DARWIN

The Low-Background Low-Threshold Observatory

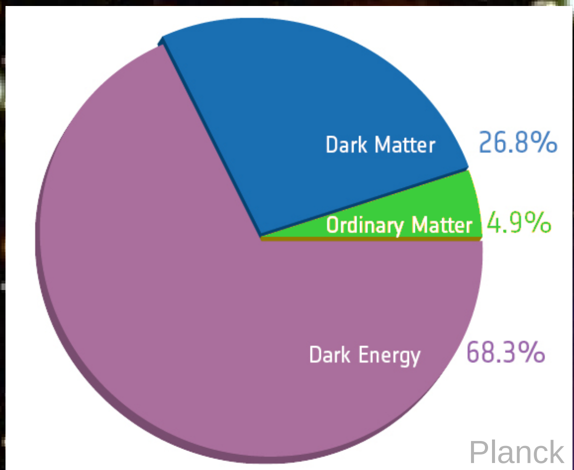
Marc Schumann *U Freiburg*

7. KAT-Strategietreffen, online, December 3, 2020

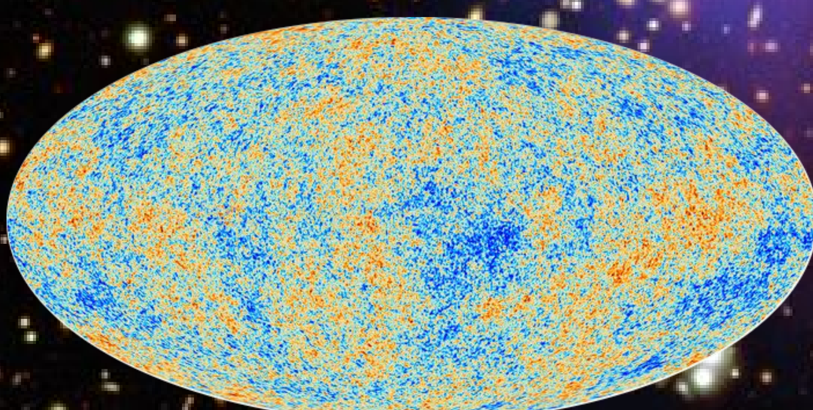
marc.schumann@physik.uni-freiburg.de
www.app.uni-freiburg.de

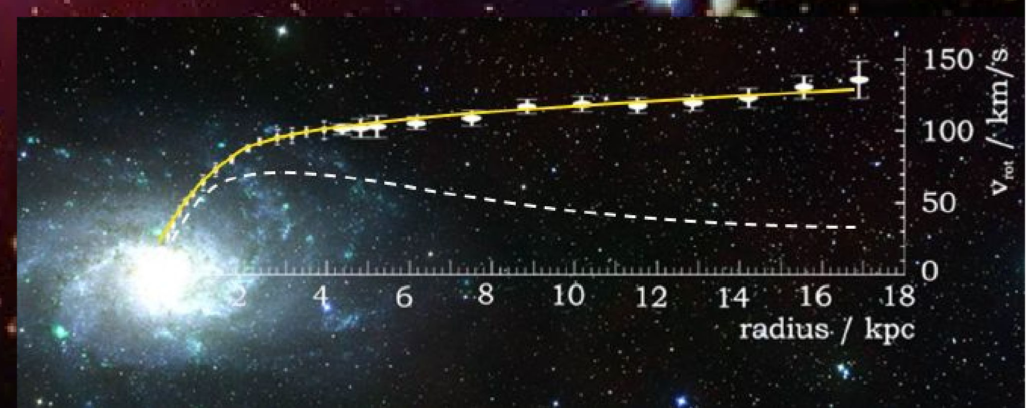
www.darwin-observatory.org

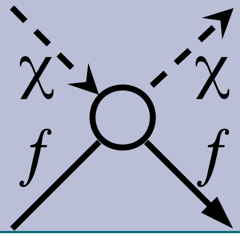
Dark Matter: (indirect) **Evidence**



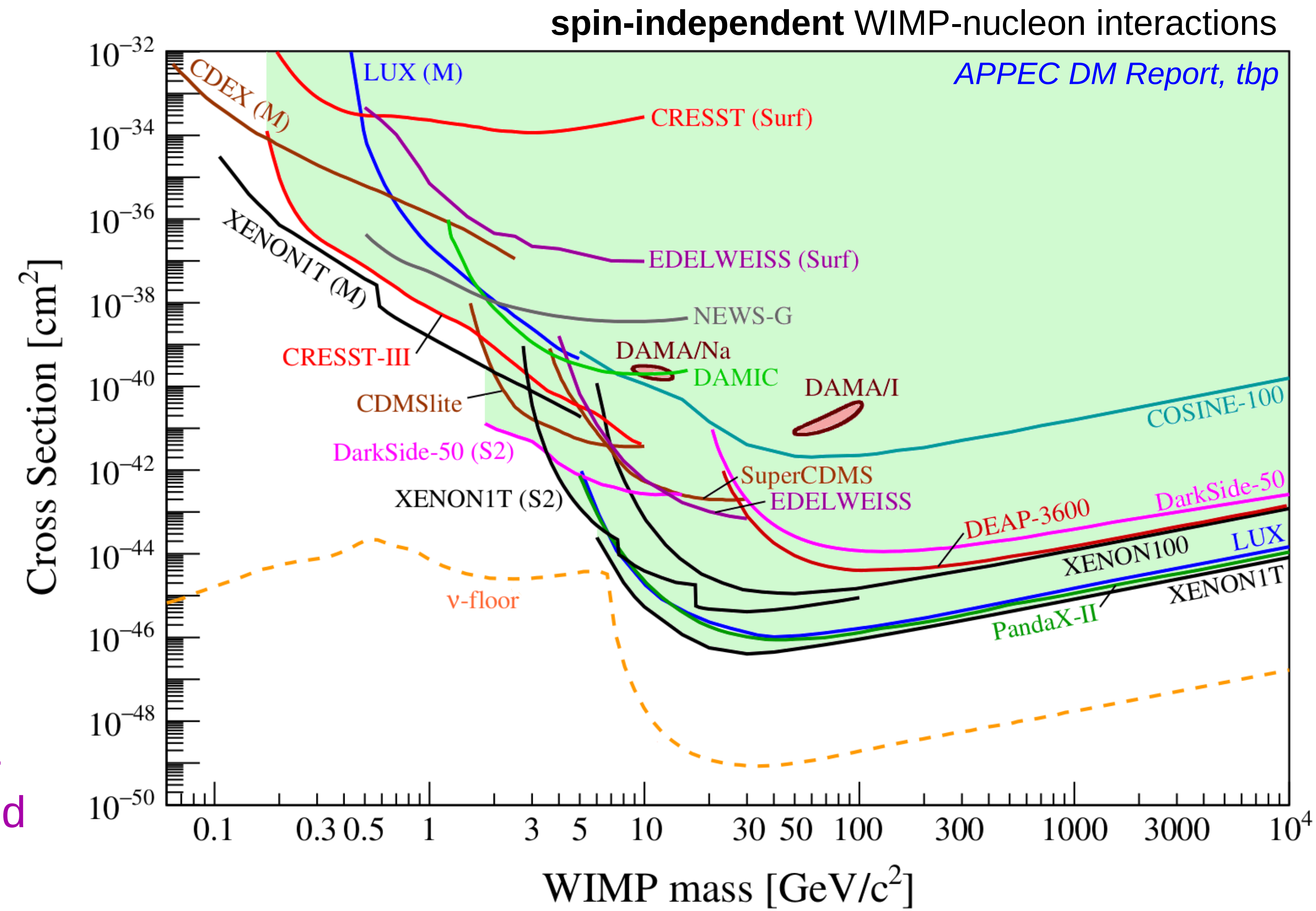
The astrophysical evidence for the existence of dark matter is a clear indication for physics beyond the Standard Model







