Dark Matter direct searches

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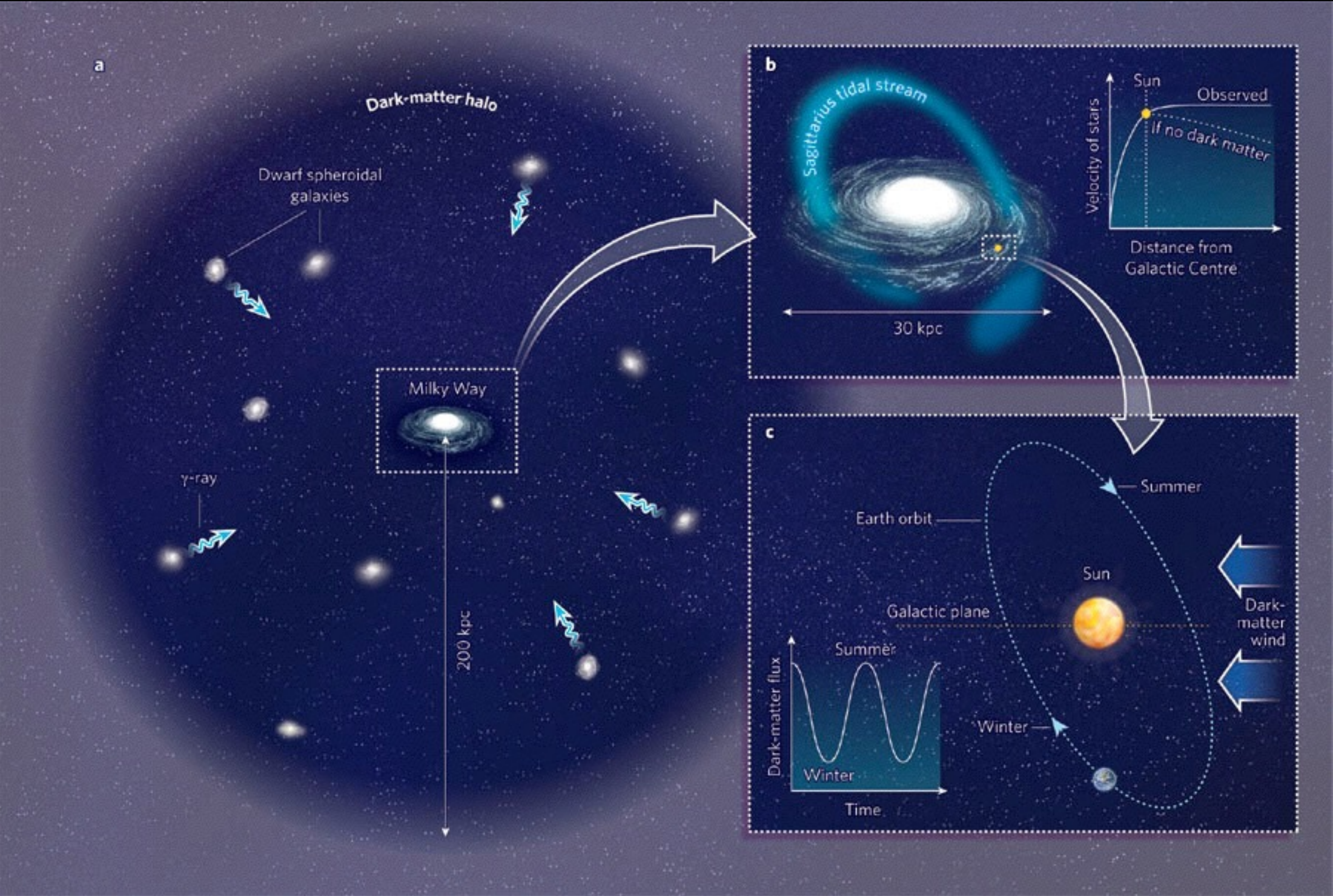
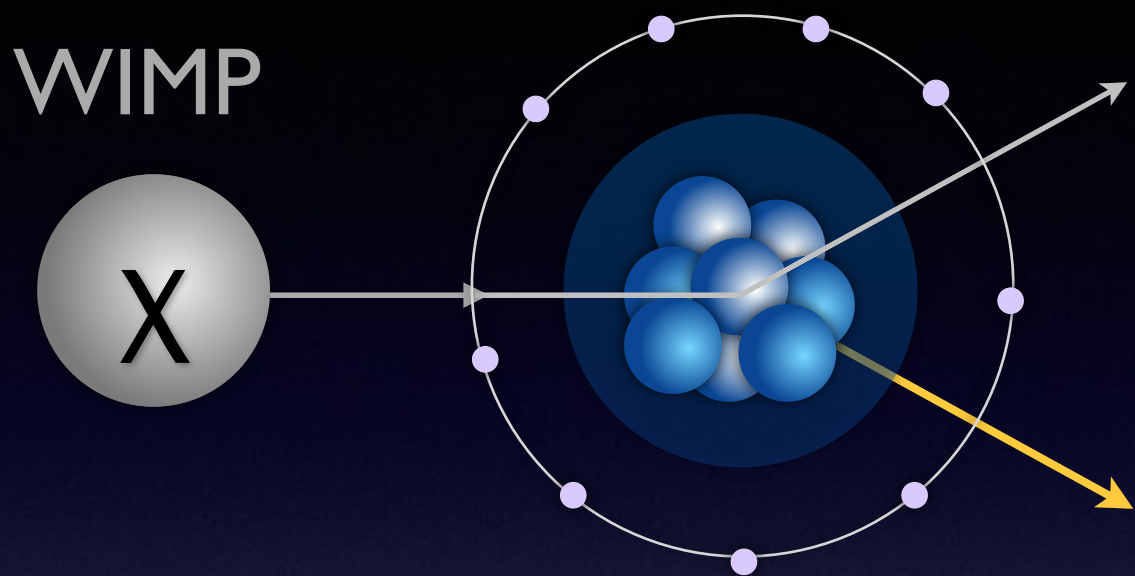


From Cosmology: Dark matter and dark energy
Robert Caldwell & Marc Kamionkowski
Nature 458, 587-589(2 April 2009)
doi:10.1038/458587a

WIMPs galactic wind

WIMP direct detection



$\chi N \rightarrow \chi N$

elastic scattering off nuclei

M. Goodman, E. Witten, PRD 1985

$\beta \approx 10^{-3}$

$m_\chi \approx 100$ GeV

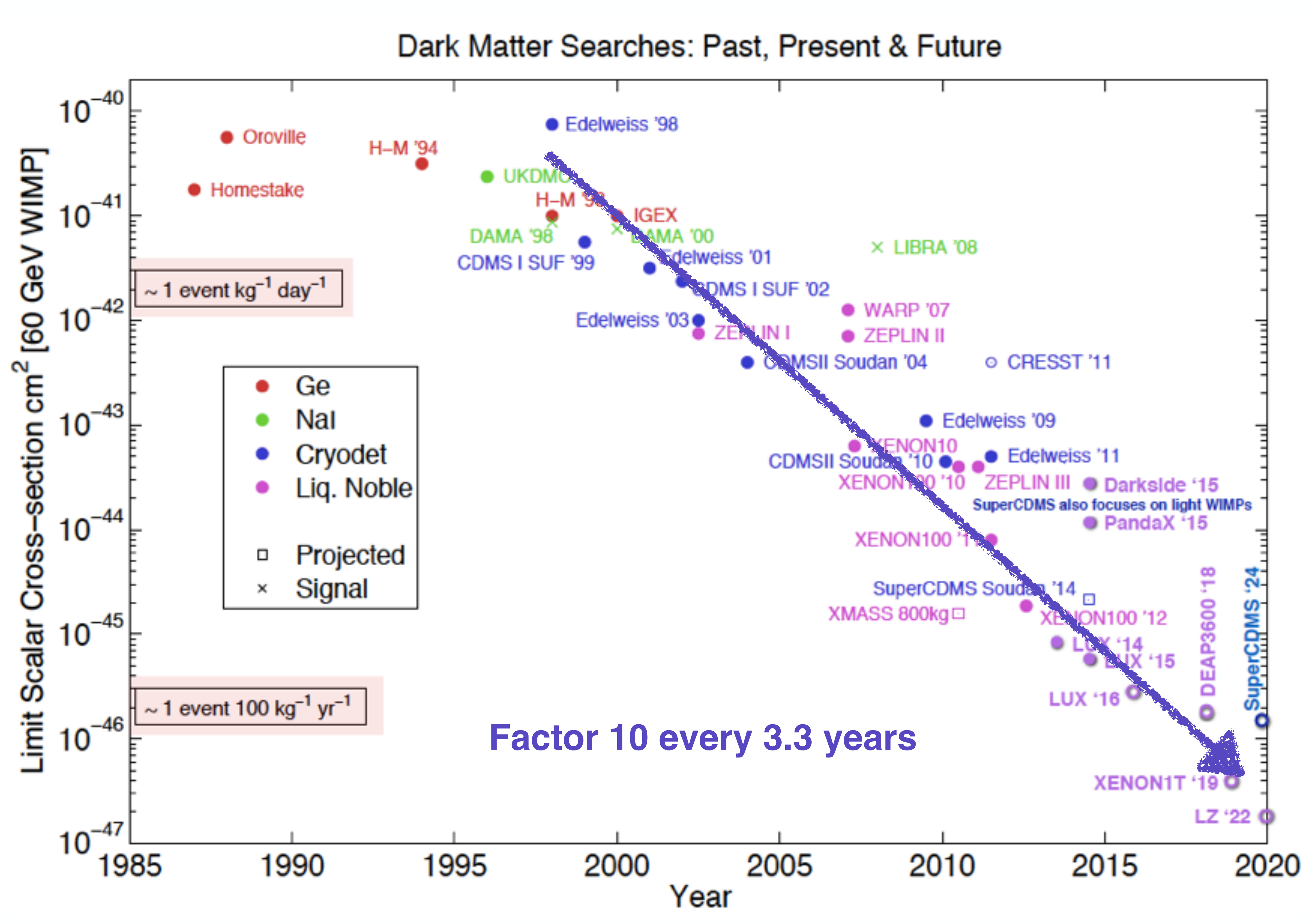
Low energy nuclear recoils (< 100 keV)

Low rate (~1 event/ton/yr for $\sigma = 10^{-47}$ cm^2)

→ Ideal WIMP Detector

- Large mass, long exposure
- Low threshold
- Low radioactive bg
- Good bg discrimination

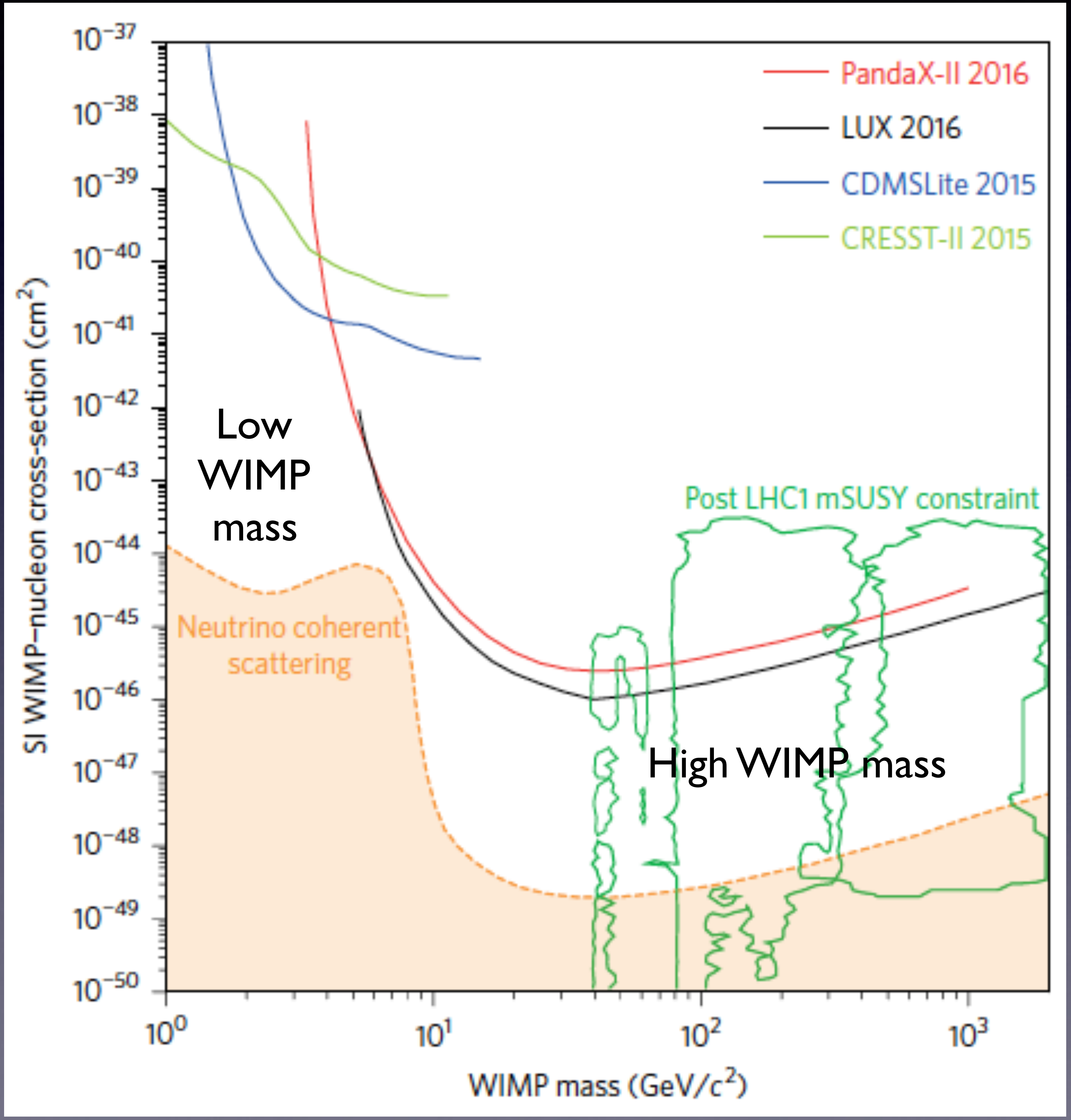
WIMP search sensitivity improvement in both directions: high and low masses



R. Gaitskell IDM2016

Available parameter space for WIMPs

- High mass
  - no observations so far
- Low mass
  - a number of close contours and exclusion limits



NATURE PHYSICS DOI: 10.1038/NPHYS4039

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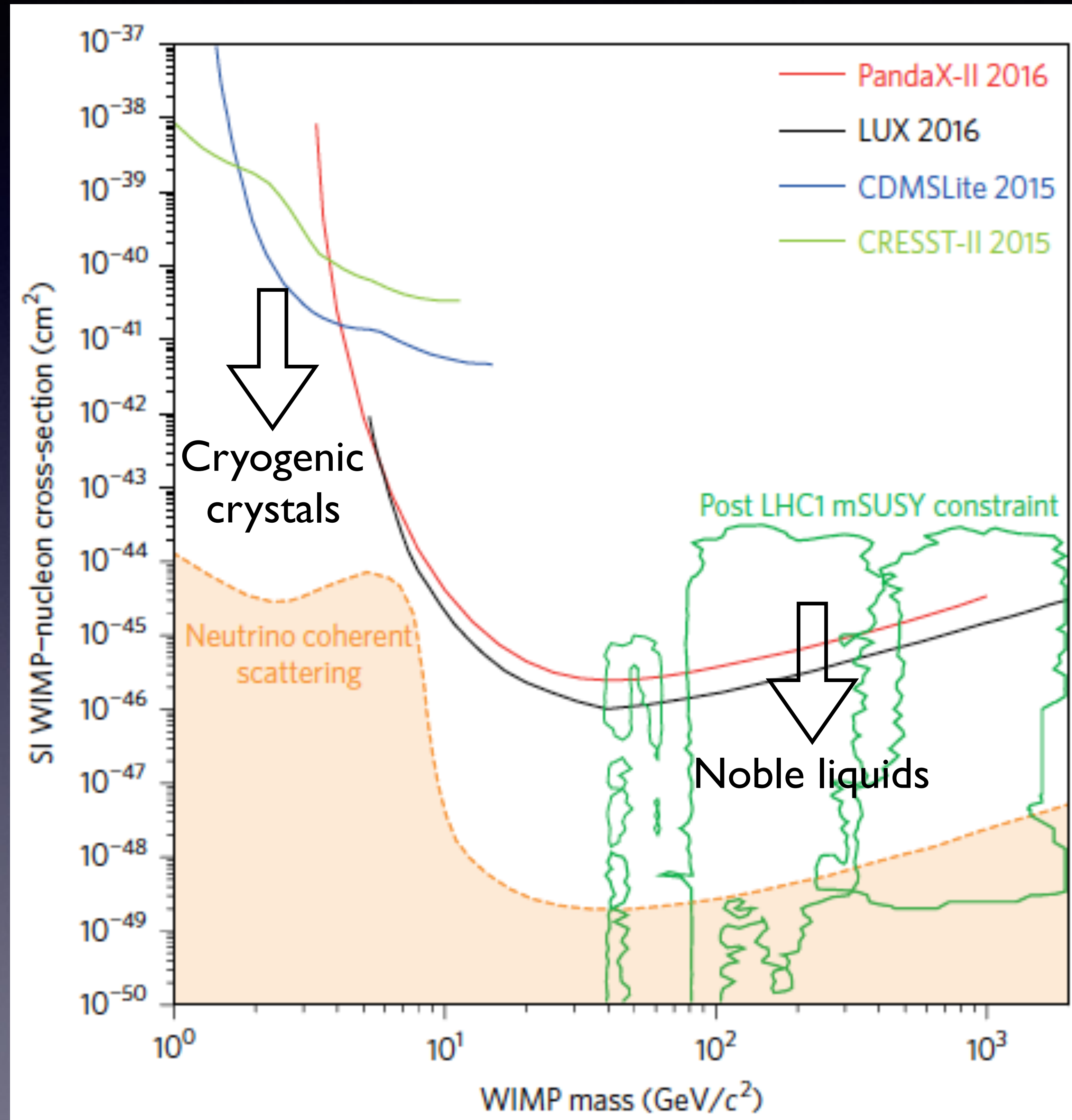


NATURE PHYSICS DOI: 10.1038/NPHYS4039

Reaching the Neutrino Floor

irreducible neutrino background (from coherent nuclear recoils) due to several astrophysical sources (Sun, atmosphere, and diffuse Supernovae)

Coherent neutrino scattering on Nucleus (CNS)

$$\nu_x + (A, Z) \rightarrow \nu_x + (A, Z)$$

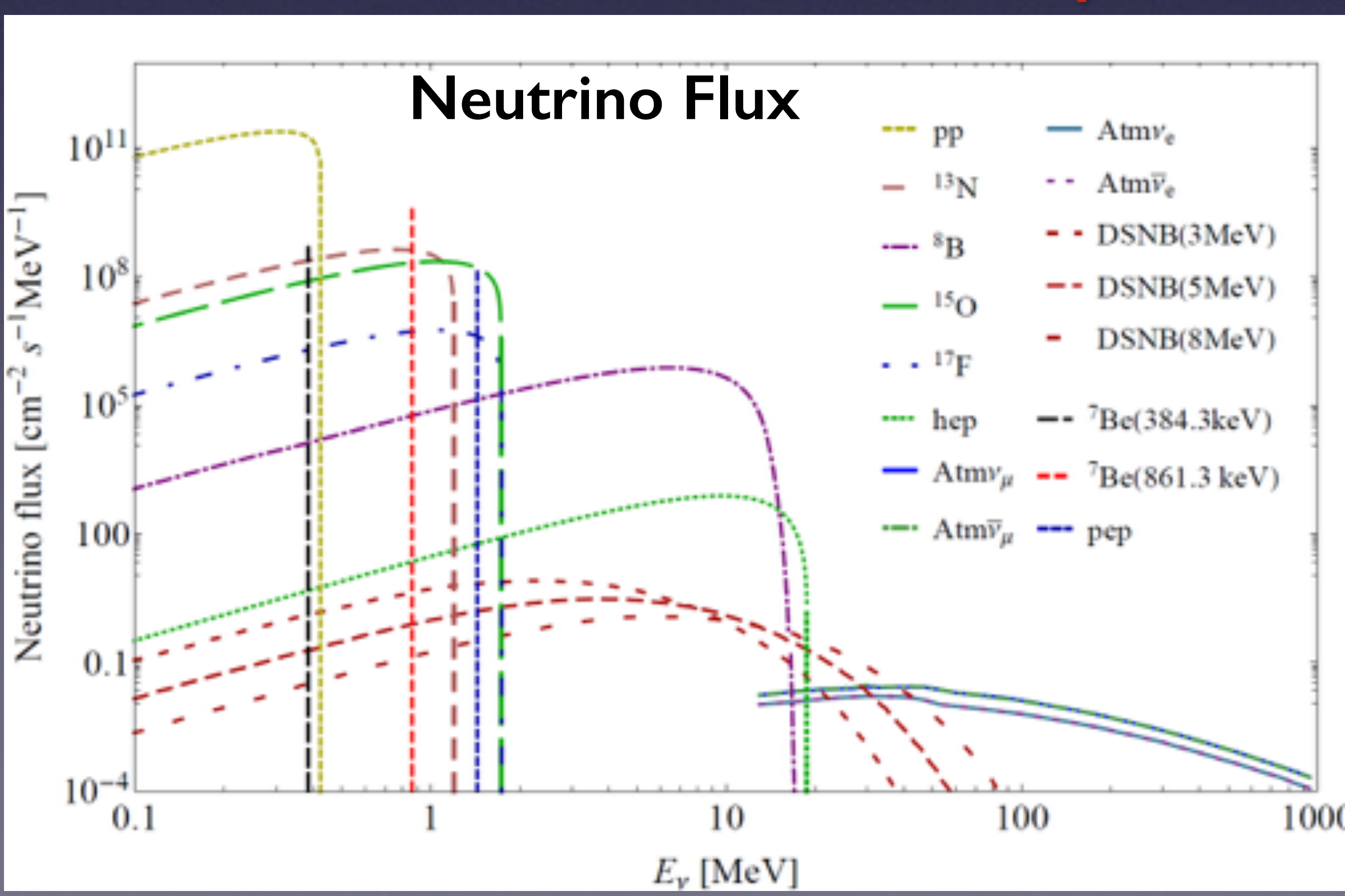
$$\frac{d\sigma^{CNS}(E_\nu, E_r)}{dE_r} = \frac{G_f^2}{4\pi} Q_w^2 m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) F^2(E_r)$$

