Search for Coherent Elastic Solar Neutrino-Nucleus Scattering in XENONnT

27 October 2023

Quentin Pellegrini

Summary

- ***XENONnT Experiment***
- ***Coherent Elastic Solar Neutrino-Nucleus Scattering (CEvNS)***
- ***CEvNS Search in XENONnT***
- ***Conclusion & Outlook***

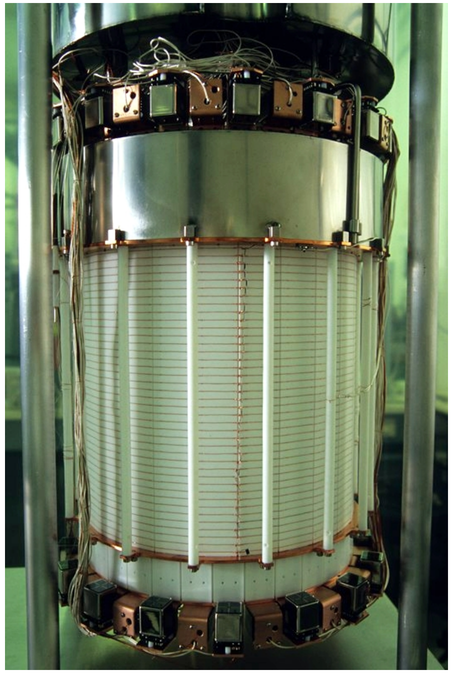
The XENON Program

PRL 100 (2008) 021303
PRD 94 (2016) 122001
PRL 121 (2018) 111302

XENON

XENON10
2005–2007

25 kg LXe
15 cm drift length
$\sigma_{SI} \sim 10^{-44}$ cm^2
(2007)



XENON100
2009–2016

161 kg LXe
30 cm drift length
$\sigma_{SI} \sim 10^{-45}$ cm^2
(2016)

XENON1T
2016–2018

3.2 t LXe
1 m drift length
$\sigma_{SI} \sim 10^{-47}$ cm^2
(2018)

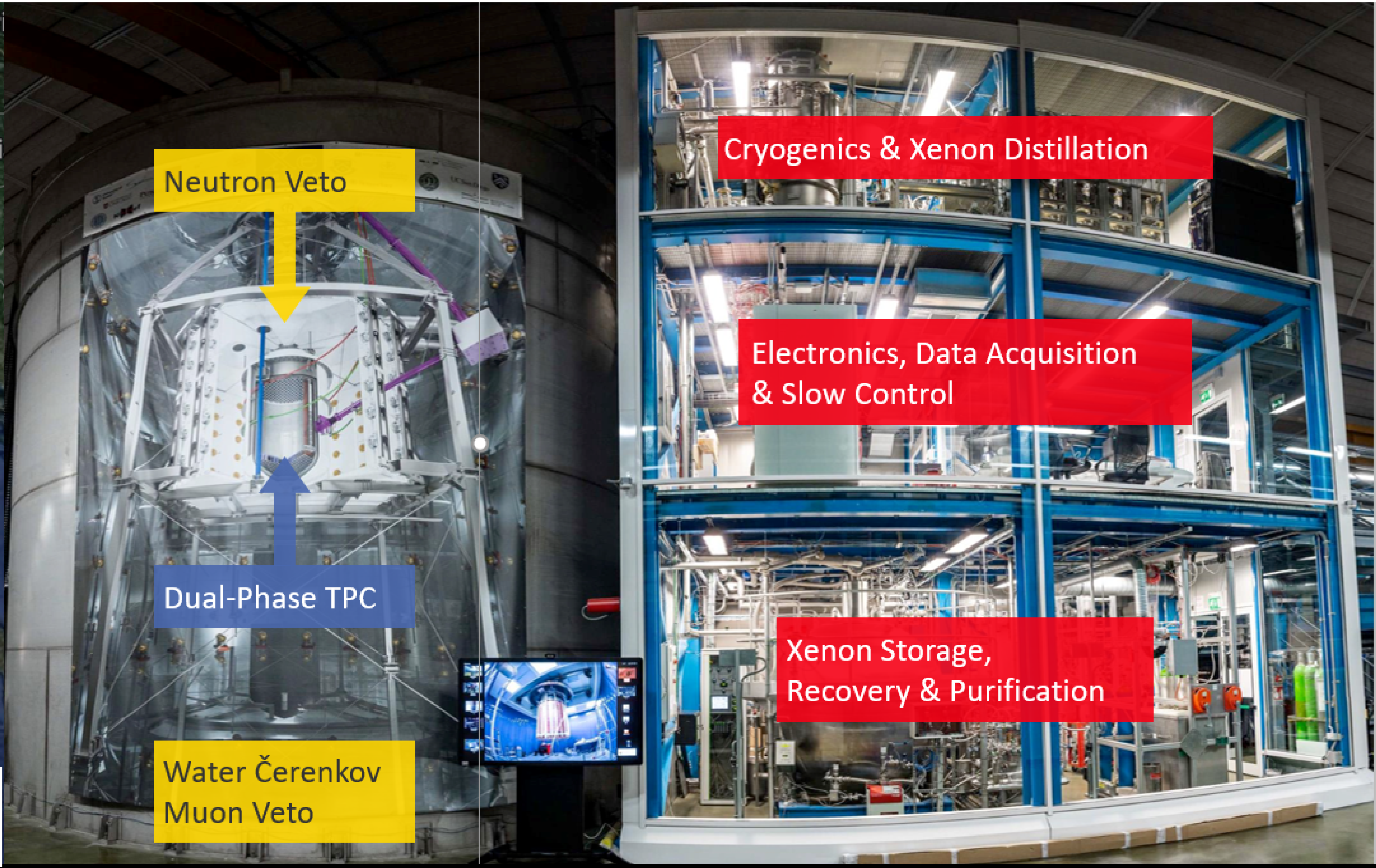
XENONnT
2020–2027

NOW

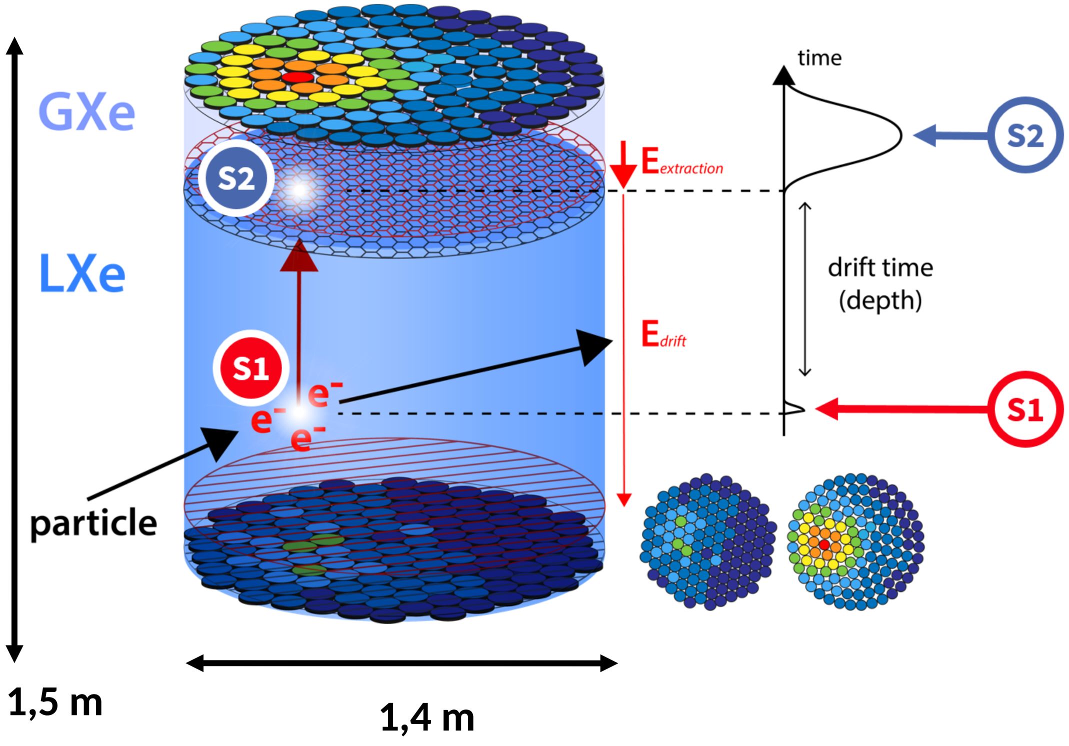
8.4 t LXe
1.5 m drift length
$\sigma_{SI} \sim 10^{-48}$ cm^2
(20 ty)

XENONnT

XENON



Detection principle



Dual Phase Time Projection Chamber (TPC)

