DARWIN observatory

– Neutrino physics with an ultimate Dark Matter detector

Andrii TERLIUK
on behalf of the DARWIN collaboration

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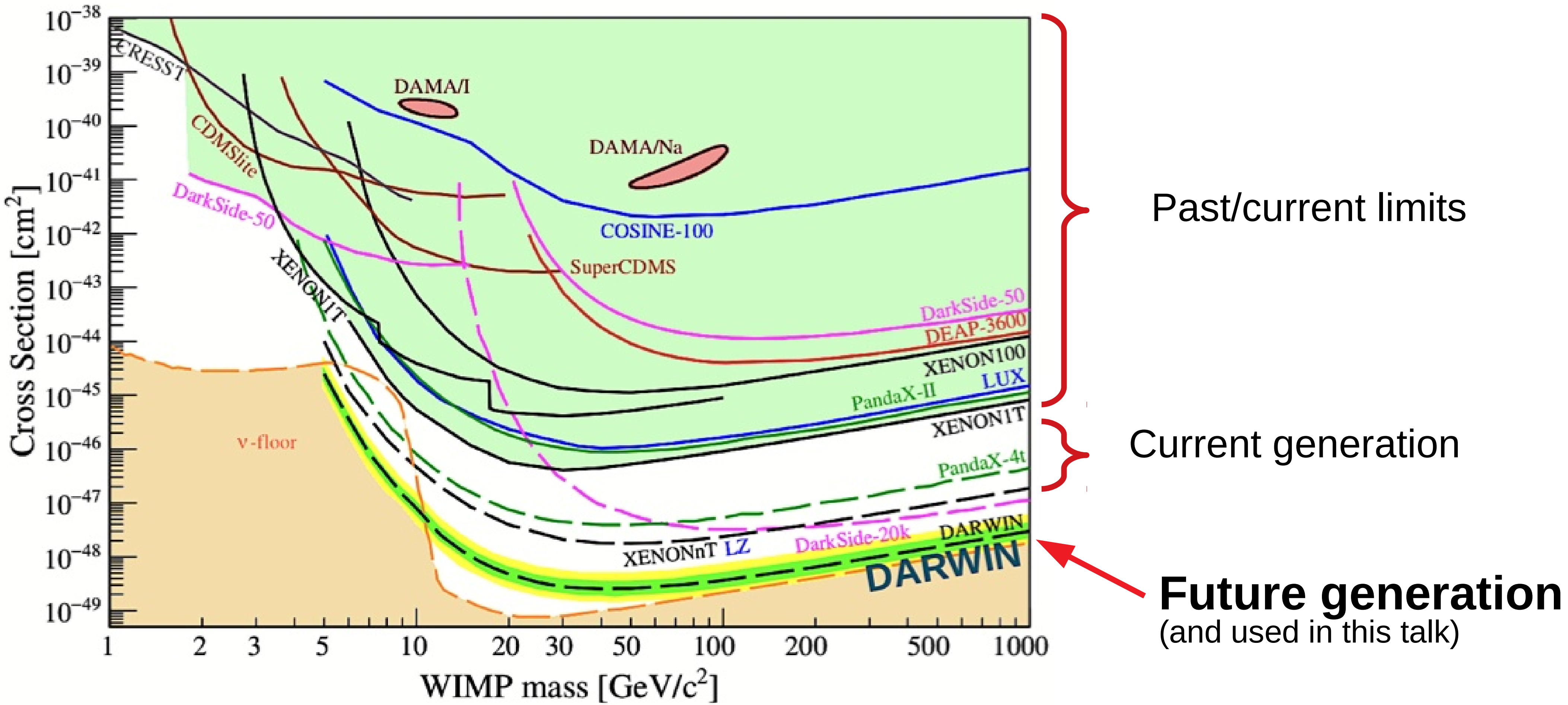
NeuTel 2021

DARWIN

UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

A hunt for Dark Matter

- Excellent progress in Dark Matter search in the last decades



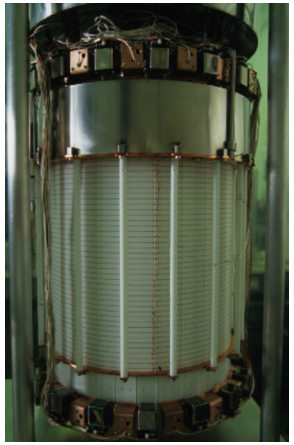
- Good Dark Matter detector makes an excellent neutrino experiment!

Evolution of XENON detectors

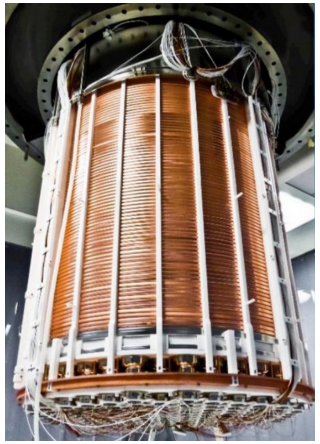
- Consistent generational improvements
  - Mass, size, cleanlinesses, sensitivity...