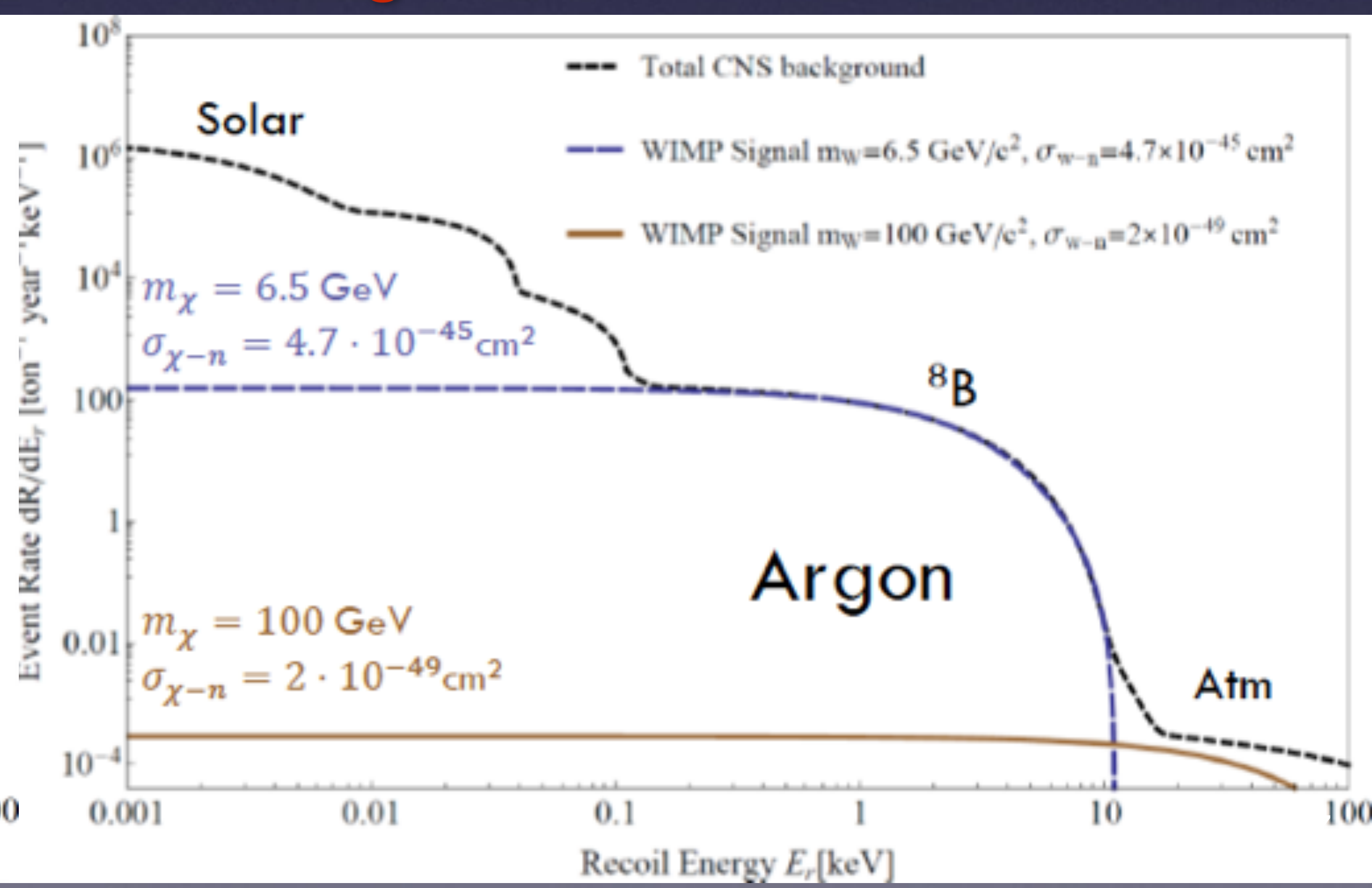
$$E_r^{max} = \frac{2E_\nu^2}{m_N + 2E_\nu}$$

$$Q_w = N - (1 - 4\sin^2\theta_W)Z$$

A WIMP signal could almost perfectly be mimicked by solar and atmospheric neutrino backgrounds

M. Cadeddu





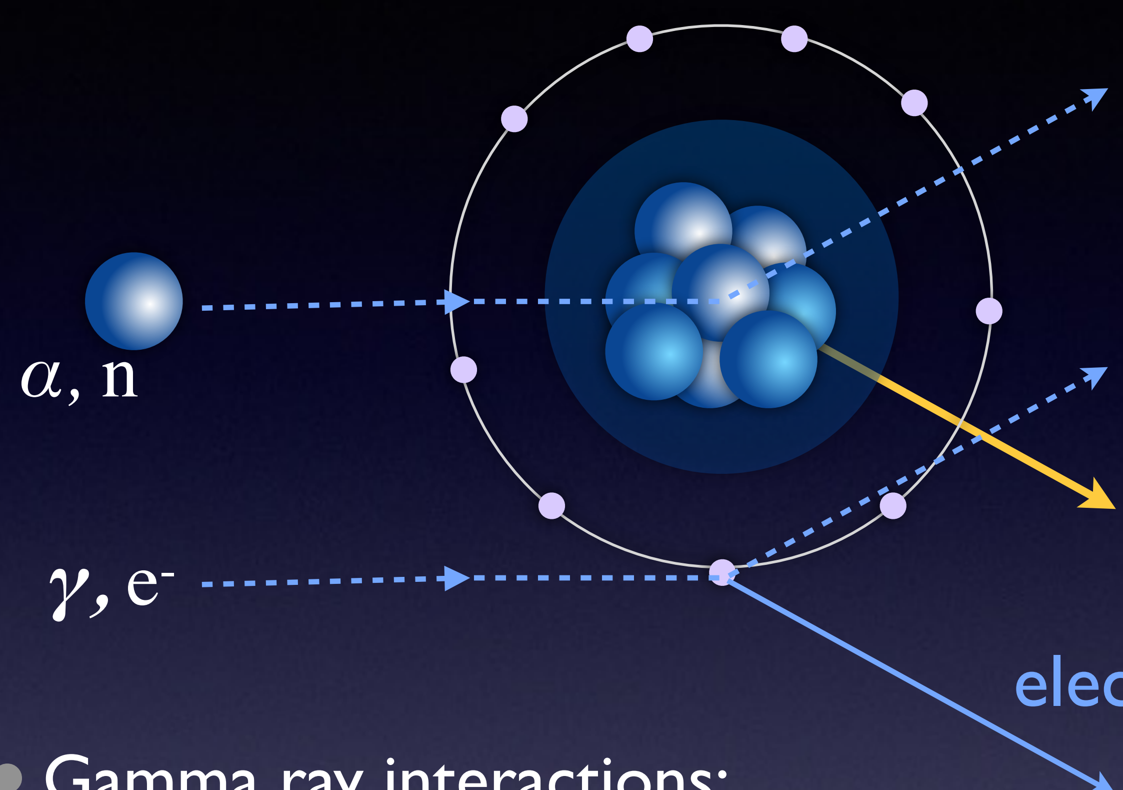
Experimental Backgrounds

from natural radioactivity:

$\gamma\, e^- \rightarrow \gamma\, e^-$

$nN \rightarrow nN$

$N \rightarrow N' + \alpha, e^-$



- Gamma ray interactions:

  mis-identified electrons mimic nuclear recoil signals

- Neutrons:

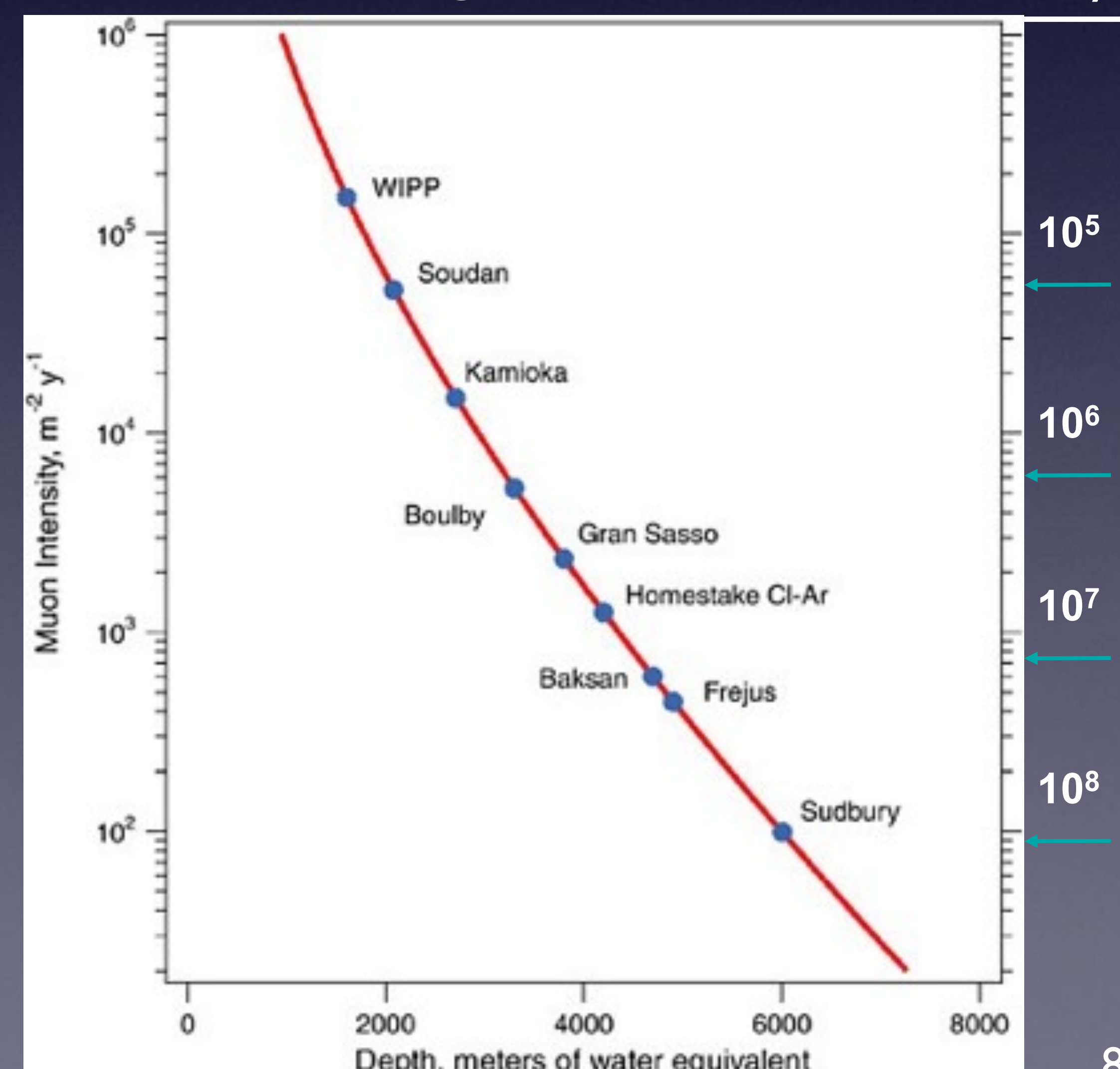
  (α,n), U, Th fission, cosmogenic spallation →

- Contamination:

  ^{238}U and ^{232}Th decays, recoiling progeny mimic nuclear recoils

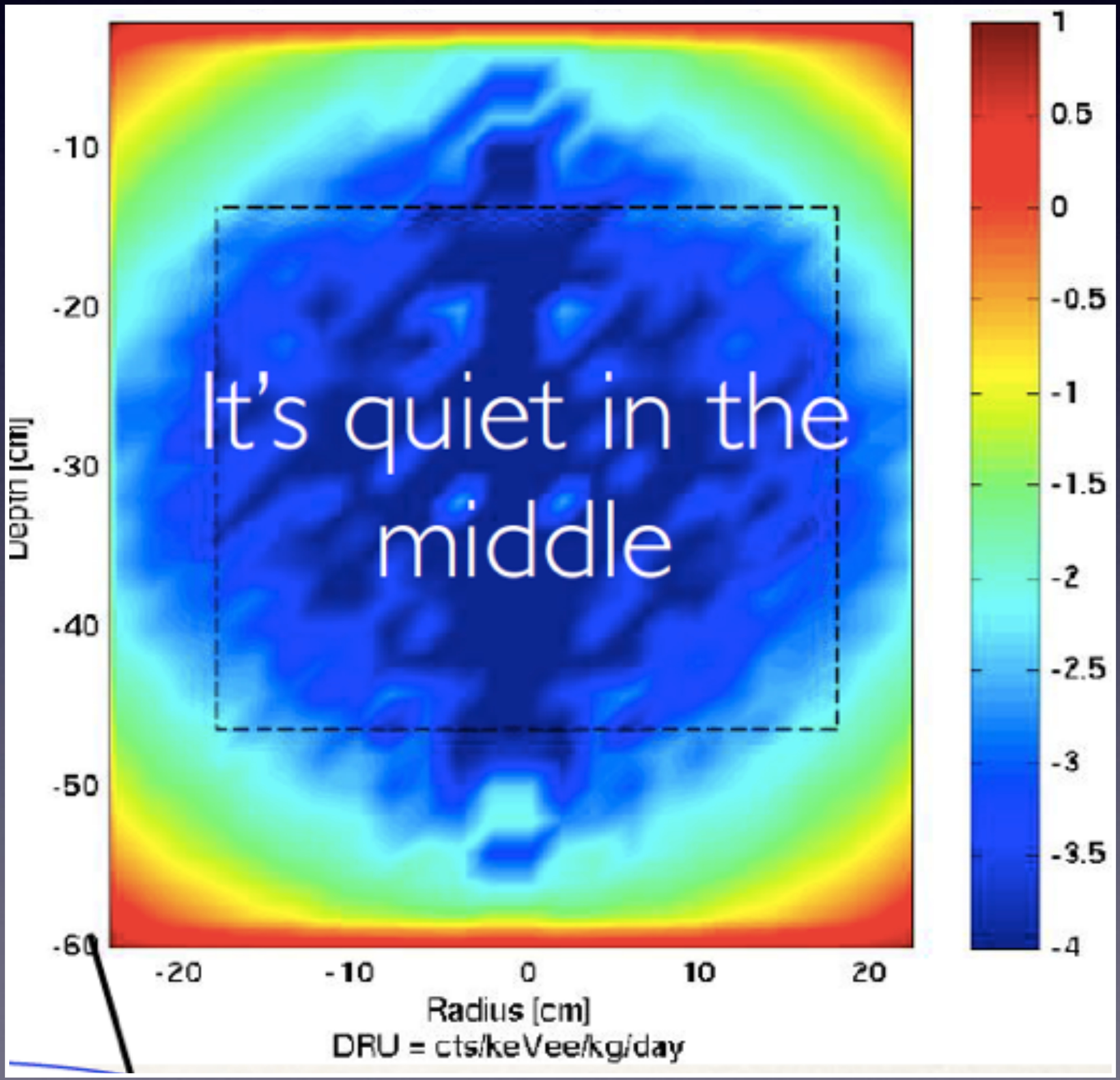
Underground labs

reduction of muon flux by:



How to defeat backgrounds

3-D localization of events can provide self fiducialization
→ background reduction

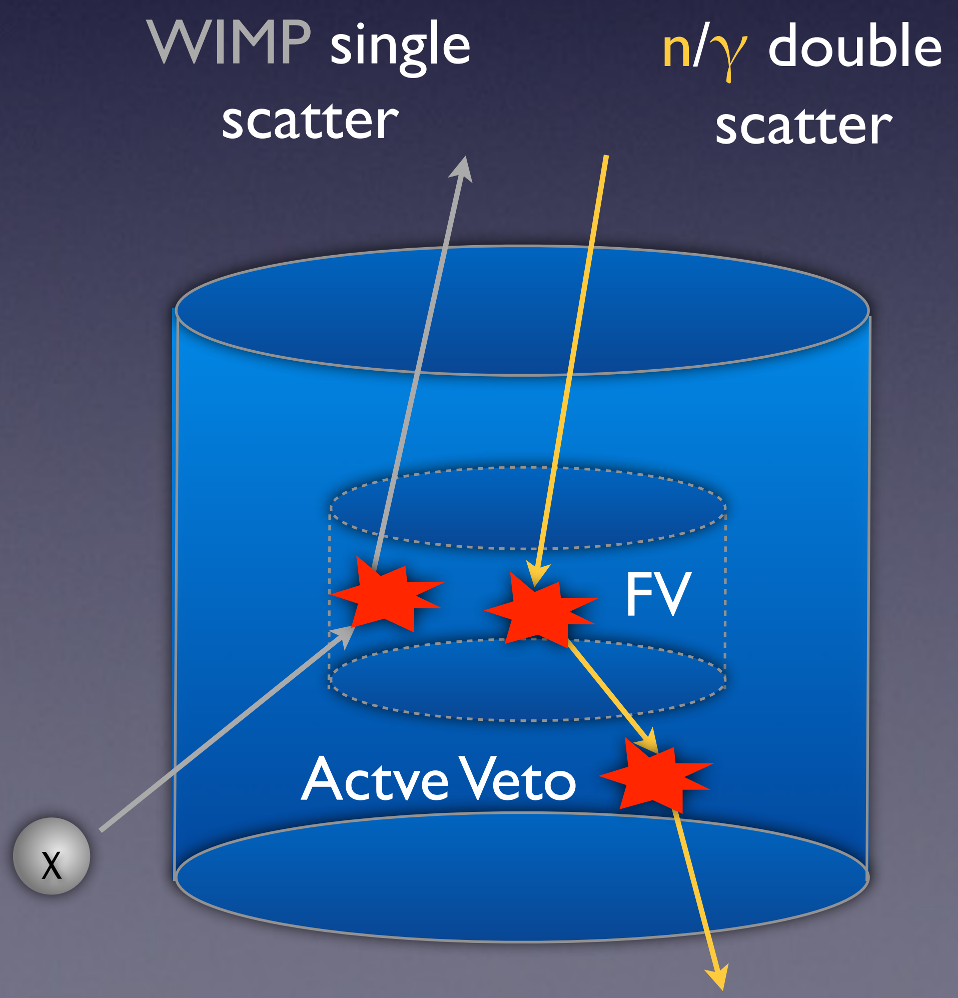


A. Manalaysay, LUX: IDM2016

Discriminating backgrounds

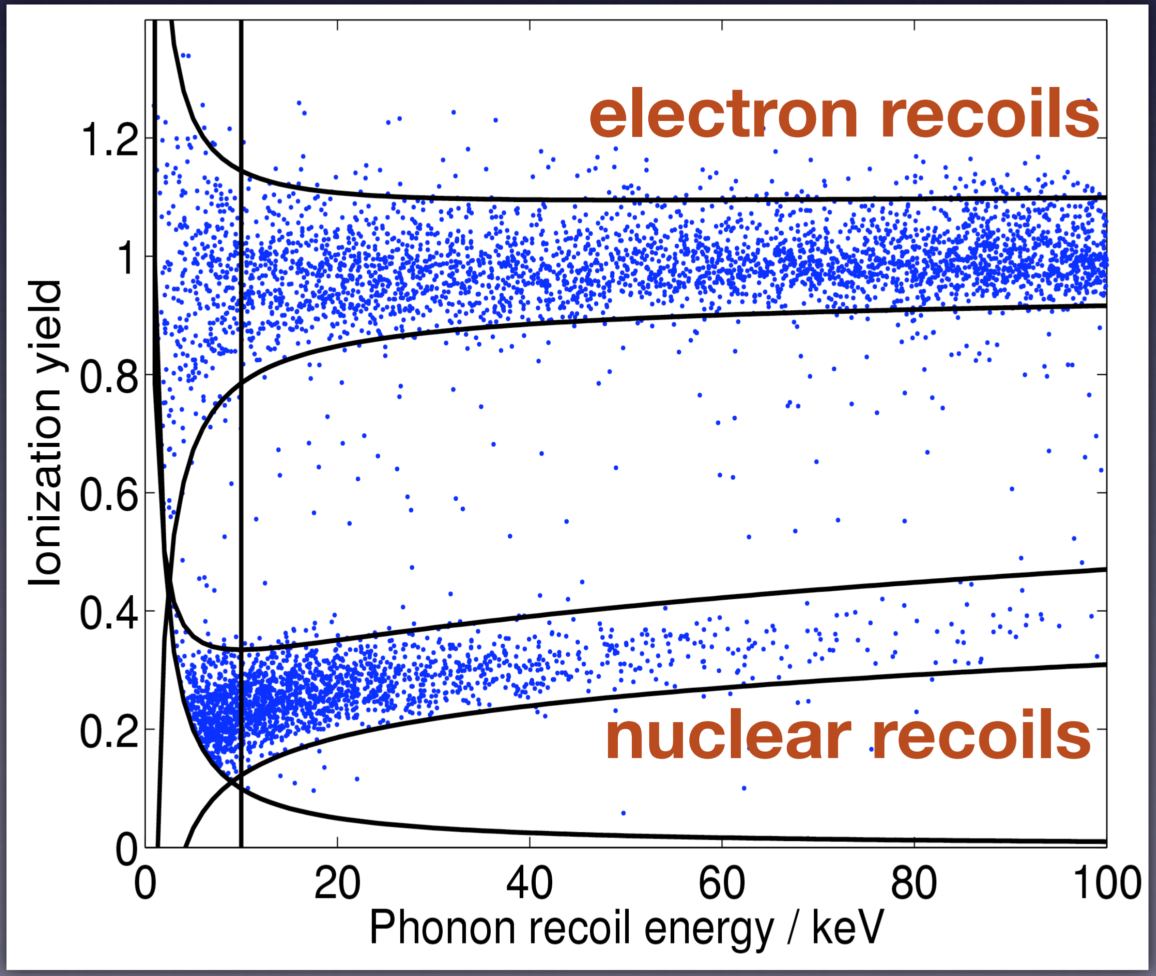
Active veto shield and fiducialization
→ identification of neutron recoils

Signal split in two components which respond differently to NR/ER
→ separation of S and B



