WIMP Searches 2018

With some focus on XENON1T

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Patras2018, June 2018

See also…

- NEWS-G by Francisco Vazquez de Sola Monday
- PICO by Andrew Sonnenschein yesterday
- Panda-X by Pengwei Xiw after this talk
- XMASS by Kazufumi Sato this afternoon
- SuperCDMS by Belina Von Krosigk, Friday
- LUX & LZ slides by Francisco Neves tomorrow

Conclusions

Experiments are probing
our most popular models

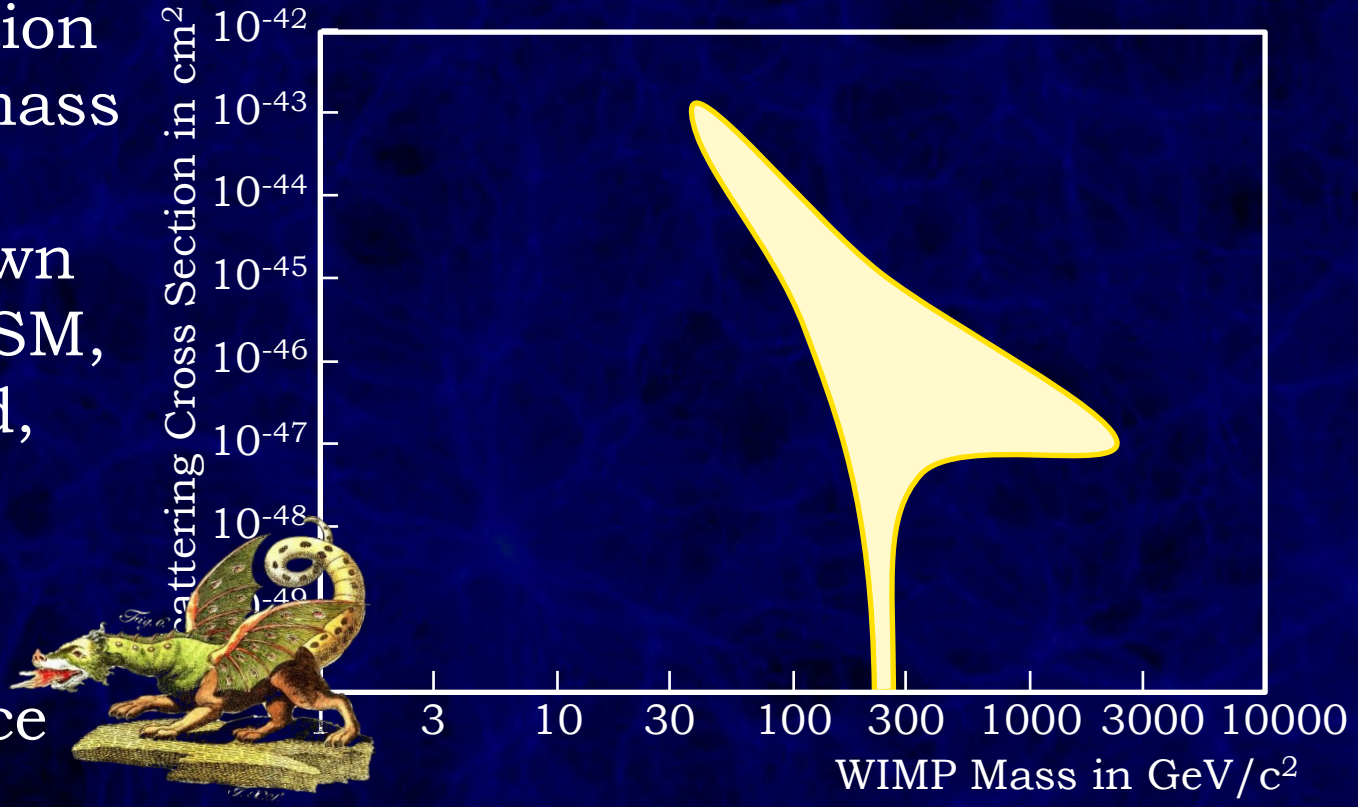
Clear path towards the neutrino
floor, but patience! Not before 2030

Many new experimental efforts
bring discovery-level science
back to the universities

WIMP Detection: Target

Plot Cross Section versus WIMP mass

fill with your own prior, e.g. cMSSM, Higgs-mediated, Z-mediation through box, Z-mediation at 10^{-10} abundance



Ellis,Ferstl&Olive hep-ph/0001005

WIMP Direct Detection 101

- coherent scattering

$$\frac{\lambda_{\mathrm{deBroglie}}}{2\pi} = \frac{\hbar}{p} = \frac{\hbar c}{mc^2\, v/c} \sim \frac{197\,\mathrm{MeV\ fm}}{100\,\mathrm{GeV}\ 10^{-3}} \approx \mathrm{fm} \approx r_{\mathrm{nucleus}}$$

- rate prefers high-A (high-J) targets

$$N = n_{\mathrm{target}} \Phi\, \sigma_{\chi,N}\, A^2 \qquad \text{or } \propto \sigma_{\chi,N}\, J(J+1)$$

- recoil spectrum: falling exponential at low energies

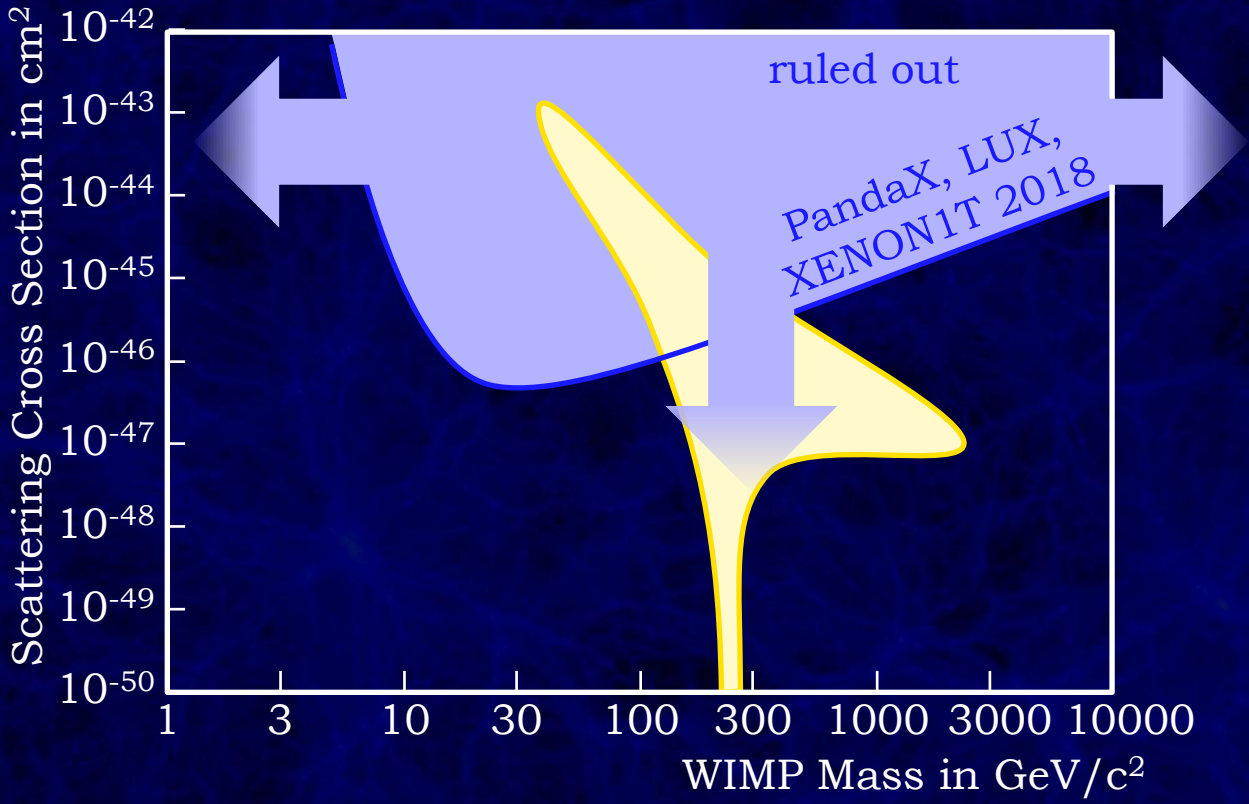
$$E_{\mathrm{r,max}} \sim \frac{p_\chi^2}{2m_{\mathrm{N}}} \sim \frac{\left(100\,\mathrm{GeV/c^2} \times 10^{-3}\mathrm{c}\right)^2}{2 \times 100\,\mathrm{GeV/c^2}} = 50\,\mathrm{keV}$$

