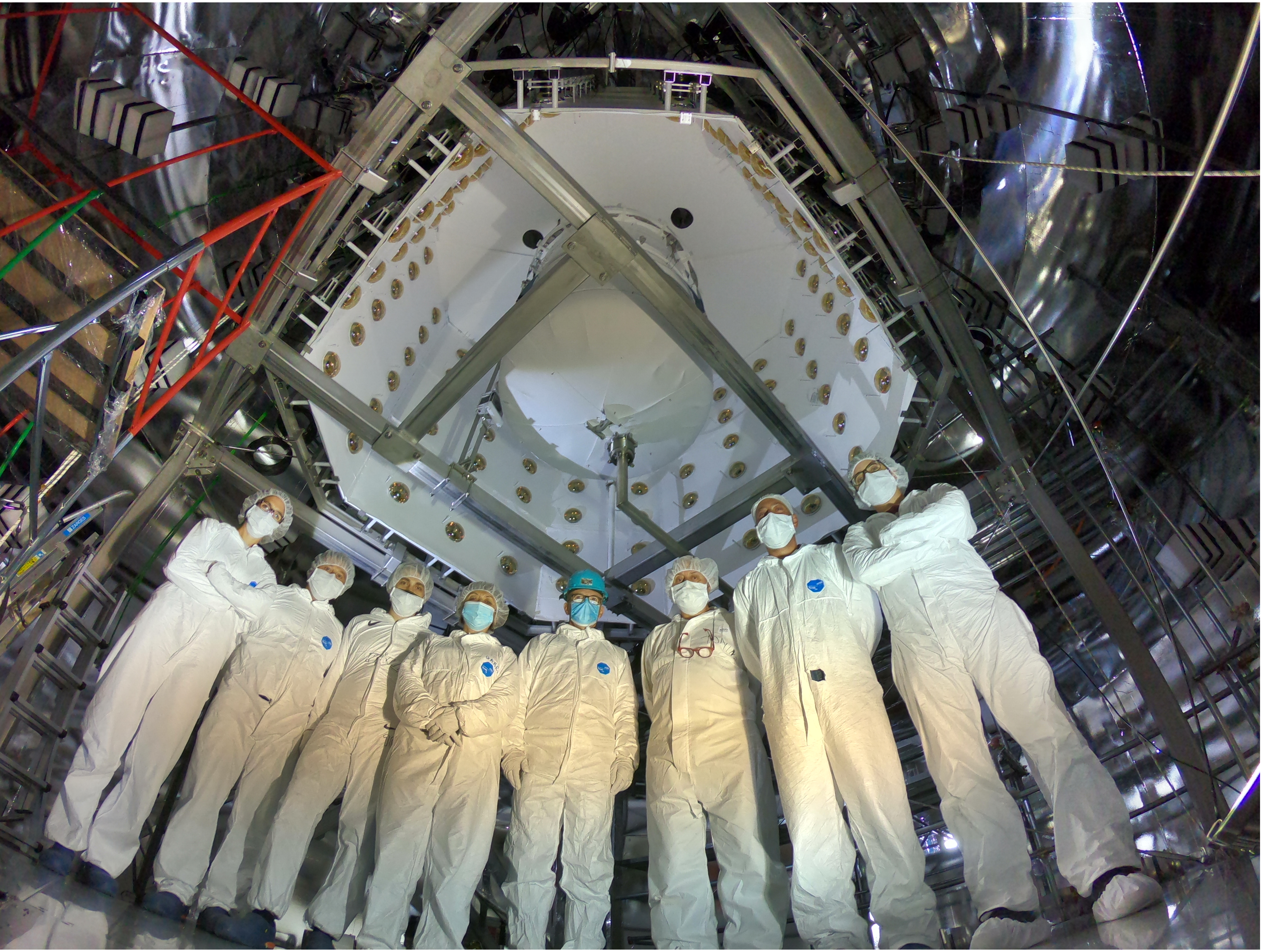
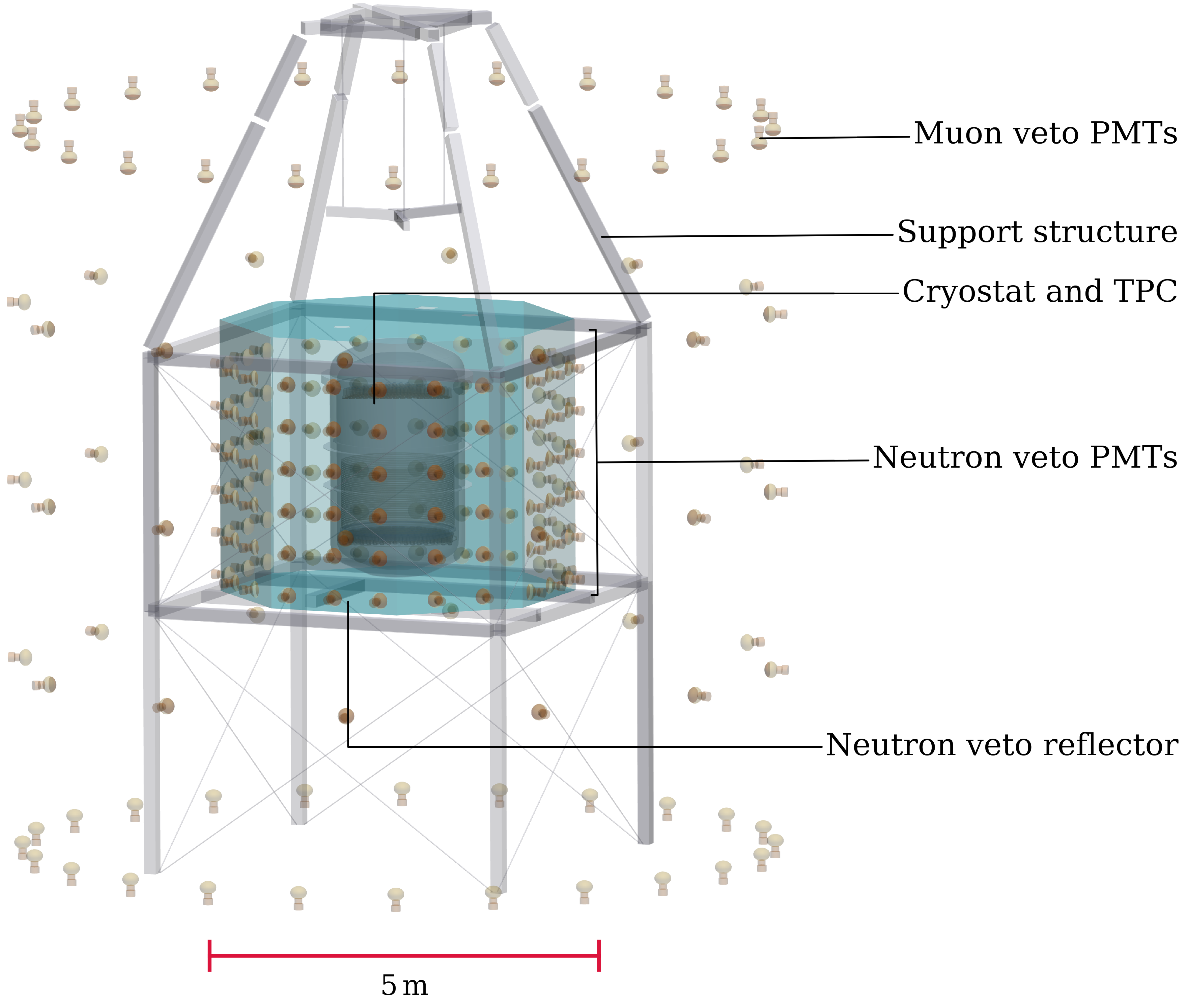
VistaUpdate from the Dark Matter Group

Patrick Decowski, Auke-Pieter Colijn, Tina Pollmann

DARWIN

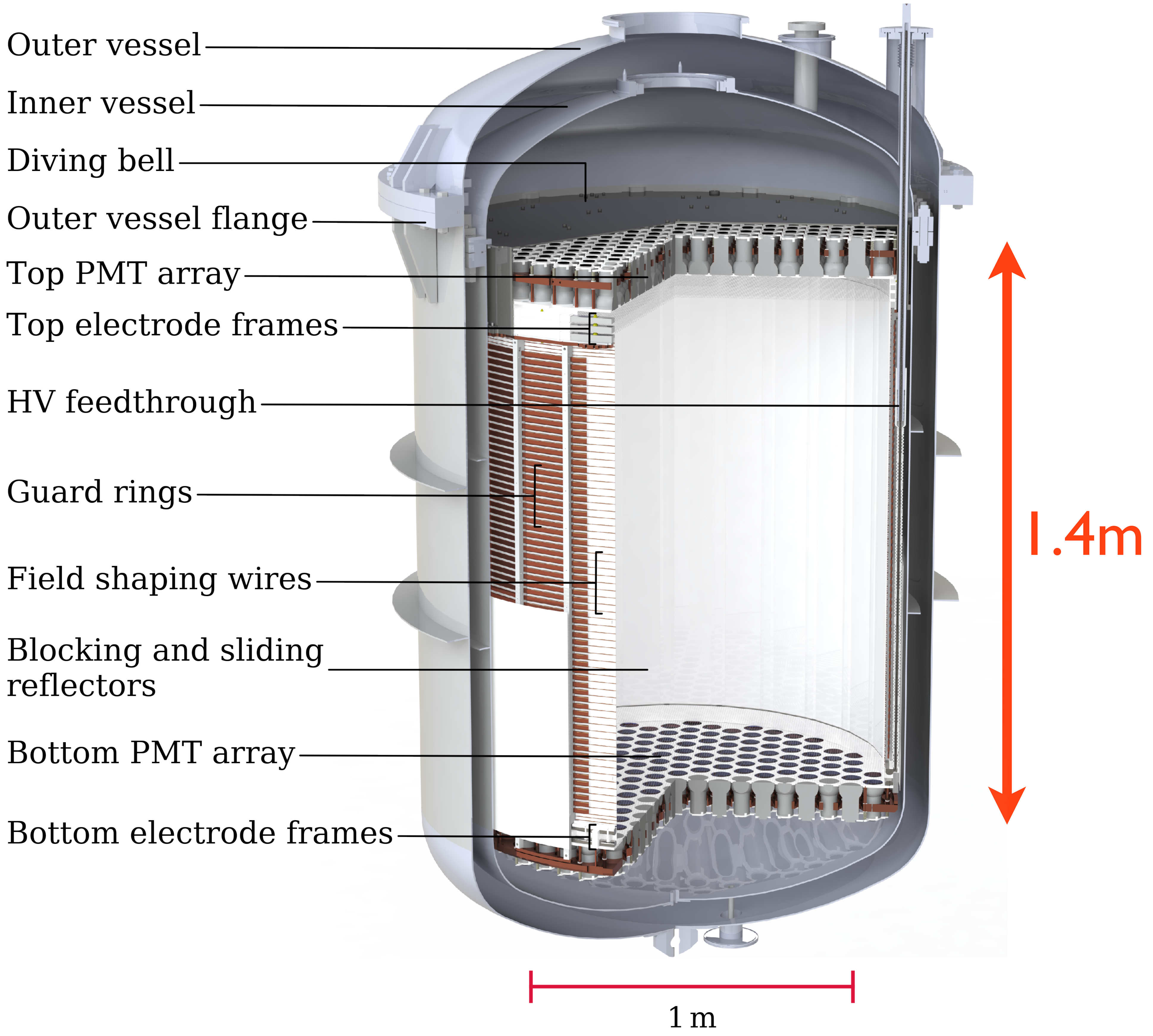
XENONnT Installation Finished

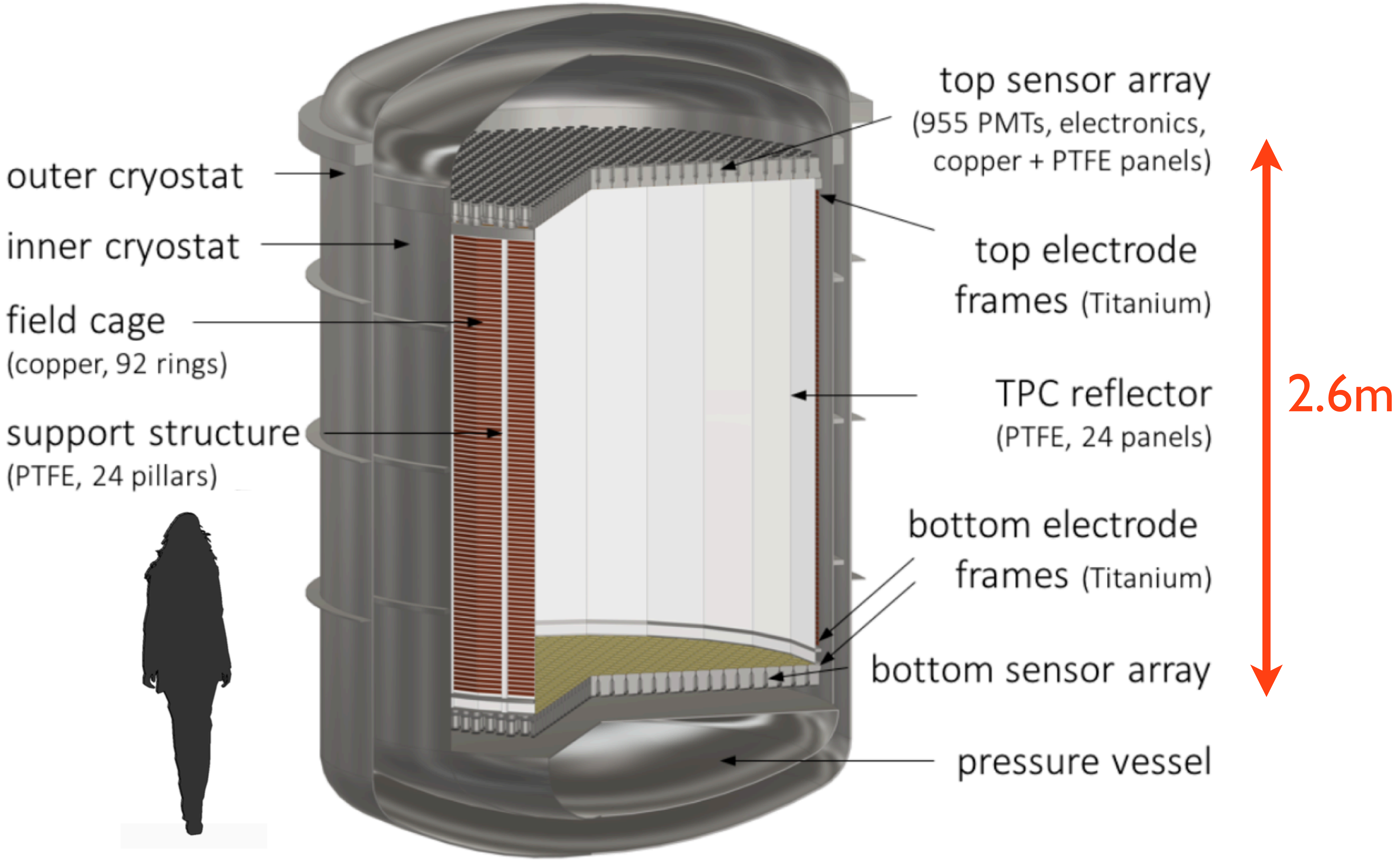




- XENONnT installation continued during Corona
- Final systems being installed
- Commissioning imminent

