Universität Zürich[UZH]

European Research Council
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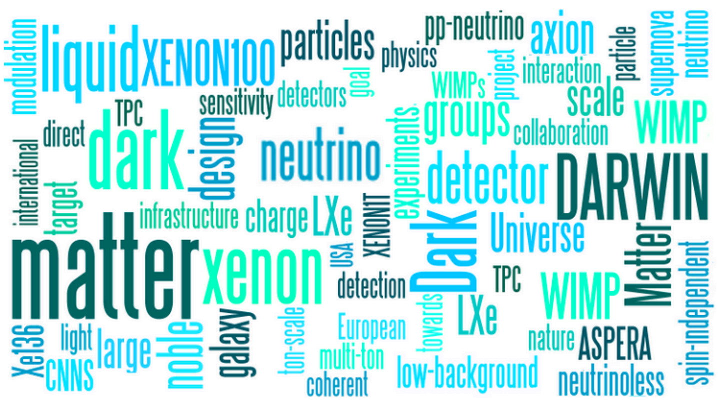
DARWIN

DARWIN: the ultimate dark matter detector

Patricia Sanchez-Lucas, Universität Zürich

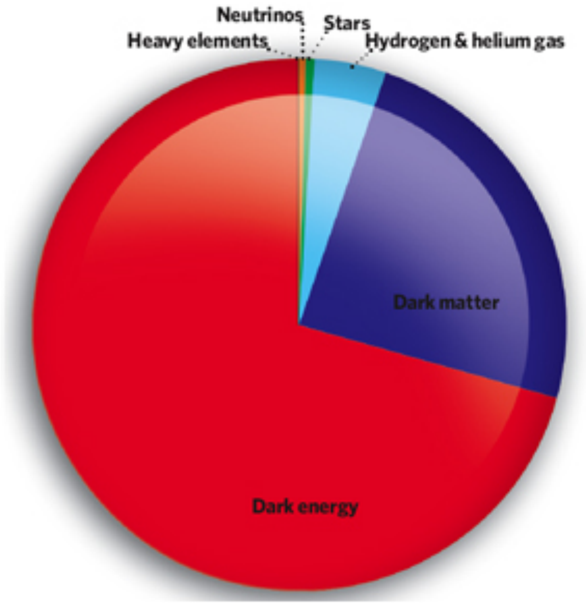
www.darwin-observatory.org



III CAFPE-Física Teórica Christmas Workshop
Granada, 20-21 December 2018

EVIDENCES OF DARK MATTER

- Success of the Cosmological Standard Model
- Dynamic of galaxy clusters
- Rotation curves of spiral galaxies
- CMB measurements
- Collision of galaxies in the Bullet cluster



Dark Matter Features

- Weak and gravitational interaction
- No relativistic particles. **Cold Dark Matter**
- Stable in time scales comparable to the age of the Universe
- Dark Matter fraction 0.25

Possible Candidate

WIMP

Weakly Interacting Massive Particle

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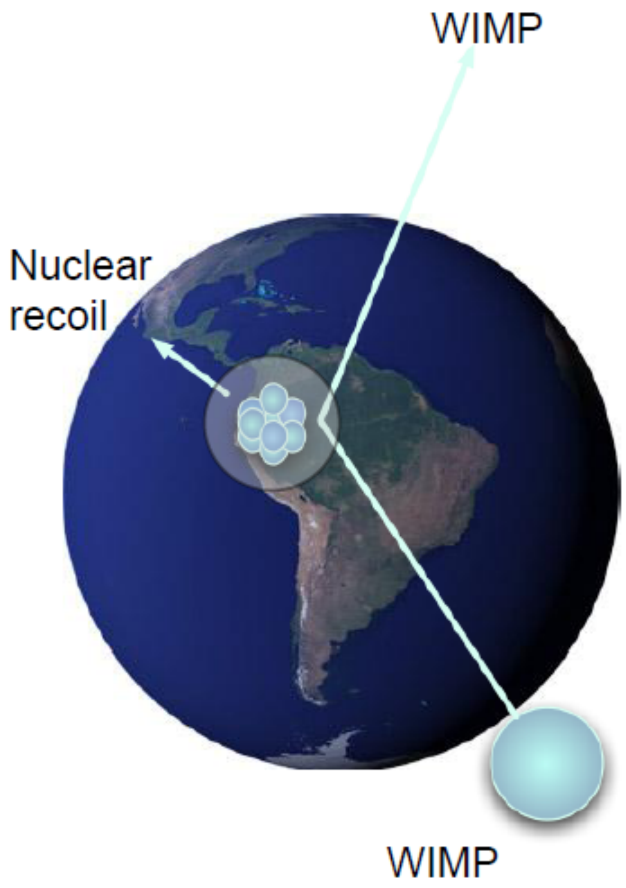
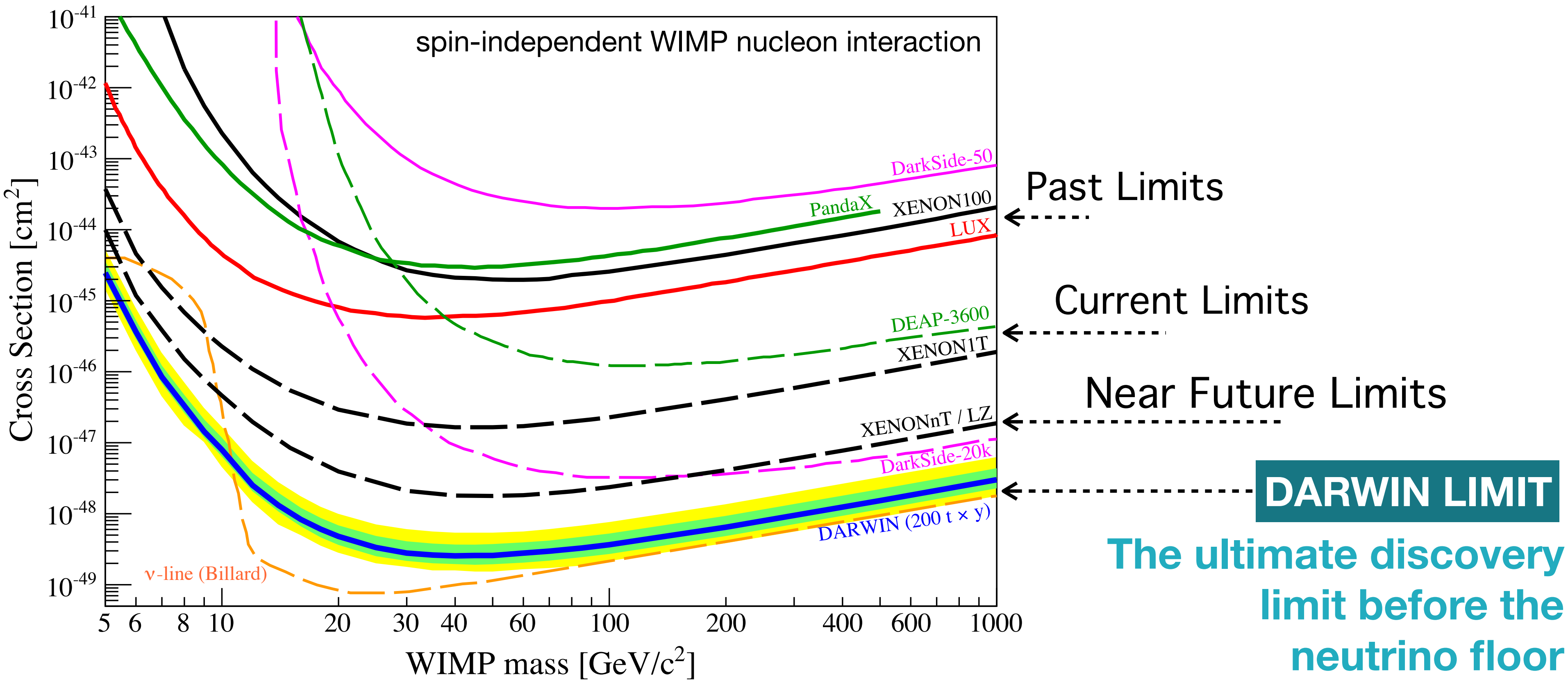
DIRECT DARK MATTER DETECTION



THE WIMP LANDSCAPE 2018

- The best sensitivity to WIMPs above 5 GeV/c² comes from experiments using liquid noble gases as sensitive detectors (Xe, Ar). (heavy target and easy scalability)
- Probing lower cross sections will require much larger detectors. **DARWIN**, with its **40 tons of active target**, aims to increase 100-fold the current sensitivity.



