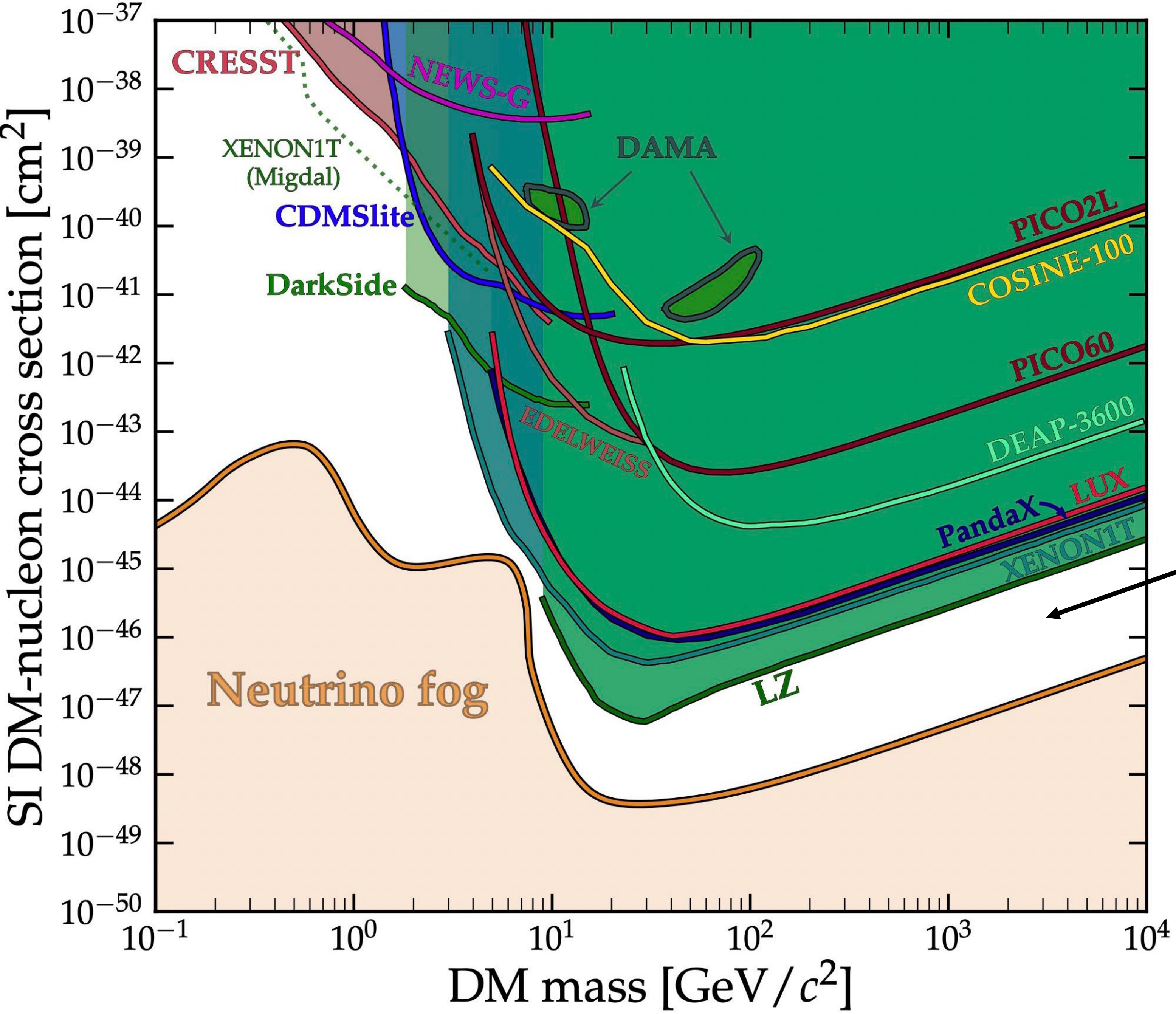
DARWIN: A LIQUID XENON OBSERVATORY FOR RARE EVENTS PHYSICS SEARCHES

Sara Diglio, SUBATECH-Nantes

On behalf of the DARWIN Collaboration

Dark Side of the Universe – 5-9 Dec 2022 – University of Sydney

CURRENT STATUS OF WIMP SEARCH

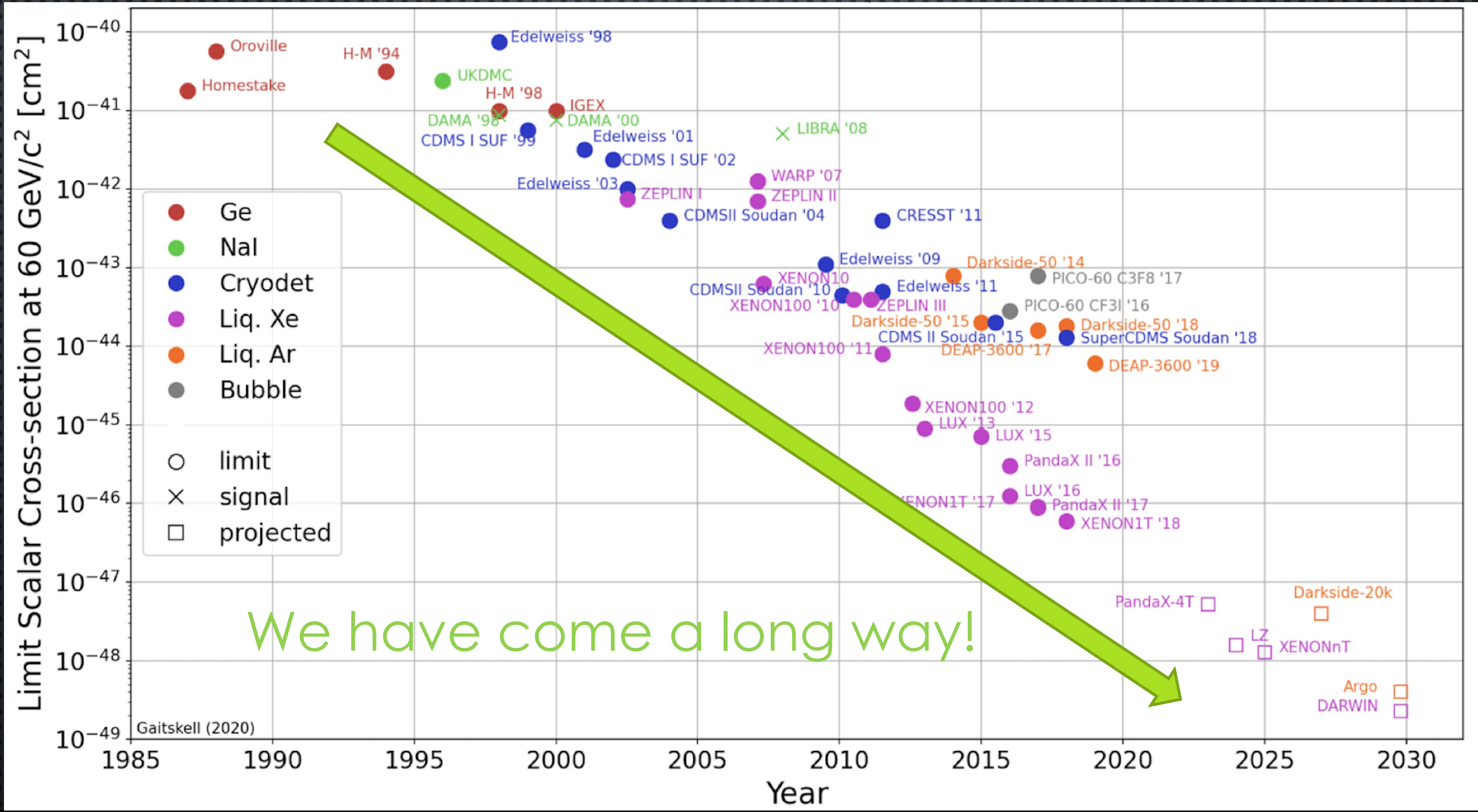


Region of the parameter space to be explored

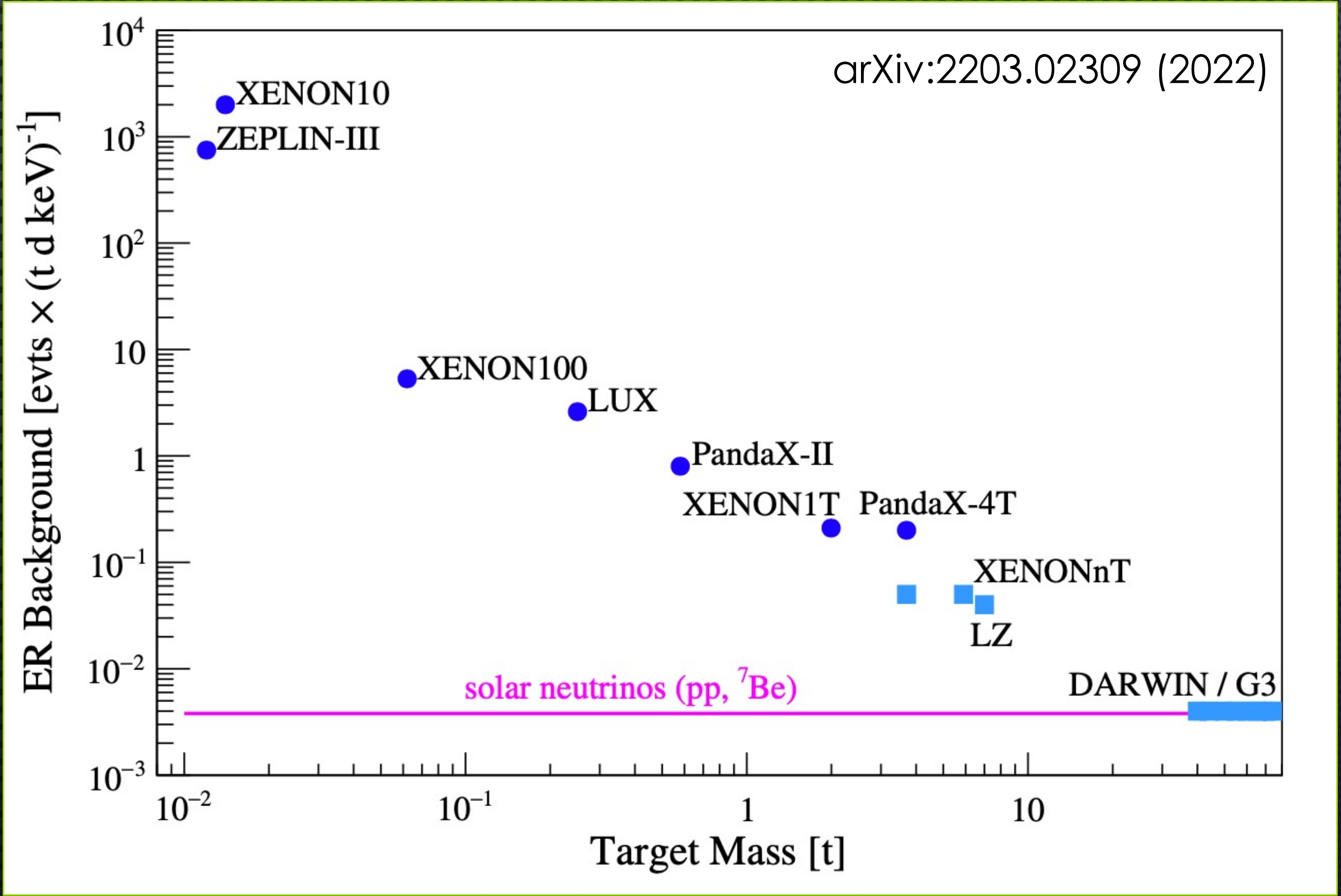
Ultimate sensitivity dominated by neutrino interactions