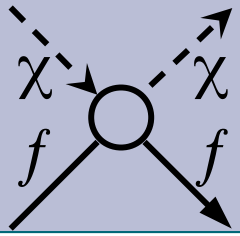
Direct Detection: Status



10^{14}

Exposure+
Background

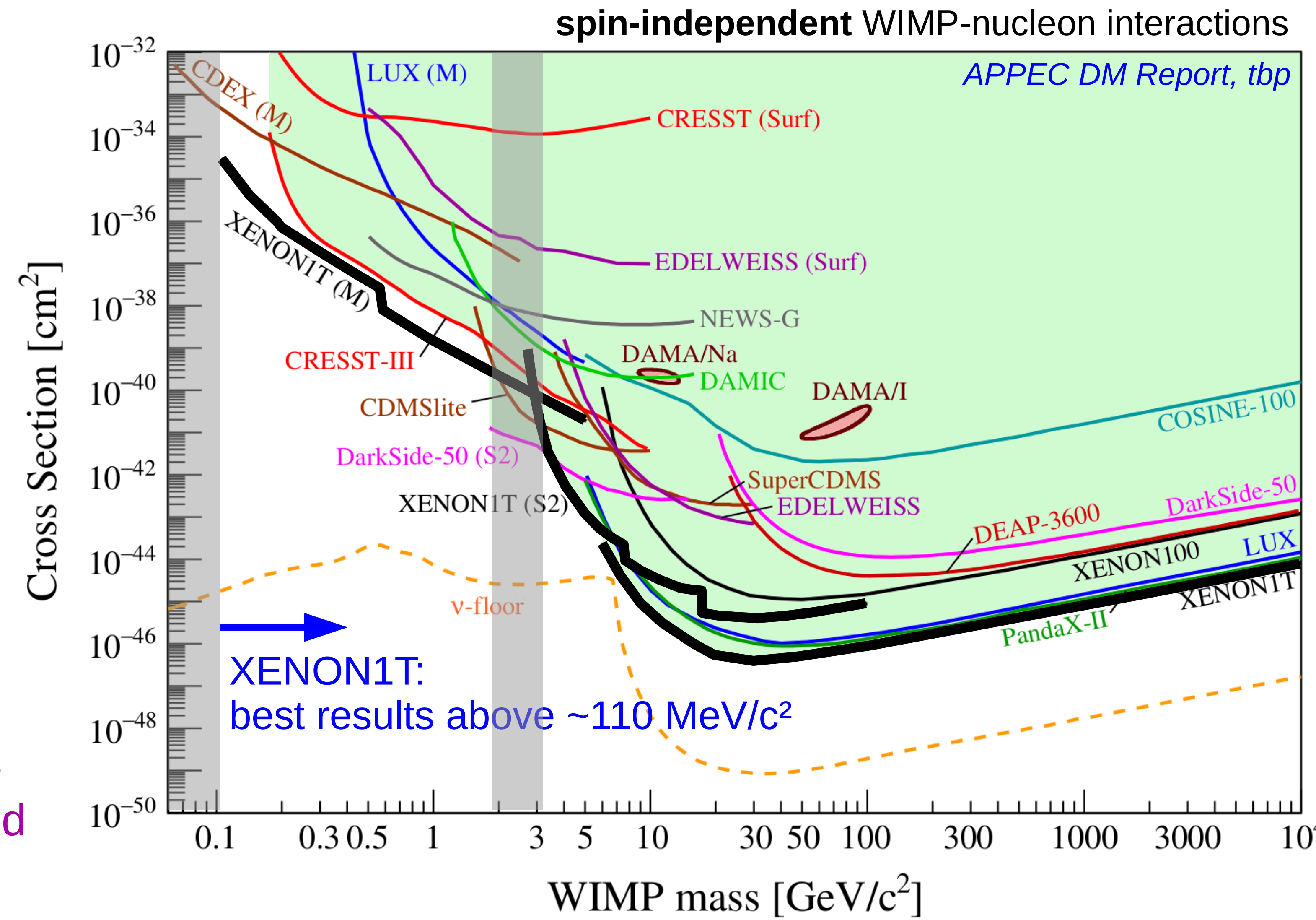
Threshold



Direct Detection: Status

DARWIN

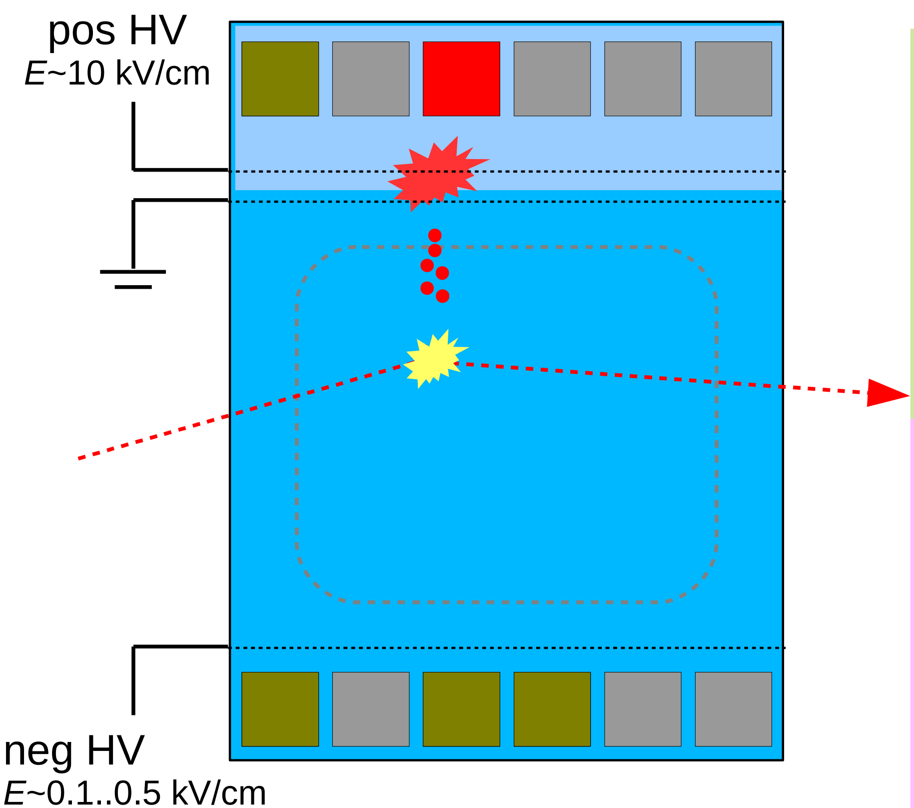
10^{14}



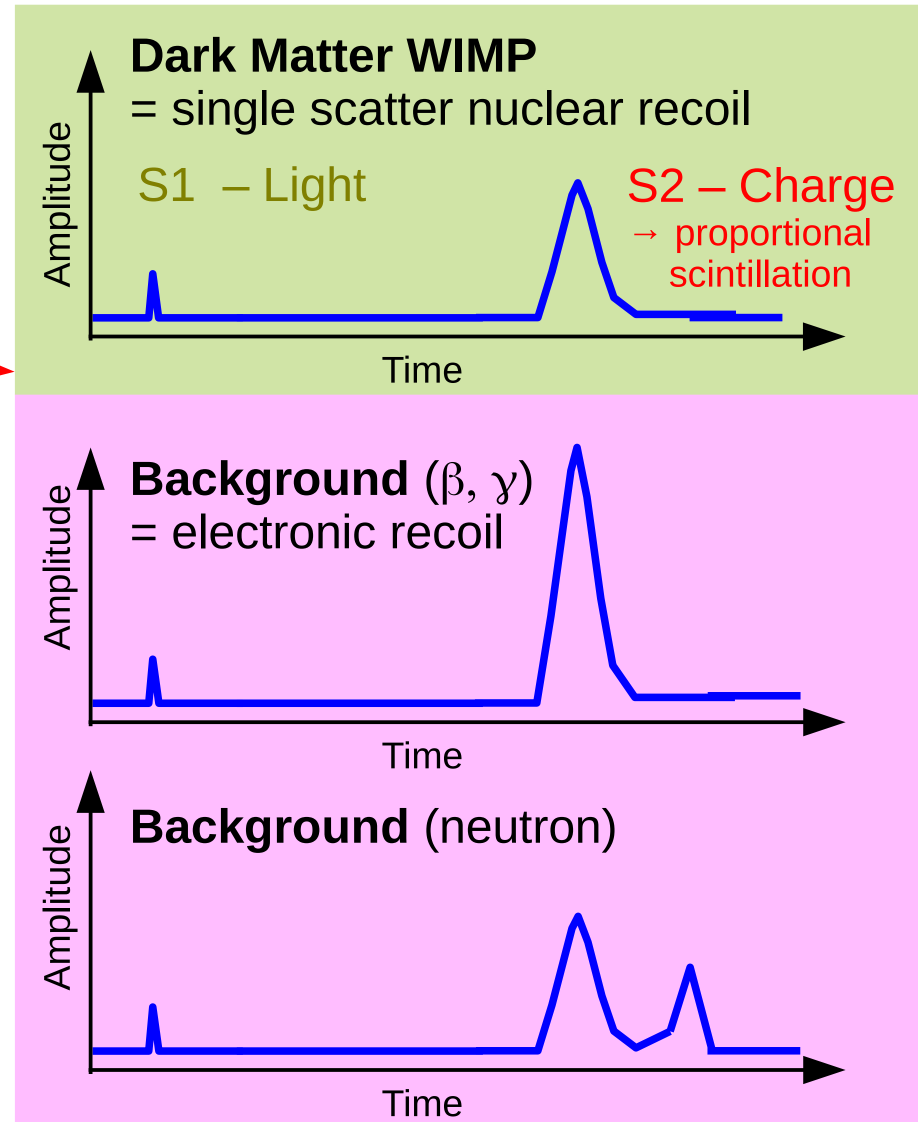
Exposure+
Background

Threshold

Dual-Phase LXe TPC

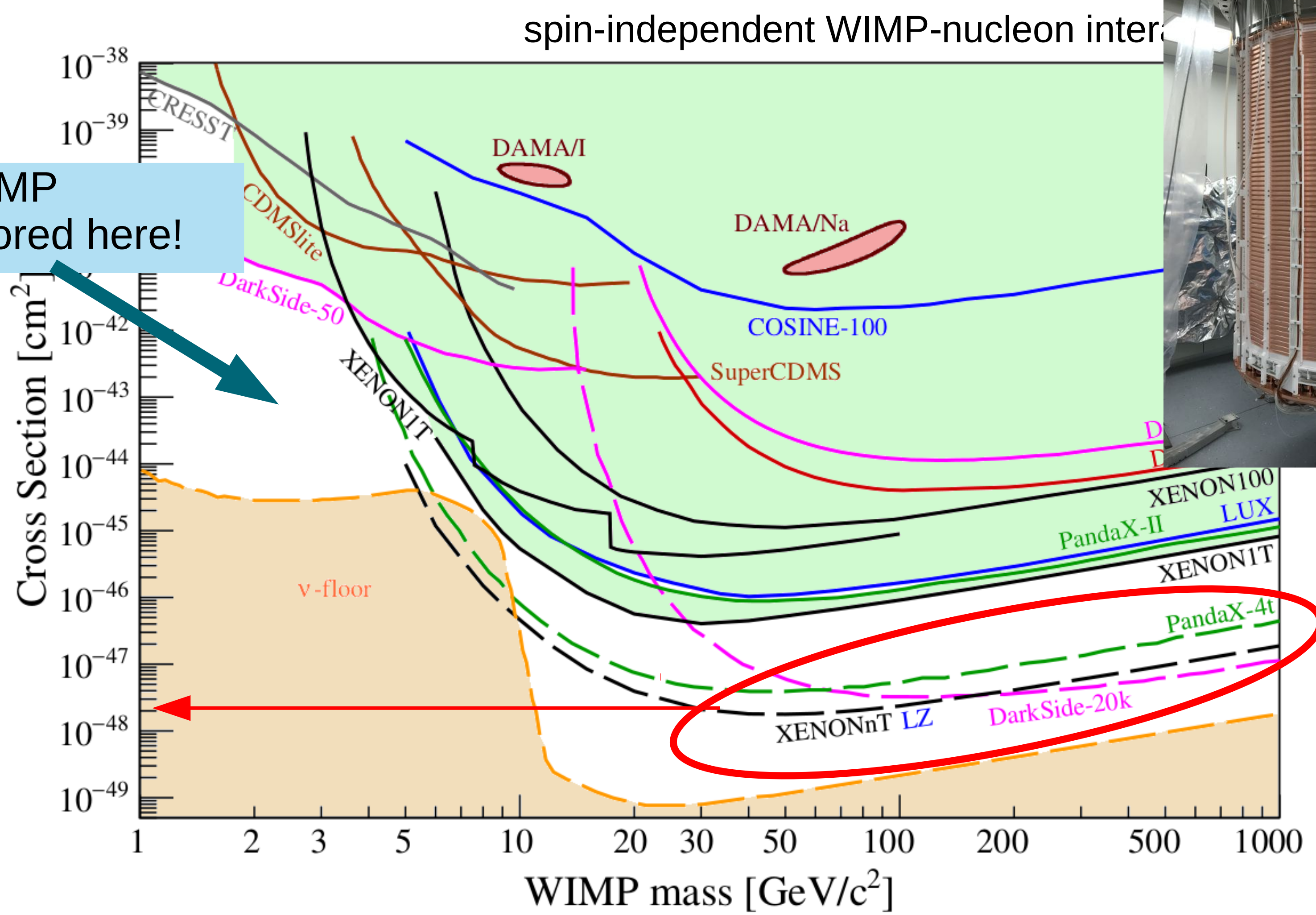


TPC = time projection chamber



- 3d position reconstruction
  → target fiducialization
  → multiple scatter rejection
- background rejection

Upcoming Projects



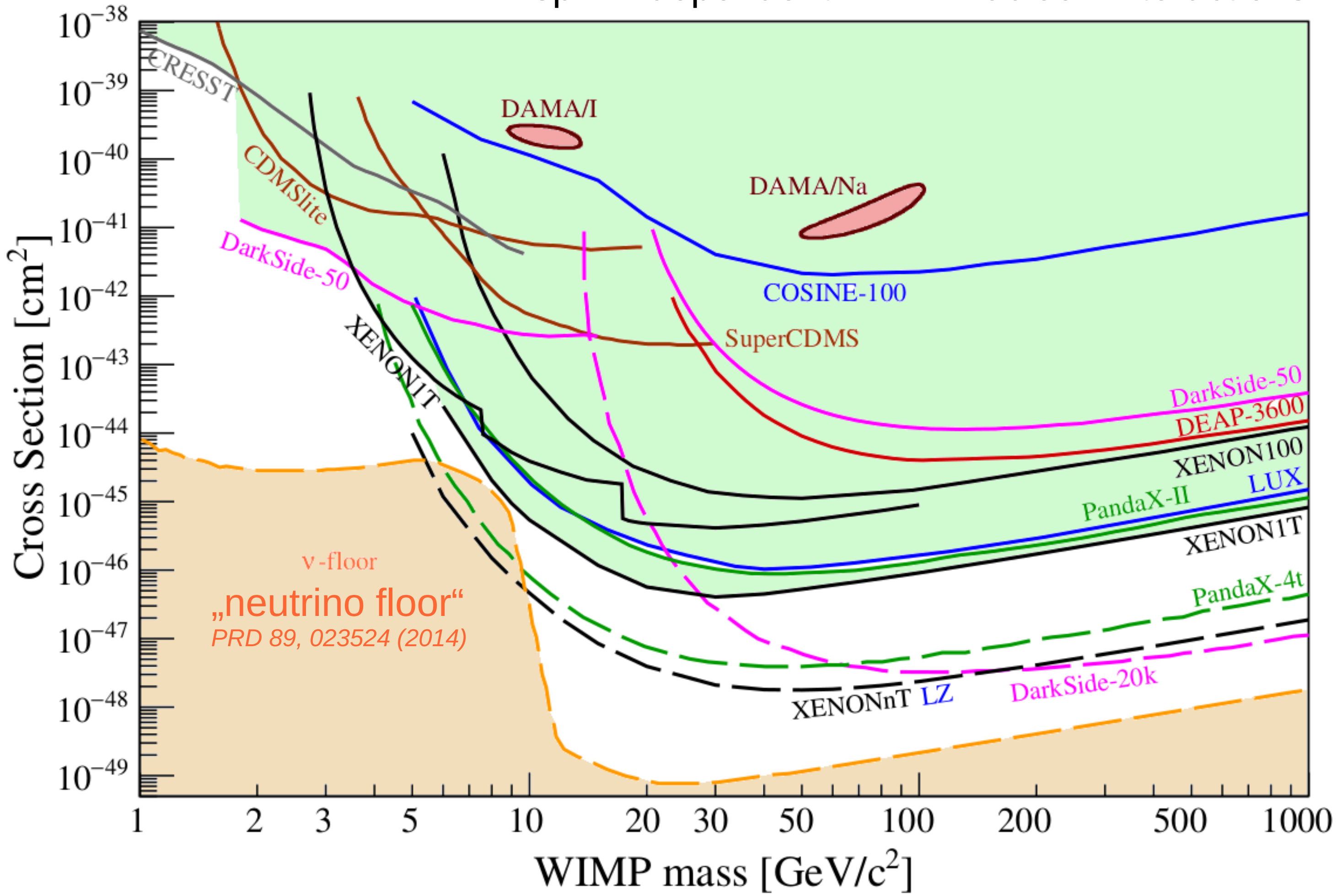
Low-mass WIMP searches ignored here!

JCAP 11, 031 (2020)

some results are missing...

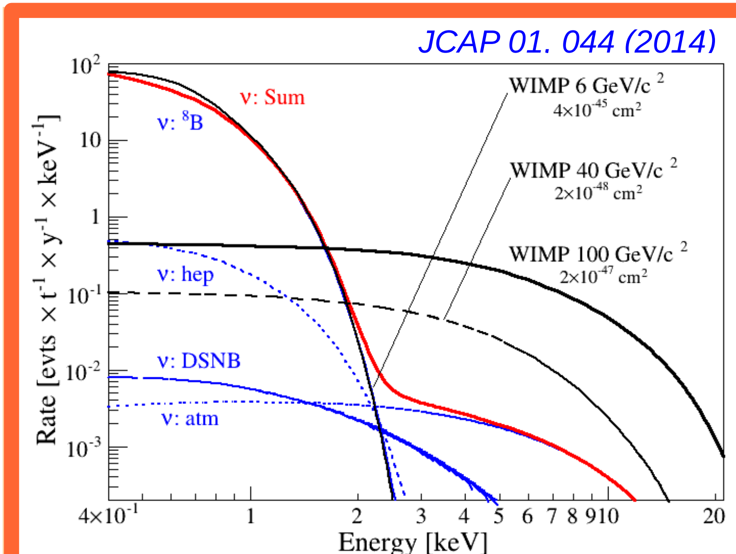
The ‚ultimate‘ Limit

spin-independent WIMP-nucleon interactions

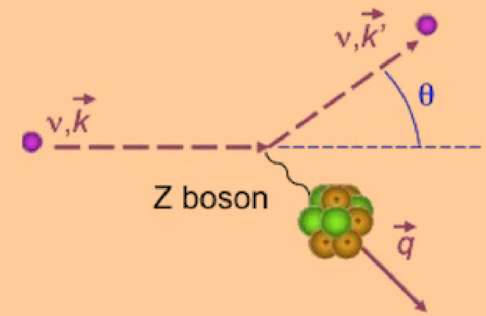


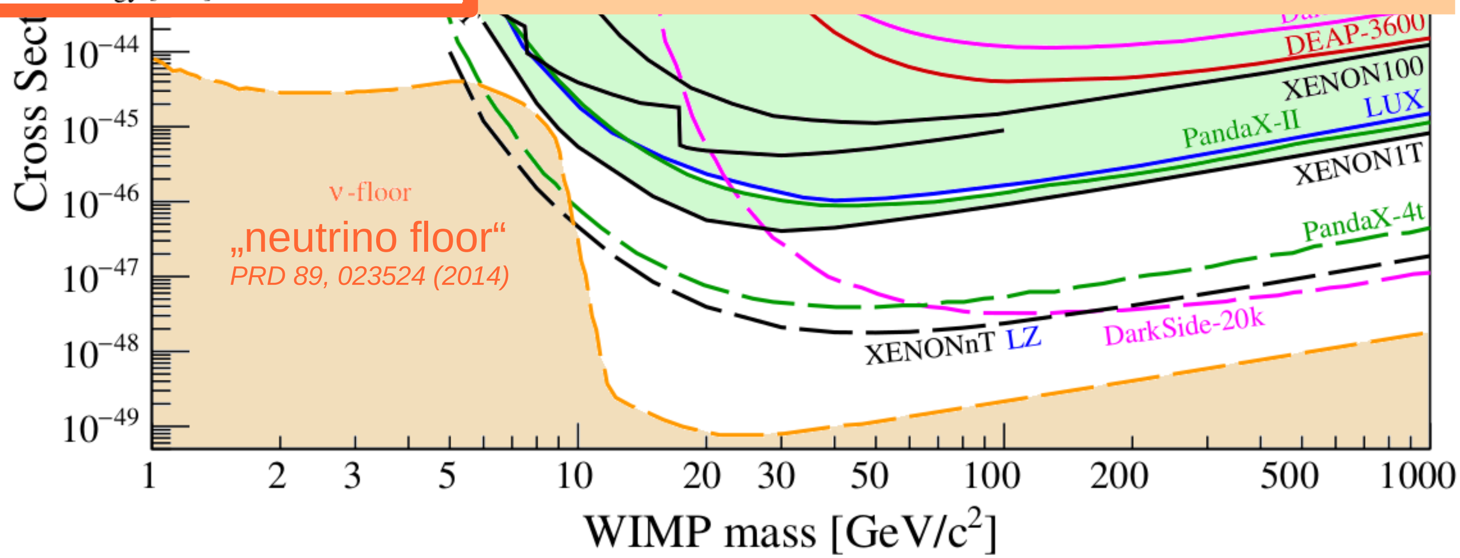
some results are missing...

