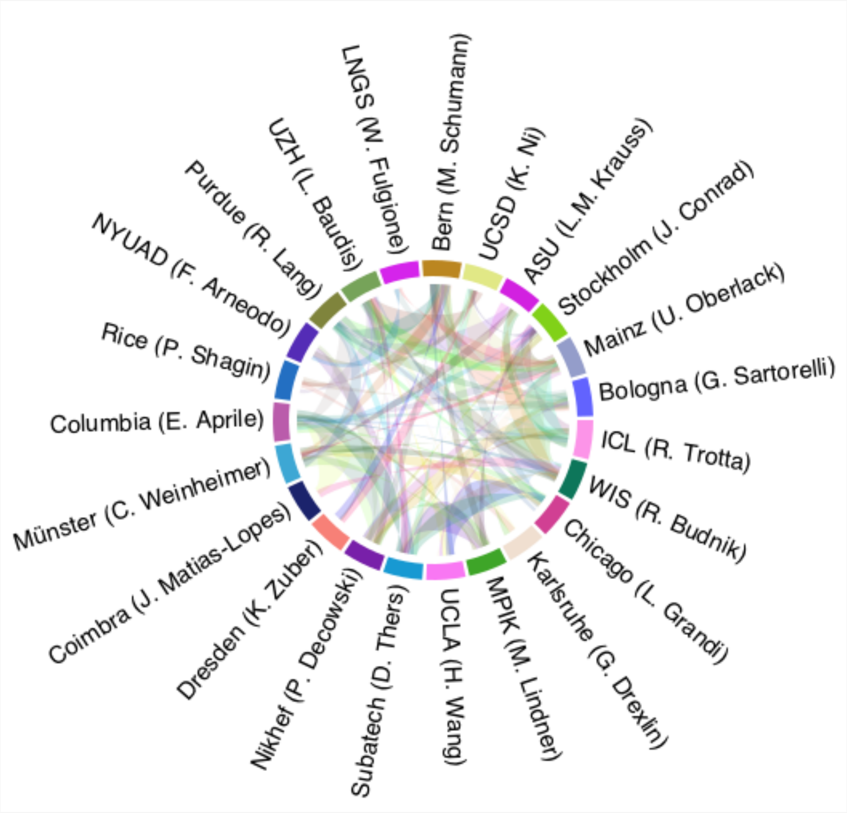
darwin-observatory.org

the DARWIN consortium




# *A 50-ton Liquid Xenon Detector for Dark Matter and Neutrino Physics*

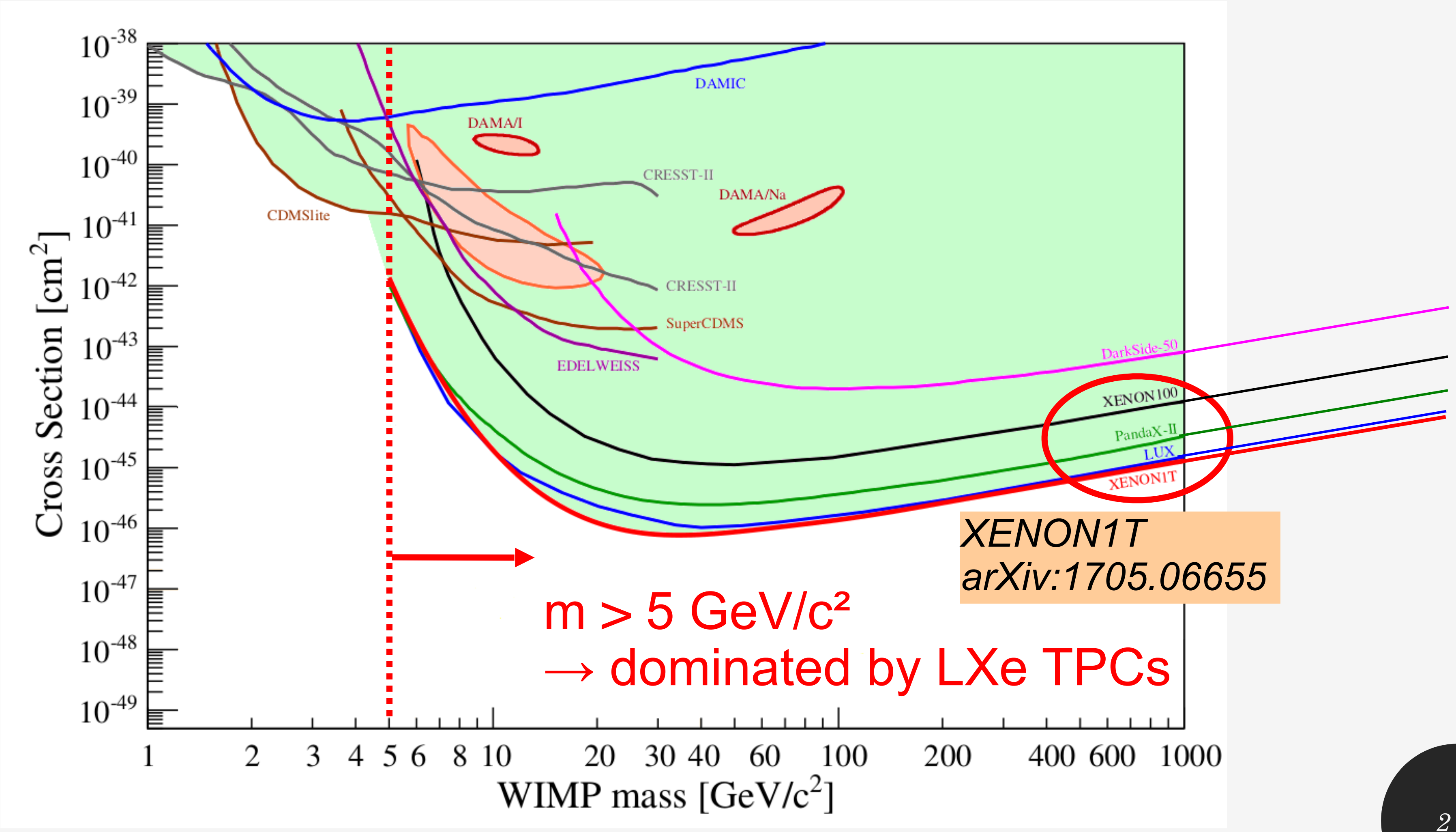

Kaixuan Ni

*University of California, San Diego*


WIN2017, June 19-23, 2017, Irvine

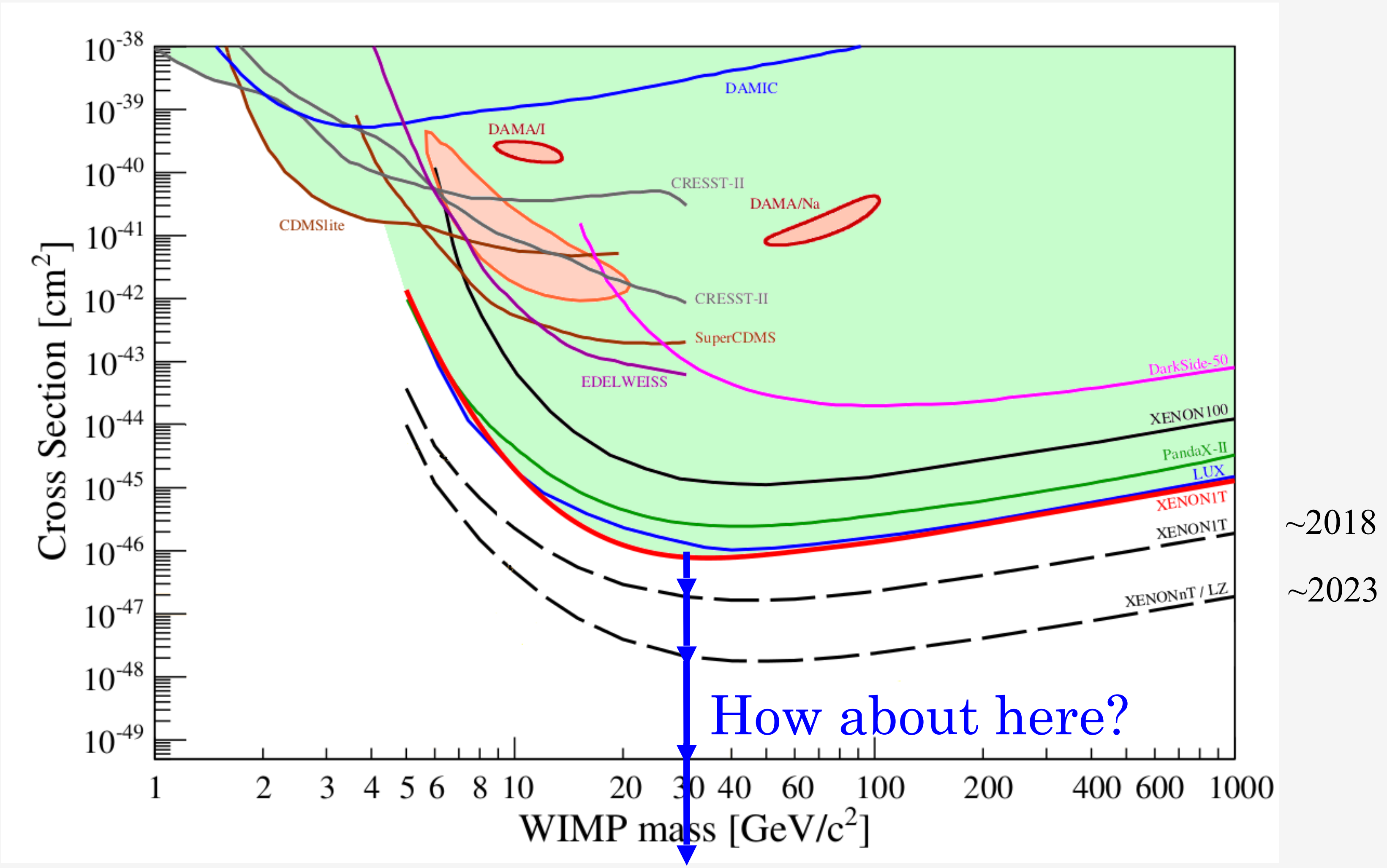
# *Dark Matter Searches: Status*

spin-independent WIMP-nucleon interactions

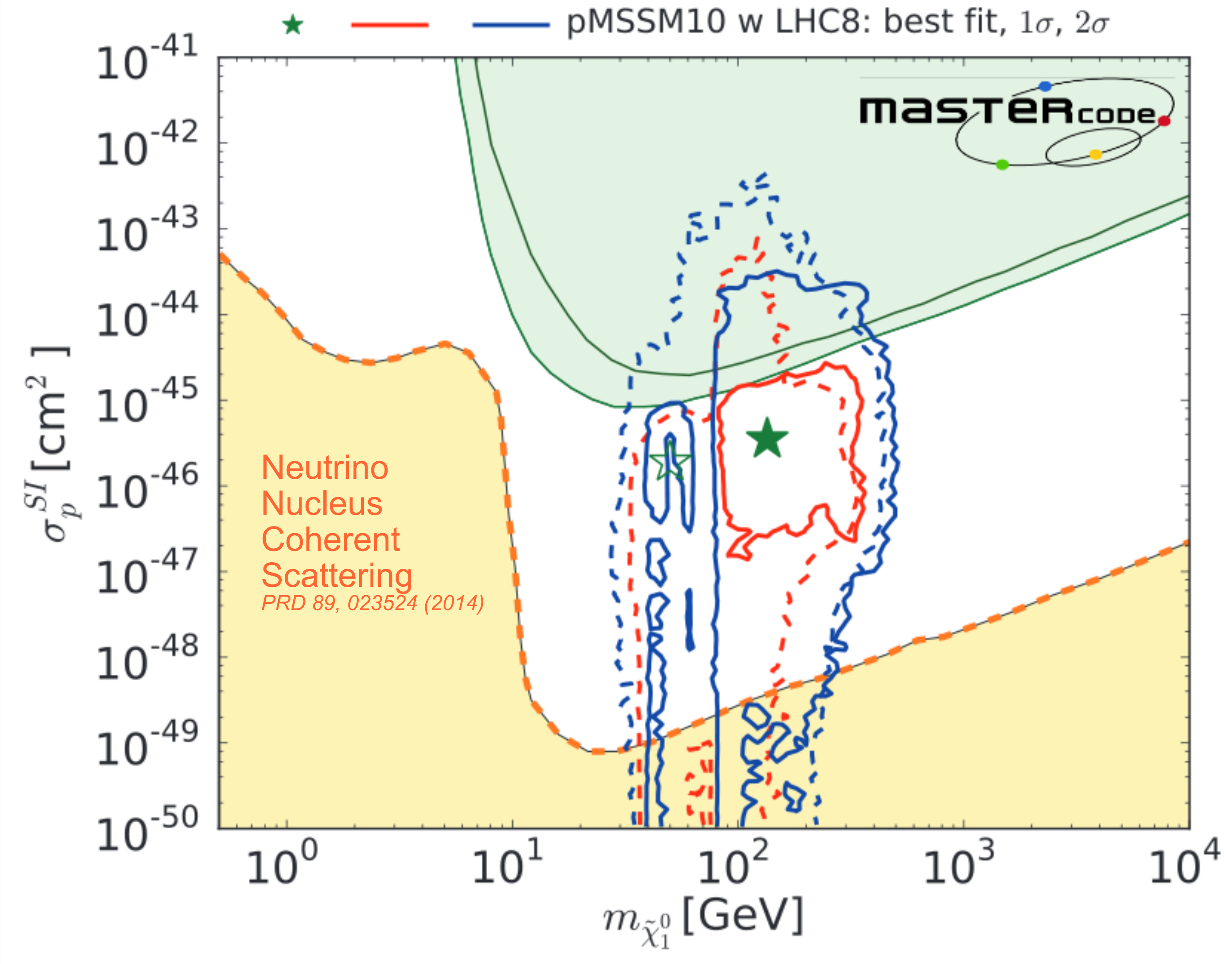


# *Dark Matter Searches: The Future*

spin-independent WIMP-nucleon interactions

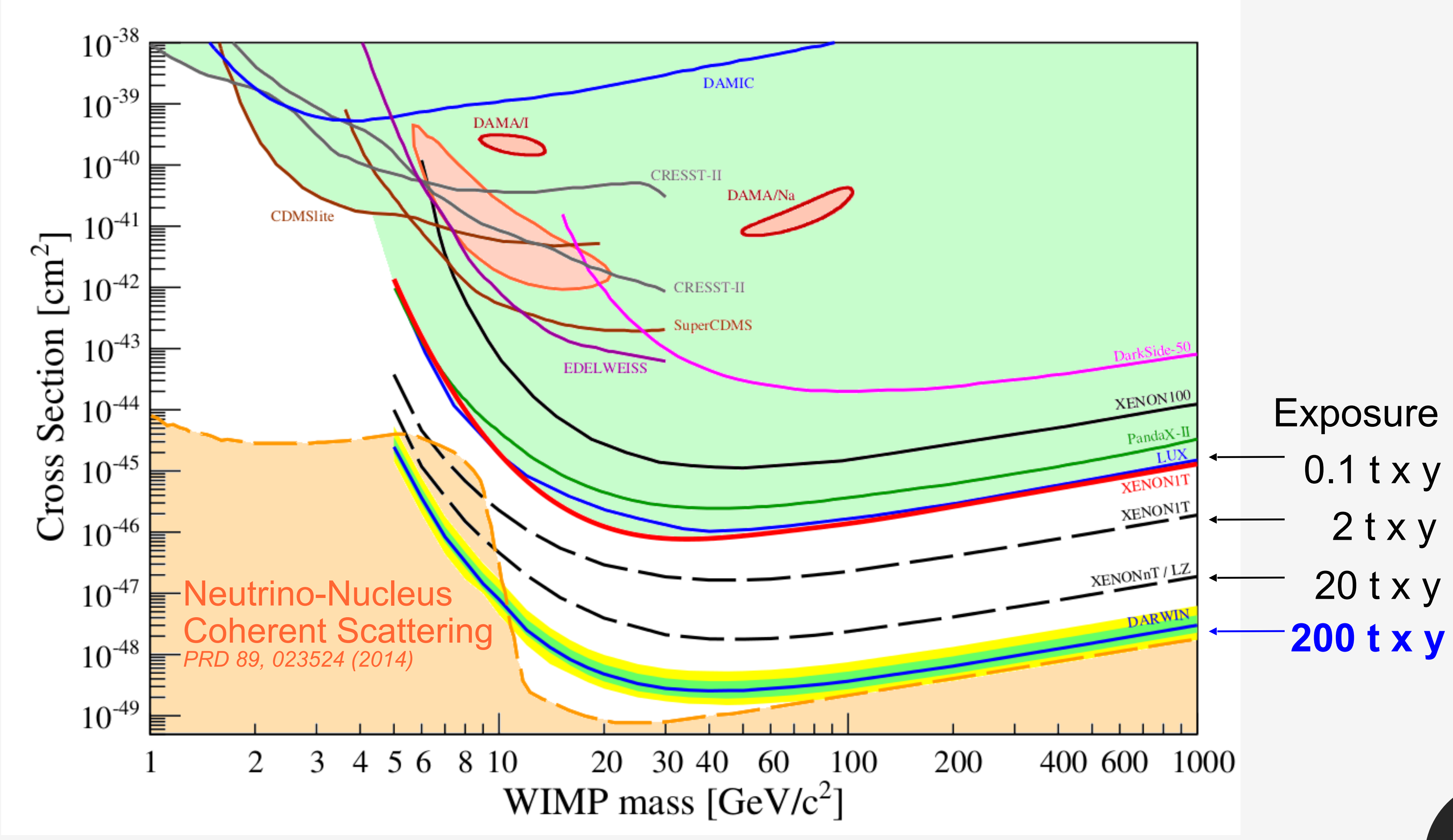


