University of Zurich[UZH]

Lecture 2: Signatures, Backgrounds and Overview of Experimental Techniques

ISAPP 2024: Particle Candidates for Dark Matter
Scuola Galileiana di Studi Superiori
Padova, July 3, 2024

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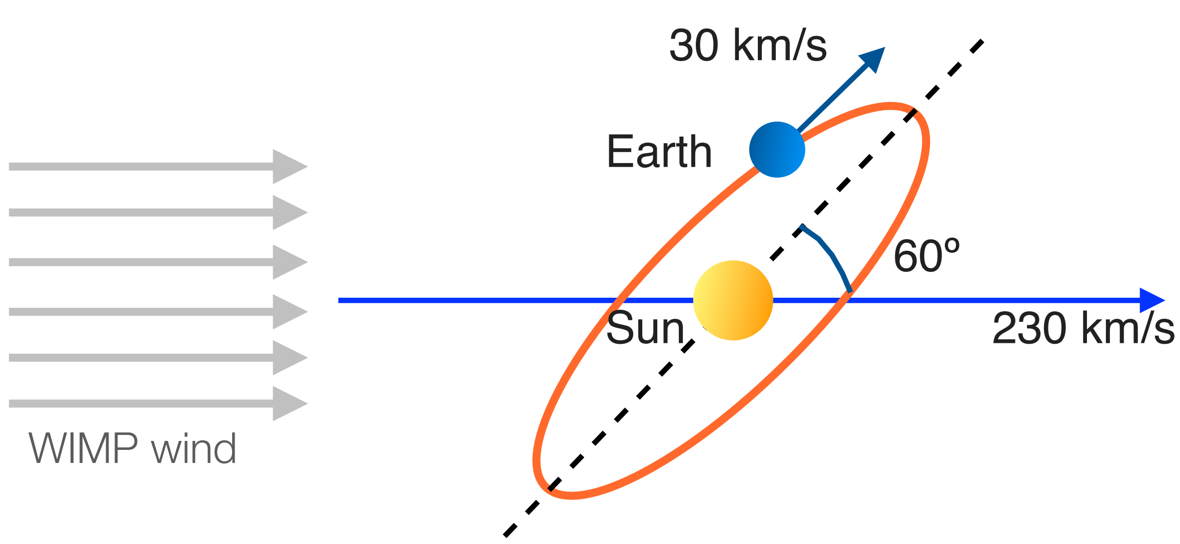
University of Zurich

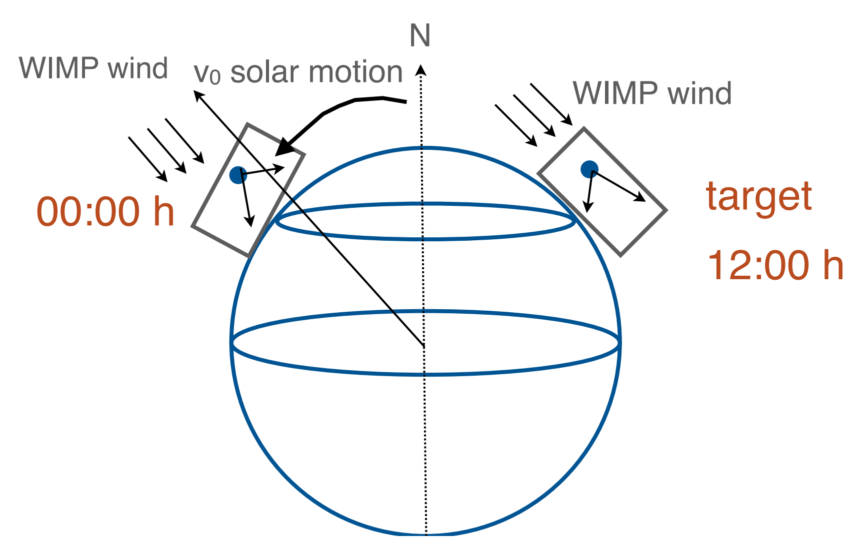
Content

- WIMP signatures
  - time dependance of the rate
  - directional dependance
  - spectral dependance on the mass of the DM and on the target mass
- Backgrounds
  - background sources
  - background discrimination
  - neutrino backgrounds
  - the neutrino fog
- Experimental techniques : overview
- The direct detection landscape

Expected WIMP-specific signatures

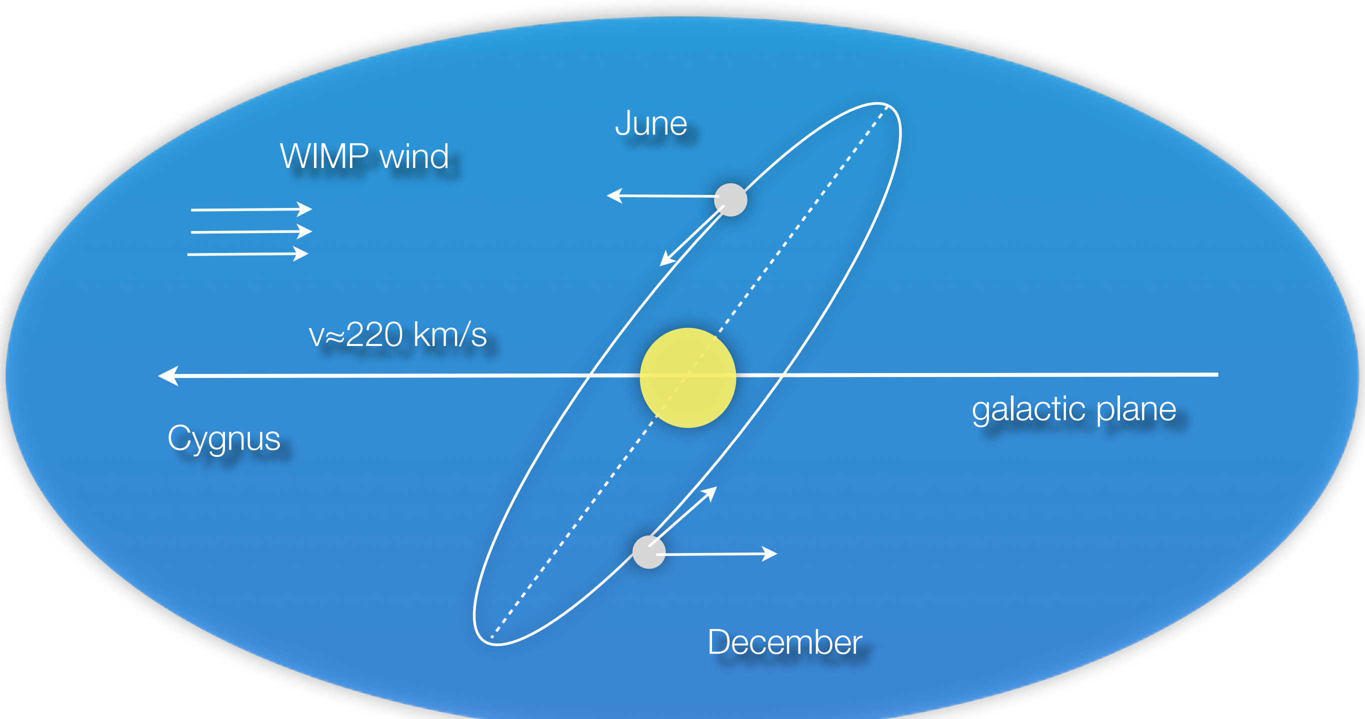
- So far: we have seen that *the recoil rate is energy dependent* due to
  - ◉ the kinematics of elastic WIMP-nucleus scattering
  - ◉ in combination with the WIMP velocity distribution
- However: due to the motion of the Earth with respect to the Galactic rest frame, the recoil rate is:
  - ◉ ***time and direction dependent***
- We will now look at the time and directional effects





Time dependance: introduction

- **The Earth's orbit about the Sun leads to a time dependance, specifically an annual modulation, in the differential event rate:**
  - the Earth's speed with respect to the Galactic rest frame is largest in summer when the components of the Earth's orbital velocity in the direction of solar motion is largest
  - therefore the number of WIMPs with high (low) speeds in the detector rest frame is largest (smallest) in summer
  - consequently, the differential event rate has an annual modulation, with an expected peak in summer and a minimum in winter



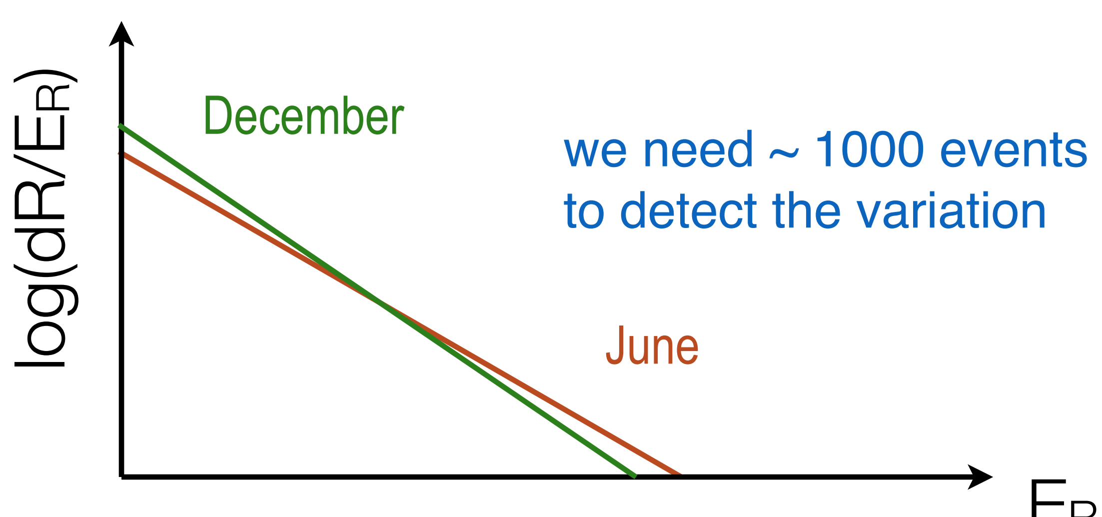
Drukier, Freese, Spergel, PRD 33,1986

Time dependance of the signal

- Since the Earth's orbital speed is significantly smaller than the Sun's circular speed, the amplitude of the modulation is small ($v_E/v_c \sim 0.07$) and the differential event rate can be written to a first approximation as:

$$\frac{dR}{dE_R}(E_R,t) \simeq \frac{dR}{dE_R}(E_R)\left[1+\Delta(E_R)\cos\frac{2\pi\,(t-t_0)}{T}\right]$$

- where T = 1 year, and t_0 = 150 days



annual variation of the rate spectrum

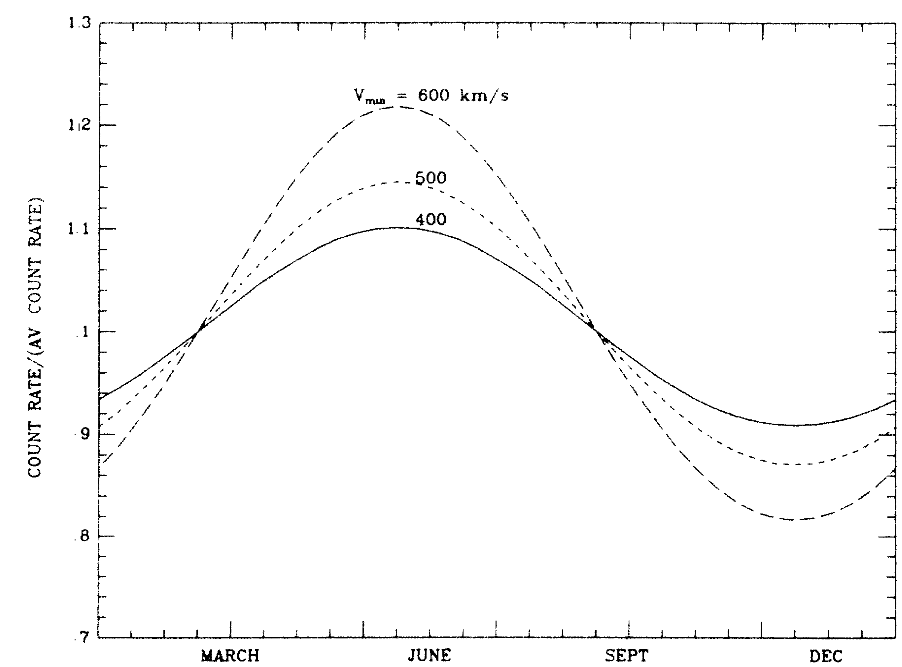
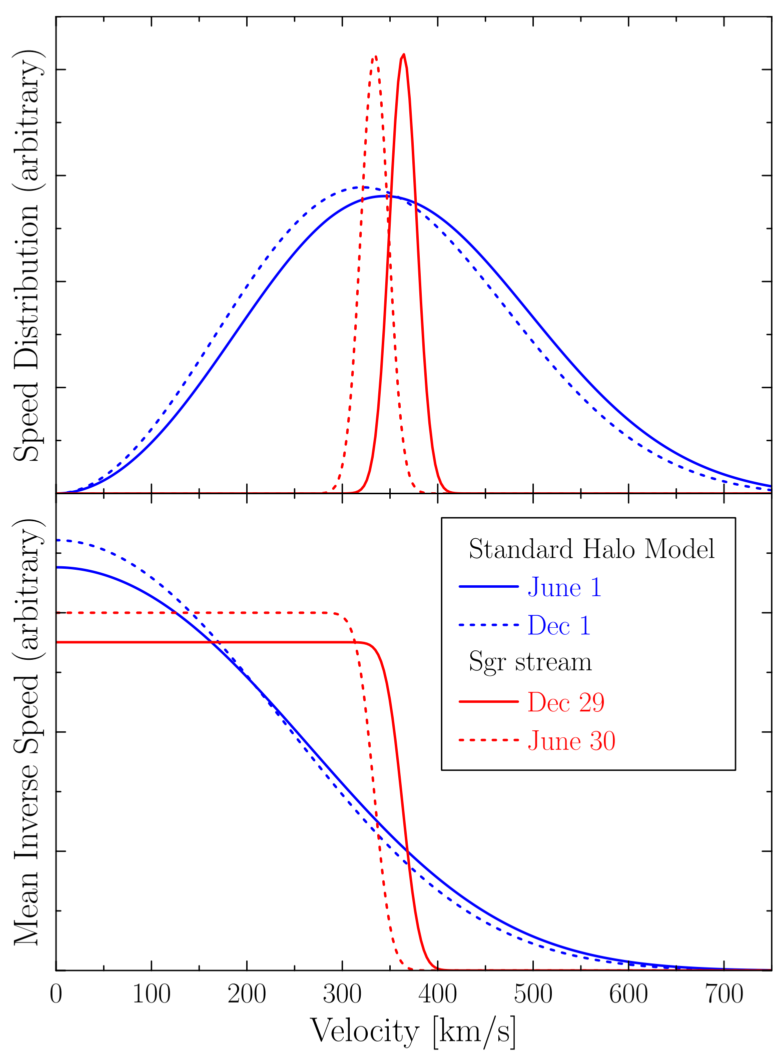


FIG. 7. Modulation of dark-matter signal in the detector due to the motion of the Earth around the Sun. Expected count rate/(averaged count rate) is plotted for different months of the year. This modulation effect can be used to enhance background subtraction.

Annual modulation

- The speed distribution, f(v), and the differential signal in a detector *depend on the halo model*
- Here two cases: the SHM, and the extreme case of a stream (modelled after the Sagittarius stream, and roughly orthogonal to the galactic plane with speed ~ 350 km/s)

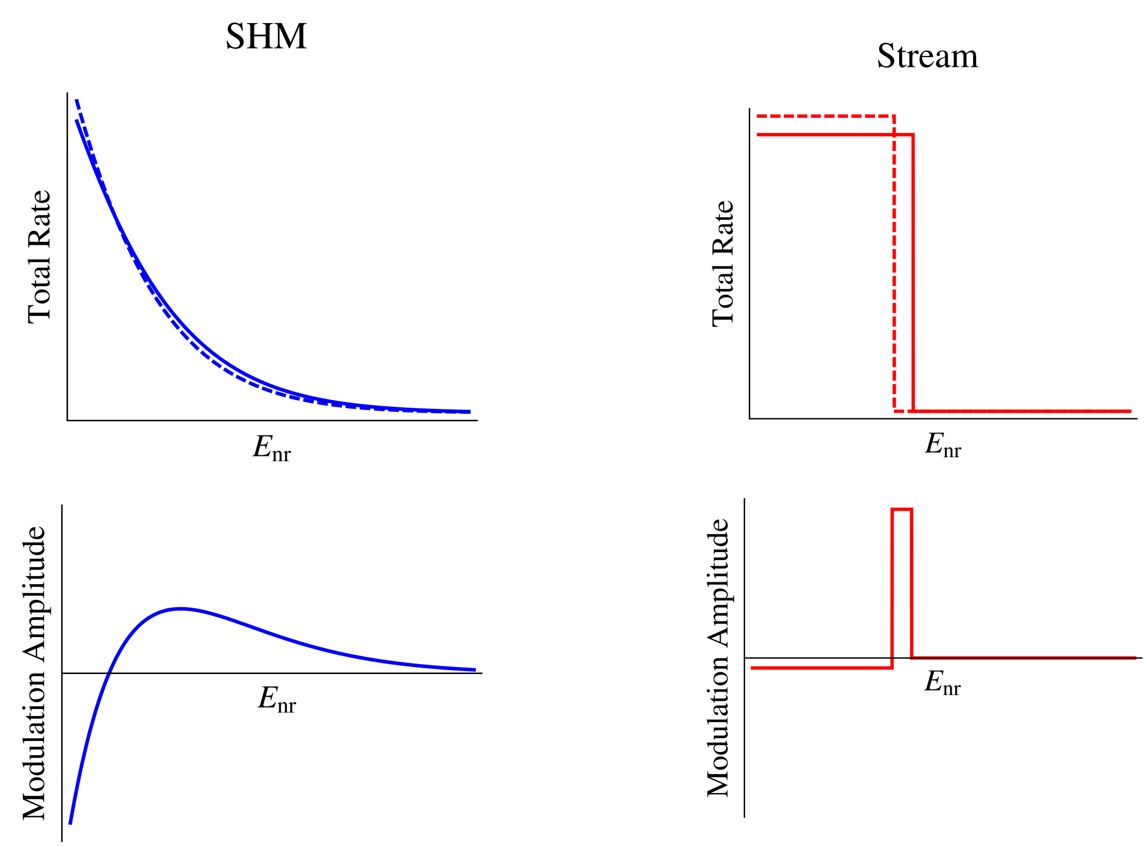


Freese, Lisanti, and Savage: *Colloquium*: Annual modulation of dark matter

Review Modern Physics 85, 2013

Amplitude of modulation:

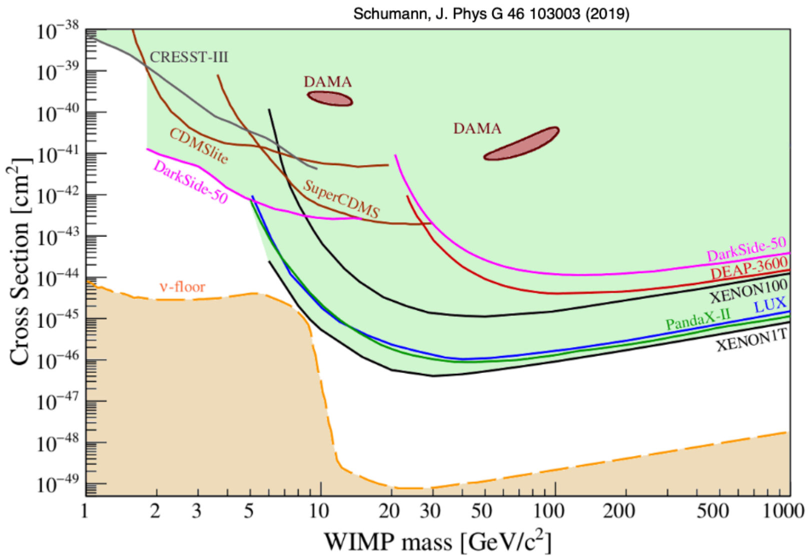
$$A(E) \approx \frac{1}{2}\left[\frac{dR}{dE}(E, \mathrm{June\,1}) - \frac{dR}{dE}(E, \mathrm{Dec\,1})\right]$$

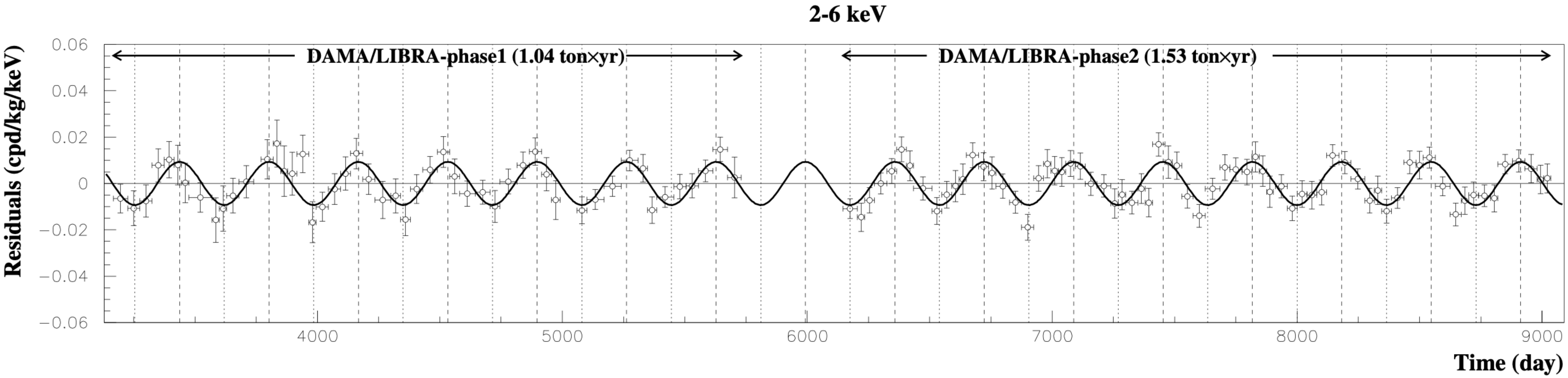


Annual modulation

DAMA/LIBRA: SciPost Phys. Proc. 12, 025 (2023)

- Observed in DAMA/LIBRA (13.7-sigma; 250 kg NaI, 2.86 tons-year, 22 annual cycles)
- Origin of the modulation is still unclear





Amplitude: ~ (0.0116 ± 0.0013) events/(kg keV d)

T = 0.99834 ± 0.00067 yr, t_0 =142.4±4.2 day (t_0 = 152.5 day ≡ June 2nd)

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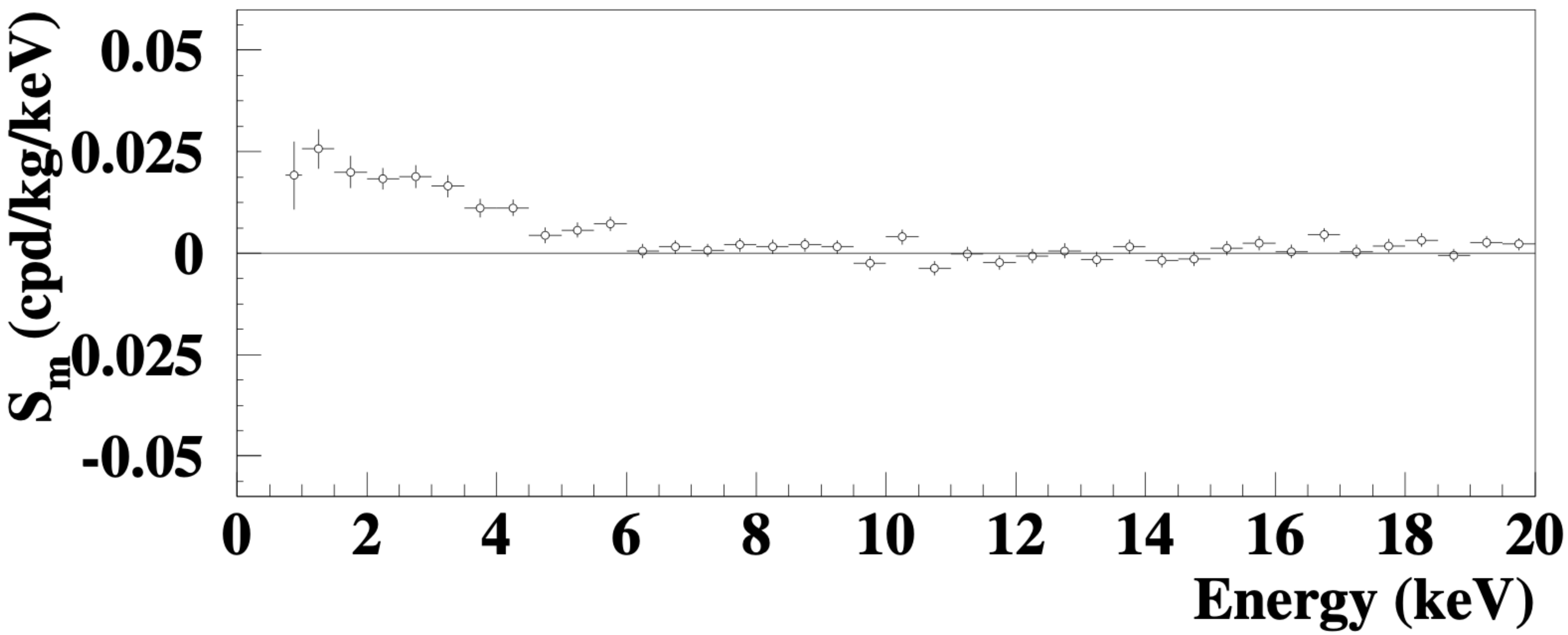
modulation amplitude



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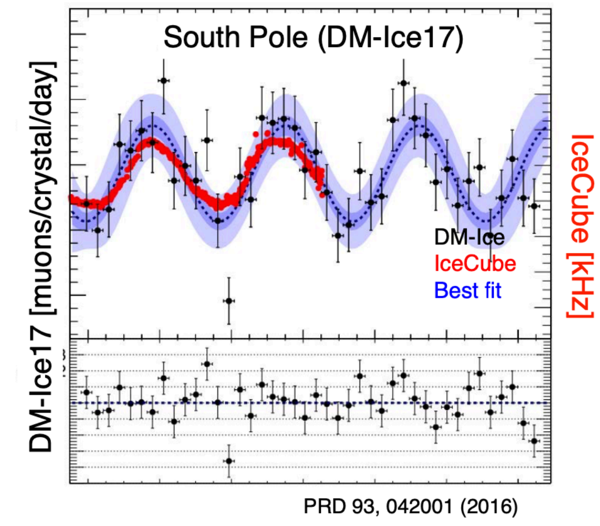
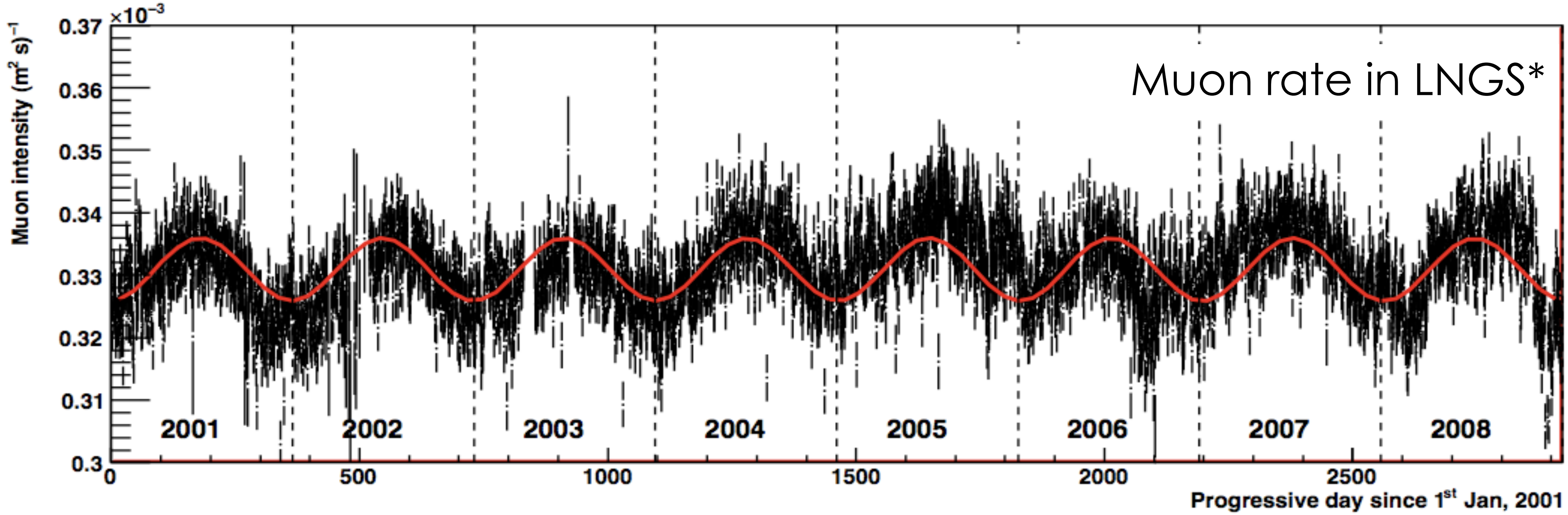
Annual modulation