Past

Past



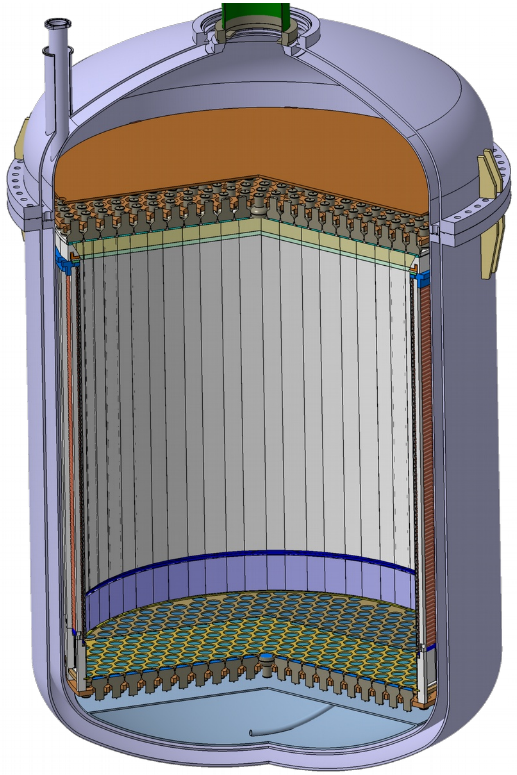
Past



Present

~~Future~~

Future

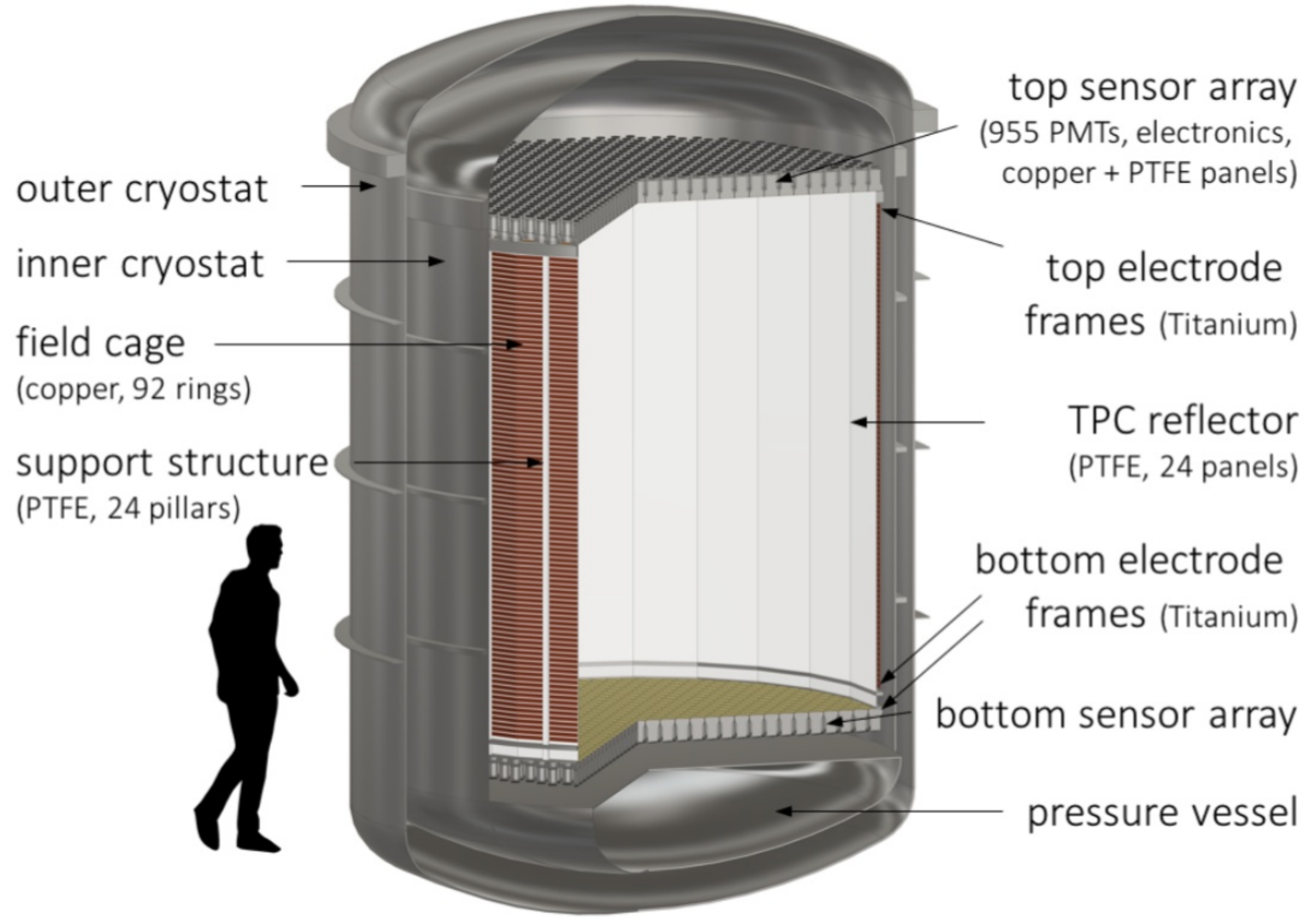


	XENON10	XENON100	XENON1T	XENONnT	DARWIN
Height	15 cm	30 cm	96 cm	148 cm	**2.6 m**
Diameter	20 cm	30 cm	97 cm	133 cm	**2.6 m**
Total mass	25 kg	161 kg	3.2 tons	8.3 tons	**50 tons**
Active mass	14 kg	62 kg	2.0 tons	5.9 tons	**40 tons**

What is DARWIN observatory?

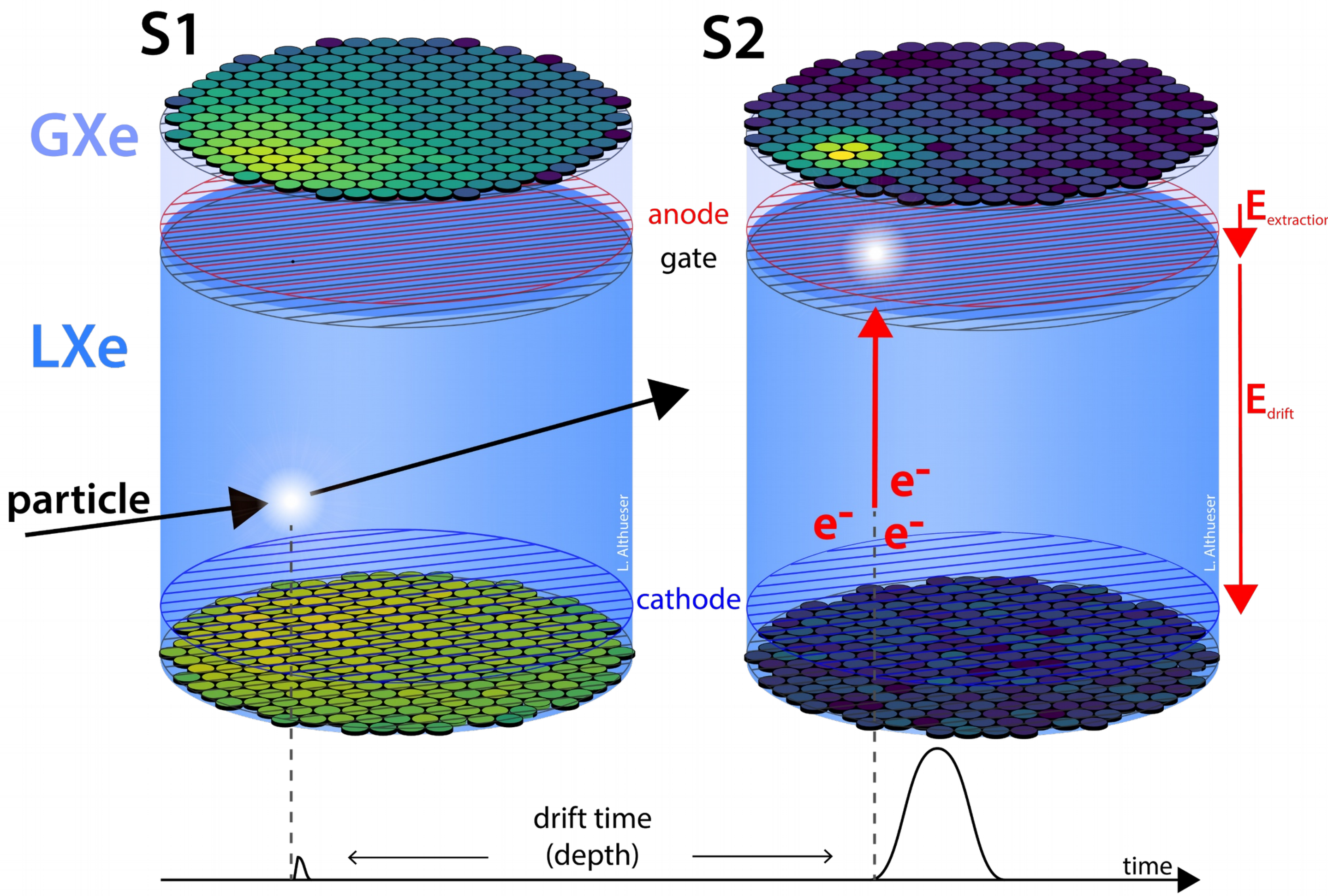
- **Time-projection chamber**
  - 40 “active” tons of LXe
  - 2.6 m in diameter and height
  - Baseline: 955+955 3” PMTs
  - PTFE reflectors for efficiency

- **Goal – low background**
  - Deep underground (3500 m.w.e @ LNGS, other labs in consideration)
  - Ultra-low background cryostat
  - Outer neutron and muon veto



- Truly multi-purpose rare-event search experiment!

Dual phase TPC



- Complete reconstruction of 3D events
- Good energy resolution
- Electron/nuclear recoil discrimination based on S2/S1 size

Physics prospects with DARWIN

Direct search for Dark Matter

Solar Axions

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

Galactic ALPs

Low energy solar neutrinos
(ν-e elastic scattering)

