DARWIN @ LNGS

The Low-Background Low-Threshold Observatory

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on behalf of the DARWIN collaboration

Scientific Committee Meeting
LNGS, October 21, 2019

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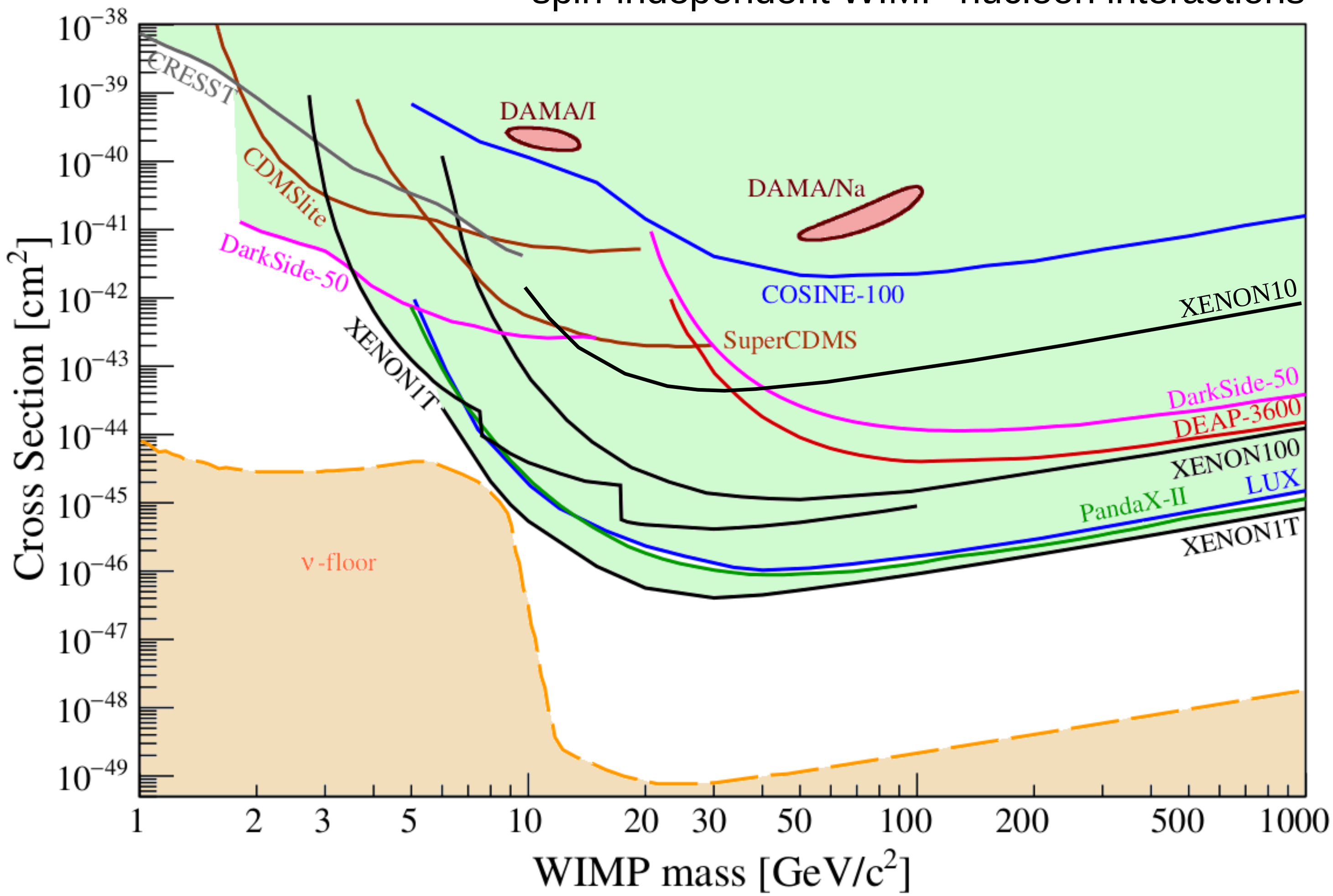
www.darwin-observatory.org

Direct Detection Today

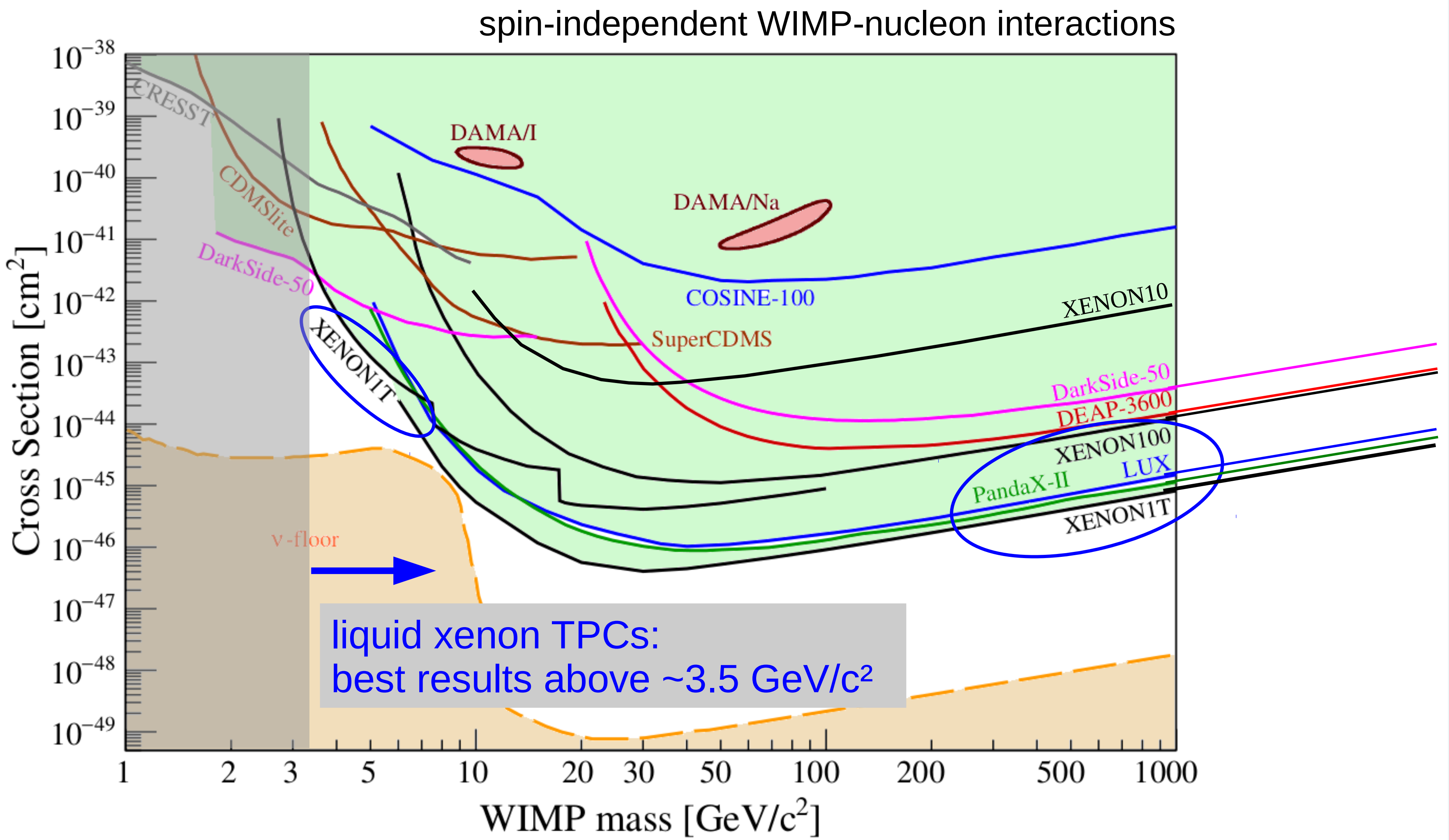
spin-independent WIMP-nucleon interactions



some results are missing...

Direct Detection Today

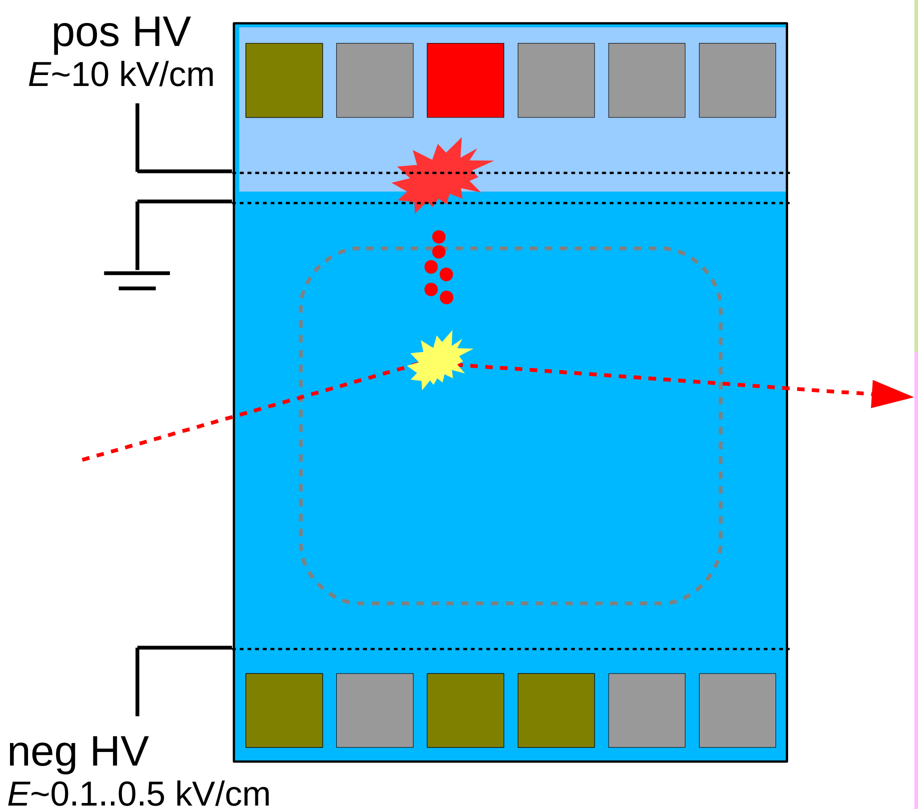
DARWIN

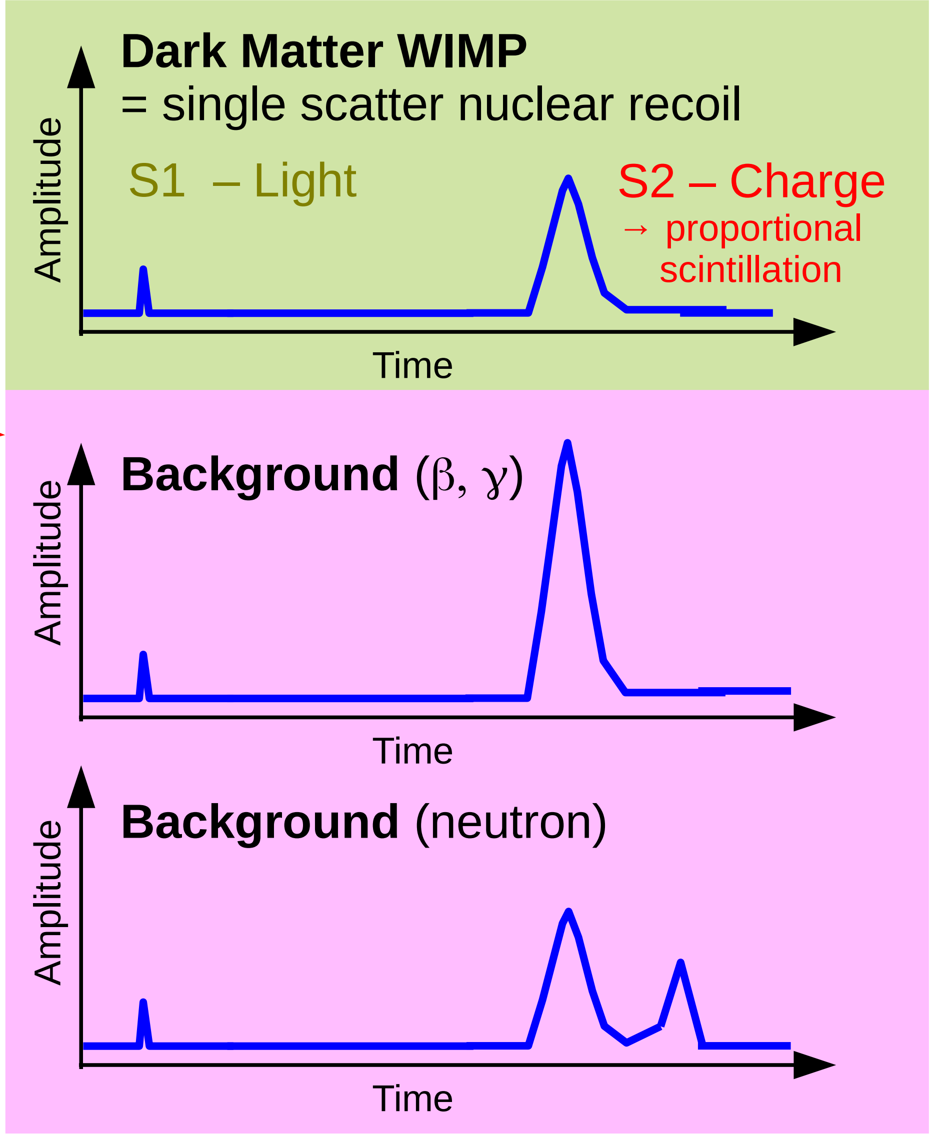


some results are missing...