- Problem: muon rate also modulates with the season
- Amplitude & phase can not explain DAMA/LIBRA however

2.93 ± 0.04 muons/crystal/day,
12.3 ± 1.7% modulation amplitude



muon modulation at South Pole, R. Maruyama, UCLA DM 2023



Muon rate variation at LNGS: Amplitude: ~ 0.015; T = 1 year, ϕ = July 15±15 days

Annual modulation: an analysis issue?

https://www.nature.com/articles/s41598-023-31688-4

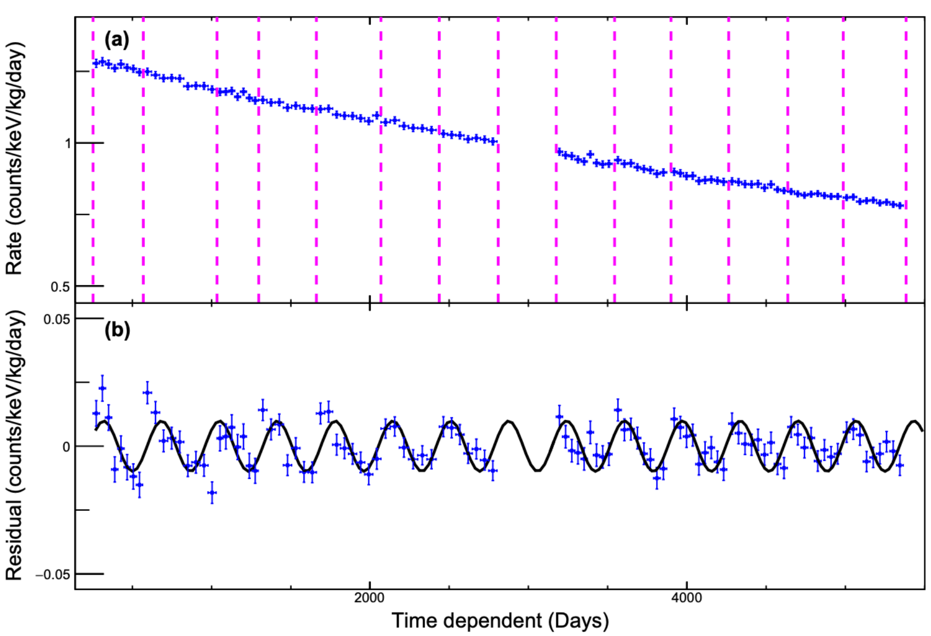
- Problem: a modulation can be induced by the data analysis method (the observed annual modulation can be reproduced by a slowly varying time-dependent background)
- However the obtained modulation phase is almost opposite to that of the DAMA/LIBRA data

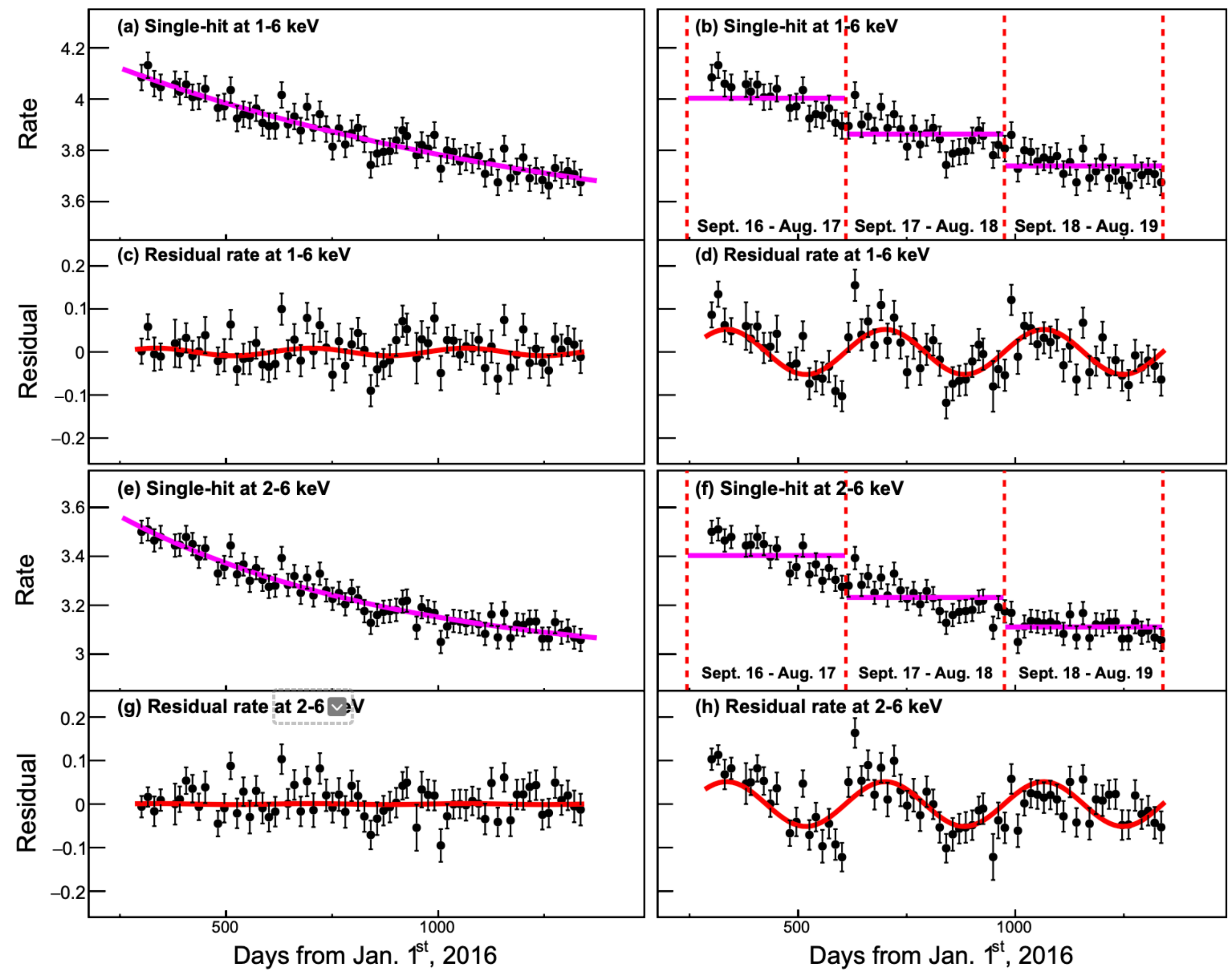
Check for updates

OPEN

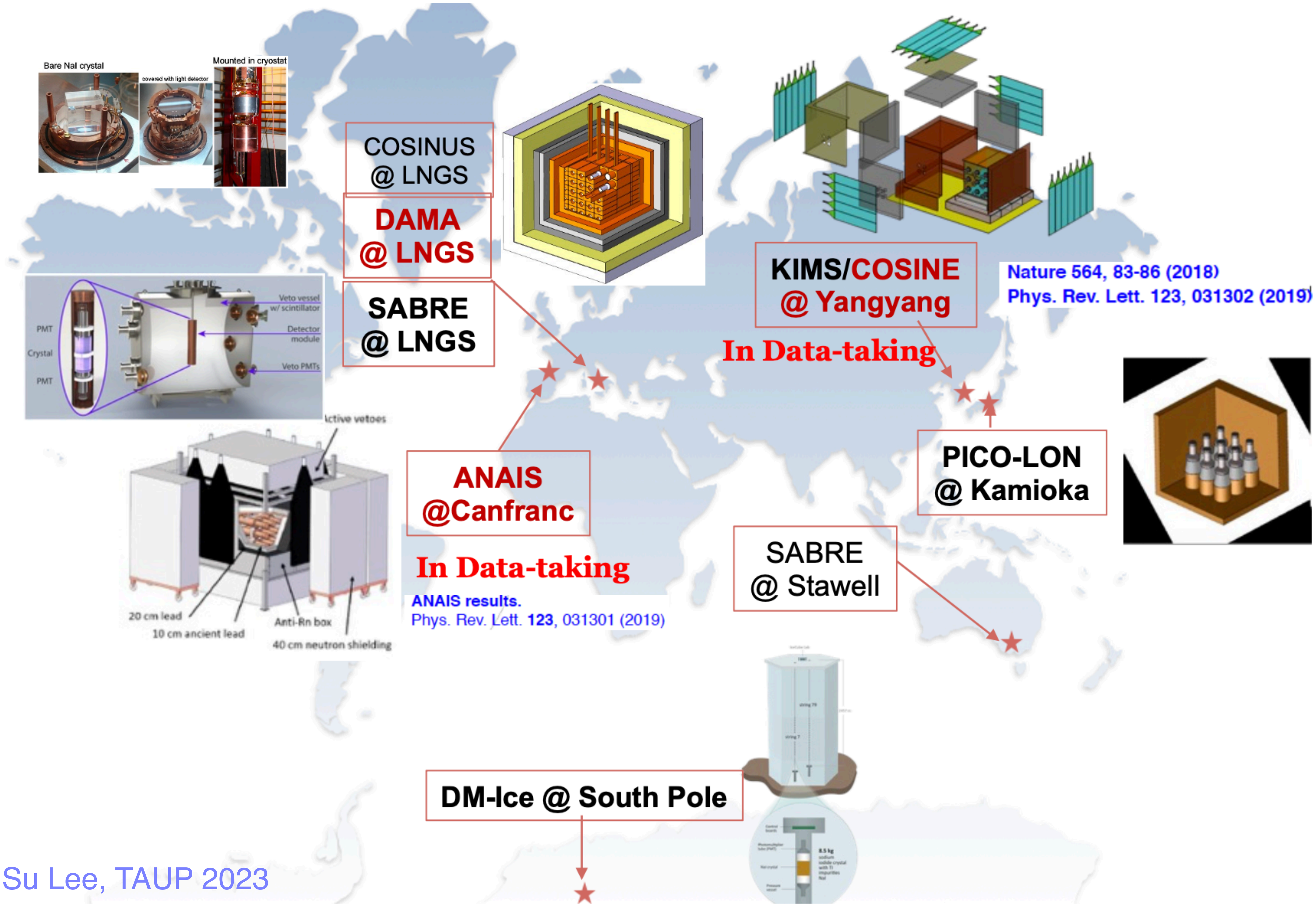
An induced annual modulation signature in COSINE-100 data by DAMA/LIBRA's analysis method

Govinda Adhikari[1], Nelson Carlin[2], JaeJin Choi[3,4], Seonho Choi[3], Anthony Ezeribe[5], Luis Eduardo França[2], Chang Hyon Ha[6], In Sik Hahn[7,8,9], Sophia J. Hollick[1], Eunju Jeon[4], Jay Hyun Jo[1], Han Wool Joo[3], Woon Gu Kang[4], Matthew Kauer[10], Bongho Kim[4], Hongjoo Kim[11], Jinyoung Kim[6], Kyungwon Kim[4], SungHyun Kim[4], Sun Kee Kim[3], Won Kyung Kim[4,9], Yeongduk Kim[4,9,12], Yong-Hamb Kim[4,9,13], Young Ju Ko[4], Doo Hyok Lee[11], Eun Kyung Lee[4], Hyunseok Lee[4,9], Hyun Su Lee[4,9]✉, Hye Young Lee[4], In Soo Lee[4], Jaison Lee[4], Jooyoung Lee[11], Moo Hyun Lee[4,9], Seo Hyun Lee[4,9], Seung Mok Lee[3], Yu Jin Lee[6], Douglas Leonard[4], Bruno B. Manzato[2], Reina H. Maruyama[1], Robert J. Neal[5], James A. Nikkel[1], Stephen L. Olsen[4], Byung Ju Park[4,9], Hyang Kyu Park[14], Hyeonseo Park[13], Kangsoon Park[4], Se Dong Park[11], Ricardo L. C. Pitta[2], Hafizh Prihtiadi[4]✉, Sejin Ra[4], Carsten Rott[15,16], Keon Ah Shin[4], Andrew Scarff[5], Neil J. C. Spooner[5], William G. Thompson[1], Liang Yang[17] & Gyun Ho Yu[4,15]





A global effort to solve the DAMA/LIBRA mystery

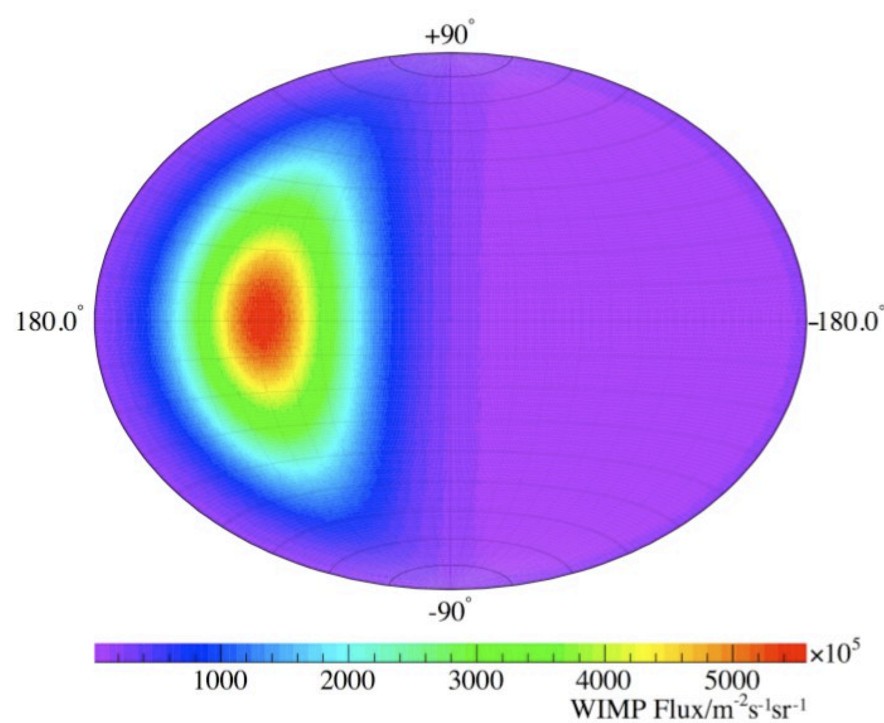


Hyun Su Lee, TAUP 2023

Directional dependance of the signal

- The Earth's motion with respected to the Galactic rest frame produces a direction dependance of the recoil spectrum
- The peak WIMP flux comes from the direction of the solar motion, which points towards the constellation Cygnus
- Assuming a smooth WIMP distribution, the recoil rate is then peaked in the opposite direction
- In the laboratory frame, this direction varies over the course of a sidereal day due to the Earth's rotation
- This effect can provide a robust signature for a Galactic origin of a WIMP signal

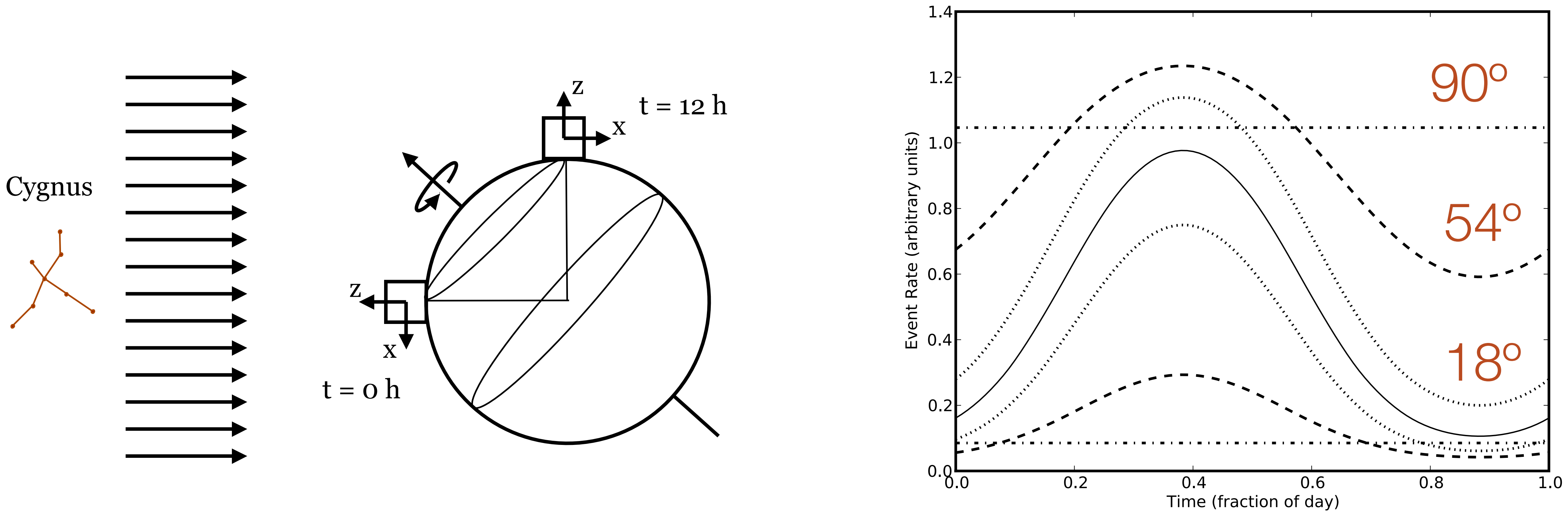
Projection of the WIMP flux in Galactic coordinates



A WIMP mass of 100 GeV was assumed

B. Morgan, A. M. Green and N. J. C. Spooner, Phys. Rev. D71, p. 103507 (2005).

Directional dependance of the signal



- The number of recoils along a particular direction in the lab frame will change over the course of a day
- No known background can mimic the signal

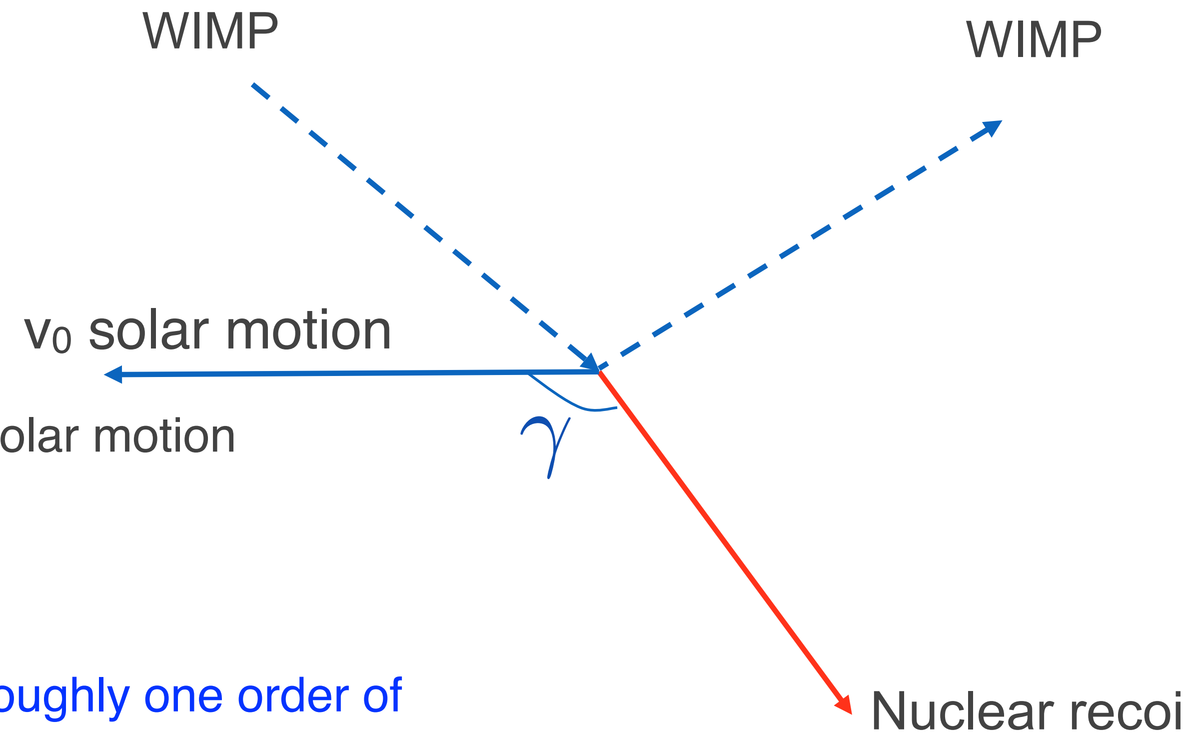
Fig. 2. (left) The daily rotation of the Earth introduces a modulation in recoil angle, as measured in the laboratory frame. (right) Magnitude of this daily modulation for seven lab-fixed directions, specified as angles with respect to the Earth's equatorial plane. The solid line corresponds to zero degrees, and the dotted, dashed, and dash-dot lines correspond to ±18°, ±54° and ±90°, with negative angles falling above the zero degree line and positive angles below. The ±90° directions are co-aligned with the Earth's rotation axis and therefore exhibit no daily modulation. This calculation assumes a WIMP mass of 100 GeV and CS_2 target gas. (from Ref. 13).

Directional dependance of the signal

- The number of nuclear recoils along a particular direction in the laboratory frame will thus change over the course of a day
- For the standard halo model, the direction dependance is given by:

$$\frac{d^2R}{dE_R d\cos\gamma} = \frac{\rho_0 \sigma_{WN}}{\sqrt{\pi}\sigma_v} \frac{m_N}{2m_W m_r^2} \exp\left[-\frac{\left[(v_{orb}^E + v_c)\cos\gamma - v_{min} \right]^2}{\sigma_v^2} \right]$$

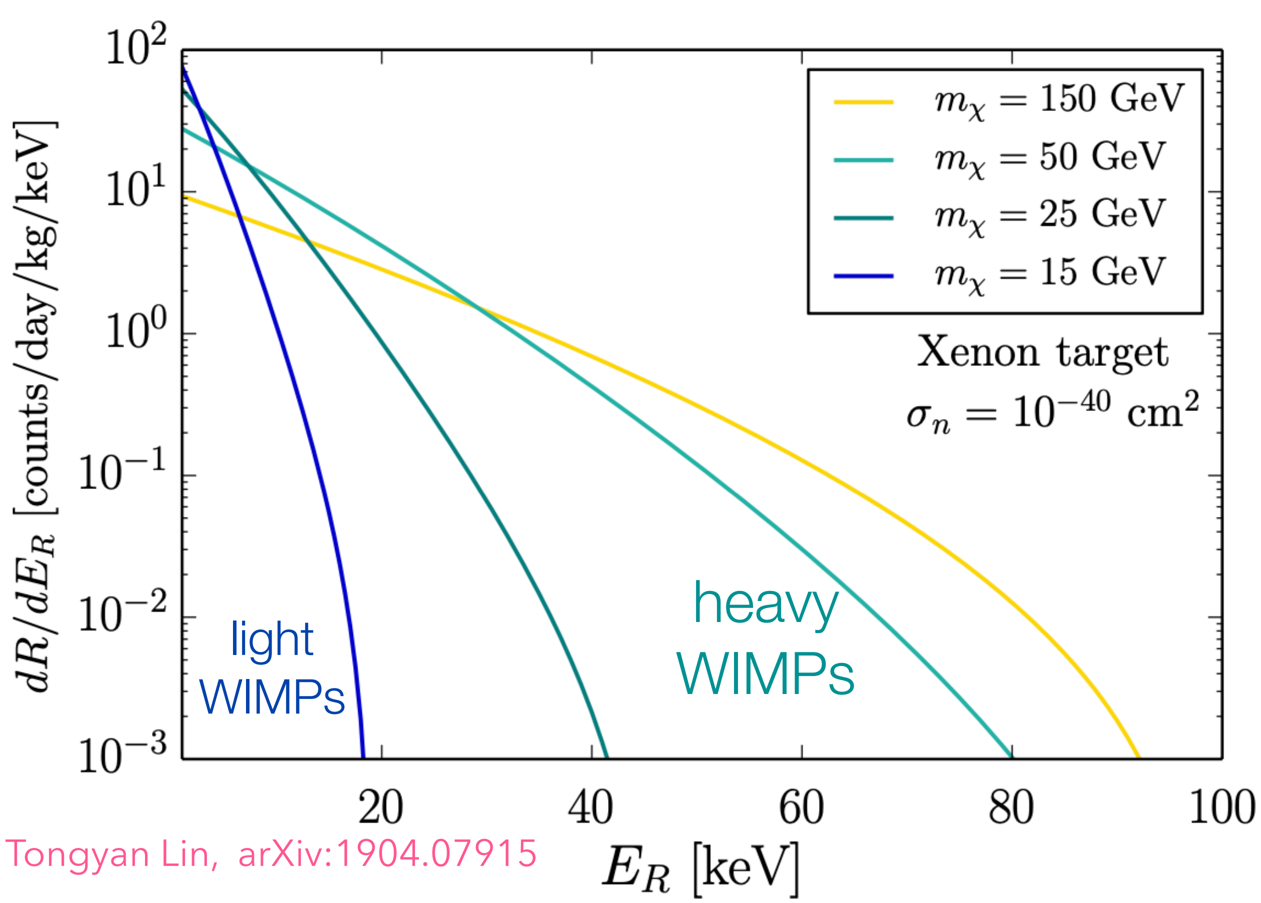
➡ with γ= angle between the recoil and the mean direction of solar motion



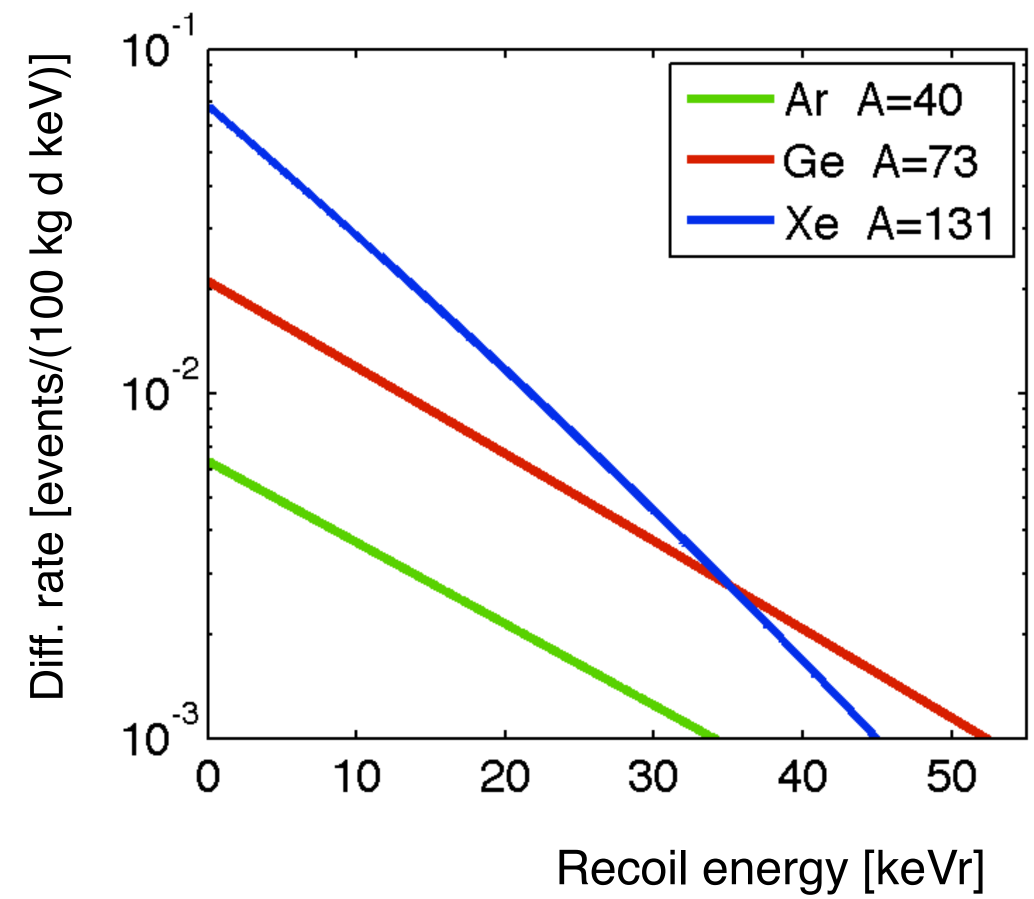
- The event rate in the forward direction is expected to be roughly one order of magnitude larger than the one on the backward direction; a detector capable of measuring the nuclear recoil momentum vector in 3-D (the axis and direction of the recoil, also called head-tail), with good angular resolution, needs a few tens of events to distinguish a WIMP from an isotropic background

