Tsinghua University

XENON

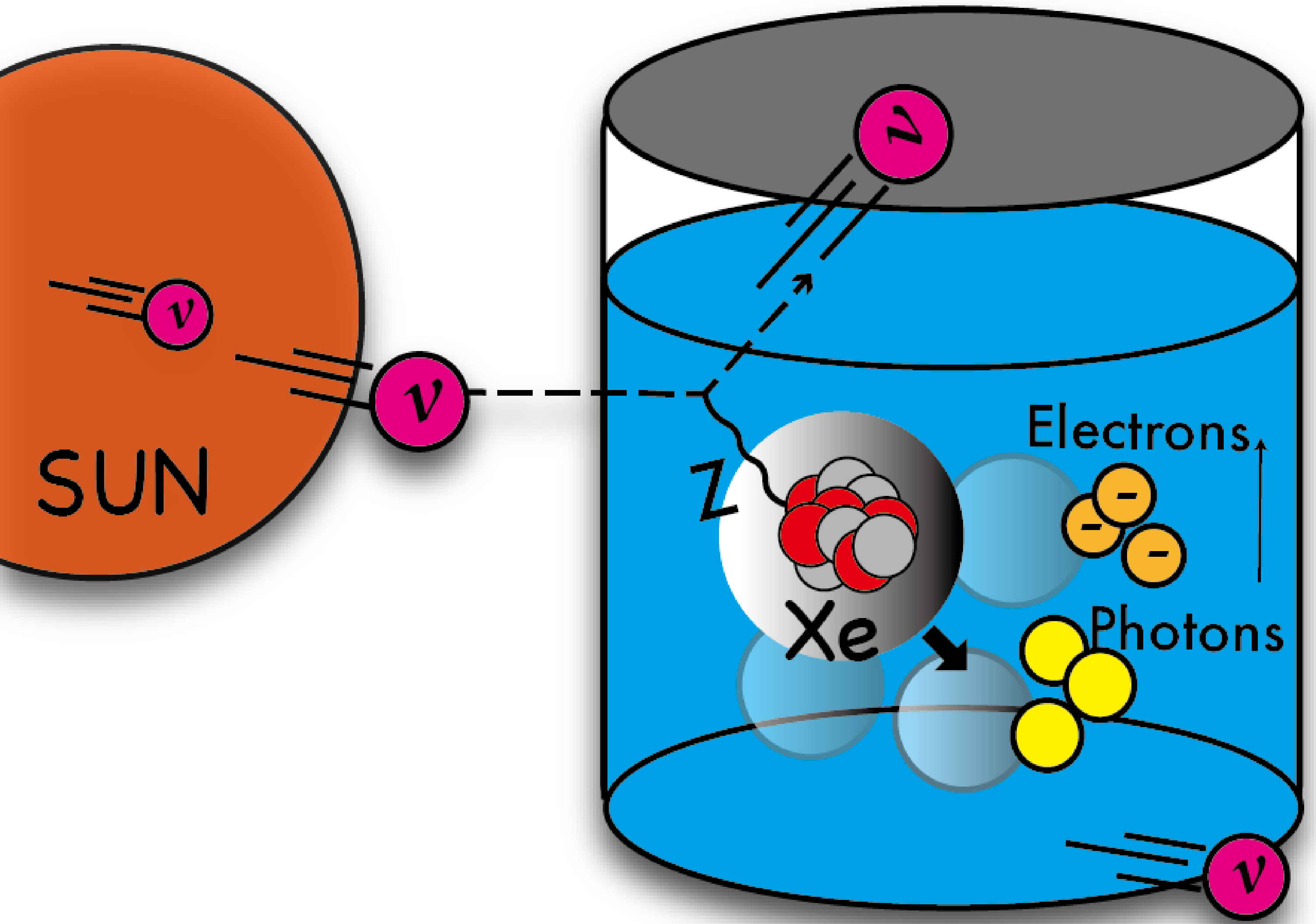
2026年紫金山暗物质研讨会

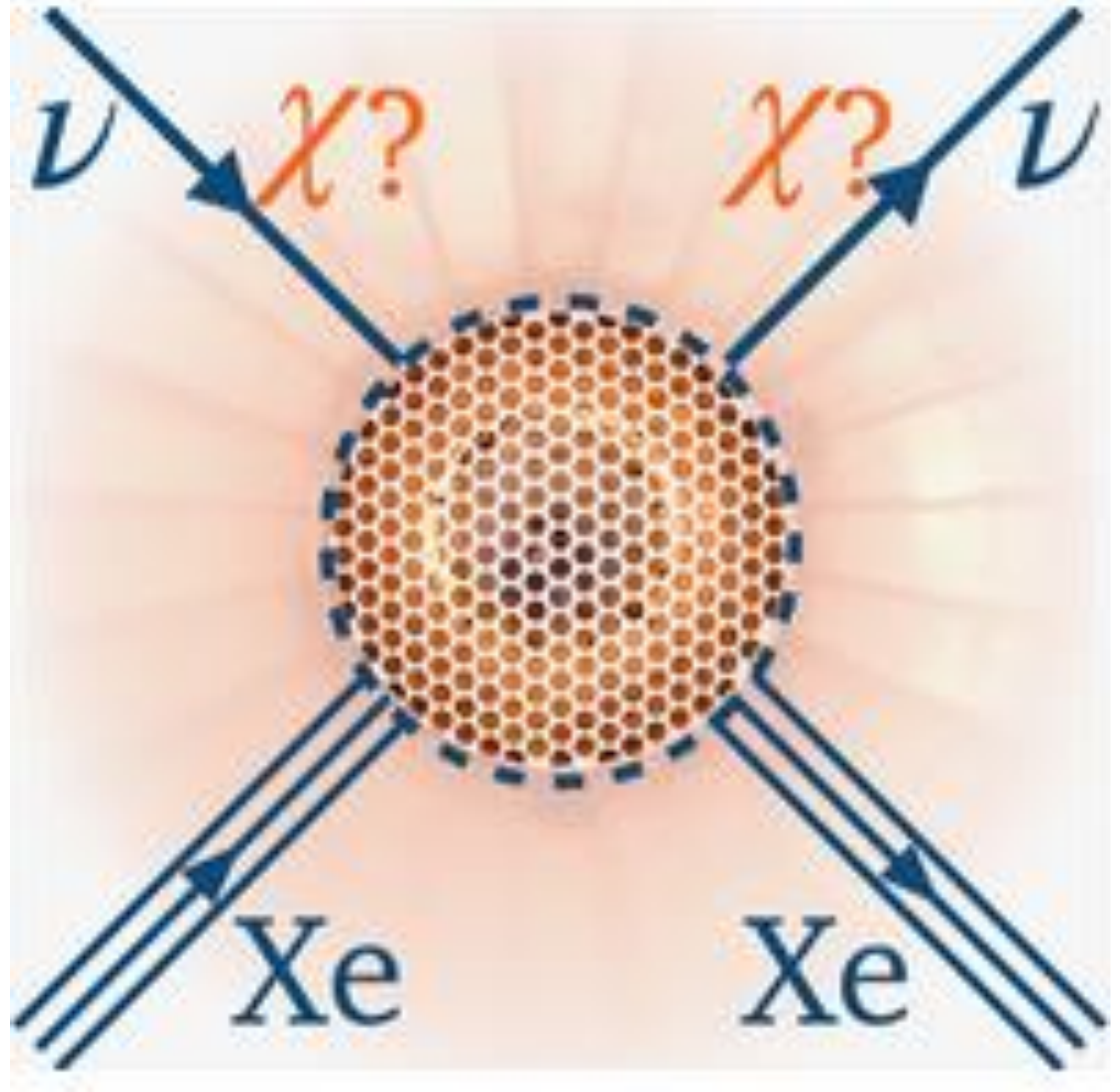
2026年7月20-25日，乌鲁木齐

利用XENONnT寻找中微子和暗物质

高飞 清华大学物理系

2026.07.21





暗物质的直接探测

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790
(Received 15 October 1973; revised manuscript received 19 November 1973)

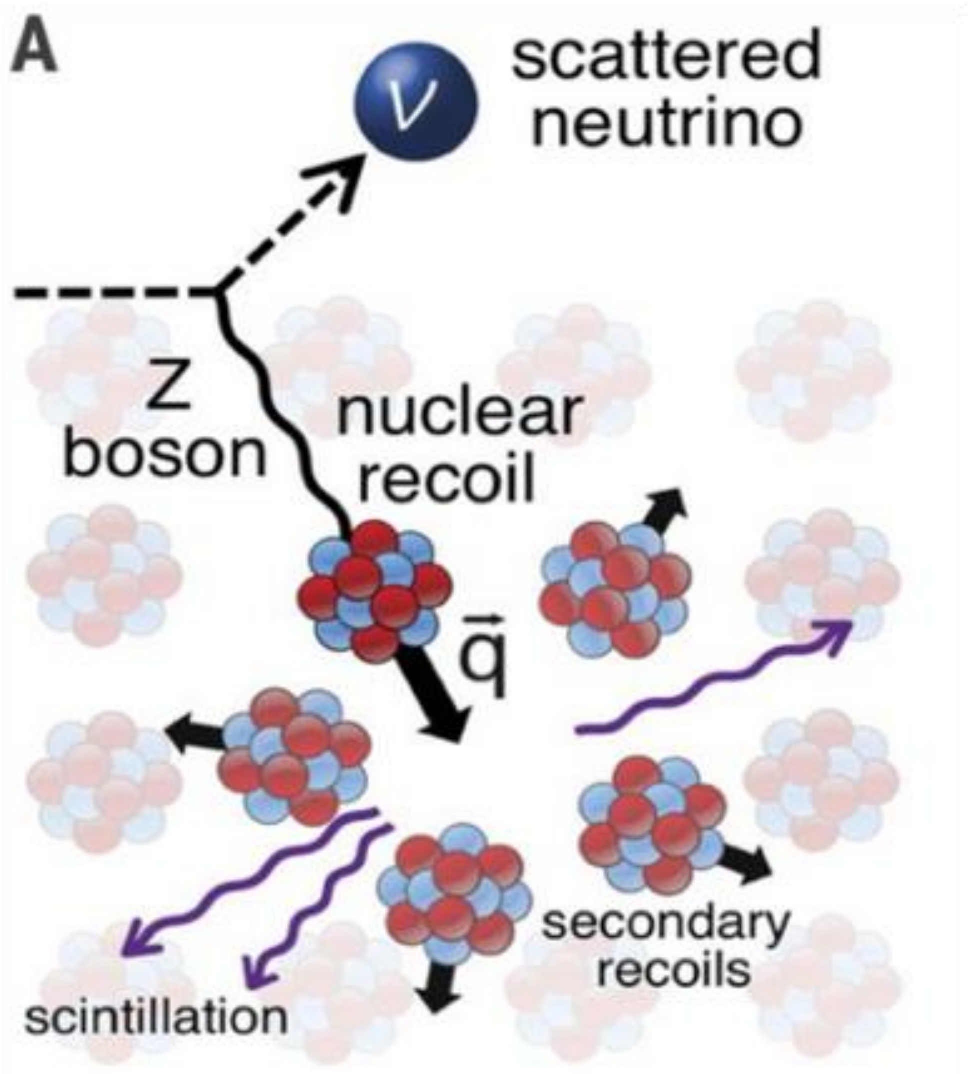
If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are very difficult, although the estimated cross sections (about 10^{-38} cm^2 on carbon) are favorable. The coherent cross sections (in contrast to incoherent) are almost energy-independent. Therefore, energies as low as 100 MeV may be suitable. Quasi-coherent nuclear excitation processes $\nu + A \to \nu + A^*$ provide possible tests of the conservation of the weak neutral current. Because of strong coherent effects at very low energies, the nuclear elastic scattering process may be important in inhibiting cooling by neutrino emission in stellar collapse and neutron stars.

PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

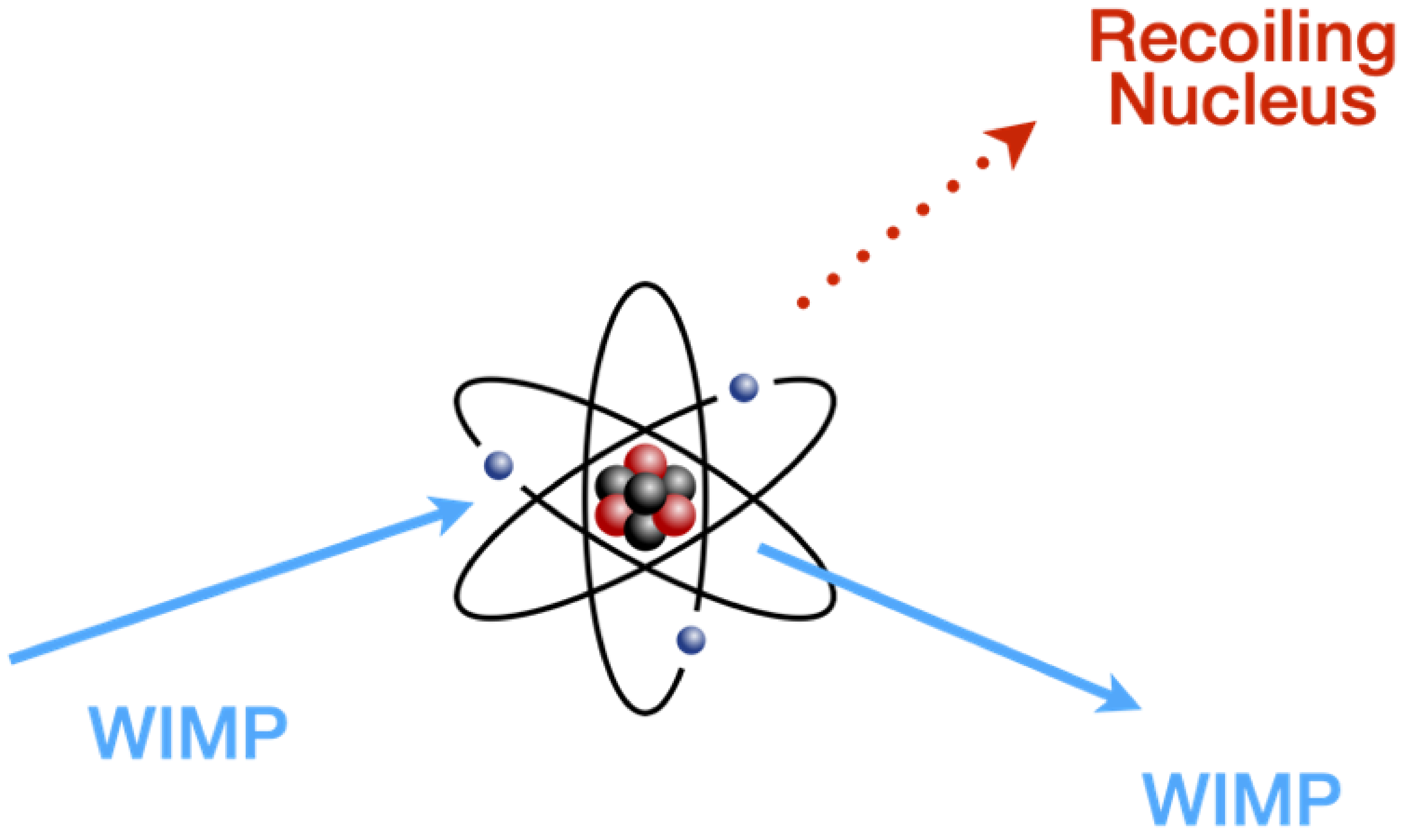
Detectability of certain dark-matter candidates

Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses 1—10^6 GeV; particles with spin-dependent interactions of typical weak strength and masses 1—10^2 GeV; or strongly interacting particles of masses 1—10^{13} GeV.