Large-scale Xe detectors





<u>XENONnT</u>

8.5t of LXe total

2020 - 2025

<u>DARWIN</u>

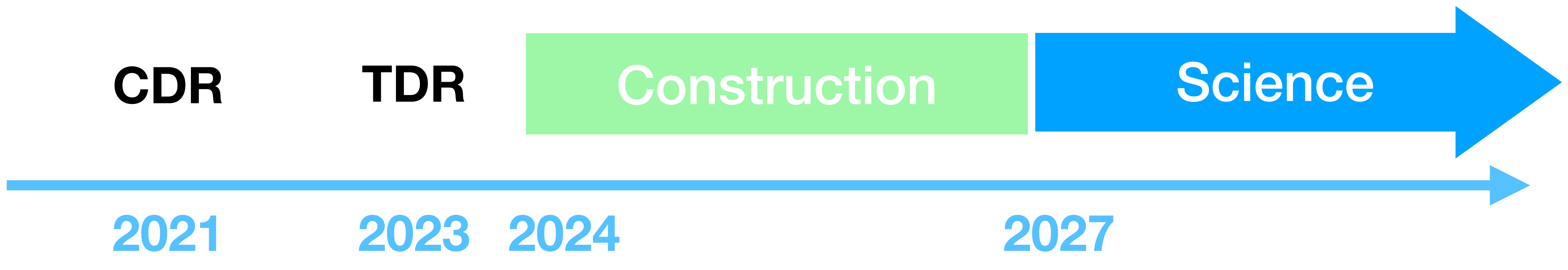
50t of LXe total

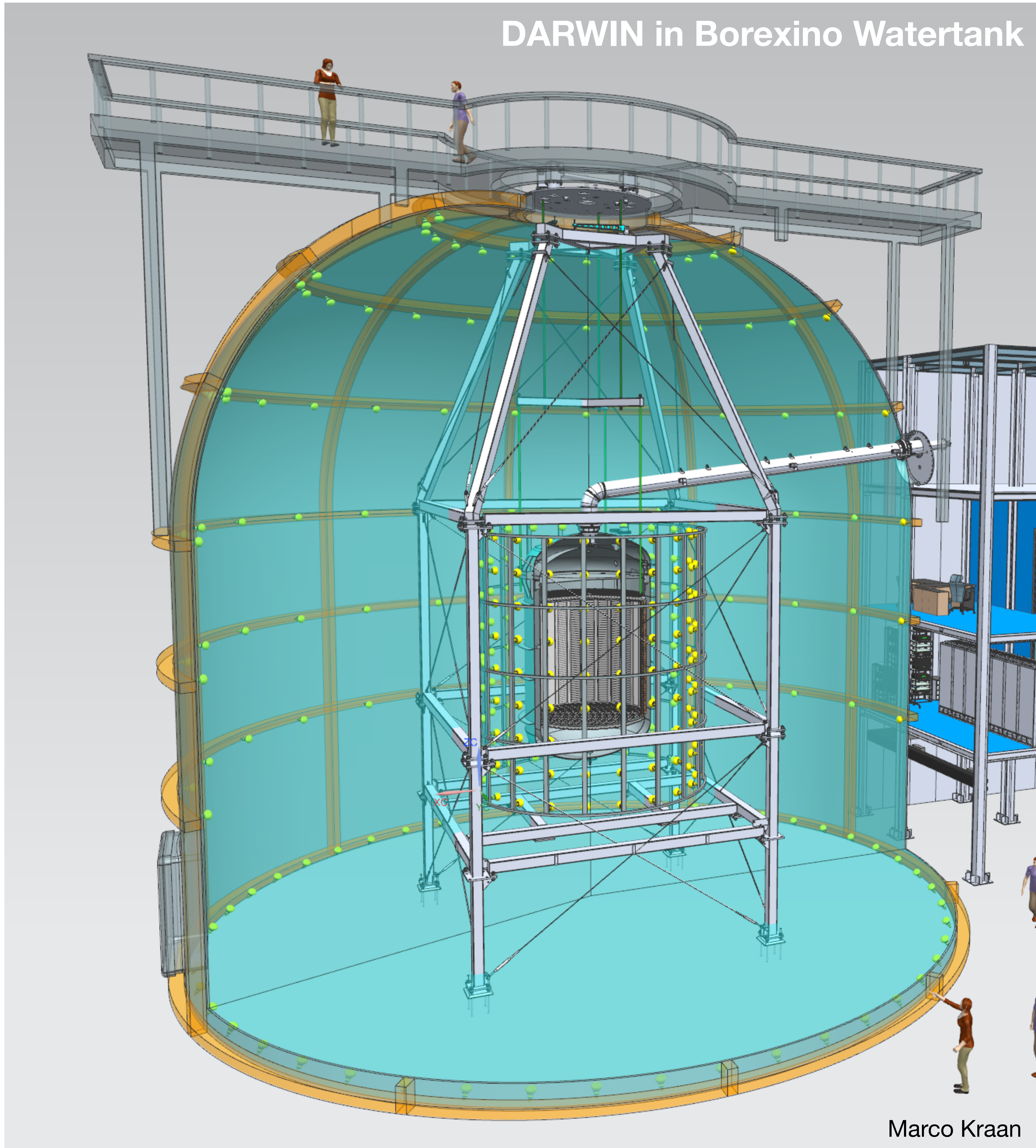
Global effort

Start in 2027

DARWIN

- Design study started in 2009
- LoI submitted to LNGS, invited to submit a CDR
- LoI submitted to ESPP
- LoI Submissions to Snowmass'21
  - Europe: DARWIN (50 ton LXe)
  - US: "G3 DM Experiment" (40-100 ton LXe)
  - China: PandaX-XT (30-100 ton LXe)
- Strong push to combine European + US efforts
- Funding requests being prepared in CH, DE, F, IT

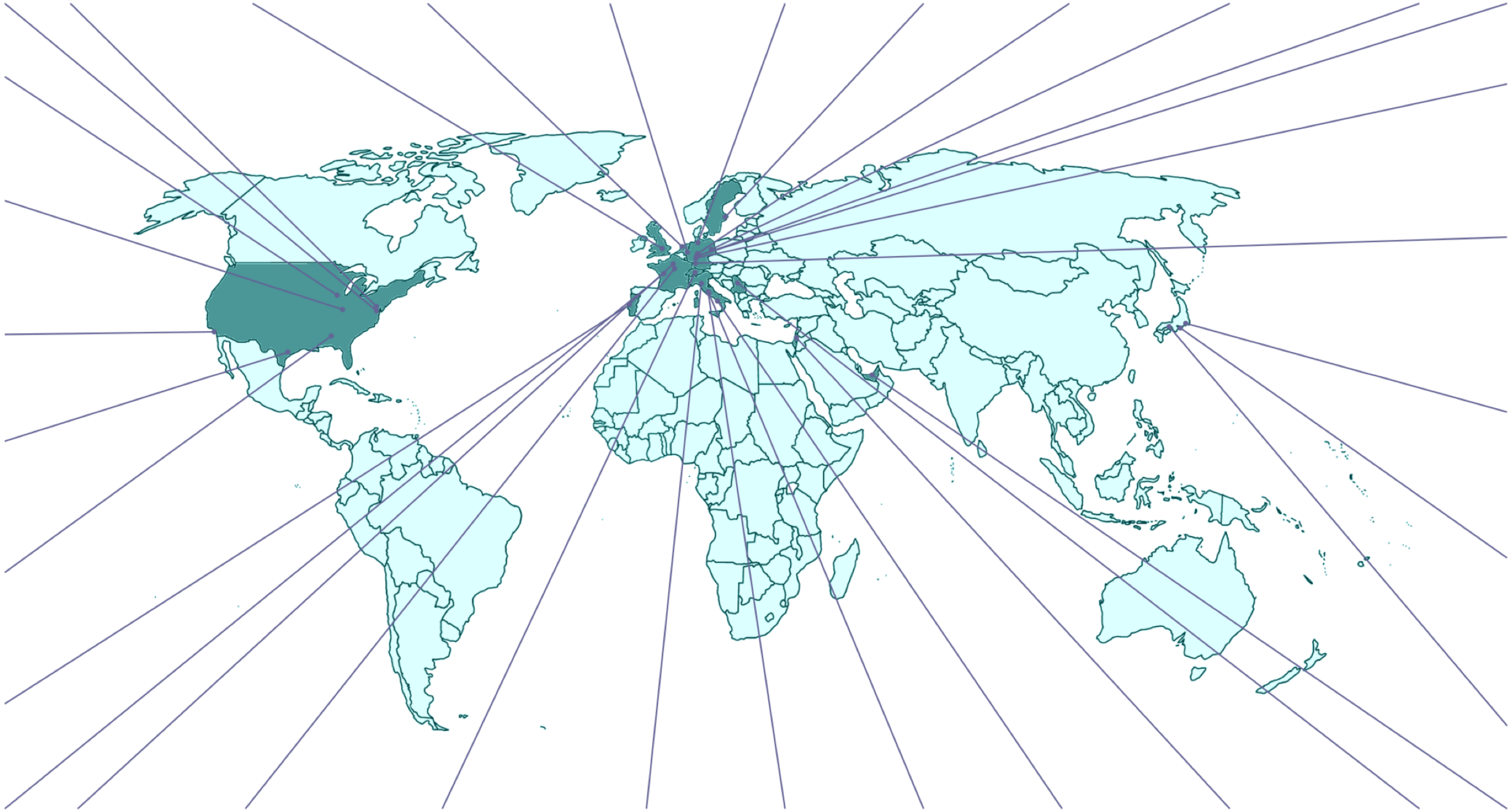




DARWIN Collaboration

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

Chicago
Rice
UCSD
Alabama
Purdue
Coimbra



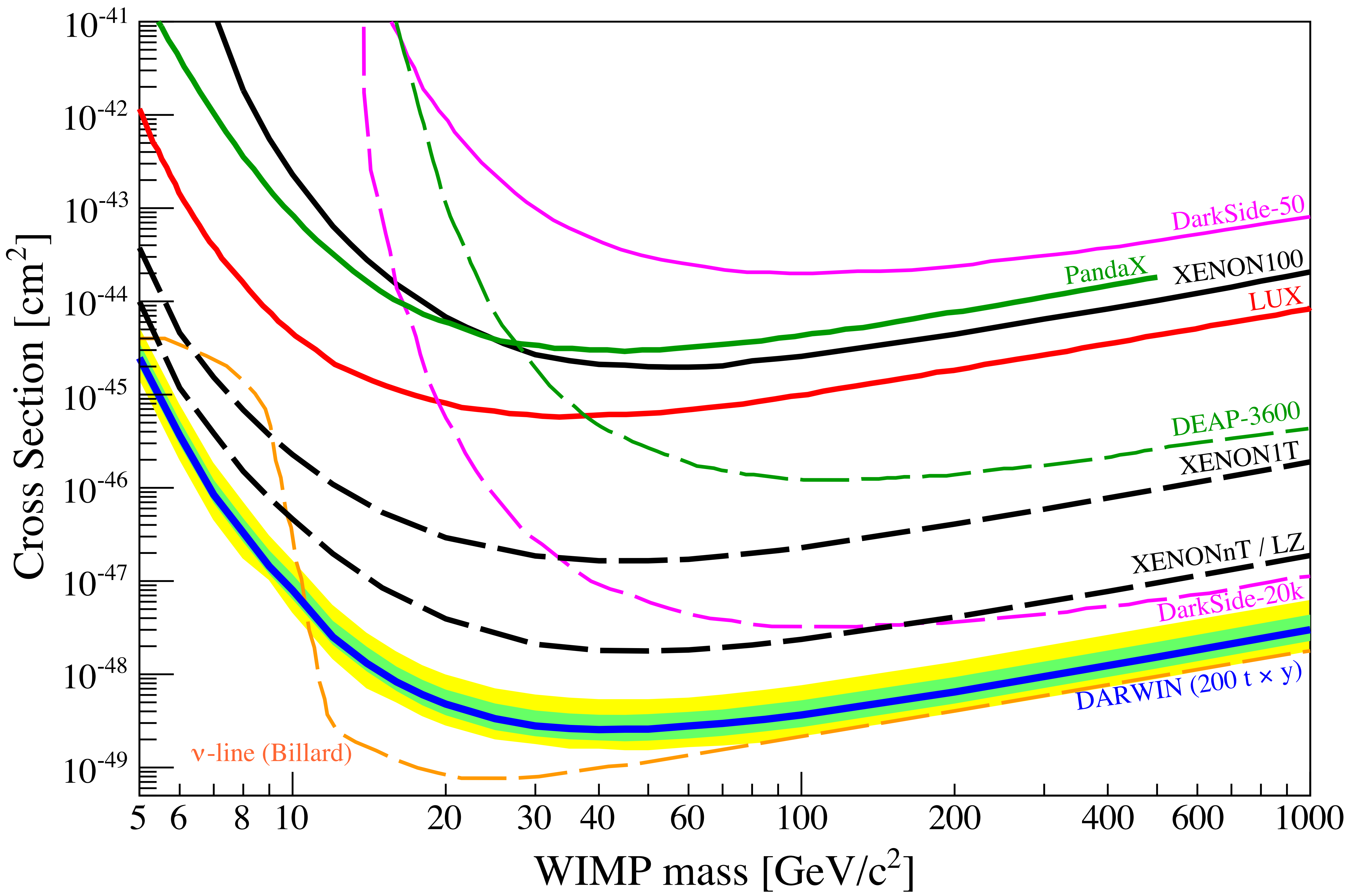
KIT
Freiburg
Tokyo
Nagoya
Kobe

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

From Nikhef:
Colijn
Decowski
Pollmann

Ultimate Dark Matter Experiment

DARWIN will explore the remaining accessible WIMP parameter space with this technology

