# Advancing Liquid Xenon Dark Matter Detection with the DARWIN observatory


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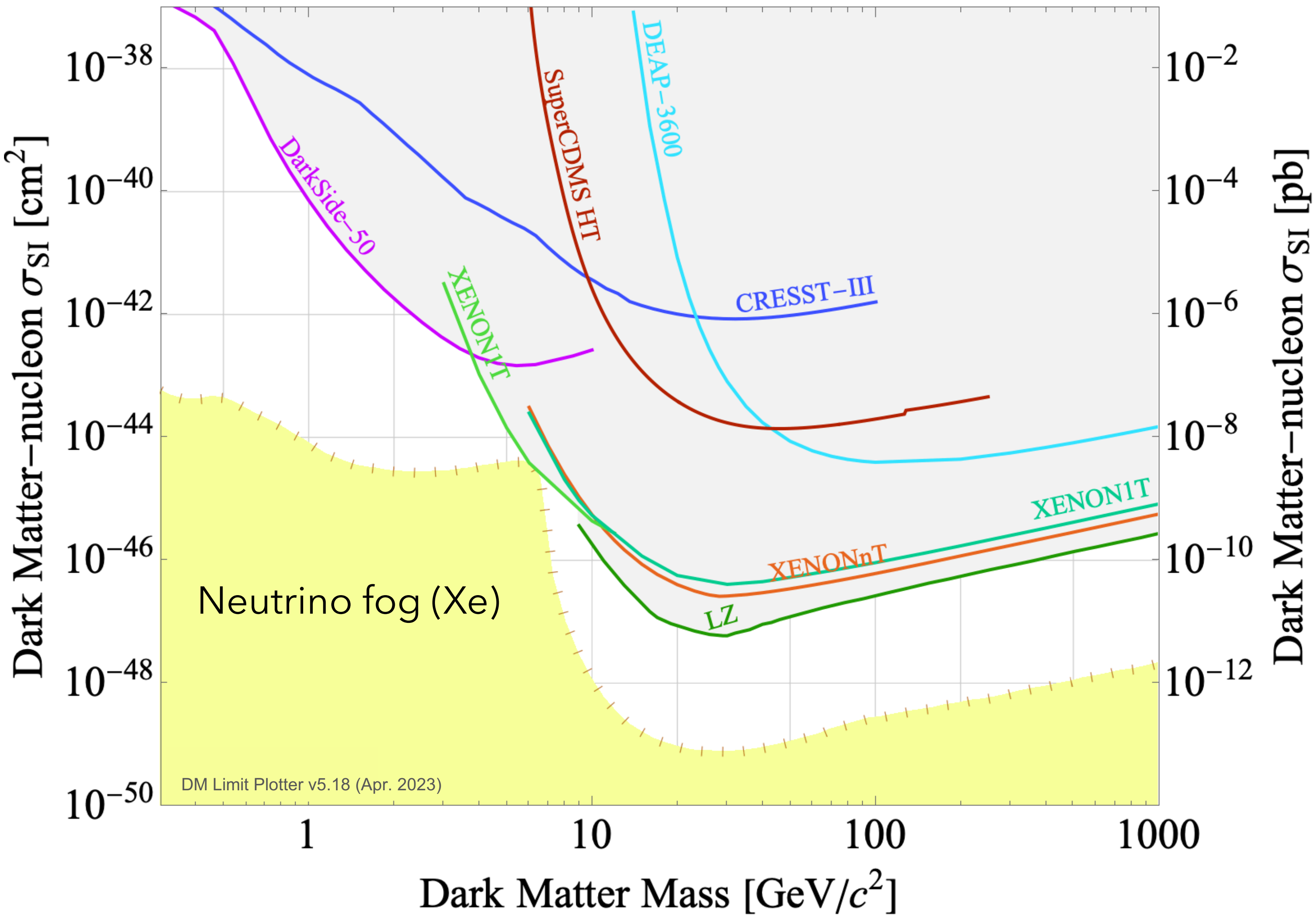
DARWIN