Position Reconstruction

- z → Drift time = t(S2) – t(S1)
- x, y → S2 signal

Energy Reconstruction

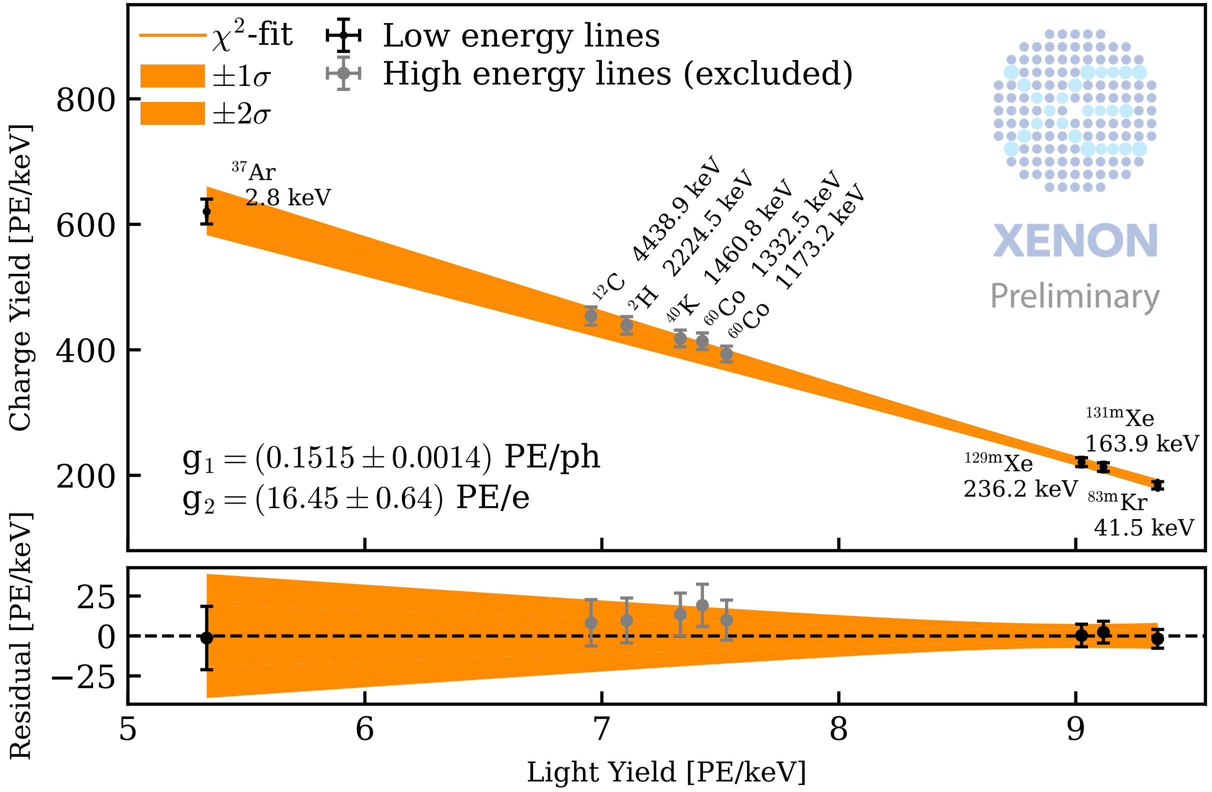
$$E = W\left(\frac{S1}{g_1} + \frac{S2}{g_2}\right) \qquad \frac{S2}{E} = -\frac{g_2}{g_1}\frac{S1}{E} + \frac{g_2}{W}$$

Mean quantum energy (13.5 eV) (W)

Detector gain constants (g_1, g_2)

Charge Yield ($S2/E$)

Light Yield ($S1/E$)

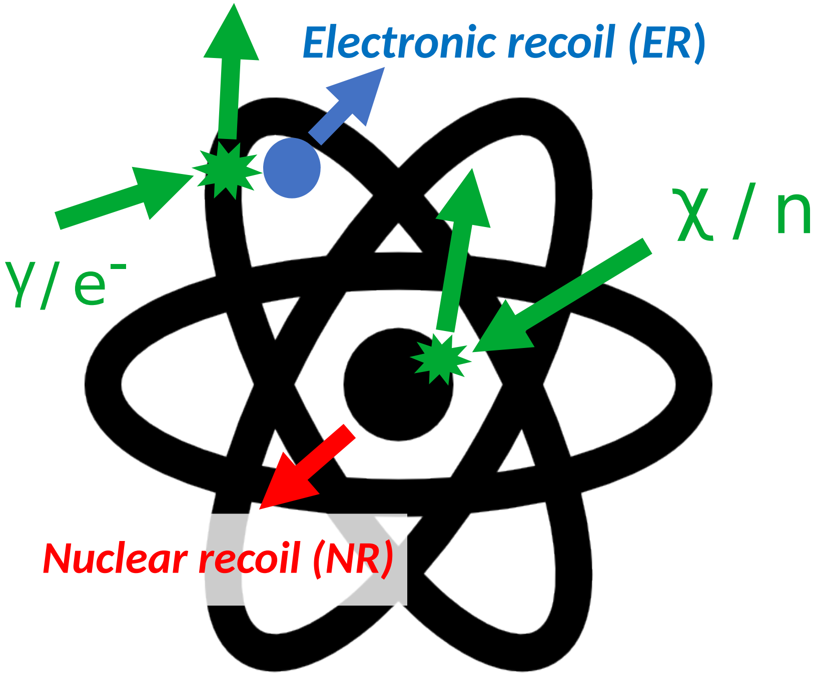


Detector gain constants fit

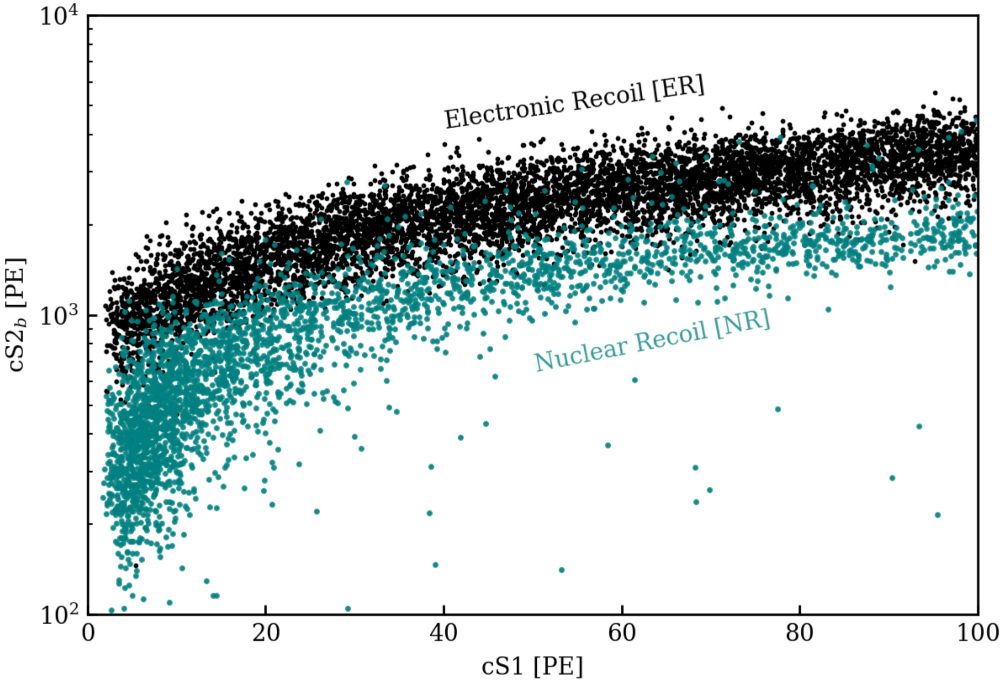
Particle discrimination

Weakly Interactive Massive Particle (WIMP or χ) is the main dark matter candidate search by XENONnT

XENON

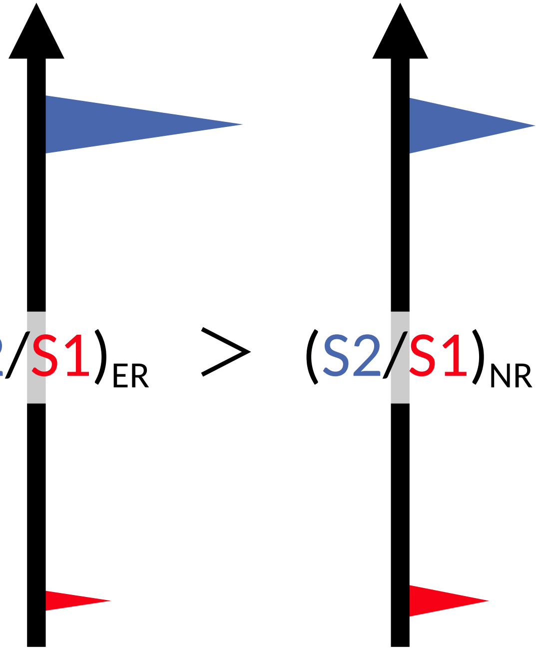


Liquid Xenon



Electronic Recoil (ER)

Nuclear Recoil (NR)



