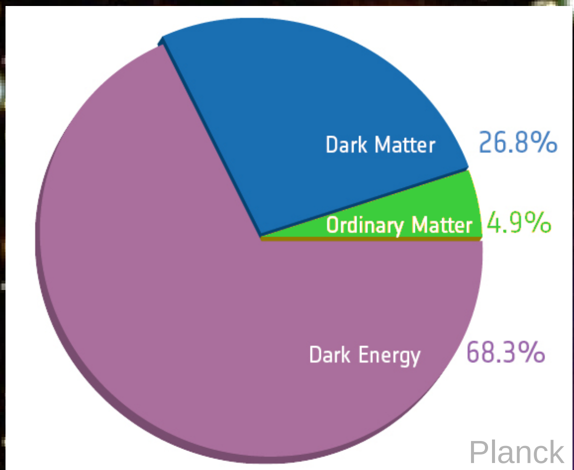
XENON & DARWIN

Marc Schumann *U Freiburg*

41st Intn. School on Nuclear Physics
Erice, September 20, 2019

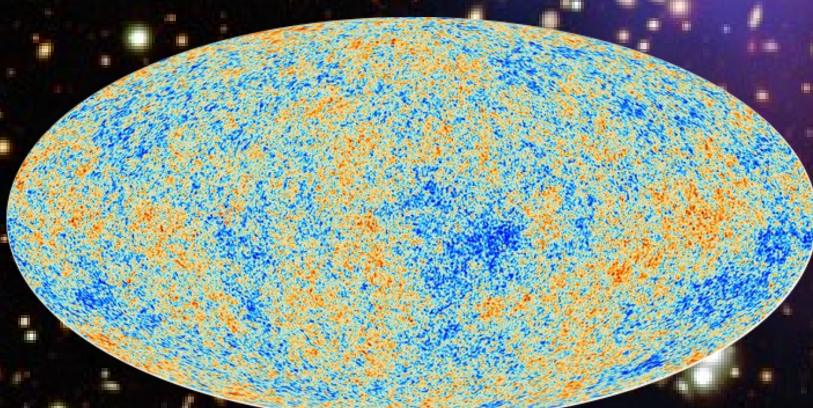
marc.schumann@physik.uni-freiburg.de
www.app.uni-freiburg.de

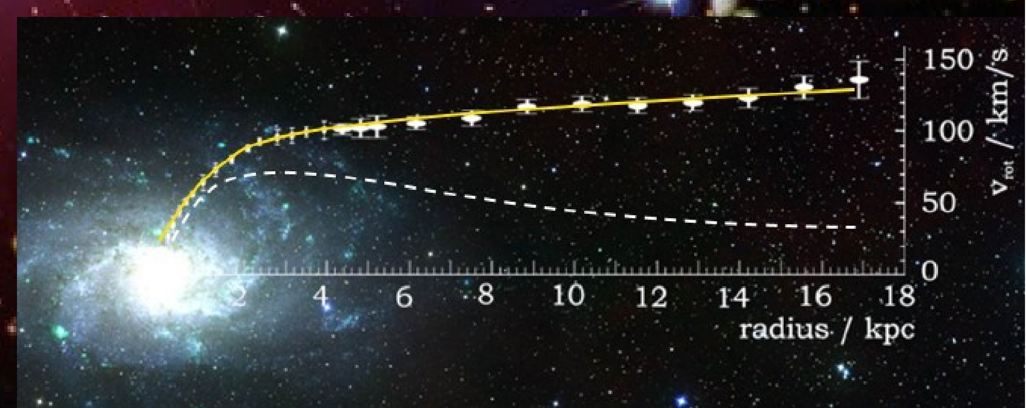
Dark Matter: (indirect) **Evidence**



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

Planck 2018: *arXiv:1807.06209*
„We find no compelling evidence for extensions to the base-ΛCDM model.“





Take-home message

The most sensitive detectors to search for dark matter have a very broad science reach.

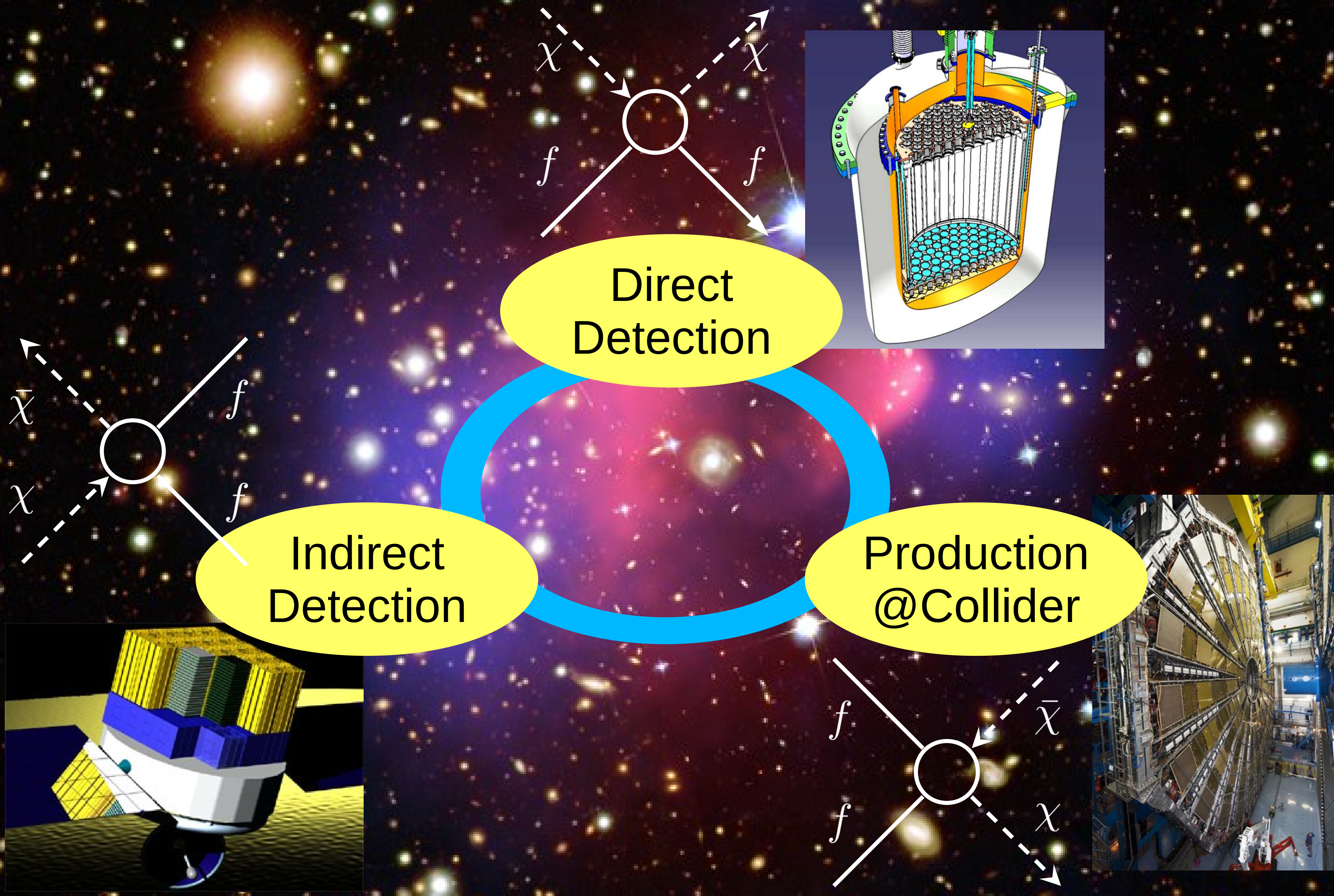
THE DM CANDIDATES ZOO

WIMPs

= weakly interacting massive particles

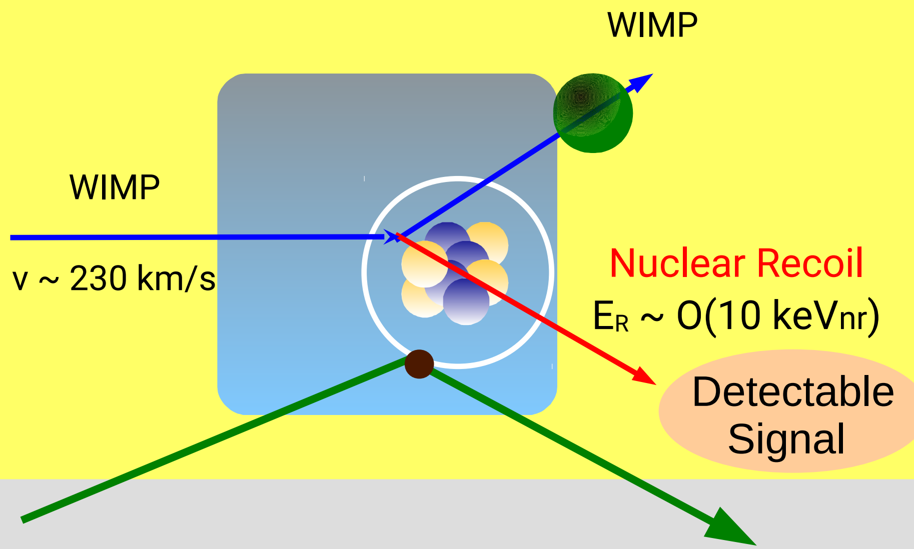
stolen from G. Bertone

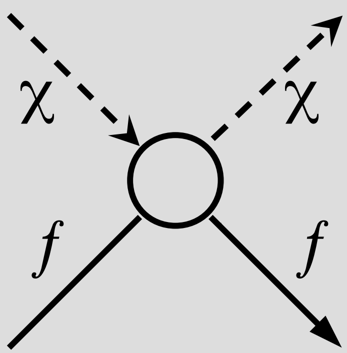
Dark Matter WIMP Search



Direct WIMP Search

Elastic Scattering of WIMPs off target nuclei
→ nuclear recoil





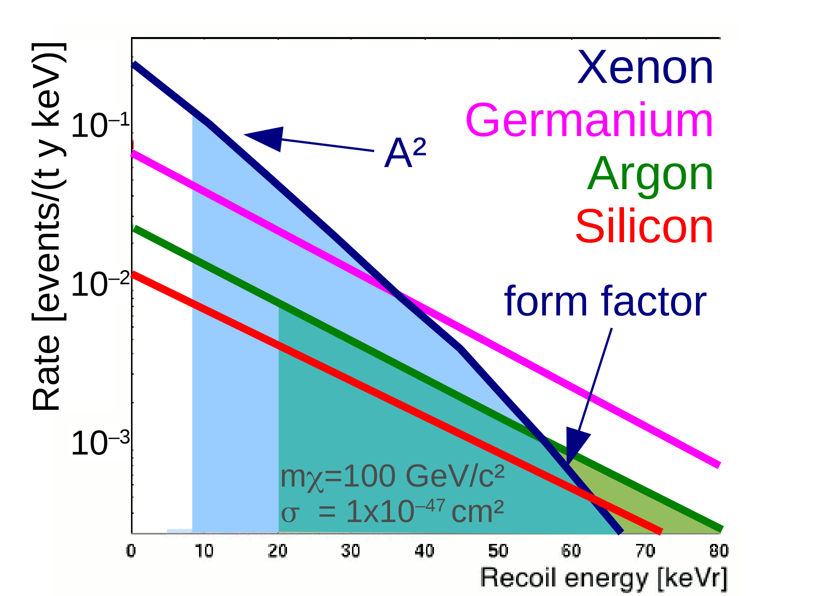
gamma- and beta-particles (background) interact with the atomic electrons
→ **electronic recoil** [in keVee]

Direct WIMP Search

Direct Detection:

$E_r < 100$ keV

$R \ll 1$ evt/kg/year

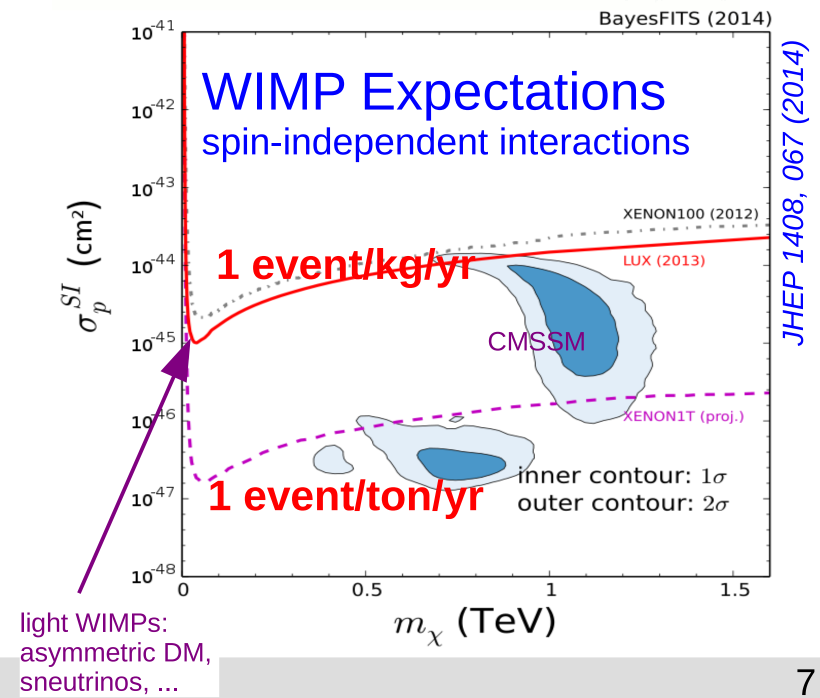


Recoil Energy: $E_r \sim \mathcal{O}(10\ \mathrm{keV})$

Event Rate: $R \propto N \dfrac{\rho_\chi}{m_\chi} \langle \sigma_{\chi-N} \rangle$

Detector — Local DM Density — Physics

$\rho_\chi \sim 0.3$ GeV/c²



WIMP-Nucleon Interactions

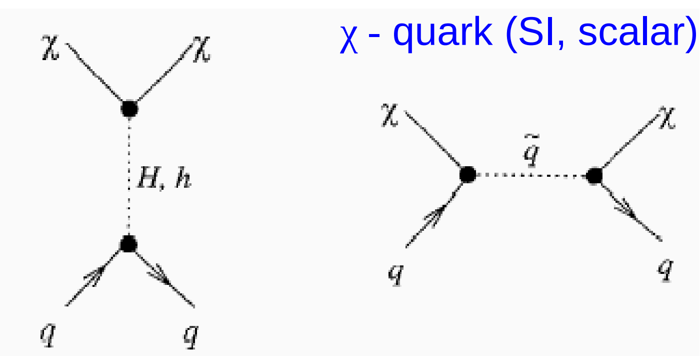
A priori, we do not know how dark matter WIMPs interact with ordinary matter

Parametrization of interactions leading to WIMP-nucleus scattering:

coupling to **matter**

Spin independent

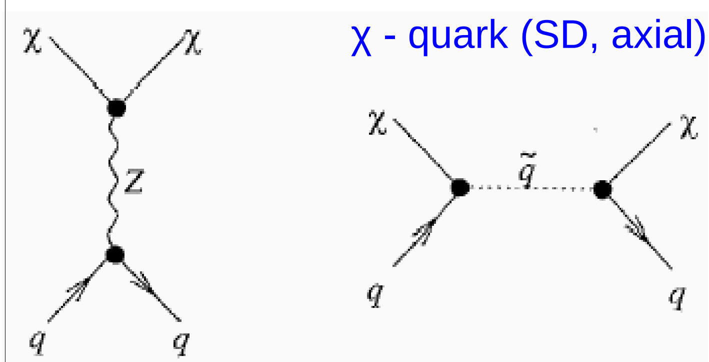
χ - quark (SI, scalar)



$$\mathcal{L}_S \sim \tilde{\chi}\chi\bar{q}q \quad \propto A^2$$

Spin dependent

χ - quark (SD, axial)



$$\mathcal{L}_A \sim \tilde{\chi}\gamma_\mu\gamma_5\chi\bar{q}\gamma^\mu\gamma_5 q \quad \propto J(J+1)$$

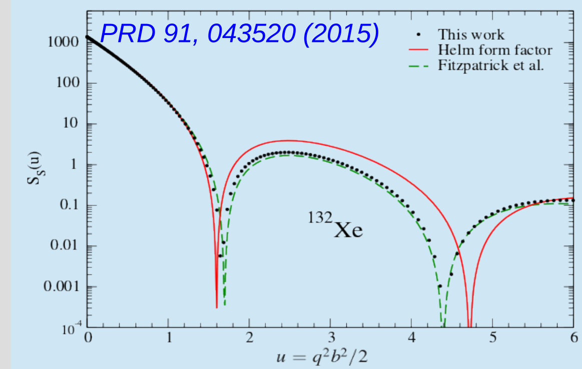
Jungmann et al. '96 Phys.Rep.

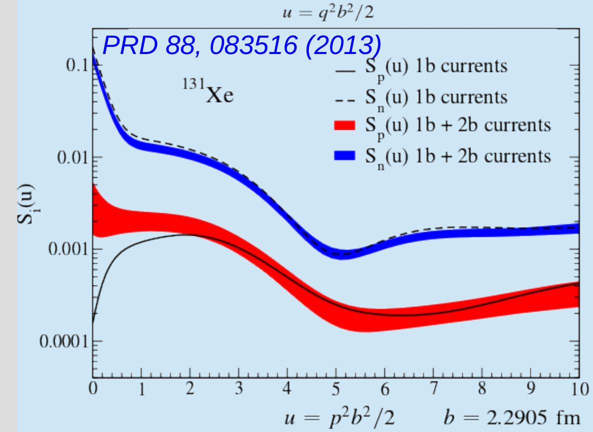
$$\frac{d\sigma}{d|\mathbf{q}|^2} = \frac{C_{spin}}{v^2} G_F^2 \frac{S(|\mathbf{q}|)}{S(0)}$$

$$C_{spin} = \frac{8}{\pi}[a_p\langle S_p\rangle + a_n\langle S_n\rangle]^2 \frac{J+1}{J}$$

often: express SD results in proton-only or neutron-only

Form factors describe loss of coherence
→ mainly for heavy targets and tail of v-distribution





Direct WIMP Search

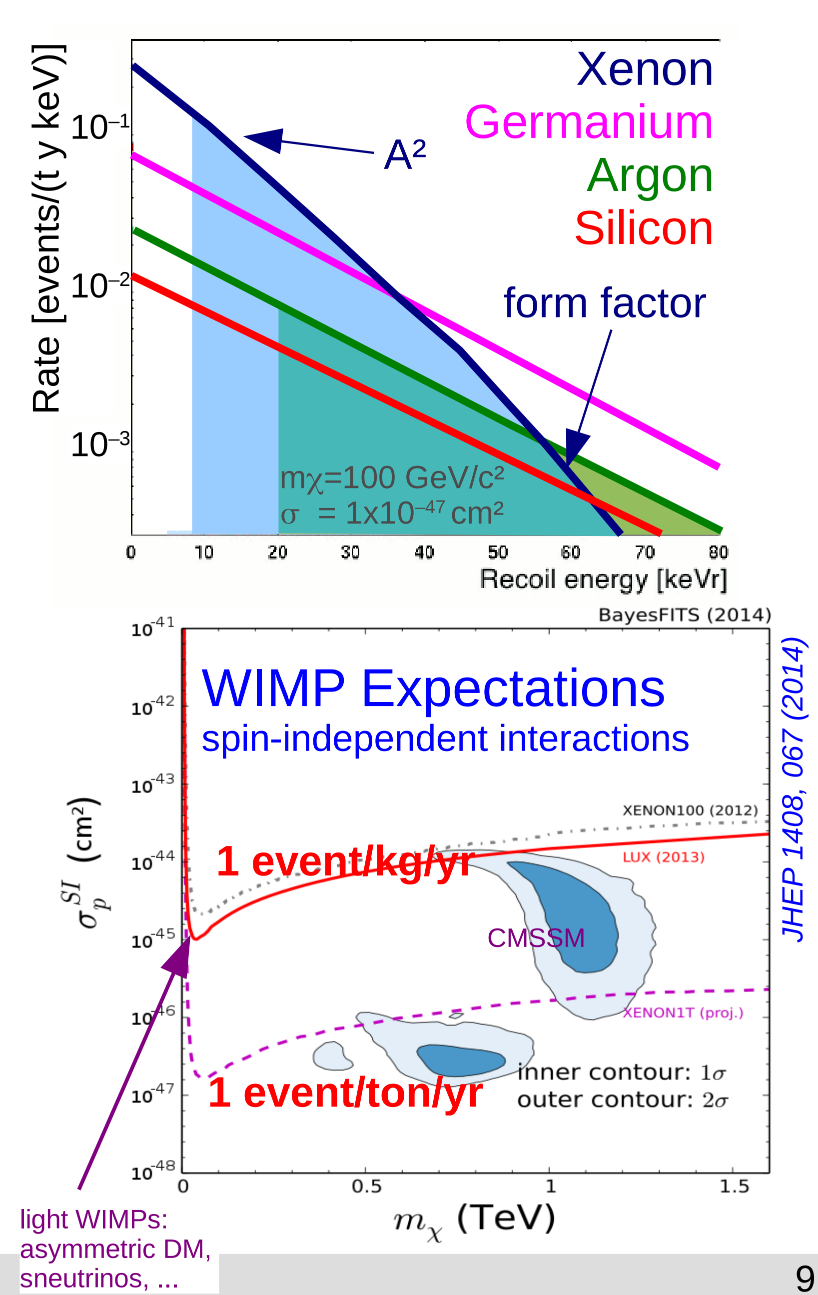
Direct Detection:

$E_r < 100$ keV
$R \ll 1$ evt/kg/year

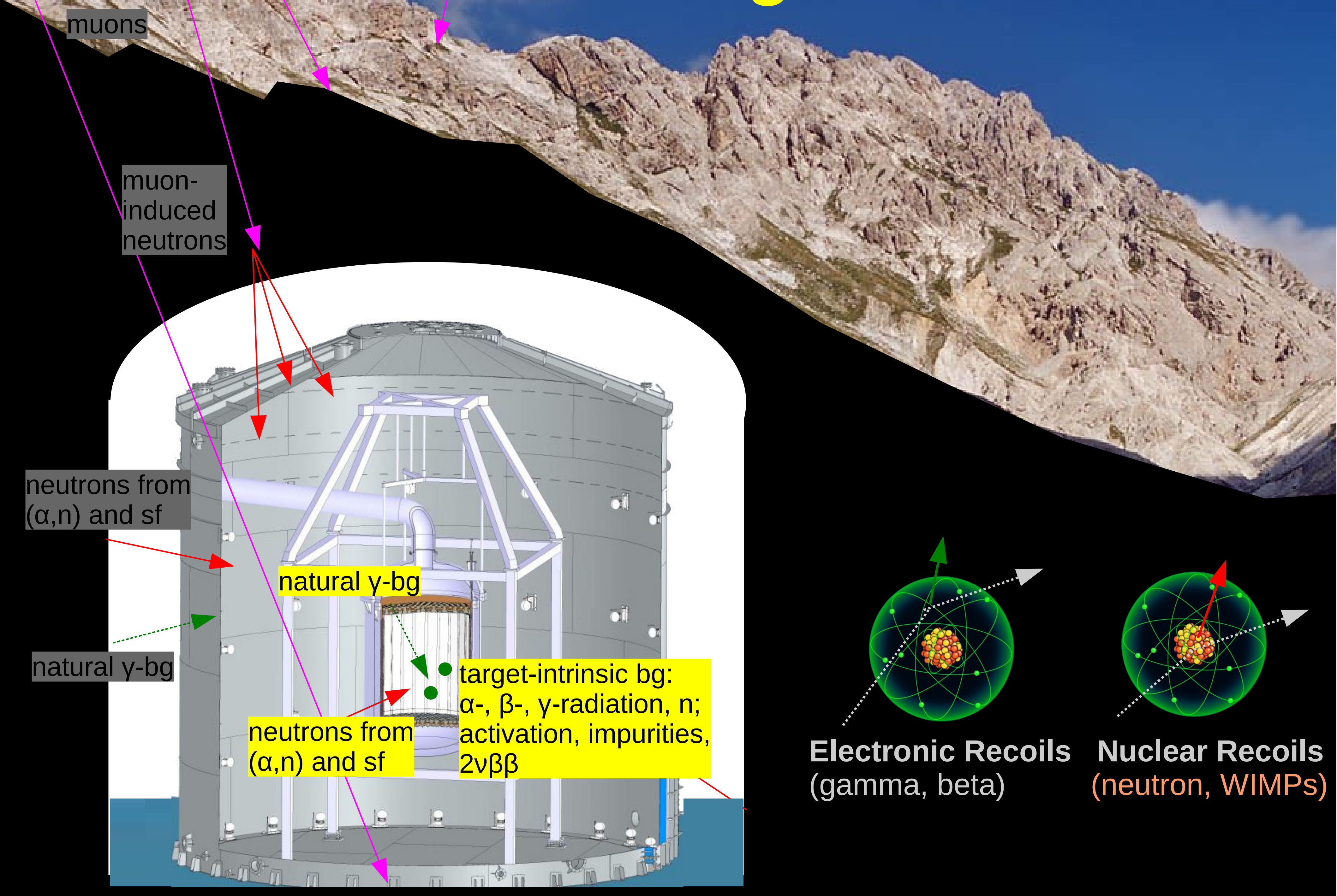
How to build a WIMP detector?

- large total mass, high *A*
- low energy threshold
- ultra low background
- good signal / background discrimination

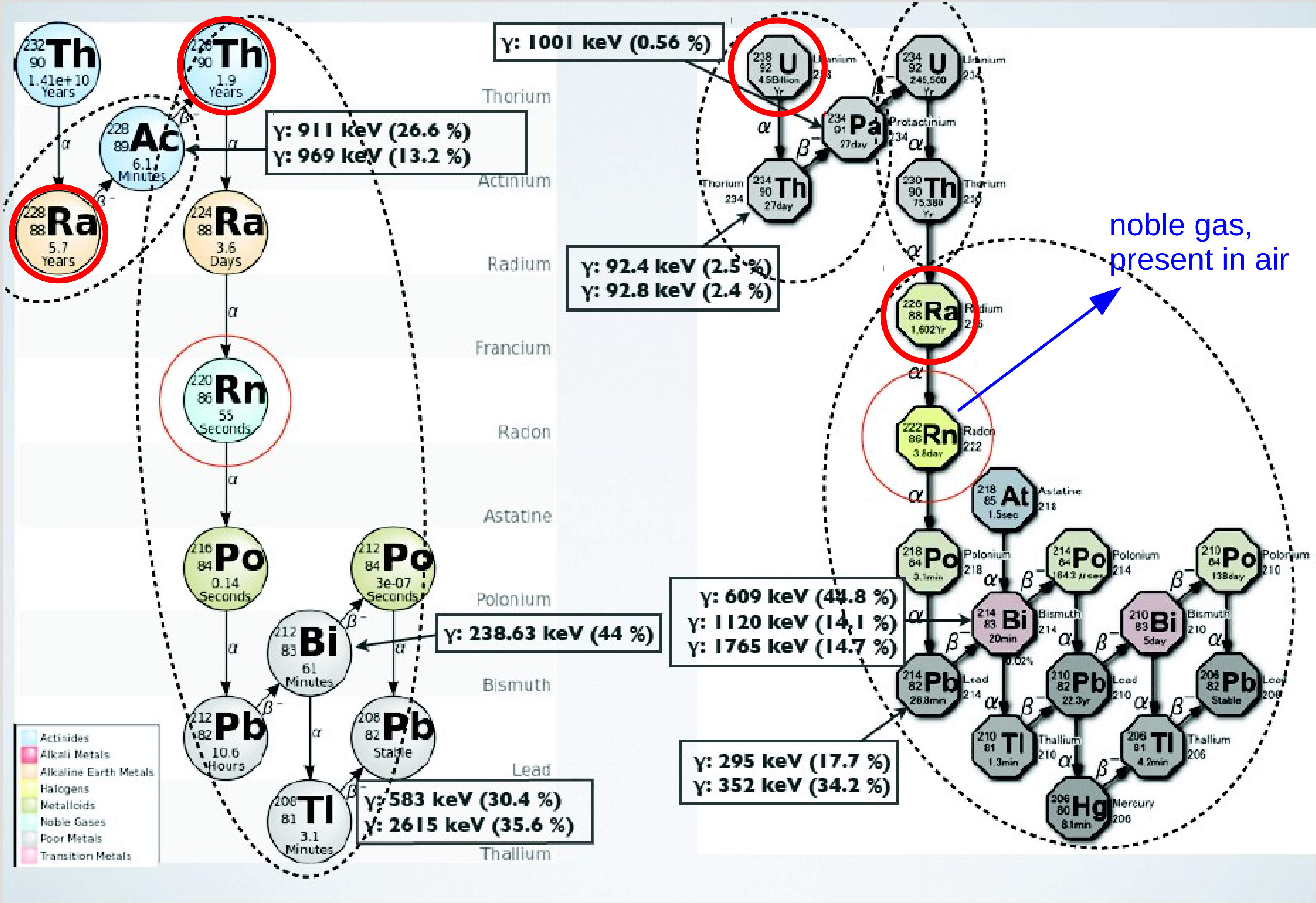
We are dealing with
- extremely **low rates** (O(1) Hz)
- very **low thresholds** (~1 keV)
- extremely **low radioactive** backgrounds



Background Sources



The U and Th Chains

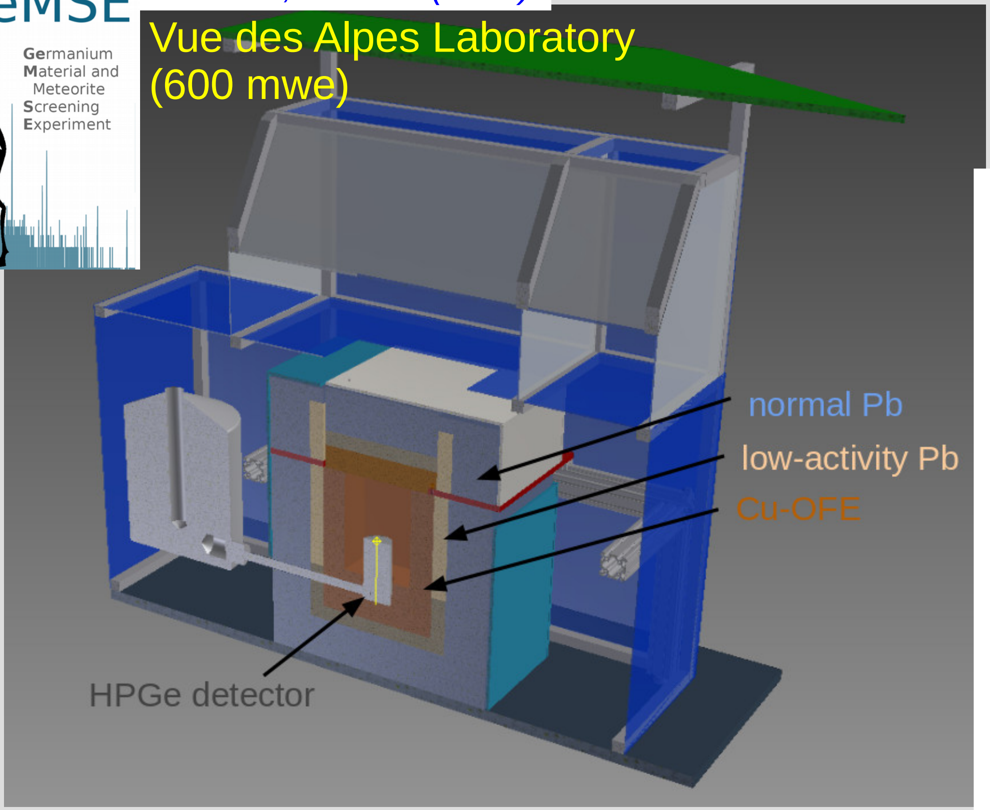


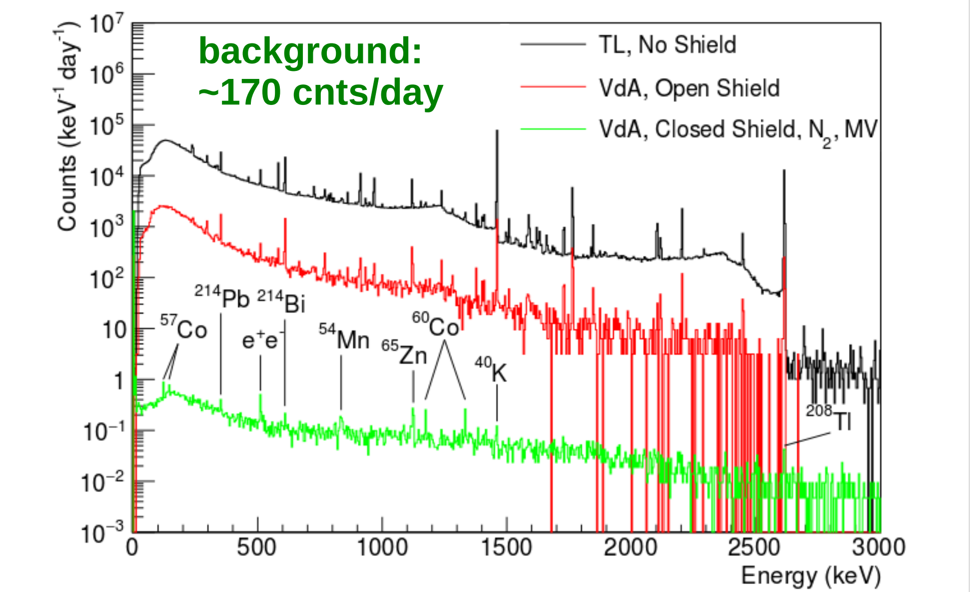

GeMSE
Germanium
Material and
Meteorite
Screening
Experiment
NON-MAGNETIC
100lbs.)

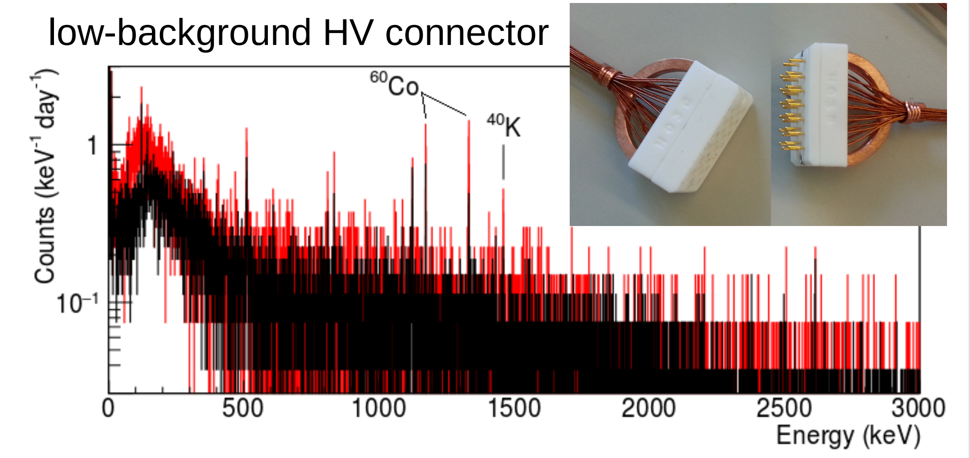
Low-background Screening

GeMSE
Germanium Material and Meteorite Screening Experiment

JINST 11, P12017 (2016)





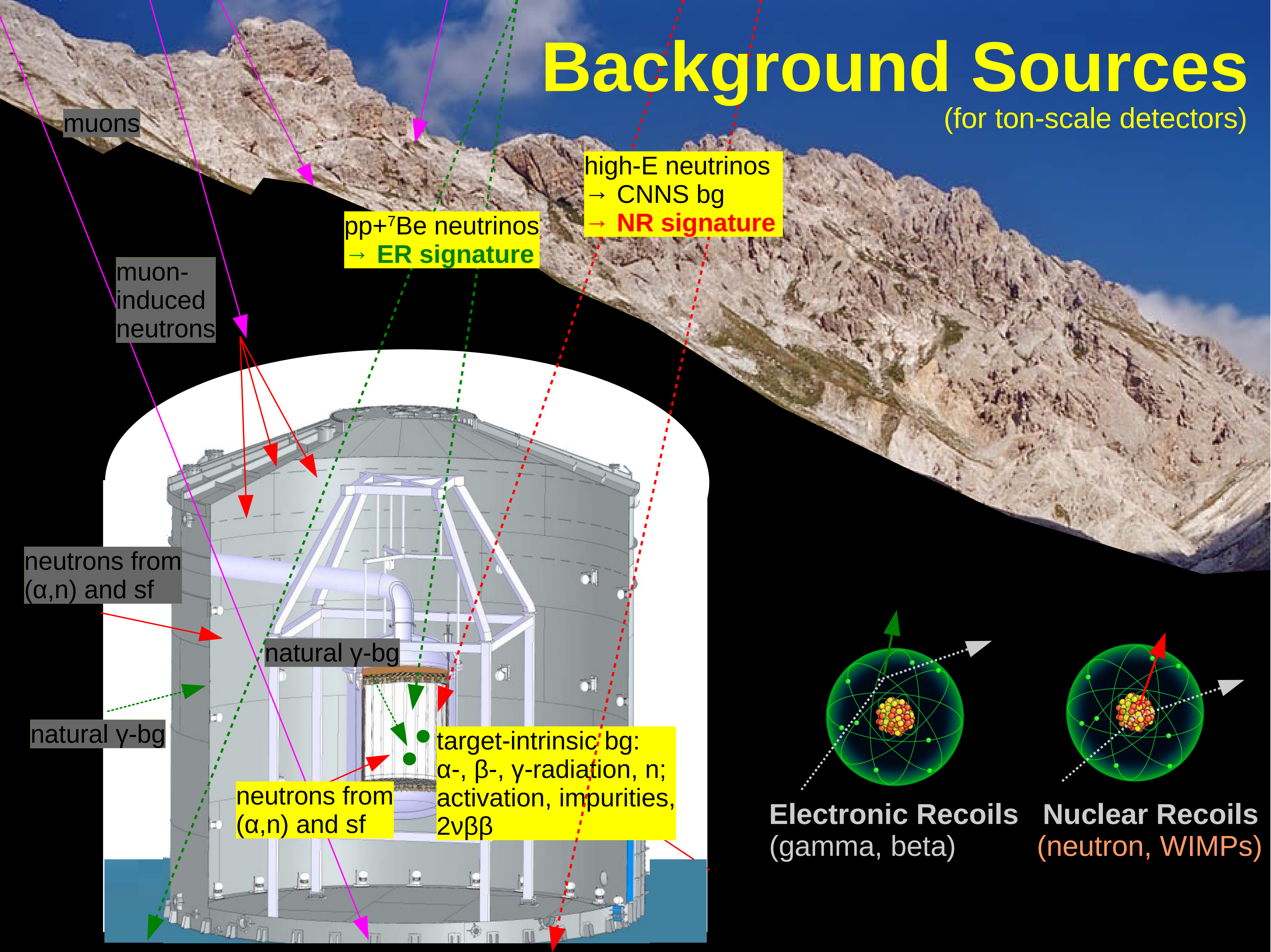


Identify materials with lowest radioactivity:

- γ-spectrometry using HPGe Detectors
- mass spectroscopy: ICP-MS, GDMS
- neutron activation analysis
- ^{222}Rn emanation

Background Sources

(for ton-scale detectors)



