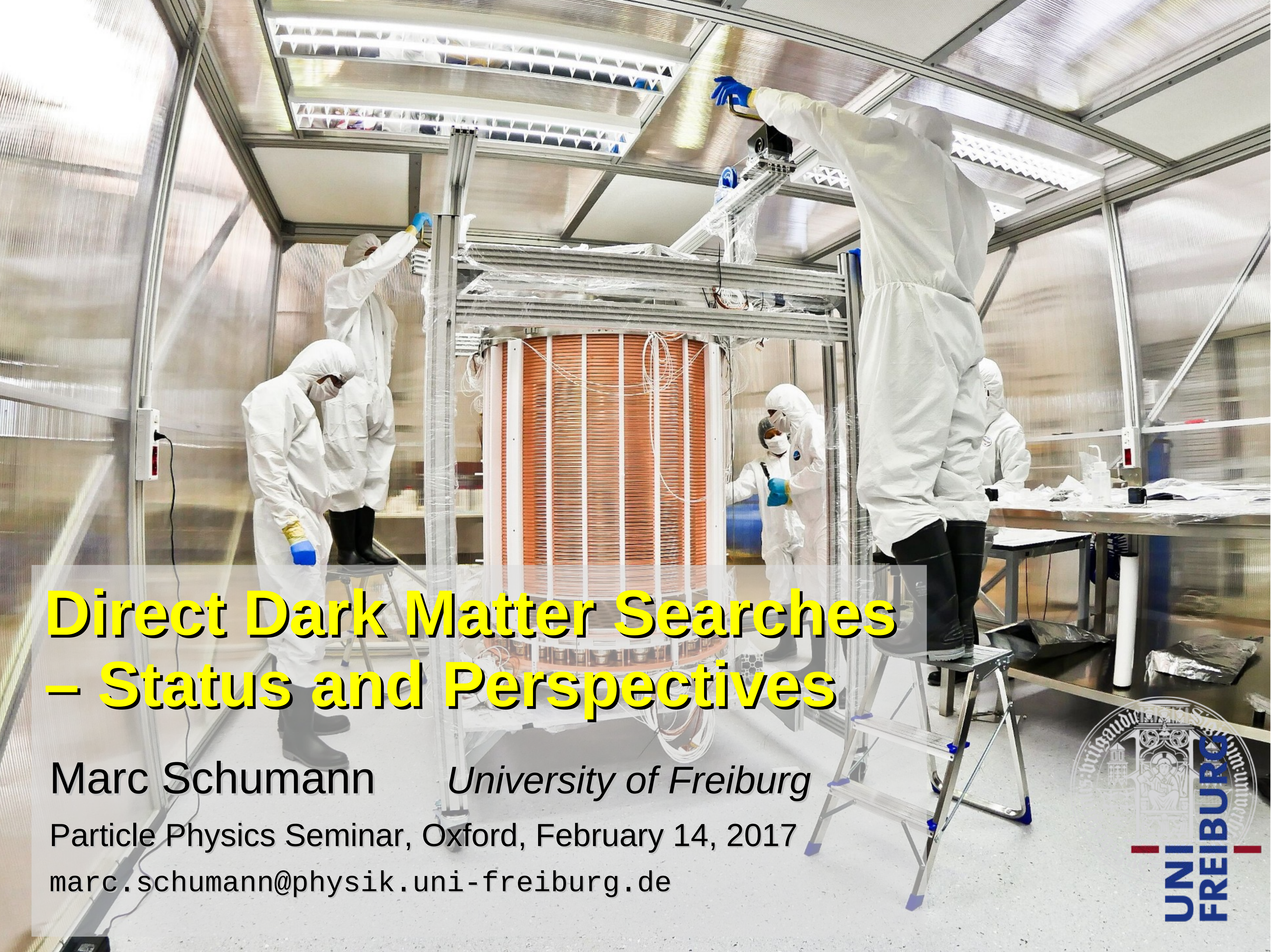


Direct Dark Matter Searches – Status and Perspectives

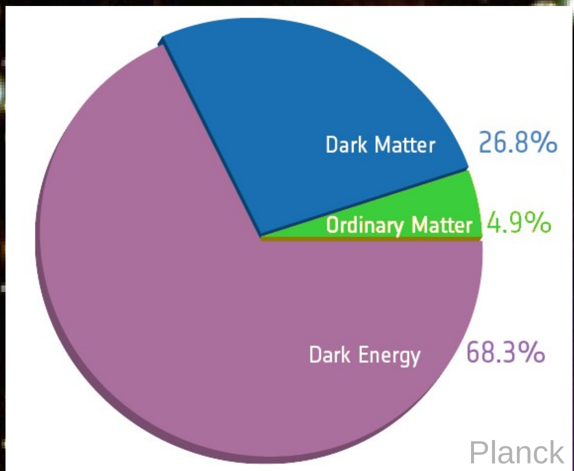
Marc Schumann *University of Freiburg*

Particle Physics Seminar, Oxford, February 14, 2017

marc.schumann@physik.uni-freiburg.de

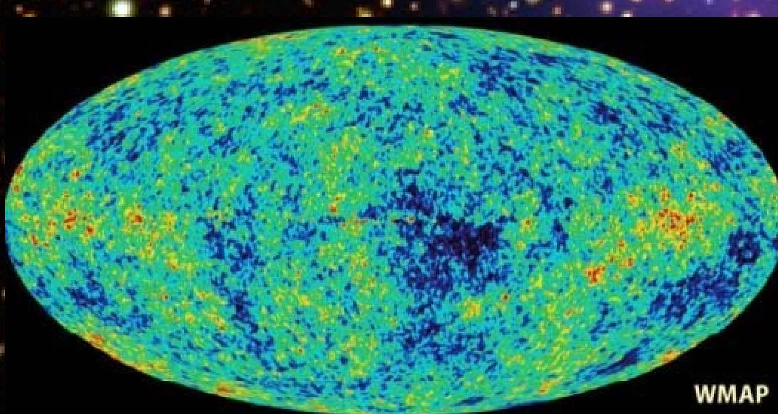
UNI FREIBURG

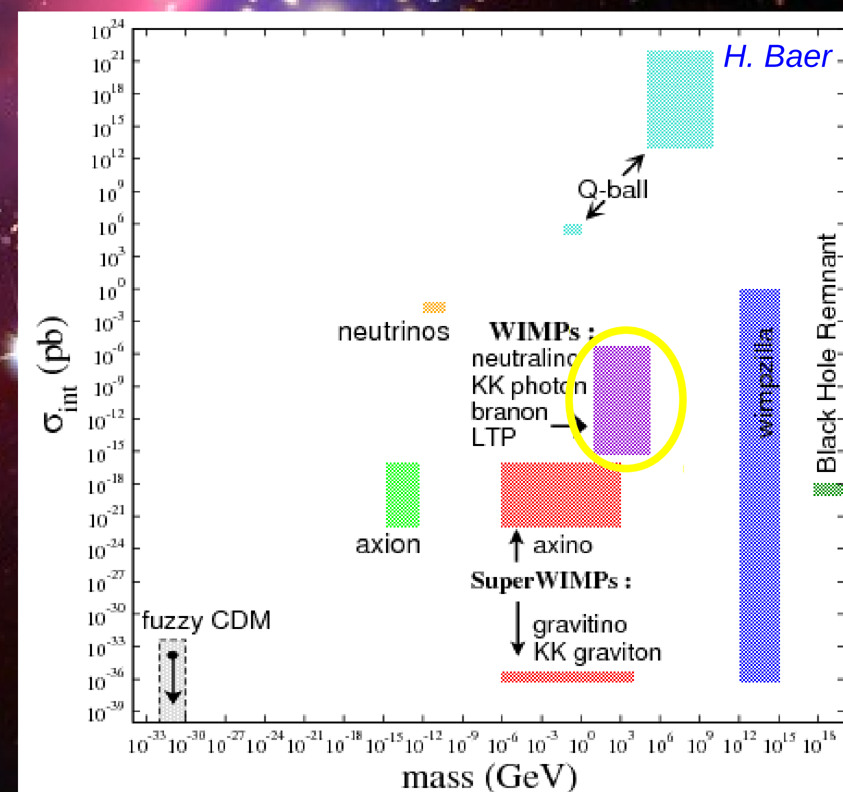
Dark Matter: (indirect) Evidence



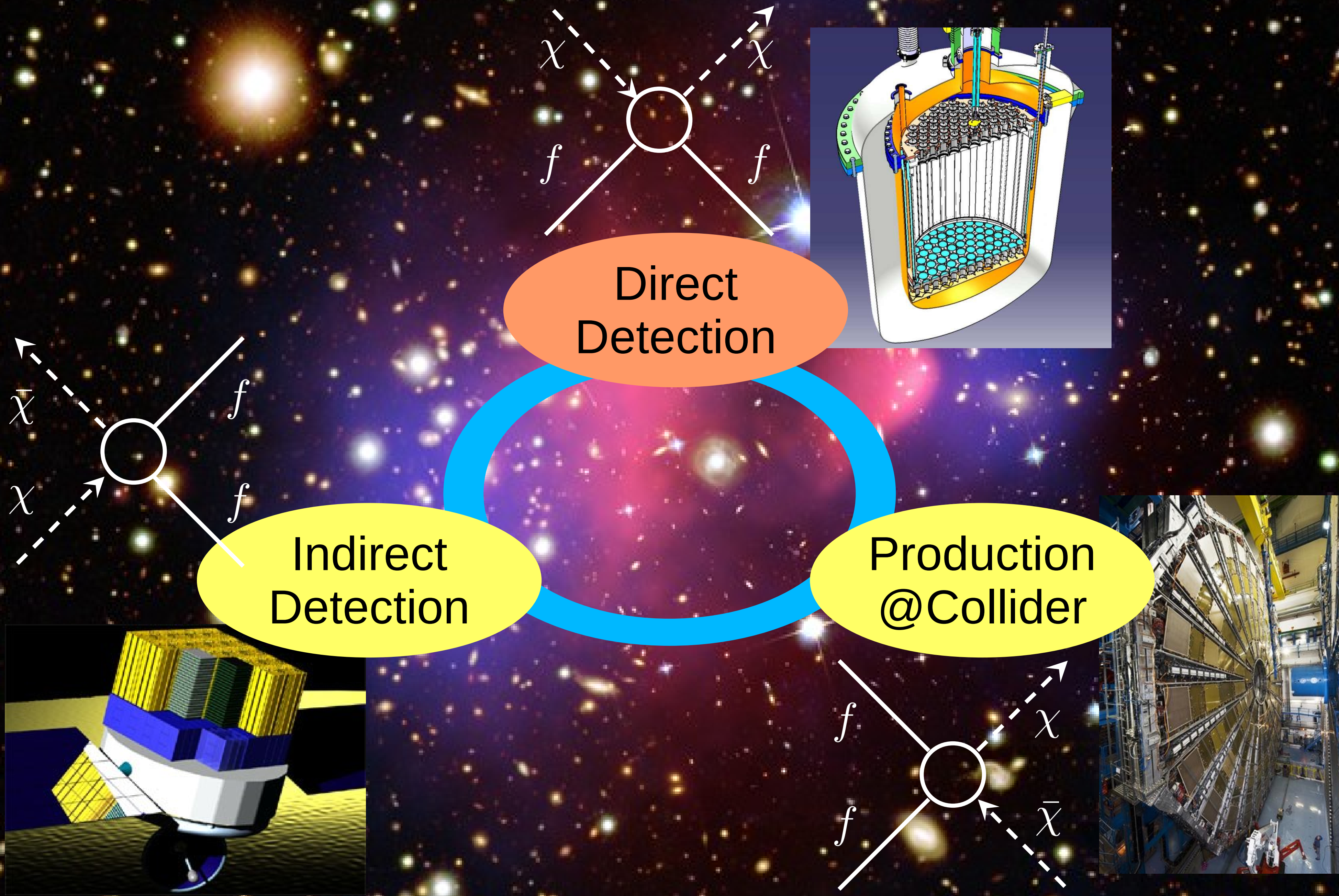
Particle Dark Matter Candidates:

- **WIMP** → *„WIMP miracle“*
- Axion
- SuperWIMPs
- sterile neutrinos
- WIMPless dark matter
- Gravitino
- ...



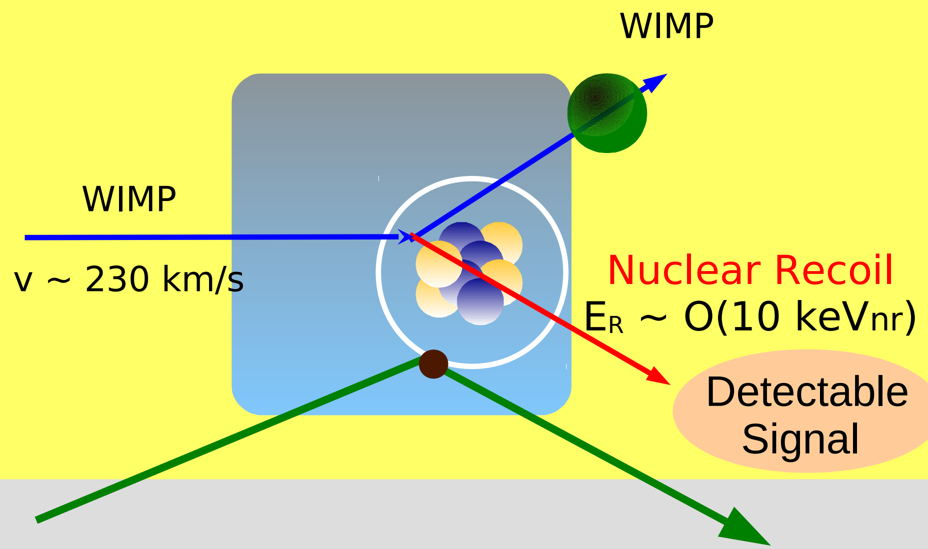


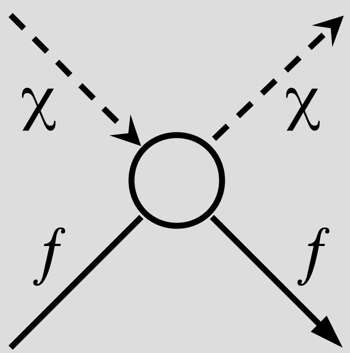
Dark Matter Search



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
$R < 1$ evt/kg/year

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

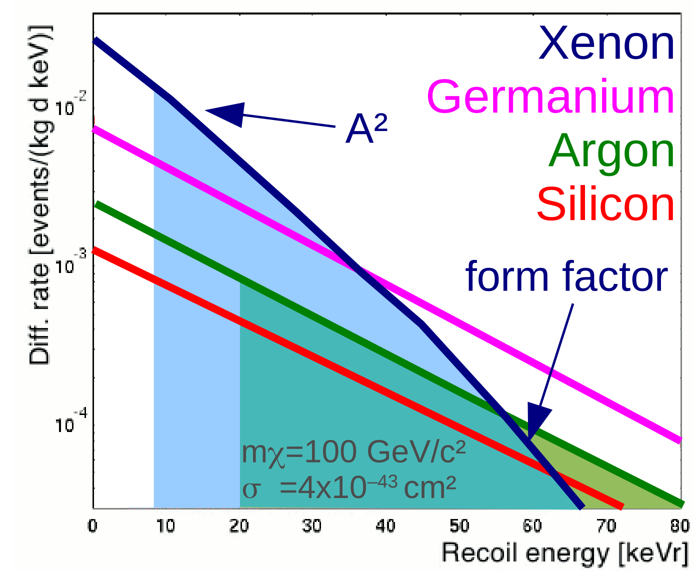
Event Rate: $R \propto N \frac{\rho_\chi}{m_\chi} \langle \sigma_{\chi-N} \rangle$

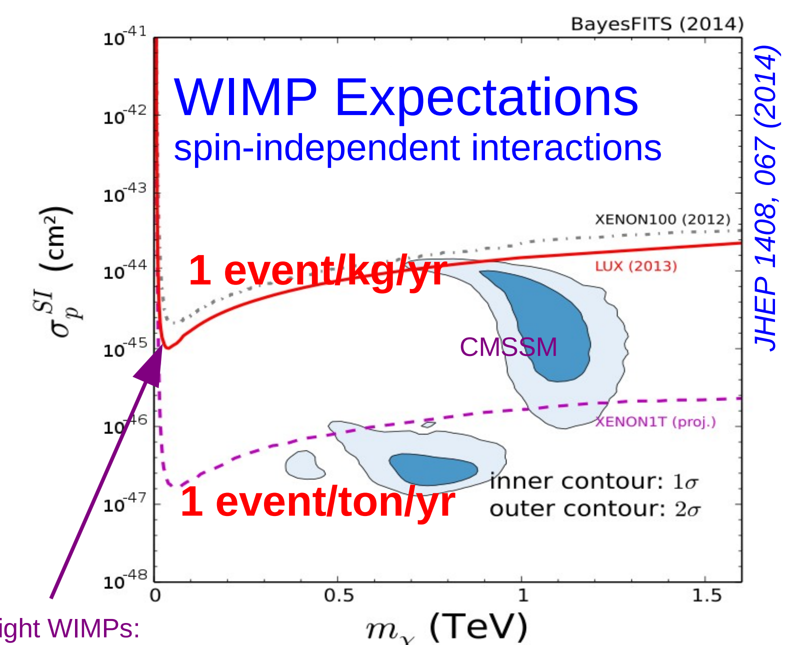
Detector

Local DM Density

Physics

$\rho_\chi \sim 0.3$ GeV/c^2





light WIMPs:
asymmetric DM,
sneutrinos, ...

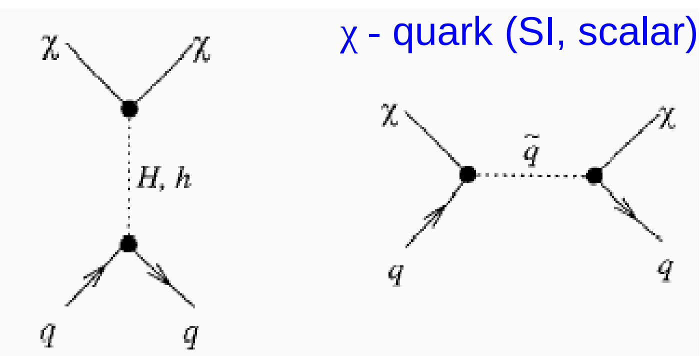
WIMP-Nucleon Interactions

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

Parametrization of interactions leading to WIMP-nucleus scattering:

coupling to **mass**
Spin independent

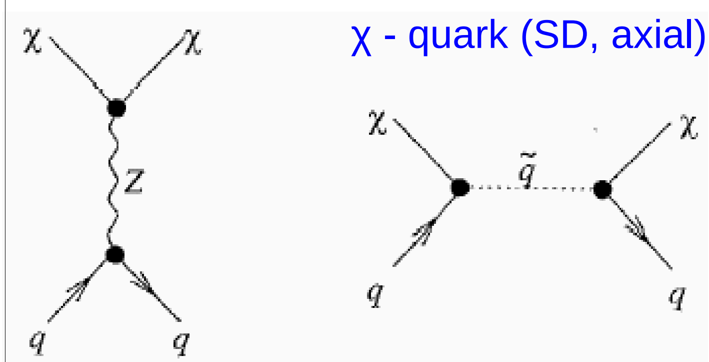
χ - quark (SI, scalar)



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

coupling to **nuclear spin**
Spin dependent

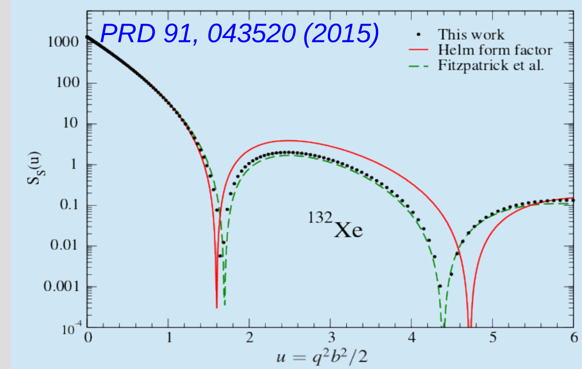
χ - quark (SD, axial)

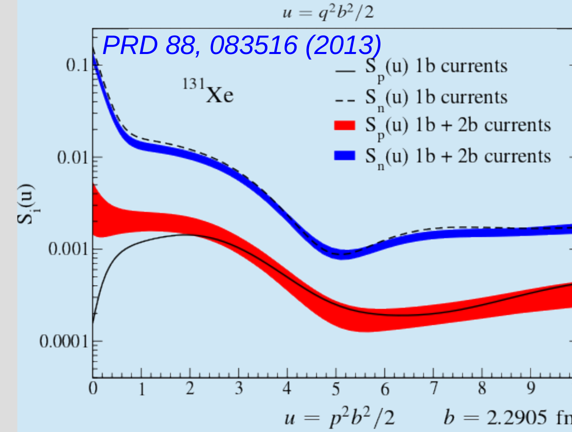


$$\mathcal{L}_A \sim \tilde{\chi}\gamma_\mu\gamma_5\chi\bar{q}\gamma^\mu\gamma_5 q \quad \propto J(J+1)$$

Jungmann et al. '96 Phys.Rep.

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





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

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

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

Direct WIMP Search

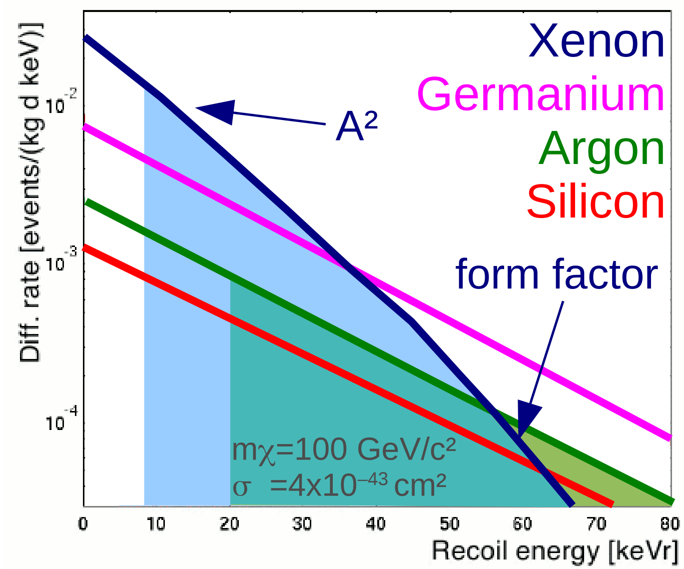
Direct Detection:

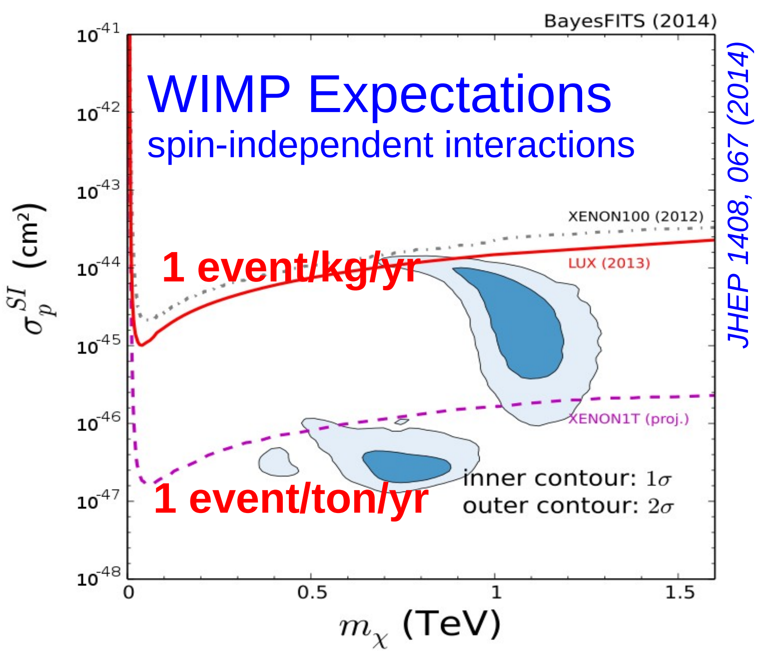
$E_r < 100$ keV
$R < 1$ evt/kg/year

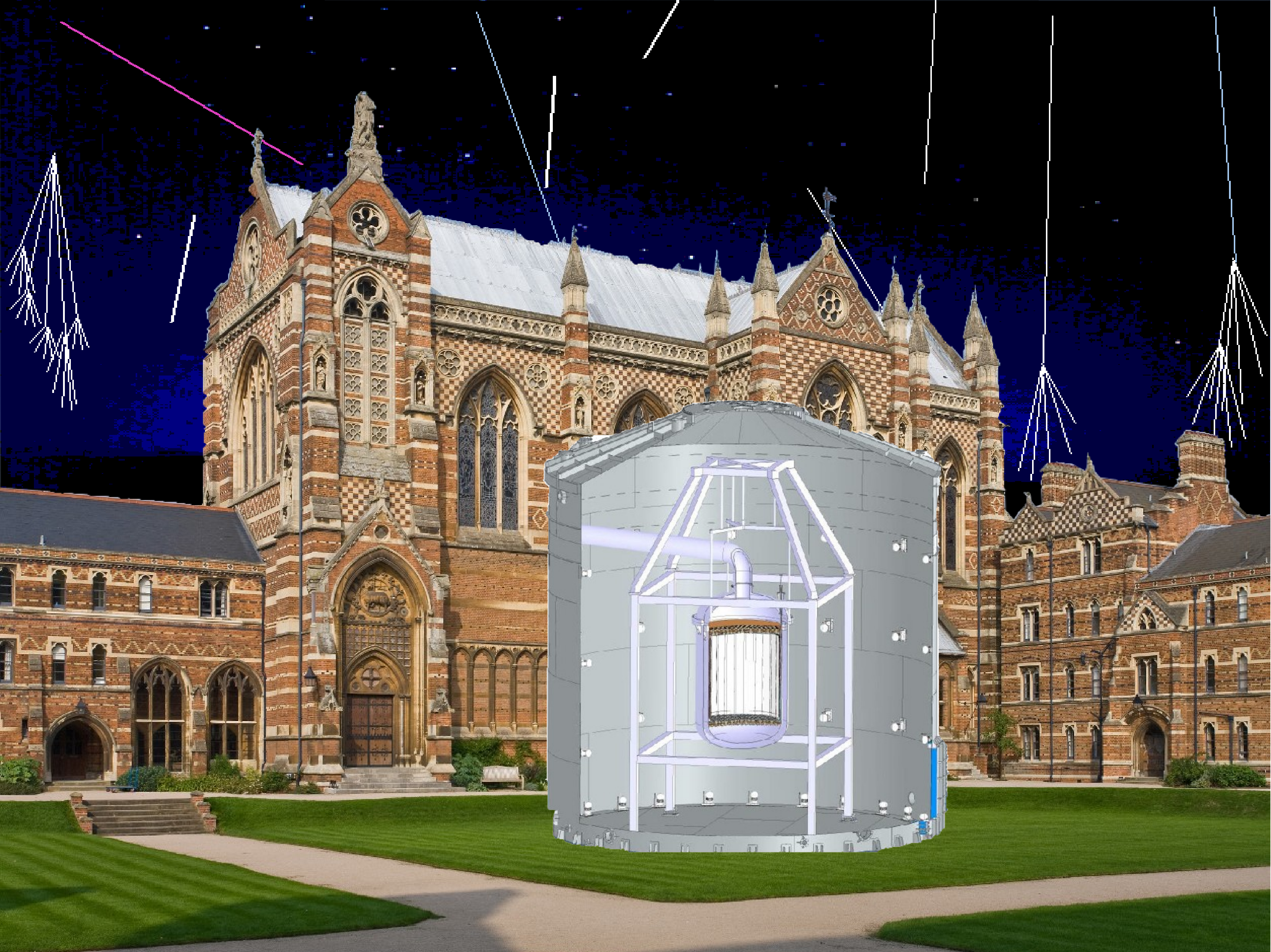
How to build a WIMP detector?

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

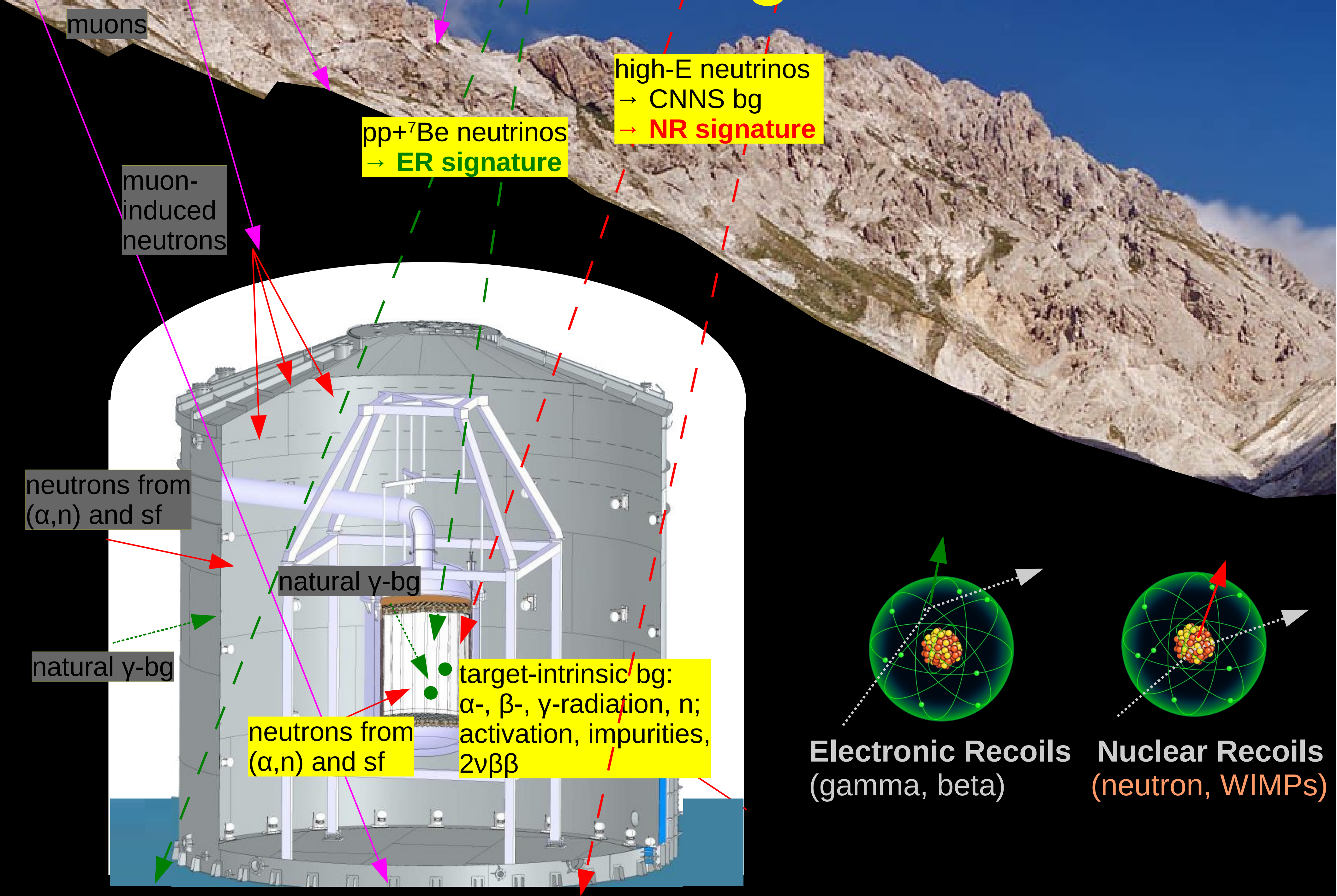
We are dealing with
- extremely **low rates** (O(1) Hz)
- extremely **low thresholds** (~2 keV)
- extremely **low radioactive** backgrounds



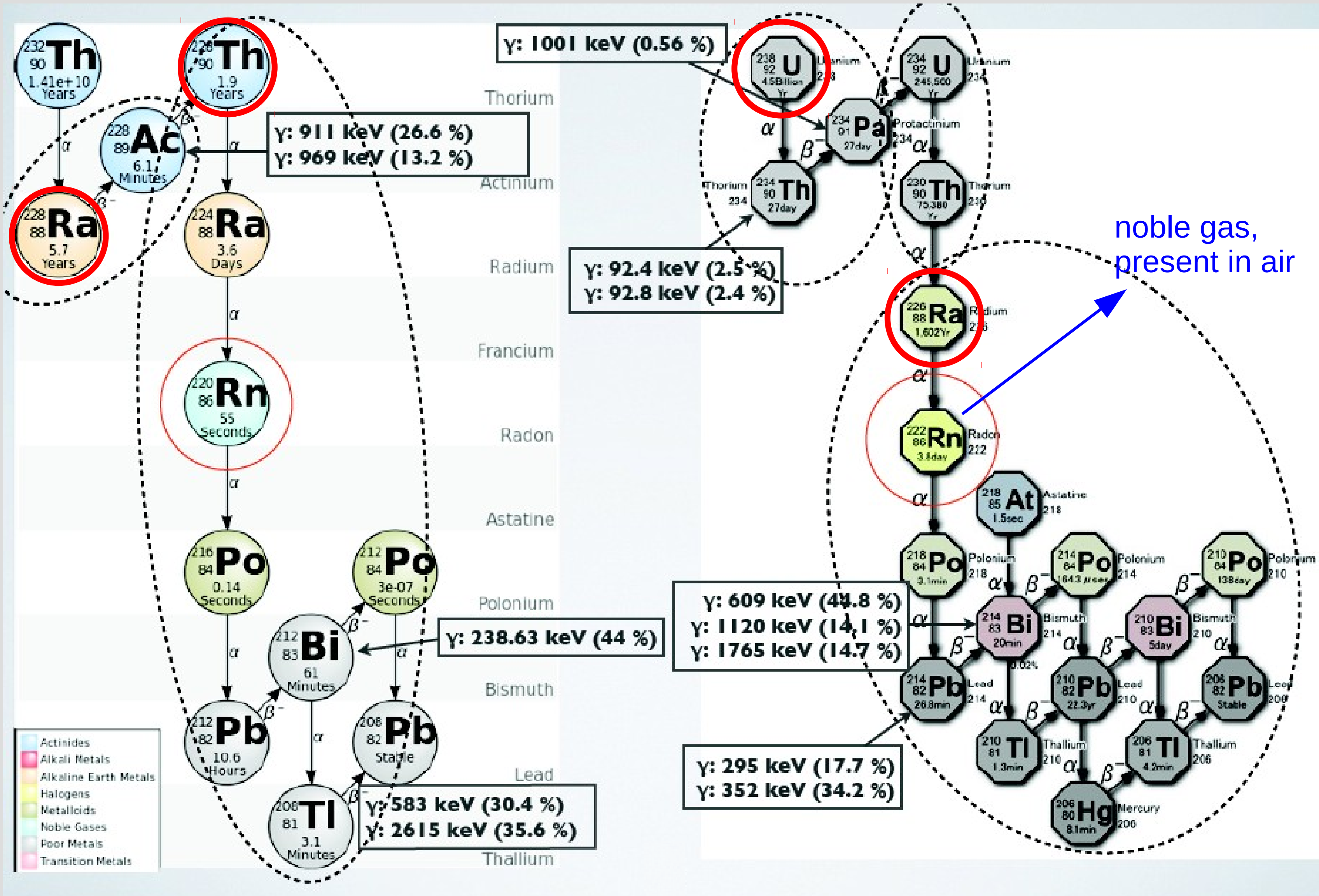




Background Sources



The U and Th Chains



Low-background Screening

GeMSE
Germanium Material and Meteorite Screening Experiment

JINST 11, P12017 (2016)

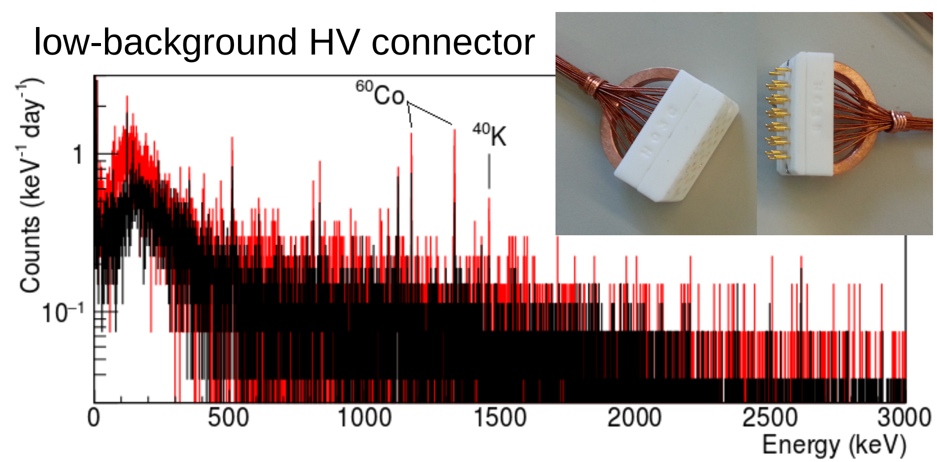
Vue des Alpes Laboratory (600 mwe)

