LPNHE
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Les deux infinis

DARWIN
darwin-observatory.org

The ultimate low-background astroparticle physics observatory

JCAP 11, 017 (2016), arXiv:1606.07001

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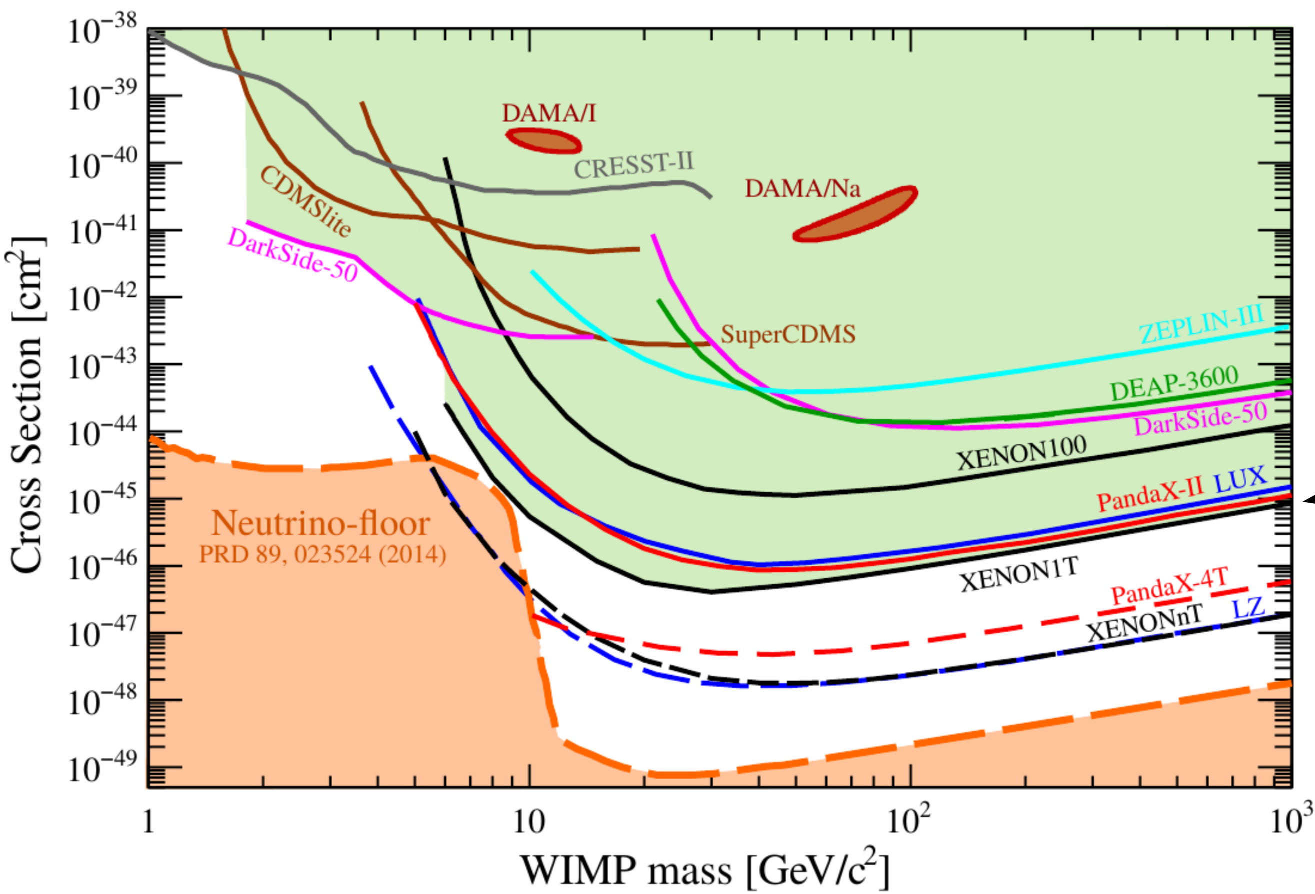
15th Patras Workshop on Axions, WIMPs and WISPs
Freiburg
June 5th, 2019

The current WIMP landscape

The best sensitivity to WIMPs for a wide mass range comes from experiments using liquid noble gases as sensitive detectors: Xe, Ar

This technology allows a relatively easy scalability to higher masses and with concrete perspectives of background reduction



Excluded region

Current limits

XENON1T Coll. Phys. Rev. Lett. 121, 111302

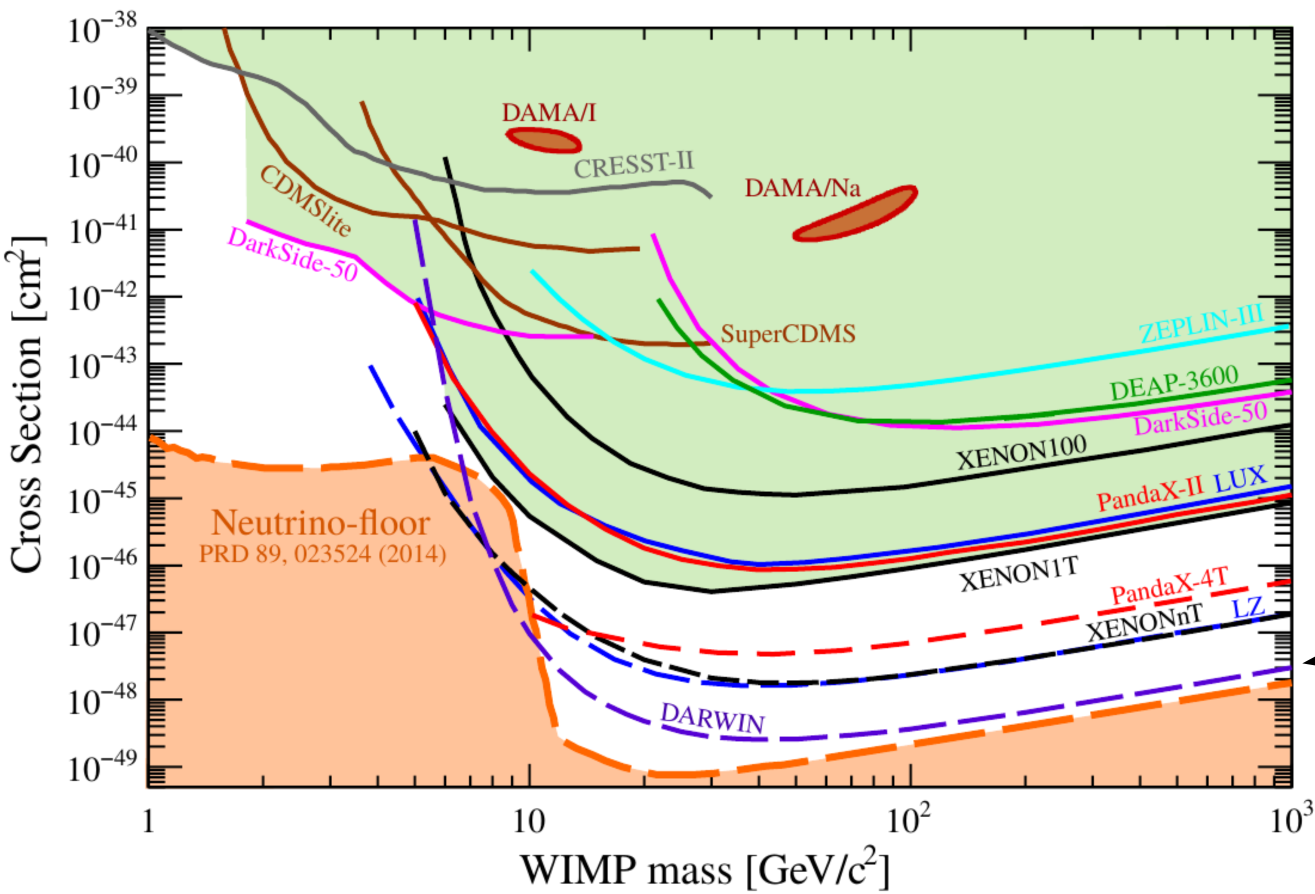
Sensitivities expected in near future

XENONnT, LZ, PandaX-4T

The current WIMP landscape

Probing lower cross sections will require much larger detectors.

