DARWIN

much more than the next-to-next generation WIMP detector

Fabian Kuger, for the DARWIN Collaboration

Astroparticle Physics in Germany – Status and Perspectives
Mainz, 17-19.09.2018

Astroparticle Physics
Physikalisches Institut
Albert-Ludwigs-Universität Freiburg

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Direct WIMP Dark Matter detection with DARWIN

WIMPs remain the best motivated dark matter candidates. Their Spin independent (SI) scattering on nucleons is the most model-independent channel for direct detection.

Best σ_{SI} exclusion limits by active target experiments with LXe:

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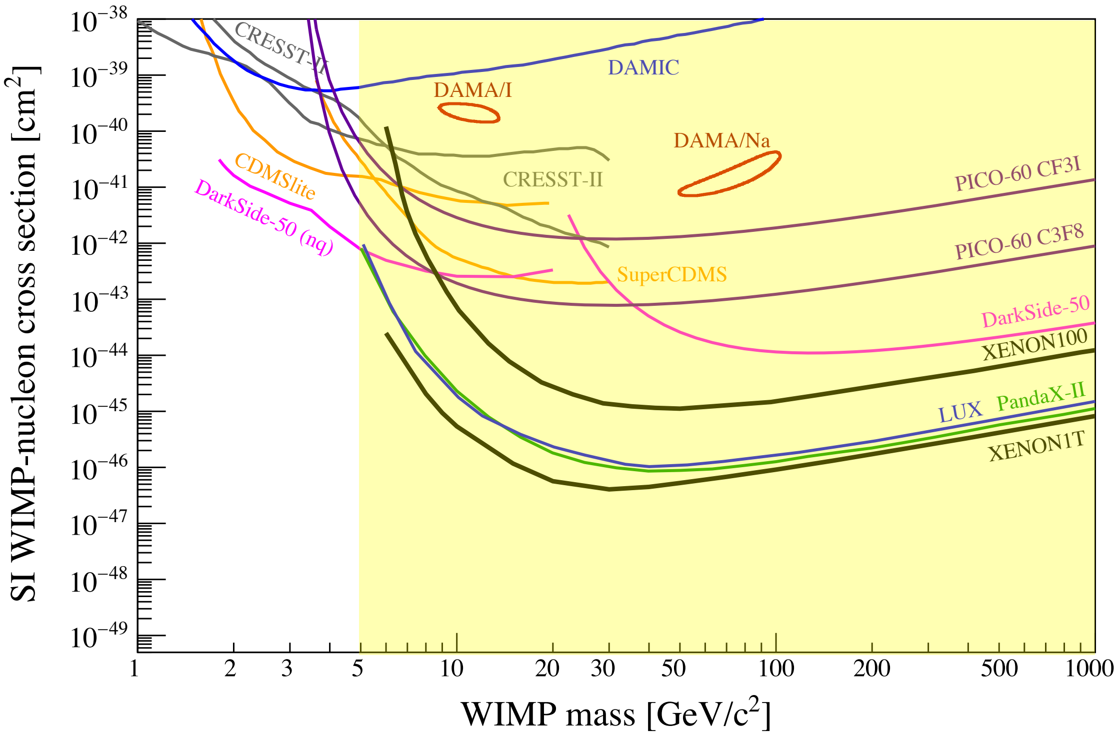

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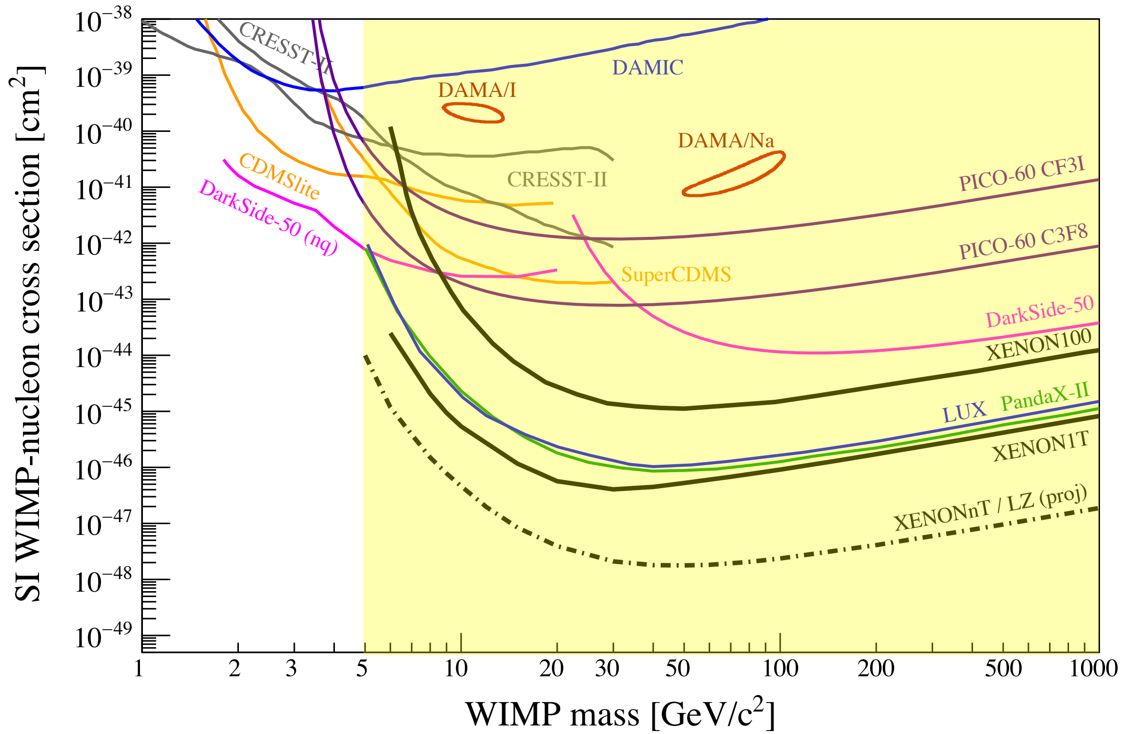
- XENONnT / LZ: ~20 t×y exposure
- … ?



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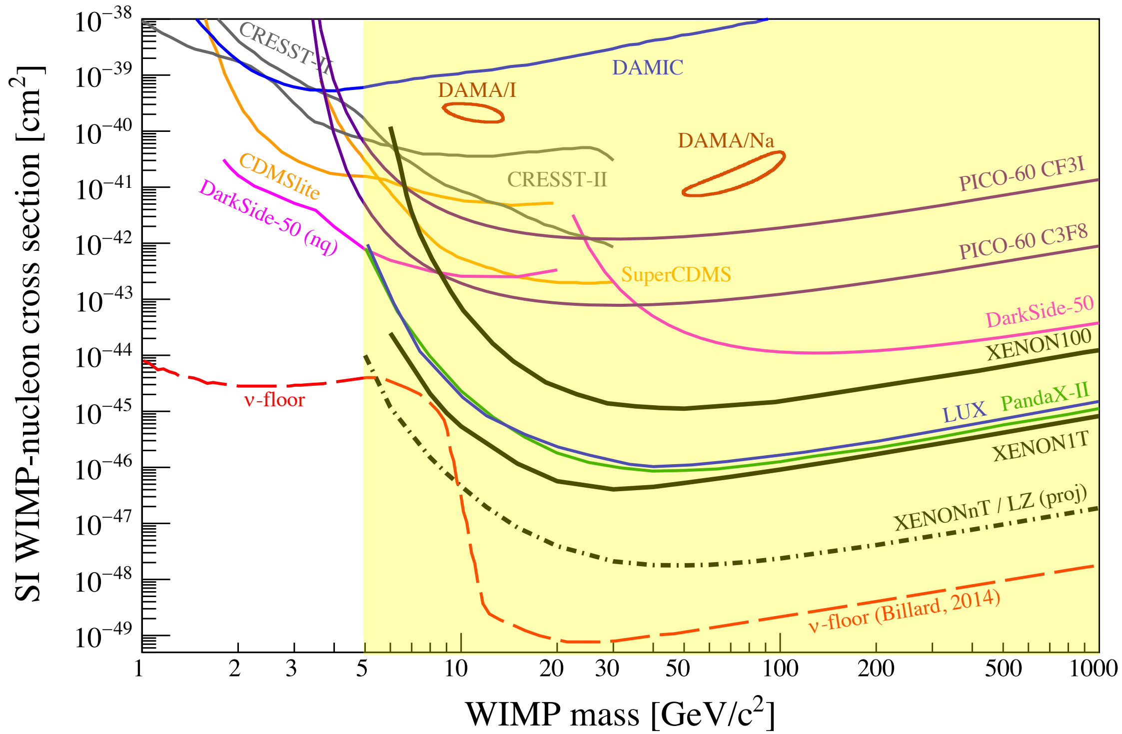
WIMP discovery limited by ν-floor

- Solar and atmospheric neutrinos mimicking WIMP signal [Billard et al. *PRD 89 (2014) 023524*]