Background Suppression

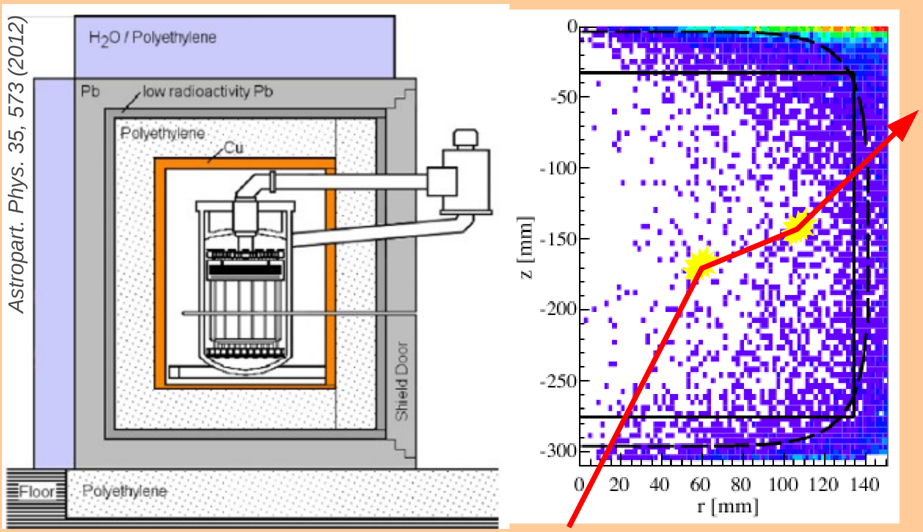
A Avoid Backgrounds

Use of radiopure materials

Shielding

deep underground location
large shield (Pb, water, poly)
active veto (µ, γ coincidence)

self shielding → fiducialization



B Use knowledge about expected WIMP signal

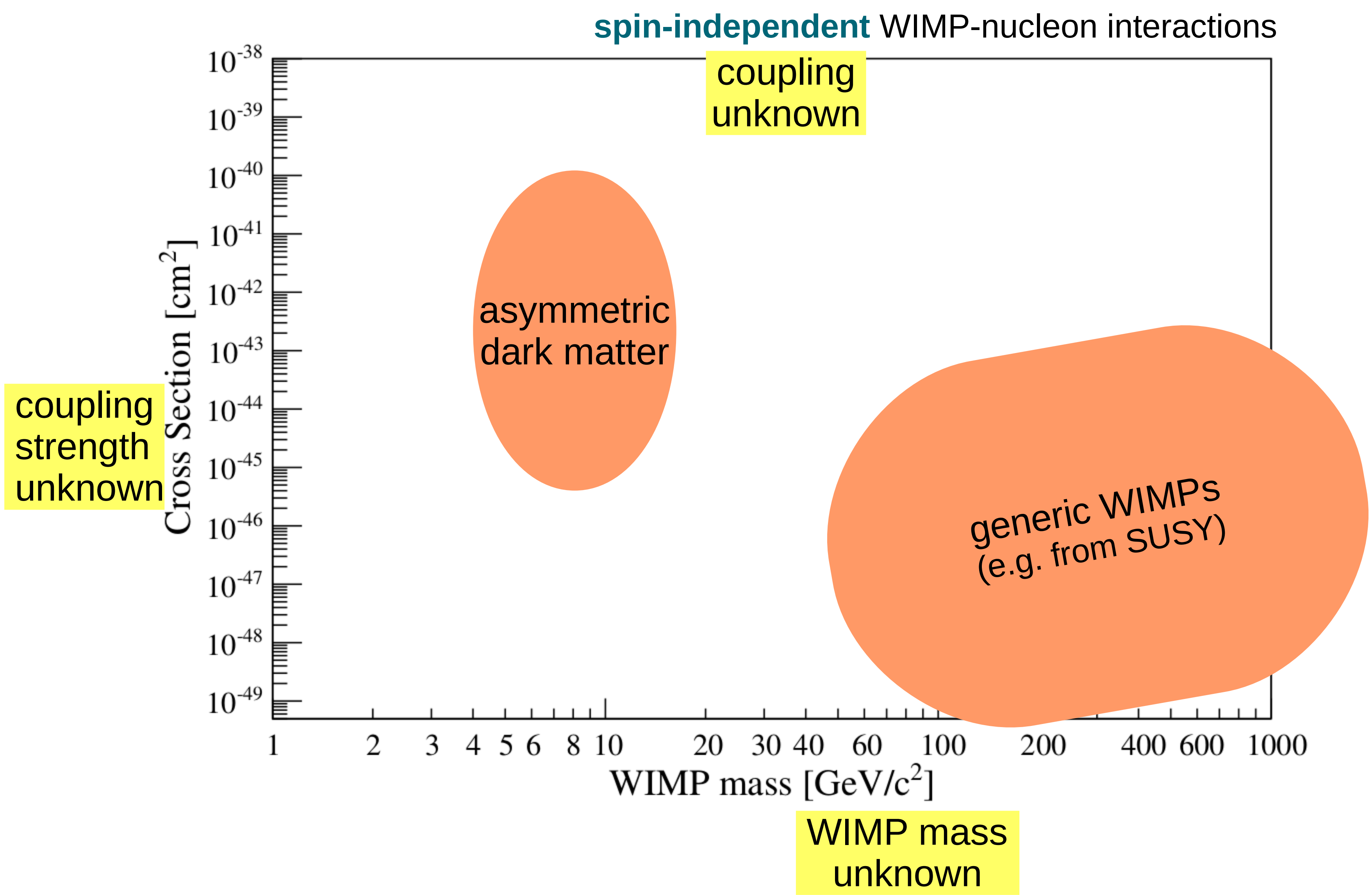
WIMPs interact only once

→ single scatter selection
require some position resolution

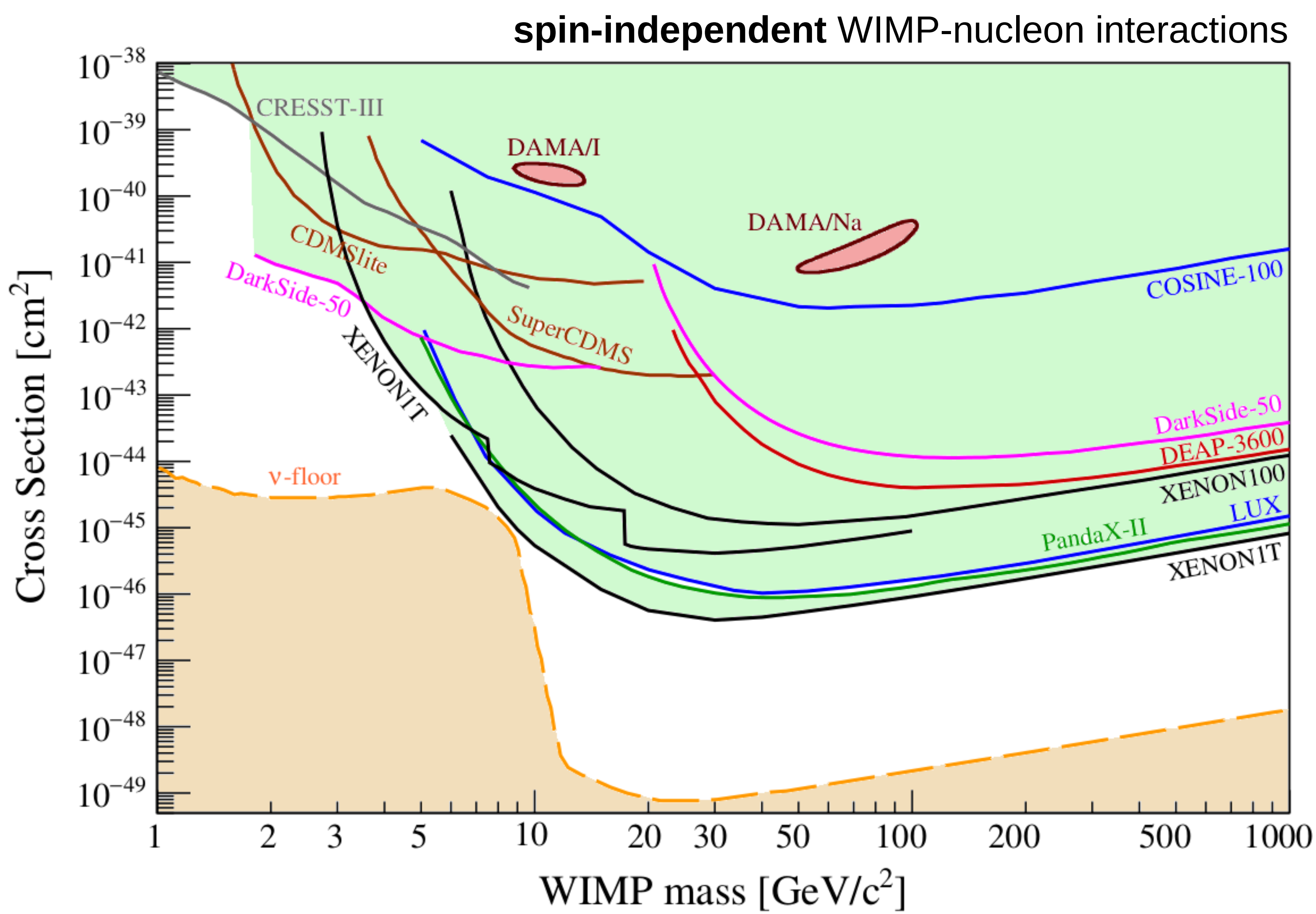
WIMPs interact with target nuclei

→ nuclear recoils
exploit different d*E*/d*x* from
signal and background

The WIMP Parameter Space

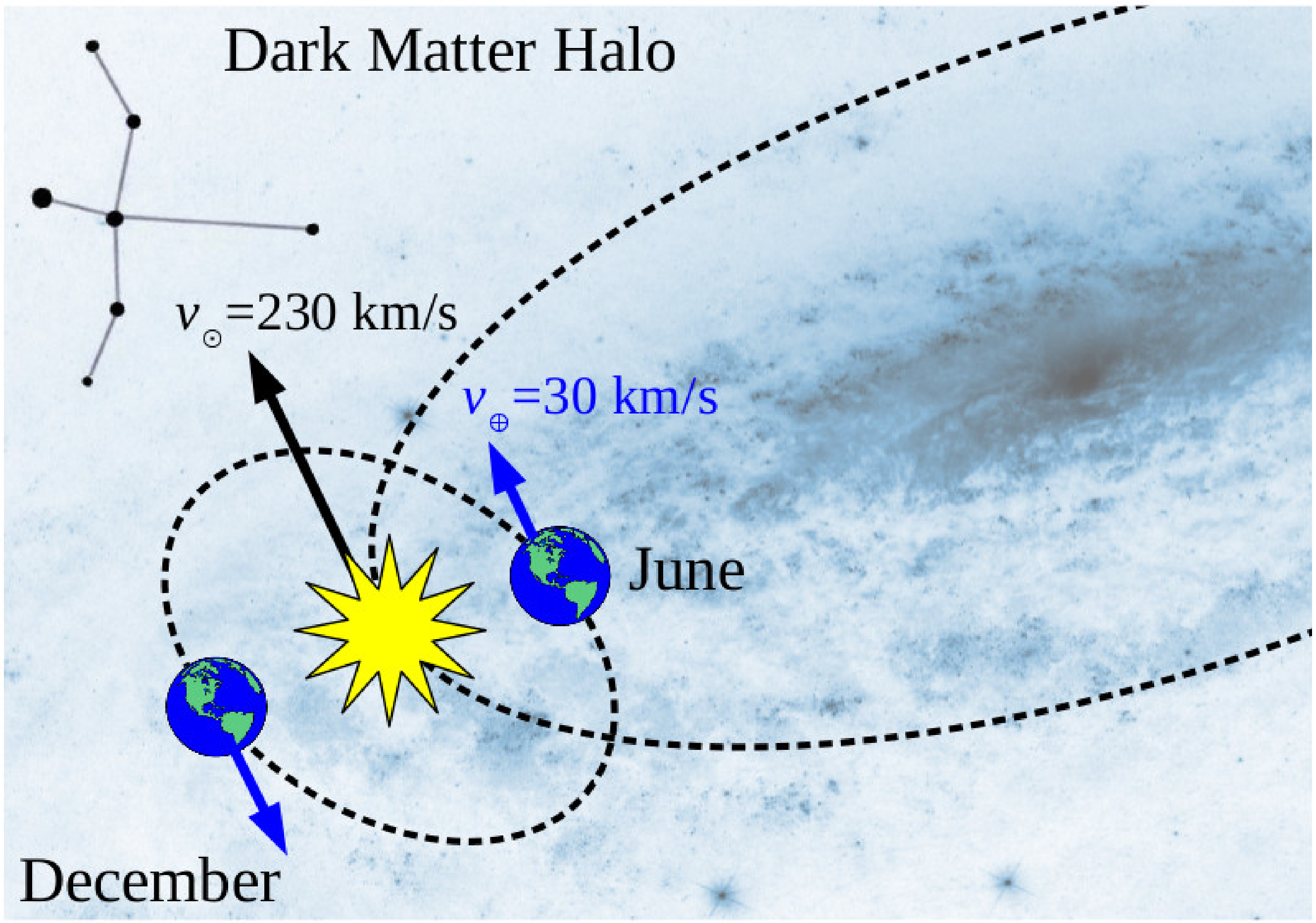


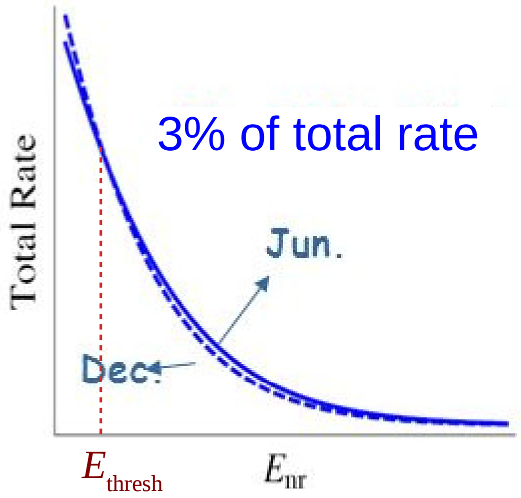
Current Status

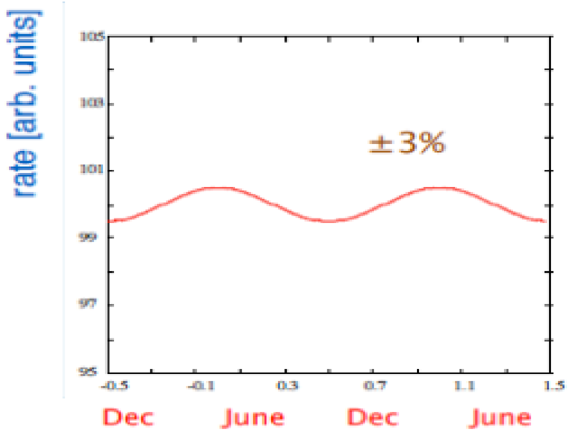


some results are missing...

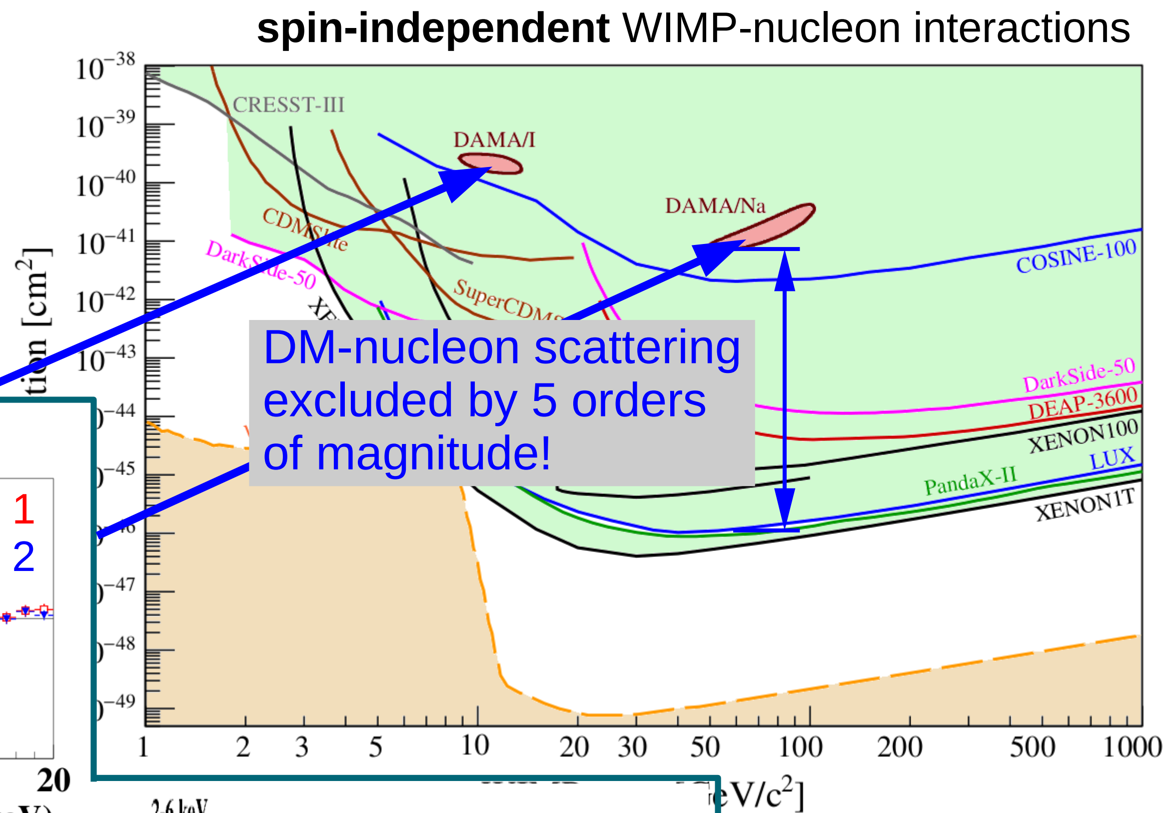
Annual Modulation



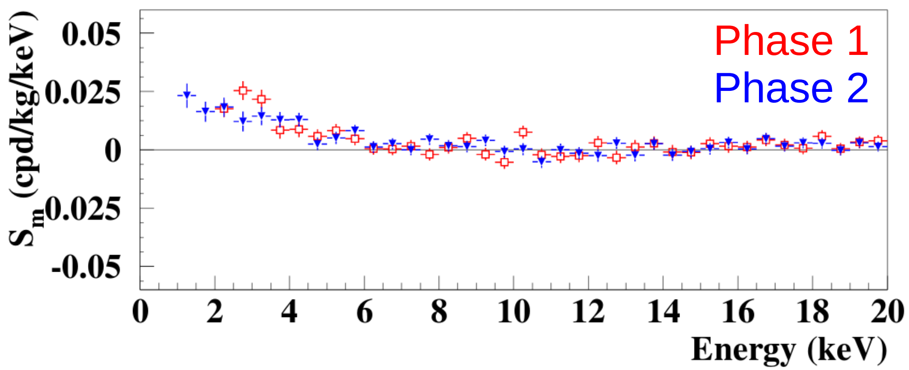


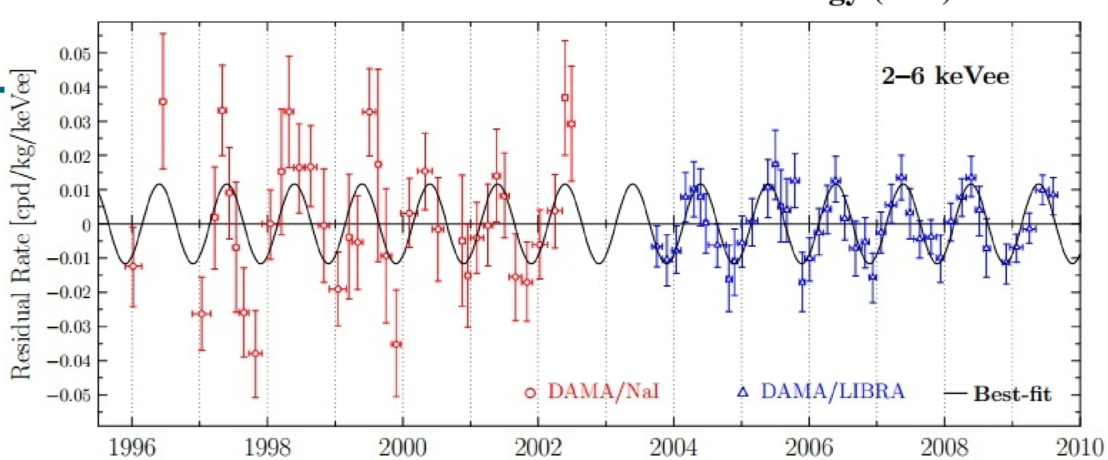


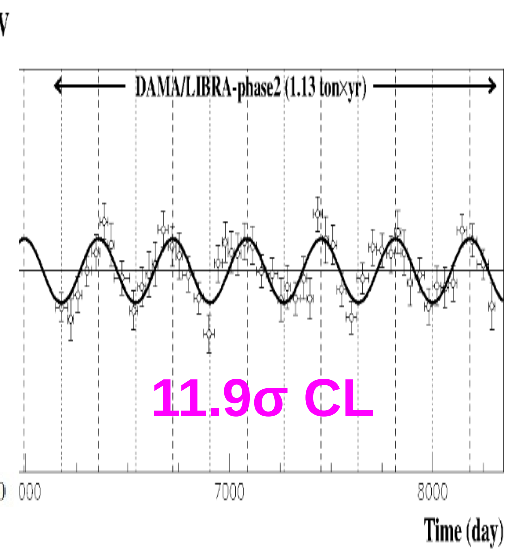
DAMA/LIBRA: New Results



DAMA/LIBRA: Universe 4 (2018) 116





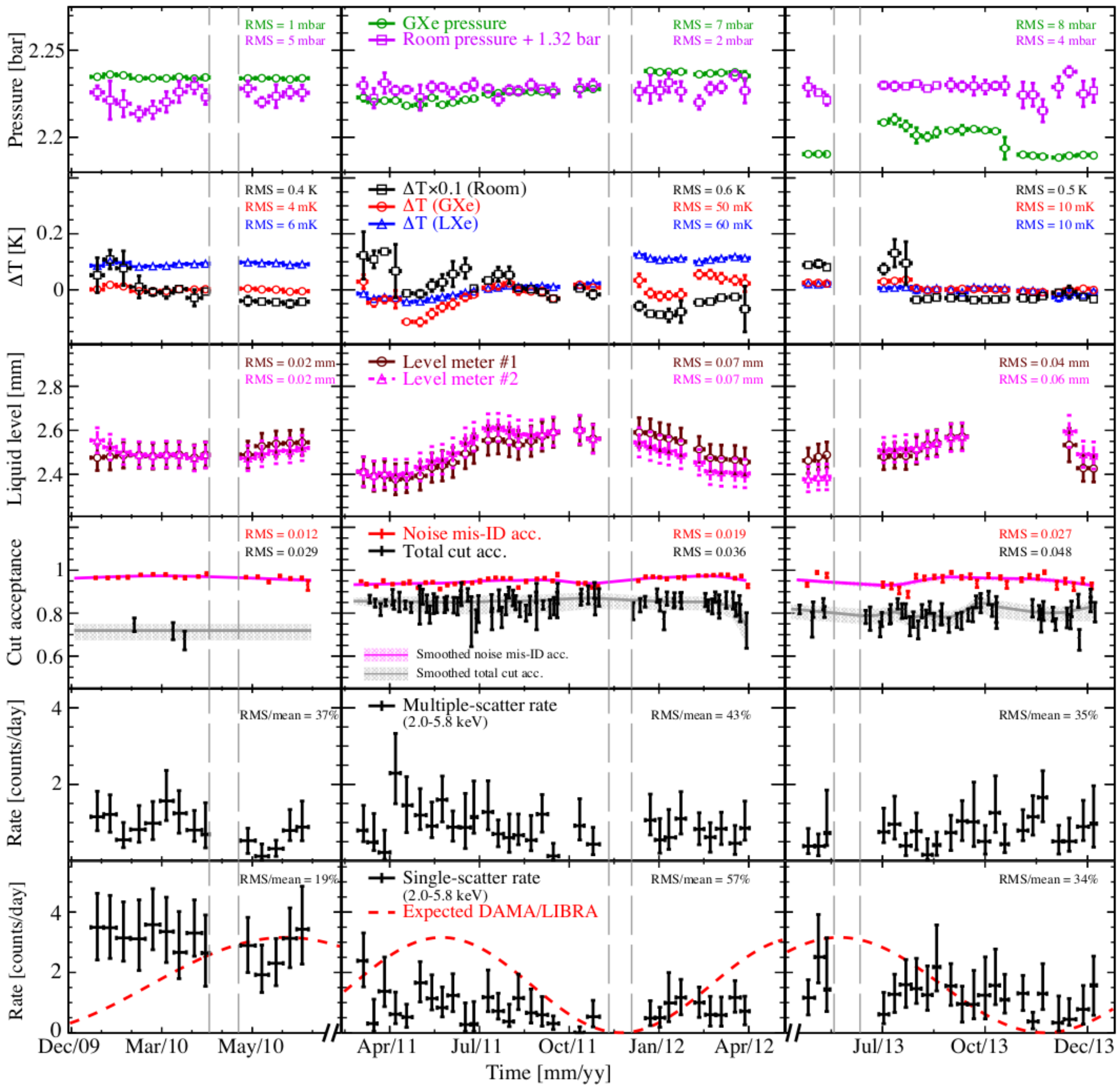


~250 kg NaI(Tl)

New data:
– 1 keVee threshold
– 6 annual cycles

Annual Modulation Searches

XENON100: PRL 118, 101101 (2017)

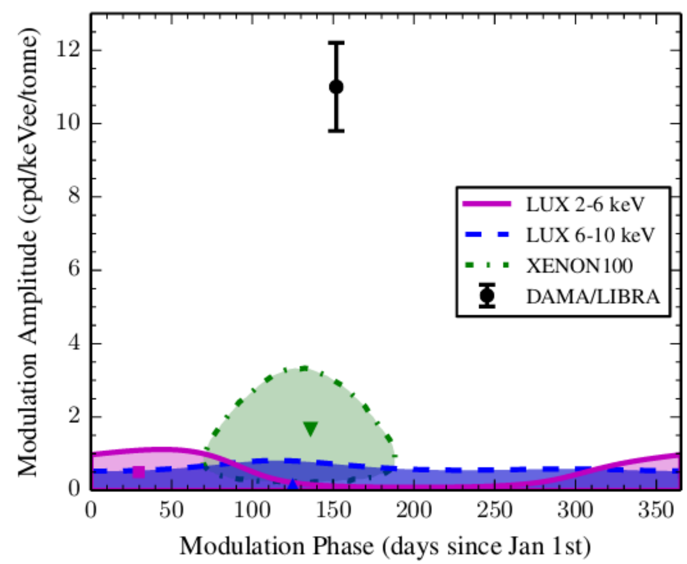


– dark matter–electron scattering

– **2-phase LXe TPCs** operated stably over long periods
XENON100: 4 years
LUX: 2 years

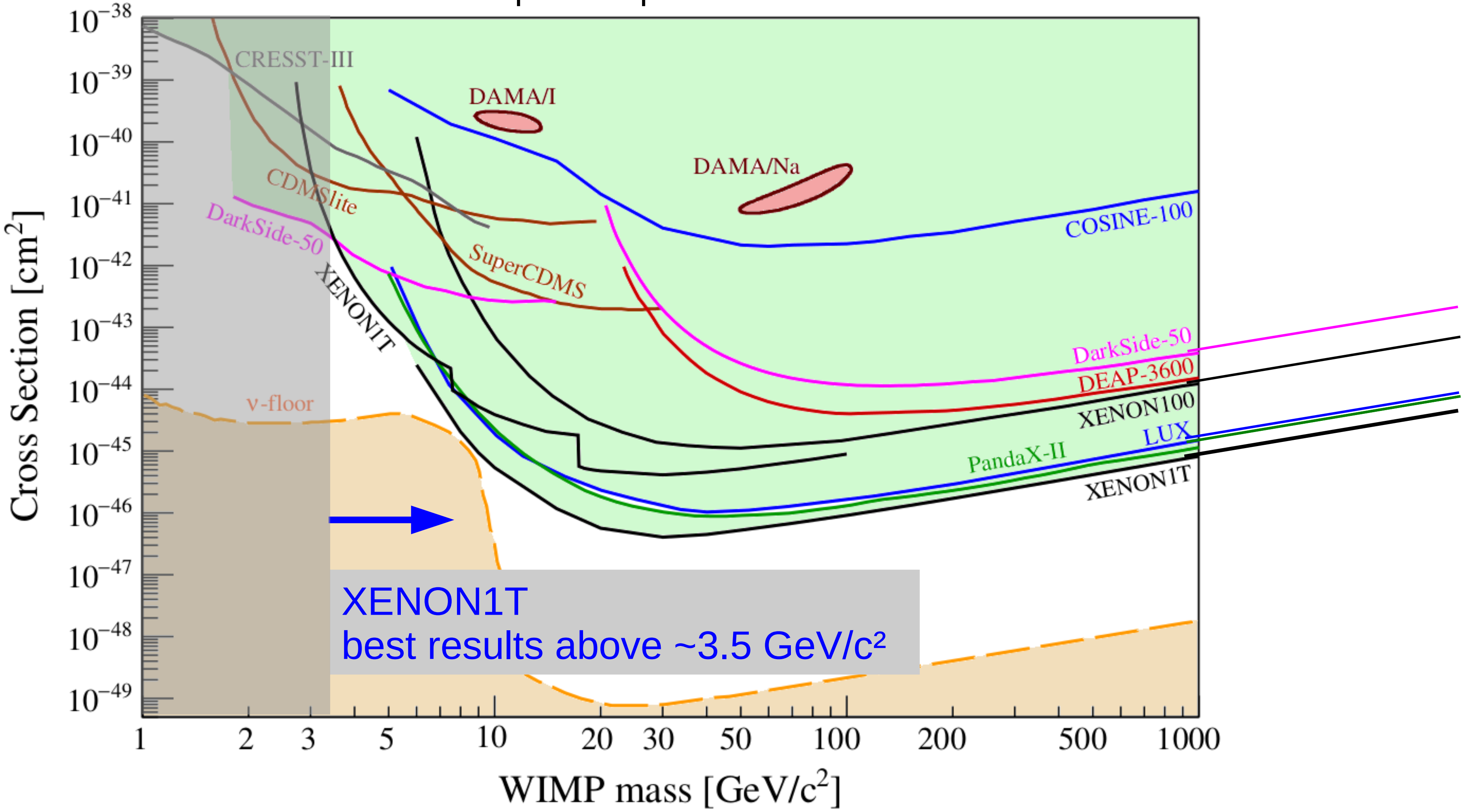
– challenges DAMA/LIBRA
XENON100: **5.7σ**
LUX: **9.2σ**

LUX: PRD 98, 062005 (2018)



Current Status

spin-independent WIMP-nucleon interactions



The XENON Collaboration

www.xenon1t.org

Columbia | RPI | Nikhef | Muenster | KIT | Stockholm | Mainz | MPIK, Heidelberg | Freiburg

Chicago

Zurich

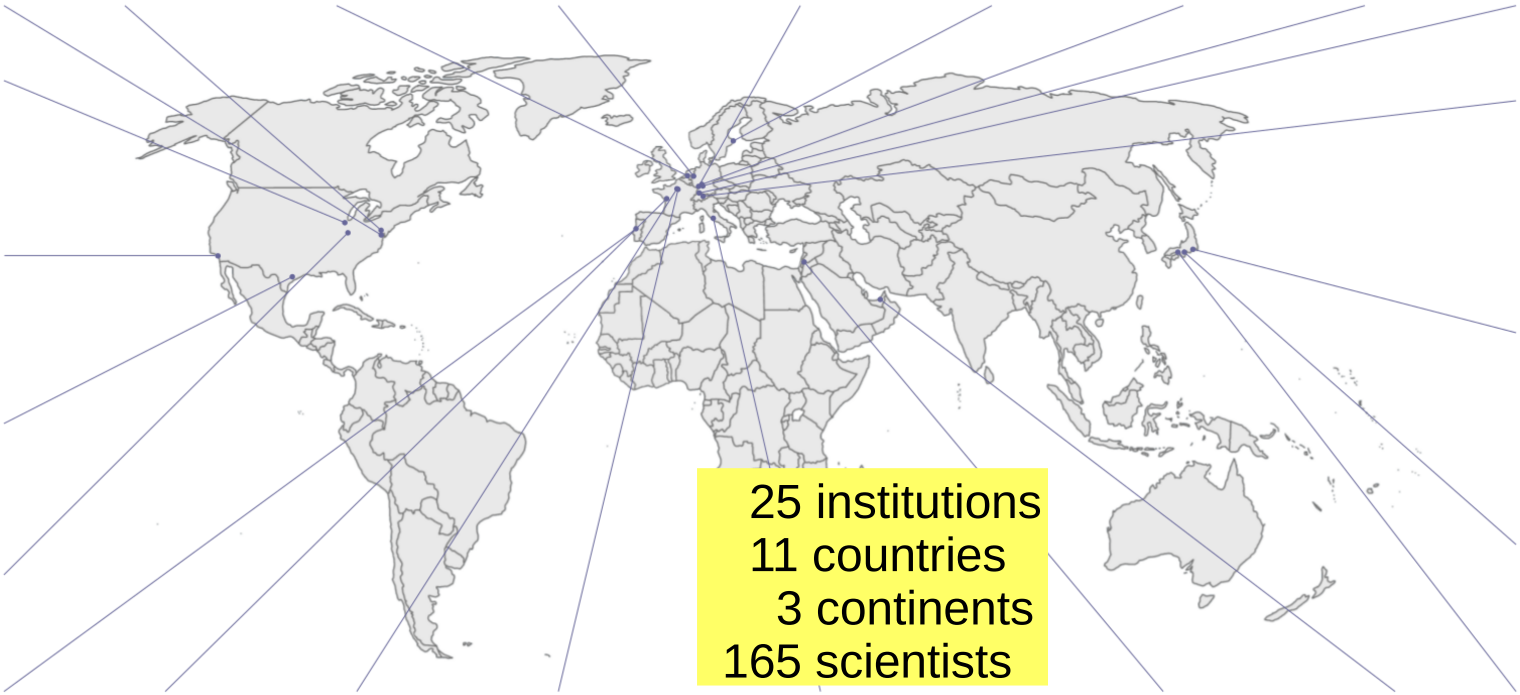
UCSD

Tokyo

Rice

Nagoya

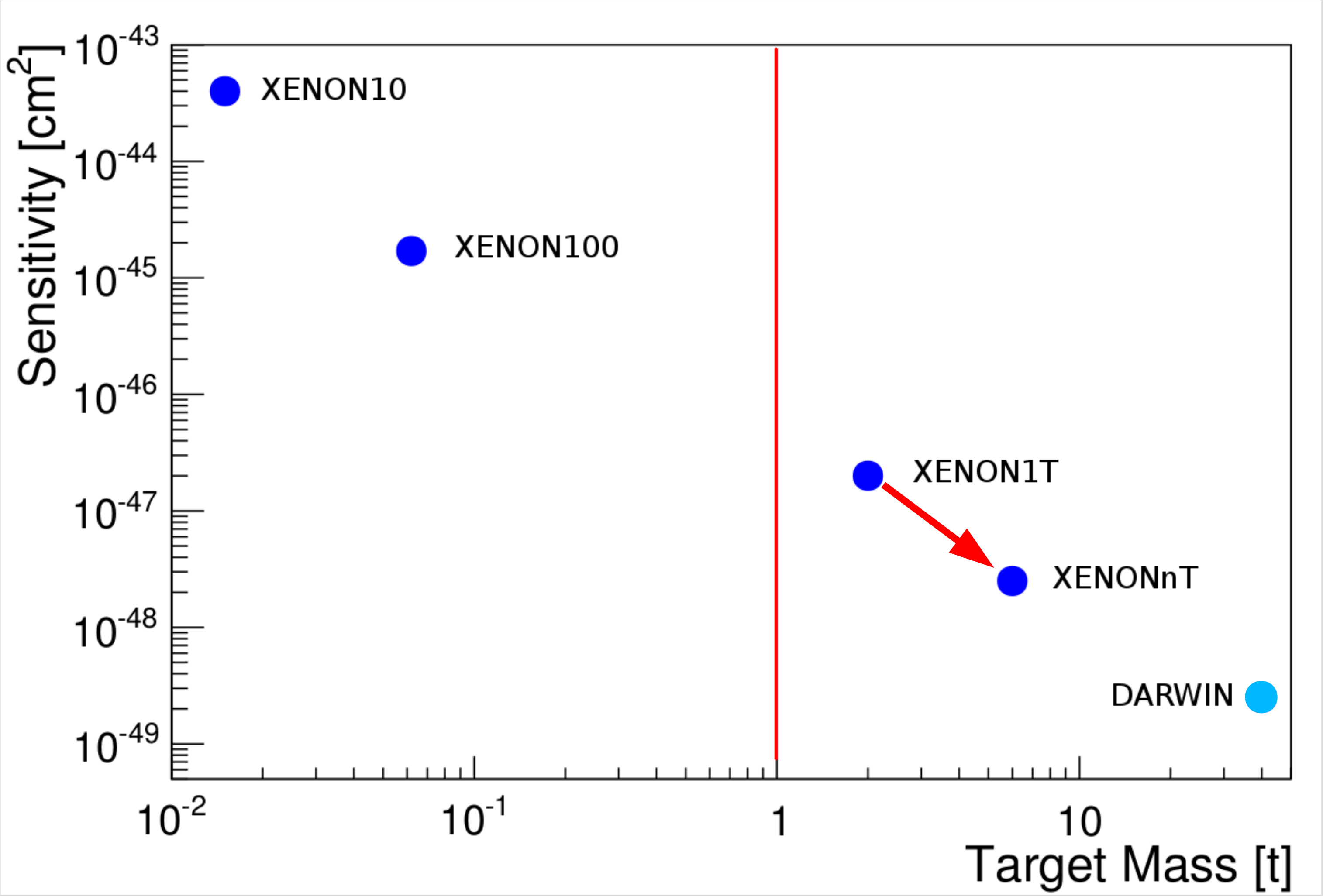
Purdue



25 institutions
11 countries
3 continents
165 scientists

Coimbra | Subatech | LPNHE | LAL | Bologna | LNGS | Torino | Napoli | Weizmann | NYUAD | Kobe

XENON Instruments

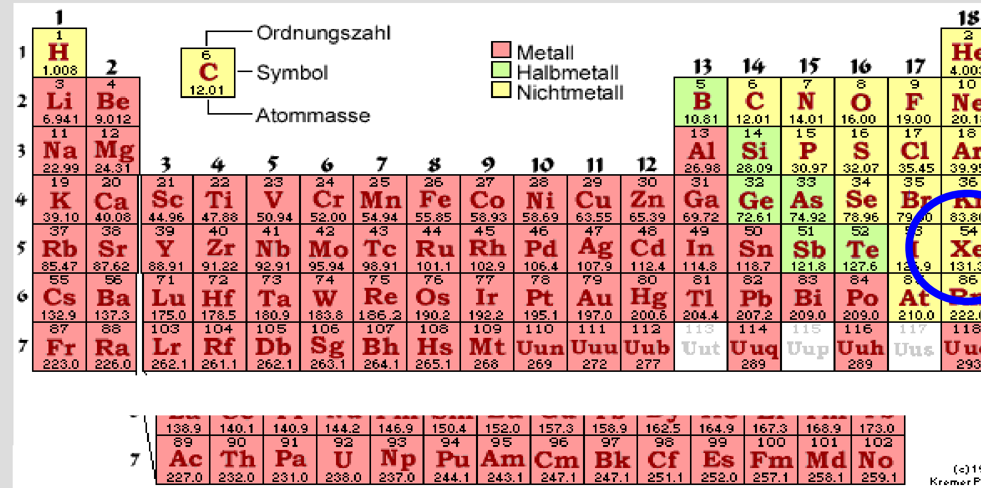


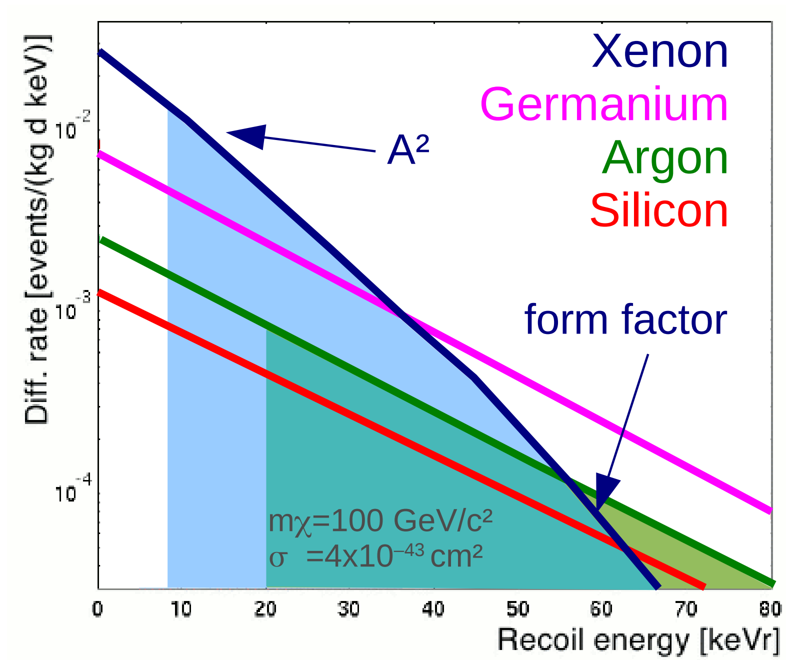
The XENON collaboration develops and operates
dark matter detectors of increasing size and sensitivity

Why Xenon?