The ‚ultimate‘ Limit



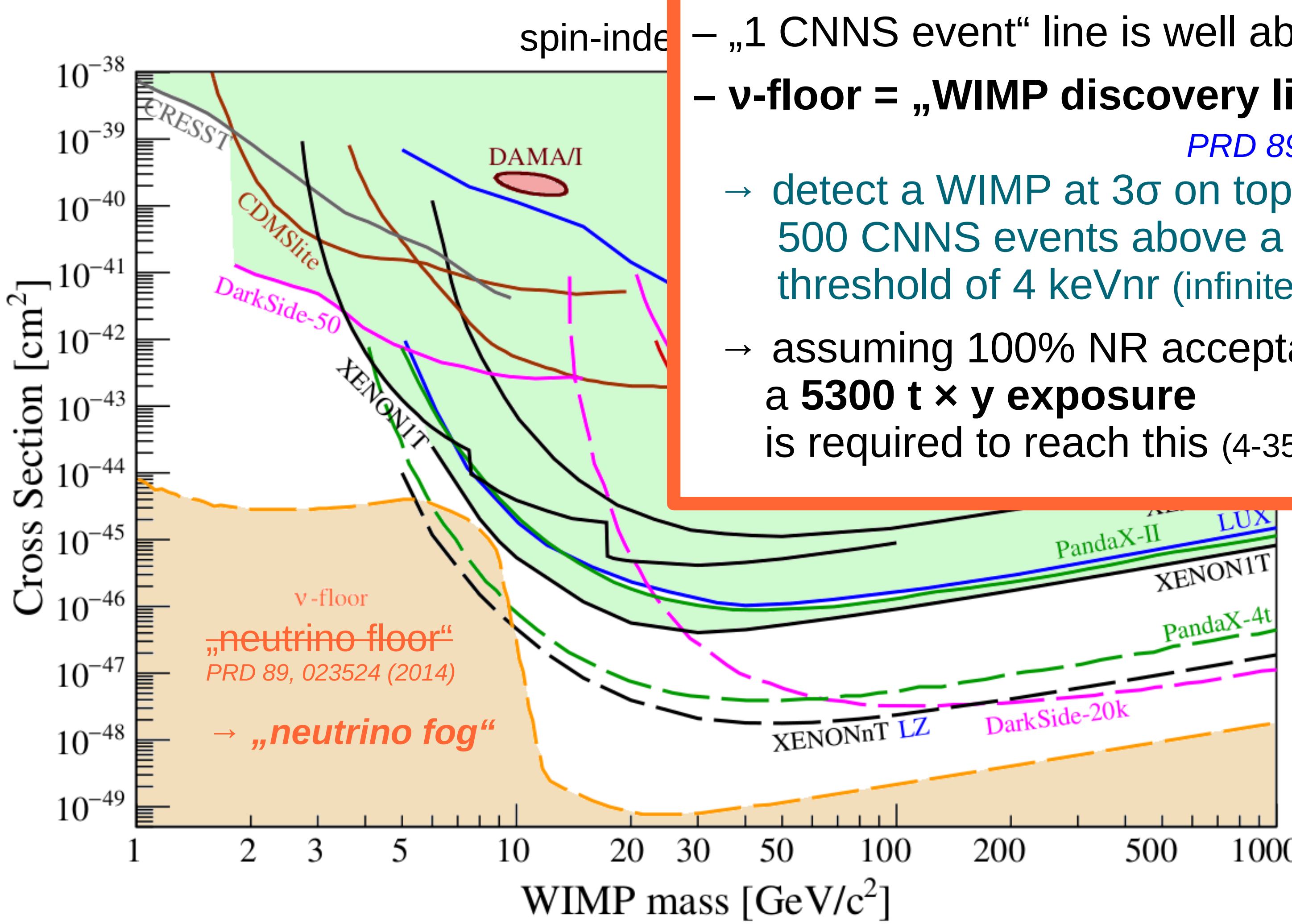
Interactions from coherent neutrino-nucleus scattering (CNNS) will dominate
→ **ultimate background** for direct detection





The ‚ultimate‘ Limit

DARWIN



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)

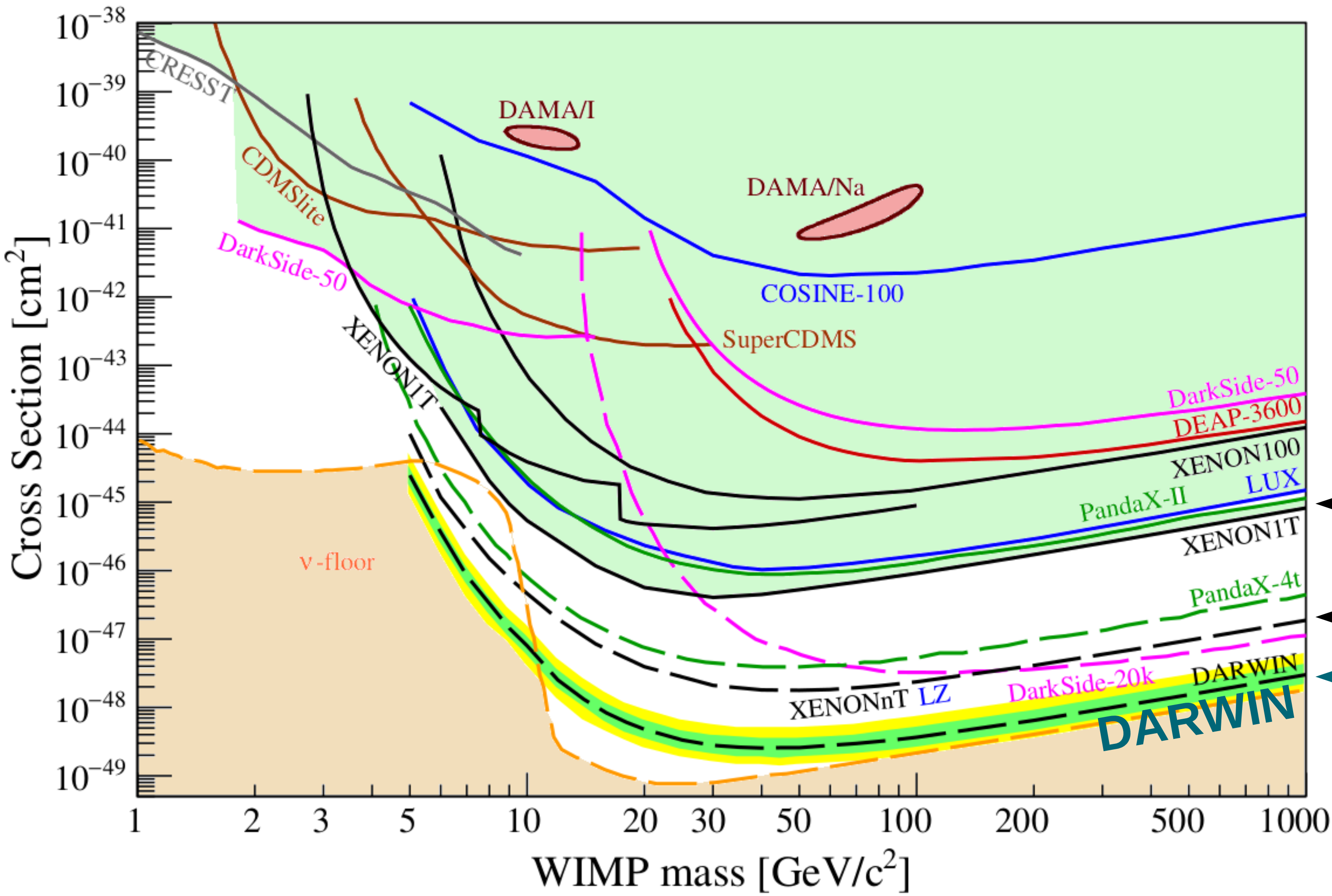
→ assuming 100% NR acceptance, a **5300 t × y exposure** is required to reach this (4-35 keVnr ROI)

some results are missing...