# *Dark Matter Searches: what to look for?*



# The need of an ultimate WIMP detector to reach 200 t x y exposure

spin-independent WIMP-nucleon interactions




***need O(10~100 ton) liquid xenon detector***

**prototype**

XENON10

2005-2007
15 cm drift TPC – 25 kg

Achieved (2007)
$\sigma_{SI} = 8.8 \times 10^{-44}$ cm$^2$

**Generation-1 (100 kg~1 ton)**

XENON100

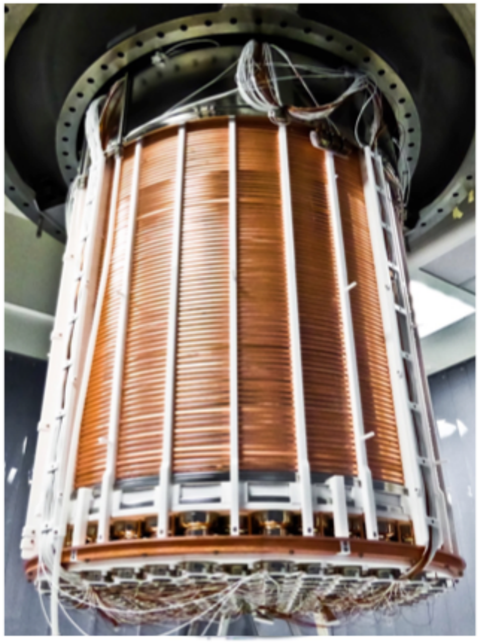
2008-2016
30 cm drift TPC – 161 kg

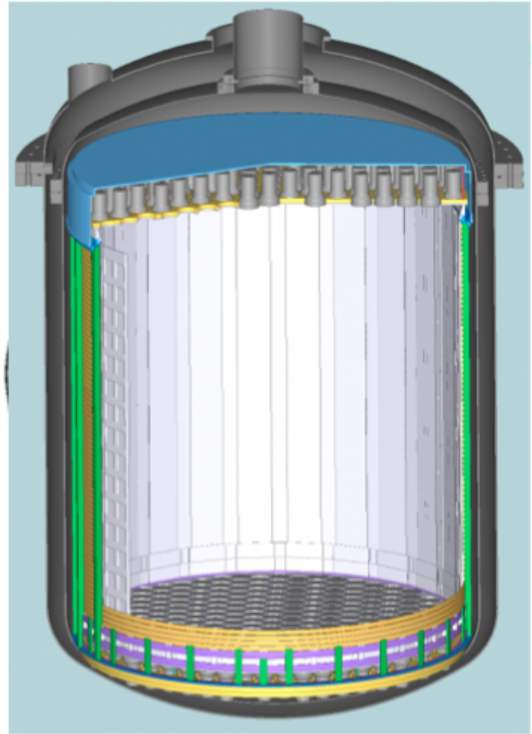
Achieved (2016)
$\sigma_{SI} = 1.1 \times 10^{-45}$ cm$^2$