+ scintillation light in VUV (178nm)
+ high mass number A~131
  SI: high WIMP rate @ low theshold
+ high Z=54, high ρ~3 kg/l:
  self shielding, compact detector
+ 50% odd isotopes
+ "easy" cryogenics @ –100°C
+ scalability to larger detectors
+ no long lived Xe isotopes
  two 2nd order weak decays
+ background discrimination
  when measuring light and charge

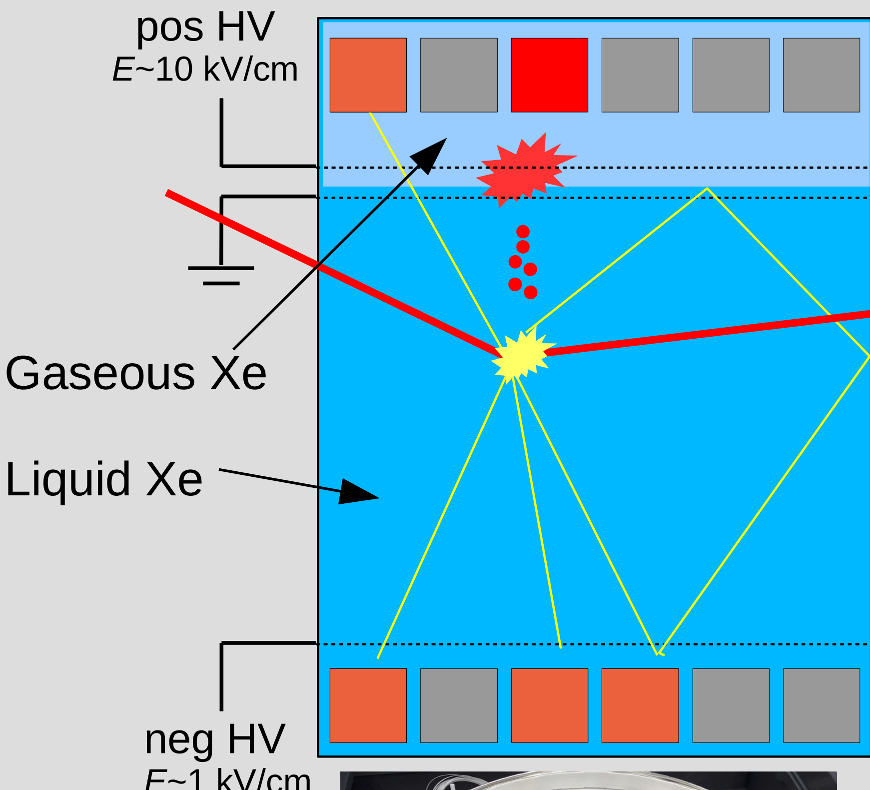
– expensive
– only fair background rejection

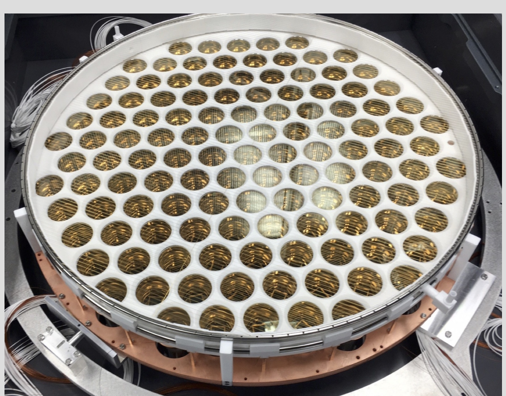


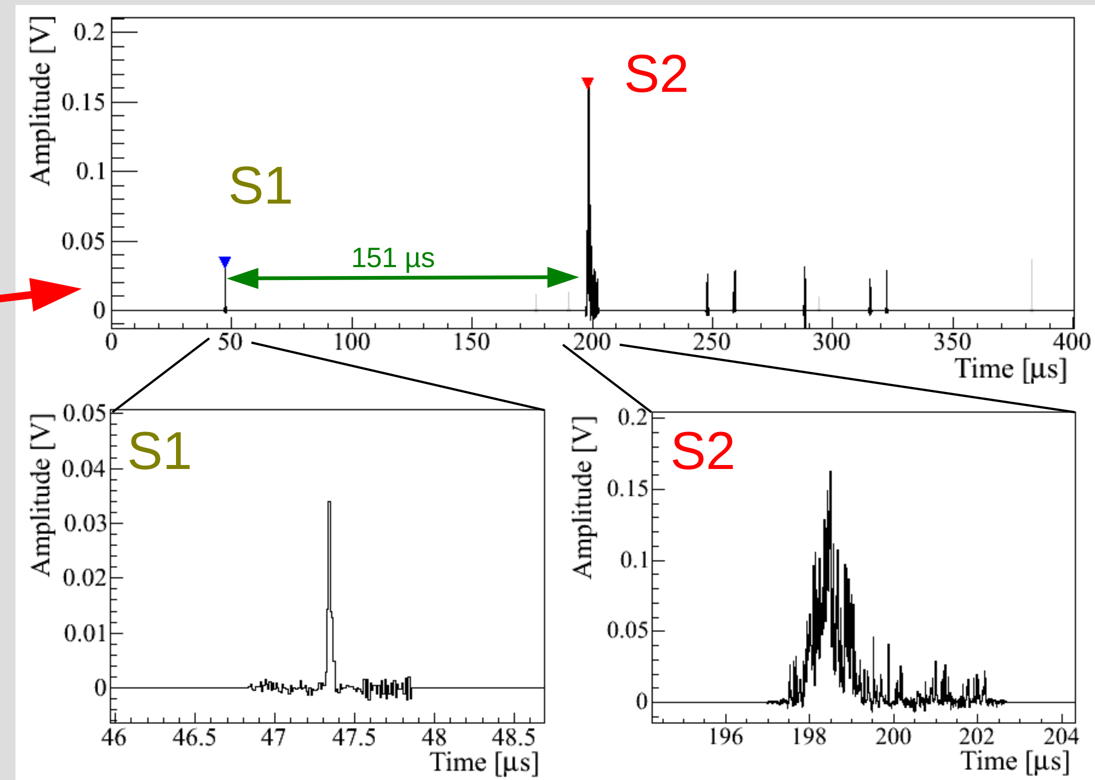


Dual Phase TPC

Dolgoshein, Lebedenko, Rodionov, JETP Lett. 11, 513 (1970)







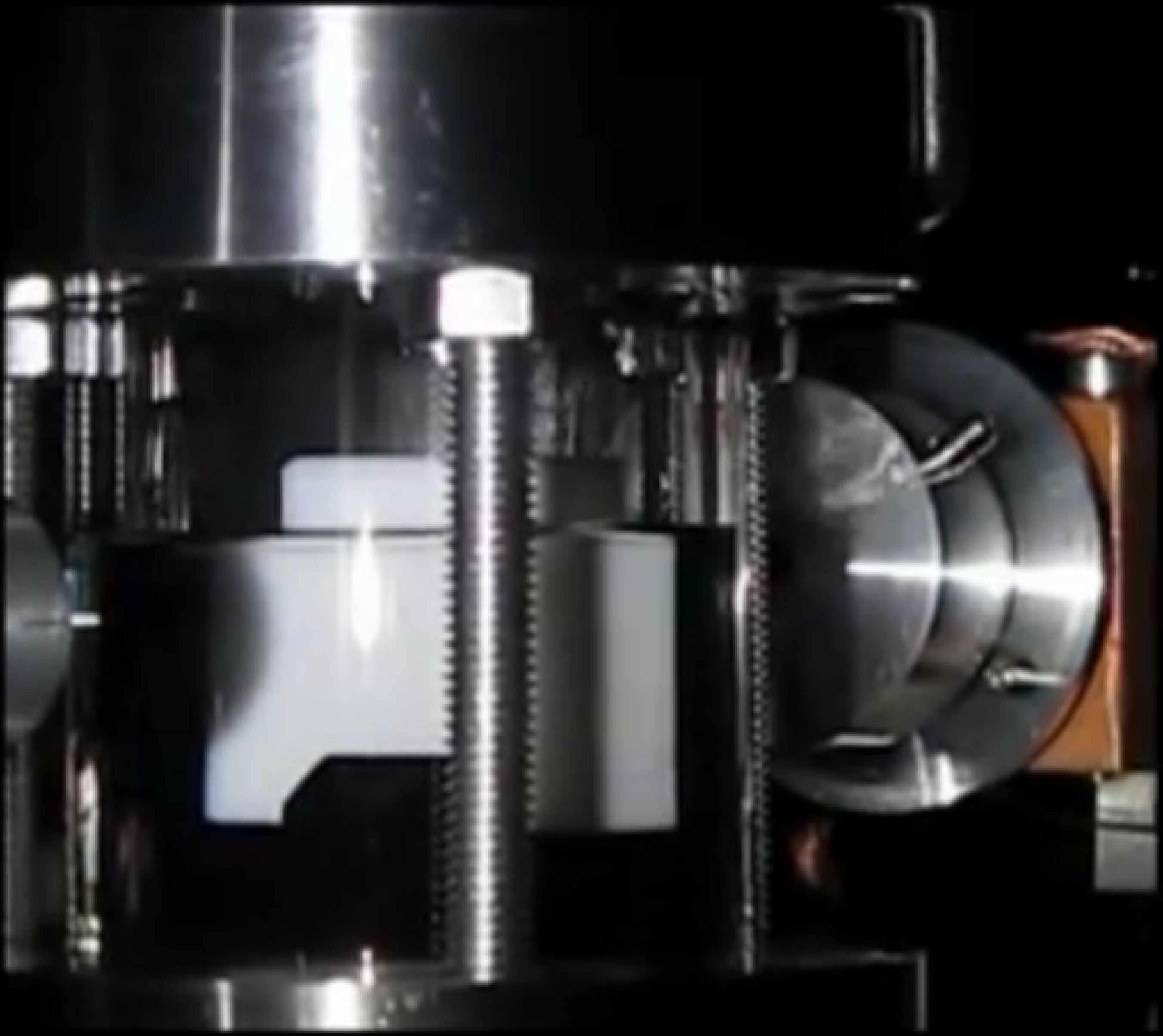


Image from C. Levy

Background Rejection

– 3dim vertex reconstruction
→ **fiducialization**

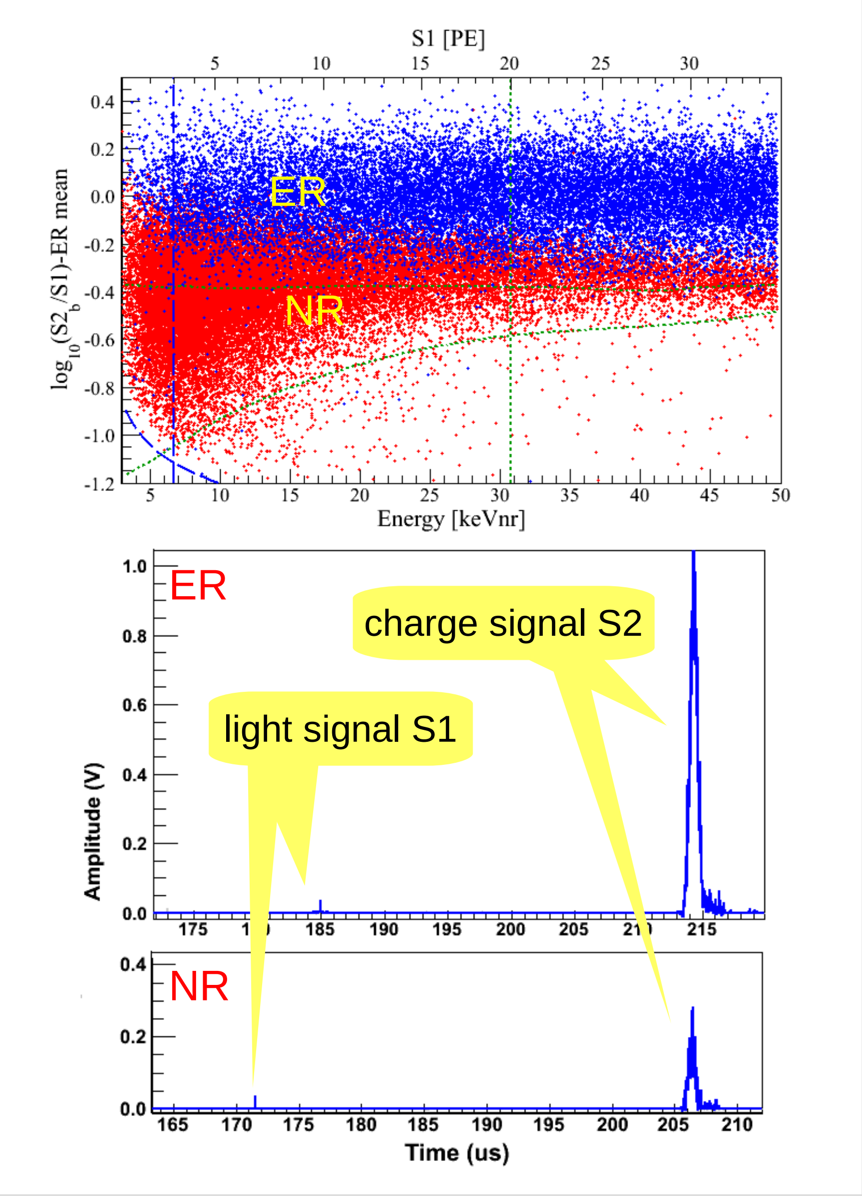
– multi-scatter rejection

– energy measurement

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

→ ER background rejection
→ significant loss of acceptance

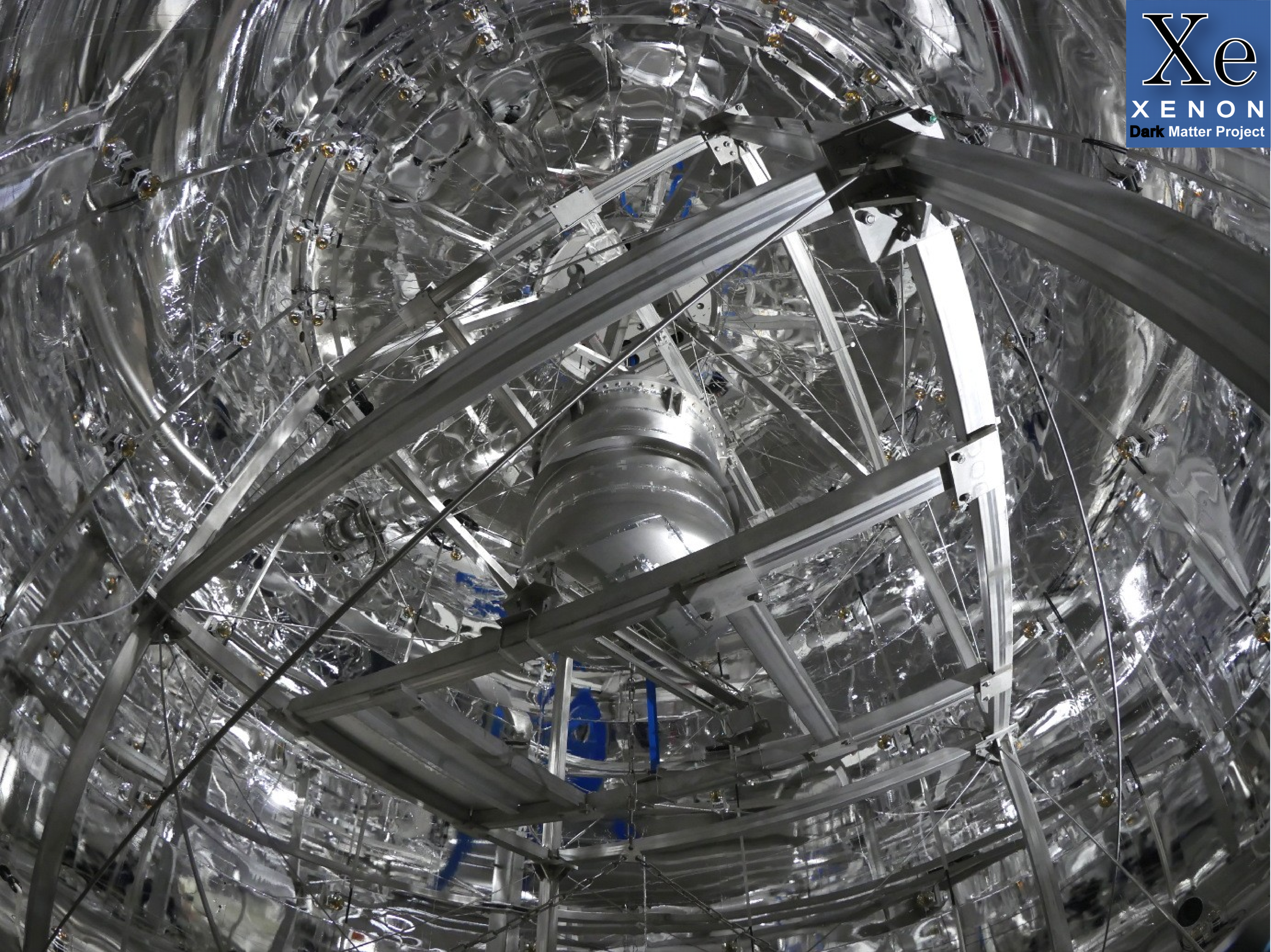
	E_{drift} [kV/cm]	LY @ 122 keV [PE/keV]	NR acc [%]	ER rej [%]
XENON100	0.53	3.8	40	2.5×10^{-3}
XENON100	0.53	3.8	30	1×10^{-3}
LUX	0.18	8.8	50	$1..10\times10^{-3}$
XENON1T	0.125	~7.5	50	2.5×10^{-3}
ZEPLIN-III	3.4	4.2	50	**1.3×10^{-4}**
K. Ni *APP14*	0.2-0.7	10	50	**$<1\times10^{-4}$**



Figures: XENON100

XENON1T @ LNGS

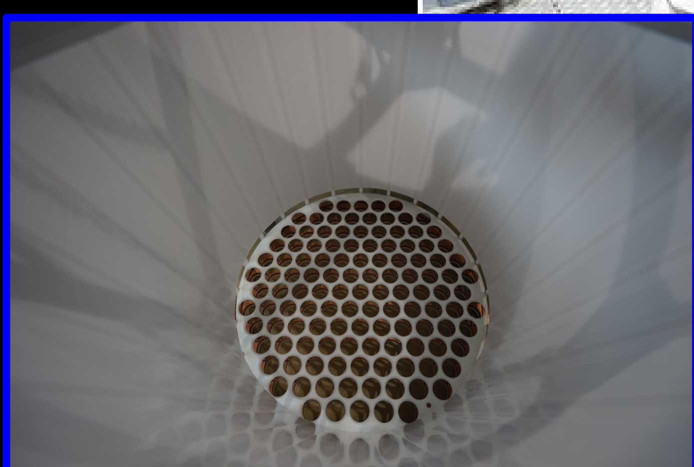
EPJ C 77, 991 (2017)



Xe
XENON
Dark Matter Project

Xe
XENON
Dark Matter Project

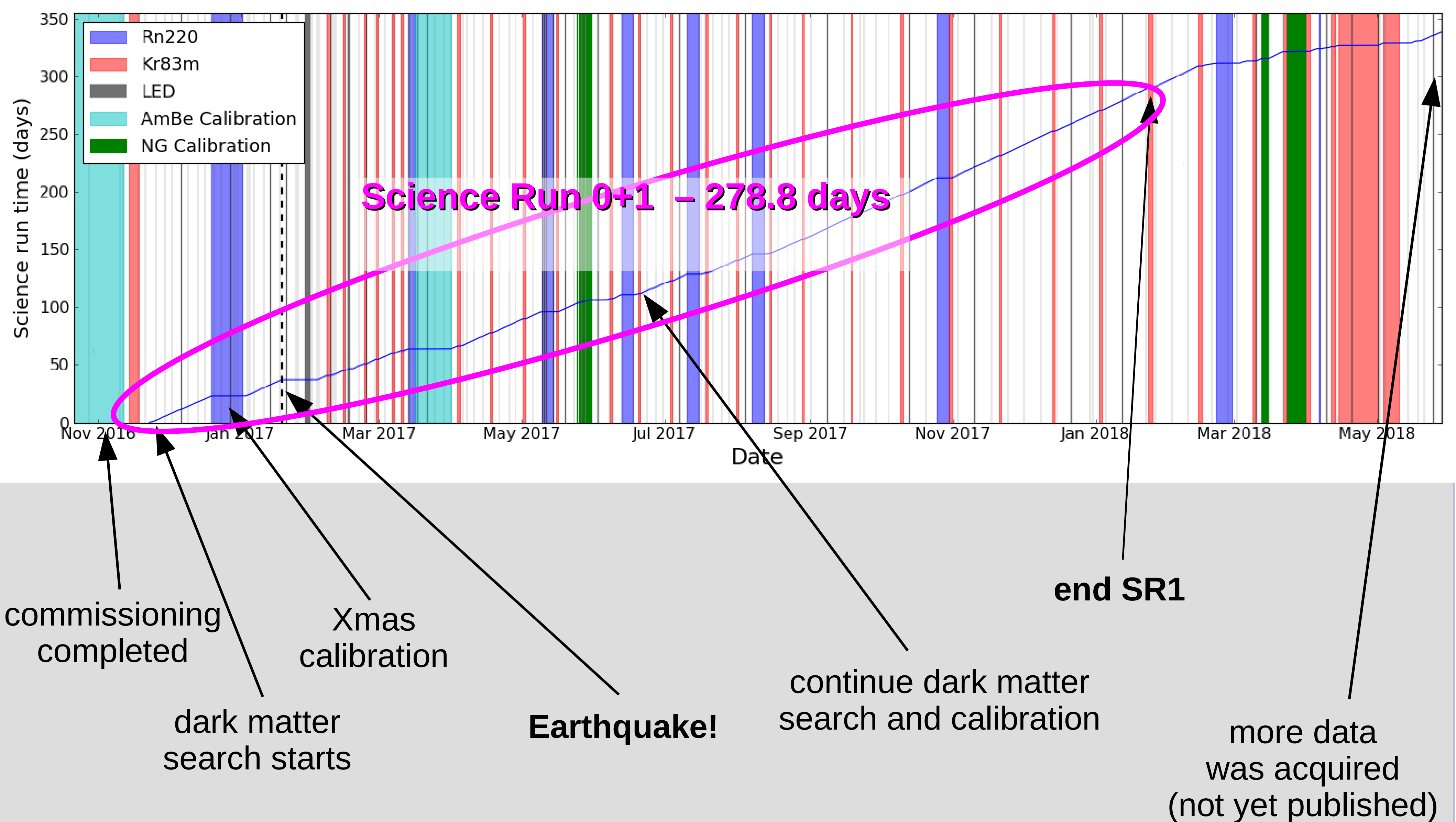
EPJ C 77, 991 (2017)



largest LXe TPC ever built

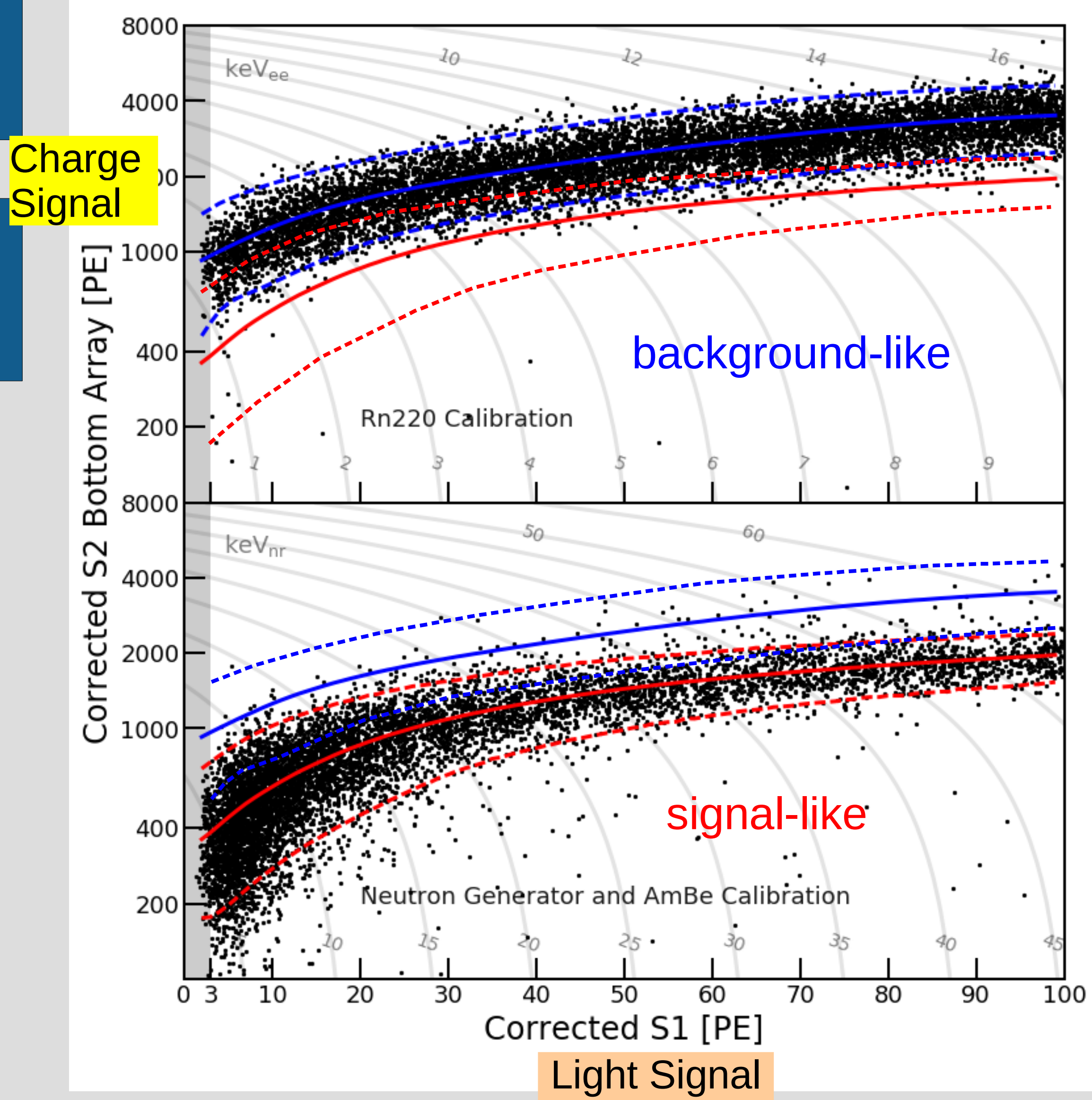
- **cylinder: 96 cm**
- **active LXe target: 2.0t** (3.2t total)
- **248 PMTs**

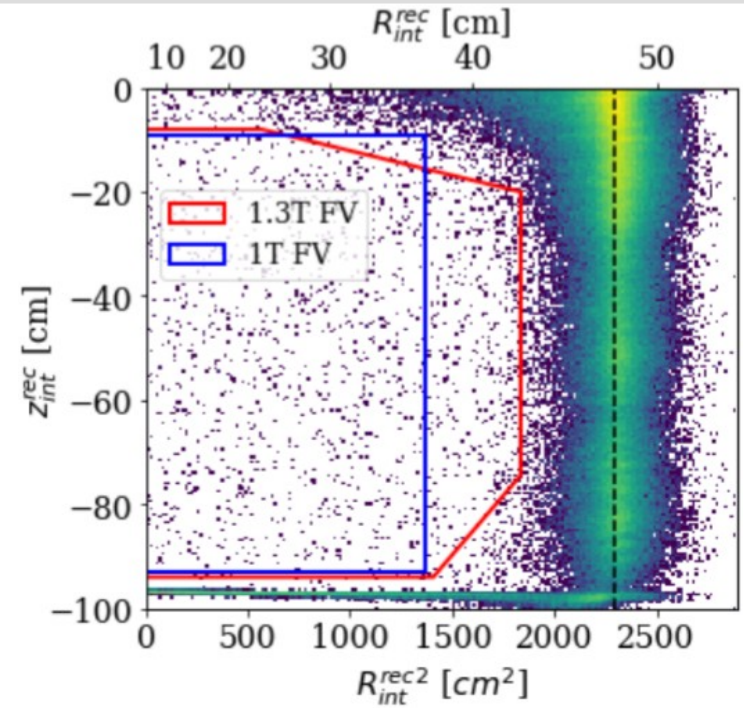
Dark Matter Data Taking



(Some) Results from XENON1T

Signal / Background Calibration



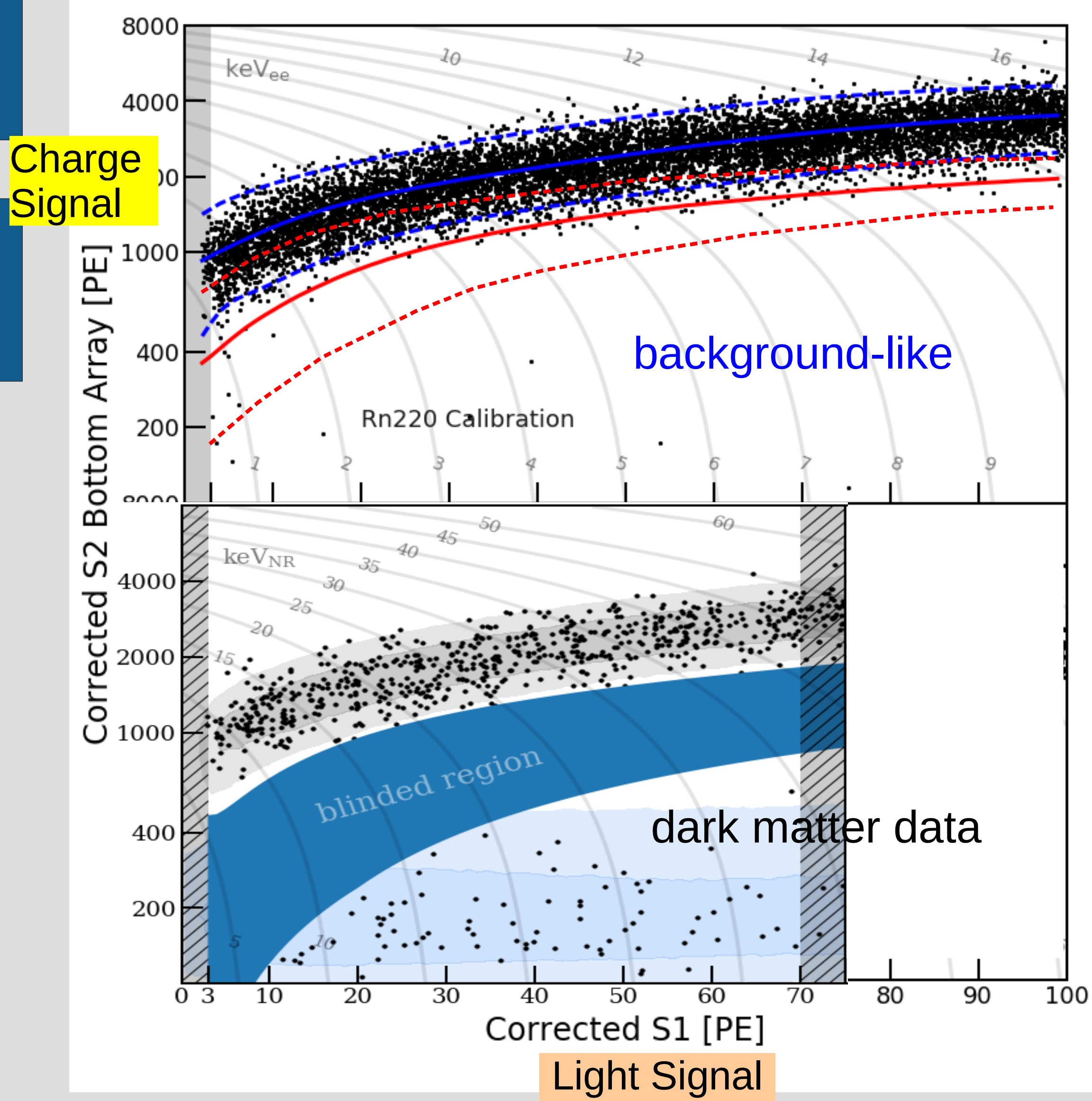


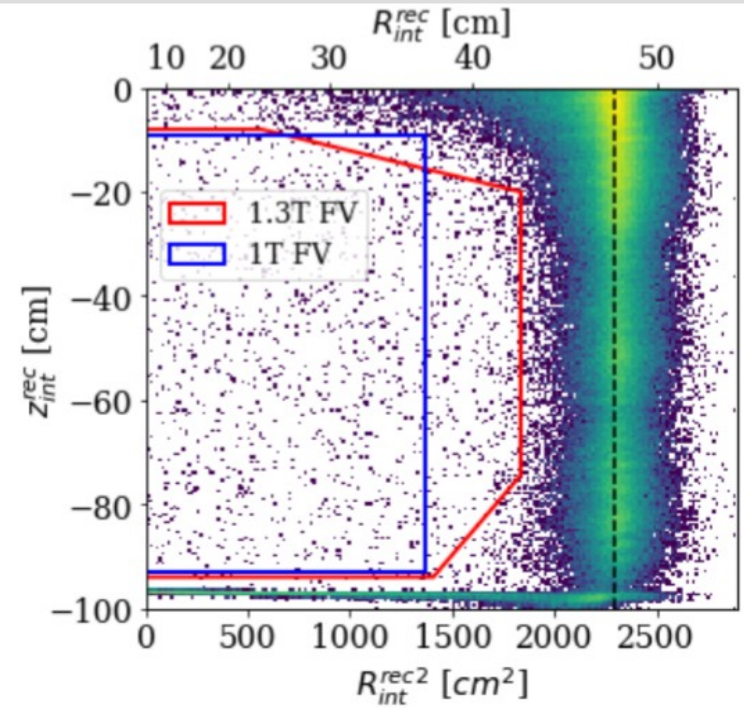
Used to construct background and signal models.

use **central 1.3 t** LXe for analysis

Exposure: 1.3 t × 278.8 d = 1.0 t×y
→ **largest low-bg exposure ever**

Blinded Data





Used to construct background and signal models.

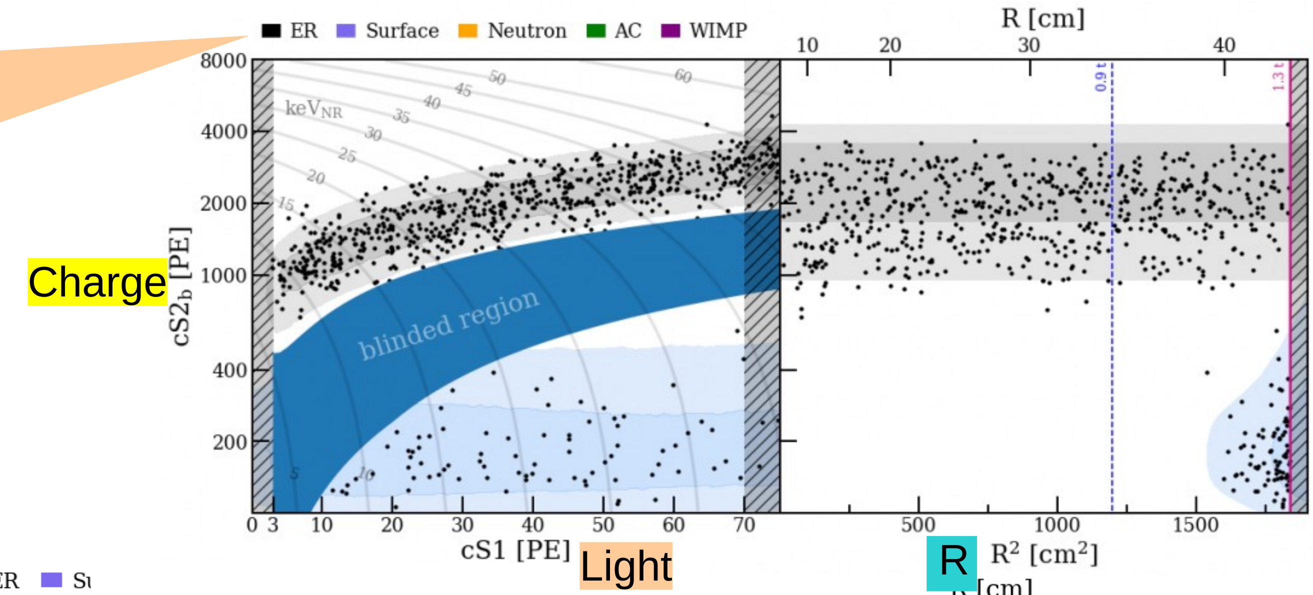
use **central 1.3 t** LXe for analysis

Blind analysis
= region of interest inaccessible during analysis to avoid human bias

Blinded Data

best-fit relative probabilities of signal/background components under best-fit model

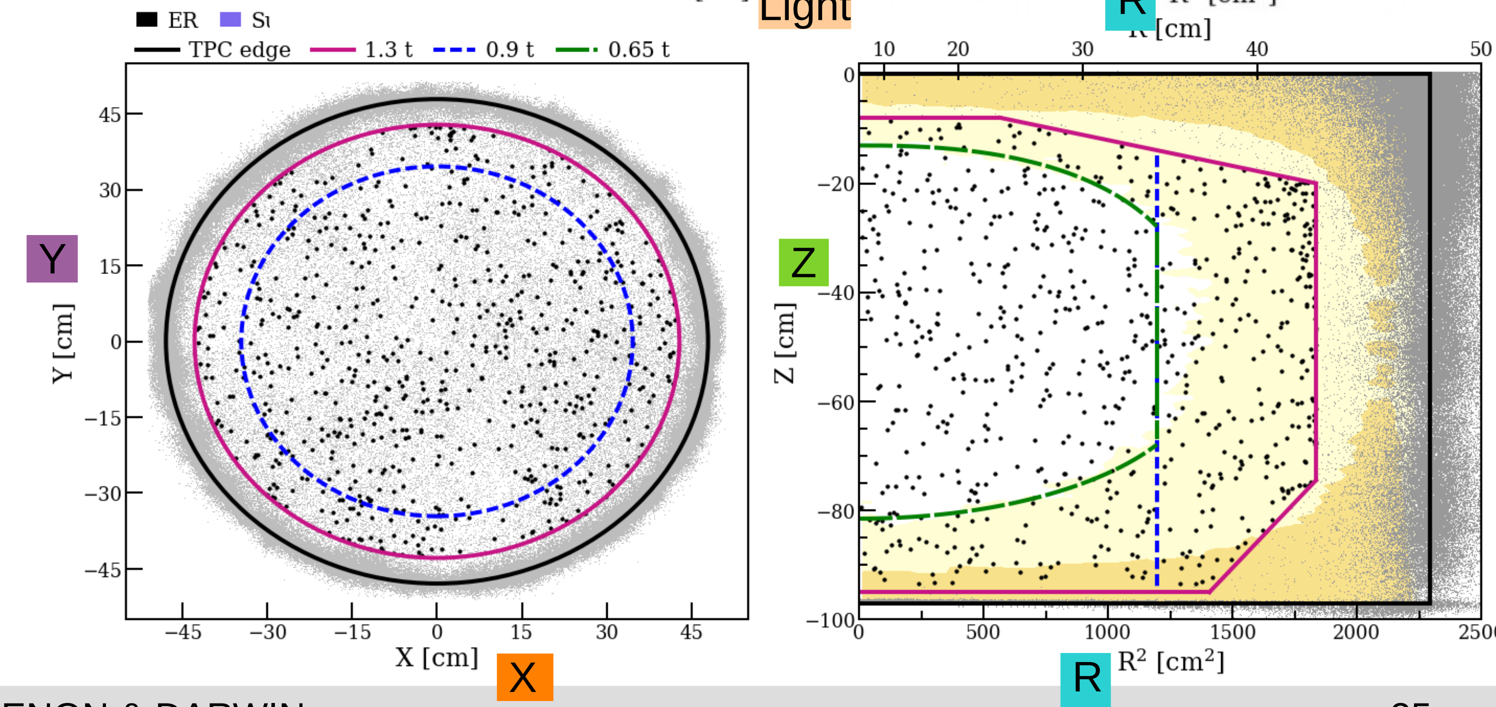
larger markers = more WIMP-like



Analysis done in
– signal (light, charge)
– position (X,Y→R, „Z“) space

event cuts and „signal/ background-like-ness“ defined using several parameters

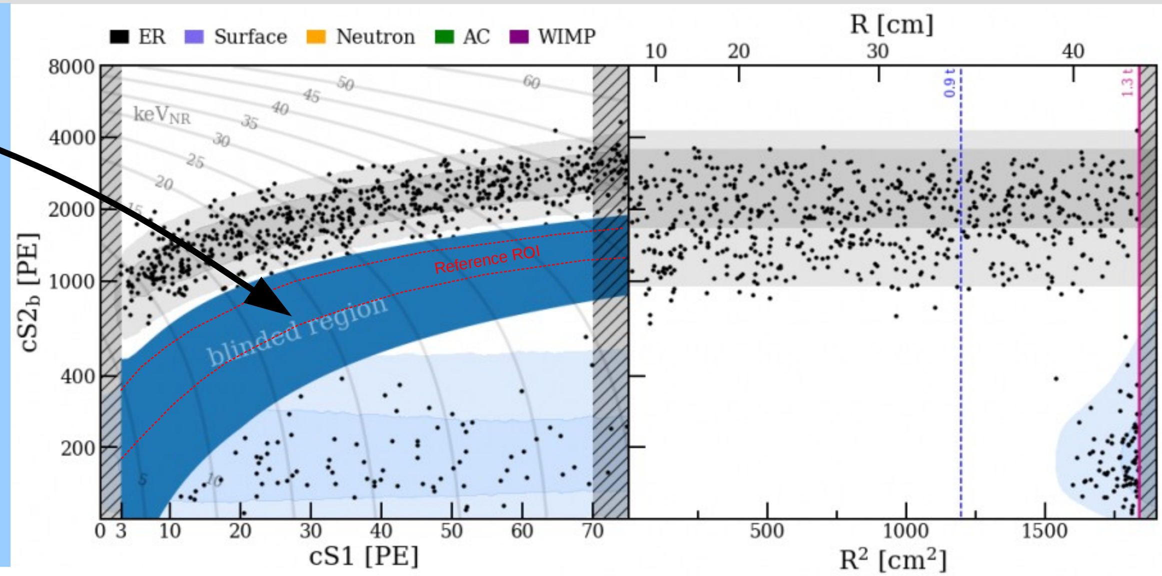
Full likelihood analysis.



