

DARWIN

- The ultimate WIMP Detector -

Fabian Kuger, for the DARWIN Collaboration

12th Int. Conference on Identification of Dark Matter (IDM)
Brown University, 23-27.07.2018



Direct WIMP Dark Matter detection with DARWIN

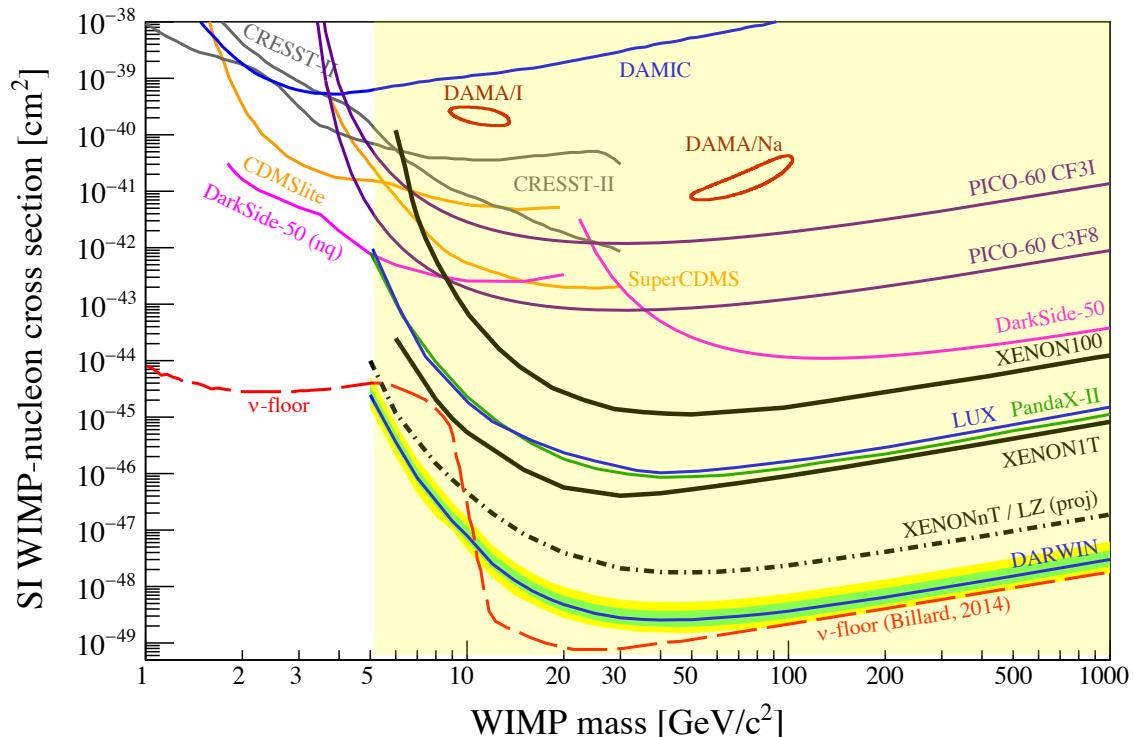


- WIMPs are one of the best motivated dark matter candidates. Their spin independent (SI) scattering on nucleons is the most model-independent channel for a direct detection.

- Best WIMP exclusion limits by active target experiments with liquid noble gases [1 t_{xy} LXe exposure]

- Next generation LXe detectors aim for an increased σ_{SI} sensitivity [~ 20 t_{xy} exposure]

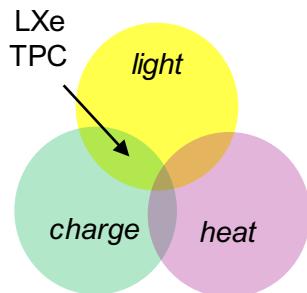
- WIMP discovery limited by v-floor
[Billard et al. *PRD* 89 (2014) 023524]



