DARWIN

A Next-Generation Observatory for Dark Matter and Neutrino Physics

EPS-HEP, Hamburg

23.08.2023

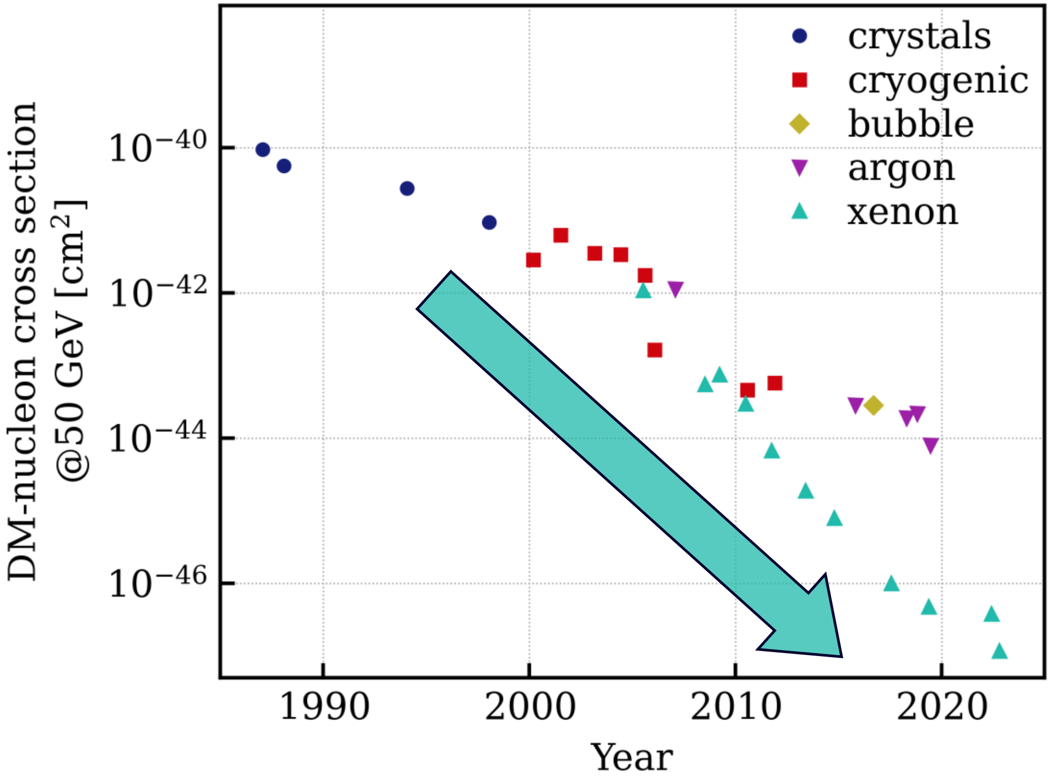
Ricardo Peres
on behalf of the DARWIN Collaboration

The search for WIMPs with LXe

DARWIN

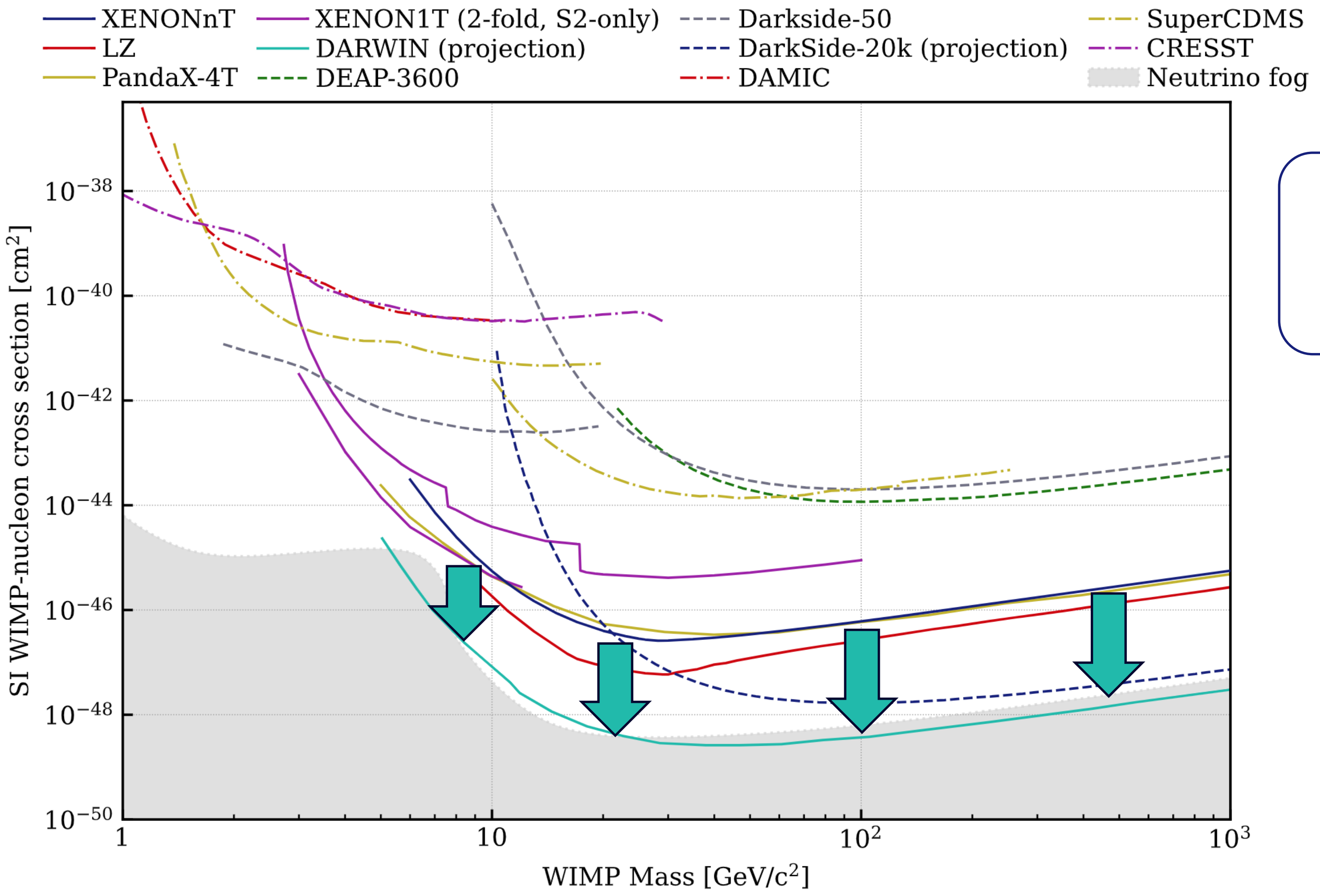
- Leading technology in direct search for high mass DM
- Scalable in mass
- Self-shielding properties
- Highly purifiable
- Ultra-low backgrounds

Adapted from Tom Shutt



~5 orders of magnitude in ~15 years!