# Noble Liquid Detectors Lead Direct WIMP Detection

Above 5 GeV/$c^2$ dominated by dual-phase noble liquid detectors



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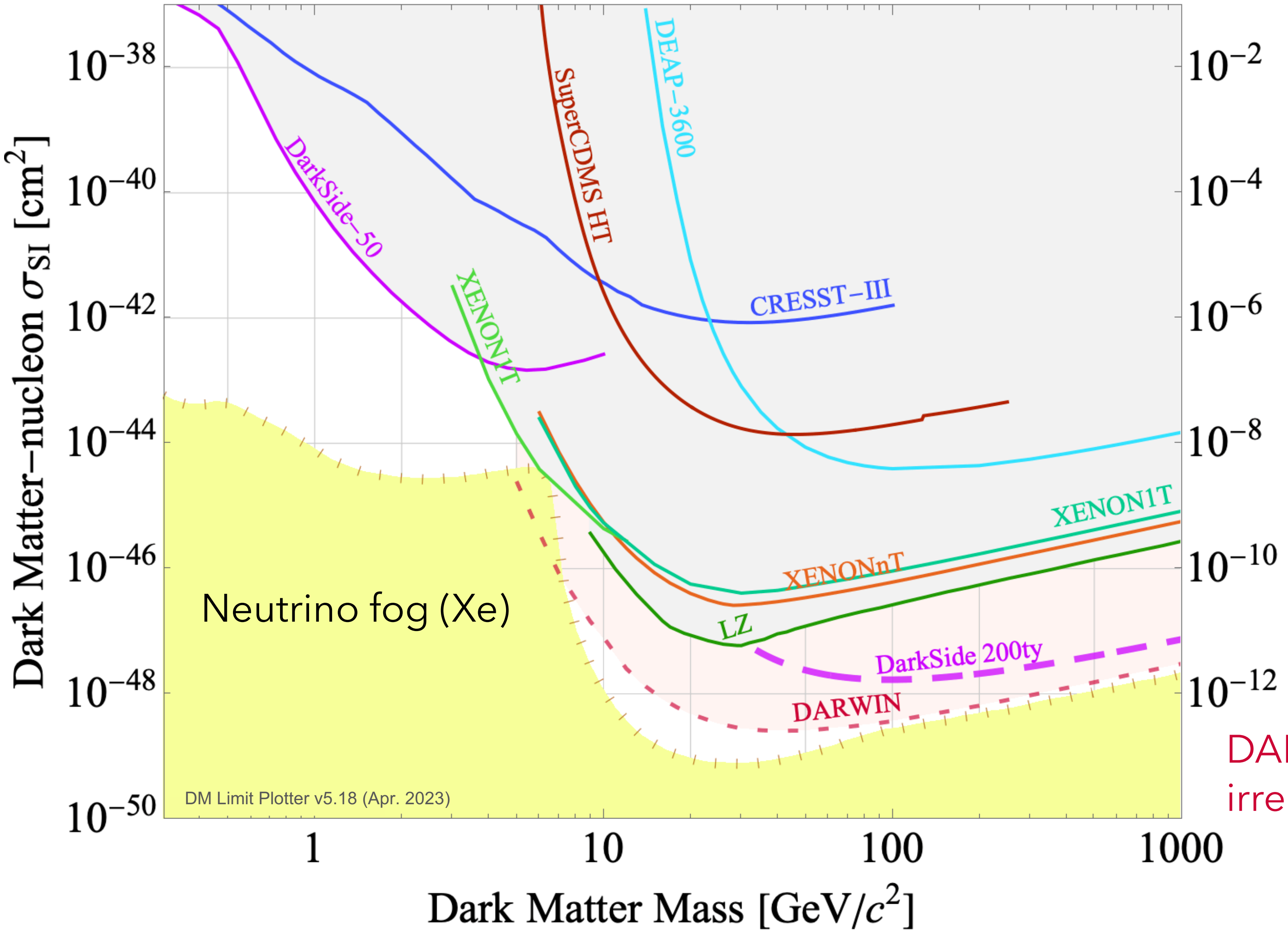
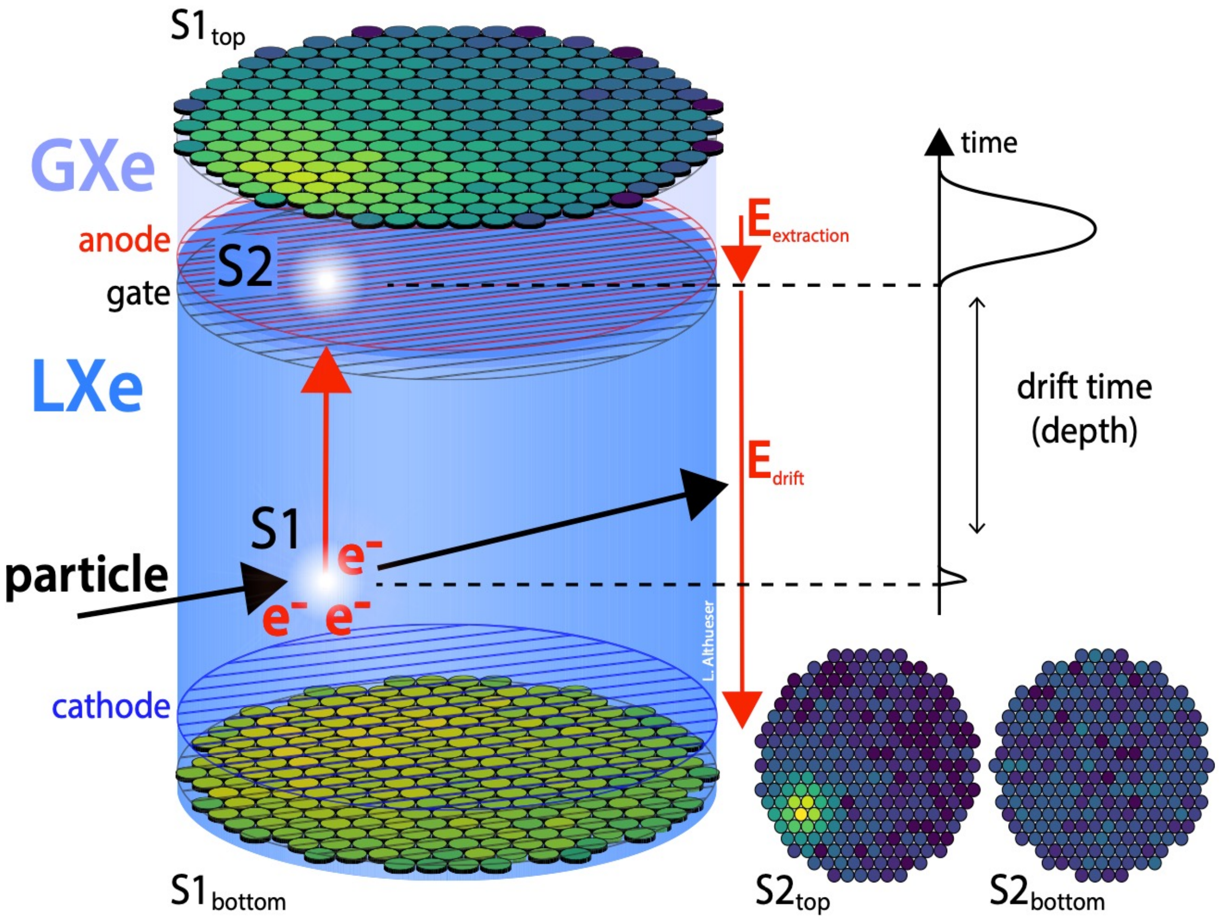