Background region

Expected signal region



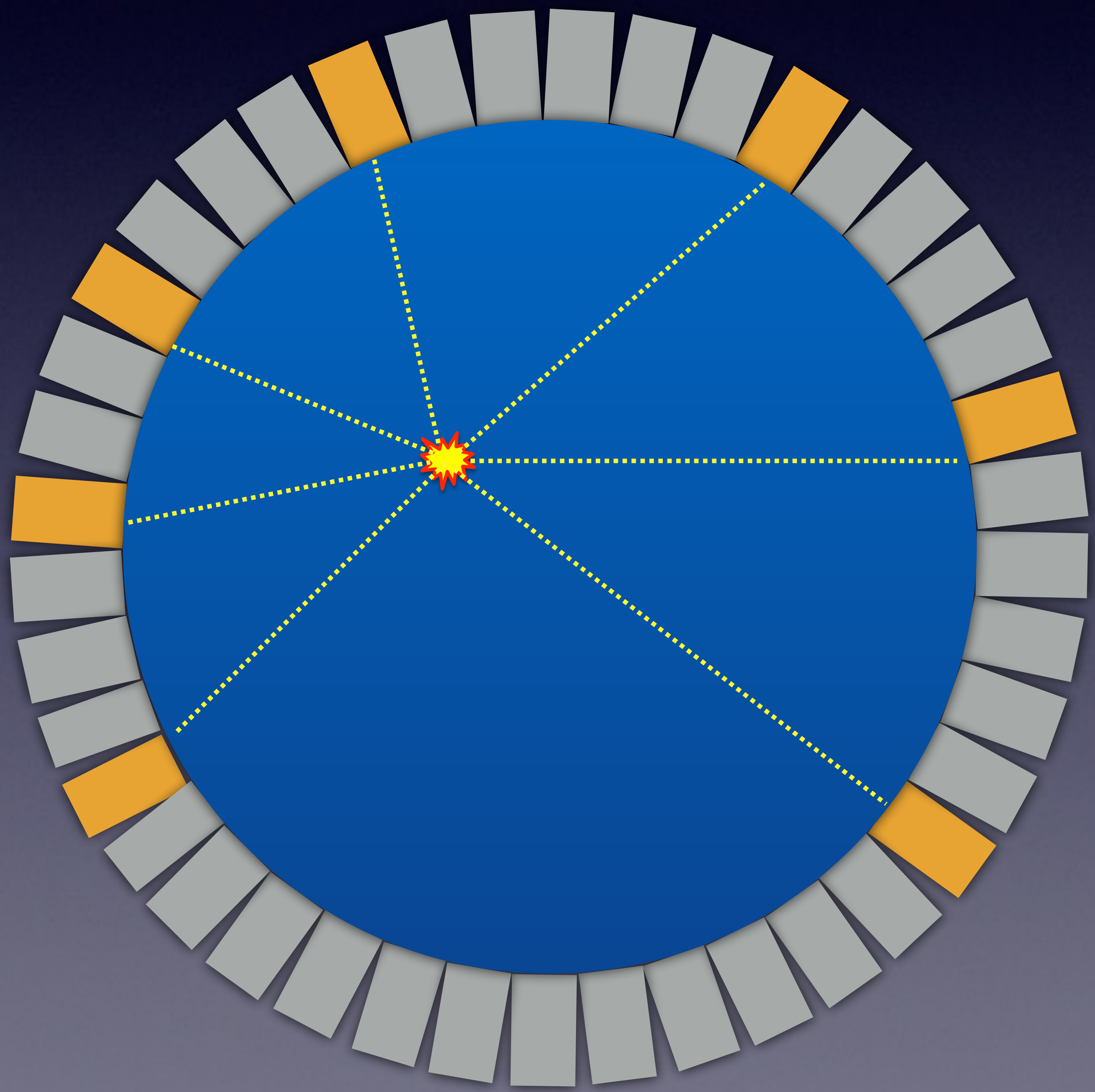
High mass WIMPs: noble liquids

Light & Charge:	Xenon
	LUX/LZ
	Panda-X
Light:	XMASS

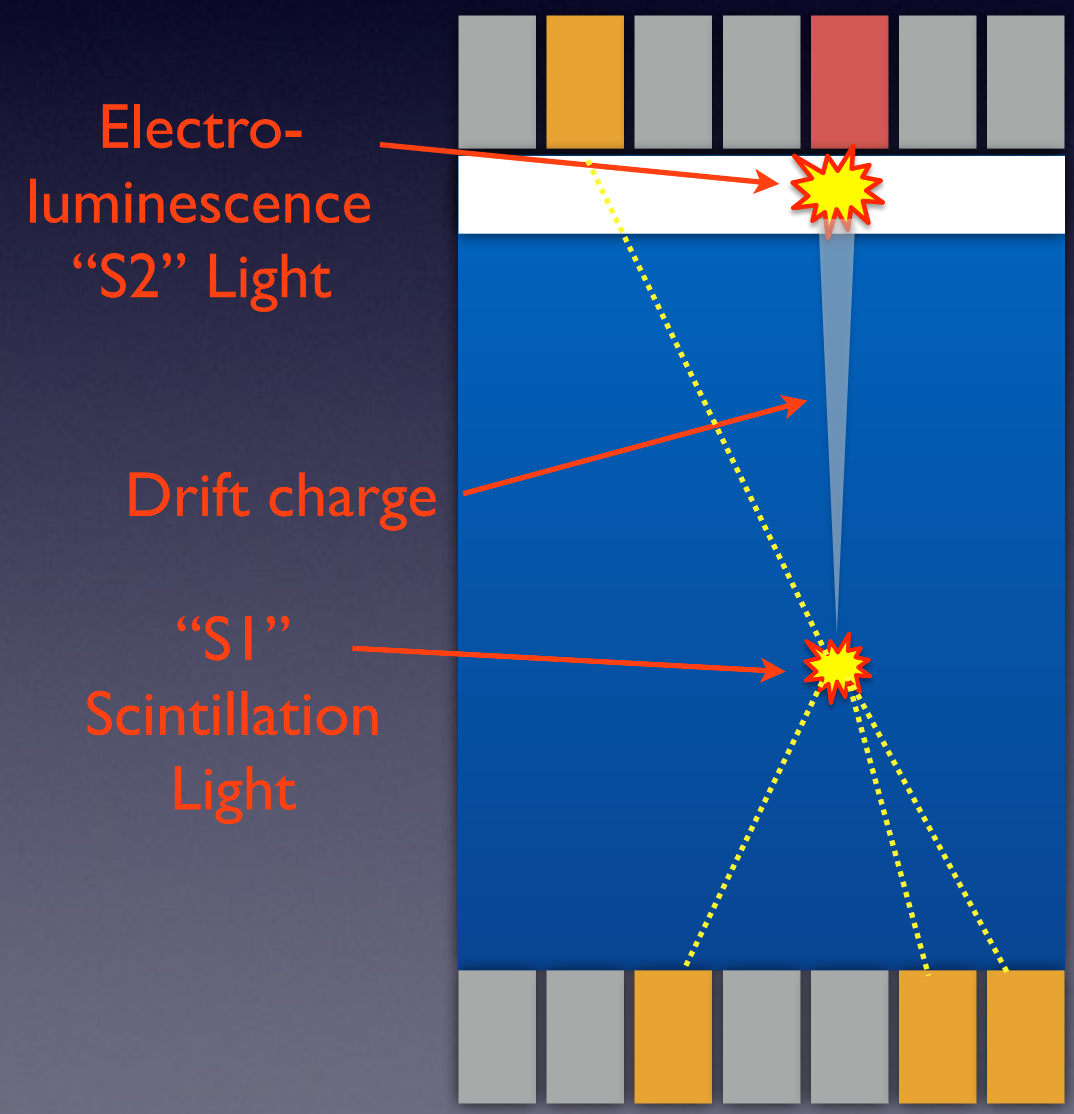
Light & Charge:	DarkSide
	ArDM
Light:	MiniCLEAN
	DEAP-3600

Detector concepts

Single phase 4π scintillation
Light



Dual phase TPC
Light & Charge

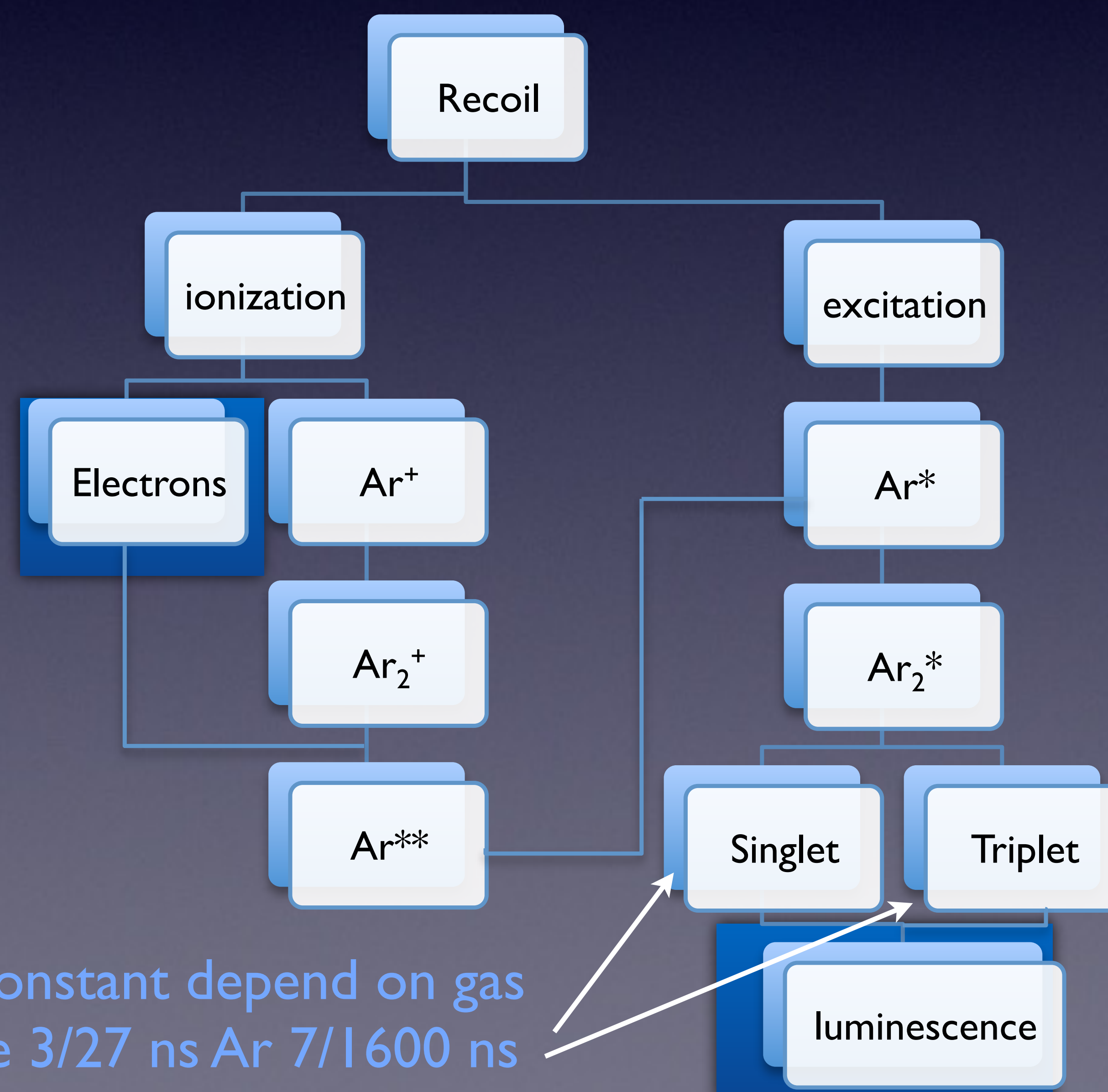


Why noble liquids

- Large mass detectors → scalability, fiducialization
- Multiple targets available: Xe, Ar
- Bright scintillators: Light Yield ~ 40 γ/keV → low threshold

Two detection channels:
ionization charge
scintillation light

different dE/dx from nuclear and electron recoils
→ background discrimination

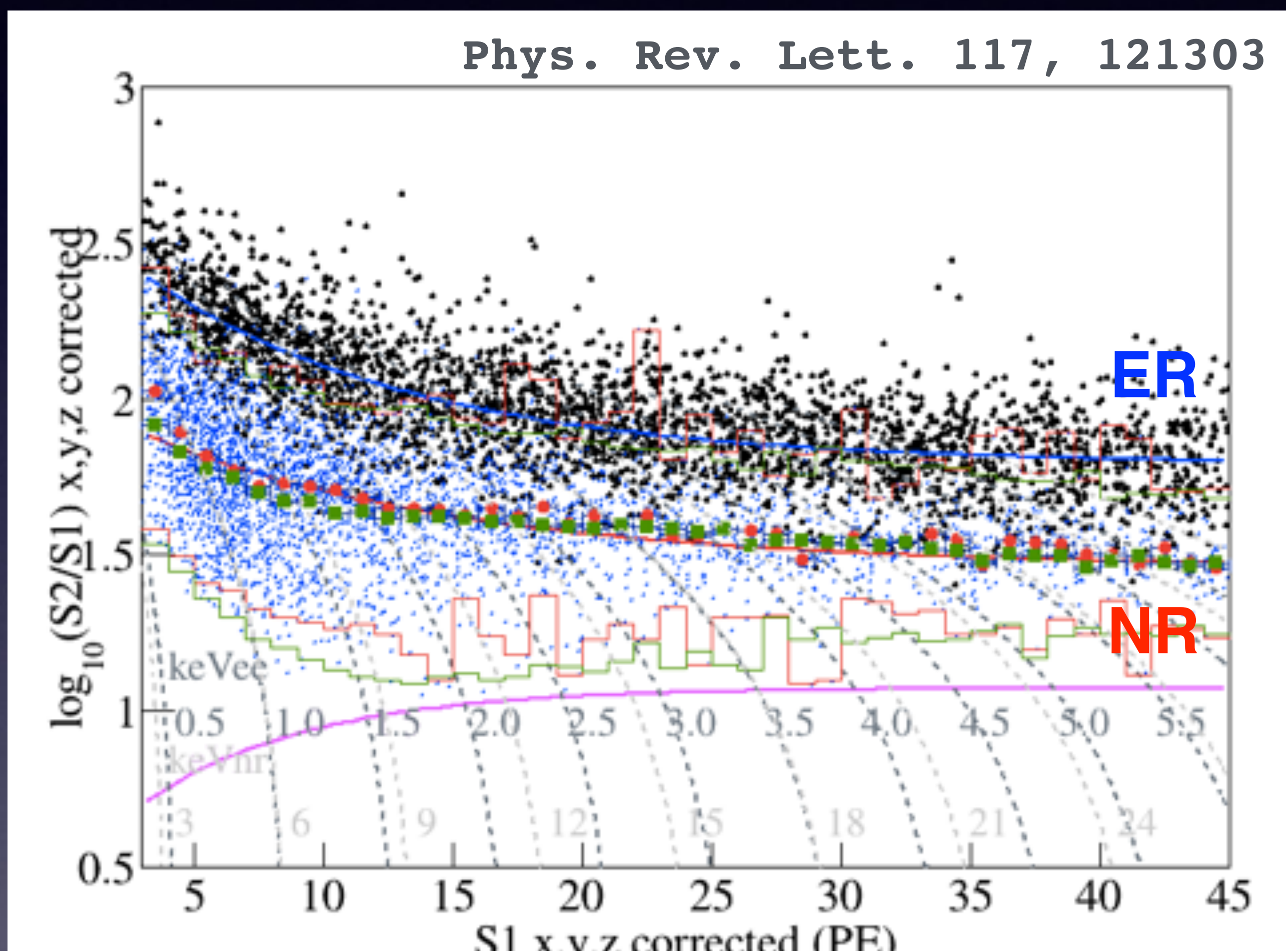


PSD in argon

time constant depend on gas
e.g. Xe 3/27 ns Ar 7/1600 ns

ER/NR discrimination

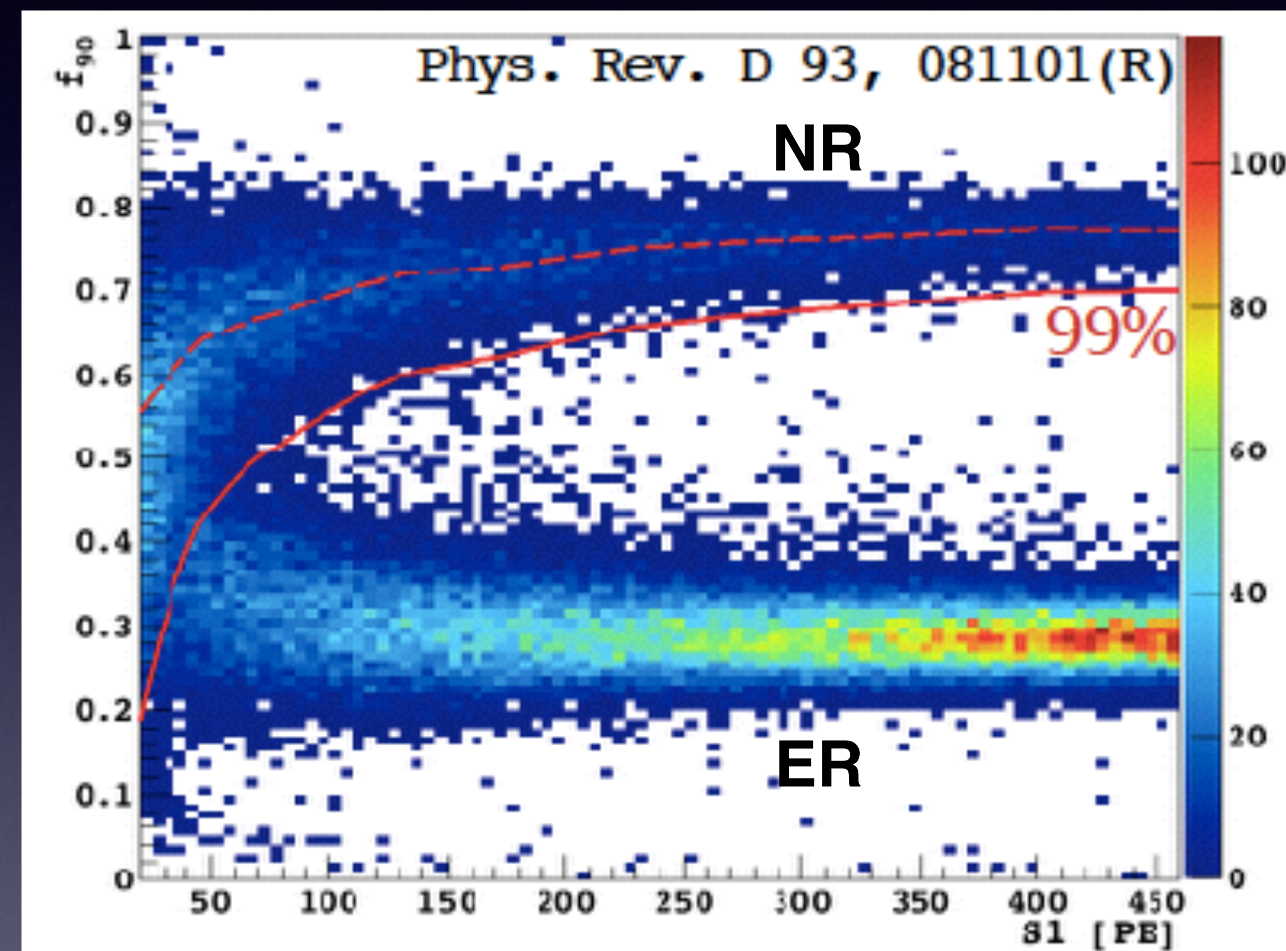
Ratio of charge to light in LXe



Tritium and AmBe calibrations in PandaX

Discrimination power ~ 10^3 (PandaX)

Pulse shape discrimination in LAr



NR band from the AmBe calibration and lower ER band from β-γ backgrounds

Exceptional discrimination > 10^8 (DarkSide)

Noble liquid dual phase TPC

LUX @ SURF LXe

- 48cm×48cm, 250 kg target
- in-situ NR calibration studies
  arXiv:1608.05381

New result August 2016

Phys. Rev. Lett. 118, 021303 (2017)

- 3.4 10^4 kg d = 0.1 t yr
- no signal excess
- 2.2 10^{-46} cm^2 @ 50 GeV

PandaX-II @ CJPL LXe

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

New result July 2016

Phys. Rev. Lett. 117, 121303 (2016)

- 3.3 10^4 kg d = 0.1 t yr
- no signal excess
- best limit above ~4.5 GeV

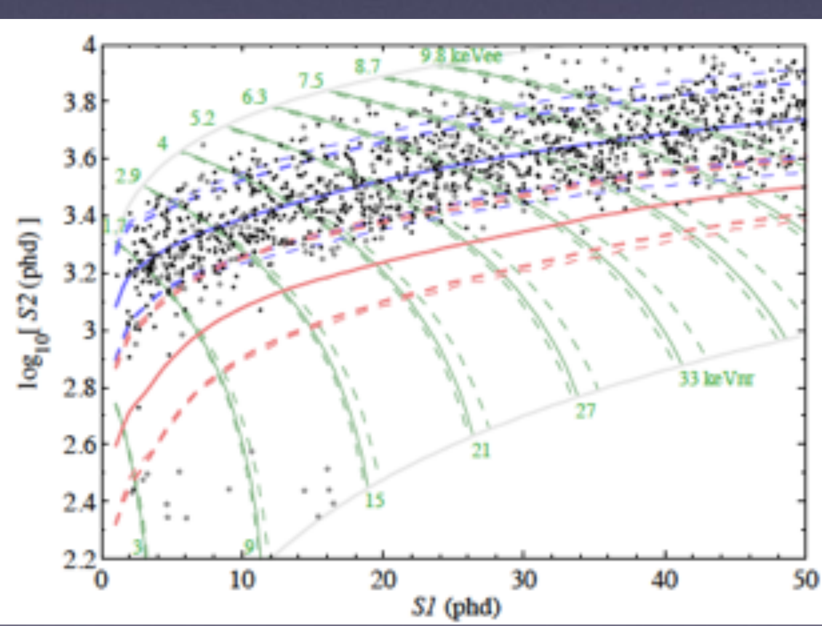
DarkSide-50 @ LNGS UAr

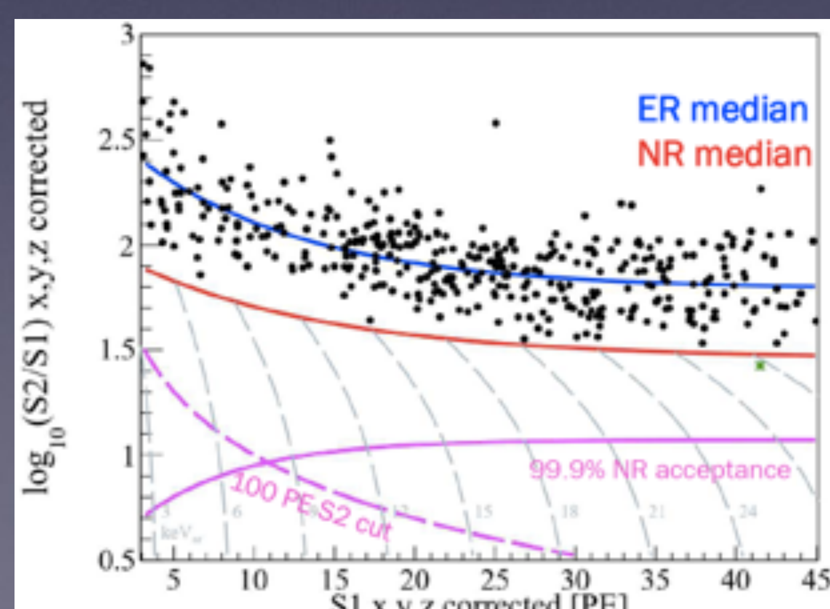
- 36cm×436cm, 46 kg active target
- inside a LSci 30 t neutron veto and a 1 kt Water Cerrenkov muon veto

