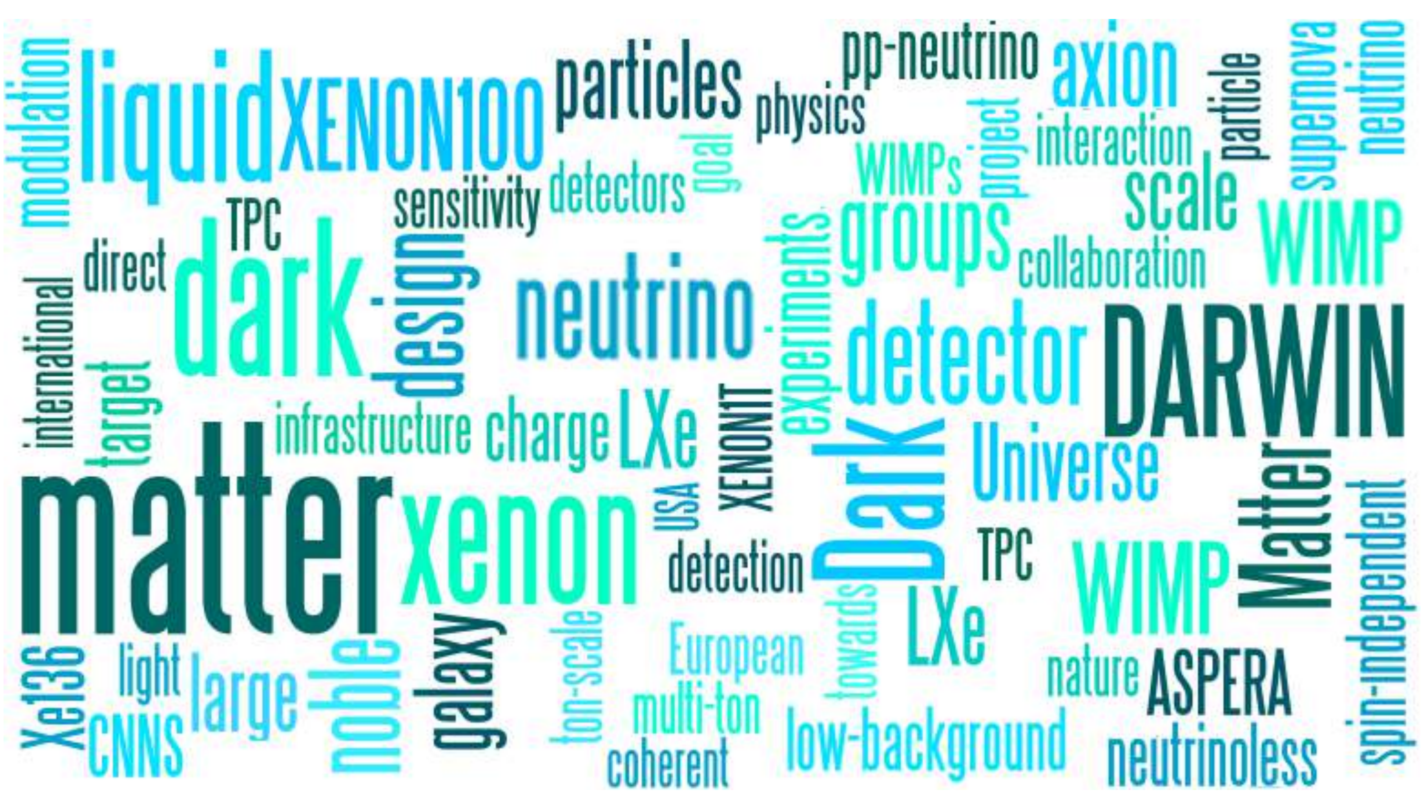
European Research Council
Established by the European Commission

University of Zurich[UZH]

DARWIN

DARWIN: The ultimate Dark Matter Detector

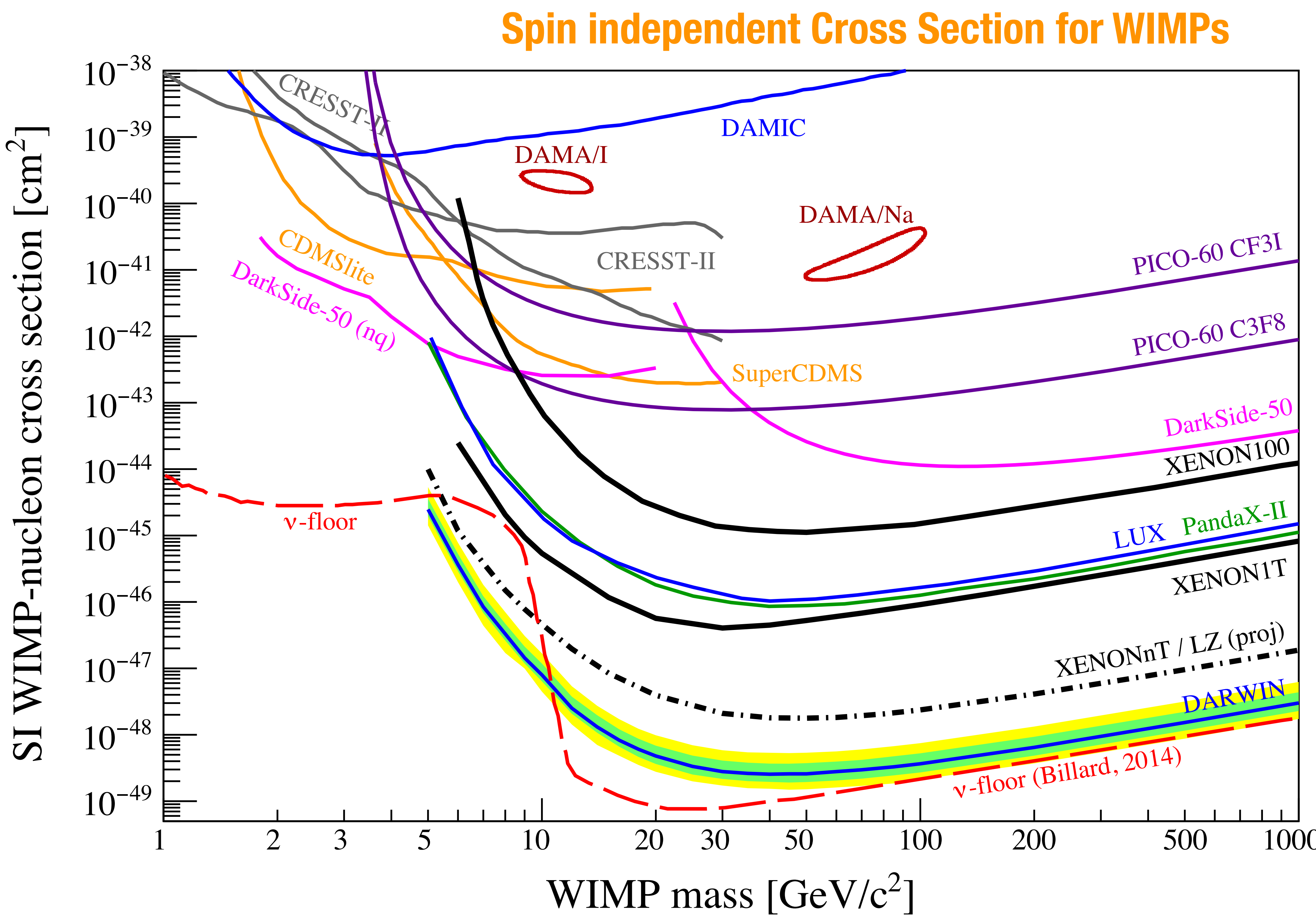
Yanina Biondi
University of Zürich
On behalf of the DARWIN collaboration



II South American Dark Matter Workshop
November 21-23, 2018
ICTP-SAIFR, São Paulo, Brazil

www.darwin-observatory.org

WIMP searches: Active field in the recent years



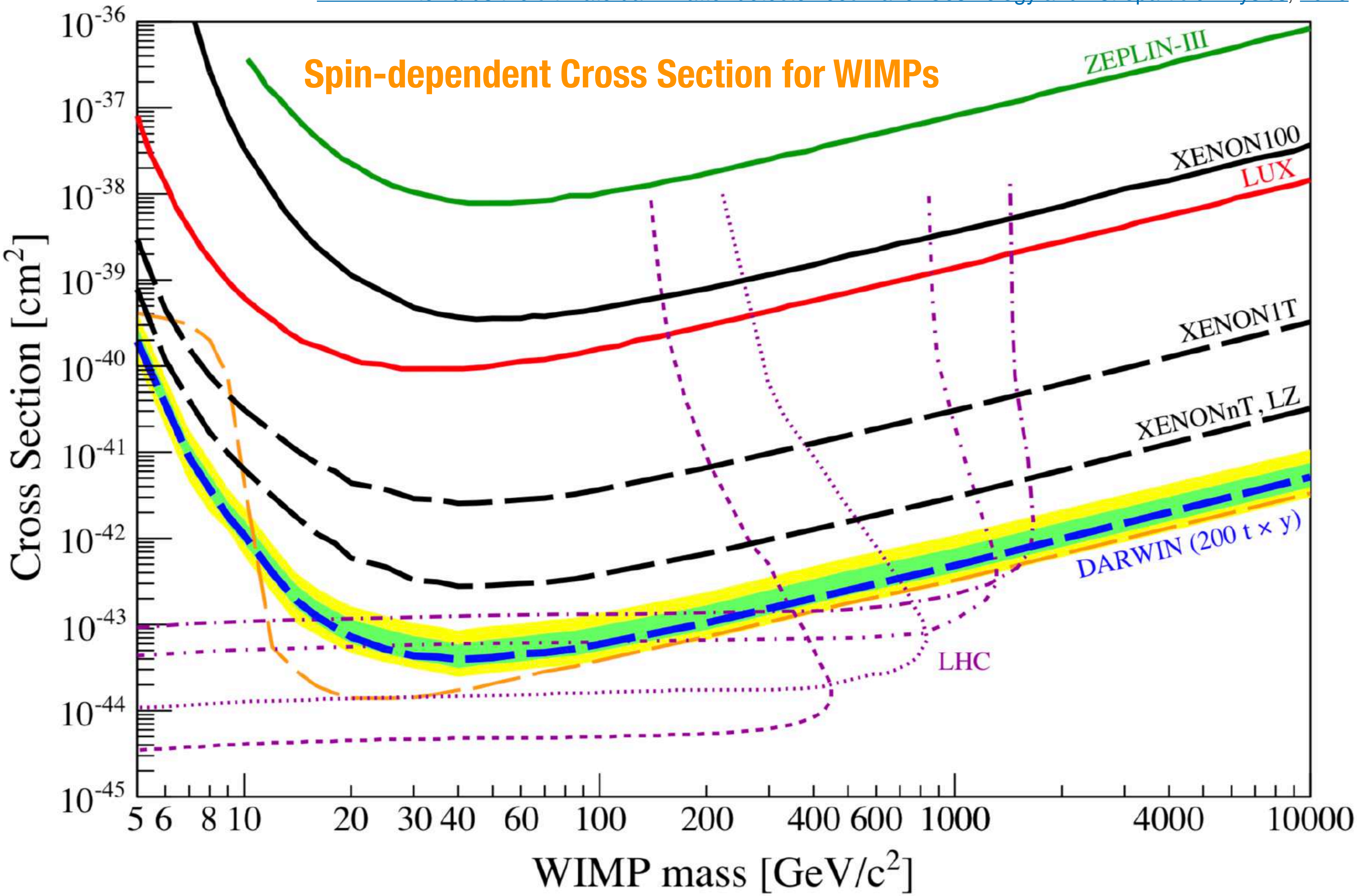
→ **Current limits**

→ **Future limits**

WIMP searches: Active field in the recent years

DARWIN

DARWIN: towards the ultimate dark matter detector. Journal of Cosmology and Astroparticle Physics, 2016



