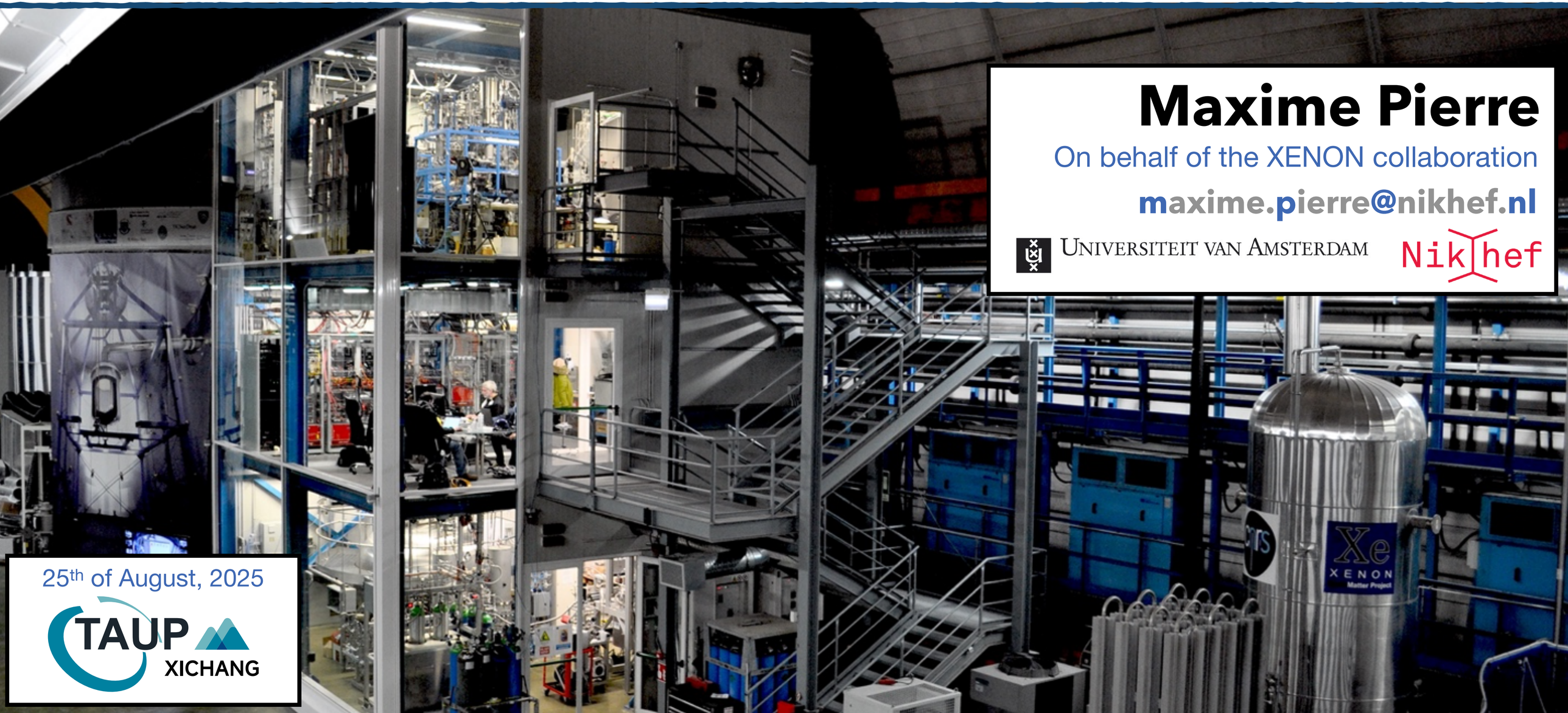
WIMP results from XENONnT with 3.1 tonne x year of exposure



Maxime Pierre

On behalf of the XENON collaboration

maxime.pierre@nikhef.nl

Universiteit van Amsterdam

Nikhef

25th of August, 2025

TAUP XICHANG

The XENON Program

Maxime Pierre
maxime.pierre@nikhef.nl

XENON

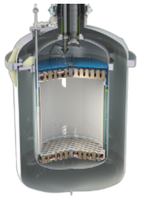
Timeline

2006

XENON10
25 kg LXe
58.6 livedays
BG: 600 / (t.d.keV)

2008

XENON100
160 kg LXe
477 livedays
BG: 5.3 / (t.d.keV)



2015

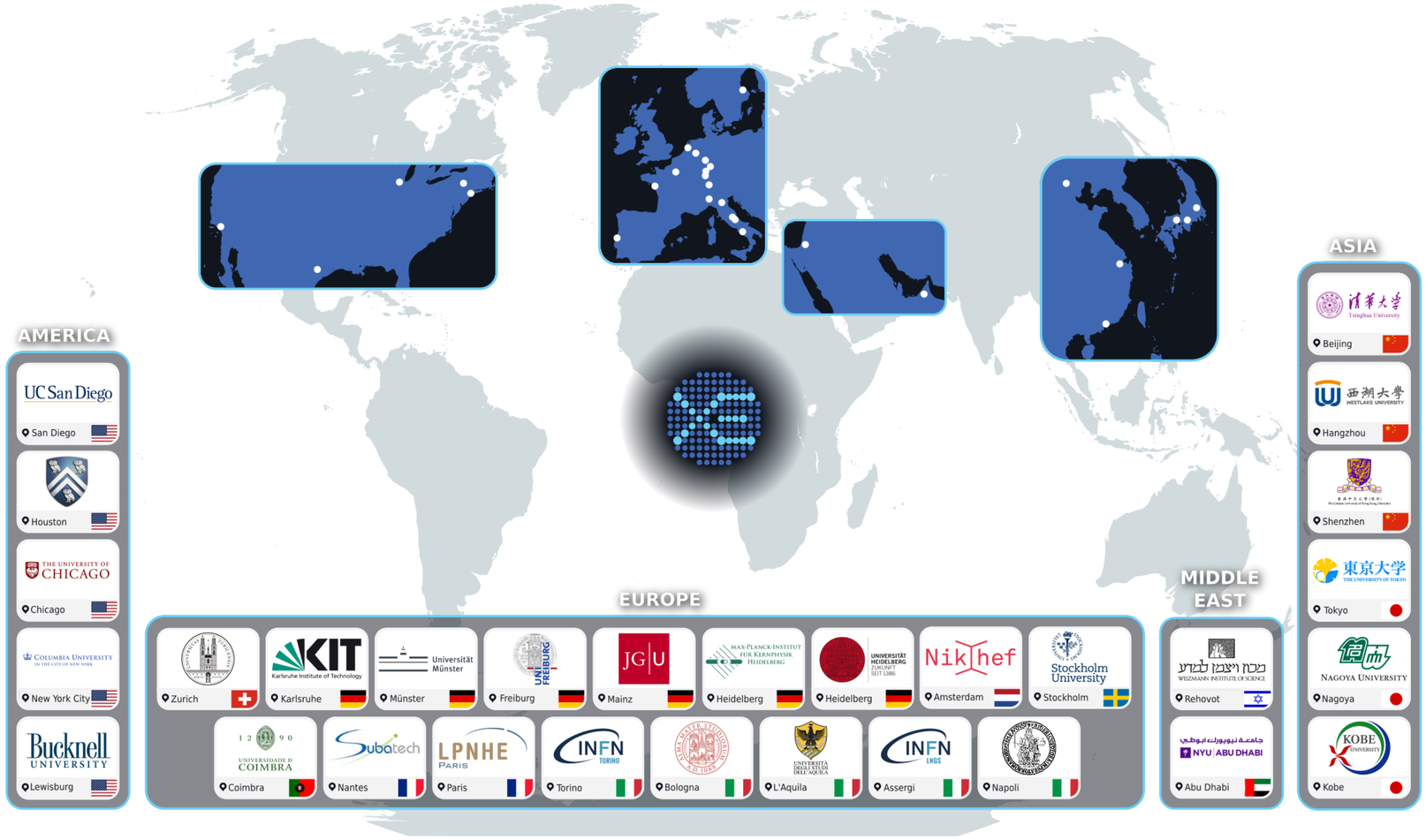
XENON1T
3200 kg LXe
279 livedays
BG: 0.2 / (t.d.keV)

2020

XENONnT
8600 kg LXe
300+ livedays
BG: 0.04 / (t.d.keV)

(ongoing)

Lowest ER background level ever achieved in LXe based experiment



200+ Scientists

30 Institutions

12 Countries

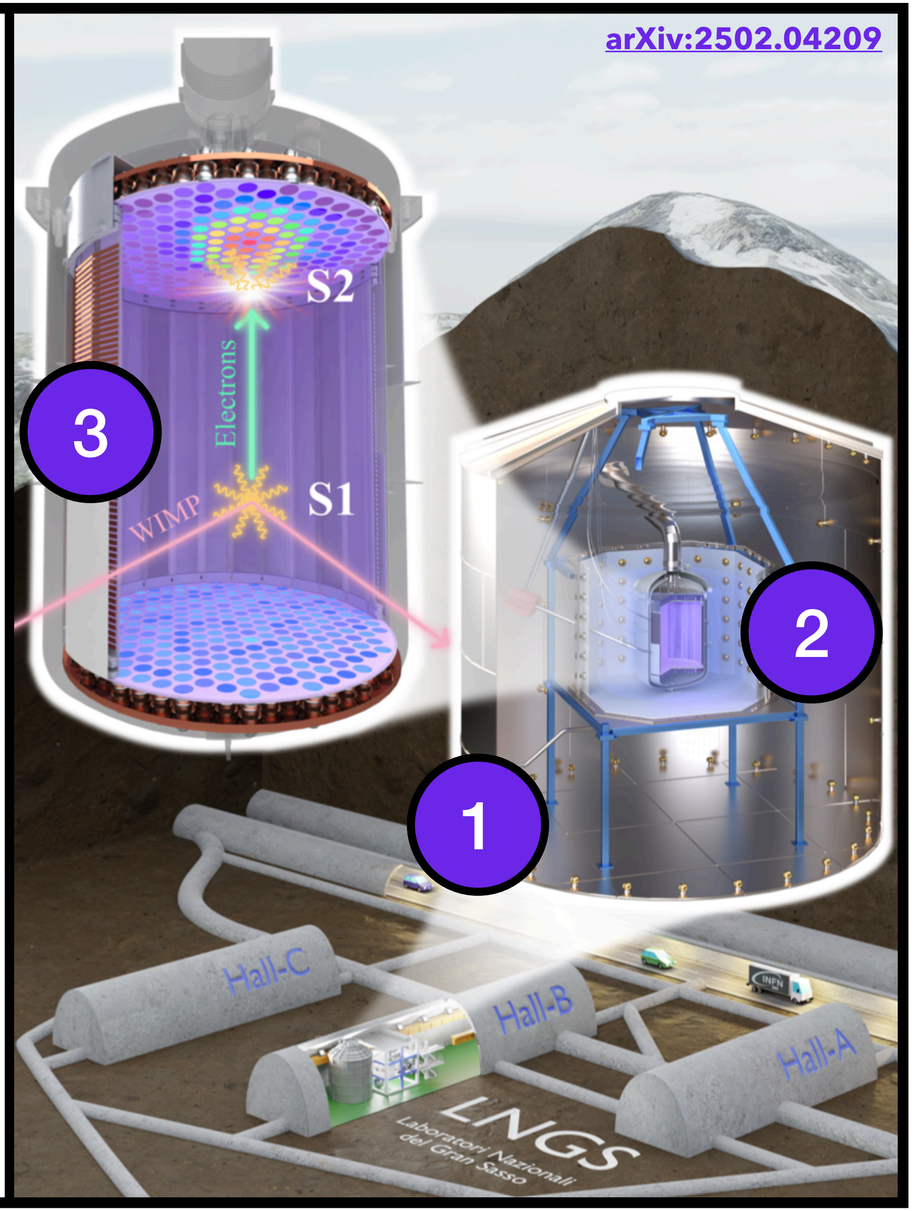
XENONnT Experiment

Maxime Pierre
maxime.pierre@nikhef.nl

Dark Matter (DM) direct search with liquid xenon

Deep Underground @ INFN Laboratory Nazionali Del Gran Sasso in Italy
1.4 km depth - 3600 mwe

3 Nested Detectors Inside 700 t Water Tank



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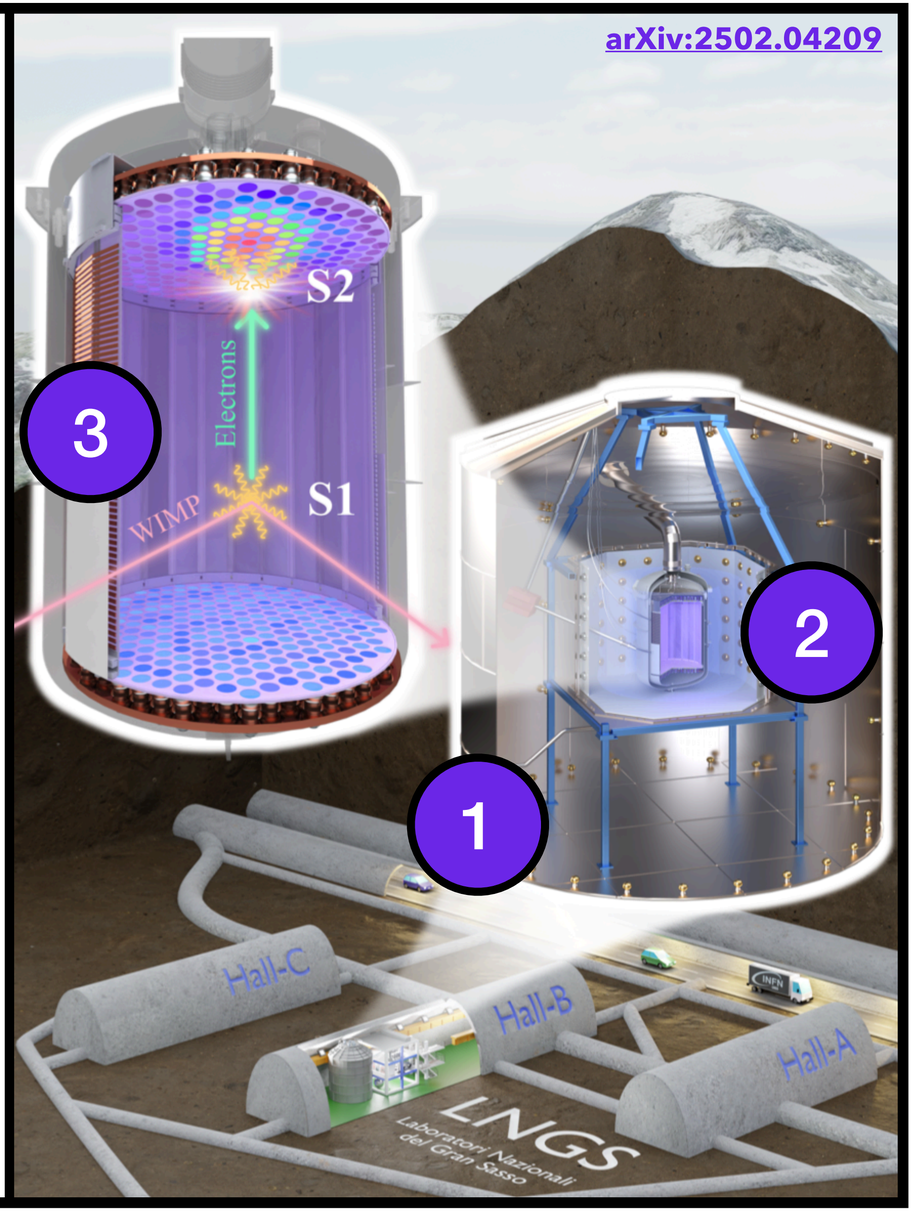
1 Muon Veto

