Direct Dark Matter Searches: Experimental Overview

remember kids: always ponder your titles...

Rafael F. Lang
Purdue University
rafael@purdue.edu
IPA2018, October 2018

Direct Dark Matter Searches: Stuff Robert and Yoni didn’t already talk about on Monday

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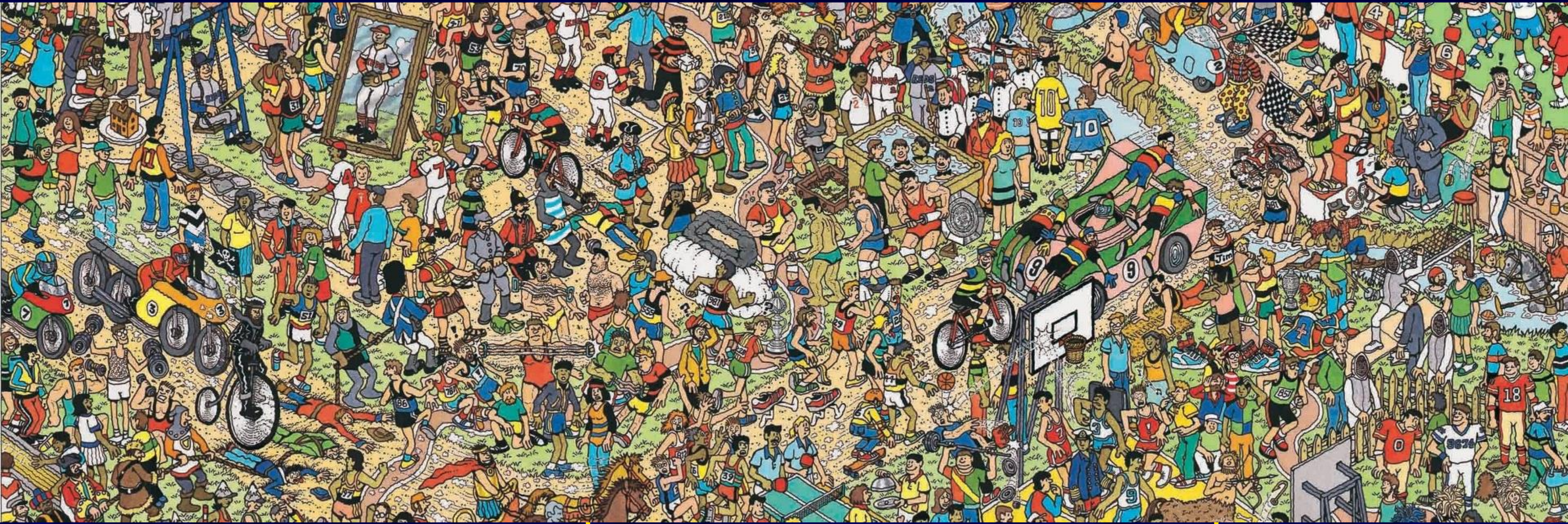
Conclusions

Experiments are probing our most popular models

Clear path towards the neutrino floor, but patience! Not before 2030

Lots of new physics channels, from WIMPs and other dark matter particles to solar, galactic and other neutrino signals

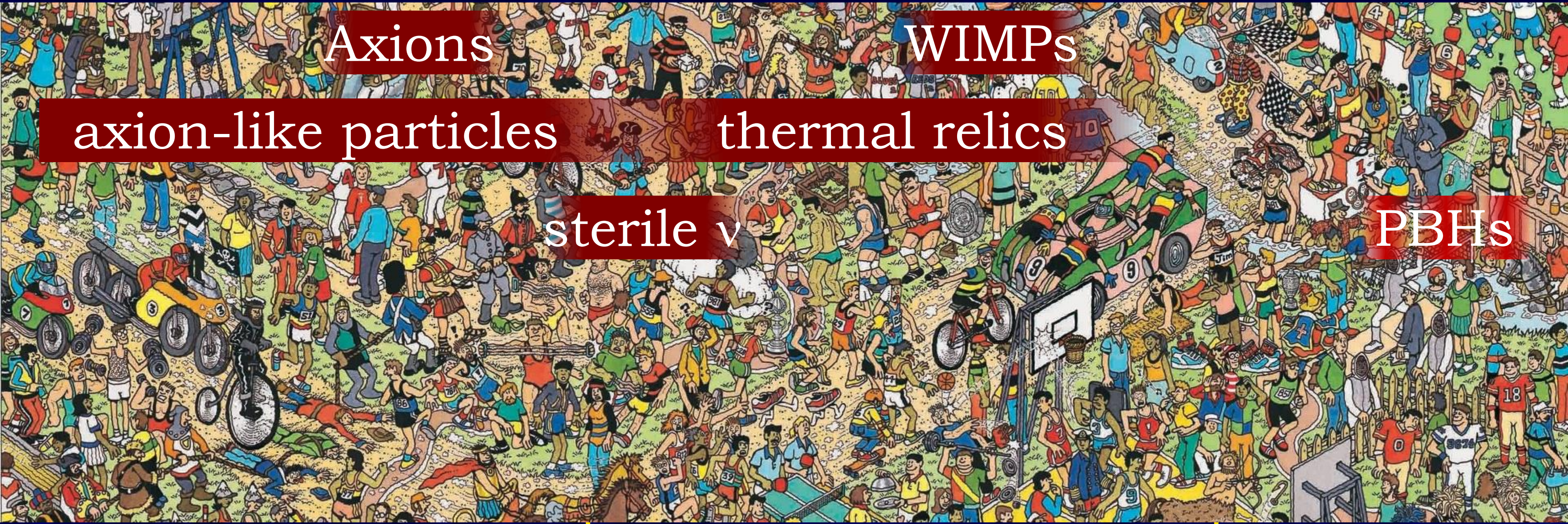
Possible Dark Matter Masses



90 orders of magnitude

10^{-21}eV μeV meV eV keV MeV GeV TeV M_{Planck} M_{solar}

Possible Dark Matter Masses



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Possible Dark Matter Masses

Eöt-Wash
MAGIS
CASPEr
DMRadio
ABRACADABRA
ADMX
HAYSTAC
MADMAX

NEWS-G XENON10 XMASS
CRESST-II Sabre XENON100
CRESST-III COSINE LUX
DAMIC LBECA PandaX DarkSide-50
SENSEI PICO XENON1T Deap3600
SF-He SuperCDMS XENONnT LZ DarkSide-20k
GaAs/Al_2O_3 Gen3/DARWIN

bosonic / field | fermionic / particle | composite

90 orders of magnitude

10^{-21}eV µeV meV eV keV MeV GeV TeV M_{Planck} M_{solar}

WIMP Detection: Target

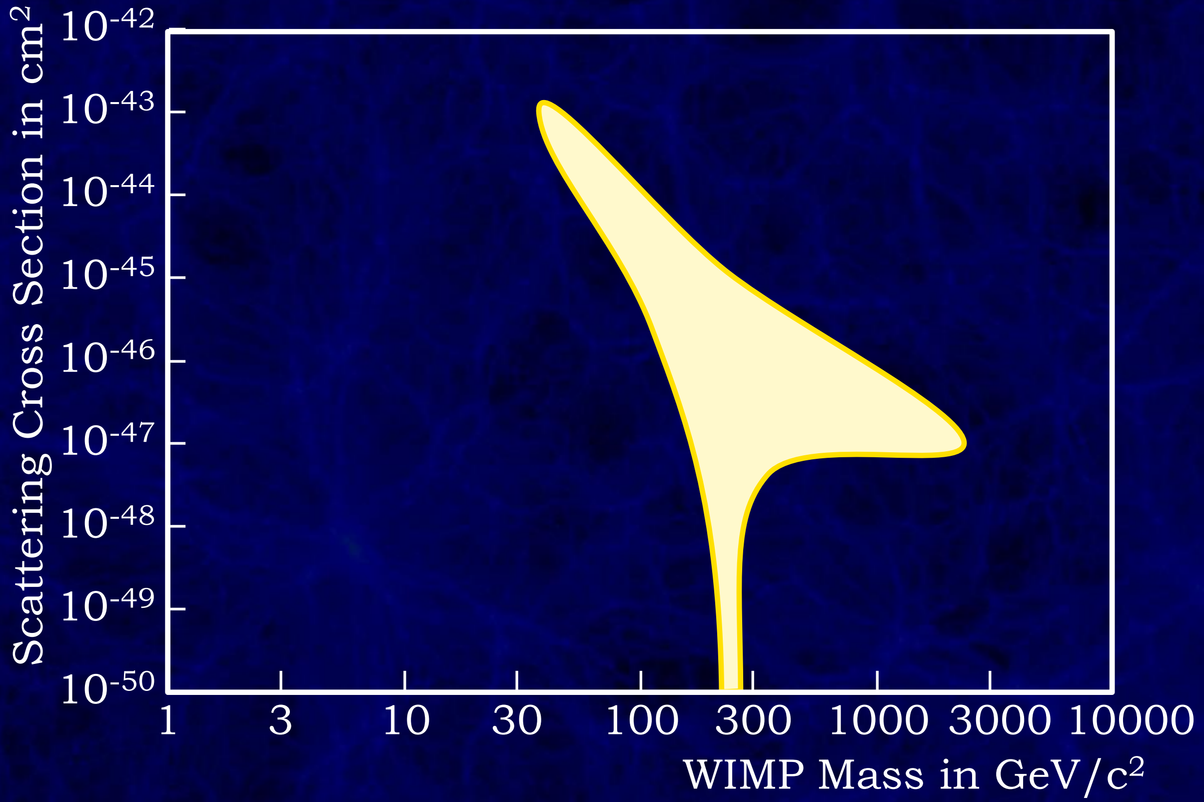
fill in your own prior, e.g:

cMSSM

Higgs-mediation

Z-mediation through box

Z-mediation at 10^{-10} abundance



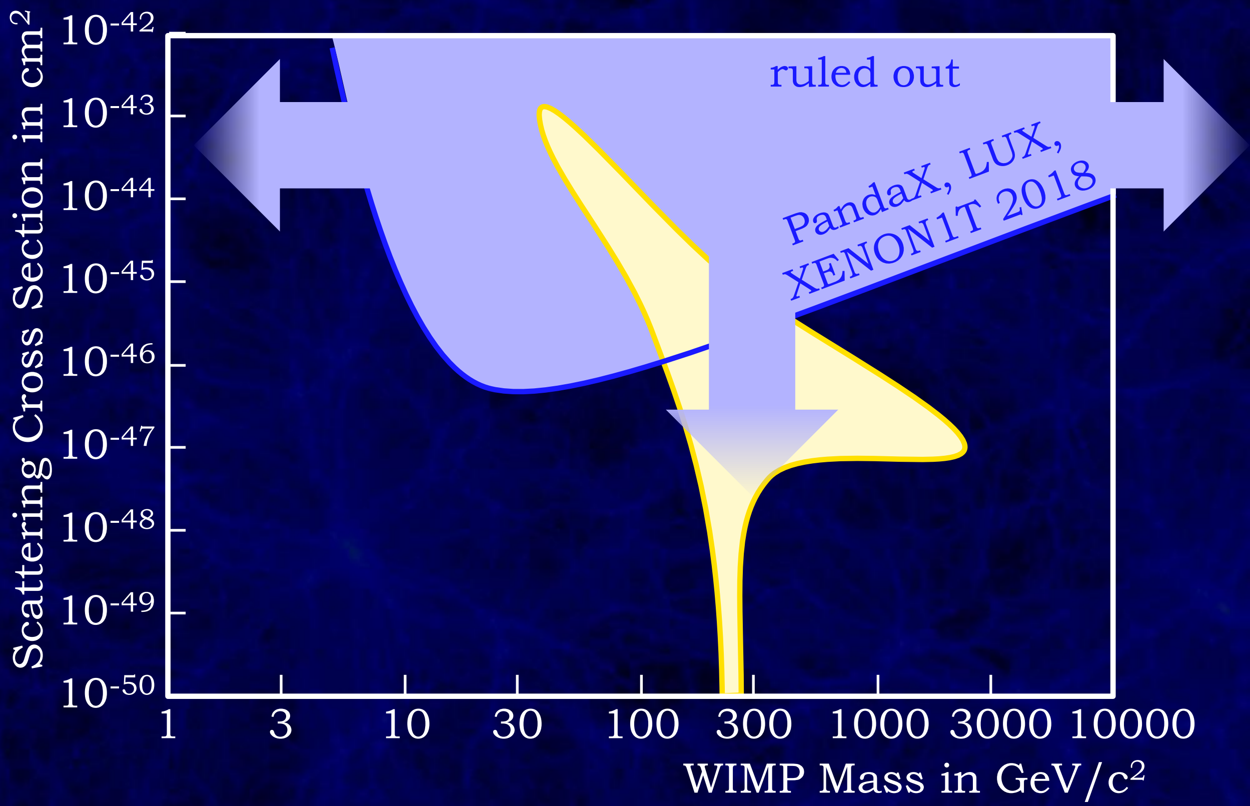
Ellis,Ferstl&Olive hep-ph/0001005

WIMP Detection: Status

Best limits all from xenon experiments

Low masses: fight threshold

High masses: number density decreases as mass density is fixed



WIMPs

- Higgs-mediation
- Z through box
- SUSY etc

Continue to provide strongly motivated prior

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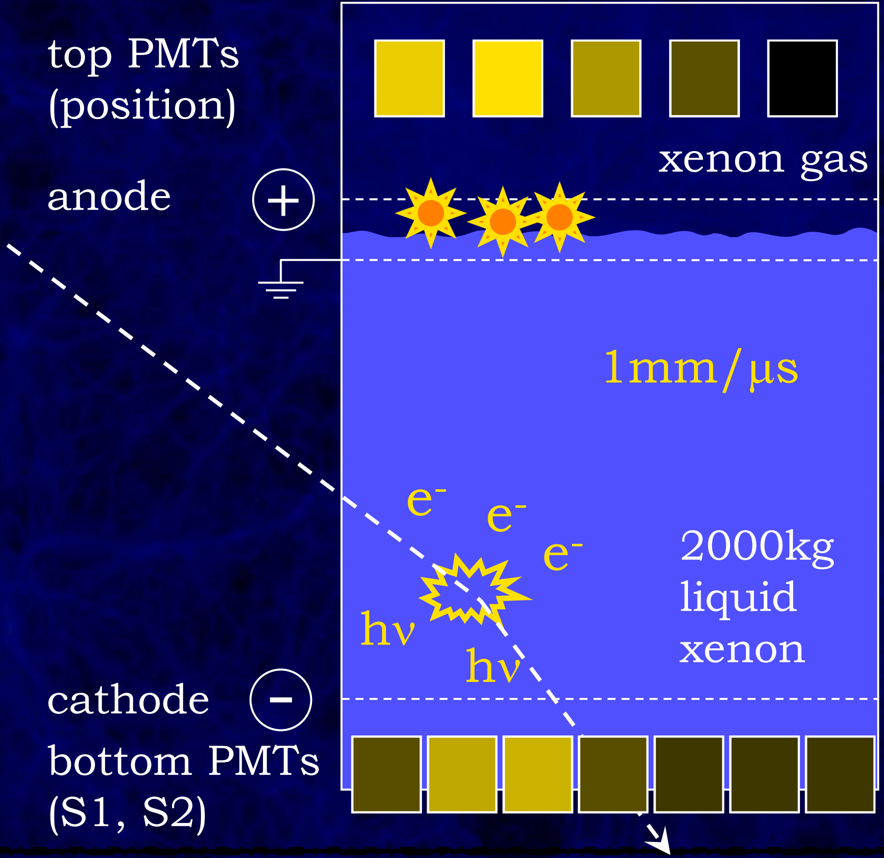
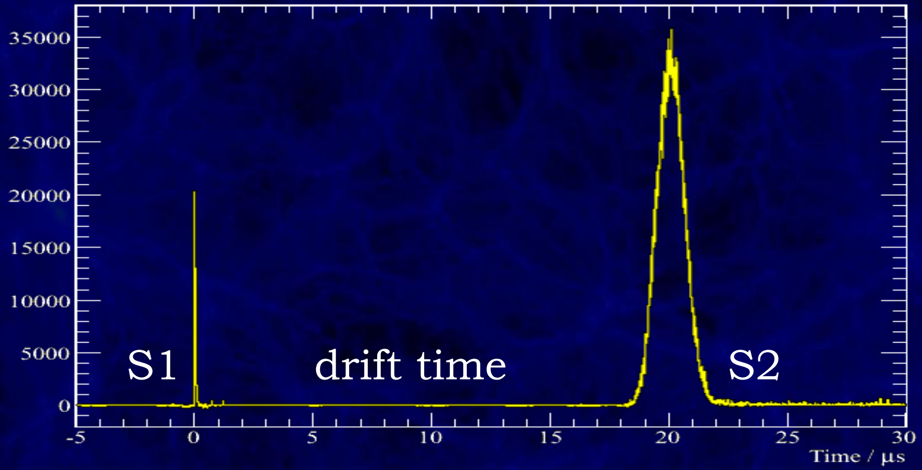
Dual-Phase TPC: e.g. XENON1T



3D position information

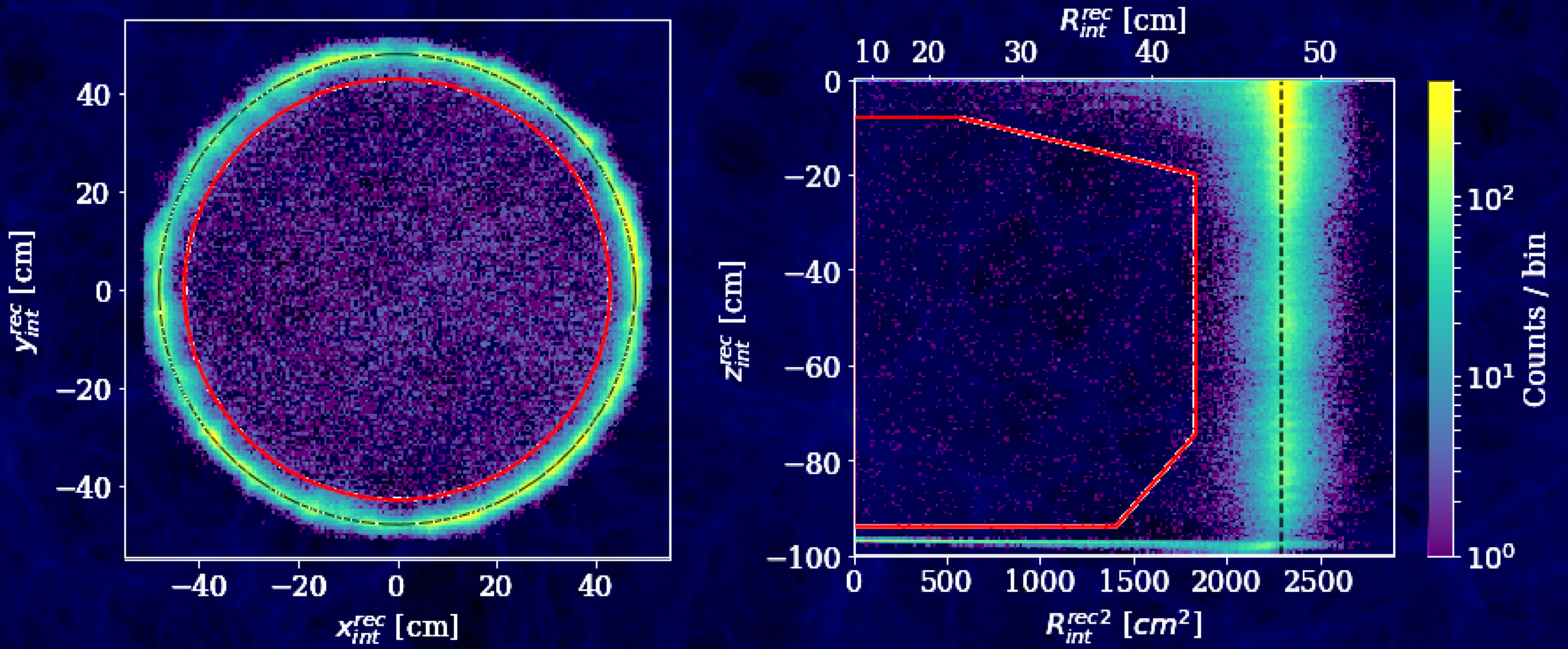
S2 hit pattern: $\delta r < 2\,\mathrm{cm}$

drift time: $\delta z < 500\,\mu\mathrm{m}$



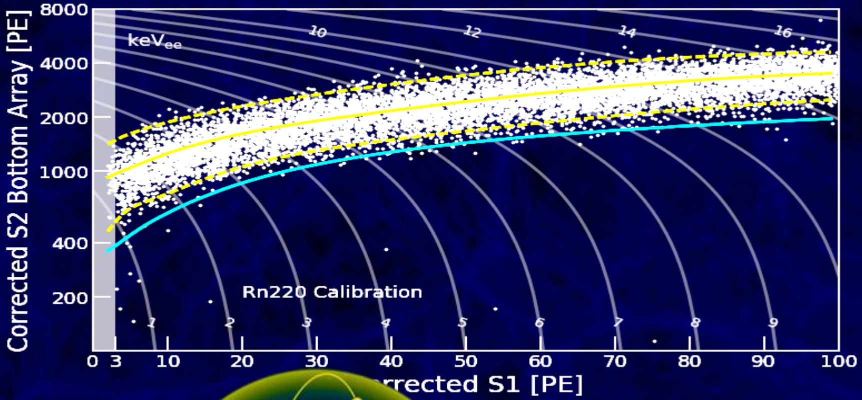
Self-Shielding in Xenon

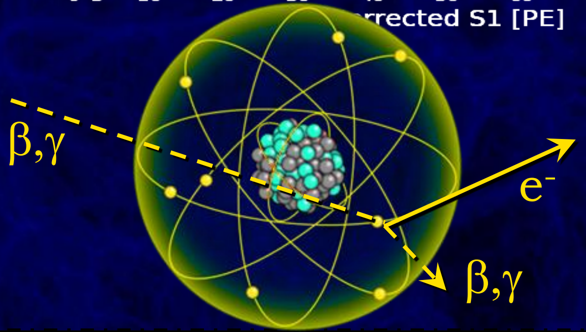
Reduce background with exp(-diameter/λ_γ)