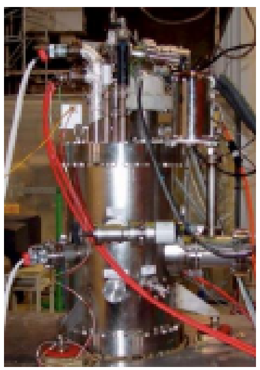
DARWIN, with its 40 tons of active target, aims to be the ultimate discovery detector before neutrino floor



DARWIN
expected sensitivity
JCAP 11, 017 (2016), arXiv:1606.07001

DARWIN as the next phase of the XENON Project

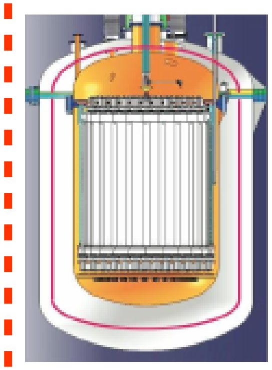
See A. Molinario talk tomorrow



XENON10
Total Xe: 25 kg
Target: 14 kg
Fiducial: 5.4 kg
Limit: $\sim 10^{-43}$

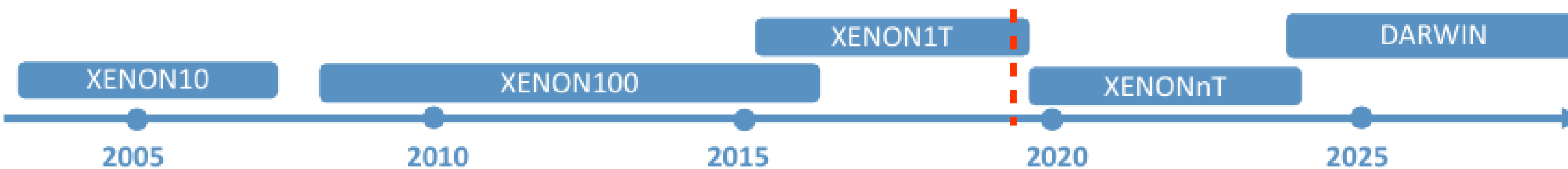
XENON100
Total Xe: 162 kg
Target: 62 kg
Fiducial: 34/48 kg
Limit: $\sim 10^{-45}$

XENON1T
Total Xe: 3.2 ton
Target: 2 ton
Fiducial: 1 ton
Limit: $\sim 10^{-47}$



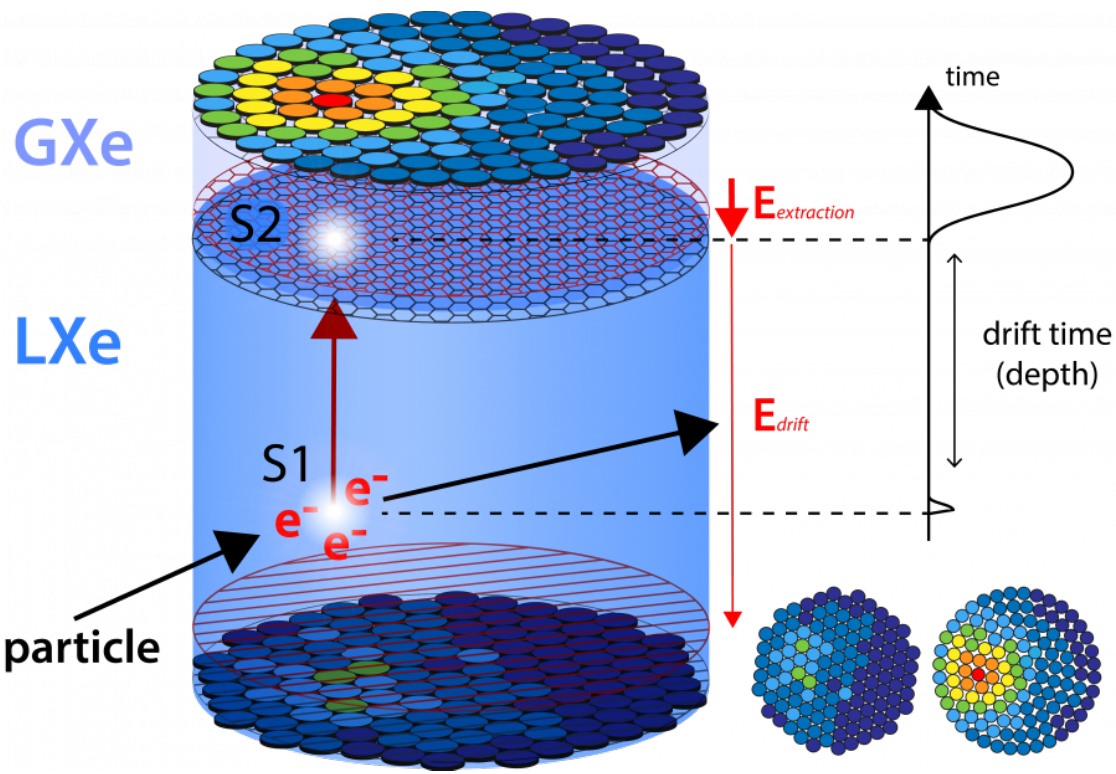
XENONnT
Total Xe: ~8 ton
Target: ~6.5 ton
Fiducial: ~5 ton
Limit: $\sim 10^{-48}$

DARWIN
Total Xe: 50 ton
Target: 40 ton
Fiducial: 30 ton
Limit: $\sim 10^{-49}$



The advantages of a dual-phase xenon TPC

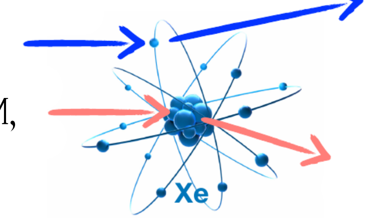
Working principle
Detection of scintillation light **S1** and the ionization through a delayed proportional scintillation signal **S2**



Particle discrimination through different interaction mechanisms

leptophilic DM,
γ, β

WIMP DM,
neutrons



electron recoil (ER)
larger S1/S2

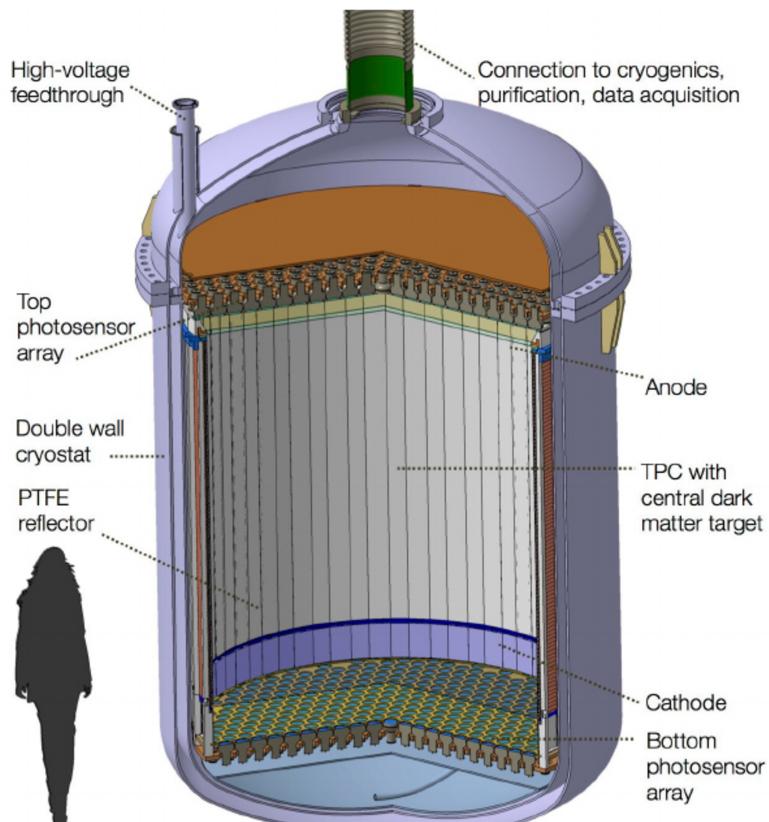
nuclear recoil (NR)
smaller S1/S2

3D position reconstruction with:
x,y from photo-sensors pattern
z from drift time

Allowing background rejection with:
Fiducialization
Single/Multiple scattering recognition

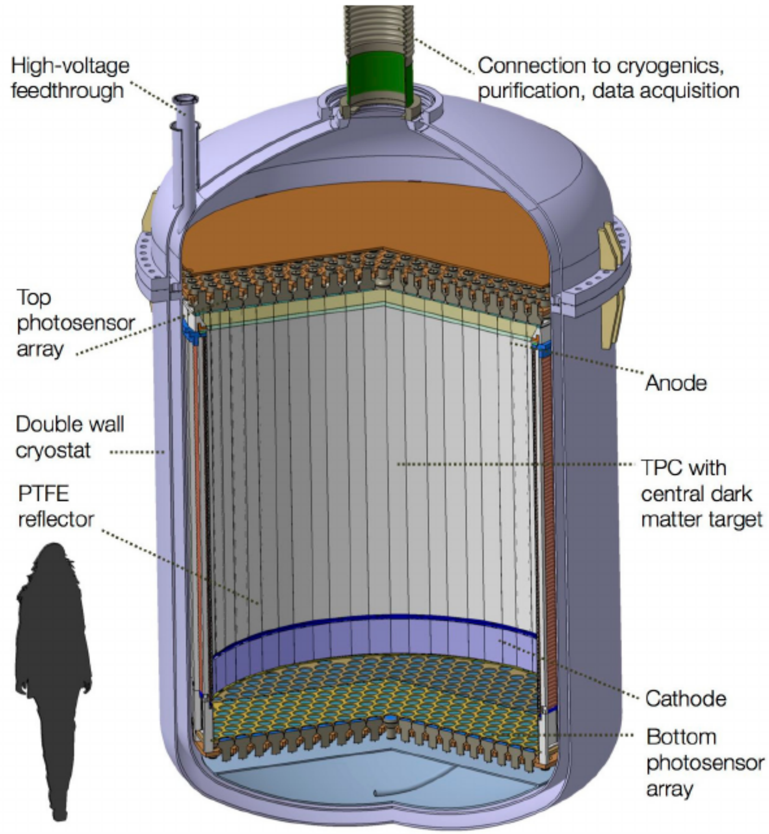
The TPC baseline concept

JCAP 11, 017 (2016), arXiv:1606.07001



- 50 t LXe in total (40 t in the TPC)
- ~ 10^3 photosensors
- 2.6 m drift length,
  2.6 m diameter TPC,
  PTFE reflectors,
  Cu field shaping rings
- Overall background
  → dominated by neutrinos only