WIMP Detection: Status

Best limits all from xenon experiments

Low masses: fight threshold

High masses: number density decreases as mass density is fixed

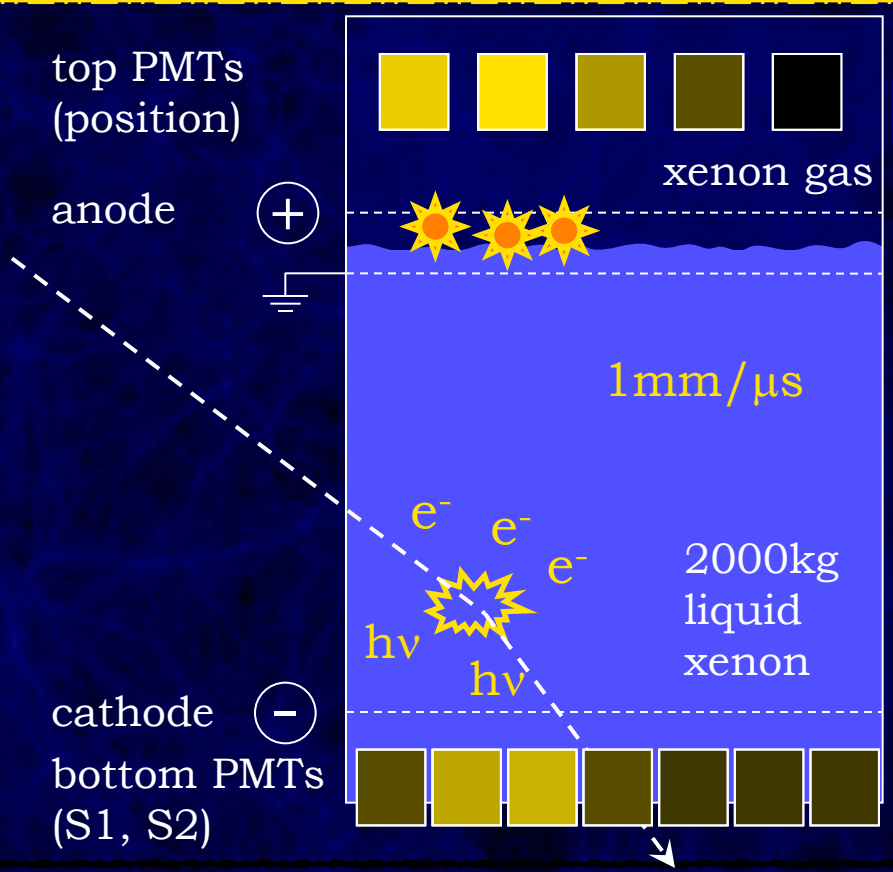


Thermal Relics & WIMPs

WIMPs: Higgs-mediation,
Z through box, SUSY etc

Simple nonrelativistic scattering

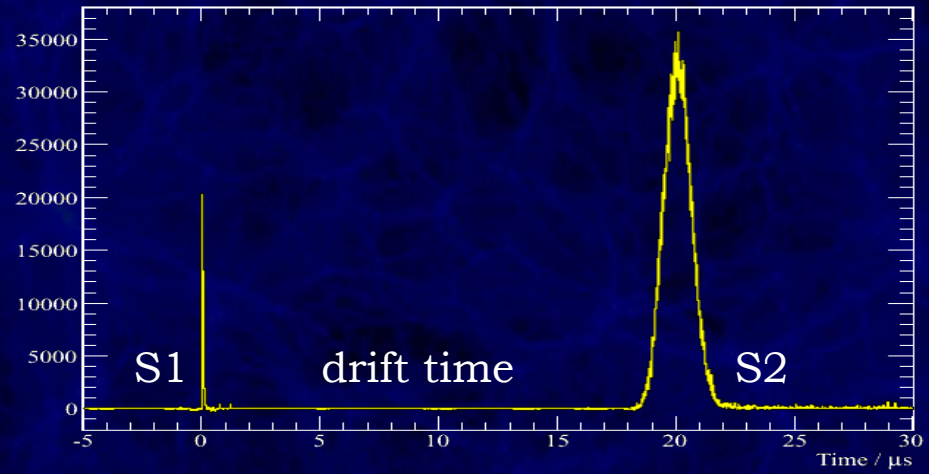
Dual-Phase TPC: e.g. XENON1T



3D position information

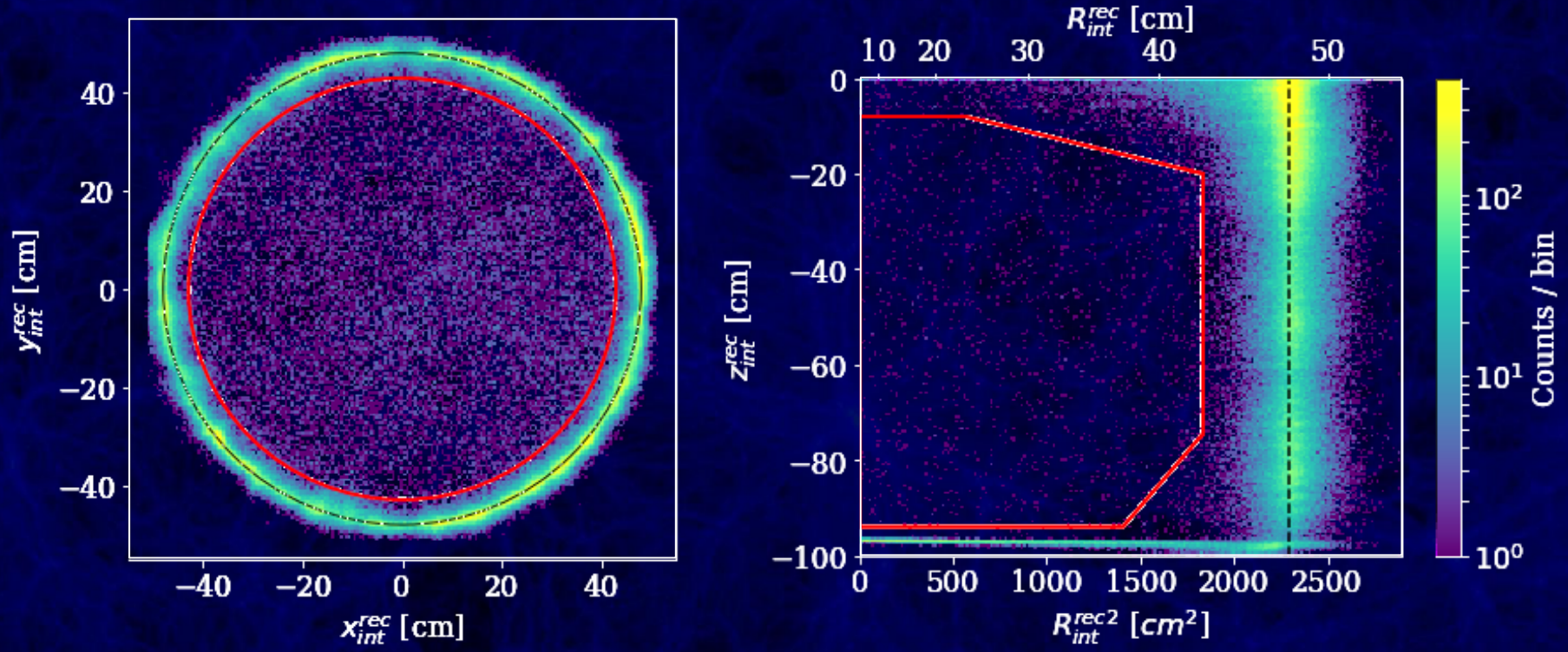
S2 hit pattern: $\delta r < 2\,\mathrm{cm}$

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

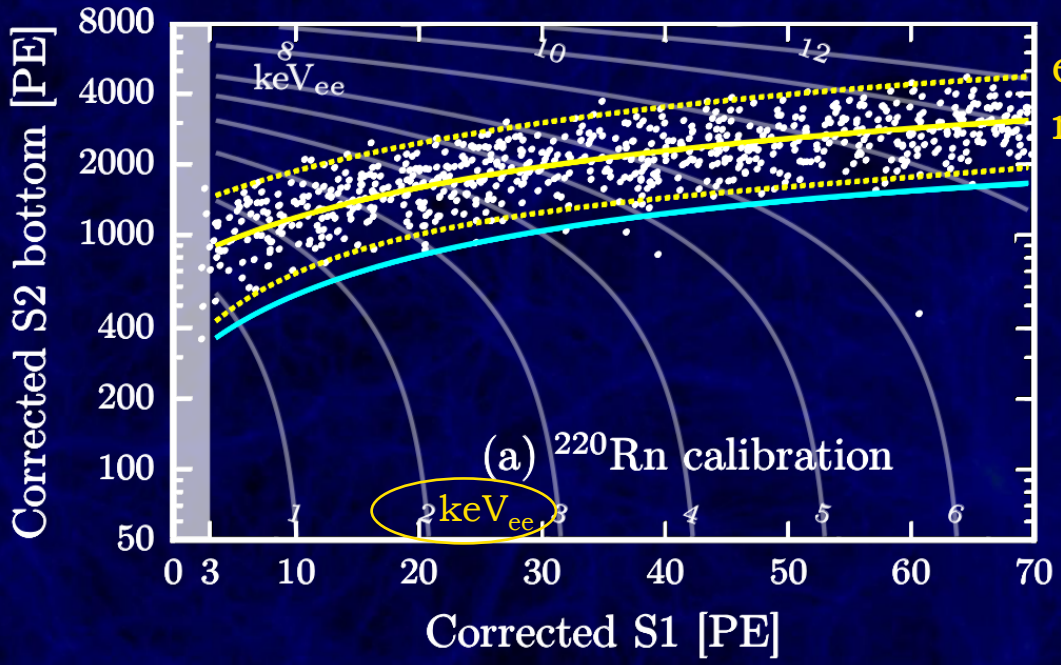


Self-Shielding in Xenon

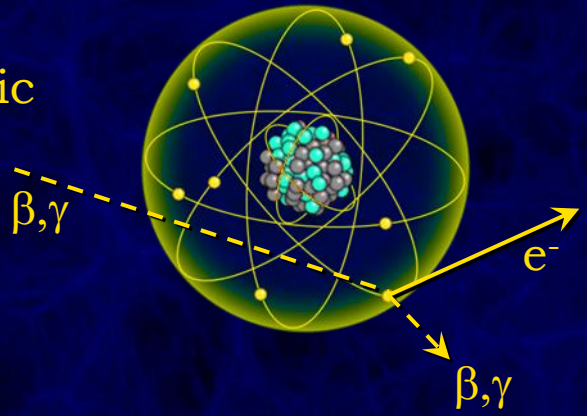
Reduce background with exp(-diameter/λ_γ)



ER/NR Discrimination

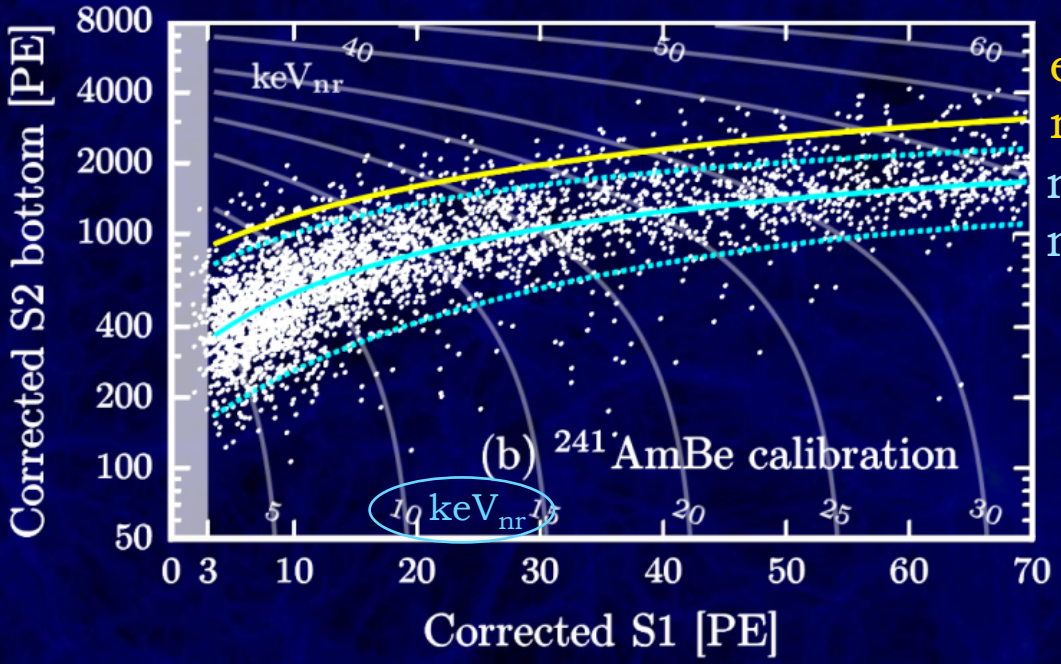


electronic recoils



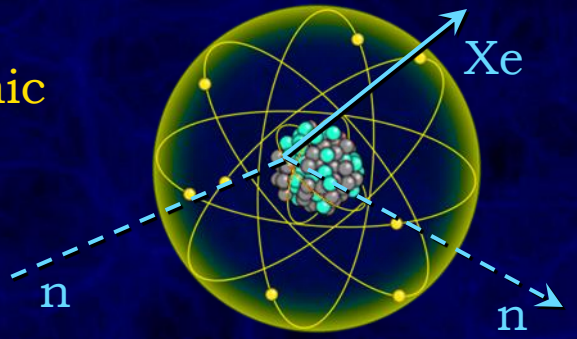
XENON 1705.06655

ER/NR Discrimination



electronic recoils

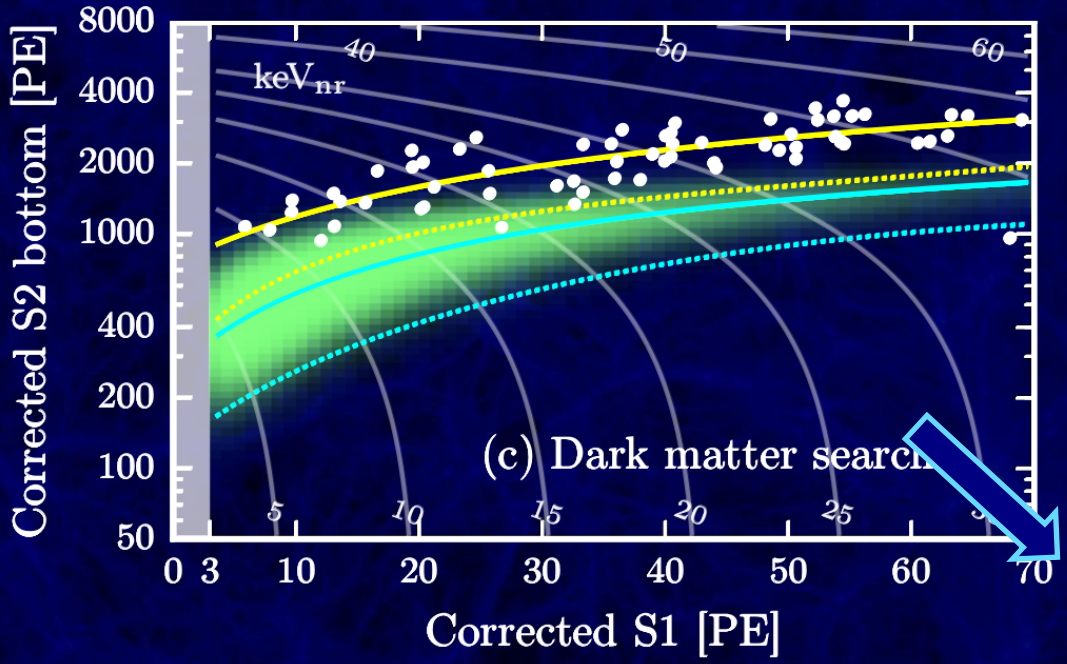
nuclear recoils



XENON 1705.06655

Dark Matter Search

First science data, 34 live days:

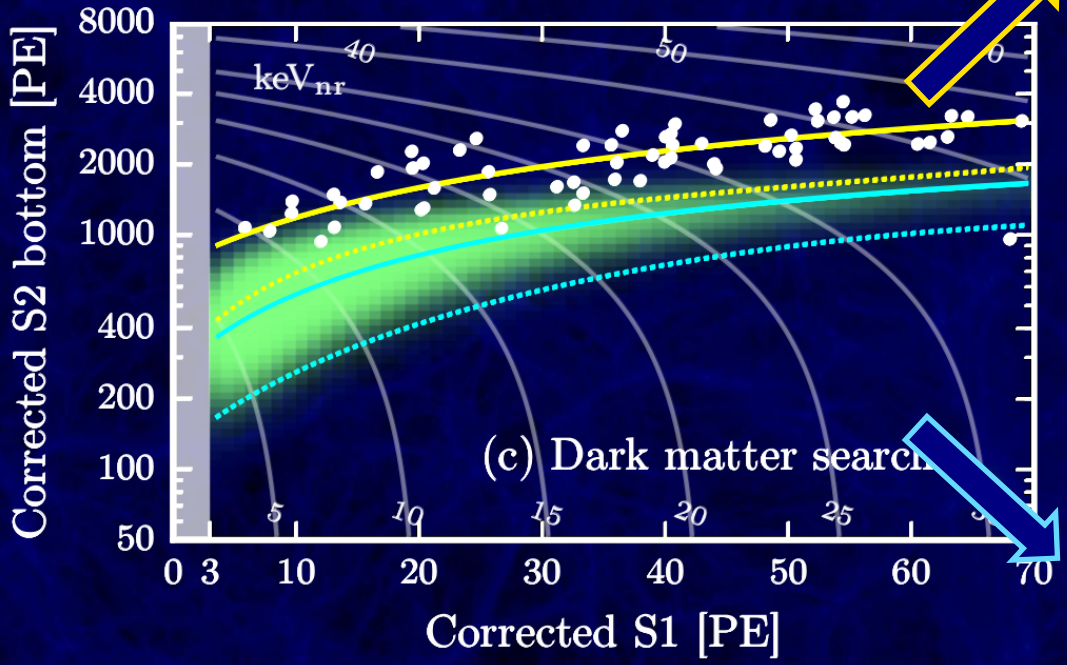


- WIMPs, SI & SD!
- iDM and other EFT
- GeV DM
- coherent ν scattering

XENON 1705.06655

Ample Science from "Background"

First science data, 34 live days:



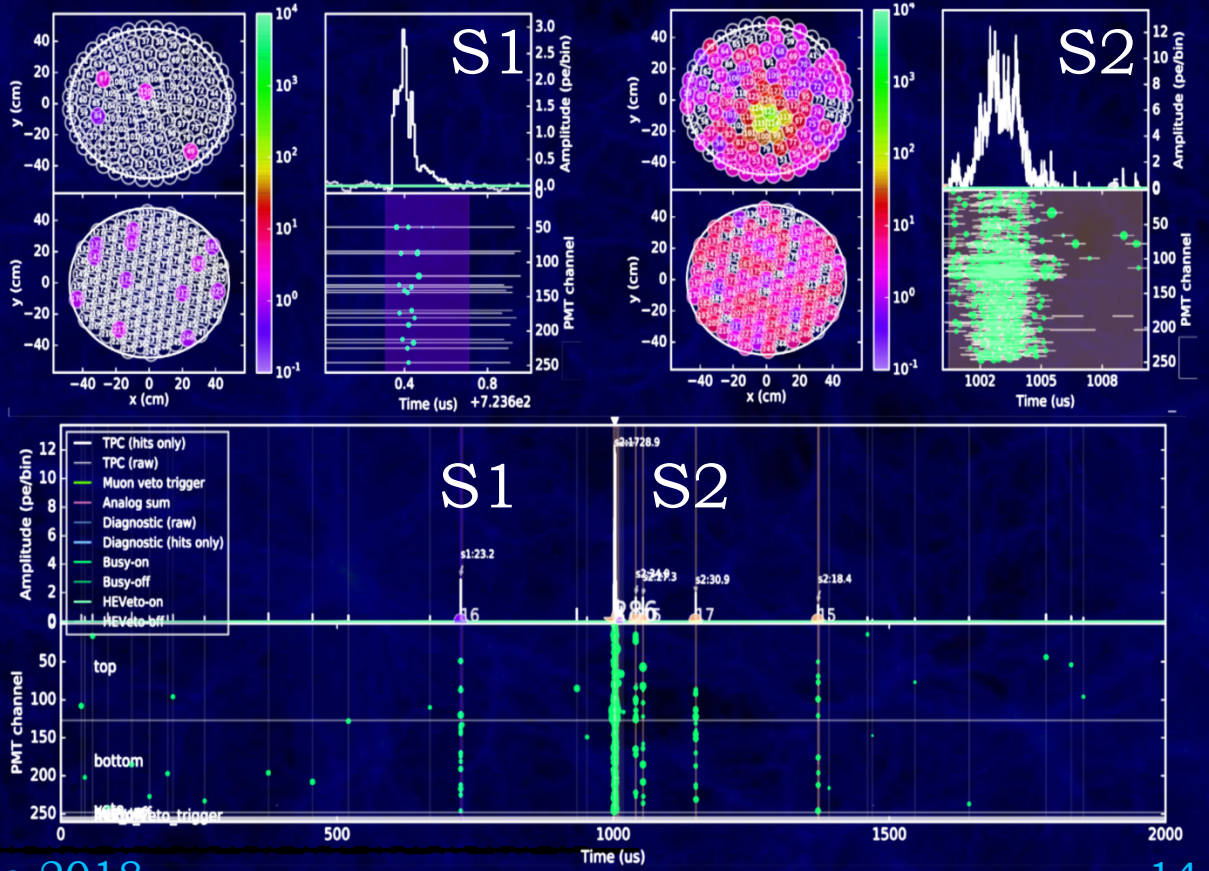
- leptophilic/axial-vector WIMPs, MeV DM
- Migdal & Bremsstrahlung
- inelastic scatter, miDM
- ALPs, dark photons, solar axions, luminous DM, mirror DM
- sterile ν
- DEC on ^{124}Xe

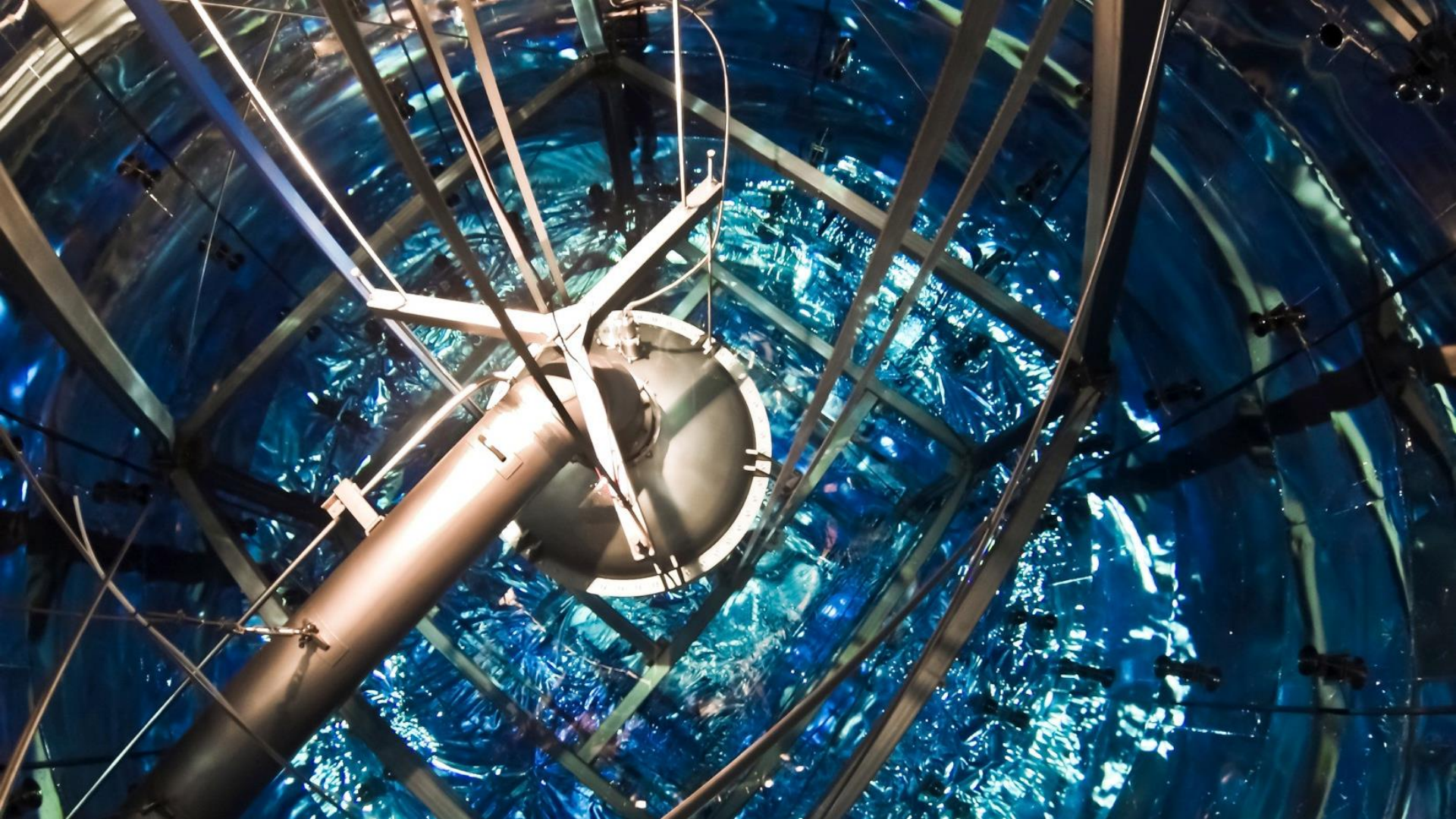
- WIMPs, SI & SD!
- iDM and other EFT
- GeV DM
- coherent ν scattering

The Secret of Success

Redundant event information:
can fight detector artefacts

(collect ~2.5MB per event)






XENON
enlightening

Liquid TPCs

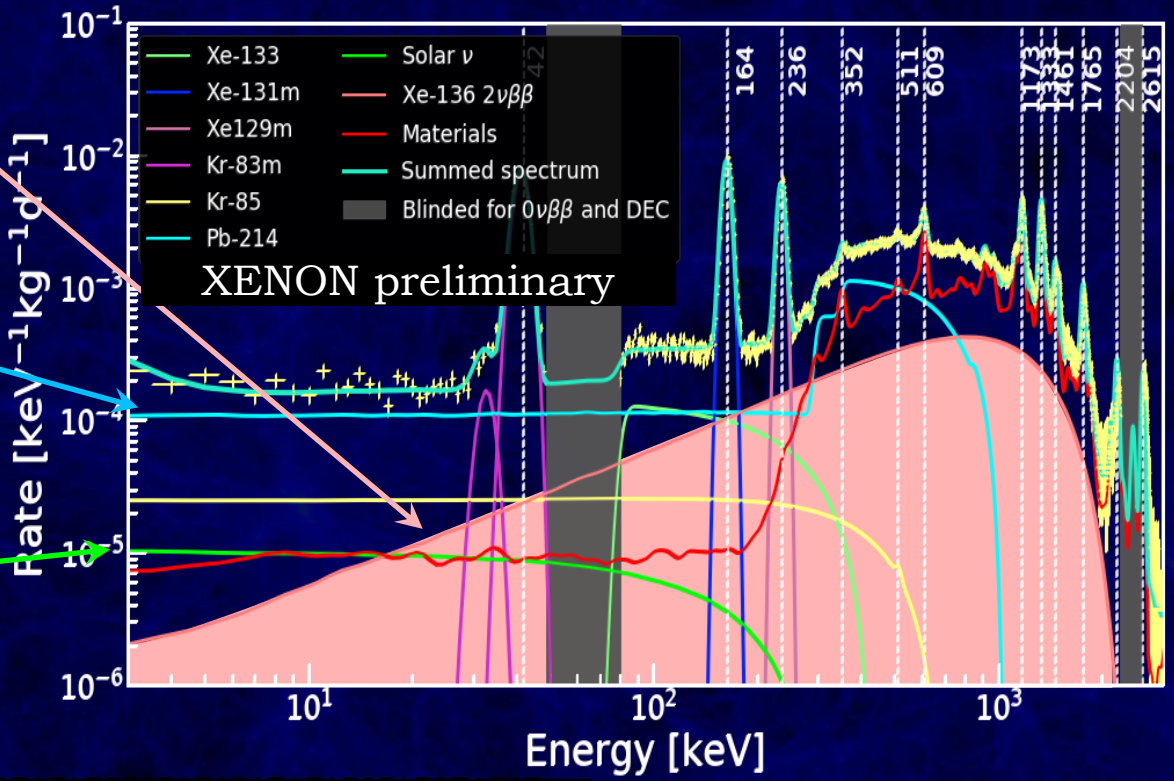
Technology of choice for WIMPs:
monolithic, scalable, cheap,
redundant event information

XENON1T Background Spectrum

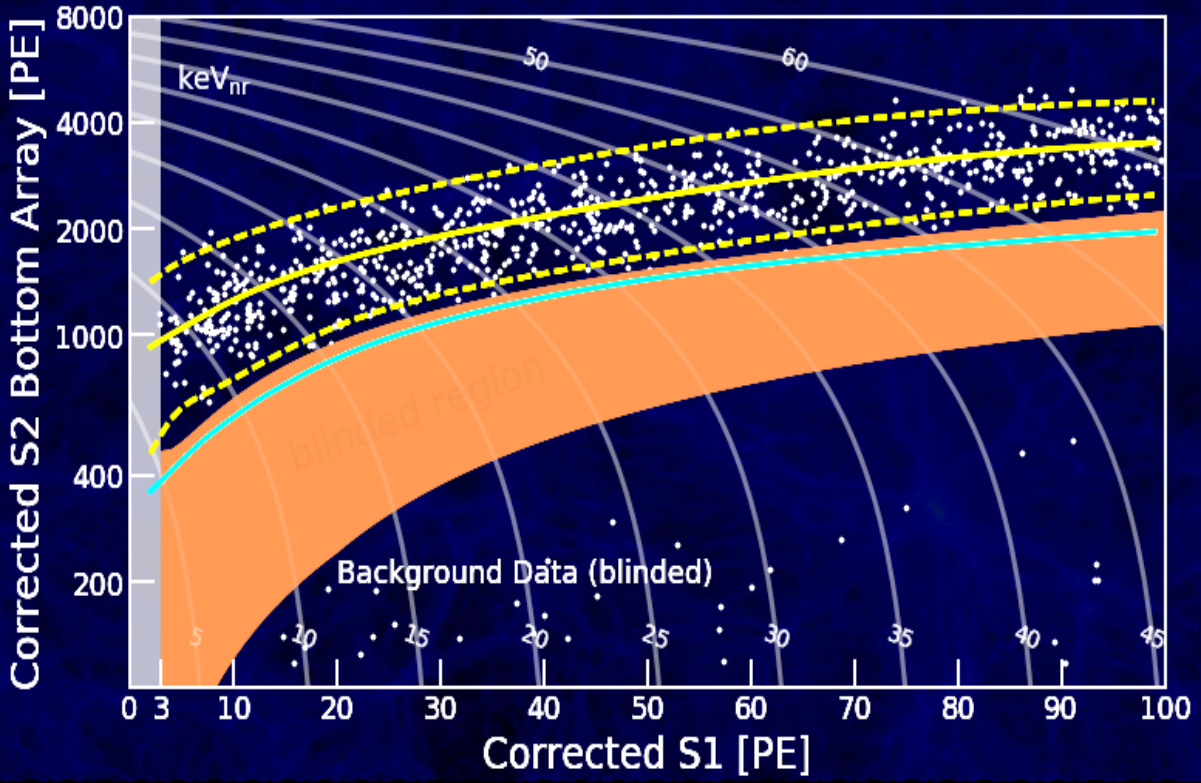
overall, 2ν2β important
($t_{1/2}$~10^{21} years!)