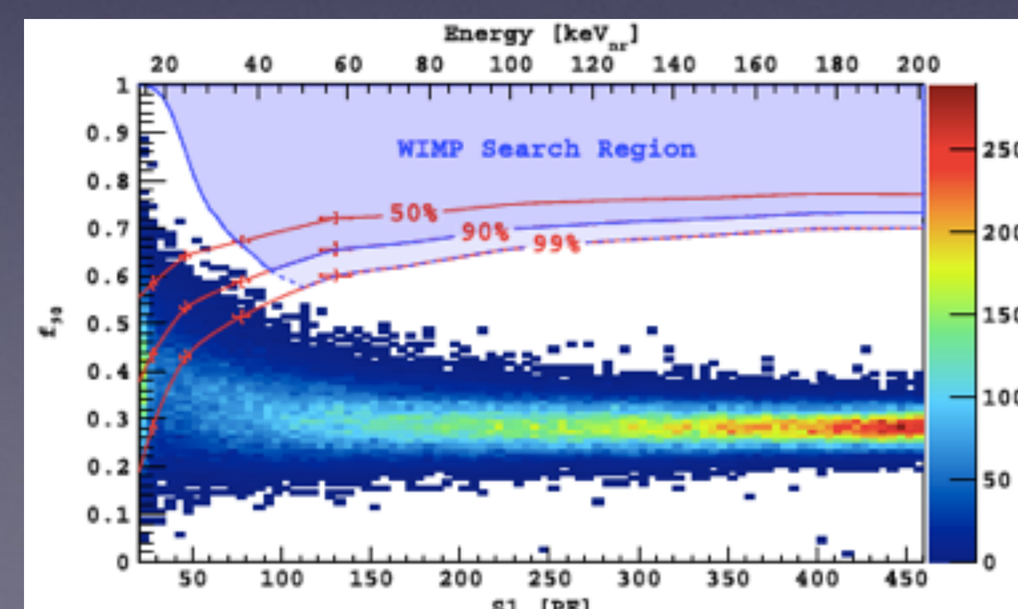
Latest result October 2015

Phys. Rev. D 93, 081101(R)

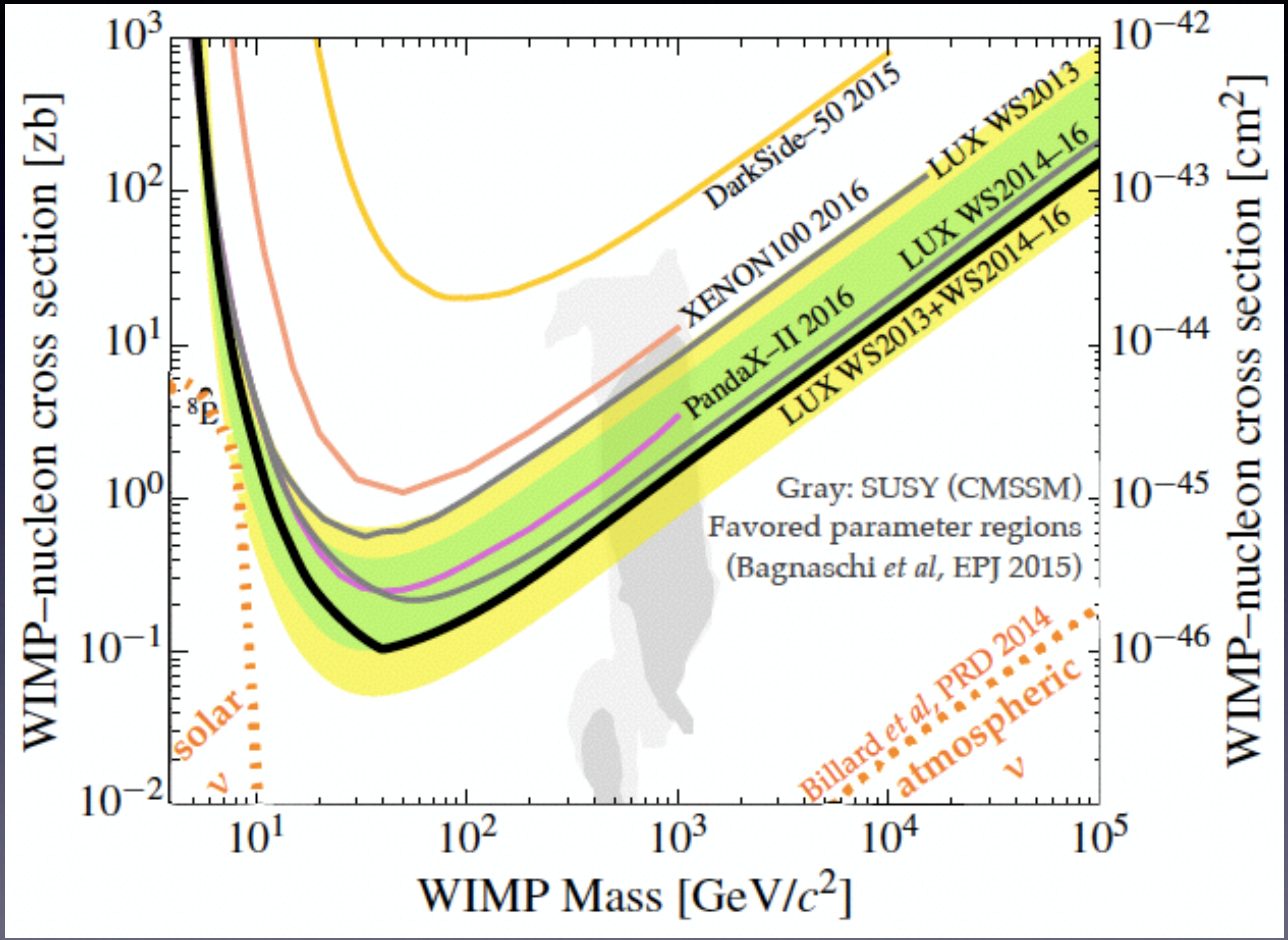
- 2616 kg d exposure
- no signal excess
- 2.0 10^{-44} cm^2 @ 100 GeV







Noble liquid dual phase TPC



E. Pease, Berkeley December 2016

LUX results combined 1.1 10^{-46} cm^2 at 50 GeV

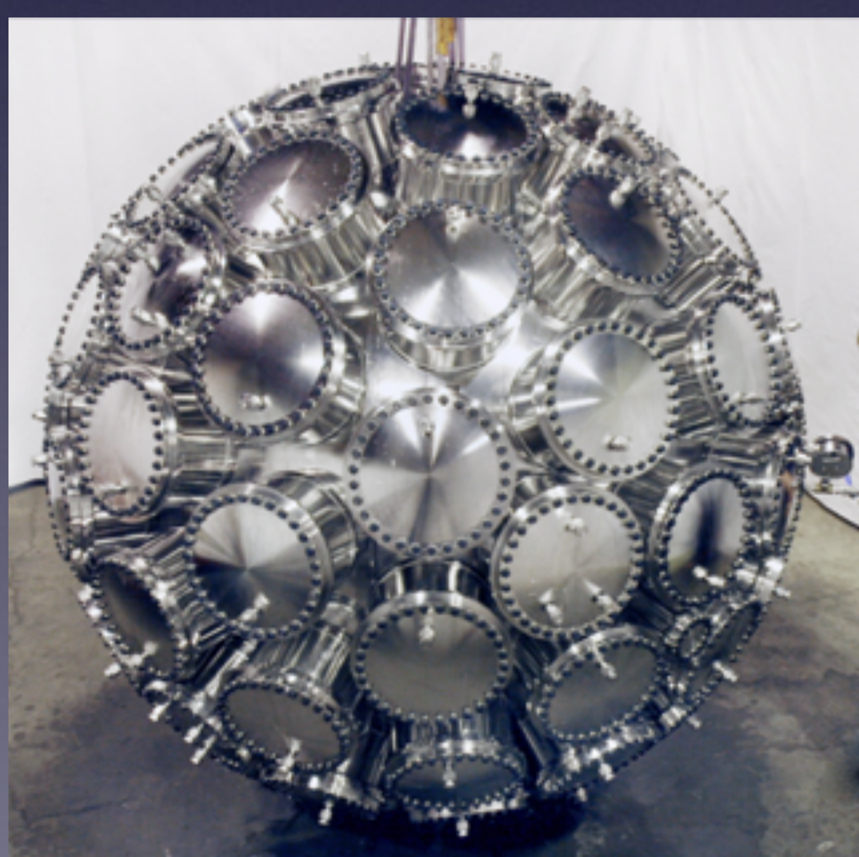
LAr reaching ton scale

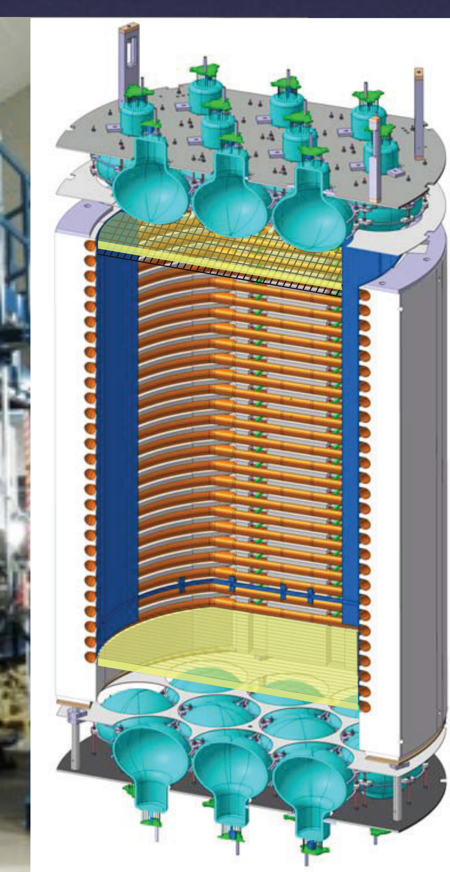
MiniCLEAN @ SNOLAB

- 500 kg active LAr, single phase
- Detector atmospheric liquid argon fill underway
- technology demonstrator: light yield, background levels, position reconstruction,…
- Planned ^{39}Ar spiked data for PSD R&D at 10^{-10} level

ArDM @ LSC

- 850kg active LAr, 500 kg fiducial, dual phase
- Summer 2015: completed first physics run (single phase)
- Summer 2016: Upgraded for double phase operation — preparation Run II

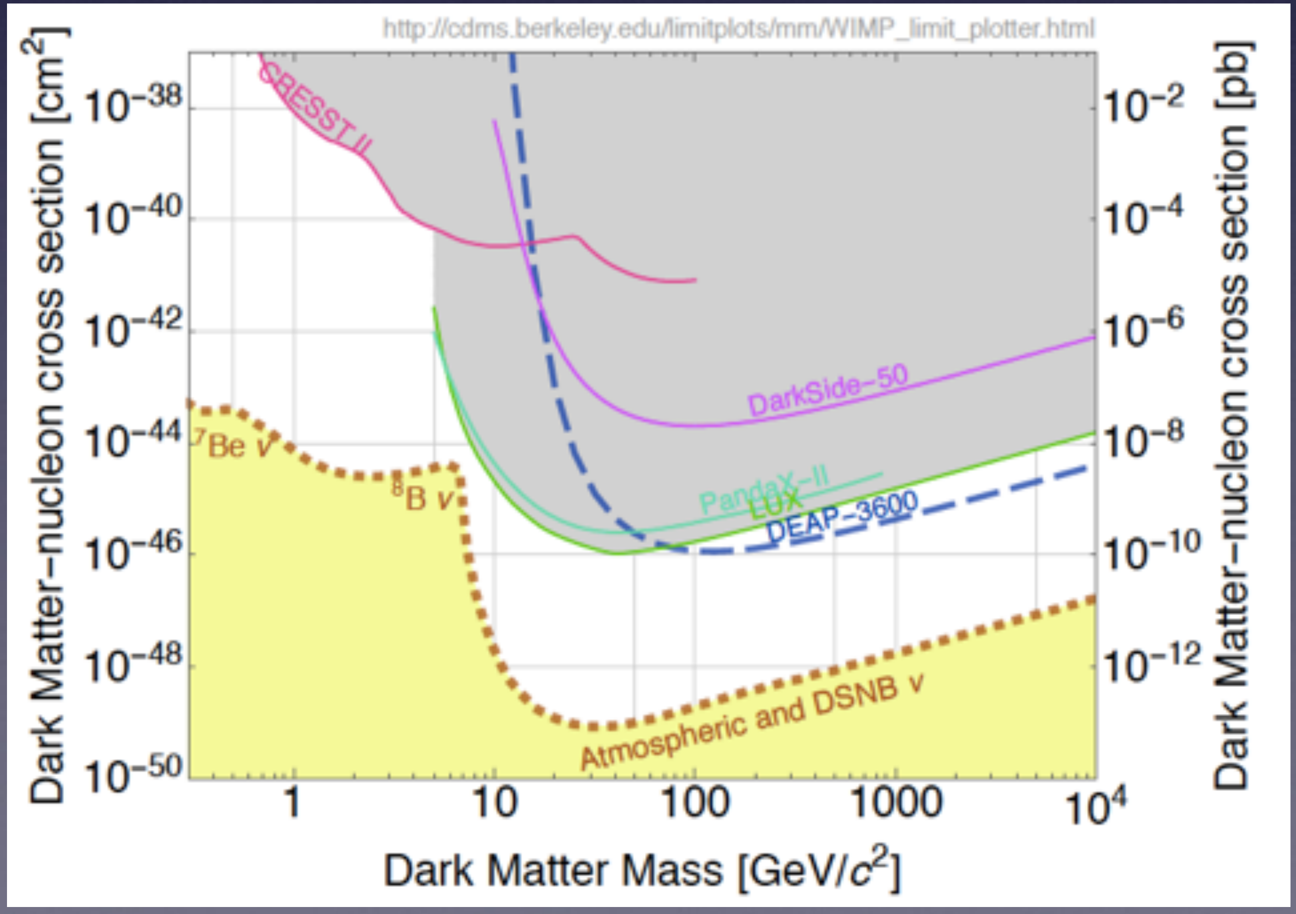




LAr single phase: DEAP-3600 @ SNOLAB

- Acrylic vessel 1.7m diameter, 3.6 ton LAr
- 255 inner PMTs and 48 muon veto PMTs
- Running stably with 3260 kg LAr
- ^{39}Ar beta decays; 1Bq/kg of natural Ar
- Need 10^{10} rejection based on PSD
- Background and WIMP search analysis on-going

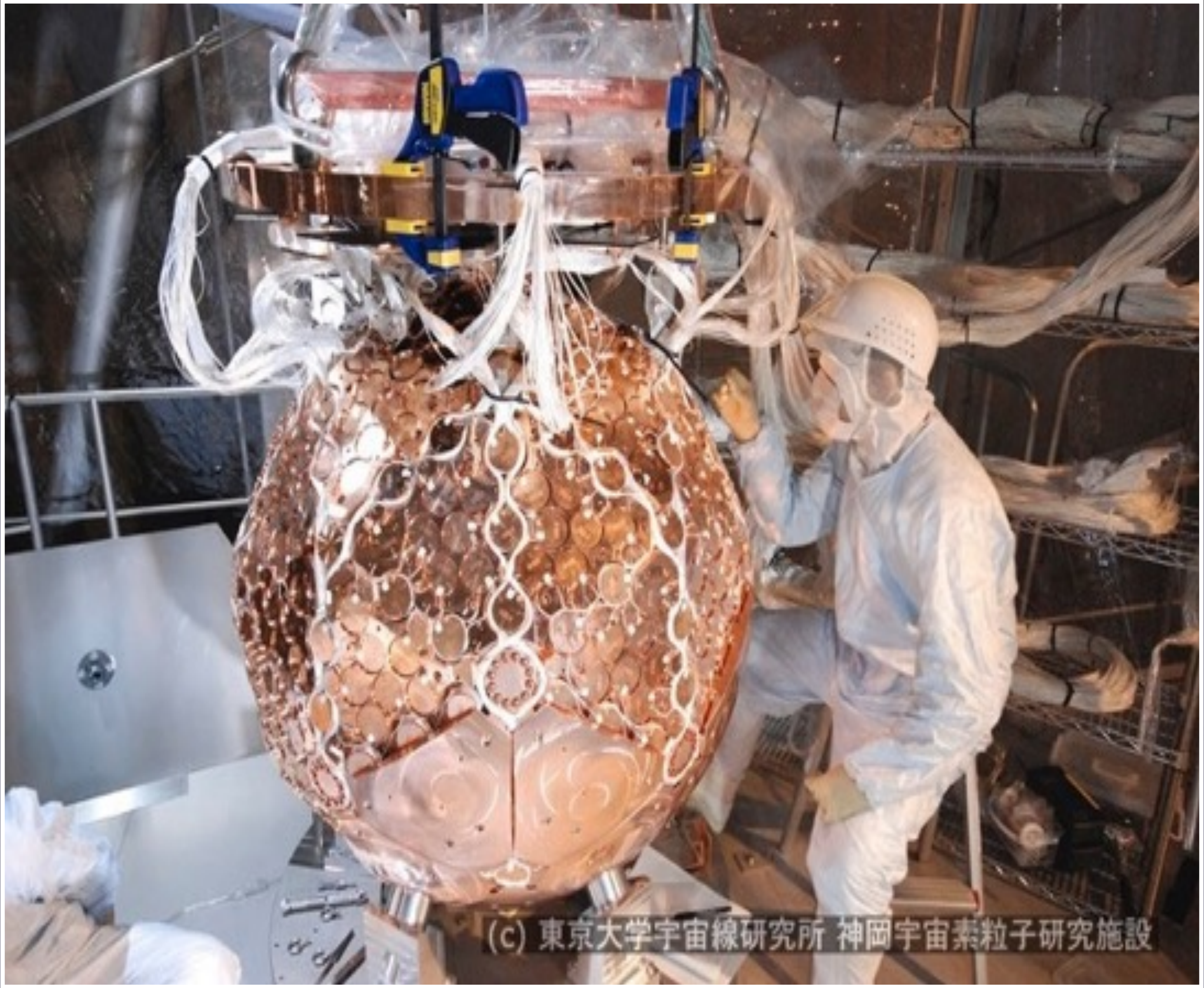
Physics result expected soon



B. Smith, February 2017 – Lake Louise Winter Institute

LXe single phase: XMASS @ KAMIOKA

- 832 kg (100 kg FV) single phase LXe
- 4π coverage, 642 PMT, 15PE/keV
- low threshold (0.5 keVee)
- no NR rejection
- data taking since > 3 yrs
- Multi purpose experiment
  - Light Mass WIMP
  - Solar Axion
  - Super-WIMPs
  - Modulation
  - Double electron capture
  - Supernova etc



Next step: XMASS1.5
- further reduction of BG (Material screening, distillation etc.)
- Reach < 10^{-46} cm^2 for SI interaction of WIMPs with 1×10^{-5} counts/day/kg/keVee BG rate

see next talk by M. Yamashita

XENON1T/XENONnT @ LNGS

Target/Detector:

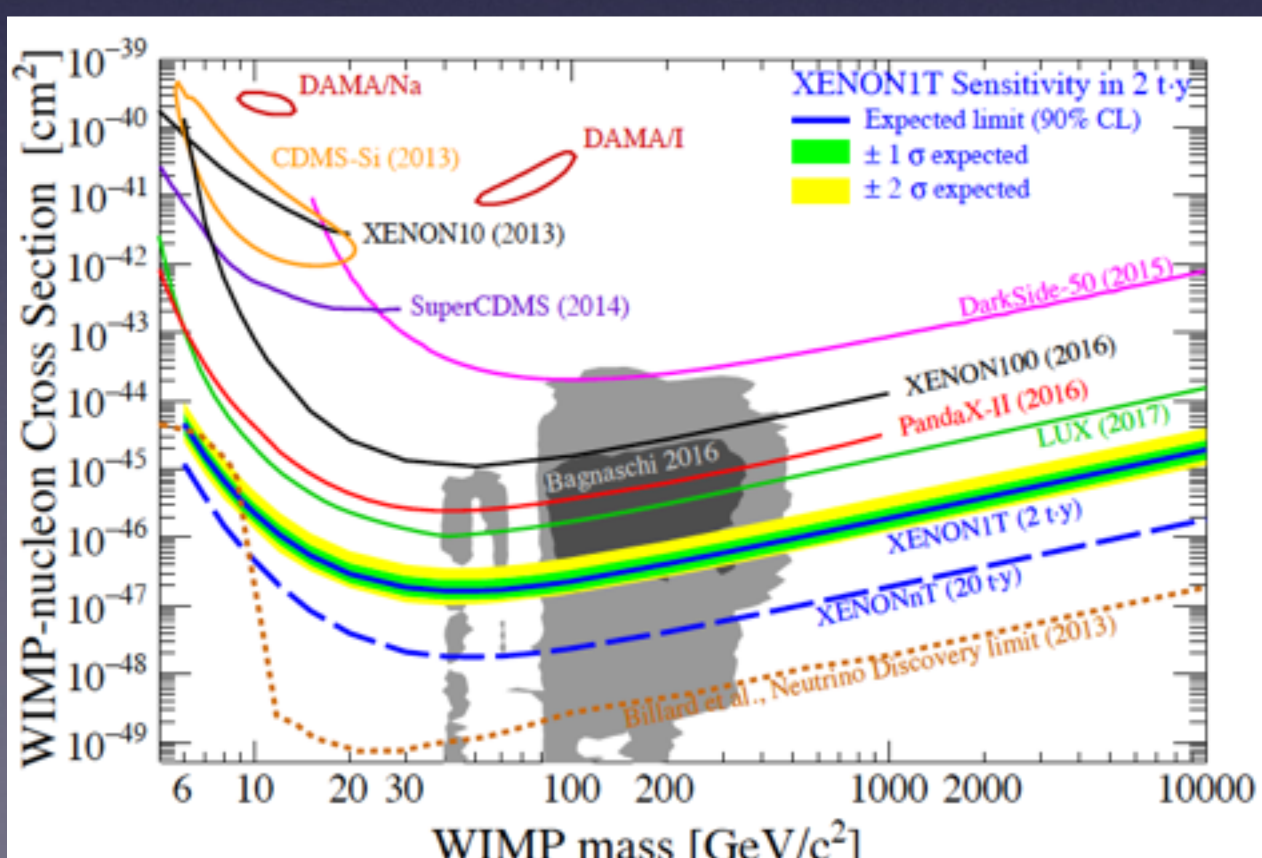
- 3.5 (8) ton XeTPC **in** water Cherenkov muon veto.