The TPC baseline concept and challenges



- 50 t LXe in total (40 t in the TPC)
  → Improving storage, purification, cooling
- ~ 10^3 photosensors
  → Alternatives to traditional PMTs (improving discrimination, cost, compactness, coverage, radioactivity)
- 2.6 m drift length,
  2.6 m diameter TPC,
  PTFE reflectors,
  Cu field shaping rings
  → High voltage, proportional scintillation
- Overall background
  → dominated by neutrinos only

Background

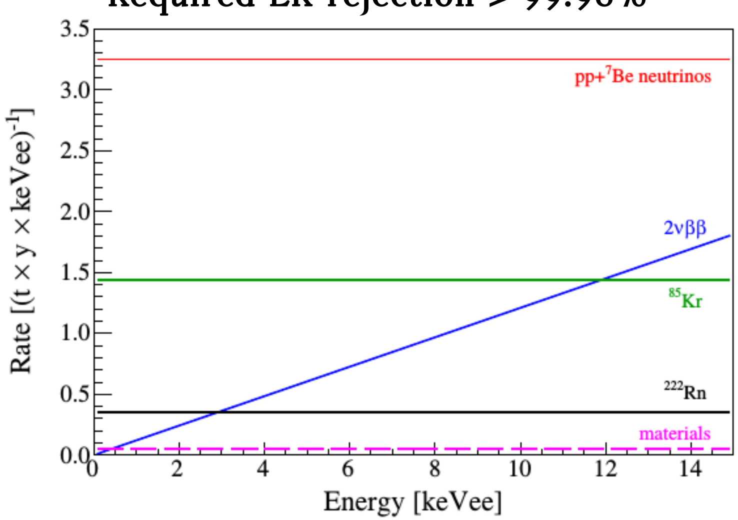
M. Schumann et al., JCAP 1510 (2015) 016

Electronic Recoils (ER)

radiogenic, intrinsic, cosmogenic

Source	Rate $(t\cdot y\cdot keV)^{-1}$
Solar neutrinos (mostly pp; ^{7}Be)	3.25
^{85}Kr ($=2\cdot10^{-11}$ ^{nat}Kr, @0.1ppt ^{nat}Kr)	1.44
^{136}Xe $2\nu\beta\beta$ (natural @8.9%)	0.73
^{222}Rn (@0.1μBq/kg)	0.35
Materials (cryostat, photosensors, TPC)	0.054

Required ER rejection > 99.98%

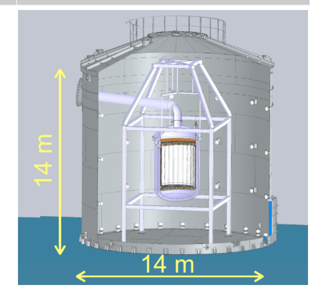


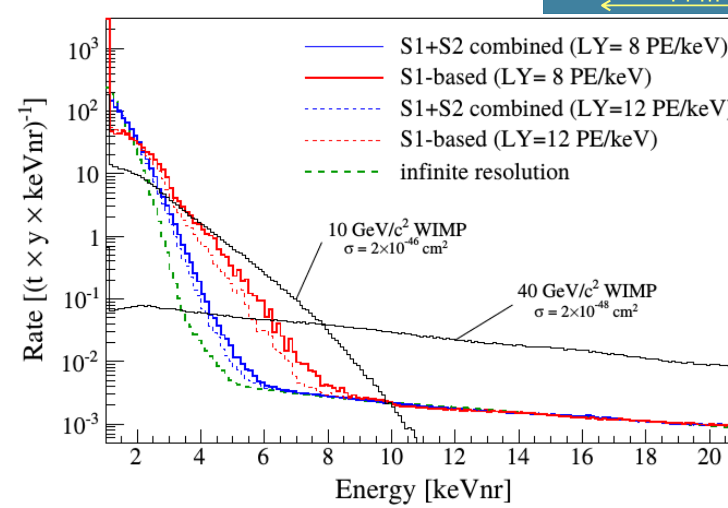
Nuclear Recoils (NR)

radiogenic, cosmogenic

Source	Rate $(t\cdot y\cdot keV)^{-1}$
Radiogenic neutrons : ((α,n), spontaneous fission)	$3.8\cdot10^{-5}$
Cosmogenic neutrons with a 14m x 14m⊘ water shield	negligible
Coherent neutrino-nucleus scattering (CNNS)	0.0022

Example: DARWIN in a water tank instrumented with a veto system





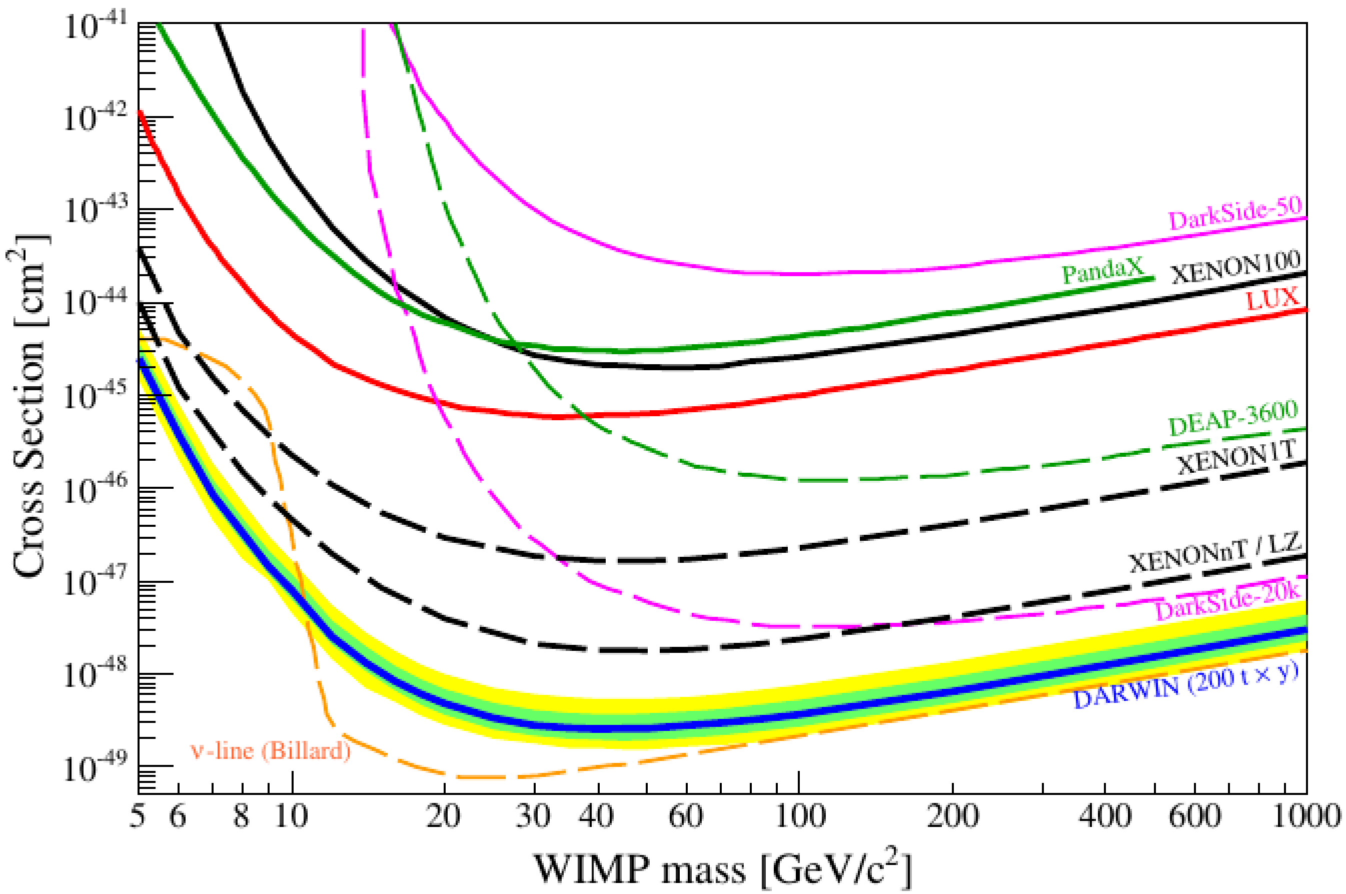
Rich science goal

The DARWIN detector, with its large mass, low-energy threshold and ultra-low background, will open a large variety of physics channels

