DARWIN: Science Opportunities with a multi-ton Xenon Dark Matter Detector

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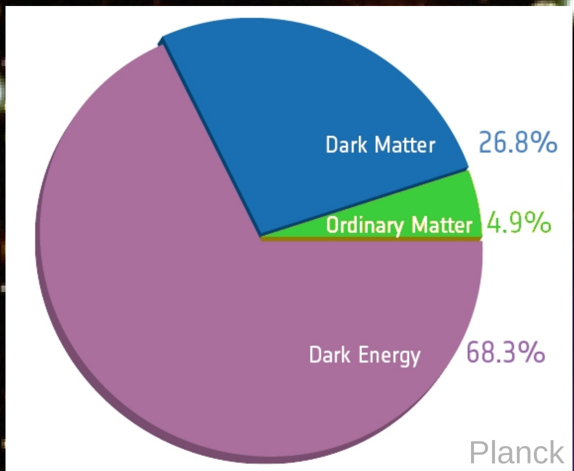
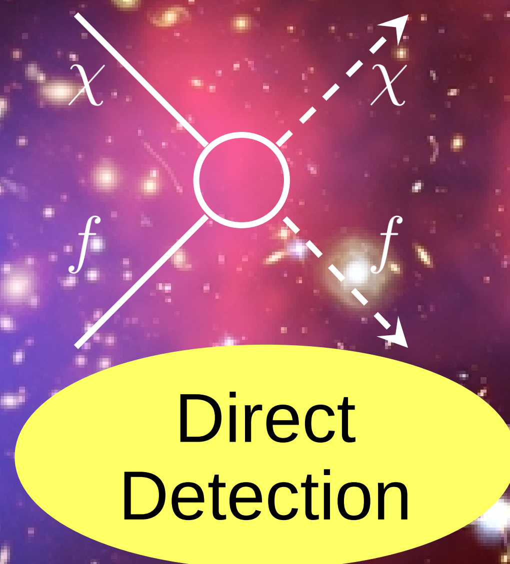
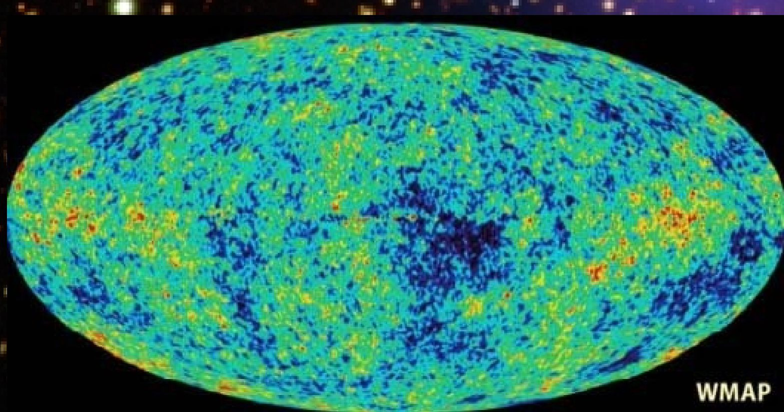
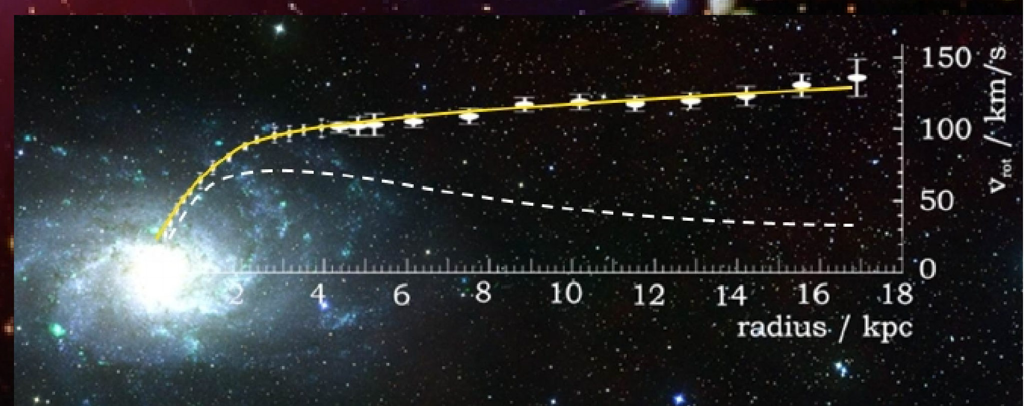
Dark Matter: (indirect) Evidence



Particle Dark Matter Candidates:
- **WIMP** → *„WIMP miracle“*
- Axion
- SuperWIMPs
- sterile neutrinos
- WIMPless dark matter
- Gravitino
- ...

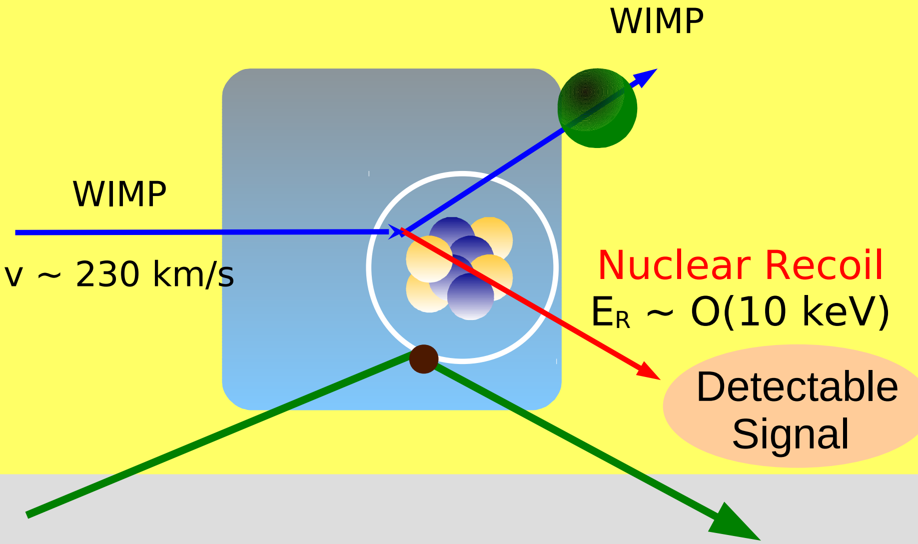






Direct WIMP Search

Elastic Scattering of WIMPs off target nuclei
➡ nuclear recoil

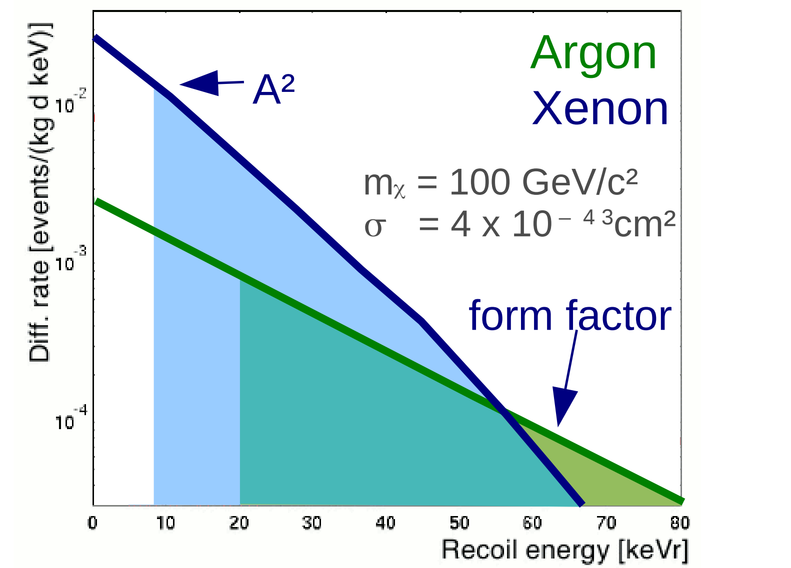


gamma- and beta-particles (background) interact with the atomic electrons
→ **electronic recoil**

Direct WIMP Search

Summary:

tiny rate $R < 0.1$ evt/kg/yr
low energy $E_R < 50$ keV



Recoil Energy: $E_r \sim \mathcal{O}(10\ \mathrm{keV})$

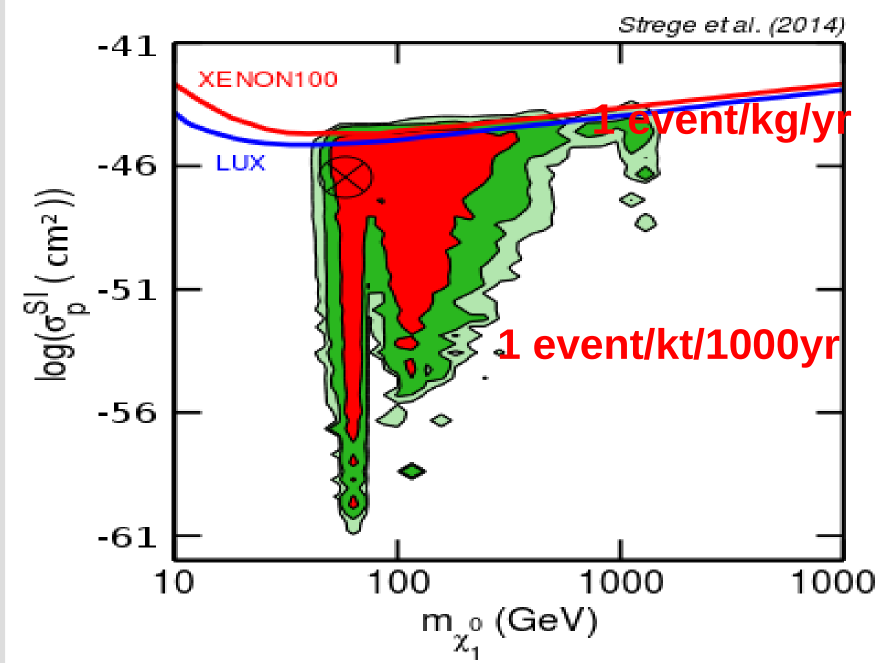
Event Rate: $R \propto N \frac{\rho_\chi}{m_\chi} \langle \sigma_{\chi-N} \rangle$

Detector

Local DM Density

Physics

ρ_χ~0.3 GeV/c²



Direct WIMP Search

Summary:

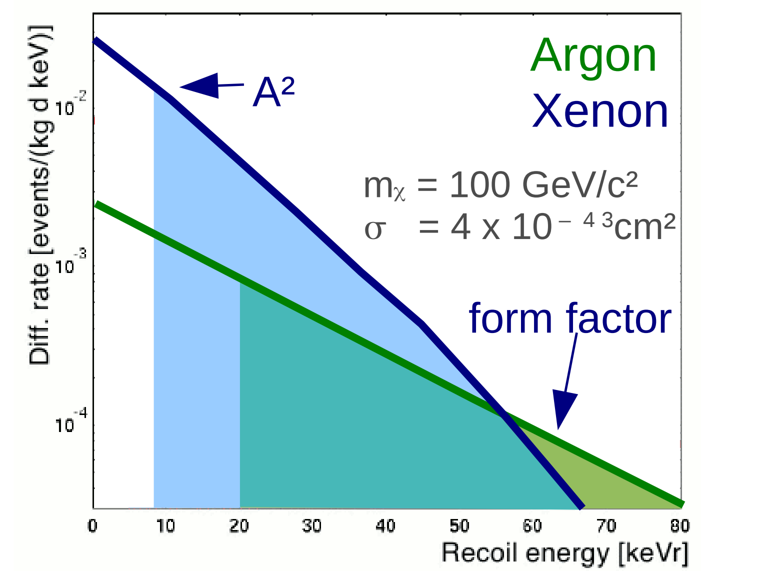
tiny rate $R < 0.1$ evt/kg/yr
low energy $E_R < 50$ keV

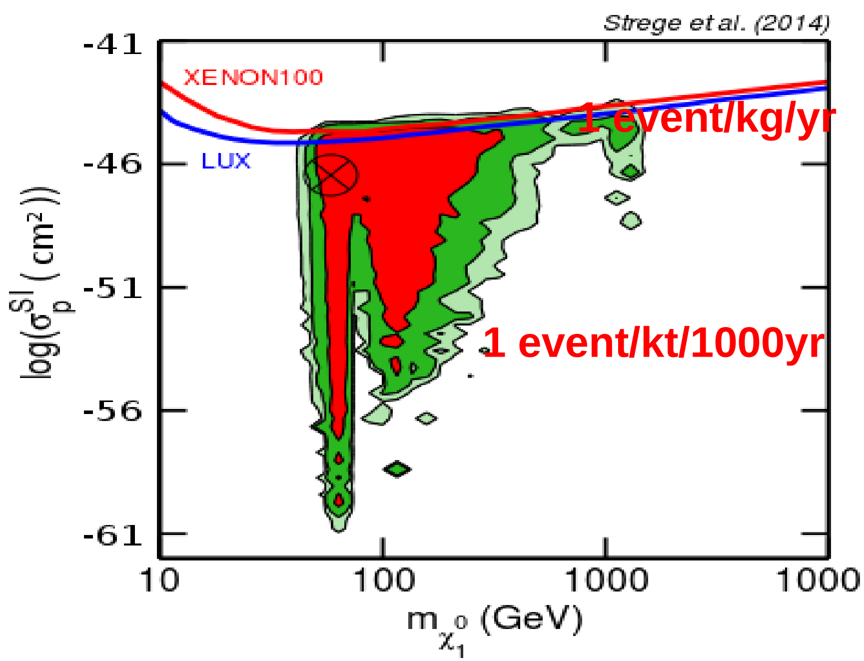
How to build a WIMP detector?

- large total mass, high *A* ✓
- low energy threshold ✓ for xenon detector
- ultra low background ✓
- good background rejection ✓

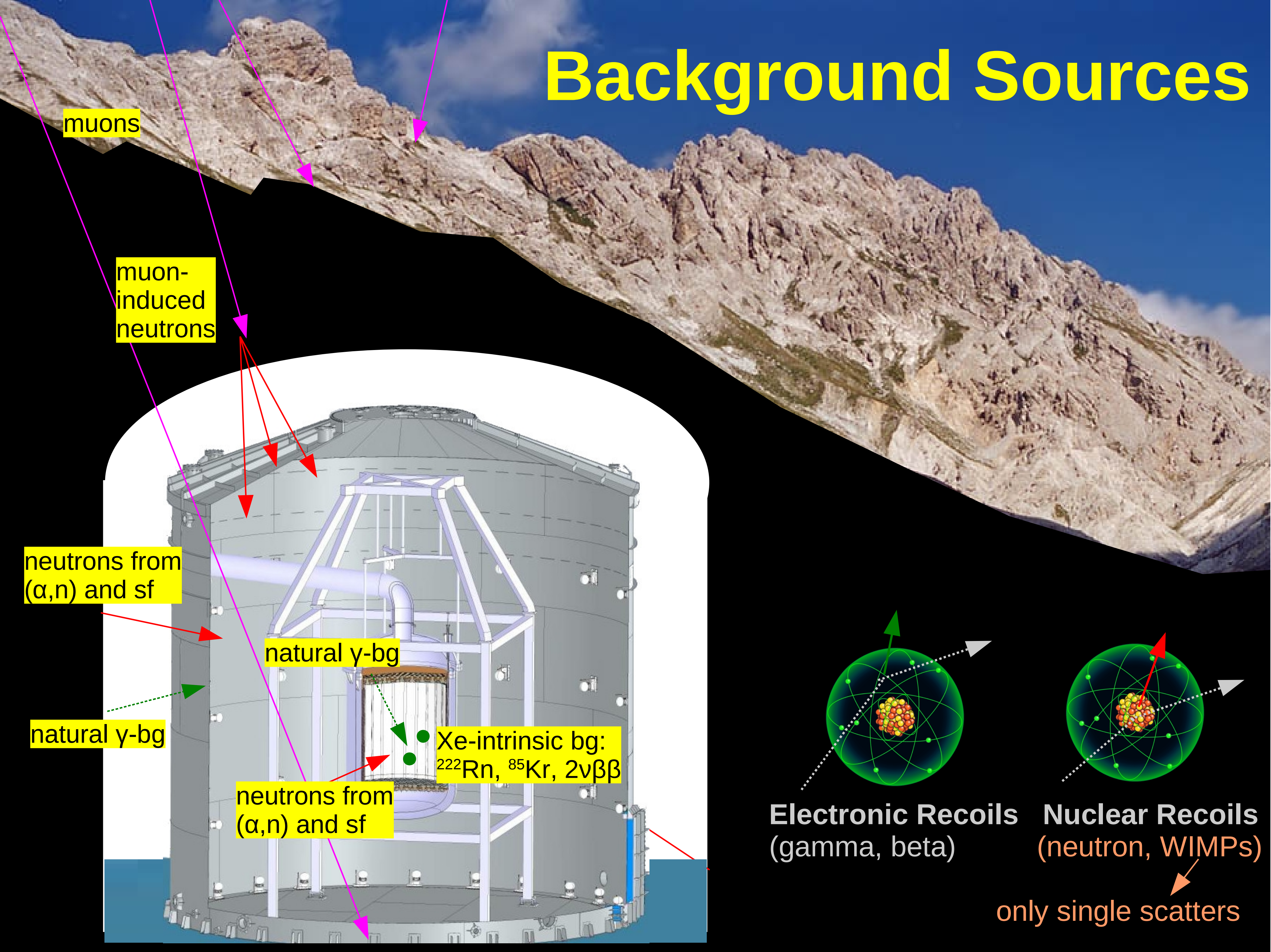
We are dealing with

- extremely **low rates** (1 – 1000 Hz)
- extremely **low thresholds** (2 keV)
- extremely **low radioactive** backgrounds