Figure: C. O'Hare

CURRENT STATUS OF WIMP SEARCH



DUAL PHASE LXE DETECTORS : INCREASING SENSITIVITY



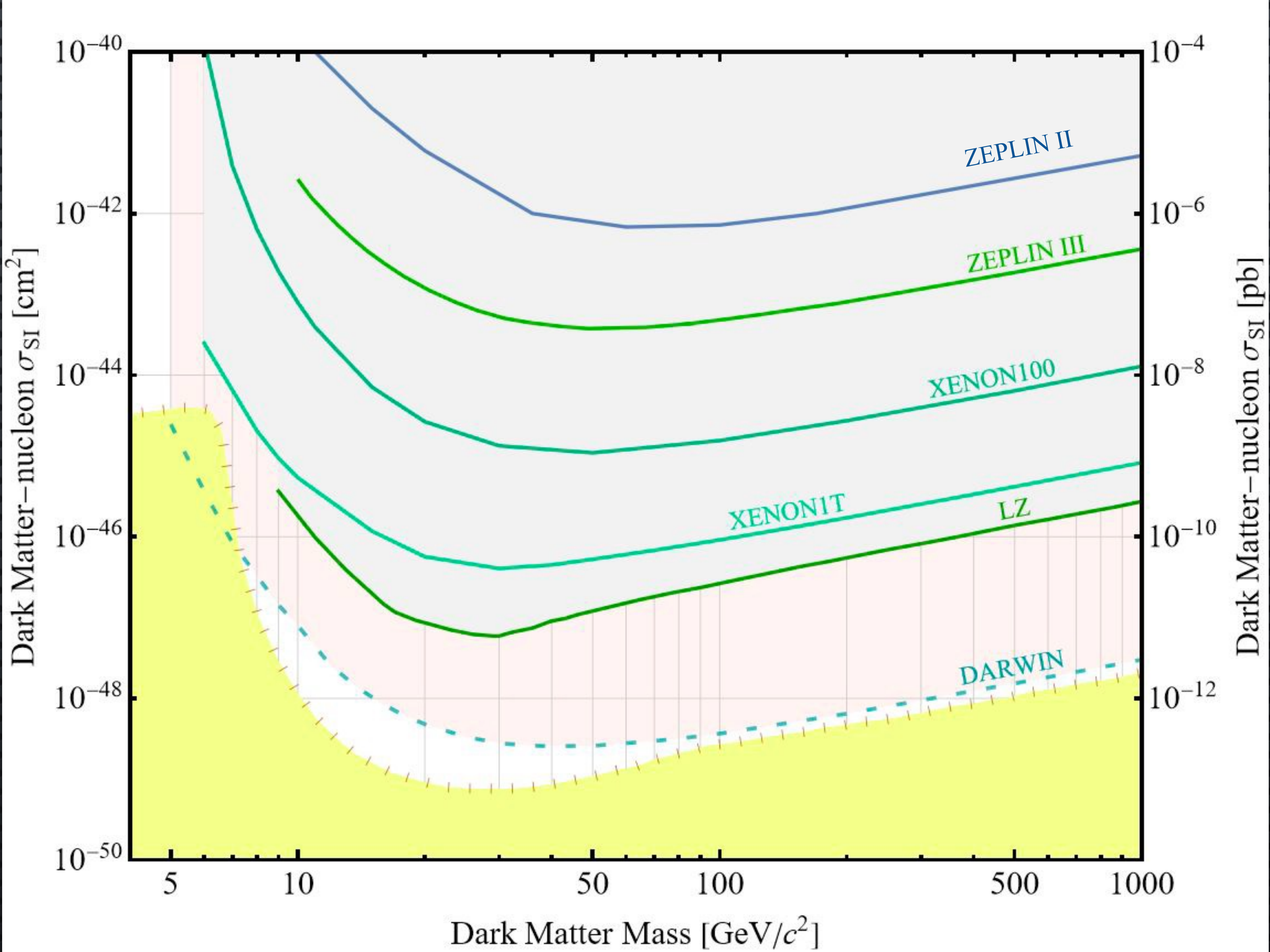
DUAL PHASE LXE DETECTORS: ULTIMATE WIMP SENSITIVITY

~10 kg

~100 kg

~1000 kg

~10000 kg



2007

2011

2013

2018

2022

~2030

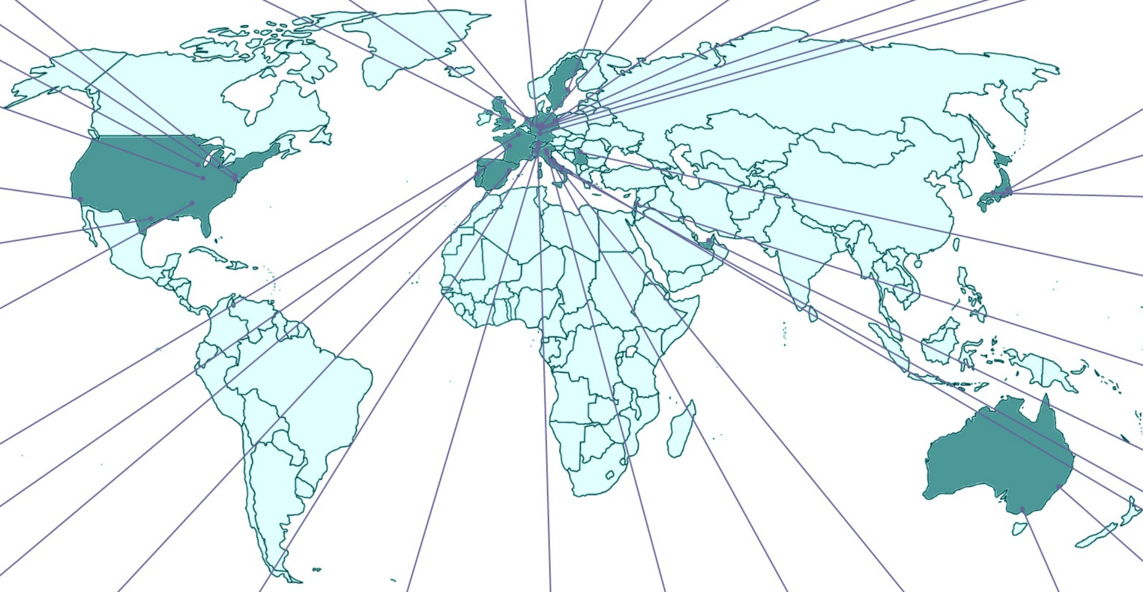
Figure: J. Newstead

THE DARWIN COLLABORATION

Columbia · RPI · London · Nikhef · Muenster · Darmstadt · Stockholm · Mainz · Dresden · MPIK, Heidelberg · Heidelberg · KIT · Freiburg

Chicago · Purdue · UCSD · Alabama · Rice · LPNHE

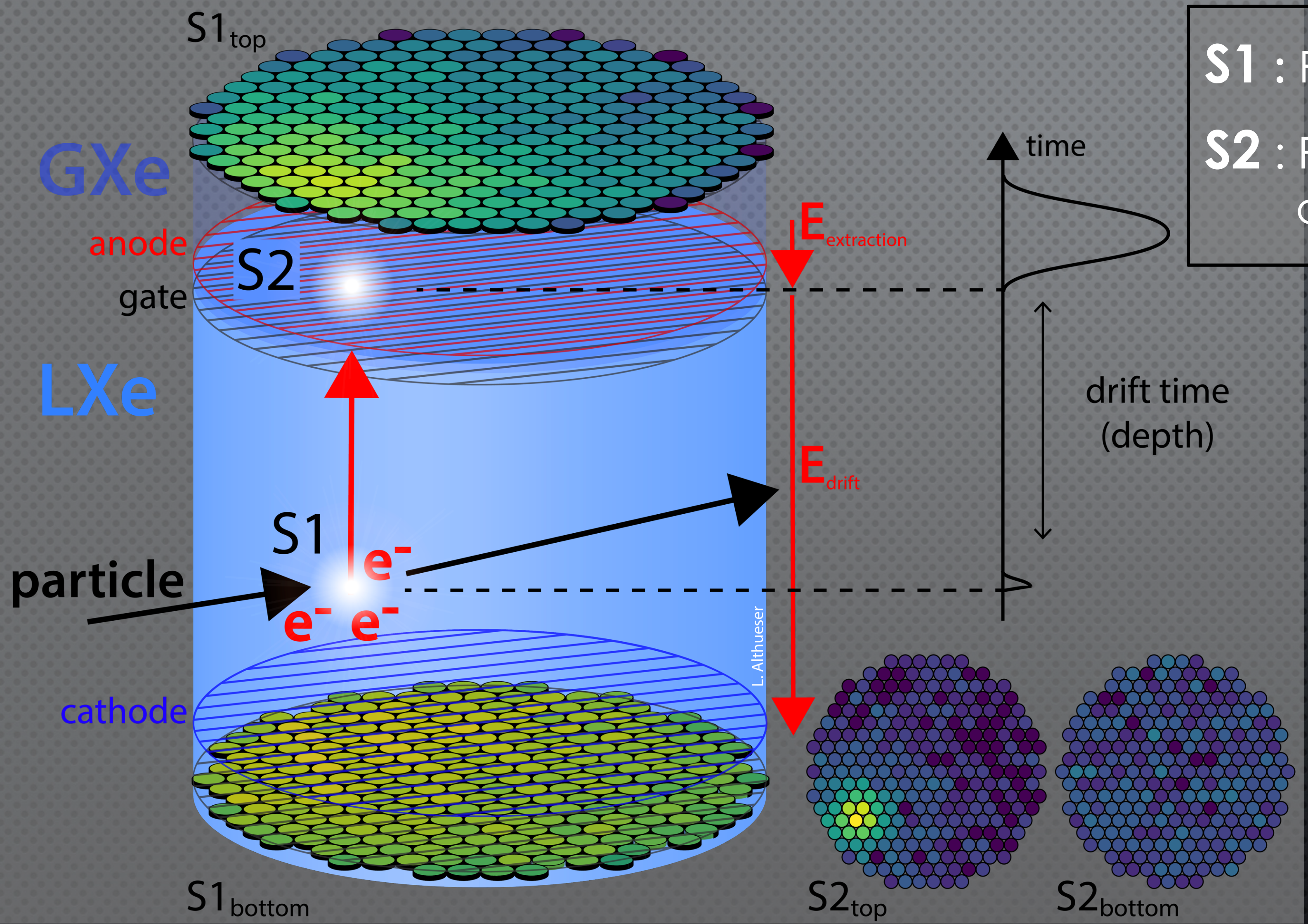
> 200 members, 38 institutions, 11 countries



Tokyo · Nagoya · Kobe · Belgrade · Weizmann · NYUAD

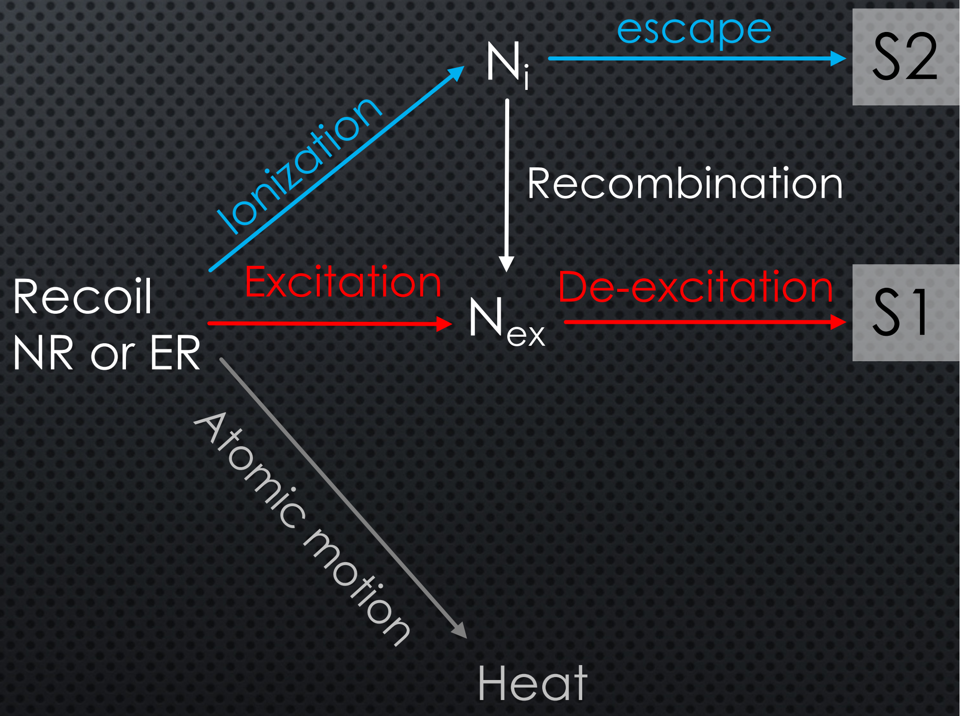
Coimbra · Subatech · Barcelona · Bern · Zurich · Torino · Ferrara · Bologna · L'Aquila · Melbourne · Sydney · LNGS · Napoli