Active Gd-water Cherenkov muon veto: muon-induced neutrons

Passive veto: **ɣ** and **n** from **natural radioactivity**

84 8" high-QE **PMTs**

JINST 9, P11006 (2014)



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JINST 9, P11006 (2014)

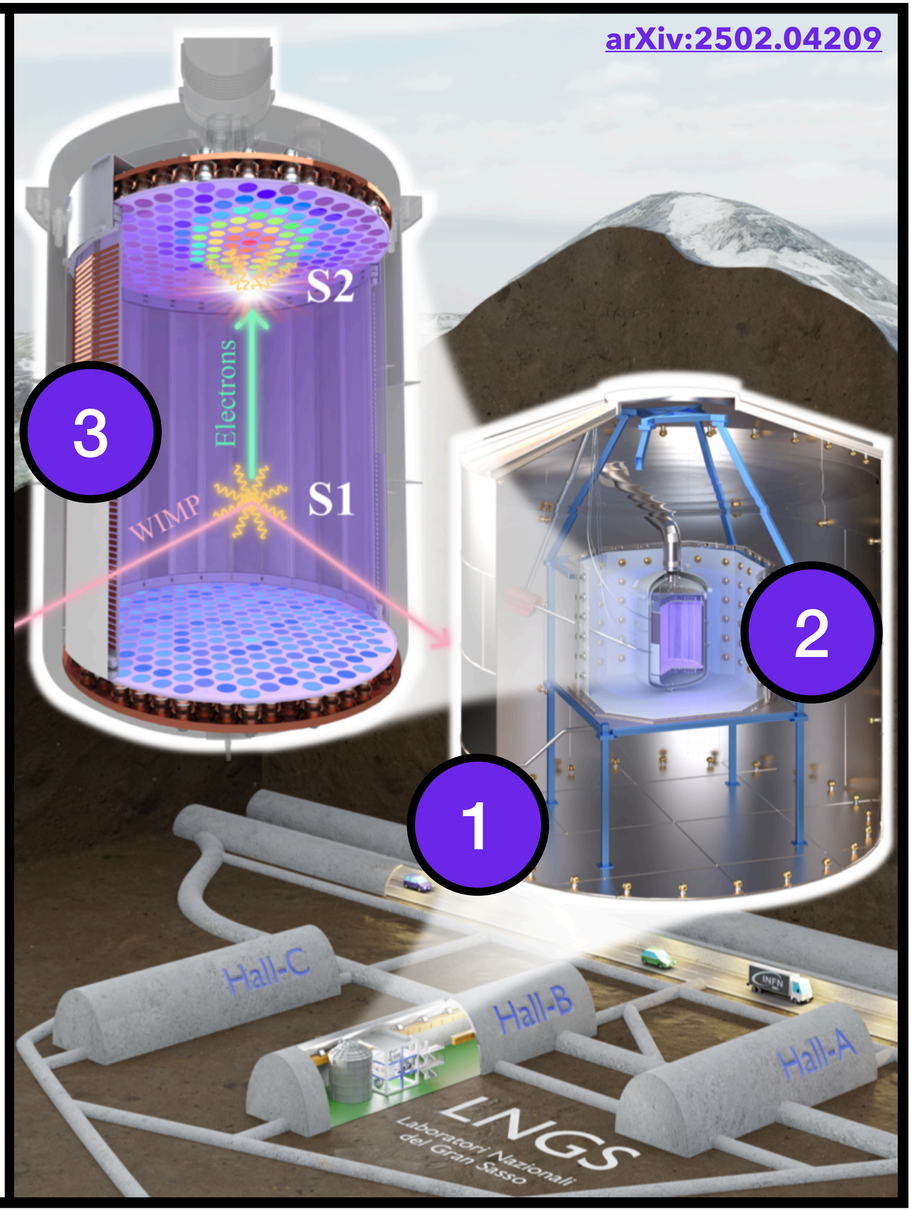
2 Neutron Veto

Active Gd-water Cherenkov neutron veto: radiogenic neutrons

33 m³ volume around cryostat

120 8" high-QE **PMTs**

Eur. Phy. J. C 85 (2025) 695



XENONnT Experiment

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Eur. Phy. J. C 85 (2025) 695

3 Time Projection Chamber

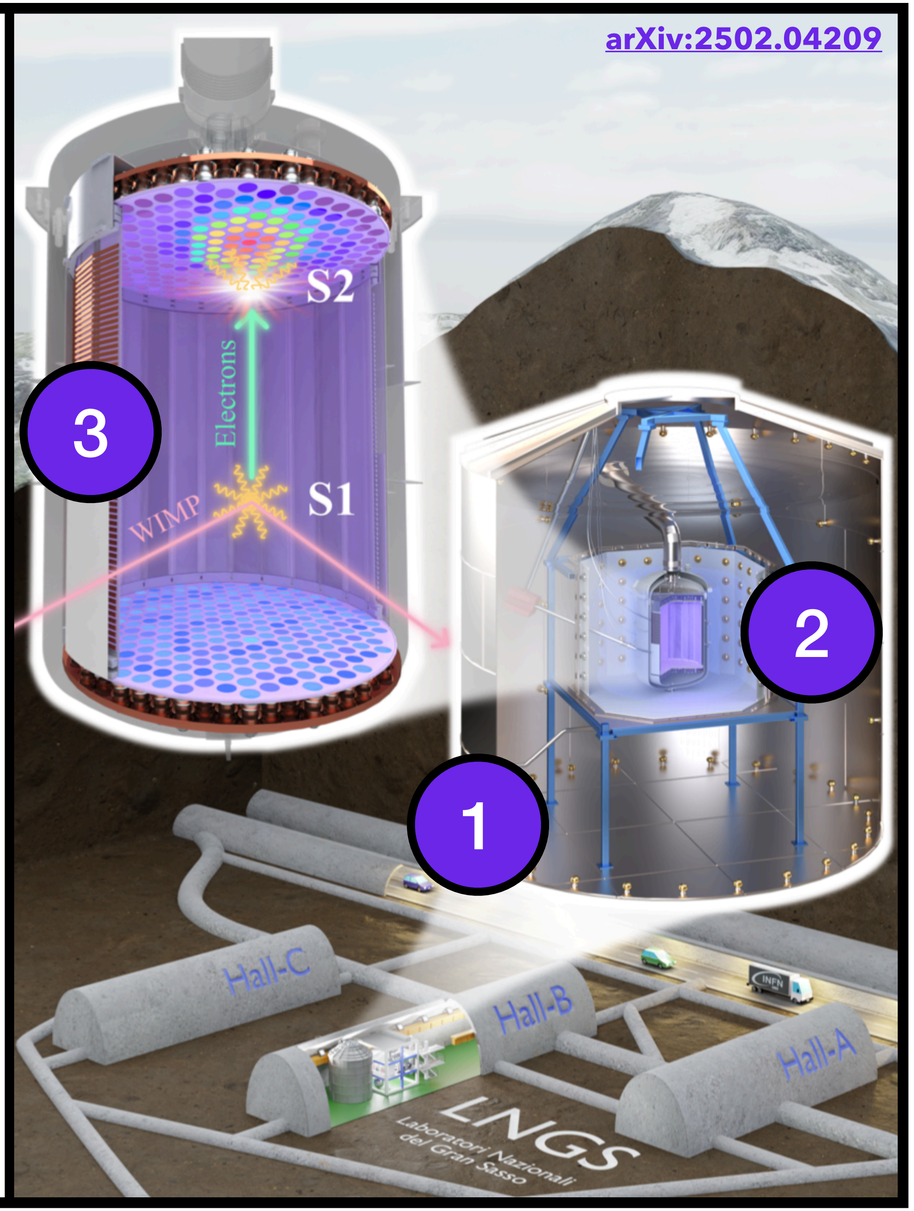
Dual-phase Xe TPC

5.9 t active target,
8.6 t total mass

1.5 m drift length,
1.3 m diameter

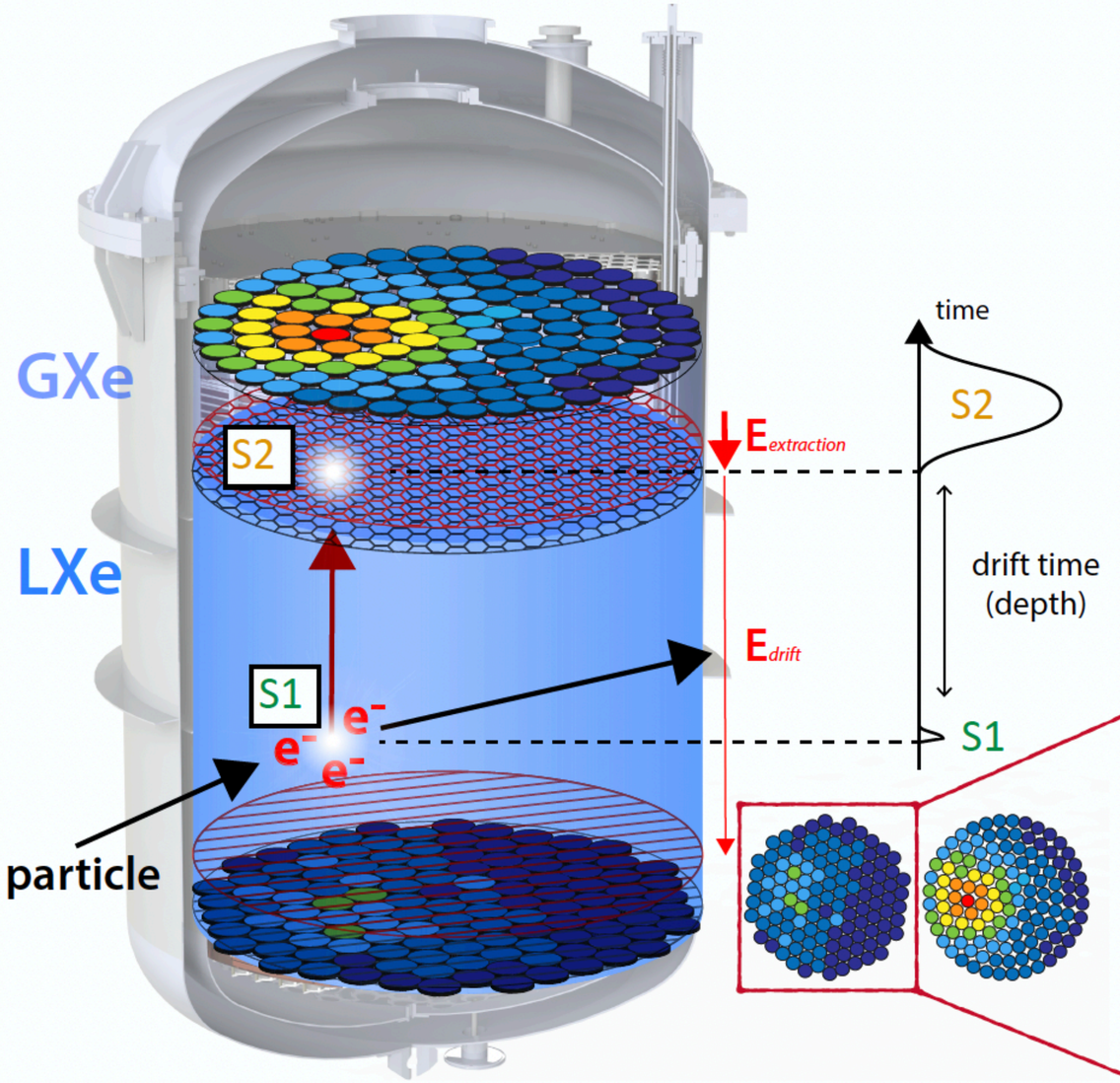
494 3" **PMTs**

Eur. Phy. J. C 84 (2024) 784



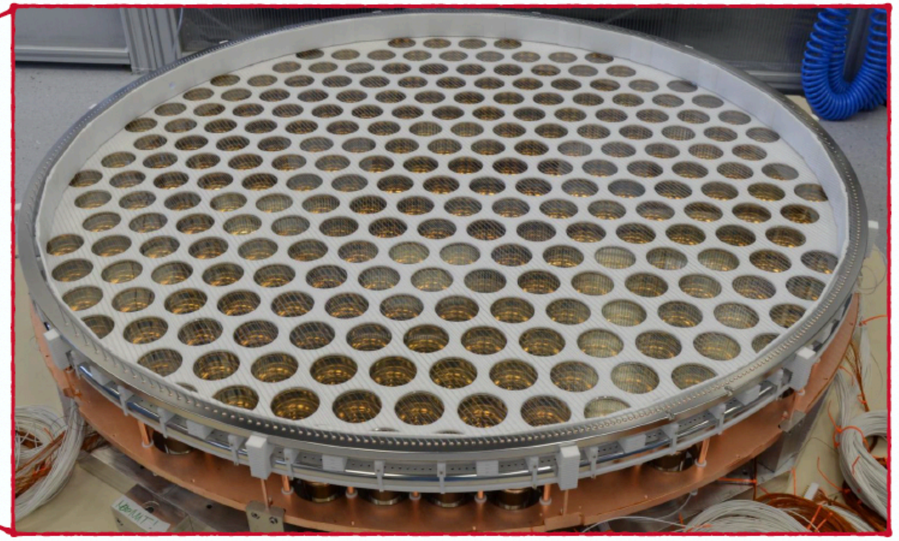
XENON TPC in a nutshell

Maxime Pierre
maxime.pierre@nikhef.nl



Light and Charge readout

- Prompt scintillation signal (**S1**)
- Secondary proportional scintillation signal in GXe from drifted electrons (**S2**)