Astropart. Phys. 35, 43 (2011)

Material	Supplier	Detector	Unit	^{228}Ra	^{228}Th	^{238}U	^{226}Ra	^{235}U	^{40}K	^{137}Cs	^{60}Co
Metal											
Lead	Plombum	Gator	mBq/kg	< 6.9	< 0.52	< 260	< 4.2	< 12	14(3)	< 0.81	< 0.11
Lead	Plombum	LNGS	mBq/kg	< 6.6	< 1.6	< 130	< 5.7	< 51	14(6)	< 2.1	< 1.1
Lead	Foundaries de Gentilly	Gator	mBq/kg	< 0.66	< 0.42	< 24	< 0.71	< 1.8	< 1.46	0.63(6)	< 0.11
Lead	Foundaries de Gentilly	LNGS	mBq/kg	< 3.9	< 4.3	< 33	< 6.8	< 20	< 28	< 0.85	< 0.19
Copper	Norddeutsche Affinerie	Gator	μBq/kg	21(7)	21(7)	70(20)	70(20)	3.4	23(6)		2(1)
Copper	Norddeutsche Affinerie	Gator	mBq/kg	< 0.37	< 0.33	< 11	< 0.37	< 0.47	< 1.3	< 0.14	0.24(6)
Stainless Steel 316Ti (1.5 mm)	NIRONIT	LNGS	mBq/kg	< 2.4	< 1.0	< 130	< 1.9	< 2.0	10(4)	< 0.9	8.5(9)
Stainless Steel 316Ti (2.5 mm)	NIRONIT	LNGS	mBq/kg	< 3.1	< 1.5	< 42	< 2.7	< 1.4	< 12	< 0.88	13(1)
Stainless Steel 316Ti (3.0 mm)	NIRONIT	Gator	mBq/kg	< 4.1	< 1.8	< 130	3.6(8)	< 5.8	< 5.7	< 1.1	7(1)
Stainless Steel 316Ti (25 mm)	NIRONIT	LNGS	mBq/kg	< 0.92	2.9(7)	< 20	< 1.3	< 1.3	< 7.1	< 0.82	1.4(3)
Screws 2-56 7/16"	McMaster	Gator	mBq/kg	24(5)	< 21	< 550	< 13	< 25	< 47	< 5.1	6(2)
Plastic											
Polyethylene	in2plastic	Gator	mBq/kg	< 5.4	< 3.7	< 170	< 5.1	< 7.6	< 14	< 1.7	< 1.4
Polyethylene	in2plastic	Gator	mBq/kg	< 4.3	< 5.8	< 220	< 6.5	< 9.9	< 13	< 2.1	< 1.7
Polyethylene	in2plastic	LNGS	mBq/kg	< 0.094	< 0.14	< 3.8	0.23(5)	< 0.37	0.7(4)	0.06(3)	
PTFE	Maagtechnic	Gator	mBq/kg	< 0.39	< 0.16	< 6.2	< 0.31	< 0.28	< 2.25	< 0.13	< 0.11
PTFE	Maagtechnic	Gator	mBq/kg	< 0.16	< 0.10	< 3.0	< 0.06	< 0.13	< 0.75	< 0.07	< 0.03
PTFE	McMaster	ICP-MS	mBq/kg	0.5(1)	0.5(1)	0.25(5)	0.25(5)	0.011(2)	< 3.1		
PTFE	McMaster	LNGS	mBq/kg	< 1.8	< 2.3	< 36	< 1.1	< 1.4	< 7.6	< 0.44	
PTFE	APT	LNGS	mBq/kg	< 0.15	< 0.13	< 12	< 0.16	< 0.59	3(1)	< 0.11	0.15(7)

Energy (keV)

low-background HV connector



Identify materials with lowest radioactivity:

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

Background Suppression

Avoid Backgrounds

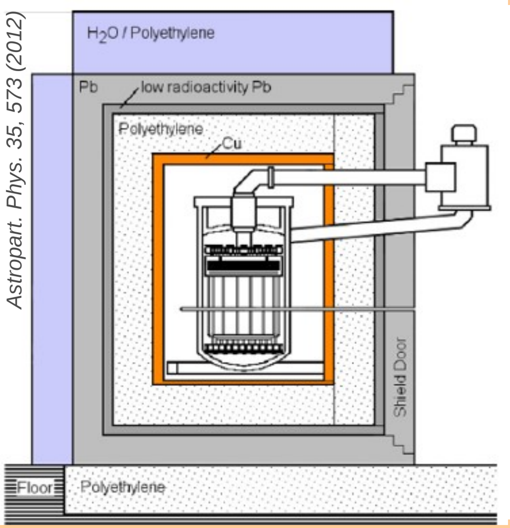
Shielding

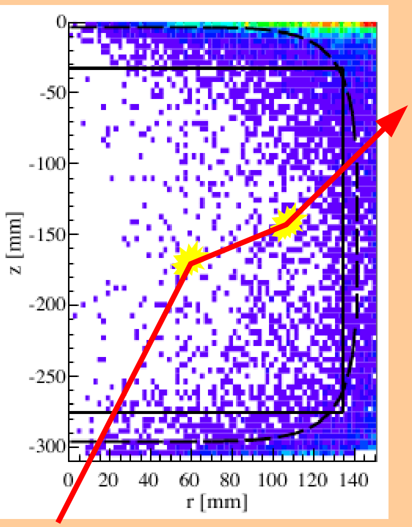
deep underground location
large shield (Pb, water, poly)
active veto (μ, γ coincidence)

self shielding → fiducialization

Use of radiopure materials

Astropart. Phys. 35, 573 (2012)





Use knowledge about expected WIMP signal

WIMPs interact only once

→ single scatter selection
requires some position resolution

WIMPs interact with target nuclei

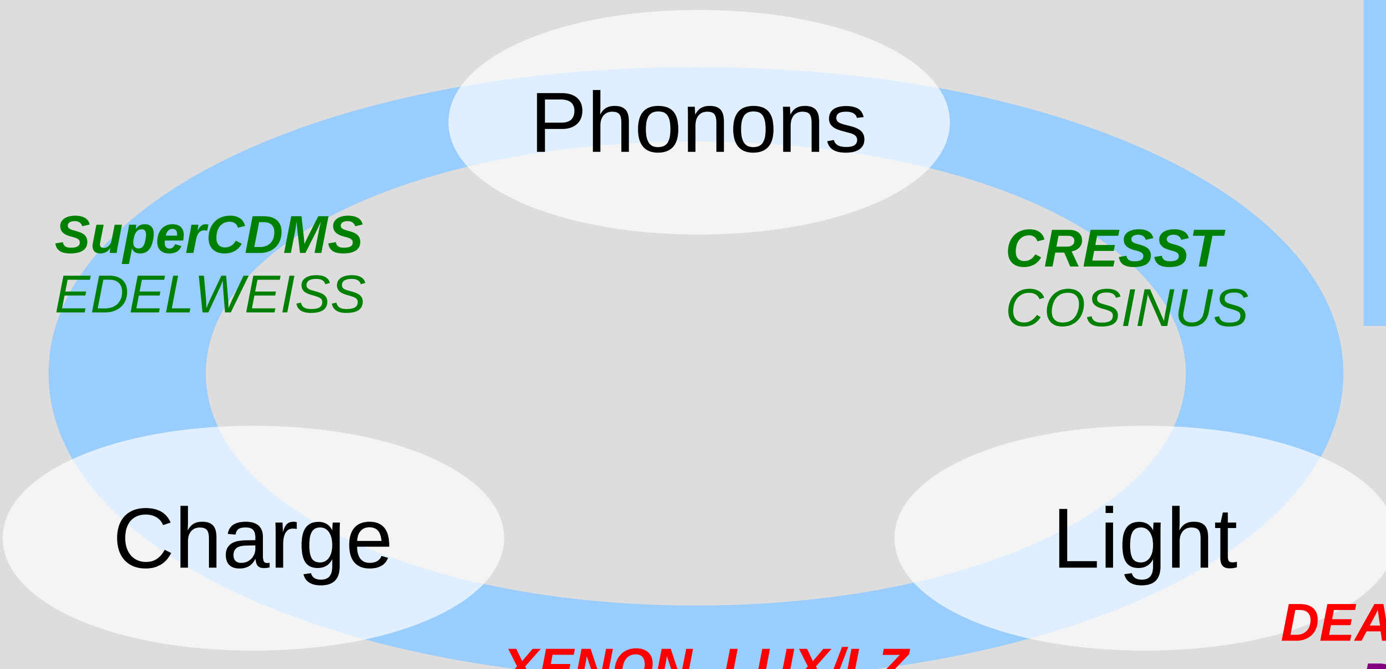
→ nuclear recoils
exploit different dE/dx from signal and background

Examples:
- scintillation pulse shape
- charge/light ratio
- ionization yield

Direct WIMP Detection

Crystals (NaI, Ge, Si)
Cryogenic Detectors
Liquid Noble Gases

CUORE



SuperCDMS
EDELWEISS

CRESST
COSINUS

CoGeNT
CDEX
Malbek
DAMIC
NEWS (gas)

XENON**, **LUX/LZ
*ArDM, **Panda-X***
DarkSide, DARWIN

***DEAP-3600**, CLEAN*
***DAMA**, KIMS*
***XMASS**, COSINE*
*ANAIS, **SABRE***

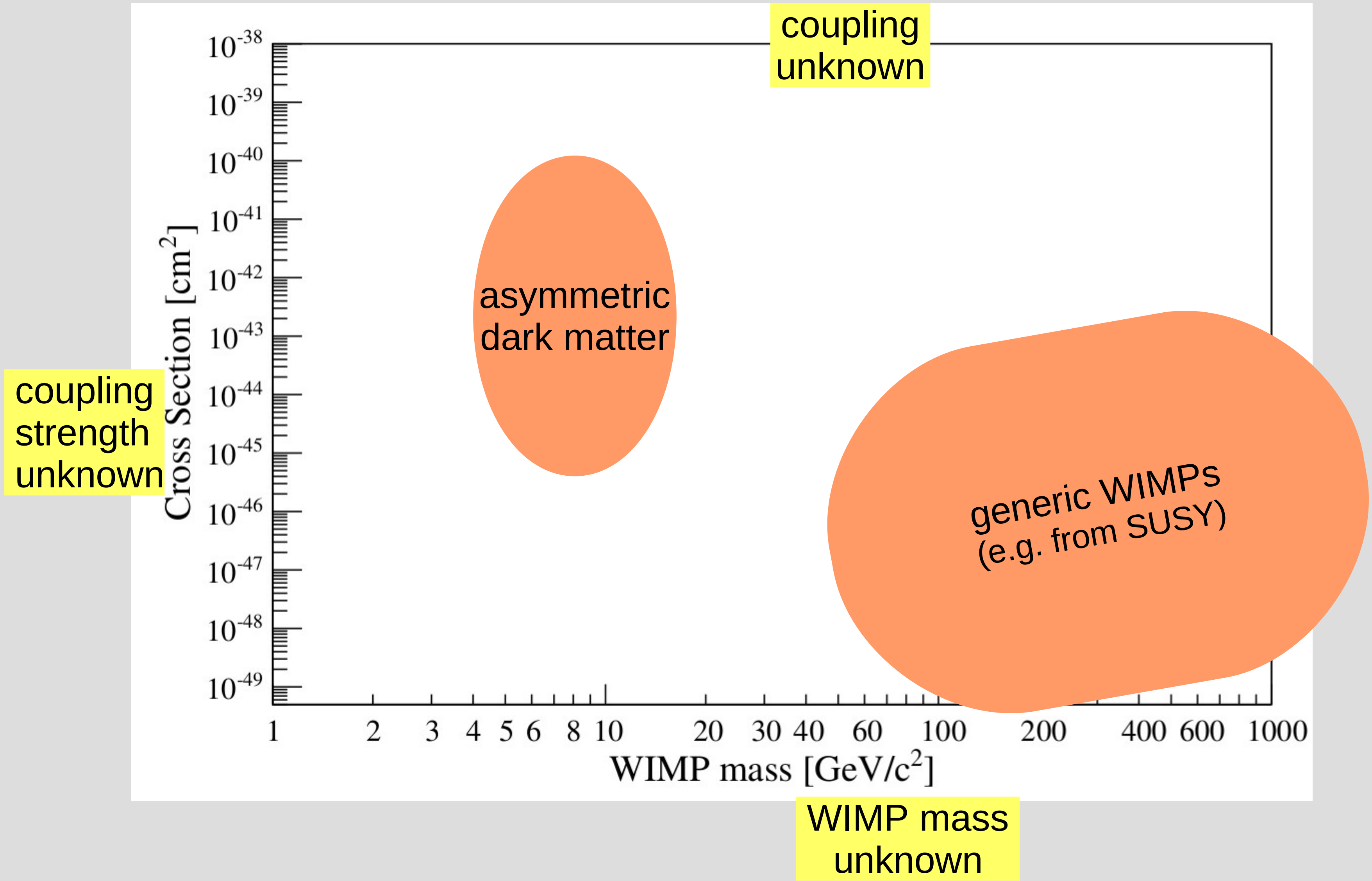
Tracking:
DRIFT, DMTPC
MIMAC, NEWS
NEWAGE

Superheated Liquids:
PICO
SIMPLE

too many experimental efforts to report on → you will see a biased selection

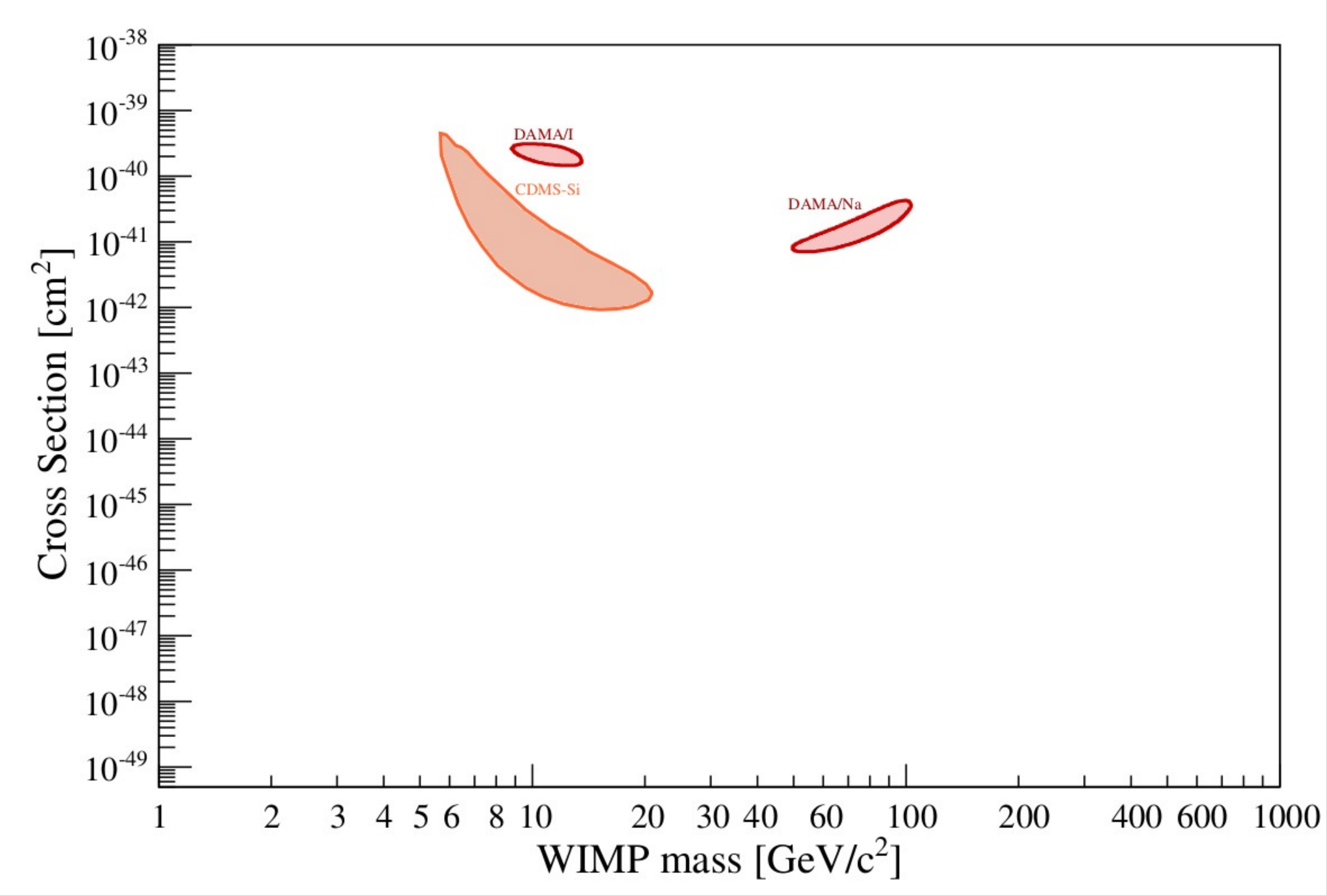
The WIMP Parameter Space

spin-independent WIMP-nucleon interactions



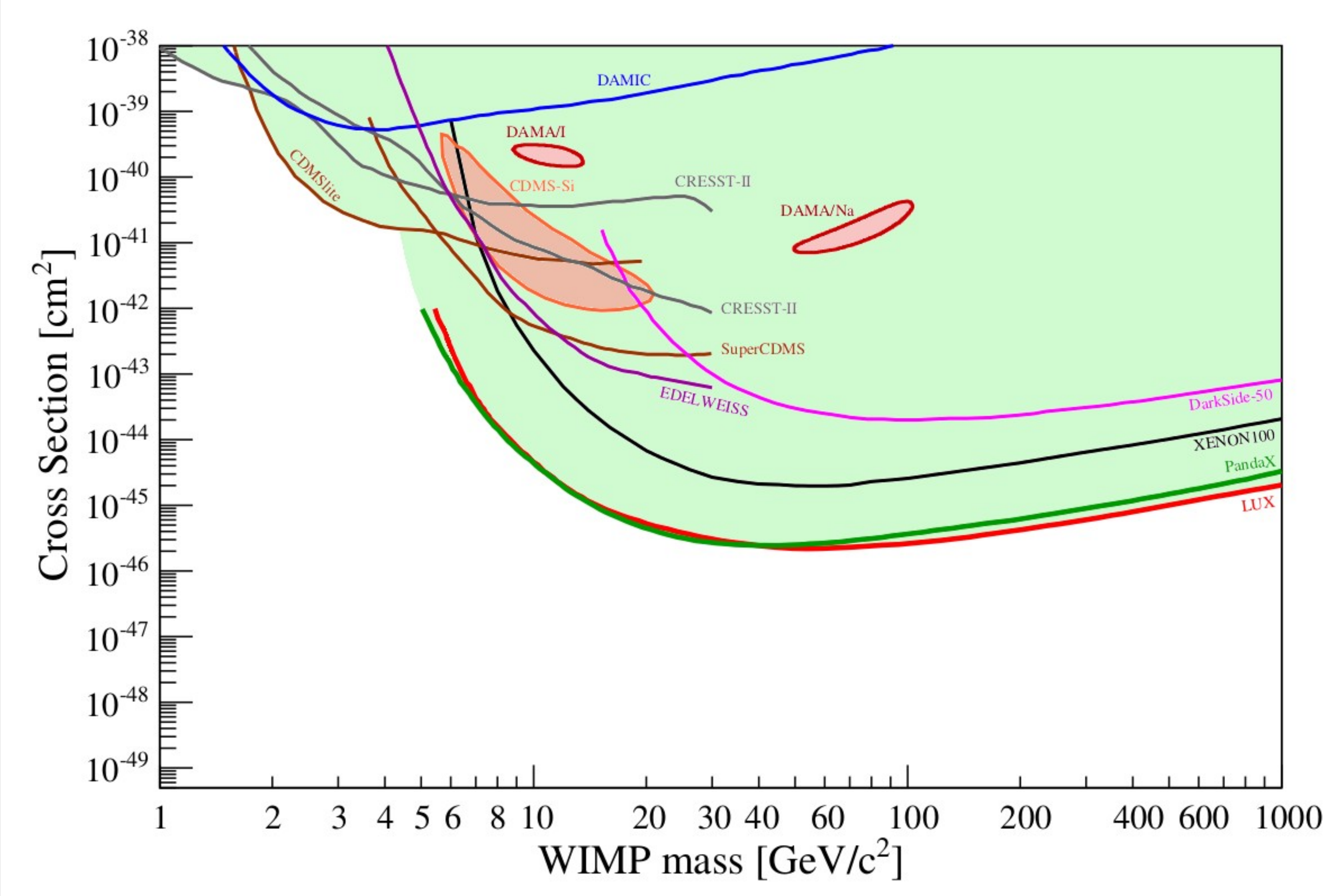
Detections?

spin-independent WIMP-nucleon interactions



Exclusions?

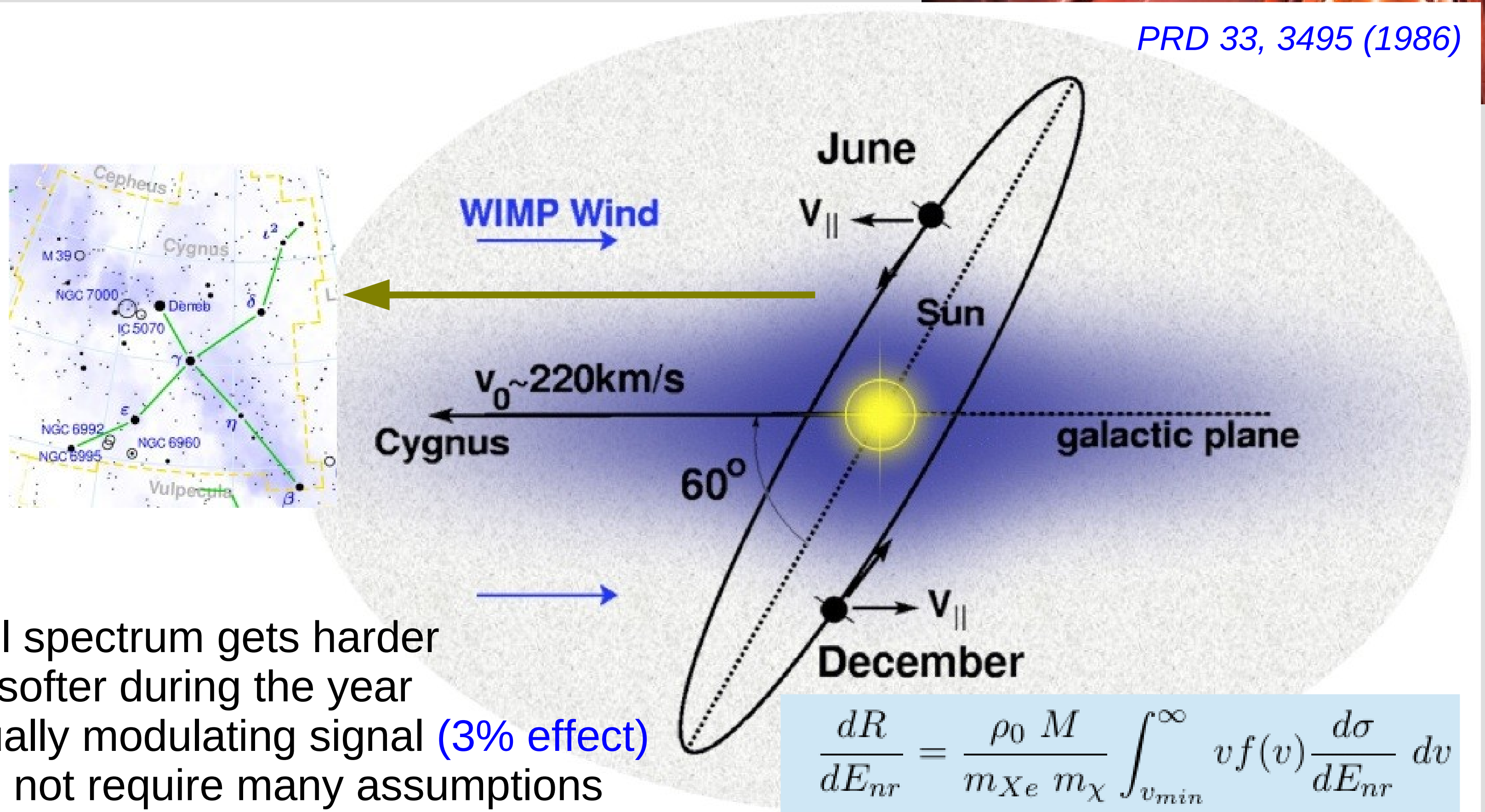
spin-independent WIMP-nucleon interactions



some results are missing...

Annual Modulation: DAMA/Libra

- PMTs coupled to **NaI(Tl)** Scintillators @ LNGS
  → extremely clean background necessary
- large mass and exposure: 1.17 t×y
- looks for **annual modulation**



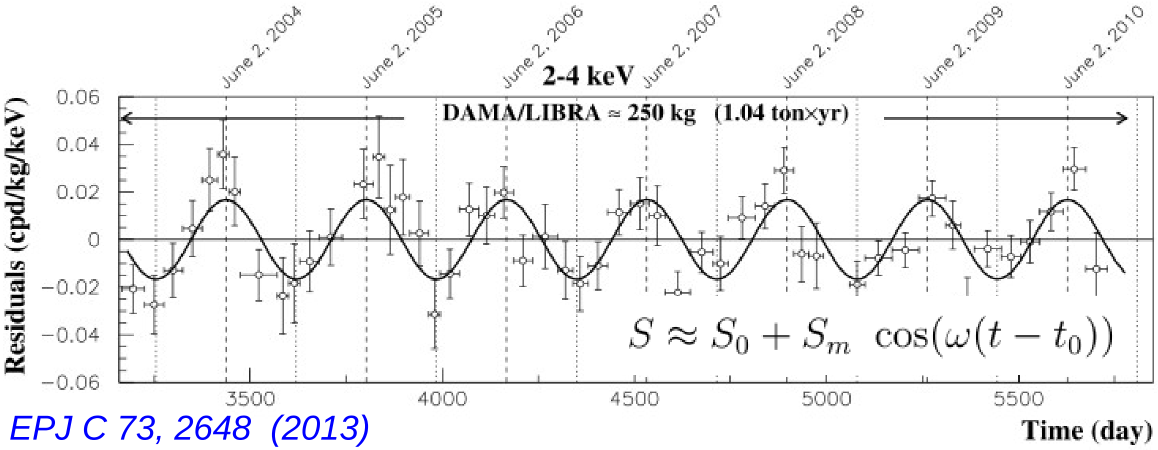
→ recoil spectrum gets harder and softer during the year
→ annually modulating signal (3% effect)
→ does not require many assumptions

$$\frac{dR}{dE_{nr}} = \frac{\rho_0 \; M}{m_{Xe} \; m_\chi} \int_{v_{min}}^{\infty} v f(v) \frac{d\sigma}{dE_{nr}} \; dv$$

Annual Modulation: DAMA/Libra

- PMTs coupled to **NaI(Tl)** Scintillators @ LNGS
  → extremely clean background necessary
- large mass and exposure: 1.17 t×y
- looks for annual modulation

- DAMA finds annual modulation @ **9.3σ CL**
- BUT: no ER/NR discrimination!



EPJ C 73, 2648 (2013)

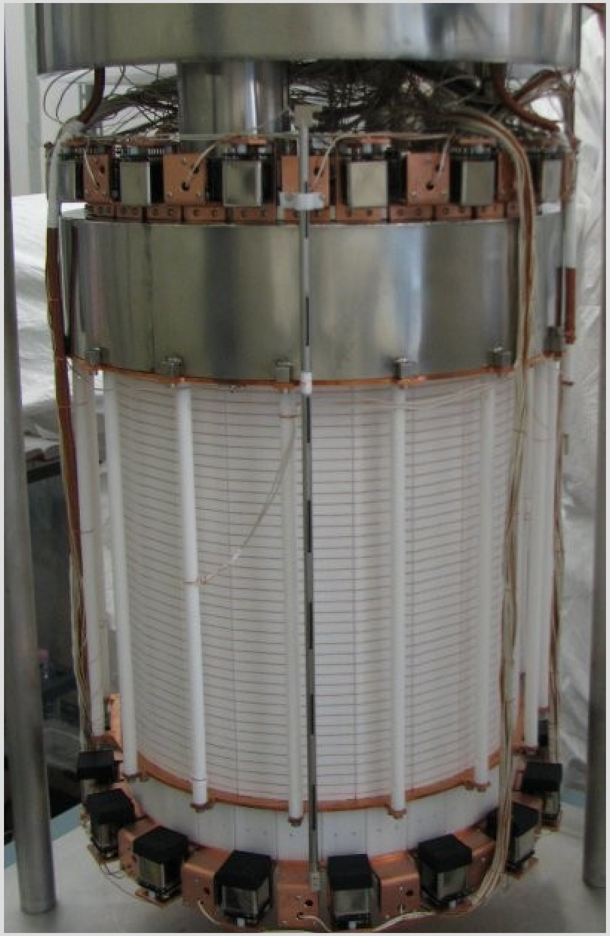
interpretation as (spin-(in)dependent, inelastic) WIMP-nucleon scattering challenged by many experiments

Reconcile DAMA/Libra with the null-results from other experiments assuming **leptophilic** dark matter?
→ DAMA might see electronic recoils

Examples:
Axial-vector couplings:
Kopp et al., PRD 80, 083502 (2009)
Changet al., PRD 90, 015011 (2014)
Bell et al., PRD 90, 035027 (2014)
Mirror dark matter:
Foot, Int.J.Mod.Phys. A29, 1430013 (2014)
Luminous dark matter:
Feldstein et al., PRD 82, 075019 (2010)

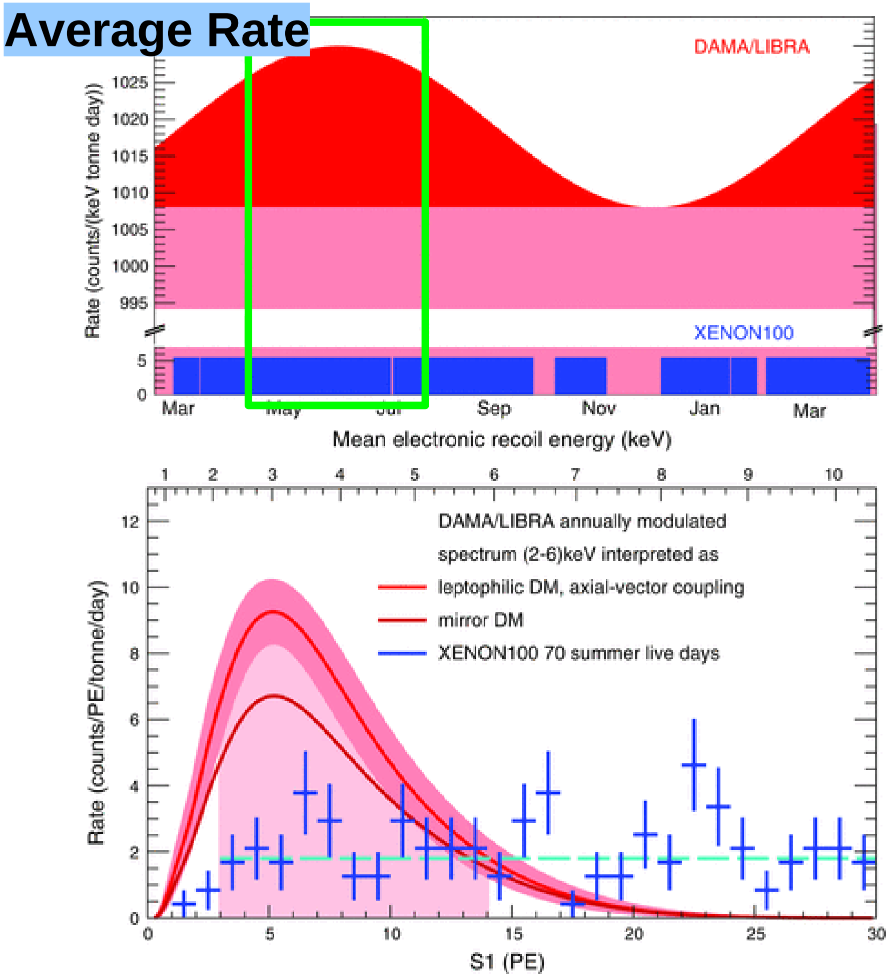
DAMA vs XENON

Science 349, 851 (2015)



XENON100 @ LNGS
Astropart. Phys. 35, 573 (2012)

result from **XMASS** *PLB759, 272 (2016)*
→ exposure comparable to DAMA
→ result inconsistent with DAMA



XENON100 excludes DAMA as being due to
– WIMP-e⁻ axial-vector couplings at **4.4σ**
– luminous dark matter at **4.6σ**
– mirror dark matter at **3.6σ**

DAMA vs XENON

Modulation

arXiv:2017.00769

Detector

Pressure [bar]

Temperature [K]

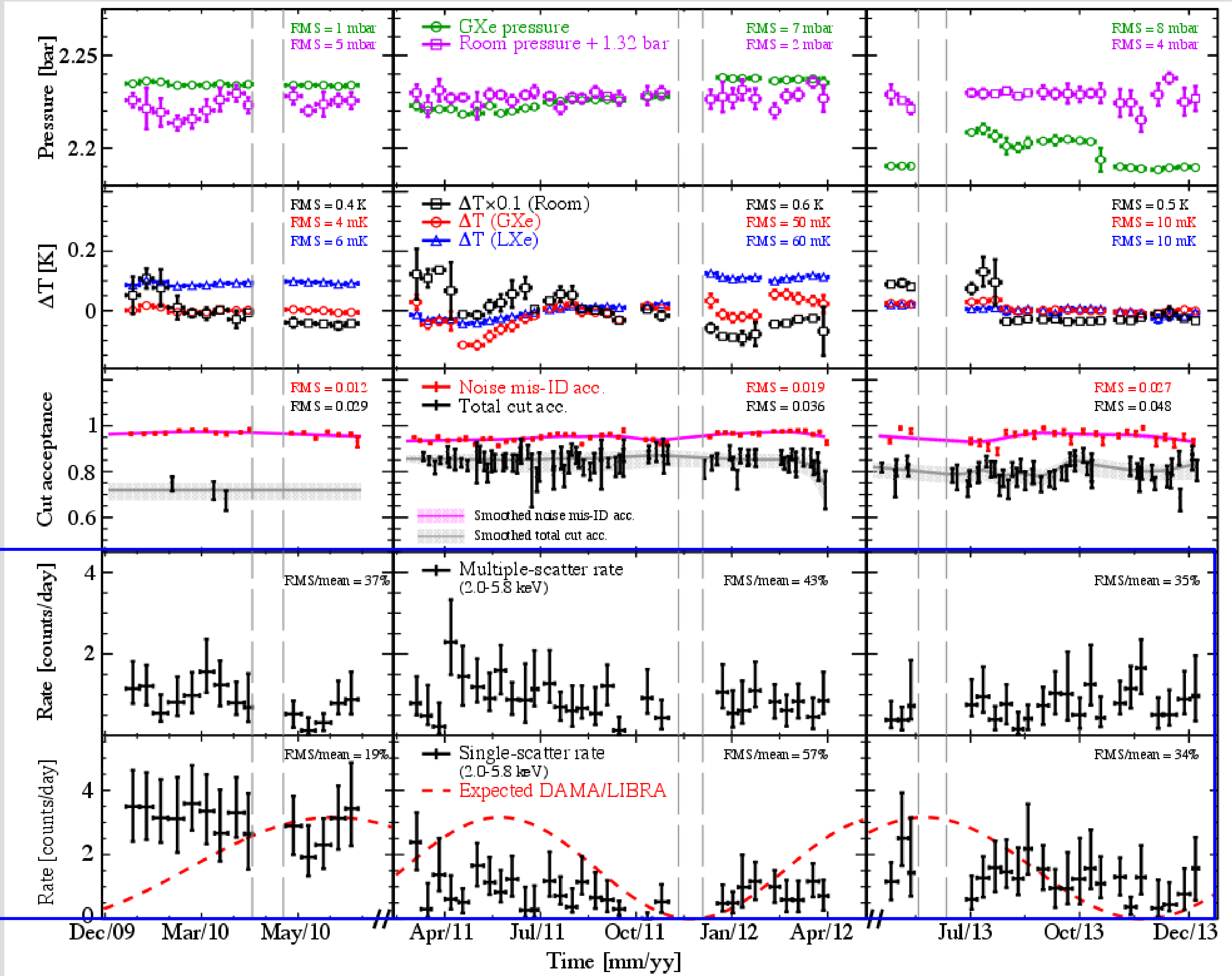
Analysis

Cut Acceptance

Rate

Multiples (=background)

