuclear recoil

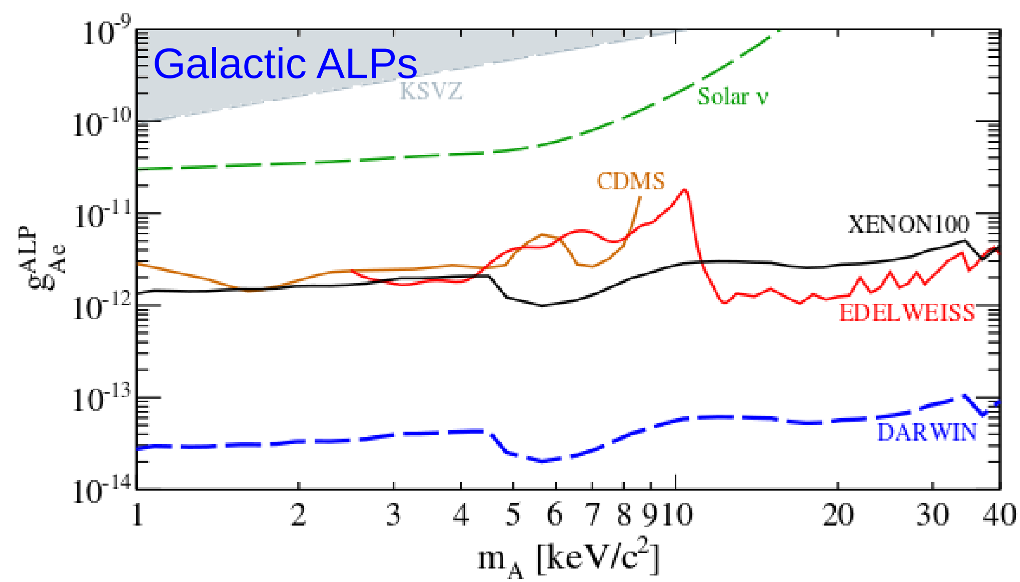
- Dark Matter
- CNNS

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**

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

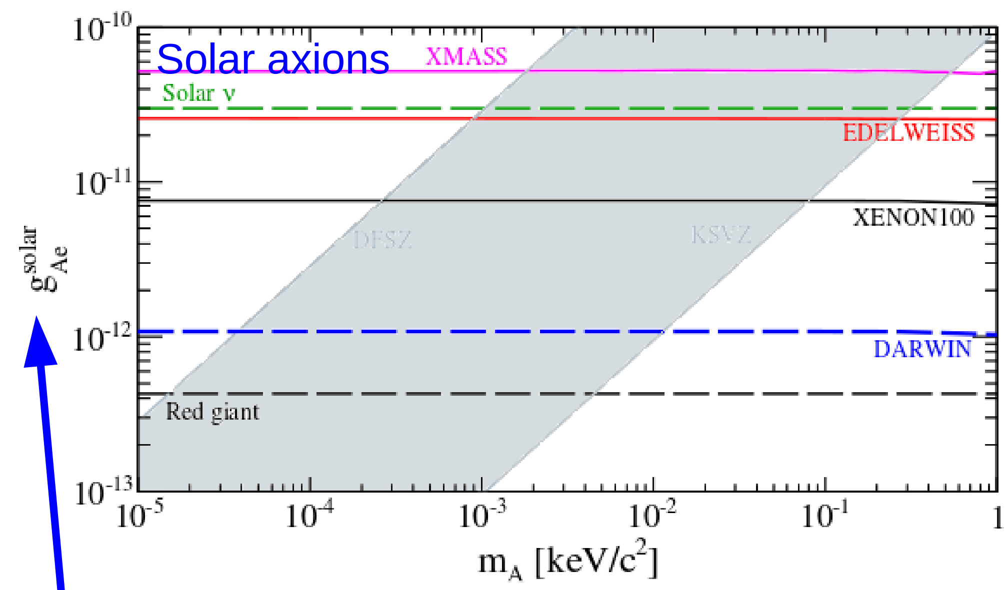
→ axion ionizes a Xe atom

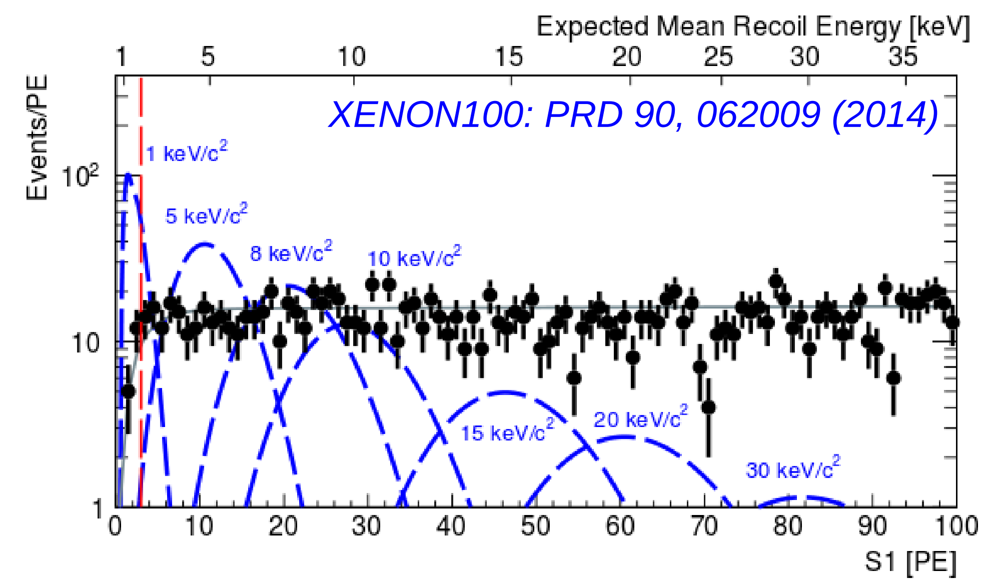
Axion
arises naturally in the Peccei-Quinn solution of the strong CP-problem
→ well-motivated dark matter candidate

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)