DUAL PHASE TIME PROJECTION CHAMBERS

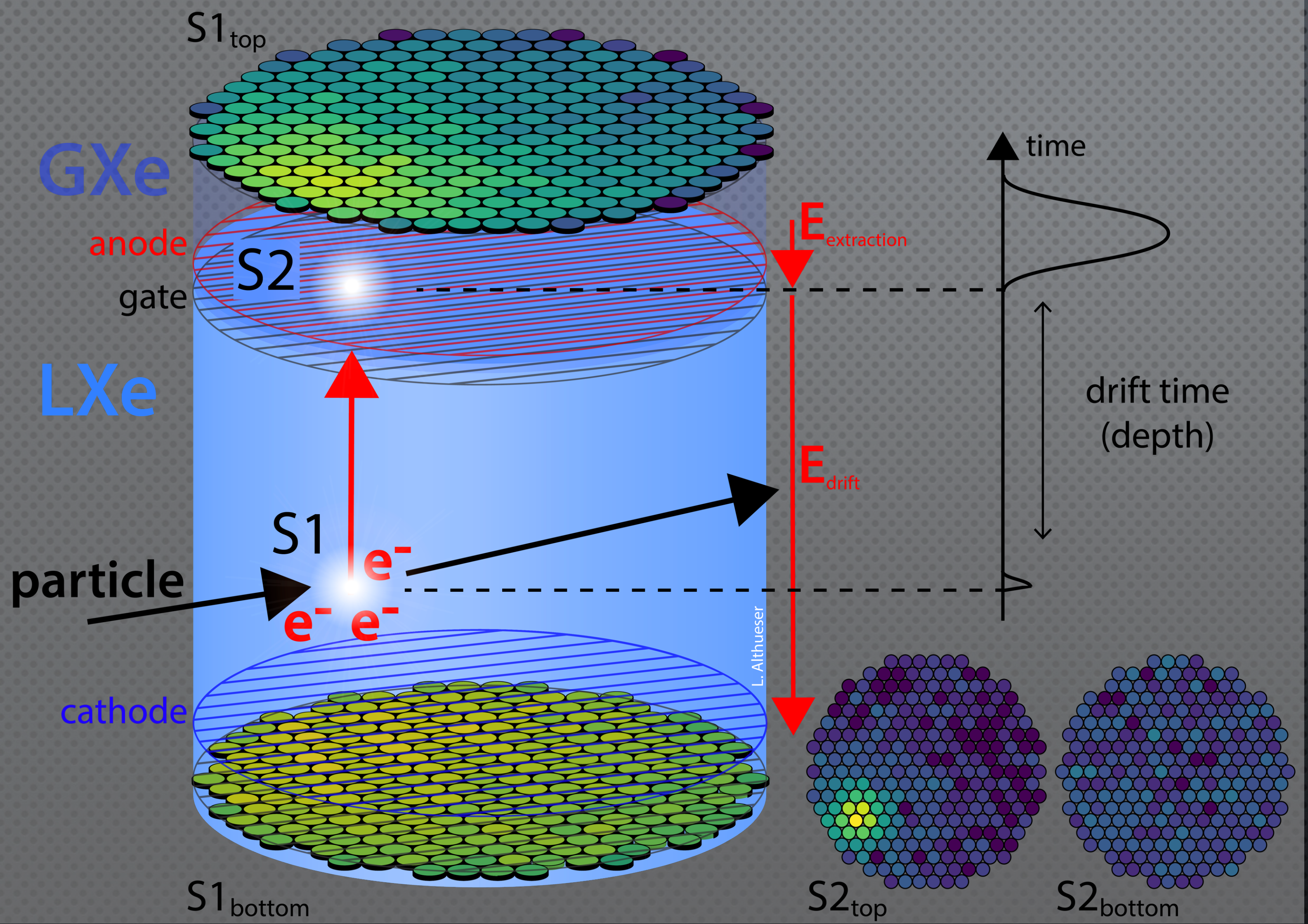


S1 : Prompt Scintillation (light)

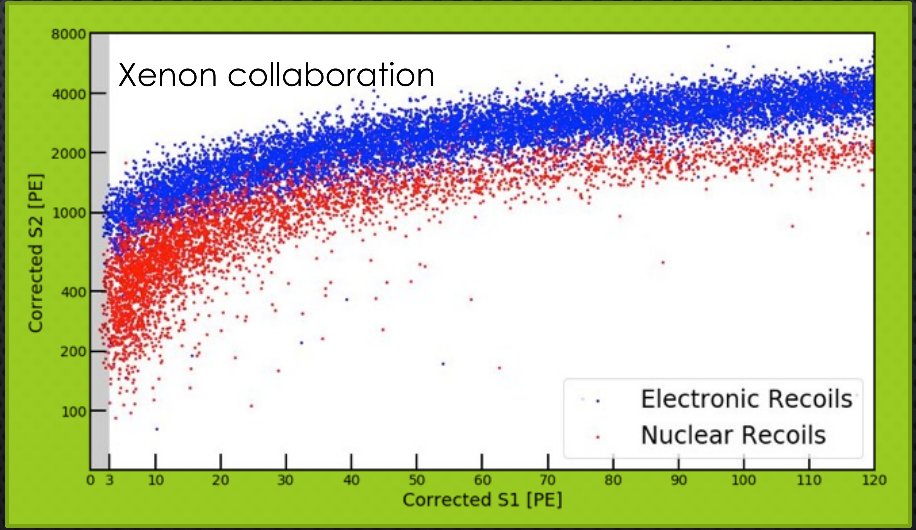
S2 : Proportional scintillation following e^- drift and extraction into gas (charge)



DUAL PHASE TIME PROJECTION CHAMBERS

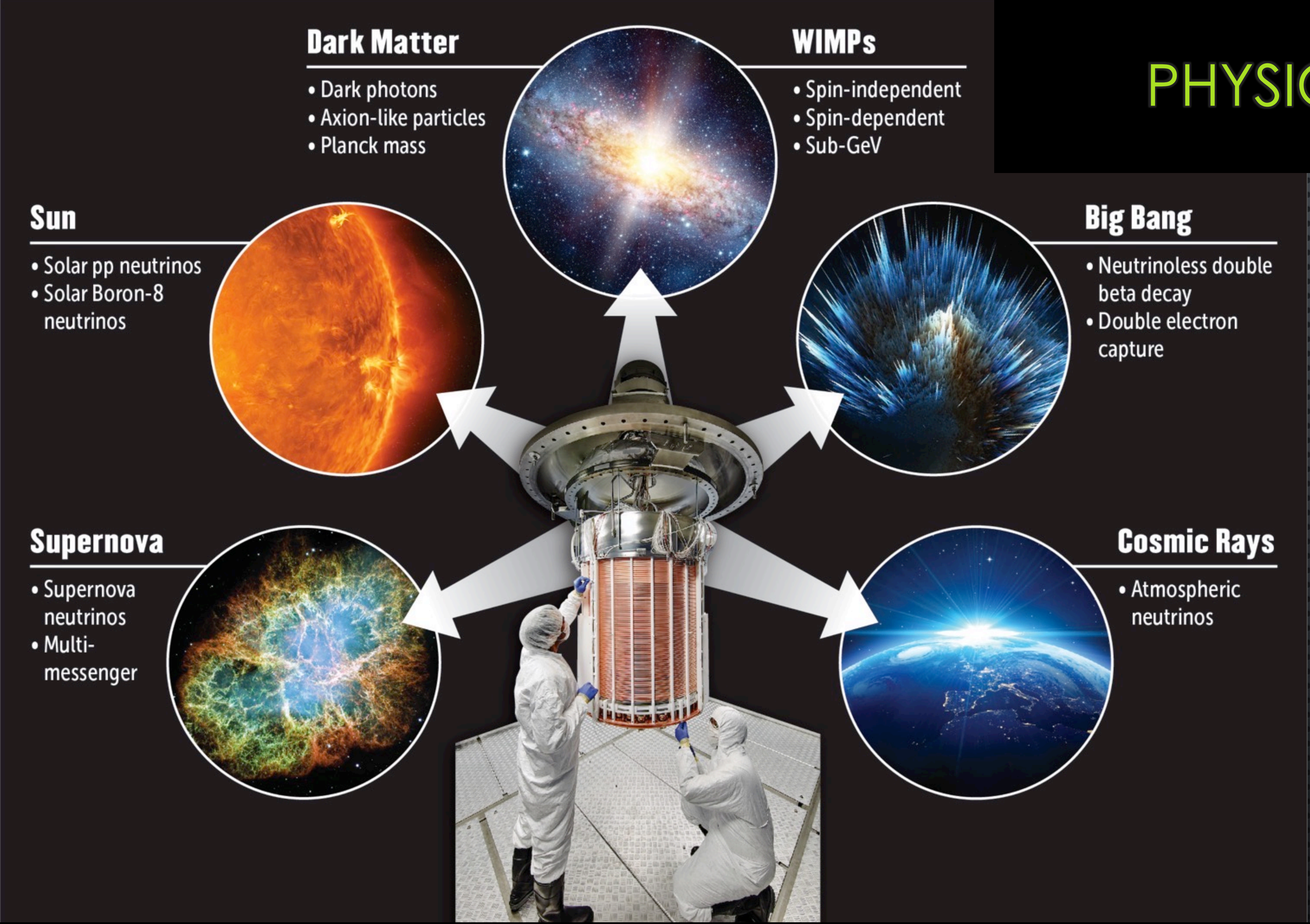


- Energy from S1 and S2
- 3D event reconstruction:
  - X , Y from S2 hit pattern on top PMTs
  - Z from electrons drift time



$(S2/S1)_{NR} < (S2/S1)_{ER}$

PHYSICS REACH



More than just WIMPs

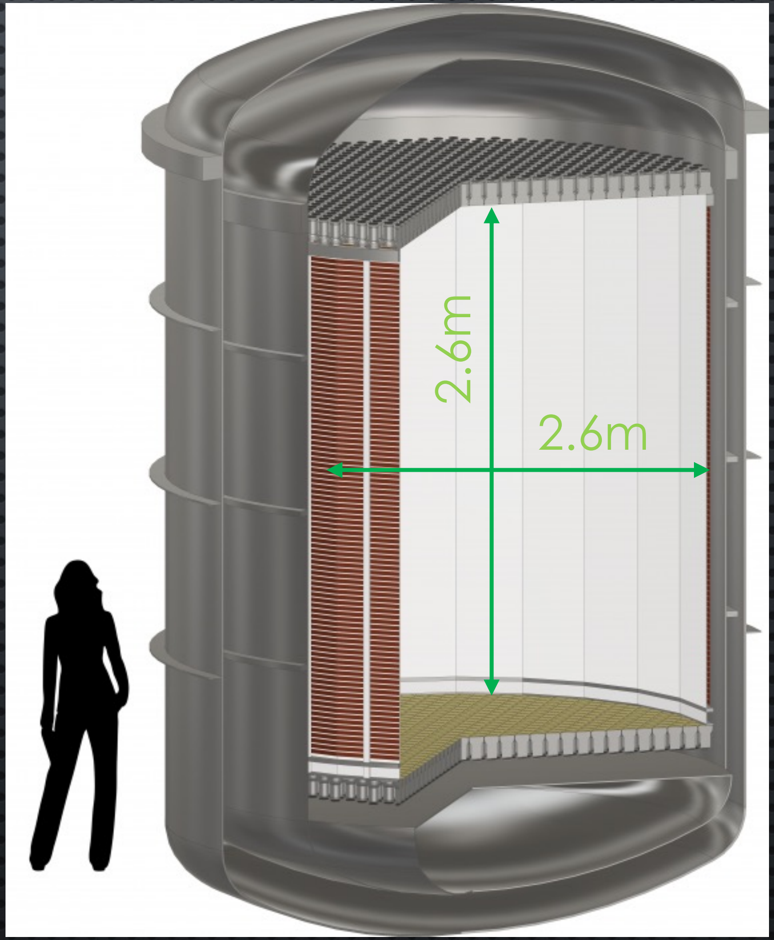
A rare events physics observatory

Arxiv : 2203.02309

DARWIN BASELINE DESIGN

BASELINE DESIGN

- Dual-phase TPC: 2.6 m ø and 2.6 m height
- 50 t (40 t) LXe in total (in TPC)
- Top & bottom arrays of photosensors (e.g., 1800 3-inch PMTs)
- PTFE reflectors and Cu field shaping rings
- Low-background Ti cryostat
- Gd-doped water as n- and μ-vetos



DARWIN Collaboration, JCAP 1611 (2016) 017

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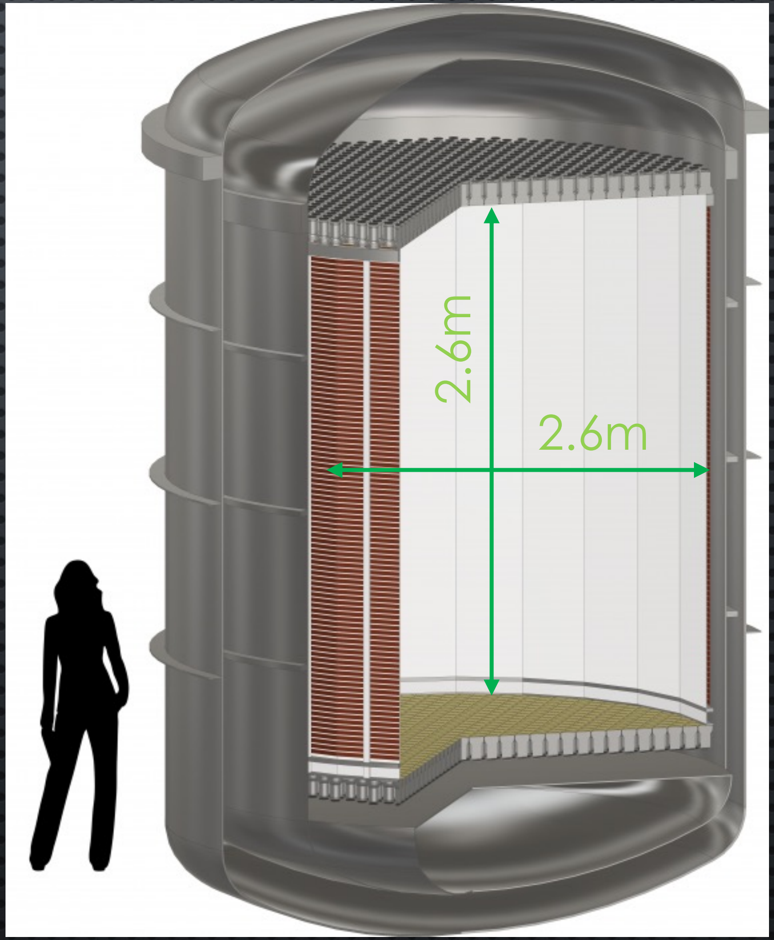
alternative designs and photosensors under consideration
→ various R&D ongoing in several institutions



