

# Synergies between Neutrino and Dark Matter Detectors



Rafael F. Lang, Purdue University, [rafael@purdue.edu](mailto:rafael@purdue.edu), Neutrino Heidelberg, June 2018

T-25 Minutes...





# Summary

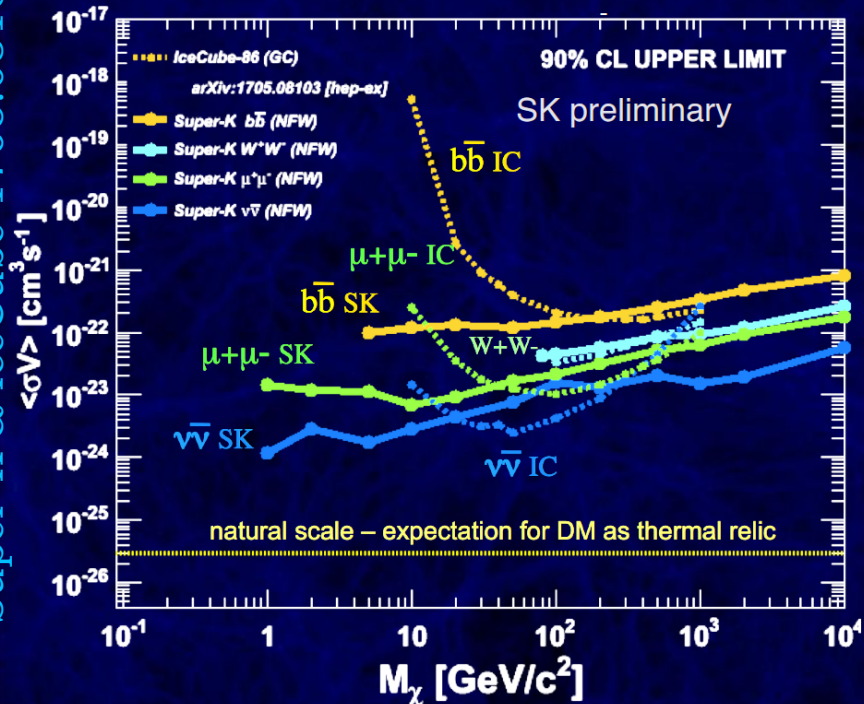
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Dark Matter phenomenology is turning to more exotic models. Your neutrino detector is sensitive to some of those. Don't miss this opportunity.

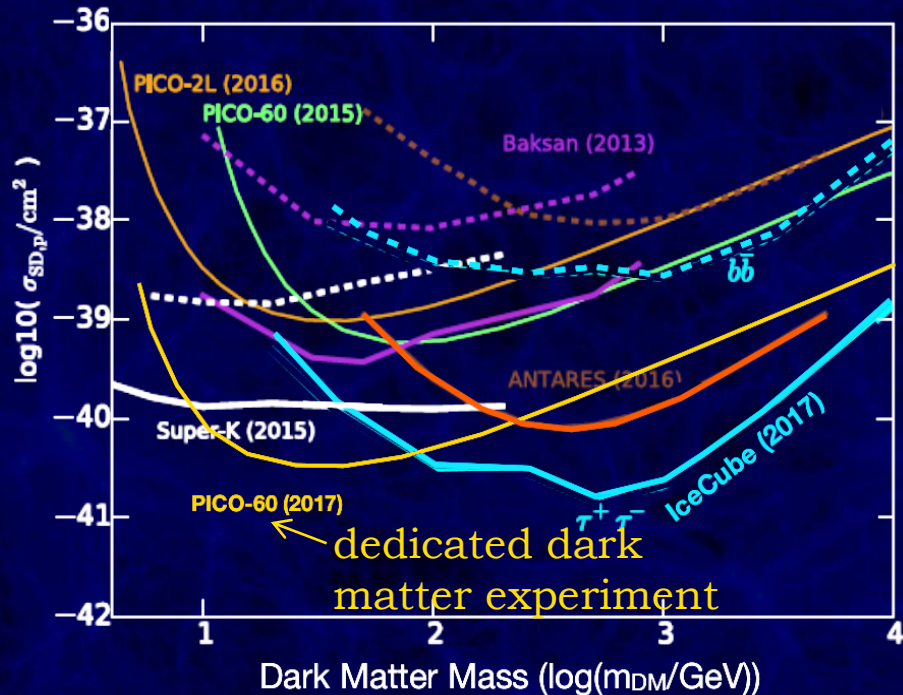
Dark Matter detectors are becoming larger and more sensitive. They start to have something meaningful to say about neutrinos.

# Indirect Dark Matter Searches

$\nu$  from annihilation  
@Galactic Center



$\nu$  from scattering &  
annihilation @Sun



# Different Energies, Different Rates

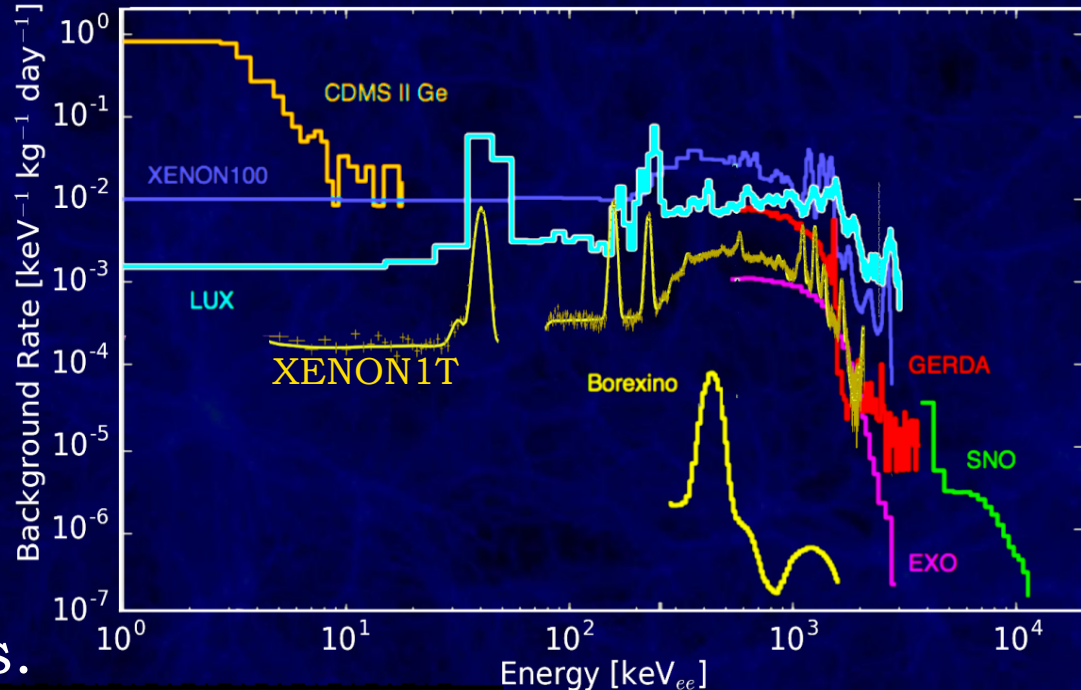
Dark Matter is non-relativistic.

falling exponential recoil spectrum at low energies

$$E_{r,\max} \sim \frac{p_{\chi}^2}{2m_N}$$
$$\sim \frac{(100 \text{ GeV}/c^2 \times 10^{-3} c)^2}{2 \times 50 \text{ GeV}/c^2}$$
$$\ll 100 \text{ keV}$$

Can you still look  
for Dark Matter?