Dual-Phase LXe TPC

TPC = time projection chamber

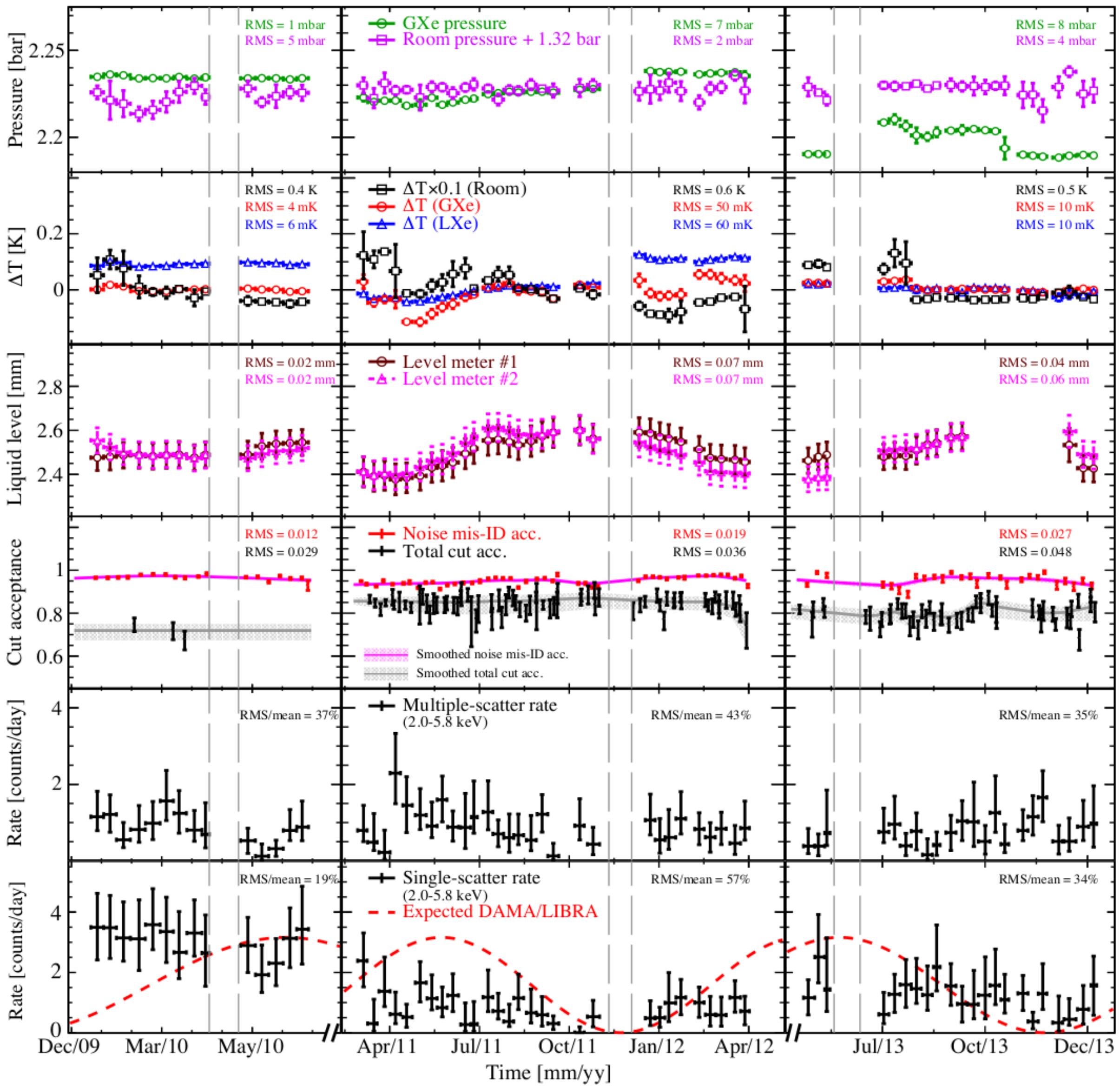




- 3d position reconstruction
  → target fiducialization
- background rejection

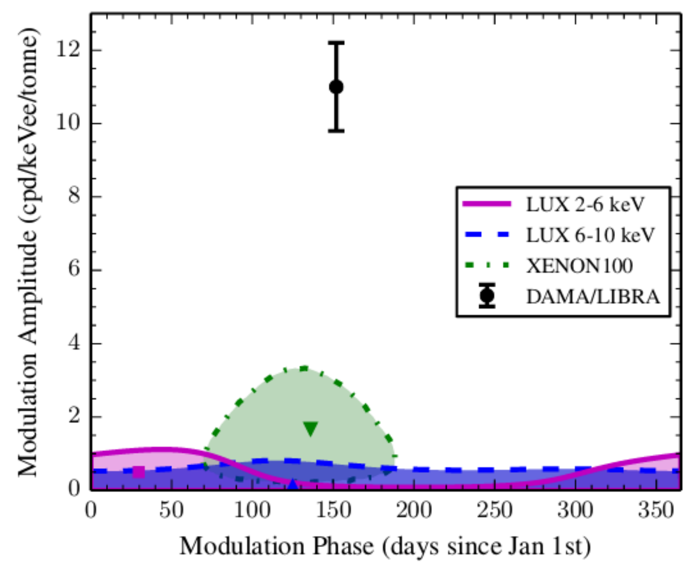
Annual Modulation Searches

XENON100: PRL 118, 101101 (2017)



- dark matter–electron scattering
- **2-phase LXe TPCs** operated stably over long periods
  - XENON100: 4 years
  - LUX: 2 years
  - XENON1T: 2 years
- challenges DAMA/LIBRA
  - XENON100: **5.7σ**
  - LUX: **9.2σ**

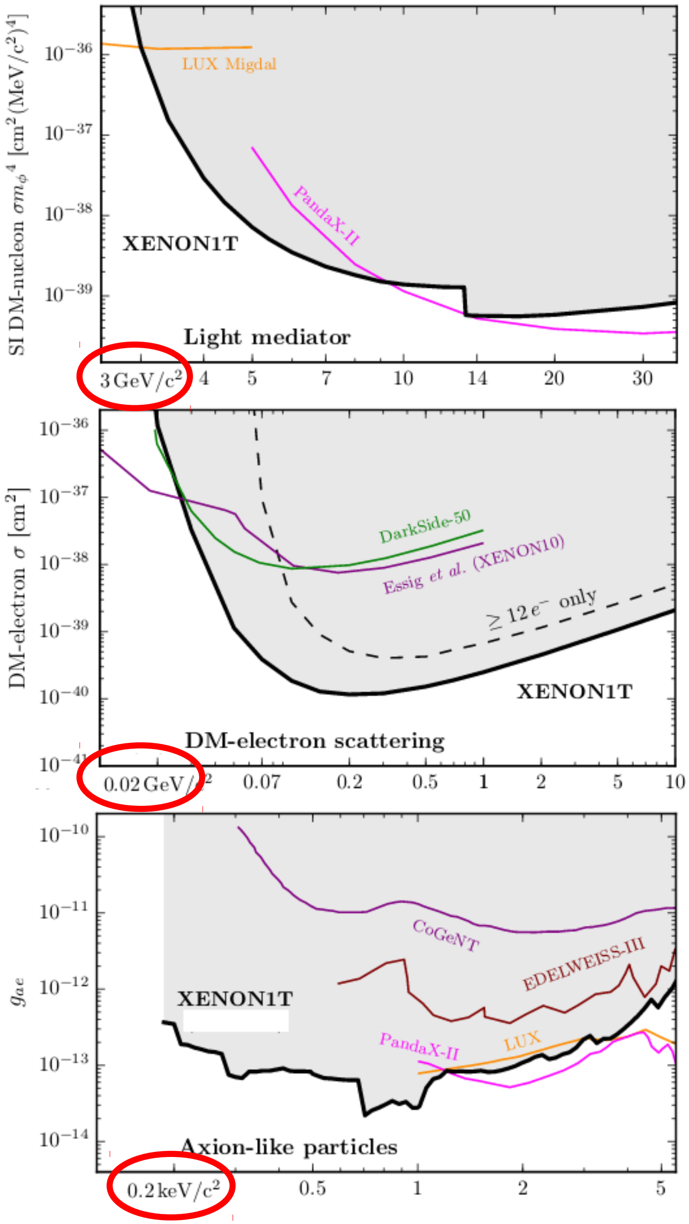
LUX: PRD 98, 062005 (2018)



