DARWIN:

Towards the Ultimate Dark Matter Detector

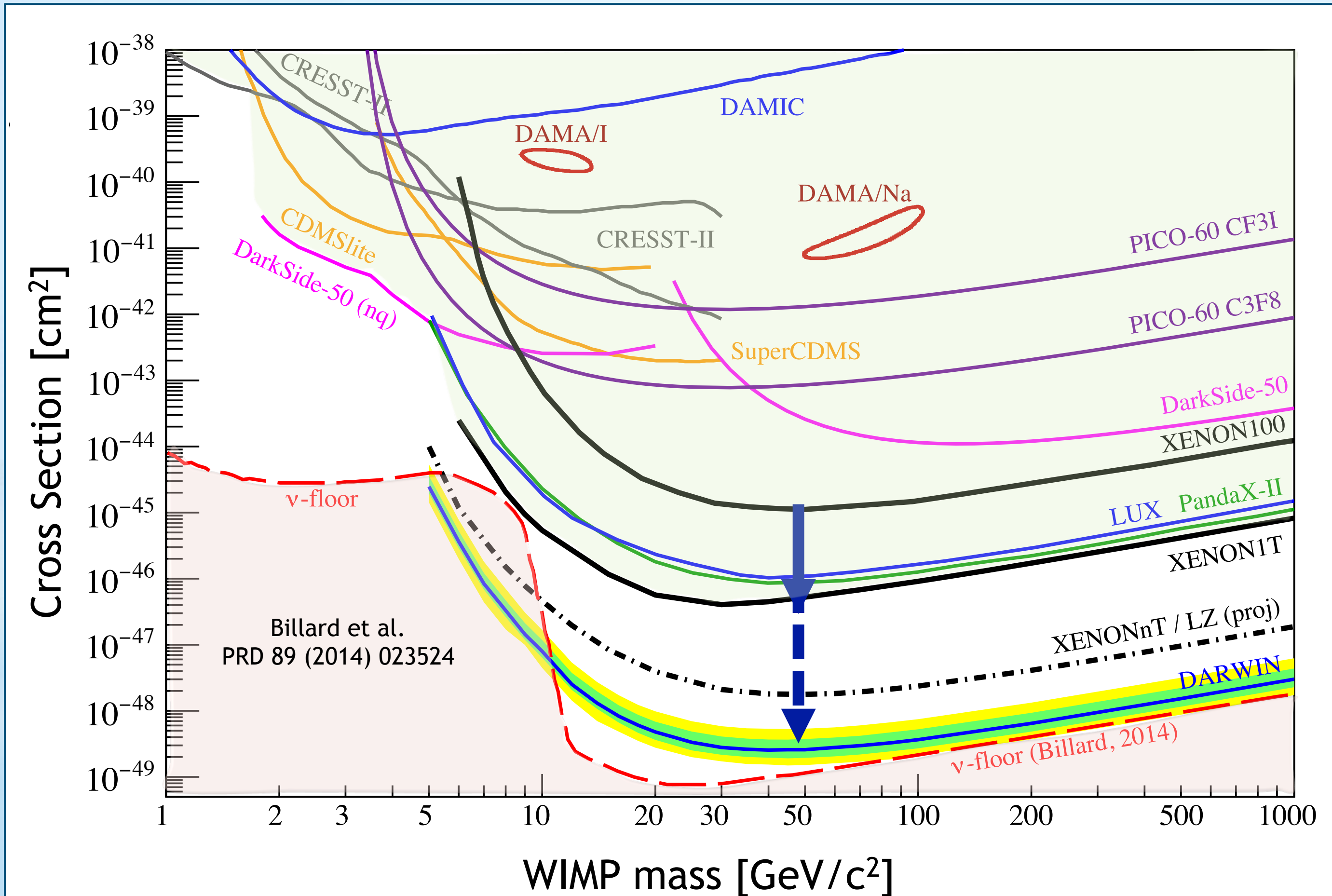
9th Symposium on Large TPCs for Low-Energy Rare Event Detection

Paris, December 2018

Michelle Galloway
University of Zürich

Status of the Field

Spin-independent WIMP-nucleon interactions



a decade of direct searches

Larger target mass
Lower background
Heavy targets

Liquid/gas xenon TPCs from m_x > ~5 GeV/c^2

The ultimate limit from CE ν NS neutrino background

DARk matter WImp search with liquid xenoN

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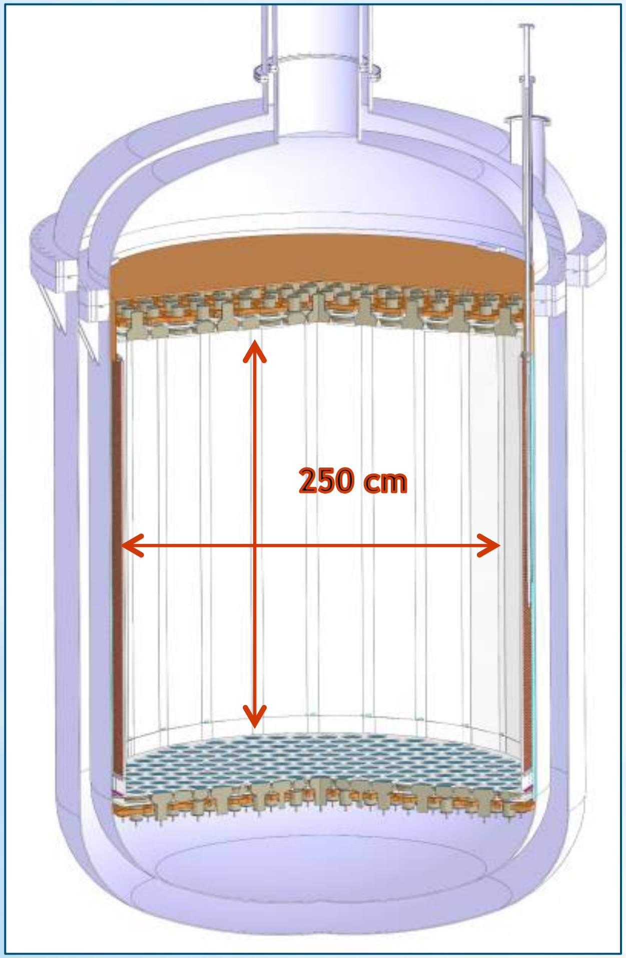
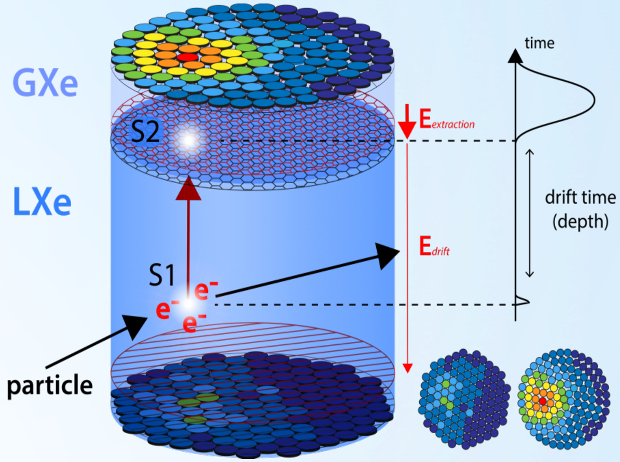
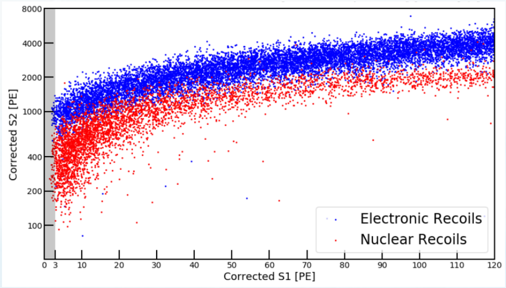


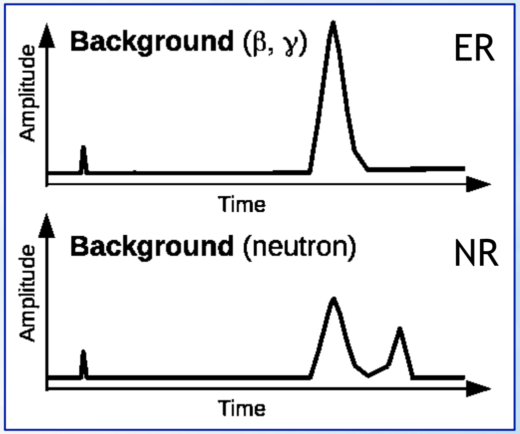
Large exposure
~50 t total Lxe
~40 t target
~30 t fiducial
→ *200 t x y goal*

