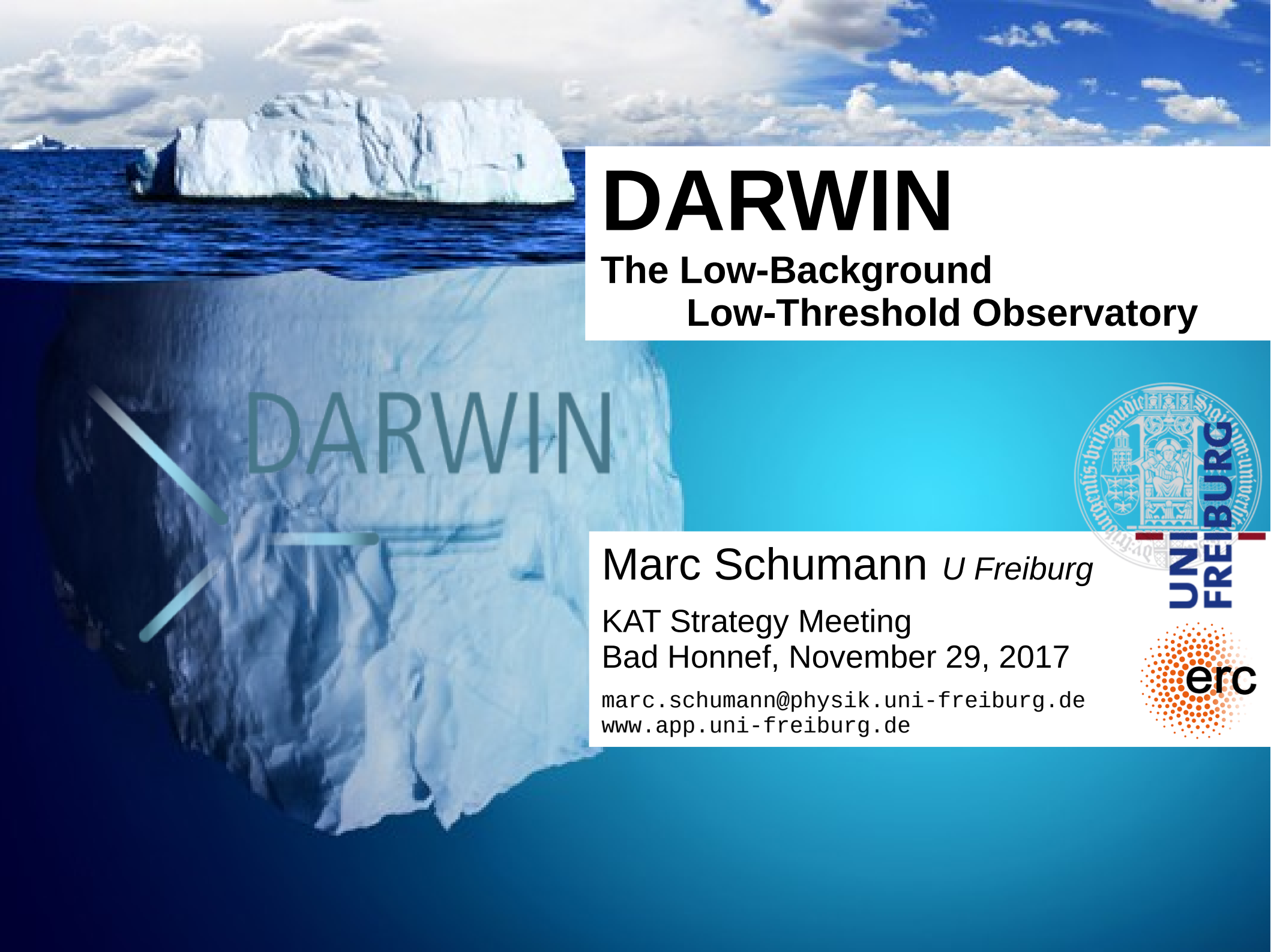


DARWIN

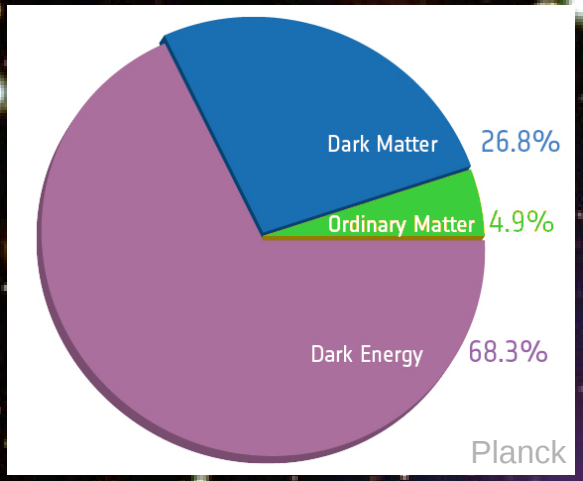
The Low-Background Low-Threshold Observatory

Marc Schumann *U Freiburg*

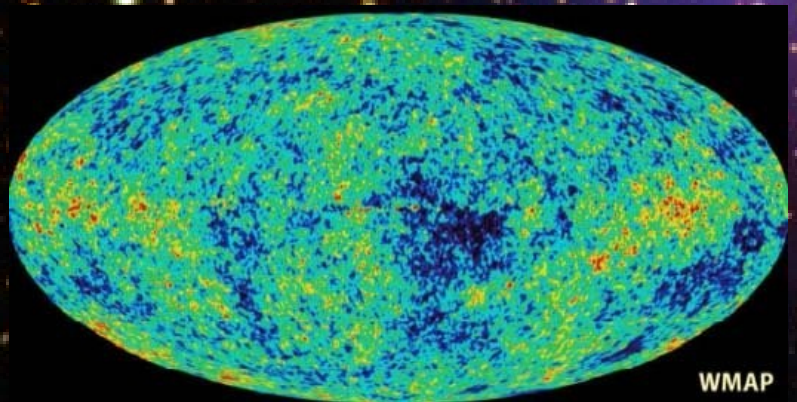
KAT Strategy Meeting
Bad Honnef, November 29, 2017

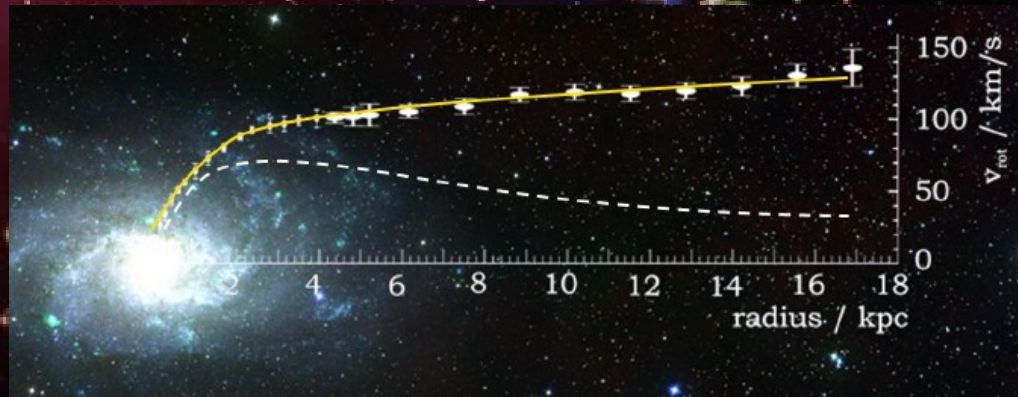
marc.schumann@physik.uni-freiburg.de
www.app.uni-freiburg.de

Dark Matter: (indirect) **Evidence**



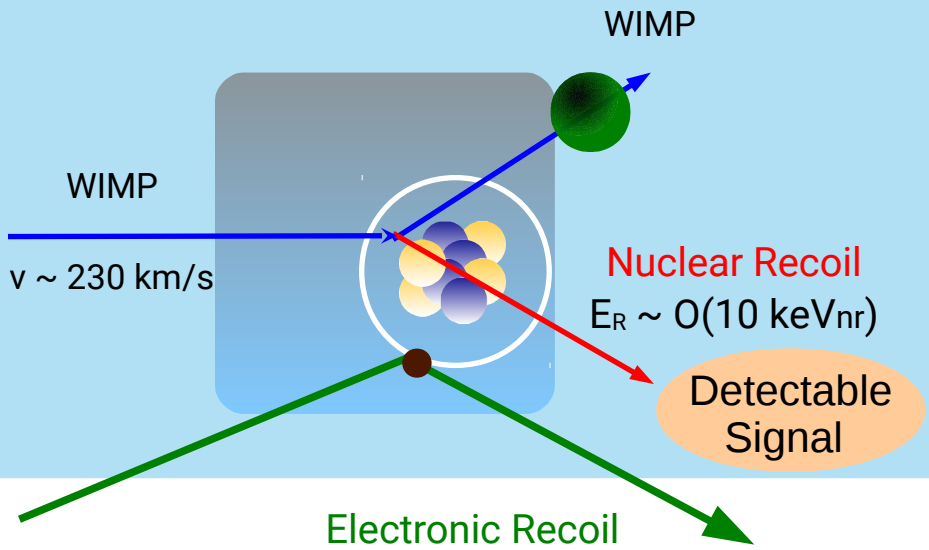
The indirect evidence for the existence of dark matter is a clear indication for physics beyond the Standard Model



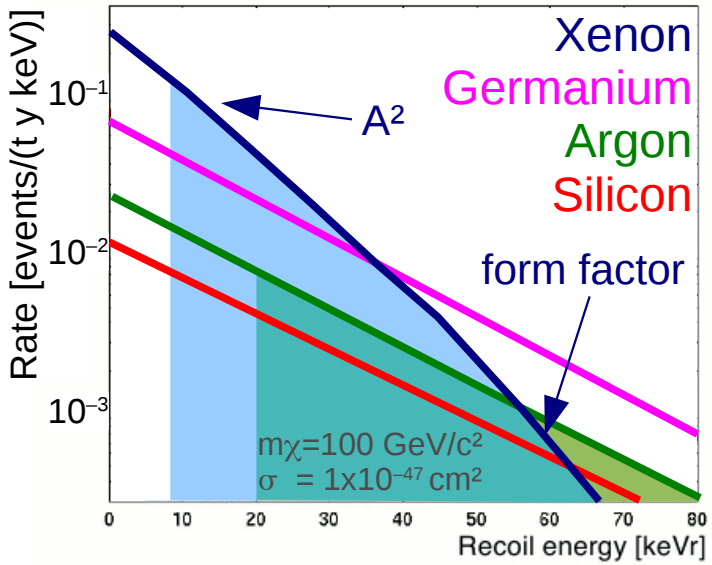


Direct WIMP Search

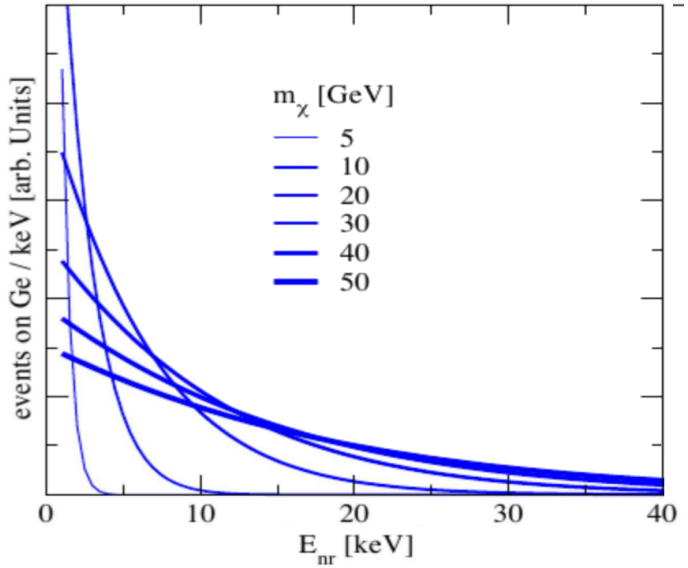
Elastic Scattering of WIMPs off target nuclei
➡ nuclear recoil



Recoil Spectra:

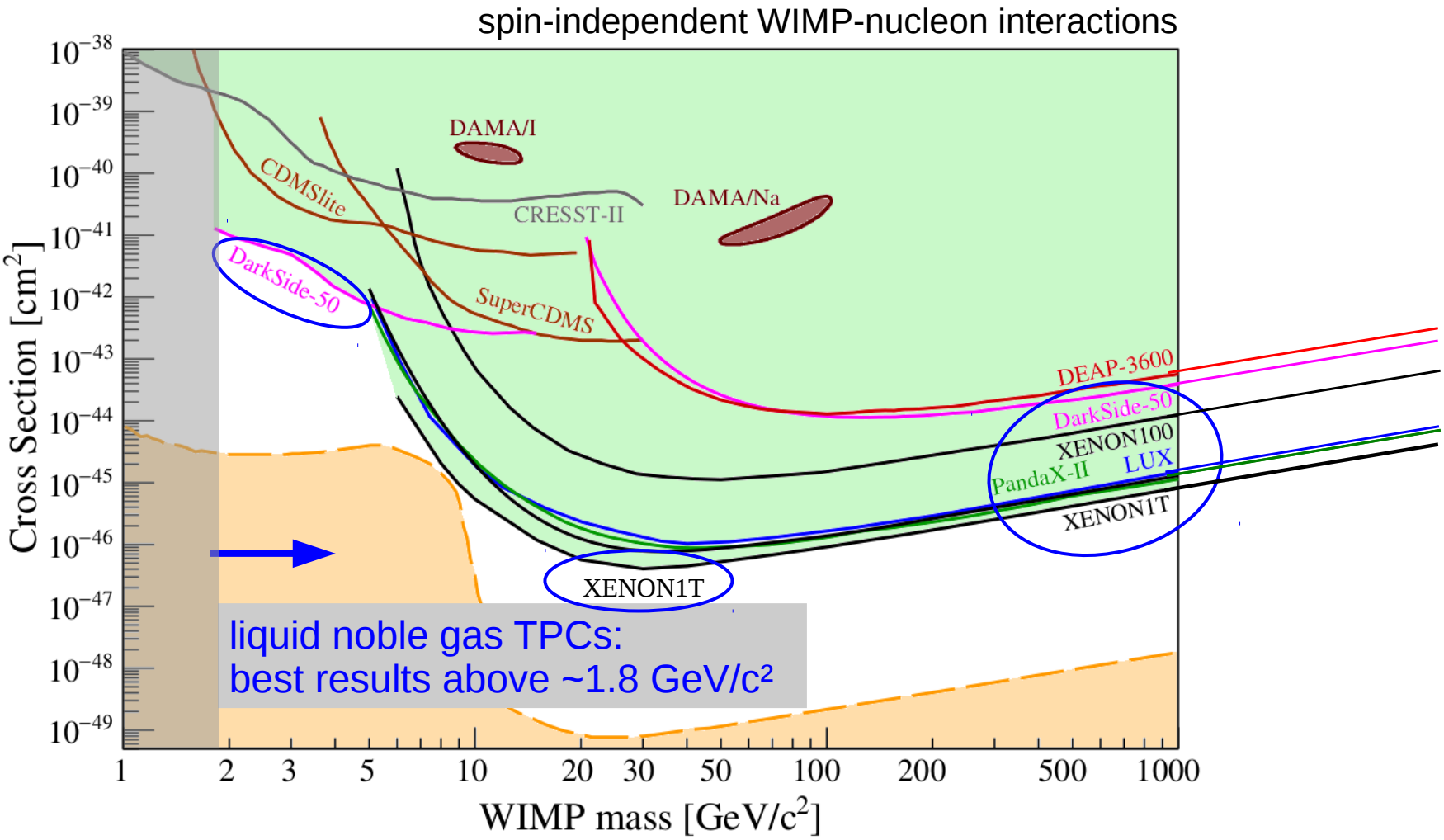


tiny!



tiny!

