Ultra-low intrinsic background for the direct dark matter search down to the neutrino fog with DARWIN/XLZD

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Obertrubach-Bärnfels

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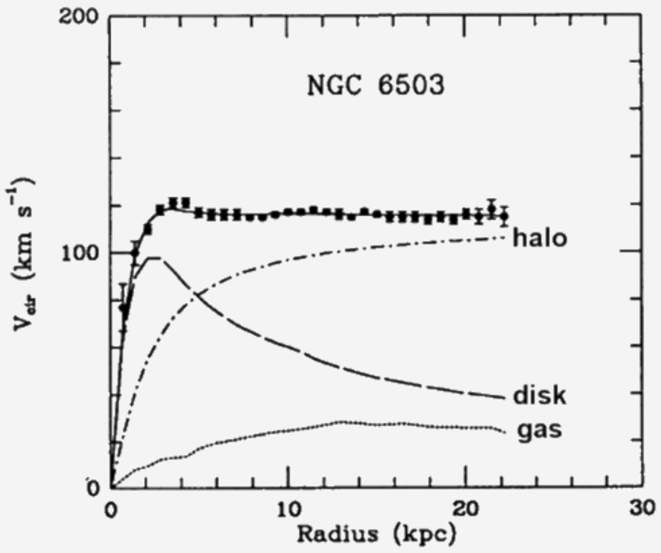
University Münster

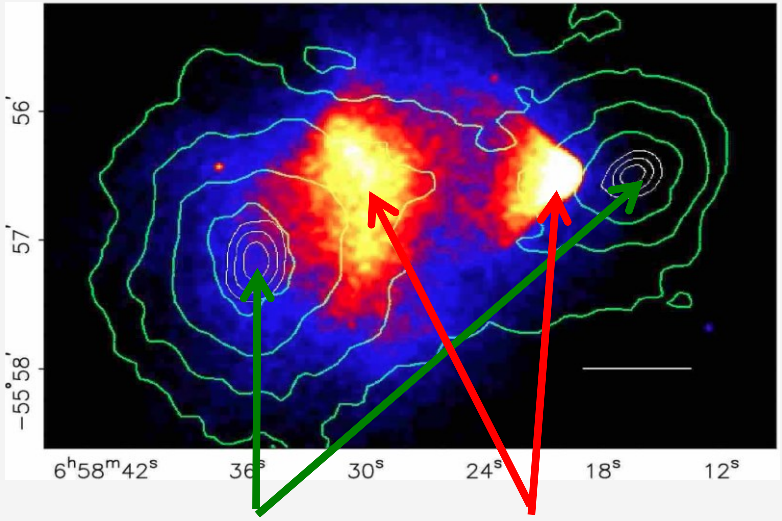
Evidences for Dark Matter

Galaxies rotation: Star velocities are faster than it could be explained by visible matter



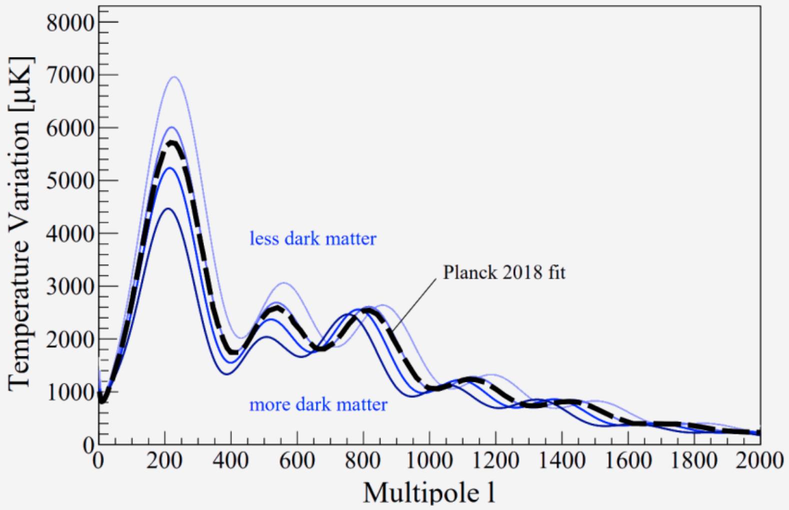
Monthly Notices of the Royal Astronomical Society, Volume 249, Issue 3, April 1991, Pages 523–537

Gravitational lensing: Light from sources is distorted by gravity



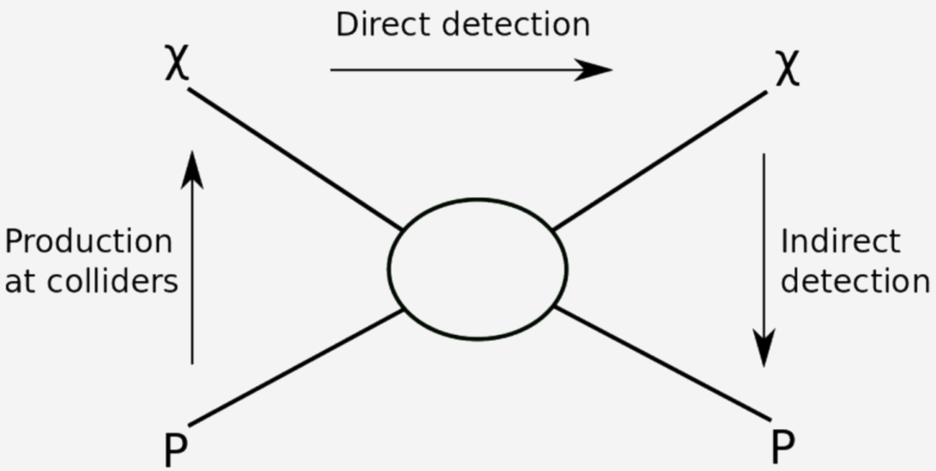
Astrophysical Journal (2006) 648 L109

Cosmic microwave background (CMB): Precision measurements reveal matter distribution

