International Symposium on Neutrino Physics and Beyond (NPB 2024)

Feb 19 – 21, 2024, HKUST

Neutrino Physics with PandaX

HAN, Ke 韩柯 (SJTU)

For the PandaX Collaboration

2024/2/20

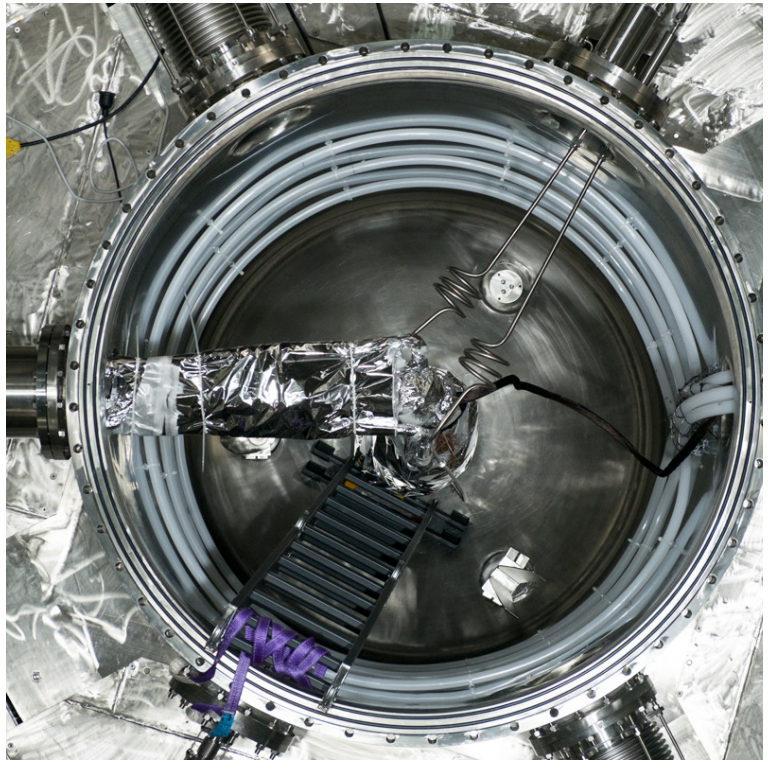
PandaX: Particle and Astrophysical Xenon Experiment

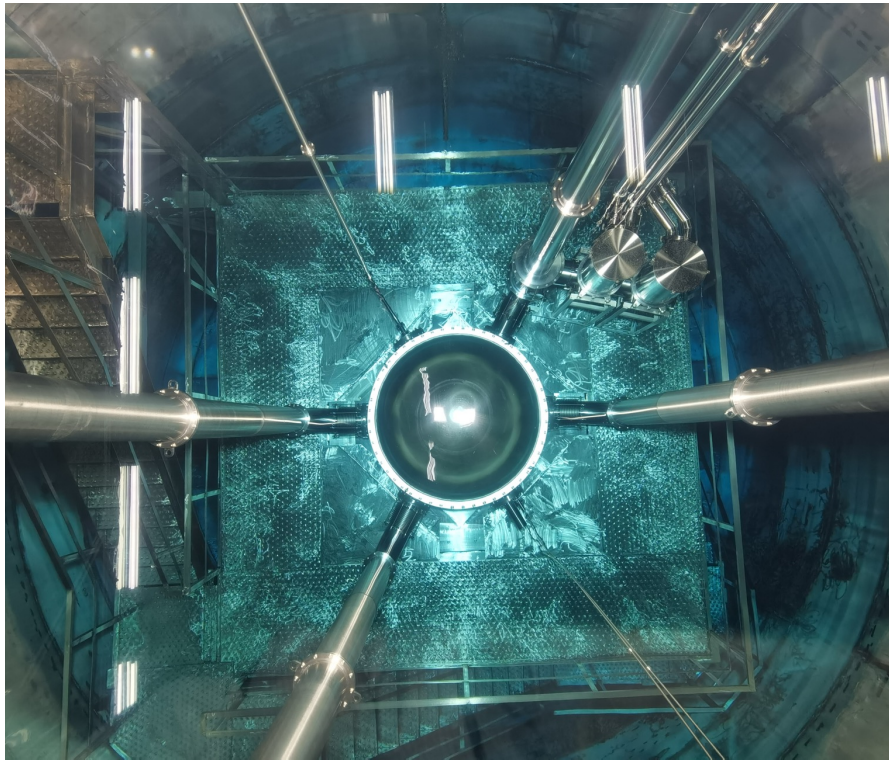
15 institutions, ~100 collaborators


North Korea
Beijing
北京
Dalian
大连市
Pyongyang
평양
Japan
Tokyo
東京
Osaka
大阪
South Korea
Fukuoka
福岡
Yellow Sea
Jiuquan
酒泉市
Yinchuan
银川市
HEBEI
Tianjin
天津
Jinan
济南市
GANSU
Xining
西宁市
NINGXIA
SHANXI
SHANDONG
QINGHAI
Lanzhou
兰州市
SHAANXI
China
Xi'An
西安市
HENAN
JIANGSU
Shanghai
上海
East China Sea
Chengdu
成都市
HUBEI
Wuhan
武汉市
ANHUI
Hangzhou
杭州市
SICHUAN
China Jinping
Underground Laboratory
GUIZHOU
HUNAN
JIANGXI
FUJIAN
Kunming
昆明市
YUNNAN
GUANGDONG
GUANGXI
Hong Kong
香港
Myanmar
(Burma)
Hanoi
Haiphong
PandaX Neutrino Physics
HAN, Ke (SJTU)
Auxiliary gate no. 2
No. 1 gateway
No. 2 auxiliary tunnel
No. 2 gateway
Service tunnel A
A1
A2
Hall A
Connecting tunnel AB
Auxiliary gate no. 1
B3
B1
B4
Service tunnel B
Middle connecting tunnel
B2
Hall B
C1
Service tunnel C
No. 1 auxiliary tunnel
C2
Hall C
Traffic tunnel B
Drainage tunnel
Service tunnel D
D1
Connecting tunnel CD
Traffic tunnel A
D2
Hall D
Auxiliary tunnel
Traffic tunnel
Drainage tunnel
Each experimental hall measures
14 m (H) × 14 m (W) × 130 m (L)

PandaX-4T

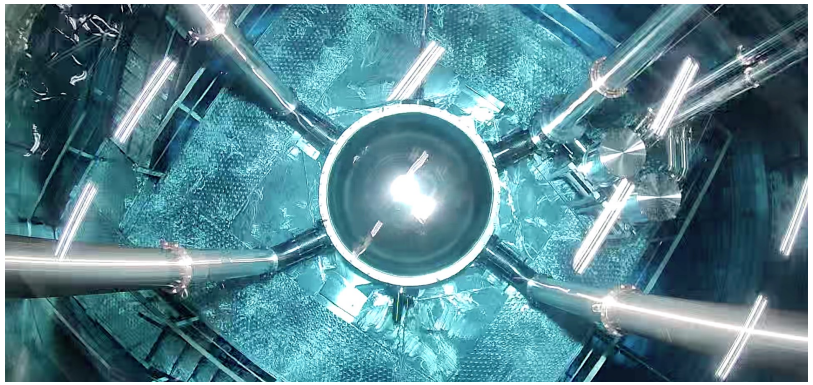
- A multi-ton dual-phase xenon TPC at B2 hall of China Jinping Underground Laboratory
- 1.2 m (D) ×1.2 m (H); Sensitive volume: 3.7-ton LXe; 3-inch PMTs: 169 top / 199 bottom
- Water shielding