$(S2/S1)_{ER} > (S2/S1)_{NR}$

WIMP
Solar neutrinos
Supernova neutrinos

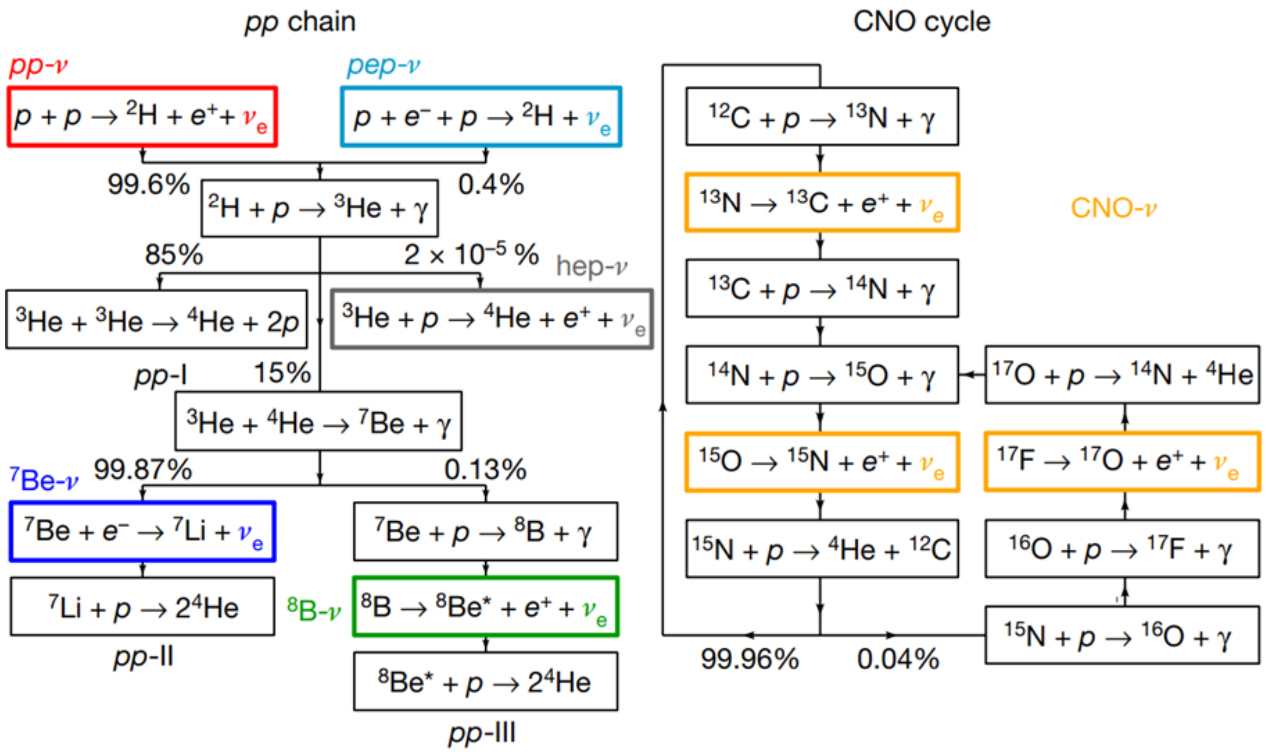
Leptophilic DM
Solar axions
Double β decay

Solar neutrinos

XENON

Nuclear reaction chains in solar core

$$4\ H^{+} + 2\ e^{-} = {}^{4}He^{2+} + 2\ \nu_e$$



Solar neutrinos

XENON

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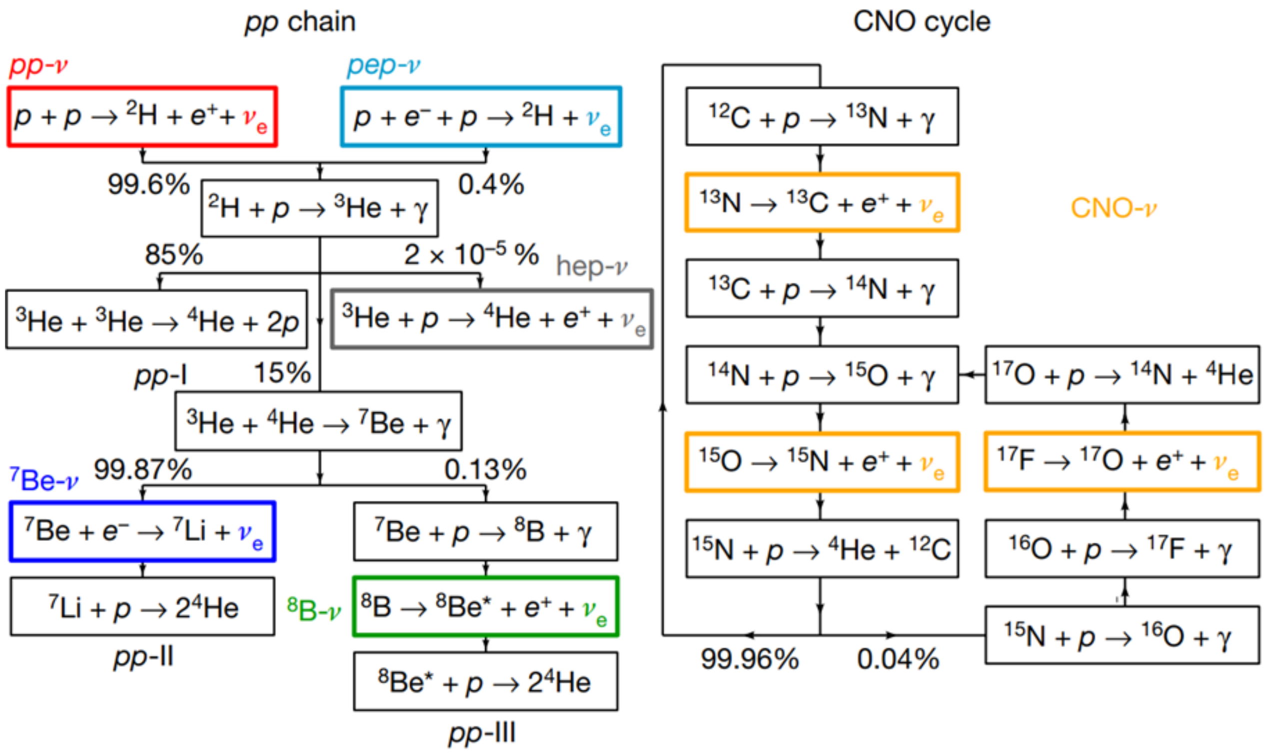
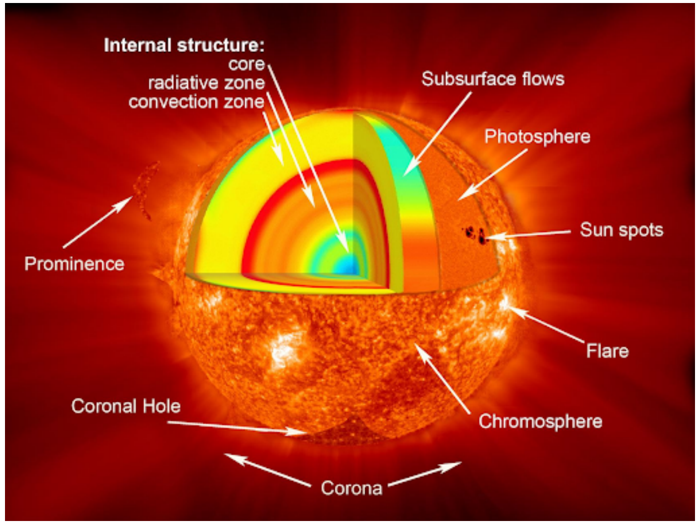


Solar neutrino fluxes

Prediction : Solar standard model (SSM)

→ Solar internal structure → **Neutrino production**



SSM includes:

- **Energy generation and chemical evolution** from nuclear fusion reaction chains in the core :
- **Energy transport** by radiative heat transfert in the radiative area and convective heat transfer in the convection area.
- **Hydrostatic equilibrium** by gaz pressure gradient.

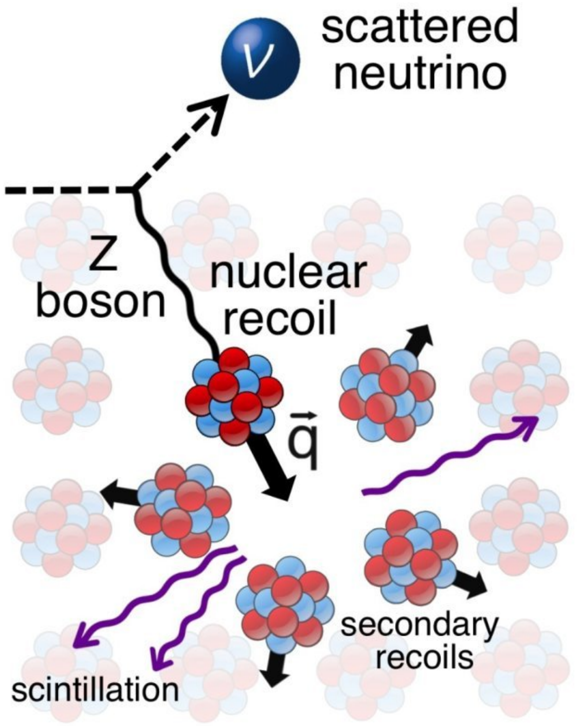
Measurements : Large volume detectors (water, scintillator...)

→ **Elastic electron neutrino scattering (ES)**

→ **Solar luminosity constraint**

SSM independent

What is CEvNS ?

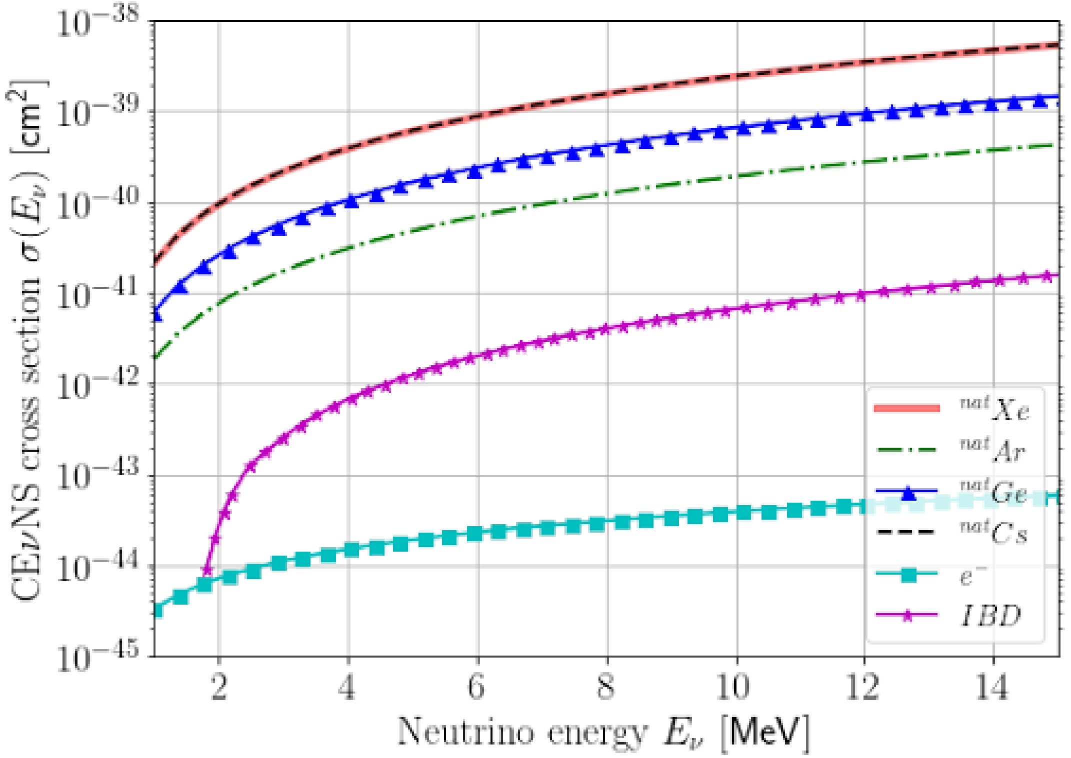


Standard Model Process

Coherence condition : qR< 1
Low-energy neutrinos (< 100 MeV)