DARWIN: THE ULTIMATE DARK MATTER DETECTOR

DARWIN

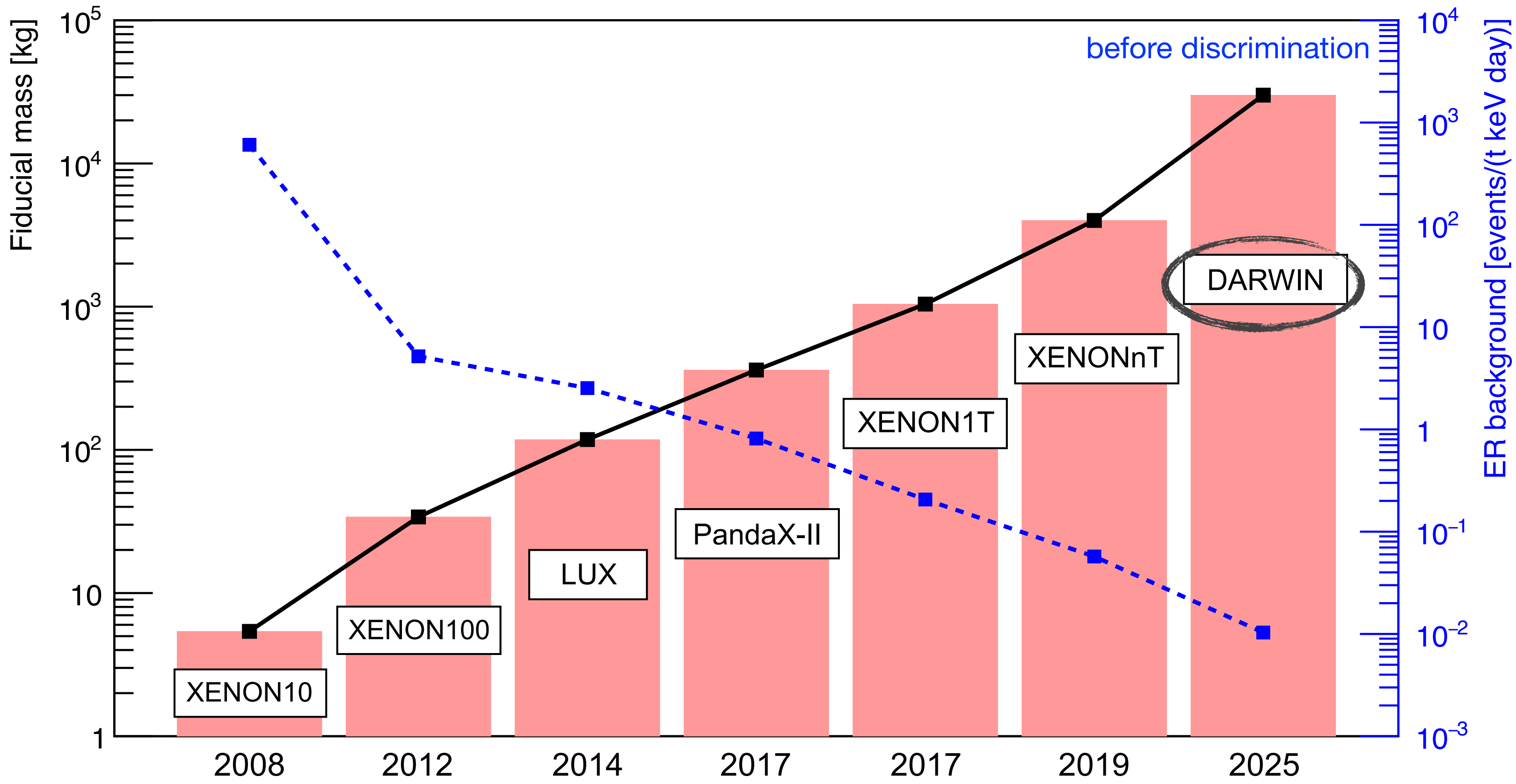
MAIN GOAL

Explore the entire experimentally accessible parameter space for WIMPs

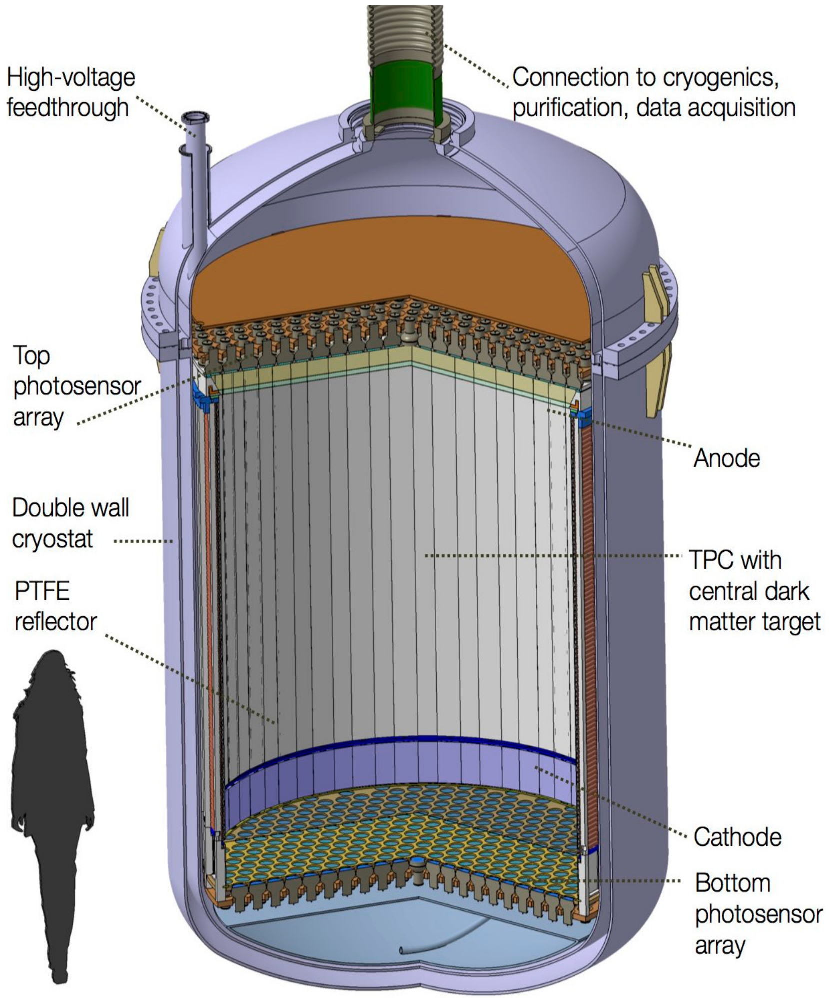
(until neutrino interactions become an irreducible background)