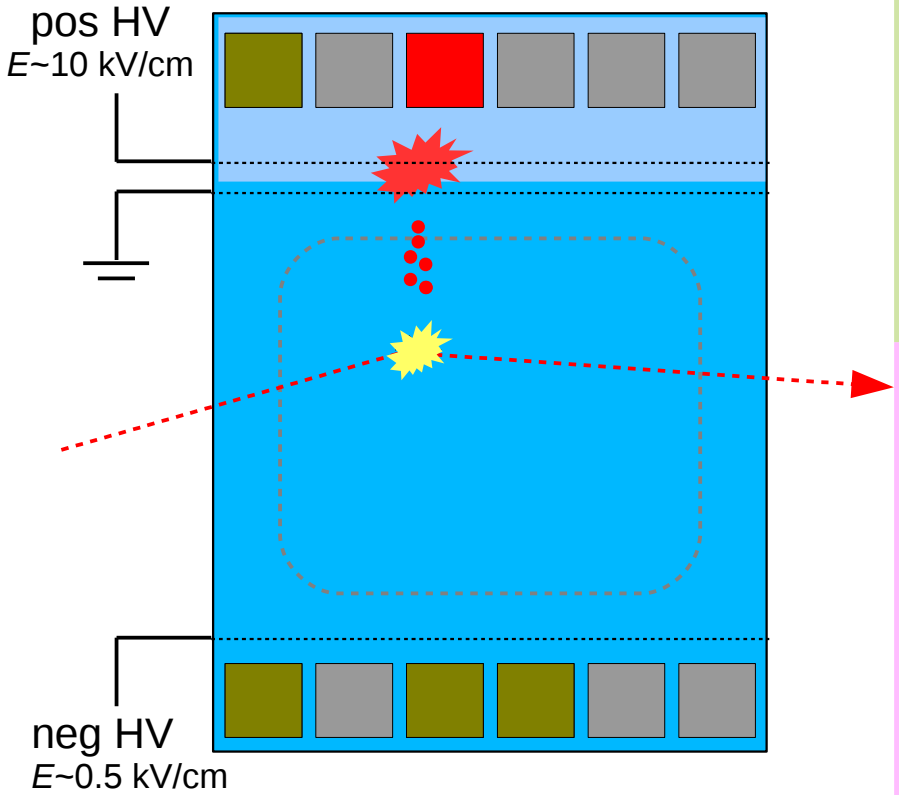
Current Status

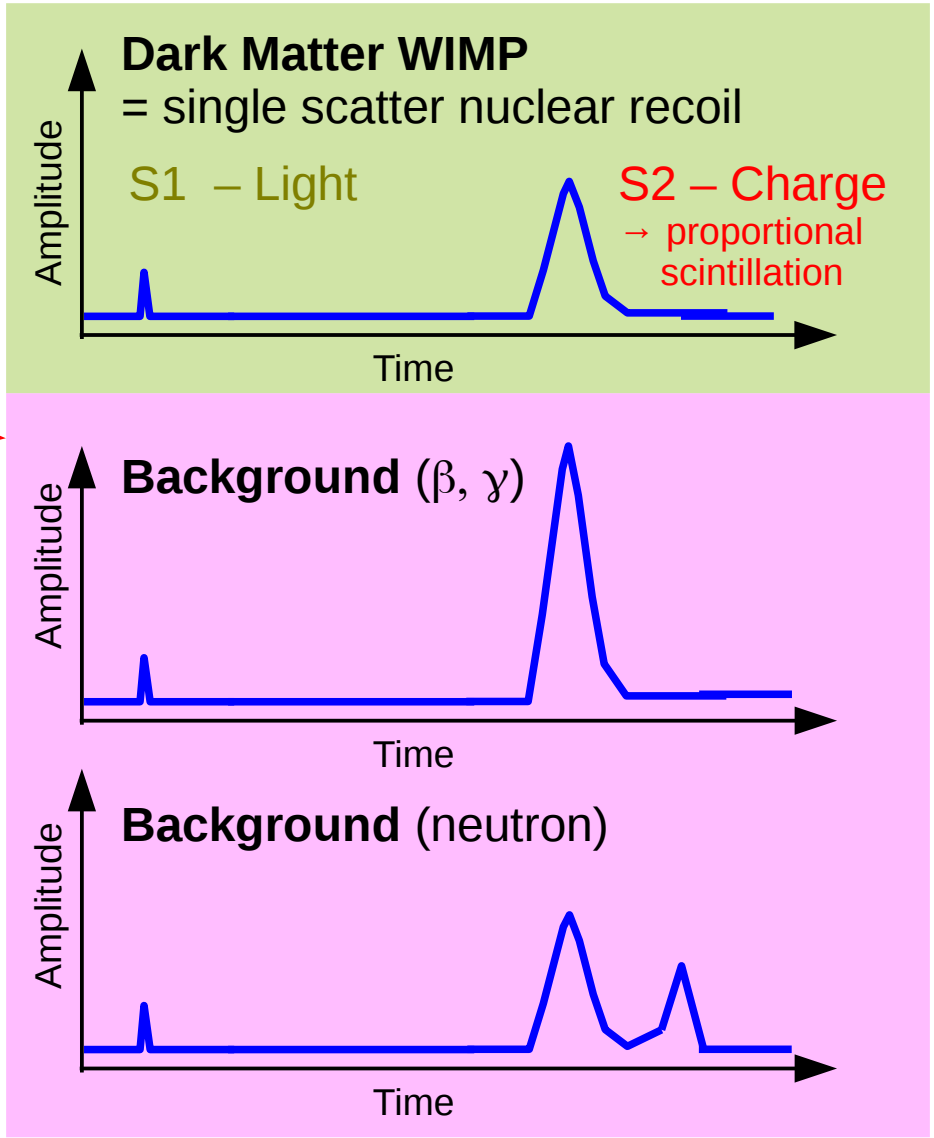


some results are missing...

Dual-Phase LXe TPC

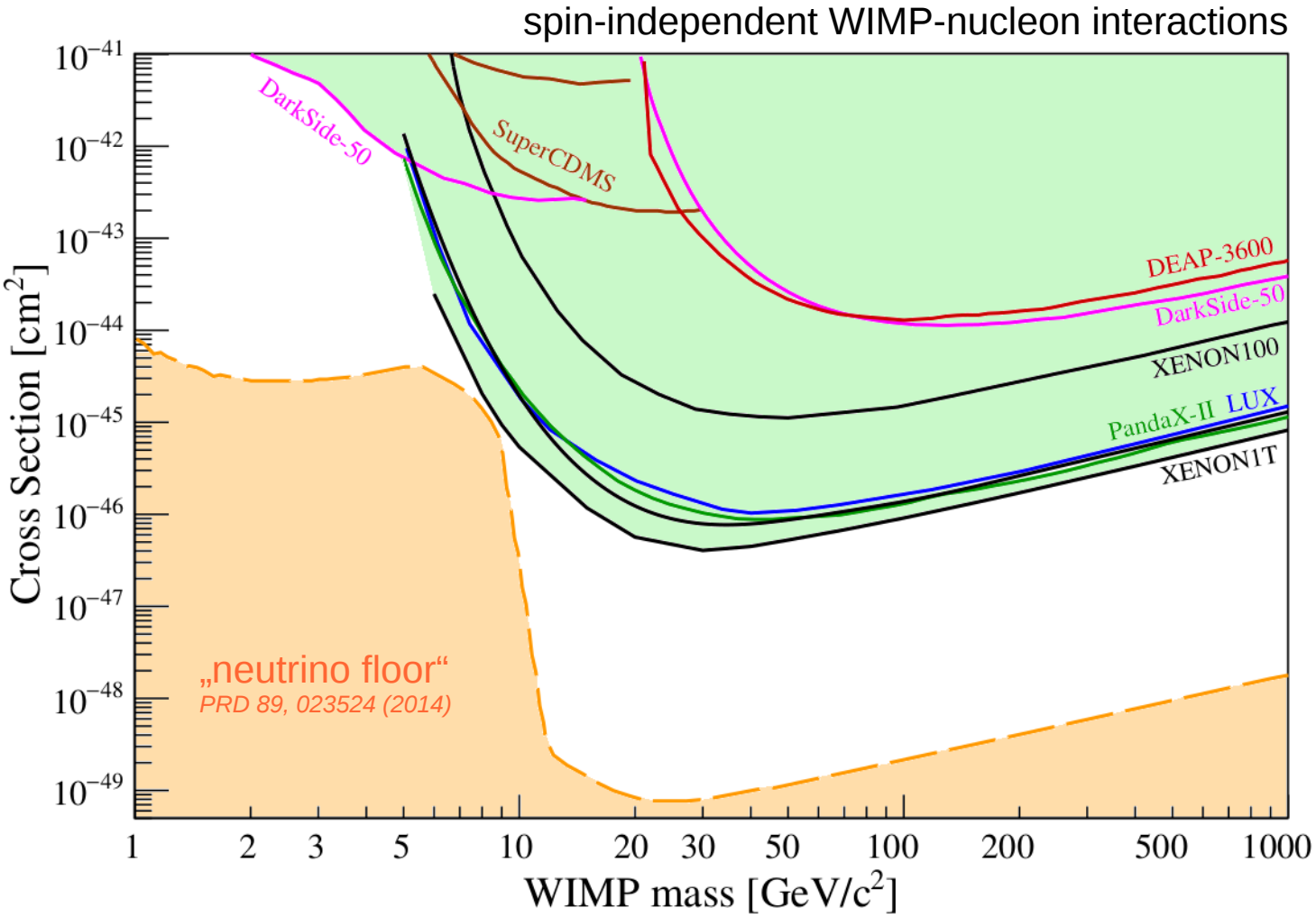
TPC = time projection chamber





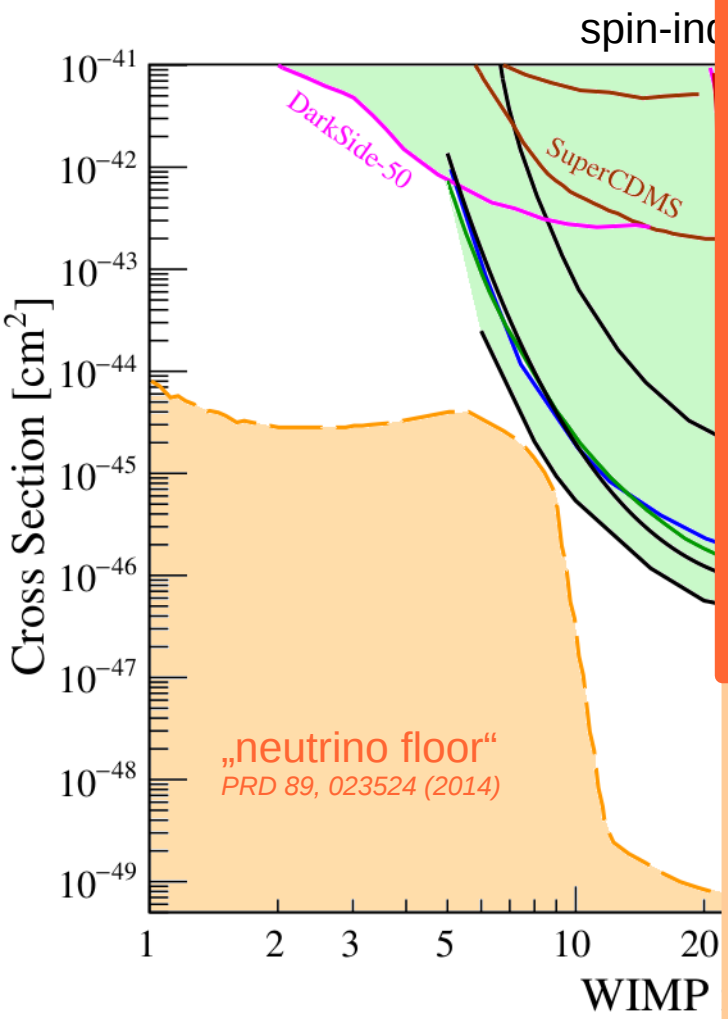
- 3d position reconstruction
  → target fiducialization
- background rejection

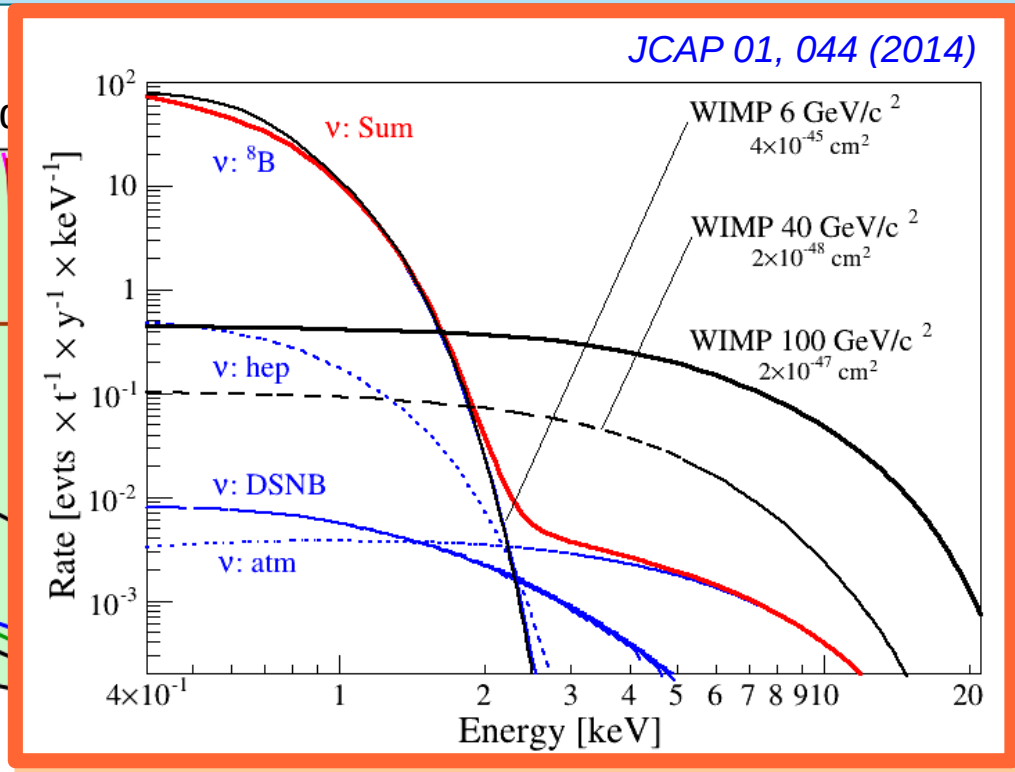
The ultimate Limit



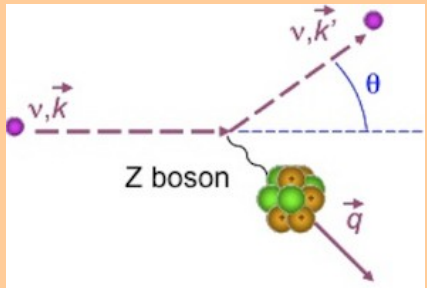
some results are missing...