$$\sigma_{CE\upsilon NS} \propto N^2$$

Low-energy NR events



- **First observation of Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) at 6,7σ by COHERENT experiment in 2017 at the Spallation Neutron Source (SNS) [3]**
- **Most neutrino experiments are not sensitive to CEvNS signal**

[3] Scholberg, K. (2018). Observation of coherent elastic neutrino-nucleus scattering by coherent. arXiv preprint arXiv:1801.05546

Solar neutrinos and DM experiments

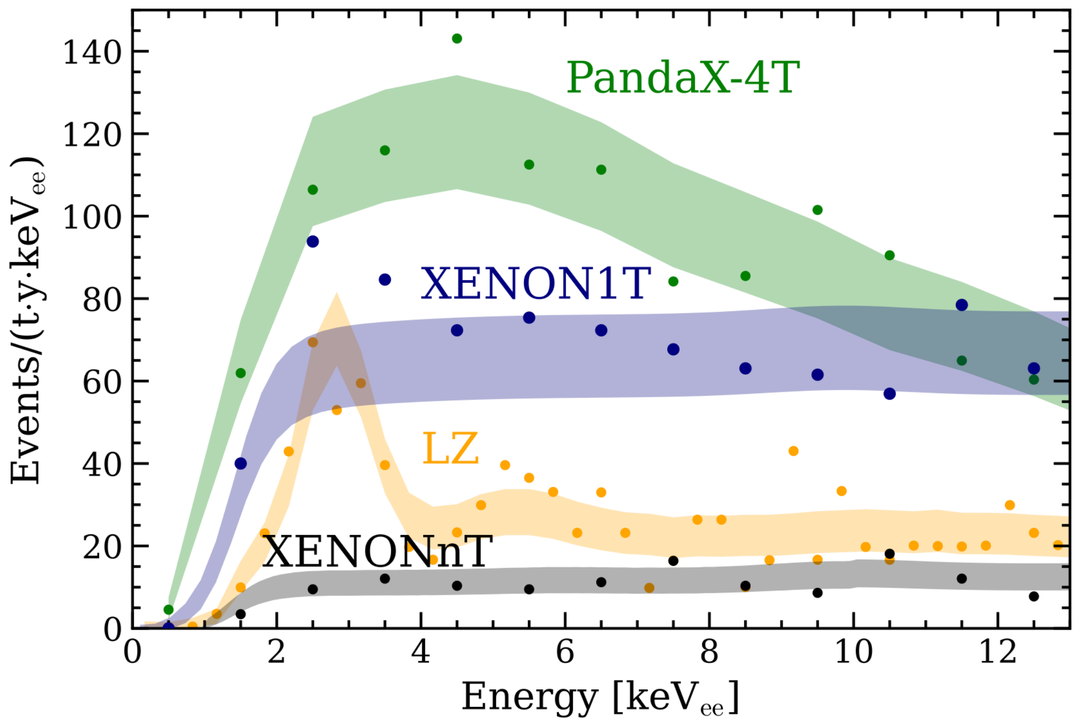
XENON

In LXe TPC experiments, Solar neutrinos interact mainly in two ways :

- Elastic electron scattering (ES) → ER signal
- Elastic coherent neutrino-nucleus scattering (CEvNS) → NR signal

Irreducible background for DM direct search

XENONnT ER study [1]



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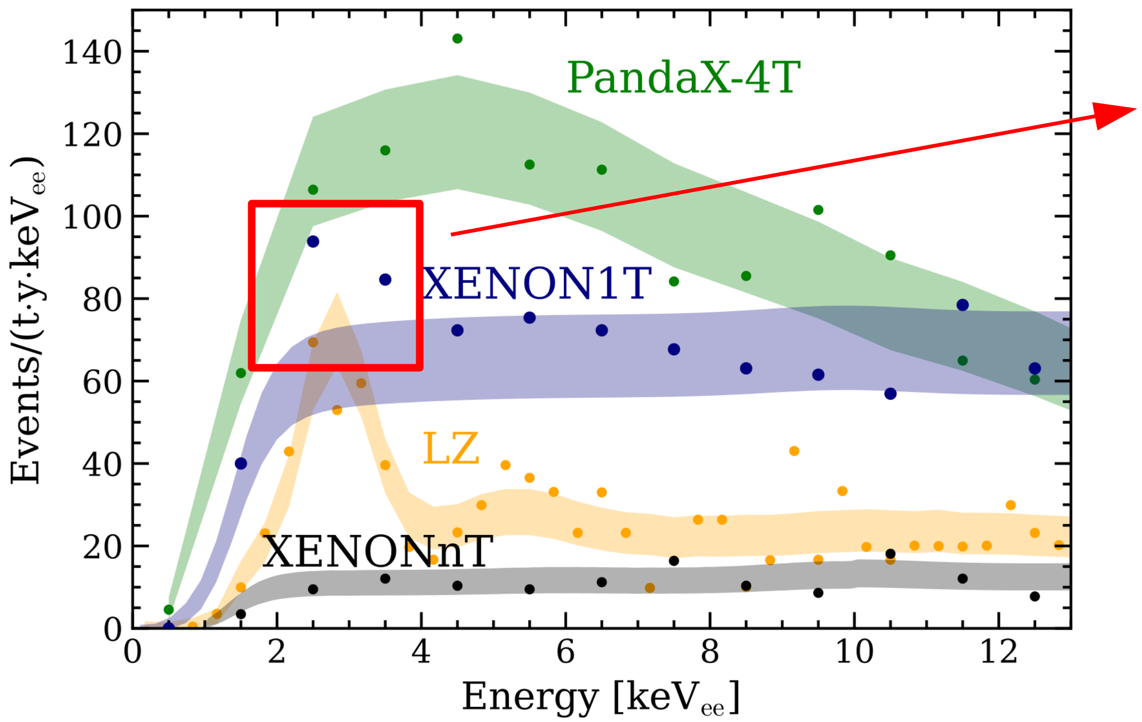

XENON1T Excess compatible with New Physics (Solar Axions, Dark photons, ...)

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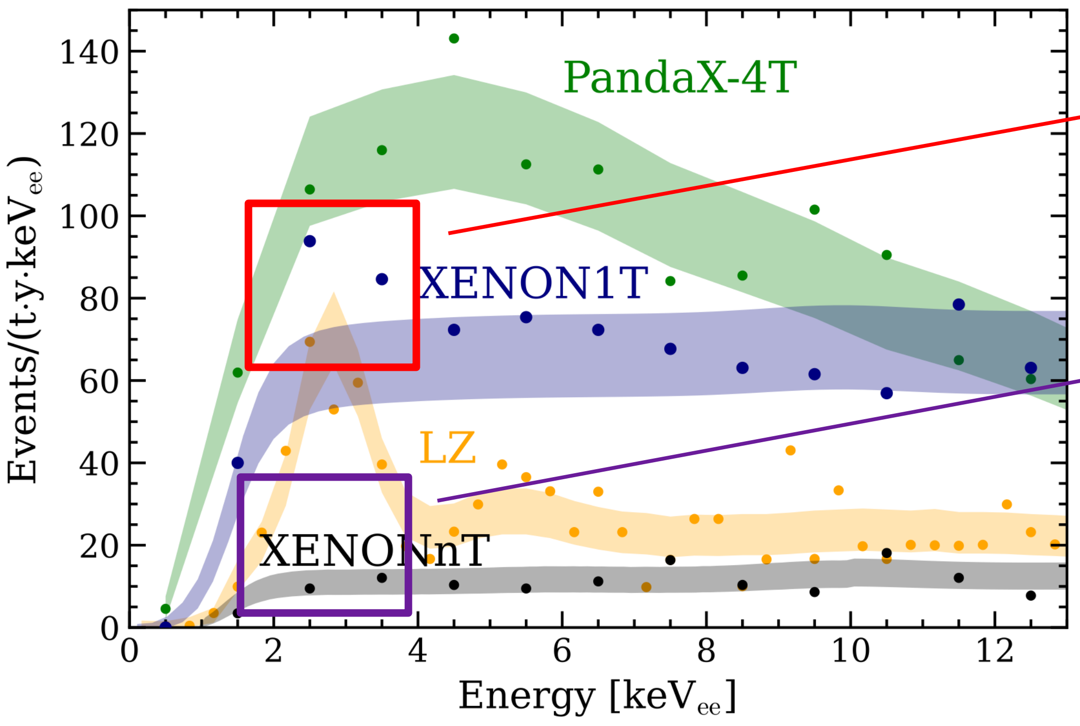

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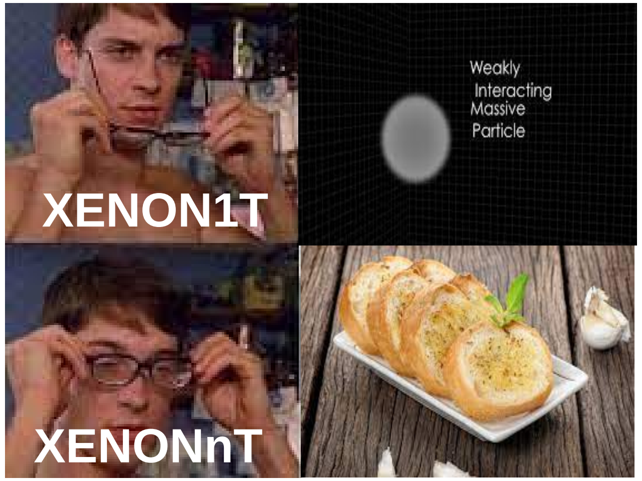
XENON1T Excess is Gone !