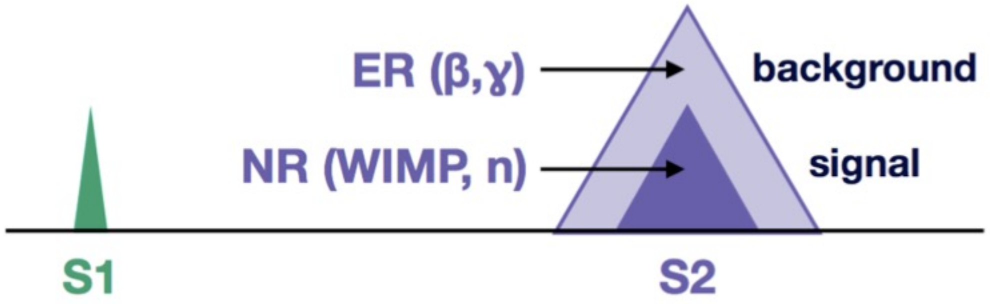

DARWIN: reach the irreducible neutrino fog

# Xenon Dual-Phase Time Projection Chamber

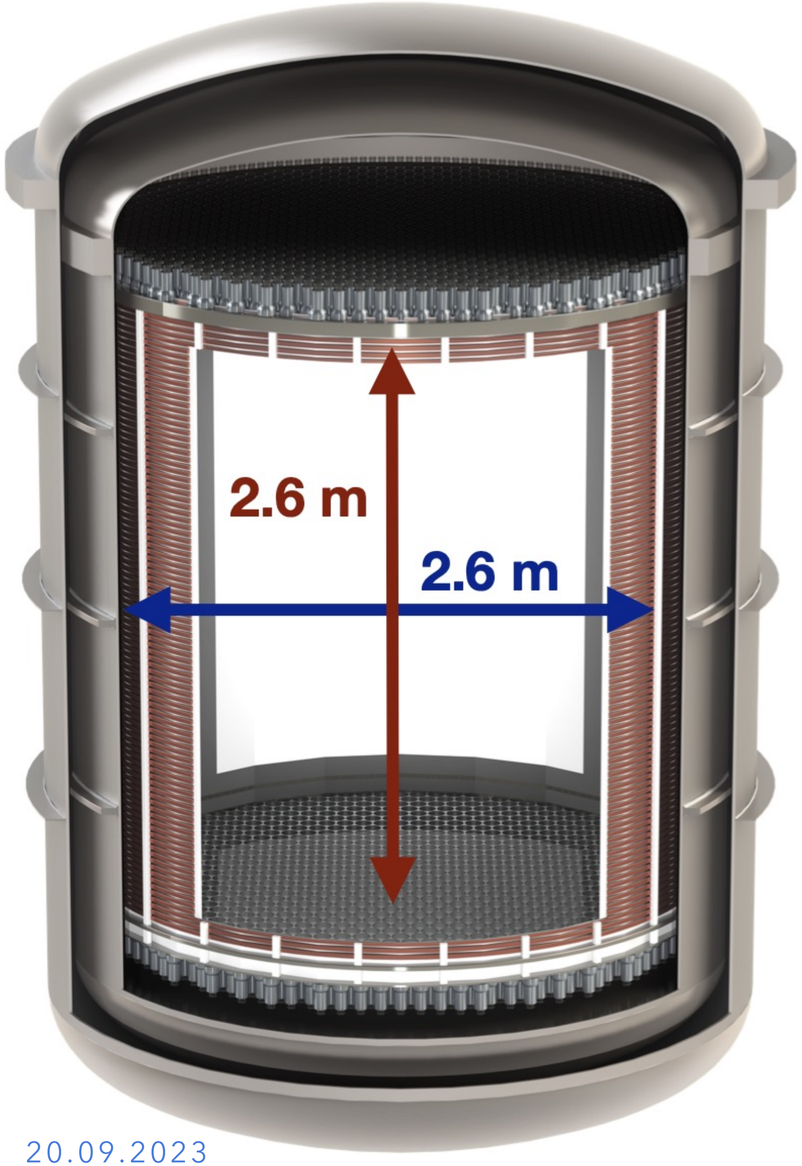



Scintillation and ionization:

- Prompt light signal (**S1**)
- Secondary light in GXe from direct charges (**S2**)
- 3D position reconstruction
- Energy reconstruction
- Particle discrimination (**ER**/**NR**)



# DARWIN Detector Baseline




- 2.6 m x 2.6 m dual-phase Xenon TPC
- 50 t (40 t active) liquid xenon (LXe) target
- Top and bottom array of 3-inch Photomultiplier Tubes (PMTs)
- Surrounded by highly reflective PTFE walls
- Drift field $\mathcal{O}(0.1)$ kV/cm
- Gd-doped neutron veto
- Min. 12 m × 12 m water Cherenkov shield and muon veto
- Located underground, e.g., at LNGS

# DARWIN Physics Reach

Dark matter

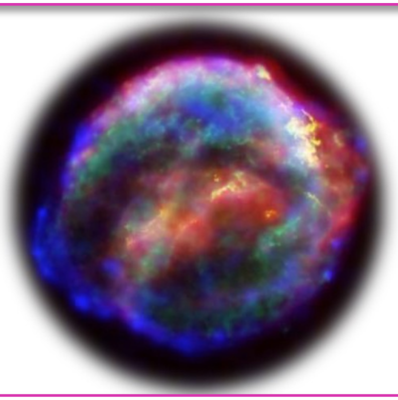
- WIMP-search
- Sub-GeV
- Dark photons
- Axion-like particles