XENON EVOLUTION

DARWIN

2008
10 kg

XENON10

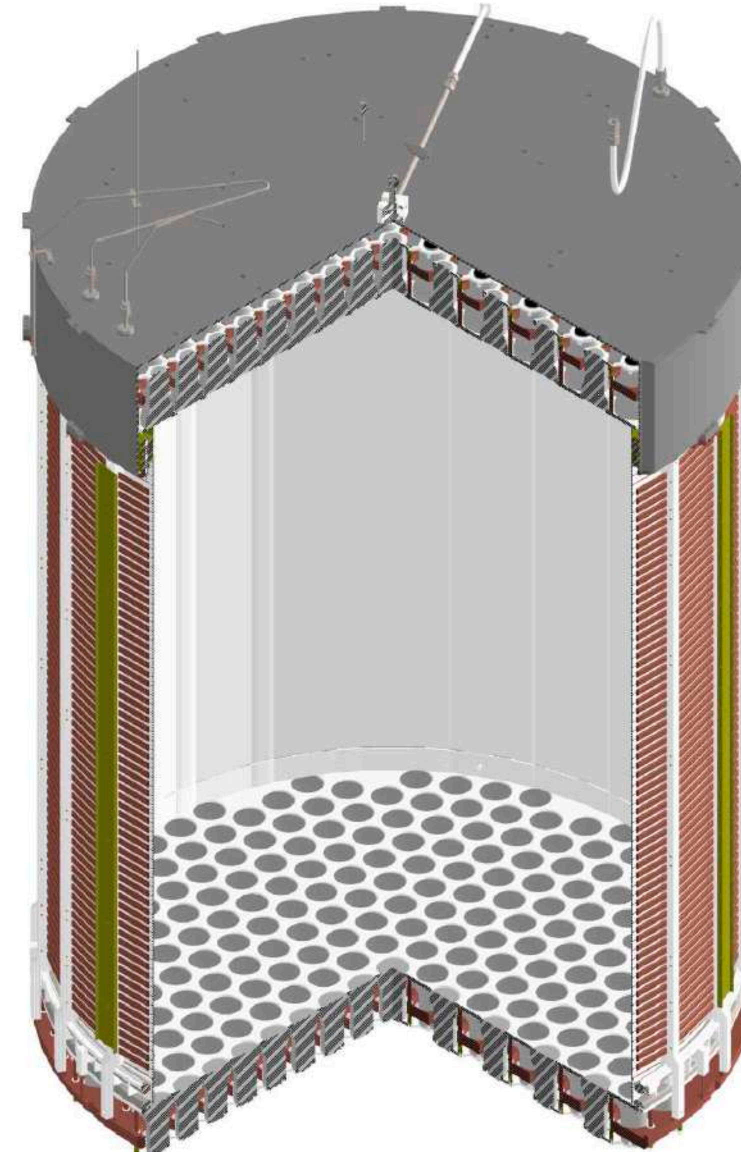
2012
100 kg

XENON100

2017
2 t

XENON1T

2019
5.9 t



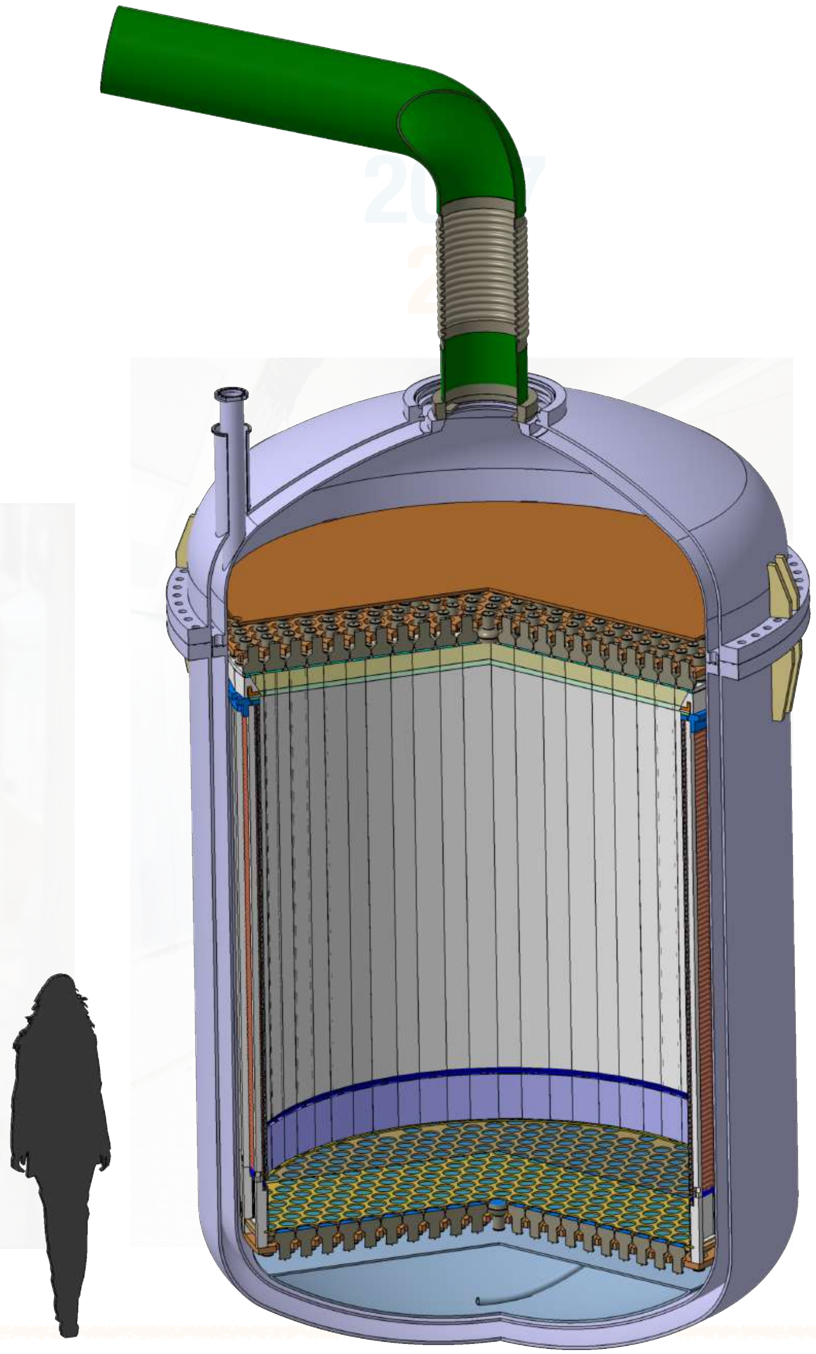
XENONnT

XENON EVOLUTION

DARWIN

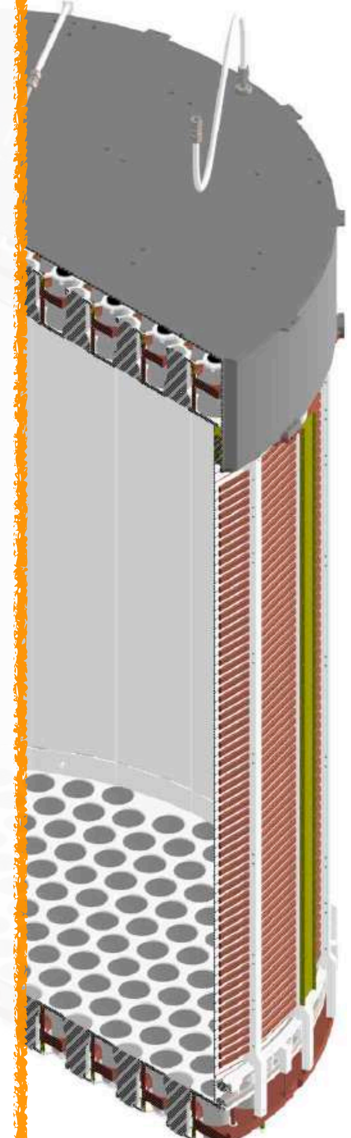
2008
10 kg

XENON10



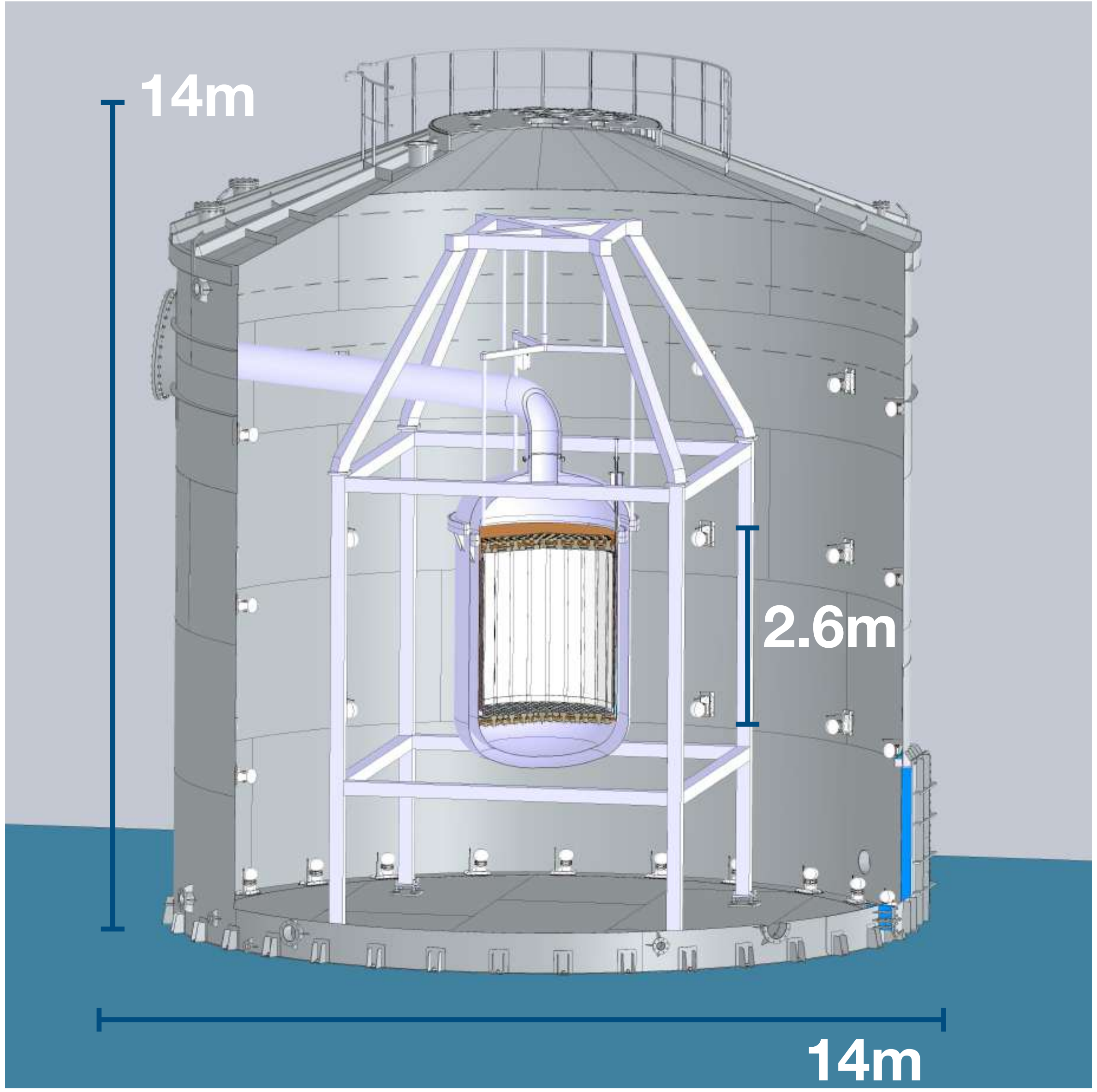
2025
40 t

DARWIN



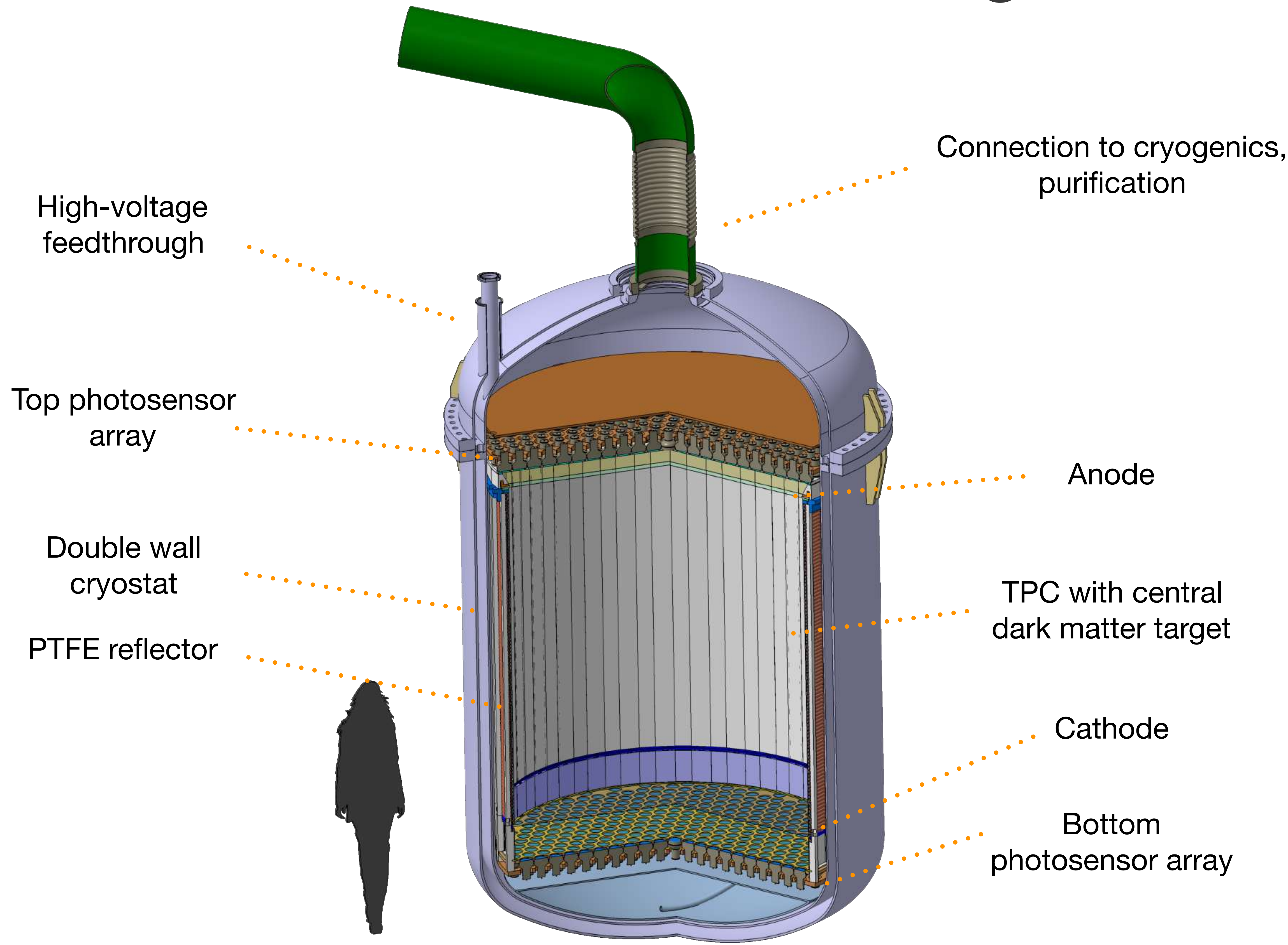
DARWIN Baseline Design

- Dual-phase Time Projection Chamber (TPC)
- 50t total (40 t active) of liquid xenon (LXe)
- Dimensions: 2.6 m diameter and 2.6 m height
- Two arrays of photosensors (top and bottom)
- PMTs and SiPM are being considered
- Drift field ~0.5 kV/cm
- Low-background double-wall cryostat
- PTFE reflector panels & copper shaping rings
- Outer shield filled with water (14 m diameter)
- Neutron veto scintillator or Gd doped water tank

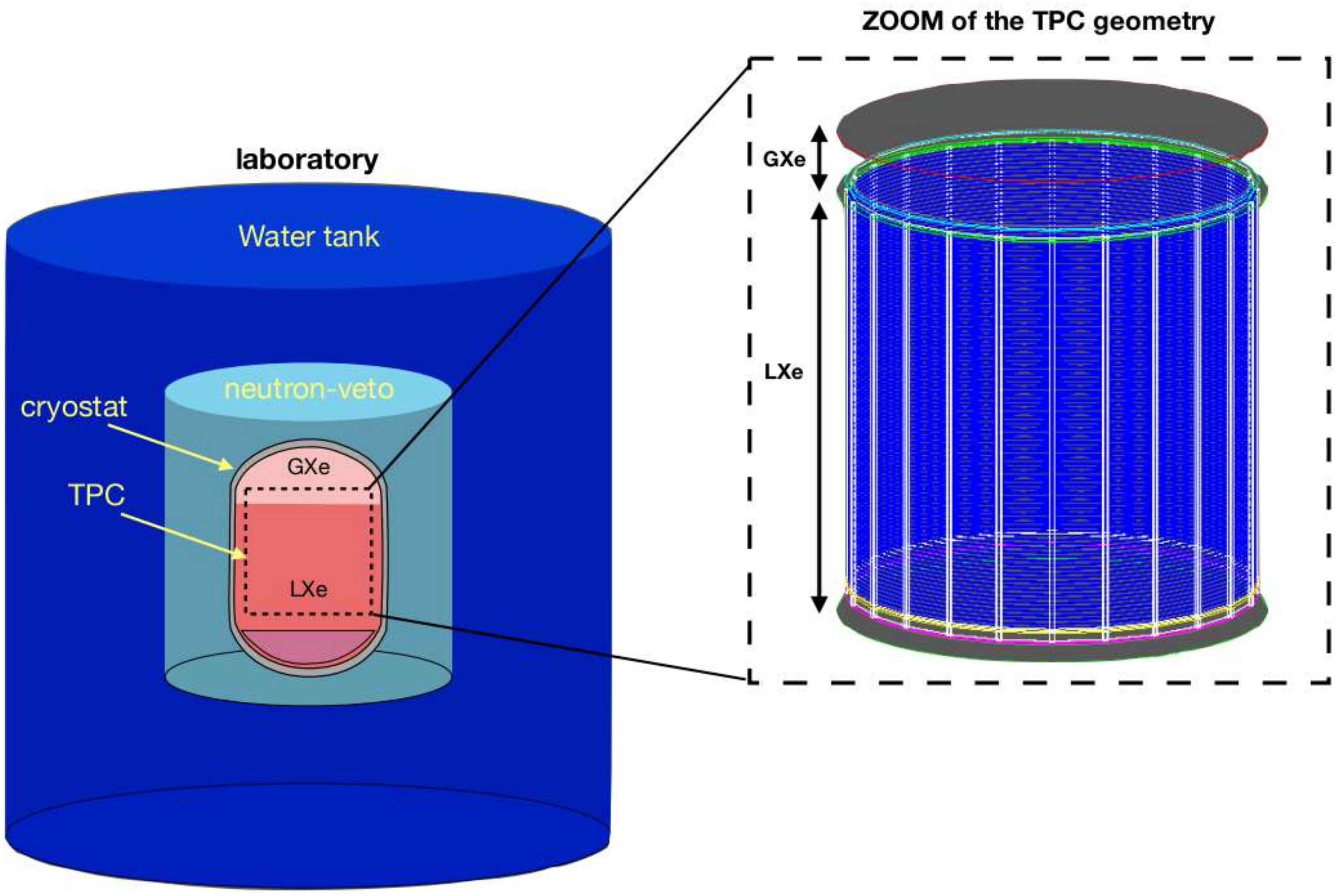


Possible realisation of DARWIN with its water tank

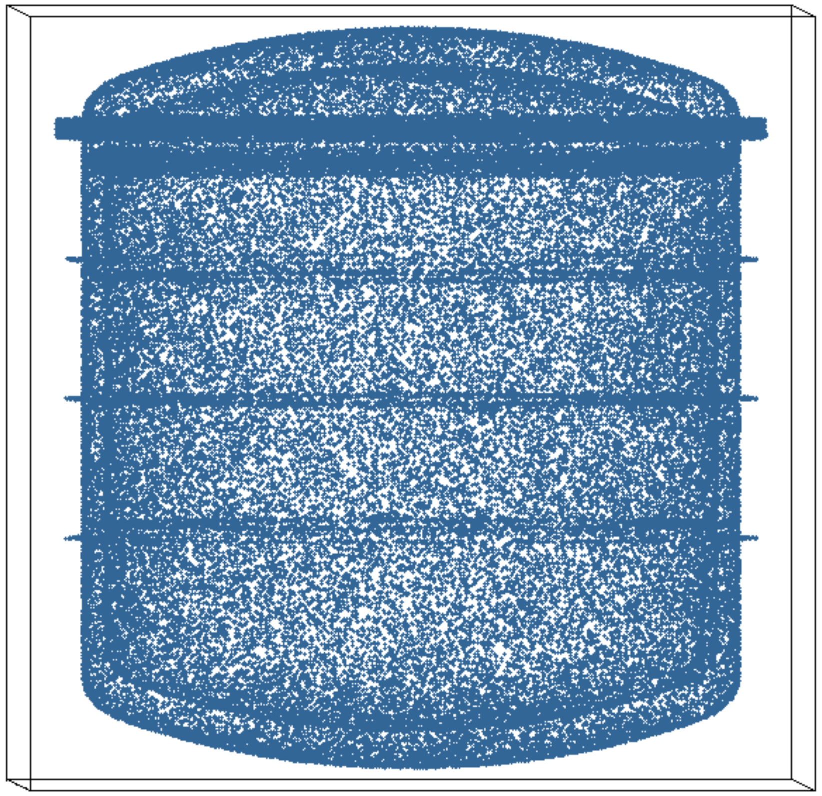
DARWIN Baseline Design



Baseline design in simulation framework:



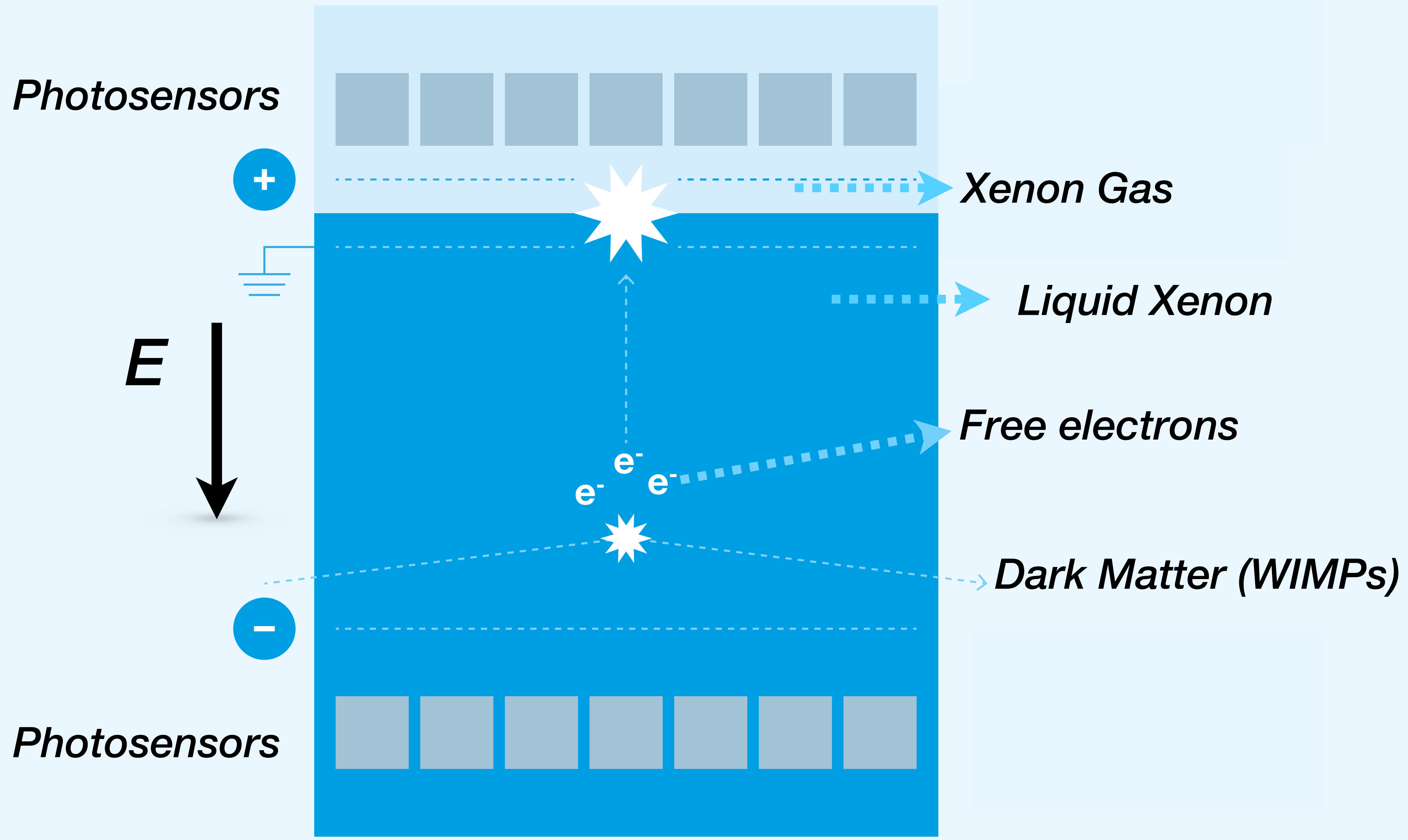
- PTFE pillars for structural support



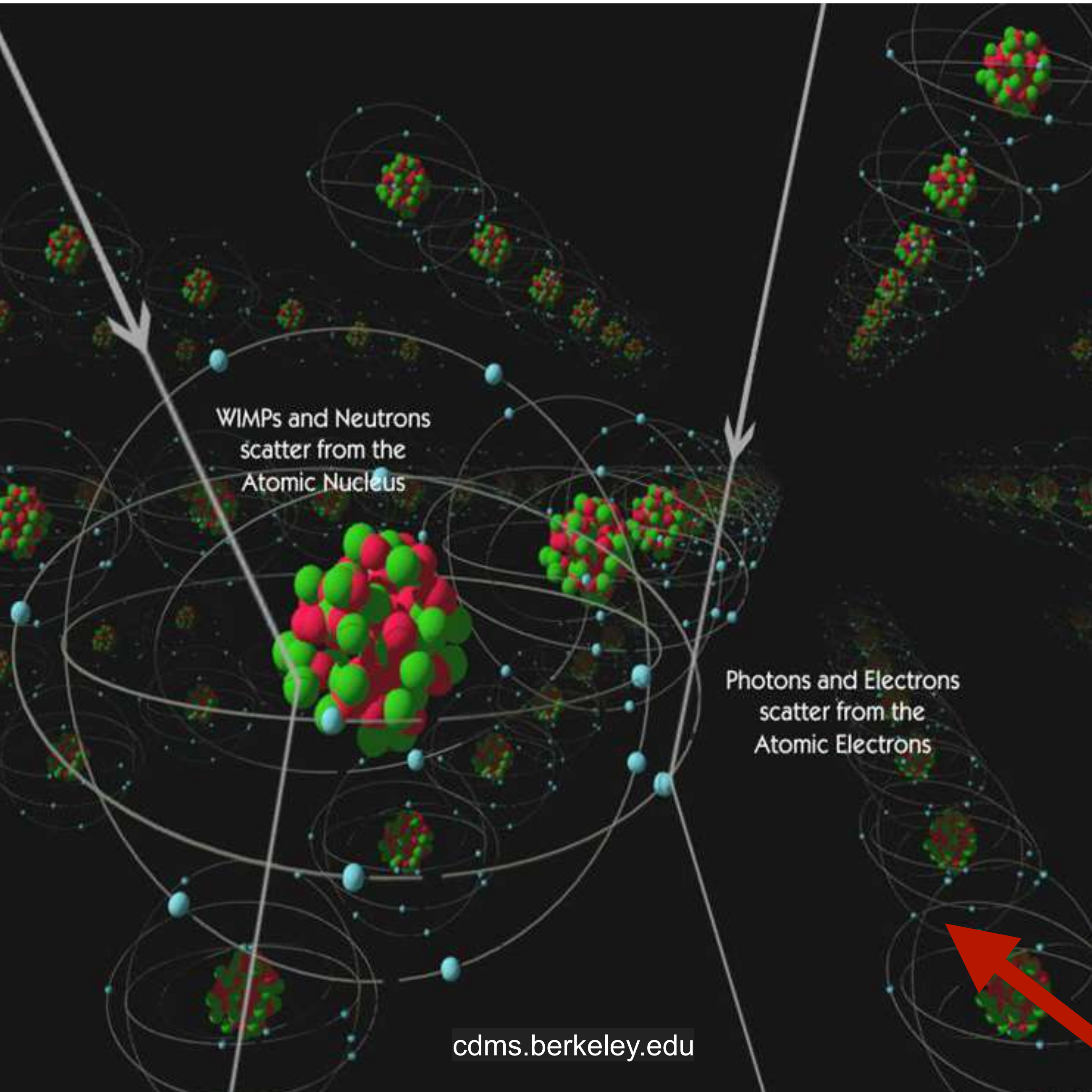
Geant4 visualization of the DARWIN cryostat using geantinos

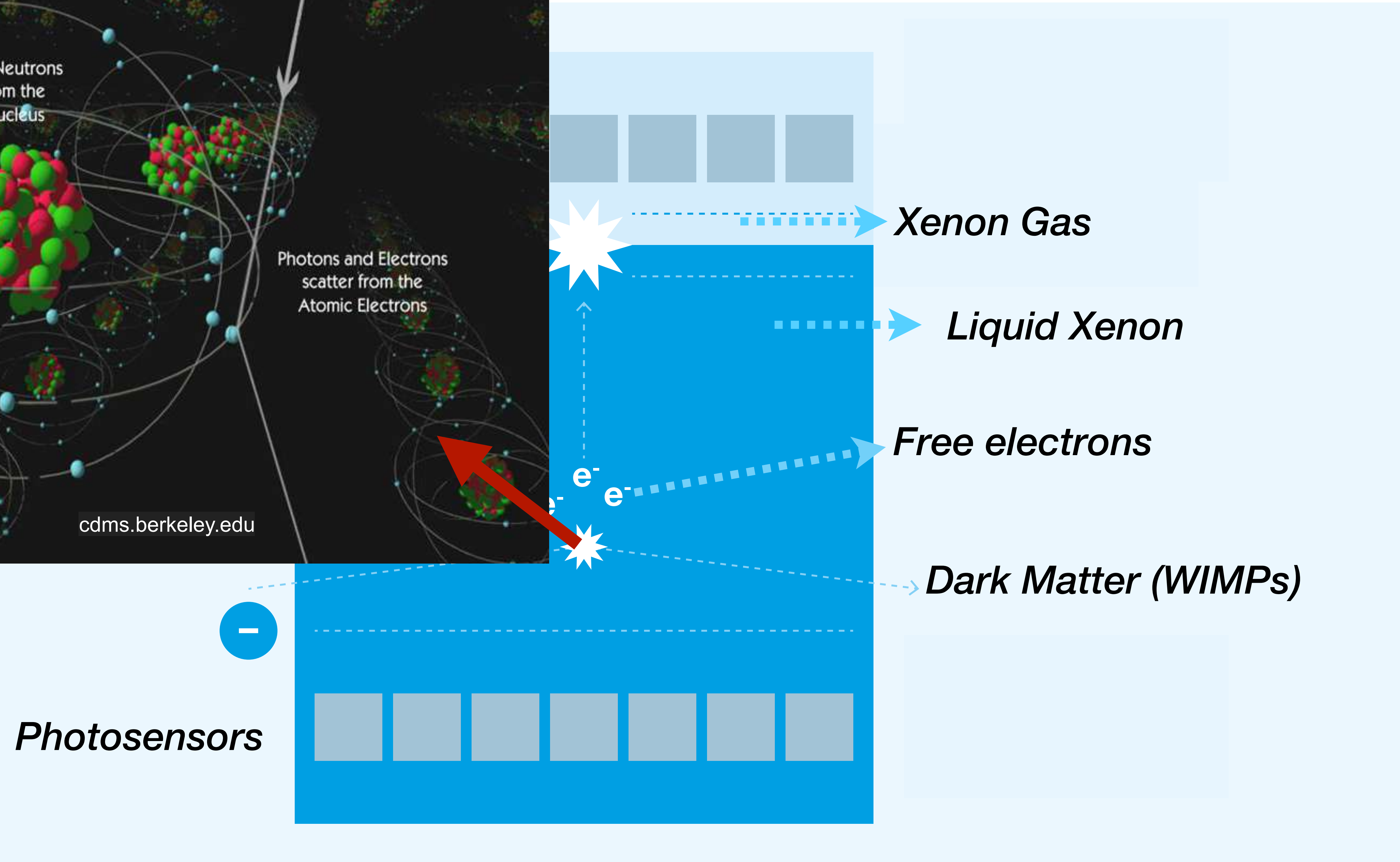
- Copper rings for electric field shaping
- Cryostat studies