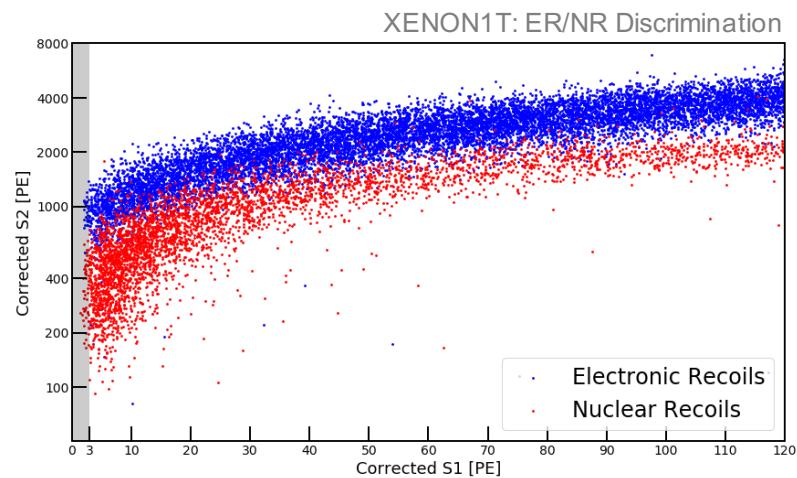
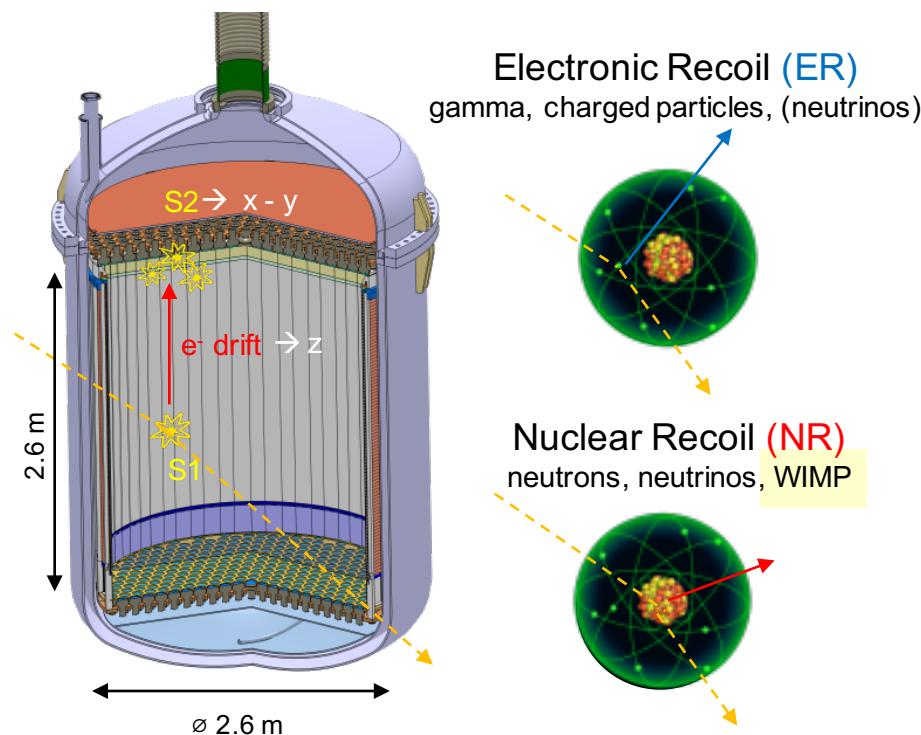
→ **DARWIN** is targeting this ultimate WIMP discovery limit,
[200+ t_{xy} LXe exposure]



WIMP detection and signal discrimination in LXe TPCs



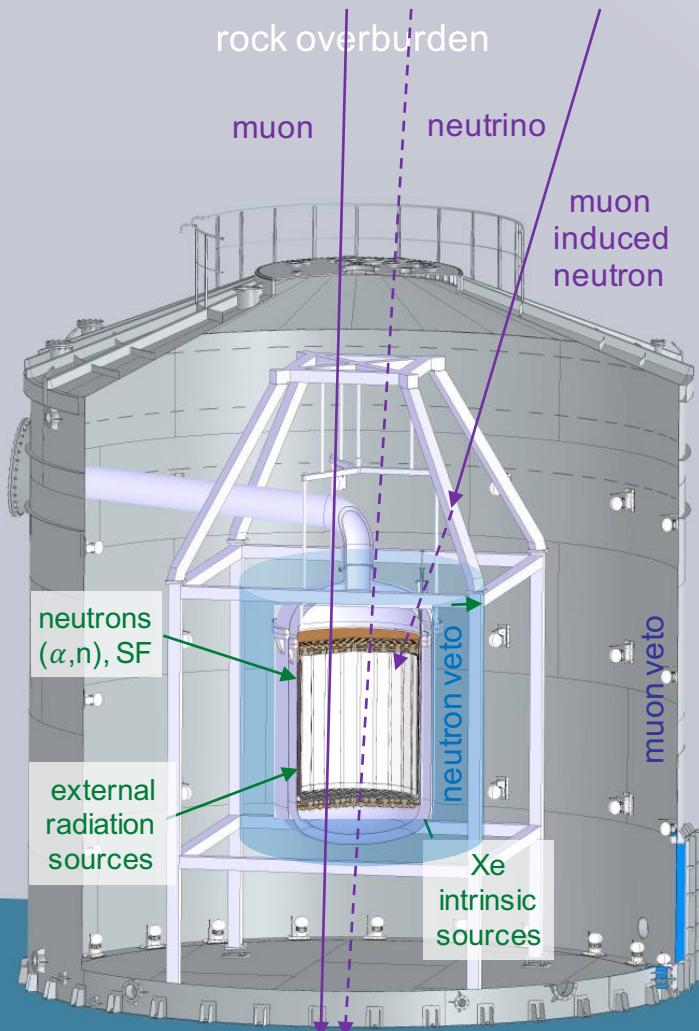
- Interaction with xenon causes prompt scintillation (**light**, S1) and ionization (**charge**), causing a delayed proportional scintillation signal (S2).
- Position reconstruction by x-y-light sensor array + drift time (z)
- Characteristic light / charge ratio for **ER** and **NR** events → discrimination