⇩

a **multi-ton detector** and extremely **ultra-low background** level

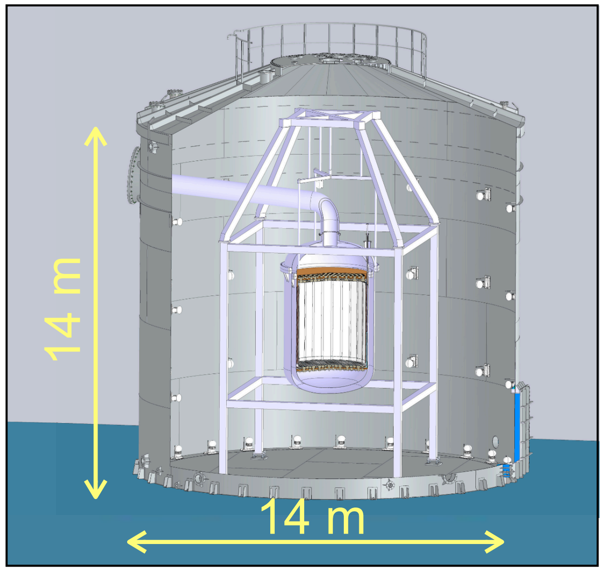


DARWIN BASELINE DESIGN



the baseline design assumes PMTs but several alternative photosensors are under consideration

- Dual-phase Time Projection Chamber (TPC).
- 50 t 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).
- 1800 PMTs of 3” diameter (~1000 of 4”).
- 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).
- Inner liquid scintillator neutron veto.

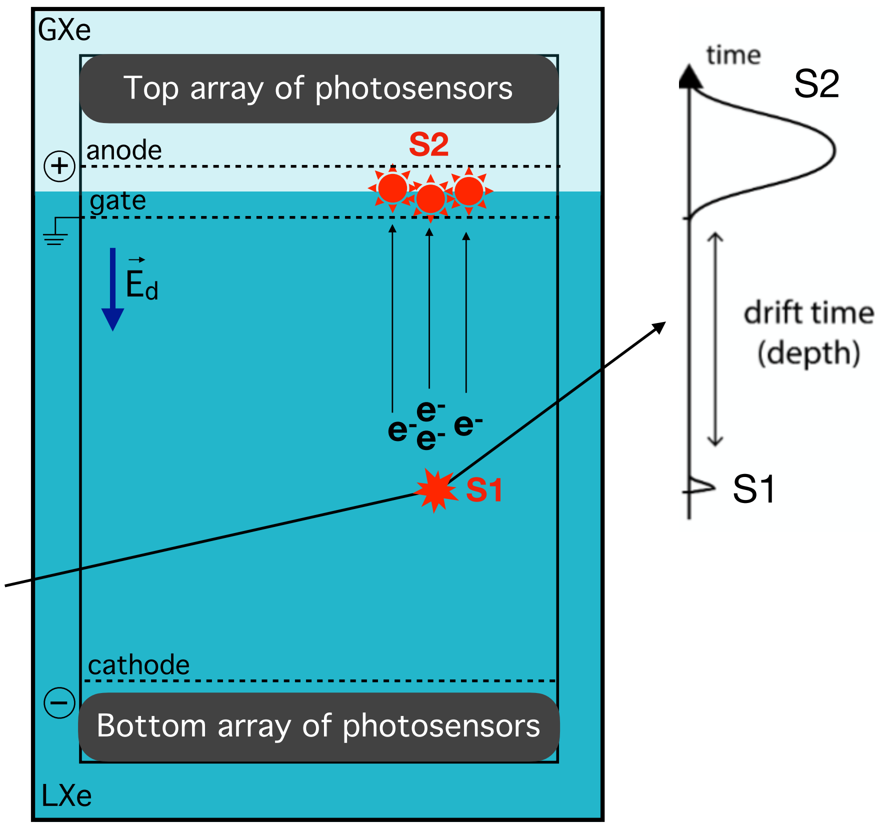


Possible realisation of DARWIN inside the water tank

DUAL-PHASE XENON TIME PROJECTION CHAMBER

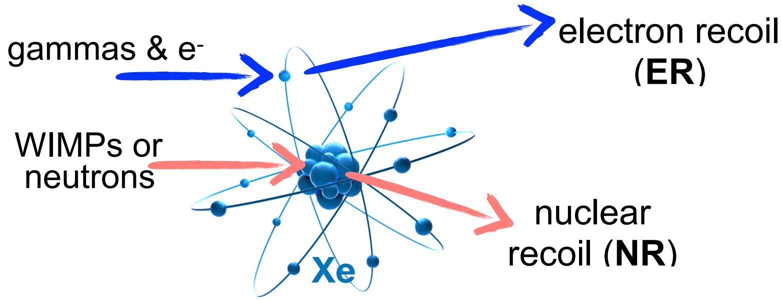
Dual phase TPC working principle

Detection of the scintillation **light** (**S1**) and the delayed scintillation light proportional to the **charge** (**S2**)



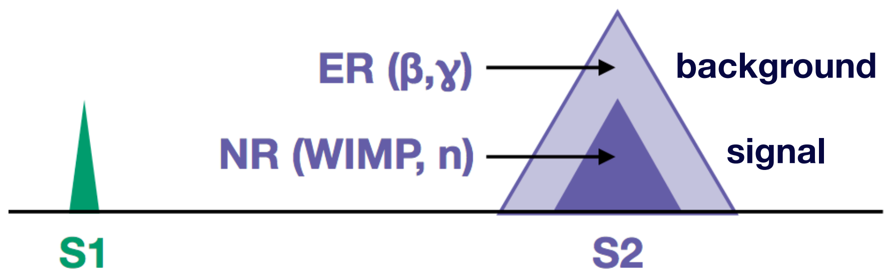
- The dual-phase TPC allows a 3D position reconstruction.
  x-y from the light sensors, z from the drift time

Particle interactions



- The ratio S2/S1 depends on the interacting particle.

Particle type discrimination



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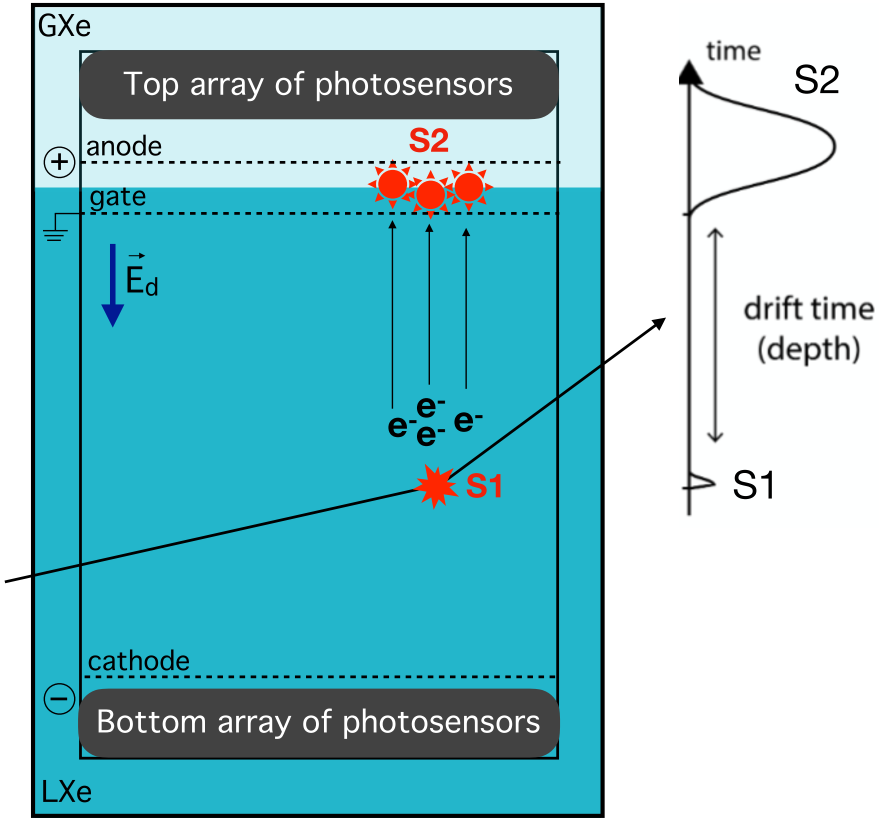