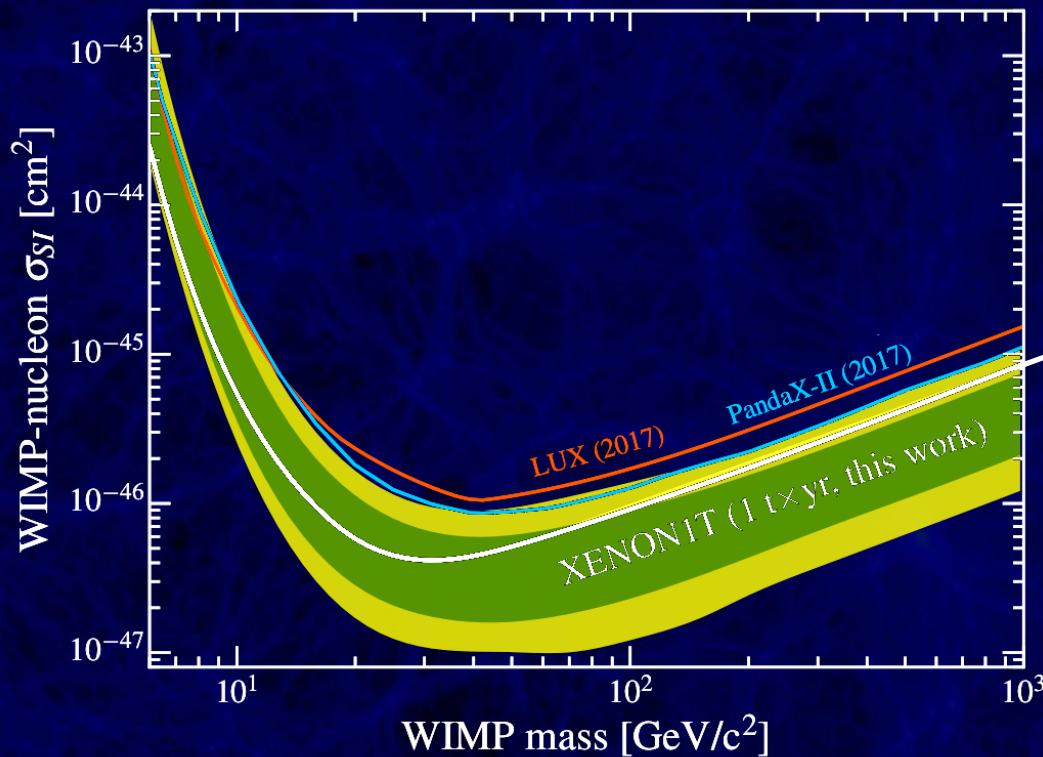
Of course! Two examples.





# Extrapolate to Higher Masses

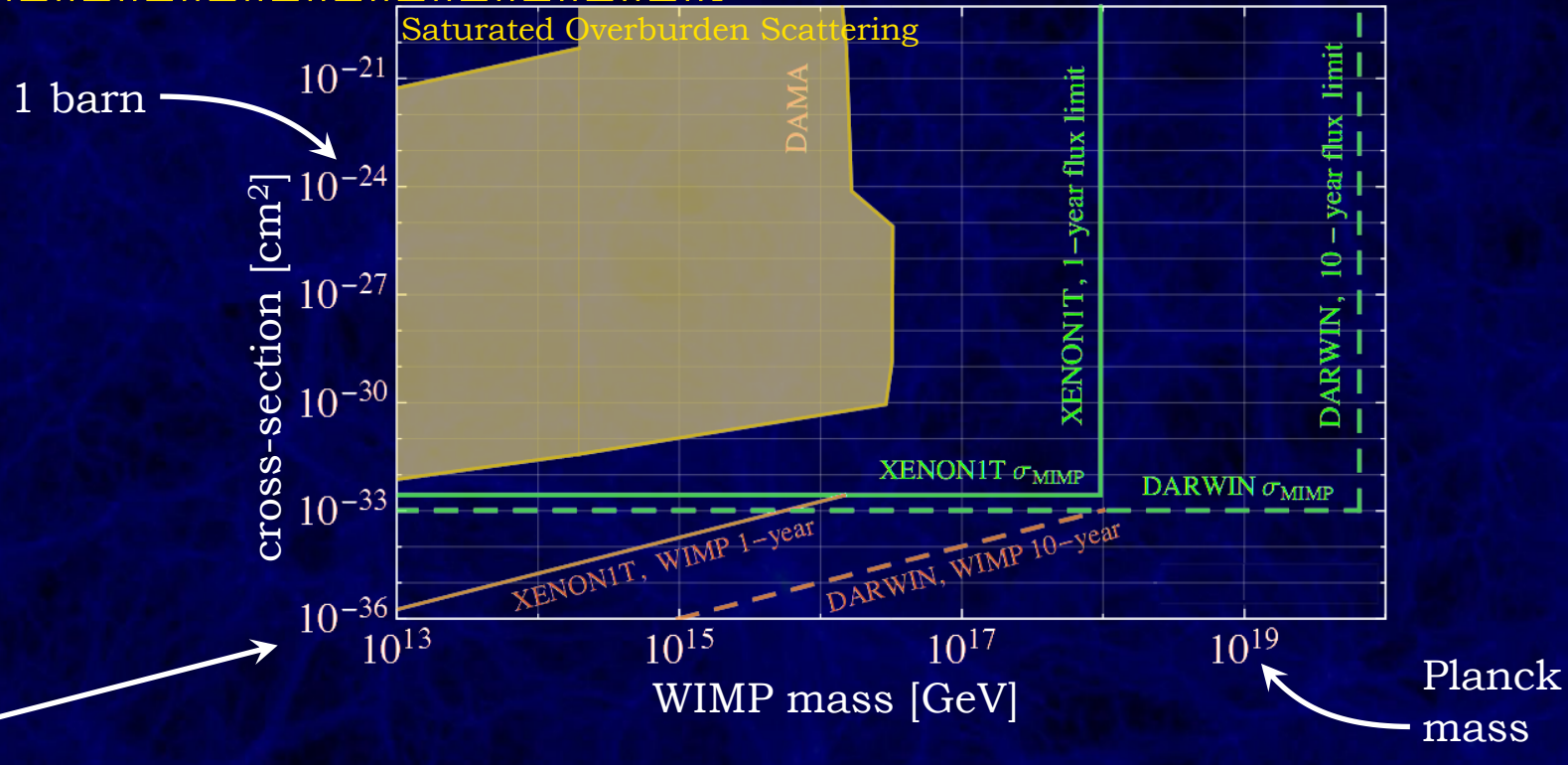
XENON 1805.12562



Does this go all the way to the Planck mass?

Which assumption breaks down?

# Direct Detection at High Mass



e.g. with BOREXINO: Look for non-relativistic tracks

# Non-Minimal Dark Sector

- Luminous Dark Matter

Feldstein, Graham, Rajendran 1008.1988

$\chi$  upscatters into excited  $\chi'$  which then emits a photon in your detector

- Boosted Dark Matter

Agashe et al. 1405.7370

$\chi$  decays e.g. in Sun into  $\chi'$  which is Lorenz boosted and then scatters in your detector

- Self-Destructing Dark Matter

Grossman et al. 1712.00455

$\chi$  scatters in Earth into unstable  $\chi'$  which then decays in detector



T-18 Minutes...