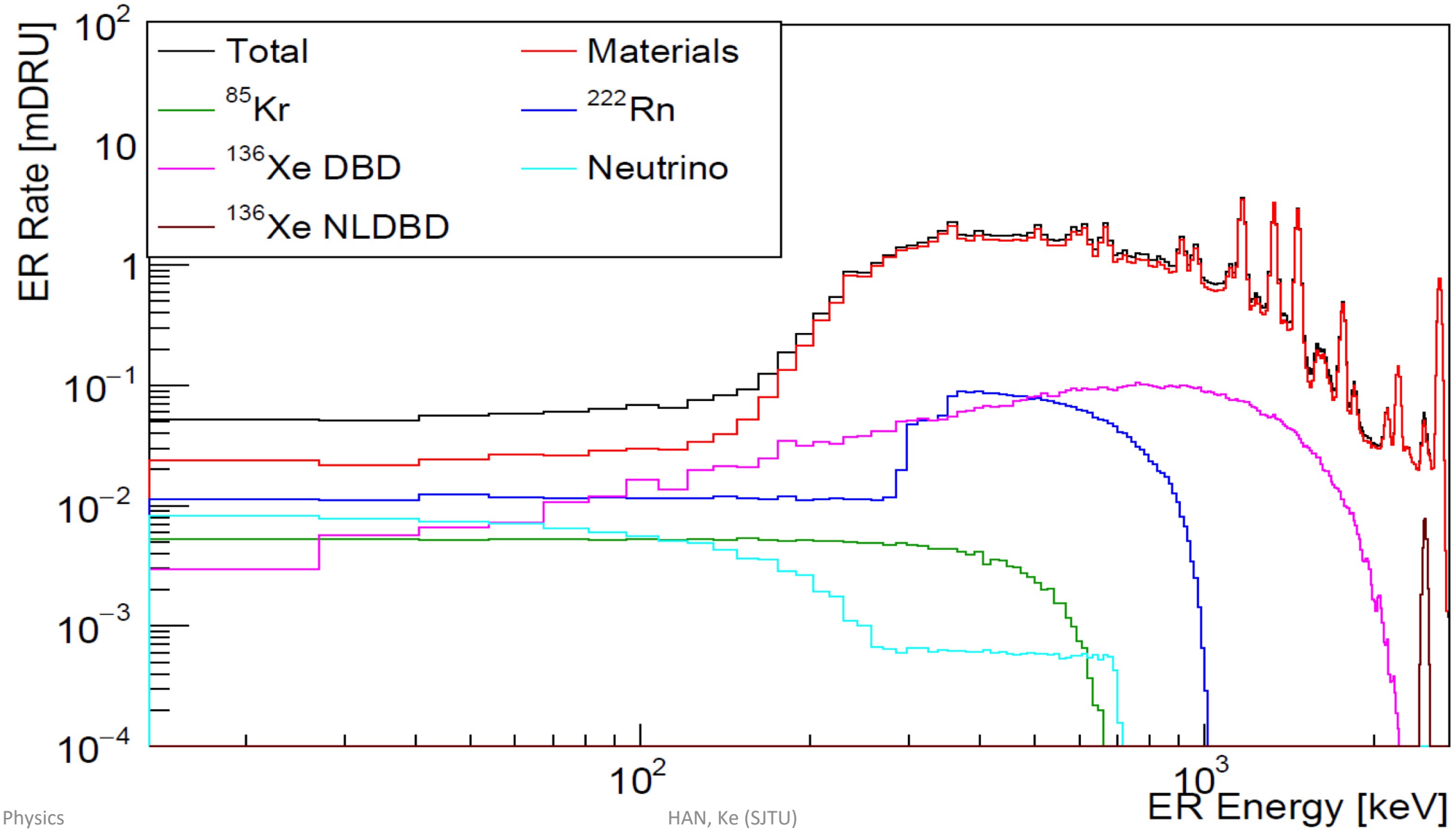


PandaX-4T timeline

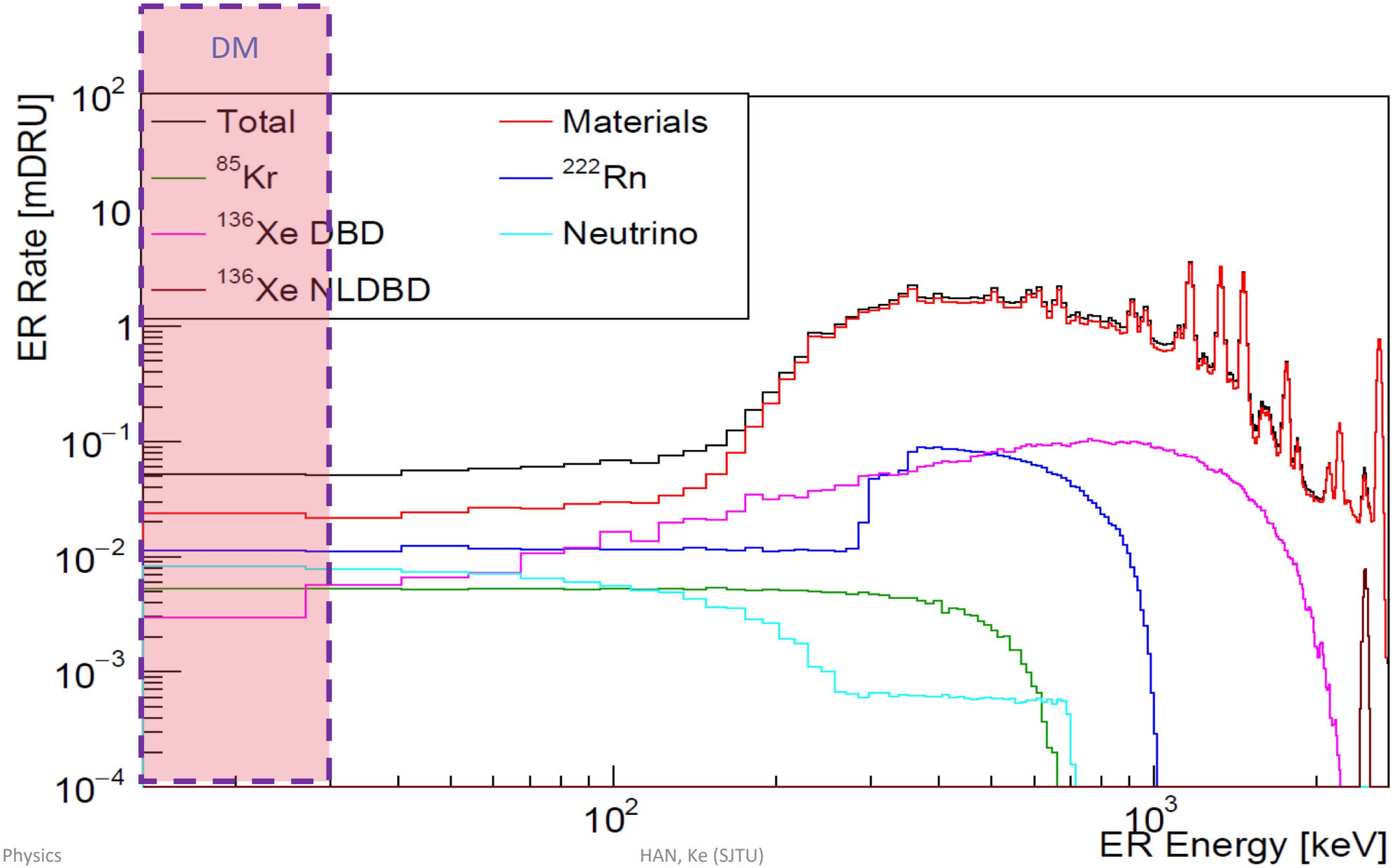
2020/11 – 2021/04	**Commissioning (Run 0)** 95 days data
2021/07 – 2021/10	**Tritium removal** xenon distillation, gas flushing, etc.
2021/11 – 2022/05	**Physics run (Run 1)** 164 days data
2022/09 – 2023/12	**CJPL B2 hall construction** xenon recuperation, detector upgrade
Detector is under-preparation for Run 2	