The direct DM search scene



Current gen. LXe experiments at 10^{-46} cm^2 @50 GeV

XENONnT/LZ aim at one order of magnitude lower

DARWIN: reach the irreducible neutrino fog

The DARWIN collaboration

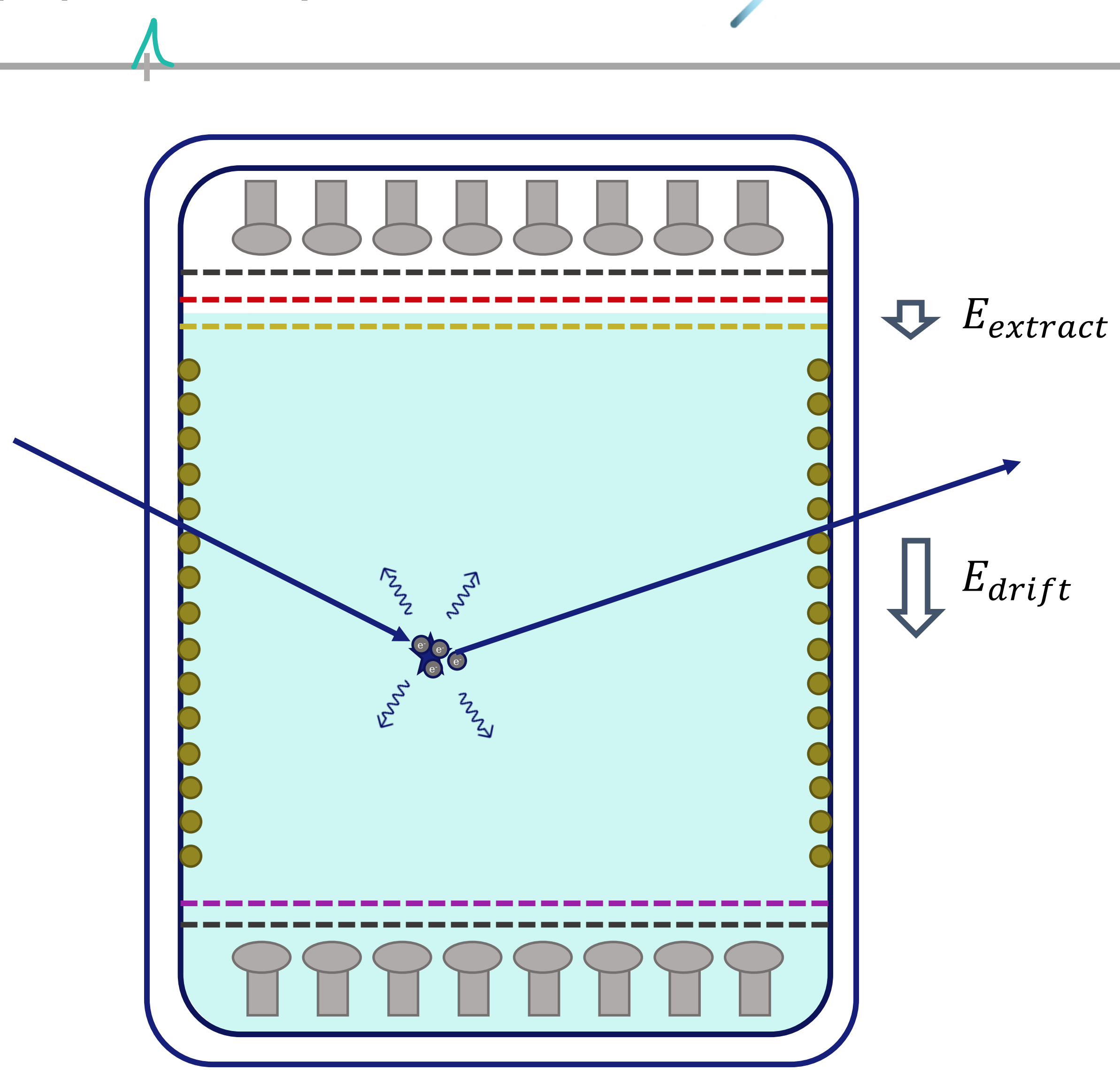
~200 members from 35 institutions

The DARWIN collaboration

Collaboration meeting in Heidelberg, 2023

The xenon dual phase TPC

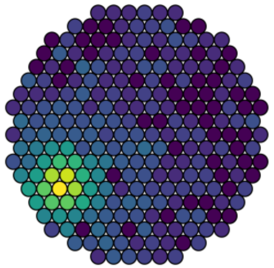
- Sensitive to both light (S1) and charges (S2)



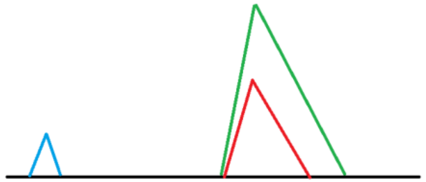
The xenon dual phase TPC

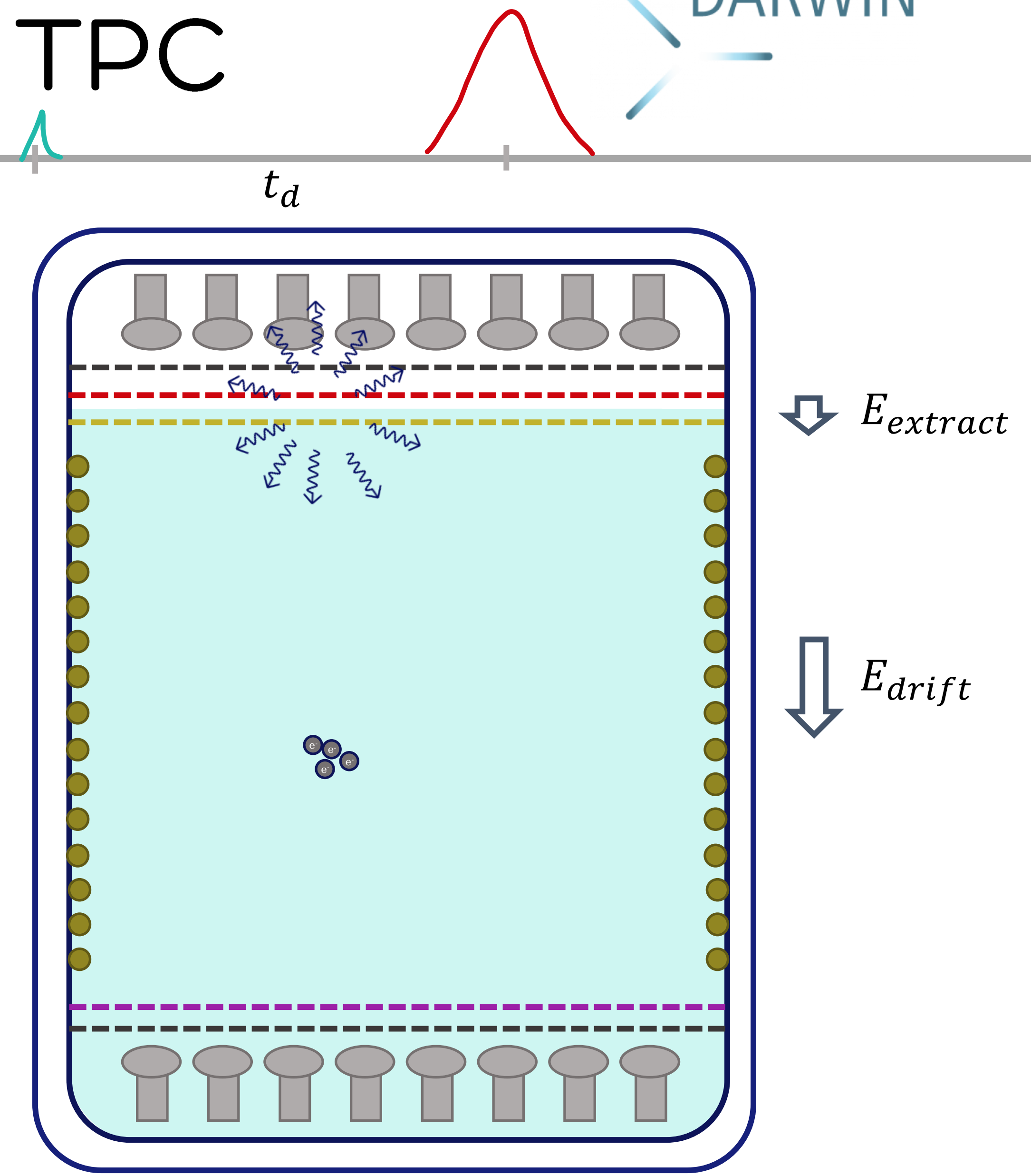
- Sensitive to both light (S1) and charges (S2)
- Event reconstruction
  - Energy
  - 3D position
  - Particle discrimination (ER/NR)

$$E = W\left(\frac{cS1}{g_1} + \frac{cS2}{g_2}\right)$$



$$z = v \cdot t_d$$





DARWIN science goals

Dark matter

- WIMP-search
  - Spin-independent
  - Spin-dependent
- Sub-GeV
- Dark photons
- Axion-like particles