Infrastructure and Cryogenic Plants:

- designed for ***XENON1T and its upgrade*** to ***XENONnT***

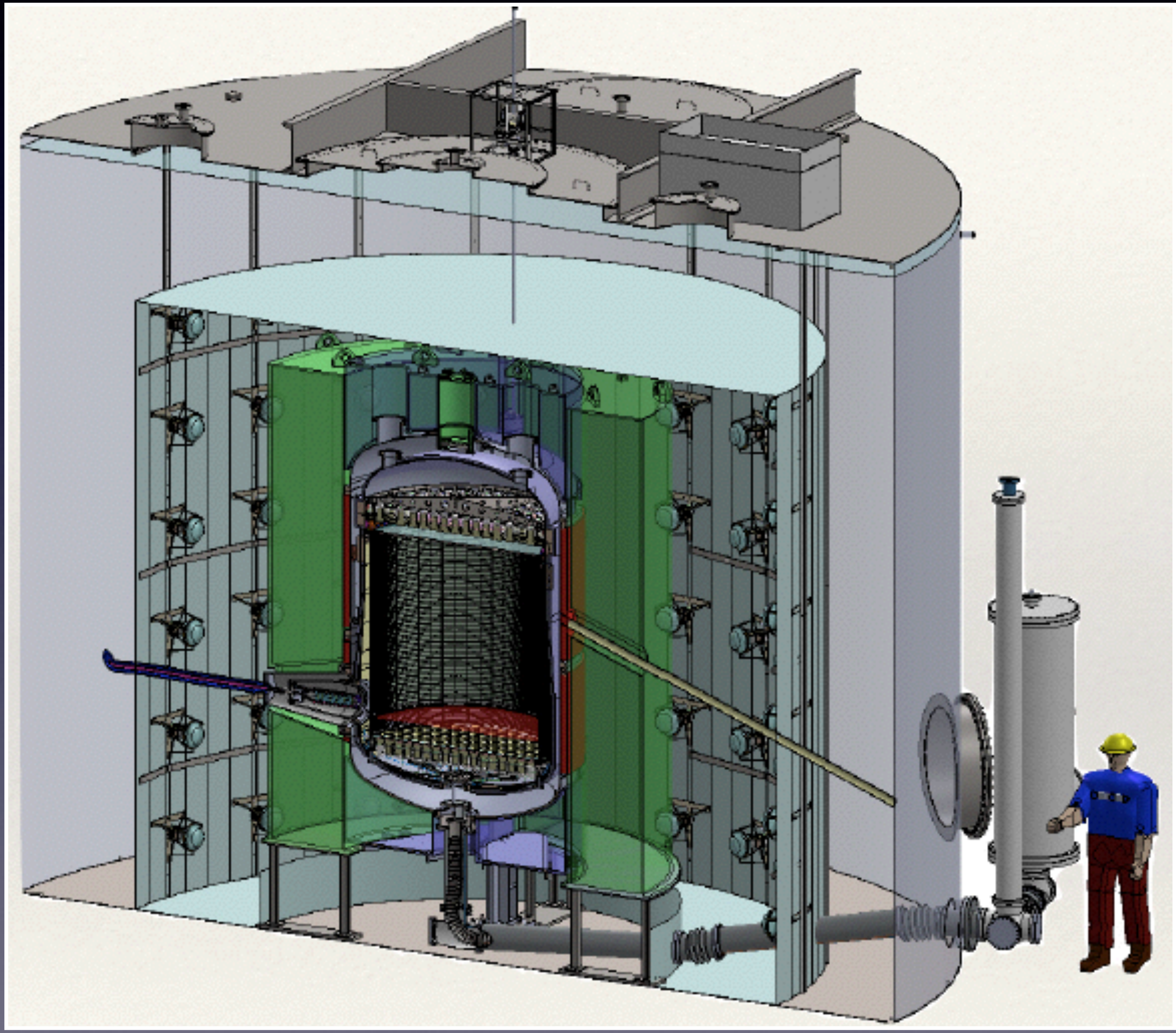
Status:

- **XENON1T** taking dark matter data since end 2016. Resources in place for XENONnT phase to start in Spring 2019

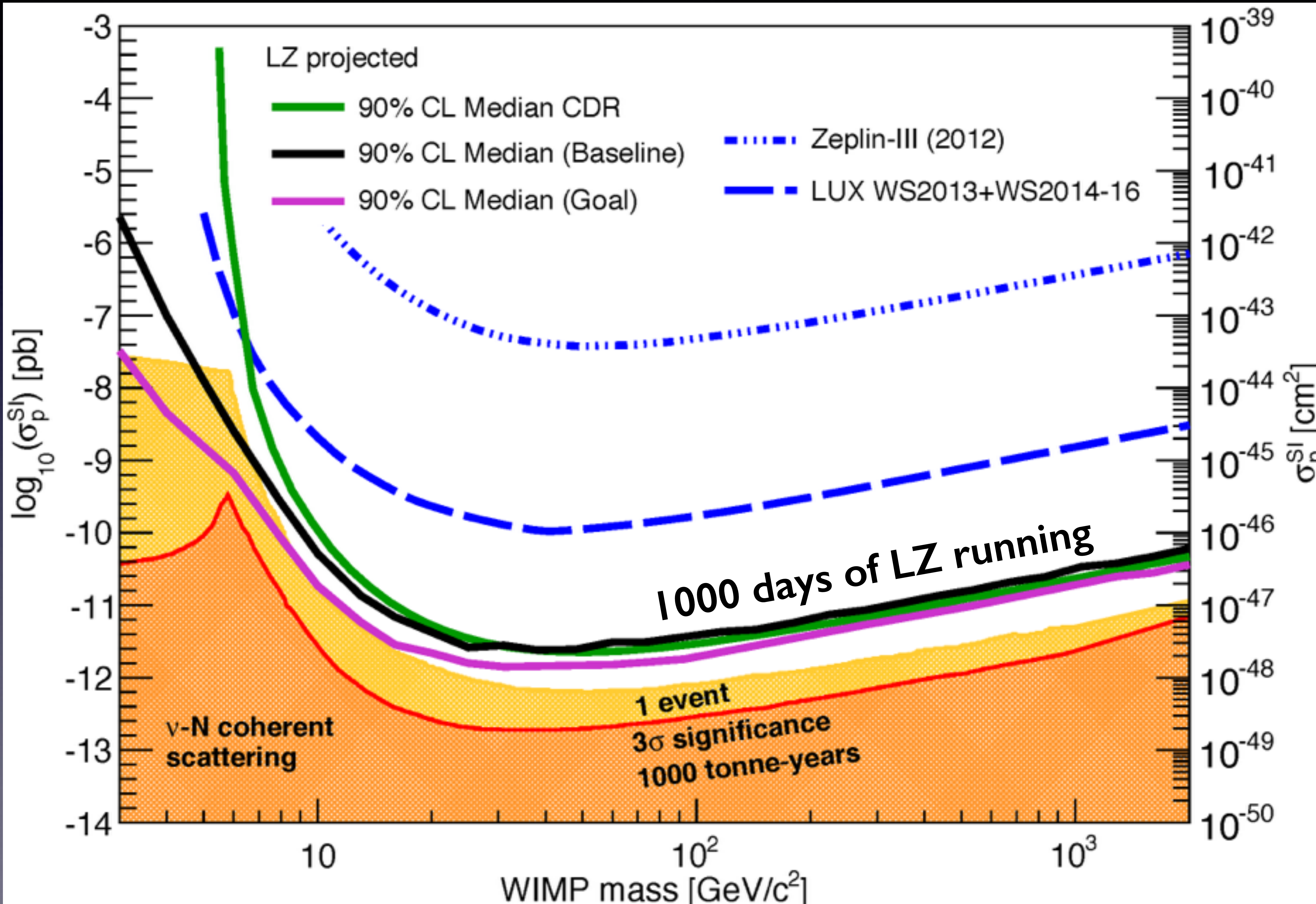


Next future: LZ @ SURF

- 50 × larger than LUX
- 10t total LXe mass, 7t active target, 5.6t fiducial target
- Gadolinium loaded liquid scintillator veto in acrylic tanks
- Received final construction approval from the DOE in February, 2017
- TDR to the arXiv this week
- Start of operation in 2020 (pushing to advance to 2019)



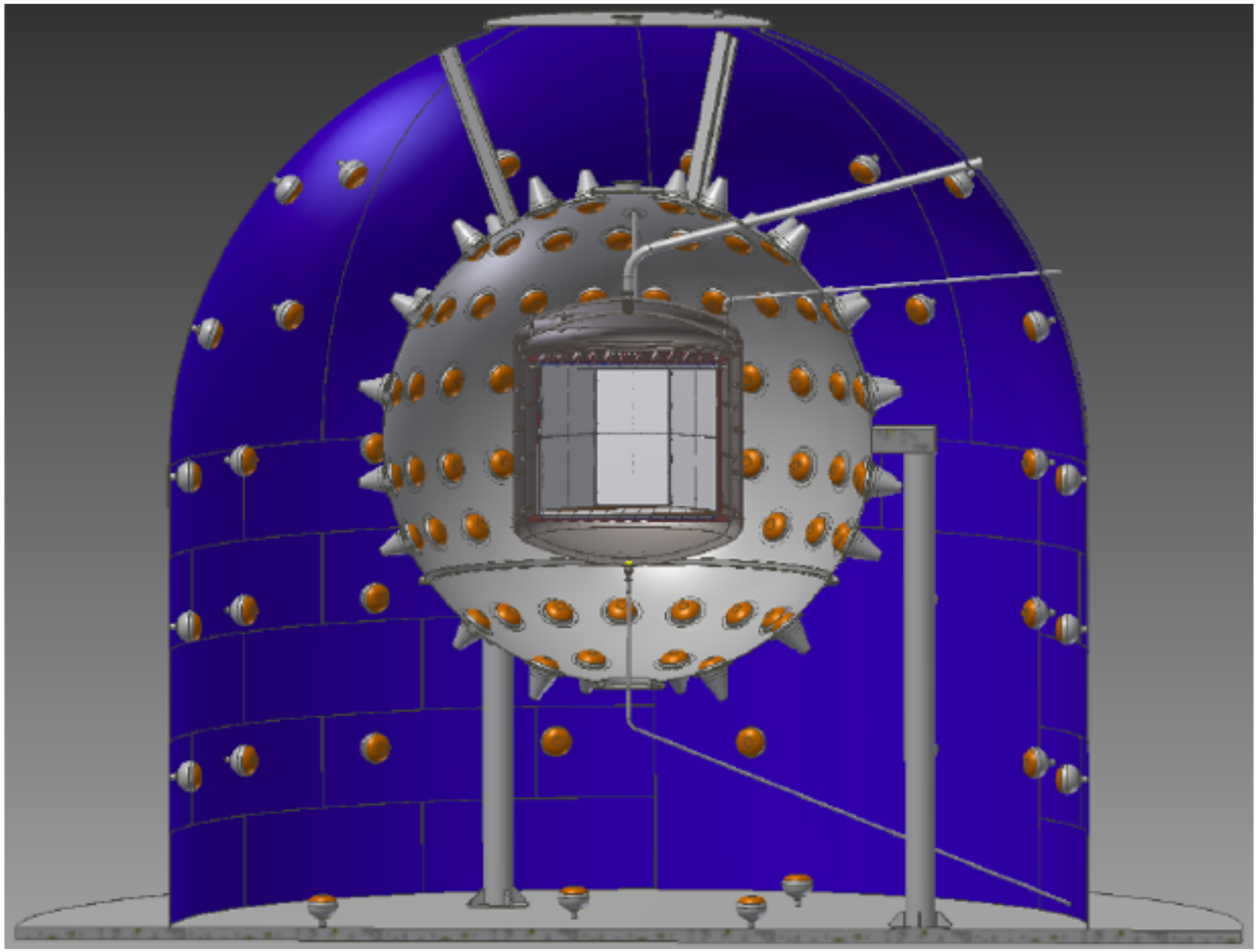
LZ sensitivity



H. Nelson

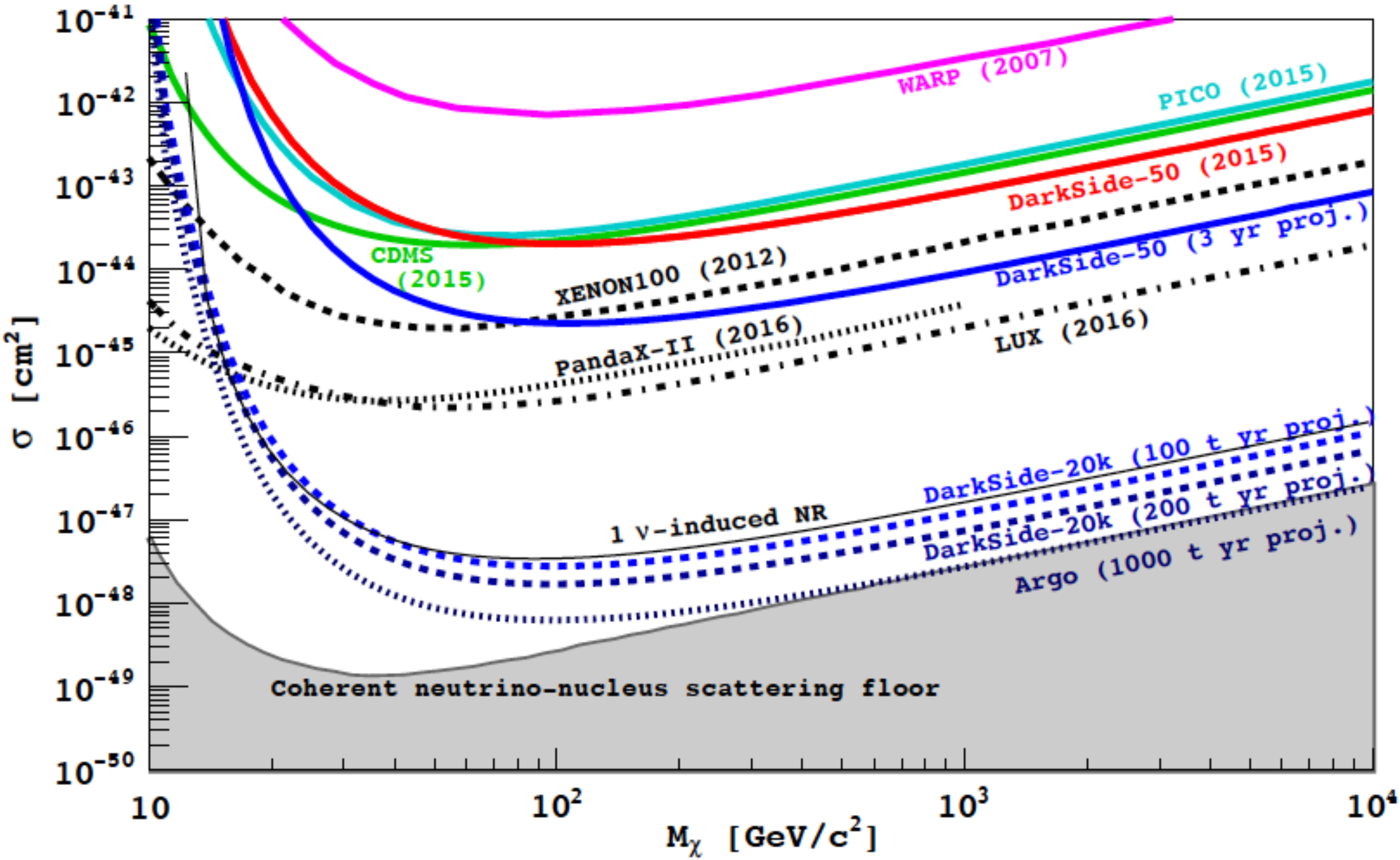
DarkSide-20k @ LNGS

- 30 ton total, 20 ton fiducial, argon from underground wells, depleted in radioactive ^{39}Ar
- inside a 8m diameter SS sphere filled with boron-loaded liquid scintillator, serving as active neutron veto
- inside a 15m diameter 16m tall water tank, as active muon veto
- radiopure construction
- 15m^2 SiPM sensors (low radioactivity, increased LY)
- Scalable design for application to larger scale detector

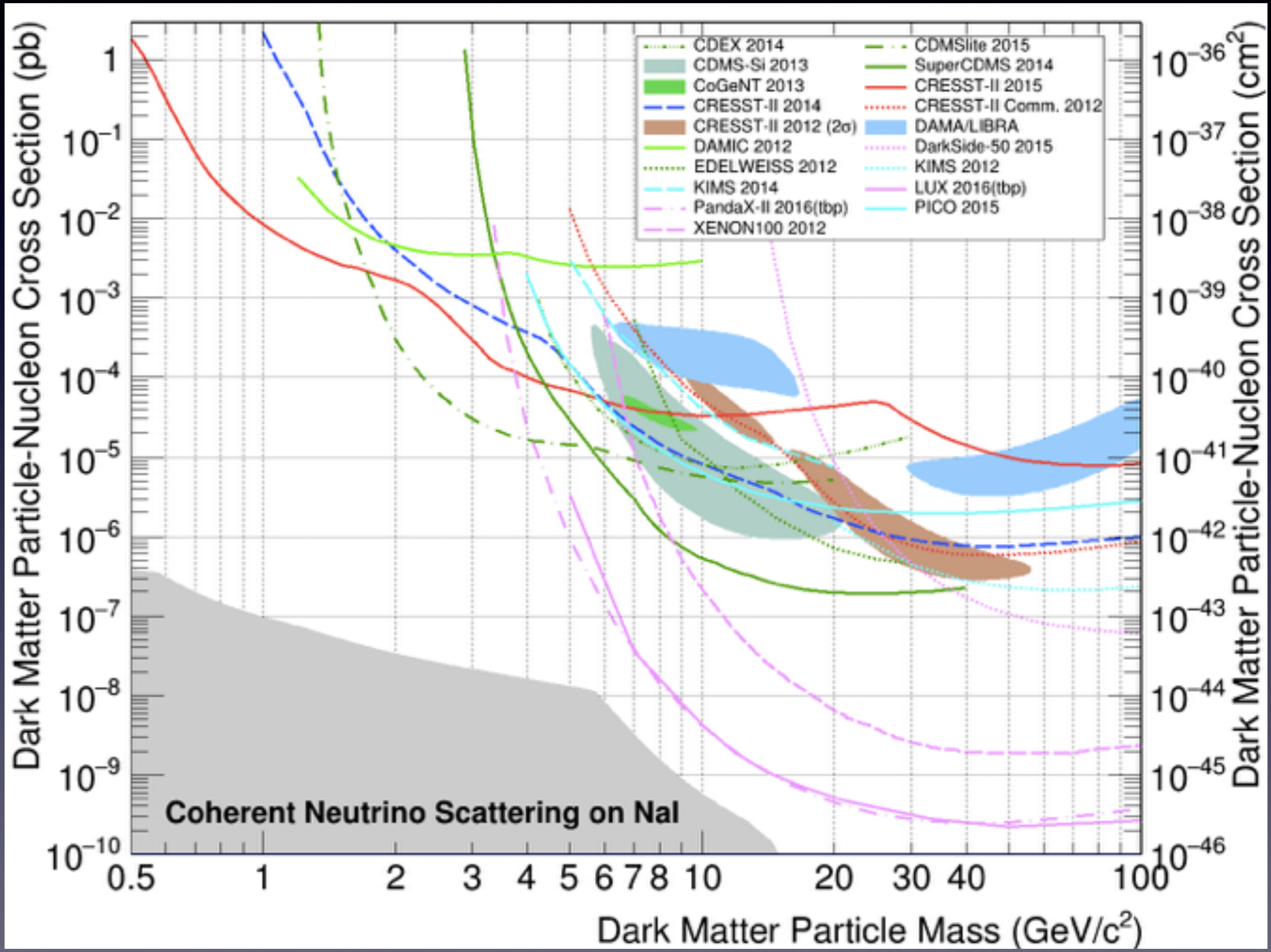


Start of operation in 2021

DarkSide-20k sensitivity



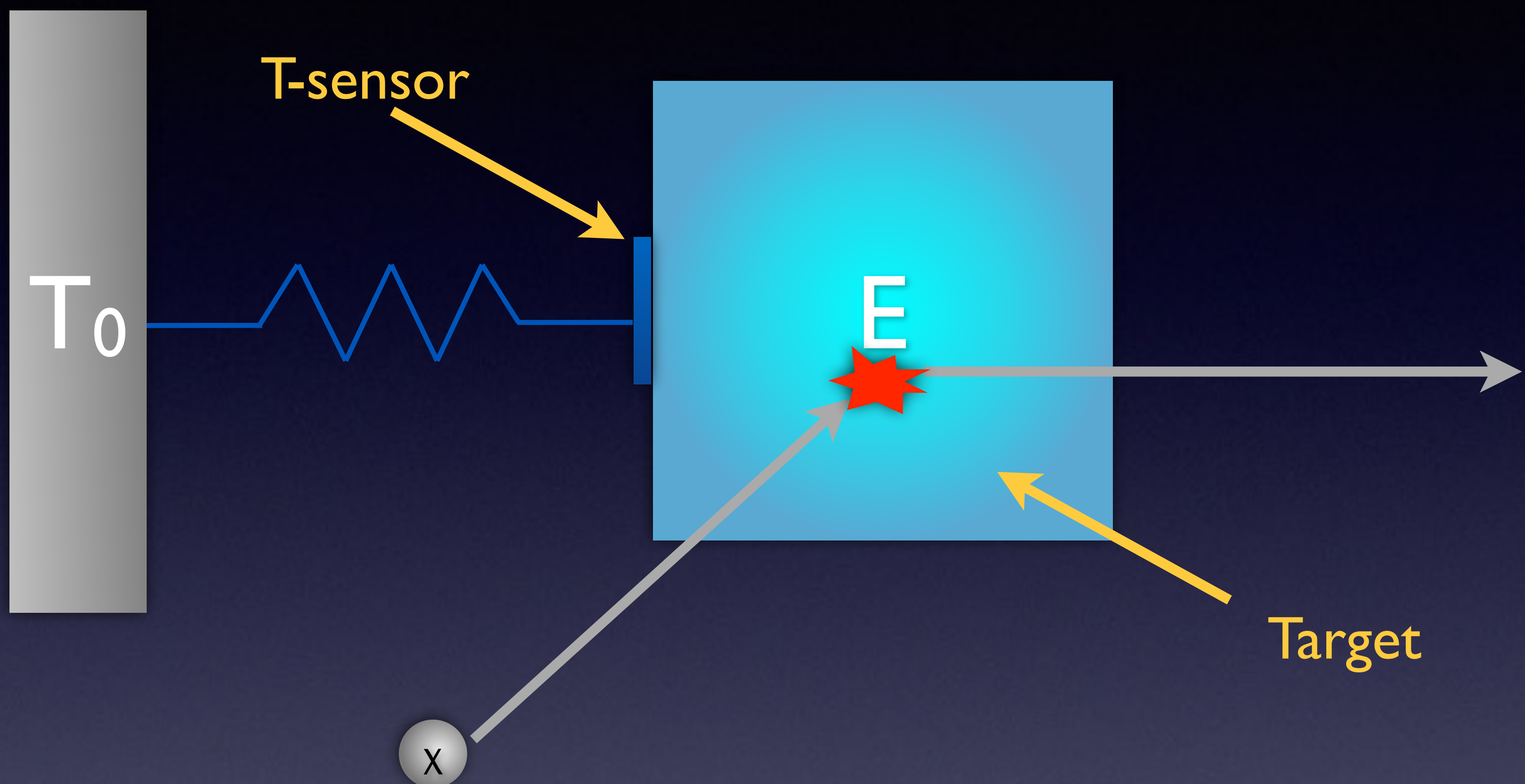
Low mass WIMPS: low threshold detectors



Comparison of experiments is model dependent.