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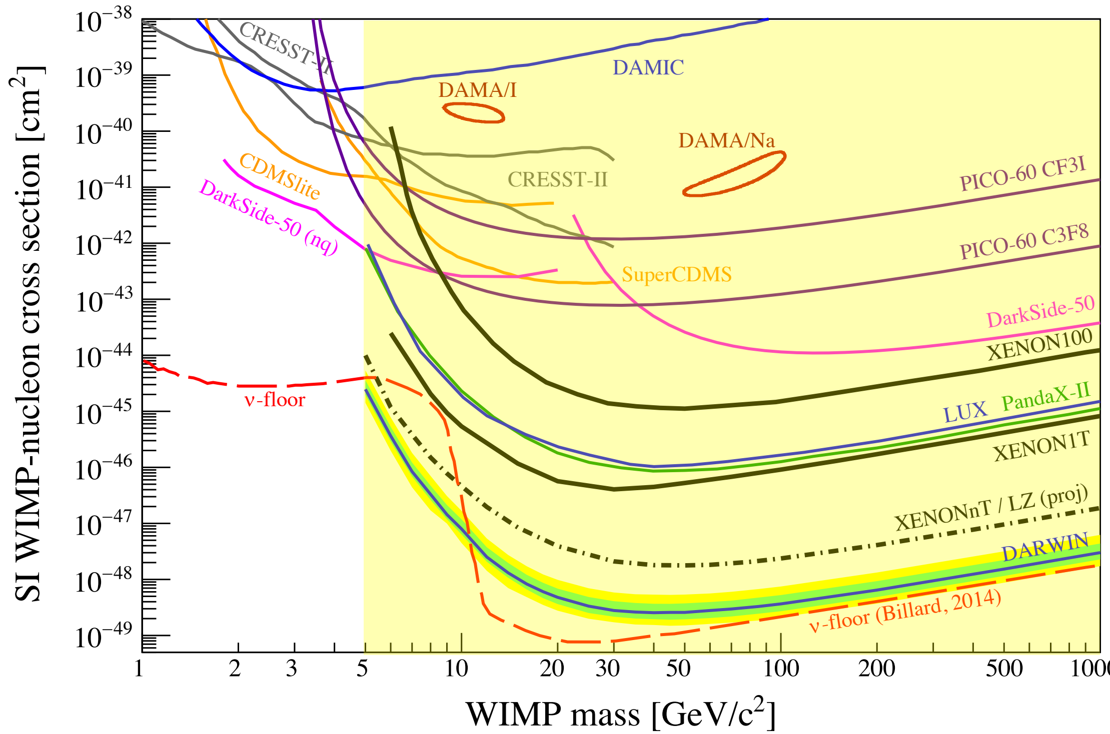
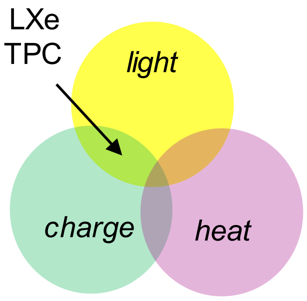


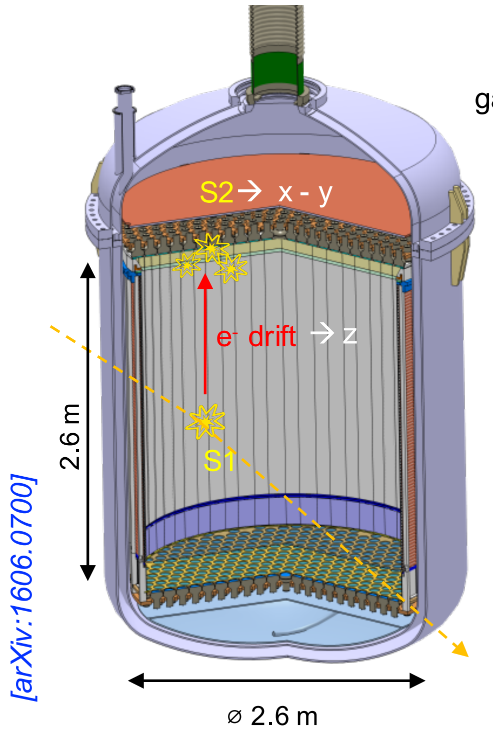
→ **DARWIN** is targeting this ultimate WIMP discovery limit: 200+ t×y LXe exposure

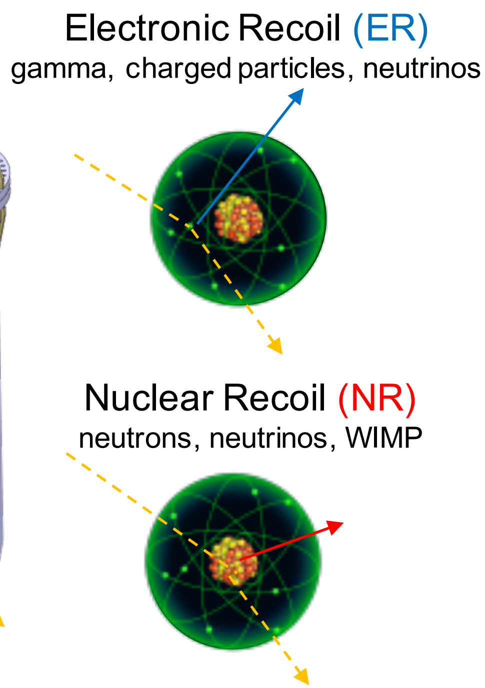
WIMP detection and signal discrimination in LXe TPCs

DARWIN baseline is a LXe active target TPC



- Interaction with xenon causes prompt scintillation (light, S1) and ionization (charge), causing a delayed proportional scintillation signal (S2).
- Position reconstruction by *x*-*y*-light sensor array + drift time (*z*)
- Characteristic light / charge ratio for ER and NR events → discrimination





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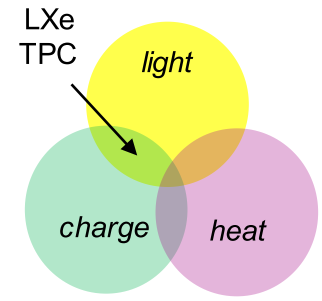

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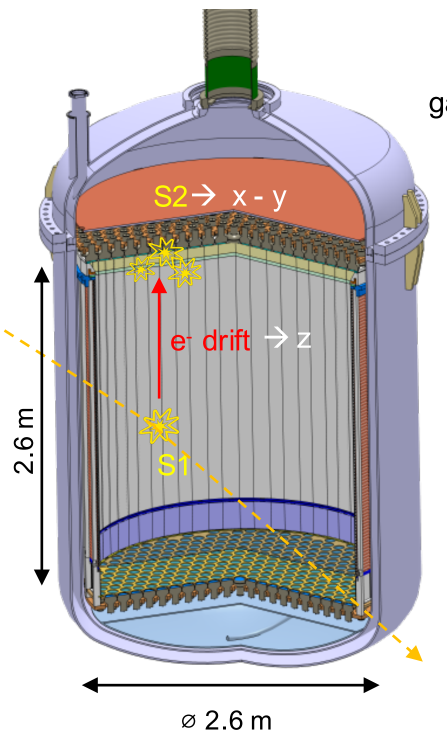
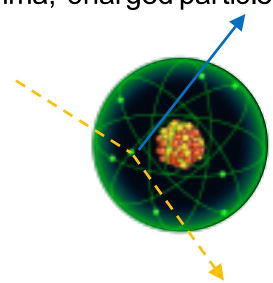
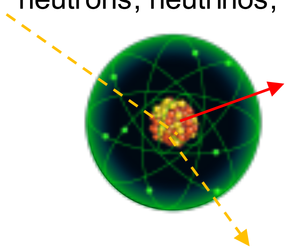


[arXiv:1606.0700]

Electronic Recoil (ER)
gamma, charged particles, neutrinos



Nuclear Recoil (NR)
neutrons, neutrinos, WIMP



⇒ High LXe mass: 40t in TPC

(30t after fiducial cut)