Likely due to ~~tritium~~ Préfou contamination



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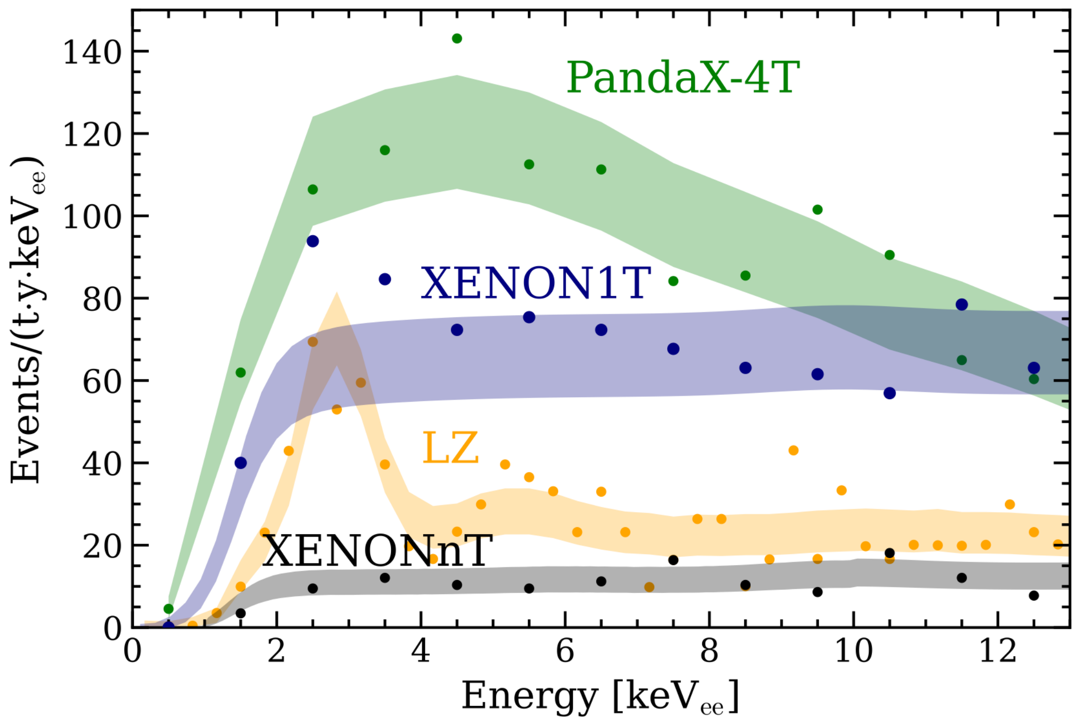


Lowest ER background in low-energy region

Solar ES becomes an important background (third)

⟹ **Solar pp Neutrinos Elastic Scattering Study**

Could lead to an improvement in precision on the properties of solar neutrinos (PP flux, Pee, Weinberg angle, etc) [2]

[1] XENON collaboration, Search for New Physics in Electronic Recoil Data from XENONnT, Phys. Rev. Lett. 129 (2022) 161805.

[2] DARWIN COLLABORATION, Solar neutrino detection sensitivity in DARWIN via electron scattering. The European Physical Journal C, 2020, vol. 80

Astrophysical CEvNS and Dark matter search

XENON

Astrophysical CEvNS :

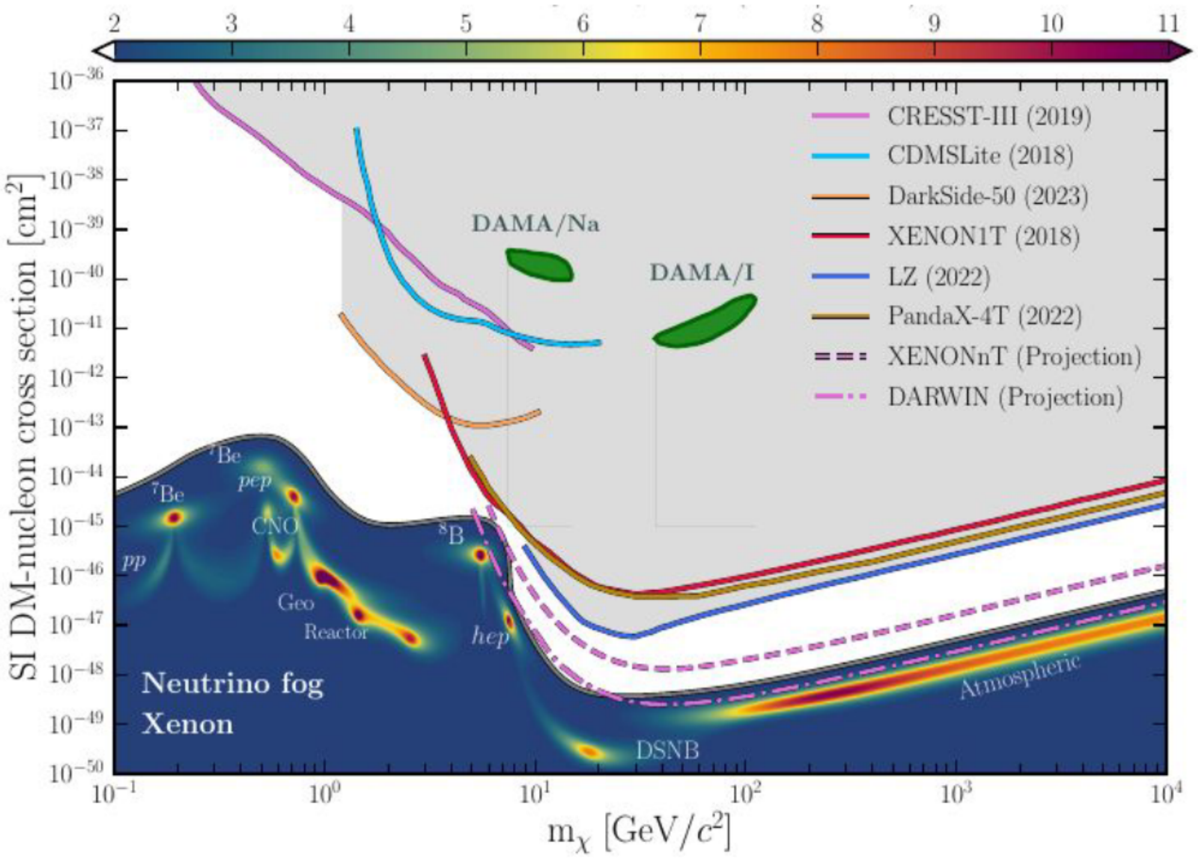
➡ Irreducible NR background

➡ WIMPs Sensitivity limits, **Neutrino Floor (grey line).**

➡ Possible distinction of WIMPs and CEvNS signals (High stat) **Neutrino Fog (Blue area)**

CEvNS and solar neutrinos

- **Background for Low-WIMPs mass (< 10 GeV)**
- **In our ROI (>10eV), only ^{8}B-ν counts (pp III chain)**



Sensitivity of DM experiments in function of WIMPs mass

Expected Event Rate

$$\frac{dR}{dE_r} = \mathcal{N} \int_{E_\nu^{min}} \Phi(E_\nu) \frac{d\sigma(E_r E_\nu)}{dE_r} dE_\nu$$

Xenon Liquid Atomic Density

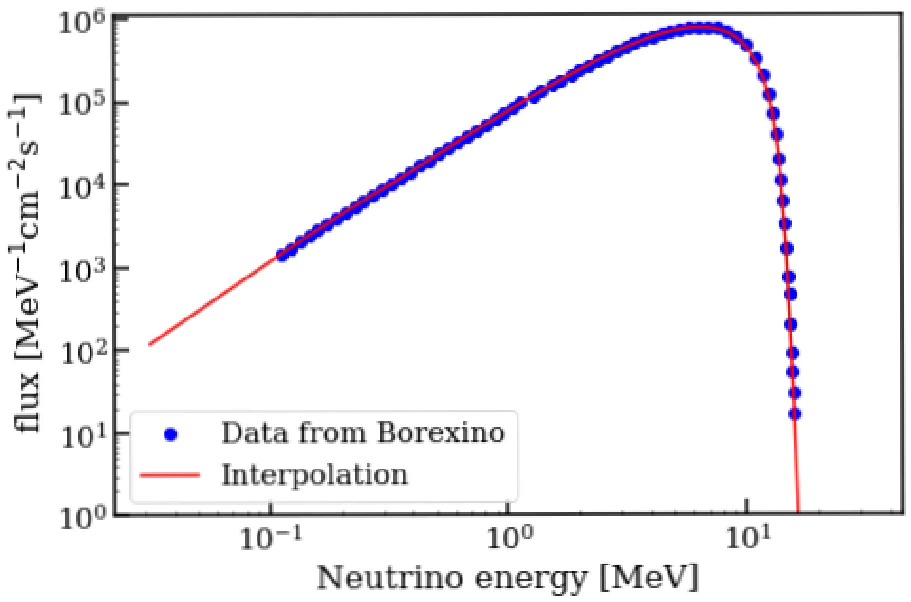
$$E_\nu^{min} = \sqrt{\frac{m_N E_r}{2}}$$