Background Sources



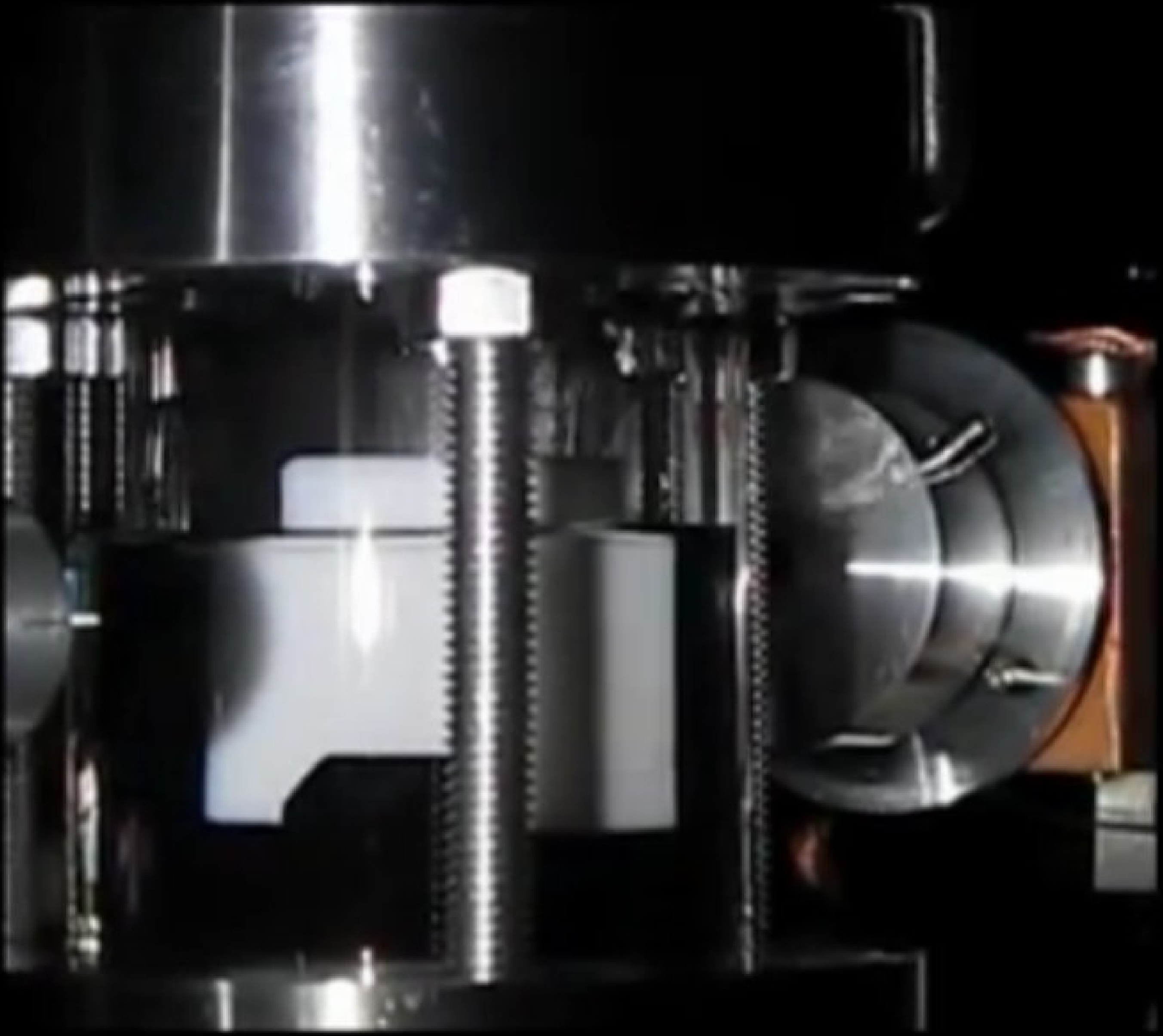
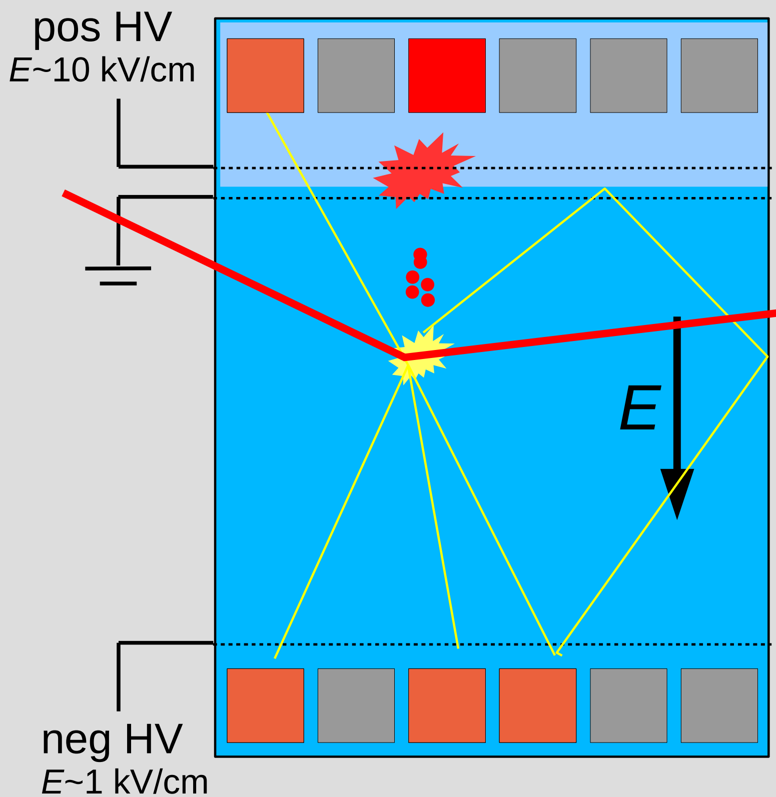


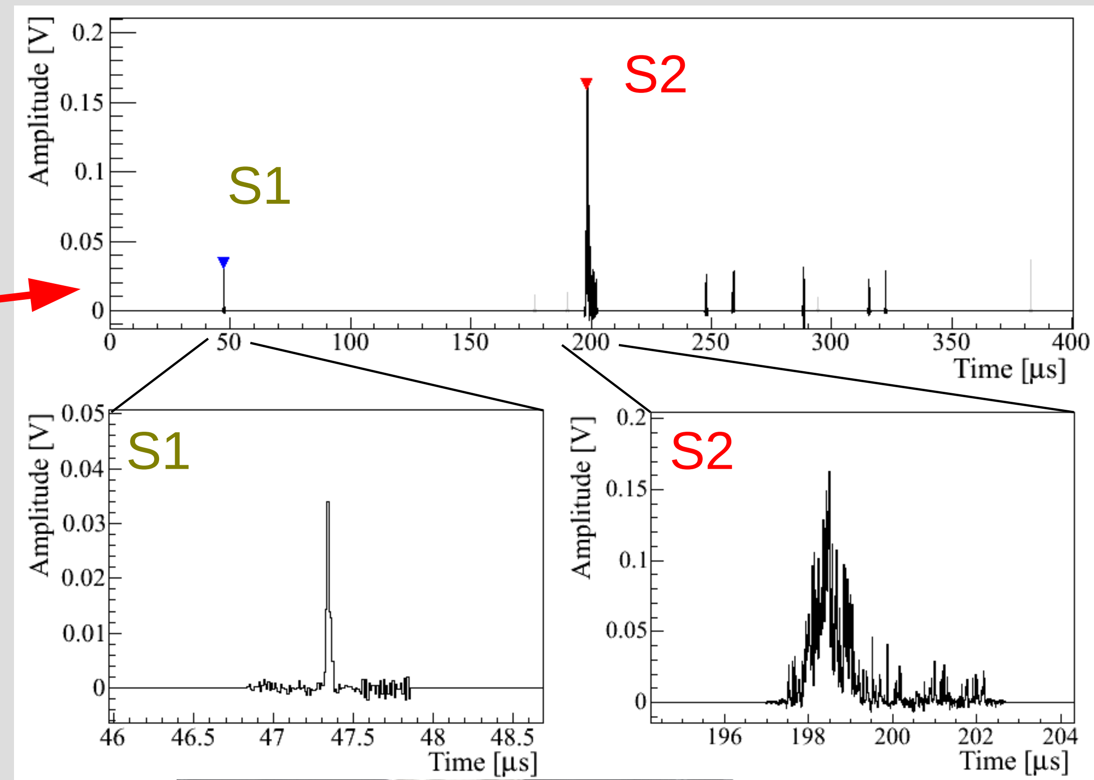
Image from C. Levy (U Münster)