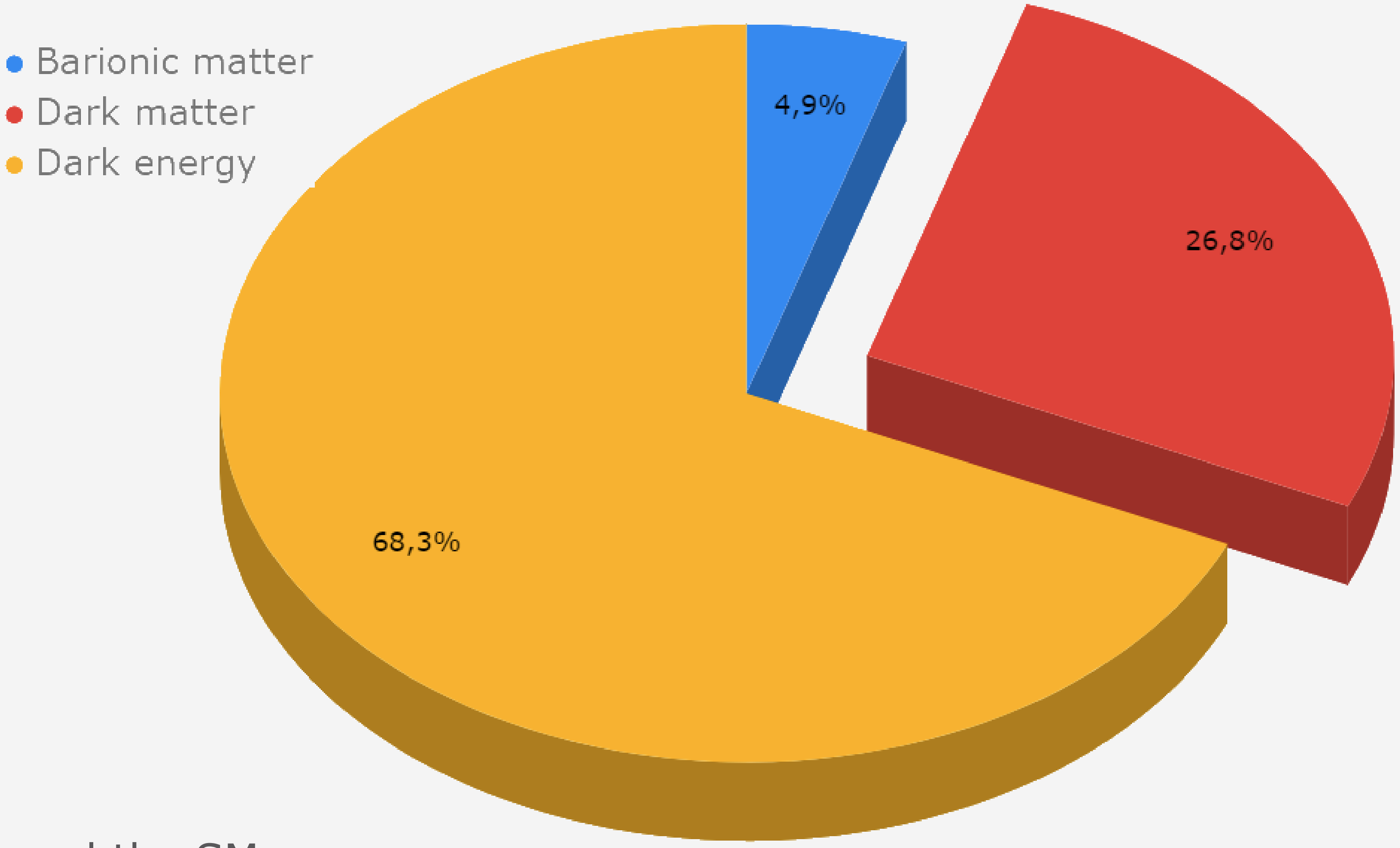


Journal of Physics G: Nuclear and Particle Physics 46 103003

Dark Matter



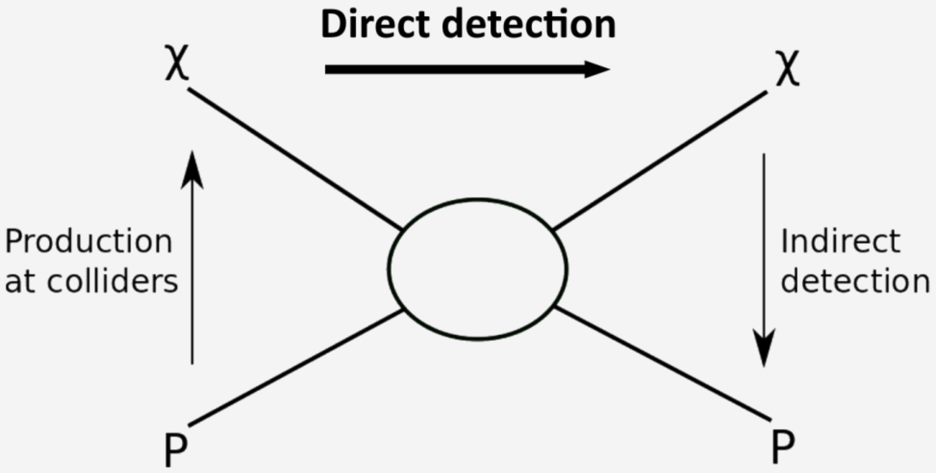
Journal of Physic: Condensed Matter 28 013001



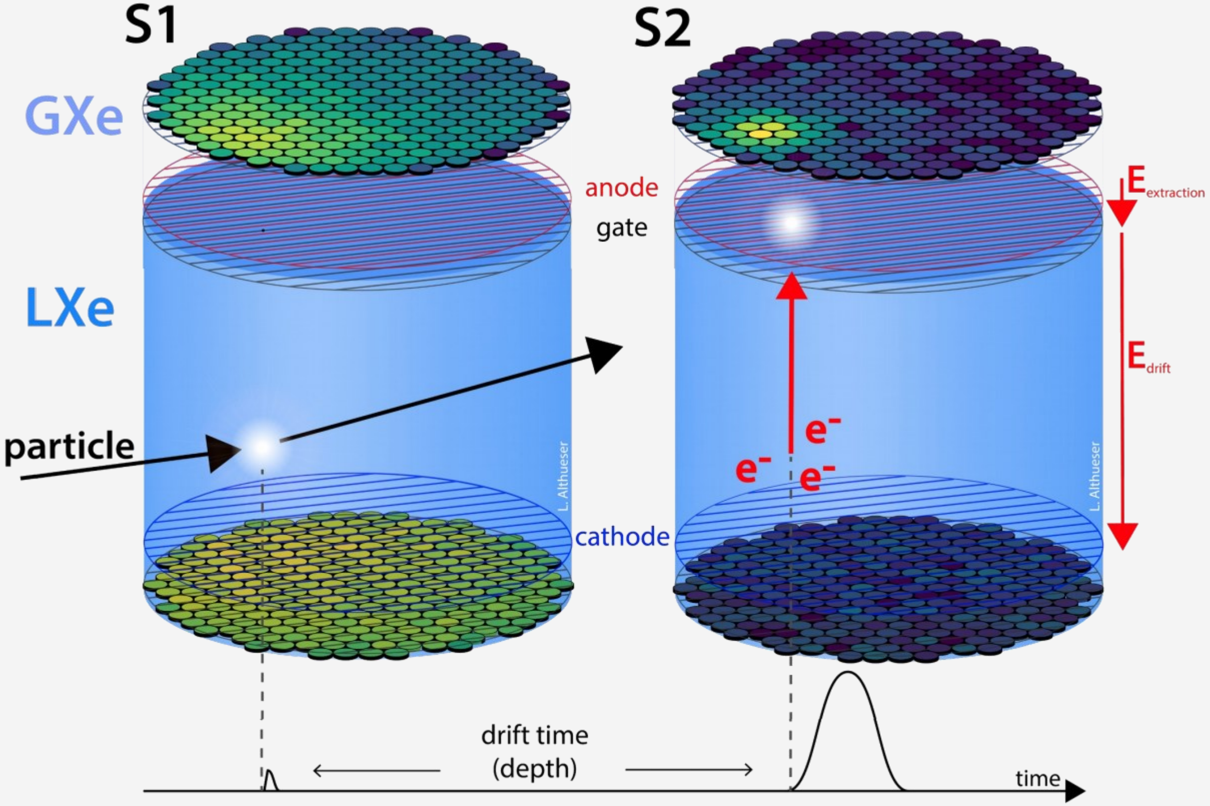
One promising candidate for Dark Matter

- Weakly Interacting Massive Particles (WIMPs):
  - Stable
  - Neutral
  - Massive particles predicted by models beyond the SM