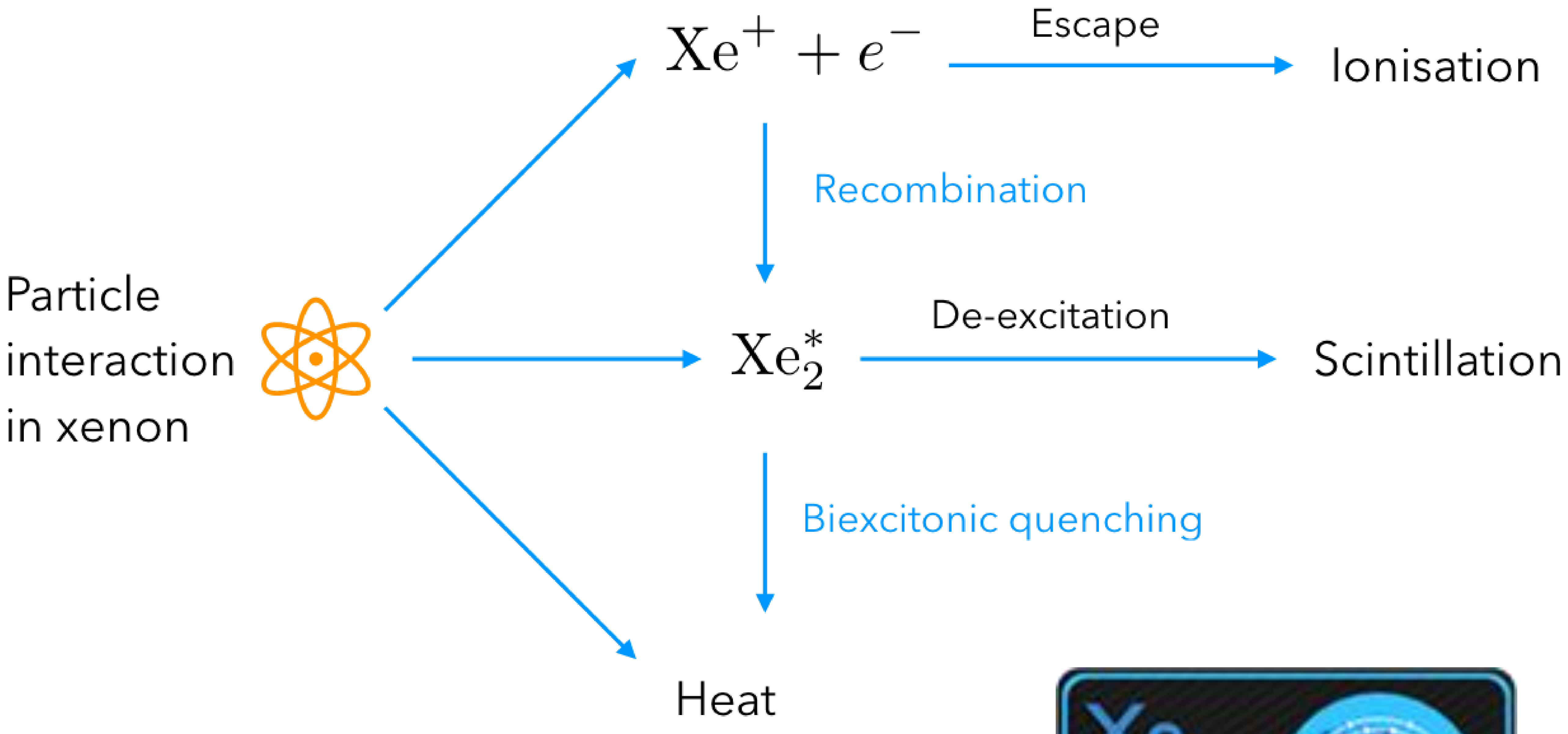


D. Akimov et al, Science 357 (2017)



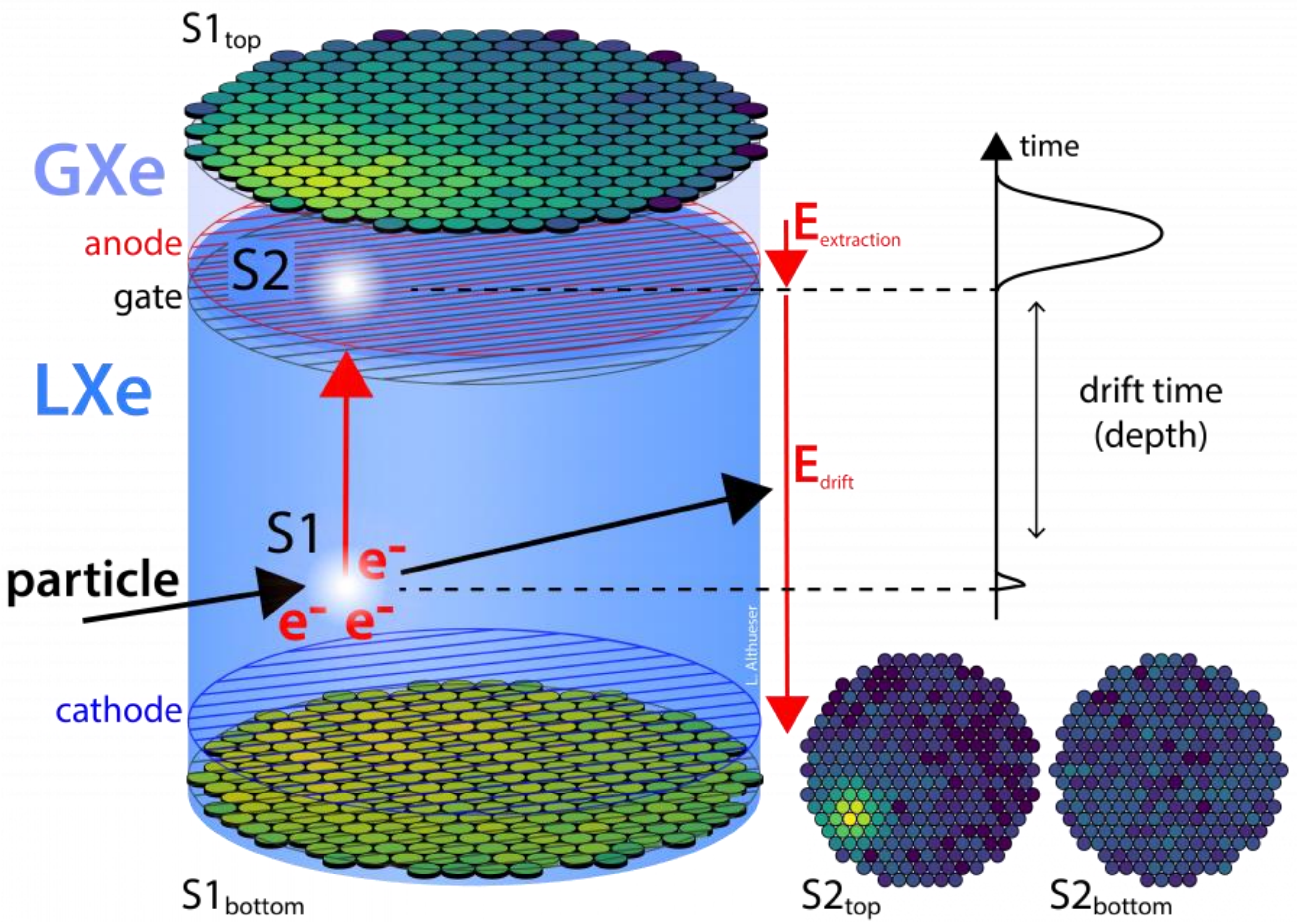
用稀有气体元素探测暗物质

- 探测介质：稀有气体原子

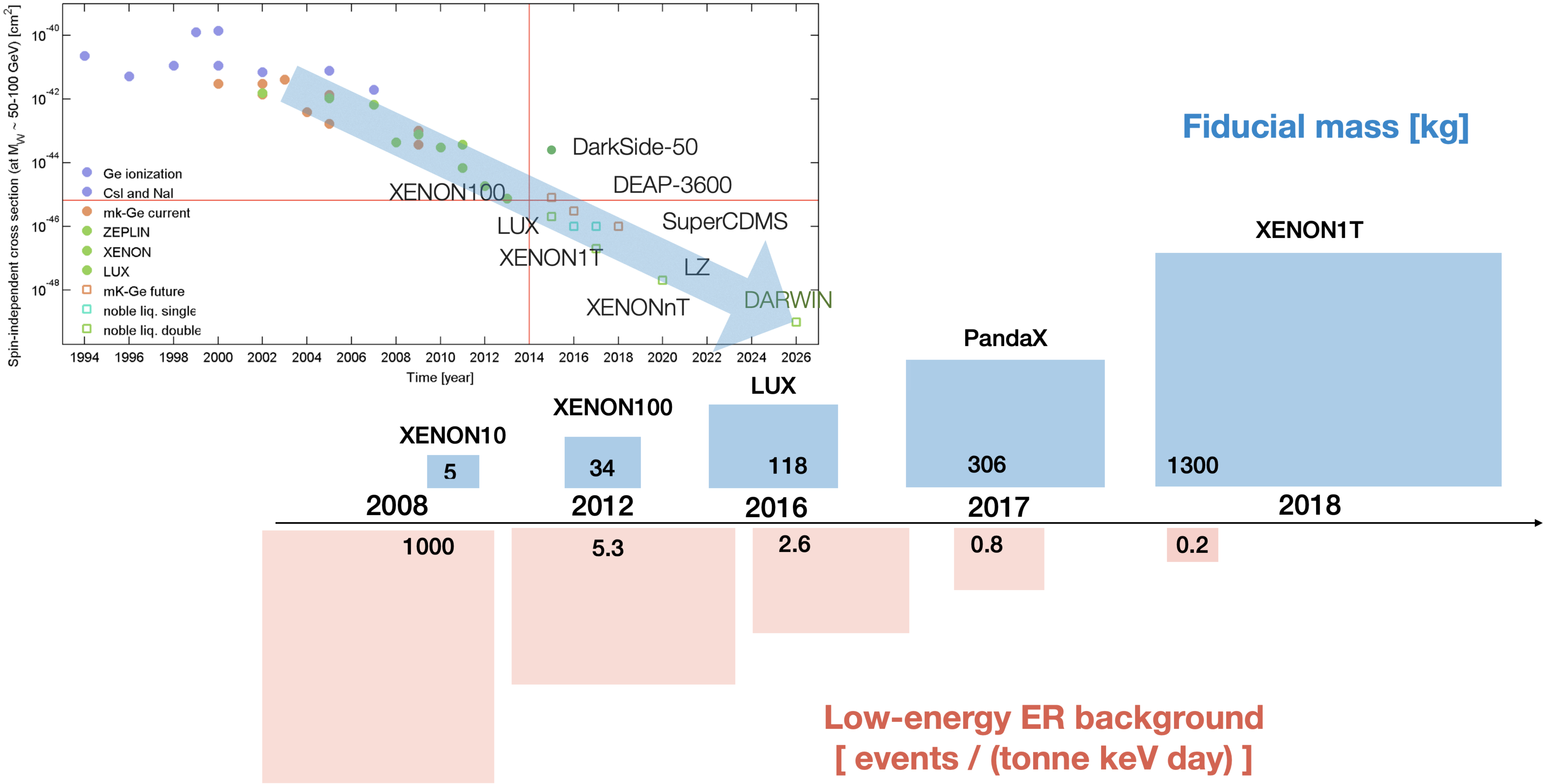


- 光子 vs.电子 与相互作用有关
- 氙（Xe）：原子数高；密度大；光产额高（低能量阈值）

- 探测器：液氙双相时间投影室
  - 光、电读出; 可用于粒子鉴别
  - 3维重建位置
  - 技术可拓展至数吨、数十吨；可稳定运行数年，获得吨·年级曝光量



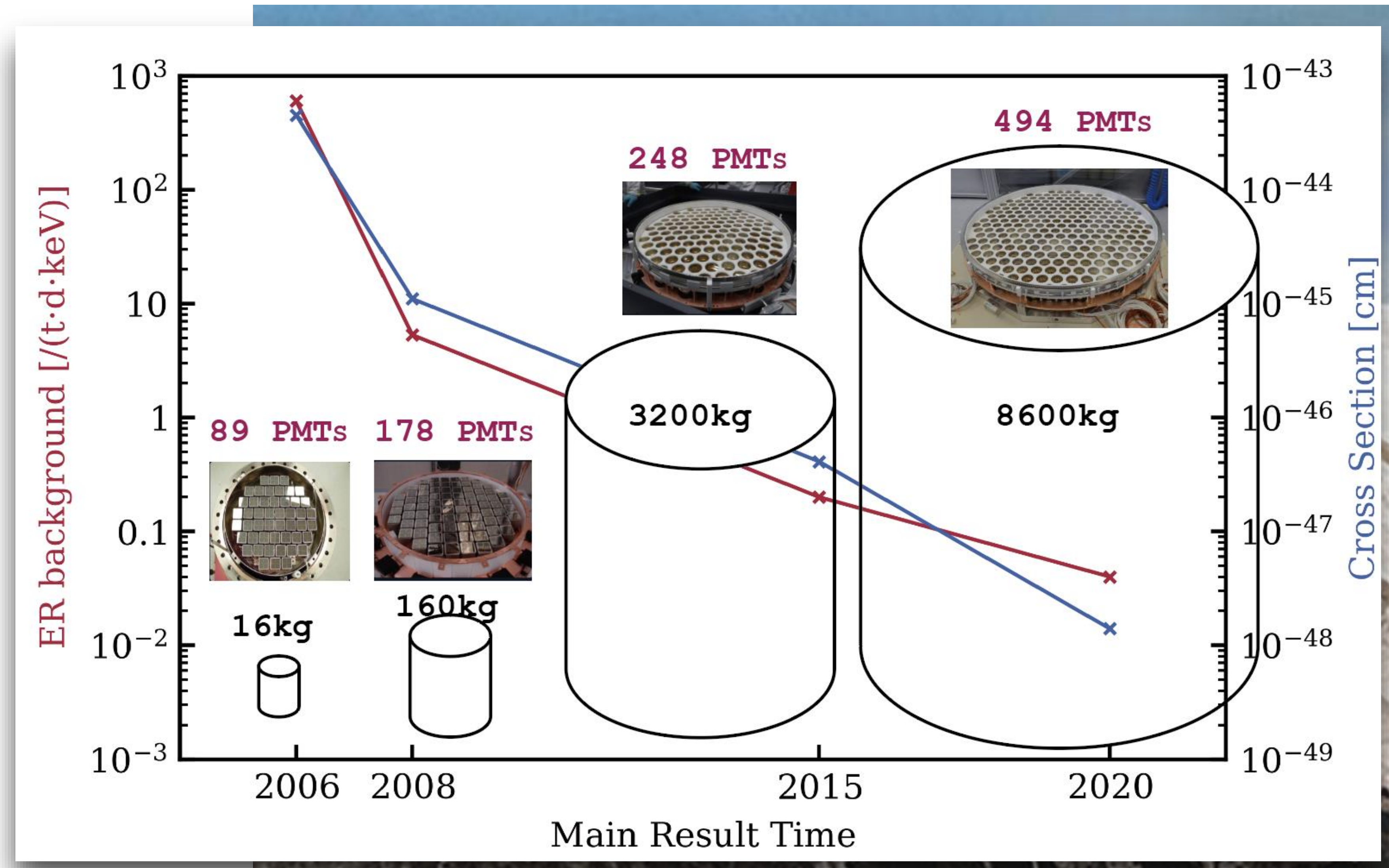
暗物质探测实验的灵敏度