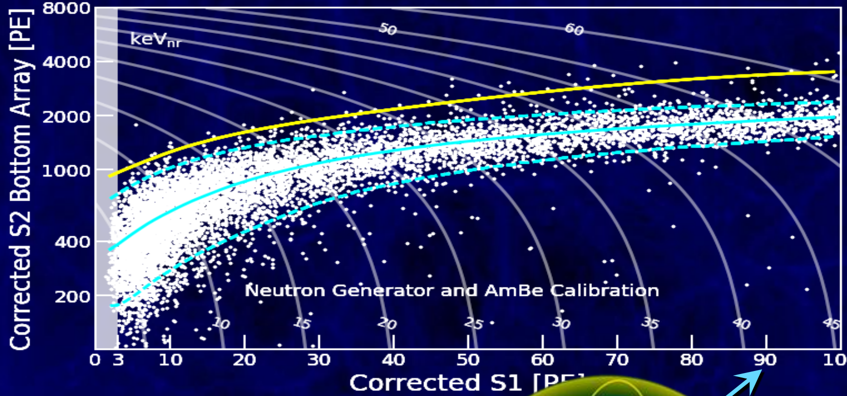
ER & NR Band calibration

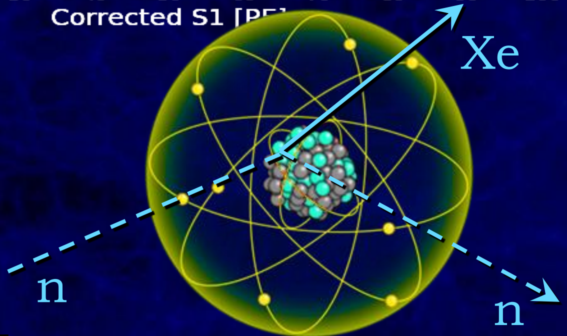
Electronic recoils, e.g. from ^{220}Rn





Nuclear recoils, e.g. from DD generator or ^{241}AmBe

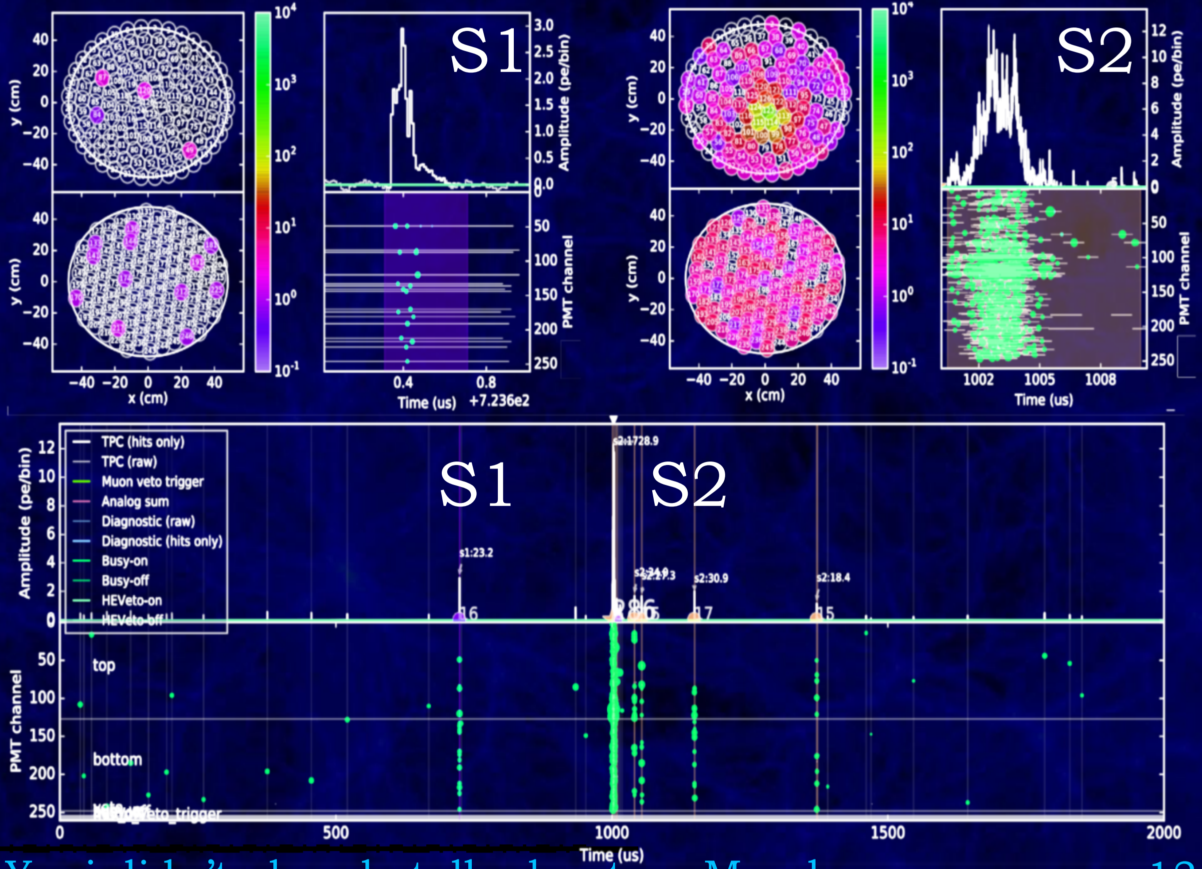




The Secret of Success

Redundant event information: can fight detector artefacts

(collect ~2.5MB per event)



Liquid TPCs

Technology of choice for WIMPs:
monolithic, scalable, cheap,
redundant event information

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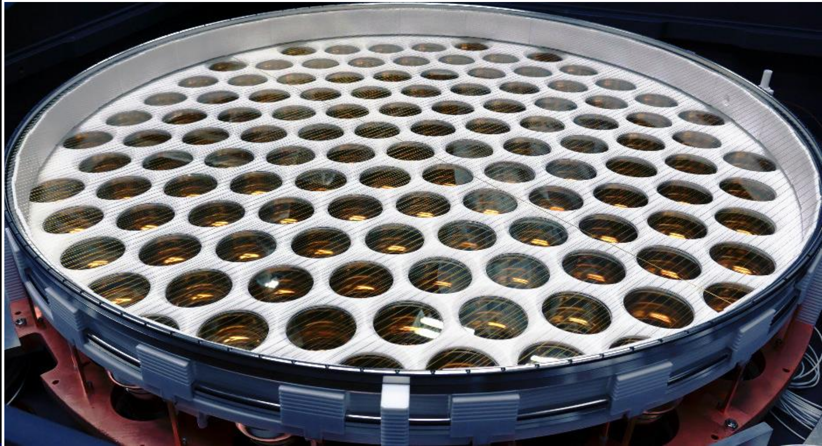
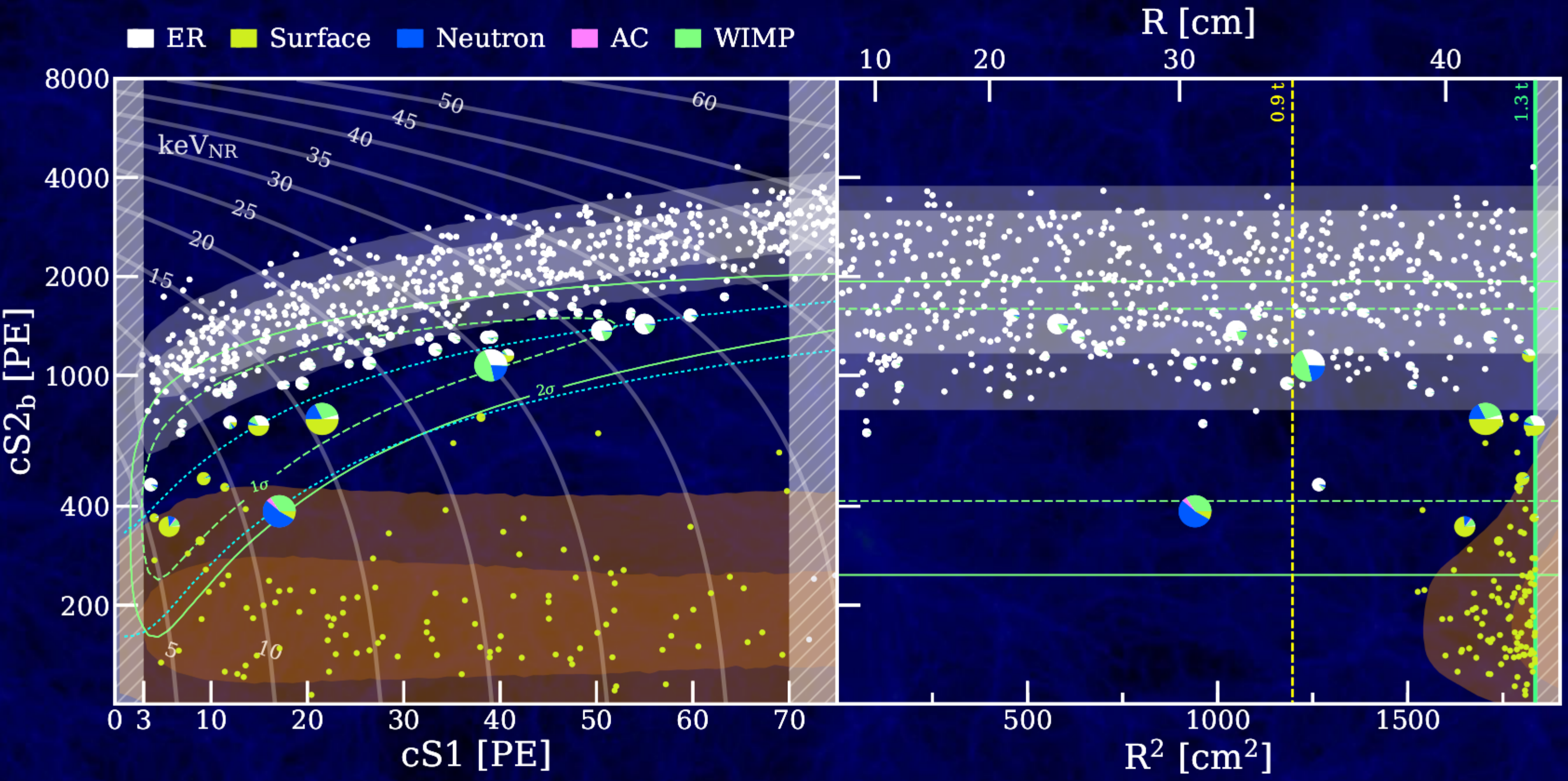