DARWIN Collaboration, JCAP 1611 (2016) 017

DARWIN BASELINE DESIGN & CHALLENGES

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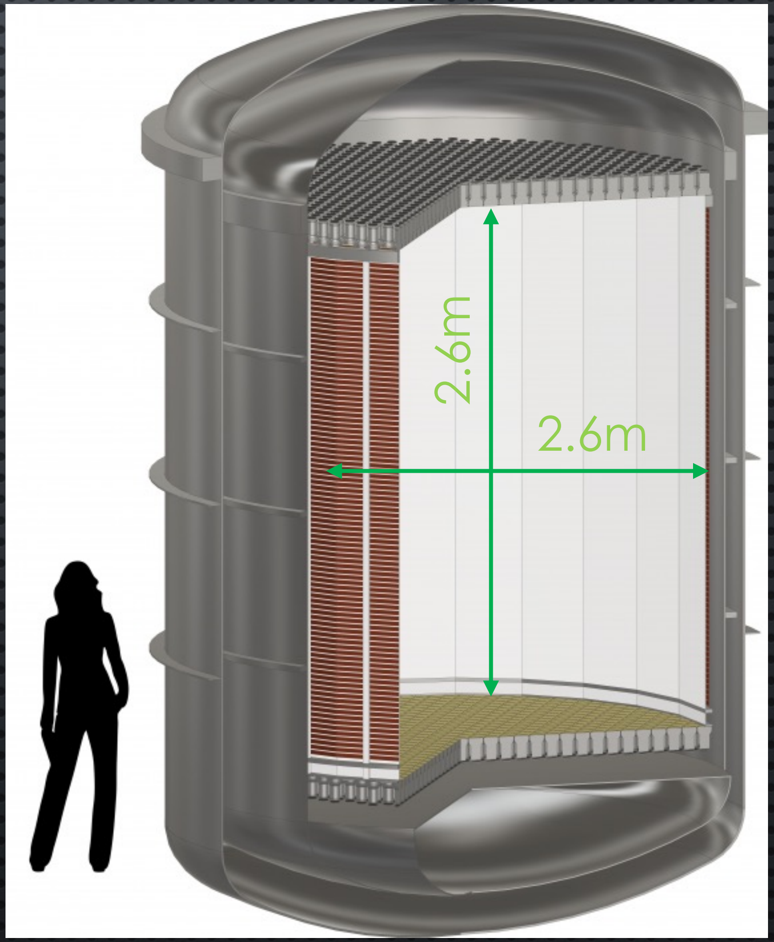
CHALLENGES

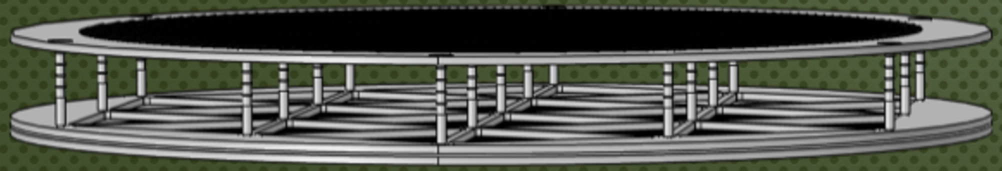
- Design of electrodes: robustness (minimal sagging/deflection), maximal transparency, reduced e- emission
- Xenon procurement & storage
- High voltage supply
- Liquid level control
- Significant staging space and UG fabrication capabilities
- …

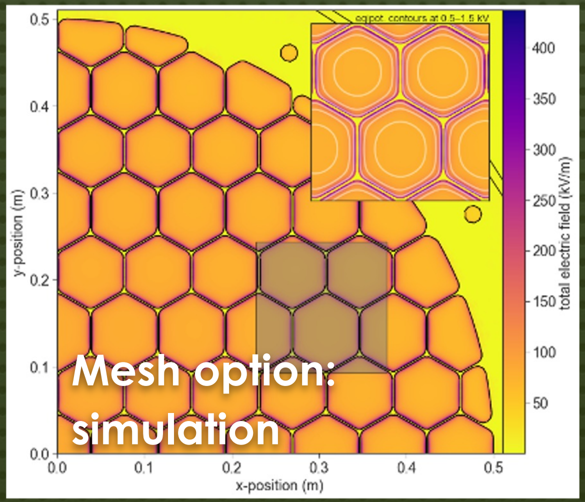


DARWIN Collaboration, JCAP 1611 (2016) 017

DARWIN R&D : ELECTRODES & XENON RECOVERY

R&D on electrodes

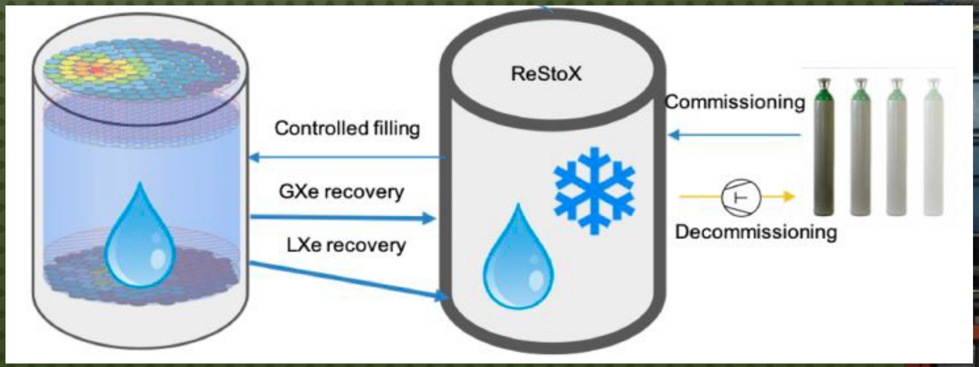




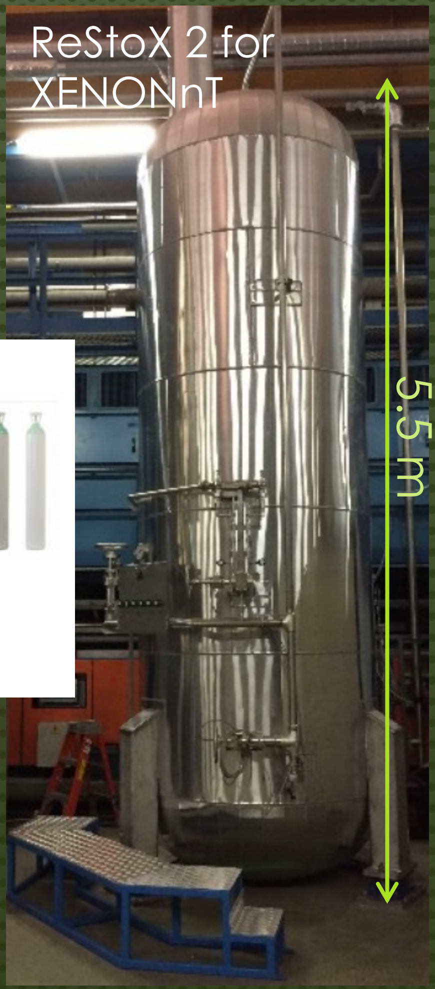
- Exploiting new alternative designs for large scale electrodes

Recovery & Storage of Xenon

- Just increasing the storage size is not reasonable
→ towards a modular approach



- Evaluating and testing the new concept of the LXe fast recovery by gravity



DARWIN R&D : DEMONSTRATORS

Horizontal demonstrator Pancake in Freiburg:

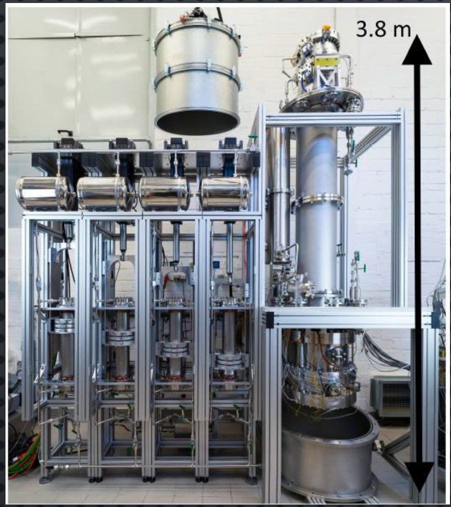
- 2.7 m diameter, 5 cm LXe height
- test horizontal components – real scale frames, electrodes etc.

Vertical demonstrator Xenoscope in Zurich:

- 16 cm inner diameter, up to 2.6 m LXe height
- Full scale electron drift demonstration – high voltage, drift field properties, purity etc

L. Baudis *et al* 2021 *JINST* **16** P08052

DARWIN R&D : RN MITIGATION



Online distillation

- Distillation column performs well in XENONnT
- XENONnT< 1 μBq/kg

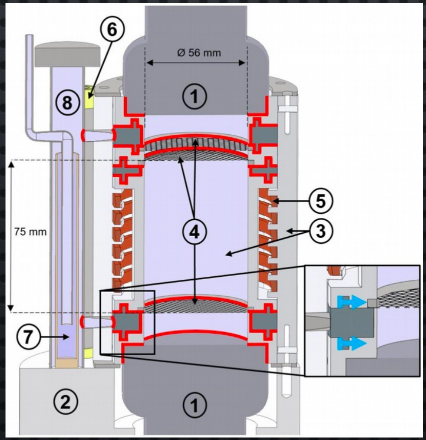
arXiv:2205.11492

Material screening and selection

- Low-emanation materials
- Multiple screening facilities available to DARWIN groups

Hermetic TPCs

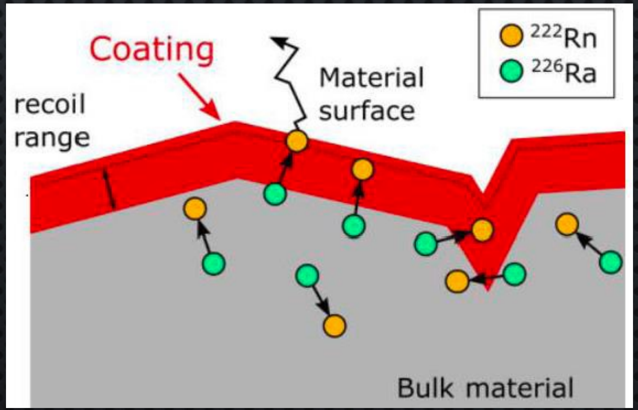
- New detector designs to reduce Rn in active volume
- Separate "clean" TPC from "dirty" outer skin region



arXiv:2209.00362

Surface treatment

- "Lock" Rn in materials
- Barrier to trap radon after radium decays

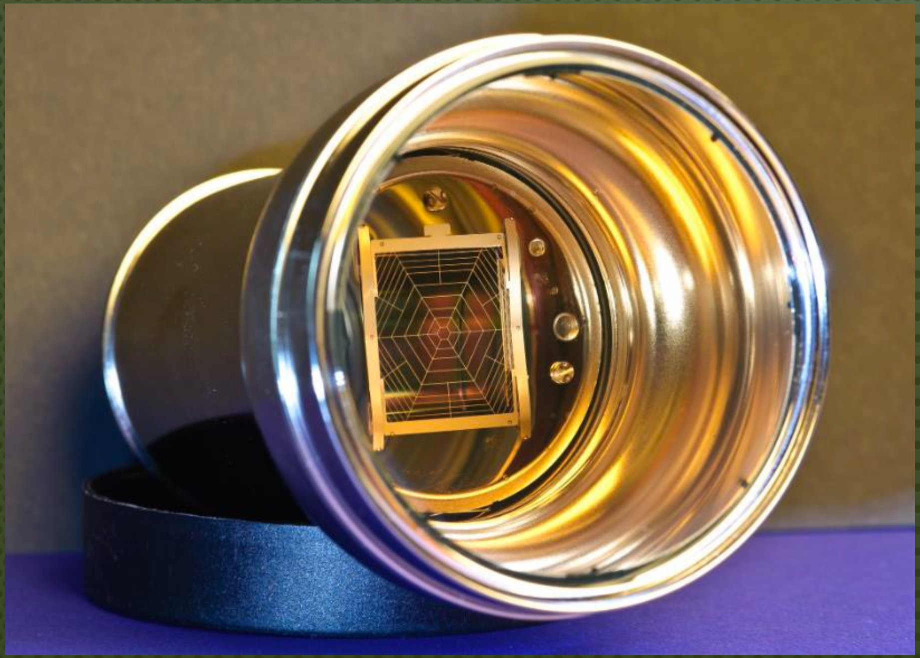


DARWIN R&D : PHOTOSENSORS

Stable and radiopure photosensors needed

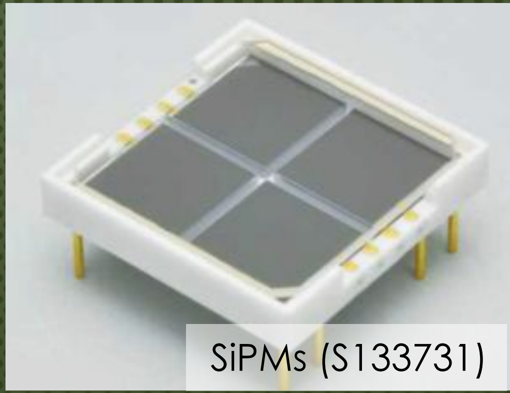
Baseline option

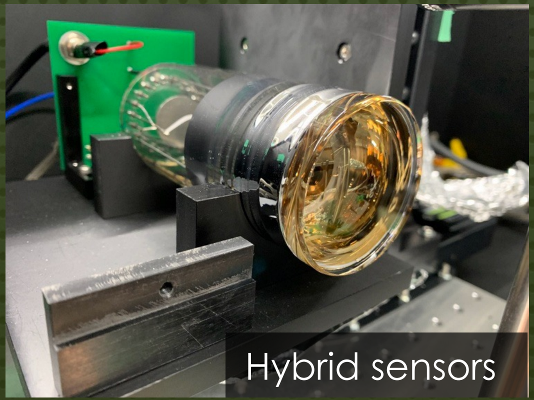
3" PMTs R11410 (XENONnT, LZ)

