DARWIN

Neutrinoless Double Beta Decay with The Low-Background Low-Threshold Observatory

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on behalf of the DARWIN collaboration

APPEC Community Meeting on $0\nu\beta\beta$
London, October 31, 2019

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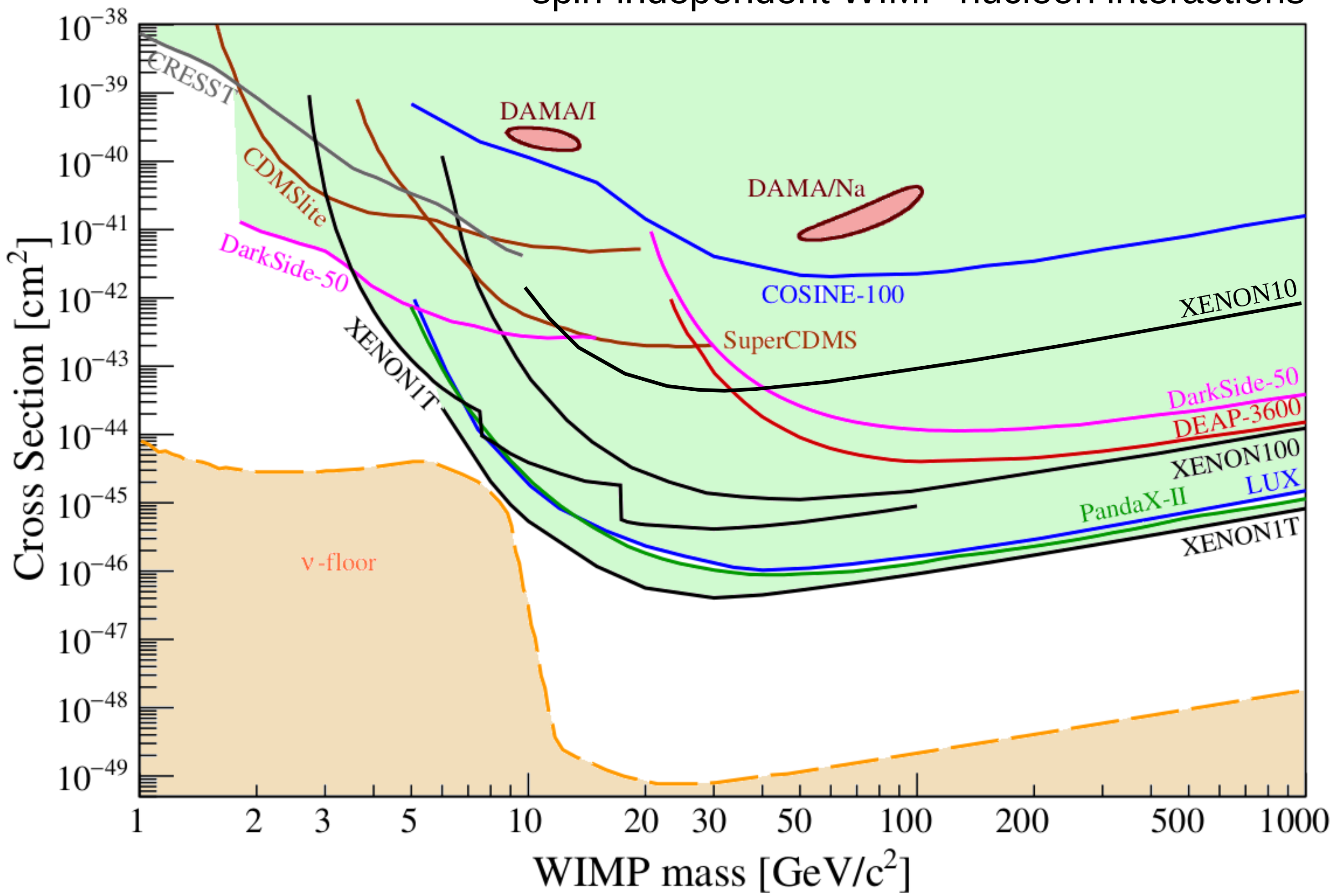
www.darwin-observatory.org

Direct WIMP Detection Today

DARWIN

spin-independent WIMP-nucleon interactions



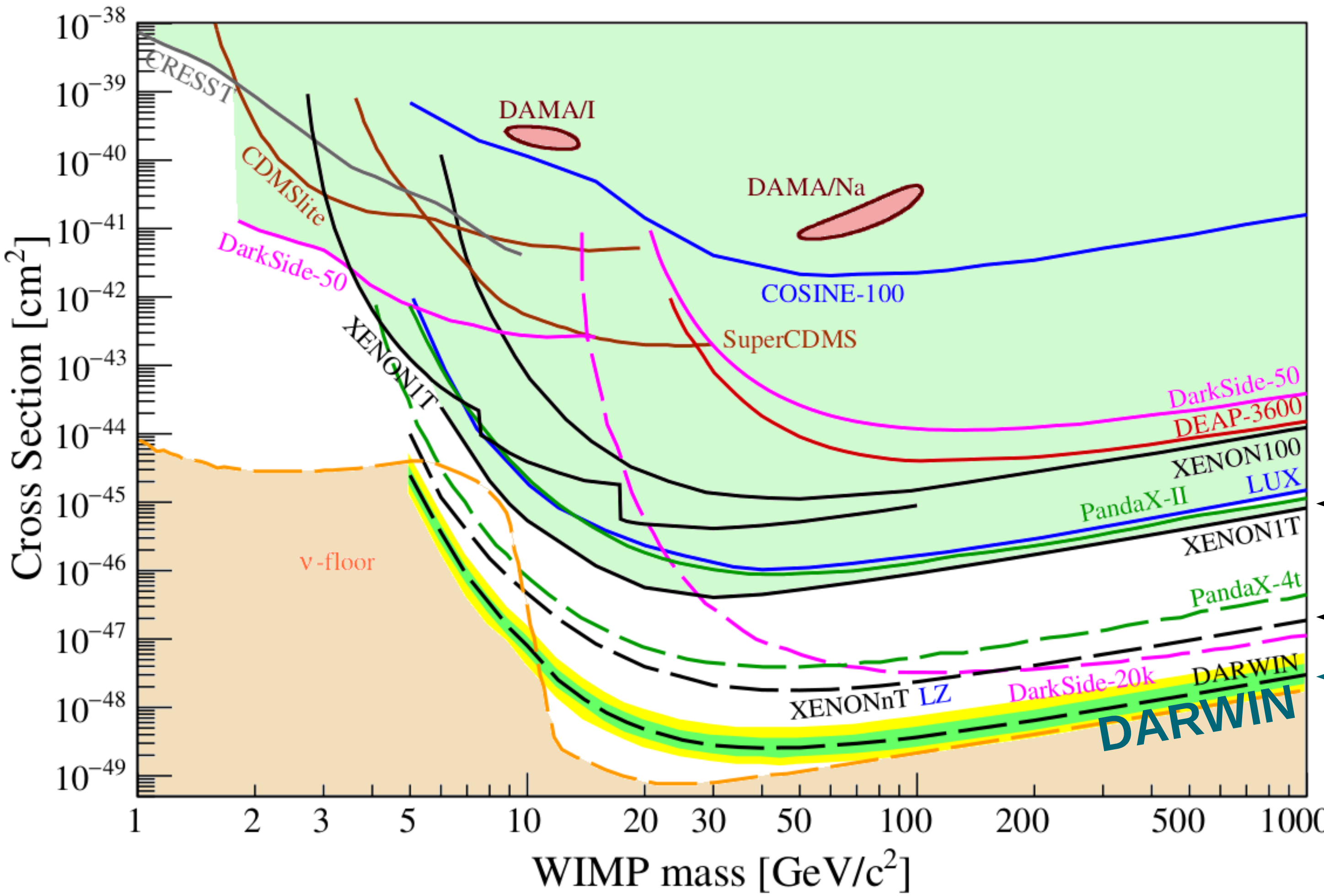
some results are missing...