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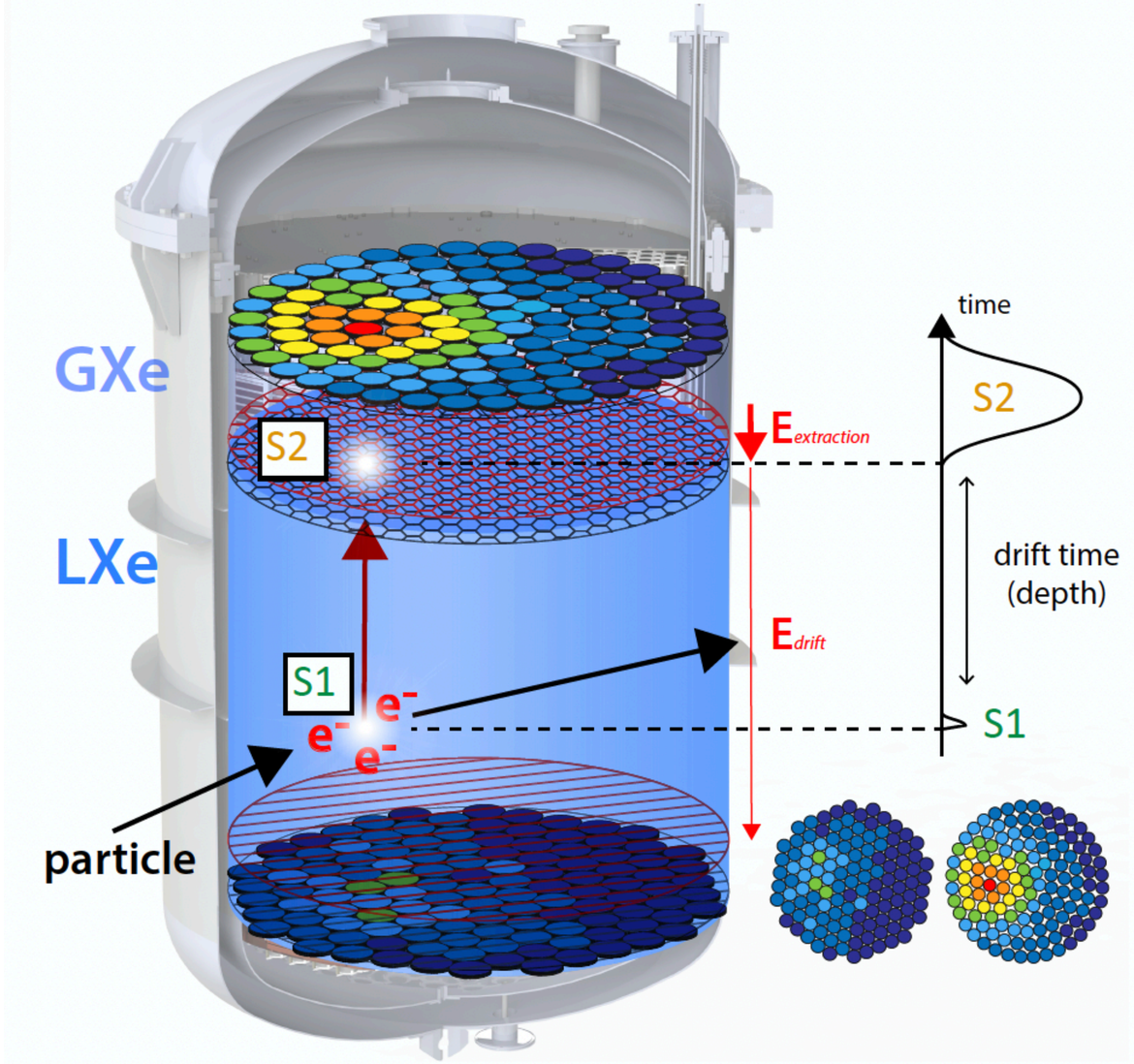

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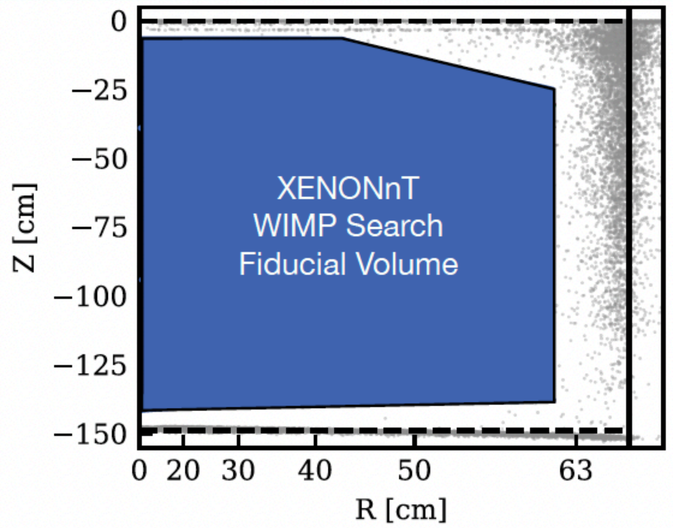
Event reconstruction

- **3D Position:**
  - **Z** from drift time
  - (**X**, **Y**) from PMTs hit pattern
- **Energy** → $E = W \cdot (n_{ph} + n_e)$



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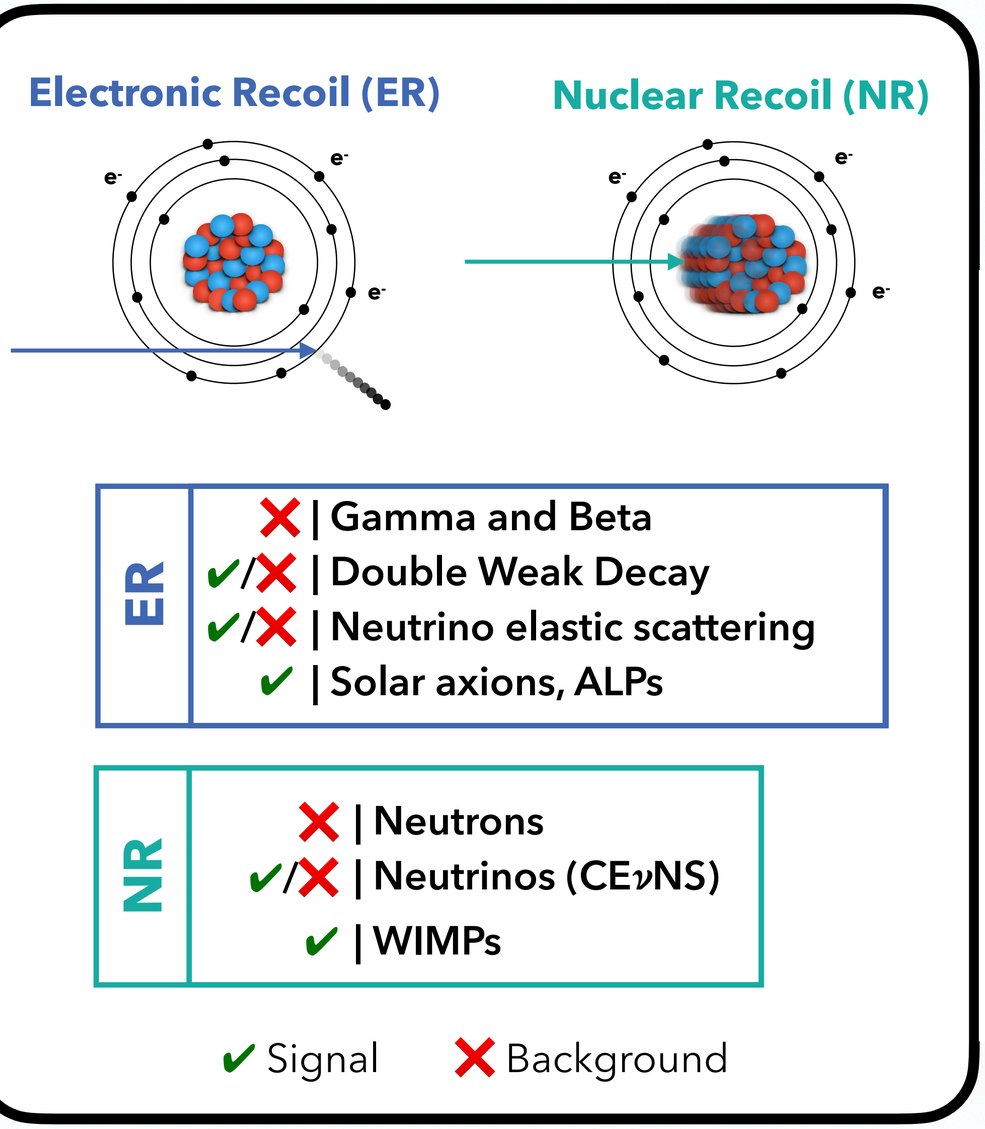

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Particle discrimination

- Interaction type **Nuclear Recoil (NR)**/**Electronic Recoil (ER)** through **S1**/**S2** ratio

$$\left(\frac{S2}{S1}\right)_{NR} < \left(\frac{S2}{S1}\right)_{ER}$$

Detector **Response** Modeling

Maxime Pierre
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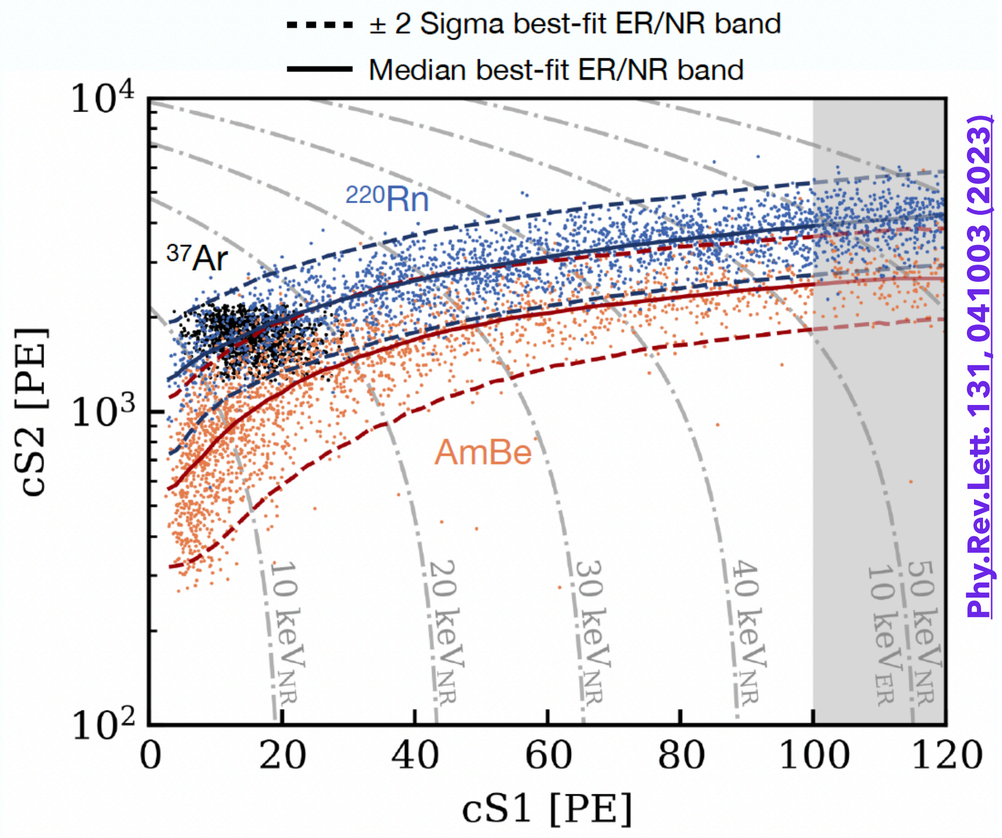

Electronic Recoil calibration:

- **^{220}Rn** intrinsic calibration: ~flat β spectrum from ^{212}Pb to estimate **cut acceptances and ER response**
- **^{37}Ar** intrinsic calibration: mono-energetic 2.8 keV peak to model the **low-energy response & resolution near threshold**