DARWIN The ultimate WIMP Detector

LXe-based

darwin-observatory.org



Exposure

1 t×y

20 t×y

200 t×y

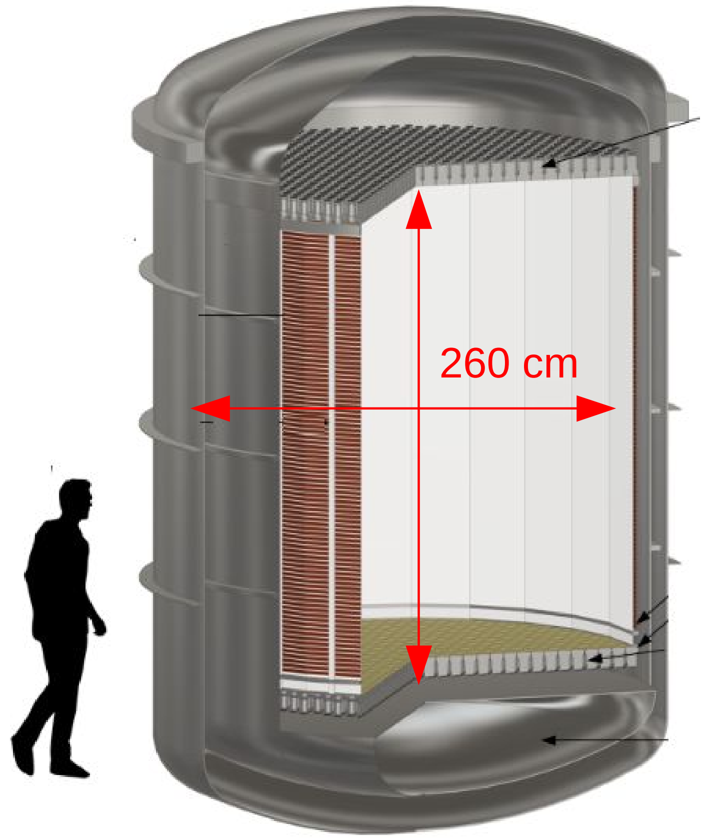
DARWIN The ultimate WIMP Detector

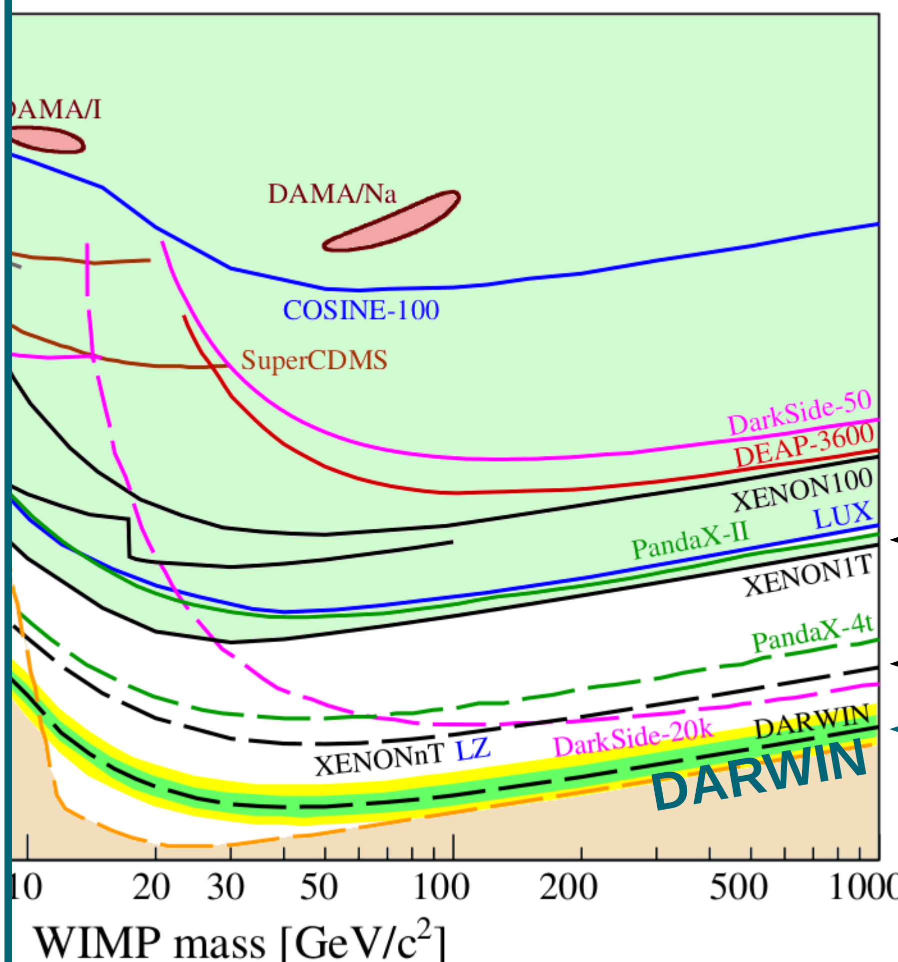
DARWIN

darwin-observatory.org

LXe-based

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



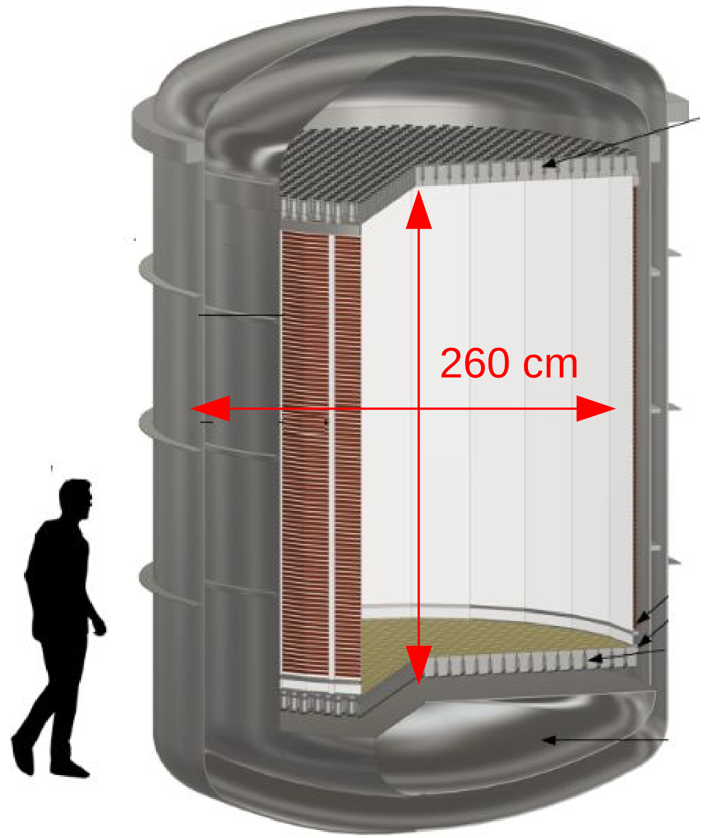


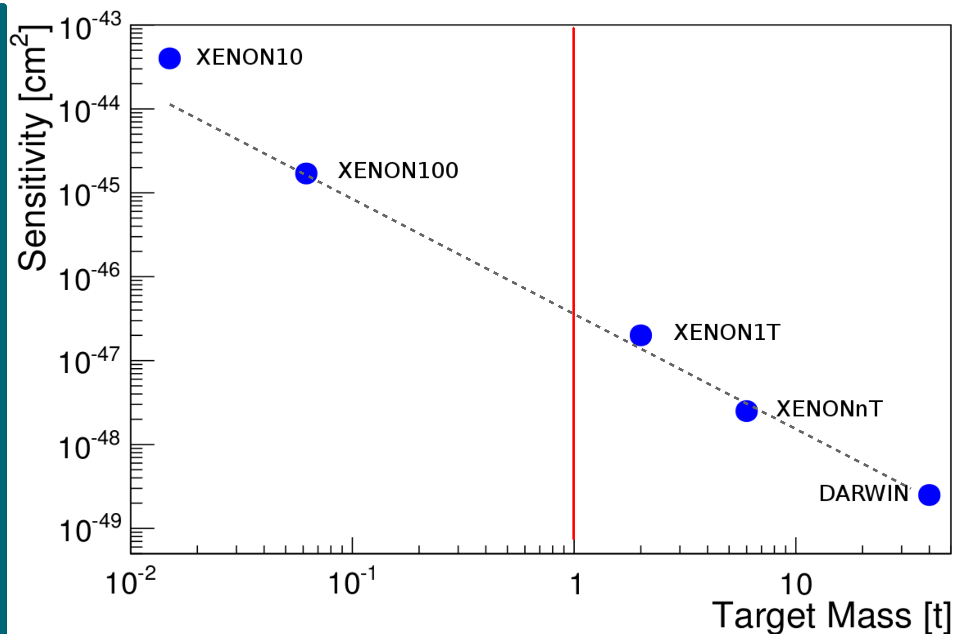
DARWIN The ultimate WIMP Detector

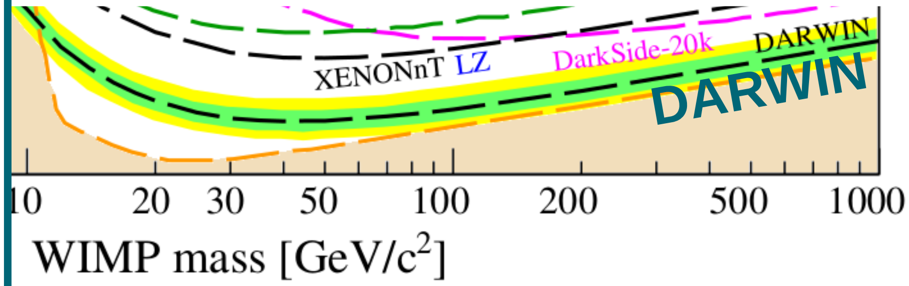
LXe-based

darwin-observatory.org

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





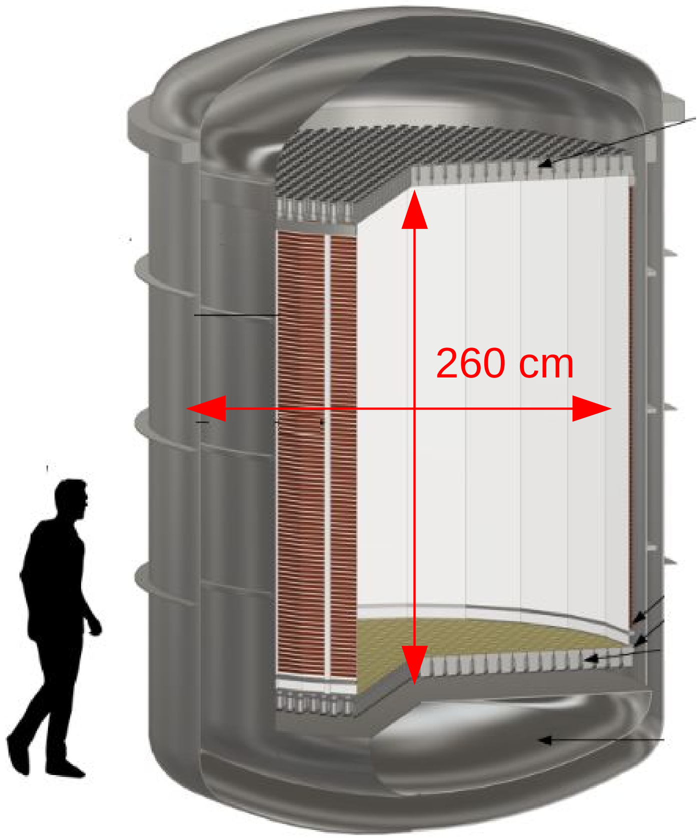


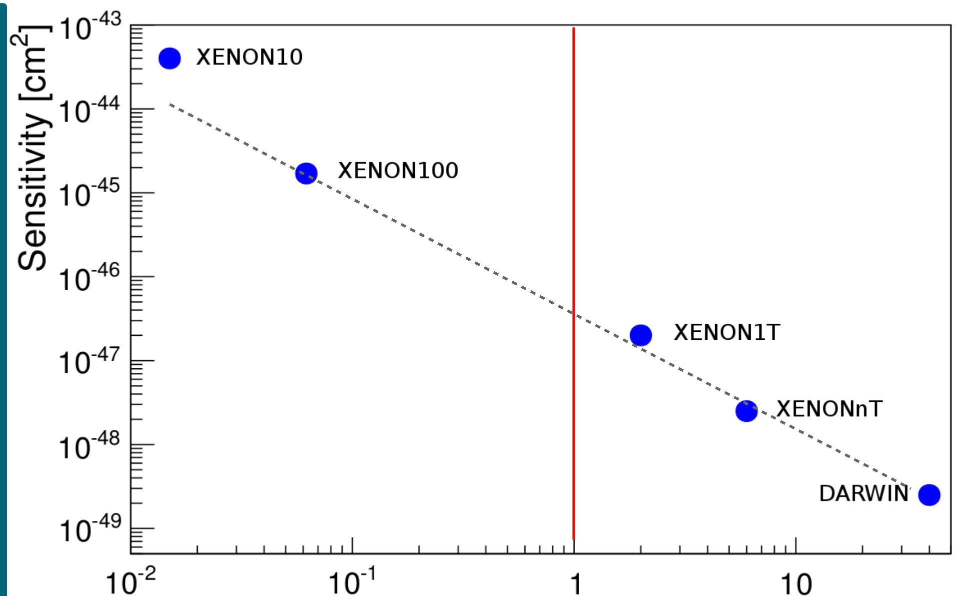
DARWIN The ultimate WIMP Detector

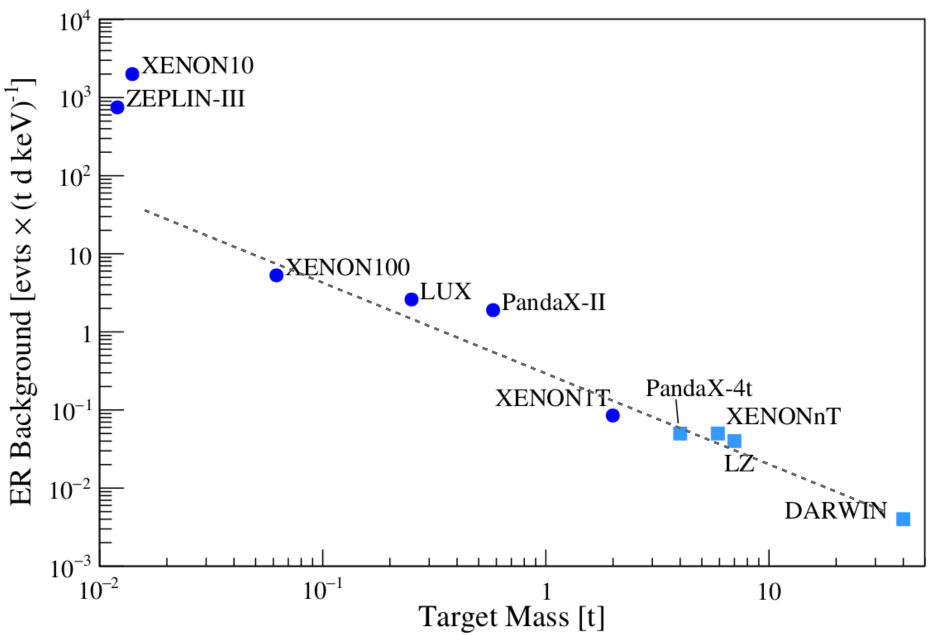
LXe-based

darwin-observatory.org

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







DARWIN Collaboration

darwin-observatory.org

TU Dresden
U Freiburg
U Hamburg
U Heidelberg
KIT
U Mainz
MPIK
U Münster

- international collaboration, 33 groups, ~170 scientists
- most XENON plus new groups → continuously growing
- strong German role: co-spokesperson, exec positions, WG leaders

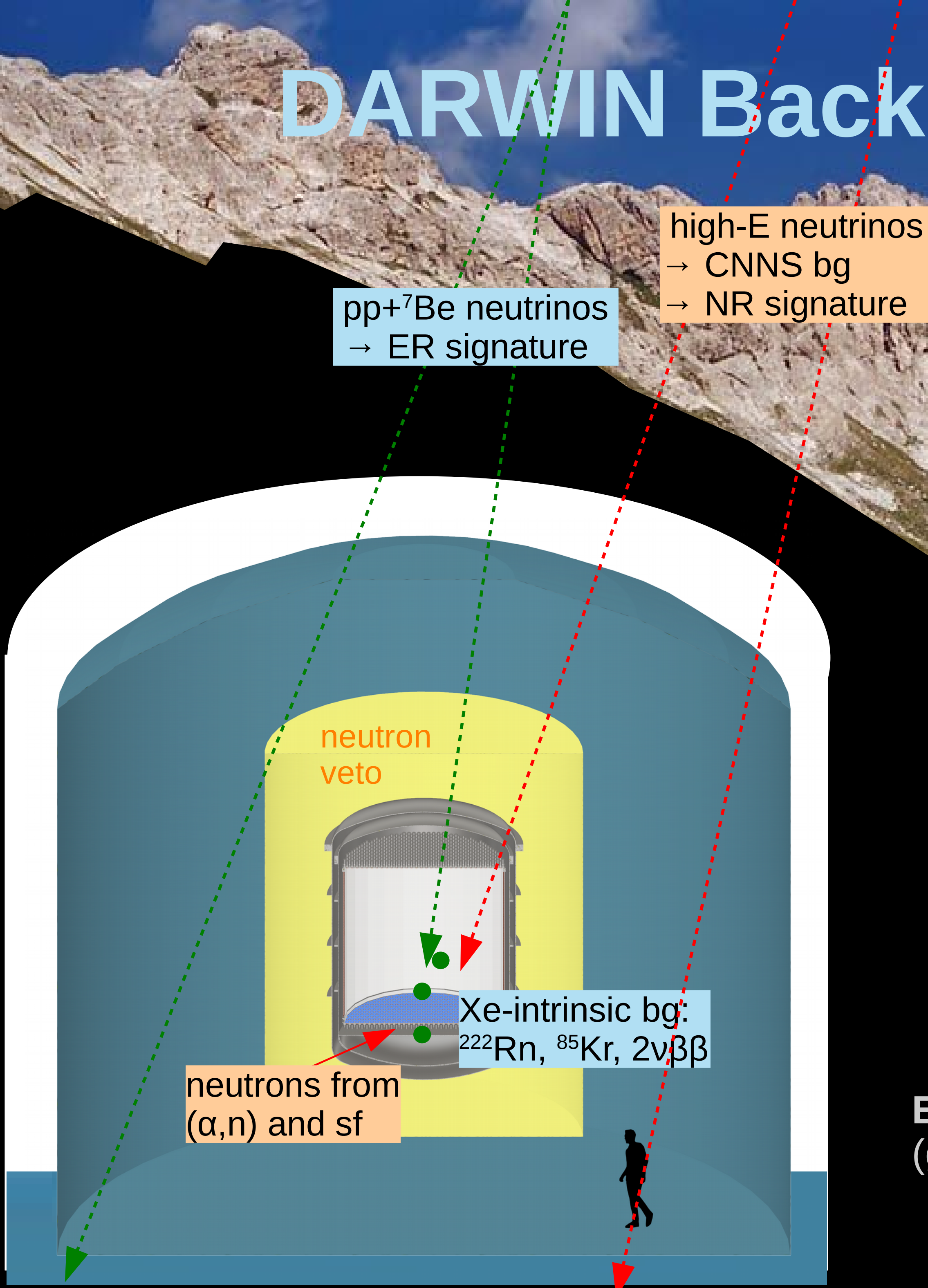
DARWIN Backgrounds

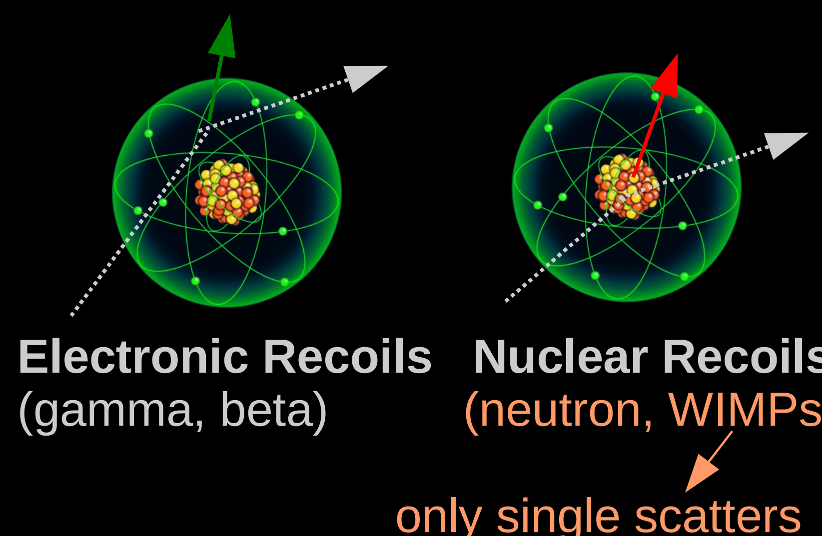
Remaining background sources:

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

(assume negligible
μ-induced background)