other exps:
LUX, PandaX-I/II

**Generation-2 (1~10 ton) operation/construction**

XENON1T / XENONnT





2013-2018 / 2019-2023
100 cm / 144 cm drift TPC - 3200 kg / ~8000 kg

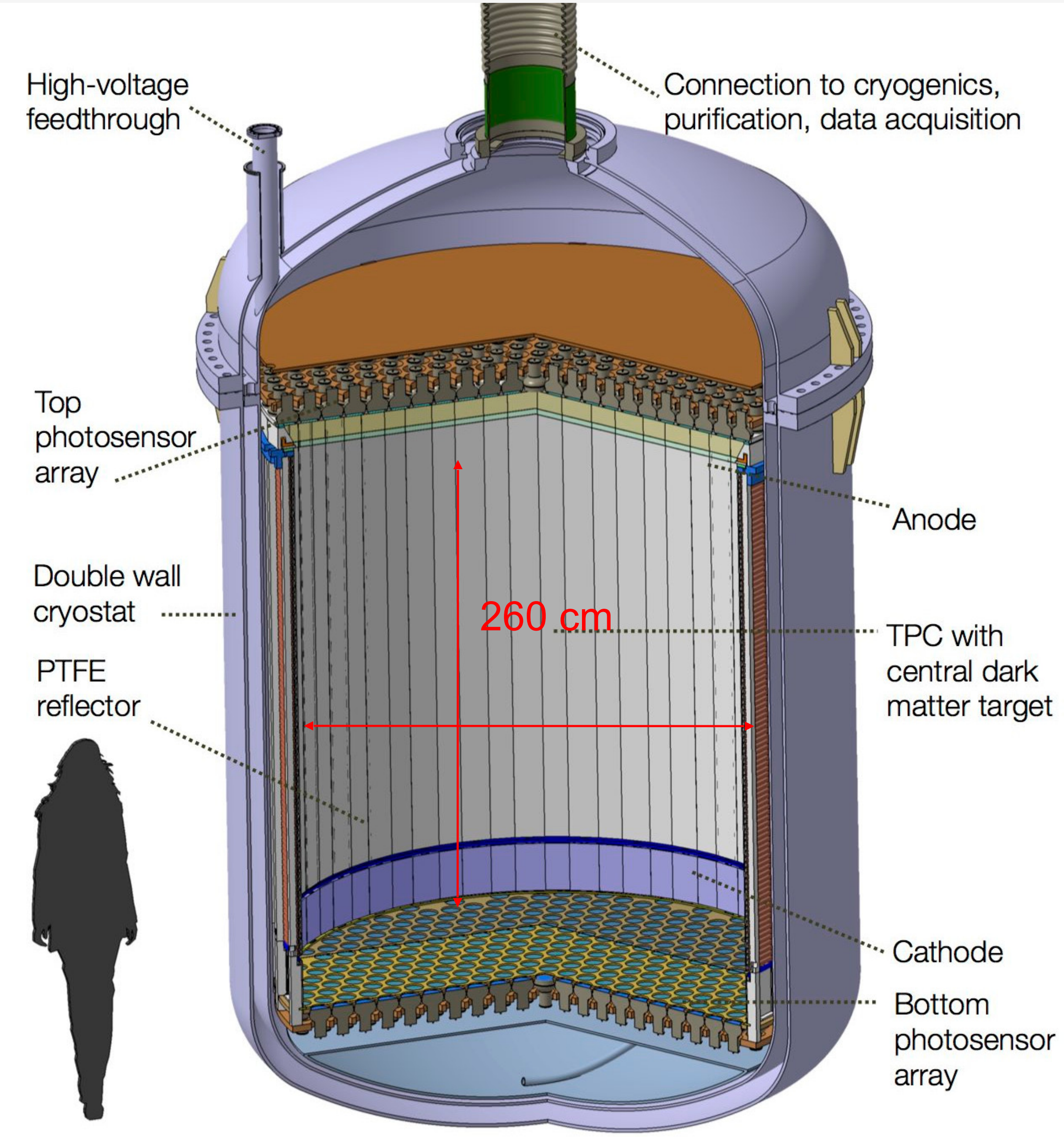
Projected (2018) / Projected (2023)
$\sigma_{SI} = 1.6 \times 10^{-47}$ cm$^2$ / $\sigma_{SI} = 1.6 \times 10^{-48}$ cm$^2$

other exps: LZ, PandaX-4T

x

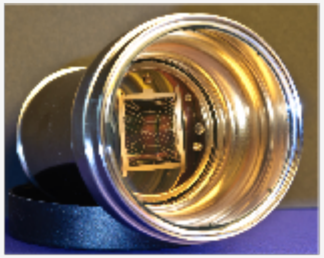
# *Generation-3*: *DARWIN the Ultimate WIMP Detector*

*JCAP 11, 017 (2016)*




Baseline scenario
~30 t fiducial mass (baseline)
**~40 t LXe TPC**
~50 t total LXe mass
~1000 photosensors

Multi-purpose detector:
- sensitivity of a few $10^{-49}$ cm² for WIMPs
- reach the sensitivity to detect CNNS
- solar and supernova neutrinos
- 0v2b



3-inch PMT, R11410-21

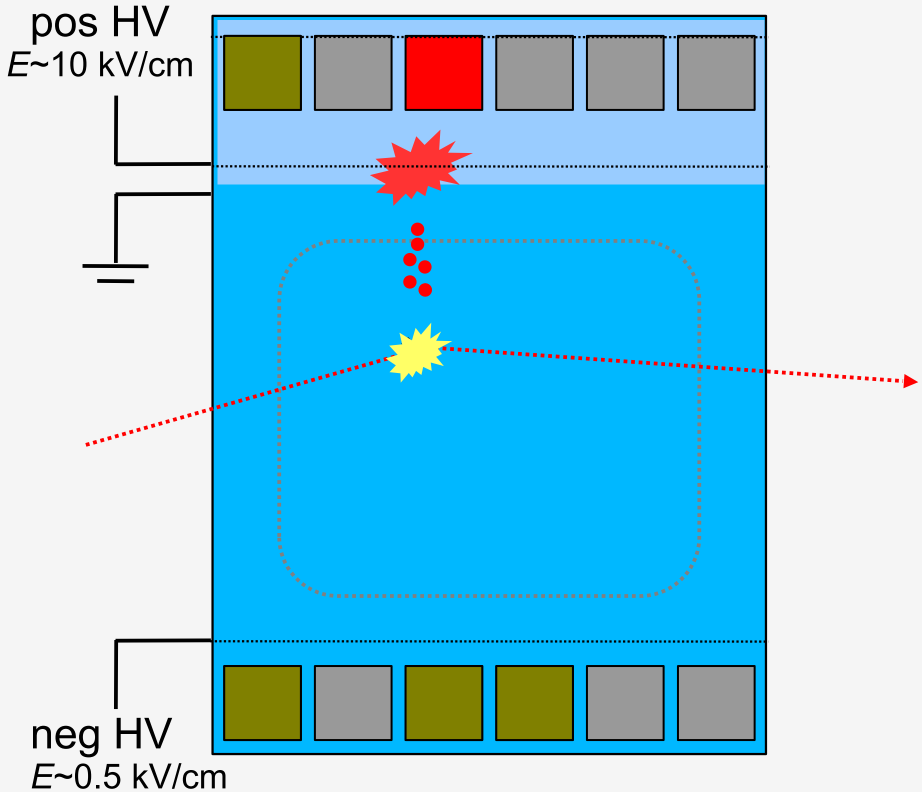
4-inch PMT





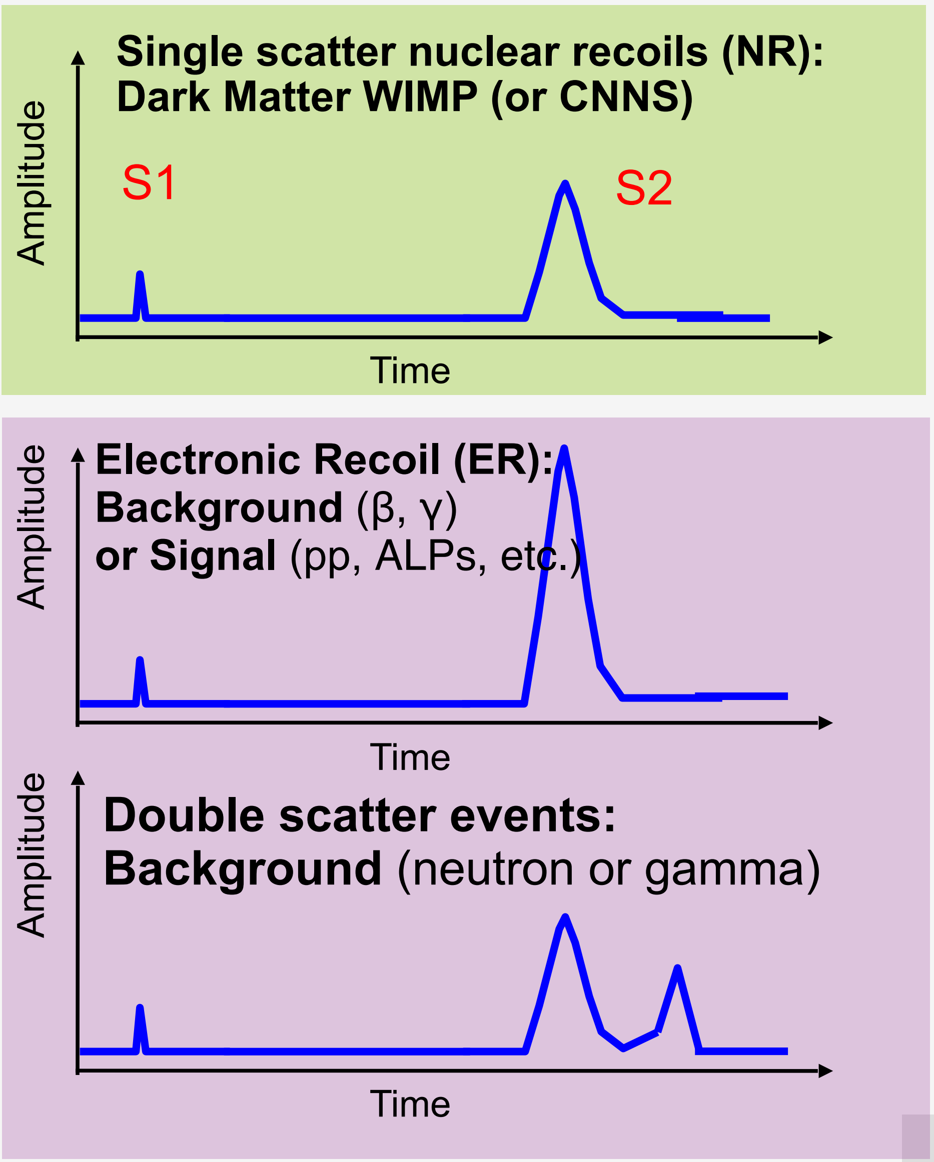
other proposed G3 LXe experiment: PandaX-30T