- Probe WIMP-nucleon interactions for WIMP masses above ~5 GeV/c2 (via spin-independent, spin-dependent and inelastic interactions)
- Probe even lower WIMP masses by using the charge signal alone (XENON10, XENON100, CDMS, EDELWEISS, DS-50, …)
- Coherent neutrino-nucleus scattering : ^{8}B neutrinos from sun
- Coherent neutrino-nucleus scattering : galactic supernova neutrinos
- "Leptophilic DM" models : look for signatures of DM scattering off electrons
- Solar neutrinos: pp-neutrinos via nu-e scattering (precision <1% on flux)
- Search for the neutrinoless double beta decay in ^{136}Xe
- Measuring double electron capture in ^{124}Xe
- Probe solar axions and axion-like particles models (axio-electric effect)
- Probe sterile neutrinos with masses in the > 10 keV range

See S. Lindemann XENON1T talk on friday

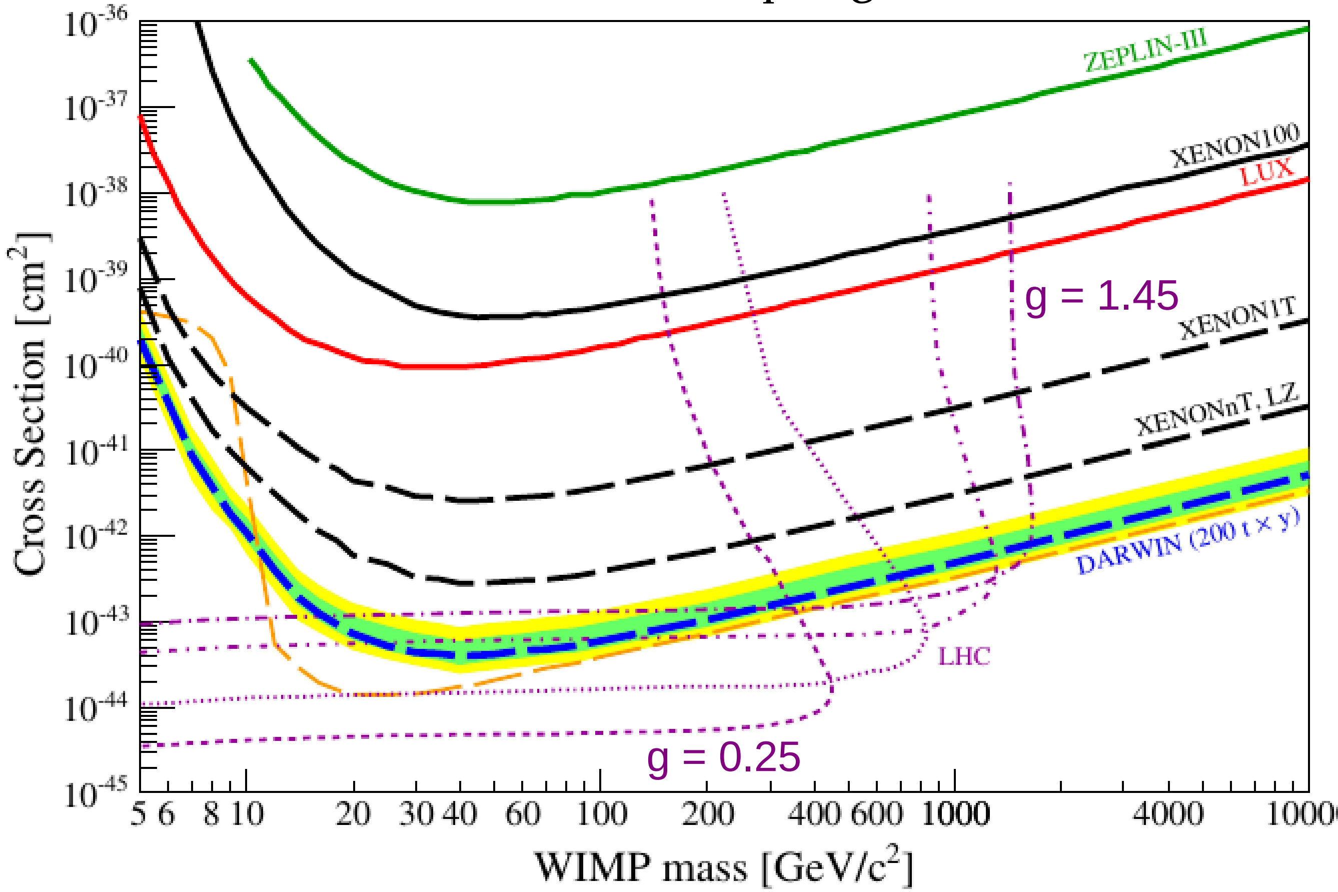
Science goal : SI WIMP-nucleon interactions



200 t·y exposure
$E = 4\text{-}50\ \mathrm{keV_{nr}}$
30% NR acceptance
99.98% ER rejection
LY = 8 PE/keV @ 122keV

Science goal : SD WIMP-nucleon interactions

neutron coupling

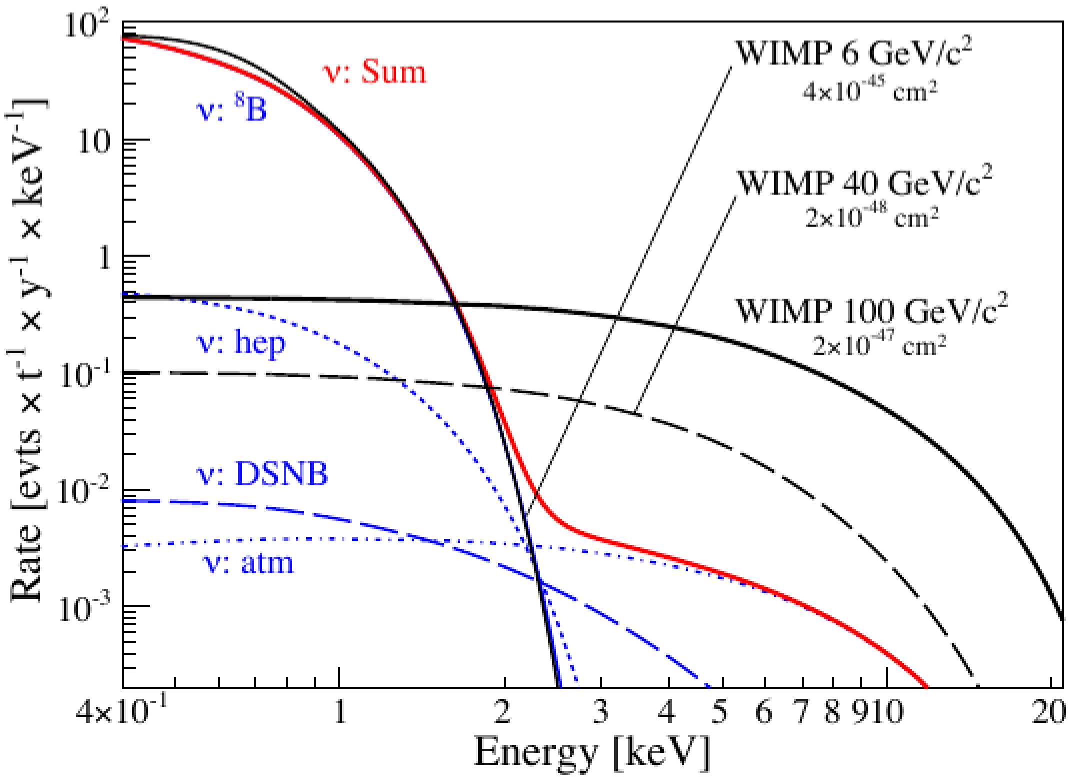


200 t·y exposure
$E = 4\text{-}50\ keV_{nr}$
30% NR acceptance
99.98% ER rejection
LY = 8 PE/keV @ 122keV

Complementarity with the LHC:
minimal simplified DM model with Dirac fermion interacting with an axial-vector mediator
$g \equiv g_q = g_{DM}$
S. A. Malik et al., Phys. Dark Univ. 9-10 (2015) 51

“neutrino floor” : nuclear recoils from neutrinos
Background and an opportunity

L. Baudis et al., JCAP 01, 044 (2014), arXiv:1309.7024



Coherent neutrino-nucleus scatters:

$$\nu + N \rightarrow \nu + N$$

(all neutrino flavours)