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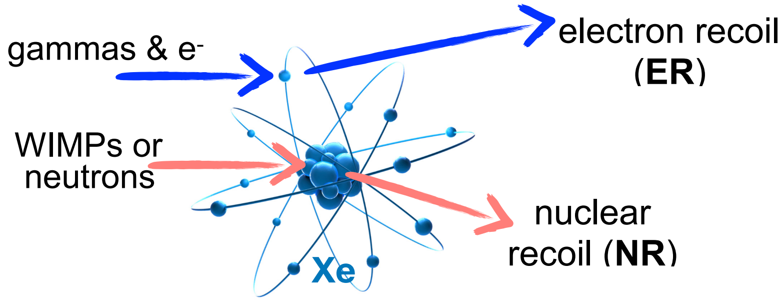

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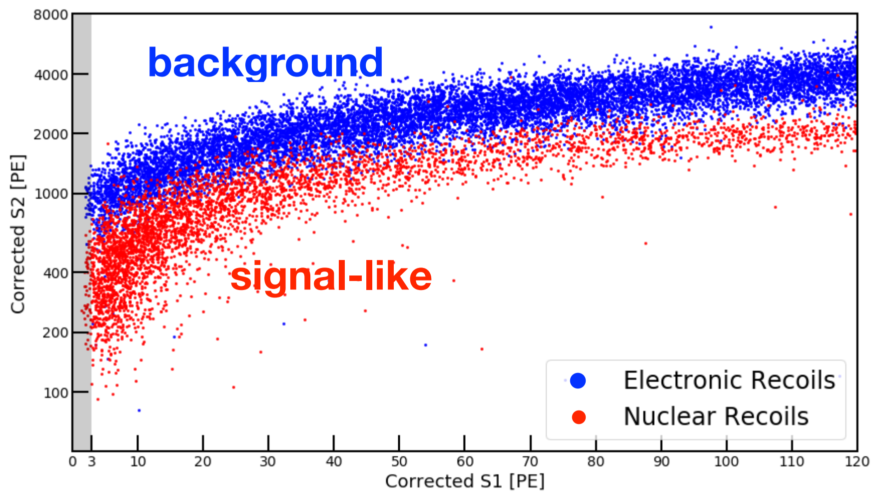


BACKGROUND PREDICTIONS

DARWIN

Two different backgrounds

Electronic Recoils

- γ-rays from materials
- Intrinsic backgrounds (^{85}Kr, ^{222}Rn, ^{136}Xe)
- Low energy solar neutrinos (pp, ^{7}Be)

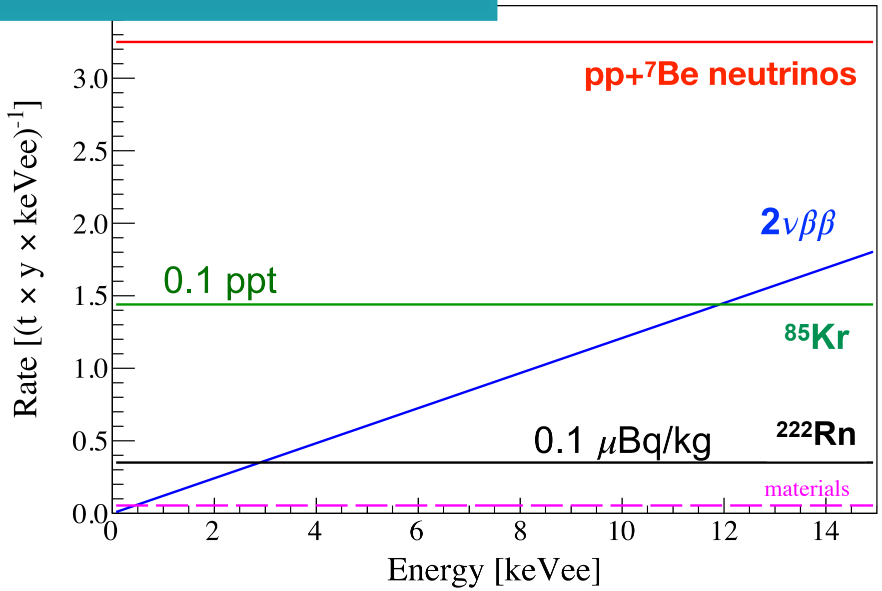
Nuclear Recoils

- CNNS (irreducible)
- Neutrons from the materials
- Cosmogenic and radiogenic (lab) neutrons

(reduced by overburden, veto and fiducialisation)

ER can be rejected based on the S1/S2 ratio

JCAP 10, 016 (2015)



Background contribution before ER discrimination

Source	Rate [events/(t·y·keV)]
γ-rays materials	0.054
neutrons*	3.8×10^{-5}
intrinsic ^{85}Kr	1.44
intrinsic ^{222}Rn	0.35
$2\nu\beta\beta$ of ^{136}Xe	0.73
pp- and ^{7}Be ν	3.25
CNNS*	0.0022

NR

DARWIN will require a ER rejection **> 99.98%**

ER = 5.824 events/(t · y · keV$_{ee}$)

lower than current experiments

THE WIDE VARIETY OF PHYSICS CHANNELS

- The DARWIN detector, with its large mass, low-energy threshold and ultra-low background, will open **a large variety of relevant physics channels**

DIRECT DETECTION OF DARK MATTER

SOLAR AXIONS

NEUTRINOLESS DOUBLE-BETA DECAY ^{136}Xe

GALACTIC AXION-LIKE PARTICLES

DARWIN

much more than a dark matter detector

LOW-ENERGY SOLAR NEUTRINOS

BOSONIC SUPERWIMPs

GALACTIC SUPERNOVA NEUTRINOS

CNNS

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BOSONIC SUPERWIMPs

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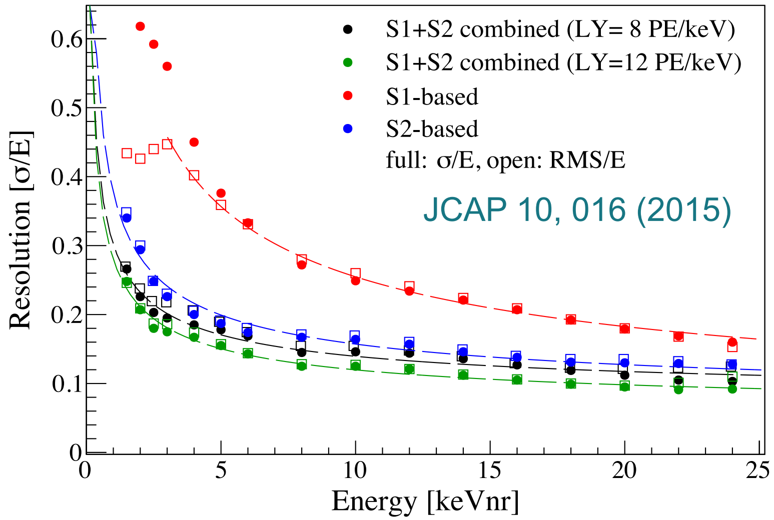
CNNS