Summary: Signal Characteristics of a WIMP

- A^2 - dependence of rates
- coherence loss (for q~μv ~ 1/r_n ~ 200 MeV)
- relative rates, for instance in Ge/Si, Ar/Xe,...
- dependance on WIMP mass
- time & directional dependence



Tongyan Lin, arXiv:1904.07915



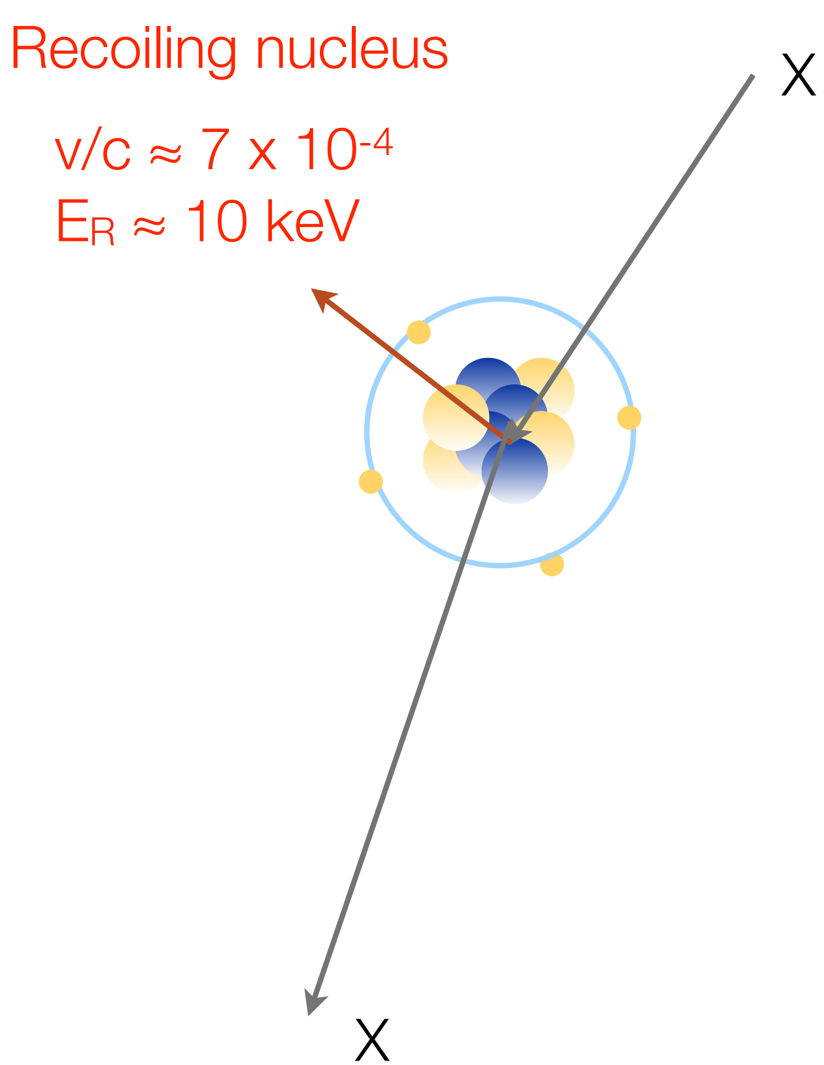
M_{WIMP} = 100 GeV
σ_{WN}=1×10^{-44} cm^2

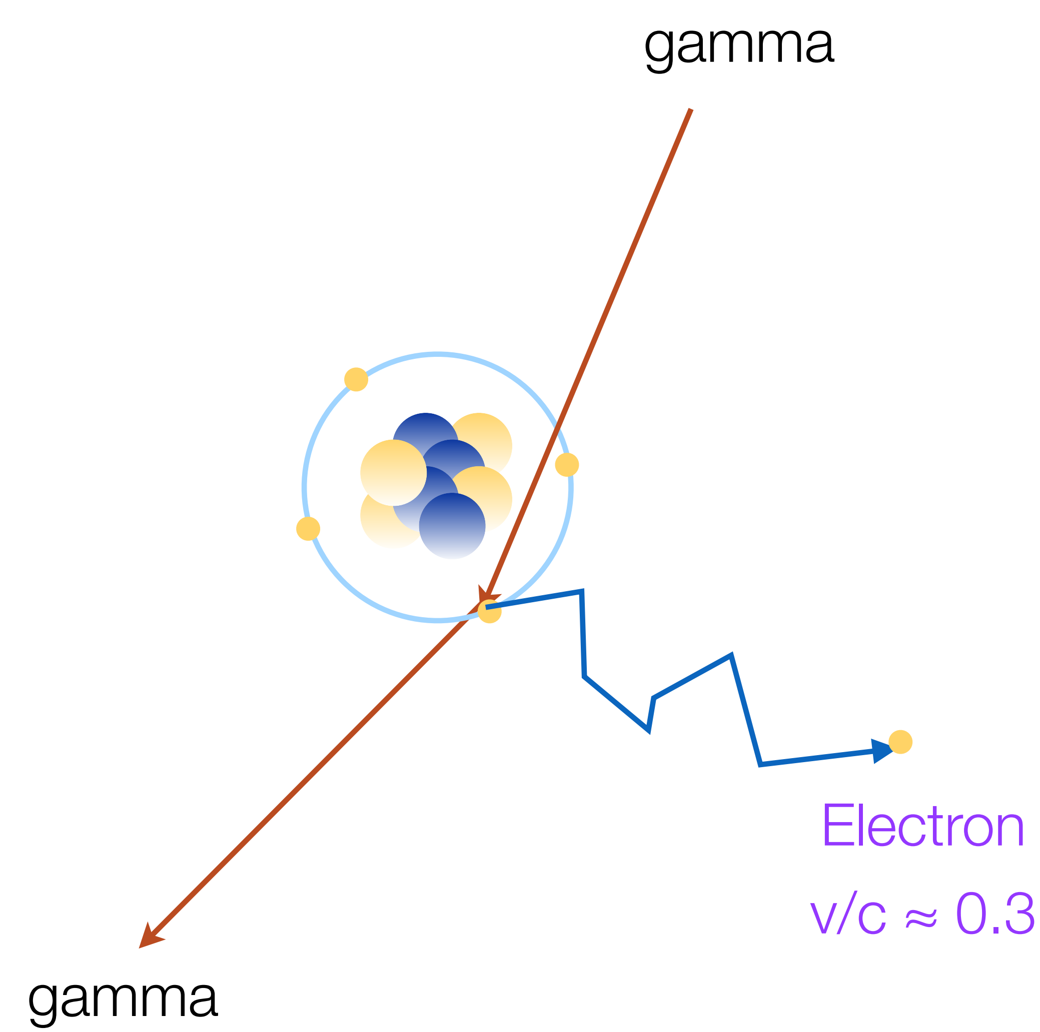
(Standard halo model with ρ= 0.3 GeV/cm^3)

Signal and Backgrounds

NRs:
DM particles
Fast neutrons
Neutrinos

ERs:
DM particles
Backgrounds (γ, β)
Neutrinos





Quenching Factor and Discrimination

- WIMPs, neutrons, neutrinos: scatter off nuclei
- LDM, background sources (γ, e^-), neutrinos: scatter off electrons
- Detectors have a different response to NRs than to ERs
- **Quenching factor (QF)** = describes the difference in the amount of visible energy (E_{vis}) in a detector for these two classes of events
  - keV_{ee} = measured signal from an electron recoil
  - keV_r = measured signal from a nuclear recoil

- **For nuclear recoil events:**

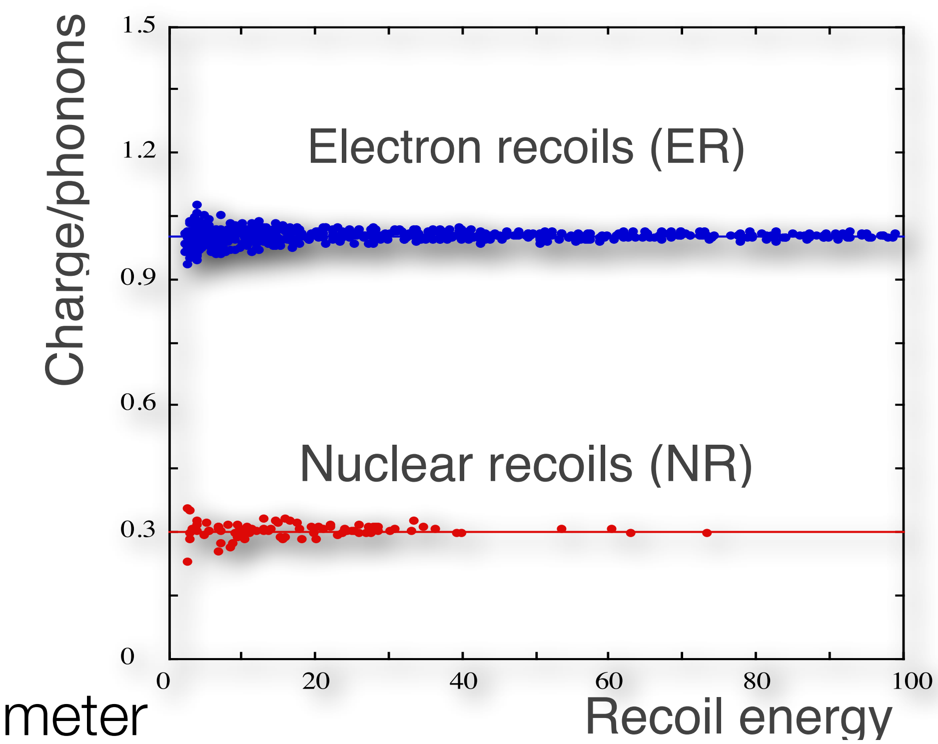
$$E_{vis}(\mathrm{keV_{ee}}) = QF \times E_R(\mathrm{keV_r})$$

- The two energy scales are calibrated with gamma & beta (^{3}H, ^{57}Co, ^{133}Ba, ^{137}Cs, ^{60}Co, ^{220}Rn, etc) and neutron (AmBe, ^{252}Cf, n-generators, etc) sources

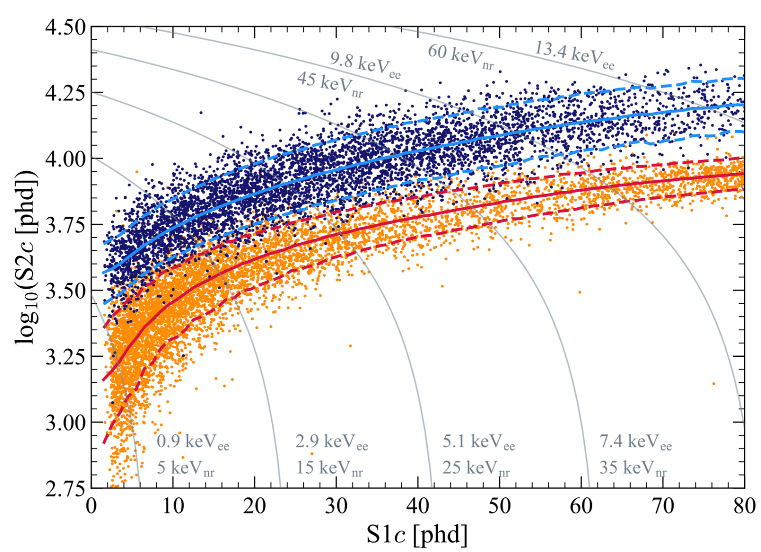
Quenching Factor and Discrimination

- The quenching factor allows to distinguish between electron and nuclear recoils if two simultaneous detection mechanisms are used

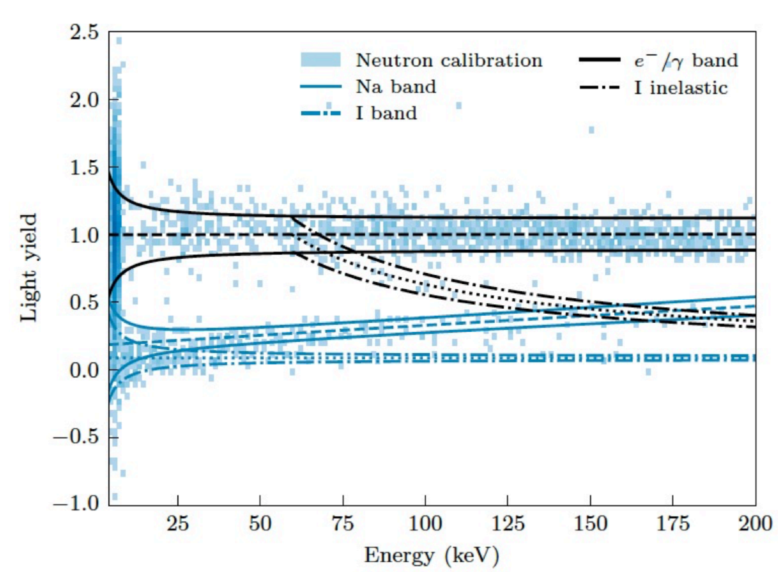
- Example:
  - ◉ charge and phonons in Ge
  - ◉ $E_{visible}$ ~ 1/3 E_{recoil} for nuclear recoils
  - ◉ QF ~ 30% in Ge



LXe TPCs

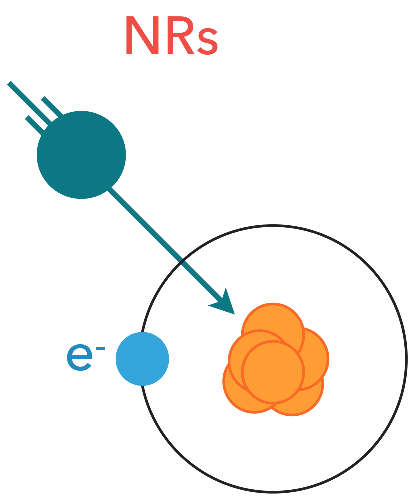


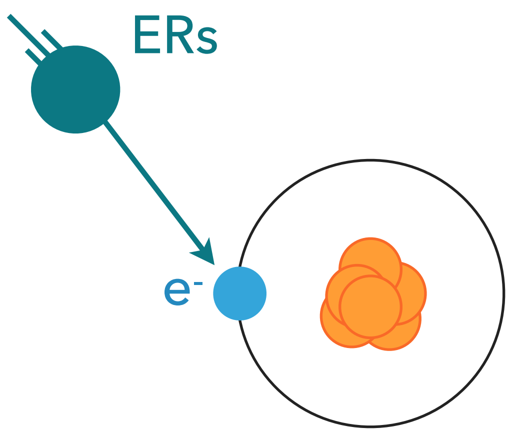
NaI bolometer

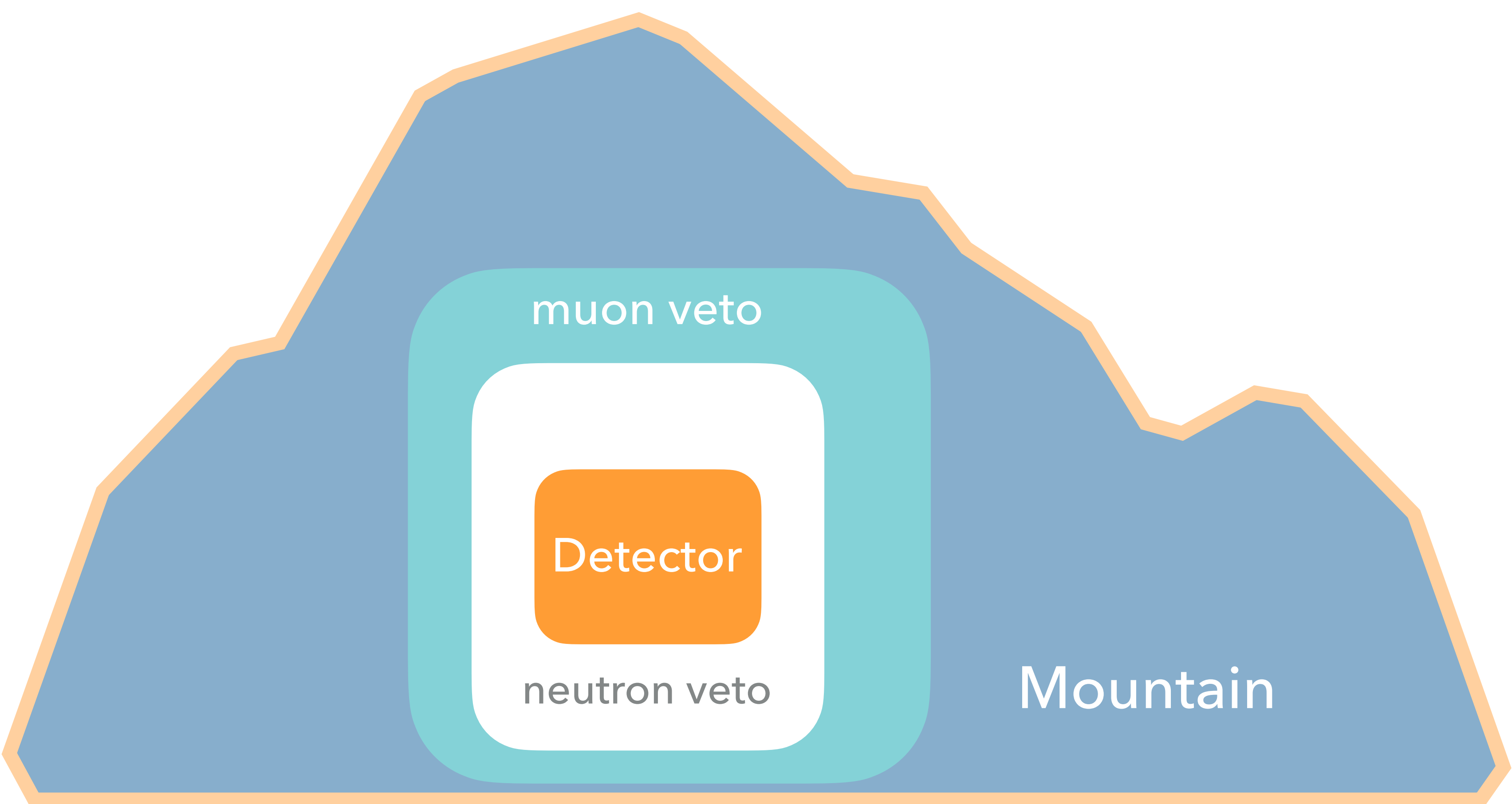


Backgrounds in DM Detectors: Overview

- Muon-induced neutrons: NRs
- Cosmogenic activation of materials/targets (^{3}H, ^{32}Si, ^{60}Co, ^{39}Ar): ERs
- Radioactivity of detector materials (n, γ, α, e^-): NRs and ERs
- Target intrinsic isotopes (^{85}Kr, ^{222}Rn, ^{136}Xe, ^{39}Ar, etc): ERs
- Neutrinos (solar, atmospheric, DSNB): NRs and ERs

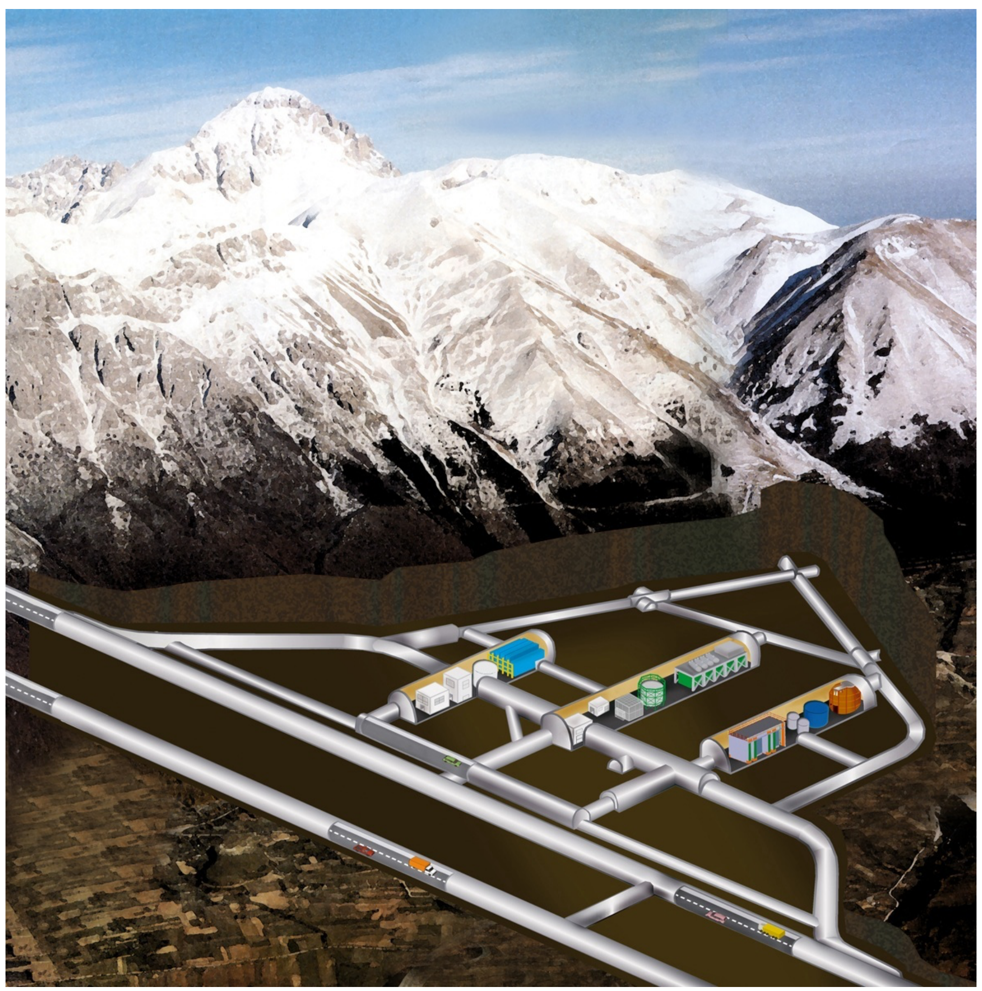




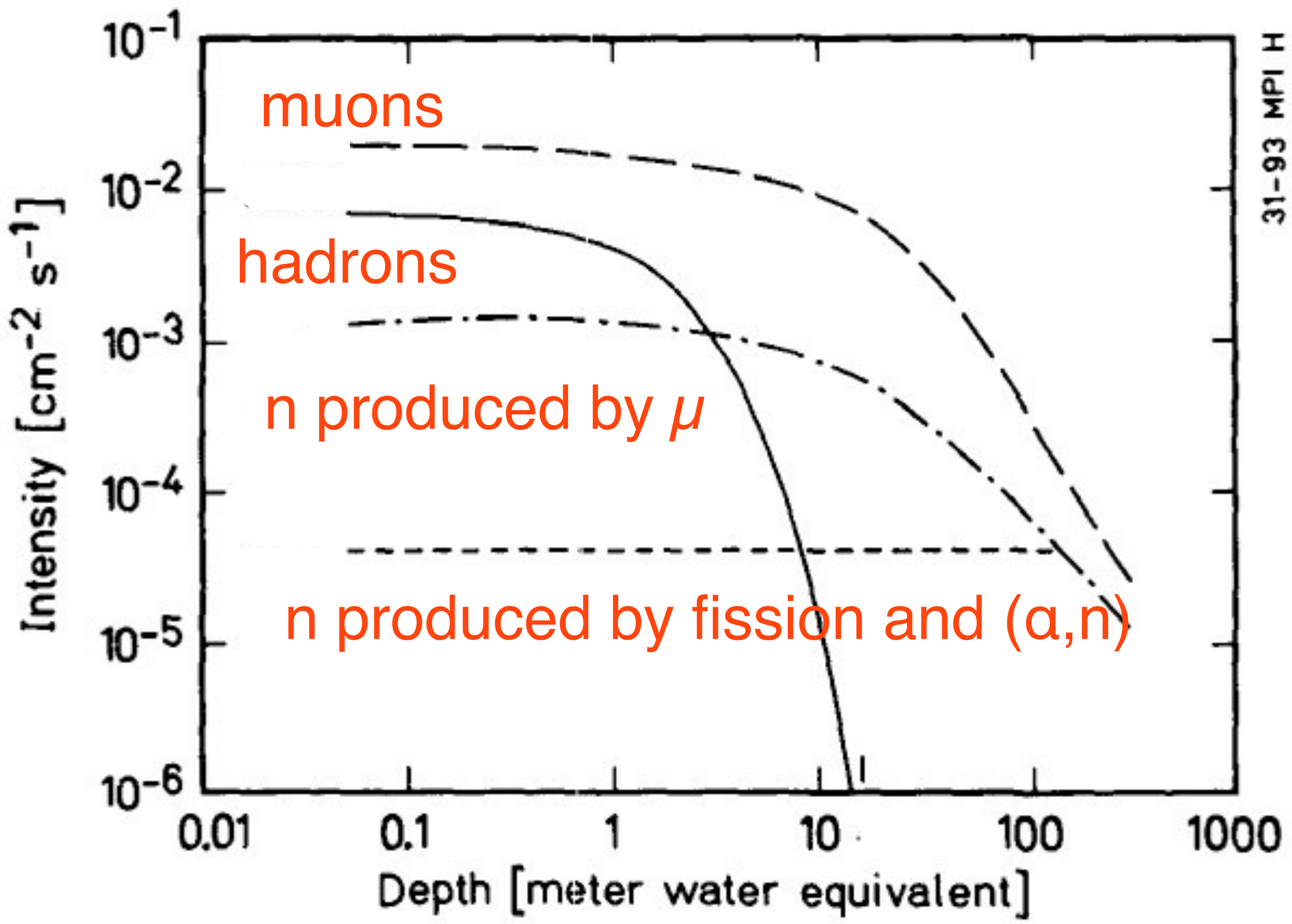


Backgrounds from cosmic rays

- Cosmic rays and secondary/tertiary particles: go underground
- Hadronic component (n, p): reduced by few meter water equivalent (m w. e.)