JCAP 10, 016 (2015)

Solar neutrinos

- ^{8}B spectrum
- pp neutrinos detection
- Solar axions

Eur. Phys. J. C 80, 12 (2020)
Phys.Rev.D 106 (2022)

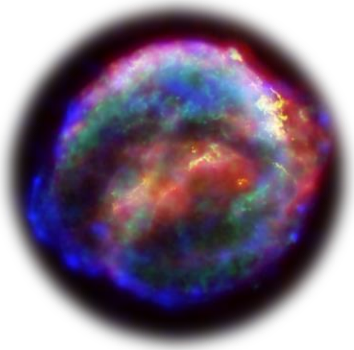
Atmospheric neutrinos

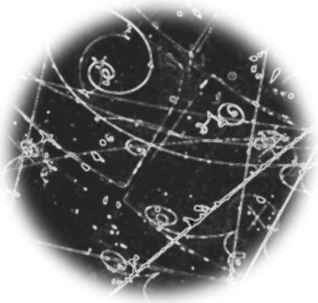
PRD 104 (2021)

Supernova neutrinos

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

PRD 94, 103009 (2016)
Phys.Rev.D 105 (2022)





Neutrino properties

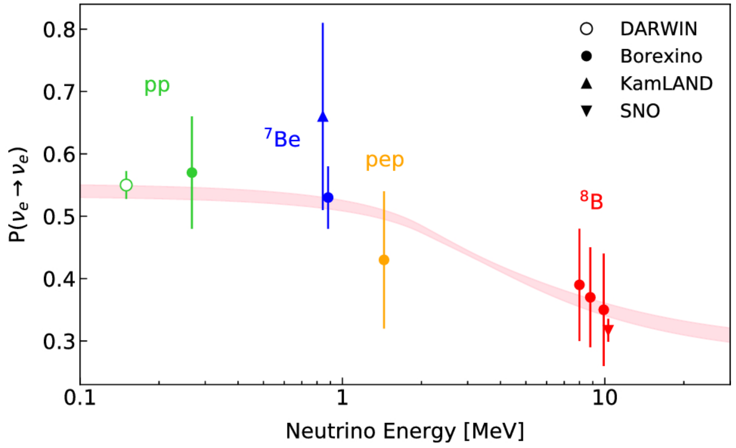
- Double beta decay of ^{136}Xe
- Double-electron capture in ^{124}Xe
- Neutrino magnetic moment

Eur. Phys. J. C 80, 9 (2020)

A LXe neutrino observatory

Solar neutrinos searches with electron scattering

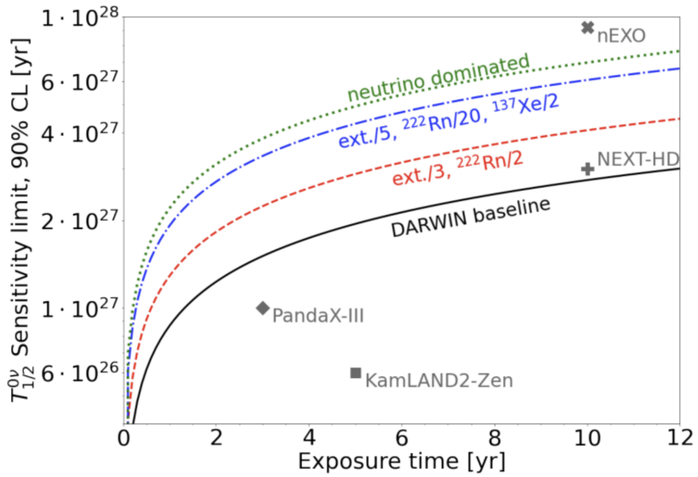
- Measurement of pp, ^7Be, ^{13}N, ^{15}O and pep flux
- Constrain the weak mixing angle
- Distinguish high and low metallicity solar models



J. Aalbers et al. (DARWIN Collaboration) Eur. Phys. J. C 80, 1133, 2020

Neutrinoless double beta decay of ^{136}Xe

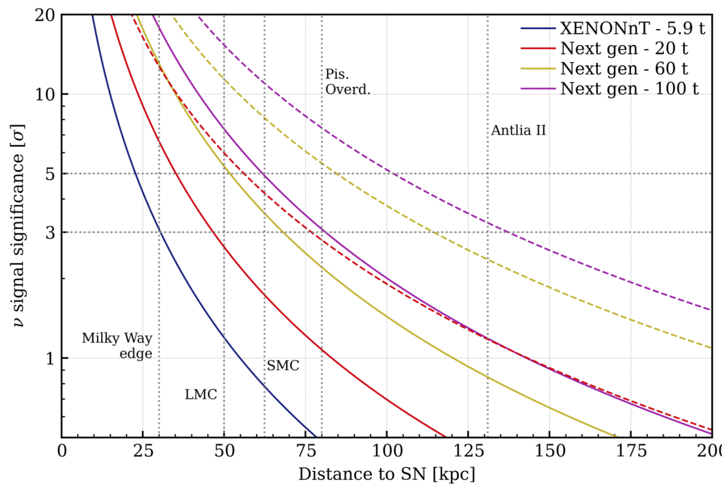
- Probe the Dirac/Majorana nature of the neutrino
- $Q_{\beta\beta} = 2458\ keV$
- Sensitivity: $T_{1/2}^{0\nu} = 3.0 \times 10^{27}\ yr\ (90\%\ C.L.)$ after 10 years of data taking



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

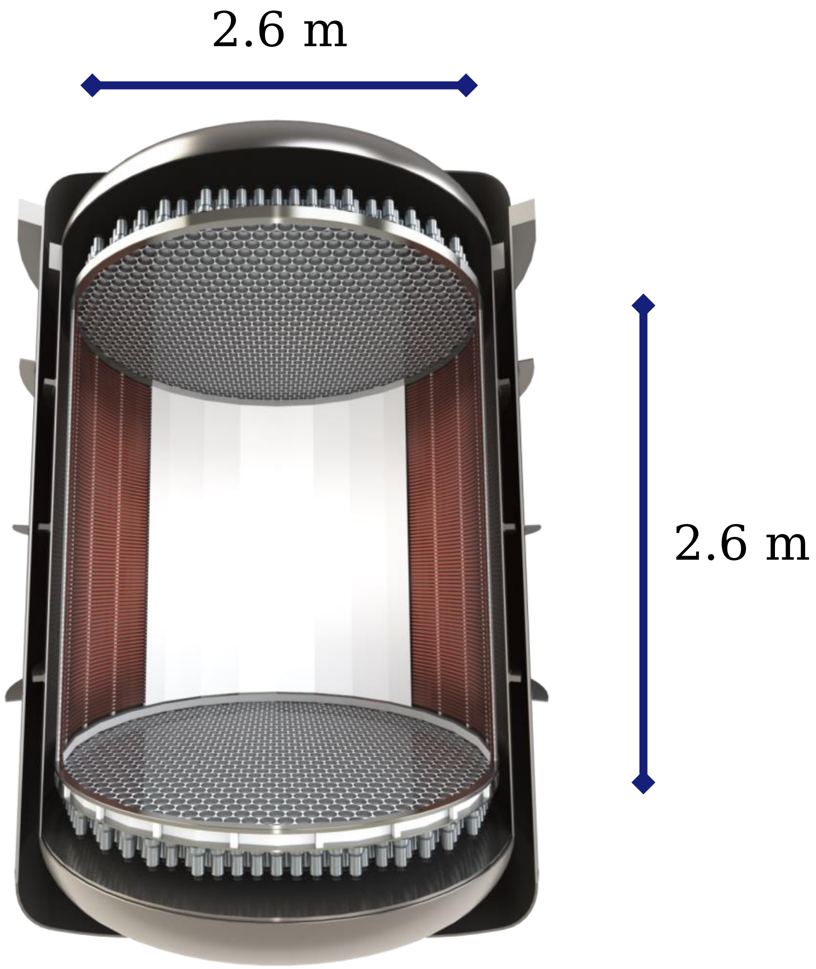
CEvNS

- Measurement of ^8B solar neutrino flux
- Measurement of atmospheric neutrinos
- Multi-messenger astrophysics via SN neutrinos