Dual phase Xe TPC



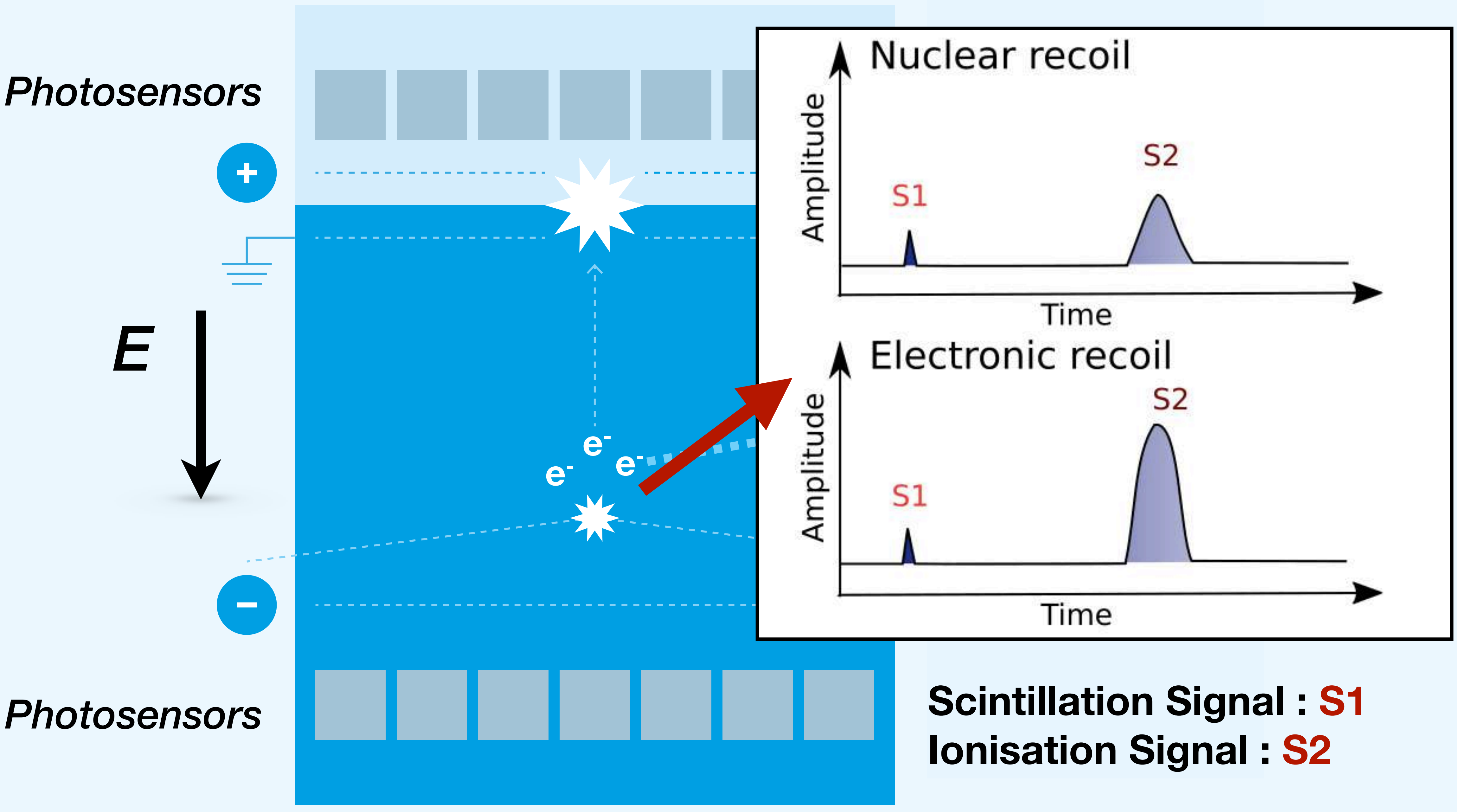
se Xe TPC


WIMPs and Neutrons scatter from the Atomic Nucleus
Photons and Electrons scatter from the Atomic Electrons
cdms.berkeley.edu


Xenon Gas
Liquid Xenon
Free electrons
e-
e-
Dark Matter (WIMPs)
Photosensors

Dual phase Xe TPC

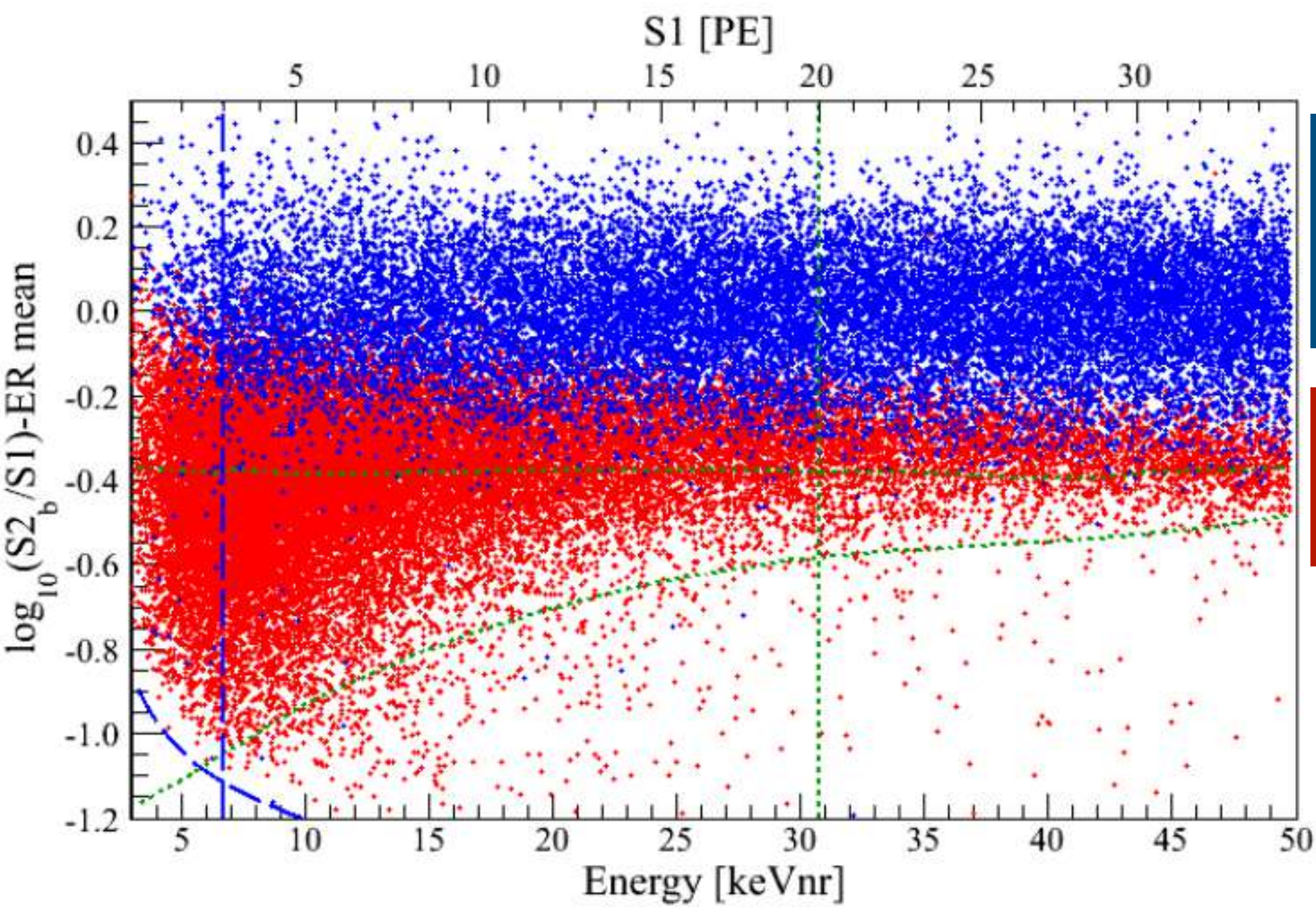
DARWIN



Scintillation Signal : S1
Ionisation Signal : S2

Interactions in LXe

In LXe the background is reduced by S1 (Scintillation) /S2 (Ionisation) discrimination



Scattering off atomic electrons, excitations, etc
Electronic Recoil (ER)

Coherent Scattering off Xe nucleus
Nuclear Recoil (NR)

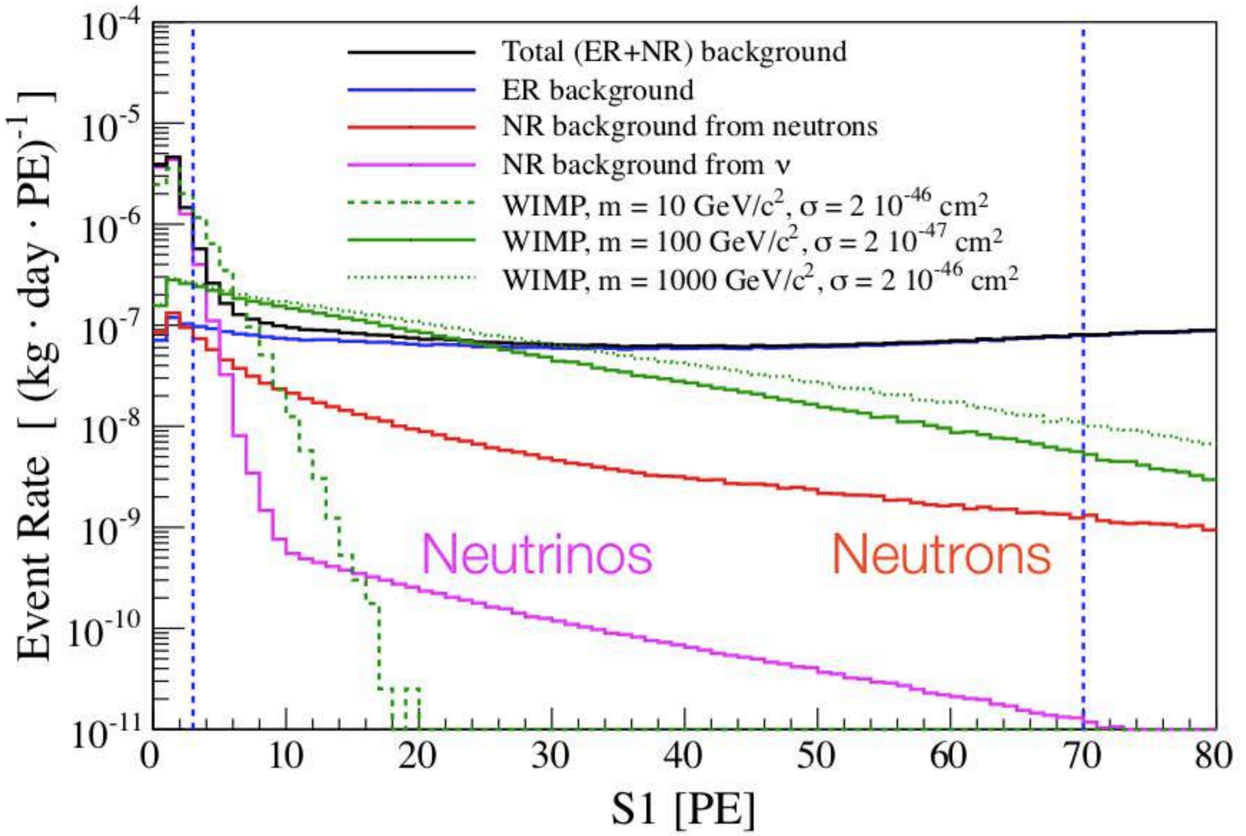
From XENON100: Low energy calibration of liquid xenon detectors, Teresa Marrodán Undagoitia, MPIK Heidelberg, May 2013

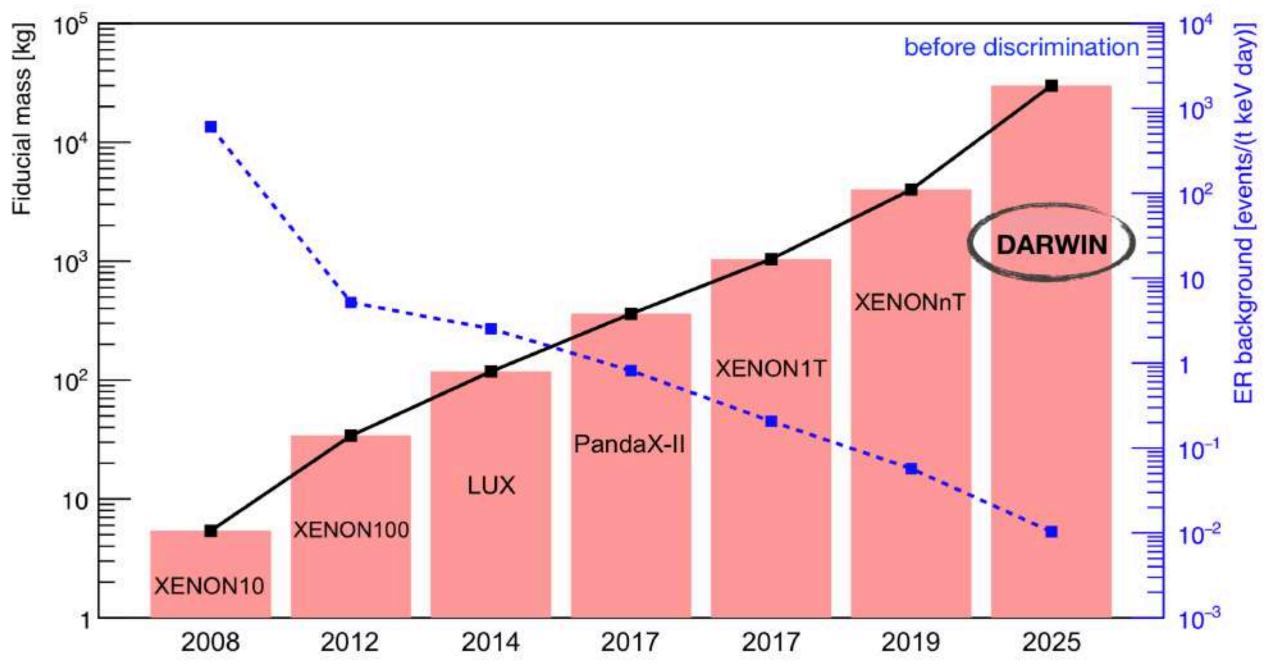
DARWIN

Electronic and Nuclear recoils

Electronic recoil
- Extrinsic from materials
- Intrinsic from LXe
- Solar Neutrinos

Nuclear recoil
- Neutrons from materials
- Cosmogenic activation
- CNNS





[Physics reach of the XENON1T dark matter experiment](#)
[XENON Collaboration (E. Aprile (Columbia U.) et al.) CAP 1604 (2016)](#)

DARWIN: Not only an observatory for Dark Matter

Given its projected low background and sensitivity, DARWIN will be sensitive to other rare physics processes such as:

DARWIN: Not only an observatory for Dark Matter

DARWIN

Given its projected low background and sensitivity, DARWIN will be sensitive to other rare physics processes such as:

Solar Axions and ALPs

DARWIN: Not only an observatory for Dark Matter

Given its projected low background and sensitivity, DARWIN will be sensitive to other rare physics processes such as:

Solar Axions and ALPs

Low energy Solar Neutrinos: pp, ^{7}Be

DARWIN: Not only an observatory for Dark Matter

DARWIN

Given its projected low background and sensitivity, DARWIN will be sensitive to other rare physics processes such as:

Solar Axions and ALPs

Low energy Solar Neutrinos: pp, ^{7}Be

Neutrinoless Double Beta Decay

DARWIN: Not only an observatory for Dark Matter

DARWIN

Given its projected low background and sensitivity, DARWIN will be sensitive to other rare physics processes such as:

Solar Axions and ALPs

Low energy Solar Neutrinos: pp, ^{7}Be

Neutrinoless Double Beta Decay

Coherent Neutrino Nucleus Scattering

DARWIN: Not only an observatory for Dark Matter

DARWIN

Given its projected low background and sensitivity, DARWIN will be sensitive to other rare physics processes such as:

- Solar Axions and ALPs
- Low energy Solar Neutrinos: pp, ^{7}Be
- Neutrinoless Double Beta Decay
- Coherent Neutrino Nucleus Scattering
- Supernova Neutrinos

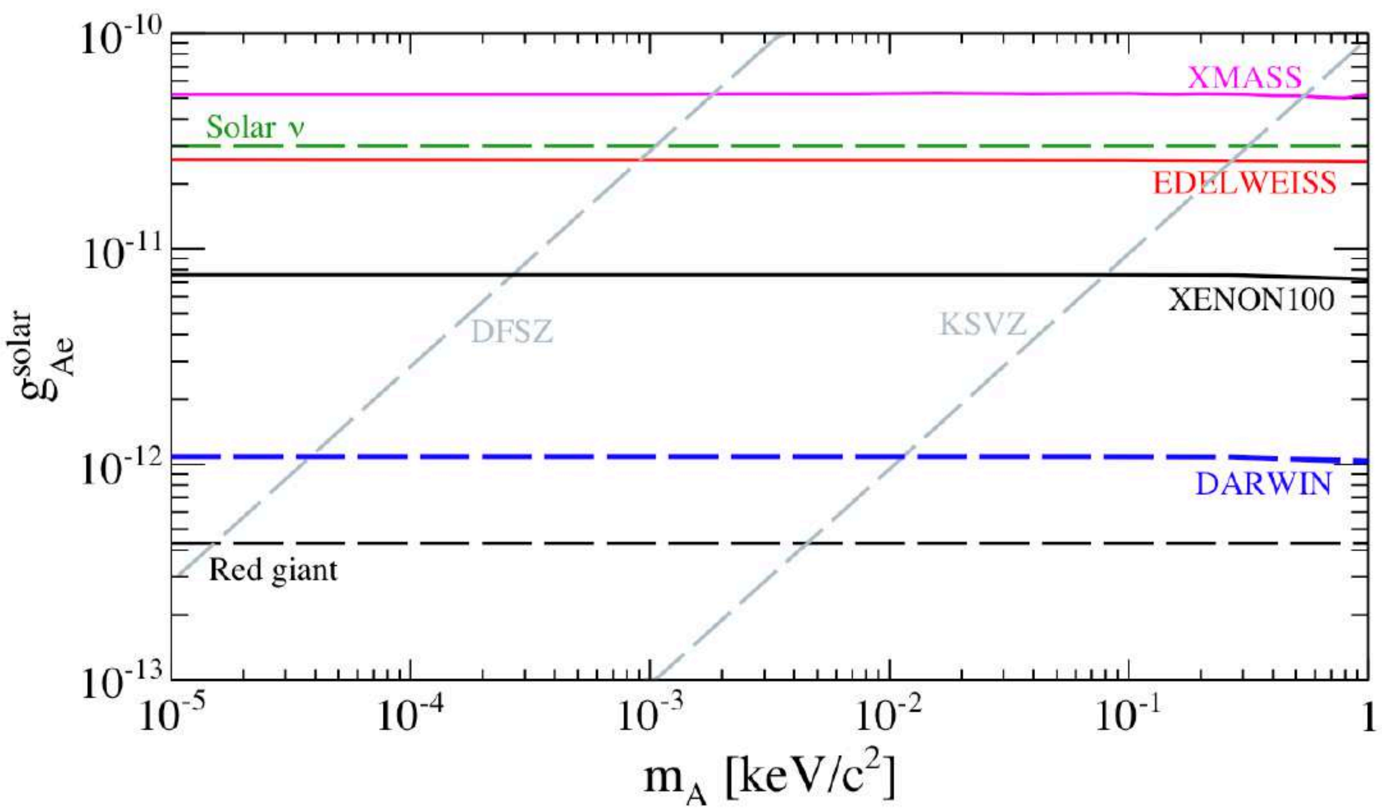
DARWIN: Not only an observatory for WIMPs

Solar Axions, Galactic Axions and ALPs

Axions couple with electrons and lead to atomic ionisation ⇒ ER

Galactic Axions and ALPs are well-motivated DM candidates

Sensitivity of DARWIN to solar axions



Solar axions can be produced via Bremsstrahlung, Compton scattering, axio-recombination and axio-deexcitation

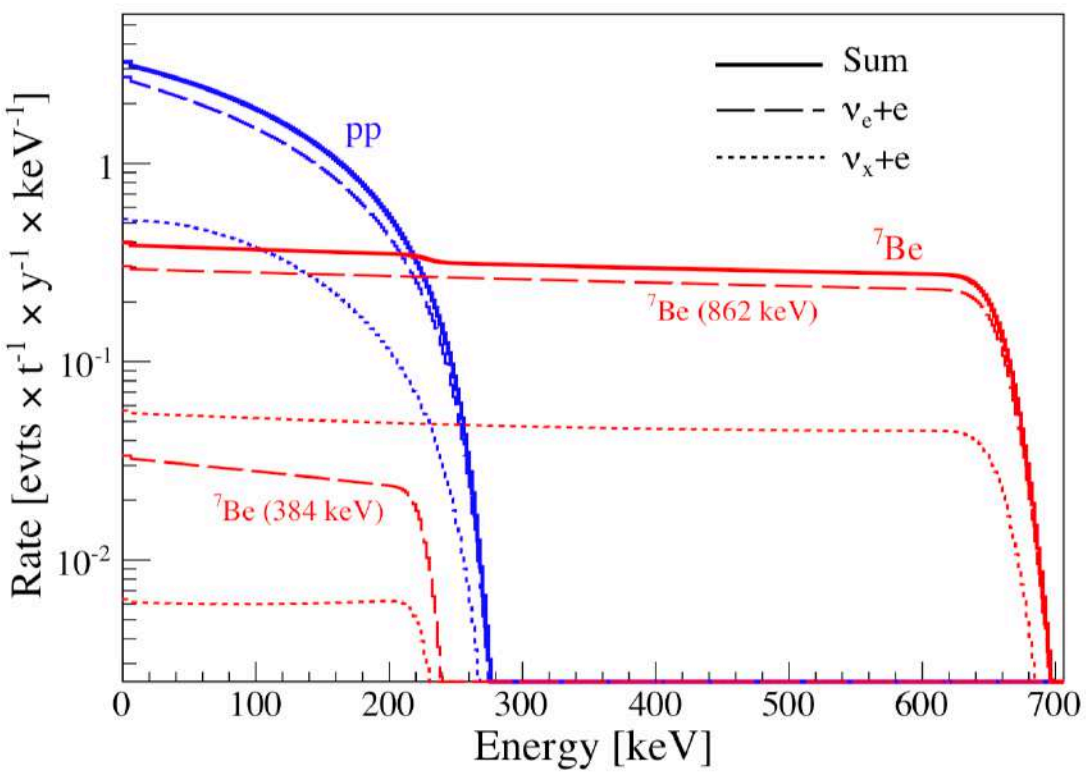
DARWIN: towards the ultimate dark matter detector. Journal of Cosmology and Astroparticle Physics, 2016

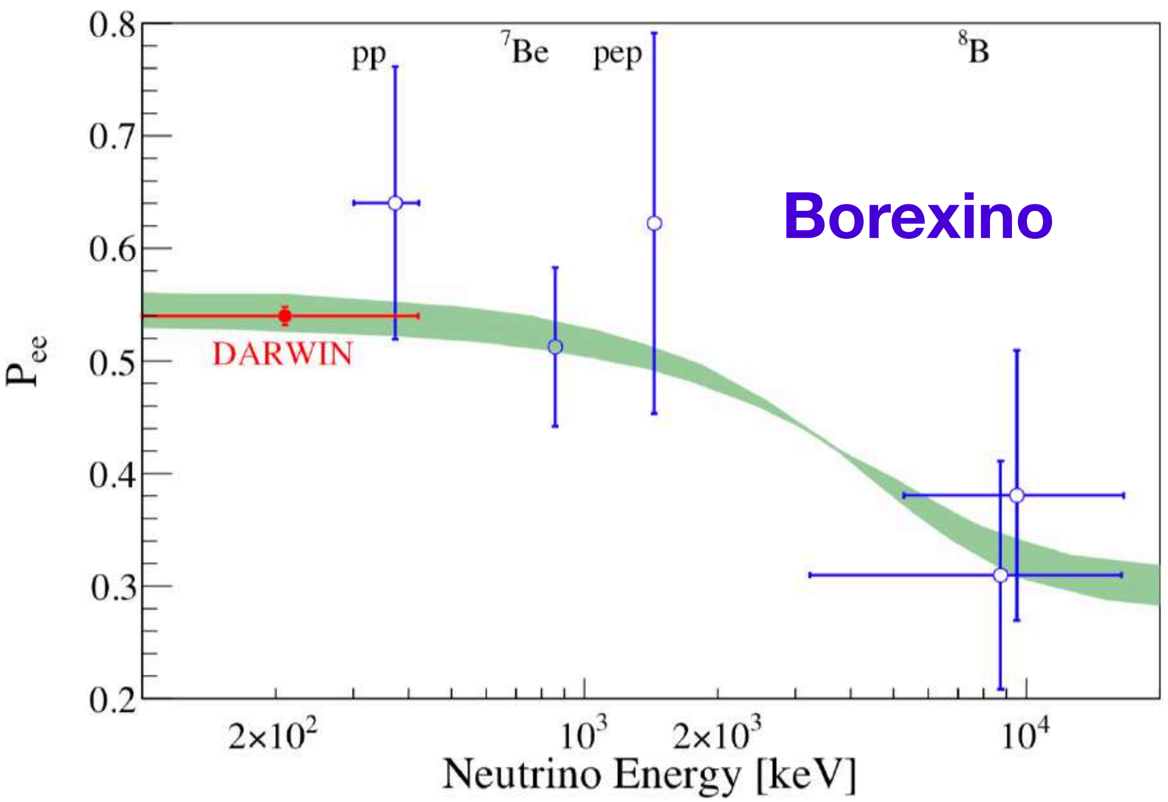
DARWIN: Not only an observatory for Dark Matter