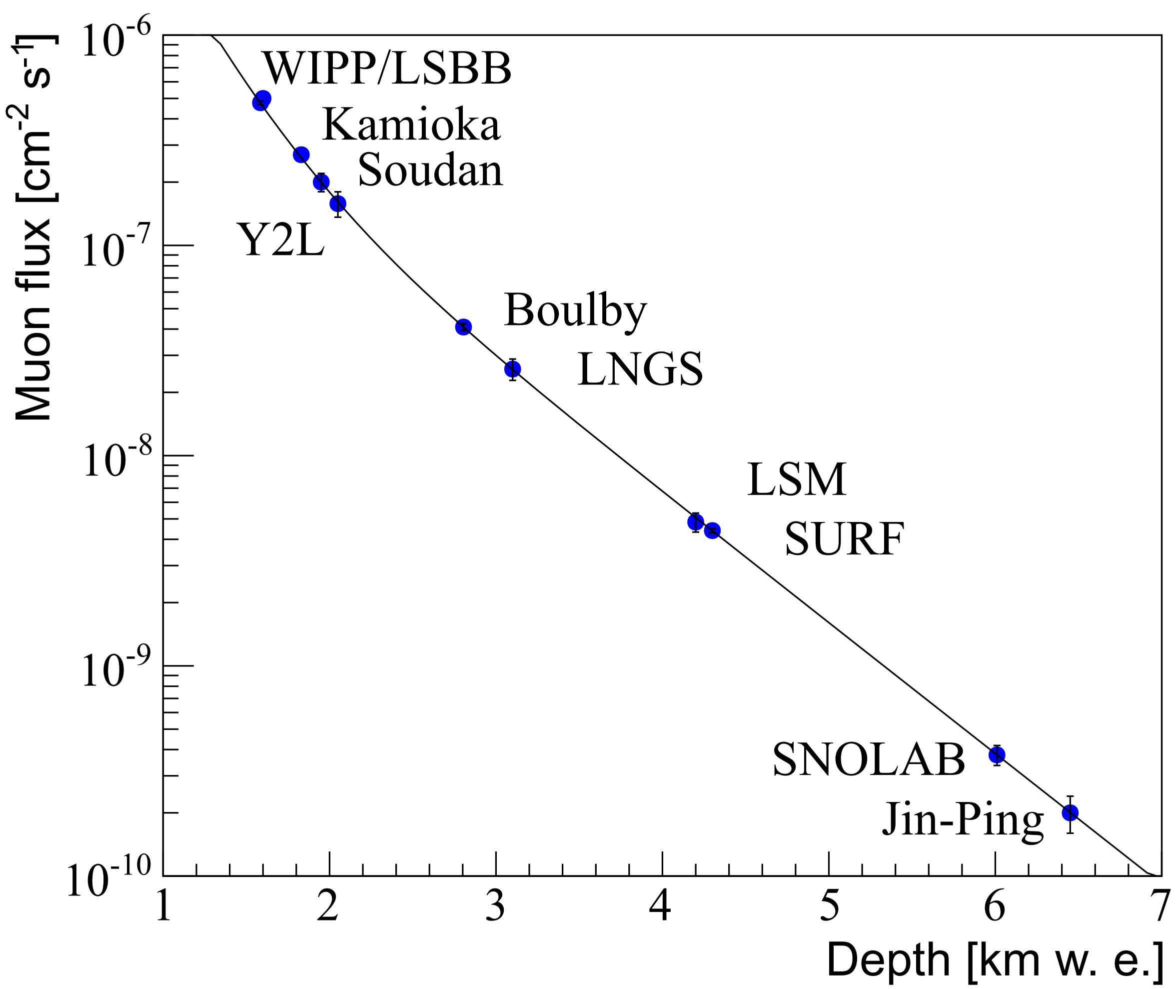


Flux of cosmic ray secondaries and tertiary-produced neutrons in a typical Pb shield vs shielding depth
Gerd Heusser, 1995



Backgrounds from cosmic rays

- **Most problematic:** muons and muon induced neutrons
  - ◉ go deep underground, several laboratories, worldwide



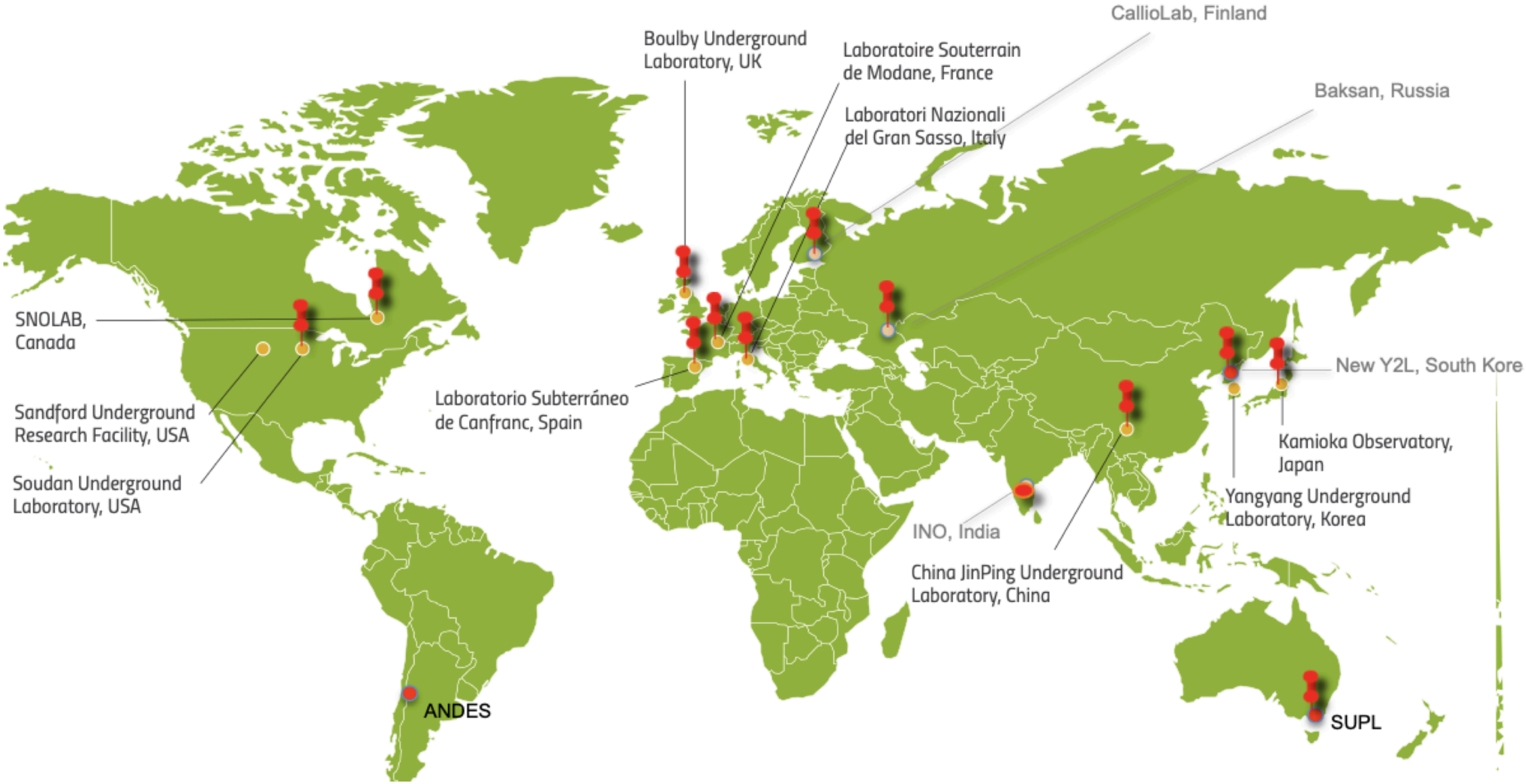
Site (multiple levels given in ft)	Relative muon flux	Relative neutron flux T > 10 MeV
WIPP (2130 ft) (1500 mwe)	× 65	× 45
Soudan (2070 mwe)	× 30	× 25
Kamioke	× 12	× 11
Boulby	× 4	× 4
Gran Sasso (3700 mwe) Frejus (4000 mwe) Homestake (4860 ft)	× 1	× 1
Mont Blanc	$\times 6^{-1}$	$\times 6^{-1}$
Sudbury	$\times 25^{-1}$	$\times 25^{-1}$
Homestake (8200 ft)	$\times 50^{-1}$	$\times 50^{-1}$

compiled by: R. Gaitskell

Backgrounds from cosmic rays

Aldo Ianni, SciPost Phys. Proc. 12, 007 (2023) ·

- **Overview of underground laboratories**



Backgrounds from radioactivity

- Radioactivity of surroundings
- Radioactivity of detector and shield materials

- Remember: activity of a source $A = \frac{dN}{dt} = -\lambda N$
- **Do you know?**

N = number of radioactive nuclei
λ = decay constant, $T_{1/2} = \ln 2/\lambda = \ln 2\ \tau$
[A] = Bq = 1 decay/s (1Ci = 3.7 x 10^{10} decays/s = A [1g pure ^{226}Ra])

1. how much radioactivity (in Bq) is in your body? where from?

1. 4000 Bq from ^{14}C, 4000 Bq from ^{40}K (e^- + 400 1.4 MeV γ + 8000 ν_e)

2. how many radon atoms escape per 1 m^2 of ground, per s?

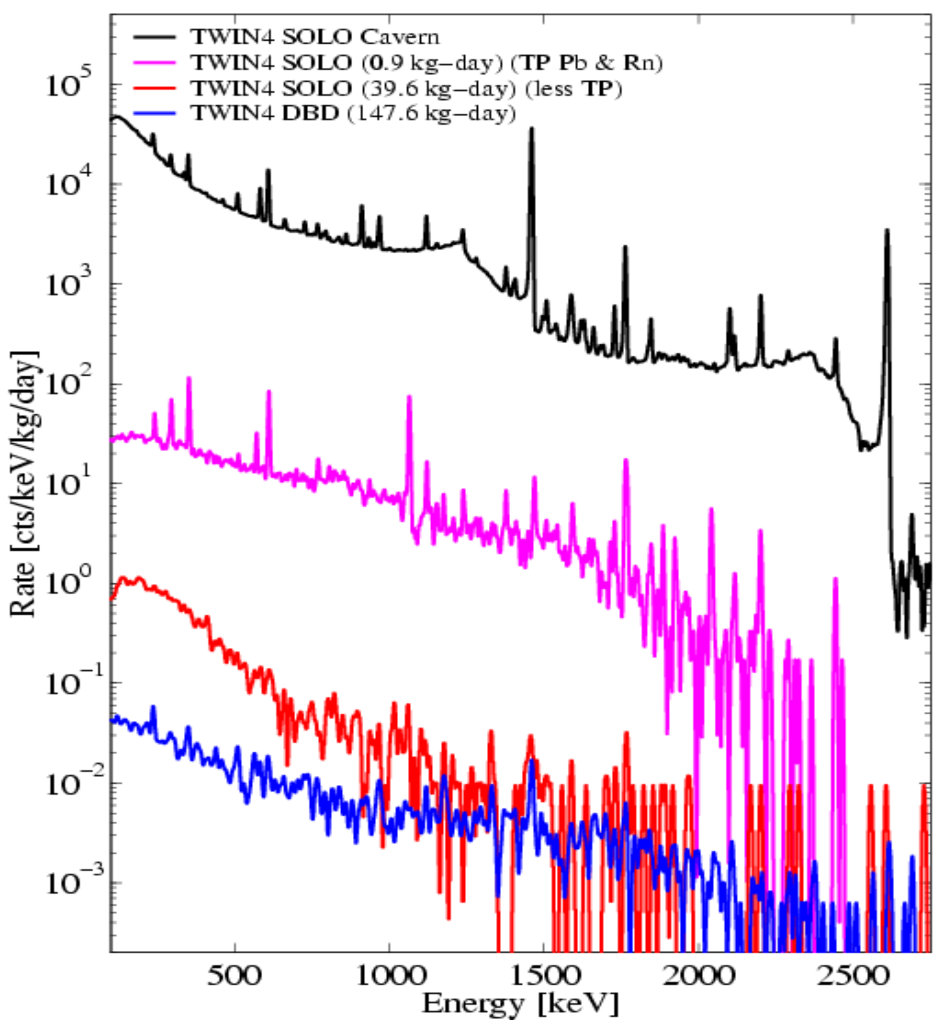
2. 7000 atoms/m^2 s

3. how many plutonium atoms you find in 1 kg of soil?

3. 10 millions (transmutation of ^{238}U by fast CR neutrons), soil: 1 - 3 mg U per kg

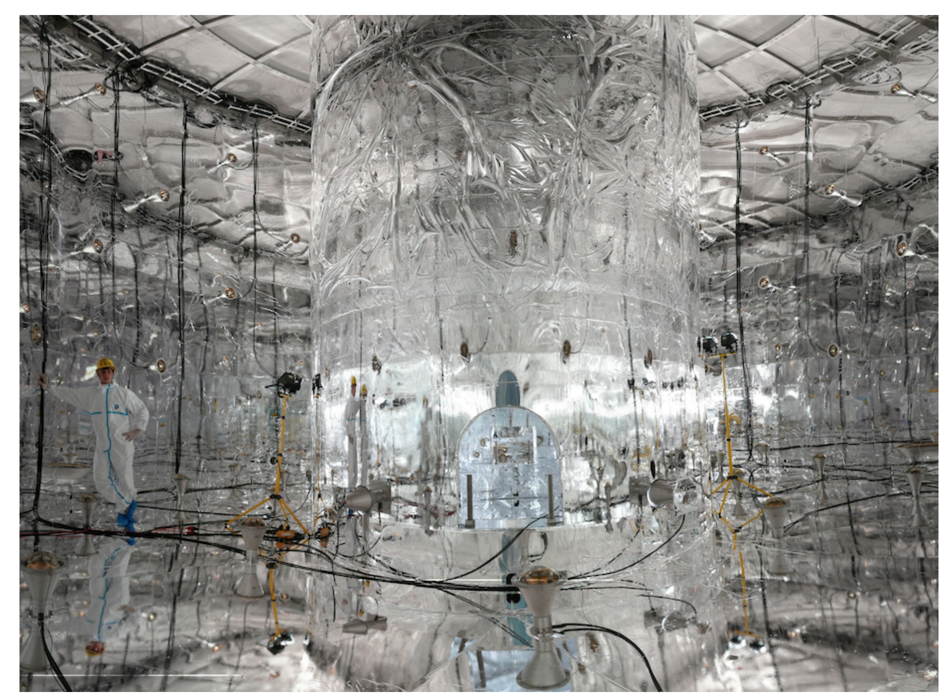
Backgrounds from radioactivity

- External, natural radioactivity: ^{238}U, ^{238}Th, ^{40}K decays in rock and concrete walls of the laboratory ⇒ mostly gammas and neutrons from (α,n) and fission reactions
- Radon decays in air:
  - ◉ passive shields: Pb against the gammas, polyethylene/water against neutrons
  - ◉ active shields: large water Cherenkov detectors or scintillators for gammas and neutrons



Ge detector underground, no shield

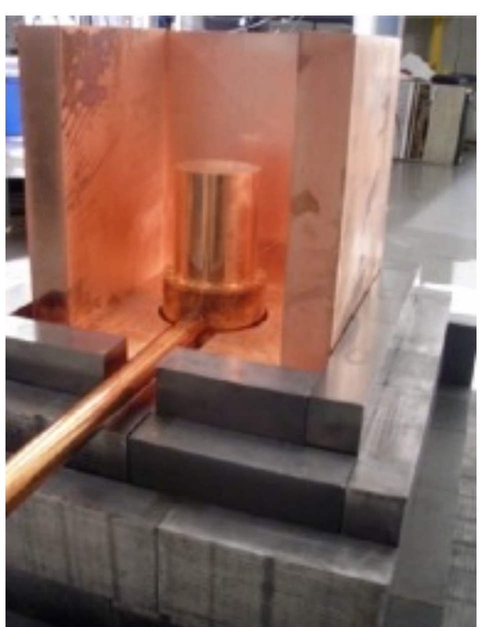
Ge detector underground, Pb shield and purge for Rn



◉ Example for an active shields

Backgrounds from radioactivity

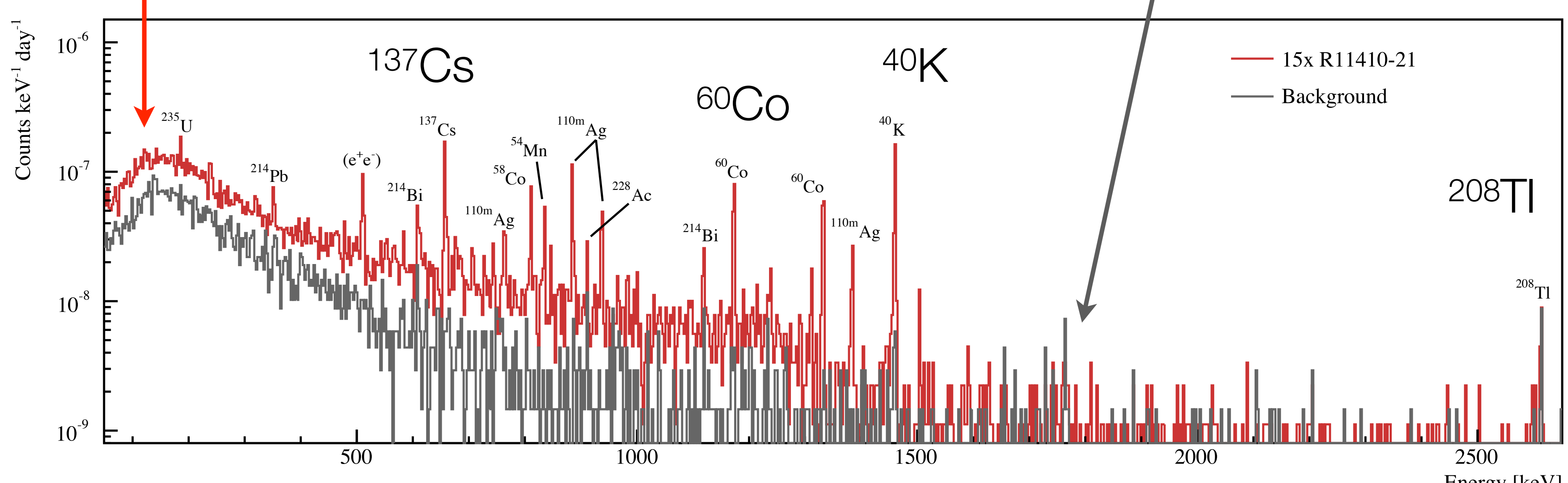
- **Internal radioactivity:**
  - ^{238}U, ^{238}Th, ^{40}K, ^{137}Cs, ^{60}Co, ^{39}Ar, ^{85}Kr, ... decays in the detector materials, target medium and shields
  - Ultra-pure Ge spectrometers (as well as other methods) are used to screen the materials before using them in a detector, down to parts-per-billion (ppb) (or lower) levels



PMT sample

$^{226}Ra/^{228}Th$:
~1 mBq/PMT

HPGe detector
background

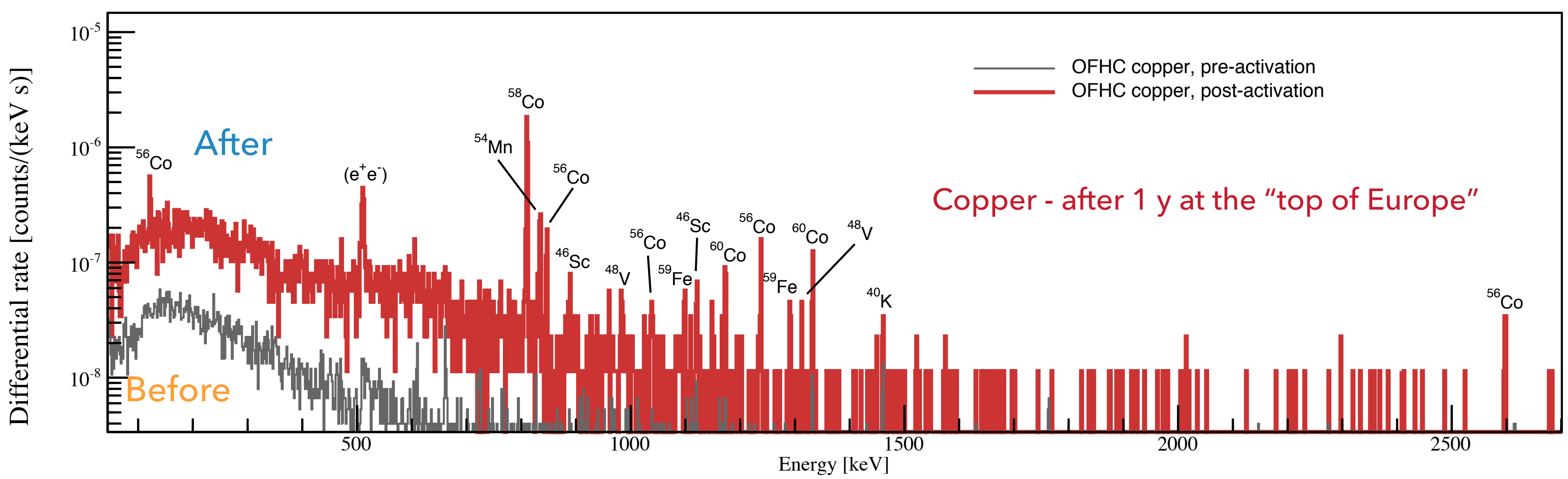


XENON collaboration, arXiv:1503.07698v1

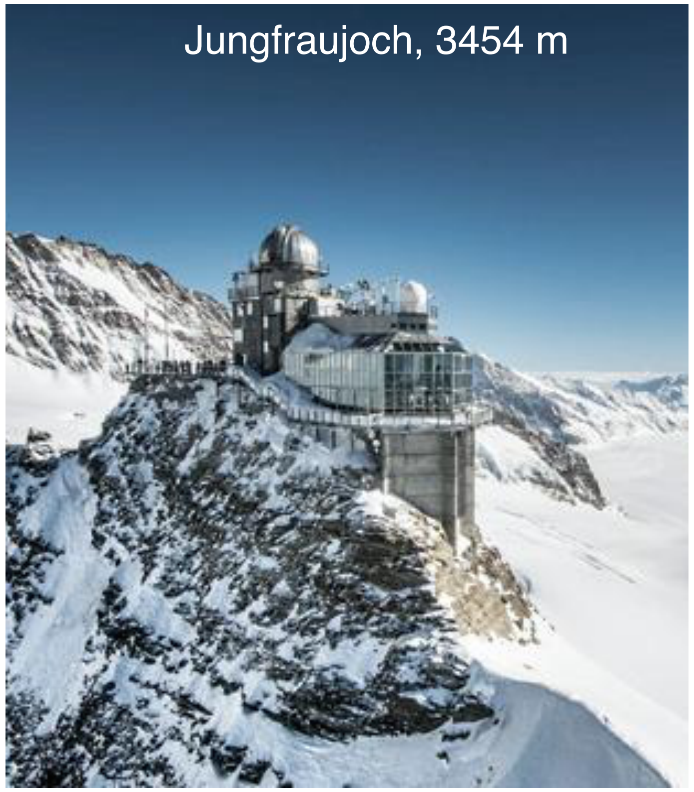
Cosmogenic backgrounds

- Activation of detector and other materials during production and transportation at the Earth's surface

LB et al., Eur. Phys. J. C75 2015



Isotope	$T_{1/2}$ [days]	Copper: specific saturation activity at sea level A_{sat} [μBq/kg]		
		This work		
		Measurement	Calculations	
			Activia	Cosmo
^{46}Sc	83.79	27^{+11}_{-9}	36	17
^{48}V	15.97	39^{+19}_{-15}	34	36
^{54}Mn	312.12	154^{+35}_{-34}	166	156
^{59}Fe	44.50	47^{+16}_{-14}	49	50
^{56}Co	77.24	108^{+14}_{-16}	101	*81*
^{57}Co	271.74	519^{+100}_{-95}	*376*	*350*
^{58}Co	70.86	798^{+62}_{-58}	*656*	*632*
^{60}Co	1925.28	340^{+82}_{-68}	304	297



Cosmogenic backgrounds

- **Activation of detector and other materials during production and transportation at the Earth's surface. A precise calculation requires:**
  - ◉ cosmic ray spectrum (varies with geomagnetic latitude)
  - ◉ cross section for the production of isotopes (only few are directly measured)
- production is dominated by (n,x) reactions (95%) and (p,x) reactions (5%)

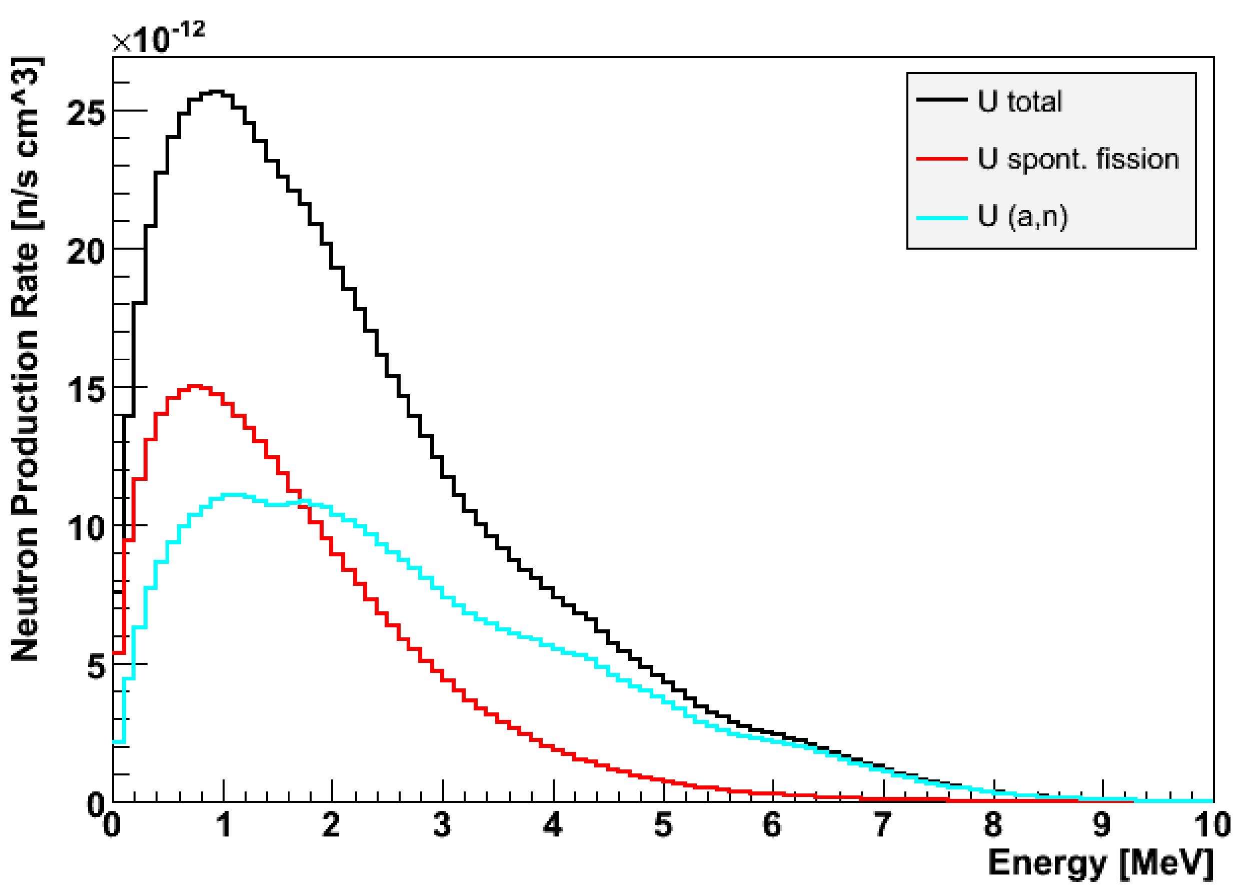
production in Ge after 30d exposure at the Earth's surface and 1 yr storage below ground

Isotope	**Decay**	**Half life**	**Energy in Ge [keV]**	**Activity [μBq/kg]**
^{3}H	β^-	12.33 yr	$E_{max(\beta-)}$=18.6	2
^{49}V	EC	330 d	$E_{K(Ti)}$ = 5	1.6
^{54}Mn	EC, β^+	312 d	$E_{K(Cr)}$ = 5.4, E_γ=841	0.95
^{55}Fe	EC	2.7 yr	$E_{K(Mn)}$ = 6	0.66
^{57}Co	EC	272 d	$E_{K(Fe)}$=6.4, E_γ=128	1.3
^{60}Co	β^-	5.3 yr	$E_{max(\beta-)}$=318, E_γ=1173,1333	0.2
^{63}Ni	β^-	100 yr	$E_{max(\beta-)}$=67	0.009
^{65}Zn	EC, β^+	244 d	$E^{K(Cu)}$ = 9, E_γ=1125	9.2
^{68}Ge	EC	271 d	$E_{K(Ga)}$ = 10.4	172