WIMP detection



Journal of Physic: Condensed Matter 28 013001



L. Althüser - xenonexperiment.org

- One direct detection method is using a dual-phase Time Projection Chambers (TPC) with xenon
- Xenon is used by virtue of heavy nucleus ($Z = 54$), high liquid density ($\sim 3\ g/cm^3$), low chemical reactivity

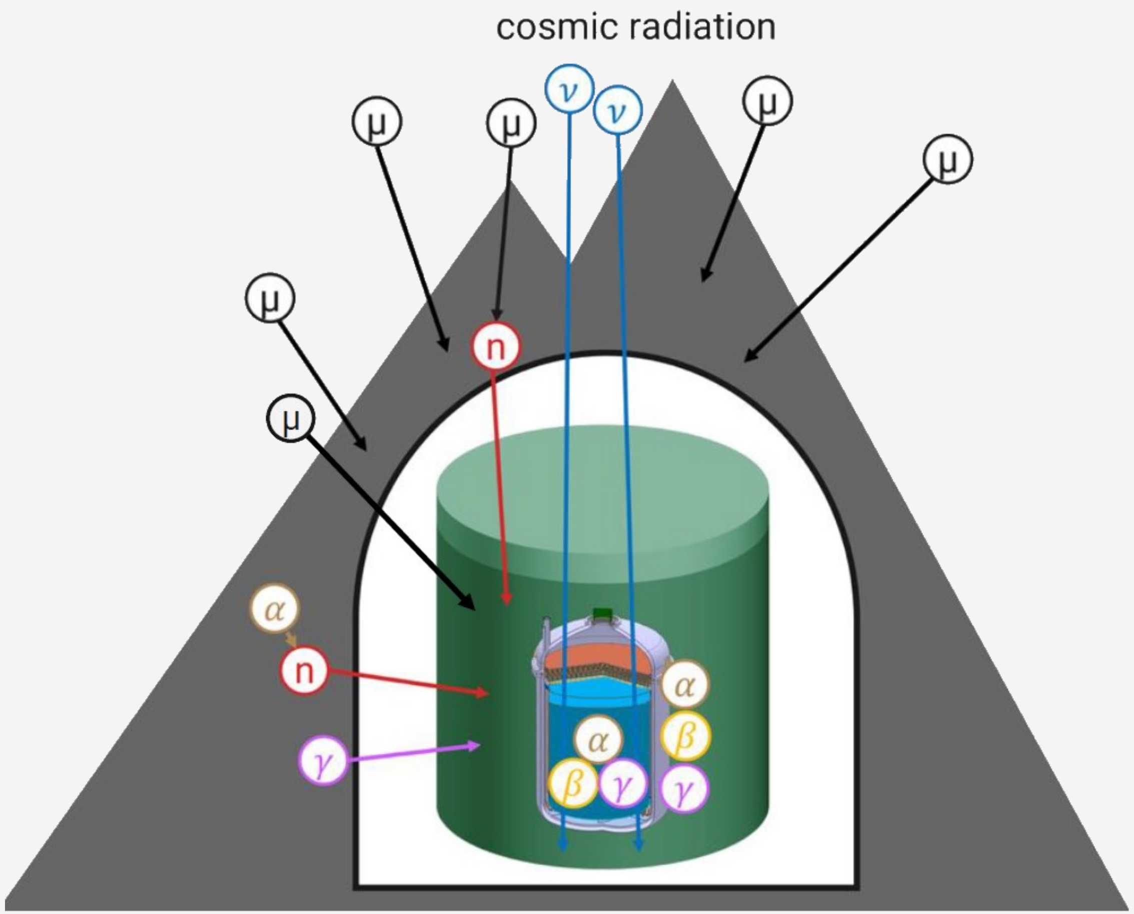
Harmful backgrounds

External backgrounds

- Cosmogenic and radiogenic neutrons & neutrinos
- Surface backgrounds from detector walls
- Natural radioactivity

Internal backgrounds

- Accidental coincidence: Random pairing of S2&S1
- Materials emitting isotopes like ^{222}Rn
- Intrinsic radioactivity like ^{222}Rn, ^{85}Kr, ^{136}Xe, ^{124}Xe



@C. Weinheimer

Background reduction for a better WIMP search

Surface background reduction

- Surface background reduced by fiducial volume cut
- Optimized by better volume-surface ratio

External background reduction

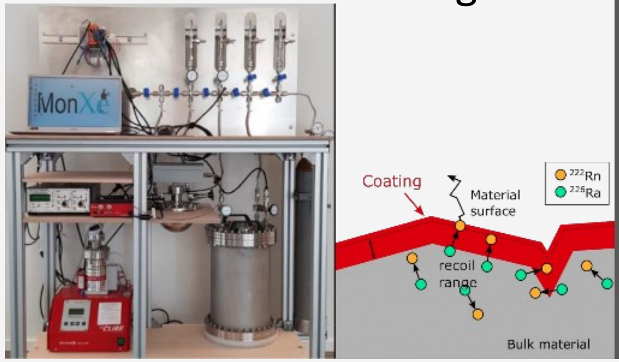
- μ-flux reduction by 10^6 by going underground (LNGS with ~1.4km rock shield)
- Active and passive shield through a water Cherenkov μ-/n-veto

Internal background reduction

- Material screening and selection → Low-emanation materials
- Coating materials → Barrier to trap radon after radium decays
- Minimization of intrinsic radioactive noble gases such as ^{85}Kr and ^{222}Rn → Cryogenic distillation