Light mass DM is not a standard WIMP: it may have large ER interactions or isospin violating interactions or velocity and angular momentum dependencies

Cryogenic Crystals

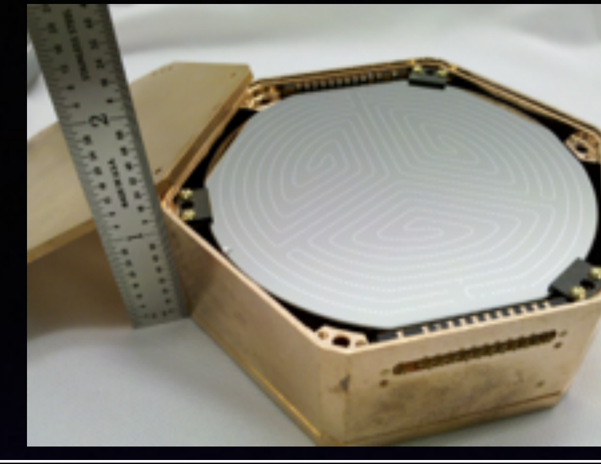


Charge & Phonons:	SuperCDMS
	CDMSLite
Light & Phonons:	CRESST

E deposition → temperature rise $\Delta T \sim \mu K$ → requires detectors at mK

- Crystals: Ge, Si, $CaWO_4$, NaI
- T-sensors:
  - superconductor thermistors (highly doped superconductor): NTD Ge → EDELWEISS
  - superconducting transition sensors (thin films of SC biased near middle of normal/SC transition): TES → CDMS, CRESST

Q&H: SuperCDMS @ SOUDAN



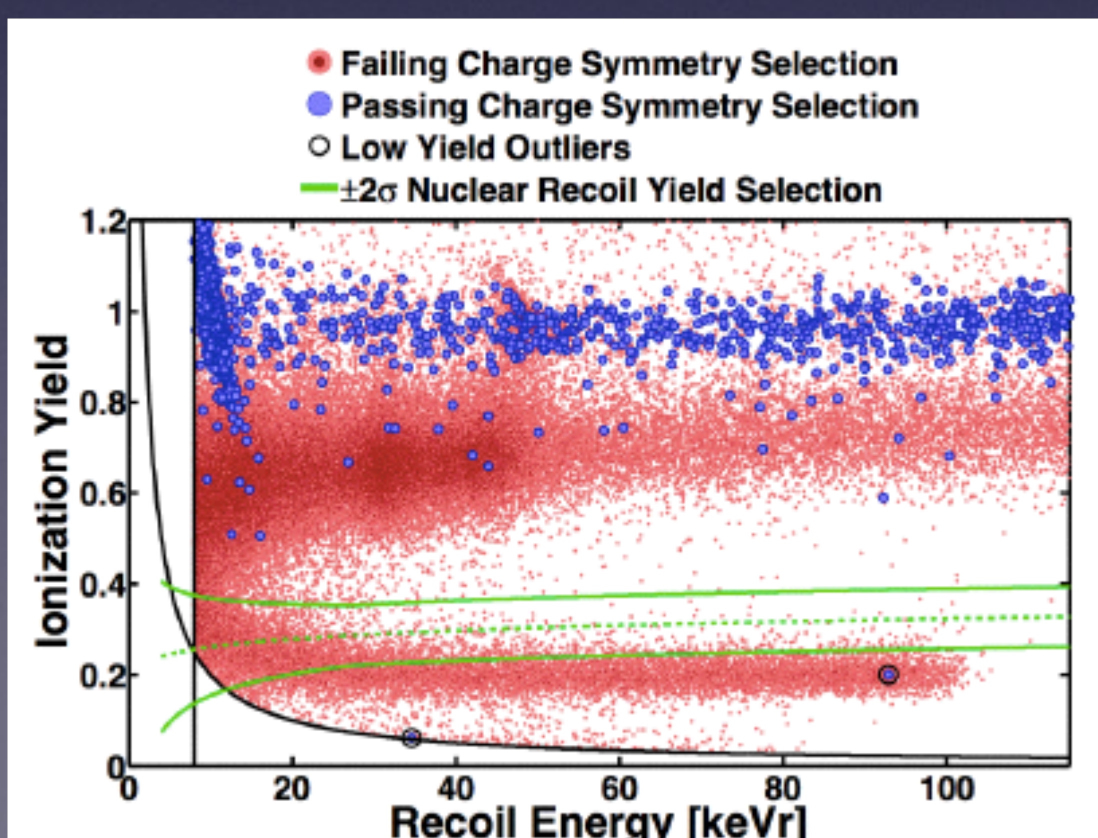
- 15 Ge iZIP detectors (9 kg) operated at 50 mK
- Data taken from 2012 to 2014: about 2500 kg-days of raw exposure
- Multiple Analyses
    - CDMSLite Phys. Rev. Lett. 116, 071301, 2016
    - Low Threshold Phys. Rev. Lett. 112, 241302, 2014
    - High Threshold (Analysis still blinded, expect to unblind soon!)

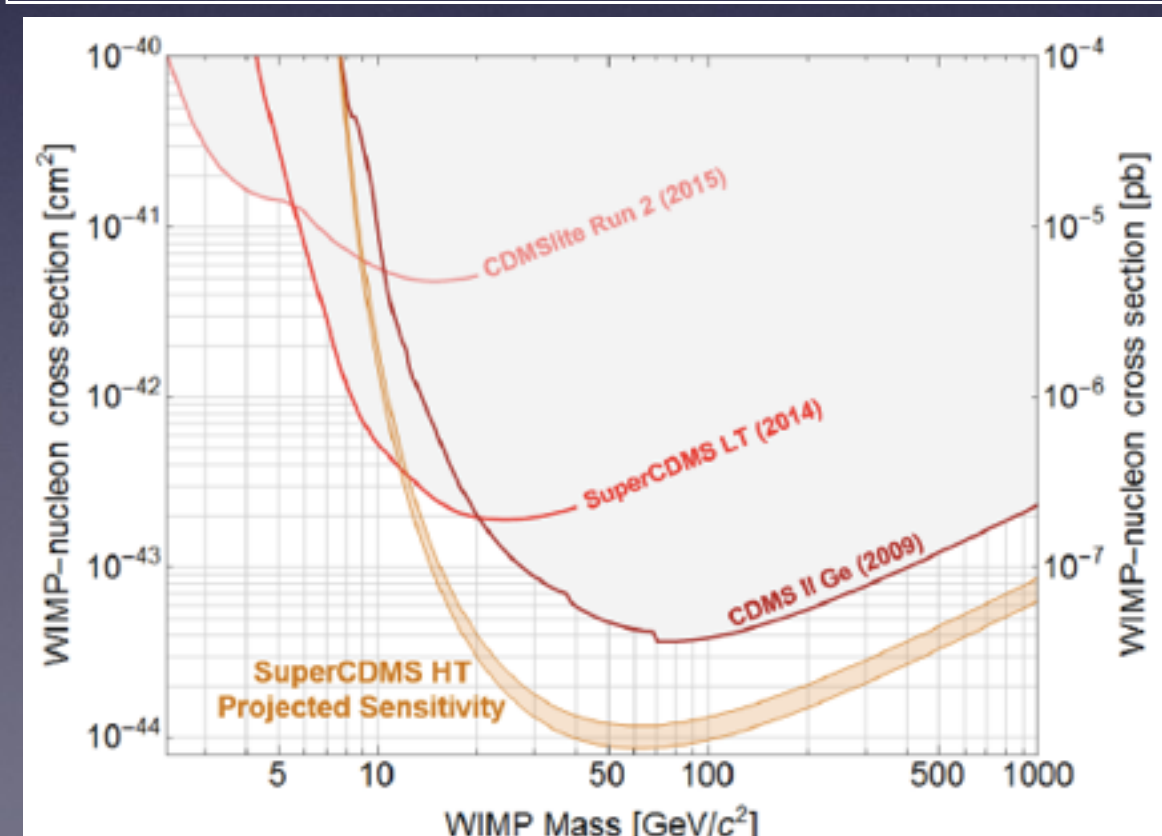
CDMSlite: Trading off NR/ER discrimination for Low Threshold

625 g iZIP detector operated at a relatively high bias voltage to amplify the phonon signal by Neganov-Luke effect on charge signal

- 70 kg d exposure
- Vb=69 V, 56 eVee threshold, 14 eVee resolution.

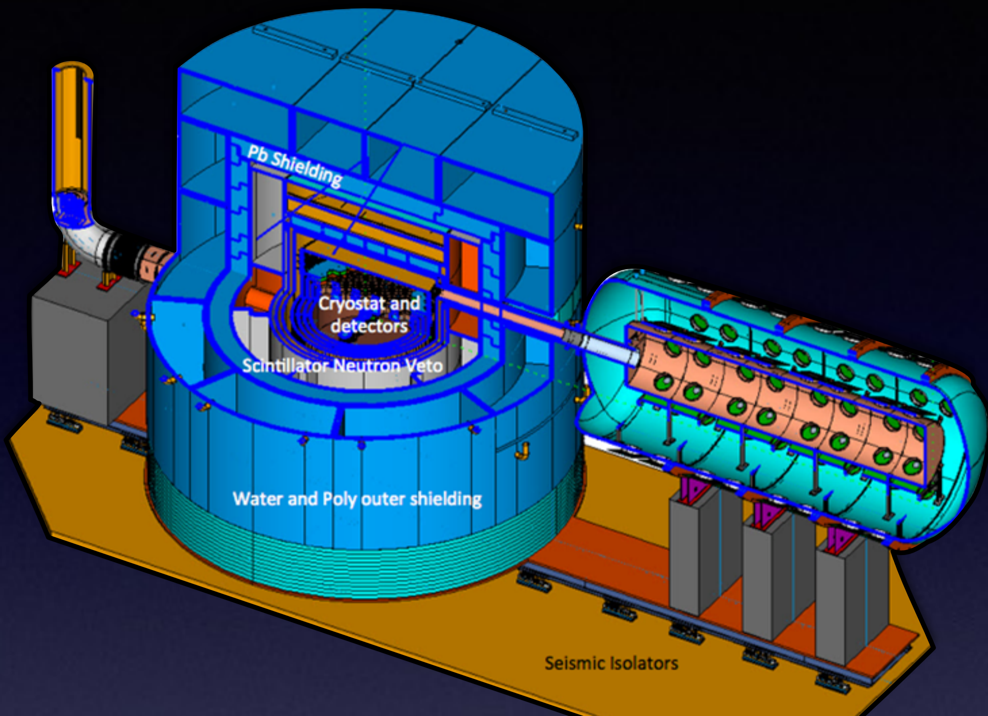
ER/NR discrimination





R. Calkins, IDM2016

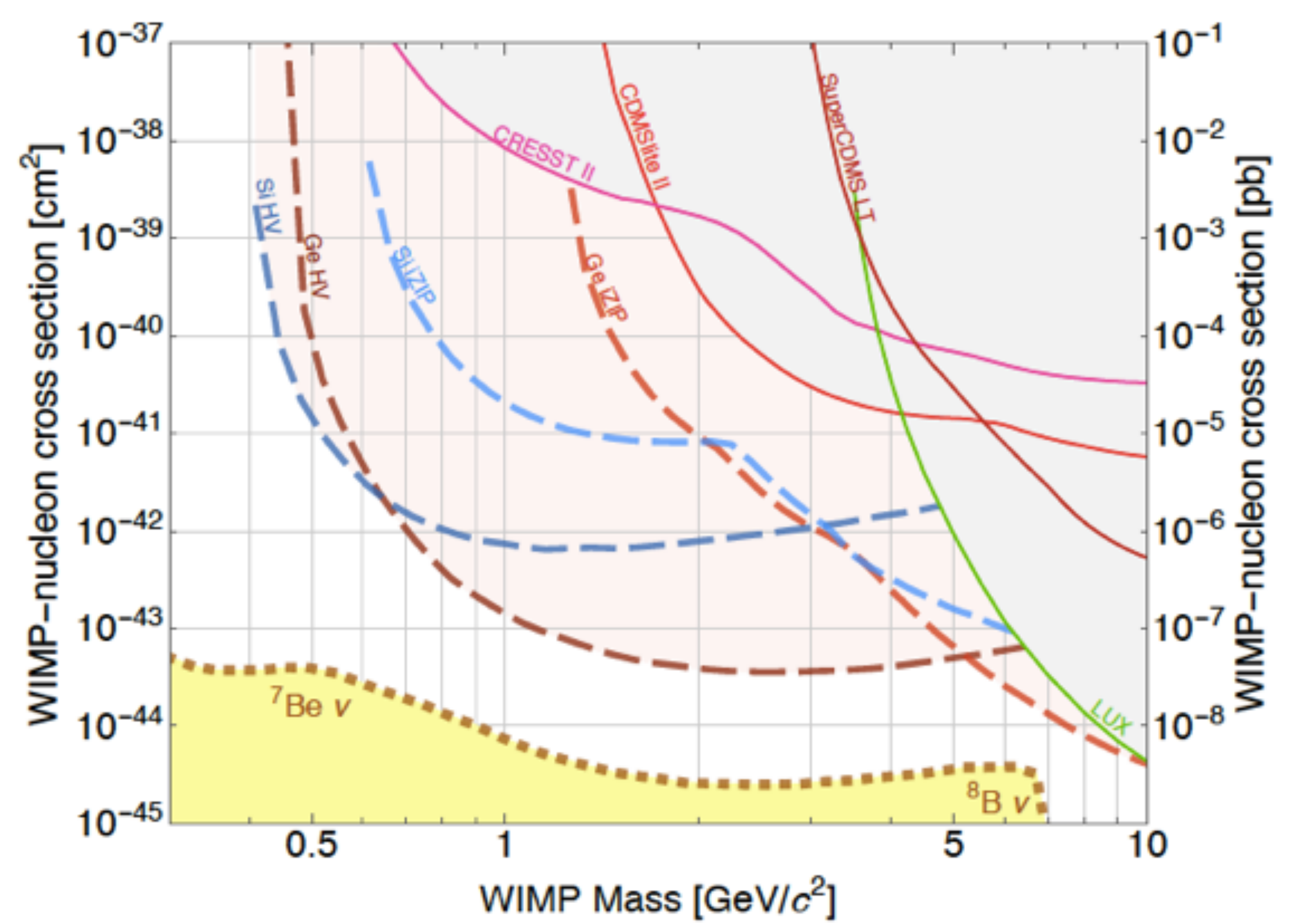
SuperCDMS @ SNOLAB



	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Exposure	56	4.8	44	9.6
Voltage bias	6	8	100	100
Threshold energy (eV)	272	166	40	78

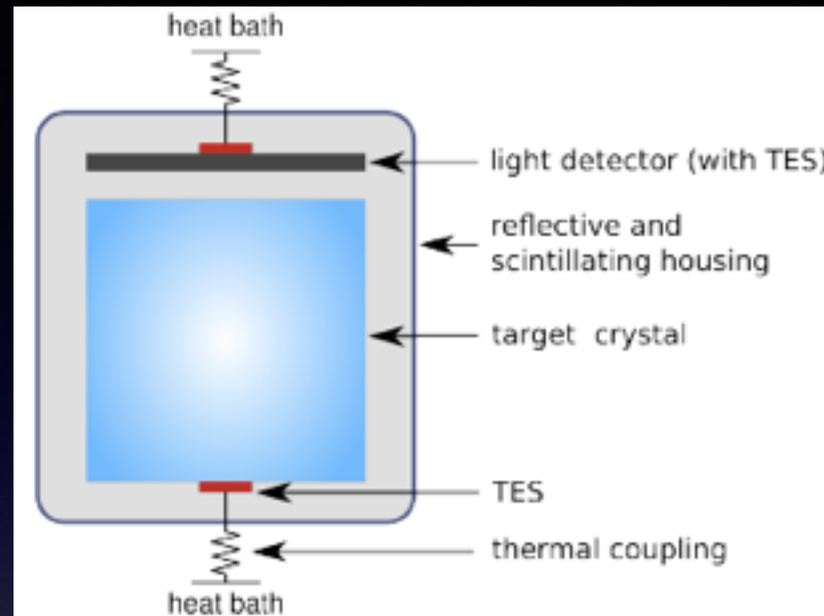
arXiv:1610.00006

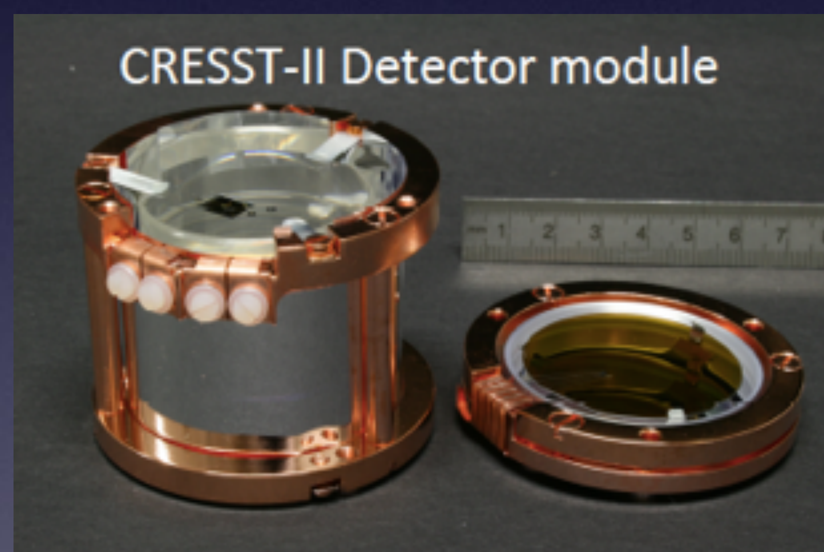
- Setup holds up to ~260 kg detectors
- Initial payload includes mix of standard and HV detectors (25kg Ge, 3.6kg Si total)
- Shielding includes water tanks (n), lead (γ), poly (n from inner parts)
- Planned data taking 2020 — 2024

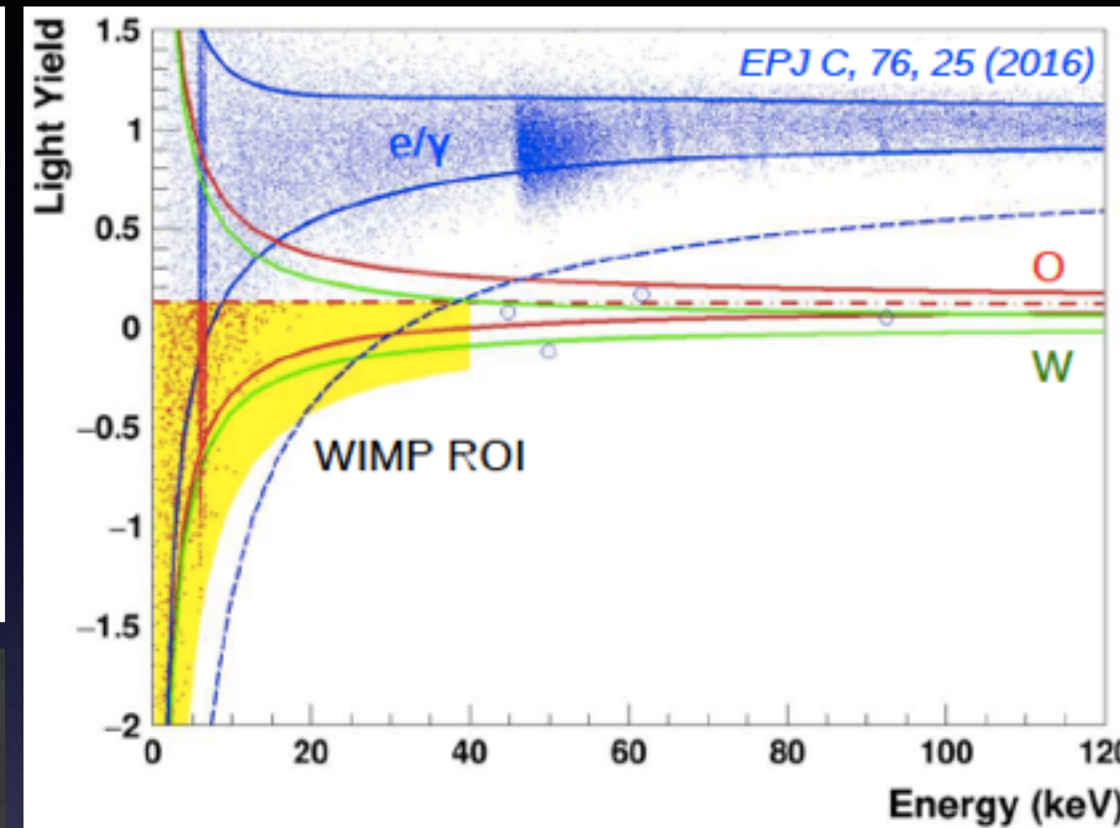


L&H: CRESST @ LNGS

- Scintillating $CaWO_4$ crystals
- Target crystals operated as cryogenic calorimeters (~15mK)
- Separate cryogenic light detector to detect the scintillation light signal