Sensitivity aim:
few 10^{-49} cm^2



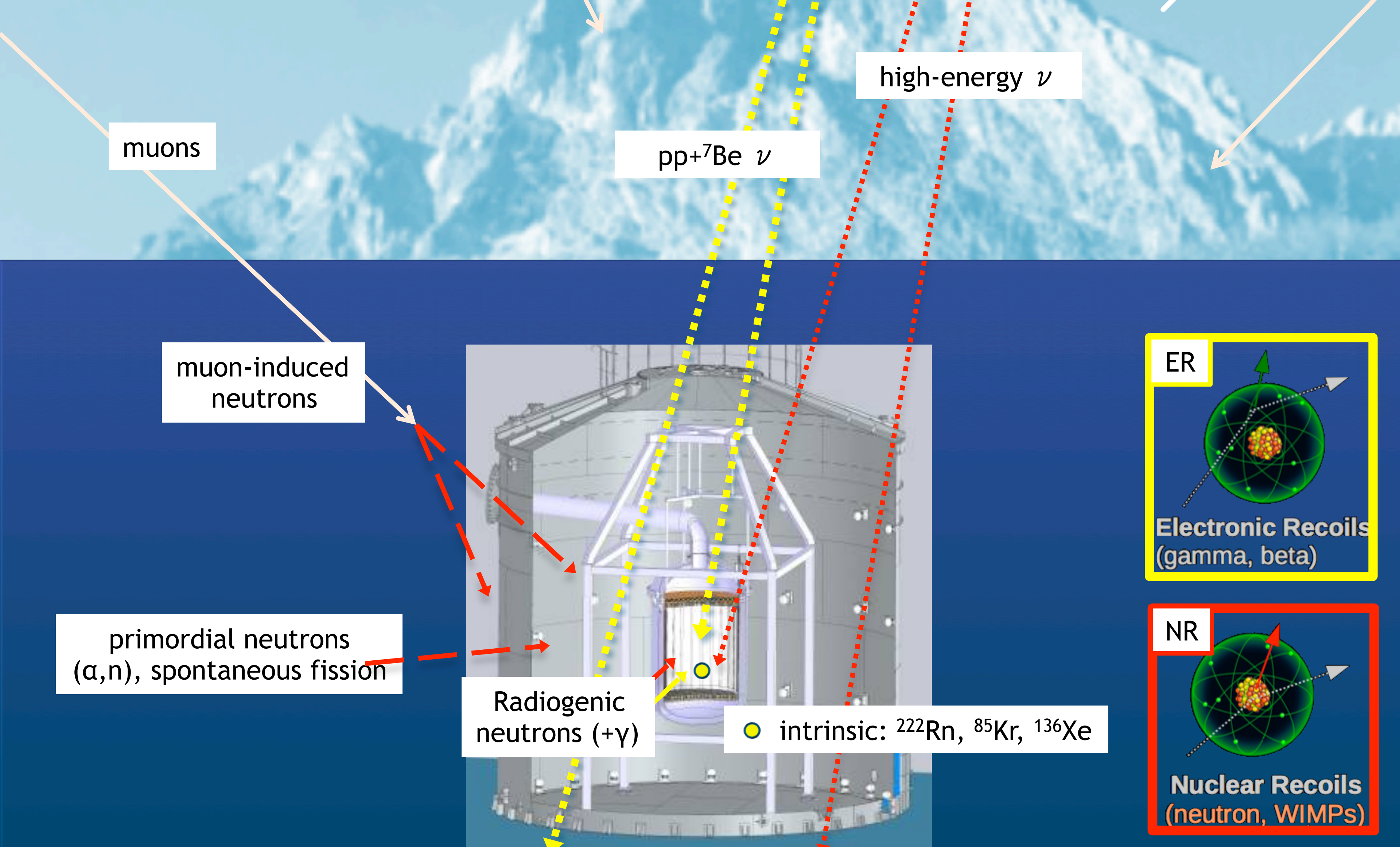
Dual-phase TPC



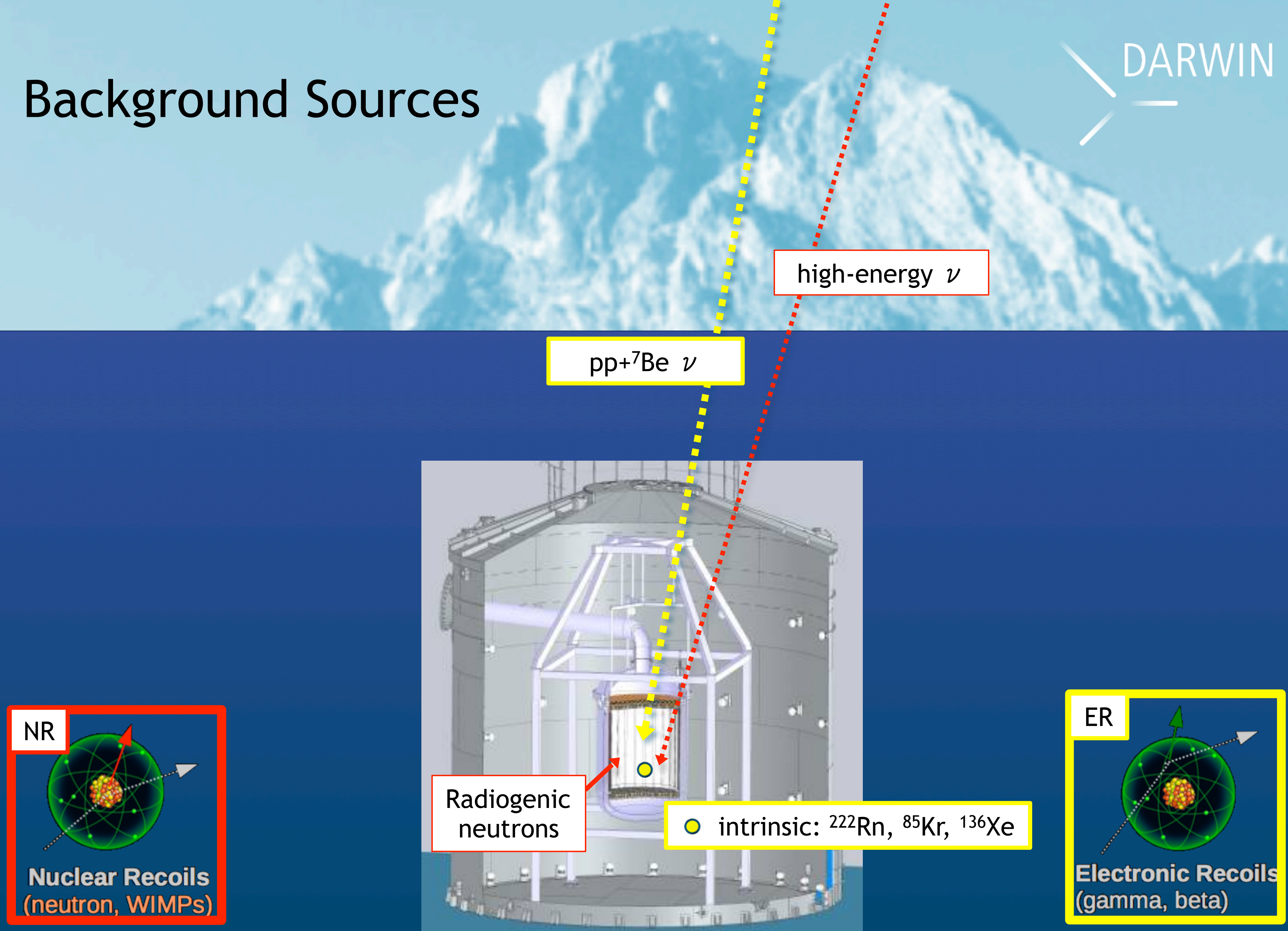


Coincidence cuts,
S2/S1 discrimination,
ultra-low ER and NR backgrounds …

Background Sources



Background Sources



Background Sources

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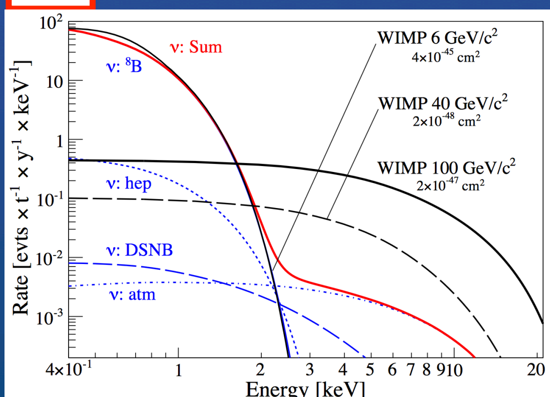
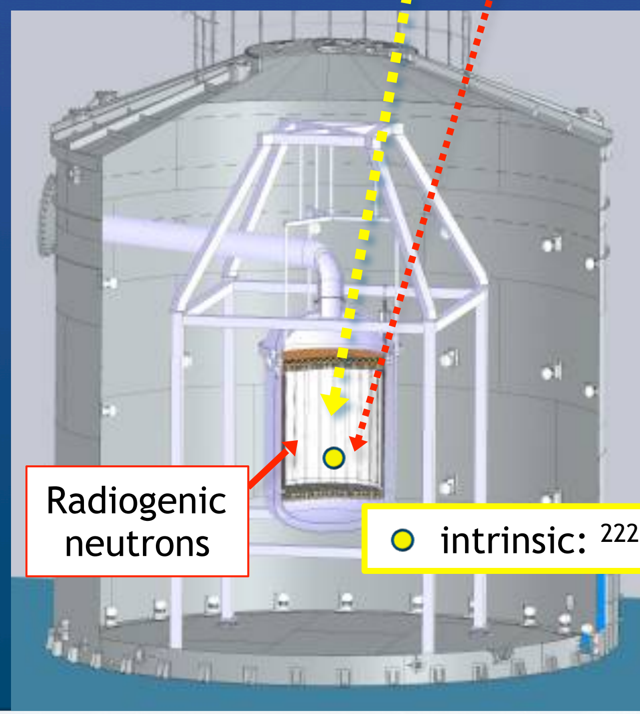
high-energy ν