^{222}Rn a technological challenge

some sensitivity at low energies to pp solar ν

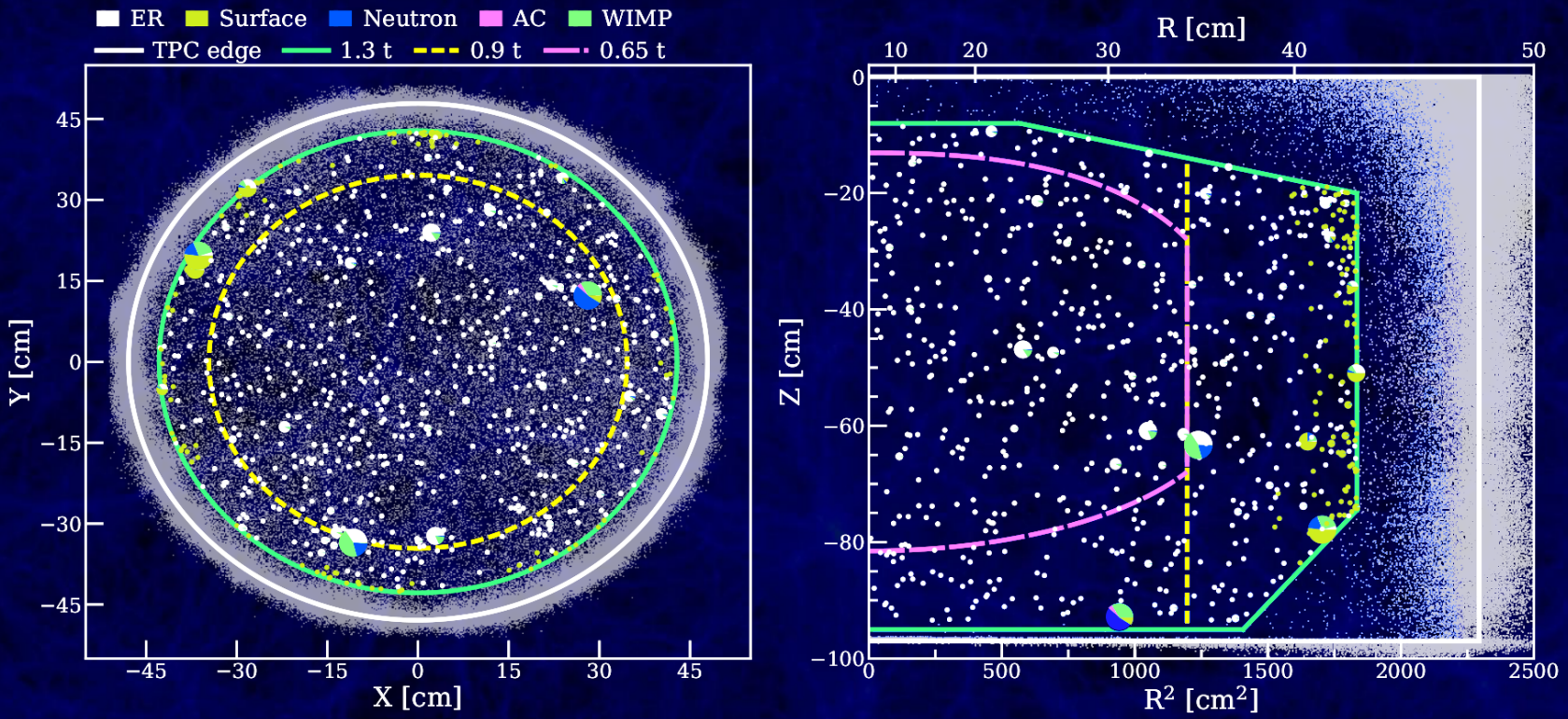


XENON1T Science Run 1



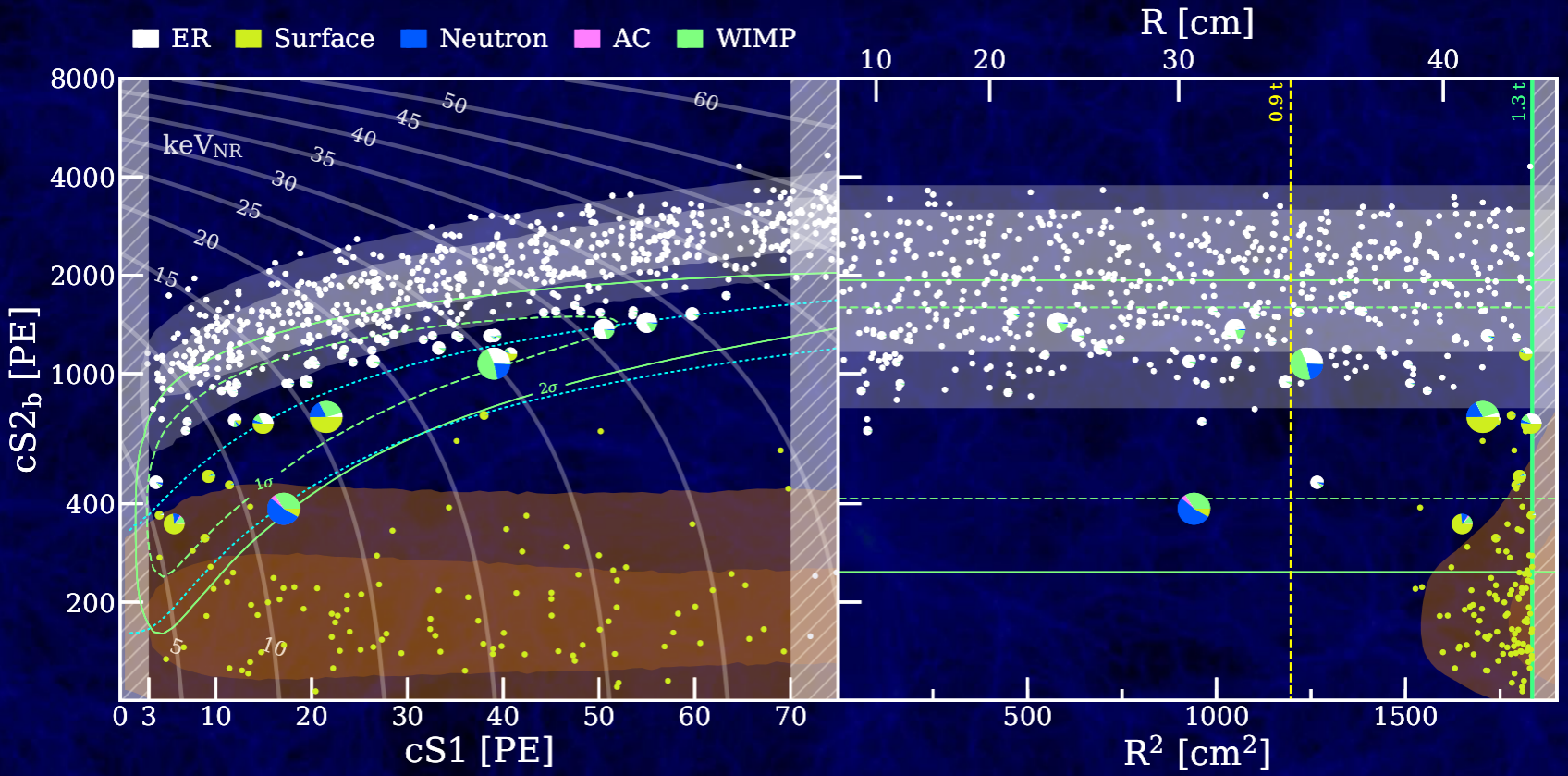
signal region both blinded and salted to avoid analysis bias

XENON1T Science Run 1



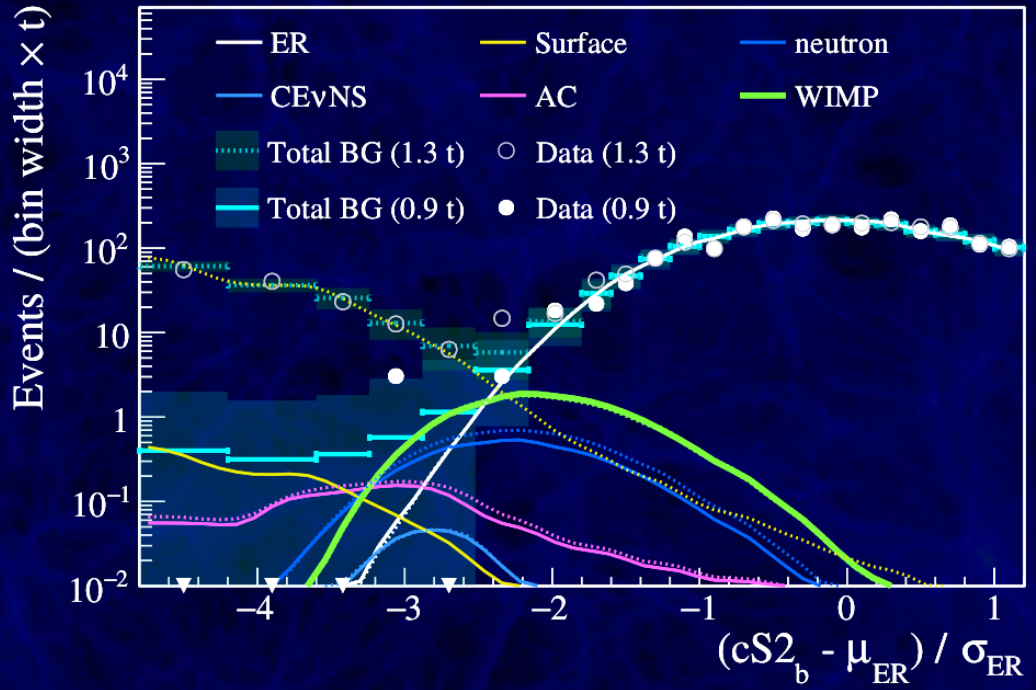
XENON 1805.12562

XENON1T Science Run 1



XENON 1805.12562

No Signal Detected

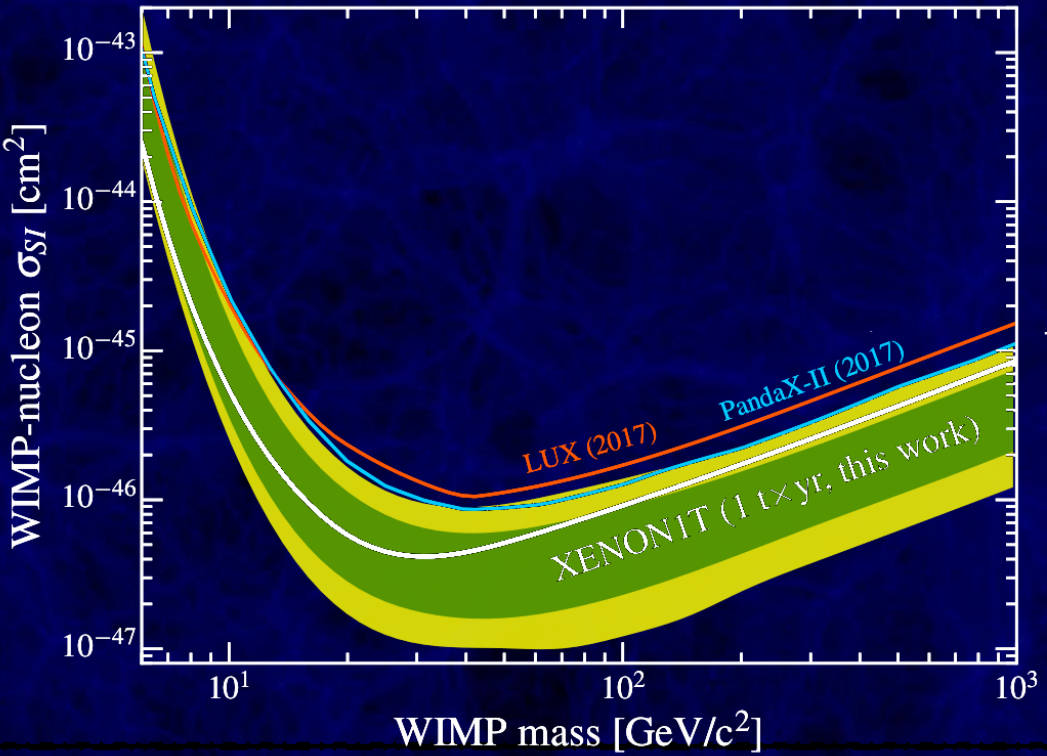


Mass	1.3 t	0.9 t
(cS1, $cS2_b$)	Full	Reference
ER	627±18	1.12±0.21
neutron	1.43±0.66	0.41±0.19
CEνNS	0.05±0.01	0.02
AC	$0.47^{+0.27}_{-0.00}$	$0.06^{+0.03}_{-0.00}$
Surface	106±8	0.02
Total BG	735±20	1.62±0.28
$WIMP_{best\text{-}fit}$	3.56	1.16
Data	739	2