Shielding

Material Screening



R&D @MPIK Heidelberg

European Physical Journal C (2022) 82:599

Distillation

European Physical Journal C (2022) 82: 1104

Background reduction for a better WIMP search

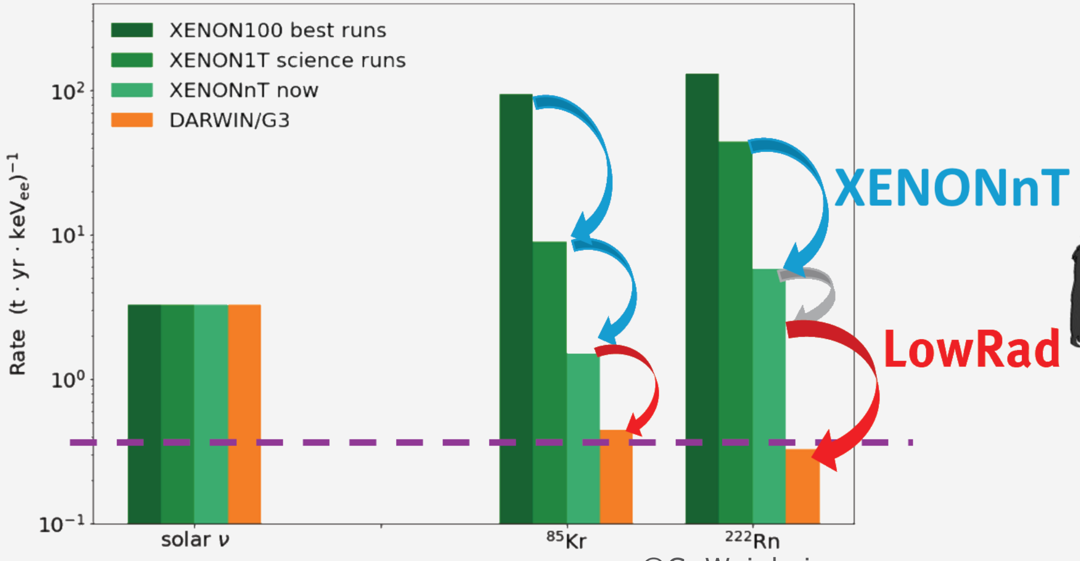
Next-Generation Xenon Detector (DARWIN)

- Planed sensitivity: ~10^{-49} cm^2 in a region for masses of ~50 GeV/c^2
- Optimizing volume-surface ratio by increasing detector
- Scaling up to 40t (or up to 80t) active xenon mass of the detector

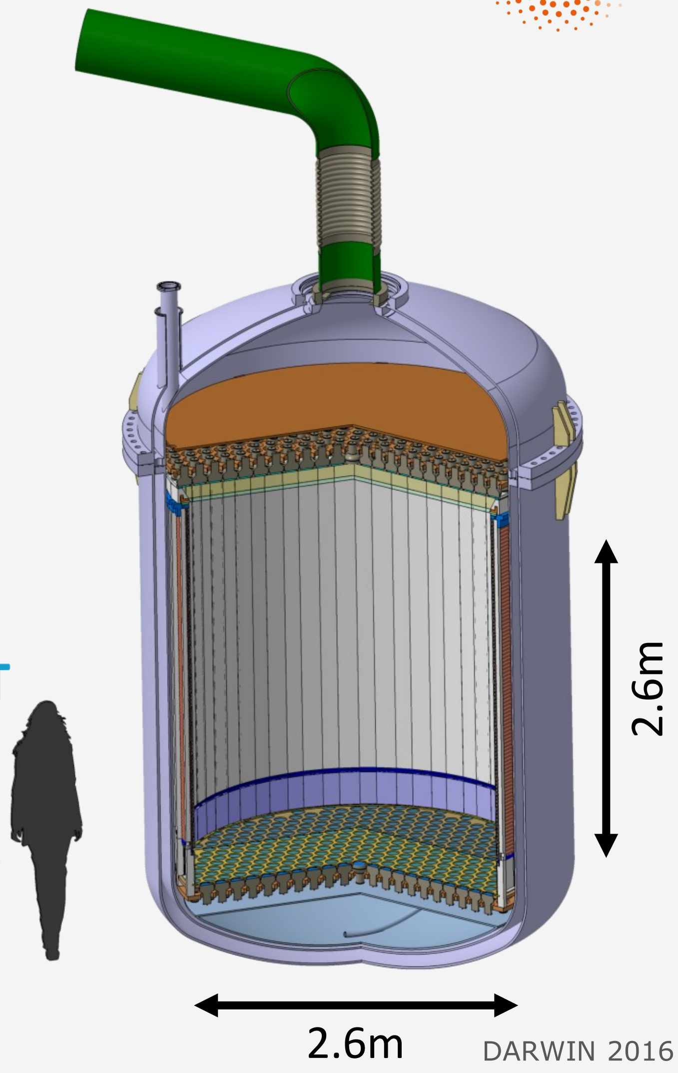
DARWIN requirements

DARWIN, JCAP 11 (2016) 017

- ^{85}Kr: ^{nat}Kr <30ppq (<$3 \cdot 10^{-14}$)
  ⇔ 1µg Kr per 50t Xe
- ^{222}Rn: <0.1 µBq/kg ⇔ $< \frac{1\,\text{atom}}{100\,\text{mol Xe}}$



@C. Weinheimer



DARWIN 2016

Distillation

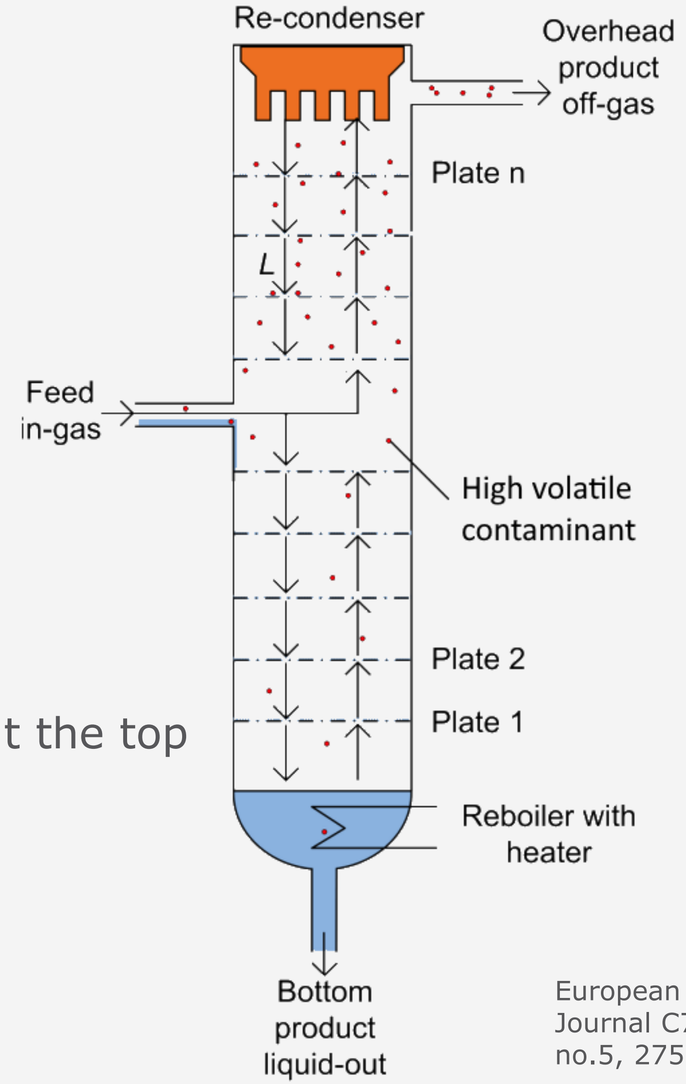
Example: Liquor distillery

- Based on difference in vapor pressure
- Obtaining pure ethanol (78°C) from a mixture with water (100°C) and methanol (65°C)
- Step 1: Methanol evaporates and is discarded as a precursor
- Step 2: Ethanol is enriched and extracted from water