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

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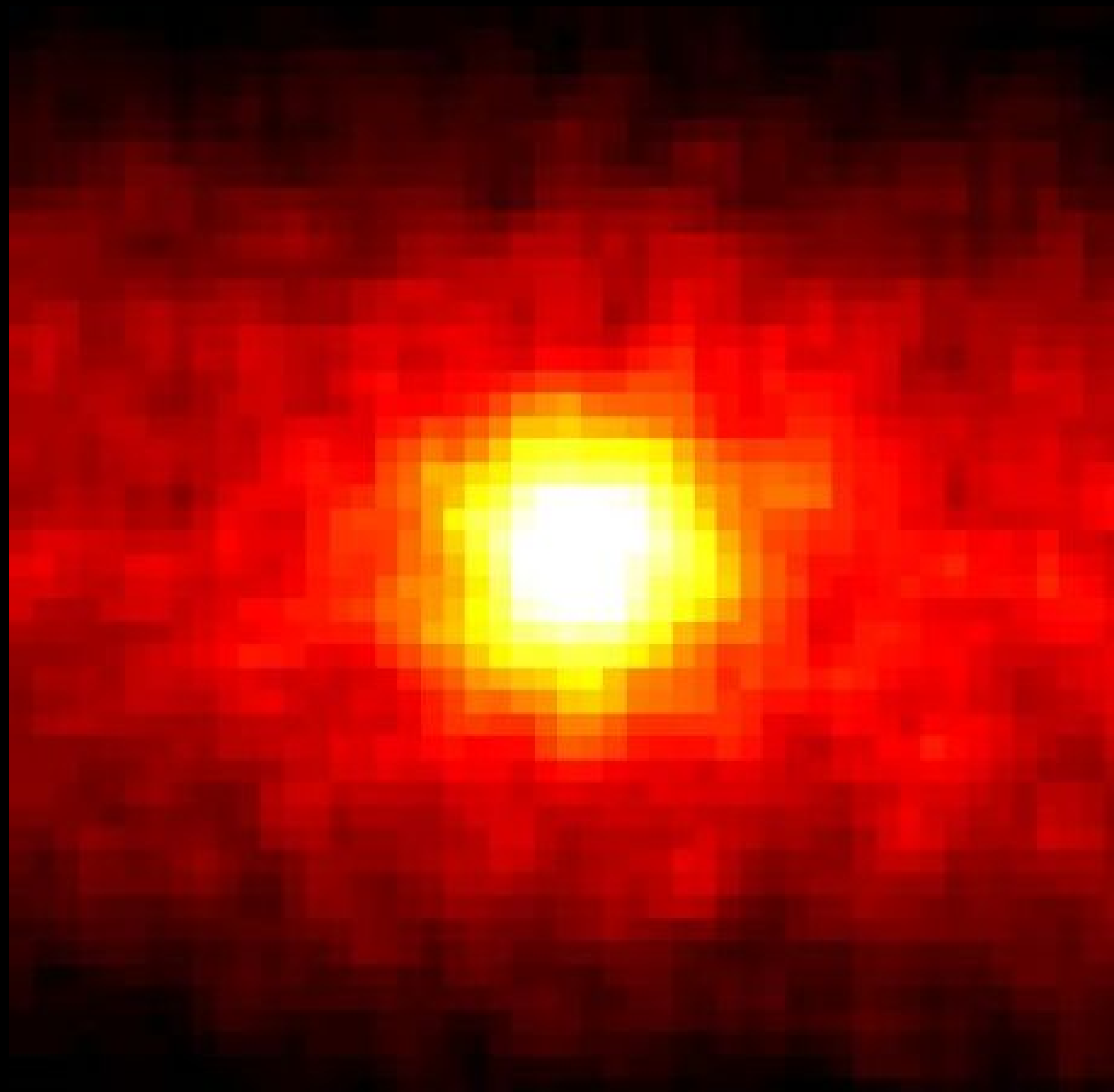
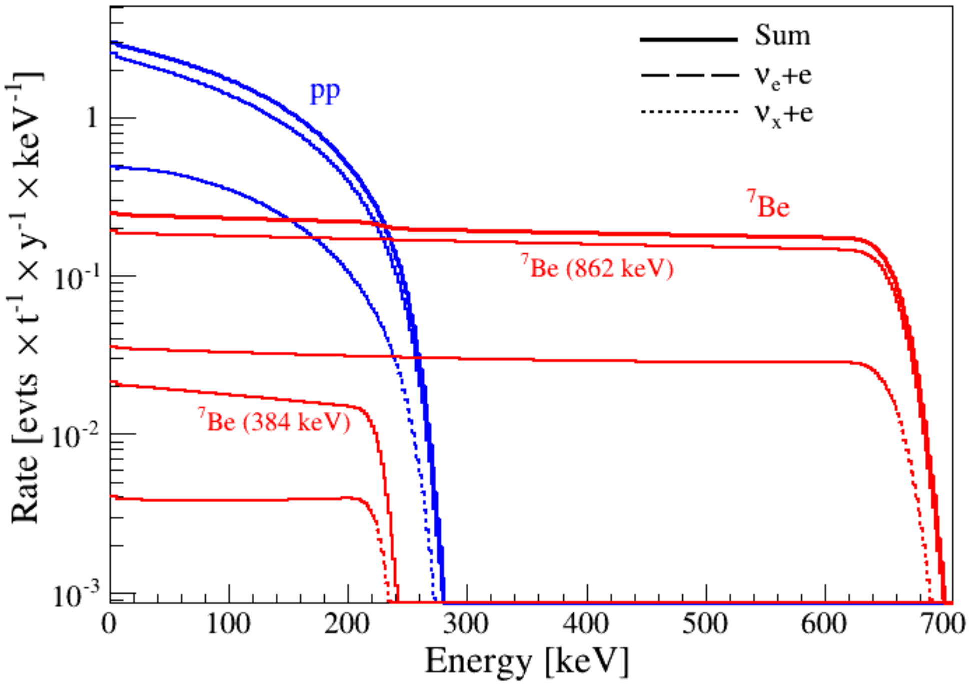


pp-Neutrinos in DARWIN

JCAP 01, 044 (2014)