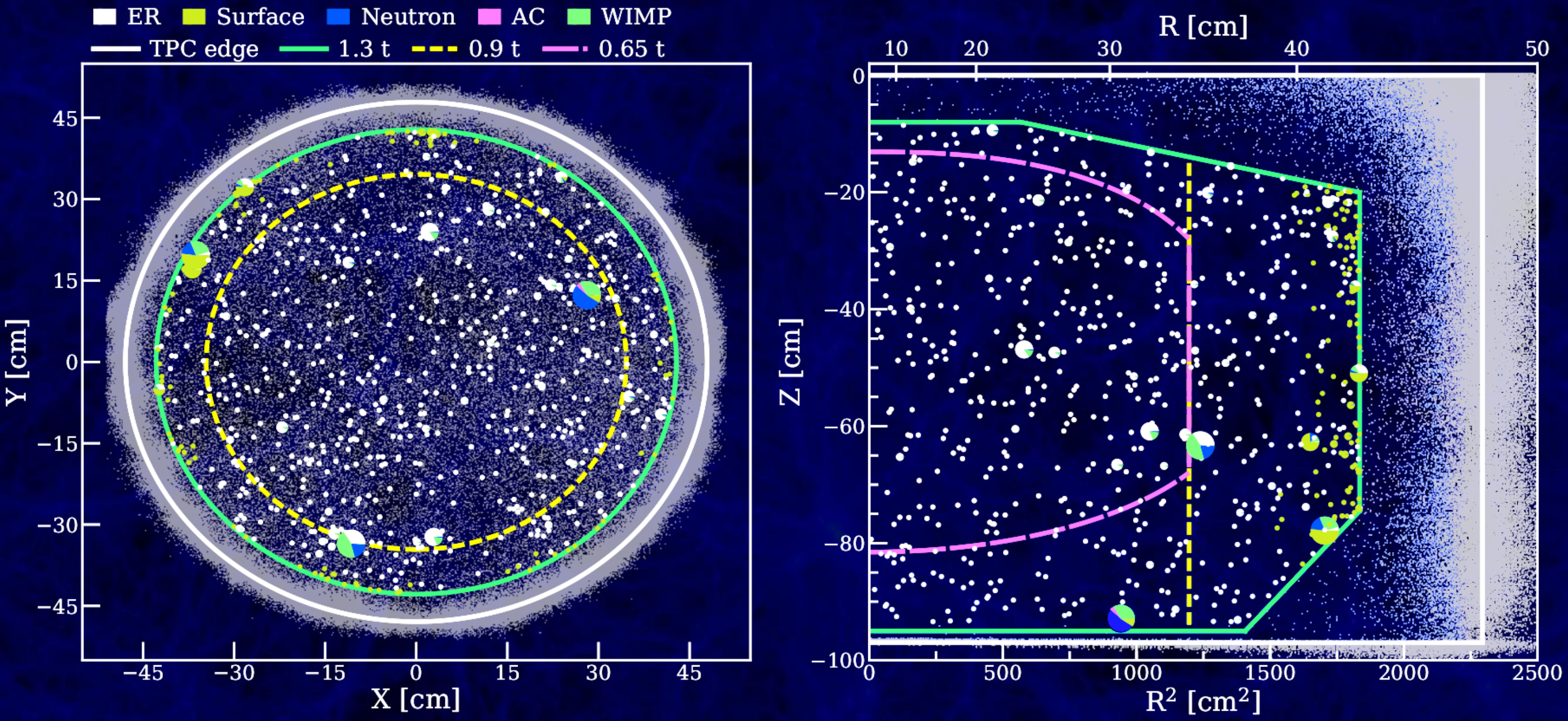

XENON
enlightening

XENON1T Science Run 1



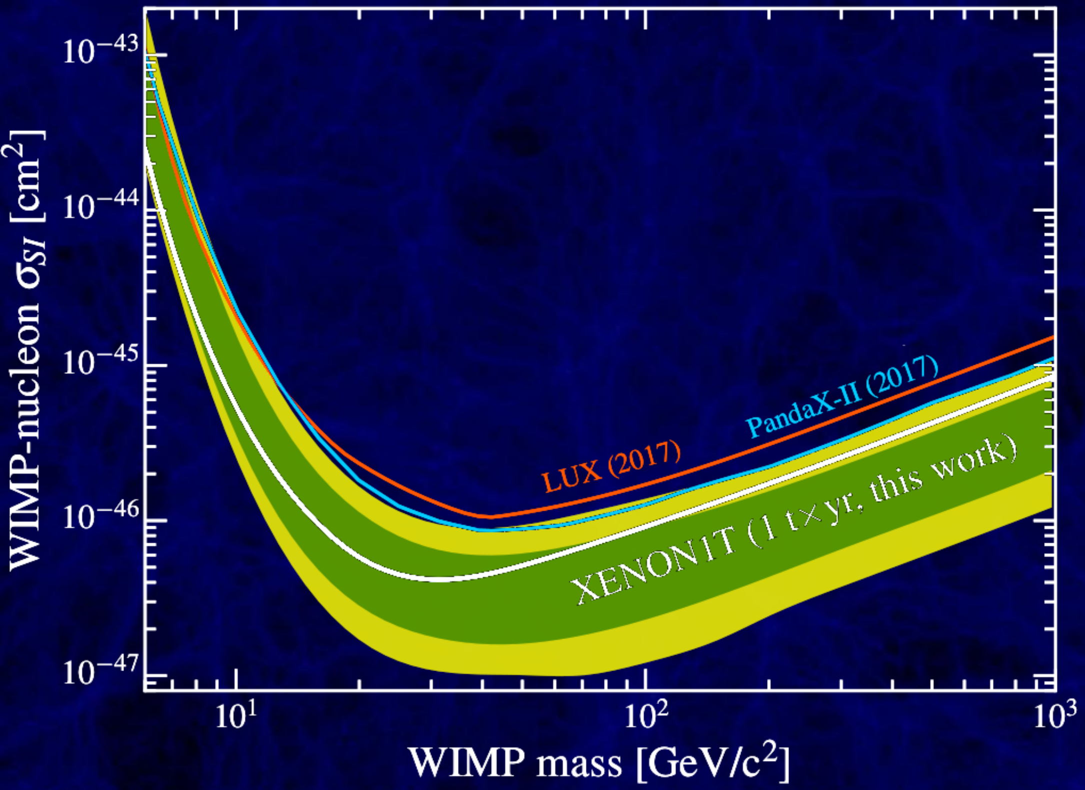
XENON 1805.12562

XENON1T Science Run 1



XENON 1805.12562

Yet another limit…



XENON 1805.12562

XENON1T Results

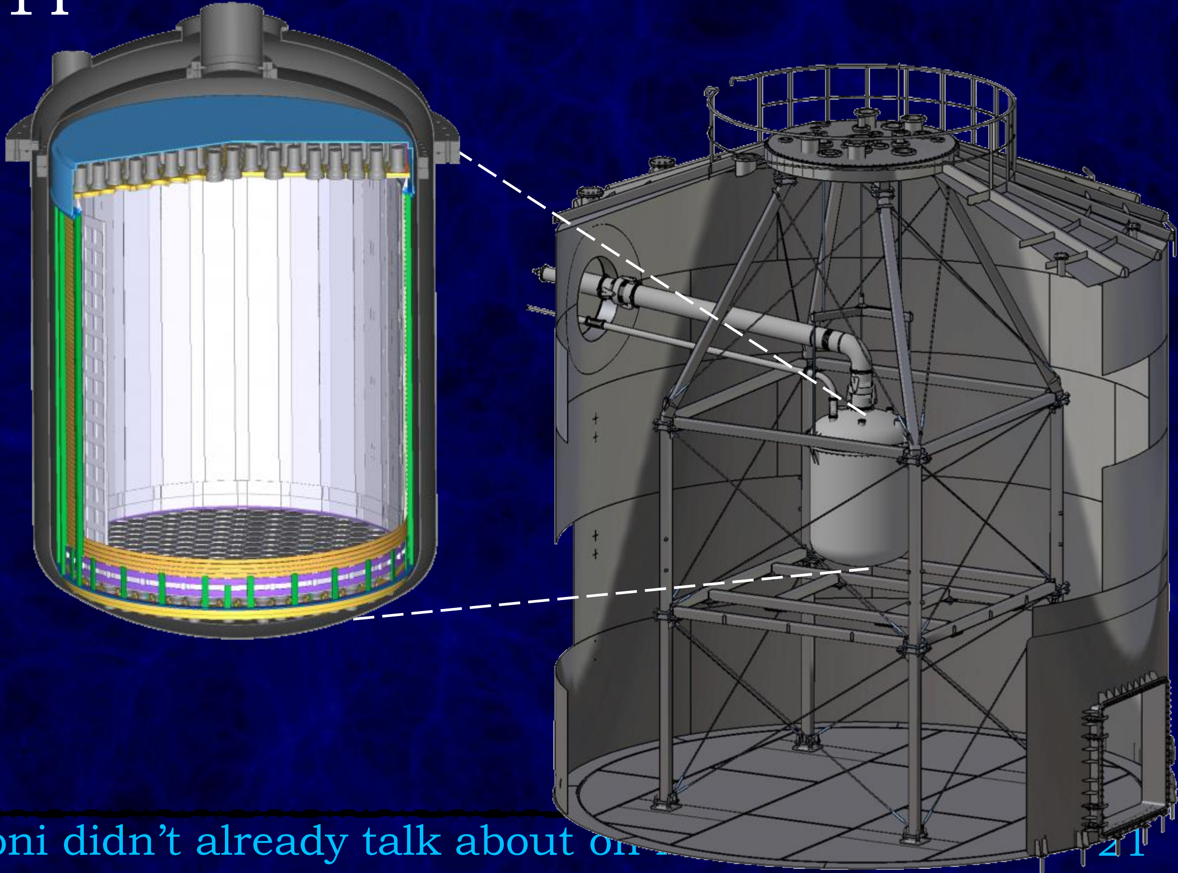
1 year, 1.3t fiducial mass:

world leading limit above ~8GeV.

sigh

Upgrade: XENONnT

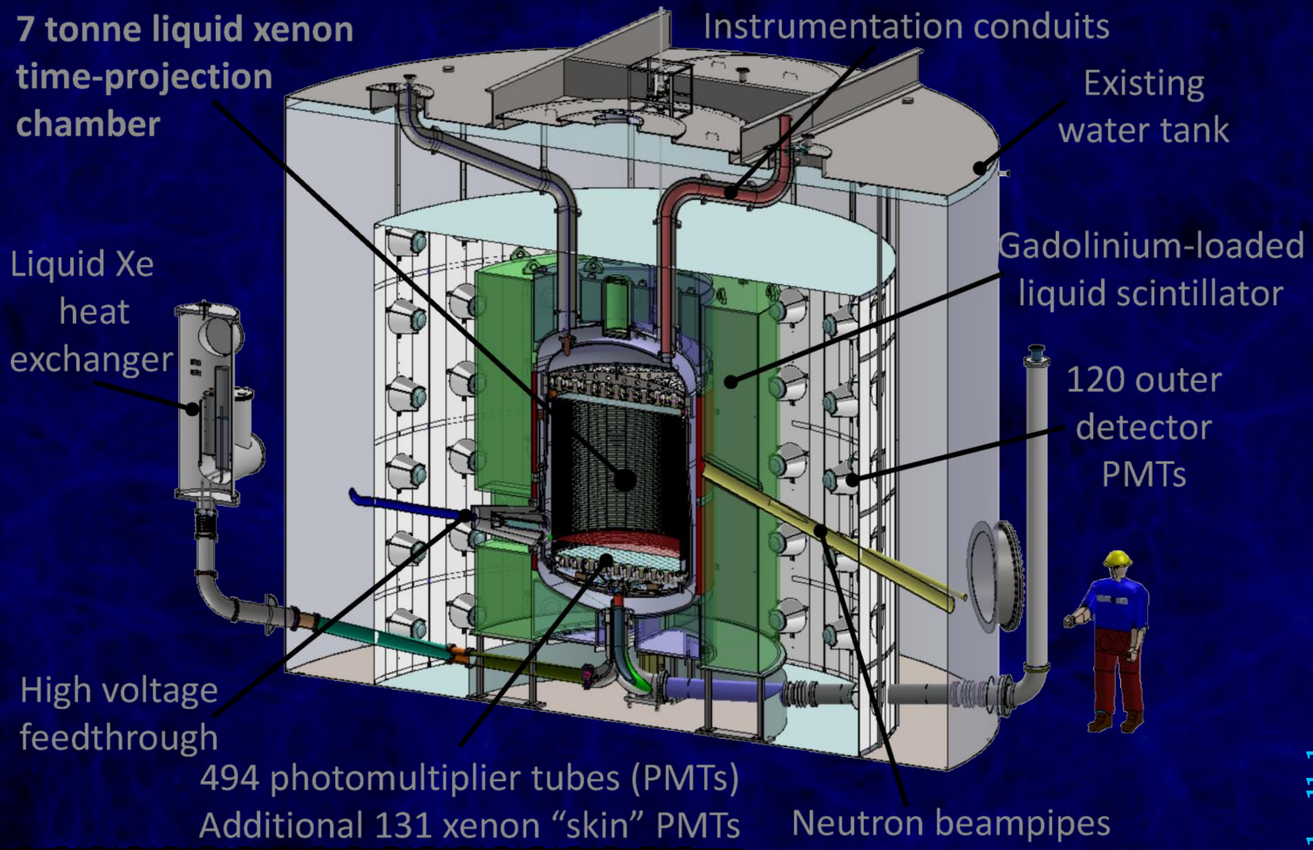
- Shut down XENON1T this year
- Rapid upgrade:
  8t total
  6t active
  >4t fiducial
  start 2019
- Re-use most sub-systems