XENON Low-Mass Results

arXiv:1907.11485

arXiv:1907.12771



Charge-only analyses

+ lower threshold

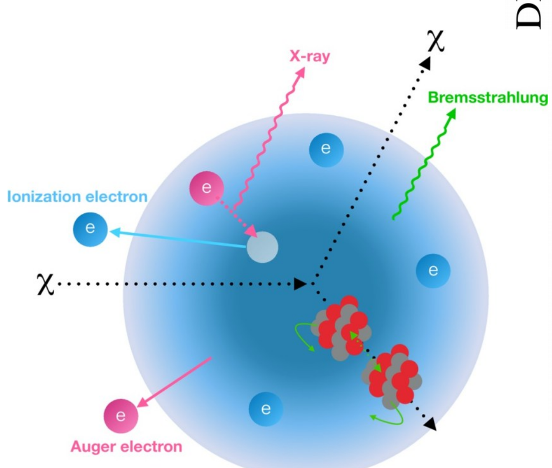
– higher background

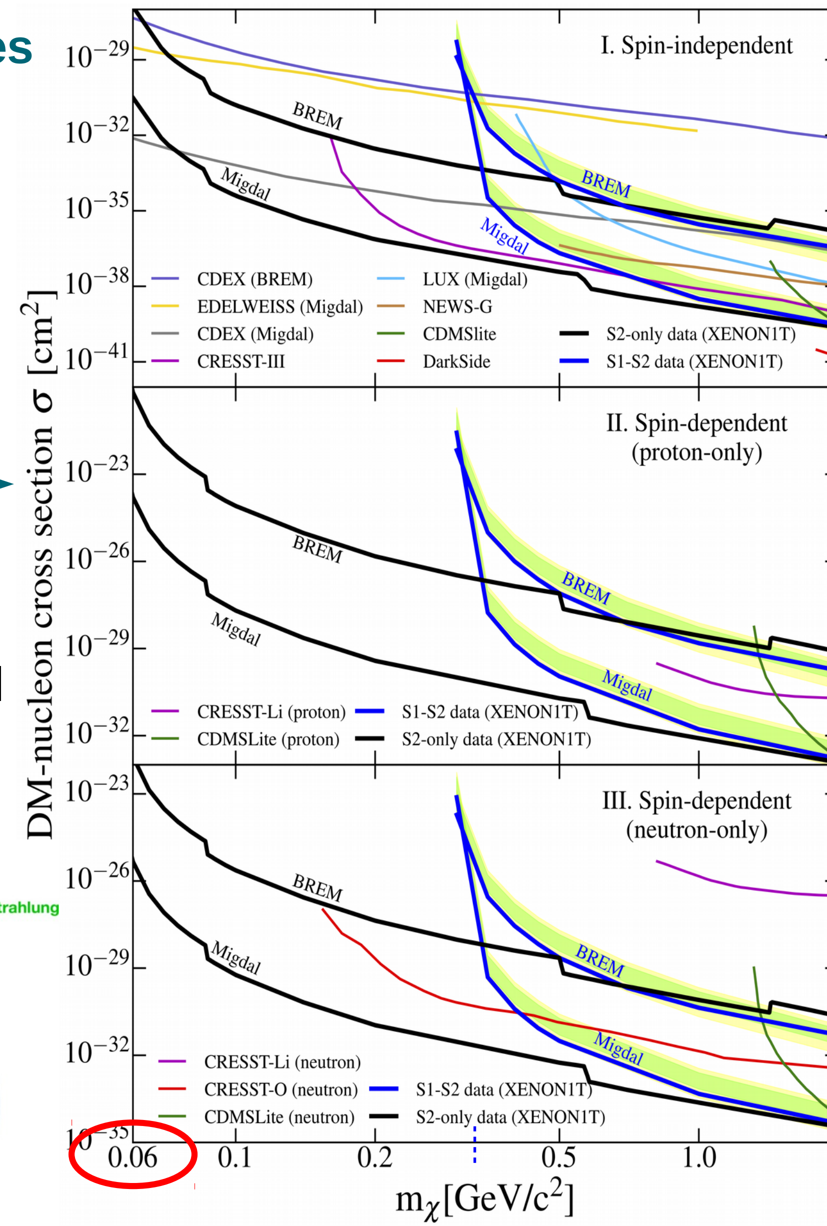
→ sensitivity to very low-mass DM

Migdal effect and Bremsstrahlung

low-E NR plus secondary ER signal

→ boost threshold

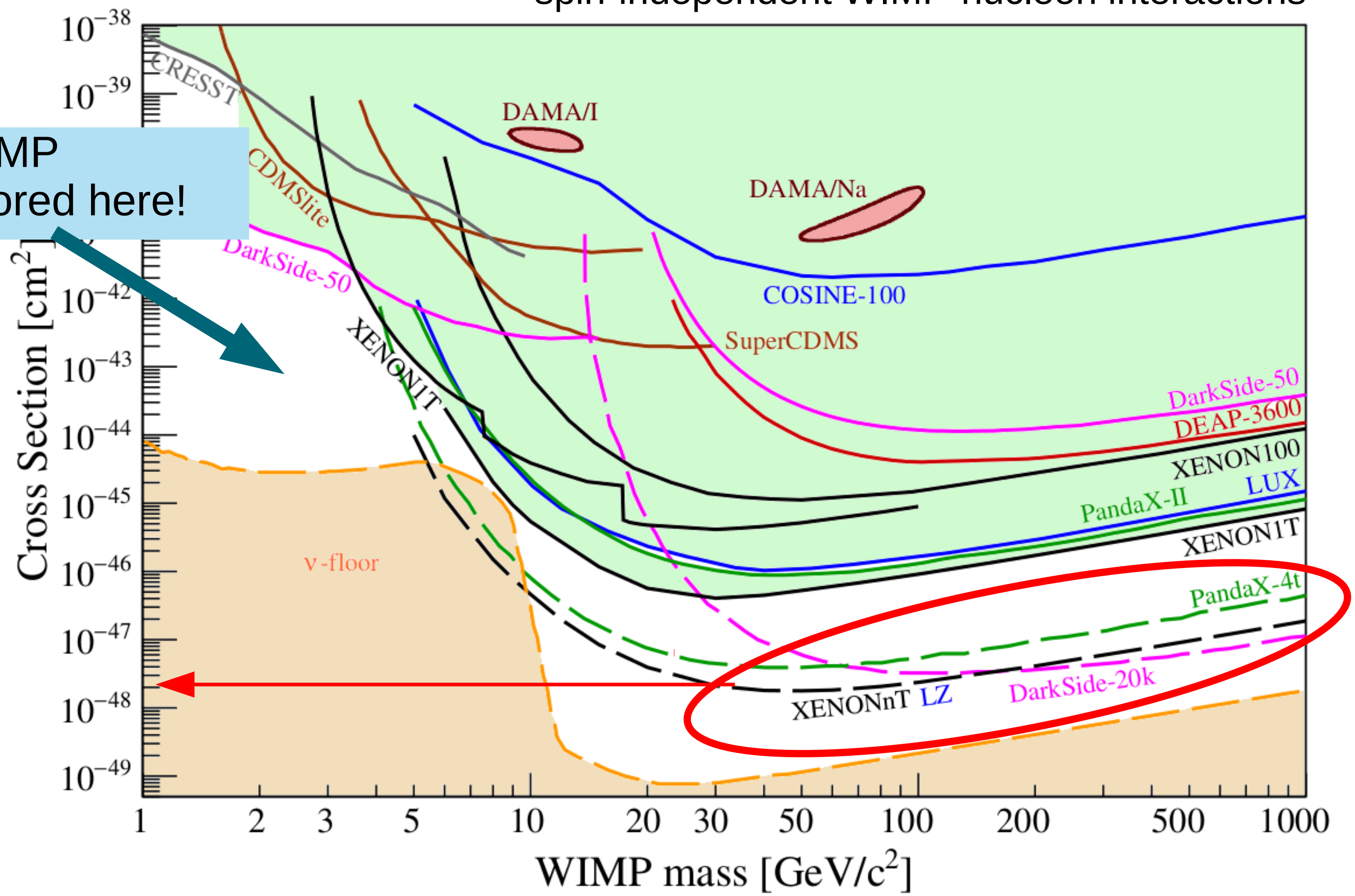




Upcoming Projects

DARWIN

spin-independent WIMP-nucleon interactions

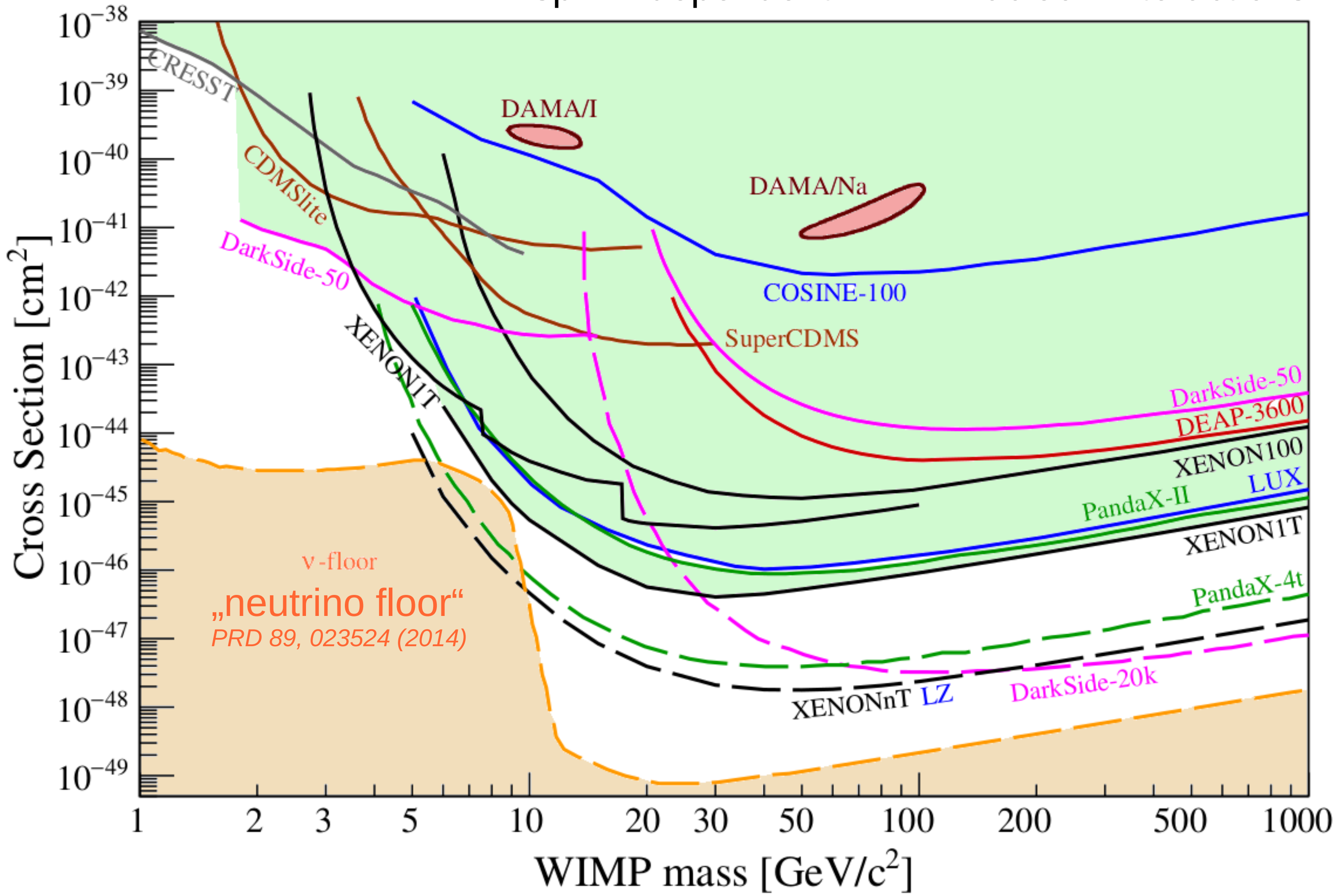


Low-mass WIMP searches ignored here!

some results are missing...

The ultimate Limit

spin-independent WIMP-nucleon interactions



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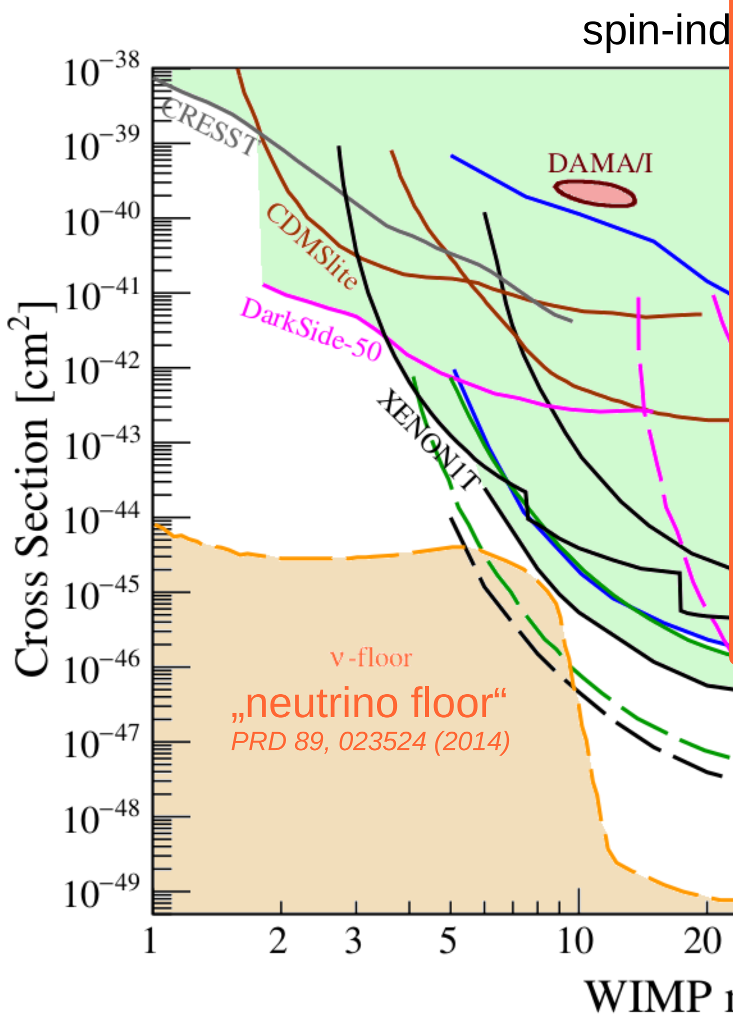
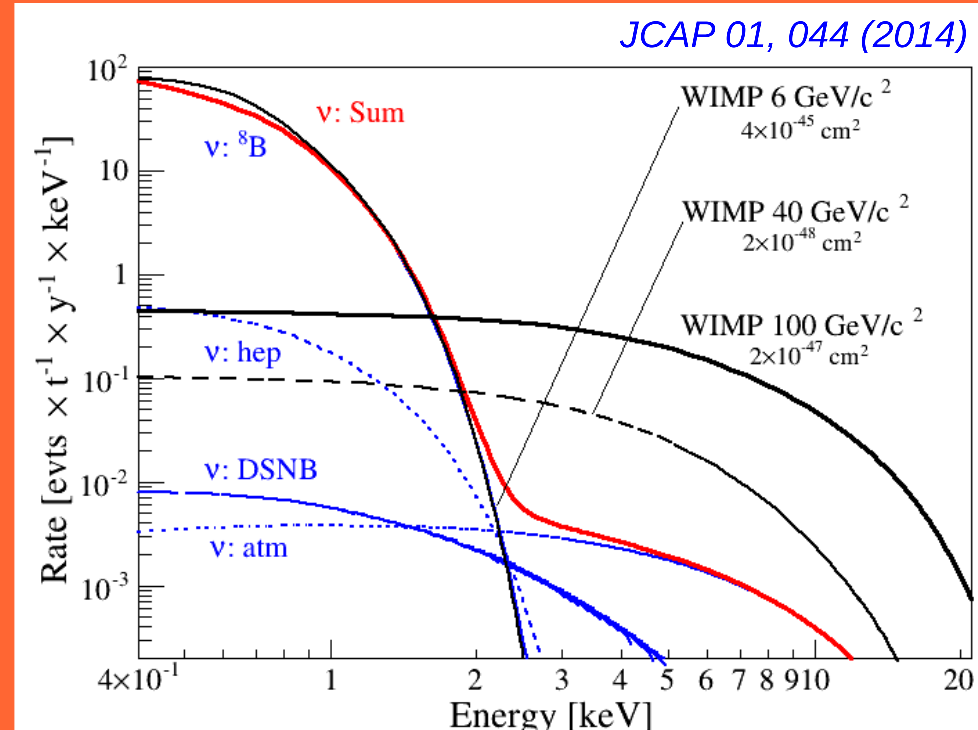
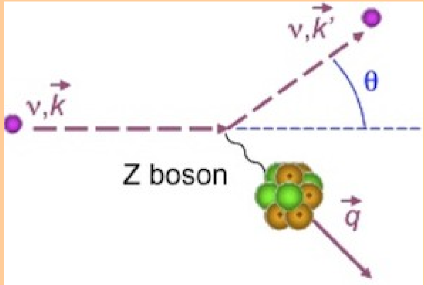
The ultimate Limit

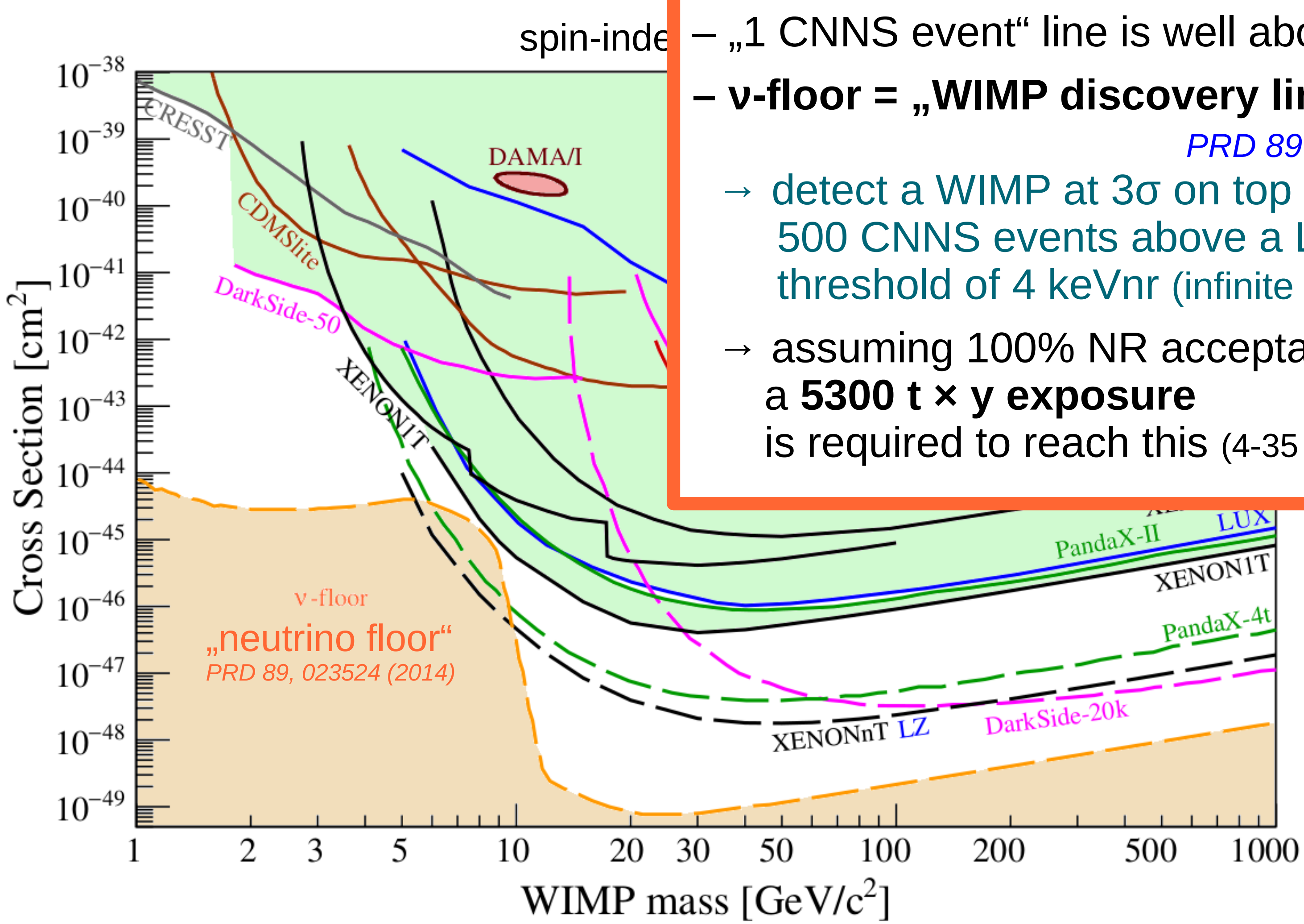




Interactions from coherent neutrino-nucleus scattering (CNNS) will dominate
→ **ultimate background** for direct detection