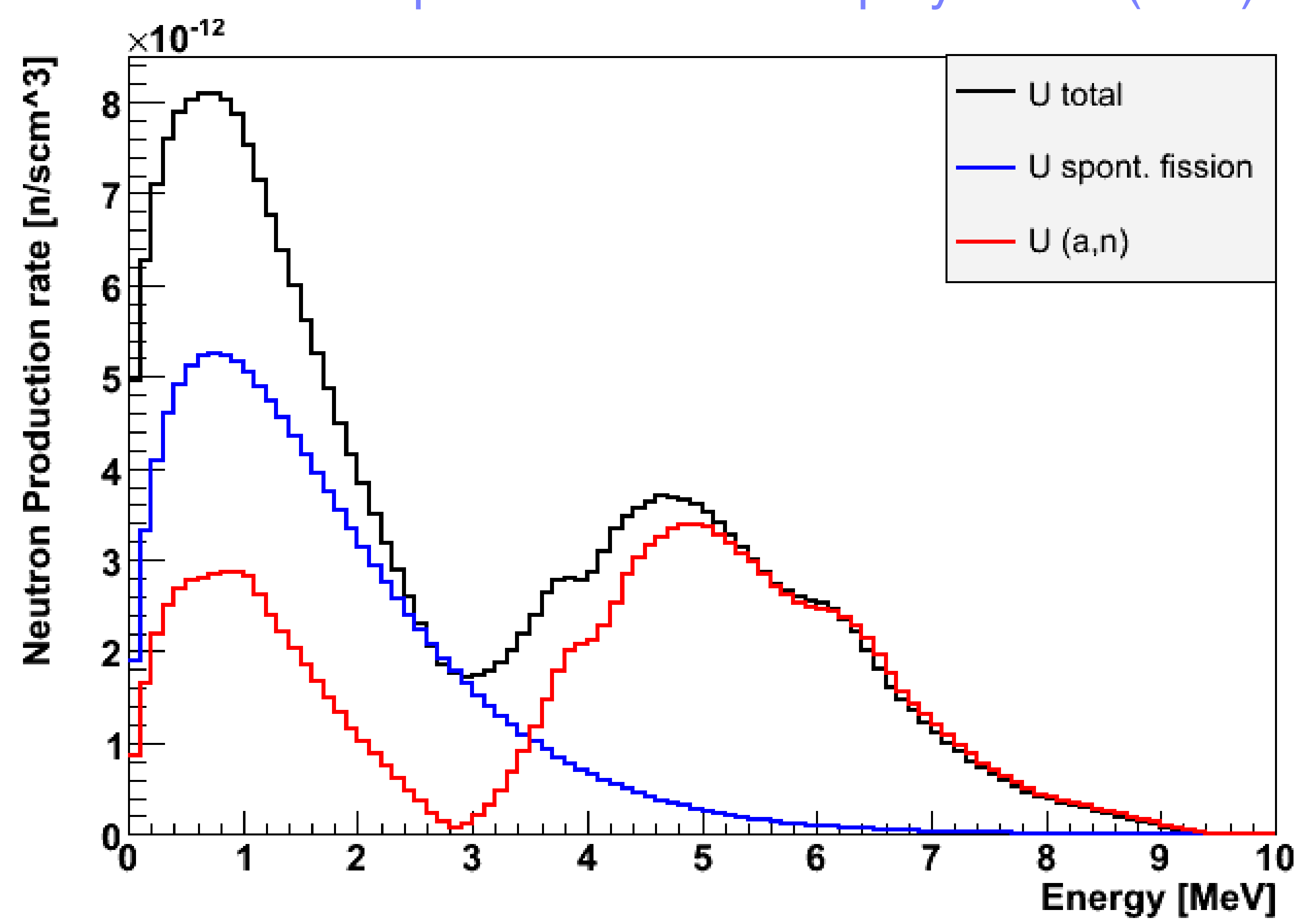
Neutron backgrounds

- MeV neutrons can mimic WIMPs by elastically scattering from the target nuclei
- the rates of neutrons from detector materials and rock are calculated taking into account the exact material composition, the α energies and cross sections for (α,n) and fission reactions and the measured U/Th contents

Example: neutrons from rock (^{238}U)



Example: neutrons from poly shield (^{238}U)

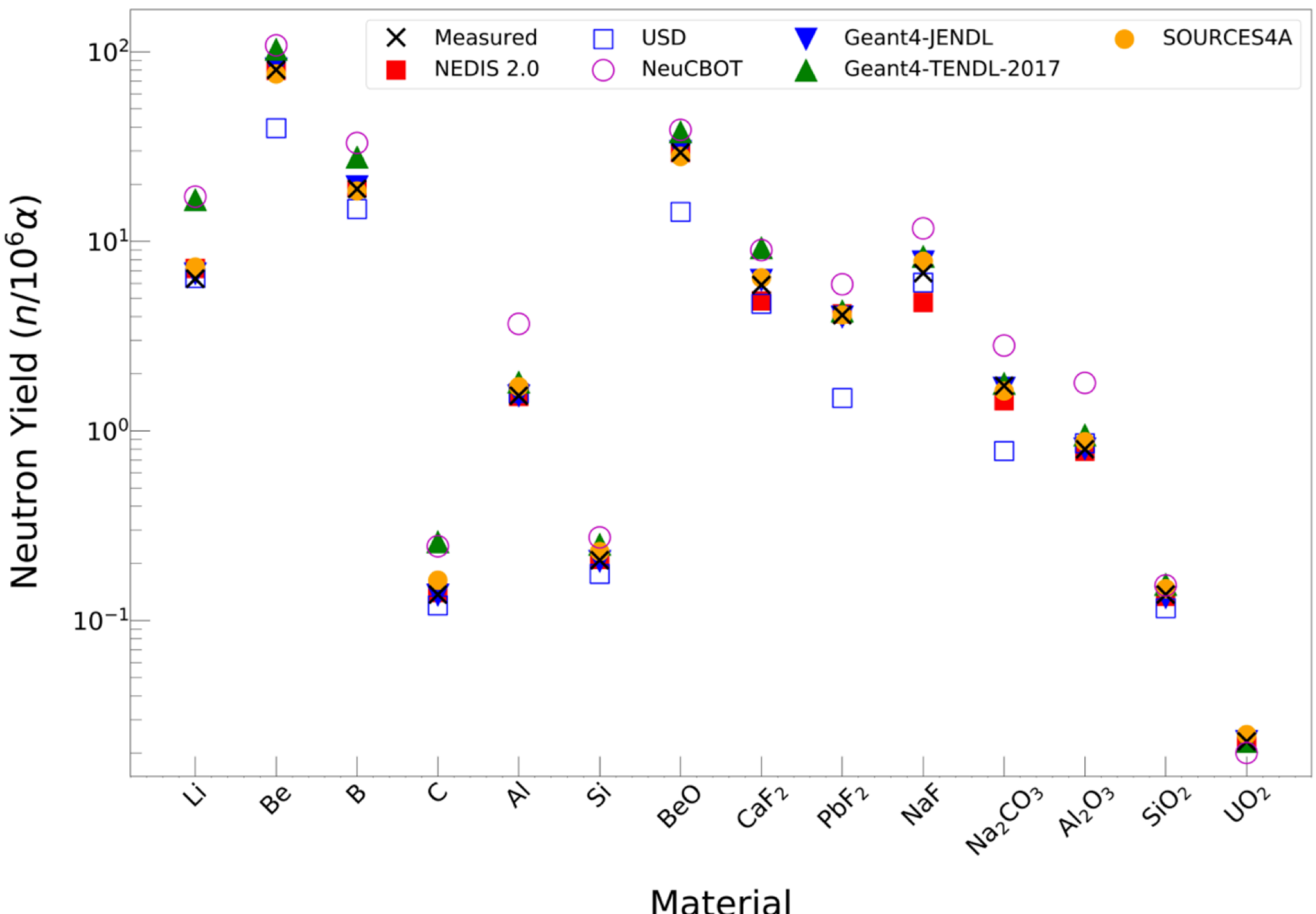


Codes: SOURCES4a, TALYS1.9, Geant4

Neutron backgrounds

- Comparison among different codes

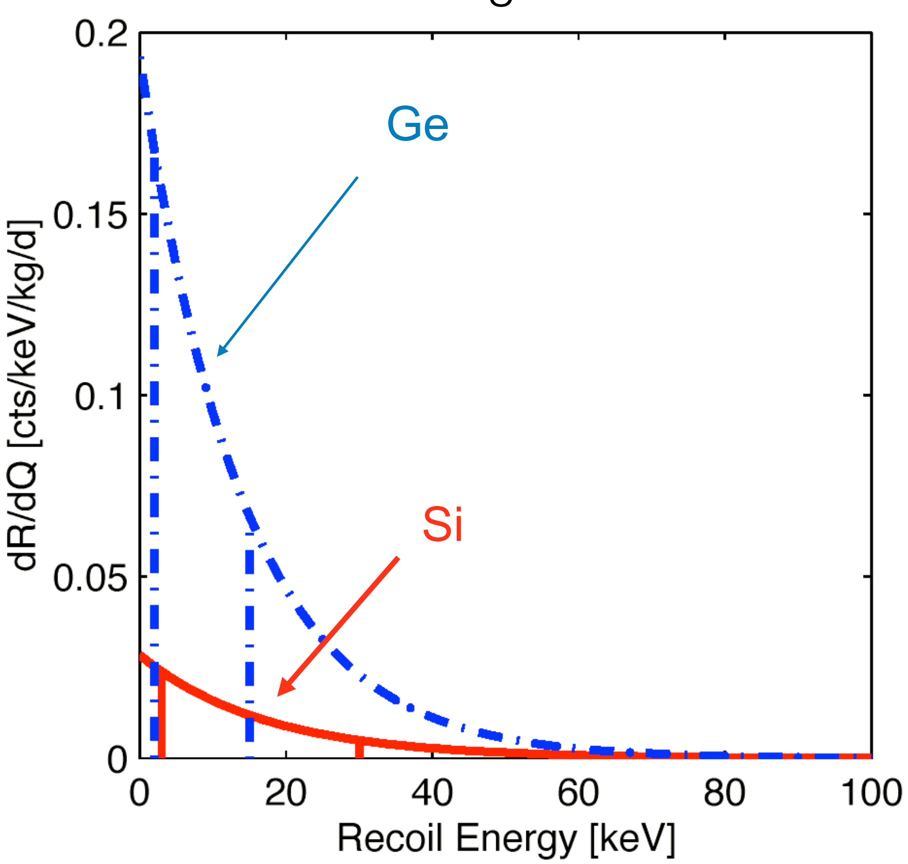
Vitaly A. Kudryavtsev, et al., SciPost Phys. Proc. 12, 018 (2023)



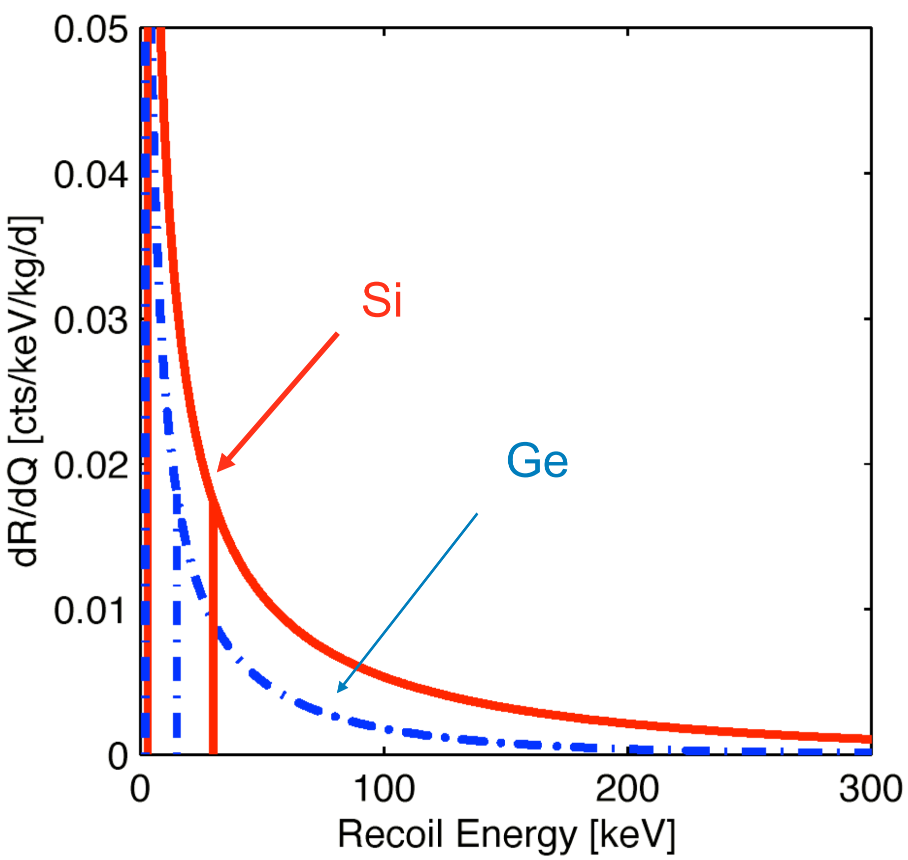
Neutrons: how can we distinguish them from WIMPs?

- mean free path of few cm (neutrons) versus 10^{10} m (WIMP)
- if n-capture ⇒ distinctive signature (can be tagged with dedicated neutron vetoes)
- material dependence of differential recoil spectrum
- time dependence of WIMP signal (if n-background is measured to be constant in time)

WIMP signal ~ A^2



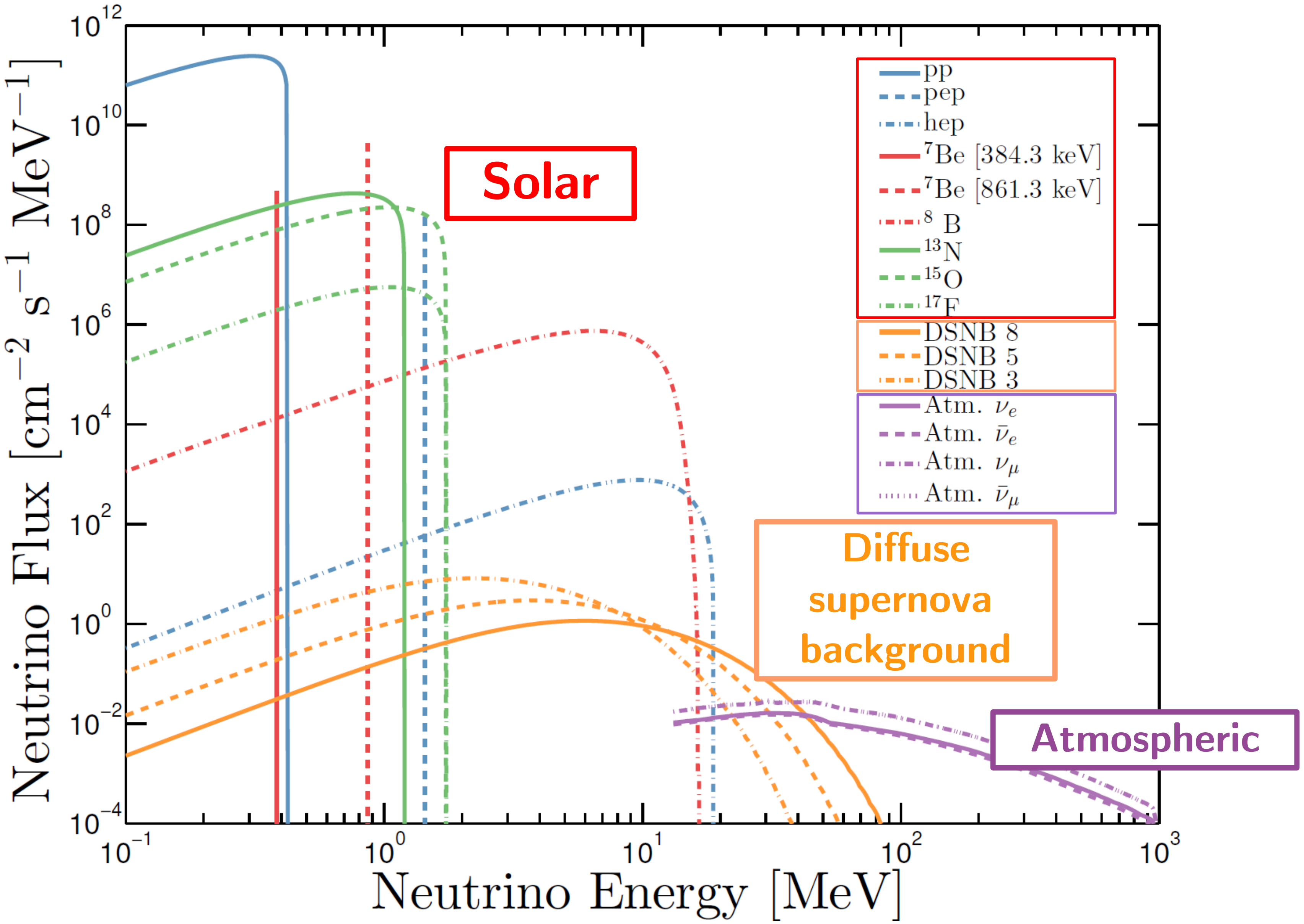
WIMPs, M_χ = 40 GeV



Background neutrons

Neutrino backgrounds

- Neutrino sources for DM detectors: solar, atmospheric, DSNB



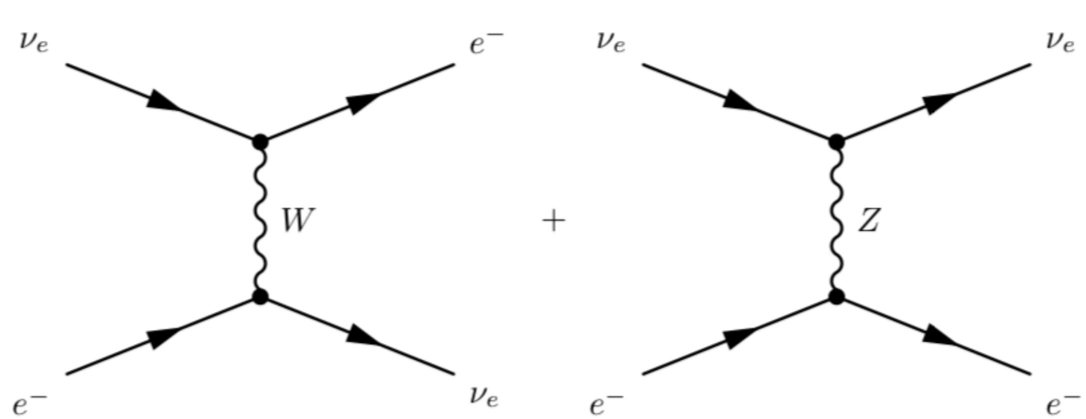
F. Ruppin et al., 1408.3581, PRD 90, 2015

Neutrino backgrounds

- Interactions: neutrino-electron and neutrino-nucleus scatters

ERs

$$\nu_x + e^- \rightarrow \nu_x + e^-$$

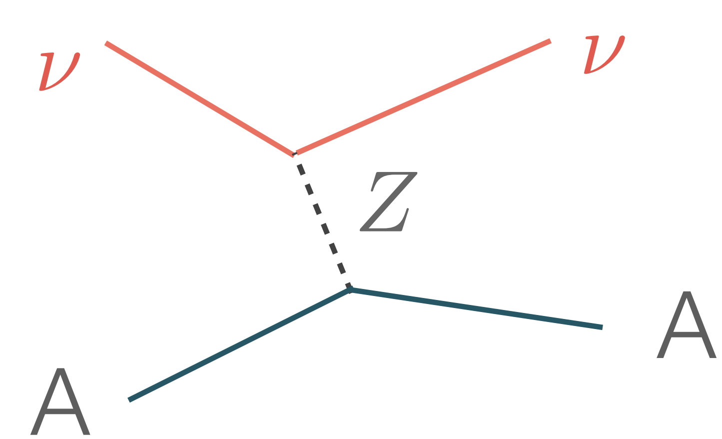


- ν_e interactions: CC & NC
- ν_μ and ν_τ interactions: only via NC

($\sigma_{tot} \approx 10^{-43}$ cm^2, solar ν have low energies and the CC reactions involving ν_μ and ν_τ are kinematically not allowed)

NRs

$$\nu_x + A \rightarrow \nu_x + A$$

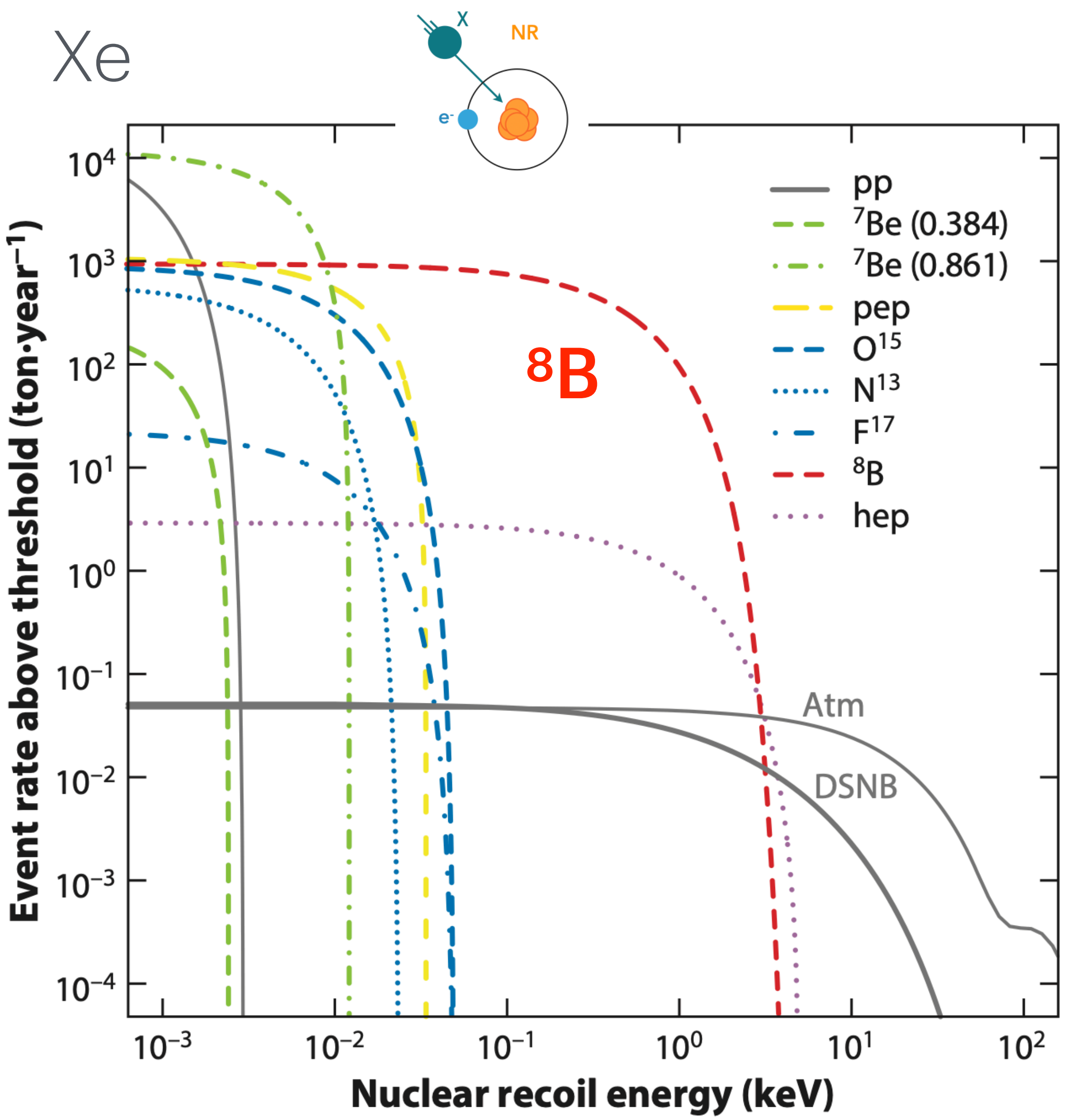


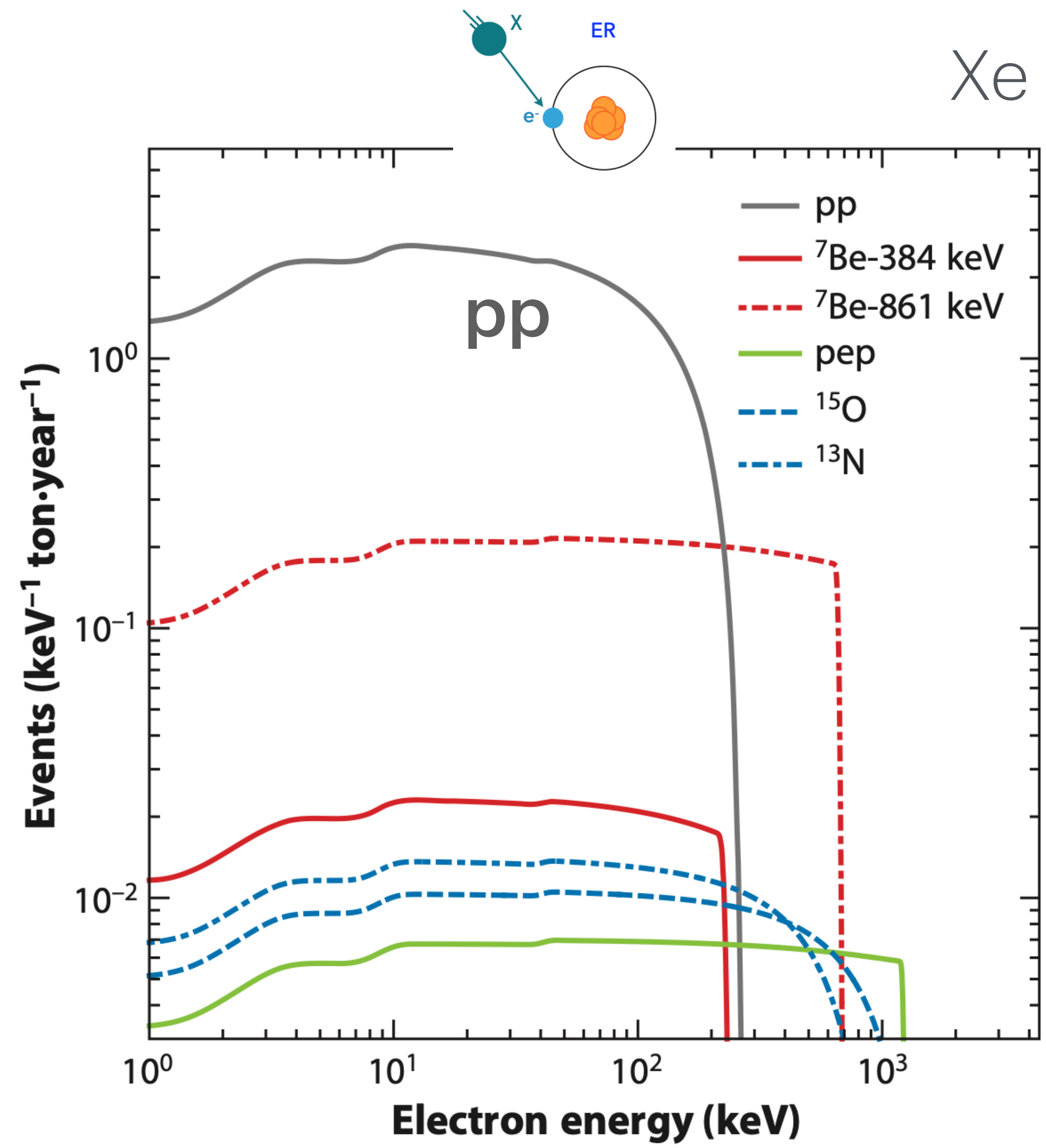
$$\frac{d\sigma(E_\nu, E_r)}{dE_r} = \frac{G_f^2}{4\pi} Q_\omega^2 m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) F_{SI}^2(E_r)$$

$$Q_\omega = N - (1 - 4\sin^2\theta_\omega)Z$$

Solar neutrinos

- ^{8}B neutrinos: NRs (CEvNS), ERs (elastic scattering)