pp+^{7}Be ν

NR



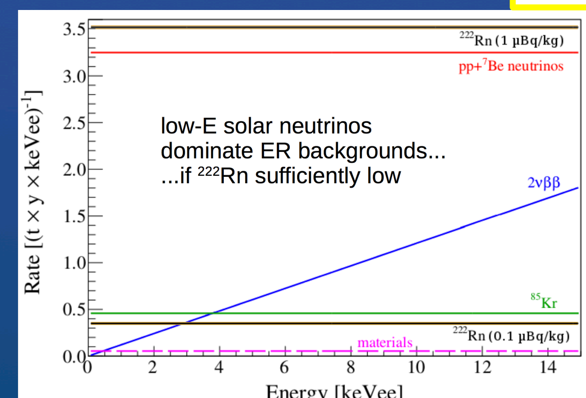
Coherent ν -nucleus scattering



Radiogenic neutrons

intrinsic: ^{222}Rn, ^{85}Kr, ^{136}Xe

ER



^{222}Rn → possibly reduce further

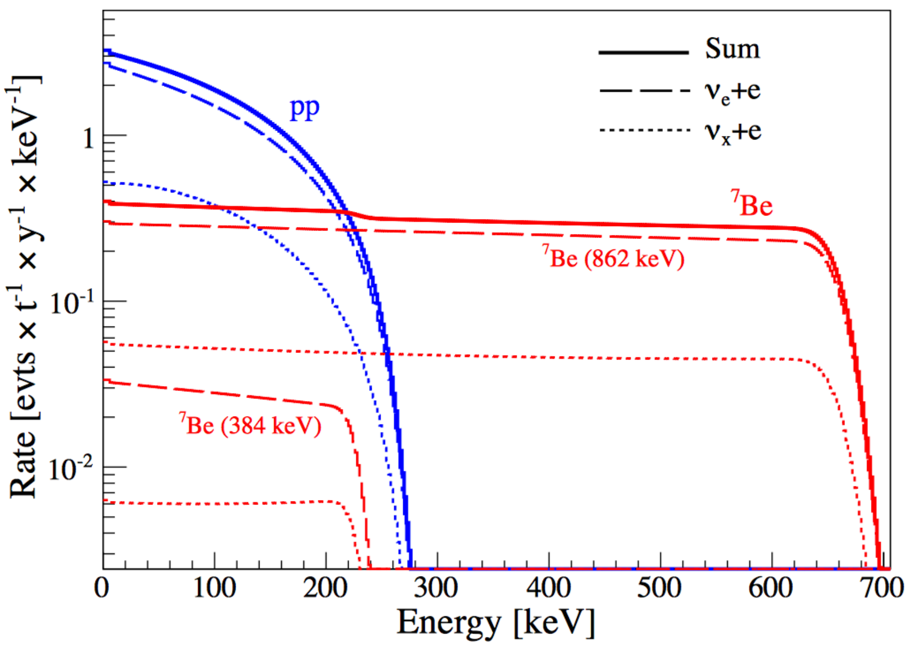
JCAP 01, 044 (2014)

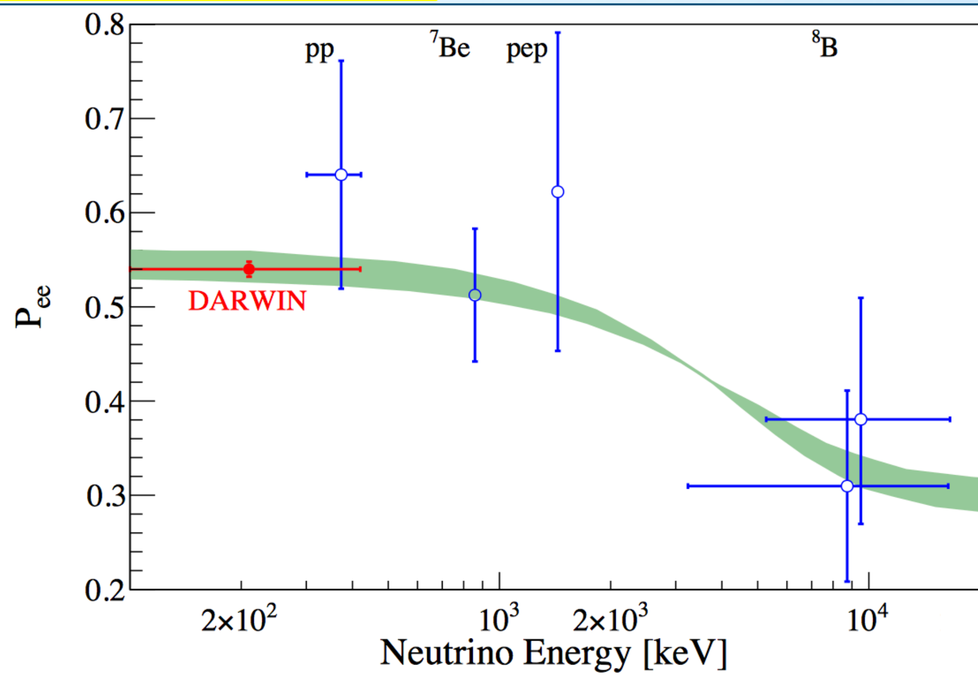
From background to signal…

Neutrino observatory

DARWIN

Solar pp and ^{7}Be neutrinos





Continuous recoil spectrum with largest rate at low E

~0.26 ν evts/t/d in low-E region (2-30 keV)

JCAP 01, 044 (2014)

Electron neutrino survival probability

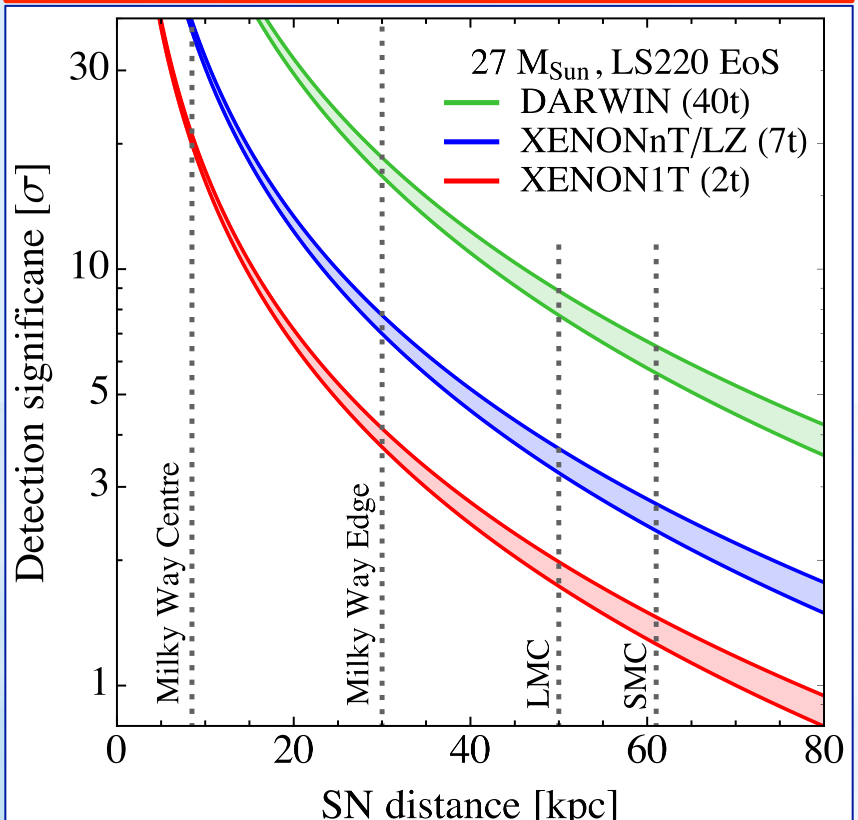
30t target mass, 2-30 keV window

2850 neutrinos per year (89% pp)

→ 1% statistical precision on pp-flux (100 t x y)

Neutrino rare-event observatory

Supernova neutrinos



Detectable via coherent neutrino-nucleus scattering- a short-lived and welcome background!