Bosonic SuperWIMPS

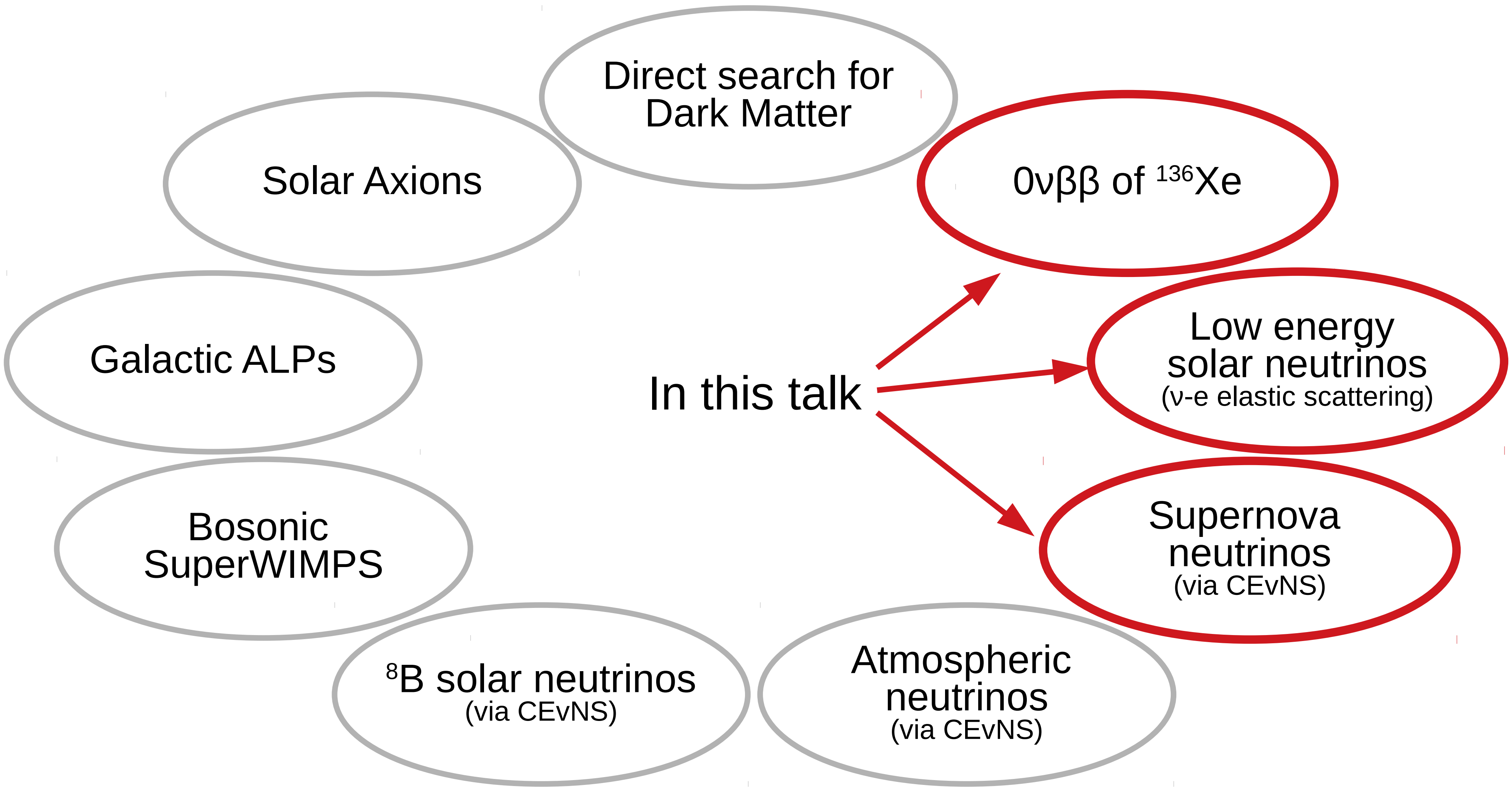
Supernova neutrinos
(via CEvNS)

^{8}B solar neutrinos
(via CEvNS)

Atmospheric neutrinos
(via CEvNS)

... and more

Physics prospects with DARWIN



... and more

Neutrinoless double beta decay

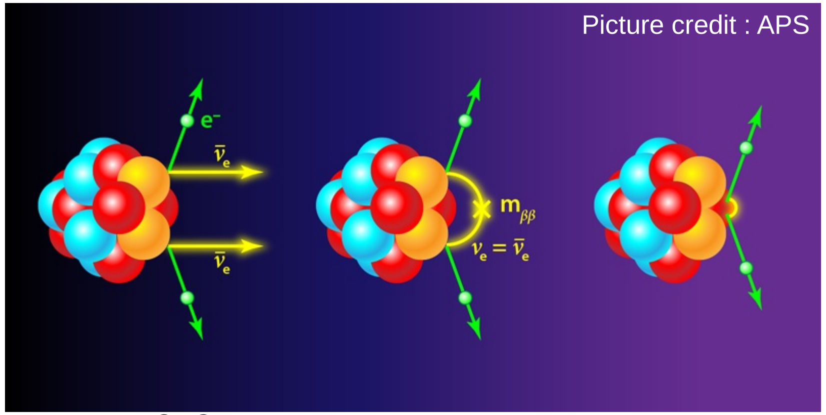
- Access to potential Majorana nature of neutrinos

- 40 tons of xenon in active volume:
  - 8.9% of ^{136}Xe → **3.5 t** in active volume
  - Potential candidate for 0νββ

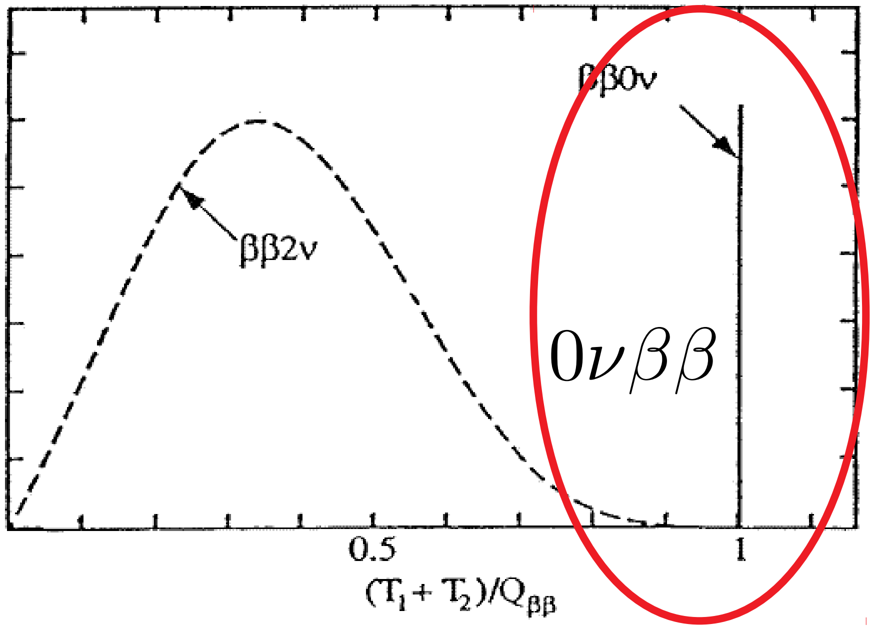
$$^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba} + 2e^{-} + \cancel{2\bar{\nu}_e}$$

  - Q value = 2458 keV

- All key components for success:
  - Large mass
  - Good position resolution
  - Good energy resolution (XENON1T: Eur. Phys. J. **C80**, 785 (2020))
  - Low background



