SCIENCES SORBONNE UNIVERSITÉ

XENON

# Solar neutrinos in XENONnT

IRN neutrinos - 17 novembre 2022

Pellegrini Quentin

## Summary

- XENONnT
- Solar neutrinos
- XENONnT first results
- XENONnT potential in neutrino physics

# The XENON Collaboration

180+ scientists
27 institutes / 11 countries

XENON

Columbia | KIT | Nikhef | Muenster | Stockholm | Mainz | MPIK, Heidelberg | Freiburg | Zurich

Chicago

UCSD

Rice

Purdue


Tsinghua

Tokyo

Nagoya

Kobe

Subatech | Coimbra | LPNHE | Torino | Bologna | L'Aquila | LNGS | Napoli | Weizmann | NYUAD

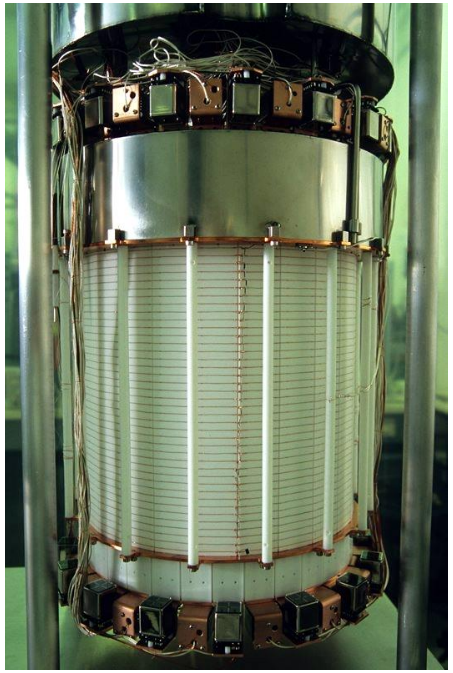
# The XENON Program

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

XENON

XENON10
2005–2007

25 kg LXe
15 cm drift length
$\sigma_{SI} \sim 9 \times 10^{-44}\ cm^2$
at 100 GeV/$c^2$ (2007)



XENON100
2009–2016

161 kg LXe
30 cm drift length
$\sigma_{SI} \sim 10^{-45}\ cm^2$
at 50 GeV/$c^2$ (2016)

XENON1T
2016–2018

3.2 t LXe
1 m drift length
$\sigma_{SI} \sim 4 \times 10^{-47}\ cm^2$
at 30 GeV/$c^2$ (2018)