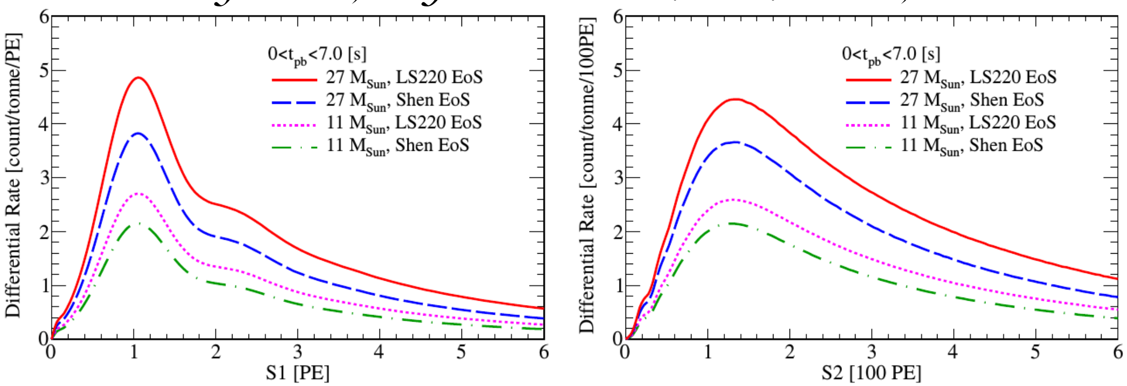
- ^{8}B solar neutrinos
  → 90 events/t/y @ E>1keV$_{nr}$
  (note: LUX re-analysis E$_{th}$>1.1keV$_{nr}$)
  About 3000 CNNS events/year

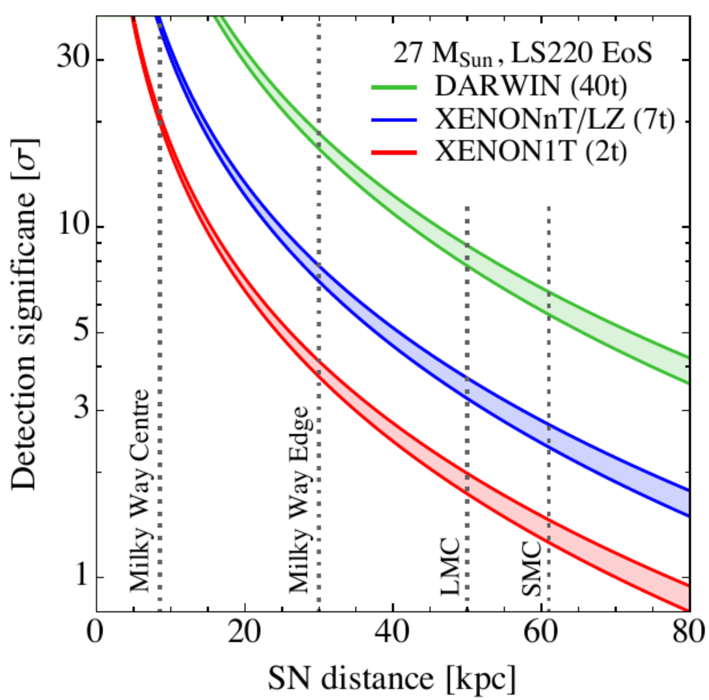
- Atmospheric neutrinos
  → $3 \cdot 10^{-3}$ events/t/y @ E>4keV$_{nr}$

A deviation from expected fluxes → signature for a new physics

Supernova neutrinos

R. Lang et al., Phys.Rev. D94 (2016) no.10, 103009





Coherent neutrino-nucleus scatters:

$$\nu + N \rightarrow \nu + N$$

(all neutrino flavours)

- Neutrinos from Supernova bursts

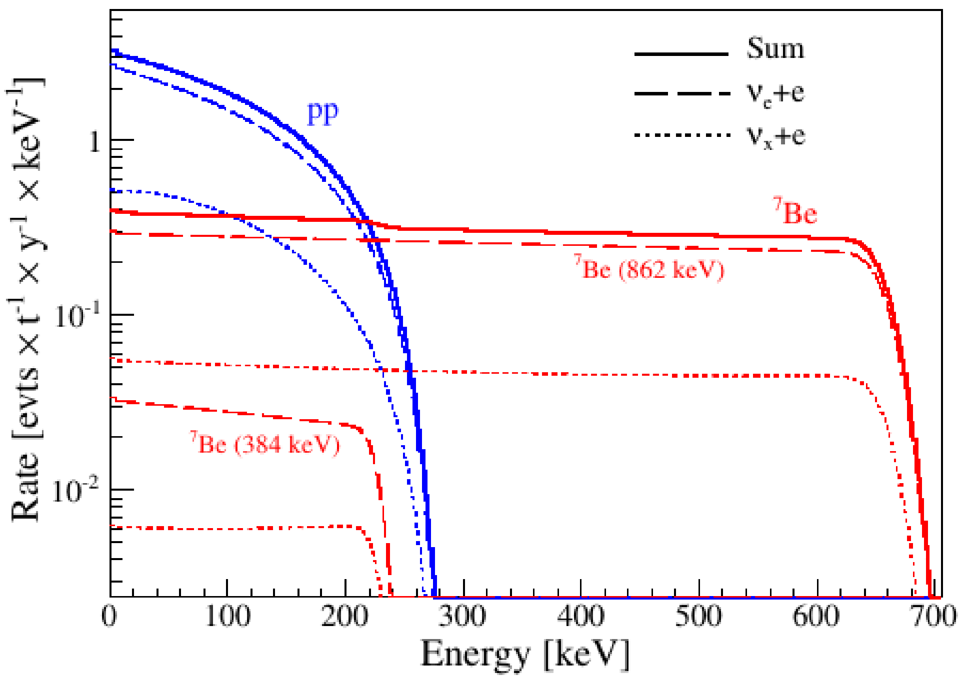
O(10) MeV ν's → O(1) keV NR

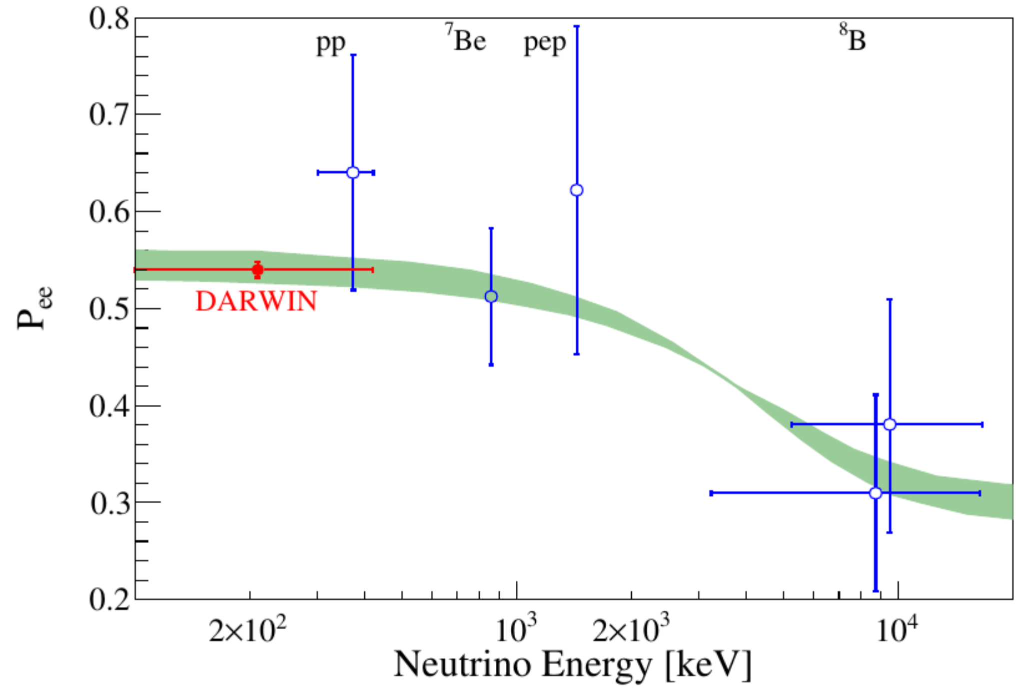
→ 5σ significance with a 27 $M_\odot$ progenitor far up to 65 kpc from Earth