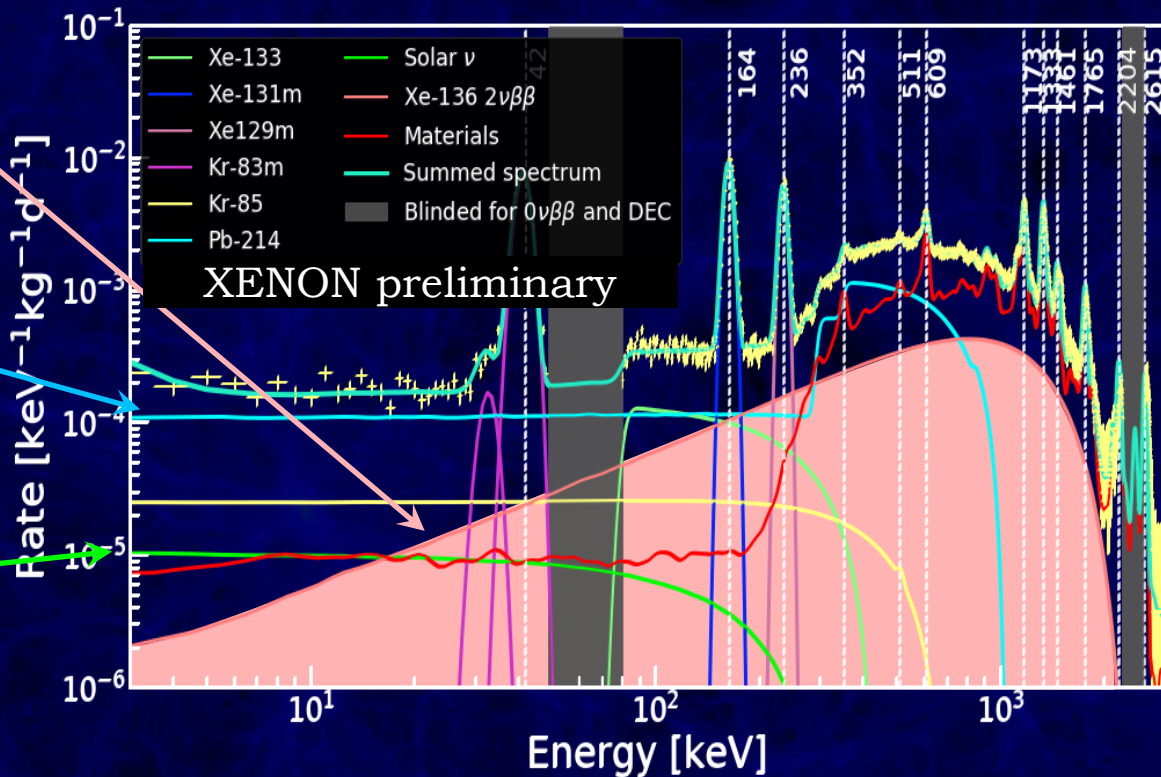


# XENON1T Background Spectrum

overall,  $2\nu 2\beta$  important  
( $t_{1/2} \sim 10^{21}$  years!)

$^{222}\text{Rn}$  a technological  
challenge

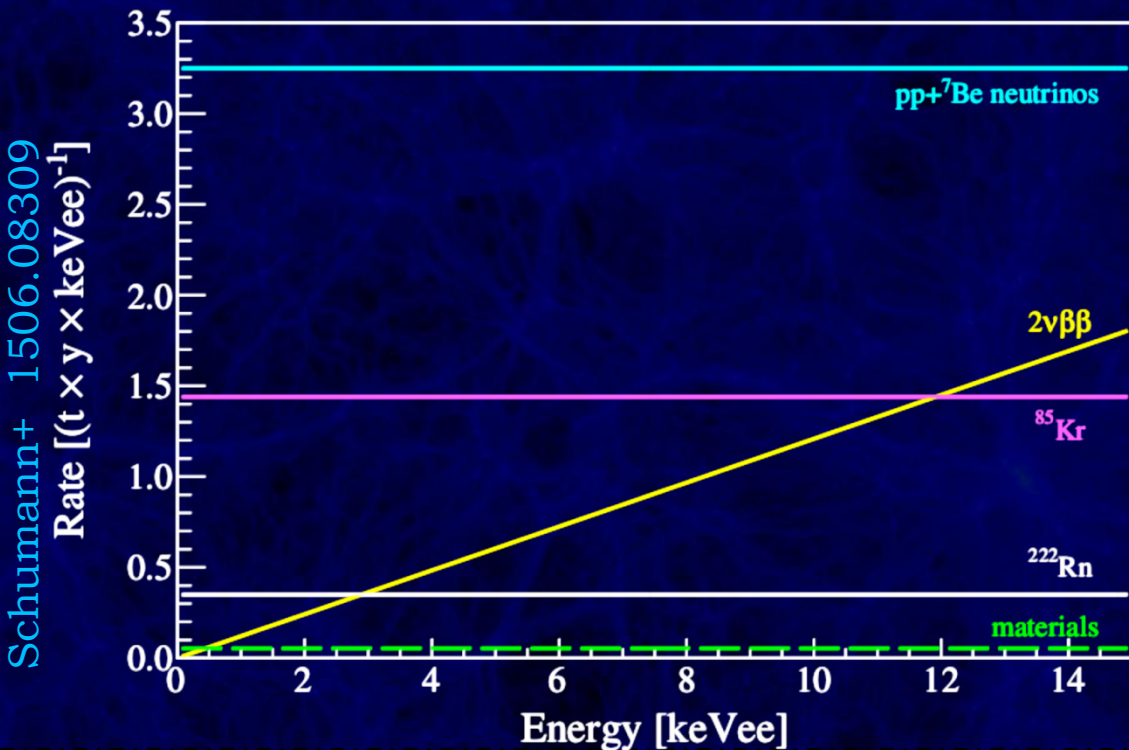
some sensitivity  
at low energies  
to  $\text{pp solar } \nu$





# Lowering the Background

DARWIN baseline design (40t LXe 2025+)



pp  $\nu$  signal  
completely dominant

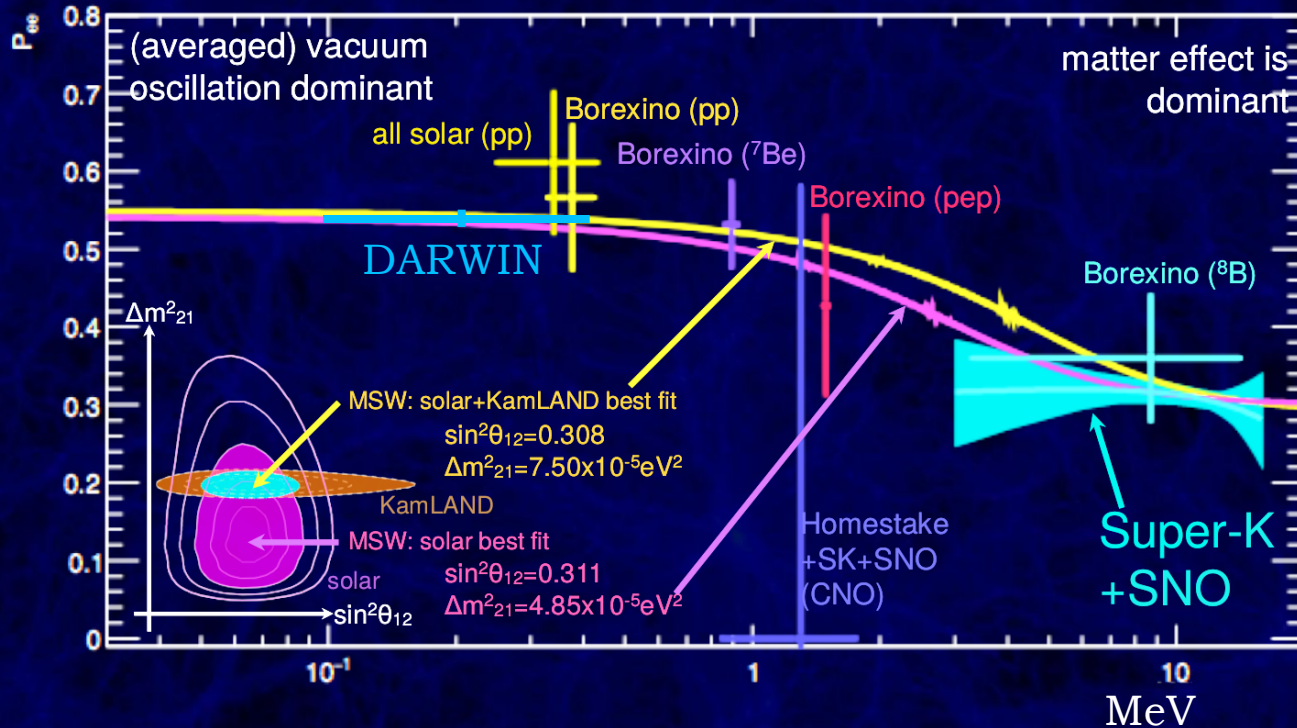
$^{136}\text{Xe}$   $2\nu\beta\beta$  (using  $^{\text{nat}}\text{Xe}$ )