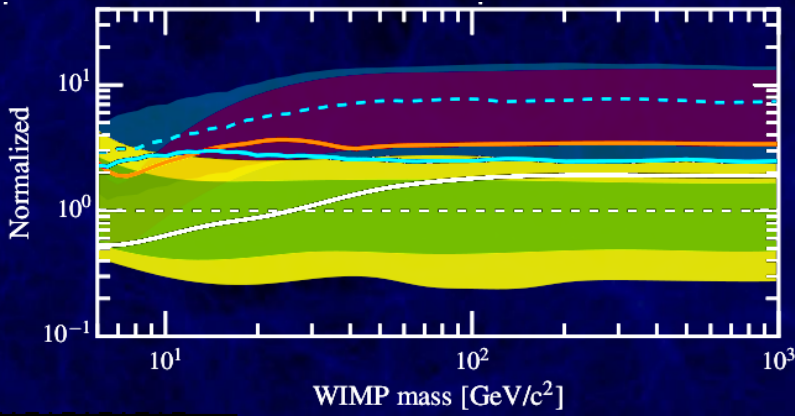
XENON 1805.12562

New Limit

for the theorist: limits



for the experimenter: sensitivities



XENON 1805.12562

XENON1T Results

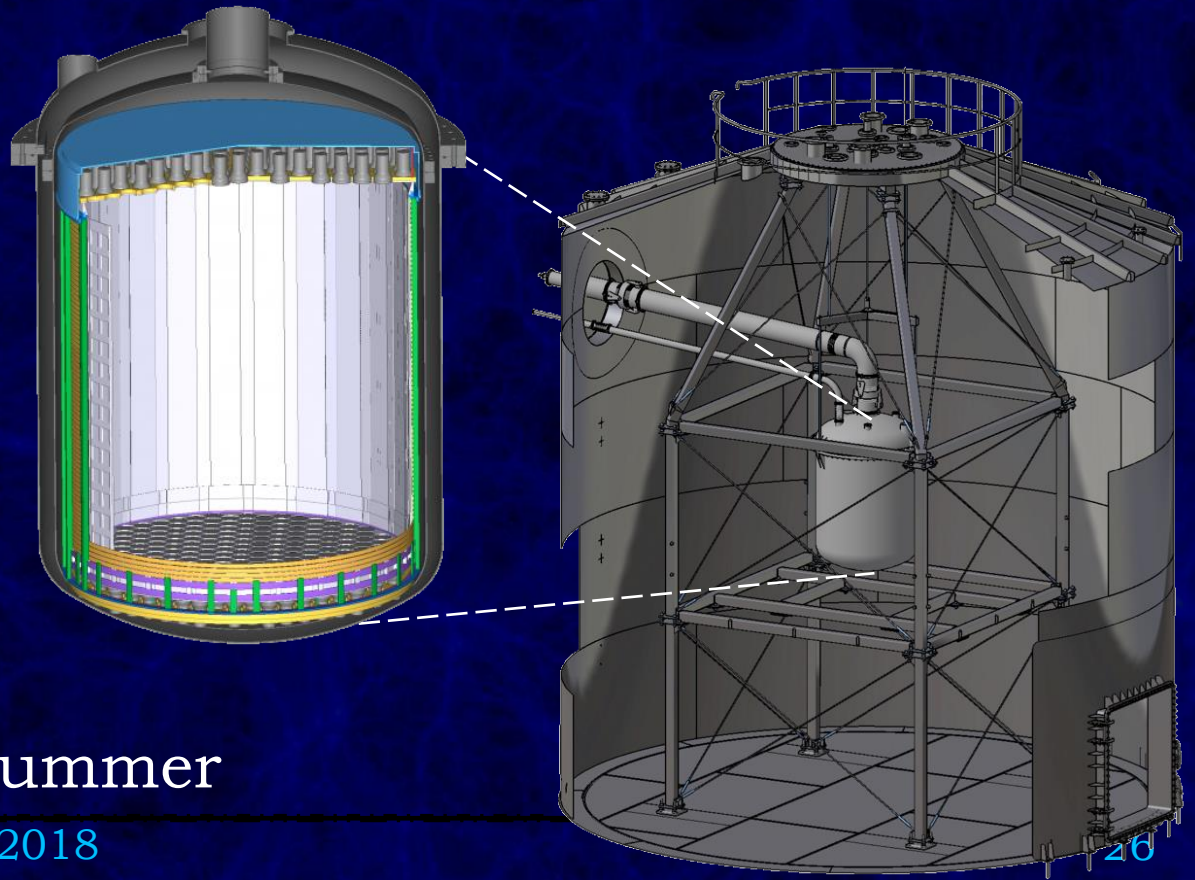
1 year, 1.3t fiducial mass:

world leading limit above ~8GeV.

sigh

Upgrade: XENONnT

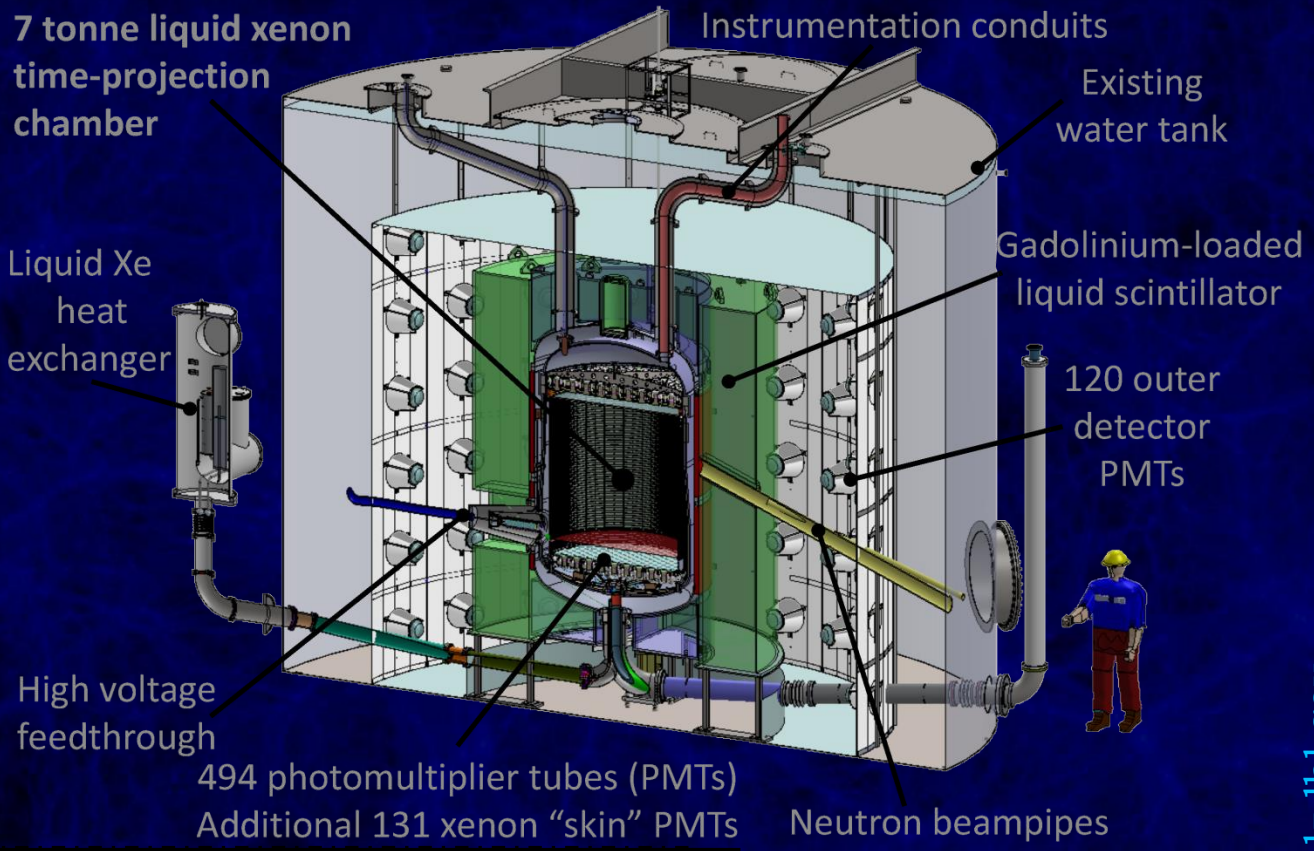
- Rapid upgrade:
  8t total
  6t active
  >4t fiducial
  start 2019
- Re-use most sub-systems
- Xenon in hand, PMTs tested, construction this summer



LZ @SURF

10t of LXe:
7t active
5.6t fiducial

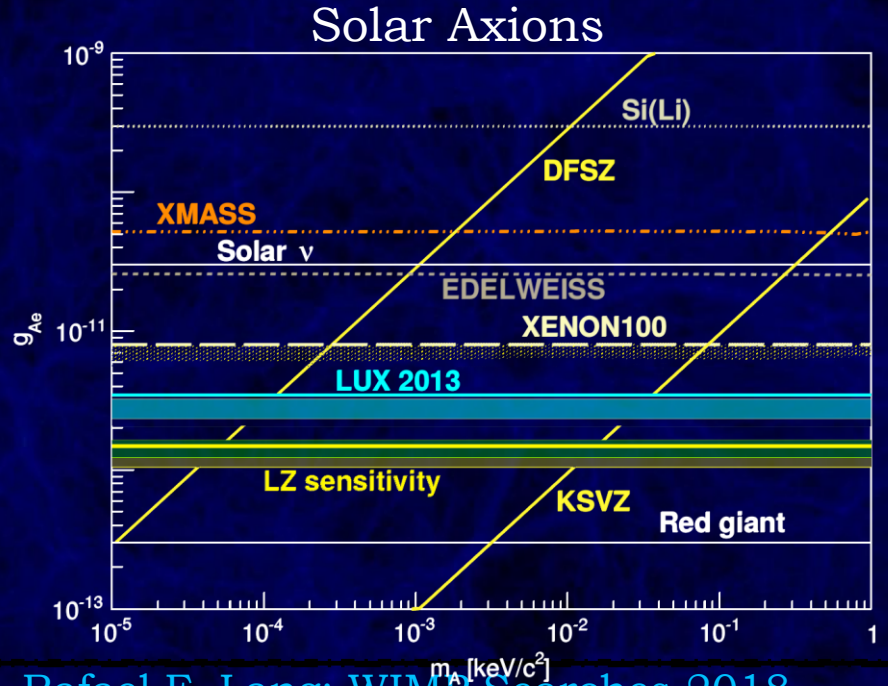
start 2020

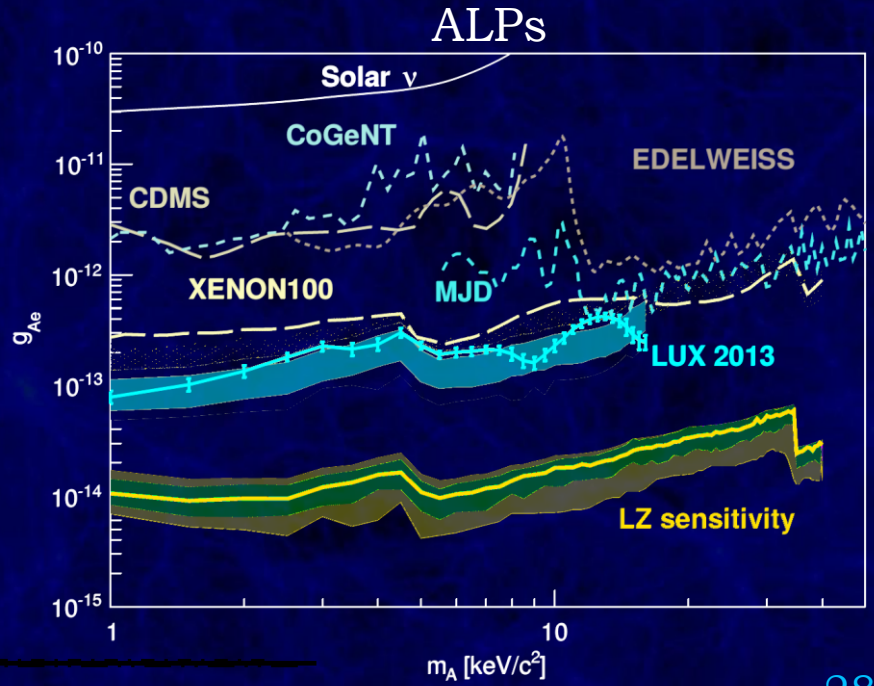


lz.lbl.gov

LUX results & LZ sensitivity

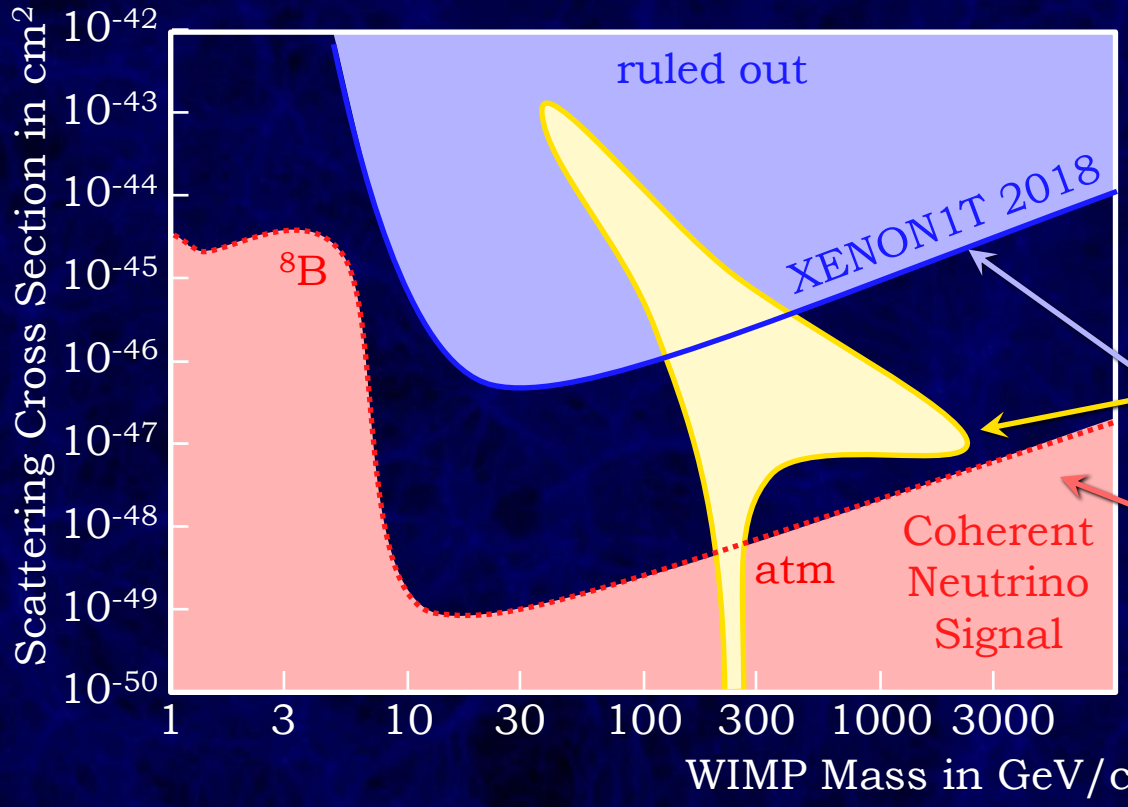
Use electronic recoils to search for axions via axio-electric effect g_{Ae}