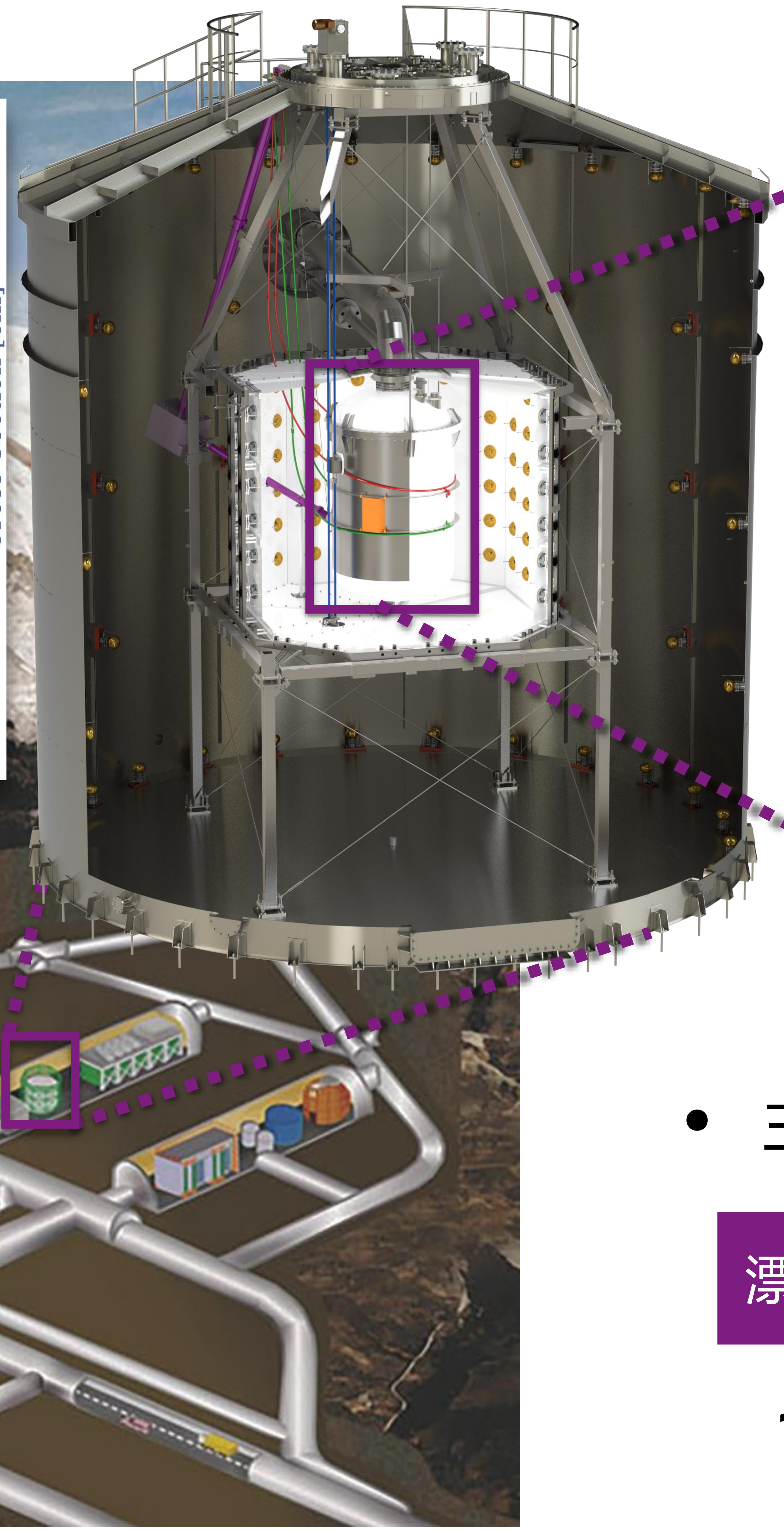
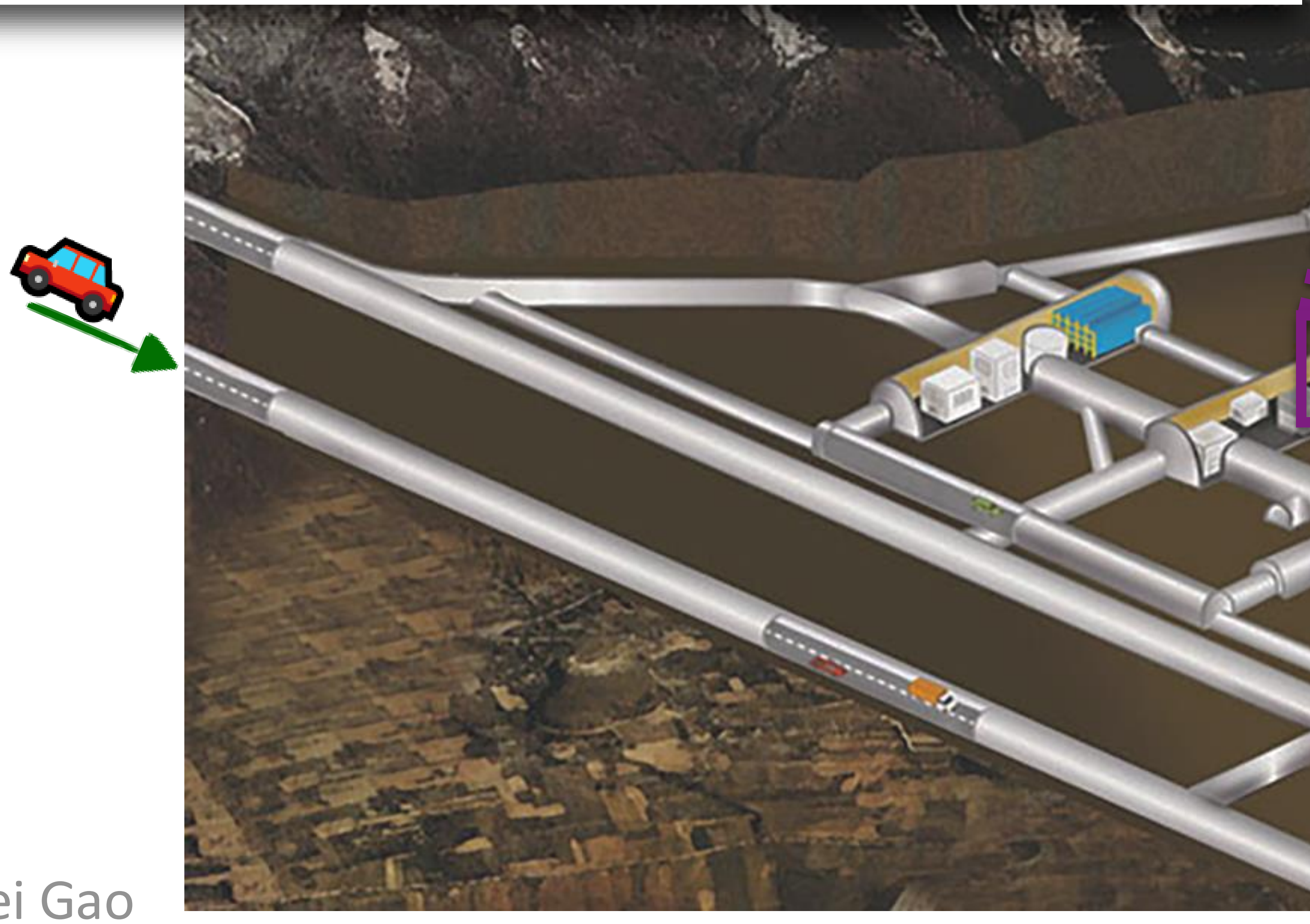


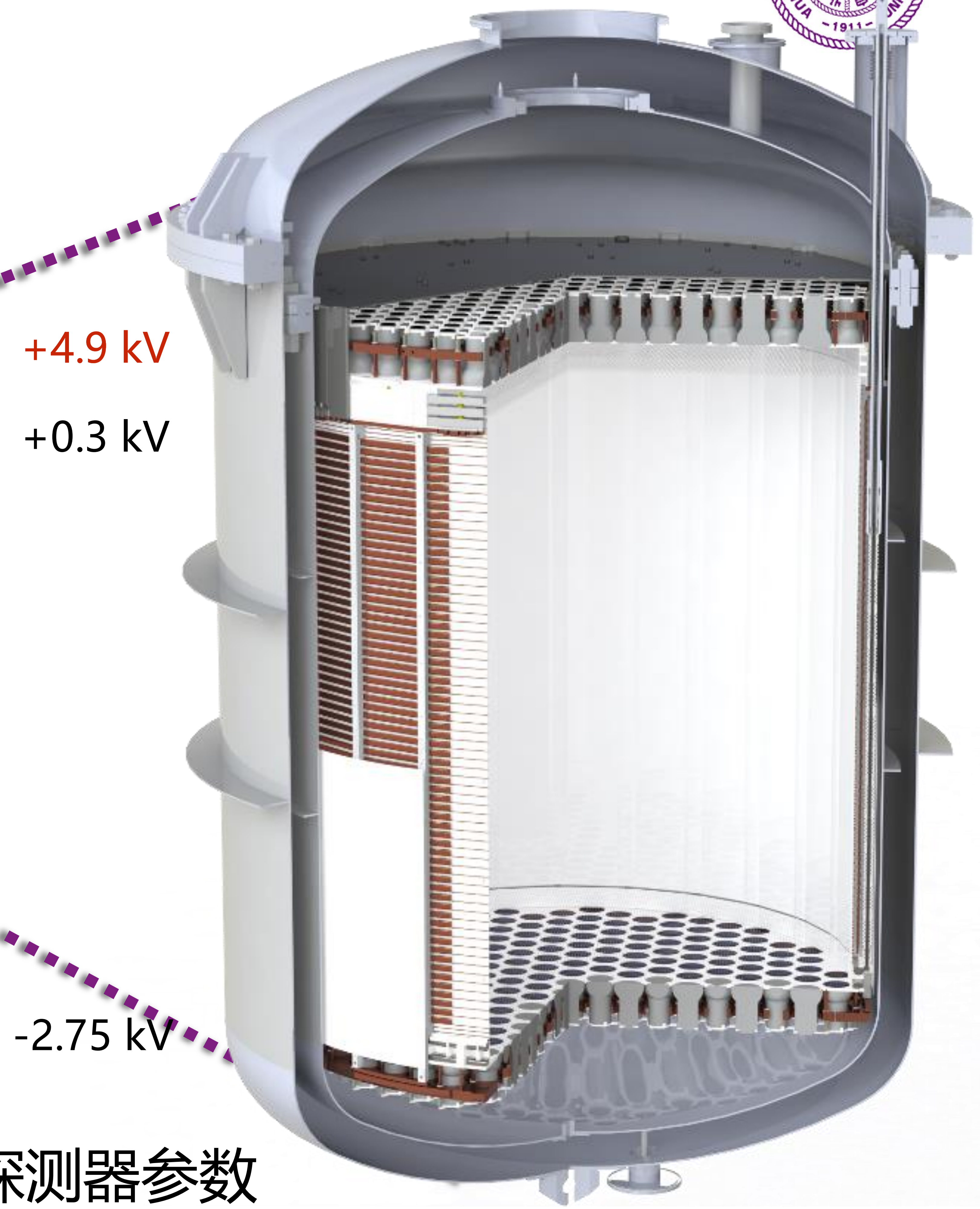
XENON合作组

~170 SCIENTISTS, 29 INSTITUTIONS, 12 COUNTRIES

XENONnT实验：地下实验室与探测器



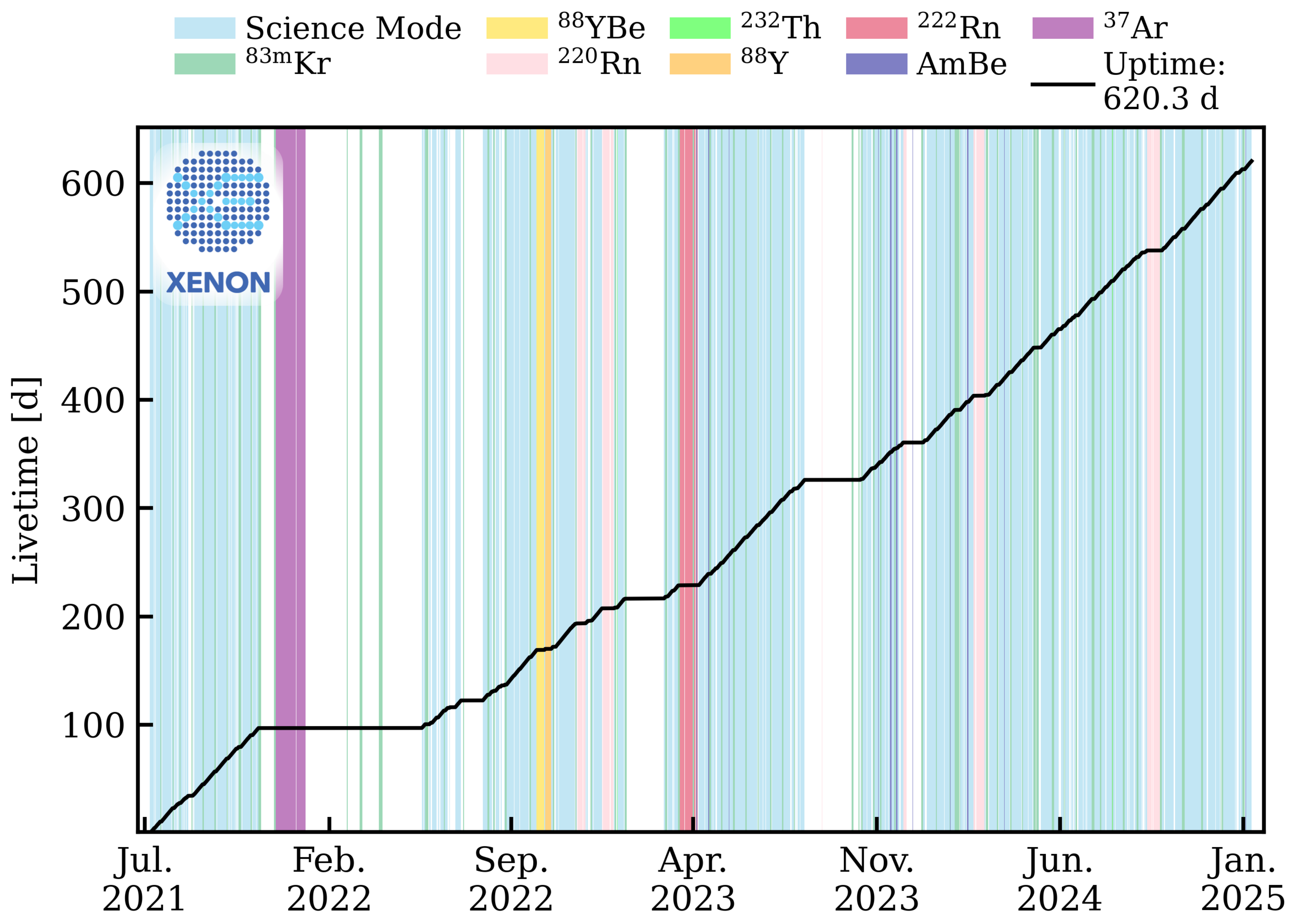


- 主探测器参数

漂移长度	直径	灵敏区液氙质量	漂移电场
1.5 米	**1.32 米**	**5.9 吨**	**23 V/cm**

EPJ-C 84, 784, 2024

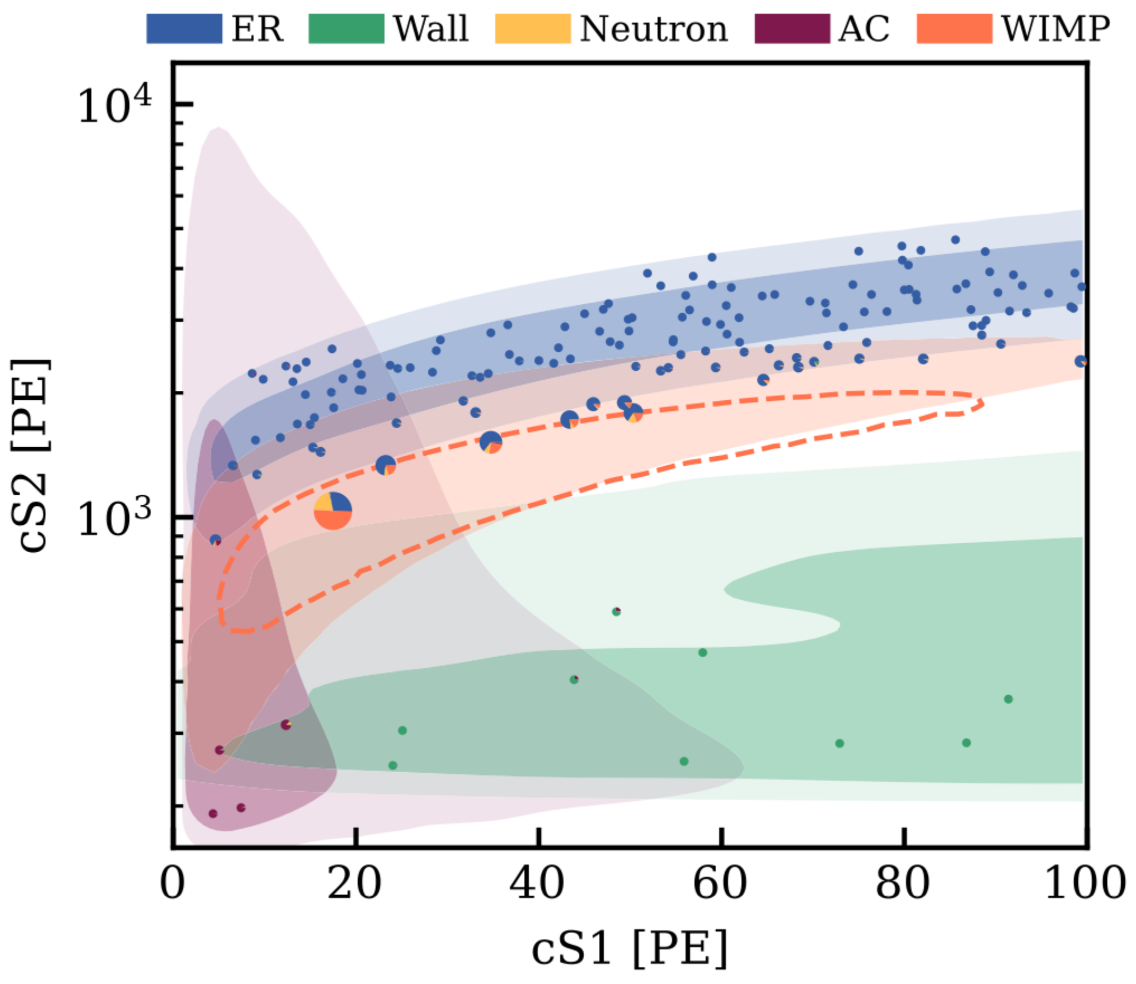
数据采集与物理分析：盲分析 (blind analysis)