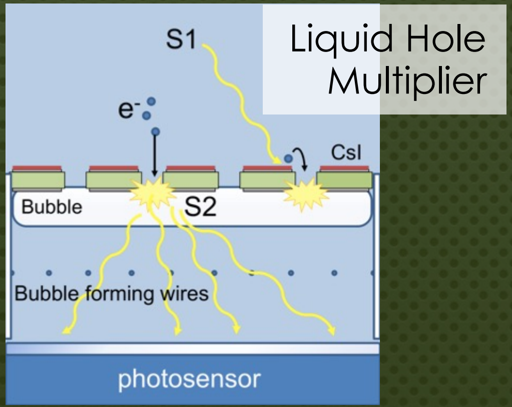


reliable well-tested solution but too high intrinsic activity for future detectors

Possible alternatives





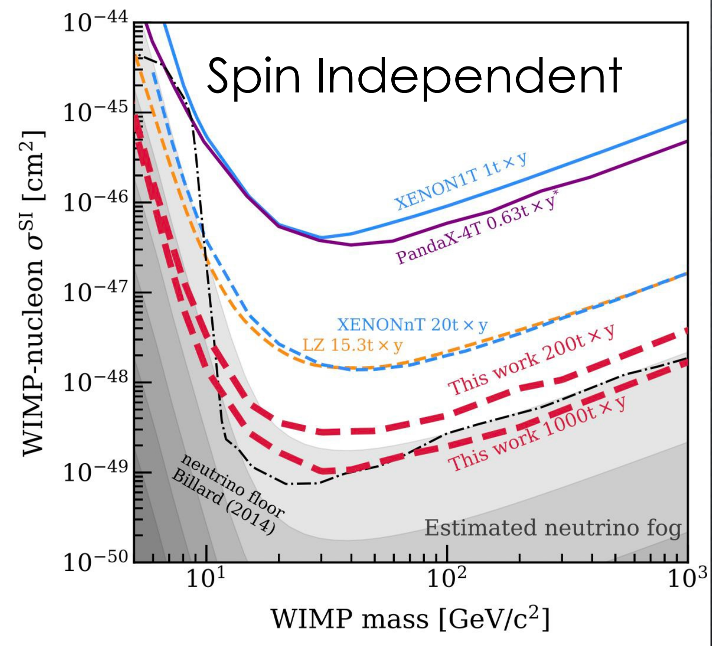


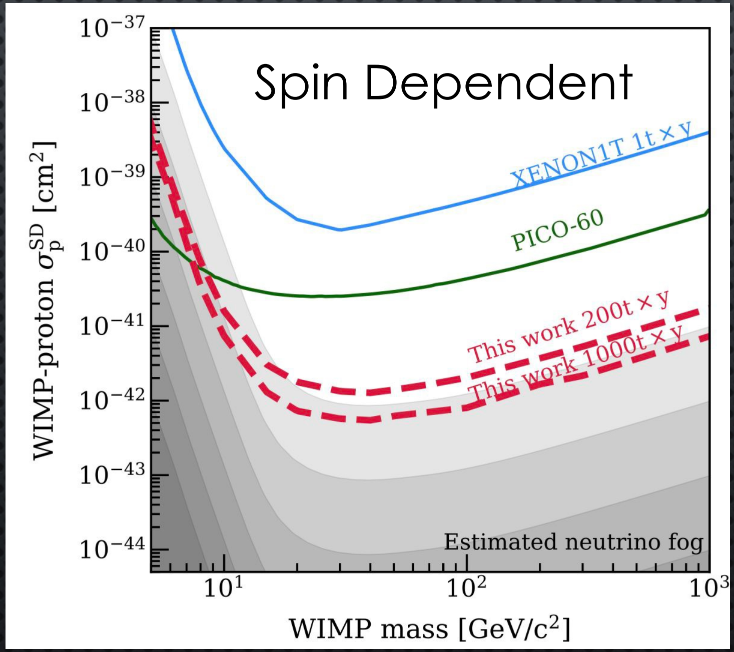
WIMPS SEARCHES

Arxiv : 2203.02309

WIMP SENSITIVITY

- Will probe entire parameter region for m_χ ~ 2 GeV/c^2 until neutrino fog
- 99.8% ER rejection @30% NR acceptance

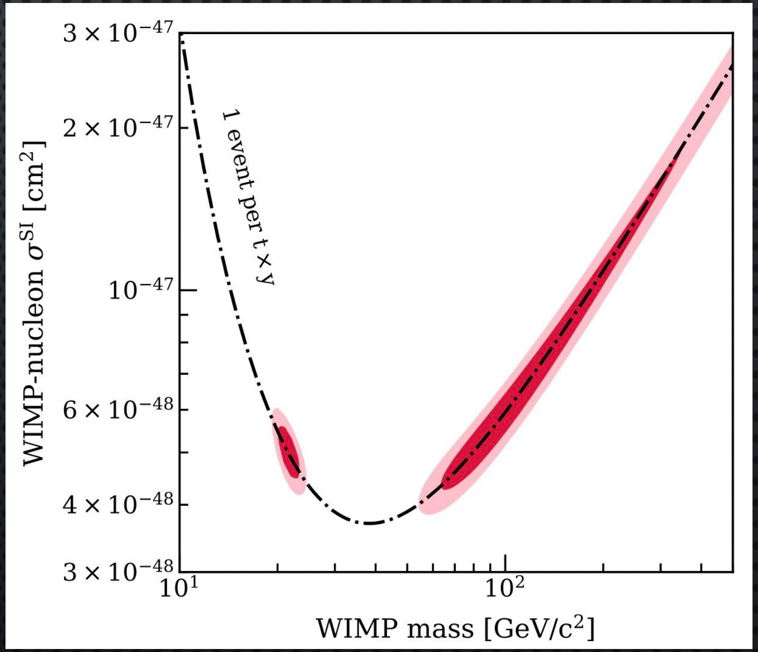




WIMP SPECTROSCOPY

Capability to reconstruct WIMP mass & cross section (SI) for various masses below 500 GeV/c^2

Exposure : 1000 t x y
Reconstruction m_χ = 20, 100 GeV/c^2

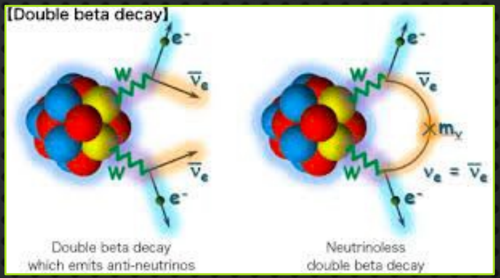


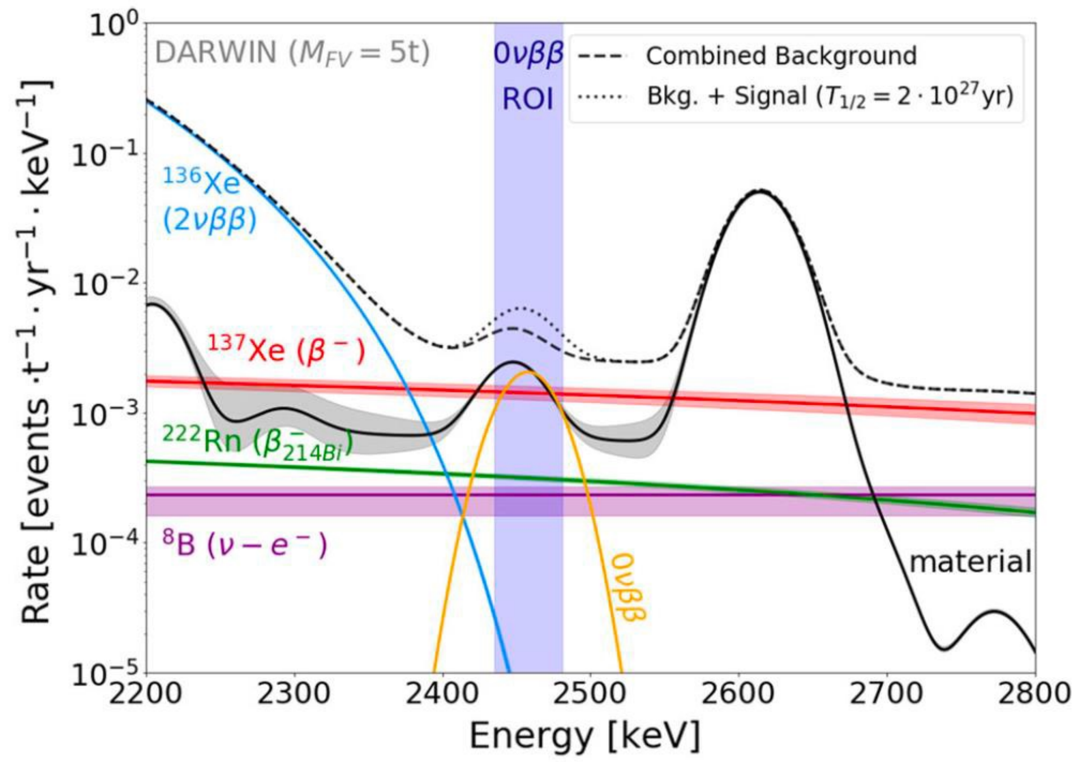
NEUTRINOLESS DOUBLE BETA DECAY

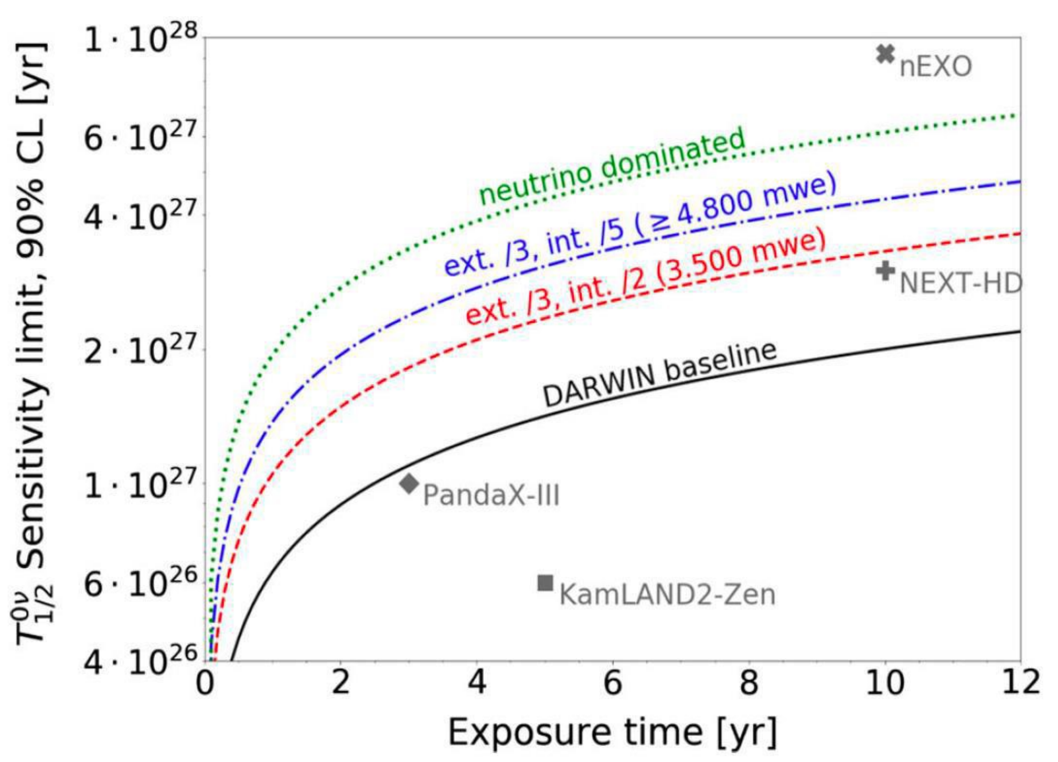
DARWIN, EPJ C 80, 808 (2020)

$0\nu\beta\beta$ in ^{136}Xe

- Abundance 8.9% ⇒3.5 t in DARWIN
- Peak at $Q_{\beta\beta}$ (^{136}Xe) = 2.5 MeV →Resolution 0.8% achieved by XENON1T
- 2.4 .10^{27}yr sensitivity with 5 t x10 yr exposure