Cryogenic xenon distillation for krypton

- Krypton (-153°C) the more volatile gas (xenon:-108°C) is collected at the top
- With ~5m height column: ^{nat}Kr <48ppq ($<4.8\cdot10^{-14}$)
- Extract krypton enriched xenon (off gas) from the top → Xenon loss

→ Darwin ^{nat}Kr <30ppq ($<3\cdot10^{-14}$) with less off-gas



European Physical Journal C77 (2017) no.5, 275

Online cryogenic distillation

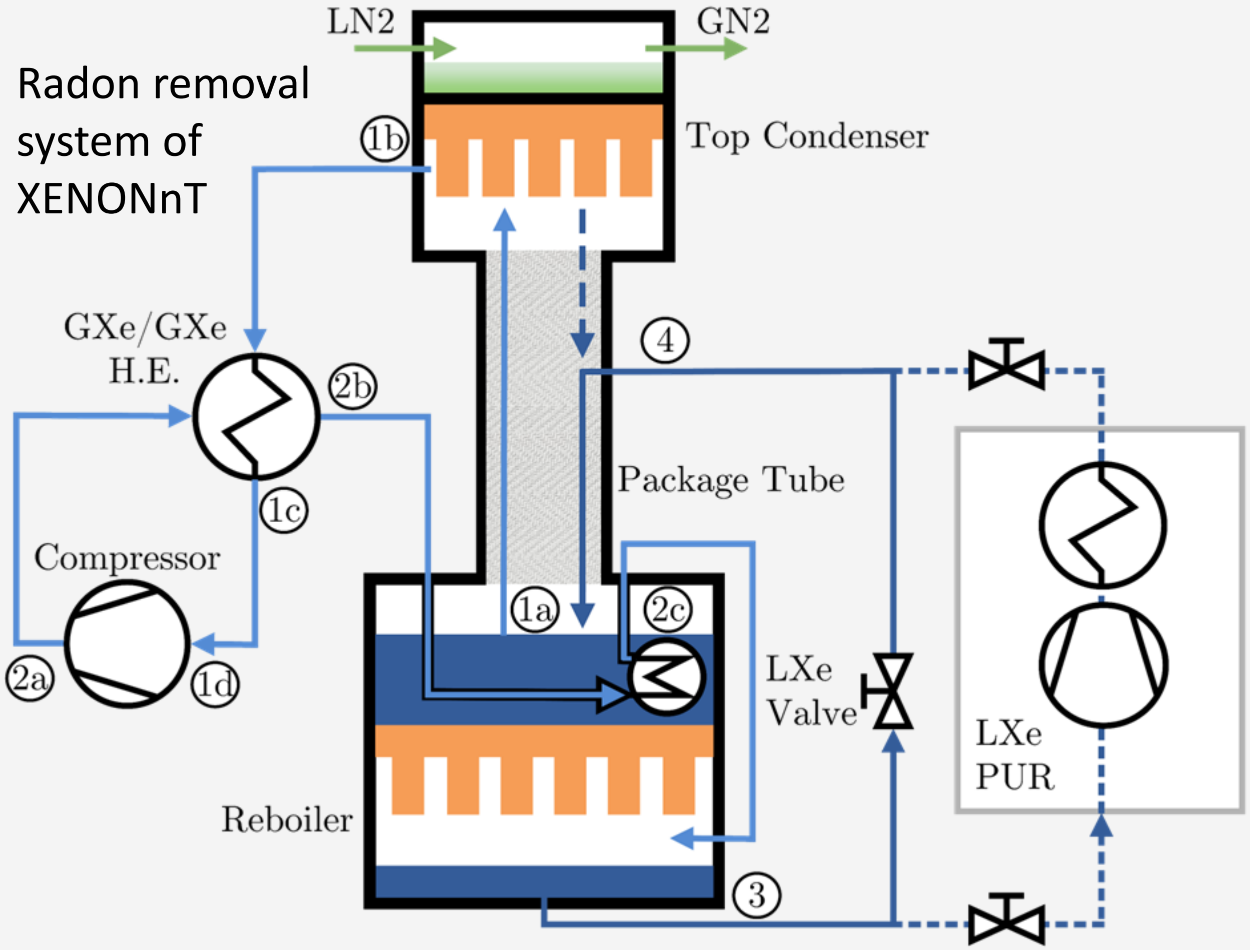
Rn column

- Rn is continuously emanated from detector material and components
- For a reduction factor 2: Circulate mass with its halftime (3.8 d)
  → Need online distillation
- Rn (-62°C) is trapped in reboiler while xenon (-108°C) is evaporated → re-liquification

DARWIN Rn column

- ^{222}Rn goal of <0.1 μBq/kg is ~10 times lower then current XENONnT limit of ~0.8 μBq/kg
- ~10 times more mass than XENONnT → Distillation throughput of 750kg/h (XENONnT: 66kg/h)
- Need a full heat pump to achieve enormous cooling