⇒ High target mass: 40t in TPC
(~30t fiducial volume)

⇒ 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
- Cosmic Neutrinos (irreducible):
 - pp + ^{7}Be neutrons (ER)
 - CEvNS of high E neutrinos (NR)

Radiogenic background sources

- External $[\alpha, \beta]$ γ 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 : $2\nu\beta\beta$

→ NR background > total ER background

→ radiogenic ER < neutrino induced ER

(Solar) neutrinos as NR background & Science Channel

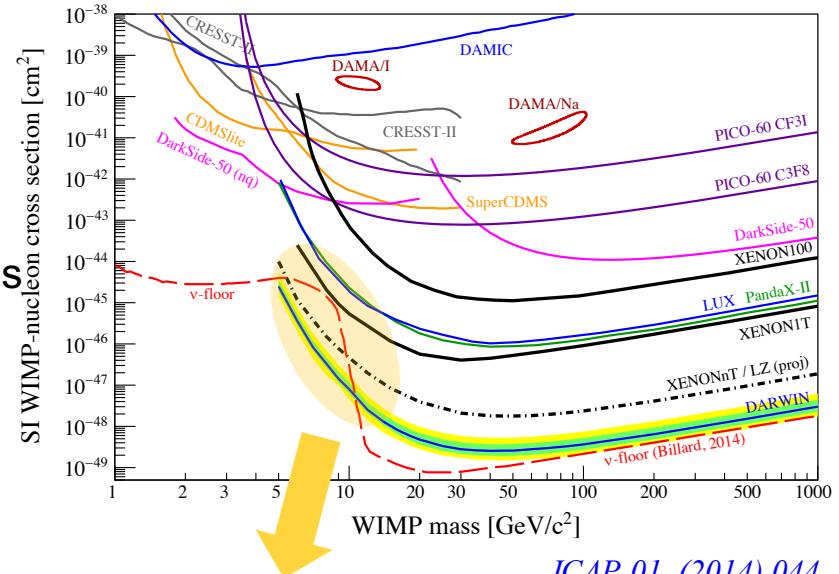


Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) of high E astrophysical neutrinos poses the irreducible background for WIMP searches.

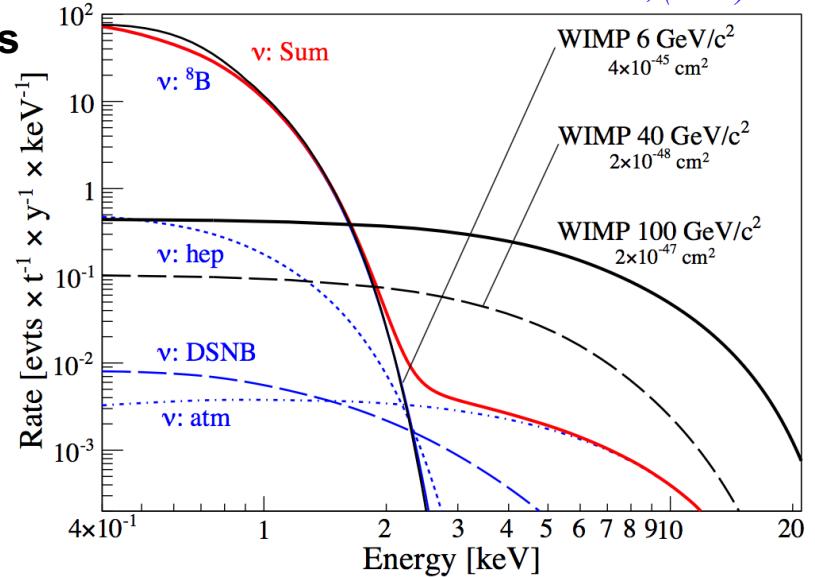
- ${}^8\text{B}$ neutrinos set a strong discovery limit towards low WIMP masses
- atmospheric neutrinos dominate the limit for higher WIMP masses

→ Observation of CEvNS by solar ${}^8\text{B}$ neutrinos
is a science goal by itself