The ultimate Limit



Be aware of the **definition**

– „1 CNNS event“ line is well above „ν-floor“

– ν-floor = „WIMP discovery limit“

PRD 89 (2014) 023524

→ detect a WIMP at 3σ on top of 500 CNNS events above a LXe threshold of 4 keVnr (infinite resolution)

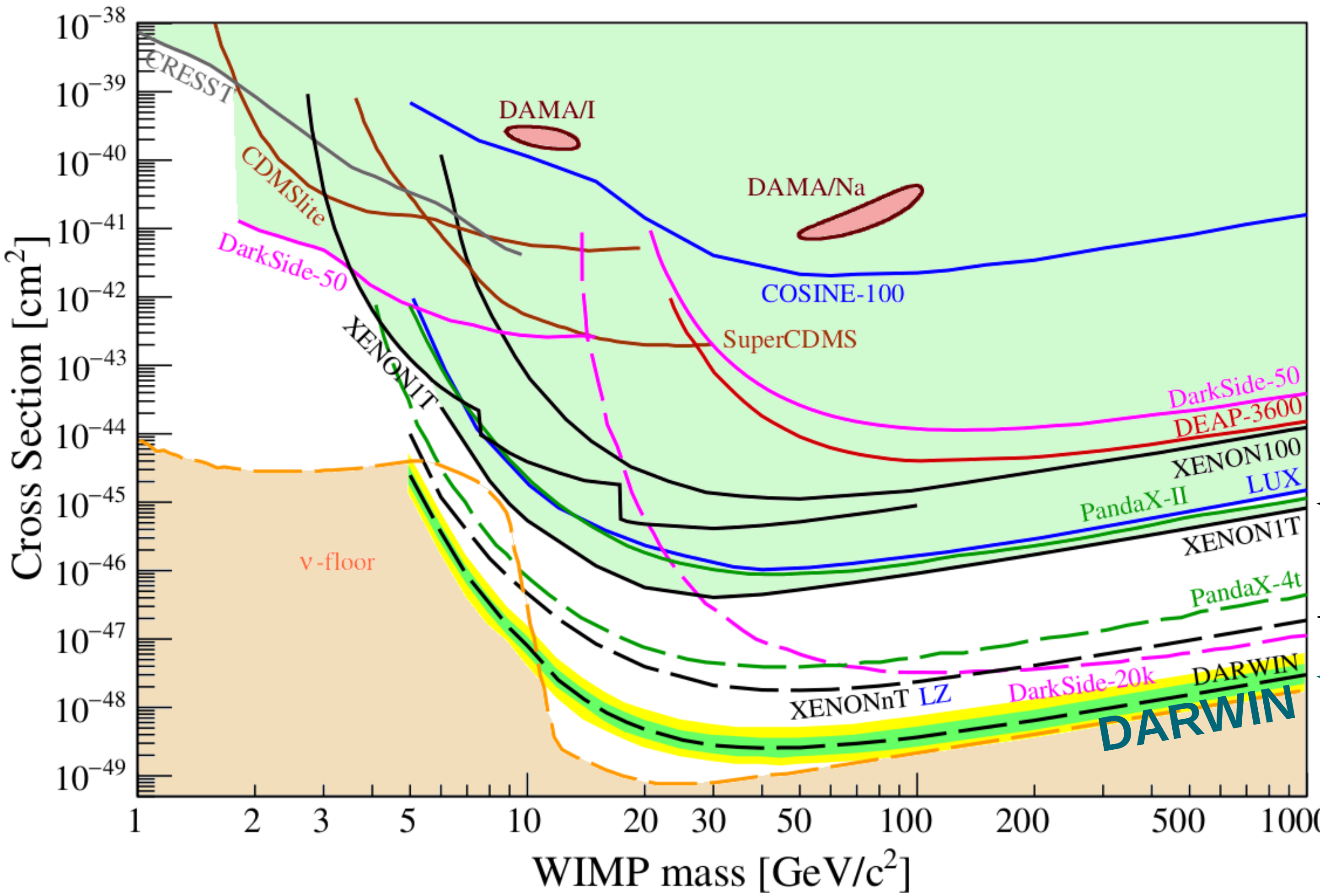
→ assuming 100% NR acceptance, a **5300 t × y exposure** is required to reach this (4-35 keVnr ROI)

some results are missing...

DARWIN The ultimate WIMP Detector

darwin-observatory.org

LXe-based



Exposure

1 t×y

20 t×y

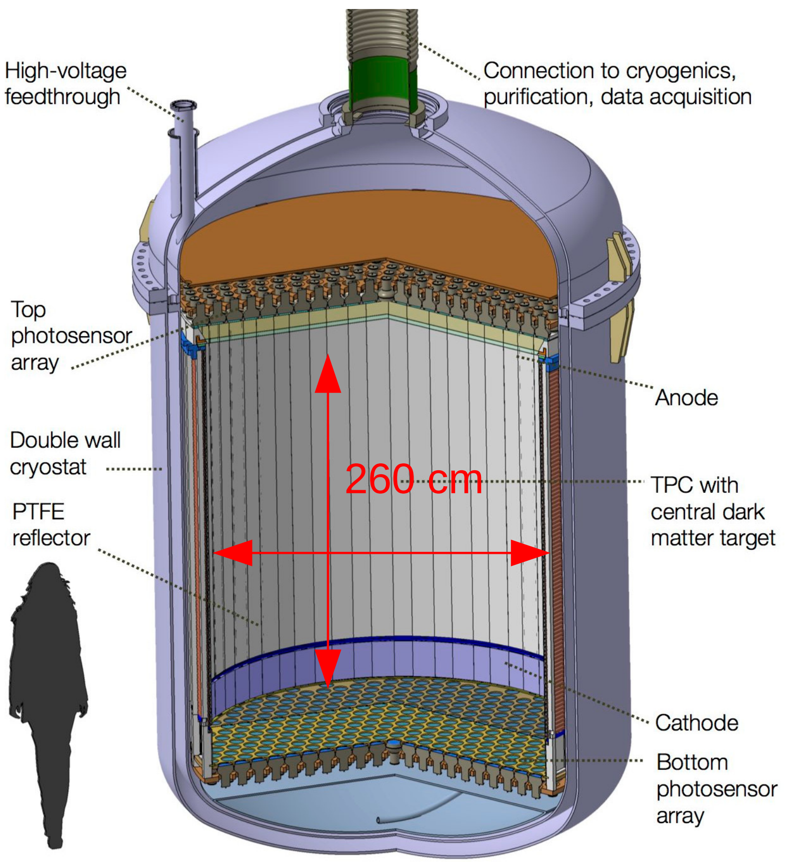
200 t×y

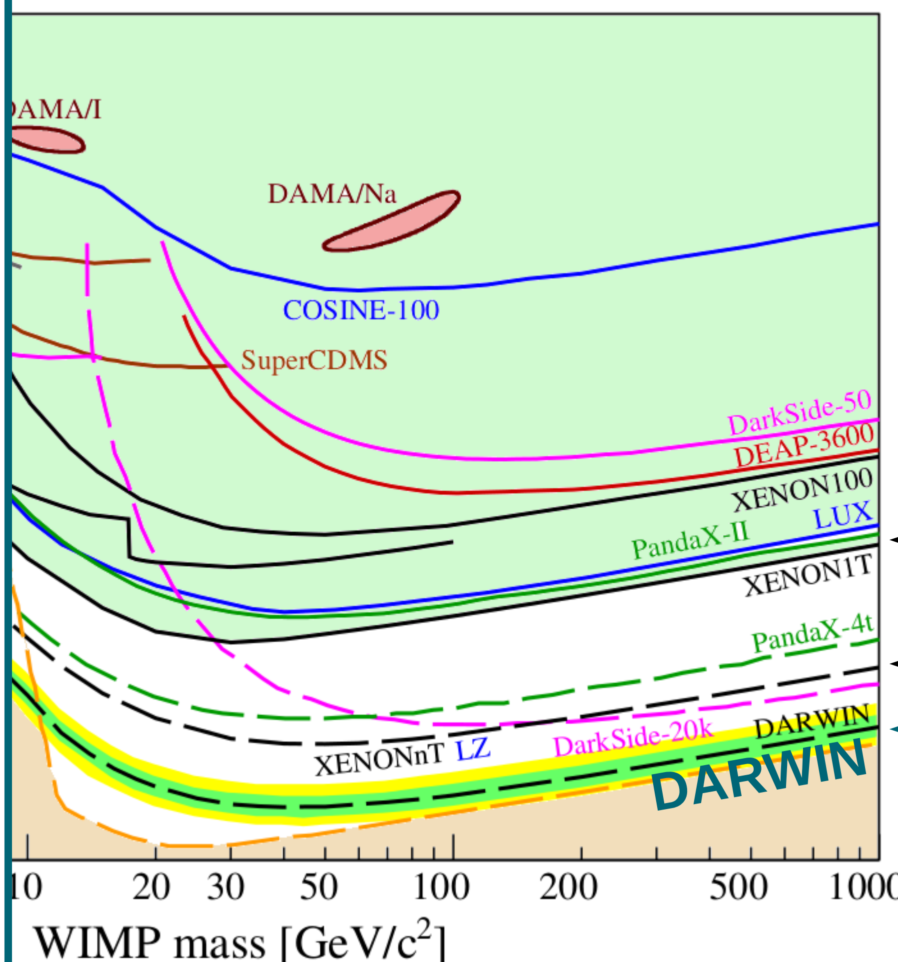
DARWIN The **ultimate** WIMP Detector

LXe-based

darwin-observatory.org

Baseline scenario
~50t total LXe mass
~40 t LXe TPC
~30 t fiducial mass



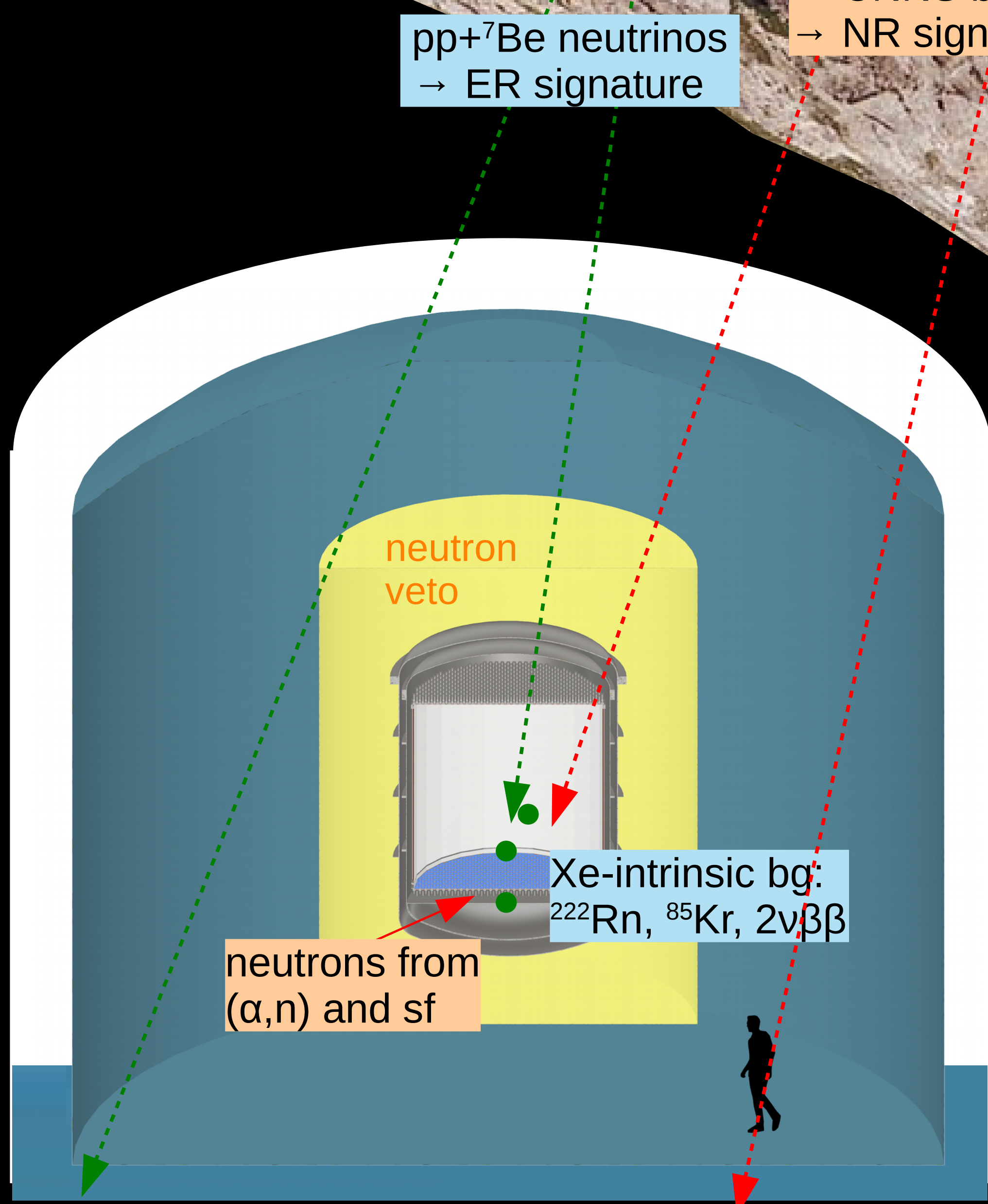


Exposure
1 t×y
20 t×y
200 t×y

DARWIN Collaboration

- international collaboration, 26 groups, ~160 scientists
  → continuously growing
- most XENON plus new groups
- endorsed by several national and international agencies