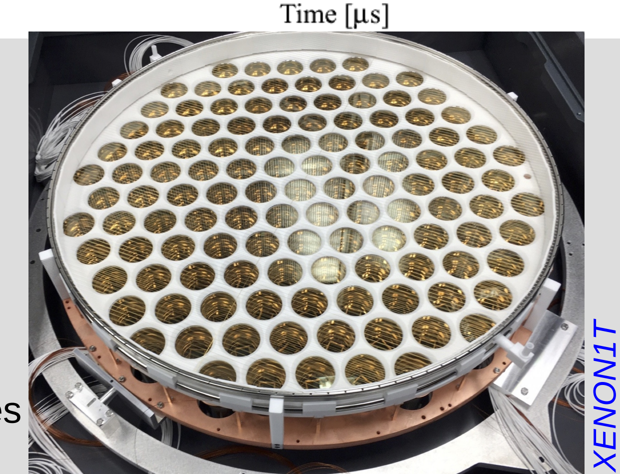
Dual Phase TPC

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

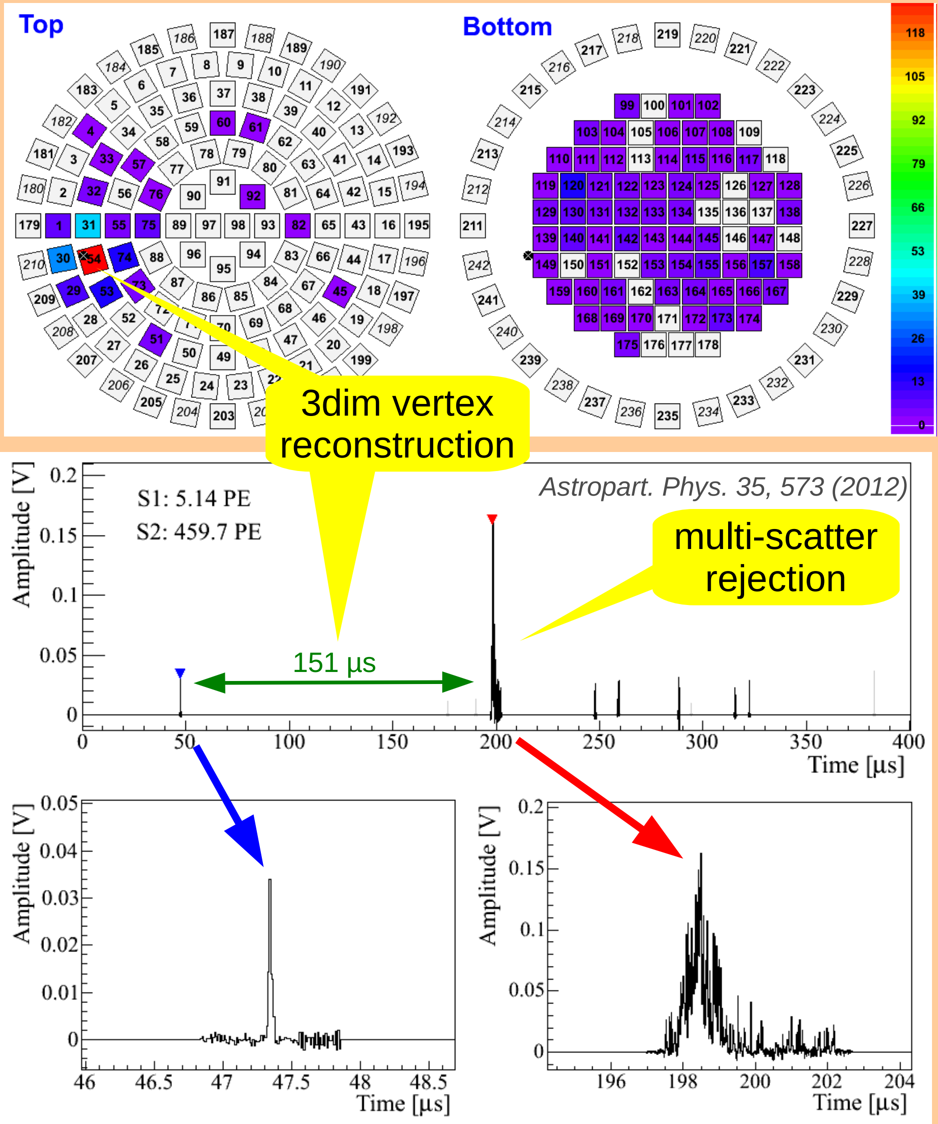
TPC = time projection chamber

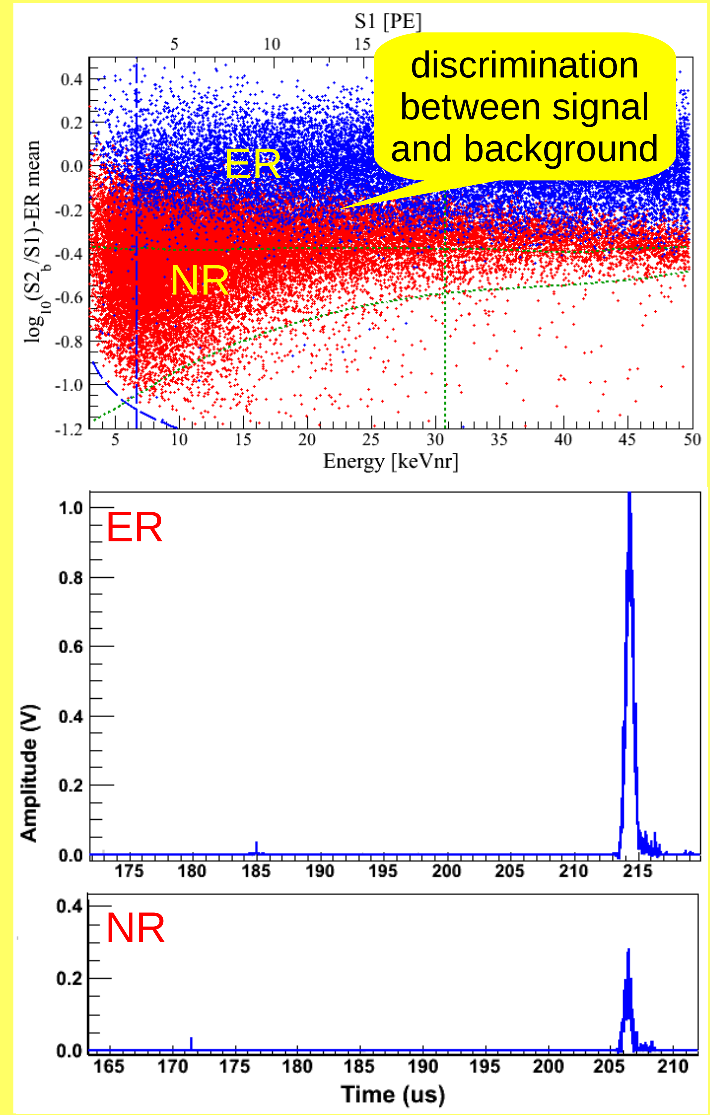






Dual Phase TPC





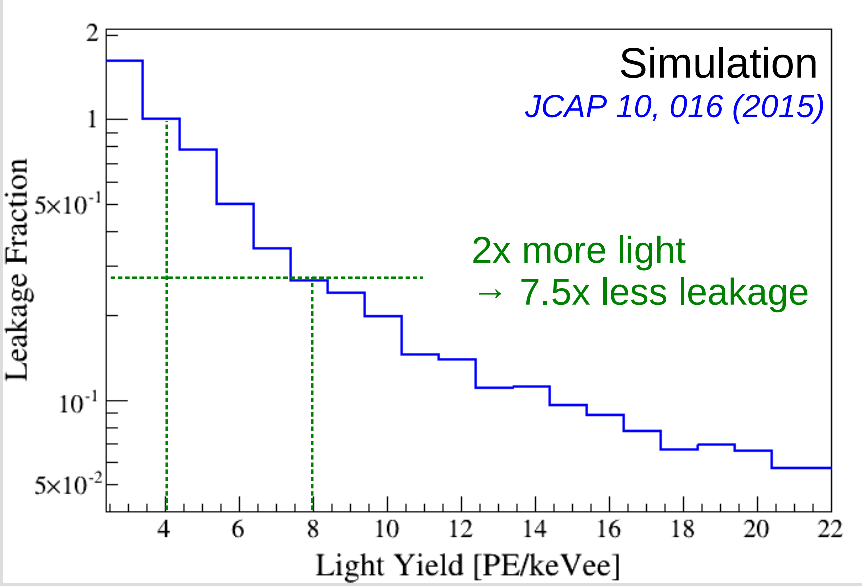
Figures from XENON100

Dual Phase TPC

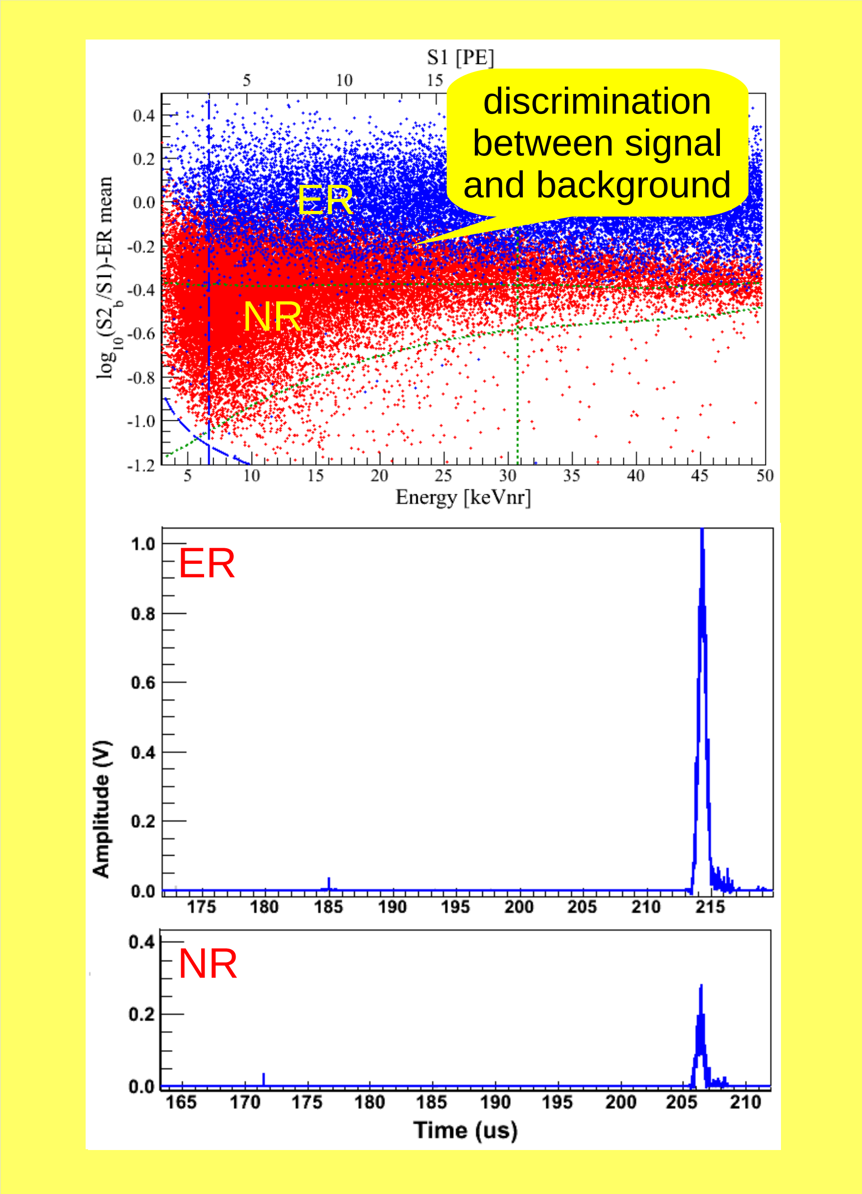
ER Rejection	NR Acceptance
99.50%	~50%
99.75%	~40%
99.90%	~30%

XENON100 achieved

Improve rejection (at a given acceptance)
→ need more S1 light!

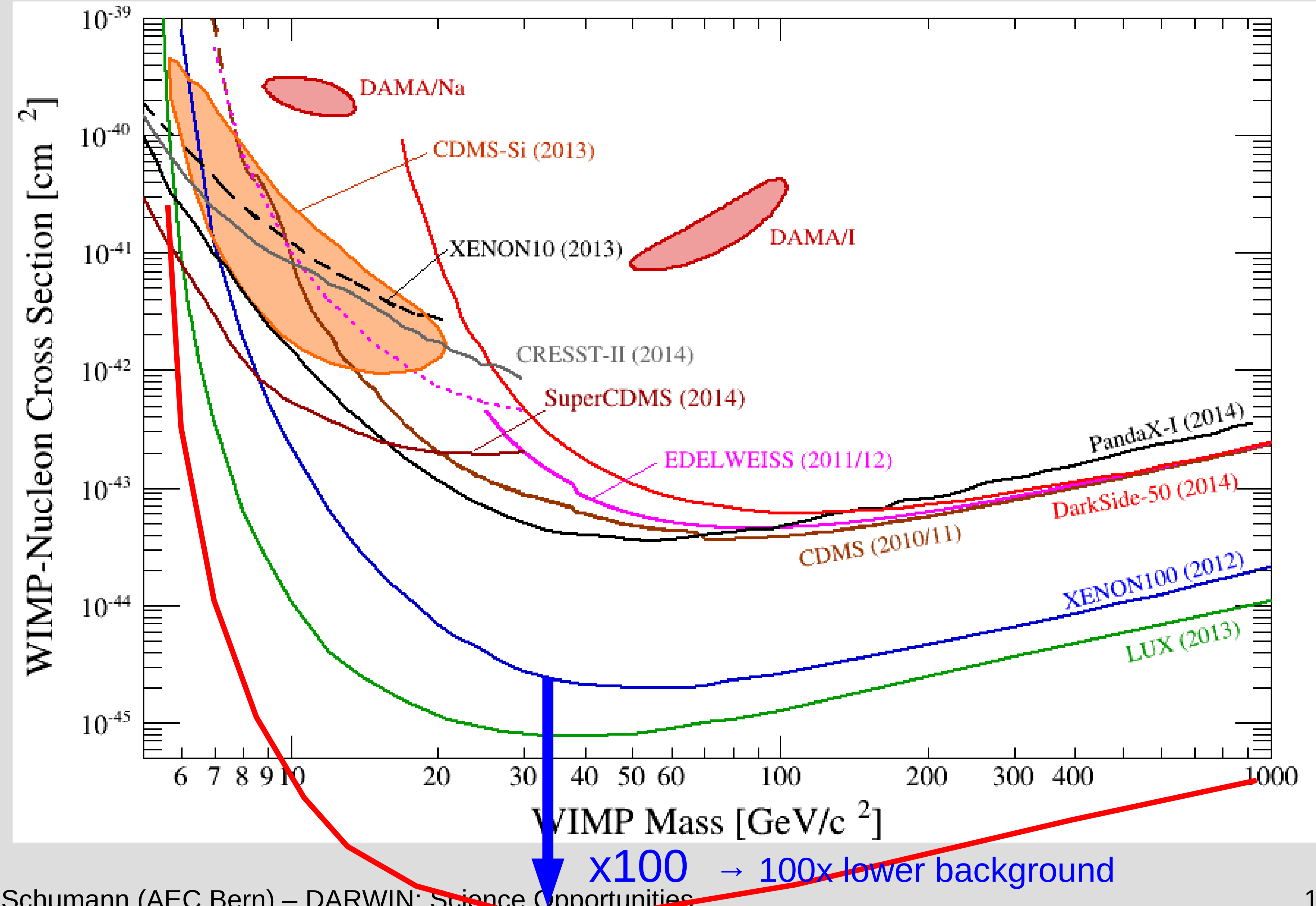


→ rejection levels of 99.98% are in reach!