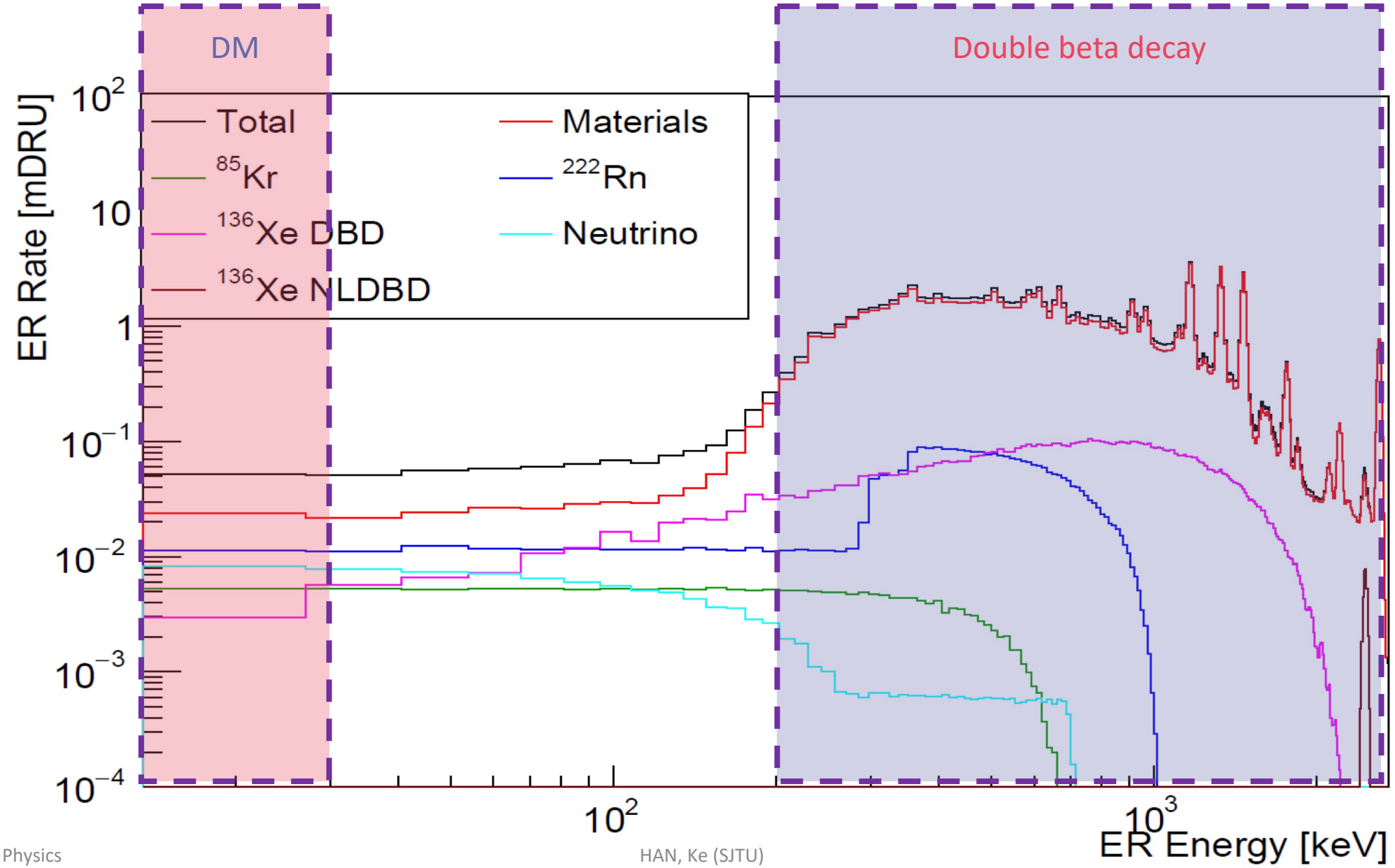
Simulated spectrum for PandaX-4T



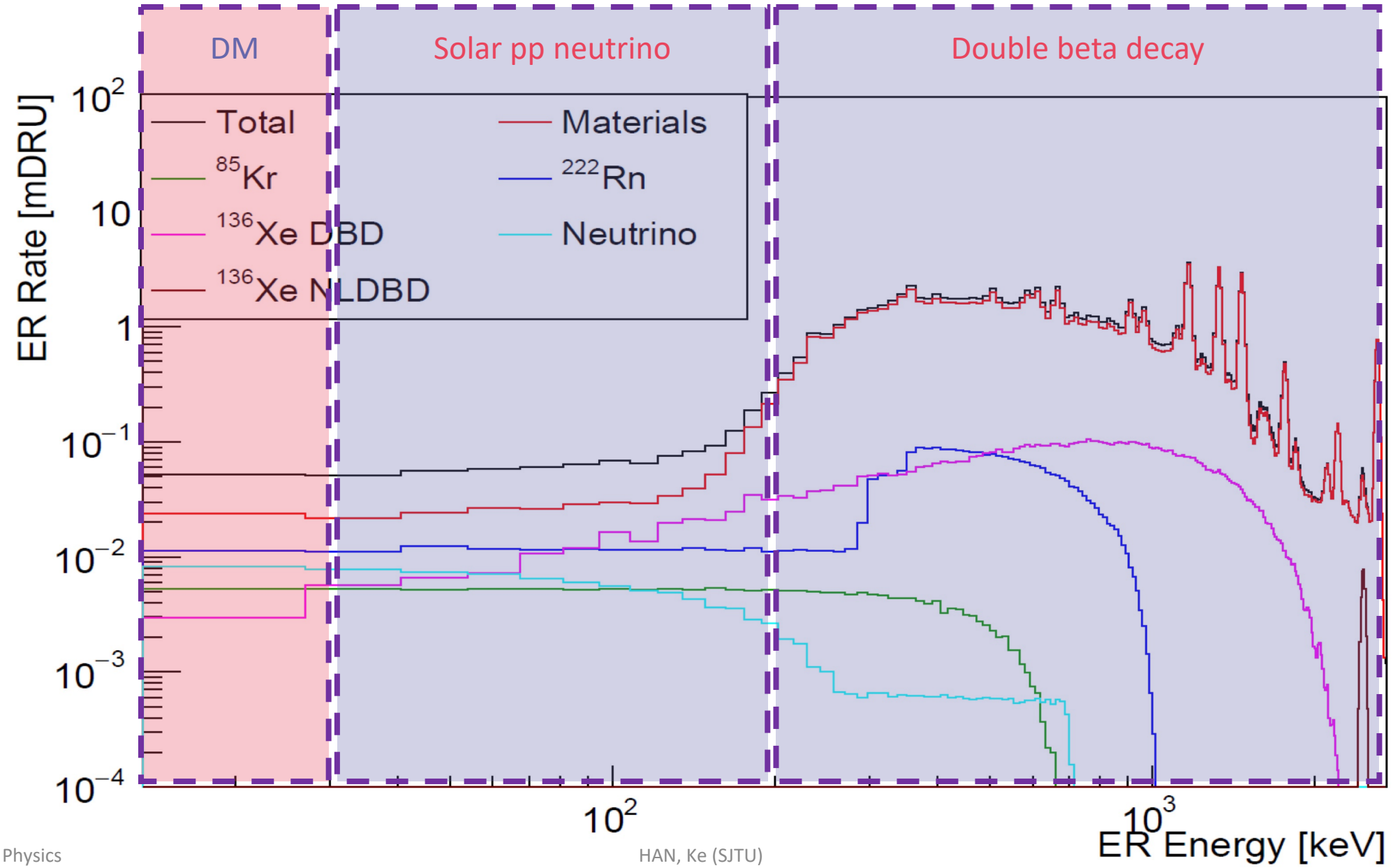
Simulated spectrum for PandaX-4T



Simulated spectrum for PandaX-4T

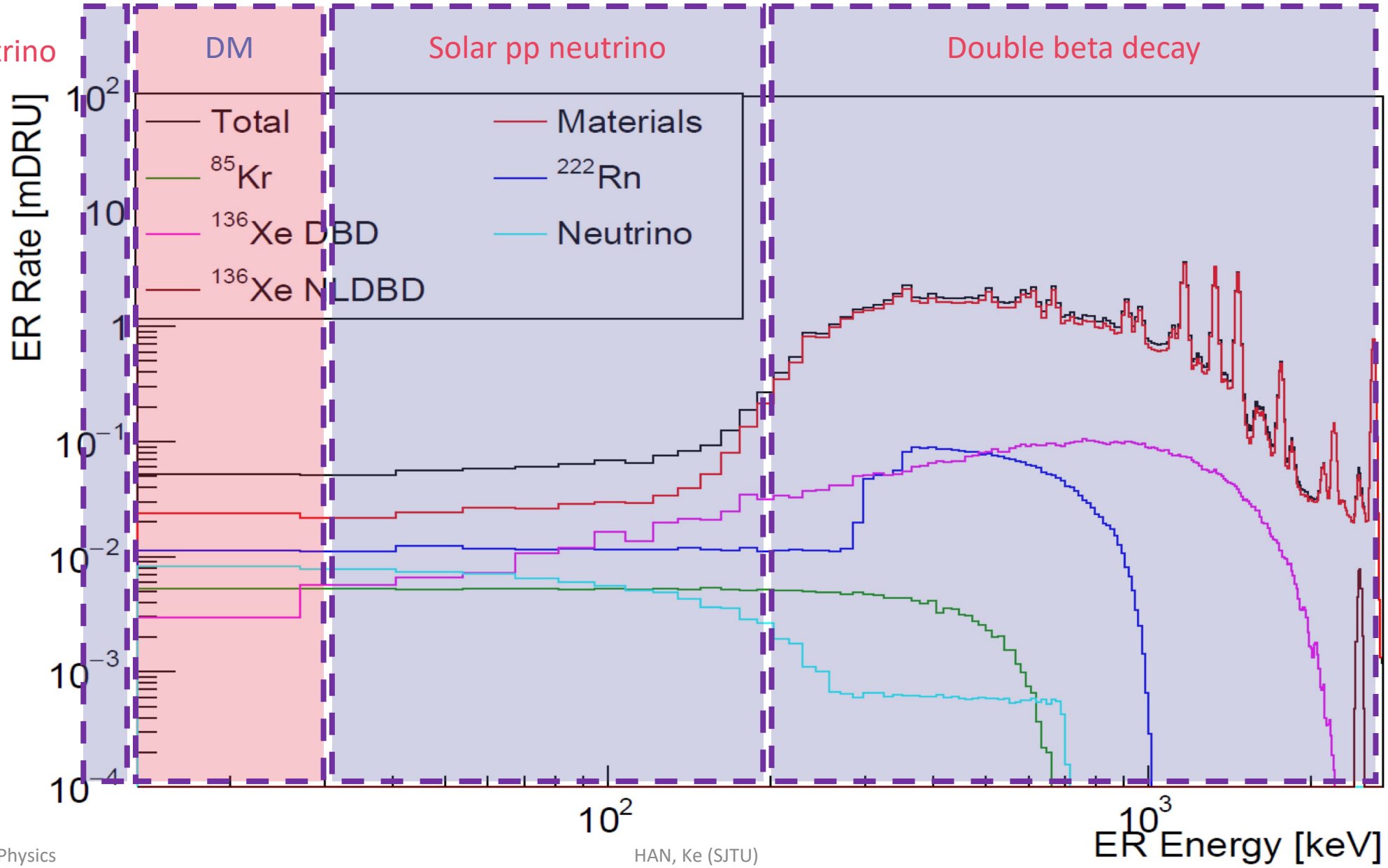


Simulated spectrum for PandaX-4T

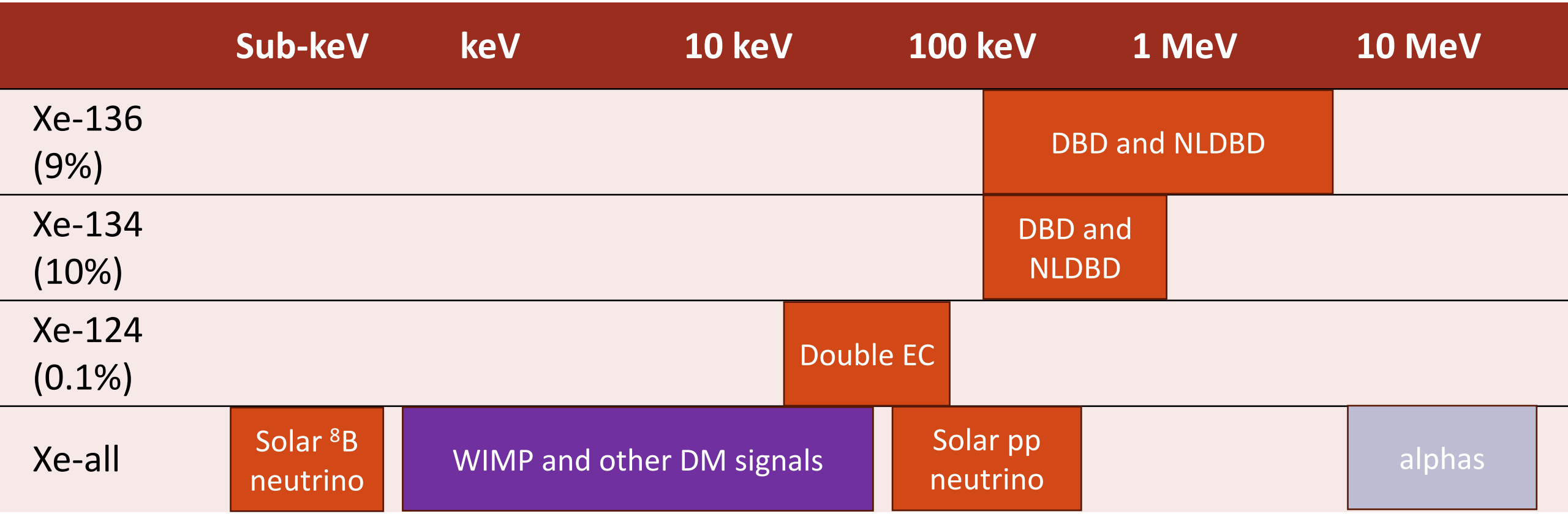


Simulated spectrum for PandaX-4T

Solar ^{8}B neutrino

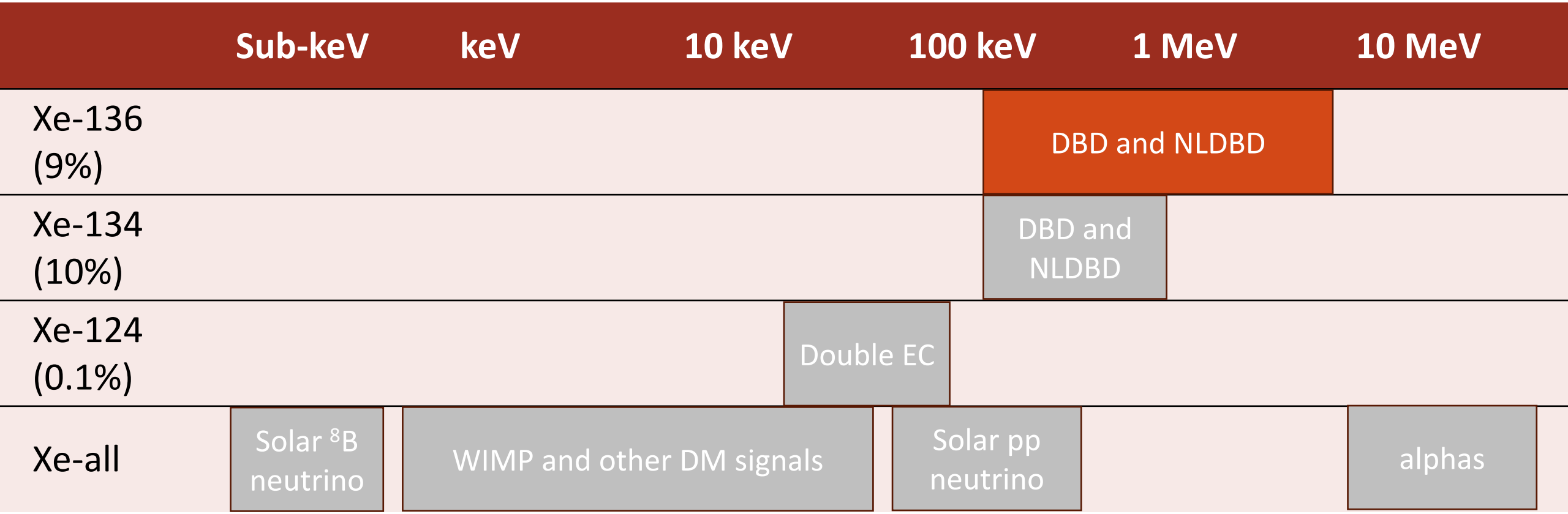


Wide E range, multiple “interesting” isotopes for neutrino



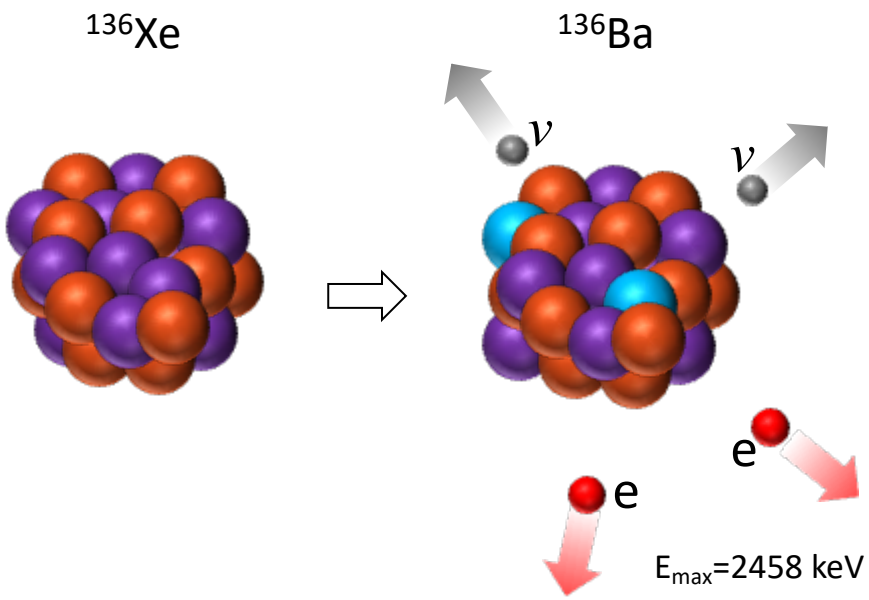
Wide E range, multiple “interesting” isotopes for neutrino

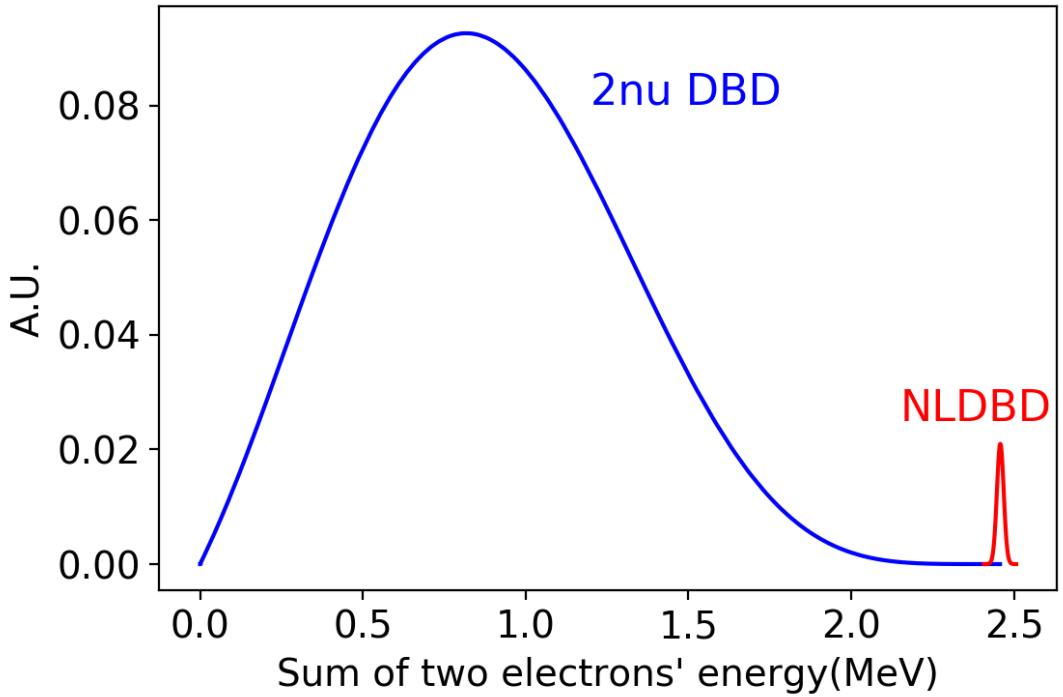
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC



Neutrinoless Double beta decay (NLDBD)

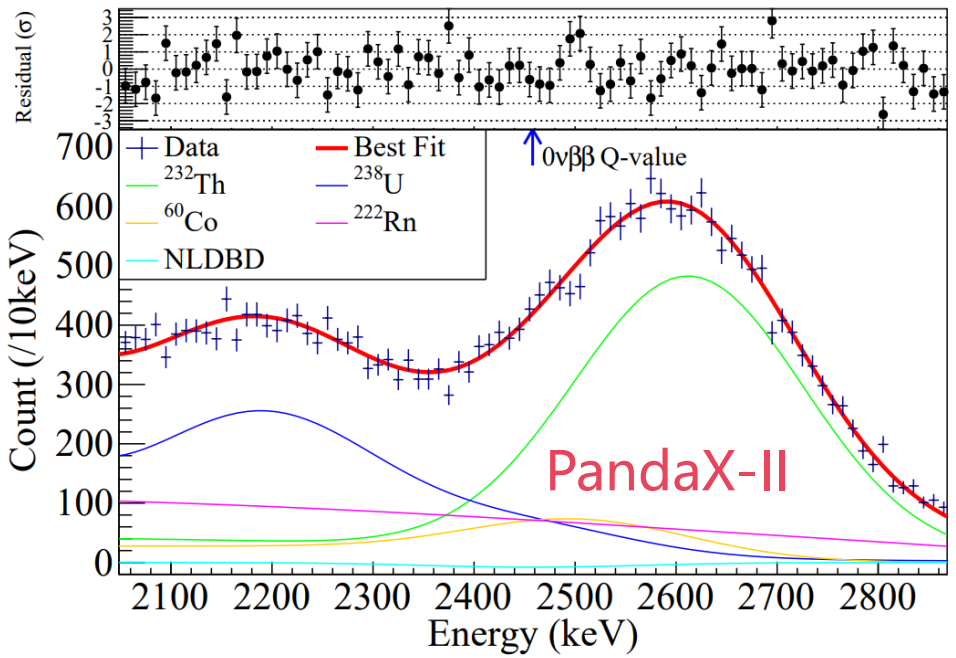
- Neutrinoless double beta decay probes the nature of neutrinos: Majorana or Dirac
- Lepton number violating process
- Measure energies of emitted electrons