0.1ppt  $^{\text{nat}}\text{Kr}$   
(1/6 XENON1T)

0.1  $\mu\text{Bq/kg}$   $^{222}\text{Rn}$   
(1/100 XENON1T)

materials fiducialized

# Solar Neutrino Elastic Scattering

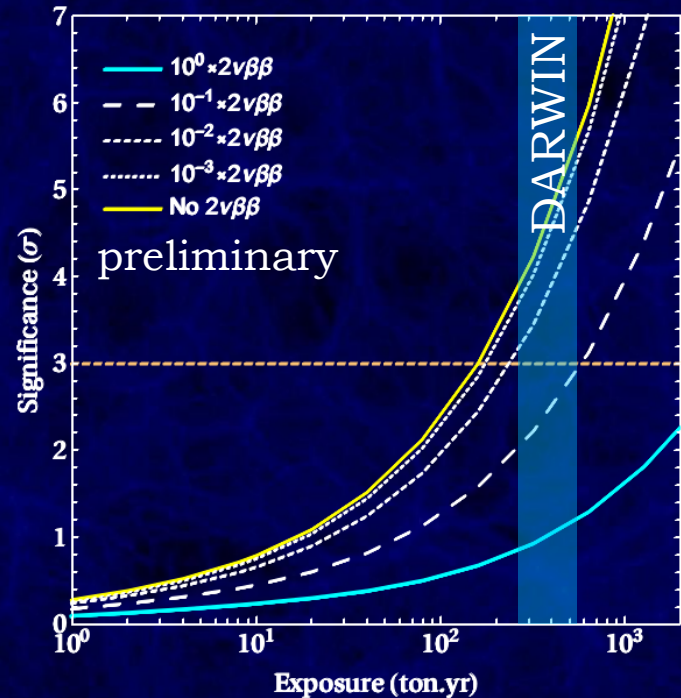
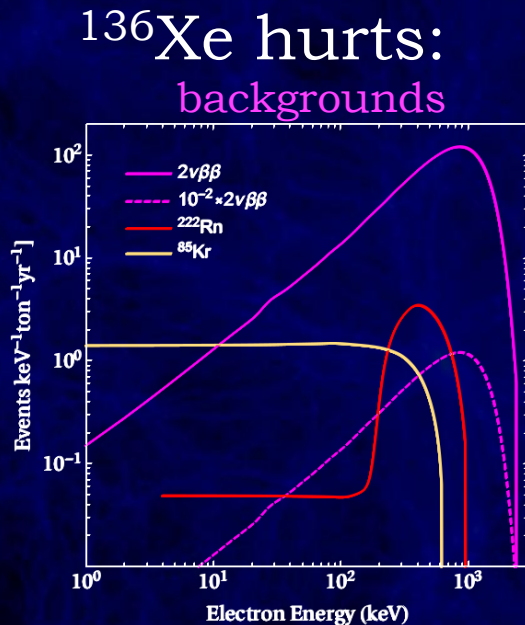
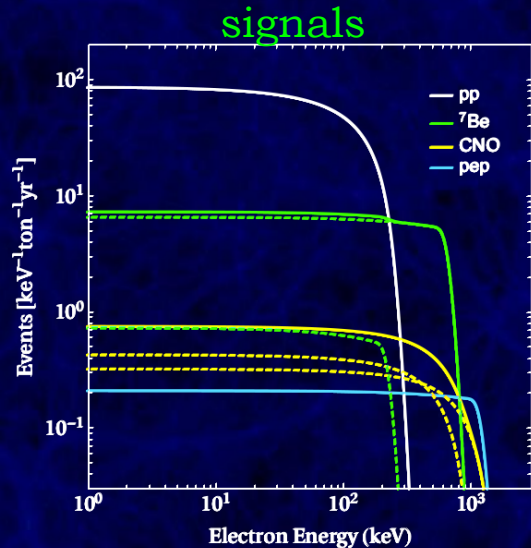




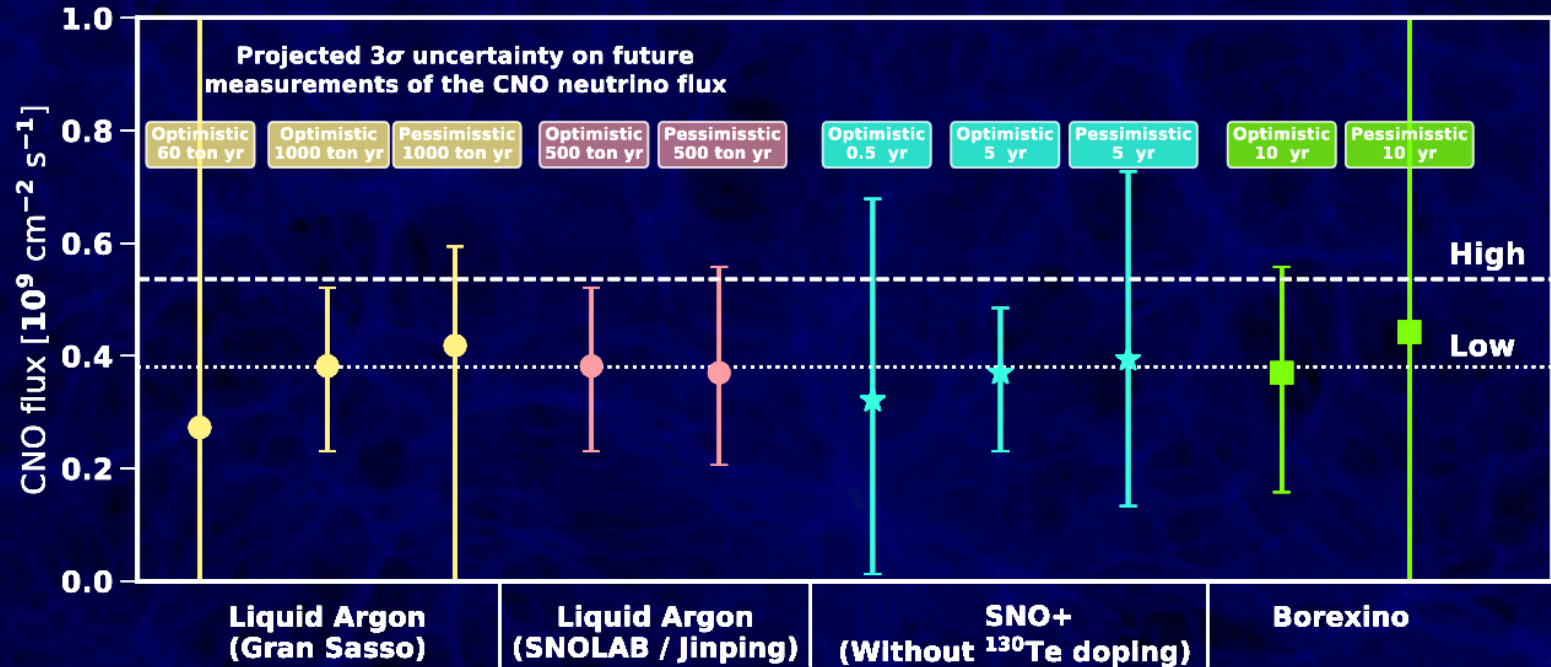
# CNO Neutrinos in 40t Xenon?