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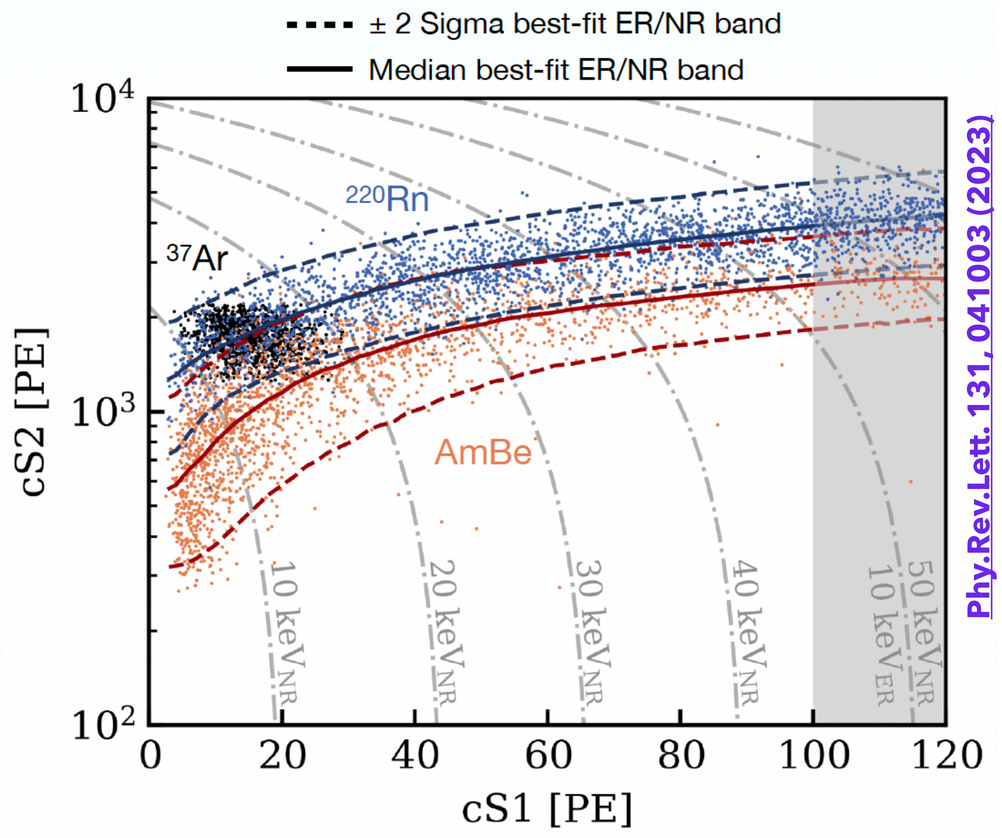

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- External **^{241}AmBe** neutron source with **clean NR selection** via **coincident** 4.4 MeV ɣ-ray observed in the **NV**
- External **YBe** neutron source for low-energy NR response

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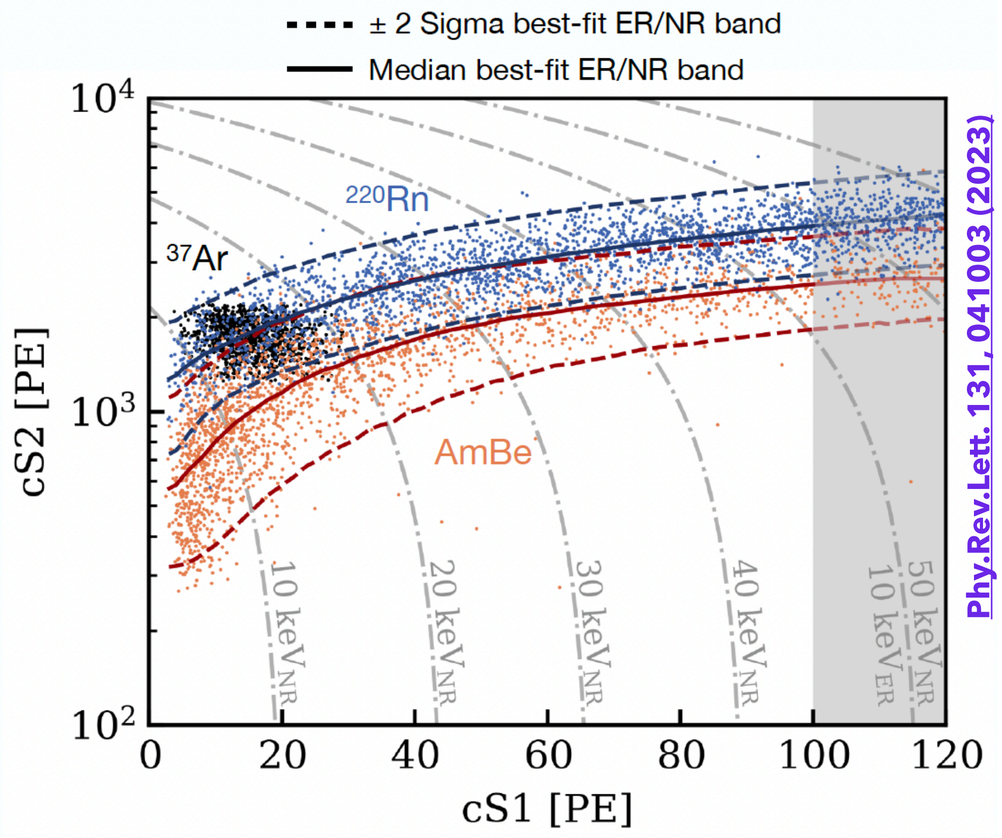

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MORE INFO

Signal reconstruction, calibration and event selection
Phys. Rev. D 111 (2025) 062006

Signal and background modelling and statistical inference
Phys. Rev. D 111 (2025) 103040

Other calibration sources (^{83m}Kr, ^{232}Th, LED, …)

- Characterise and correct detector effects impacting our signal measurements
- Monitor detector stability

Science Data Overview

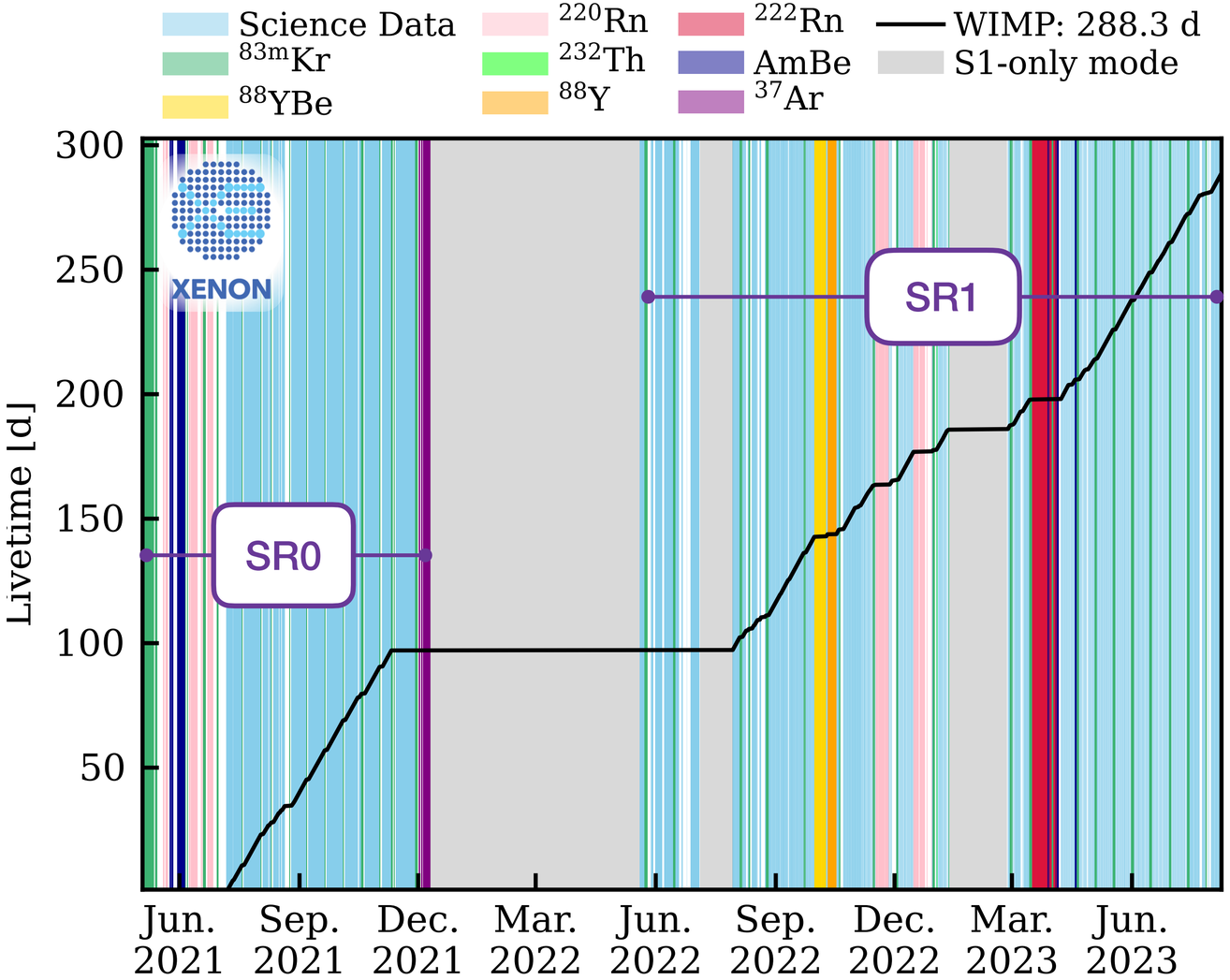
Maxime Pierre
maxime.pierre@nikhef.nl

XENON

Fiducial Mass:
about 4 tonne

Exposure:
3.1 tonne x year

Stable Light (Charge) Yield with **variation < 1% (3%)**



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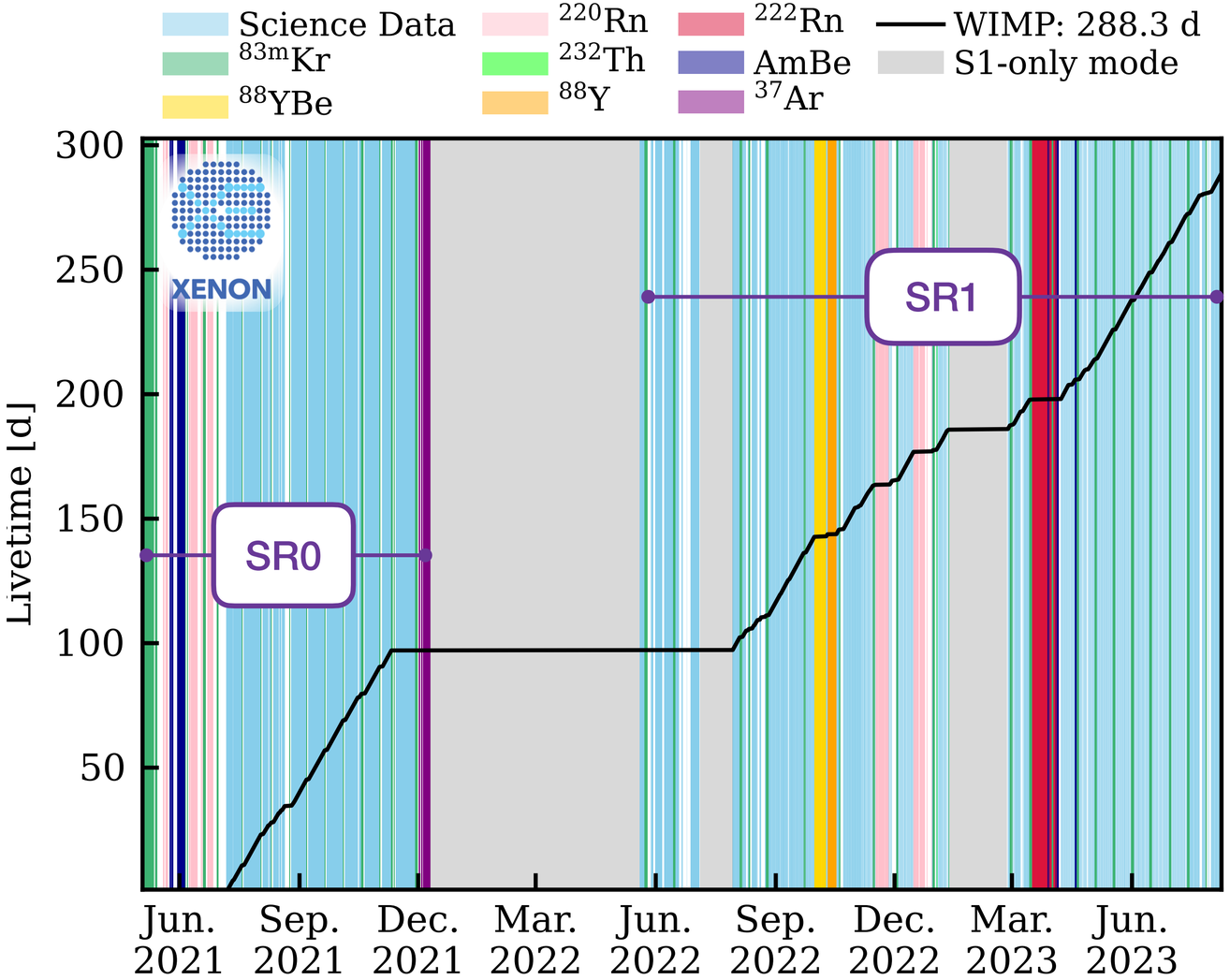