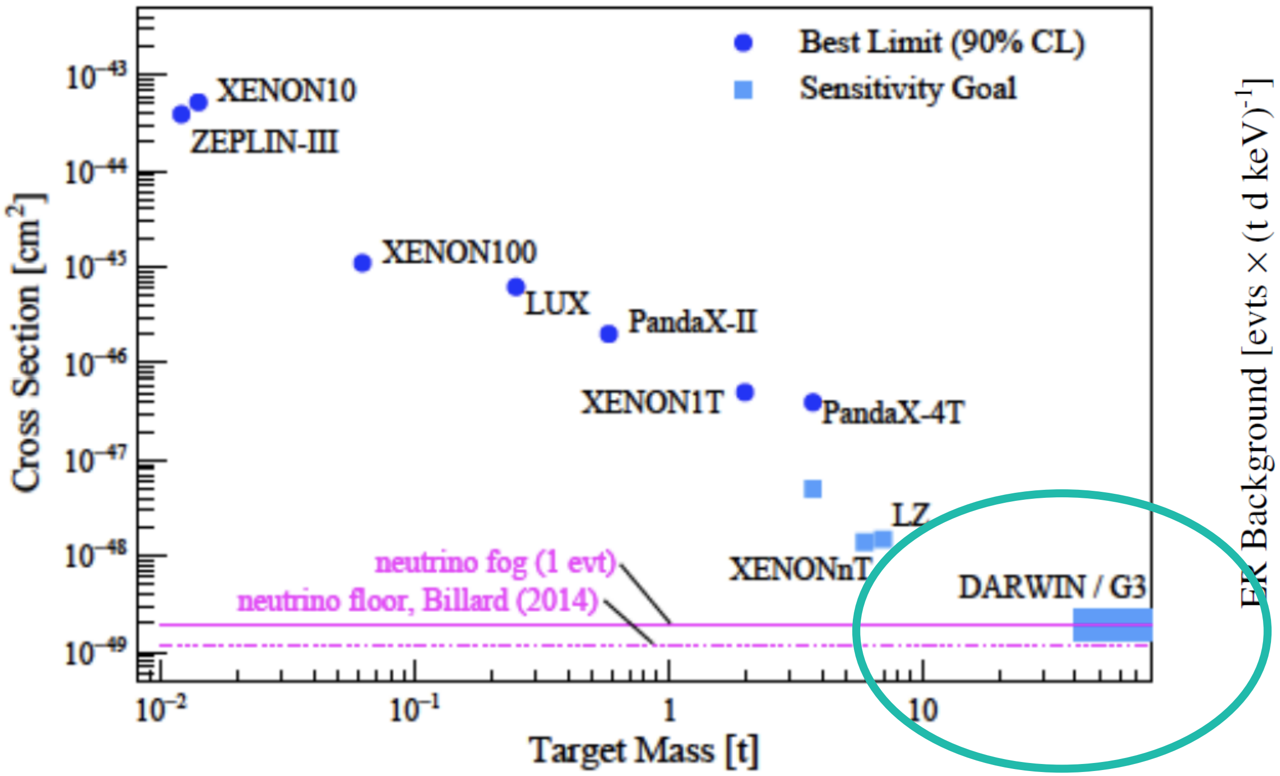
DARWIN baseline design

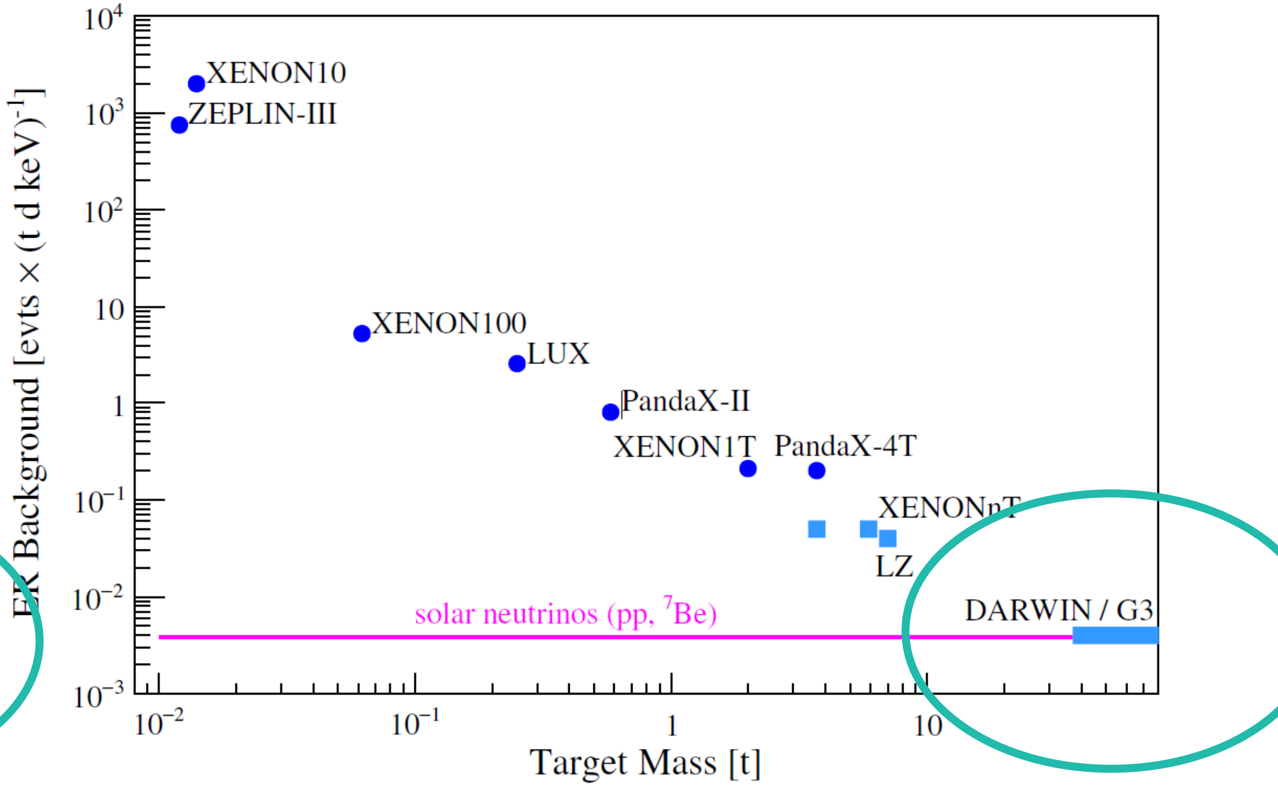
- 2.6 m diameter x 2.6 m height
- 40 t LXe active target
- Two arrays of photosensors (1910 3” PMTs)
- 24 PTFE reflector walls
- Passive and active muon and neutron vetos
- Located at LNGS