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

CNO detection  
significance



# Or try with Argo (100t Ar)





# Add Neutrino Magnetic Moment

Gives new  $\nu$ - $\gamma$  interaction:  
modifies elastic scattering  
predictions for

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

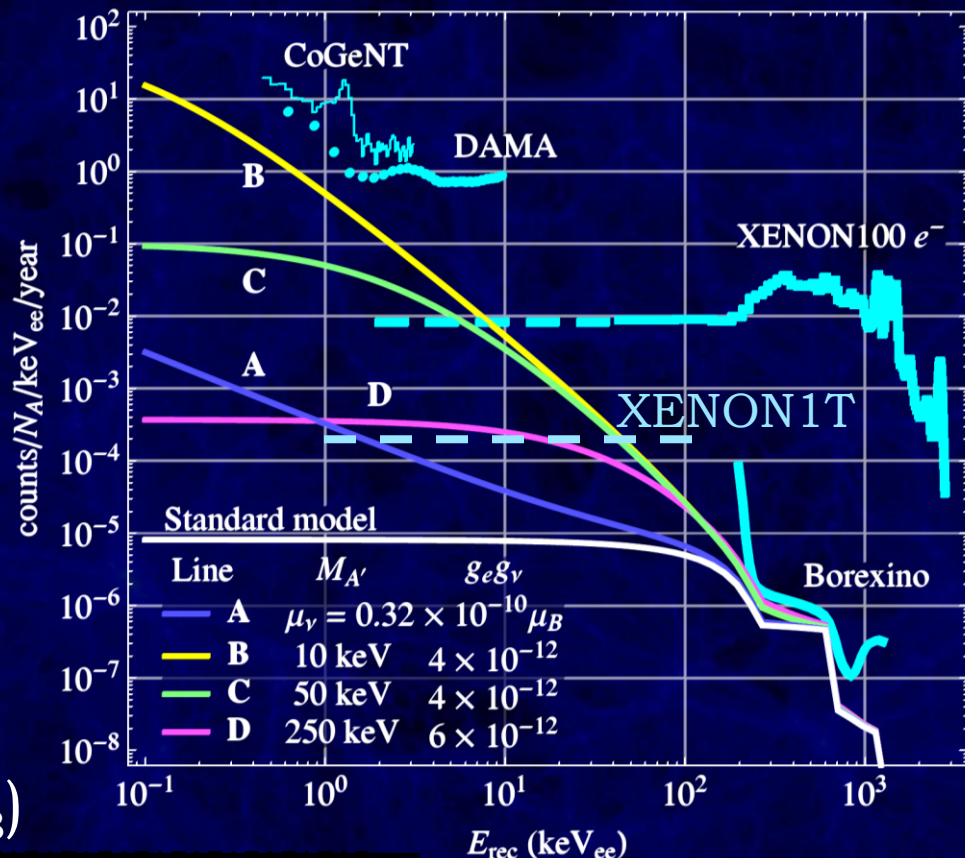
$$\text{Rate} \propto \mu_\nu^2$$

BOREXINO:  $\mu_\nu < 6 \times 10^{-11} \mu_B$

XENON1T sensitivity

$$\mu_\nu \sim 3 \times 10^{-11} \mu_B$$

(SM expectation  $\mu_\nu \sim 10^{-19} \mu_B$ )

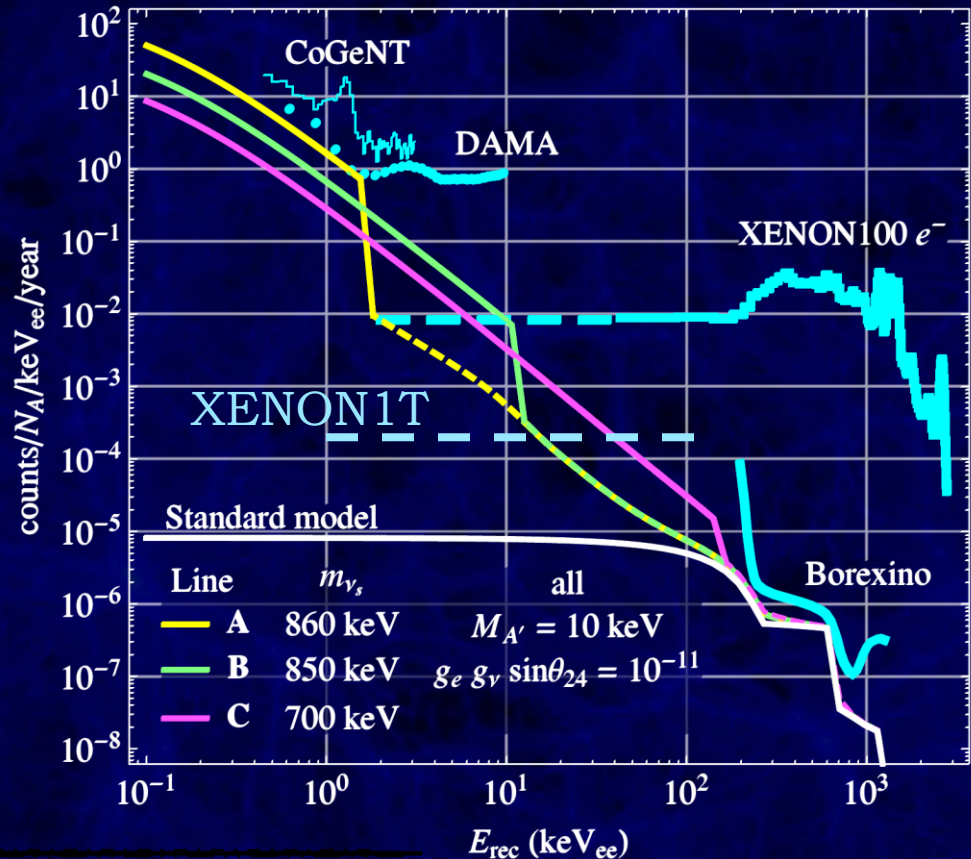


# Heavy Sterile Neutrinos

Modified predictions for  
neutrino elastic  
scattering

$$\nu_{e,\mu/\tau} + e^- \rightarrow \nu_{e,\mu/\tau} + e^-$$

Might enhance coherent  
rates below some  
threshold





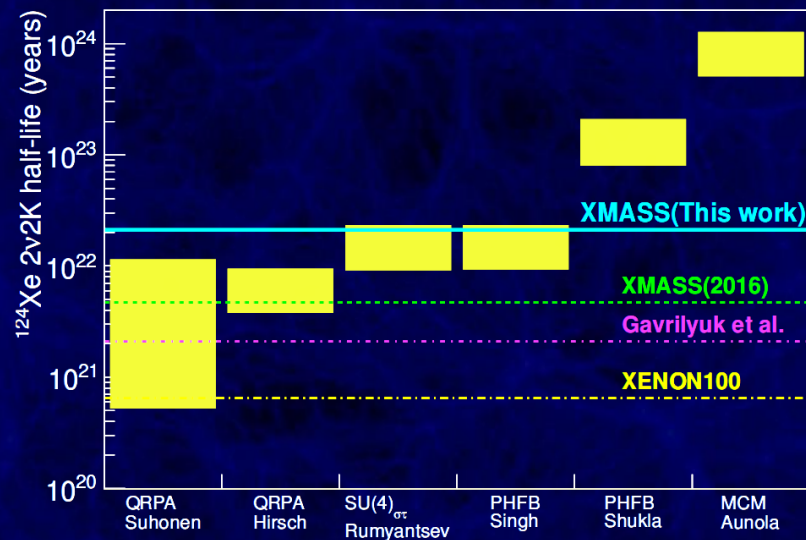
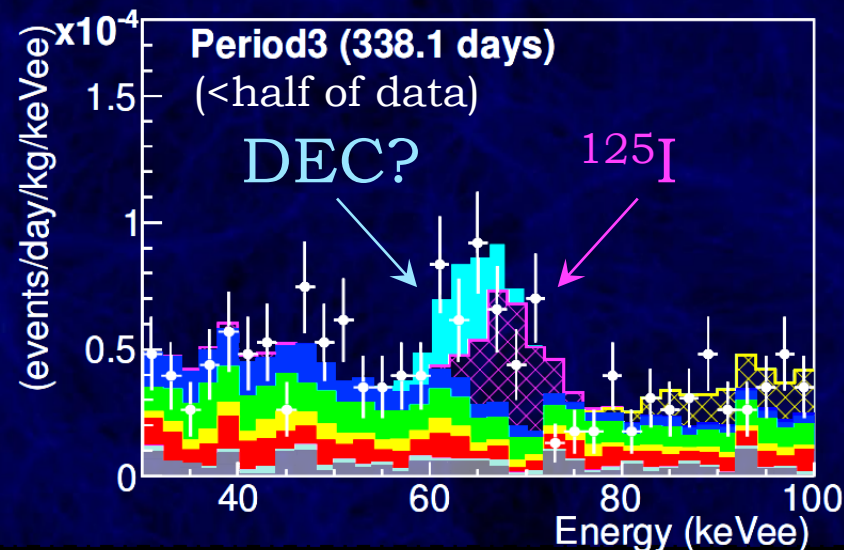
# Double-Electron Capture: XMASS



$2\nu\beta\beta$  the other way around: help nuclear matrix models.