- signal from accretion phase of a ~18 M_{sun} supernova at 10 kpc is clearly visible in DARWIN

- Can gain precise time information – complementarity with other experiments

→ DARWIN can provide an additional trigger for SNEWS

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

Probe of fundamental physics

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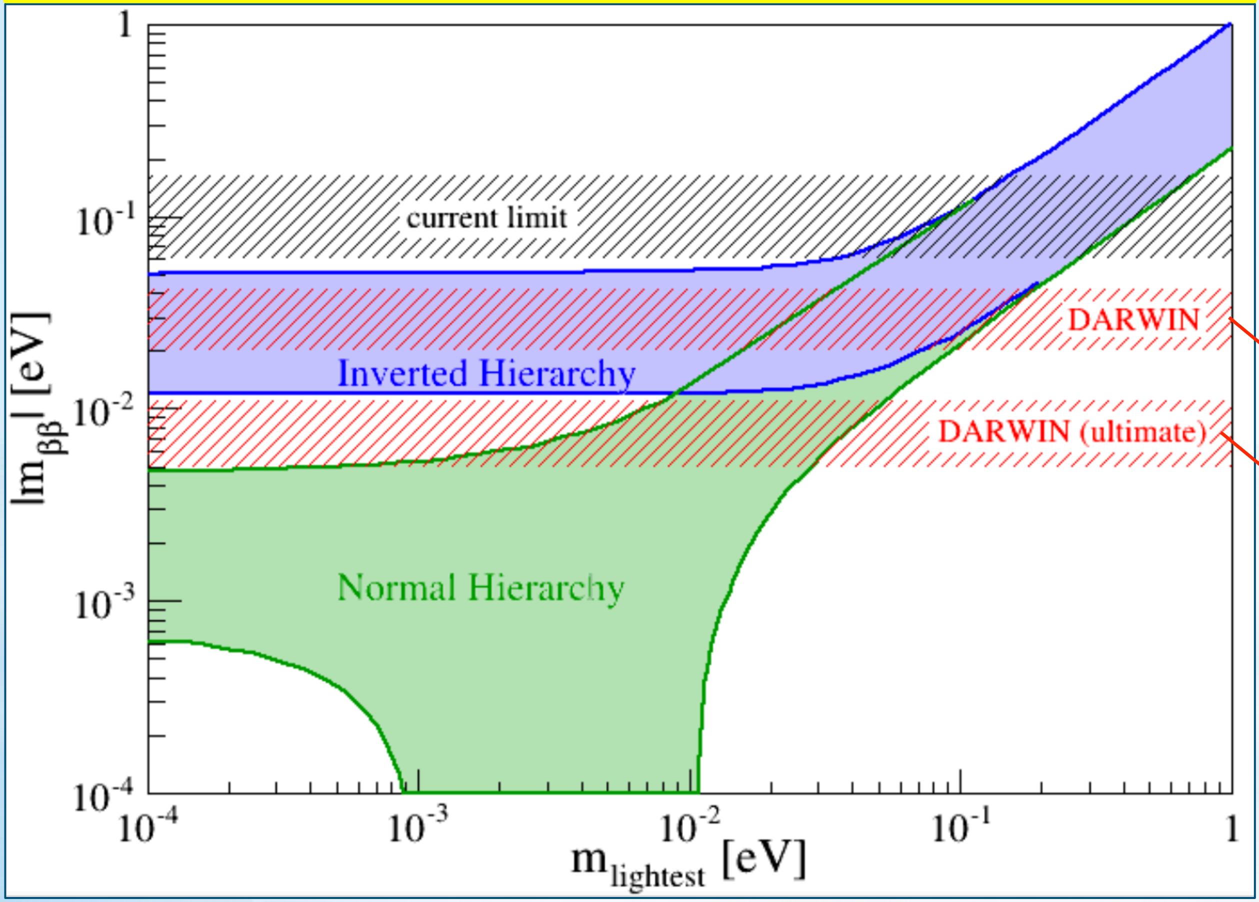
Neutrinoless double beta decay of ^{136}Xe



- Identify Majorana or Dirac nature of neutrino
- Probe effective Majorana mass
- Determine mass heirarchy
- Test lepton number conservation

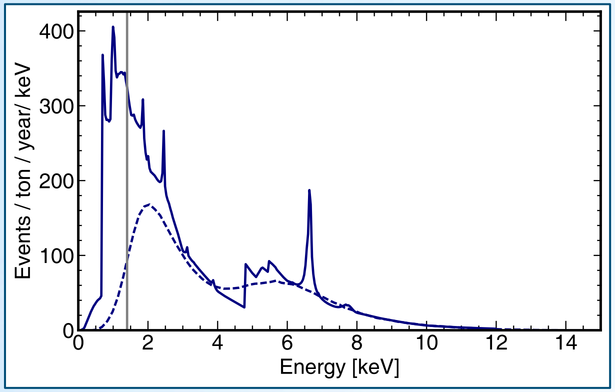
30 ton-year

140 ton-year

→ $Q_{\beta\beta}$ 2.46 MeV
→ Natural abundance in xenon is 8.9% (3.5 tons in target)

JCAP 11, 017 (2016)

Probe of fundamental physics



Expected signal in xenon based on solar models

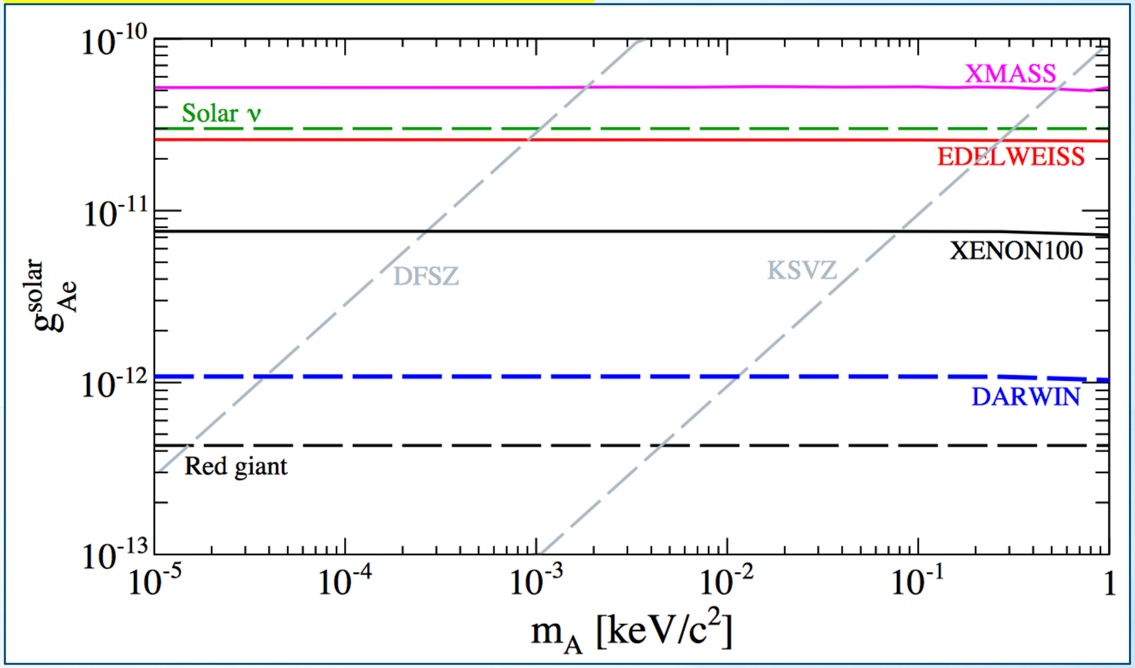
Interaction strength times mass is fixed

$$\sigma_{ae} = \sigma_{pe} \frac{g_{ae}^2}{\beta} \frac{3E_a^2}{16\pi\alpha m_e^2} \left(1 - \frac{\beta^{2/3}}{3}\right)$$

Rate scales as ~g_{ae}^4

Redondo, JCAP 12, 08 (2013)
JCAP 11, 017 (2016)

Solar axions



- Proposed as solution to the strong CP problem
- Absorbed via the axio-electric effect
- DM axions out of range, but axions from the sun from Primakoff process detectable
- Sensitivity goes as $(MT)^{-1/8}$

Search for other dark matter candidates

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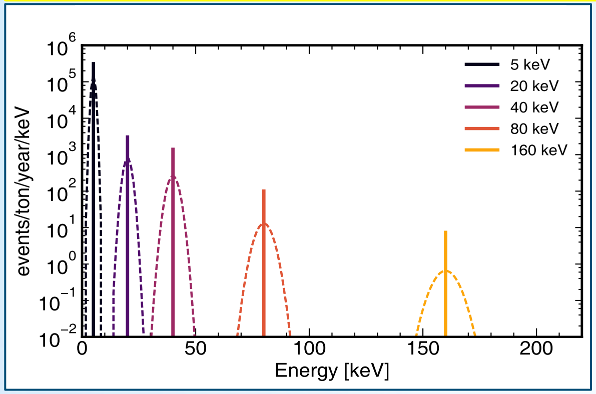
Bosonic vector and pseudoscalar DM candidates (ALPs)