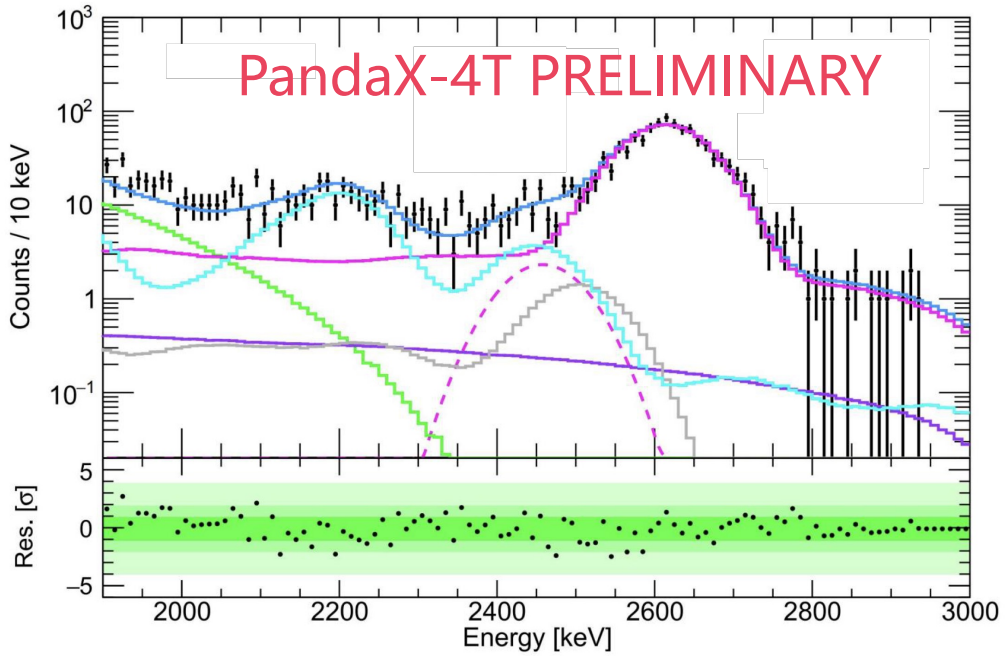




Search for ^{136}Xe NLDBD with LXe TPC

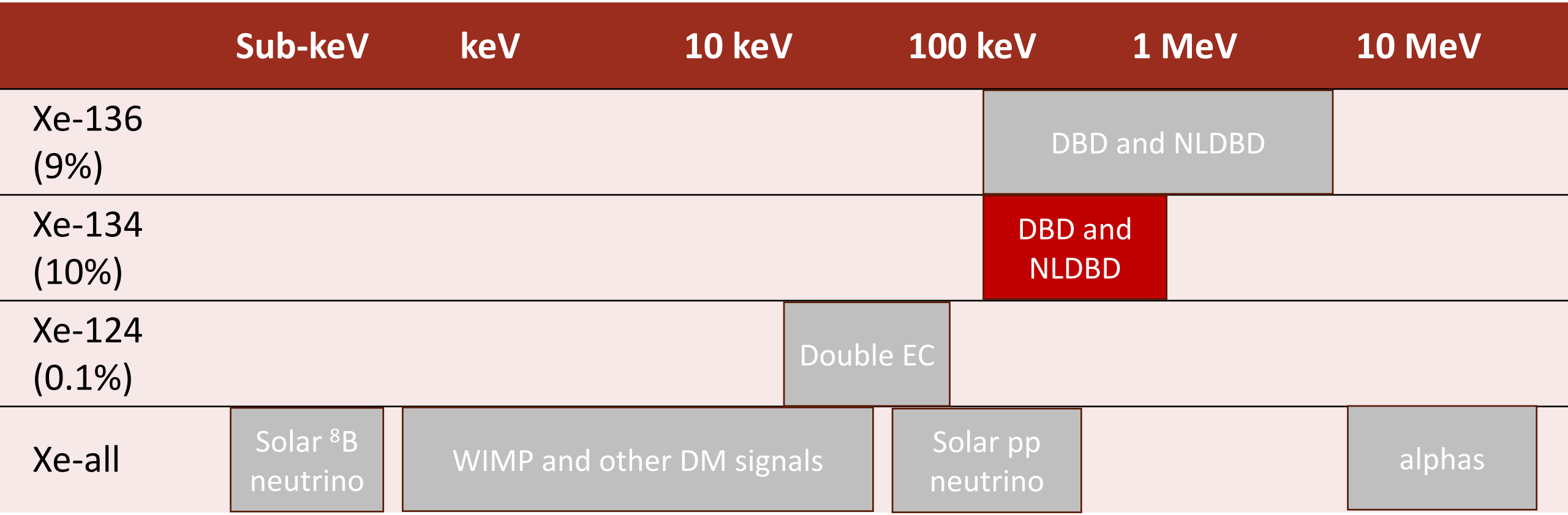
	Bkg rate (/keV/ton/y)	Energy resolution	FV mass (kg)	Run time	Sensitivity/Limit (90% CL, year)	Year
PandaX-II	~200	4.2%	219	403.1 days	2.4×10^{23}	2019
XENON1T	~20	0.8%	741	202.7 days	1.2×10^{24}	2022
PandaX-4T	6	1.9%	~650	~250 days	$> 10^{24}$	Future





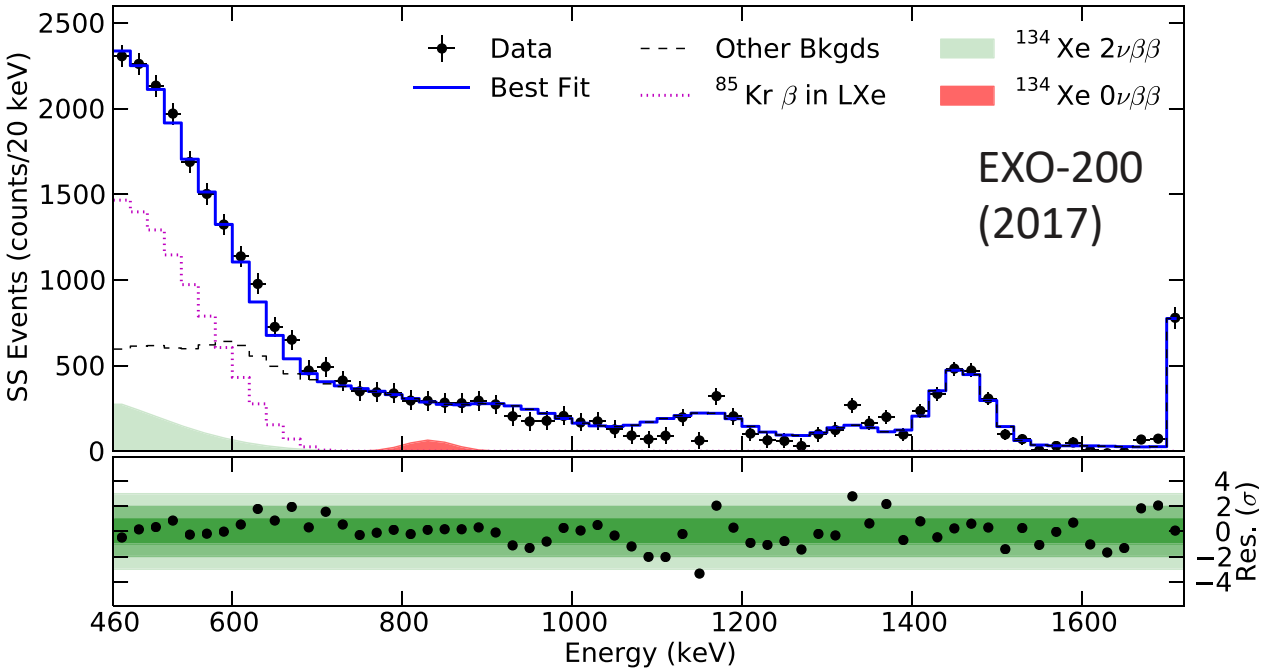
Wide E range, multiple “interesting” isotopes for neutrino

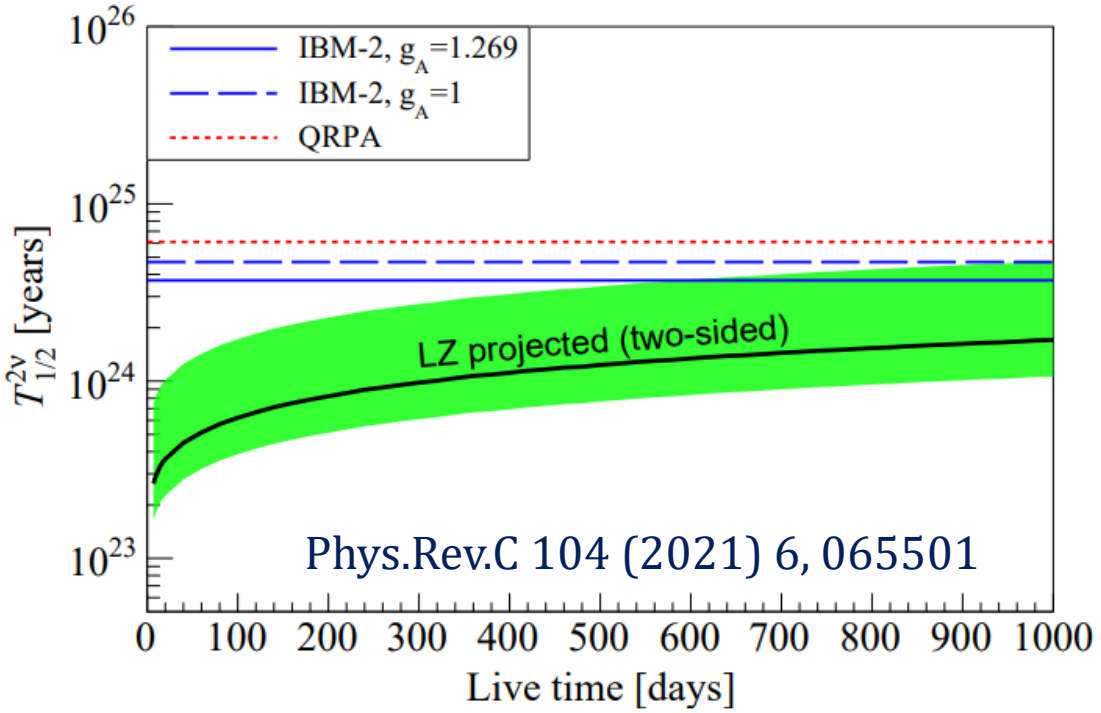
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC



^{134}Xe DBD and NLDBD

- Q=826 keV; Half-life from theoretical predictions: 10^{24}-10^{25} yr; Never been observed
- Current DBD (NLDBD) half-life limit from EXO-200 : T >8.7x10^{20} yr (1.1x10^{23} yr) at 90% CL
- Discovery within reach with a natural Xe TPC

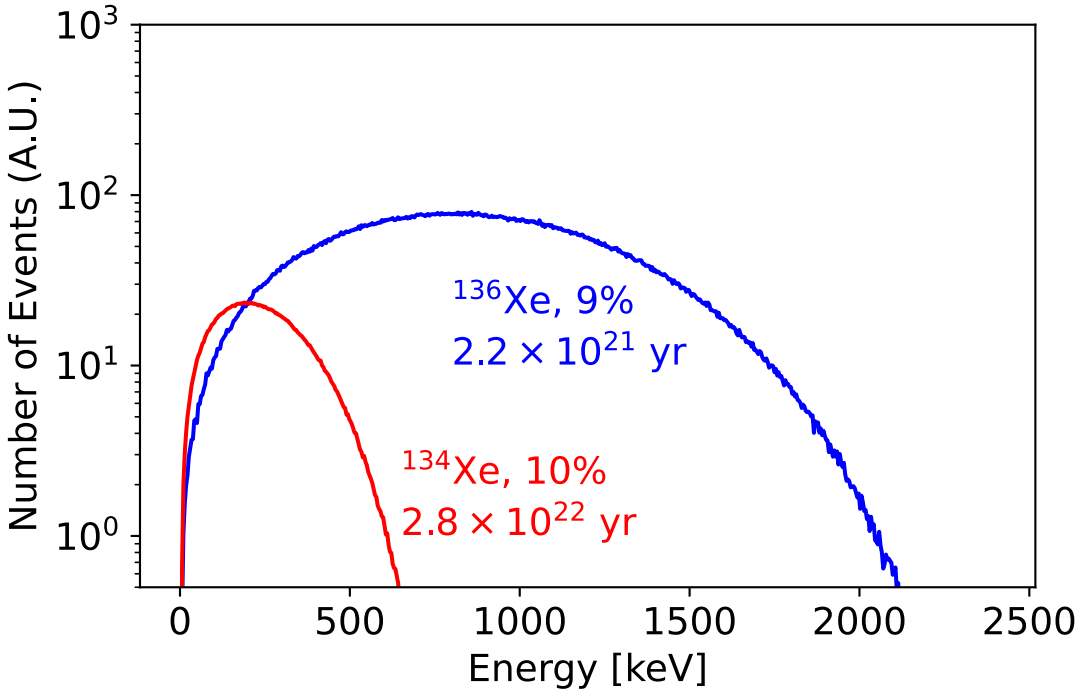




^{134}Xe (NL)DBD searches at PandaX-4T

- PandaX-4T: more ^{134}Xe; much less ^{136}Xe; wider energy range; discovery possible