DARWIN Backgrounds

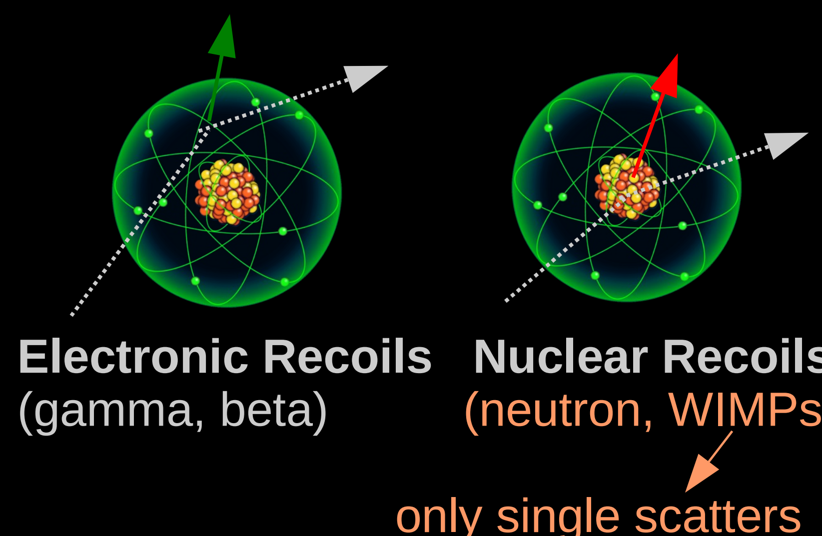


Remaining background sources:

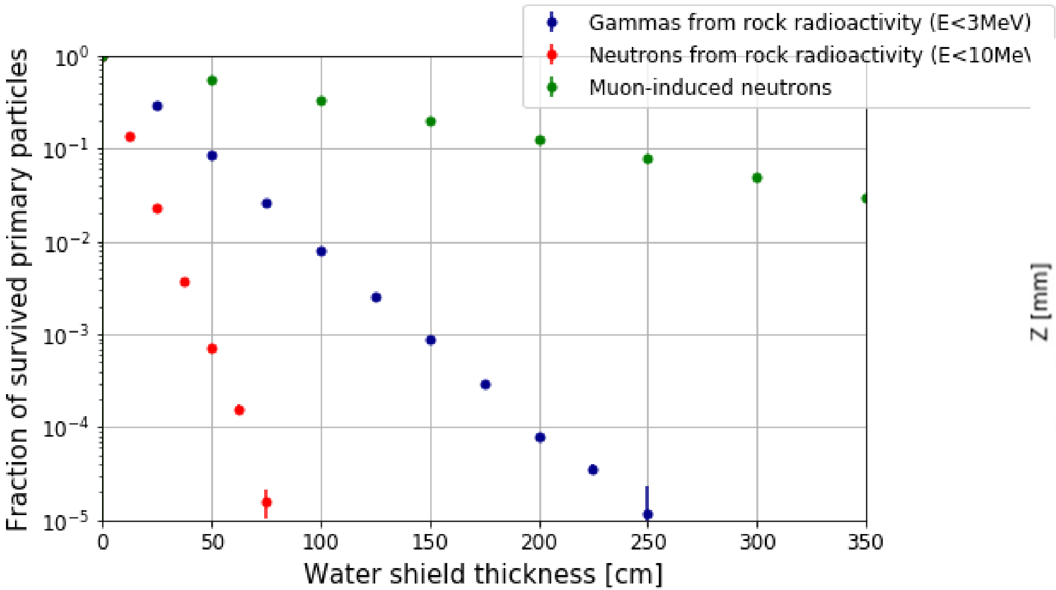
– Neutrinos (→ ERs and NRs)
– Detector materials (→ n)
– Xe-intrinsic isotopes (→ e^{-})

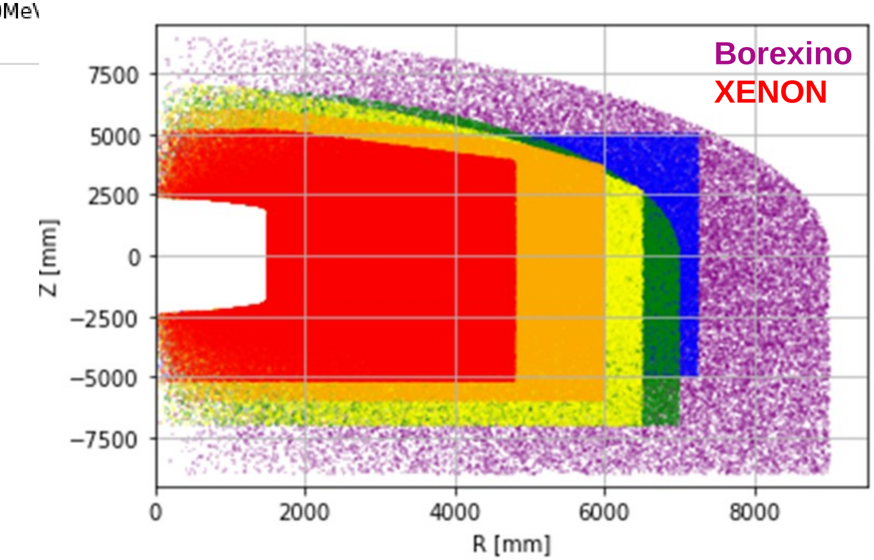
(assume negligible
μ-induced background)

JCAP 10, 016 (2015)



Water Shield @ LNGS ✓





Full MC Simulation for 3600 mwe

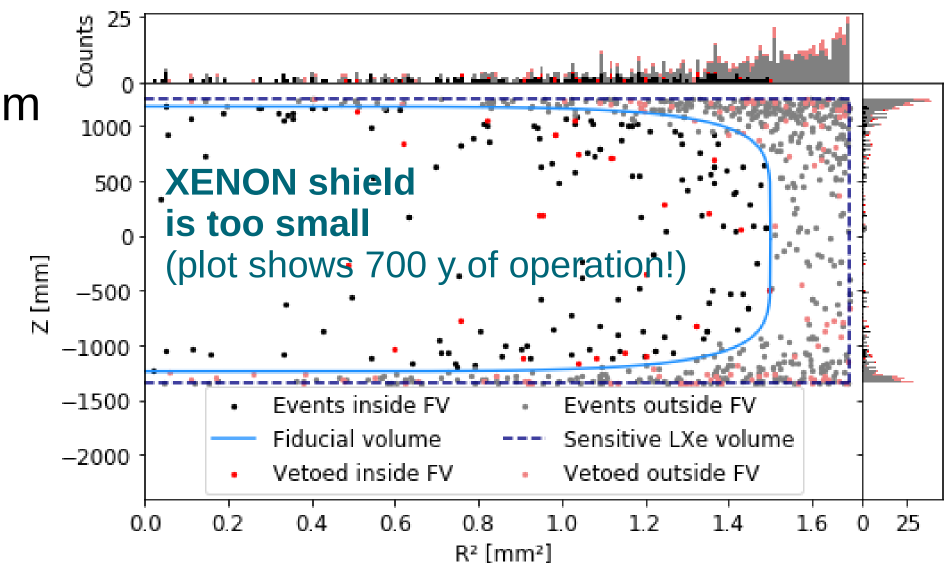
– external γ, n background irrelevant after >2.5m

– critical: µ-induced neutrons of high energy

– studied several water shield geometries between XENON and Borexino tank

– **12m tank: ~0.4 n/(200 t×y)**
Borexino: <0.05 n/(200 t×y)

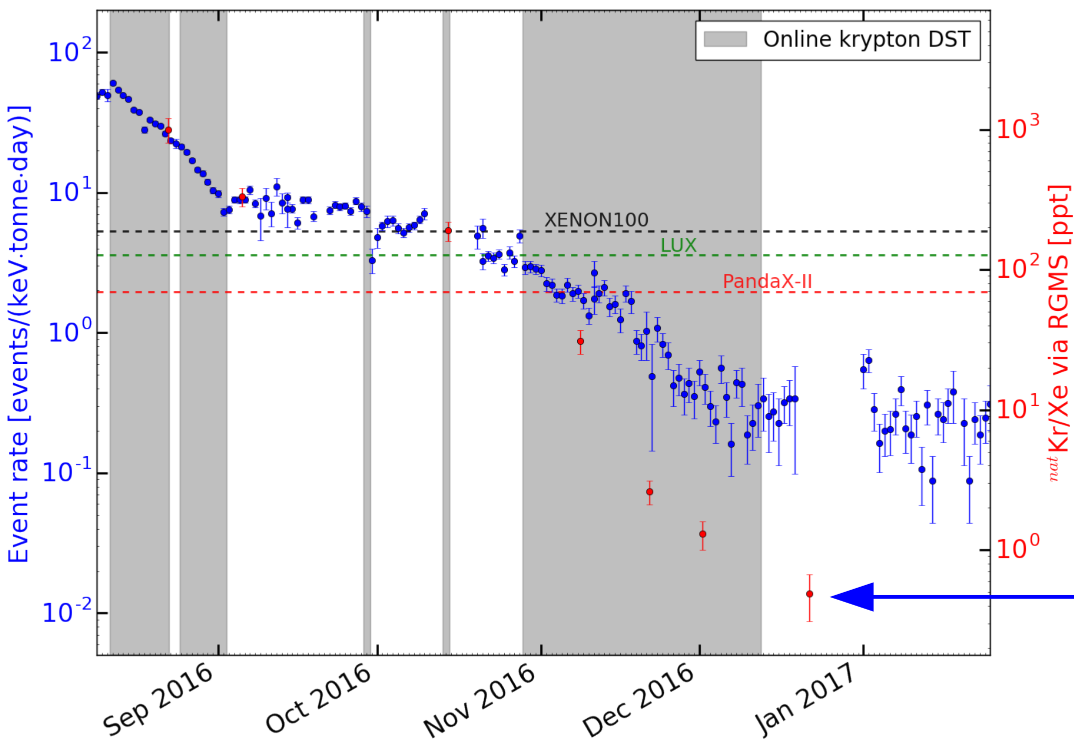
– Gd-loaded water further reduces numbers



LXe: Krypton Removal

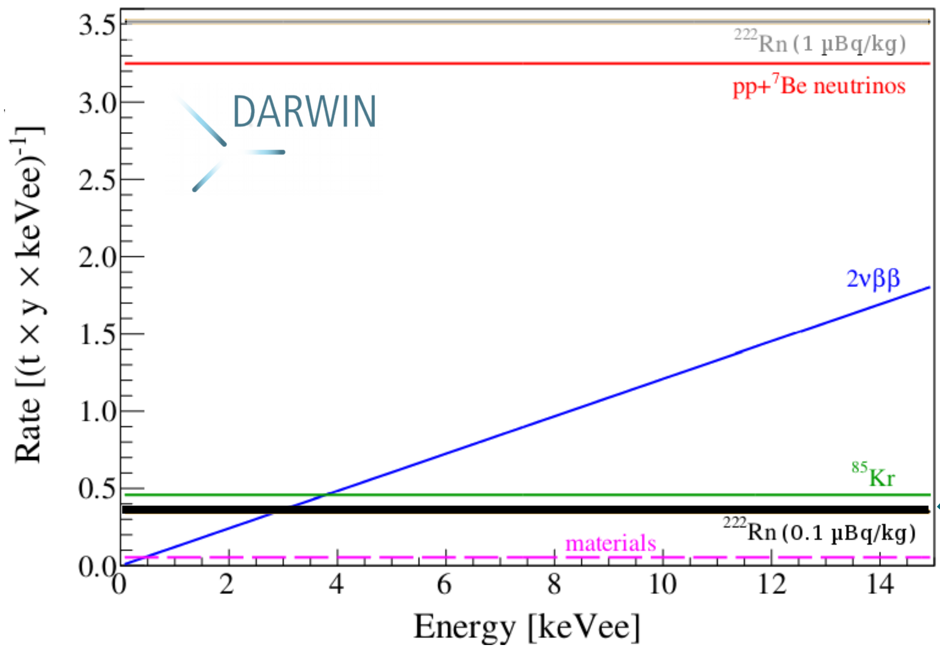
– DARWIN goal: **0.03 ppt** (~ 0.1 × pp-neutrinos)
– removal by cryogenic distillation

XENON1T: distillation column *EPJ. C 77, 275 (2017)*
^{nat}Kr/Xe = (0.6±0.1) ppt achieved
by novel online distillation
→ lowest value in LXe experiments ever



XENON1T column has produced
gas sample **<0.026 ppt** = 2.6×10^{-14} (90% CL)
→ **DARWIN goal achieved**

LXe: Radon Background



DARWIN goal:
ER background dominated by solar neutrinos

^{222}Rn concentration
factor ~100 below XENON1T
^{222}Rn atoms in target
factor ~5 below XENON1T

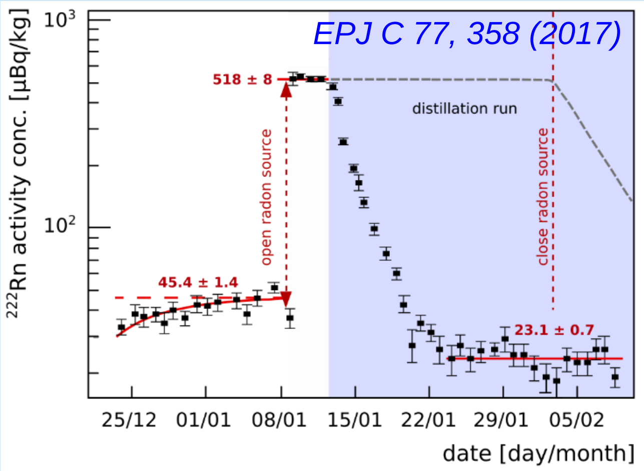
→ **main background challenge**

Strategy DARWIN

– avoid Rn emanation by
→ optimal material production
→ material selection
→ surface treatment
→ optimized detector design