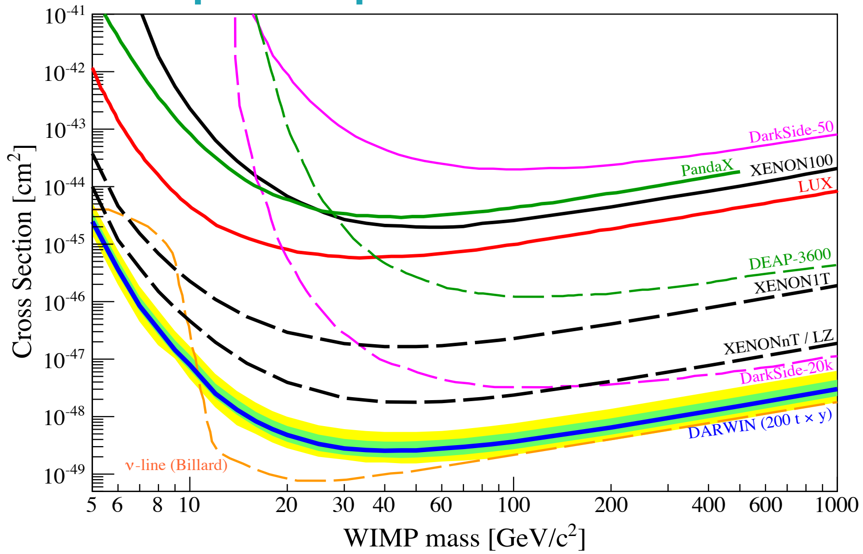
SENSITIVITY TO WIMPS

DARWIN

- Considered all mentioned background
- Assumed an exposure 200 t x y
- 99.98% ER rejection
- Combined (S1+S2) energy scale
- Energy window 5-35 keV_{NR}
- Light yield 8PE/keV

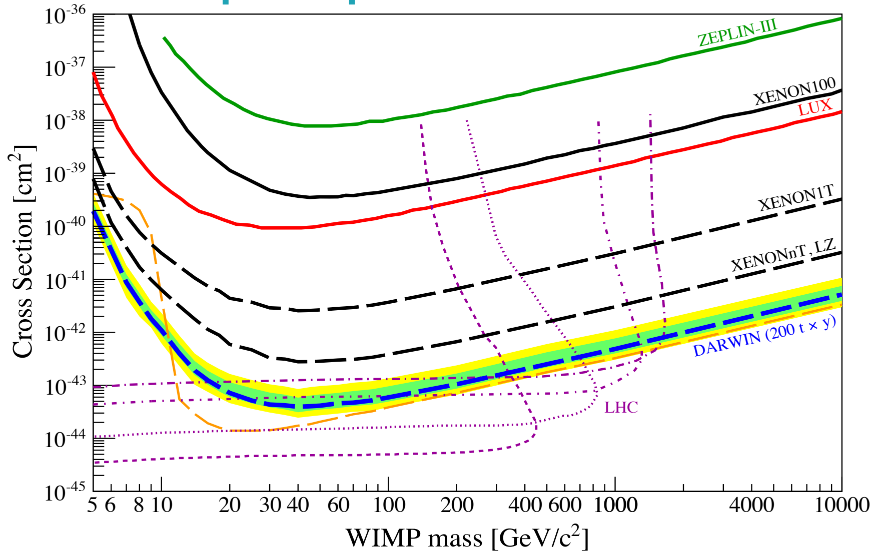


spin-independent interaction



minimum: 2.5x10^{-49} cm^2 at 40 GeV/c^2

spin-dependent interaction



Complementary to LHC searches (14TeV)

NEUTRINOLESS DOUBLE-BETA DECAY

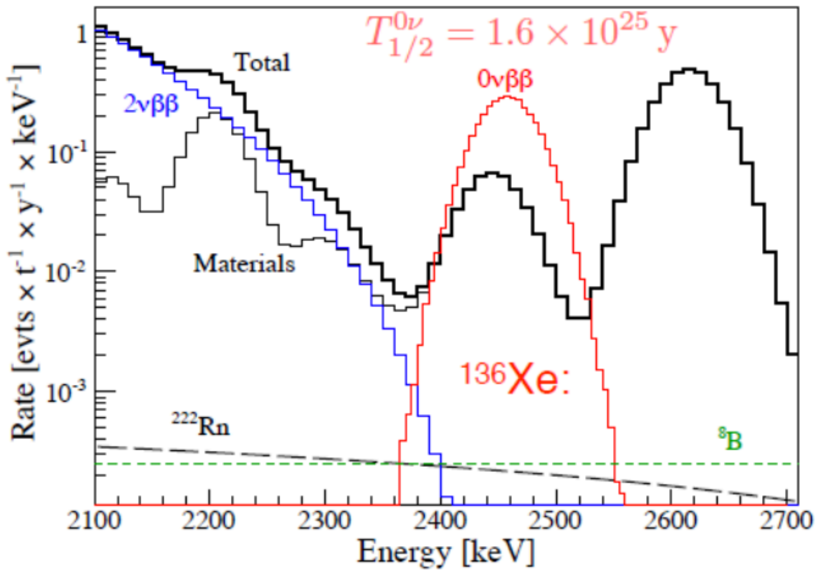
DARWIN

the question whether neutrinos are Majorana fermions is studied via the neutrinos less double-beta decay ($0\nu\beta\beta$)

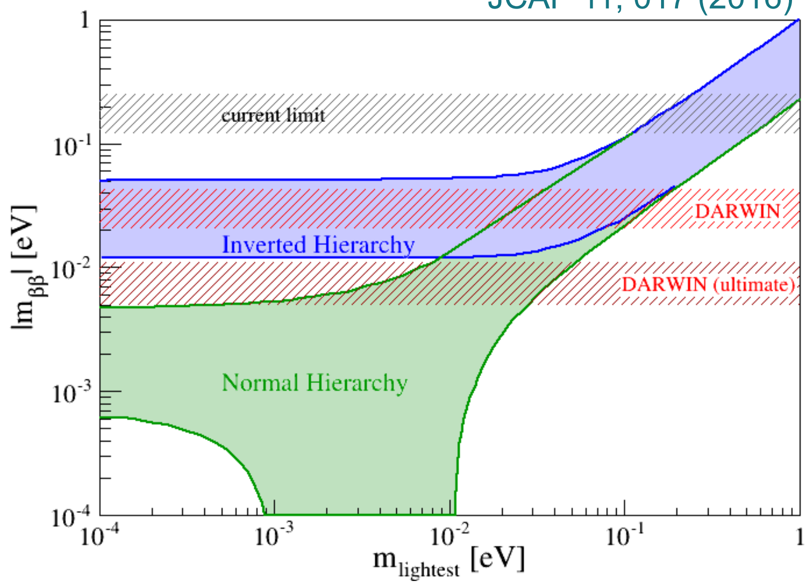
- ^{136}Xe has an abundance of 8.9% in natural xenon.
- DARWIN will have more than 3.5 t of ^{136}Xe. (without enrichment)
- Q-value = 2.458 MeV (above the ROI of WIMPs)
- Ultra-low background environment: ^{222}Rn, $2\nu\beta\beta$ decays and interactions of solar ^{8}B neutrinos.
- Preliminary study with 6 tons fiducial mass.
- With a resolution (σ/E) ~2% at 2.5 MeV the sensitivity will be comparable to future dedicated experiments

Projected sensitivity at 90% CL

- 30 ton×year	⟶	$T_{1/2} > 5.6\times10^{26}$ yr
- 140 ton×year	⟶	$T_{1/2} > 8.5\times10^{27}$ yr



JCAP 11, 017 (2016)