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



JCAP 01, (2014) 044



Xenon-intrinsic radiogenic background (ER)

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

→ Challenging requirements on the xenon radioactivity:



${}^{136}\text{Xe}$ (8.9% nat. ab.) introducing $2\nu\beta\beta$ background

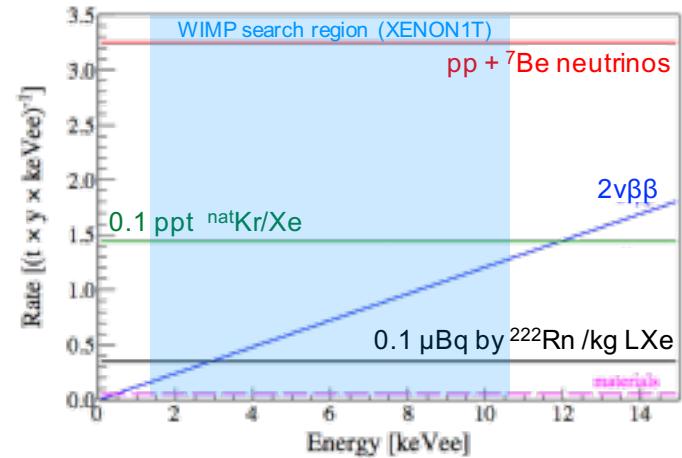
Spectrum of $2\nu\beta\beta$ is subdominant in WIMP search region

→ Major science channel: $0\nu\beta\beta$

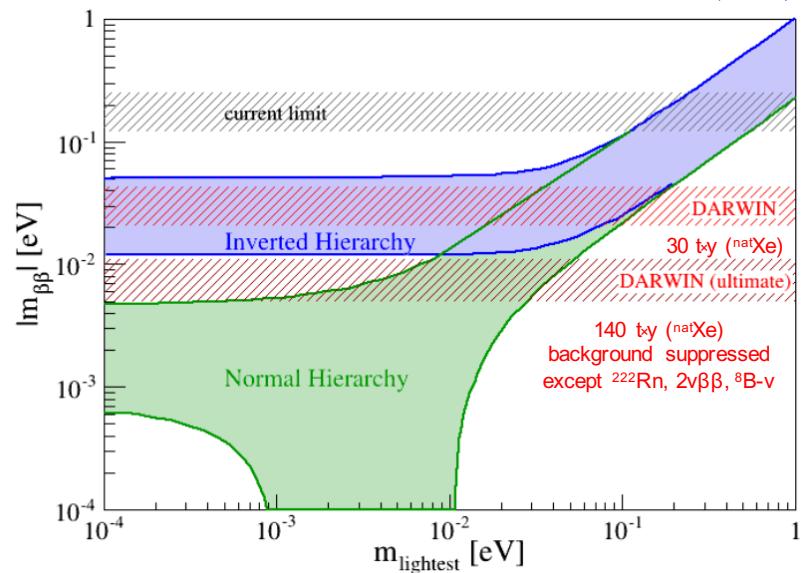
- SS vs. MS discrimination (x,y,z reconstruction)
- $\sigma_E | Q_{\beta\beta}$ optimization with extra readout channel

→ High $T_{1/2}$ sensitivity, due to $m_{\beta\beta} > 3.5t$,
low background + fiducial cut / self shielding

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



JCAP 11, 017 (2016)



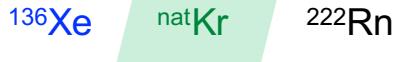
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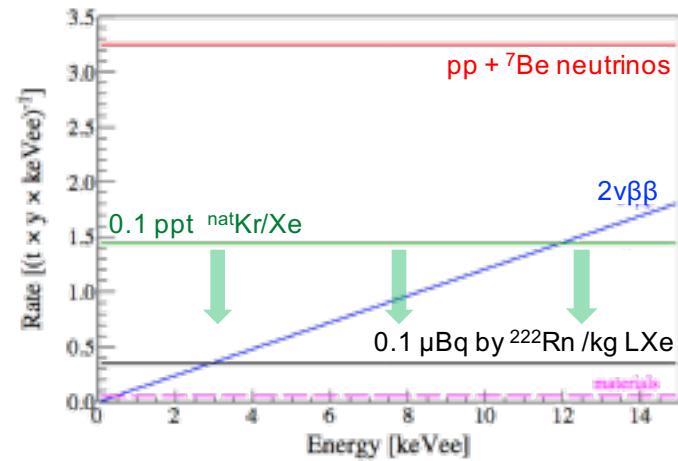