→ 704 events @ 10 kpc

Electronic recoils : solar neutrinos

L. Baudis et al., JCAP 01, 044 (2014), arXiv:1309.7024





$\nu + e^- \rightarrow \nu + e^-$

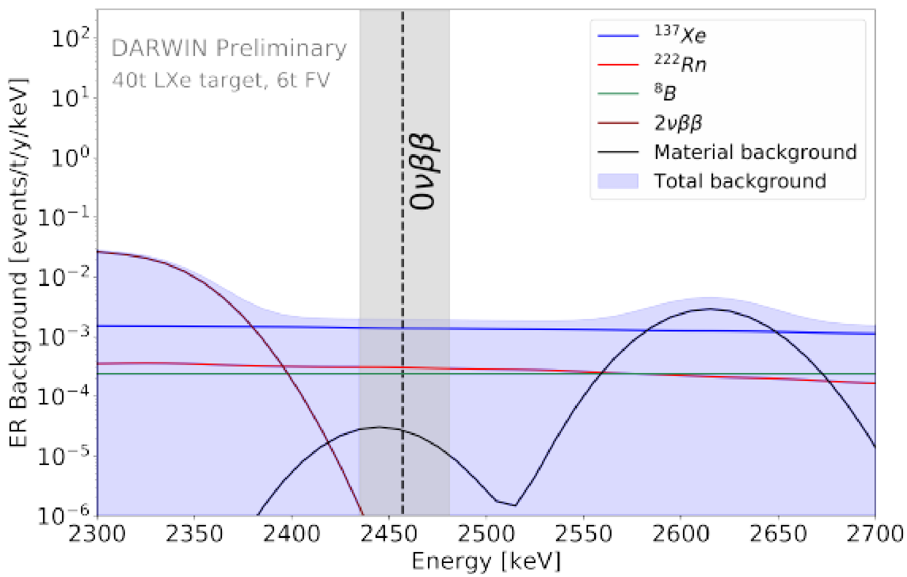
Expected rate at 2-30 keV_{ee}

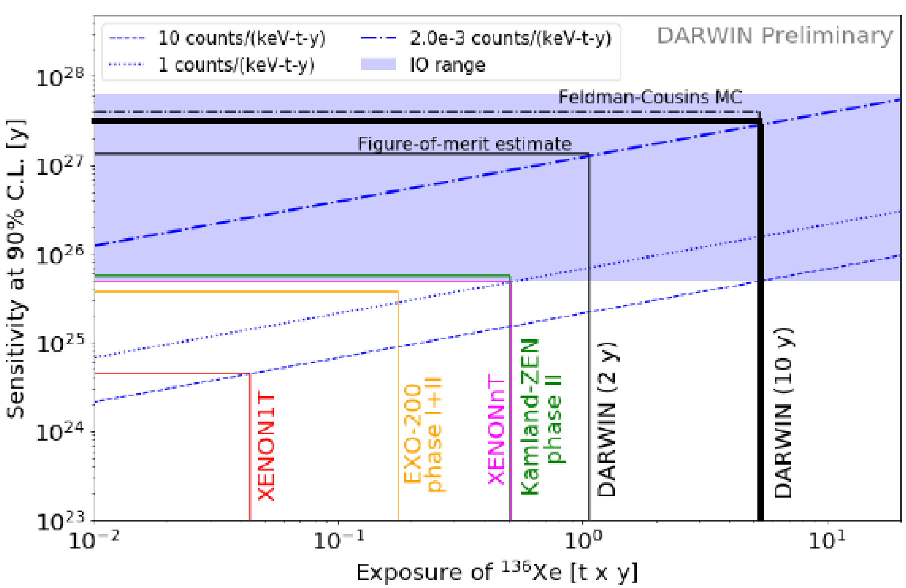
- pp neutrinos : 7.2 events/day
- ^{7}Be neutrinos : 0.9 events/day

More than 2000 neutrino pp events per year
2% precision in a year, 1% after 5 years
Scoping neutrino and solar models

Any deviation would imply new physics

Neutrinoless double beta decay





^{136}Xe: $Q_{\beta\beta}$ = 2458.7 ± 0.6 keV

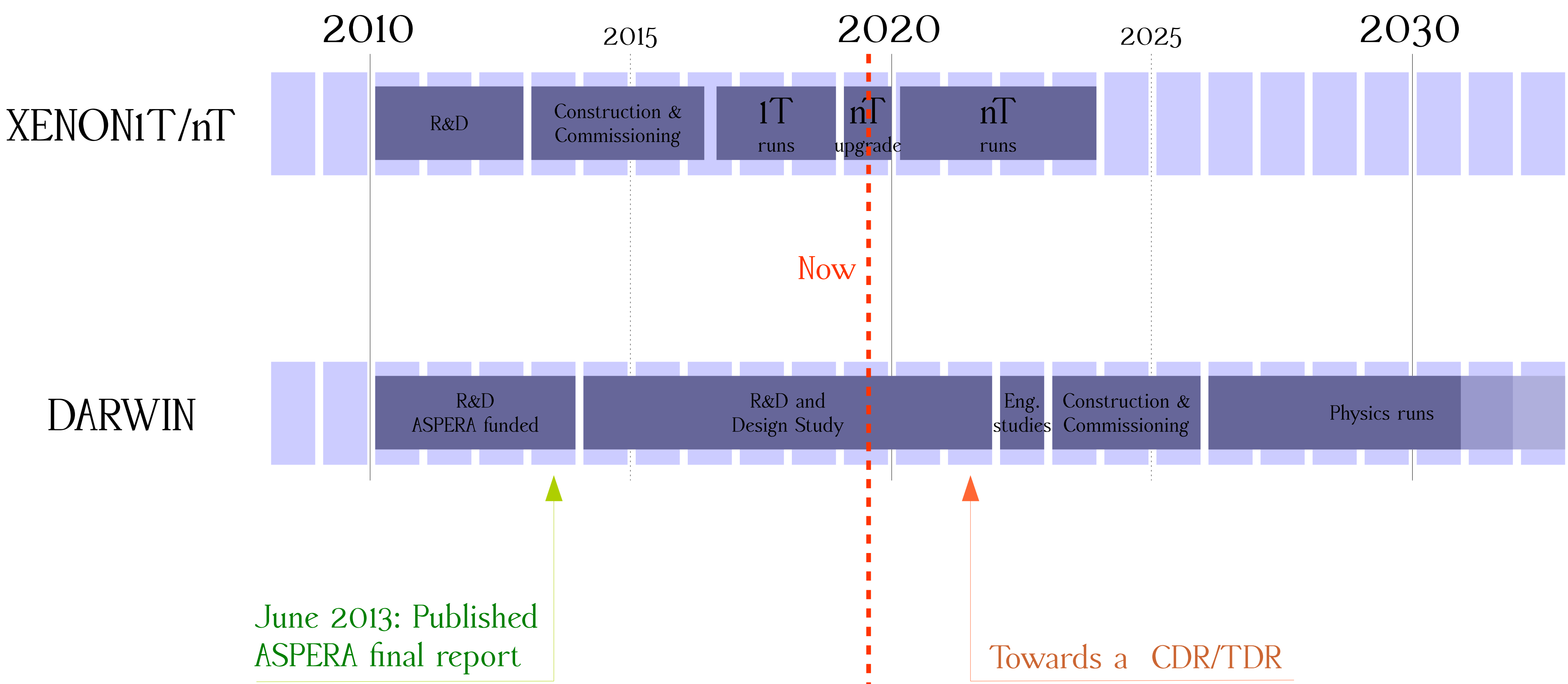
Sensitivity to $0\nu\beta\beta$ by ^{136}Xe (8.9%)):

- $T_{1/2} > 5.6 \cdot 10^{26}$ yr (95% CL) in 30 t y
- $T_{1/2} > 8.5 \cdot 10^{27}$ yr (95% CL) in 140 t y

Assumptions:

- Fiducial mass 6 t ^{nat}Xe (needed stronger fiducialisation)
- ^{222}Rn: 0.1 μBq/kg (rate compatible with ^{8}B)
- σ_E/E = 1-2% at $Q_{\beta\beta}$
- DARWIN "ultimate" assumes negligible background from detector materials

Estimated timescale



- Currently 28 groups from 11 countries
- Present in the APPEC roadmap
- 2 ERC obtained for large scale demonstrators (Zurich and Freiburg)
- Growing national supports for R&D (cryogenics, light detection and bg suppression)
- 6 WPs to follow studies and R&D activities

Two large scale prototypes

DARWIN full-length demonstrator

Universität Zürich[UZH]

The main goal is the demonstration of the electron drift over the full height of DARWIN