The ultimate Limit



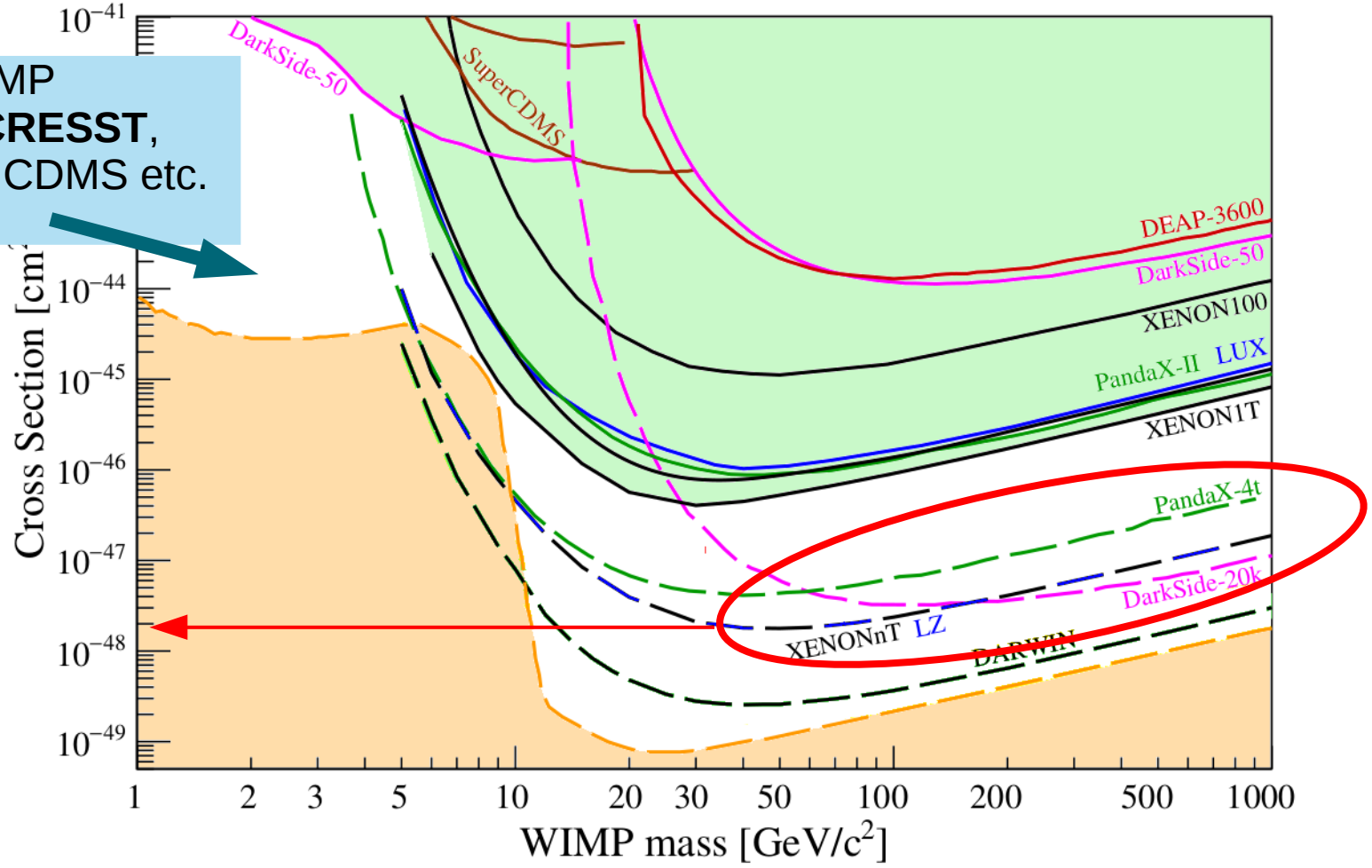


Interactions from coherent neutrino-nucleus scattering (CNNS) will dominate
→ **ultimate background** for direct detection



Upcoming Projects

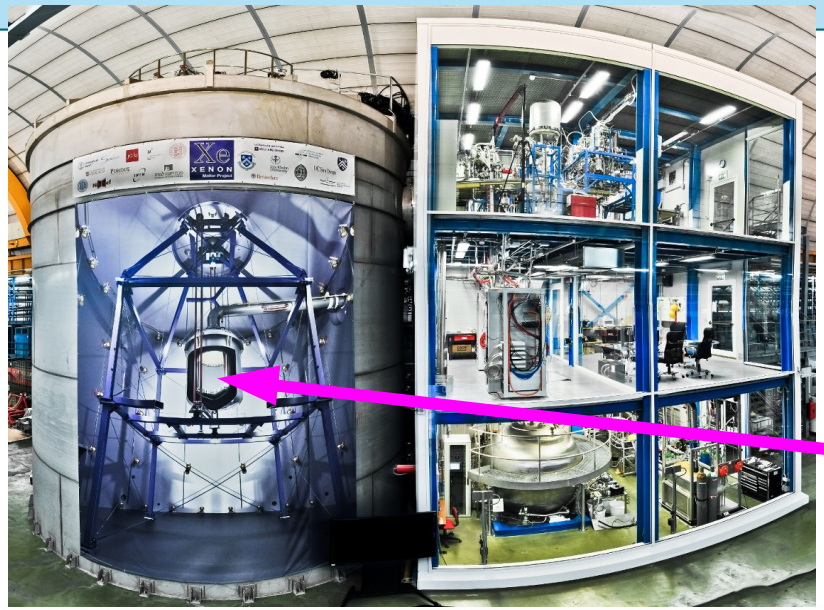
Low-mass WIMP searches by **CRESST**, EDELWEISS, CDMS etc. ignored here!



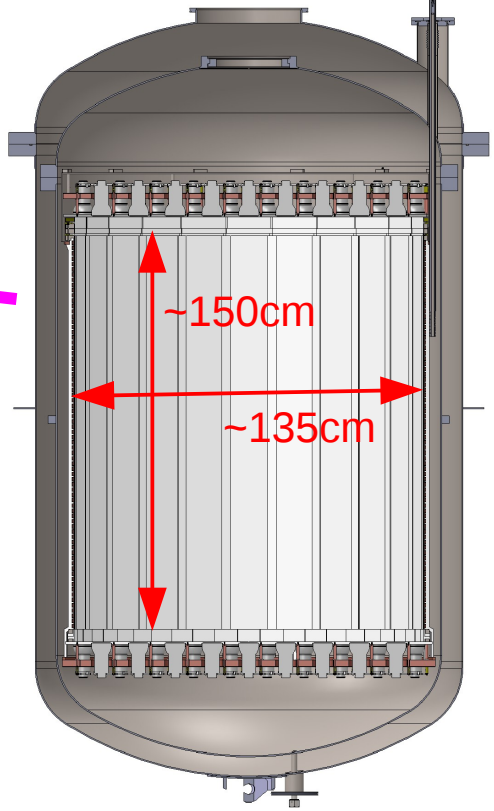
some results are missing...

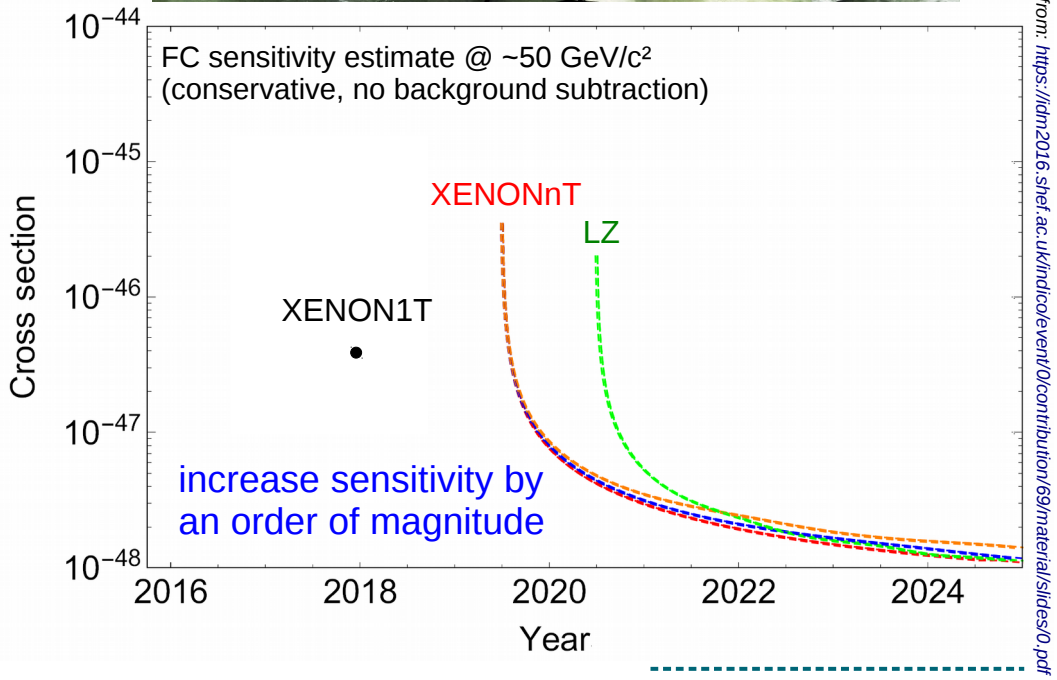
XENONnT

JCAP 04, 027 (2016)



- @ LNGS using existing XENON1T systems (existing μ-veto + new n-veto)





LZ info from: https://idm2016.shef.ac.uk/indico/event/0/contribution/69/material/slides/0.pdf

- **3x larger** than XENON1T

5.9t active LXe target

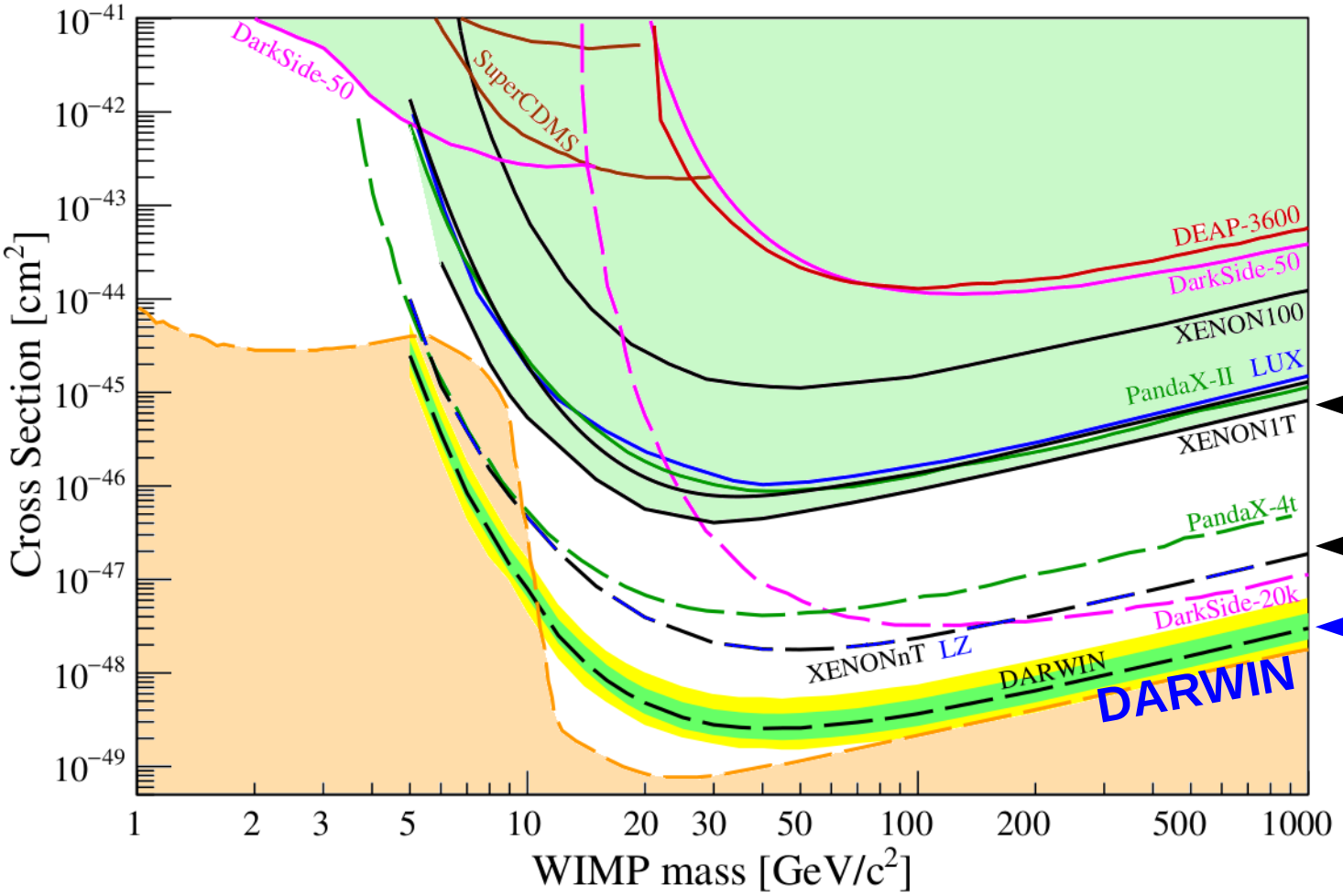
- start science by *mid 2019*

DARWIN The ultimate WIMP Detector

DARWIN

darwin-observatory.org

LXe-based



DARWIN The ultimate WIMP Detector

JCAP 11, 017 (2016)