SOLAR NEUTRINOS

DARWIN

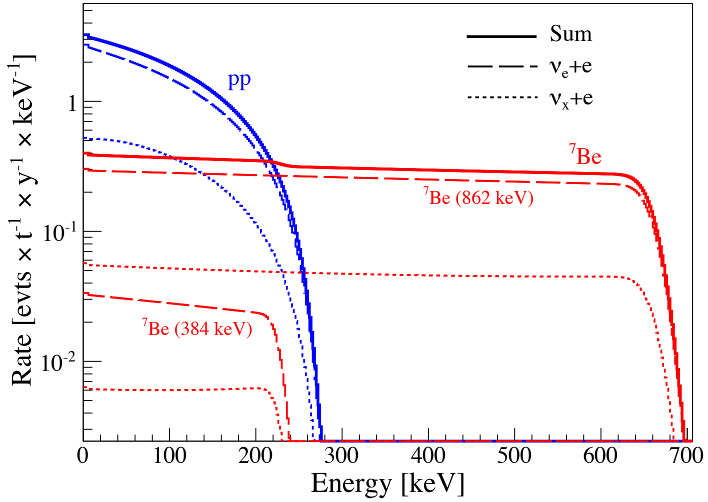
the precise measurement of pp- neutrinos would test the main energy production mechanisms in the Sun

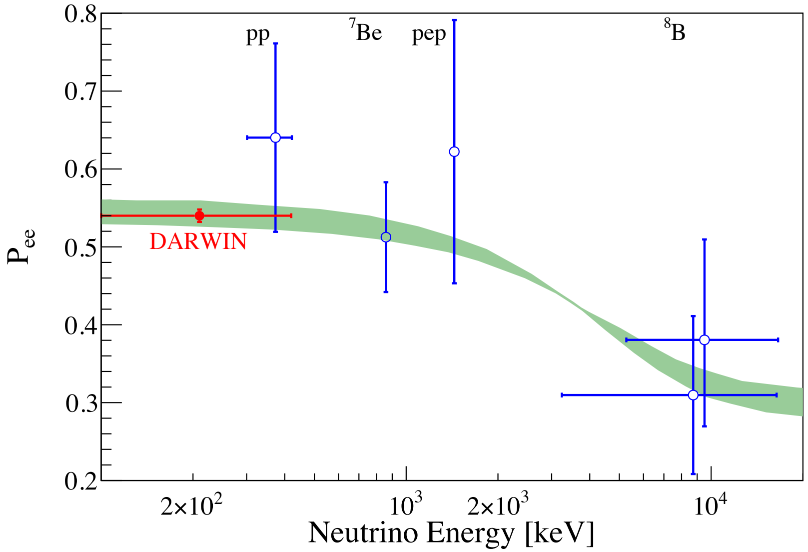
- pp- neutrinos are ~92% of the solar neutrino flux (SSM)
- Detection through neutrino-electron elastic scattering

$$\nu_x + e \longrightarrow \nu_x + e$$

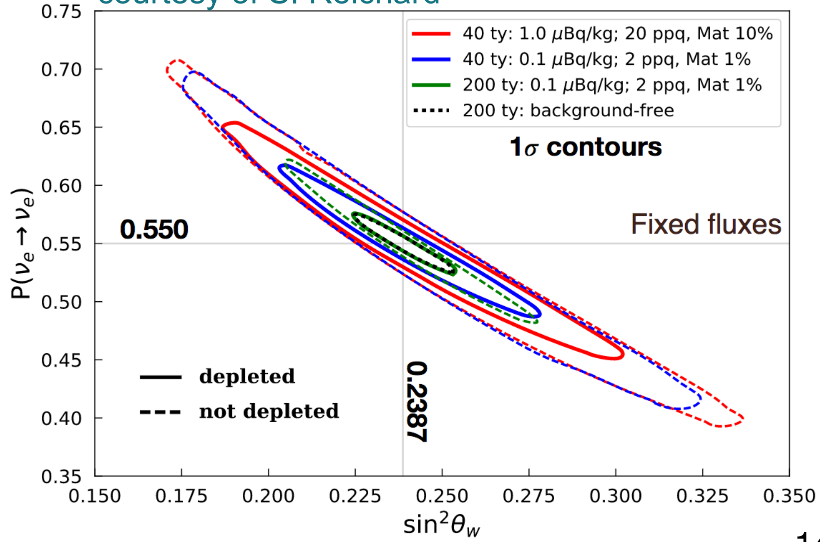
- Real-time measurement of the neutrino flux: **371 events/(t x y)**
  (whole energy window)
- Flux with 2% statistical precision after 1 year
- Measurement of electron neutrino survival probability (P_{ee}) and the neutrino mixing angle below 300 keV
  (deviation from prediction would indicate new physics)

JCAP 11, 017 (2016)





courtesy of S. Reichard



COHERENT NEUTRINO NUCLEUS SCATTERING (CNNS)

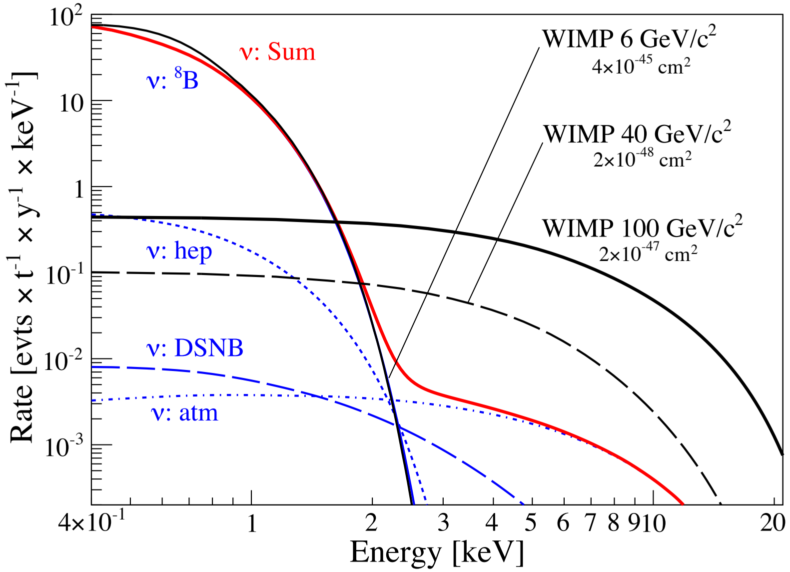
DARWIN

CNNS is a irreducible background for WIMP searches but also one of the scientific goals of DARWIN

$$\nu + A \longrightarrow \nu + A$$

sensitive to all neutrino flavours

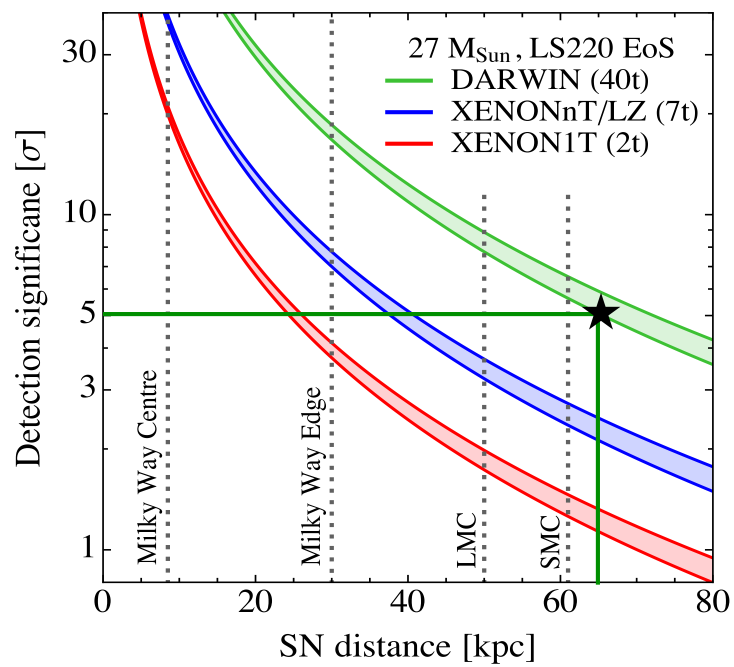
^{8}B solar neutrinos



- ^{8}B neutrinos from the Sun:
  E_{th} > 1 keV ⟶ **90 events/(t × y)**
- Atmospheric neutrinos:
  E_{th} > 1 keV ⟶ **0.003 events/(t × y)**