CEvNS SM Cross Section

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

$$Q_w = N - (1 - 4\sin 2\theta_w) Z \sim N$$

Boron 8 Solar Neutrino Flux



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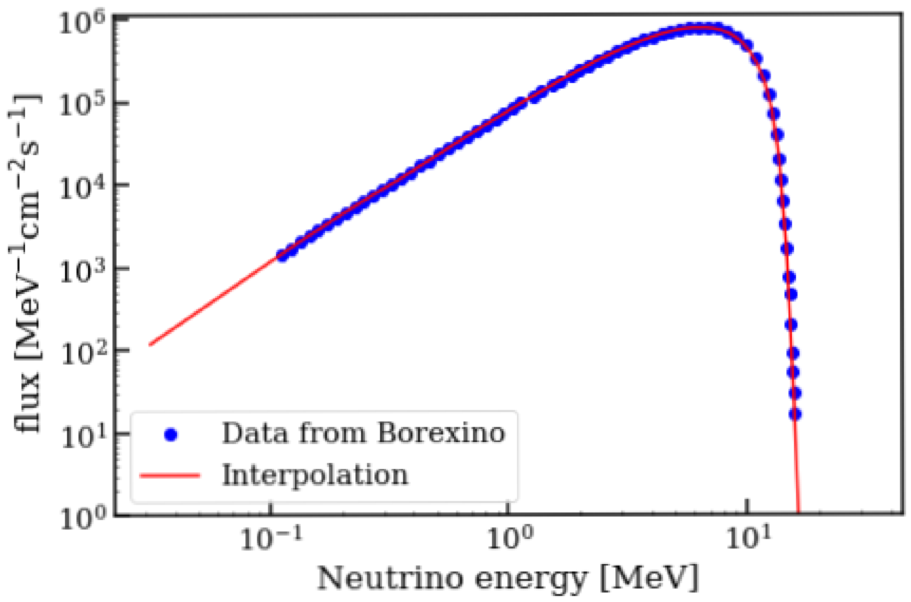
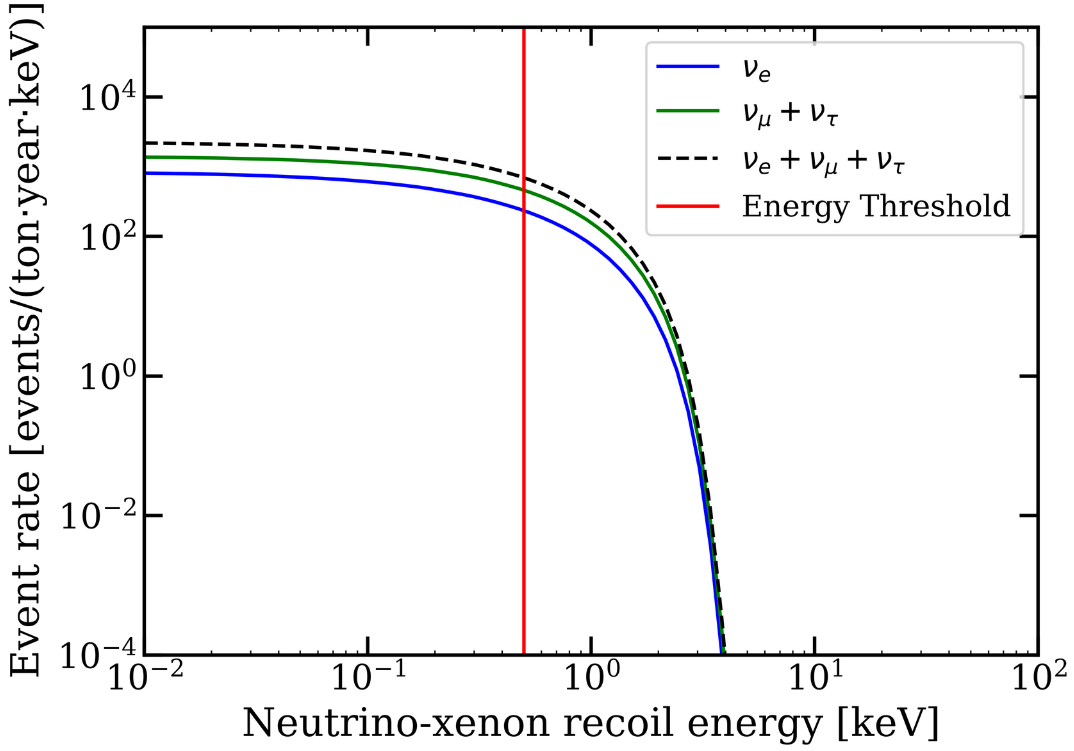
Solar Boron 8 Neutrino Flux

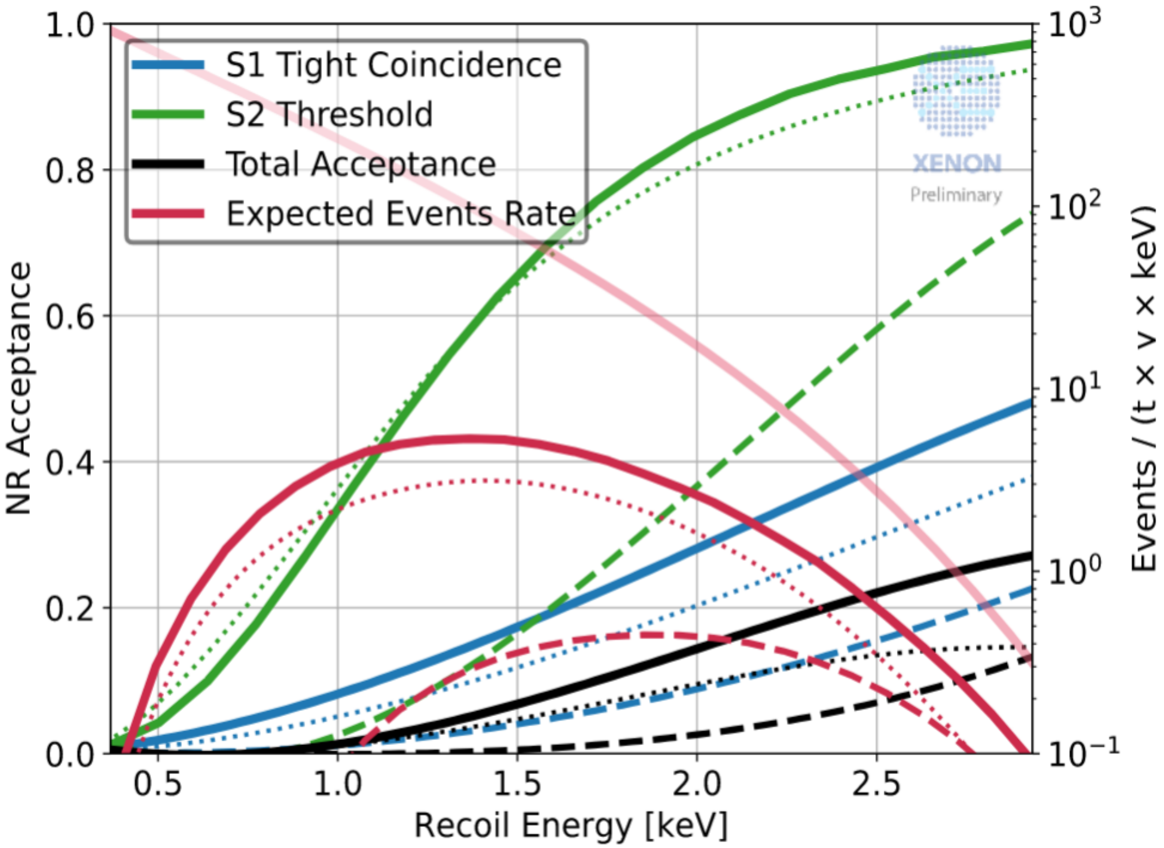


Solar Boron 8 CEvNS rate



Detection Efficiency

- Driven by **2-fold PMT coincidence for S1** (2 photons) & **S2 threshold** (100 PE)
- **Emission models** for low nuclear recoils (Light Yield & Charge Yield) from data fitting with NESTv2 parametrisation & morph parameters for yield fluctuation quantification