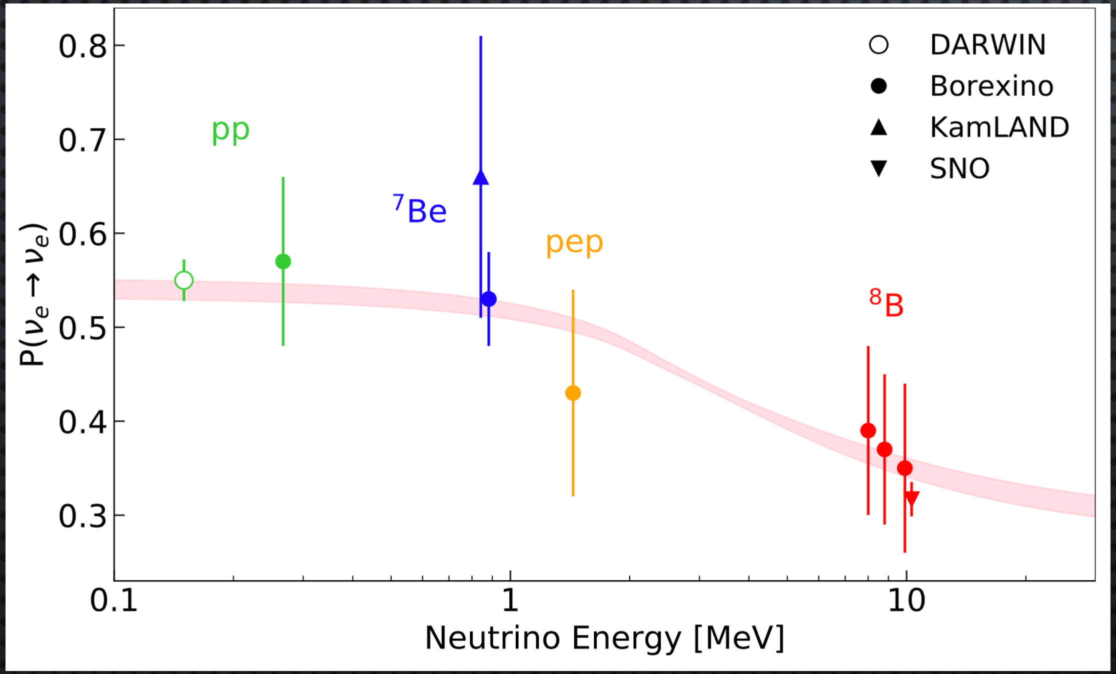


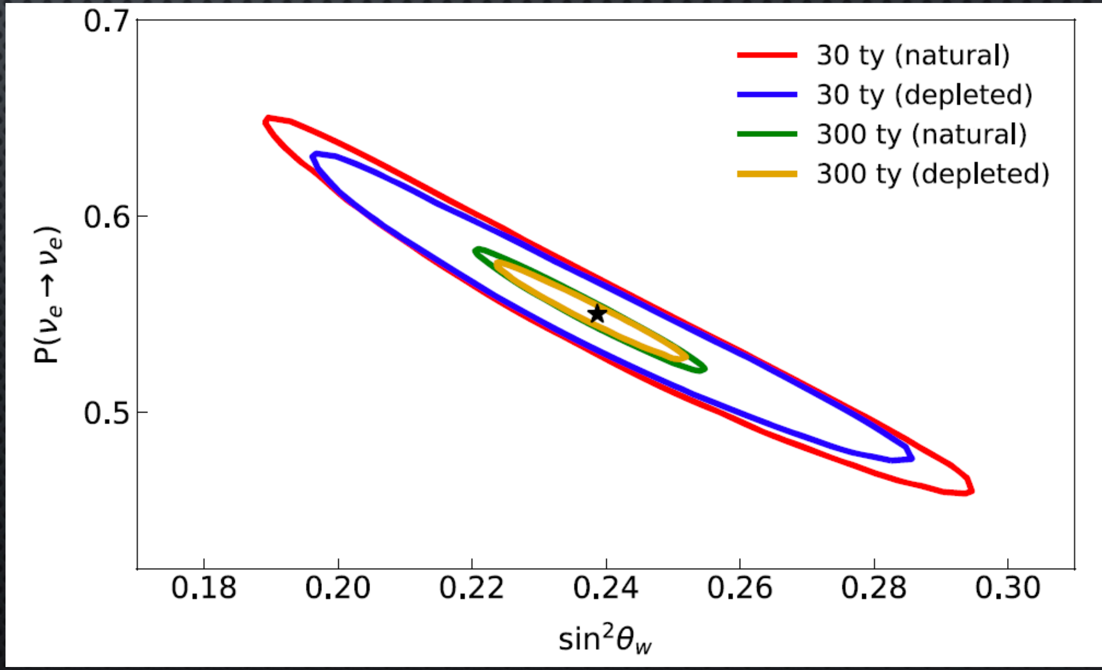
SOLAR NEUTRINOS

DARWIN, EPJ C 80, 1133 (2020)

Elastic electron-neutrino scattering $\nu + e^- \rightarrow \nu + e^-$

- 0.15% precision in the pp flux measurement with 300 ty exposure
- Measurement of electron neutrino survival probability and weak mixing angle
- 7.2 events/day in 30 t for the energy range E = (2 – 30) keV_{ee}(pp-neutrinos)





XLZD CONSORTIUM

XLZD consortium (xlzd.org) to design and build a common multi-ton xenon experiment

- currently 104 group-leaders in 16 countries : MoU signed in July 2021
- joint "white paper" on physics reach : 600 authors, 141 institutions
- Already official and active:
    - first in-person meeting at KIT in June 2022
    - second in person meeting in US in Spring 2023
    - Weekly calls to discuss working group progress and status

XENON LZ DARWIN

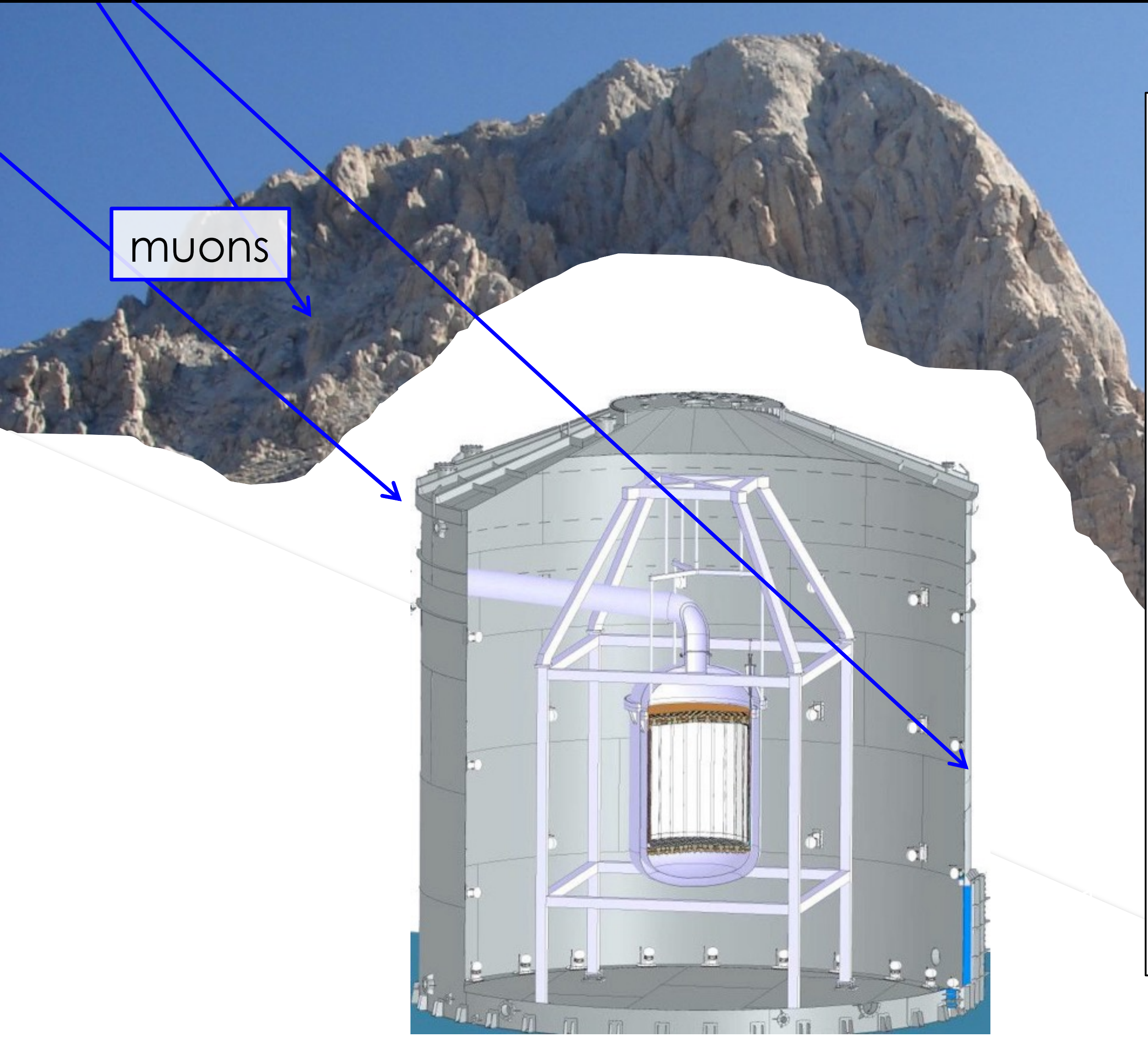
XLZD

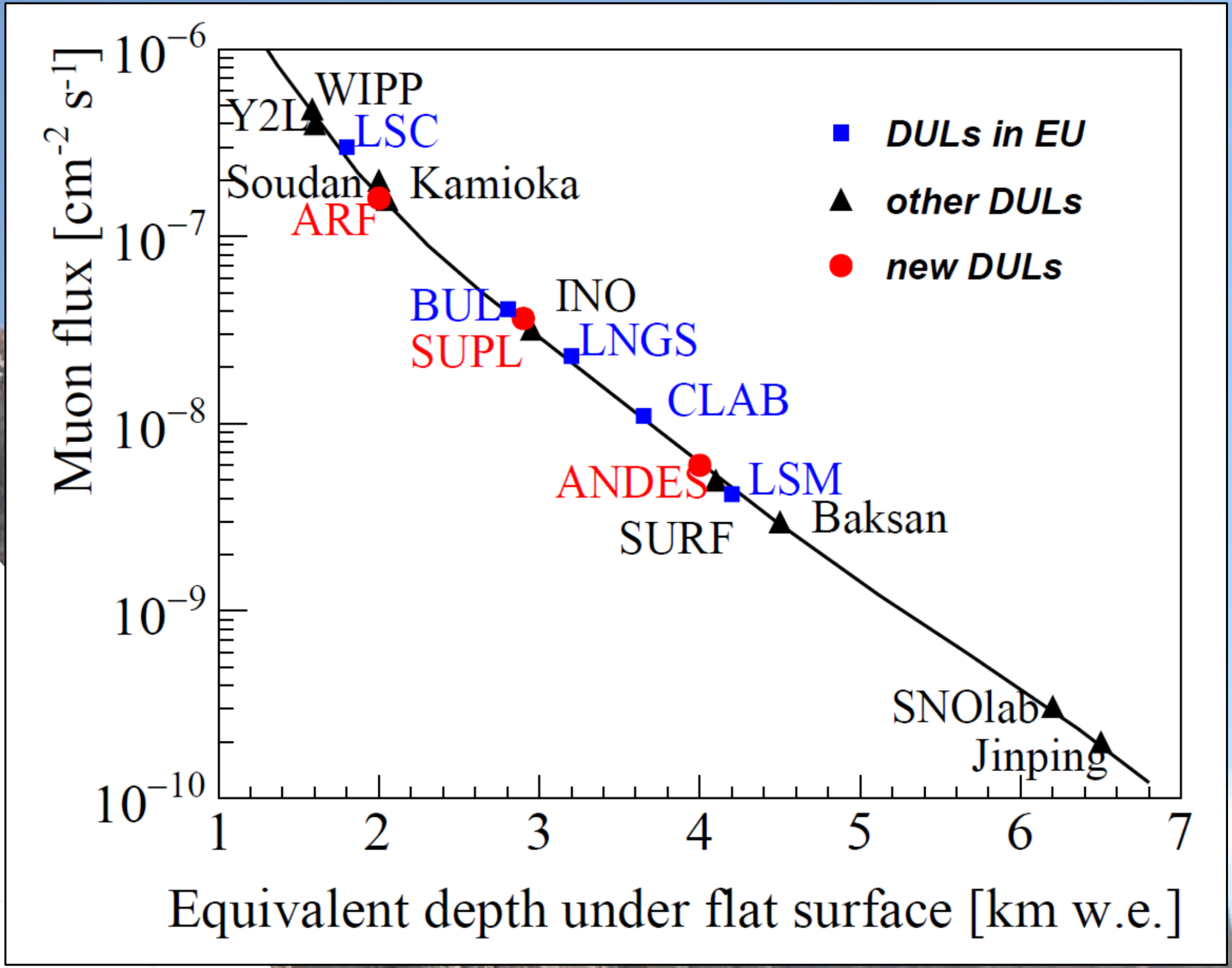
CONCLUSION & OUTLOOK

- Dual phase LXe TPC demonstrated to be the leading technology to exploit WIMPs searches in the high mass region
- The DARWIN experiment will be the ultimate low-background LXe observatory probing a variety of physics channels
- DARWIN will be a challenging detector→ R&D and design on different aspects are ongoing
- XLZD : new consortium for the next generation LXe observatory recently created , grouping XENON+LZ+DARWIN collaborations