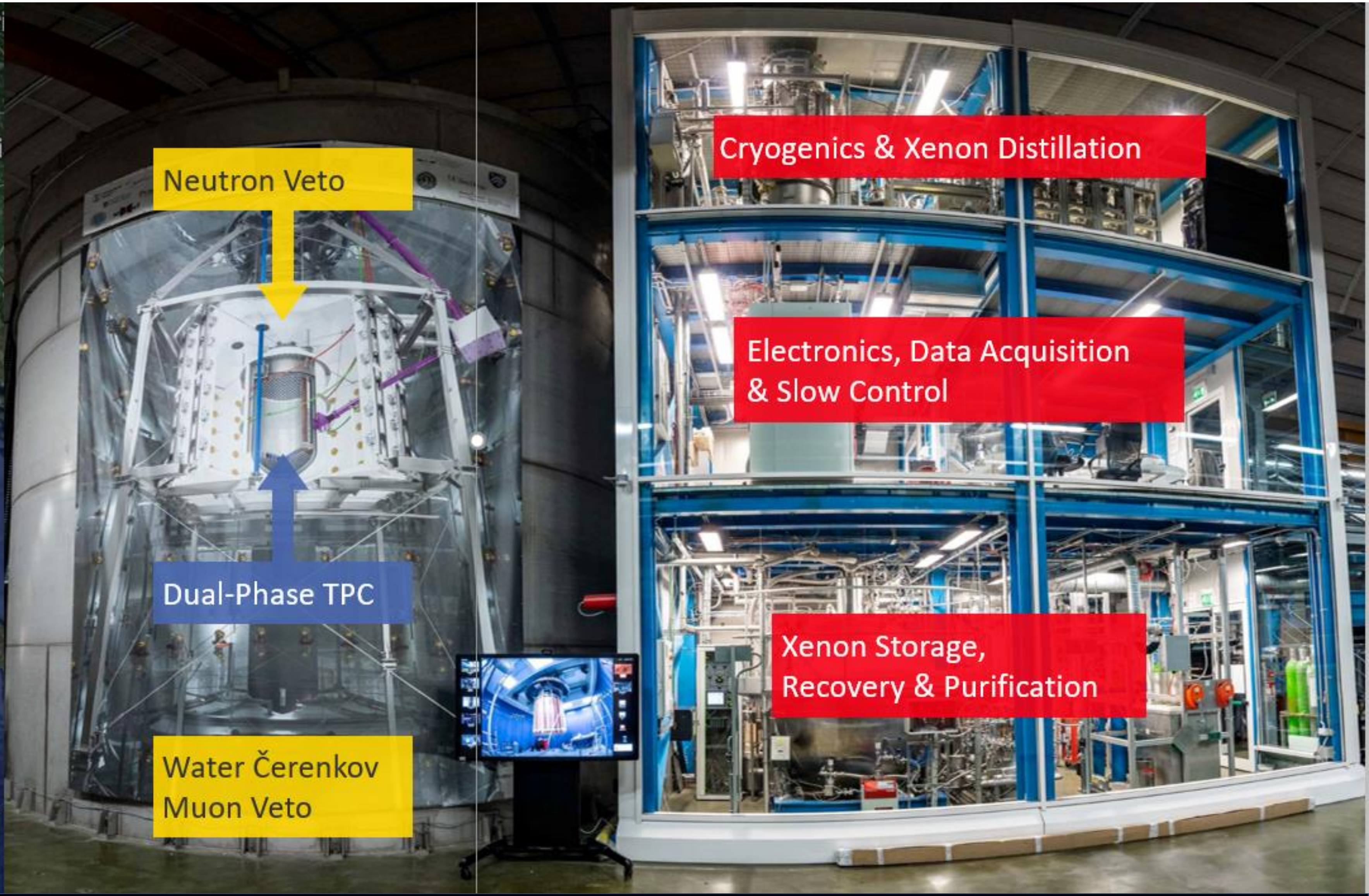
XENONnT
2020–2025

NOW

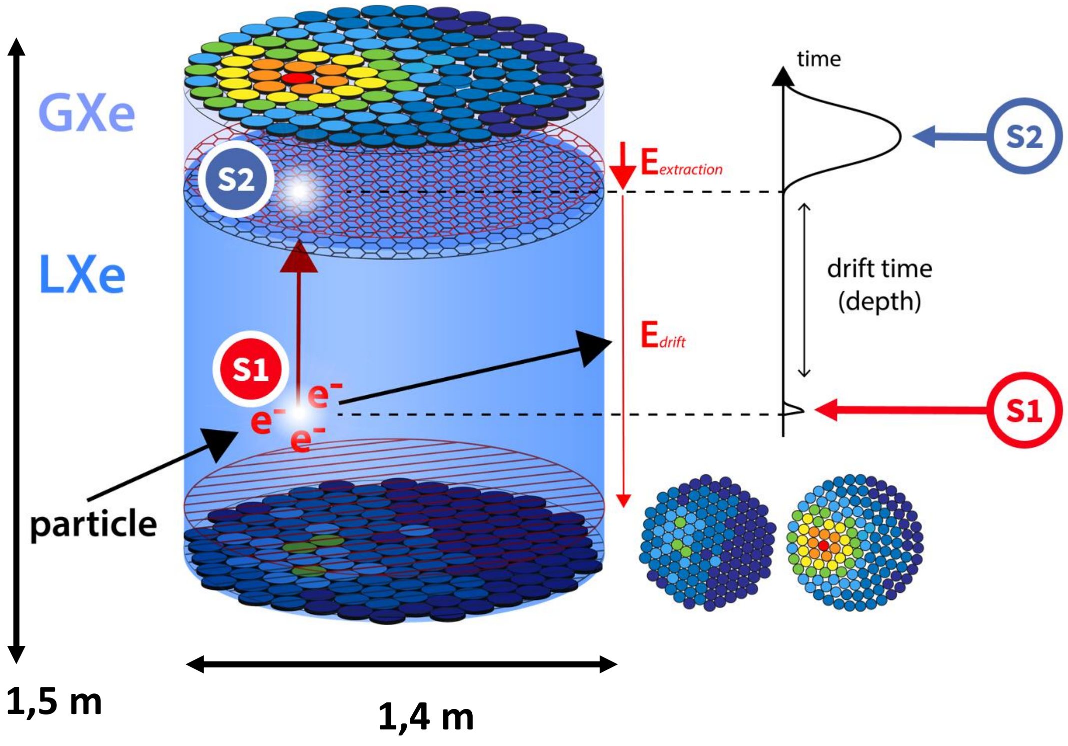
8.4 t LXe
1.5 m drift length
$\sigma_{SI} \sim 1.4 \times 10^{-48}\ cm^2$
at 50 GeV/$c^2$ (20 t $\times$ yr)

# XENONnT


Austri
Milan
Sloveni
Monaco
Croatia
Italy
Rome
Tyrrhenian Sea
Tunis
تونس
INFN


Neutron Veto
Dual-Phase TPC
Water Čerenkov Muon Veto
Cryogenics & Xenon Distillation
Electronics, Data Acquisition & Slow Control
Xenon Storage, Recovery & Purification

# Detection principle




Dual Phase Time Projection Chamber (Dual TPC)

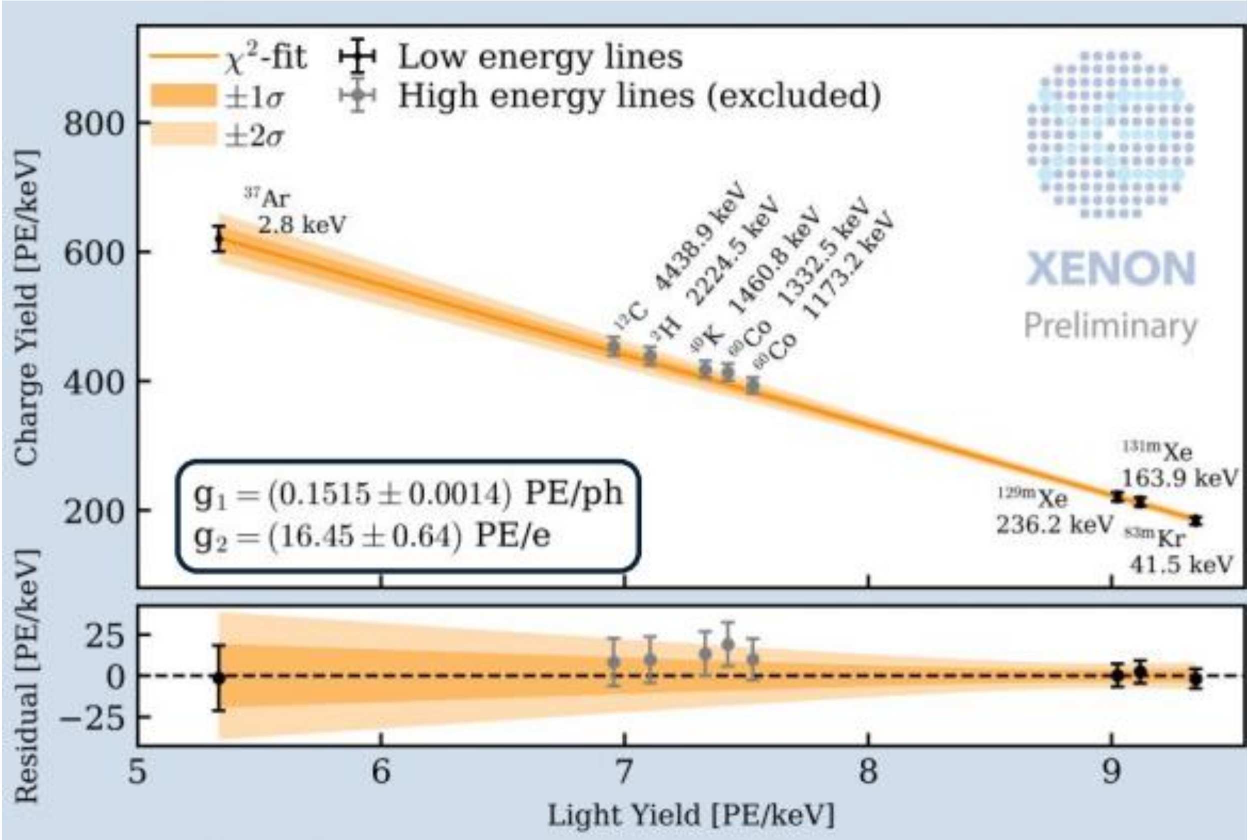
**Position reconstruction :**

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

**Energy reconstruction:**

$$E = W\left(\frac{S_1}{g_1} + \frac{S_2}{g_2}\right) \qquad \frac{S_2}{E} = -\frac{g_2}{g_1}\frac{S_1}{E} + \frac{g_2}{W}$$

*Mean quantum energy (13,5 eV)* — *Detector gain constants* — *Charge Yield* — *Light Yield*