# Key Detector – Dual Phase Xenon TPC

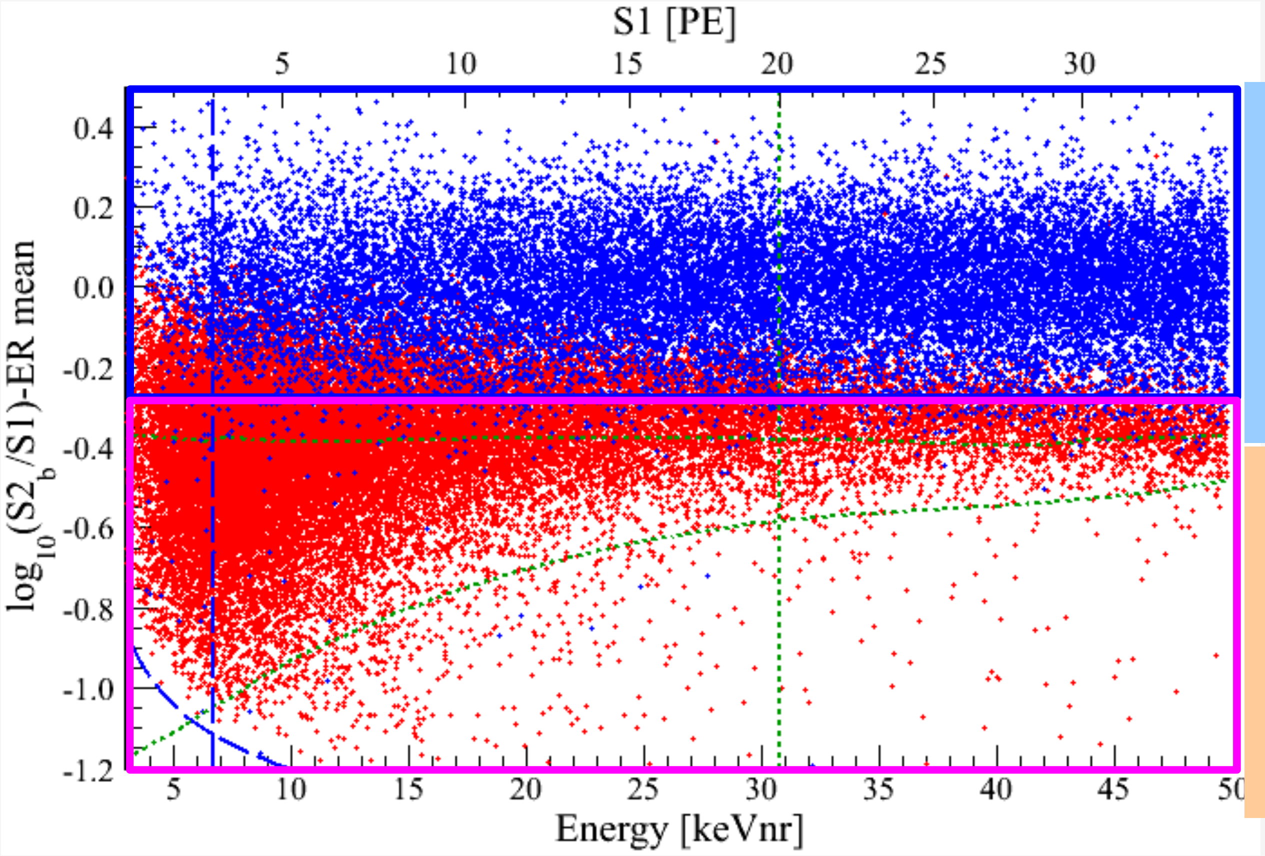



- 3d position reconstruction
  → target fiducialization
- ER/NR discrimination
  - $(S2/S1)_{ER} >> (S2/S1)_{NR}$

TPC = Time Projection Chamber



# *Interactions in LXe Detectors*




scattering off atomic electrons, excitations etc.
→ electronic recoil

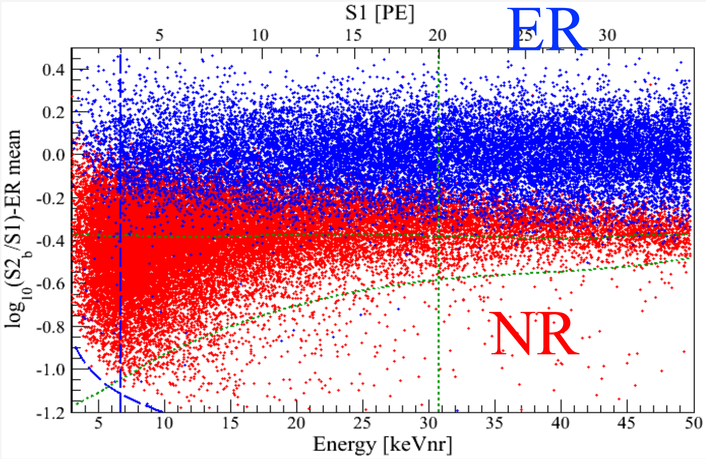
- rare processes detectable if ER background is low

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.

# *DARWIN: not only the WIMP Detector*

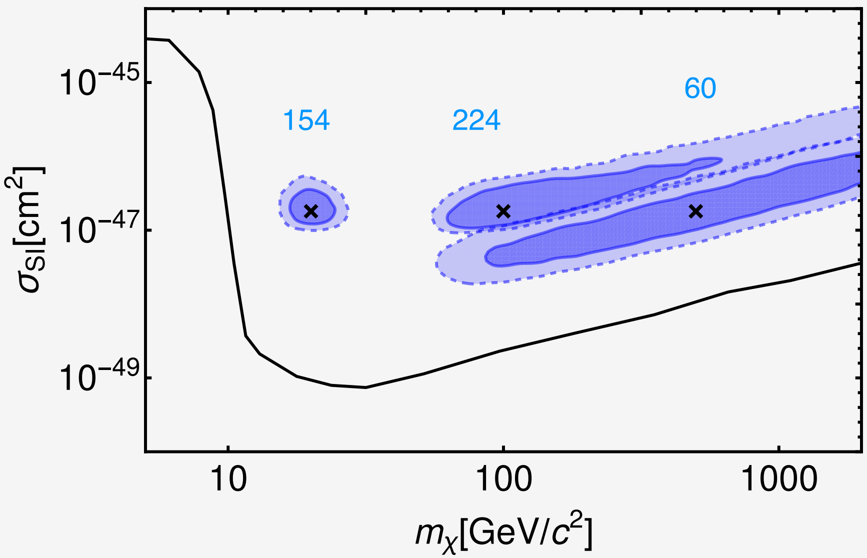



- WIMP searches (NR)
    - Spin-independent
    - Spin-dependent and inelastic interactions
- Coherent neutrino-nucleus scattering (NR)
    - Predicted by SM, not yet observed
- Supernova neutrinos (NR)
    - Sensitive to all neutrino flavors (CNNS)
    - Complementarity to large-scale neutrino detectors
- Low-energy solar neutrinos: pp, $^{7}$Be (ER)
    - Test/improve solar model, test neutrino models
- Solar axions and galactic axion-like particles (ER)
    - Alternative dark matter candidates
    - Coupling to electrons via axio-electric effect
- Neutrinoless double beta decay (ER)
    - Lepton number violating process, effective Majorana mass
    - No enrichment in $^{136}$Xe required

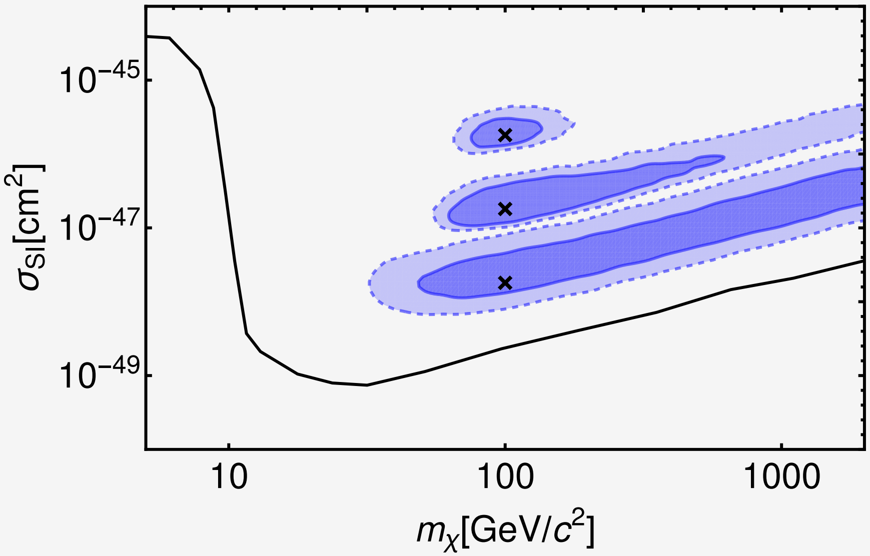
# *WIMP physics: spectroscopy*

- Capability to reconstruct the WIMP mass and cross section for various masses - here **20, 100, 500 GeV/c²** - and cross sections

**Exposure: 200 t y**




**Exposure: 200 t y**




**1 and 2 sigma credible regions after marginalising the posterior probability distribution over:**

$$v_{esc} = 544 \pm 40\,\mathrm{km/s}$$

$$v_0 = 220 \pm 20\,\mathrm{km/s}$$

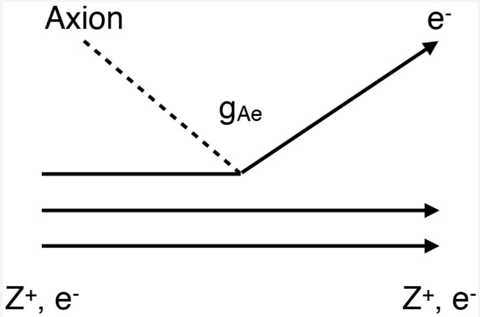
$$\rho_\chi = 0.3 \pm 0.1\,\mathrm{GeV/cm^3}$$

Update: Newstead et al., PRD D 88, 076011 (2013)