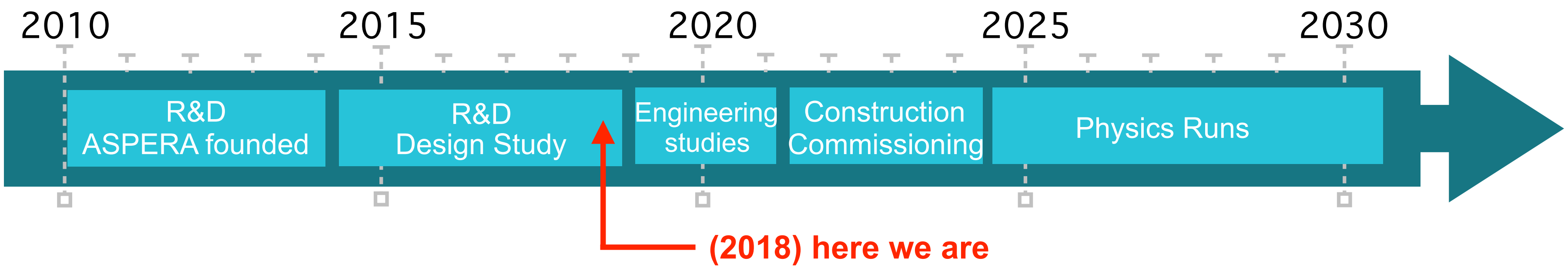
Supernova neutrinos

DARWIN will detect SN bursts up to 65 kpc from Earth (5σ), observing **~700 events** from a 27 M⊙ SN progenitor at 10 kpc (window of 7s).

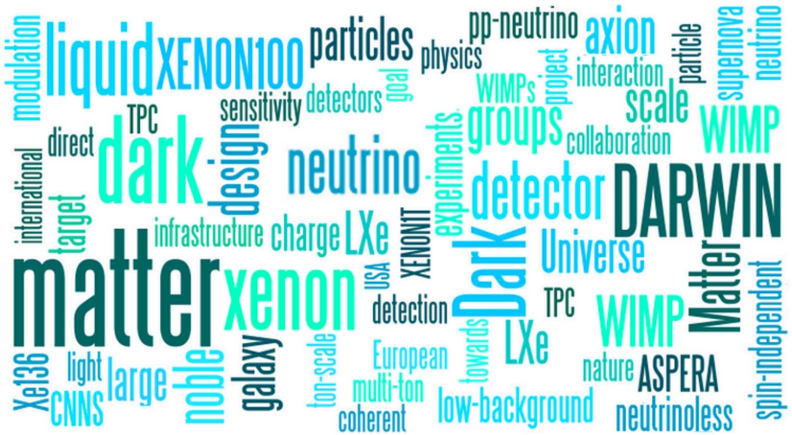


R. F. Lang et al., *Phys. Rev. D* **94** (2016) 103009

CURRENT STATUS OF DARWIN



- 28 groups from 11 countries
- Working towards a CDR and TDR
- DARWIN is in the APPEC roadmap
- Funding with two ERC grants for R&D:
  ULTIMATE (UniFr) and Xenoscope (UZH)
  - R&D on detector design
  - testing different sensor technologies (SiPMs)
  - building demonstrators
  - mechanical mock-ups
  - screening of new materials



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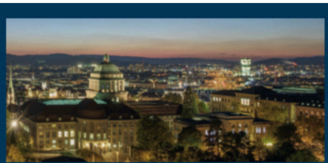
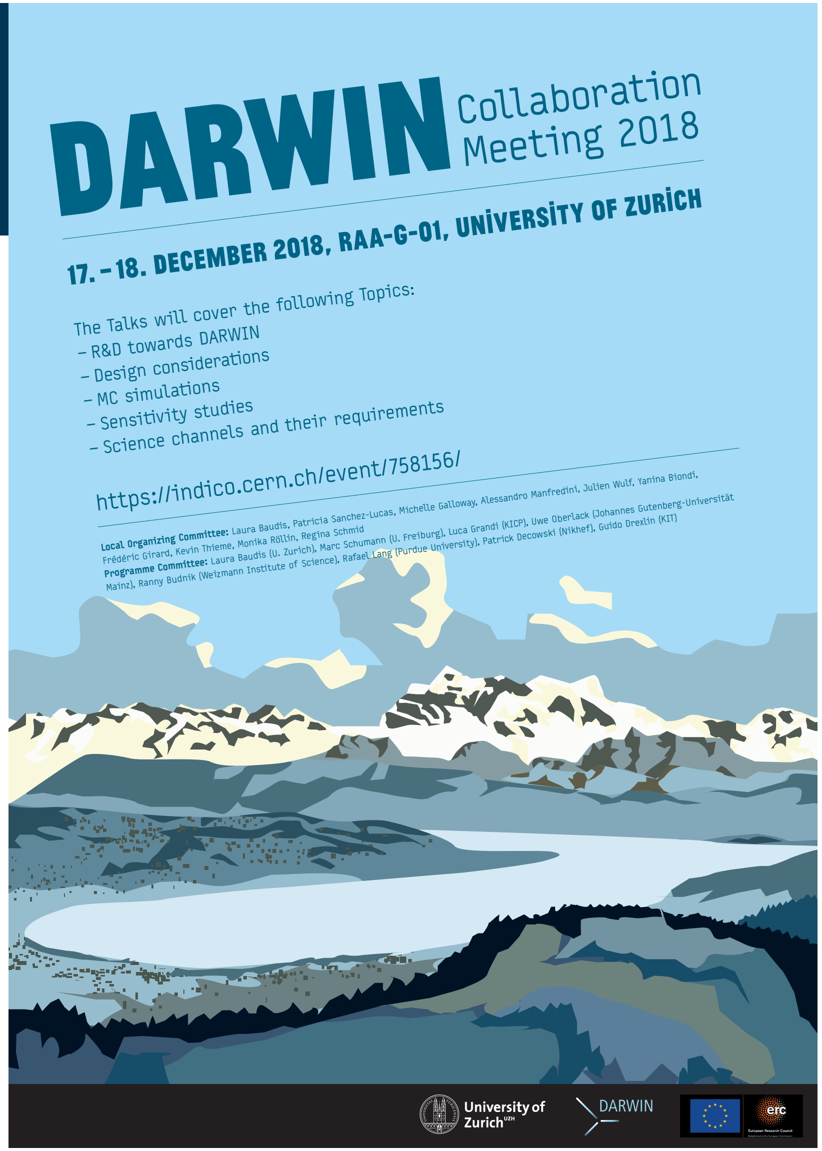
DARWIN COLLABORATION MEETING IN ZURICH