Stable Light (Charge) Yield with **variation < 1% (3%)**

Milestones Highlights

Continuous Rn online distillation

$^{222}Rn_{SR0}$: 1.9 μBq/kg

$^{222}Rn_{SR1}$: **0.9 μBq/kg**

Eur. Phys. J. C 82 (2022) 1104

Kr distillation

^{nat}Kr/Xe concentration **< 50 ppq**

Eur. Phys. J. C 77 (2017) 275

LXe Purification

Electron Lifetime **> 10 ms**

Eur. Phys. J. C 82 (2022) 860

Triggerless DAQ

DAQ shared between three detectors

Improve low-energy sensitivity

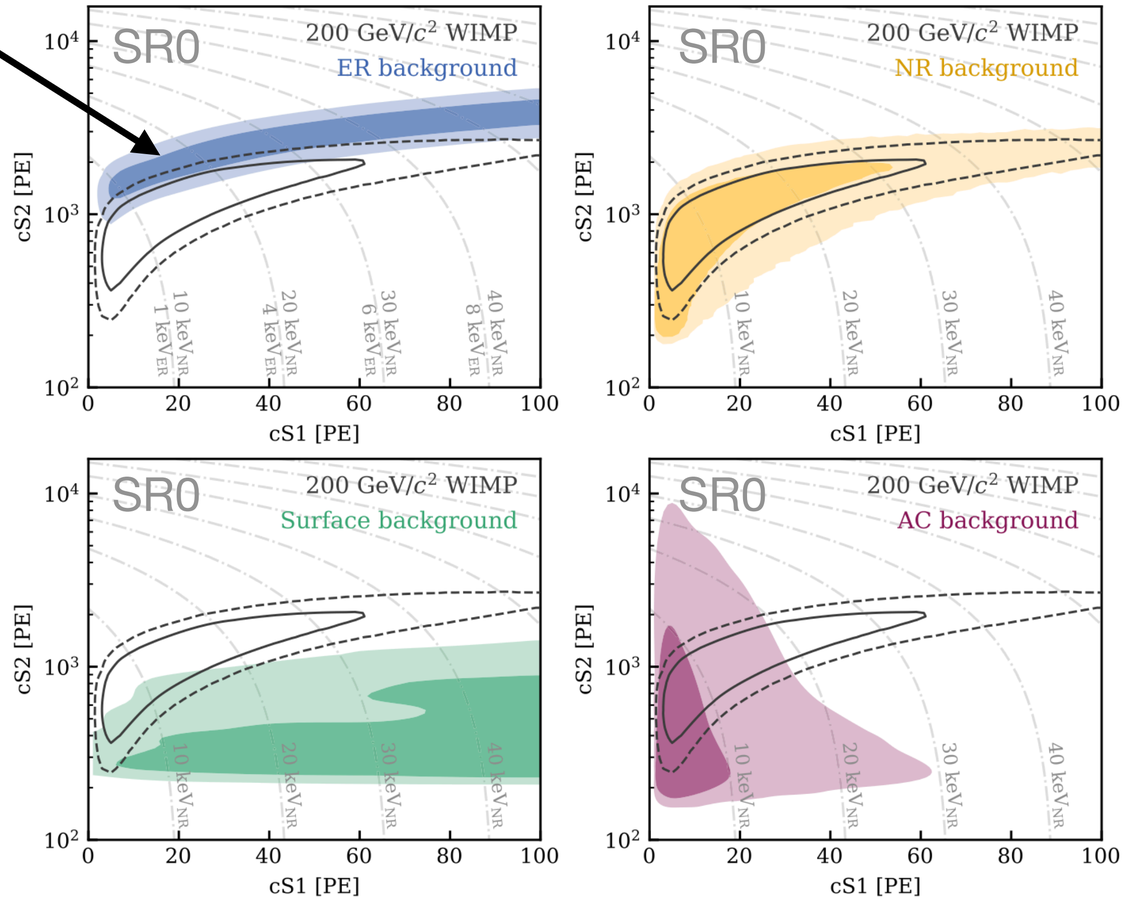
JINST 18, P07054 (2023)

WIMP **Background** Model

Maxime Pierre
maxime.pierre@nikhef.nl

Electronic Recoils:

- **^{214}Pb, ^{85}Kr** β-decays, **^{124}Xe** 2**ν**ECEC, **solar ν-e$^-$** scatter
- Shape constrained with **^{220}Rn calibration**
- Rate constrained by **fit to reconstructed spectrum** in [20, 140] keV_{ER}



[Phys. Rev. D 111 (2025) 103040]

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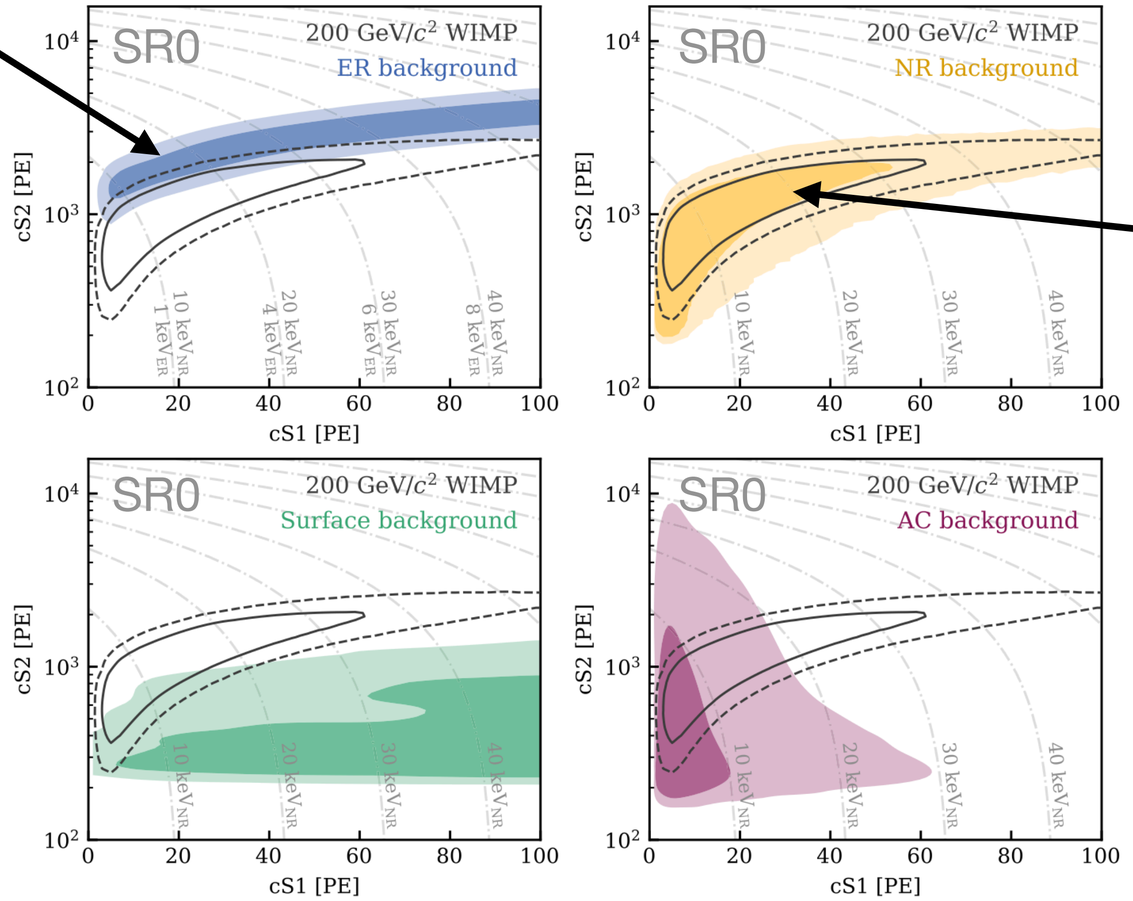

Nuclear Recoils:

- **Radiogenic neutrons** from materials, suppressed by **NV tagging** and **multi-scatter** (MS) **rejection** and constrained by **sideband** of MS and single-scatter events tagged by NV
- **CEvNS**, constrained by **neutrino flux** and **uncertainties on NR emission model**

[Phys. Rev. D 111 (2025) 103040]

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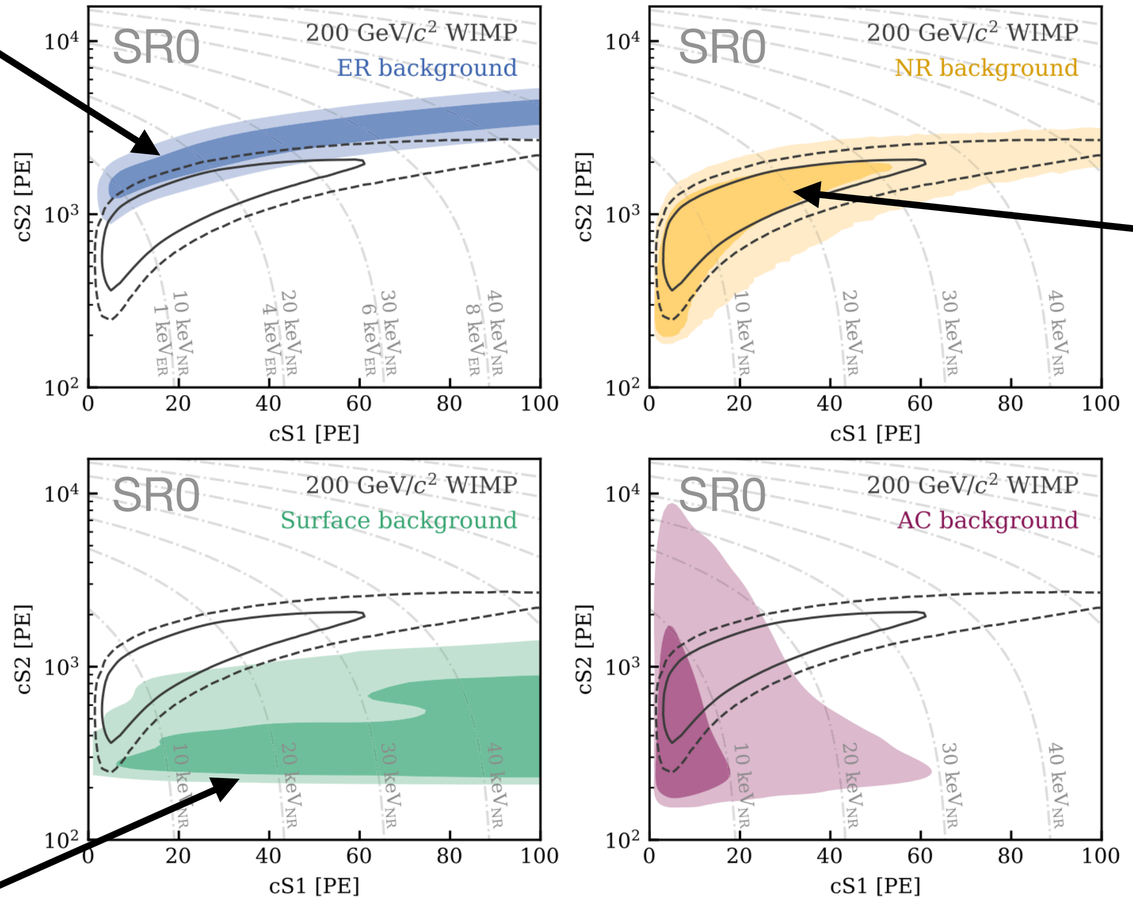
Surface:

- **^{210}Pb β-decay** from PTFE walls due to **plate-out effect**
- Suppressed by **fiducial volume** (FV) selection
- **Data-driven** constrain validated **outside FV**



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Phys. Rev. D 111 (2025) 103040

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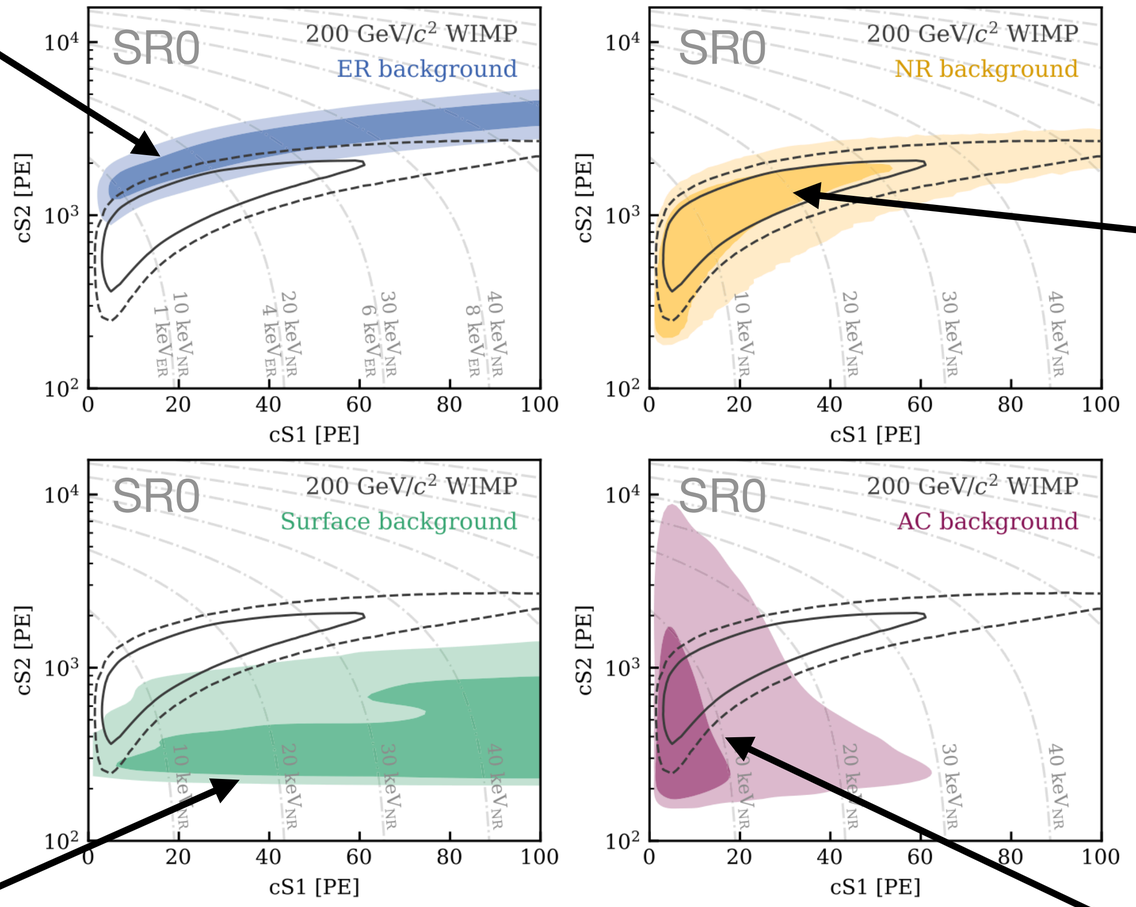