LZ @SURF

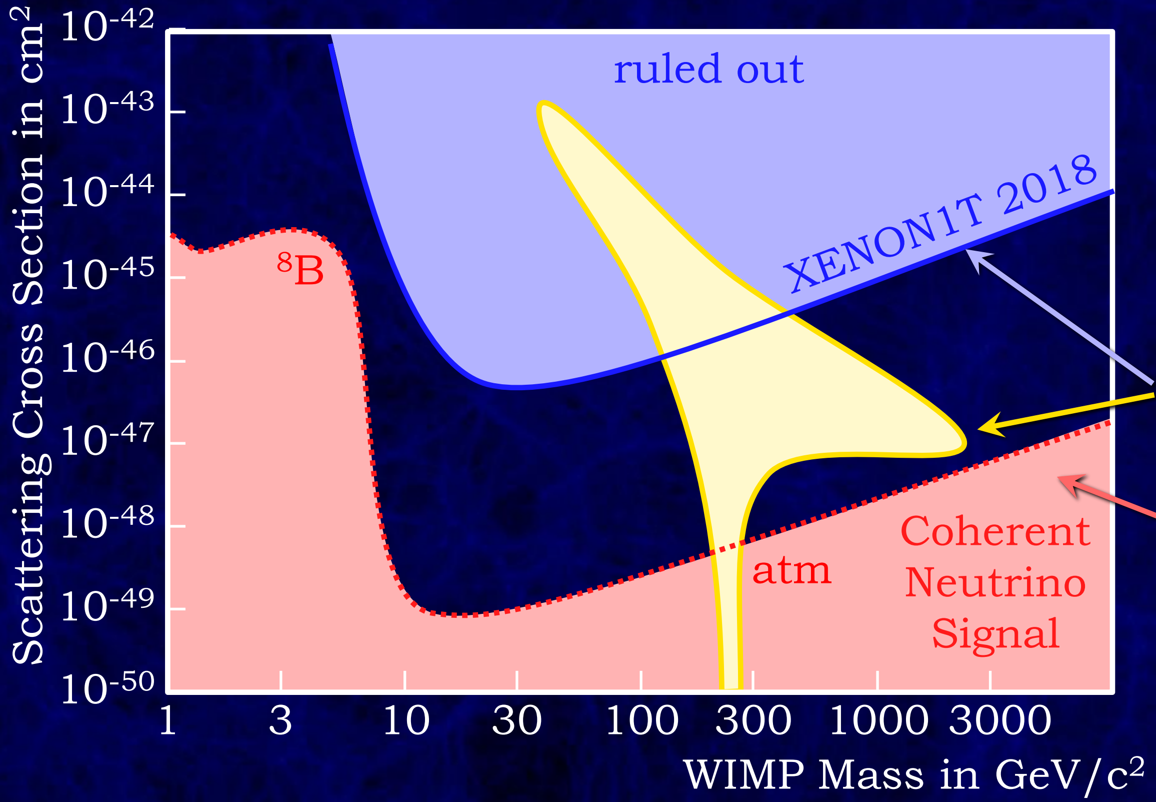
10t of LXe:
7t active
5.6t fiducial

start 2020



lz.lbl.gov

Coherent Neutrino-Nucleus Scattering



Simple scattering kinematics: degenerate in momentum

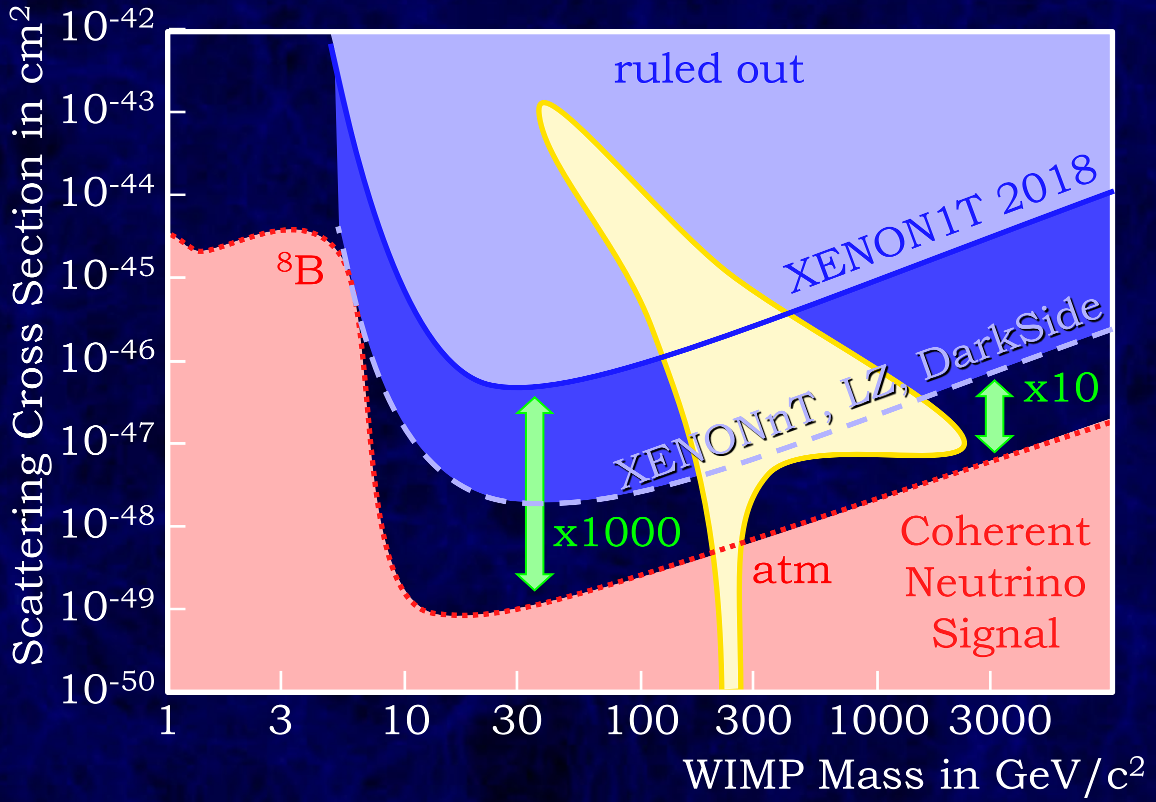
heavy WIMP, $v \sim 10^{-3}c$

Coherent Neutrino-Nucleus Scattering

light ν, v~c

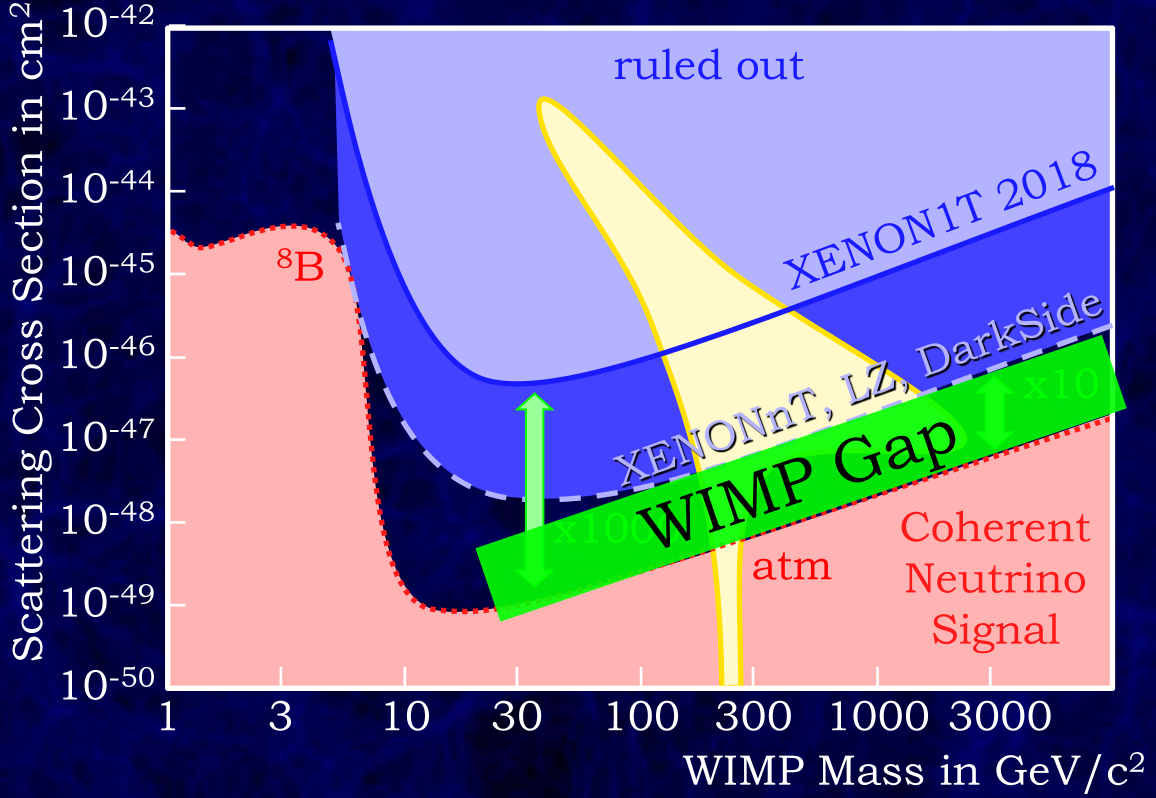
Billard, Strigari, Figueroa-Feliciano 1307.5458

“Neutrino Floor” Far, Far Away



strong program to improve factor 100

WIMP Gap Requires Generation-3



strong program to improve factor 100

current program leaves a WIMP gap: requires next-generation detector!