# *Solar axions and ALPs*

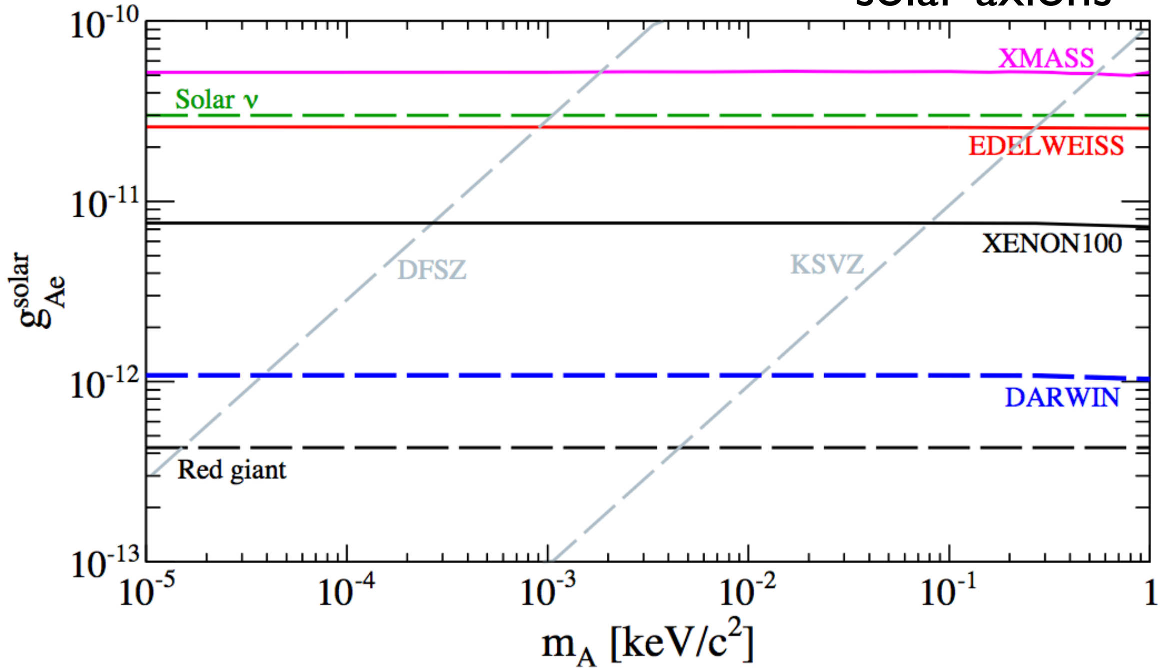
JCAP 11 (2016) 017

- Measurement via axio-electric effect (ER channel)
- Expect mono-energetic peak at the particle mass
- Sensitivity to solar axions
  - x10 improvement relative to XENON100
- Sensitivity to galactic Axion Like Particles (ALPs)
  - x100 improvement relative to XENON100
- Dominant backgrounds: solar neutrinos and $2\nu\beta\beta$ of $^{136}Xe$



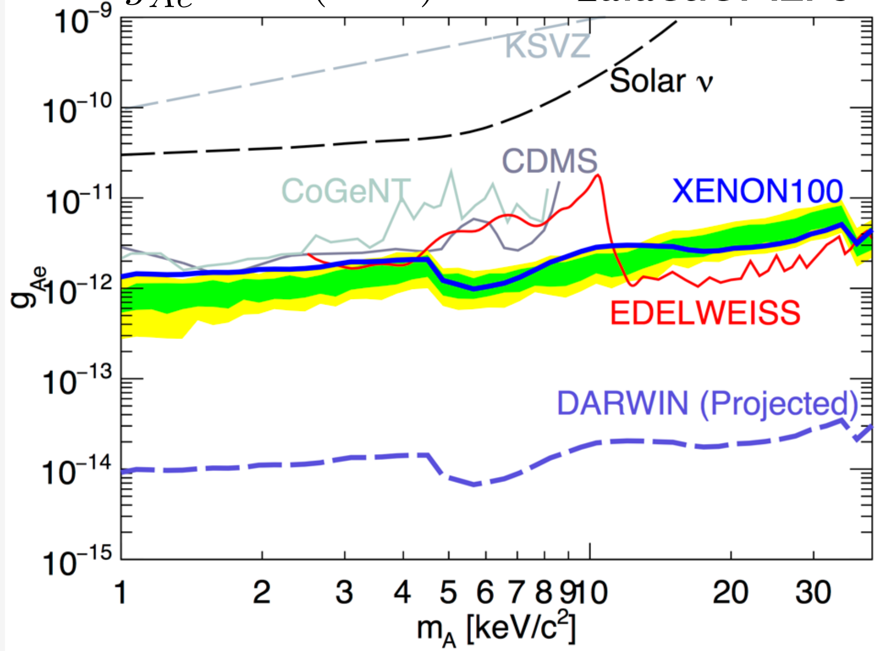

$$g_{Ae}^{\mathrm{solar}} \propto (M\,T)^{-1/8}$$

solar axions




$$g_{Ae}^{\mathrm{ALP}} \propto (M\,T)^{-1/4}$$

galactic ALPs

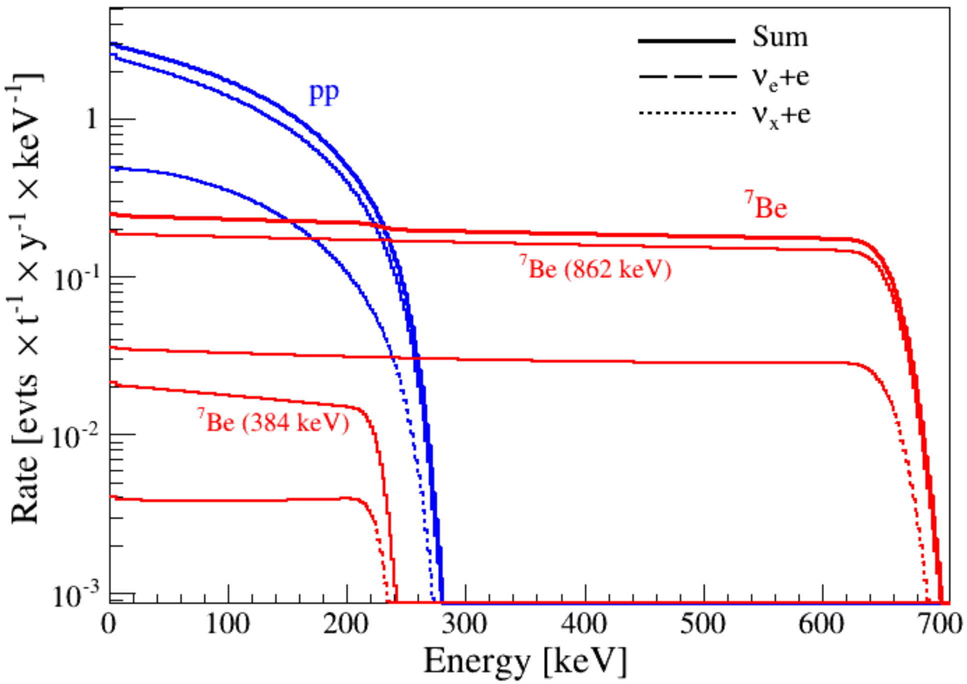


# *Solar neutrino-electron scattering in DARWIN*

**a background for the WIMP search**

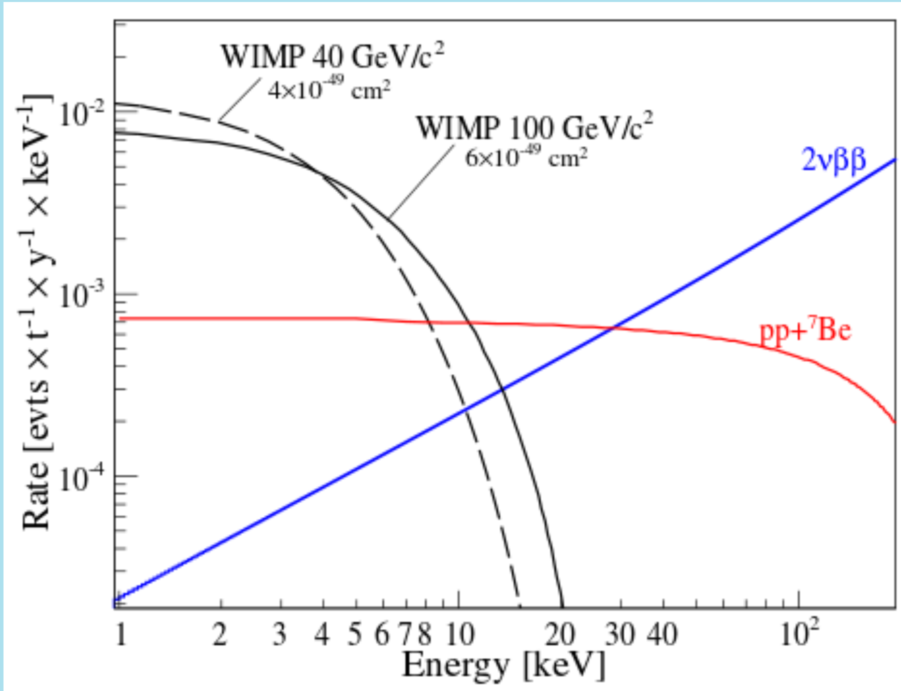
*JCAP 11, 017 (2016)*

## Differential Recoil Spectrum in Xe




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

## Neutrino interactions



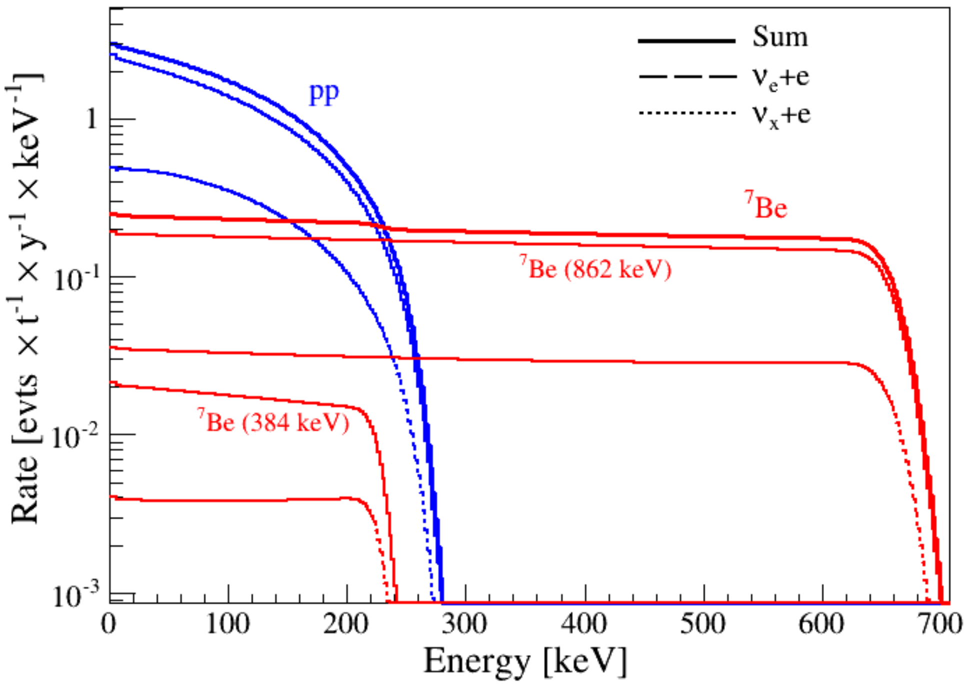

- ER rejection efficiencies ~99.98% at 30% NR efficiency are required to reduce to sub-dominant level