⇒ Optimized technology

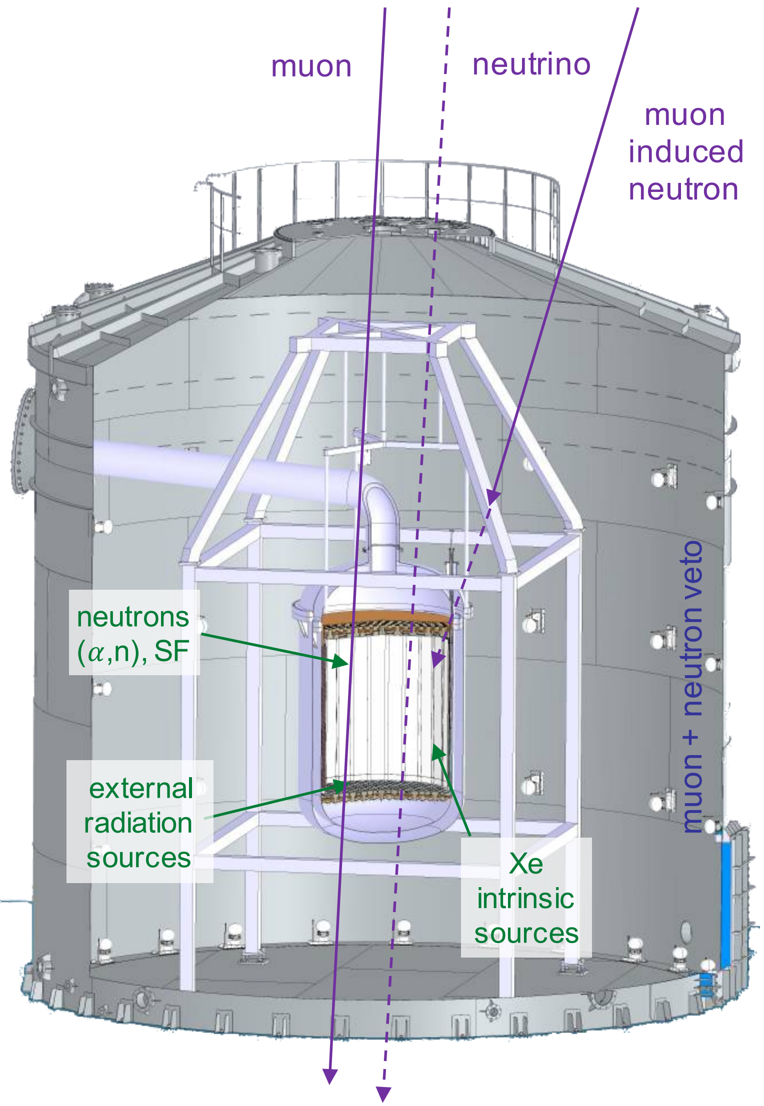
(Photo sensors: QE, stability, darkcounts, E-range

TPC: light collection efficiency, S2 amplification, electrostatics, low-background, material budget …)

⇒ Ultra low ER and NR background

\+ efficient ER/NR discrimination

Background sources assessment



Cosmogenic background sources

- Cosmic muons (ER) and muon induced neutrons (NR) → rock overburden + muon veto + neutron veto
- Cosmic Neutrinos (irreducible):
  - pp + ^{7}Be neutrons (ER)
  - CEvNS of high E neutrinos (NR)

Radiogenic background sources

- External [α, β,] ɣ background (ER) → fiducial volume
- Neutrons from (α,n) and SF (NR) → fiducial volume + neutron veto + multiple scatter discrimination
- Xe intrinsic background (ER): ^{85}Kr, ^{222}Rn, ^{136}Xe: 2vββ

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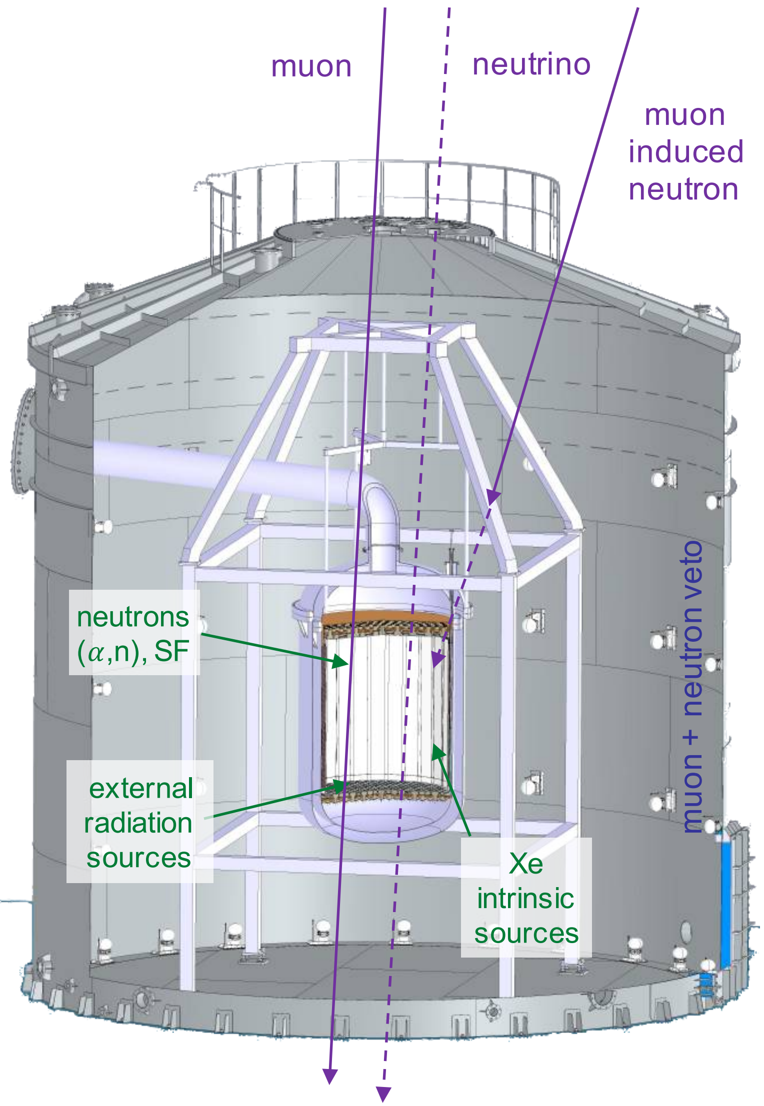

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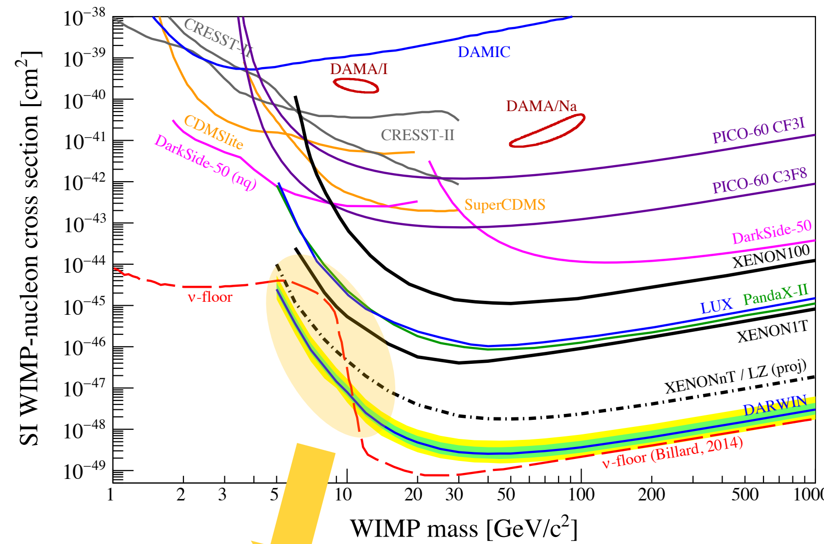
➔ NR background > total ER background

➔ radiogenic ER < neutrino induced ER

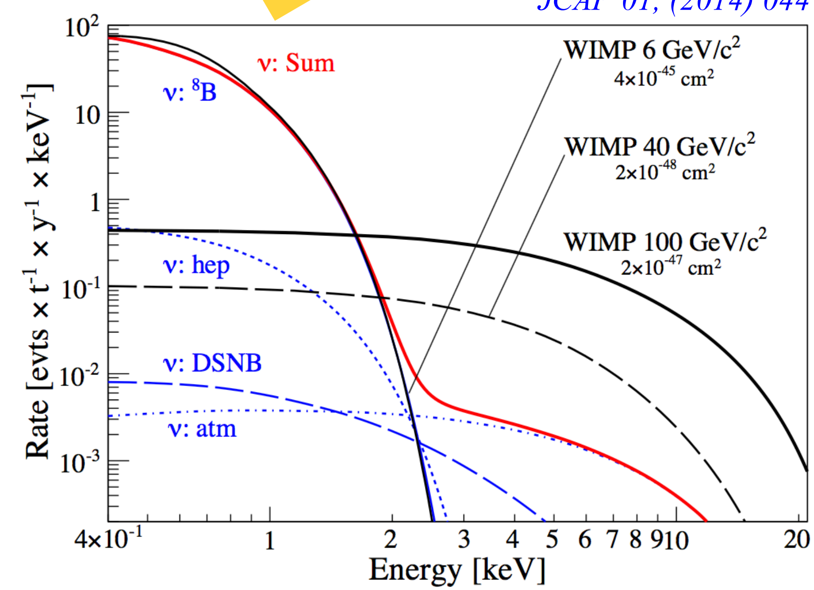
(Solar) neutrinos as NR background

Coherent elastic Neutrino-Nucleus Scattering (CEvNS) of high E astrophysical neutrinos poses the irreducible background for WIMP searches.