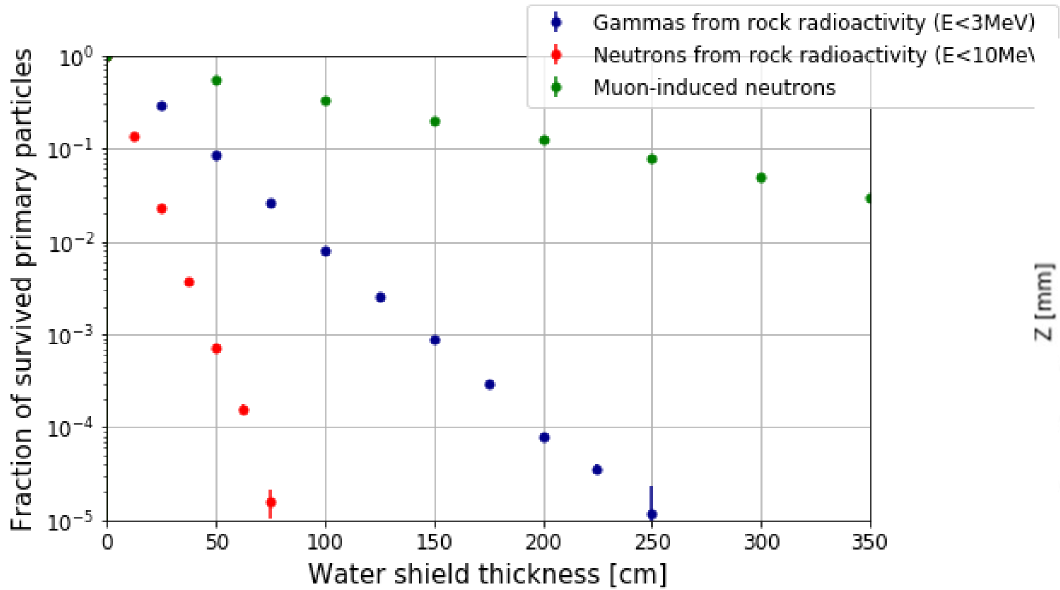
JCAP 10, 016 (2015)

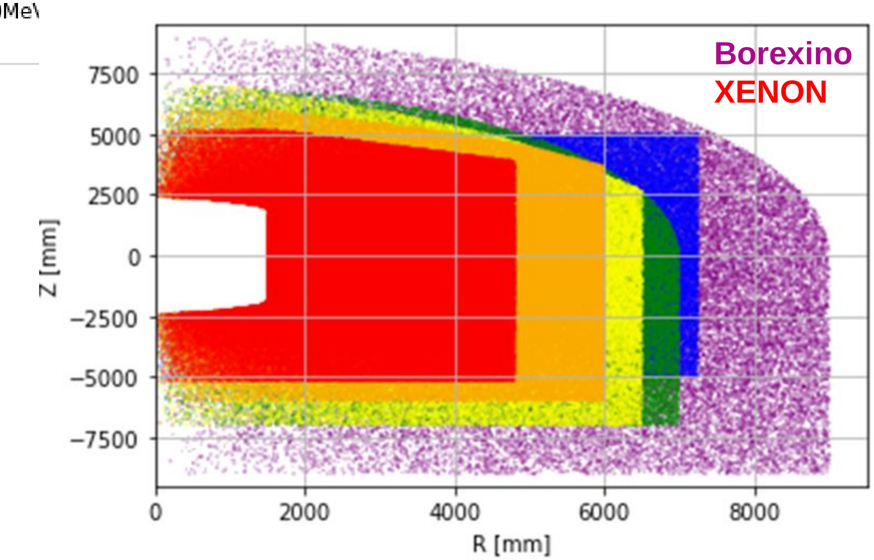




Water Shield @ LNGS ✔

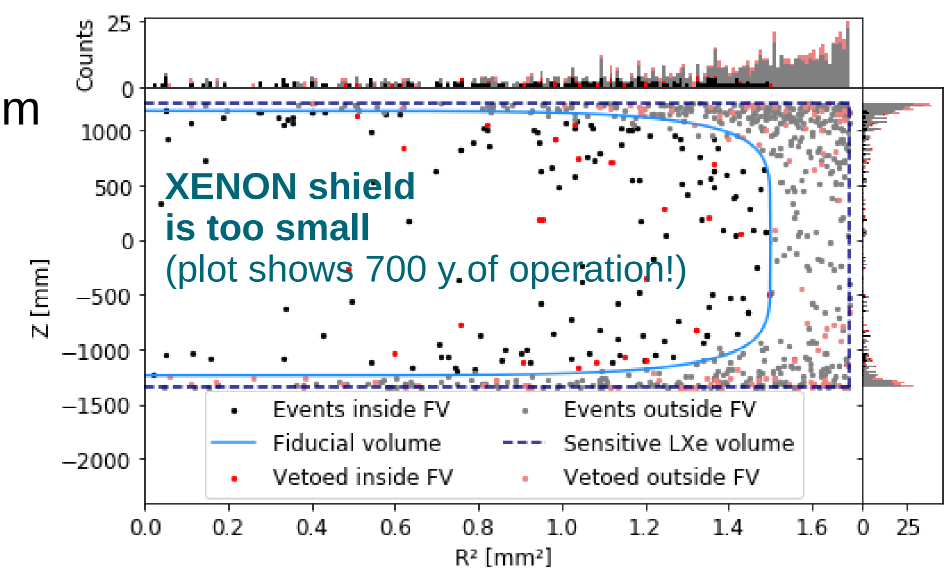
DARWIN





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



Neutron Background Studies

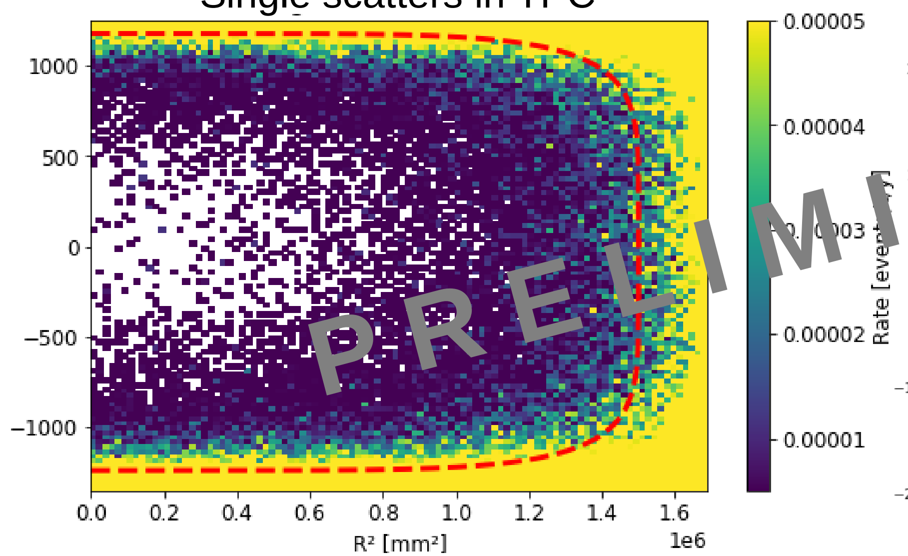
DARWIN

– define material and design requirements

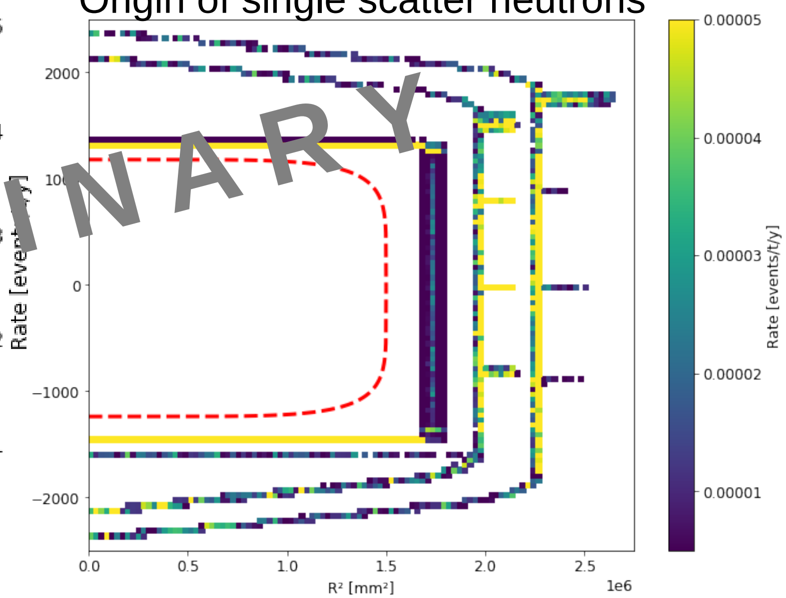
		Activity					
Material	**Unit**	^{238}**U**	^{226}**Ra**	^{235}**U**	^{232}**Th**	^{228}**Th**	**Ref.**
Titanium	mBq/kg	< 1.6	< 0.09	< 0.02	0.28	0.23	LZ
PTFE	mBq/kg	< 5e-3	< 5e-3	< 2e-4	<1.4e-3	<1.4e-3	EXO
Copper	mBq/kg	< 1	< 0.035	< 0.18	< 0.033	< 0.026	XENON
PMT	mBq/unit	8	0.6	0.37	0.7	0.6	XENON
PMT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

Start with realized radioactivity values
→ work on improvement

Single scatters in TPC



Origin of single scatter neutrons



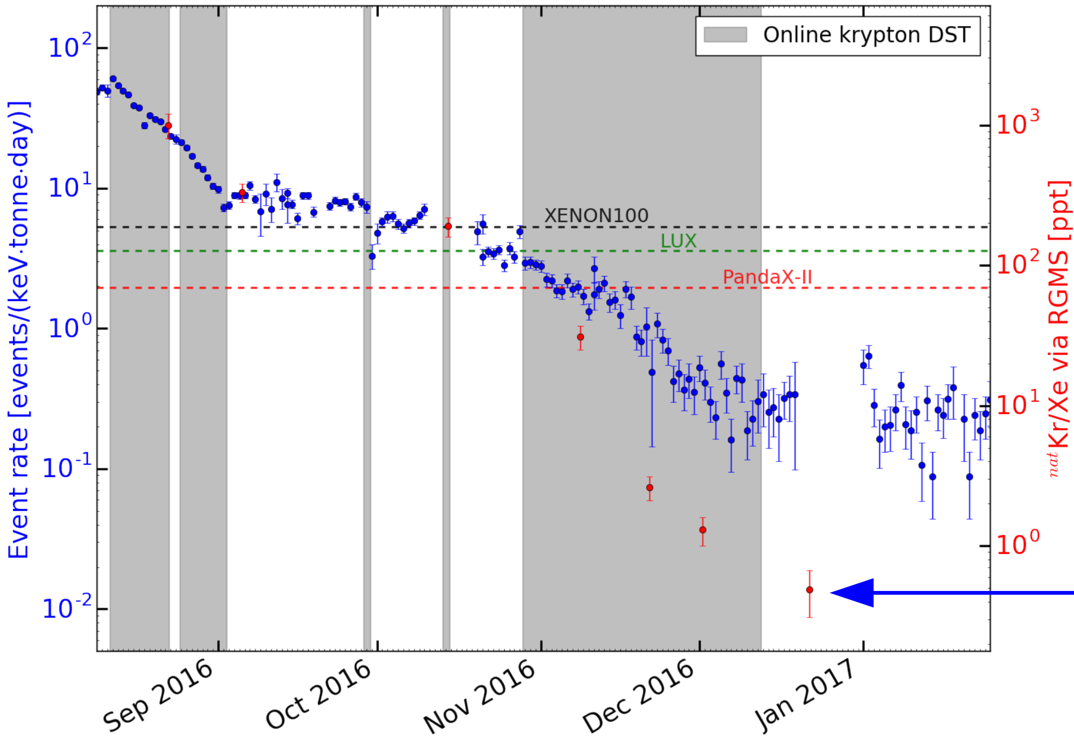
→ Gd-based water Cherenkov **neutron veto** not yet considered

LXe: Krypton Removal

U Münster

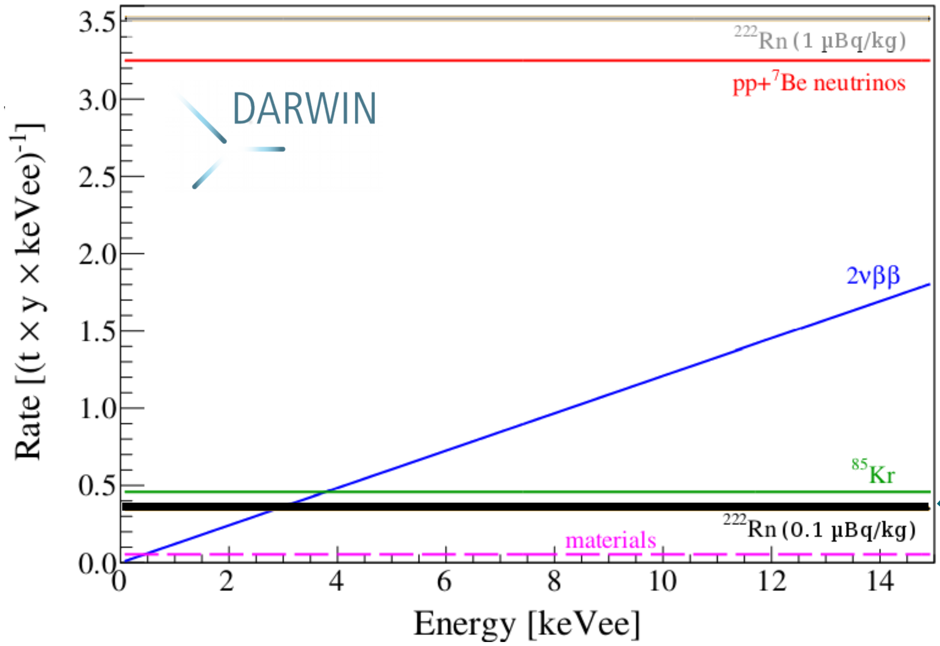
– DARWIN goal: **0.03 ppt** (~ 0.1 × pp-neutrinos)
– removal by cryogenic distillation

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

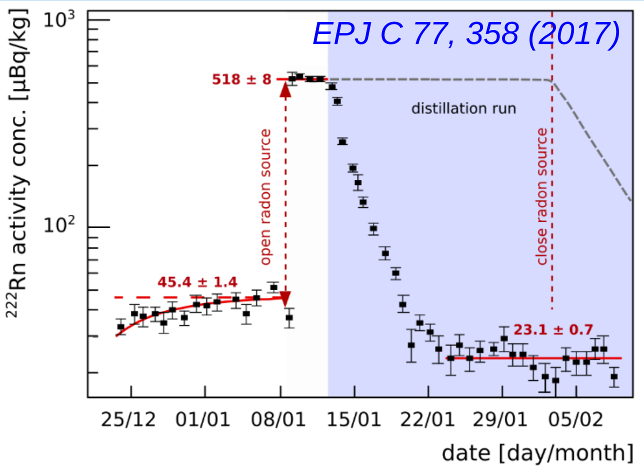
→ **main background challenge**

Strategy DARWIN

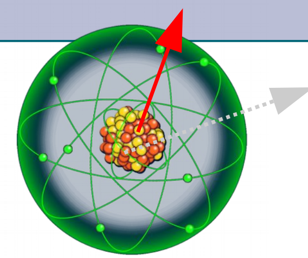
– avoid Rn emanation by
→ optimal material production
→ material selection
→ surface treatment
→ optimized detector design