# *Solar neutrino-electron scattering in DARWIN*

**a new physics channel!**

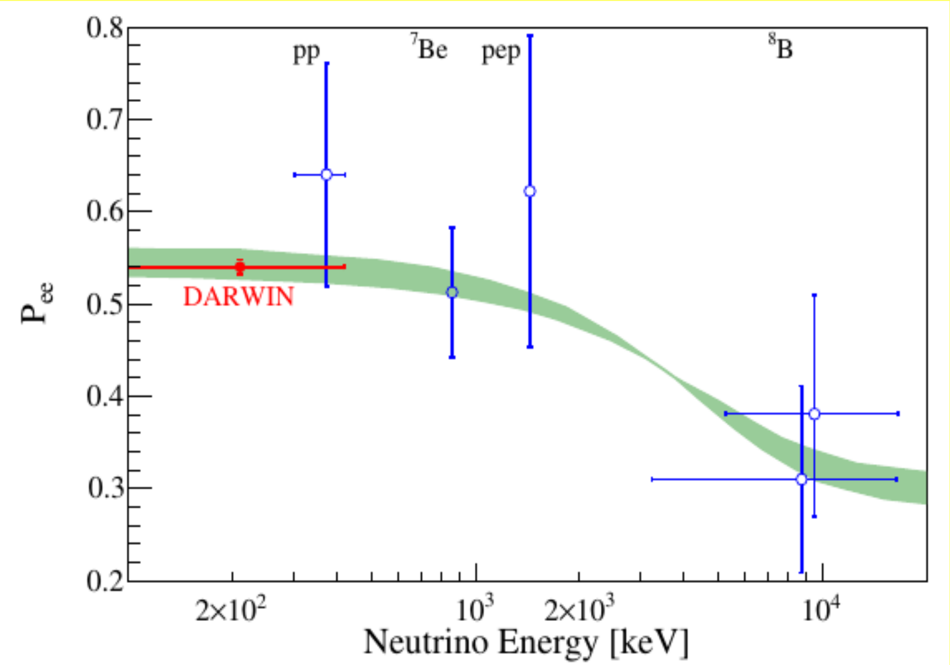
*JCAP 11, 017 (2016)*

## 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

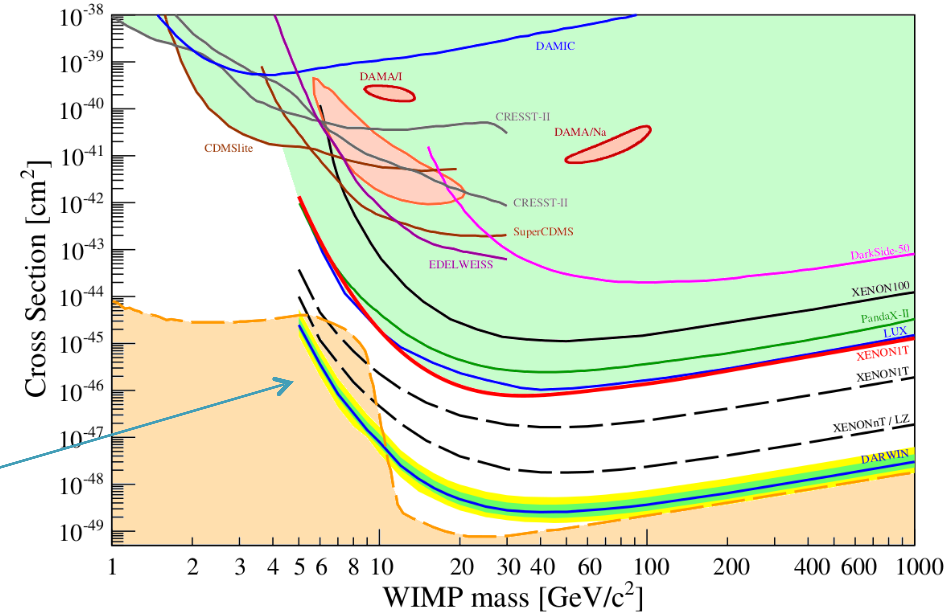


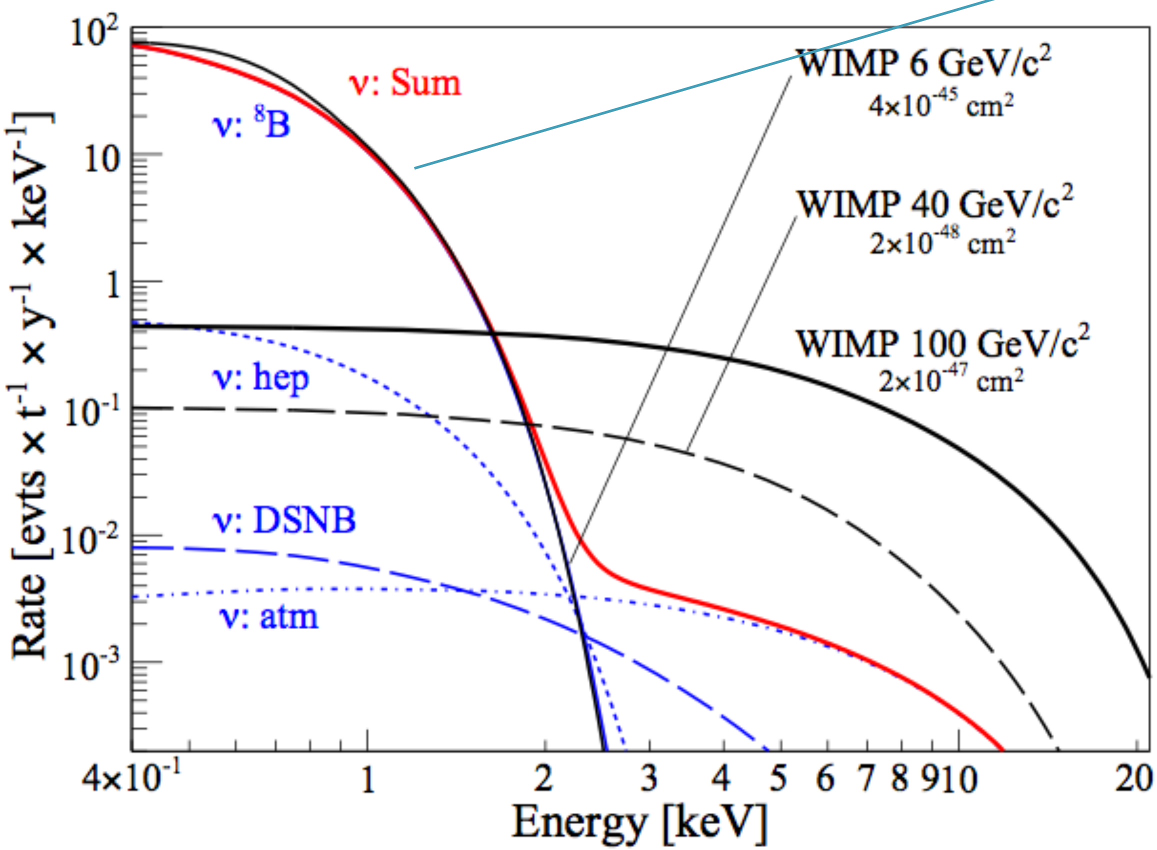

- 30t target mass, 2-30 keV window
  → 2850 neutrinos per year (89% pp)
  → achieve 1% statistical precision
  on pp-flux (→$P_{ee}$) with 100 t x y

# *Solar Neutrinos Coherent Scattering (NR)*

Bo

- $\nu + N_{Xe} \rightarrow \nu + N_{Xe}$
- Predicted by SM but not yet observed
- CNNS is background for WIMPs,
- Steeply falling spectrum




$^8$B neutrinos from the Sun:

→ 90 events/ton/yr, $E_R$ > 1 keV

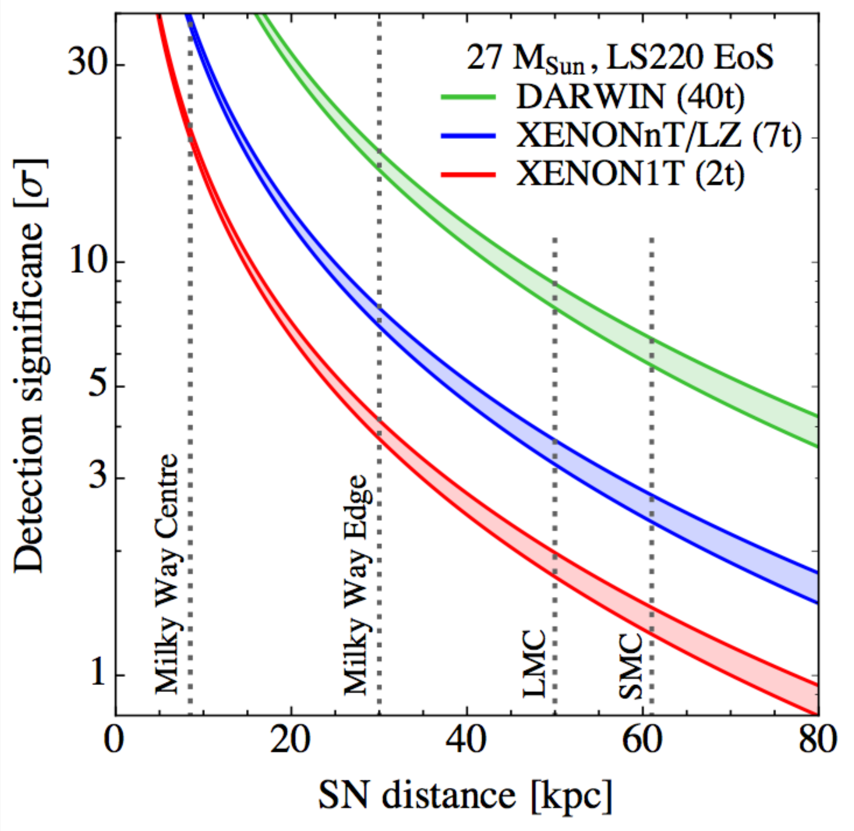
Atmospheric neutrinos:

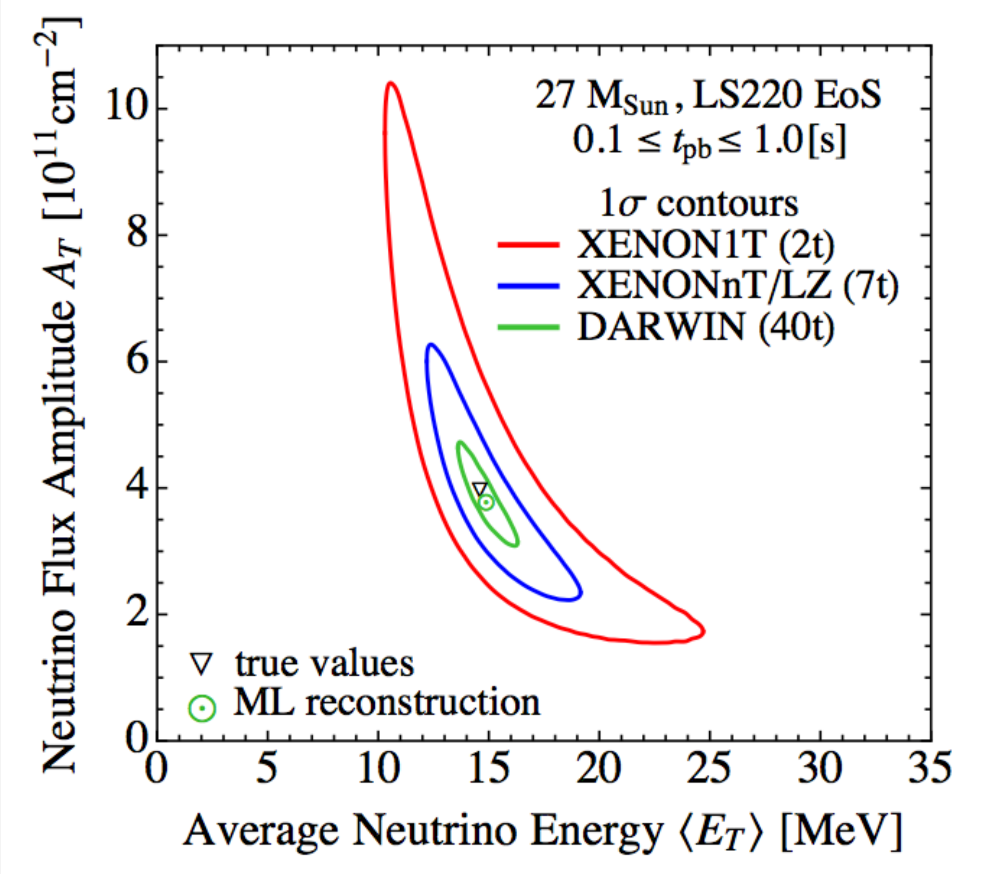
→ $3\times10^{-3}$ events/ton/yr, $E_R$ > 3 keV

# *Supernova Neutrinos*

R. Lang et al., arXiv:1606.09243

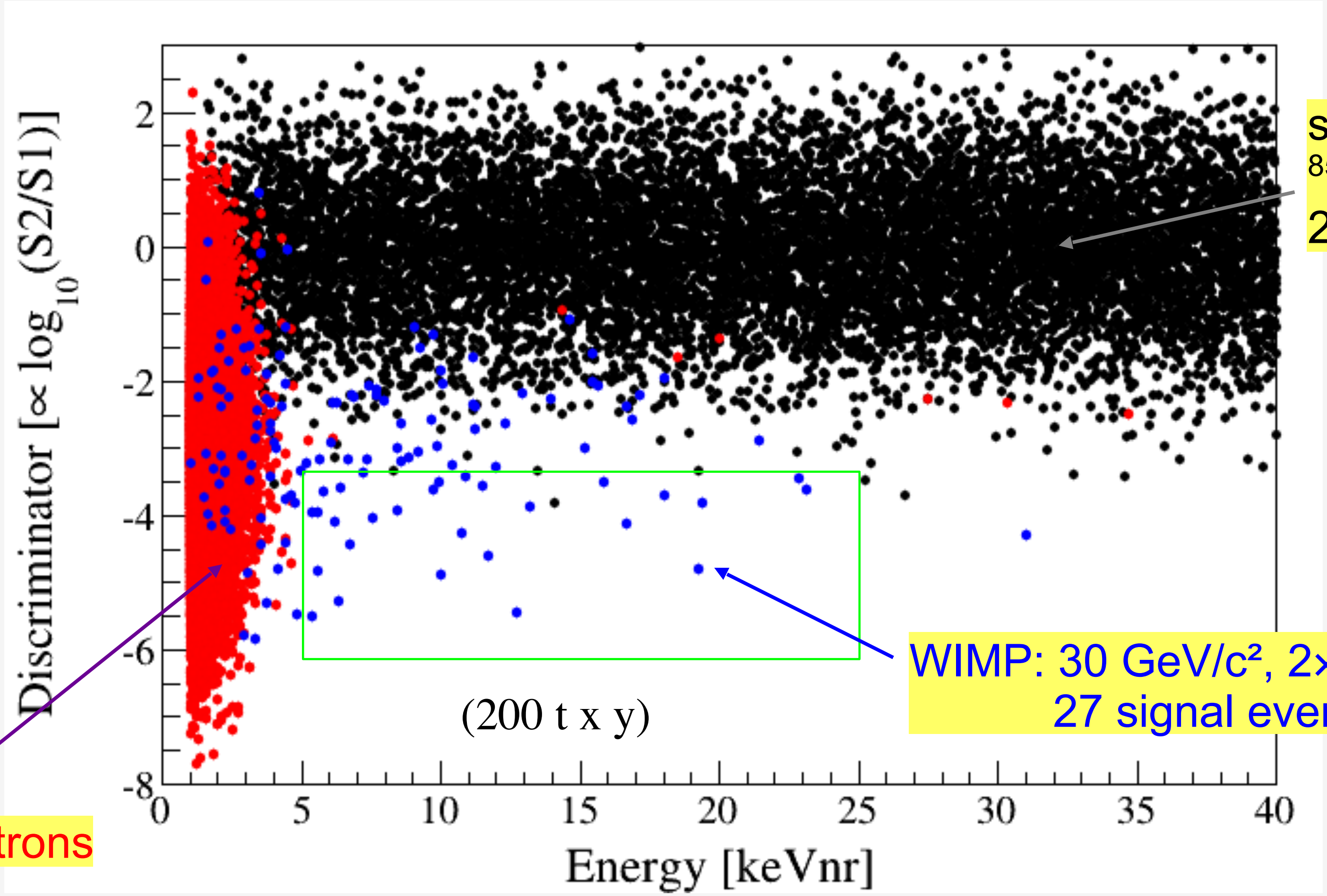
- Low threshold using proportional scintillation signal (S2) only
- Negligible background due to short burst (~sec)
- 5σ sensitivity to a supernova burst up to 65 kpc from Earth
- Detection of all 6 neutrino species via neutral current reactions




- ~700 events for a 27M$_\odot$ SN progenitor at 10 kpc
- Flavor-insensitive neutrino energy measurement
  - → constrain total explosion energy and reconstruct the SN light curve

# *What do we expect to see at low energy?*




solar neutrinos, $^{85}$Kr, $^{222}$Rn, 2νββ, materials

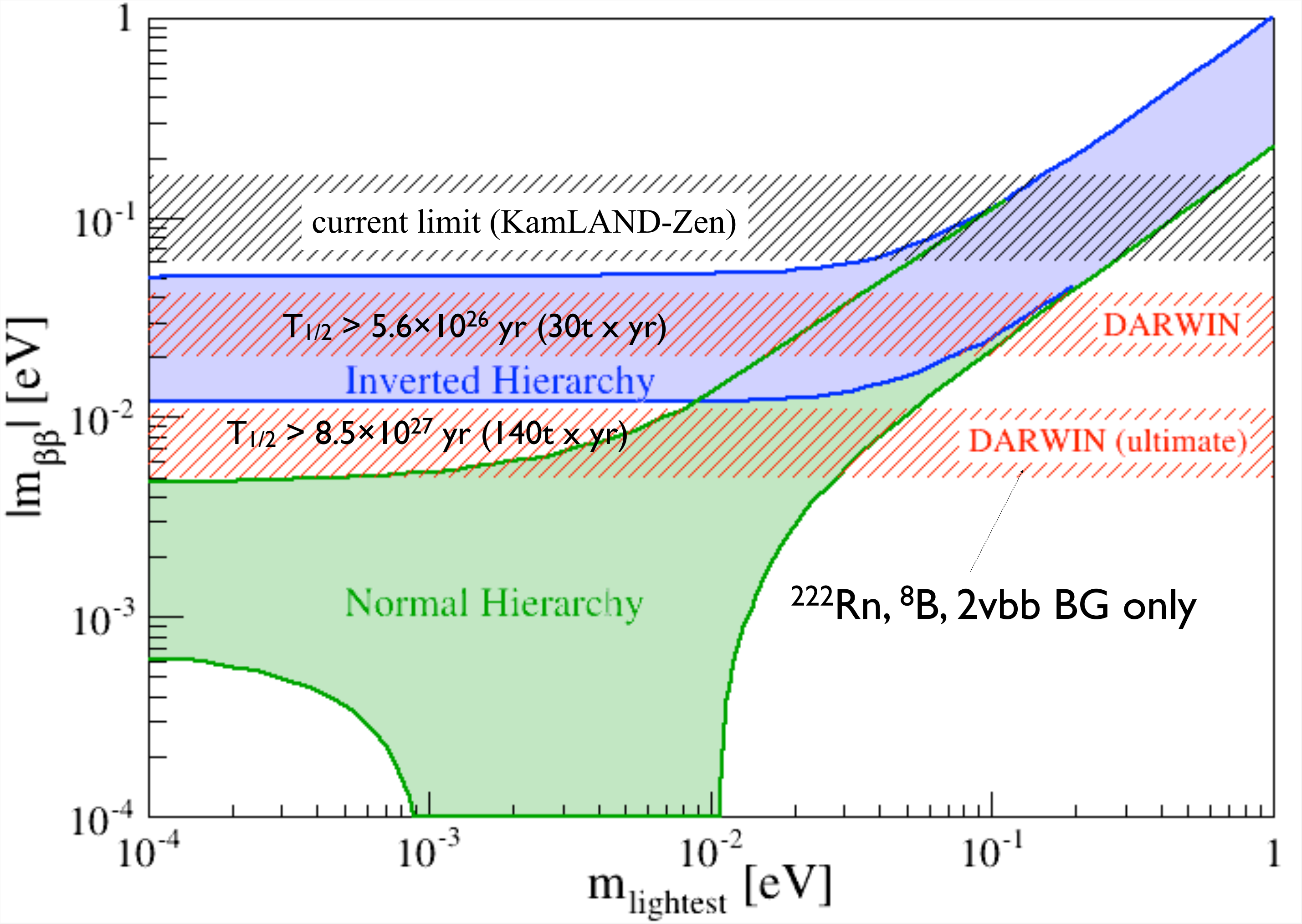
WIMP: 30 GeV/c², 2×10$^{-48}$ cm²
27 signal events in box