[Phys. Rev. D 111 (2025) 103040]

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Accidental Coincidence:

- Accidental pairing of isolated S1-S2, removed by **dedicated machine learning** based **cuts**
- **Data-driven** modeling, validated with **sideband** unblinding

SR0+1: WIMP Search **Datasets**

Maxime Pierre
maxime.pierre@nikhef.nl

SR0
95.1 days

- **Updated neutron background model**
- Rest of the analysis unchanged

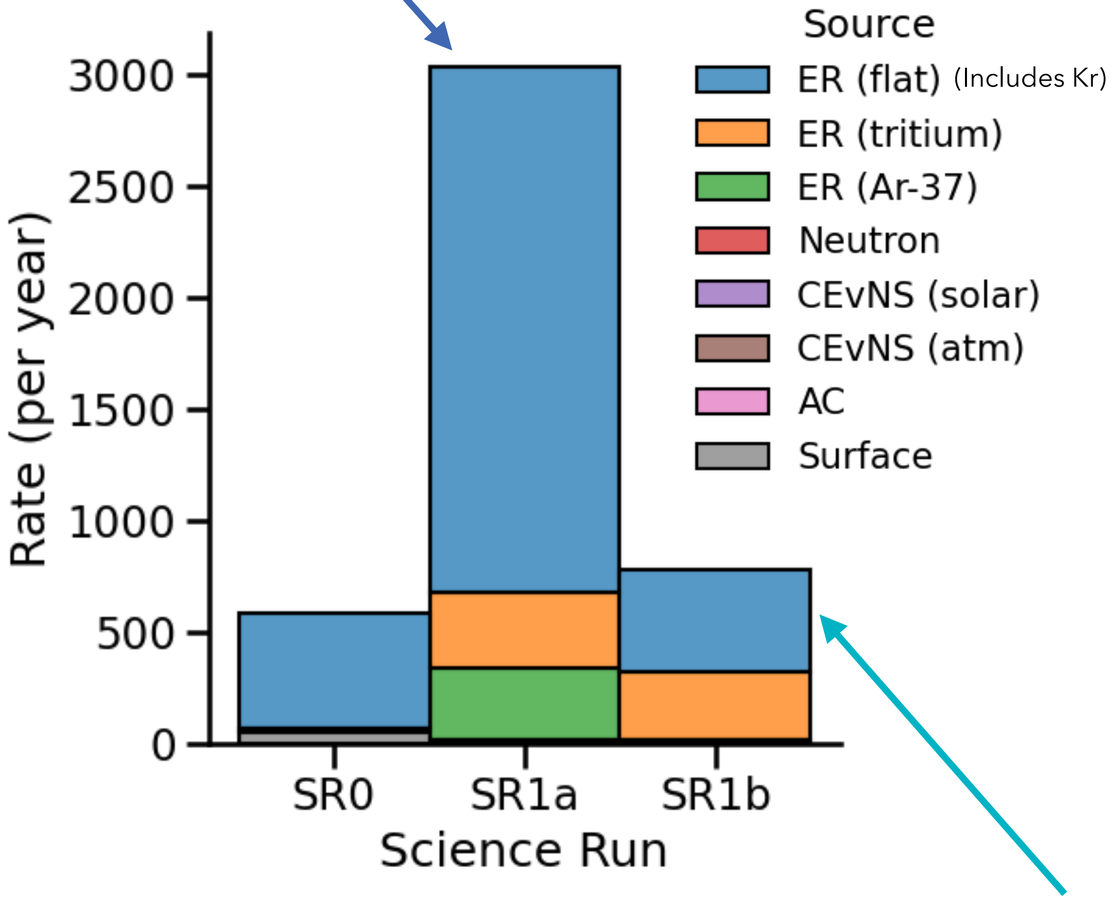
SR1a
66.6 days

- Higher ER rate from accidental mixture of Kr-rich gas: **high rate of ^{85}Kr and ^{37}Ar**
- **^{3}H-like** background: rate unconstrained
- Smaller FV to reduce surface background

SR1b
119.9 days

- **ER rate back to SR0 levels**
- **^{3}H-like** components remains
- Smaller FV to reduce surface background

Accidental small injection of Kr-rich gas



Distillation during SR1a brought background down

SR0+1: WIMP Search **Unblinding**

Maxime Pierre
maxime.pierre@nikhef.nl

Blind analysis with 3.1 tonne x year exposure

- **Unbinned likelihood:** separate terms for SR0, SR1a, and SR1b and near and far-wire regions

- **Two steps unblinding in SR1 to identify ER leakage:**
  - ➡ Small region above NR median and E > 5 keV_{ER}
  - ➡ Followed by full unblinding

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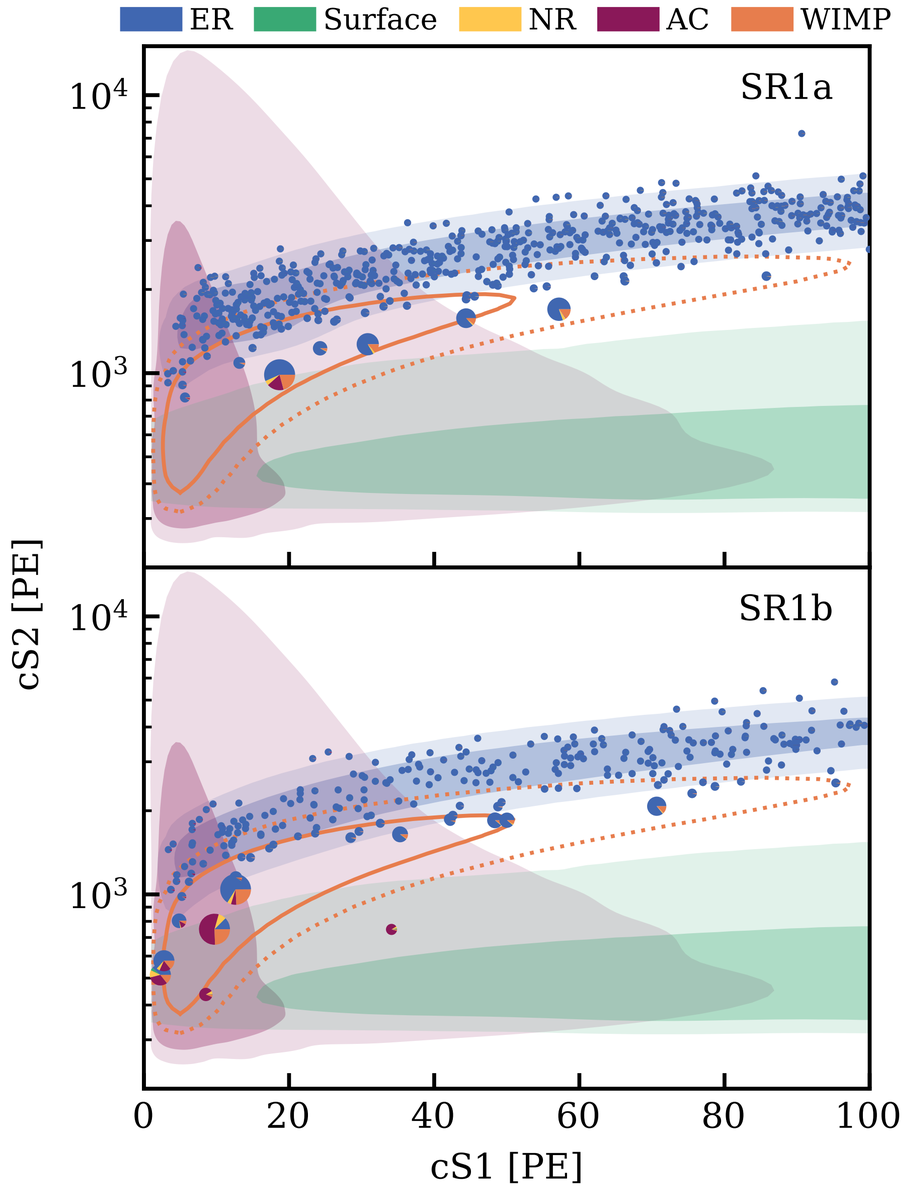
No excess over background observed



Charge Yield of ^{124}Xe 2νECEC

Maxime Pierre
maxime.pierre@nikhef.nl

XENON

- **Suppressed CY for single EC** of ^{127}Xe (~0.9 Q_β) reported by XELDA (Phys. Rev. D 104, 112001), and pre-print from LZ (arXiv:2503.05679)

- **No measurement available at the XENONnT electric field**

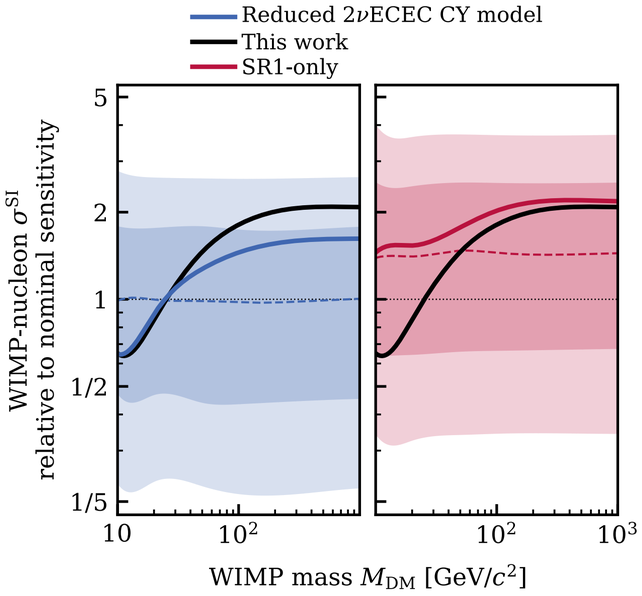
- CY-suppression can "absorb" other background sources!
  - ➡ Bias limit downward

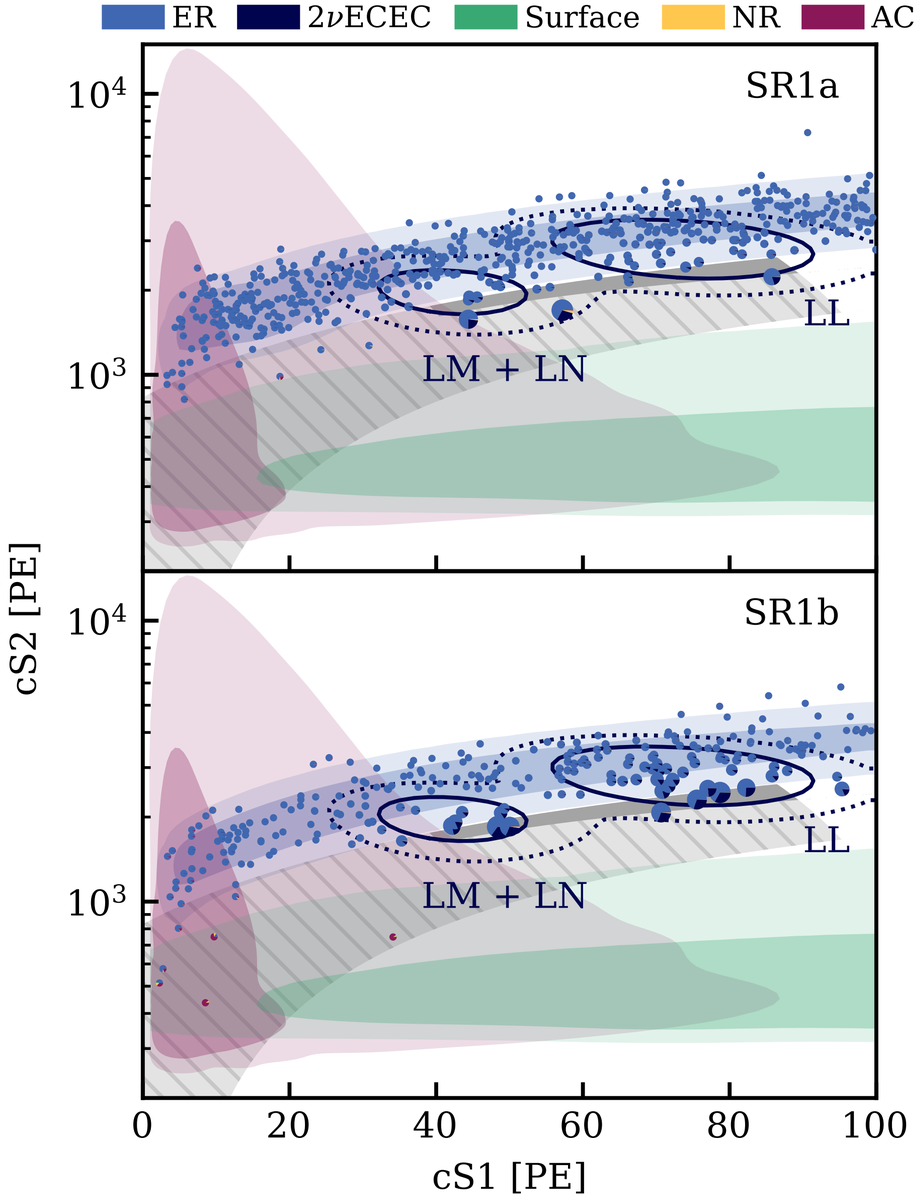
- Perform a PLR test at unblinding:

p-value = 0.09

Do not reject the nominal β model

$$Q_{LL} = 0.8^{+0.08}_{-0.04}\, Q_\beta\,,\; Q_{LM} = 0.72^{+0.11}_{-0.04}\, Q_\beta$$