Solar physics

- $^{8}B$ neutrinos
- pp neutrinos
- Solar axions

Supernova neutrinos

- Actively communicate with SNEWS
- Multi-messenger in DM experiments

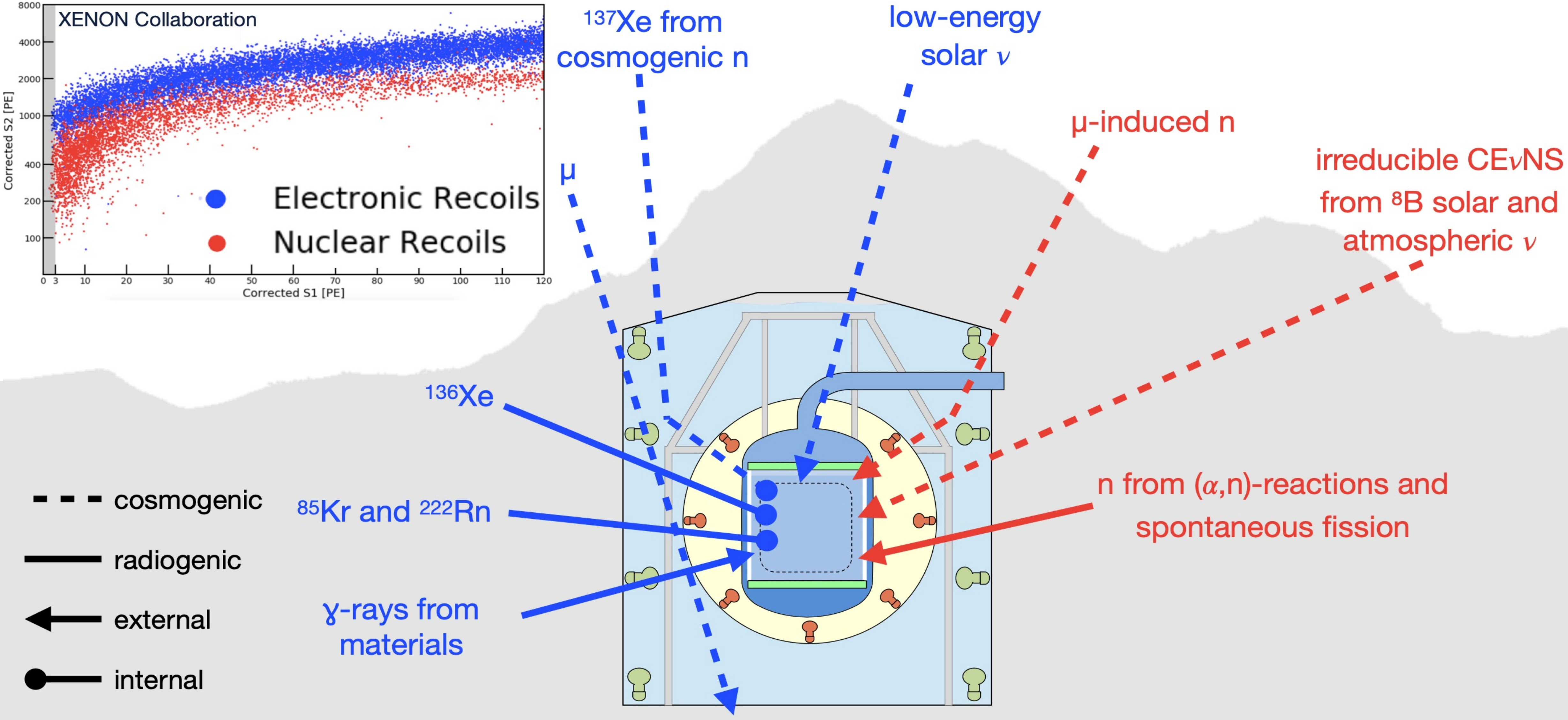


Neutrino properties

- Double beta decay of $^{136}Xe$
- Double electron capture in $^{124}Xe$
- Neutrino magnetic moment

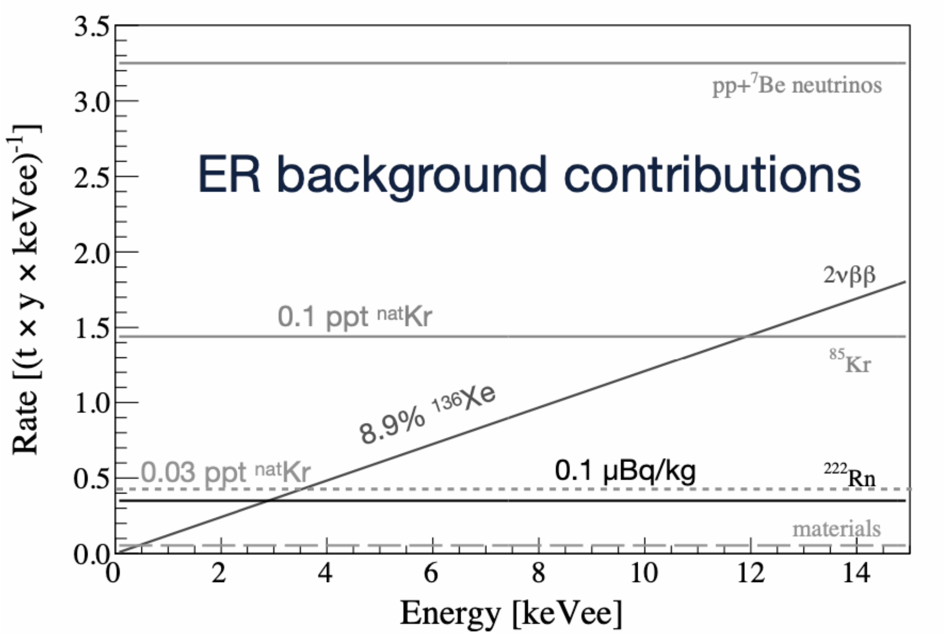
Atmospheric neutrinos

# Expected Events in DARWIN



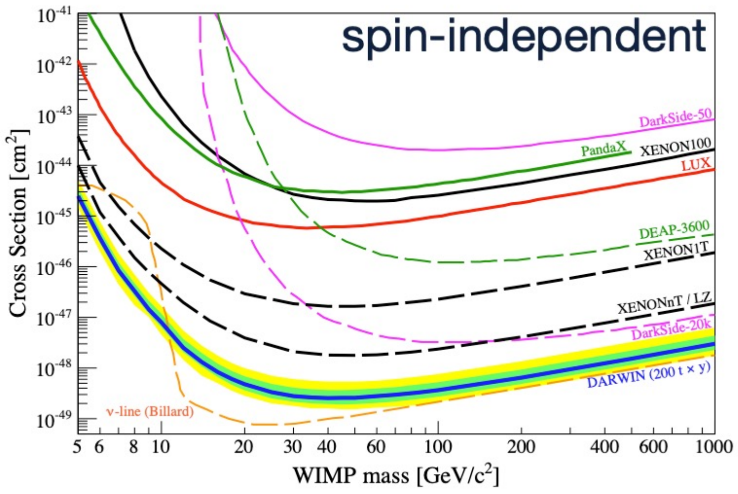
# WIMP Sensitivity

- 30 t fiducial volume and 200-ton-yr exposure
- 99.98% electronic recoils (ER) rejection
- at 30% NR acceptance
- 0.1 ppt $^{nat}$Kr: XENON achieved 0.03 ppt in distillation test (Eur. Phys. J. C 77 (2017) 275)
- 0.1 $\mu$Bq/kg $^{222}$Rn: (<1 $\mu$Bq/kg achieved) Eur. Phys. J. C 82, 1104 (2022)
- 8 PE/keV light yield

