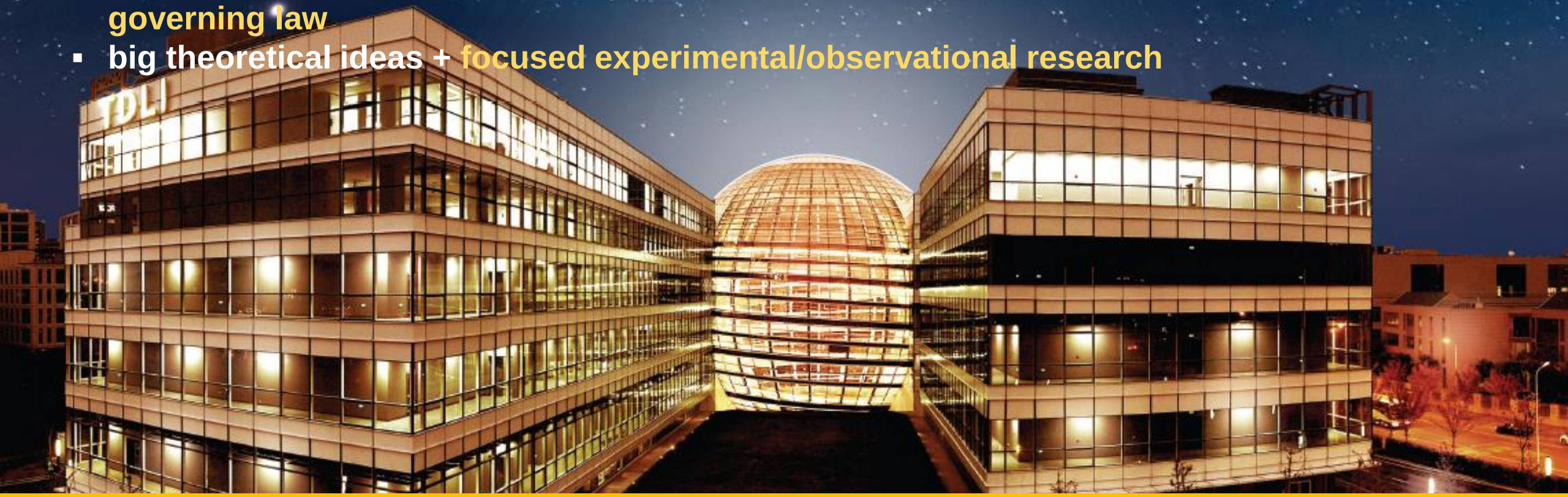
Unlocking the Deepest Mysteries of the Universe with a Deep Underground Liquid Xenon Observatory

Jianglai Liu 刘江来
Tsung-Dao Lee Institute• School of Physics & Astronomy
Shanghai Jiao tong university

JINR Seminar, May 13, 2026

Proposed by T. D. Lee and founded in 2016, Tsung-Dao Lee Institute (TDLI) is a fundamental research institute in physics dedicated to

- elucidating the origin, evolution, and structure formation of matters, and unraveling its governing law
- big theoretical ideas + focused experimental/observational research



- Astronomy & Astrophysics
- Particle and Nuclear Physics
- Condensed Matter Physics

} State key Laboratory of Dark Matter Physics

A New Hub for Global Physicists in Shanghai



JUNO “Old boys” Chorus

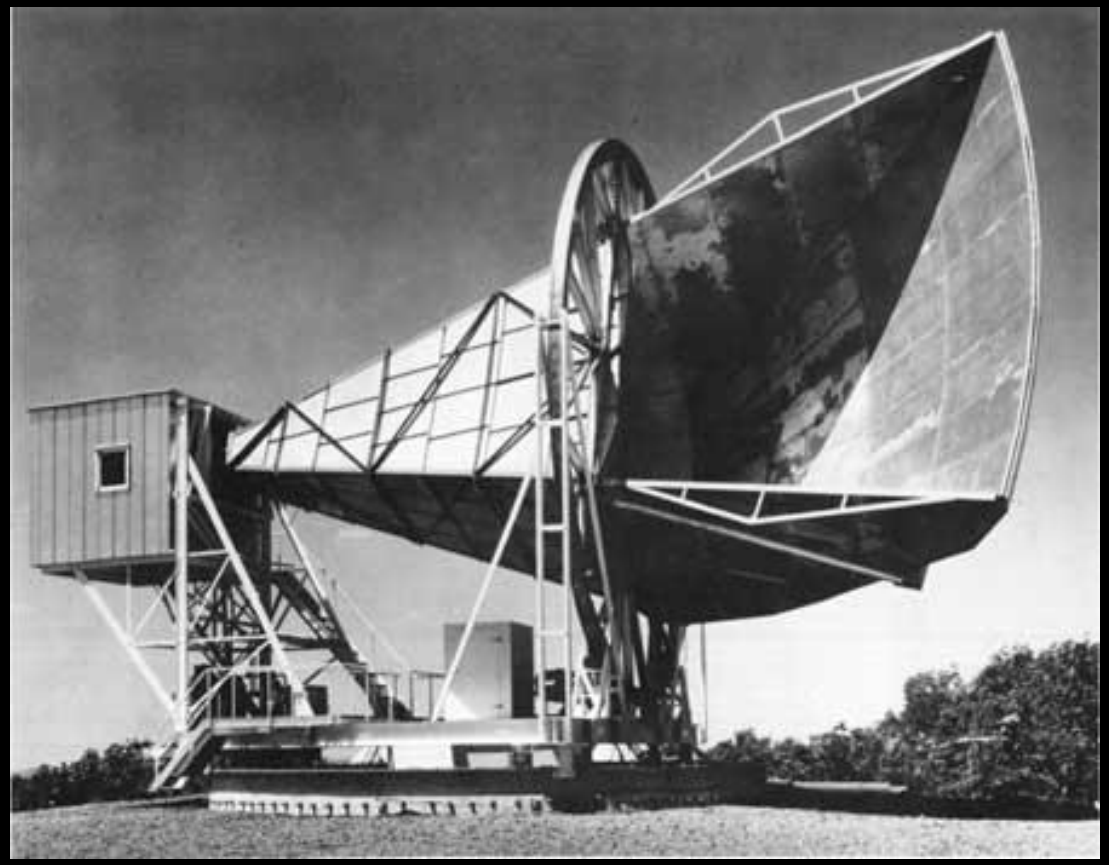
Two PandaX Open Meetings





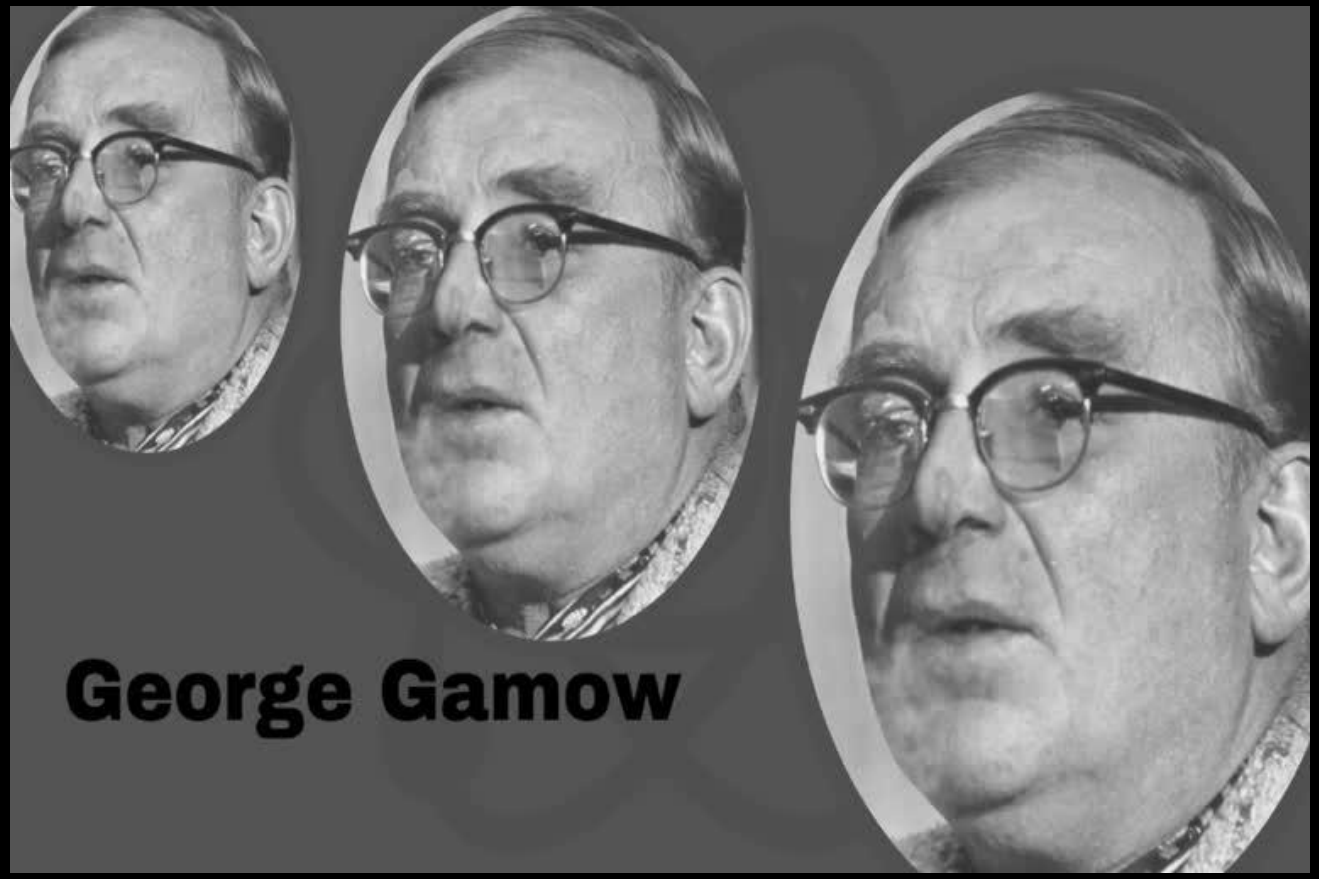
- A few groups in Russian (MSU, BSU), Japan (Tohoku), and UK (Warwick and Liverpool) decided to participate in the development.
- Some NSFC-CJPL international cooperation “incubator” funding

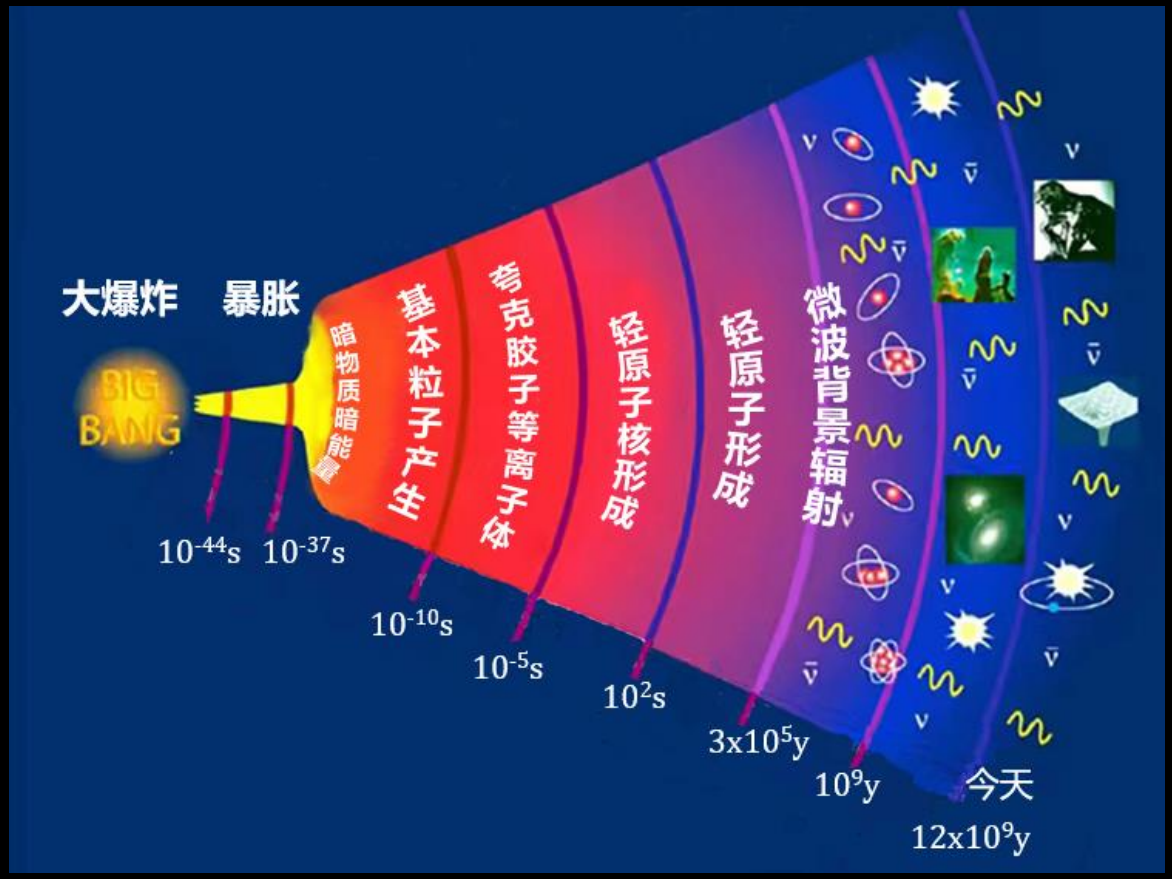
New Jersey, 1964



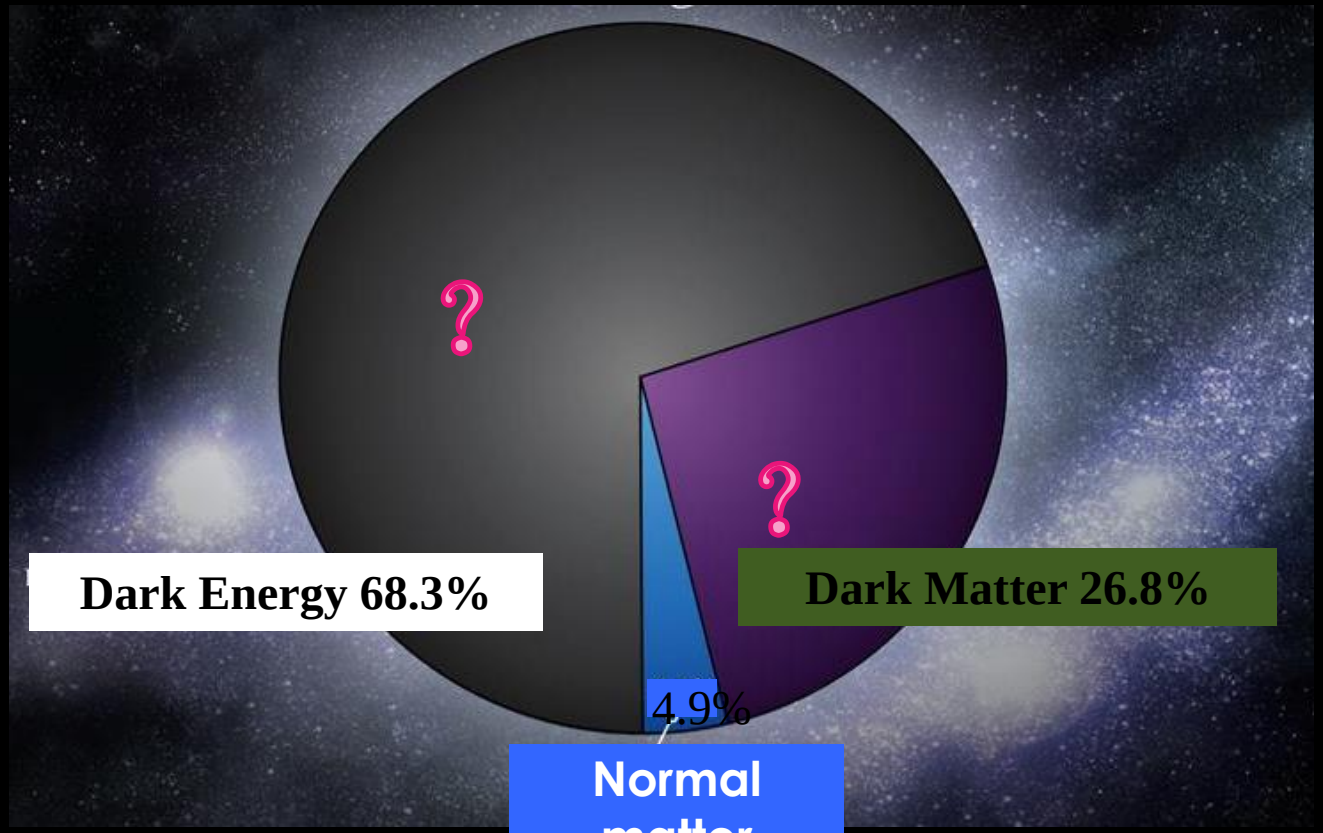


1948 Gamow's "Big Bang"





Standard Cosmology: ΛCDM





1/3 proton mass/cm^3, v ~1/1000c

What are these invisible matter?

REST MASS OF MUONIC NEUTRINO AND COSMOLOGY

S. S. Gershtein and Ya. B. Zel'dovich
Submitted 4 June 1966
ZhETF Pis'ma 4, No. 5, 174-177, 1 September 1966

Low-accuracy experimental estimates of the rest mass of the neutrino [1] yield $m(\nu_e) < 200$ eV/c^2 for the electronic neutrino and $m(\nu_\mu) < 2.5 \times 10^6$ eV/c^2 for the muonic neutrino.

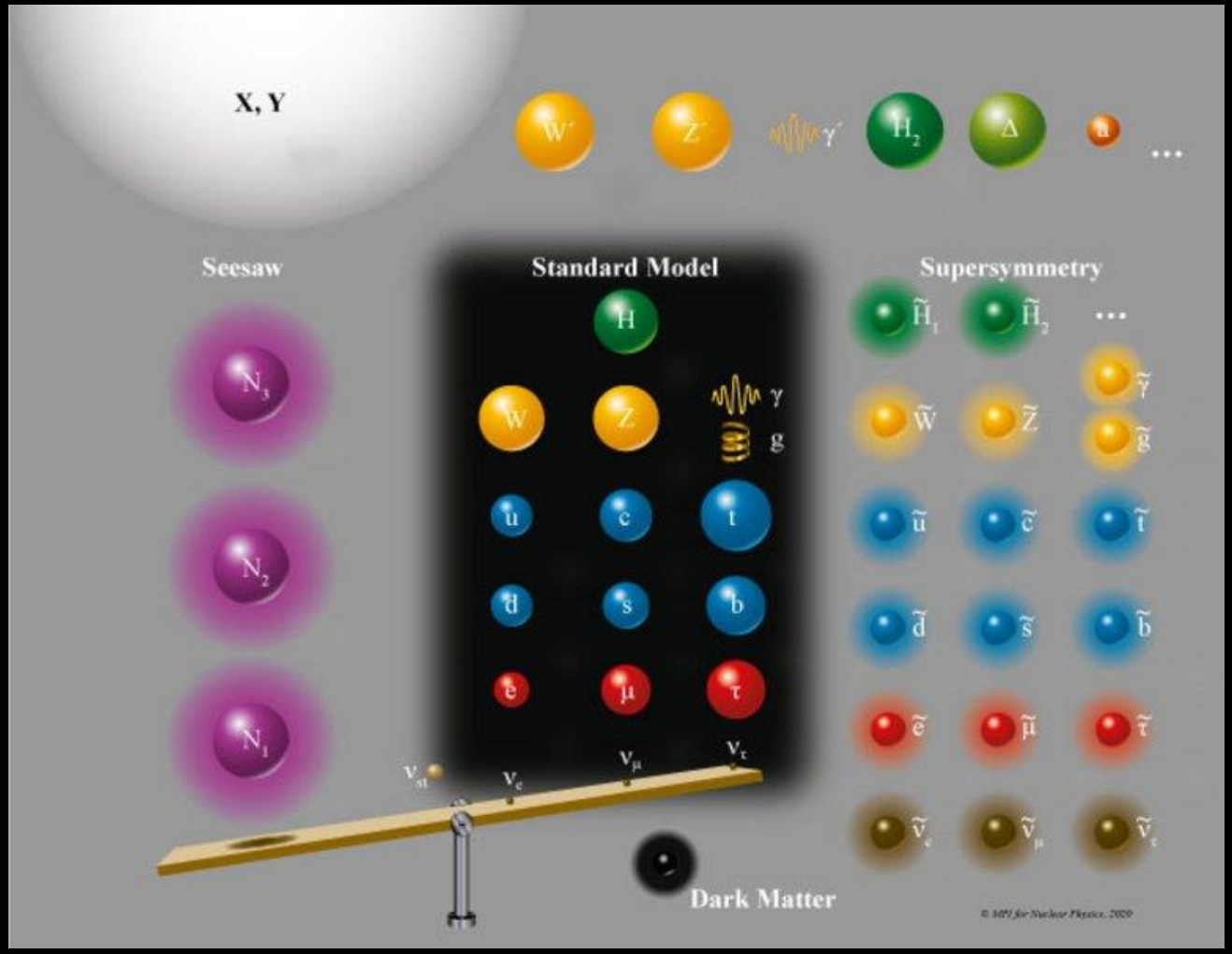
Cosmological considerations connected with the hot model of the Universe [2] make it possible to strengthen greatly the second inequality. Just as in the paper by Ya. B. Zel'dovich and Ya. A. Smorodinskii [3], let us consider the gravitational effect of the neutrinos on the dynamics of the expanding Universe. The age of the known astronomical objects is not smaller than 5×10^9 years, and Hubble's constant H is not smaller than 75 km/sec-Mparsec = $(13 \times 10^9 \text{ years})^{-1}$. It follows therefore that the density of all types of matter in the Universe is at the present time [1)]

$$\rho < 2 \times 10^{-28} \text{ g/cm}^3.$$





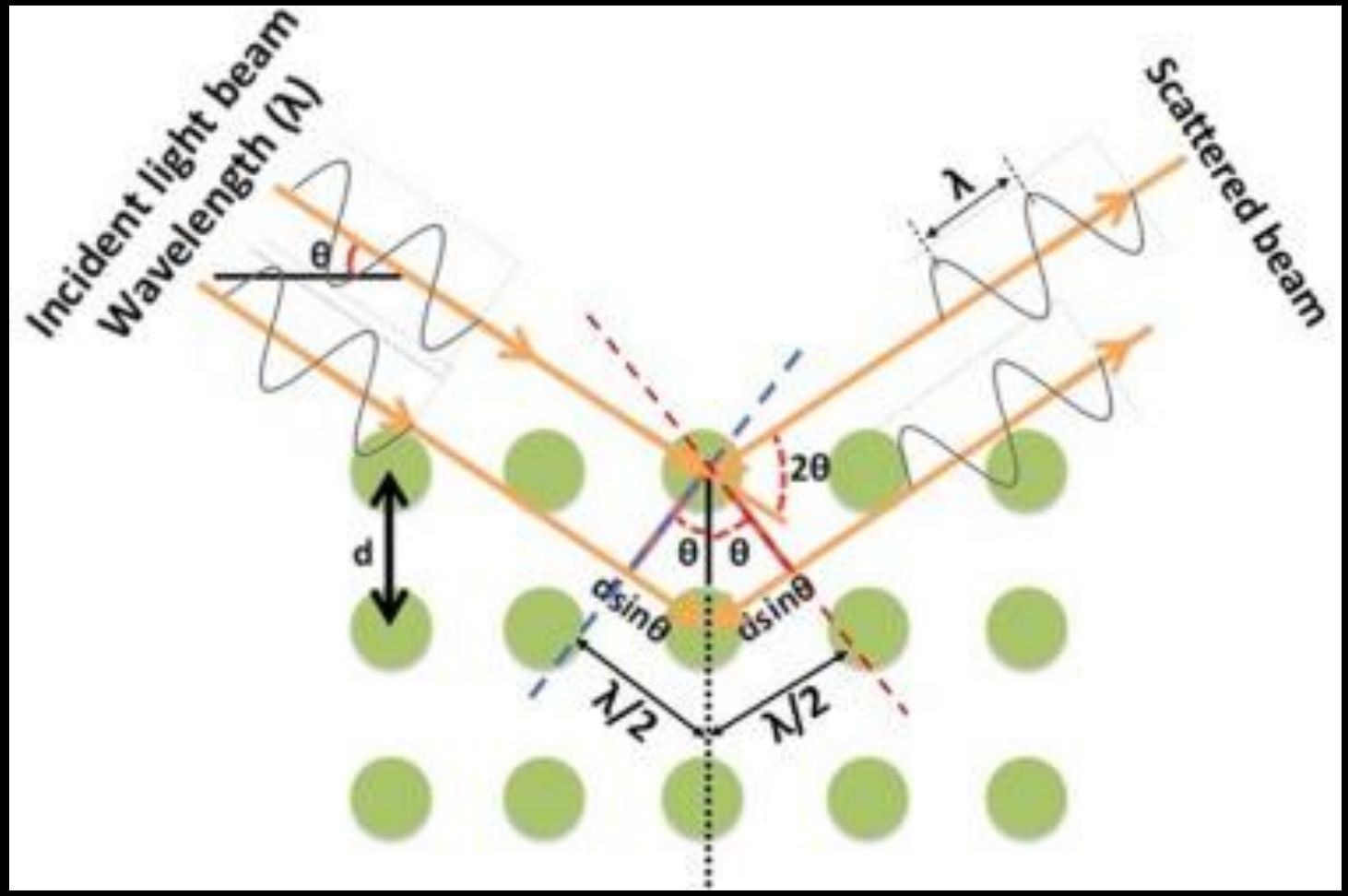
Elementary particles?