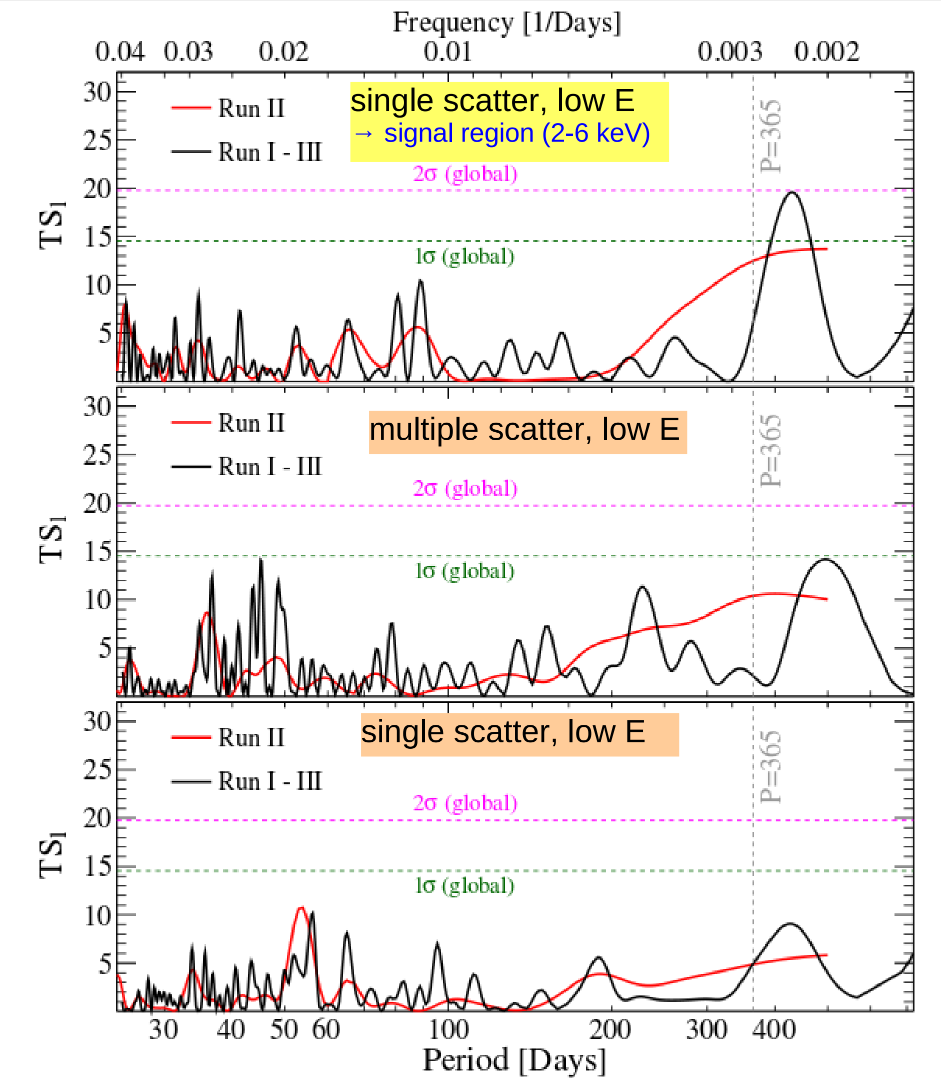
Singles (=signal)

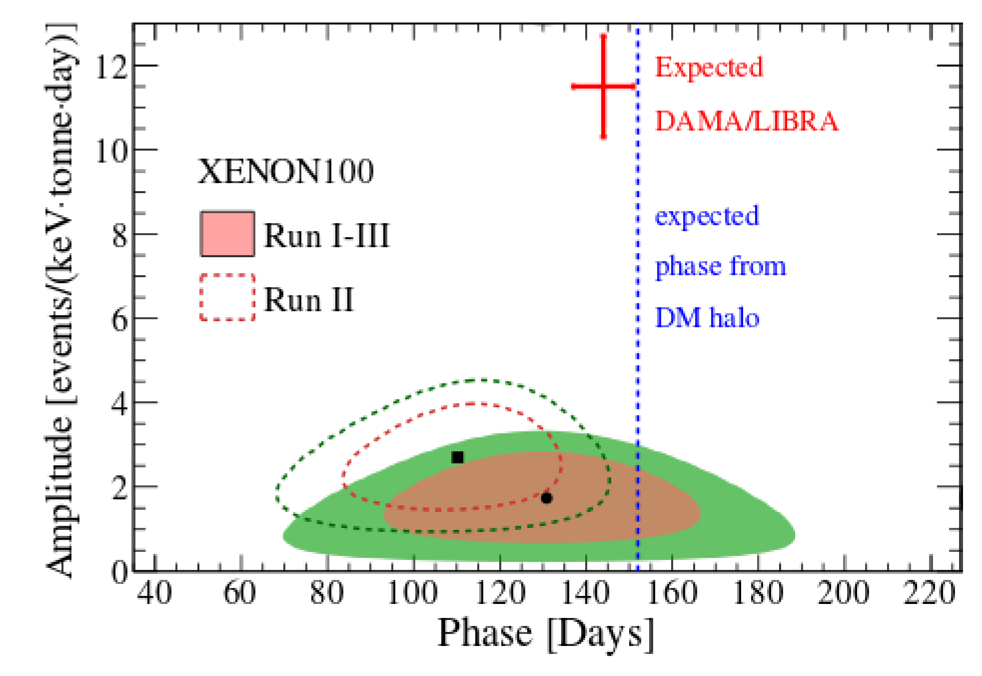


DAMA vs XENON

Modulation

arXiv:2017.00769





- additional data improves upon previous analysis *PRL 115, 091302 (2015)*
- no significant modulation observed
- Dark matter explanation of DAMA/LIBRA signal excluded @ **5.7σ**

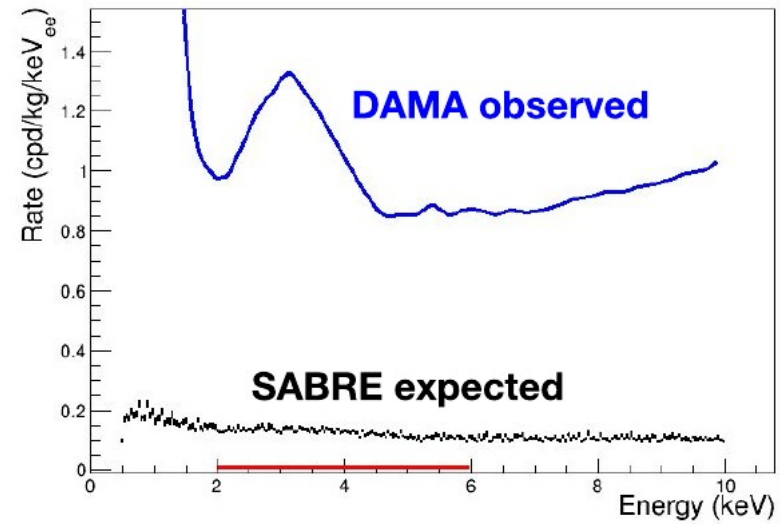
New NaI Projects to test DAMA

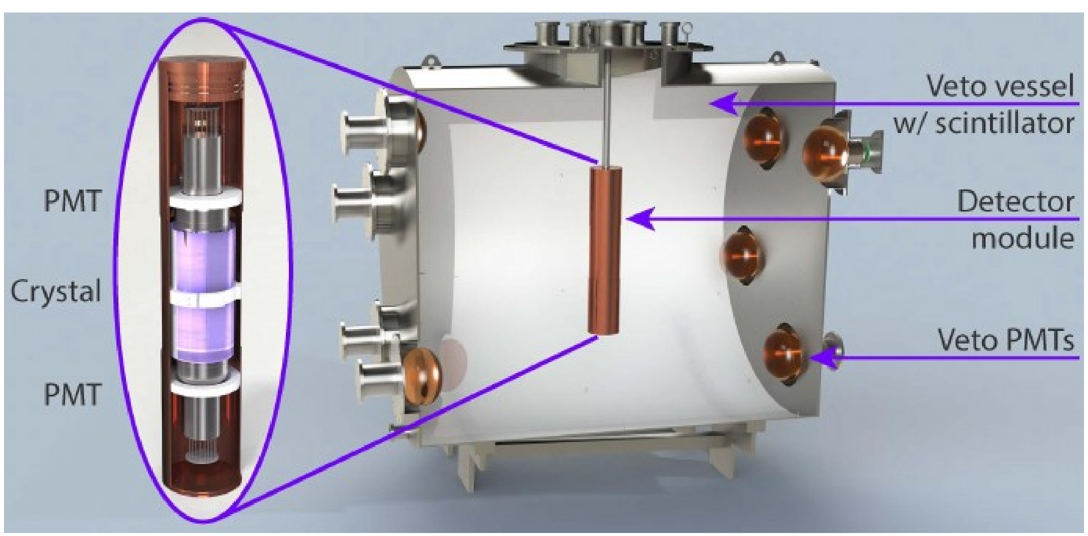
aim at testing the DAMA claim using the same target/detector
→ main challenges: crystal purity, low threshold, target mass

SABRE *NIM A 845, 418 (2017)*
*S*odium-iodine with *A*ctive *B*ackground *RE*jection

Strategy:
- lower background: better crystals ✓, PMTs
- liquid scintillator veto against ^{40}K (factor 10)
- lower threshold (PMTs directly coupled to NaI)
- North (LNGS) and South (Australia)

- *Status*: proof-of-principle prepared at LNGS (5 kg)





DM-Ice: 17 kg @ South Pole
arxiv:1602.05939

COSINE = KIMS+DM-Ice
~100 kg @ Yangyang → start soon

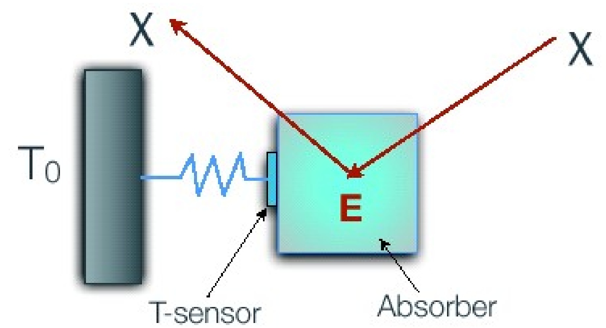
ANAIS: 112 kg @ Canfranc
→ background ~2-3x DAMA

COSINUS R&D: *EPJ C 76, 441 (2016)*
NaI with bolometric+light readout

Cryogenic Detectors

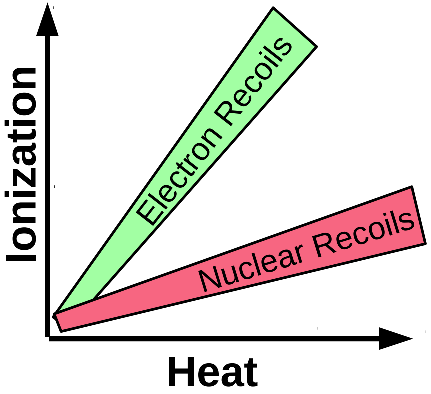
measure charge and heat (phonons) in crystals:
E deposition → temperature rise *ΔT*

→ requires detecors at mK temperatures



Crystals: **Ge**, (**Si)** cooled to few mK
– low heat capacity
– Δ*T* ~ µK   (→ TES)

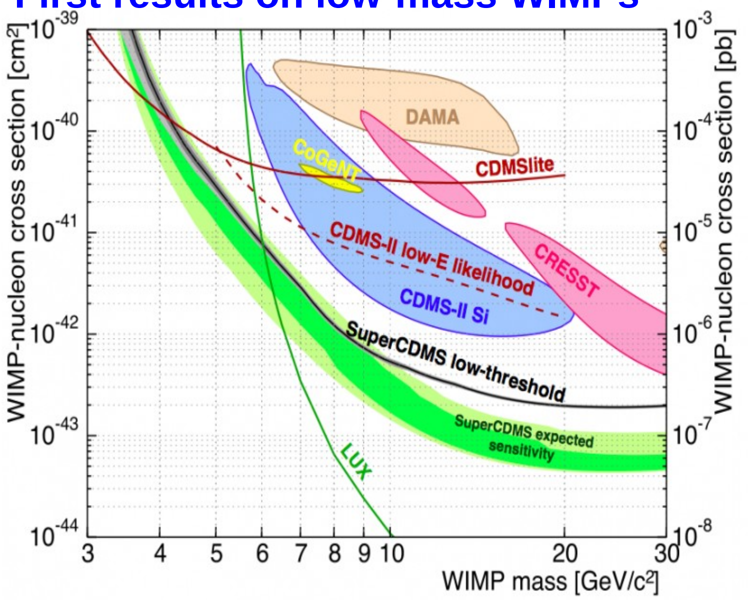
Very good discrimination
→ BUT: need to reject surface events



SuperCDMS @ SNOLAB

- selected by NSF-DOE downselection
- ~50 kg (upgrade to 400 kg possible)
- low threshold
  → focus on 1-10 GeV/c² mass range
- deeper lab, better materials & shield, improved resolution, electronics, ...
- 100 x 33.3 mm IZPs (1.4 kg Ge, 0.6 kg Si)

First results on low-mass WIMPs

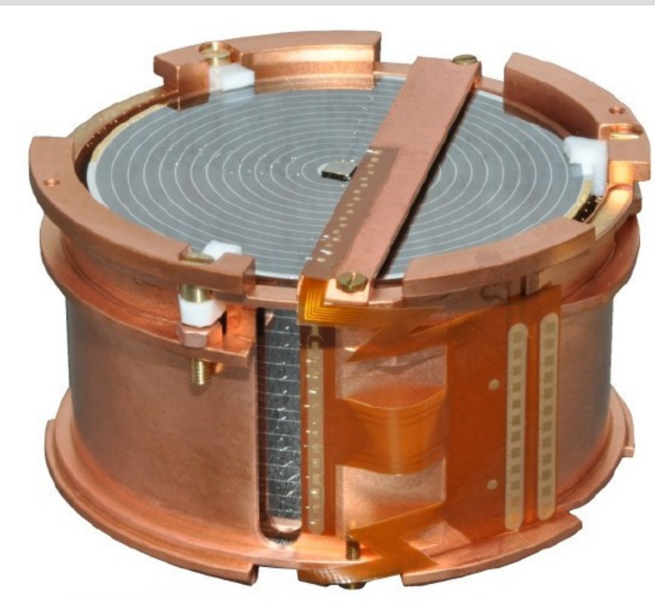


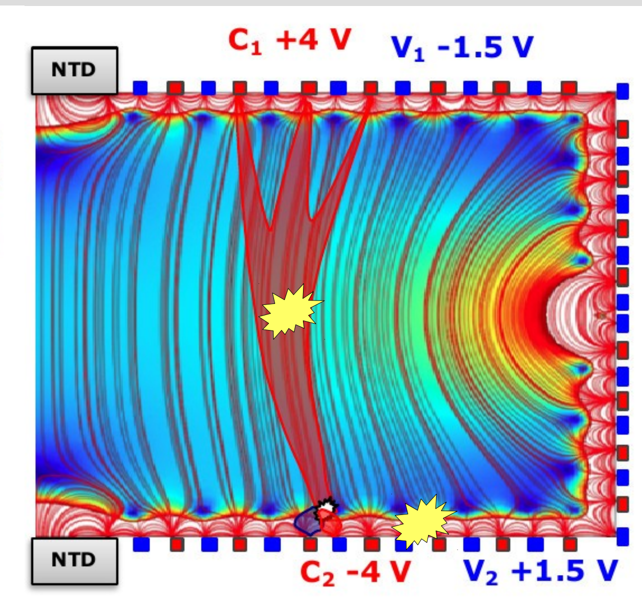
PRL 112, 241302 (2014)

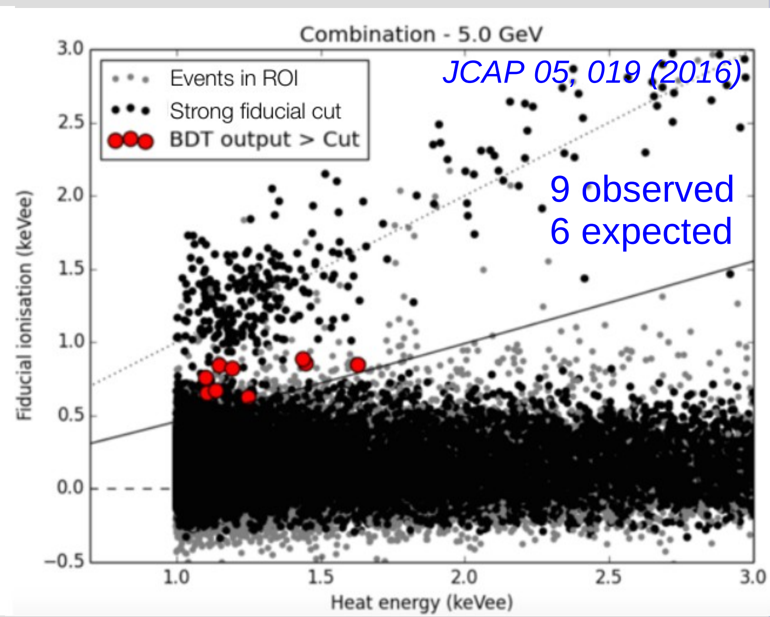
Sensitivity Study: *arXiv:1610.00006*

EDELWEISS-III

- operating 20 kg of Ge detectors in Modane Lab (F)
- 800 g Ge crystals measure ionization and heat (NTD sensors)
  → apply small voltage to extract charge
- interdigitized electrodes: fiducialization (~600 g)
- simultaneous measurement allows for NR/ER discrimination





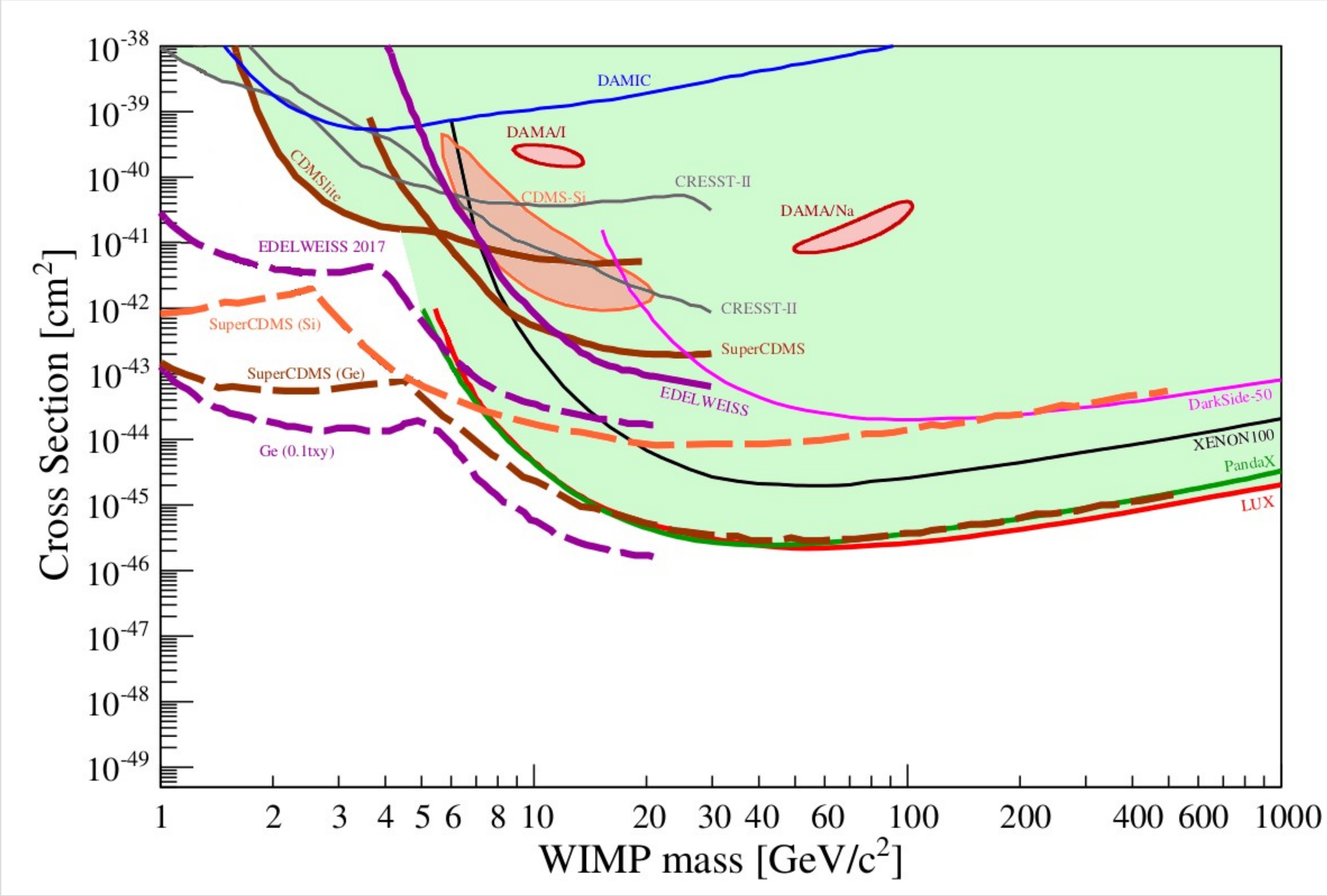


- new **low-threshold result**: 8 detectors with lowest thresholds (2.5–20 keVnr)
  → no statistically significant excess
  → 40× better limit than EDW-II @ 5 GeV/c²

BDT: JCAP 05, 019 (2016)
PL: EPJ C 76, 548 (2016)

Ge / Si: Status and Prospects

spin-independent WIMP-nucleon interactions

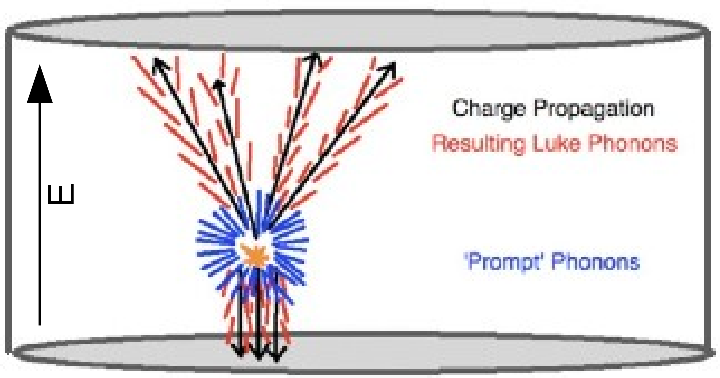


some projects are missing...

Very low WIMP masses

very low threshold for sensitivity to very low-mass WIMPs:
amplify signal → HV operation: **Neganov-Luke effect** to amplify charge signal

convert work done by E-field on e^--hole pairs to phonons



$$E_{tot} = E_r + E_{luke} = E_r + n_{eh} e V_b = E_r \left(1 + \frac{eV_b}{\epsilon_{eh}}\right)$$

bias voltage (V_b)

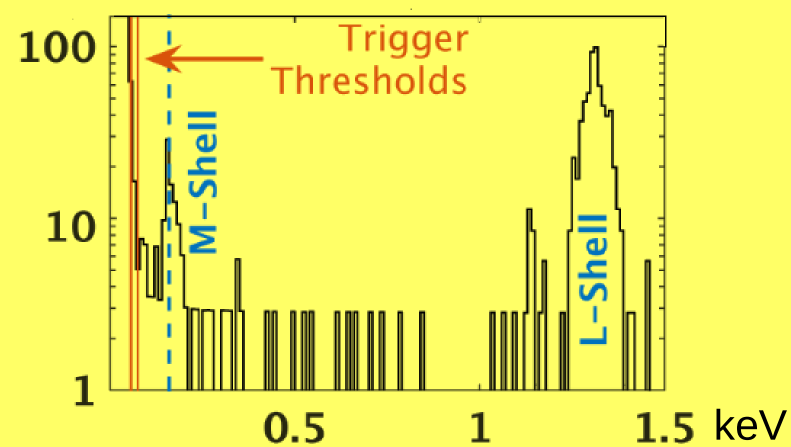
initial recoil (E_r)

3 eV/pair (ϵ_{eh})

EDELWEISS plans:
2017:
350 kg×d in HV mode
afterwards:
join forces with CDMS

SuperCDMS plans:
2018-20: construction
2020: begin data taking

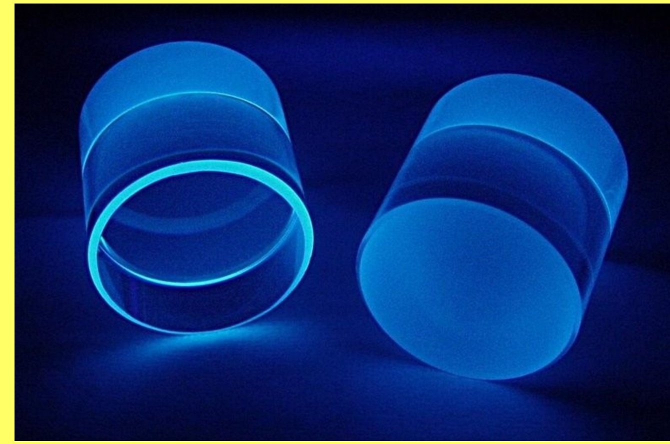
CDMSlite *PRL 116, 071301 (2016)*
- 625 g iZIP detector, 70 kg×d exposure
- V_b=69 V, **56 eV$_{ee}$ threshold!** 14 eV$_{ee}$ resolution
- no ionization measured
  → no ER rejection

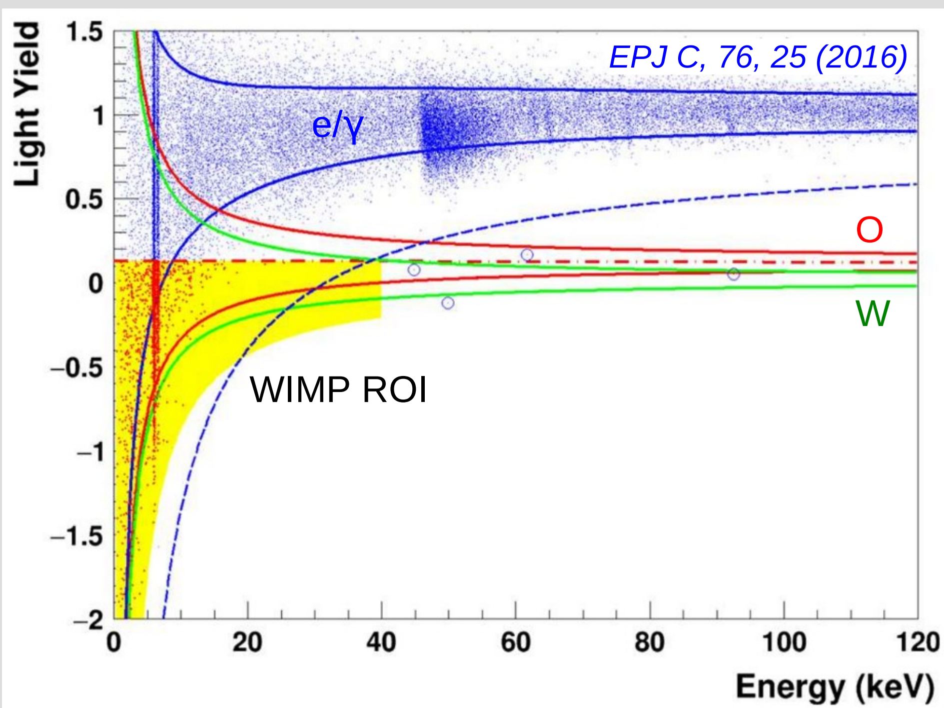


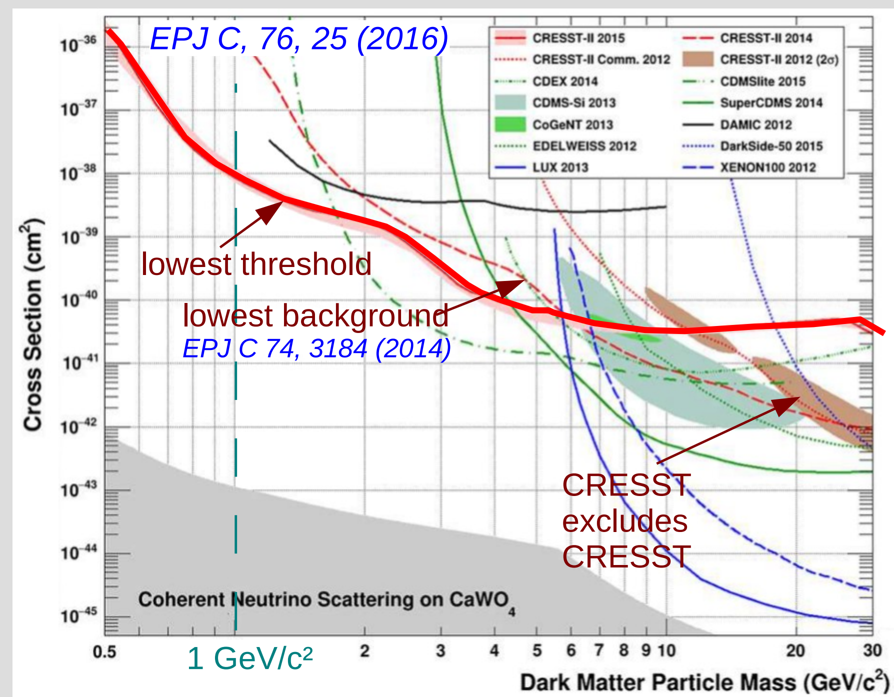
CRESST: the low-mass record

CRESST-II @ LNGS

- read phonons and scintillation light
- target: **$CaWO_4$** → multi-element material
- successful background reduction; data taking 2013-2015, 52 kg×d
- **new result** *EPJ C, 76, 25 (2016)* detector with **300 eV_{nr}** threshold







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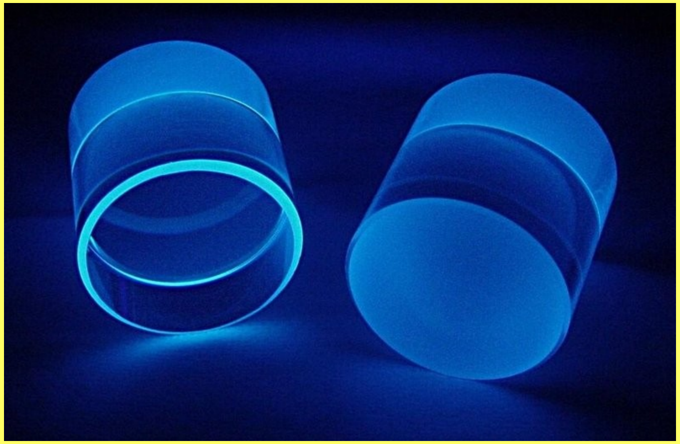


CRESST-III: lower threshold to 100 eV_{nr}

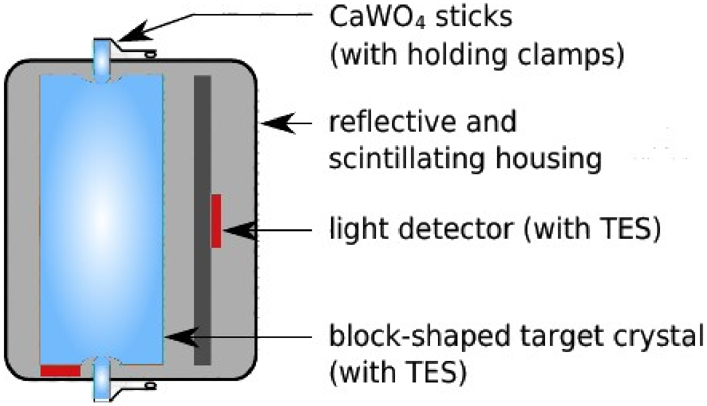
arXiv:1503.08065

- smaller crystals (250 g → 24 g)
- all-scintillating detector design
  → avoid partial energy depositions
- improve signal-to-noise

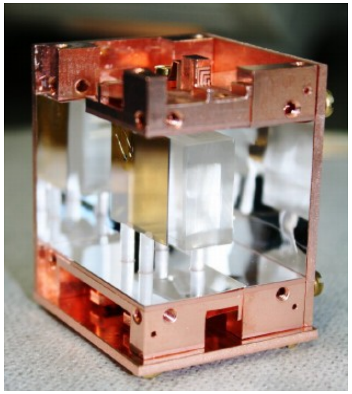
Status:

• Prototype exceeds design goal:
  50 eV_{nr} threshold

• commissioning and
  calibration started 2016

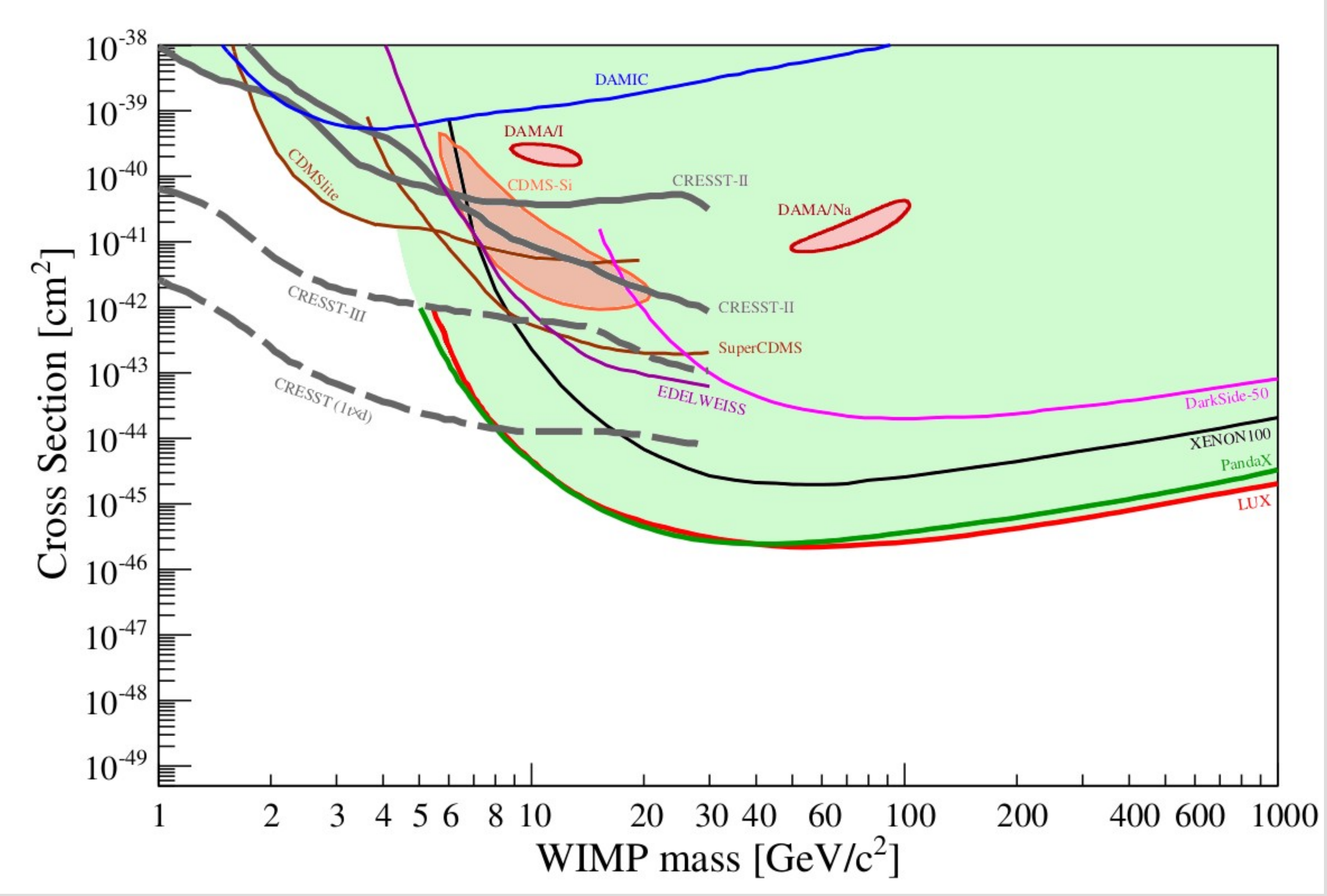


Reindl @ Lake Louise 2016



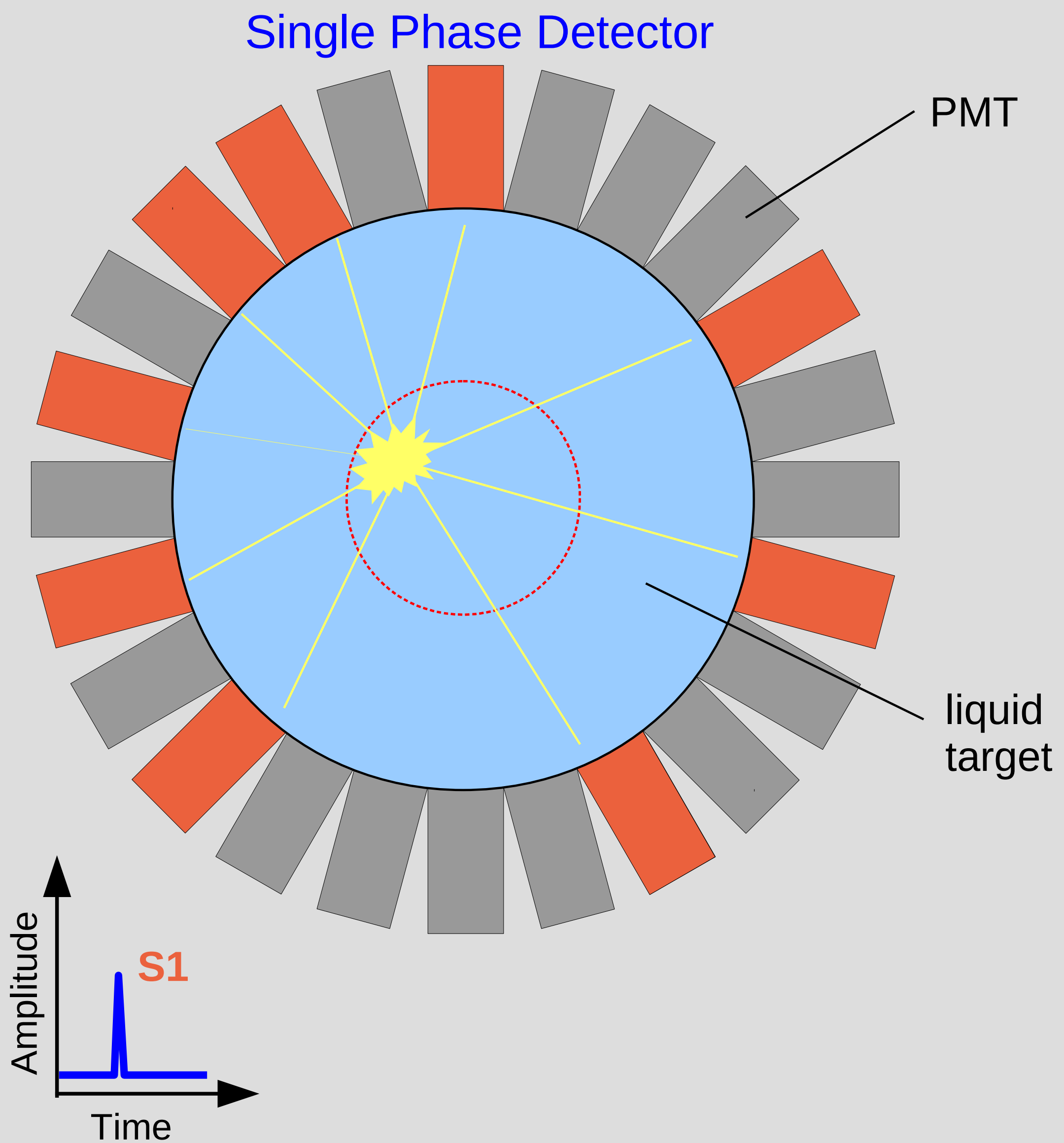
CRESST: Status and Prospects

spin-independent WIMP-nucleon interactions



some projects are missing...