- ^{8}B neutrinos set a strong discovery limit towards low WIMP masses
- atmospheric neutrinos dominate the limit for higher WIMP masses



JCAP 01, (2014) 044



(Solar) neutrinos as NR background & Science Channel

DARWIN

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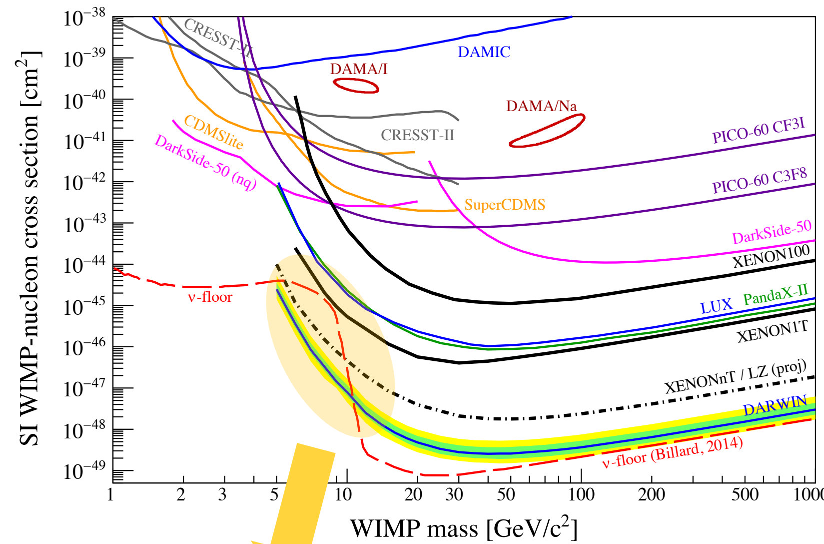

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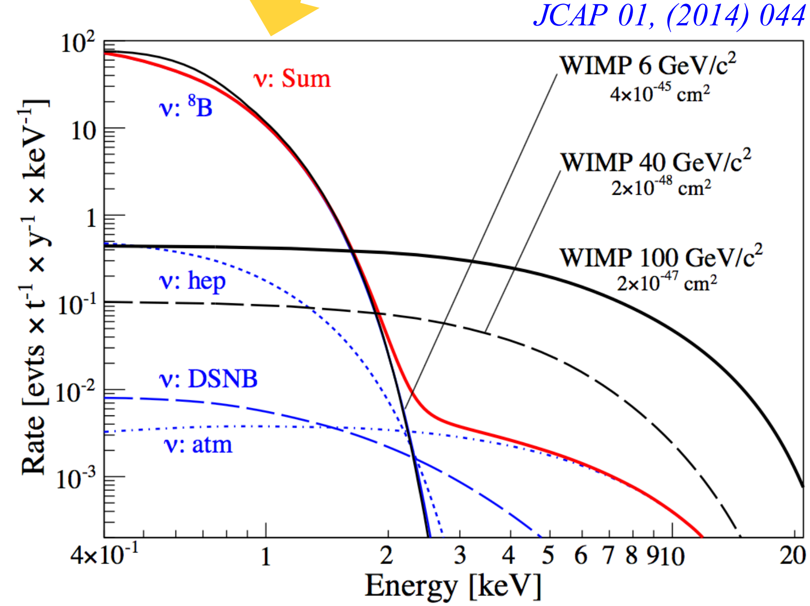


➔ **Observation of CEvNS by solar ^{8}B neutrinos is a science goal by itself**

- DARWIN will observe $\nu_{\,8B\text{-}CNNS}$ events
- rate depends strongly on the E_{NR} threshold

⇒ spectral observation within reach

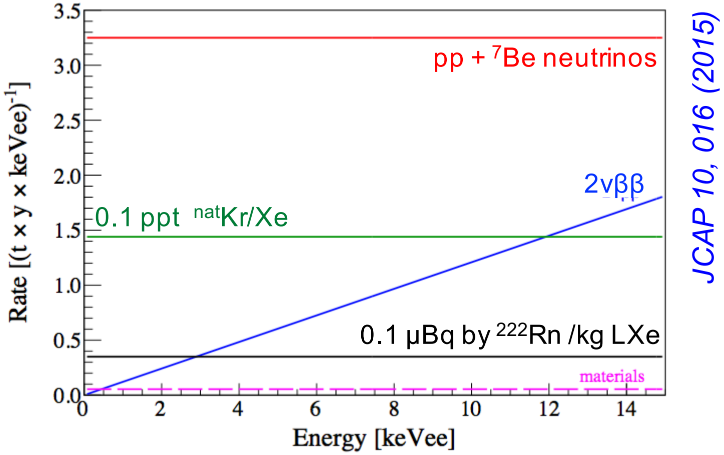
→ Talk by W. Maneschg

Xenon-intrinsic radiogenic background (ER)

Goal: radiogenic ER < neutrino induced ER (pp + ^{7}Be)

→ Challenging requirements on the xenon radioactivity:

^{nat}Kr ^{222}Rn ^{136}Xe



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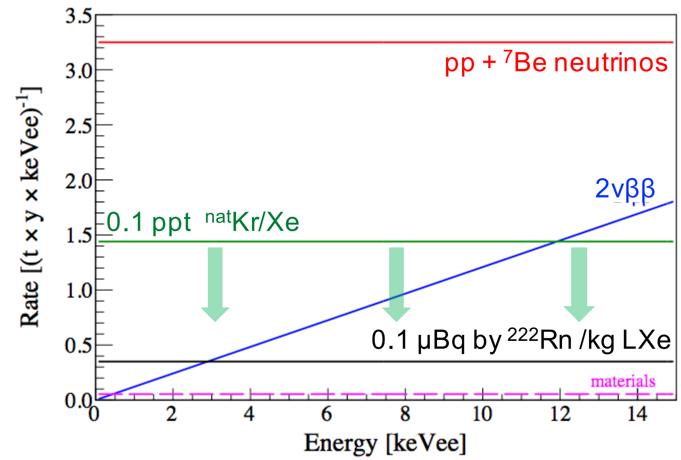


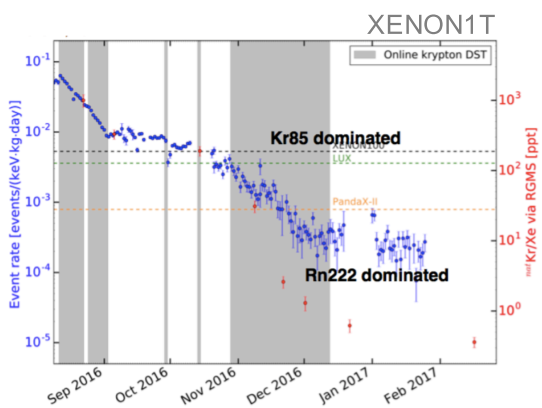
JCAP 10, 016 (2015)

0.1 ppt of ^{nat}Kr

Eur. Phys. J.C. (2017) 77:275

< 0.05 ppt ^{nat}Kr/Xe demonstrated and measured (RGMS) by cryo-distillation

⇒ Outperforms requirement



➔ *Poster X2 by M. Murra*

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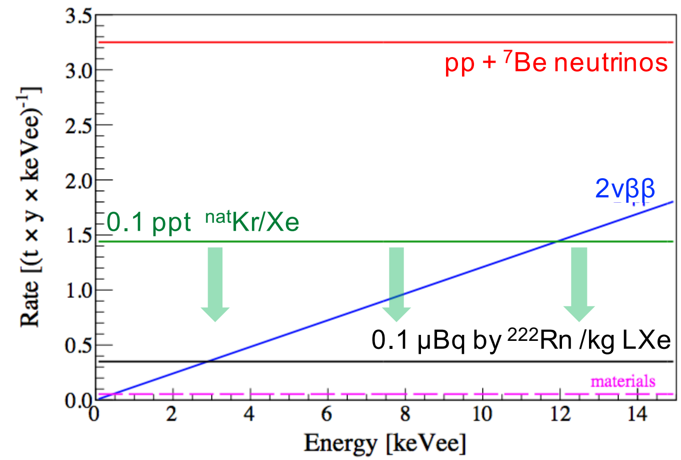

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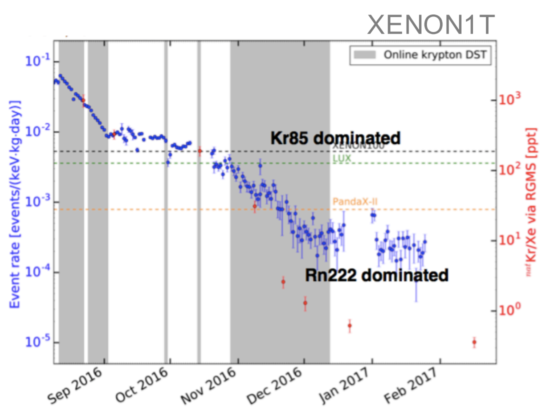

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0.1 µBq ^{222}Rn activity / kg of LXe:

XENON1T : ^{222}Rn activity of 10µBq/kg → / 100

- Distillation achieved factor > 27 ^{222}Rn reduction (XENON100) *Eur. Phys. J.C. (2017) 77:358*
  → higher throughput required for DARWIN
- Replace sources of ^{222}Rn, e.g. magnetically coupled piston pump *arXiv:1803.08498*
- Screening & selection of radio-pure material
- Improved surface / volume + R&D on TPC design, reducing emanation into active volume
- ER background analysis / rejection techniques