DARWIN The ultimate WIMP Detector

DARWIN

darwin-observatory.org

LXe-based



DARWIN The ultimate WIMP Detector

LXe-based

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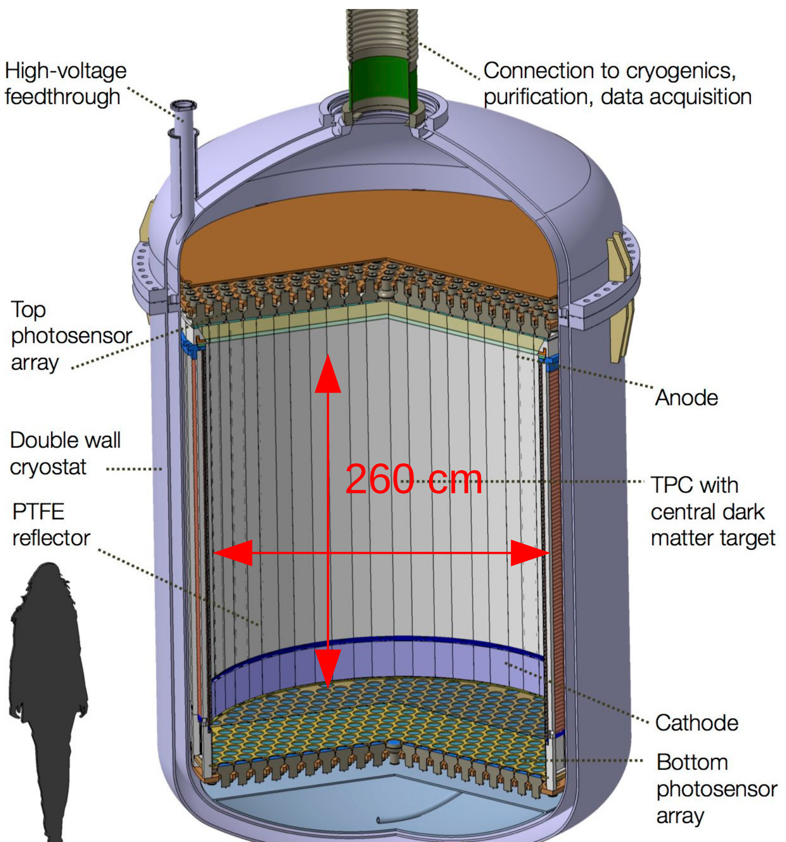
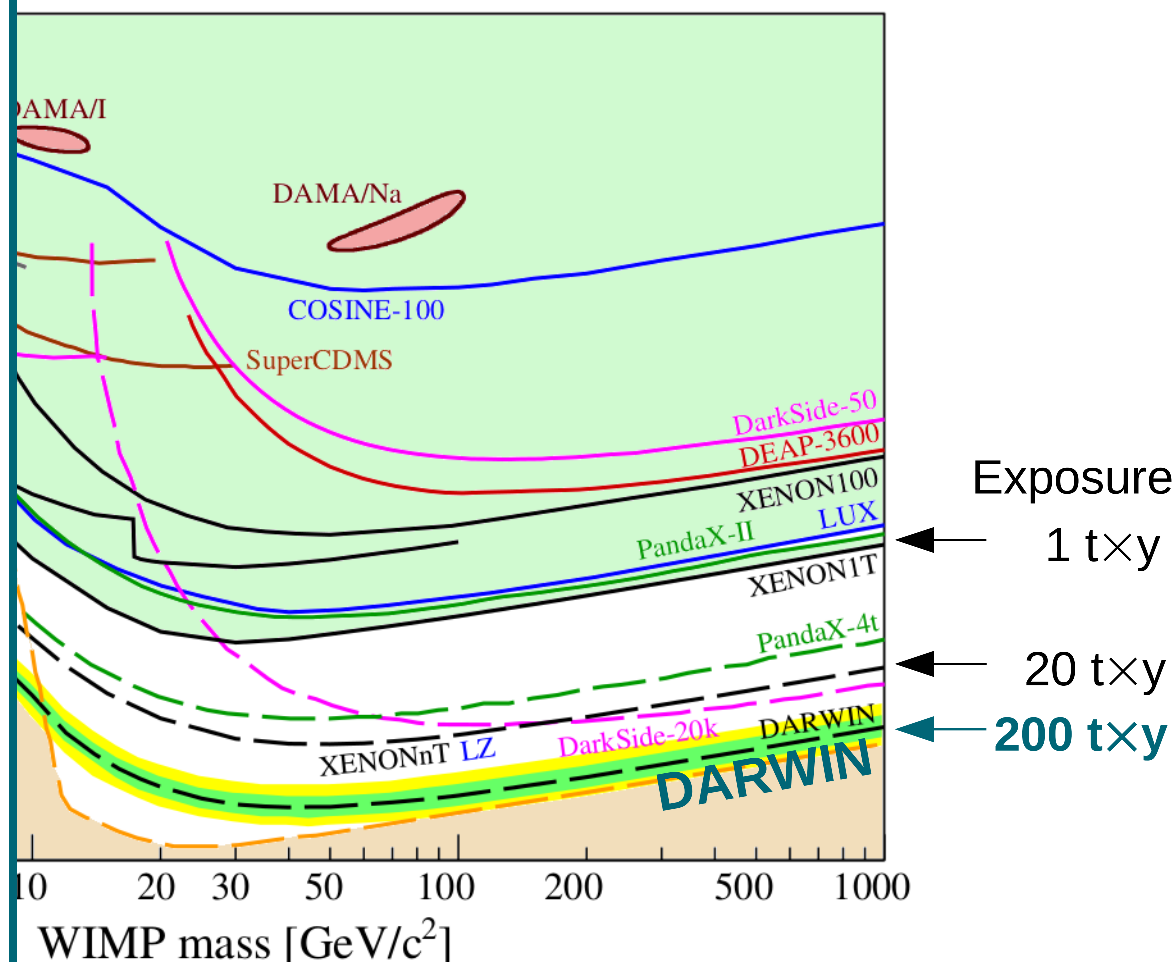
Baseline scenario