Particle scattering



Quantum coherence in scattering



Chadwick 1932: discovery of neutron

- alpha + Be9 -> C + x (production)

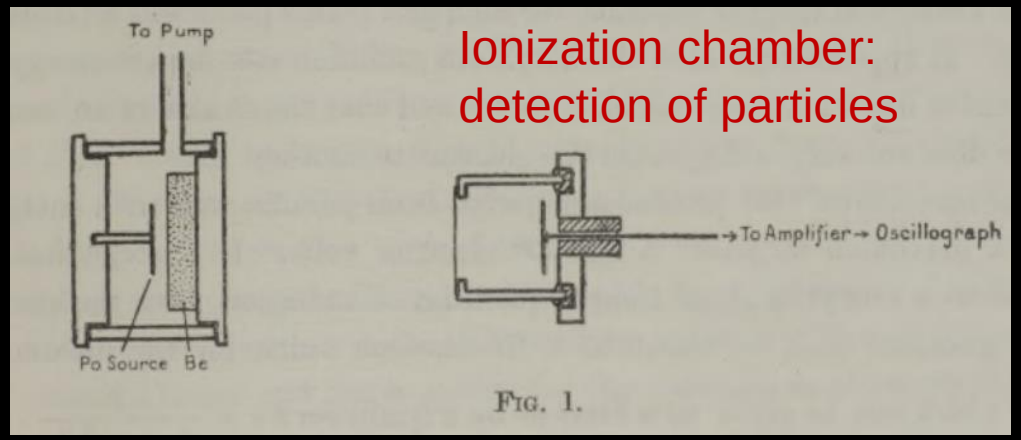


FIG. 1.

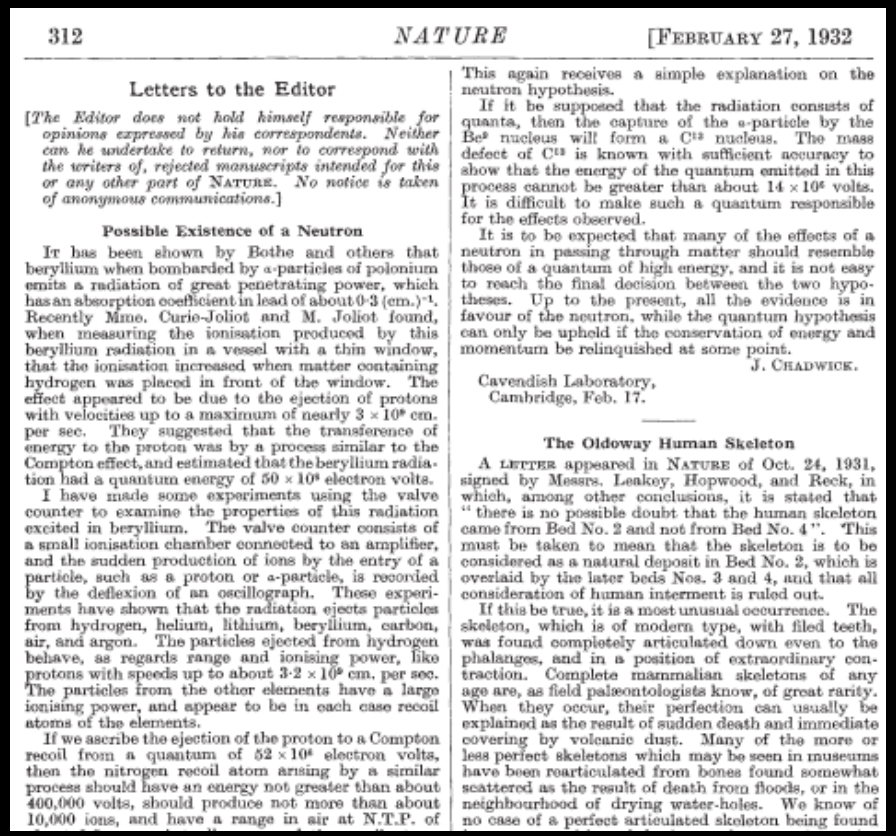


Nobel prize 1935

- x + A -> x + A (detection)

$1\text{GeV}/c^2 * 0.1\ c \sim 10\ \text{fm}$

and (coherent) strong interaction!


312 NATURE [FEBRUARY 27, 1932

Letters to the Editor

[*The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, nor to correspond with the writers of, rejected manuscripts intended for this or any other part of* NATURE. *No notice is taken of anonymous communications.*]

Possible Existence of a Neutron

IT has been shown by Bothe and others that beryllium when bombarded by α-particles of polonium emits a radiation of great penetrating power, which has an absorption coefficient in lead of about 0·3 (cm.)$^{-1}$. Recently Mme. Curie-Joliot and M. Joliot found, when measuring the ionisation produced by this beryllium radiation in a vessel with a thin window, that the ionisation increased when matter containing hydrogen was placed in front of the window. The effect appeared to be due to the ejection of protons with velocities up to a maximum of nearly 3×10^9 cm. per sec. They suggested that the transference of energy to the proton was by a process similar to the Compton effect, and estimated that the beryllium radiation had a quantum energy of 50×10^6 electron volts.

I have made some experiments using the valve counter to examine the properties of this radiation excited in beryllium. The valve counter consists of a small ionisation chamber connected to an amplifier, and the sudden production of ions by the entry of a particle, such as a proton or α-particle, is recorded by the deflexion of an oscillograph. These experiments have shown that the radiation ejects particles from hydrogen, helium, lithium, beryllium, carbon, air, and argon. The particles ejected from hydrogen behave, as regards range and ionising power, like protons with speeds up to about $3{\cdot}2 \times 10^9$ cm. per sec. The particles from the other elements have a large ionising power, and appear to be in each case recoil atoms of the elements.

If we ascribe the ejection of the proton to a Compton recoil from a quantum of 52×10^6 electron volts, then the nitrogen recoil atom arising by a similar process should have an energy not greater than about 400,000 volts, should produce not more than about 10,000 ions, and have a range in air at N.T.P. of

This again receives a simple explanation on the neutron hypothesis.

If it be supposed that the radiation consists of quanta, then the capture of the α-particle by the Be^9 nucleus will form a C^{12} nucleus. The mass defect of C^{12} is known with sufficient accuracy to show that the energy of the quantum emitted in this process cannot be greater than about 14×10^6 volts. It is difficult to make such a quantum responsible for the effects observed.

It is to be expected that many of the effects of a neutron in passing through matter should resemble those of a quantum of high energy, and it is not easy to reach the final decision between the two hypotheses. Up to the present, all the evidence is in favour of the neutron, while the quantum hypothesis can only be upheld if the conservation of energy and momentum be relinquished at some point.

J. CHADWICK.

Cavendish Laboratory,
Cambridge, Feb. 17.

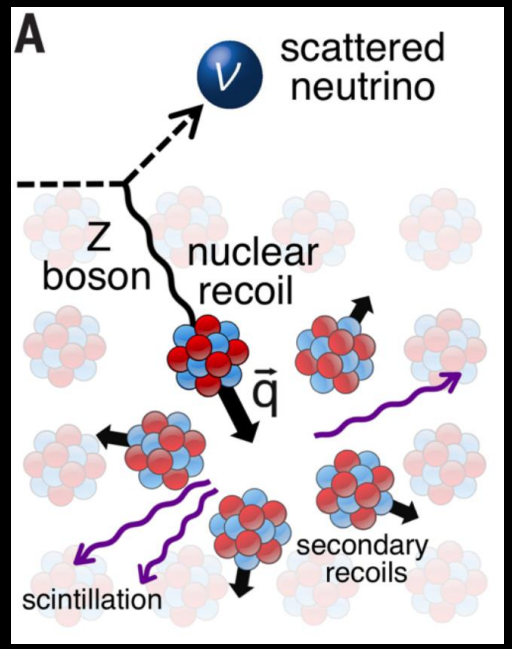
The Oldoway Human Skeleton

A LETTER appeared in NATURE of Oct. 24, 1931, signed by Messrs. Leakey, Hopwood, and Reck, in which, among other conclusions, it is stated that "there is no possible doubt that the human skeleton came from Bed No. 2 and not from Bed No. 4". This must be taken to mean that the skeleton is to be considered as a natural deposit in Bed No. 2, which is overlaid by the later beds Nos. 3 and 4, and that all consideration of human interment is ruled out.

If this be true, it is a most unusual occurrence. The skeleton, which is of modern type, with filed teeth, was found completely articulated down even to the phalanges, and in a position of extraordinary contraction. Complete mammalian skeletons of any age are, as field palæontologists know, of great rarity. When they occur, their perfection can usually be explained as the result of sudden death and immediate covering by volcanic dust. Many of the more or less perfect skeletons which may be seen in museums have been rearticulated from bones found somewhat scattered as the result of death from floods, or in the neighbourhood of drying water-holes. We know of no case of a perfect articulated skeleton being found

Coherent elastic neutrino-nucleus scattering (CEvNS)

Quantum mechanics: 200 MeV ~ 1 fm
So MeV neutrino cannot resolve nucleons in nucleus



Coherent effects of a weak neutral current

Daniel Z. Freedman
Phys. Rev. D **9**, 1389 – Published 1 March 1974

Article | References | Citing Articles (412) | PDF | Export Citation

ABSTRACT

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.

N=num neutrons

$$\sigma = \frac{G^2}{16\pi} N^2 \Delta_{\max}{}^2 = \frac{G^2 N^2}{4\pi} E^2 .$$

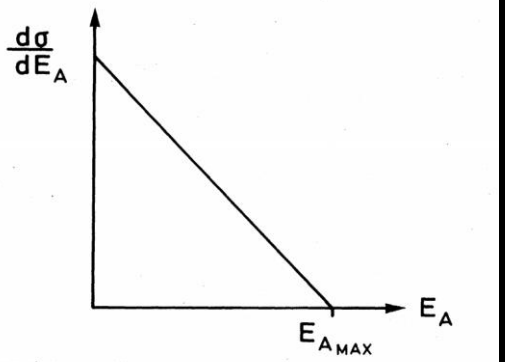


FIG. 1. Recoil-energy spectrum of the struck nucleus A in elastic neutrino scattering.

$$\bar{E}_A = \frac{2}{3A}(E/1\ \text{MeV})^2\ \text{keV}$$

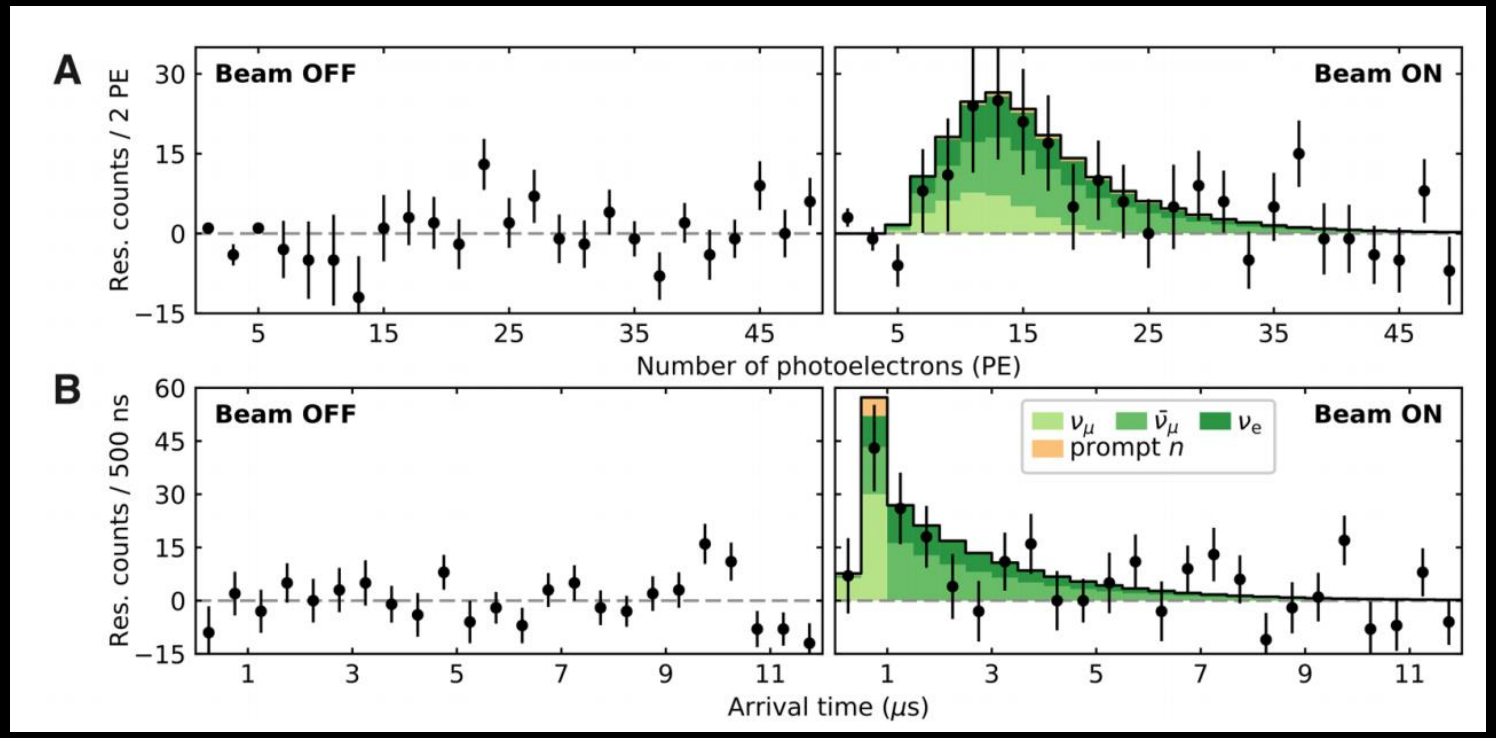
Oak Ridge, 2017

Science

REPORTS

Cite as: D. Akimov *et al.*, *Science*
10.1126/science.aao0990 (2017).

Observation of coherent elastic neutrino-nucleus scattering



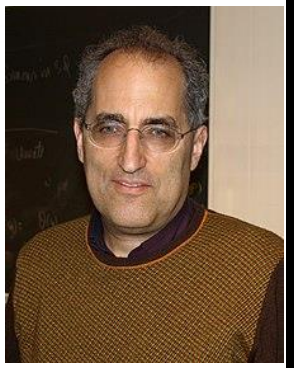
"Application"

PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

Detectability of certain dark-matter candidates

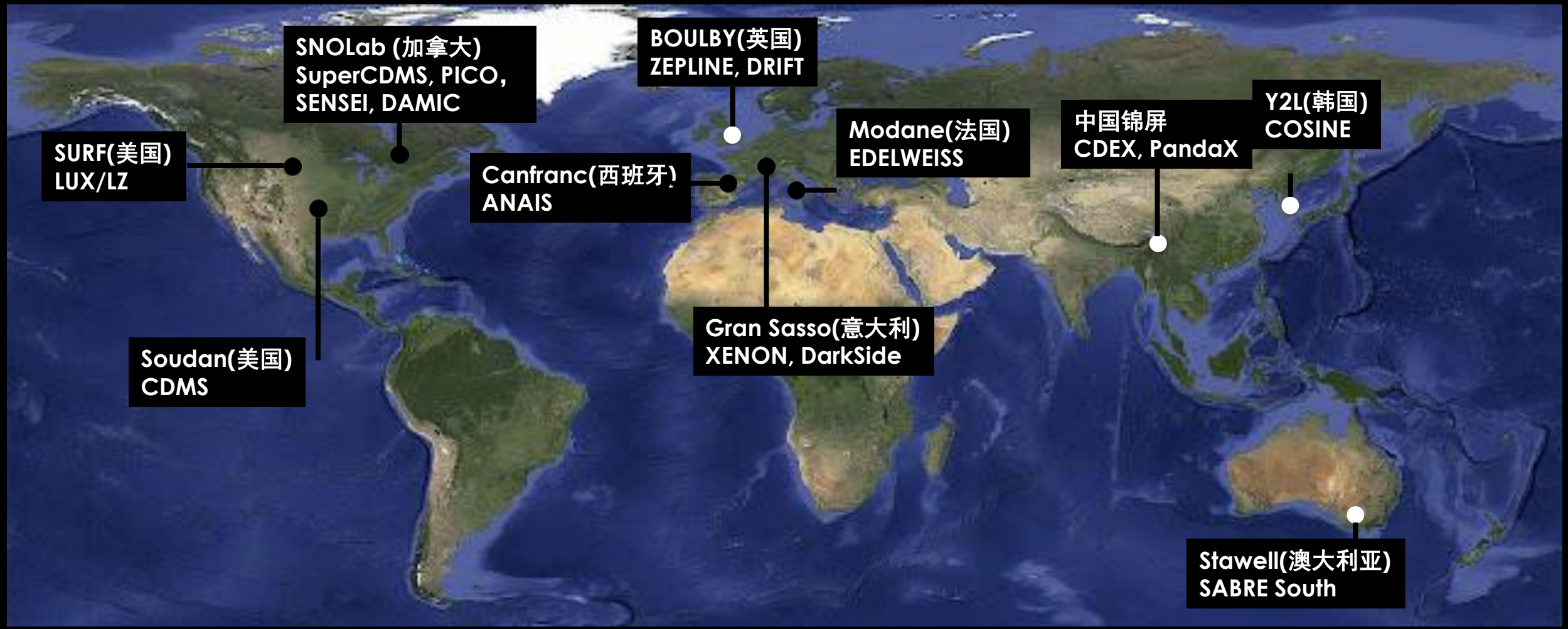
Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

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.

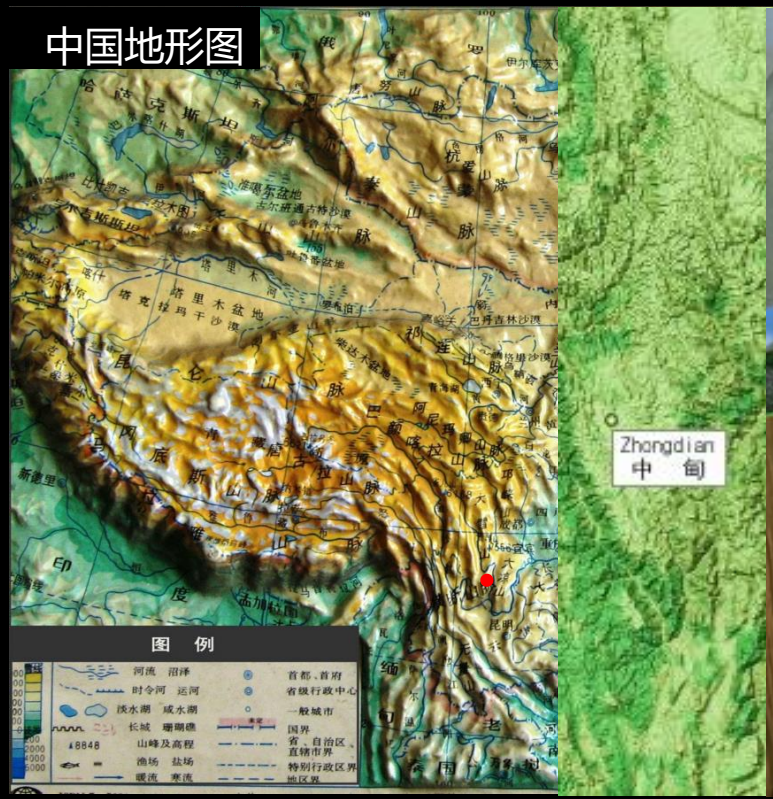


In this paper, we will calculate the sensitivity of the detector considered in Ref. 5 to various dark-matter candidates. Although this detector is not very sensitive to

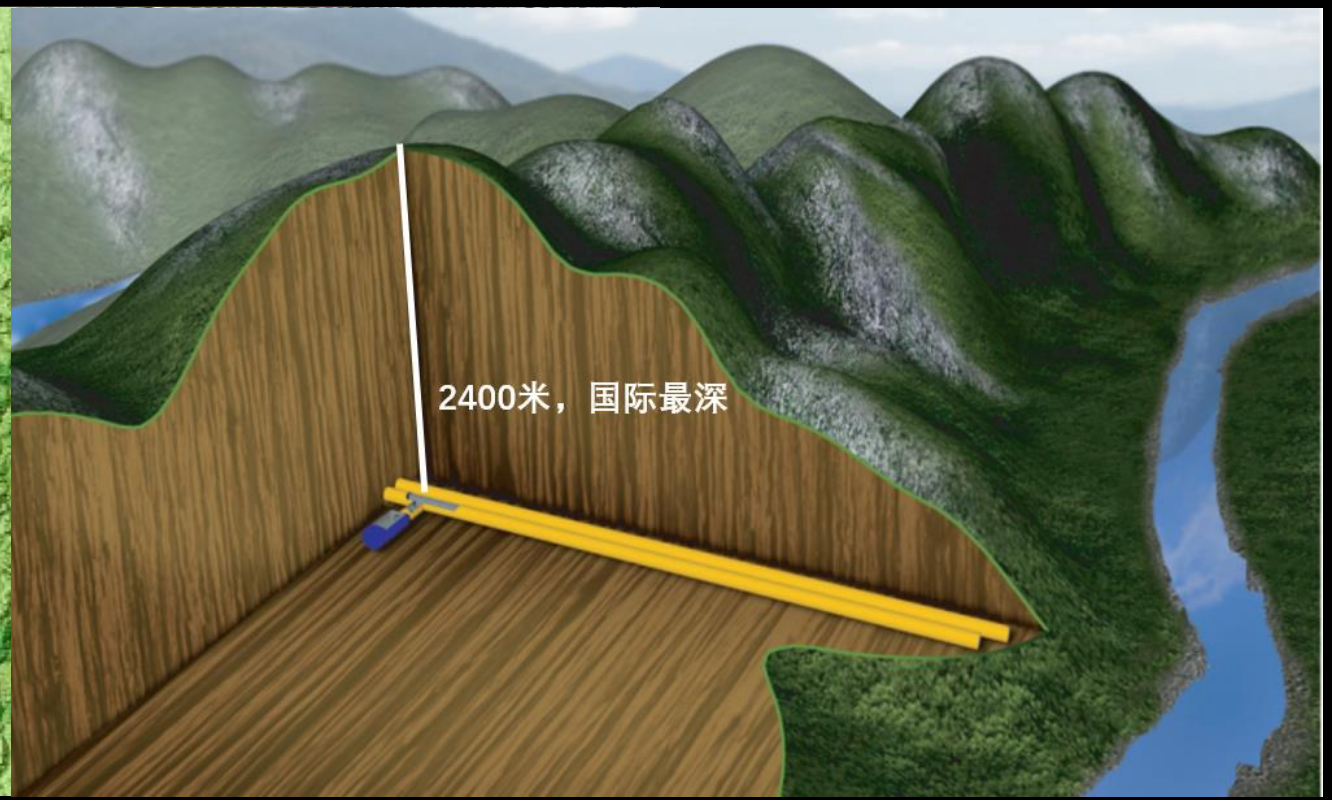
For a 100 GeV dark matter, v=1/1000c, p=100 MeV/c, λ~10 fm
So coherent scattering with nucleons inside nucleus!