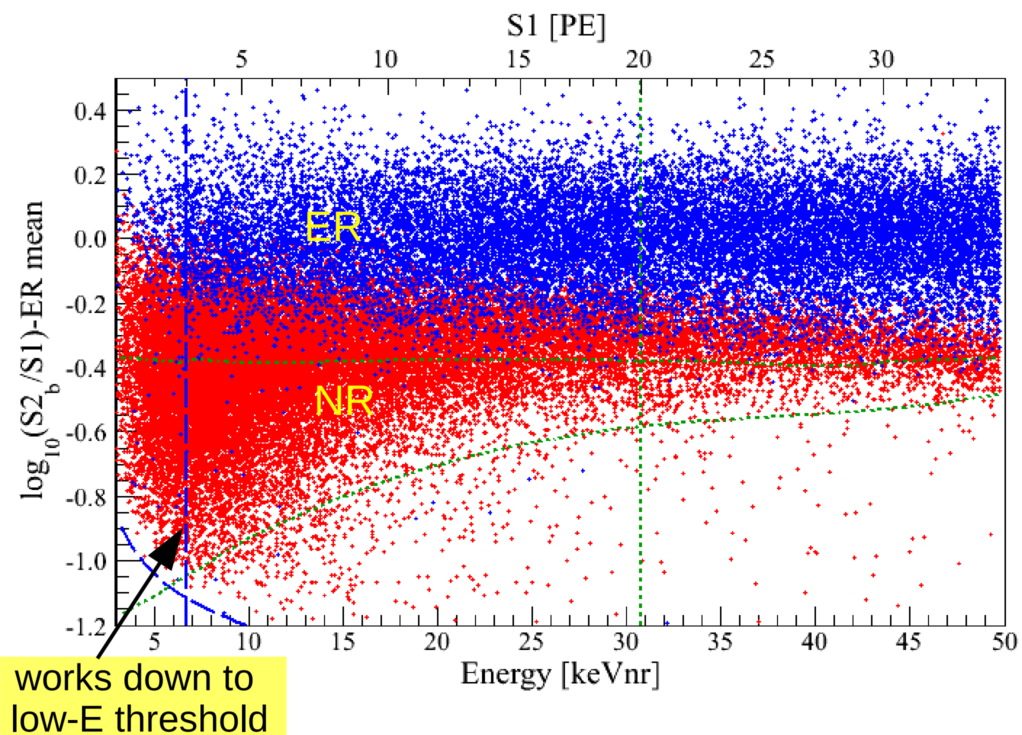
– **active Rn removal via cryogenic distillation**

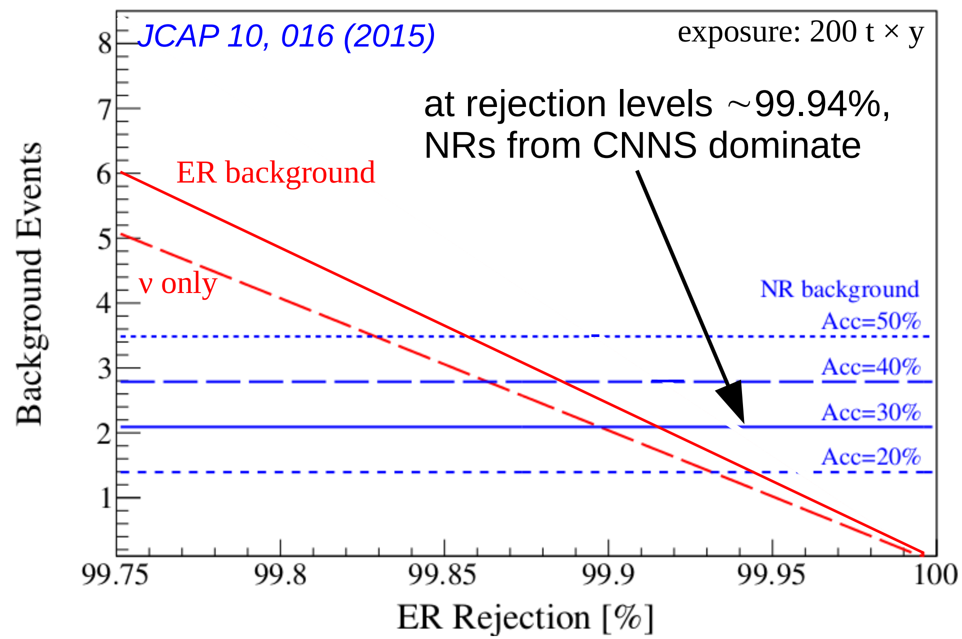
XENON1T distillation column installed @ XENON100
→ demonstrated **reduction factor >27** (@ 95% CL)
→ dedicated column developed for XENONnT



ER Background Rejection

DARWIN





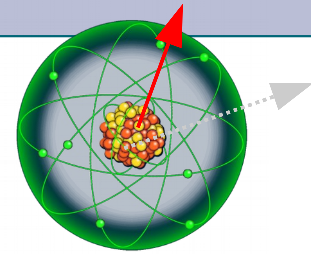
Charge-Light-Ratio (S2/S1):
Signal partition in light/charge depends on d*E*/d*x*
→ the interaction type

→ high light yield should improve rejection level

	E_{drift} [kV/cm]	LY @ 122 keV [PE/keV]	NR acc [%]	ER rej [%]
XENON100	0.53	3.8	40	2.5×10^{-3}
XENON100	0.53	3.8	30	1×10^{-3}
LUX	0.18	8.8	50	$1..10\times10^{-3}$
XENON1T	0.125	~7.5	50	2.5×10^{-3}
ZEPLIN-III	3.4	4.2	50	**1.3×10^{-4}**
K. Ni *APP14*	0.2-0.7	10	50	**$<1\times10^{-4}$**

DARWIN: Science Channels

Nuclear Recoil Interactions



WIMP dark matter *JCAP 10, 016 (2015)*

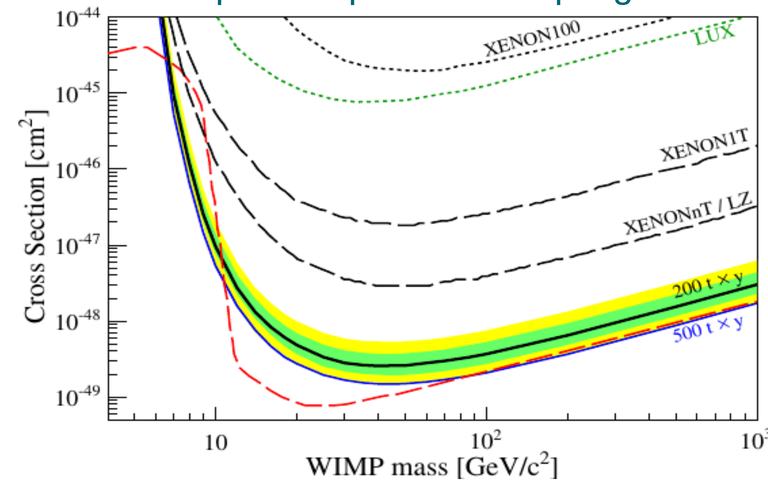
– **spin-independent** (S1-S2, charge-only)

– **spin-dependent** *Phys.Dark Univ. 9-10, 51 (2015)*

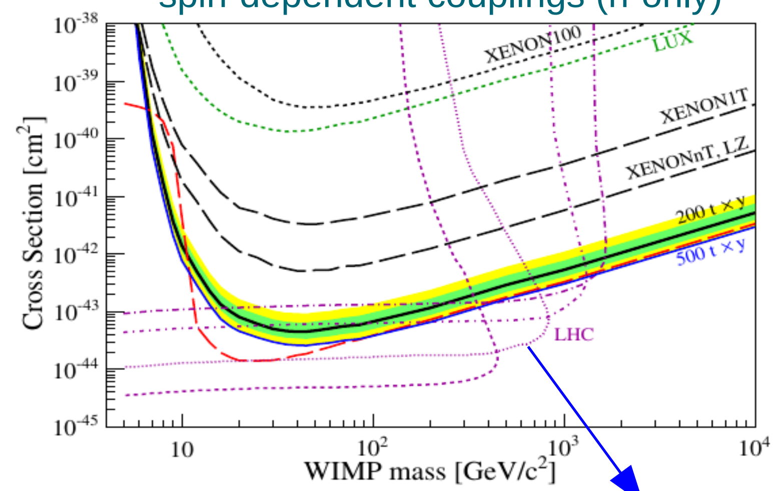
→ complementary with LHC, indirect det.

– various inelastic models, most EFT couplings

spin-*in*dependent couplings



spin-dependent couplings (n-only)



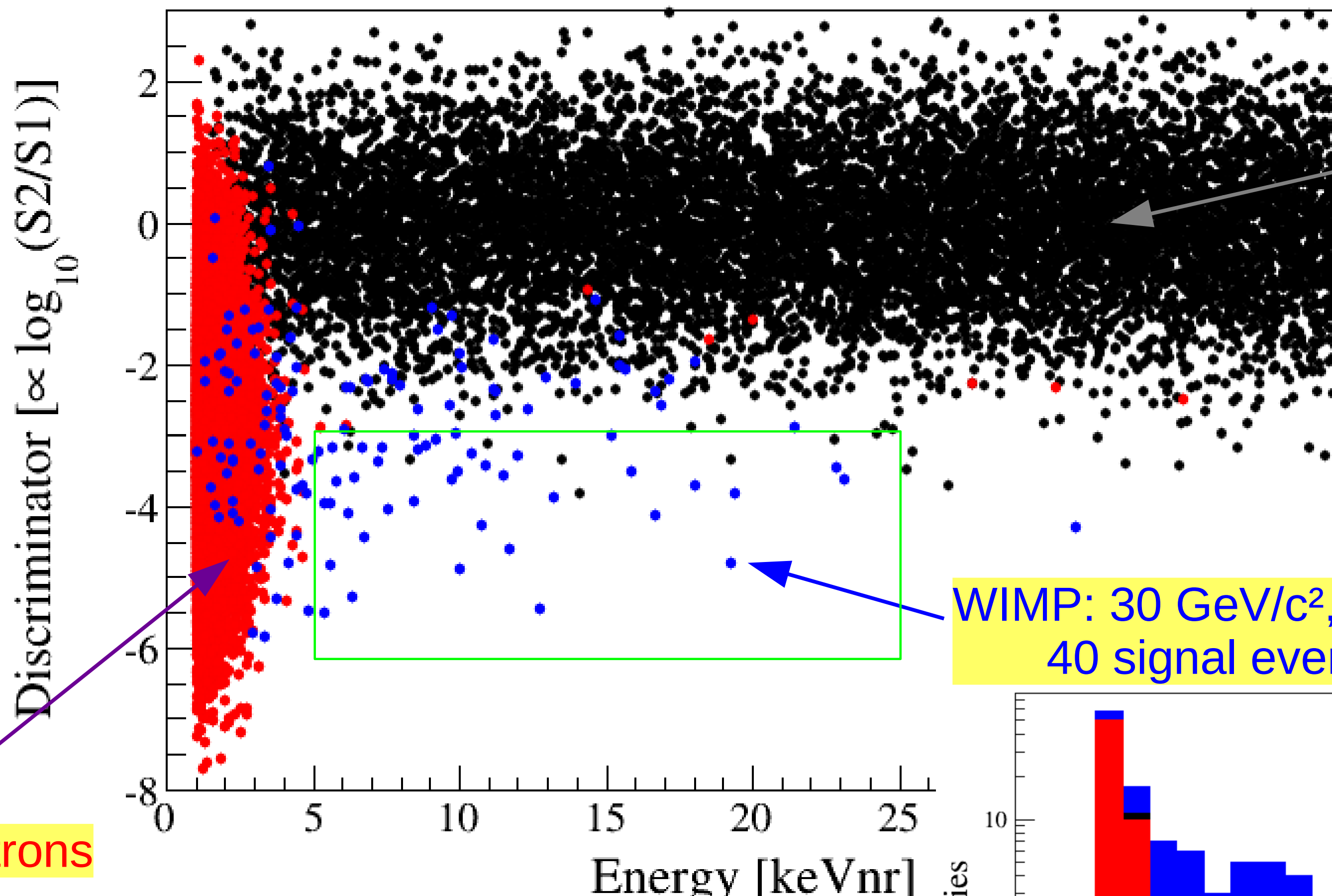
excellent complementarity to LHC searches

p-only complementary to indirect searches

WIMP Detection

DARWIN

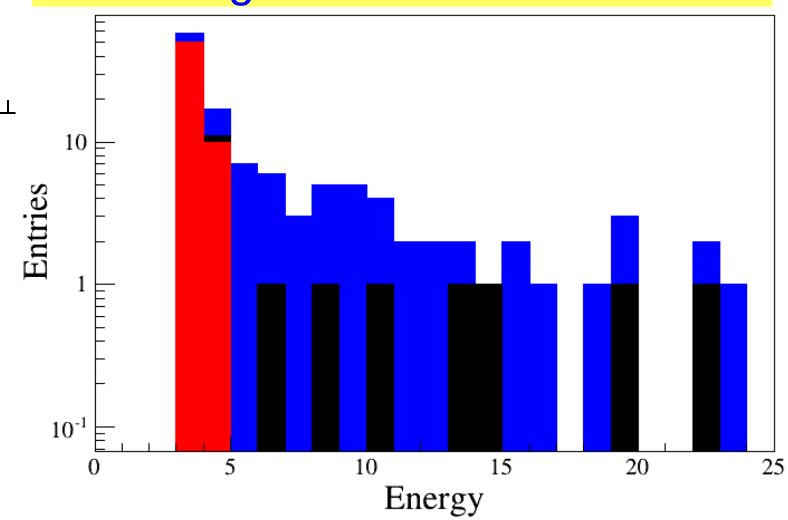
Backgrounds from JCAP 10, 016 (2015)



solar neutrinos, ^{85}Kr, ^{222}Rn, $2\nu\beta\beta$, materials

WIMP: 30 GeV/c², $\sigma = 2\times10^{-48}$ cm²
40 signal events in box

CNNS+neutrons



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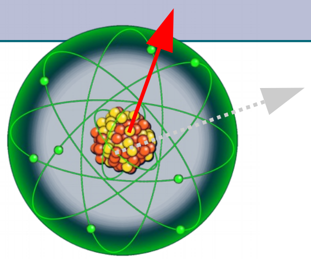