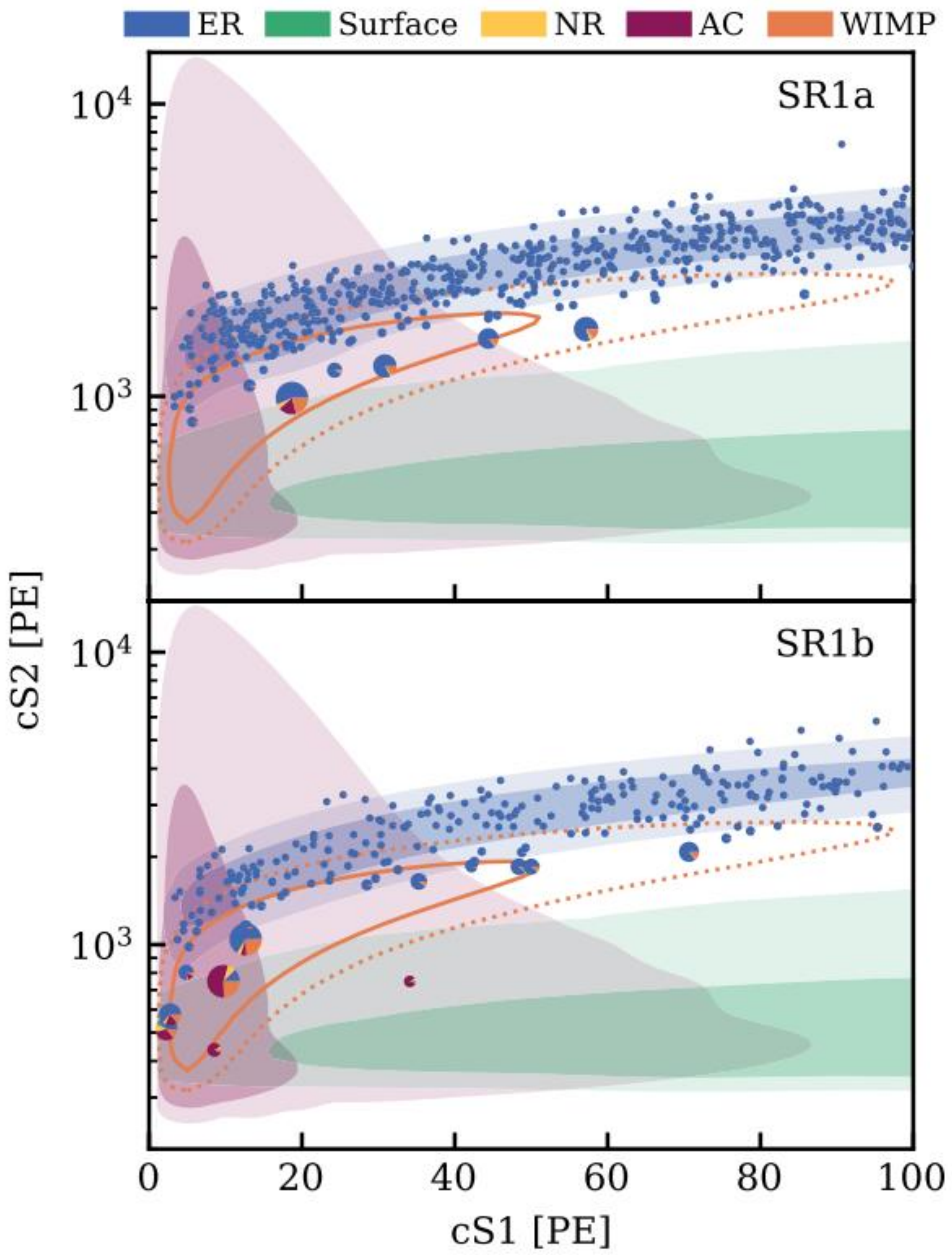
SR0 **SR1** **SR2**

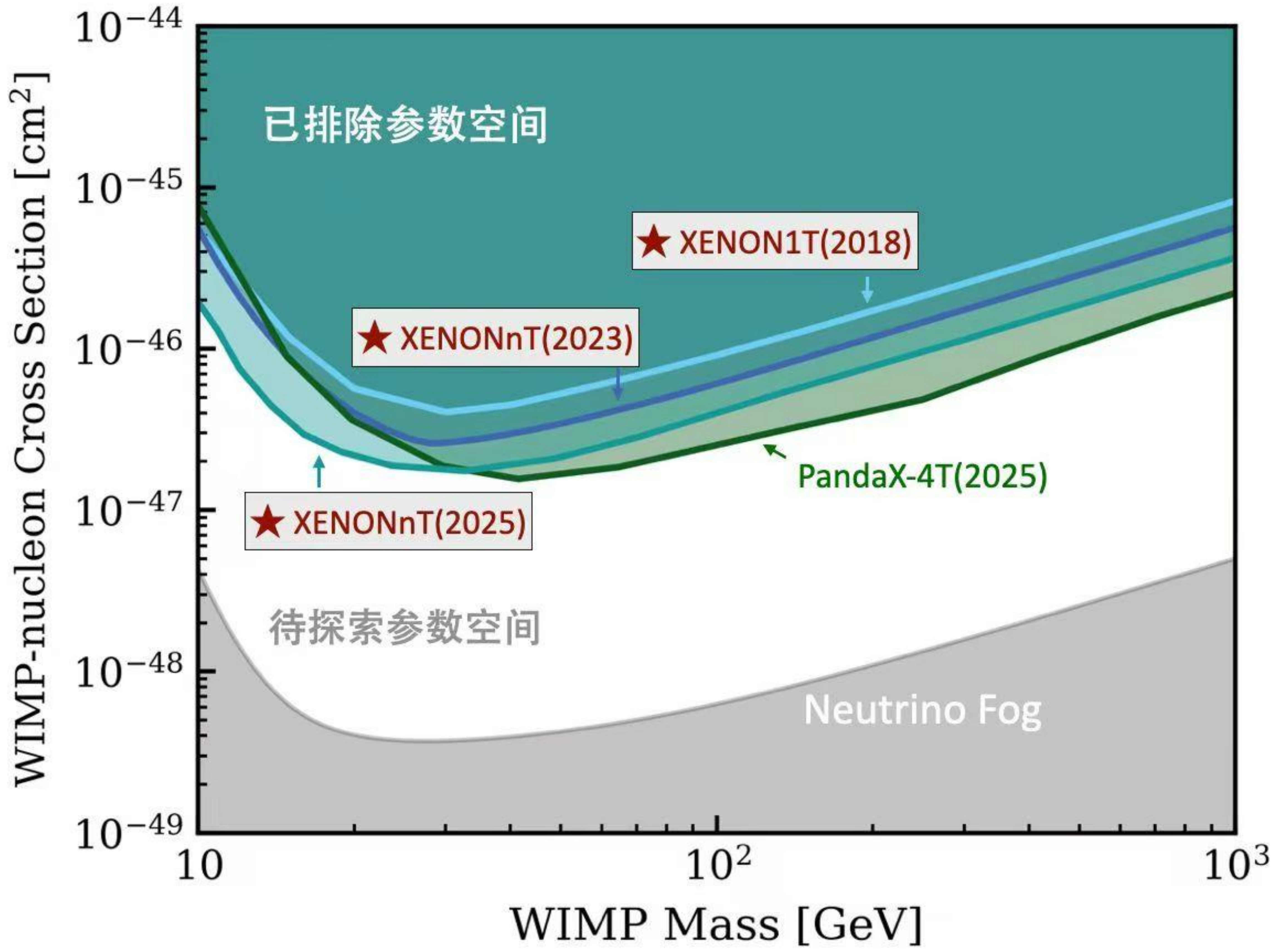
暗物质探测结果

SR0



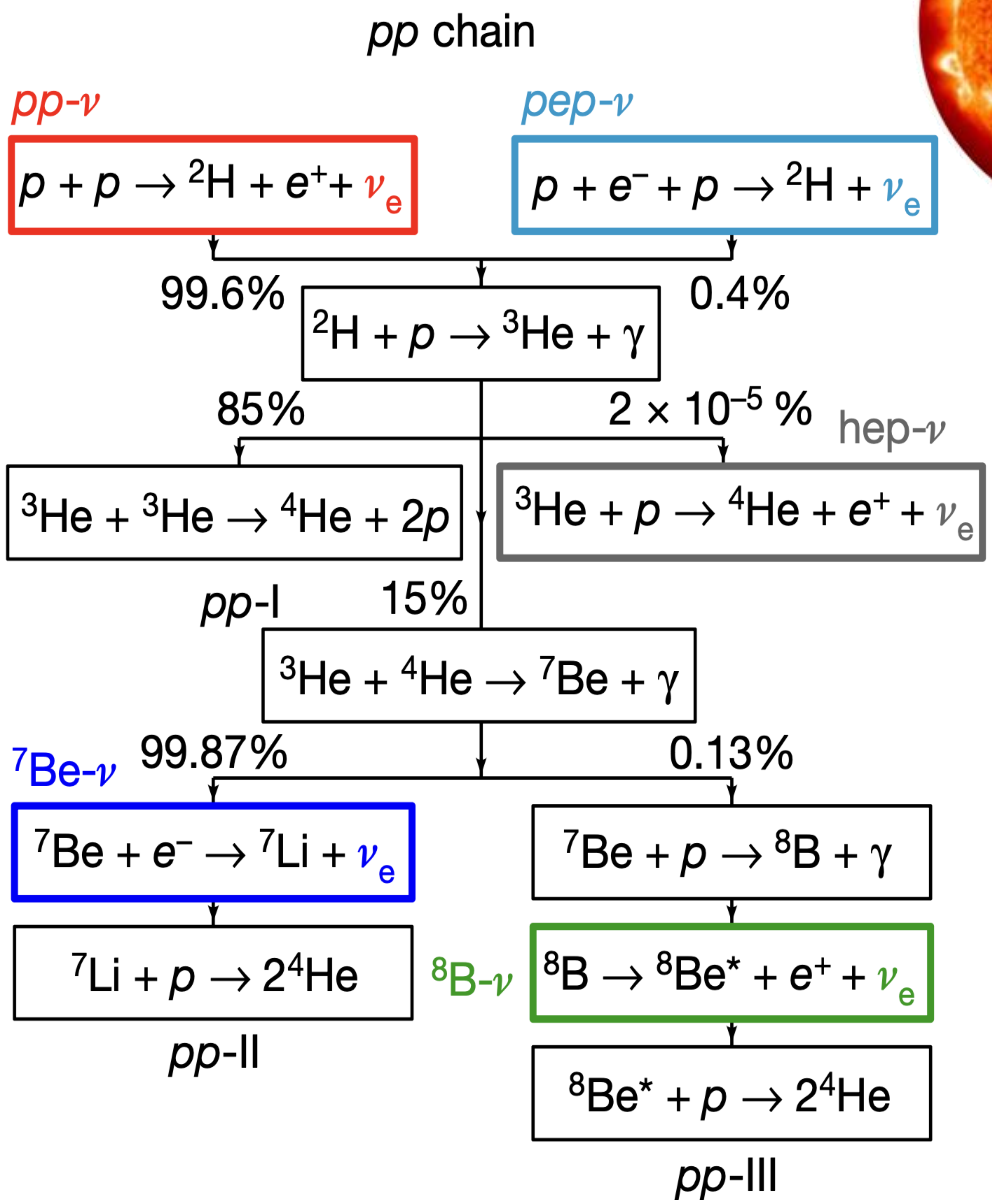
SR1



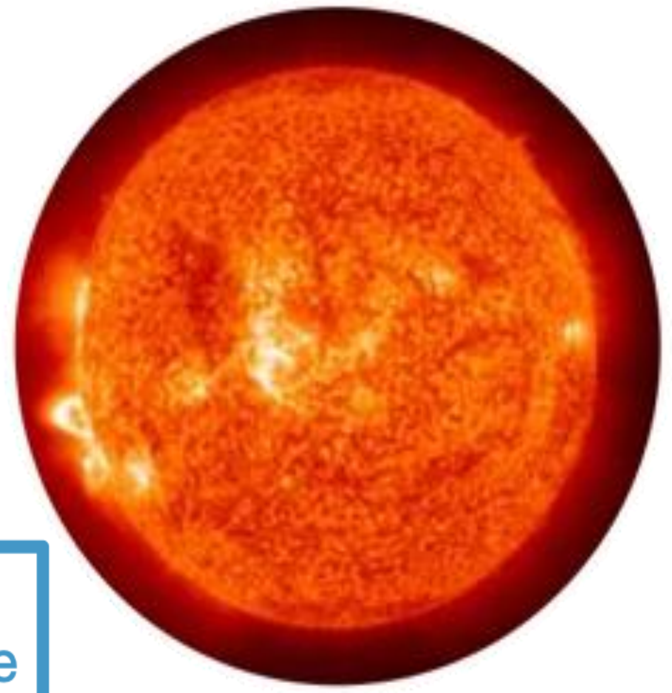


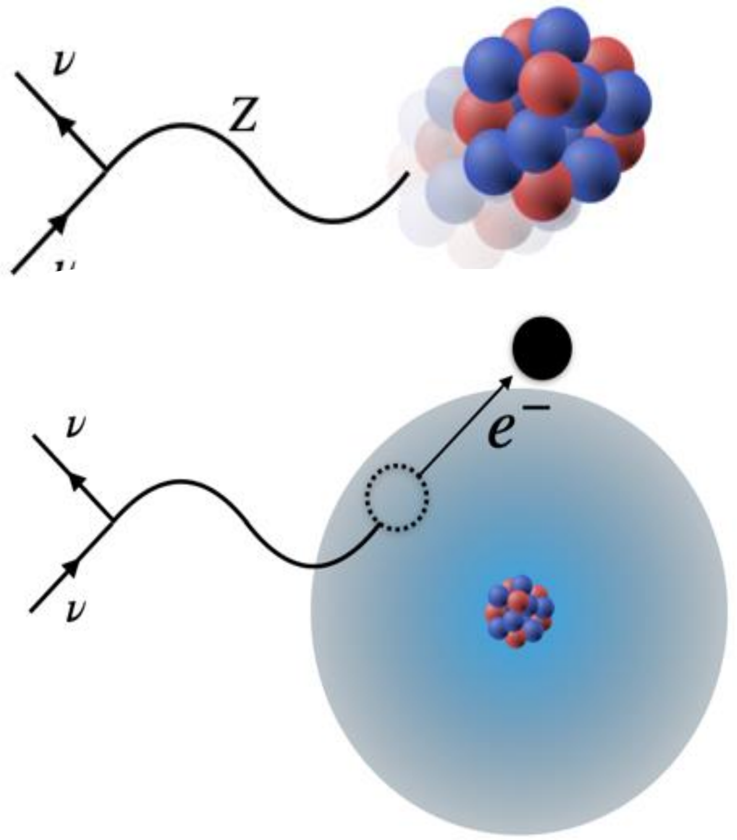
- **PRL 131, 041003, 2023**
- **PRL 135, 221003, 2025**

太阳中微子的探测

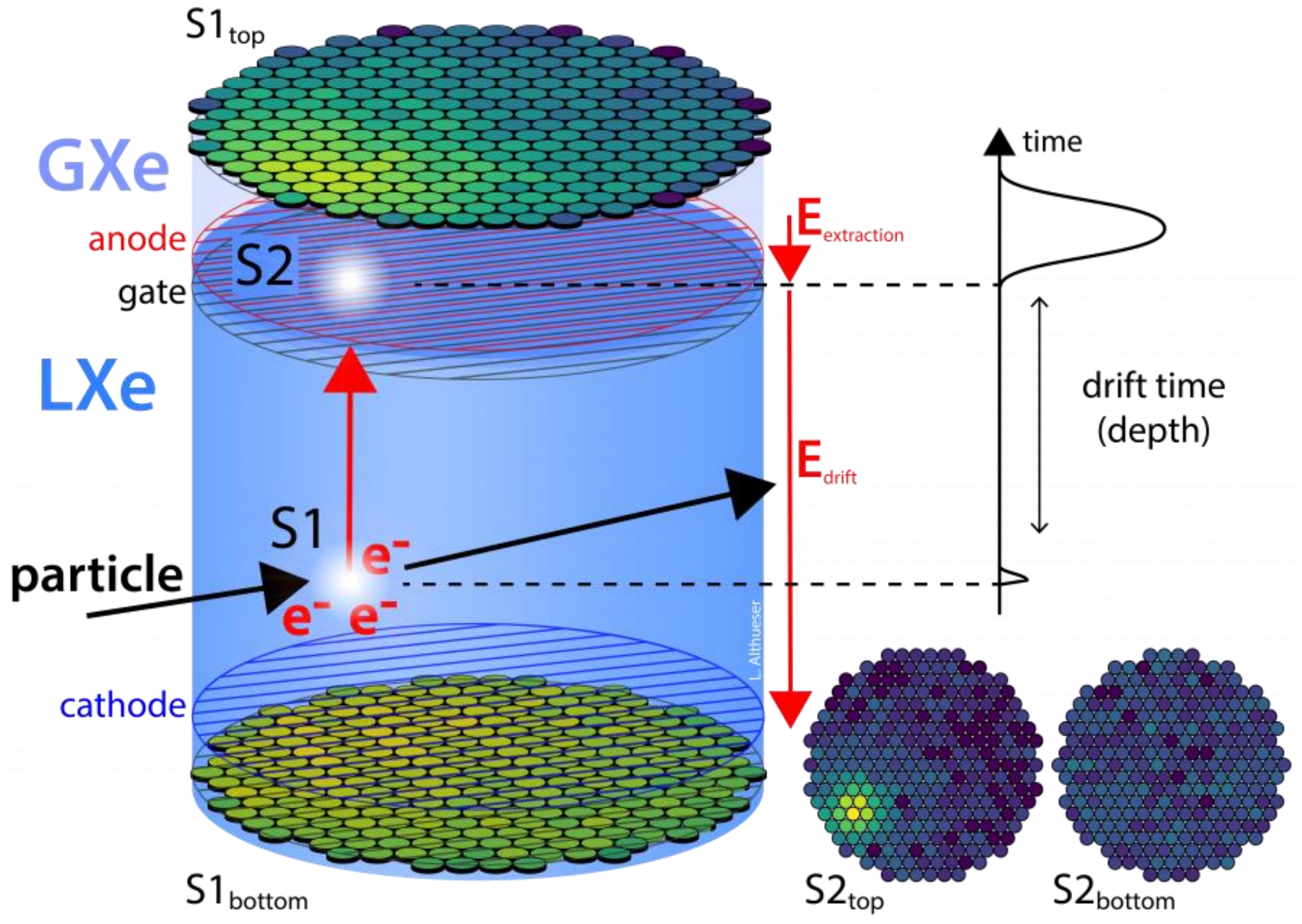


pp chain
pp-ν
pep-ν
$p + p \to {}^2H + e^+ + \nu_e$
$p + e^- + p \to {}^2H + \nu_e$
99.6%
0.4%
$^2H + p \to {}^3He + \gamma$
85%
2×10^{-5} %
hep-ν
$^3He + {}^3He \to {}^4He + 2p$
$^3He + p \to {}^4He + e^+ + \nu_e$
pp-I
15%
$^3He + {}^4He \to {}^7Be + \gamma$
^{7}Be-ν
99.87%
0.13%
$^7Be + e^- \to {}^7Li + \nu_e$
$^7Be + p \to {}^8B + \gamma$
$^7Li + p \to 2\,{}^4He$
^{8}B-ν
$^8B \to {}^8Be^* + e^+ + \nu_e$
pp-II
$^8Be^* + p \to 2\,{}^4He$
pp-III