SNOLab (加拿大)
SuperCDMS, PICO,
SENSEI, DAMIC
BOULBY(英国)
ZEPLINE, DRIFT
SURF(美国)
LUX/LZ
Canfranc(西班牙)
ANAIS
Modane(法国)
EDELWEISS
中国锦屏
CDEX, PandaX
Y2L(韩国)
COSINE
Soudan(美国)
CDMS
Gran Sasso(意大利)
XENON, DarkSide
Stawell(澳大利亚)
SABRE South

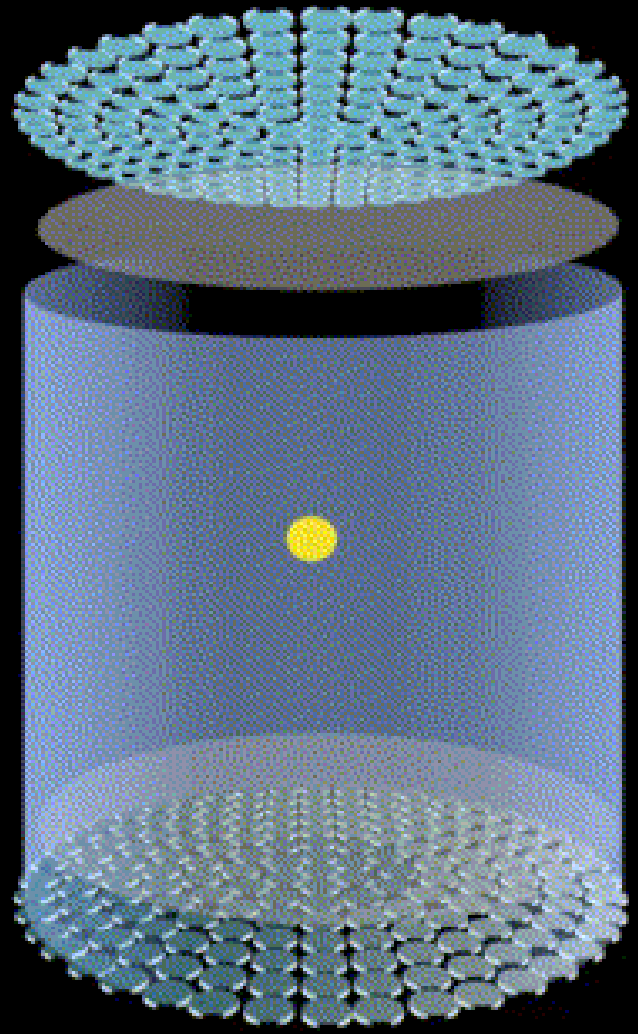
中国地形图


图 例
河流 沼泽
时令河 运河
淡水湖 咸水湖
长城 珊瑚礁
8848 山峰及高程
渔场 盐场
暖流 寒流
首都、首府
省级行政中心
一般城市
国界
省、自治区、直辖市界
特别行政区界
地区界

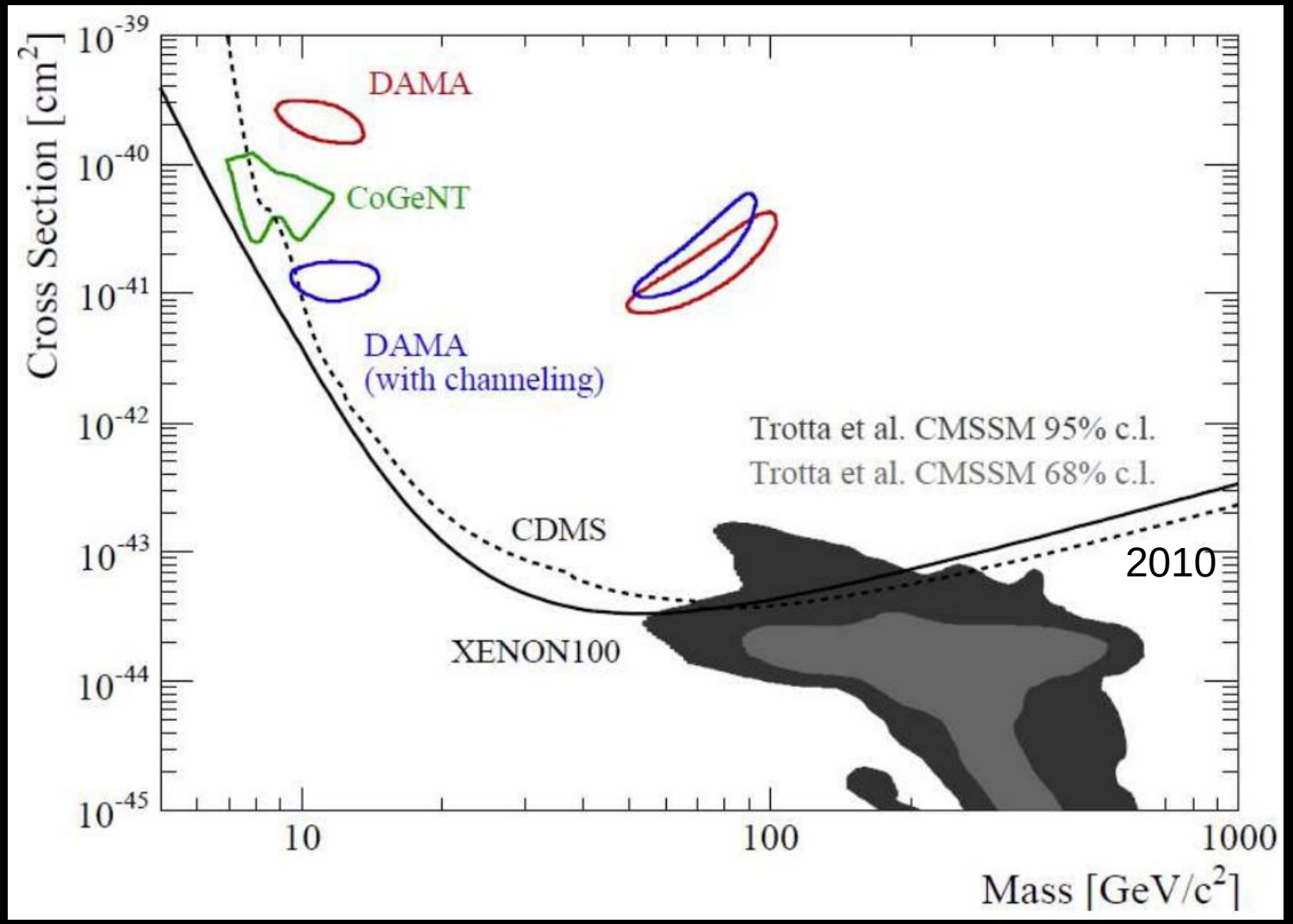
Zhongdian
中 甸


2400米，国际最深

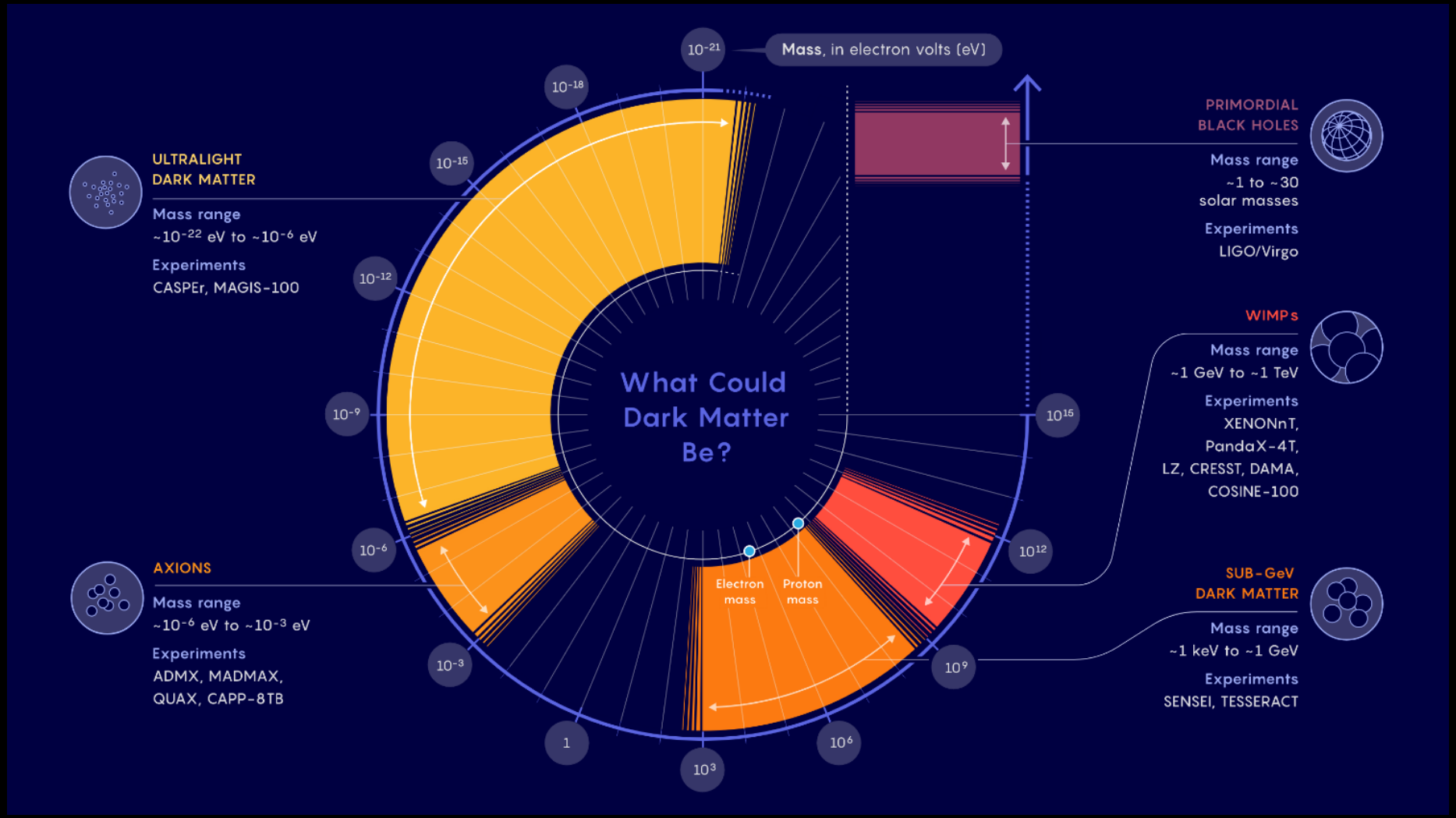




Low Hanging Fruit?



Total Solution/Confusion?

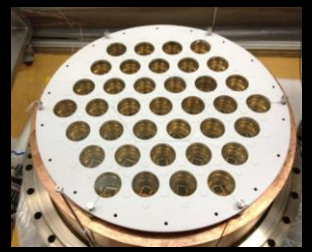


PandaX-I（2009-2014），120 kg

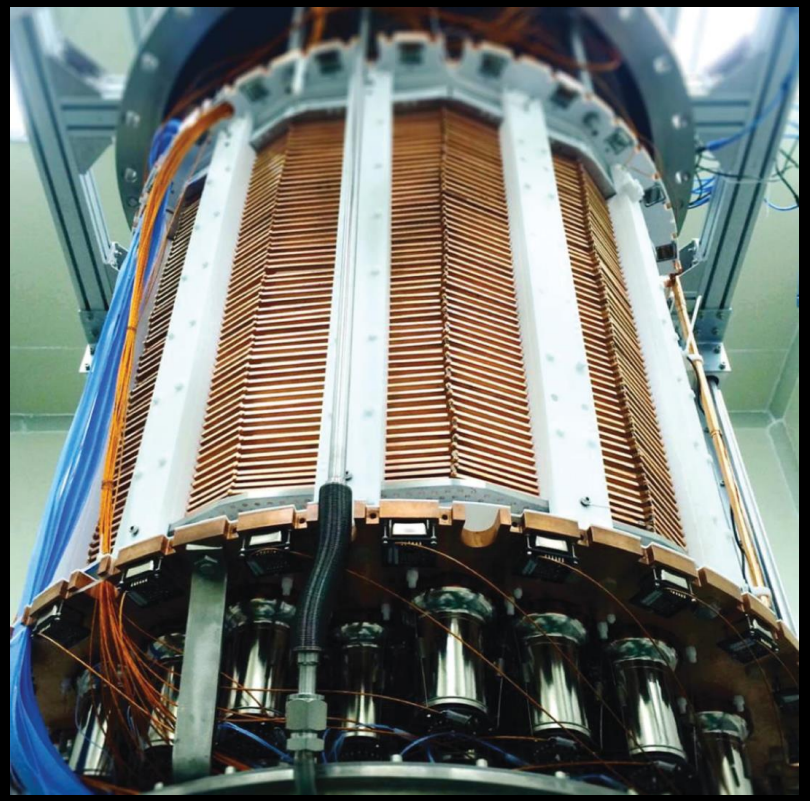


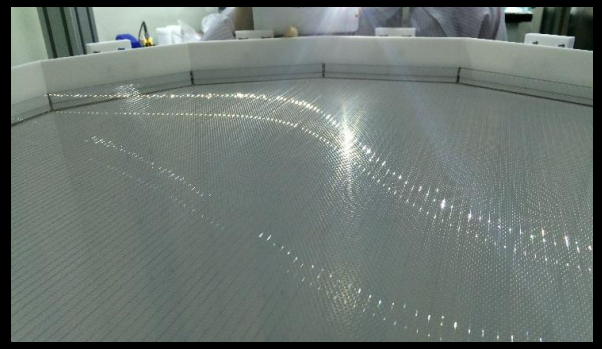


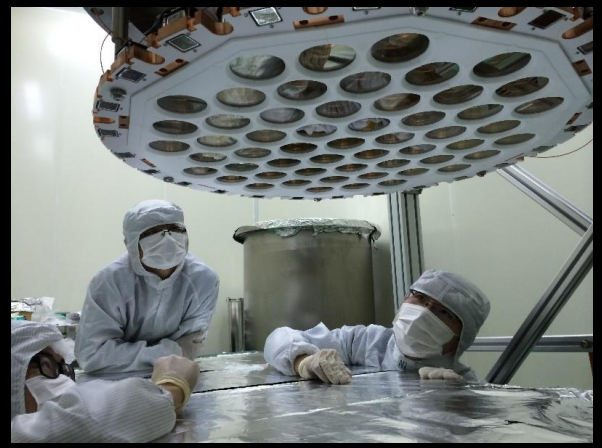




PandaX-II (2015-2019)

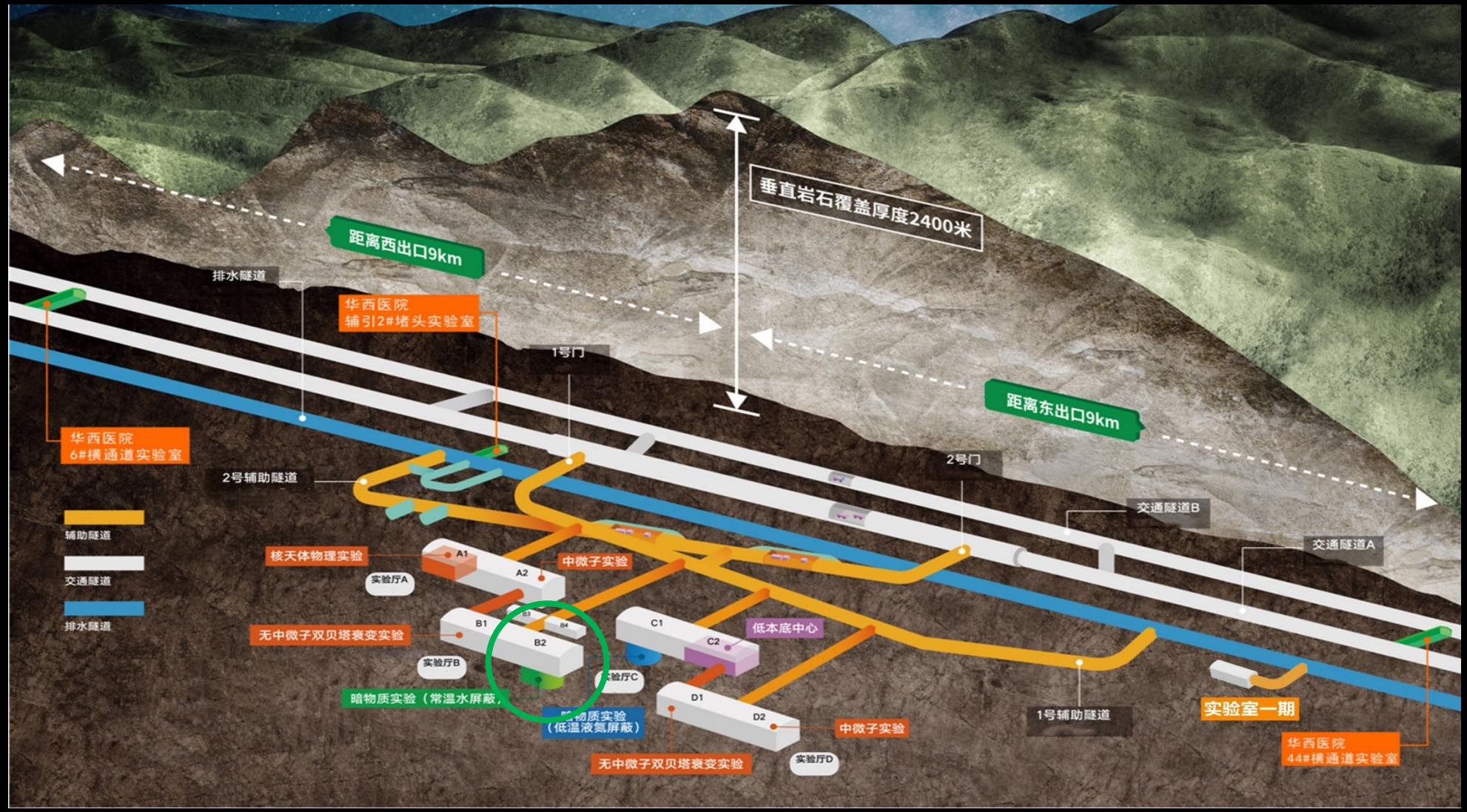






580kg

120kg


垂直岩石覆盖厚度2400米
距离西出口9km
距离东出口9km
排水隧道
华西医院
辅引2#堵头实验室
1号门
华西医院
6#横通道实验室
2号辅助隧道
2号门
交通隧道B
交通隧道A
辅助隧道
交通隧道
排水隧道
核天体物理实验
A1
A2
中微子实验
实验厅A
无中微子双贝塔衰变实验
B1
B2
B3
B4
C1
C2
低本底中心
实验厅B
实验厅C
暗物质实验（常温水屏蔽）
暗物质实验
（低温液氮屏蔽）
D1
D2
中微子实验
无中微子双贝塔衰变实验
实验厅D
1号辅助隧道
实验室一期
华西医院
44#横通道实验室

2018.4 water tank construction





2019.8 PandaX-4T instllation





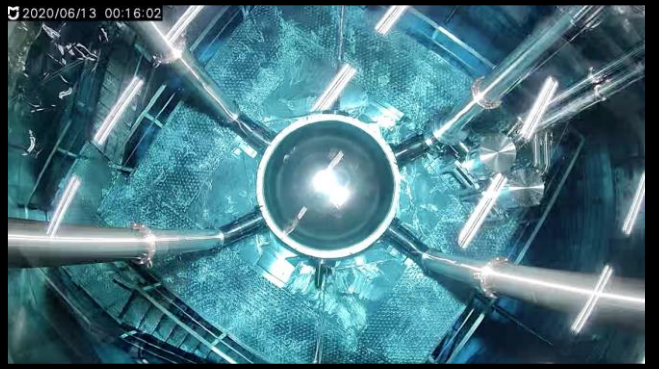


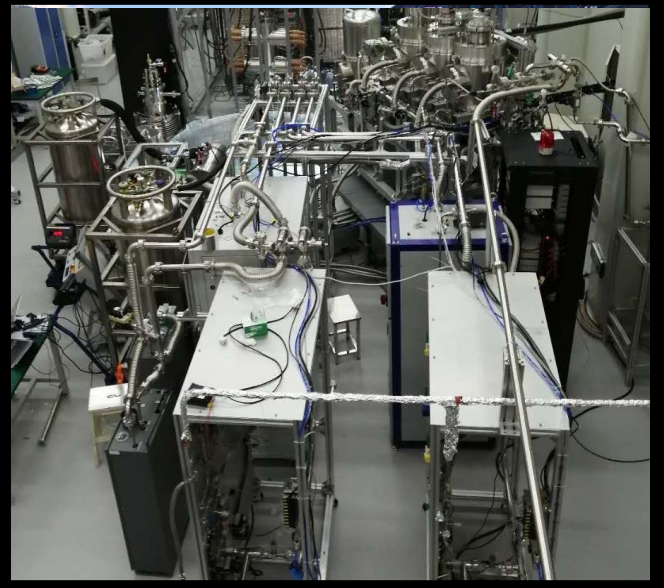
2020.5 liquid xenon filling





2020/6-2020/11 integration tests

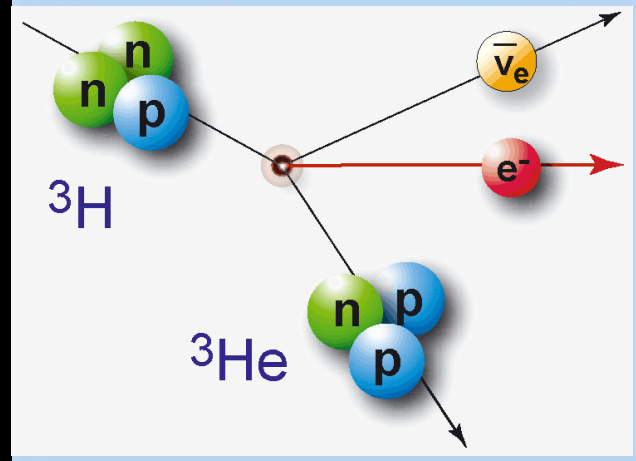




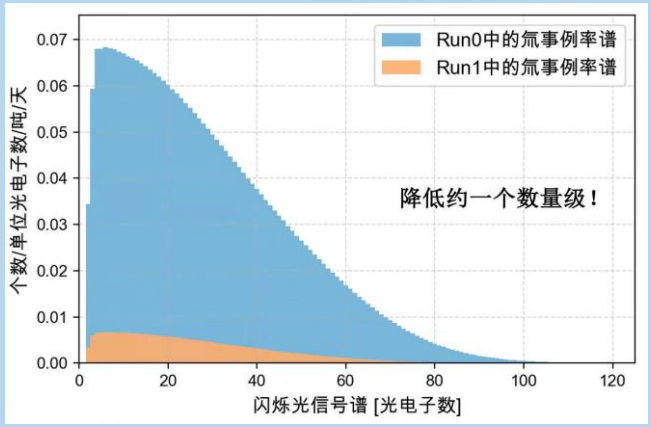
First recorded event in PandaX-4T（2020/6/3 17:19:35）