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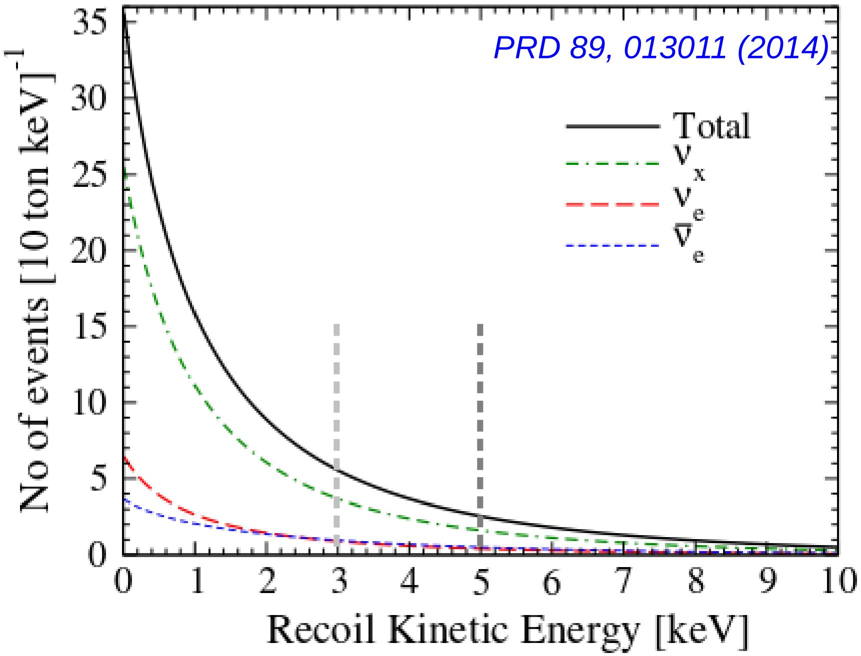
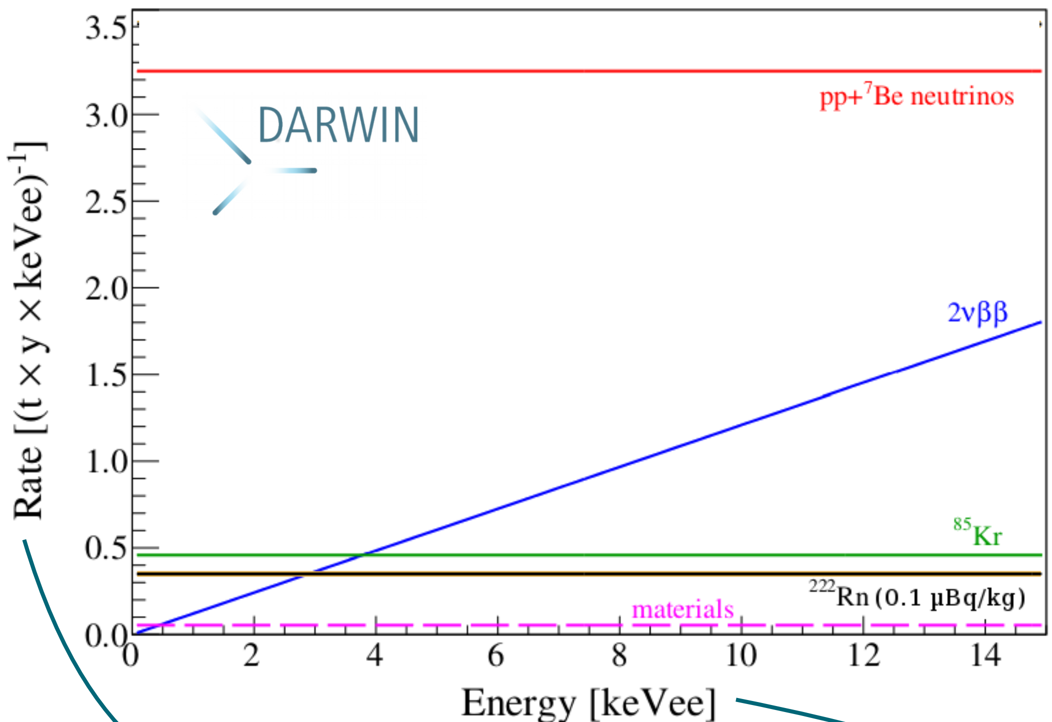
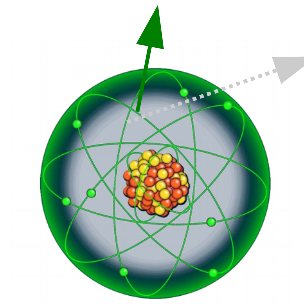
– various inelastic models, most EFT couplings

Coherent neutrino-nucleon scattering (CNNS)
– ^{8}B neutrinos (low E), atmospheric (high E)
– **supernova neutrinos** *JCAP 1611, 017 (2016)*
PRD 89, 013011 (2014), PRD 94, 103009 (2016)



DARWIN ER Background





DARWIN = A low-background, low-threshold observatory for astroparticle physics

DARWIN: Science Channels

DARWIN

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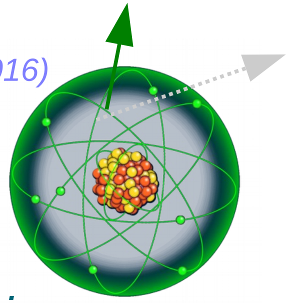
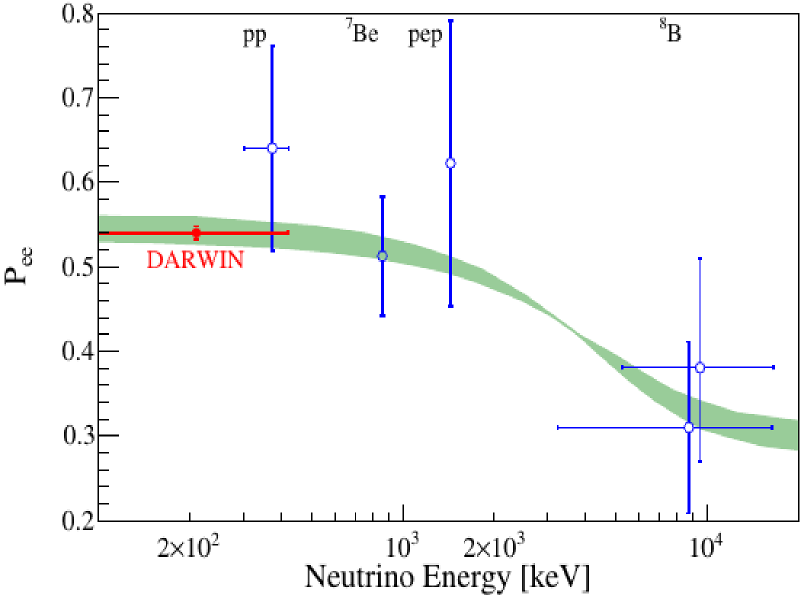


Electronic Recoil Interactions

Non-WIMP dark matter and neutrino physics
– axions, ALPs *JCAP 1611, 017 (2016)*
– sterile neutrinos *JCAP 01, 044 (2014)*
– **pp, ^{7}Be: precision flux measurements**
– CNO neutrinos with ^{136}Xe-depleted Xe *PRD 99, 043006 (2019)*



30t target mass, 2-30 keV window
→ 2850 neutrinos per year (89% pp)
→ **real-time solar neutrino experiment**
→ 1% statistical precision on pp-flux (→P_{ee}) with 100 t×y

DARWIN: Science Channels

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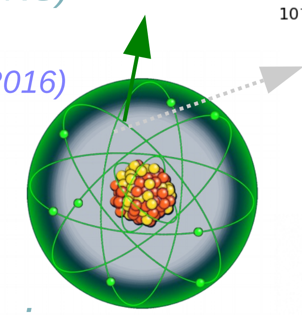

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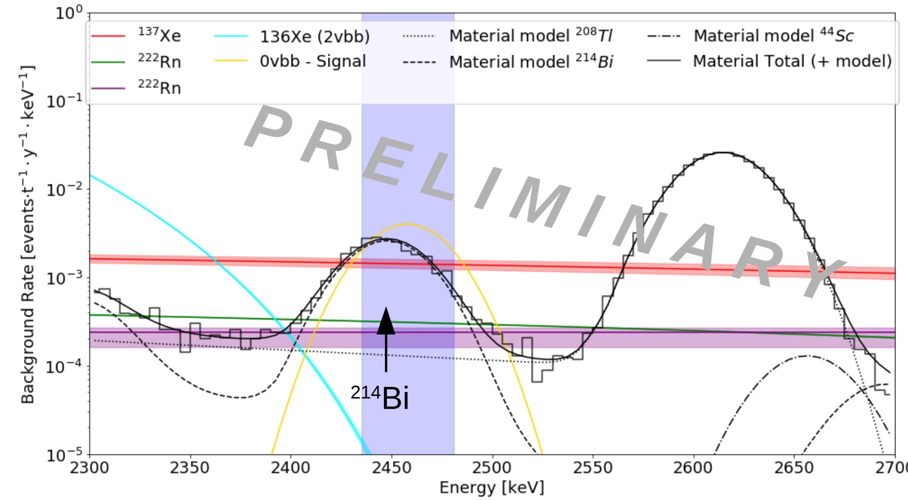
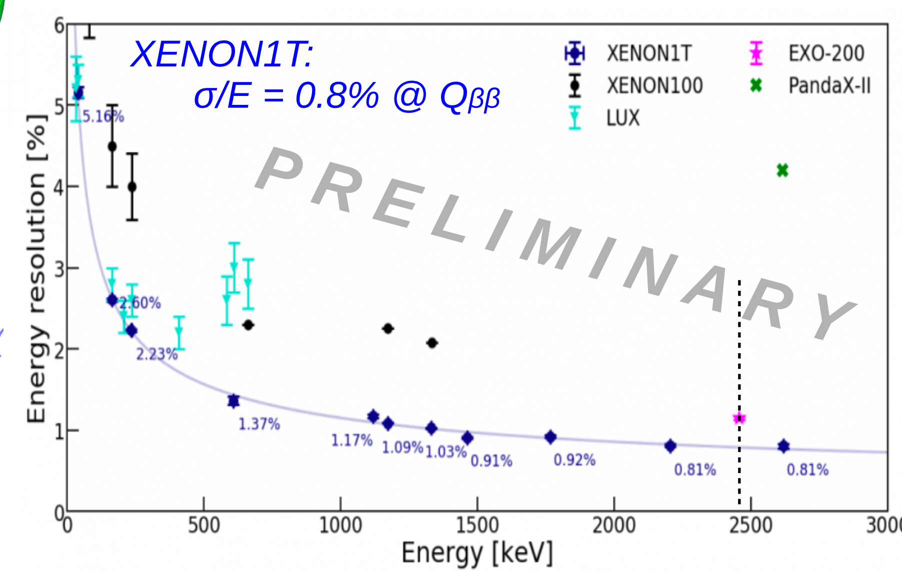
Rare nuclear events
– **$0\nu\beta\beta$ (^{136}Xe)**, $0\nu EC$ (^{134}Xe), ...
JCAP 01, 044 (2014)



Sensitivity: $T_{1/2} \gtrsim 2\times10^{27}$ y @ 90% CL



Neutron Background Studies

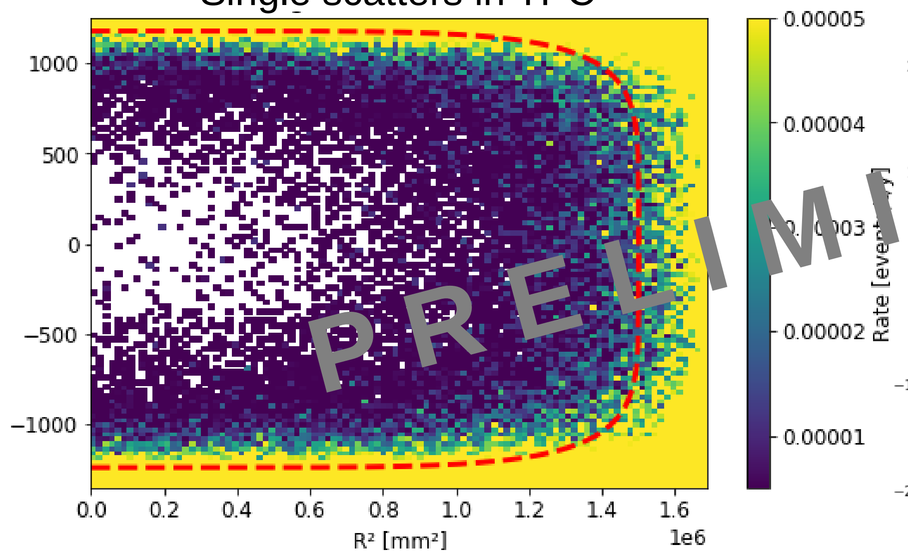
DARWIN

– define material and design requirements

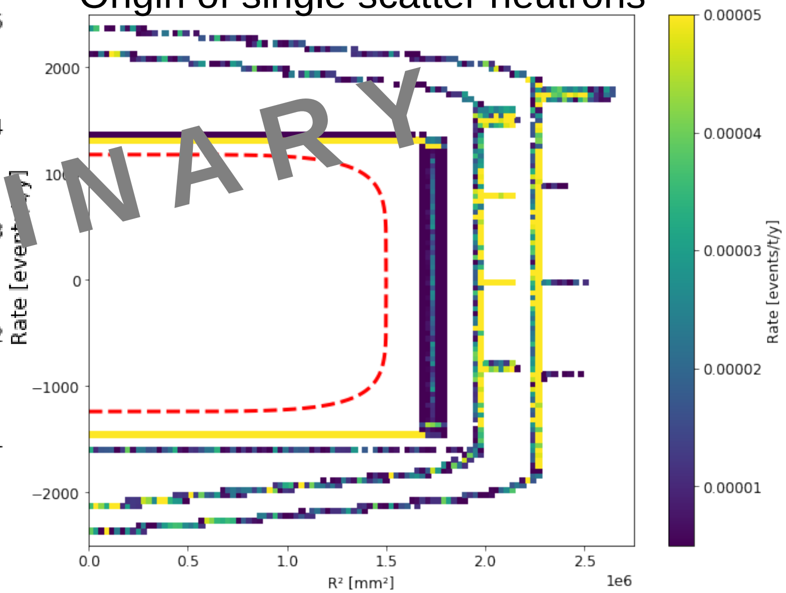
		Activity					
Material	**Unit**	**^{238}U**	**^{226}Ra**	**^{235}U**	**^{232}Th**	**^{228}Th**	**Ref.**
Titanium	mBq/kg	< 1.6	< 0.09	< 0.02	0.28	0.23	LZ
PTFE	mBq/kg	< 5e-3	< 5e-3	< 2e-4	<1.4e-3	<1.4e-3	EXO
Copper	mBq/kg	< 1	< 0.035	< 0.18	< 0.033	< 0.026	XENON
PMT	mBq/unit	8	0.6	0.37	0.7	0.6	XENON
PMT bases	mBq/unit	0.82	0.32	0.071	0.20	0.15	XENON