Low energy Solar Neutrinos: pp, ^{7}Be

Irreducible background for DARWIN's WIMP channel program : Opportunity for neutrino physics!

pp and ^{7}Be-neutrinos more than 98% of the total neutrino flux predicted by the SSM





[Neutrino physics with multi-ton scale liquid xenon detectors,Journal of Cosmology and Astroparticle Physics 2014](#)

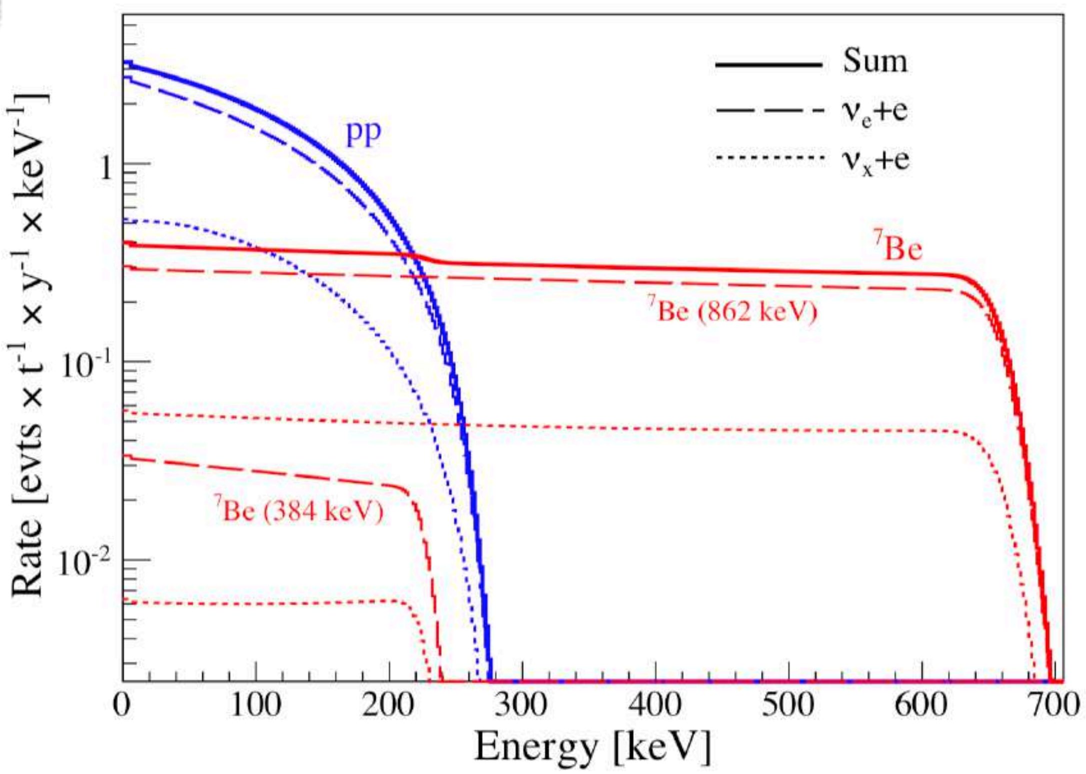
DARWIN: Not only an observatory for Dark Matter

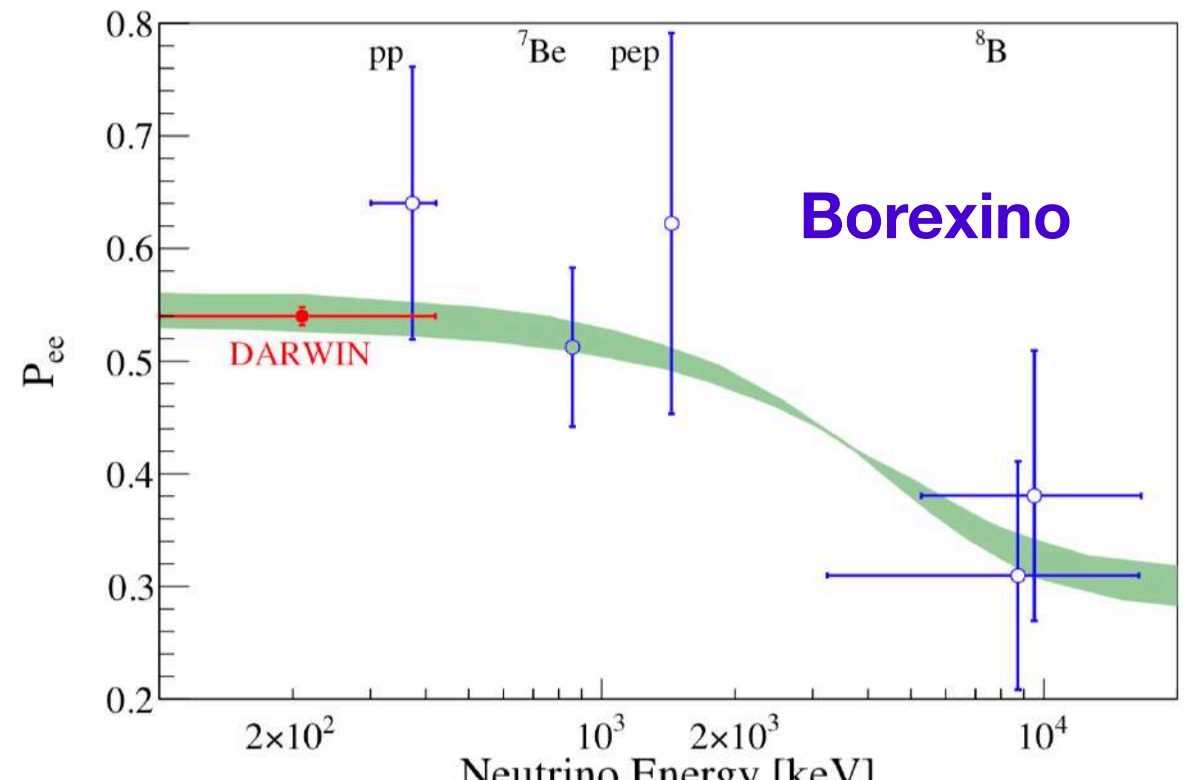
DARWIN

Low energy Solar Neutrinos: pp, ^{7}Be

Irreducible background for DARWIN's WIMP channel program : Opportunity for neutrino physics!

More than 2 10^3 pp-neutrino events will be observed per year
Precision below 1% would be reached after 5 years of data taking





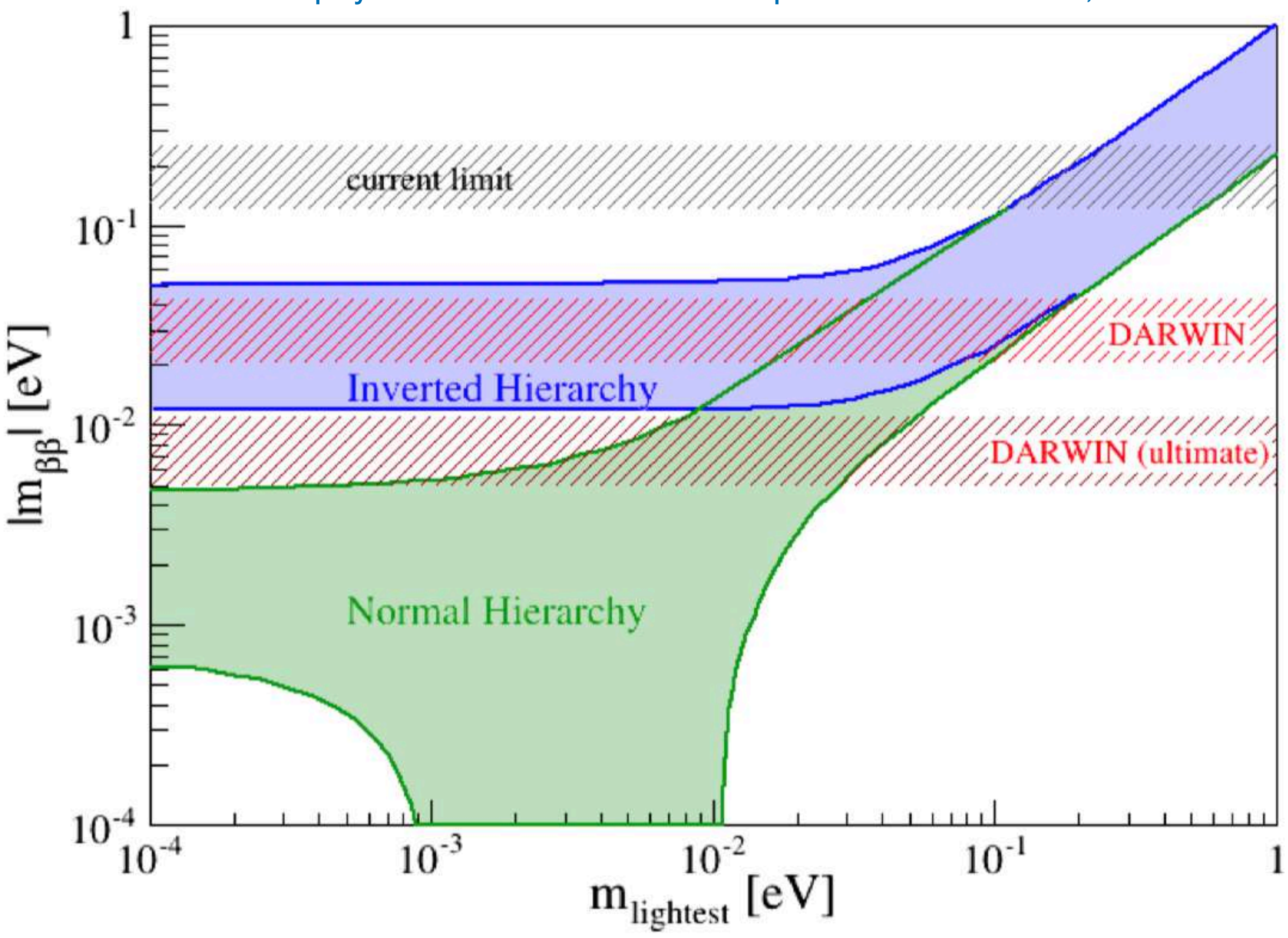
[Neutrino physics with multi-ton scale liquid xenon detectors,Journal of Cosmology and Astroparticle Physics 2014]

DARWIN: Not only an observatory for Dark Matter

DARWIN

Neutrinoless Double Beta Decay

Neutrino physics with multi-ton scale liquid xenon detectors,Journal of Cosmology and Astroparticle Physics 2014



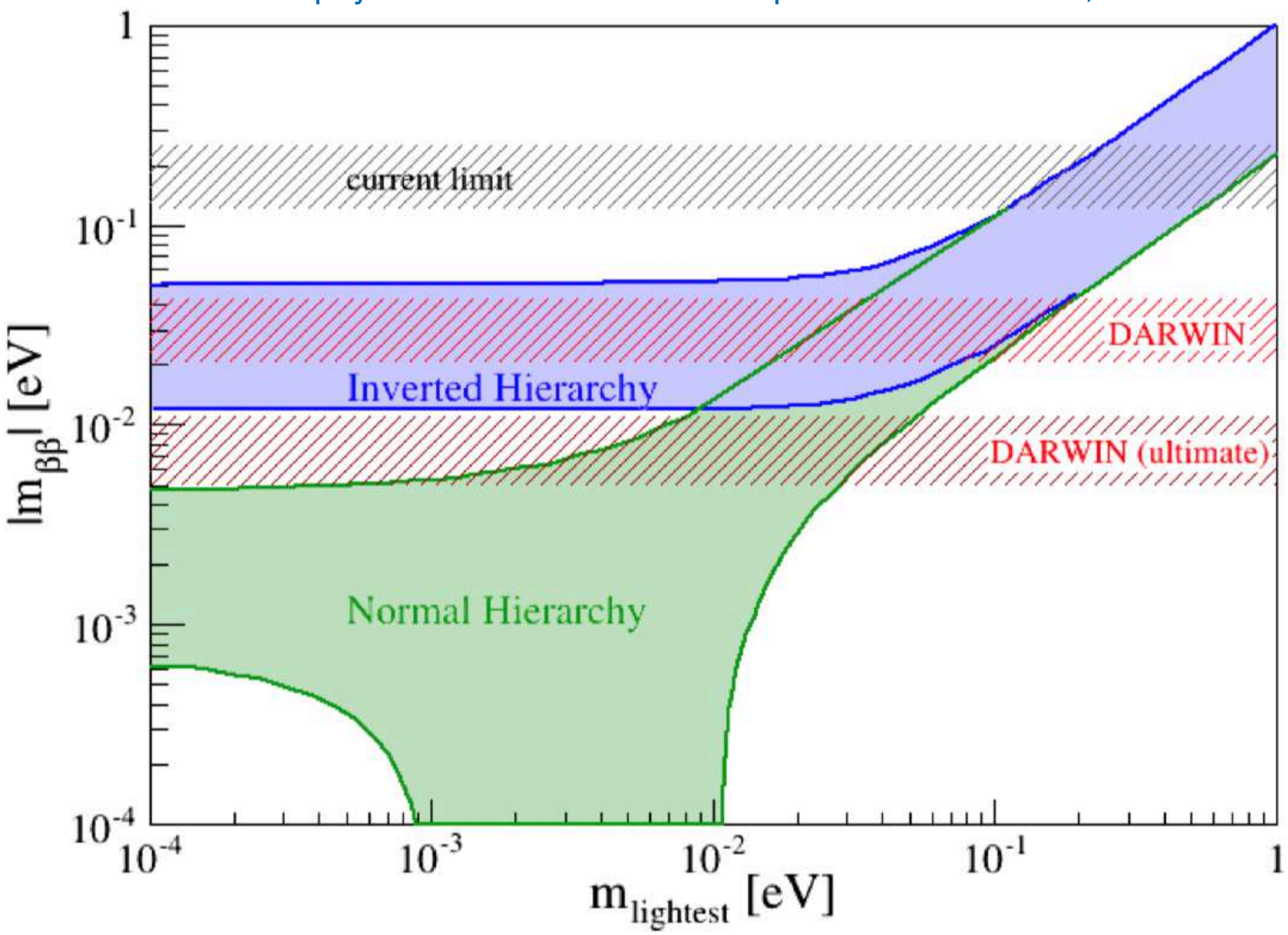
^{136}Xe $0\nu\beta\beta$-decay candidate with natural abundance of 8.9%

$Q_{\beta\beta}$-value at 2.458 MeV, well above the energy-range expected from a WIMP signal

DARWIN: Not only an observatory for Dark Matter

Neutrinoless Double Beta Decay

Neutrino physics with multi-ton scale liquid xenon detectors,Journal of Cosmology and Astroparticle Physics 2014



^{136}Xe $0\nu\beta\beta$-decay candidate with natural abundance of 8.9%

$Q_{\beta\beta}$-value at 2.458 MeV, well above the energy-range expected from a WIMP signal

Without isotopic enrichment, DARWIN's target contains ***more than 3.5 t of*** ^{136}***Xe***
Can perform a search for its $0\nu\beta\beta$-decay in an ultra-low background environment.

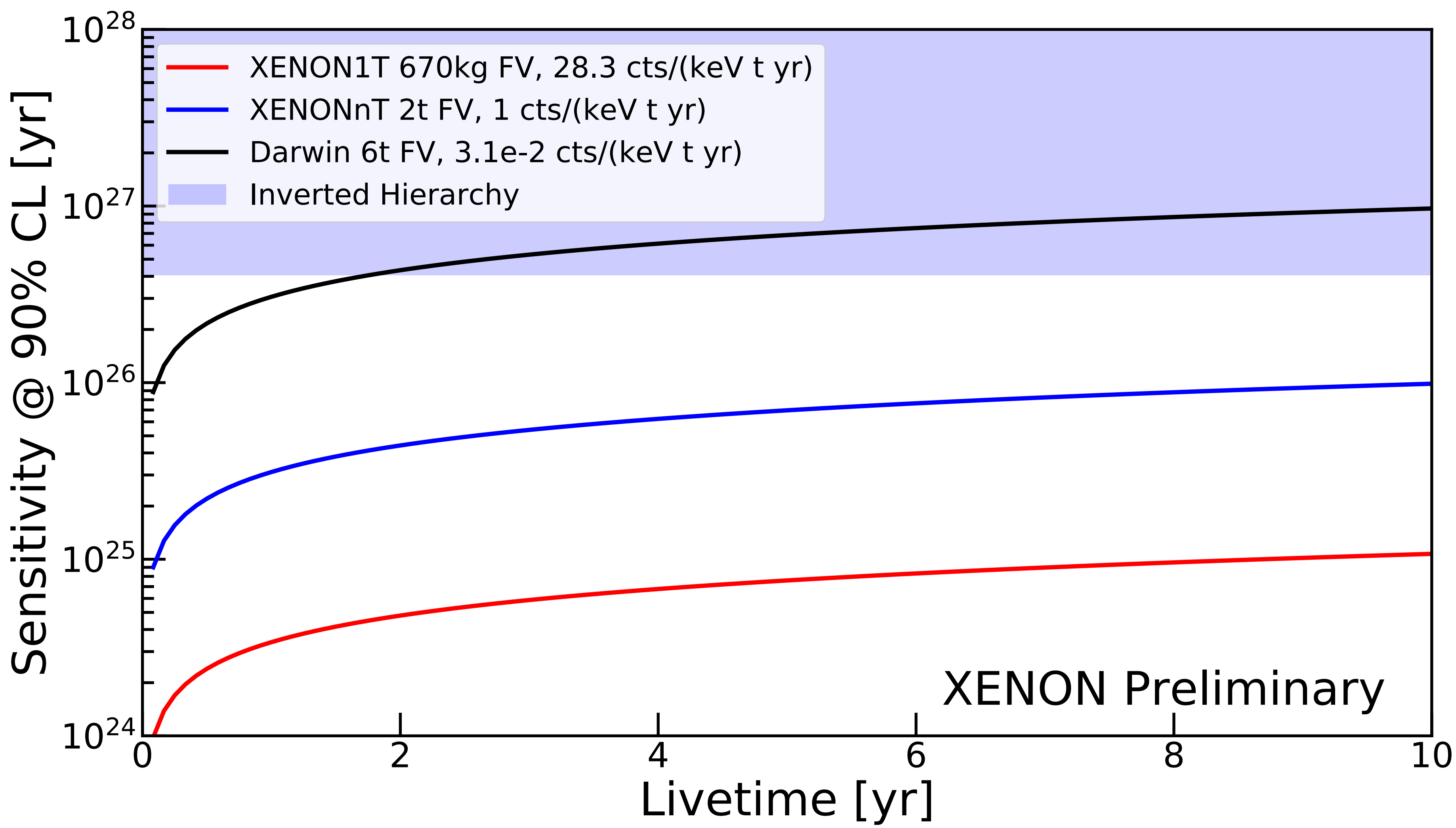
DARWIN: Not only an observatory for Dark Matter

DARWIN

Neutrinoless Double Beta Decay

A new study with the current geometry is being conducted.

Expected sensitivity for DARWIN: 6 tonnes fiducial volume ⇒ two orders of magnitude improvement in sensitivity compared to XENON1T

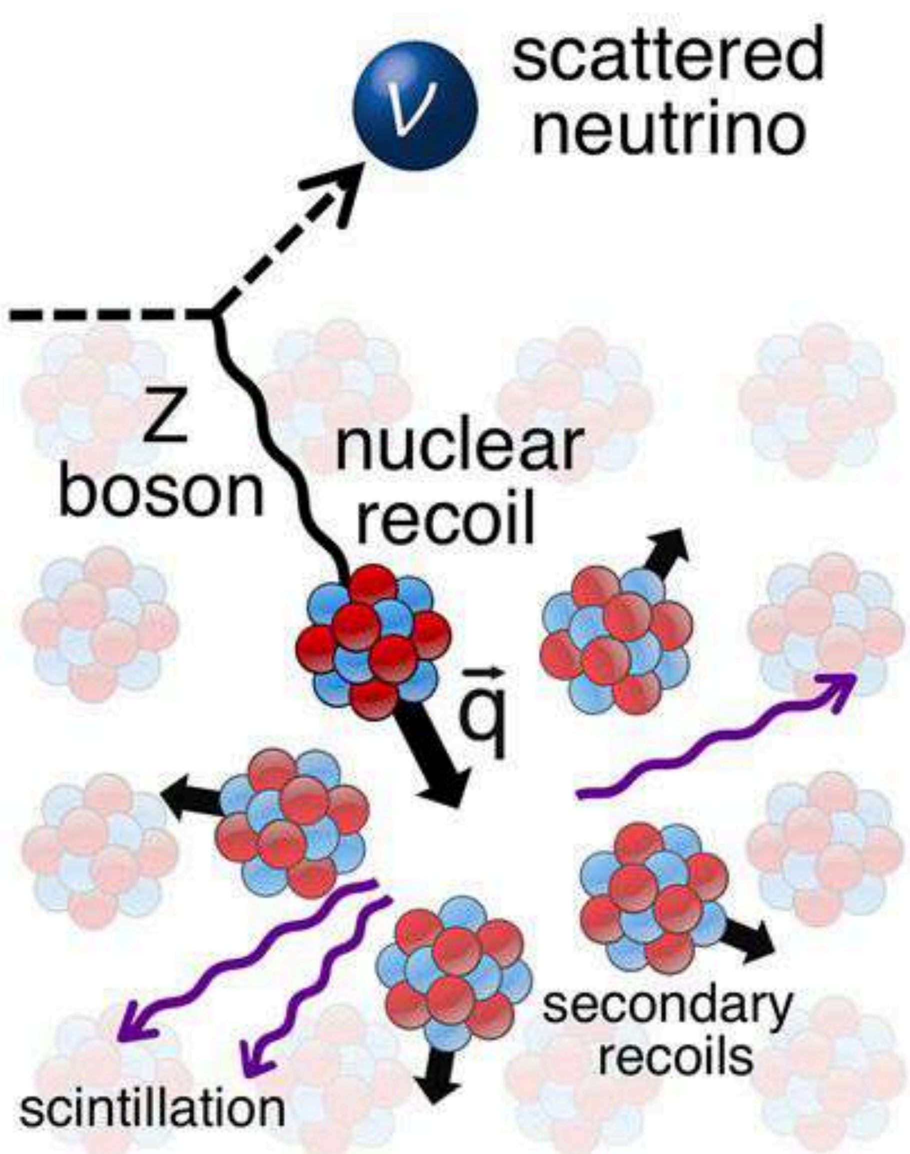


Chiara Capelli, Neutrinoless double beta decay searches with the XENON dark matter experiment, Neutrino 2018

DARWIN: Not only an observatory for Dark Matter

DARWIN

Coherent Neutrino Nucleus Scattering



Observation of coherent elastic neutrino-nucleus scattering
10.1126/science.aao0990

L. E. Strigari, Neutrino Coherent Scattering Rates at Direct Dark Matter Detectors, New J. Phys.

The rate of low-energy signals in all multi-ton WIMP detectors will eventually be dominated by interactions of cosmic neutrinos via CNNS

The largest CNNS rate comes from the relatively high-energy ^{8}B solar neutrinos which produce nuclear recoils ≤ 3 keV_{nr}.