Radon removal system of XENONnT



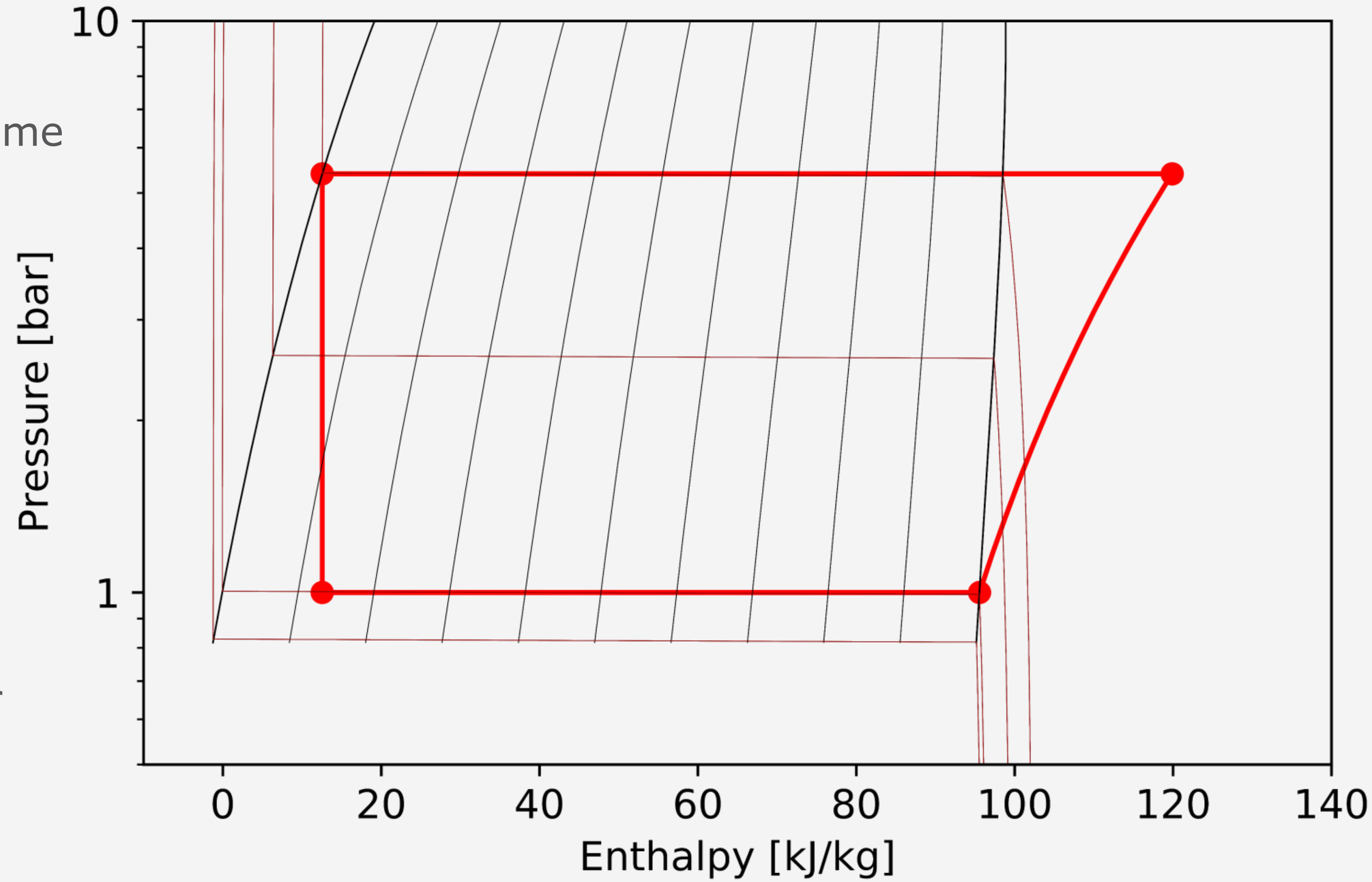
European Physical Journal C (2022) 82: 1104

The LowRad Project

Heat pump for re-liquification of xenon

- Reduction factor 2: circulate mass with halftime
- $t = \frac{1}{\lambda_{Rn}} = 5.5d \rightarrow \frac{50t}{132h} = 380\,\frac{\text{kg}}{\text{h}}$
- For a purification of 50t in $\leq$ 2d
  $\rightarrow 750\,\frac{\text{kg}}{\text{h}} = 2120\text{slpm}$
- 1slpm needs 10W of cooling power → 21kW
- Cooling power of a cool head $\sim 100 - 200\text{W}$

→ Heat pump to achieve enormous cooling for the liquefying xenon



Not reducible background
The neutrino fog

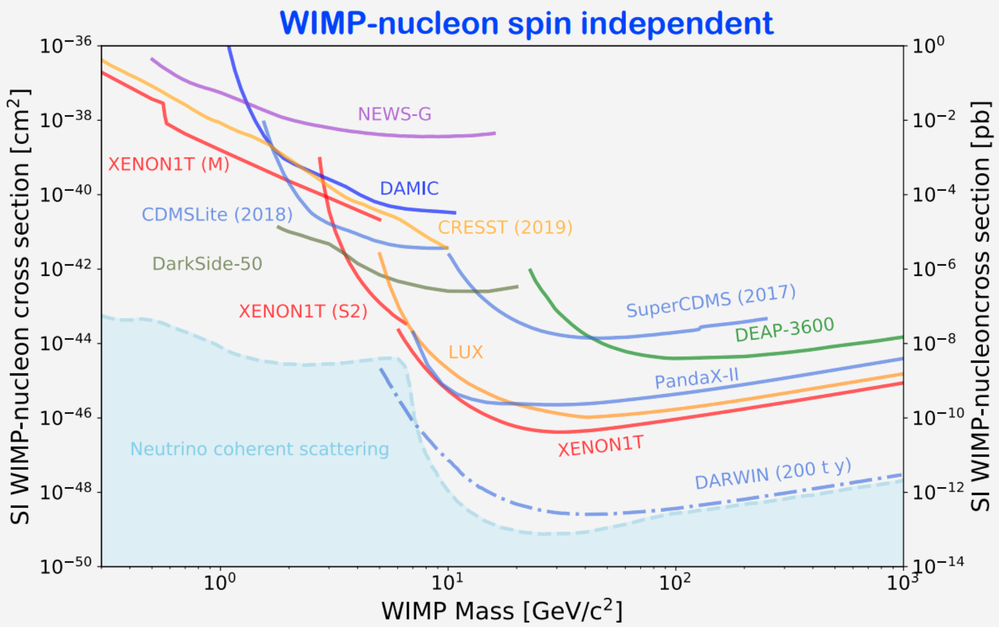
Neutrino fluxes

- Solar neutrinos: Proton-Proton chain, Bethe–Weizsäcker cycle
- Atmospheric neutrinos: Produced by cosmic rays
- Diffuse supernova neutrinos (DSNB)

Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

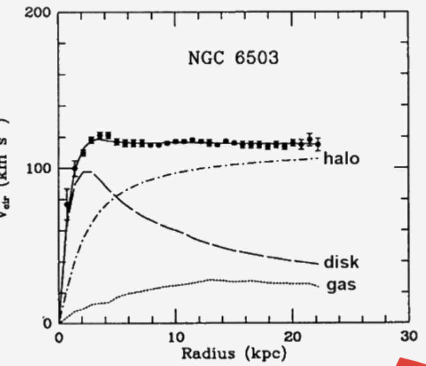
- Standard model process were neutrino scatters with nucleus
- Nucleus remains in ground state and recoils
  → Mimic WIMP signal
- Not reducible background
- Background reductions only down to the neutrino fog