Eur. Phys. J.C. (2017) 77:275

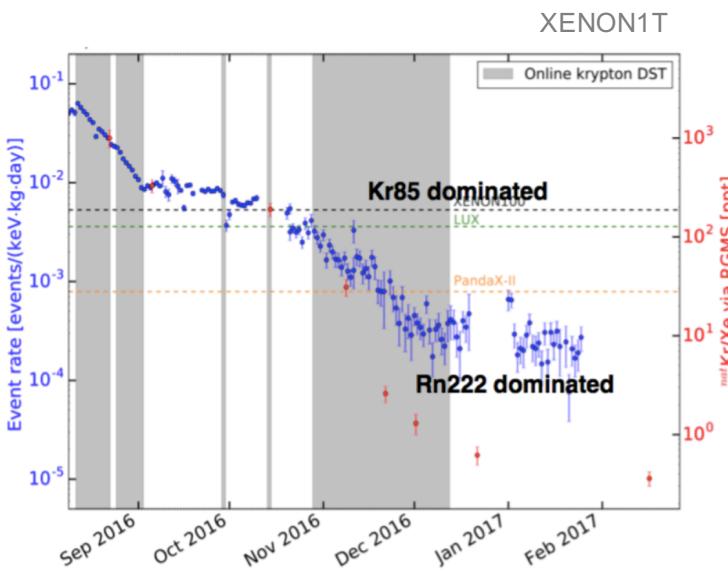


0.1 ppt of natKr:

- <0.05 ppt ${}^{\text{nat}}\text{Kr}/\text{Xe}$ demonstrated in XENON1T by cryogenic distillation
→ Outperforms requirement !
- RGMS measurement of ${}^{\text{nat}}\text{Kr}/\text{Xe}$
[Eur. Phys. J.C. (2014) 74:27 46]



JCAP 10, 016 (2015)



XENON1T

UNI
FREIBURG

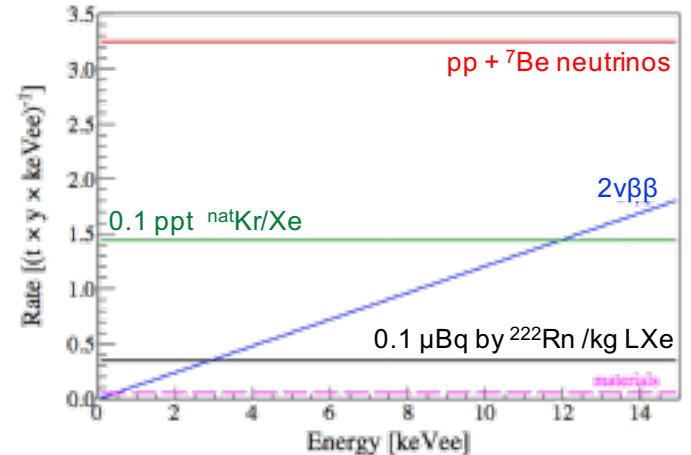
Xenon-intrinsic radiogenic background (ER)



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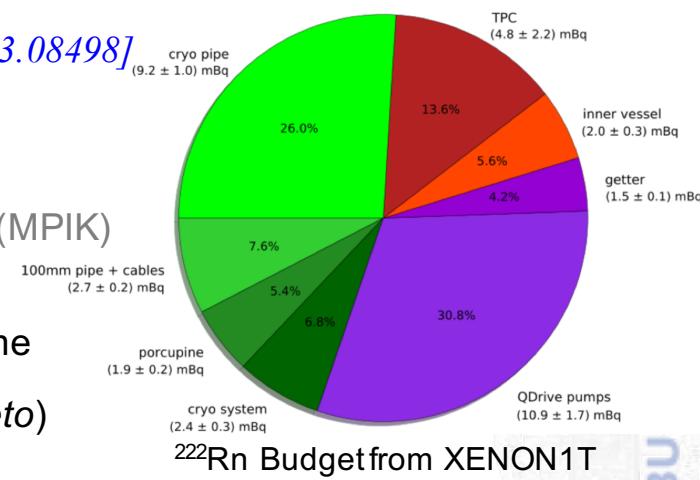
→ Challenging requirements on the xenon radioactivity:

${}^{136}\text{Xe}$ ${}^{\text{nat}}\text{Kr}$ ${}^{222}\text{Rn}$



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

- XENON1T demonstrated ${}^{222}\text{Rn}$ activity of $10\mu\text{Bq}/\text{kg}$ → factor 100 to requirement
- Distillation in XENON100 demonstrated factor >27 ${}^{222}\text{Rn}$ reduction [[Eur. Phys. J.C. \(2017\) 77:358](#)] → higher throughput required for DARWIN
- Development of magnetically coupled piston pump [[arXiv:1803.08498](#)] ${}^{222}\text{Rn}$ emanation rate of $(330 \pm 60)\mu\text{Bq}$, ~ 180 slpm xenon
- Screening & selection of radio-pure material
GEMPI (MPIK-LNGS), GEMSE (UniFr), Gator(UZH), GIOVE (MPIK)
- Improved surface / volume ratio
+ optimized design reducing emanation into active TPC volume
- ER background analysis / rejection techniques (*Radon self veto*)