Figures from XENON100

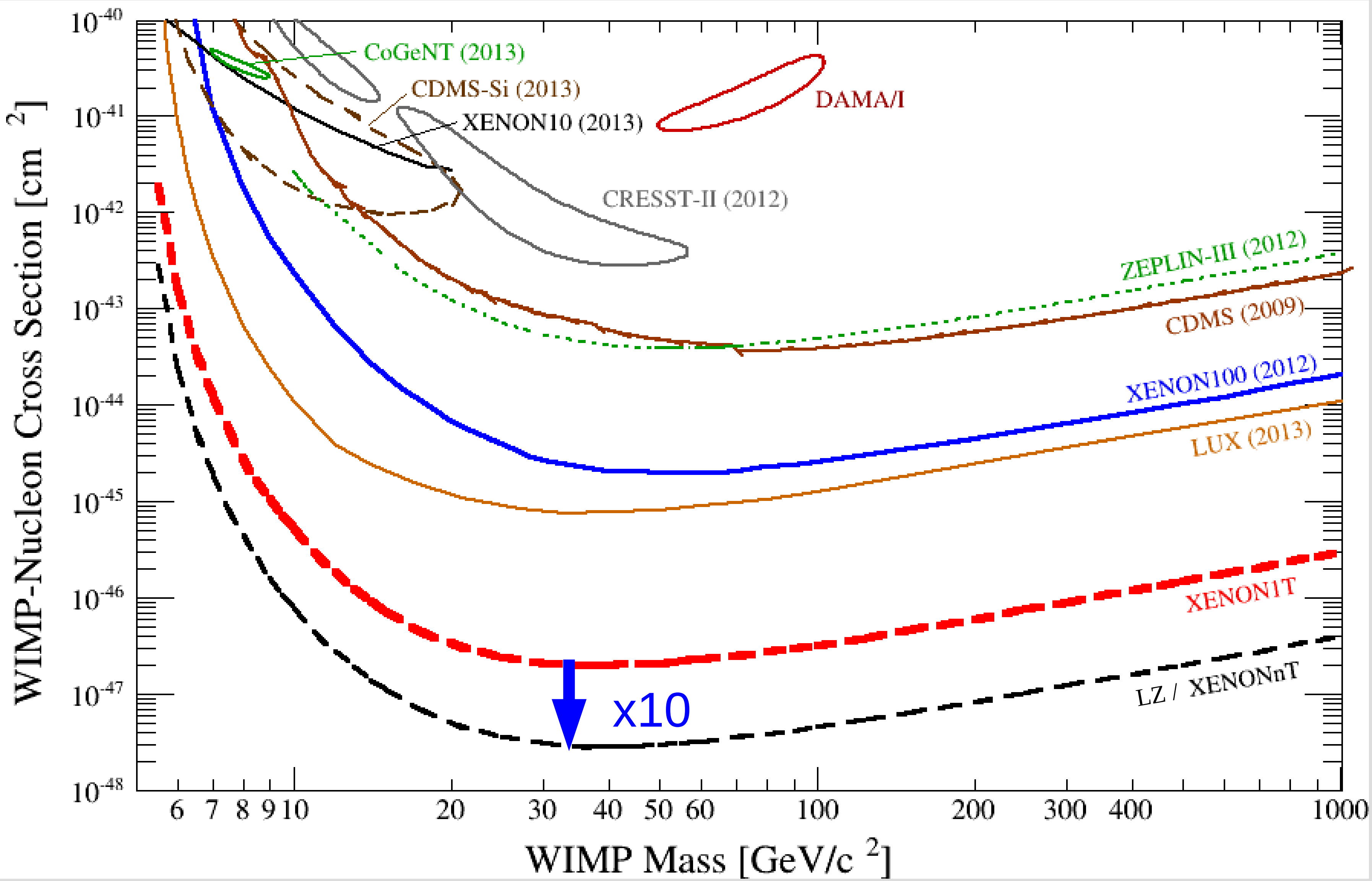
The current WIMP Landscape



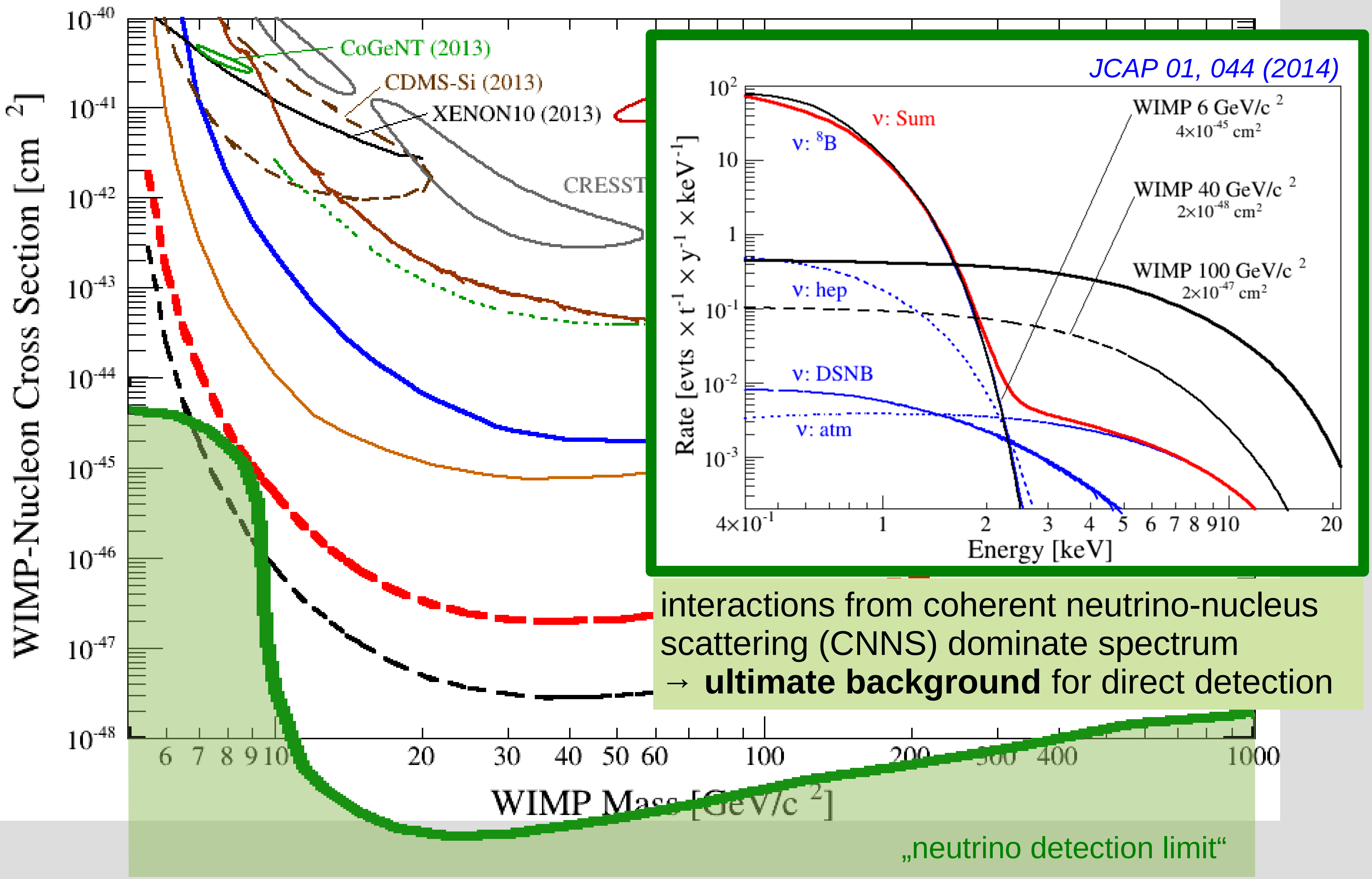
XENON1T @ LNGS


Xe
XENON
Dark Matter Project

The XENON Future

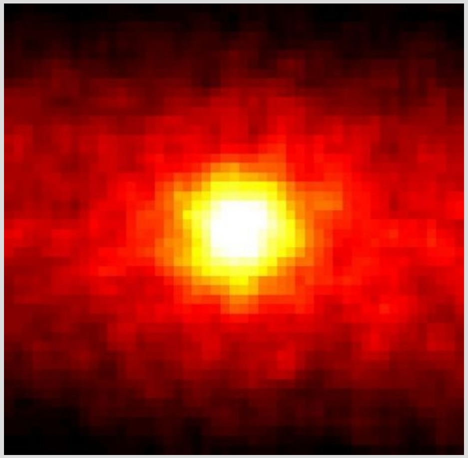


The XENON Future

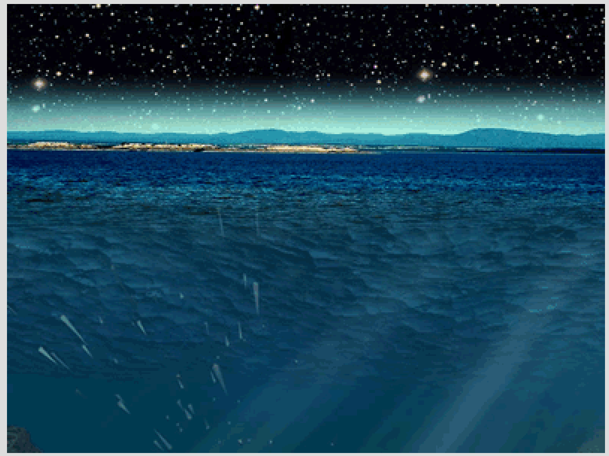


interactions from coherent neutrino-nucleus scattering (CNNS) dominate spectrum
→ **ultimate background** for direct detection

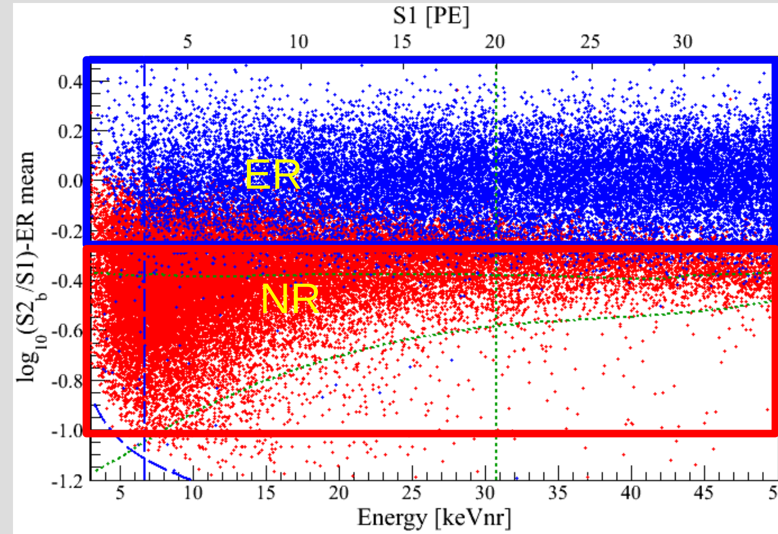
Cosmic Neutrino Sources

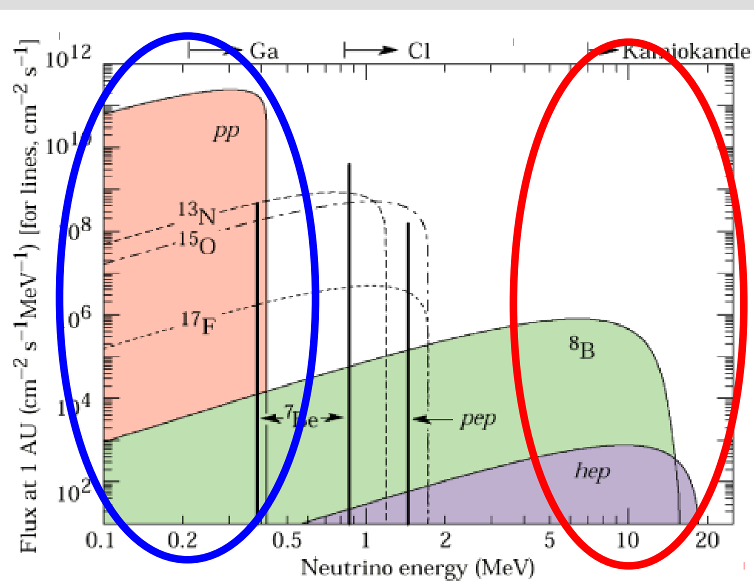


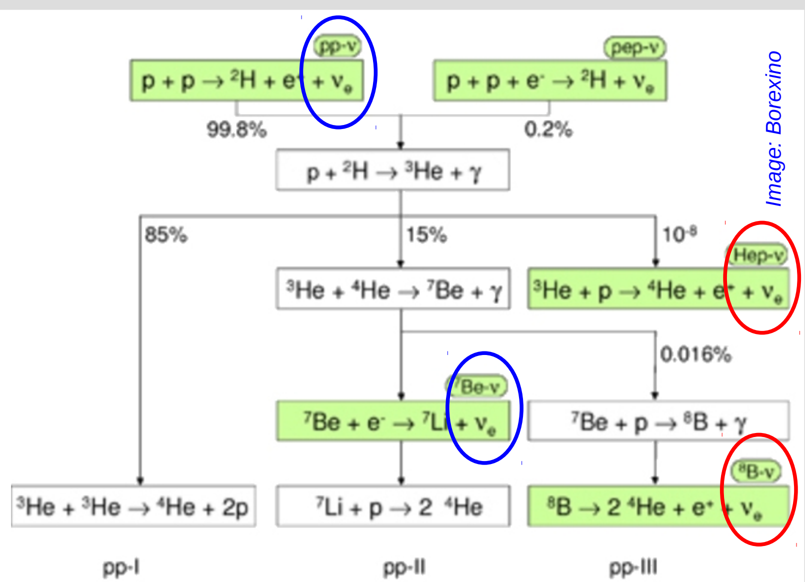
Solar neutrinos:
pp, ^{7}Be – ^{8}B, hep



Atmospheric neutrinos
+ diffuse SN background



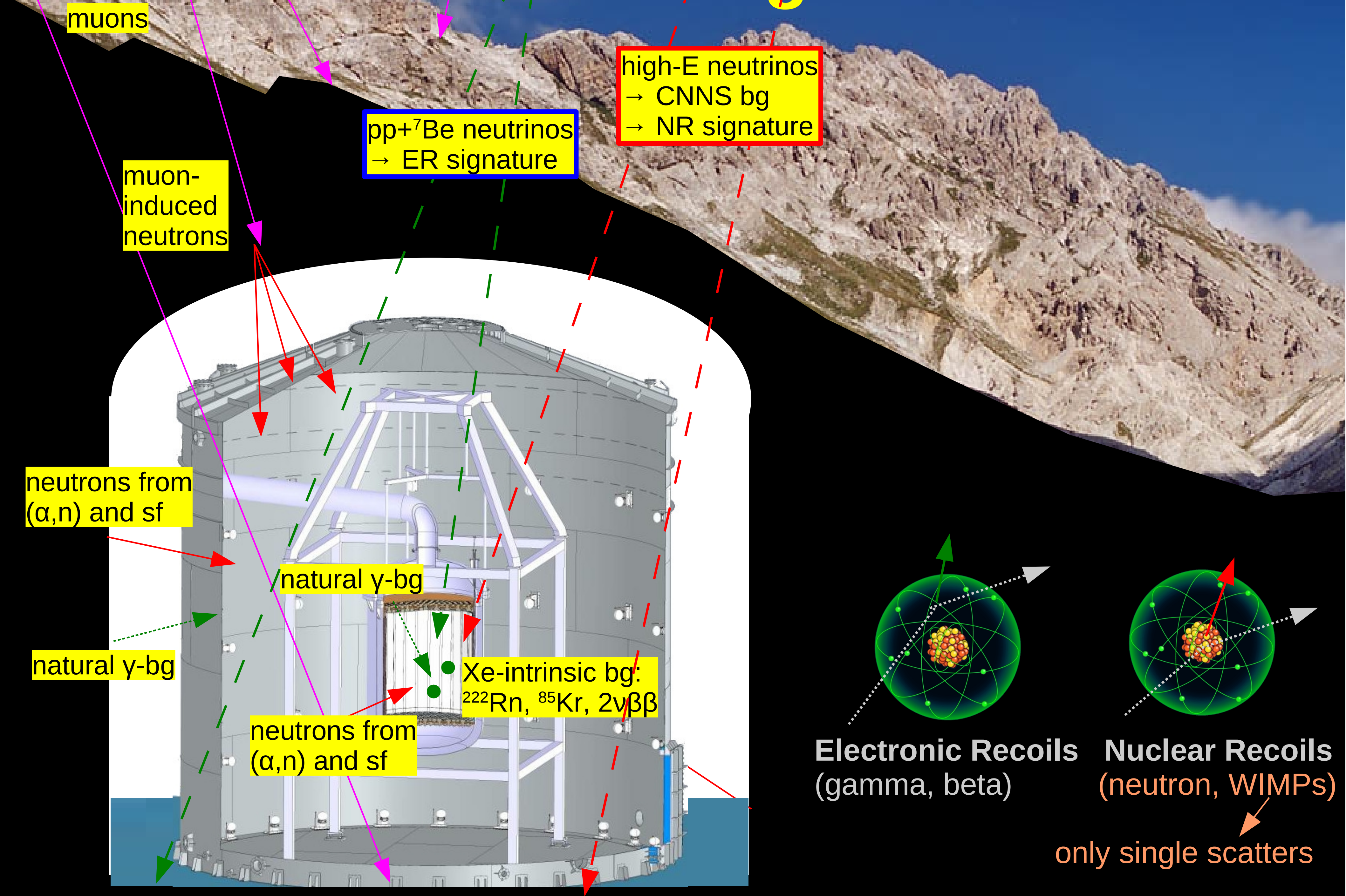




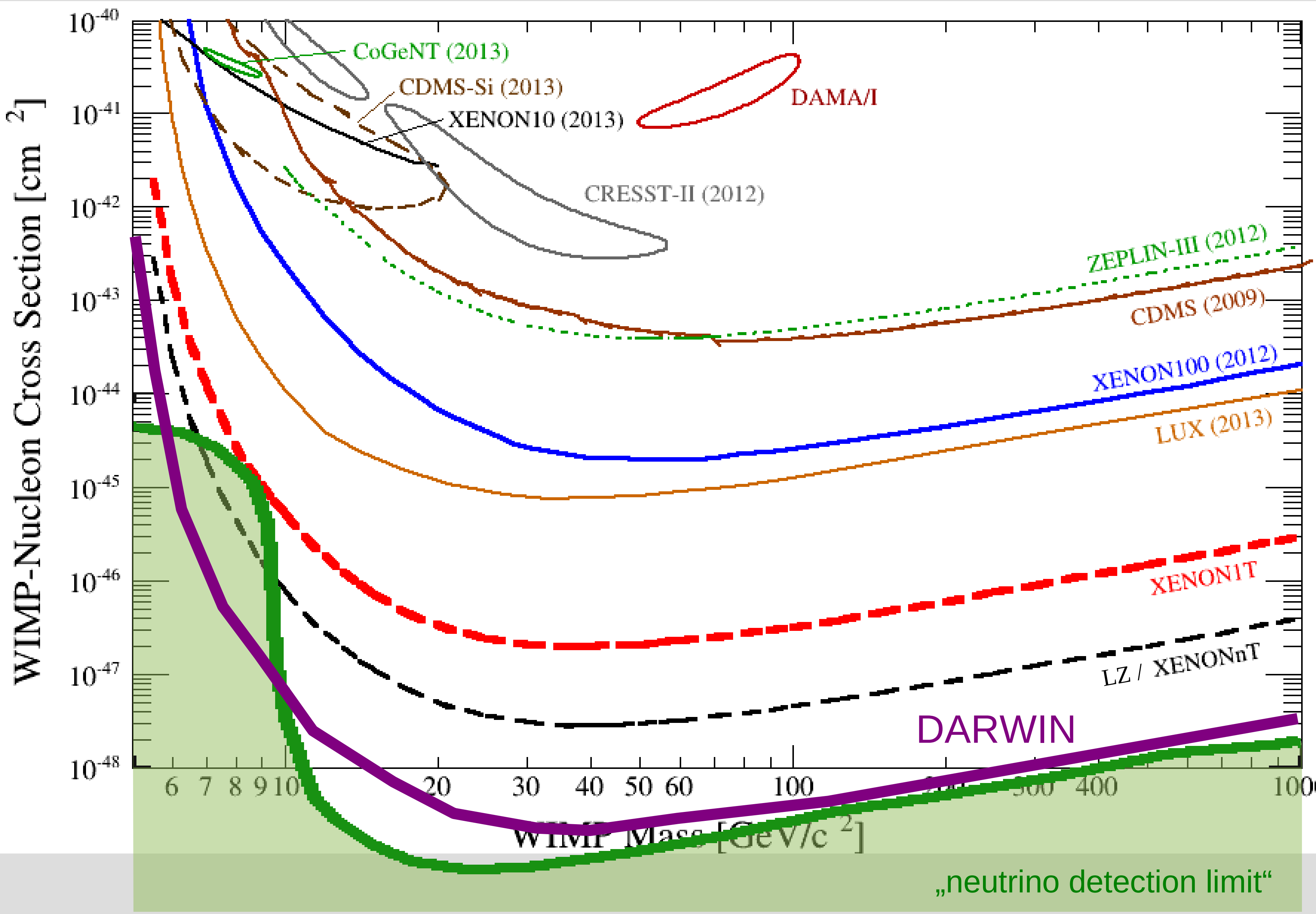
low-E solar neutrinos interact with electrons
→ electronic recoil
→ **can be rejected**

high E neutrinos (solar+DSNB) interact with Xe nuclei
→ nuclear recoil
→ **looks like a WIMP**