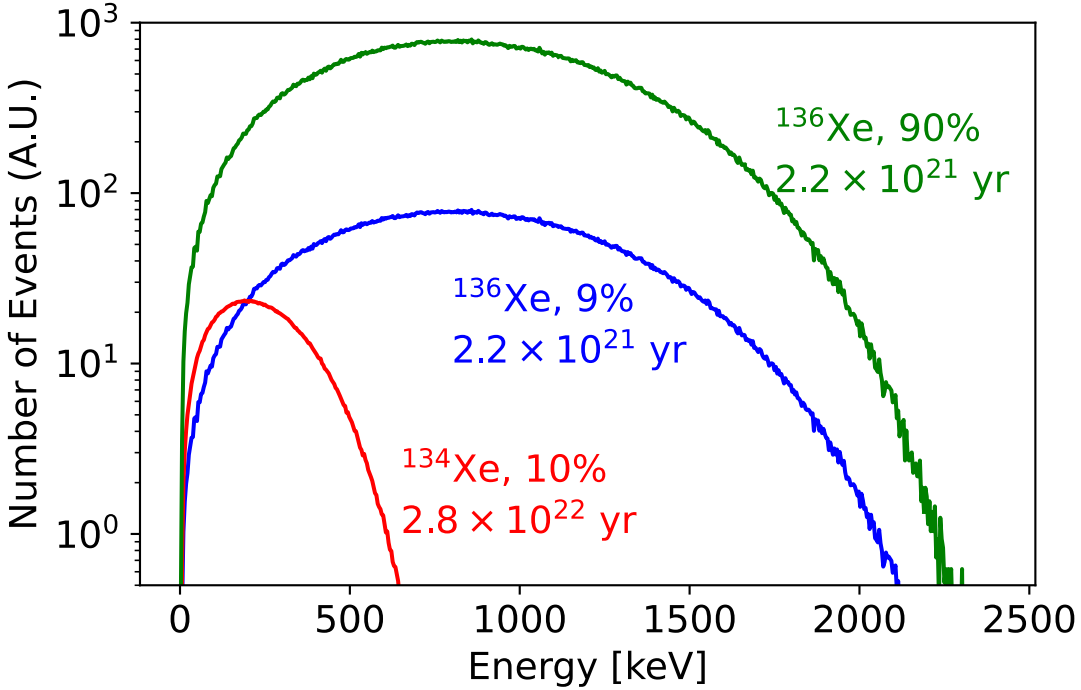
	^{134}Xe mass	^{136}Xe abundance	Analysis threshold	Live Time
PandaX-4T	68.7 kg	8.9%	200 keV	94.9 days
EXO-200	18.1 kg	81%	460 keV	600 days



^{134}Xe (NL)DBD searches at PandaX-4T

- PandaX-4T: more ^{134}Xe; much less ^{136}Xe; wider energy range; discovery possible

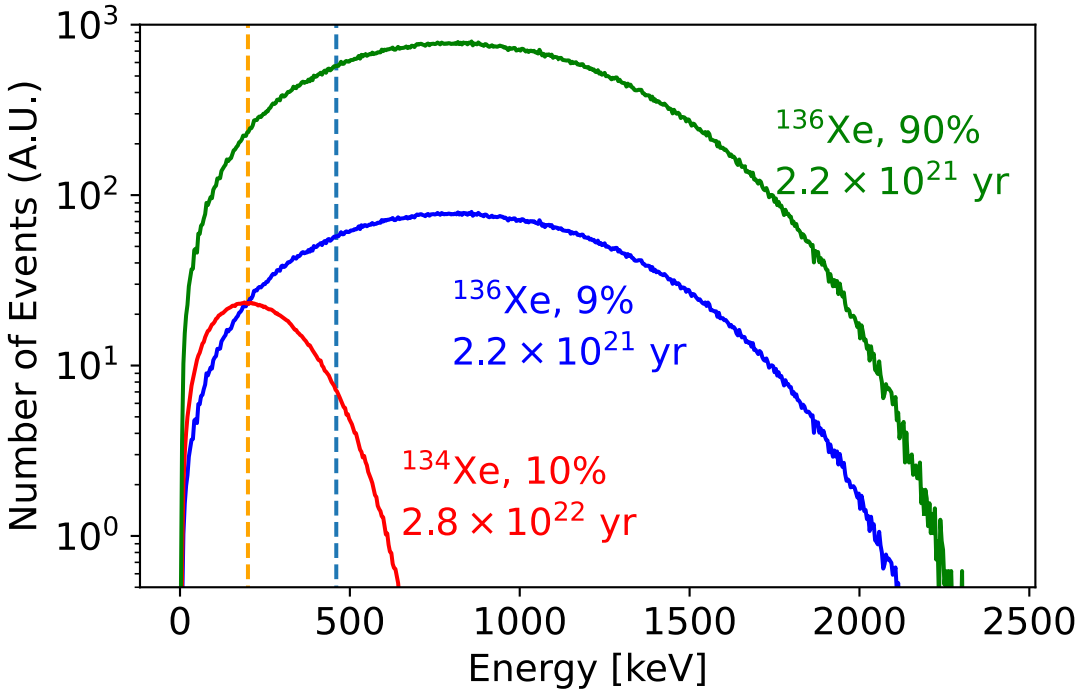
	^{134}Xe mass	^{136}Xe abundance	Analysis threshold	Live Time
PandaX-4T	68.7 kg	8.9%	200 keV	94.9 days
EXO-200	18.1 kg	81%	460 keV	600 days



^{134}Xe (NL)DBD searches at PandaX-4T

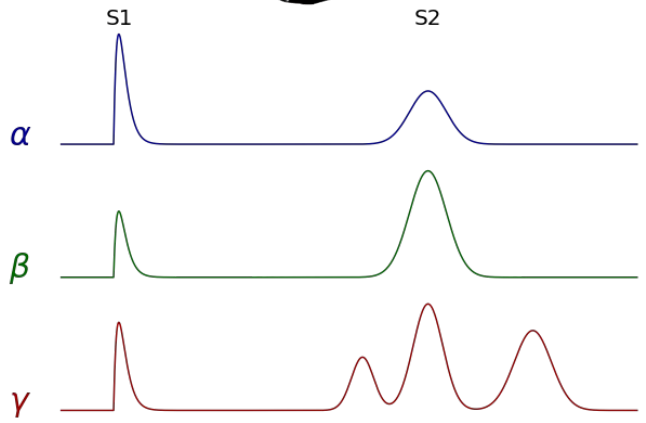
- PandaX-4T: more ^{134}Xe; much less ^{136}Xe; wider energy range; discovery possible

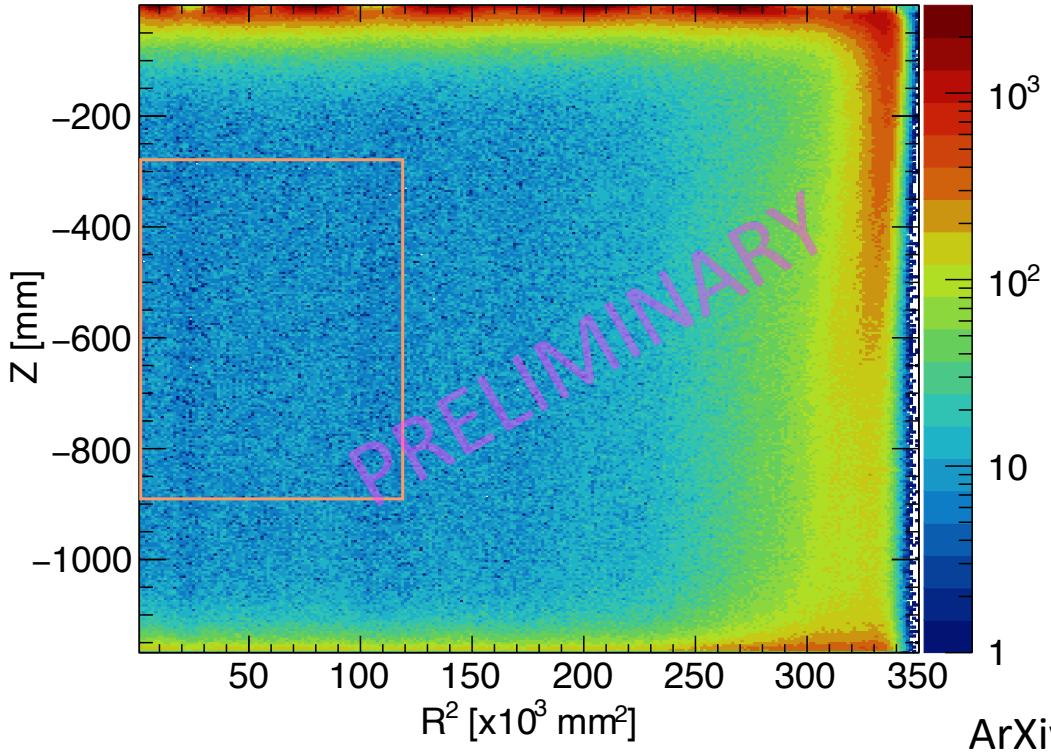
	^{134}Xe mass	^{136}Xe abundance	Analysis threshold	Live Time
PandaX-4T	68.7 kg	8.9%	200 keV	94.9 days
EXO-200	18.1 kg	81%	460 keV	600 days

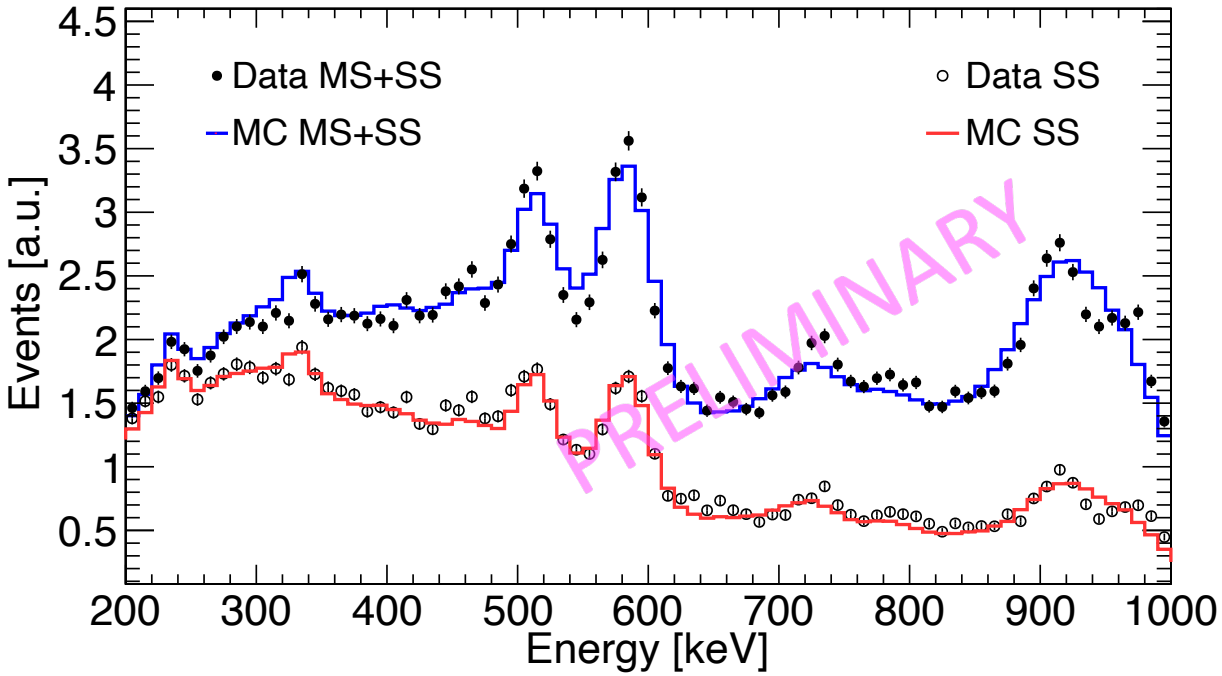


Data selection

- An identical FV as in ^{136}Xe analysis
- Single site vs multi-site selection measured by ^{232}Th calibration data
  - Little impact to DBD signals (β SS events)