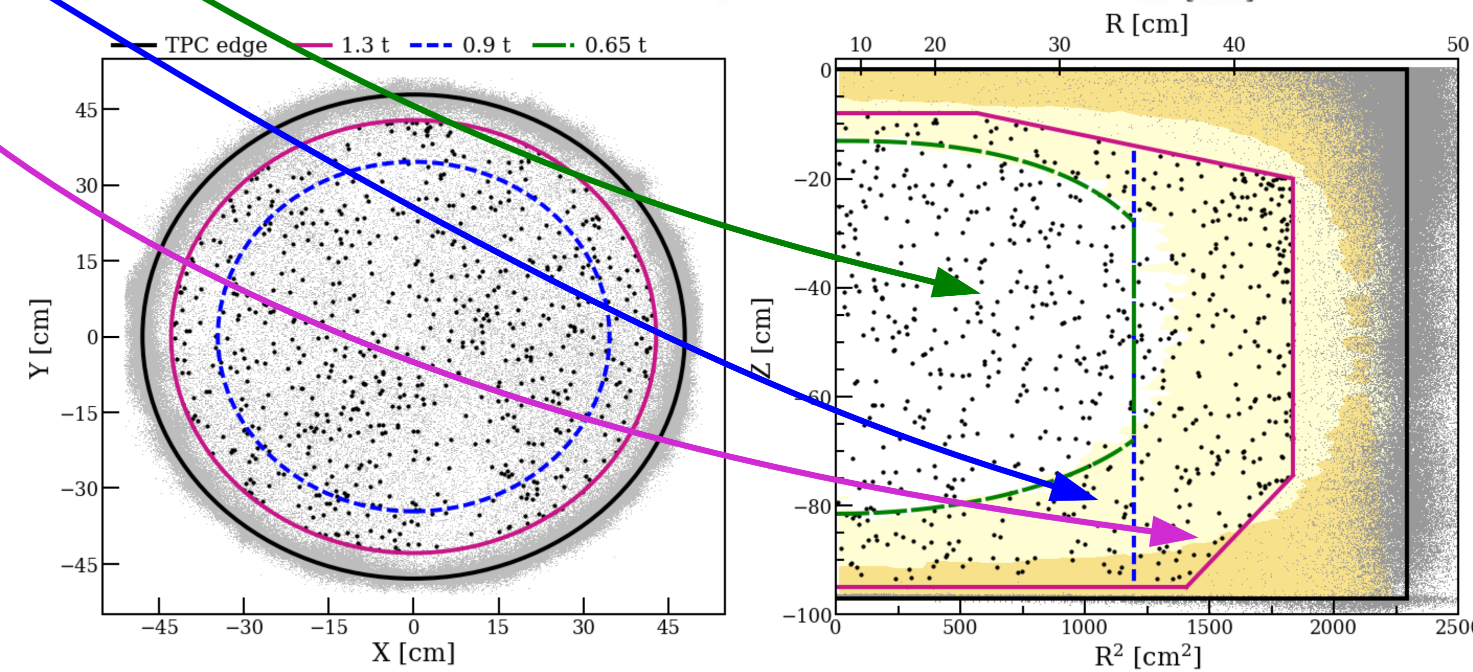
Background Prediction

What is expected here?
→ depends on Fiducial Mass

Mass (cS1, $cS2_b$)	1.3 t Full	1.3 t Reference	0.9 t Reference	0.65 t Reference
ER	627±26	2.17±0.09	1.53±0.06	0.86±0.04
neutron	1.44±0.61	0.75±0.30	0.42±0.18	0.14±0.06
CEνNS	0.05±0.02	0.02±0.01	0.02±0.01	0.01
AC	$0.47^{+0.29}_{-0.02}$	$0.10^{+0.06}_{-0.00}$	0.05±0.02	0.04±0.01
Surface	106±11	5.36±0.54	0.02	0.01
BG	736±28	8.40±0.63	2.05±0.18	1.06±0.07



85 evts $t^{-1}y^{-1}keV_{ee}^{-1}$
→ lowest background ever achieved in dark matter experiment!

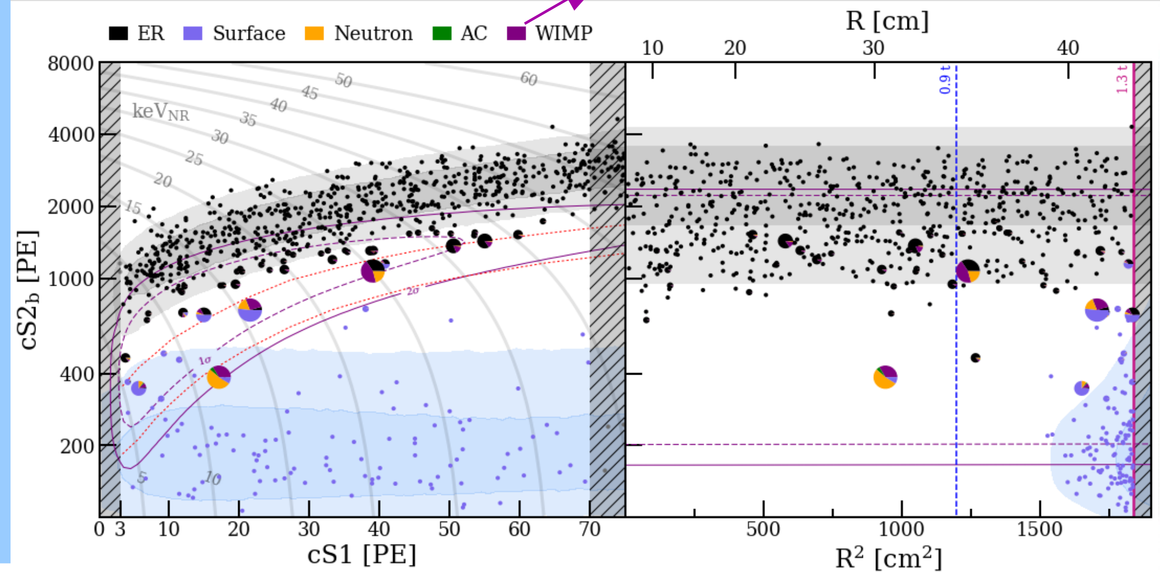


Unblinding

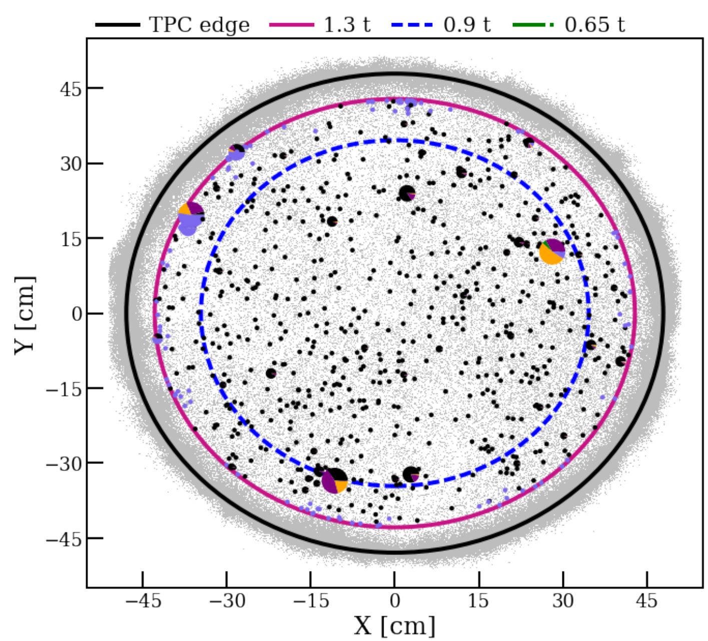
What is expected here?
→ depends on Fiducial Mass

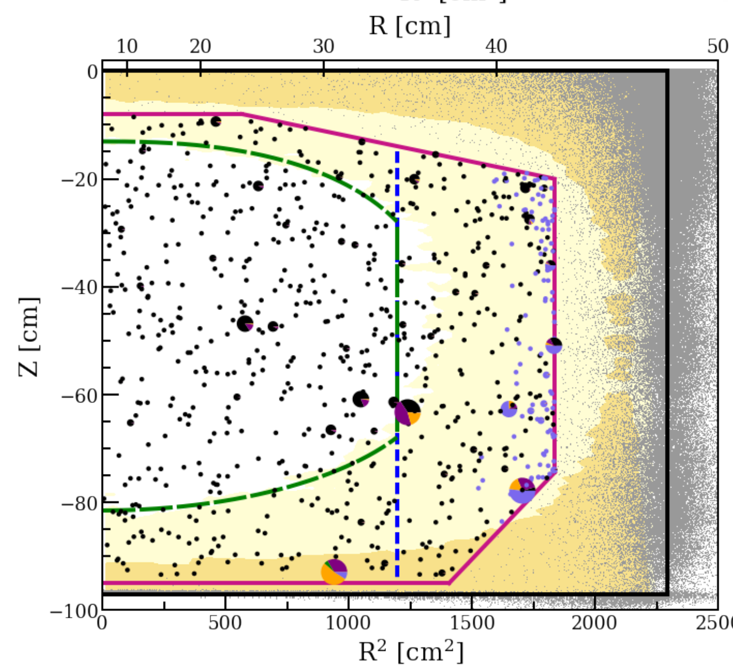
Mass	1.3 t	1.3 t	0.9 t	0.65 t
(cS1, $cS2_b$)	Full	Reference	Reference	Reference
ER	627±26	2.17±0.09	1.53±0.06	0.86±0.04
neutron	1.44±0.61	0.75±0.30	0.42±0.18	0.14±0.06
CEνNS	0.05±0.02	0.02±0.01	0.02±0.01	0.01
AC	$0.47^{+0.29}_{-0.02}$	$0.10^{+0.06}_{-0.00}$	0.05±0.02	0.04±0.01
Surface	106±11	5.36±0.54	0.02	0.01
BG	736±28	8.40±0.63	2.05±0.18	1.06±0.07
Data	739	11	0	0

200 GeV/c²



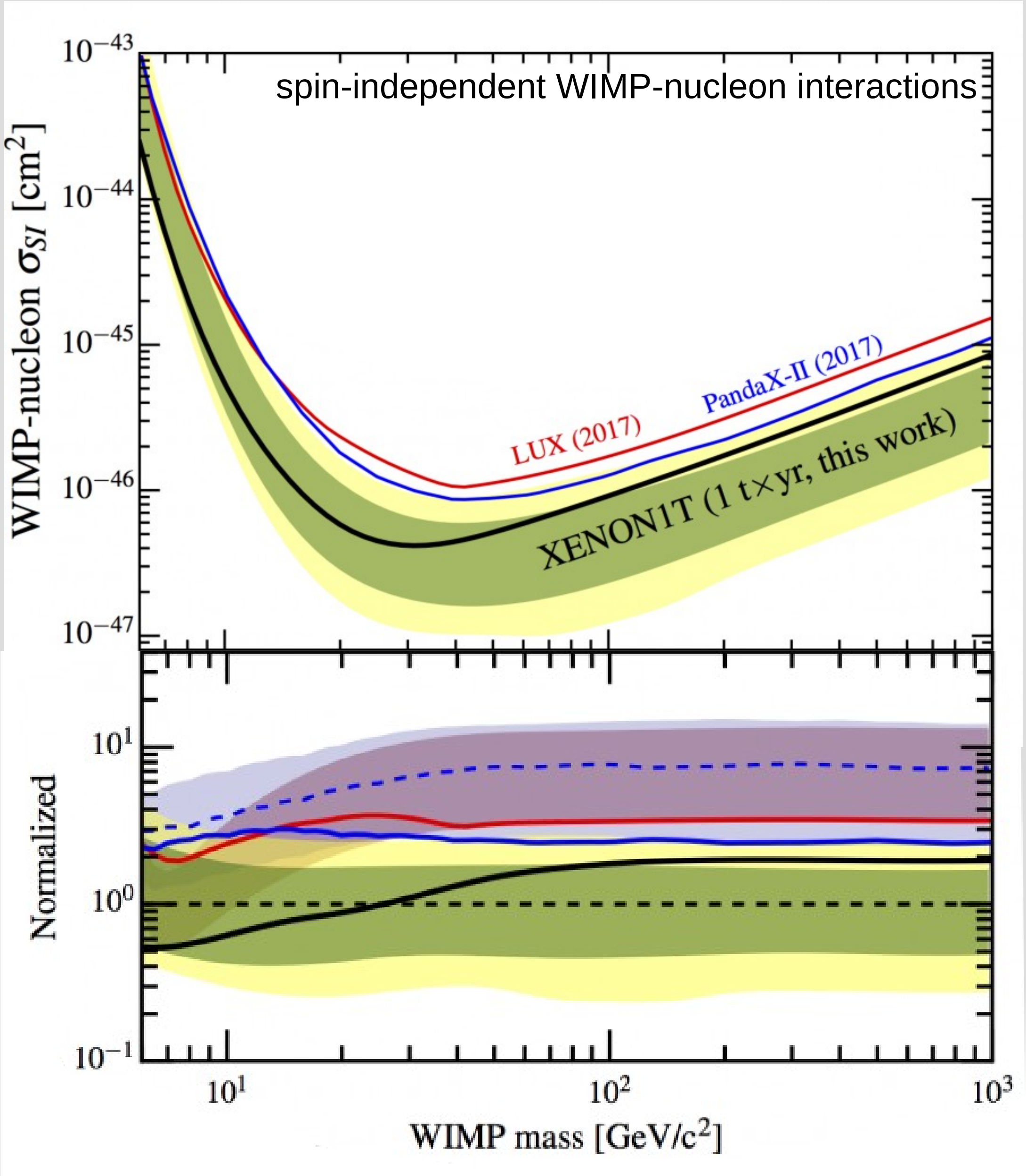
→ no statistically significant excess observed





No Signal → Exclusion Limit

PRL 121, 111302 (2018)



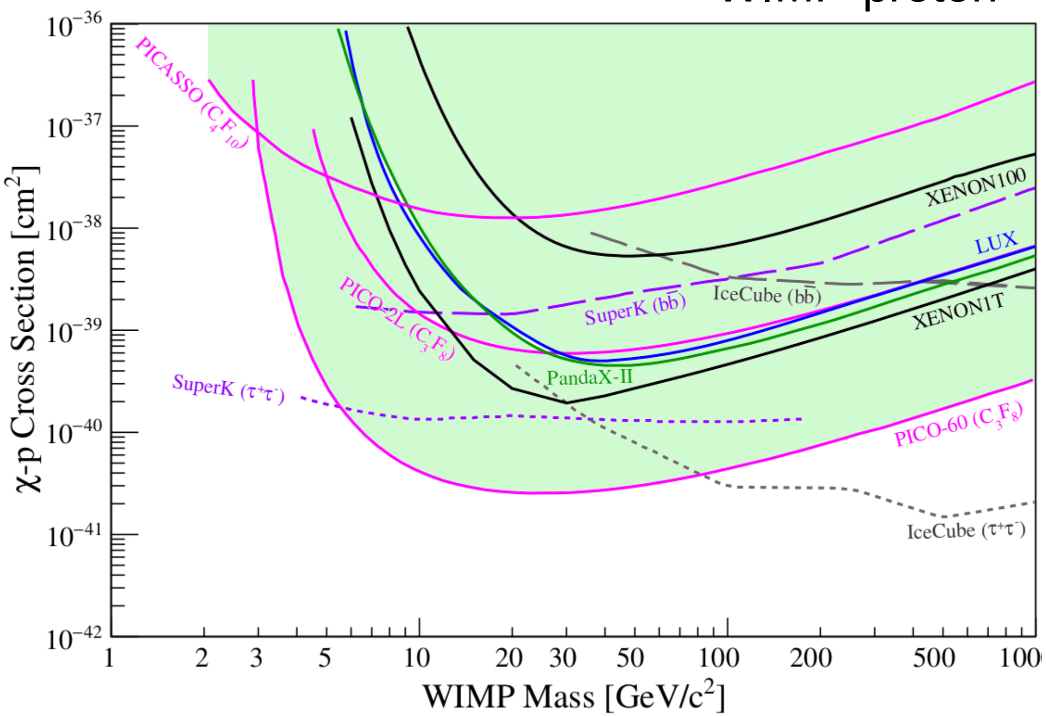
Spin-Dependent Couplings

PRL 122, 141301 (2019)

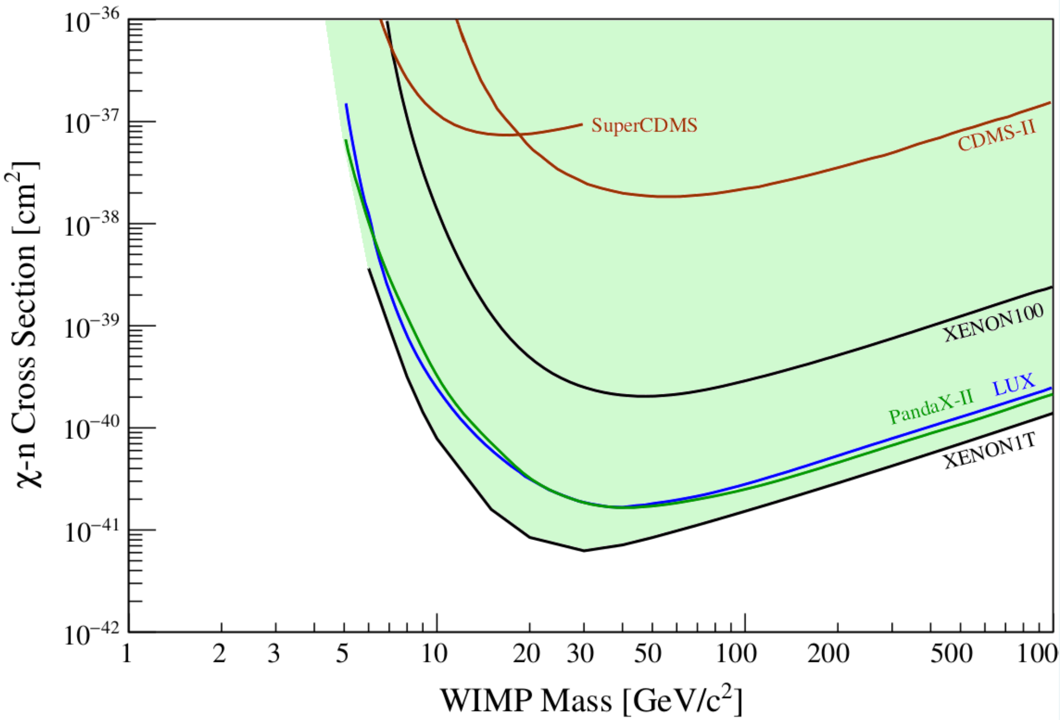
- coupling of WIMP to unpaired nucleon spins
- traditionally separated in proton-only and neutron-only
- same parameter space explored by indirect and collider searches

Isotope	Abundance	Spin	Unpaired Nucleon	Relative Strength
^{7}Li	92.6%	3/2	proton	12.8
^{19}F	100.0%	1/2	proton	100.0
^{23}Na	100.0%	3/2	proton	1.3
^{29}Si	4.7%	1/2	neutron	9.7
^{73}Ge	7.7%	9/2	neutron	0.3
^{127}I	100.0%	5/2	proton	0.3
^{131}Xe	21.3%	3/2	neutron	1.7

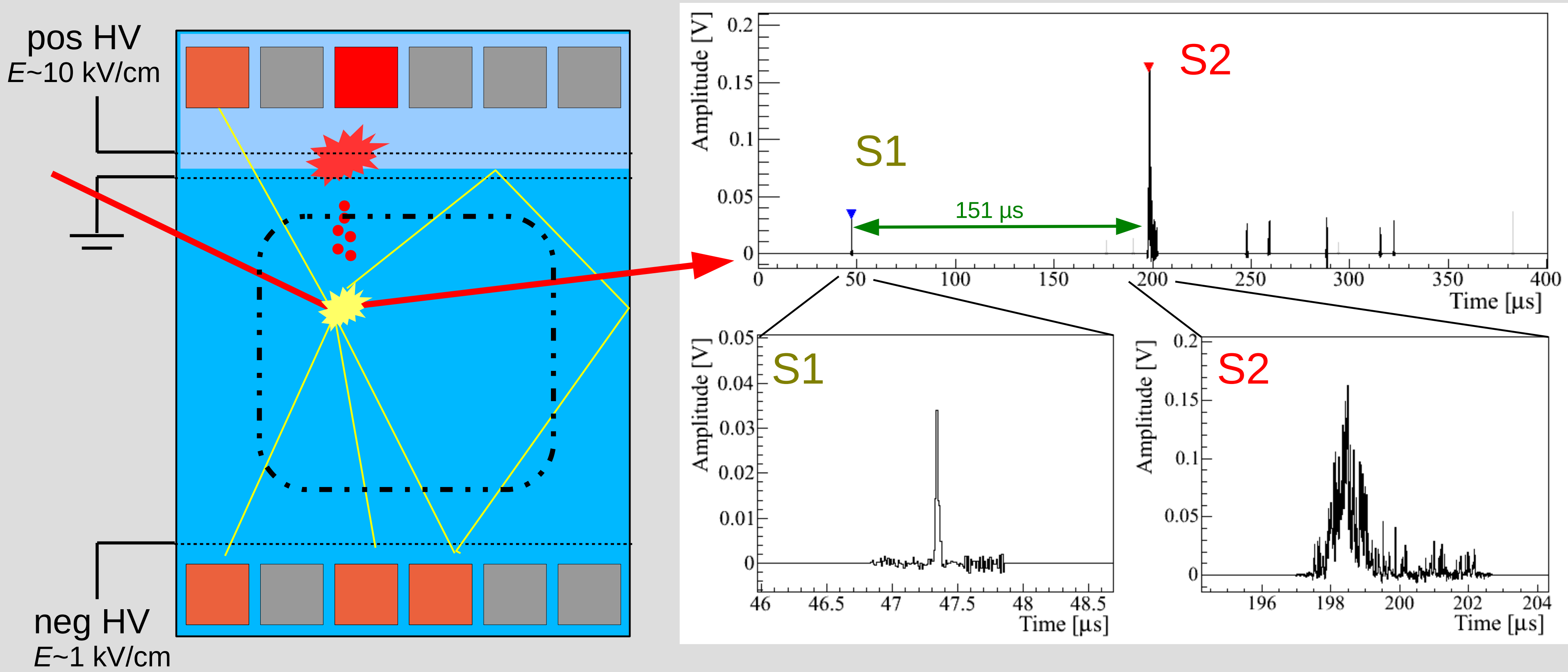
WIMP-proton



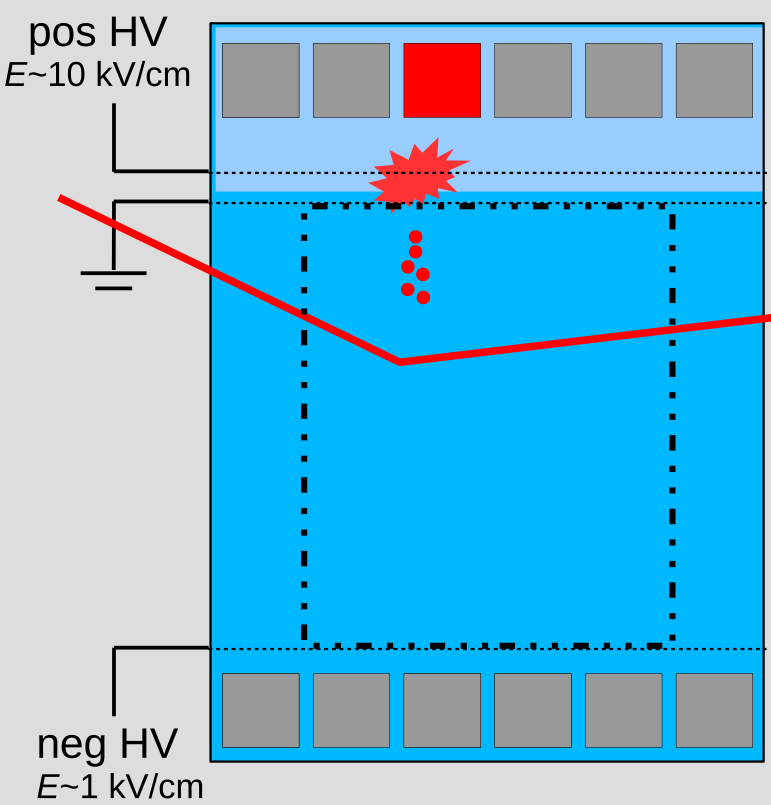
WIMP-neutron

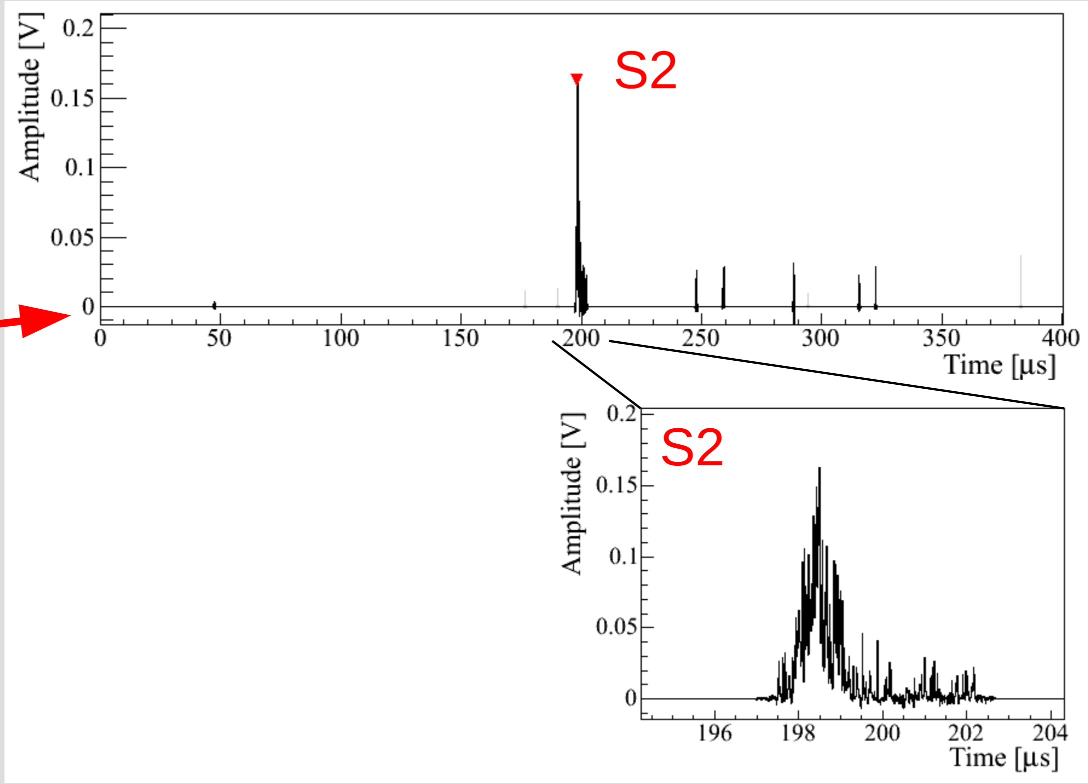


Standard Analysis



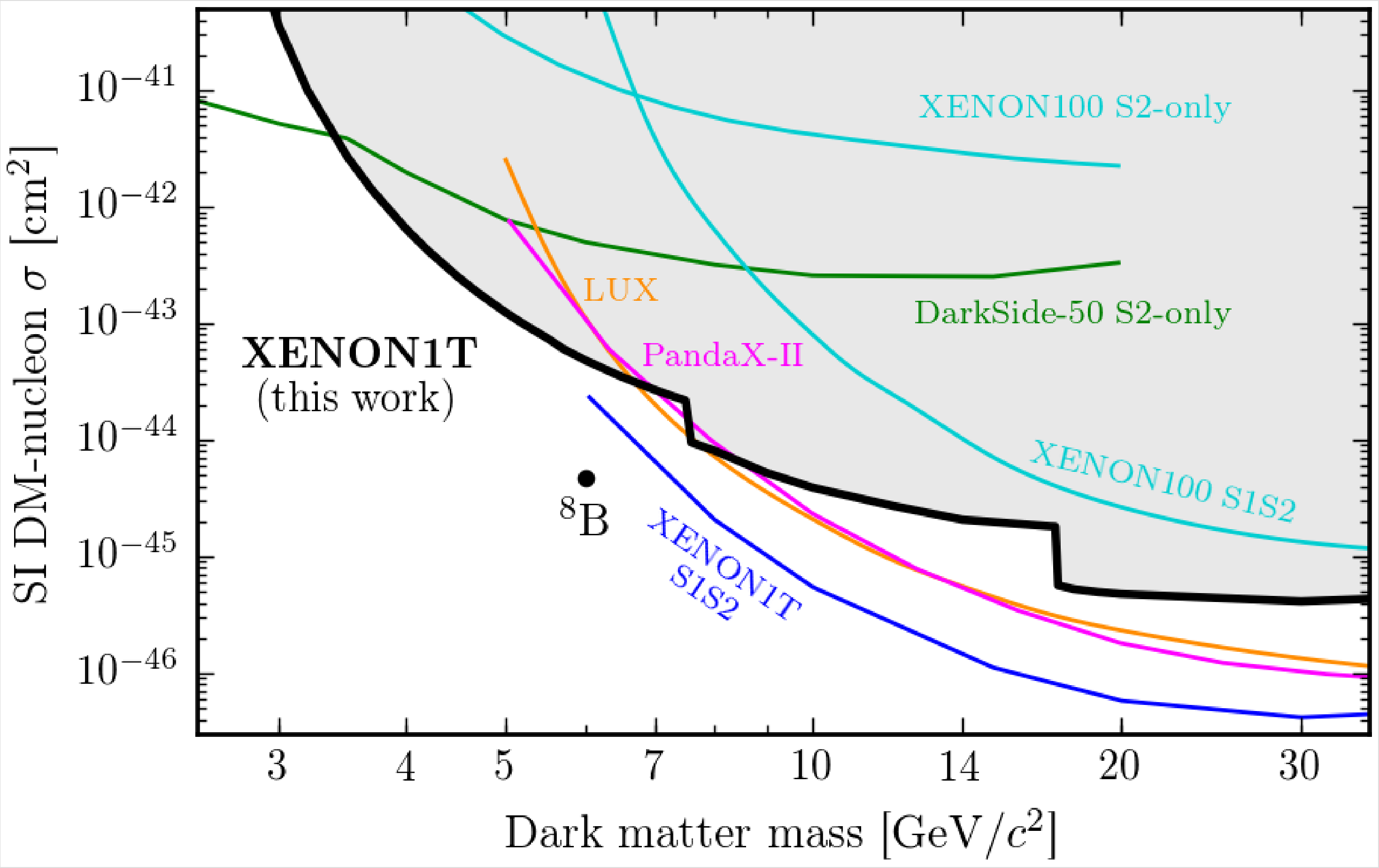
Charge-Only Analysis





Charge-Only Analysis

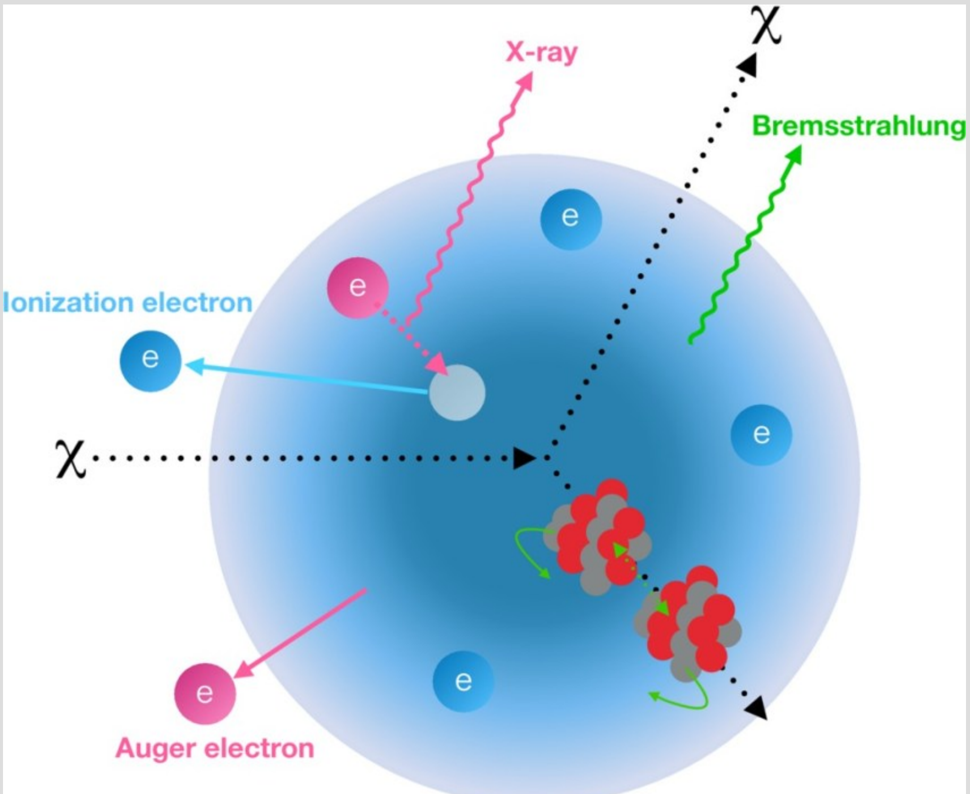
arXiv:1907.11485

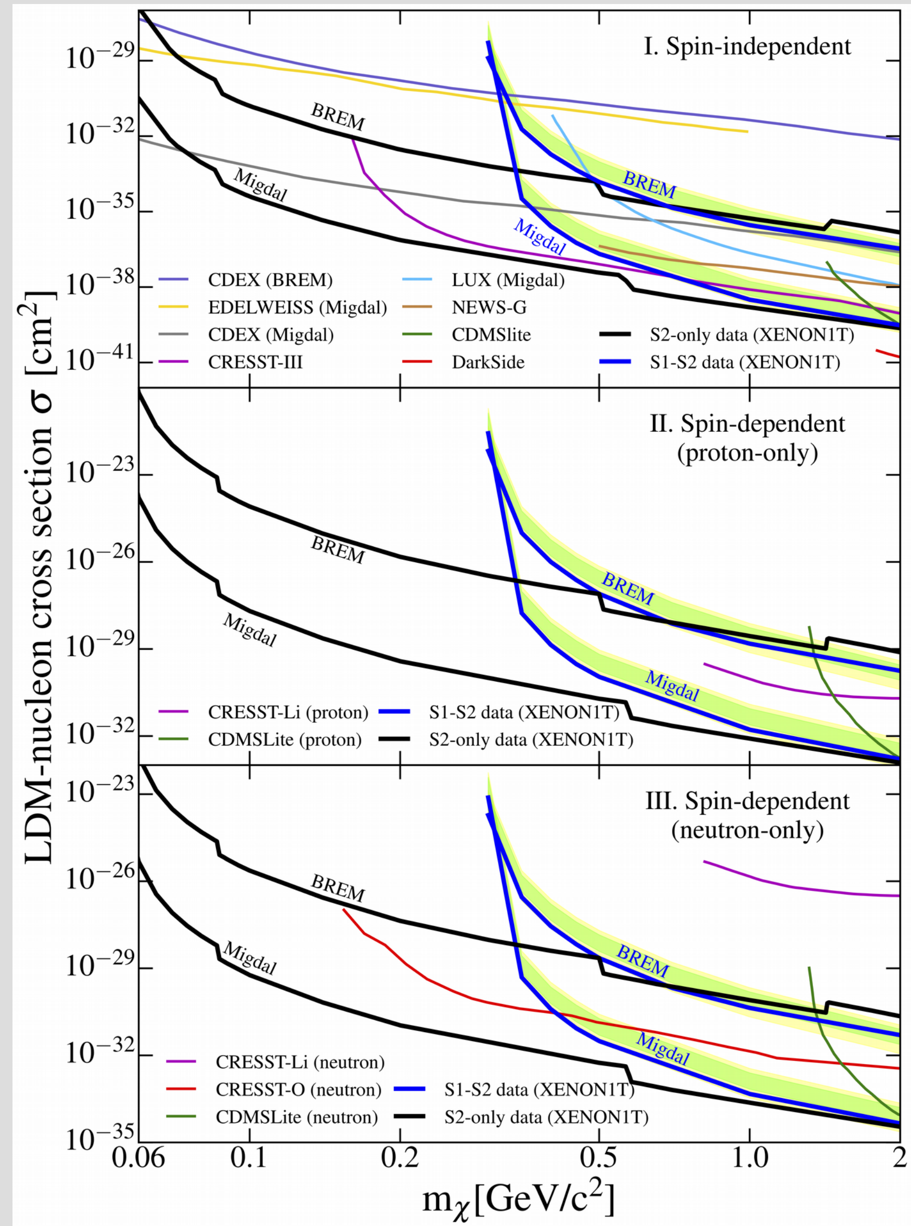


Xe XENON Dark Matter Project

Migdal Effect, Bremsstrahlung

arXiv:1907.12771



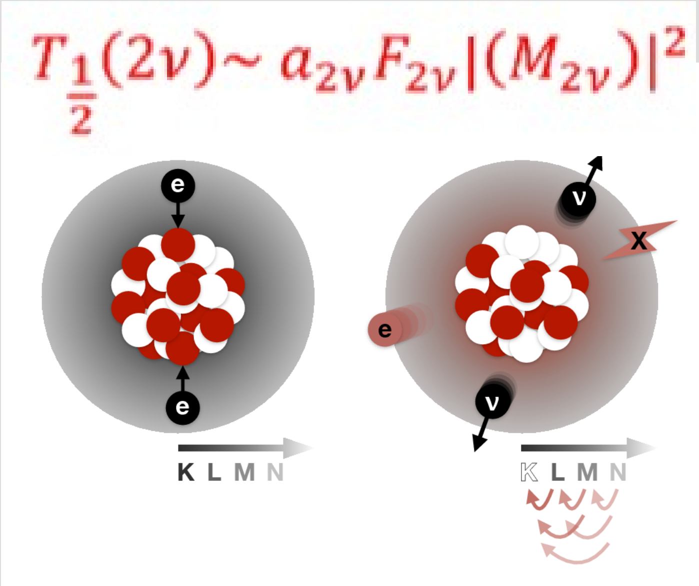


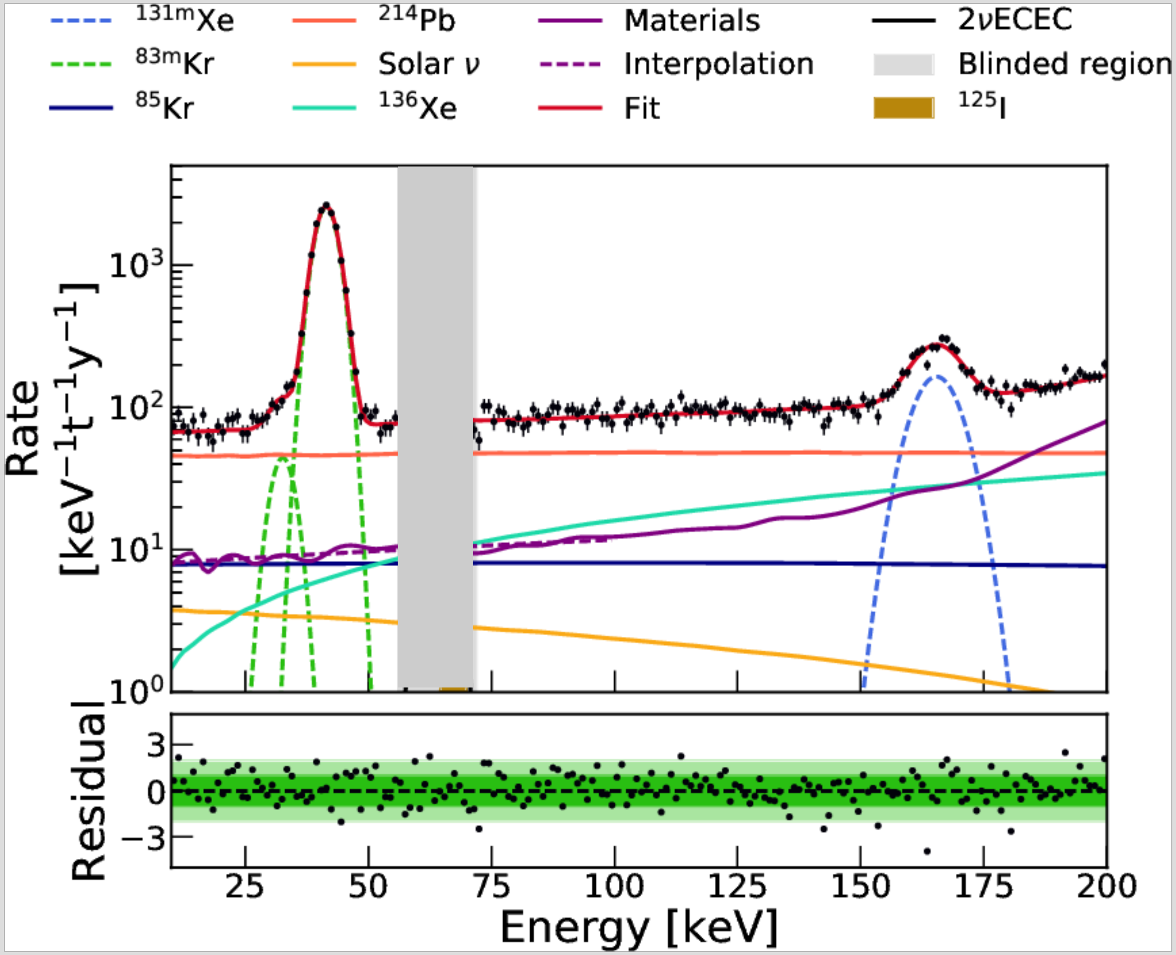
– exploit expected effects after nuclear recoil
→ very low threshold