new Background Sources

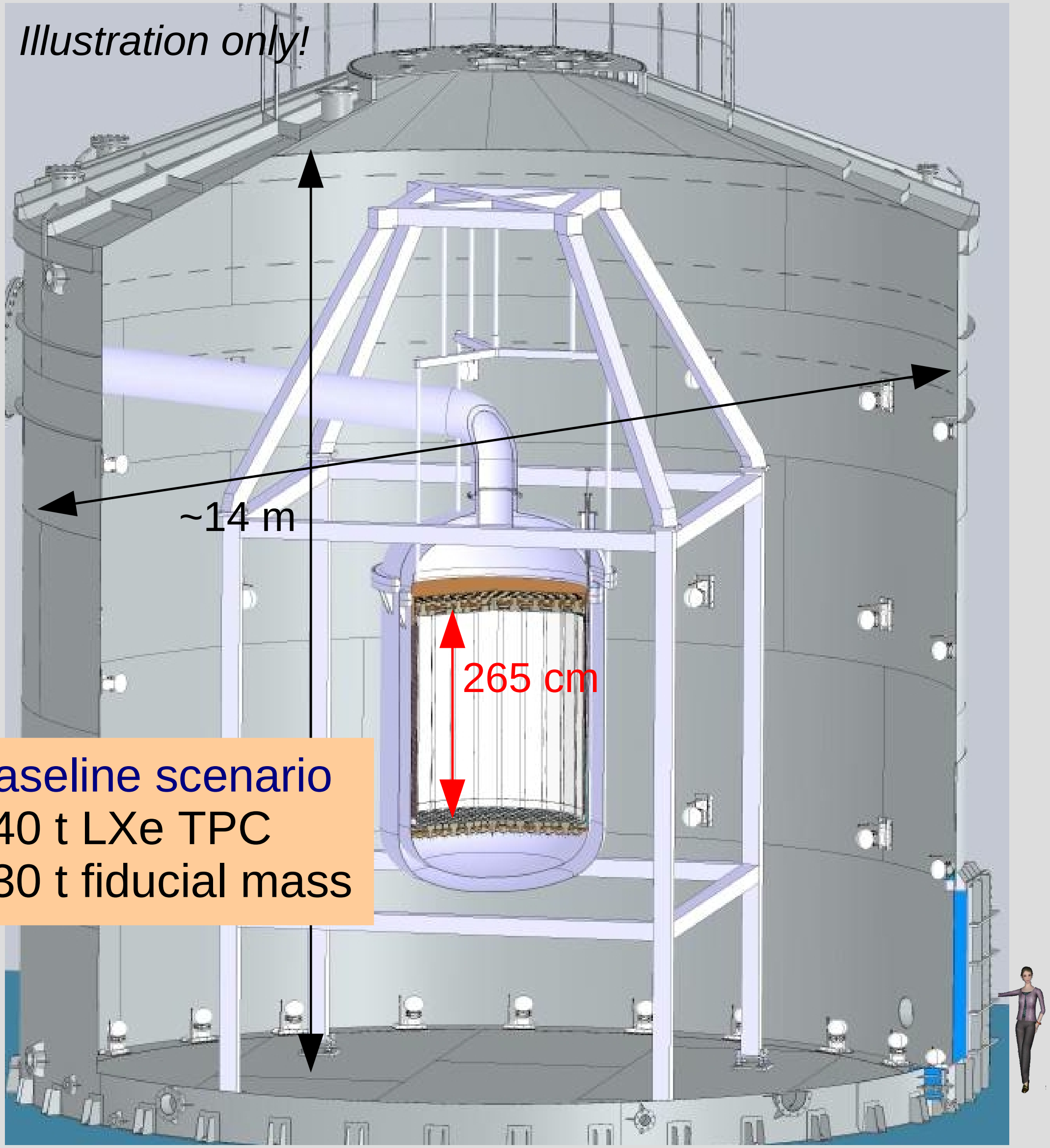


The DARWIN goal



DARWIN The ultimate WIMP Detector

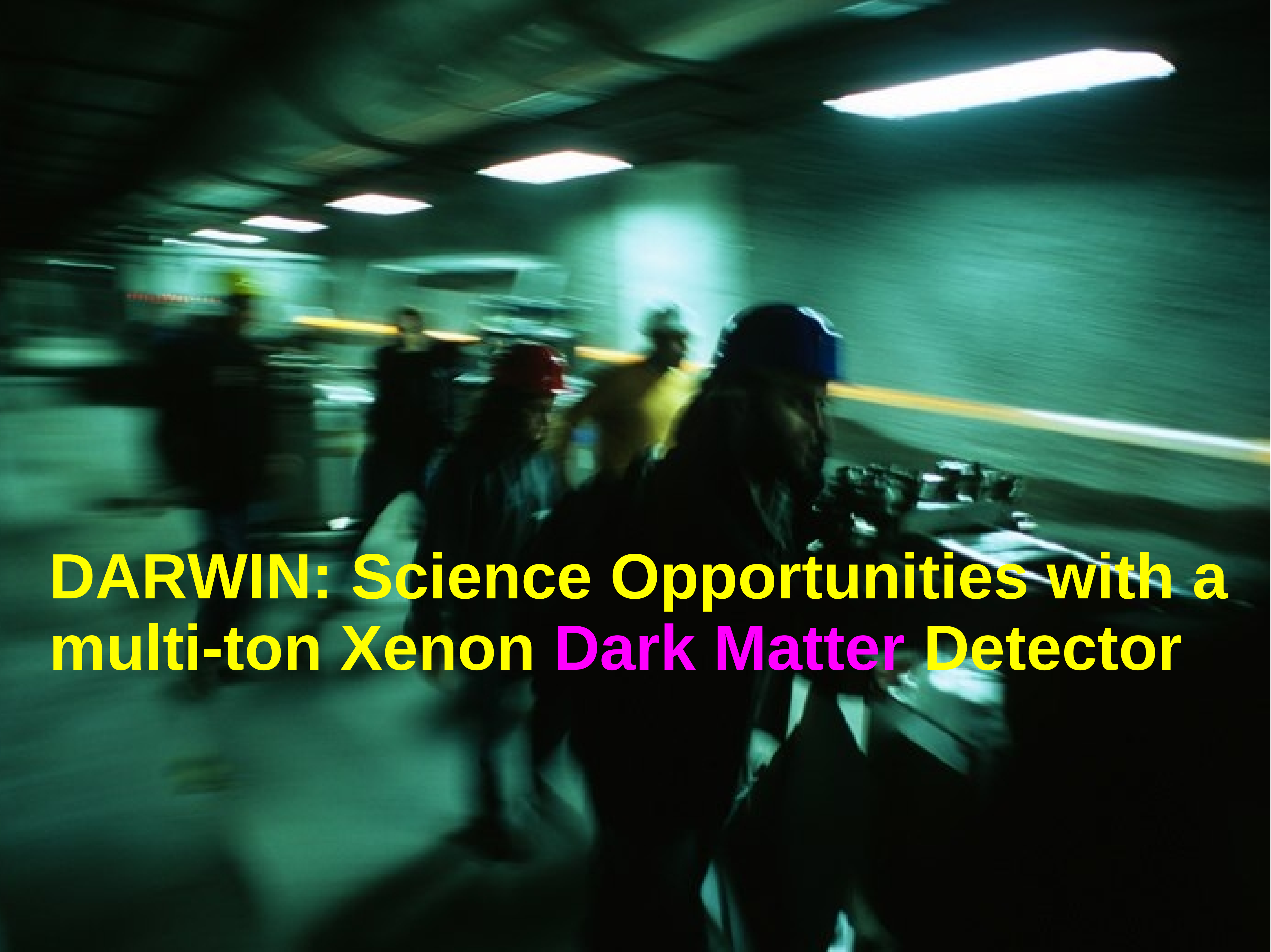
www.darwin-observatory.org

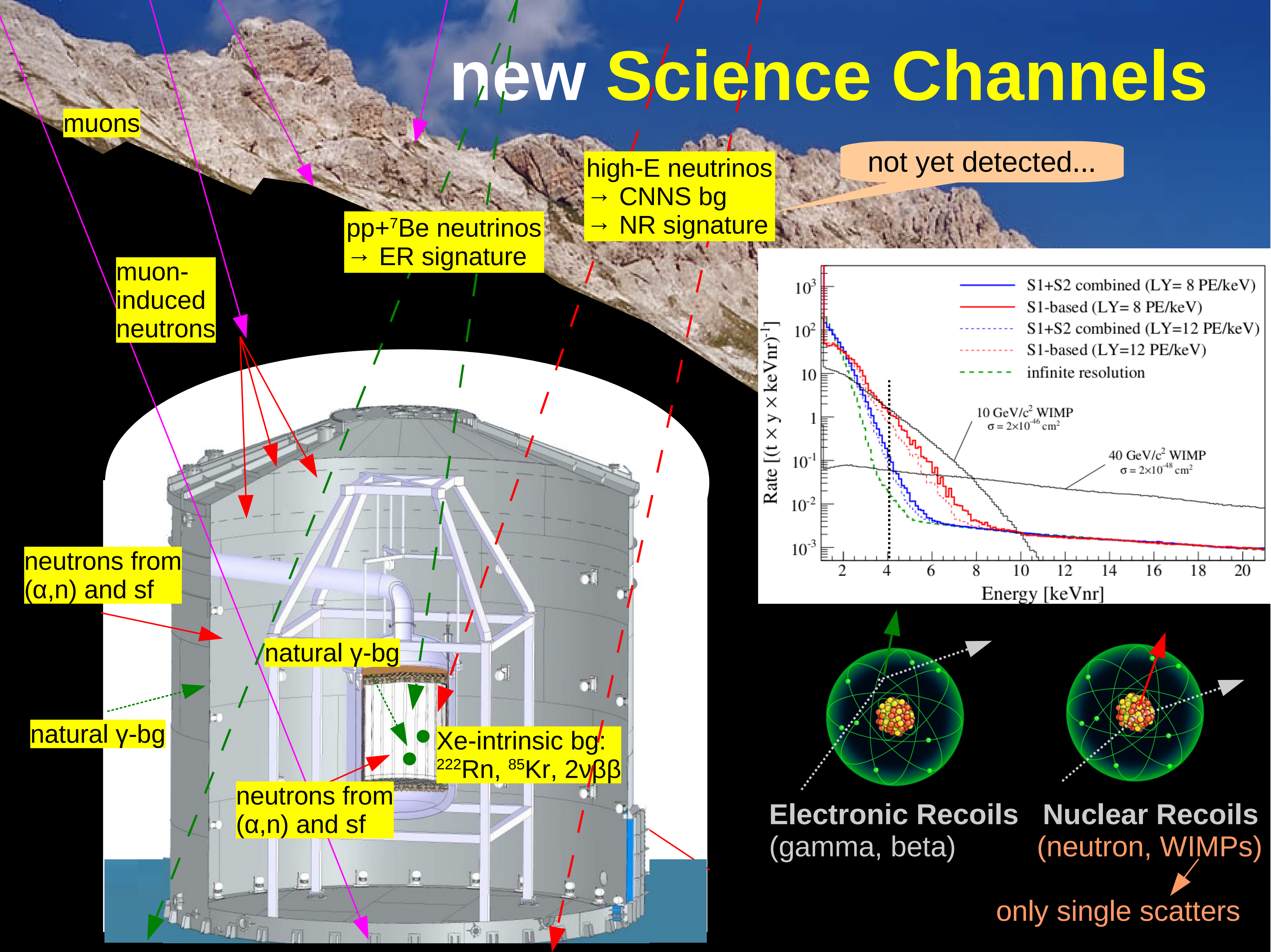


Baseline scenario
~40 t LXe TPC
~30 t fiducial mass

- 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

DARWIN: Science Opportunities with a multi-ton Xenon Dark Matter Detector




new Science Channels
muons
muon-induced neutrons
pp+^{7}Be neutrinos → ER signature
high-E neutrinos → CNNS bg → NR signature
not yet detected...
neutrons from (α,n) and sf
natural γ-bg
natural γ-bg
Xe-intrinsic bg: ^{222}Rn, ^{85}Kr, 2νββ
neutrons from (α,n) and sf
S1+S2 combined (LY= 8 PE/keV)
S1-based (LY= 8 PE/keV)
S1+S2 combined (LY=12 PE/keV)
S1-based (LY=12 PE/keV)
infinite resolution
10 GeV/c^2 WIMP σ = 2×10^{-46} cm^2
40 GeV/c^2 WIMP σ = 2×10^{-48} cm^2
Rate [(t × y × keVnr)$^{-1}$]
Energy [keVnr]
Electronic Recoils (gamma, beta)
Nuclear Recoils (neutron, WIMPs)
only single scatters

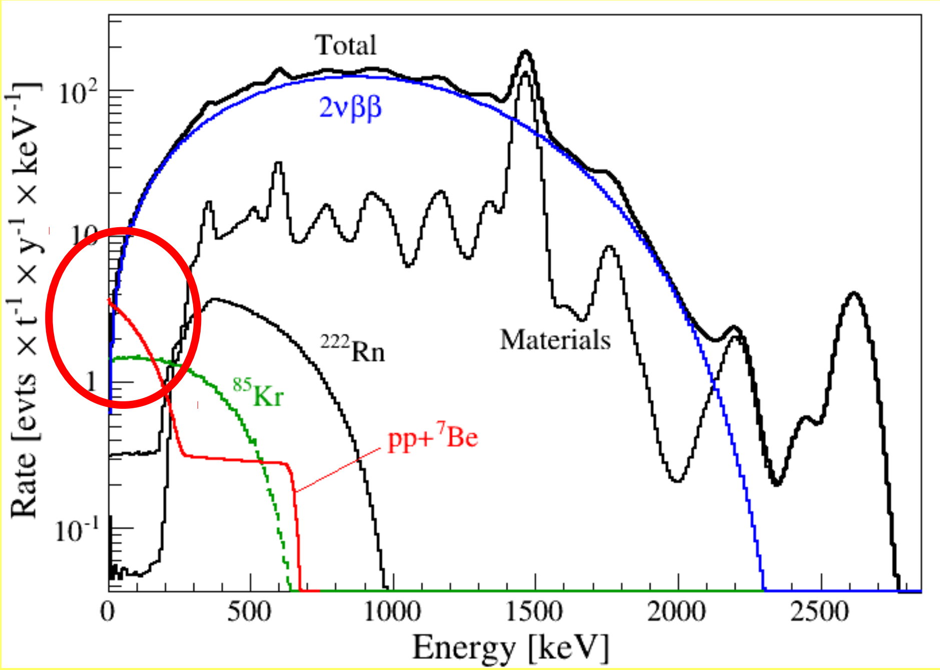
CNNS
solar ν

pp-Neutrinos in DARWIN

a new physics channel!

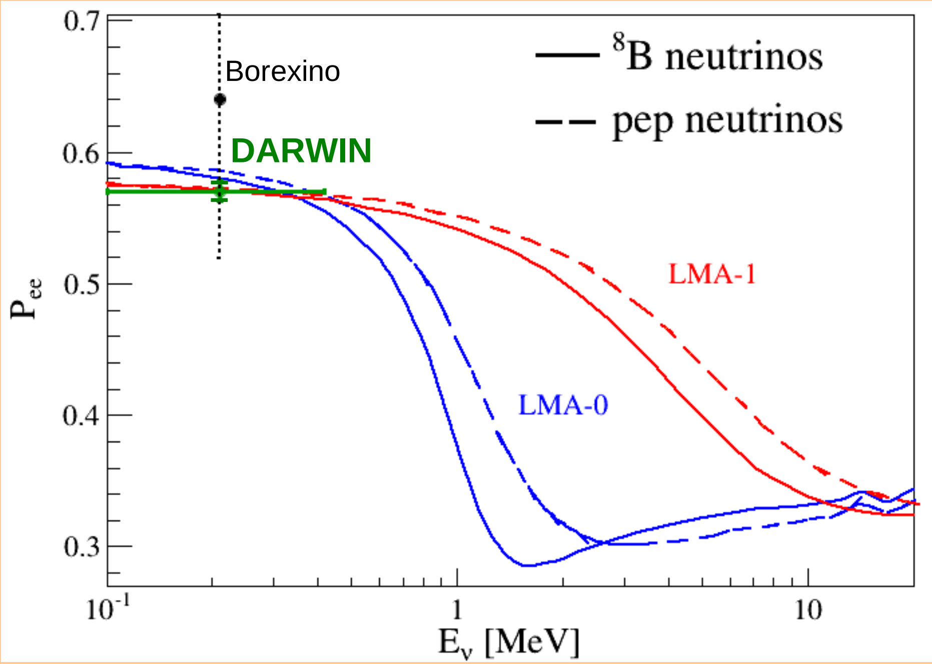
JCAP 01, 044 (2014)

Realistic, detailed background study



- pp-neutrinos dominate low *E* spectrum
- main ER spectrum from 2νββ of ^{136}Xe
- ^{85}Kr (0.1 ppt ^{nat}Kr) and ^{222}Rn (0.1 μBq) small, detector materials irrelevant