Liquid Noble Gases: Detector Concepts



+ no high voltage, very high light yield

– O(cm) resolution, no double scatter rejection

Noble Gas: Single Phase Detectors

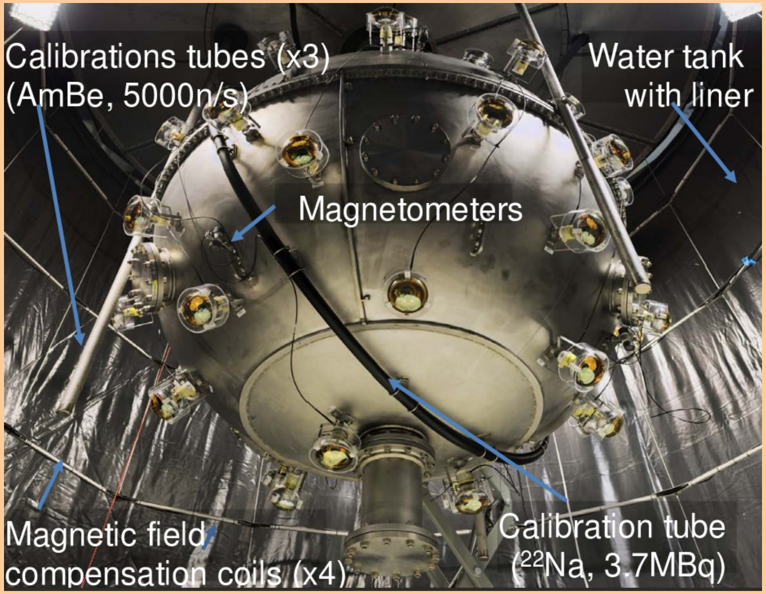
XMASS @ Kamioka (JP) **LXe**

– **832 kg** LXe target, 642 PMTs
– very high light yield, low threshold (0.5 keV_{ee})
BUT: **no possibility to reject NRs**
– many results: summary: *arXiv:1506.08939*

– background reduced after commissioning run
→ stable data taking since >2 years
– plans towards XMASS-1.5t and XMASS-II (24t)

DEAP-3600 @ SNOLAB (CA) **LAr**

– **light pulse-shape for discrimination**
3×10^{-8} achived in 43-86 keV_{ee}
→ prediction: 10^{-10} above 15 keV_{ee} in DEAP-3600
– **3.6t** liquid argon target;
high ^{39}Ar background when using ^{nat}Ar (~1 Bq/kg)
– data taking right now... high light yield,
→ results expected in spring 2017
– sensitivity: 1×10^{-46} cm² @ 100 GeV/c²



F. Retiere (LIDINE 2015)

Noble Gas: Single Phase Detectors

XMASS @ Kamioka (JP) — LXe

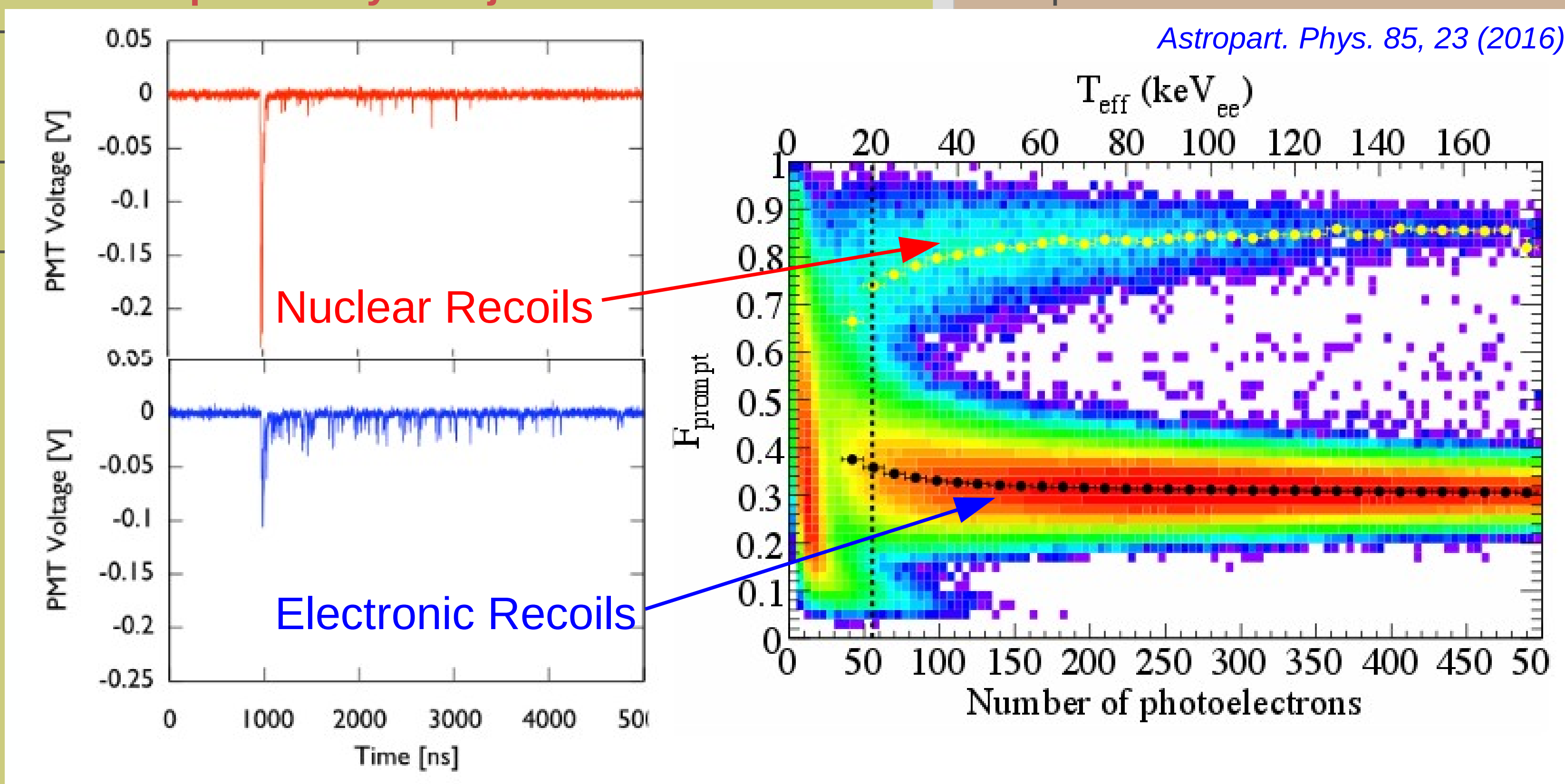
- 832 kg LXe target, 642 PMTs
- very high light yield, low threshold (0.5 keVee)
  BUT: **no possibility to reject NRs**

DEAP-3600 @ SNOLAB (CA) — LAr

- **light pulse-shape for discrimination**
  3×10^{-8} achived in 43-86 keVee
  → prediction: 10^{-10} above 15 keVee in DEAP-3600

g ^{nat}Ar (~1 Bq/kg)

n LAr...
GeV/c²



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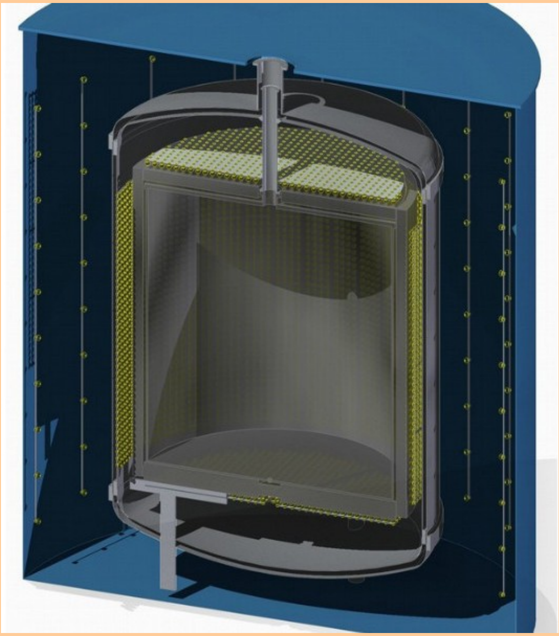
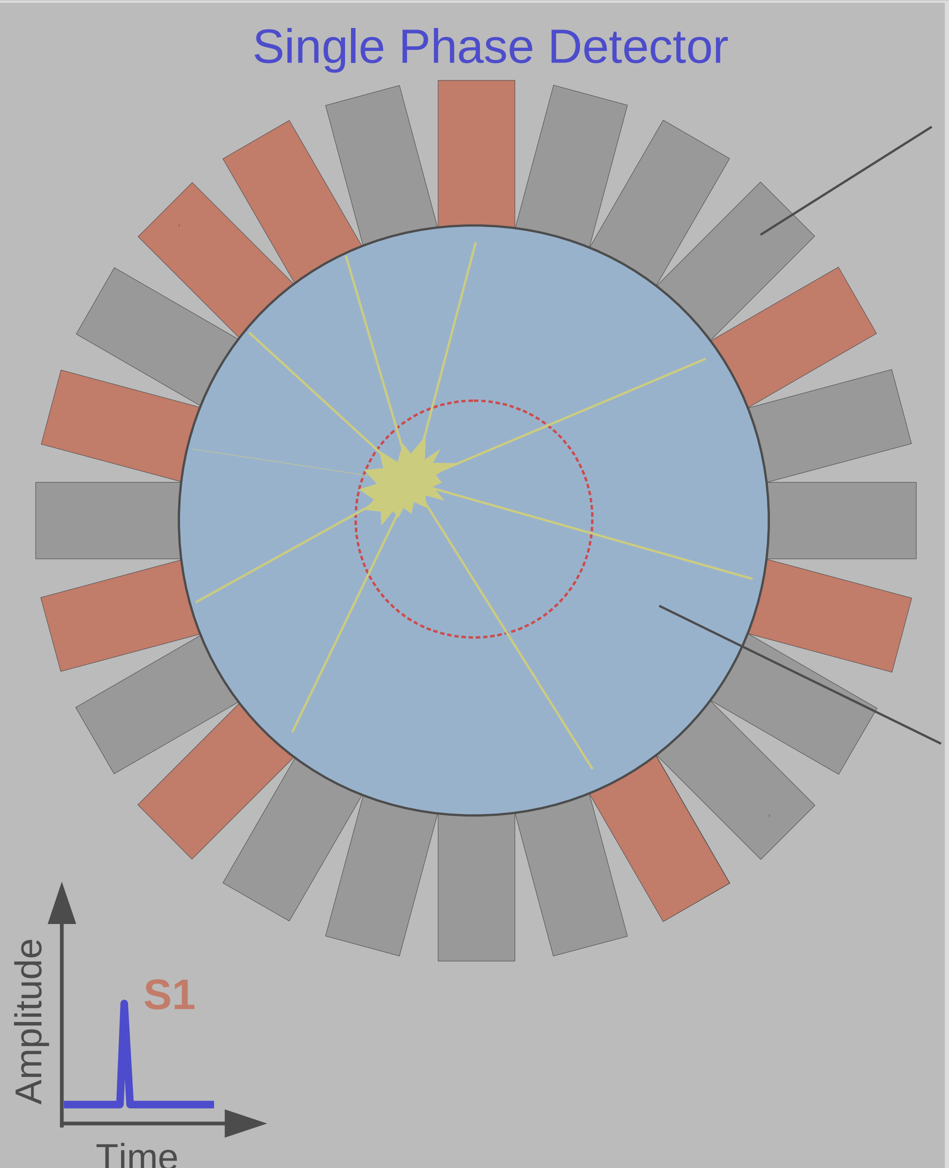
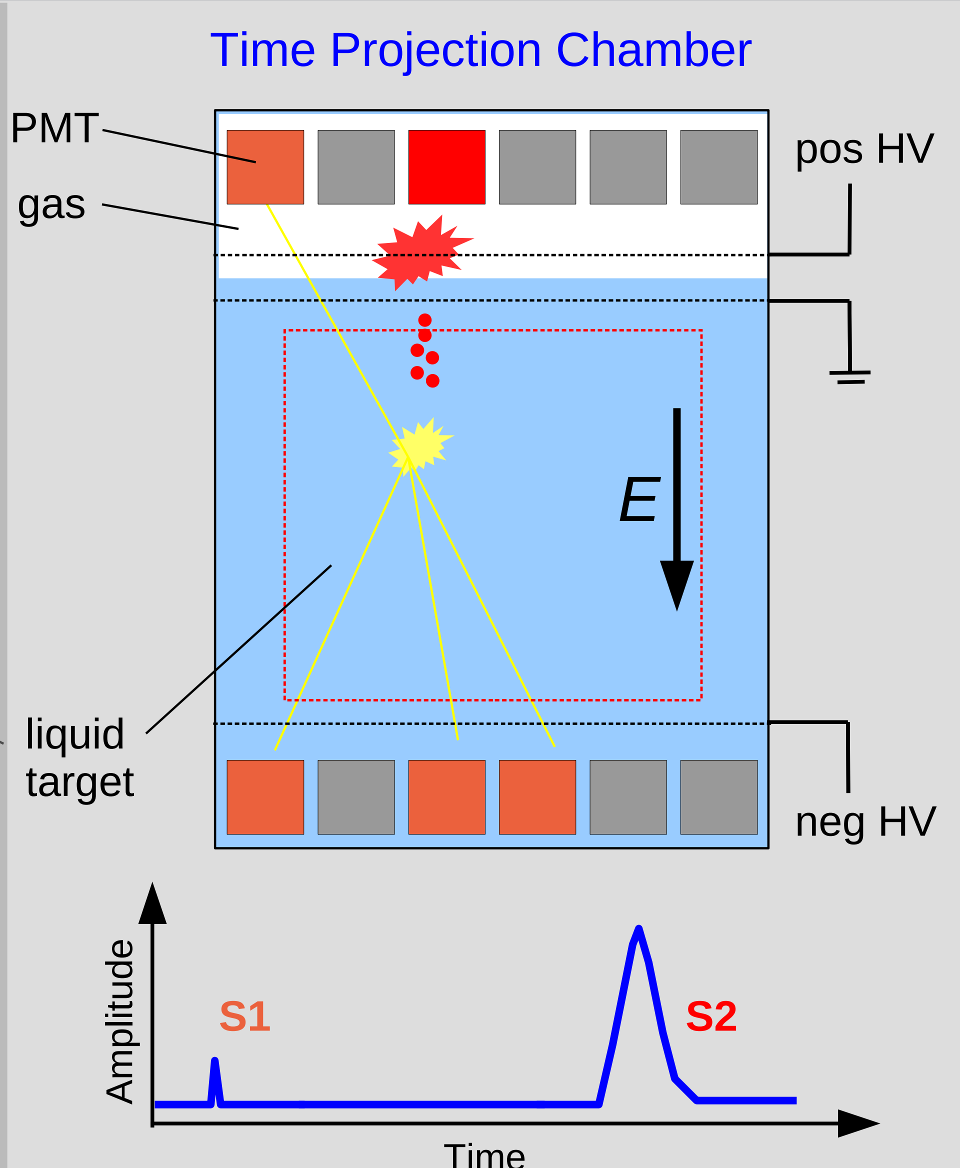
M. Kuzniak (IDM 2016)



future:
DEAP-50T
150t target
50t fiducial
→ 150 m² photo-coverage!

Liquid Noble Gases: Detector Concepts

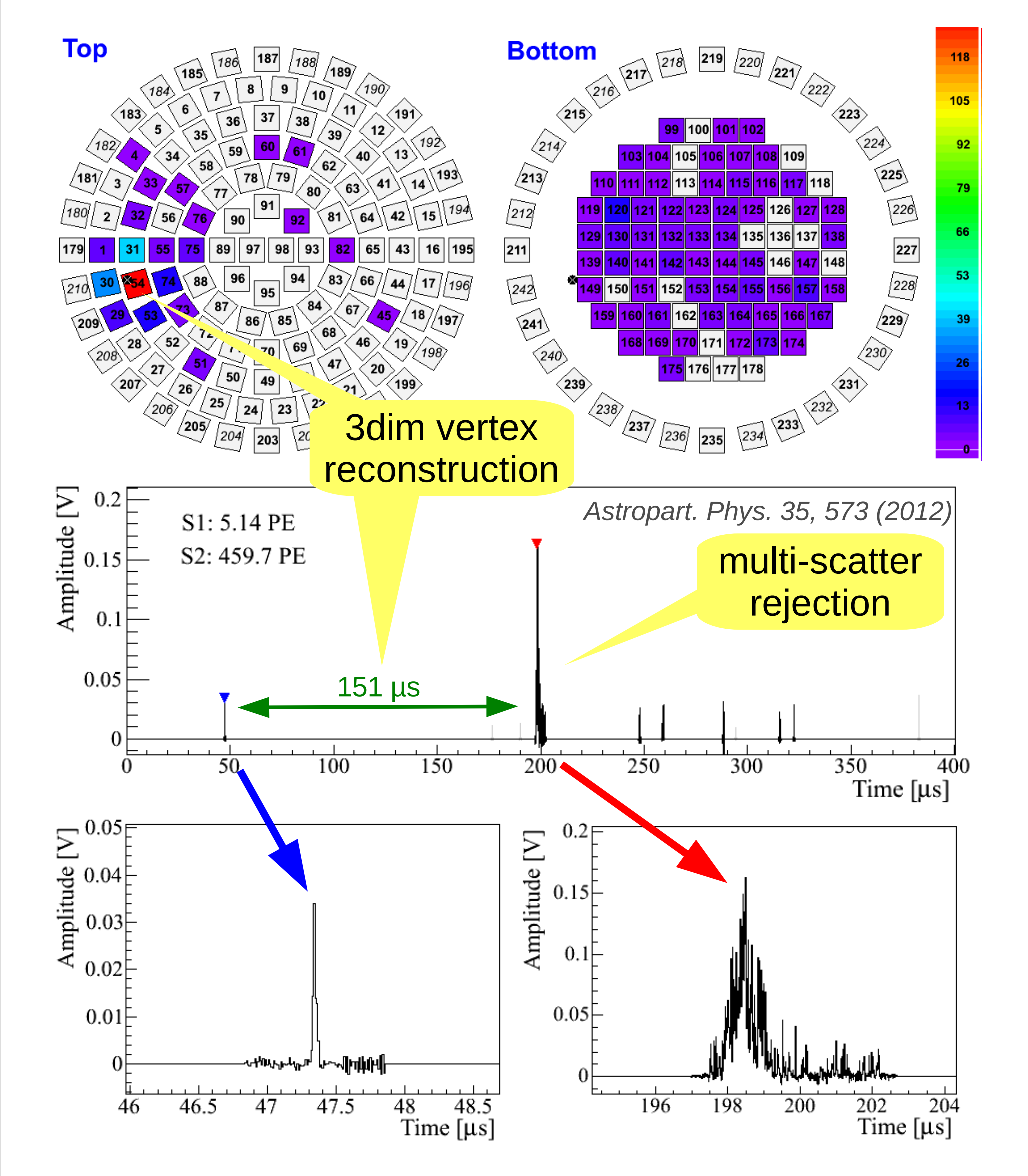


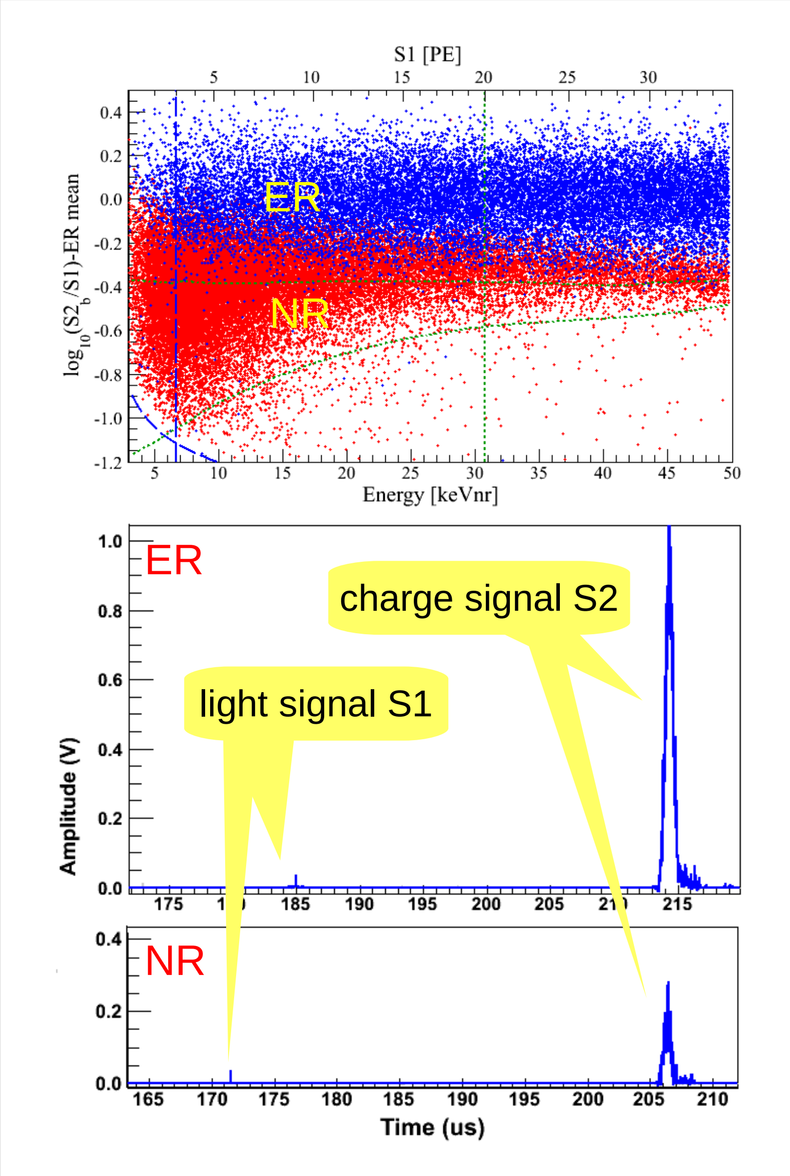


+ no high voltage, very high light yield
– O(cm) resolution, no double scatter rejection

+ O(mm) resolution, S2/S1 NR rejection
– technical challenges (HV), less light

Dual Phase TPC





Figures from XENON100

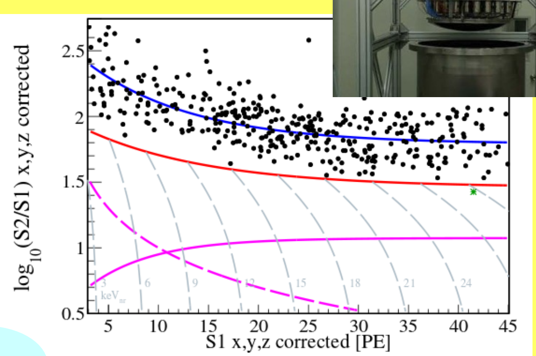
Existing dual phase detectors

LXe

PandaX-II @ CJPL (CN)
PRL 117, 121303 (2016)

- 60cm×60cm, **500 kg** target
- 2nd largest operational LXe TPC

New result July 2016:
- combines data from 2 runs (^{85}Kr differs by factor 10)
- 3.3×10^{4} kg×d = 0.1 t×y exposure
- no signal excess
- best limit above ~4.5 GeV/c²
- still taking data aim for 2 years of data

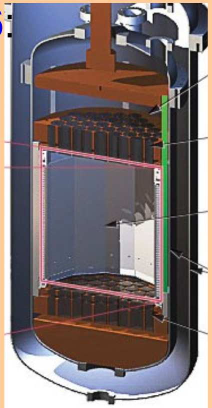


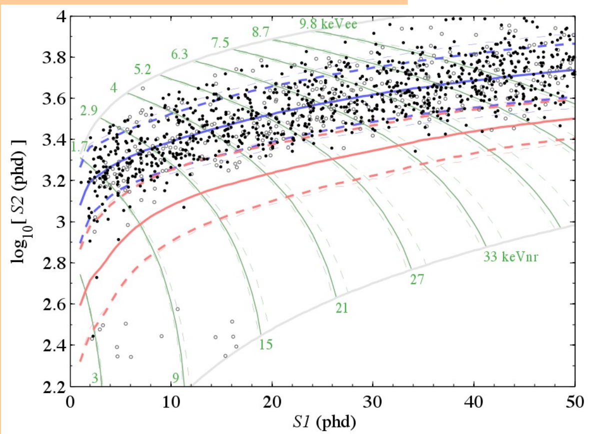
LXe

LUX @ SURF (USA)
PRL 118, 021303 (2017)

- 48cm×48cm, **251 kg** target
- in-situ NR calibration studies *arXiv:1608.05381*

New result July 2016:
- 332d exposure: 3.4×10^{4} kg×d = 0.1 t×y
- no signal excess
- 2.2×10^{-46} cm² @ 50 GeV/c²
- stopped

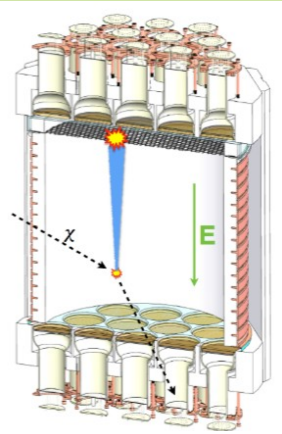


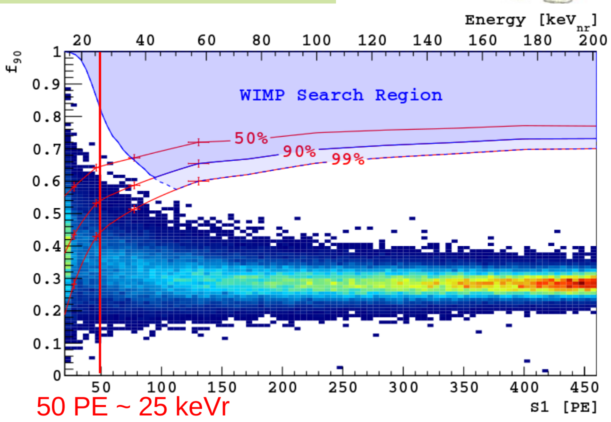


LAr

DarkSide-50 @ LNGS (IT)
PRD 93, 081101 (2016)

- **46 kg** LAr, which is ^{39}Ar-depleted by a factor 1400
- 71d×37kg exposure
- no event in ROI
- taking data





LXe

XENON100 @ LNGS (IT) **New:** 447 live days *PRD 94, 122001 (2016)* low-mass WIMPs *PRD 94, 092001 (2016)*

Existing dual phase detectors

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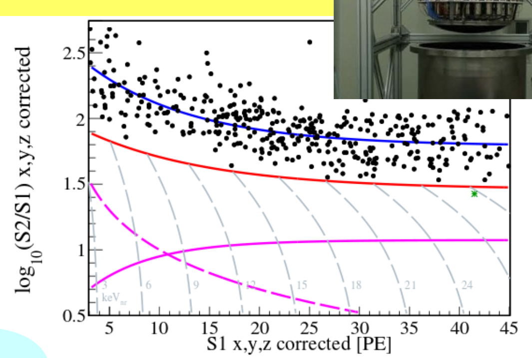

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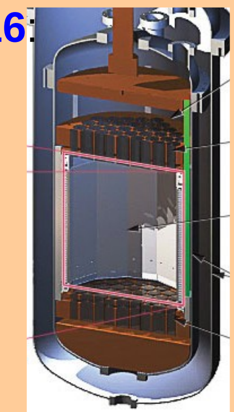
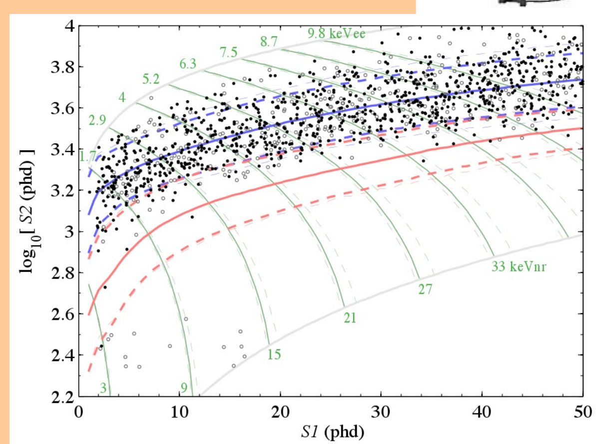
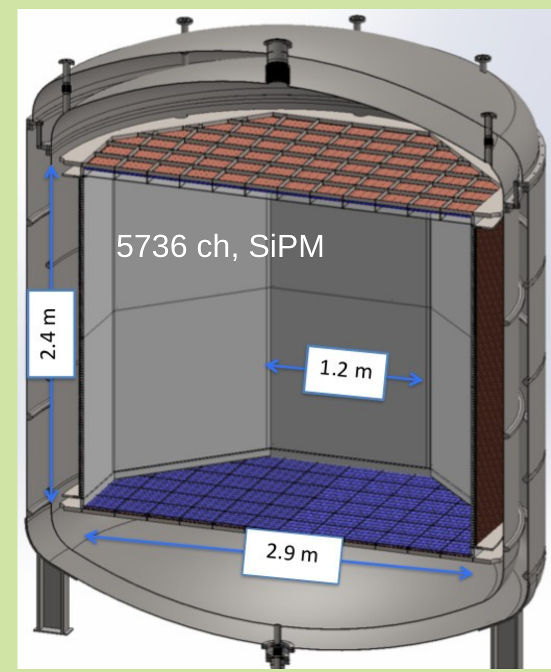




LAr

DarkSide-50 @ LNGS (IT)
PRD 93, 081101 (2016)

- **46 kg** LAr, which is ^{39}Ar-depleted by a factor 1400
- 71d×37kg exposure
- no event in ROI
- taking data
- proposal for **DarkSide-20k**
  → 30t depleted Ar needed



G. Fiorillo (IDM 2016)

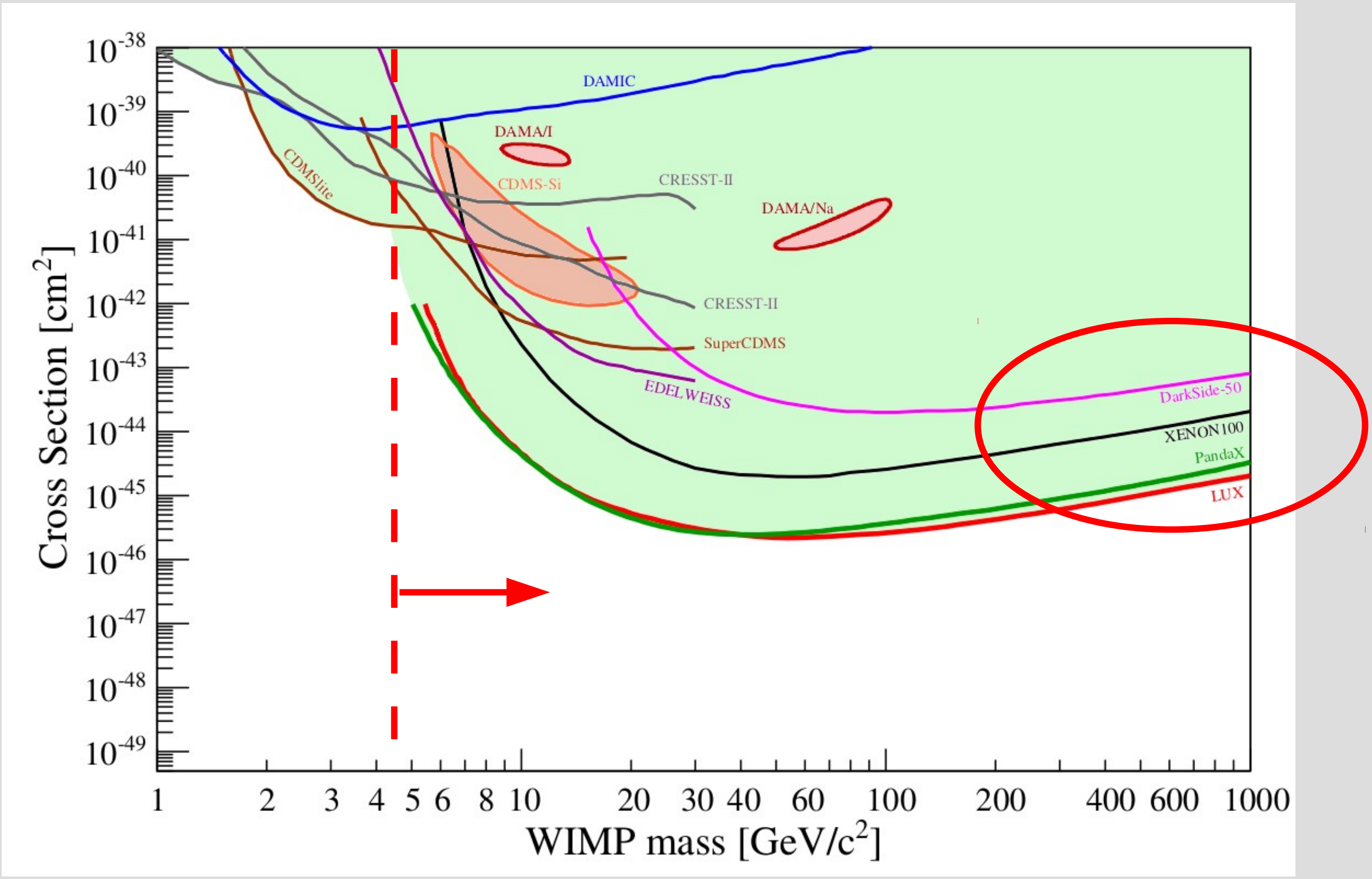
LXe

XENON100 @ LNGS (IT) **New:** 447 live days *PRD 94, 122001 (2016)* low-mass WIMPs *PRD 94, 092001 (2016)*

High WIMP-masses TPC dominated

≥4.5 GeV/c²

spin-independent WIMP-nucleon interactions

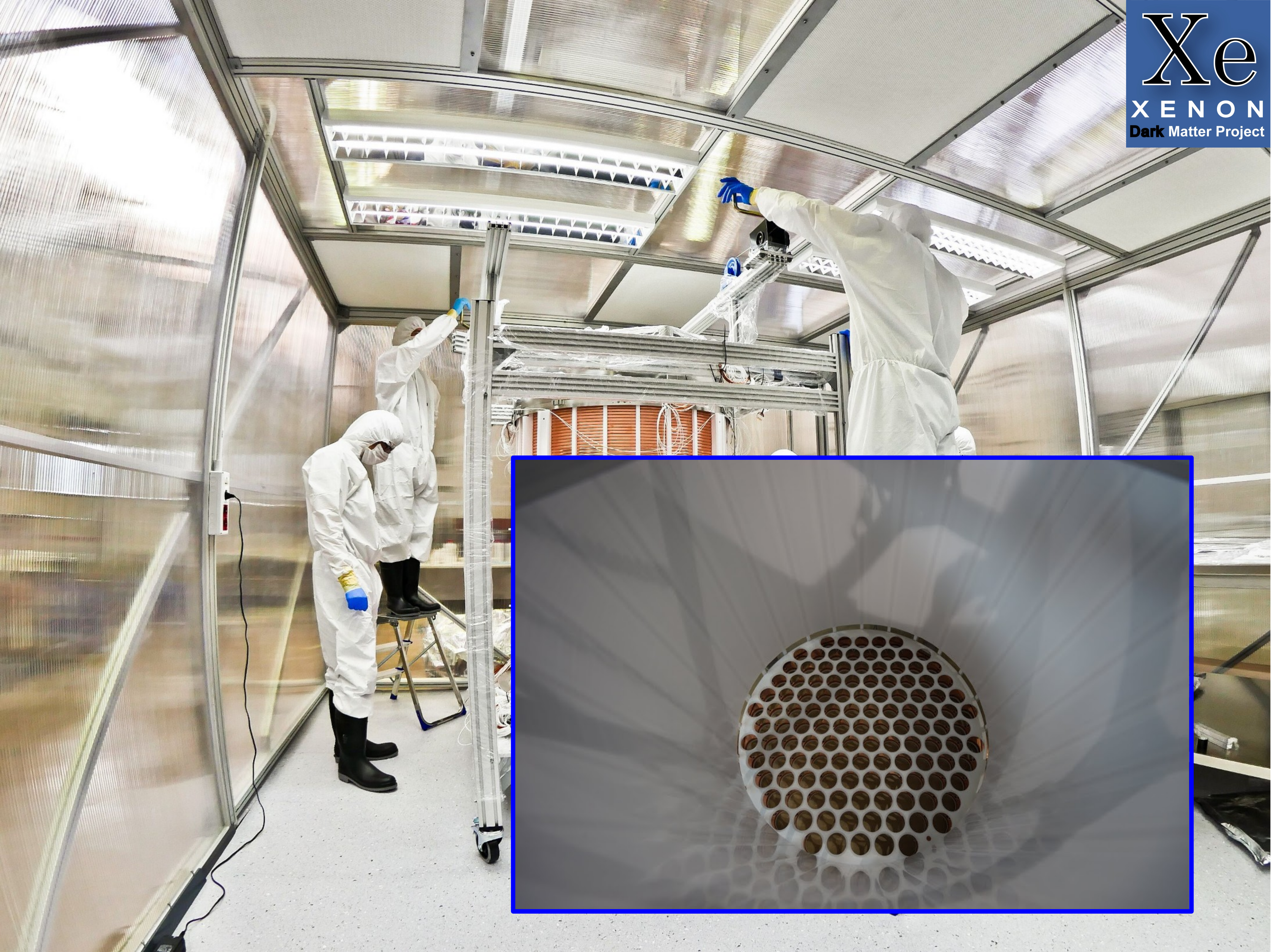


some projects are missing...