B. Dutta, E. Strigari, Annu. Rev. Nucl. Part. Sci. 2019

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Solar neutrinos

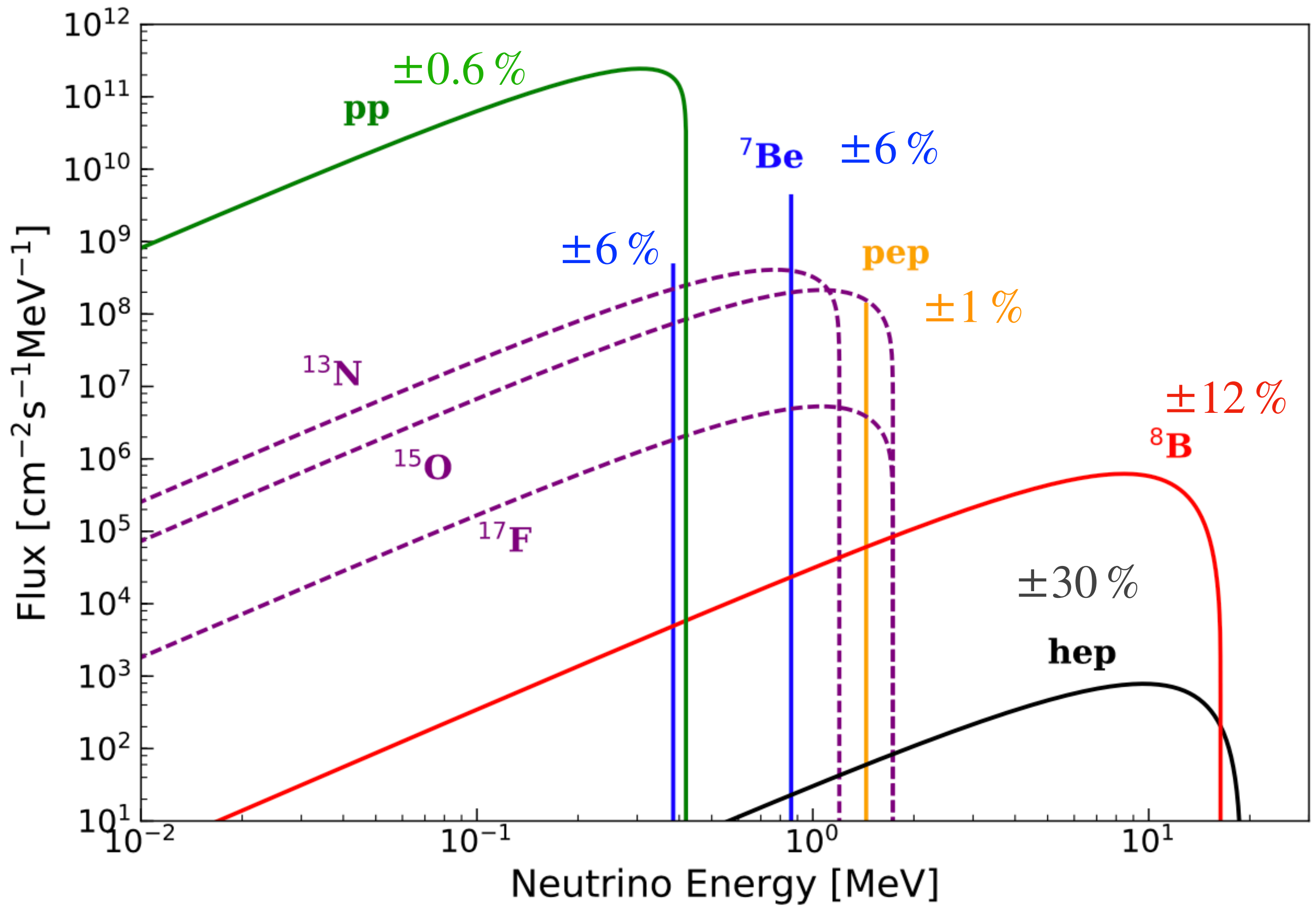

Table 1 The characteristic values of the flux scales [50], their relative uncertainties, the maximum neutrino energies, and the MSW-LMA ν_e survival probability [51] used in this study

Component	$\Phi\,(\mathrm{cm}^{-2}\mathrm{s}^{-1})$	σ (%)	Q(keV)	P_{ee}
pp	5.98×10^{10}	0.6	420	0.55
^{7}Be	4.93×10^{9}	6	862, 384	0.52
^{13}N	2.78×10^{8}	15	1200	0.52
^{15}O	2.05×10^{8}	18	1732	0.50
pep	1.44×10^{8}	1	1442	0.50

$$\frac{dR}{dT} = N_e \int \frac{d\Phi}{dE_\nu}\left(P_{ee}\frac{d\sigma_e}{dT} + (1 - P_{ee})\frac{d\sigma_{\nu,\tau}}{dT}\right) dE_\nu$$

$$\frac{d\Phi}{dE_\nu} = \Phi_i (Q_i + m_e - E_\nu)[(Q_i + m_e - E_\nu)^2 - m_e^2]^{\frac{1}{2}} E_\nu^2$$

Flux scale

Maximum energy

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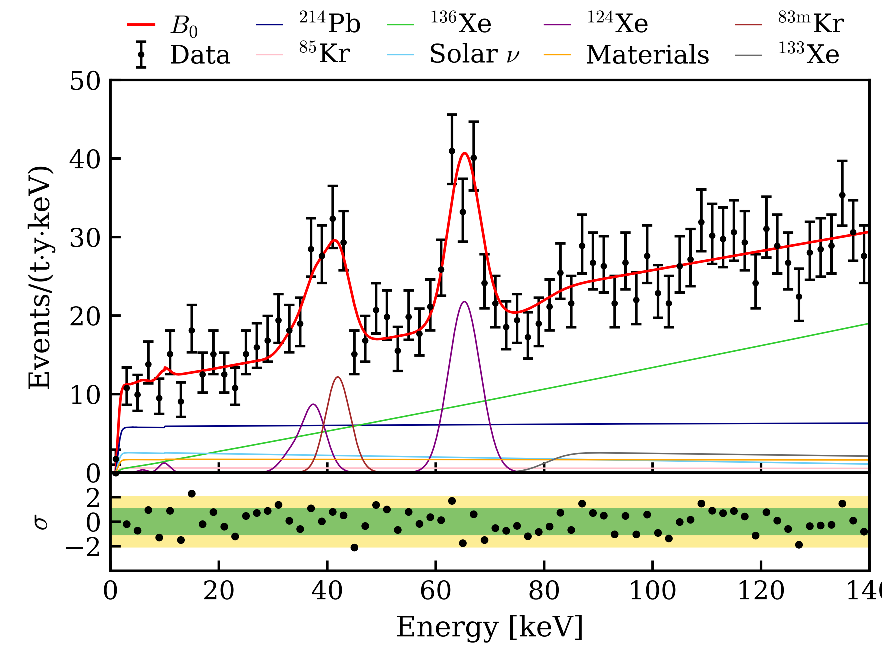
Solar neutrino electron scattering

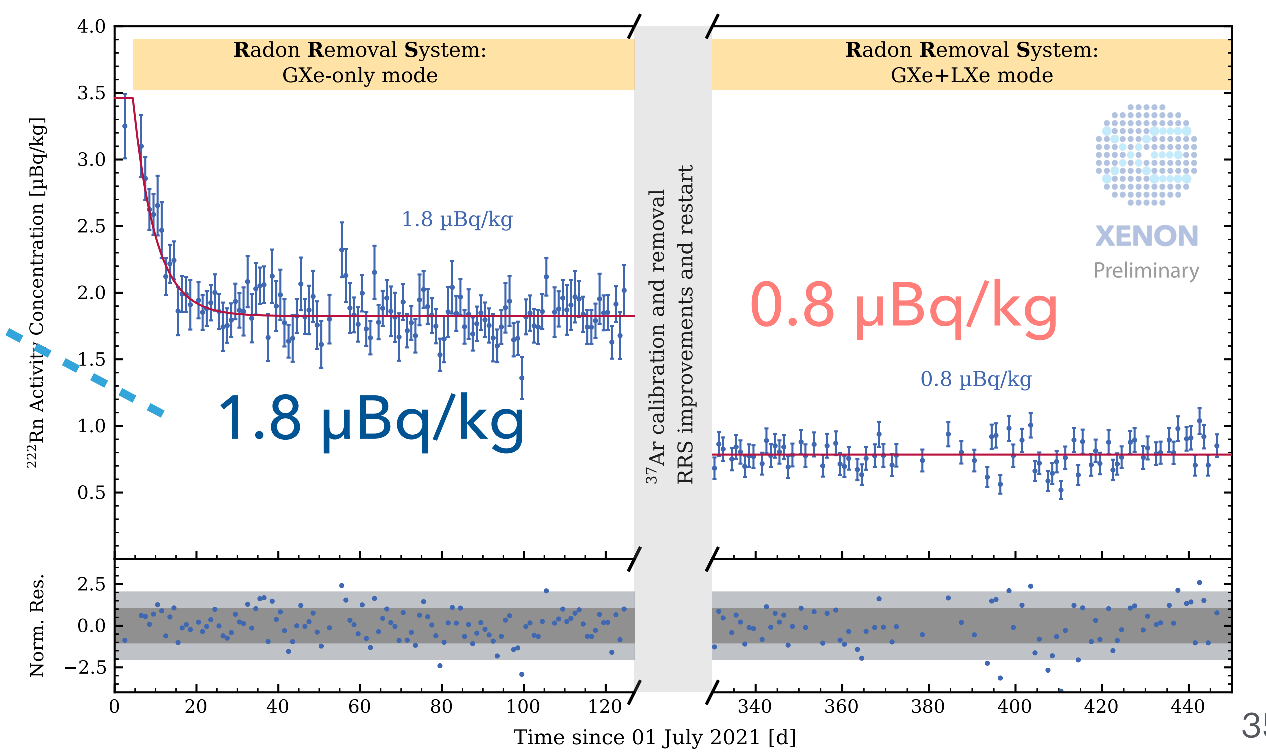
- Already starting to dominate the low-energy ER background in liquid xenon detectors
- In LXe: ~ 365 events/(t y) from pp ν and 140 events/(t y) from ^{7}Be ν

XENON collaboration, PRL 129, 2022



Example: XENONnT backgrounds, SR0

Component	(1,10) keV
^{214}Pb	**56±7**
^{85}Kr	6±4
Materials	16±3
Solar ν	**25±2**
^{124}Xe	2.6±0.3
^{136}Xe	8.7±0.3
Accidentals	0.7±0.03



XENONnT: Rn concentration reduced for SR1

Remarks on CEνNS

- Proposed almost 50 years ago (Daniel Z. Freedman PRD 9, March 1974)
  - Observed by COHERENT (CsI, LAr & Ge detectors), 43 y later, with ν's from πDAR
  - **Never observed on xenon & never observed using wild neutrinos**
  - For ^{8}B solar neutrinos, the process is fully coherent (even for heavy nuclei)

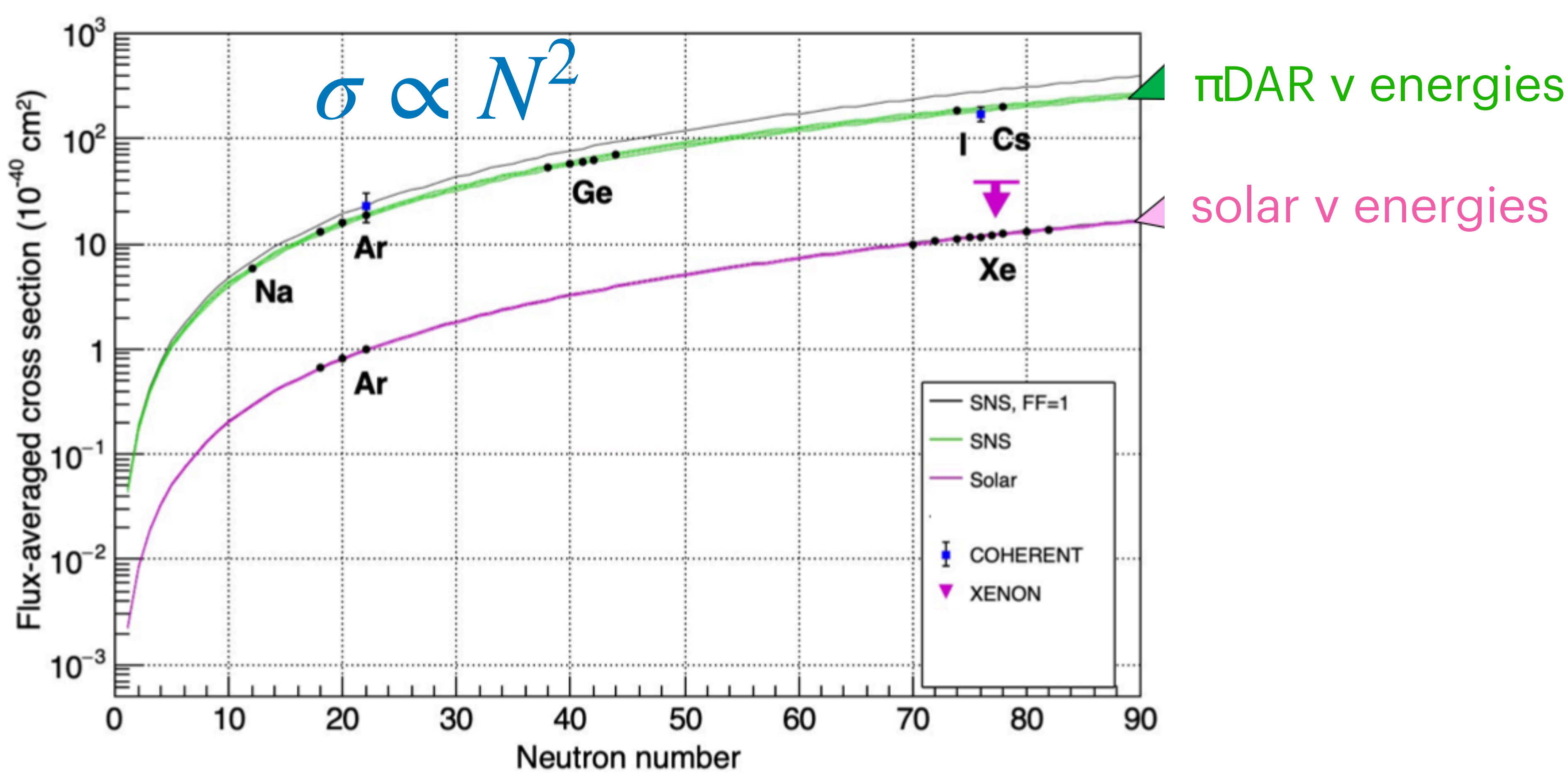
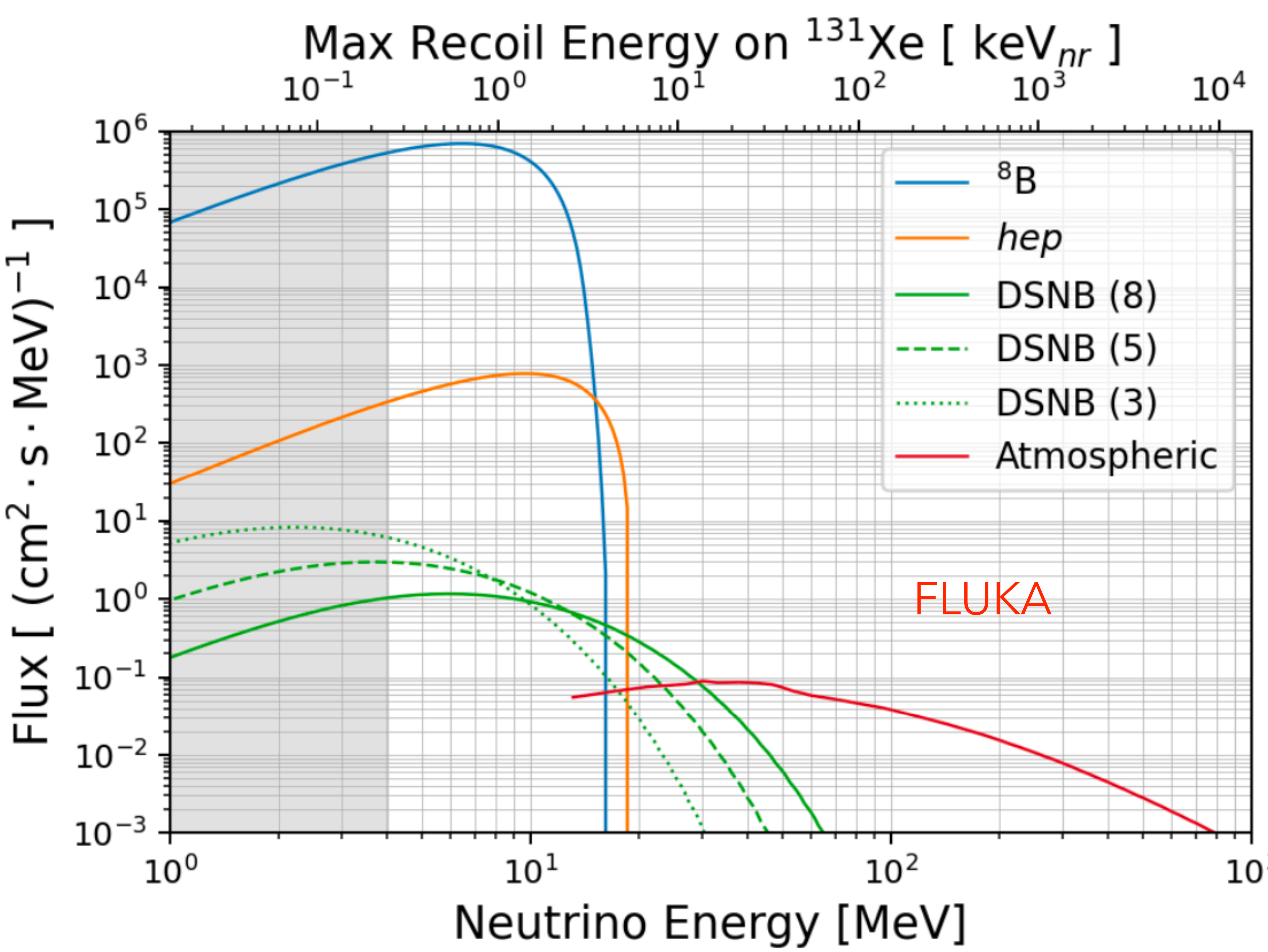


Figure by Kate Scholberg

Remarks on CEvNS

- **Sources**: solar ^{8}B and hep ν's; core-collapse SN; DSNB and atmospheric ν's

$$T_{\max} \propto \frac{2E_\nu^2}{M}$$



X. Xiang et al., 2304.06142

$$\sin^2\theta_W = 0.231$$

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

weak nuclear charge

kinematics

$$\frac{d\sigma}{dT} \simeq \frac{G_F^2 M}{2\pi}\frac{Q_W^2}{4}F^2(Q)\left(2 - \frac{MT}{E_\nu^2}\right)$$

form factor F = 1 full coherence

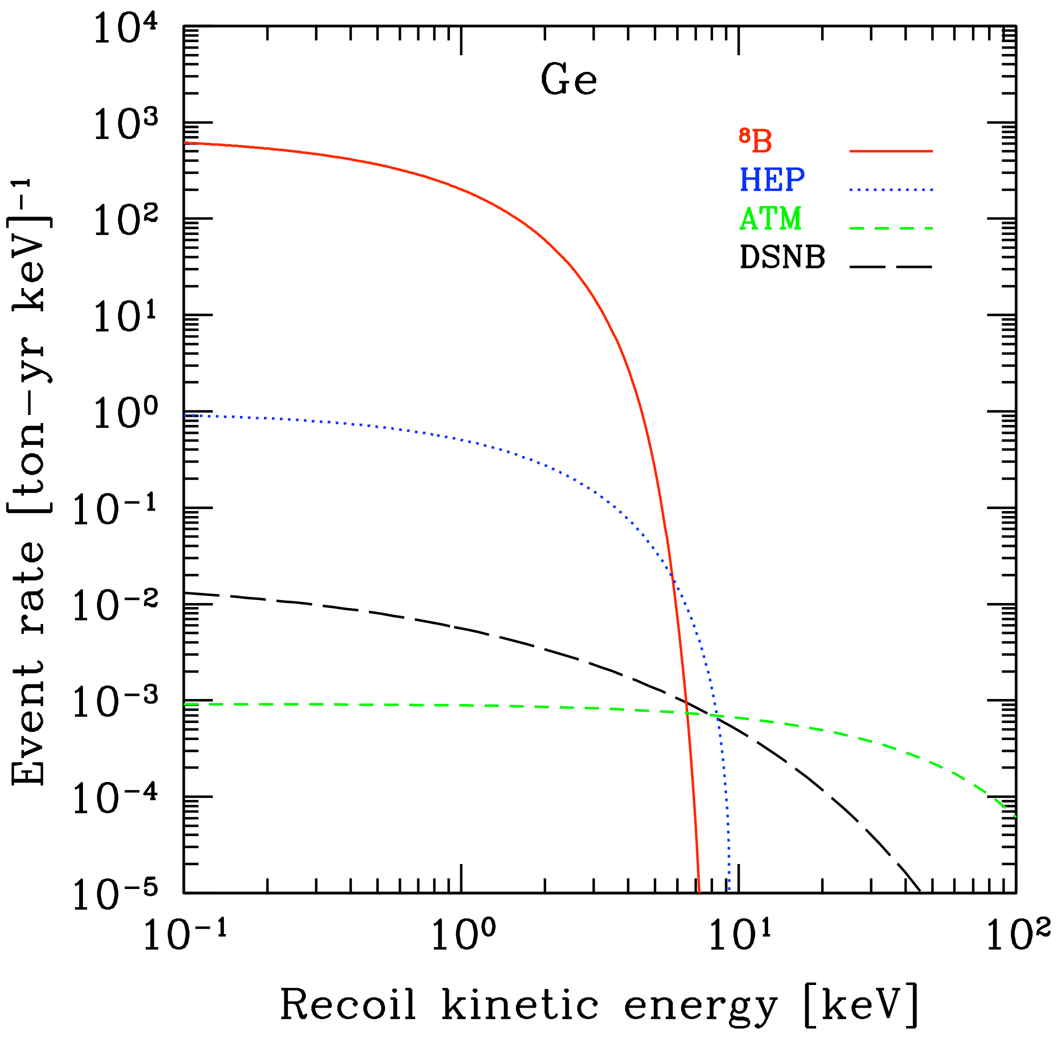
$$\Rightarrow \frac{d\sigma}{dT} \propto N^2$$

Solar neutrino-nucleus scattering

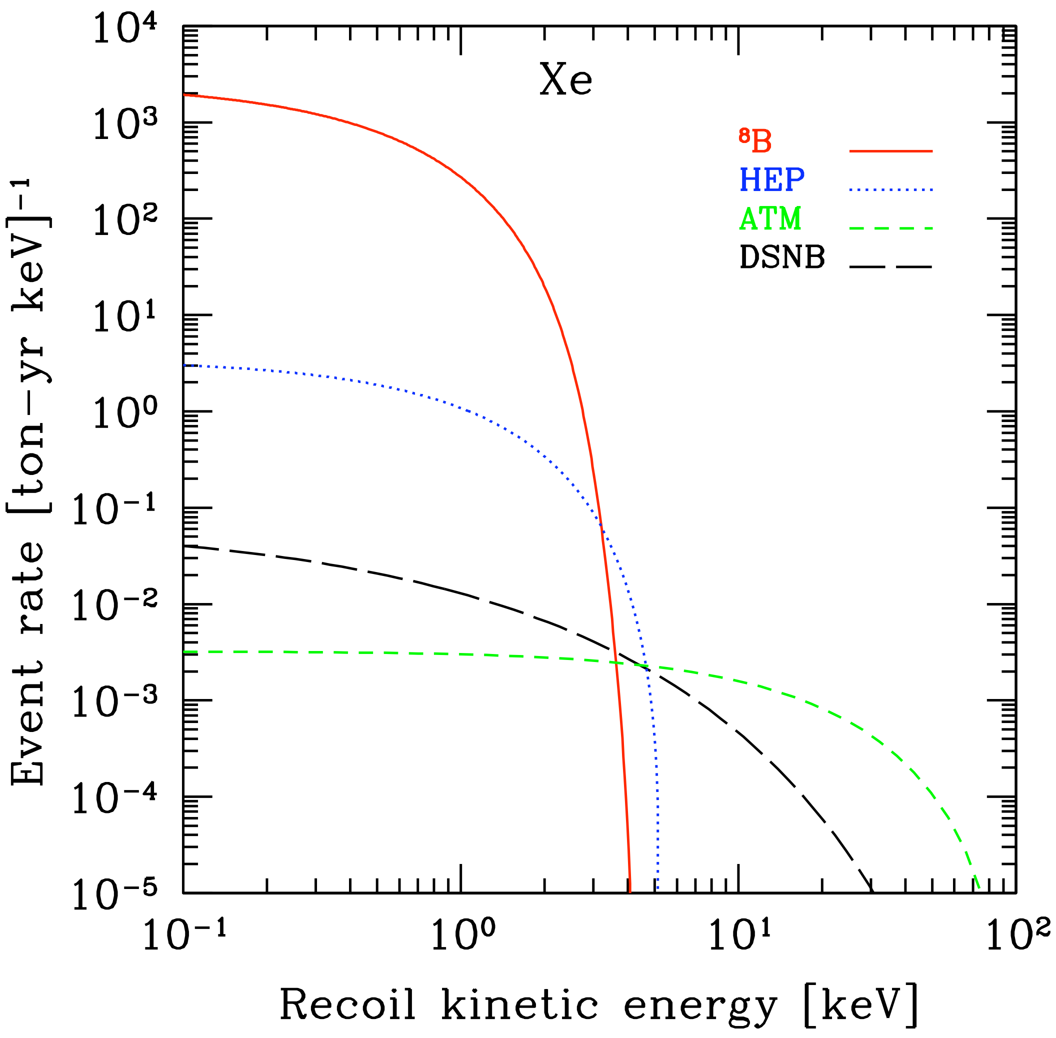
- ^{8}B neutrinos dominate: serious background if the WIMP-nucleon cross section < 10^{-10} pb
- But: energy of nuclear recoils: <4 keV (heavy targets, Xe, I etc) to <30 keV in light targets (F, C)
- Non-^{8}B neutrino backgrounds: impact on WIMP detectors at much lower WIMP-nucleon cross sections