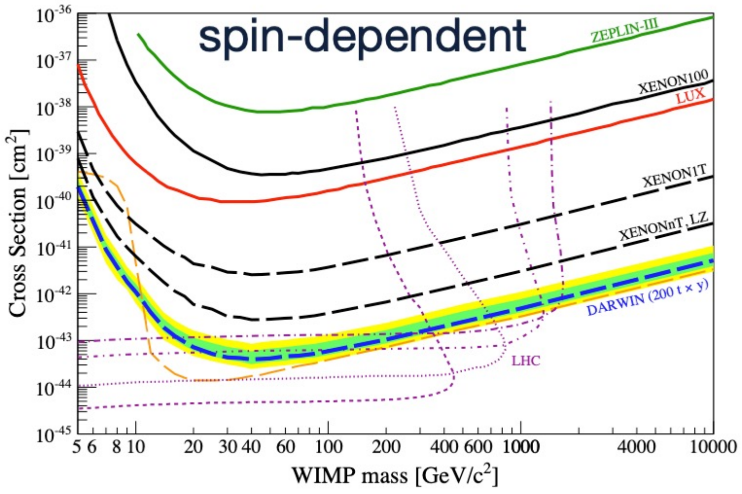



M. Schumann et al., JCAP10 (2015) 016

J. Aalbers et al., JCAP11 (2016) 017




$2.5 \times 10^{-49}$ cm$^2$ at 40 GeV/c$^2$

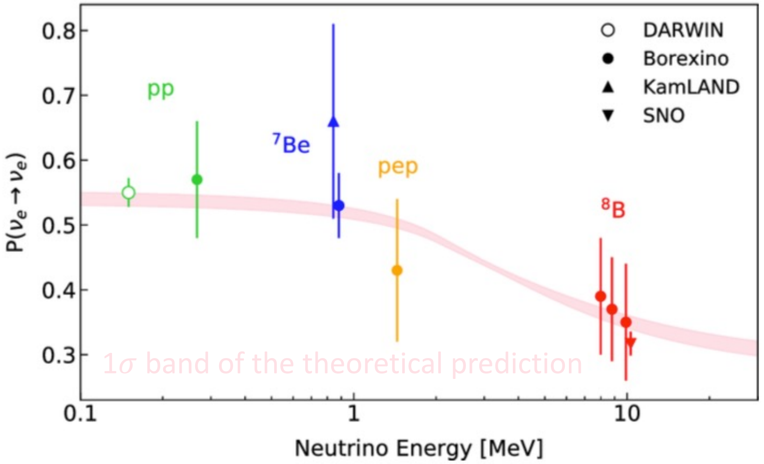



complementary to 14 TeV LHC

# Neutrino Physics at DARWIN

**Low-energy solar neutrinos**:

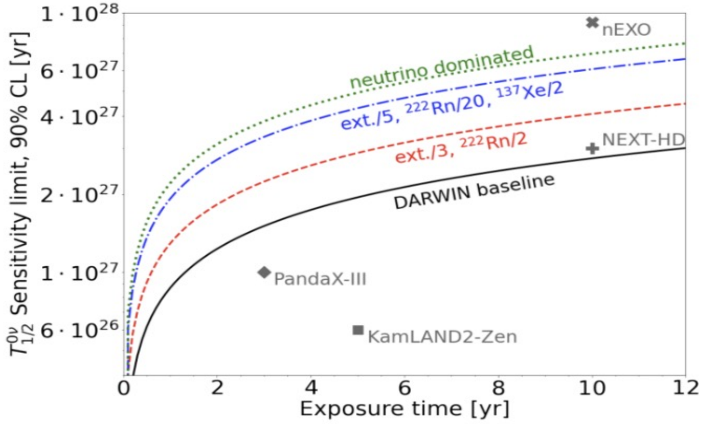
- Measurement of pp, $^{7}$Be, $^{13}$N, $^{15}$O and pep flux
- Constrain the weak mixing angle
- Distinguish high and low metallicity solar models




J. Aalbers et al. Eur. Phys. J. C 80, 1133, 2020

**$0\nu\beta\beta$-decay of $^{136}$Xe**:

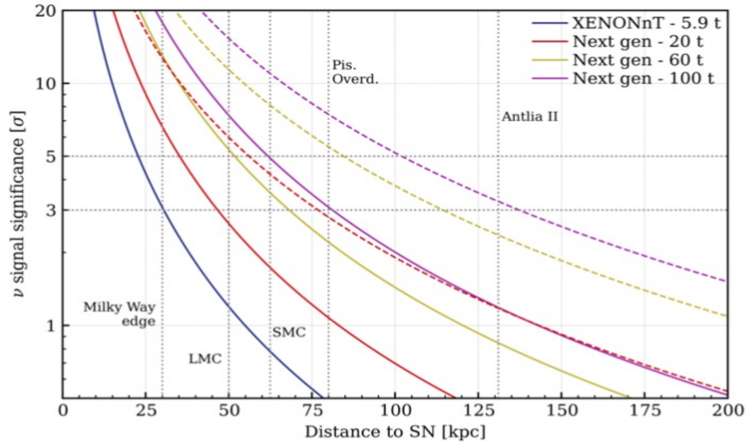
- Probe the Dirac/Majorana nature of the neutrino
- $Q_{\beta\beta}$ = 2458 $keV$
- Sensitivity: $T^{0\nu}$= 3.0×10$^{27}$$yr$ (90% $C.L.$) after 10 years of data taking




Eur. Phys. J. C 80, 808 (2020)

**CEvNS**:

- Measurement of $^{8}$B solar neutrino flux
- Measurement of atmospheric neutrinos
- Multi-messenger astrophysics via supernovae neutrinos