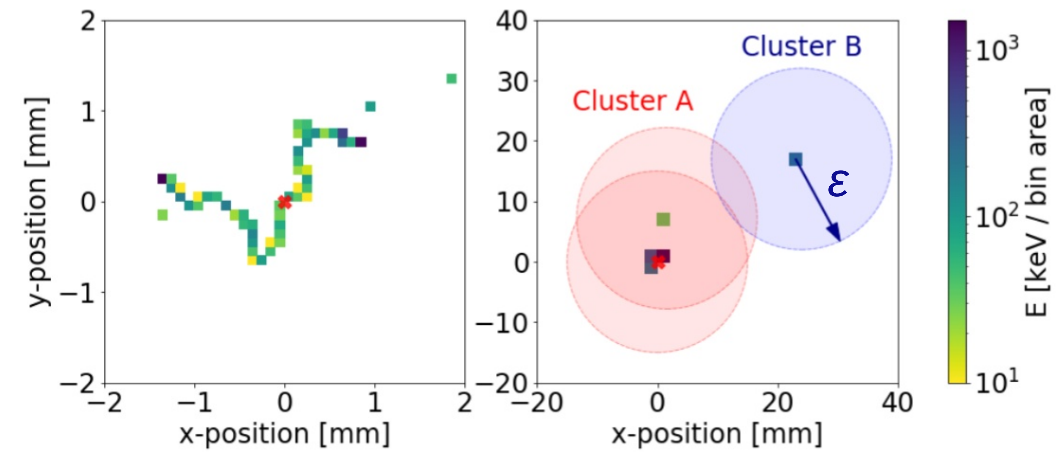
$2\nu\beta\beta$ $0\nu\beta\beta$

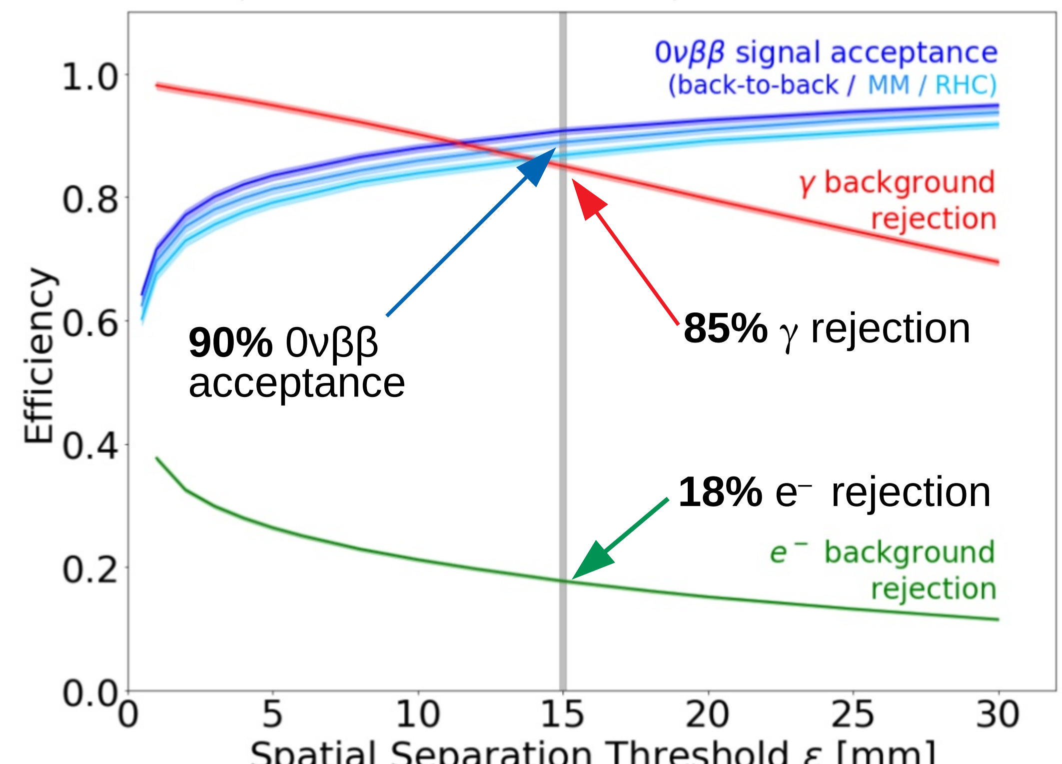


Identifying double beta decays

Eur. Phys. J. **C80**, 808 (2020)

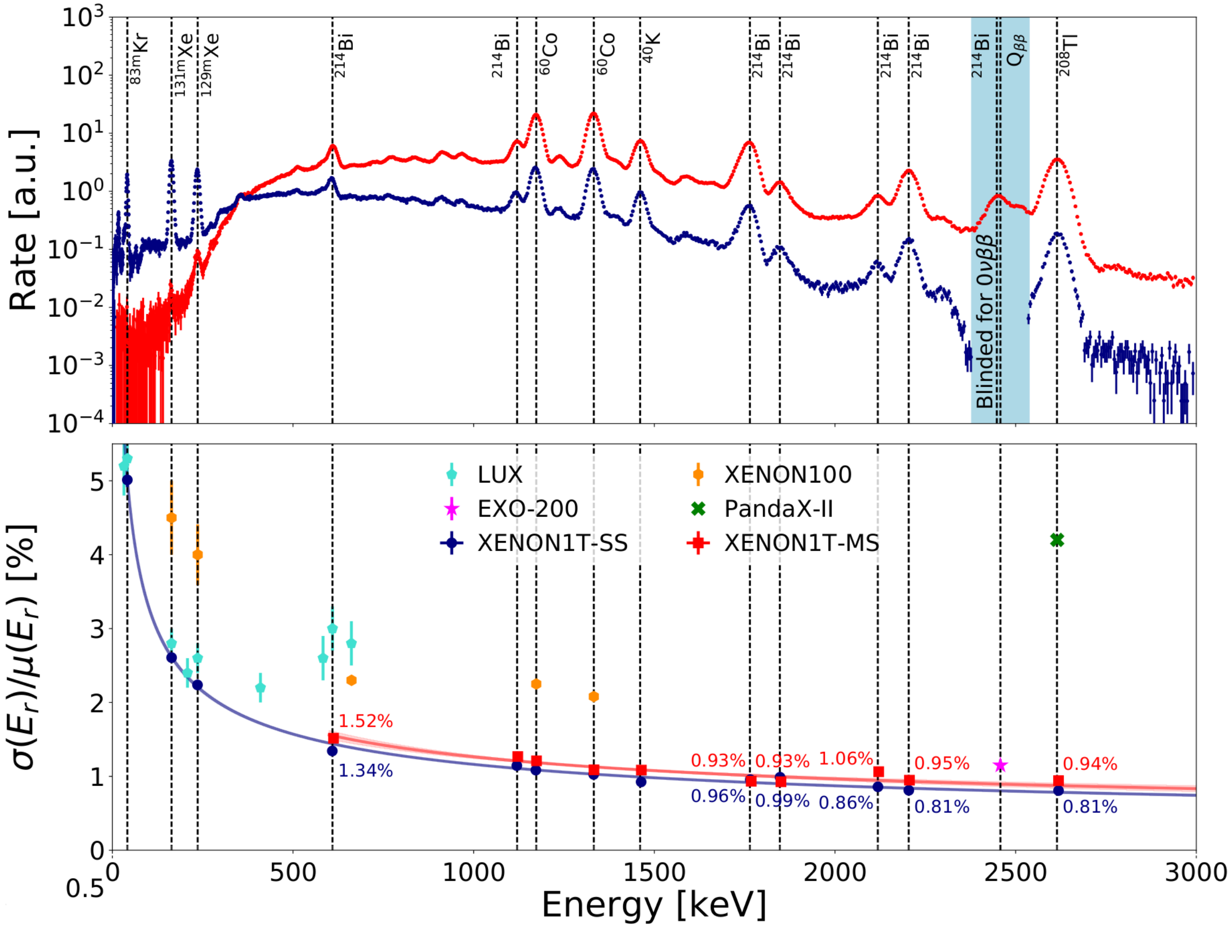
- **0νββ signal:**
  - Two electrons with $\Sigma E = Q_{\beta\beta}$
  - Low probability to emit Bremsstrahlung photon → “single site events”
- **Background:**
  - gammas → Compton scattering → multiple sites
  - Beta (electrons) → (sometimes) Bremsstrahlung → multiple sites
- **For our studies:**
  - Cluster search on Geant4 output
  - Conservative ε=15 mm estimate
  - Likely large room for improvement





Energy resolution

Eur. Phys. J. **C80**, 785 (2020)



- Recent results from XENON1T $$\frac{\sigma_E}{E} = \frac{0.3171}{\sqrt{E[\text{ keV }]}} + 0.0015$$ ~**0.8%** at $\mathbf{Q_{\beta\beta}}$

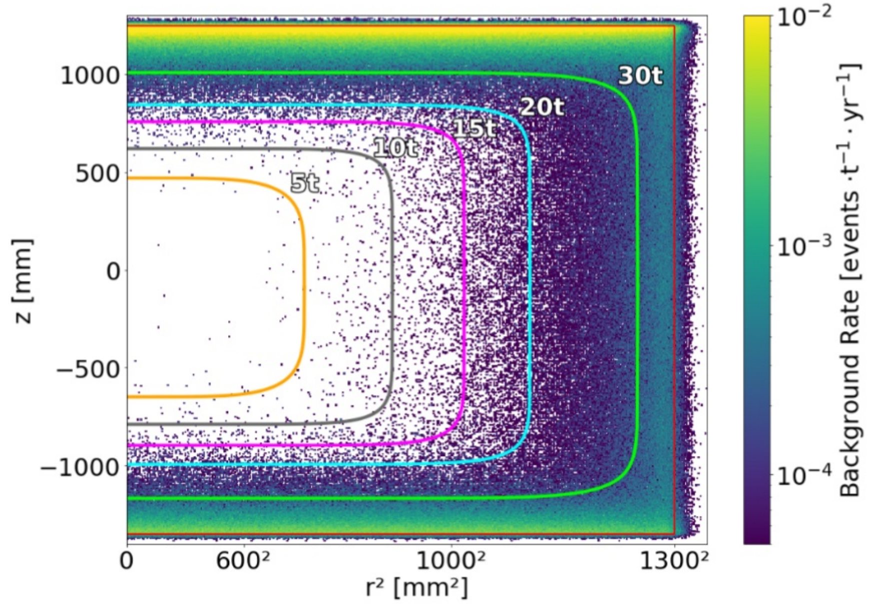
- Potential of improvement (dedicated HE readout, improved reconstructions)