SR0+1: WIMP Search **Results**

Maxime Pierre
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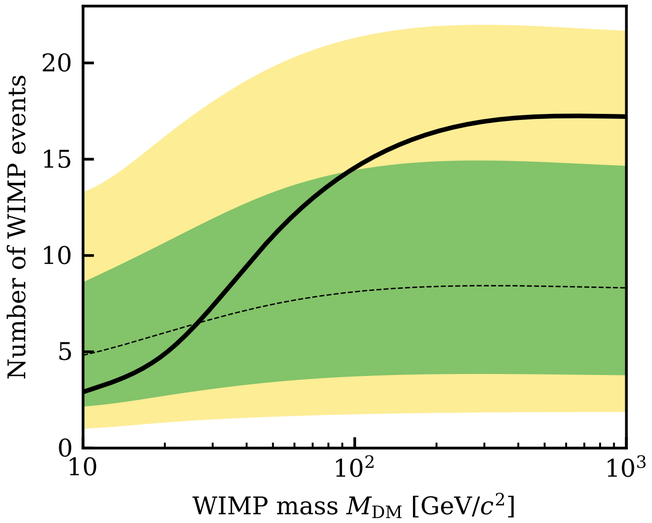
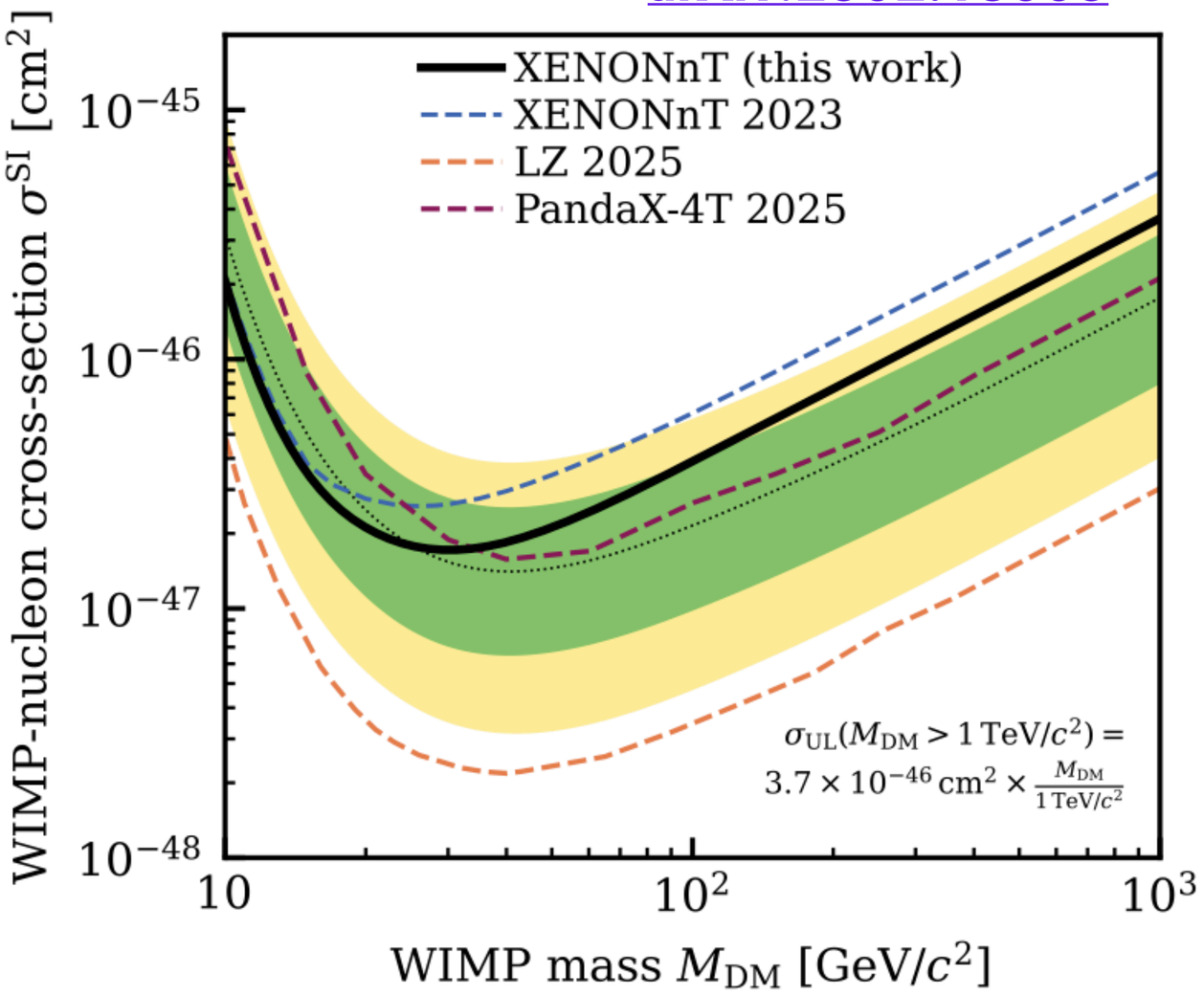
New limits on WIMP-nucleon cross-section. Improvement from SR0 by a factor ~1.5

Most stringent limit :
1.7 x 10^{-47} cm^2 @ 90% CL for WIMP mass of 30 GeV/c^2



arXiv:2502.18005



Summary and Outlook

Maxime Pierre
maxime.pierre@nikhef.nl

New Result

arXiv:2502.18005

SR0 + SR1 WIMP

- **No excess observed**
- Most stringent limit set at 1.7 x 10^{-47} cm^2 for 30 GeV/c^2 WIMP

Future Results

SR0 + SR1

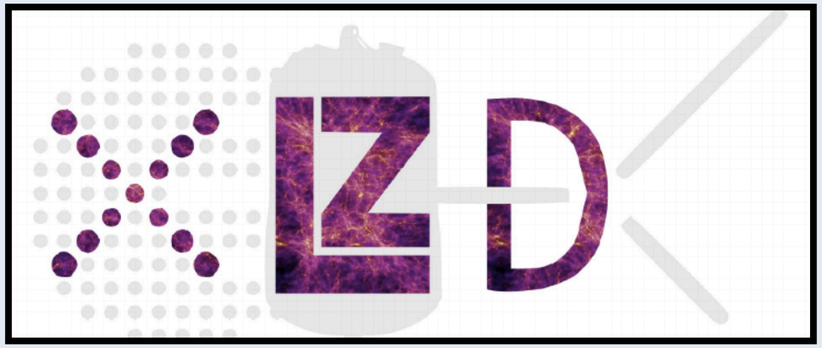
- **Broad Physics program with more results to come (Light DM, solar-pp, $2\nu/0\nu\beta\beta$, …)**

SR2

- **New Science Run performed**
- **Gd-doping** in n-Veto for **improved tagging efficiency** ~ 77%

Future Perspective

- Xenon, Lux Zeplin, Darwin collaboration established to build the next Generation LXe Observatory down to the neutrino fog



Masaki Yamashita & Knut Dundas Morå Talks

Talks and Posters Advertisement

Maxime Pierre
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Talks

- **Measurement of Solar Boron-8 Neutrinos via Coherent Elastic Neutrino-Nucleus Scattering with XENONnT**, *Kexin Liu*, 26 Aug 14:20
- **Progress of solar pp neutrino search with XENONnT**, *Jingqiang Ye*, 26 Aug 14:40
- **Search for Light Dark Matter with XENONnT**, *Shenyang Shi*, 27 Aug 16:00
- **Low-energy Yttrium-Beryllium calibration in XENONnT**, *Shengchao Li*, 28 Aug 18:00

Posters

- **^{85}Kr Background Estimation for Solar-pp Neutrino Measurement in XENONnT**, *Yoshino Kaminaga*, 27 Aug 18:00
- **The XENONnT Neutron Veto**, *Masashi Yoshida*, 27 Aug 18:00

Talks and Posters Advertisement

Maxime Pierre
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Thank You for your attention!

Talks

- M… …ONnT,
  K…
- P…
- S…
- L…

Post…

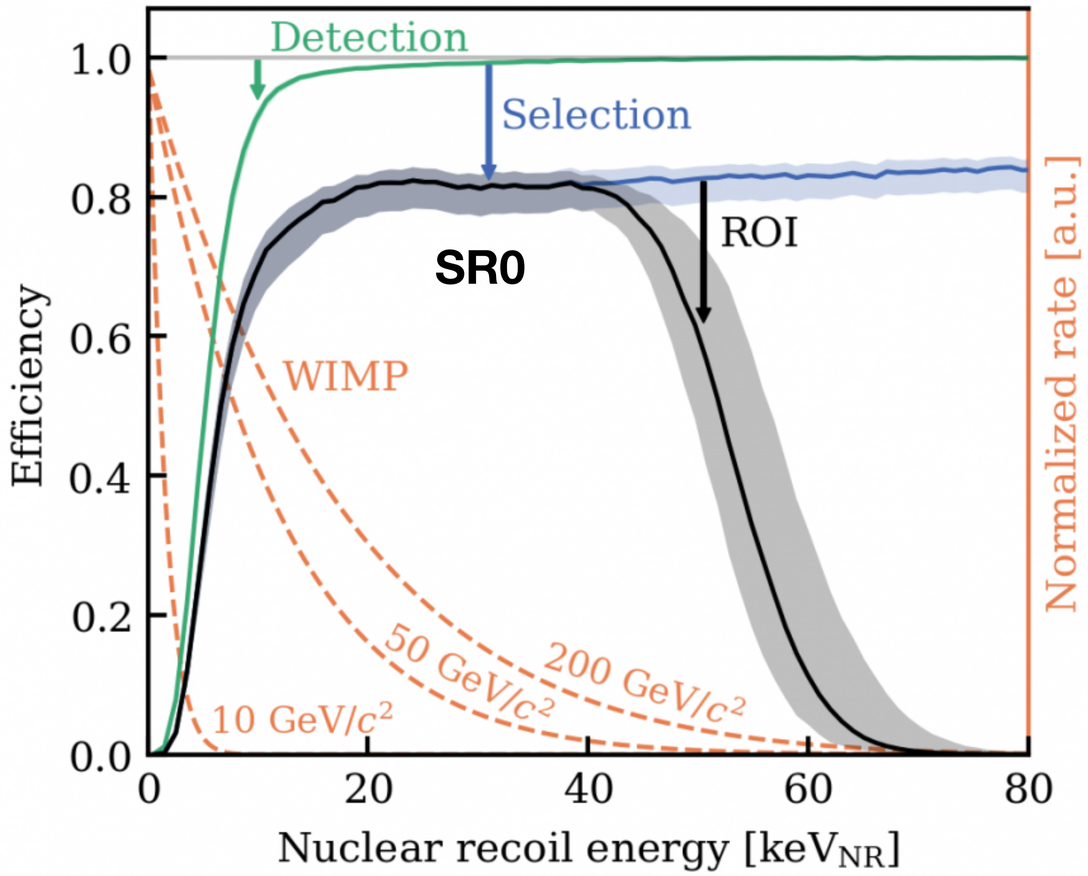
- 8…
  Y…
- T…

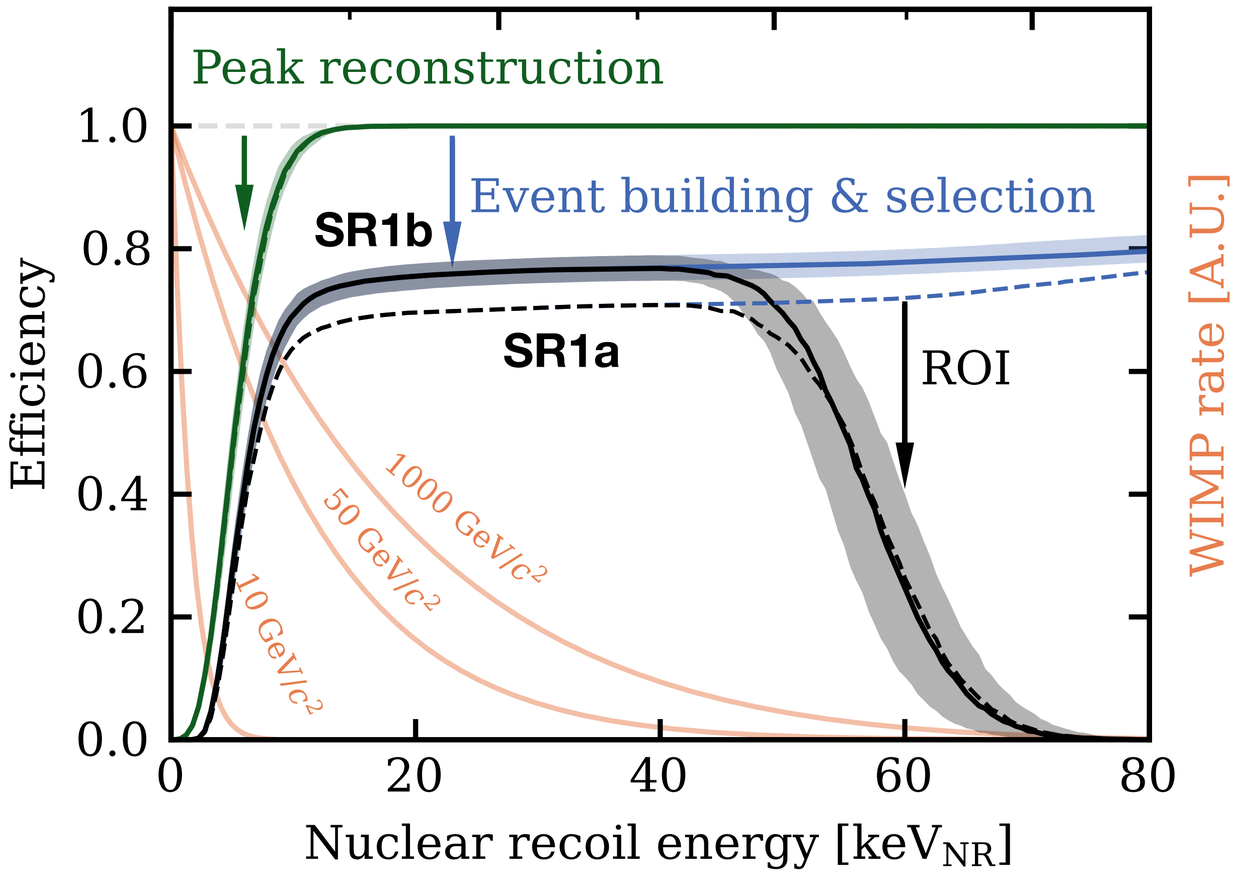
Back-Up

XENON

SR0+1: WIMP Search **Efficiencies**

Maxime Pierre
maxime.pierre@nikhef.nl





- **Detection:** dominated by 3-fold requirement (3 PMTs to be in coincidence)
- **Event building:** whether an event is successfully reconstructed
- **Selection:** efficiency due to cut acceptance