# Navigating the Challenges of Scaling up

- Liquid xenon purity
- High-voltage delivery
- Electrodes design and construction at 2.6 m
- Electric field homogeneity
- Light collection efficiency throughout the TPC
- Background mitigation
- Photosensor performance

XENONnT – 8 t

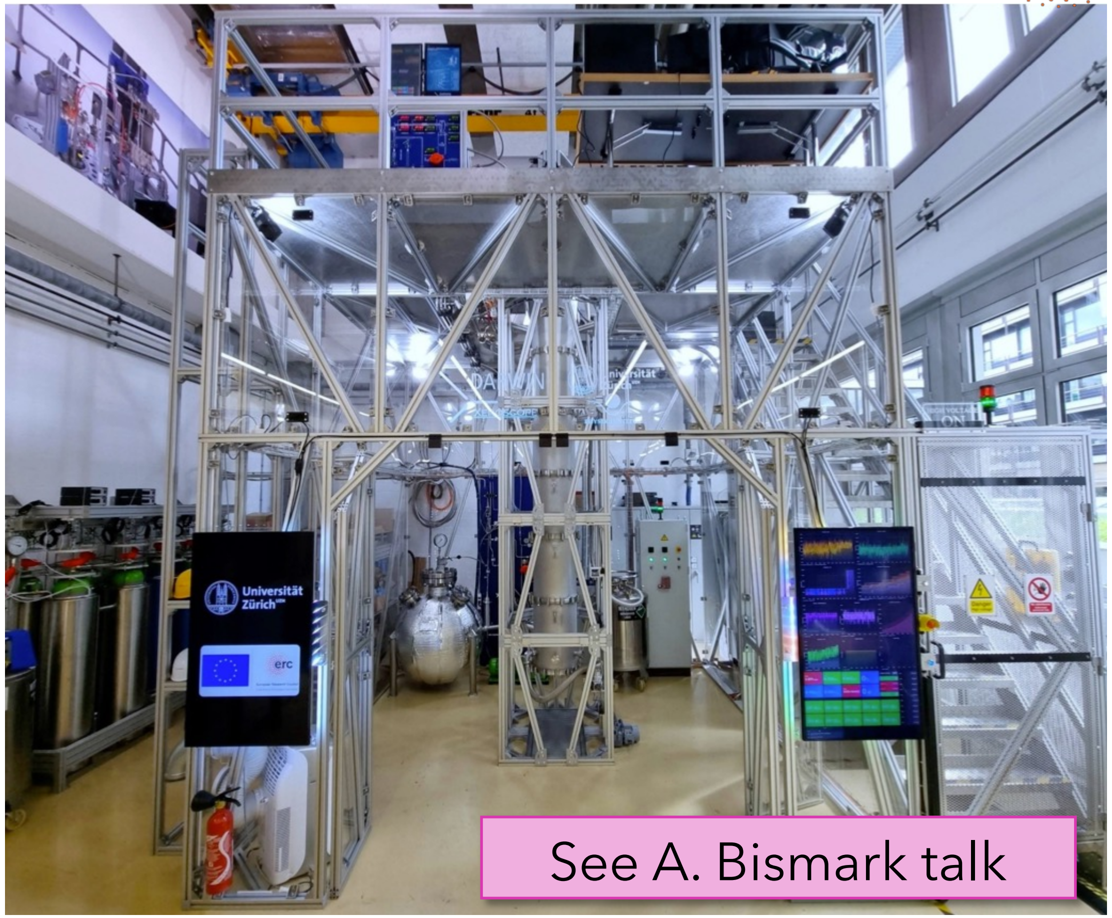
DARWIN – 50 t

# R&D: Full Scale Demonstrators

Xenoscope at Uni. Zurich

erc European Research Council

Pancake at Uni. Freiburg

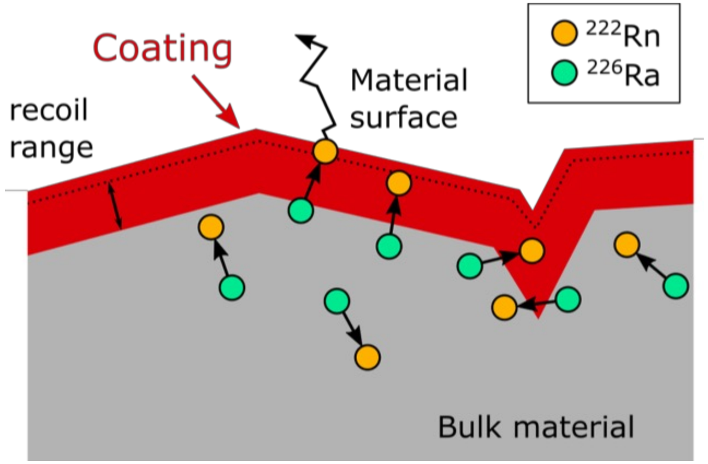



JINST 16 P08052 (2021)

# R&D: Rn Mitigation

- Online distillation
  - Developed for XENONnT
  - Achieved 0.8 μBq/kg
- Surface coating
  - Trap $^{222}$Rn after $^{226}$Ra decays
  - Avoid Rn emanation
- Material screening
  - Selection of low-emanation materials
- Hermetic TPC
  - Inner Xe volume (clean) separated from outer (dirty)