Background: toughest battle





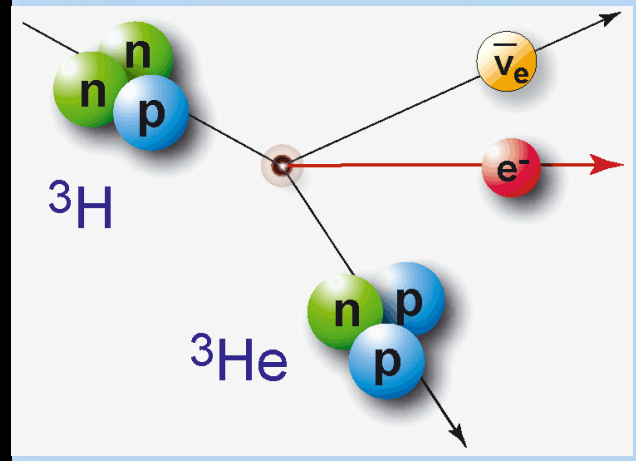


氚：^{3}H，5trillion/kg of water

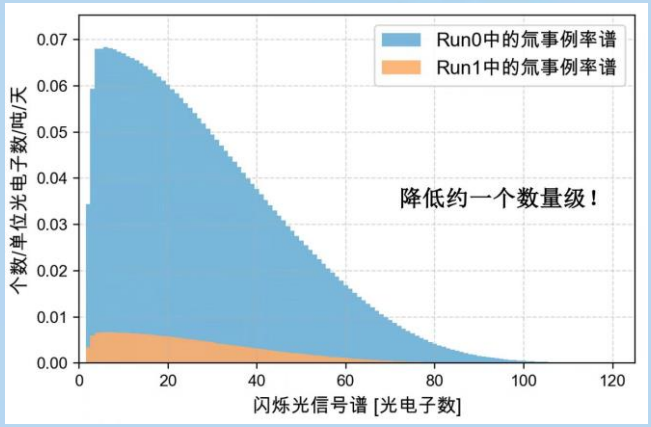
20 atom/kg => 2 atom/kg of xenon

Similarly: ^{85}Kr ~ 10 atom/kg, ^{222}Rn ~ 1 atom/kg in xenon

Background: toughest battle





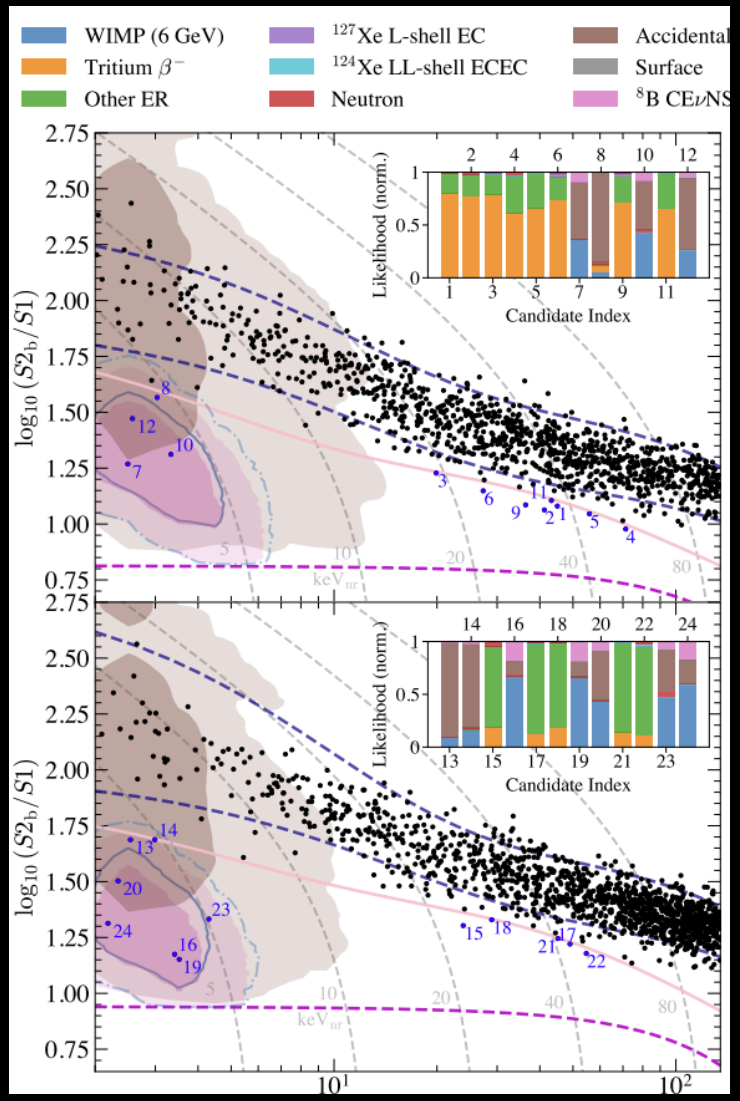


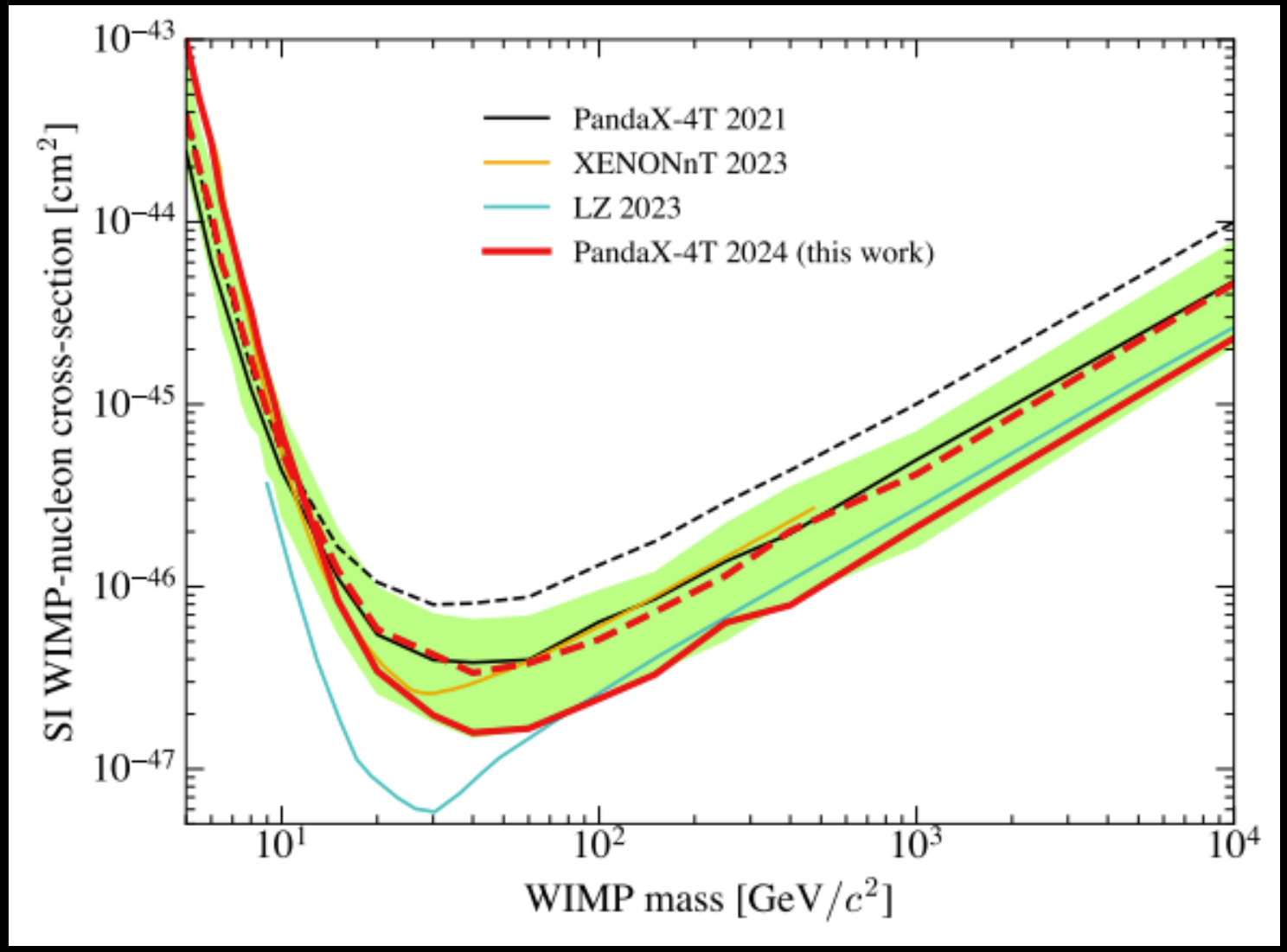
氚：^{3}H，5trillion/kg of water

20 atom/kg => 2 atom/kg of xenon

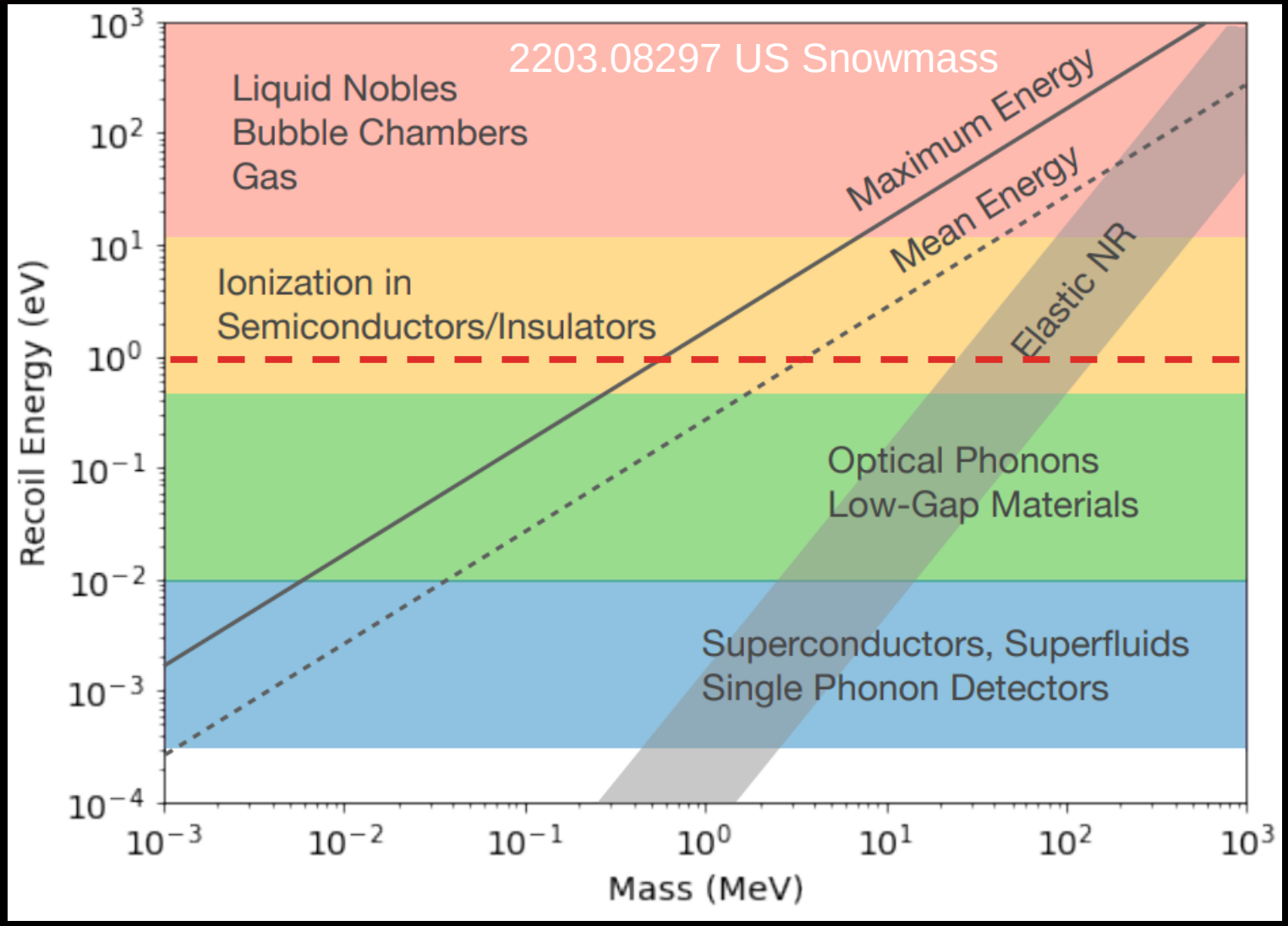
Similarly: ^{85}Kr ~ 10 atom/kg, ^{222}Rn ~ 1 atom/kg in xenon

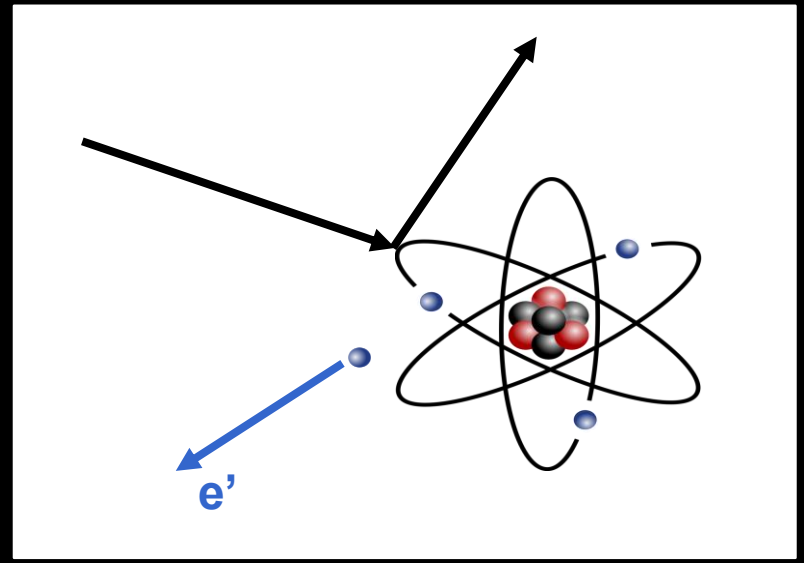
1.5 ton*year Exposure





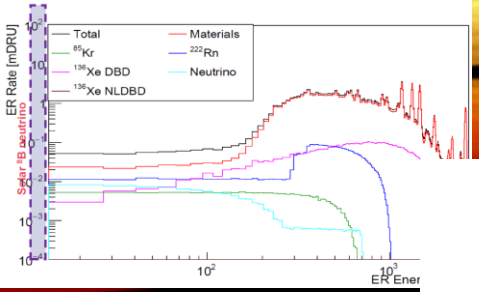
Low mass DM detection techniques

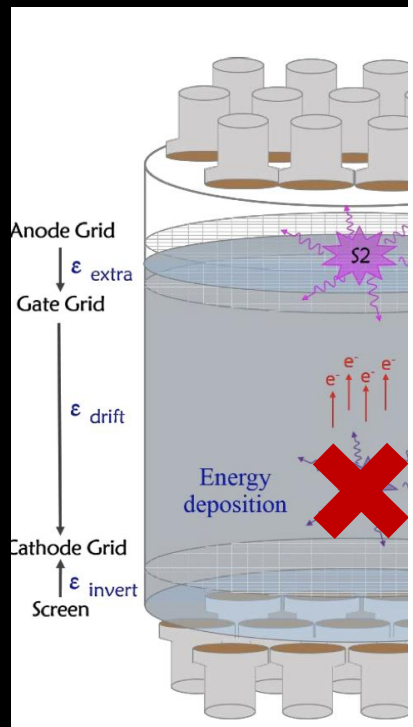


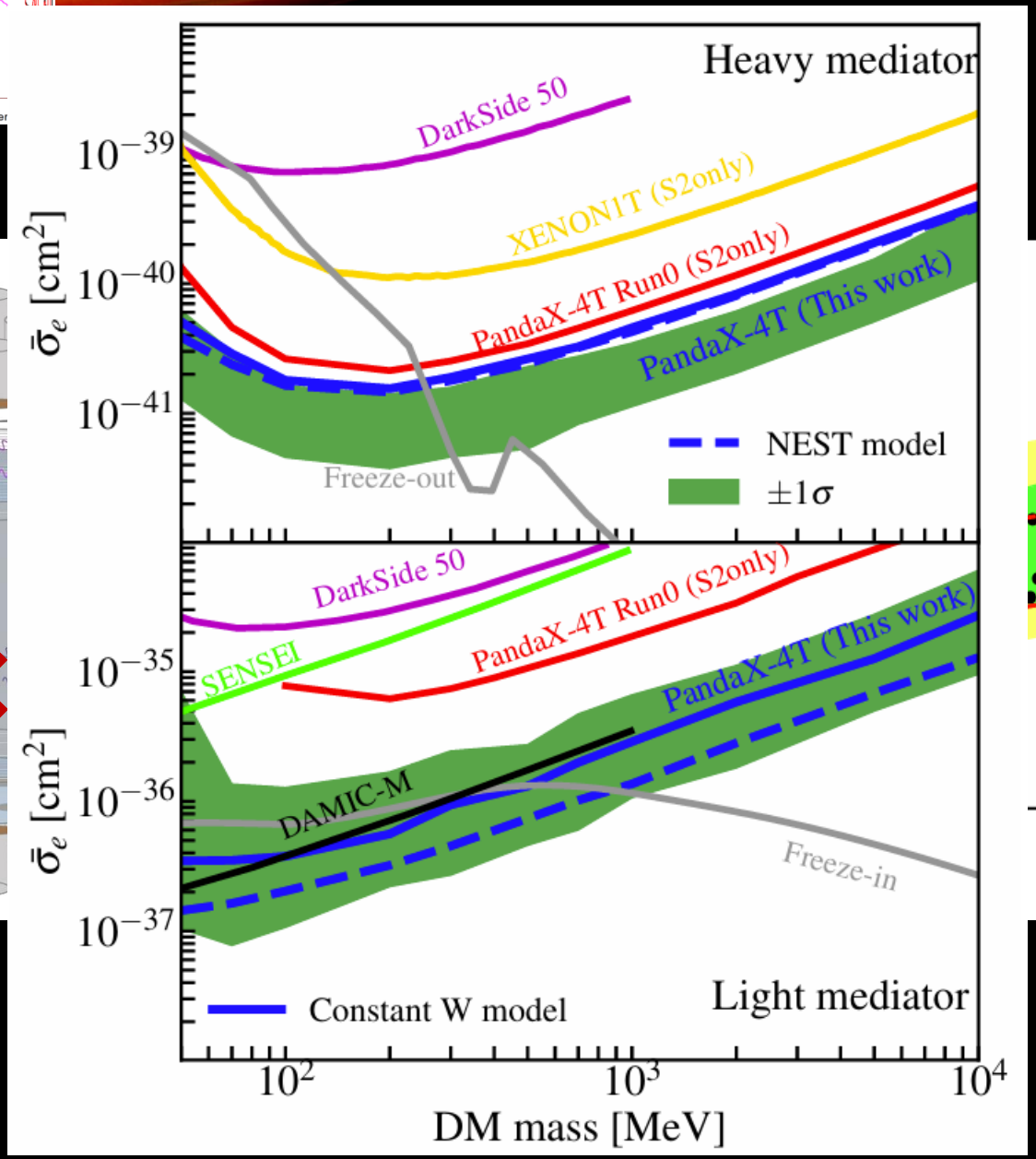


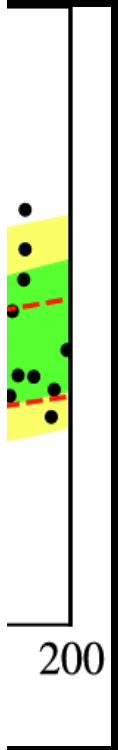
Atomic inelastic scattering: accessing full DM KE-binding. Essig, Mardon, Volansky, PRD 85, 076007 (2012)