F. Neves Patras2018

Coherent Neutrino-Nucleus Scattering



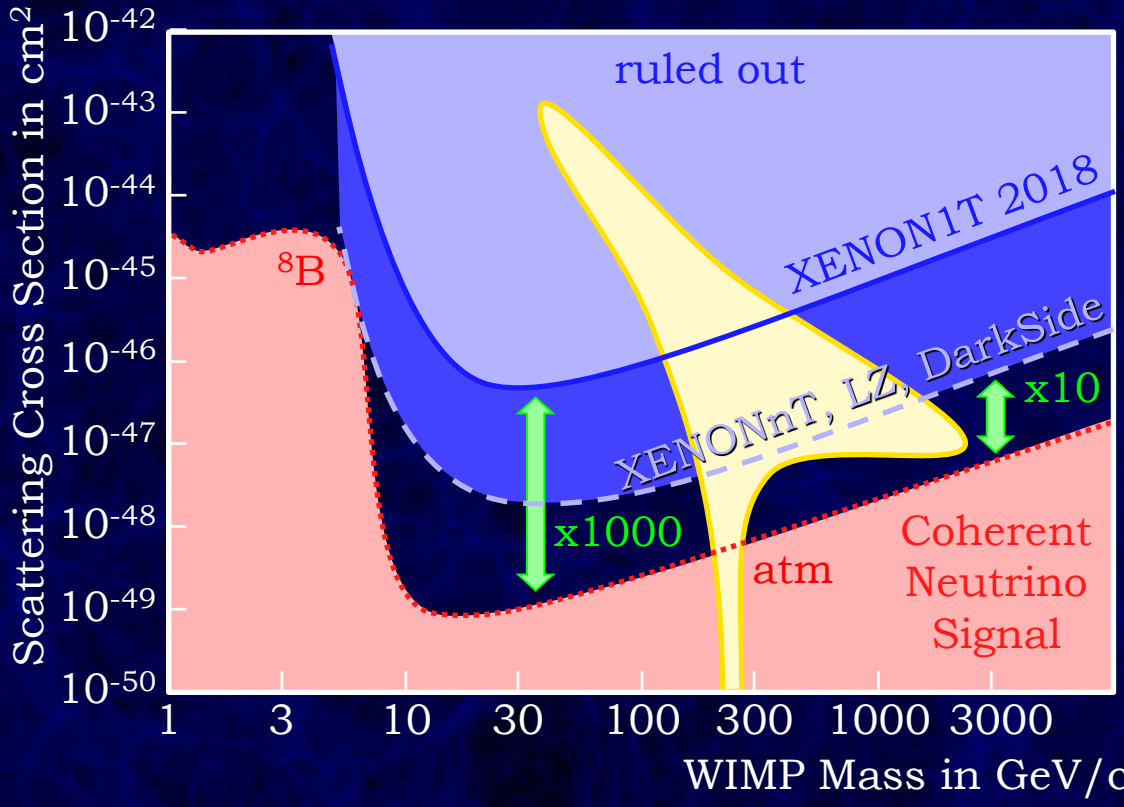
Simple scattering kinematics: degenerate in momentum

heavy WIMP v~10^{-3}c

Coherent Neutrino-Nucleus Scattering light ν, v~c

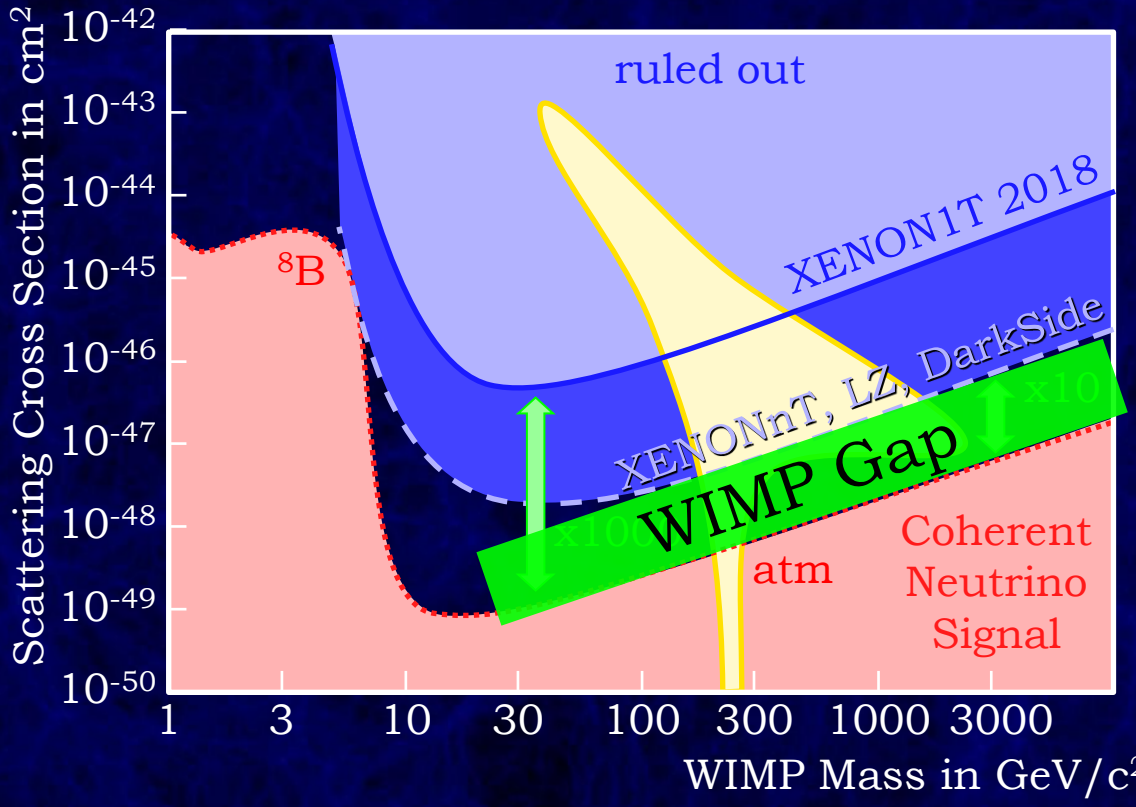
Billard, Strigari, Figueroa-Feliciano 1307.5458

"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:
DARWIN & Argo
40t Xe 100t Ar

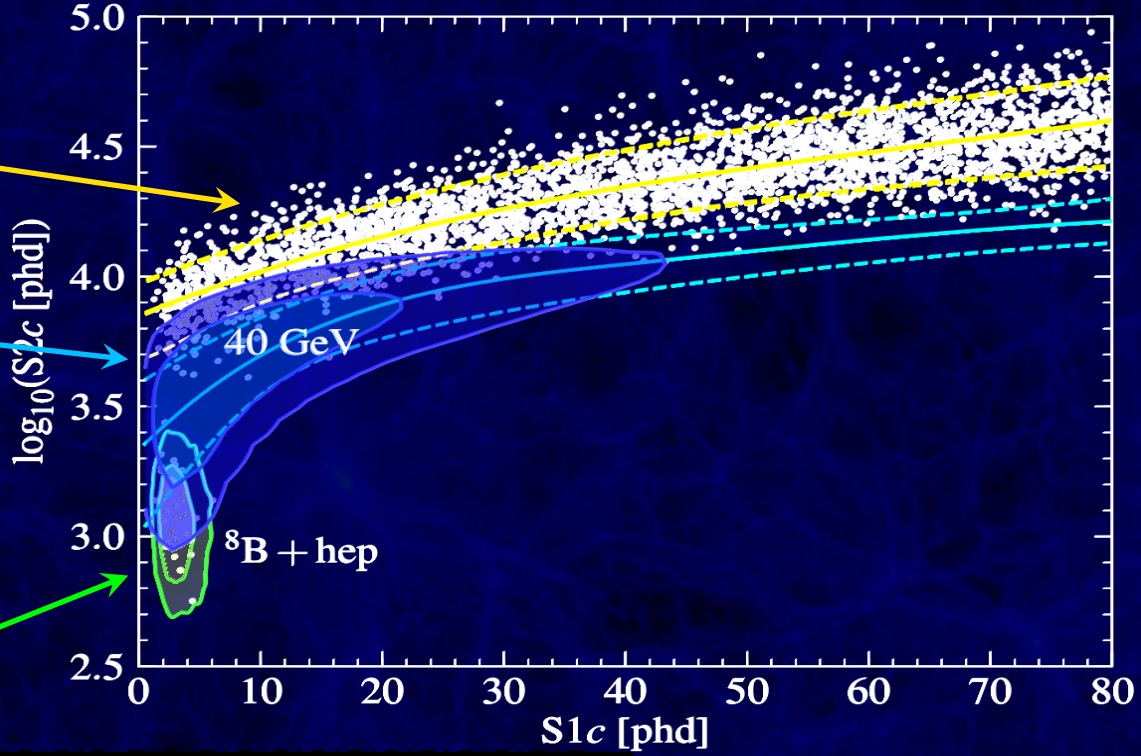
Solar ^{8}B Neutrinos ~2023

simulation: 1000 days LZ

electronic recoil background

dark matter nuclear recoils

~36 ^{8}B solar neutrino nuclear recoils



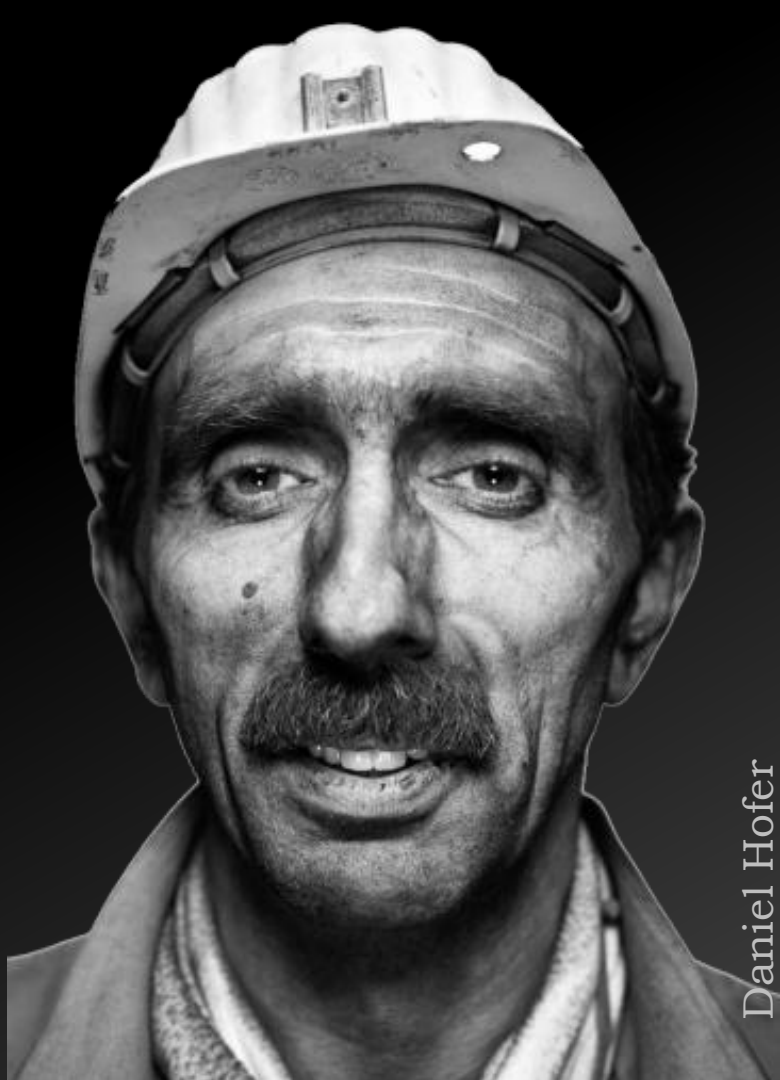
LZ/Dobson UCLA 2018

Neutrinos

Direct dark matter experiments become sensitive to solar neutrinos…

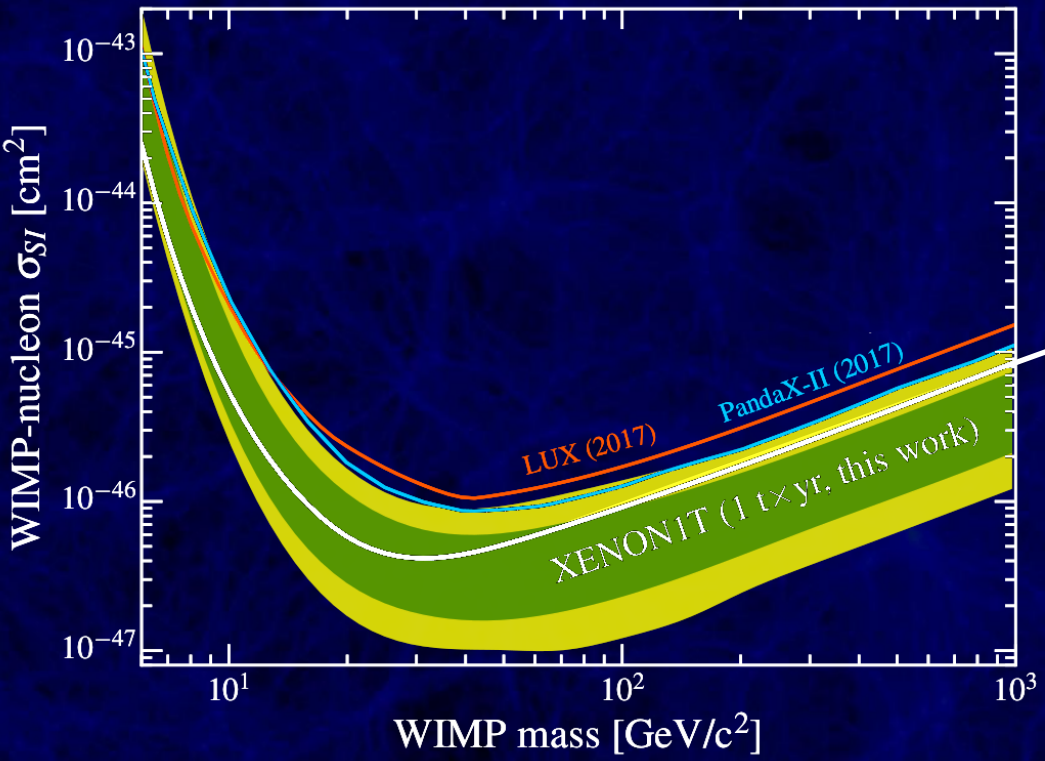
…but the neutrino floor is far and requires Generation-3

Plus: galactic supernova neutrinos & neutrinoless double-beta decay!