Digging Down

Excellent prospects with new experiments starting next year

Require dedicated generation-3 experiment to probe down to neutrino floor

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Solar ^{8}B Neutrinos ~2023

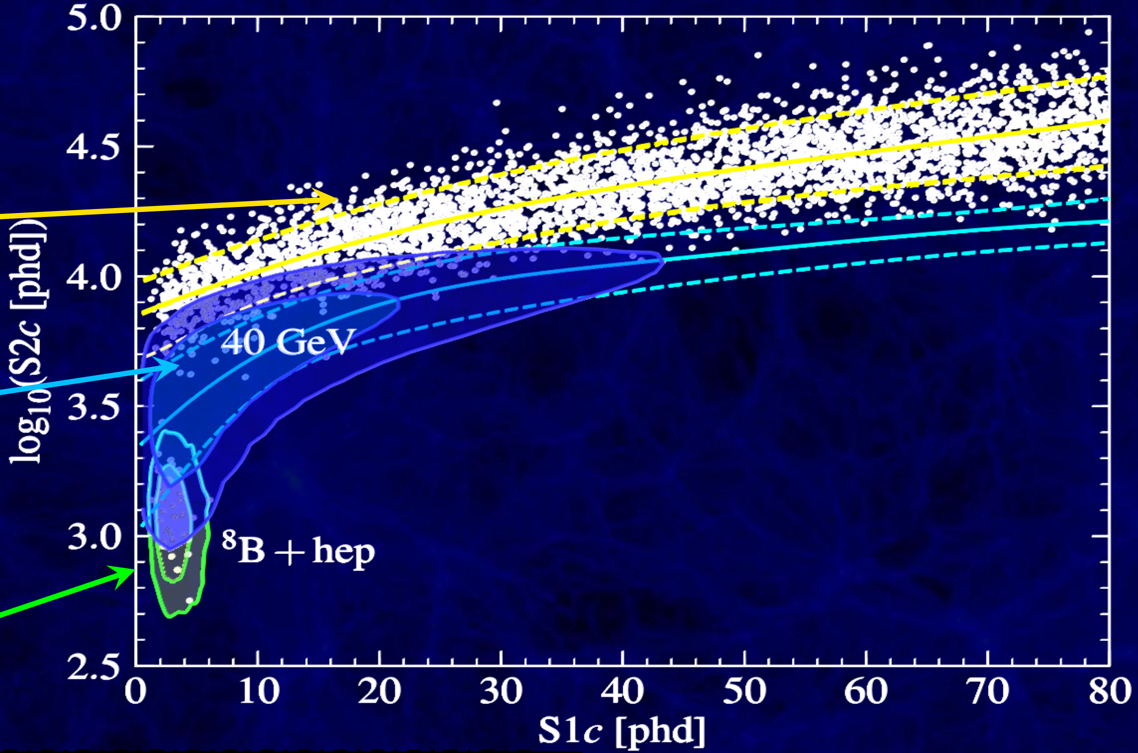
here: neutrinos scattering off nuclei

simulation: 1000d LZ

electronic recoil background

dark matter nuclear recoils

~36 ^{8}B solar neutrino nuclear recoils



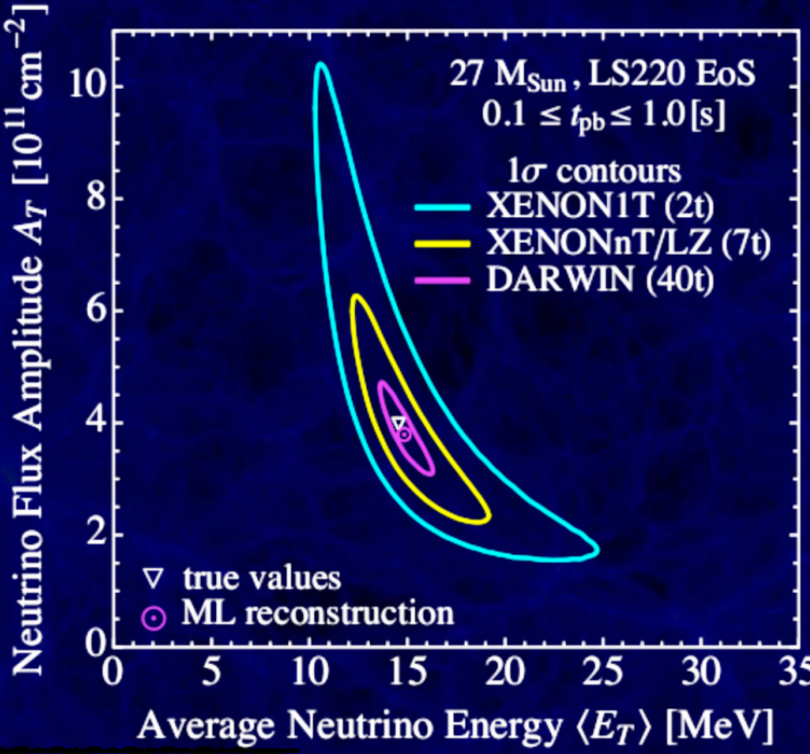
LZ/Dobson UCLA 2018

Supernova Neutrinos

few second burst $\nu_x + N \rightarrow \nu_x + N$

With SNEWS: XENON1T sensitive (3σ) across entire Milky Way

flavor-independent: complementary information



Rafael+ 1606.09243

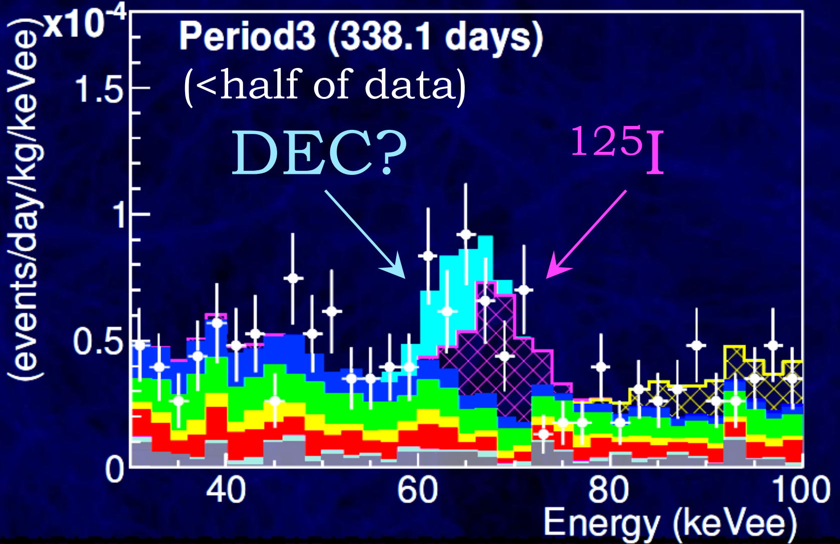
Double-Electron Capture: XMASS

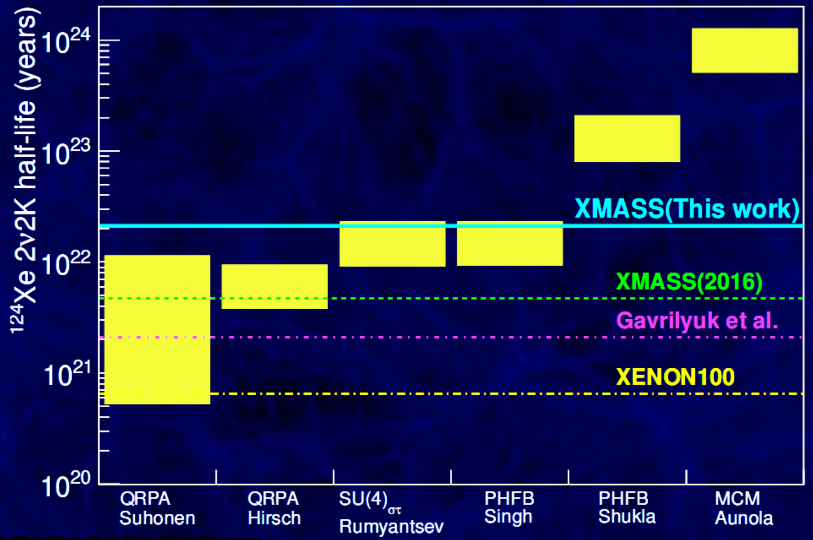
$$2e^- + {}^{124}\mathrm{Xe} \to {}^{124}\mathrm{Te} + 2\nu_e + 64\,\mathrm{keV}\,(\mathrm{E}_{2\mathrm{K}})$$

2νββ the other way around: help nuclear matrix models.