– **active Rn removal via cryogenic distillation**

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



DARWIN: Science Channels



Nuclear Recoil Interactions

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

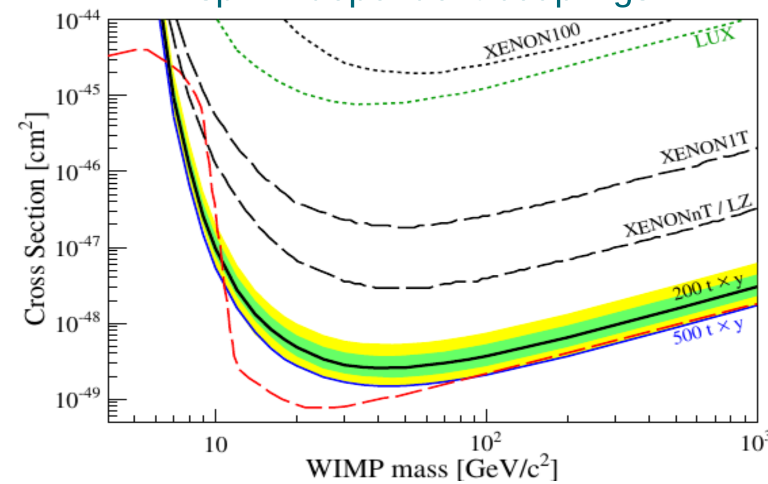
– **spin-independent** (S1-S2, charge-only)

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

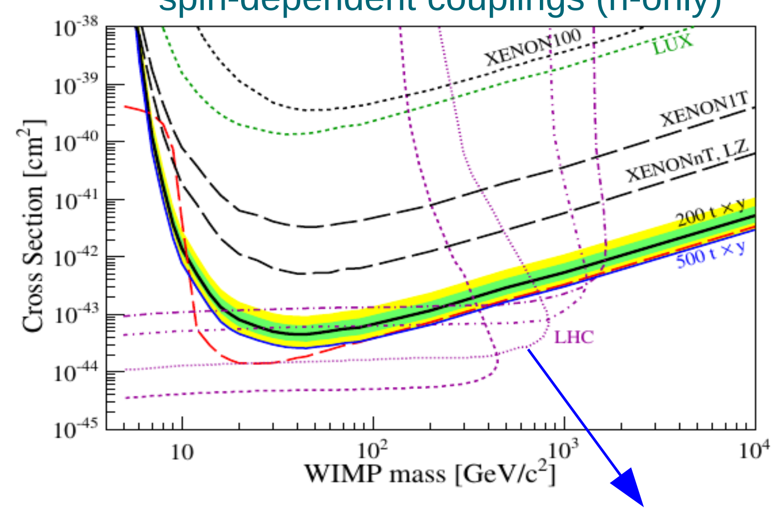
→ complementary with LHC, indirect det.

– various inelastic models, most EFT couplings

spin-*in*dependent couplings



spin-dependent couplings (n-only)

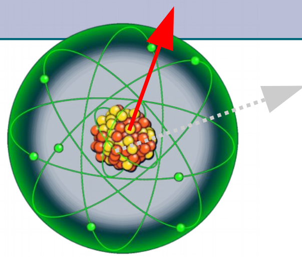


excellent complementarity to LHC searches

p-only complementary to indirect searches

DARWIN: Science Channels

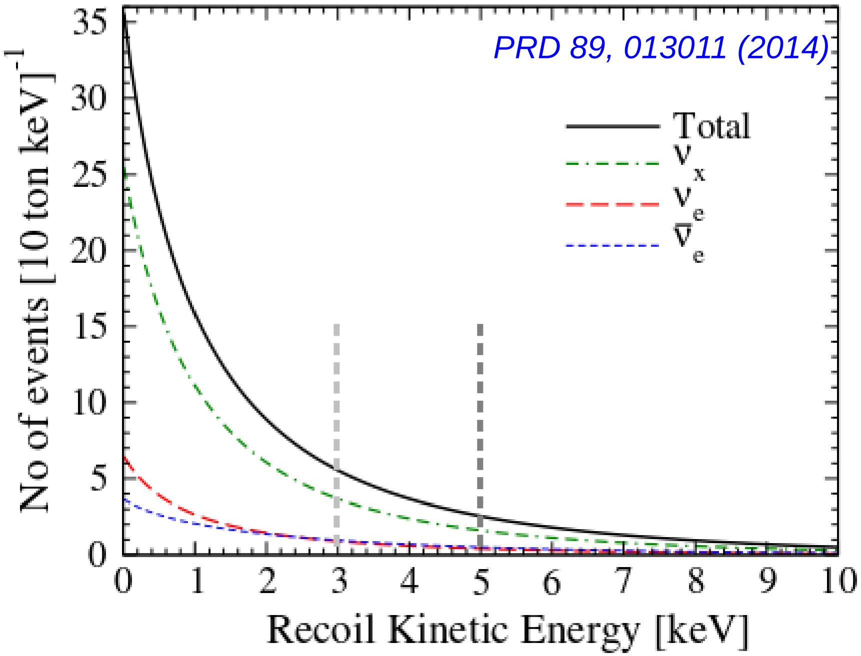
DARWIN



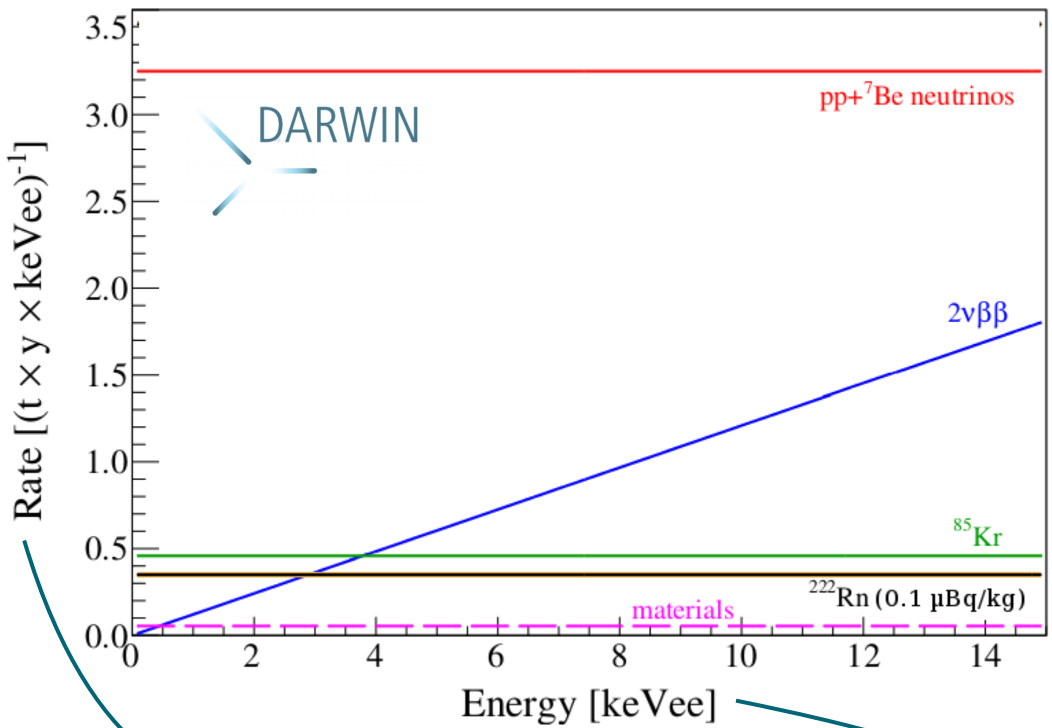
Nuclear Recoil Interactions

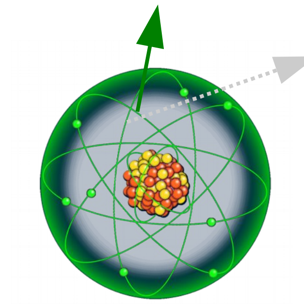
WIMP dark matter *JCAP 10, 016 (2015)*
– spin-independent (S1-S2, charge-only)
– spin-dependent *Phys.Dark Univ. 9-10, 51 (2015)*
→ complementary with LHC, indirect det.
– various inelastic models, most EFT couplings

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

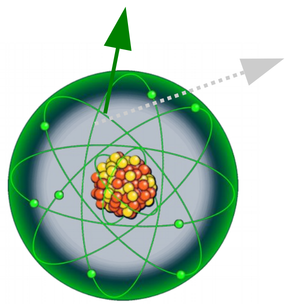
DARWIN: Science Channels

DARWIN

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

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)



Electronic Recoil Interactions

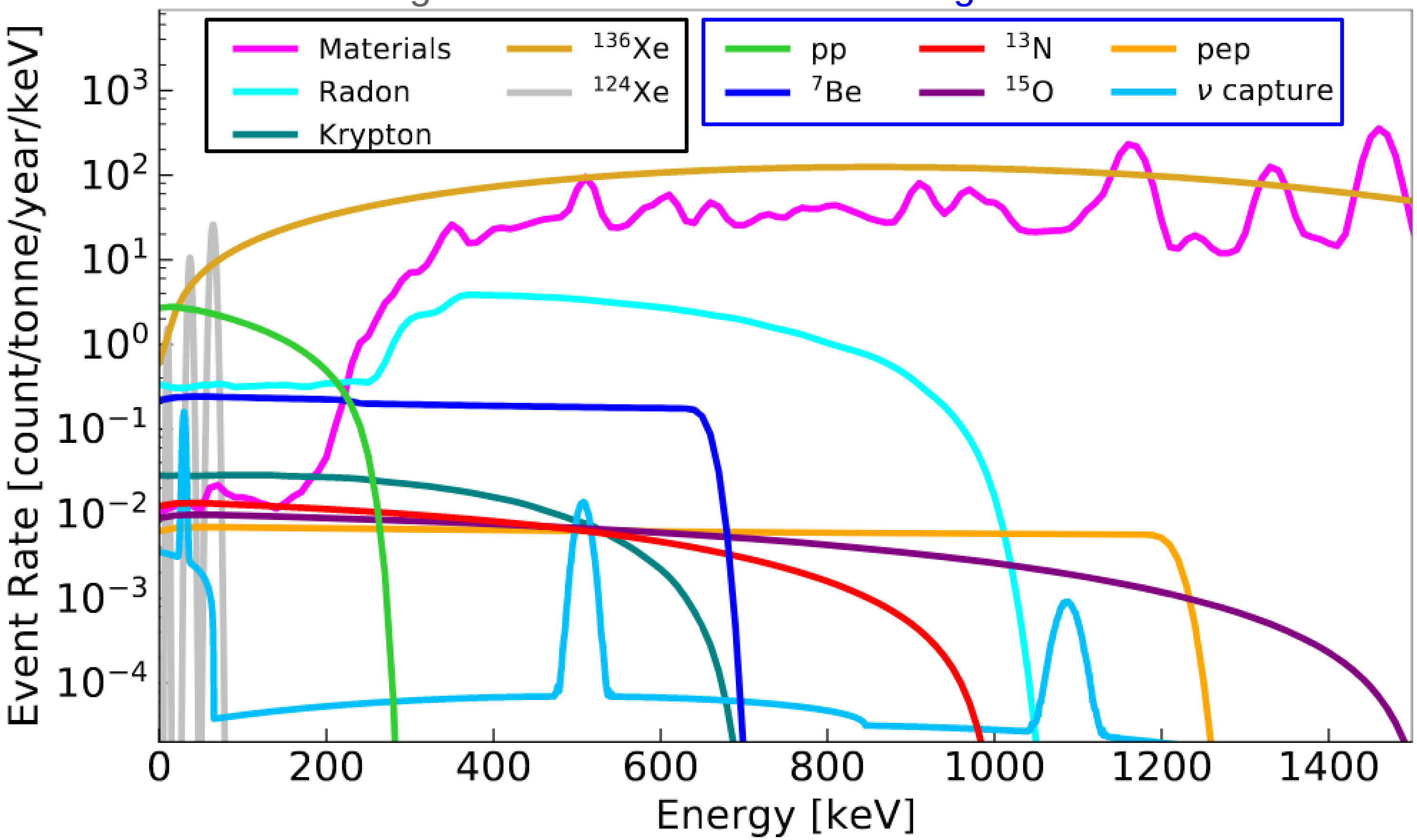
Non-WIMP dark matter and neutrino physics
– axions, ALPs *JCAP 1611, 017 (2016), XENON1T excess*
– sterile neutrinos *JCAP 01, 044 (2014)*
– **pp, ^{7}Be: precision flux measurements** *arXiv:2006.03114*
– CNO neutrinos with ^{136}Xe-depleted Xe *PRD 99, 043006 (2019)*

Rare nuclear events
– 0νββ (^{136}Xe), 2νEC (^{134}Xe), ...
JCAP 01, 044 (2014) *arXiv:2002.04239*
EPJ C 80, 808 (2020)