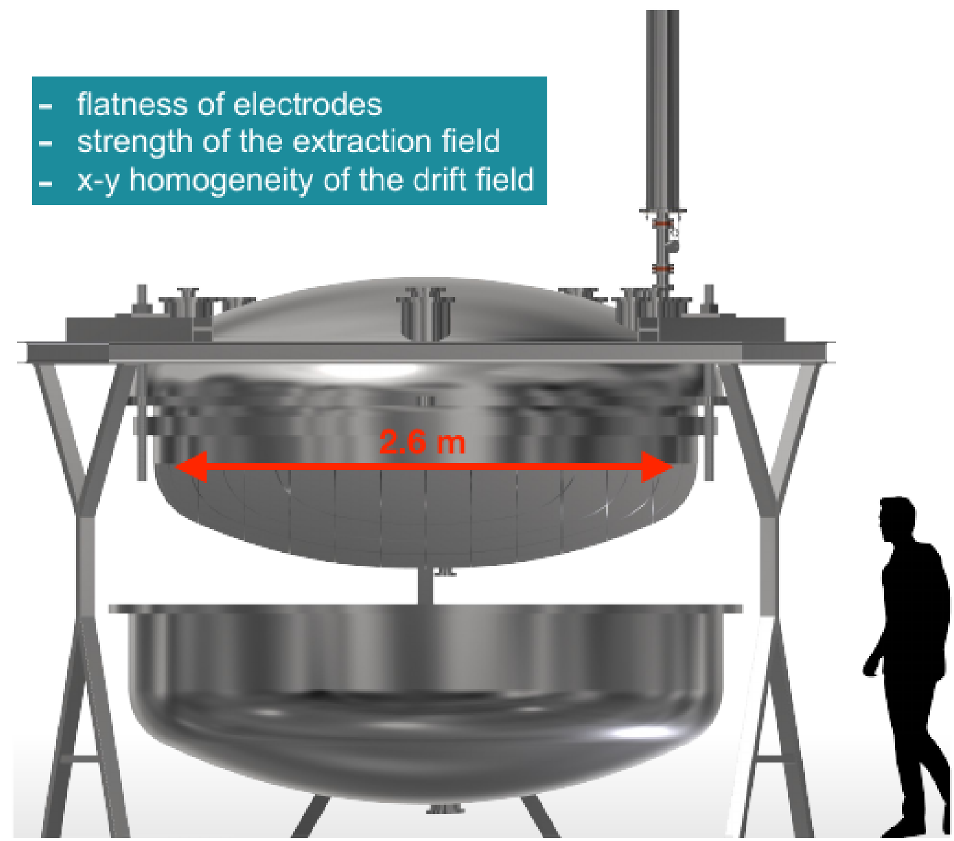
build a TPC of 2.6 m height and 20 cm diameter filled with ~300kg LXe

DARWIN full-(x,y) scale demonstrator

UNI FREIBURG

The main goal is to test components at real diameter under real conditions

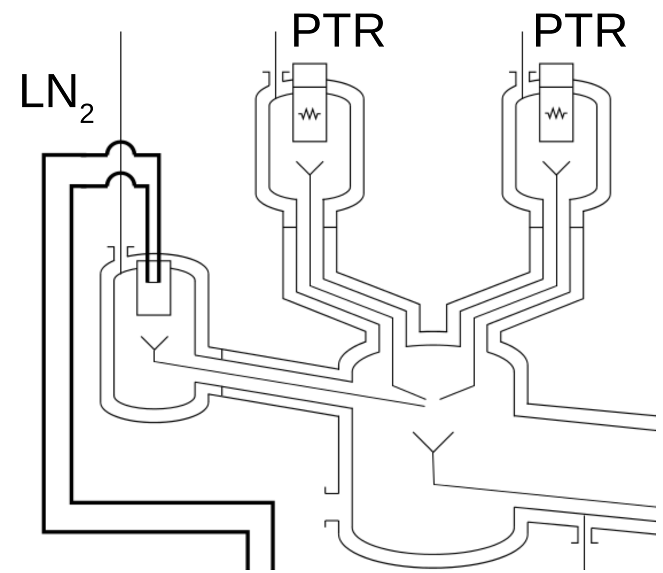
- flatness of electrodes
- strength of the extraction field
- x-y homogeneity of the drift field



Technical challenges in cryogenics : cooling, purification

Cooling:

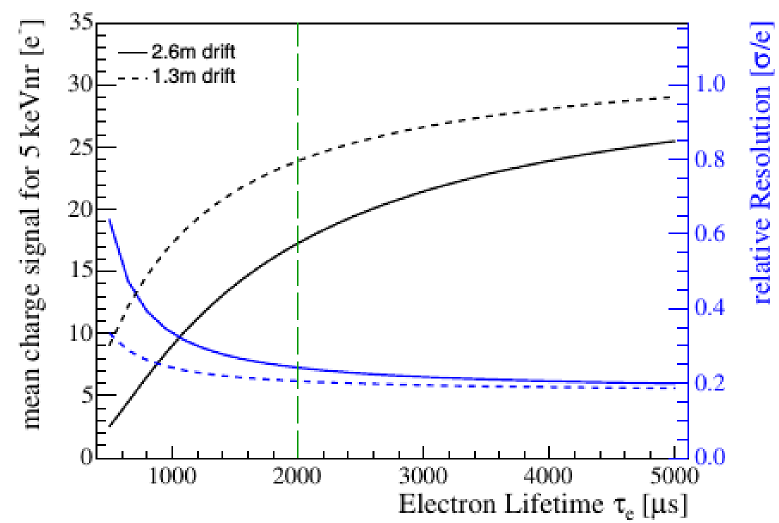
Stability is the key. Use of highly redundant cooling systems: pulse tube refrigerators (PTR) and nitrogen-based cooling. XENON1T already makes use of high redundancy and will serve as a validation of the technique.



Extract of XENON1T cooling system

Purification (from electronegative impurities):

"electron lifetime" during drift > 2ms
Improved charge signal and its resolution
R&D on novel ultra-clean pumps



Technical challenge in cryogenics : storage

Goal: Store, fill and quickly recuperate tons of liquid xenon to/from the detector

Solution for XENON1T/nT is **ReStoX(1+2)**:

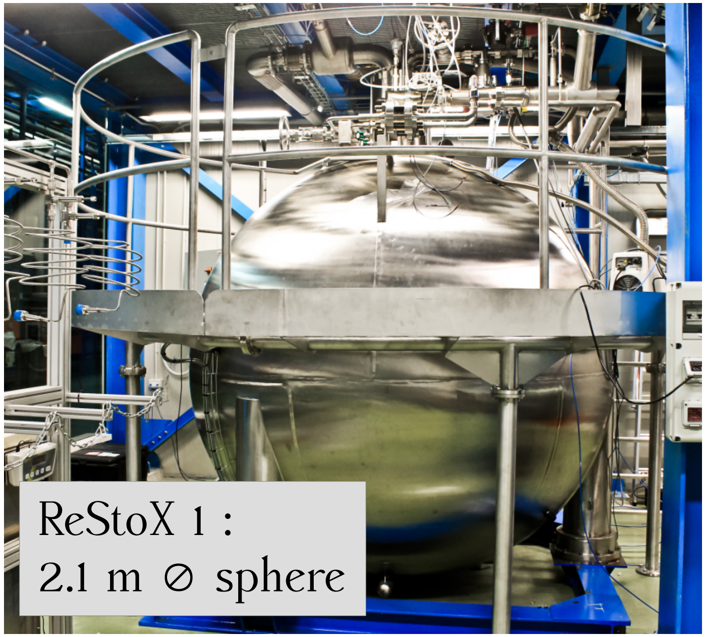
ReStoX 1 :

Two nitrogen-based cooling systems:
- External cooling system (very high cooling power)
- Inner cooling system (~3kW, fine tuning, pressure regulator)

ReStoX 2 :

High
- High capacity (10 tons)
- Fast cooling and recovery (by crystallization)

Both of them capable to withstand high pressures (72 bars) in absence of cooling



ReStoX 1 :
2.1 m ⌀ sphere

ReStoX 2 :
5.5 m high cylinder

Summary

DARWIN is the ultimate low-background astroparticle physics observatory

Extremely rich variety of physics channels, ranging from

Dark Matter search (WIMPs, axions, leptophilic models, ...)

to

Neutrino physics ($0\nu\beta\beta$ decay; solar, atmospheric and supernova neutrinos)

In both cases we showed how it can be extremely competitive on those fields

DARWIN is a Collaboration, it has groups from 11 countries and it's growing

R&Ds on any aspect of the detector are already ongoing in order to arrive over the horizon of the new decade with a concrete TDR

This is the right moment to come aboard !

Thanks

Technical challenge : lowering background

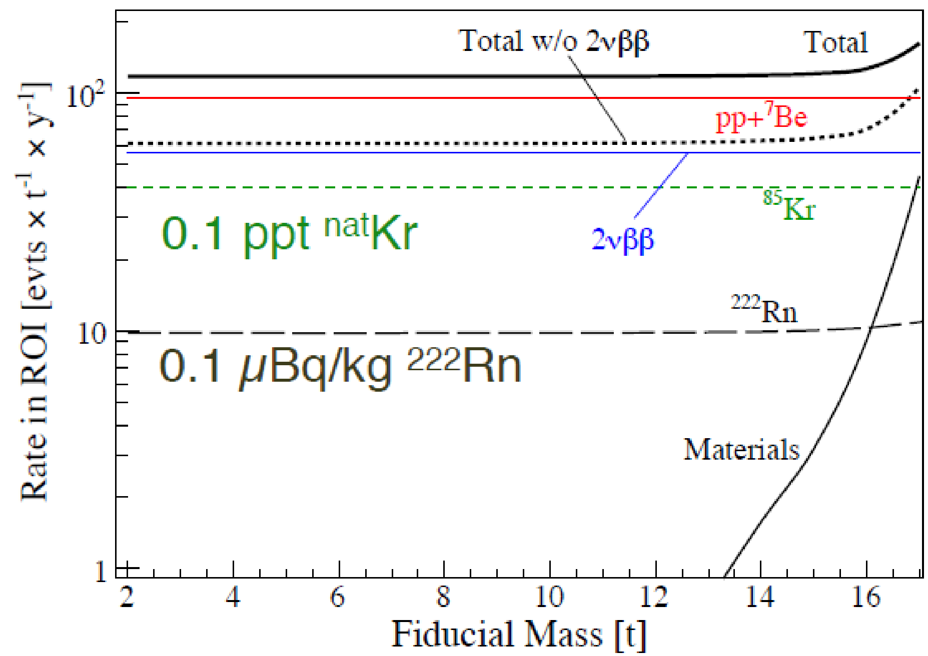
Goal: Electron recoils dominated by solar neutrinos only → having ^{85}Kr and ^{222}Rn rate sub-dominant

- ^{85}Kr: 0.1 ppt of ^{nat}Kr

  Method : separation of ^{nat}Kr with a distillation column

  → A test run with new XENON1T apparatus from Munster group provided < 0.03 ppt (factor x3 better than needed), measured by MPIK RGMS system.