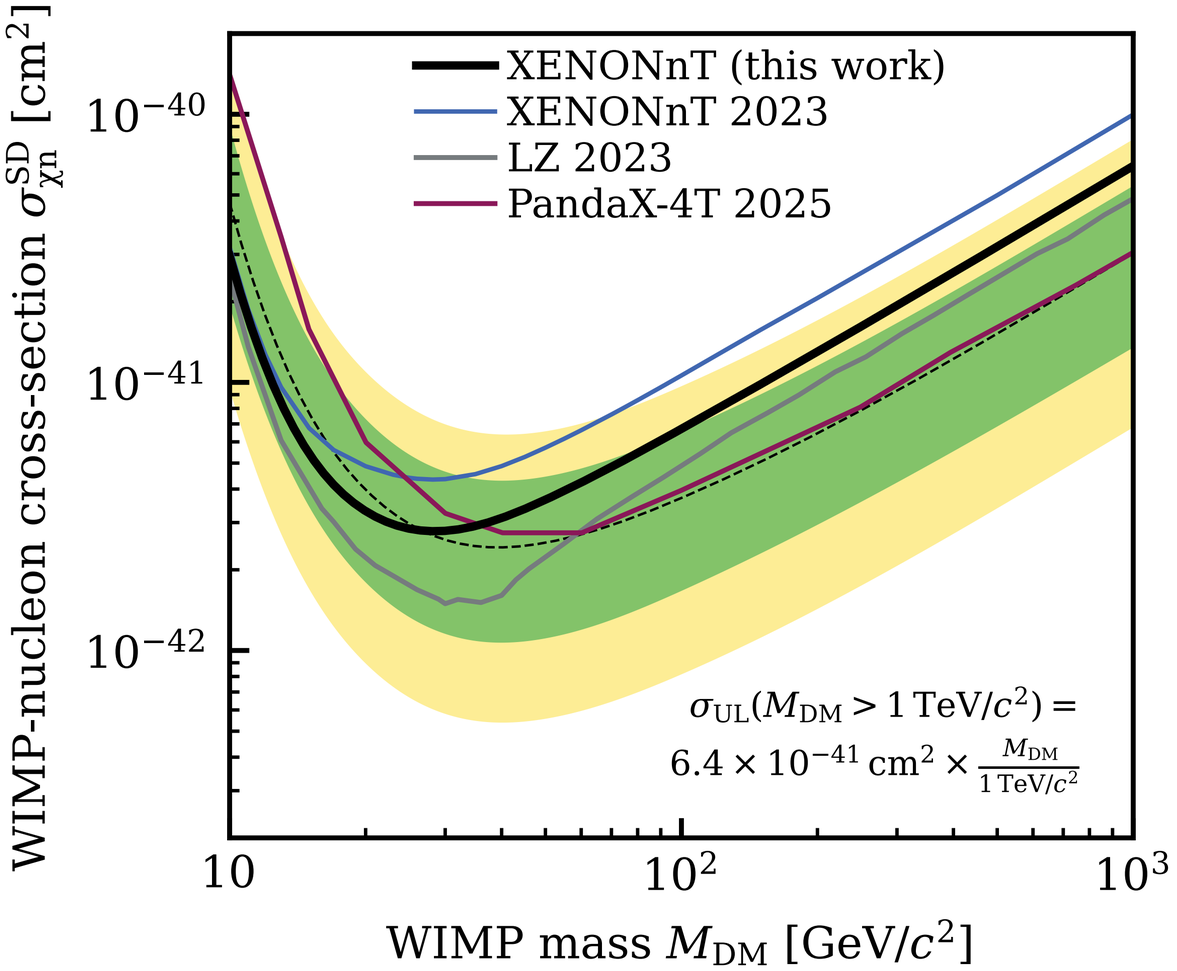
Region of Interest (ROI)

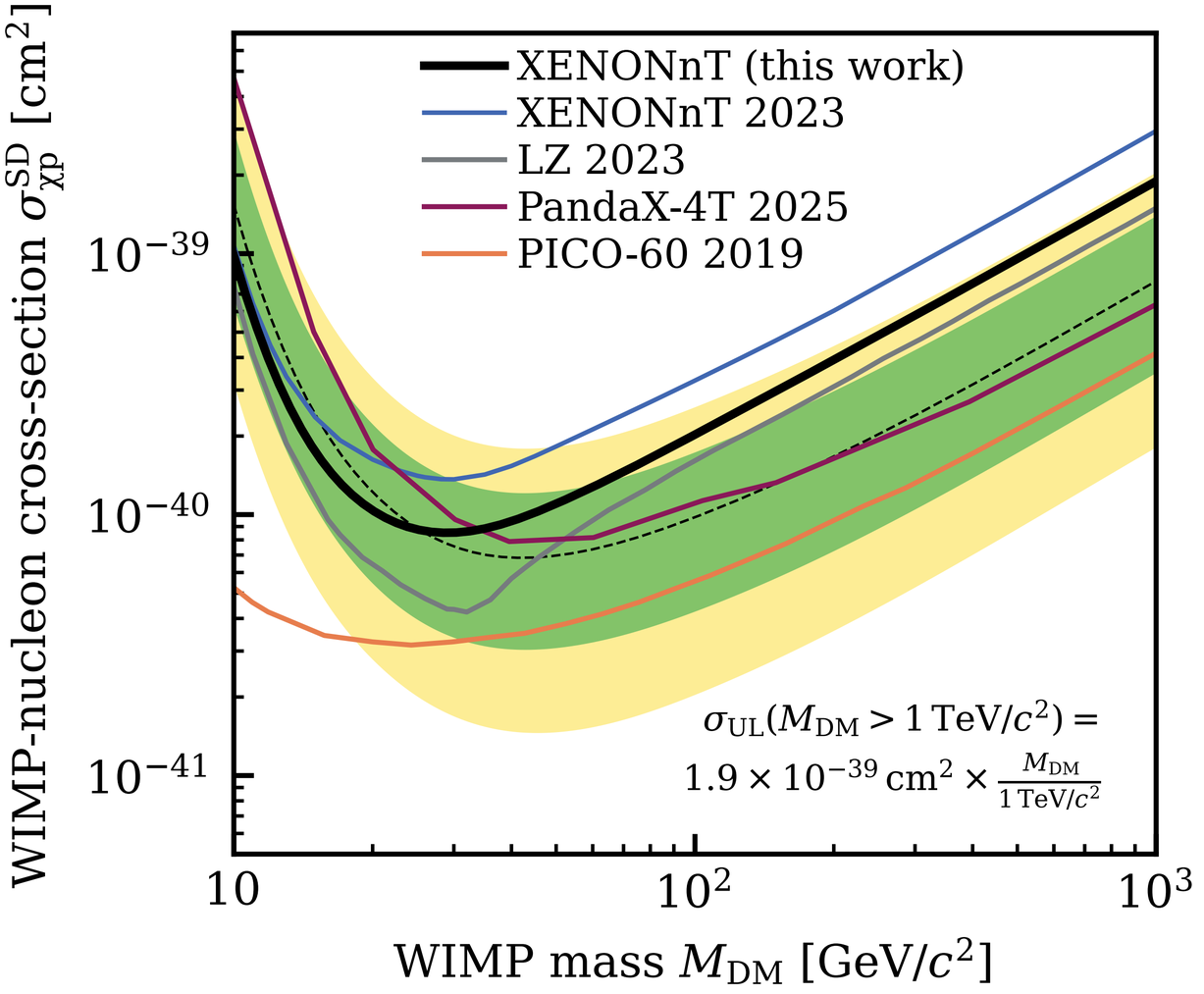
cS1 < 100 PE

cS2 ∈ [$10^{2.1}$, $10^{4.1}$] PE

Spin-Dependent Results

Maxime Pierre
maxime.pierre@nikhef.nl





Backgrounds best-fit

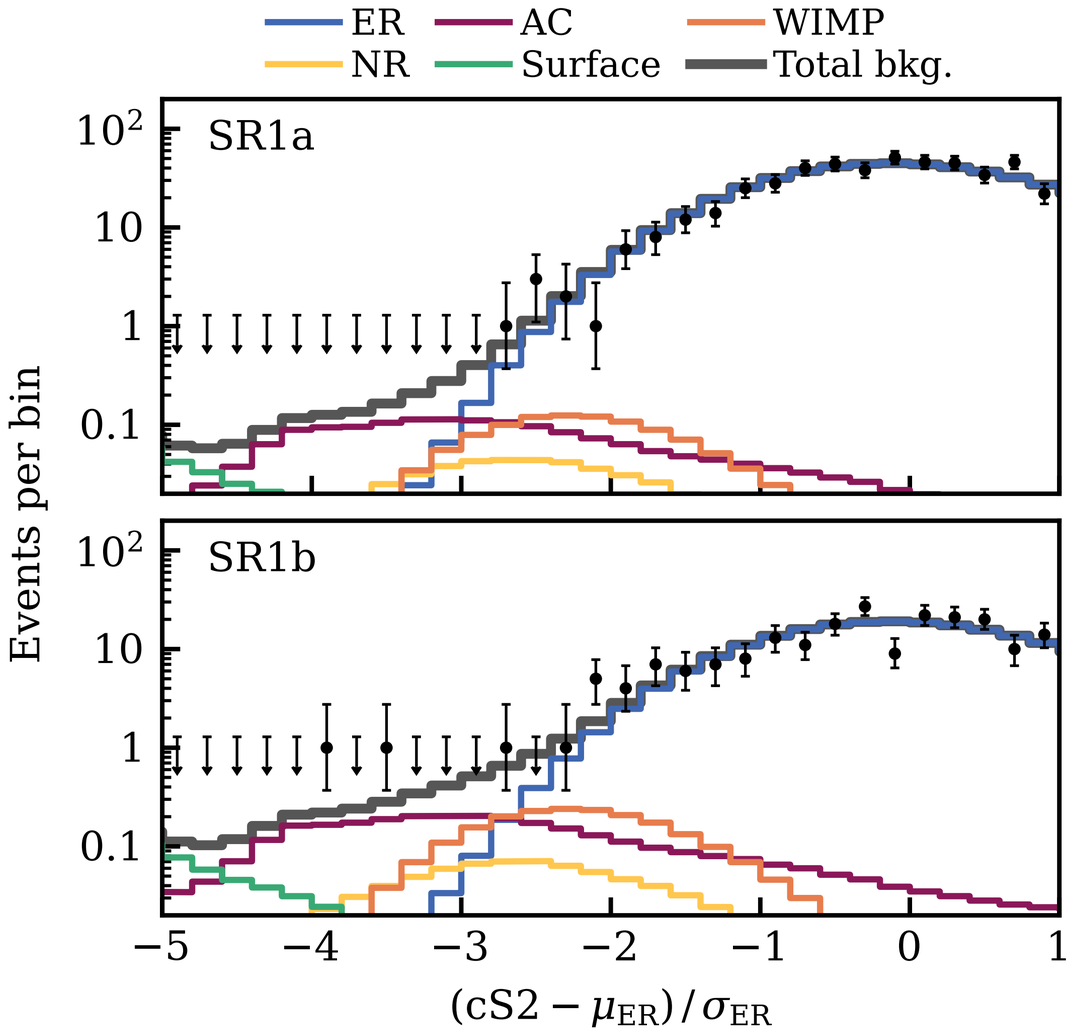
Maxime Pierre
maxime.pierre@nikhef.nl

TABLE I. Expectation values of the nominal (pre-fit) and best-fit models for SR0 (1.09 tonne × year), SR1a (0.73 tonne × year), and SR1b (1.31 tonne × year), including an unconstrained WIMP signal with a mass of 200 GeV/c^2. Connected background colors (c.f. Figure 2) indicate which components share a scaling parameter, coupling their rates across different science runs.

	SR0		SR1a		SR1b	
	Nominal	Best fit	Nominal	Best fit	Nominal	Best fit
ER (flat)	134	136 ± 12	430 ± 30	450 ± 20	151 ± 11	154 ± 10
ER (^{3}H-like)	–	–	62	40 ± 30	101	80^{+18}_{-17}
ER (^{37}Ar)	–	–	58 ± 6	55 ± 5	–	–
Neutron	0.7 ± 0.3	0.6 ± 0.3	0.47 ± 0.19	0.45 ± 0.19	0.7 ± 0.3	0.7 ± 0.3
CEνNS (solar)	0.16 ± 0.05	0.16 ± 0.05	0.010 ± 0.003	0.010 ± 0.003	0.019 ± 0.006	0.019 ± 0.006
CEνNS (atm.+DSNB)	0.04 ± 0.02	0.04 ± 0.02	0.024 ± 0.012	0.024 ± 0.012	0.05 ± 0.02	0.05 ± 0.02
AC	4.3 ± 0.9	$4.4^{+0.9}_{-0.8}$	2.12 ± 0.18	2.10 ± 0.18	3.8 ± 0.3	3.8 ± 0.3
Surface	13 ± 3	11 ± 2	0.43 ± 0.05	0.42 ± 0.05	0.77 ± 0.09	0.76 ± 0.09
Total background	152	152 ± 12	553	550 ± 20	257	239 ± 15
WIMP (200 GeV/c^2)	–	1.8	–	1.1	–	2.1
Observed	152		560		245	

Additional Tests

Maxime Pierre
maxime.pierre@nikhef.nl



- After unblinding, further tests performed to identify mismodeling**. No evidence of mismodeling** observed**.**
- Test for spatial homogeneity in XY: **No evidence of asymmetry in SR1**