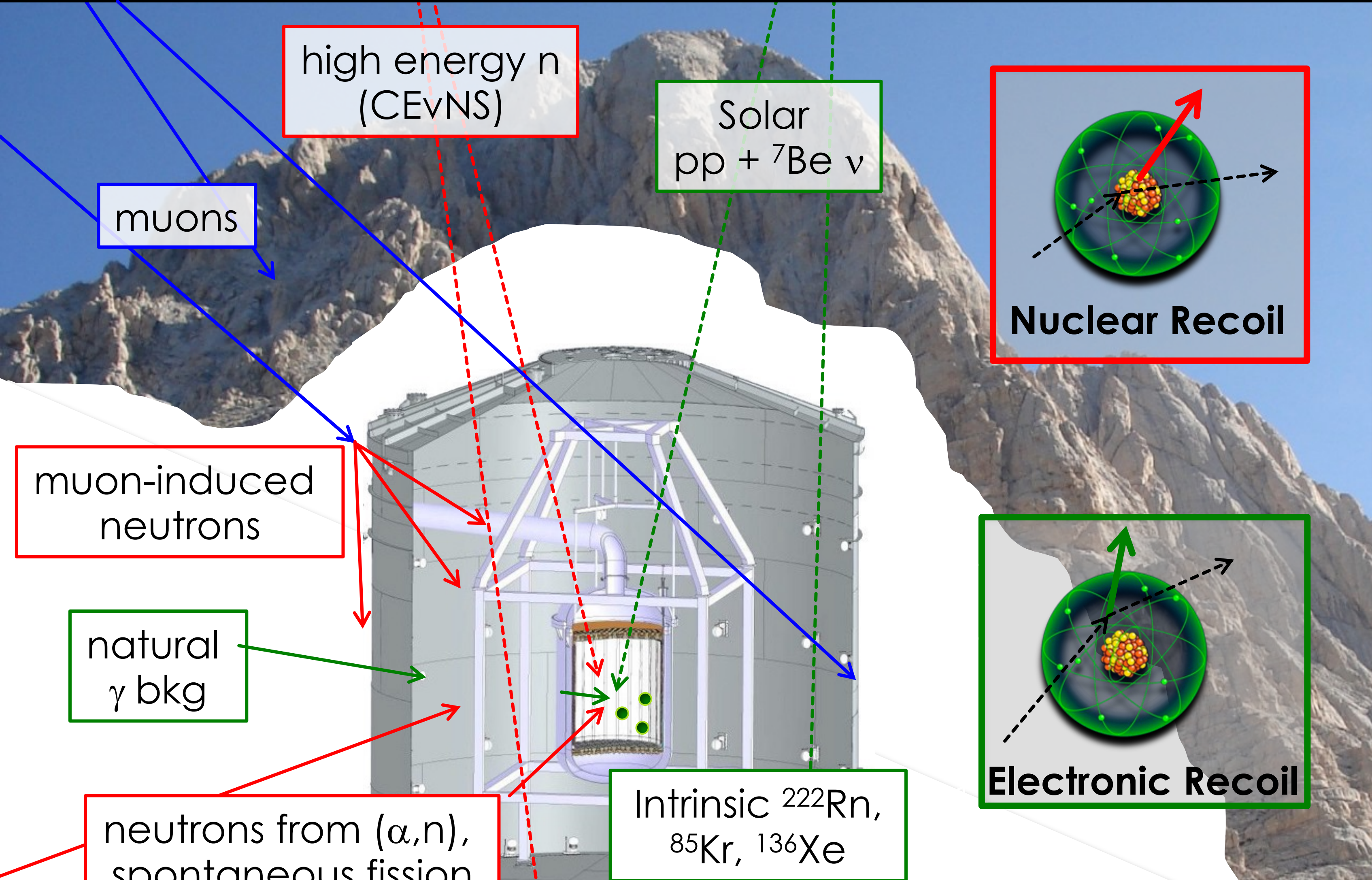
BACKUP

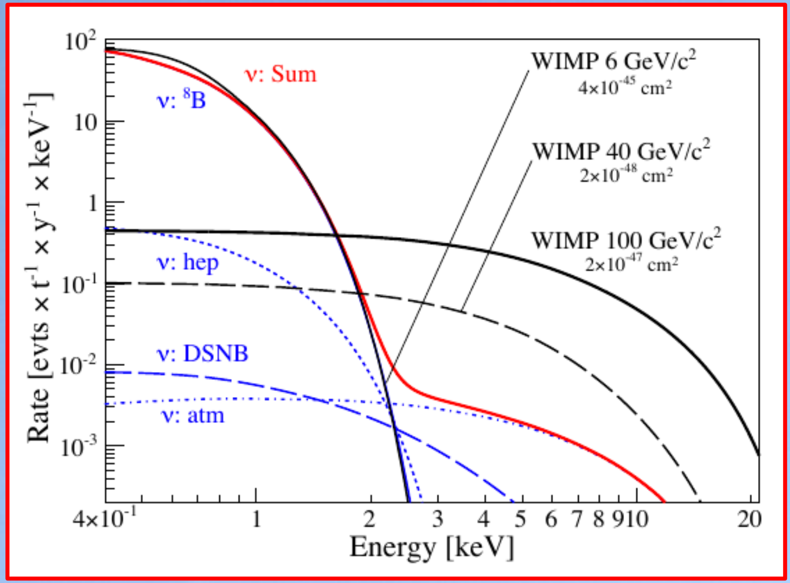
BACKGROUND SOURCES

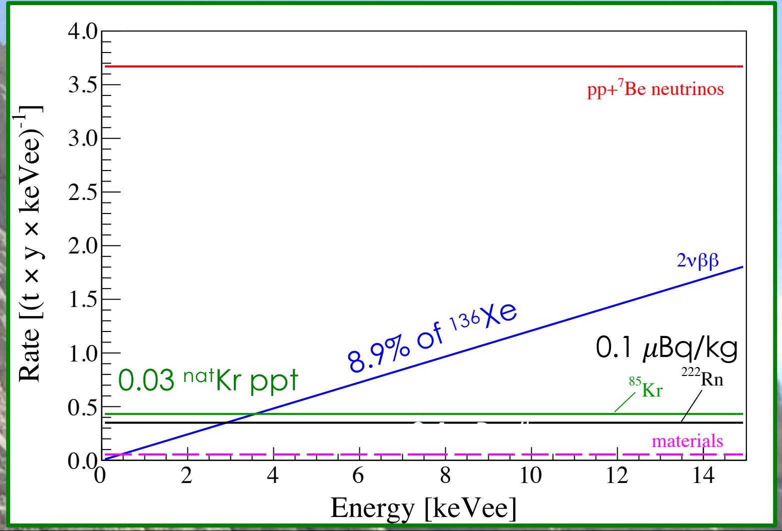




BACKGROUNDS (OR SIGNALS?)

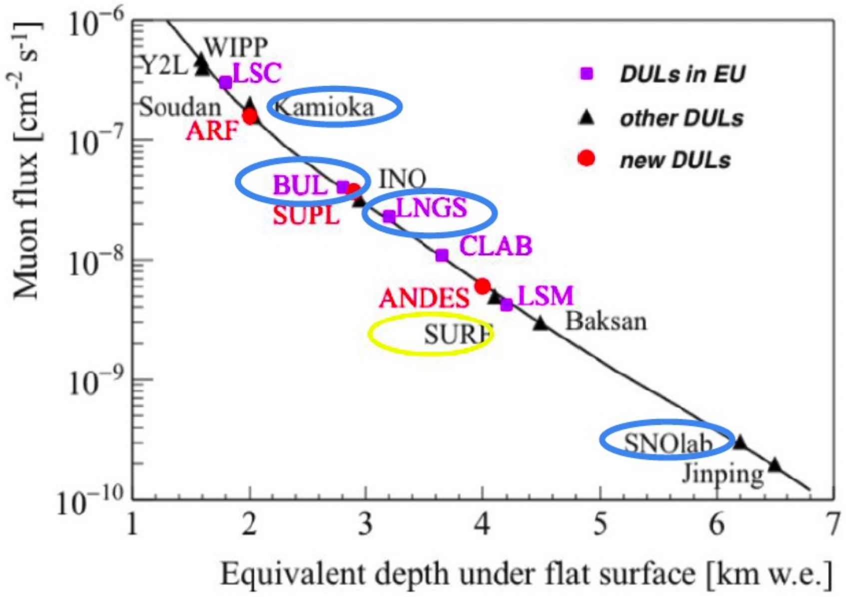






JCAP 10, 016 (2015)

DARWIN / XLZD SITING



- 5 sites are being evaluated for XLZD (SURF, KAMIOKA, BOULBY, SNOLAB & LNGS)
  - Well known sites which demonstrated good supporting capabilities (SC) to carry out the science goals of state-of-the-art rare event search experiments.
- A next generation G3 detector like XLZD (~**3 meter** scale) will require **additional SC**: significant staging space and underground fabrication capabilities (e.g. larger and lower RRCR) than what currently exist in most of these facilities.
  - Required **cavity ~20 to 25 meters in diameter:** Gran Sasso (exist), Boulby (new construction), SURF (new construction or shared with LBNF)
  - UG access is generally a challenge and should be carefully planned

From
Alvine Kamaha (UCLA)

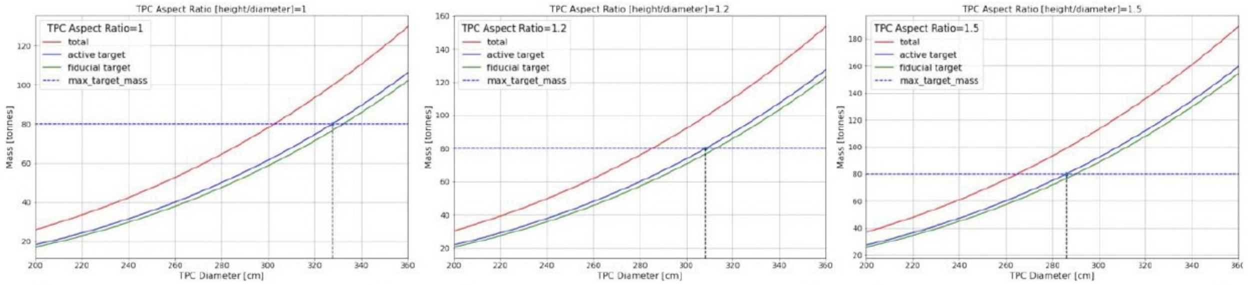
DARWIN R&D : DETECTOR CONCEPTUAL DESIGN & SIZE

Stage approach vs **Monolithic approach**

...to serve as an example

Courtesy of Frédéric Girard (fgirard@physik.uzh.ch)

In either approach, optimum size is **~ 100 tones** in volume (linear dimensions **~3 meter**) → *huge detector!*



AR =1
- TPC Act. Mass = **40 tonnes**:
  → TPC ∅=259 cm & drift=259 cm
- TPC Act. Mass = **60 tonnes**:
  → TPC ∅=297 cm & drift=297 cm
- TPC Act. Mass = **80 tonnes**:
  → TPC ∅=327 cm & drift=327 cm

AR =1.2
- TPC Act. Mass = **40 tonnes**:
  → TPC ∅=244 cm & drift=292 cm
- TPC Act. Mass = **60 tonnes**:
  → TPC ∅=280 cm & drift=336 cm
- TPC Act. Mass = **80 tonnes**:
  → TPC ∅=308 cm & drift=369 cm

AR =1.5
- TPC Act. Mass = **40 tonnes**:
  → TPC ∅=227 cm & drift=340 cm
- TPC Act. Mass = **60 tonnes**:
  → TPC ∅=259 cm & drift=388 cm
- TPC Act. Mass = **80 tonnes**:
  → TPC ∅=286 cm & drift=429 cm

AR: Aspect Ratio

Pancake (AR <1) vs Oval (AR>1)