Differential Recoil Spectrum in Xe



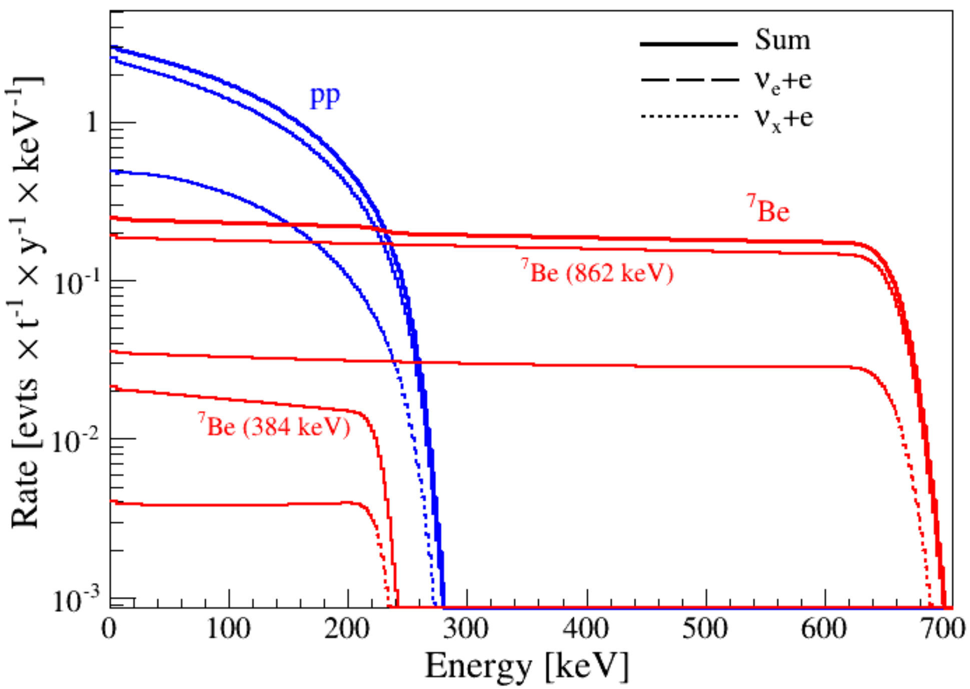
- neutrinos interact with Xe electrons
  → electronic recoil signature
- continuous recoil spectrum
  → largest rate at low E

pp-Neutrinos in DARWIN

a background for the WIMP search

JCAP 11, 017 (2016)

Differential Recoil Spectrum in Xe



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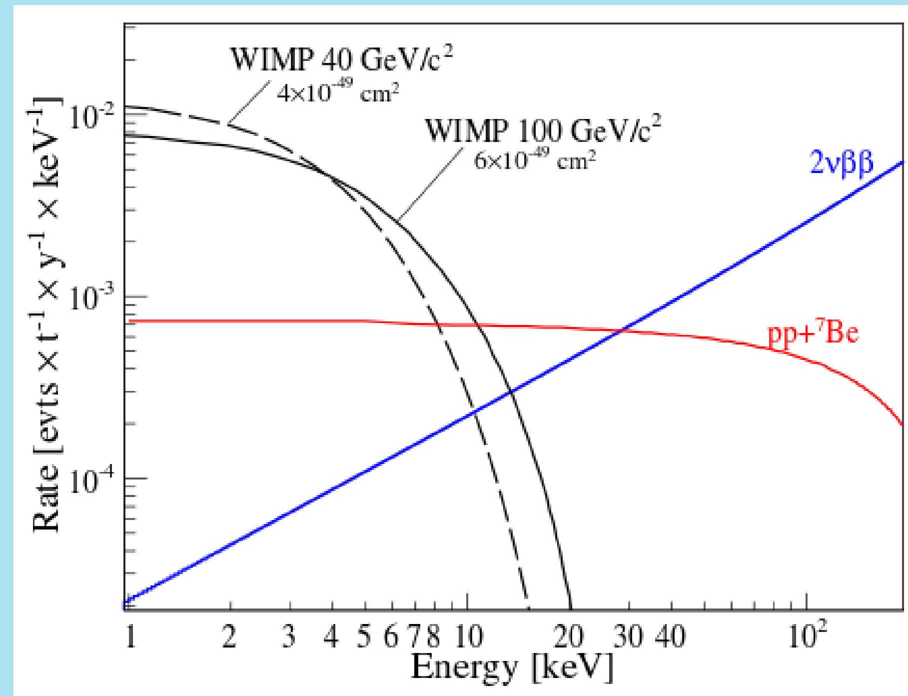
Neutrino interactions