Material backgrounds

Eur. Phys. J. **C80**, 808 (2020)

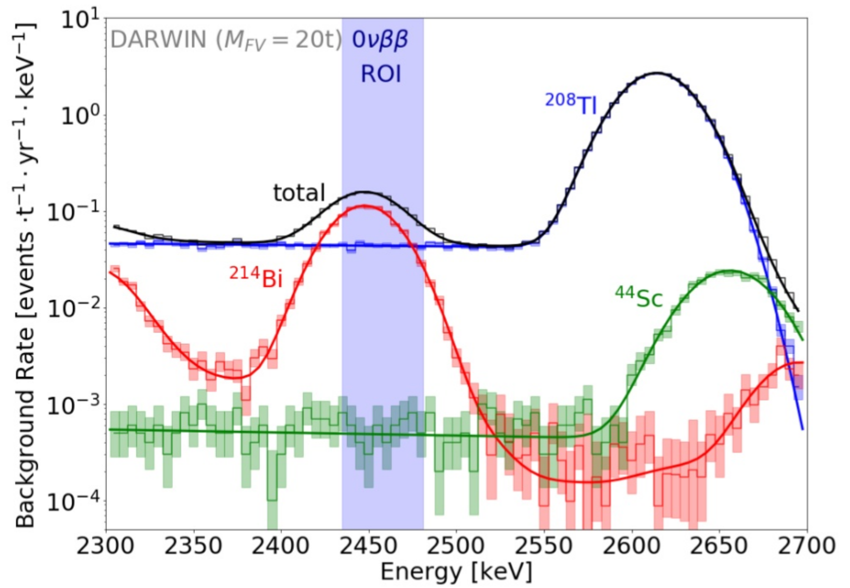
- Masses of components

Component	Material	Mass
Outer cryostat	Titanium	3.0 t
Inner cryostat	Titanium	2.1 t
Bottom pressure vessel	Titanium	0.4 t
LXe instrumented target	LXe	39.3 t
LXe buffer outside the TPC	LXe	9.0 t
LXe around pressure vessel	LXe	270 kg
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	Titanium	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)	composite	363 kg
Sensor electronics (1910 units)	composite	5.7 kg



- Conservative activity estimates (current materials from XENON and LZ)

Material	Unit	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{60}Co	^{44}Ti
Titanium	mBq/kg	<1.6	<0.09	0.28	0.25	<0.02	<1.16
PTFE	mBq/kg	<1.2	0.07	<0.07	0.06	0.027	-
Copper	mBq/kg	<1.0	<0.035	<0.033	<0.026	<0.019	-
PMT	mBq/unit	8.0	0.6	0.7	0.6	0.84	-
Electronics	mBq/unit	1.10	0.34	0.16	0.16	<0.008	-



- Fiducialization to reject
- Cleaner materials are possible

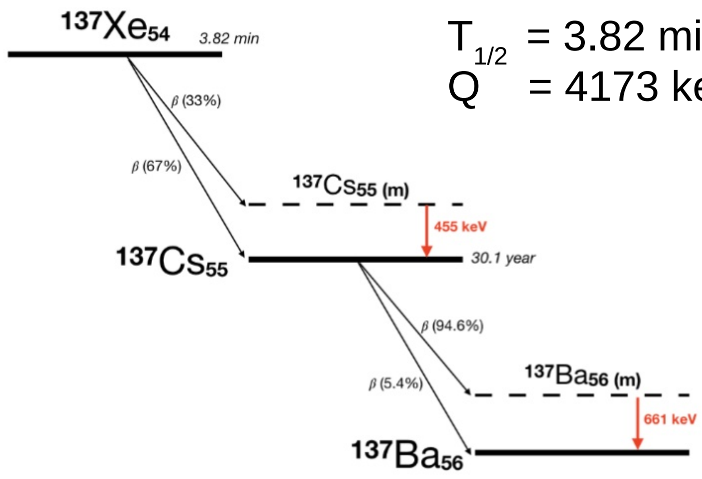
Intrinsic backgrounds

Eur. Phys. J. **C80**, 808 (2020)

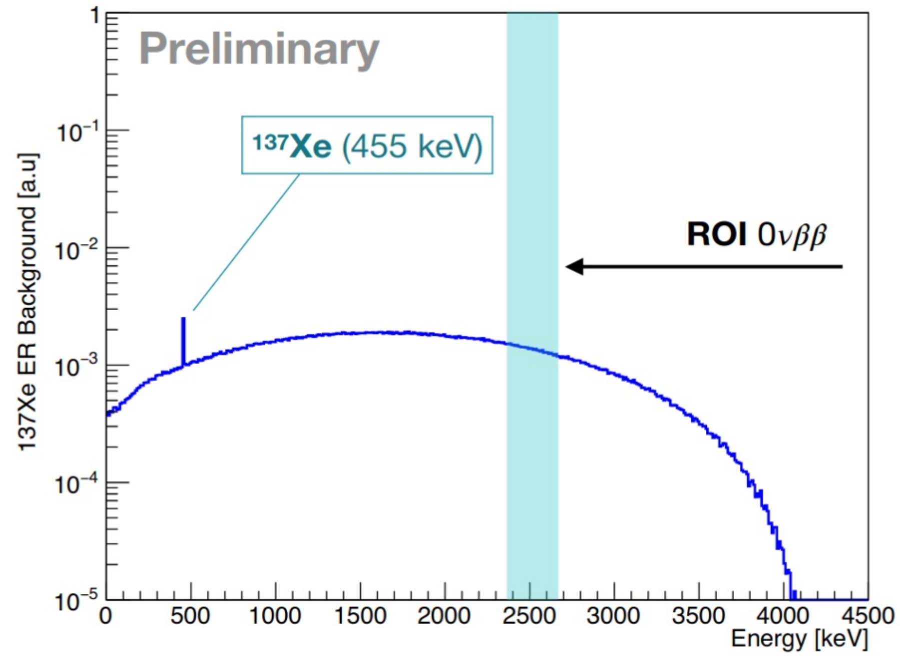
- ^{222}Rn in LXe:
  - 0.1 μBq/kg (x10 lower than XENONnT)
  - 99.8 % rejection with Bi-Po tagging
- ^{8}B solar neutrinos (ν-e scattering):
  - Irreducible flat background
- 2νββ of ^{136}Xe:
  - Negligible due to good energy resolution
- Decay of ^{137}Xe
  - Neutron activation due to cosmogenic muons

$$n + {}^{136}Xe \rightarrow {}^{137}Xe$$

  - 6.9 atoms/(t·yr) at 3500 m.w.e. depths (LNGS)
  - Better at deeper laboratories