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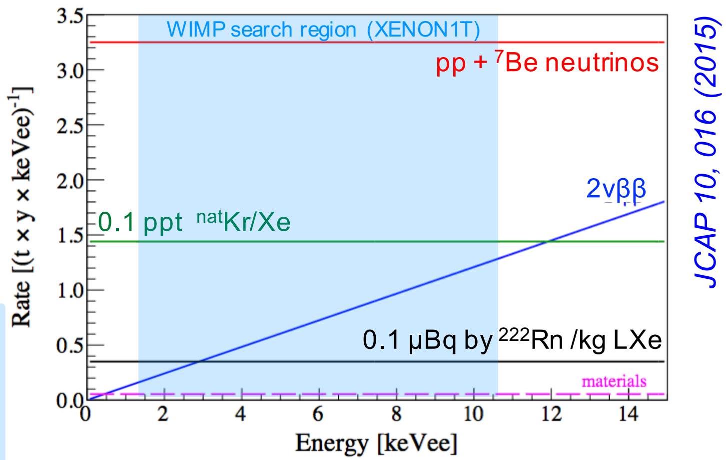

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Spectrum of 2νββ is subdominant in WIMP search region

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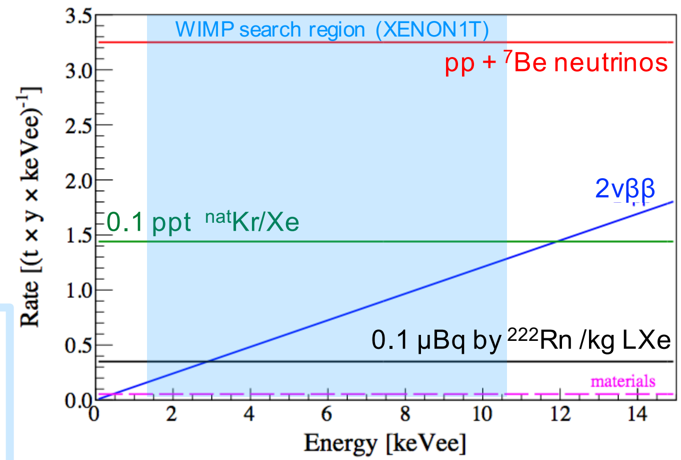
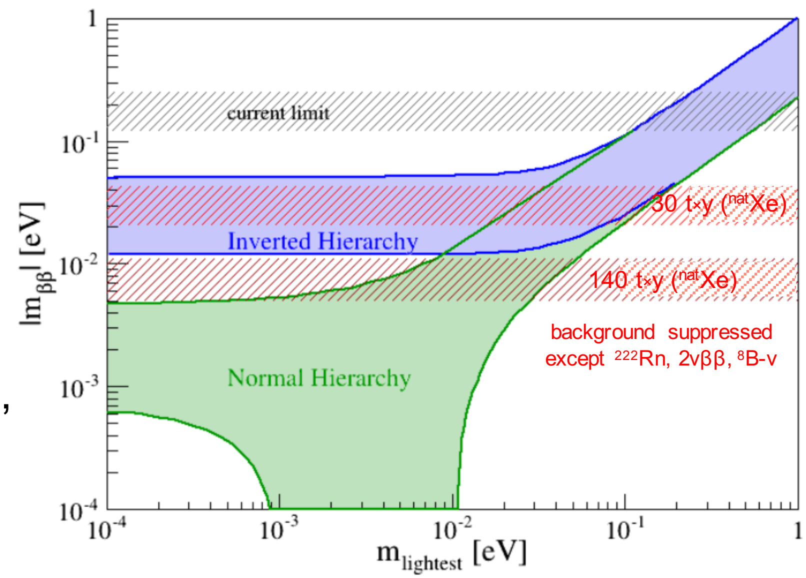


JCAP 10, 016 (2015)

➔ **Major science channel: $0\nu\beta\beta$**

- SS vs. MS discrimination (x,y,z reconstruction)
- $\sigma_E|Q_{\beta\beta}$ optimization with extra readout channel
- High $T_{1/2}$ sensitivity, due to $m_{136Xe} > 3.5$t, low background + fiducial cut / self shielding

DARWIN will be a competitive **$0\nu\beta\beta$** experiment*, probing $<m_{\beta\beta}>$ in IH-range



JCAP 11, 017 (2016)

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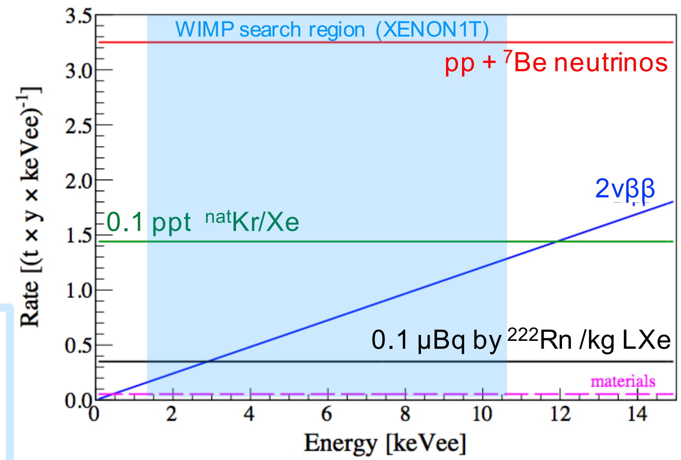

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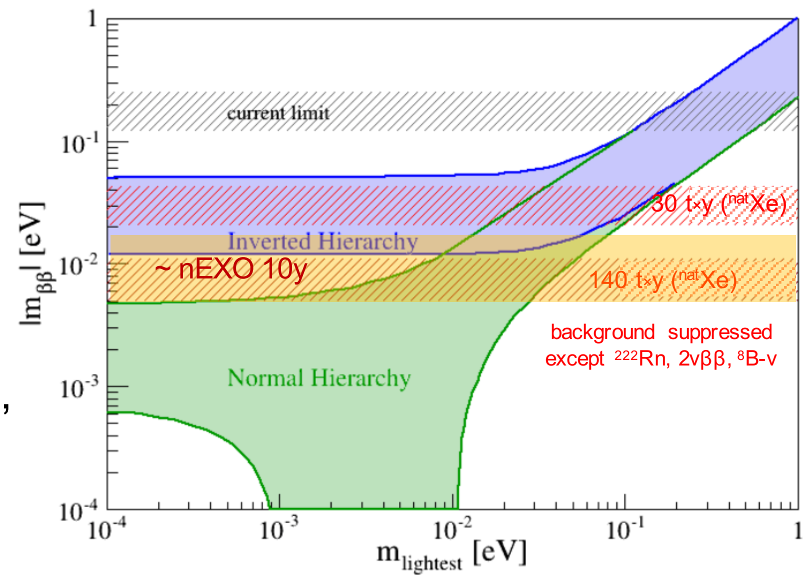


JCAP 11, 017 (2016)

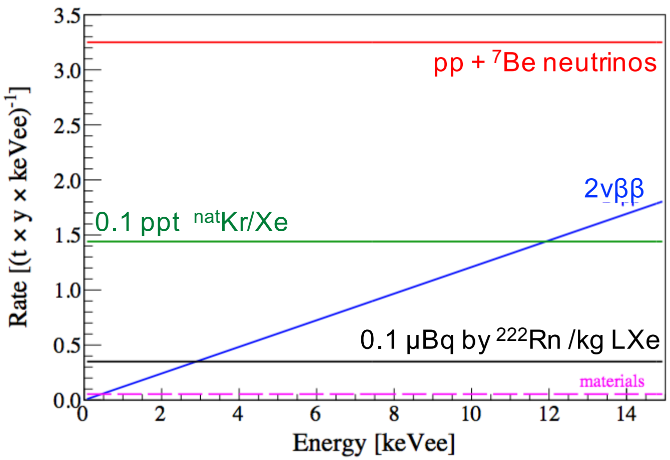
* proj. sensitivity comparable to 10y runtime of nEXO [arXiv:1805.11142]

pp+^{7}Be neutrinos as ER background

ER events from low energetic (pp + ^{7}Be) solar neutrinos remain as background events and must be suppressed

ER/NR disc.: 99.98% ER rejection @ 30% NR acceptance

JCAP 10, 016 (2015)