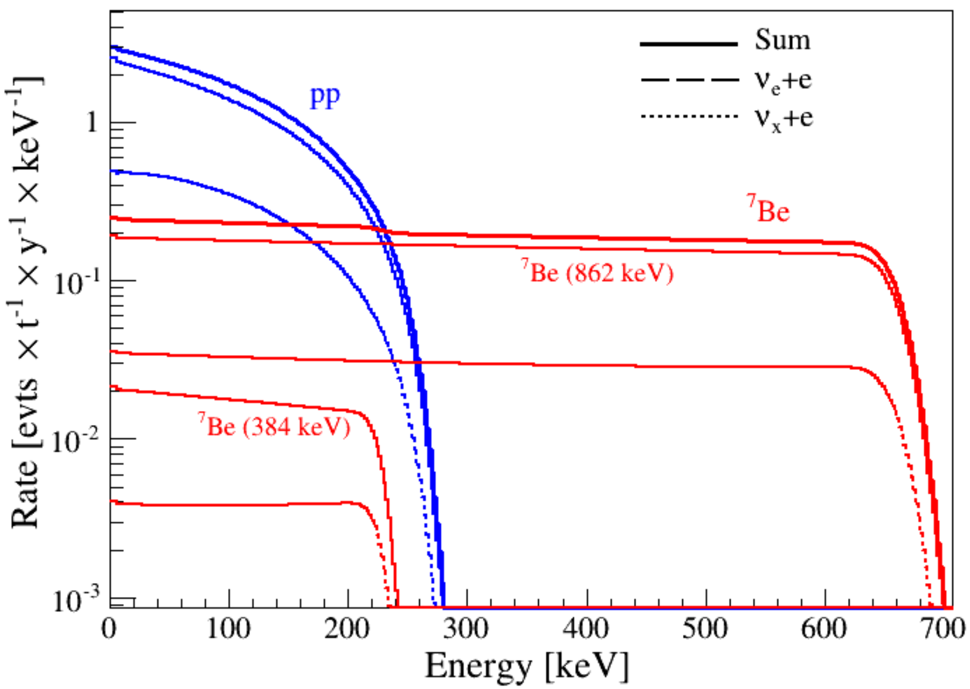
- ER rejection efficiencies ~99.98% at 30% NR efficiency are required to reduce to sub-dominant level

pp-Neutrinos in DARWIN

a new physics channel!

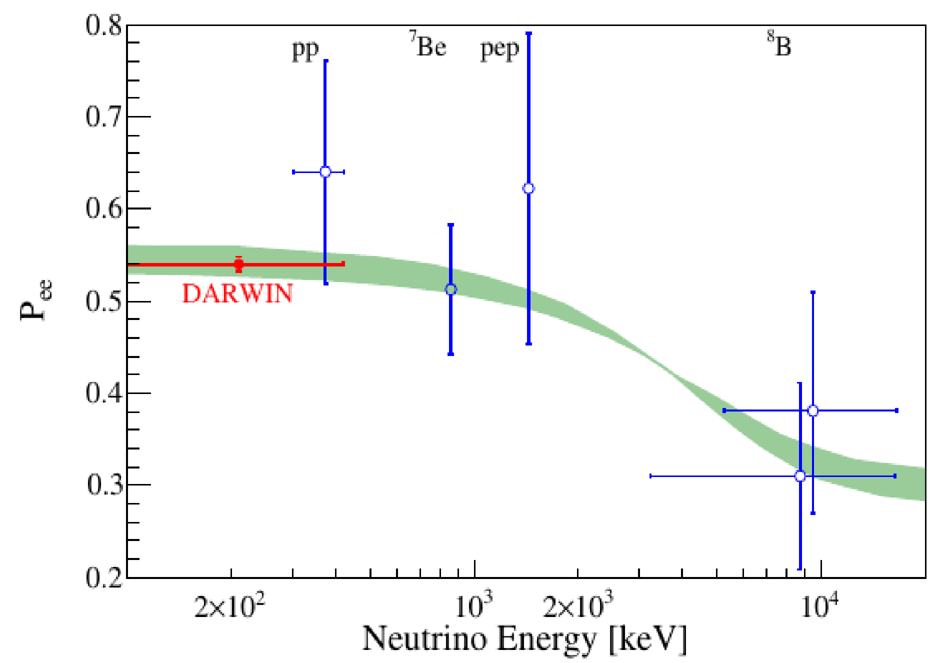
JCAP 11, 017 (2016)