Solar Neutrinos

ER Spectrum in Xe

JCAP 01, 044 (2014)
arXiv:2006.03114

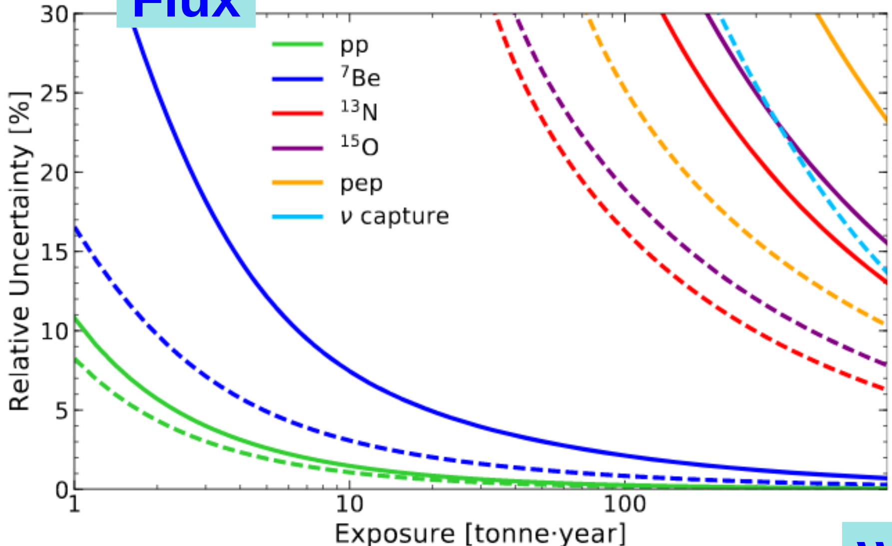


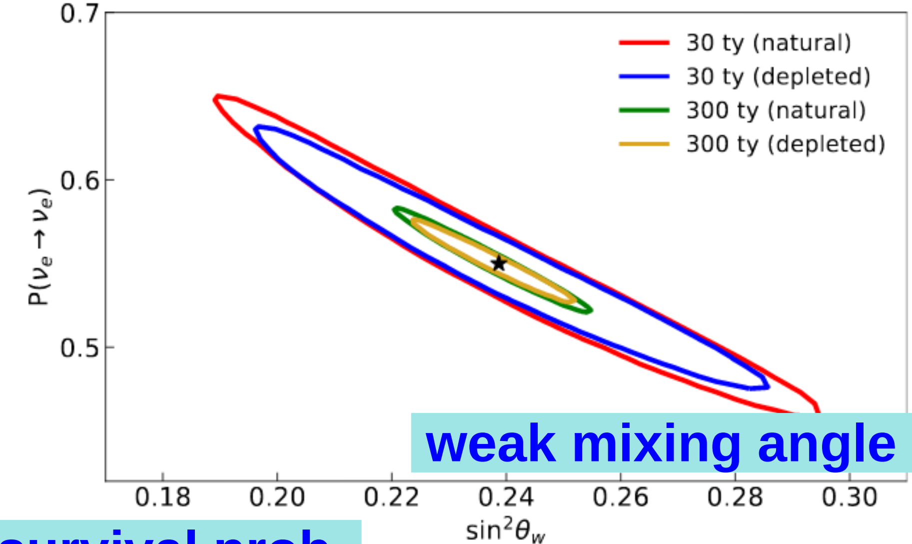
- DARWIN's ER spectrum will be dominated by pp neutrinos (and 2νDEC+2νββ)
- distinct features in ν spectra allow extracting neutrino fluxes
  → full spectral fit of all components up to 3 MeV
  (possibility to enhance sensitivity by more sophisticated analysis)

Solar Neutrinos

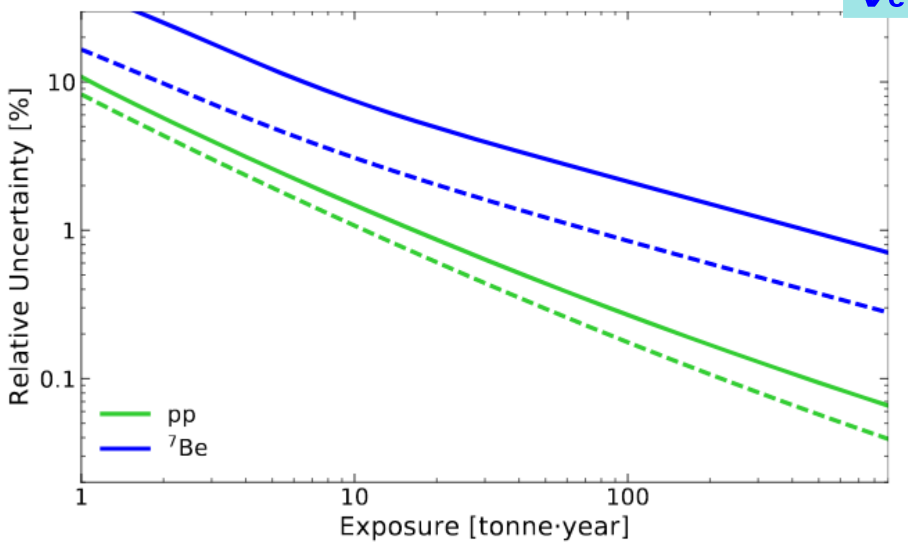
JCAP 01, 044 (2014)
arXiv:2006.03114

Flux

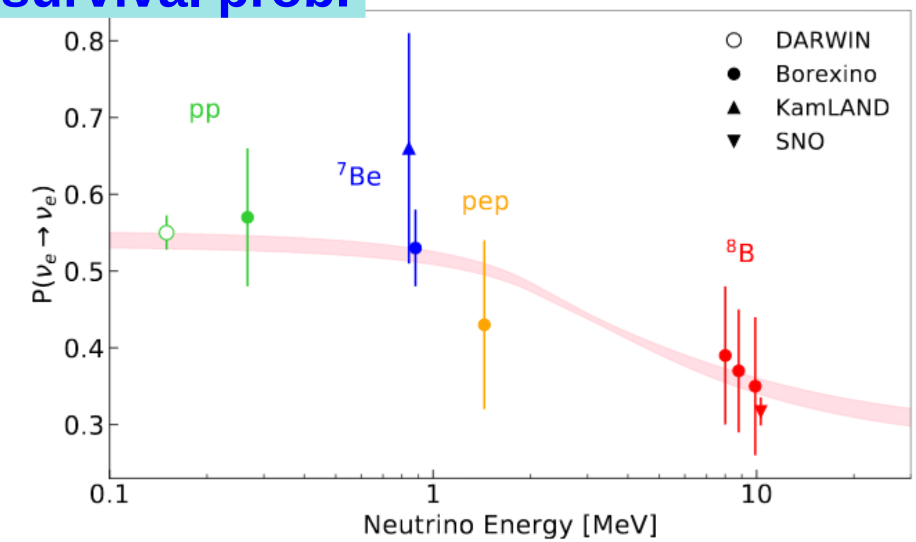




weak mixing angle



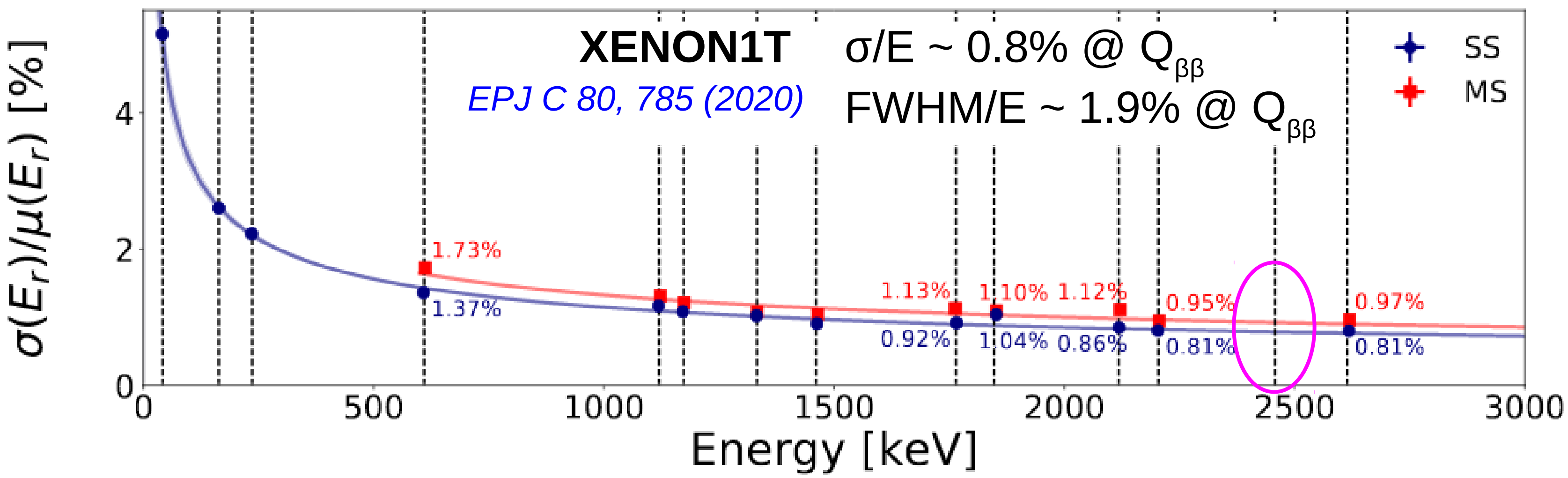
ν_e survival prob.

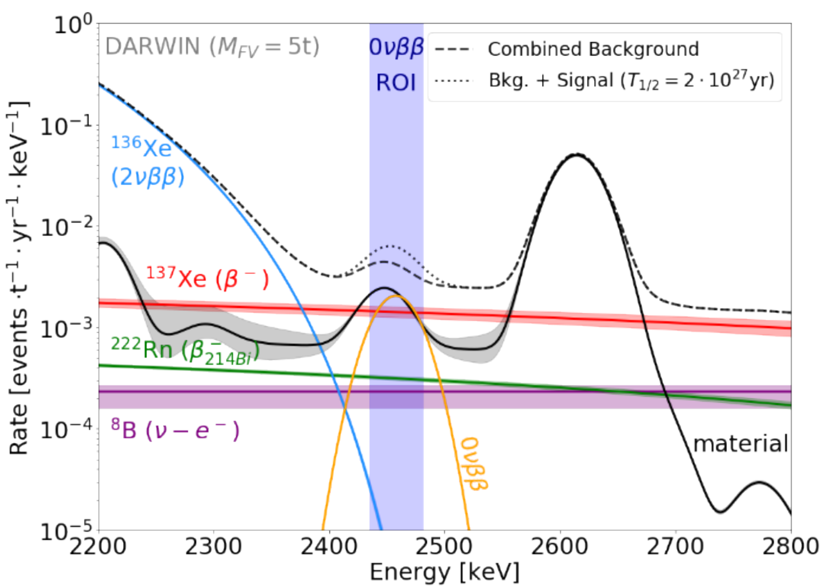


^{136}Xe: 0ν double-beta Decay

EPJ C 80, 808 (2020)

- 40t DARWIN LXe target contains 3.5t of ^{136}Xe **without any enrichment**!





DARWIN Sensitivity

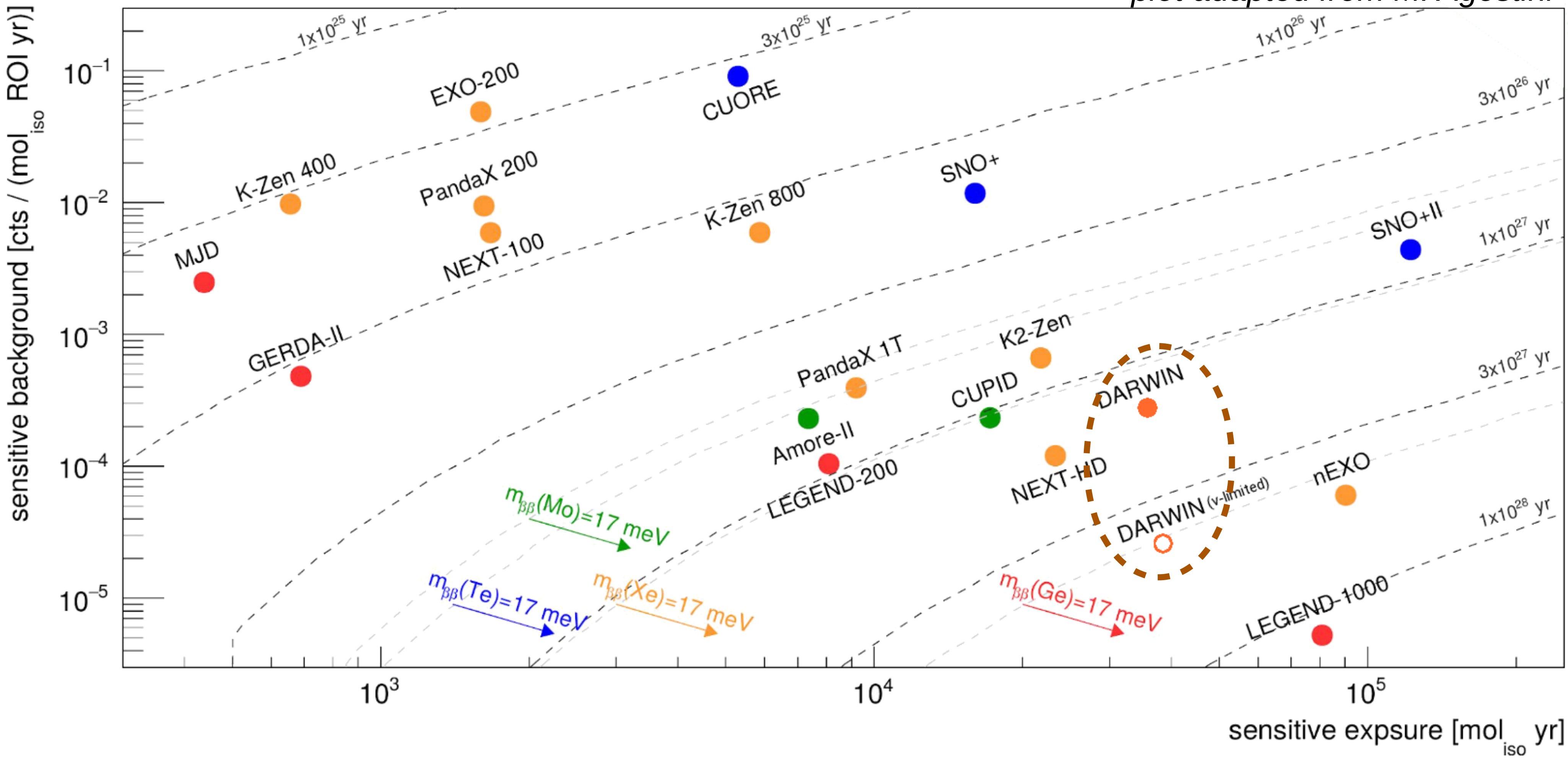
- optimize sensitivity by fiducialization
- important background from decays of neutron-activated ^{137}Xe
  → assume LNGS depth
- **half-life sensitivity: 2.4 × 10^{27} y**

^{136}Xe: 0ν double-beta Decay

DARWIN

EPJ C 80, 808 (2020)