darwin-observatory.org

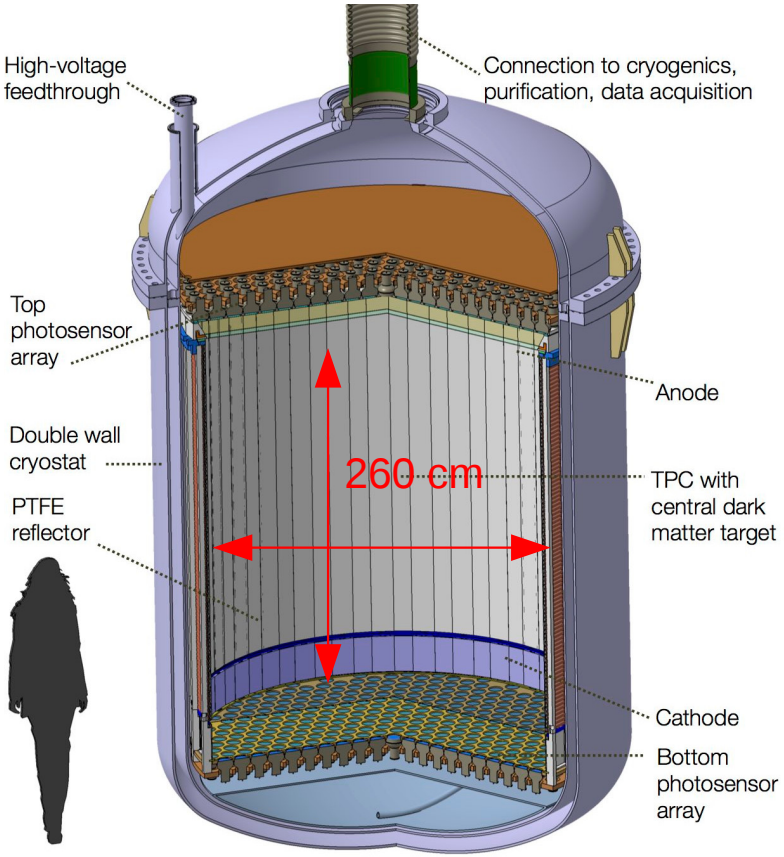
LXe-based

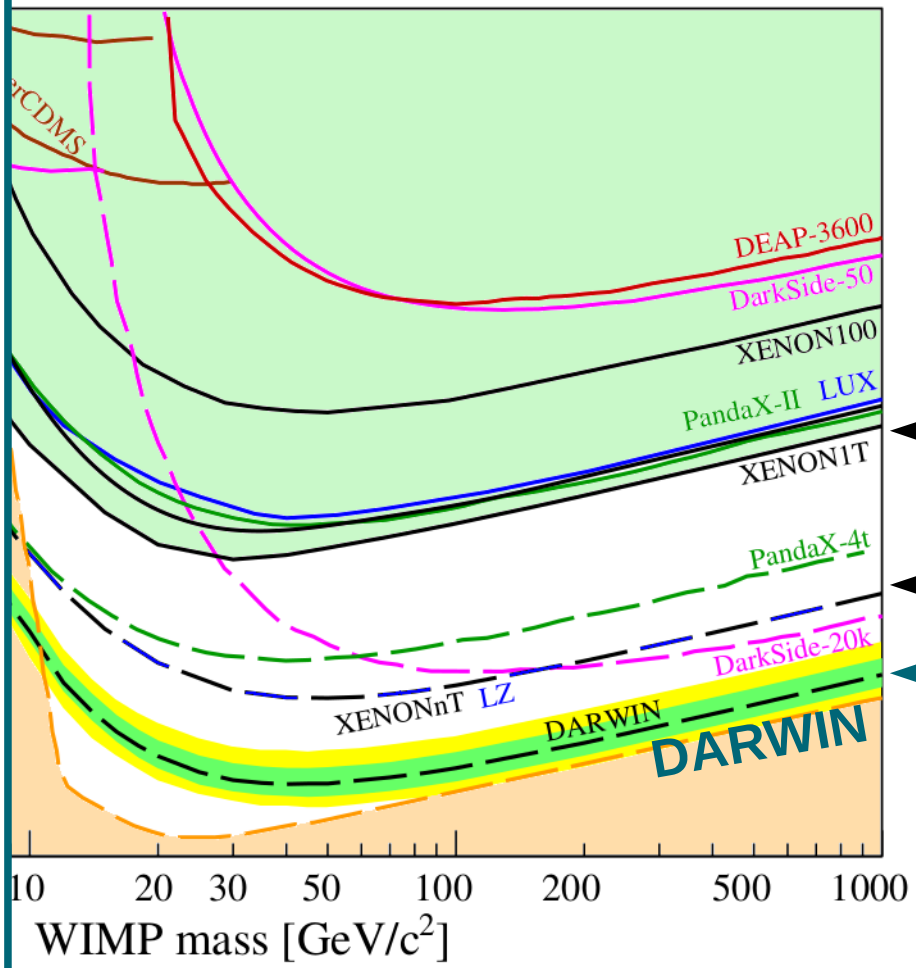
Baseline scenario

~50t total LXe mass

~40 t LXe TPC

~30 t fiducial mass





Exposure

1 t×y

20 t×y

200 t×y

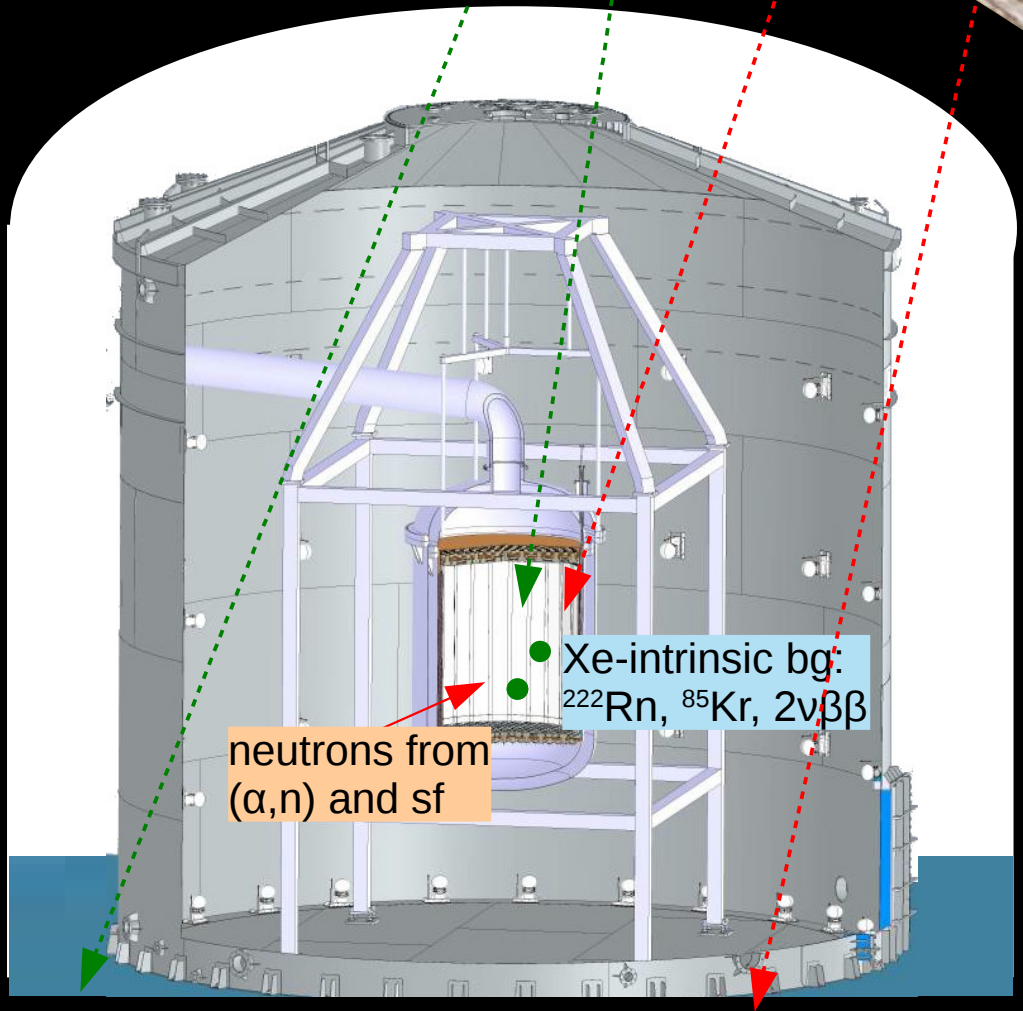
DARWIN Backgrounds

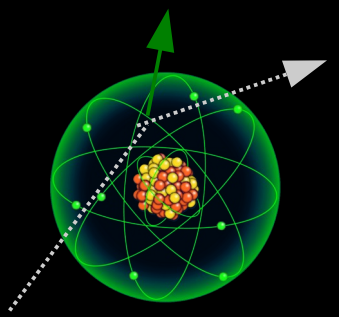
pp+^{7}Be neutrinos
→ ER signature

high-E neutrinos
→ CNNS bg
→ NR signature

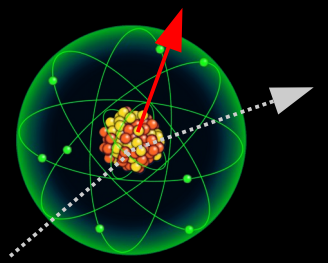
Remaining background sources:
– Neutrinos (→ ERs and NRs)
– Detector materials (→ n)
– Xe-intrinsic isotopes (→ e^-)
(assume 100% effective shield (~15m) against μ-induced background)

JCAP 10, 016 (2015)





Electronic Recoils
(gamma, beta)



Nuclear Recoils
(neutron, WIMPs)

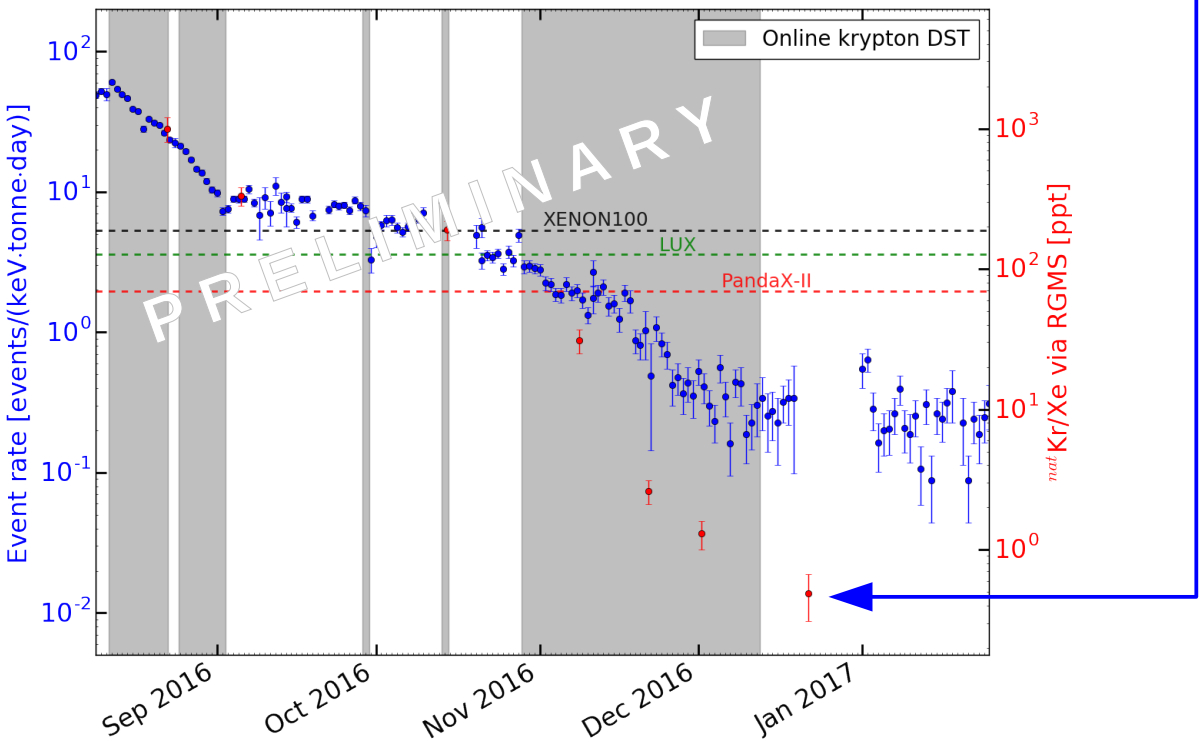
only single scatters

LXe: Krypton Removal

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

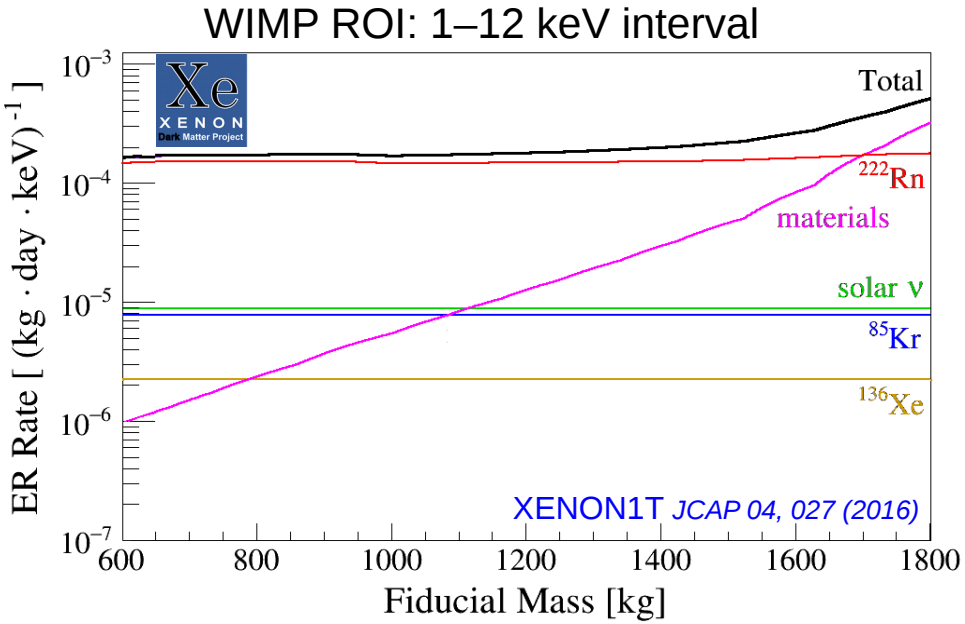
XENON1T: distillation column built by Münster group *EPJ. C 77, 275 (2017)*