# Particle discrimination

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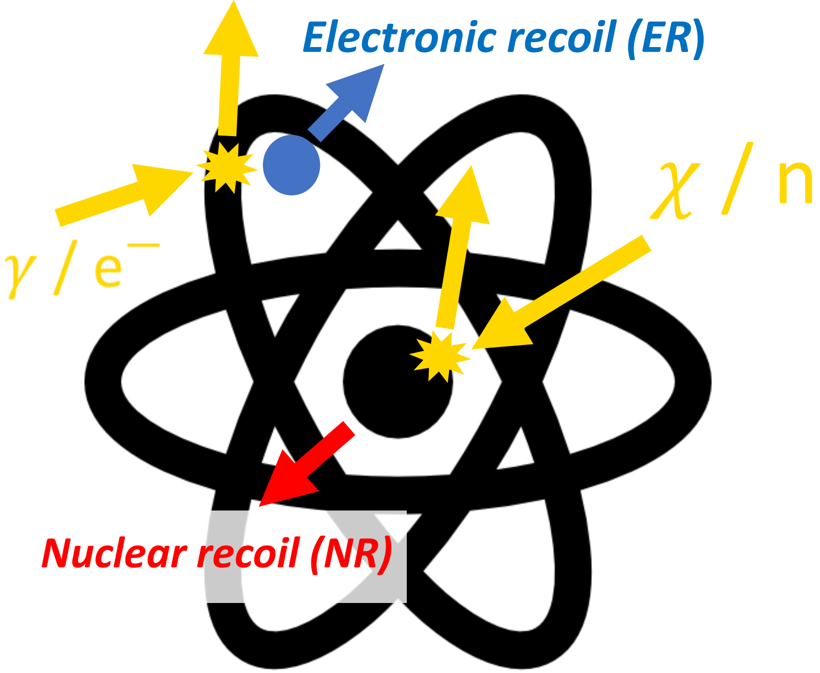
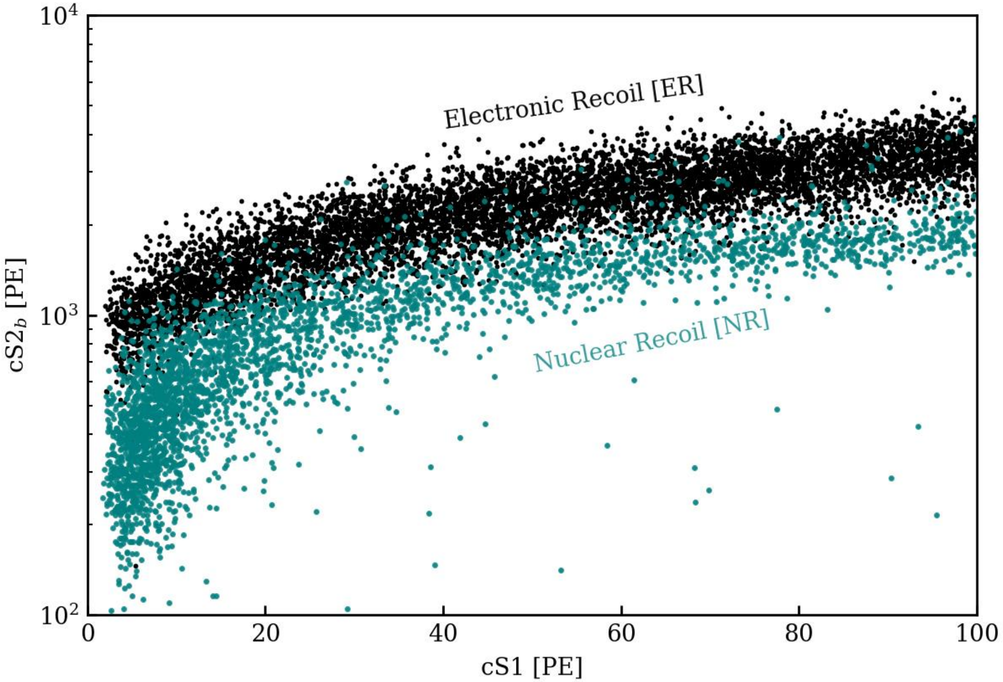
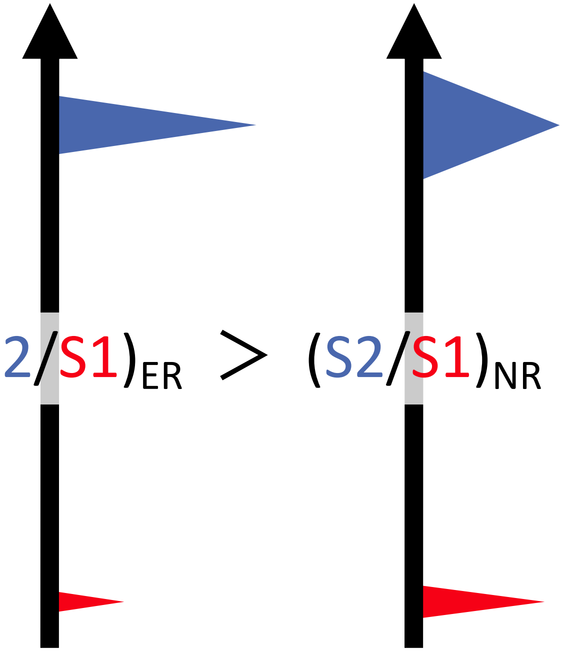



Electronic Recoil (ER) | Nuclear Recoil (NR)