Larger mass, lower backgrounds

DARWIN





D. Akerib et al., Snowmass2021 Cosmic Frontier Dark Matter Direct Detection to the Neutrino Fog, 2203.08084

Nuclear recoil backgrounds

- Muon-induced neutrons
- Radiogenic neutrons

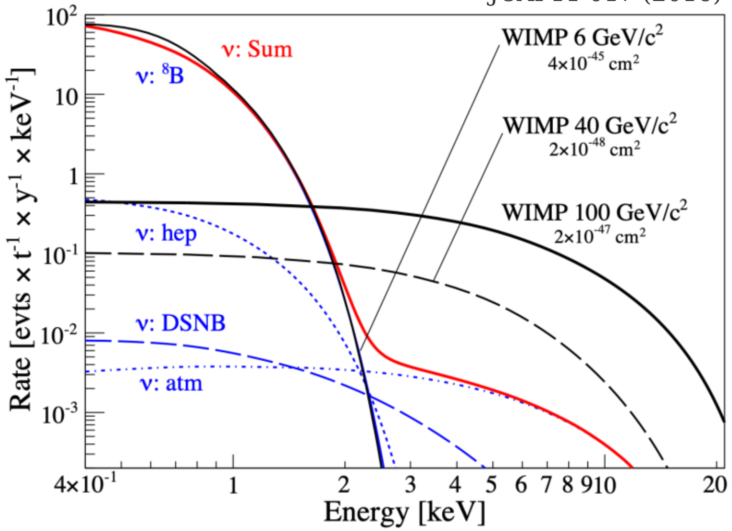
→

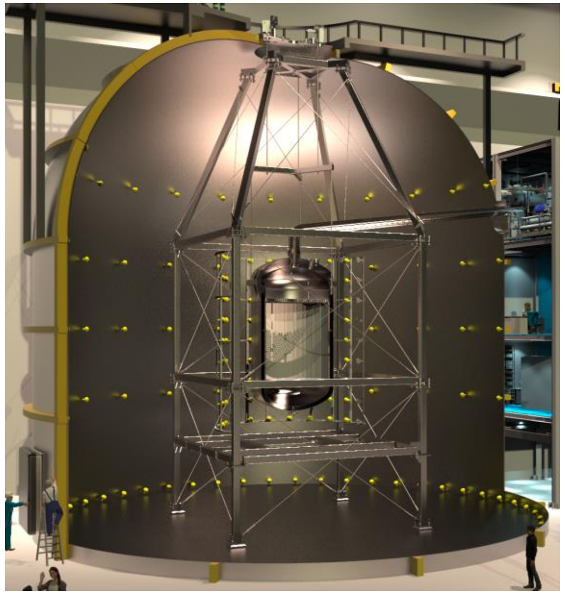
- Water tank (Gd-doped)
- Design and material selection

→

- ~0.4 events/(200 t x y)*
- <1.5 events/(200 t x y)

- Neutrinos:
  - Solar (^8B)
  - Atmospheric
  - Diffuse SN background





* For a 12 m diameter WT at LNGS. For a Borexino-like WT: <0.05/(200 t x y)

Electronic recoil backgrounds

- ^{222}Rn
- ^{85}Kr
- Materials

→

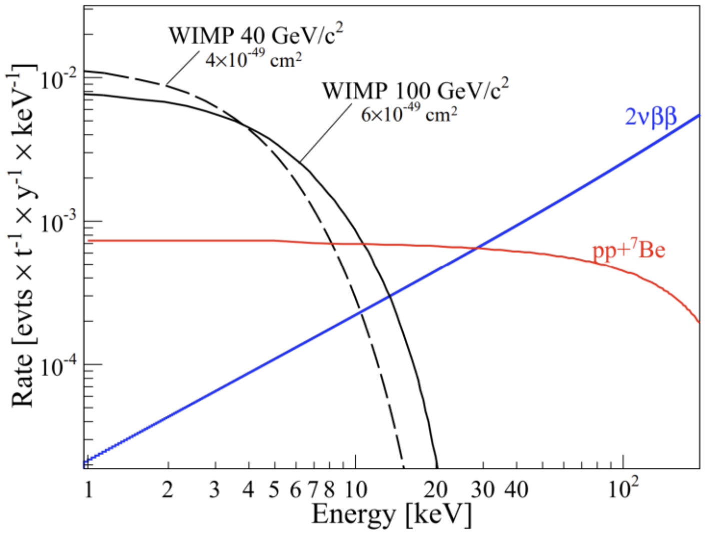
- Material selection, distillation, coating
- Distillation
- Material selection

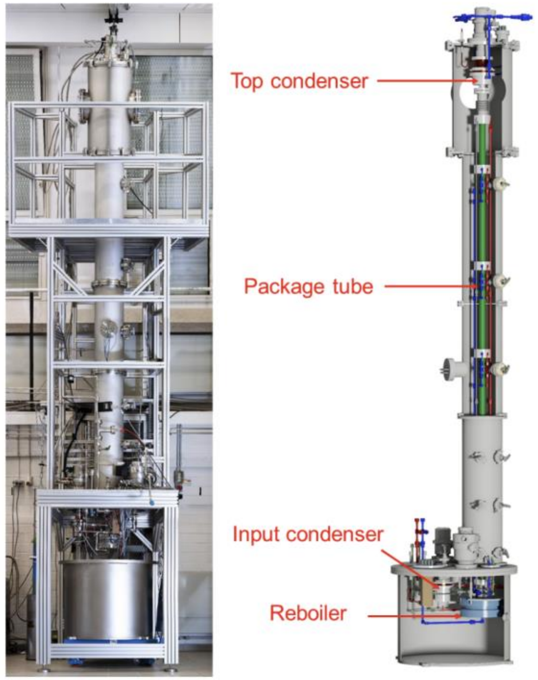
→

- 0.1 µBq/kg (<1 µBq/kg * achieved!)
- 0.1 ppt (< 26 ppq ** achieved!)

- Neutrinos:
  - pp
  - ^{7}Be

JCAP11 017 (2016)





* Eur. Phys. J. C 82, 1104 (2022)

** Eur. Phys. J. C 77 (2017)

Scale up: a set of challenges

- 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
@Uni. Zurich

JINST 16 P08052 (2021)

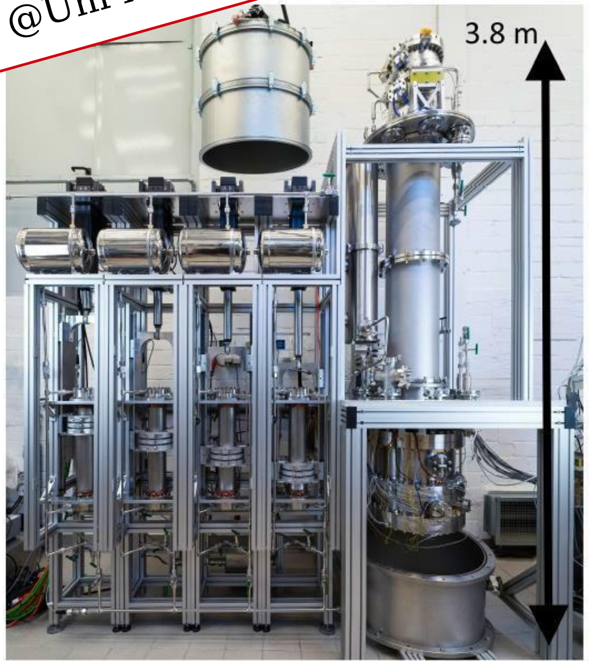
Next talk by Y. Biondi!