pp+⁷Be neutrinos as ER background & science channel

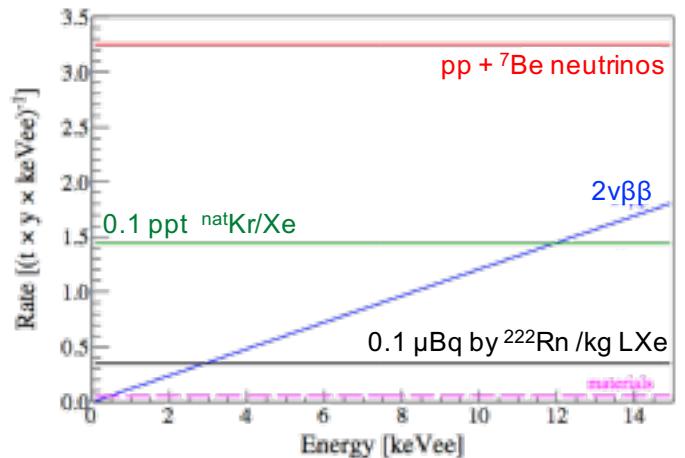


ER events from low energetic (pp + ⁷Be) solar neutrinos remain as background events and must be suppressed

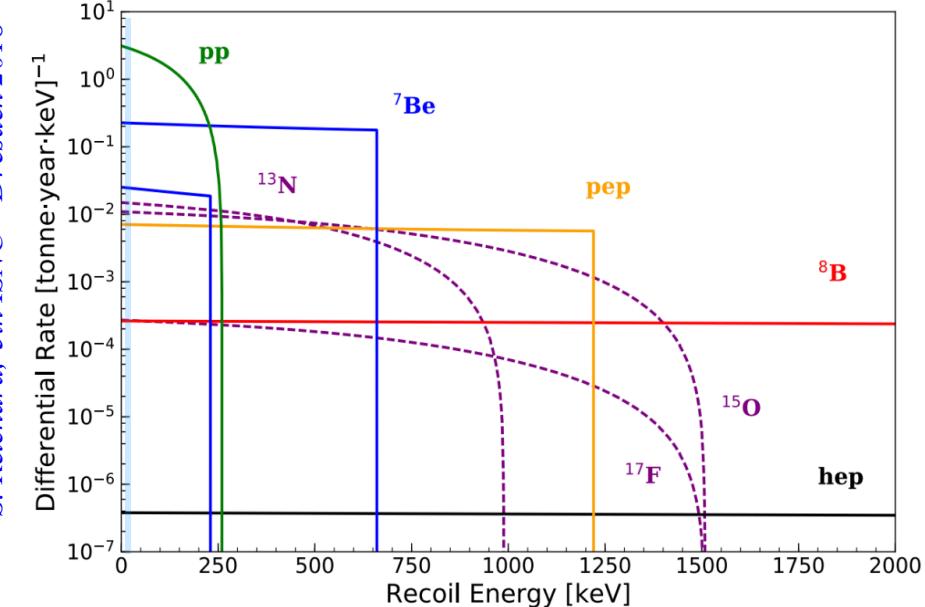
ER/NR discrimination: 99.98% ER rejection
→ estimated 30% NR acceptance

JCAP 10, 016 (2015)