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

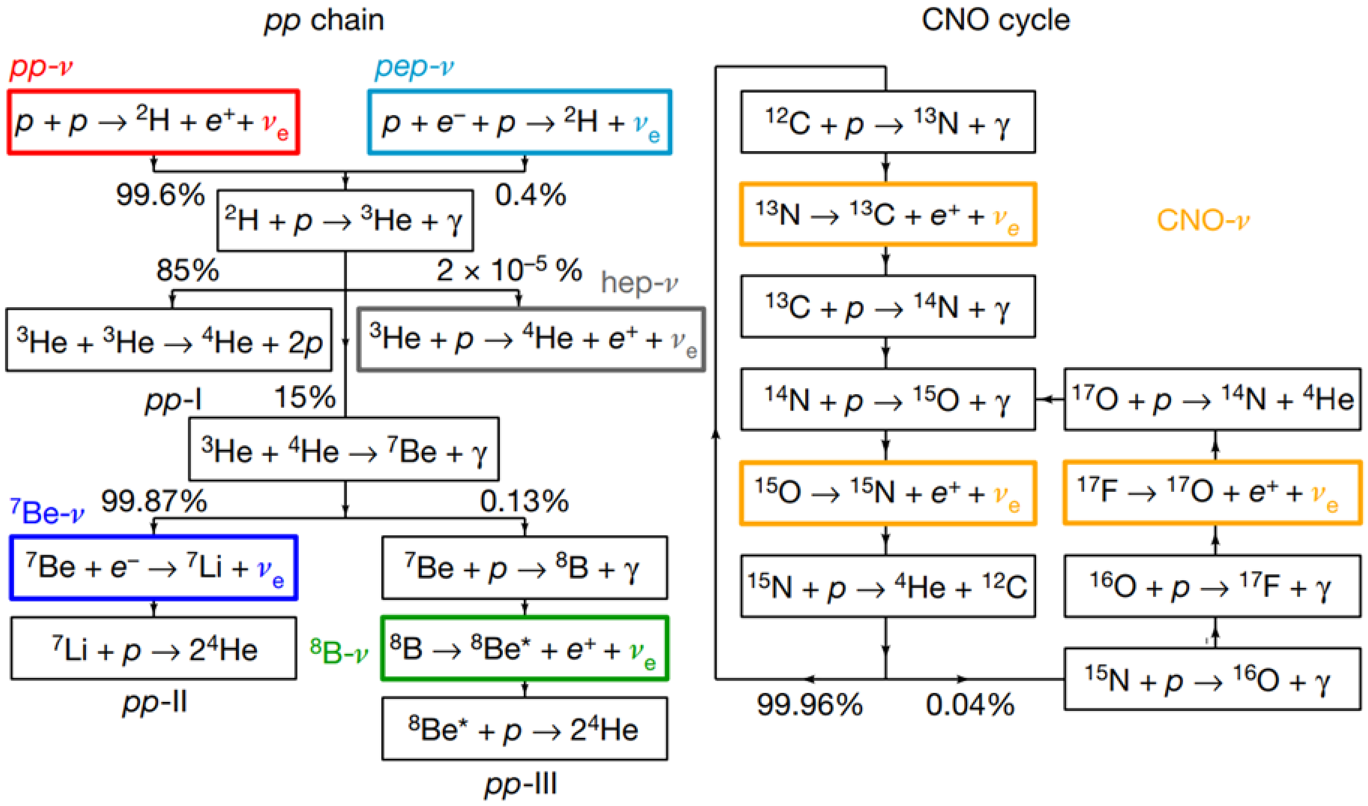
**WIMP**
**Solar neutrinos**
Supernova neutrinos

Leptophilic DM
Solar axions/ALPs
Double β decay

# Solar neutrinos

### Nuclear reaction chains in solar core

$$4\ {}^{1}H^{+} + 2\ e^{-} \rightarrow {}^{4}He^{2+} + 2\ \nu_e$$




### Solar neutrinos fluxes

**Solar standard model (SSM)**
→ **Solar internal structure**
→ **Neutrino production**

**SSM constrained parameters :**
**Solar Radius, Solar luminosity**
**Solar metallicity (Z) → Reduced recently**
**Low-Z SSM → loss of consistency with solar data → Solar abundance problem**

- **Measurements :**

**Elastic electron neutrino scattering (ES) in large active volume detector (water cherenkov, scintillator…) + solar luminosity constraint**
→ **Independent of SSM**

# Solar neutrinos

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In LXe TPC experiments, Solar neutrinos can 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

Dark matter detectors are designed to be sensible at low-energy NR, which implies good energy resolution and energy threshold for both ER and NR.

Therefore, they are suited to study neutrino signals in order to constrain neutrino physics (properties, sources, BSM…)

# XENONnT first results

**Low energy electronic recoil study [1]**

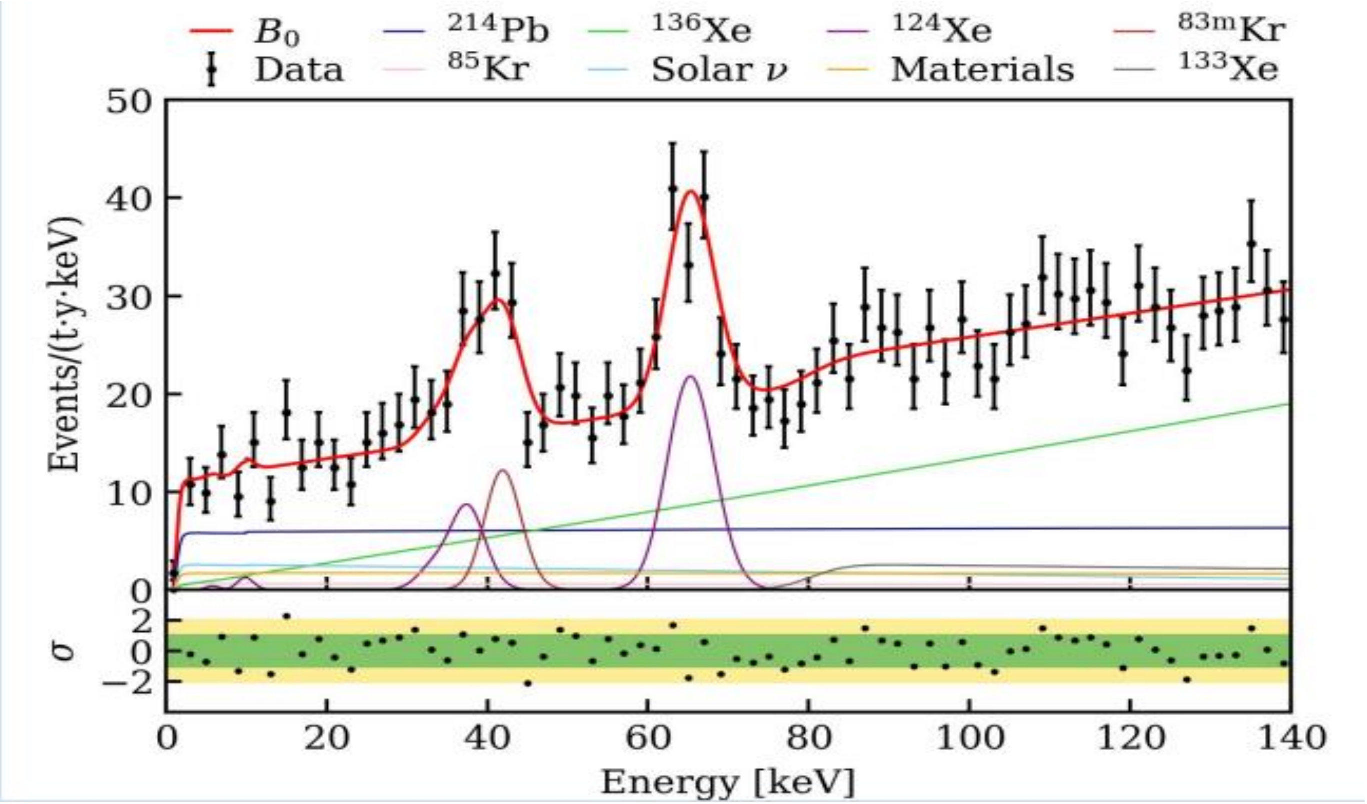
- Science Run 0, July–Nov. 2021 ~ 100 days of data (4t fiducial mass)
  → **1.16 tonne.years**