Neutrino interactions



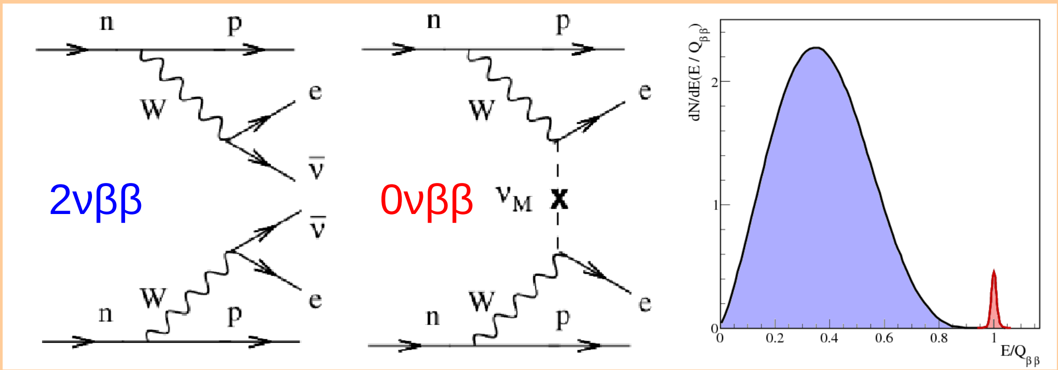
- 30t target mass, 2-30 keV window
  → 2850 neutrinos per year (89% pp)
  → achieve 0.8% statistical precision on pp-flux (→ P_{ee}) in 5 years

CNNS
solar ν
0νββ

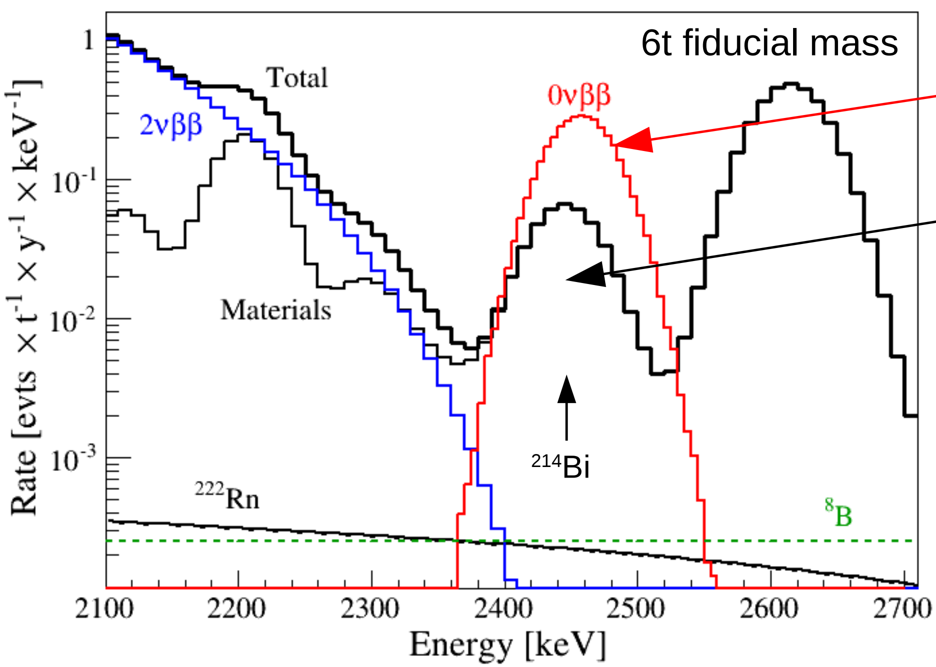
^{136}Xe: 0ν double-β decay

DARWIN

JCAP 01, 044 (2014)



also accessible: ^{134}Xe, ^{126}Xe, ^{124}Xe
N. Barros et al., J. Phys. G 41, 115105 (2014)



EXO-200 limit

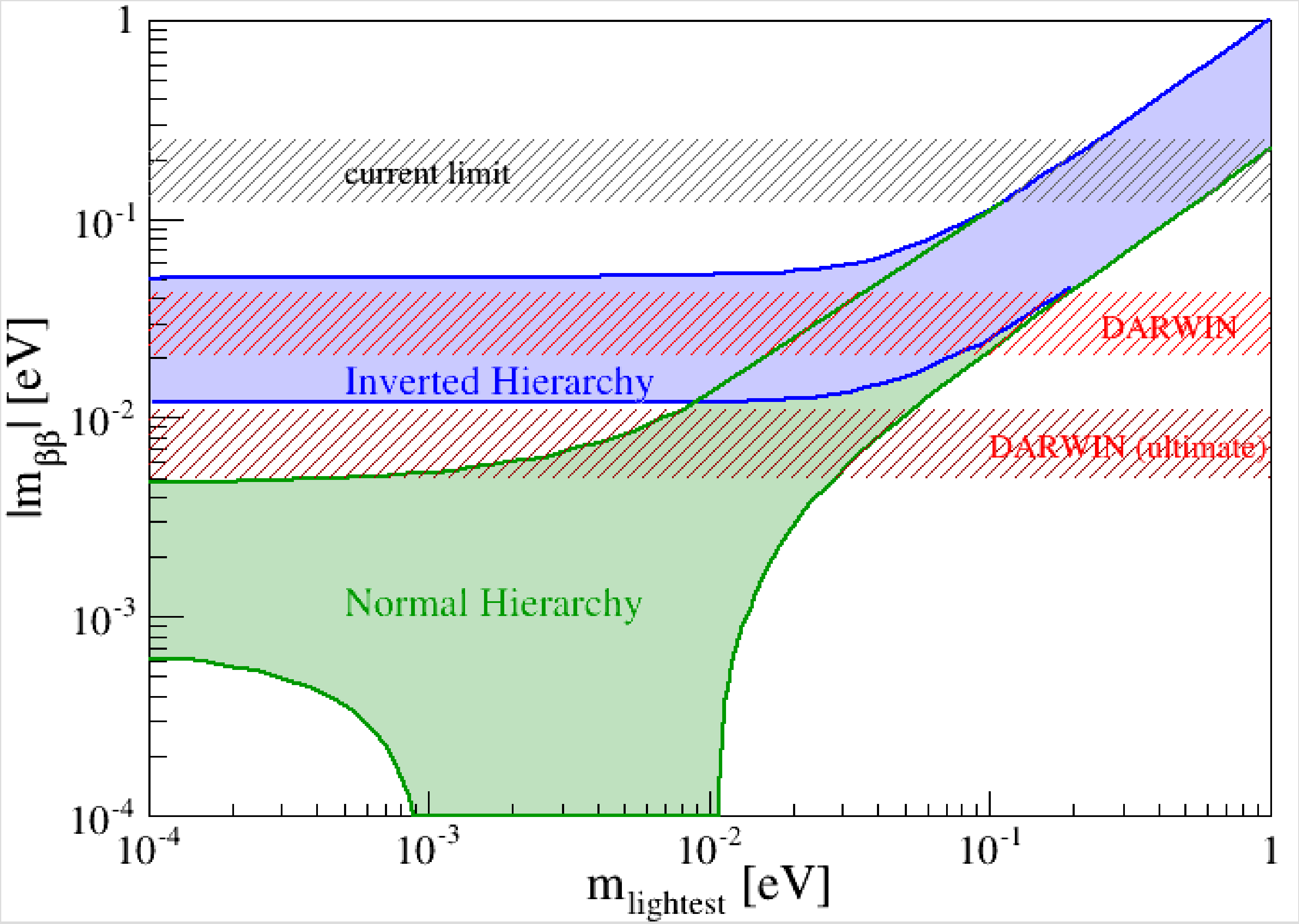
no ^{136}Xe enrichment!

Background (6t out of 14t): 4.6 evts/t/y in ±3σ

- σ/E~1% at $Q_{\beta\beta}$, 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)

^{136}Xe: 0ν double-β decay

to be published



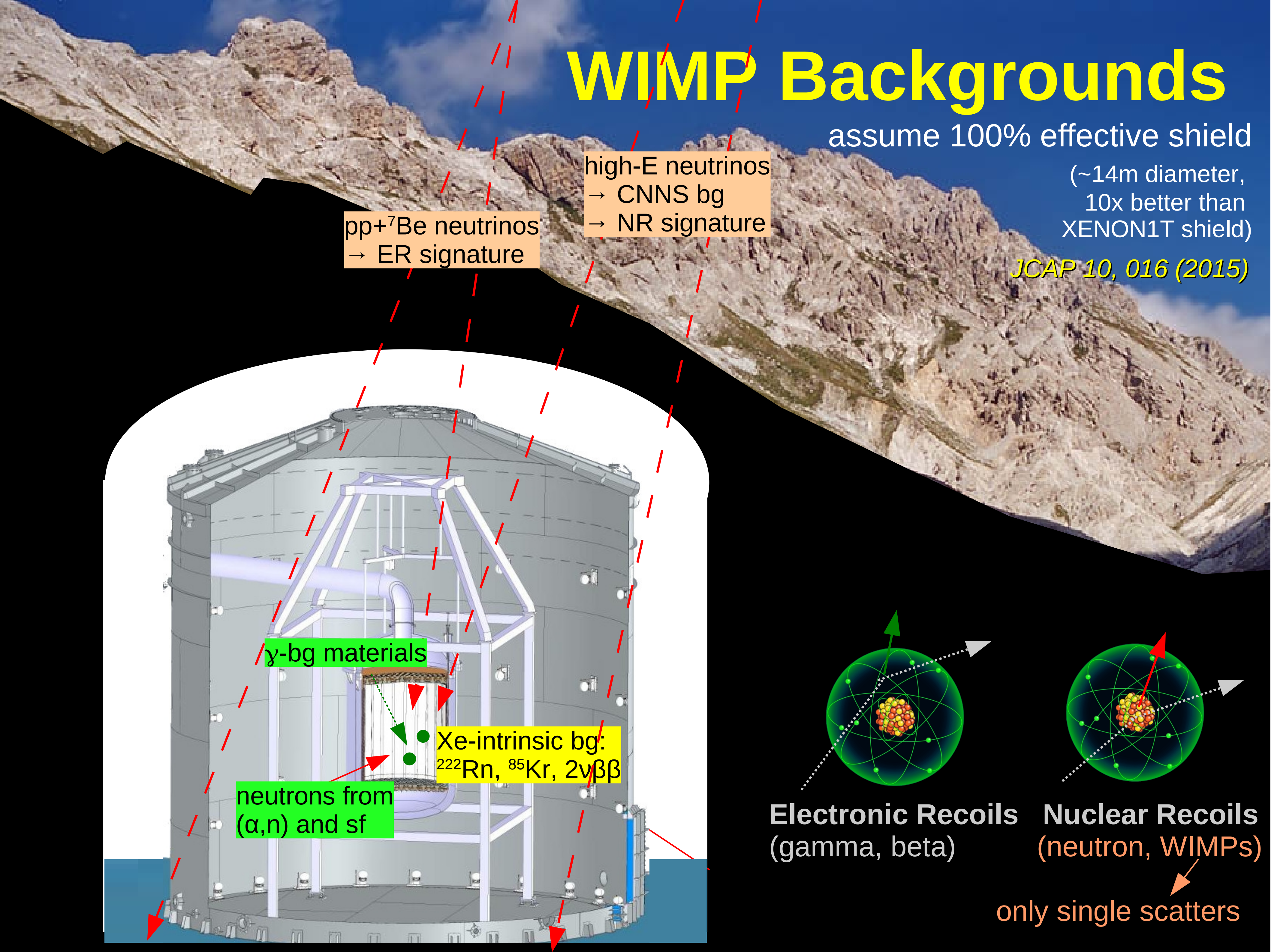
only neutrino background

WIMP Backgrounds

assume 100% effective shield

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

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

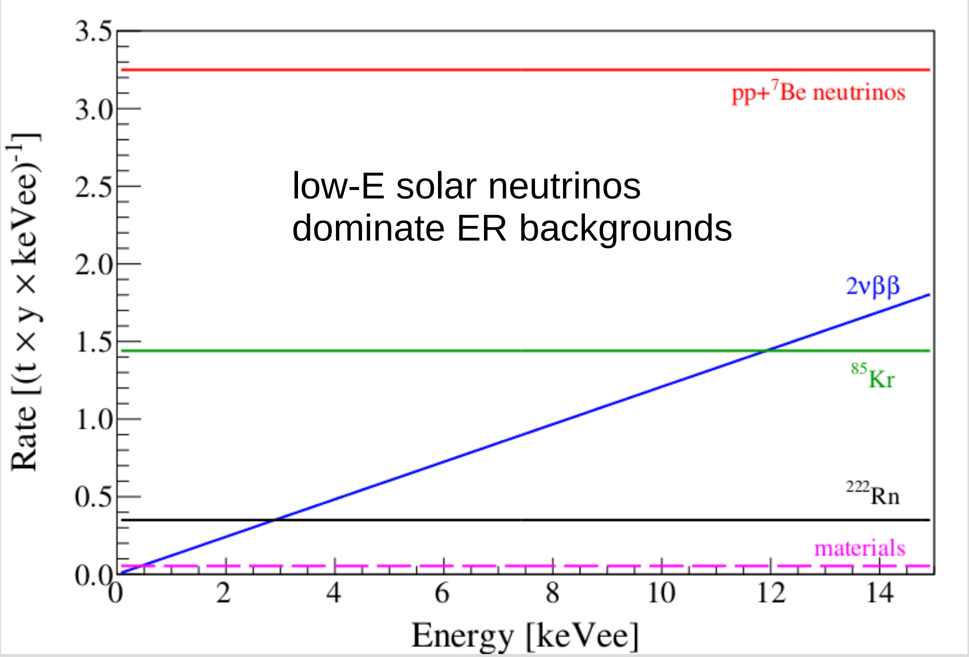
MC simulation of detector made of main components (PTFE, CU, PMTs): subdominant after ~15 cm fiducial cut

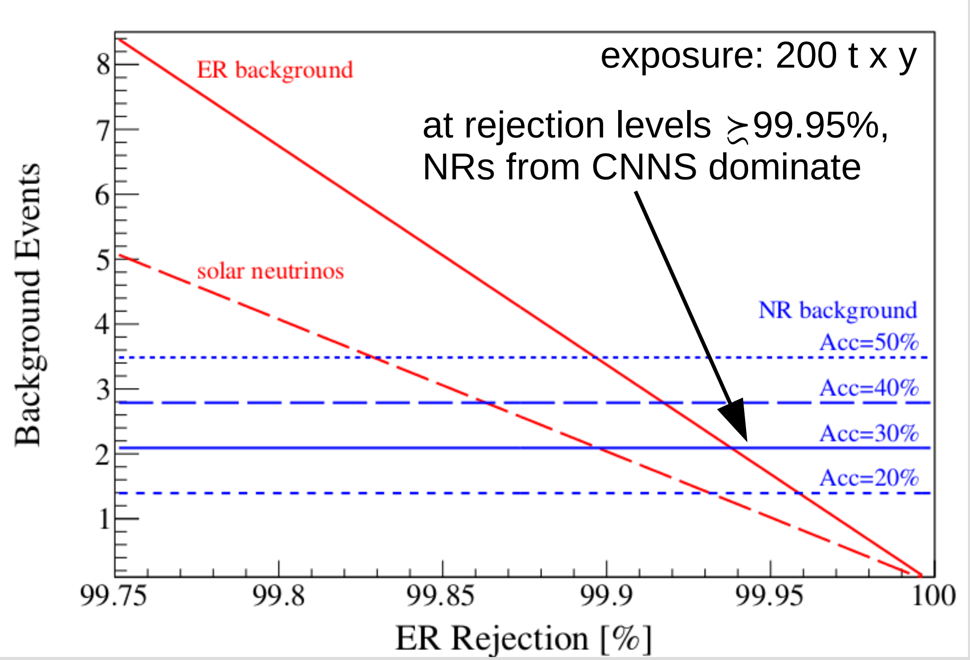
^{85}Kr: 2x below XENON1T design
(0.03 ppt achieved: *EPJ C 74 (2014) 2746*)