  S. Rosendahl, Gas purification of the XENON dark matter search, PhD thesis, University of Münster (2015)

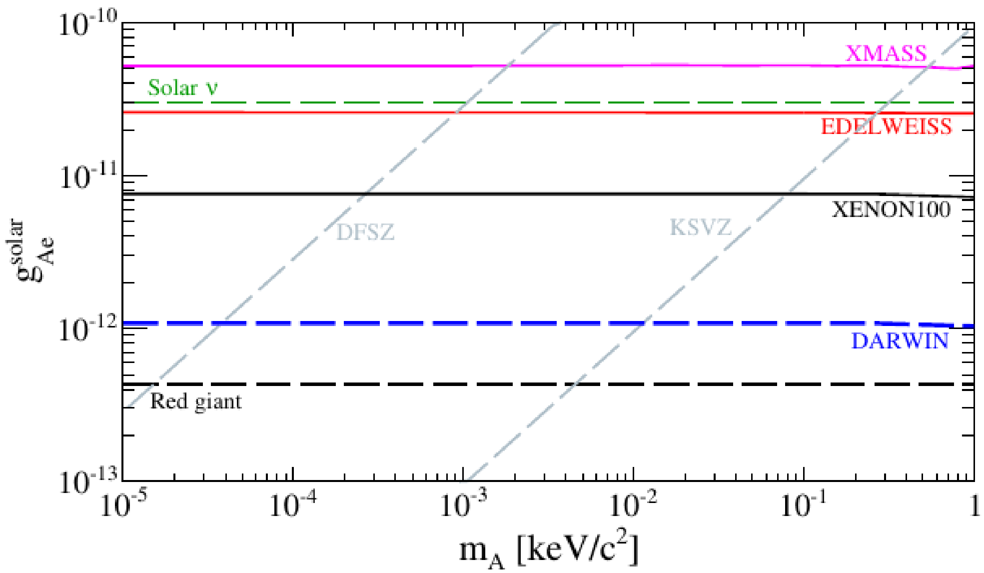


- ^{222}Rn: 0.1 μBq/kg
- 10 μBq/kg is target for XENON1T

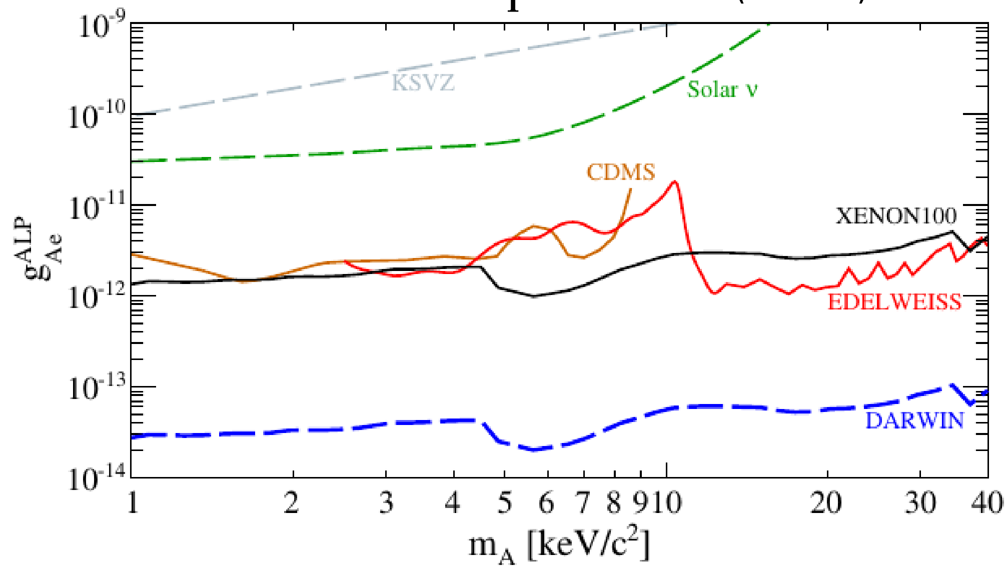
  → Challenging. Control Rn levels with low-emanation materials & cryogenic distillation (use different vapour pressure), adsorption

Science goal : axions and axion-like particles

Solar axions



Axion-like particles (ALPs)



Assumptions:

- 200 t·y exposure
- Similar energy threshold as in XENON100
- 30% better energy resolution

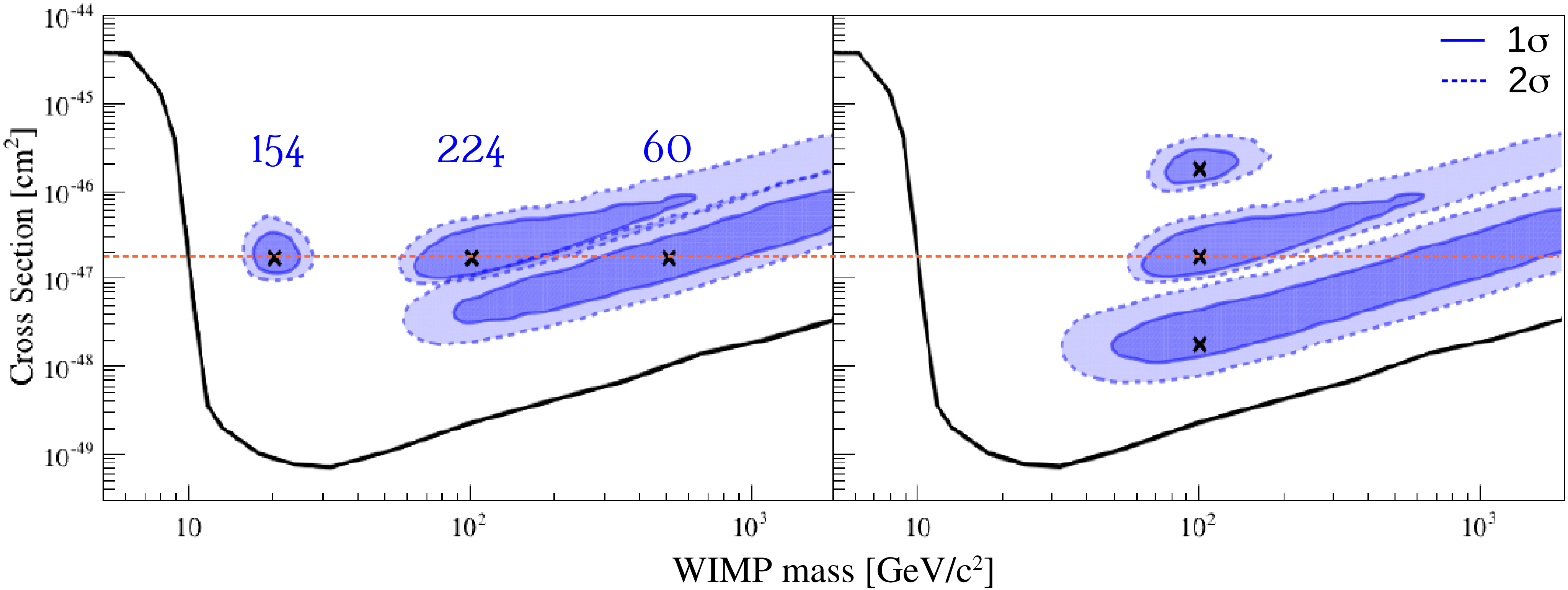
Dependency from exposure:

$G^{solar}_{Ae} \propto (MT)^{-1/8}$

$G^{ALP}_{Ae} \propto (MT)^{-1/4}$

Dominating background: solar neutrinos and 2νββ ^{136}Xe

WIMP spectroscopy



200 t·y exposure
v_{esc} = 544 ± 40 km/s
v_0 = 220 ± 20 km/s
ρ_χ = 0.3 ± 0.1 GeV/cm³

Capability on reconstructing the WIMP mass and cross section for various masses (20, 100, 500 GeV/c2) and cross sections (reference line: XENON1T sensitivity)