– caveat: effect not yet observed in calibration

Double Electron Capture of ^{124}Xe

Nature 568, 532 (2019)





- 2nd order weak process with very long $T_{1/2}$
- so far only seen in ^{78}Kr, ^{130}Ba
- test of nuclear structure models

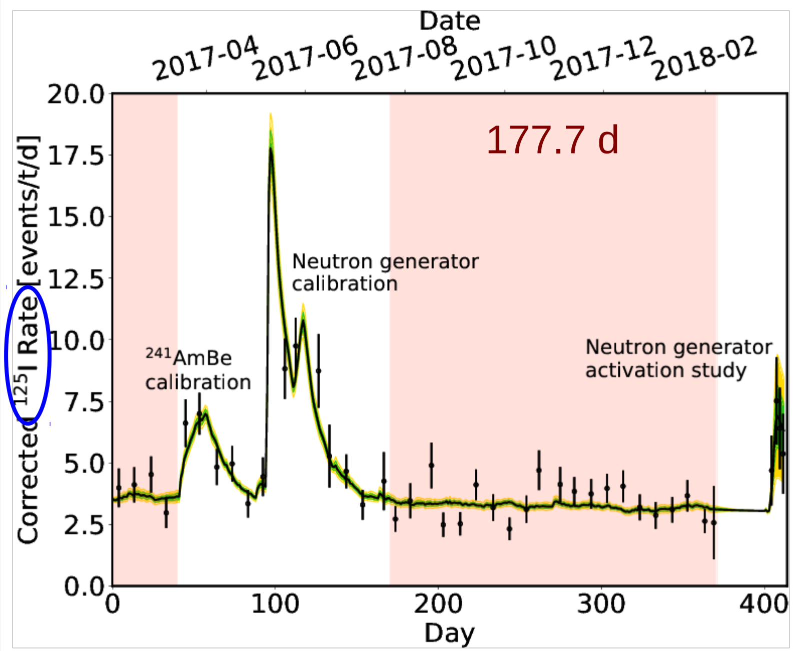
  e.g., PLB 797, 134885 (2019)
- $^{124}Xe + 2\,e^{-} \rightarrow {}^{124}Te^{**} + 2\,\nu_e$

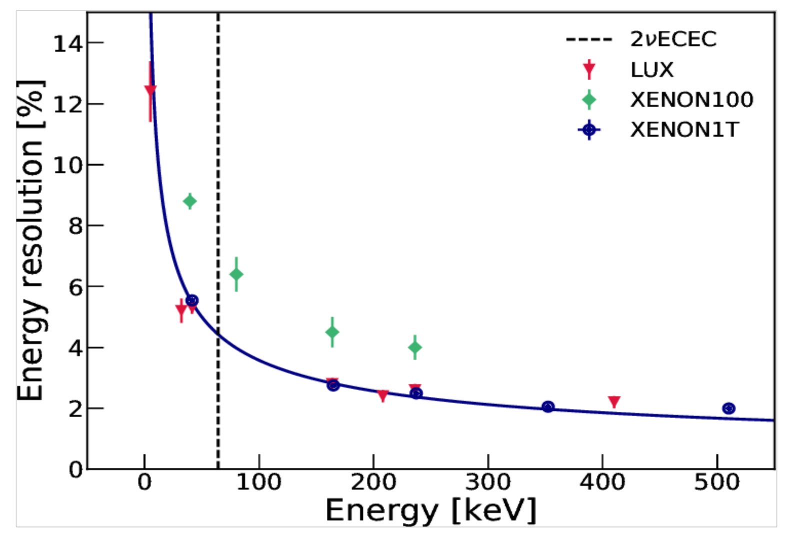
line at 64.33 keV

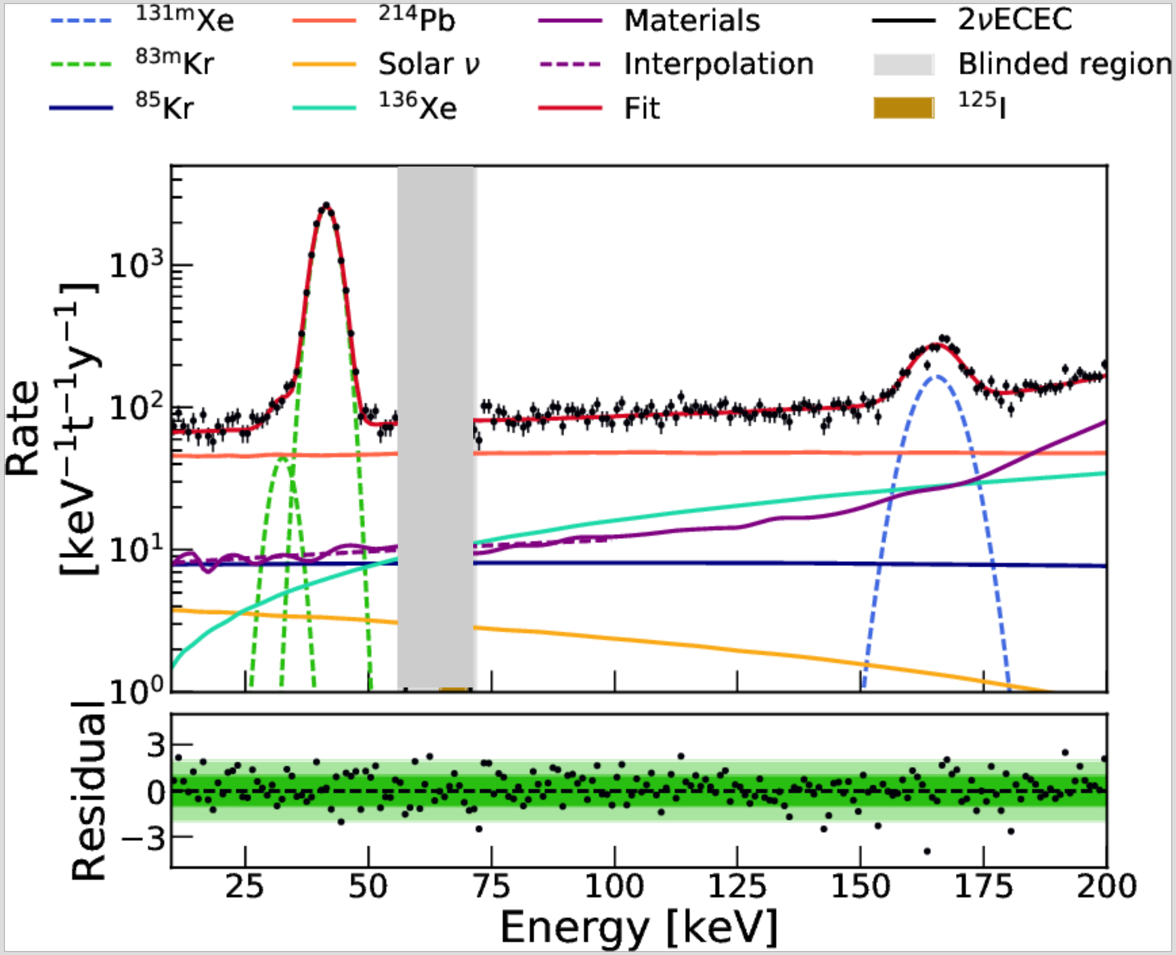
^{nat}Xe contains ~1 kg ^{124}Xe per tonne

DEC of ^{124}Xe: ^{125}I Background

Nature 568, 532 (2019)



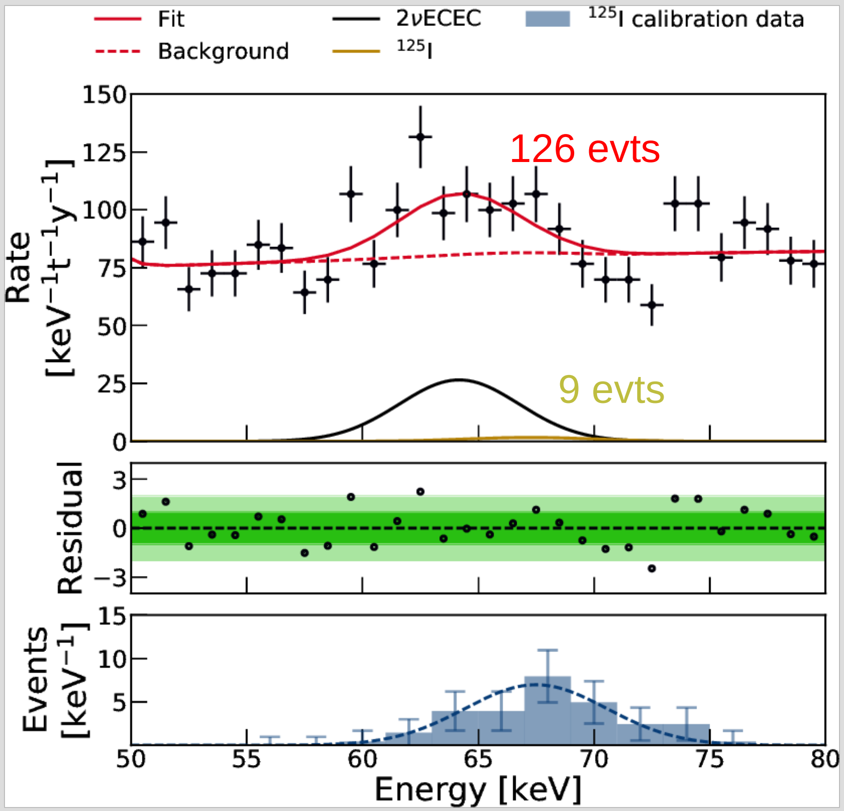


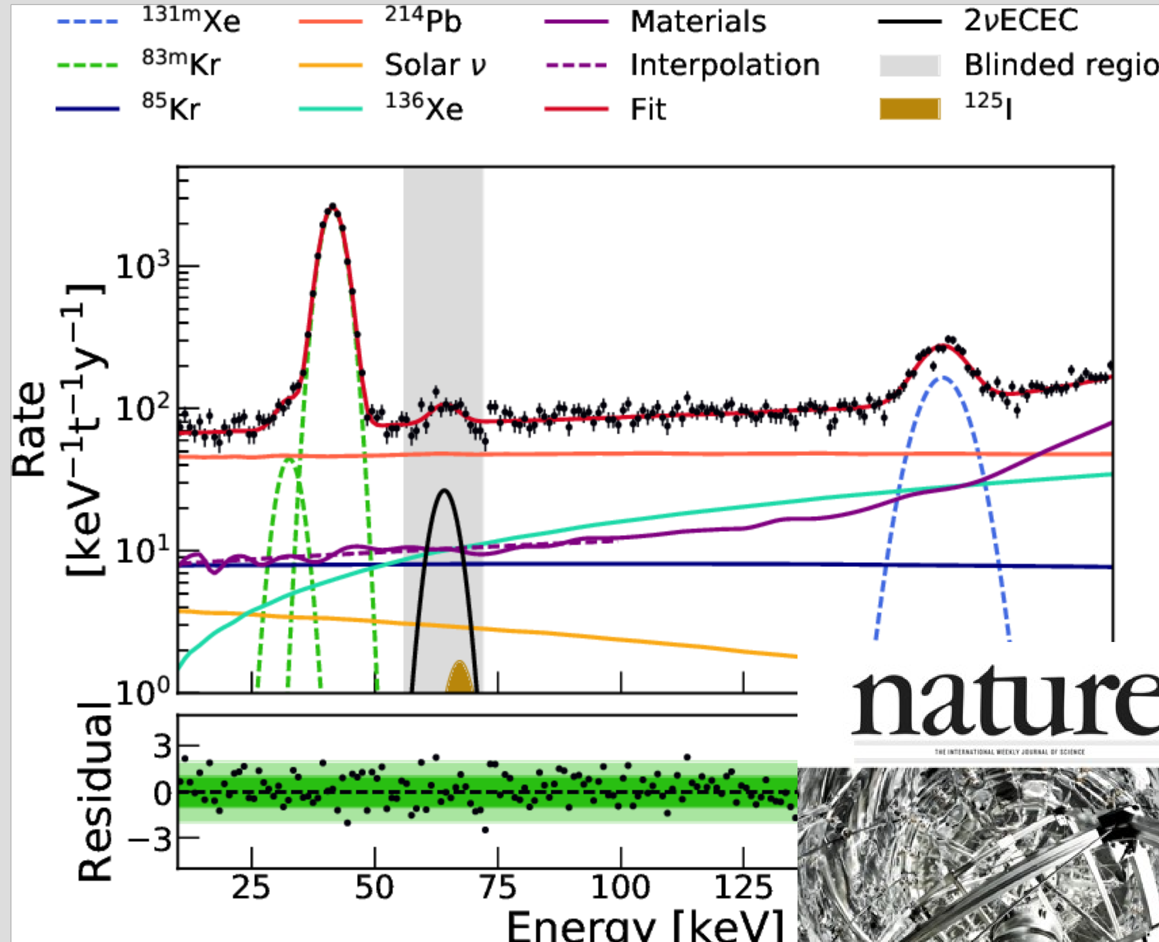


- ^{124}Xe + n → ^{125}Xe + γ
  ↳ ^{125}I + … → ^{125}Te* + ...
  ↳ γ @ 67.3 keV

DEC of ^{124}Xe

Nature 568, 532 (2019)

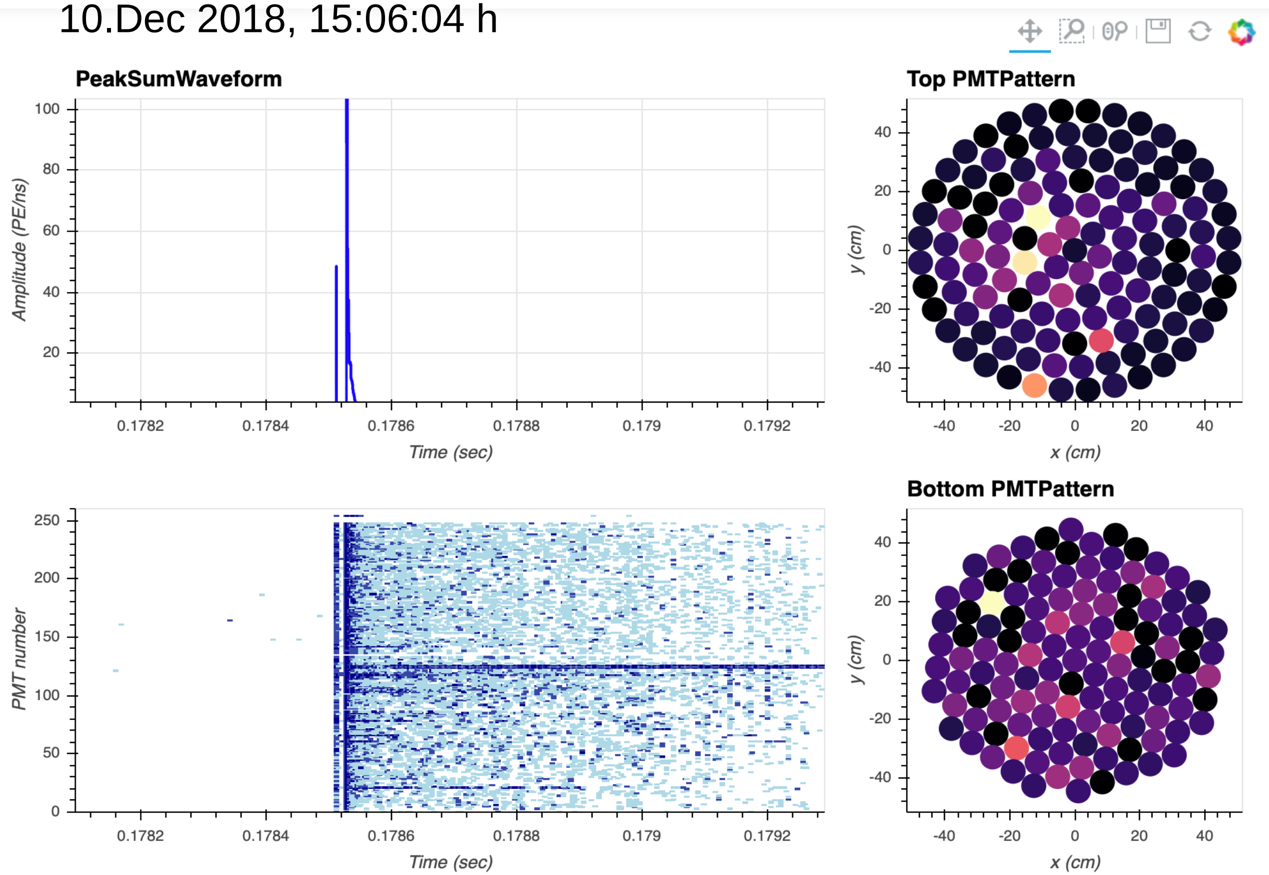




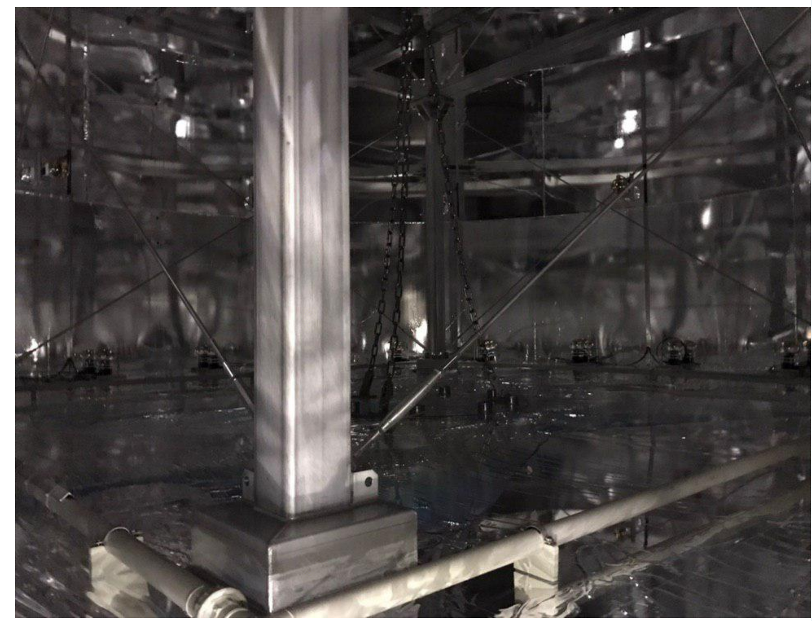
- 126 events above background observed in 1.5 t FV
- $T^{2\nu ECEC}_{1/2} = (1.8 \pm 0.5_{stat} \pm 0.1_{sys}) \times 10^{22}$ y
- longest half-life ever measured directly

Dec 2018: XENON1T Stopped

10.Dec 2018, 15:06:04 h

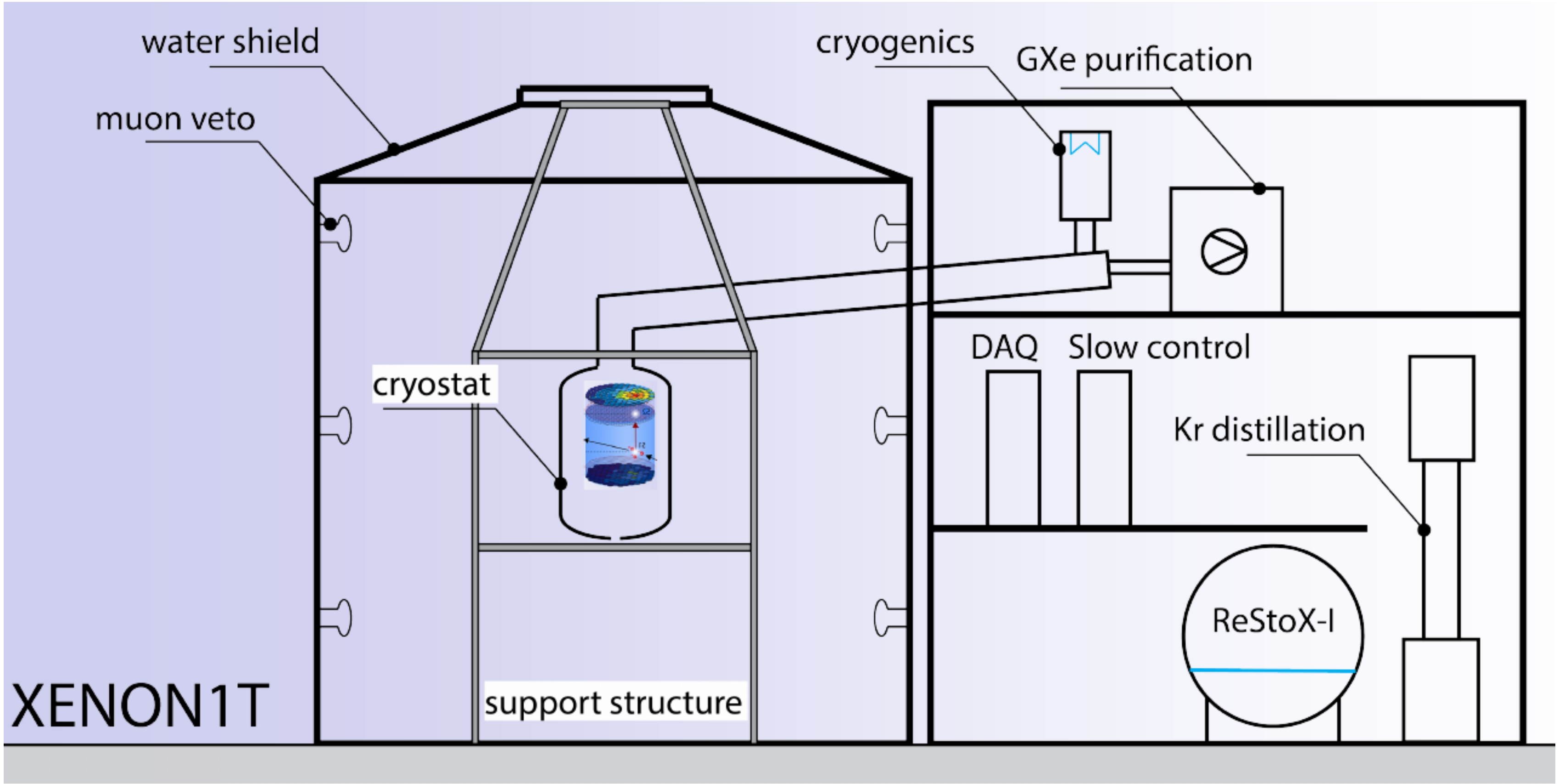


Last recorded event



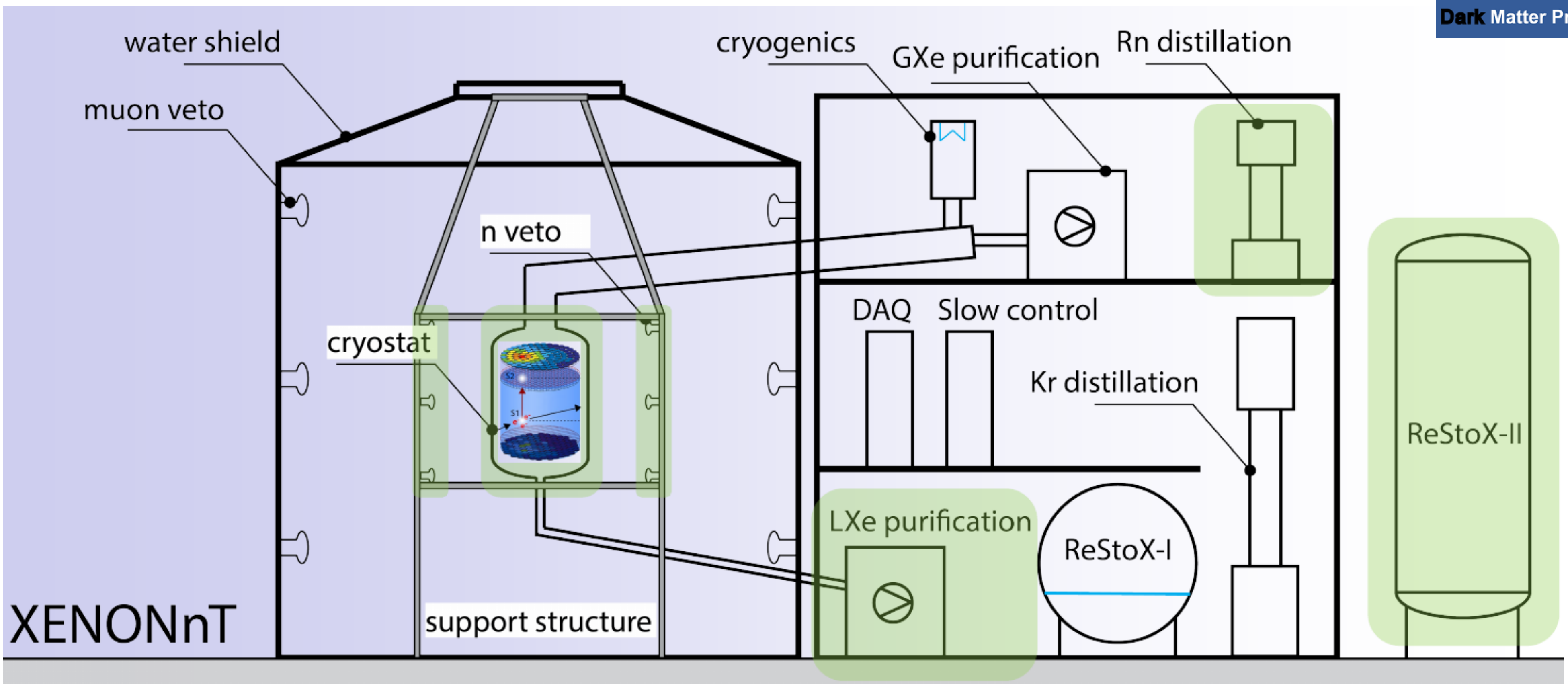
Water shield accessible again

From XENON1T



From XENON1T to XENONnT

JCAP 04, 027 (2016)



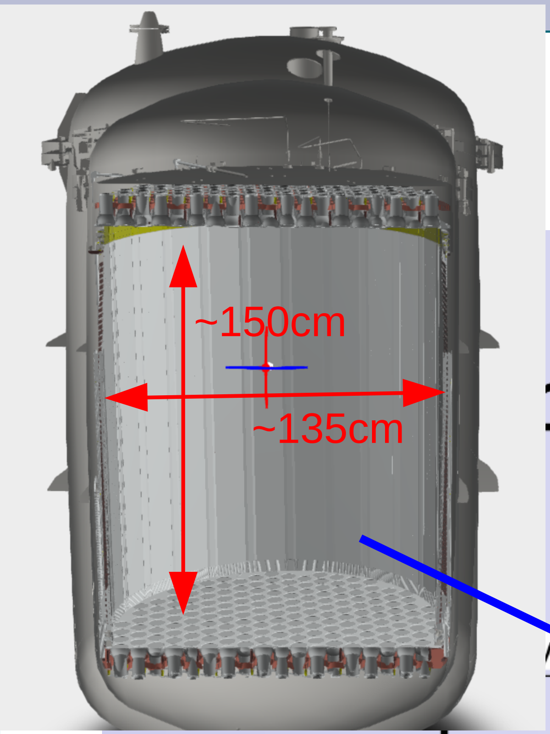
- **3x larger** than XENON1T

5.9t active LXe target
~8.5t total mass

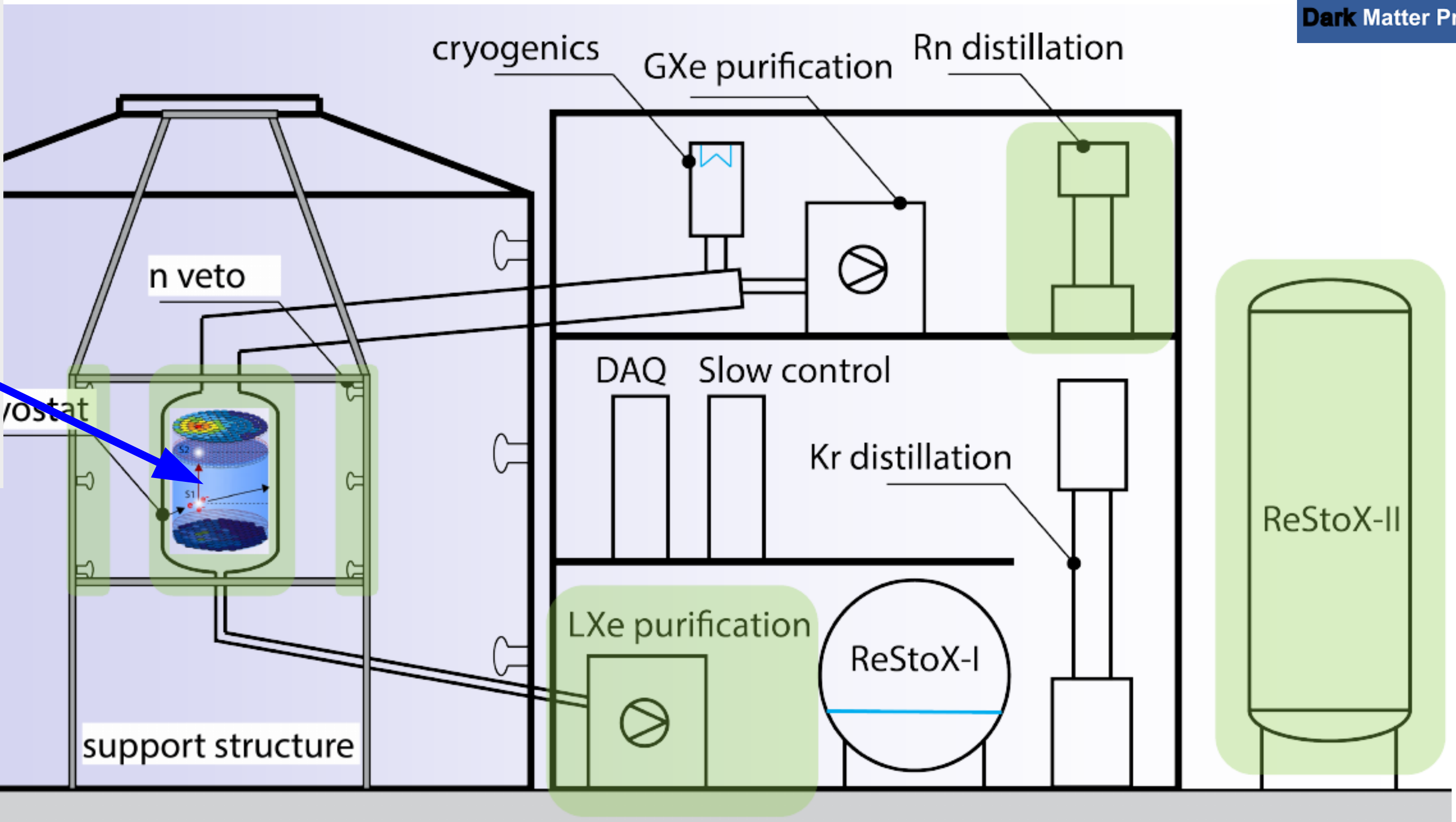
- goal: ER bg reduced x0.1, 0.6 NR neutrons in 20 t×y

From XENON1T to XENONnT

JCAP 04, 027 (2016)



– low-background TPC
– novel field cage design
– 494 R11410-21 PMTs



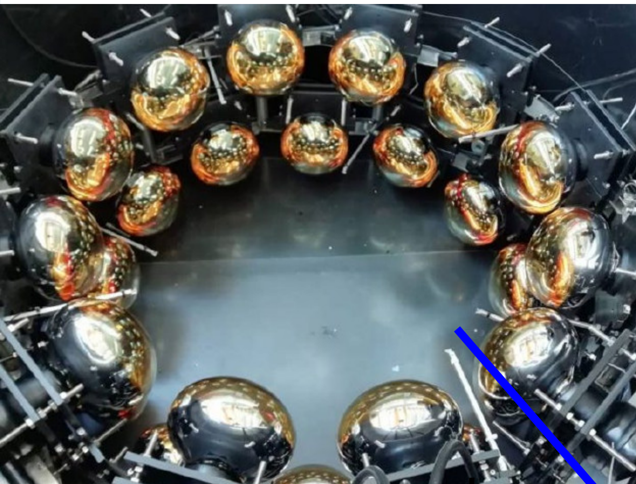
- **3x larger** than XENON1T

5.9t active LXe target
~8.5t total mass

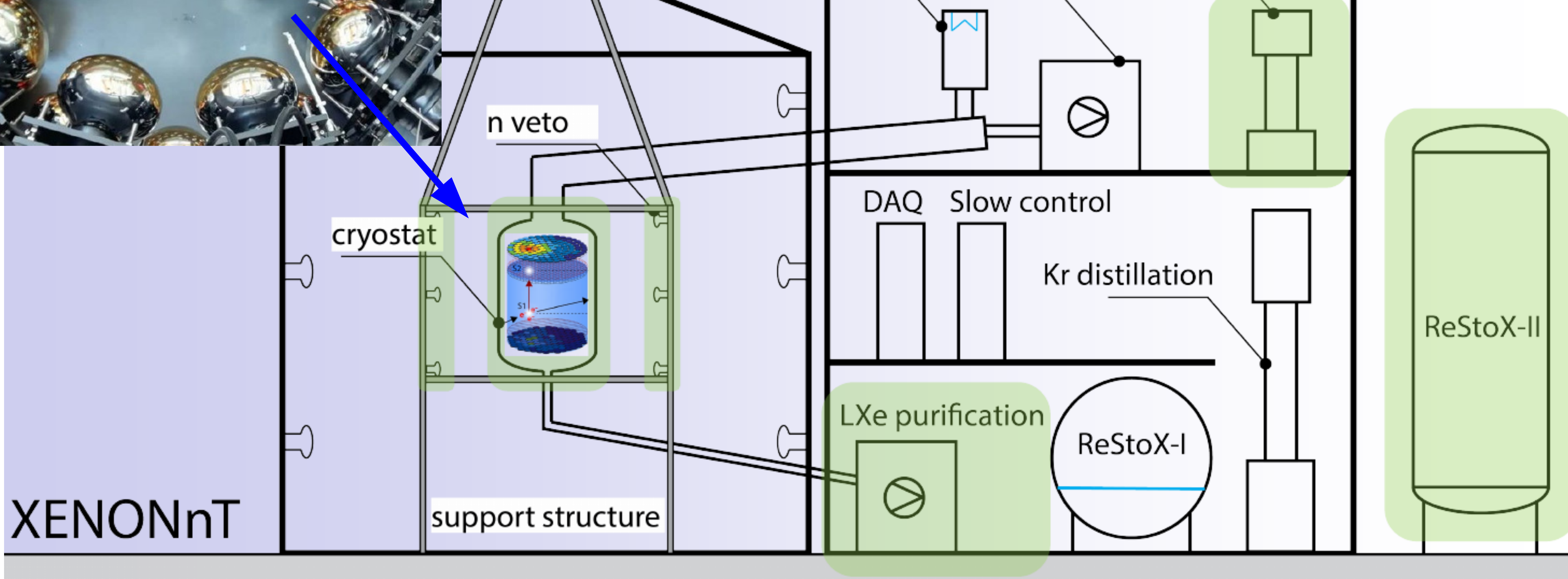
- goal: ER bg reduced x0.1, 0.6 NR neutrons in 20 t×y

From XENON1T to XENONnT

JCAP 04, 027 (2016)