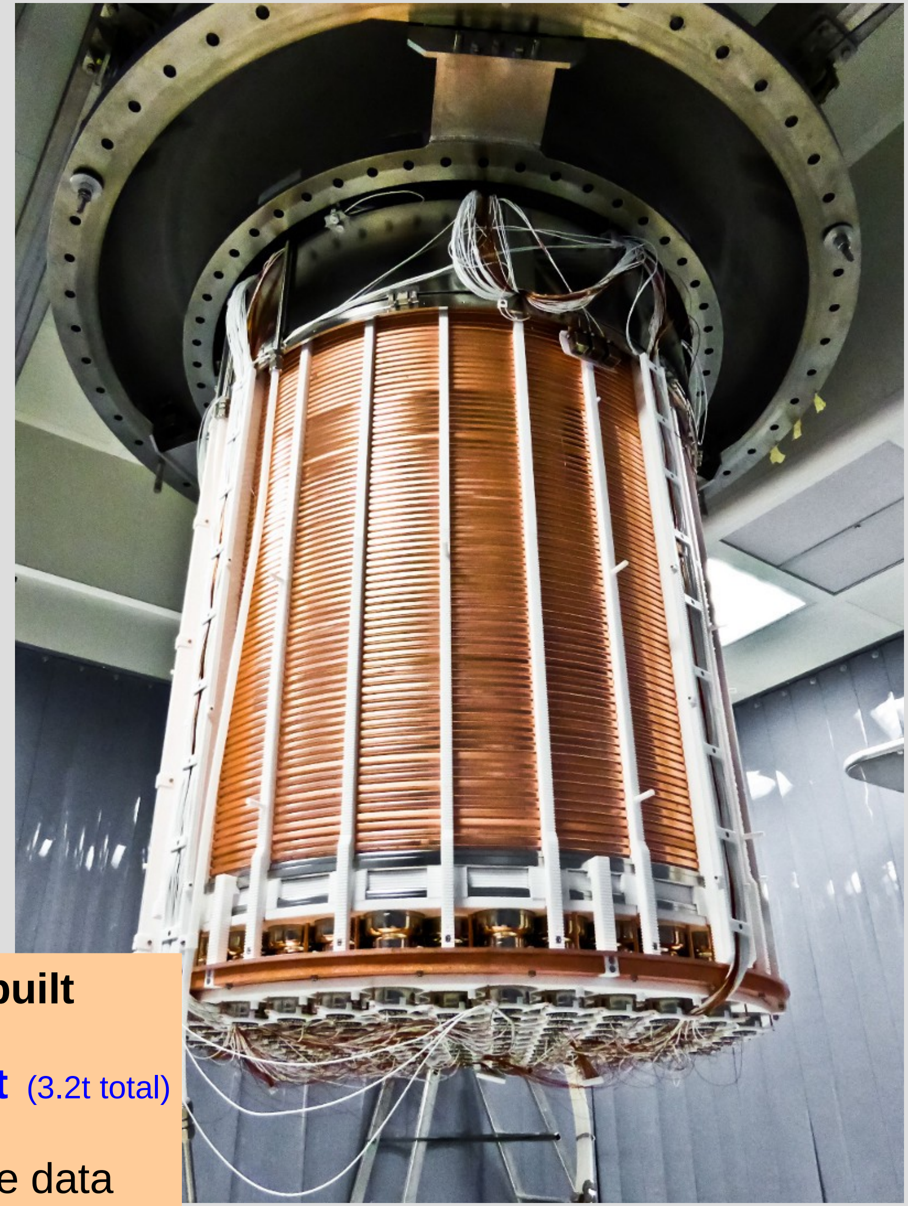
XENON1T @ LNGS

LXe

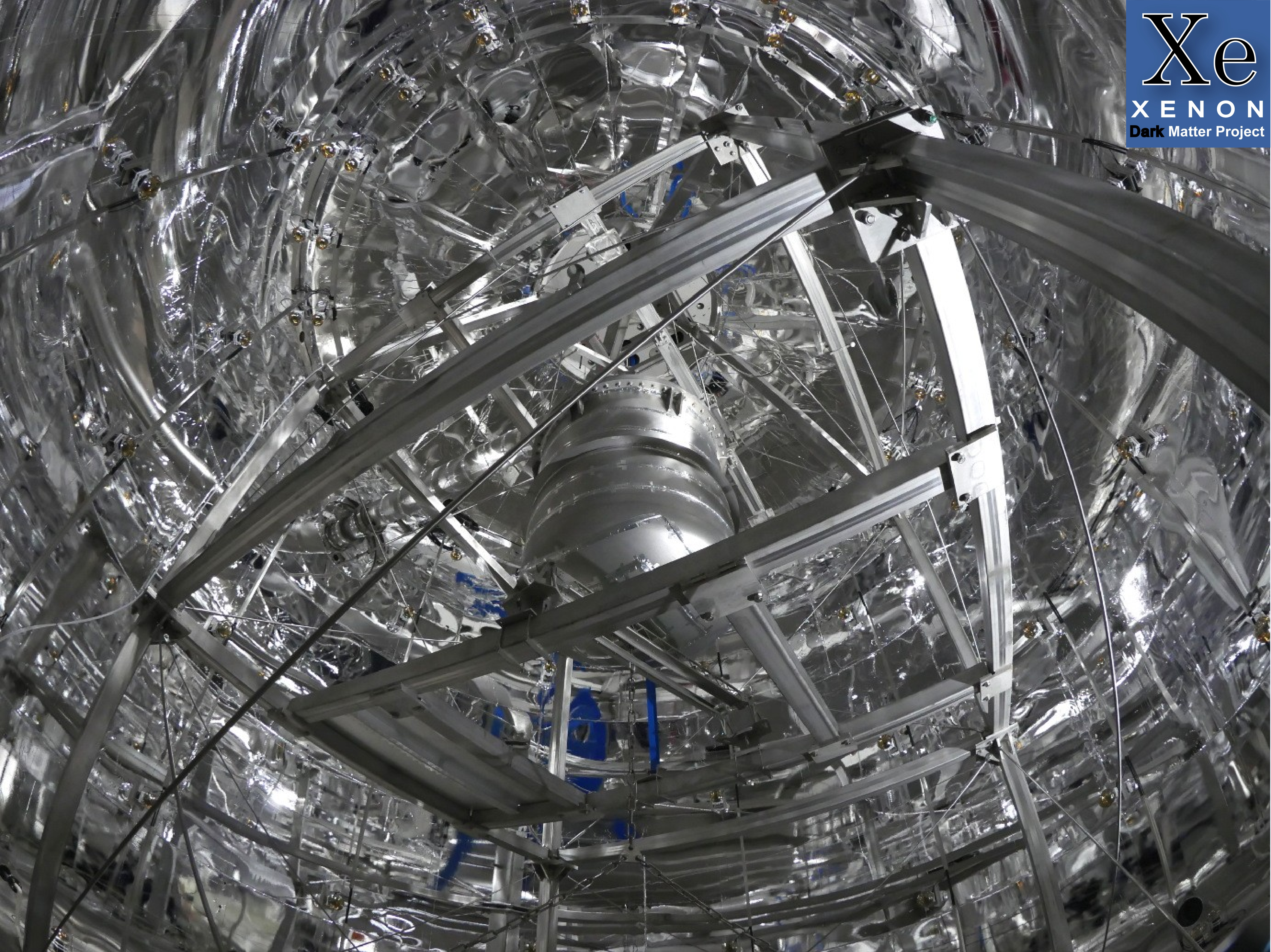

Xe
XENON
Dark Matter Project


Xe
XENON
Dark Matter Project

XENON1T

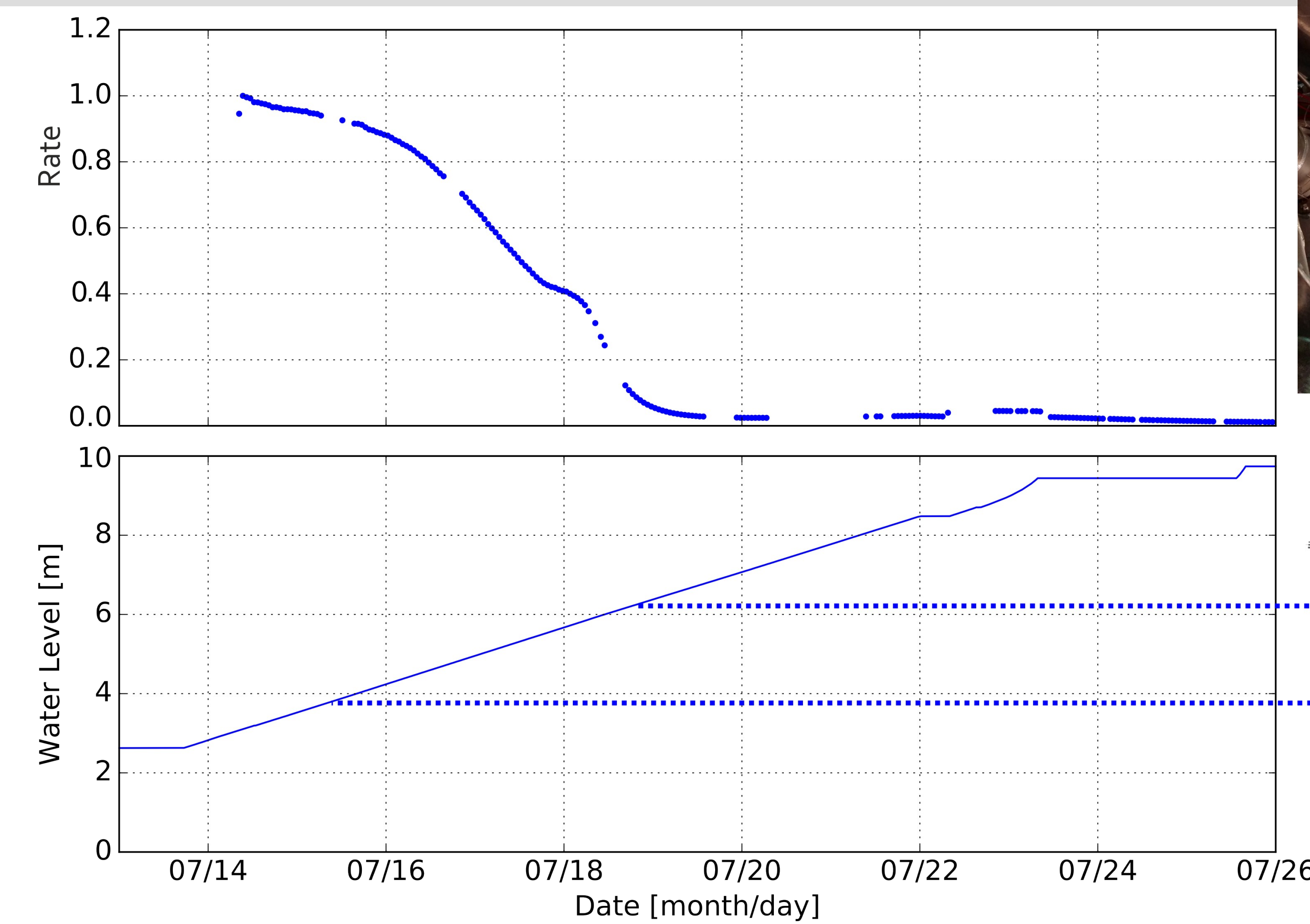


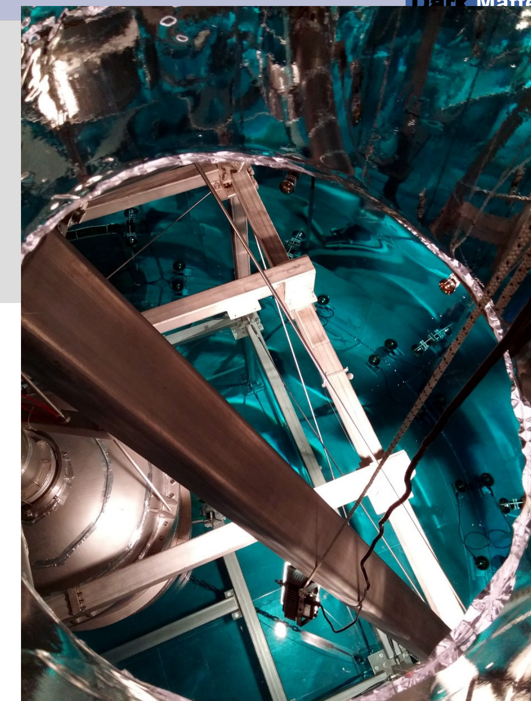
- **largest LXe TPC ever built**
  cylinder: 96 cm
  active LXe target: 2.0t (3.2t total)
  248 PMTs
- operating: taking science data

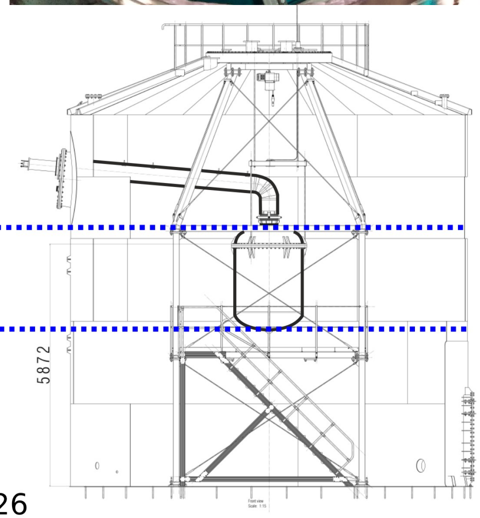

Xe
XENON
Dark Matter Project

XENON1T Performance

Water shield filled since Summer...



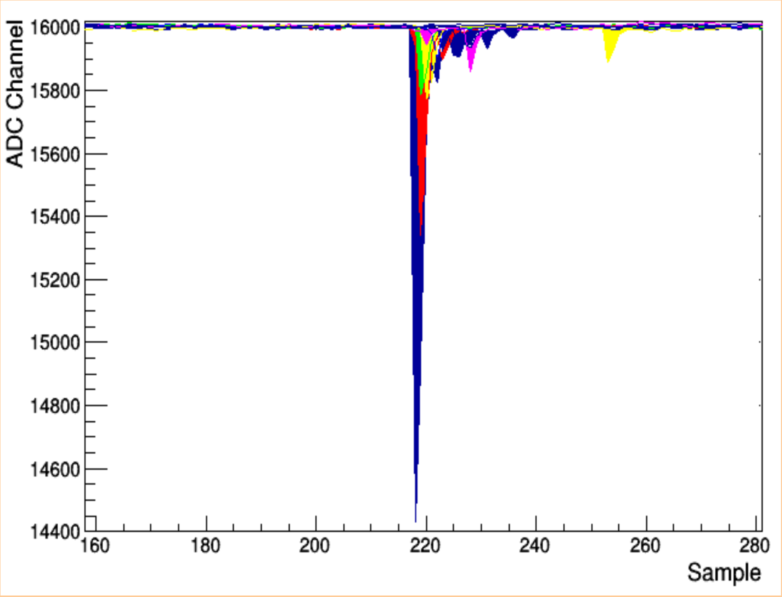


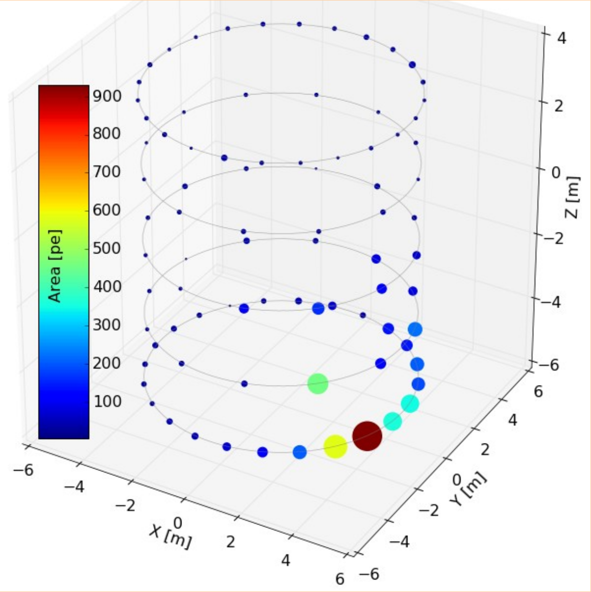


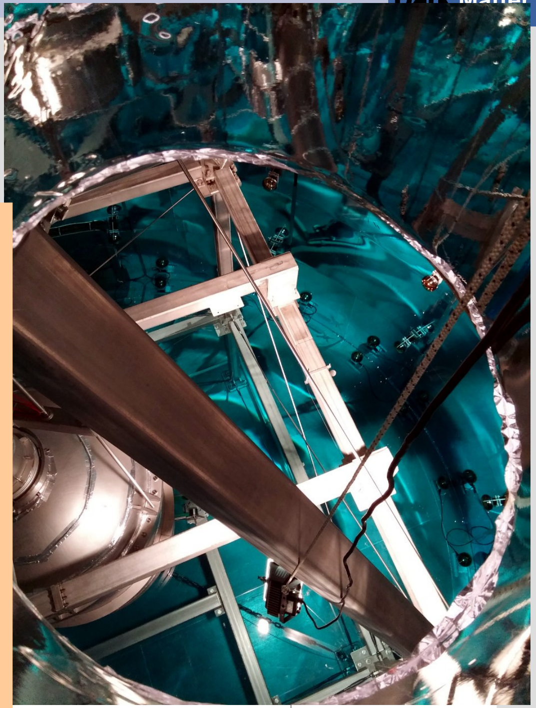
XENON1T Performance

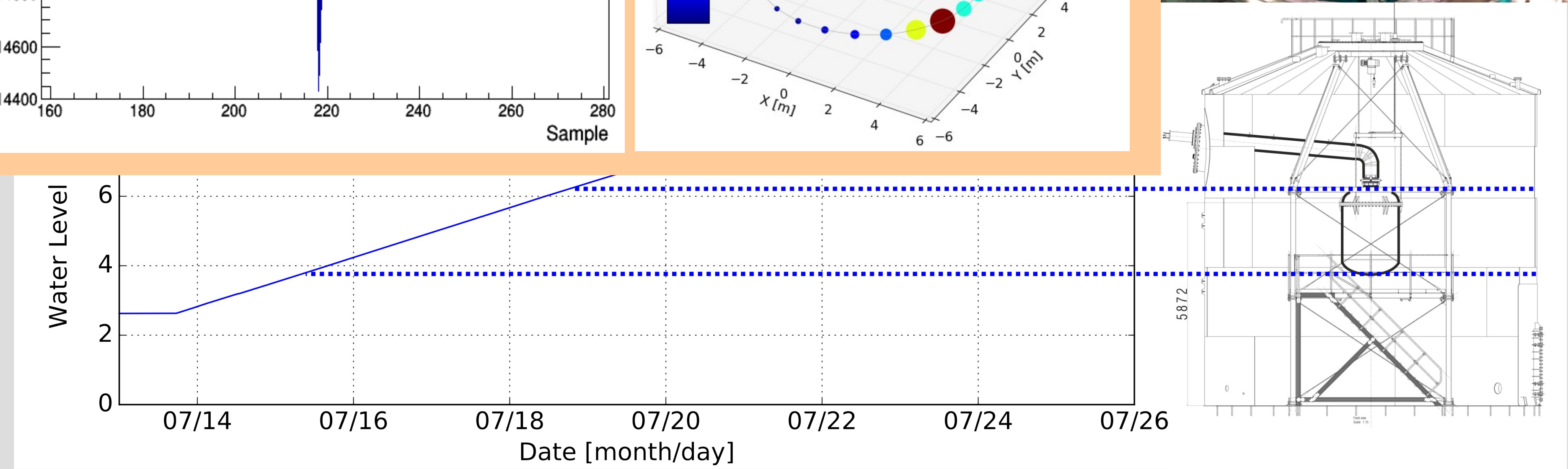
Water shield continuously filled since Summer...

Cerenkov detector sees muons...



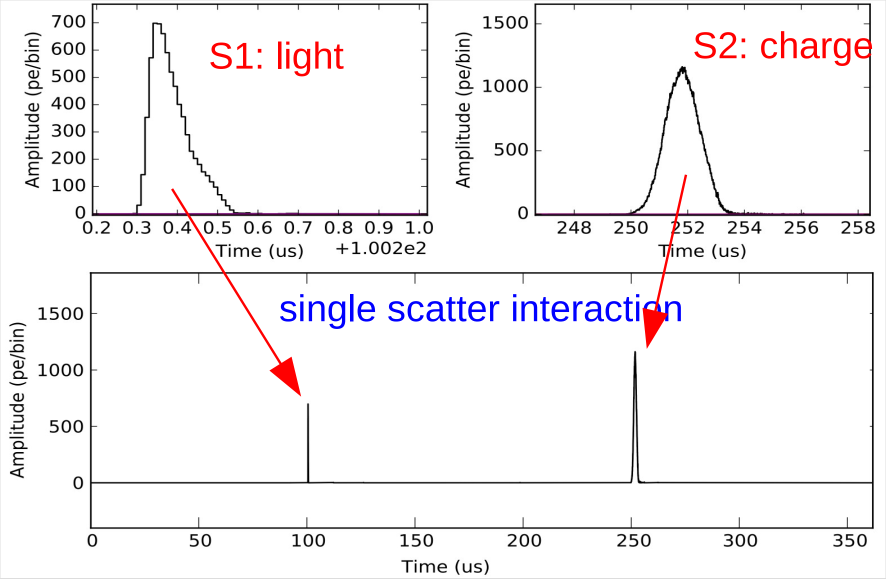


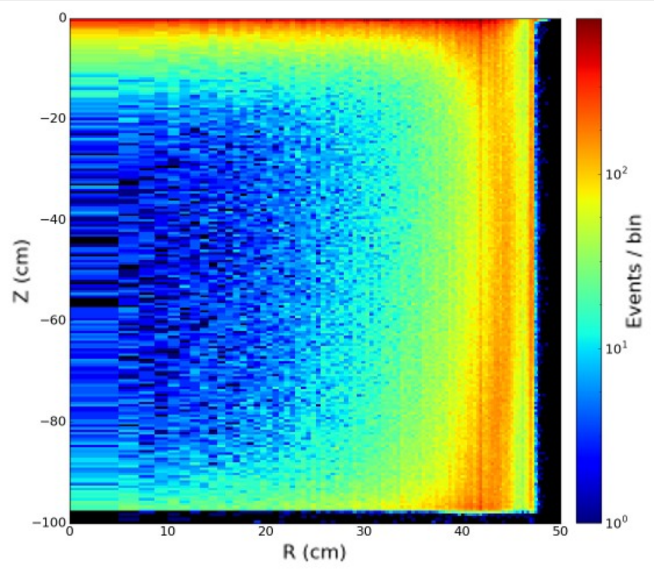




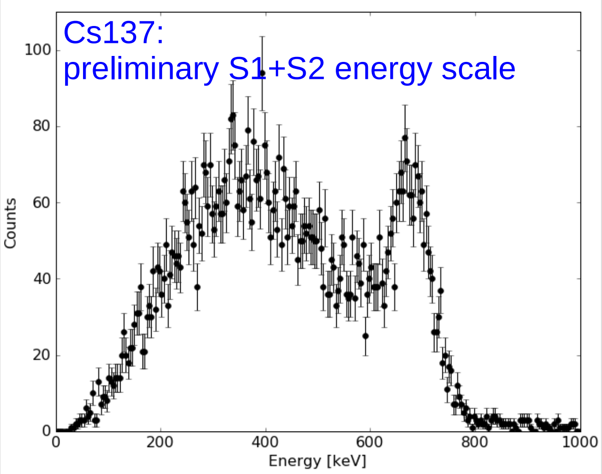
XENON1T Performance

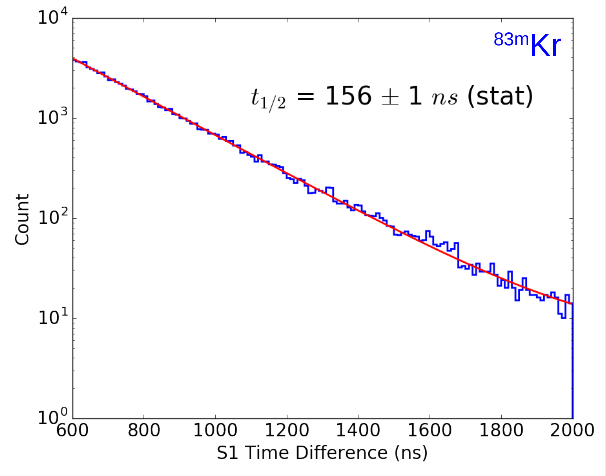
Recording light (S1) and light signals (S2) from the entire detector





Calibration: external (^{137}Cs, AmBe), internal (^{83m}Kr, ^{220}Rn)



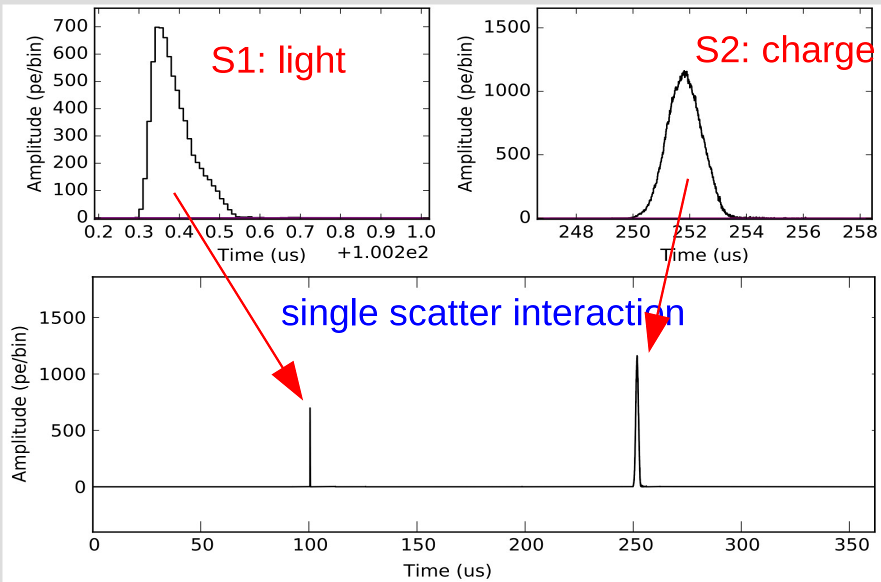


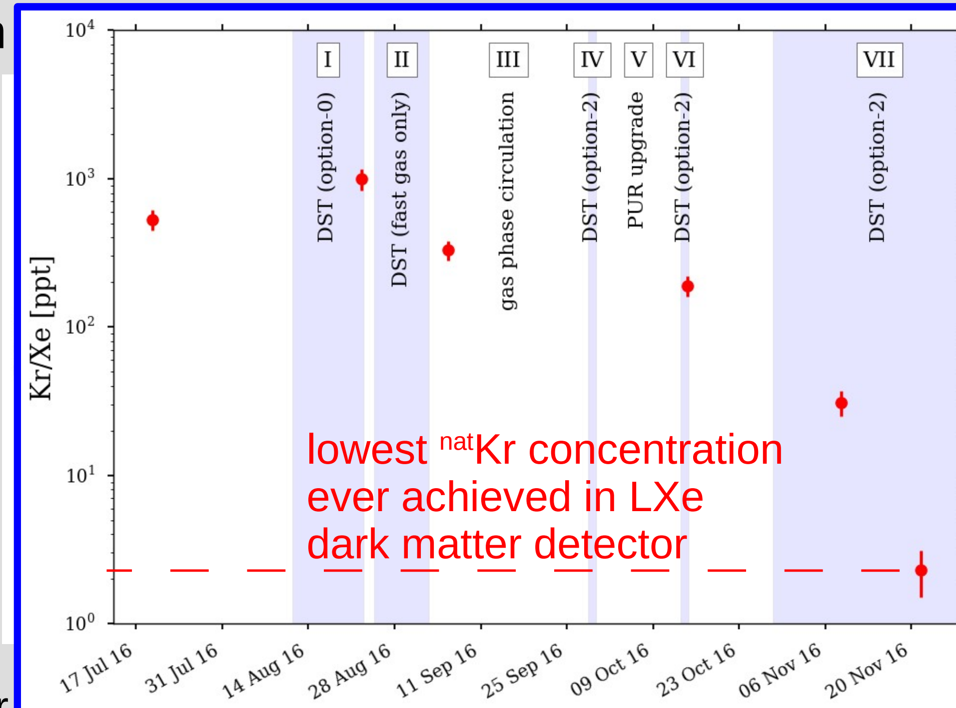
Backgrounds

- material background low, self-shielding effective
- ^{222}Rn background agrees with predictions
- online removal of ^{85}Kr via cryogenic distillation very successful

XENON1T Performance

Recording light (S1) and light signals (S2) from





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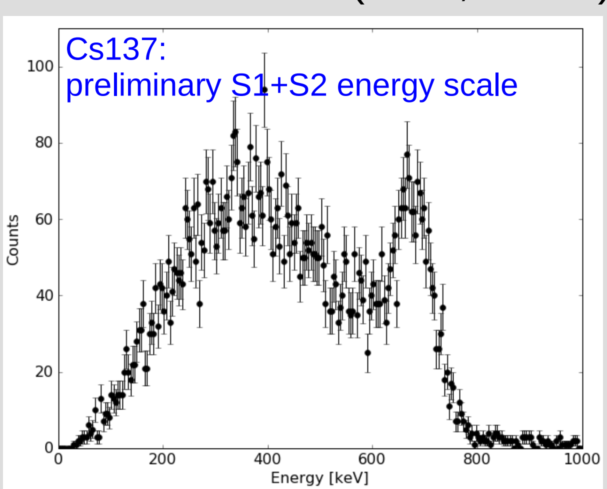

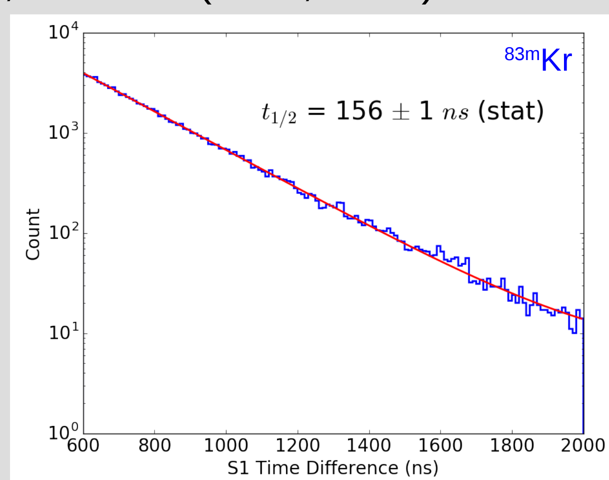

Backgrounds

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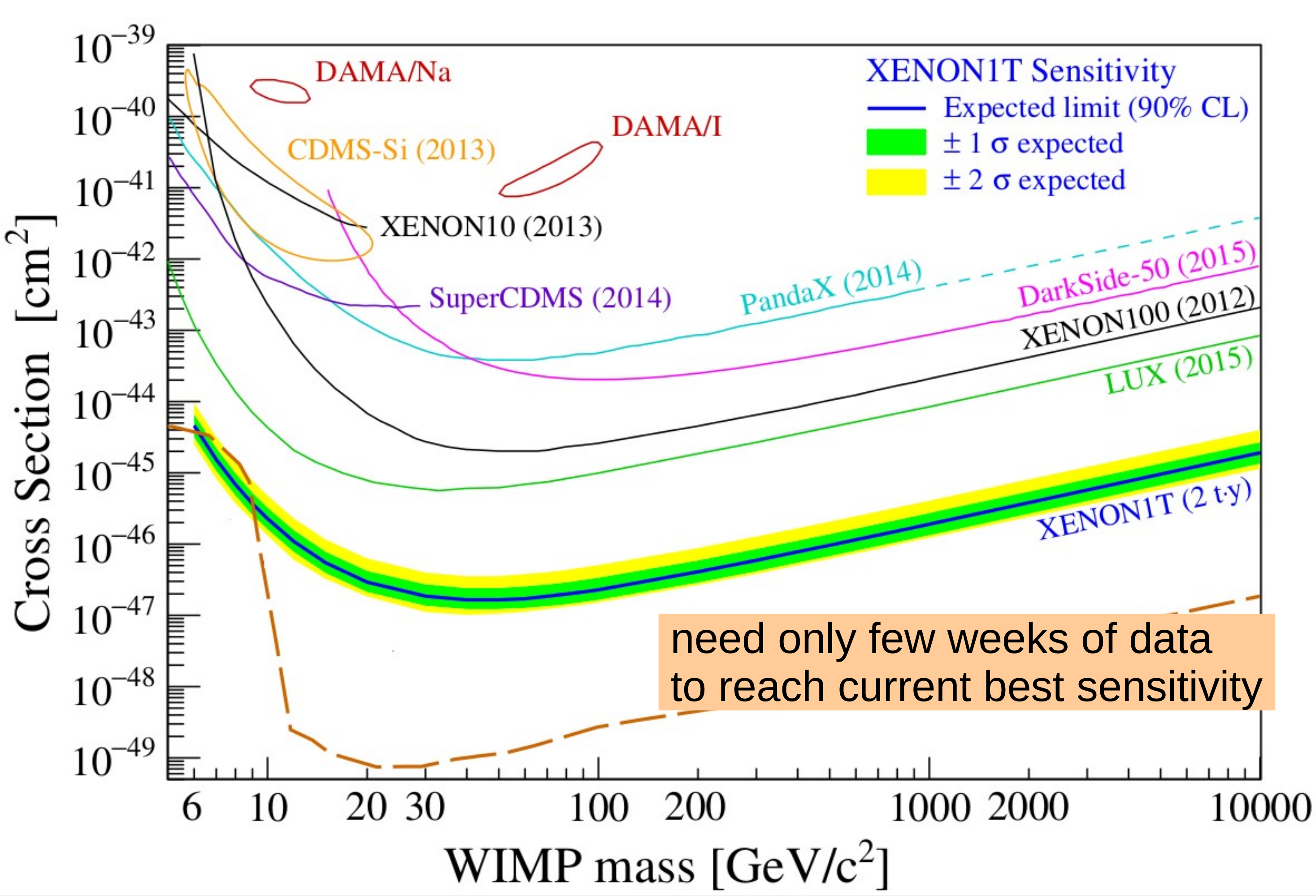
XENON1T Sensitivity

JCAP 04, 027 (2016)

based on detailed background predictions, 2 t×y exposure:



assumptions: energy interval: 4 – 50 keVr, ER rejection as XENON100: 99.5% @ 50% NR acc.
→ expected LY is 2x higher than in XENON100!