DARWIN will be able to detect and study this process

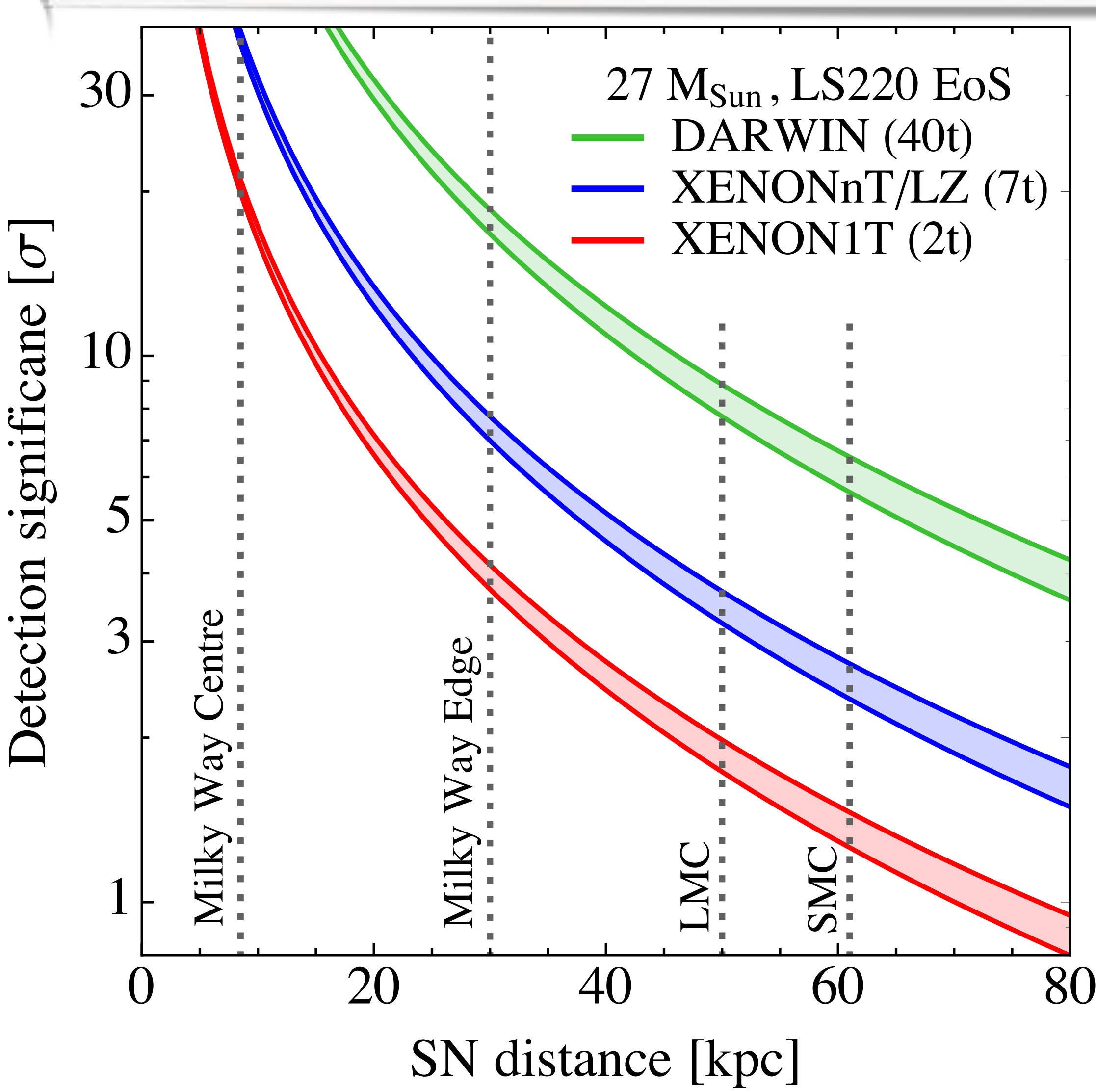
DARWIN: Not only an observatory for Dark Matter

DARWIN

Supernova Neutrinos

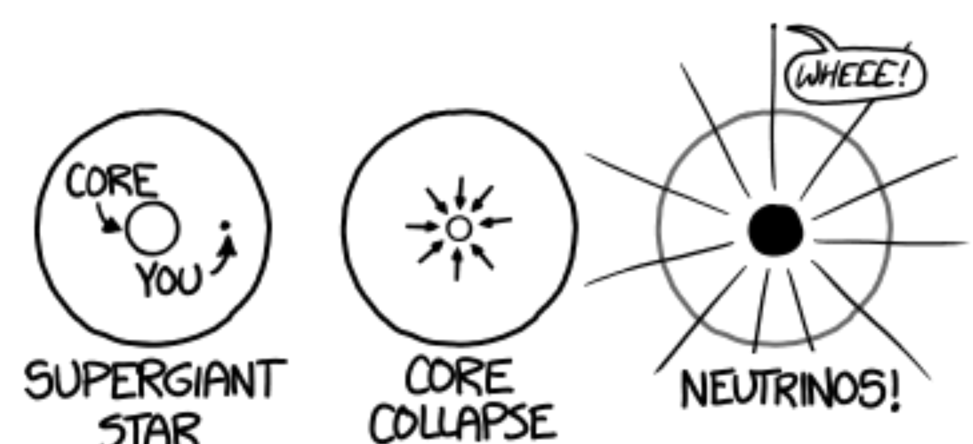
Dark matter astrophysical uncertainties and the neutrino floor Ciaran A.J. O'Hare DOI: 10.1103/PhysRevD.94.063527

DARWIN would be sensitive to all six neutrino species via neutral current interactions



Supernova neutrino physics with xenon dark matter detectors: A timely perspective, Lang, Rafael F. et al,Phys. Rev. D, 2016

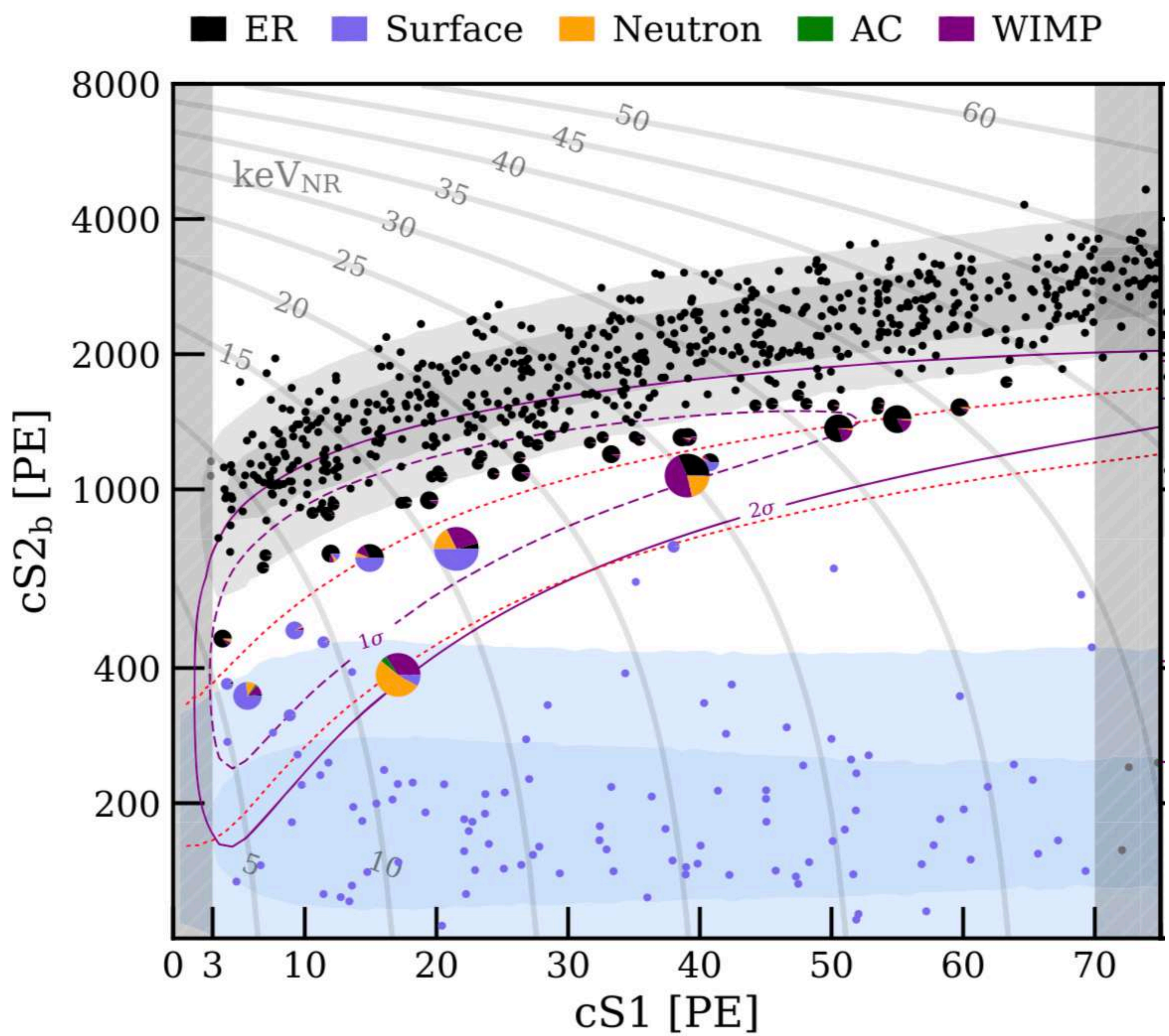
Including neutrinos and anti-neutrinos that are emitted by core-collapse supernovae in a burst lasting a few tens of seconds



Source: xkcd

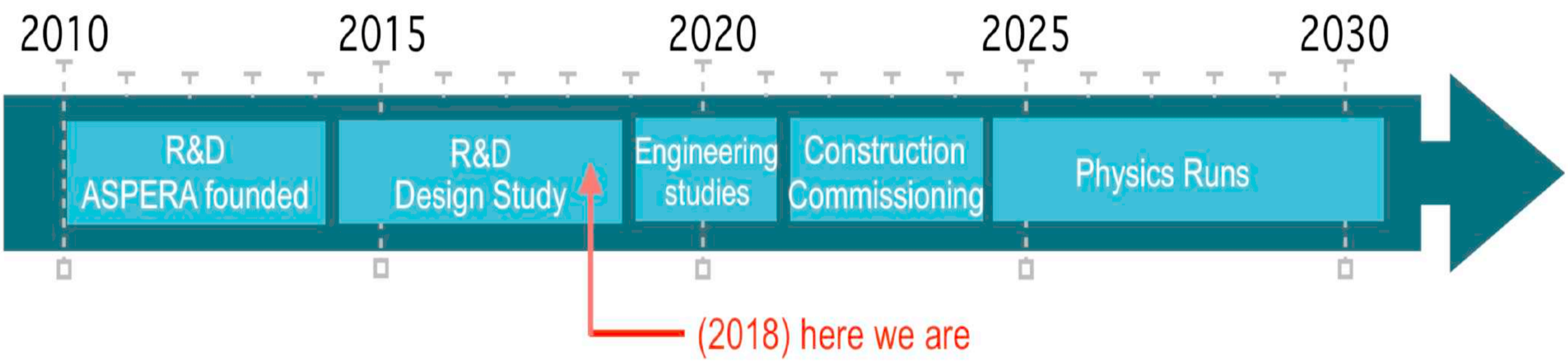
Which signals do we expect to see in each region?

DARWIN



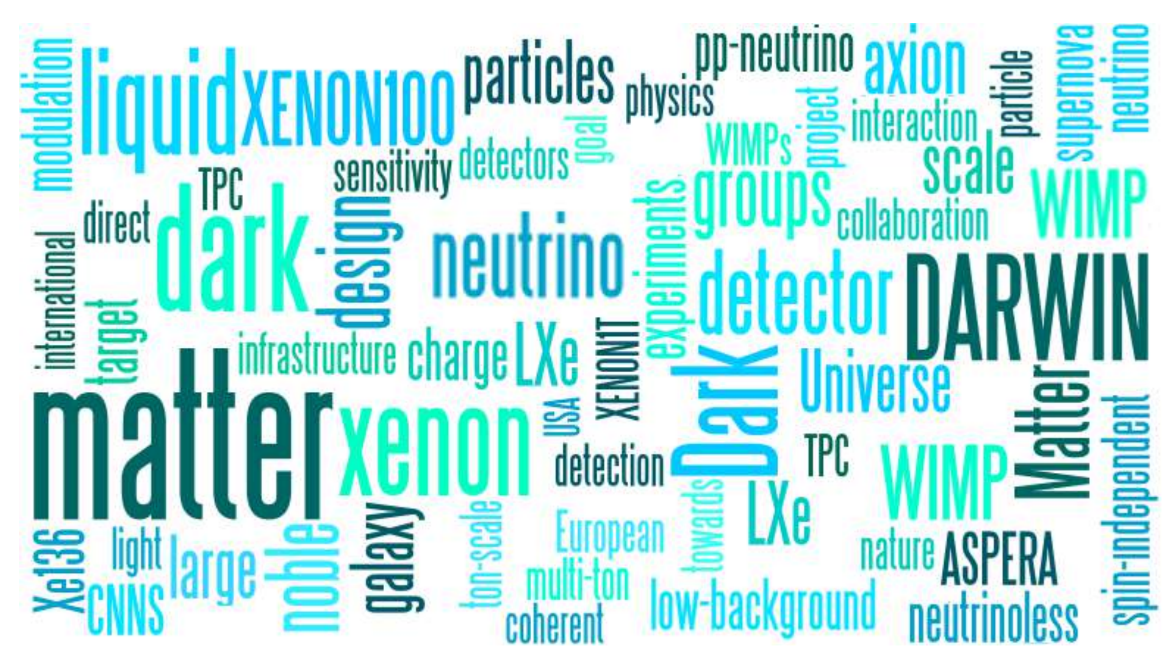
[Dark Matter Search Results from a One Ton-Year Exposure of XENON1T PHYSICAL REVIEW LETTERS 121, 111302 (2018)]

Current Status of DARWIN



- 28 groups from 11 countries
- DARWIN is on the APPEC roadmap
- Working towards a CDR and TDR
- Synergy with XENONnT R&D

www.darwin-observatory.org

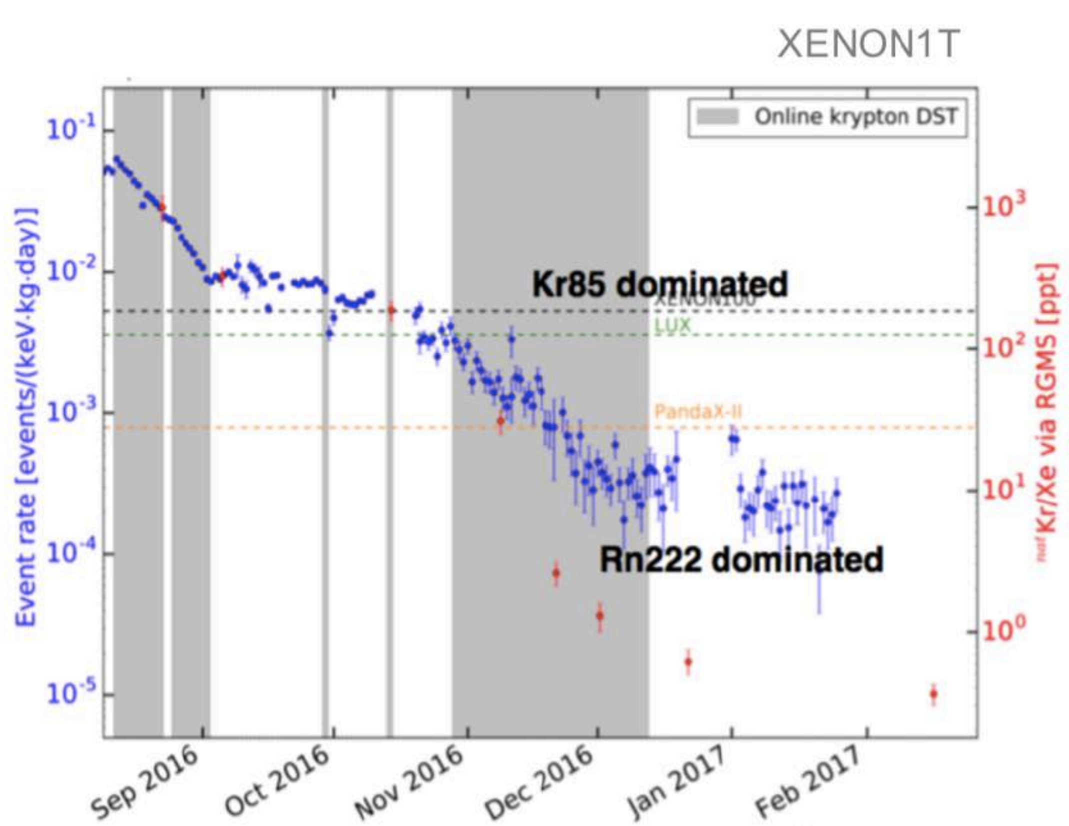


Design challenges and R&D

DARWIN

Scale related :

- **Longer drift length ⇒ Deliver the necessary HV**
- **Increased mass ⇒ Cryogenics, LXe purification…**
- **Detector response ⇒ Calibration, Corrections, Readout**
- **Optimization of Cryostat Design**

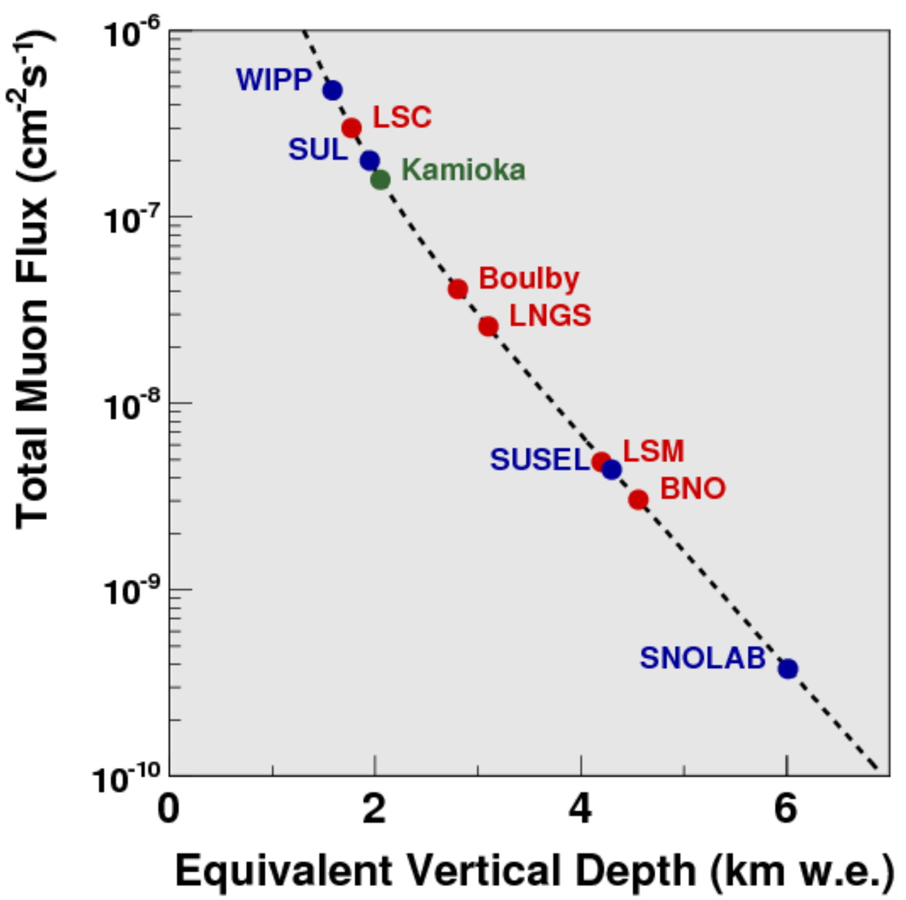


Design challenges and R&D

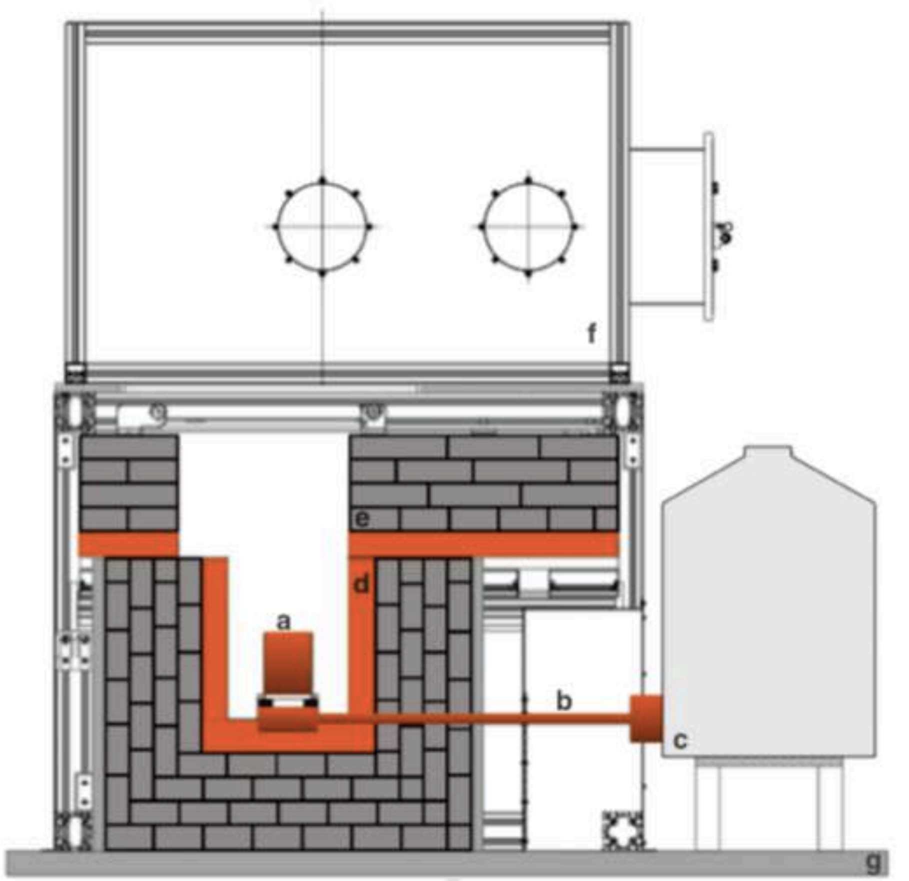
DARWIN

Backgrounds:

- **Active background suppression ⇒ distillation**
- **Techniques to select clean materials ⇒ gamma and Rn screening**
- **Techniques to monitor LXe purity at required level**
- **Cosmogenic background ⇒ go deep enough, add μ-veto and n-veto**

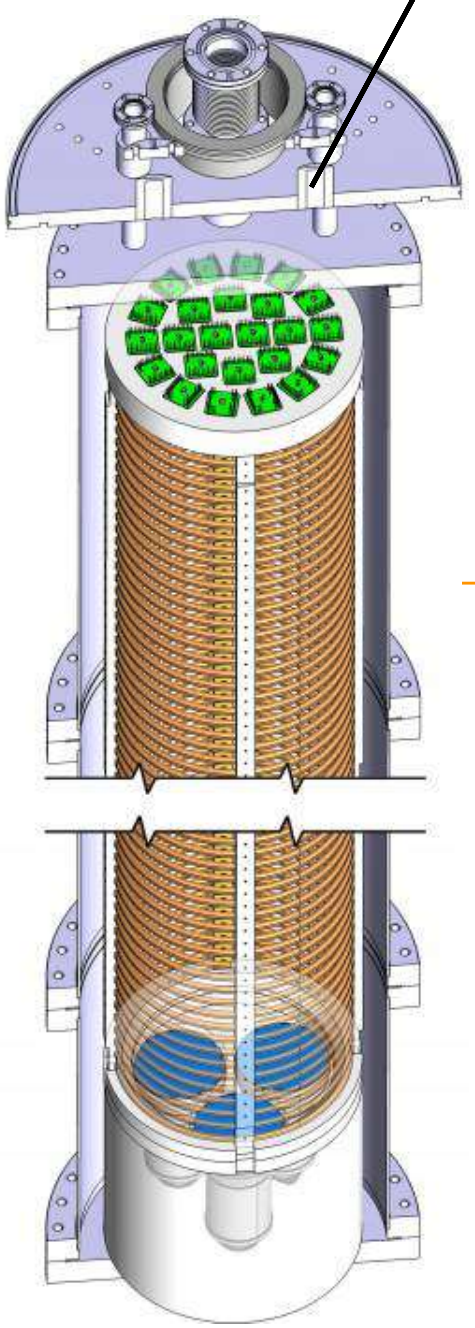


GATOR facility at LNGS



TPCs R&D

European Research Council
Established by the European Commission

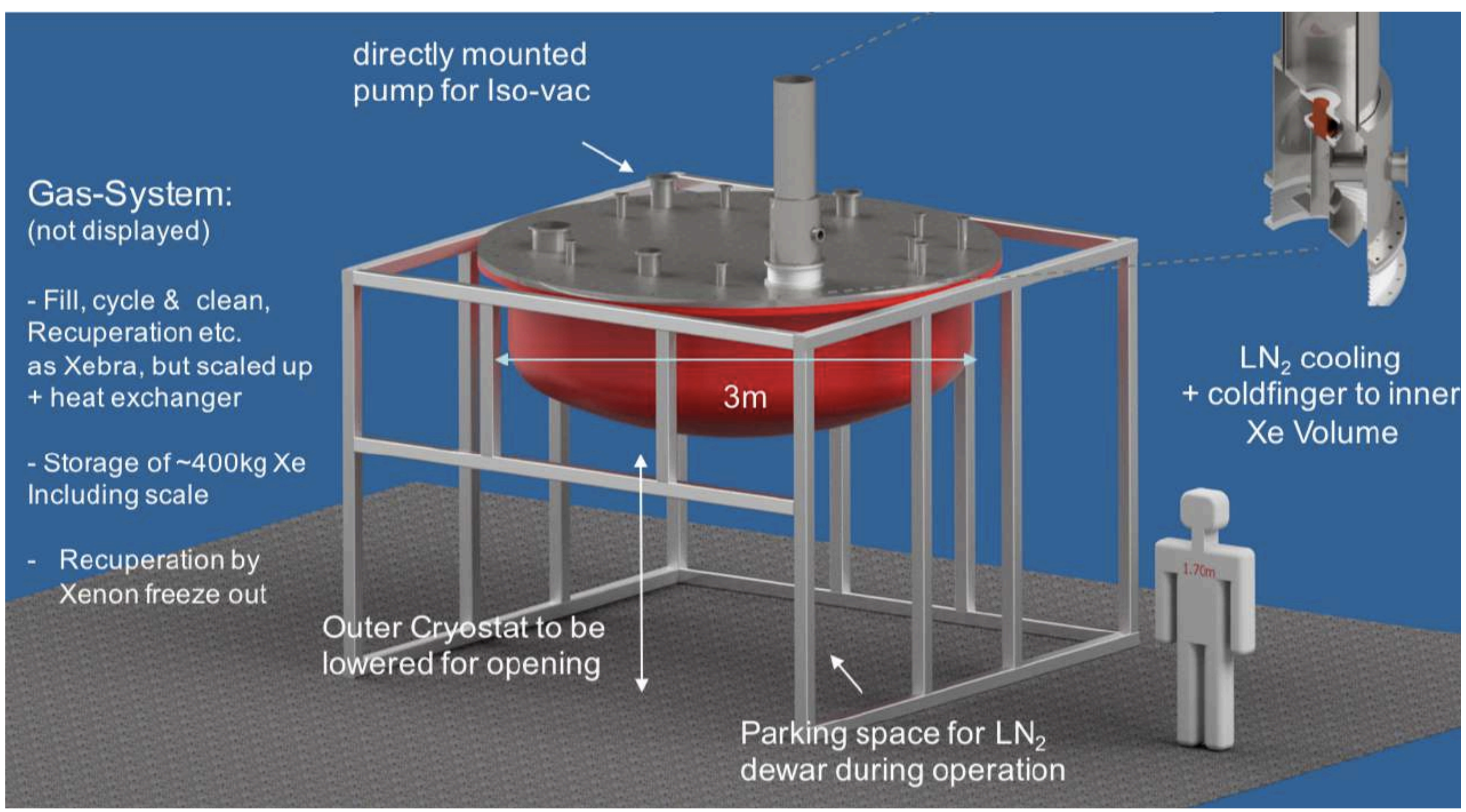


Long Size LXe TPC for DARWIN electron drift, gas purity and more

- Height 2.6m
- Field 100-200 V/cm (or higher)
- Applied Voltage : planned test up to 100kV
- Electron lifetime > 2ms
- Modular design
- Focus: cathode and HV feed-trough test

University of Zurich

Large Size LXe Cryostat for DARWIN size electrical and mechanical tests



University of Freiburg

Summary

DARWIN

- DARWIN will be the ultimate liquid xenon dark matter detector

- DARWIN will also provide a unique opportunity for other rare event searches such as:

  Low Energy solar neutrinos
  Neutrinoless double-beta decay
  CNNS
  Axions and axion-like particles

DARWIN : growing collaboration, currently **28 groups from 11 countries**.

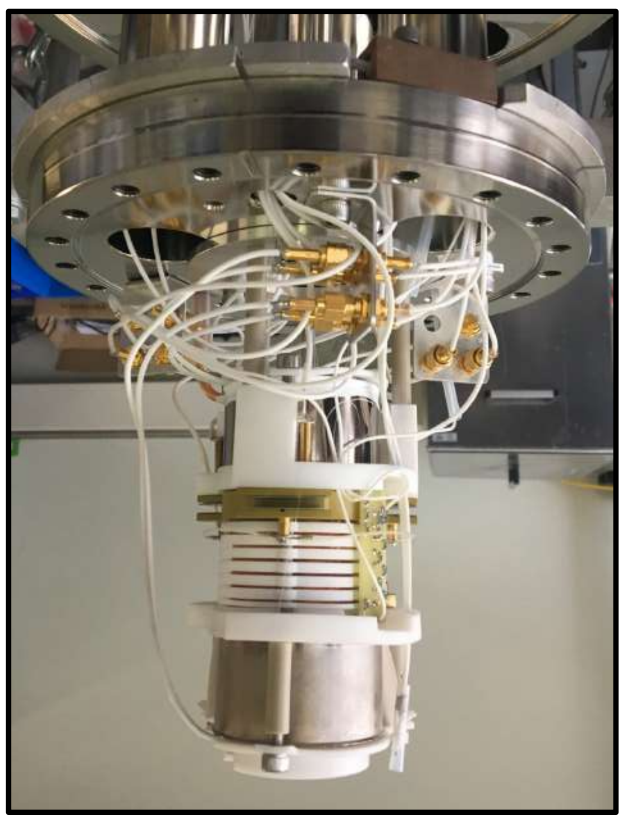
DARWIN

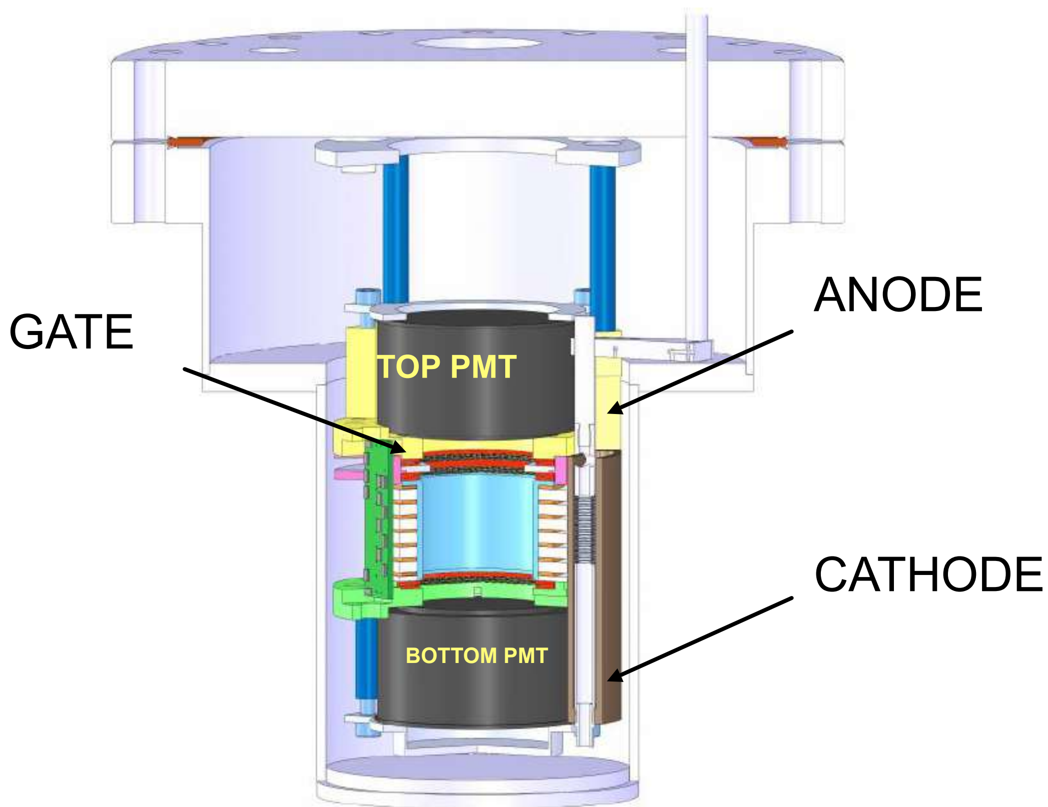
Thanks
Gracias
Obrigado

Backup slides

R&D in UZH

Our group counts with one LXe TPC, Xurich II

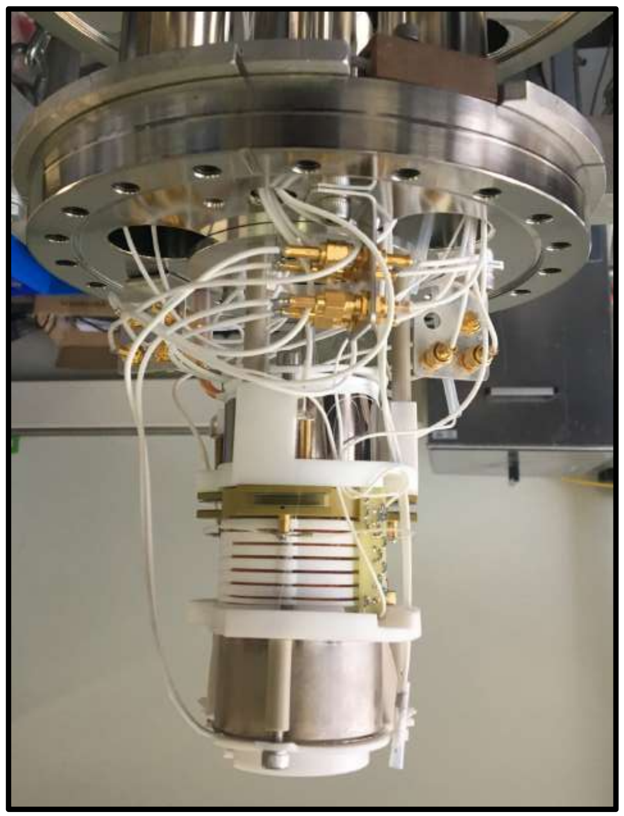


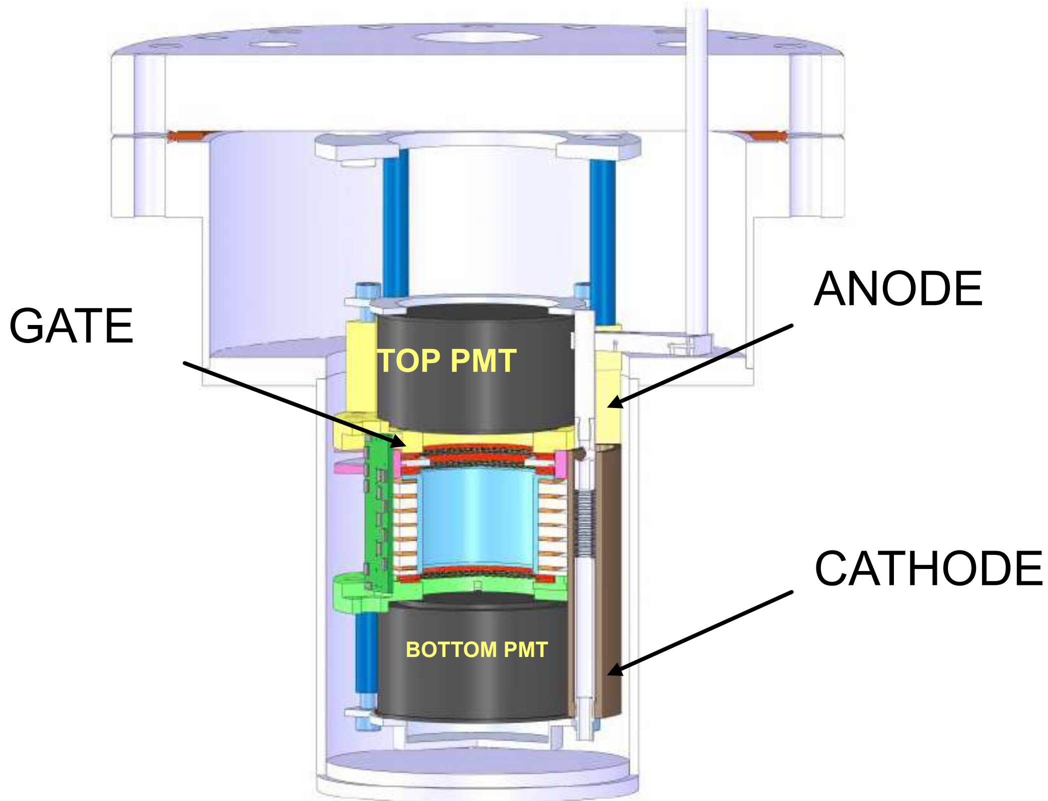


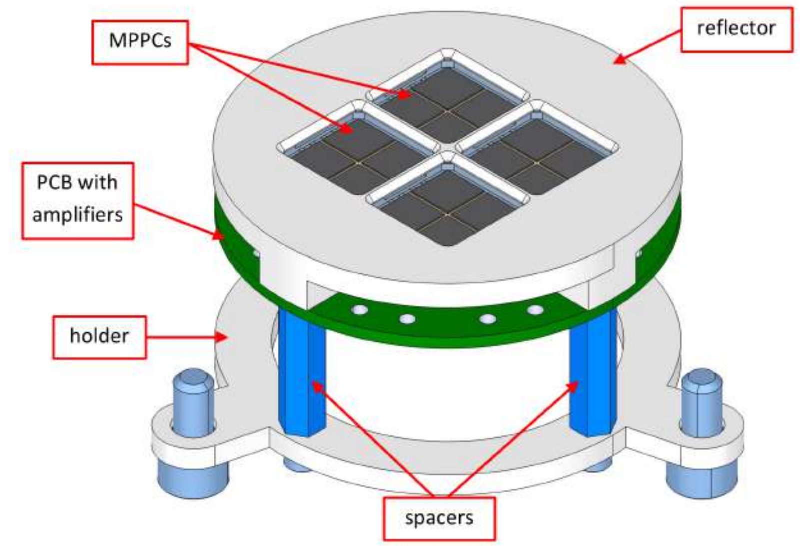
Original configuration with two 2-inch PMTs, top and bottom

R&D in UZH

Our group counts with one LXe TPC, Xurich II



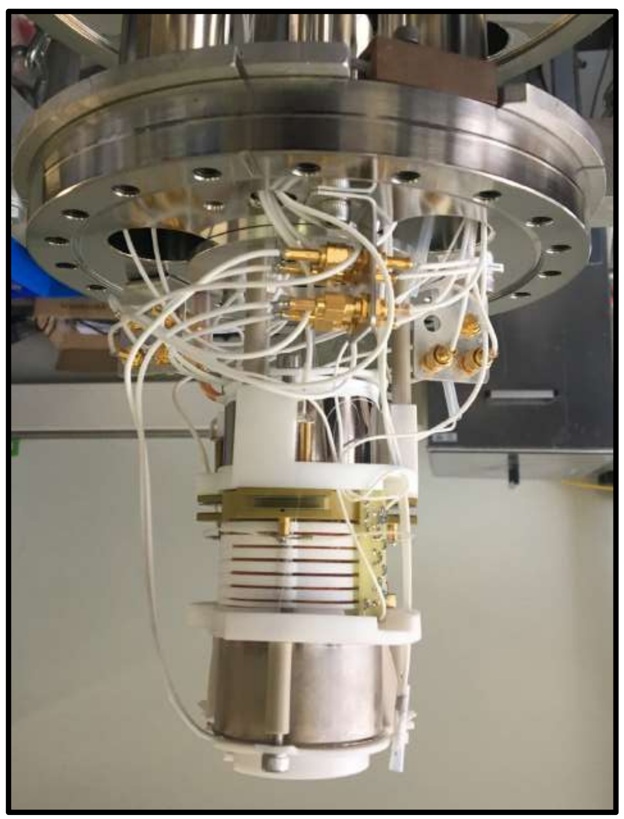


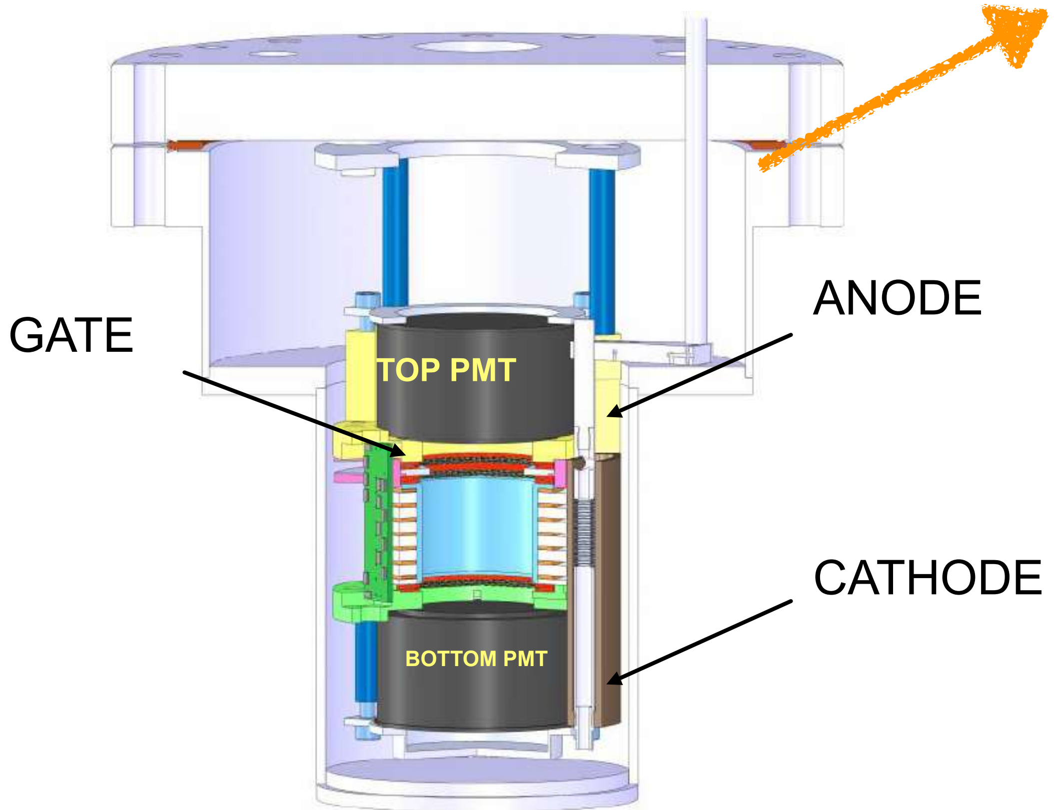


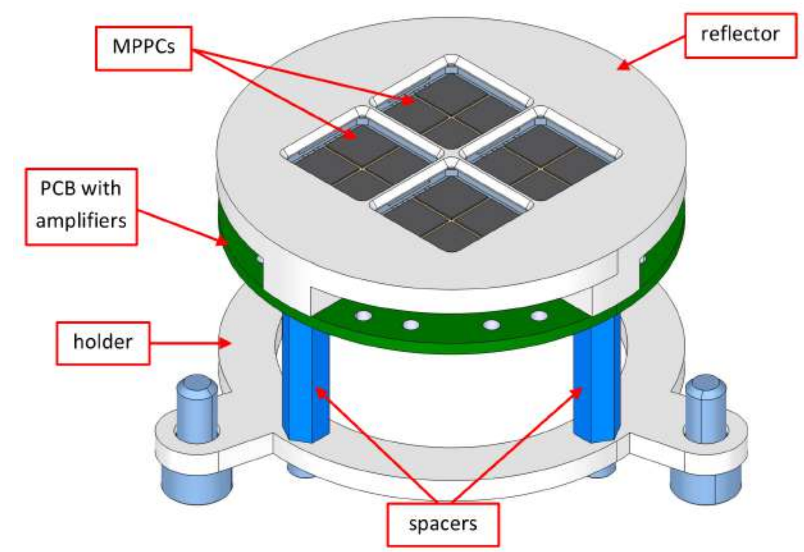
Original configuration with two 2-inch PMTs, top and bottom