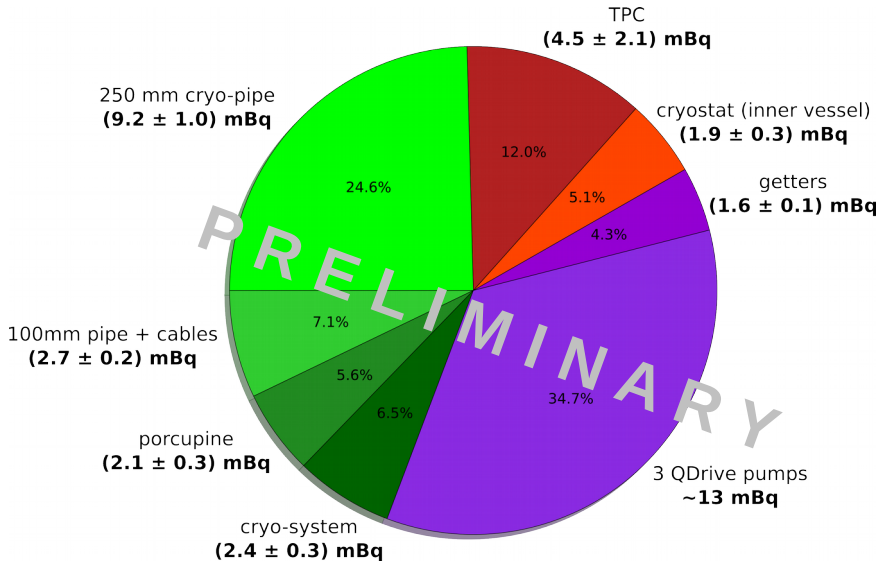
^{nat}Kr/Xe = (0.6±0.1) ppt achieved
by novel online distillation
→ lowest value in LXe experiments ever



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

LXe: Radon Background





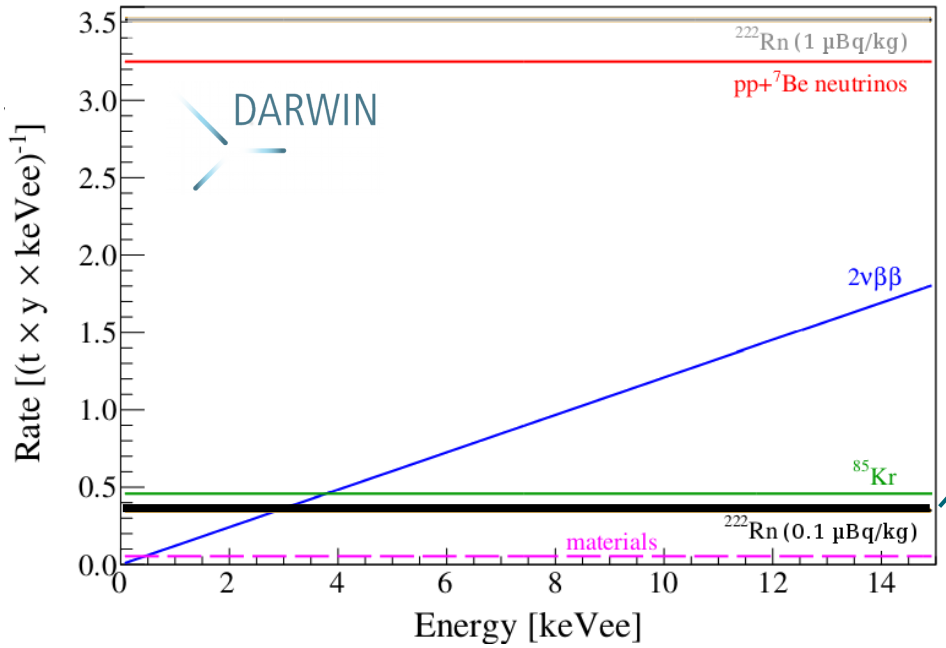
Current Strategy avoid Rn emanation → select clean materials

MPIK expertise

XENON1T goal 10 µBq/kg

measured **(12±1) µBq/kg**

LXe: Radon Background

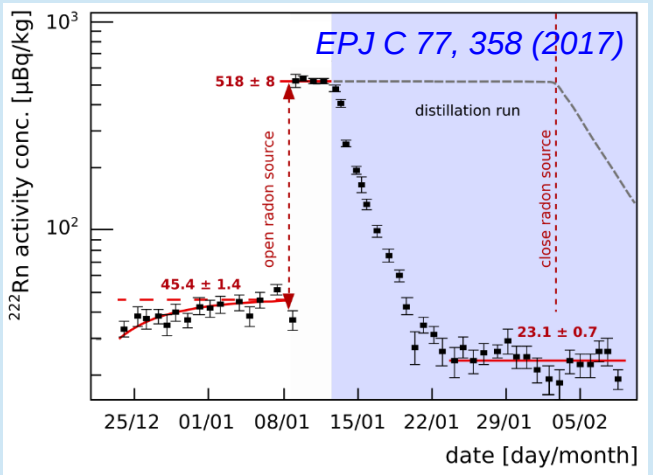


DARWIN goal:
ER background dominated
by solar neutrinos

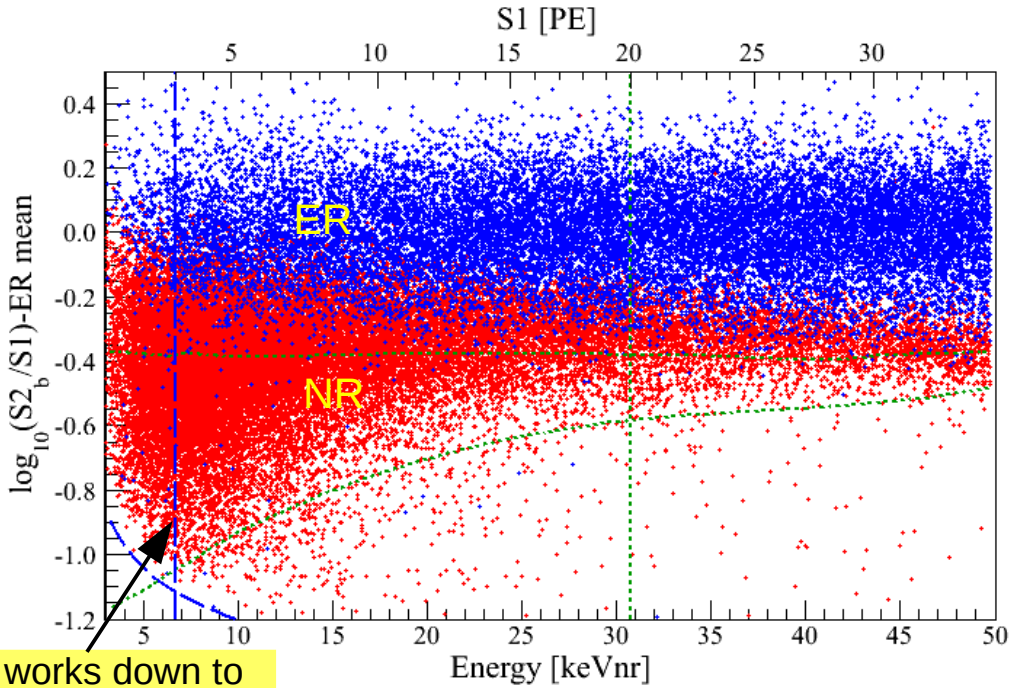
^{222}Rn factor 100 below XENON1T
→ **this is the main background challenge**

Strategy XENONnT → DARWIN
– avoid Rn by material selection
– avoid Rn by detector design
– NEW: **active Rn removal**

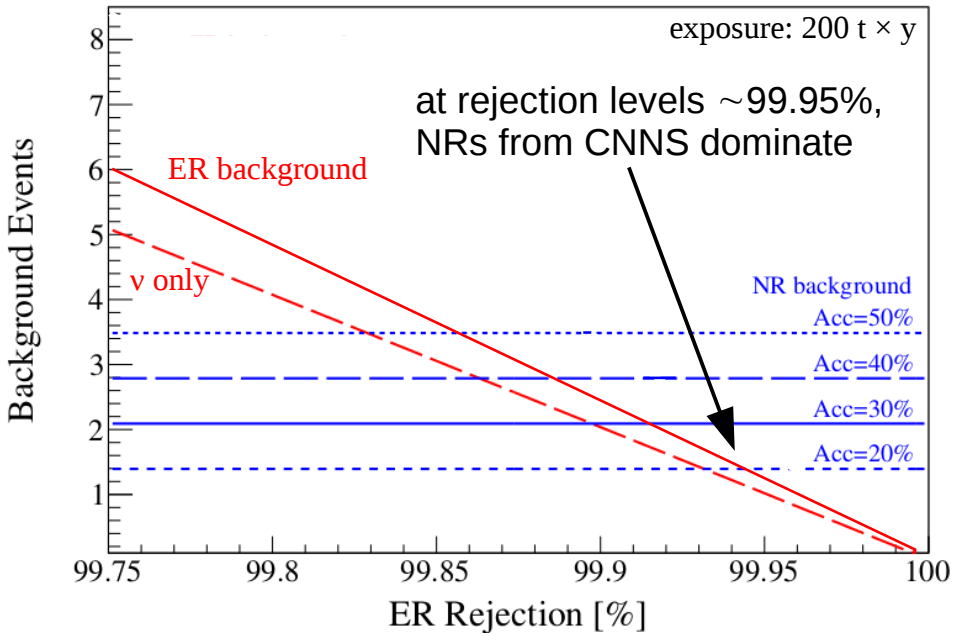
– **cryogenic distillation**
XENON1T distillation column installed @ XENON100
→ demonstrated **reduction factor >27** (@ 95% CL)
→ dedicated column under development @ Münster



ER Background Rejection



works down to low-E threshold



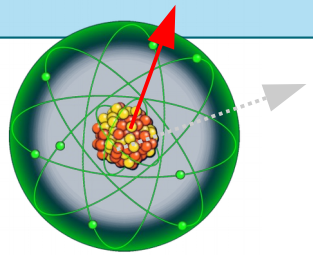
Charge-Light-Ratio (S2/S1):
Signal partition in light/charge depends on d*E*/d*x*
→ the interaction type

→ high light yield should improve rejection level

	E_{drift} [kV/cm]	LY @ 122 keV [PE/keV]	NR acc [%]	ER rej [%]
XENON1T	0.08	8.0	50	2×10^{-3}
XENON100	0.53	3.8	30	1×10^{-3}
LUX	0.18	8.8	50	$1..10\times10^{-3}$
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)*

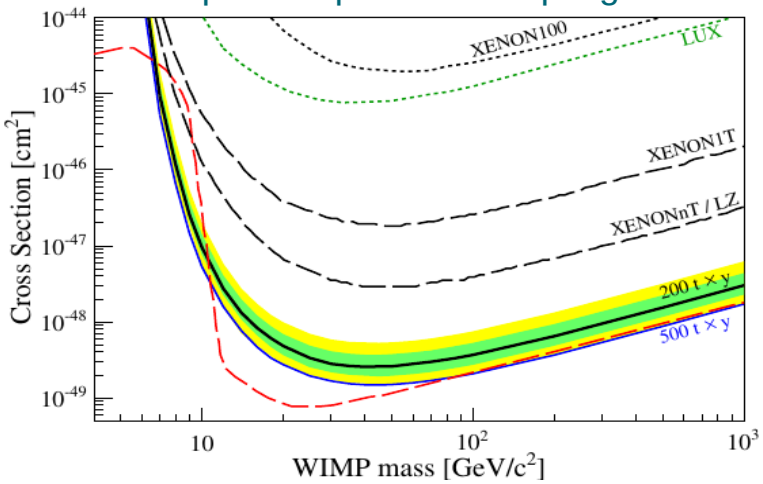
– **spin-independent** mid/high mass

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

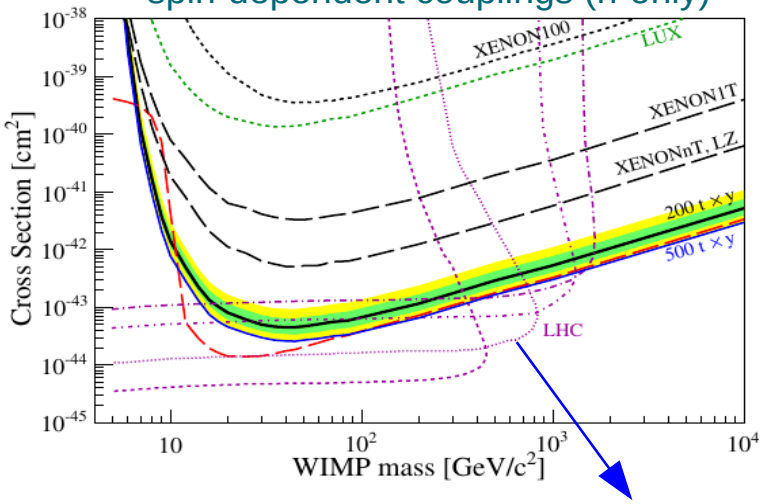
→ complementary with LHC, indirect det.