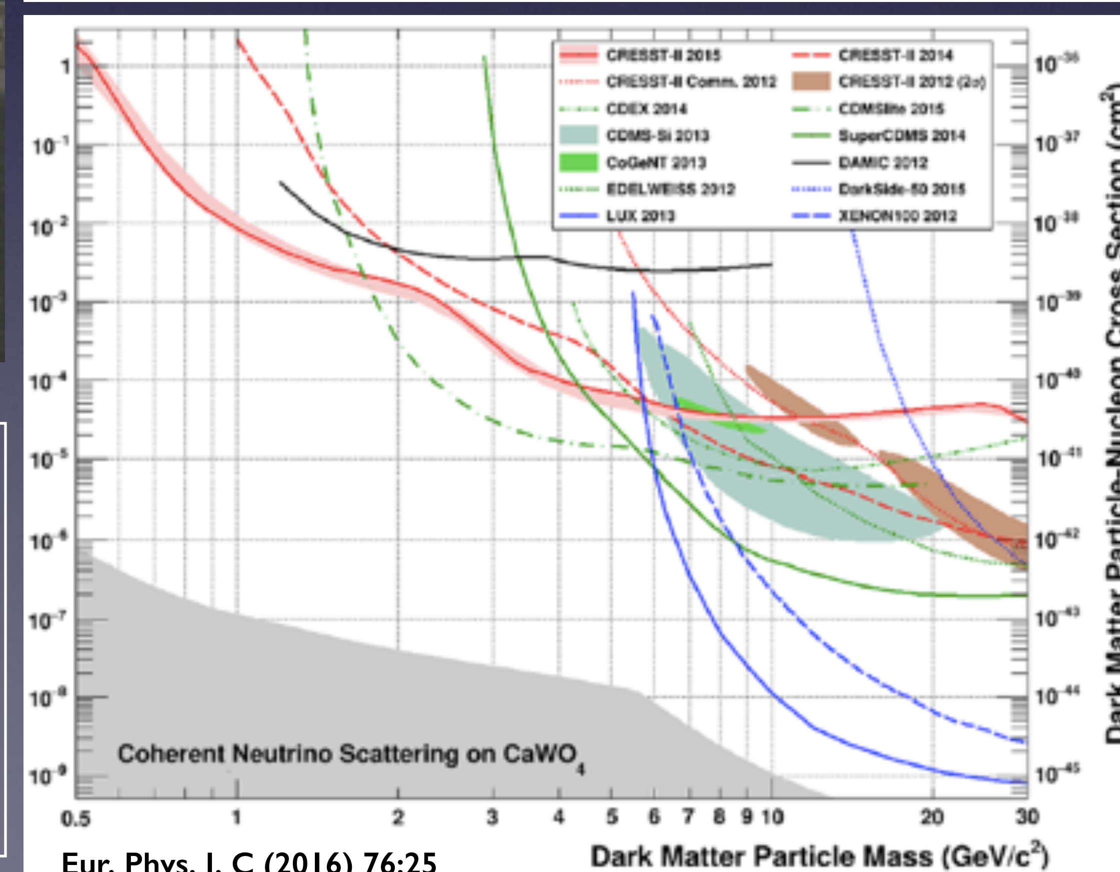






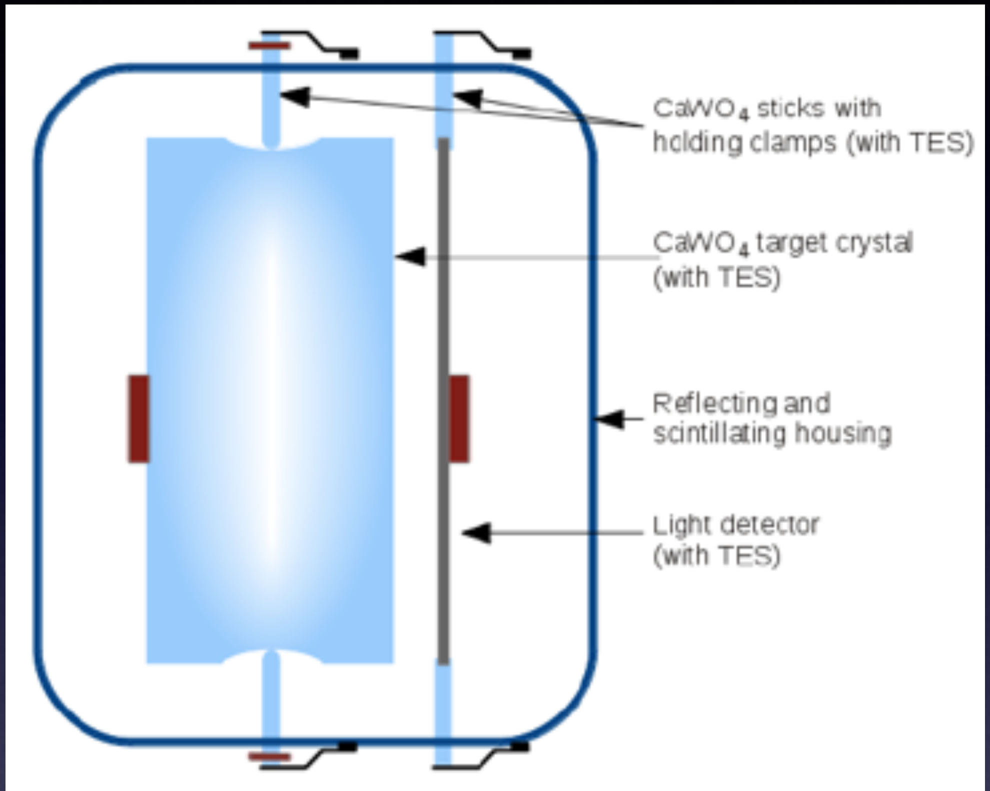
CRESST-II:

- 300 g crystal
- 307eV nuclear recoil threshold
- world-leading result below 1.7GeV/c2
- first experiment to explore masses in the sub-GeV range

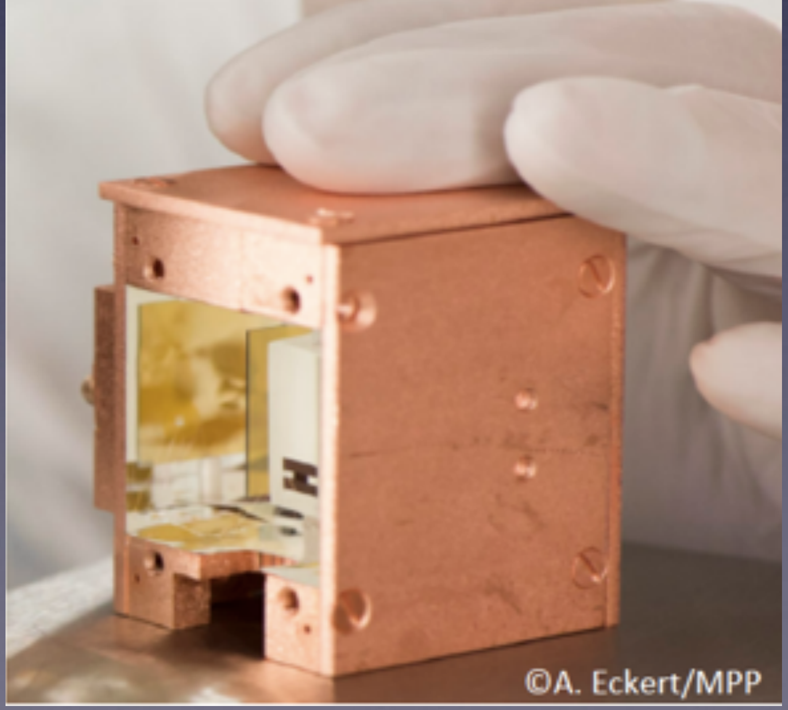


CRESST-III

- Detector layout optimized for low-mass dark matter
- clean self-grown crystals
- small crystal of (20×20×10)mm^3 (25g)
- 100eV threshold design goal
- small light detector (20×20)mm^3

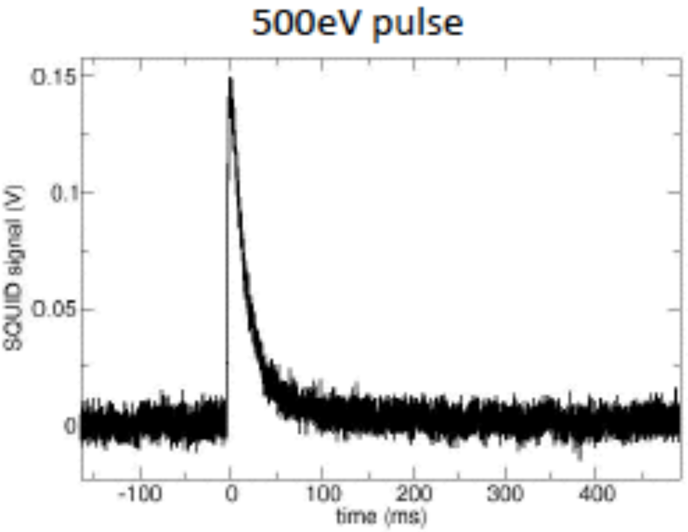


CRESST-III Detector module



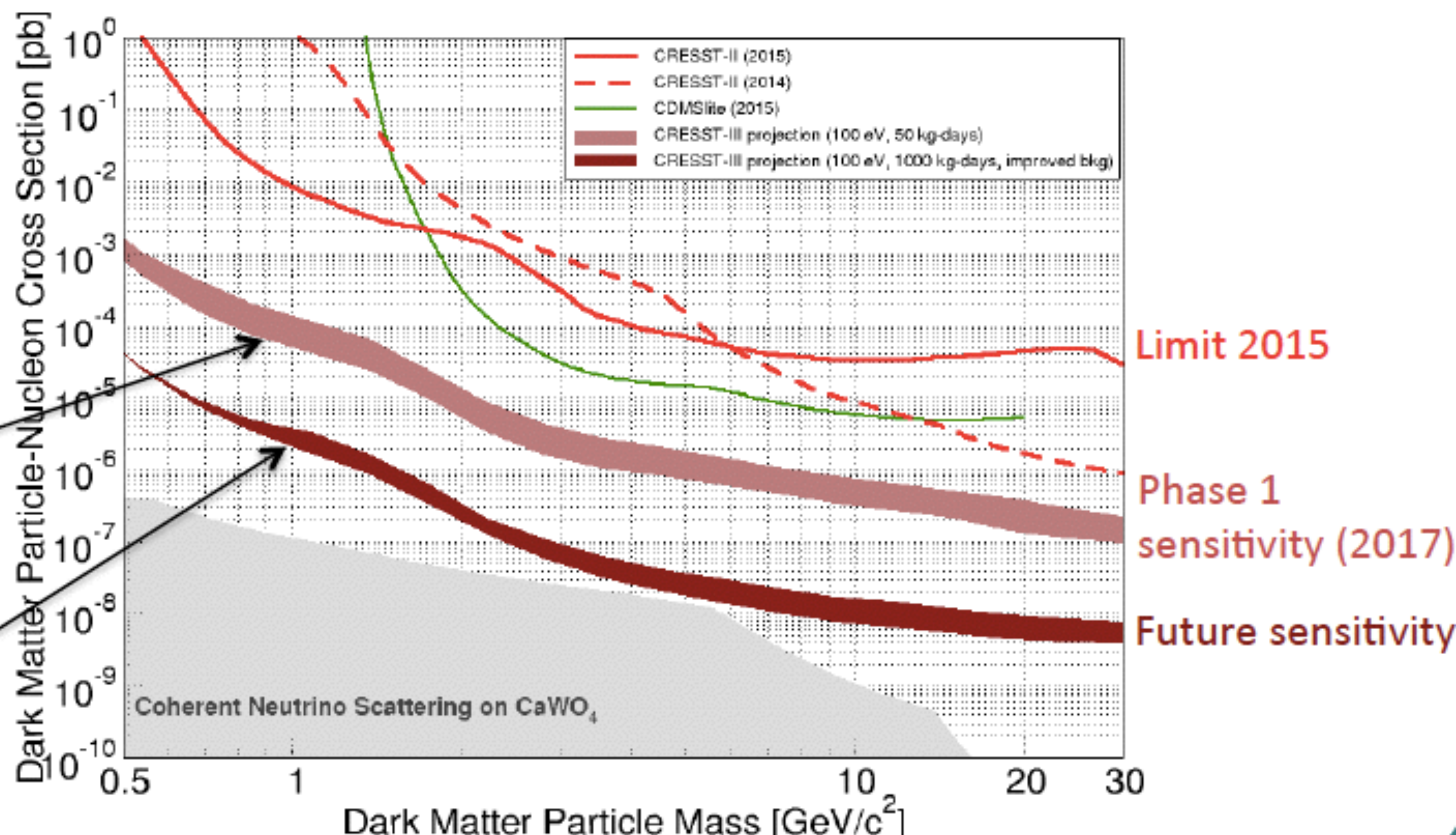
- 6 modules with threshold <100eV running at LNGS
- Threshold design goal exceeded

CRESST-III projected sensitivity



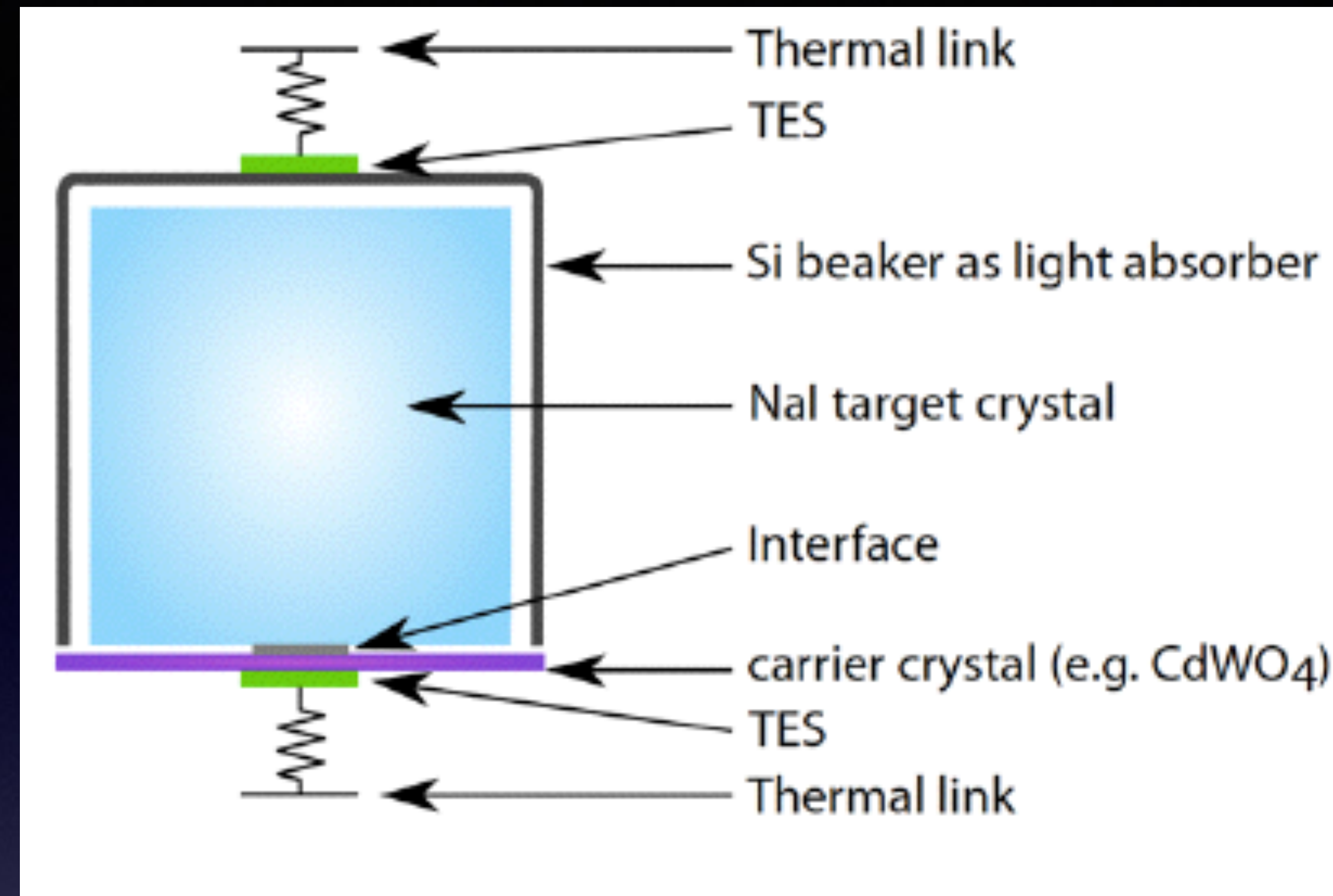
Projected sensitivity for 50kg days (1 year) with design goal threshold (100eV)

Projected sensitivity for 1000kg days (2 year with 100 detectors) with design goal threshold (100eV)



K. Schaffner

New scintillating crystal: COSINUS @ LNGS

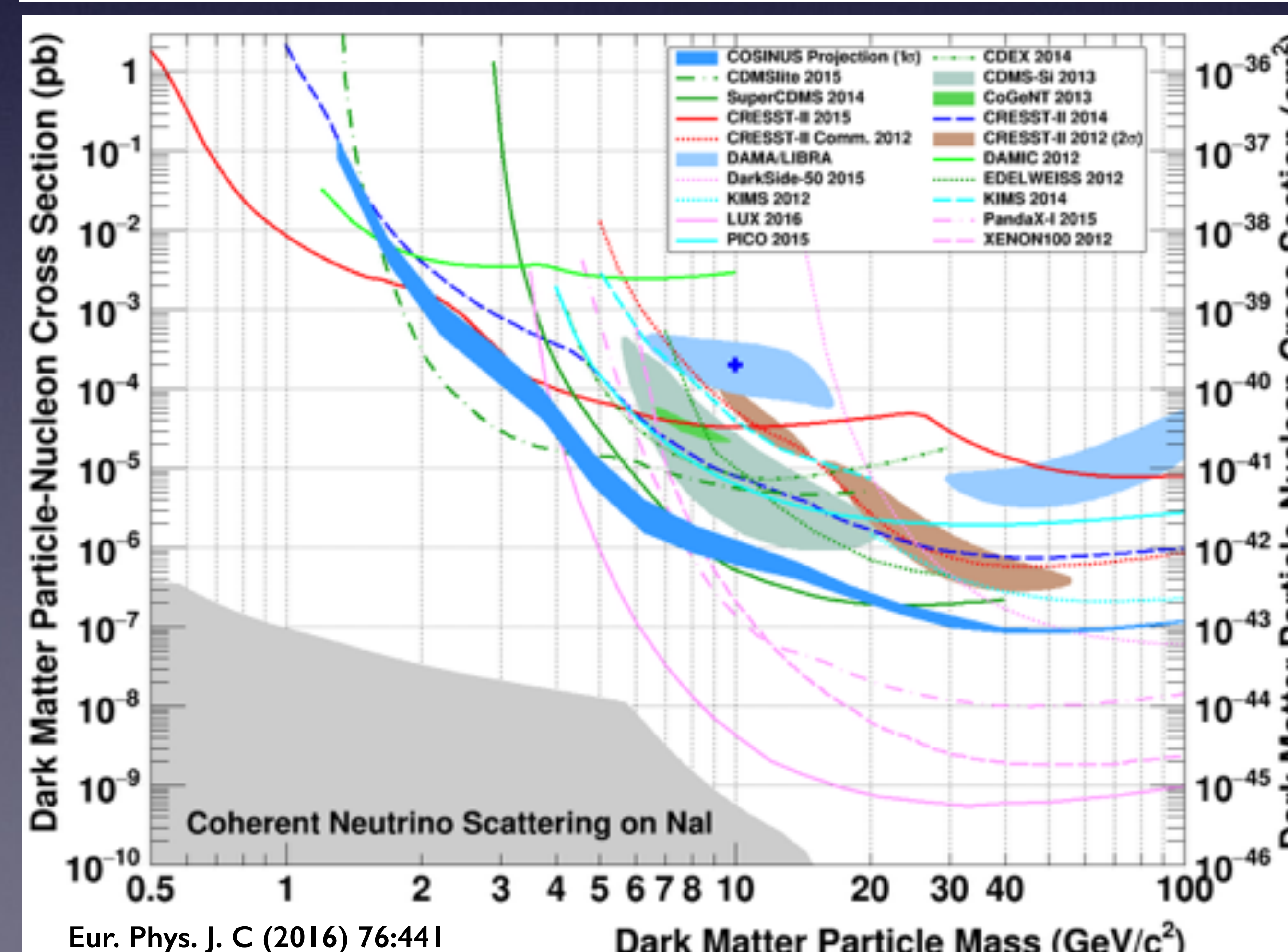


R&D towards first NaI detector with particle discrimination via second and independent channel

- first successfully operated NaI cryogenic calorimeter did prove feasibility of building a cryogenic NaI detector
- reaching performance of existing scintillating bolometers
  - can answer the question whether the DAMA/LIBRA (NaI) modulation signal is nuclear recoils or interactions with the electrons → exposure of only few 10 kg-days needed
  - with higher target mass: COSINUS technique also suited for modulation detection

Simulated background for an exposure: 100 kg d

- NaI energy resolution σ=200 eV
- NaI energy threshold 1 keV
- at least 4% of deposited energy detected in form of light
- light detector baseline noise σ=10 eV



Other low mass/threshold techniques

Low mass/threshold: CDEX @ CJPL

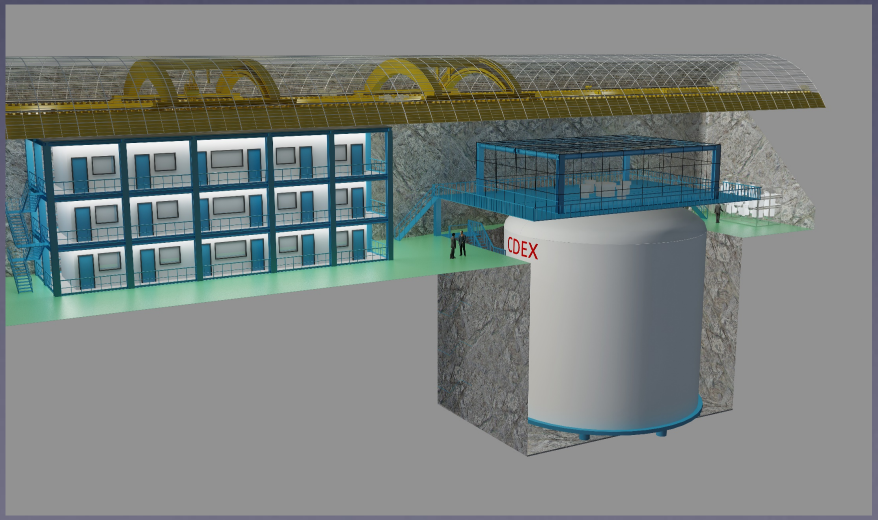
- Point-contact HPGe detector (PCGe)
- Low energy threshold (~ 100eVee), very good energy resolution, easy to scale up
- 1 kg pPCGe detector, NaI(Tl) as anti-Compton detector