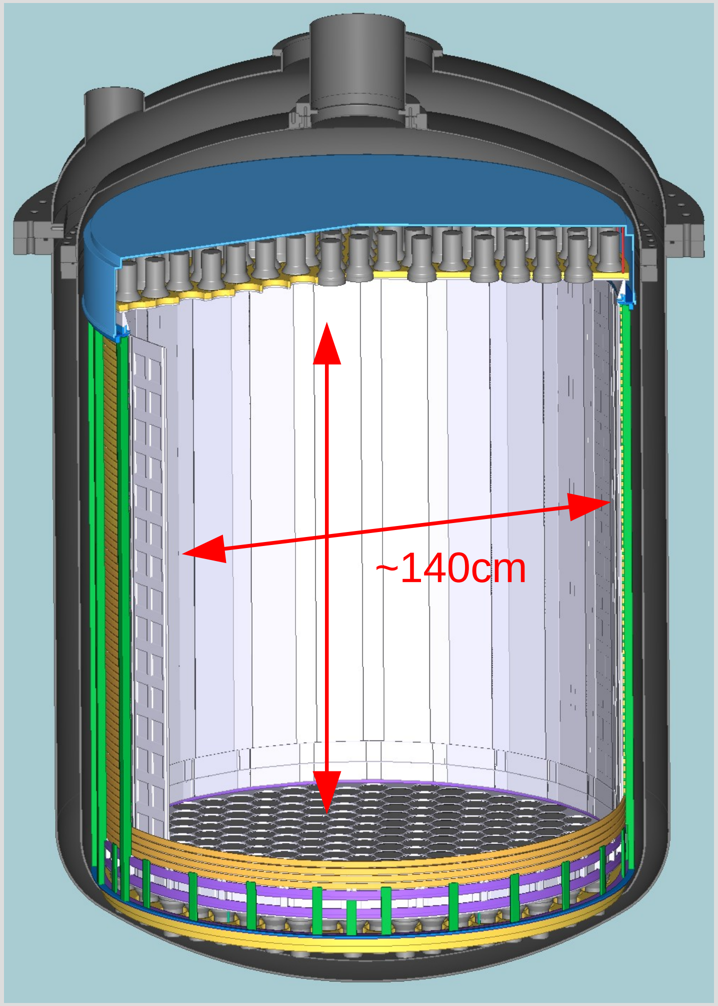
confirmed by measurement!

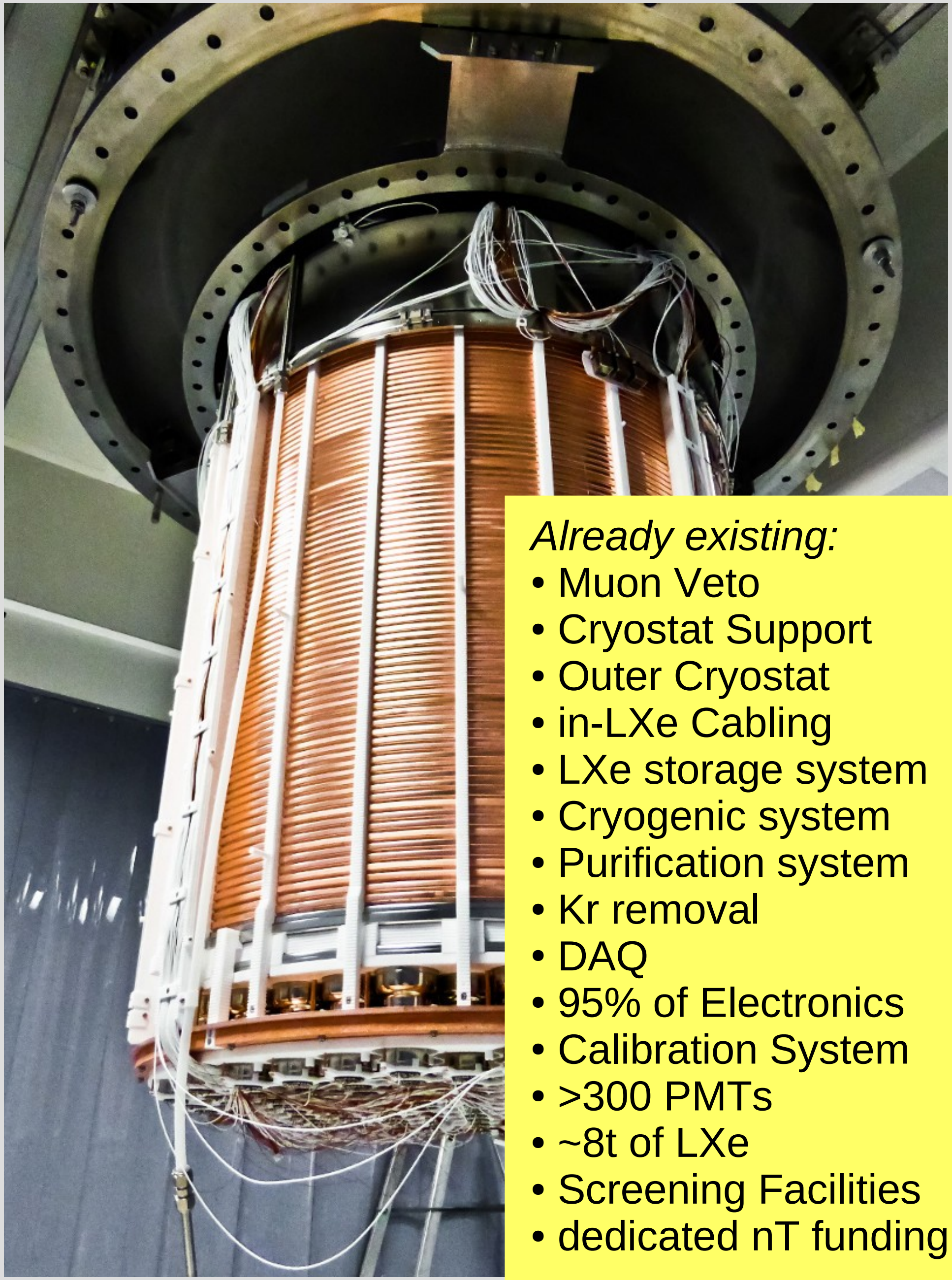
XENON1T → XENONnT

JCAP 04, 027 (2016)

XENON1T
- **2t** active LXe target
- operating
- science run started

XENONnT
- **6t** active target
- projected to start end of 2018





Already existing:
- Muon Veto
- Cryostat Support
- Outer Cryostat
- in-LXe Cabling
- LXe storage system
- Cryogenic system
- Purification system
- Kr removal
- DAQ
- 95% of Electronics
- Calibration System
- >300 PMTs
- ~8t of LXe
- Screening Facilities
- dedicated nT funding

LZ – LUX/ZEPLIN

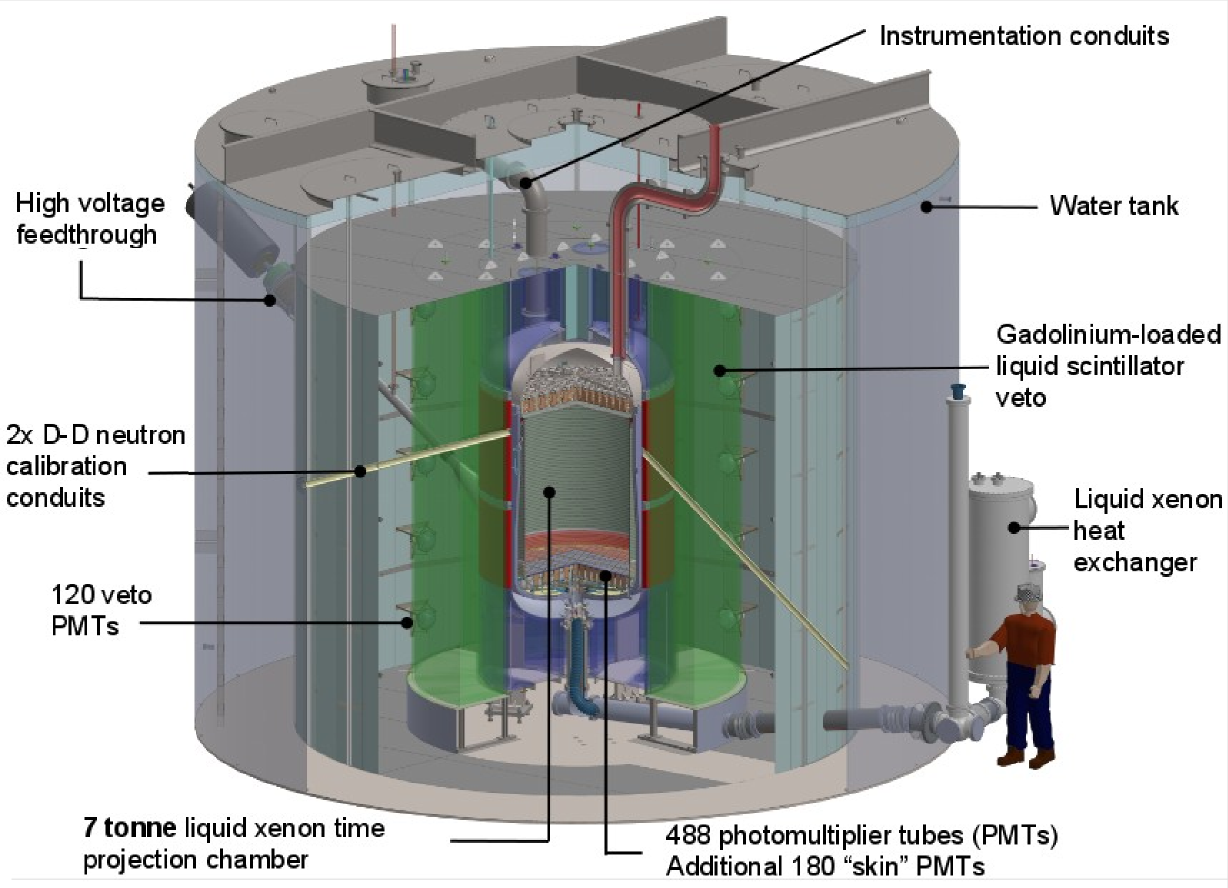
arXiv:1509.02910

LXe

- **LZ = LUX+ZEPLIN**
  selected by 2014
  US DOE-NSF downselection
- to be installed @ SURF (USA)
- 50× larger than LUX

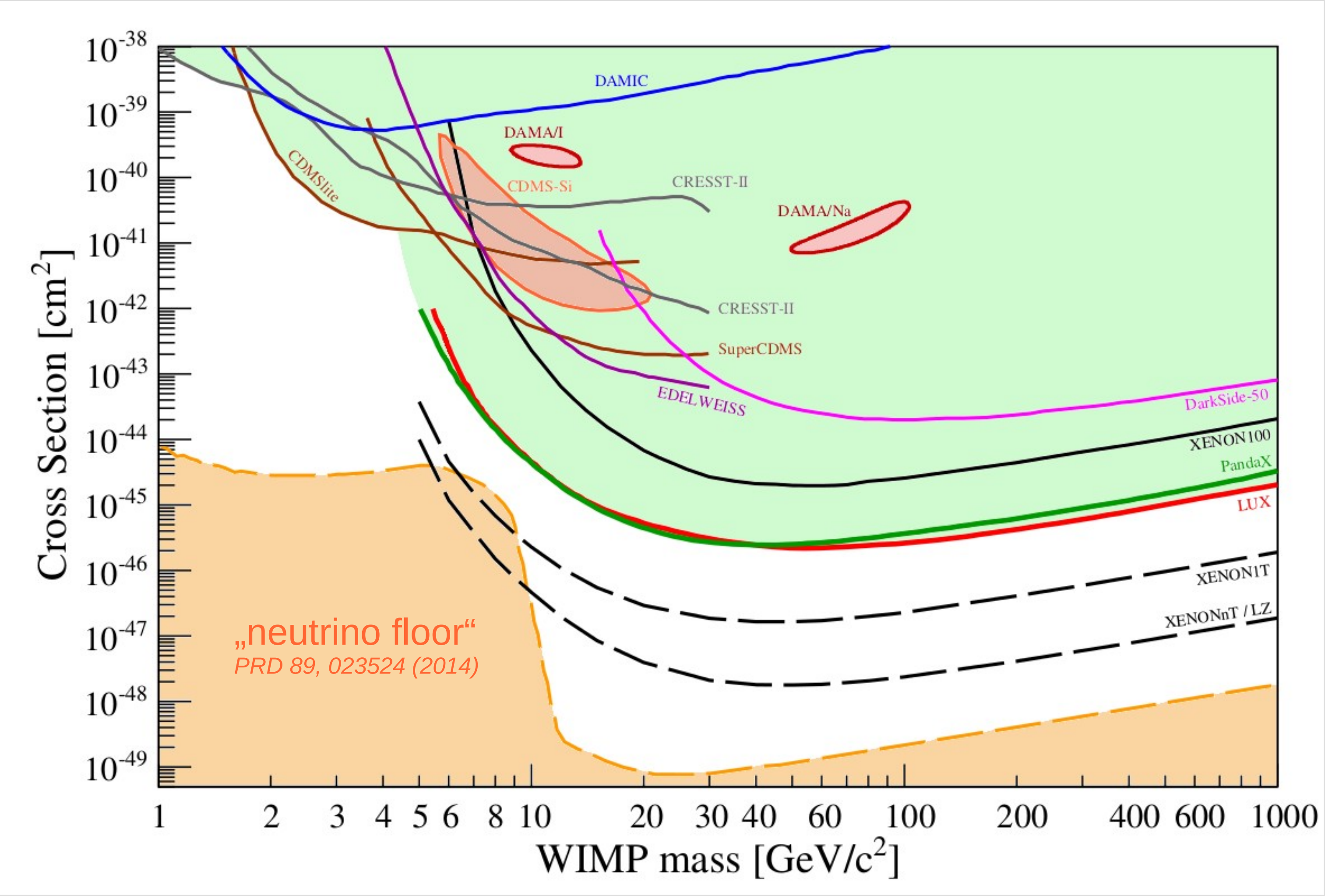
  10t total LXe mass,
  7t active target,
  5.6t fiducial target

- 488 R11410 PMTs
- *2015*: started procurement of xenon gas, PMTs, ...
  04/2020: end of construction
- goal: 2×10^{-48} cm² @ ~50 GeV/c² after 15 t×y exposure



Dark Matter Searches: The Limit

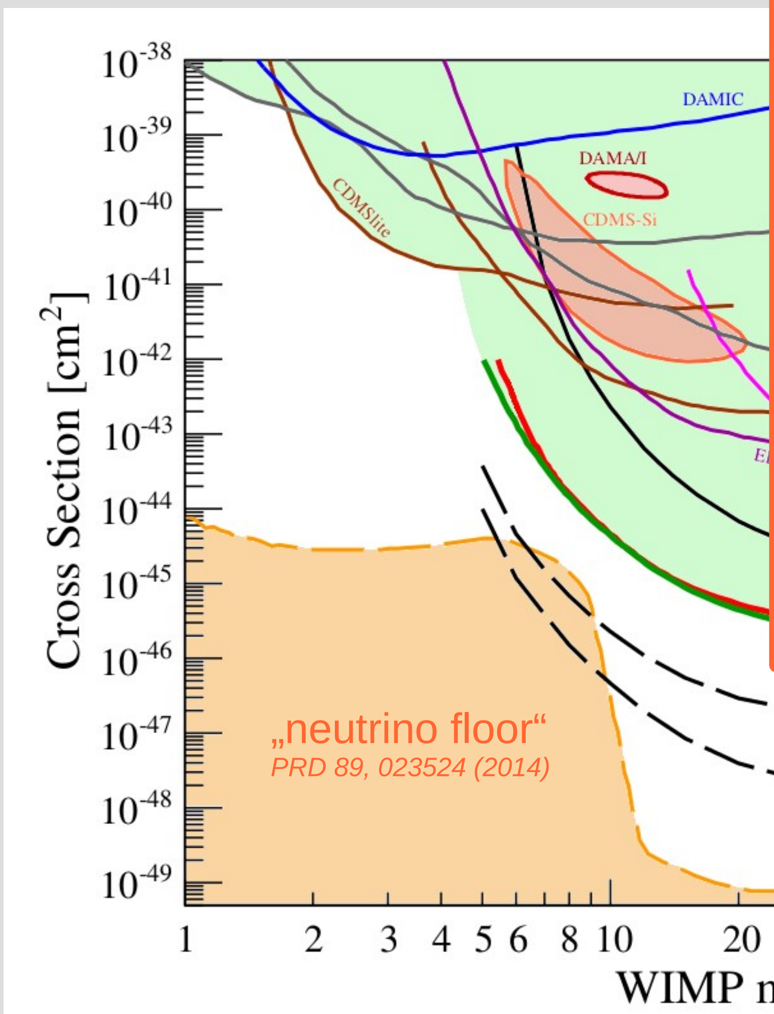
spin-independent WIMP-nucleon interactions

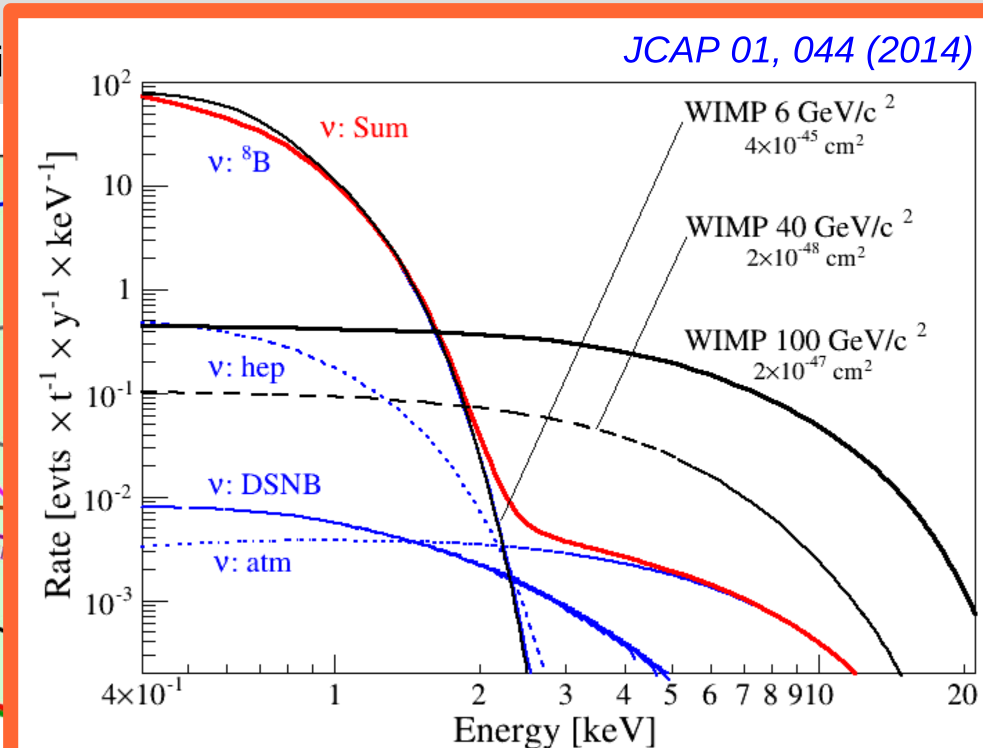


some projects are missing...

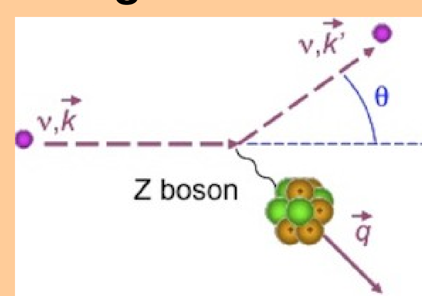
Dark Matter Searches: The Limit

spin-i



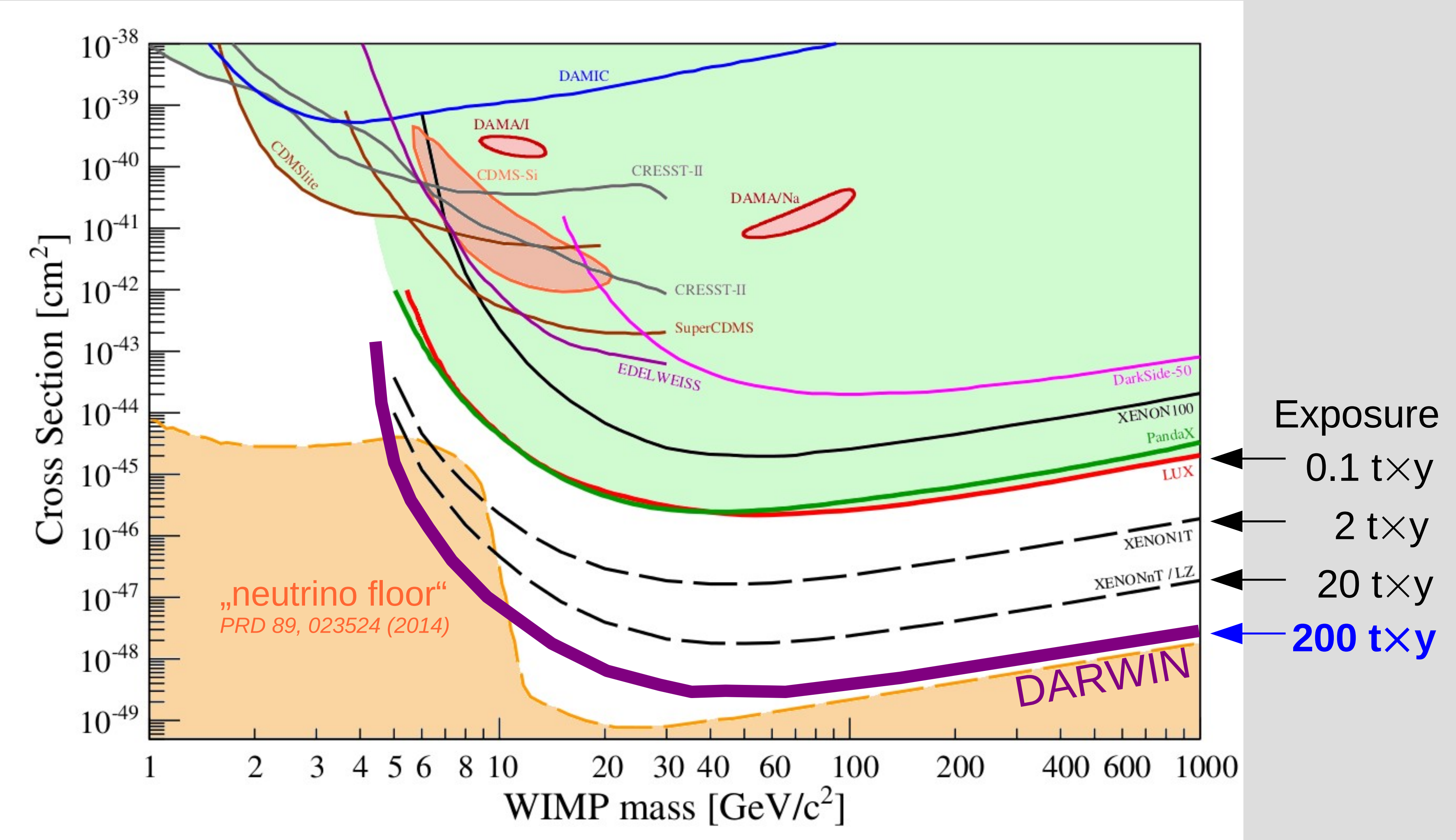


Interactions from coherent neutrino-nucleus scattering (CNNS) will dominate
→ **ultimate background** for direct detection



DARWIN The **ultimate** WIMP Detector

spin-independent WIMP-nucleon interactions

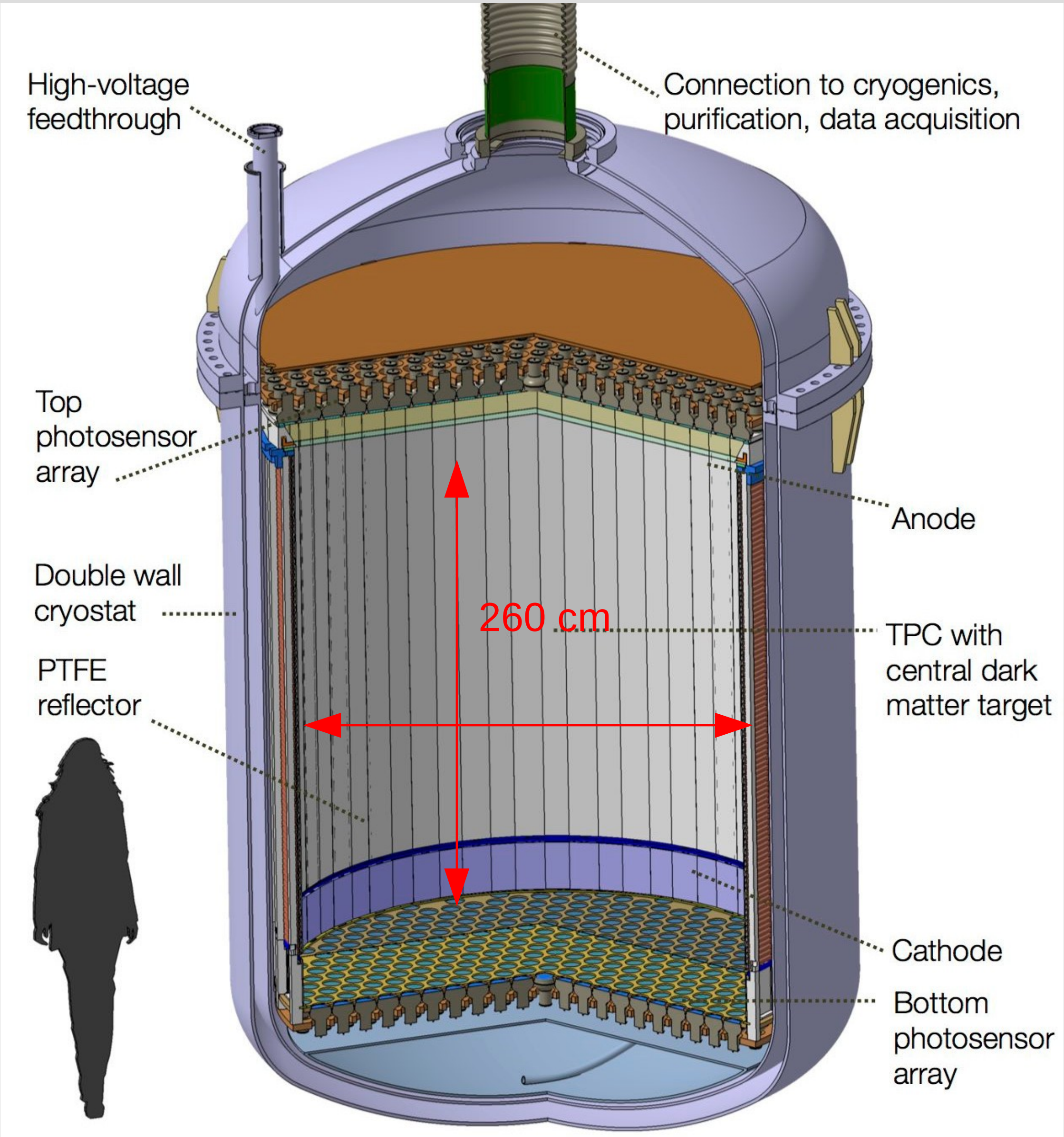


some projects are missing...

DARWIN The ultimate WIMP Detector

JCAP 11, 017 (2016)

LXe



- aim at sensitivity of a few 10^{-49} cm², limited by **irreducible ν-backgrounds**
- international consortium, 21 groups
  → R&D ongoing

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

- Timescale: start after XENONnT

www.darwin-observatory.org

DARWIN Backgrounds

Remaining background sources:

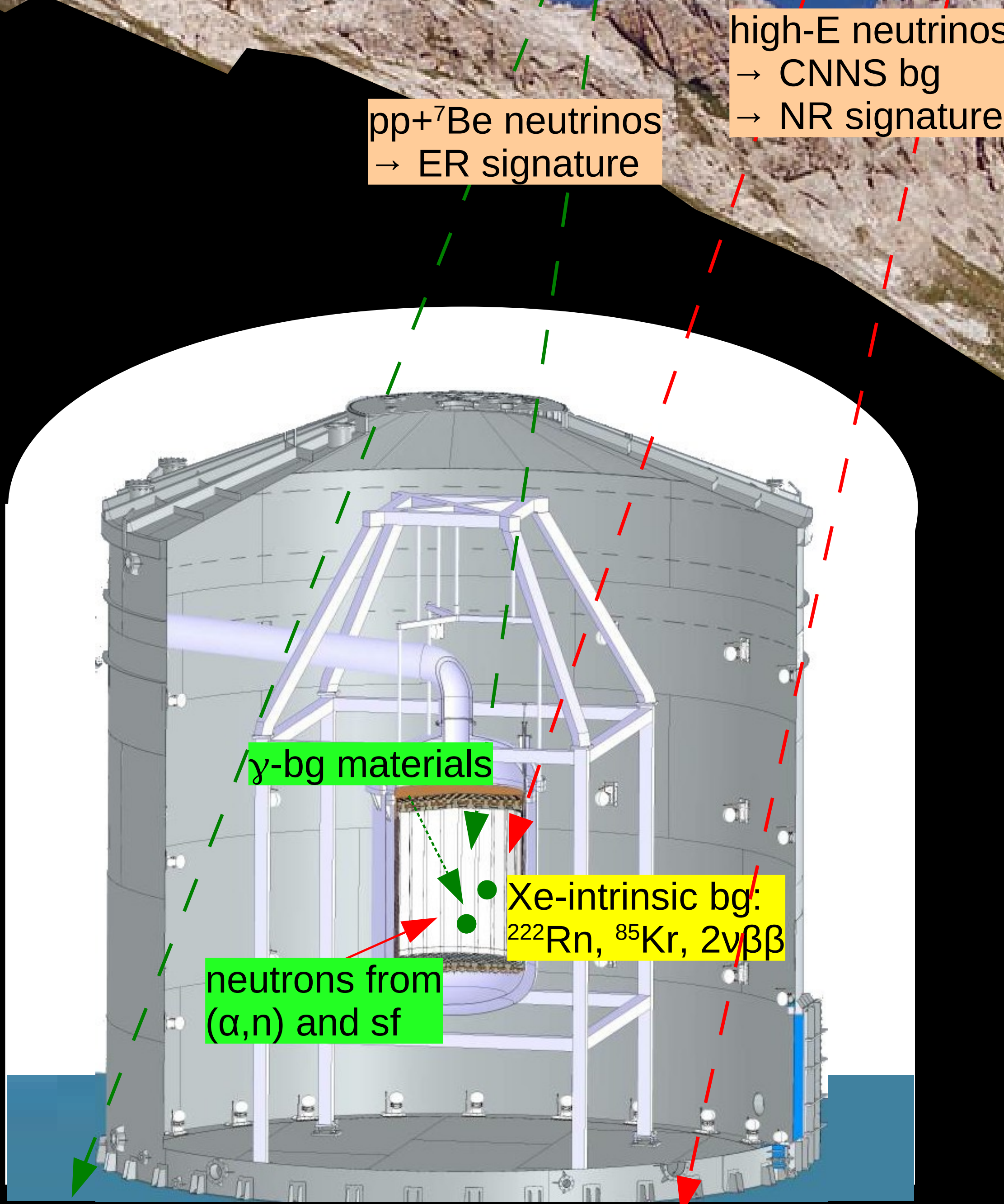
– Neutrinos (→ ERs and NRs)

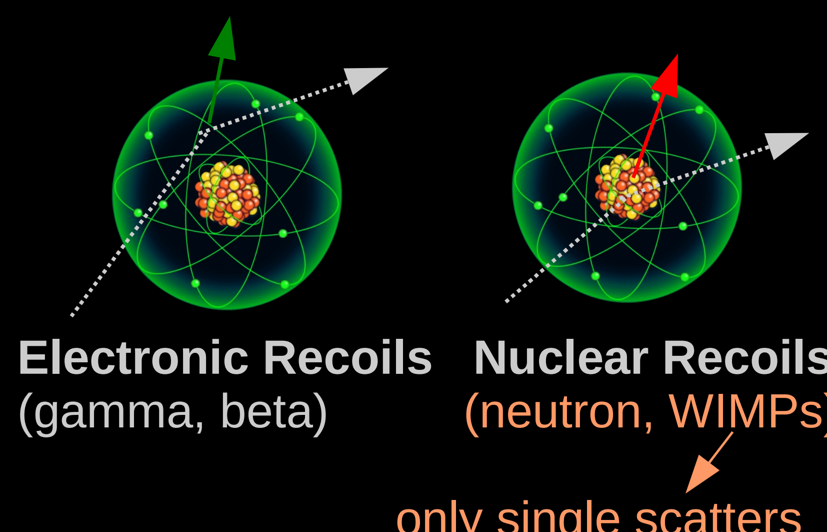
– Detector materials (→ γ, n)

– Xe-intrinsic isotopes (→ e^-)

(assume 100% effective shield (~15m) against μ-induced background)

JCAP 10, 016 (2015)



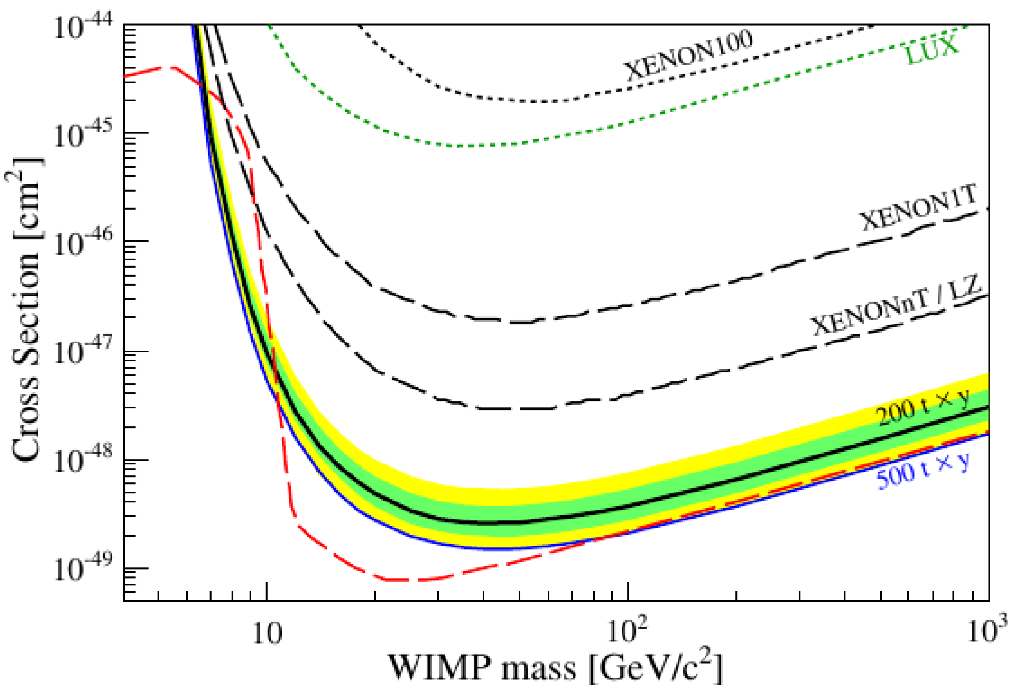


DARWIN WIMP Sensitivity

JCAP 10, 016 (2015)

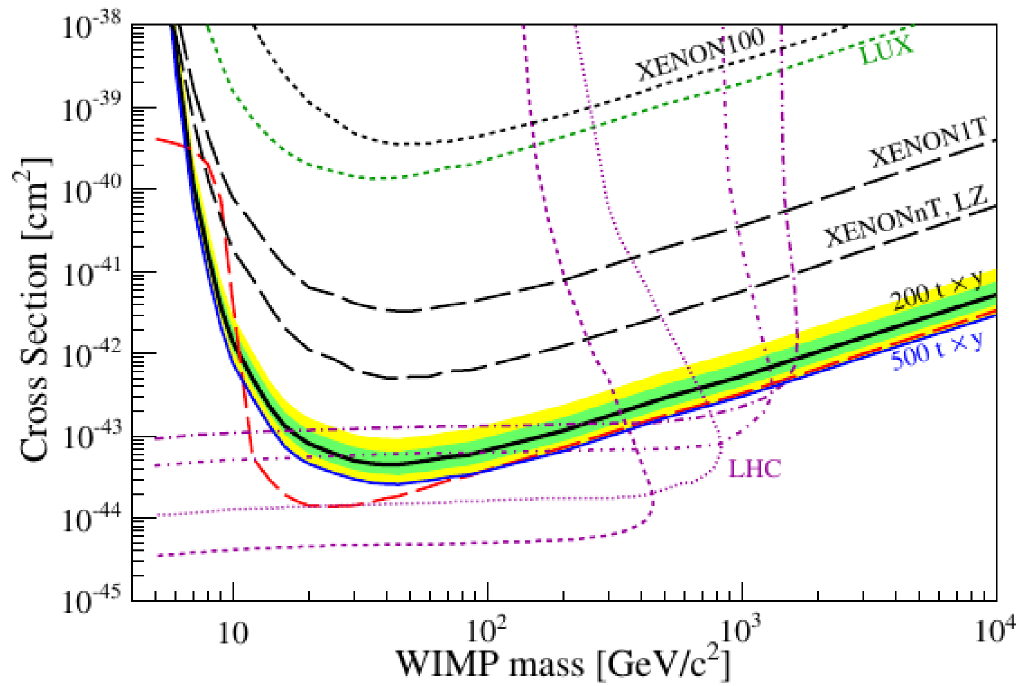
- exposure: 200 t × y; **all backgrounds included**
- likelihood analysis
- 99.98% ER rejection @ 30% NR acceptance, S1+S2 combined energy scale, LY=8 PE/keV, 5-35 keV_{nr} energy window

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).