$T_{1/2}$ = 3.82 min
Q = 4173 keV



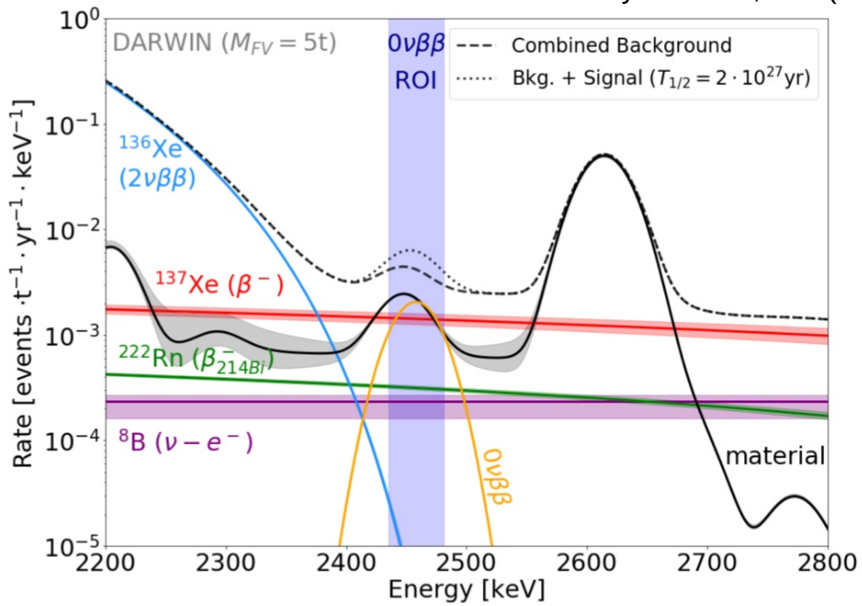
Expected sensitivity to 0νββ

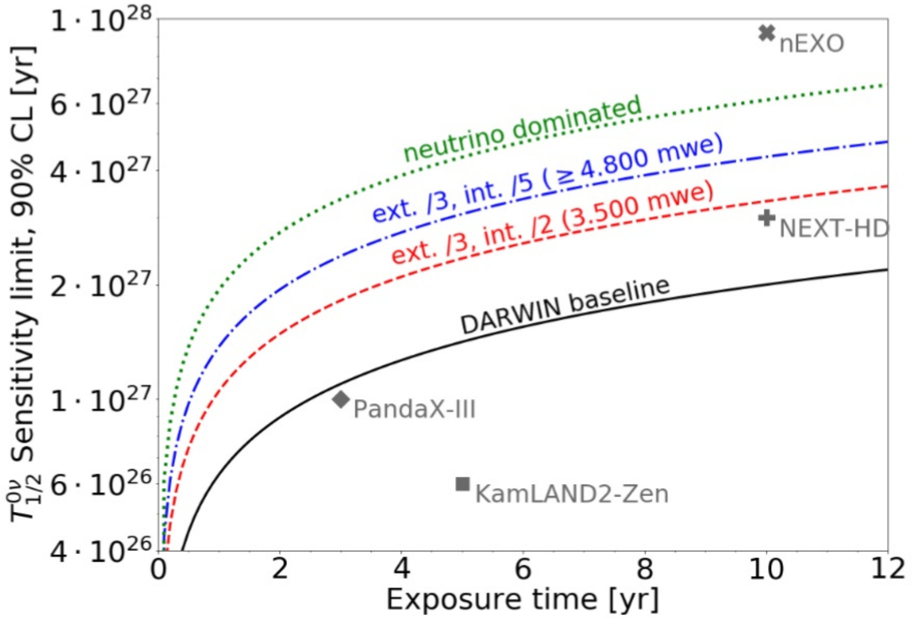
Eur. Phys. J. **C80**, 808 (2020)

- Optimal 5t fiducial volume:
  - Main remaining backgrounds : ^{214}Bi and ^{137}Xe
- Expected sensitivity after 10 years (baseline)

$$T_{1/2} = 2.4 \cdot 10^{27} \text{ years (90 \% C.L.)}$$

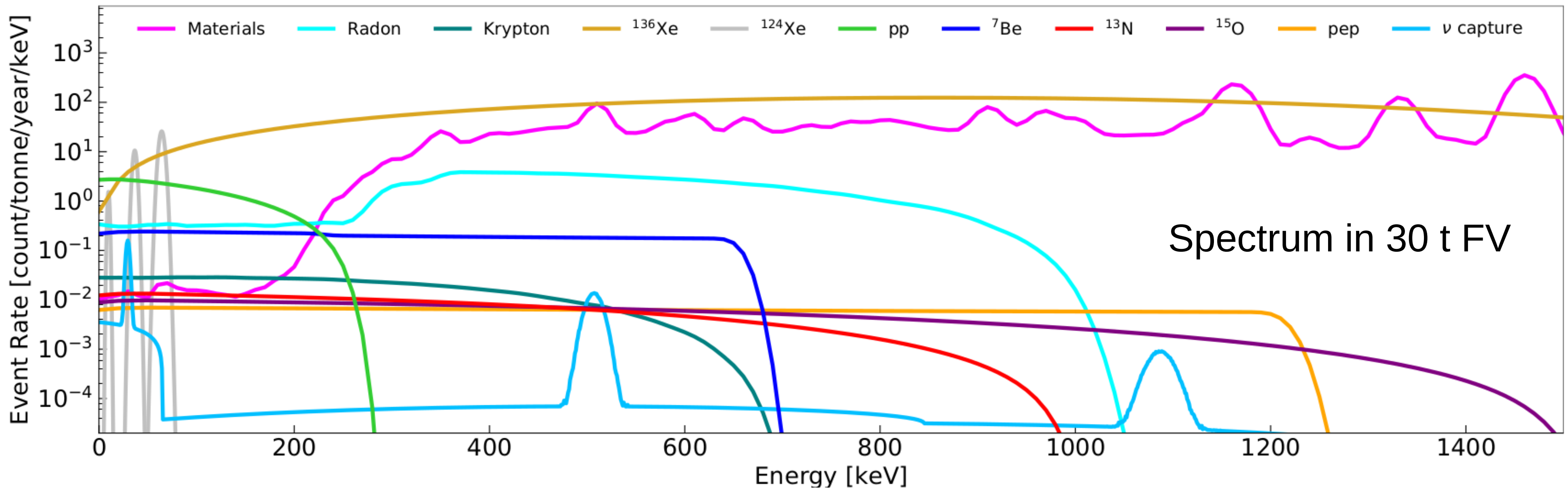
- Further improvements are possible
  - Better materials
  - Better analysis
  - Going deeper



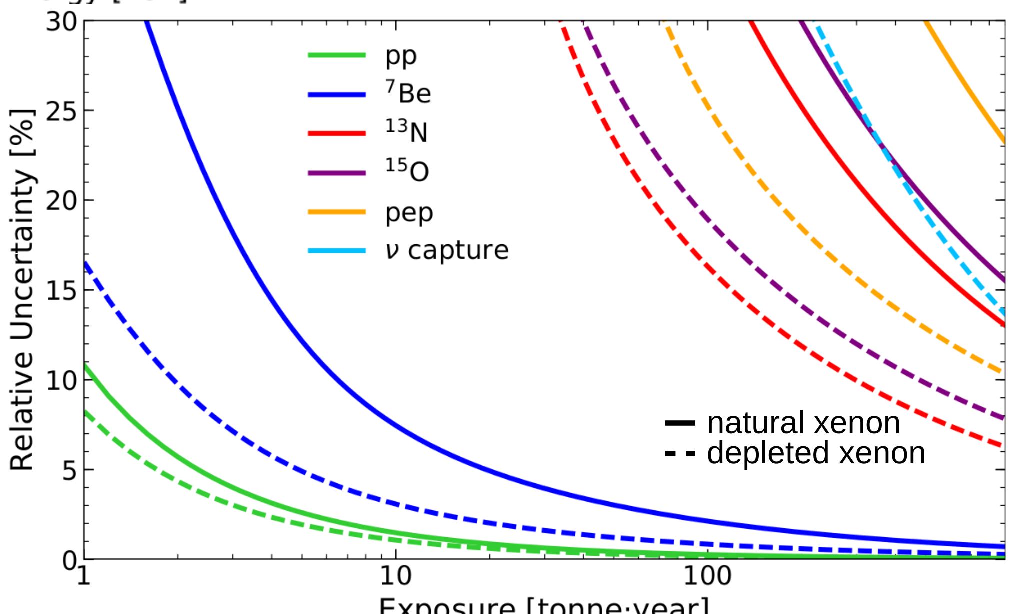


Solar neutrinos with DARWIN

Eur. Phys. J. C 80, 1133 (2020)



- Detection of solar neutrinos via ν-e elastic scattering
- Excellent precision in solar neutrino flux (300 t·y exposure)
  - 0.15% precision for *pp*
  - 1% for ^{7}Be reactions
  - Over 3σ detection for ^{13}N and ^{15}O