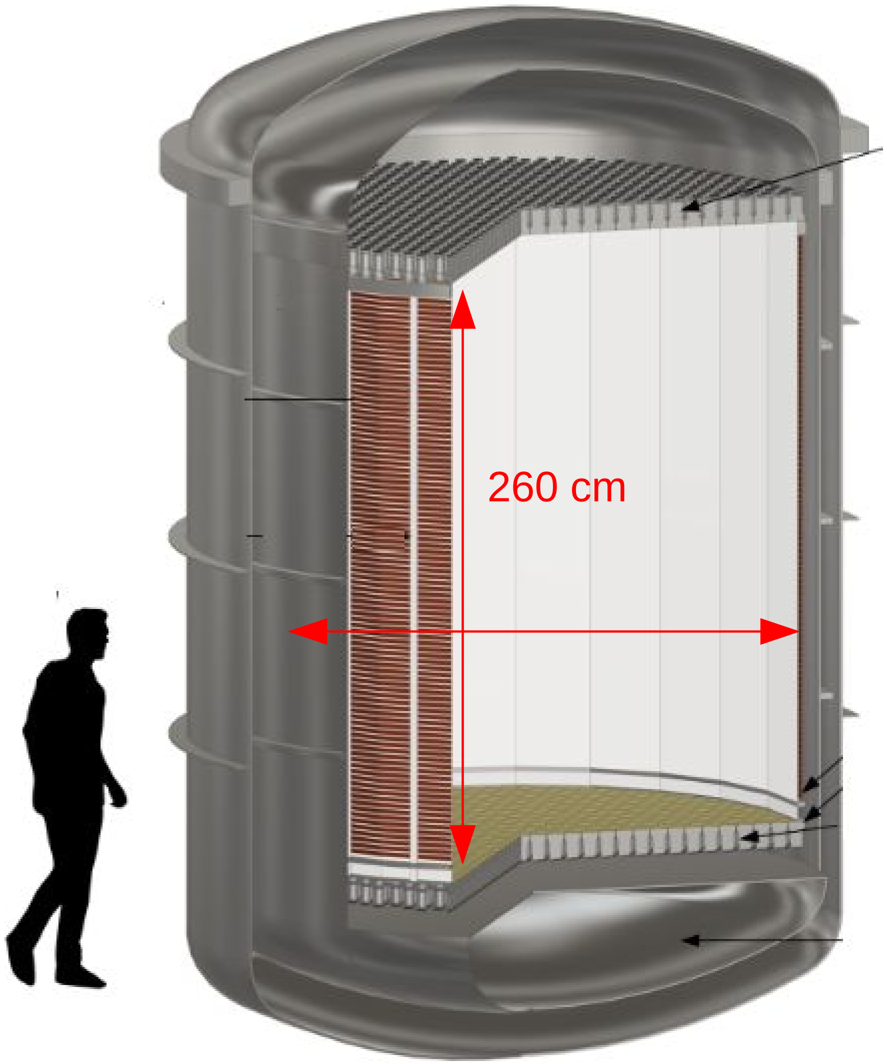
plot adapted from M. Agostini



DARWIN: 40t LXe TPC

JCAP 11, 017 (2016)

darwin-observatory.org



Challenges

- **Size**
  - → electron drift (HV)
  - → diameter (TPC electrodes)
  - → mass (LXe purification)
  - → dimensions (radioactivity)
  - → detector response (calibration, corrections)
- **Backgrounds**
  - → ^{222}Rn: factor 100 required
  - → (α,n) neutrons (PTFE, metal)
- **Photosensors**
  - → high light yield (QE)
  - → low radioactivity
  - → long-term stability
- etc etc

R&D needed

DARWIN LXe Testplatform in **Freiburg**:
– 2.7 m inner diameter
– up to ~15 cm height (~5 cm LXe)
→ ~400 kg Xe gas
→ test horizontal components,
real-scale electrodes etc.

DARWIN LXe Testplatform in **Zürich**:

– 16 cm inner diameter

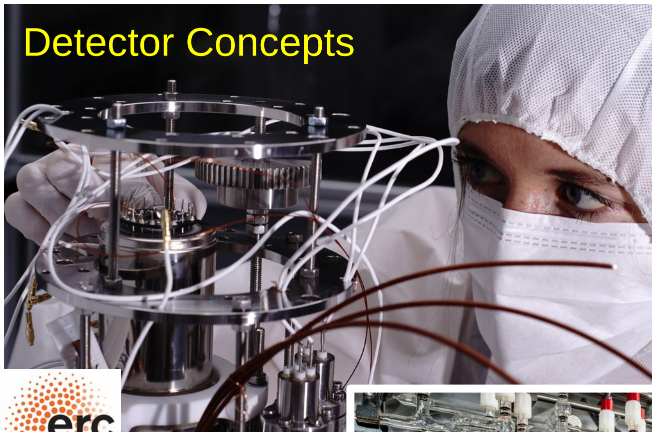
– up to 2.6 m LXe height

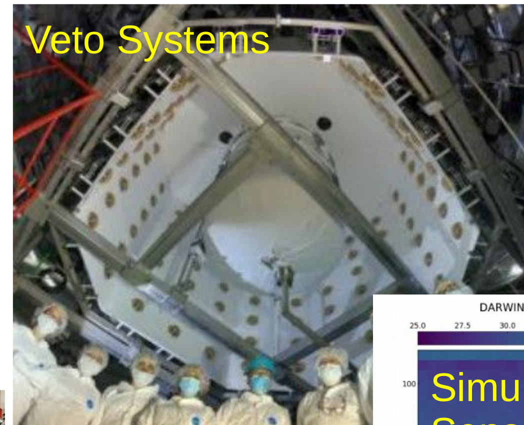
→ ~400 kg Xe gas

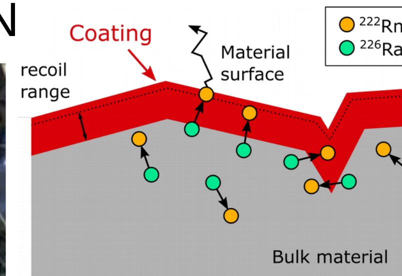
→ test vertical components,
  e^- drift, HV feedthrough etc.

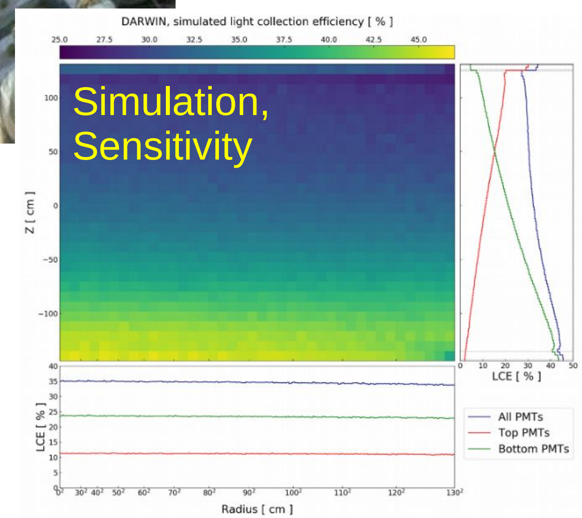
DARWIN: R&D Examples

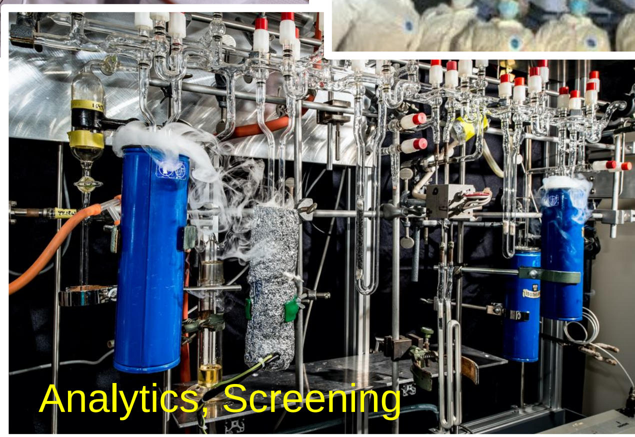
R&D for XENONnT: often directly applicable for DARWIN

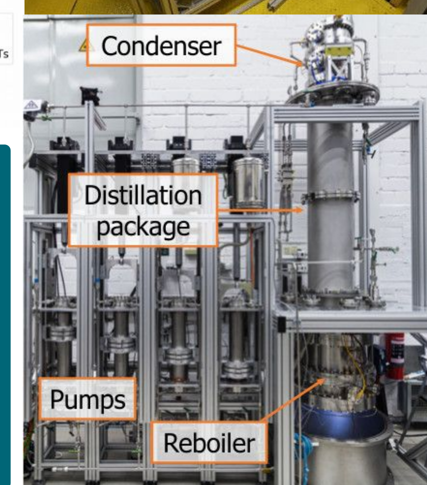










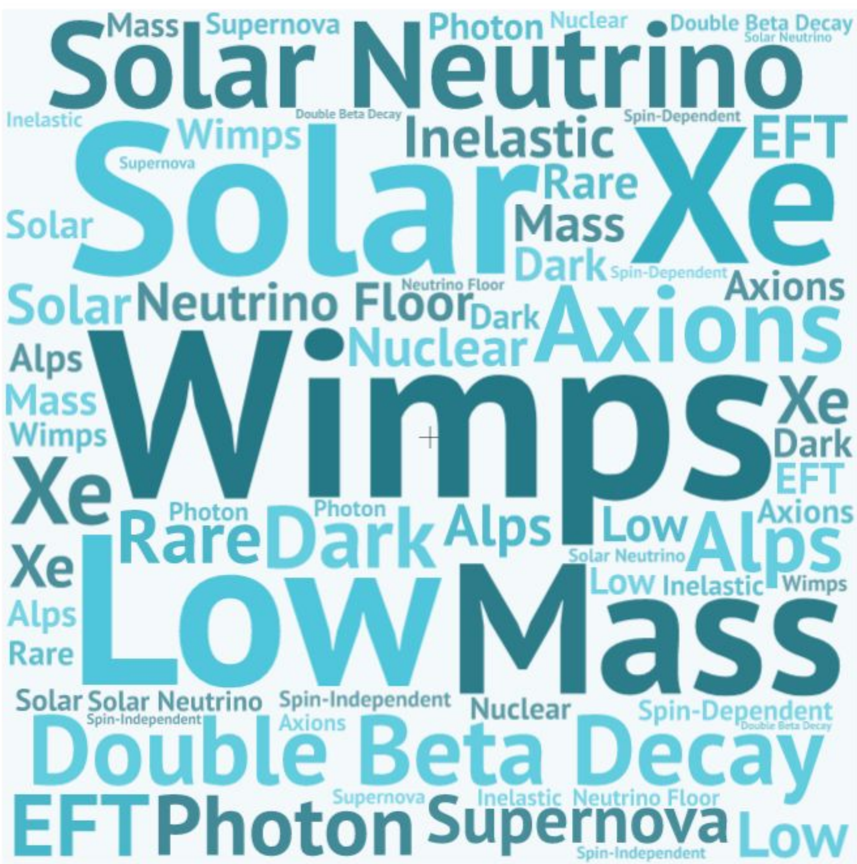


DARWIN: Exciting Opportunities

DARWIN: much more than

The ultimate Dark Matter Detector

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

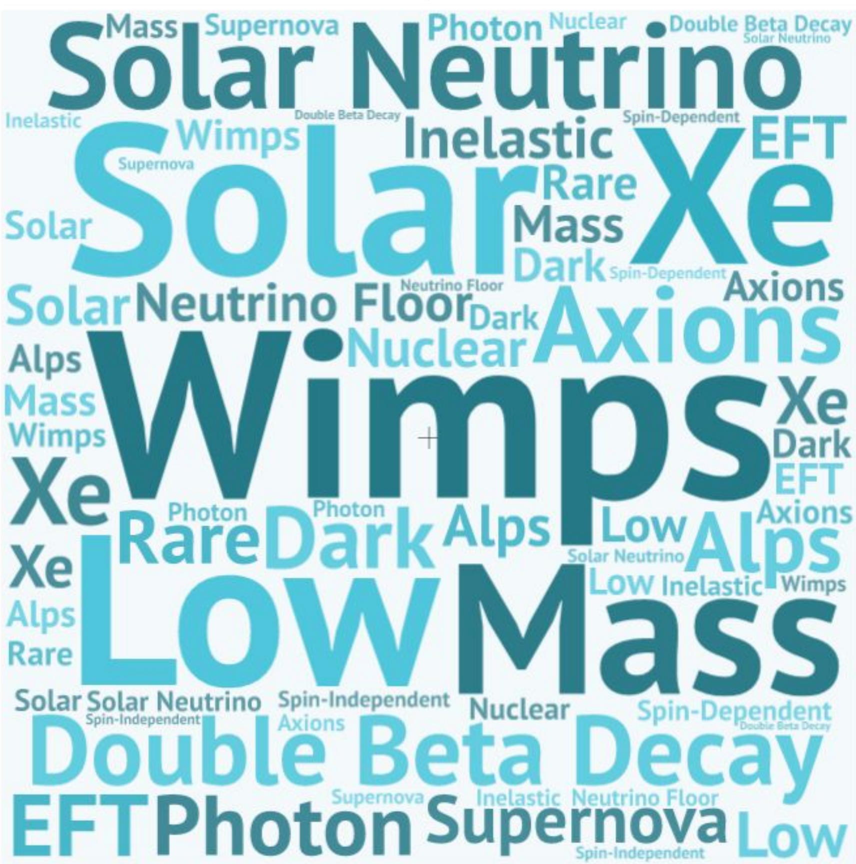


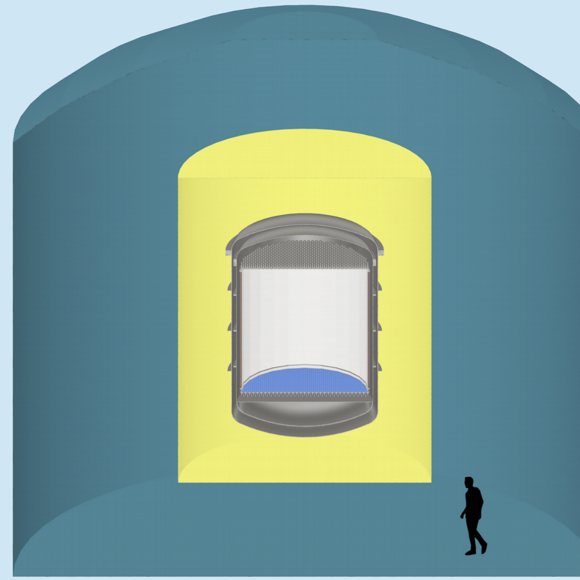
DARWIN: Exciting Opportunities

DARWIN: much more than

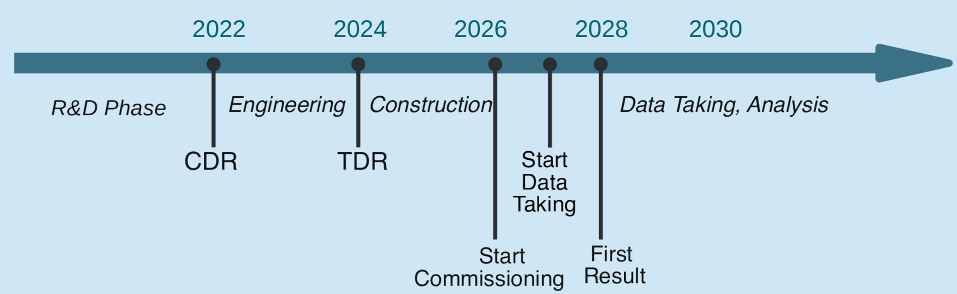
The ultimate (LXe) **Dark Matter Detector**

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





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



Backup

Dependence of Sensitivity

Reference WIMP mass = 40 GeV/c²

JCAP 10, 016 (2015)