Mono-energetic peak searches

Coupling and mass are independent

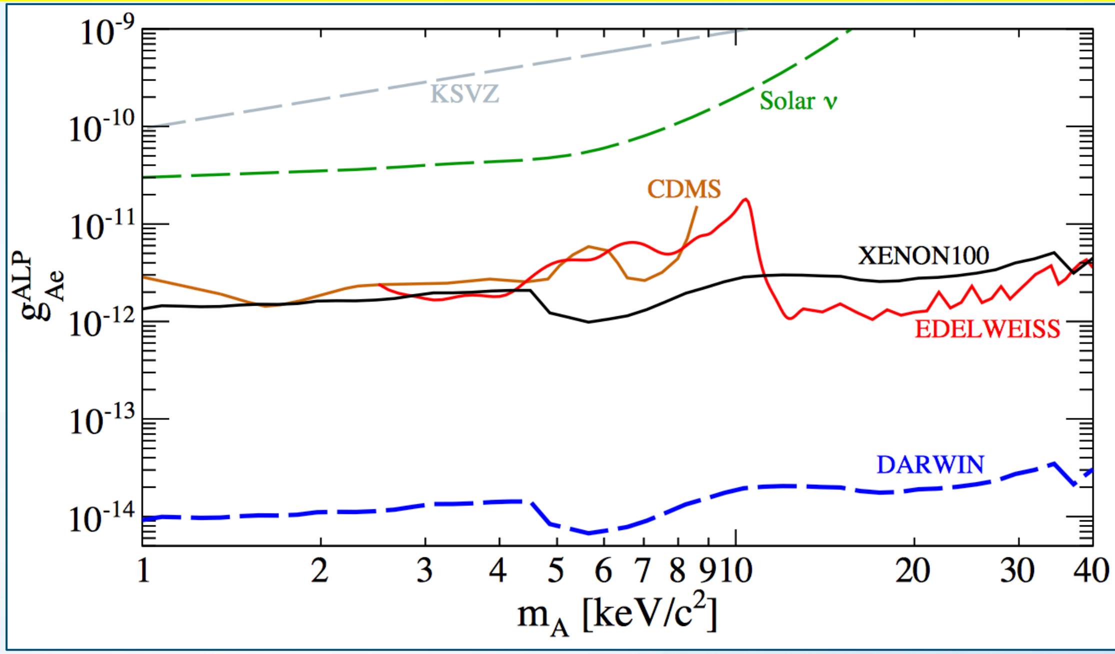
For vector bosons:

$$\sigma_v \simeq \frac{\sigma_{pe}}{\beta}\frac{\alpha'}{\alpha}$$

where α’/α = κ^2

$$R \simeq \frac{4\times10^{23}}{A}\frac{\alpha'}{\alpha}\left(\frac{\text{keV}}{m_V}\right)\left(\frac{\sigma_{photo}}{\text{bn}}\right)\ \text{kg}^{-1}\text{day}^{-1}$$

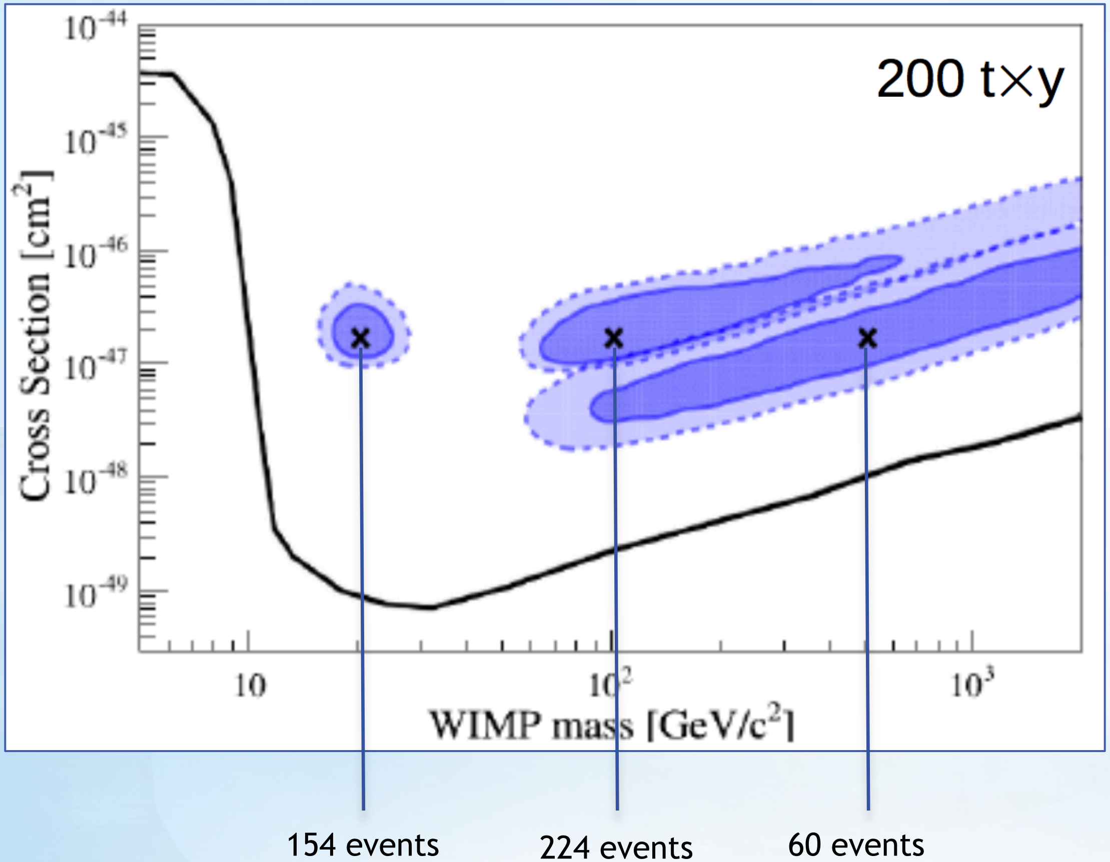
JCAP 11, 017 (2016)



dark photons, super-WIMPs, Axion-Like Particles

- Results from spontaneously broken U(1) symmetry → Nambu-Goldstone boson
- Could be keV-scale relic dark matter (doesn’t address strong CP problem)
- Also interacts via axio-electric effect

WIMP Spectroscopy



- Reconstruction of WIMP properties: mass and scattering cross-section
- mx=20, 100, 500 GeV/c^2
- spin-independent cross section: 2 x 10^{-47} cm^2
- 1σ/2σ credible regions shown, marginalized over astrophysical parameter uncertainties.

→ Tightest constraints for up to a few 100 GeV

JCAP 11, 017 (2016)