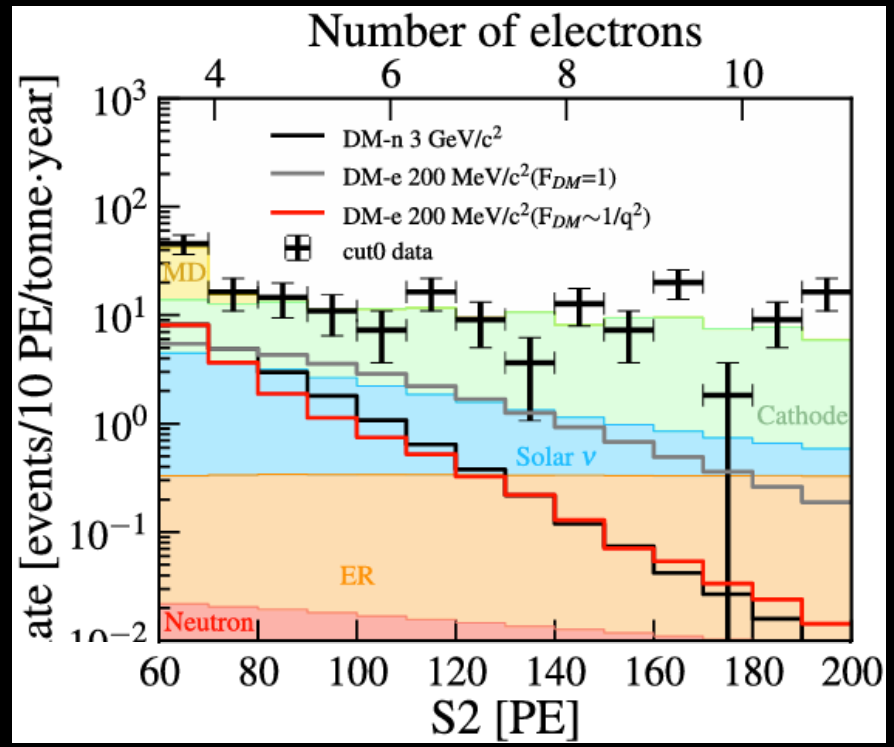
S2-only approach



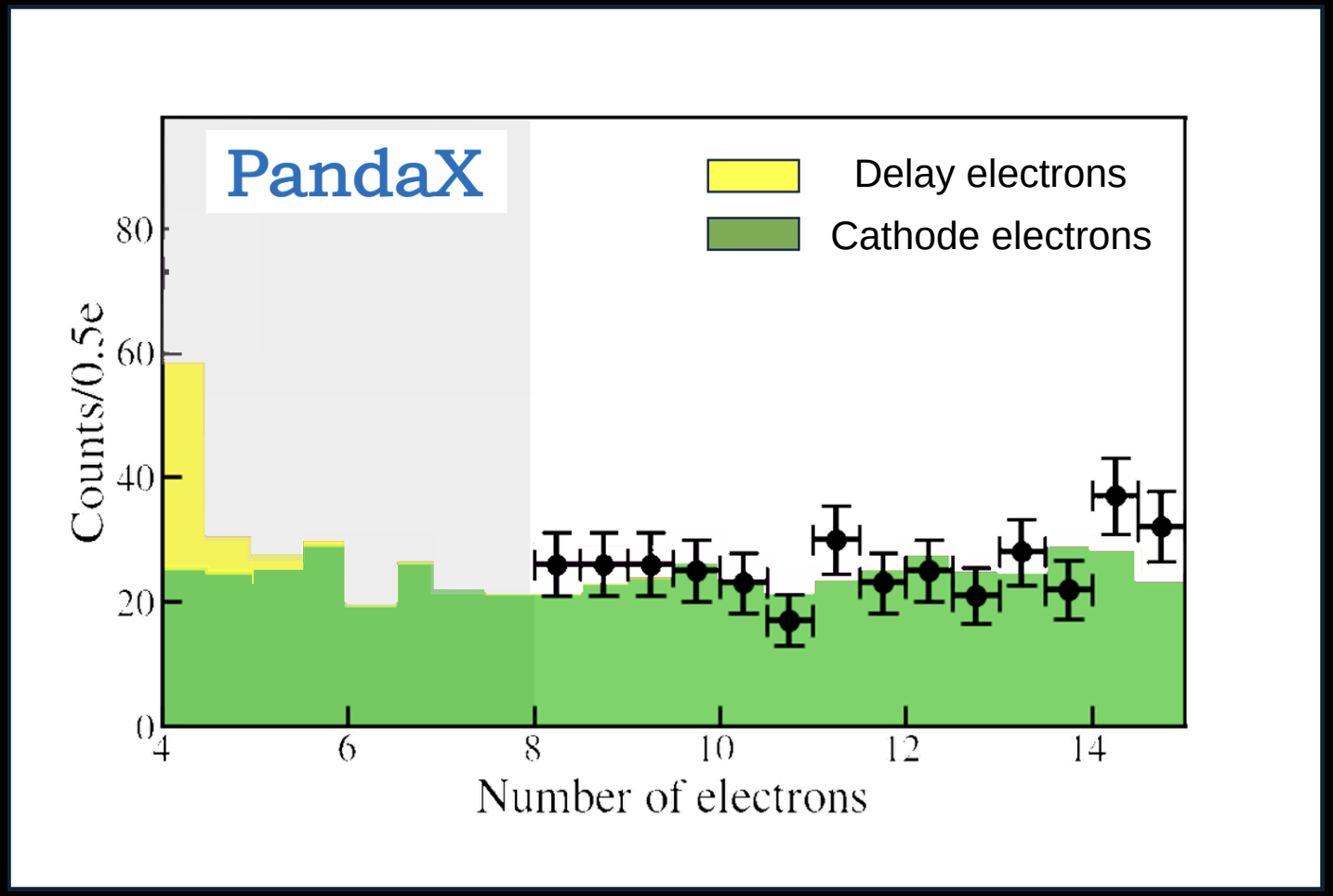


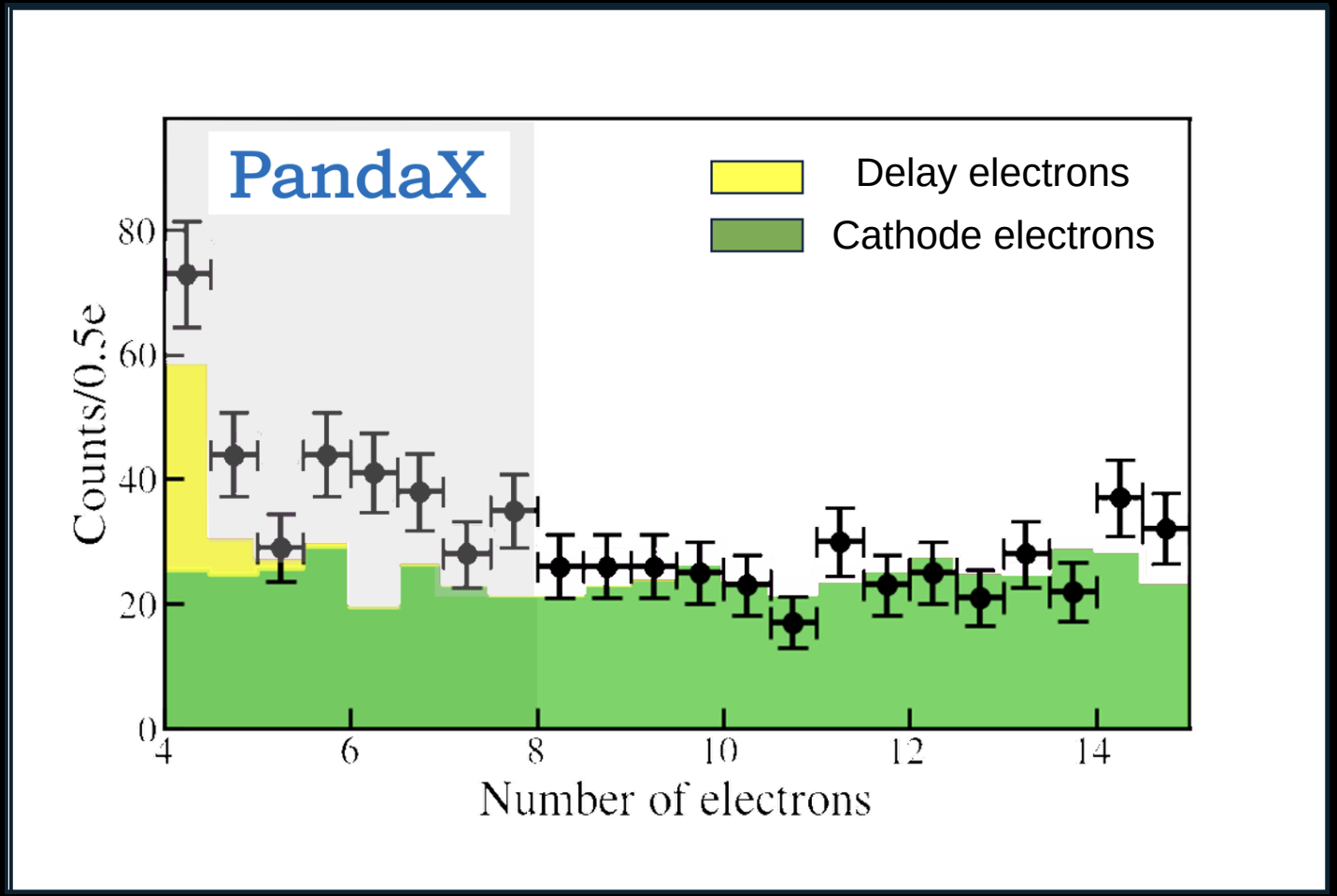


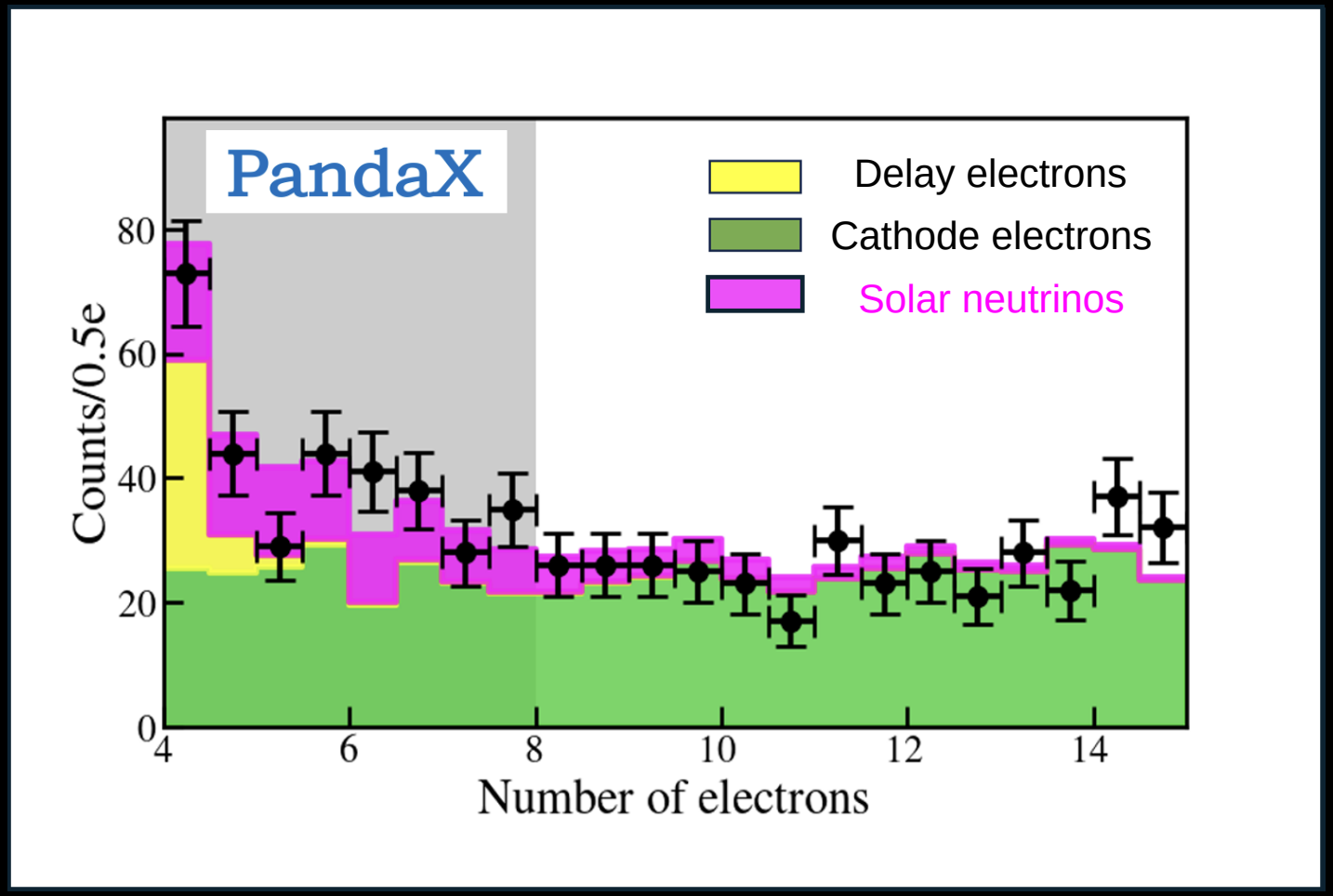


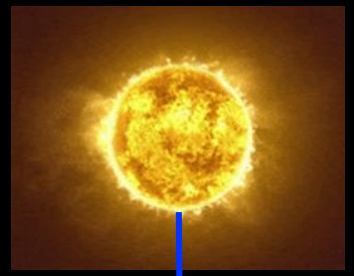


PRL 130, 261001 (2023)
PRL 135, 211001 (2025)

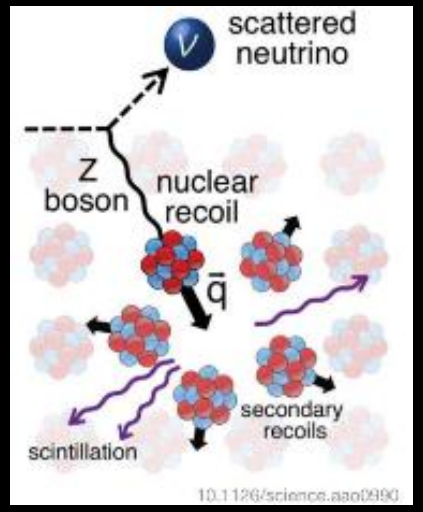

PandaX
Delay electrons
Cathode electrons
Counts/0.5e
0
20
40
60
80
4
6
8
10
12
14
Number of electrons

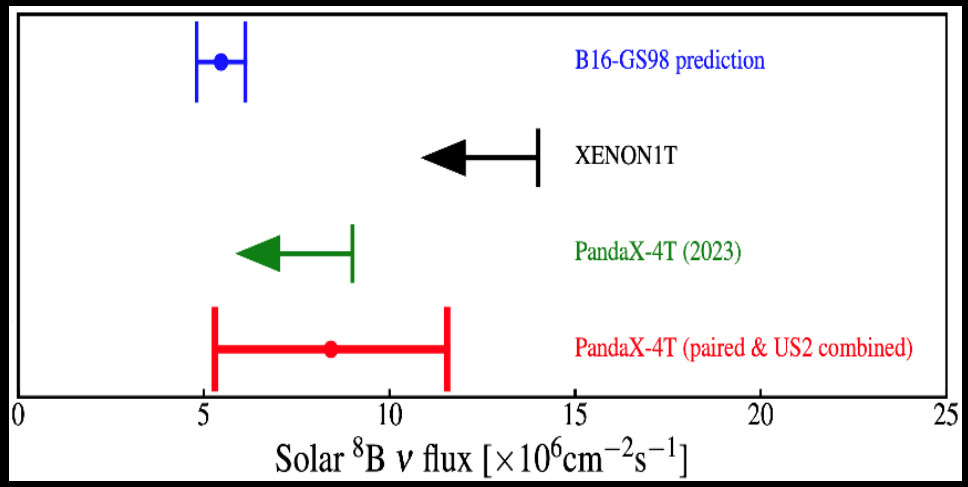

PandaX
Delay electrons
Cathode electrons
Counts/0.5e
0
20
40
60
80
4
6
8
10
12
14
Number of electrons


PandaX
Delay electrons
Cathode electrons
Solar neutrinos
Counts/0.5e
0
20
40
60
80
4
6
8
10
12
14
Number of electrons

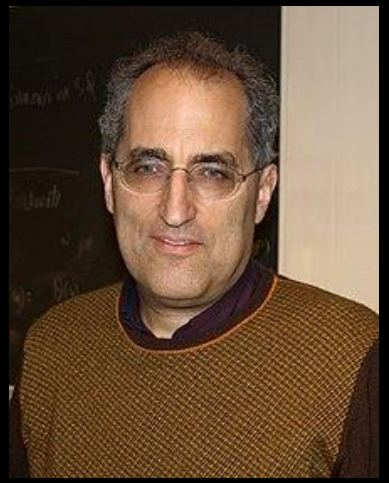


ν


scattered neutrino
Z boson
nuclear recoil
q̄
secondary recoils
scintillation
10.1126/science.aao0990

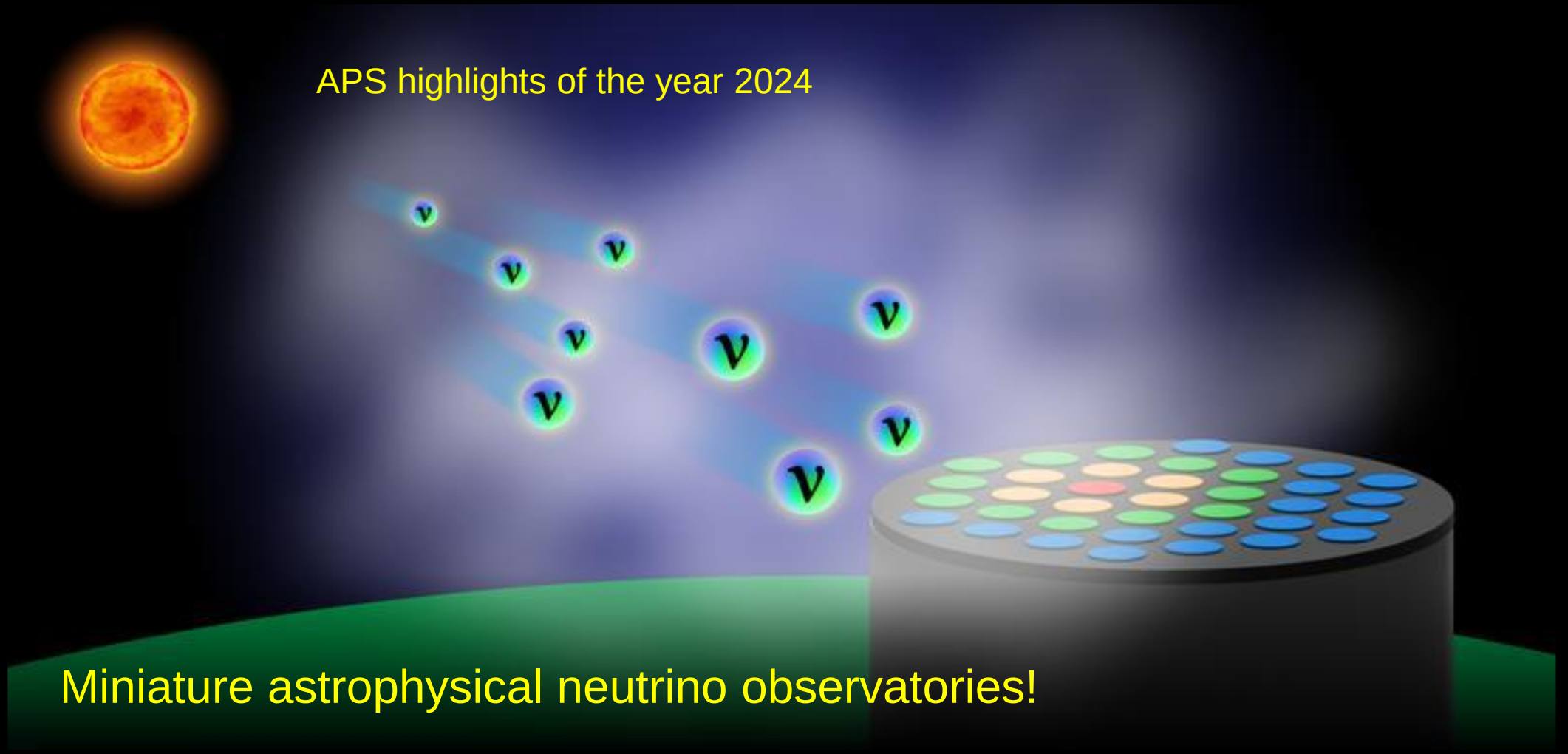

B16-GS98 prediction
XENON1T
PandaX-4T (2023)
PandaX-4T (paired & US2 combined)
0
5
10
15
20
25
Solar ^{8}B ν flux [$\times 10^6$cm^{-2}s^{-1}]







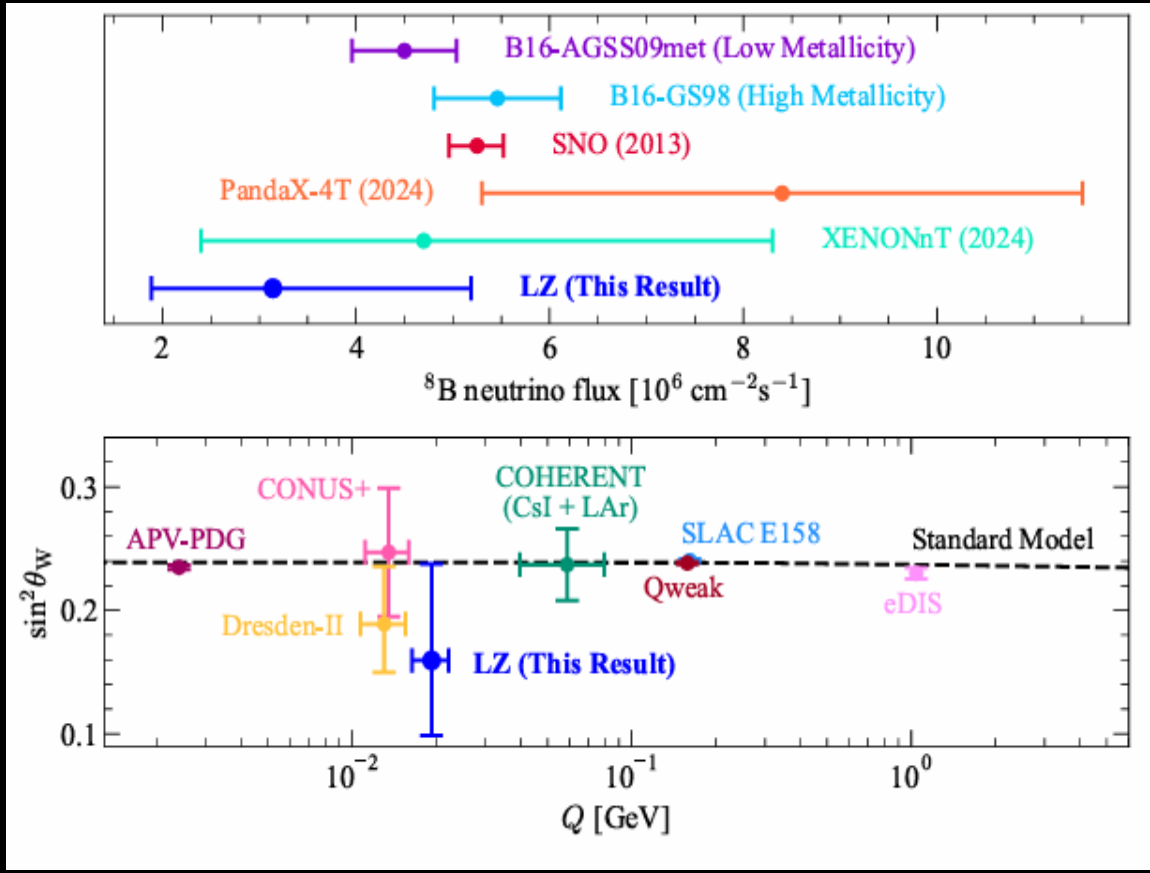
APS highlights of the year 2024



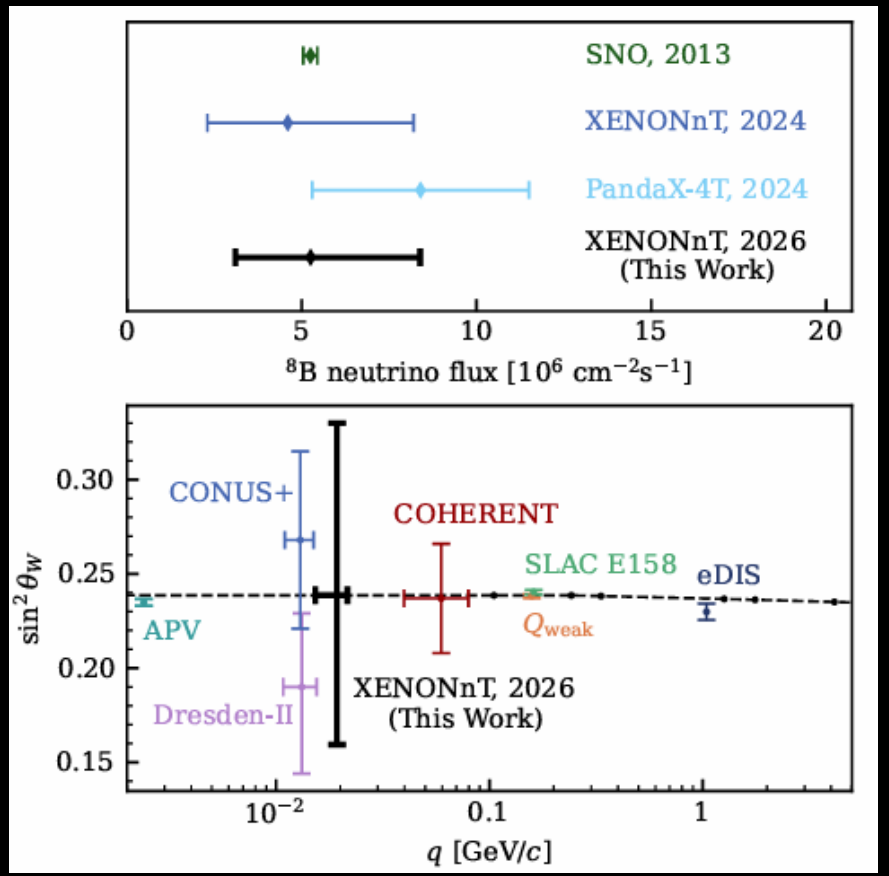
Miniature astrophysical neutrino observatories!

LZ/XENON latest results

LZ: 2512.08065



XENON: 2604.06002



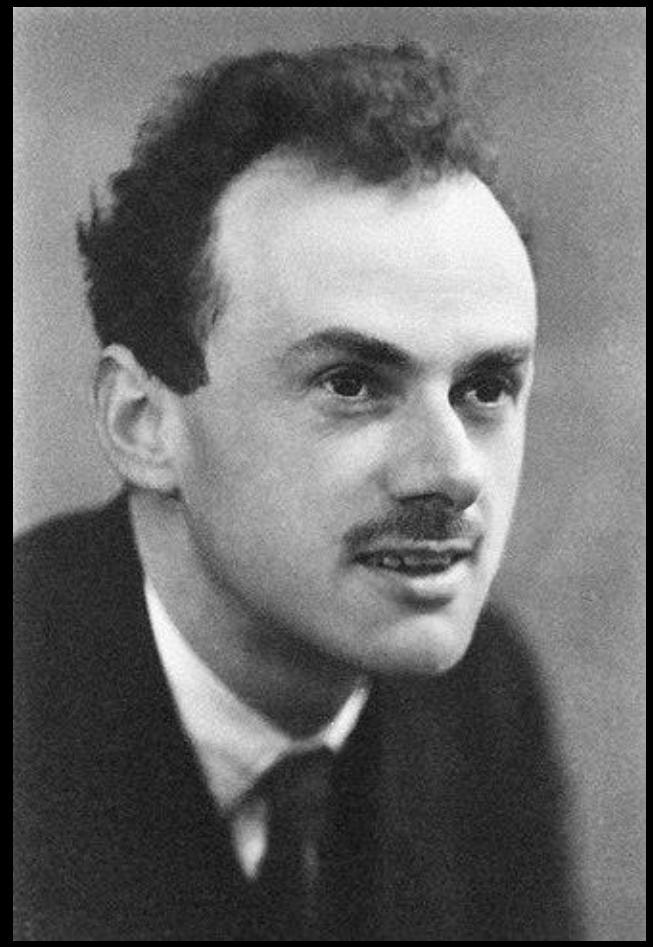
A platform to study neutrino interactions + astrophysical neutrino observatory

“Bigger fish”: Majorana neutrinos



$\bar{\nu} = \nu$



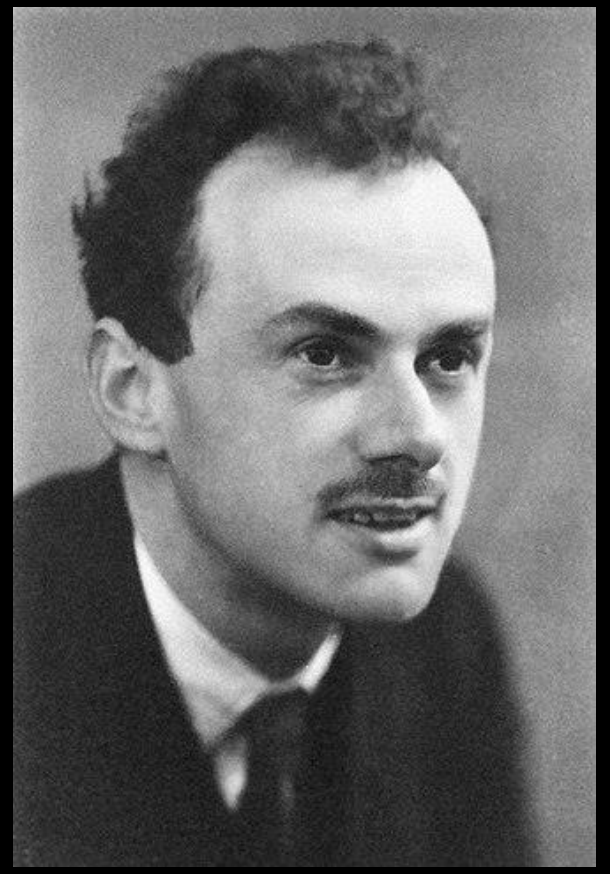


$\bar{\nu} \neq \nu$

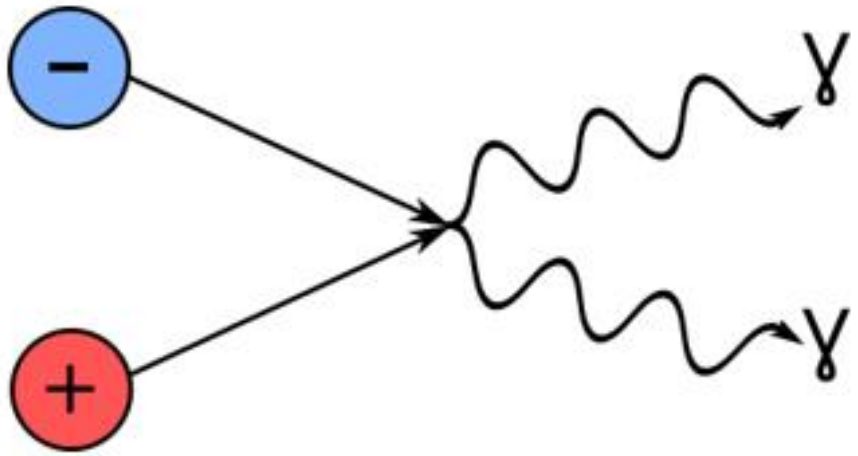
Dirac, 1928

$$\left(i\partial\!\!\!/ - m\right)\psi = 0$$

Negative energy solution $\Leftrightarrow$ positron (e^+)



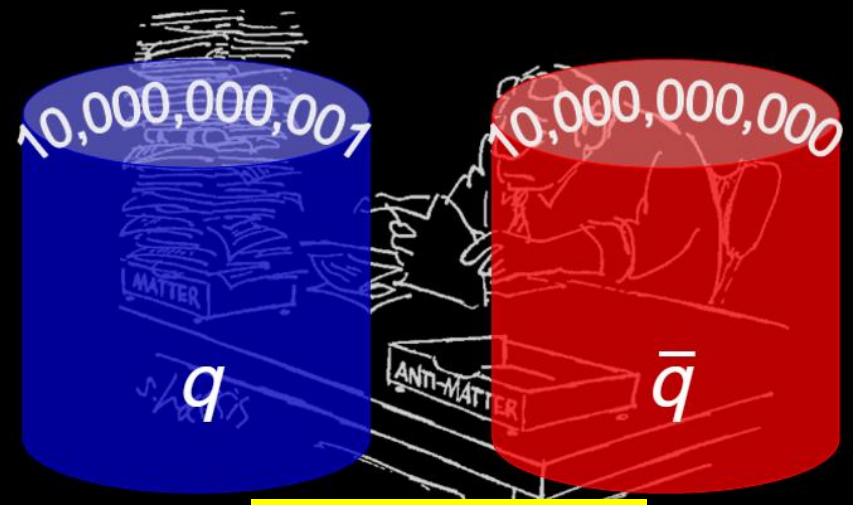
Matter⇔Energy



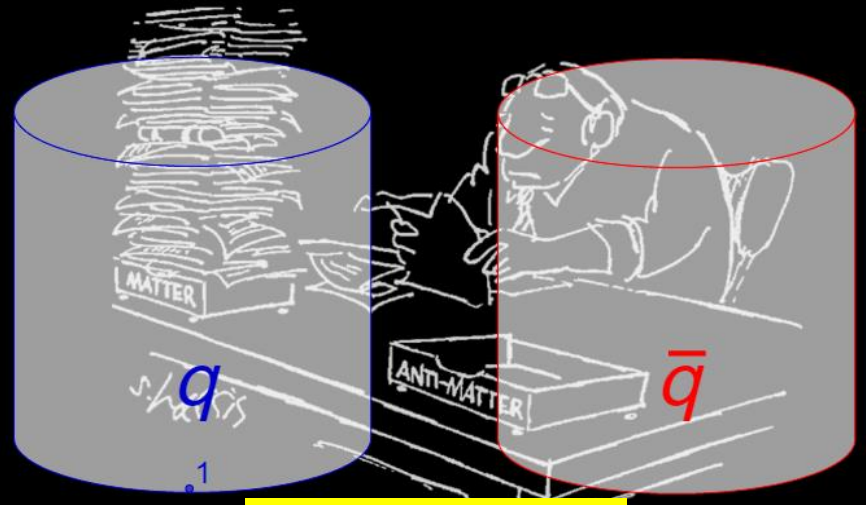


1/Billion Asymmetry?

$$\eta = \frac{n_B - n_{\overline{B}}}{n_\gamma} \simeq 5 \times 10^{-10}$$



Early Universe



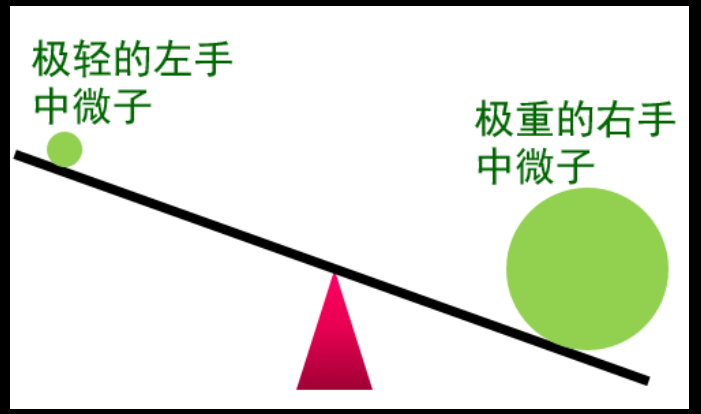
Today Universe

Neutrino Connection?