- **ROI (1-144 keV), blind analysis (< 20 keV)**

- Large part of background is constrained by external measurements

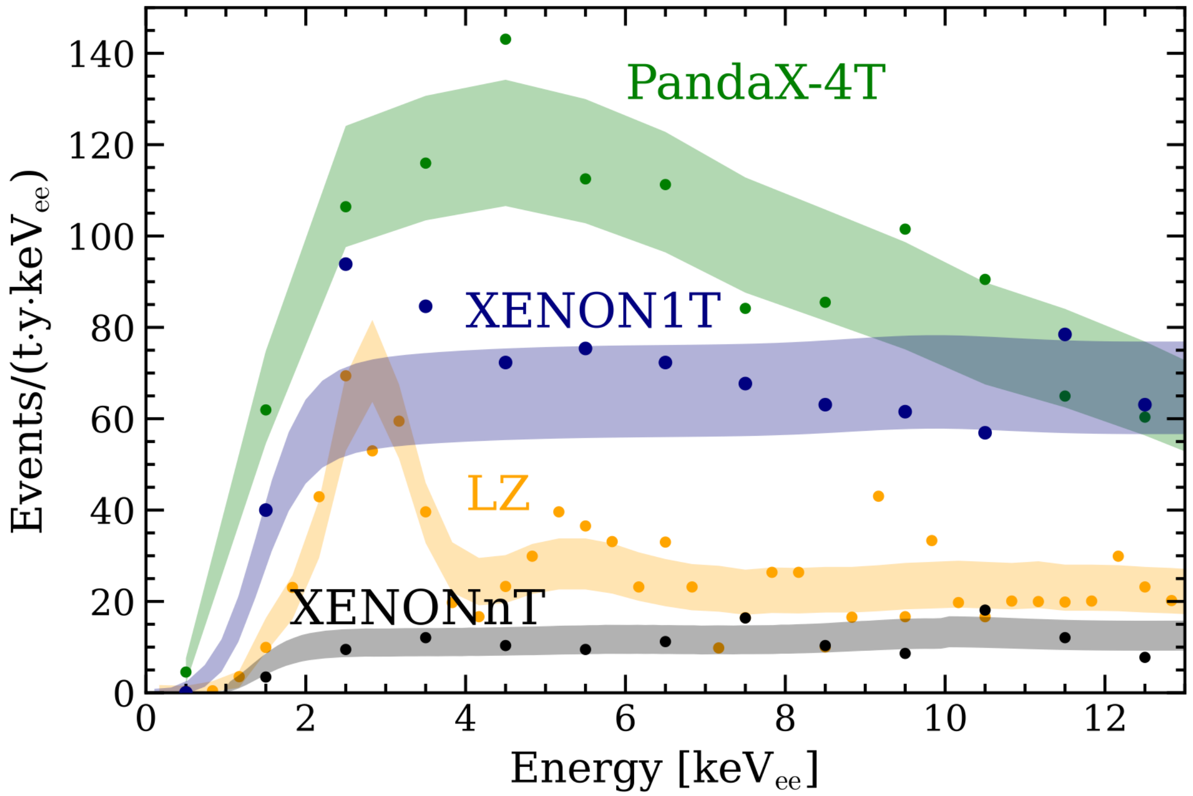
TABLE I. The background model $B_0$ with fit constraint and best-fit number of events for each component in (1, 140) keV.

| Component | Constraint | Fit |
|---|---|---|
| $^{214}$Pb | (584, 1273) | 980 ± 120 |
| $^{85}$Kr | 90 ± 59 | 91 ± 58 |
| Materials | 266 ± 51 | 267 ± 51 |
| $^{136}$Xe | 1537 ± 56 | 1523 ± 54 |
| Solar neutrino | 297 ± 30 | 298 ± 29 |
| $^{124}$Xe | - | 256 ± 28 |
| AC | 0.70 ± 0.04 | 0.71 ± 0.03 |
| $^{133}$Xe | - | 163 ± 63 |
| $^{83m}$Kr | - | 80 ± 16 |




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

# XENONnT first results




- **ER Background reduced by a factor 5** (16.1 ± 1.3 events / (tonne × year × keV) compare to XENON1T
  ➡ **Lowest ER background**

- Current $^{222}$Rn activity **1.77 µBq/kg** (7× lower than XENON1T➞ Goal : < 1 µBq/kg

- **XENON1T excess [2] excluded at 8.6σ ➞** <u>XENON1T excess likely caused by a small tritium contamination</u>


**[2]** XENON collaboration, Excess electronic recoil events in XENON1T, Phys. Rev. D 102 (2020) 072004.

# Solar ES and XENONnT

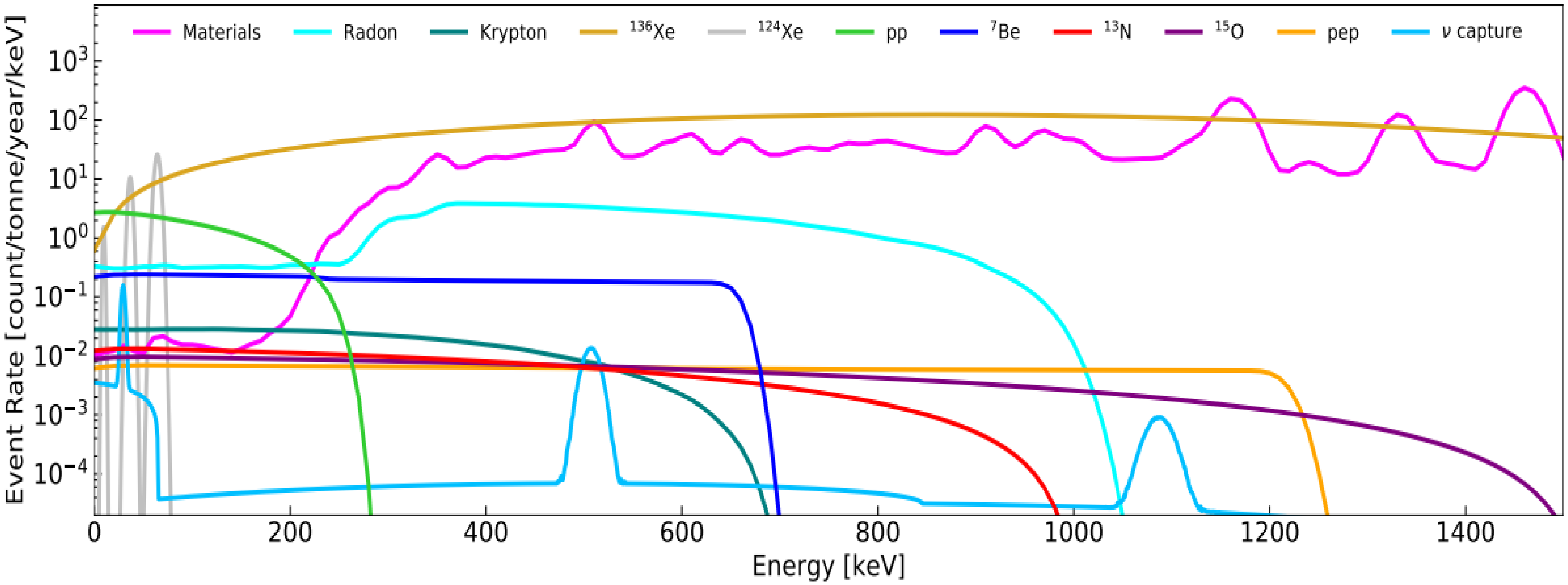
**Darwin** : Next phase of XENON Collaboration using a LXe TPC of 40 tonnes (fiducial mass of 30 tonnes).