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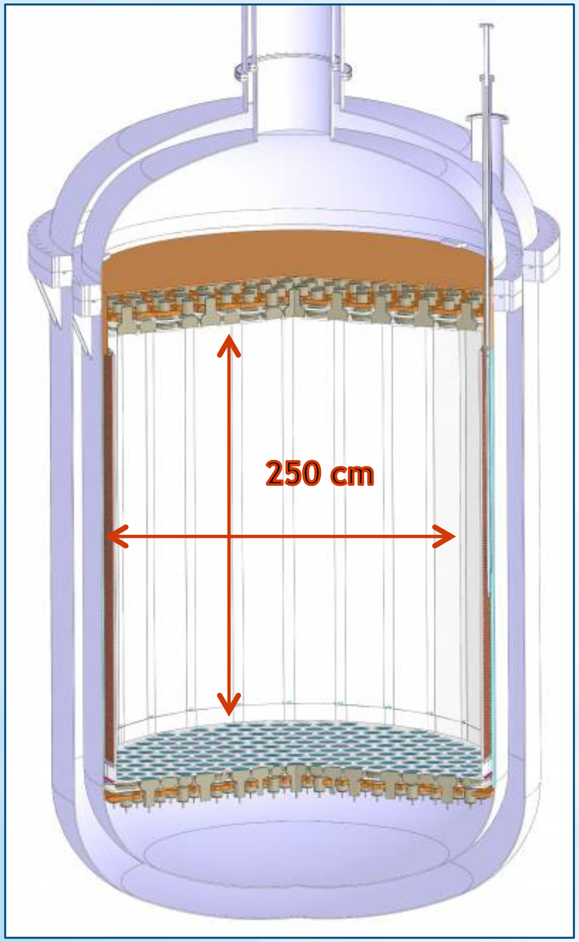
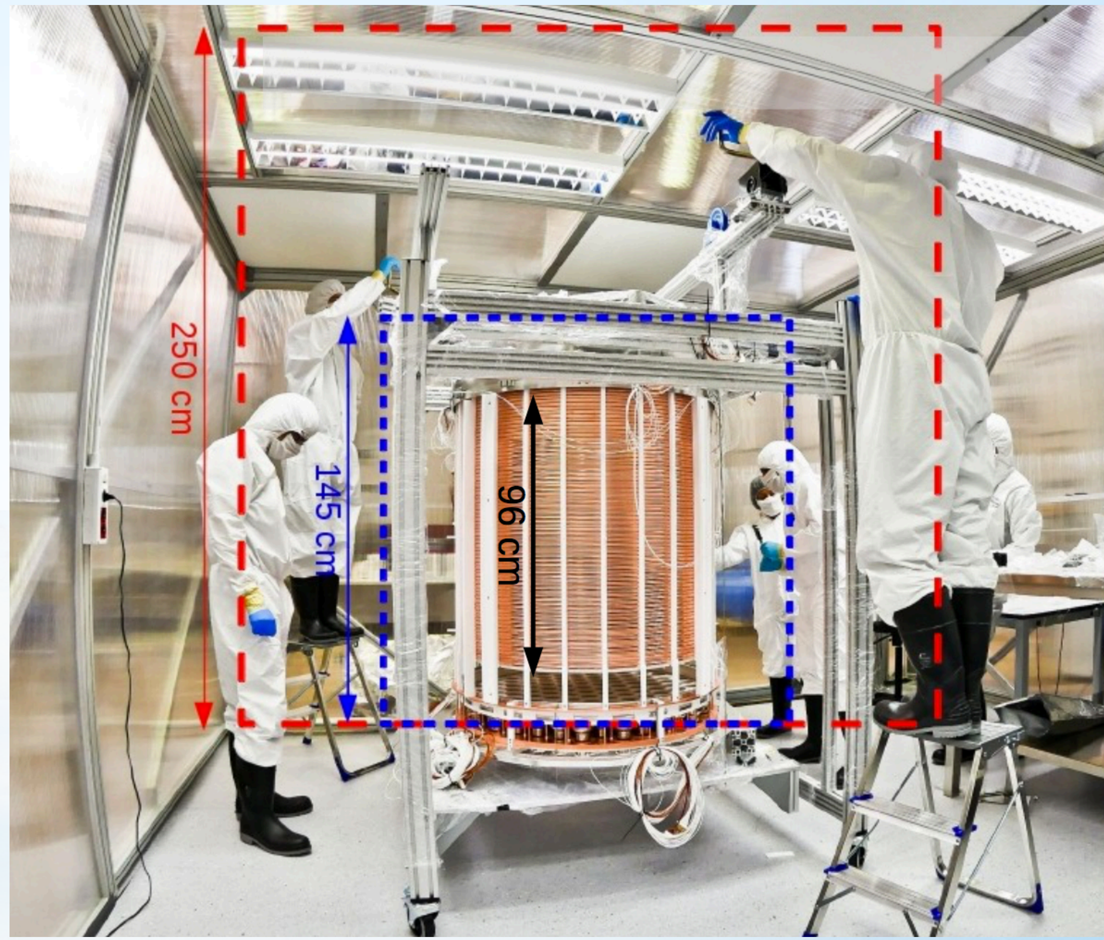
Status and outlook

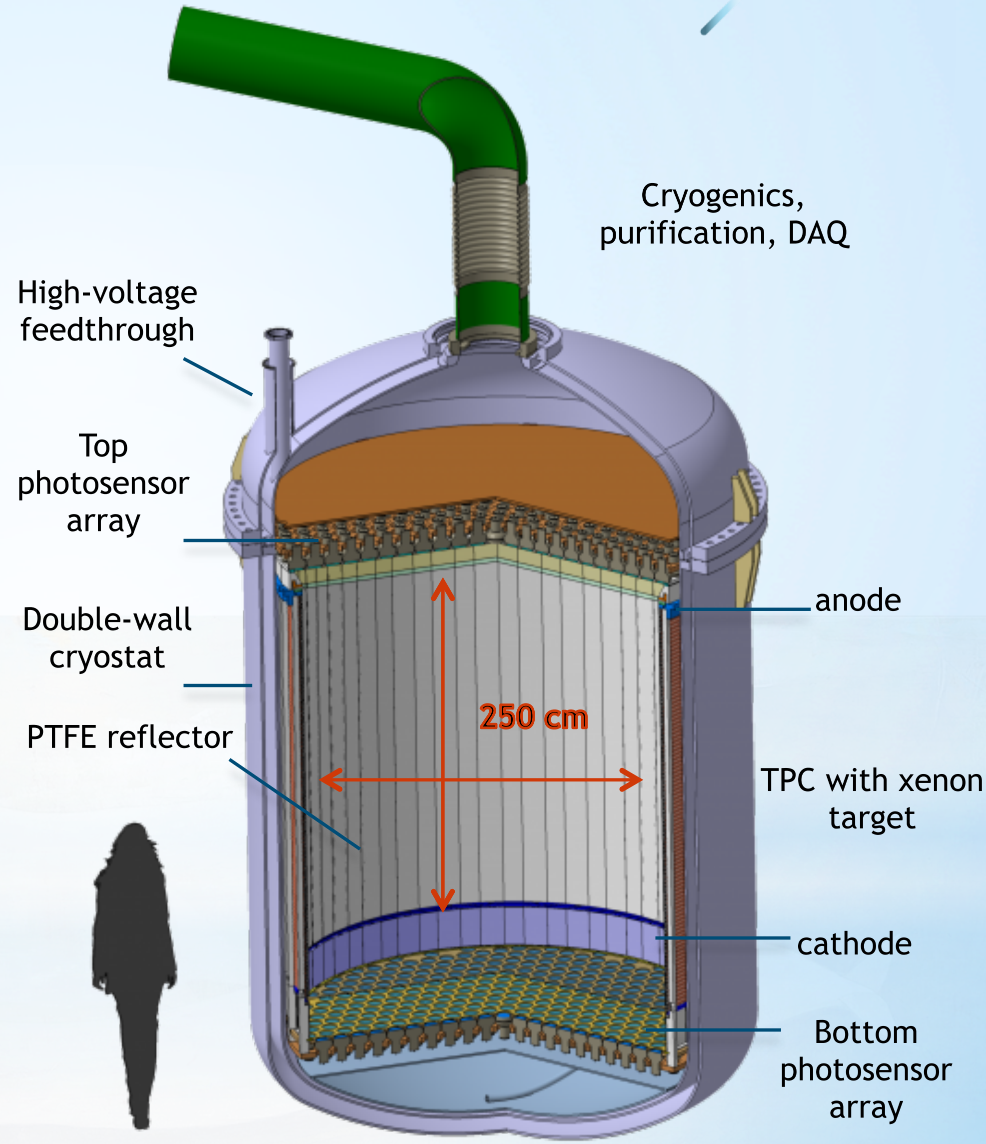




Status: Detector R&D

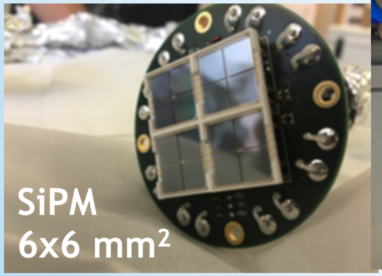
Challenges

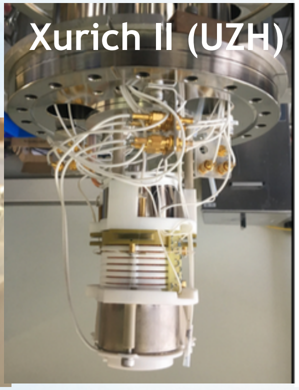
- **Electron drift** over ~2.5 meters
- **High-voltage** capabilities (> -100 kV for drift field ~0.5 kV/cm)
- **Purification:** Long LXe absorption length → high-speed (~100 slpm)
- **Light collection efficiency:** possible 4pi photosensors
- **Photosensors:** high QE, low dark count, long-term stability (PMTs? SiPMs?)
- **Background**: reduce ^{222}Rn (materials, distillation) and (α,n) from PTFE