- Gd-loaded water (0.2%)
- technology from EGADS
- high LY in inner volume



- **3x larger** than XENON1T

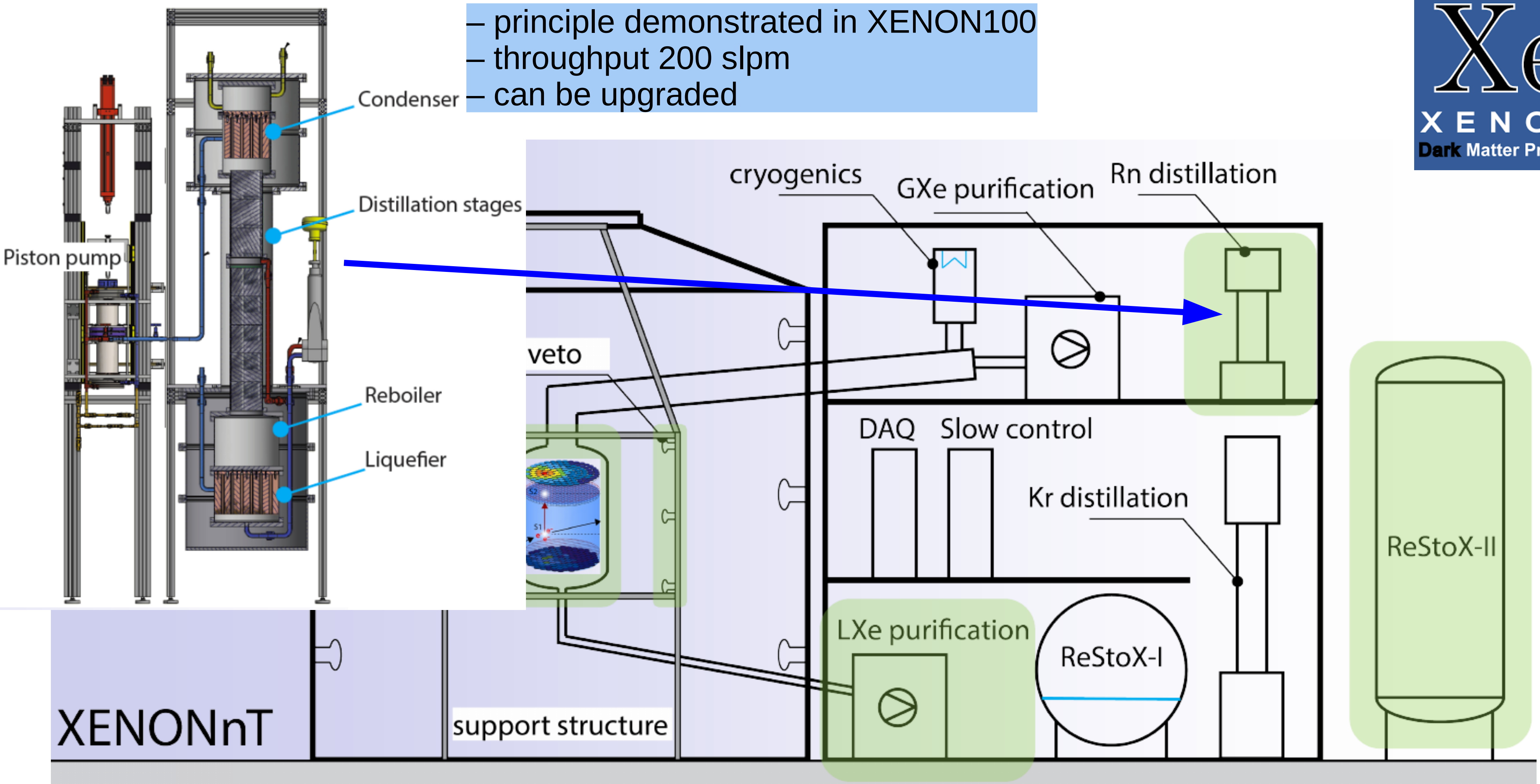
5.9t active LXe target
~8.5t total mass

- goal: ER bg reduced x0.1, 0.6 NR neutrons in 20 t×y

From XENON1T to XENONnT

JCAP 04, 027 (2016)

– principle demonstrated in XENON100
– throughput 200 slpm
– can be upgraded



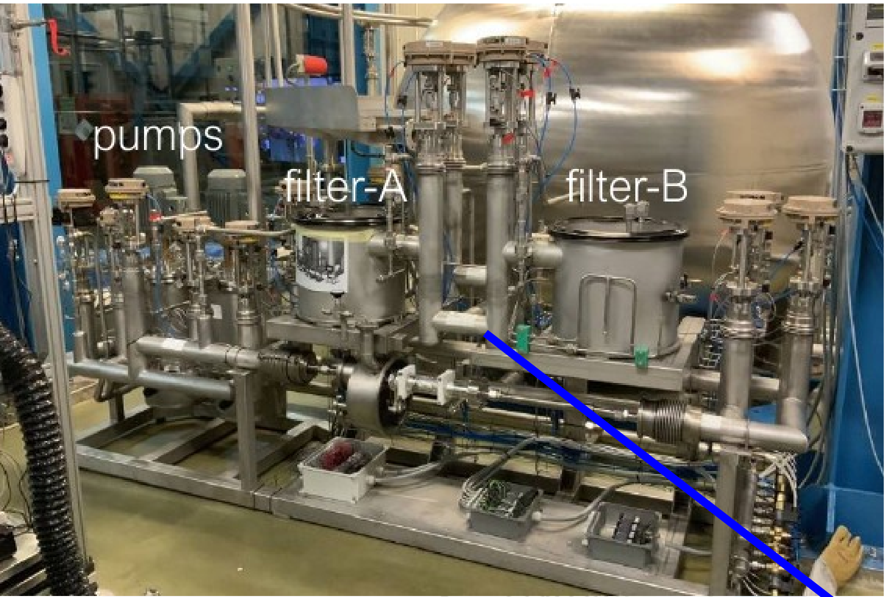
- **3x larger** than XENON1T

5.9t active LXe target
~8.5t total mass

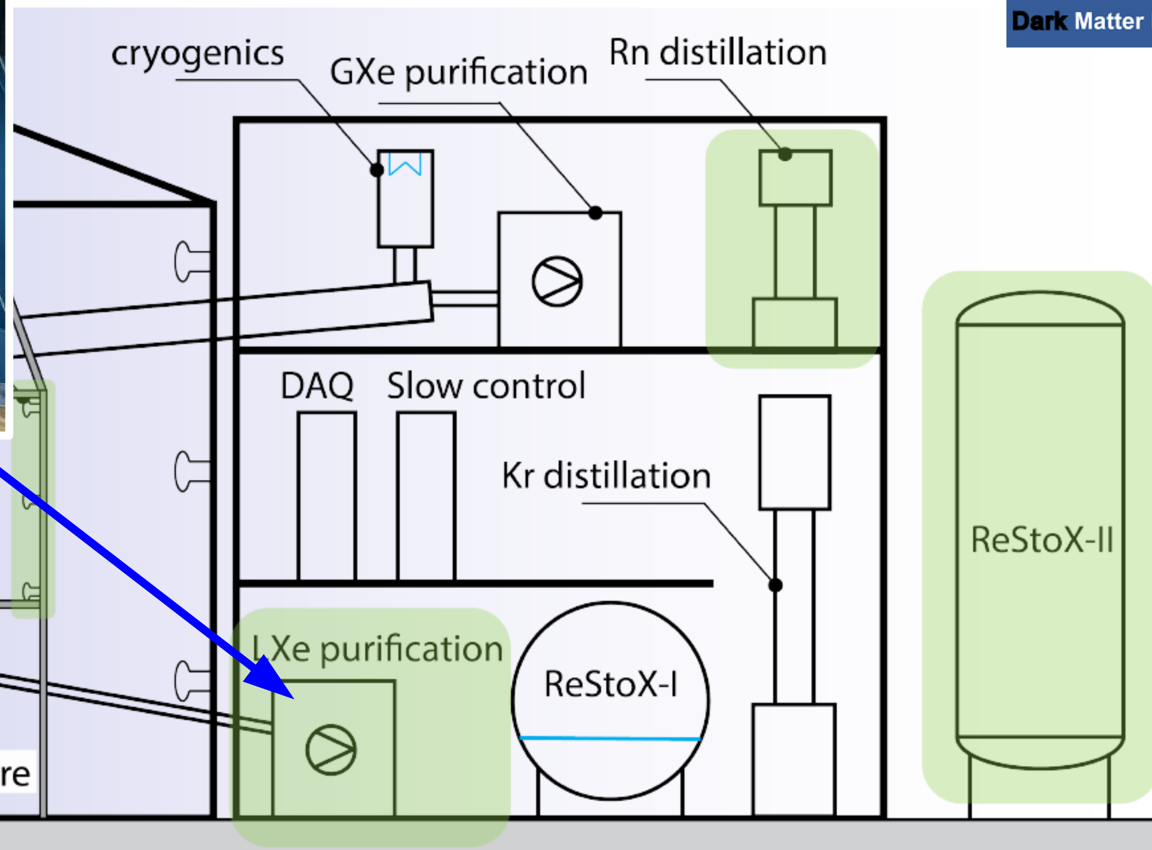
- goal: ER bg reduced x0.1, 0.6 NR neutrons in 20 t×y

From XENON1T to XENONnT

JCAP 04, 027 (2016)



- efficient purification at 5 l/min
- 2 Cu + O_2 → 2 CuO
- LXe from bottom of cryostat



- 3x larger than XENON1T

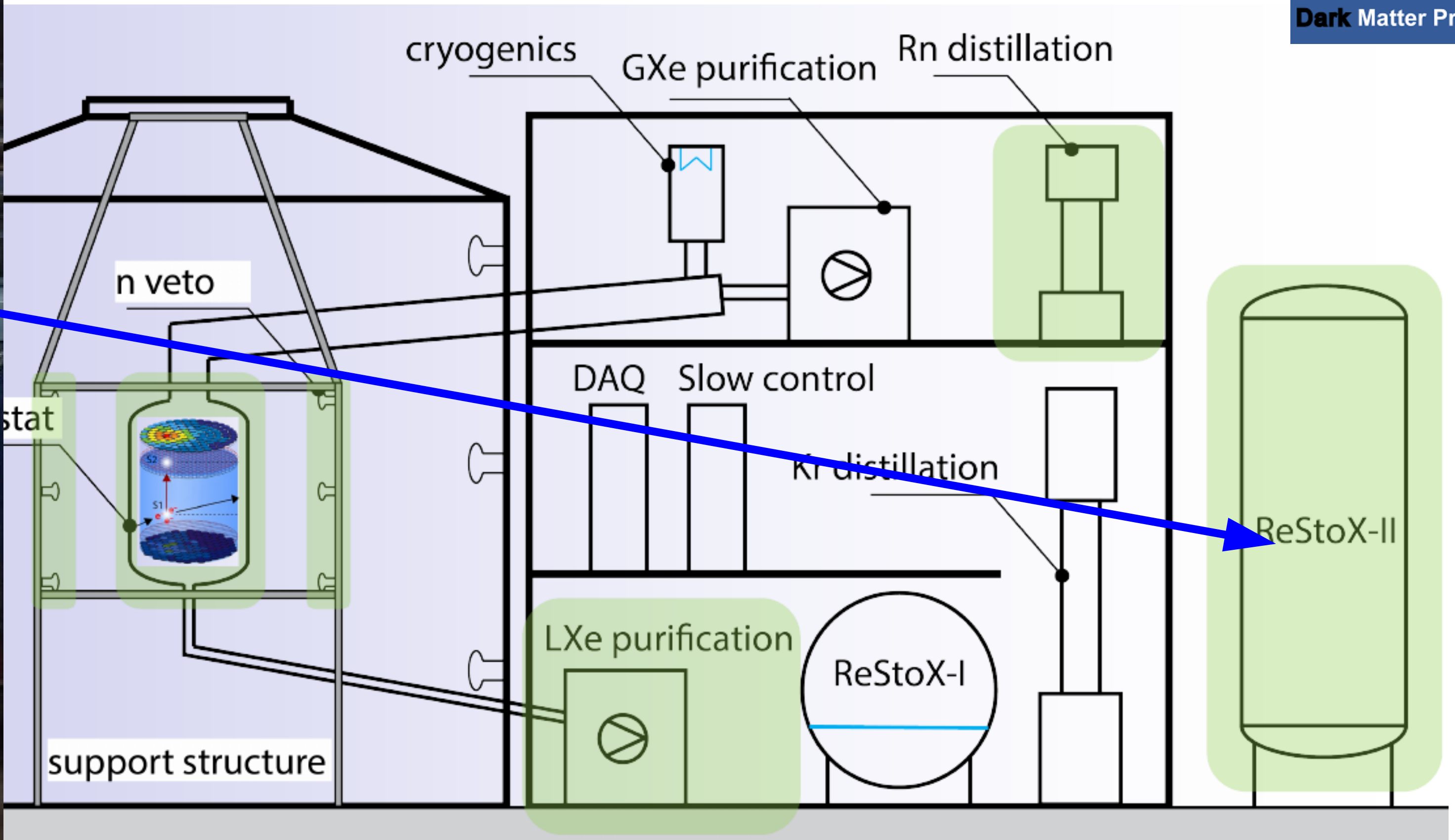
5.9t active LXe target
~8.5t total mass

- goal: ER bg reduced x0.1, 0.6 NR neutrons in 20 t×y

From XENON1T to XENONnT

JCAP 04, 027 (2016)

– store 10t of LXe or GXe
– currently: 8.3t of Xe in both storage systems



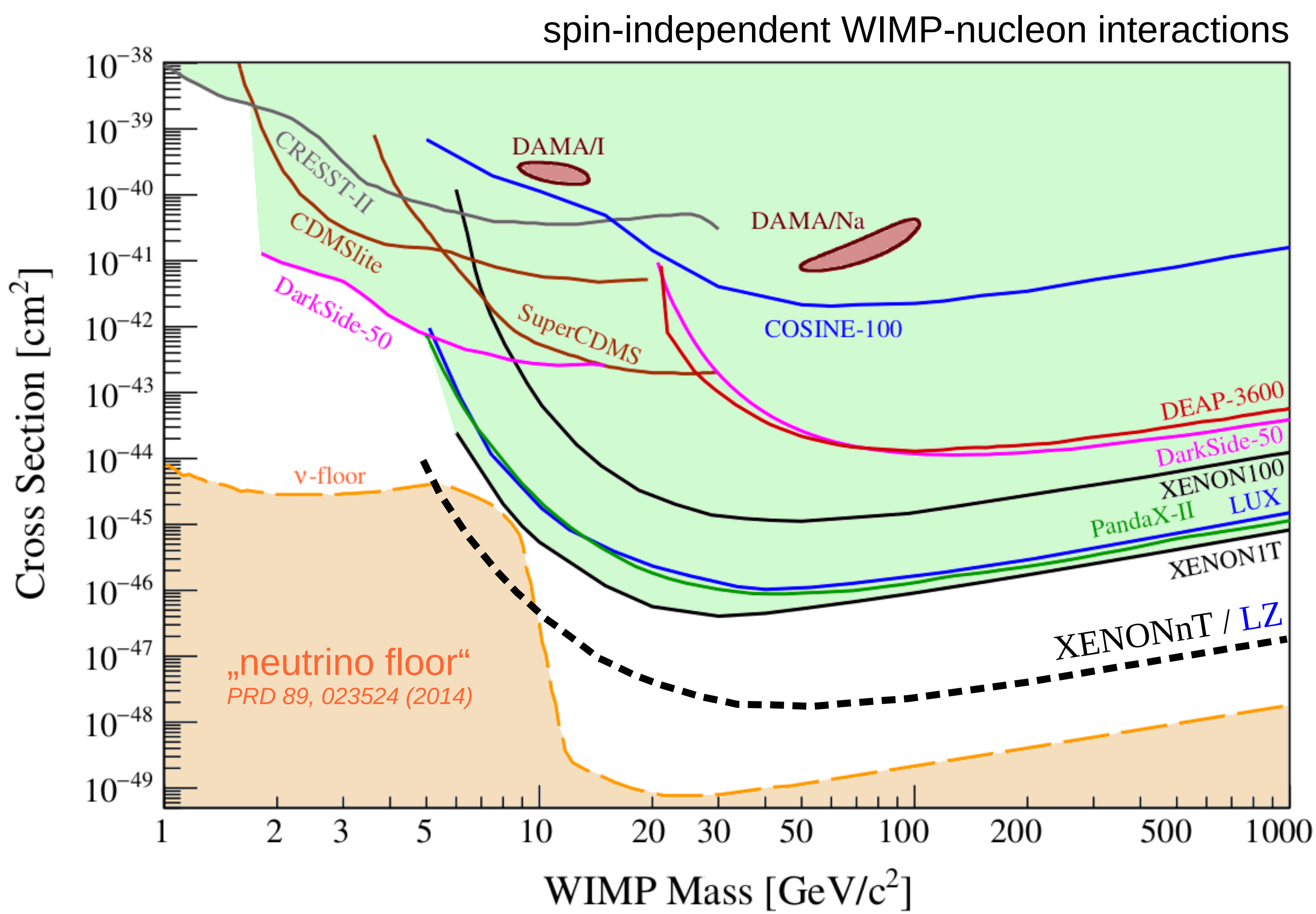
- 3x larger than XENON1T

5.9t active LXe target
~8.5t total mass

- goal: ER bg reduced x0.1, 0.6 NR neutrons in 20 t×y

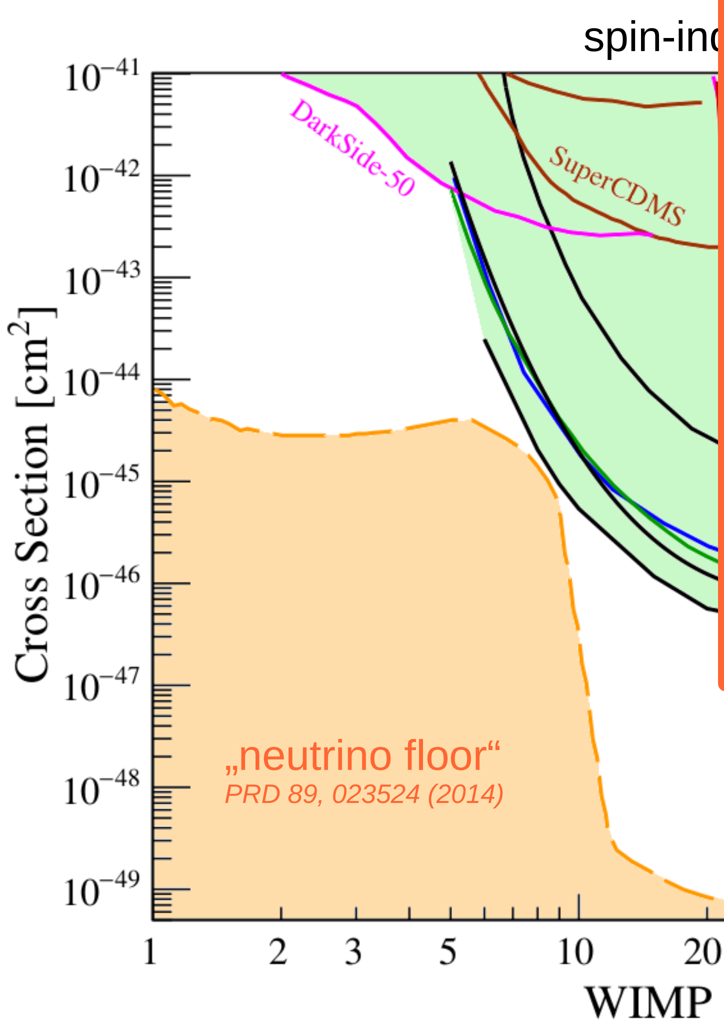
XENONnT: Busy Times….

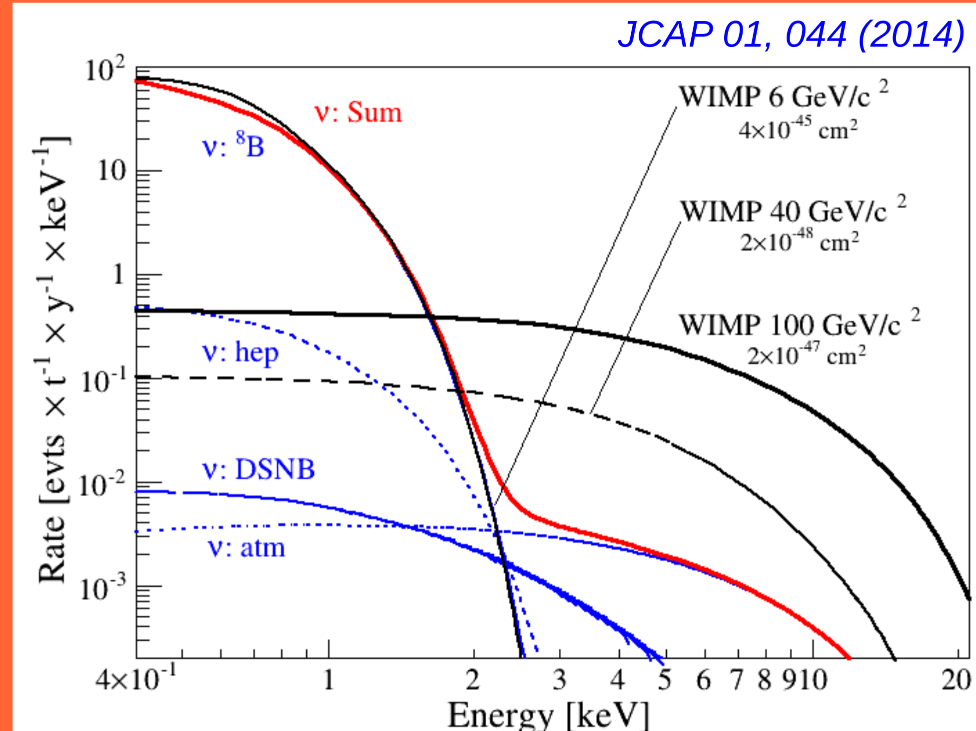
XENONnT Sensitivity Goal



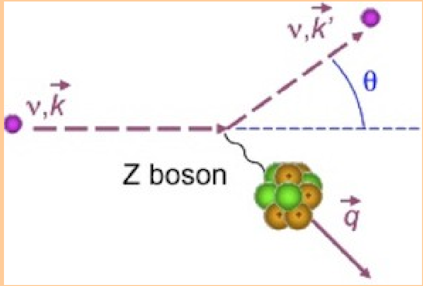
some results are missing...

The ultimate Limit





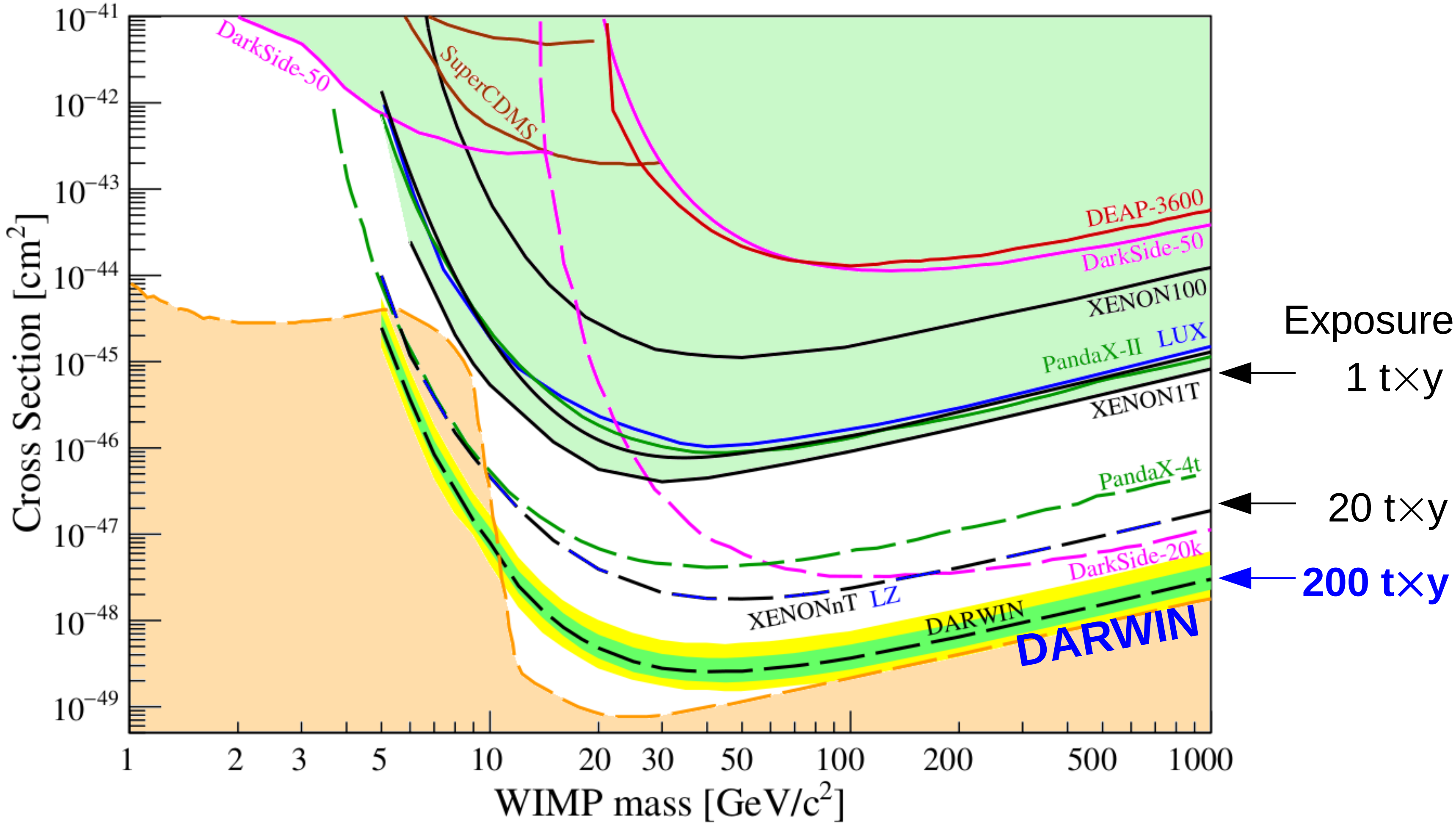
Interactions from coherent neutrino-nucleus scattering (CNNS) will dominate
→ **ultimate background** for direct detection



DARWIN The **ultimate** WIMP Detector

LXe-based

darwin-observatory.org



DARWIN The ultimate WIMP Detector

LXe-based

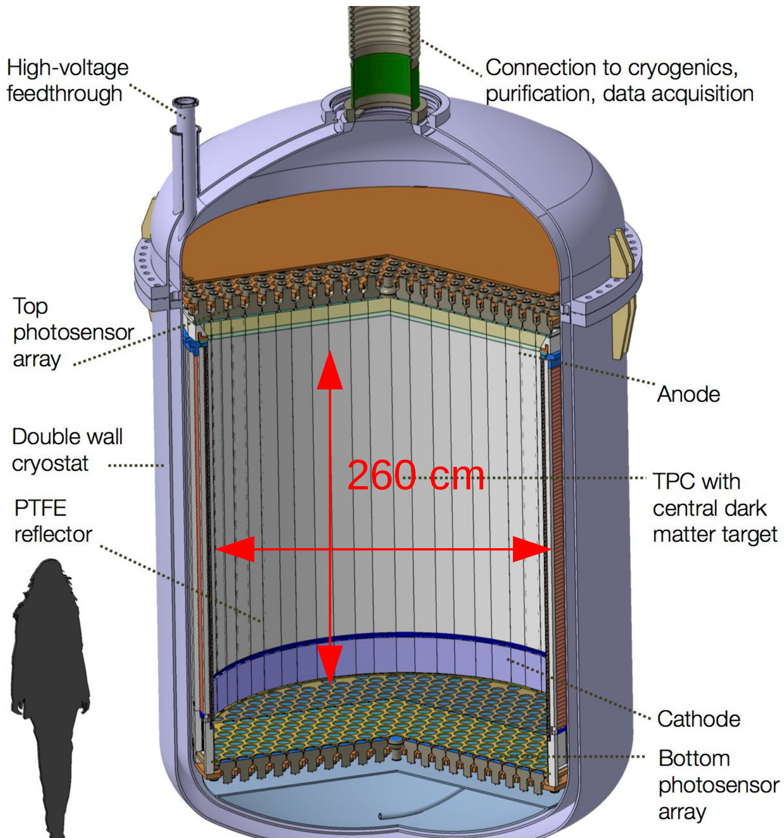
darwin-observatory.org

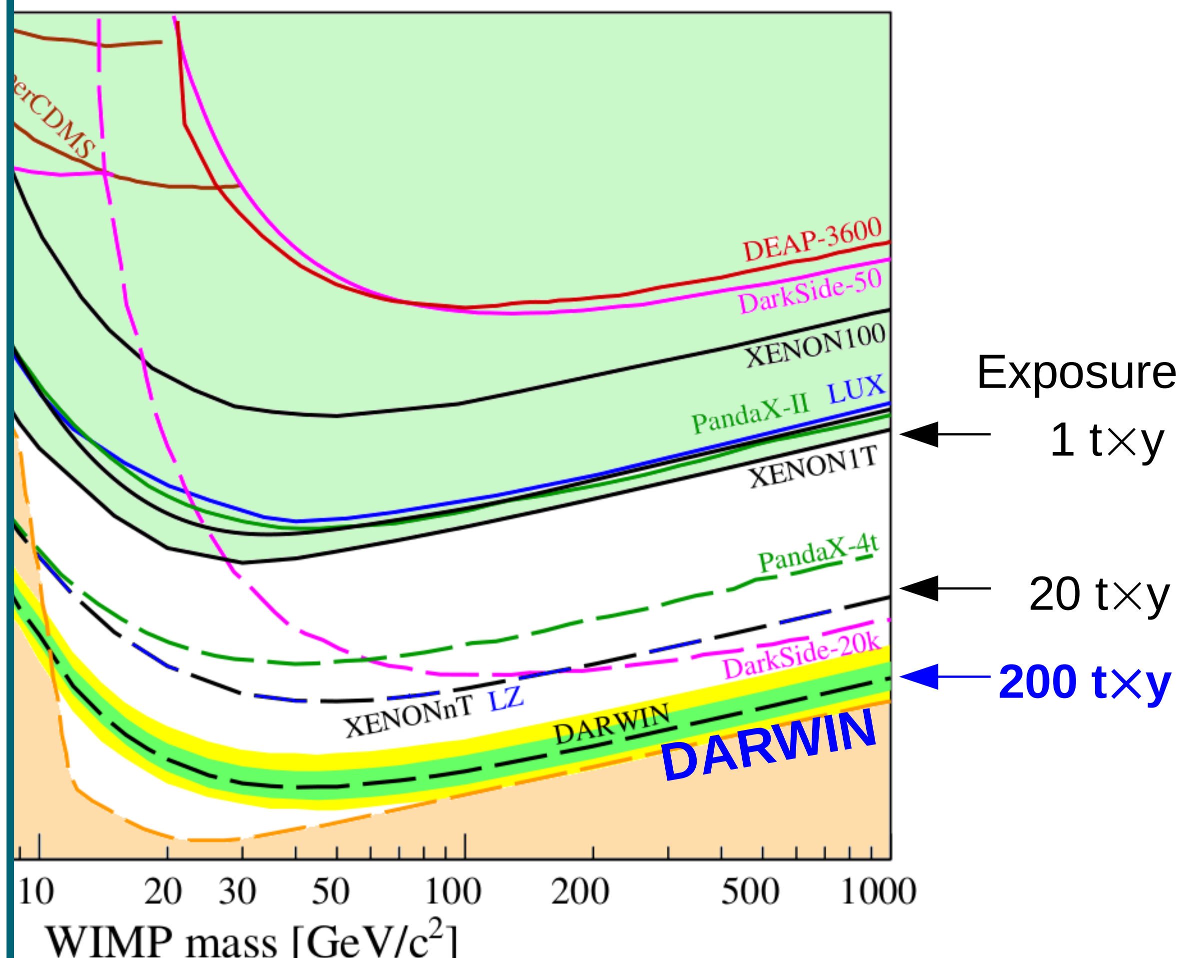
Baseline scenario

~50t total LXe mass

~40 t LXe TPC

~30 t fiducial mass

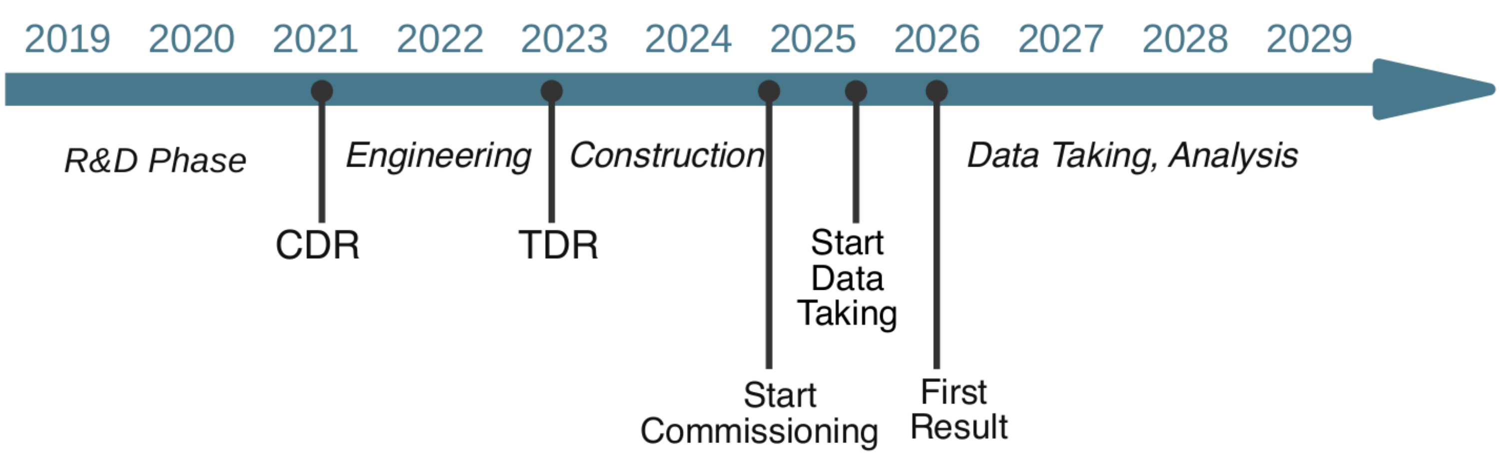




DARWIN

www.darwin-observatory.org

- aim at sensitivity of a few 10^{-49} cm², limited by **irreducible ν-backgrounds**
- international collaboration, 26 groups, ~160 scientists
  → continuously growing
- endorsed by several national and international agencies
- LOI to LNGS submitted
- Timescale: start after XENONnT



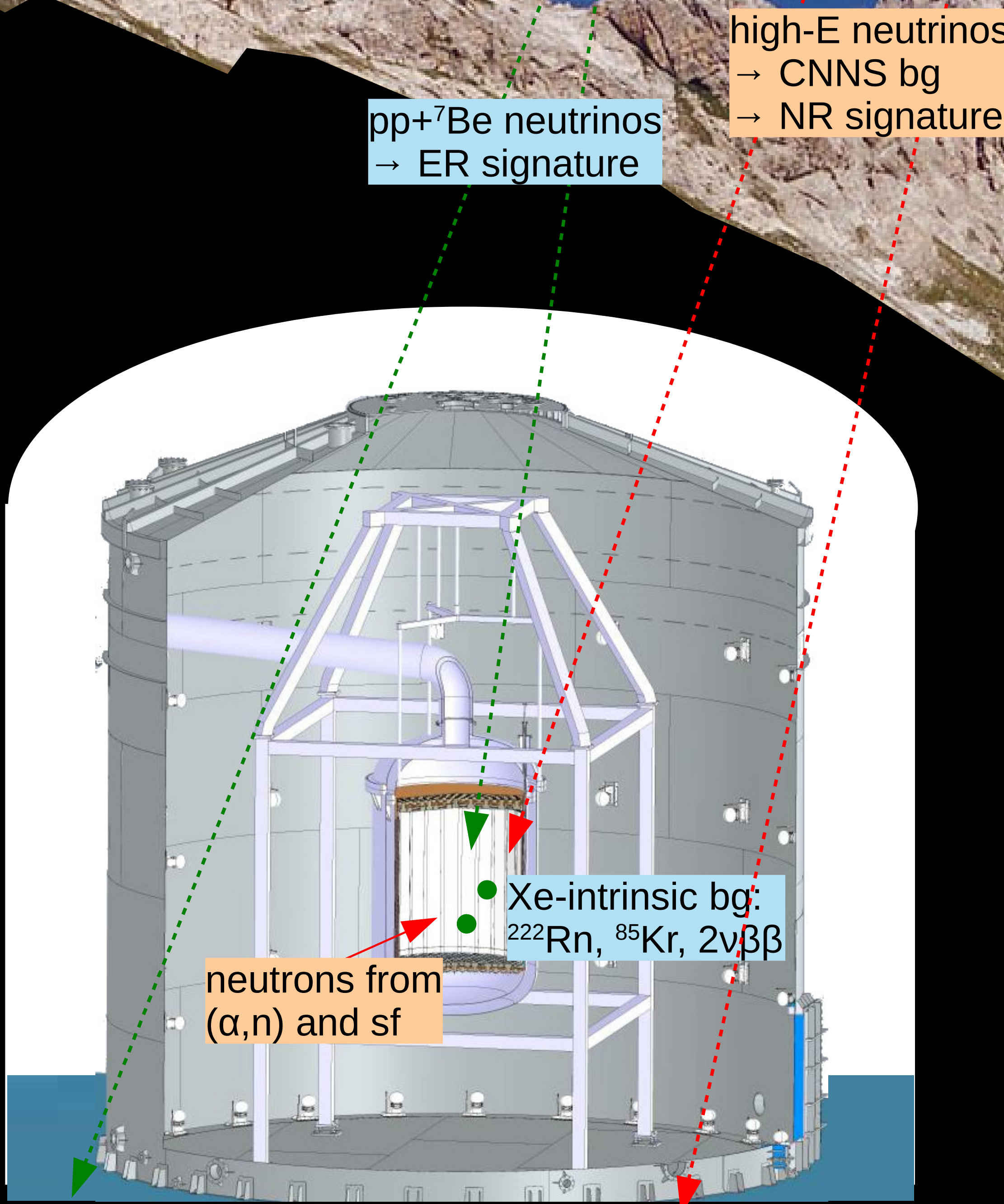
DARWIN Backgrounds

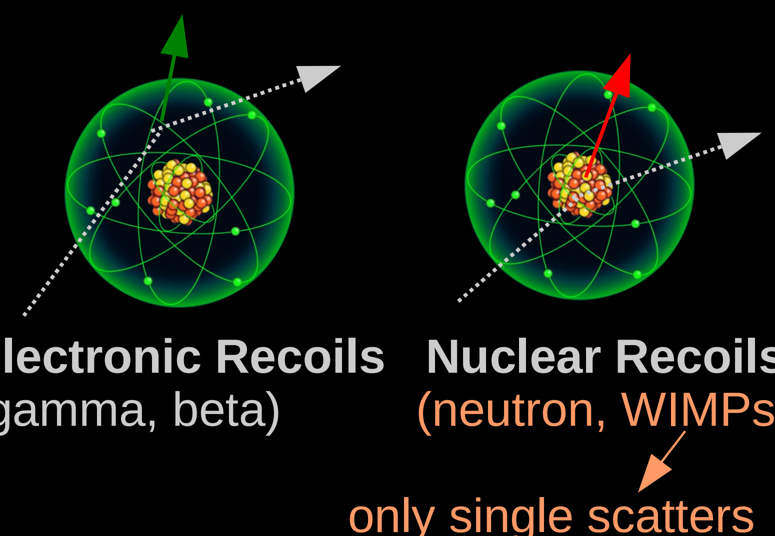
Remaining background sources:

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

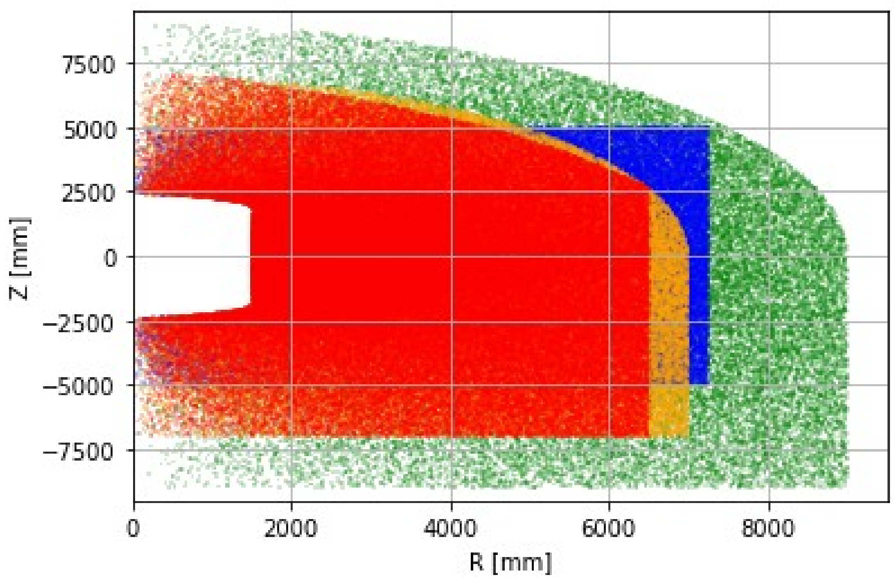
(assume 100% effective shield against μ-induced background)