**Darwin sensitivity paper [3] → XENONnT potential**

*Background differences*

| Background | XENONnT | Darwin |
|---|---|---|
| $^{222}$Rn activity | 1 µBq/kg | 0.1 µBq/kg |
| AC, $^{83m}$Kr | YES | NO |
| $^{85}$Kr | YES | Negligible |

*Solar neutrinos fluxes*
*High-Z SSM*




**Solar ES Integrated rate (per tonne-year) : pp (365), $^{7}$Be (133 + 7,6), $^{13}$N, $^{15}$O and pep (7).**


**[3]** DARWIN Collaboration, Aalbers J et al 2020 Solar neutrino detection sensitivity in Darwin via electron scattering Eur. Phys. J. C 80 1133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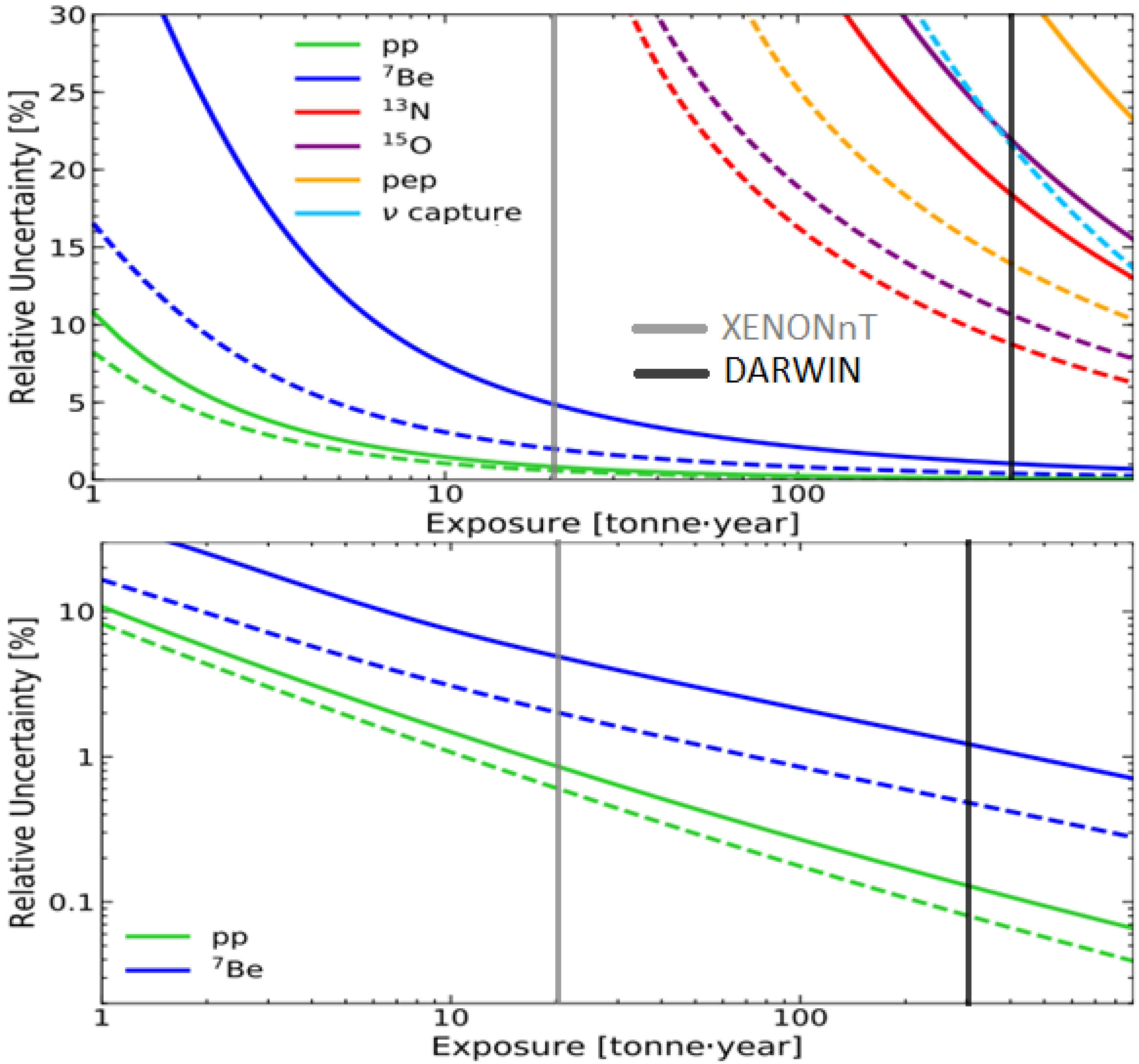
# Solar ES and XENONnT : Flux measurements