^{124}Xe abundance 0.095%

XMASS: 800.0 d, fiducial 327kg ^{nat}Xe = 311g ^{124}Xe

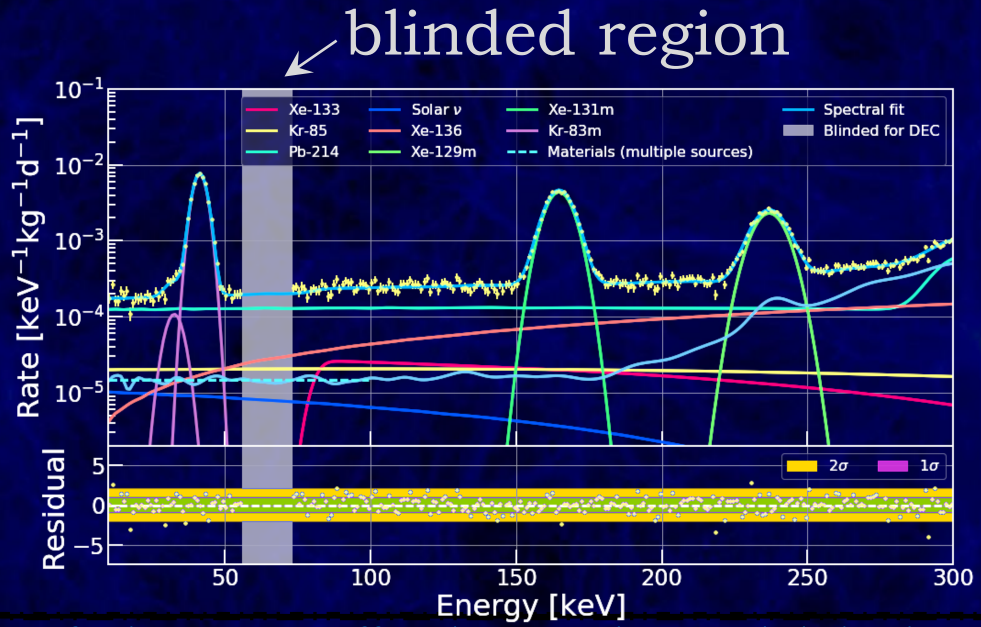


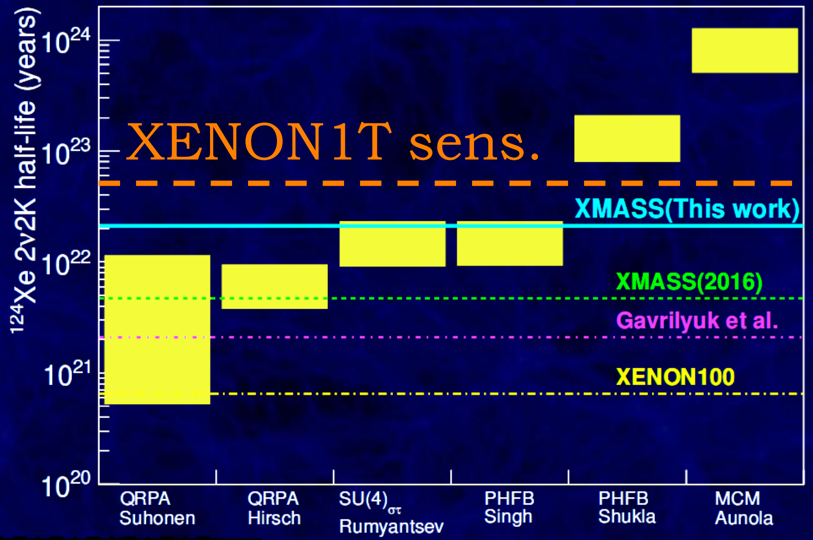


XMASS 1801.03251

Double-Electron Capture: XENON1T

better resolution, 1ton-year exposure, getter removes ^{125}I





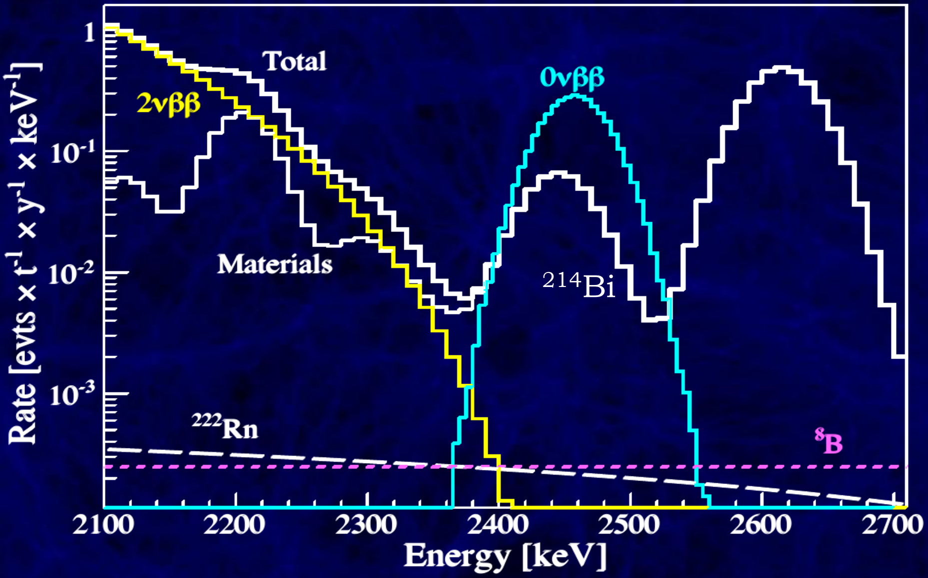
XENON preliminary

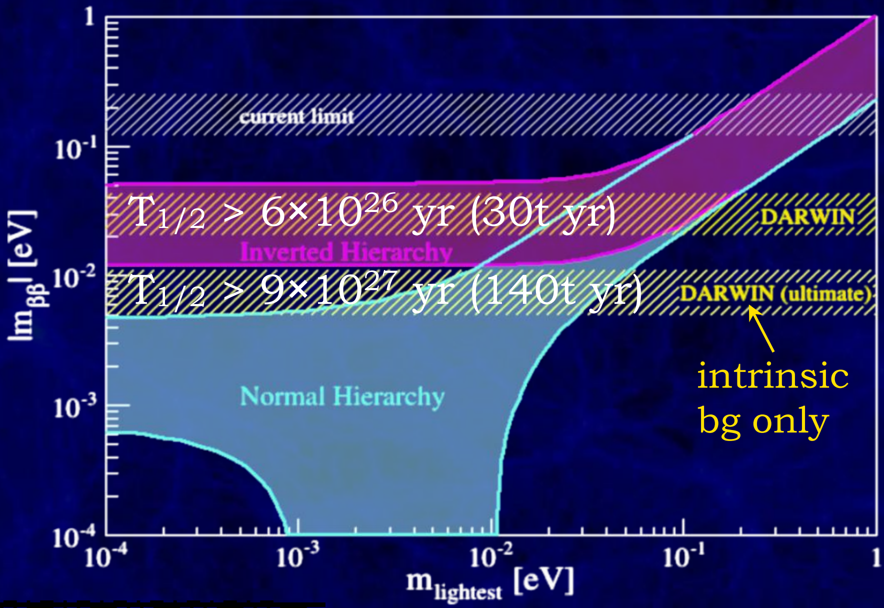
^{136}Xe 0ν2β with ^{nat}Xe Target

$$^{136}\mathrm{Xe} \rightarrow {}^{136}\mathrm{Ba} + 2e^{-}$$ (abundance 8.9%, i.e. ~4t in target)

Requires large dynamic range of detector

Baudis+ 1309.7024



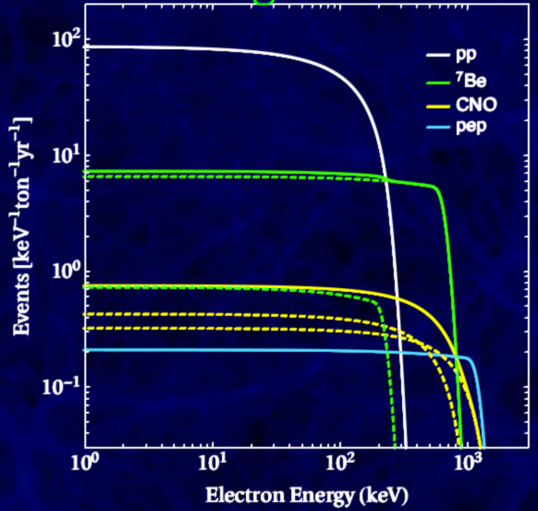


DARWIN 1606.07001

CNO Neutrinos in 60t Xenon?

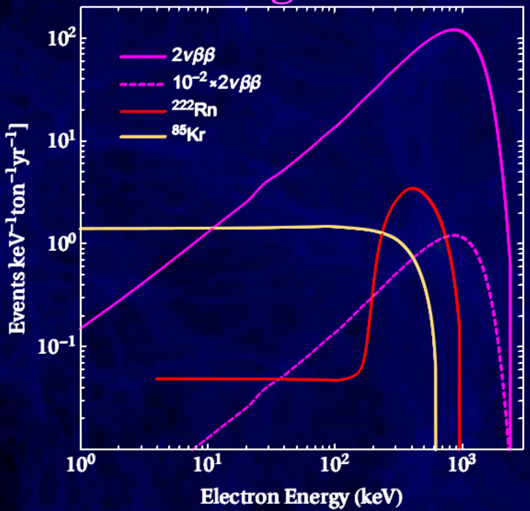
elastic scattering $\nu_e + e^- \rightarrow \nu_e + e^-$

signals

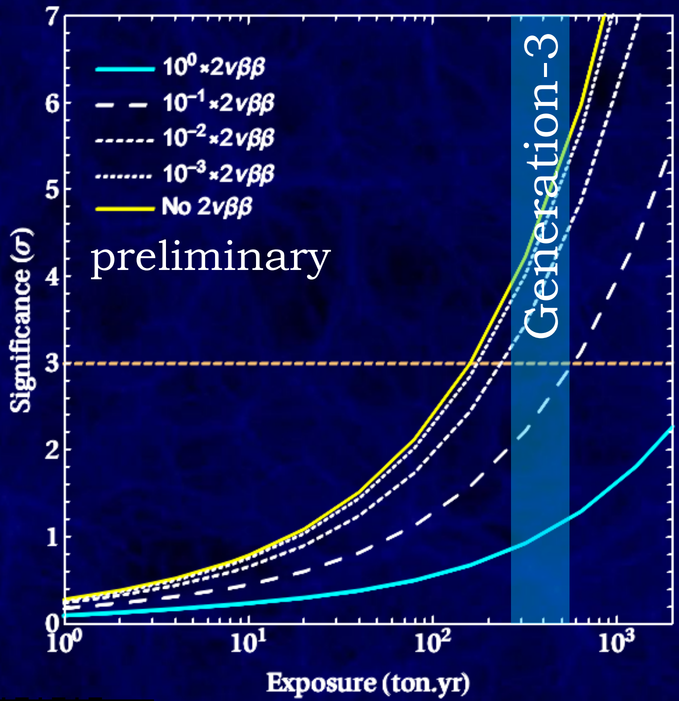


^{136}Xe hurts:

backgrounds



CNO detection significance



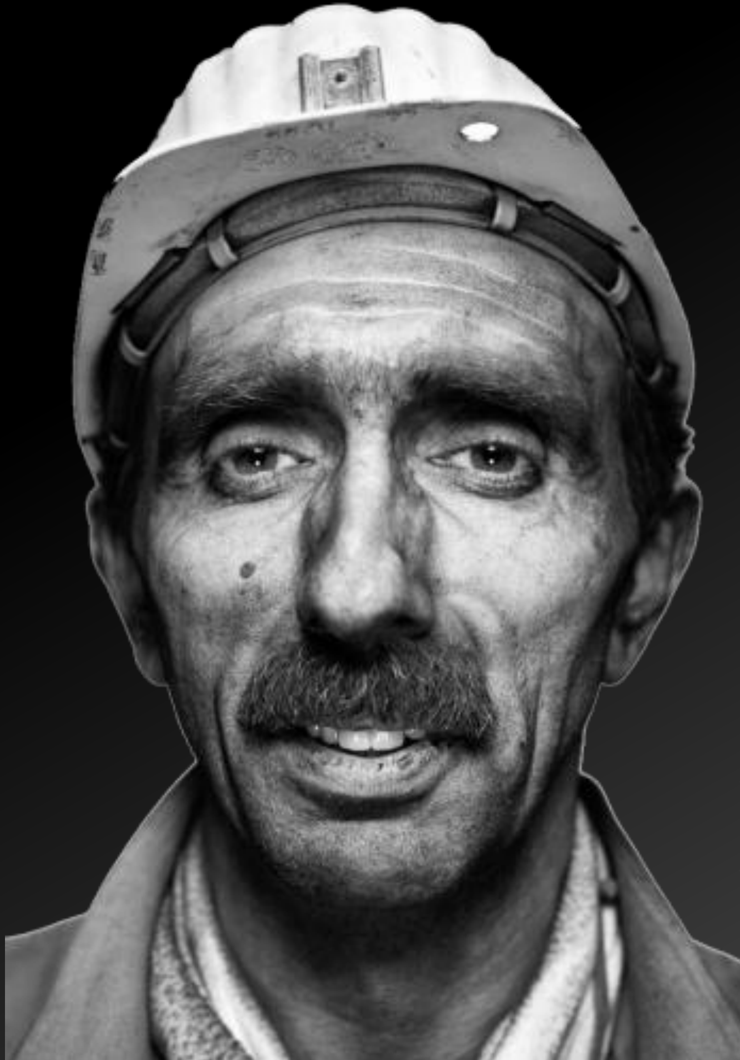
Newstead, Strigari & Rafael 1807.07169

Neutrinos

Direct dark matter experiments become sensitive to solar neutrinos…

…but the neutrino floor is far and requires Generation-3

Plus: galactic supernovae, double electron capture, neutrinoless double-beta decay!



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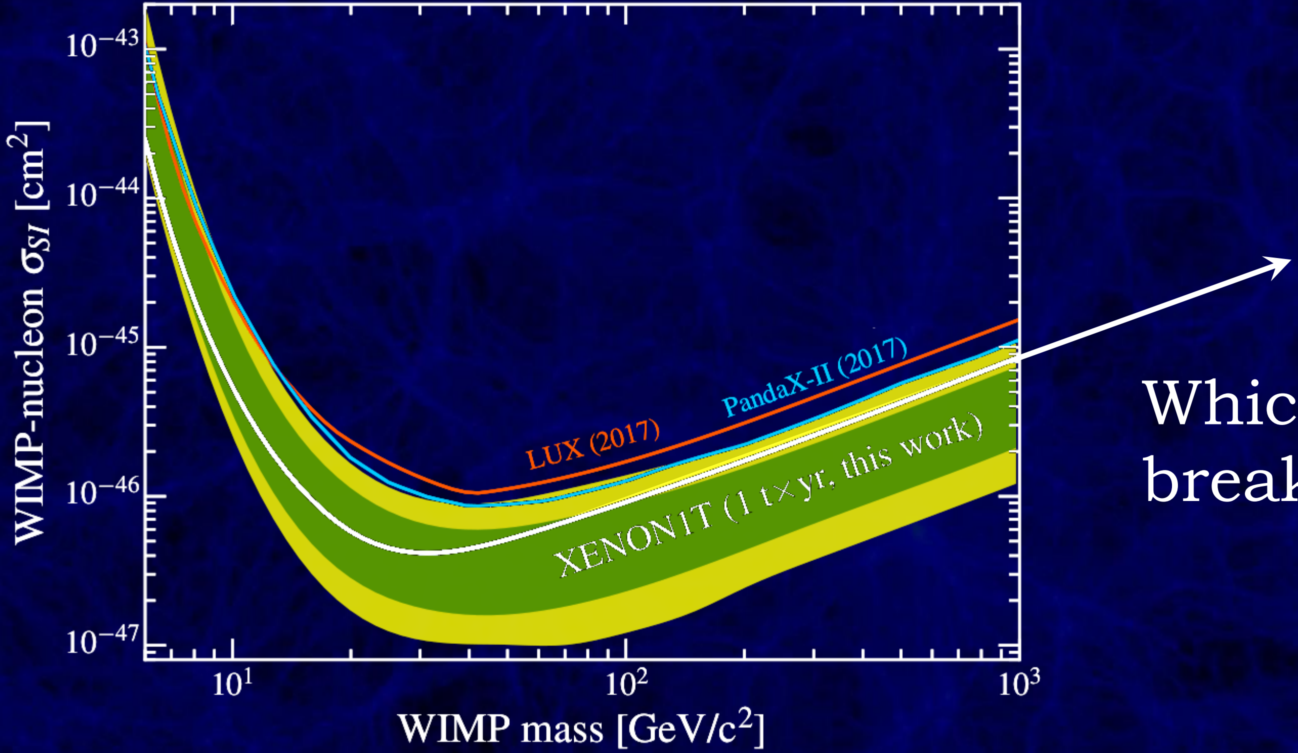
Extrapolate to Higher Masses