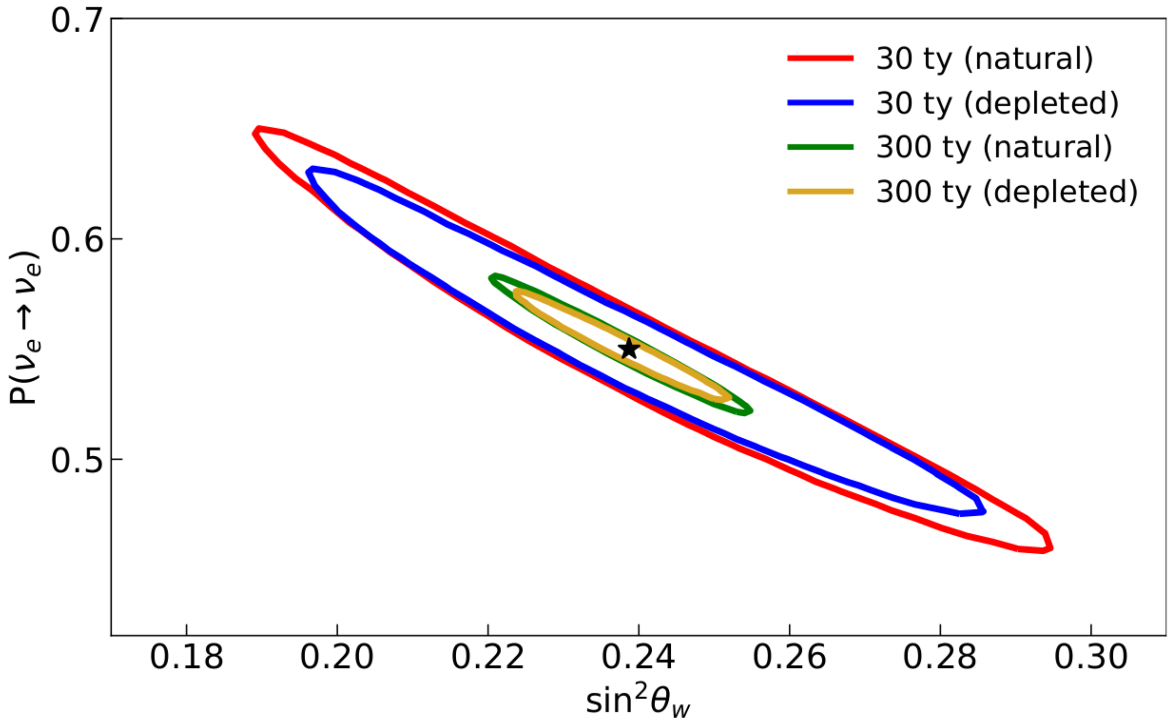


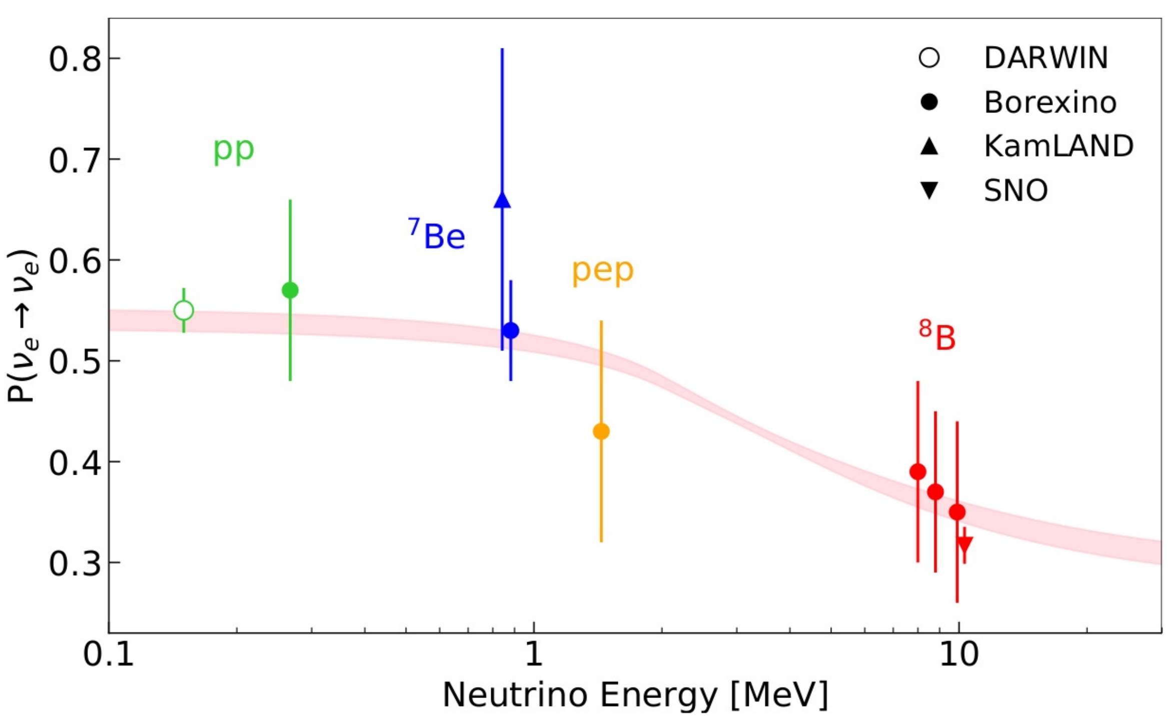
Solar neutrinos

Eur. Phys. J. C 80, 1133 (2020)

- Precise measurements of solar survival probability and electroweak mixing angle using pp neutrinos