***XENONnT competitve for : pp 0,9% vs 10% (borexino)***

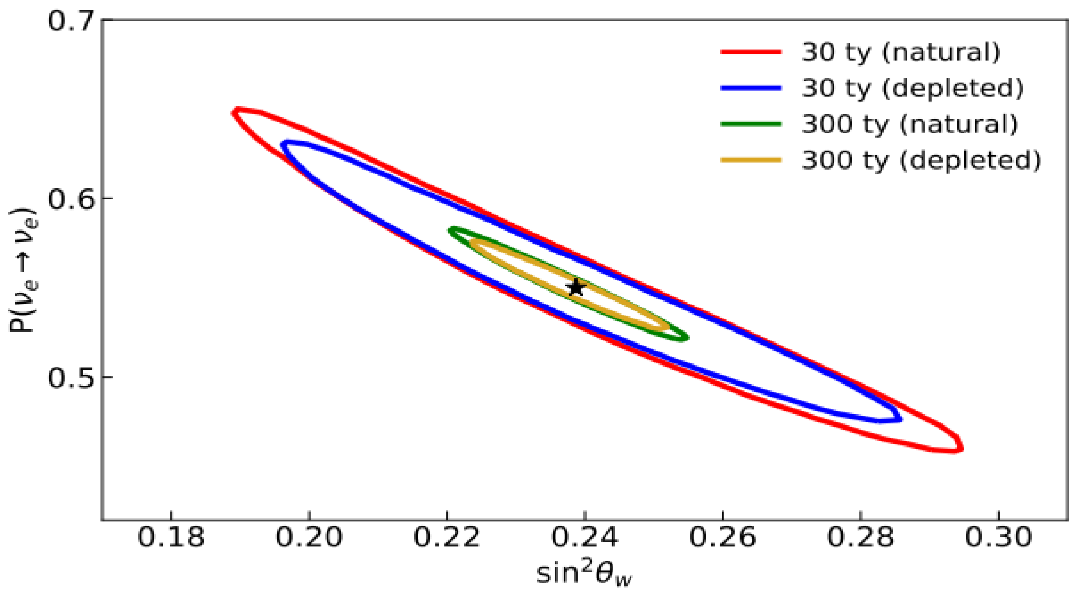
***SSM metallicity discrimination : NO [3]***

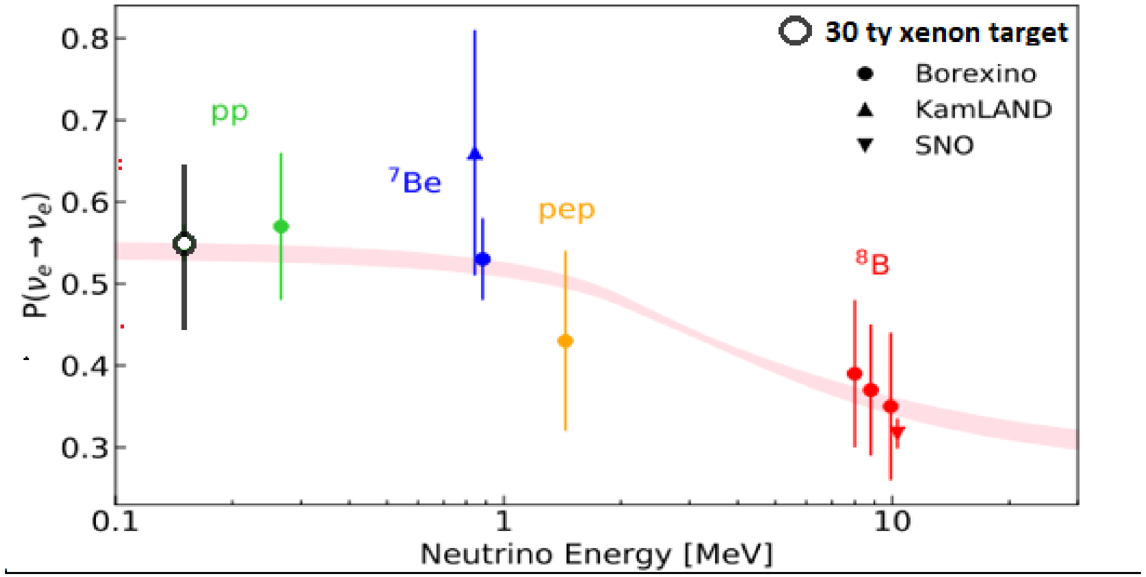
Darwin competitive for : pp 0,15%
$^{7}$Be 1,4% vs 2,7% (borexino)
$^{13}$N, $^{15}$O > 3σ detection
pep > 2σ detection (depleted case)

**SSM metallicity discrimination : > 2σ (could be increased with $^{8}$B CEvNS measurement) [3]**

**Full lines** : Xenon classic target
**Dashed lines** : depleted $^{136}$Xe target by two orders

# Solar ES and XENONnT : Weinberg angle and neutrino survival probability



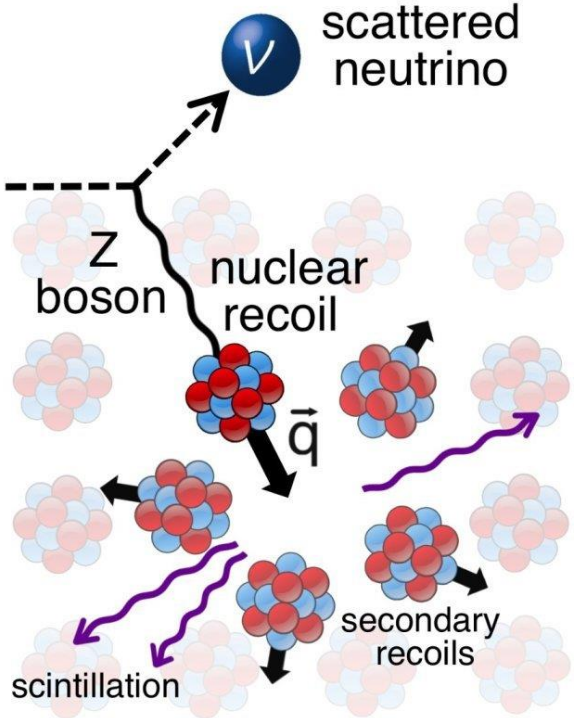




Likelihood function : $\sin^2\theta_w$, Pee are free to vary
Solar Flux scales are fixed

First measurement of Pee and $\sin^2\theta_w$ in [0-200] keV area

# CEvNS : Reminders

- **First observation of coherent elastic neutrino-nucleus scattering (CEvNS) at 6,7σ by COHERENT experiment in 2017 at the Spallation Neutron Source (SNS)**