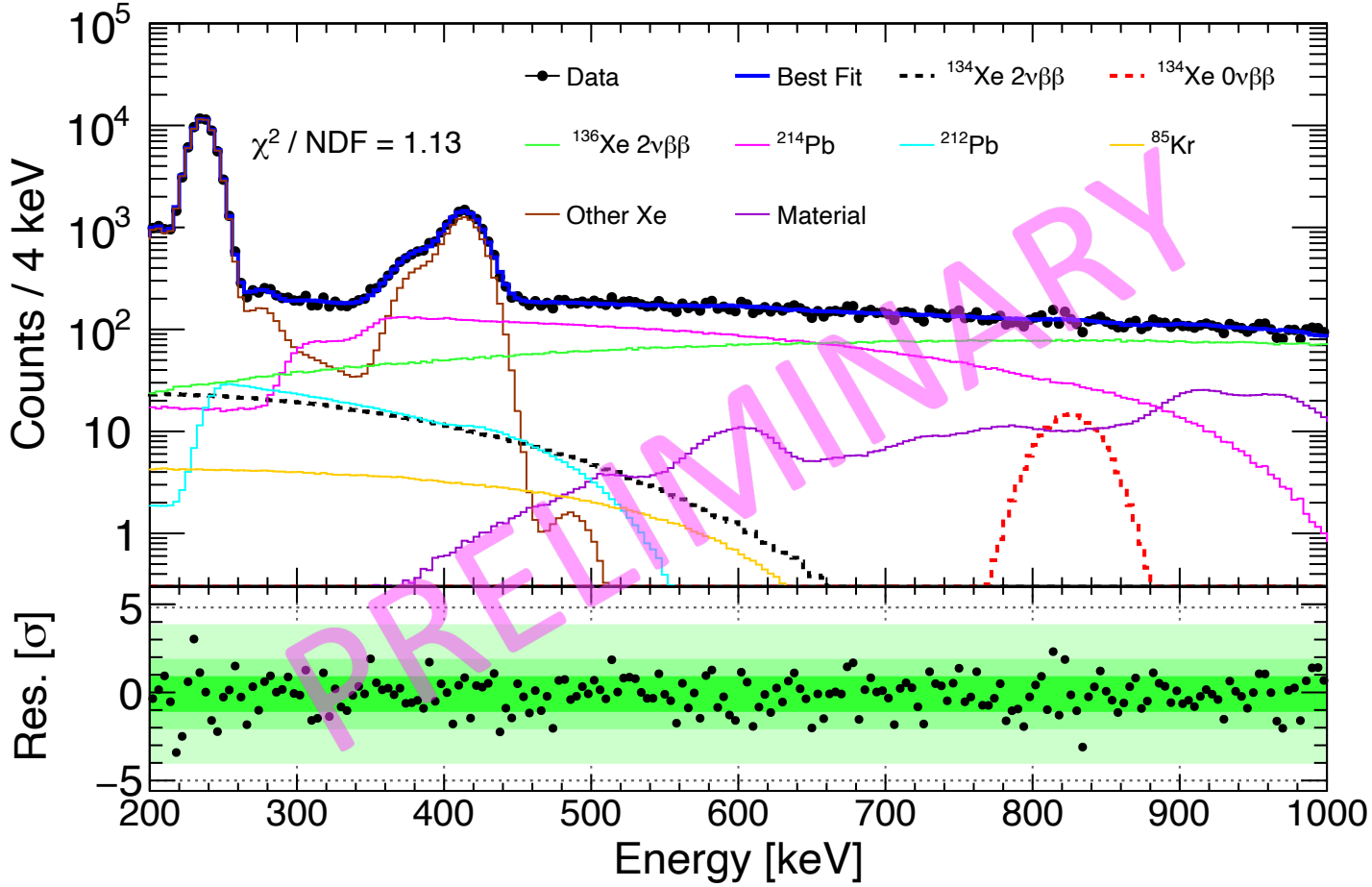
ArXiv: 2312.15632

DBD and NLDBD Half-life limits (90% CL):

DBD: 2.8×10^{22} yr; 32 × improvement w.r.t. EXO-200

NLDBD: 3.0×10^{23} yr; 2.7 × improvement w.r.t. EXO-200

ArXiv: 2312.15632



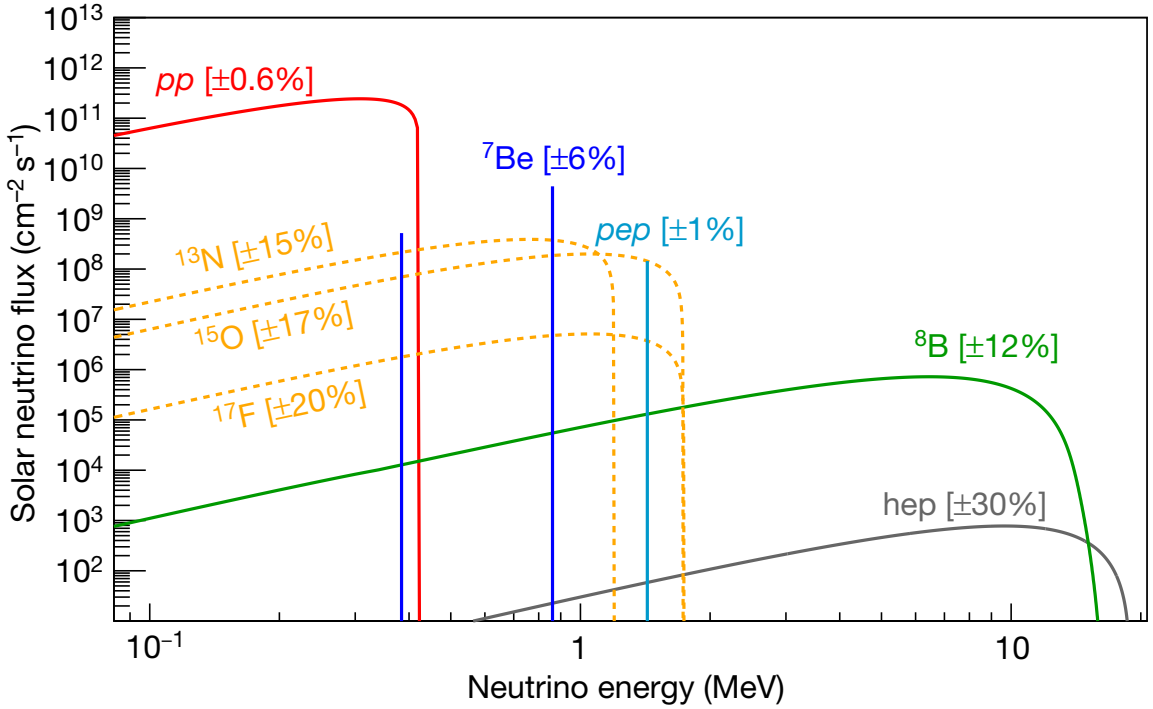
Wide E range, multiple “interesting” isotopes for neutrino

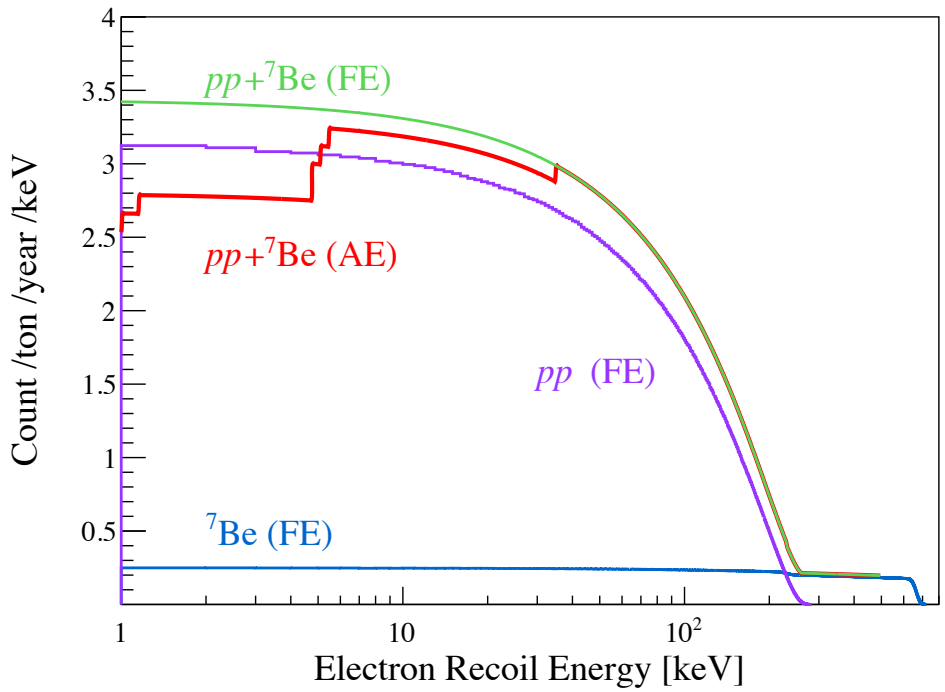
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

	Sub-keV	keV	10 keV	100 keV	1 MeV	10 MeV
Xe-136 (9%)				DBD and NLDBD		
Xe-134 (10%)				DBD and NLDBD		
Xe-124 (0.1%)			Double EC			
Xe-all	Solar ^{8}B neutrino	WIMP and other DM signals		Solar pp neutrino		alphas

Solar pp neutrino scattering on electrons

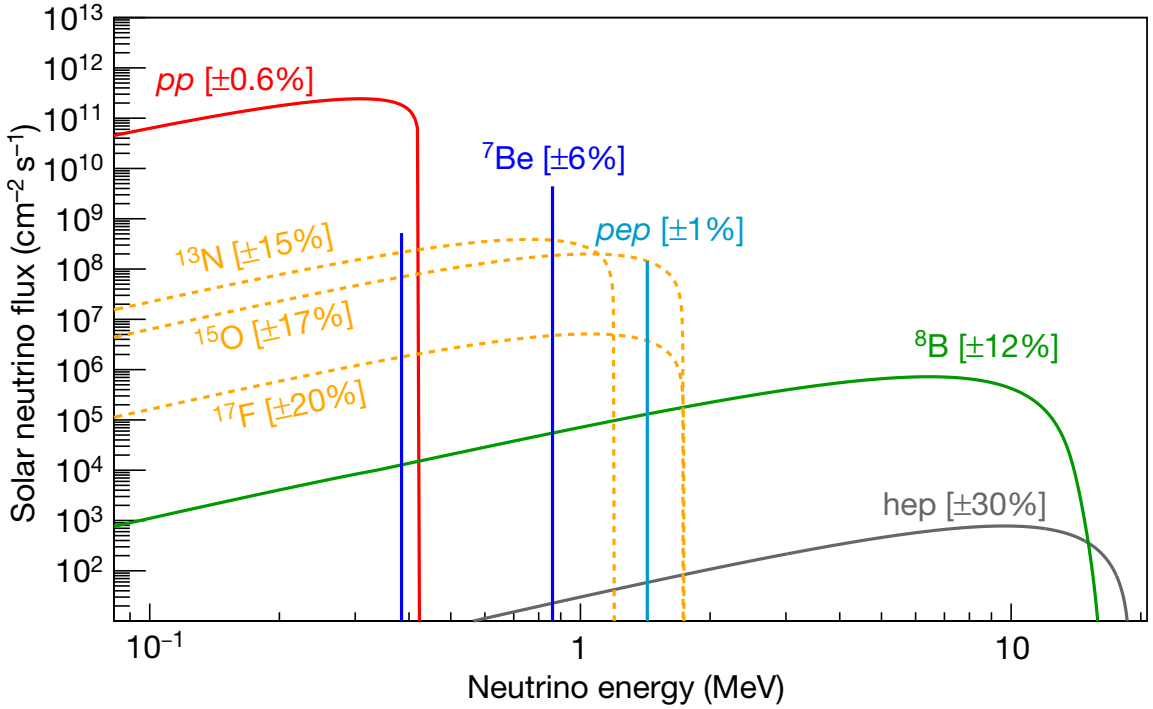
- The world's leading direct detection result is from Borexino with a recoil energy of >165 keV
- PandaX-4T aims to measure the lower energy spectrum than Borexino