- Further improvements possible with depleted target

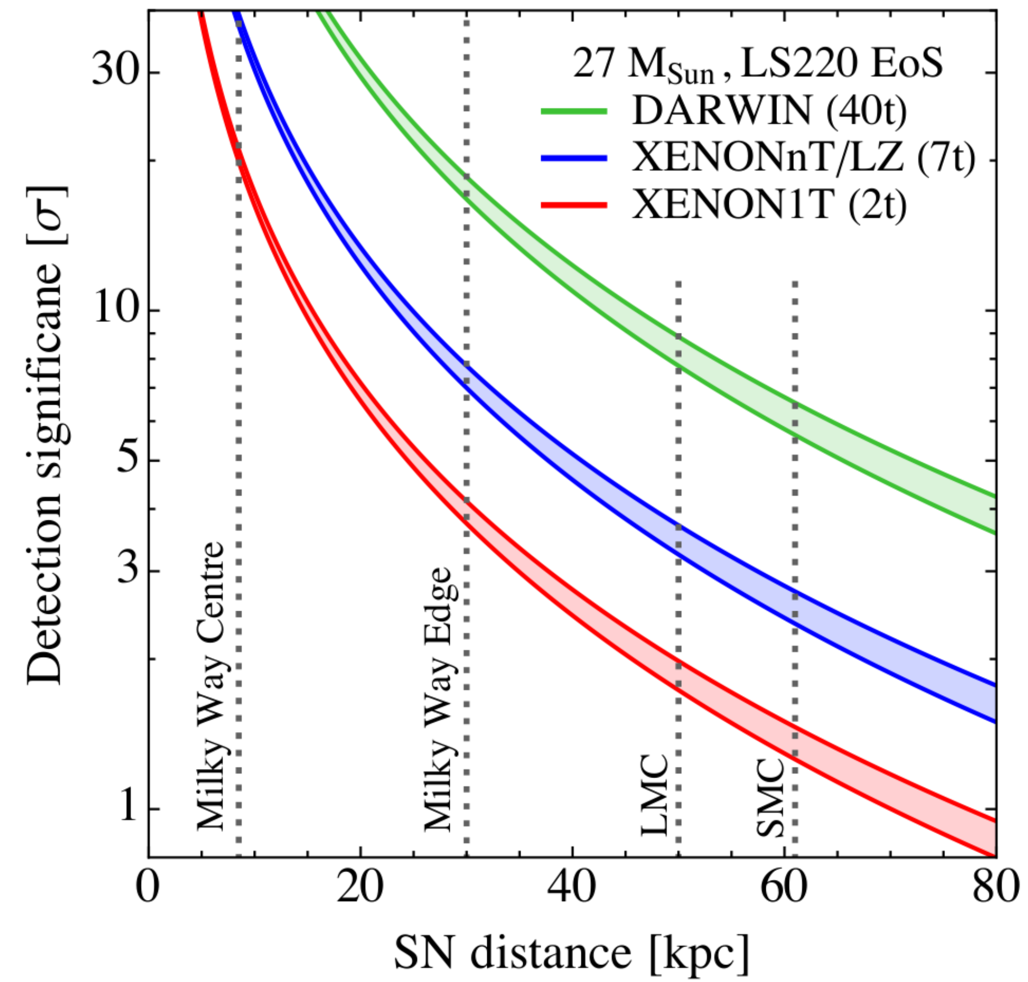




Supernova neutrinos

Phys. Rev. D94 (2016) no.10, 103009

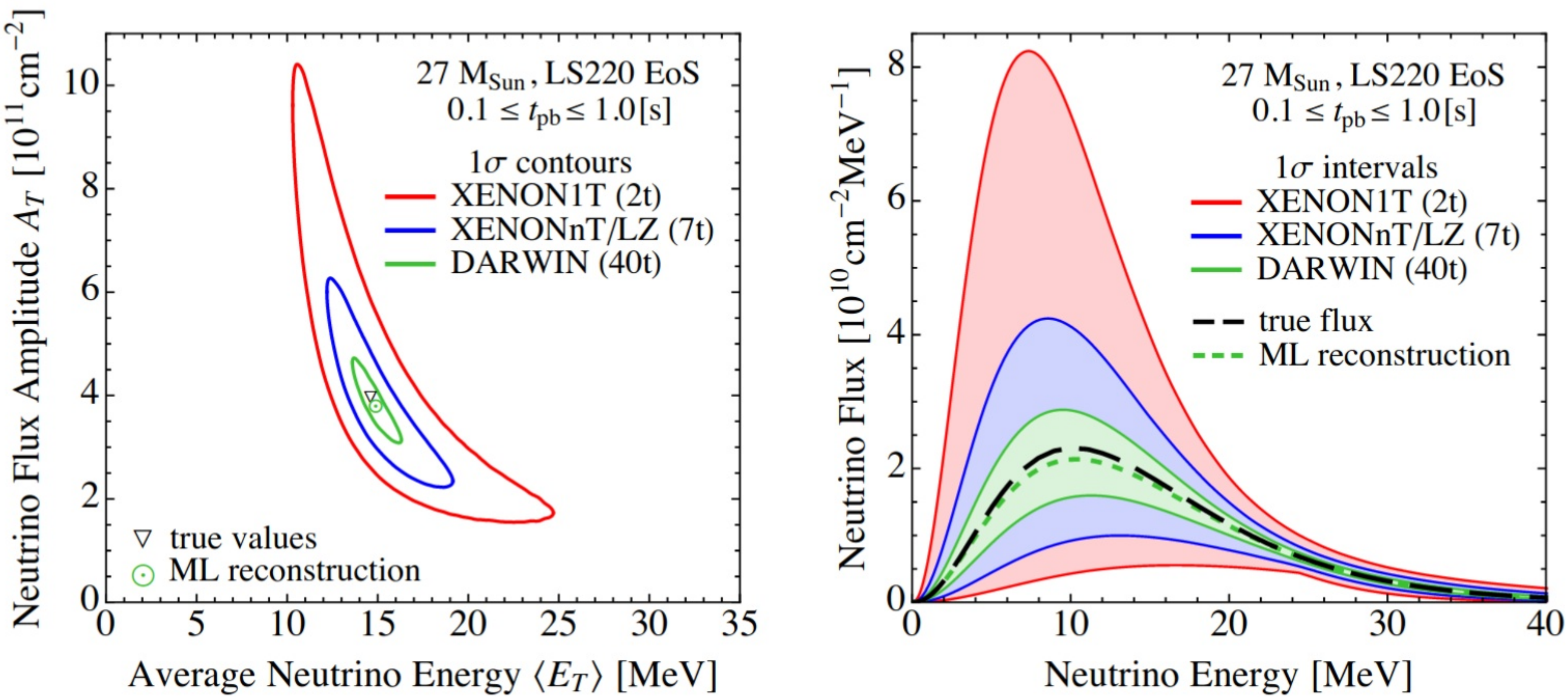
- Expect hundreds/thousands events for a galactic supernova due to CEvNS in nuclear recoil band
- Sensitive to all six neutrino flavours – complementary to other experiments
- S2 only analysis to reduce threshold
- Sensitive to supernovas up to Small Magellanic Cloud
- Can be used as a supernova alert system for multi-messenger measurements



Supernova neutrinos

Phys. Rev. D94 (2016) no.10, 103009

- Access to differential spectra of SN neutrinos
- Window to measure and constrain properties of supernova explosion



DARWIN collaboration

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

Chicago

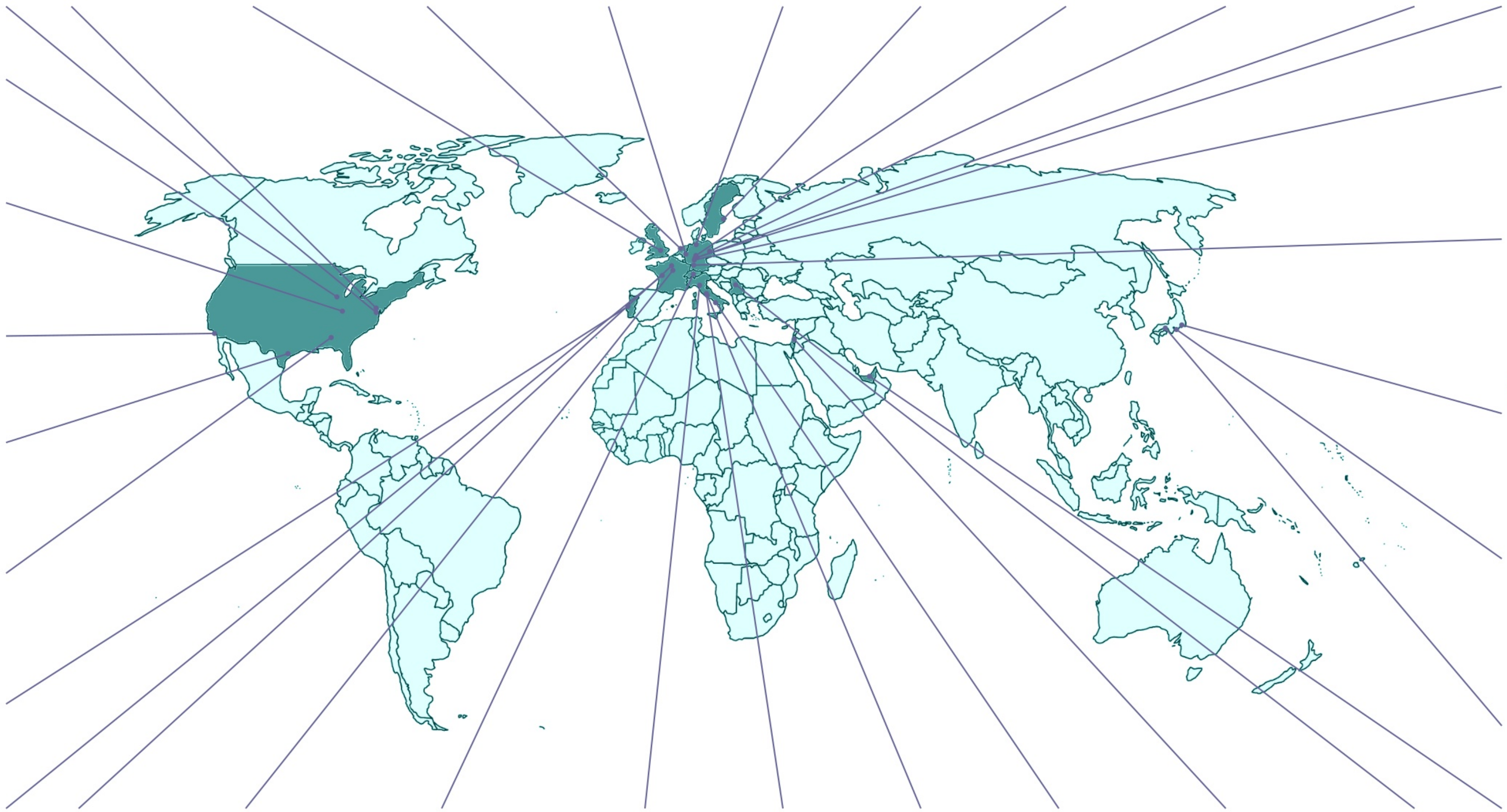
Purdue

UCSD

Alabama

Rice

Coimbra



KIT

Freiburg

Tokyo

Nagoya

Kobe

Subatech | LPNHE | IJCLab | Zurich | Bologna | L'Aquila | LNGS | Napoli | Weizmann | Belgrade | NYUAD

> 165 members, 30 institutions, 13 countries

Summary

- DARWIN is a truly multi-purpose detector
- Extensive neutrino physics program:
  - Neutrinoless double beta decay
  - Solar neutrinos
  - Supernova neutrinos
  - And many other topics
- Expecting data in 2027
- Stay tuned:
  - More R&D
  - New physics prospects