~50t total LXe mass

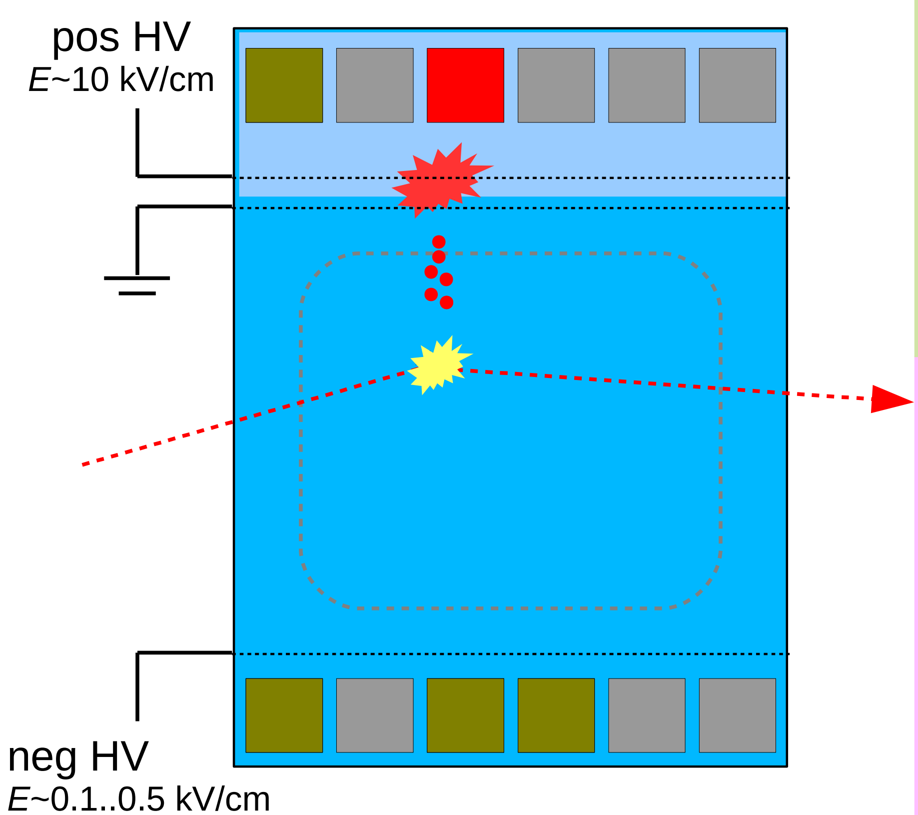
~40 t LXe TPC

~30 t fiducial mass

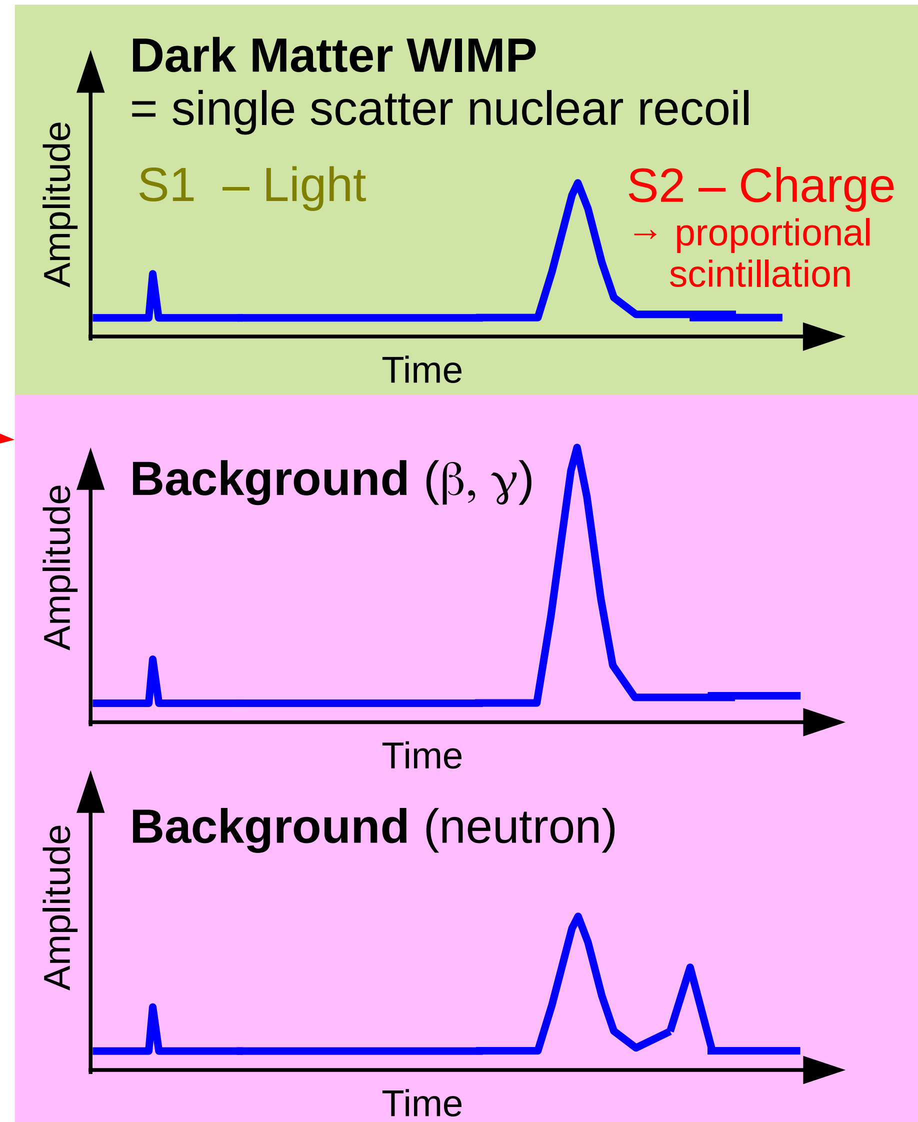




Dual-Phase LXe TPC



TPC = time projection chamber



- 3d position reconstruction
  → target fiducialization
- background rejection

DARWIN Collaboration

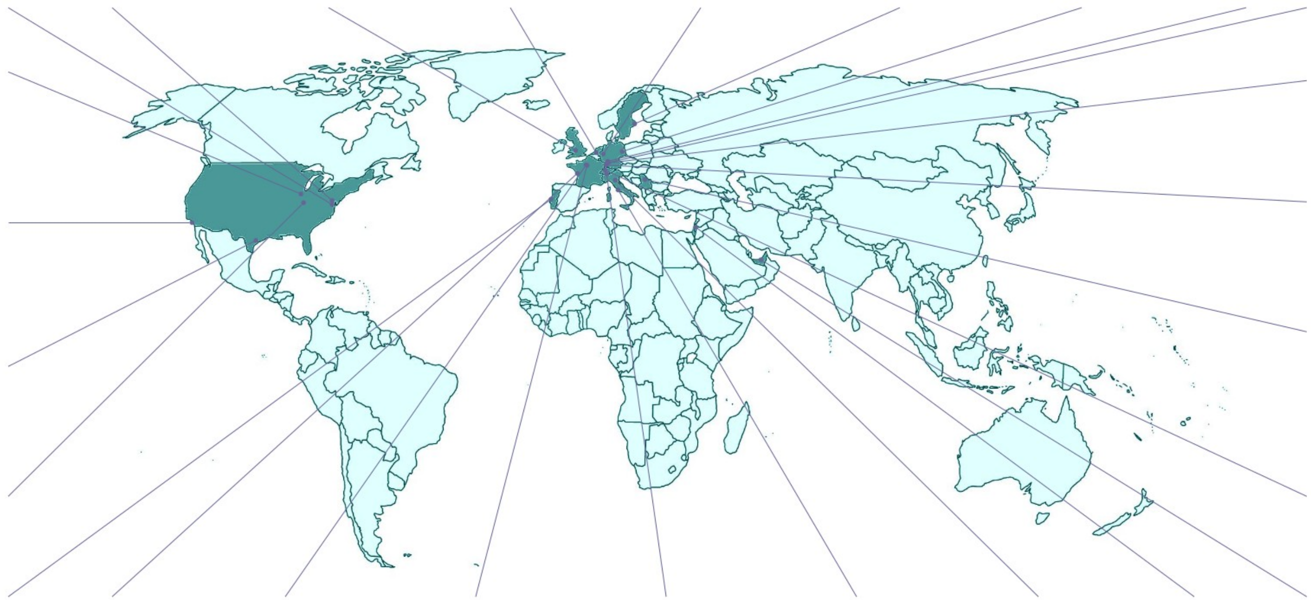
Columbia | RPI | London | Nikhef | Muenster | Stockholm | Dresden | Mainz | MPIK, Heidelberg

Chicago

UCSD

Rice

Purdue



Heidelberg

KIT

Belgrade

Freiburg

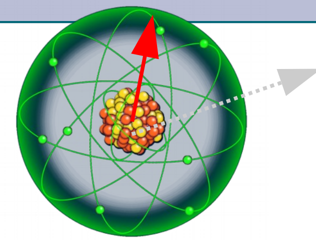
Coimbra | Subatech | LPNHE | LAL | Zurich | LNGS | Bologna | Weizmann | NYUAD

- international collaboration, 26 groups, ~160 scientists → continuously growing
- most XENON plus new groups
- endorsed by several national and international agencies

DARWIN: Science Channels

DARWIN

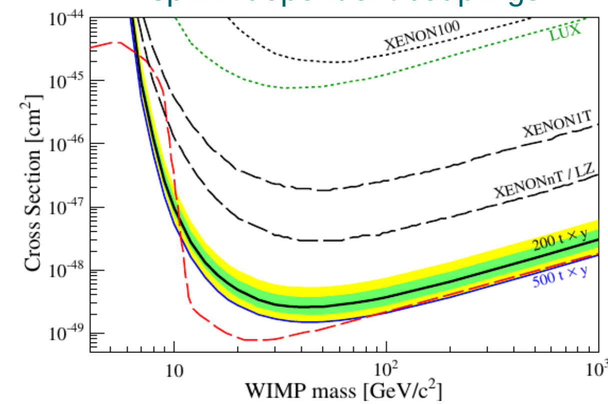
Nuclear Recoil Interactions



WIMP dark matter *JCAP 10, 016 (2015)*

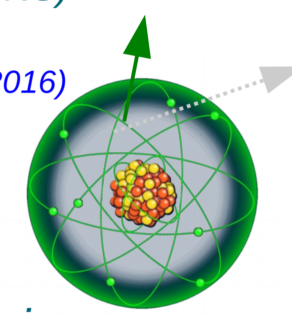
– spin-independent (S1-S2, charge-only)
– spin-dependent *Phys.Dark Univ. 9-10, 51 (2015)*
  → complementary with LHC, indirect det.
– various inelastic models, most EFT couplings

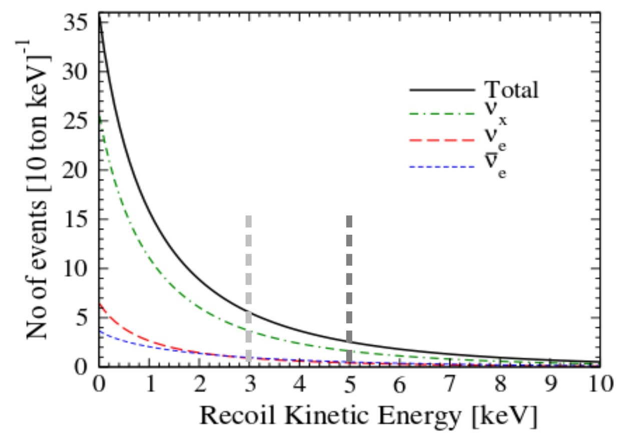
spin-*in*dependent couplings



Coherent neutrino-nucleon scattering (CNNS)

– ^{8}B neutrinos (low E), atmospheric (high E)
– supernova neutrinos *JCAP 1611, 017 (2016)*
PRD 89, 013011 (2014), PRD 94, 103009 (2016)