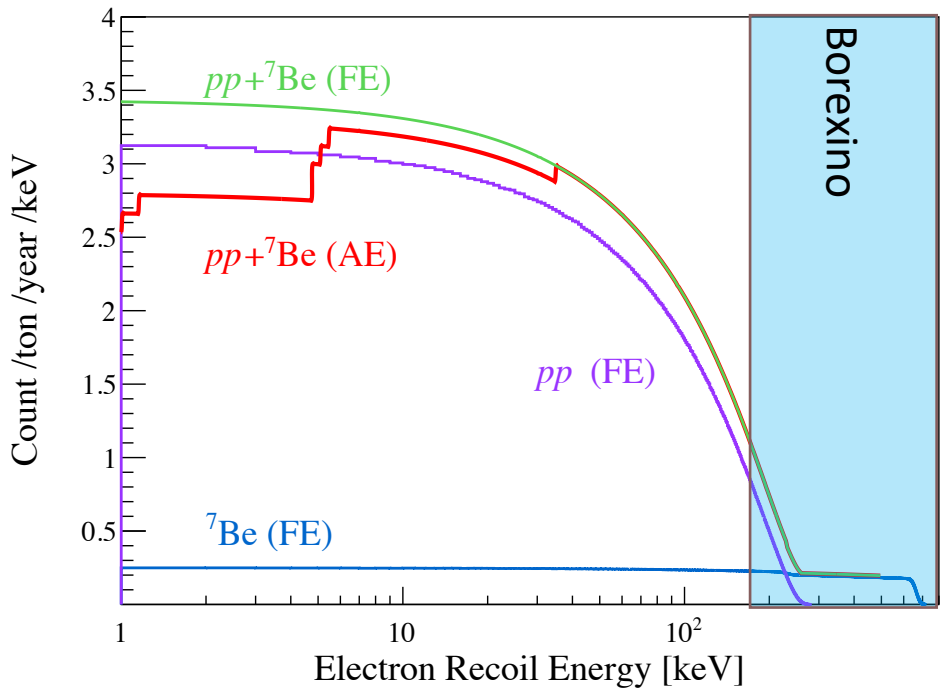




Solar pp neutrino scattering on electrons

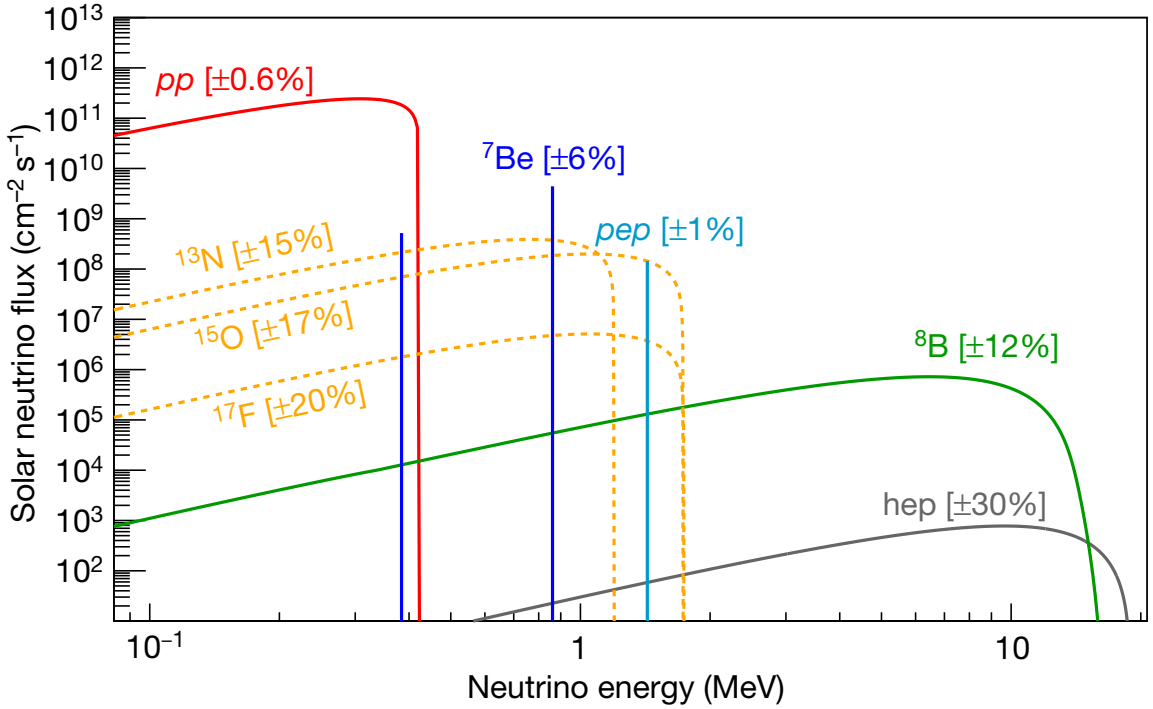
- The world's leading direct detection result is from Borexino with a recoil energy of >165 keV
- PandaX-4T aims to measure the lower energy spectrum than Borexino

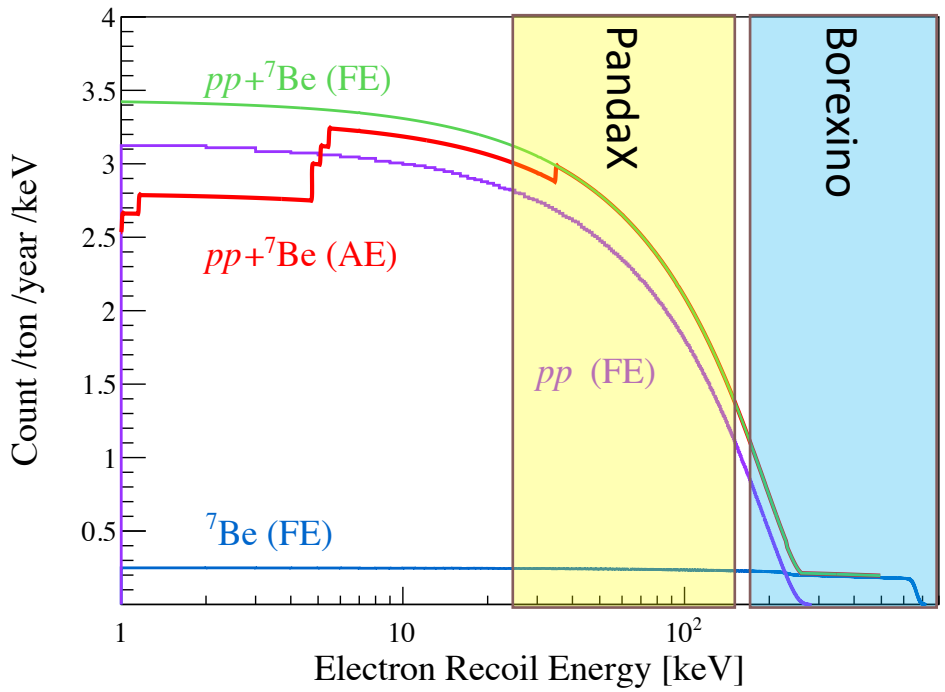




Solar pp neutrino scattering on electrons

- The world's leading direct detection result is from Borexino with a recoil energy of >165 keV
- PandaX-4T aims to measure the lower energy spectrum than Borexino