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)

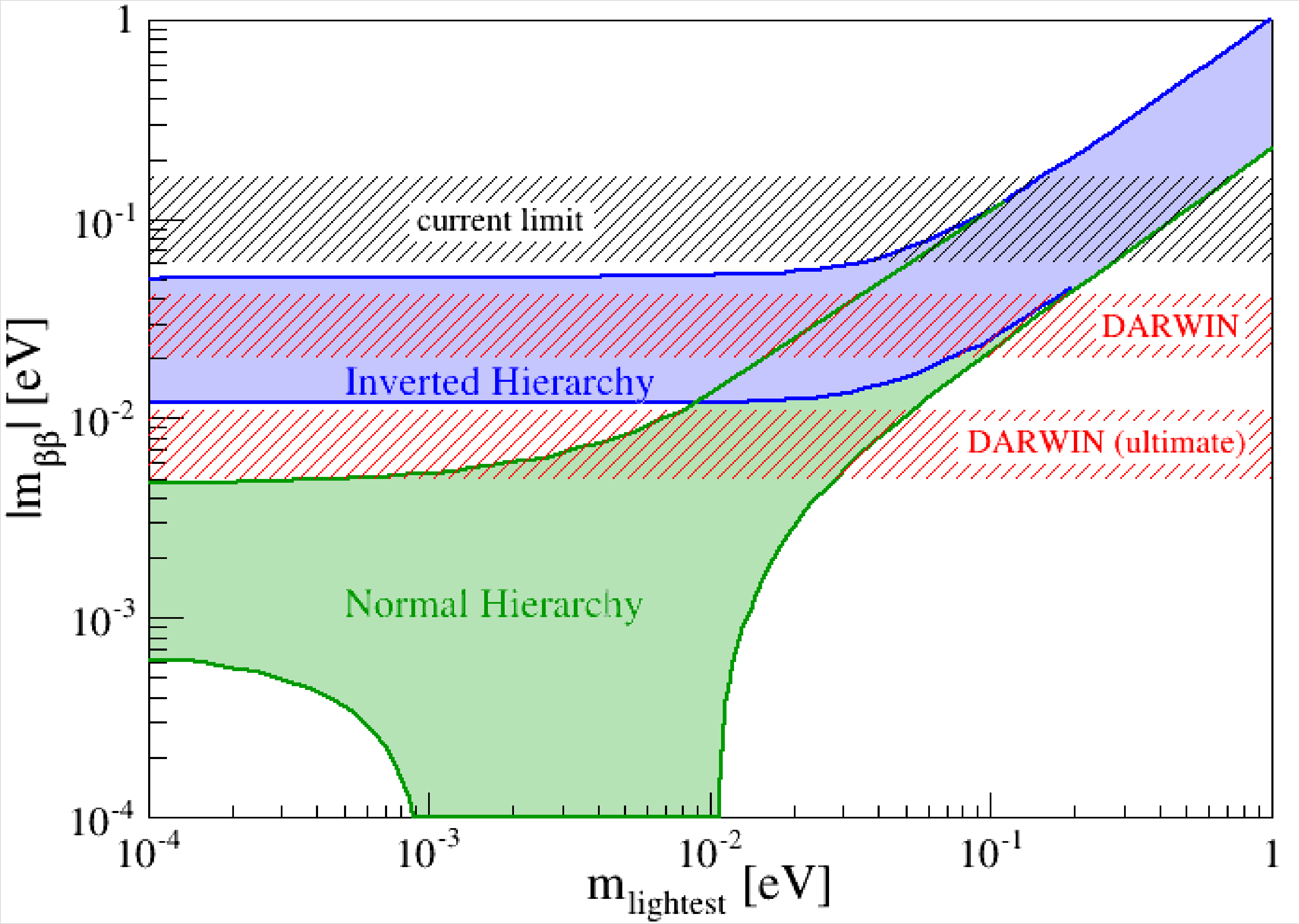
Neutrino interactions



- 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)