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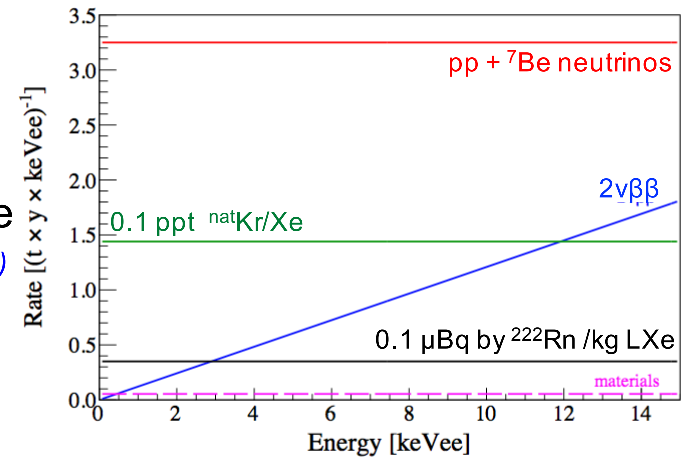
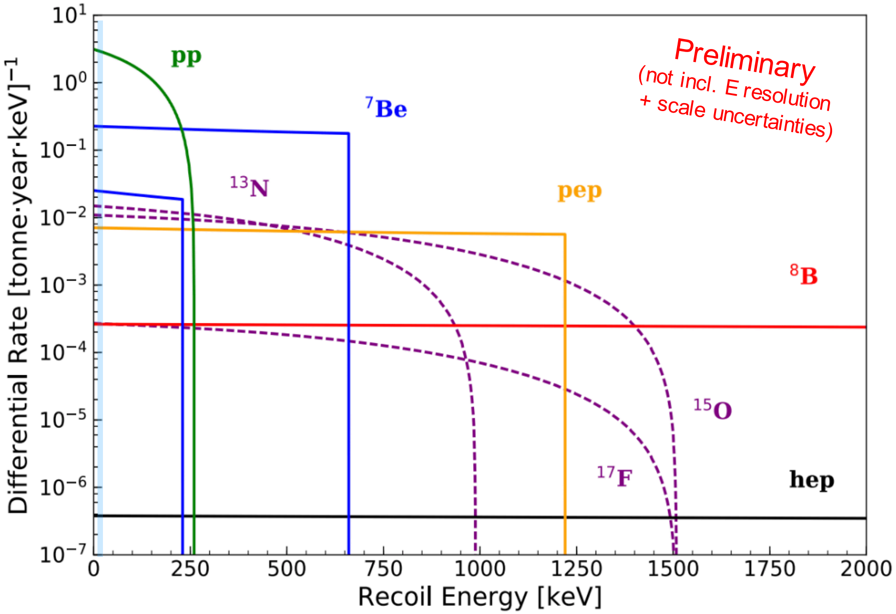


JCAP 10, 016 (2015)

➔ **Solar neutrinos as science channel (ϕ_{pp} and ϕ_{7Be})**

S. Reichard, 5th ISNC – Dresden 2018



→ Several 10^3 ν-induced events/year

→ Precision measurement of ϕ_{pp} and ϕ_{7Be} with sub-% and few-% accuracy

→ Conclusion on the weak mixing angle and ν-survival probability below 200keV

Further DARWIN Science Channels

DARWIN

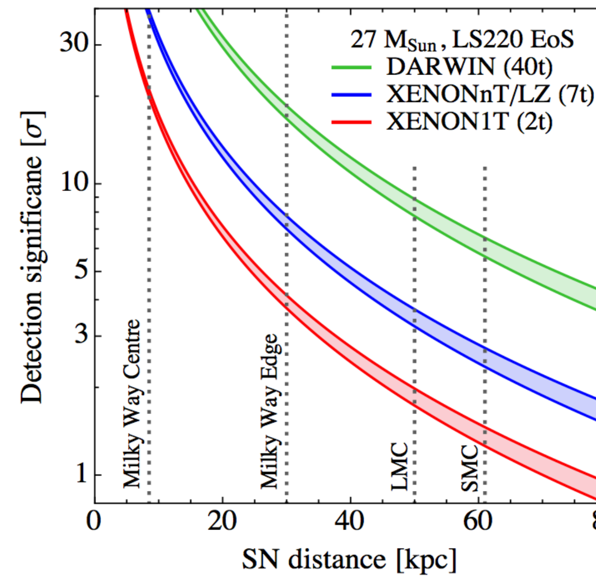
- Observation of supernova neutrinos with all 6 ν-flavors

  [→ extending > 5σ sensitivity for a 27$M_\odot$ SN up to 65kpc]

  → complementary to water based ν-experiments

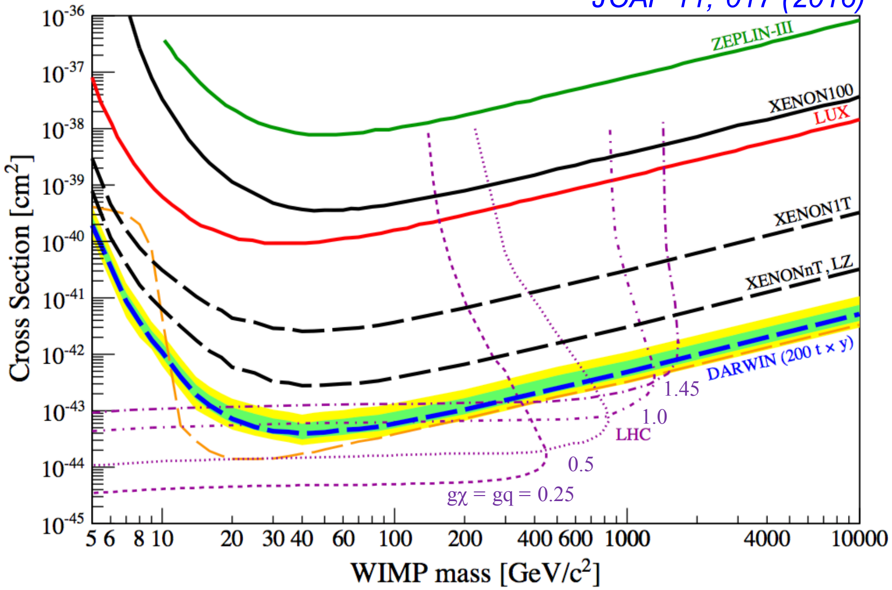
- SD WIMP nucleon cross section

  [^{129}Xe (26,4%, I=1/2+) ; ^{131}Xe (21,2% I=3/2+)]



Phys. Rev. D 94 (2016)

JCAP 11, 017 (2016)



- Solar Axions [sensititvity on g^{solar}_{Ae} ~10^{-12}]

- Dark Matter ALPs [g^{ALP}_{Ae} ~10^{-13}-10^{-14}]

JCAP 11, 017 (2016)

- (CNO Solar Neutrinos → sun metallicity only for depleated target)

ArXiv:1807.07169

DARWIN – Status and Perspective

- Collaboration of 28 groups (11 countries) – major German contribution
- DARWIN is on national and international roadmaps
  - ➢ KET, KHuK, KAT statement (2018), Helmholtz strategy paper
  - ➢ APPEC Roadmap (2017)
- R&D is ongoing (photosensors, TPC design, low bkg. solutions, electronics …)
  - ➢ synergy with XENONnT developments
  - ➢ dedicated DARWIN funding: erc ULTIMATE (UniFr), Xenoscope (UZH)
- Science channels (beyond the WIMP case) are under study
- investigate 'out of the way' ideas:
  - depleted Xe (→ CNO neutrinos, omitting $0\nu\beta\beta$)
  - target doping (→ sensitivity to light WIMPs)

⇒ CDR within 2-3 years, TDR ~ 2023(±1), physics after XENONnT

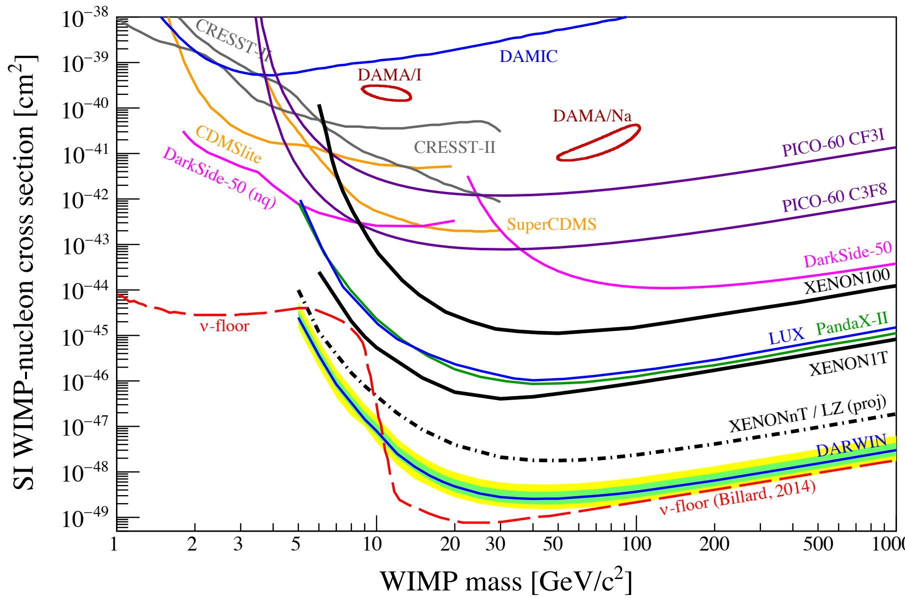
The DARWIN observatory …

www.darwin-observatory.org

DARWIN

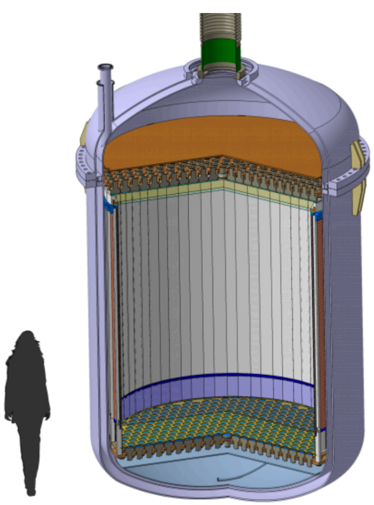
… is the ultimate WIMP detector.