Start with realized radioactivity values

Single scatters in TPC



Origin of single scatter neutrons



→ investigate Gd-based water Cherenkov **neutron veto** as well

DARWIN: 40t LXe TPC

JCAP 11, 017 (2016)

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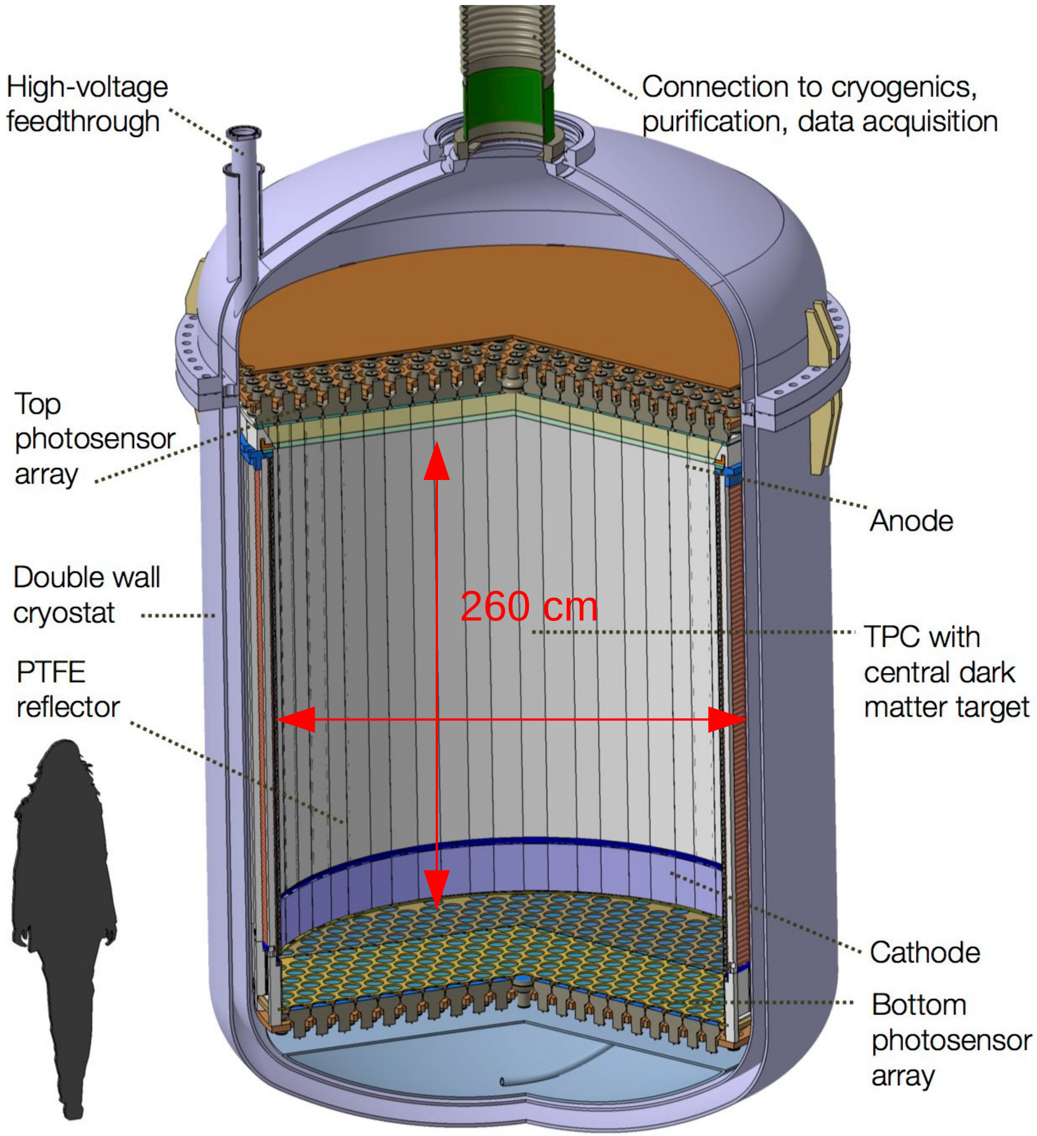
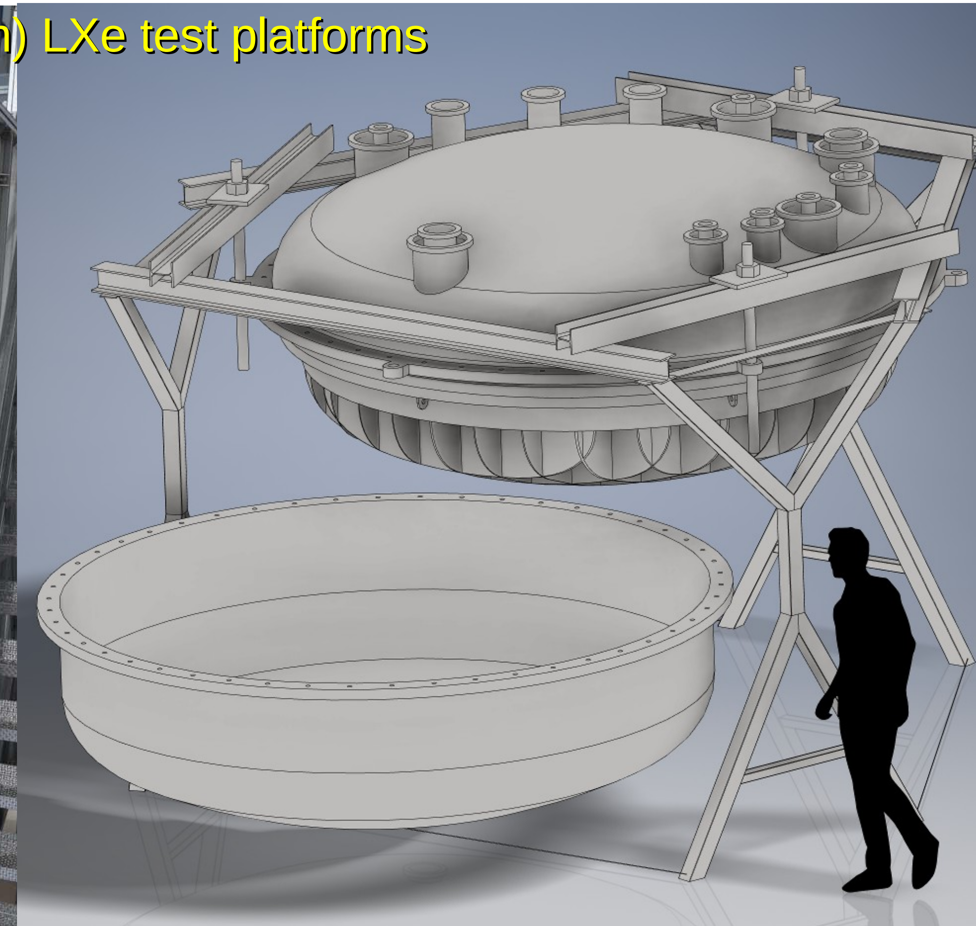


Challenges

- Size
  - → electron drift (HV)
  - → diameter (TPC electrodes)
  - → mass (LXe purification)
  - → dimensions (radioactivity)
  - → detector response (calibration, corrections)
  - → Xe gas procurement
- Backgrounds
  - → ^{222}Rn
  - → (α,n) neutrons
  - → shielding (n-tagging)
  - → ER rejection
- Photosensors
  - → high light yield (QE)
  - → low radioactivity
  - → long-term stability
- etc etc **R&D needed**

DARWIN: R&D Examples



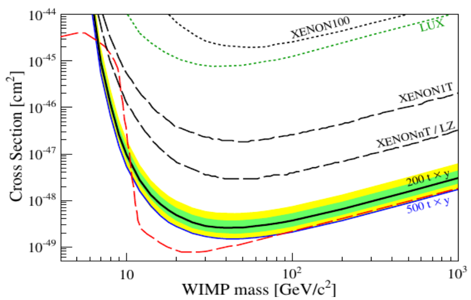
– R&D within XENON collaboration ++
– **two ERC projects**
ULTIMATE (Freiburg)
Xenoscope (Zürich)

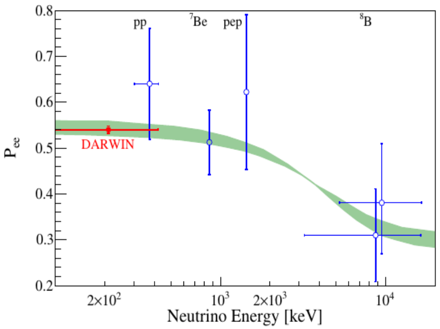
DARWIN: Exciting Opportunities

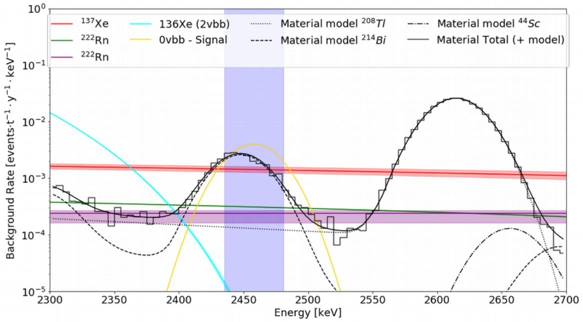
DARWIN: much more than

The ultimate Dark Matter Detector

→ The low-background, low-threshold Astroparticle Physics Observatory







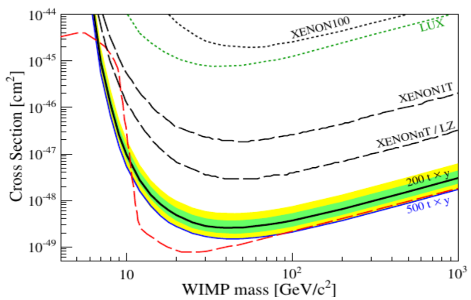
DARWIN: Exciting Opportunities

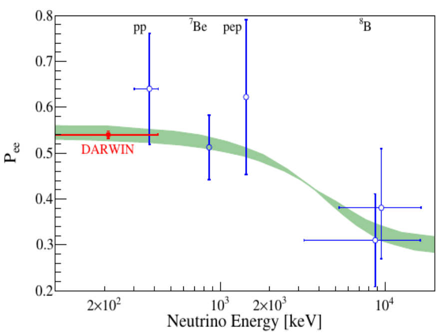
DARWIN
darwin-observatory.org

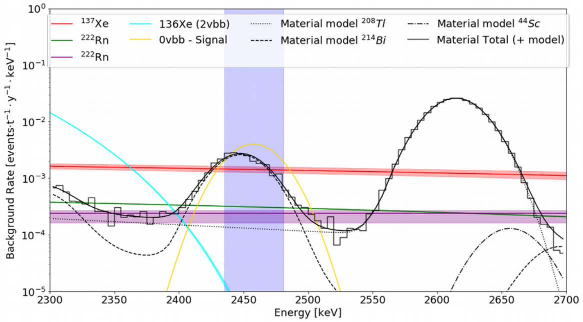
DARWIN: much more than

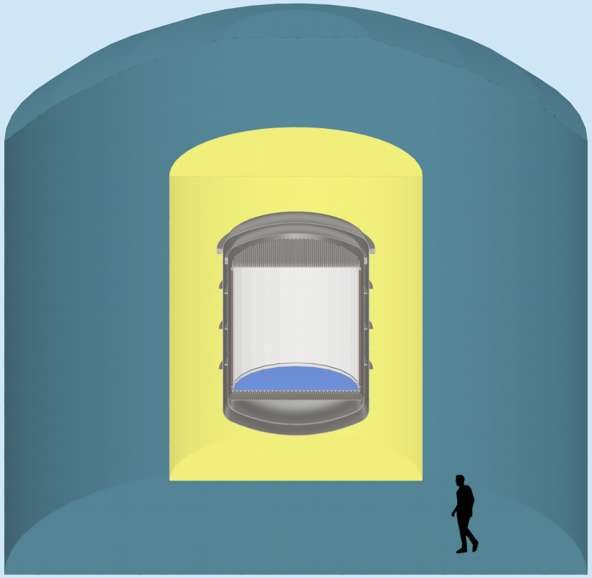
The ultimate Dark Matter Detector

→ The low-background, low-threshold Astroparticle Physics Observatory

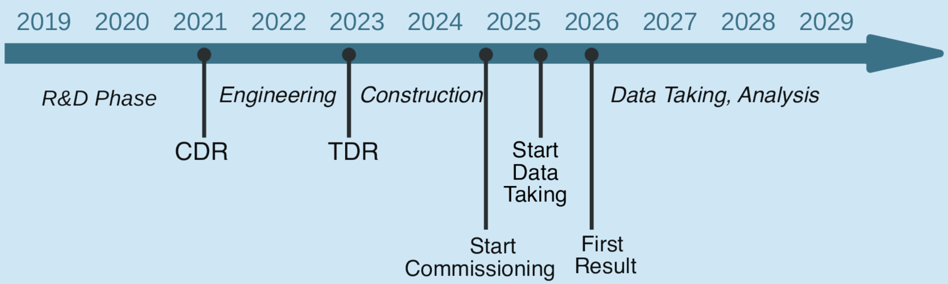








- **DARWIN can be done at LNGS**
  → need ≥12m water shield
- Timeline: R&D and construction parallel to XENONnT data taking



Backup

Dependence of Sensitivity

Reference WIMP mass = 40 GeV/c²

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