→ Solar neutrinos are an interesting science channel



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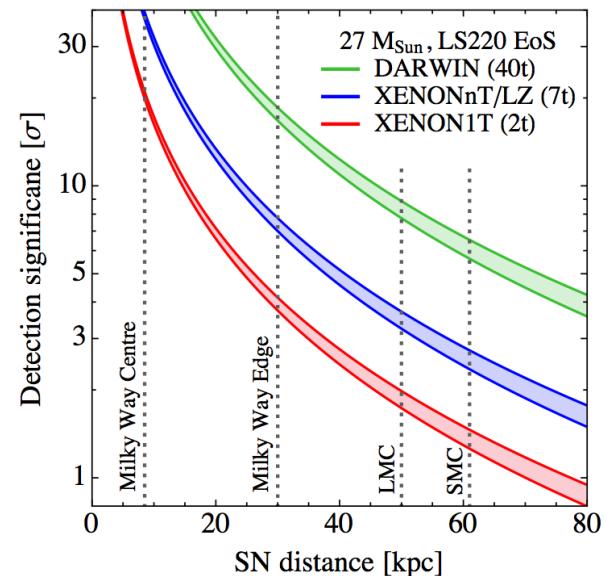
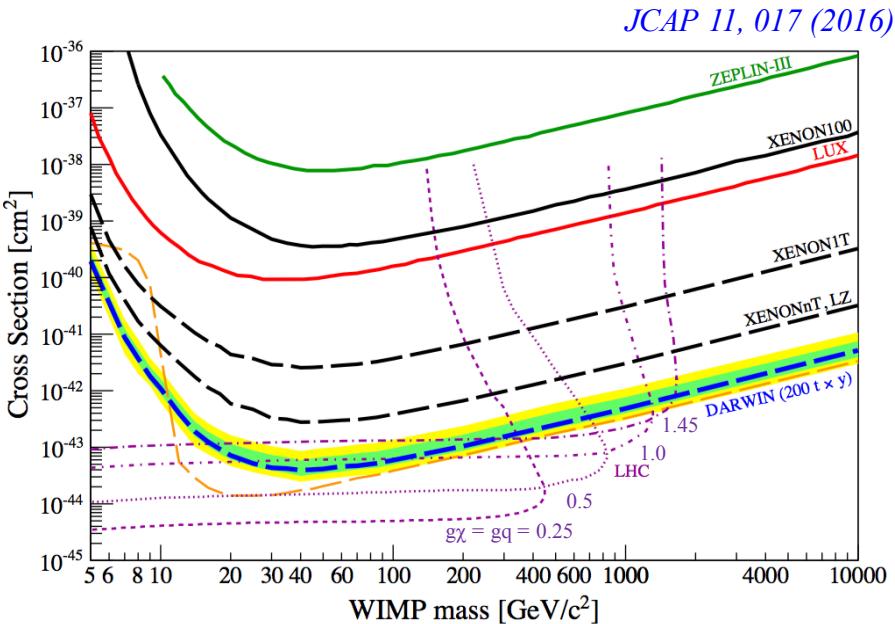
- Highest flux from pp and ⁷Be
- Several hundred ν-induced events/year
- Precision measurement of ϕ_{pp} and ϕ_{7Be} with ±0.3% and ±2.3% accuracy
- Conclusion on the weak mixing angle and ν-survival probability below 200keV



Further DARWIN Science Channels



- Observation of supernova neutrinos with all 6 ν -flavors
[\rightarrow extending $> 5\sigma$ sensitivity for a $27M_{\odot}$ SN up to 65kpc]
 \rightarrow 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)

- Solar Axions [sensitivity on $g_{\text{Ae}}^{\text{solar}} \sim 10^{-12}$]
- Dark Matter ALPs [$g_{\text{Ae}}^{\text{ALP}} \sim 10^{-13}-10^{-14}$]

JCAP 11, 017 (2016)

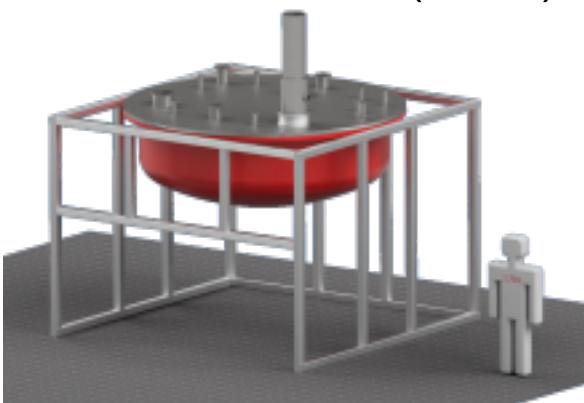
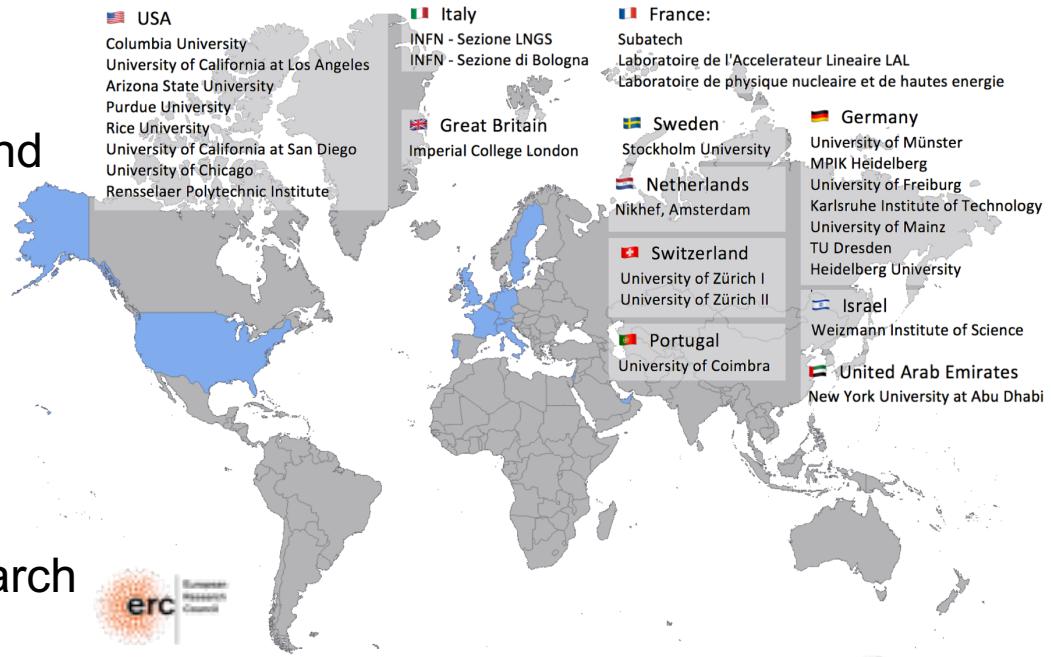
Before mentioned:

- Neutrino-less-double-beta decay of ^{136}Xe
- Solar pp + ^{7}Be neutrino fluxes
- CEvNS of solar ^{8}B neutrinos

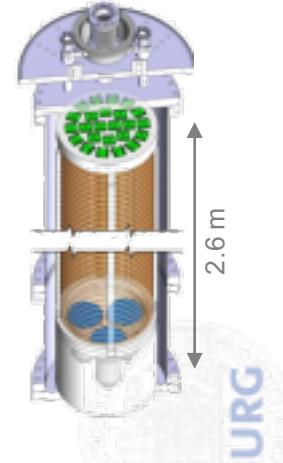


DARWIN – Status and Perspective

- 28 groups from 11 countries
- DARWIN is on several national and international (APPEC) roadmaps
- Working towards a conceptual design report (2-3 years)
- Synergy with XENONnT R&D
- Seed funding by university / research institute contributions and ERC:



→ R&D on detector design, sensor technologies (PMTs vs. SiPMs ...), TPC scaling and mechanical mock-ups



The DARWIN observatory ...

www.darwin-observatory.org

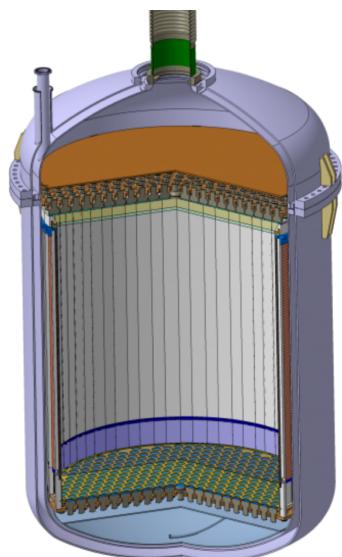


... is the ultimate WIMP detector.

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

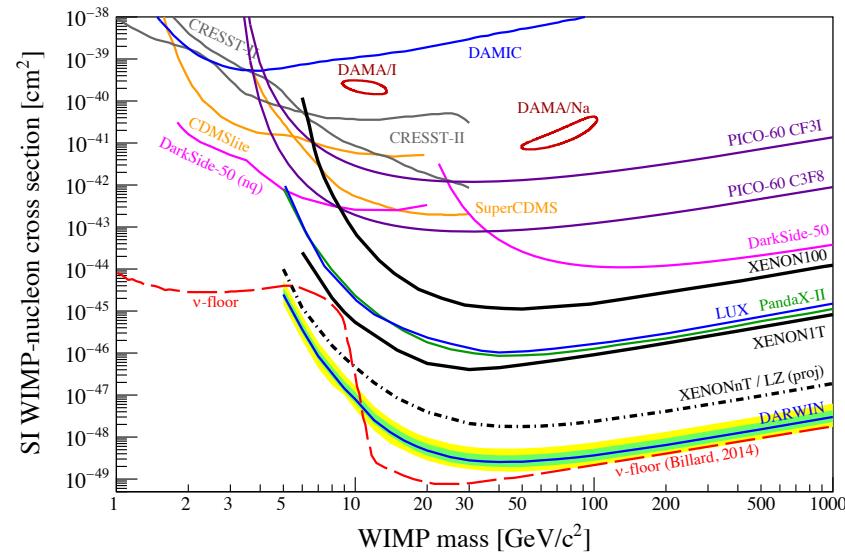
... offers a rich additional physics program:

- Solar neutrinos (ER)
- CEvNS (NR) of ${}^8\text{B}$ ν
- Supernova neutrinos
- $0\nu\beta\beta$ of ${}^{136}\text{Xe}$
- 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 an enthusiastic collaboration!