${}^{124}\text{Xe}$  abundance 0.095%

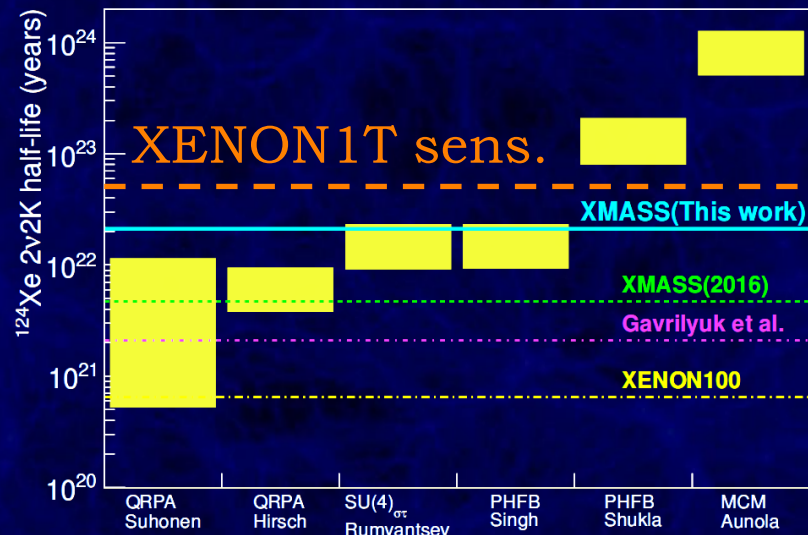
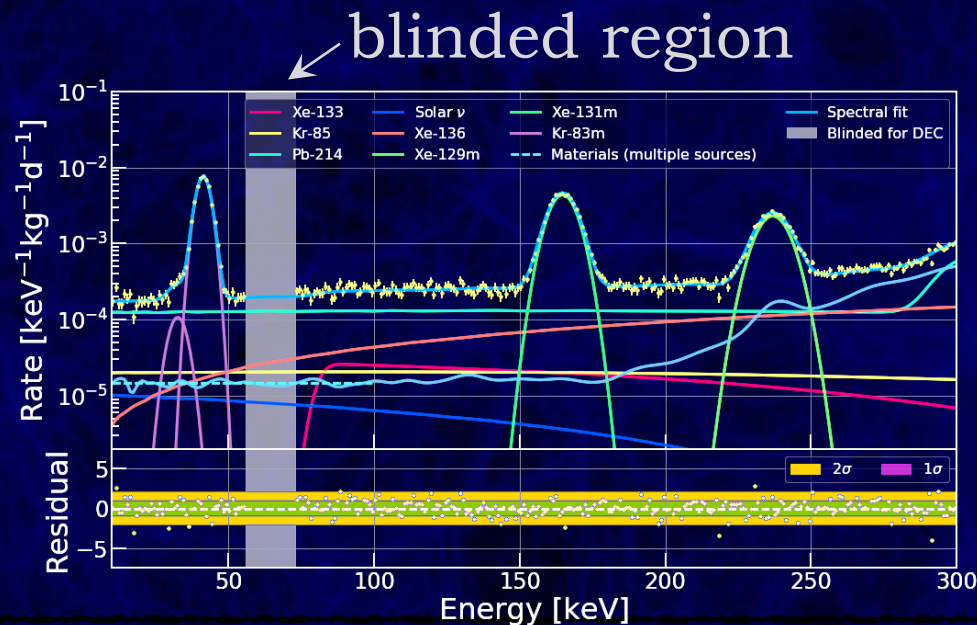
XMASS: 800.0 d, fiducial 327kg  ${}^{\text{nat}}\text{Xe} = 311\text{g } {}^{124}\text{Xe}$



XMASS 1801.03251

# Double-Electron Capture: XENON1T

better resolution, larger exposure, getter removes  $^{125}\text{I}$   
1 ton-year exposure