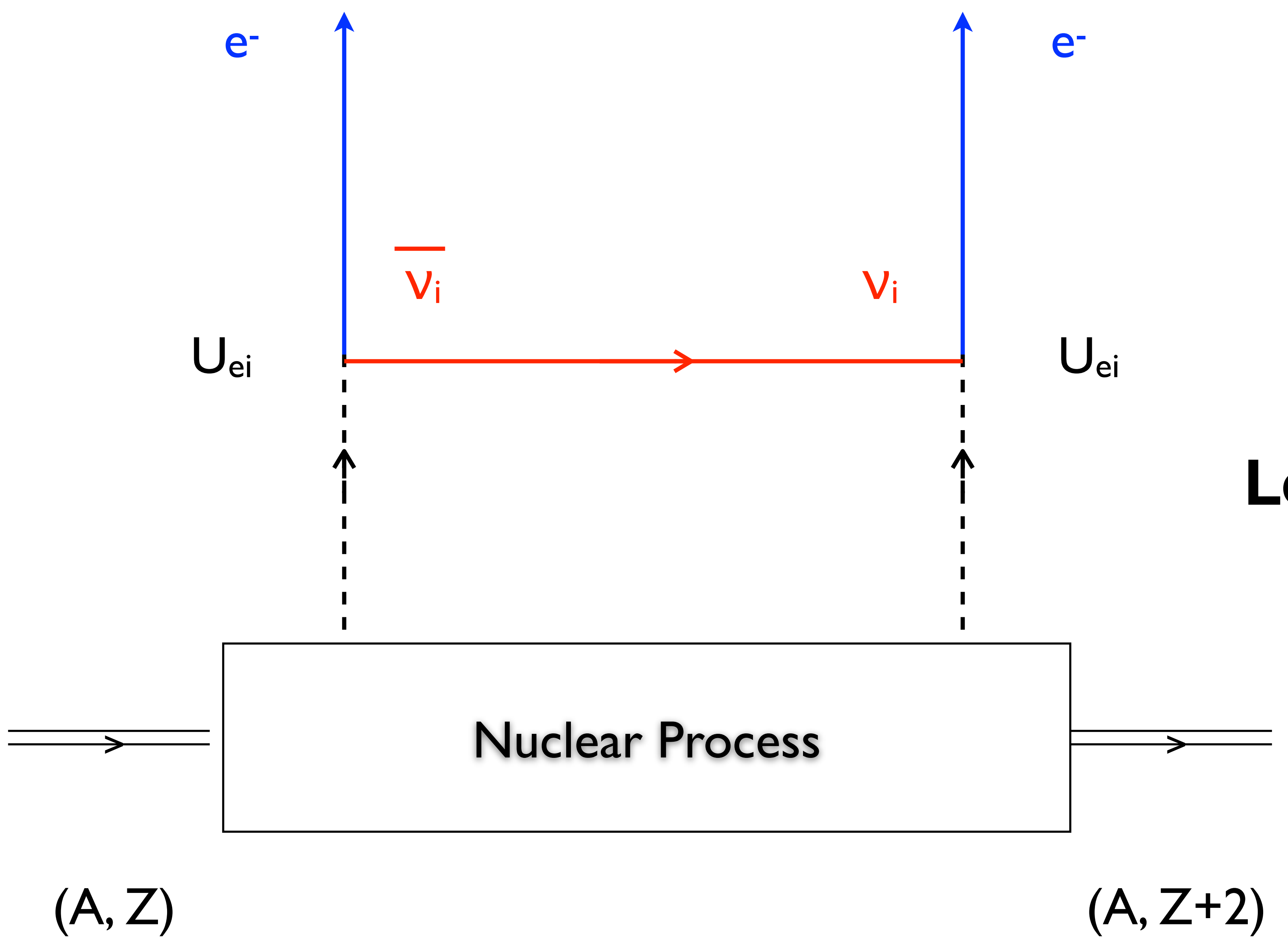


- Explore other DM candidates:
  - **Axion-like particles**: pseudo-scaler bosonic DM candidates
  - **Dark Photons**: vector bosonic DM candidates

DARWIN, JCAP 1611 (2016) no.11, 017; arXiv:1606.07001

DARWIN: Is the ν Majorana?

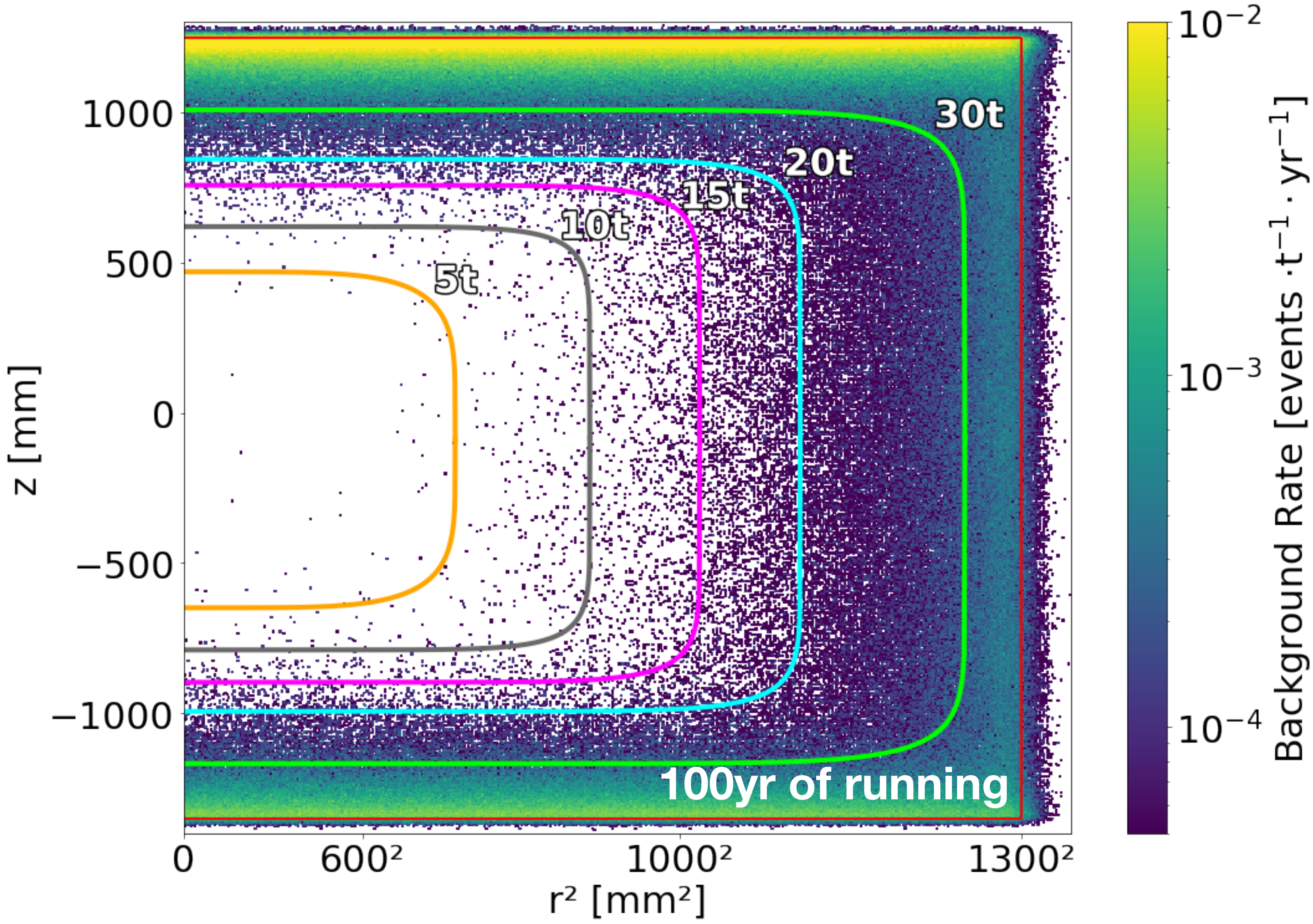
Look for 0ν2β in ^{136}Xe



$$\begin{aligned} M_\nu &\neq 0 \\ |\Delta L| &= 2 \end{aligned}$$

Lepton Number Violating process

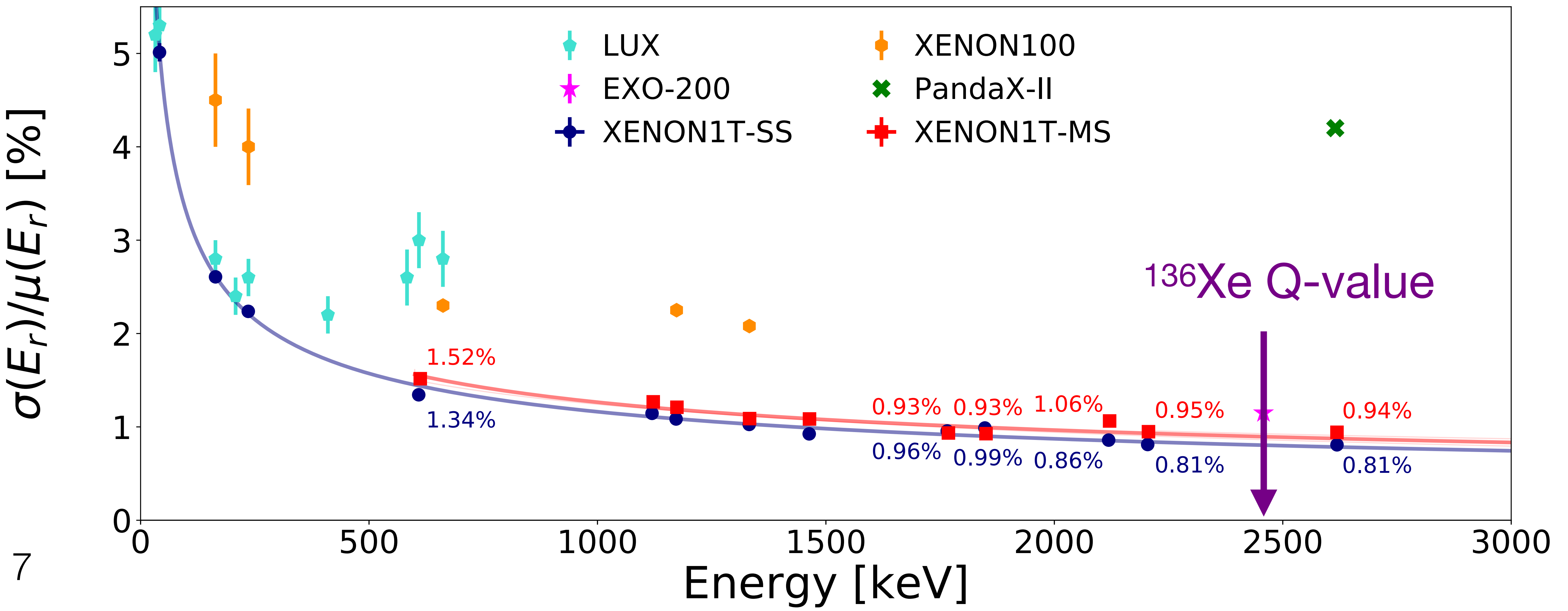
DARWIN, EPJC 80, 808 (2020); arXiv:2003.13407



- DARWIN has 40t of natural Xe → 3.5 tons of ^{136}Xe
- Extremely low backgrounds, due to LXe shielding
- LXe has excellent energy resolution

$$T^{0\nu}_{1/2} \propto \epsilon \frac{a}{A}\sqrt{\frac{Mt}{b\Delta E}}$$

XENON, EPJC 80, 785 (2020); arXiv:2003.03825



World-Competing 0v2β sensitivity

$$(T^{0\nu}_{1/2})^{-1} = G_{0\nu}(Q,Z)|M_{0\nu}|^2\langle m_{\beta\beta}\rangle^2$$