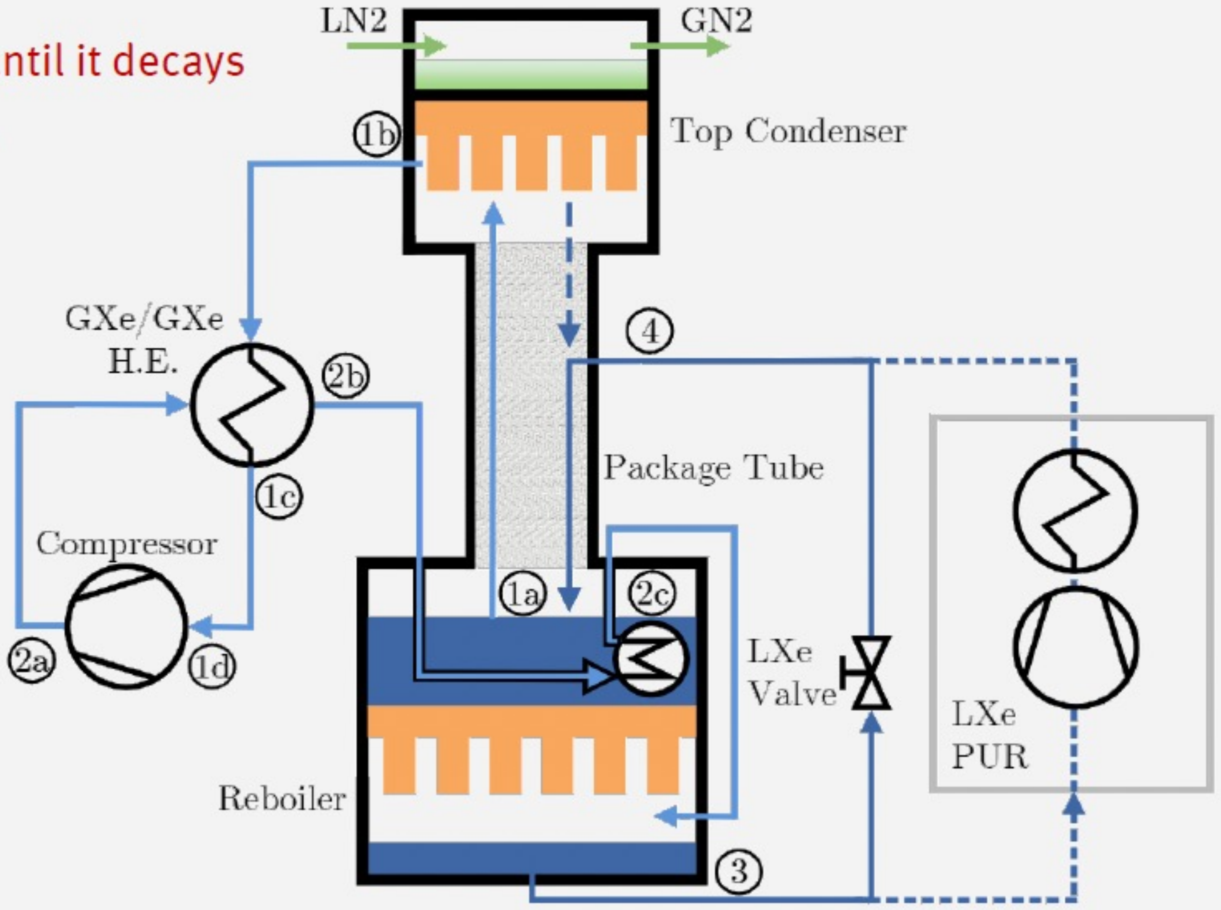
PHOTODETECTOR PERFORMANCE COMPARISON

	PMT	SiPM	Hybrid (SiPM)
PC area/unit	3" = 40 cm^2 2" sq. = 20 cm^2	0.5 - 2 cm^2	~40 cm^2
QE	30-40%	25% goal but seeing variable performance	?
Overall Fill Factor -> effective g1	50% readily achievable -> 10% at 7t active	Details of Si arrangement and Packing	
Bias V & Gain	1.3-1.5 kV / 2-5 10^6	50-60 V	PC 1.5-2 kV SiPM 50-60 V
Sphe Rates @ LXe (165K) Hz/cm^2 DM Threshold	0.11 measured in LZ (Event Acc. Coin. scales as sphe $rate^{Nphe}$ so this is critical to threshold)	100	~1
Radioactive BG DM RoI (γ ER) DM (n NR SS)	Already subdominant component for 10-100 tonne Xe exp.		
Radioactive BG DBD (γ 214Bi)	~10-25% See Detailed Studies	Intrinsically much less, but what is achieved in full package?	Intrinsically much less, but what is achieved in full package?

Radon removal system for XENONnT

High-flow radon removal distillation column

- Radon as less volatile noble gas is trapped in reboiler until it decays
- Radon-depleted GXe extracted from the top condenser
- Target flow: 72 kg/h (200 slpm) ($T < \tau_{Rn}$)
- Reduction factor: 100 between inlet and top
- Enrichment factor: 1000 between inlet and bottom
- Reflux ratio: 0.5
- 1 kW cooling power required at top
- LXe inlet and outlet
- Requires additional ›2 kW cooling power for LXe outlet



Radon removal system for XENONnT

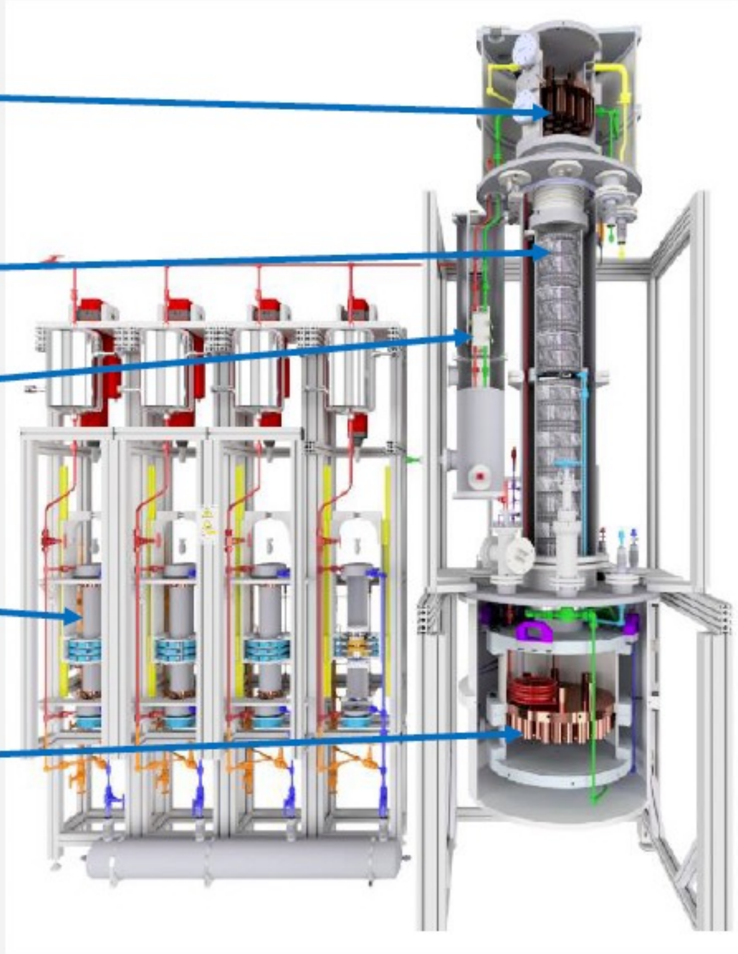
Top Condenser
Custom bath-type LN_2/GXe heat exchanger (arXiv:2203.01026)

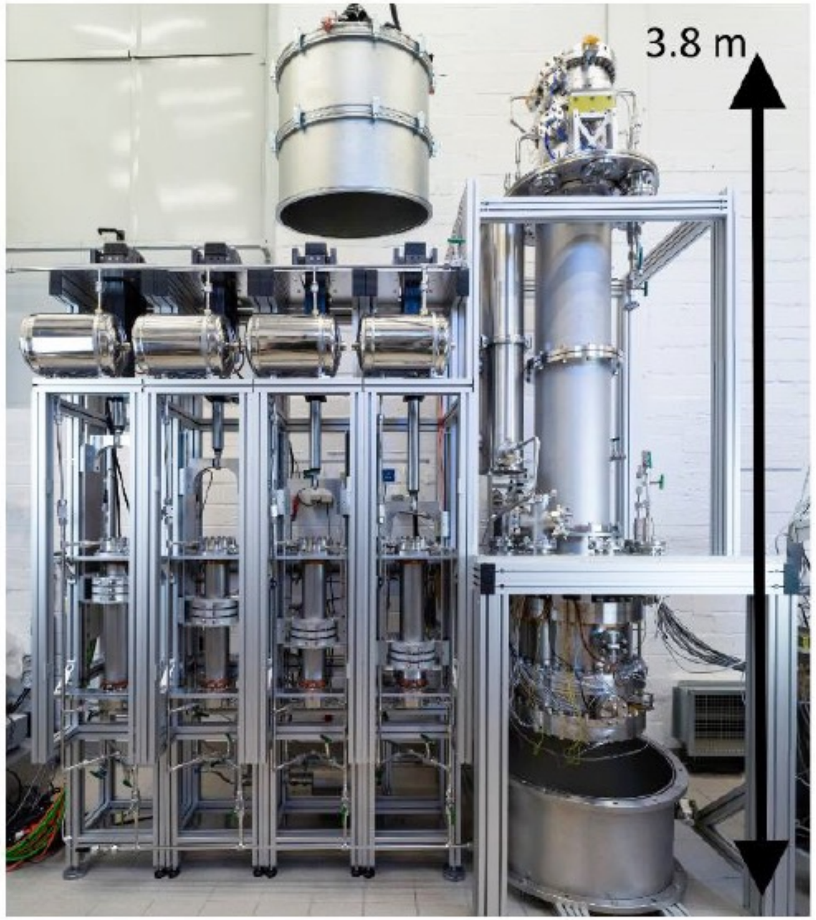
PackageTube
Large-surface package material

Auxiliary
Commercial GXe/GXe heat exchangers

Compressor
Custom four cylinder magnetically-coupled piston pump: JINST 16 (2021) P09011

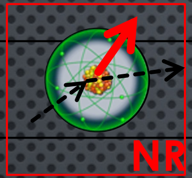
Reboiler
Custom bath-type Xe/Xe heat exchanger JINST 17 (2022) P05037



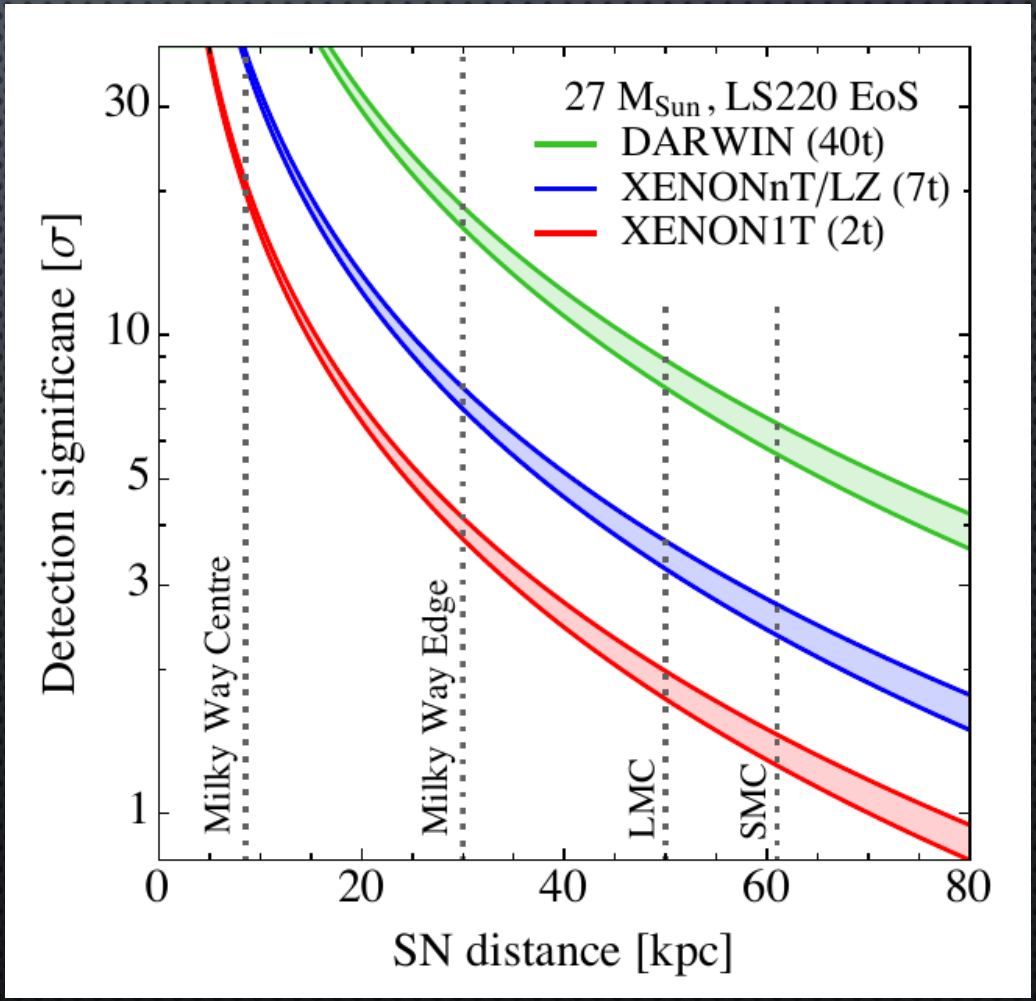


SUPERNOVA NEUTRINOS

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



- Low threshold using proportional scintillation signal (S2) only
- Negligible background due to short burst (~sec)
- 5σ significance to a supernova burst far up to ~65 kpc from Earth
- Detection of all 6 neutrino species
- ~700 events for a $27M_{\odot}$ SN progenitor at 10 kpc



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DARWIN, EPJ C 80, 1133 (2020)

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