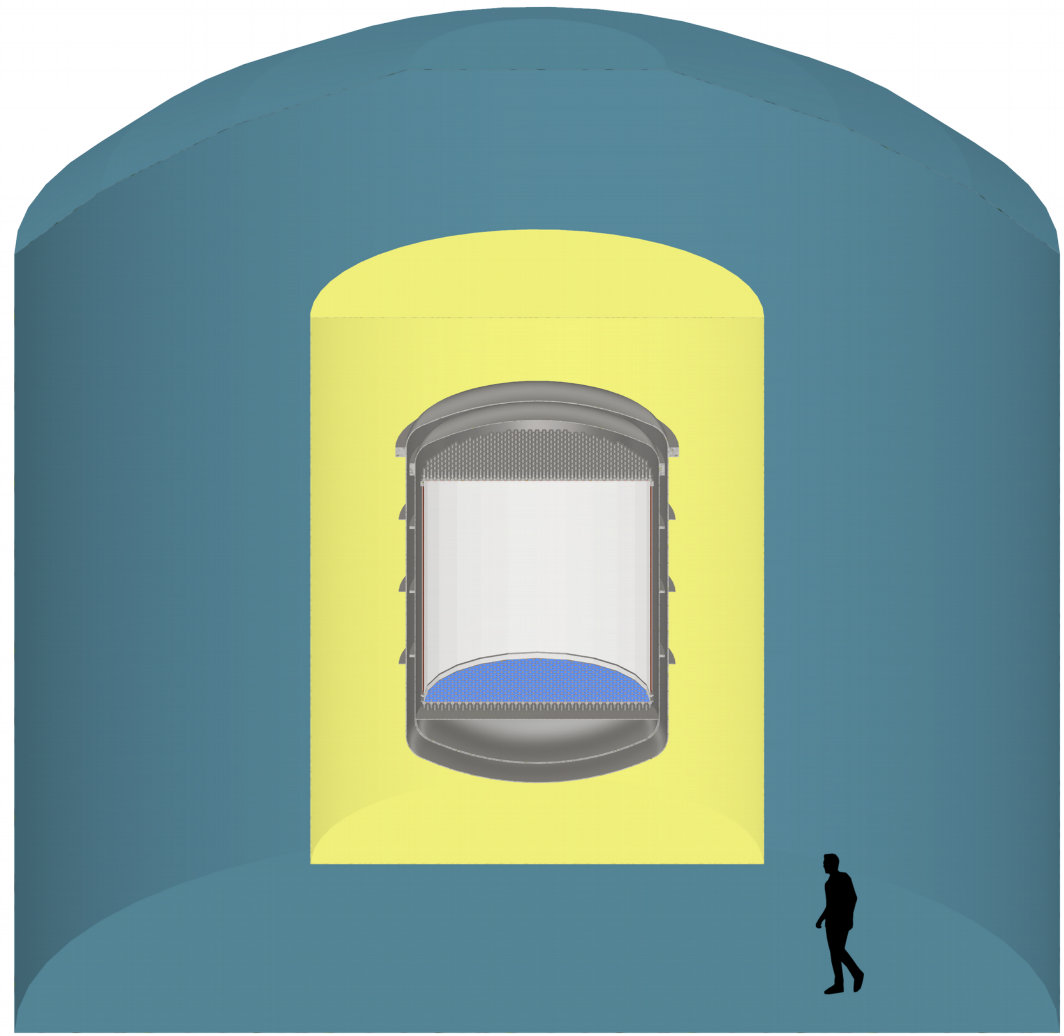
JCAP 10, 016 (2015)





Water Shield Studies

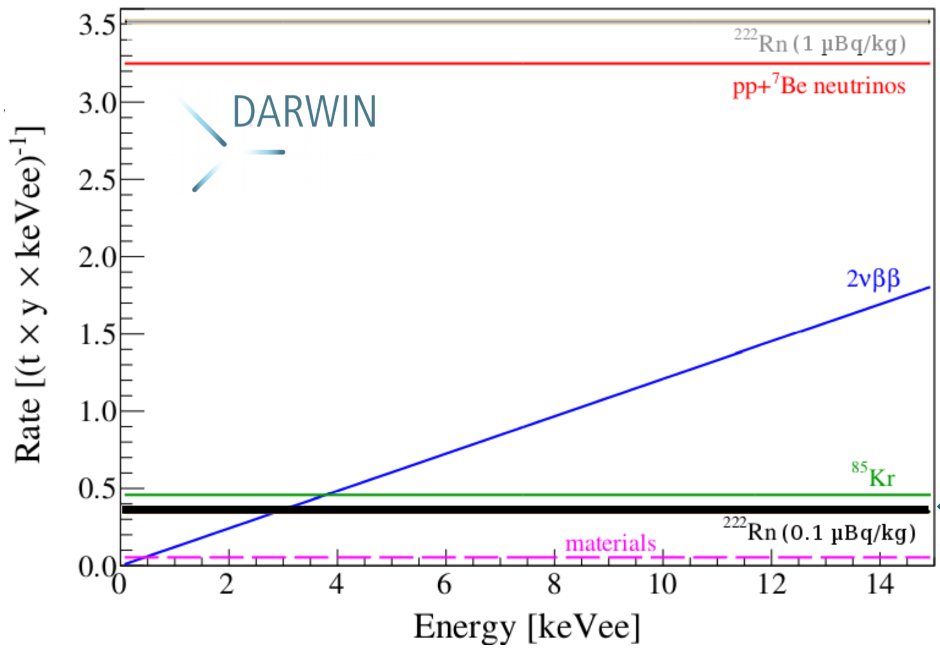




Various water shield geometries were studied for LNGS depth

→ the more shielding the better, but 12m appears sufficient

LXe: Radon Background

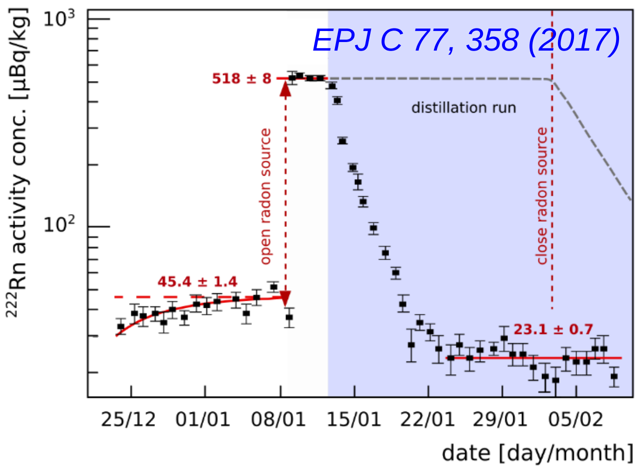


DARWIN goal:
ER background dominated by solar neutrinos

^{222}Rn factor 100 below XENON1T
→ **this is the main background challenge**
(DEAP-3600 achieved 0.18 µBq/kg)

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

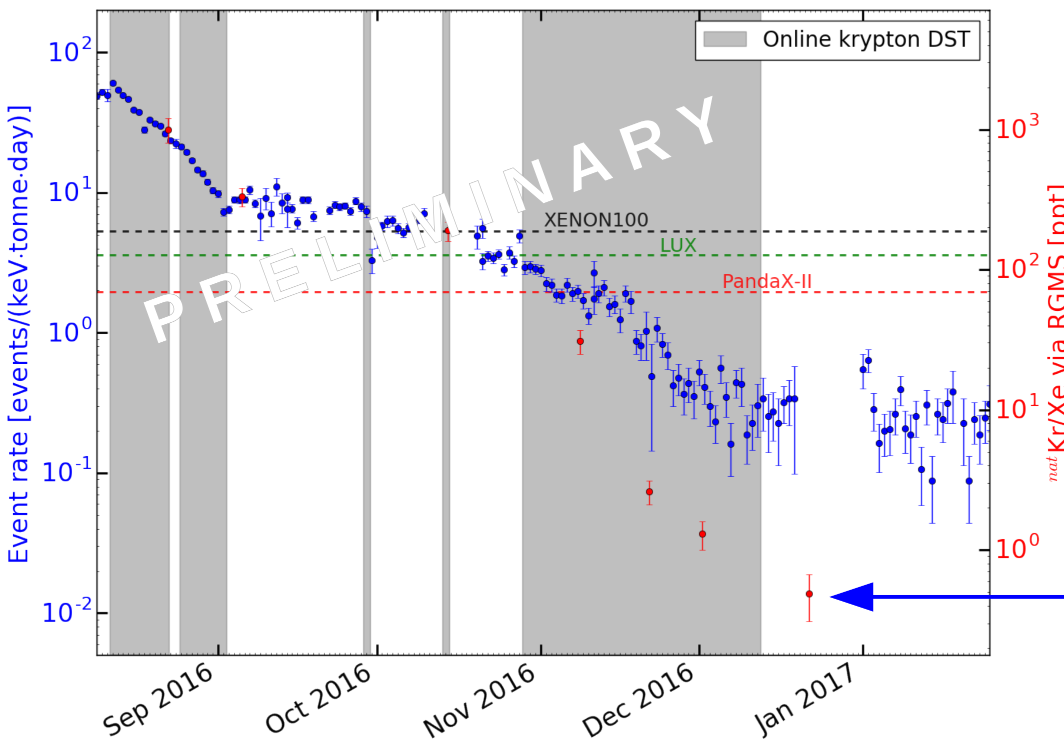
– **cryogenic distillation**
distillation column installed @ XENON100
→ demonstrated **reduction factor >27** (@ 95% CL)
→ dedicated column under development



LXe: Krypton Removal

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

XENON1T: custom designed 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



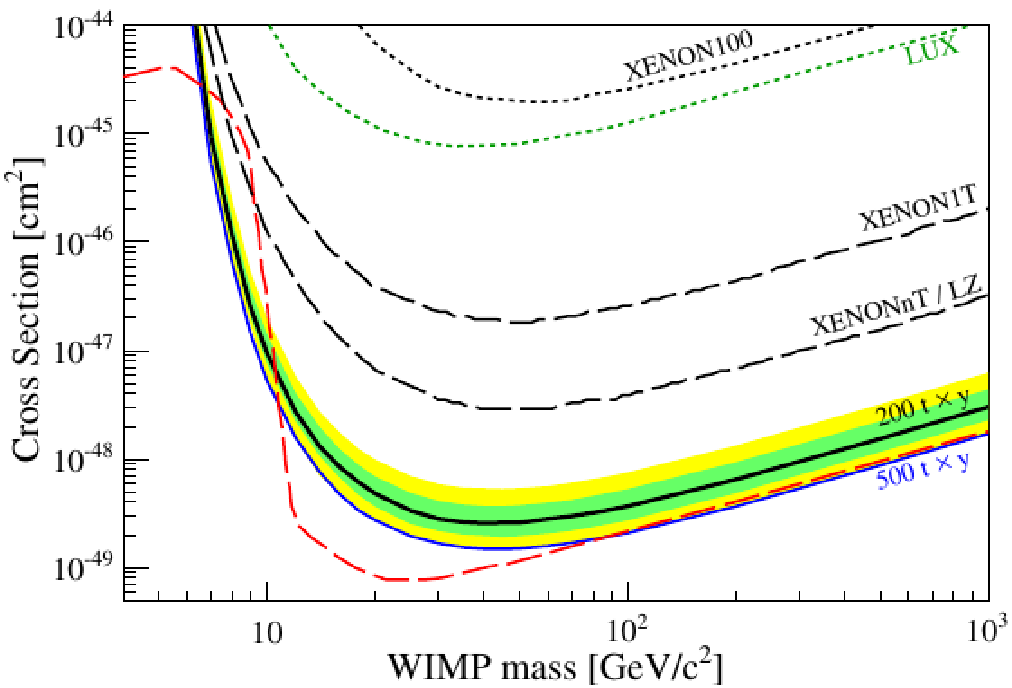
XENON1T column has produced
gas sample **<0.026 ppt** = 2.6×10^{-14} (90% CL)
→ **DARWIN goal achieved**

DARWIN WIMP Sensitivity

JCAP 10, 016 (2015)

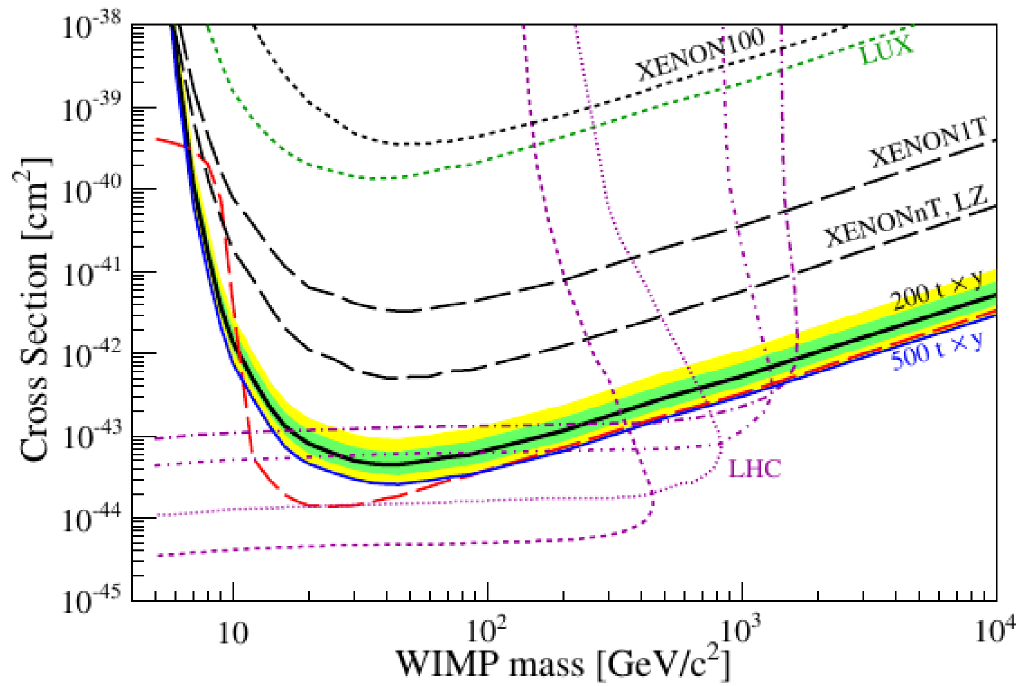
- exposure: 200 t × y; **all backgrounds included**
- likelihood analysis
- 99.98% ER rejection @ 30% NR acceptance,
  S1+S2 combined energy scale, LY=8 PE/keV, 5-35 keV_{nr} energy window

spin-*in*dependent couplings



200 t×y: σ < 2.5 x 10^{-49} cm² @ 40 GeV/c²

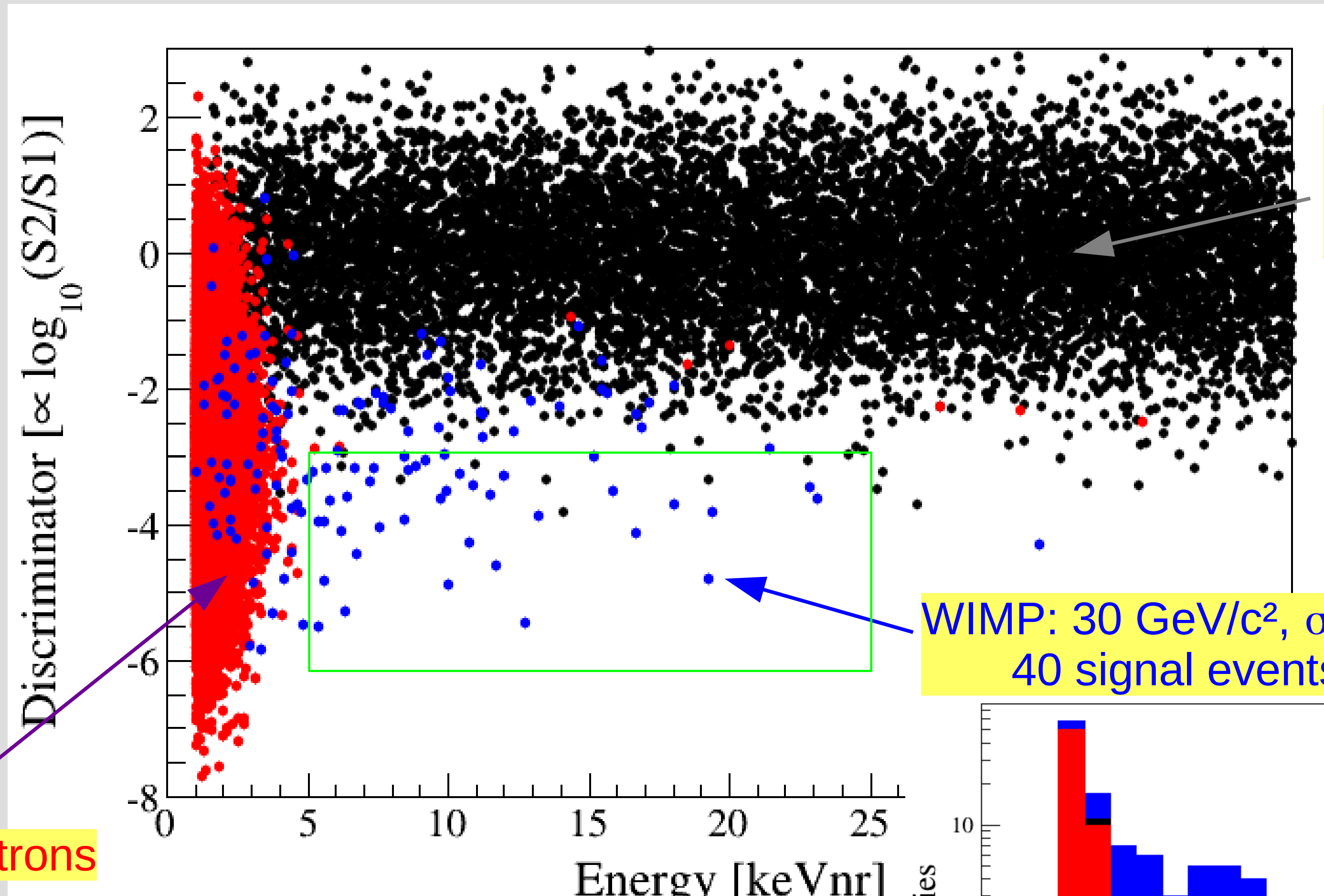
spin-*de*pendent couplings (n-only)



excellent complementarity to LHC searches

Phys.Dark Univ. 9-10, 51 (2015).

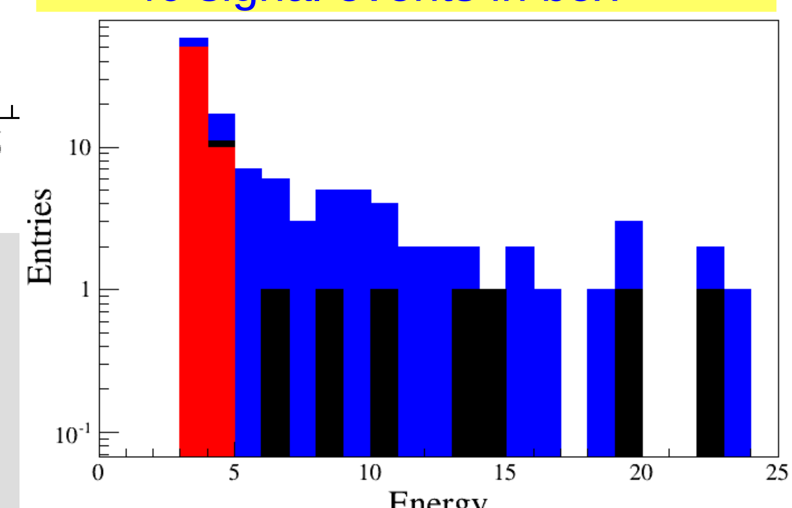
WIMP Detection



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

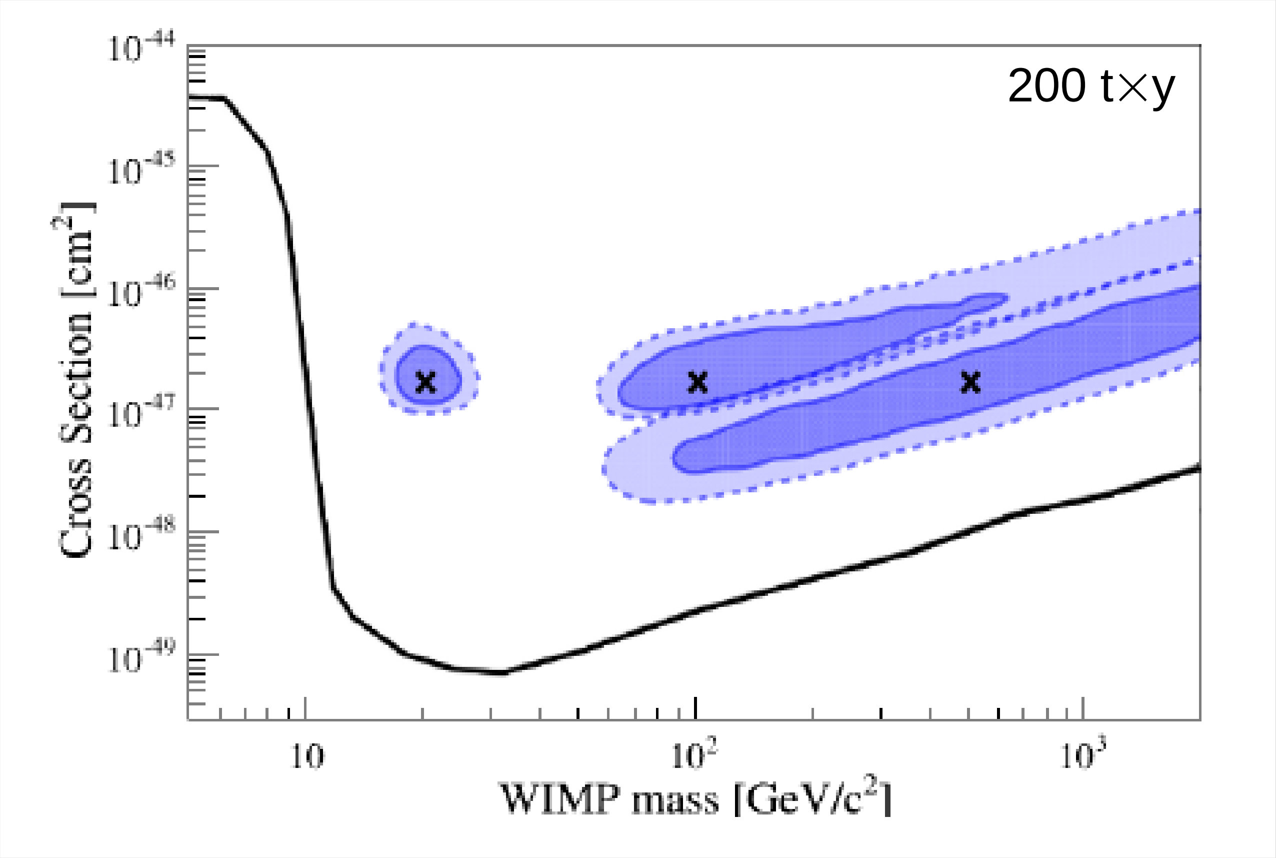
CNNS+neutrons



WIMP Spectroscopy

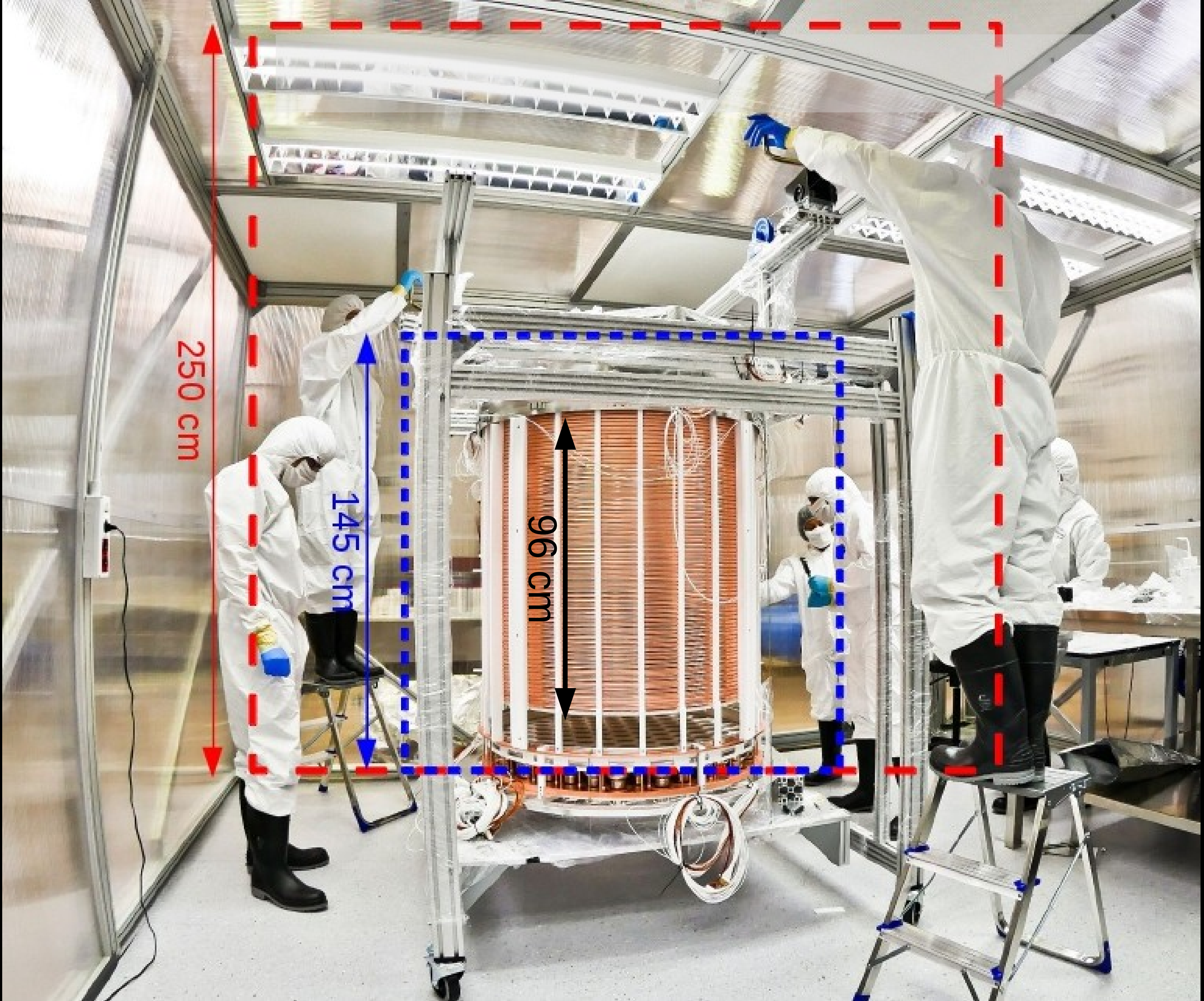
JCAP 11, 017 (2016)

Reconstruction: 2×10^{-47} cm²



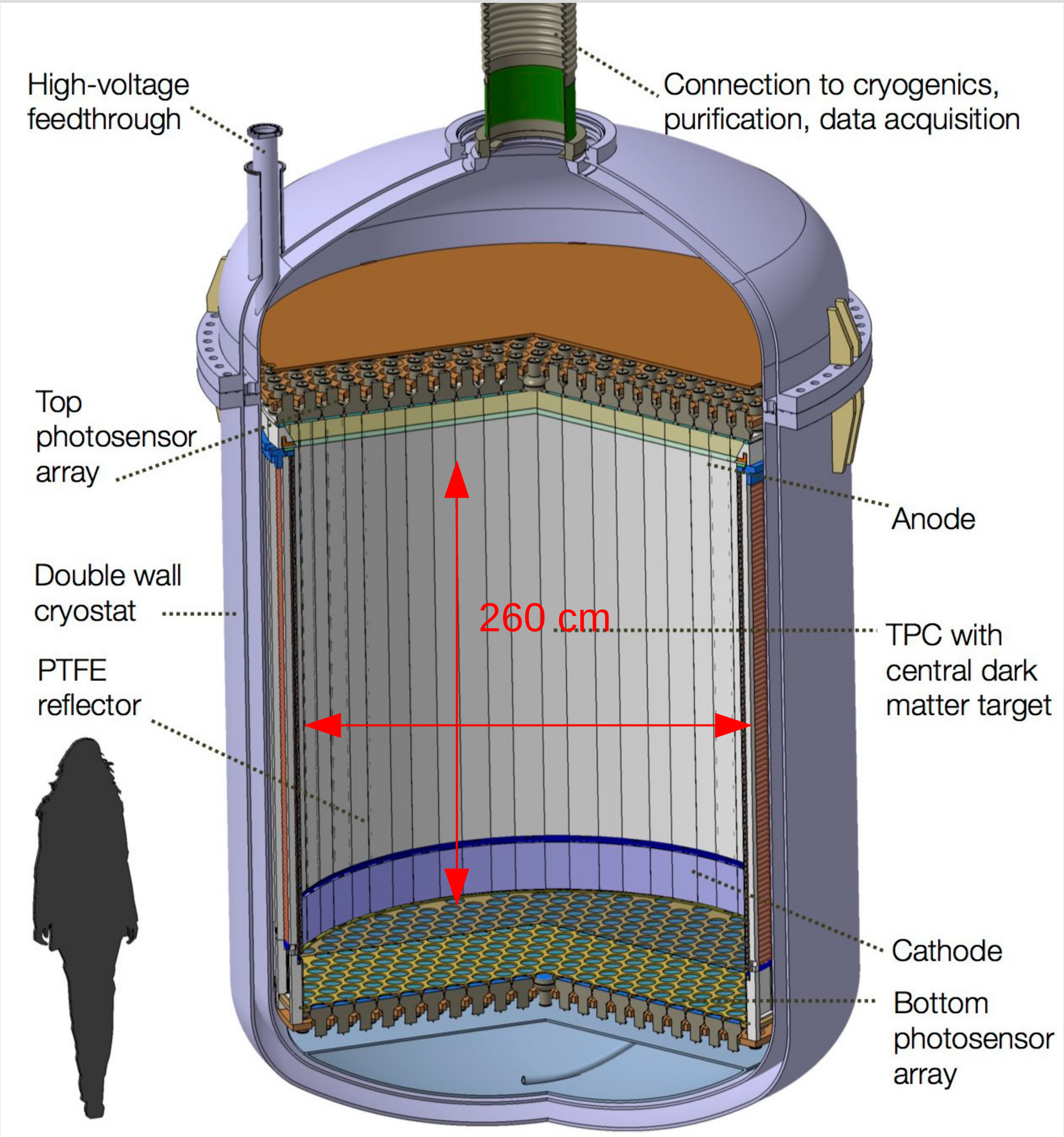
Capability to reconstruct WIMP parameters

- m_χ=20, 100, 500 GeV/c²
- 1σ/2σ CI, marginalized over astrophysical parameters
- due to flat WIMP spectra, no target can reconstruct masses >500 GeV/c²


250 cm
145 cm
96 cm

DARWIN The ultimate WIMP Detector

JCAP 11, 017 (2016)

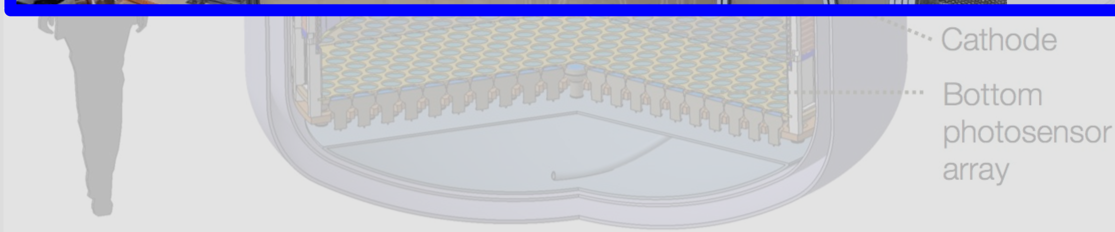


Challenges

- **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 (from PTFE)
- **Photosensors**
  - → high light yield (QE)
  - → low radioactivity
  - → long-term stability
- etc etc

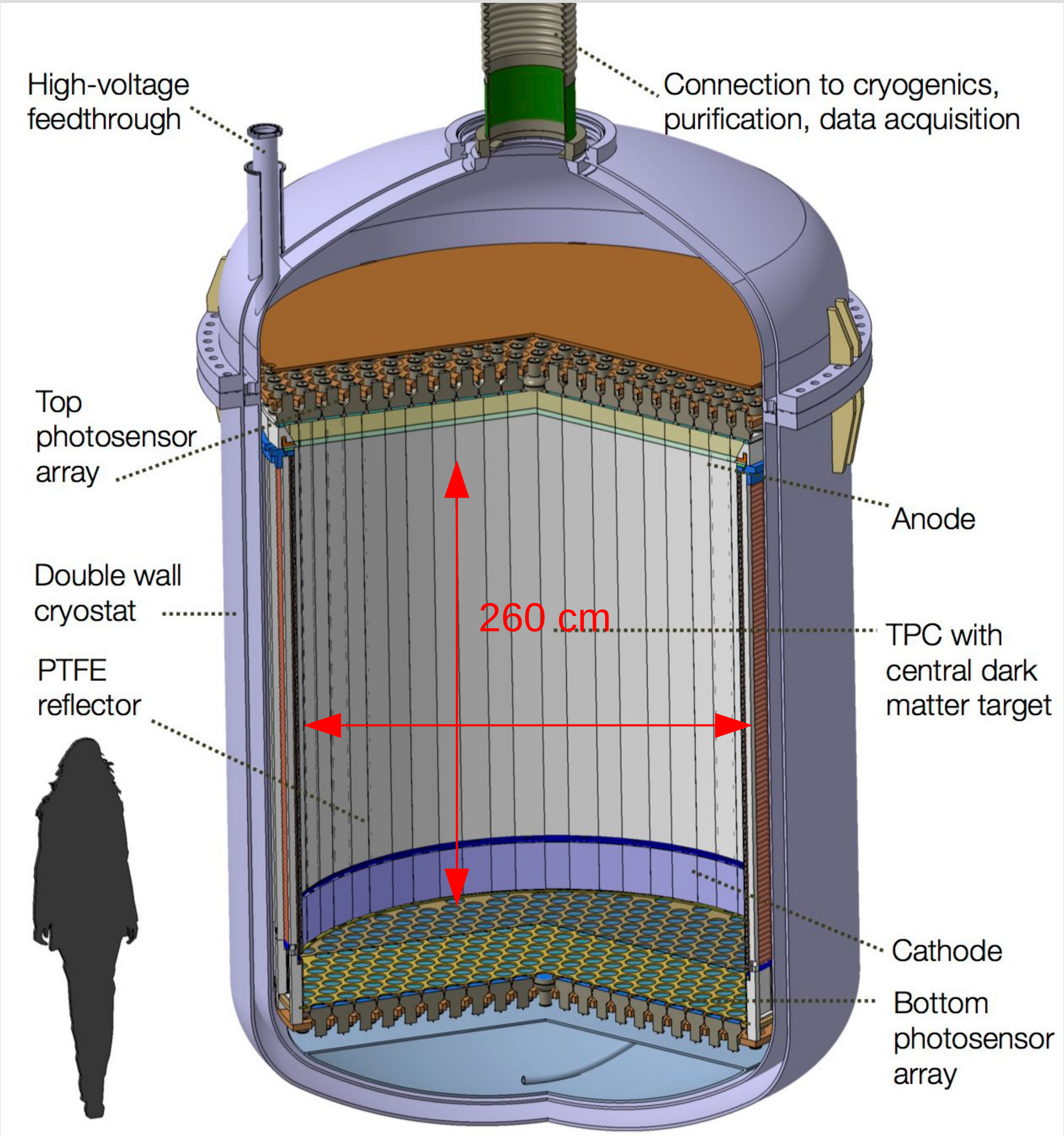
DARWIN The **ultimate** WIMP Detector

JCAP 11, 017 (2016)



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

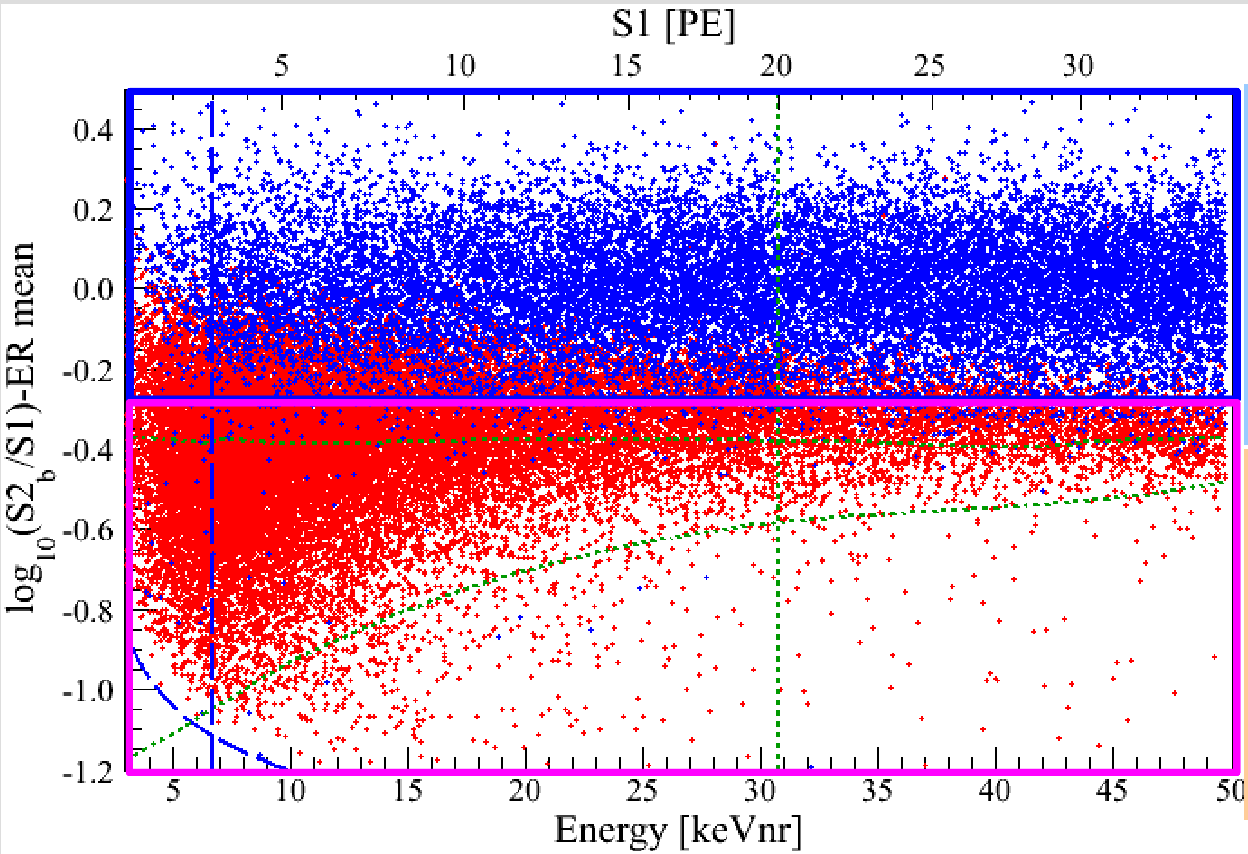
DARWIN The ultimate WIMP Detector



other than WIMPs

What (else) can we do with these instruments?