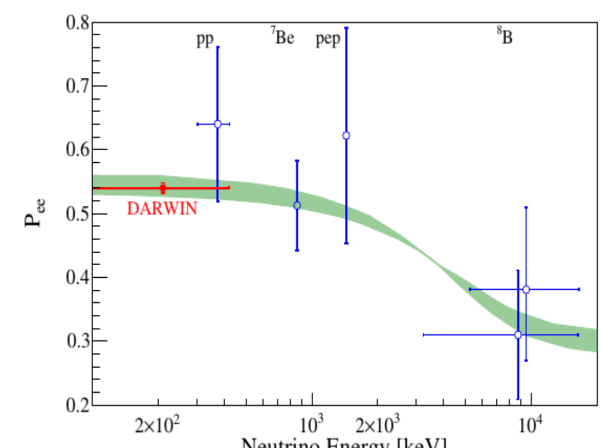
Electronic Recoil Interactions

Non-WIMP dark matter and neutrino physics

– axions, ALPs *JCAP 1611, 017 (2016)*
– sterile neutrinos
– pp, ^{7}Be: precision flux measurements *JCAP 01, 044 (2014)*
– CNO neutrinos with ^{136}Xe-depleted Xe *PRD 99, 043006 (2019)*

Rare nuclear events

– **0νββ (^{136}Xe)**, 0νEC (^{124}Xe), ...
JCAP 01, 044 (2014)



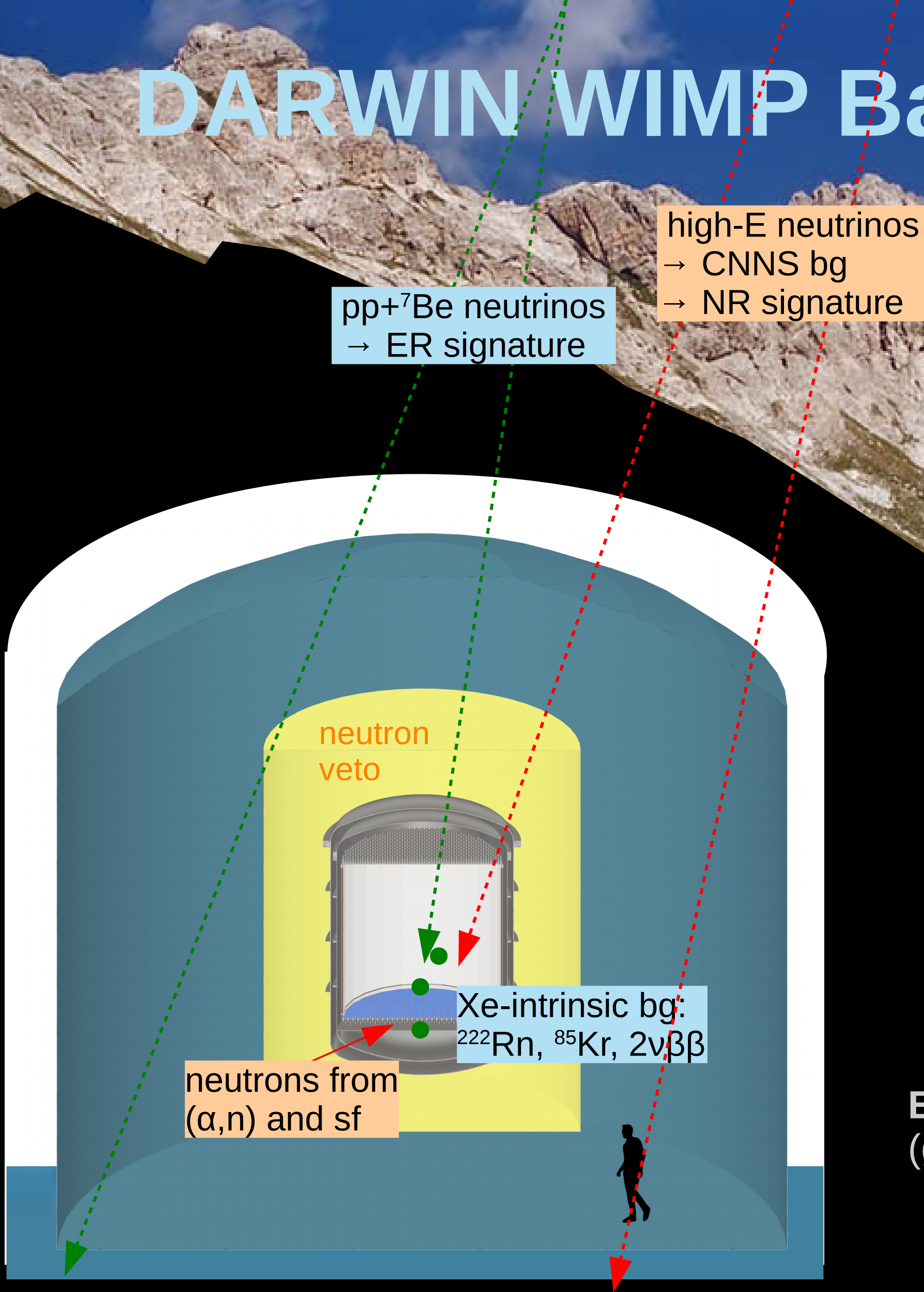
DARWIN WIMP Backgrounds

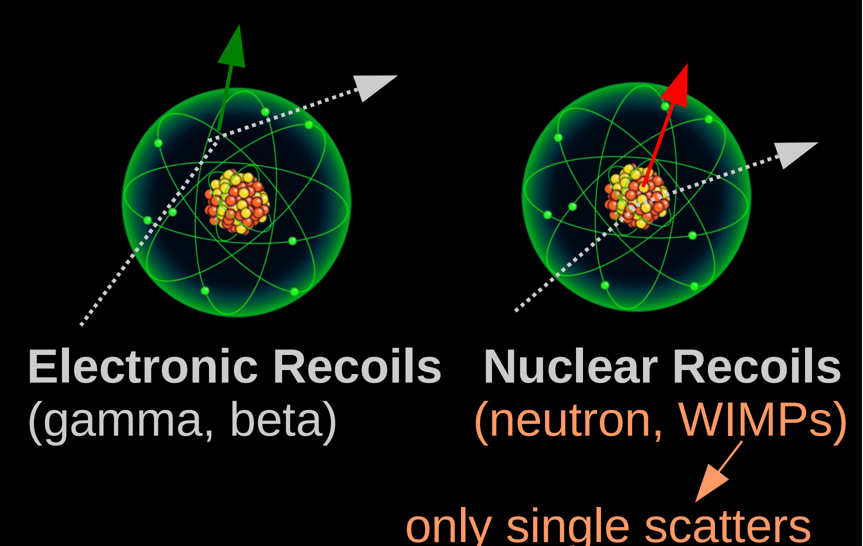
Remaining background sources:

– Neutrinos (→ ERs and NRs)
– Detector materials (→ n)
– Xe-intrinsic isotopes (→ e^-)

(assume negligible
μ-induced background)

JCAP 10, 016 (2015)





Water Shield @ LNGS

Full MC Simulation for 3600 mwe

– site not yet chosen, LoI to LNGS submitted

– external γ, n background irrelevant after >2.5m

– critical: μ-induced neutrons of high energy

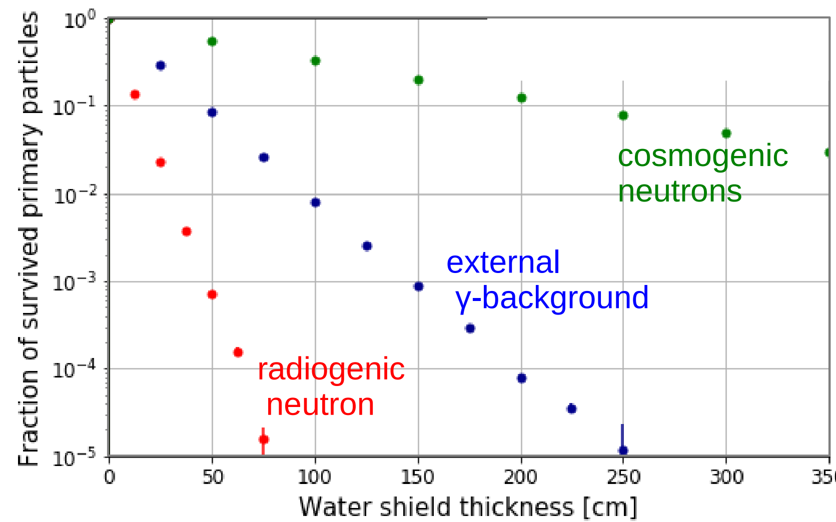
– studied several water shield geometries between XENON and Borexino tank