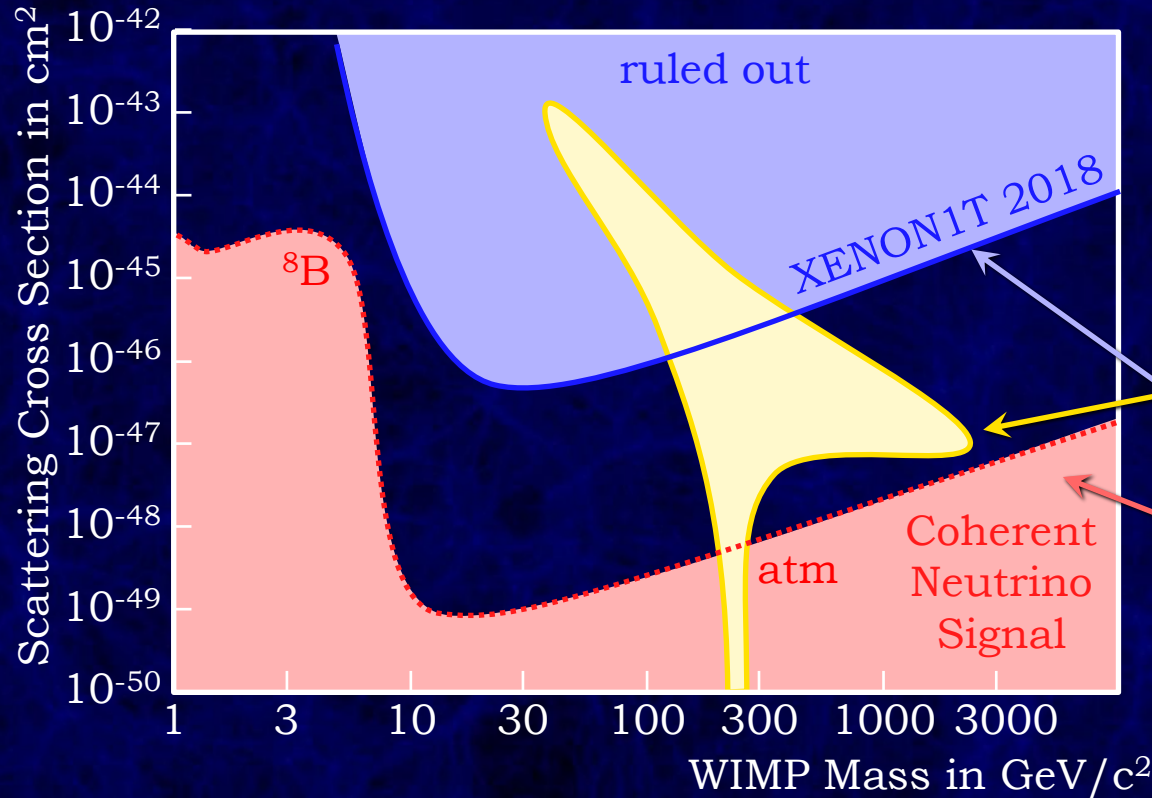




# T-10 Minutes...



# Coherent Neutrino-Nucleus Scattering



Simple scattering kinematics:  
degenerate in  
momentum

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

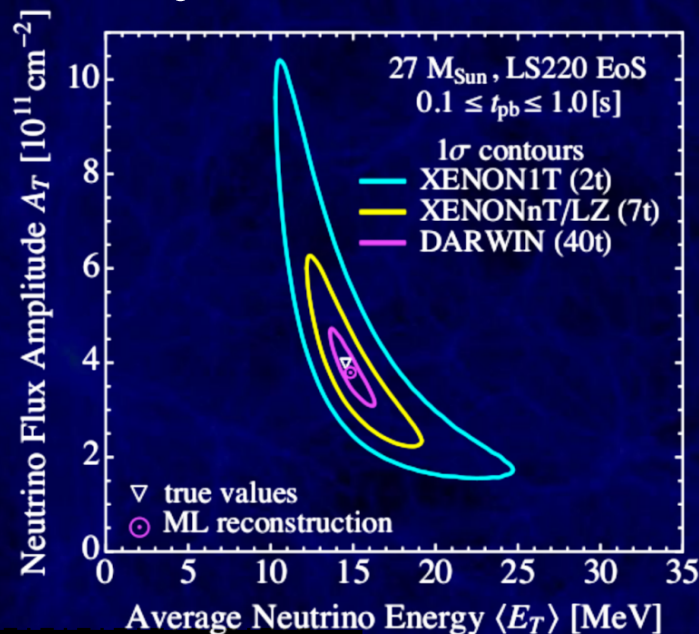
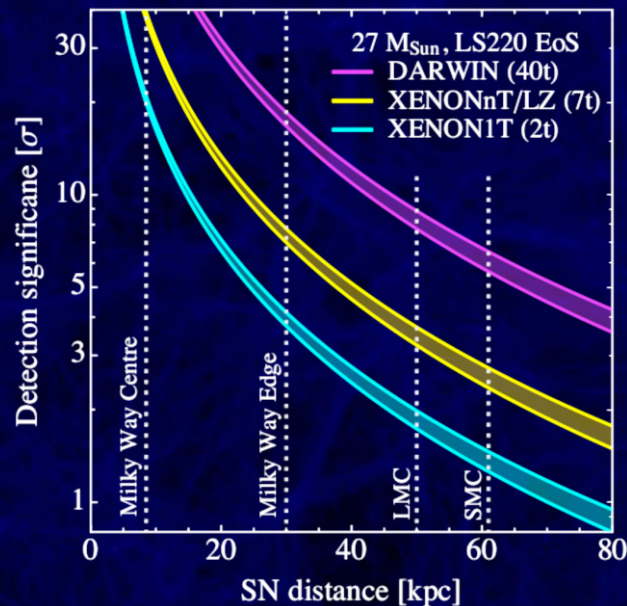
Coherent Neutrino-Nucleus Scattering  
light  $v$ ,  $v \sim c$



# Supernova Neutrinos

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

With SNEWS: XENON1T sensitive across entire Milky Way  
flavor-independent: complementary information