R&D in UZH

Our group counts with one LXe TPC, Xurich II



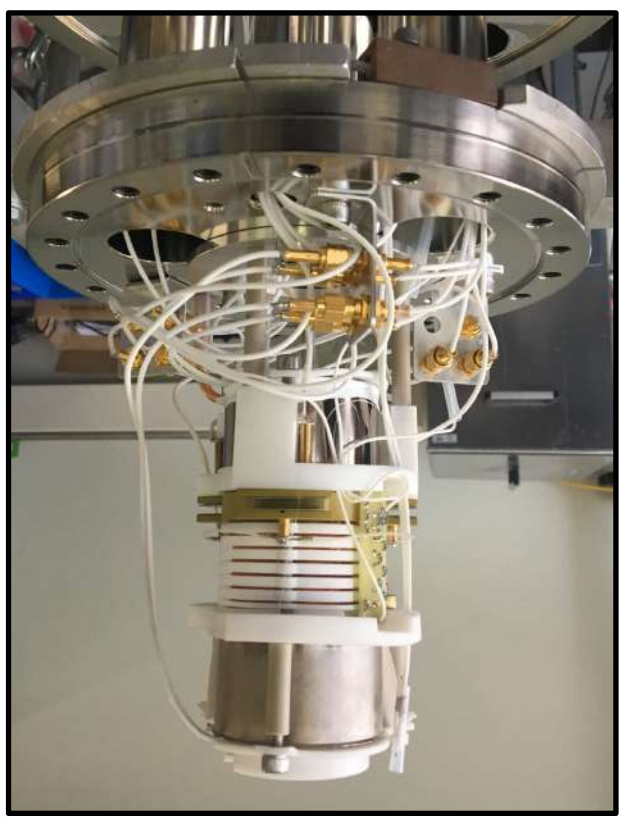


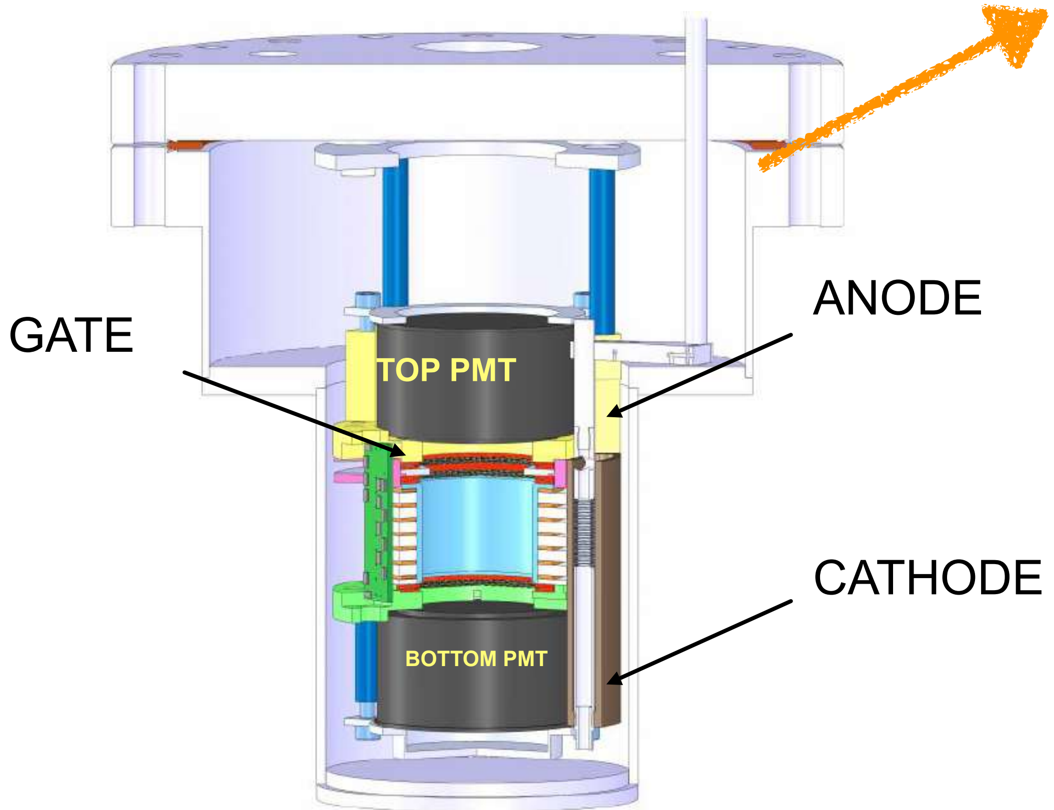


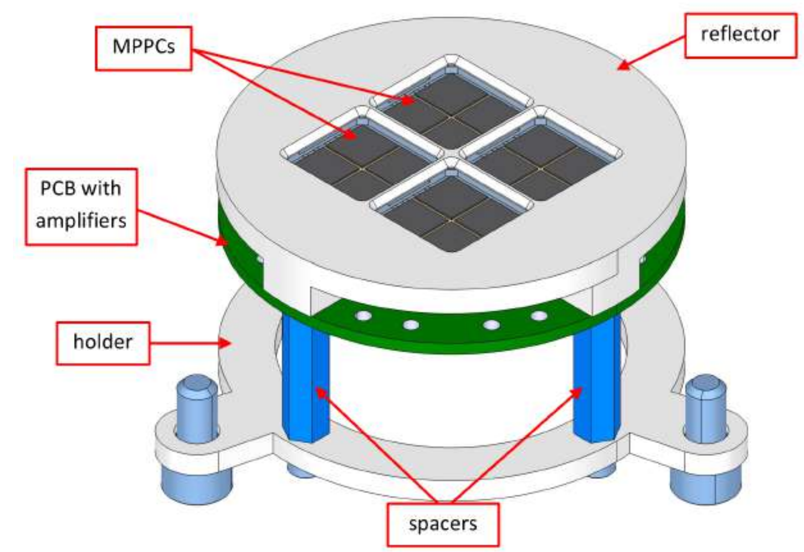
Original configuration with two 2-inch PMTs, top and bottom

R&D in UZH

Our group counts with one LXe TPC, Xurich II



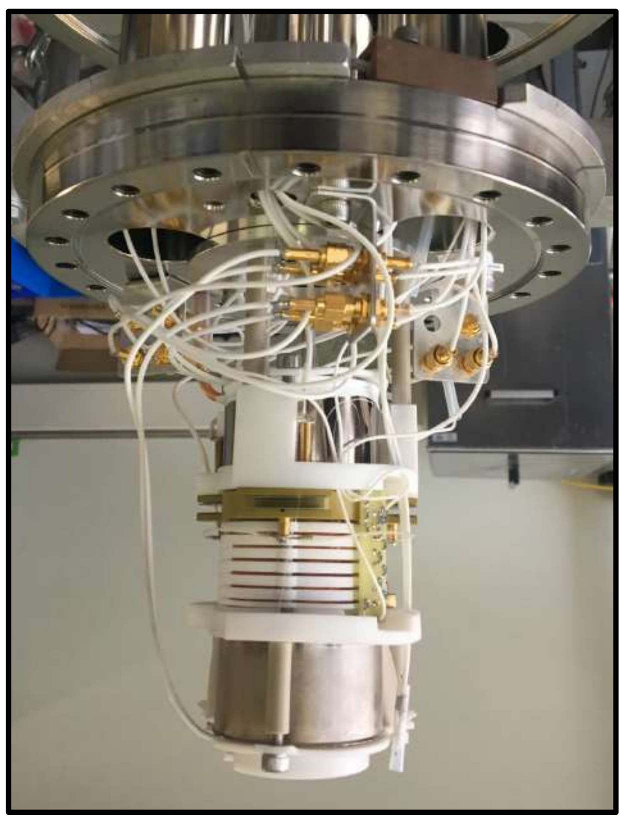


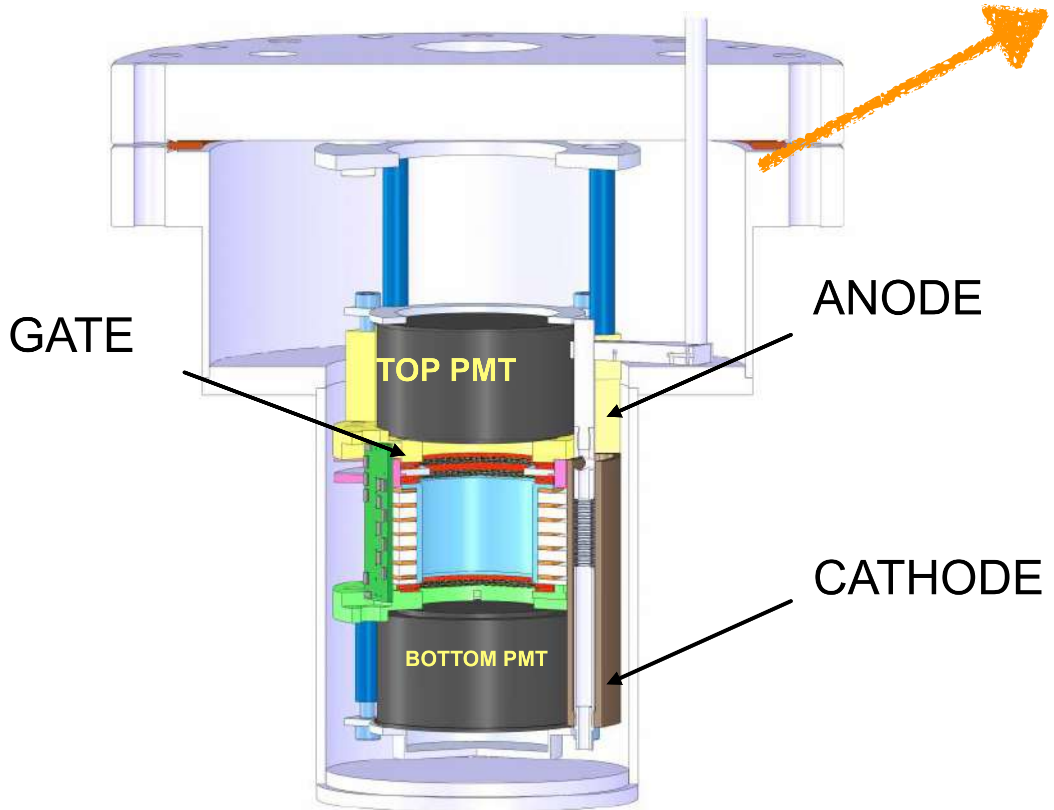


Original configuration with two 2-inch PMTs, top and bottom

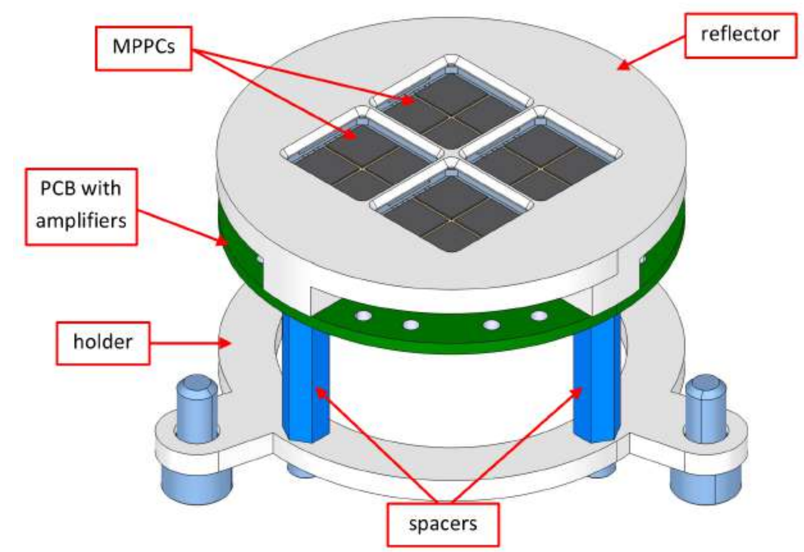
R&D in UZH

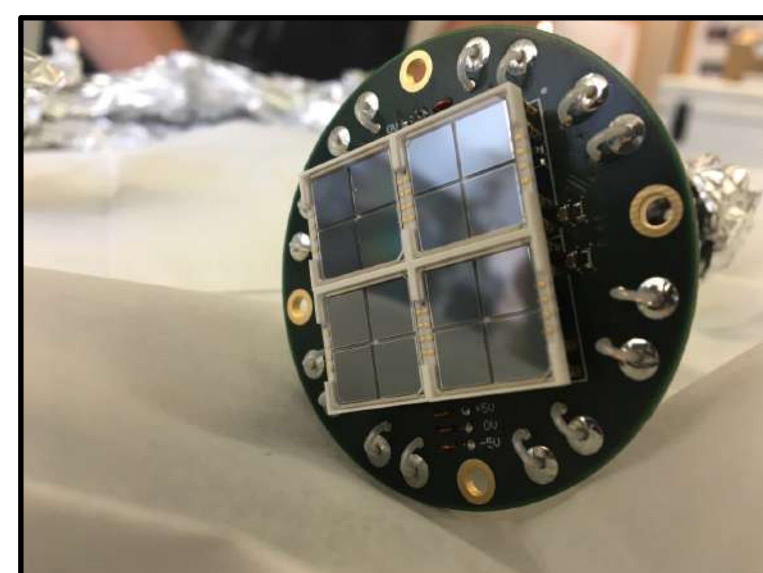
Our group counts with one LXe TPC, Xurich II





Original configuration with two 2-inch PMTs, top and bottom

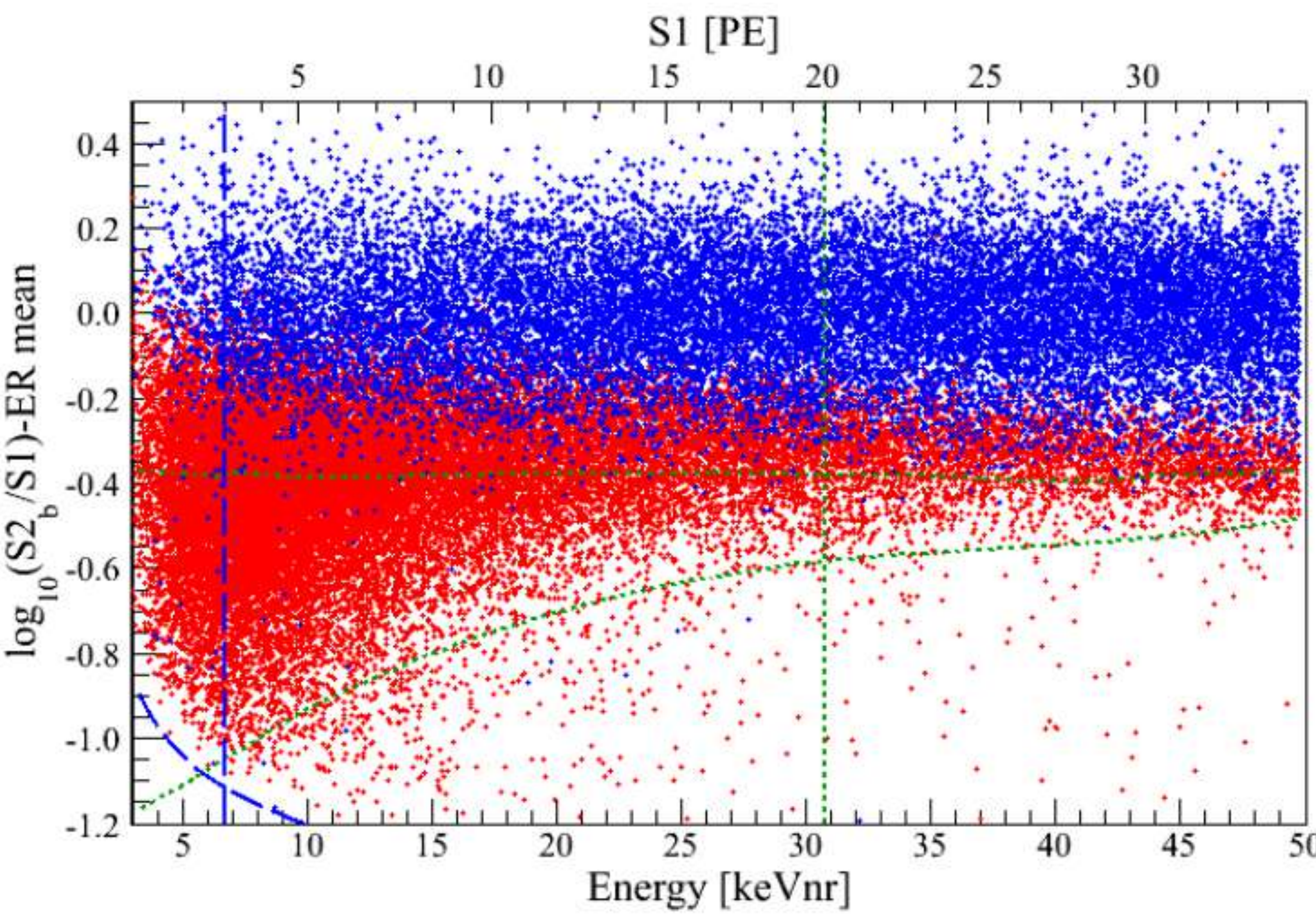




SiPM arrays of Xurich-II with custom-made pre-amplified base

Signal Calibration in LXe

In LXe the background is reduced by S1 (Scintillation) /S2 (Ionisation) discrimination

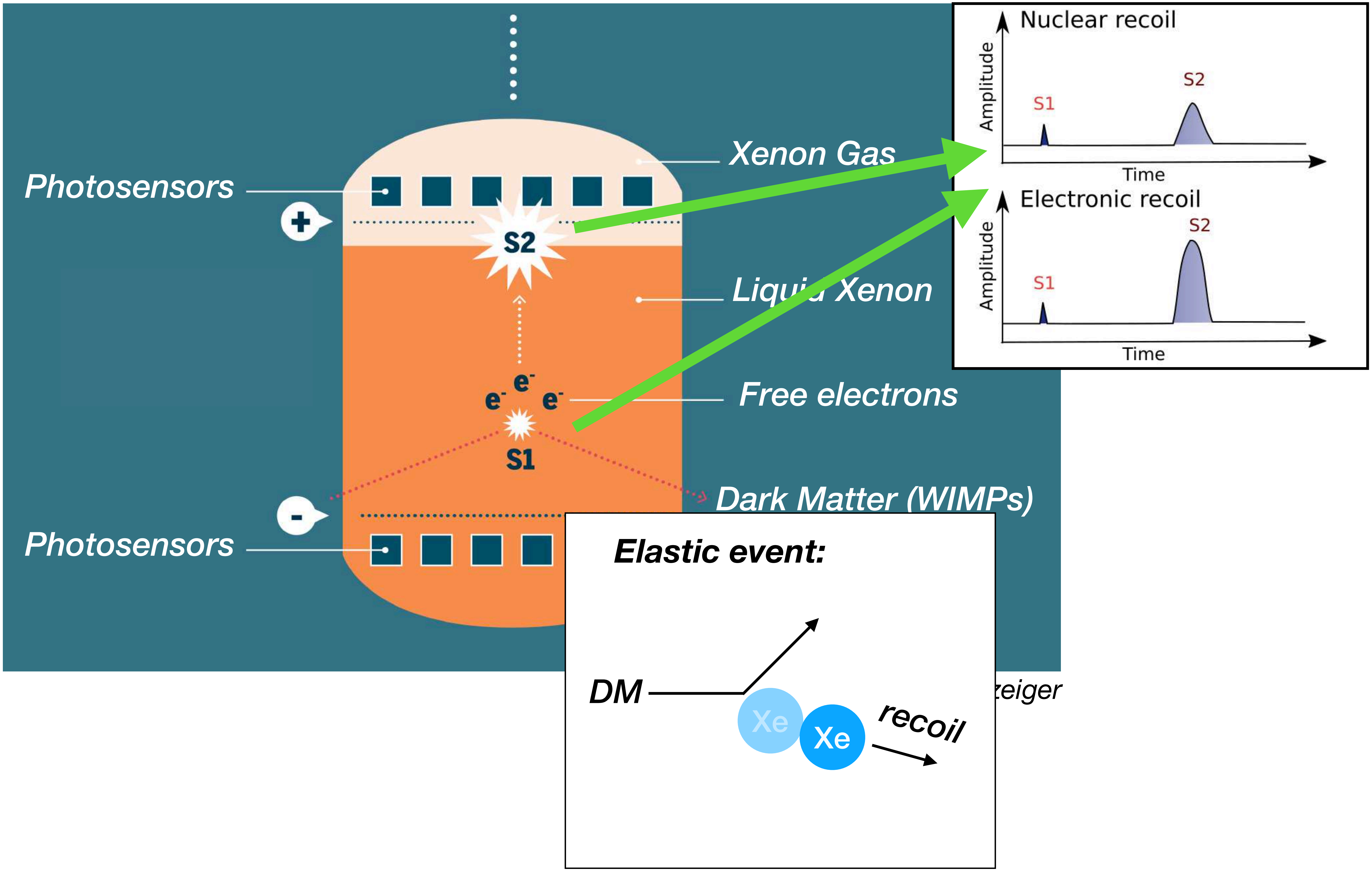


ER BAND: ^{60}Co and ^{232}Th sources

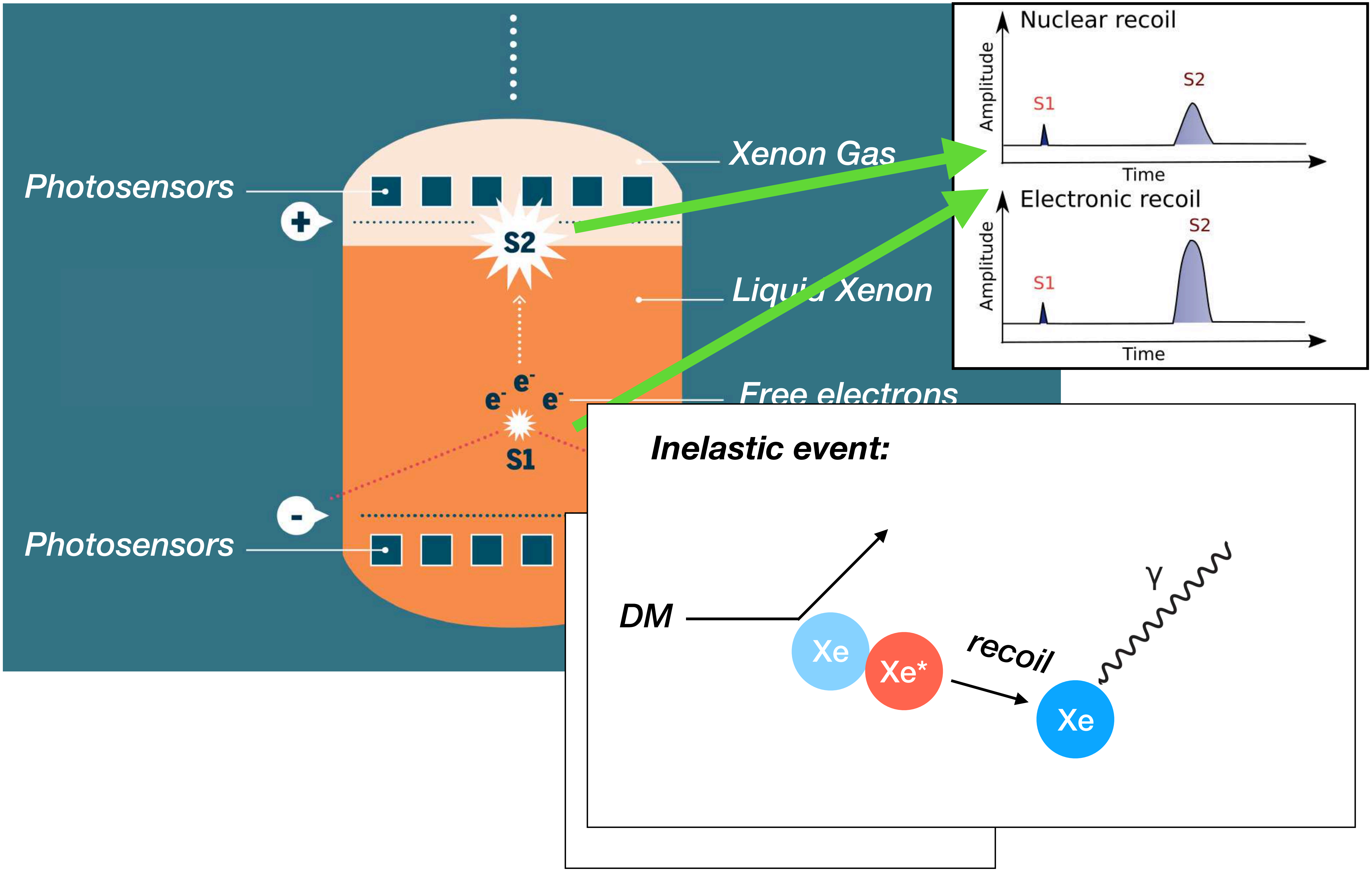
NR BAND : AmBe neutron source. Neutron Generator