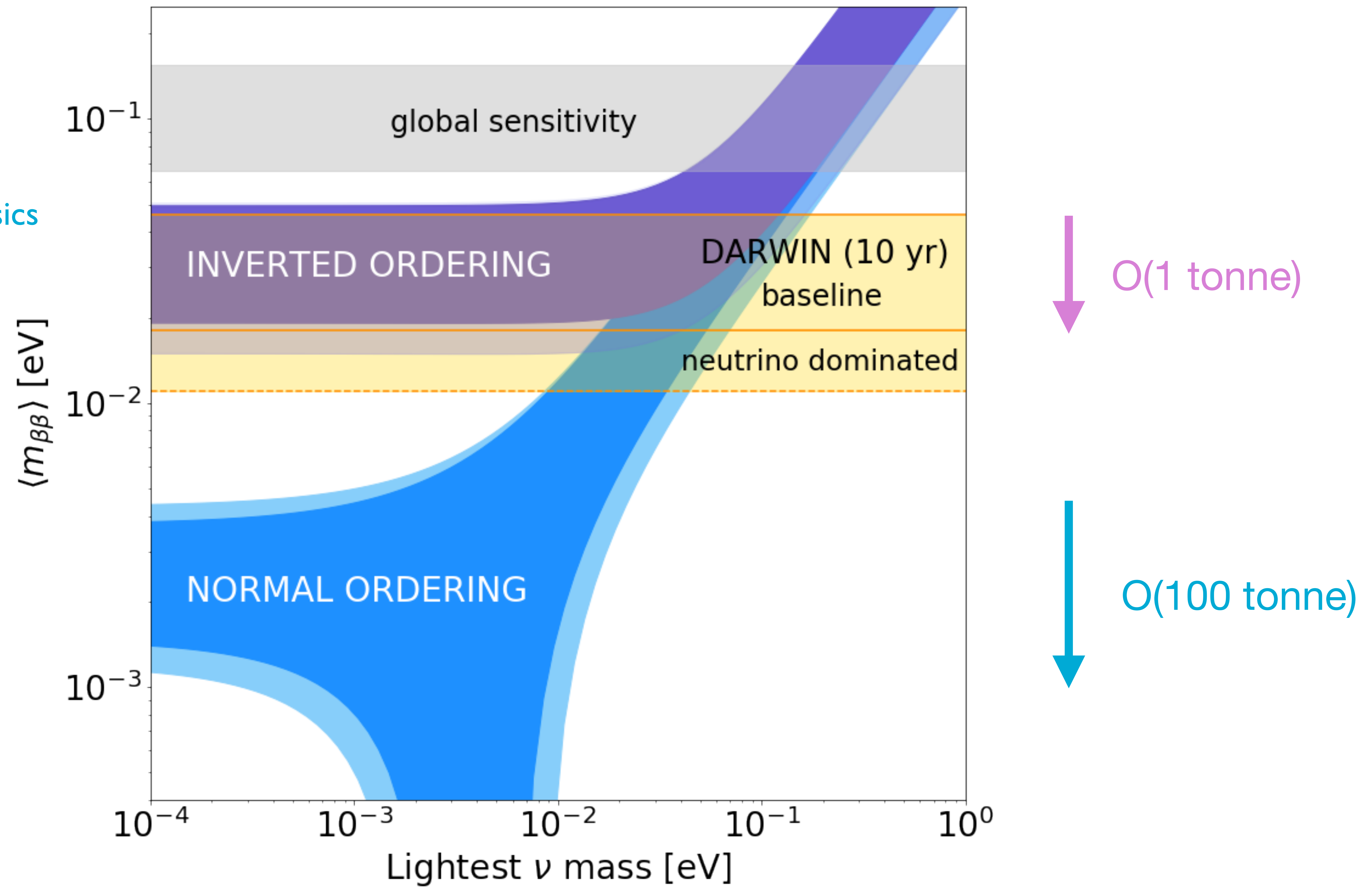
Phase Space factor

Nuclear Matrix Element

Interesting physics

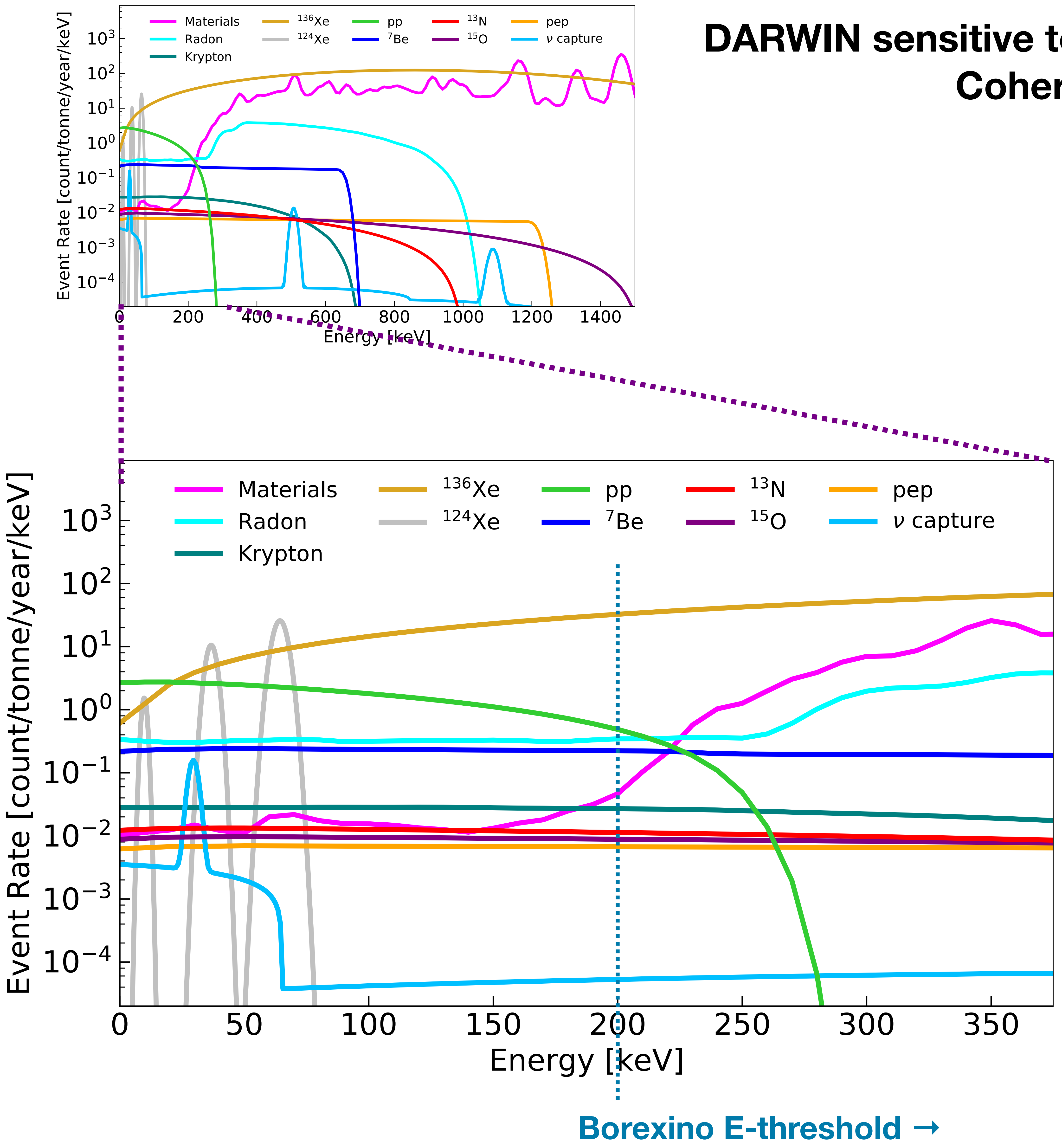
Effective Majorana mass: $\langle m_{\beta\beta}\rangle = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right|$

DARWIN, EPJC 80, 808 (2020); arXiv:2003.13407

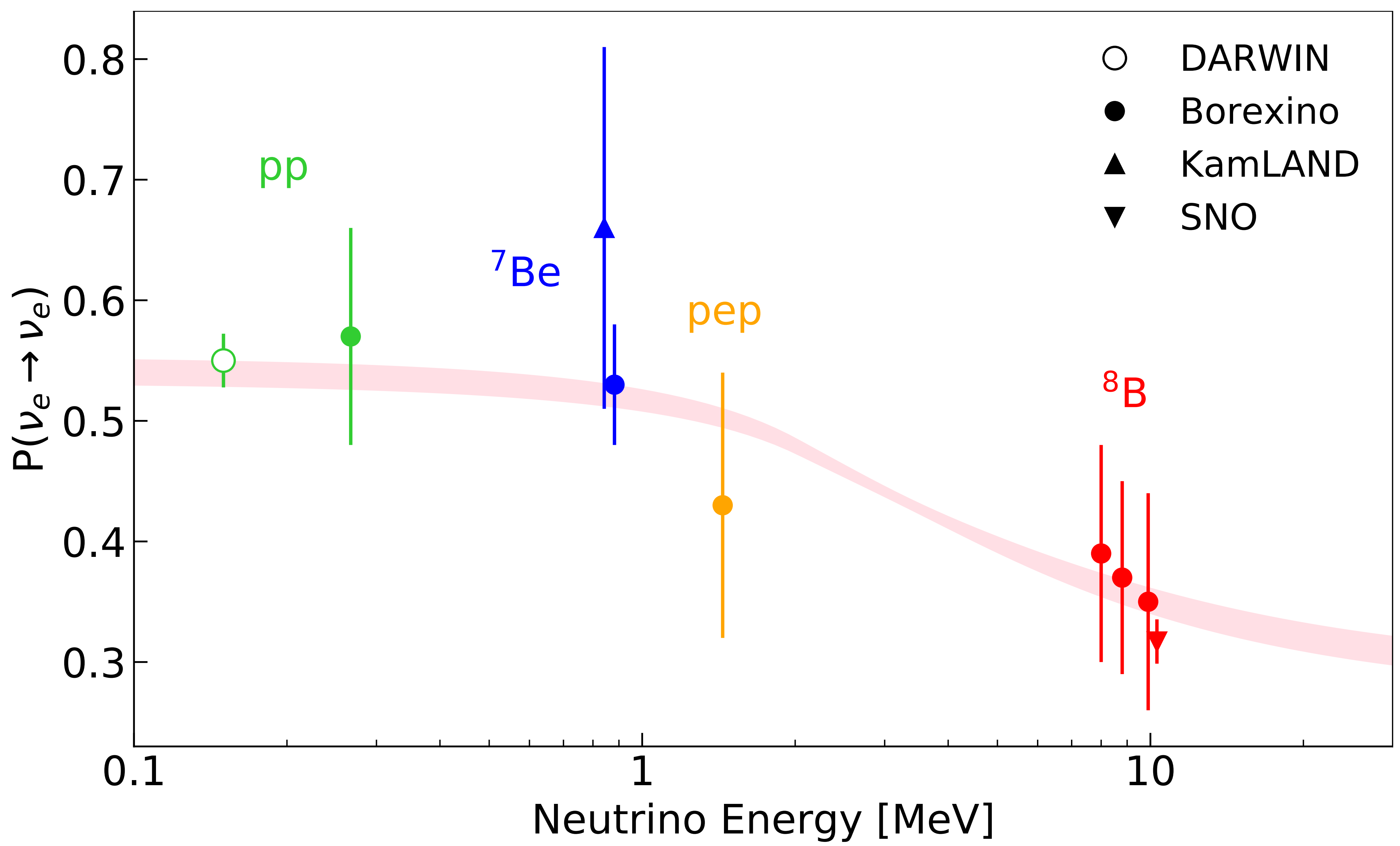


DARWIN will have world-competing 0v2β sensitivity, covering most of the Inverted Ordering

Unique: Low-Energy Solar Neutrinos



DARWIN sensitive to: Elastic scattering of solar ν on Xe electrons
Coherent Neutrino-Nucleus Scattering