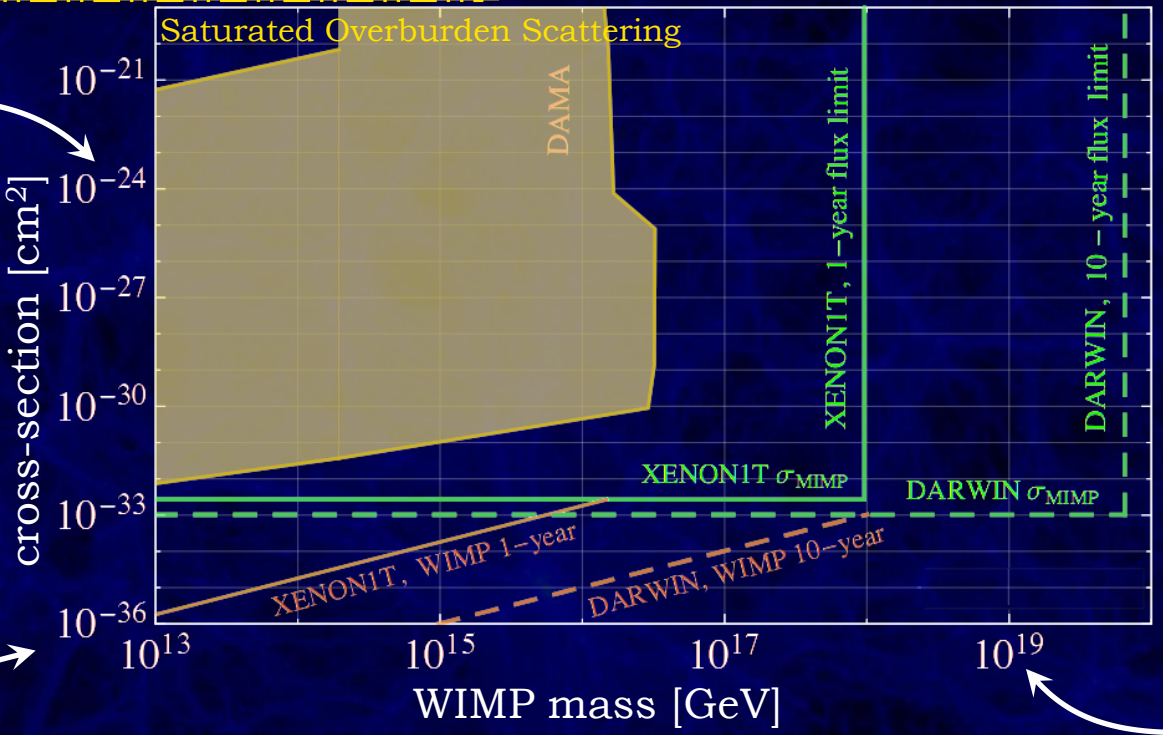
Extrapolate to Higher Masses

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

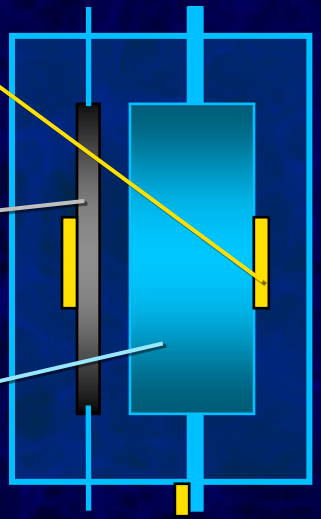
CRESST-III

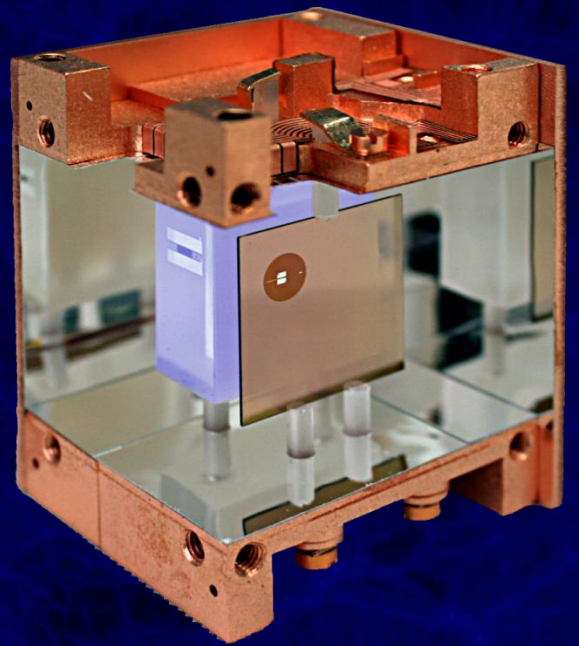
Scintillating 24g $CaWO_4$ calorimeters

thermometer @10mK

light absorber

$CaWO_4$ target





cresst.de

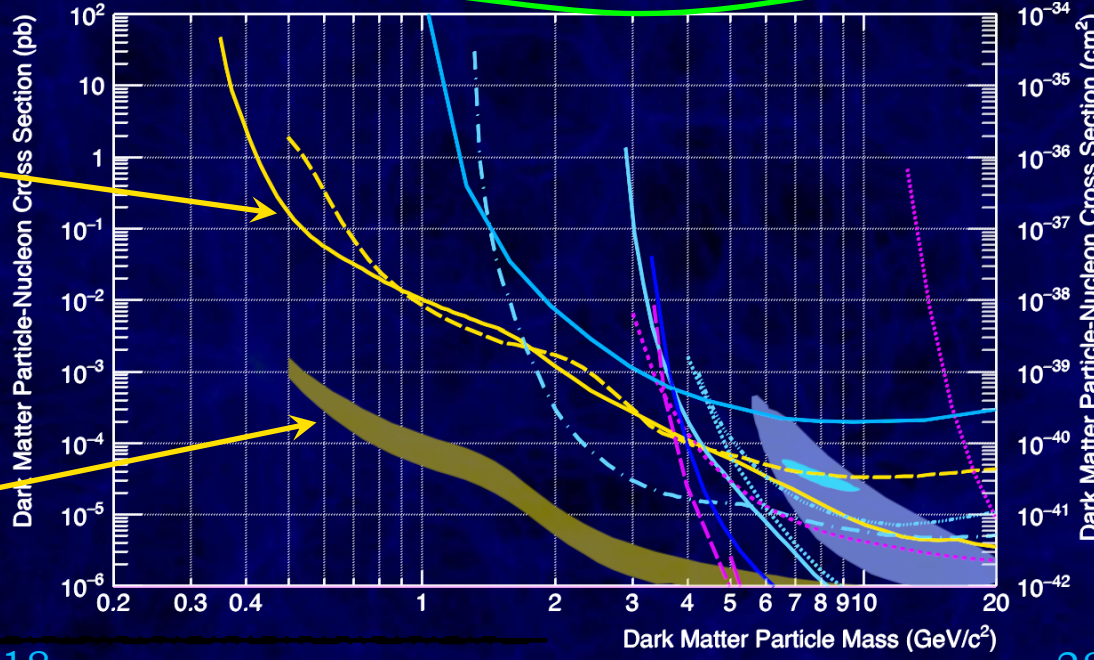
CRESST-III

Scintillating
24g $CaWO_4$
calorimeters

2.2kg d limit
E>100eV
(30eV running)

50kg d
sensitivity

0.5g Al_2O_3 limit, E>20eV
surface run



CRESST 1711.07692 and 1707.06749

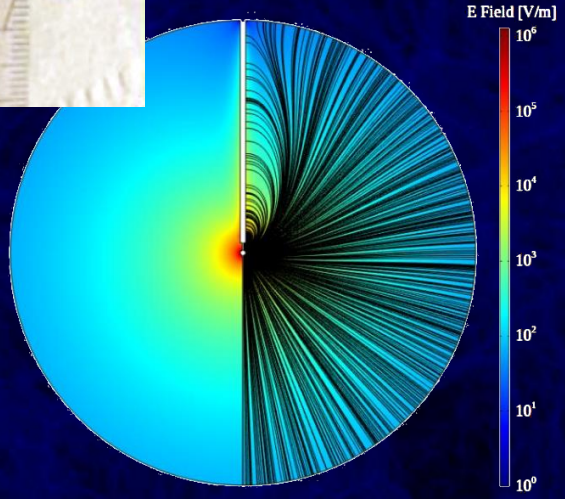
CRESST-III

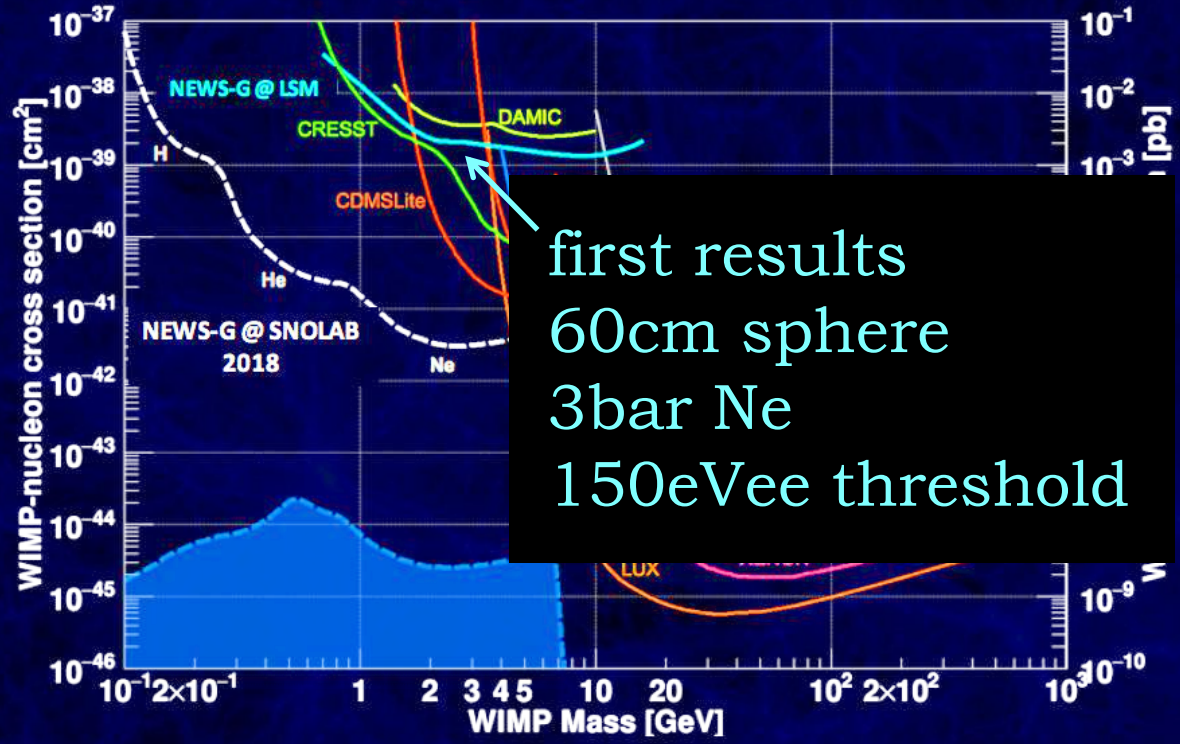
Scatter on $CaWO_4$
with 10s eV threshold