^{222}Rn: 100x below XENON1T design

^{136}Xe: assume natural xenon

consider all relevant neutrinos



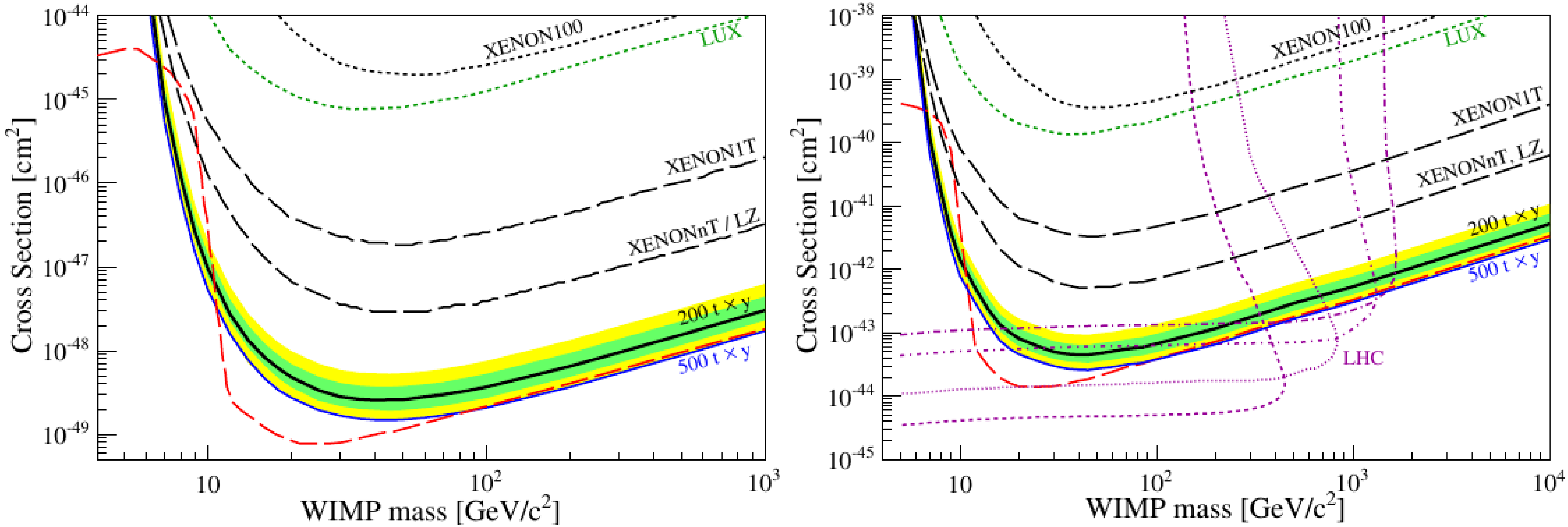


DARWIN WIMP Sensitivity

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 keVnr energy window

spin-*in*dependent couplings | spin-*de*pendent couplings (n-only)

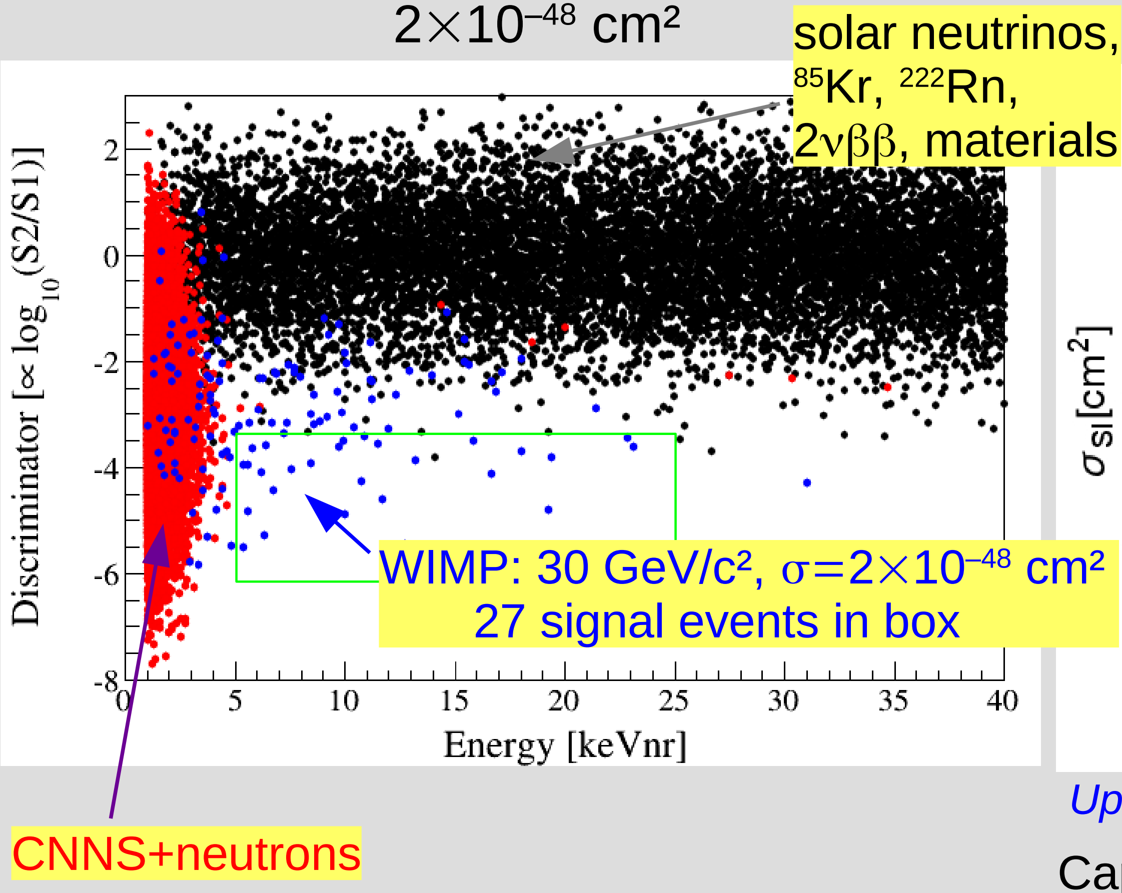


best sensitivity: 2.5 x 10^{-49} cm² @ 40 GeV/c² | excellent complementarity to LHC searches

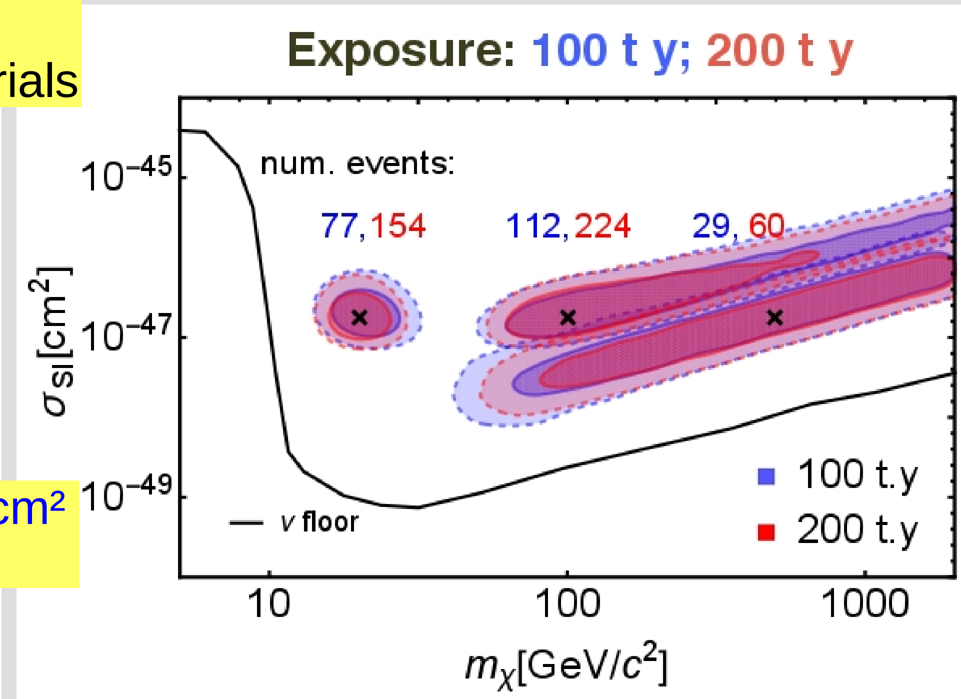
→ also sensitive to inelastic WIMP interactions

WIMP Spectroscopy

2×10^{-48} cm²



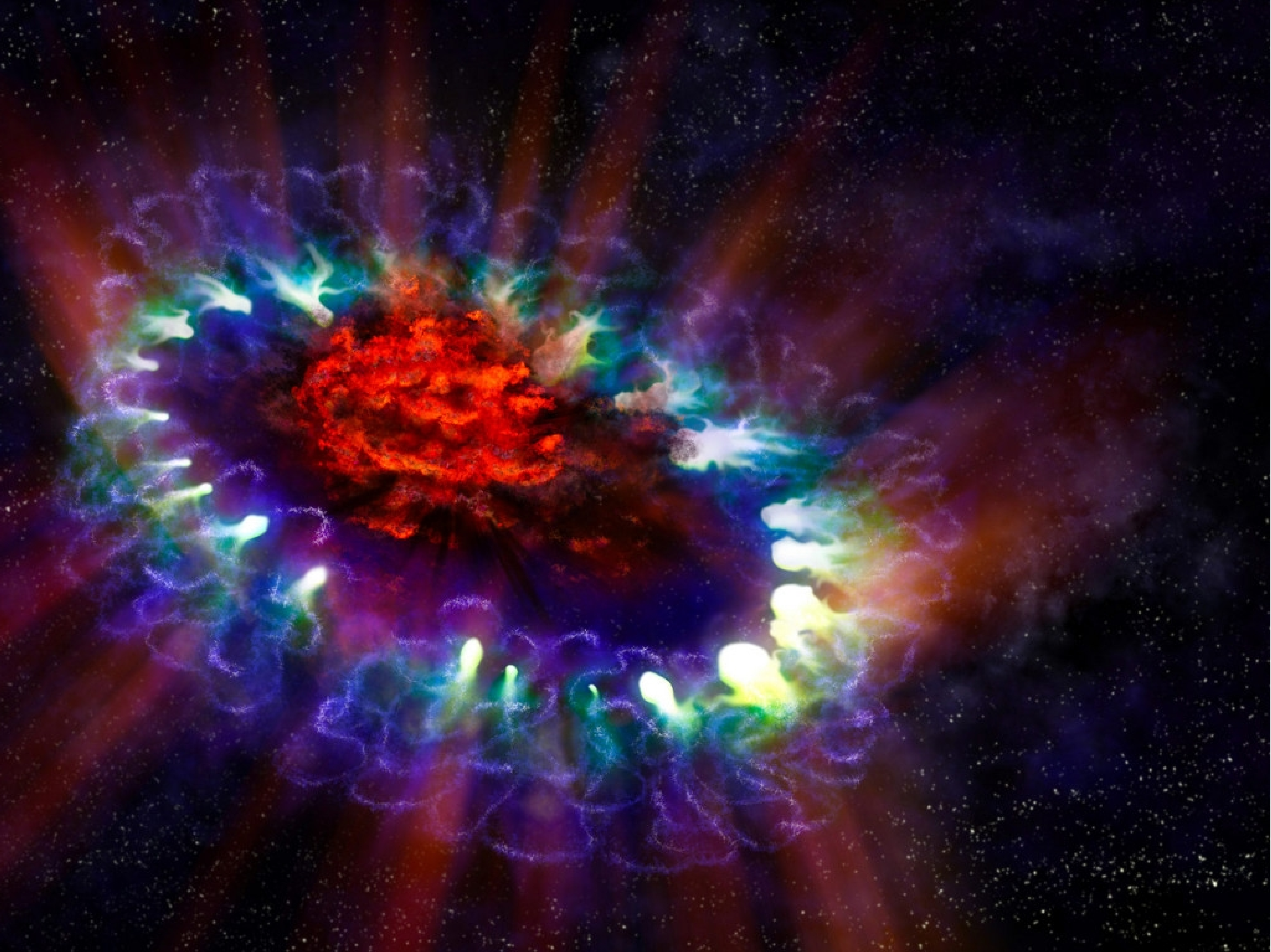
2×10^{-47} cm²

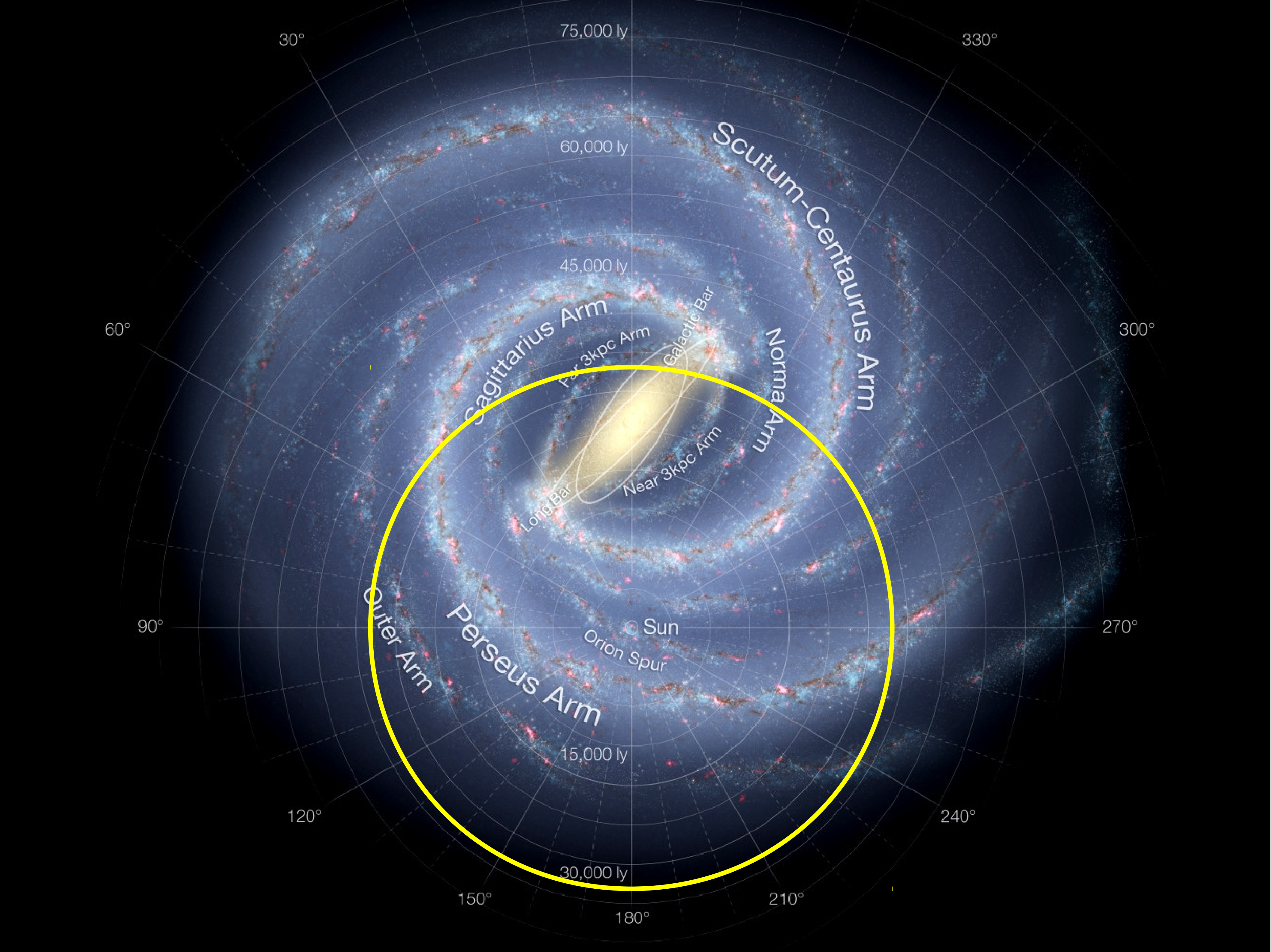


Update of Newstead et al., PRD 8, 076011 (2013)