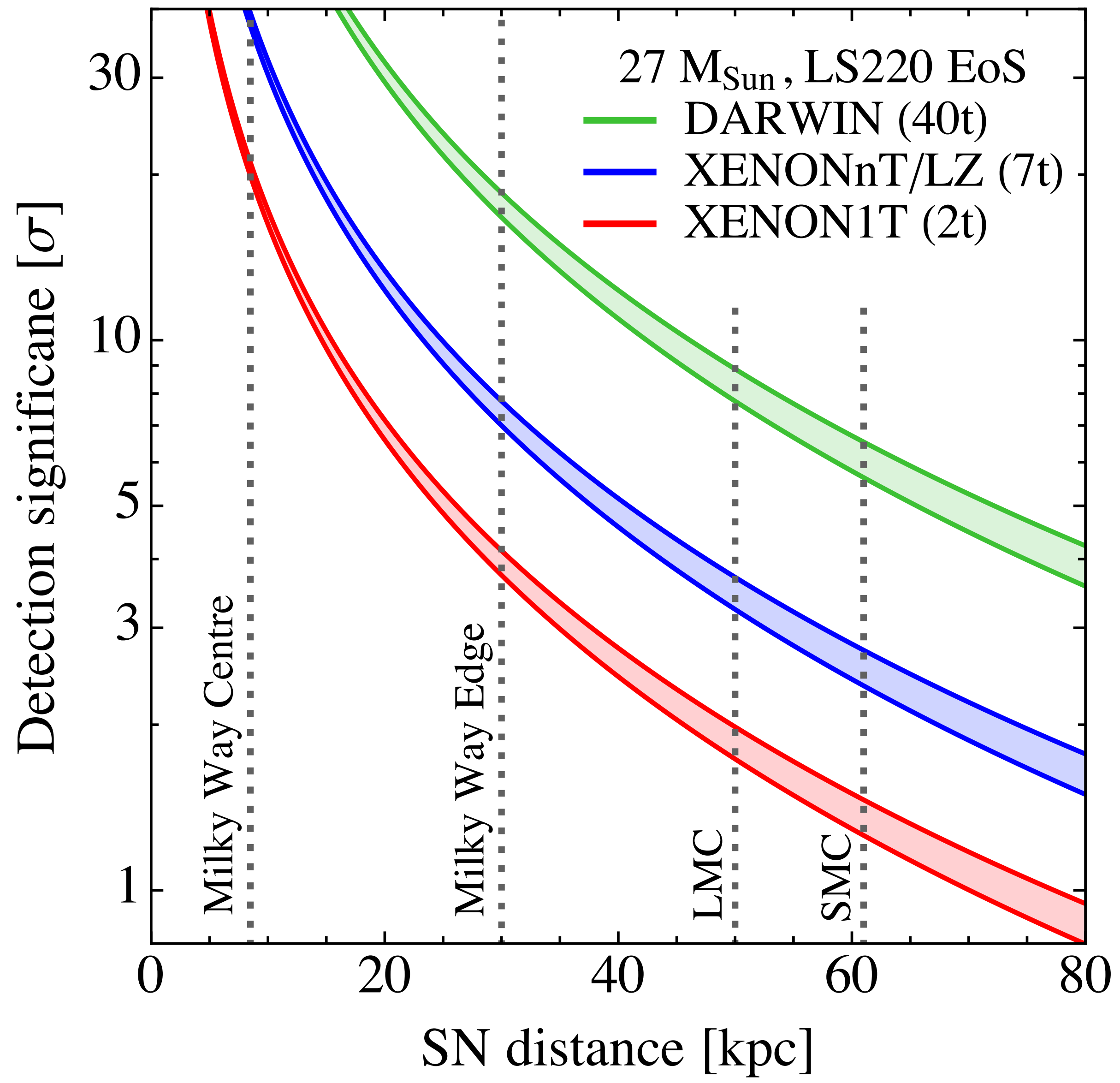


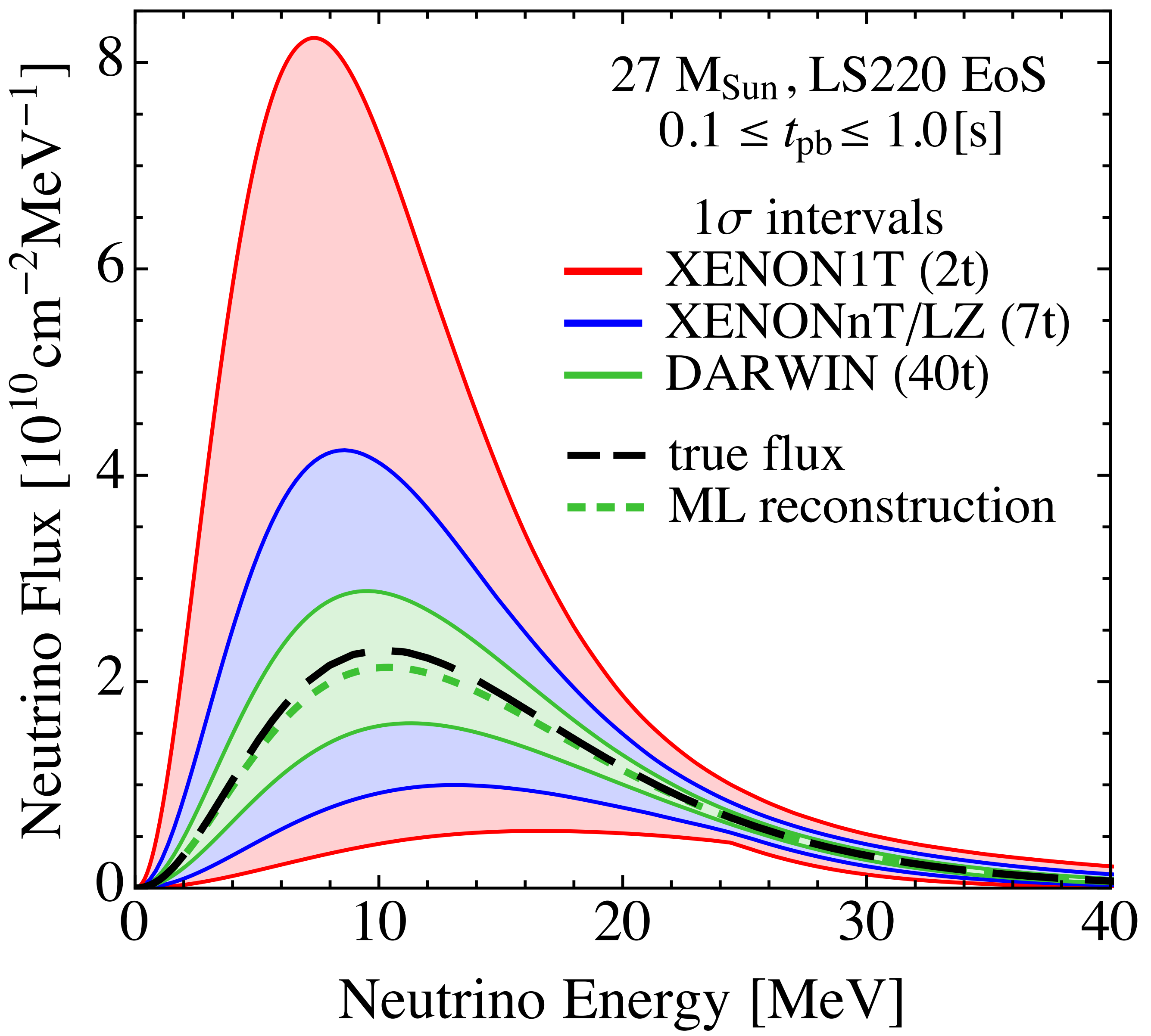
- 1% measurement of solar pp-neutrinos
- Map out the vacuum to matter oscillation transition
- Detailed measurement of other ν components allows to determine metallicity of the Sun
- Non-standard neutrino interactions

DARWIN, arXiv:2006.03114

Other Neutrino Physics

- Extremely rare radioactive decays → important input for nuclear models
  - Detailed 2ν2β spectrum of ^{136}Xe
  - Double-electron capture in ^{124}Xe
  - (with depleted target) double-beta in ^{134}Xe and ^{126}Xe
- Galactic supernova
  - sensitive to all active neutrino species from Type-1a and failed core-collapse supernovae
- Enhanced neutrino magnetic moment

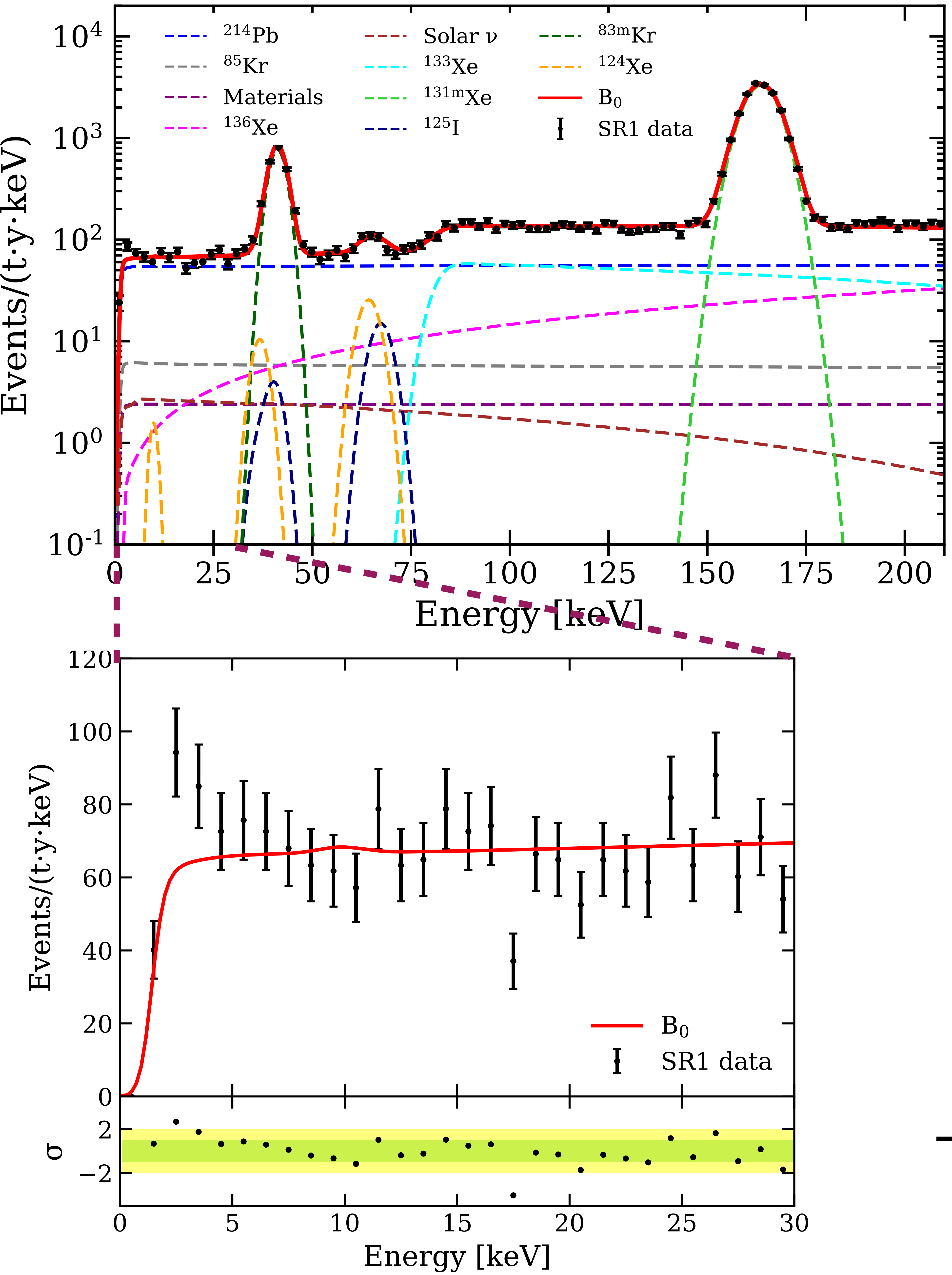




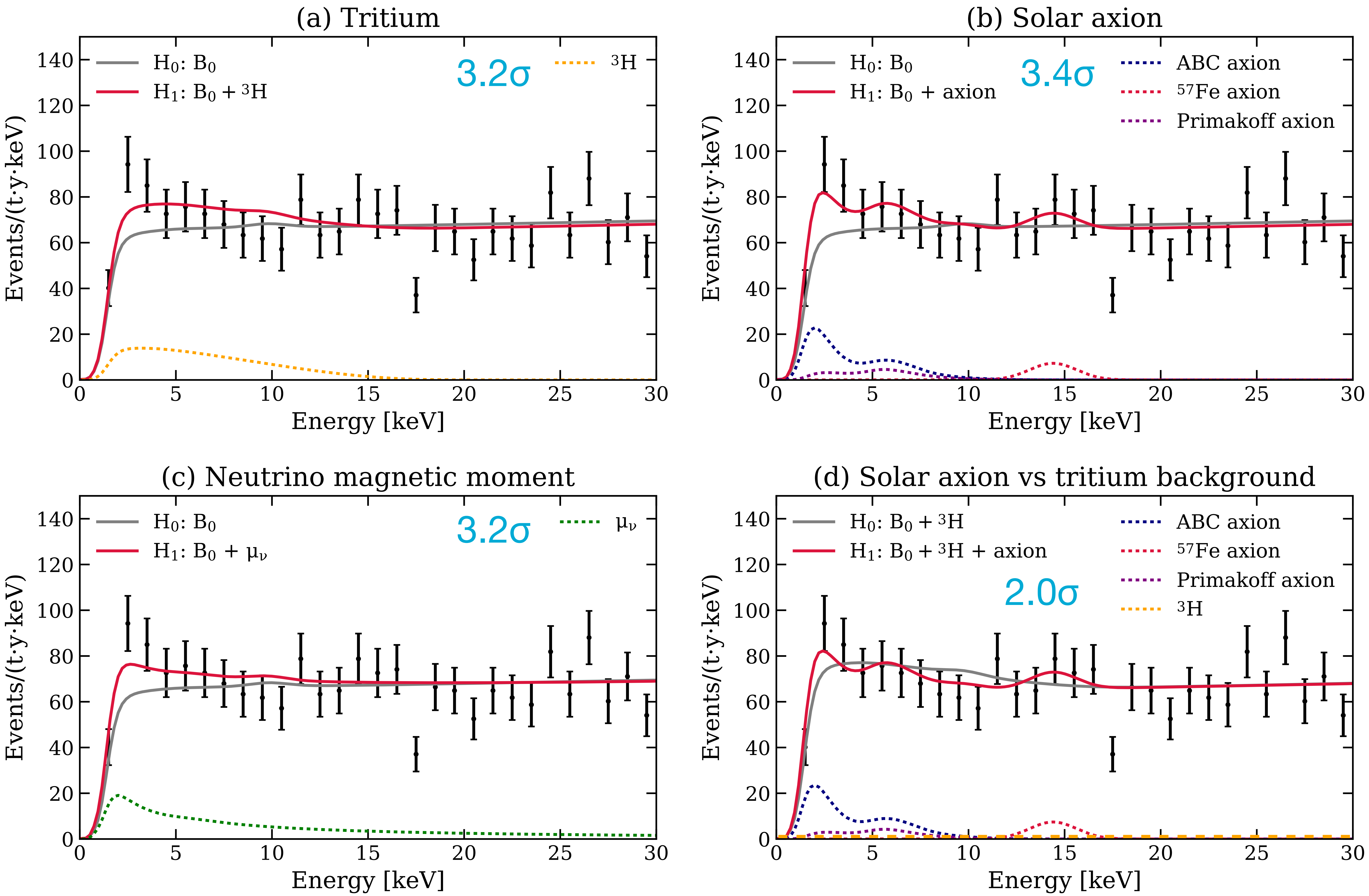
Hundreds of events will allow detailed ν measurements

R. Lang et al, PRD 94 (2016) 10, 103009; arXiv:1606.09243

Unexpected Excess of ER events in XENON1T



Interactions with atomic electrons in LXe



>3σ results. Unexpected Tritium BG? More Statistics? Signal?

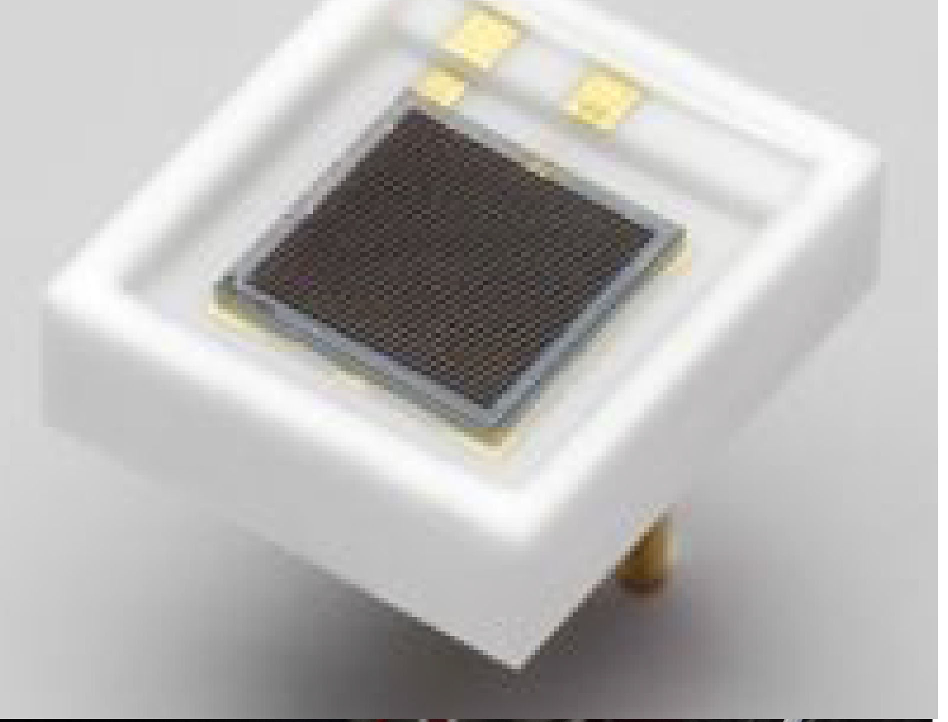
→ ultra low-background facility, expect the unexpected