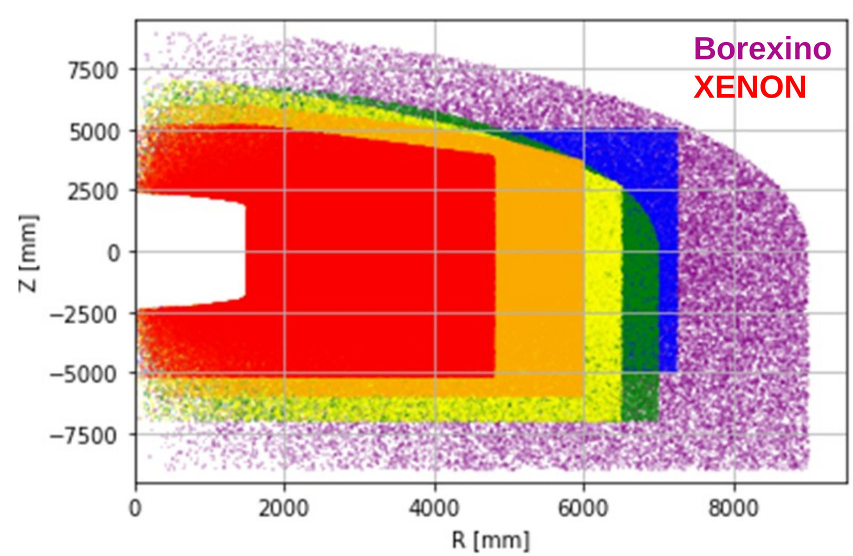
– **12m tank: ~0.4 n/(200 t×y)**
Borexino: <0.05 n/(200 t×y)

– Gd-loaded water further reduces numbers

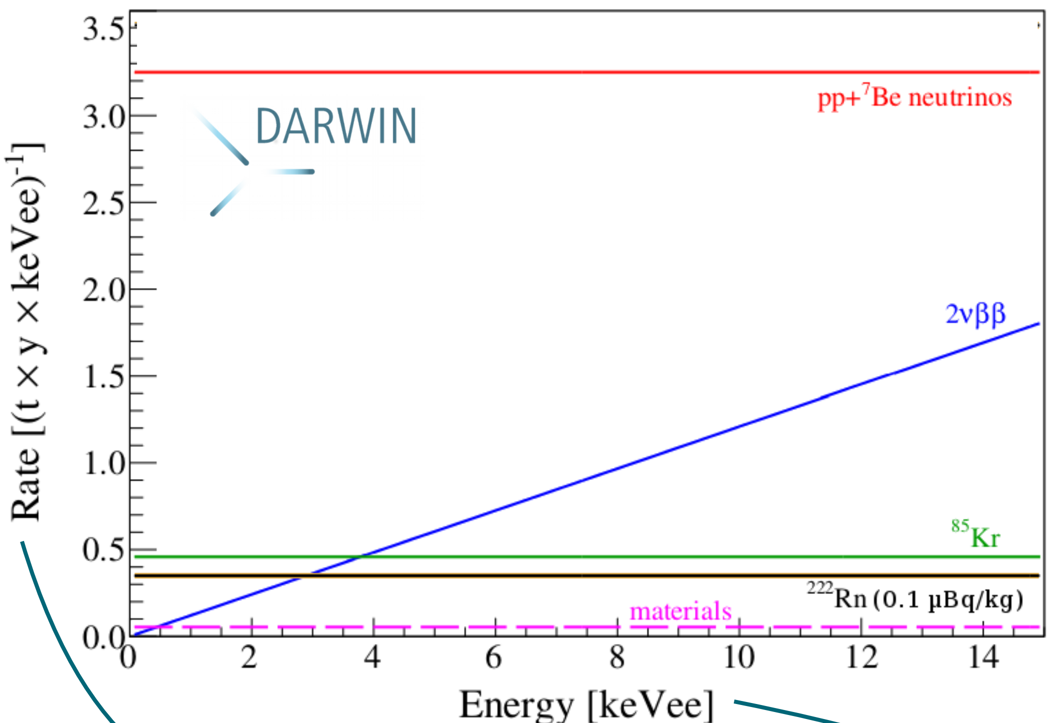
→ **direct radiogenic and cosmogenic background irrelevant for 0νββ**

→ **only muon-induced activation matters**





DARWIN ER Background



- Kr removed by cryogenic distillation *EPJ. C 77, 275 (2017)*
  → DARWIN goal already achieved!
- Rn removed by combination of
  – material production
  – material selection
  – surface treatment
  – detector design
  – cryogenic distrillation *EPJ C 77, 358 (2017)*

DARWIN = A low-background, low-threshold observatory for astroparticle physics

0νββ with DARWIN?!!!

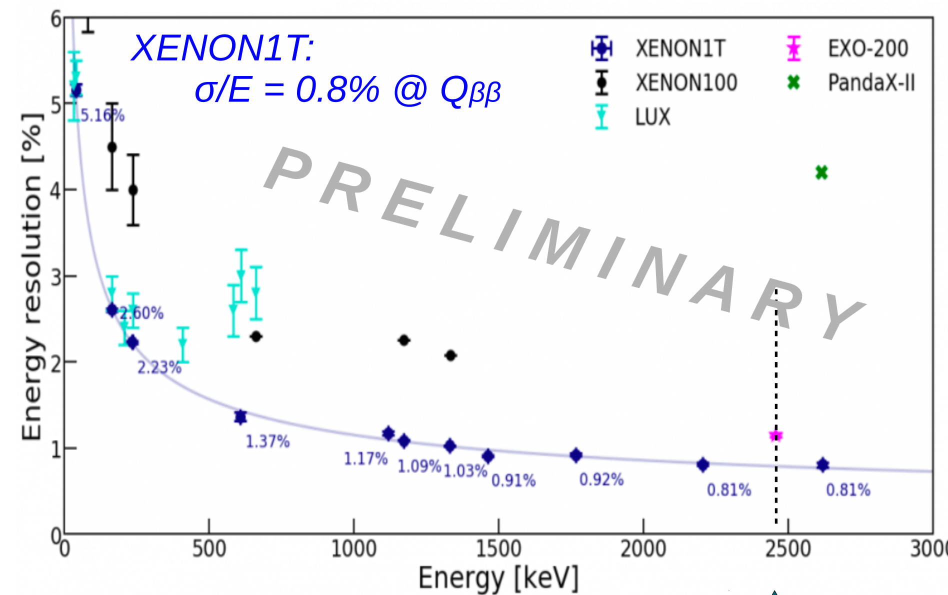
The 40t LXe target contains **3.5t of ^{136}Xe** without any expensive enrichment.

immediate advantages:

– get 0νββ detector „for free“

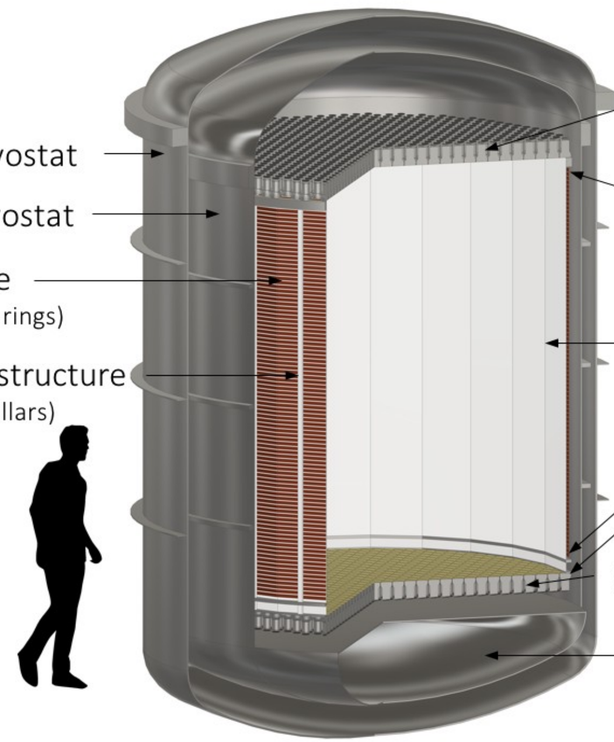
– fiducialization is much „cheaper“

– excellent *E*-resolution demonstrated by XENON1T



Sensitivity Studies

DARWIN



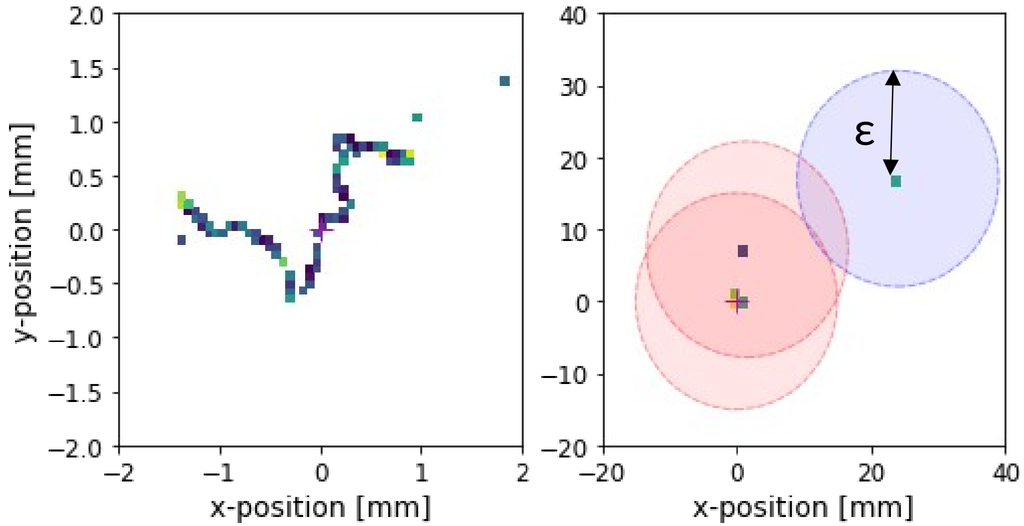
Element	Material	Mass
Outer Cryostat	Ti	3.04 t
Inner Cryostat	Ti	2.10 t
Bottom Pressure Vessel	Ti	0.38 t
LXe instrumented Target	LXe	39.3 t
LXe Buffer outside the TPC	LXe	9.00 t
LXe around Pressure Vessel	LXe	0.27 t
GXe in top dome + TPC top	GXe	30 kg
TPC Reflector (3mm thickness)	PTFE	146 kg
Structural support Pillars (24 units)	PTFE	84 kg
Electrode Frames	Ti	120 kg
Field Shaping Rings (92 units)	Copper	680 kg
Photosensor Arrays (2 disks):		
Disk structural support	Copper	520 kg
Reflector + sliding panels	PTFE	70 kg
Photosensors: 3" PMTs (1910 Units)	PMT	363 kg
Sensor Electronics (1910 Units)	composite	5.7 kg

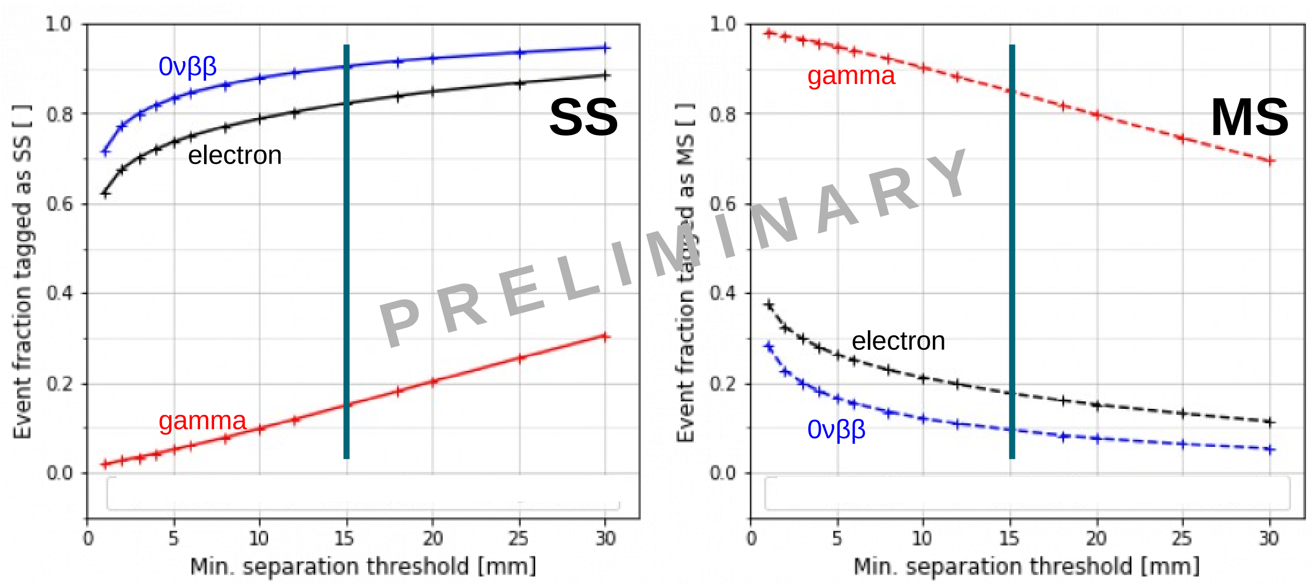
- Geant4 model with reasonable level of details
- Inputs: published materials from XENON1T (PTFE, Cu, R11410-21 PMTs+electronics)
  LZ (Ti + cosmogenic activation of ^{44}Ti)

→ **room for improvement**
– better materials (no optimization for $0\nu\beta\beta$)
– upper limits considered as detection

Event Topology

- treat 0νββ as single-site (SS) event
  → not true if e^- emits Bremsstrahlung
  → event misidentified as MS and rejected
- gamma background mostly multi-site (MS)
- assume ε=15 mm for SS/MS identification
  → optimum probably smaller (especially in z)
  → diffusion limited → room for improvement



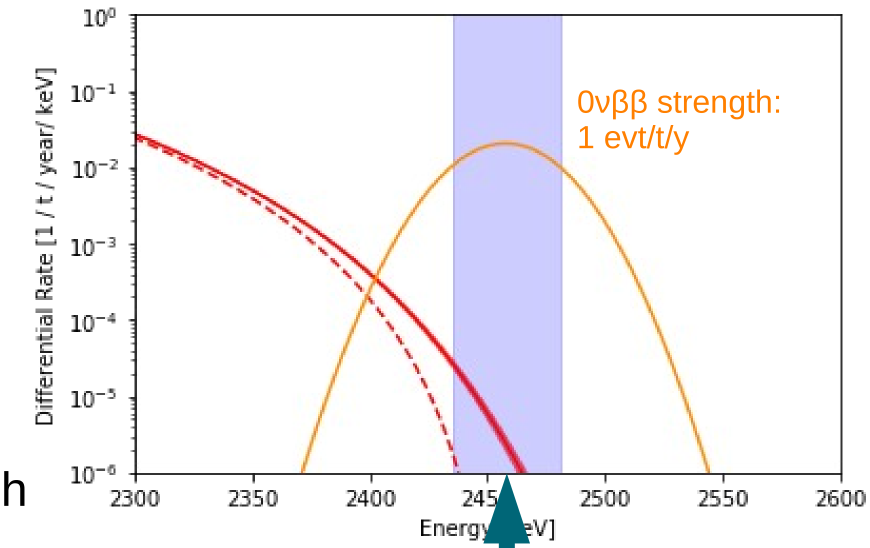


Intrinsic Backgrounds

DARWIN

2νββ: subdominant due to 0.8% E-resolution

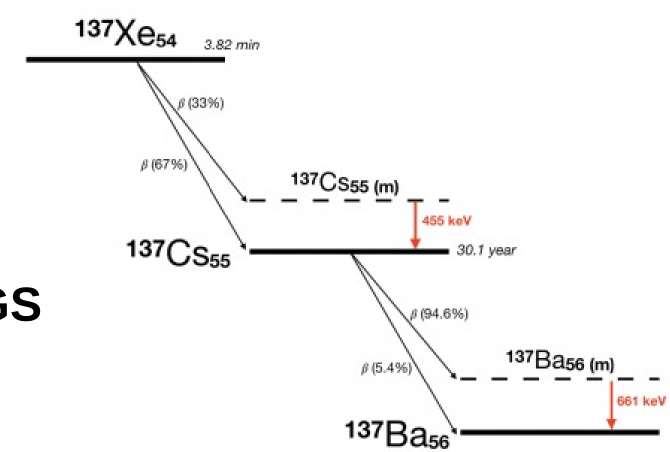
^{8}B neutrinos: irreducible, flat background
11% of intrinsic background at $Q_{\beta\beta}$