CNNS+neutrons

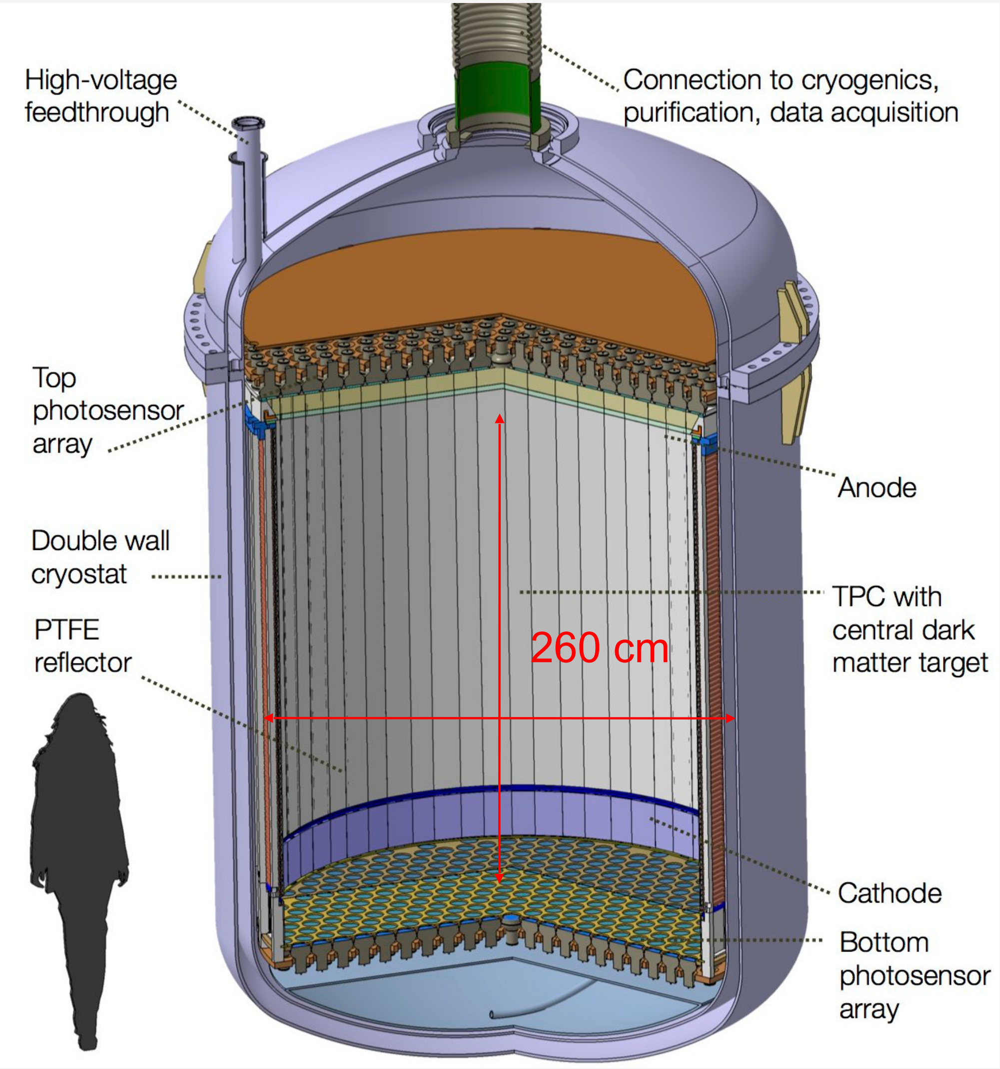
# *Neutrinoless double beta decay*

JCAP 01, 044 (2014)

- $^{136}Xe$ abundance in natural xenon 8.9%
  - 40t of Xe has 3.6t of $^{136}Xe$
- Q-value (2458.7±0.6) keV
- Energy resolution (σ/μ) at $Q_{\beta\beta}$ 1%



# *DARWIN the Ultimate WIMP Detector*



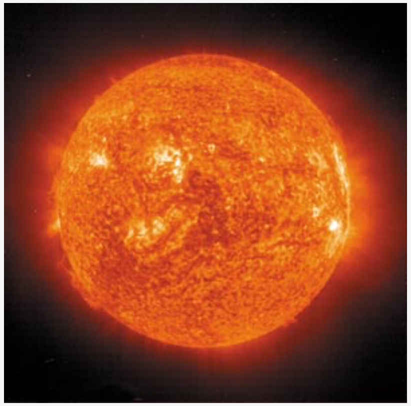

**Challenges**

- Size
  - → electron drift (HV)
  - → diameter (TPC electrodes)
  - → mass (LXe purification)
  - → dimensions (radioactivity)
  - → detector response (uniformity, threshold)
  - → calibration
  - → resolution (0nbb)
- Backgrounds
  - → $^{222}Rn$: factor 100 reduction
  - → (α,n) neutrons (from PTFE)
  - → >99.98% ER rejection
- Photosensors
  - → high light yield (QE)
  - → low radioactivity
  - → long-term stability

experience from XENON1T/nT + R&D on-going

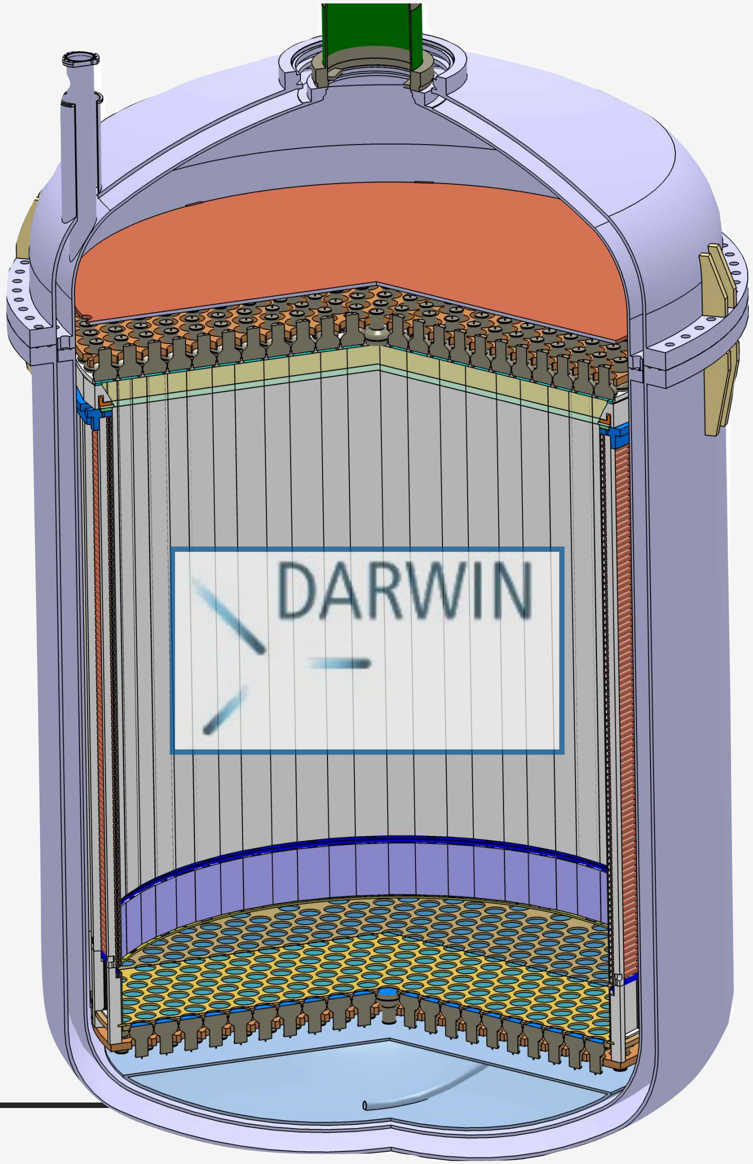
# *Exciting prospects for DARWIN: **the ultimate direct WIMP detector** and **a multi-purpose neutrino experiment***

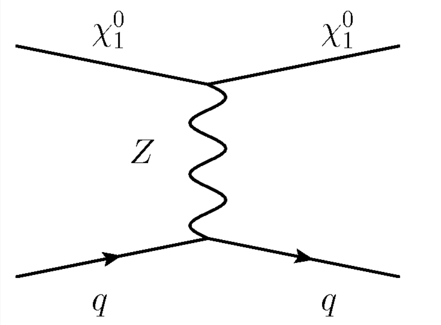
**www.darwin-observatory.org**



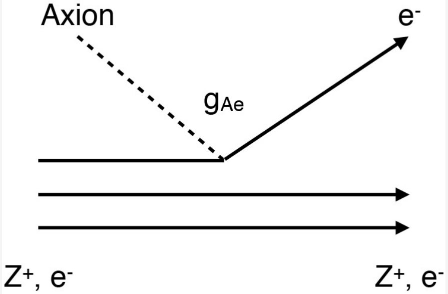
Solar Neutrino

Supernova Neutrino

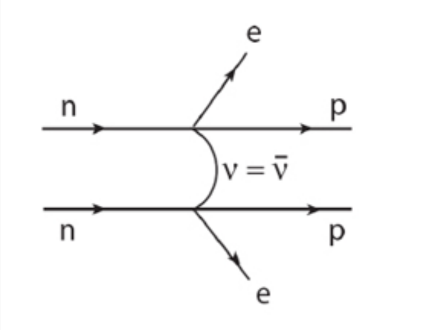



WIMP




Axion & ALP




Double Beta Decay