It will uncover any trace of medium to heavy mass WIMPs above the neutrino floor.



… offers a rich physics program:

- Solar neutrinos (ER)
- CEνNS (NR) of ^{8}B ν
- Supernova neutrinos
- 0νββ of ^{136}Xe
- SD WIMP coupling
- Axions and ALPs



… is a challenging detector construction,

involving technology optimization, R&D on new concepts, in depth material screening and construction / design studies...

… is pursued by a growing collaboration,

with a German fingerprint.

DARWIN

Backup Slides

Backup – Neutrino Floor

Neutrinos mimic a WIMP signal in LXe TPC
[w/o directional measurement no discrimination]

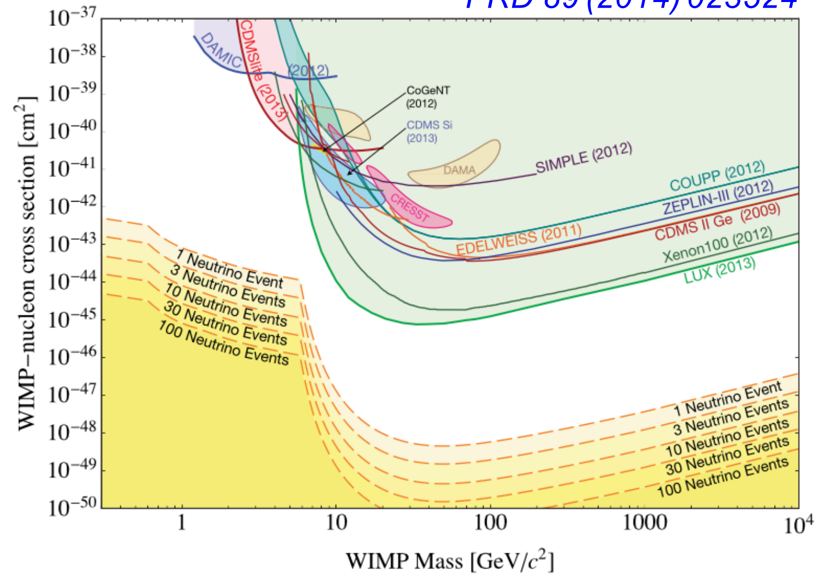
Various definitions of the 'neutrino floor'

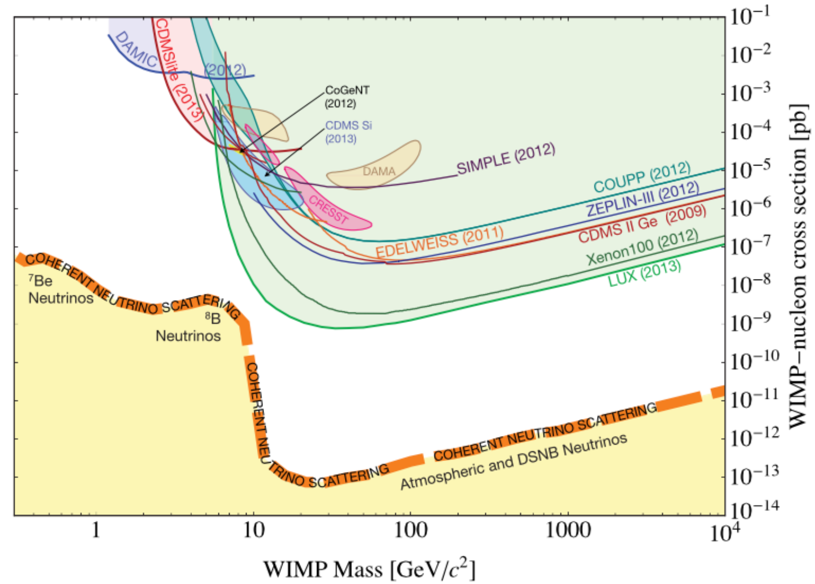
Billard et al. *PRD 89 (2014) 023524*
„1/3/10... - CEvNS event line"

Billard et al. *PRD 89 (2014) 023524*
„WIMP discovery limit"
= 3σ WIMP detection on top of **500 CEvNS events** above a LXe threshold of 4 keV_{NR} (infinite E resolution)
→ assuming an unrealistic 100% NR acceptance, a **> 5000 t × y exposure** is required to reach this (4-35 keV_{NR} window)

… and others

PRD 89 (2014) 023524



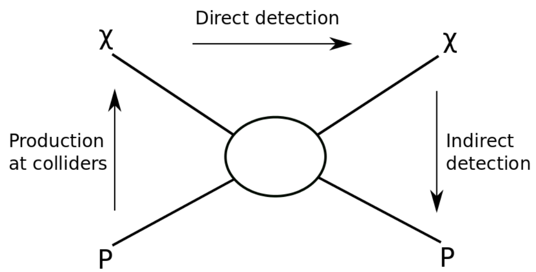


Backup – SD WIMP nucleus cross section

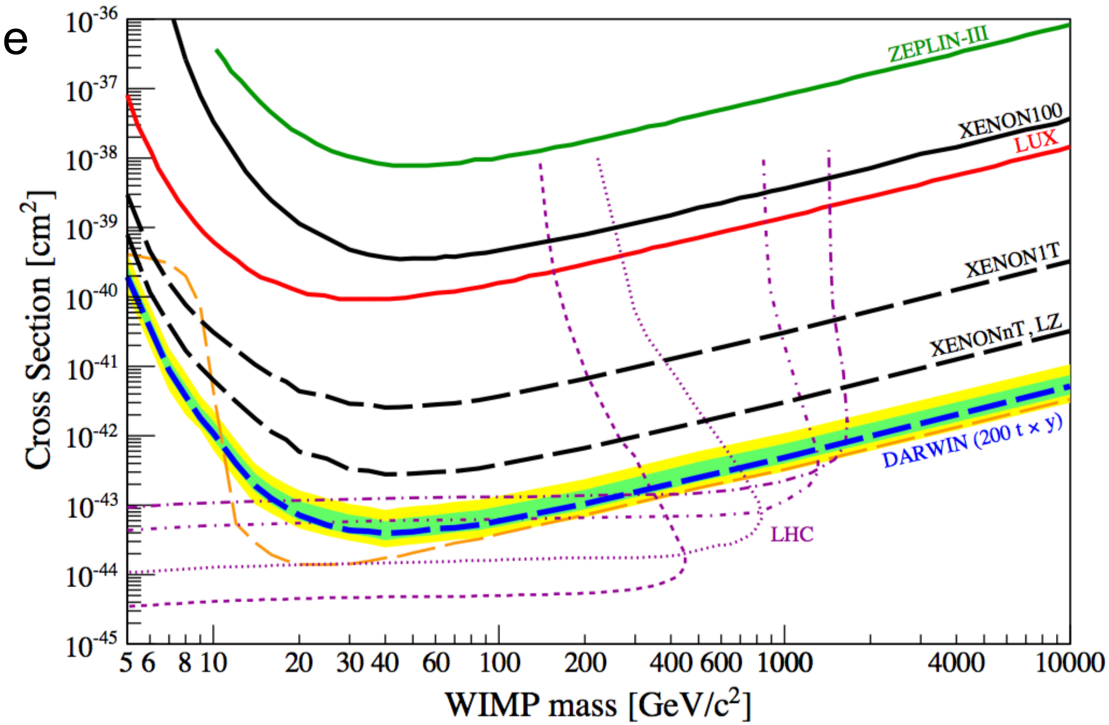
DARWIN

Natural abundance of ^{129}Xe (26,4% nucl. spin 1/2+) + ^{131}Xe (21,2% nucl. spin 3/2+) in the LXe target allows for measurement of (SD) WIMP-nucleus cross section.

DARWIN sensitivity comparable to LHC sensitivity (DM production, highly model dependent).



JCAP 11, 017 (2016)



Upper limits on the spin-dependent WIMP-neutron cross section of ZEPLIN-III, XENON100 and LUX as well as projections for XENON1T, XENONnT, LZ and DARWIN. For the 14 TeV LHC limits for the coupling constants $g_\chi = g_q = 0.25, 0.5, 1.0, 1.45$ (bottom to top) are shown.