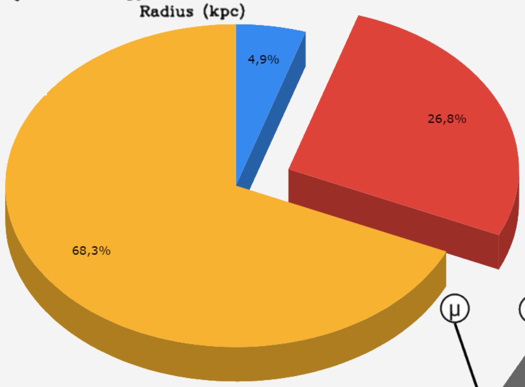
Physical Review Letters 127, 251802

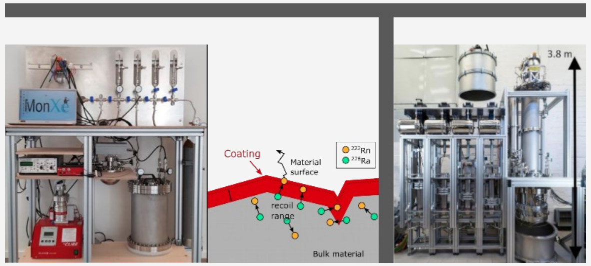


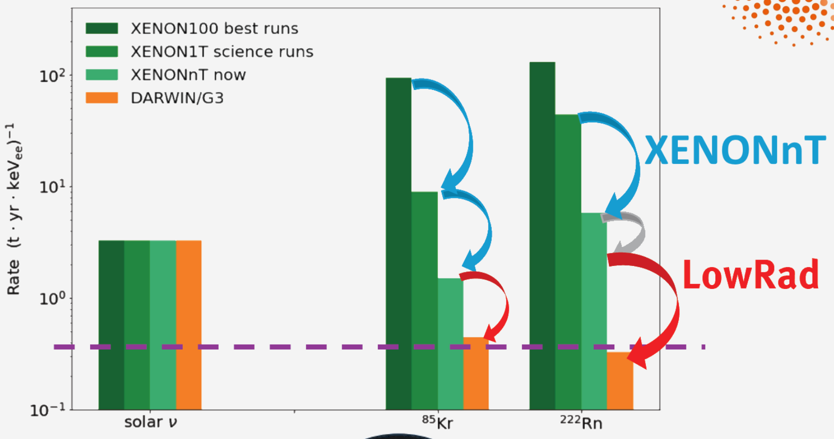
Progress of Theoretical and Experimental Physics (2020) 083C01