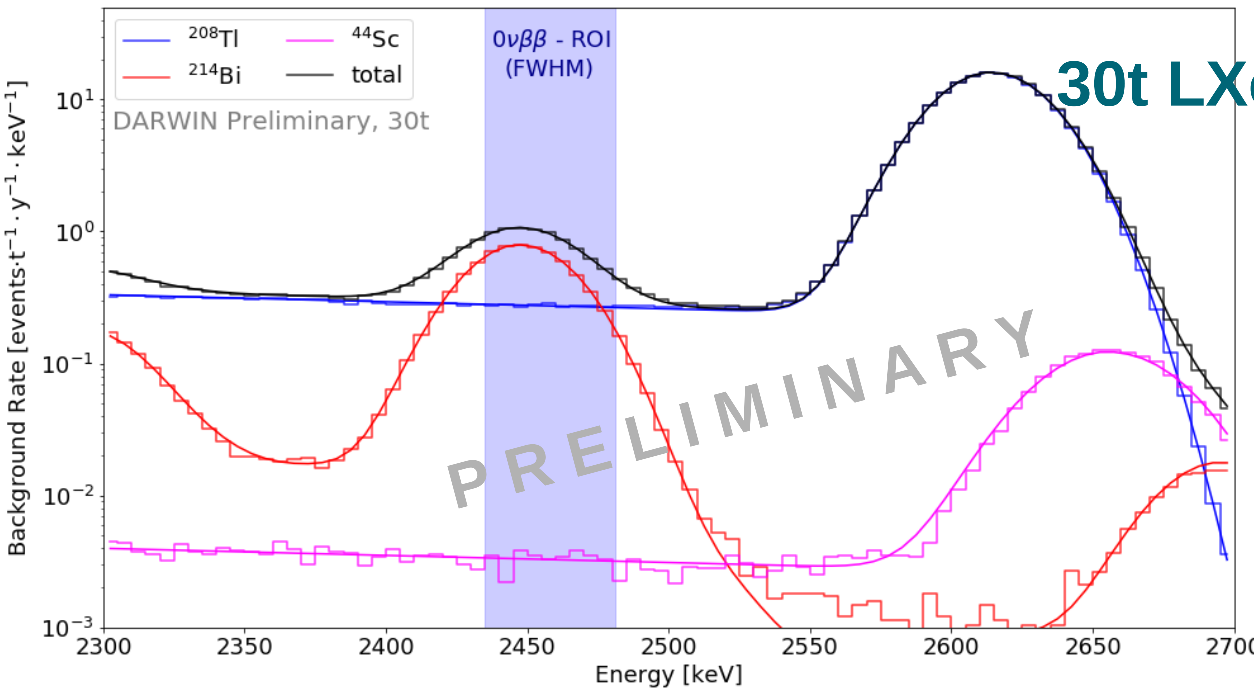
ROI = 1 FWHM
= 2435-2481 keV

^{222}Rn in LXe: reduced to 0.1 µBq/kg for WIMP search
„naked“ ^{214}Bi beta-decay (BR~20%)
→ some SS/MS misidentification
→ 99.8% suppression by BiPo tagging

^{137}Xe decay: production via ^{136}Xe + n → ^{137}Xe → e^{-} + ^{137}Cs
production dominated by µ-induced neutrons
τ=3.8 min → hard to veto
„naked“ beta-decay: BR=67%
→ **if no further suppression, this is the dominating intrinstic background at LNGS**