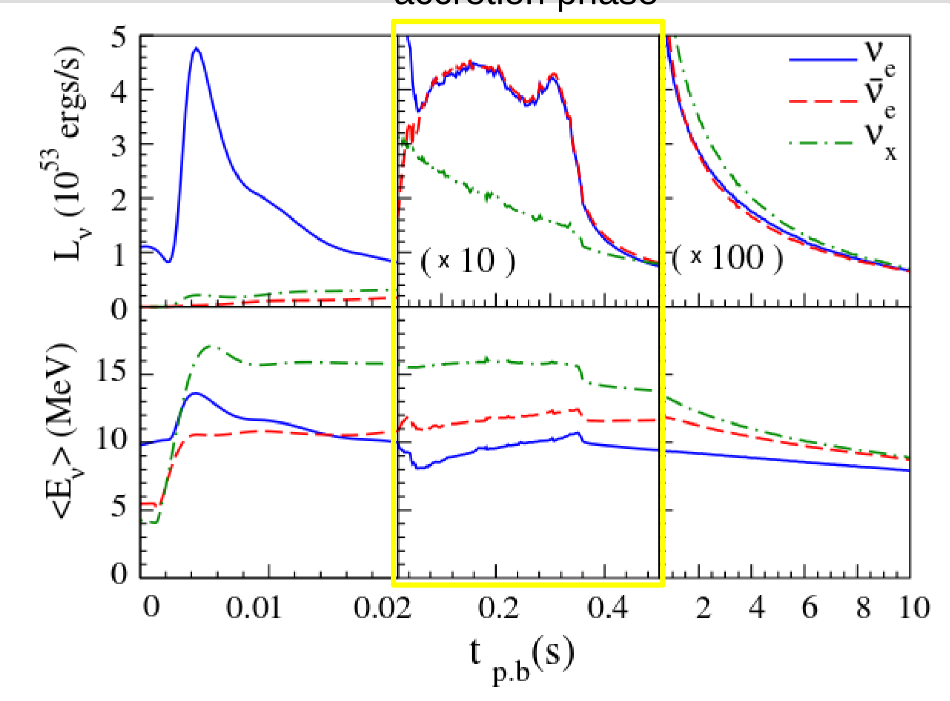


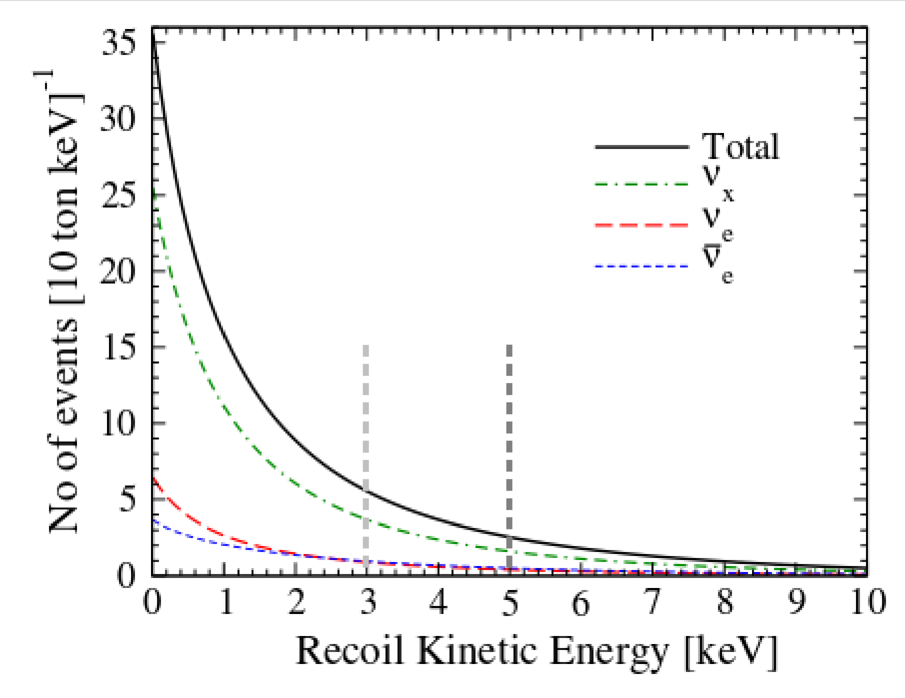
Supernova Neutrinos

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

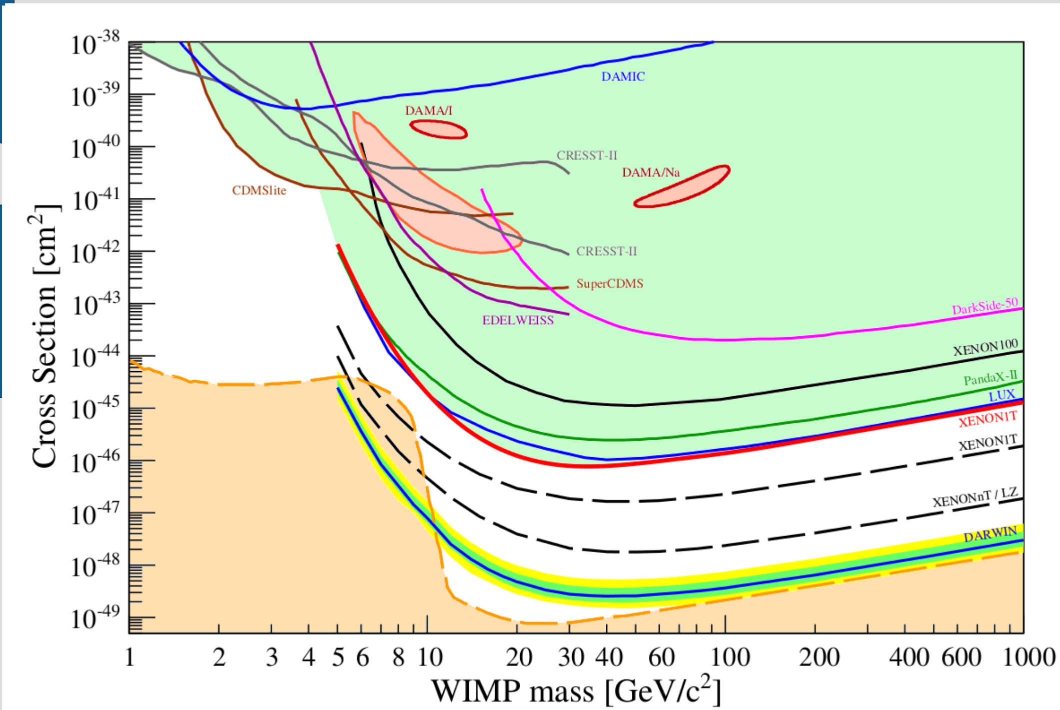
- ν from supernovae could be detected via CNNS as well
- signal fom accretion phase of a ~18 M_{sun} supernova @ 10 kpc is clearly visible in DARWIN
- signal: NRs plus precise time information
  → information on total energy loss in neutrinos
  → complementary to larger detectors

accretion phase





DARWIN – exciting prospects



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
– 0νββ (^{136}Xe), 2νEC (^{134}Xe), ... *JCAP 01, 044 (2014)*