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



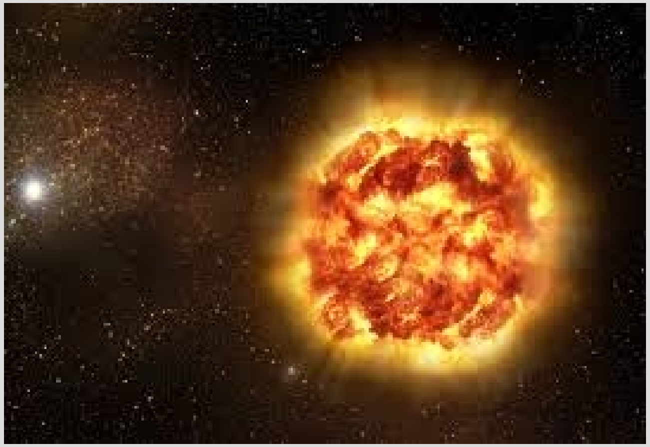


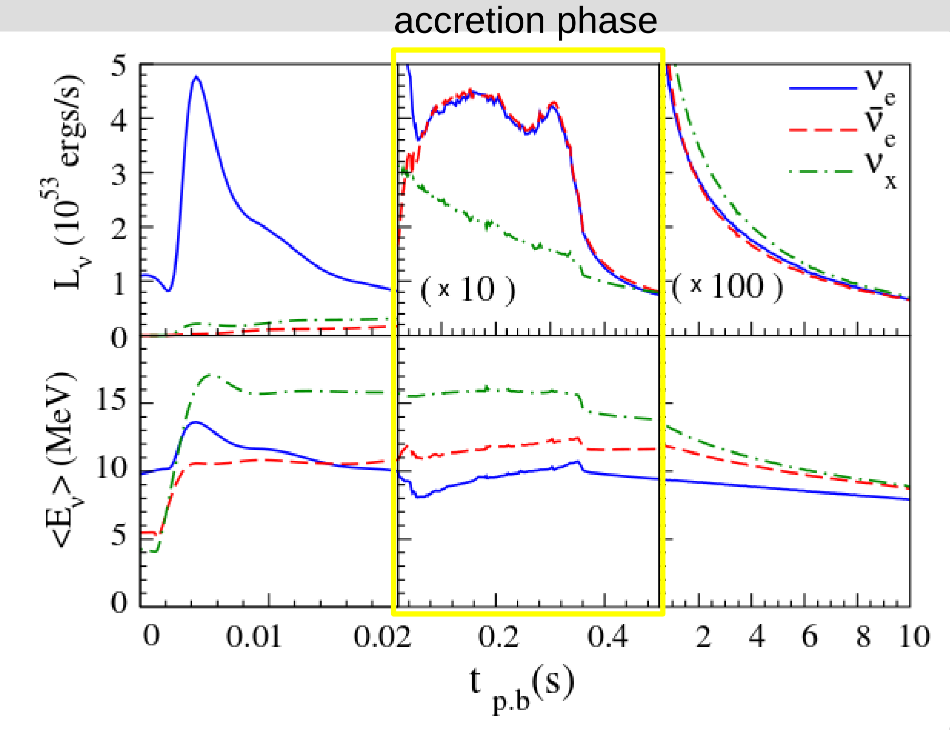
75,000 ly
30°
330°
60,000 ly
Scutum-Centaurus Arm
45,000 ly
Galactic Bar
Sagittarius Arm
Far 3kpc Arm
Norma Arm
60°
300°
Near 3kpc Arm
Long Bar
Outer Arm
Perseus Arm
Sun
Orion Spur
90°
270°
15,000 ly
120°
240°
30,000 ly
150°
210°
180°

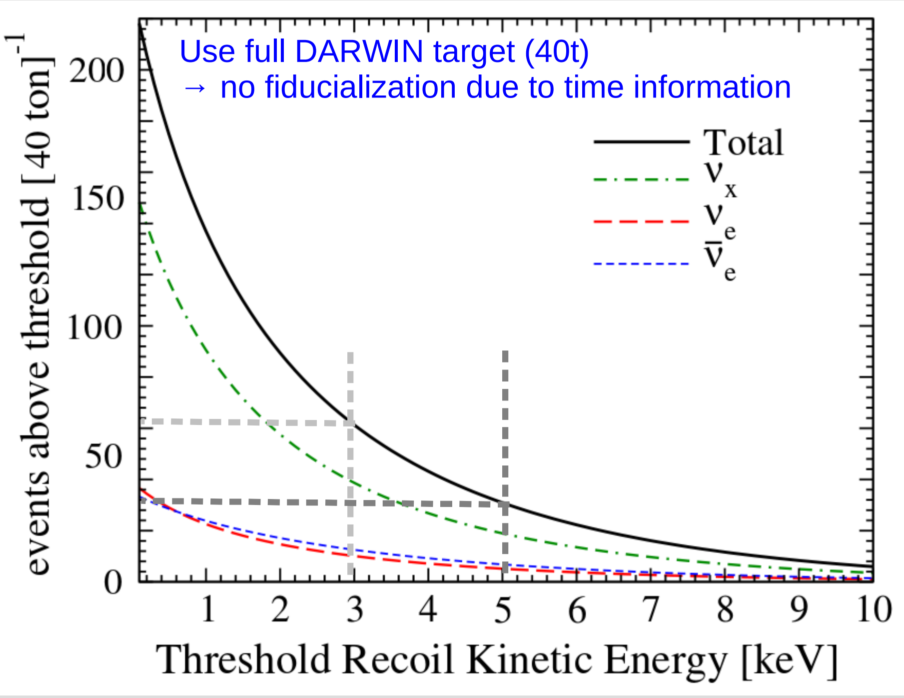
Supernova Neutrinos

Chakraborty et al., PRD 89, 013011 (2014)

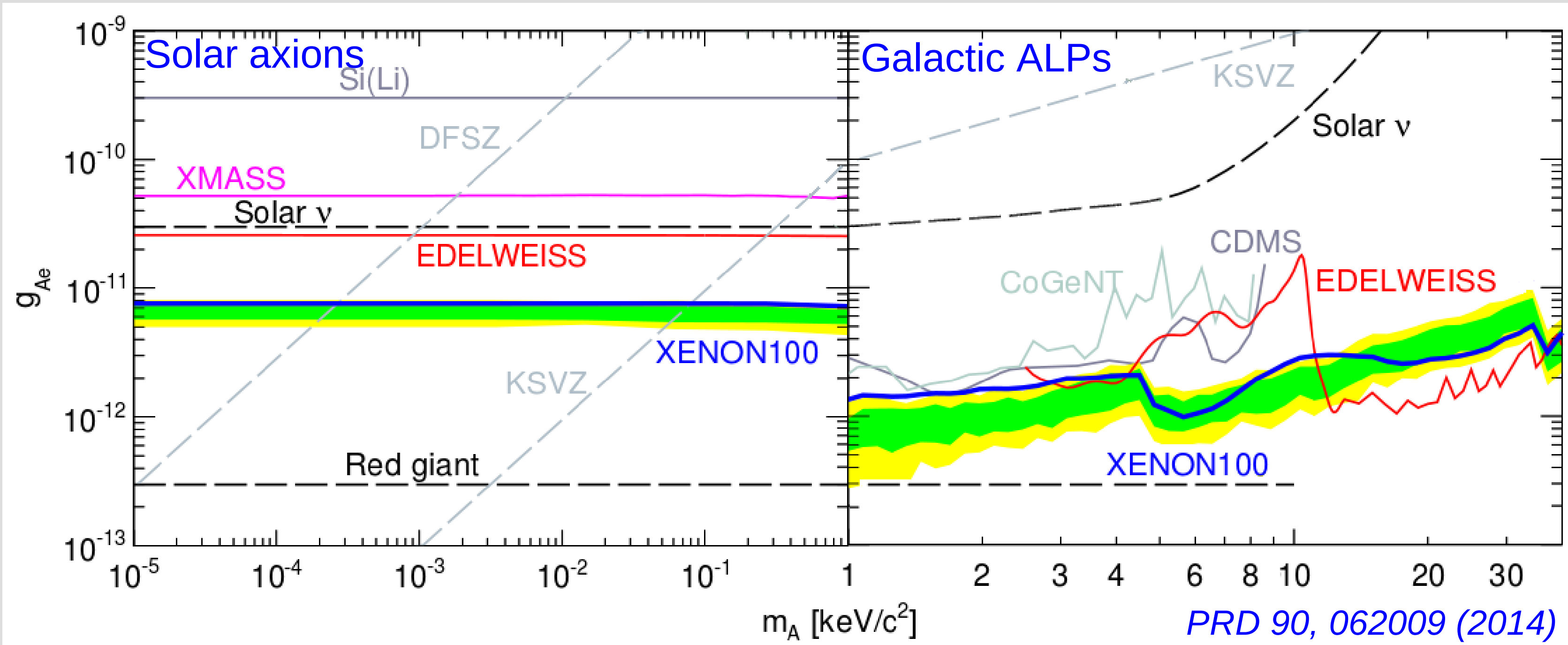
- ν from supernovae could be detected via CNNS as well
- signal fom accretion phase of a ~18 Msun supernova @ 10 kpc is visible in a DARWIN-LXe detector
- signal: NRs plus precise time information → complementary to water Cerenkov detectors
- challenge: theshold

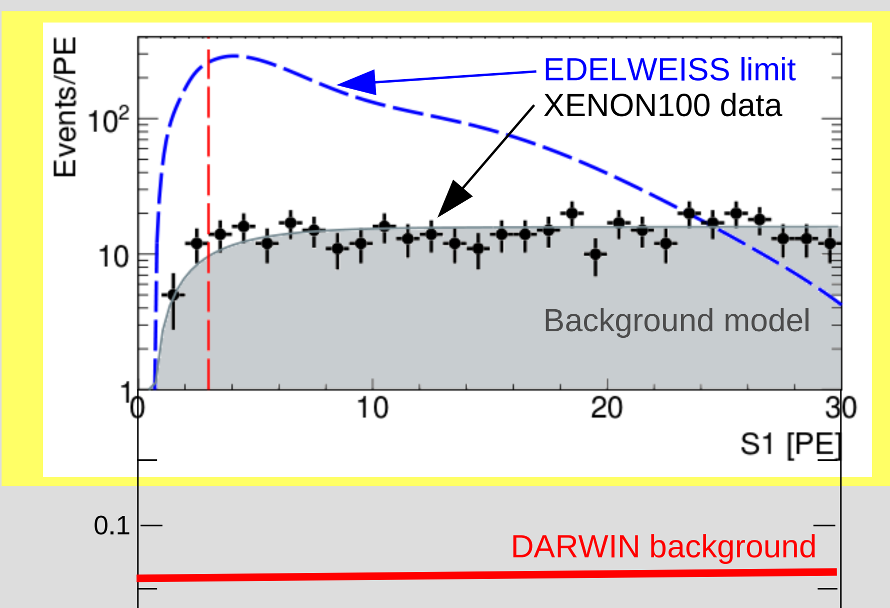


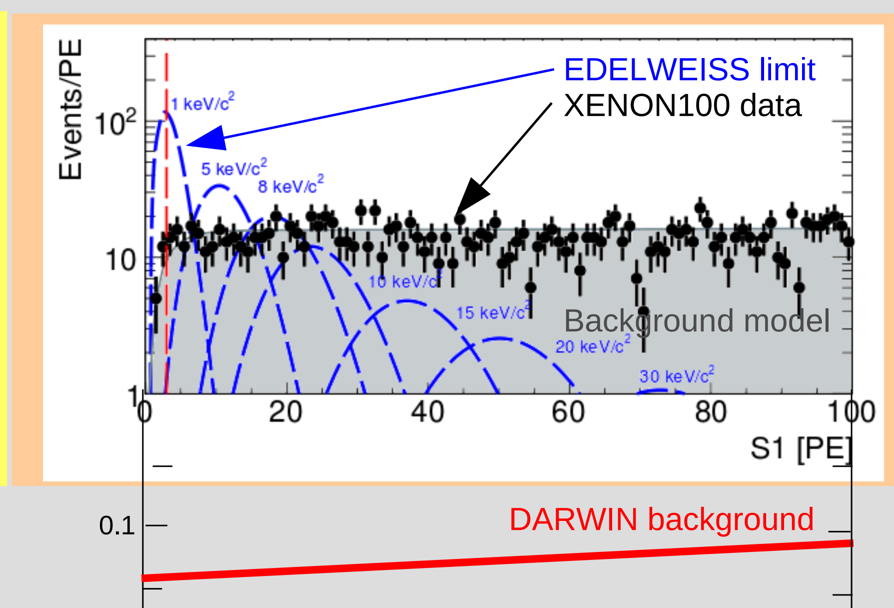




Solar Axions and Galactic ALPs

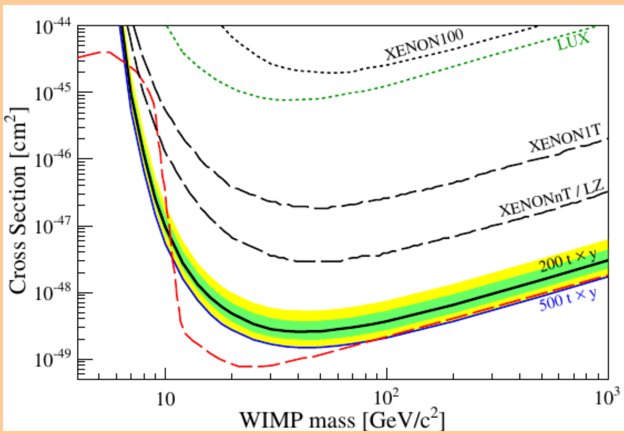




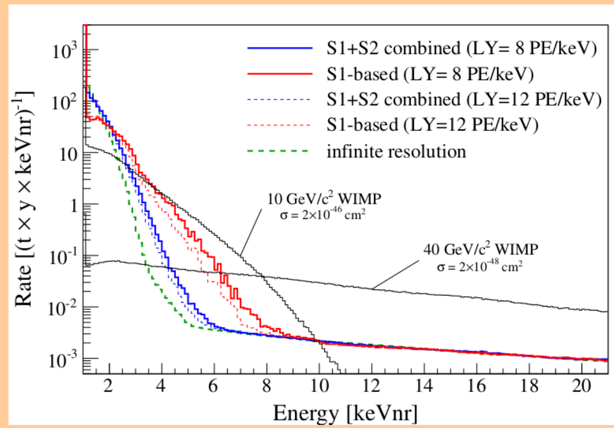


Conclusion: Many Science Channels!

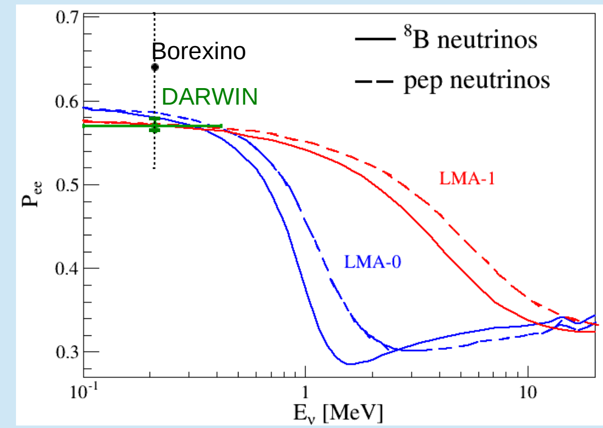
www.darwin-observatory.org



WIMPs

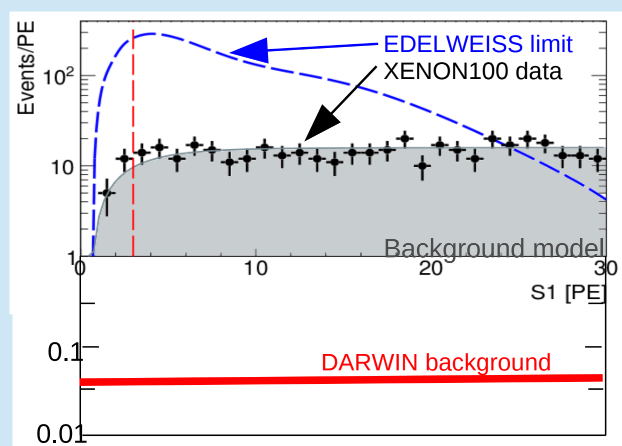


CNNS

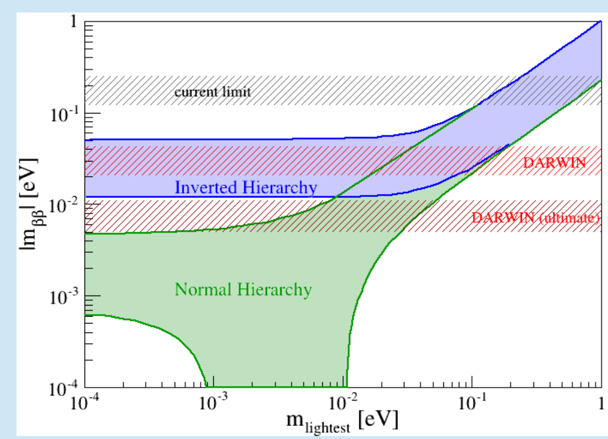


low-E solar Neutrinos

Supernova Neutrinos



Axions and ALPs



Neutrinoless double β-Decay