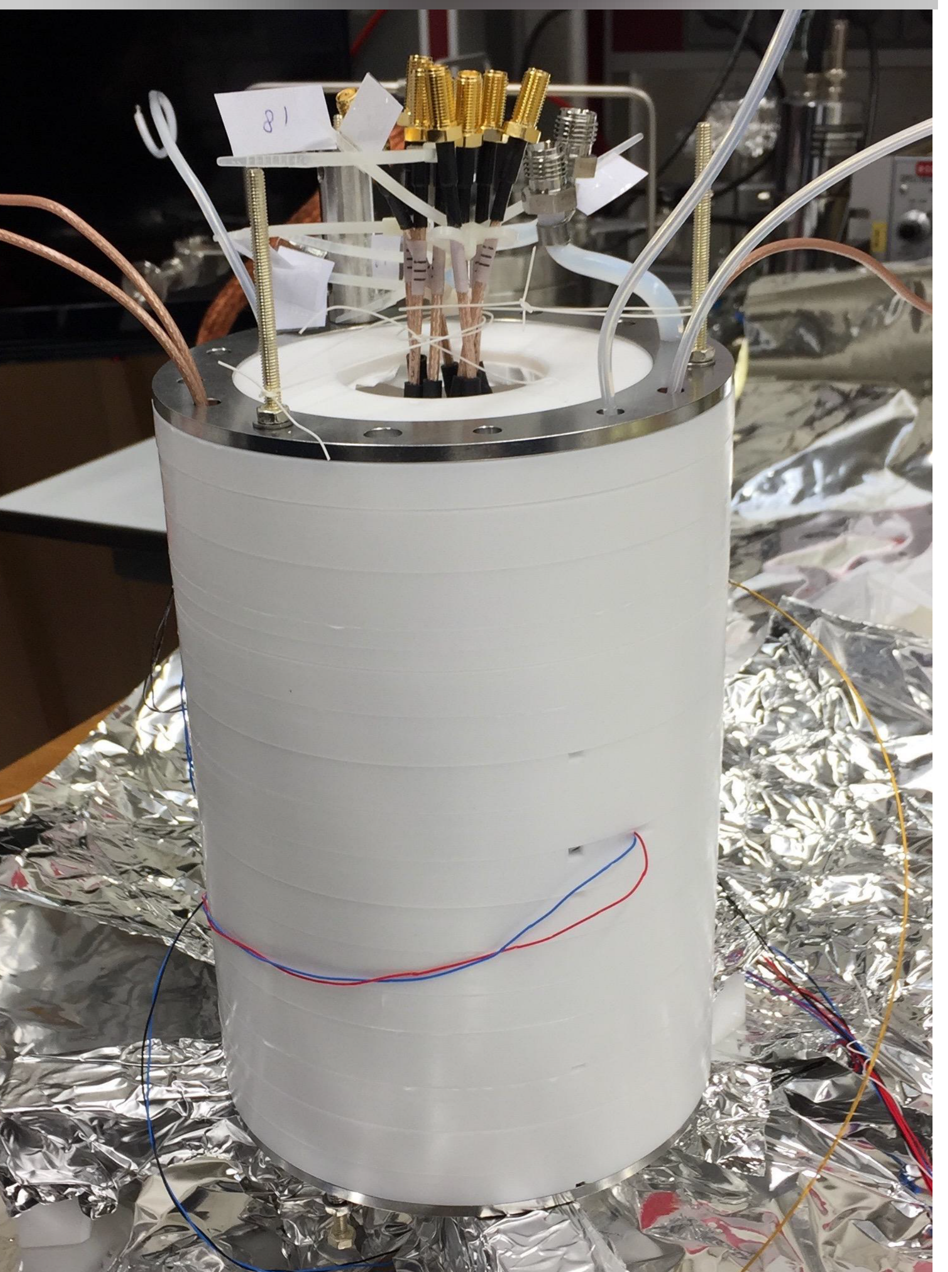
XENON, PRD 102, 072004 (2020); arXiv:2006.09721
(~150 citations already)

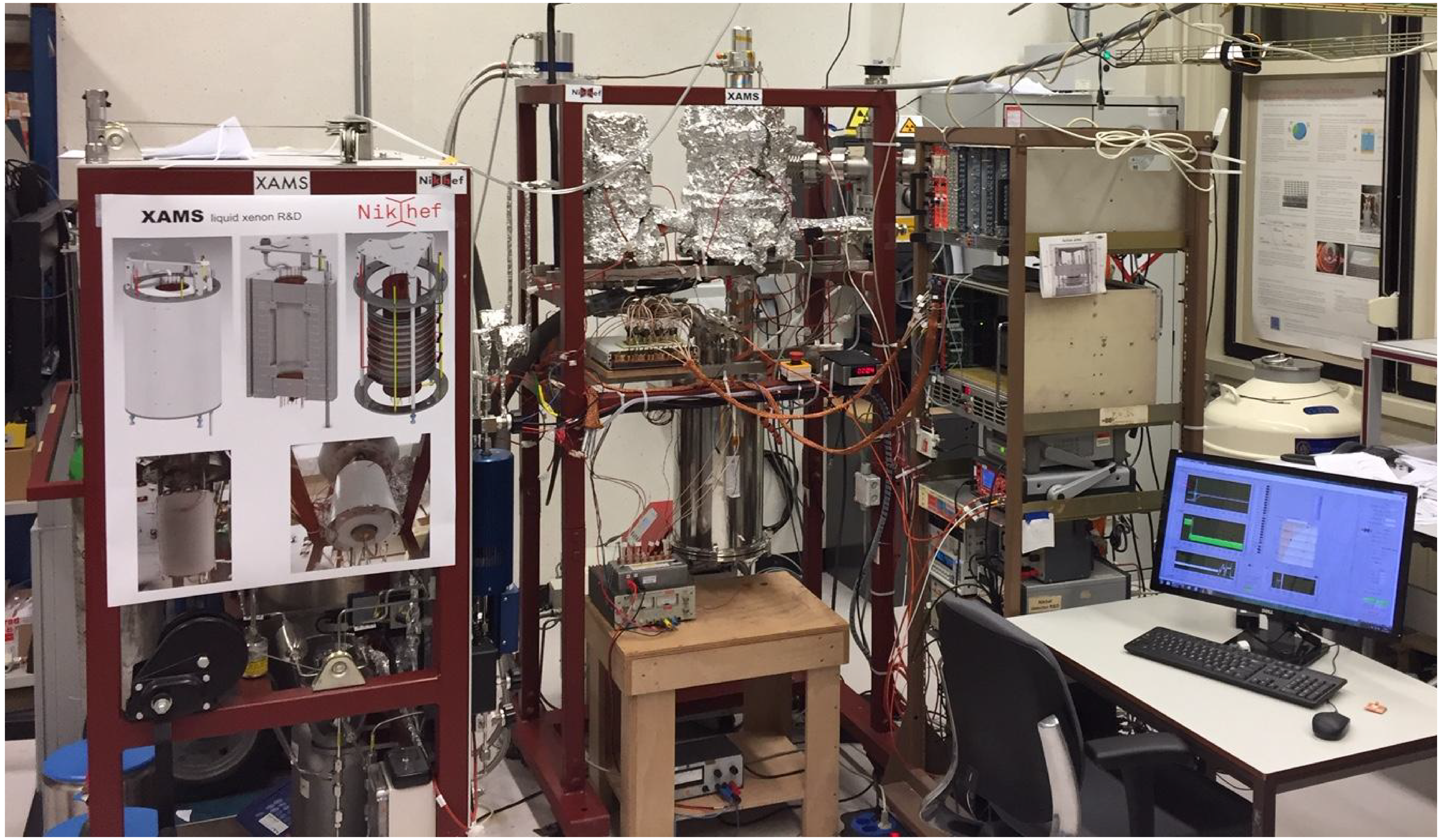
R&D

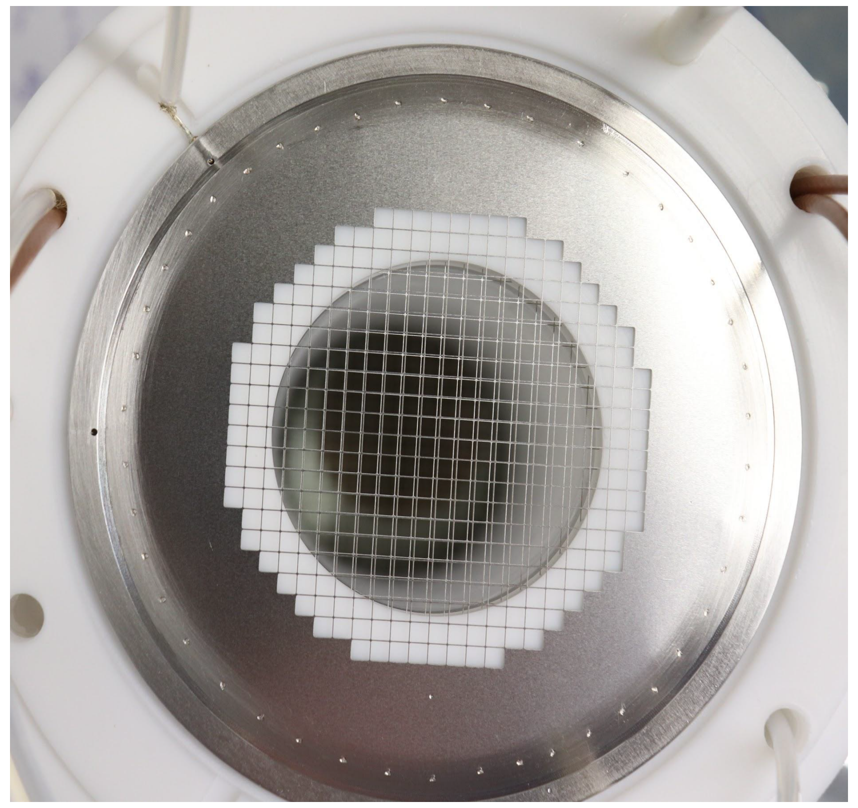
XAMS: Local LXe R&D

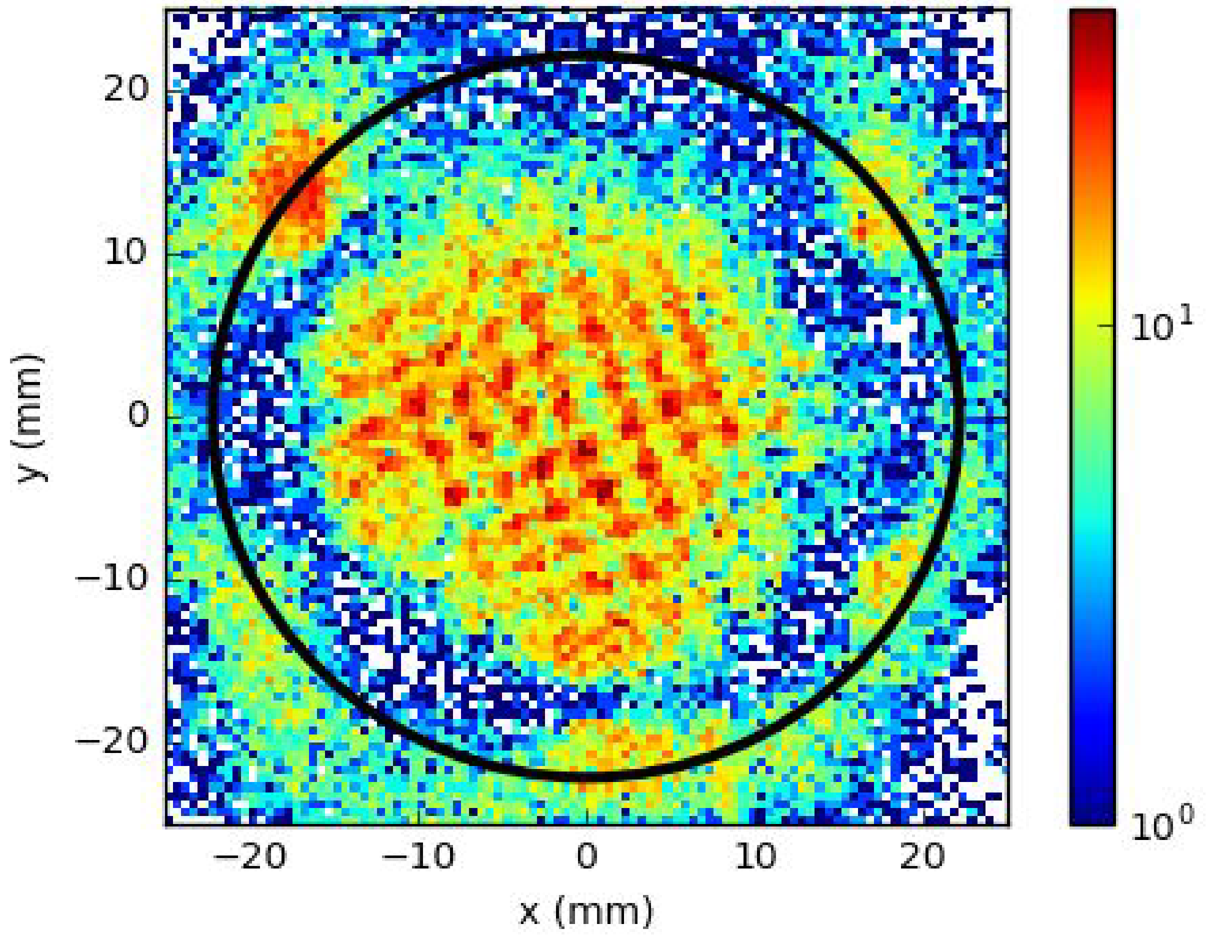
Hamamatsu S13370-3025CN
3x3 mm² active area











R&D for large liquid Xe detectors:

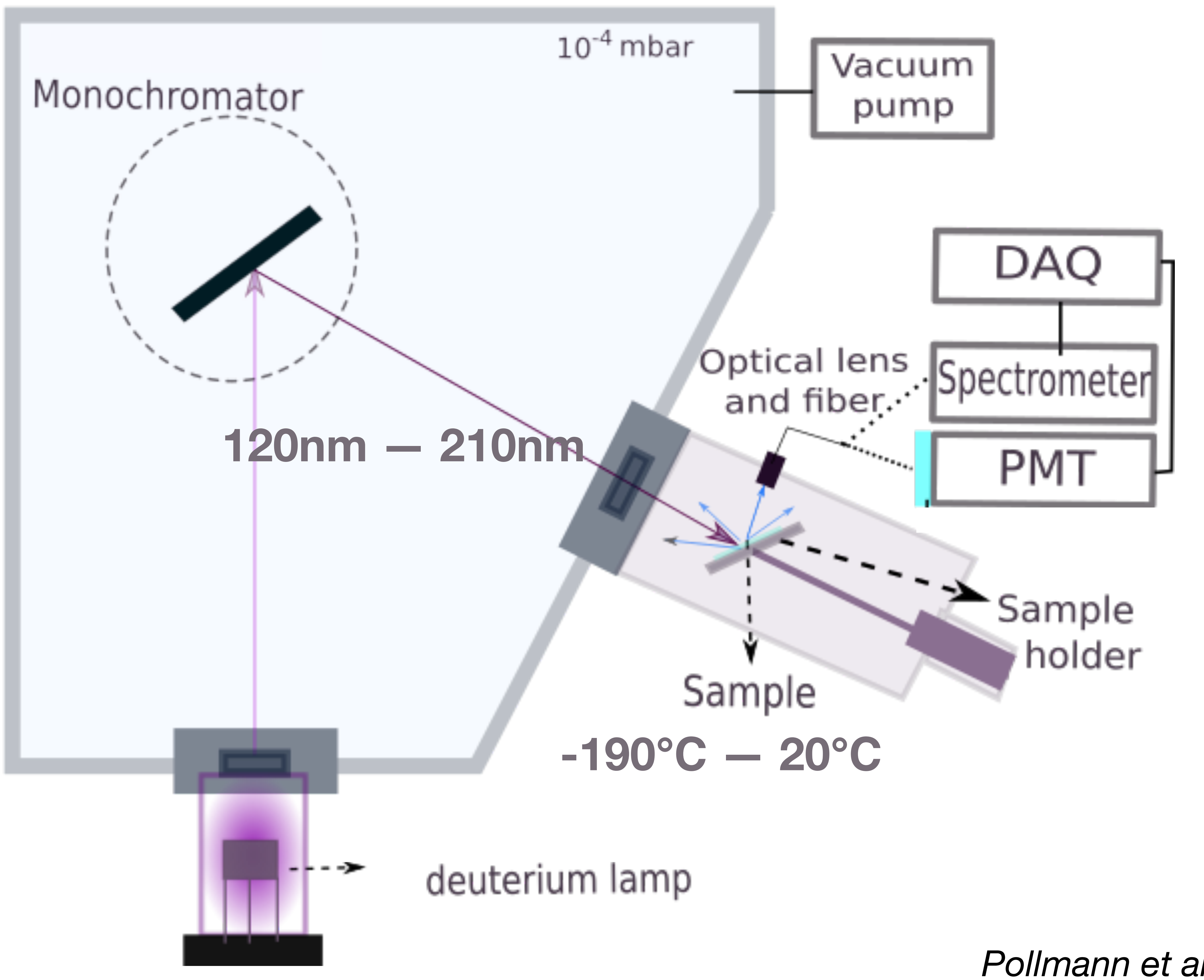
- Substituting SiPMs in the top array
- Background measurements, e.g. ^{214}Pb spectrum
- Optimizing anodes
- LXe properties