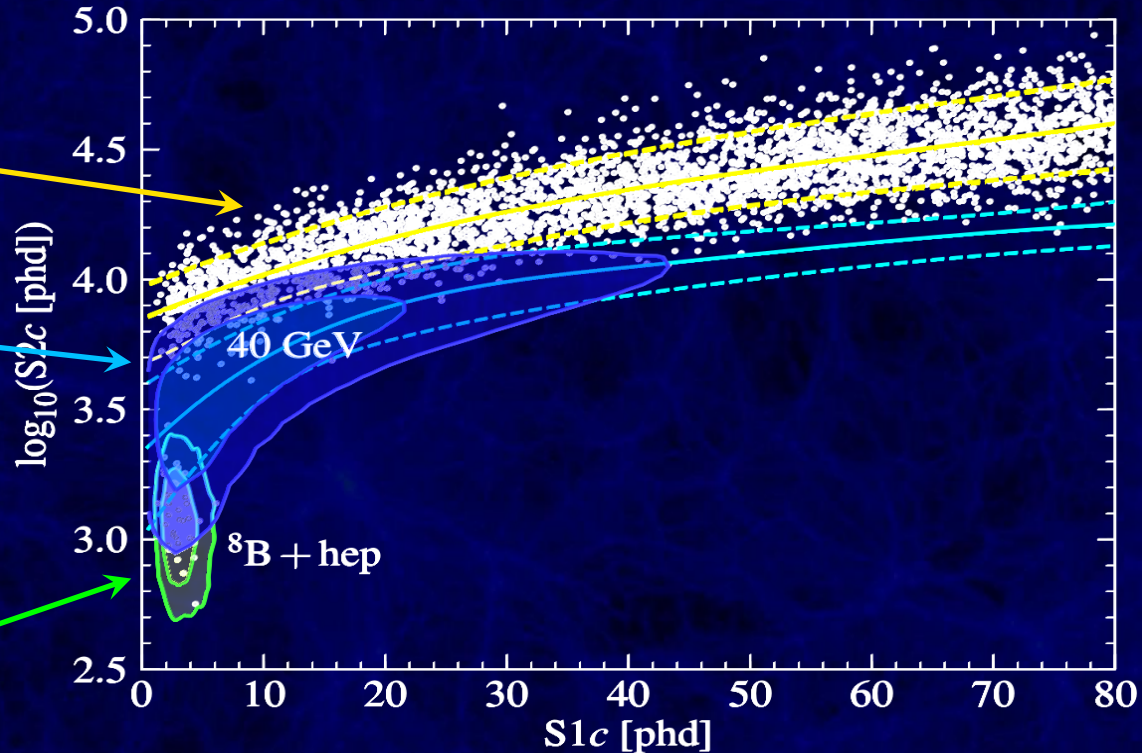
# Solar $^8\text{B}$ neutrinos ~2023

simulation: 1000 days LZ

electronic recoil  
background

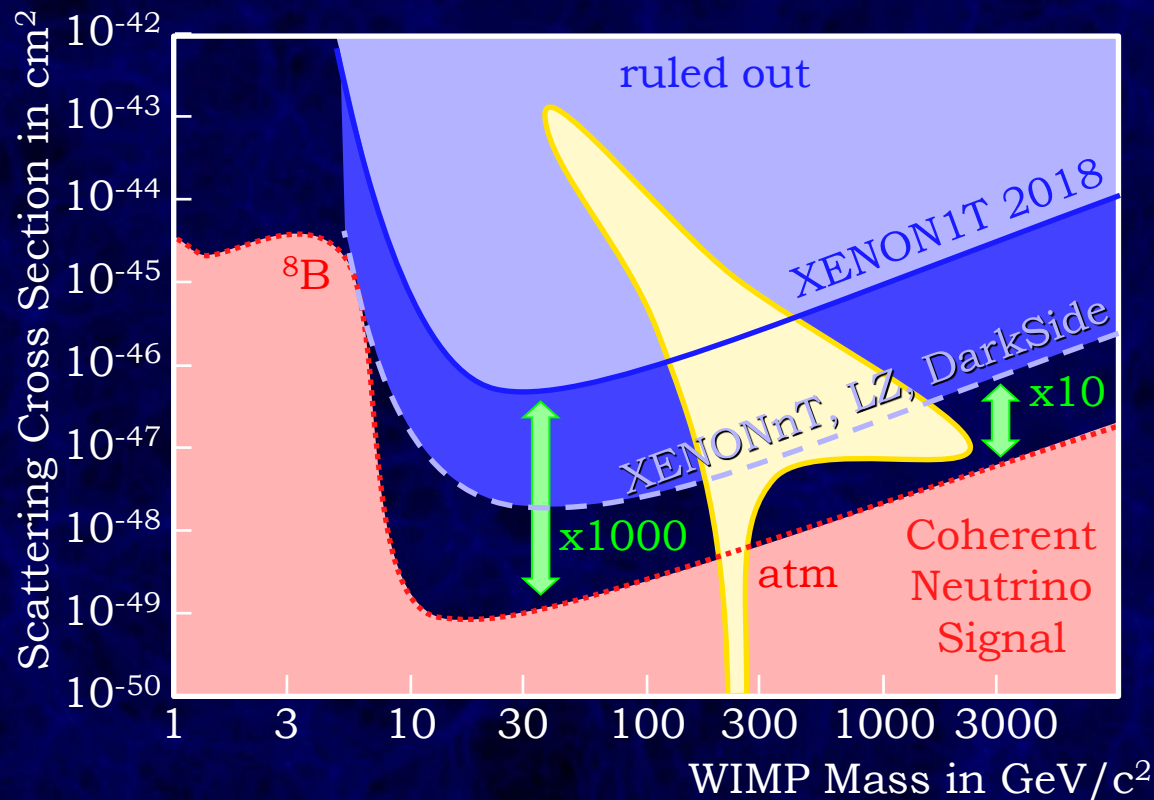
dark matter  
nuclear recoils

~36  $^8\text{B}$  solar  
neutrino  
nuclear recoils





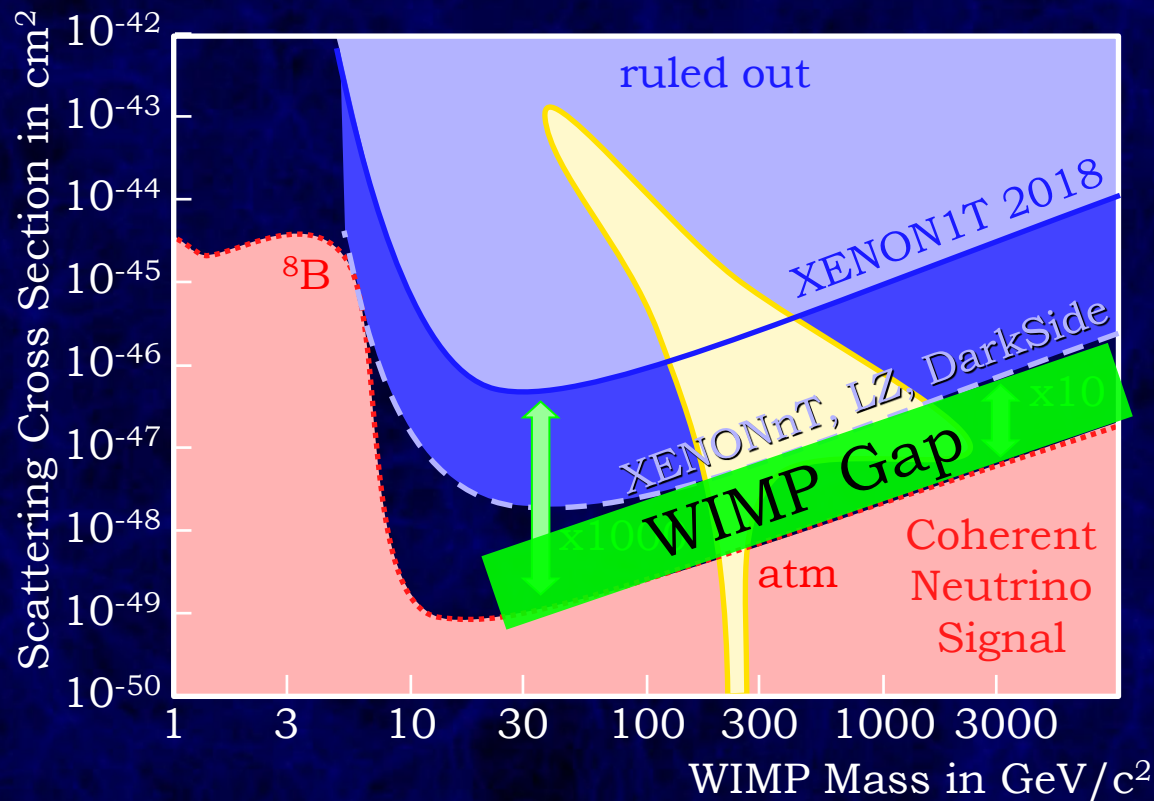
# “Neutrino Floor” Far, Far Away



best limits set by  
liquid xenon TPCs

strong program to  
improve factor 100

# WIMP Gap Requires Generation-3



best limits set by  
liquid xenon TPCs

strong program to  
improve factor 100

current program  
leaves a WIMP gap:  
DARWIN & Argo  
40t Xe      100t Ar



# T-5 Minutes...



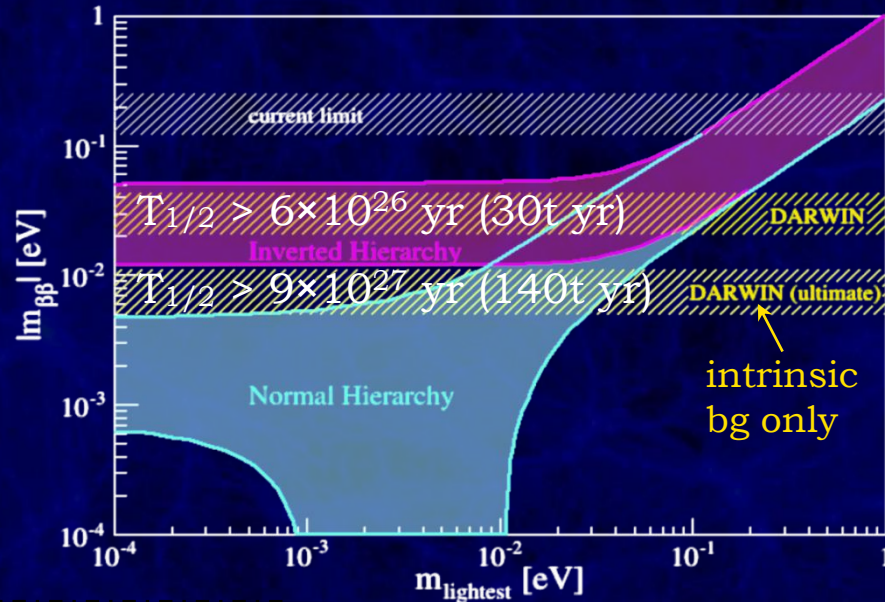
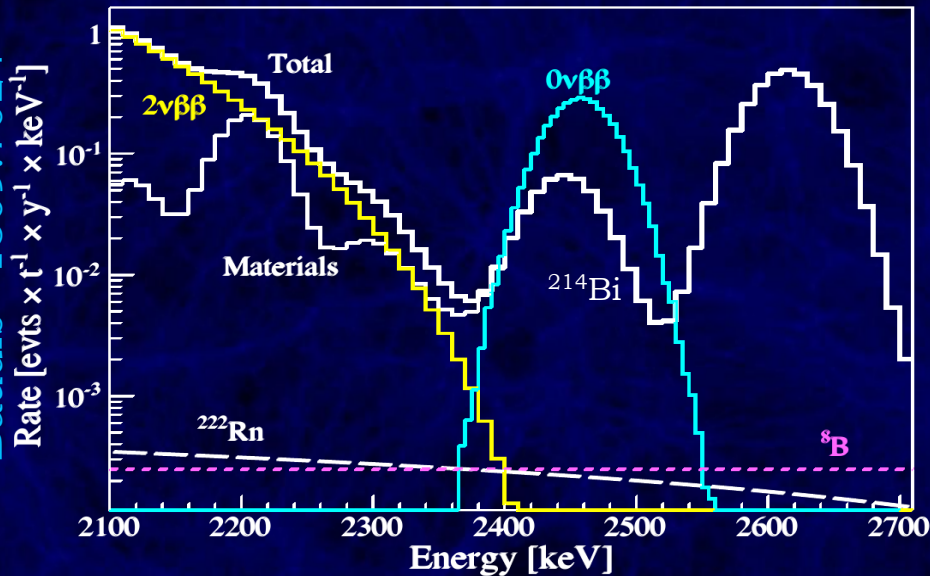


# $^{136}\text{Xe } 0\nu 2\beta$ with $^{\text{nat}}\text{Xe}$ Target

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

Requires large dynamic range of detector

Baudis+1309.7024



DARWIN 1606.07001



# Finally: Lunch.

(well, after your questions)