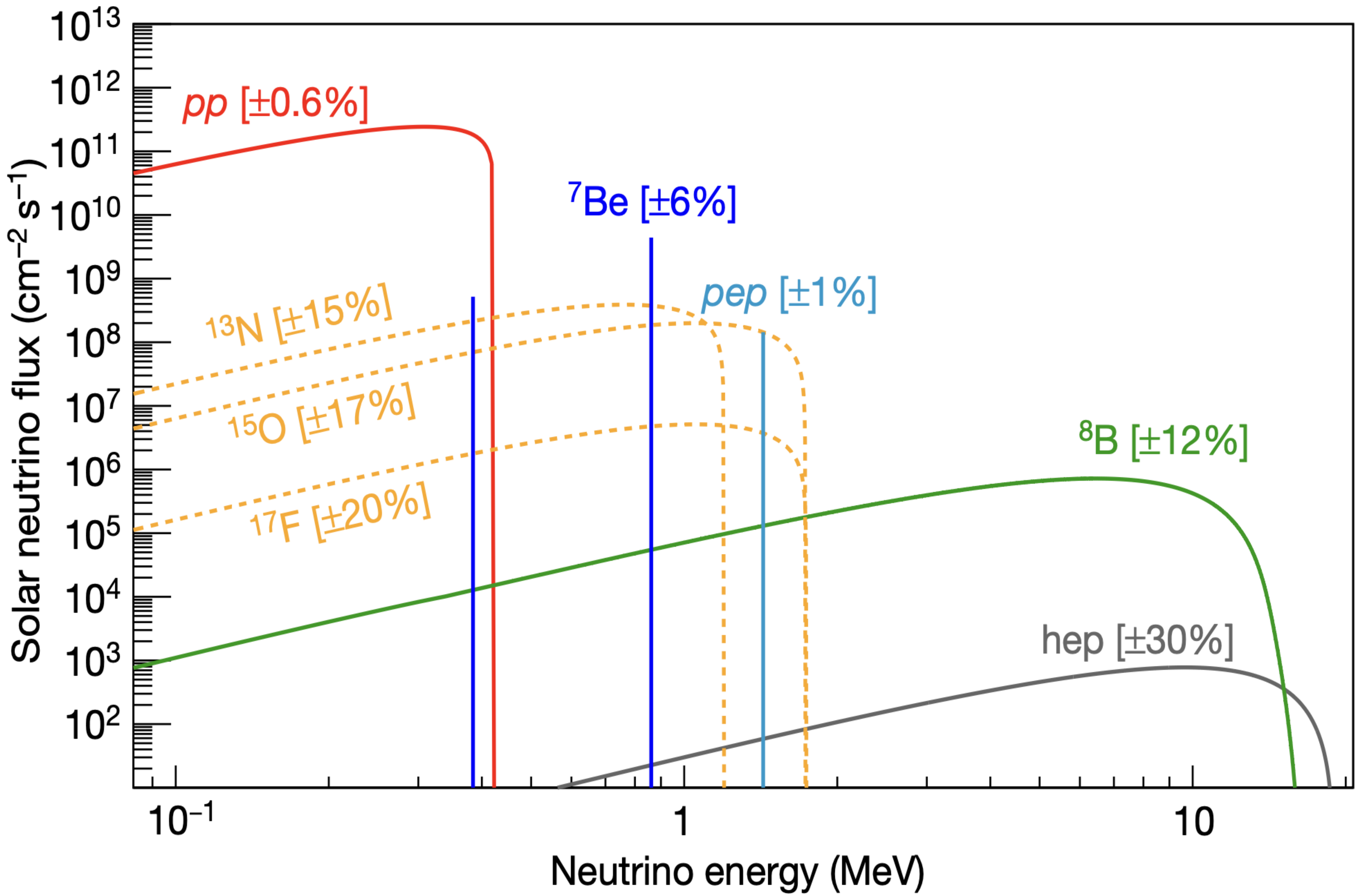




ν
Z
ν
e^-
ν

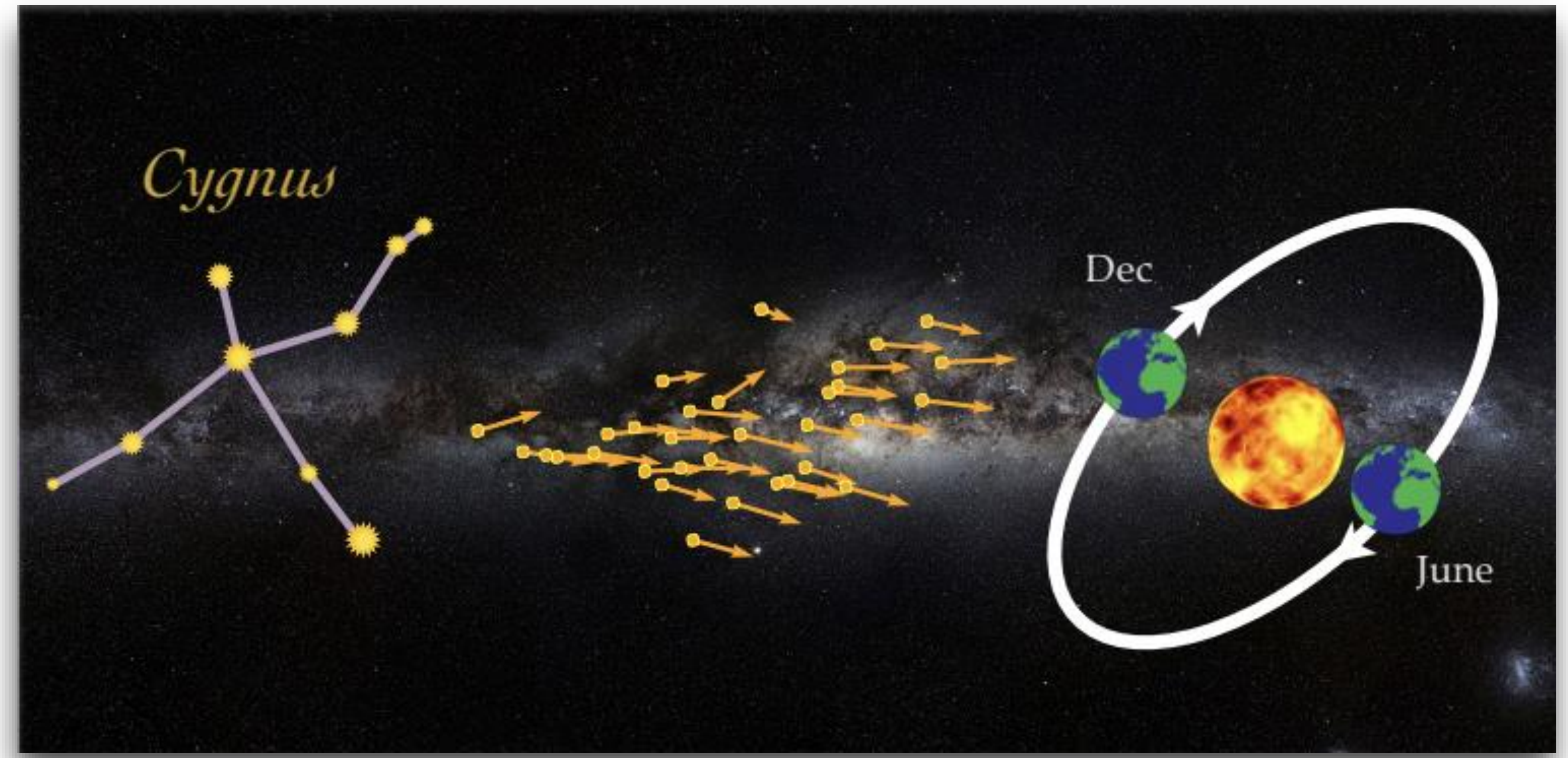


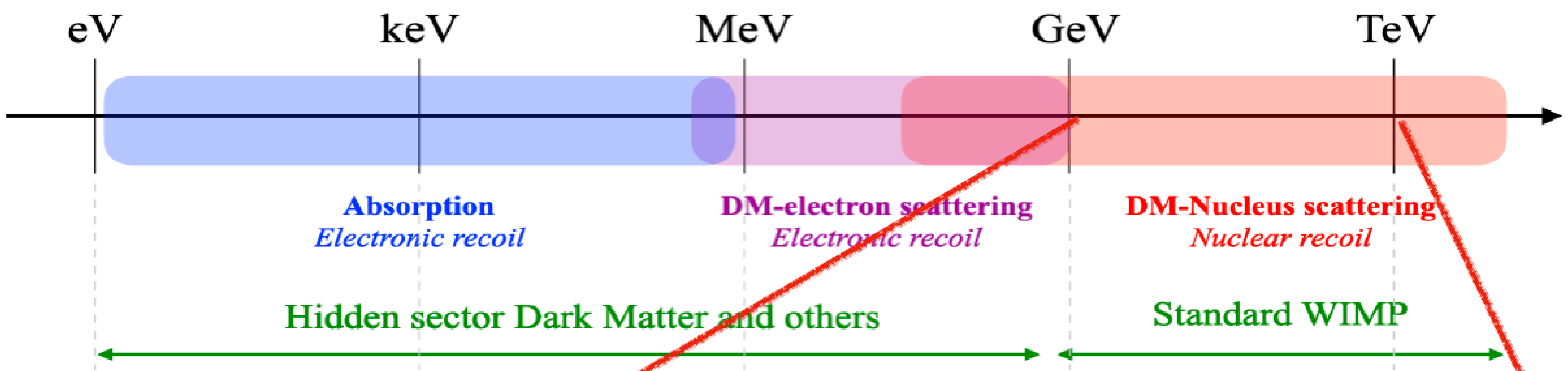
$S1_{top}$
GXe
anode
gate
S2
LXe
$E_{extraction}$
time
drift time
(depth)
E_{drift}
S1
particle
e^-
e^- e^-
cathode
$S1_{bottom}$
$S2_{top}$
$S2_{bottom}$

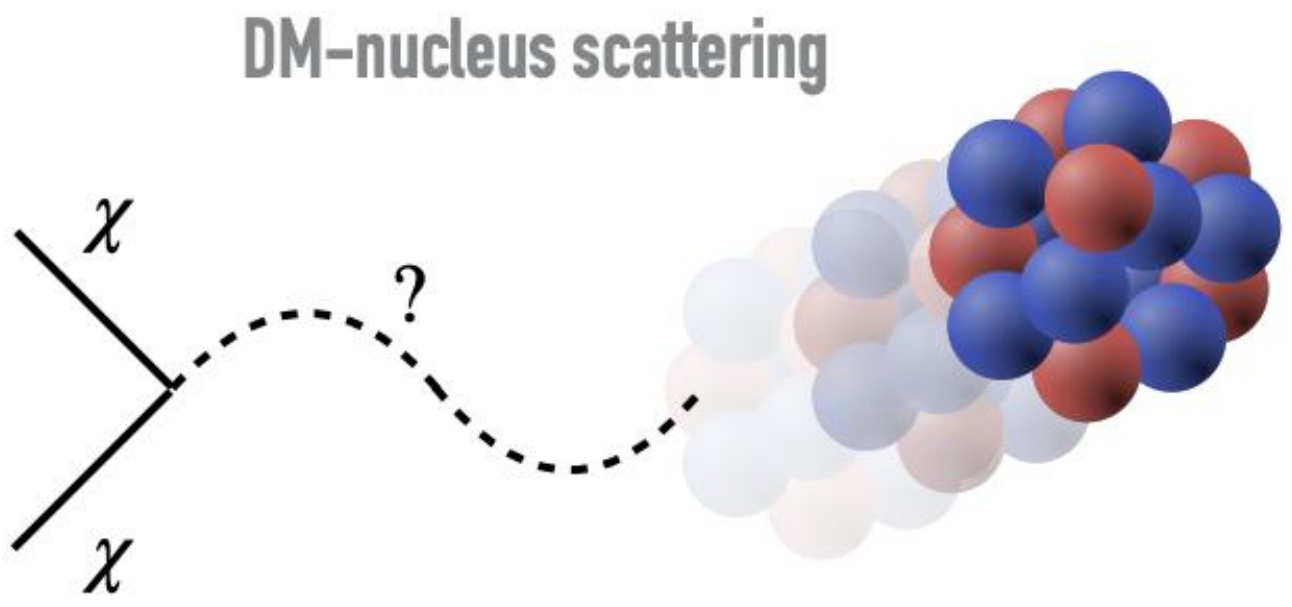


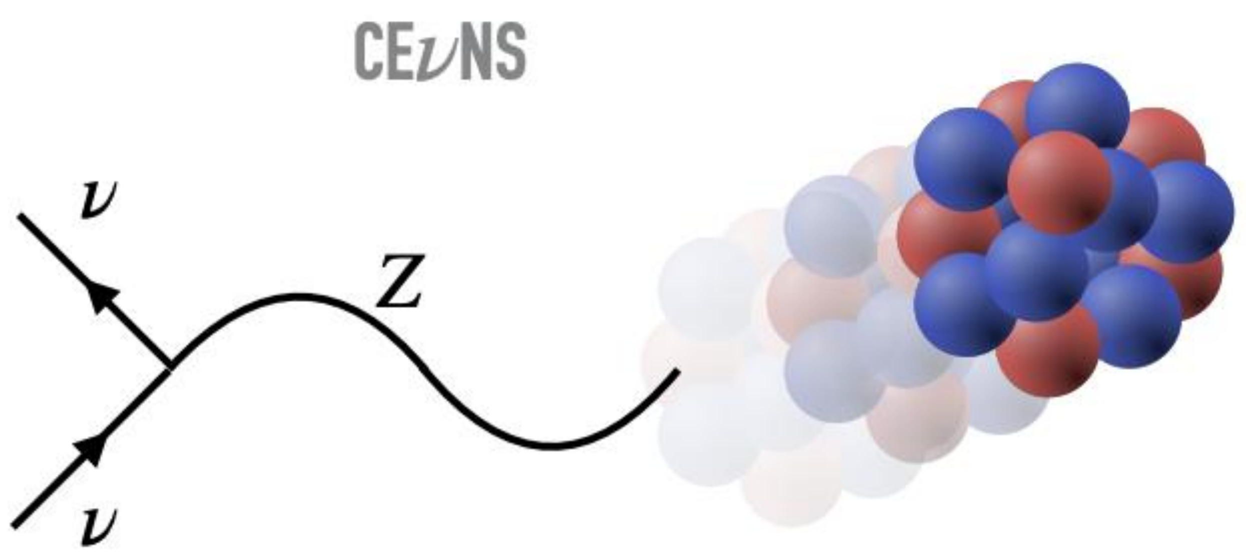
Solar neutrino flux ($cm^{-2}\,s^{-1}$)
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
pp [±0.6%]
^{7}Be [±6%]
^{13}N [±15%]
pep [±1%]
^{15}O [±17%]
^{8}B [±12%]
^{17}F [±20%]
hep [±30%]
10^{-1}
1
10
Neutrino energy (MeV)

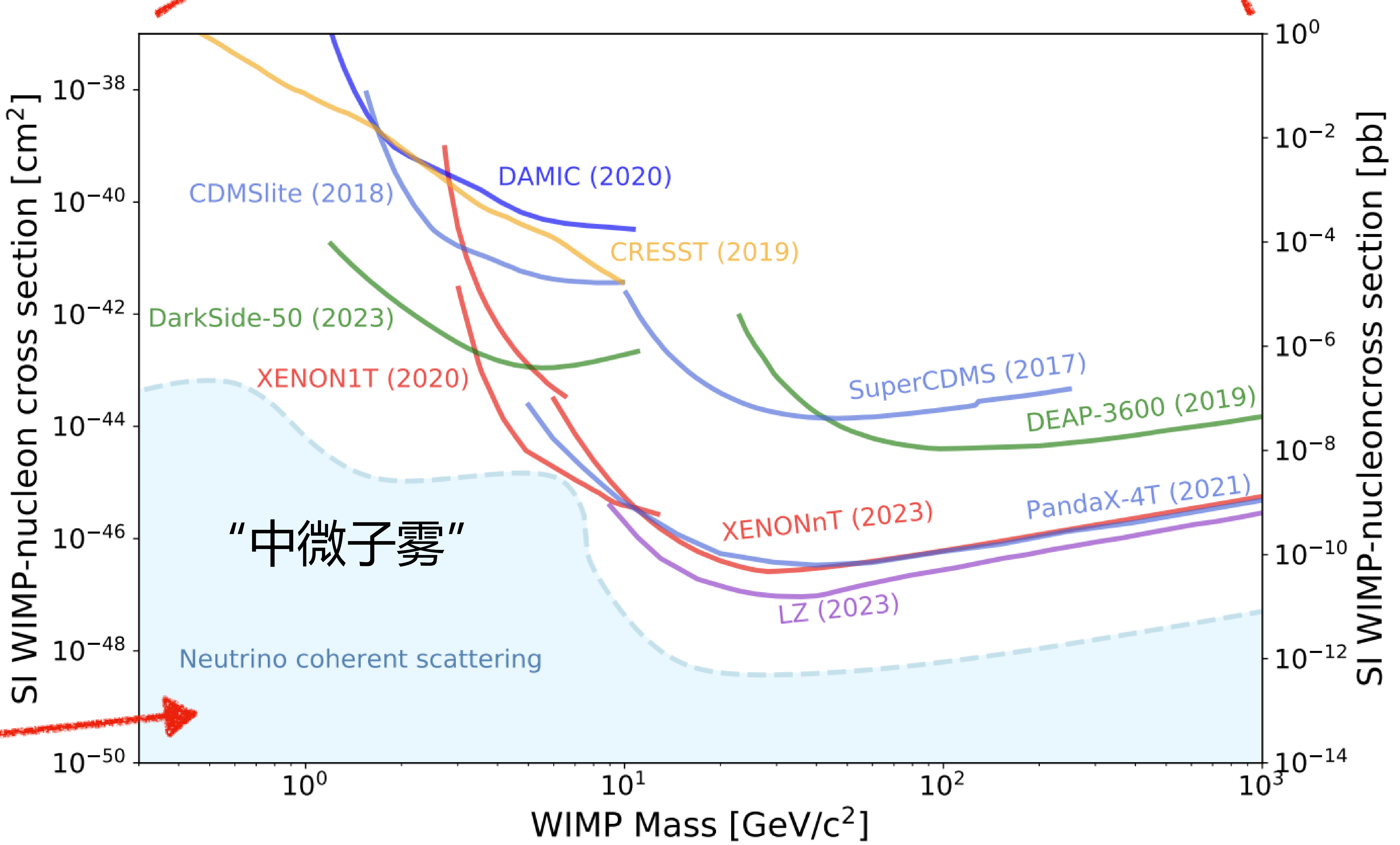
暗物质直接探测的“中微子雾”？







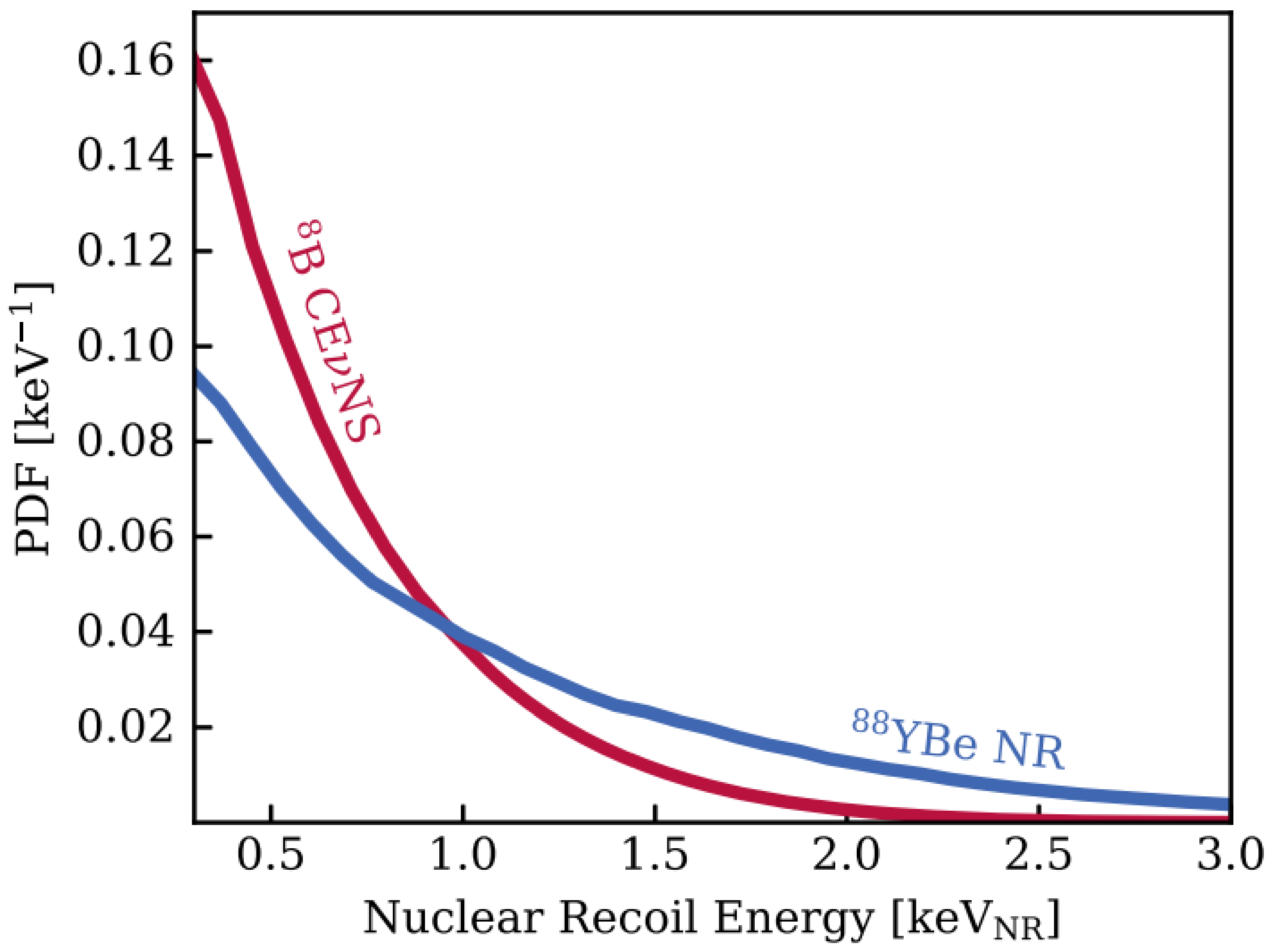


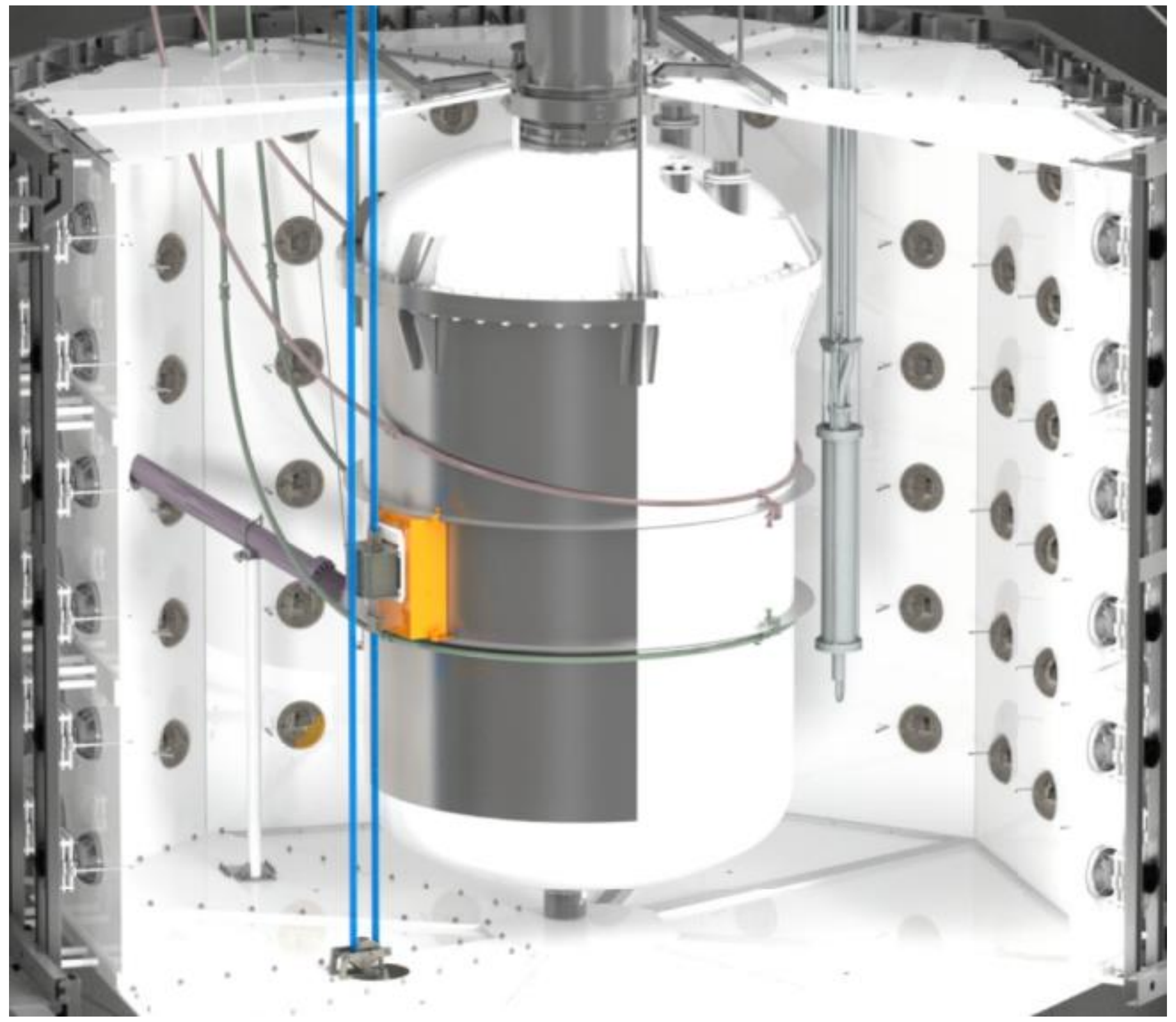


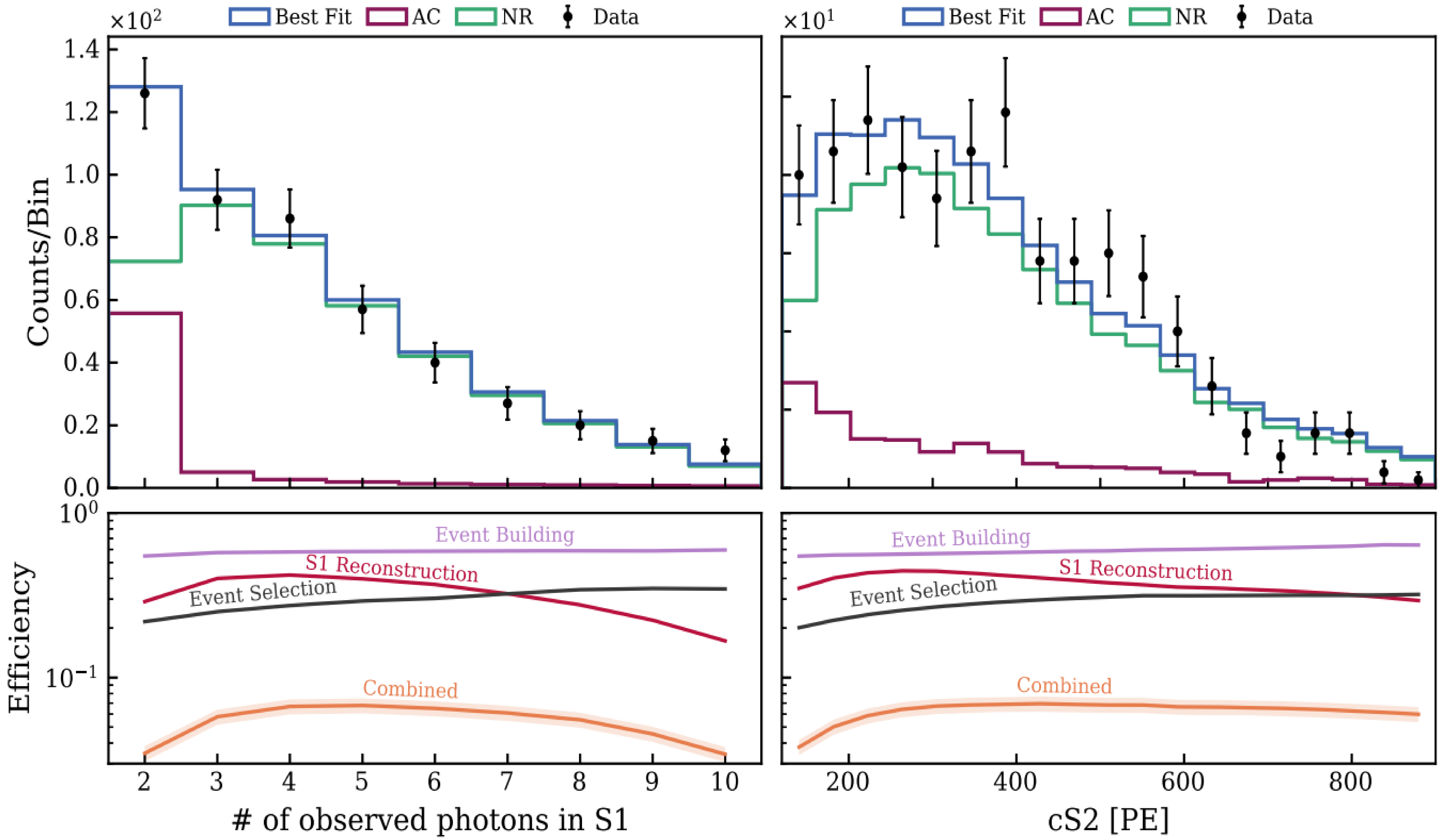
R.L. Workman et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2022, 083C01 (2022) and 2023 update