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

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

**Low-energy NR events**

# CEvNS : Astrophysicals CEvNS and Dark matter search

**Astrophysicals CEvNS :**

➡ Irreducible NR background

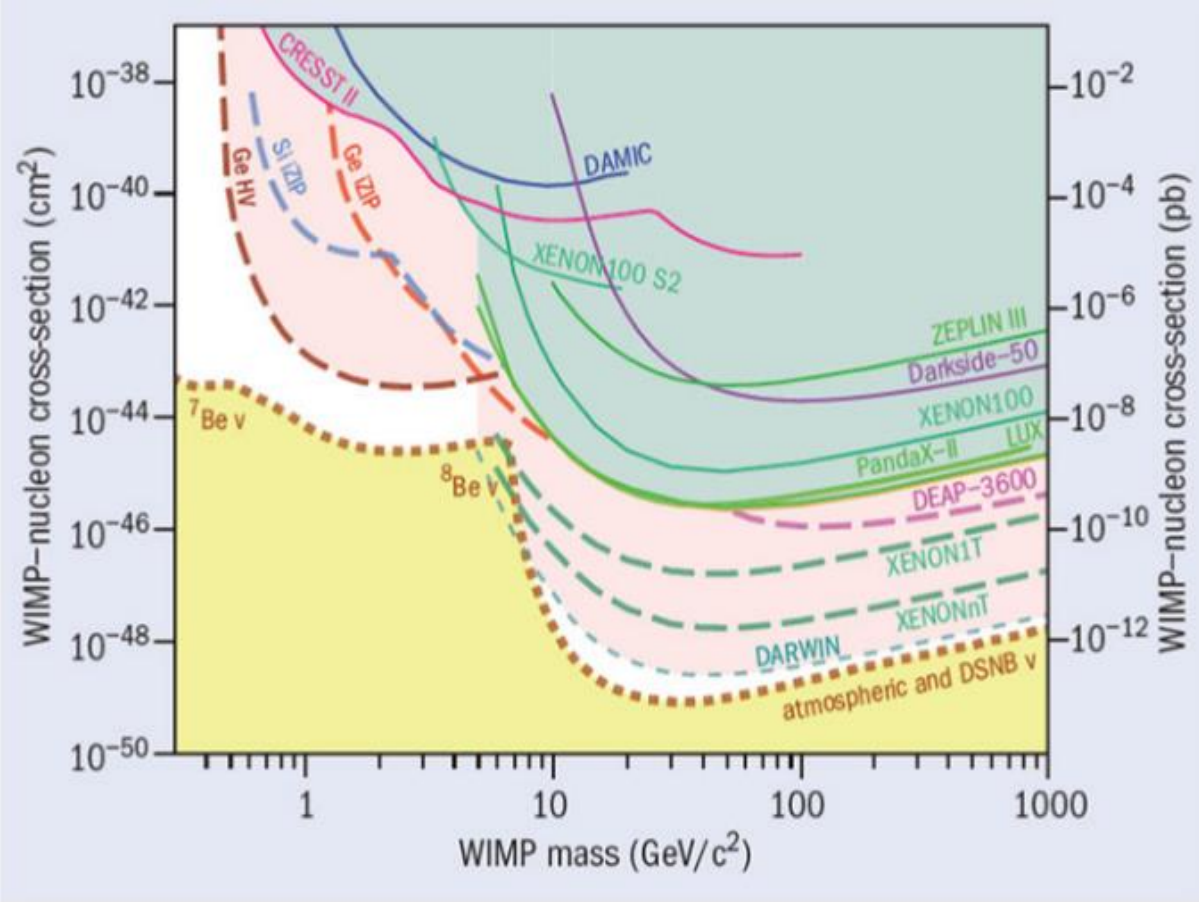
➡ WIMPs Sensitivity limits, **Neutrino Floor (red dotted line).**

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

**CEvNS and solar neutrinos**

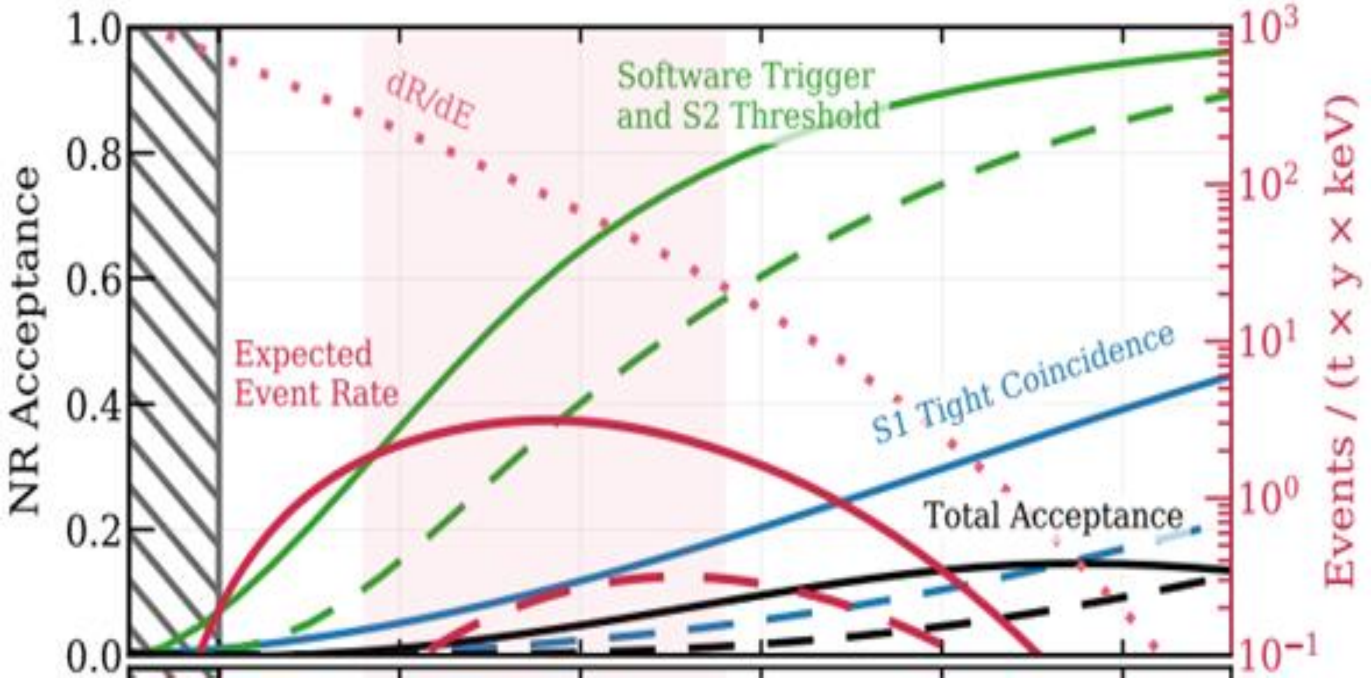
- **Background for Low-WIMPs mass (< 10 GeV)**

- **In our ROI (>10eV), only $^{8}$B-ν counts (pp III chain).**




Sensitivity of DM experiments in function of WIMPs (DM candidate) mass

# CEvNS : XENON1T results




**Full lines** : CEvNS XENON1T analysis **[4]**
**Dashed lines** : DM analysis

### 0,6t.y exposure result

| AC | ER | Total BG | CE$\nu$NS | Data |
|---|---|---|---|---|
| 5.14 | 0.21 | 5.38 | 2.11 | 6 |

**Accidental Coincidence (AC)** : Pairing of single S1s (lone PMT hits pile up) and S2s (TPC surface event) simuling a physical events.

Main background for CEvNS Analysis

### XENONnT CEvNS analysis

- Improve AC Background rejection
- Improve Ly and Qy model for low NR recoils
- 20 ty exposure (30 times XENON1T analysis)


**[4]** XENON Collaboration, Aprile E et al 2020 Search for coher ent elastic scattering of solar 8B neutrinos in the XENON1T dark matter experiment Phys. Rev. Lett. 126 091301

# Thank you for your attention

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