Interactions in LXe Detectors



scattering off atomic electrons, excitations etc.
→ electronic recoil

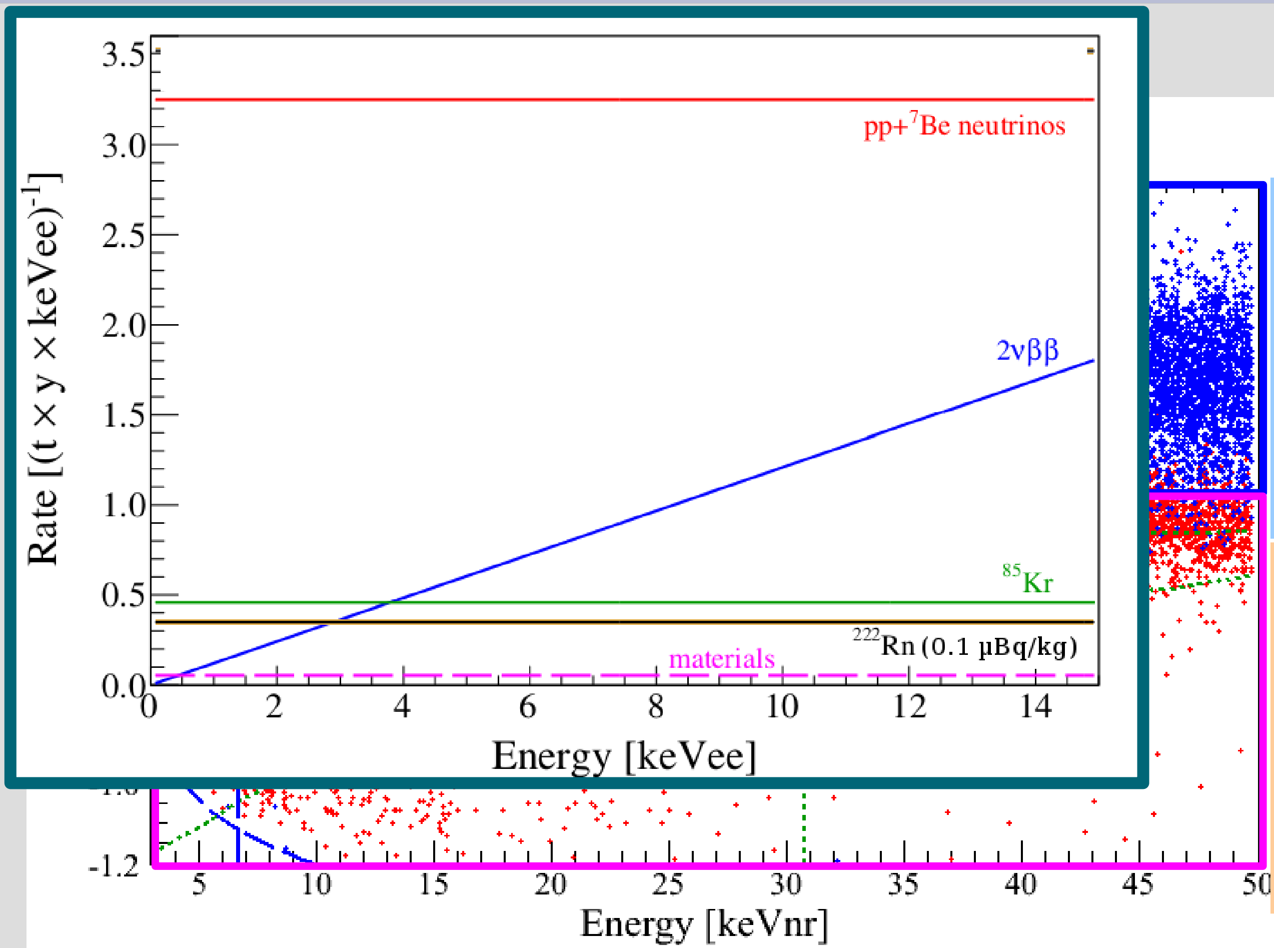
- rare processes detectable if ER background is low

coherent scattering off xenon nucleus
→ nuclear recoil

- Dark Matter
- CNNS

SM process, not yet measured.
Deviation from expectation
→ new physics?

Interactions in LXe Detectors



scattering off atomic electrons, excitations etc.
→ electronic recoil

- rare processes detectable since ER background **is low**

coherent scattering off xenon nucleus
→ nuclear recoil

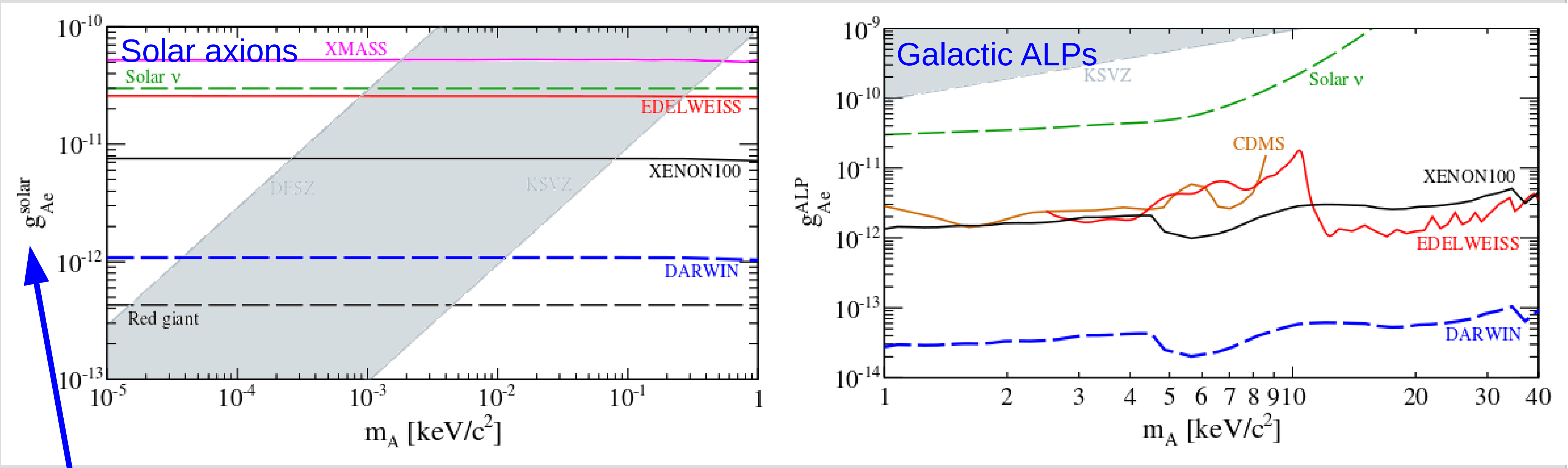
- Dark Matter
- CNNS

→ Many **science channels** are accessible

DARWIN = A low background, low threshold **astroparticle physics observatory**

Solar Axions, Dark Matter ALPs

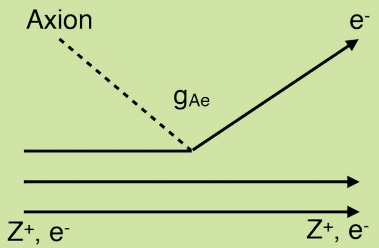
JCAP 11, 017 (2016)



Axions and ALPs couple to xenon via **axio-electric-effect**

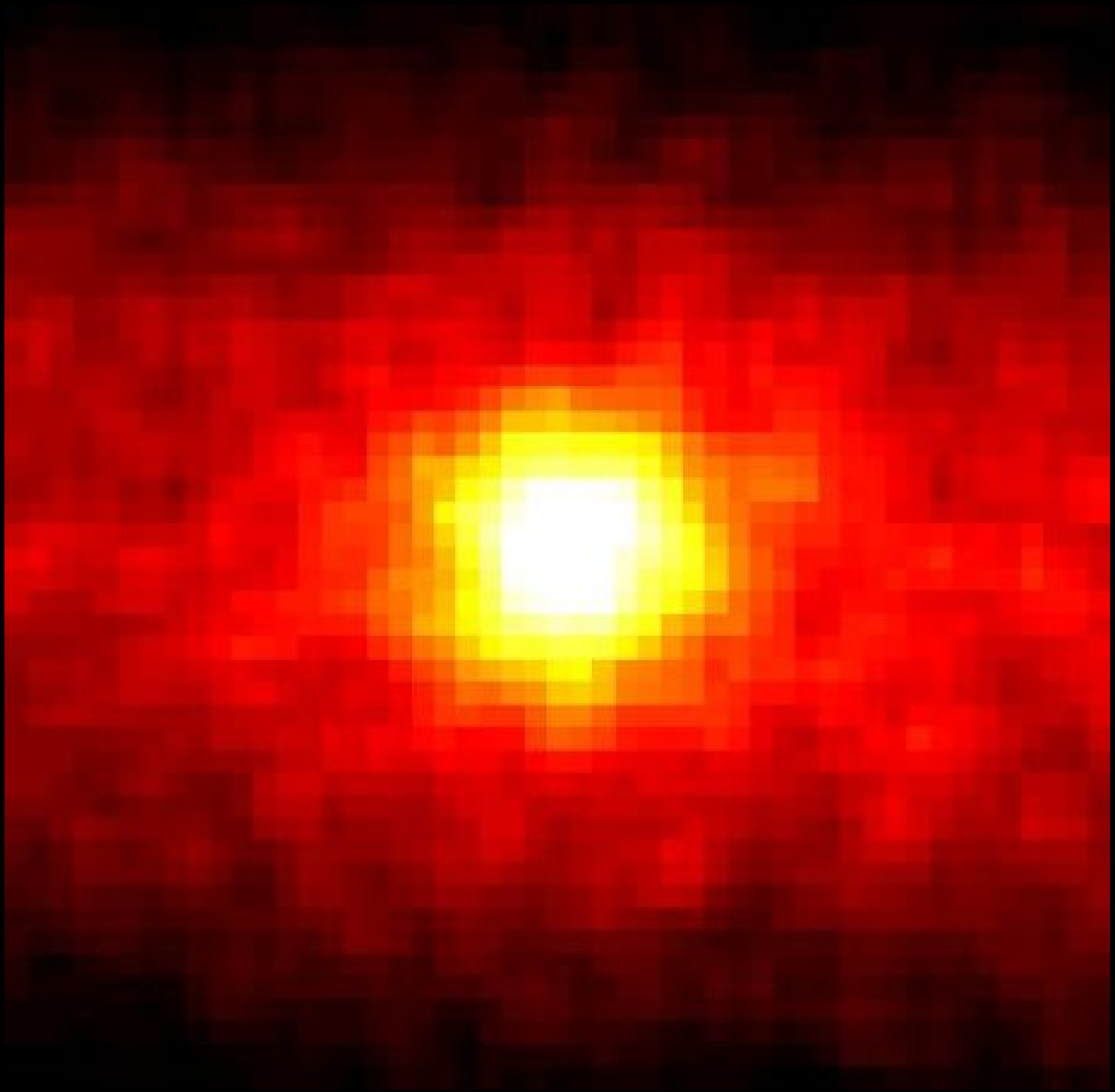
$$\sigma_{Ae}(E_A) = \sigma_{pe}(E_A)\frac{{g_{Ae}}^2}{\beta_A}\frac{3{E_A}^2}{16\pi\,\alpha\,{m_e}^2}\left(1-\frac{\beta_A}{3}\right)$$

→ axion ionizes a Xe atom



Axion
arises naturally in the Peccei-Quinn solution of the strong CP-problem
→ well-motivated dark matter candidate

Axion-like particle (ALP)
generalization of the axion concept, but without addressing strong CP problem
(ALPs = Nambu-Goldstone bosons from breaking of some global symmetry)

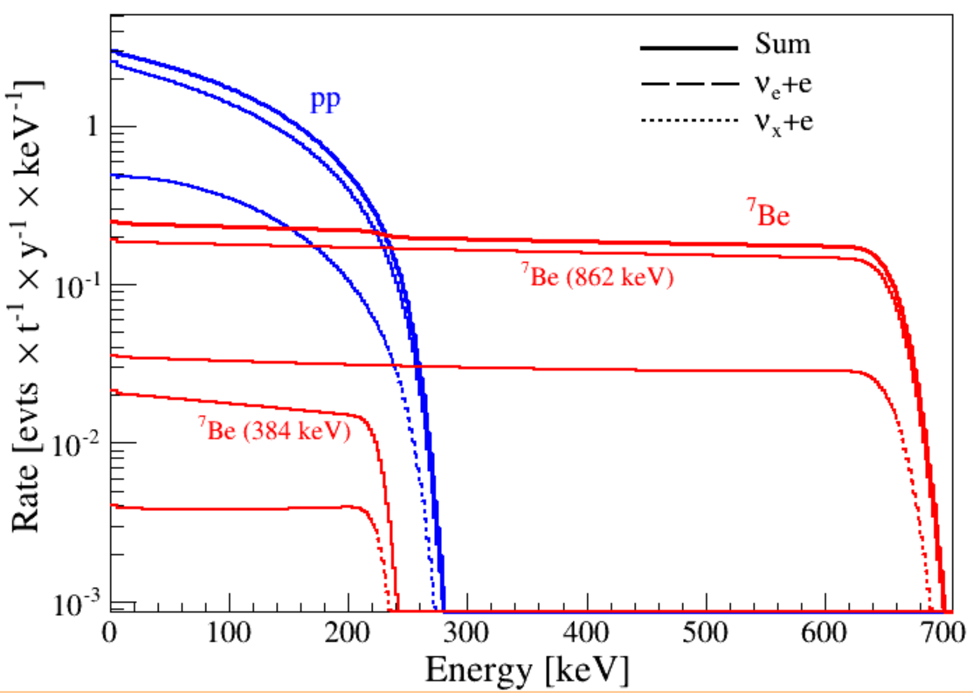


pp-Neutrinos in DARWIN

a background for the WIMP search

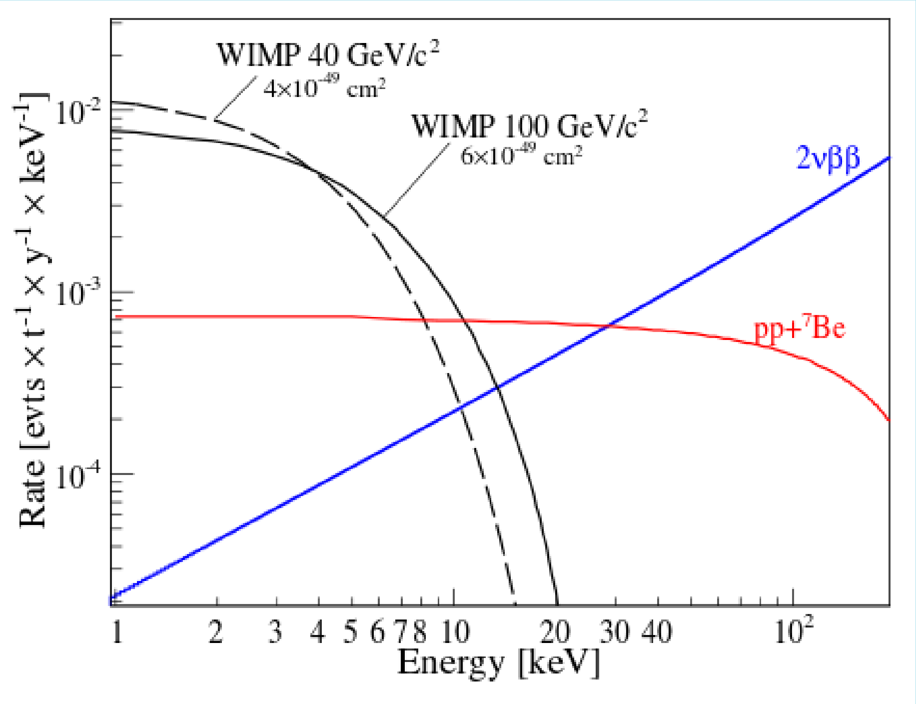
JCAP 11, 017 (2016)

Differential Recoil Spectrum in Xe



- neutrinos interact with Xe electrons
  → electronic recoil signature
- continuous recoil spectrum
  → largest rate at low E

Neutrino interactions



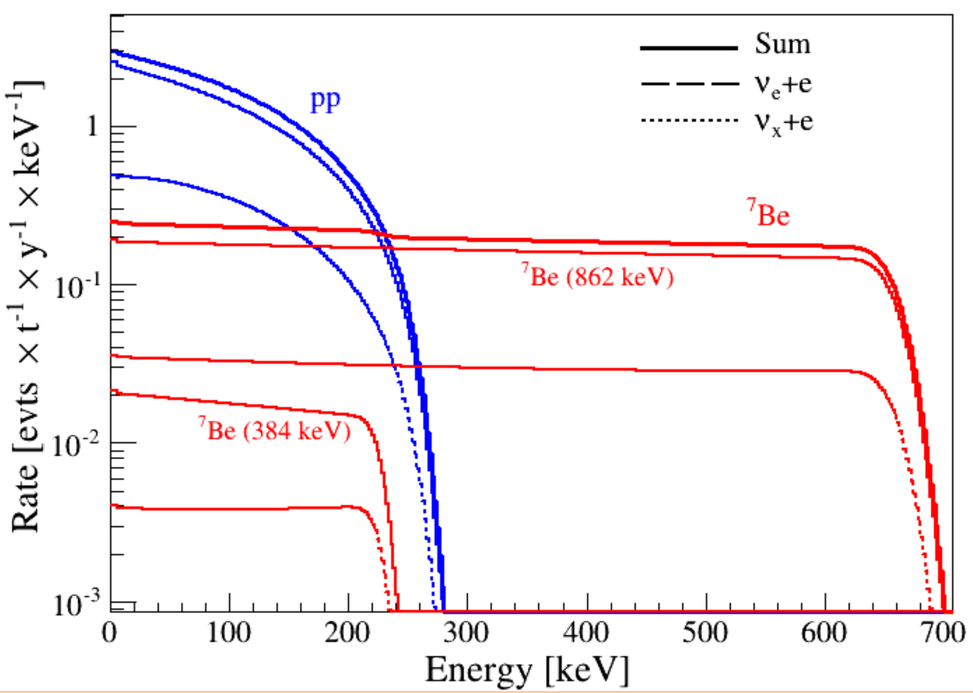
- ER rejection efficiencies ~99.98% at 30% NR efficiency are required to reduce to sub-dominant level

pp-Neutrinos in DARWIN

JCAP 11, 017 (2016)

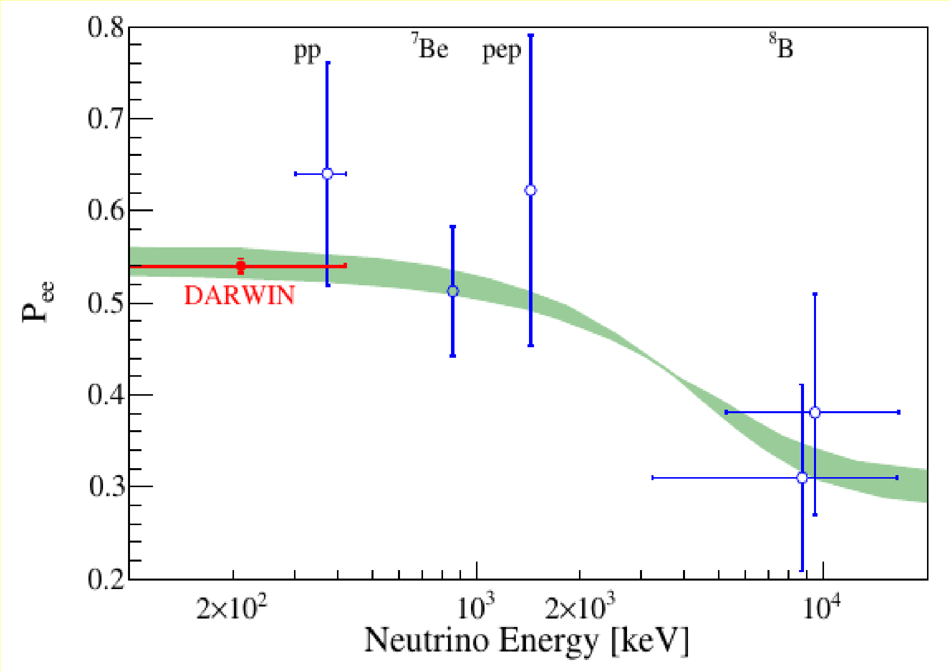
a new physics channel!

Differential Recoil Spectrum in Xe



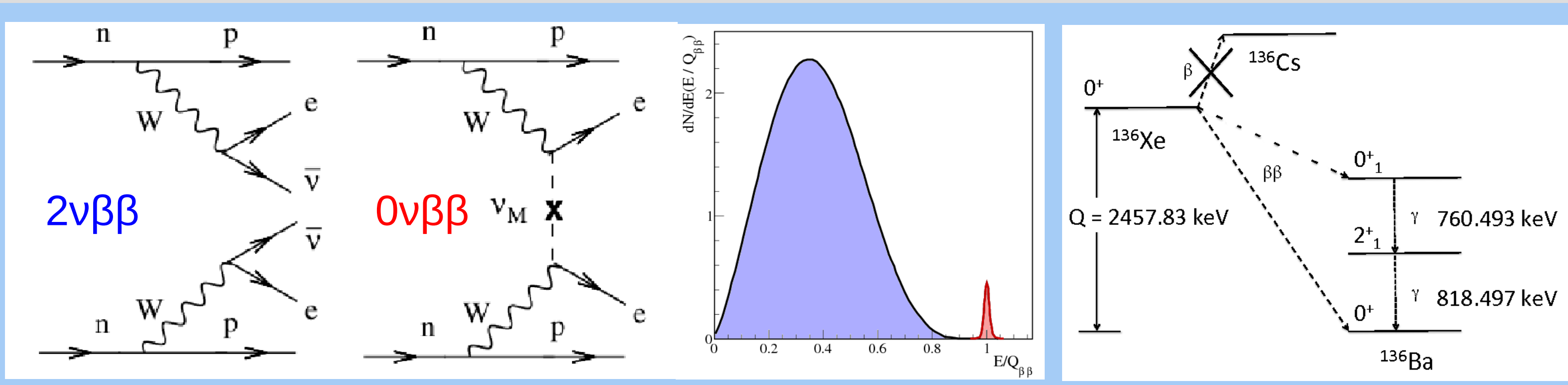
- neutrinos interact with Xe electrons
  → electronic recoil signature
- continuous recoil spectrum
  → largest rate at low E
  ~0.26 ν evts/t/d in low-E region (2-30 keV)

Neutrino interactions



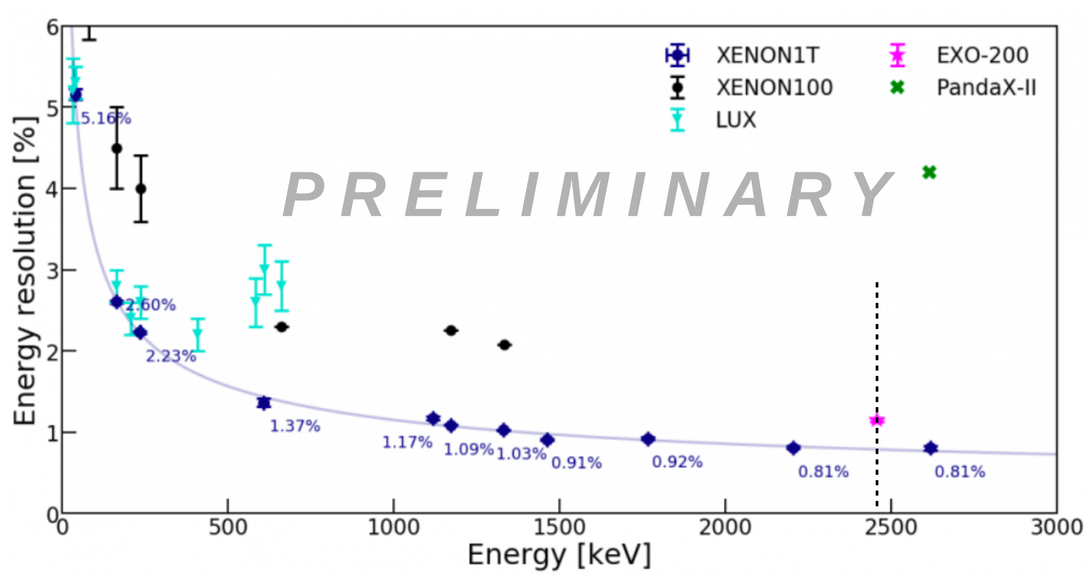
- 30t target mass, 2-30 keV window
  → 2850 neutrinos per year (89% pp)
  → achieve 1% statistical precision
  on pp-flux (→P_{ee}) with 100 t x y

^{136}Xe: 0ν double-beta Decay



ΔL ≠ 0

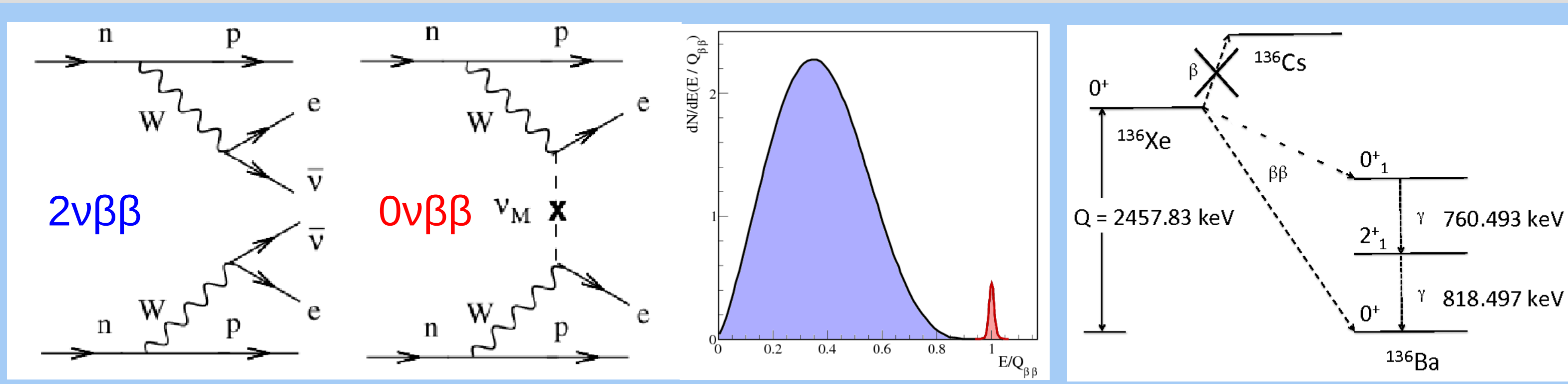
- 0νββ candidate with $Q_{\beta\beta}$=2.46 MeV
- 40t DARWIN LXe target contains 3.5t of ^{136}Xe **without any enrichment**!



Energy Resolution of XENON1T

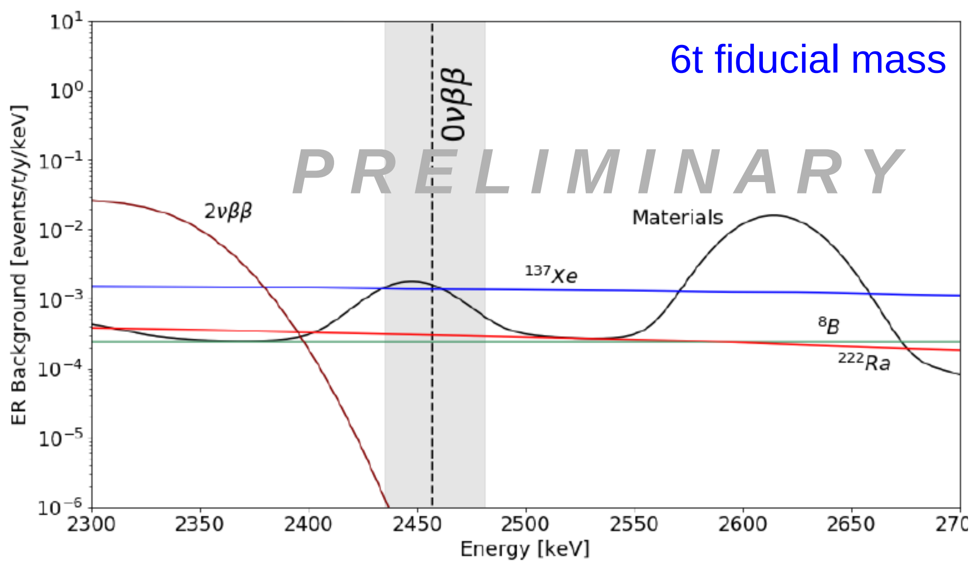
- Combine light and charge signals
- σ/E ~ 0.8% @ $Q_{\beta\beta}$
  FWHM/E ~ 1.9% @ $Q_{\beta\beta}$

^{136}Xe: 0ν double-beta Decay



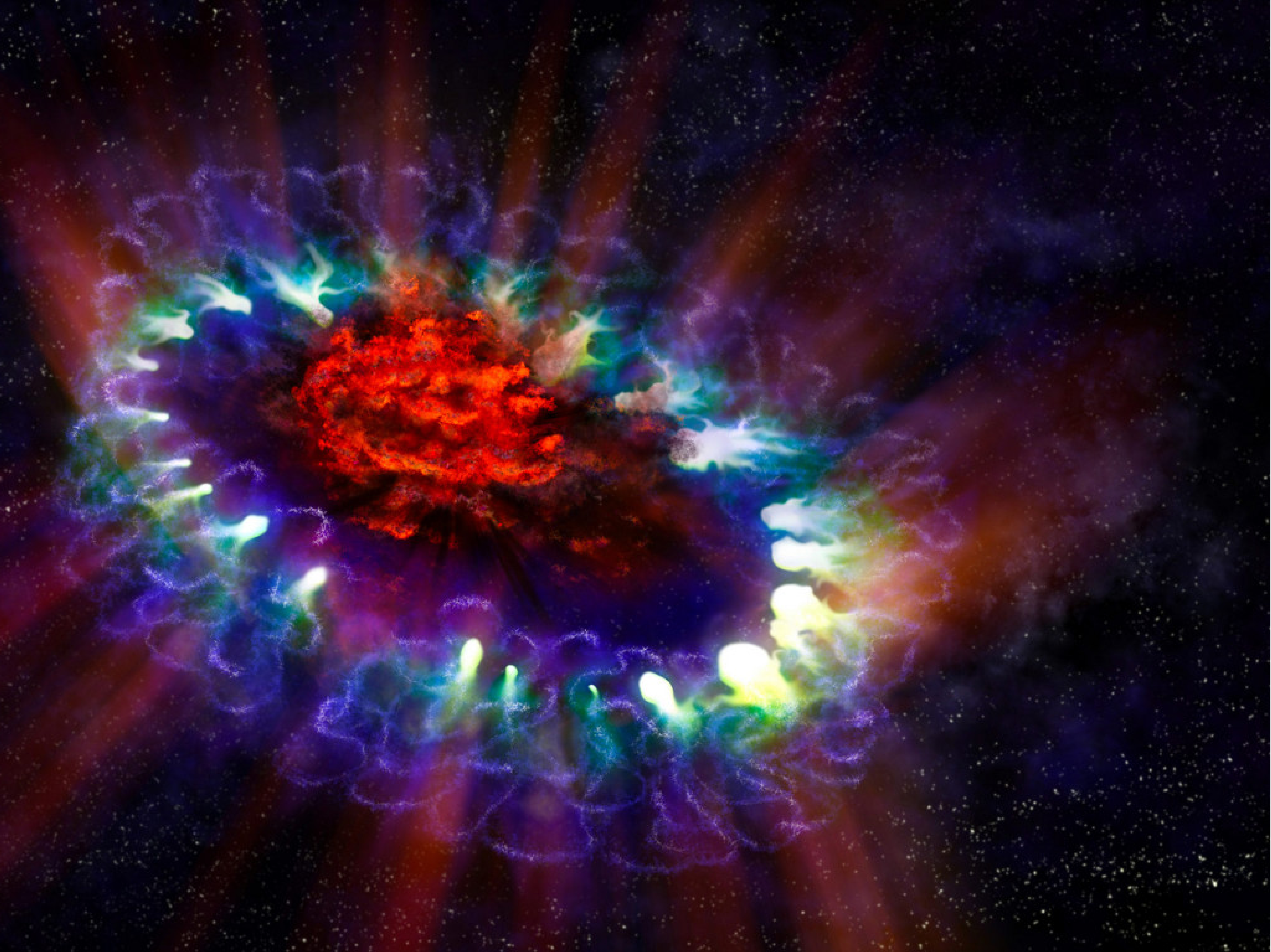
ΔL ≠ 0

- 0νββ candidate with $Q_{\beta\beta}$=2.46 MeV
- 40t DARWIN LXe target contains 3.5t of ^{136}Xe **without any enrichment**!



Background Study is ongoing

- Material background depends on contamination and self-shielding → optimize sensitivity
- Important background from decays of neutron-activated ^{137}Xe
- Aim for **few × 10^{27} y sensitivity**

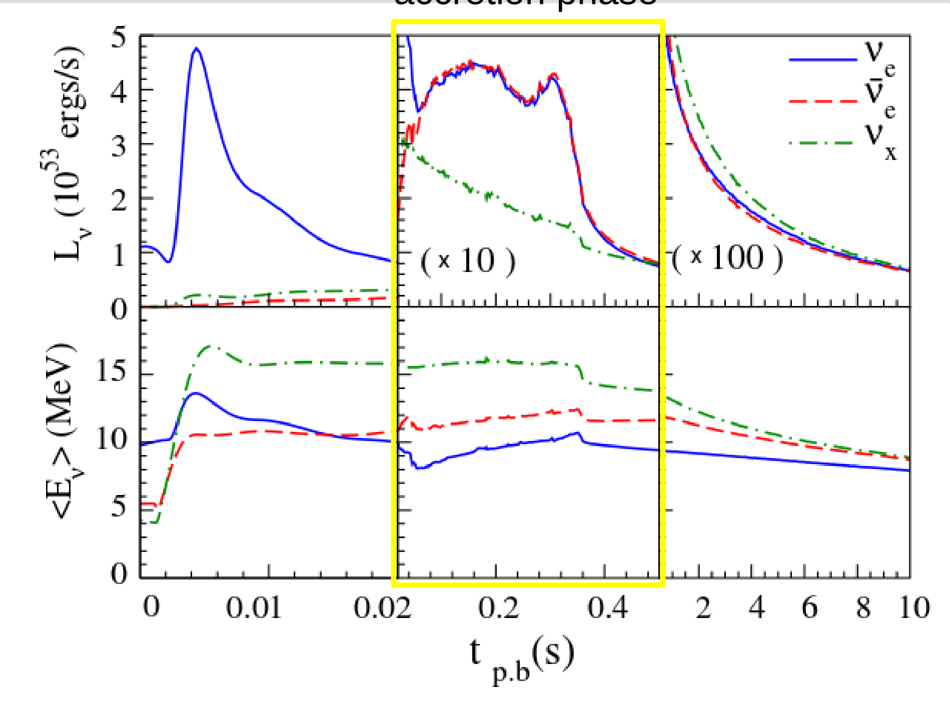


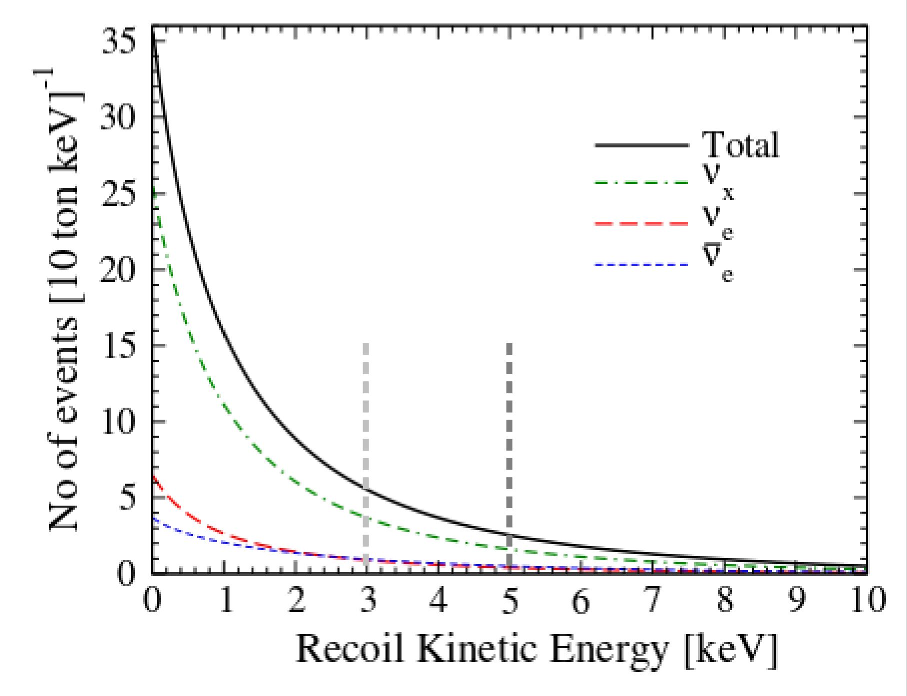
Supernova Neutrinos

Chakraborty et al., PRD 89, 013011 (2014)
Lang et al., PRD 94, 103009 (2016)

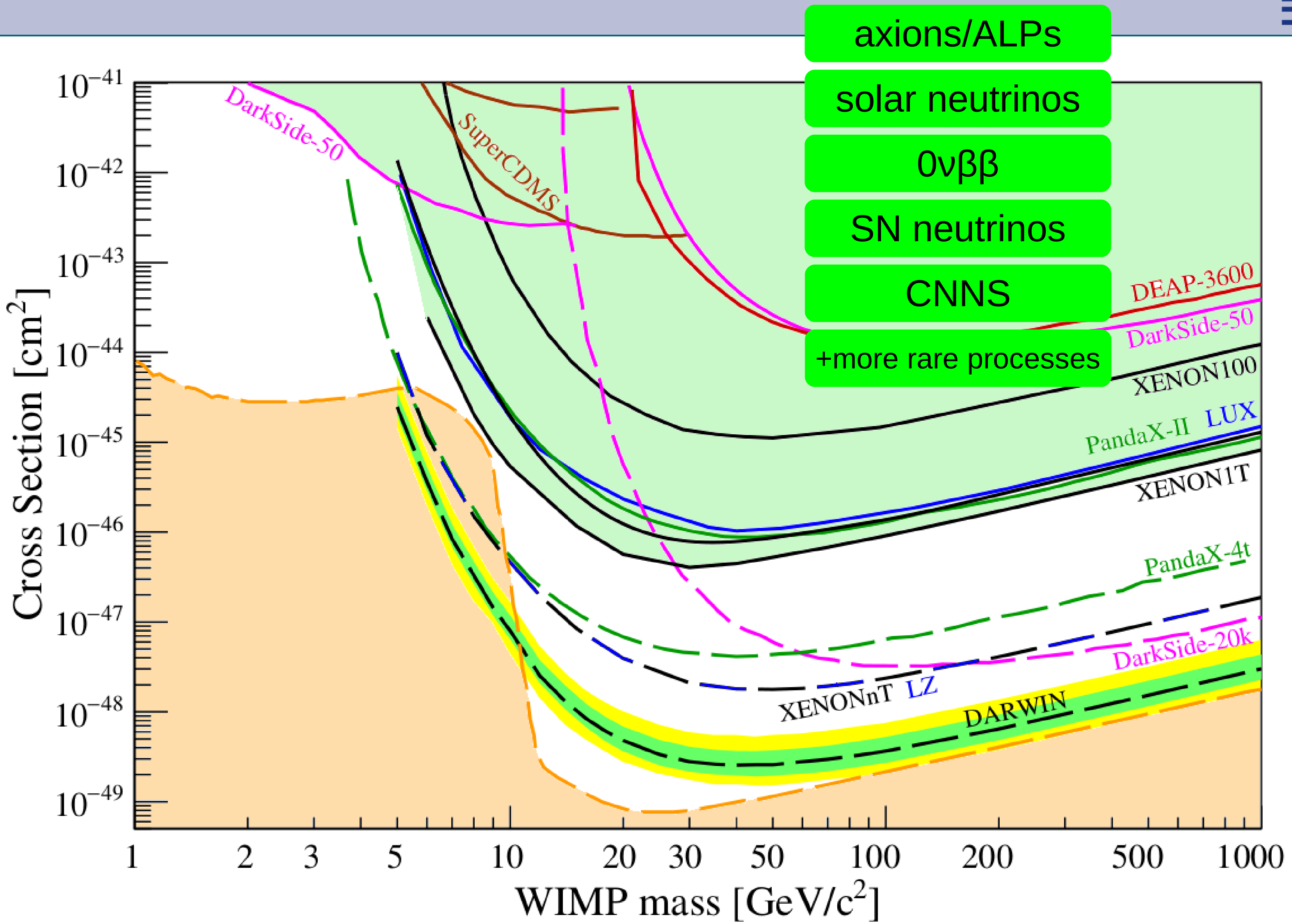
- ν from supernovae could be detected via CNNS as well
- signal fom accretion phase of a ~18 M_{sun} supernova @ 10 kpc is visible in a 10t-LXe detector (=DARWIN)
- signal: NRs plus precise time information
- challenge: theshold

accretion phase





XENON & DARWIN: Exciting Times



DARWIN: A low-background, low threshold astroparticle observatory