XENONnT: The Smallest Solar Neutrino Detector

太阳^{8}B中微子信号的标定 -- ^{88}YBe

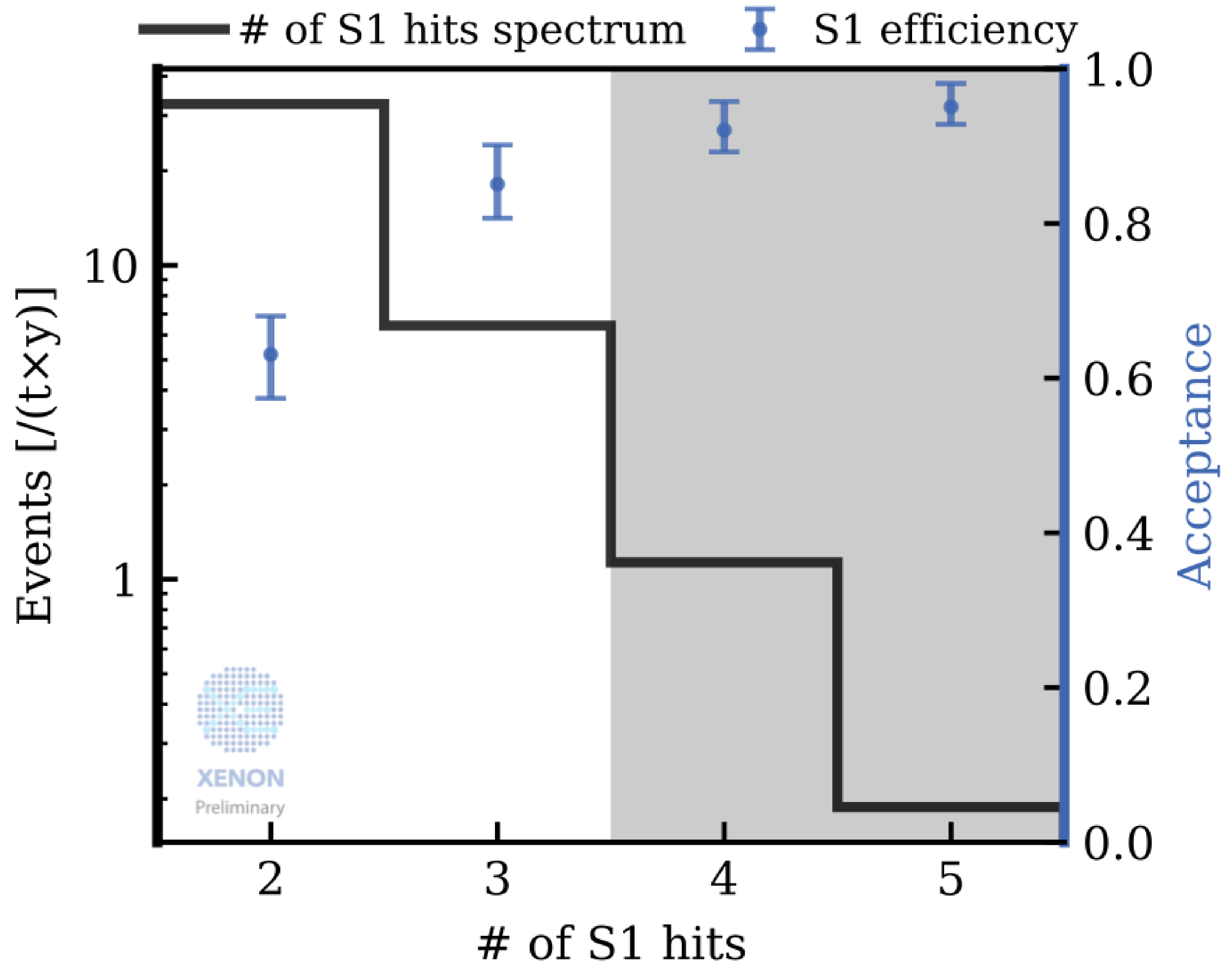


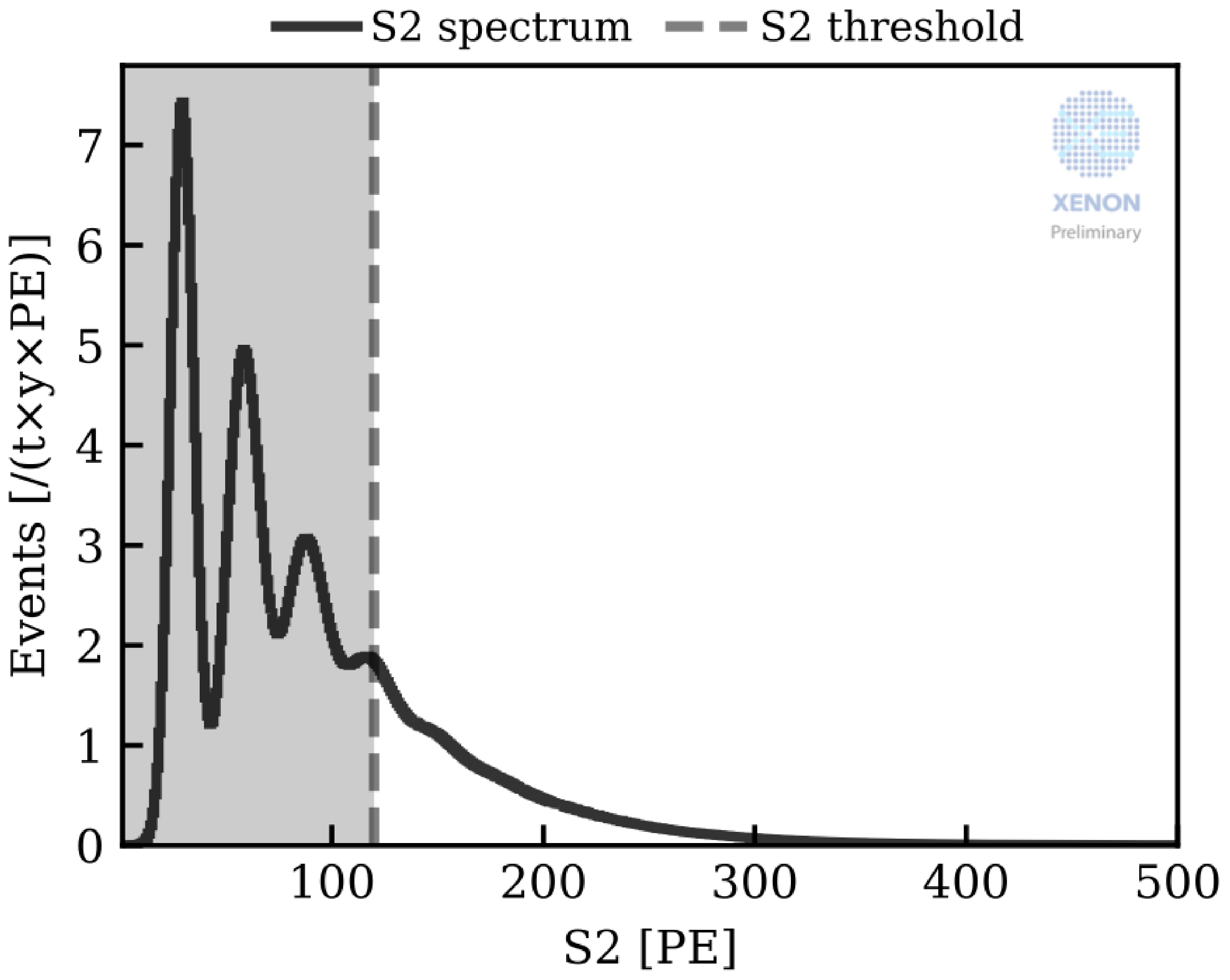


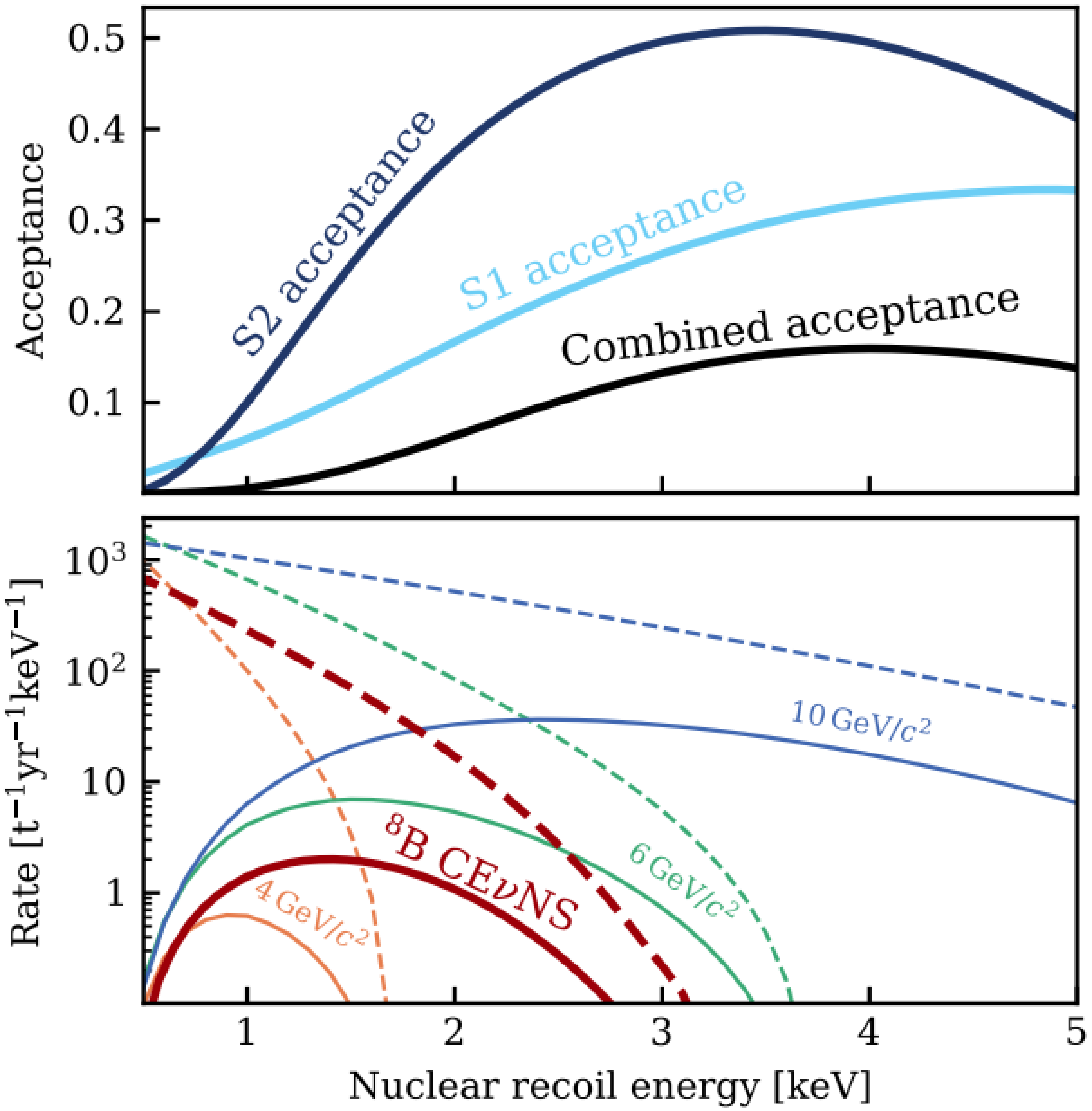


- **PRD 113, 112017, 2026**

太阳^{8}B中微子的探测效率

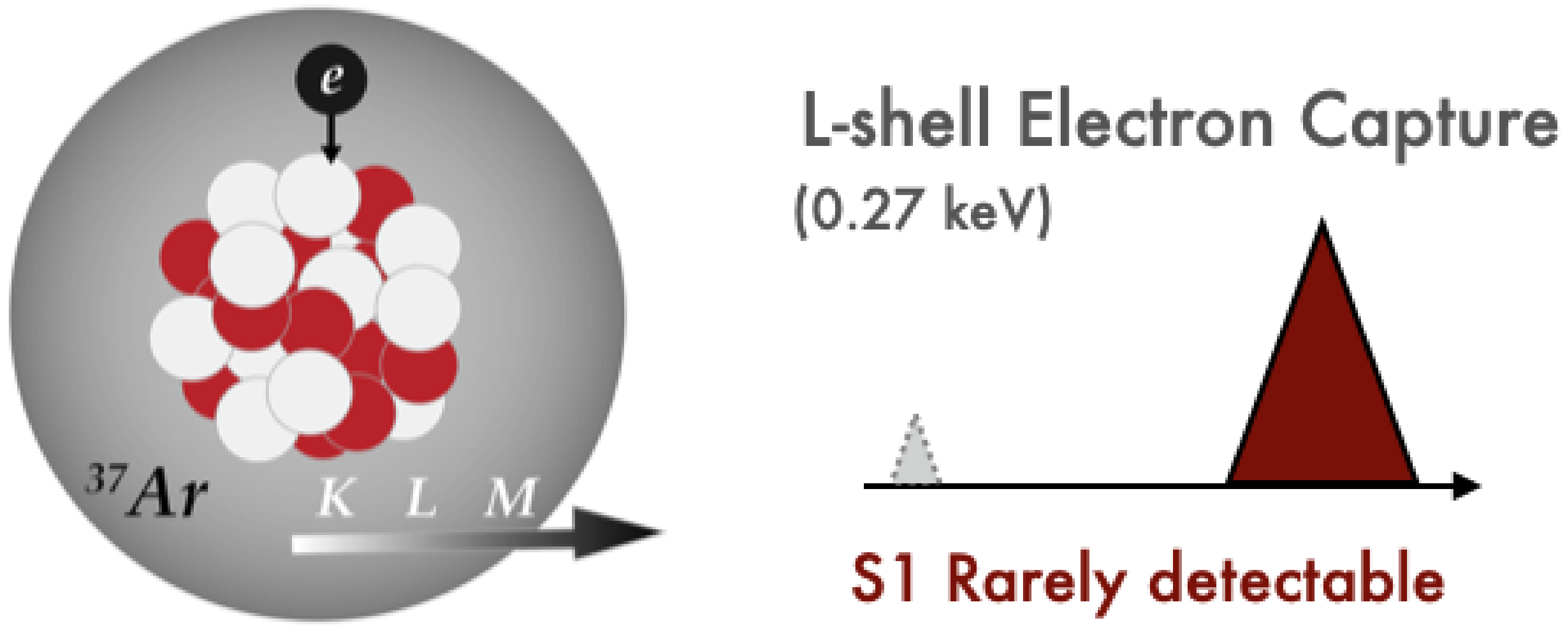


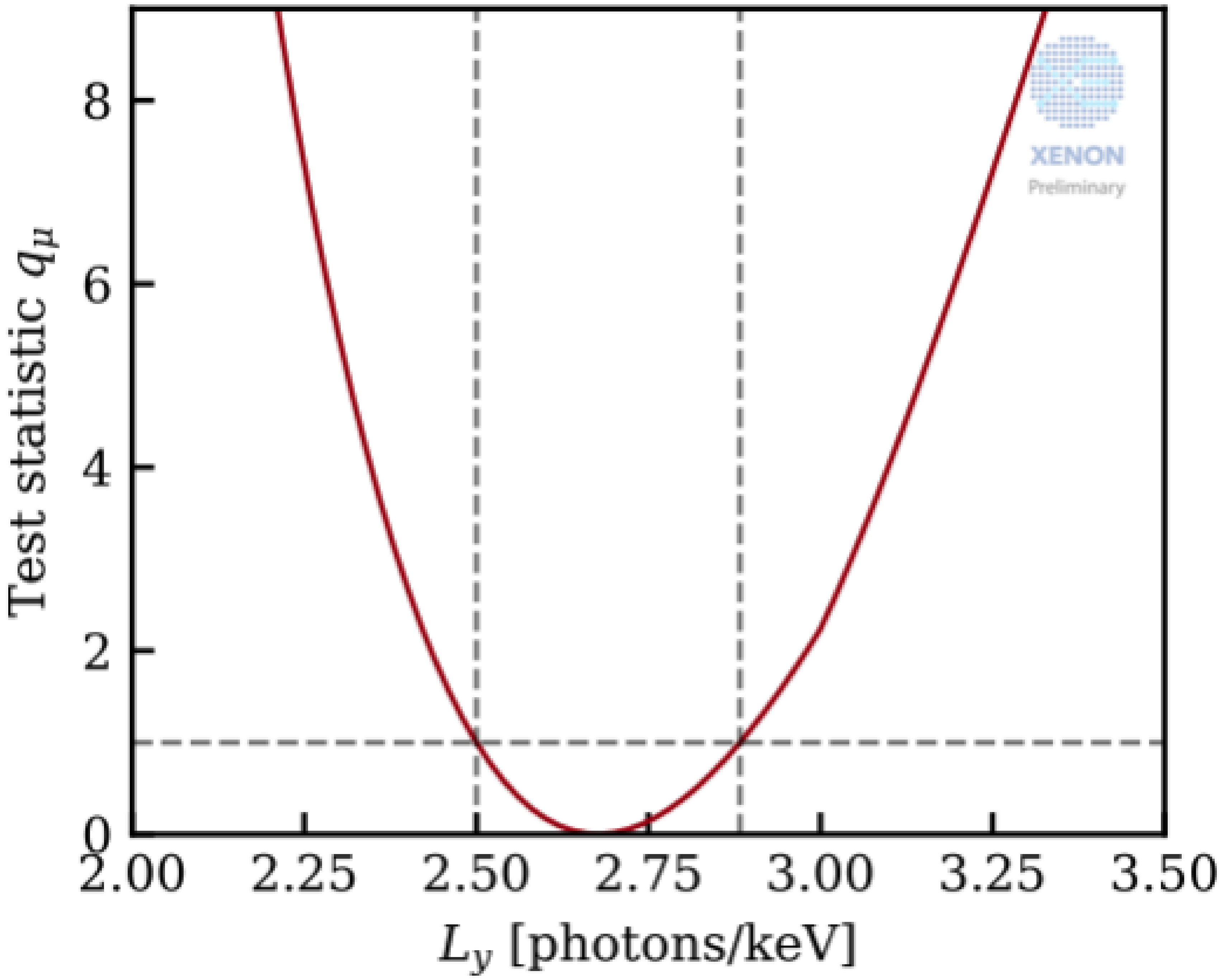


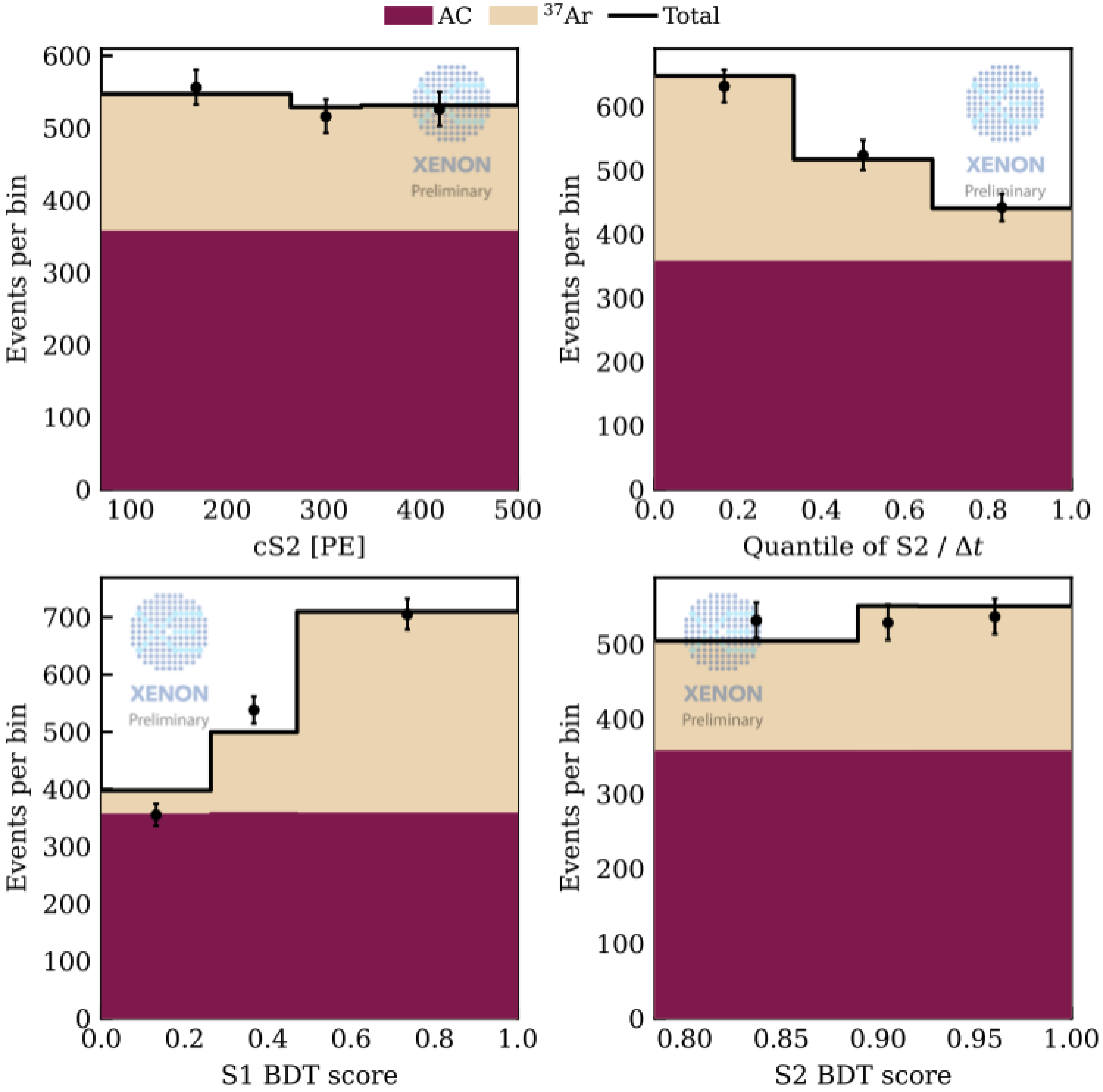


- **PRL 133, 191002, 2024**

太阳^{8}B中微子分析方案的直接验证

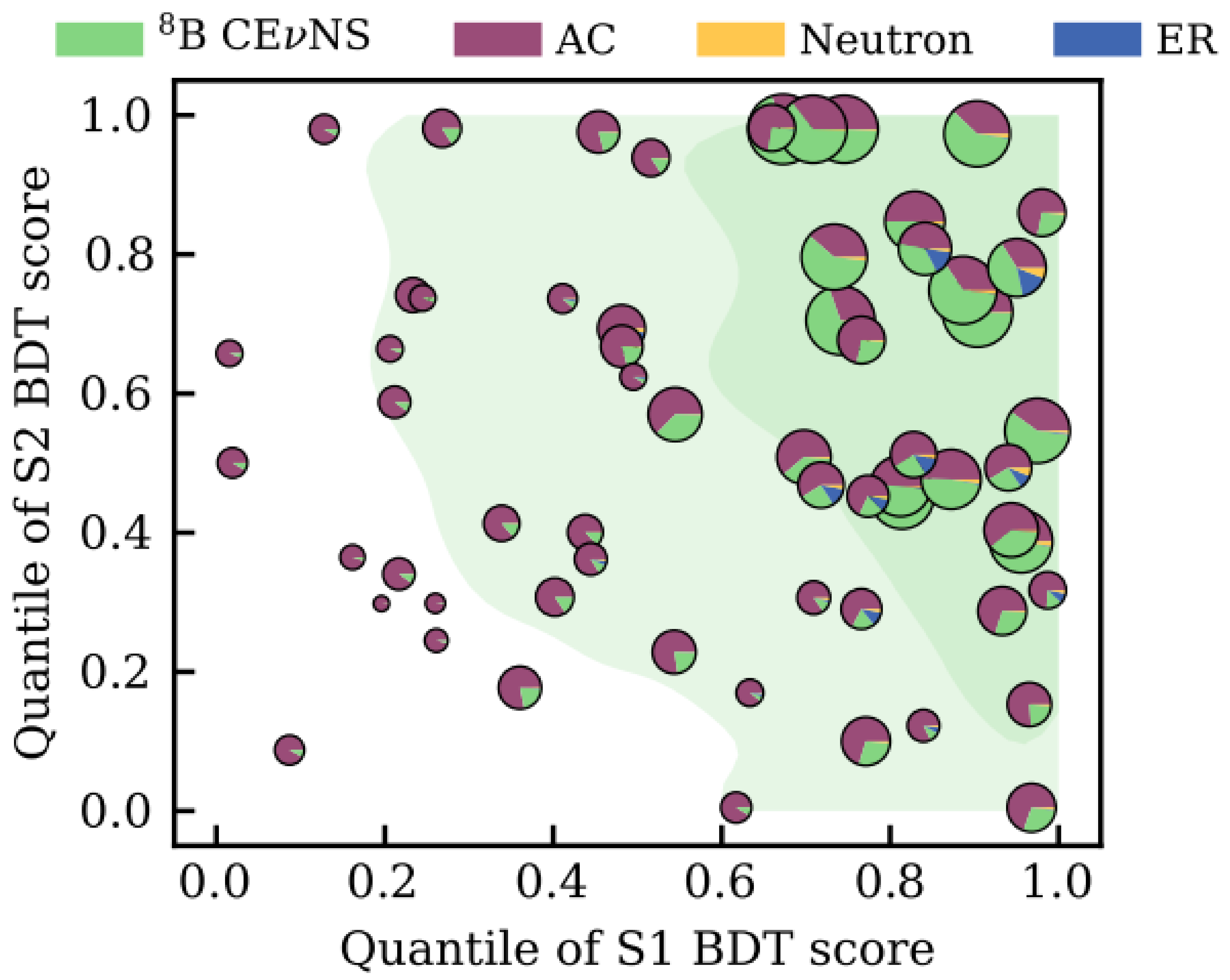






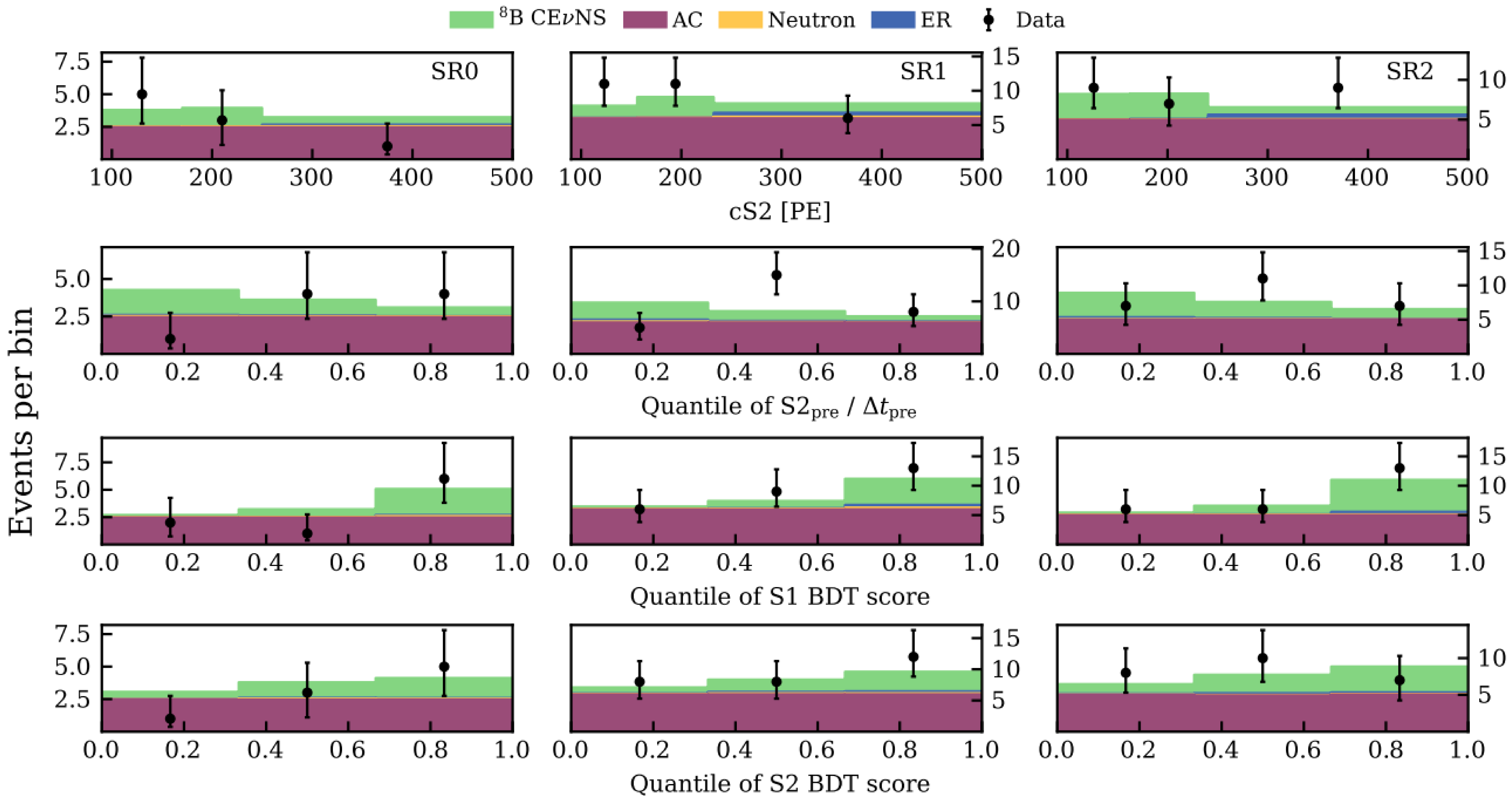
太阳^{8}B中微子的探测结果

成分	预测	本底 + ^{8}B best fit
AC – SR0	7.5 ± 0.7	7.4
AC – SR1	17.8 ± 1.0	17.9
AC – SR2	14.9 ± 0.7	14.9
ER	1.2 ± 1.2	1.4
Neutron	0.8 ± 0.4	0.8
总本底	42.1 ± 1.9	42.4
^{8}B – SR0	3.2 ± 1.0	3.3
^{8}B – SR1	5.9 ± 1.8	6.1
^{8}B – SR2	7.2 ± 2.2	7.3
^{8}B Total	16 ± 4.5	17
观测	9 (SR0) + 28 (SR1) + 25 (SR2) = 62	



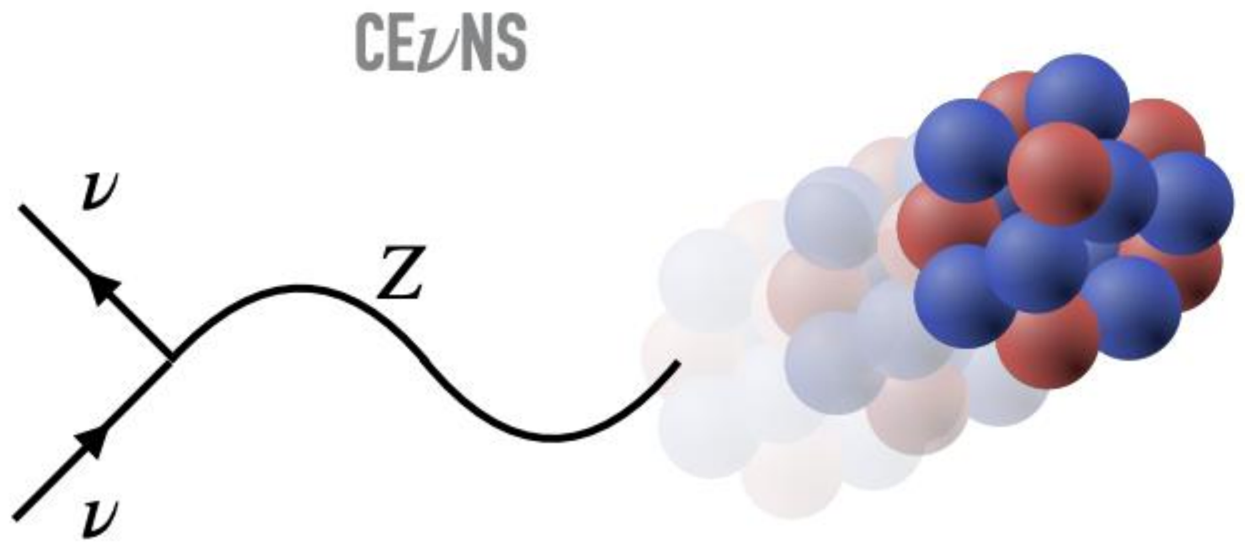
- **PRL 133, 191002, 2024**
- **arXiv: 2604.06002, accepted by PRL**