Daniel Hofer

NEWS-G at LSM

Spherical Proportional Counter filled with various gases





first results
60cm sphere
3bar Ne
150eVee threshold

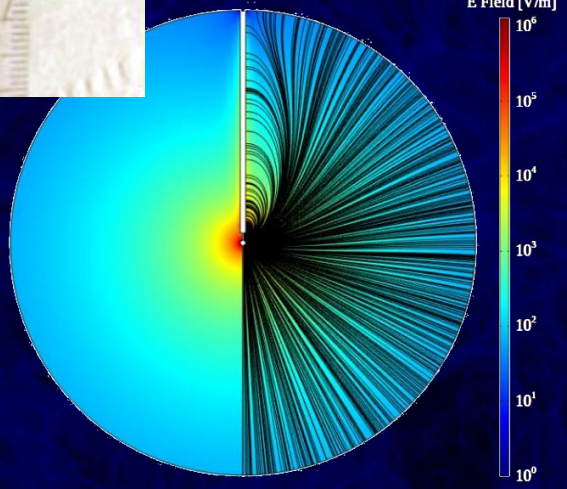
NEWS-G 1706.04934

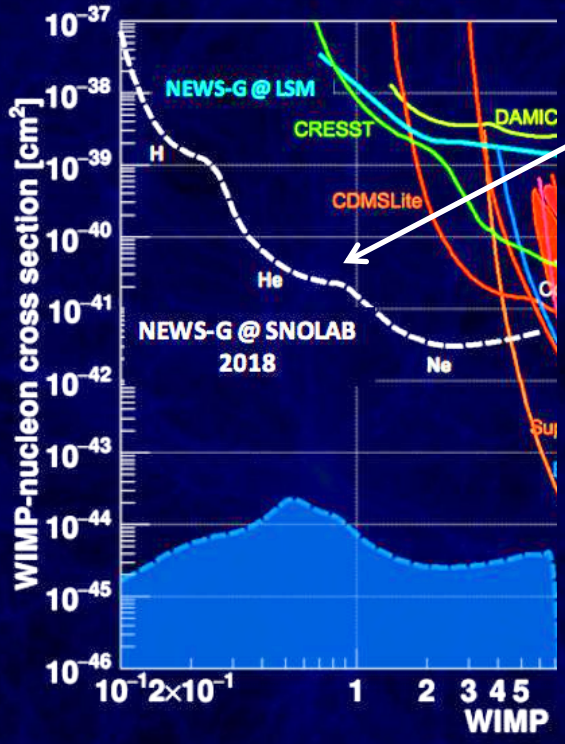
I. Katsioulas LDMA2017

NEWS-G at SNOLab

Spherical Proportional Counter: 140cm ∅, 3bar

installation this summer





NEWS-G 1706.04934

I. Katsioulas LDMA2017

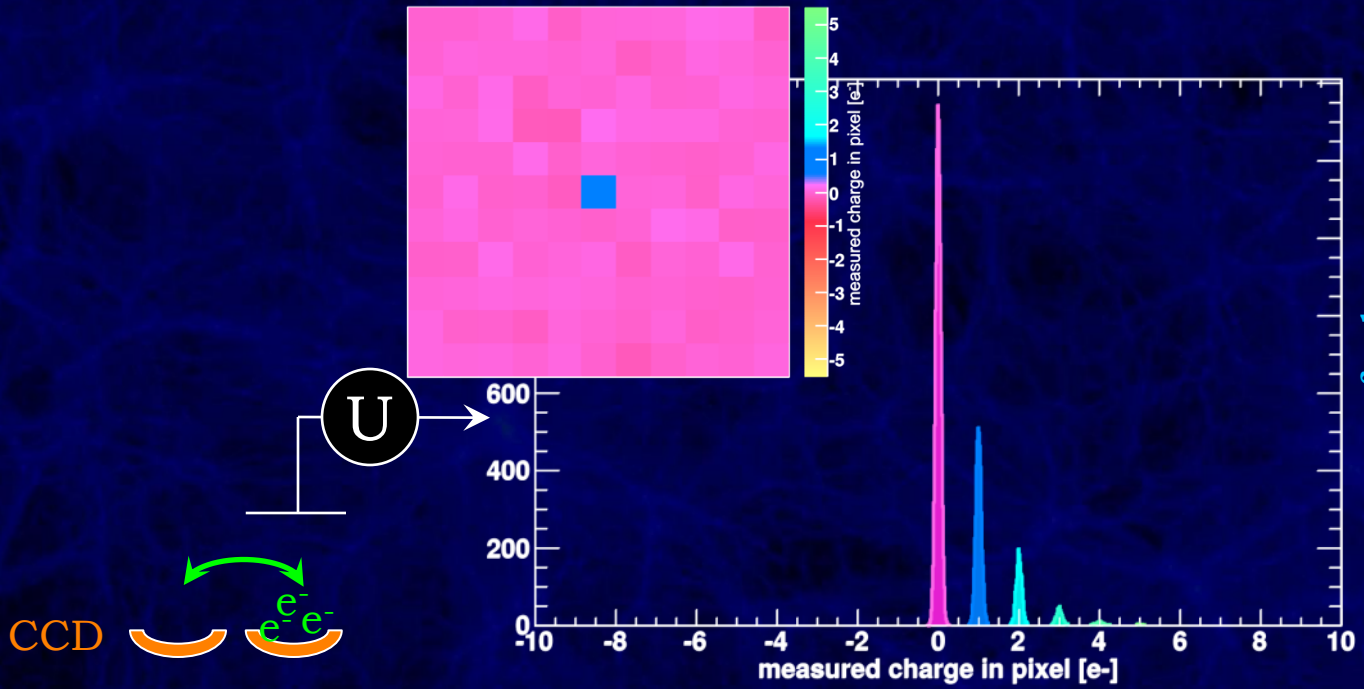
NEWS-G

Promising for fast results down to 100MeV

SENSEI: Skipper CCDs

Only modify CCD readout to sample pixel many times

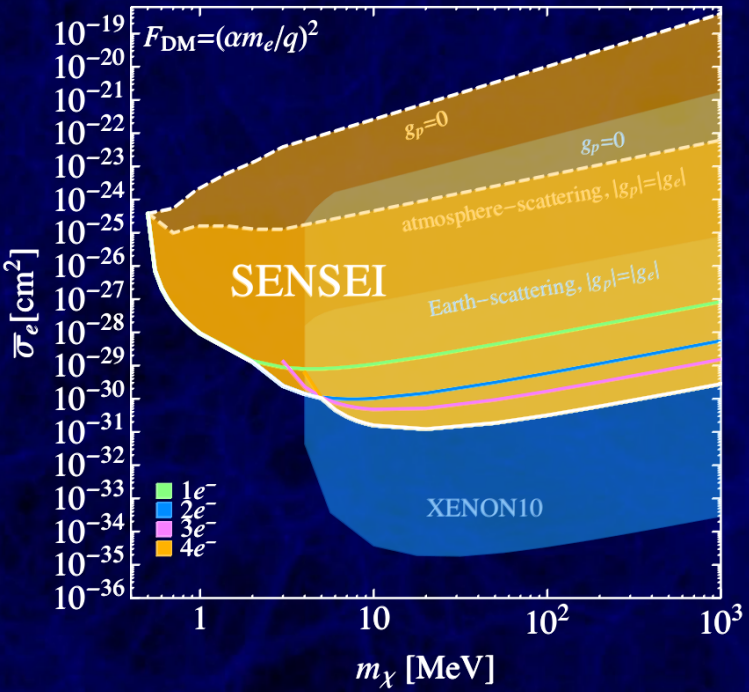
Reduce readout noise below 0.07 e^- RMS



fnal.gov

SENSEI: First results

Limits down to 0.5MeV from 19 mg d surface run



SENSEI 1804.00088

Now moved to MINOS hall (100m UG)

SENSEI & DAMIC

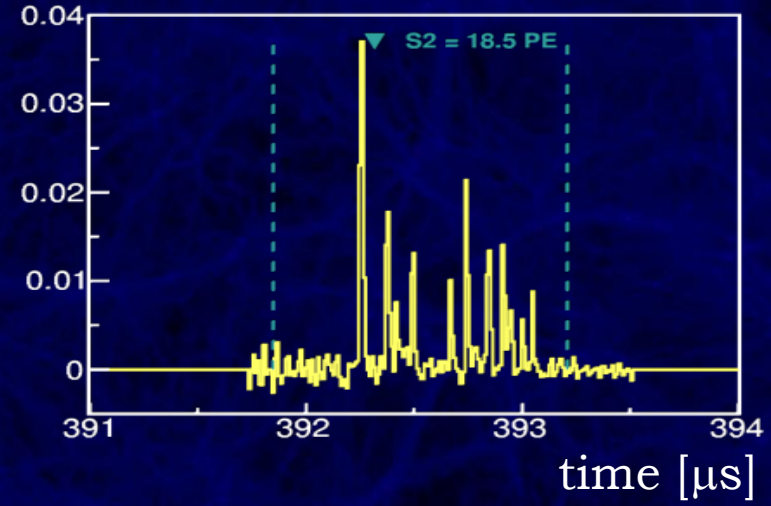
Skipper CCDs with no-noise single-electron sensitivity

Limits down to 500keV

Daniel Hofer

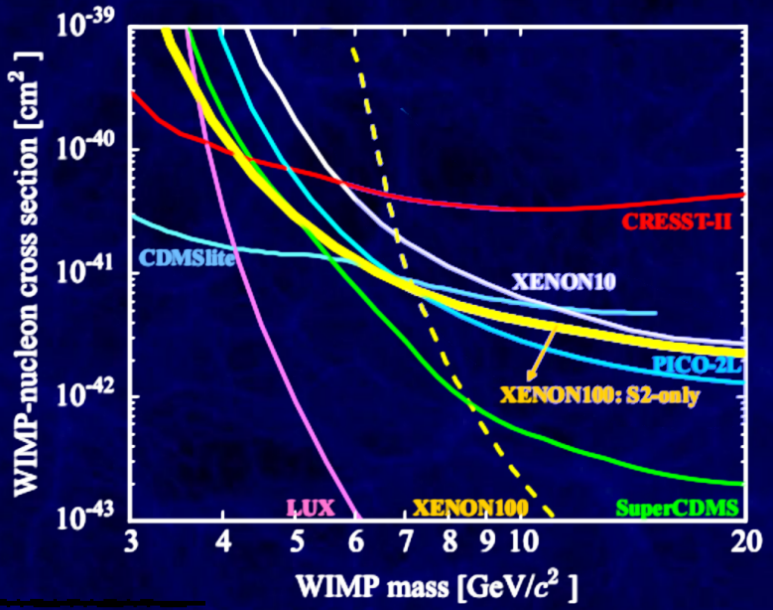
Electron Scattering in Xenon

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



XENON100 1311.1088

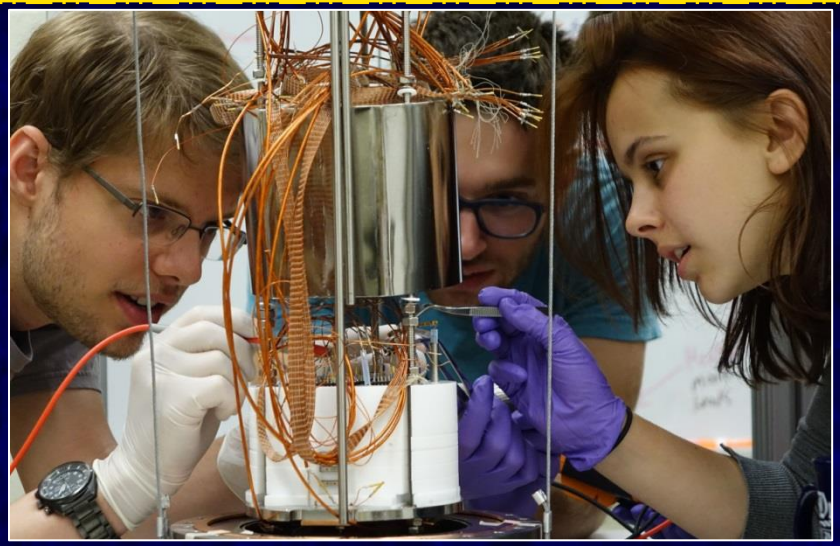
But backgrounds not yet tackled:

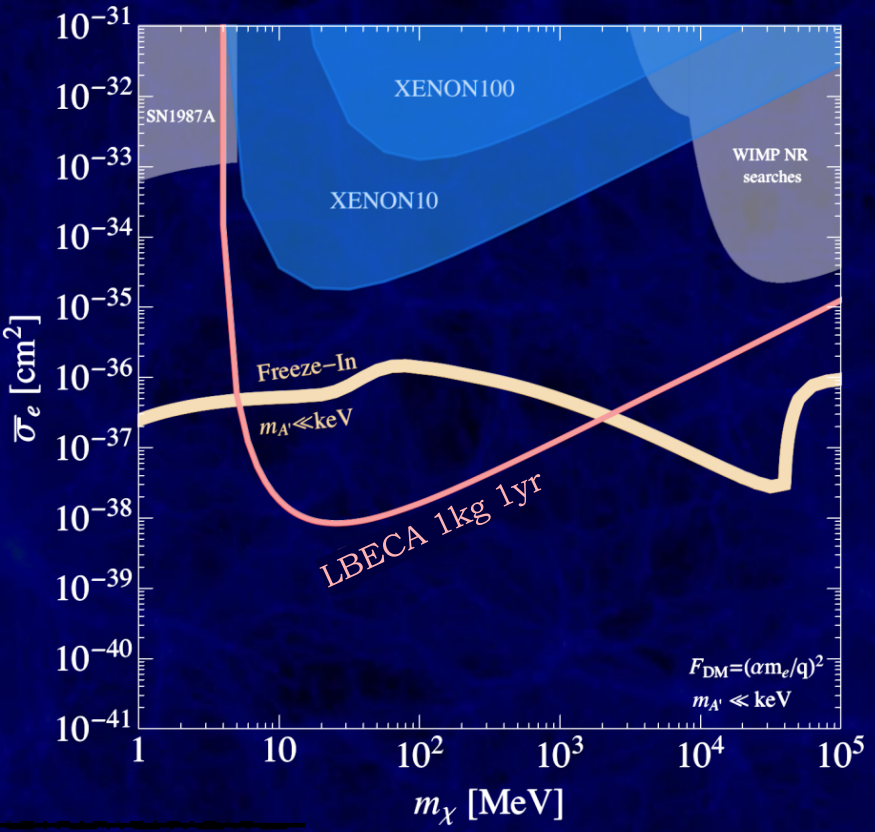


XENON100 1605.0626

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

Conclusions

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