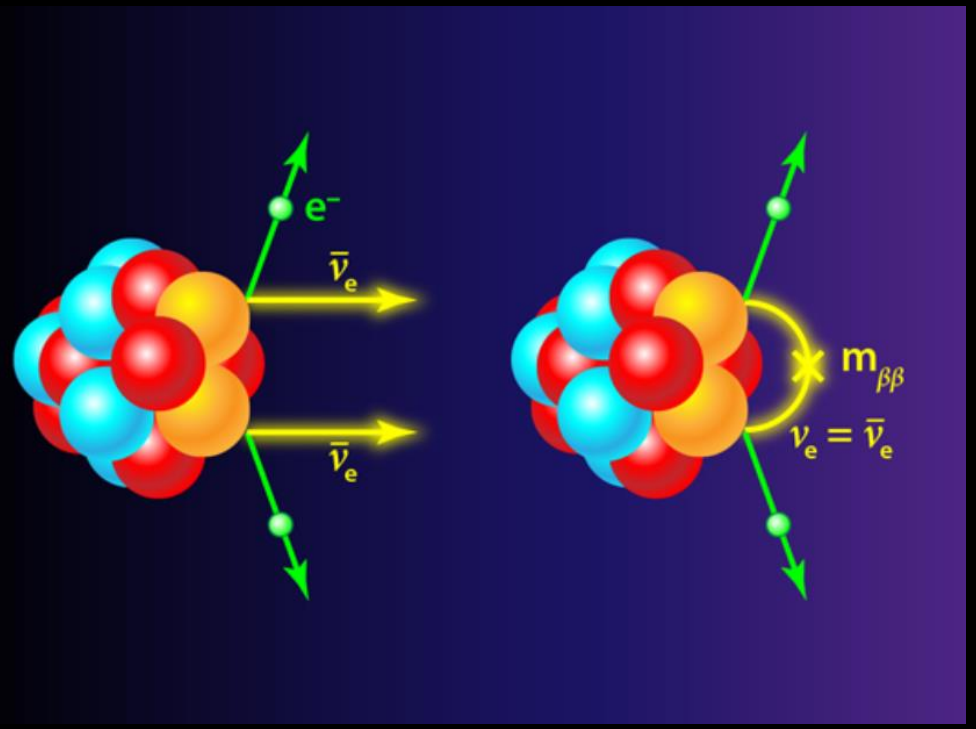


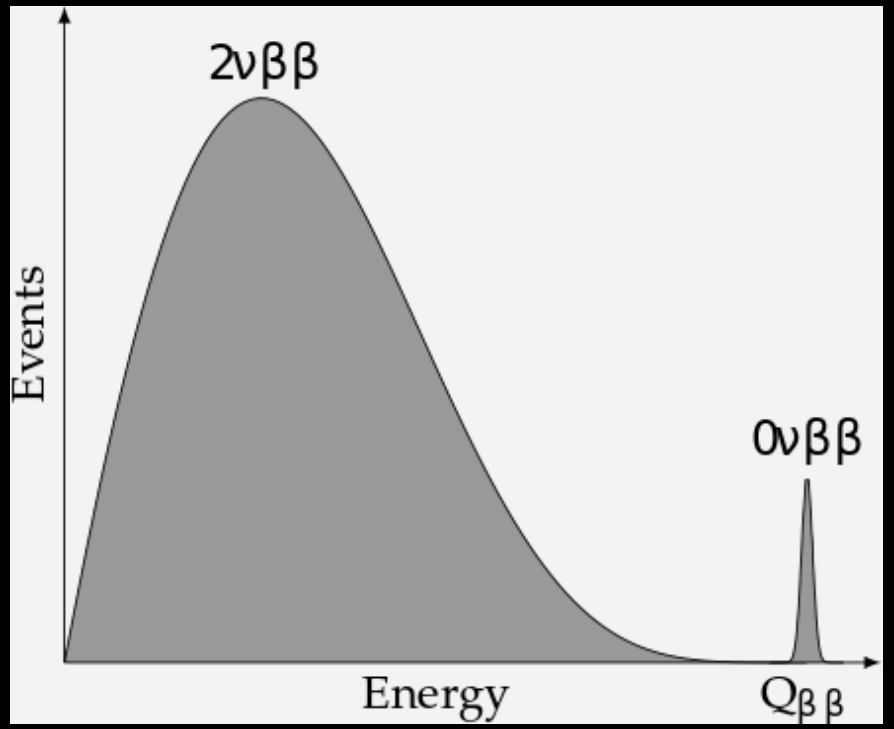
Leptogenesis: Fukugita and Yanagida

1. Neutrino is majorana
2. Neutrino violate CP
3. Neutrino mass is produced by seesaw mechanism

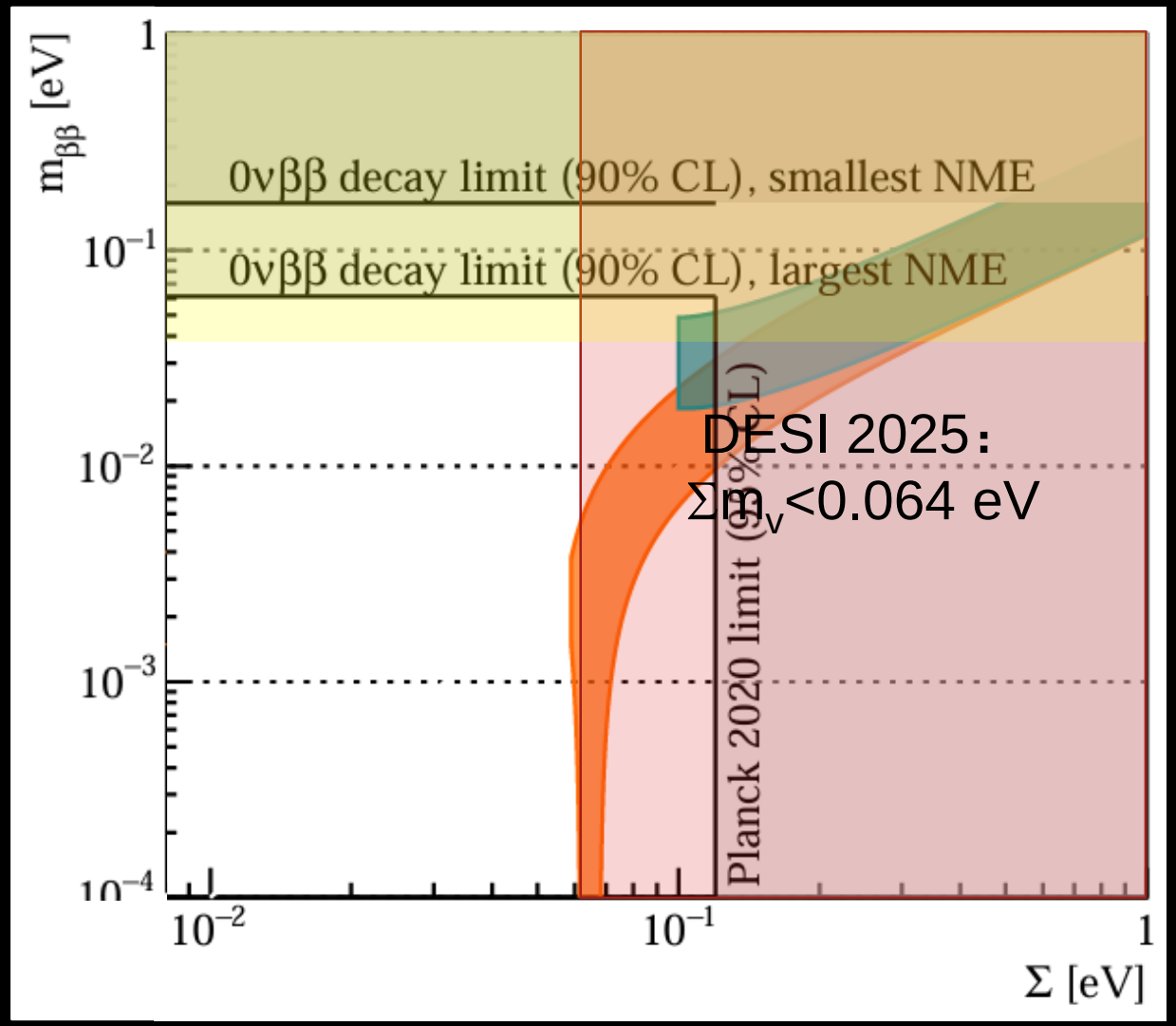


How to Tell a Majorana Neutrino?





Particle Experiments vs Cosmology

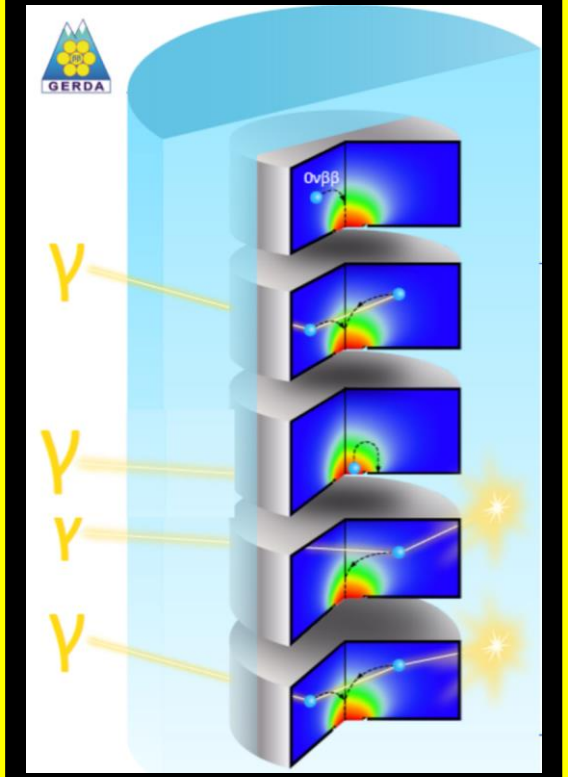




^{130}Te/^{100}Mo

CUORE/CUPID

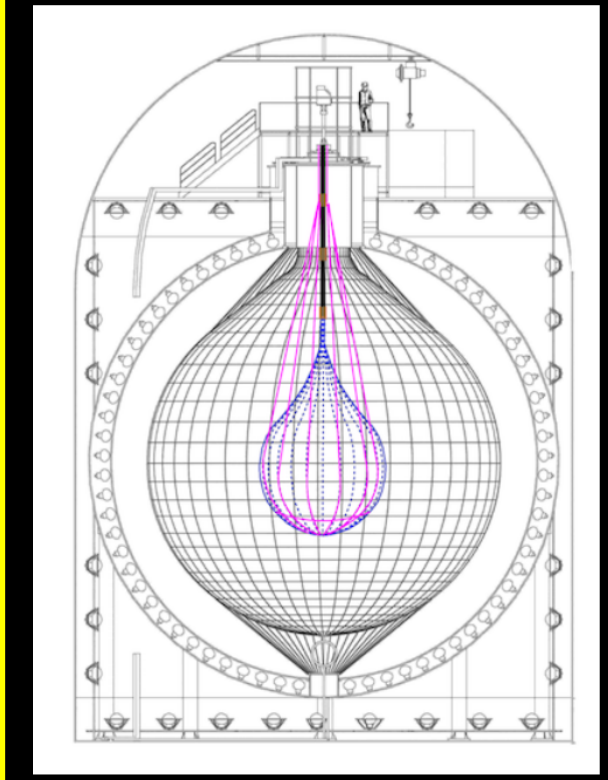
Bolometer

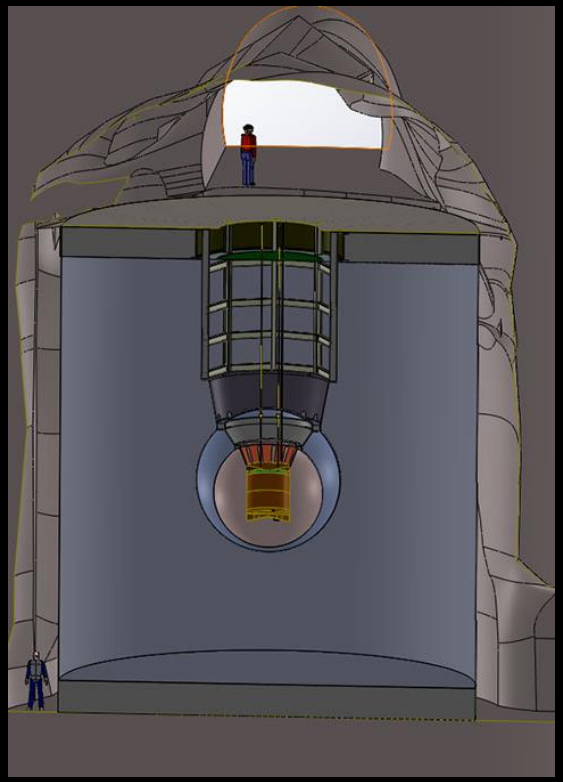


^{76}Ge

LEGEND family

HPGe





^{136}Xe (8.9% natural abd.)