Pancake
@Uni. Freiburg

R&D: Rn mitigation

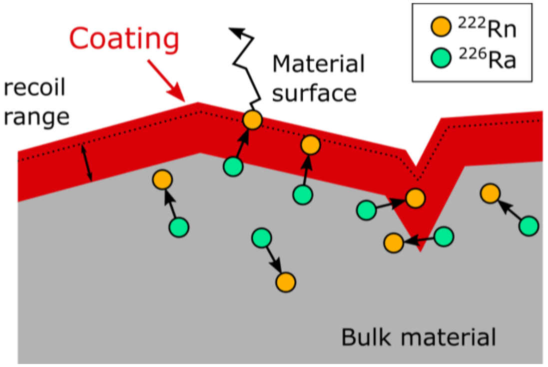
- Online distillation
  - Developed for XENONnT
  - Achieved 0.8 µBq/kg
- Surface coating
  - Trap ^{222}Rn after ^{226}Rn decays
  - Avoid Rn emanation
- Material screening
  - Selection of low-emanation materials
- Hermetic TPC
  - Inner Xe volume (clean) separated from outer (dirty)

R&D @Uni Münster



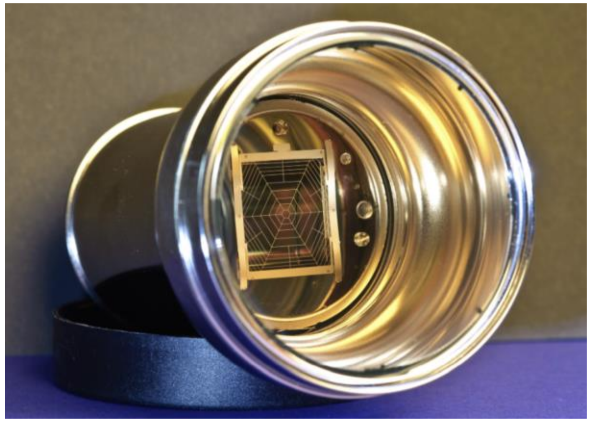
Eur. Phys. J. C 82, 1104 (2022)

R&D @MPIK Heilderberg



R&D: photosensors - PMTs

Current gen.



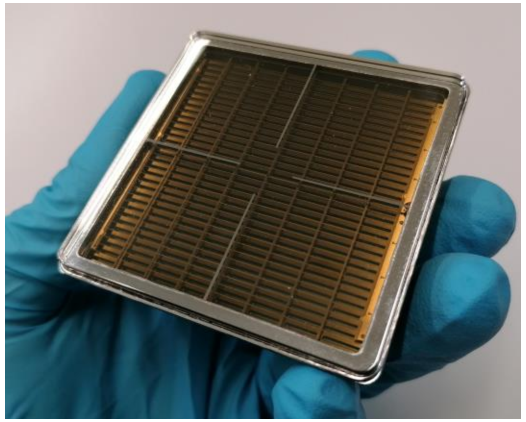
3” R11410

- Used in XENONnT, LZ, PandaX-4T

3” R13111

- Used in XMASS

R&D @Uni Zurich



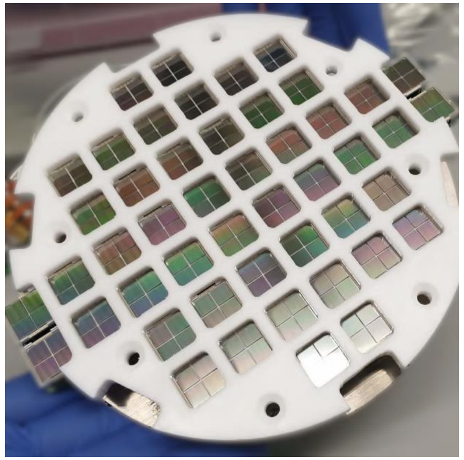
2” R12699

- Larger effective area and coverage
- Multi-anode
- Material selection ongoing

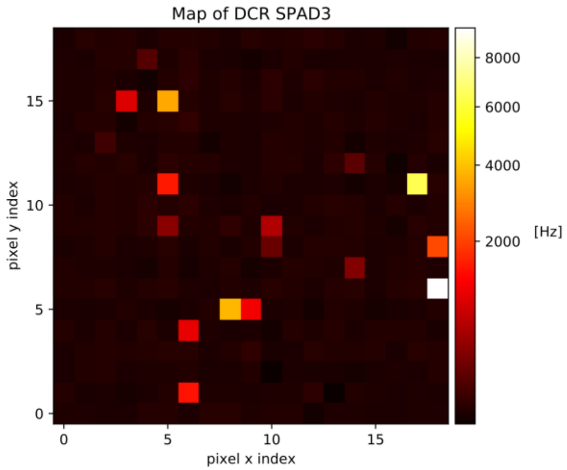
R&D: photosensors - SiPMs

R&D @Uni Zurich

R&D @Uni. Heidelber



JINST 18 C03027 (2023)



FBK VUV-HD Cryo

- Low SPEres, high CTP
- Characterisation at LXe temperature

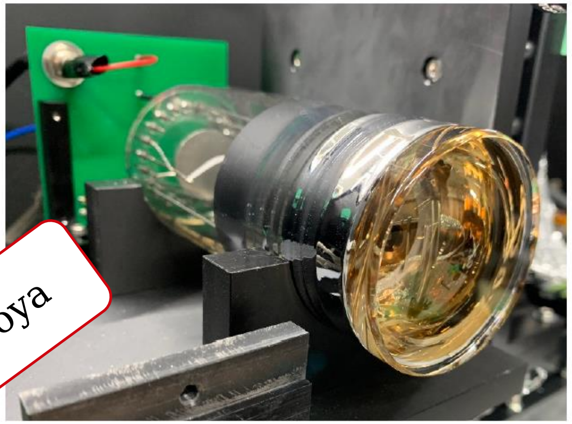
Hamamatsu VUV4

- Array of 48 12x12 mm^2 units
- Characterisation at LXe temperature

Digital SiPMs

- Low DCR
- Ability to turn off problematic pixels

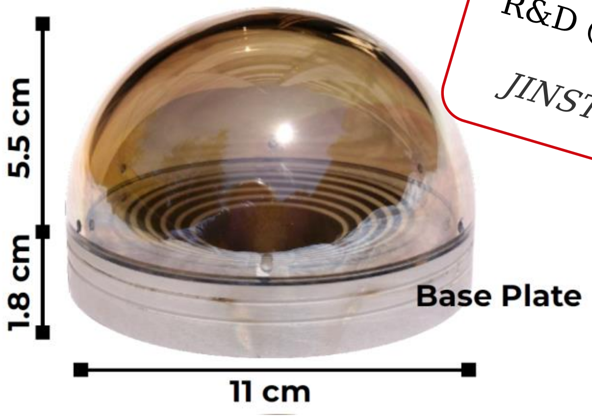
R&D photosensors - hybrid



R&D @Uni. Nagoya

XE5859

- Bialkali photocathode
- Photoelectrode detected in VUV4 MPPC
- O(100) lower DCR than current SiPMs available



R&D @LNGS/Uni. Aquila + Stockholm
JINST 17 C01038 (2022)

Abalone

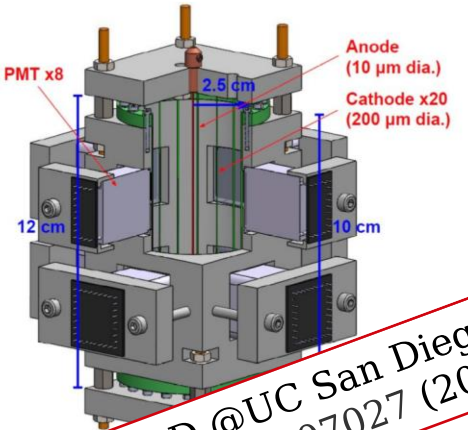
- Base + Dome + Windowlet
- Dome at high voltage (~25 kV)
- SiPM detects scintillation photons

R&D: alternative designs

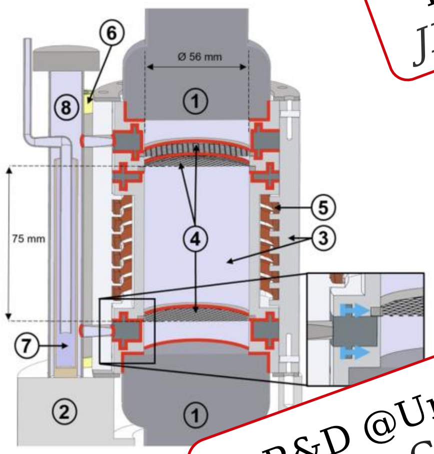
- Single-phase TPC
  - Both S1 and S2 created in liquid phase
  - No liquid level control required
  - Reduce single-electron emission

- Hermetic TPC
  - Prevent Rn and impurity diffusion into inner volume

R&D @Uni. Freiburg
JINST 17 P03027 (2023)