– various inelastic models (χ, n, MiDM, …)

spin-*in*dependent couplings



spin-dependent couplings (n-only)

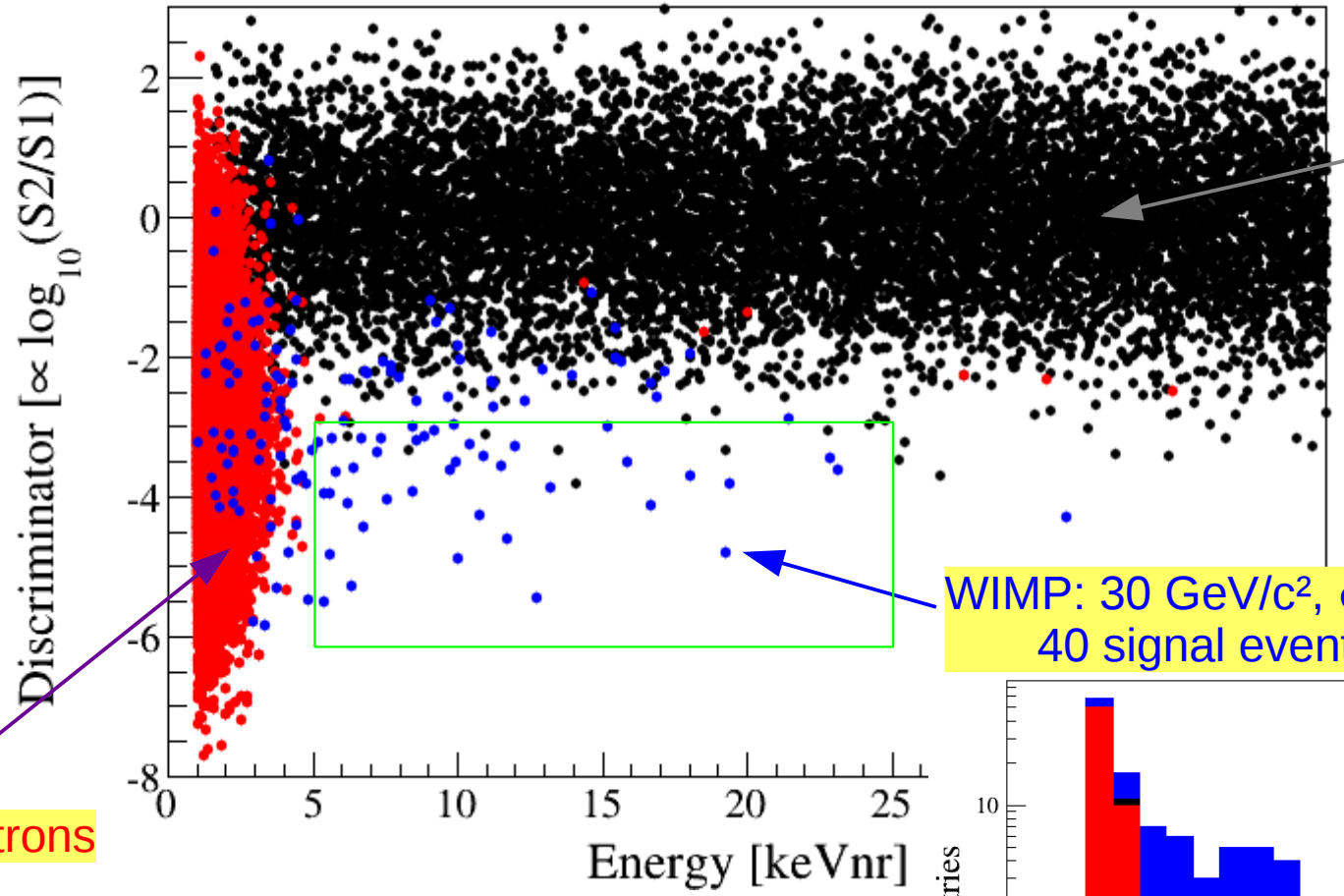


excellent complementarity to LHC searches

p-only complementary to indirect searches

WIMP Detection

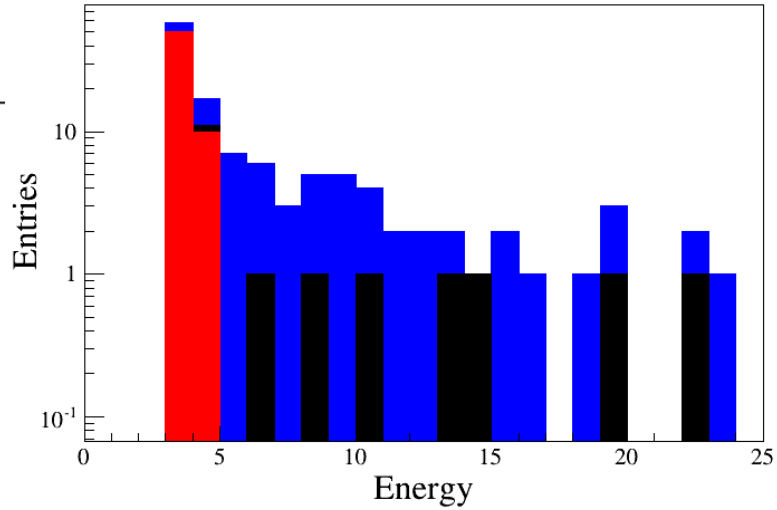
Backgrounds from JCAP 10, 016 (2015)



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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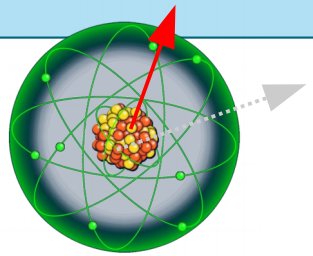

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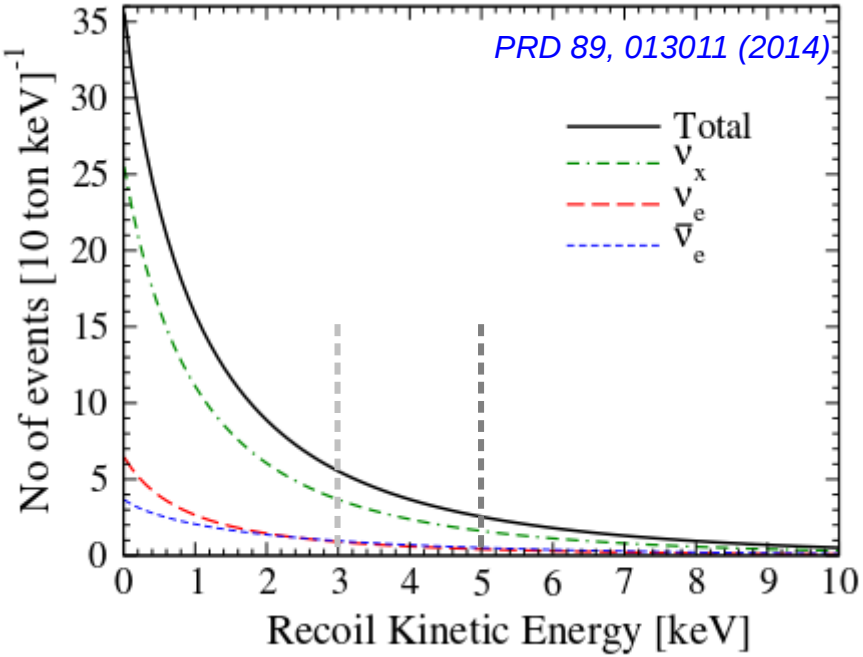
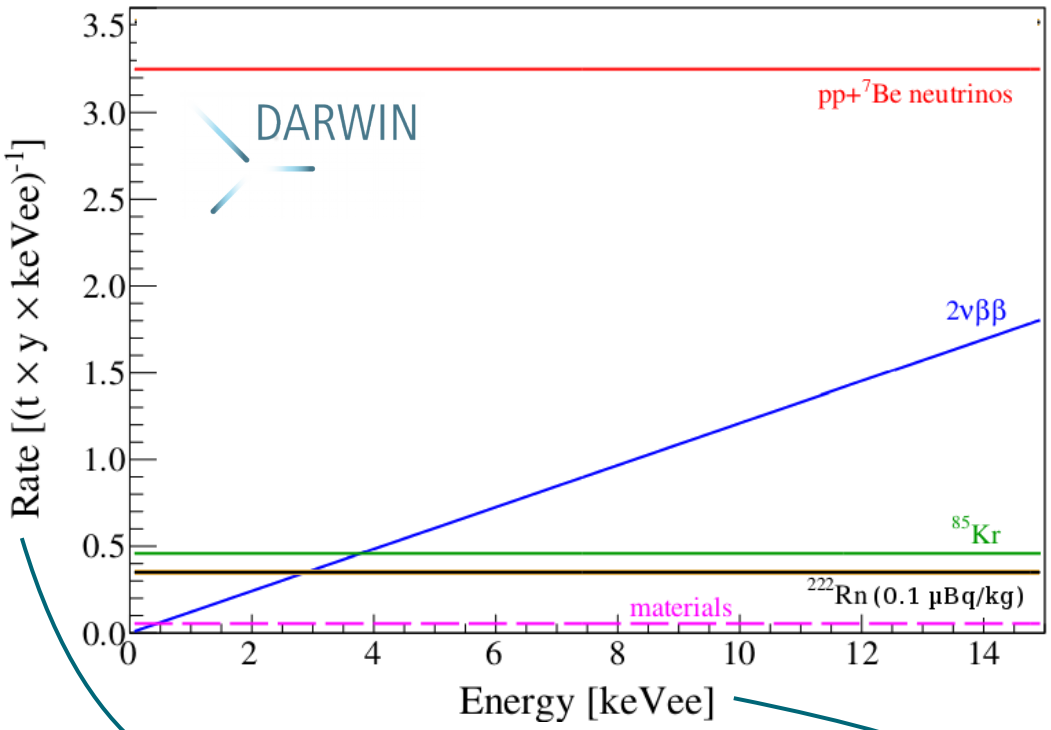
– various inelastic models (χ, n, MiDM, …)

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

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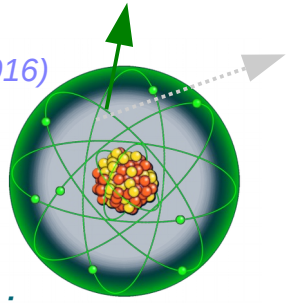
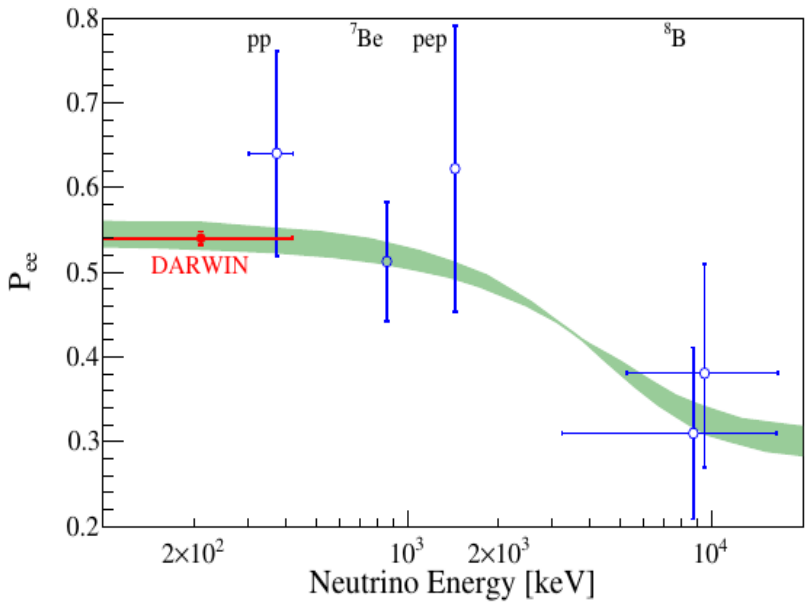


Electronic Recoil Interactions

Non-WIMP dark matter and neutrino physics
– axions, ALPs *JCAP 1611, 017 (2016)*
– sterile neutrinos
– **pp, ^{7}Be: precision flux measurements** *JCAP 01, 044 (2014)*
– CNO neutrinos with ^{136}Xe-depleted Xe *arXiv:1807.07169*



30t target mass, 2-30 keV window
→ 2850 neutrinos per year (89% pp)
→ achieve 1% statistical precision on pp-flux (→P_{ee}) with 100 t x y

DARWIN: Science Channels

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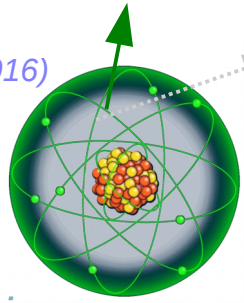

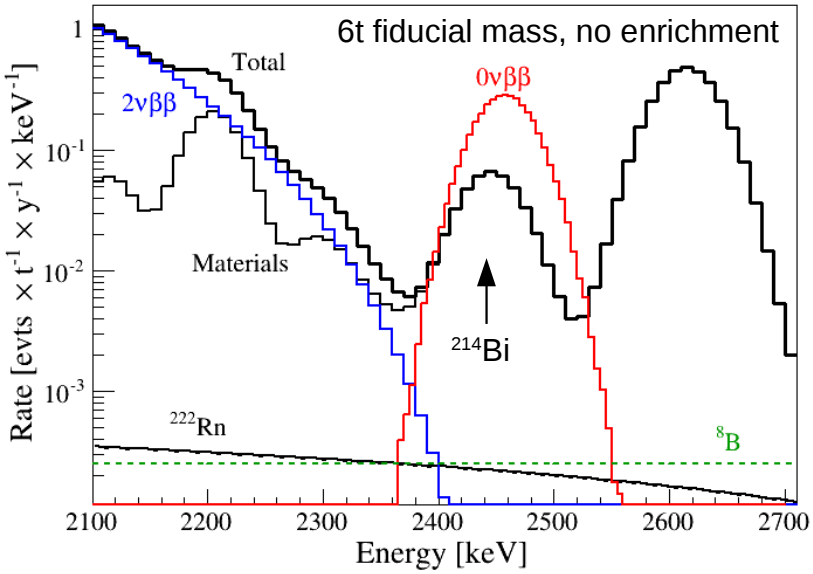

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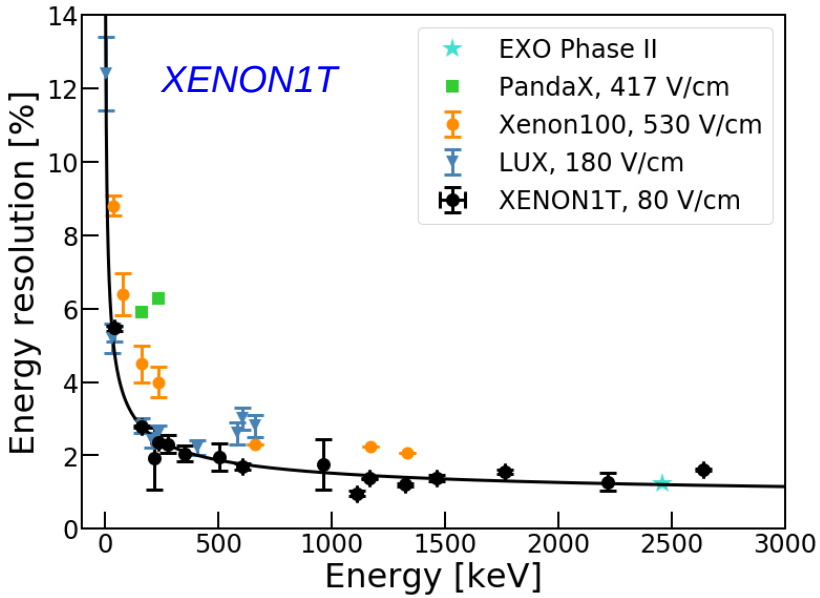
Rare nuclear events
– **0νββ (^{136}Xe)**, 2νEC (^{134}Xe), …
JCAP 01, 044 (2014)