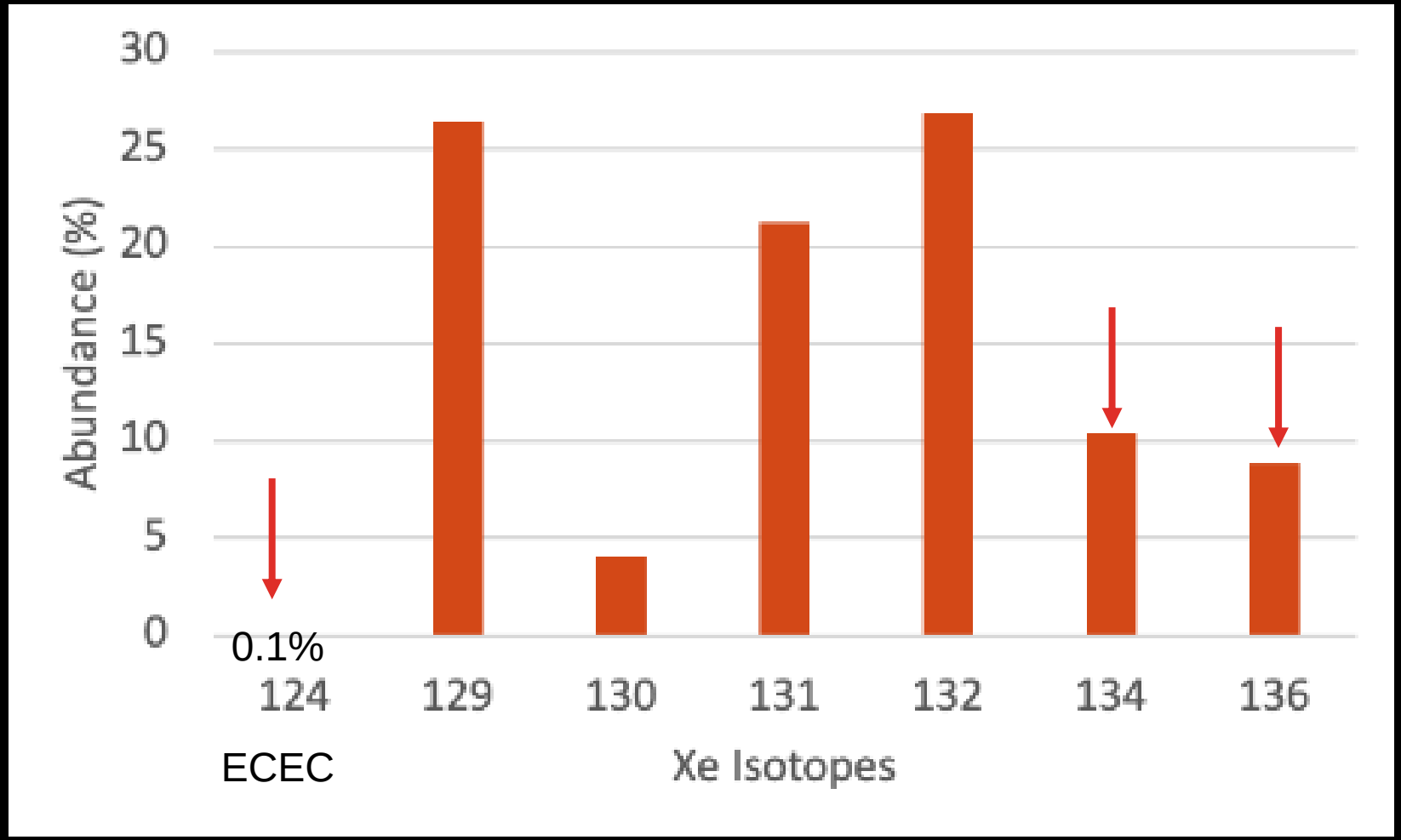
KamLAND-ZEN

Doped LS

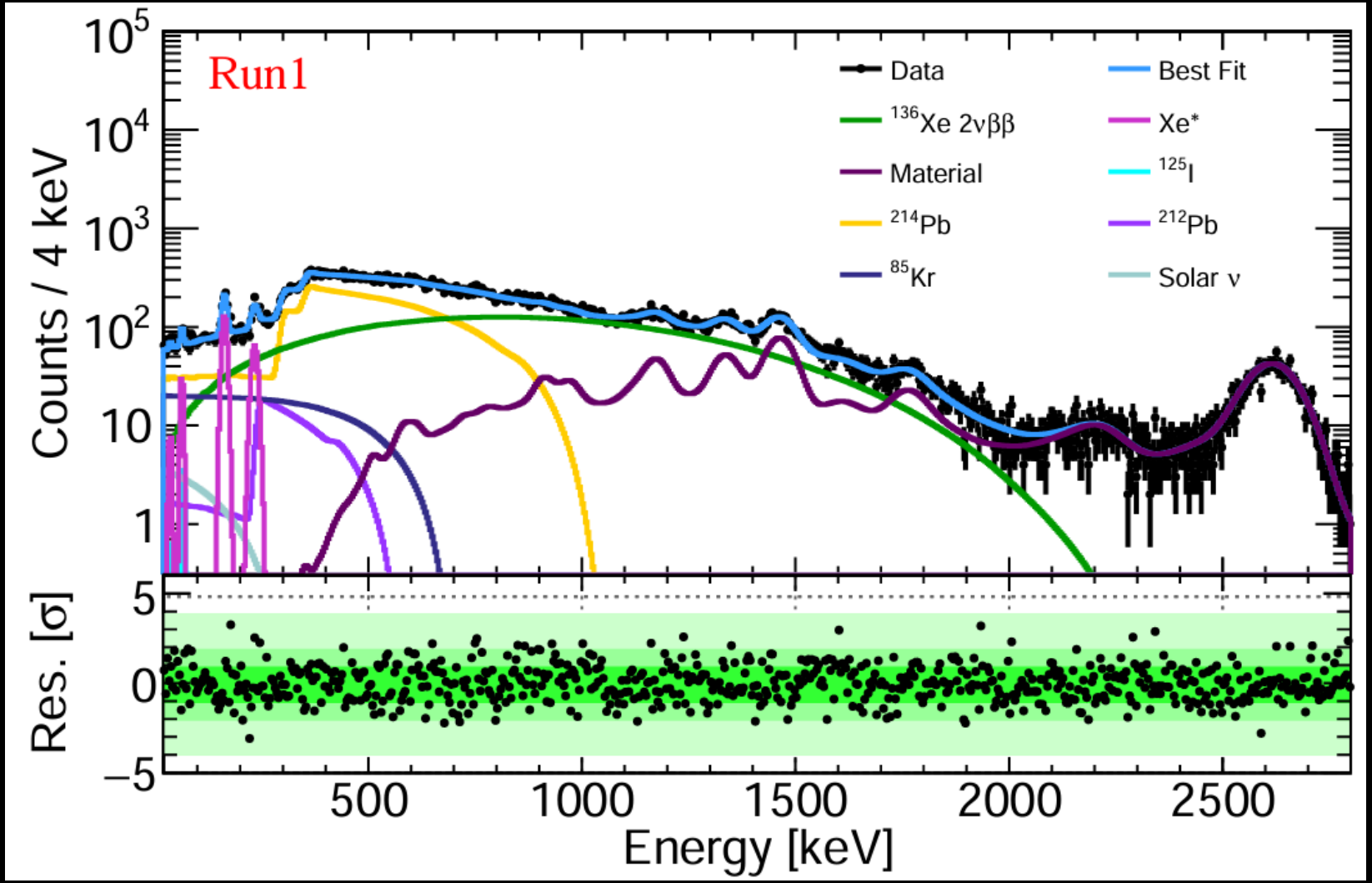
EXO/nEXO

LXe TPC

Magical Xenon

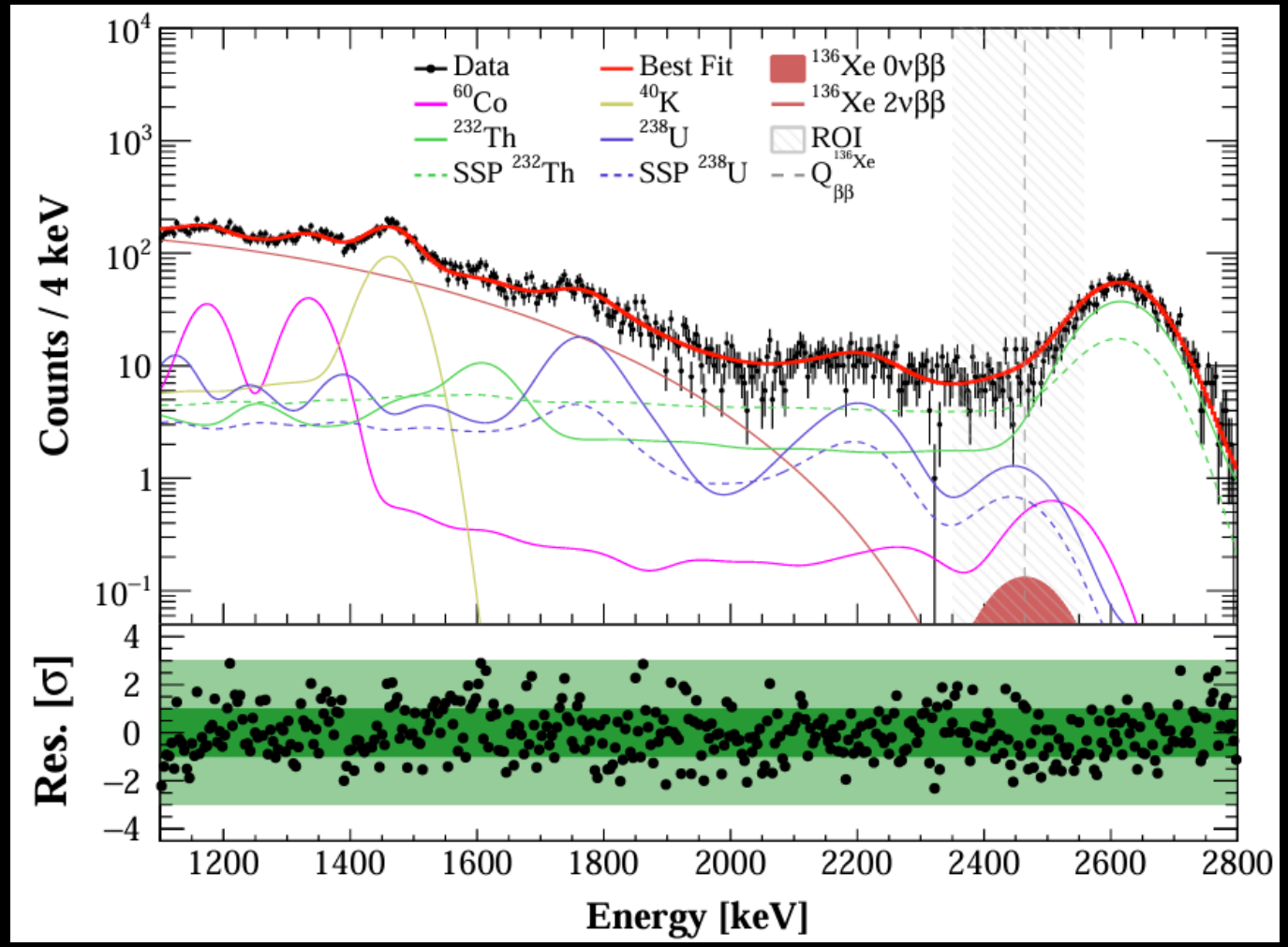


Most accurate Xe136 2vbb



arXiv:2512.04849
PRL

Xe136 0vbb：Best Results in Natural Xenon

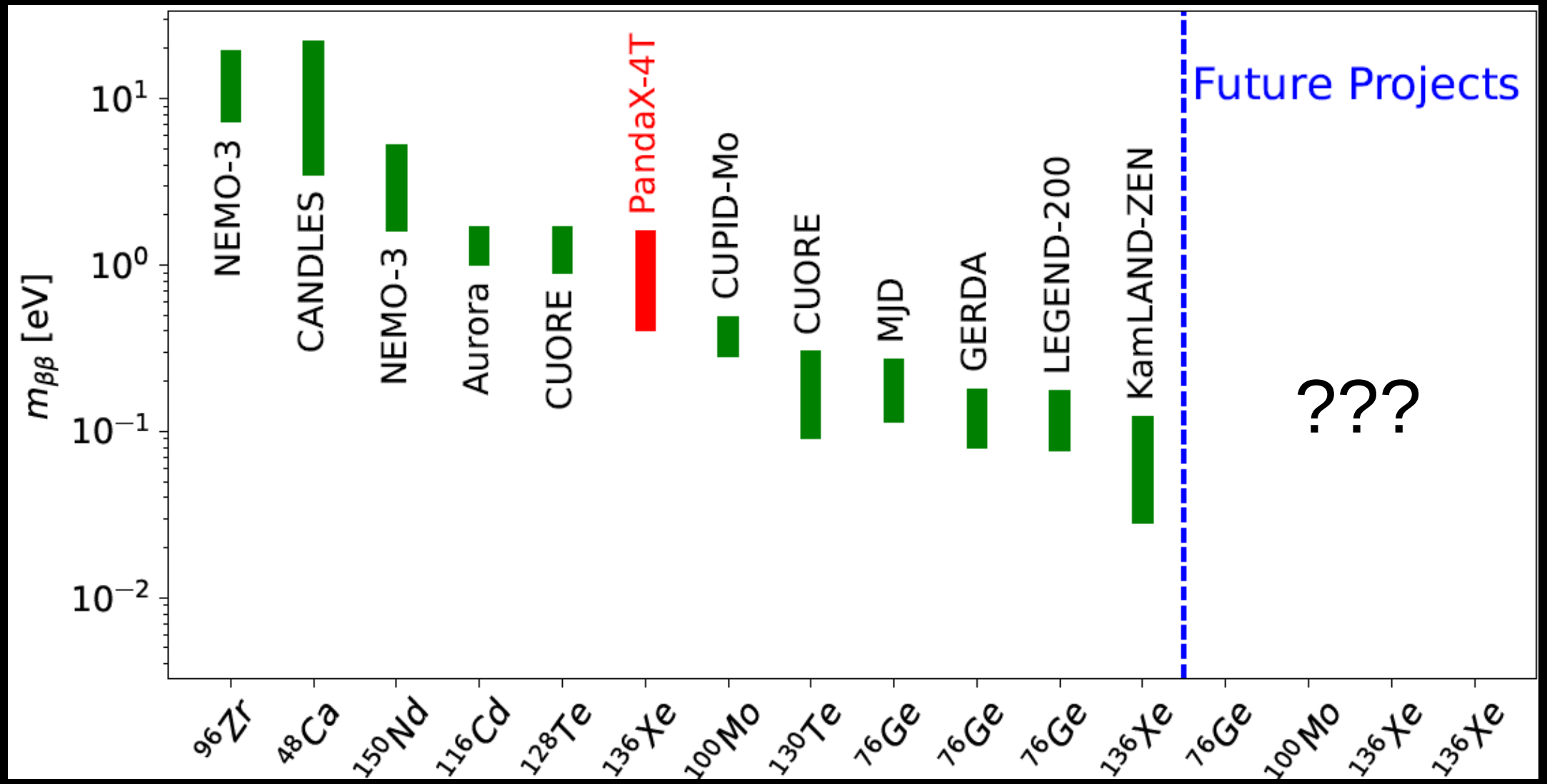


Science Bulletin 2025
arXiv:2412.13979

Lifetime
$> 2.1 \times 10^{24}$year
90% CL

Median sensitivity
2.7×10^{24}year

Race of Majorana neutrino mass



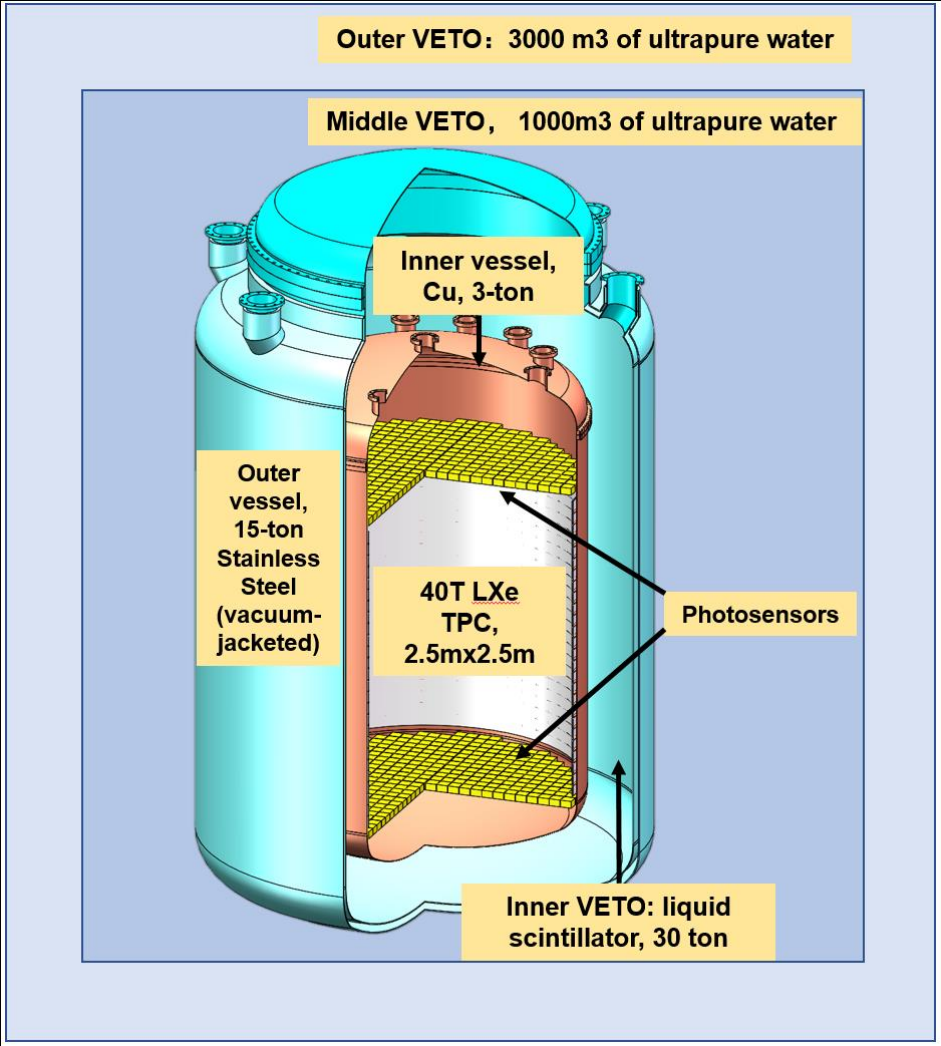
What are we doing now?



April 17,2026

Bye bye PandaX-4T!

PandaX-xT



- Eventually, 47-ton xenon, including 40-ton sensitive volume
  - TPC 2.5 meters in diameter and height
  - Cold LS veto right outside Cu cryostat
  - Staged and upgradable
  - Dual-phase or single-phase options
- First stage PandaX-20T “fully” funded (by many patrons)

Transporting Xenon to CJPL





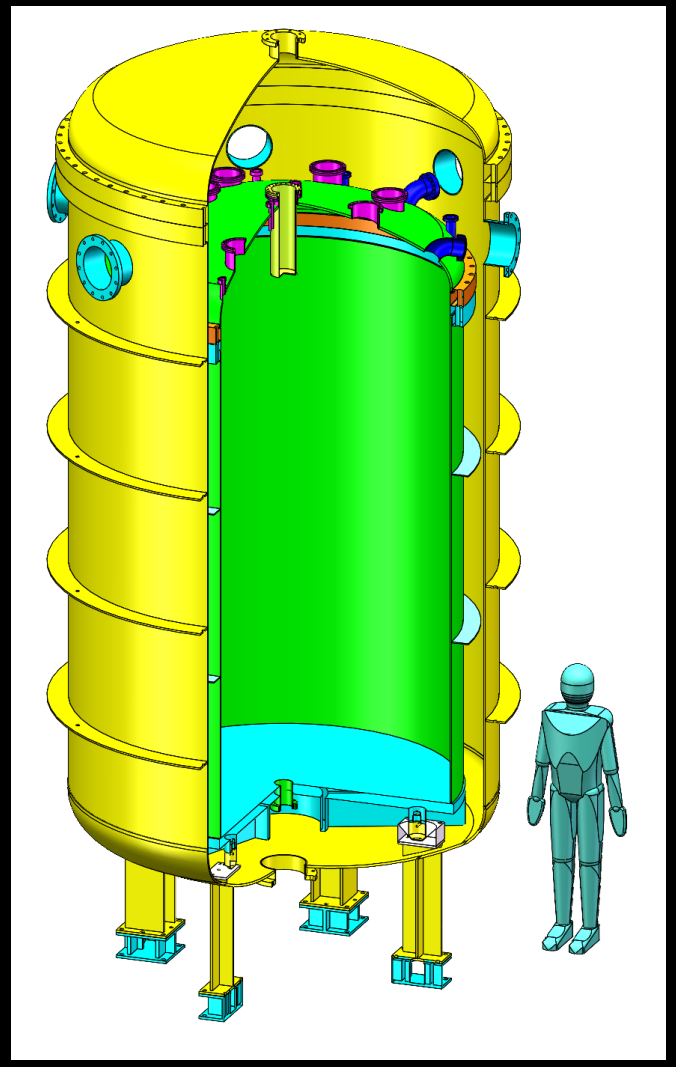
Infrastructure construction

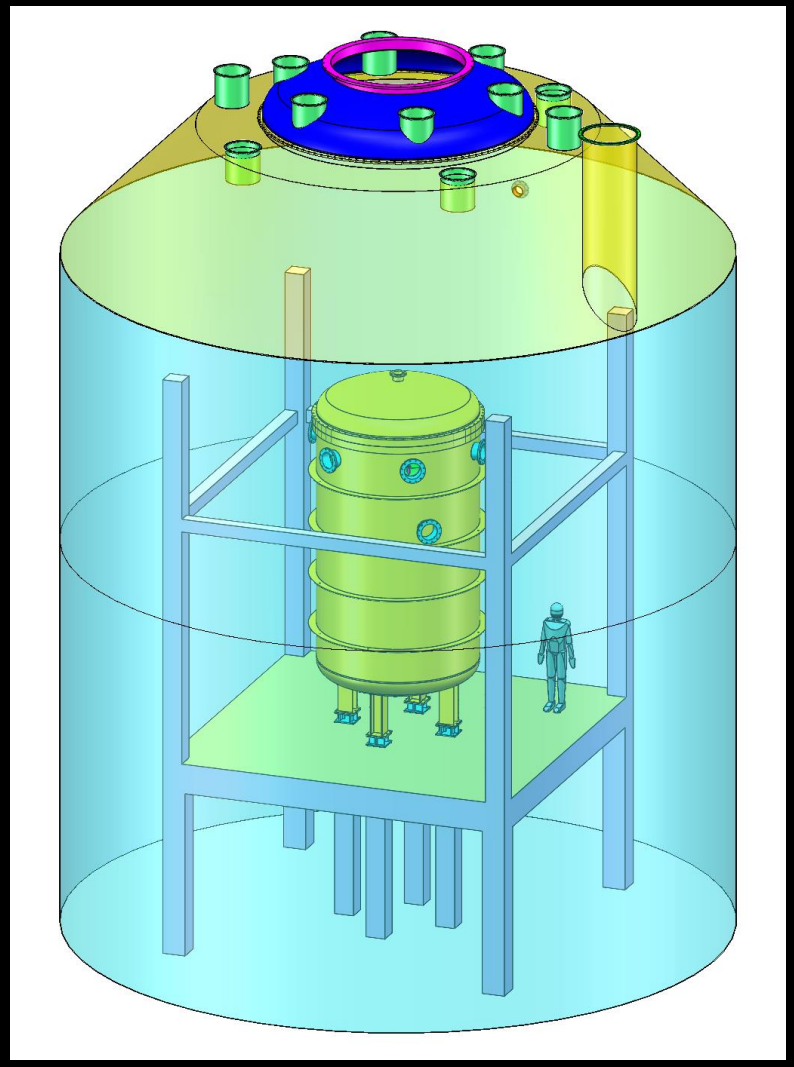






Ti cryostat





IV

- ID 2000mm, height 3000mm
- Barrel thickness 8mm
- 0.1~0.45MPa

OV

- ID 2400mm
- Barrel thickness 10 mm

Water shield

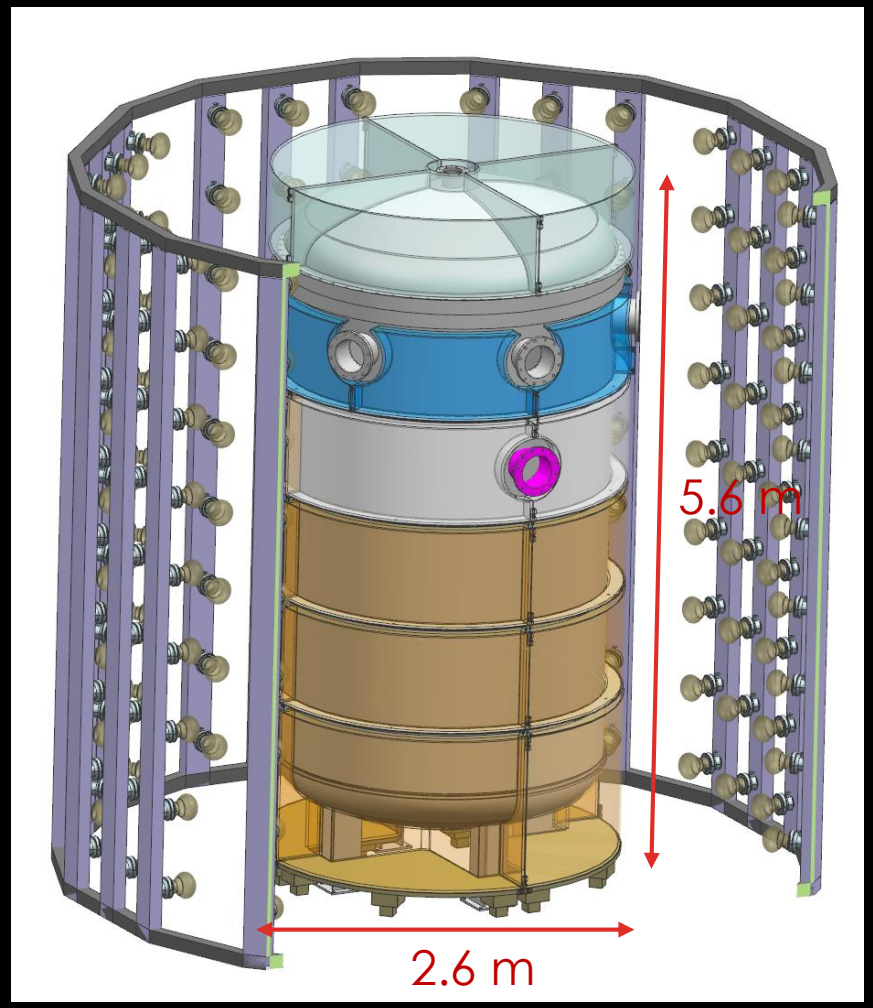
- 10m diameter and 13m height

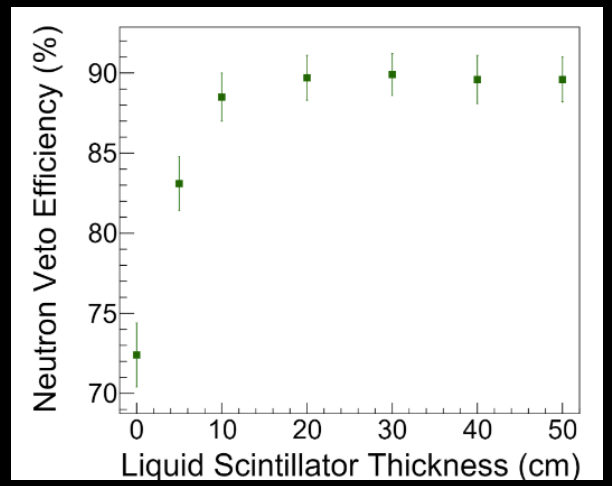
In fabrication

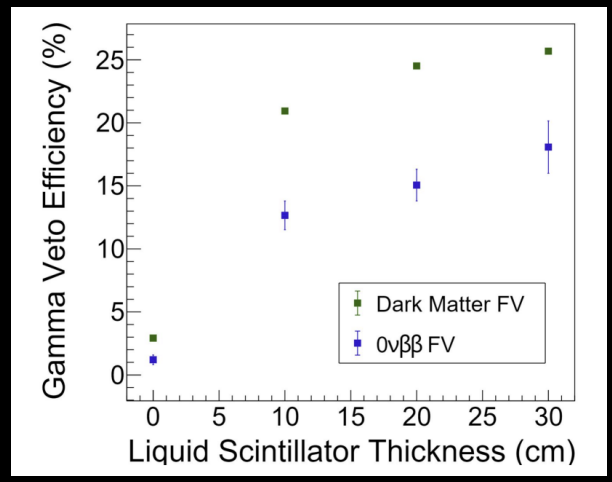




Veto Detector(s) for PandaX-20T



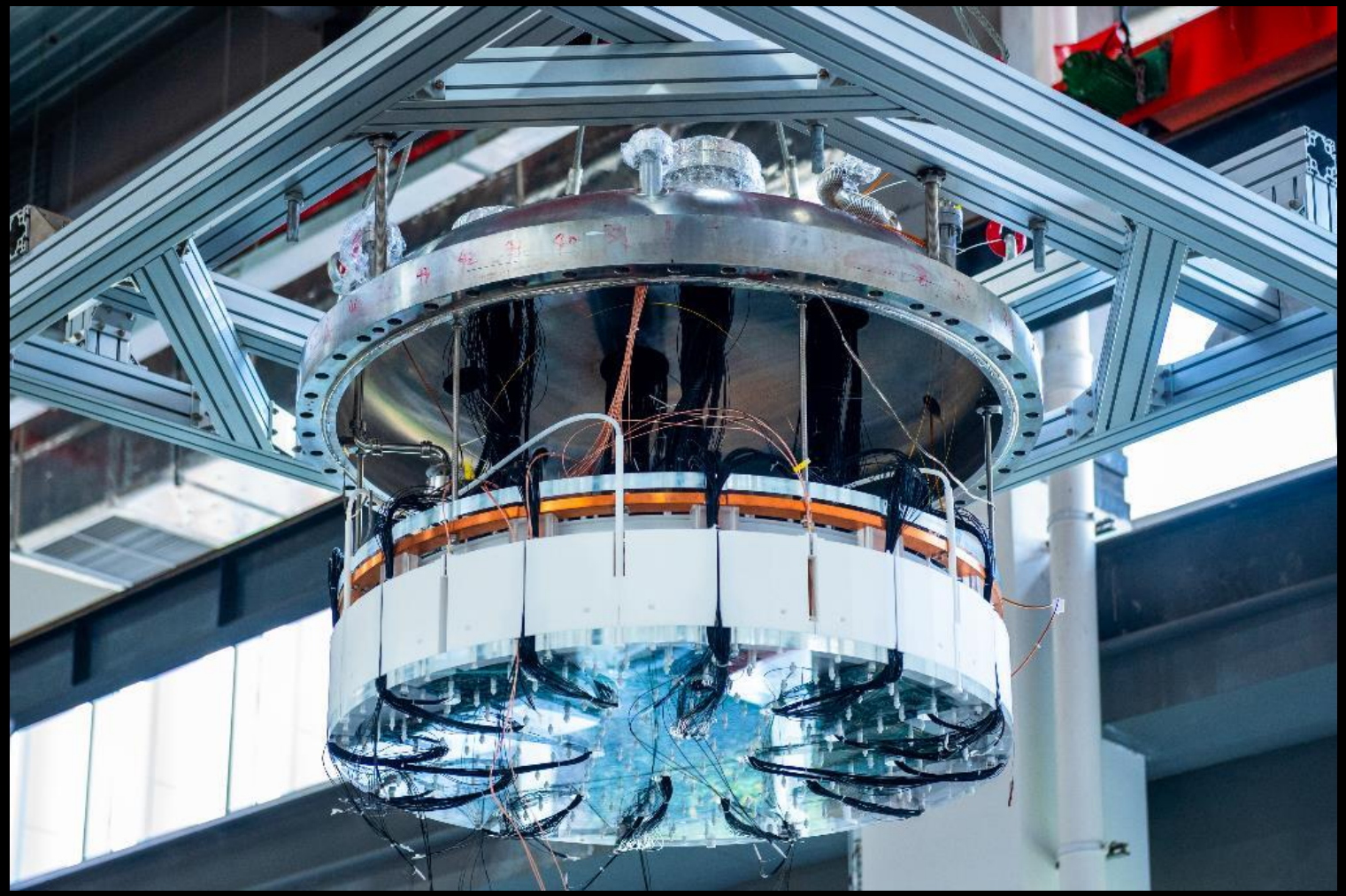




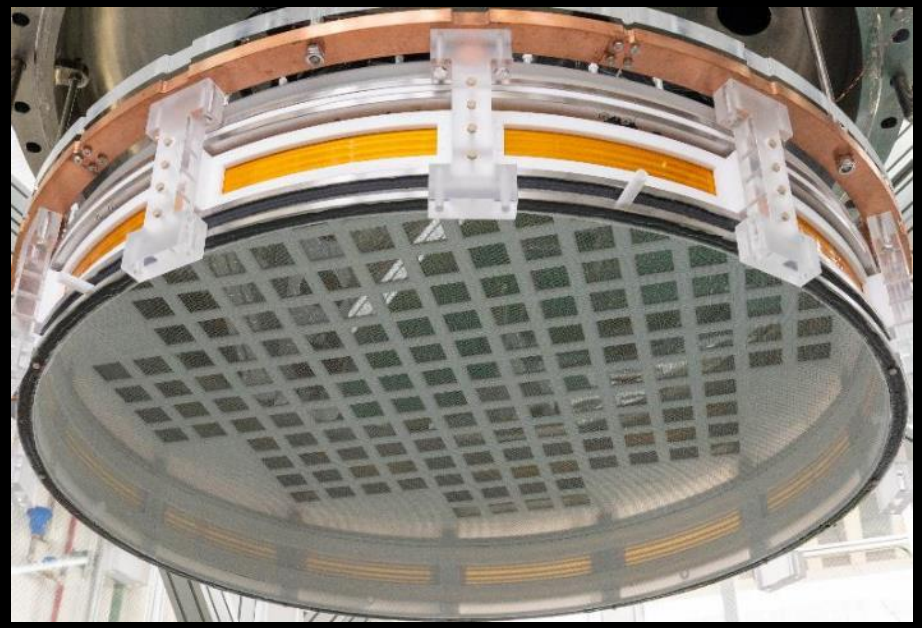
- 10 cm thickness JUNO liquid scintillator（LAB + PPO + bisMSB）in acrylic containers
- optical simulation: close to 90% neutron veto efficiency, about 20% gamma veto efficiency