From XENON100: Low energy calibration of liquid xenon detectors, Teresa Marrodán Undagoitia, MPIK Heidelberg, May 2013

Dual phase Xe TPC

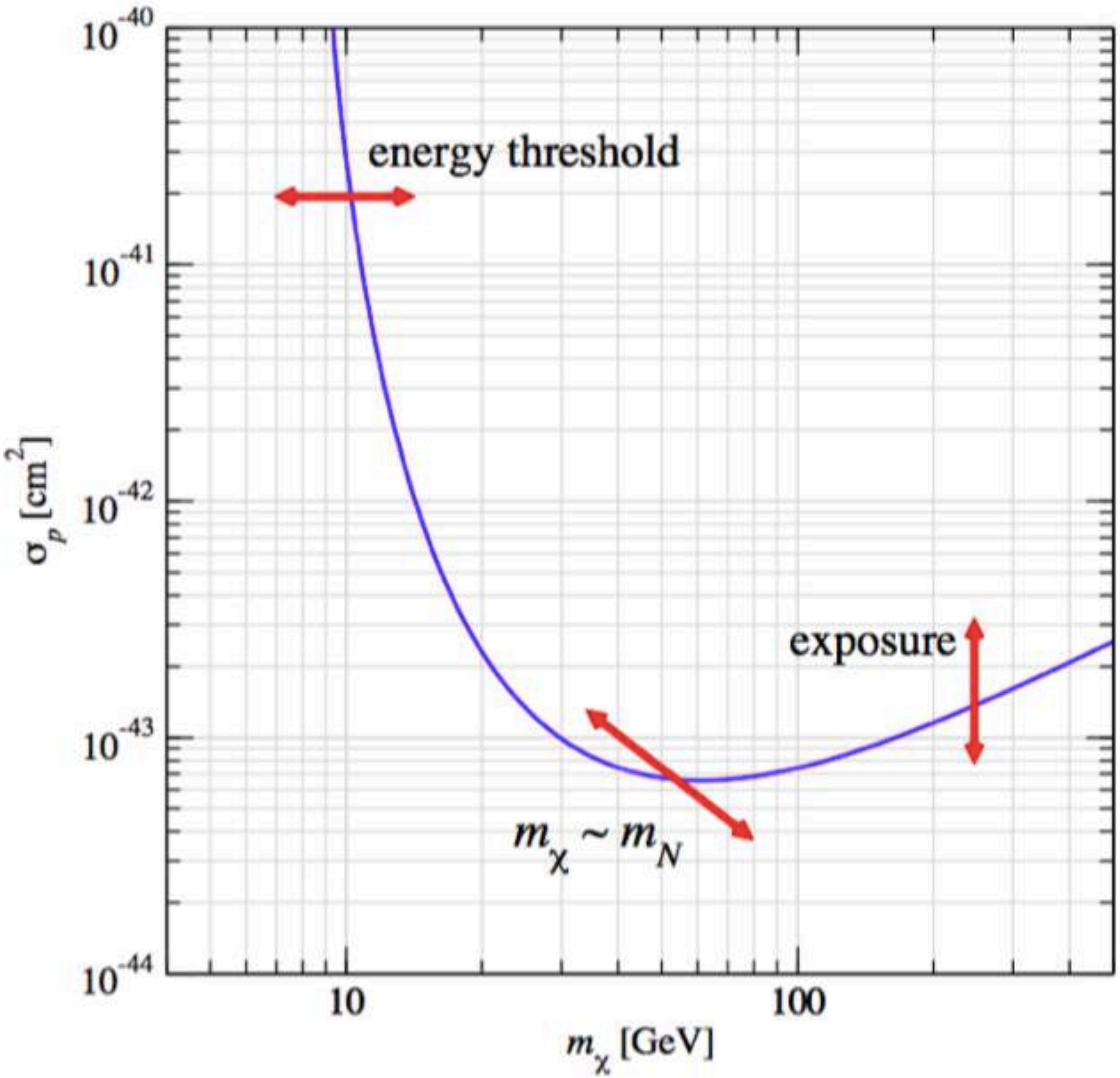


Dual phase Xe TPC



Result of a Direct Detection DM Experiment

DARWIN

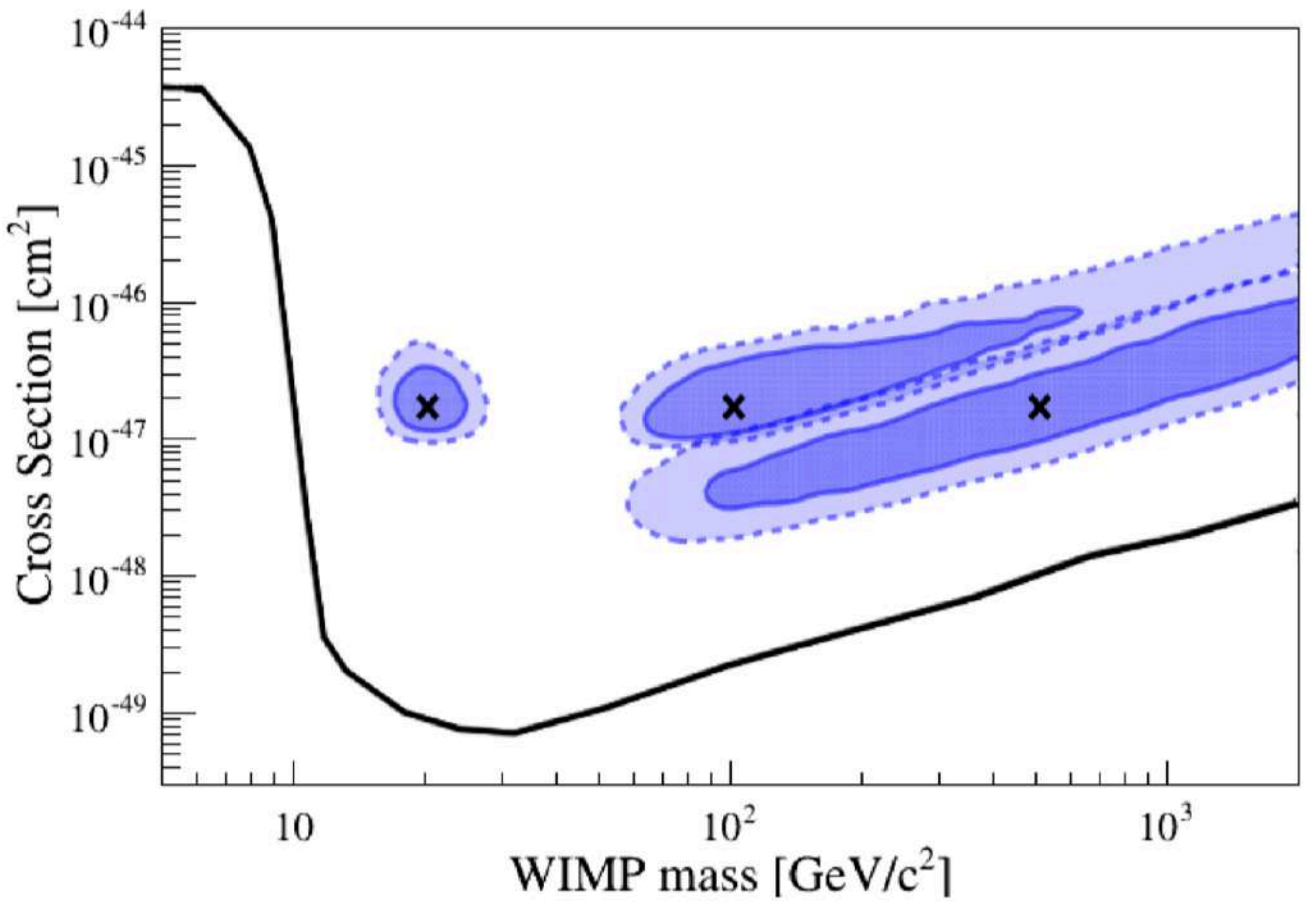


- **Positive Signal:**
  Region in the cross section vs mass parameter space
- **Zero Signal:**
  Exclusion of a parameter region
- **Low WIMP Masses:**
  Detector Threshold matters
- **Minimum of the curve:**
  Depends on target nuclei
- **High WIMP masses:**
  Exposure matters e = m x t

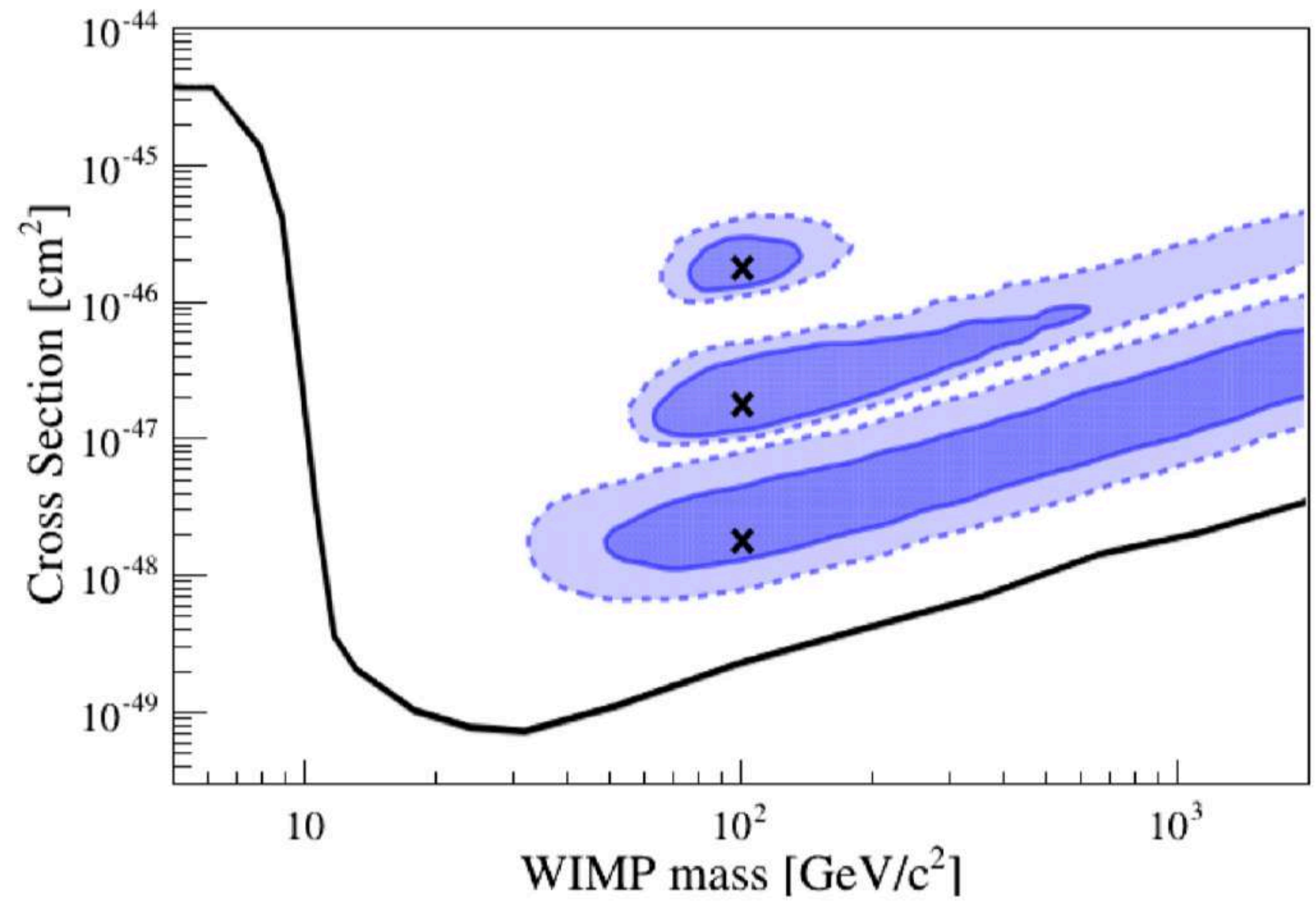
WIMP physics

Not only studies with spin-independent WIMP-nucleon interactions; DARWIN's would have an excellent sensitivity to spin-dependent interactions, especially for ^{129}Xe, that can be extended to axial vector couplings as well.

arXiv:1606.07001v1



Reconstruction for three different WIMP masses of 20 GeV/c2, 100 GeV/c^2 and 500 GeV/c^2 and a cross section of 2 × 10^{47} cm^2 , close to the sensitivity limit of XENON1T.



Reconstruction for cross sections of 2 × 10^{46} cm^2, 2 × 10^{47} cm^2 and 2 × 10^{48} cm^2 for a WIMP mass of 100GeV/c^2. The black curve indicates where the WIMP sensitivity will start to be limited by neutrino-nucleus coherent scattering.

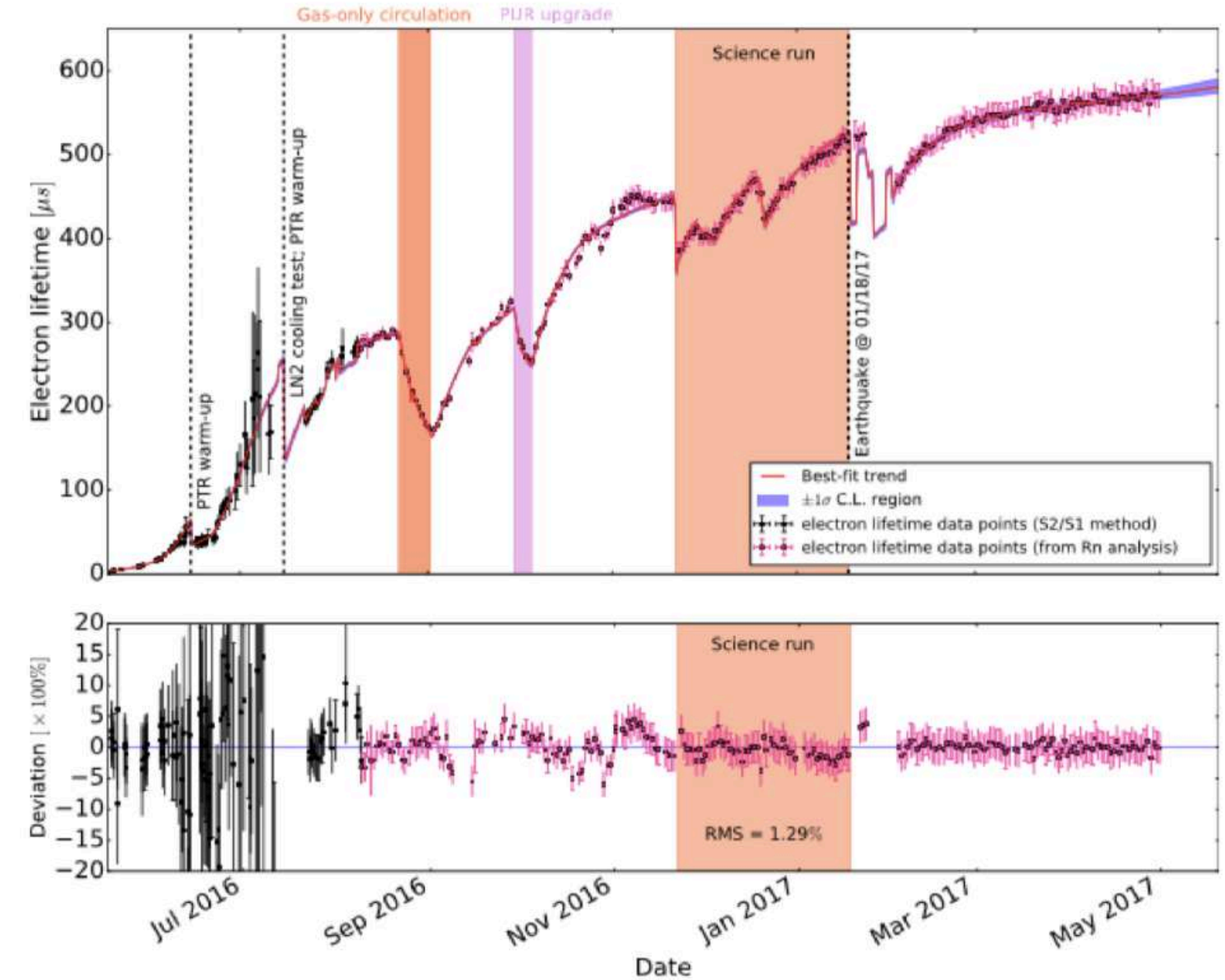
Purification system to reduce the intrinsic background in LXe

purification system:
- clean Xe from electronegative impurities below 1 ppb with continuous gas circulation through heated getters

Reflected in the Electron Lifetime in LXe (Drift electrons)

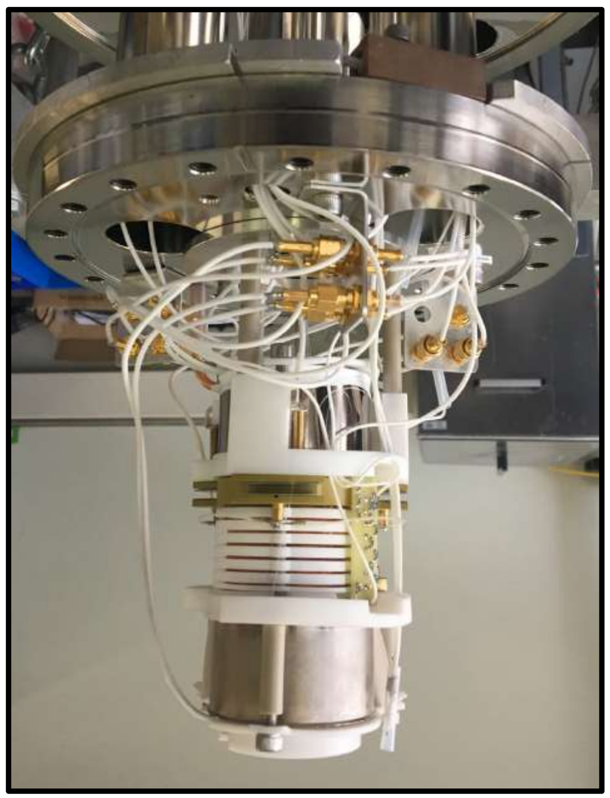
M. Lindner MPIK TAUP, July 24-28 , 2017

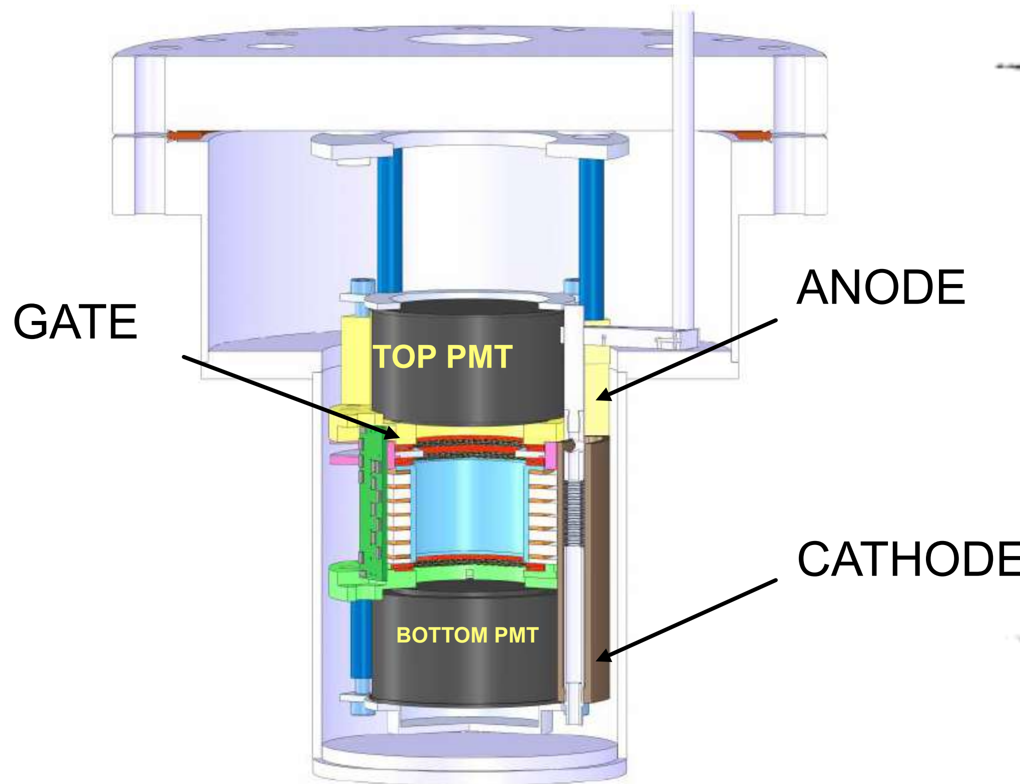
M. Lindner MPIK TAUP, July 24-28 , 2017



Unstable ^{85}Kr in air impurity in Xenon gas - active removal by distillation - control by precise measurements

Towards DARWIN: R&D in UZH





Xurich-II is a small scale, two phase xenon Time-Projection Chamber (TPC) operated at the University of Zürich.

Original configuration with two 2-inch PMTs, top and bottom

- This detector was built to study particle interactions in Liquid xenon (LXe) at very low energies (50 keV)