L. E. Strigari, New J. Phys. 11 (2009) 105011

Germanium

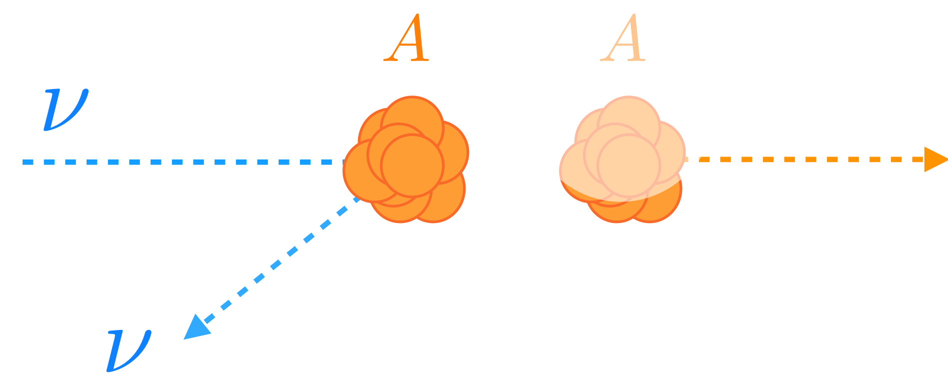


Xenon

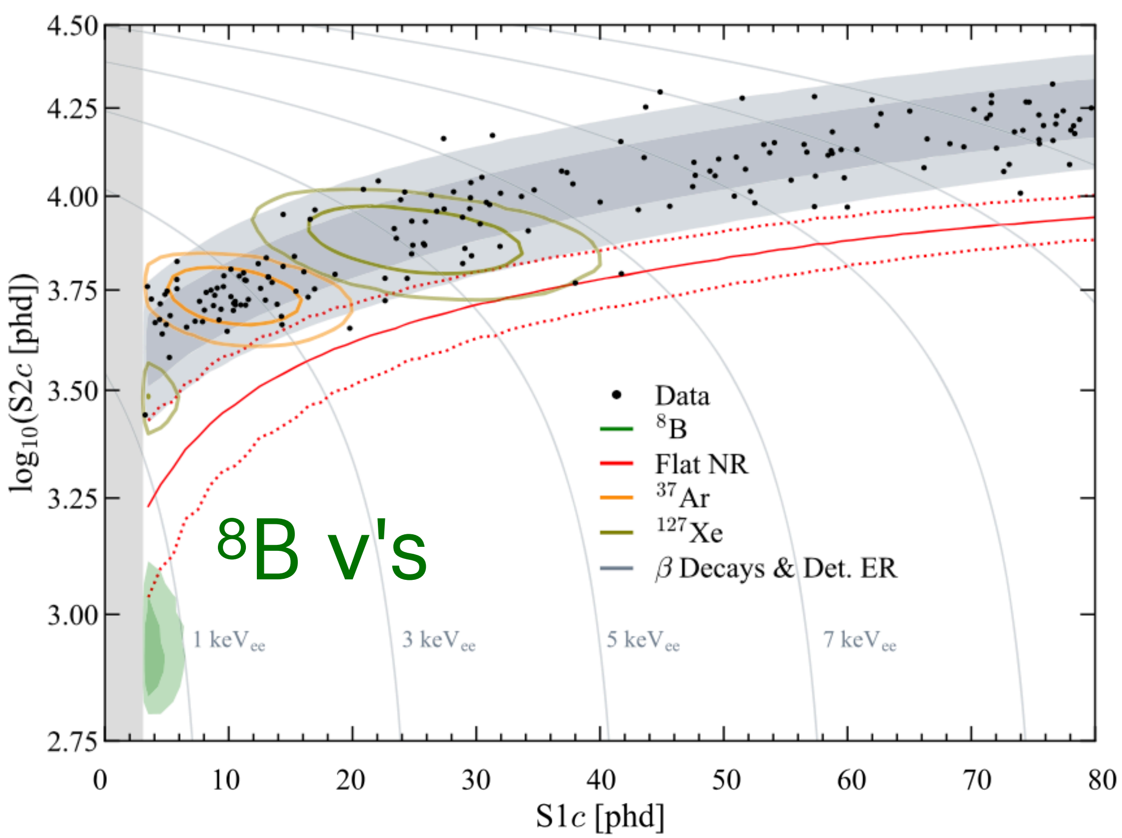


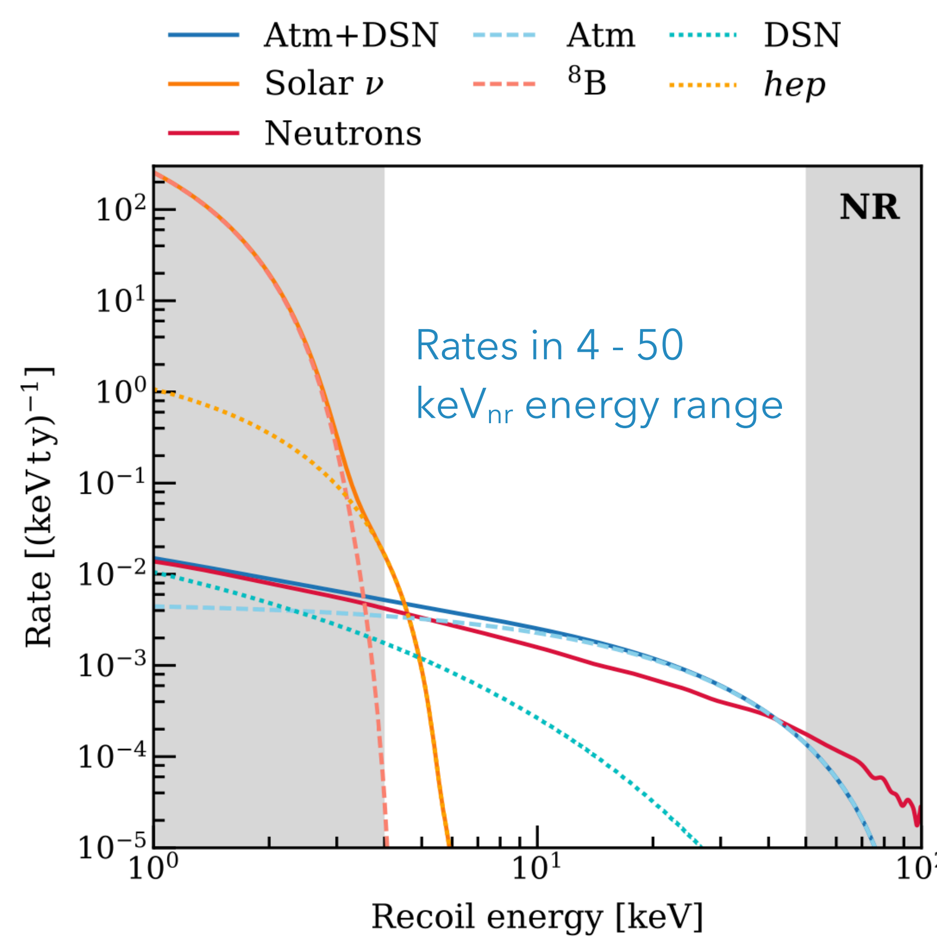
Solar neutrino-nucleus scattering

- In LXe: ~99% of events expected < 4 keV NR energy
- Expect: 10^4 events/(200 t y) for 2-fold S1 and 5 n_e S2*
- Background for light WIMPs



LZ, PRD 108, 2023





XENON collaboration,
JCAP11(2020)031

*e.g., X. Xiang et al., PRD 108, 2023

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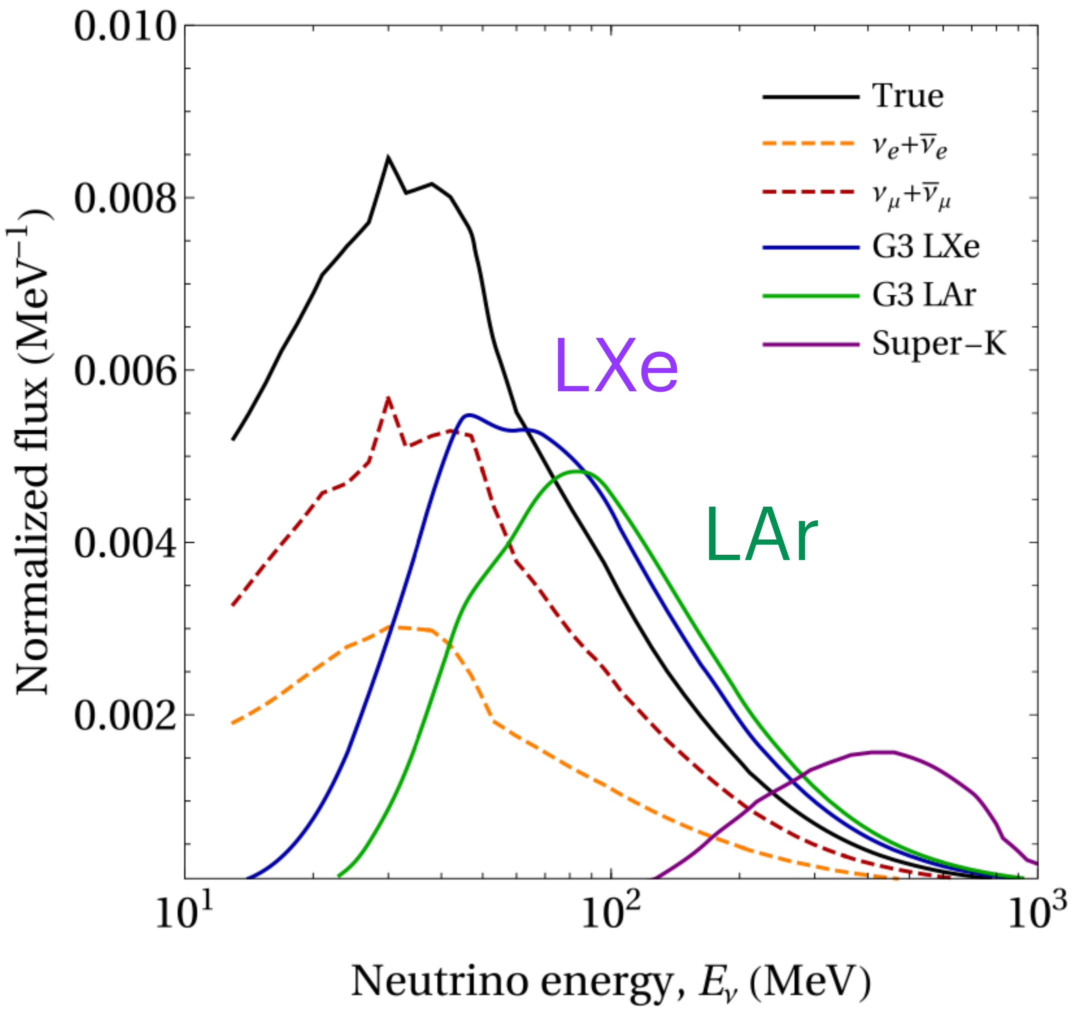
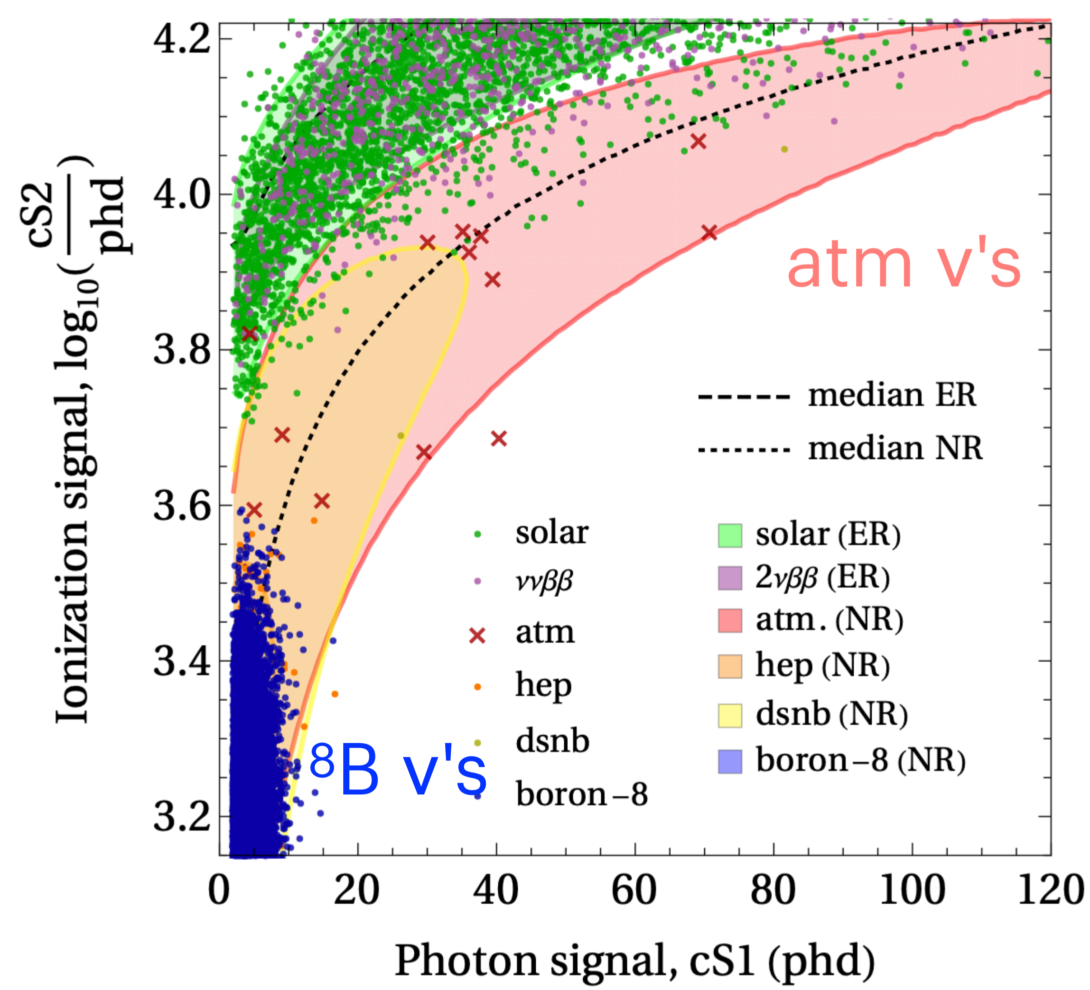
Atmospheric neutrino-nucleus scattering

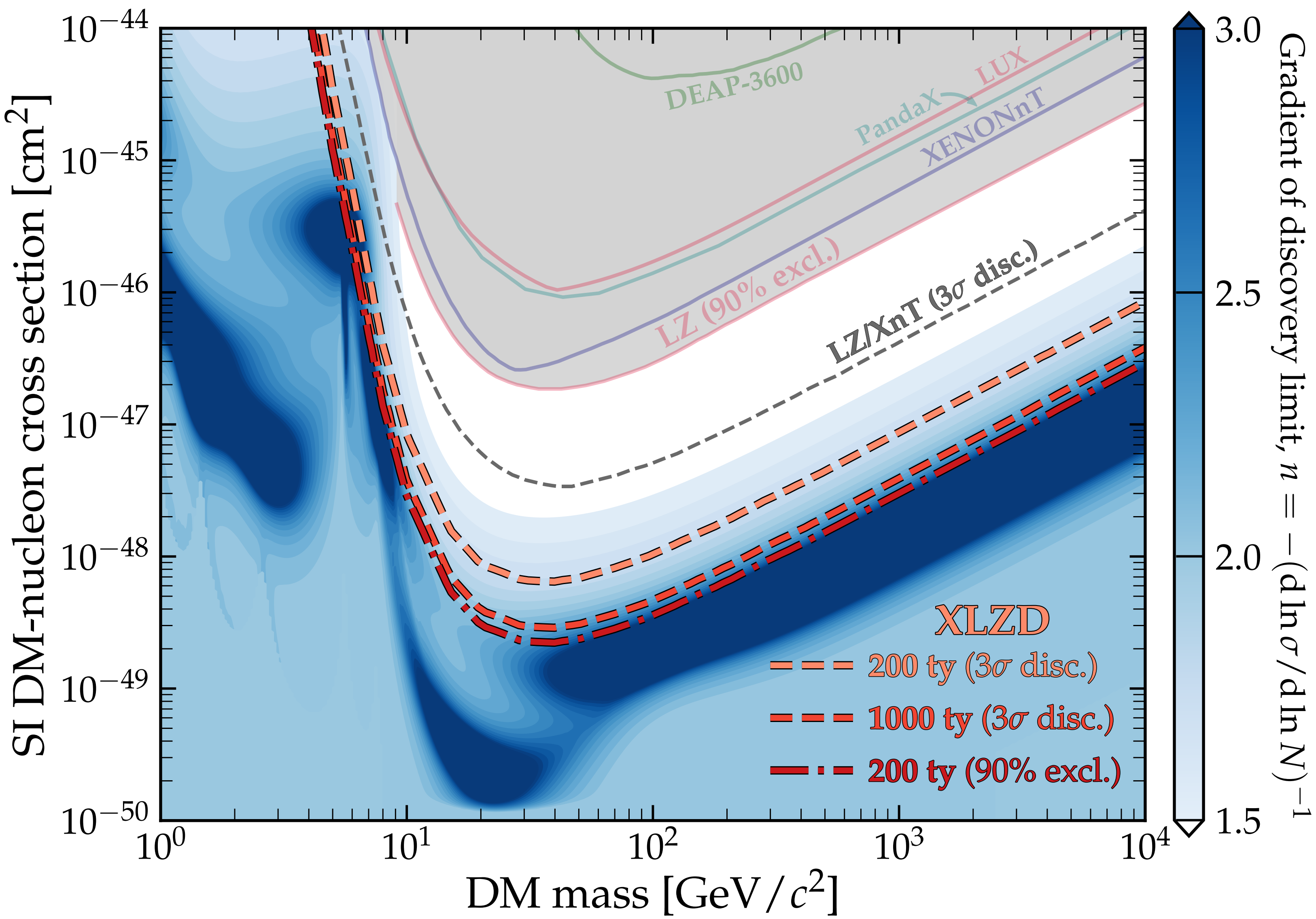
- Backgrounds for medium-heavy WIMPs
- But, exposures > few 100 t y are needed for 5-σ detection





Newstead, Lang, Strigari, PRD 104, 2021

The neutrino floor → fog



Credit Ciaran O'Hare

There is no hard ν floor

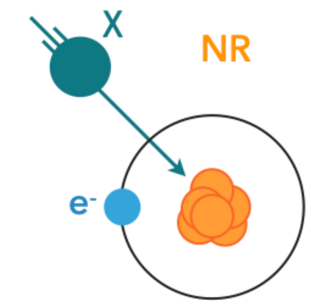
The effect of astrophysical ν backgrounds: gradual, hence the "neutrino fog"

Shown here is the ν fog for a Xe target: as a blue contour map

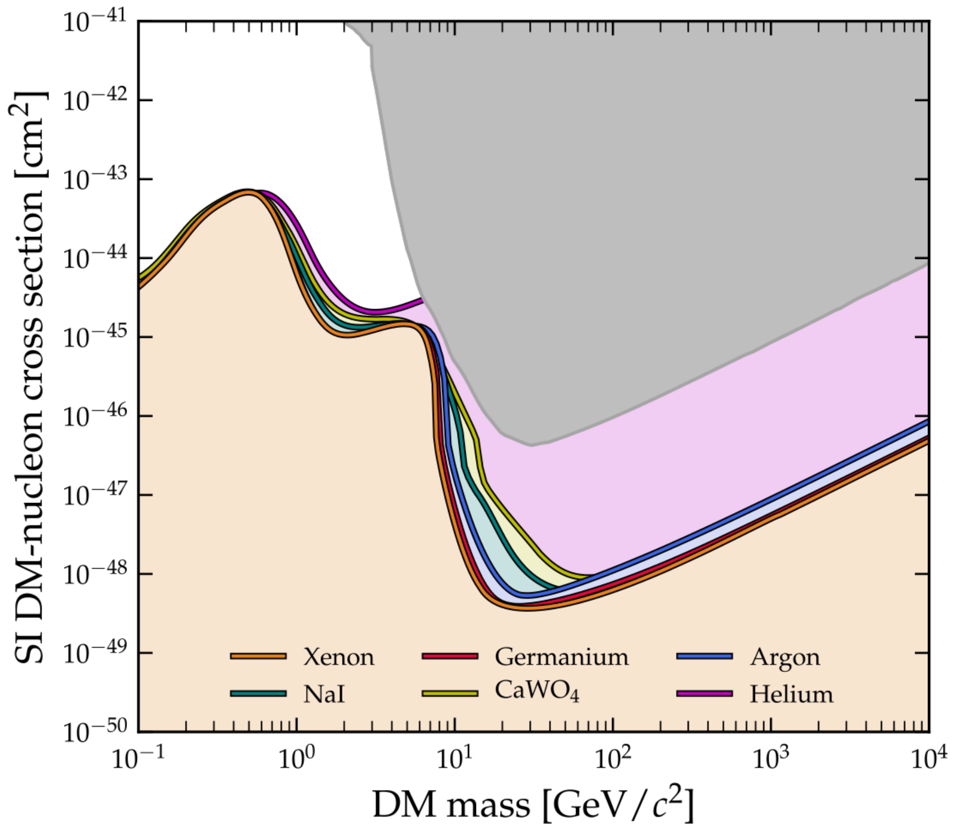
At contour n: obtaining a 10 times lower cross section sensitivity requires an increase in exposure of at least 10^n

The neutrino floor → fog

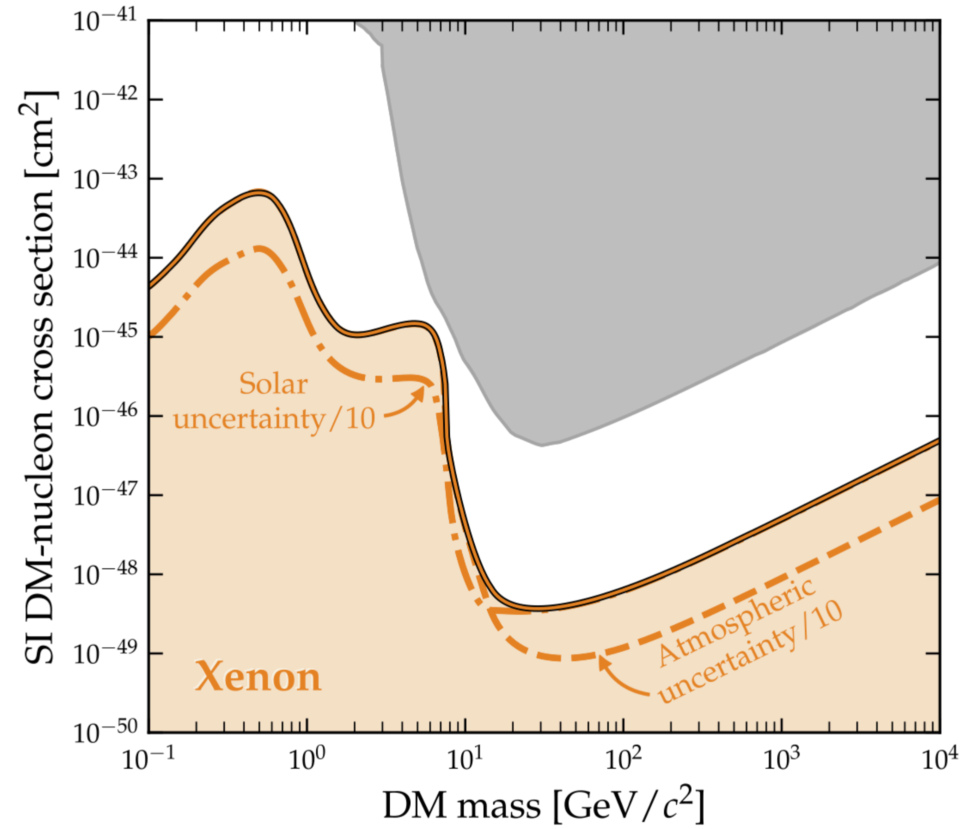
- Here shown for nuclear recoils (ν floor as boundary to "ν fog")
- Region where experiments leave the Poissonian regime*



The "fog" for different targets



Effect of ν fluxes uncertainties

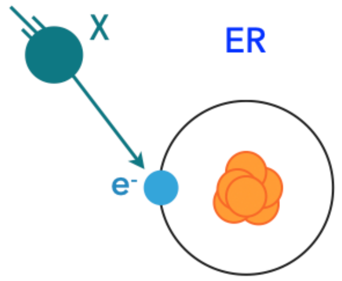


C. O'Hare, PRL 127, 2021

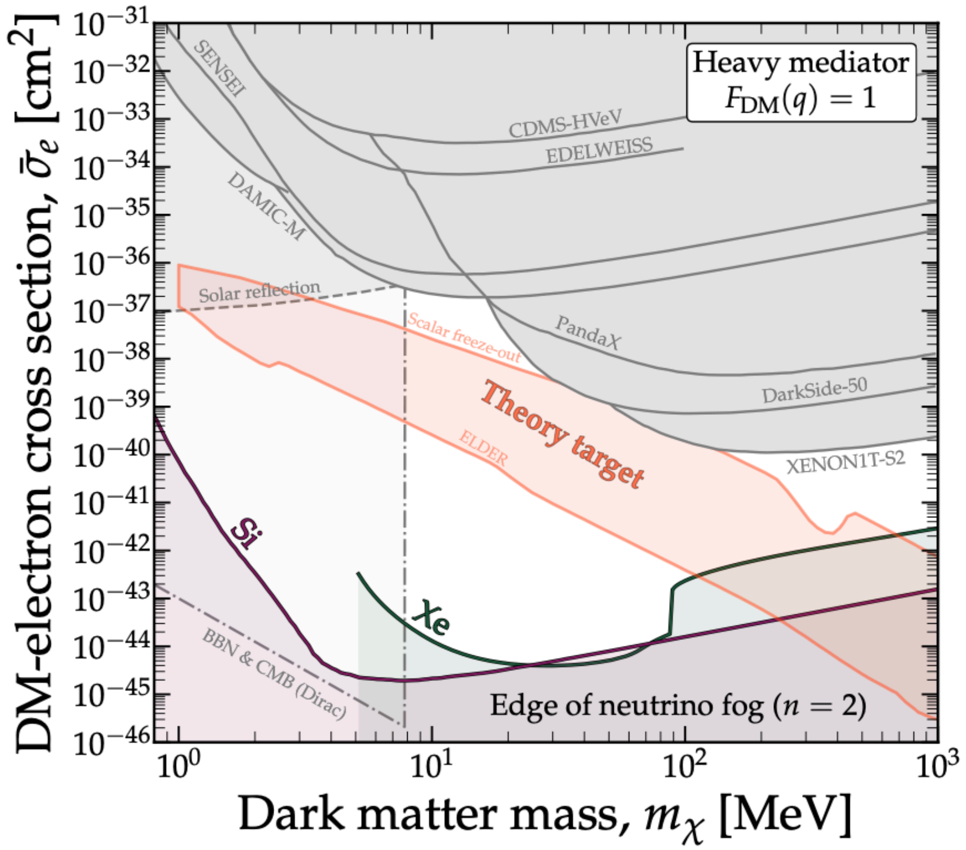
* σ where the DM discovery limit scales as $\sim (Mt)^{-1/n}$

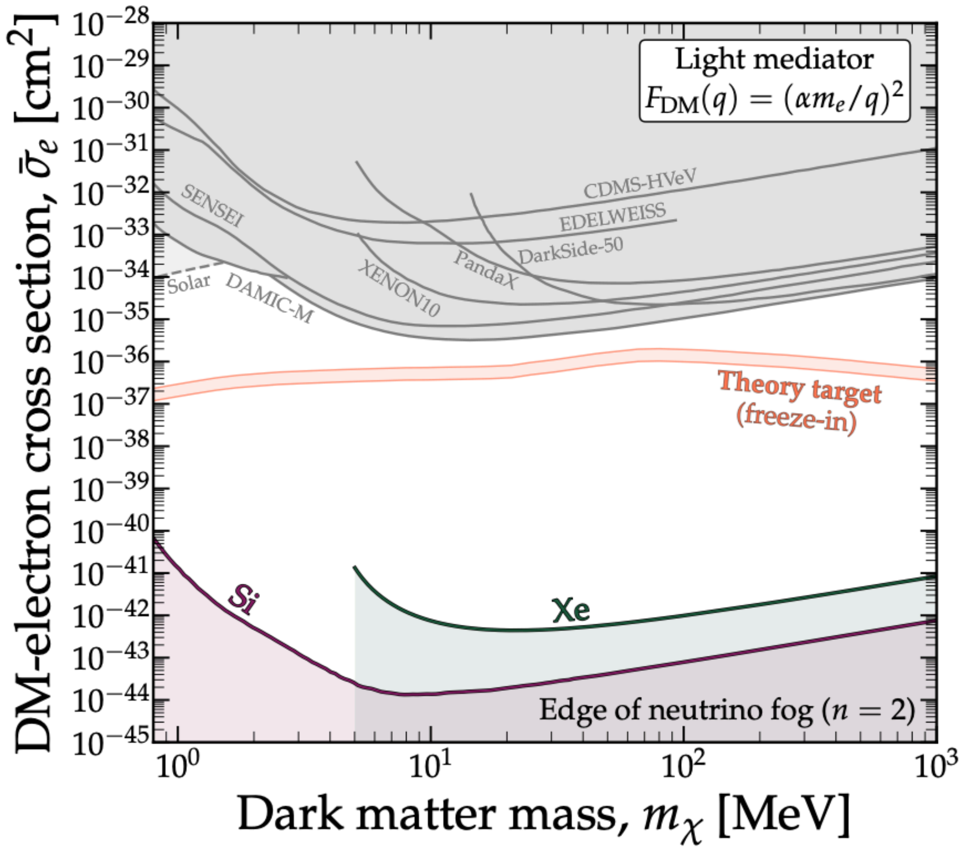
The neutrino floor → fog

- Here shown for electronics recoils (ν floor as boundary to "ν fog")
- Region where experiments leave the Poissonian regime*