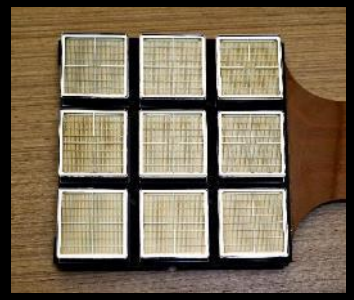
TPC and prototype tests

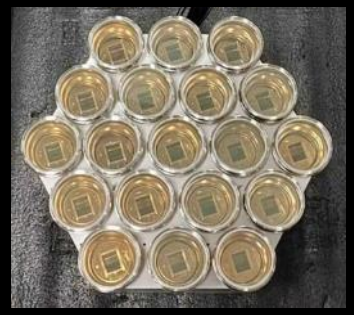




Photosensors



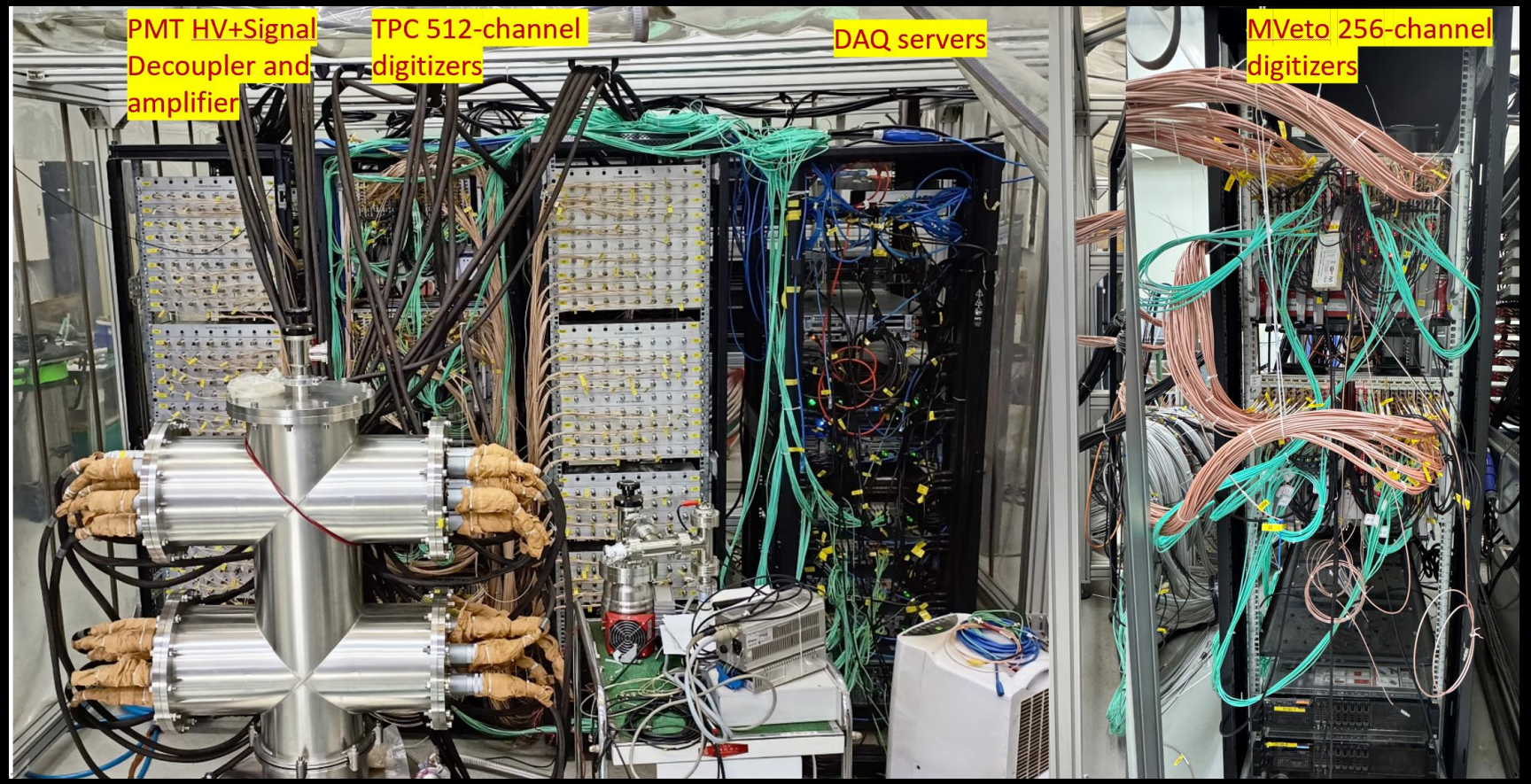




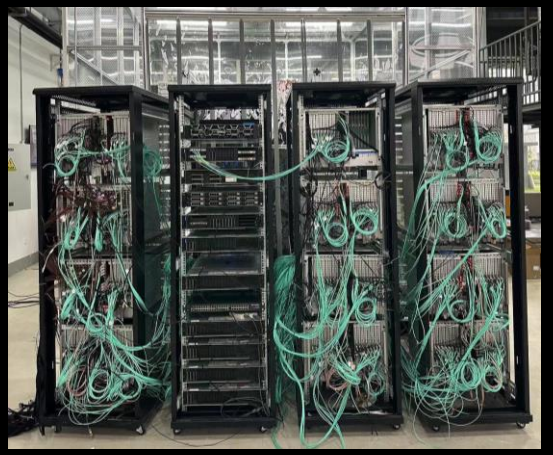


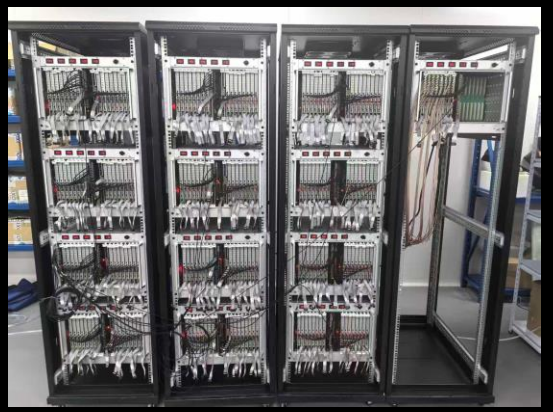
- Top and bottom PMT array design finalized
- Low-radioactivity R12699 PMTs under production, with delivery scheduled for 2026
- Assembly and system-level testing in progress

500 MS/sDigitizers



768-channel in PandaX-4T CJPL





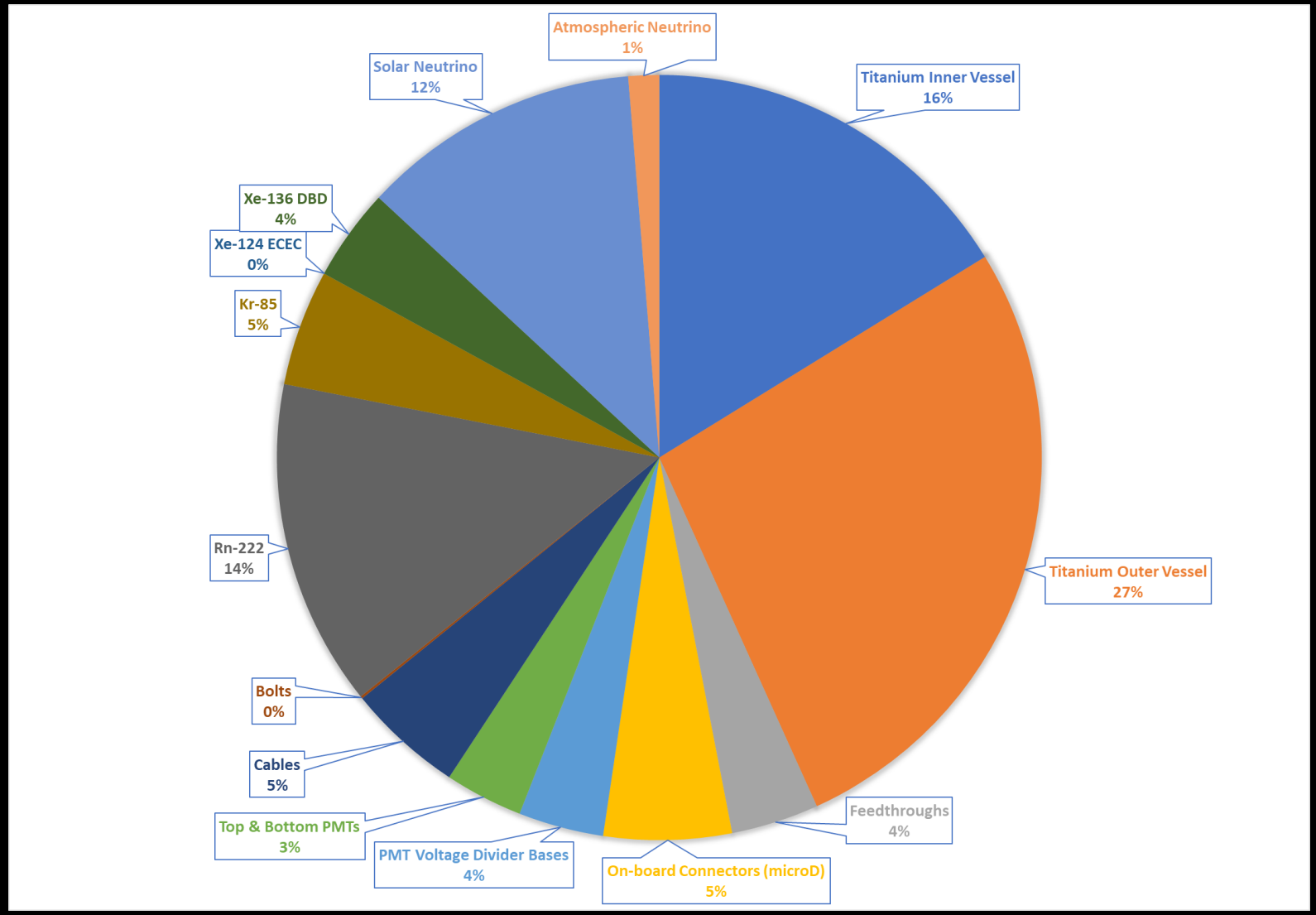
3000-channel in TDLI

Cryogenics and recirculation





Background contribution

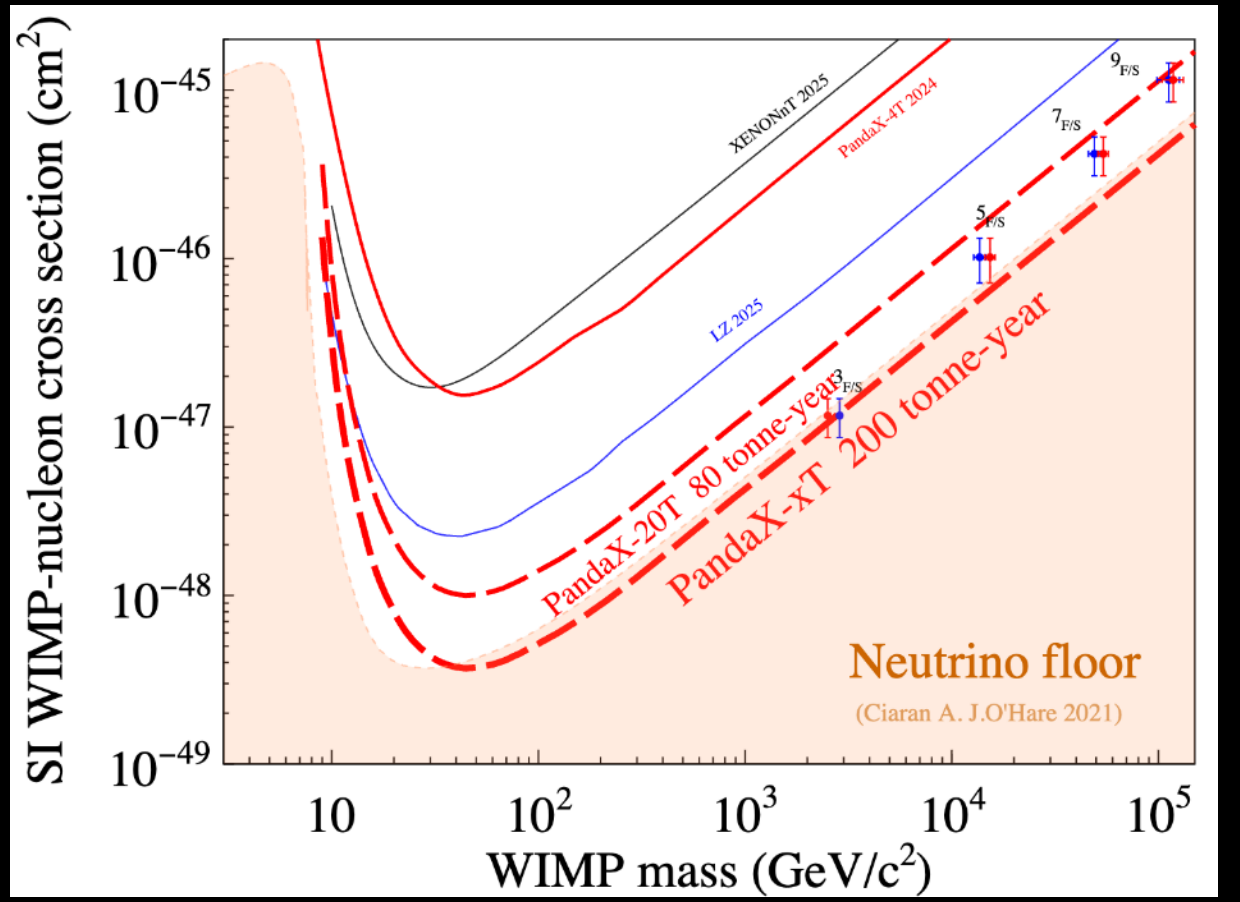


ULR Ti development with Russia



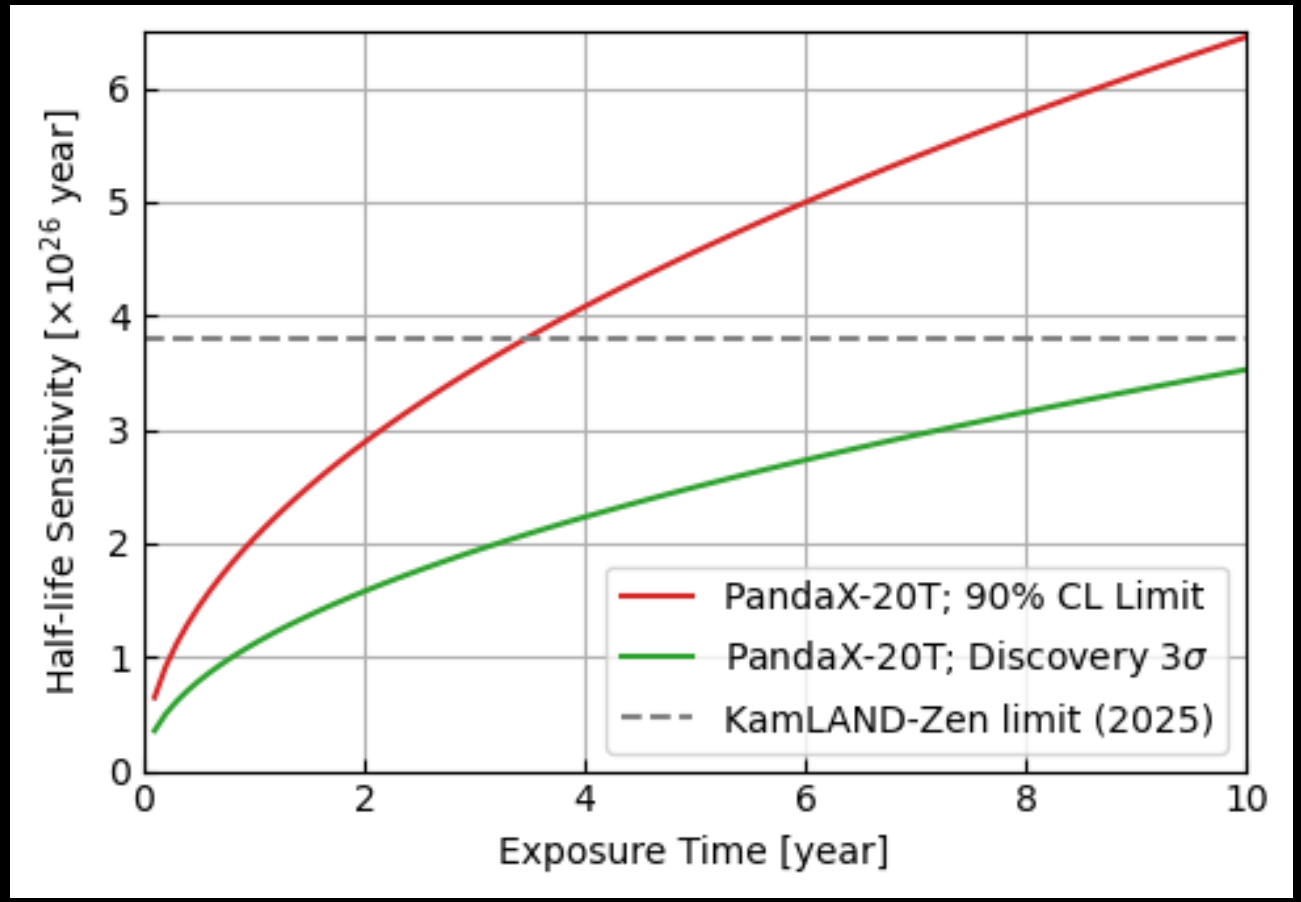


Baseline scientific potential



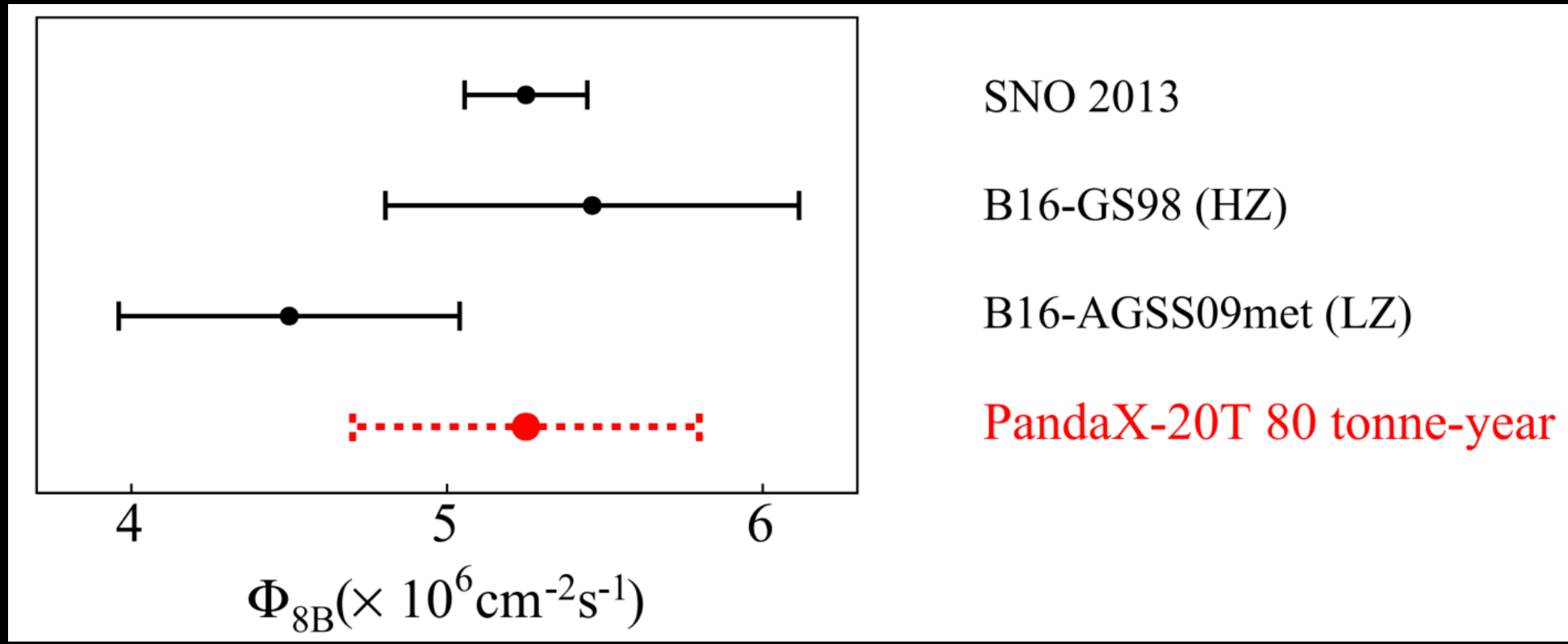
FV 13 ton, ROI 1-10 keVee, 99.7% ER rejection

Baseline scientific potential



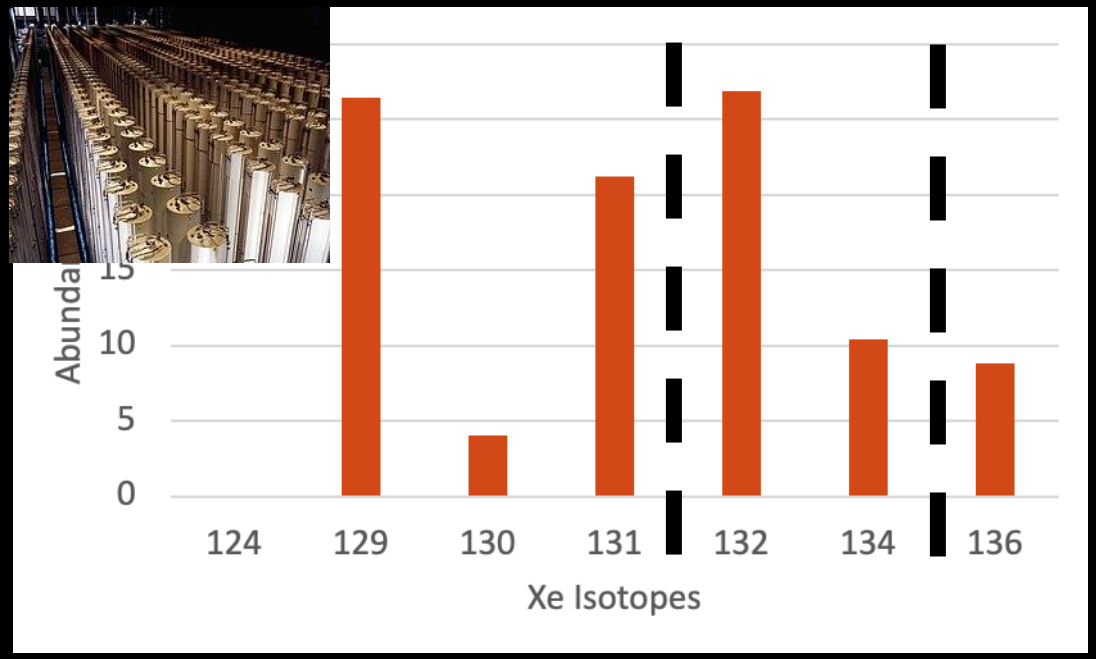
FV 2.4 ton natural, 1% resolution

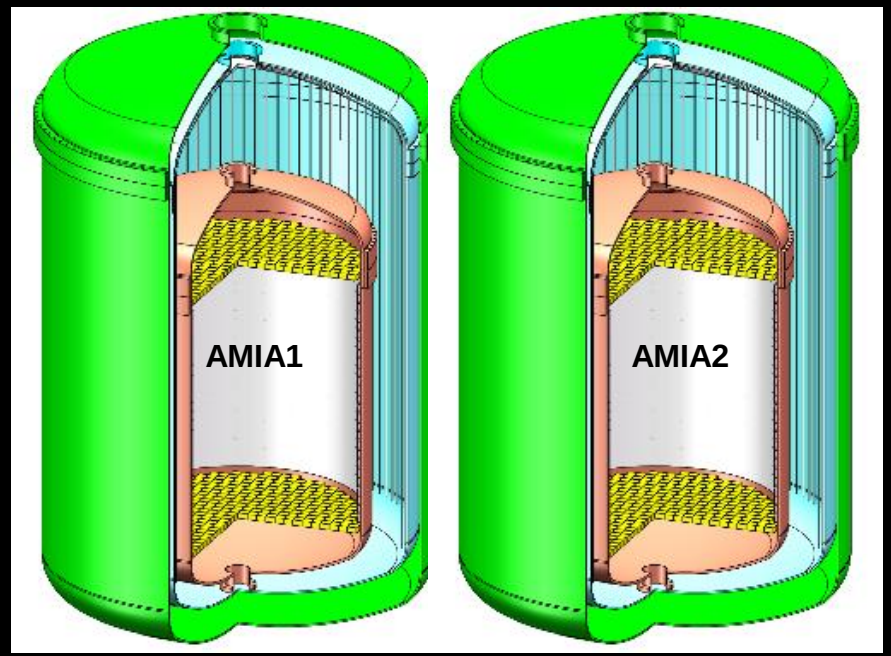
Baseline scientific potential



10 Years from Now?

Isotopic separation according to scientific findings





Discovery smoking gun!

Schedule

- 2026.4-6 PandaX-4T decommissioning
- 2026.6-12 PandaX-20T infrastructure construction
- 2027.1-2027.6 PandaX-20T installation
- 2027.7-2027.12 PandaX-20T commissioning
- 2028.1- Physics operation

Possible points of collaboration (20T)

- Background
  - Vessel
  - Photosensors boards and cables
  - Outgassing (electronegative)⇒liquid circulation
  - Emanation (radioactive)
- Calibration
- Veto
- Analysis/simulation/slow control in the AI era
- Experience sharing highly welcome

THANK YOU!