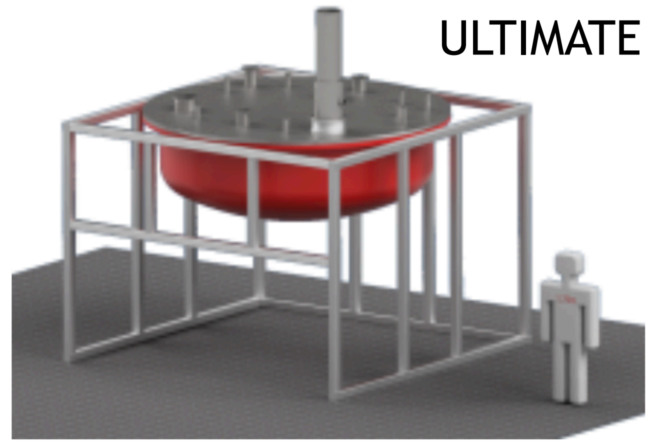


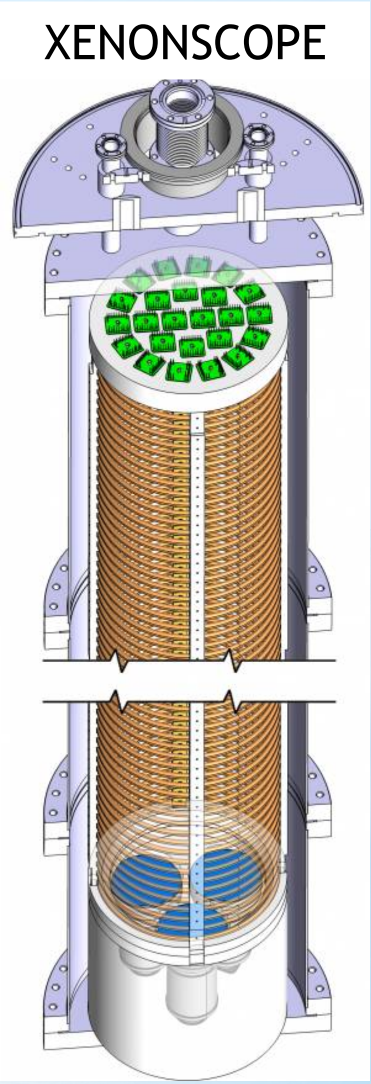
Status: ongoing R&D

- DARWIN is on several national and international roadmaps (APPEC)
- ERC and institute funding:
  - XENONSCOPE (UZH) - 2.6 m HV demonstrator
  - ULTIMATE (Uni. Freiburg) – large diameter electrode R&D
  - Synergy with XENONnT
- Ongoing materials and muon-induced background Monte Carlo studies
- Low-background material screening ongoing
- Photosensor studies (PMTs, SiPMs) with R&D TPCs
  JINST 13 (2018) P10022

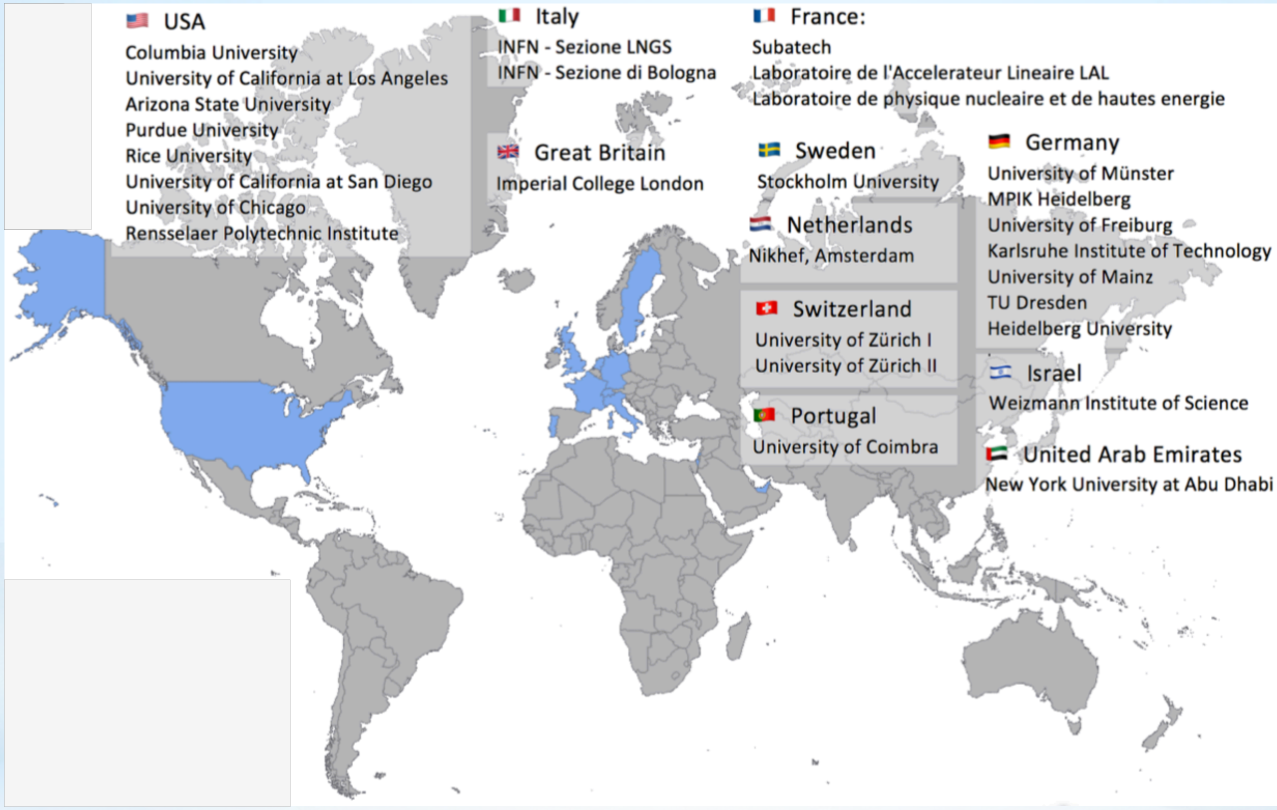








Status and outlook



www.darwin-observatory.org

28 groups from 9 countries
Timeline construction ~2025

Summary

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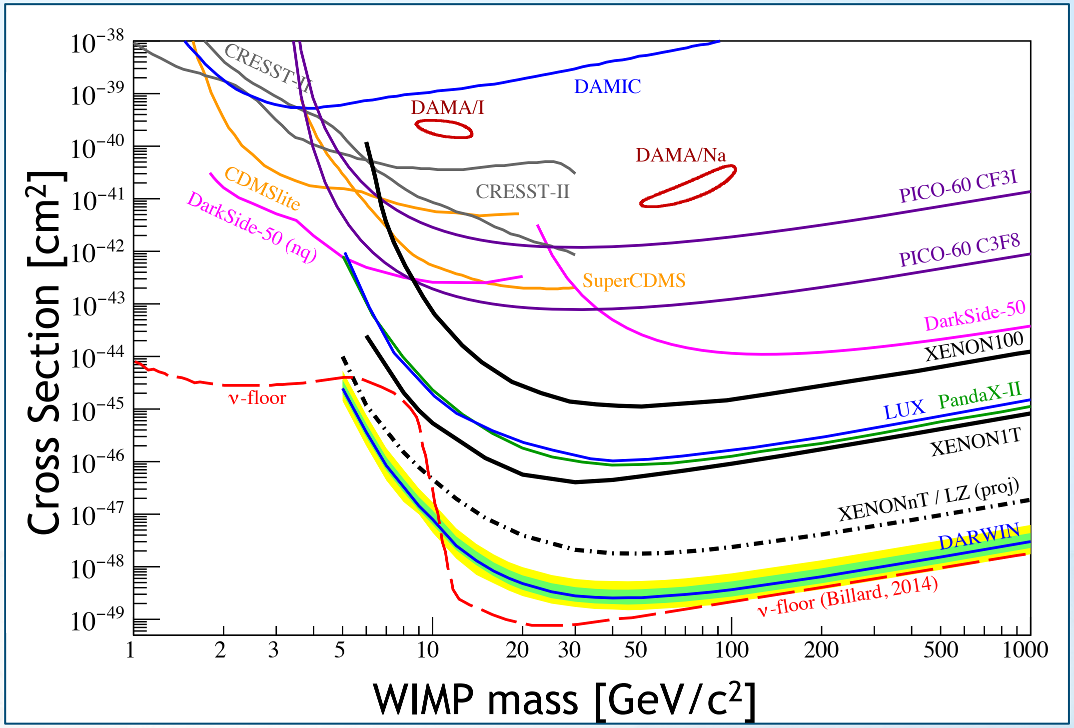
DARWIN will cover viable parameter space for low-medium mass WIMPs down to the irreducible neutrino background.



Several compelling science channels can be explored:

- Neutrinoless double beta decay
- Solar neutrinos
- Solar axions
- Dark photon, super-WIMP and ALP keV-scale dark matter
- Supernova neutrinos

The collaboration is gaining momentum…

R&D at several institutions is ongoing, utilizing expertise from 3 generations of xenon TPC dark matter and other experiments.