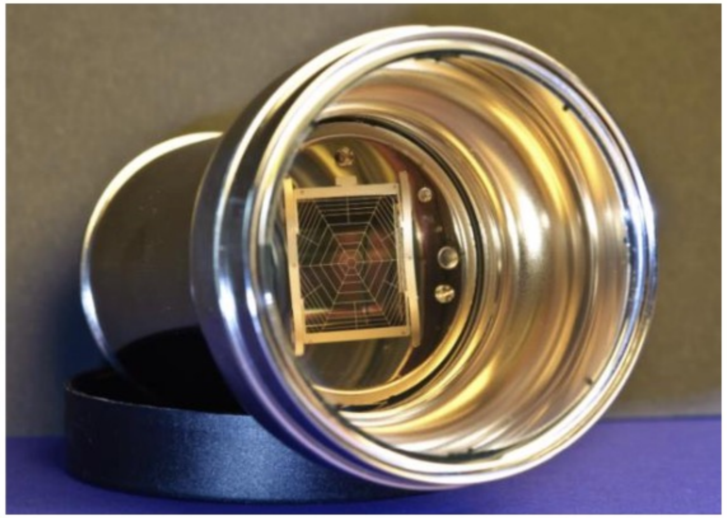

R&D at Uni. Munster




R&D at MPIK Heidelberg

# R&D: Photosensors (PMTs)

R&D at Uni. Zurich

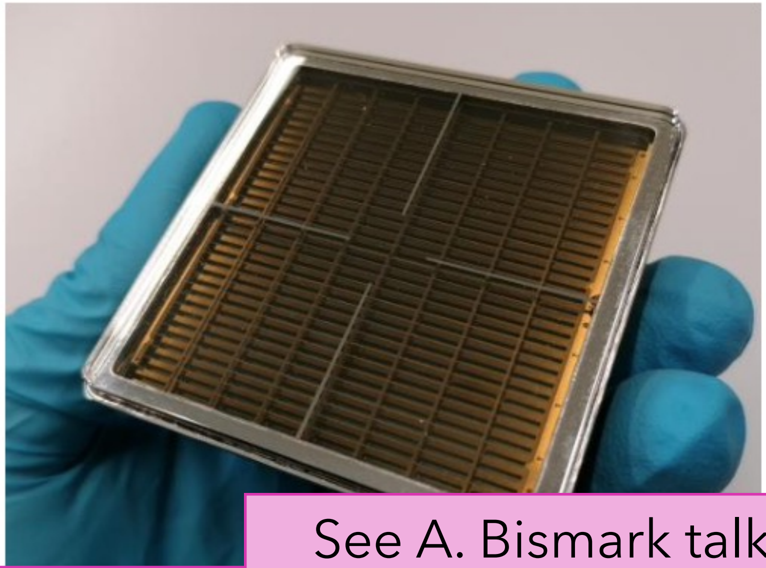


3″ R11410

Used in XENONnT, LZ, PandaX-4T

3″ R13111

Developed by XMASS



See A. Bismark talk

2″ R12699

Larger effective area and coverage

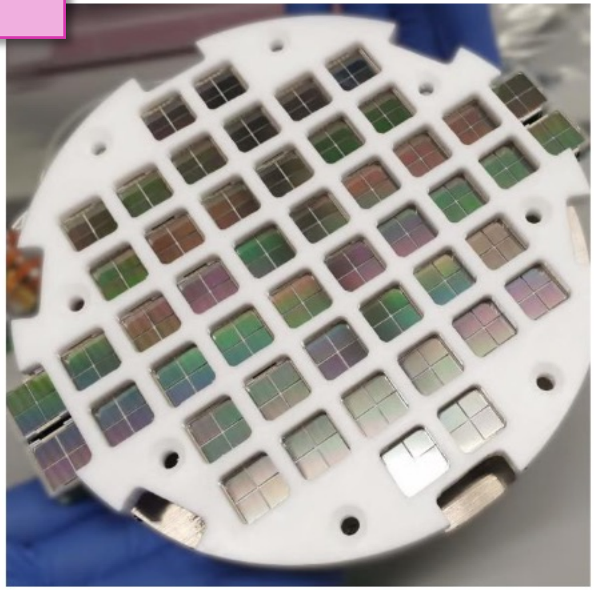
Multi-anode

Material selection ongoing

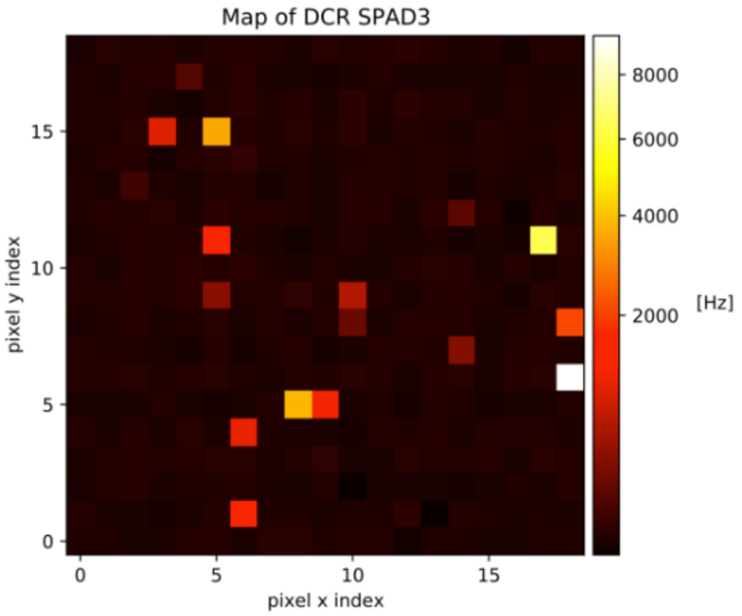
# R&D: Photosensors (SiPMs)

R&D at Uni. Zurich

*JINST* 18 C03027 (2023)