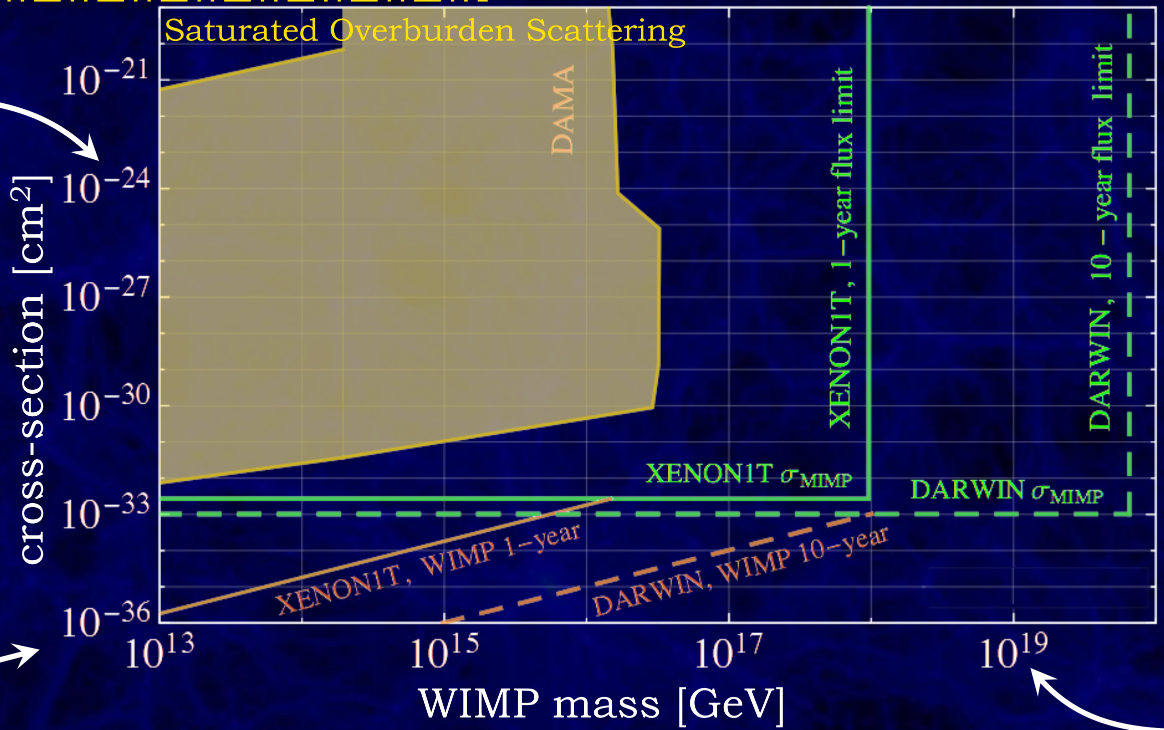
XENON 1805.12562



Which assumption breaks down?

Direct Detection at High Mass

1 barn



Planck mass

Non-relativistic tracks can probe large uncovered parameter space

Bramante, Broerman, Rafael & Raj 1803.08044

Probing High Masses

Requires dedicated analyses

Probe even around Planck mass

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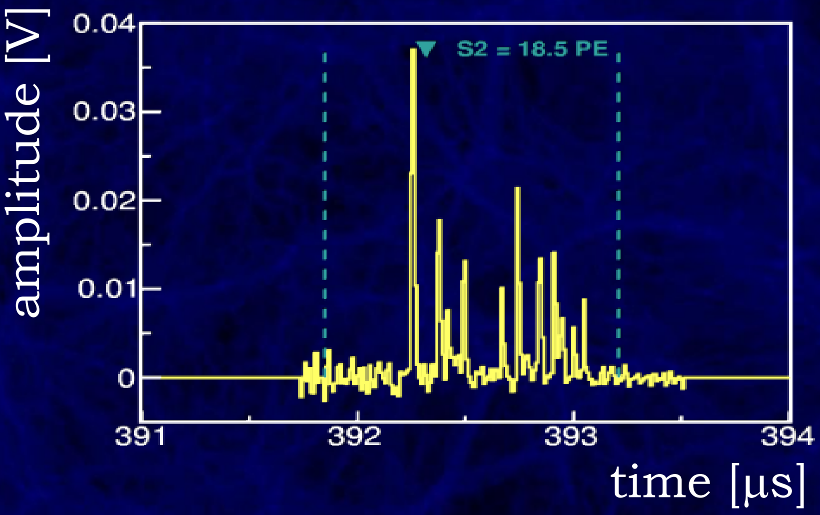
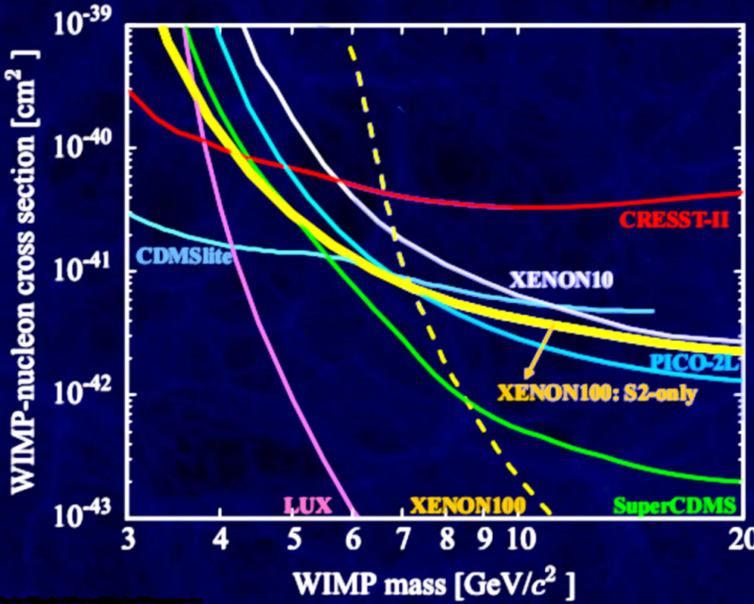
Electron Scattering in Xenon

Detect even individual electrons liberated anywhere in 2000kg of Xenon:



XENON100 1311.1088

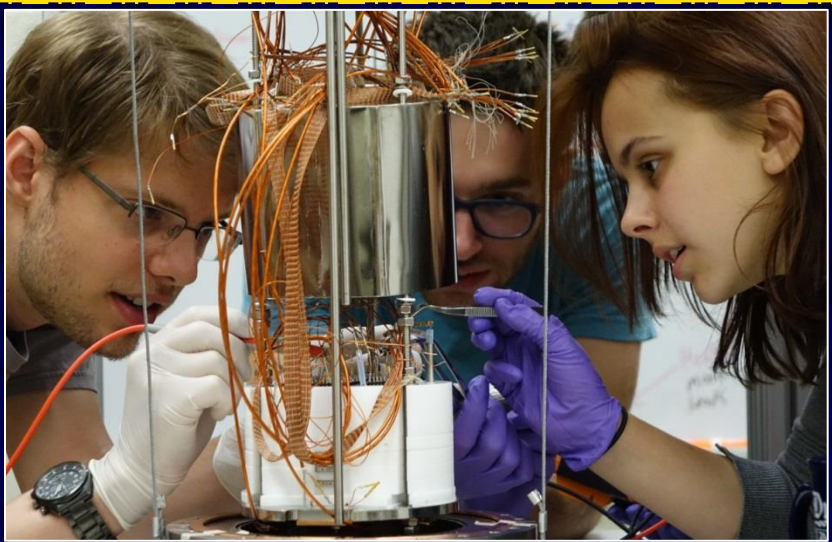
But backgrounds not yet tackled:



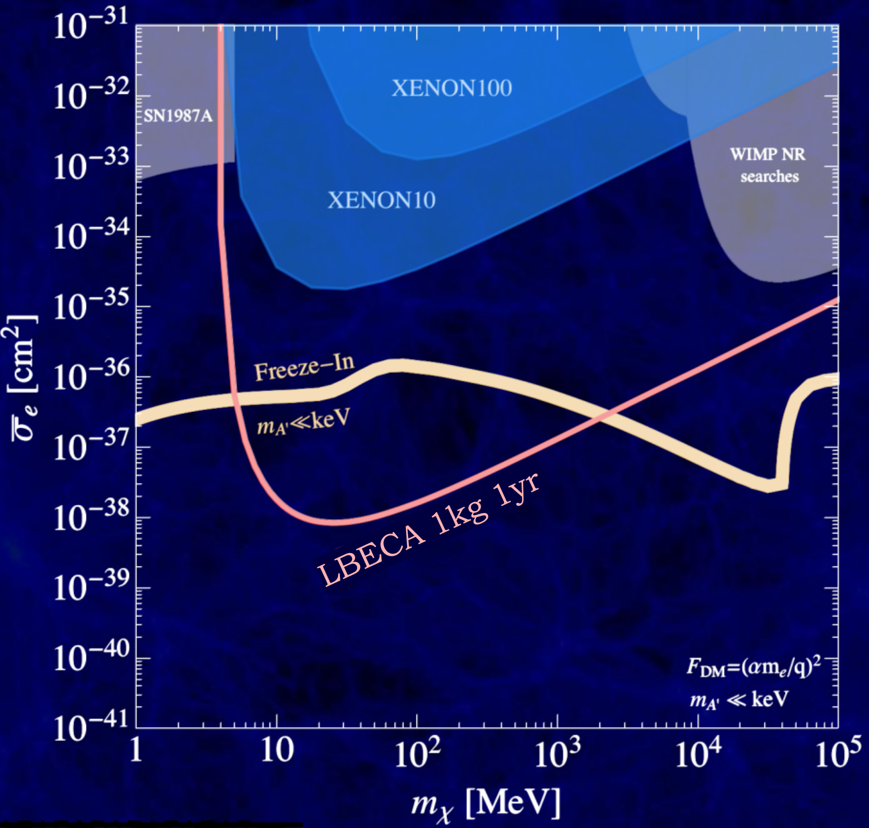
XENON100 1605.0626

LBECA

A.Bernstein, J.Xu, P.Sorensen, K.Ni, R.Essig, M.Fernandez-Serra, Rafael



Build dedicated, conventional detector to tackle backgrounds and probe Dark Matter



LBECA

Promising for fast results
even below 10MeV

Bringing discovery-level science
back to the universities

Much more than just WIMPs!

Dark Matter:

- spin-independent WIMPs
- spin-dependent WIMPs
- EFT couplings and inelastic WIMPs
- GeV and MeV WIMPs (“S2-only”)
- Planck mass dark matter
- Migdal & Bremsstrahlung searches
- Annual modulation searches
- Magnetic Inelastic WIMPs
- inelastic scattering
- axial-vector coupling
- Mirror & luminous DM
- Axion-like particles
- SuperWIMPs
- Dark photons
- Planck-mass Dark Matter

Neutrinos:

- solar pp neutrinos
- ^{8}B solar neutrinos
- galactic supernovae
- CNO neutrinos
- neutrino oscillations
- sterile neutrinos
- neutrino magnetic moment

- $2\nu\beta\beta$ decay of ^{136}Xe
- $0\nu\beta\beta$ decay of ^{136}Xe
- double-EC on ^{124}Xe

Other:

- solar axions
- fractionally charged particles

Conclusions

- Liquid Xe TPCs became versatile science machines
- Generation-3 detectors required to cover WIMPs
- Much-needed diversification of experimental program is happening

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