DARWIN

Thank you for your attention.

backup

Background Sources

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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

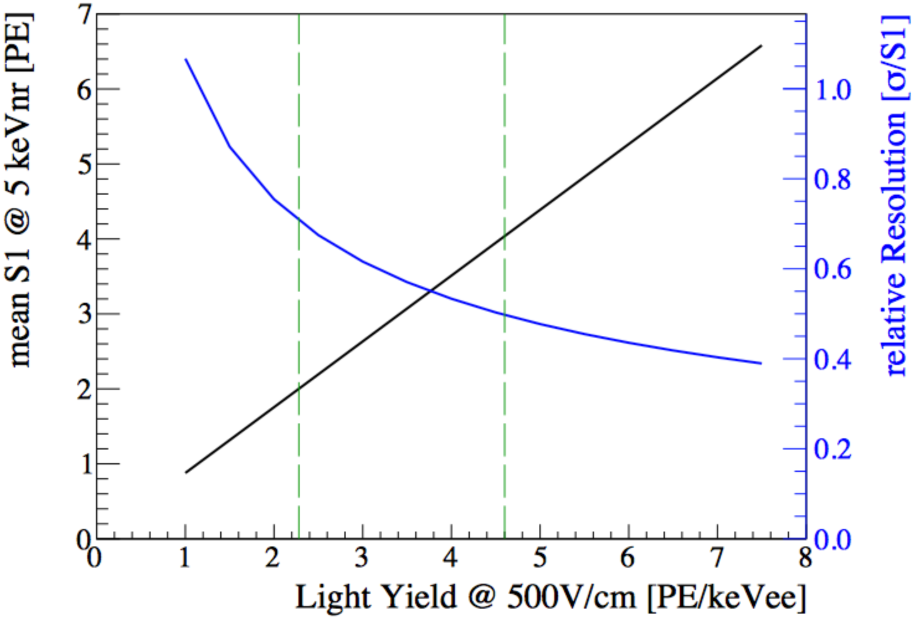
MC simulation of detector made of main components (PTFE, CU, PMTs): subdominant after ~15 cm fiducial cut

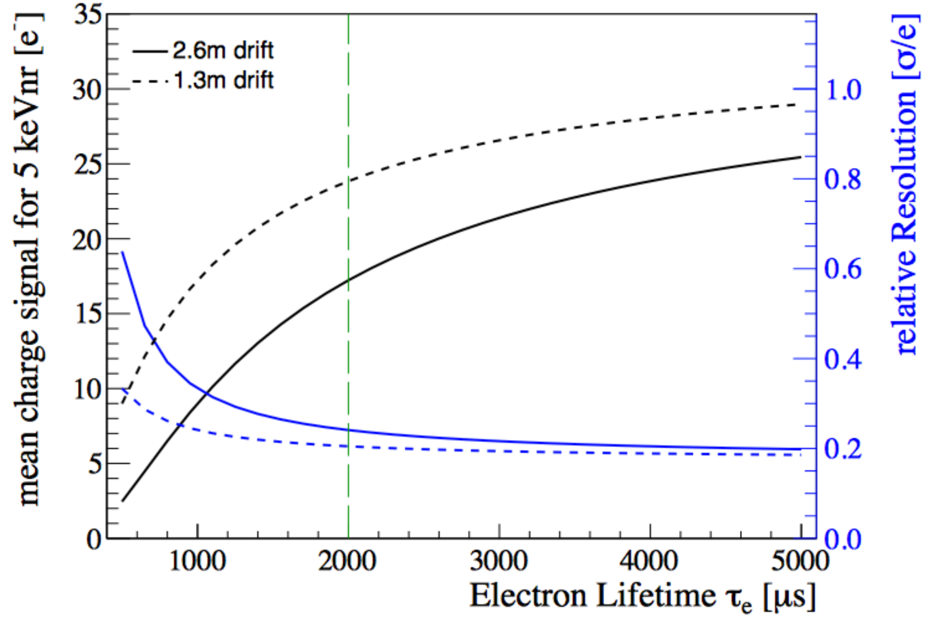
^{85}Kr: 2x below XENON1T design
(0.03 ppt achieved: *EPJ C 74 (2014) 2746*)

^{222}Rn: 100x below XENON1T design

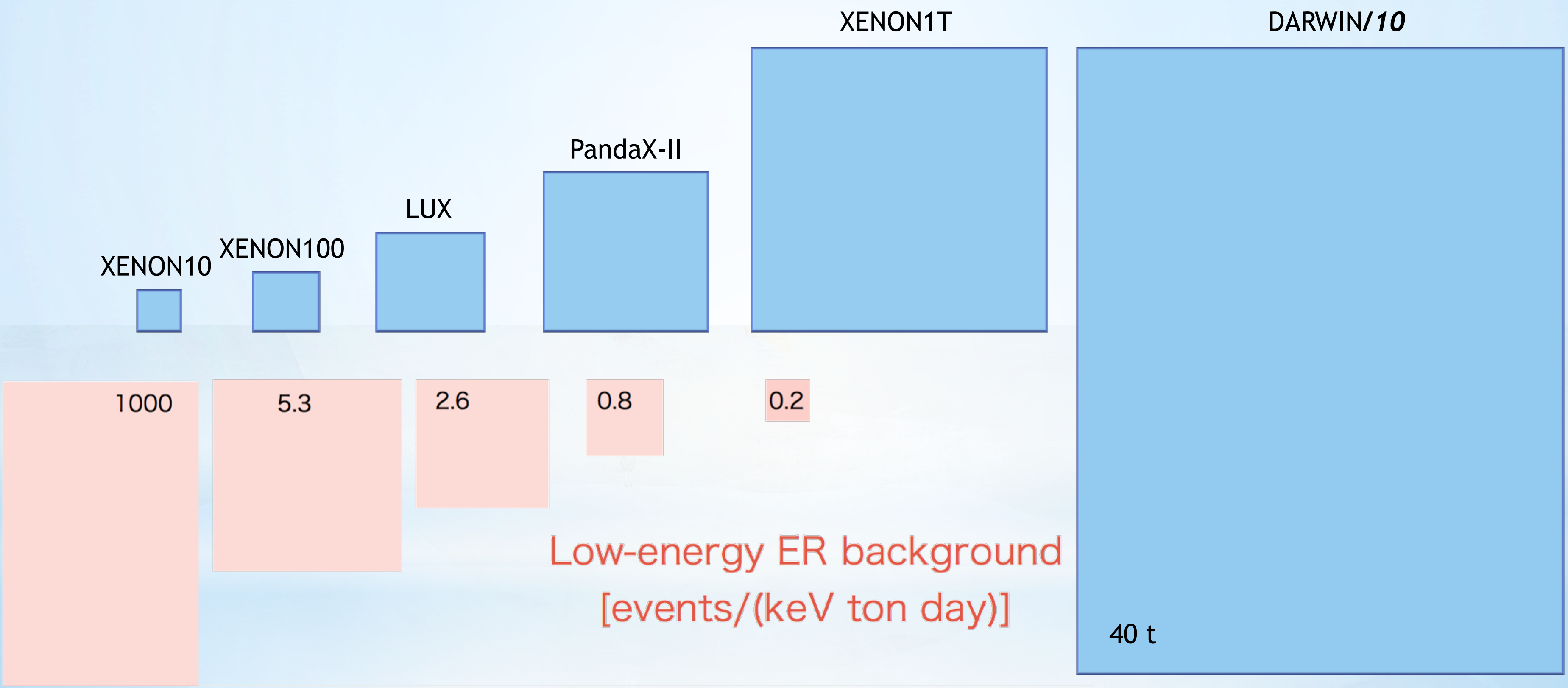
^{136}Xe: assume natural xenon

consider all relevant neutrinos

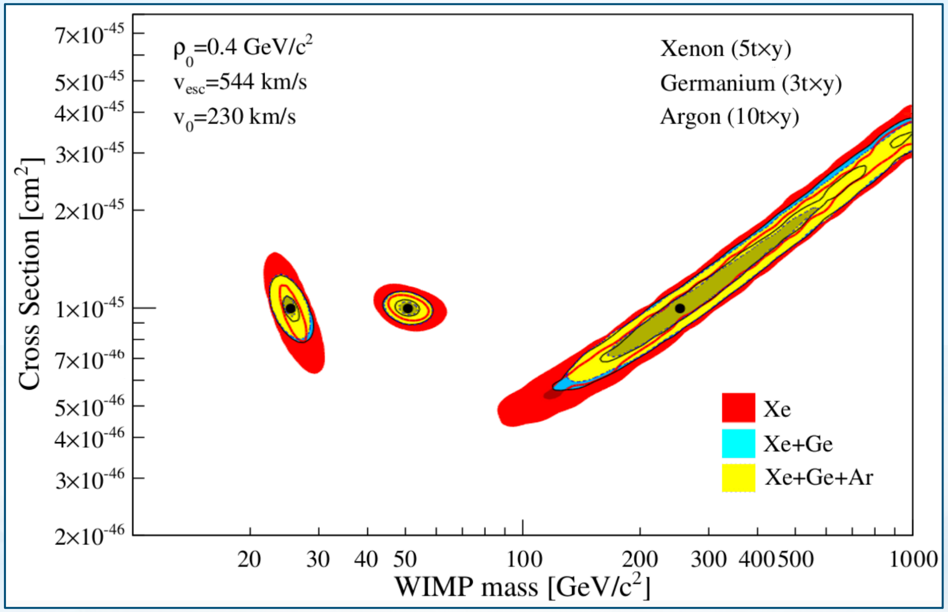

mean S1 @ 5 keVnr [PE]
relative Resolution [σ/S1]
Light Yield @ 500V/cm [PE/keVee]


2.6m drift
1.3m drift
mean charge signal for 5 keVnr [e⁻]
relative Resolution [σ/e]
Electron Lifetime τe [μs]

Evolution


XENON10
XENON100
LUX
PandaX-II
XENON1T
DARWIN/*10*
40 t
1000
5.3
2.6
0.8
0.2
Low-energy ER background
[events/(keV ton day)]

Target complementarity

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