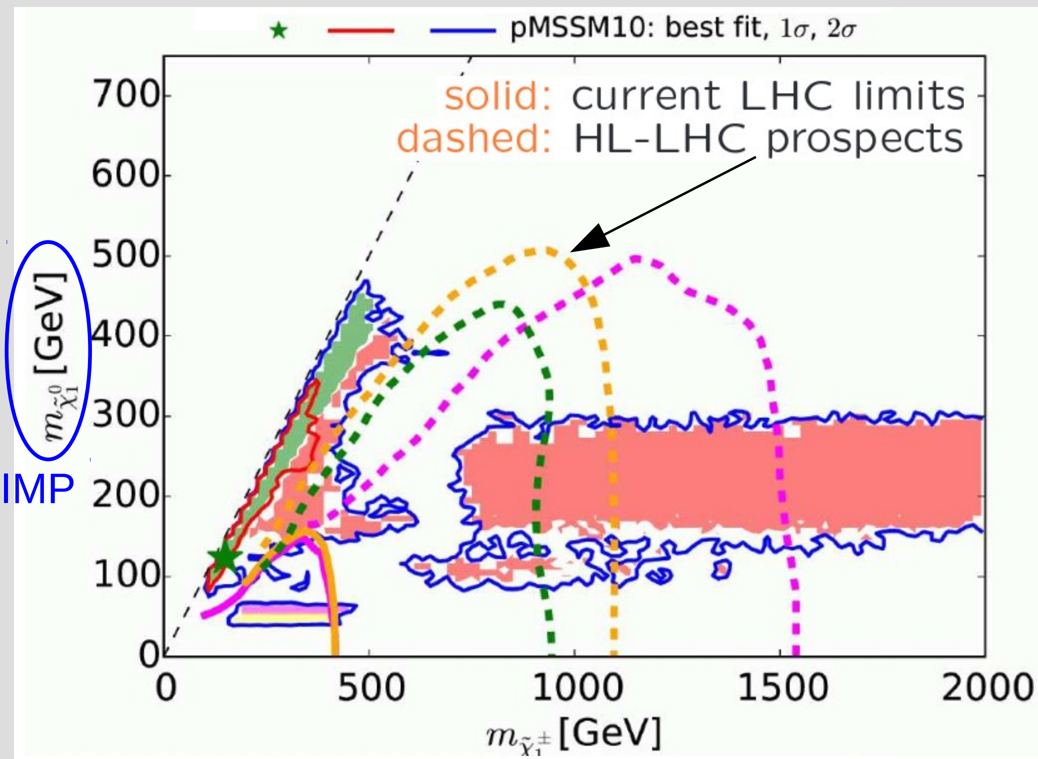
SUSY Dark Matter

plots: Sven Heinemeyer (MasterCode 2015)

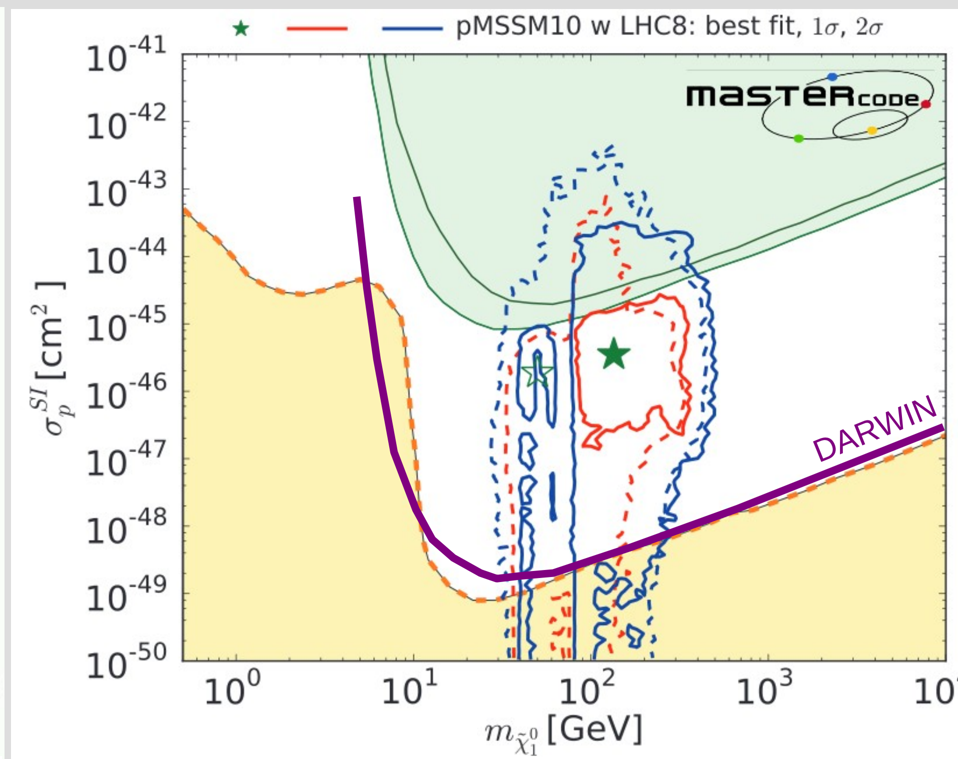
SUSY under pressure because not found at LHC?
→ true for some very constraint models (CMSSM etc.) but looks different
when more parameters are left unconstrained

Example: pMSSM10 ← 10 SUSY parameters, *e.g. EPJ C75, 422 (2015)*

WIMP



$m_{neutralino} \approx m_{chargino}$



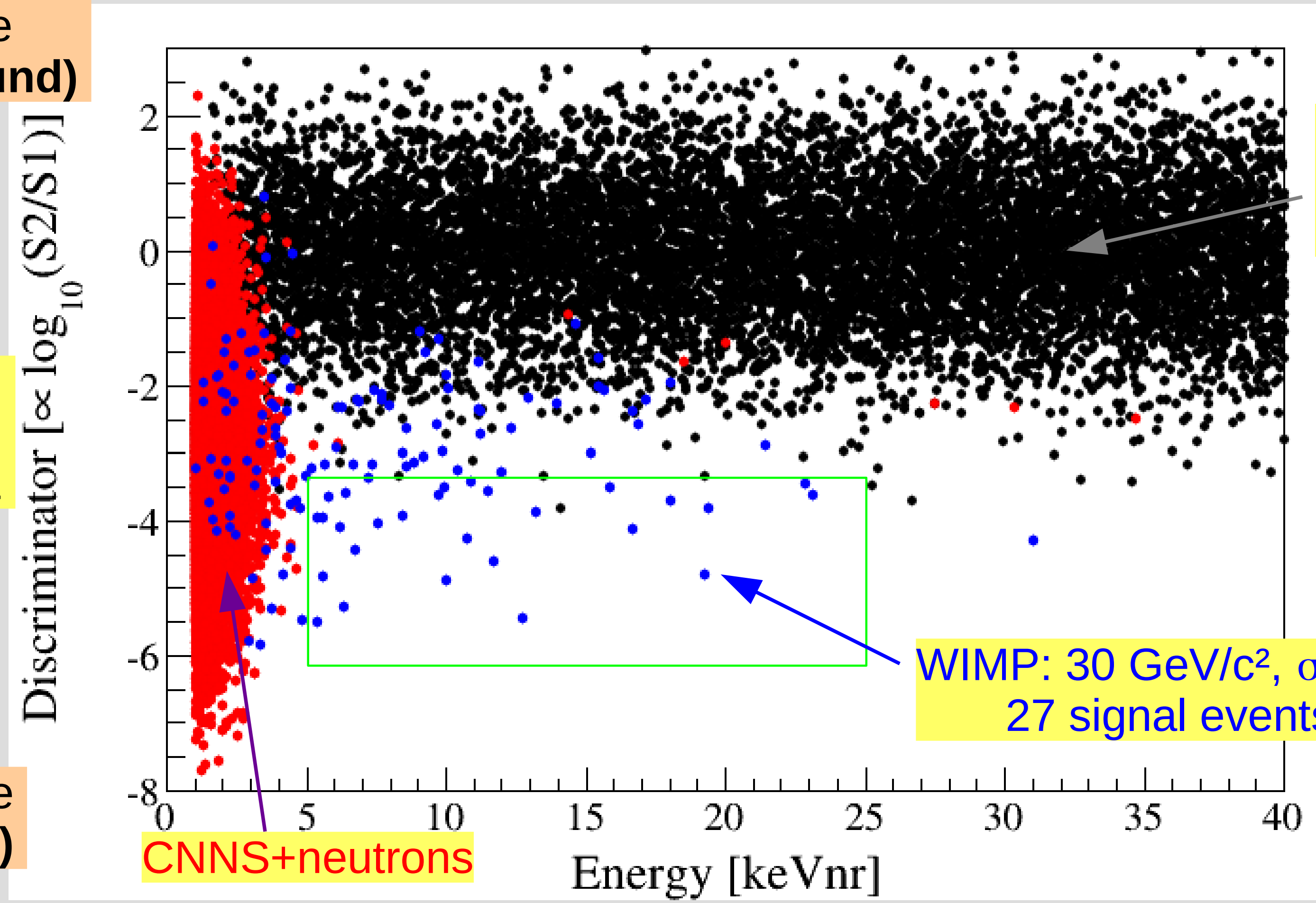
WIMP out of reach of HL-LHC (best-fit regions not covered), but accessible by DARWIN

WIMP Detection

ER-like **(background)**

discrimination variable; based on S2/S1

NR-like **(signal)**



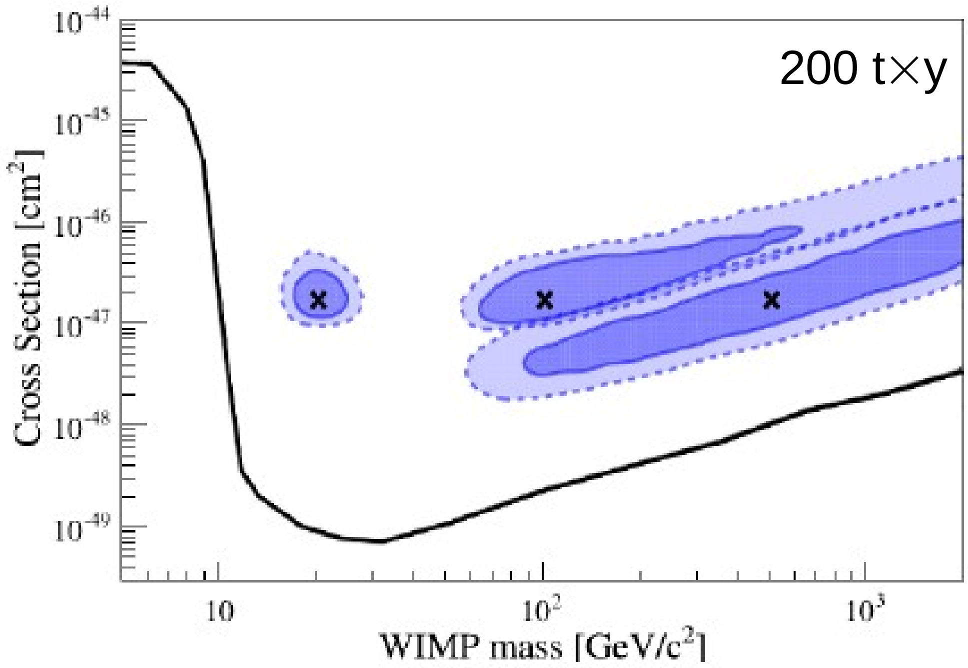
solar neutrinos, ^{85}Kr, ^{222}Rn, 2νββ, materials

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

reconstructed energy, based on S1 and S2 signal

WIMP Spectroscopy

Reconstruction: 2×10^{-47} cm²

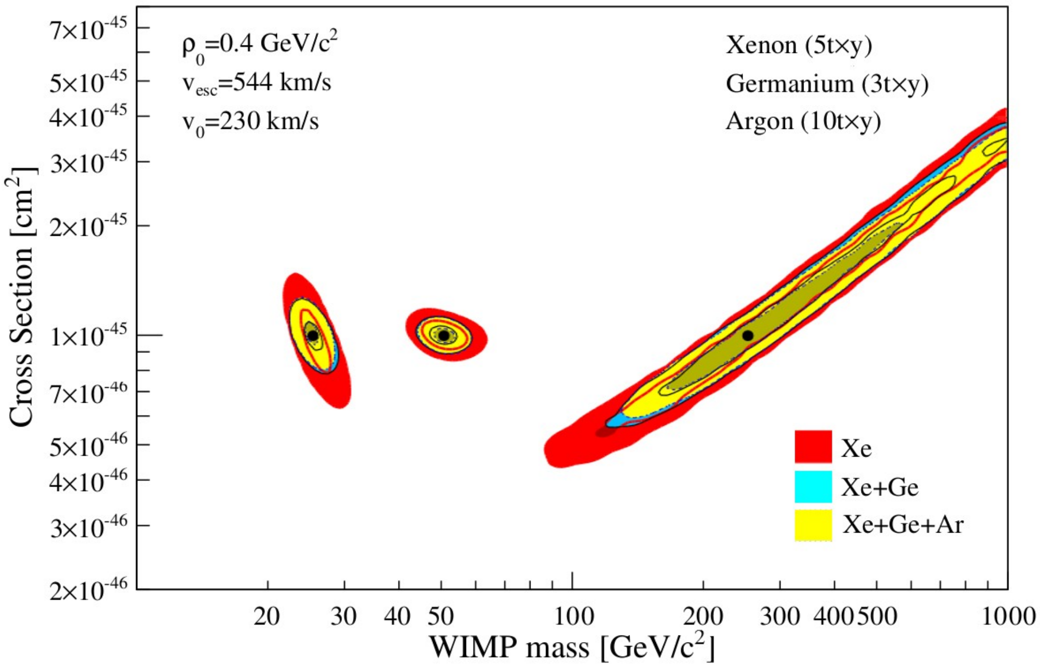


JCAP 11, 017 (2016)

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

Target Complementarity

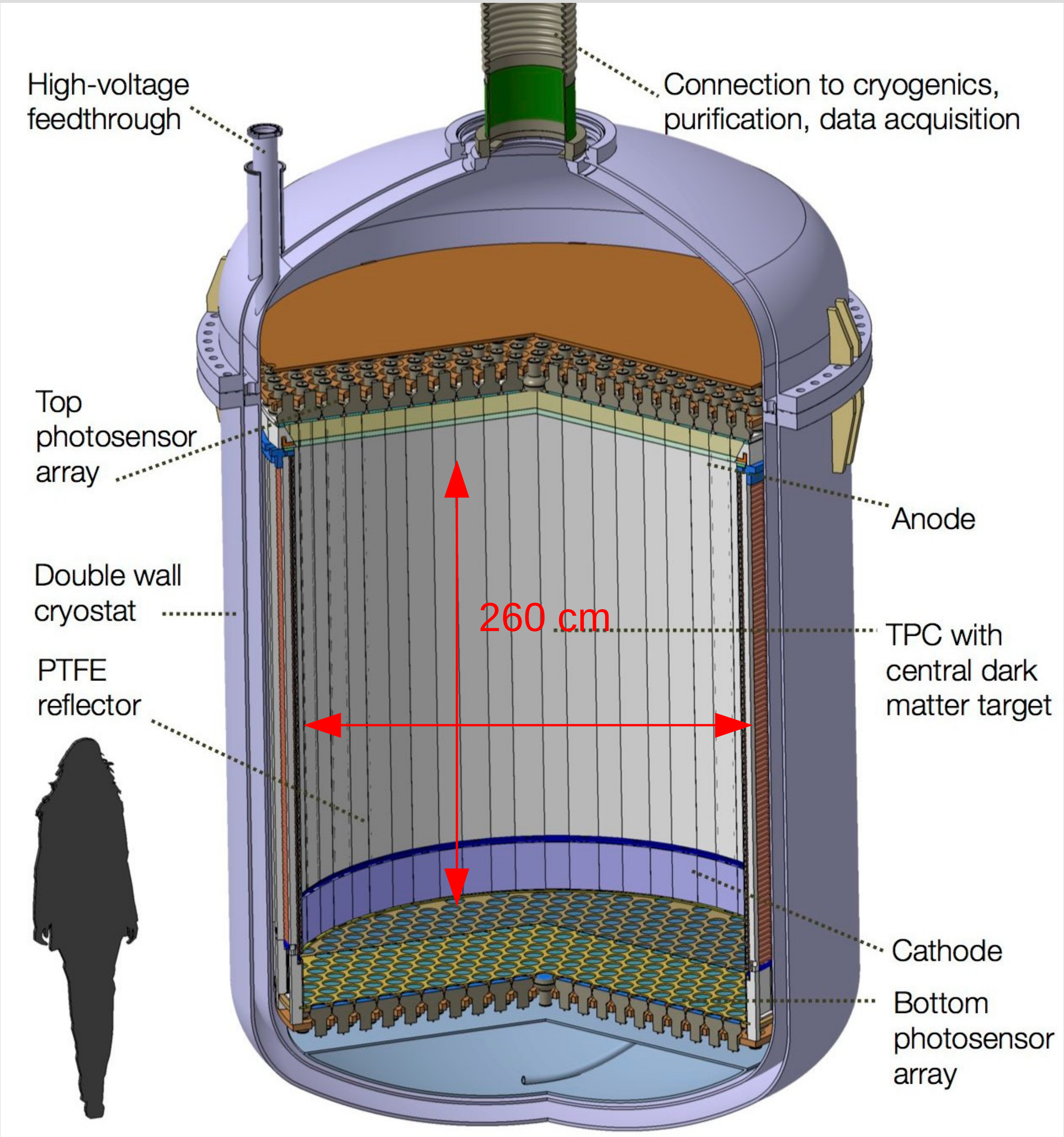


PRD 83, 083505 (2011)

Reconstruction improves considerably by adding Ge-data to Xe.

Only minimal improvement for Ar.

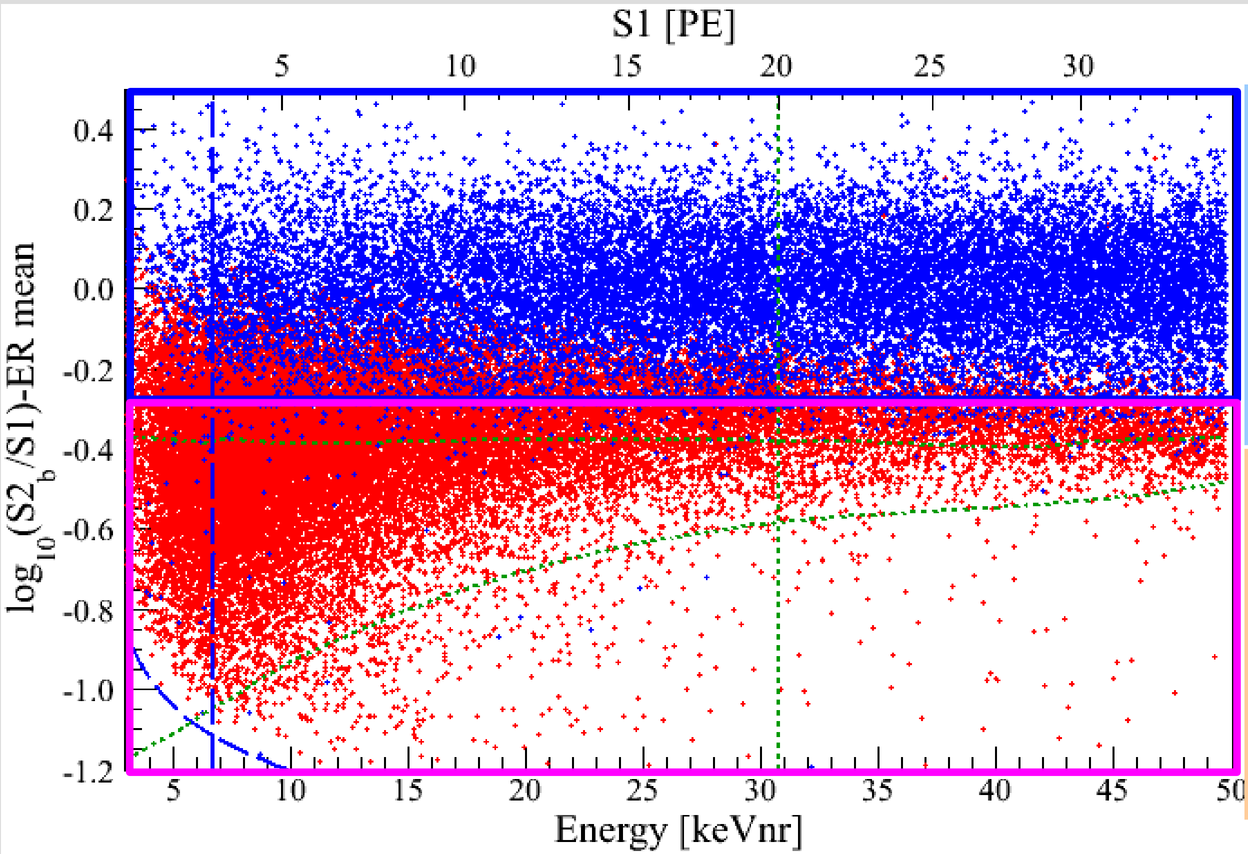
DARWIN The ultimate WIMP Detector



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

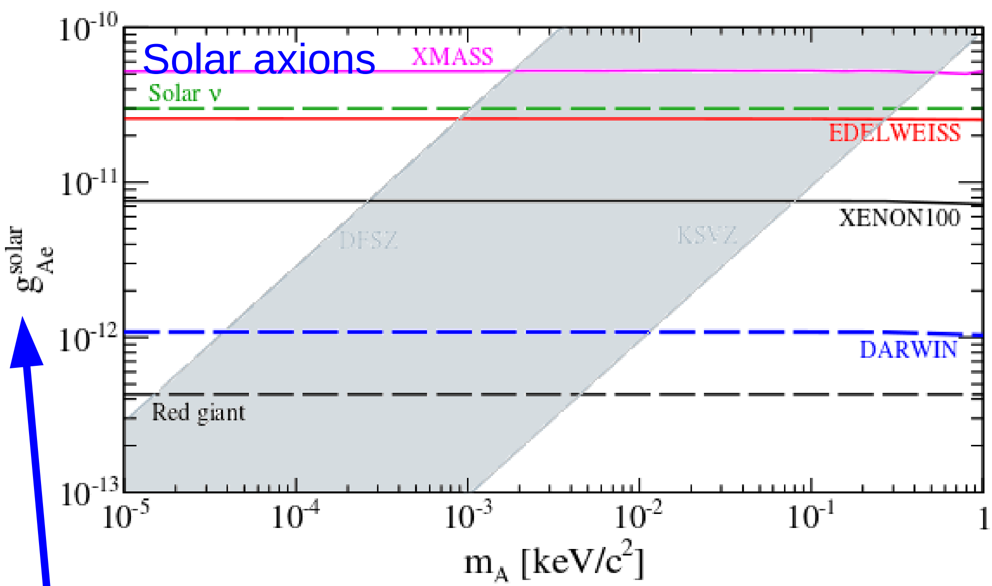
coherent scattering off xenon nucleus
→ nuclear recoil

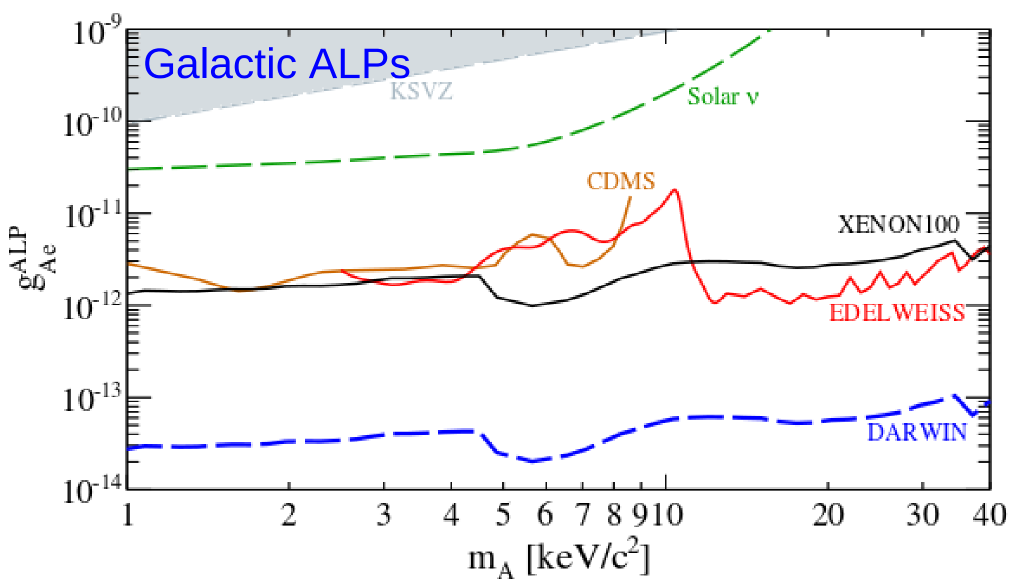
- Dark Matter
- CNNS

Many **science channels** are accessible with a multi-ton DARWIN detector thanks to its extremly low ER background.

Solar Axions, Dark Matter ALPs

JCAP 11, 017 (2016)





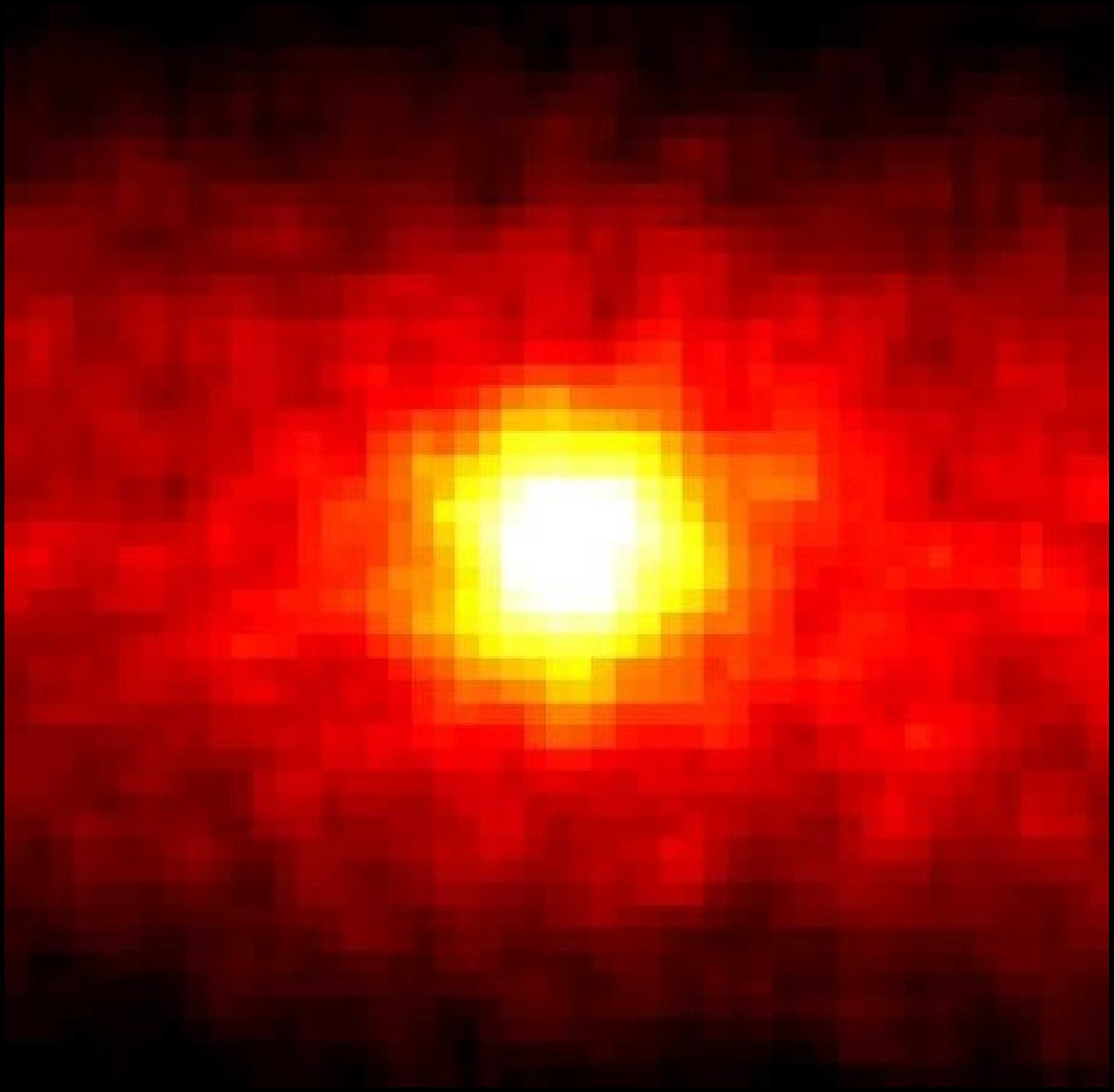
Axions and ALPs couple to xenon via **axio-electric-effect**

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

→ axion ionizes a Xe atom

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

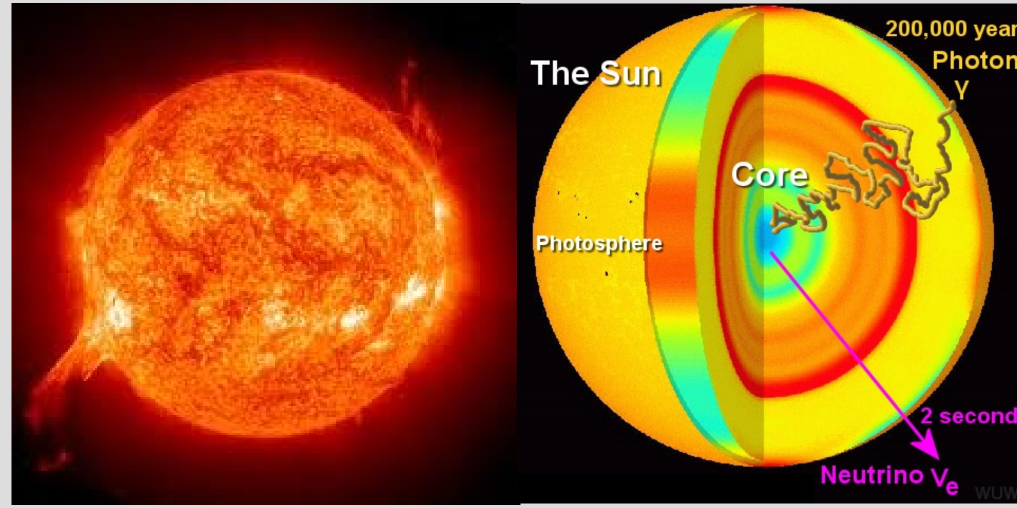
Axion-like particle (ALP)
generalization of the axion concept, but without addressing strong CP problem
(ALPs = Nambu-Goldstone bosons from breaking of some global symmetry)