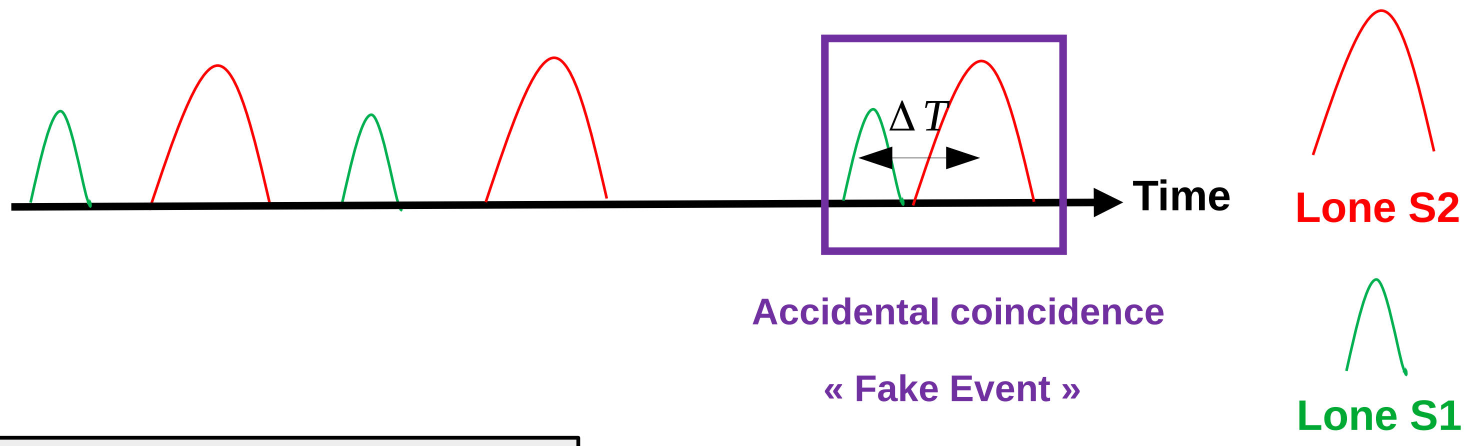
Detection Efficiency Plot

Full line → *CEνNS (nT)*
Dashed line → *Standard (nT)*
Dotted line → *CEνNS (1T)*

Accidental Coincidences (AC)

XENON

Random Pairing of lone S1 & S2 Signals by the Event Builder



Randomly distributed over time

Lone S1

- *PMT Dark Count*
- *Below Cathode and surface Events*

Lone S2

- *Single electrons*
- *Misidentified PMT afterpulse*

Lone S2 Rate

$$AC = \int R_{S1}(t) \times R_{S2}(t) \times \Delta T \times dt$$

Lone S1 Rate

Max Electron Drift Time

AC Rate

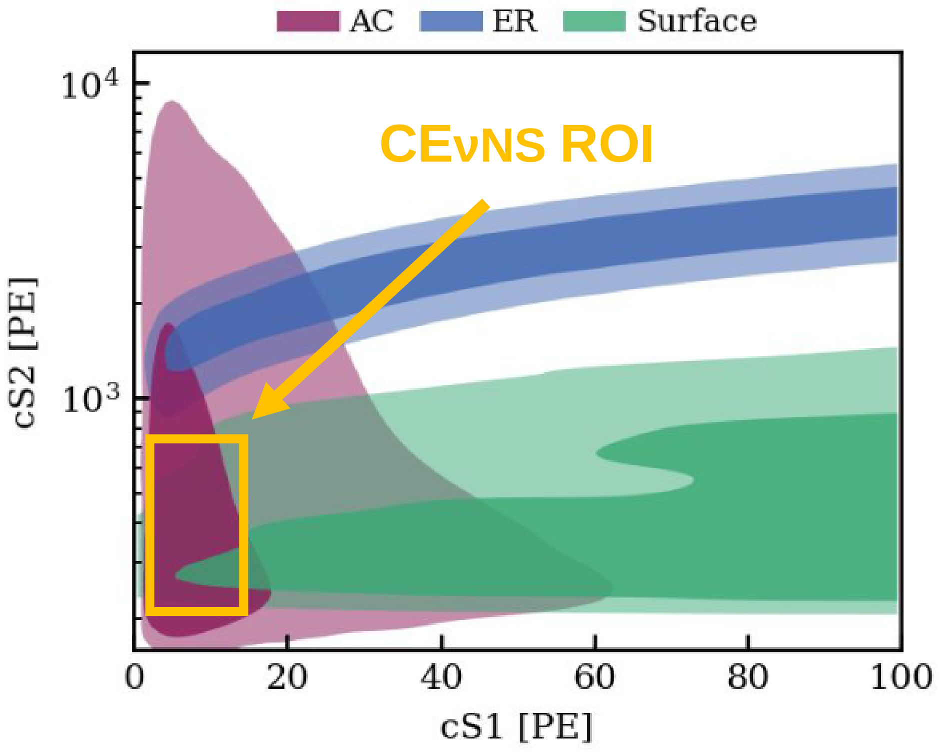
Accidental Coincidences (AC)

Science Run 0: 05 2021 – 12 2021
Science Run 1: 05-2022 - Now

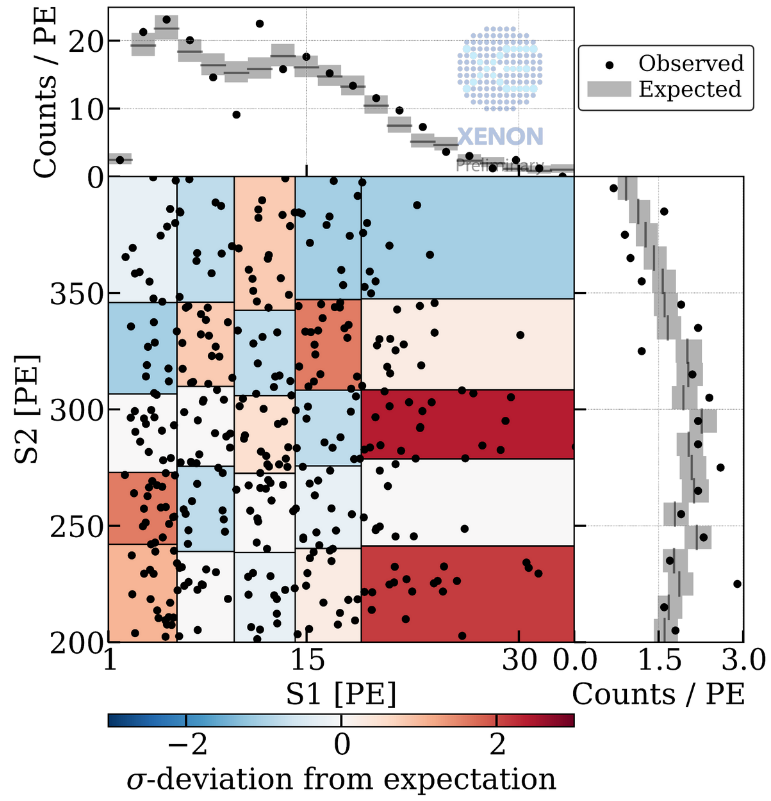
XENON

Main Background for Solar CEvNS Search

5% precision on AC in SR0



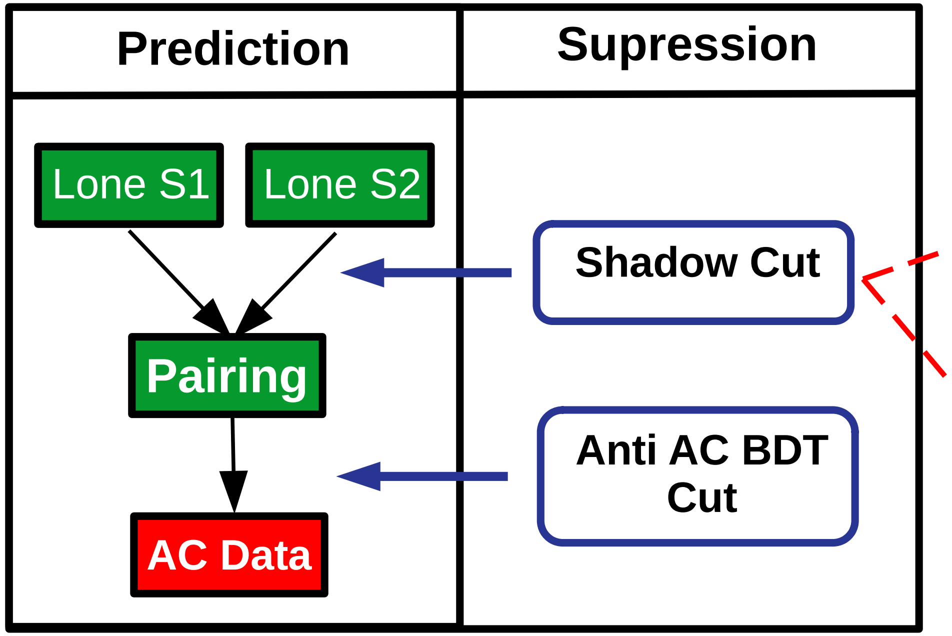
XENONnT Background in S2 vs S1 space

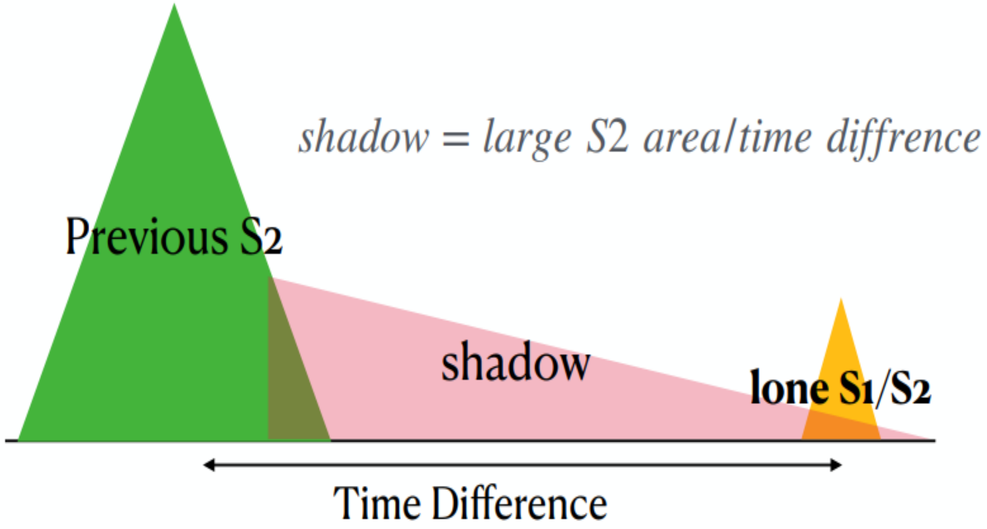


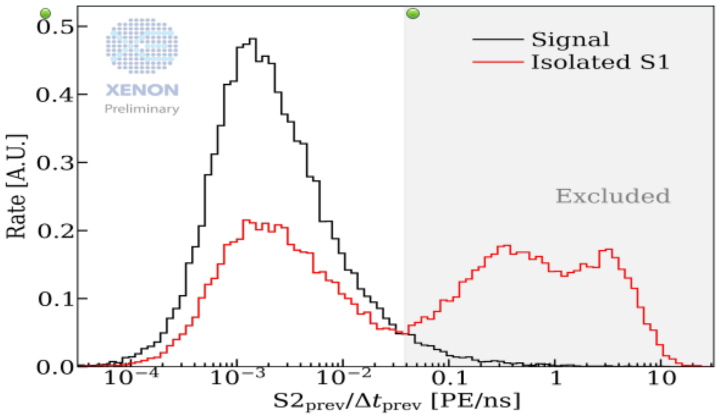
Expected AC data vs true data (Ar37)