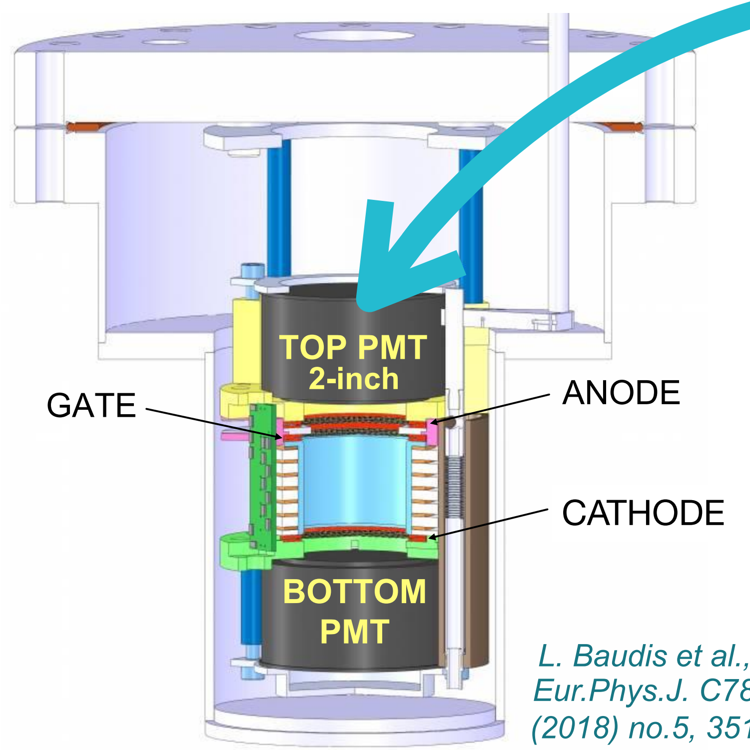
DARWIN Collaboration Meeting

- Organised by the University of Zurich
- 80 participants from 20 different institutions
- 33 contributions
- Discussions about R&D and design considerations
- Sensitivities studies



R&D AT THE UZH: XURICH TPC WITH SiPMs

Previous configuration of the Xurich TPC

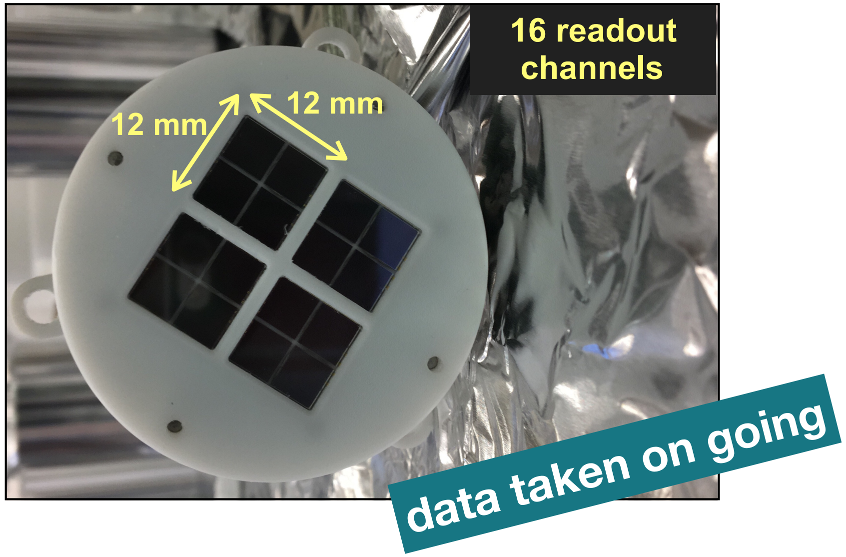


L. Baudis et al., Eur.Phys.J. C78 (2018) no.5, 351

- Small-scale, dual-phase xenon TPC (3.1cm diameter x 3.1cm height)
- Under operation at the University of Zürich
- Designed to investigate particle interactions in LXe at energies below 50 keV

Upgrade of the TPC

Replacement of the top PMT with an array of 16 SiPMs (6 x 6 mm²)



- 3D position reconstruction adding x-y coordinates (possible fiducialisation)
- Direct comparison between the performance of SiPMs and PMT in the same experiment.
- Test for the **first time the performance of SiPMs in a dual-phase TPC** to show if they are a viable solution for large TPCs like DARWIN

R&D AT THE UZH: DEMONSTRATOR

Medium Term Plan

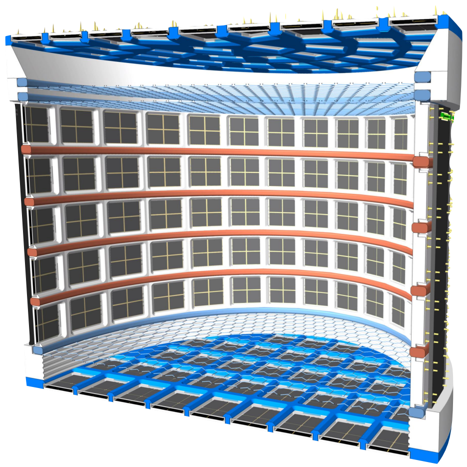
4π-coverage TPC

Design and operation of a LXe TPC with a full 4π-coverage using our large cryostat MarmotXL

- 15 cm diameter x 10 cm height
- 60 SiPMs in the top array
- 61 SiPMs in the bottom array
- 5 rings with 28 SiPms each

current configuration

261 SiPMs in total



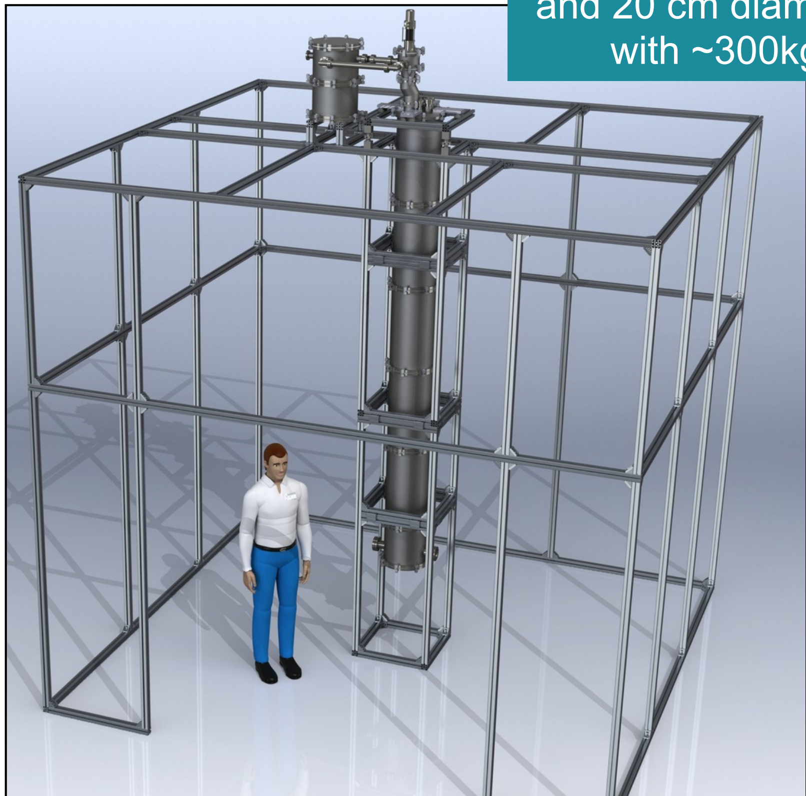
Design of the MarmotXL-TPC

Long Term Plan

DARWIN demonstrator

The main goal of Xenoscope is the demonstration of the electron drift over the full height of DARWIN

build a TPC of 2.6 m height and 20 cm diameter filled with ~300kg LXe



courtesy of F. Girard

DARWIN

SUMMARY

- DARWIN will be the **ultimate dark matter detector**, probing a wide mass-range and WIMP-nucleon cross sections down to the irreducible background from neutrinos.
- The large mass, low-energy threshold and ultra-low background, will open **a large variety of relevant physics channels:**
  - WIMP dark matter
  - Neutrinoless double-beta decay
  - Low energy solar neutrinos
  - CNNS
  - Axions and axion-like particles
- DARWIN is a growing collaboration, currently **28 groups from 11 countries**.
- R&D and prototypes supported by two ERC grants: Ultimate (Freiburg) and **Xenoscope (Zürich)**.
  - TPC with SiPMs
  - DARWIN demonstrator to drift electrons over 2.6m