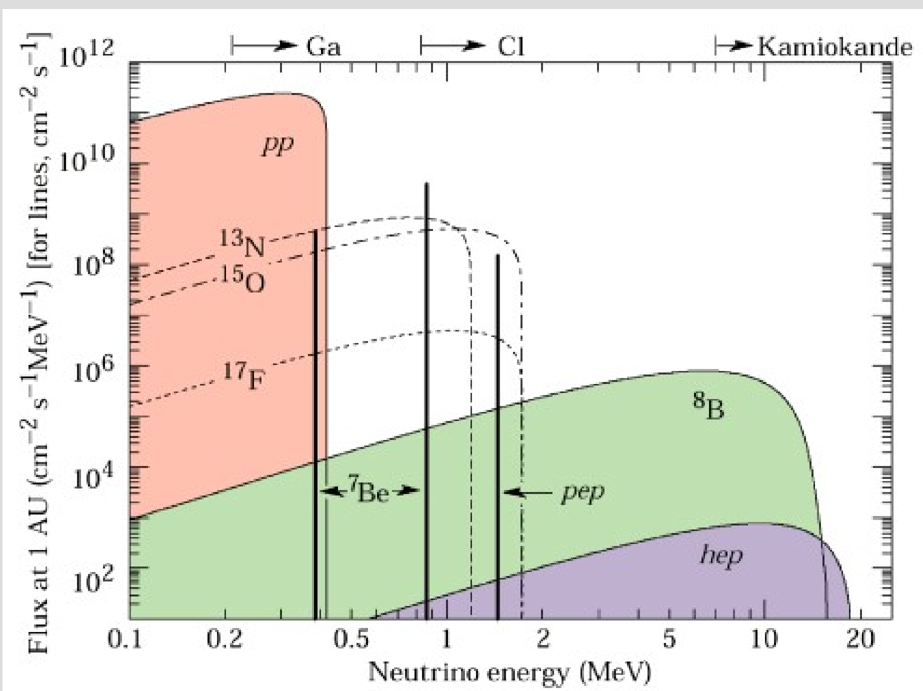


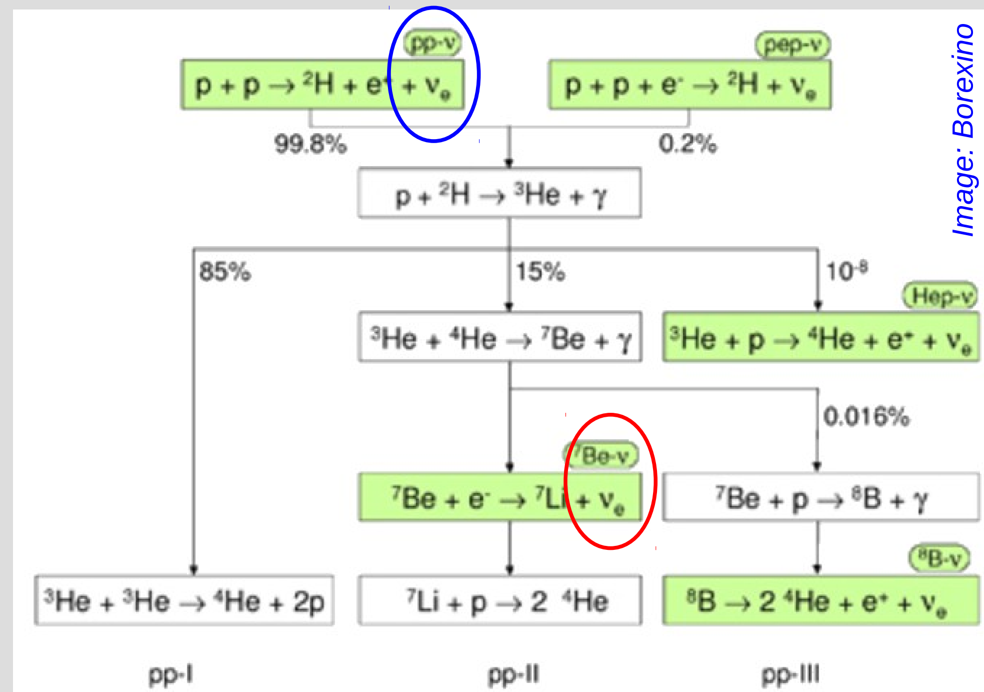
Low-E solar Neutrinos

Low-energy solar Neutrinos: pp, ^{7}Be

→ vast majority of solar neutrinos;
help to understand how the Sun works
→ very low energetic, hard to detect
→ mainly pp-neutrinos





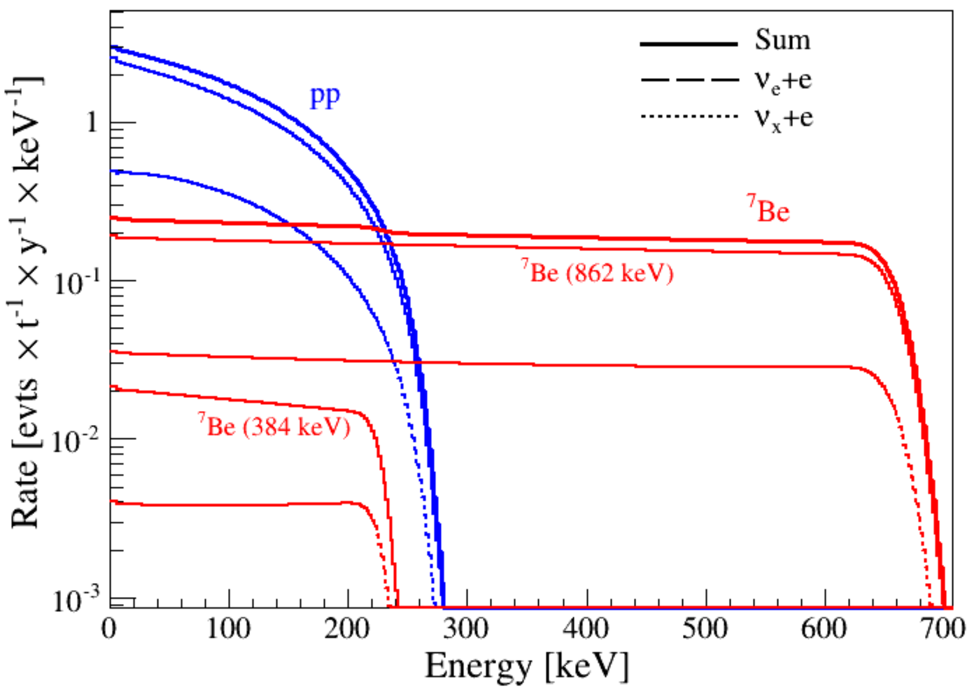


pp-Neutrinos in DARWIN

a background for the WIMP search

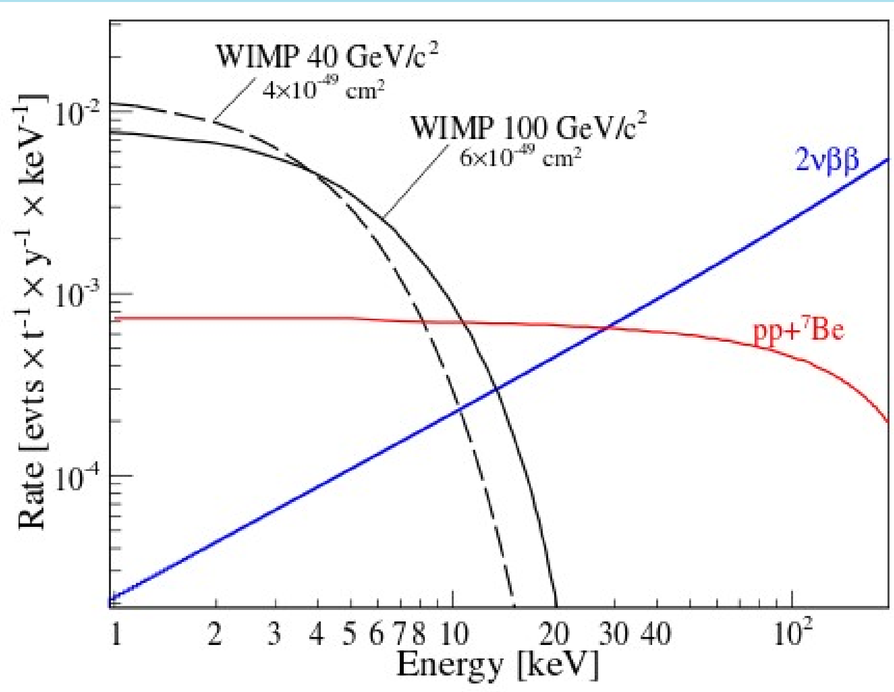
JCAP 11, 017 (2016)

Differential Recoil Spectrum in Xe



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

Neutrino interactions



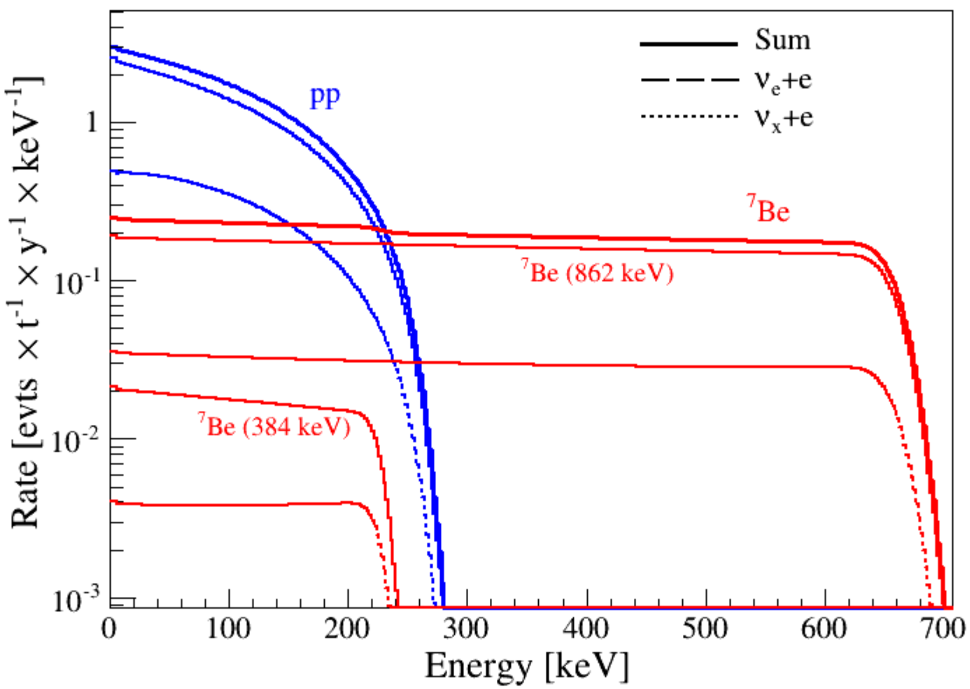
- ER rejection efficiencies ~99.98% at 30% NR efficiency are required to reduce to sub-dominant level

pp-Neutrinos in DARWIN

a new physics channel!

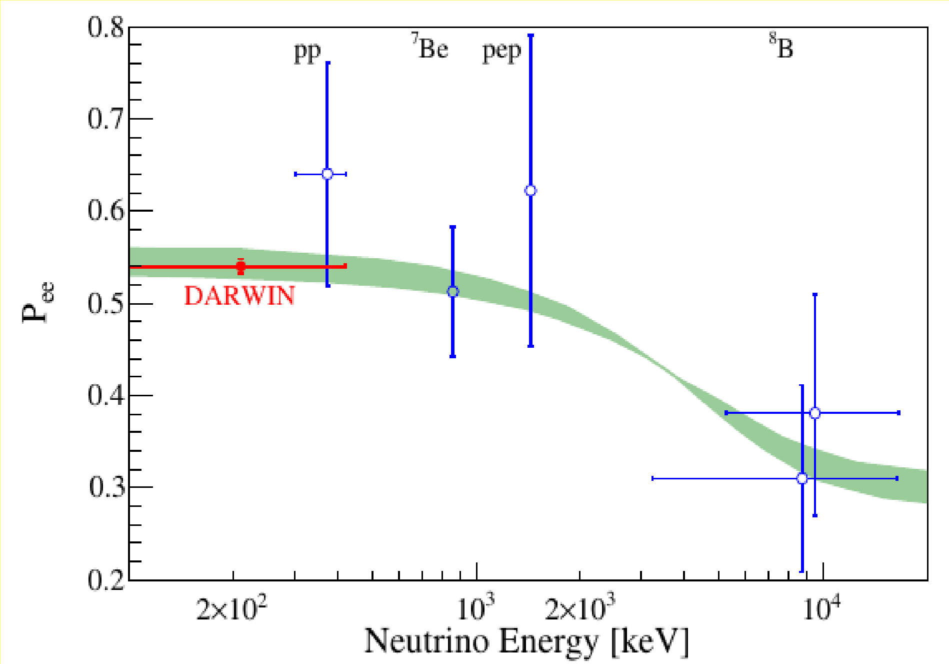
JCAP 11, 017 (2016)

Differential Recoil Spectrum in Xe



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

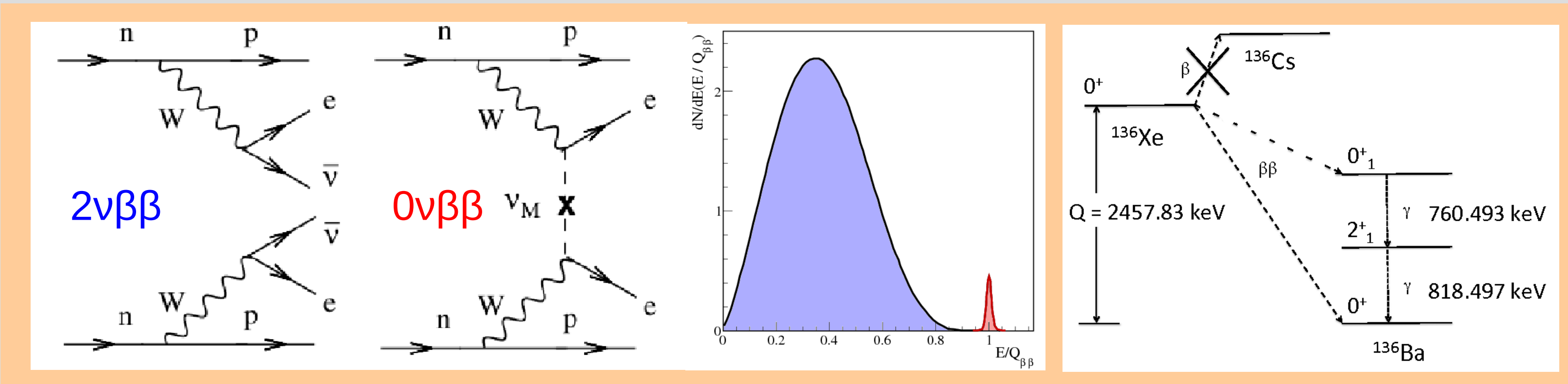
Neutrino interactions

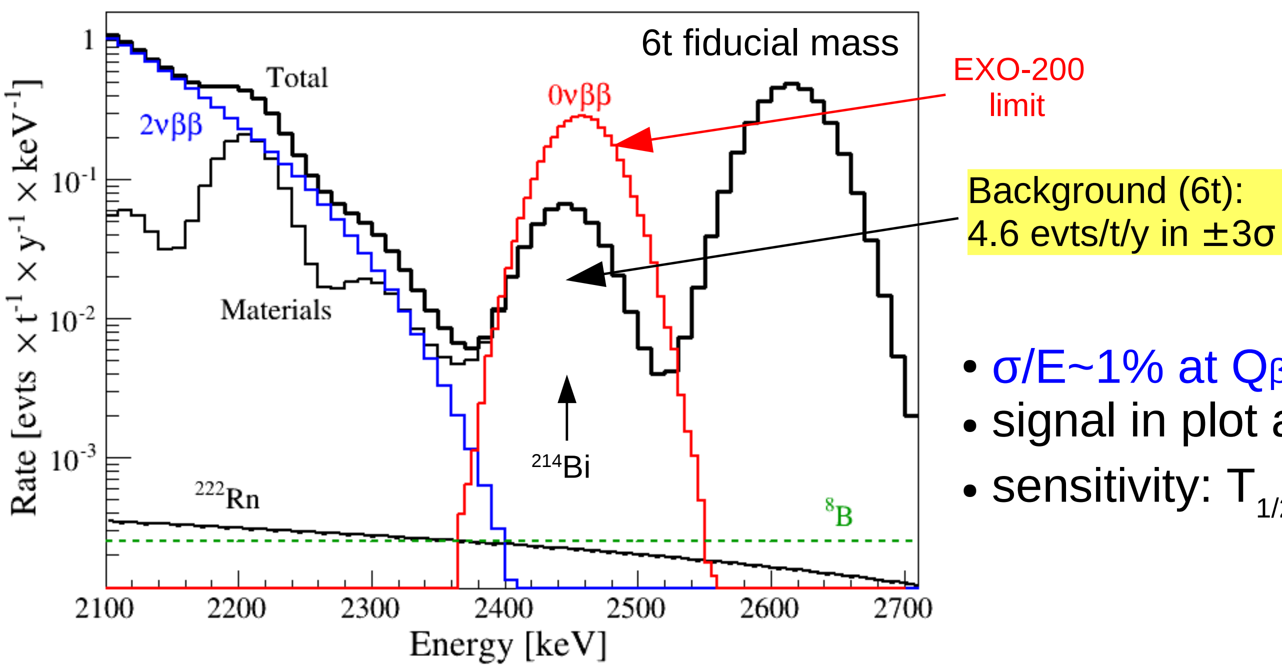


- 30t target mass, 2-30 keV window
  → 2850 neutrinos per year (89% pp)
  → achieve 1% statistical precision on pp-flux (→P_{ee}) with 100 t x y

^{136}Xe: 0ν double-beta Decay

JCAP 01, 044 (2014)



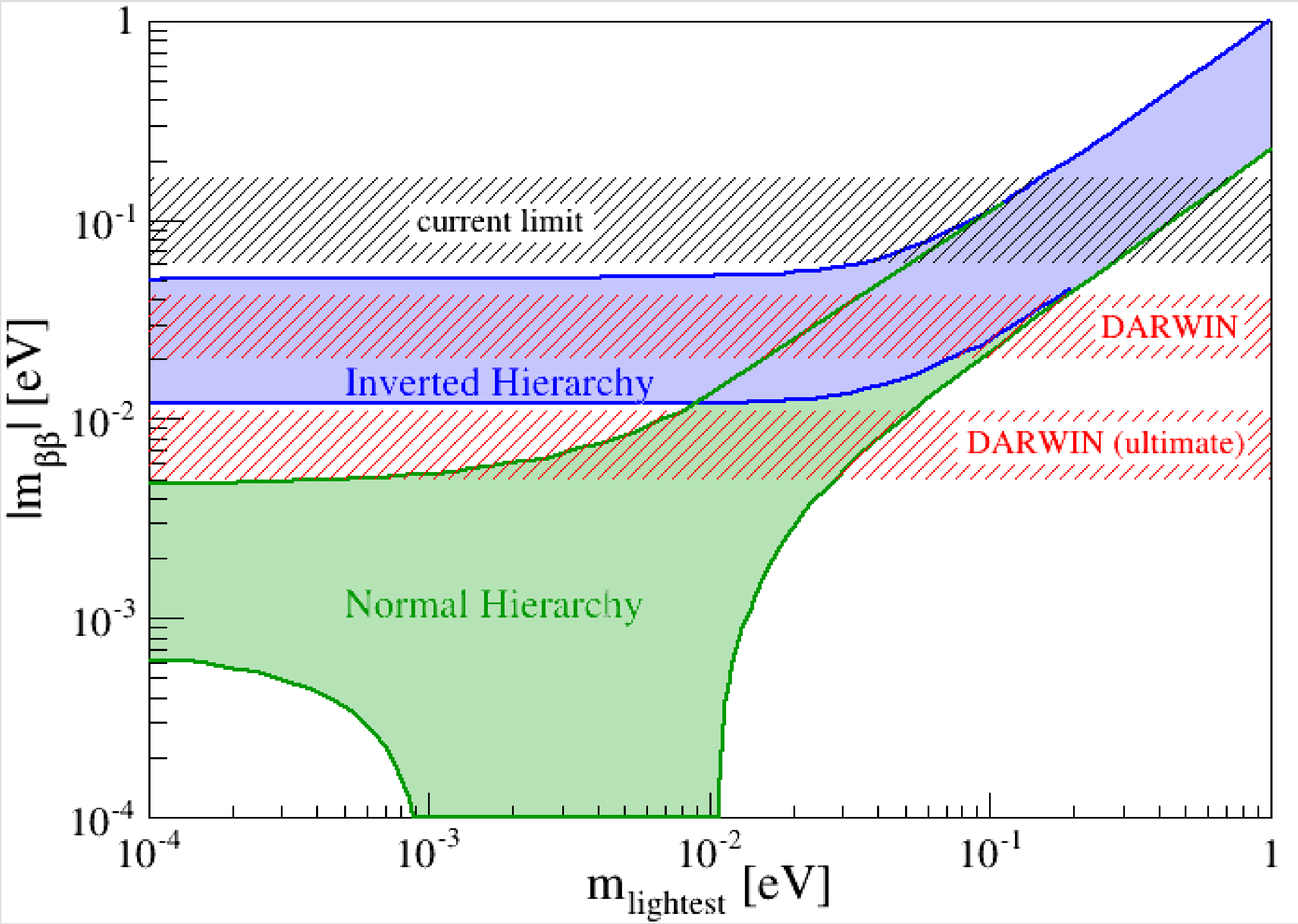


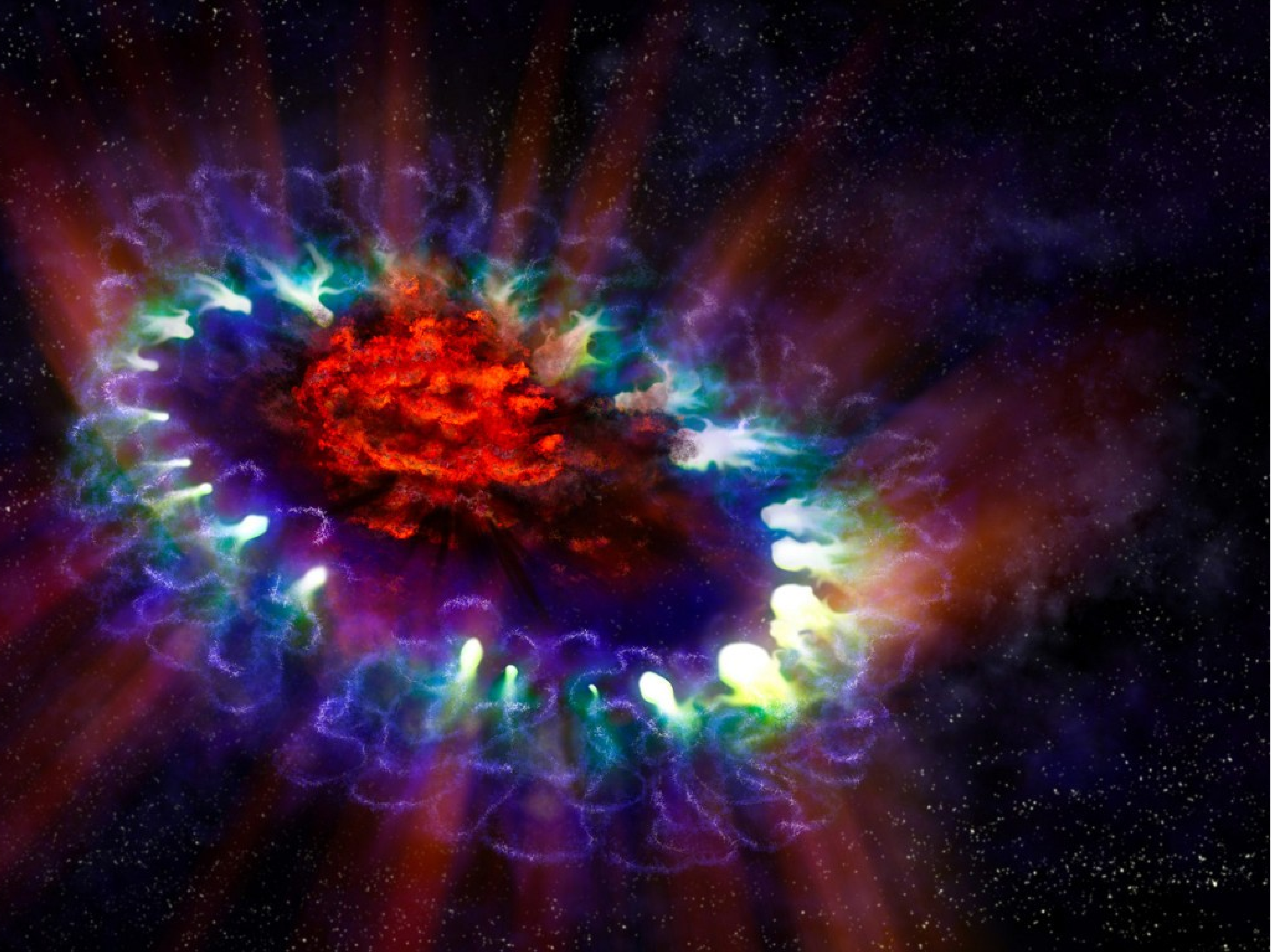
no ^{136}Xe enrichment!

- σ/E~1% at $Q_{\beta\beta}$, combined *E*-scale
- signal in plot assumes $T_{1/2}$=1.6 x 10^{25} y
- sensitivity: $T_{1/2}$=5.6 x 10^{26} y (95% CL, 6t x 5y)

0ν Double-beta Decay

JCAP 11, 017 (2016)

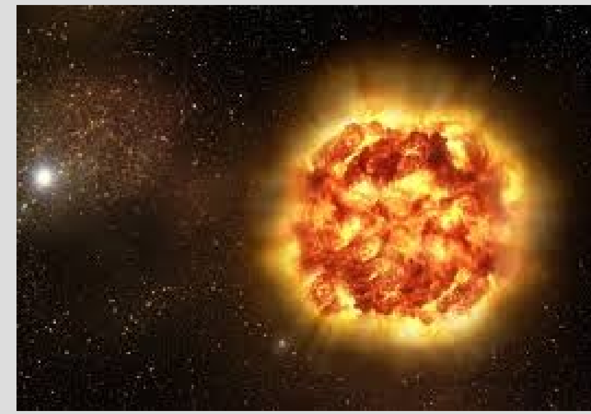


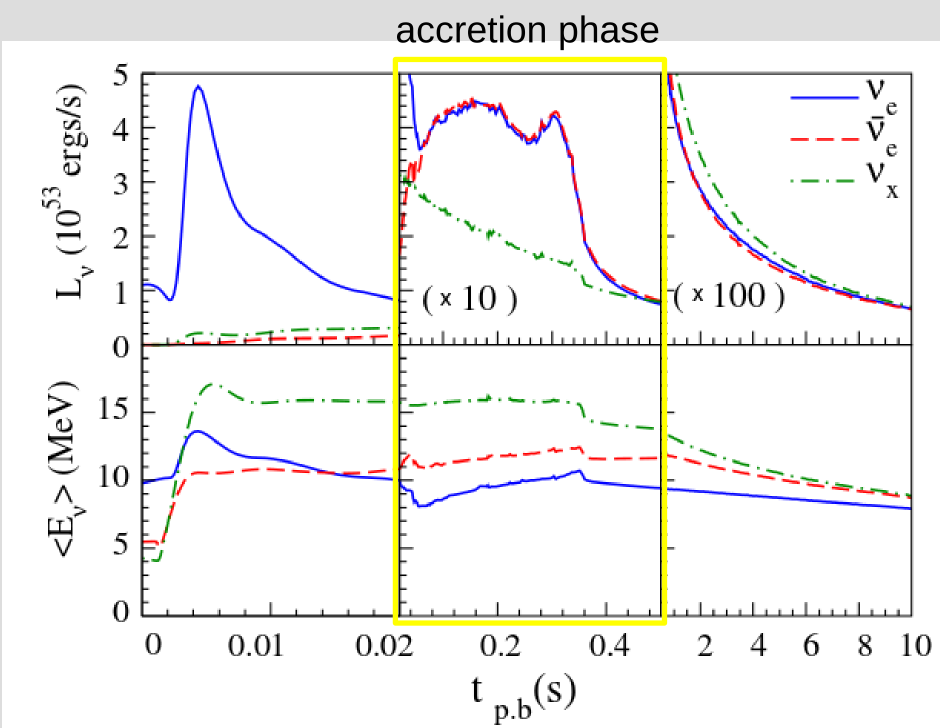


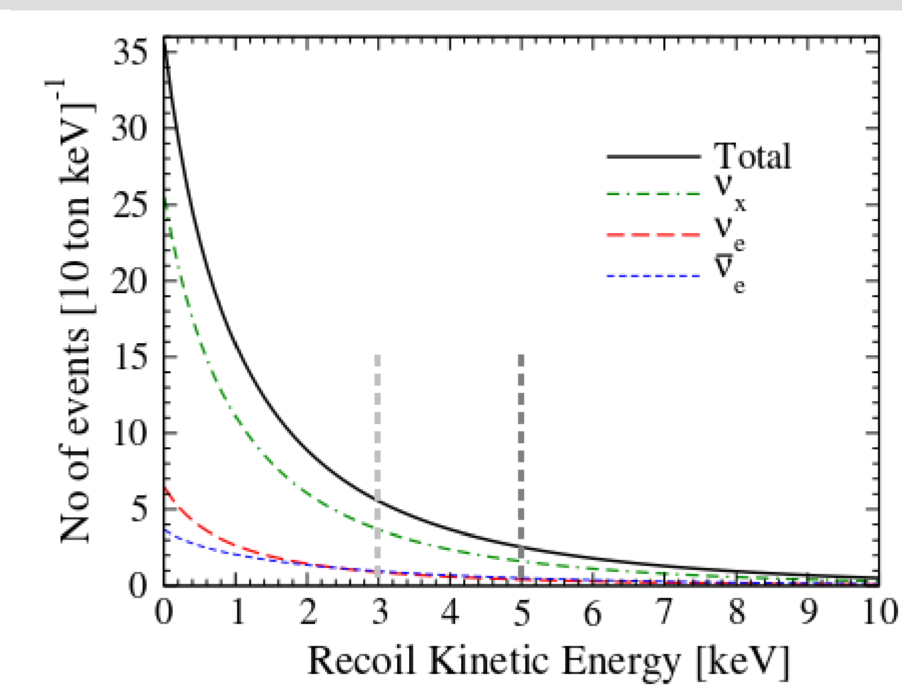
Supernova Neutrinos

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

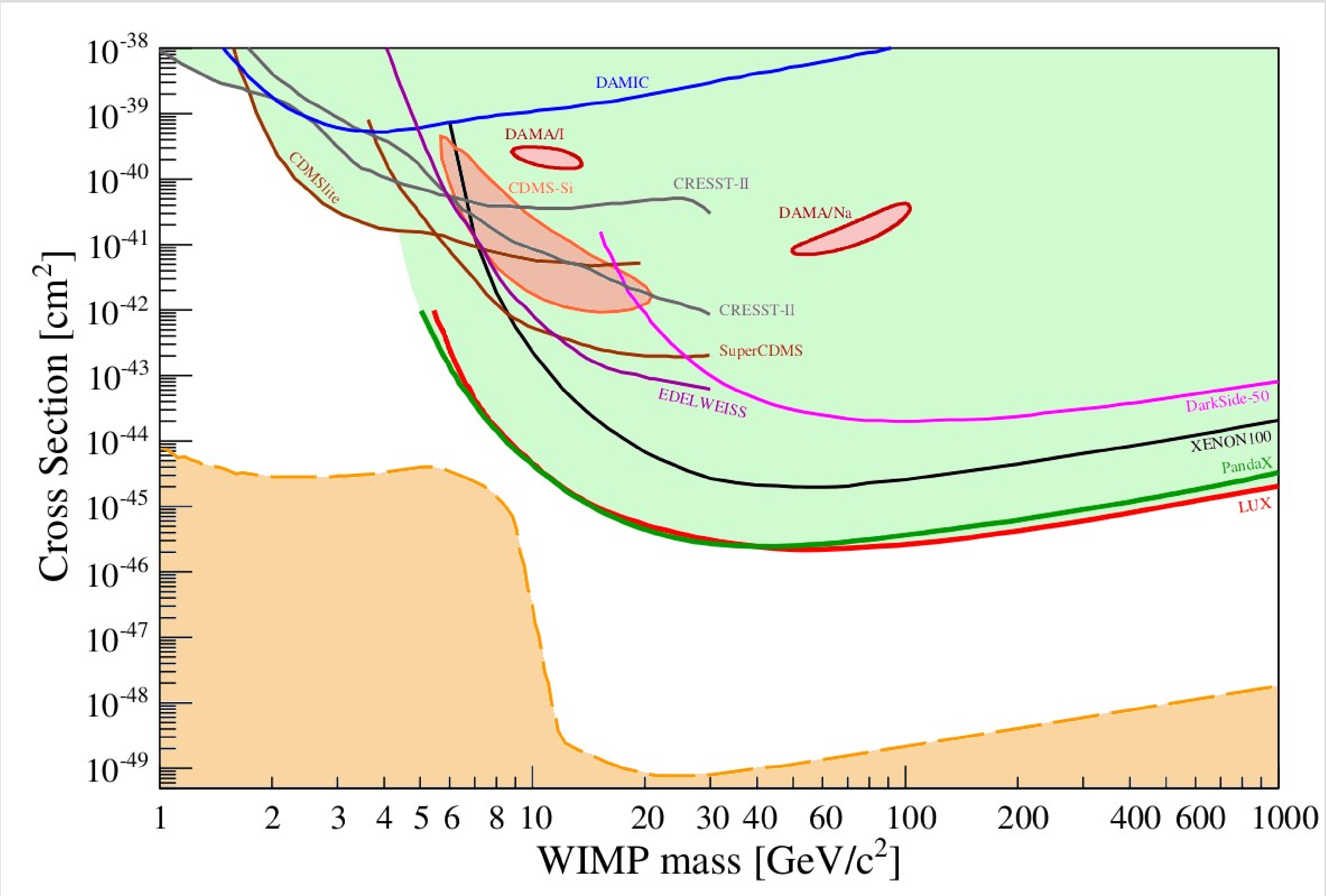
- ν from supernovae could be detected via CNNS as well
- signal fom accretion phase of a ~18 M_{sun} supernova @ 10 kpc is clearly visible in DARWIN
- signal: NRs plus precise time information
- challenge: theshold

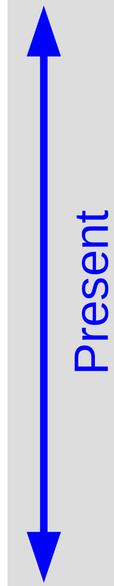




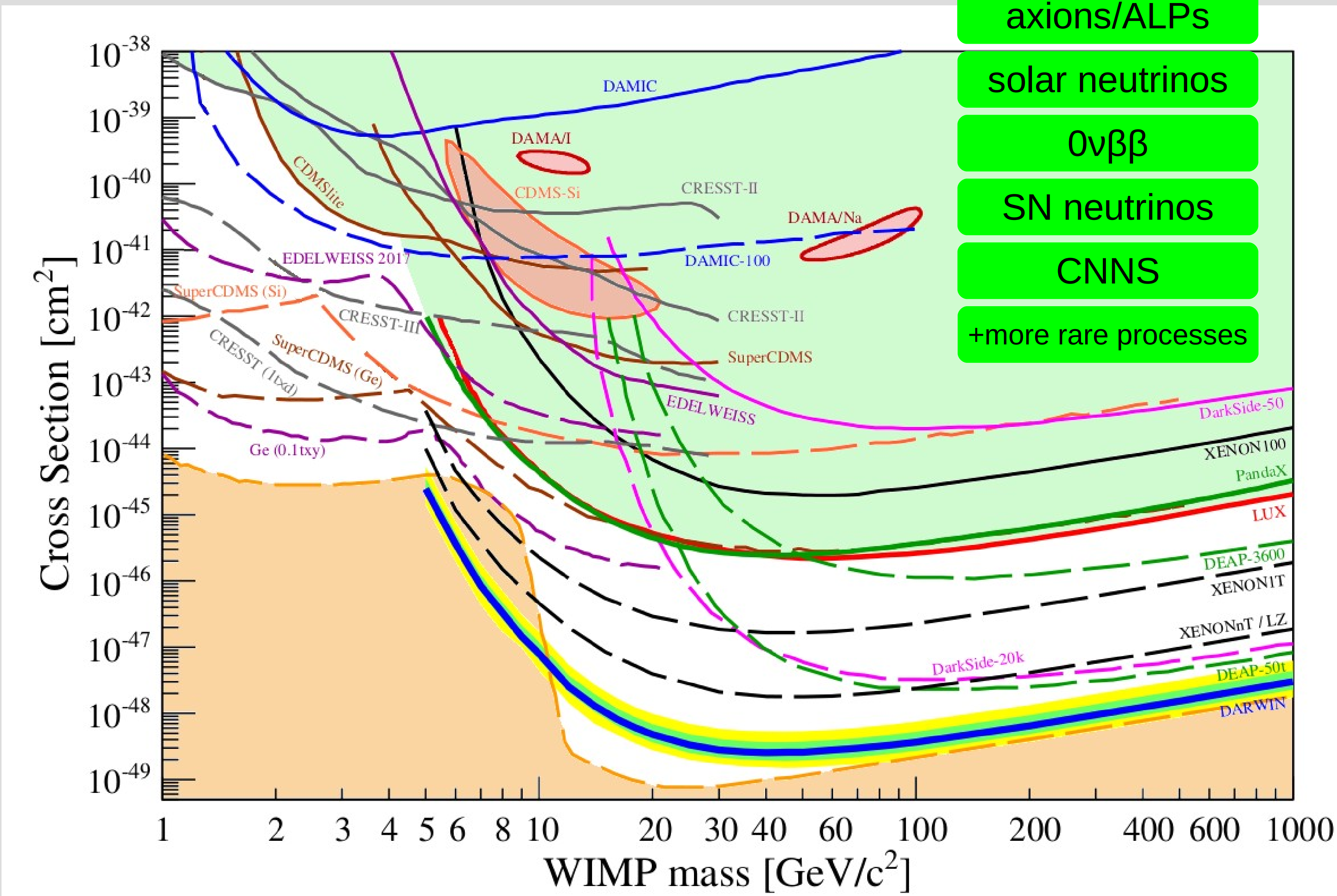


The WIMP Landscape today





Exciting times ahead of us



axions/ALPs

solar neutrinos

0νββ

SN neutrinos

CNNS

+more rare processes

Present

Future