Data Selection

- Minimum cutlist: Muon & Neutron Veto, ...
- ROI Cuts : Two fold coincidence & S2 Threshold
- Wall Background: Fiducial Cut
- S1 & S2 Quality Cuts
- Anti AC cuts: Data-driven method







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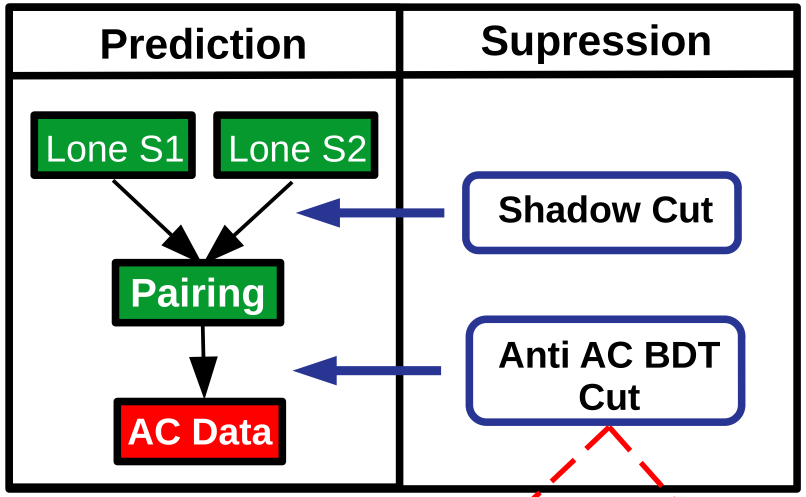

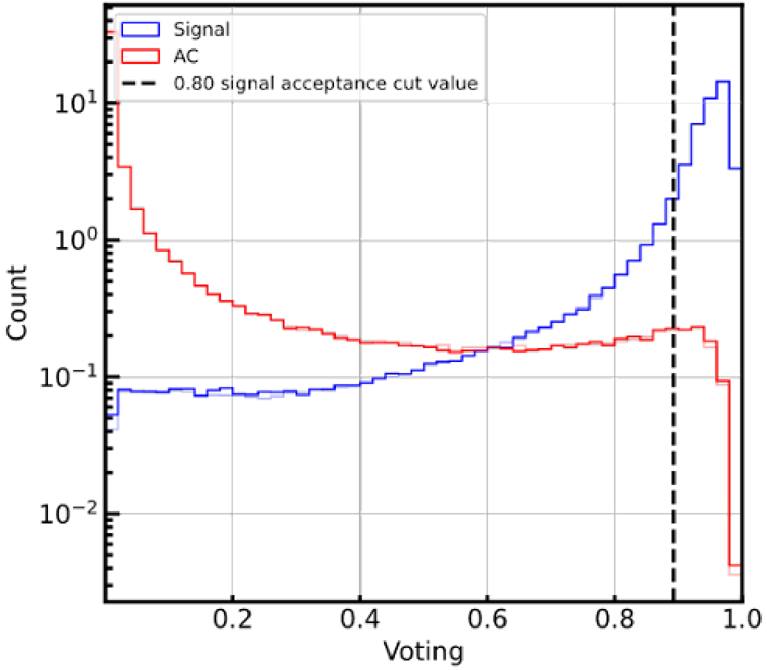

Trained AI with simulated CEvNS & AC data (5 parameters of events)

BDT cut suppress the AC background by **two orders of magnitude**, signal acceptance at ~ 80%

Conclusions & Outlook

- Current estimation of signal & backgrounds (Detector Efficiency & Cuts) per ton per year

	CEvNS	AC	NR	ER
XENONnT	4.84	10.6	0.01	0.04
XENON1T	2.11	5.14	none	0.21

XENONnT vs XENON1T

Increased Exposure

Increased Detector Efficiency

Increased AC Background

XENONnT CEvNS Status

SR0: Very advanced

SR1: Detector conditions changes (lot of work to do)

Expectations

Reach XENON1T AC

SR0+SR1 analysis for CEvNS evidence

Thank you for your attention

27 October 2023

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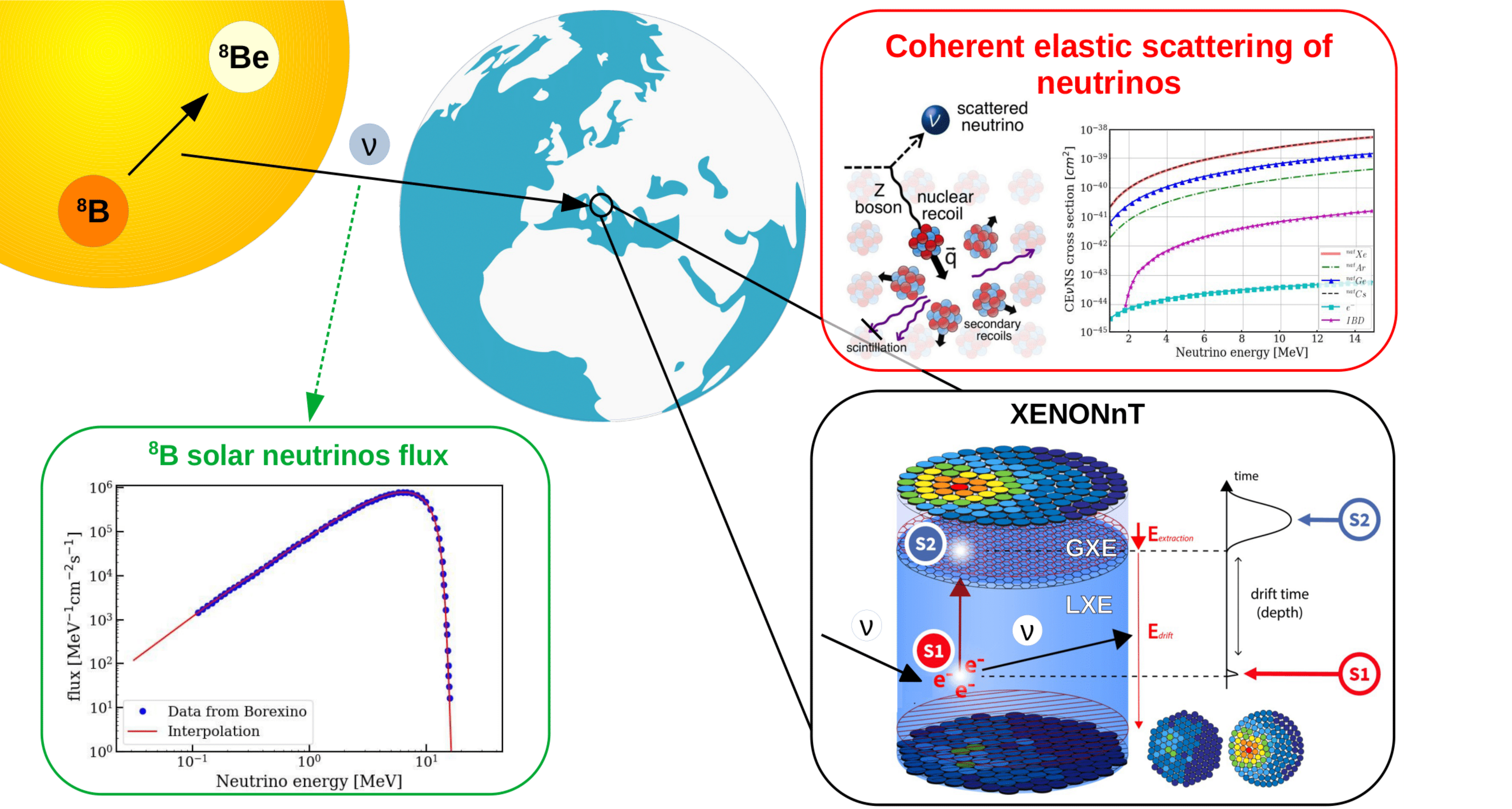

8Be
8B
ν
Coherent elastic scattering of neutrinos
scattered neutrino
Z boson
nuclear recoil
q
secondary recoils
scintillation
CEνNS cross section [cm²]
Neutrino energy [MeV]
natXe
natAr
natGe
natCs
e⁻
IBD
8B solar neutrinos flux
flux [MeV⁻¹cm⁻²s⁻¹]
Neutrino energy [MeV]
Data from Borexino
Interpolation
XENONnT
time
S2
GXE
LXE
E extraction
E drift
drift time (depth)
S1
e⁻