R&D at Uni. Heidelberg




FBK VUV-HD Cryo

Low SPE, high CTP

Characterised at LXe Temperature

Hamamatsu VUV4

Array of 48 12x12 mm2

Characterisation at LXe temperature

Digital SiPMs

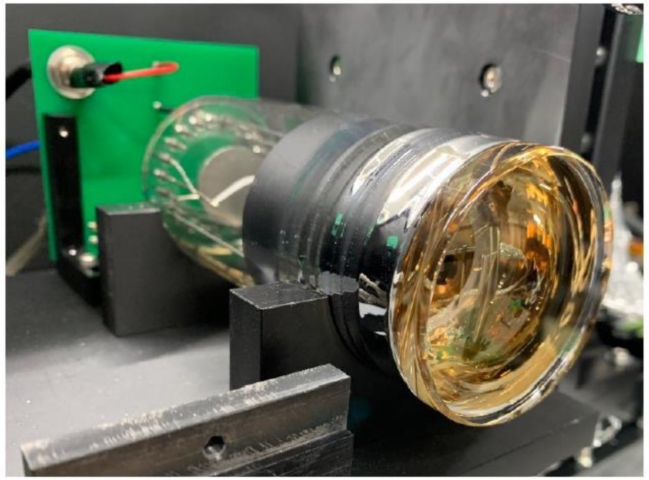
Low DCR

Ability to turn off problematic pixels

See M. Keller talk

# R&D: Photosensors (hybrid)

R&D at Uni. Nagoya



XE5859

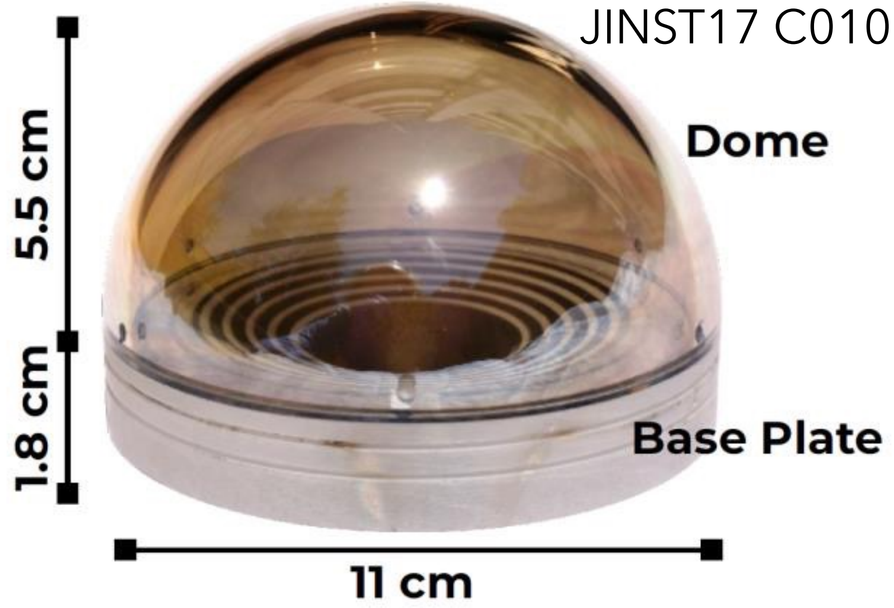
Bialkali photocathode

Photoelectron detected in VUV4 MPPC

$\mathcal{O}$(100) lower DCR than current SiPMs available

R&D at LNGS/Uni. Aquila + Stockholm

JINST17 C01038 (2022)




Abalone

Base + Dome + Windowlet

Dome at HV (~25 kV)

SiPM detects scintillation light

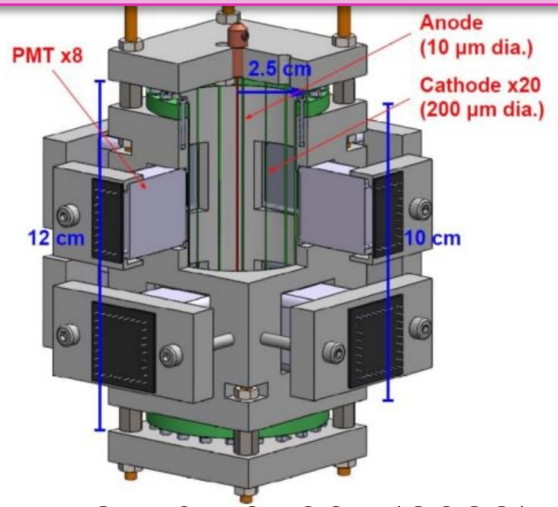
# R&D: Alternative Designs

- Single-phase TPC
  - Both S1 and S2 created in liquid phase
  - No liquid level control required
  - Reduce single-electron emission
- Hermetic TPC
  - Prevent Rn and impurity diffusion into inner volume

R&D at Uni. Freiburg and Uni. Nagoya

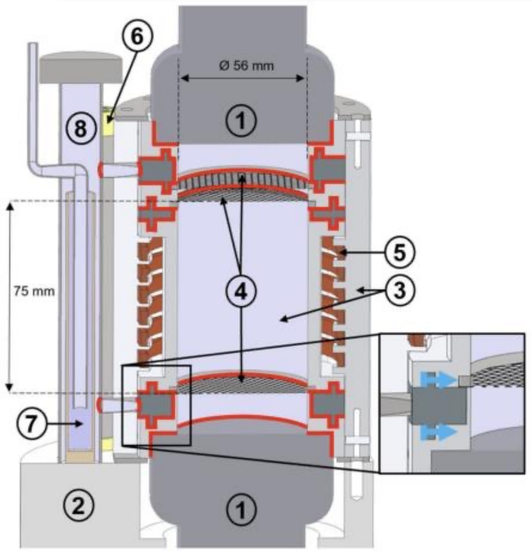
JINST17 P03027 (2023)
PTEP 2020, 11, 113H02

R&D at UC San Diego




JINST18 P07027 (2023)

R&D at Uni. Freiburg

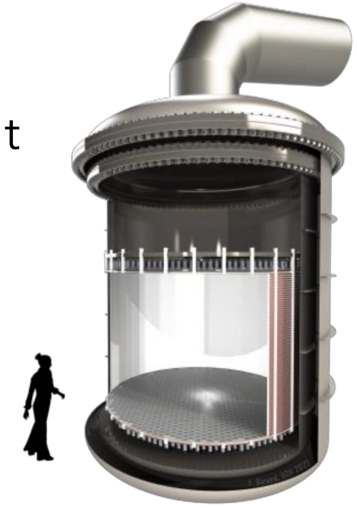



Phys. J. C. 83, 9 (2023)

# Collaborative Efforts

- Consortium merging DARWIN/XENON and LUX-ZEPLIN
- Common effort to build the next generation LXe TPC

40 t



60 t

- MoU signed July 6th, 2021
- 104 research group leaders from 16 countries
- Community whitepaper: J. Phys. G: Nucl. Part. Phys. 50 013001 (2023)

# Summary

- LXe TPCs have been successful in constraining the WIMP-nucleon cross-section.
- DARWIN leads the effort for next-generation LXe dark matter and neutrino experiments.
- Active development of crucial detector subsystems within DARWIN collaborators ongoing.
- The XLZD consortium fosters collaboration and paves the way for a shared future in scientific discovery.

# Backup Slides

# Legend for the first plot