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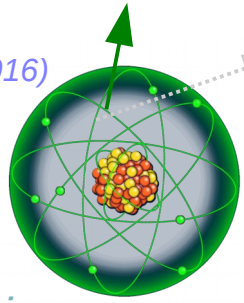
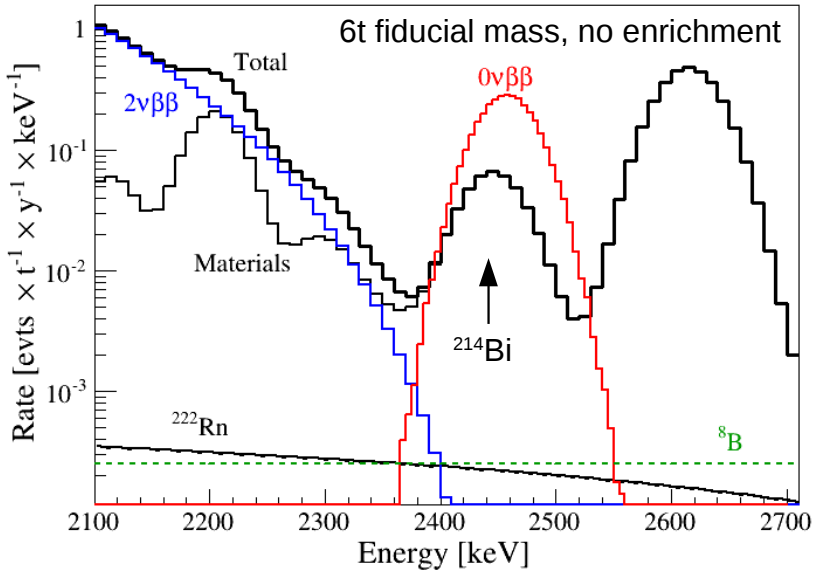
Coherent neutrino-nucleon scattering (CNNS)
– ^{8}B neutrinos (low E), atmospheric (high E)
– supernova neutrinos *JCAP 1611, 017 (2016)*
PRD 89, 013011 (2014), PRD 94, 103009 (2016)

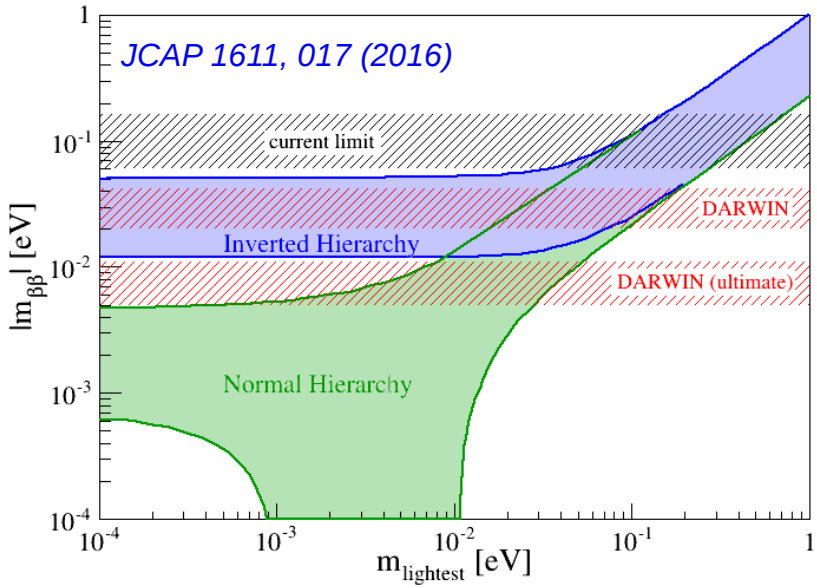




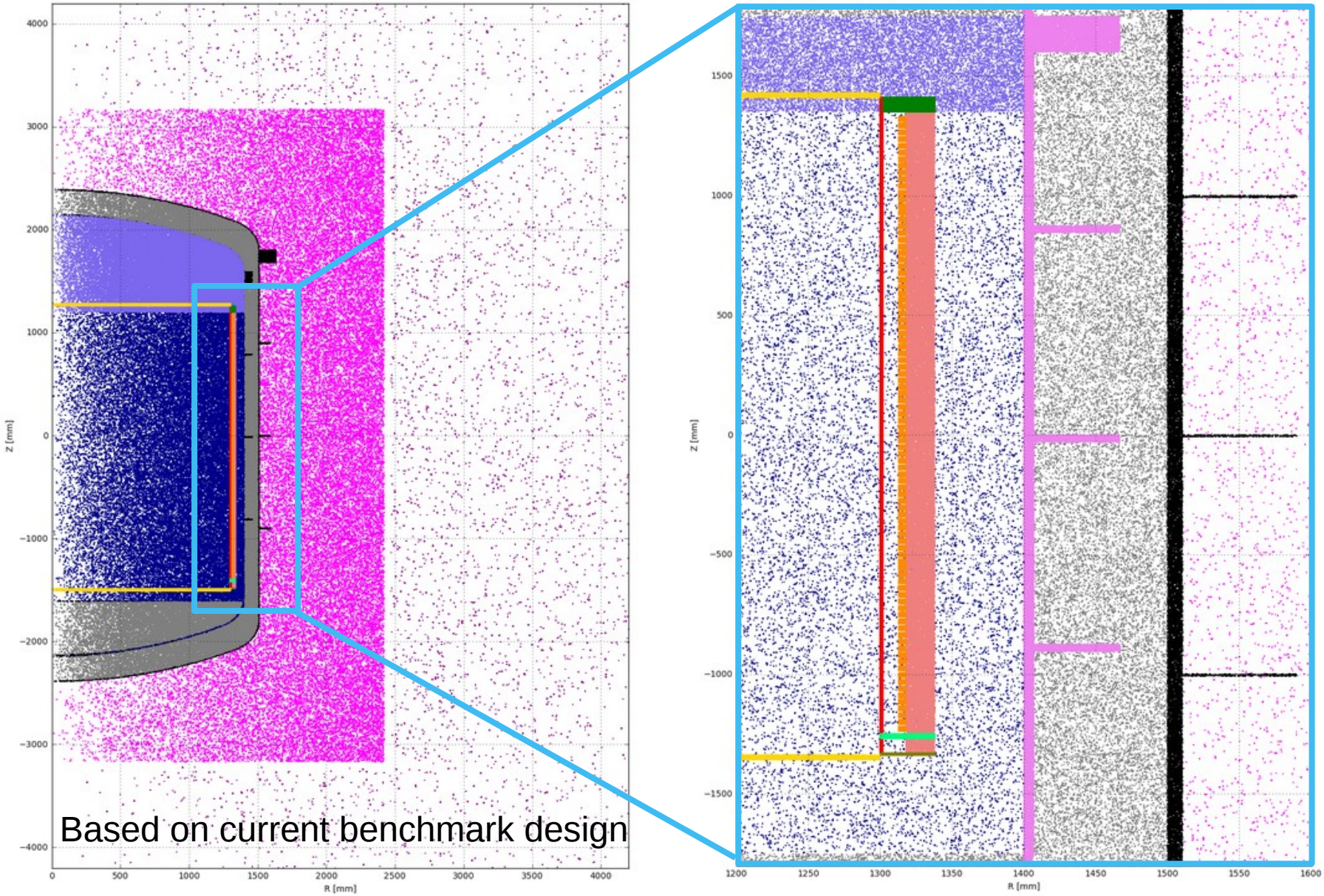
Electronic Recoil Interactions

Non-WIMP dark matter and neutrino physics
– axions, ALPs *JCAP 1611, 017 (2016)*
– sterile neutrinos *JCAP 01, 044 (2014)*
– pp, ^{7}Be: precision flux measurements
– CNO neutrinos with ^{136}Xe-depleted Xe *arXiv:1807.07169*

Rare nuclear events
– **0νββ (^{136}Xe)**, 2νEC (^{134}Xe), …
JCAP 01, 044 (2014)



Monte Carlo Studies Ongoing

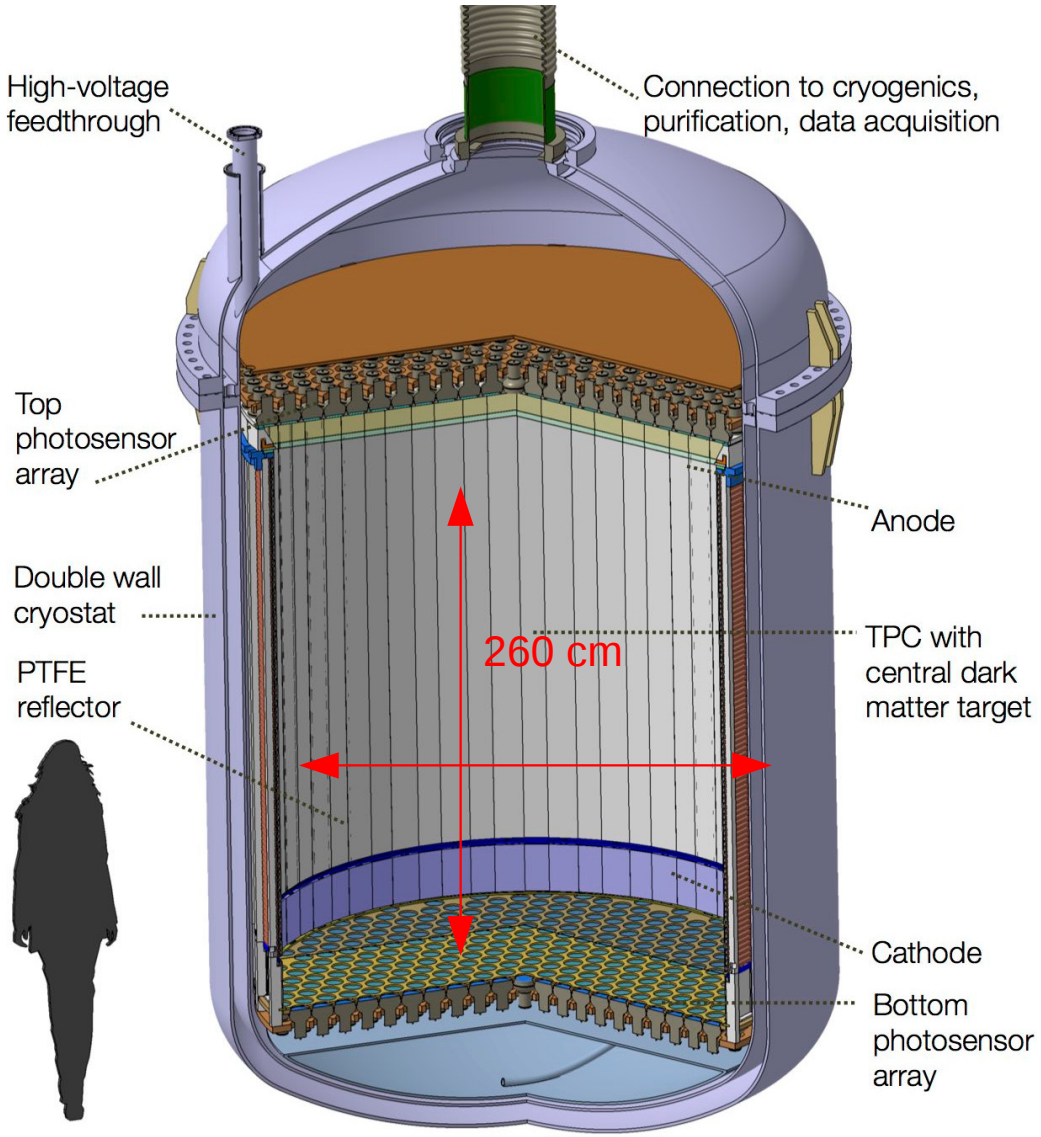


DARWIN: 40t LXe TPC

JCAP 11, 017 (2016)

DARWIN

darwin-observatory.org

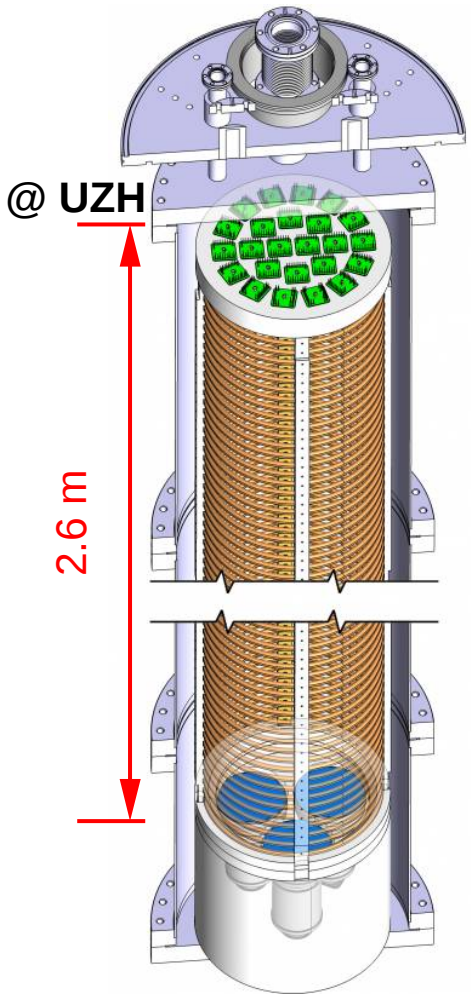


Challenges

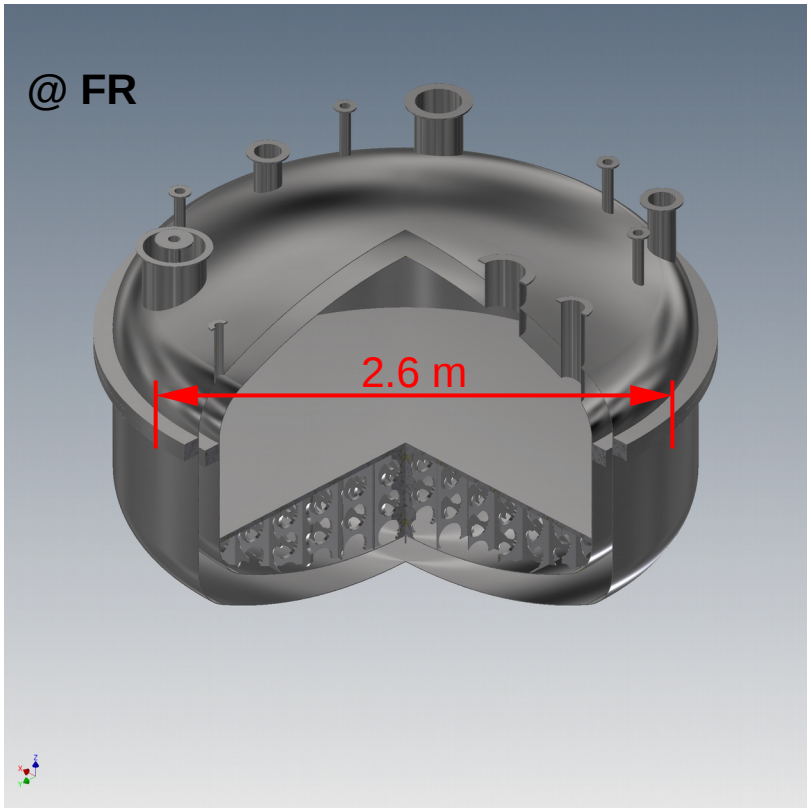
- Size
  - → electron drift (HV)
  - → diameter (TPC electrodes)
  - → mass (LXe purification)
  - → dimensions (radioactivity)
  - → detector response (calibration, corrections)
  - → Xe gas procurement
- Backgrounds
  - → ^{222}Rn: factor 100 required
  - → (α,n) neutrons (from PTFE)
  - → shielding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