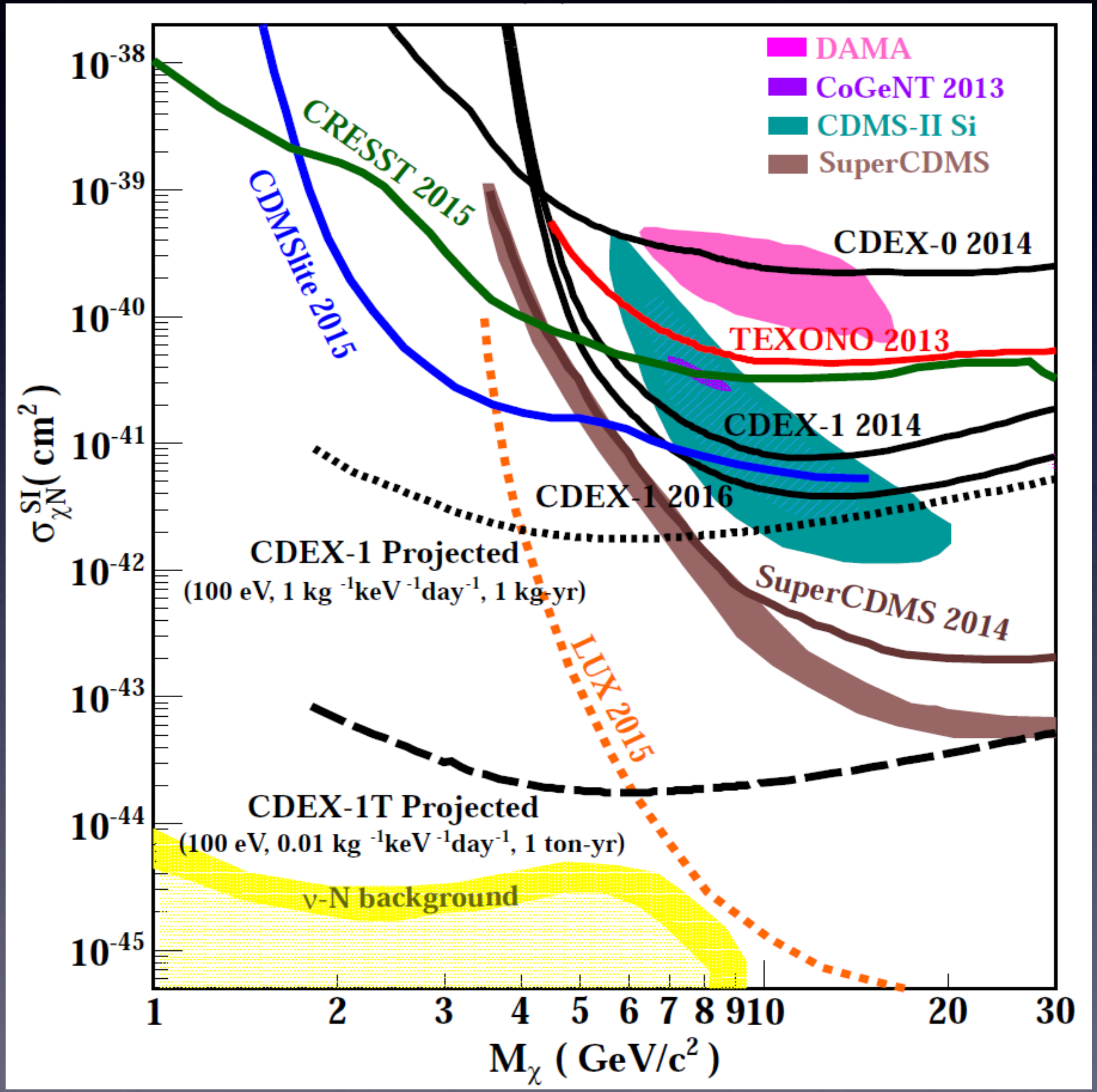
CDEX-1 result January 2016 PRD93, 092003, 2016

- 336 d kg dataset, no signal excess
- allowed region implied by CoGeNT probed and excluded with an identical detector target

CDEX-10 and CDEX-1T planned

CDEX Space at CJPL-II





Qian Yue

Low mass/threshold: DAMIC @ SNOLAB

- High resistivity, fully depleted CCD, ≈ 40 cm^2, 675 μm thick, 5.8 g each
- Very low energy threshold (~ 60eVee), Exquisite spatial resolution: particle id, surface bkg. rejection, bkg. measurements

DAMIC result July 2016 PRD94, 082006 (2016)

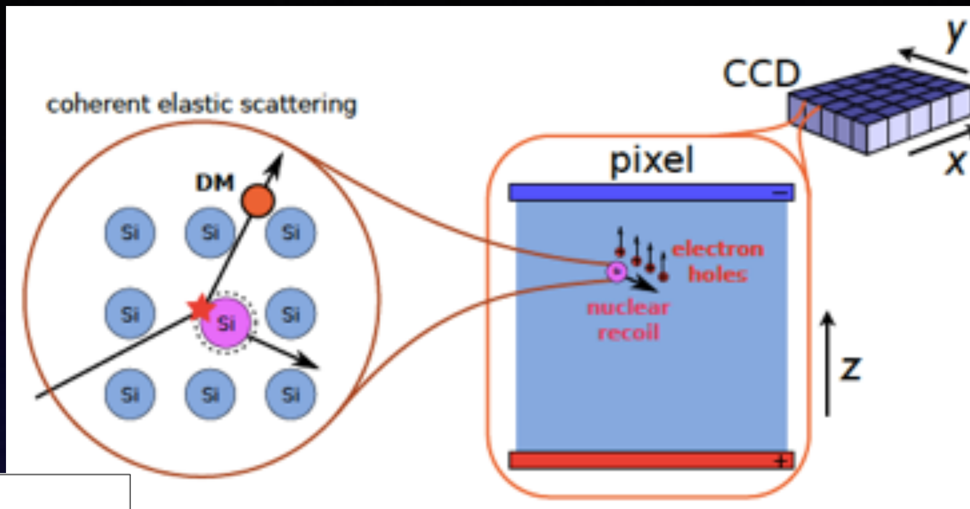
- 0.6 kg d exposure, demonstrates sensitivity

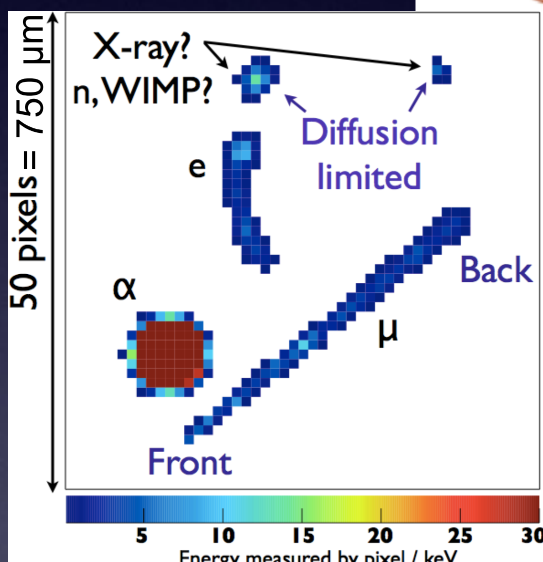
DAMIC100 @ SNOLAB

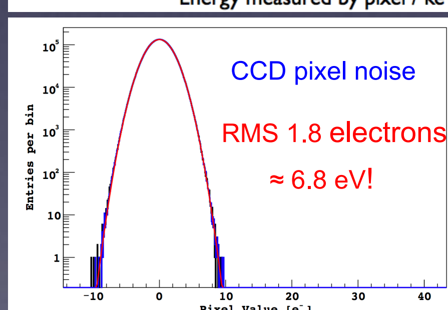
- 40 g, bkg < 5 dru
- results in late 2017

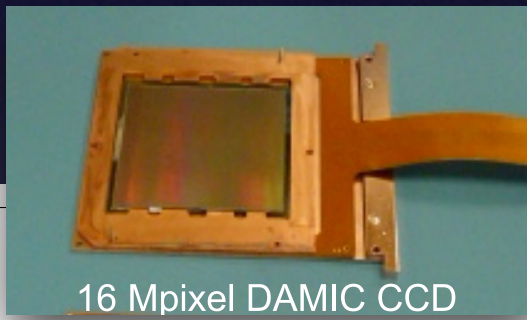
DAMIC1K

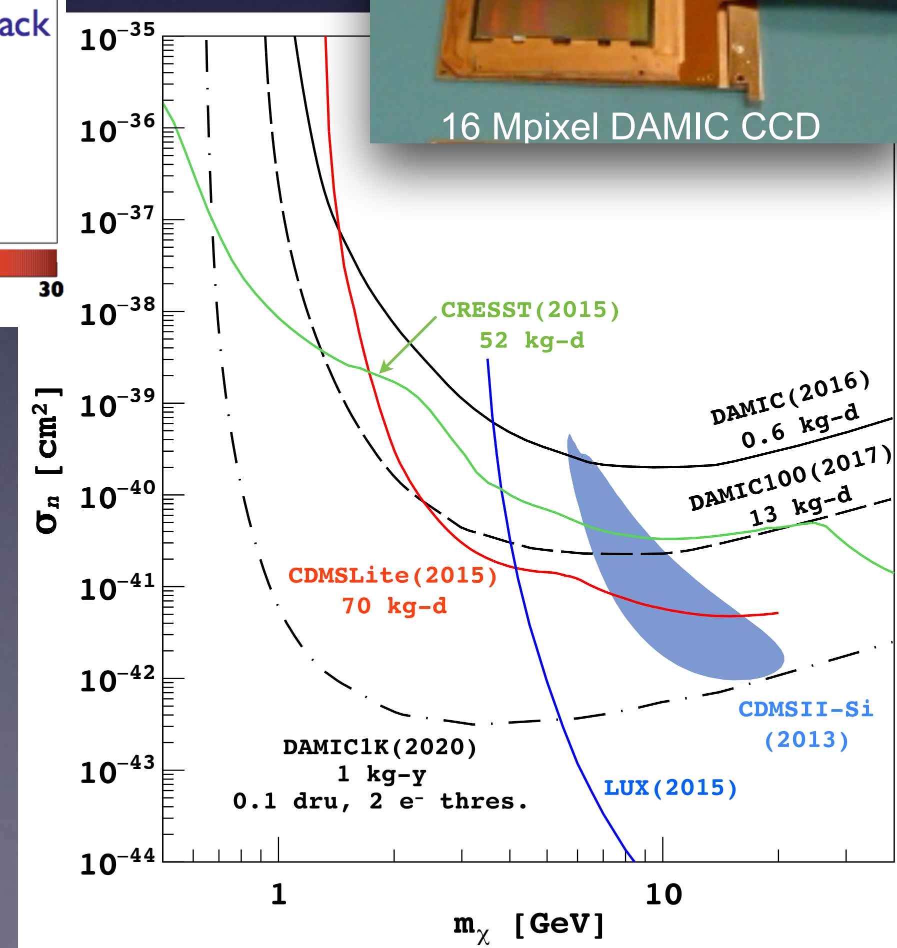
- expected limit for 1 year running of a 1 kg detector, assuming a bkg of 0.1 dru
- ≈ kg detector with sub-eV resolution
- will improve limits on DM-electron scattering by 6 orders of magnitude!











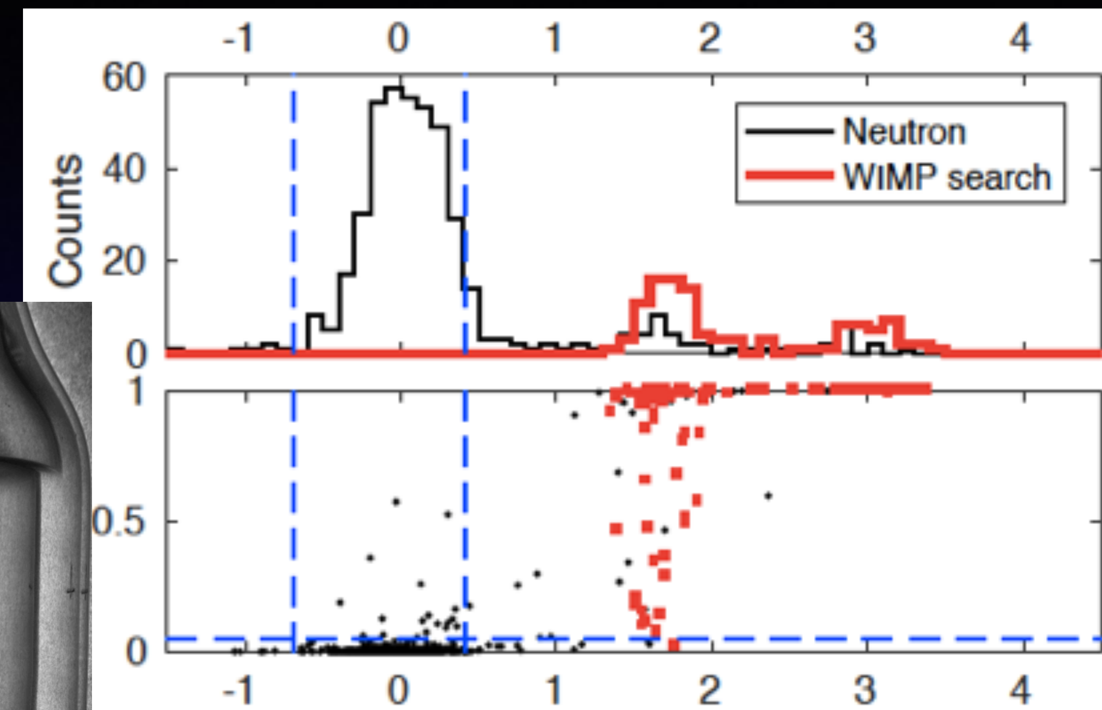
P. Privitera

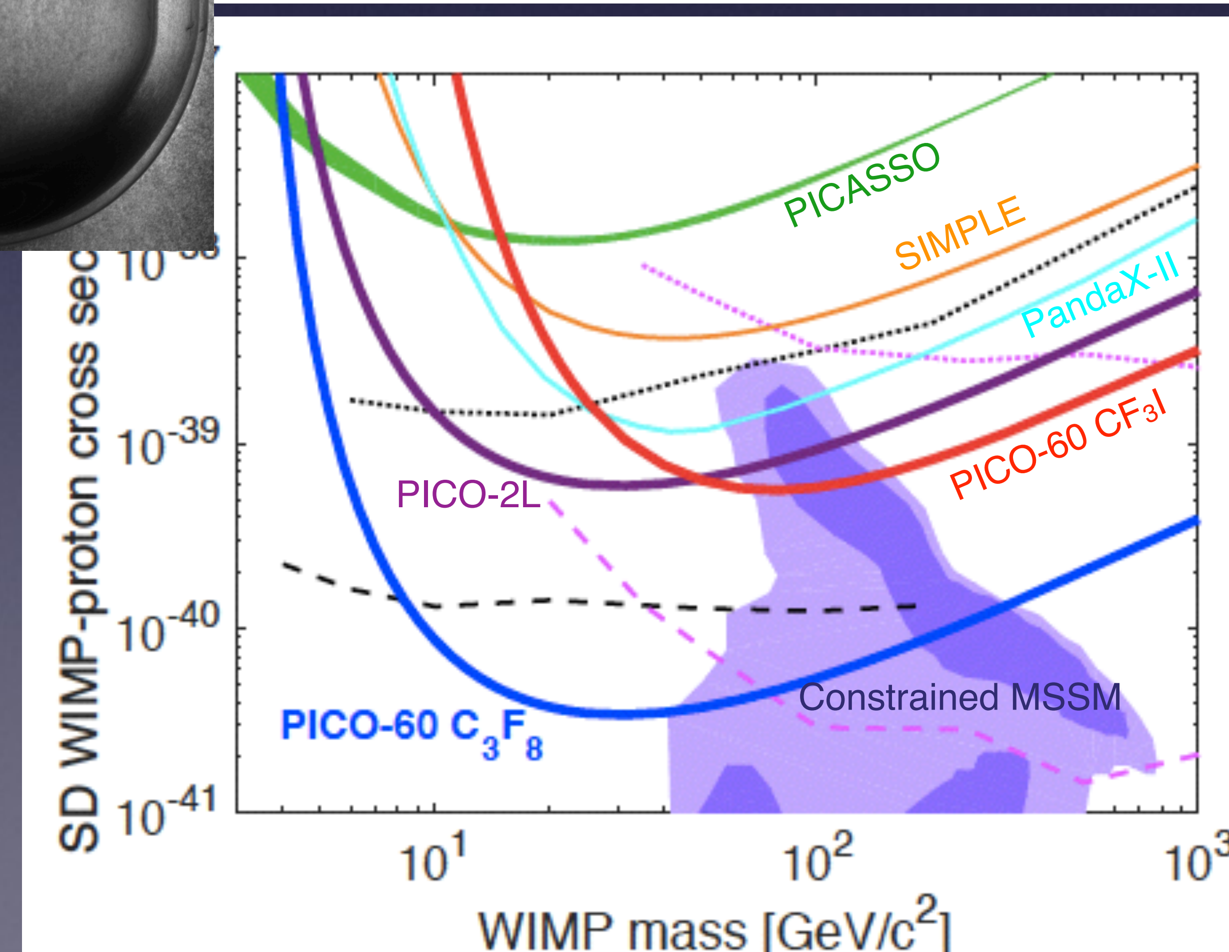
Spin-dependence: PICO @ SNOLAB

- Superheated bubble chambers operated in thermodynamic conditions at which they are virtually insensitive to gamma or beta radiation.
- Acoustic emission for discrimination between alpha decay and NR

PICO-60 spin-dependent limit February 2017 arXiv:1702.07666

- detector recommissioned after cleaning procedure to remove particulate contamination
- 52 kg of C_3F_8, 1167 kg d exposure
- 3.3 keV thermodynamic threshold, no single-scatter NR candidates
- 3.4 10^{-41} cm^2 @ 30 GeV
- world-leading constraints in the WIMP-proton spin-dependent sector, 17x improvement from previous PICO results

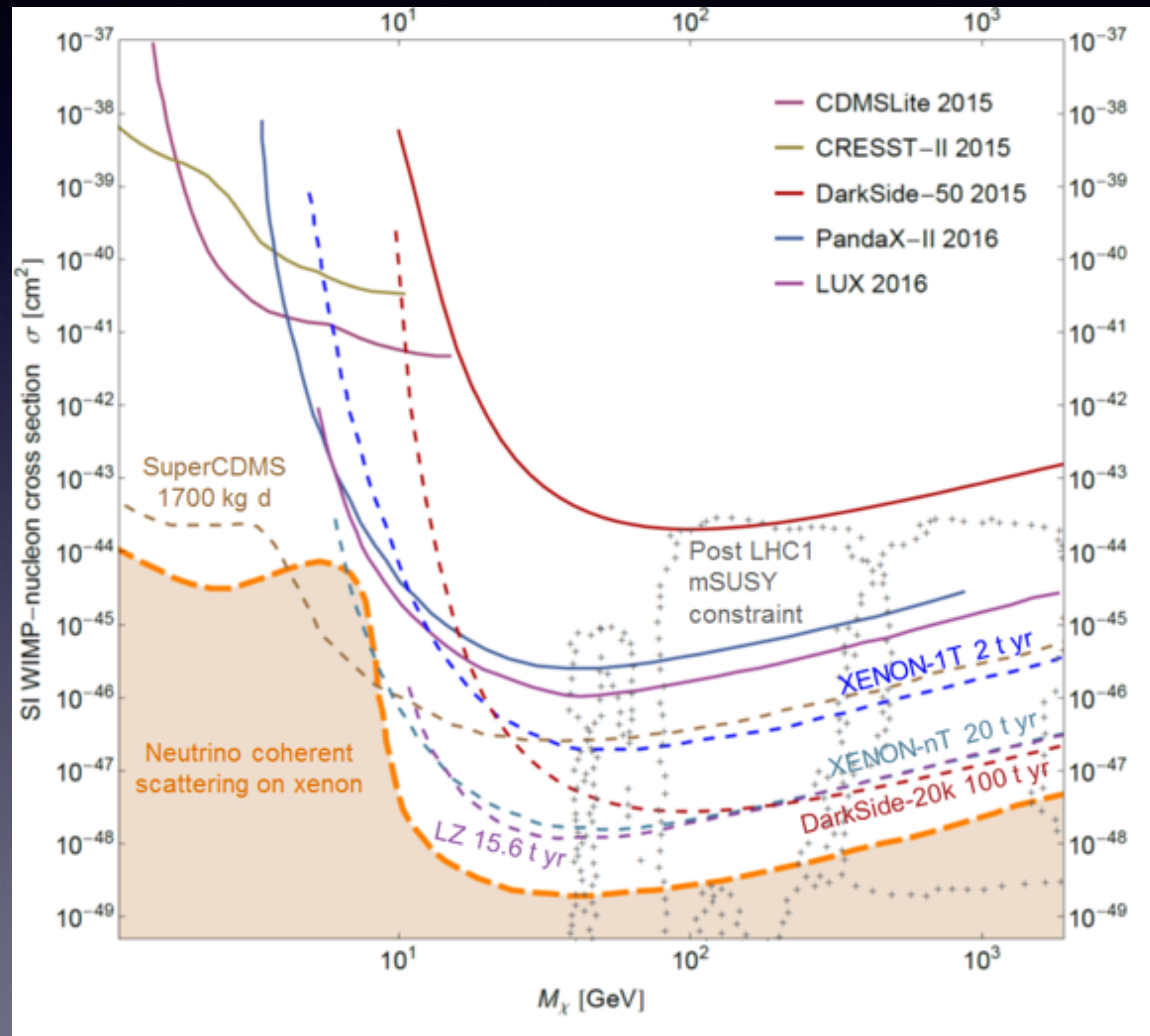




Summary & Conclusions

- Complementarity of experiments
  - Both low and high mass regions
  - >1 experiments with similar sensitivity to confirm signals
  - Variety of targets to understand couplings
- Massive targets and long exposures
- Low threshold
  - high yields + good calibration
- Low radioactive background
  - good background rejection
- Through the neutrino floor
  - directional measurements?

by M. Cadeddu (adapted from **NATURE PHYSICS** DOI: 10.1038/NPHYS4039)



Thank you