E. Hogenbirk et al., NIM A840 (2016) 87, arXiv:1602.01974
E. Hogenbirk et al., JINST 13 (2018) 05, P05016, arXiv:1805.12562
E. Hogenbirk et al., JINST 13 (2018) 10, P10031, arXiv:1807.07121

R&D Multi-purpose VUV excitation experiment

Study the response of light detectors and materials to LXe and LAr scintillation light

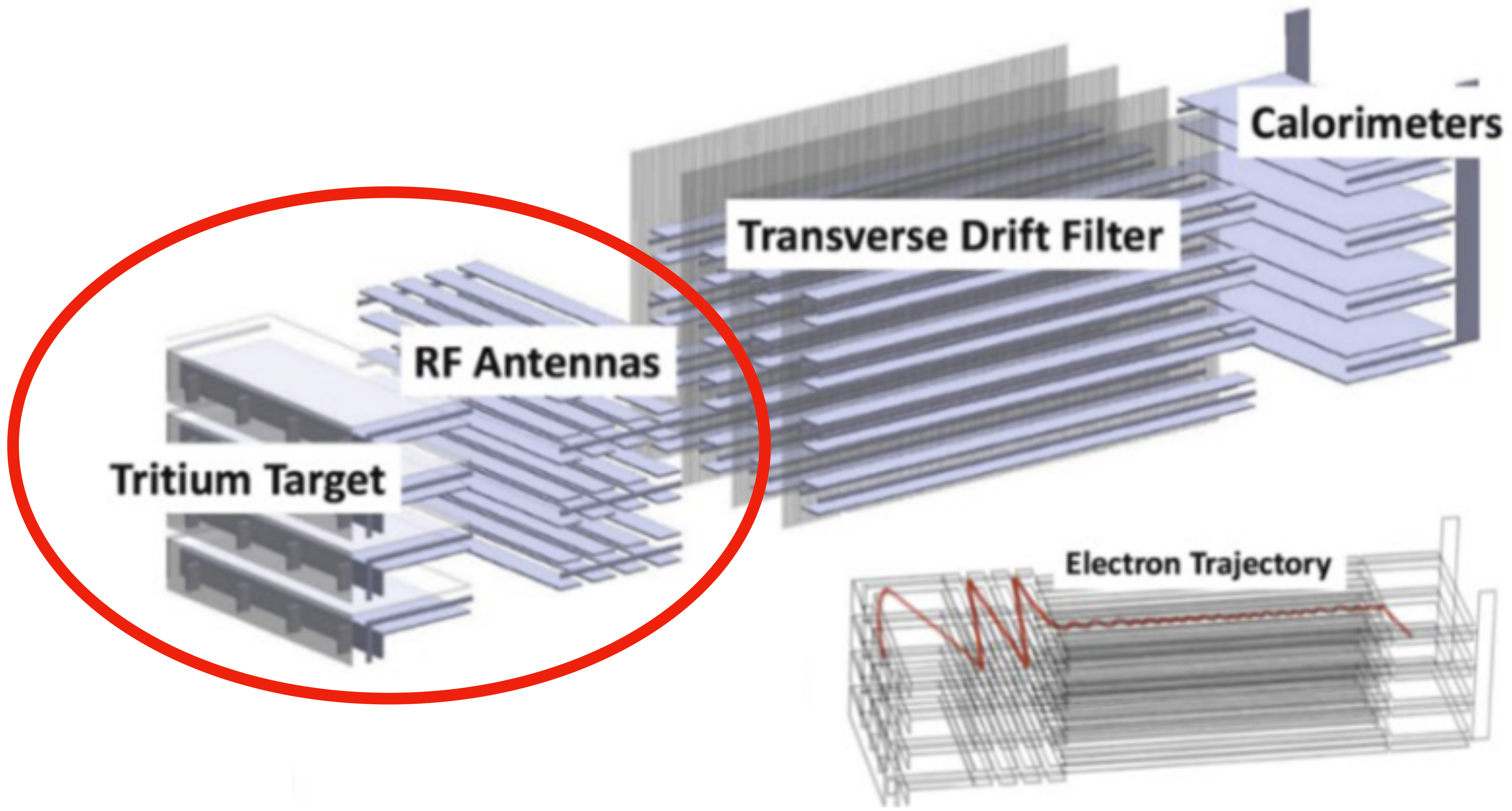
New faculty/staff Tina Pollmann (UvA/Nikhef) setting up new lab



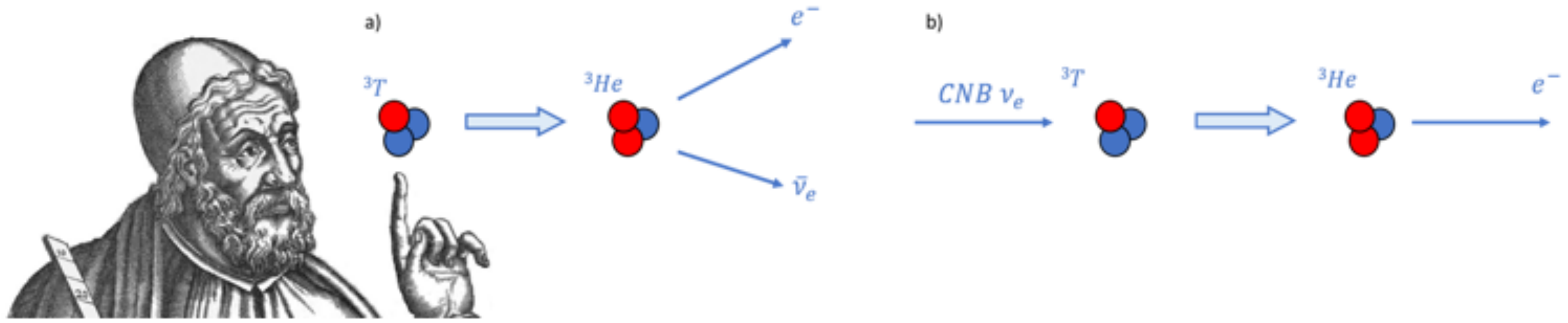
Pollmann et al, EPJC 79 (2019) 8, 653; arXiv:1905.03044
Pollmann et al, EPJC 79 (2019) 4, 291; arXiv:1806.04020

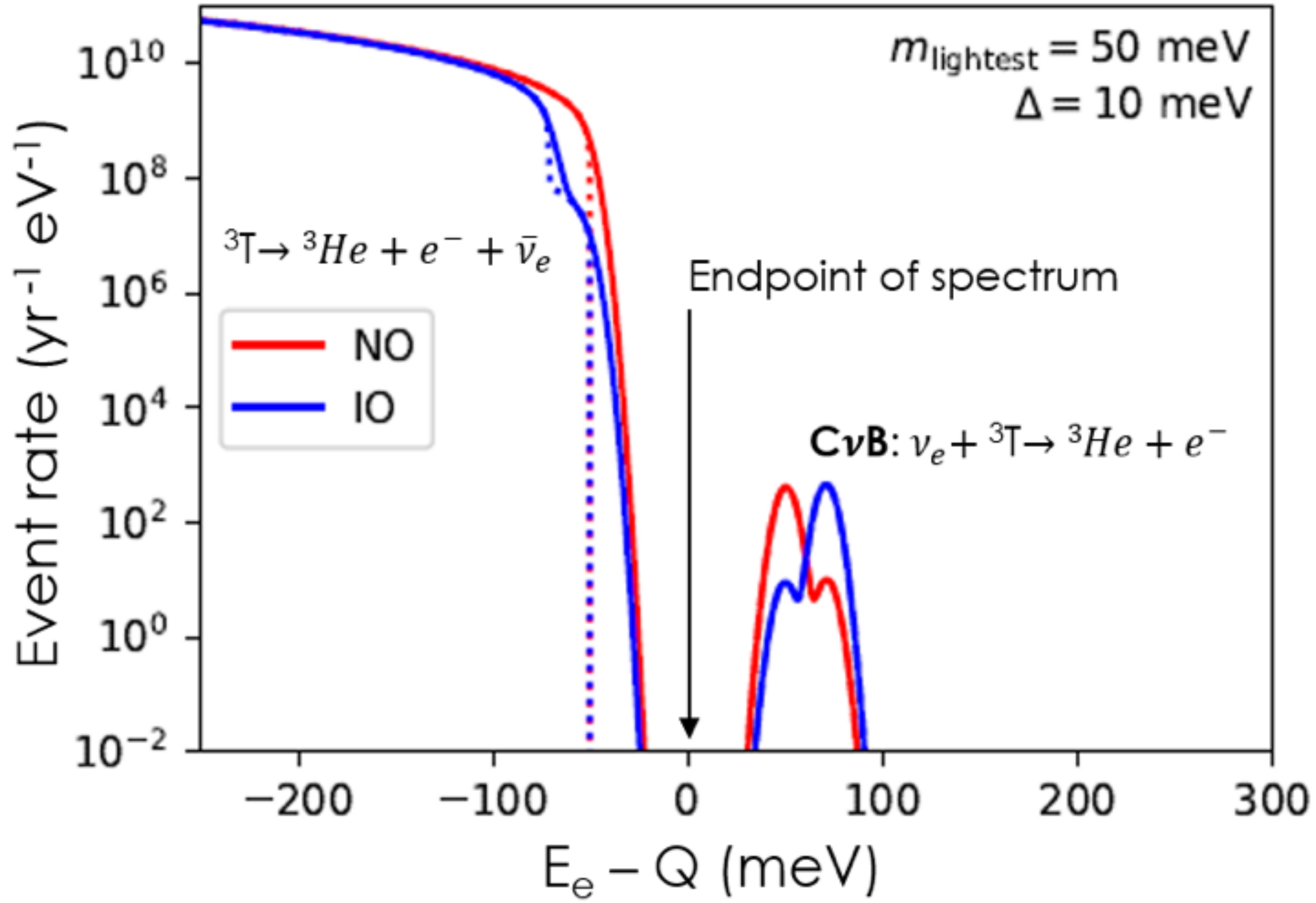
R&D

Relic Neutrino Detection with PTOLEMY



Ultimate Goal





- R&D phase in 2020-2025: **Proof of concept**
- Dutch contributions
  - Theory (UvA)
  - Tritium-graphene targets (RU)
  - RF detection of electrons (UvA/TNO)
- Expect decision on NWA-ORC mid-November

Applicants**: Colijn (UvA/Nikhef), de Groot (RU/Nikhef),** Ando (UvA), Zeitler (RU), van Rossum (TNO), Lock (THUAS)

Pitch

DARWIN

- DARWIN will be a low-background ultra-rare physics observatory
  - Ultimate **dark matter** experiment:
    - Explore remaining WIMP parameter space
    - Sensitivity to other DM candidates and models
  - Unique or world-class **neutrino physics** sensitivity:
    - Are neutrinos Majorana?
    - Detailed determination of the solar neutrino flux
    - Other neutrino properties
- “Secondary” experiments, with "low-background physics” cross-pollination
  - Detection techniques, background mitigation
- Essential R&D at Nikhef