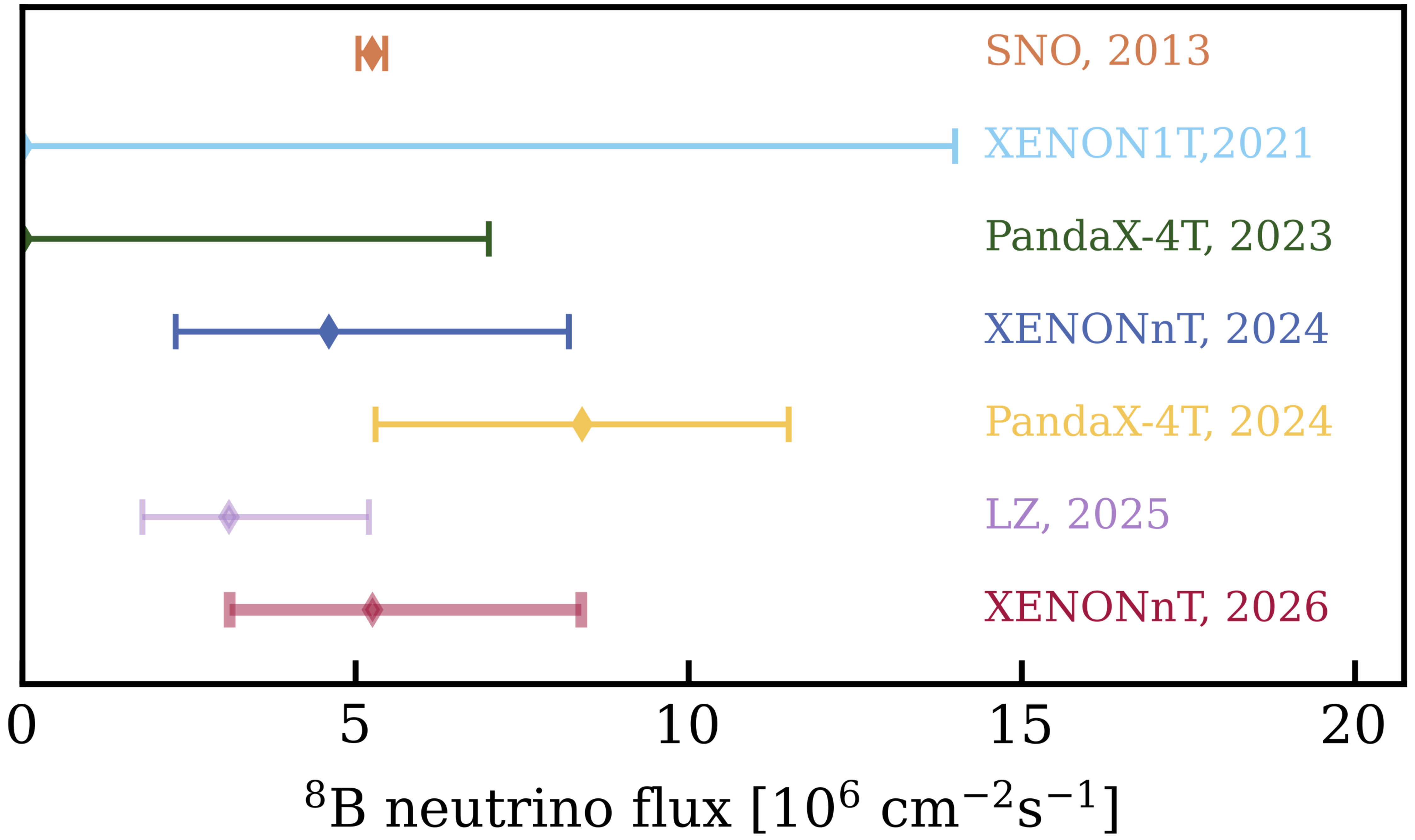
太阳^{8}B中微子的事件分布特征

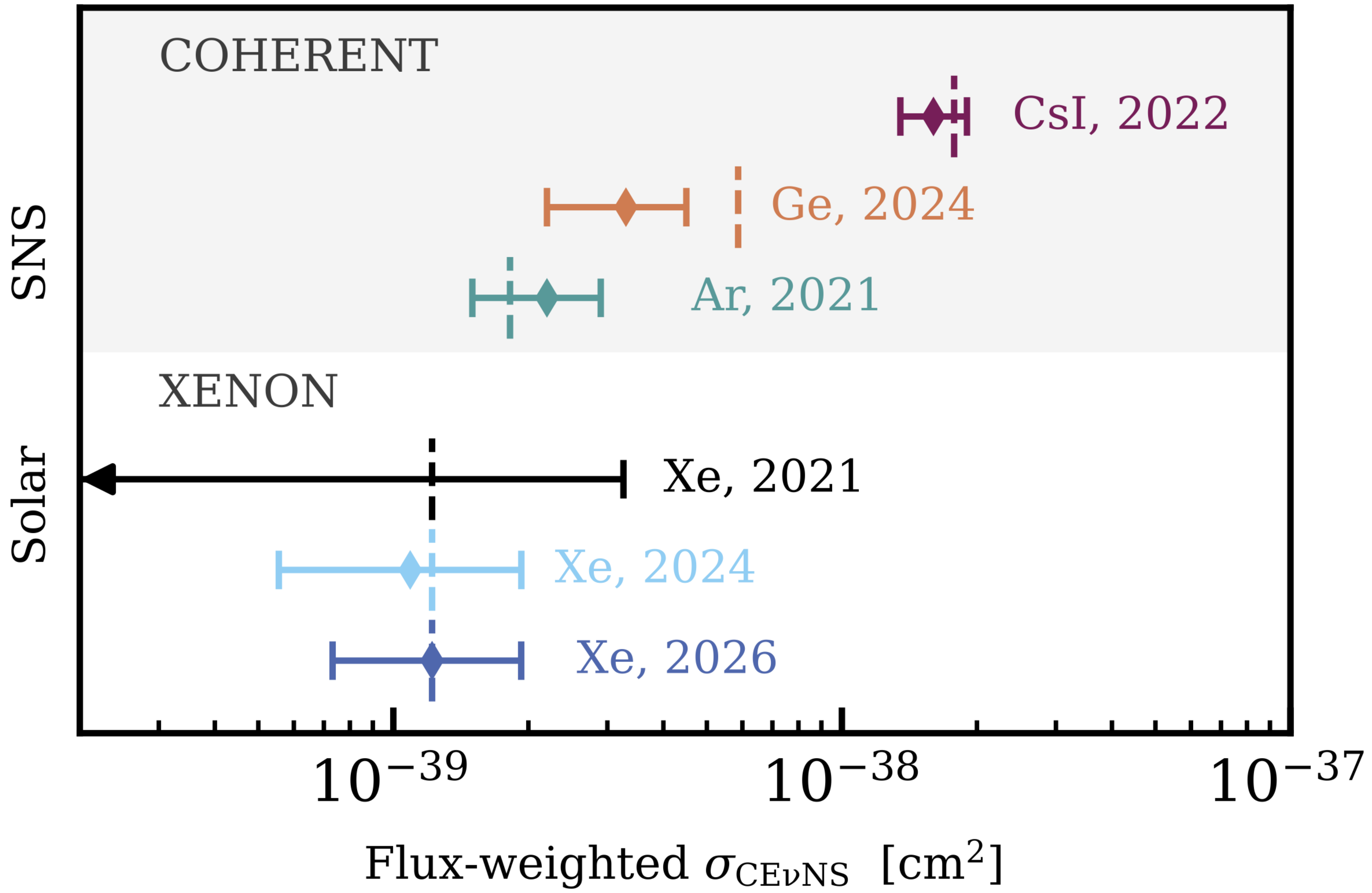


- **PRL 133, 191002, 2024**
- **arXiv: 2604.06002, accepted by PRL**

太阳^{8}B中微子流强和相干散射截面测量

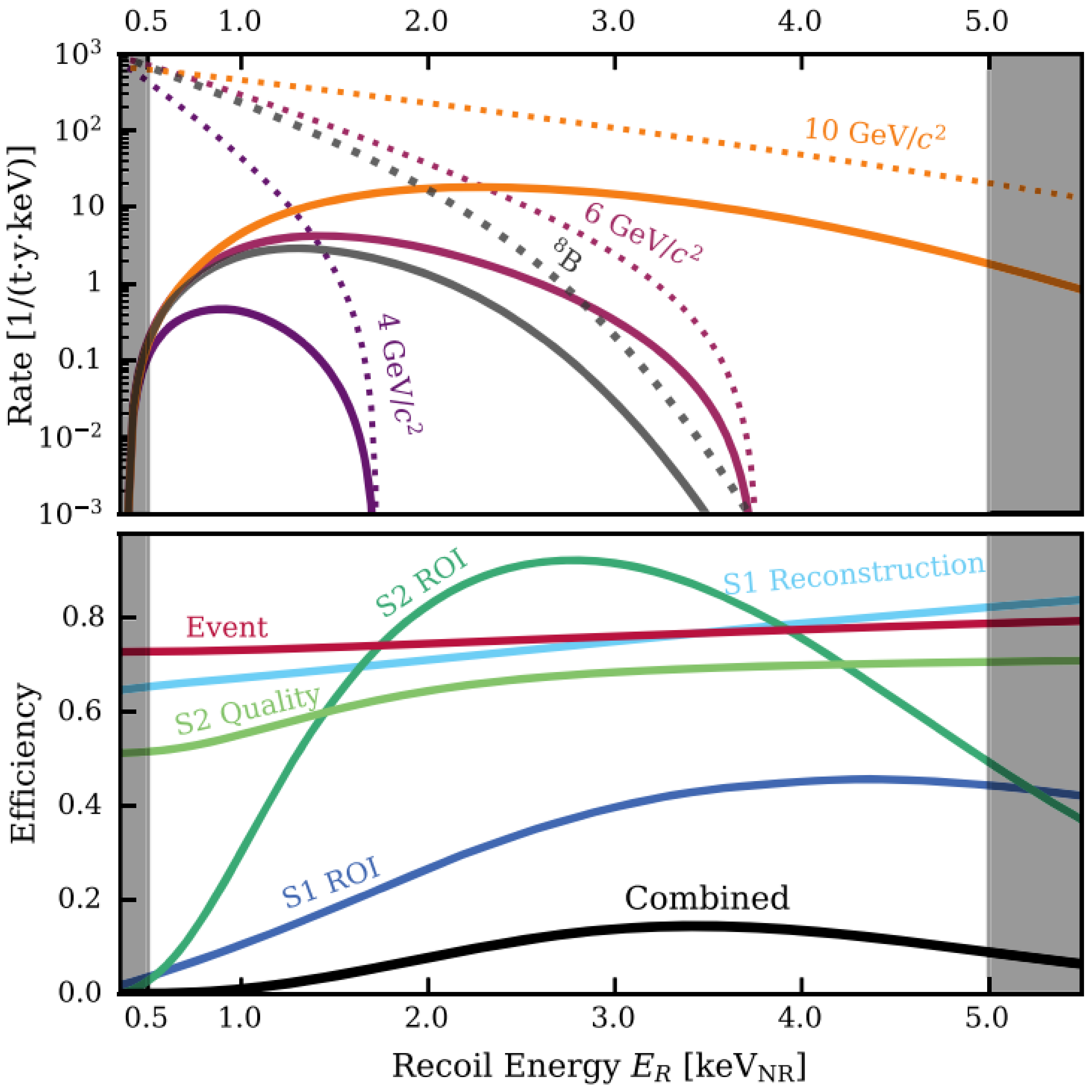


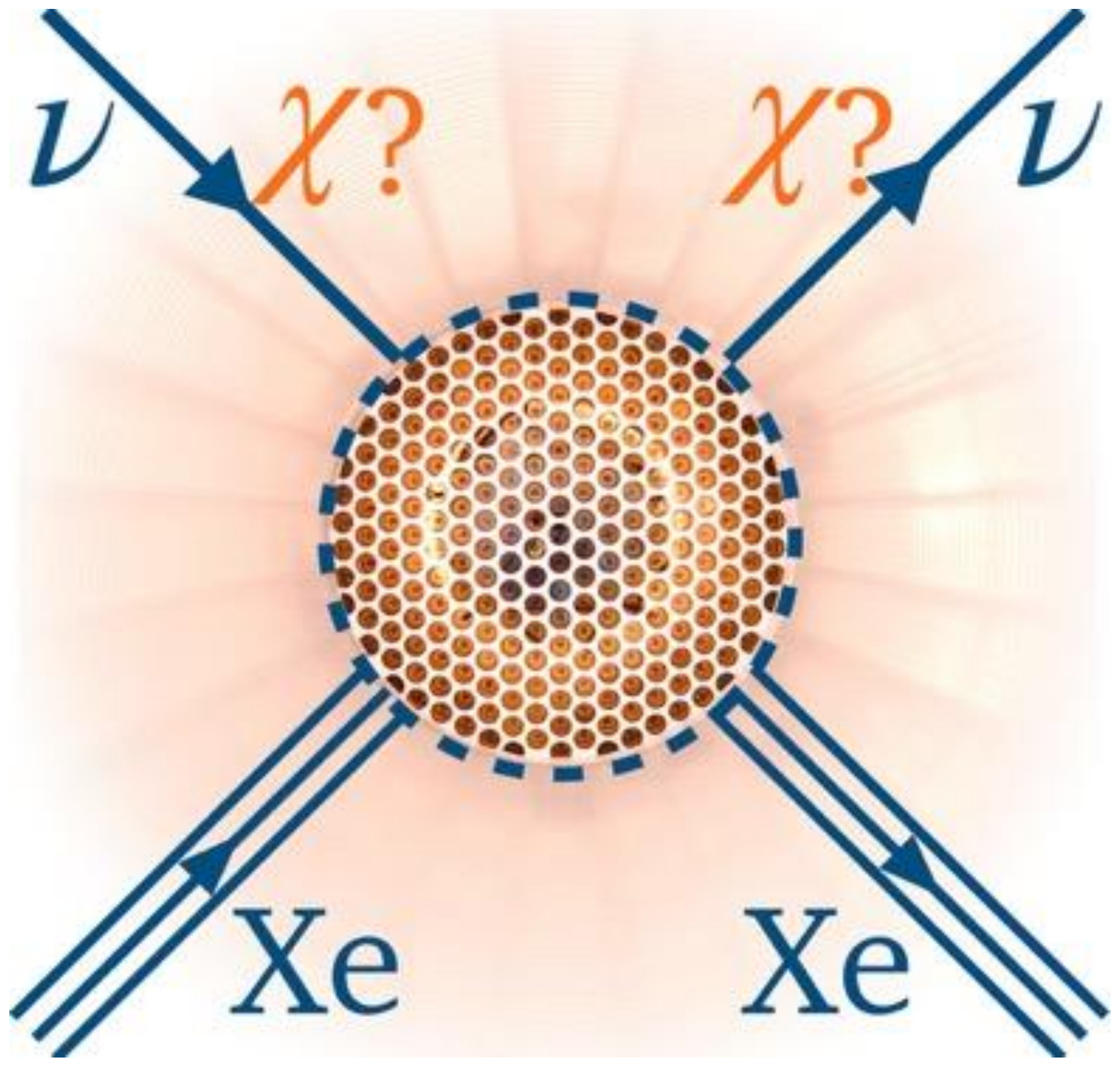


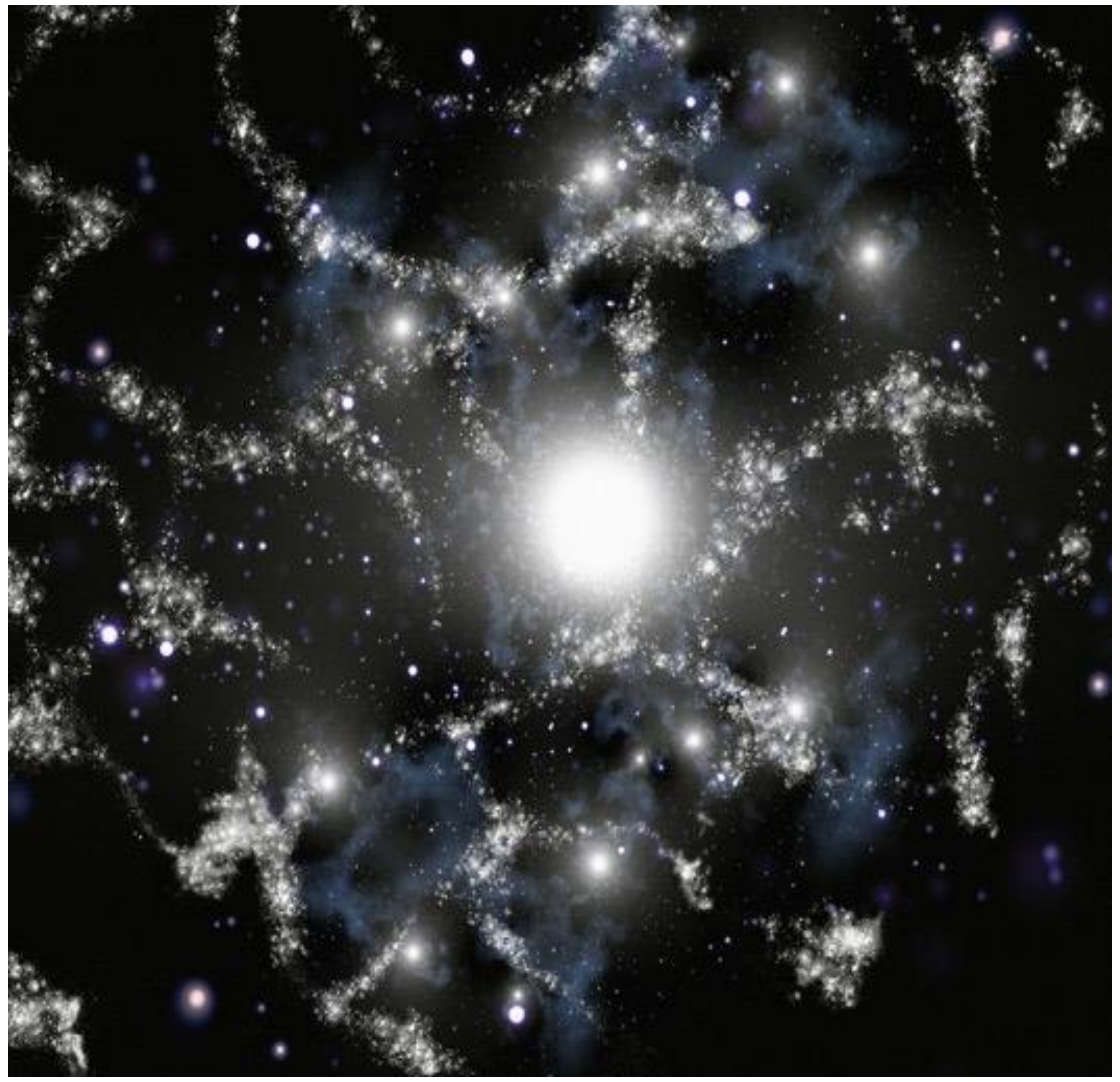


- **PRL 134, 111802, 2025**
- **arXiv: 2604.06002, accepted by PRL**

在“中微子雾”中寻找暗物质

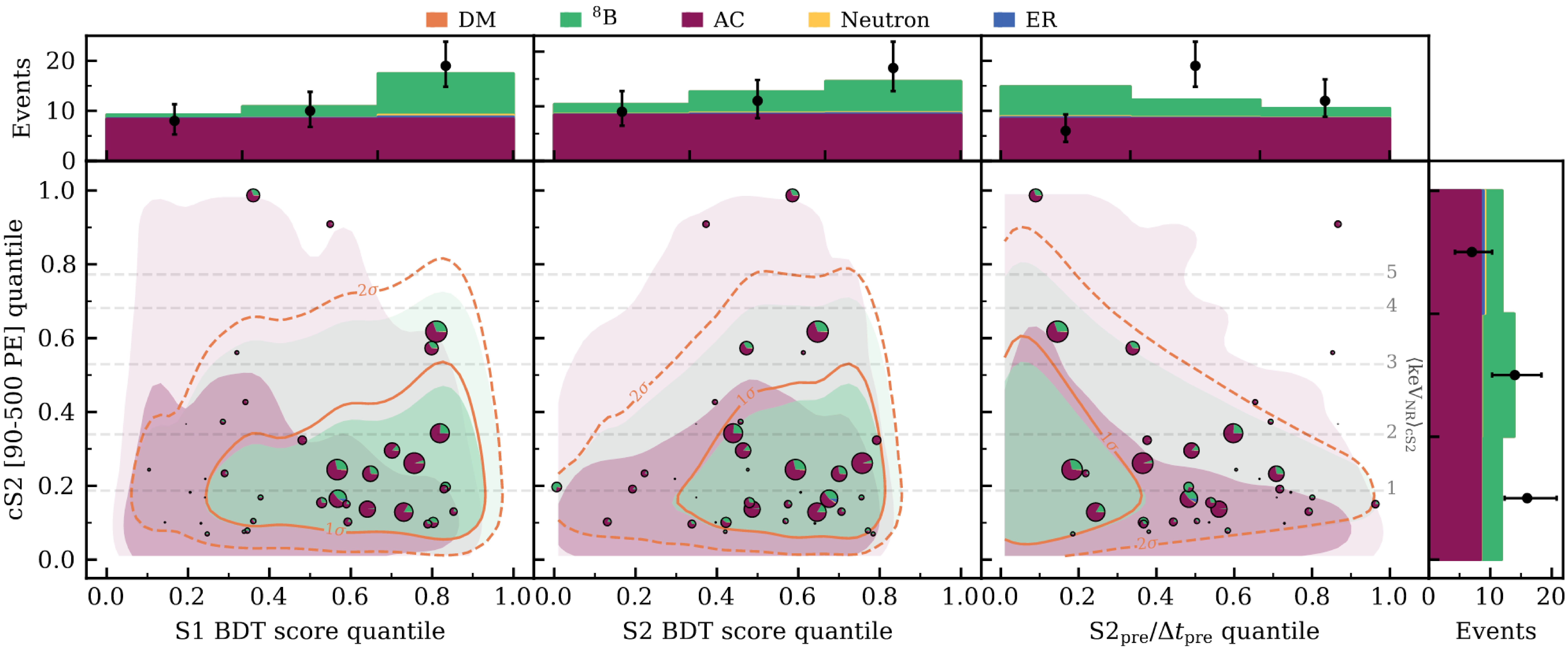






- **PRL 134, 111802, 2025**
- **arXiv: 2604.06002, accepted by PRL**

在“中微子雾”中寻找暗物质



- **PRL 134, 111802, 2025**
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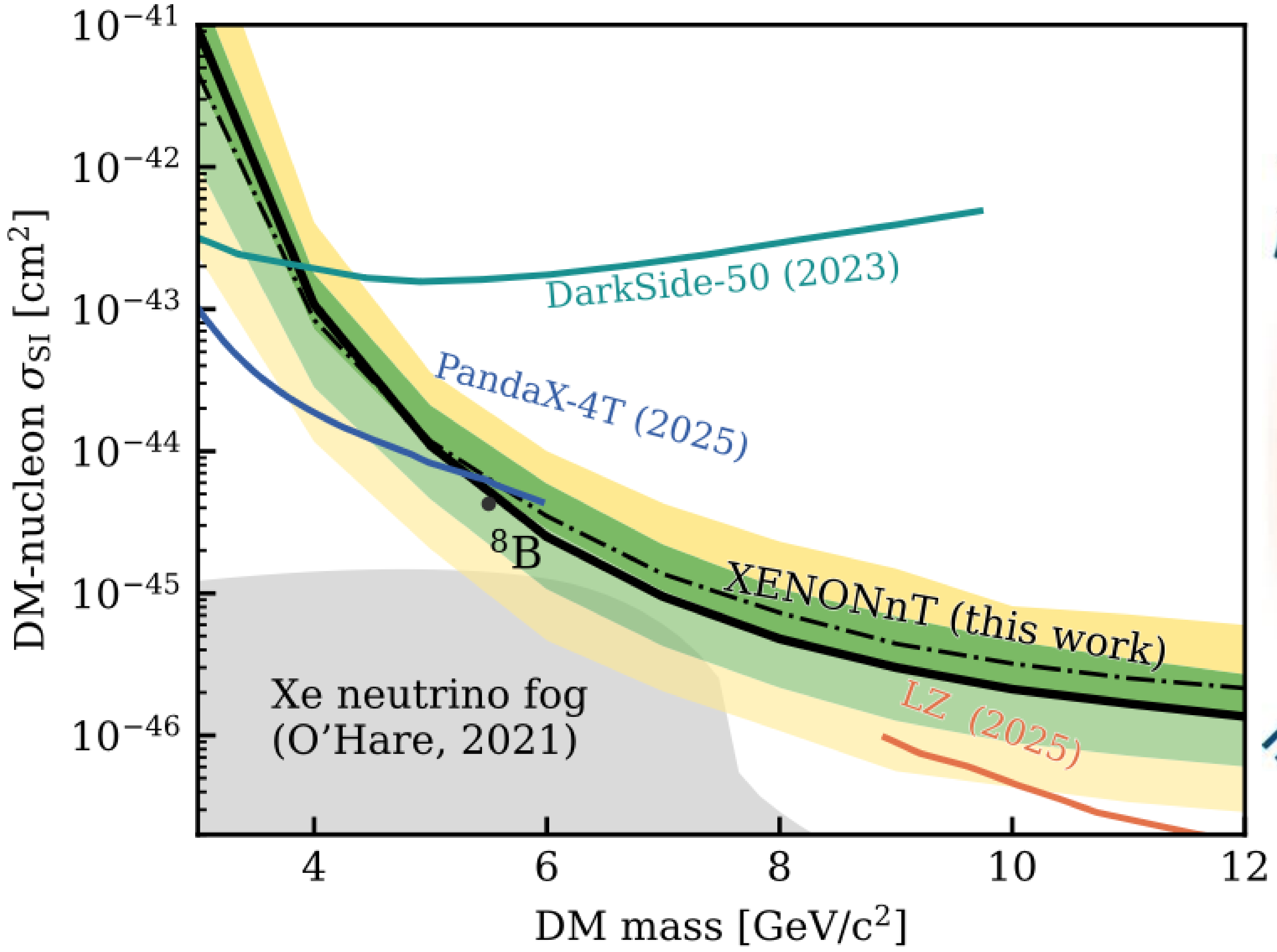
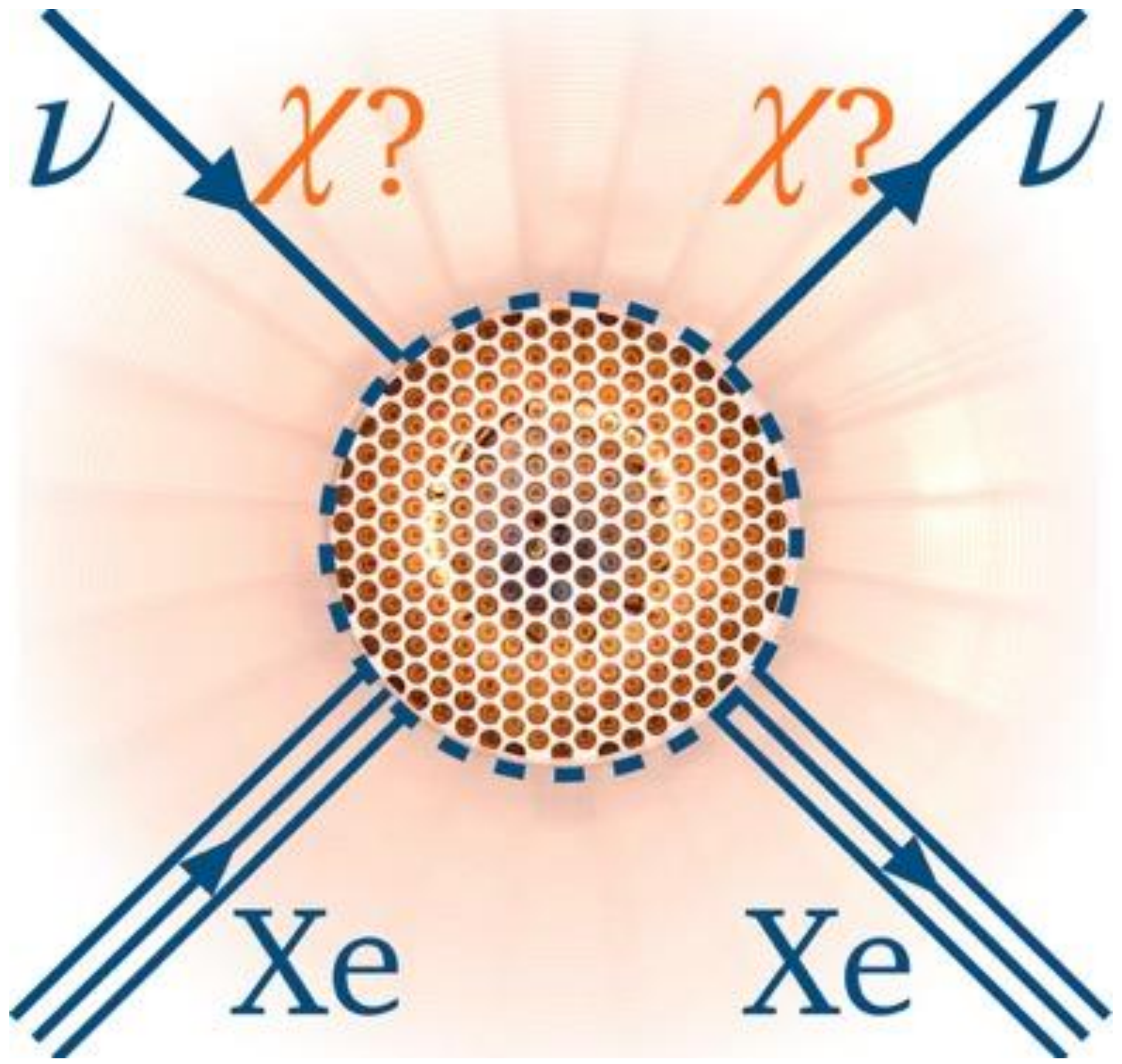
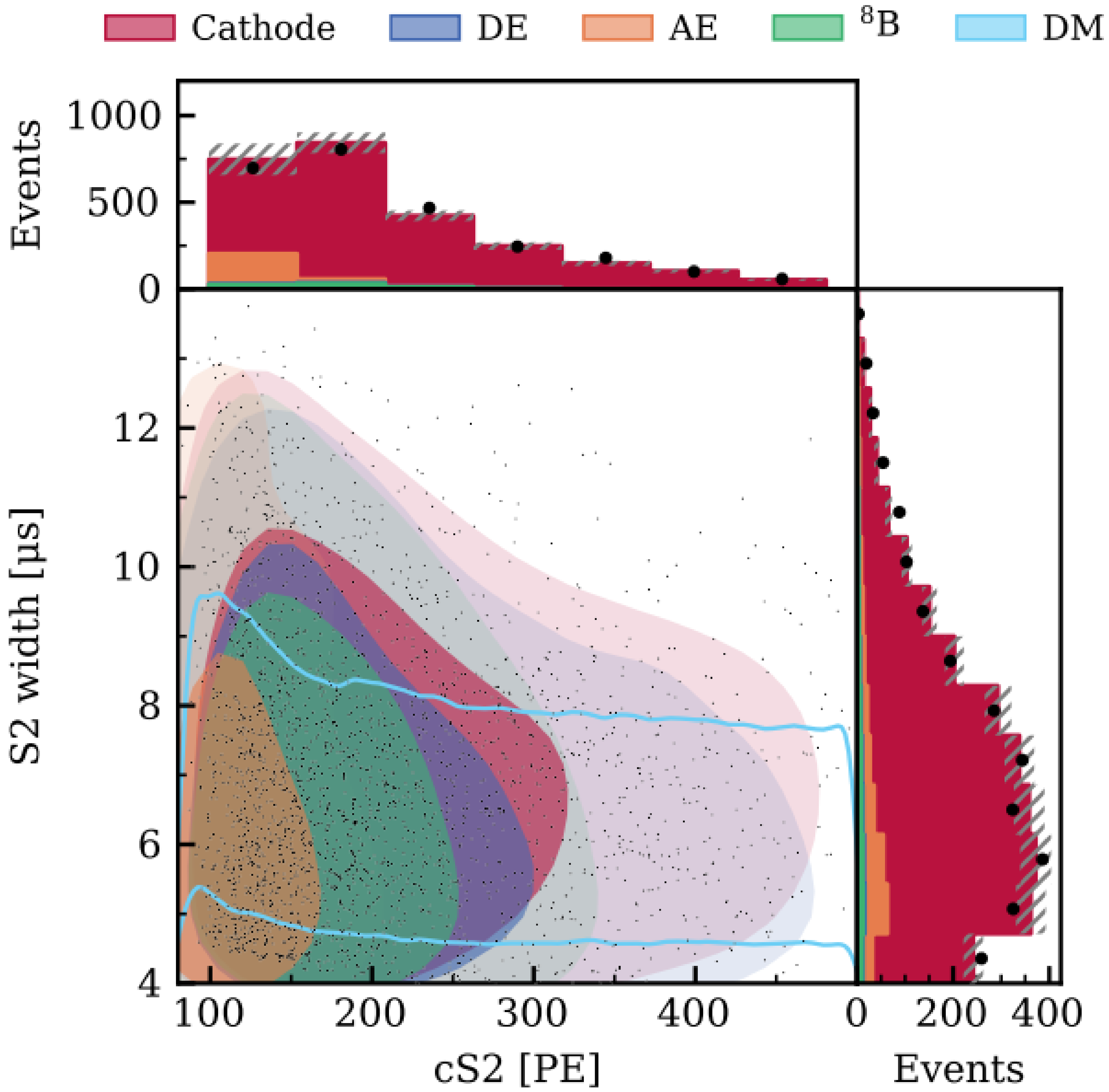
在“中微子雾”中寻找暗物质