R&D @UC San Diego
JINST 18 P07027 (2023)



R&D @Uni. Freiburg
Phys. J. C 83, 9 (2023)

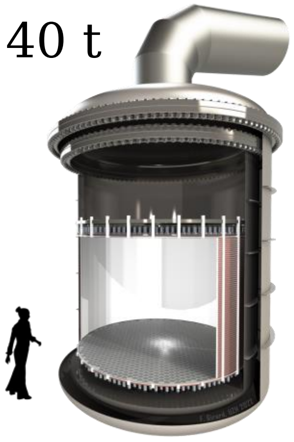
Collaborative future: XLZD

DARWIN

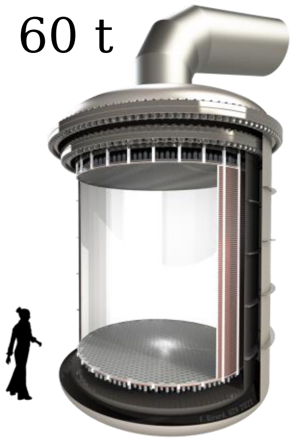
- Consortium merging DARWIN/XENON and LUX-ZEPLIN
- Common effort to build the next generation LXe TPC

- First meeting online in 2021
- MoU signed July 2021
- General meetings in KIT 2022 and UCLA 2023
- Meeting regularly and active internal working groups and structure

40 t



60 t



Community white paper: *J. Phys. G: Nucl. Part. Phys.* 50 013001 (2023)

xlzd.org

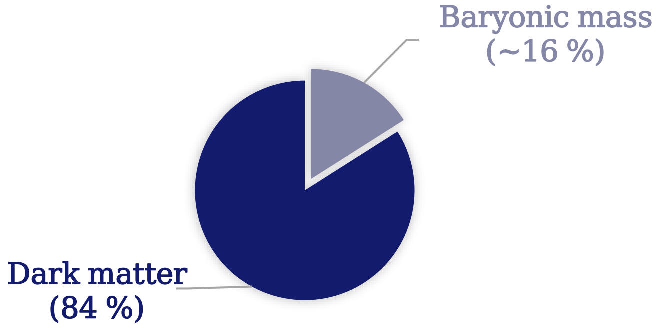
Summary and outlook

- A DM particle is yet to be detected
- LXe TPCs have been successful in constraining the WIMP-nucleon cross-section
- DARWIN leads the effort for a next-generation LXe DM and neutrinos experiment
- Vast amount of R&D ongoing
- Combining knowledge, expertise and funding, the XLZD consortium paves the way to a collaborative future!

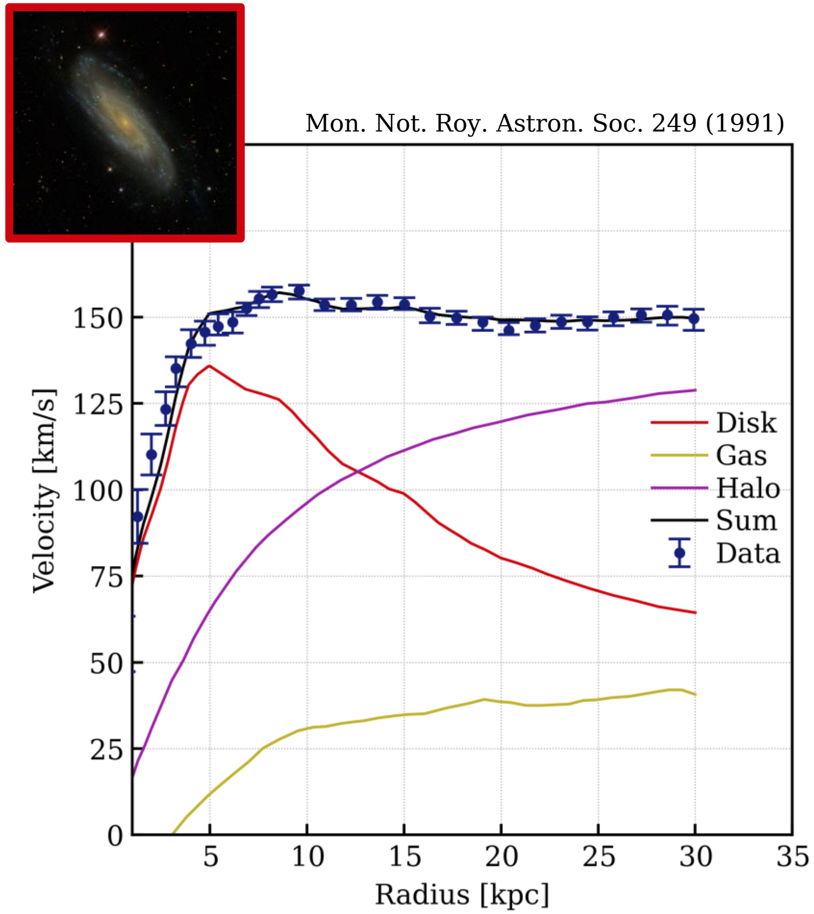
Thank you!

The dark matter puzzle

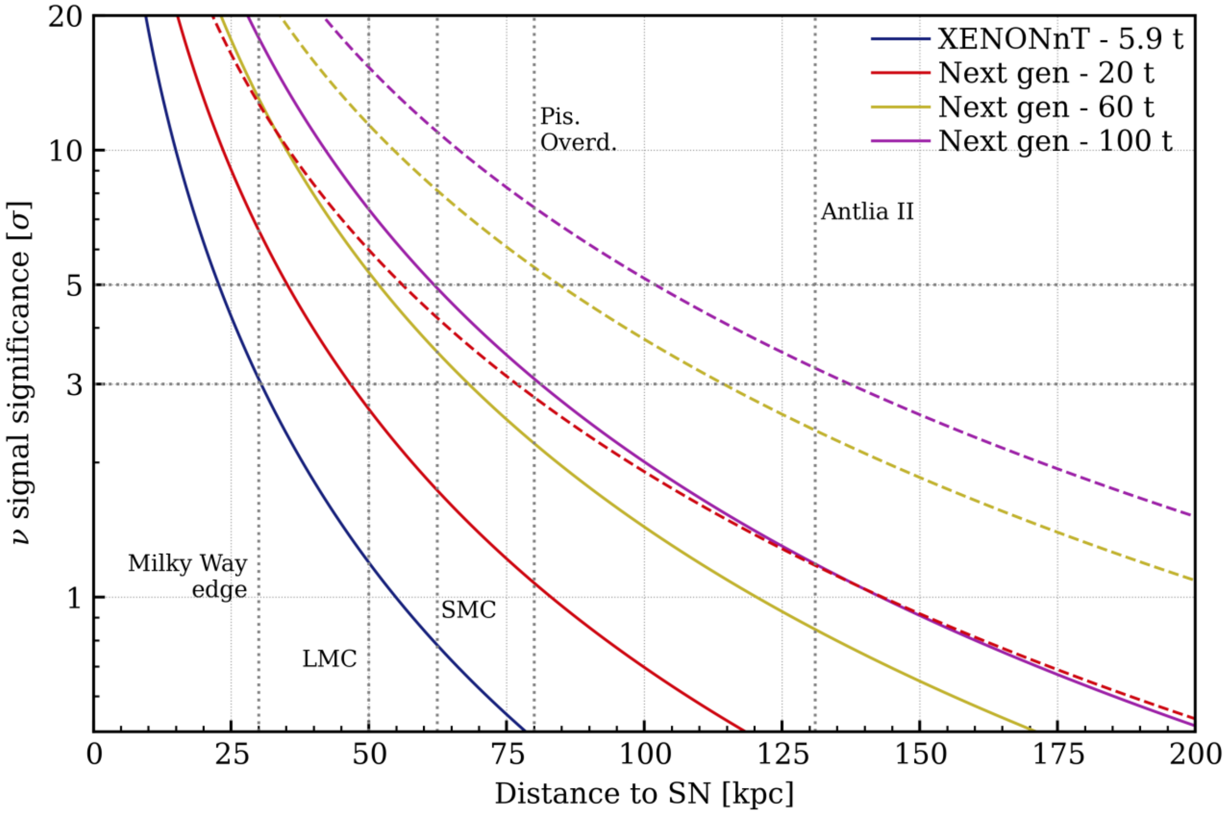
- Evidence shows a missing mass component
- From cosmological measurements:



- Dark matter particles expected:
    - Massive
    - Neutral
    - Stable (lifetime longer than the Universe age)
    - Weakly-interactive
- Weakly-interacting massive particle (WIMP)



Sensitivity to galactic SNe



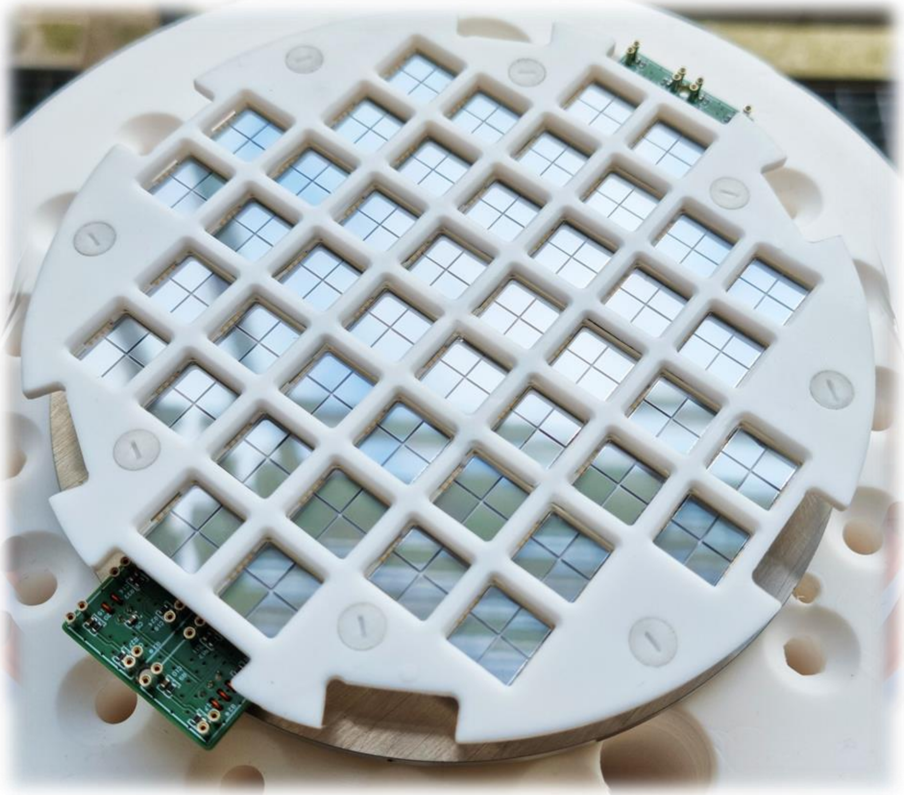
SiPMs or PMTs

	PMT	SiPM
Bias voltage	O(1) kV	O(10) V
QE @175 nm	~35 %	~25 %
SPE resolution	30 %	4 – 6 %
DCR @170-190K	O(0.01) Hz/mm^2	O(0.1 - 1) Hz/mm^2
Fill factor	~ 60 % (XENONnT)	Up to 90% (no packaging)
Radioactivity	Large mass/radioactivity per area	Low radioactivity per area

The top SiPM array of Xenoscope

- Testing SiPMs on a large-scale dual-phase LXe TPC
- Dimensions:
  - Back plate: ø ~16 cm
  - TPC/active area: ø ~15 cm
- Total of 48 12x12 mm^2 VUV4 MMPCs from Hamamatsu

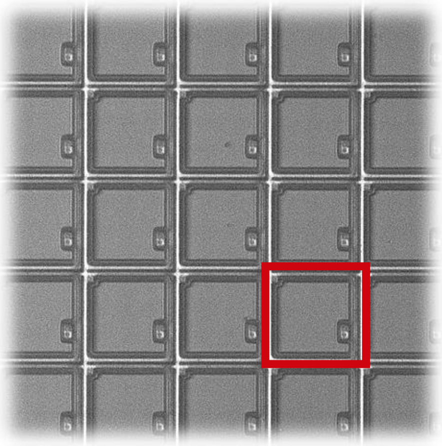
R.Peres, JINST 18 (2023)



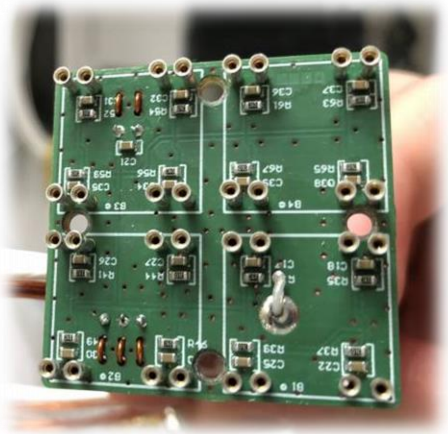
The VUV4 MPPCs and the summed readout

DARWIN

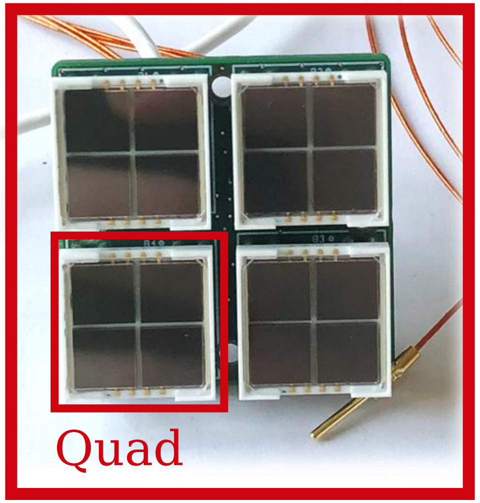
- Latest generation of VUV SiPMs from Hamamatsu Photonics
- 50-µm pitch cells
- Tiled array with 4 12x12 mm^2 MPPCs
- Summed readout (parallel) with a x20 pre-amplifier circuit

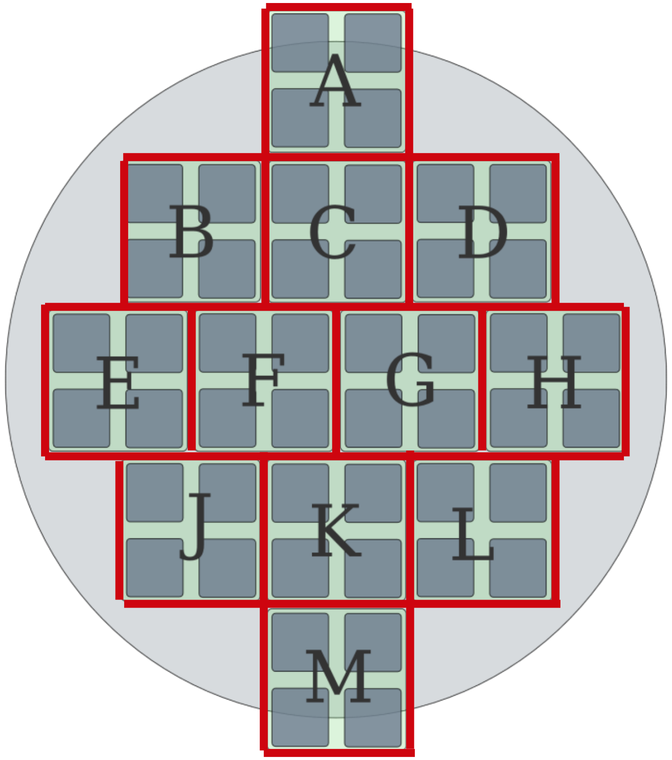


Cell



Tile





Assembling the array in Xenoscope