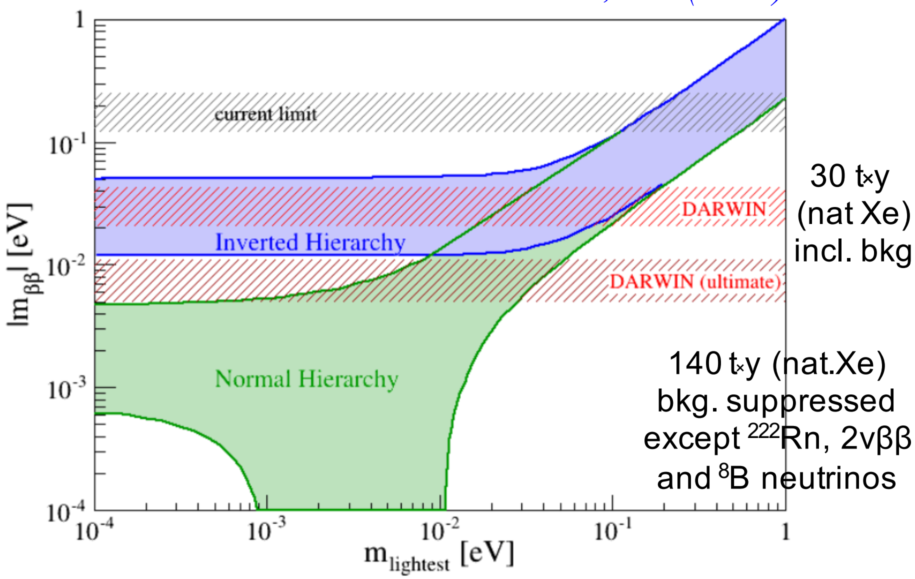
Backup - 0νββ in DARWIN

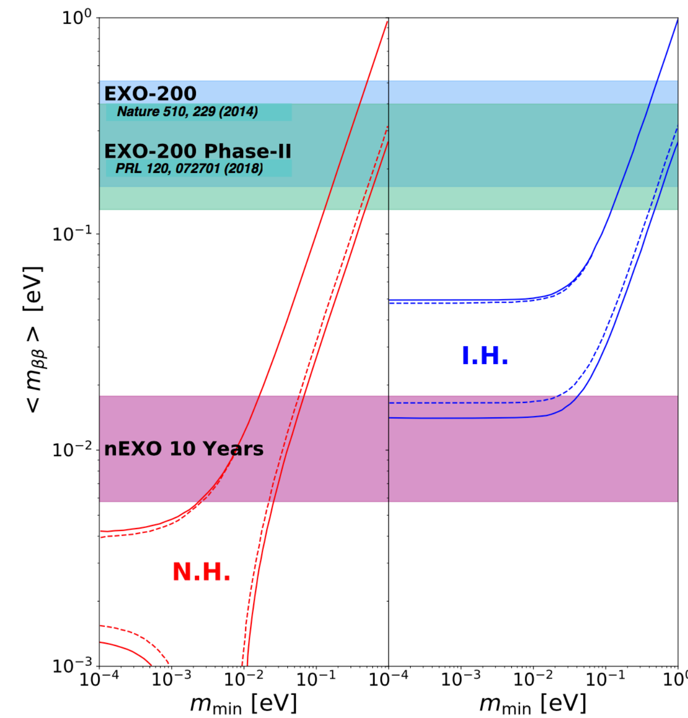
^{136}Xe (8.9% in nat. Xe) corresponds to 3.5t in the DARWIN fiducial volume.

Estimated DARWIN sensitivity (@ 95% CL):

- 30 t*yr → $T_{1/2} > 5.6 \cdot 10^{26}$ yr
- 140 t*yr → $T_{1/2} > 8.5 \cdot 10^{27}$ yr

JCAP 11, 017 (2016)





Projected <ββ> sensitivity of nEXO after 10y runtime [arXiv:1805.11142]

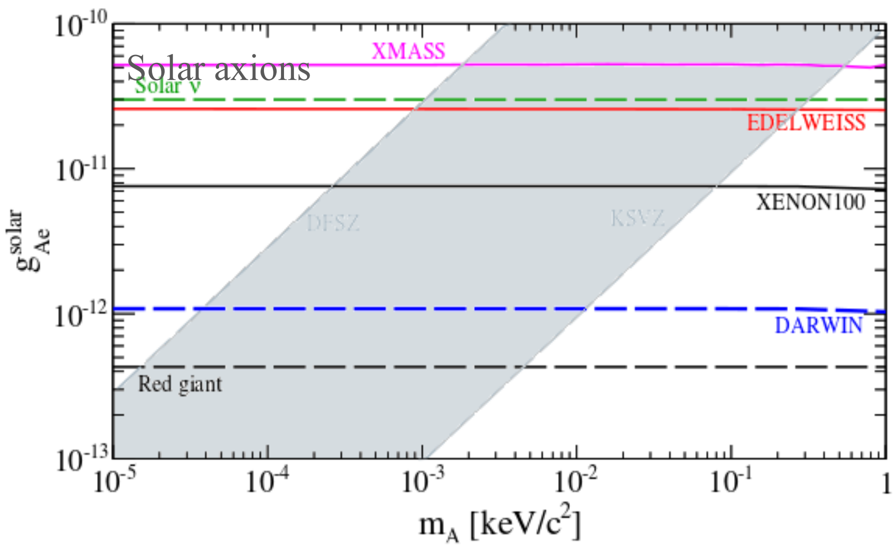
DARWIN will become a competitive 0νββ decay experiment!

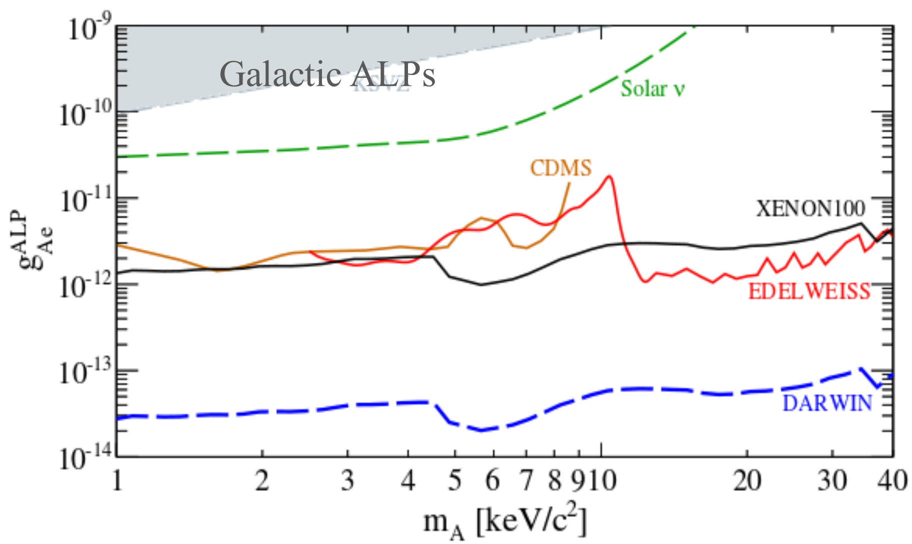
Backup – Solar Axions and DM ALPs in DARWIN

JCAP 11, 017 (2016)

- Solar Axions and Dark Matter ALPs (axio-electric-effect):

  [ER → continuous spectrum (Axions); mono-E peak (ALPs)]



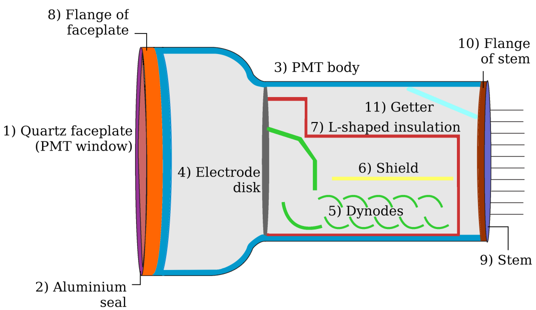


A 'glimpse' on DARWIN R&D – Photo sensors

DARWIN

Identification of the 'ideal' cryogenic photo sensor [quantum efficiency (QE), collection efficiency (CE), fill factor → photon detection efficiency (PDE); Dark count rate, robustness, cost …]

Photomultiplier tubes (PMT – e.g. R11410)



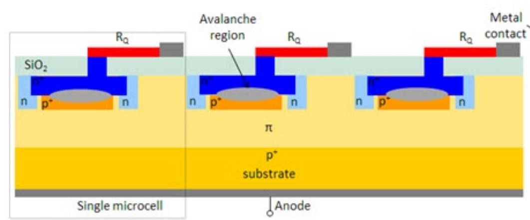
Established and well known technology,
PDE ~ 14%, fill factor 55%
+ commercially available
+ optimized radio-purity,

- still a major source of radiogenic bkg.
- bulky & costly

JINST 8 (2013) P04026, [1303.0226]

Eur. Phys. J. C75 (2015) 546, [1503.07698].

Silicon Photomultipliers (SiPM)



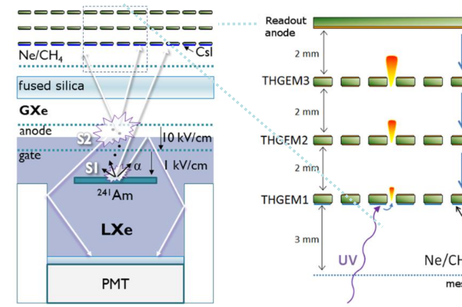
Rapidly developing technology
PDE ~ 10% @ 175-178nm
+ good fill factor (75%)
+ low space / material budget
→ 4π coverage feasible

- high dark count rate

Arxiv: 1808.06827

IEEE Trans. Nucl. Sci. (2015) 1825 [1502.07837]

Gaseous Photomultiplier (GPM)



Highly adaptable detector feat.:
+ compact geometry,
+ high QE (CsI cathode)
+ high fill factor (90%)
[+ excellent spatial resolution]

- No commercial availability
→ R&D ongoing

JINST 10 (2015) P10020, [1508.00410].

… and more: Silicon Geiger Hybrid Tube (SiGHT), …