The "fog" for Si and Xe targets, for 2 mediators



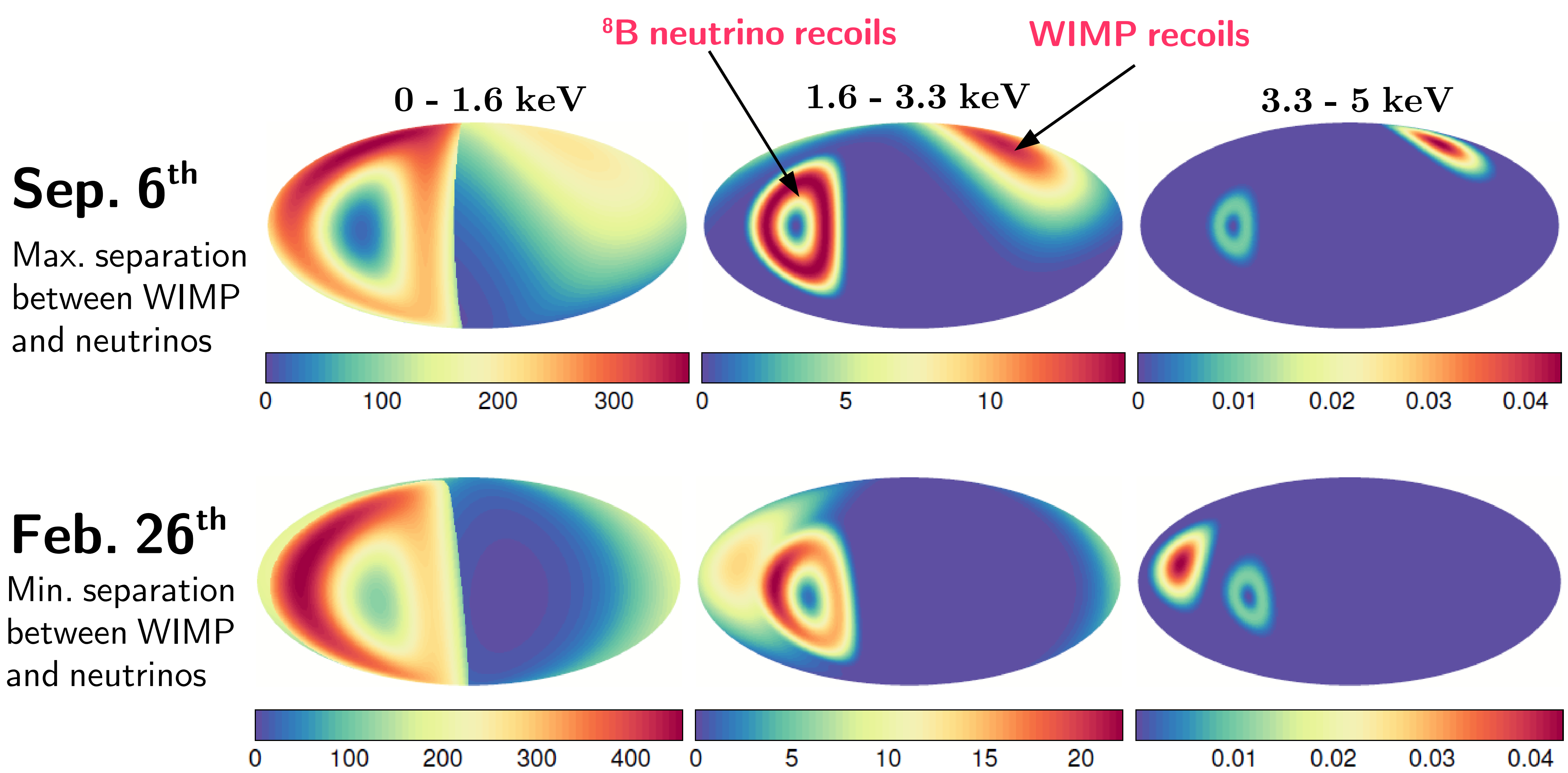


B. Carew at al, 2312.04303

* σ where the DM discovery limit scales as $\sim (Mt)^{-1/n}$

Overcoming the neutrino background

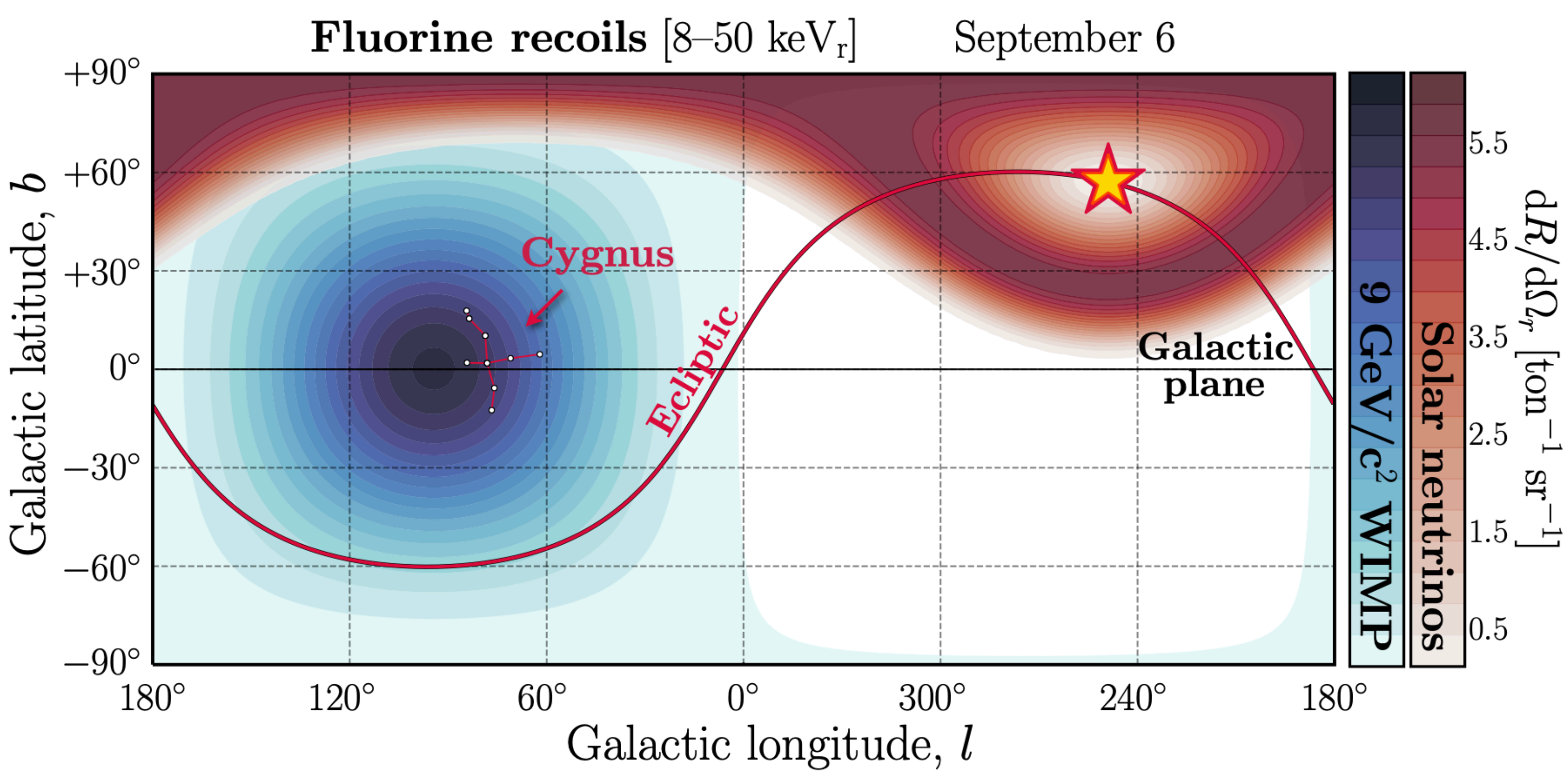
- Directional signature: Sun does not coincide with WIMP direction at any time

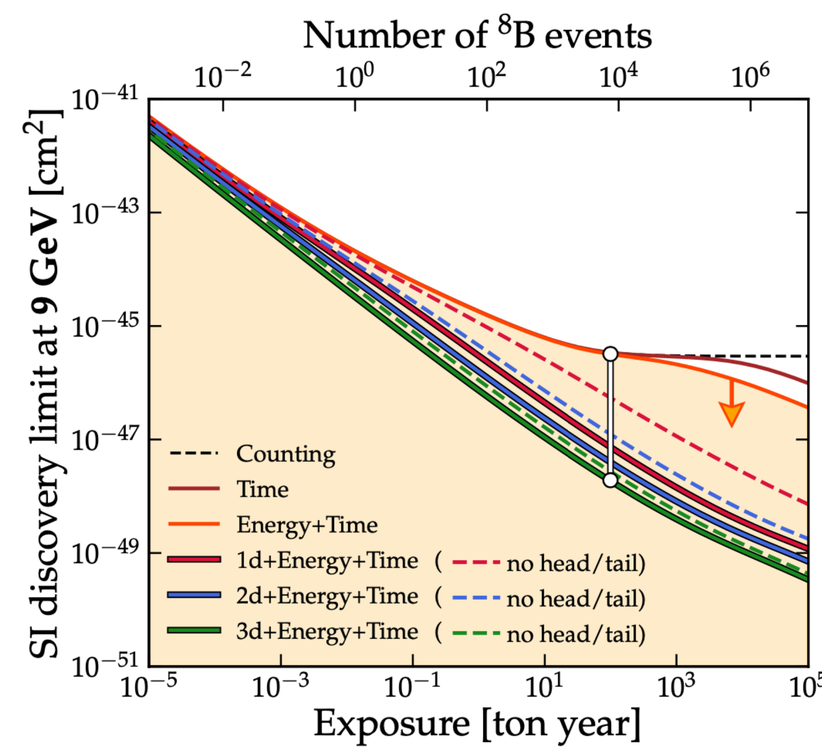


CAJ O'Hare *et al* [1505.08061]

Overcoming the neutrino background

- The incoming direction of WIMPs and solar neutrinos differs: this can be exploited to overcome the solar "neutrino fog"





Directional Recoil Detection

Sven E. Vahsen,[1] Ciaran A. J. O'Hare,[2] and Dinesh Loomba[3]

[1]Department of Physics and Astronomy, University of Hawaii, Honolulu, Hawaii 96822, USA; email: sevahsen@hawaii.edu
[2]ARC Centre of Excellence for Dark Matter Particle Physics, The University of Sydney, School of Physics, NSW 2006, Australia; email: ciaran.ohare@sydney.edu.au
[3]Department of Physics and Astronomy, University of New Mexico, NM 87131, USA, email: dloomba@unm.edu

Annual Review of Nuclear and Particle Science
2021. 71:1–41

This article's doi:
10.1146/annurev-nucl-020821-035016

Towards the neutrino fog

- General goal: quieter detectors, with ER and NR backgrounds below the rates from astrophysical neutrinos

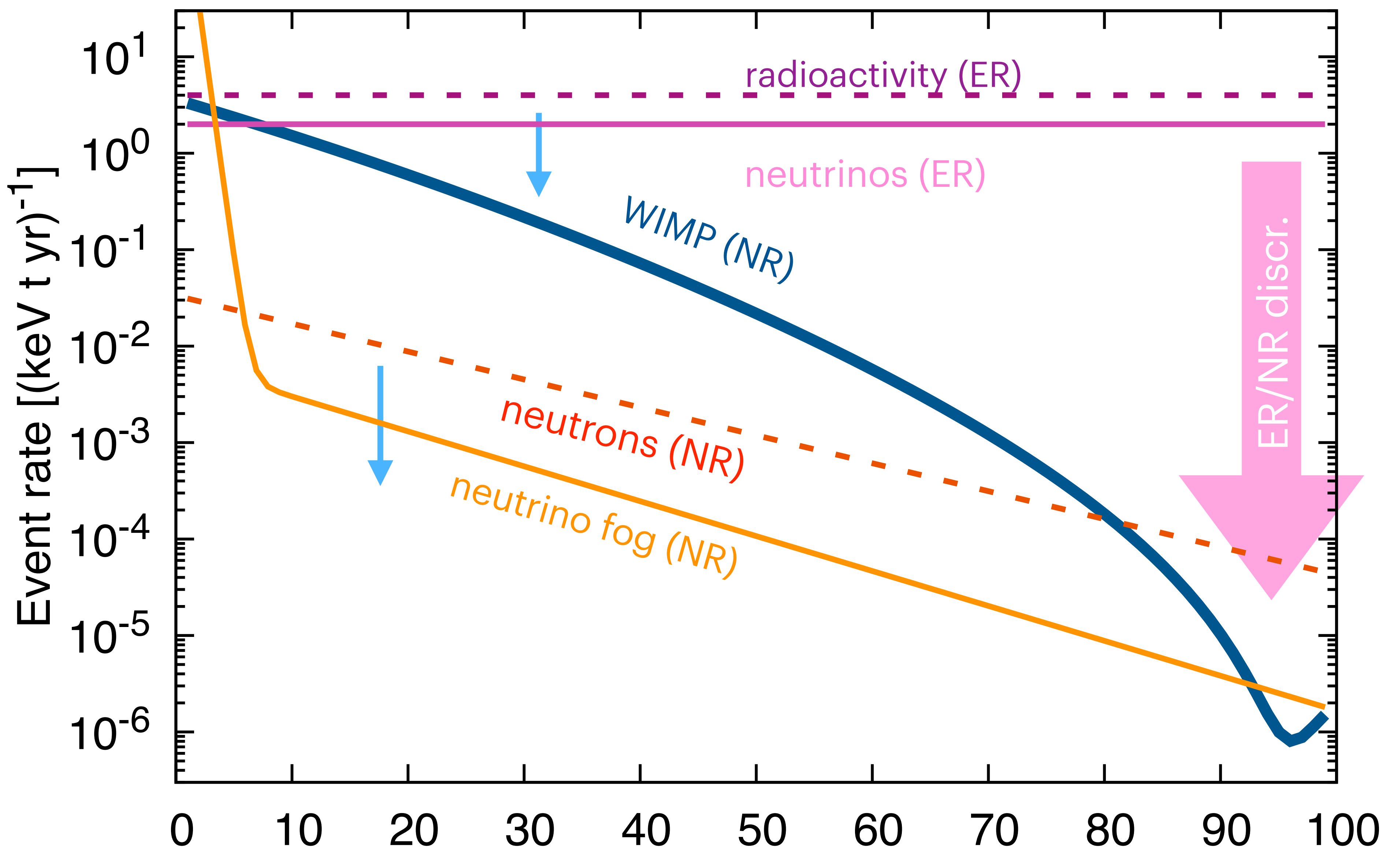


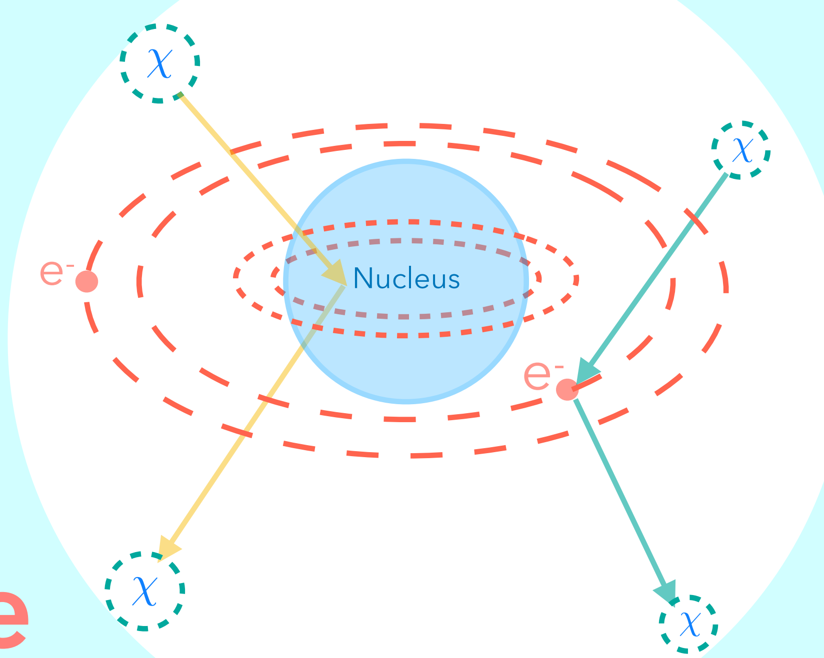
Figure: Tina Pollmann

Direct Detection Techniques: Overview

Heat

$CaWO_4$:
CRESST
NaI:
COSINUS

Ge, Si:
SuperCDMS
EDELWEISS



Ar: DEAP-3600
Xe: XMASS
NaI: ANAIS
DAMA/LIBRA,
COSINE, SABRE

Charge

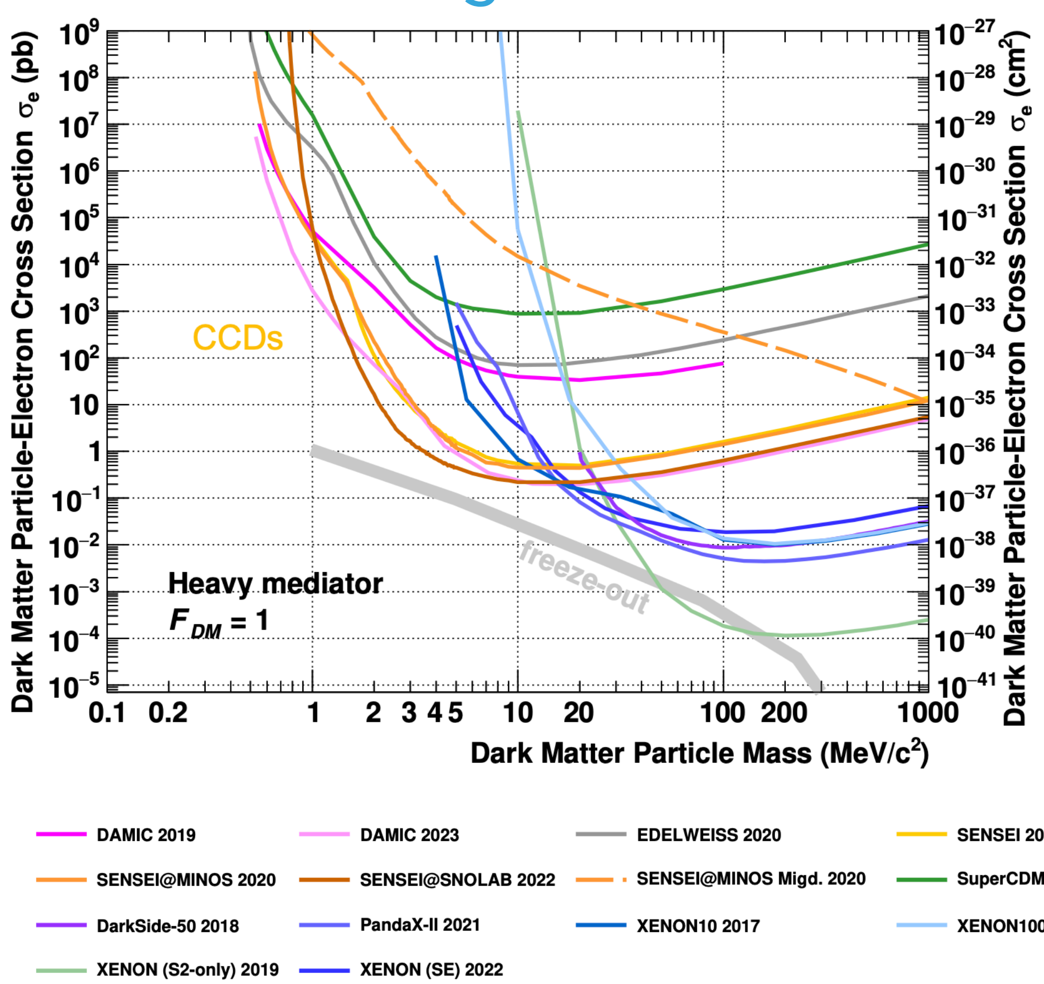
Light

C_3F_8: PICO, Ge: CDEX
Si: DAMIC-M, SENSEI,
OSCURA, Ne: TREX-DM;
He:SF_6: CYGNUS, Ag, Br,
C: NEWSdm, H, He, Ne:
NEWS-G

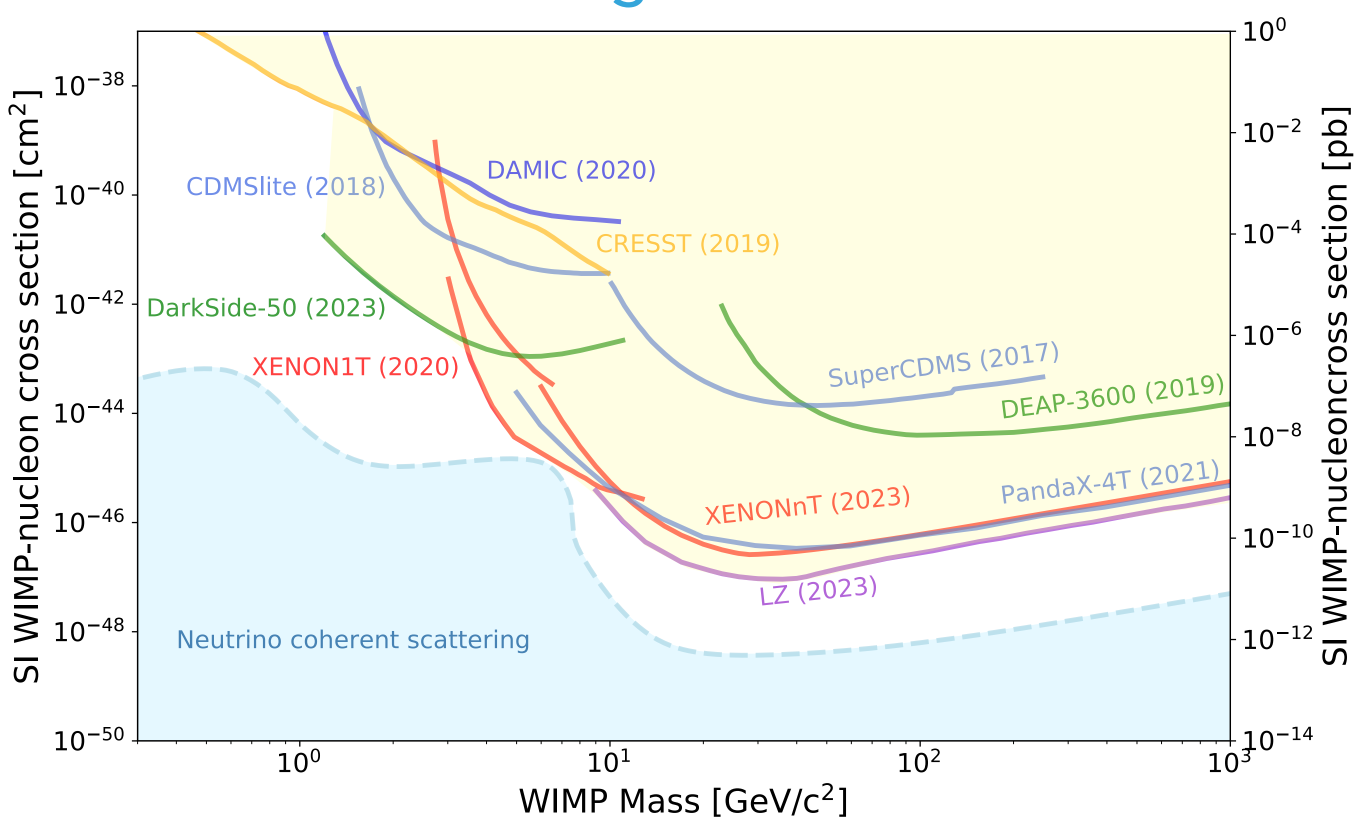
Xe: LZ, PandaX-4T, XENONnT,
DARWIN/XLZD, PandaX-xT
Ar: DarkSide-50, SBC-LAr,
DarkSide-20k, Argo

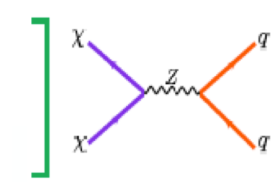
Direct detection landscape

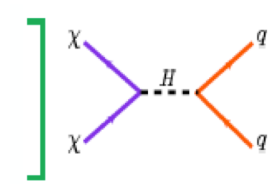
Scattering off electrons



Scattering off nuclei





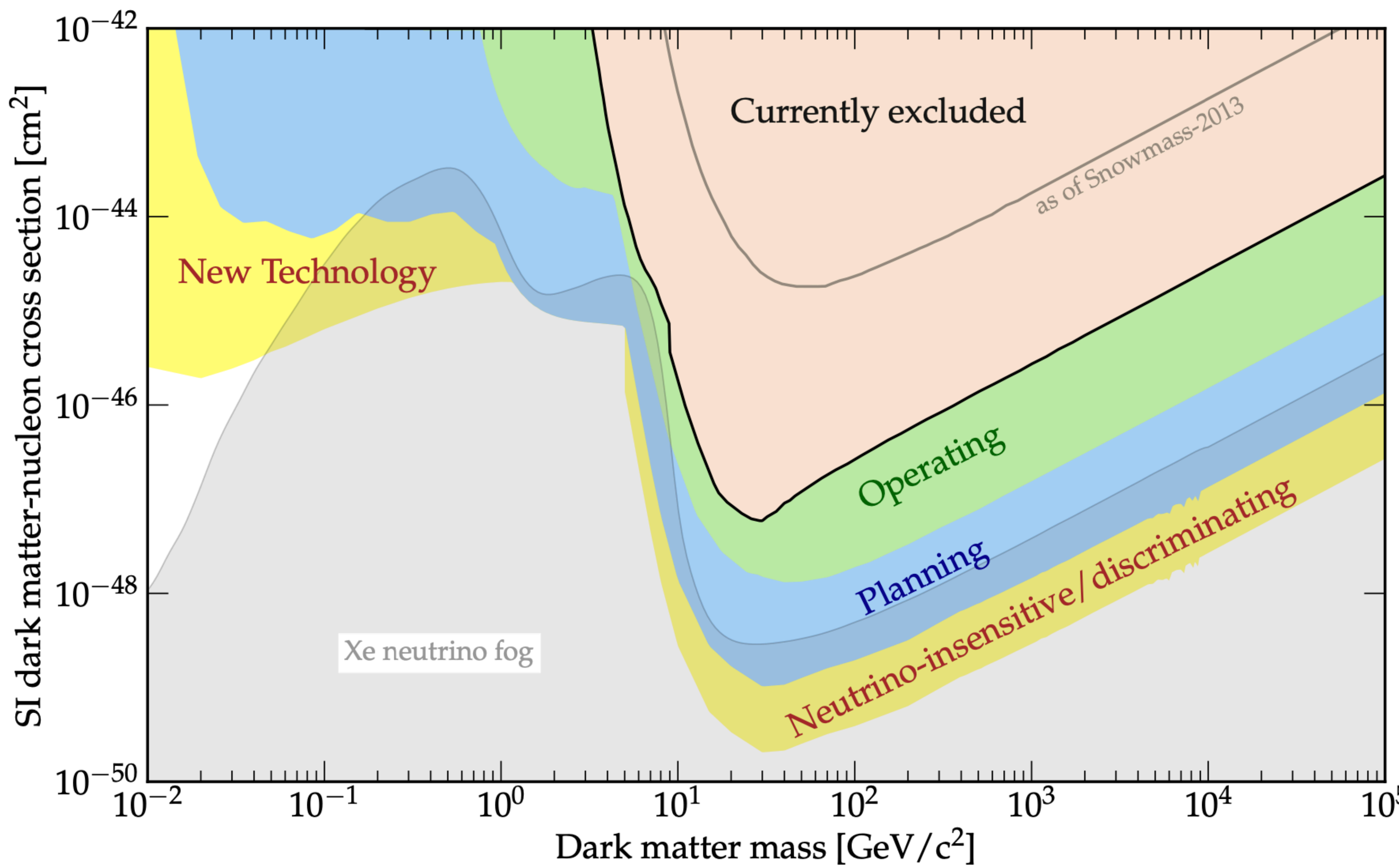


LB, S.Profumo: PDG2024

K. Schäffner, TAUP2023

Direct detection landscape

Bolometers, CCDs (plus many new technologies)



Noble liquids

Here scattering off nuclei

Snowmass, Cosmic Frontier Report, arXiv: 2211.09978

End of Lecture 2