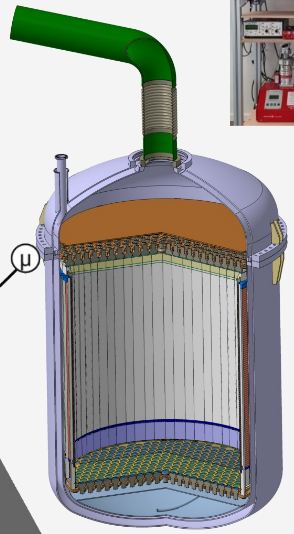
Summary and outlook

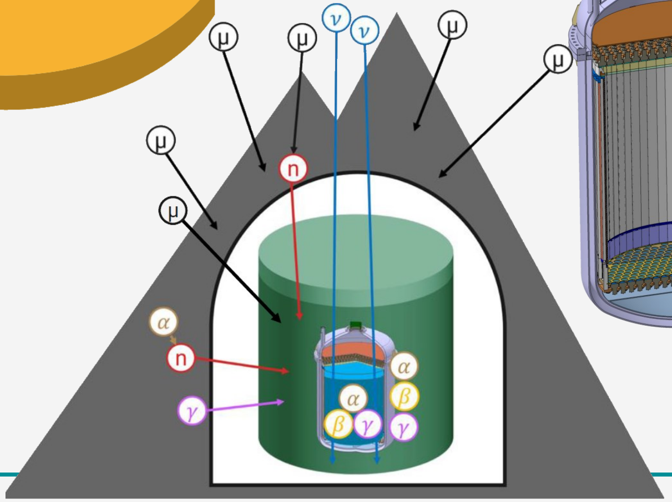


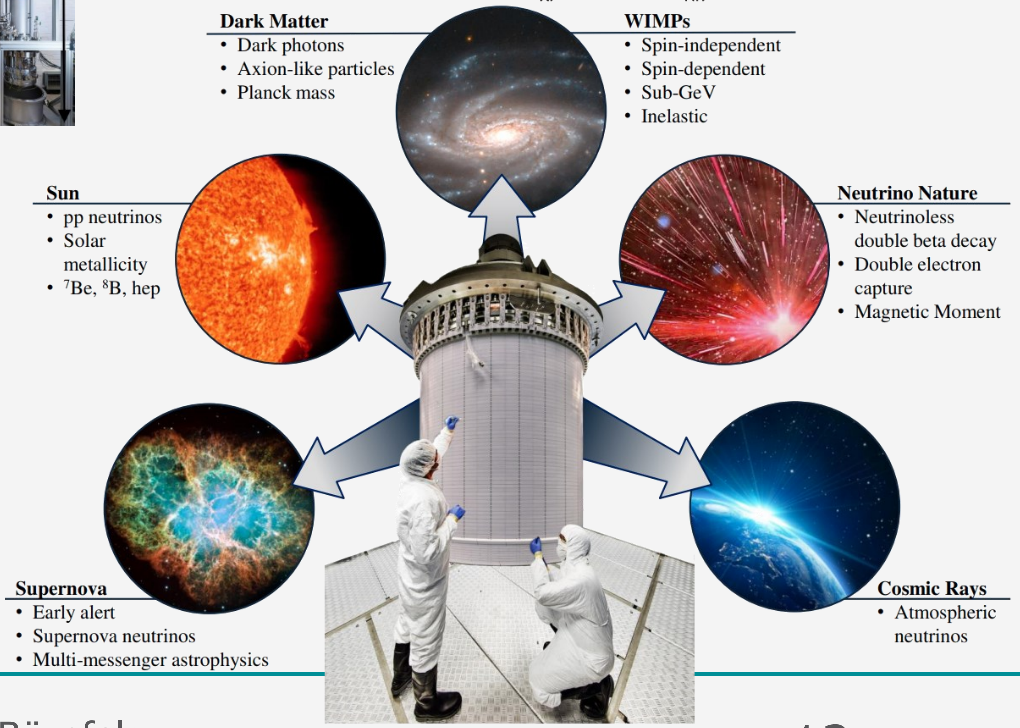












Thank you for Attention

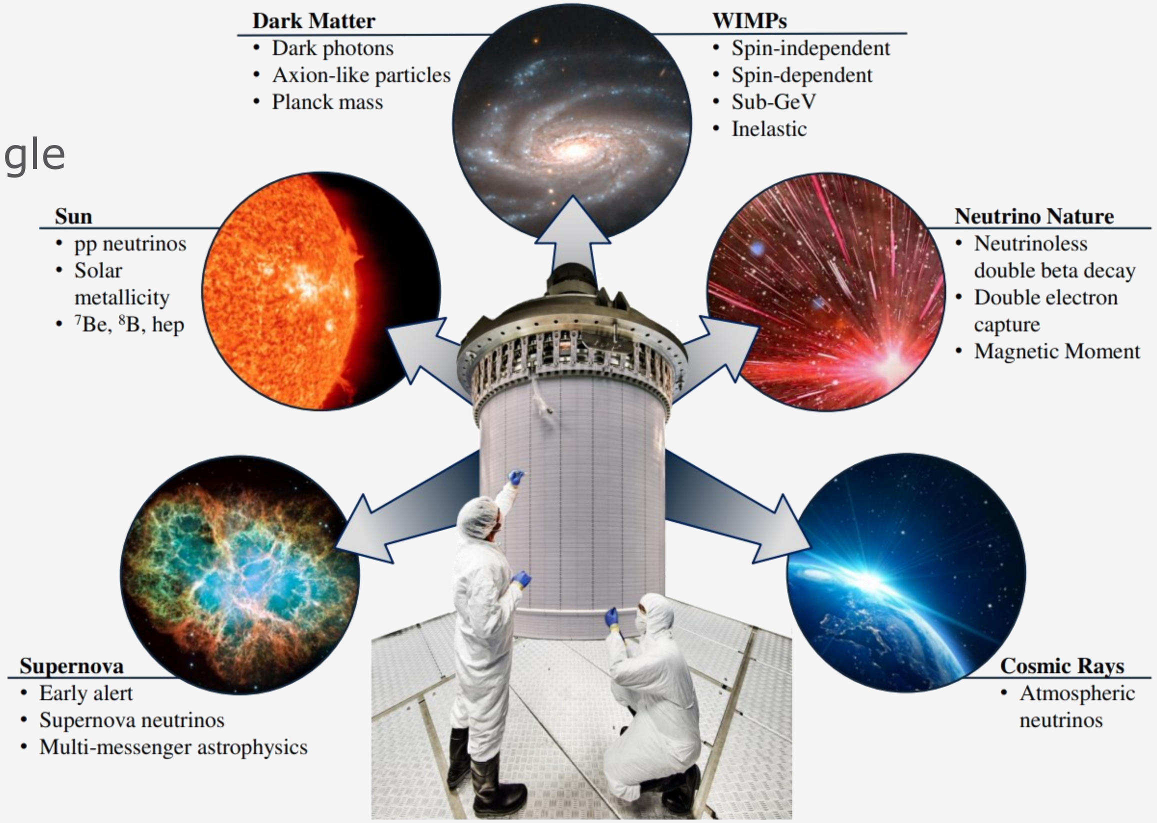
Back up

Research program of the DARWIN/XLZD detector

Investigation of solar neutrinos
DARWIN, JCAP 11 (2016) 017
- 7.2 ev/day in 30t for E=(2-30)keV_{ee} (pp-neutrinos)
- Precision on neutrino flux of 0.15% (300tyr exposure)
- Measurement of ν_e survival probability and weak mixing angle

Study of solar axions and axion-like particles (ALPs)
JCAP 11, 017 (2016)
- Detecting hypothetical particles like solar axions and ALPs
- Measurement via axio-electric effect

Exploration of neutrinoless double beta decay
Eur. Phys. J. C 80 (2020) 9, 808
- Searching for the extremely rare process of $0\nu\beta\beta$
- 8.9% of ^{136}Xe in natural xenon → ~3.5t in DARWIN
- Projected sensitivity $T_{1/2}=2.4\times10^{27}$yr (50tyr exposure)



arXiv:2203.02309 (2022)

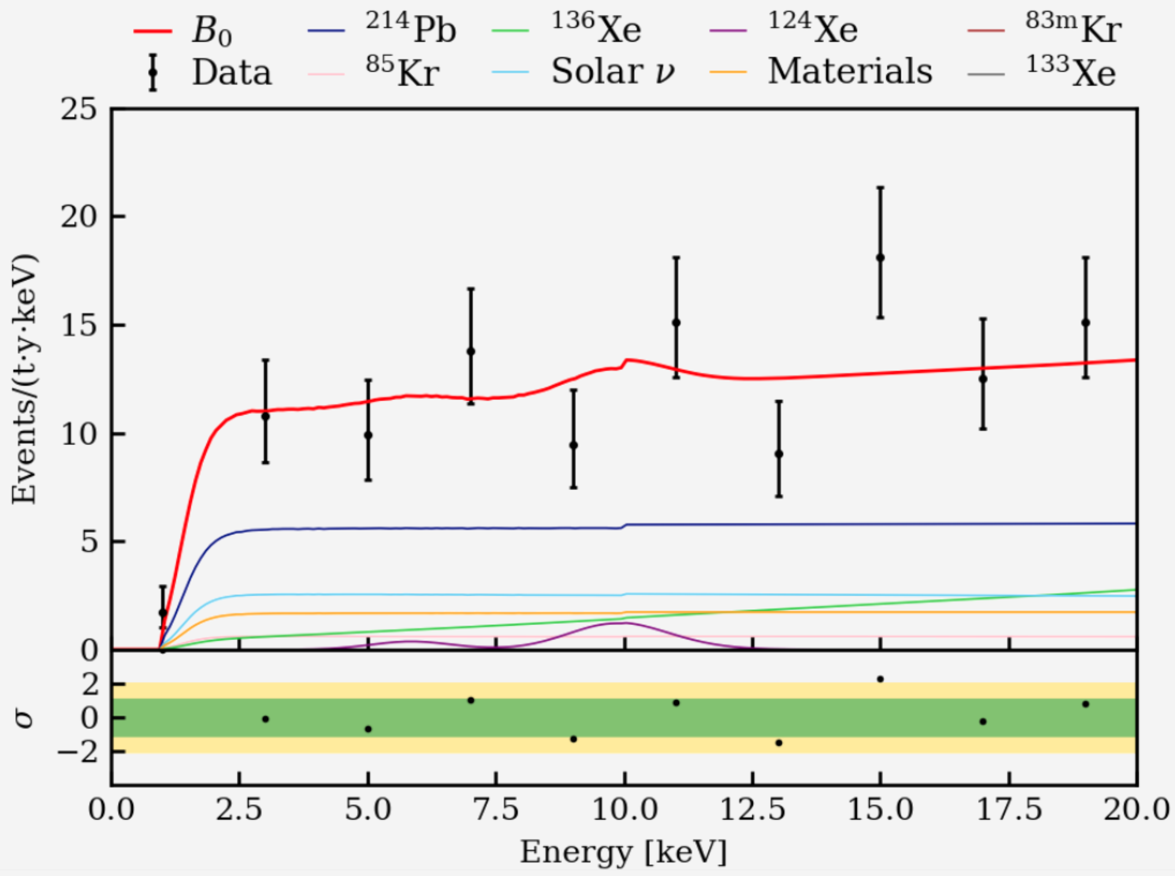
ER background

- Dominated by beta decays from ^{214}Pb a daughter of ^{222}Rn
- Additional components:
    - Solar neutrino electron-scattering
    - Beta decay of 85Kr
    - Material backgrounds
- Factor x5 improved background compared to XENON1T

➔ 134 events in ER band of ROI
(15.8±1.3) events/(t·y·keV)

➔ Assume flat ER background spectrum between
1 keV and 10 keV electronic recoil energies

XENONnT



arXiv:2203.02309 (2022)