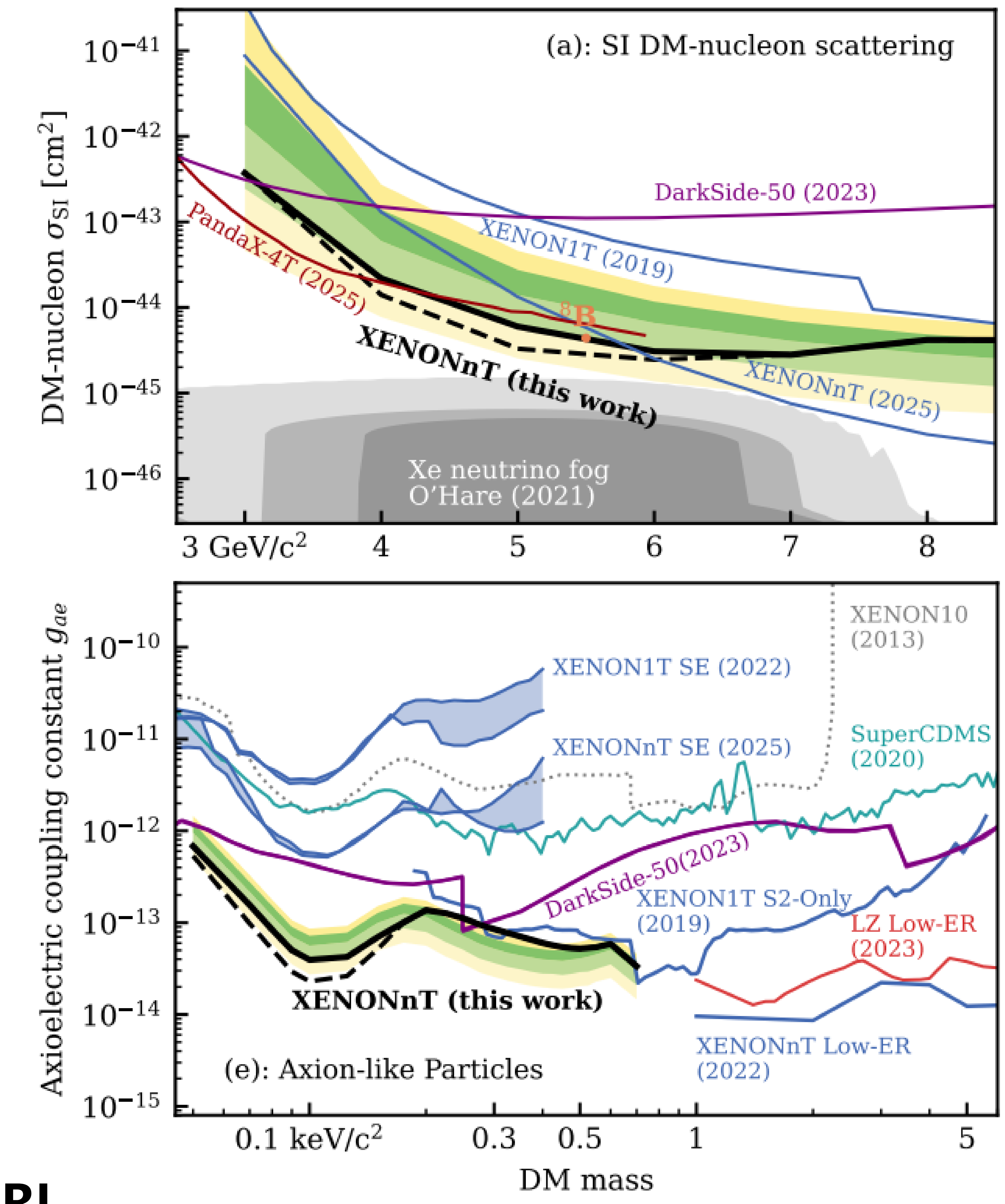




- **PRL 134, 111802, 2025**
- **arXiv: 2604.06002, accepted by PRL**

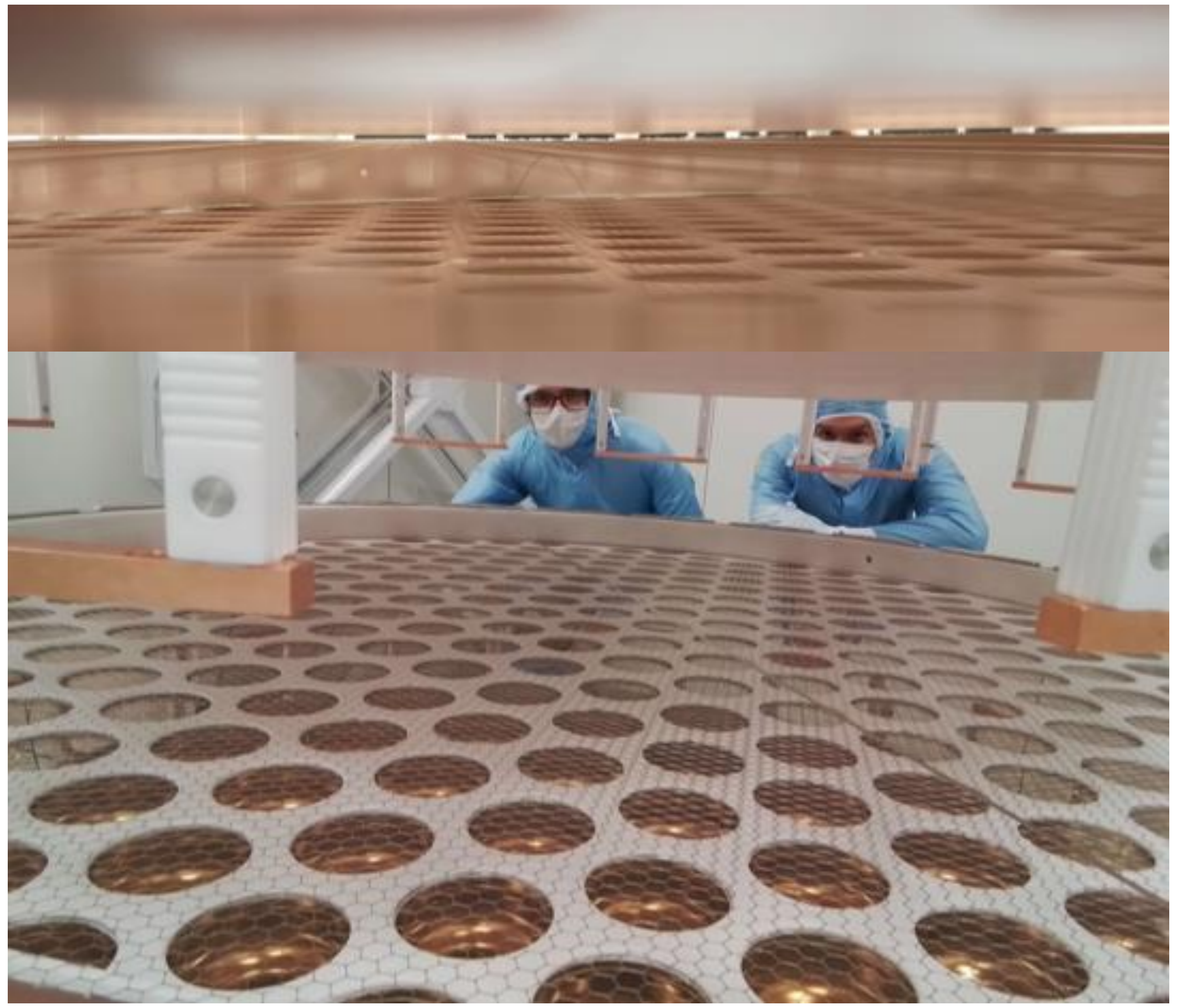
基于电离信号的暗物质探测

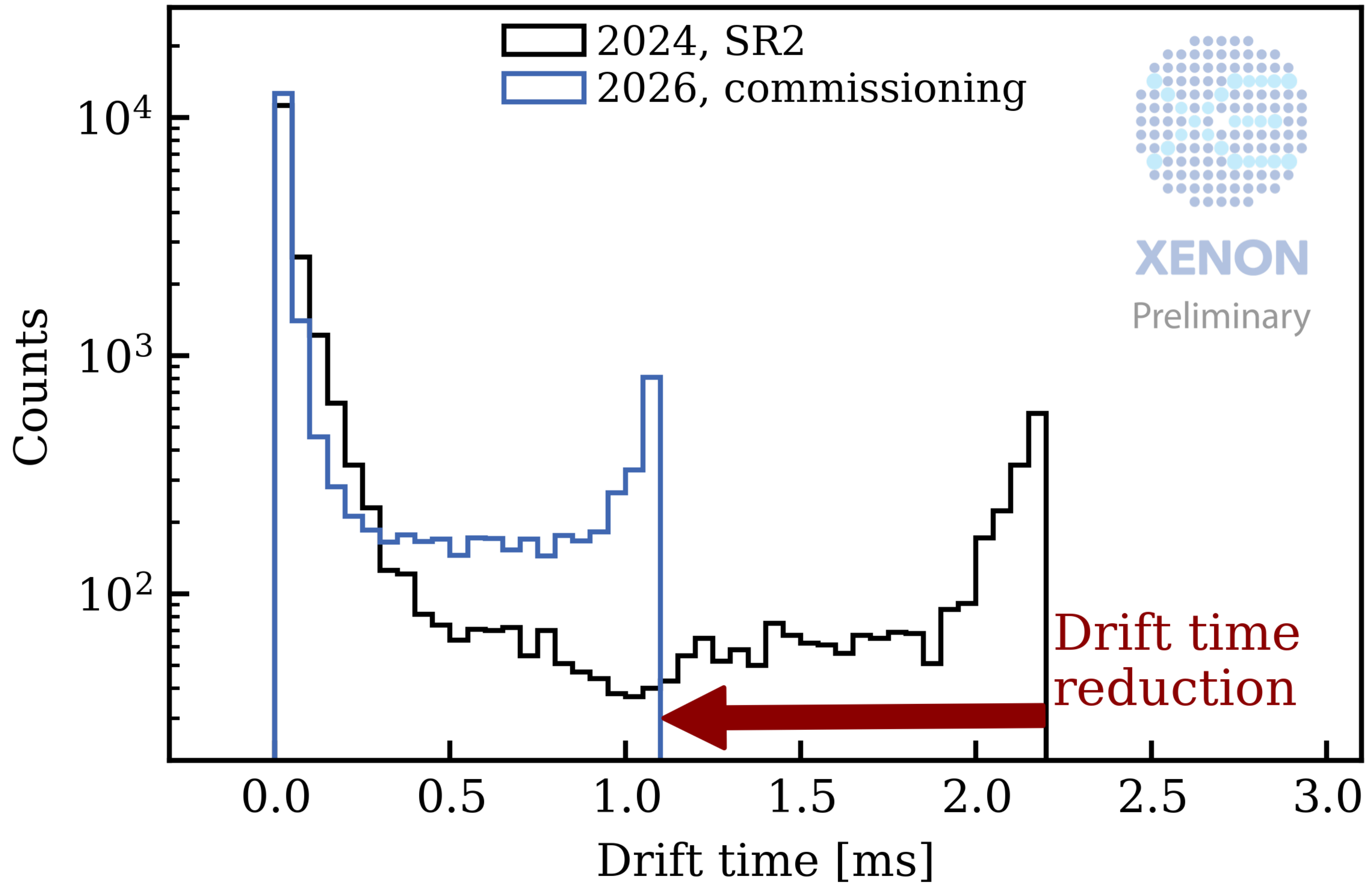


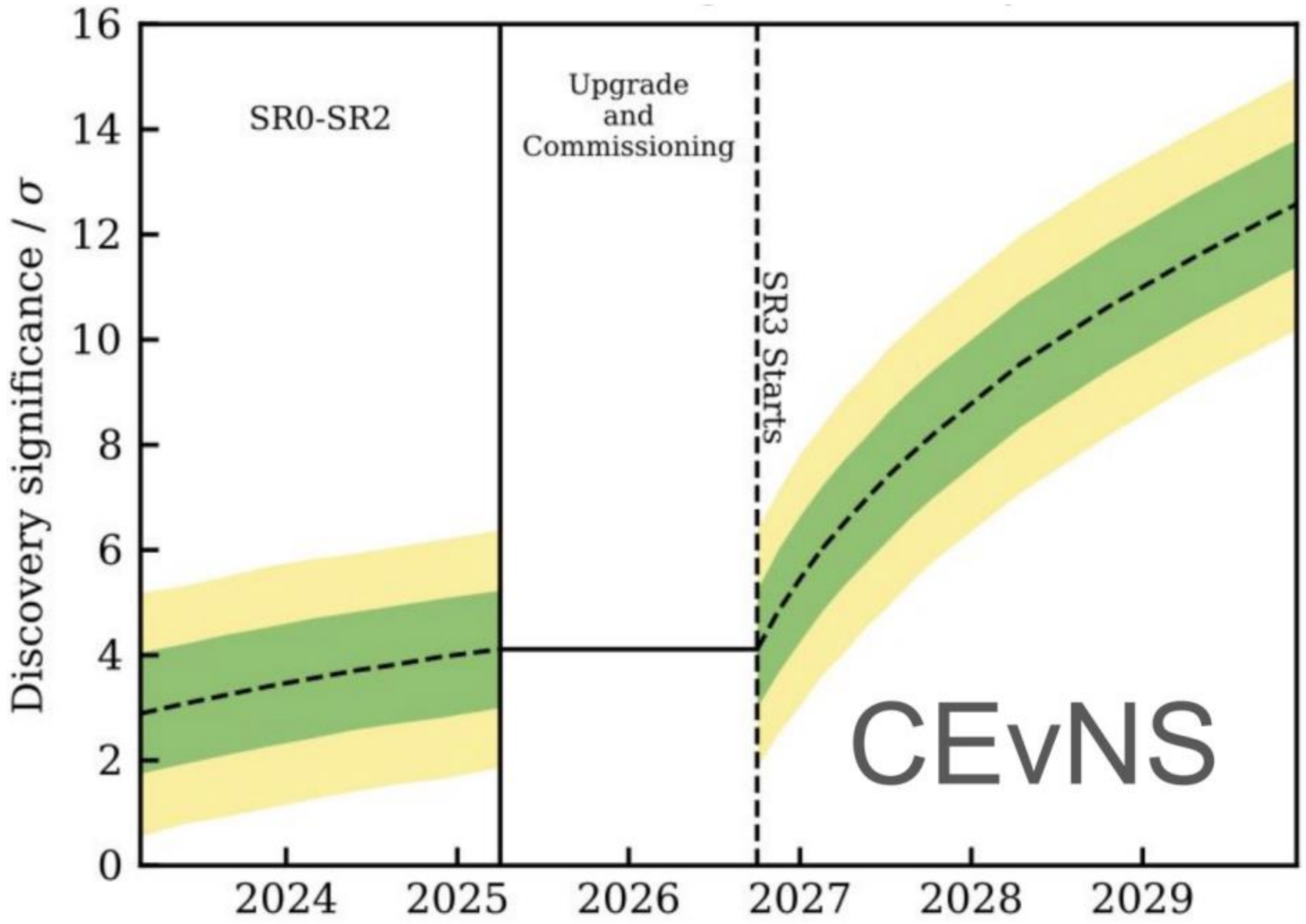


- **arXiv: 2601.11296, accepted by PRL**

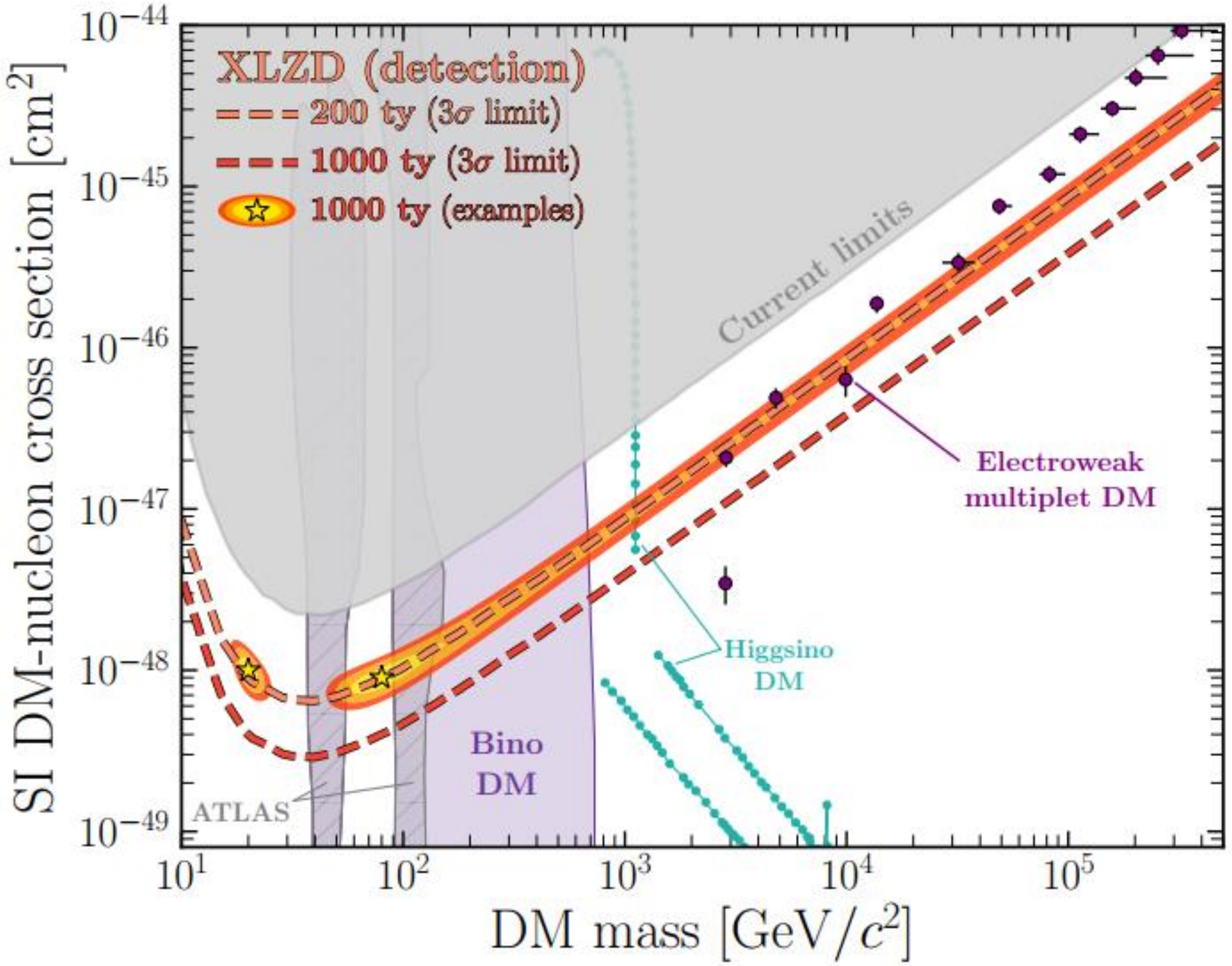
XENONnT的升级和未来计划

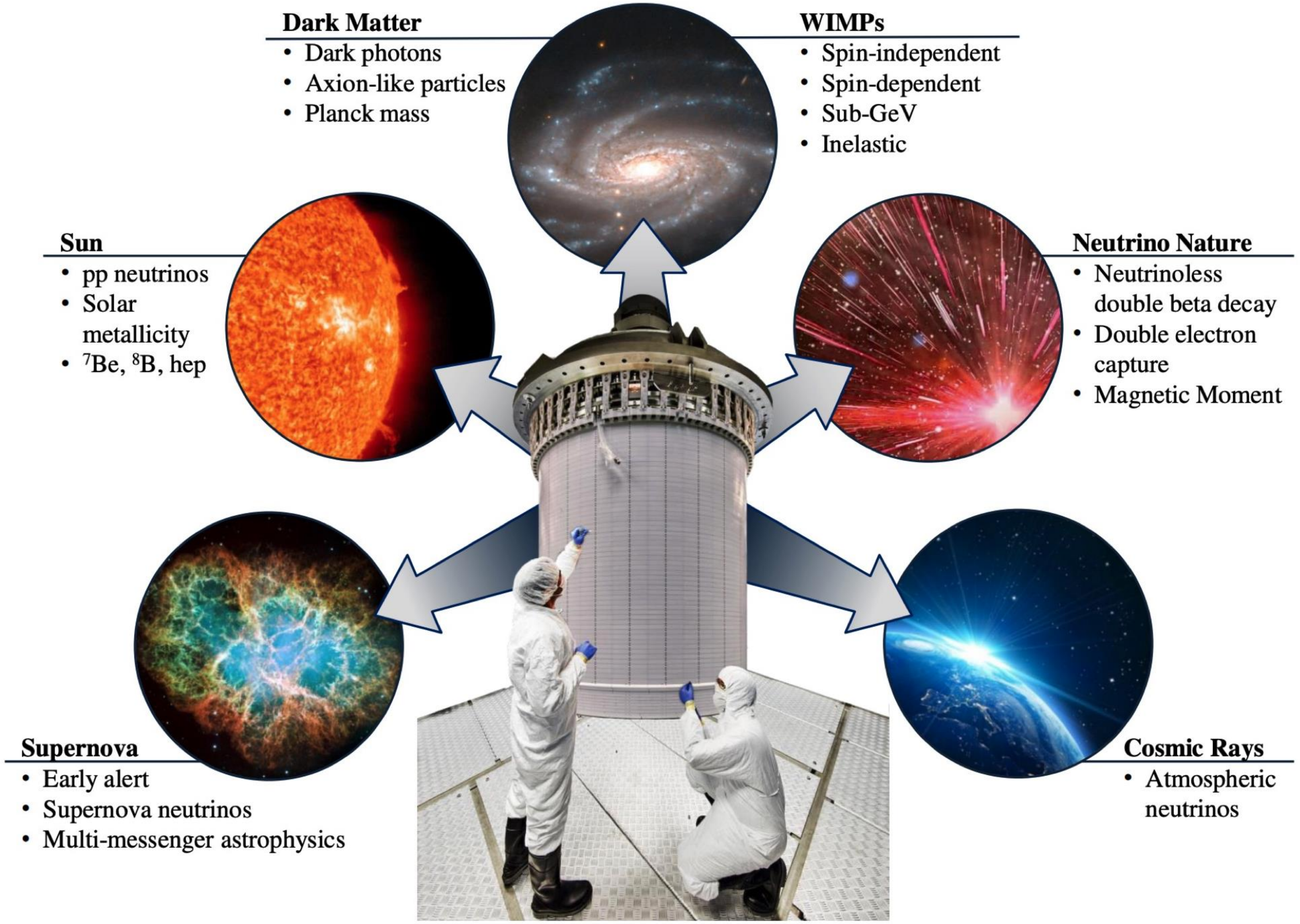






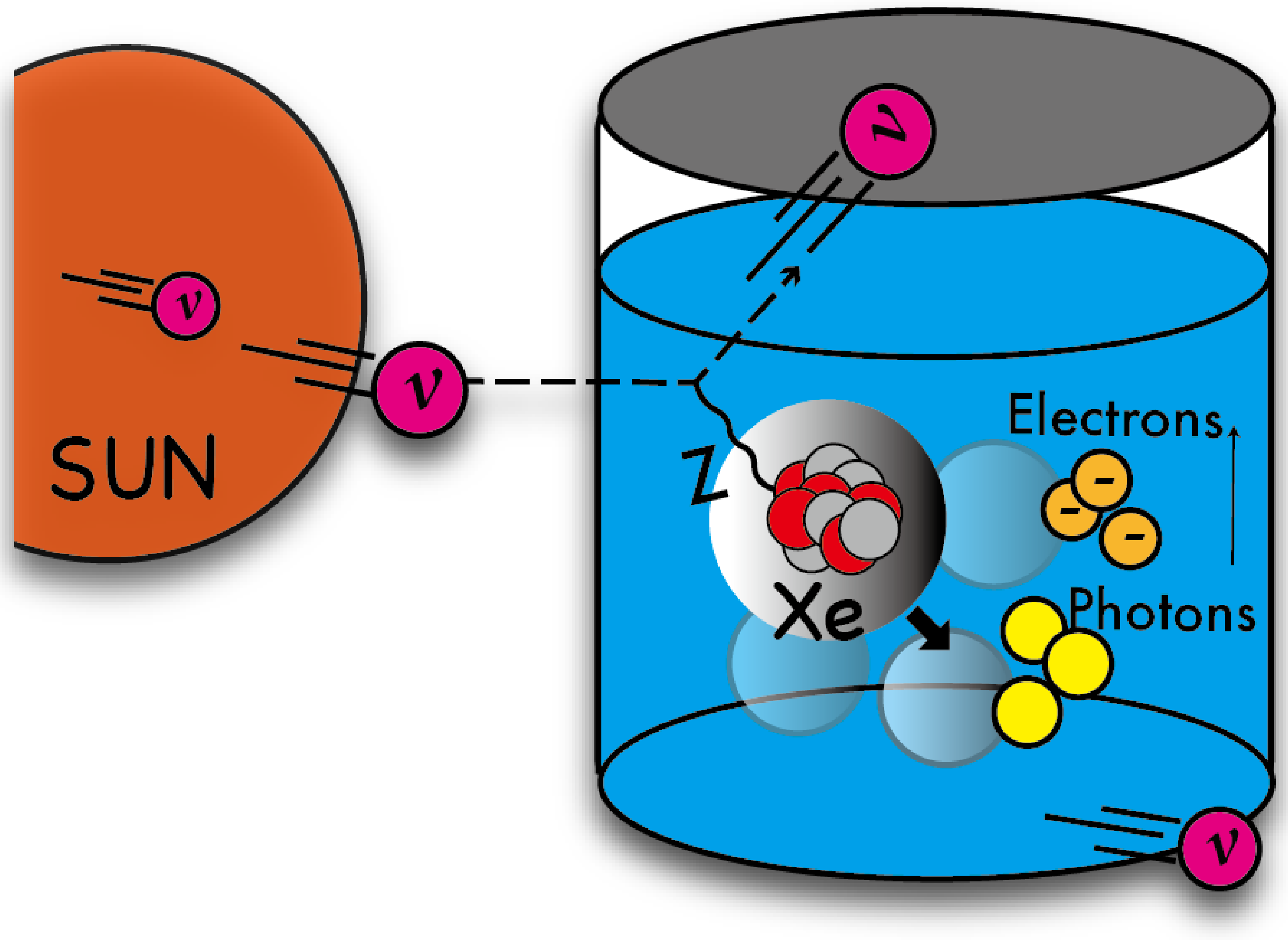
第三代液氙暗物质探测器灵敏度

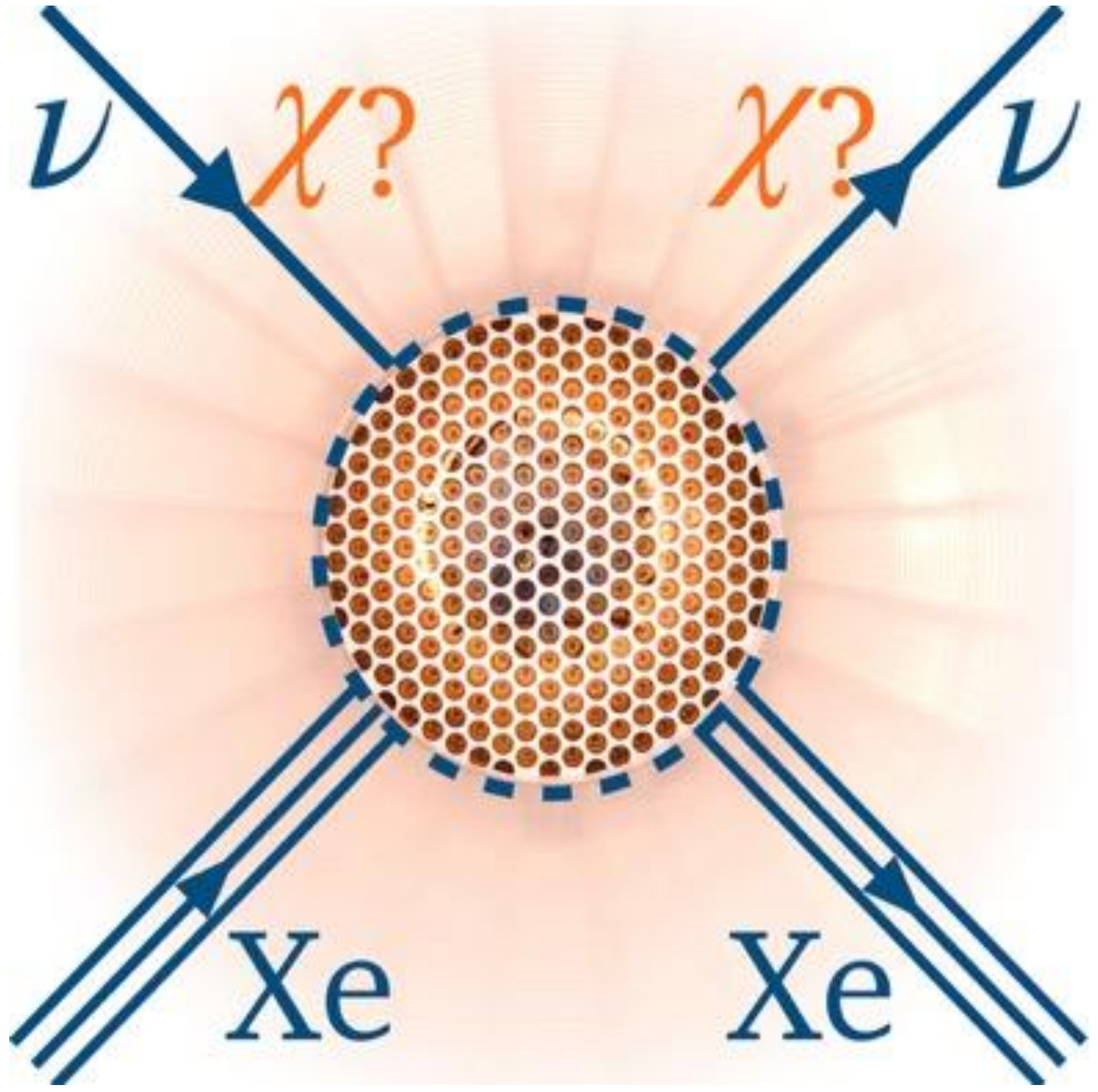


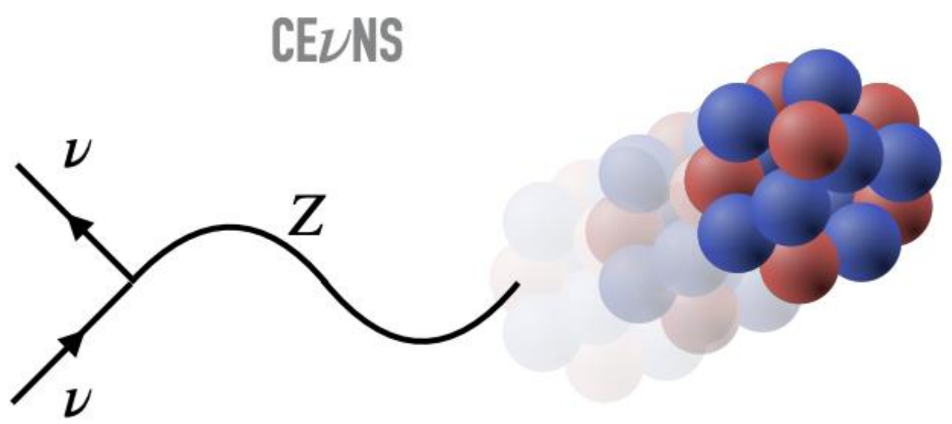


未来100吨级探测器有望测量到主流模型预言的暗物质信号

总结


SUN
Electrons
Photons
Xe
Z


Xe
Xe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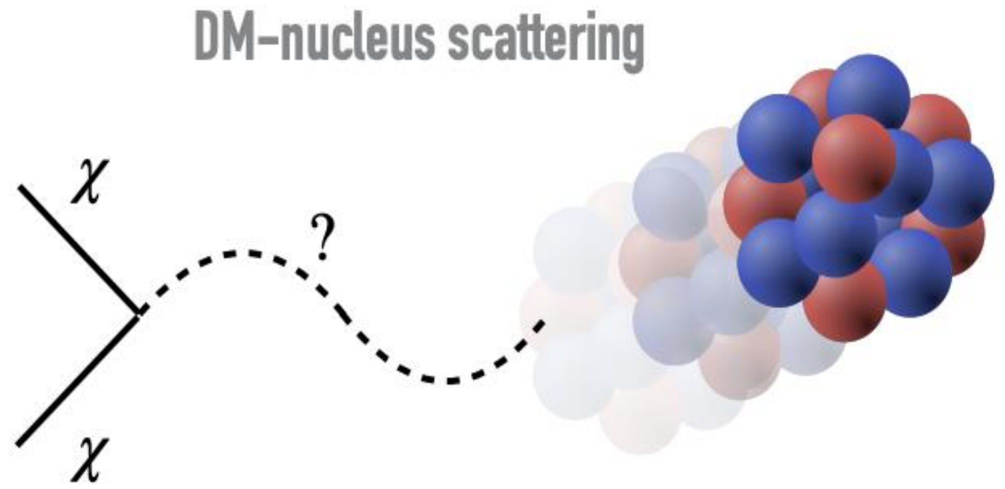
DM-nucleus scattering
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谢谢!

电离信号分布特征的数据论证