Test Platforms + R&D

→ test components at real scale under real conditions in LXe

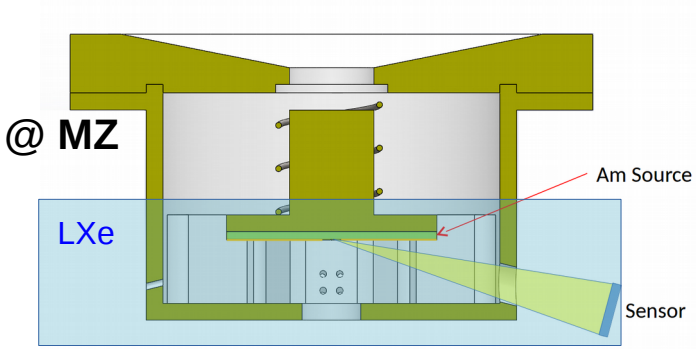


2.6 m

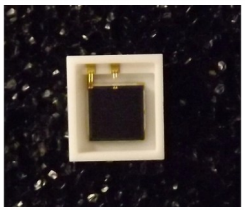


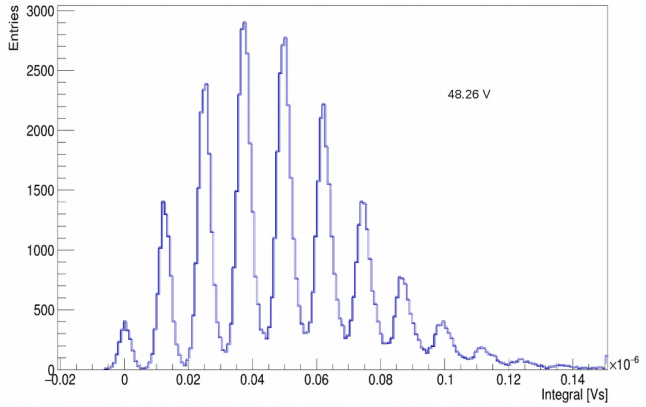
R&D for DARWIN:
– all relevant topics addressed

example: **SiPMs in LXe**



Hamamatsu S13370
(Gen4): 3x3 mm²





Both test-platforms are funded and currently being designed.

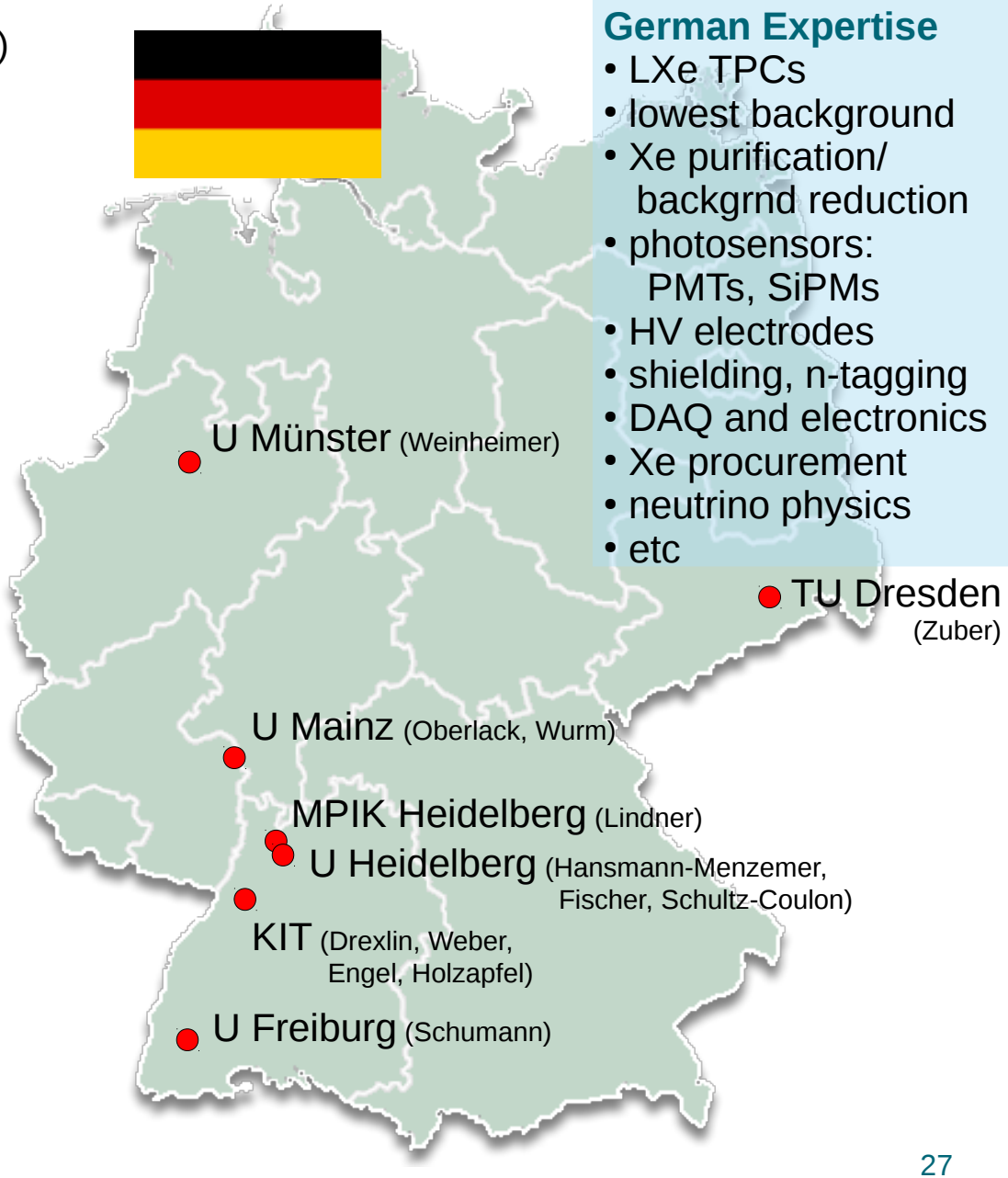
DARWIN Collaboration

DARWIN
darwin-observatory.org

- international collaboration (XENON + new)
- ~150 members, 27 institutions
  - 70% European groups
  - **Germany strongest national group with highly-visible core expertise**
- German leadership roles
  - Drexlin – Exec Board Member
  - Oberlack – Exec Board Member
  - Schumann – Co-Spokesperson
- site for experiment not yet chosen, but close contacts with LNGS
  → submit LOI in spring

→ **unique chance for German-lead European project**

- Current R&D funding:
  - two ERC grants (FR, ZH)
  - start-up funding
  - minor institutional (seed) funding
  - so far neither BMBF nor DFG



German Expertise
- LXe TPCs
- lowest background
- Xe purification/ backgrnd reduction
- photosensors: PMTs, SiPMs
- HV electrodes
- shielding, n-tagging
- DAQ and electronics
- Xe procurement
- neutrino physics
- etc

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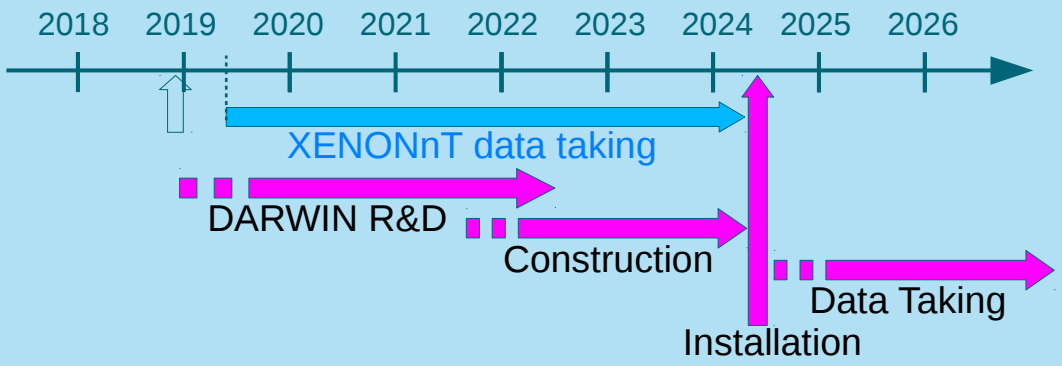
Timeline



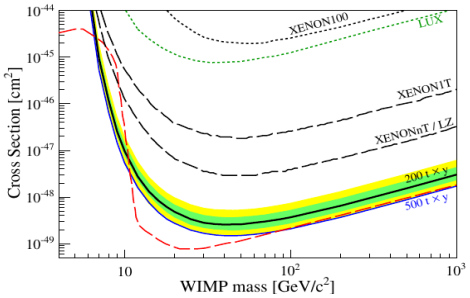
MPIK Heidelberg (Lindner)
U Heidelberg (Hansmann-Menzemer, Fischer, Schultz-Coulon)
KIT (Drexlin, Weber, Engel, Holzapfel)
U Freiburg (Schumann)

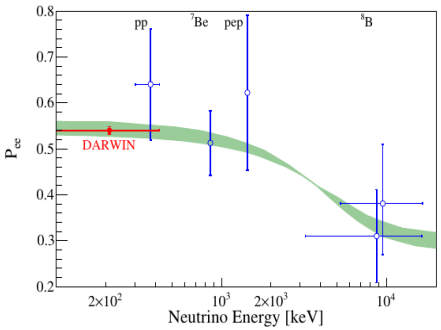
DARWIN: Exciting Opportunities

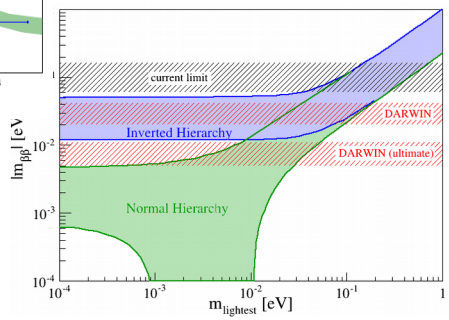
DARWIN: much more than

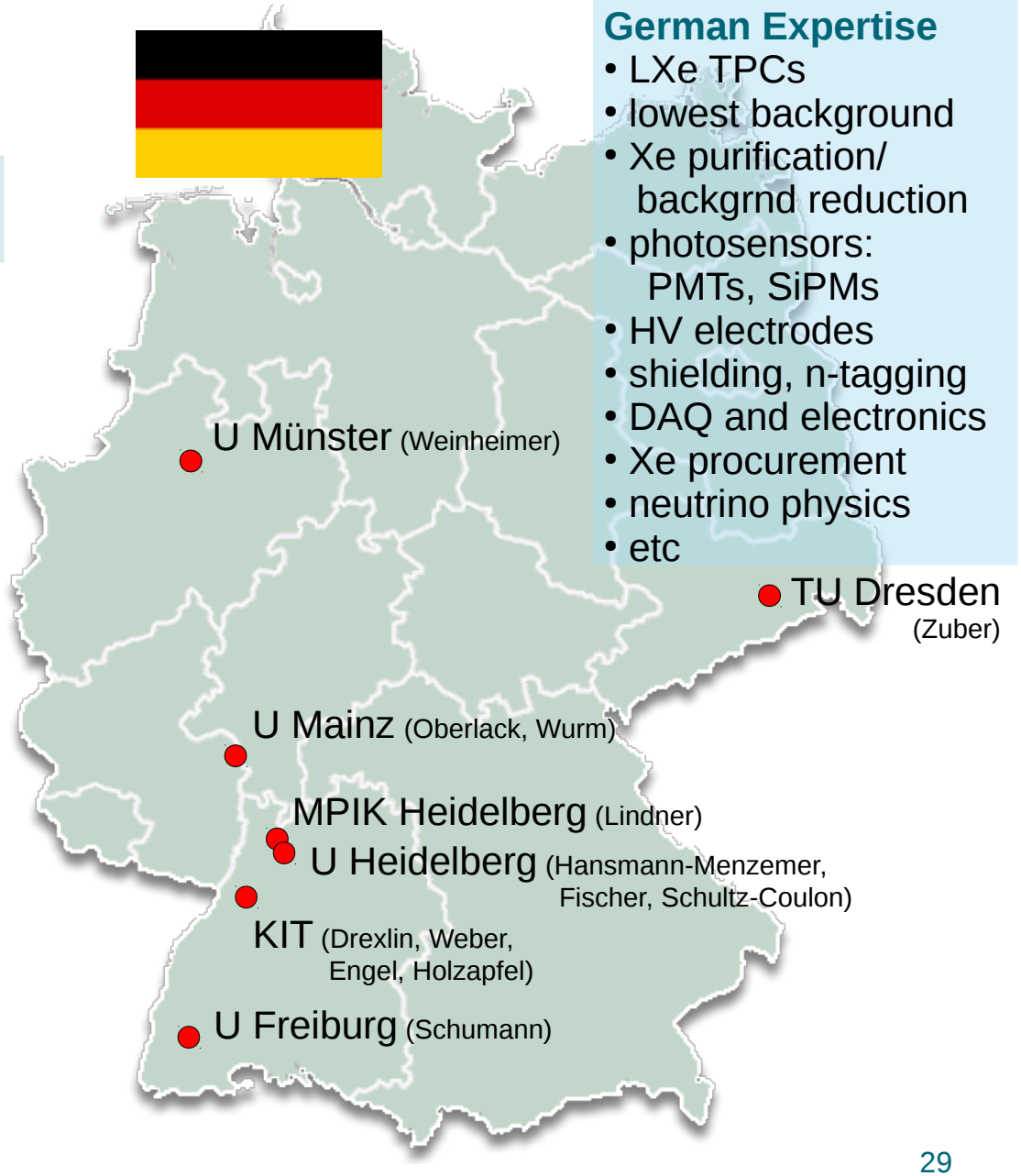
The ultimate Dark Matter Detector

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









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- etc