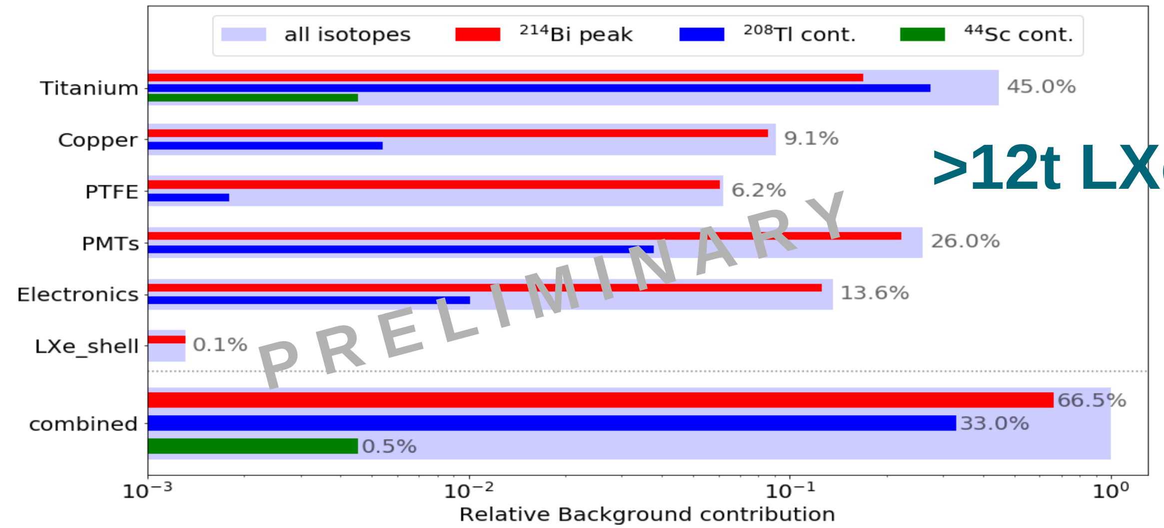
External (Material) Background



30t LXe

External Background around $Q_{\beta\beta}$

External Background Sources

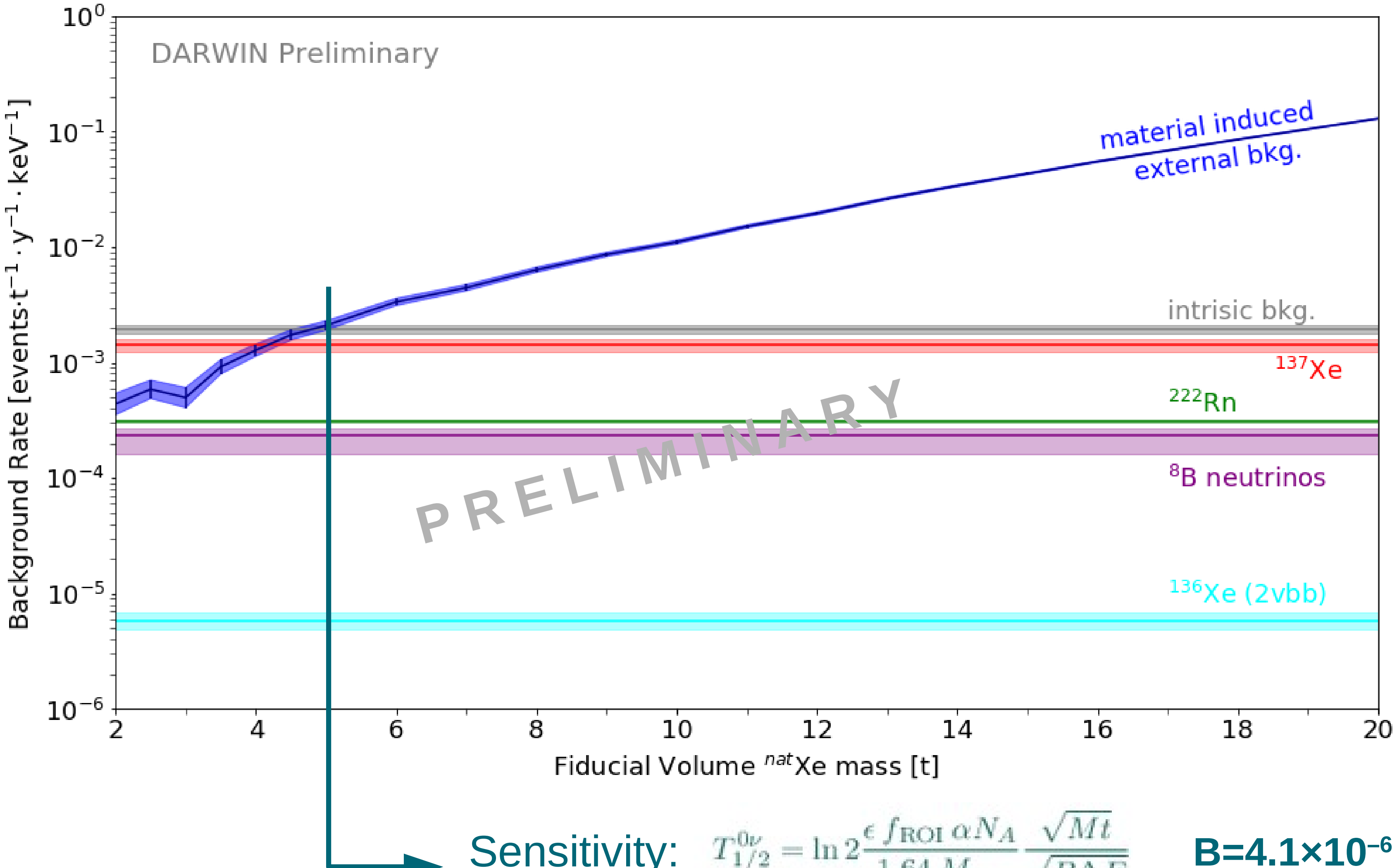


>12t LXe

→ **Optimize Fiducialization to optimize Background**

Background Optimization

DARWIN



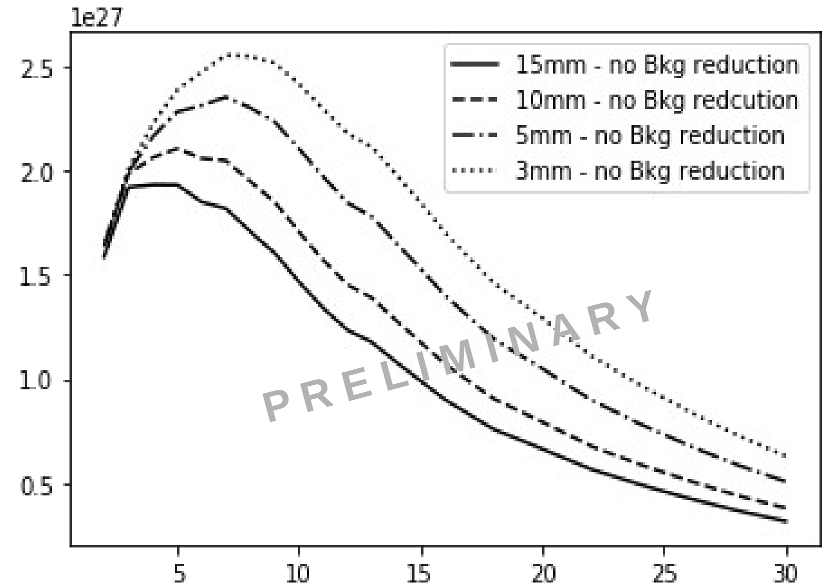
Sensitivity: $T^{0\nu}_{1/2} = \ln 2 \frac{\epsilon\, f_{\mathrm{ROI}}\, \alpha N_A}{1.64\, M_{Xe}} \frac{\sqrt{Mt}}{\sqrt{B\Delta E}}$ **B=4.1×10^{-6} cts/kg/y/keV**

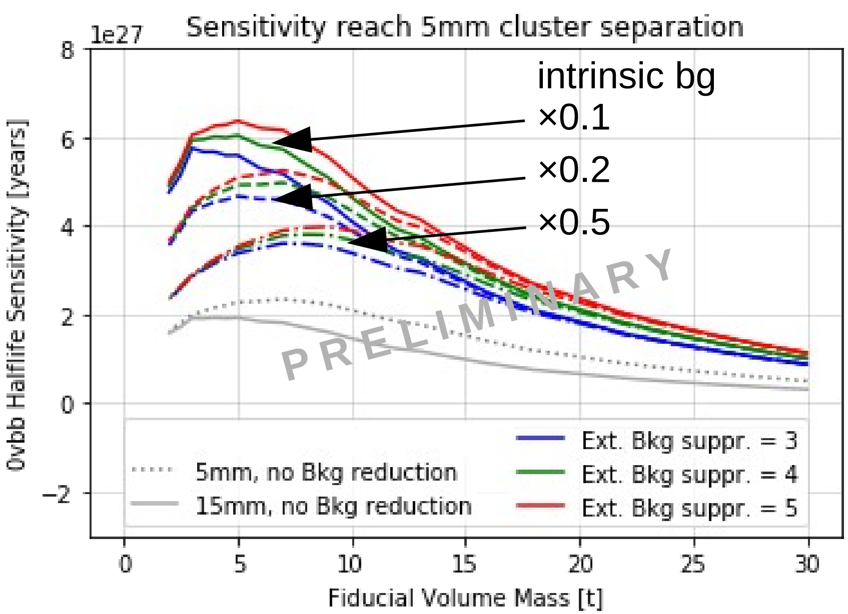
$T_{1/2}$ > 2 × 10^{27} y (4.4 t×y ^{136}Xe exposure)

DARWIN Sensitivity Reach

- current study not „optimized“ for 0νββ
- pre-achieved radioactivity levels

- What could possibly be improved?
  – top array made of SiPM
    → improve xy-resolution, reduce ε
    → factor 2 reduction of PMT background
  – identify cleaner materials
    → low-background R11410 PMTs
    → EXO-type PTFE
    → better cryostat, electronics
    → suppression of external bg
  – reduction of intrinsic background
    → veto for ^{137}Xe? (maybe factor ~2?)
    → deeper lab (almost factor 10 possible)
  – improve energy reconstruction
    → mitigate detector effects
    → machine learning techniques





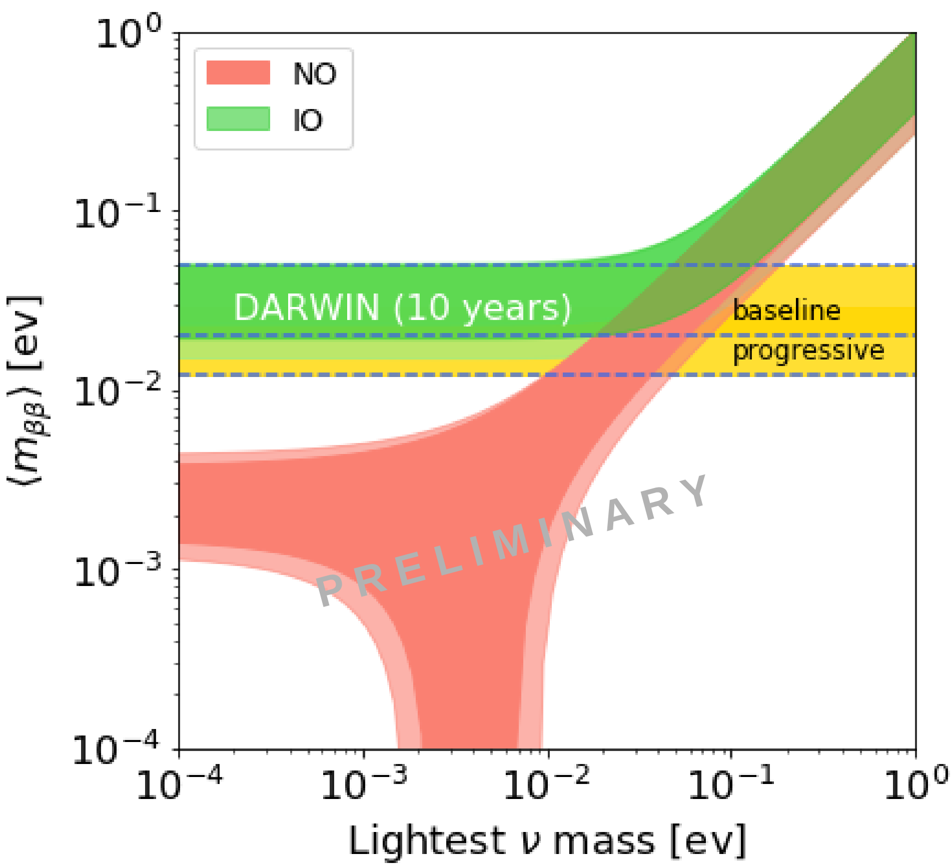
Exciting 0νββ Opportunities

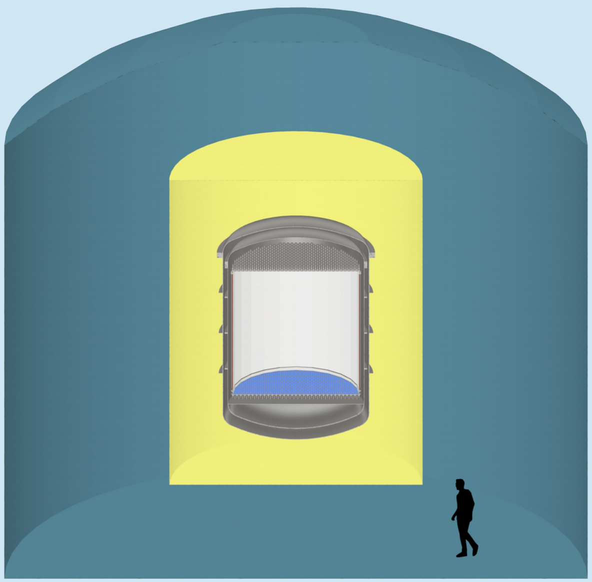
DARWIN: much more than

The ultimate Dark Matter Detector

→ **The low-background, low-threshold Astroparticle Physics Observatory**

with competitive 0νββ-sensitivity





- **DARWIN can be done at LNGS**
  → need ≥12m water shield
- Timeline: R&D and construction parallel to XENONnT data taking