Backup

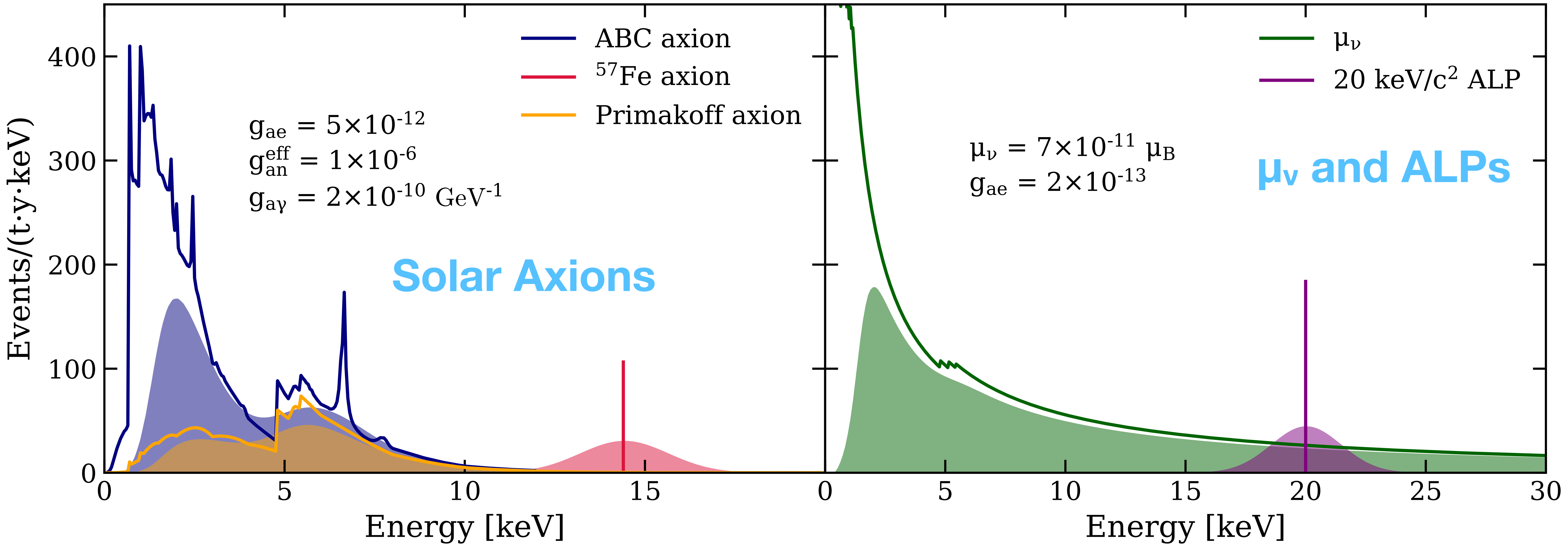
DARWIN: A Low Background Observatory

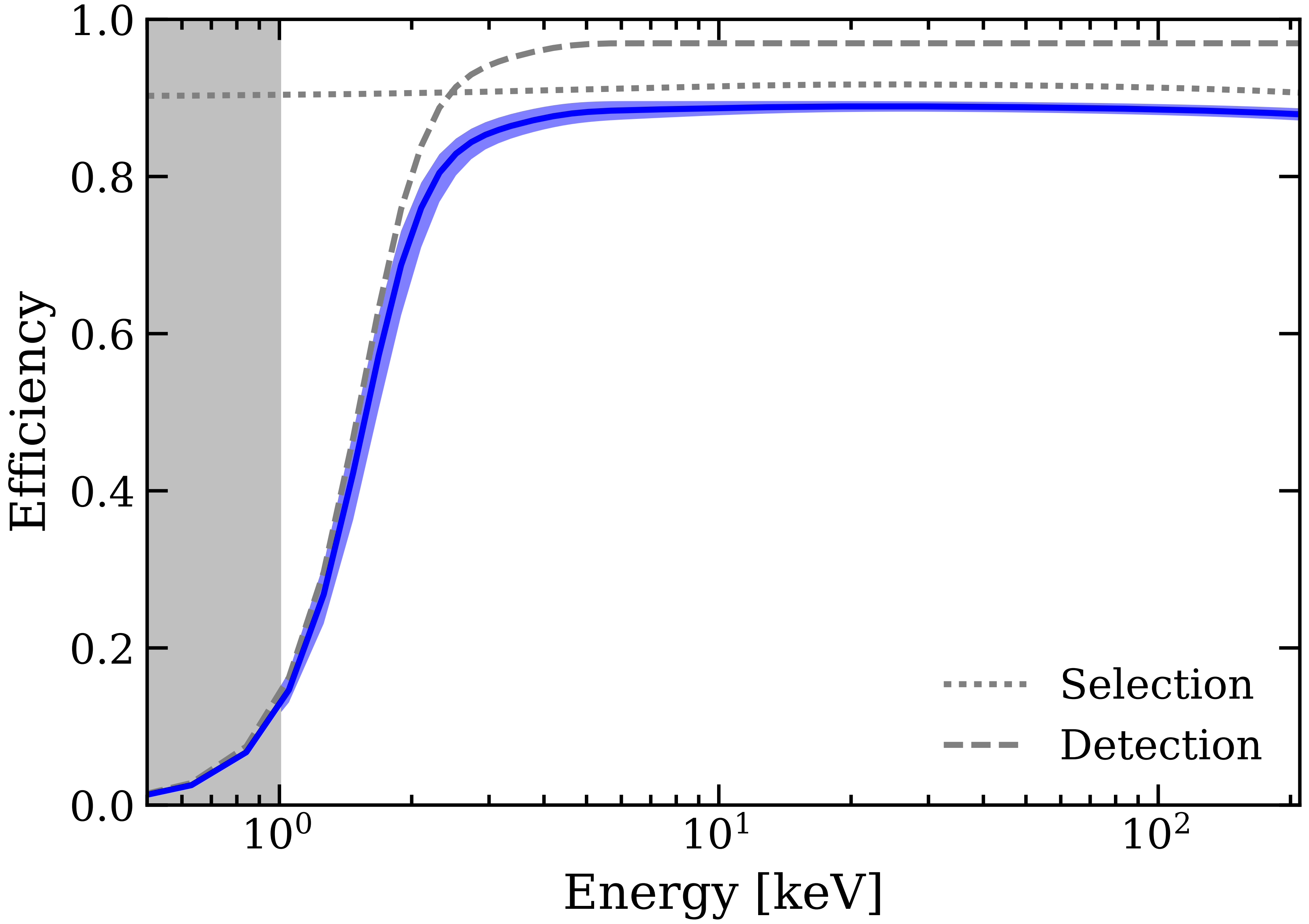
As detector size increases physics channels open up

- **WIMP searches** — NR
  - Spin-independent
  - Spin-dependent and inelastic interactions
- **Solar axions and galactic axion-like particles (ALPs)** — ER
  - Alternative dark matter candidates
  - Coupling to electrons via axio-electric effect
- **Supernova neutrinos** — NR
  - Sensitivity to all neutrino flavors (via CEvNS)
  - Complementarity to large-scale neutrino detectors
- **Coherent neutrino-nucleus scattering (CEvNS)** — NR
  - Predicted by SM, *only very recently observed!*
- **Low-energy solar neutrinos: pp, ^{7}Be** — ER
  - Test/improve solar model, test neutrino models
- **Neutrinoless double beta decay** — ER
  - Lepton number violating process, effective Majorana mass
  - No enrichment in ^{136}Xe required

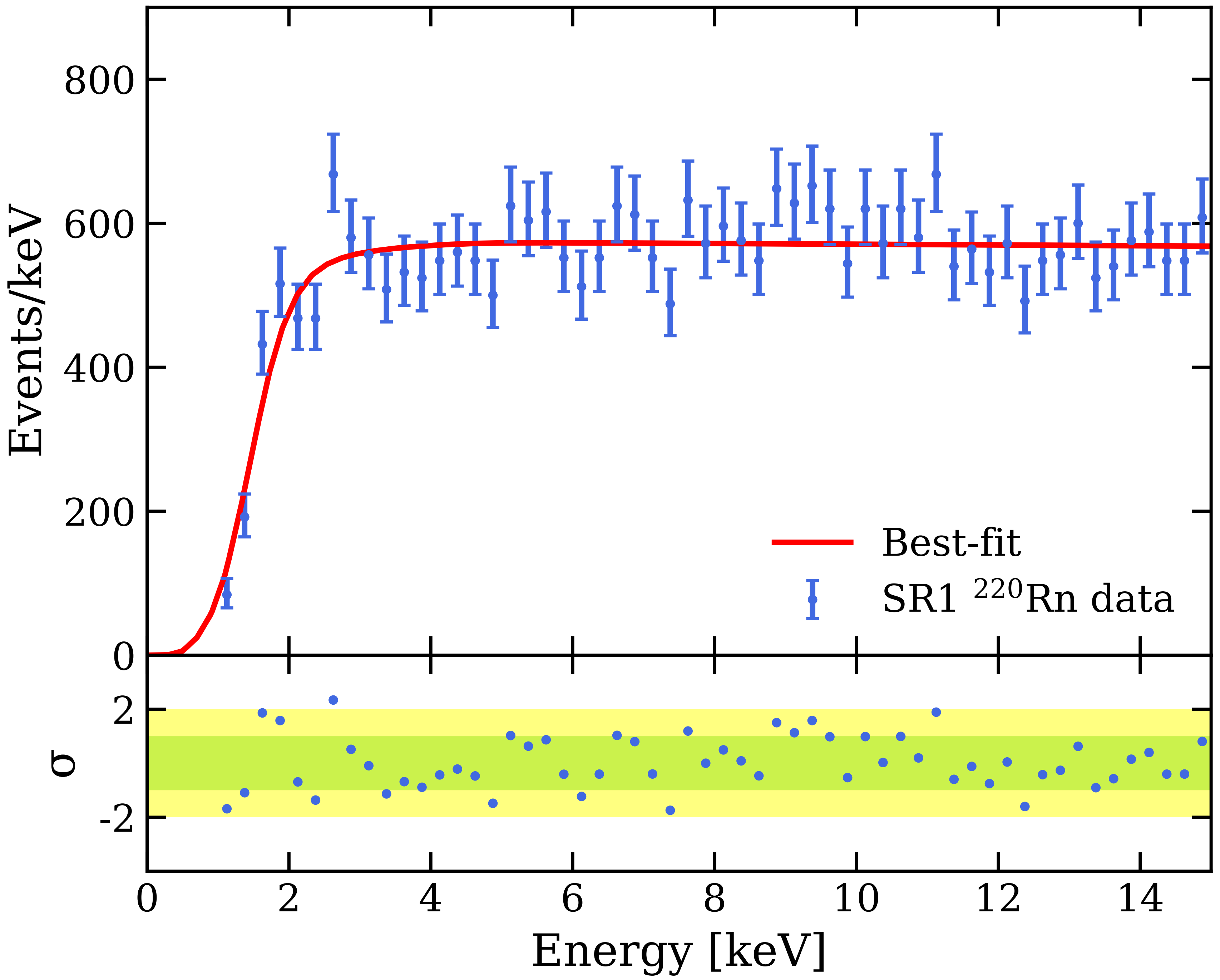
Low-energy ER Excess in XENON1T

Signal Models





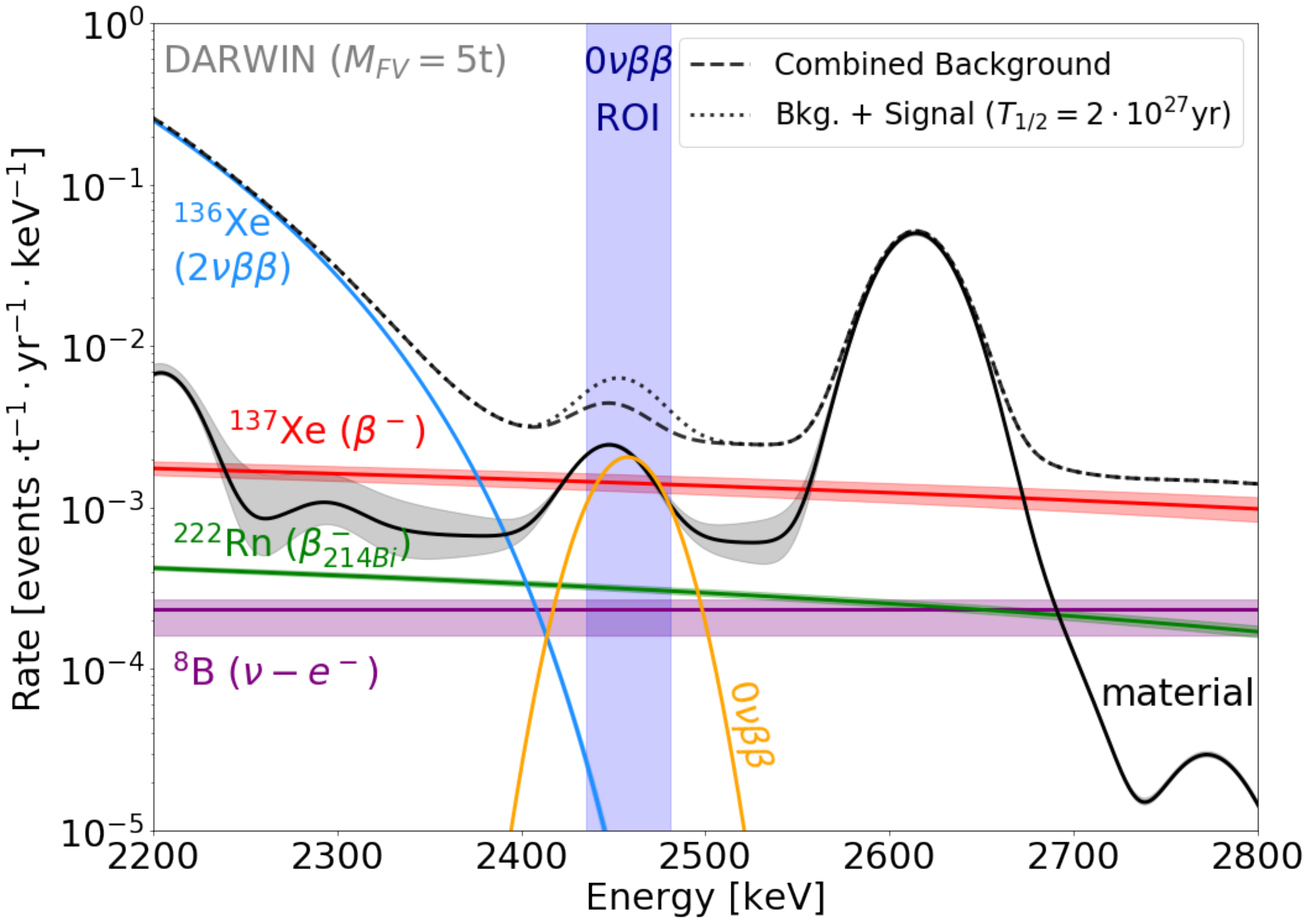
Radon-220 Calibration Source



We understand the Efficiency Curve

XENON, PRD 102, 072004 (2020); arXiv:2006.09721

Comparison to other 0v2β Experiments



Experiment	Isotope	Sensitivity limit (90% C.L.) $T^{0\nu}_{1/2}$ [yr]	$m_{\beta\beta}$ [meV]	Exposure time [yr]	Reference
DARWIN (baseline)	^{136}Xe	2.4×10^{27}	18-46	10	this work
DARWIN (ν dominated)	^{136}Xe	6.2×10^{27}	11-28	10	this work
KamLAND2-Zen	^{136}Xe	6×10^{26}	37-91	5	[37]
PandaX-III	^{136}Xe	1×10^{27}	28-71	3	[9]
NEXT-HD	^{136}Xe	3×10^{27}	16-41	10	[8]
nEXO	^{136}Xe	9.2×10^{27}	9-23	10	[10]
SNO+-II	^{130}Te	7×10^{26}	20-70	5	[37]
AMoRE-II	^{100}Mo	5×10^{26}	15-30	5	[37]
CUPID	^{130}Te / ^{100}Mo	(2-5)$\times 10^{27}$	6-17	10	[37]
LEGEND-1000	^{76}Ge	1×10^{28}	11-28	10	[37]

Table 4: Comparison of $T^{0\nu}_{1/2}$ and $m_{\beta\beta}$ sensitivity limits (90% C.L.) between DARWIN and future $0\nu\beta\beta$ experiments. For experiments using ^{136}Xe the $m_{\beta\beta}$ ranges are calculated with the nuclear matrix element ranges from [36], those using other isotopes are taken from [37].

DARWIN, EPJC 80, 808 (2020); arXiv:2003.13407