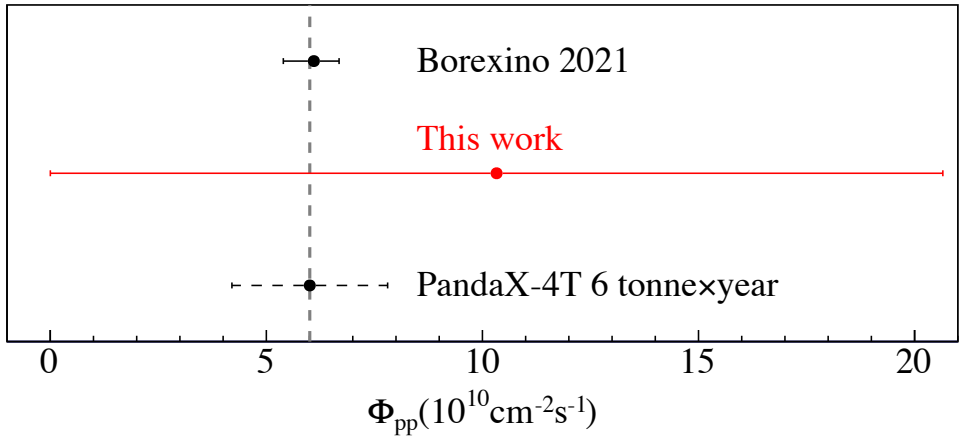


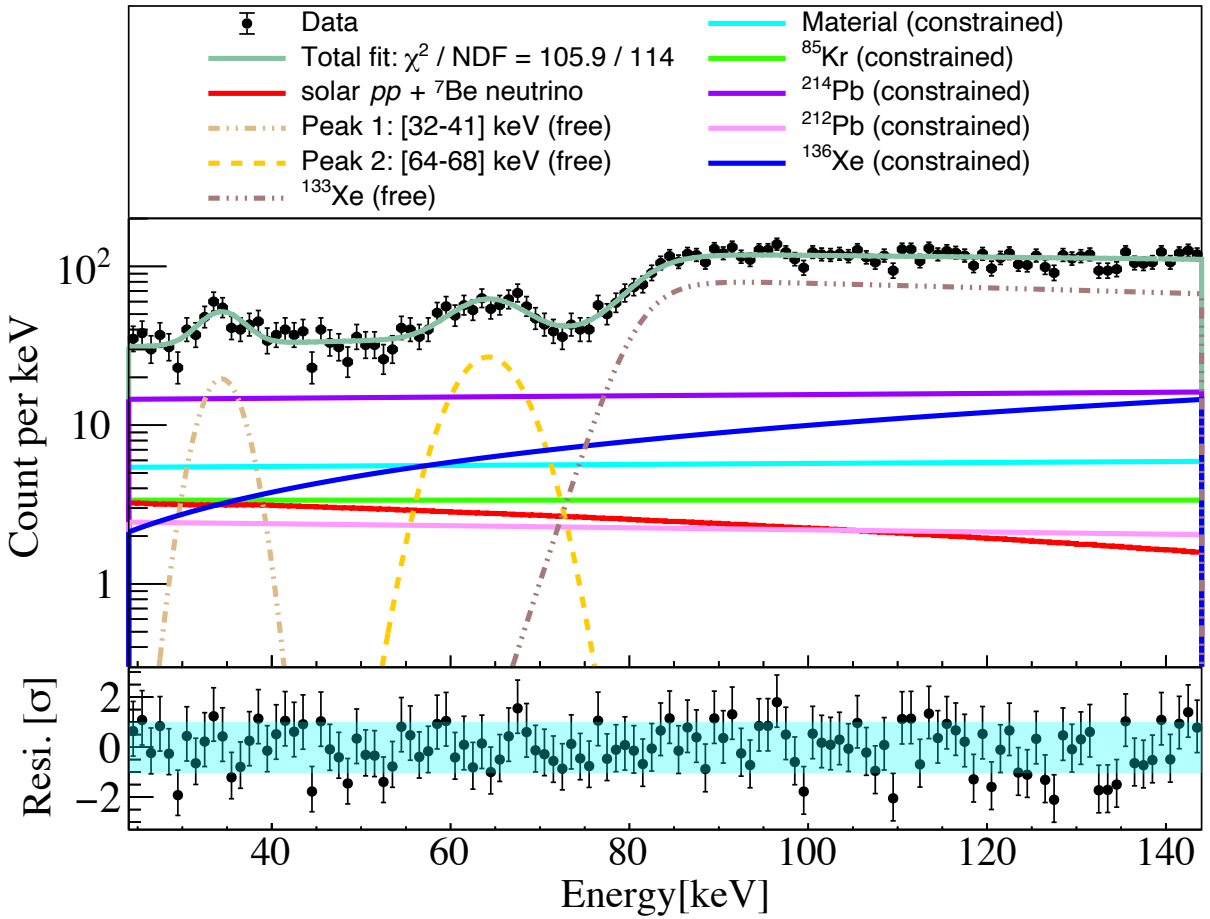


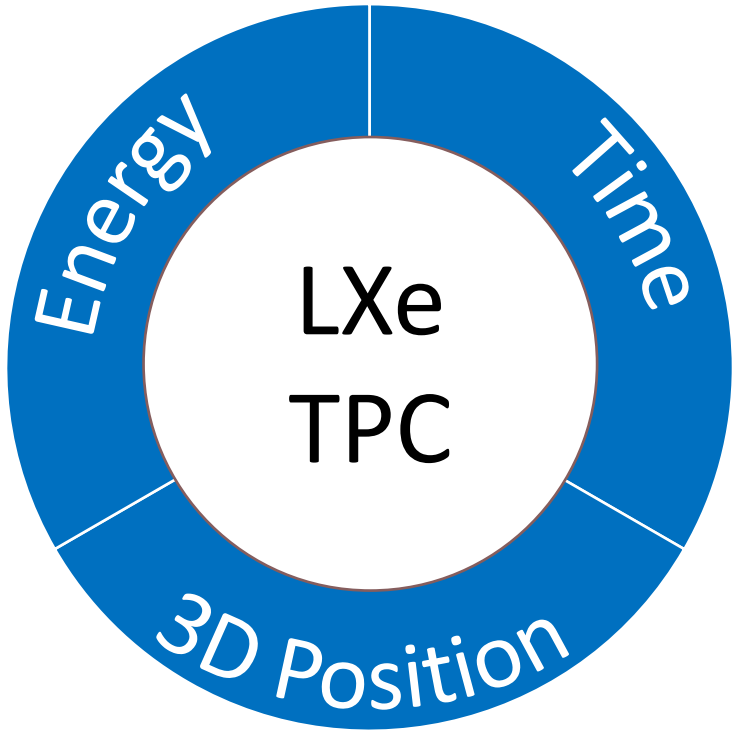
PandaX-4T result

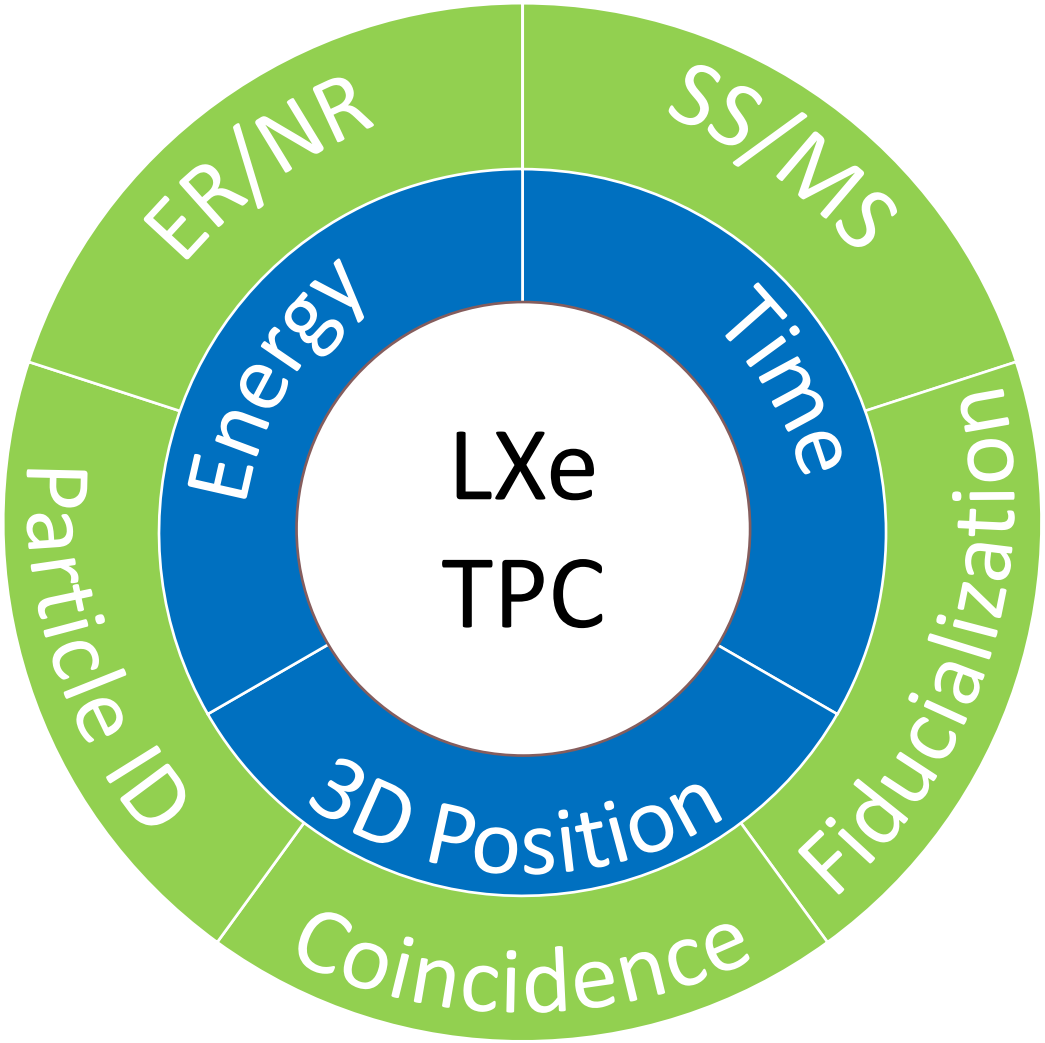
- The first solar pp neutrino measurement in recoil energy from 24 to 144 keV with 0.63-tonne × year of PandaX-4T Run 0 exposure
- Consistent with Standard Solar Model and existing measurements.

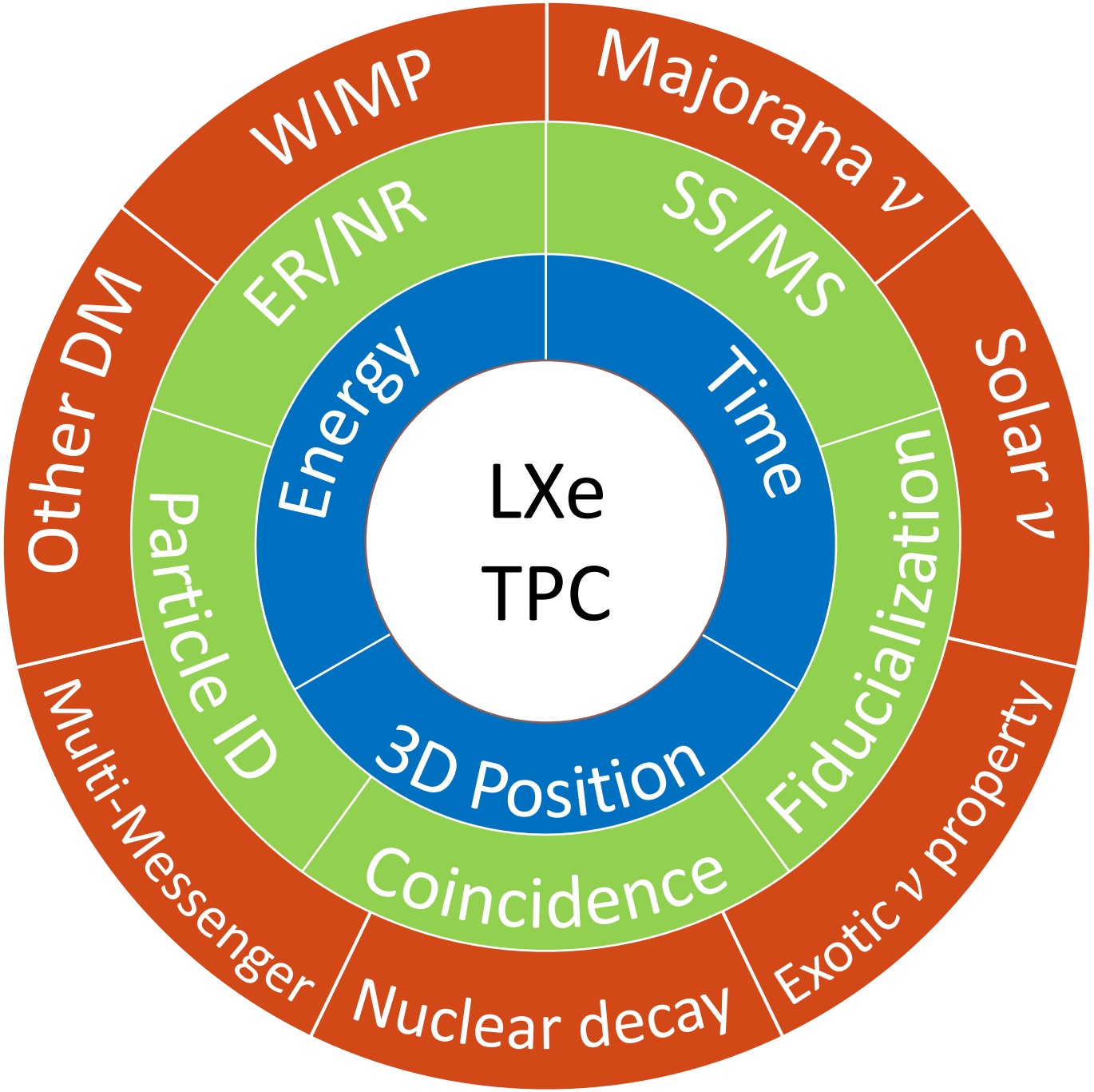
ArXiv: 2401.07045

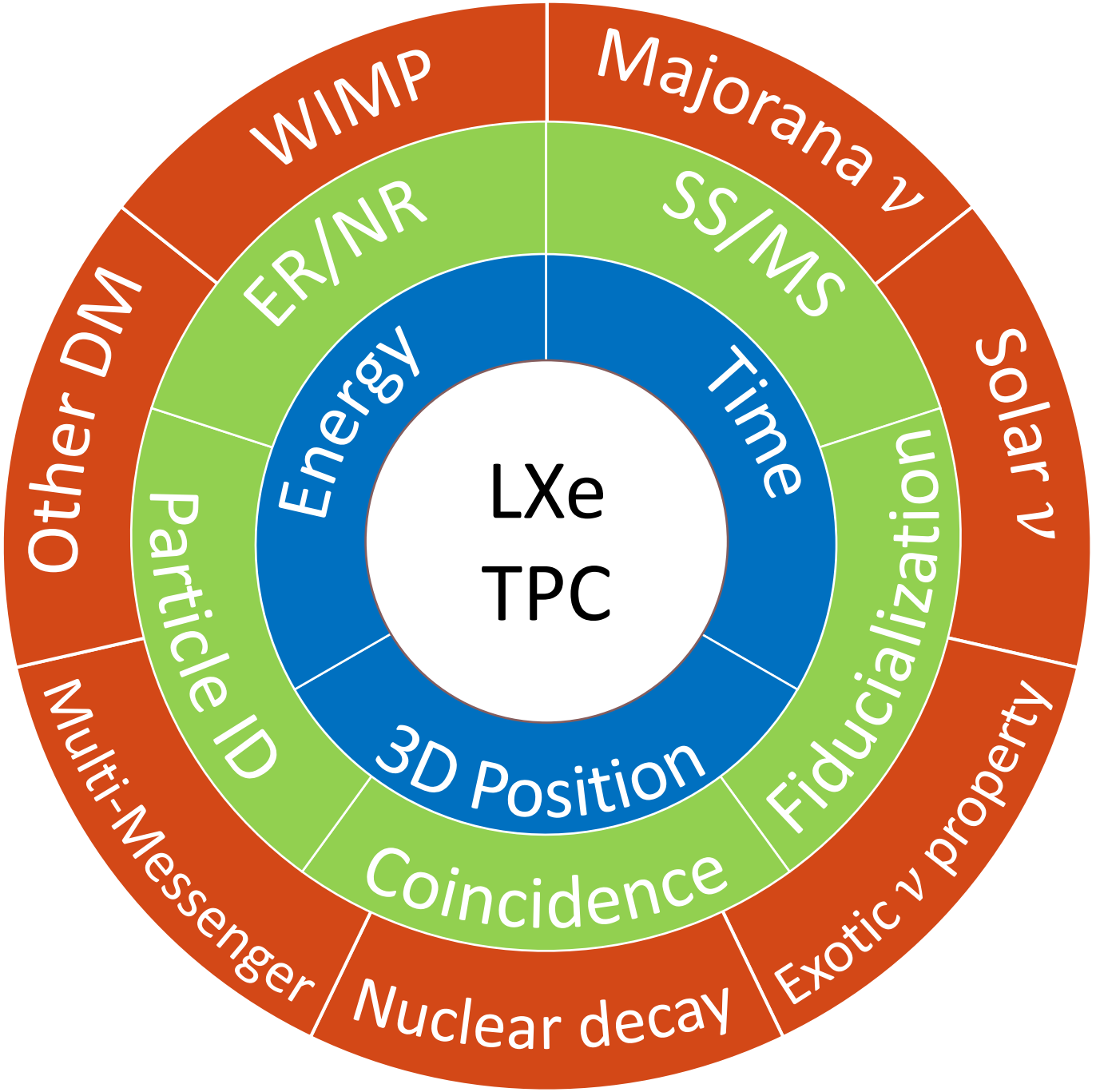





Energy
Time
LXe
TPC
3D Position


ER/NR
SS/MS
Energy
Time
LXe
TPC
Particle ID
Fiducialization
3D Position
Coincidence

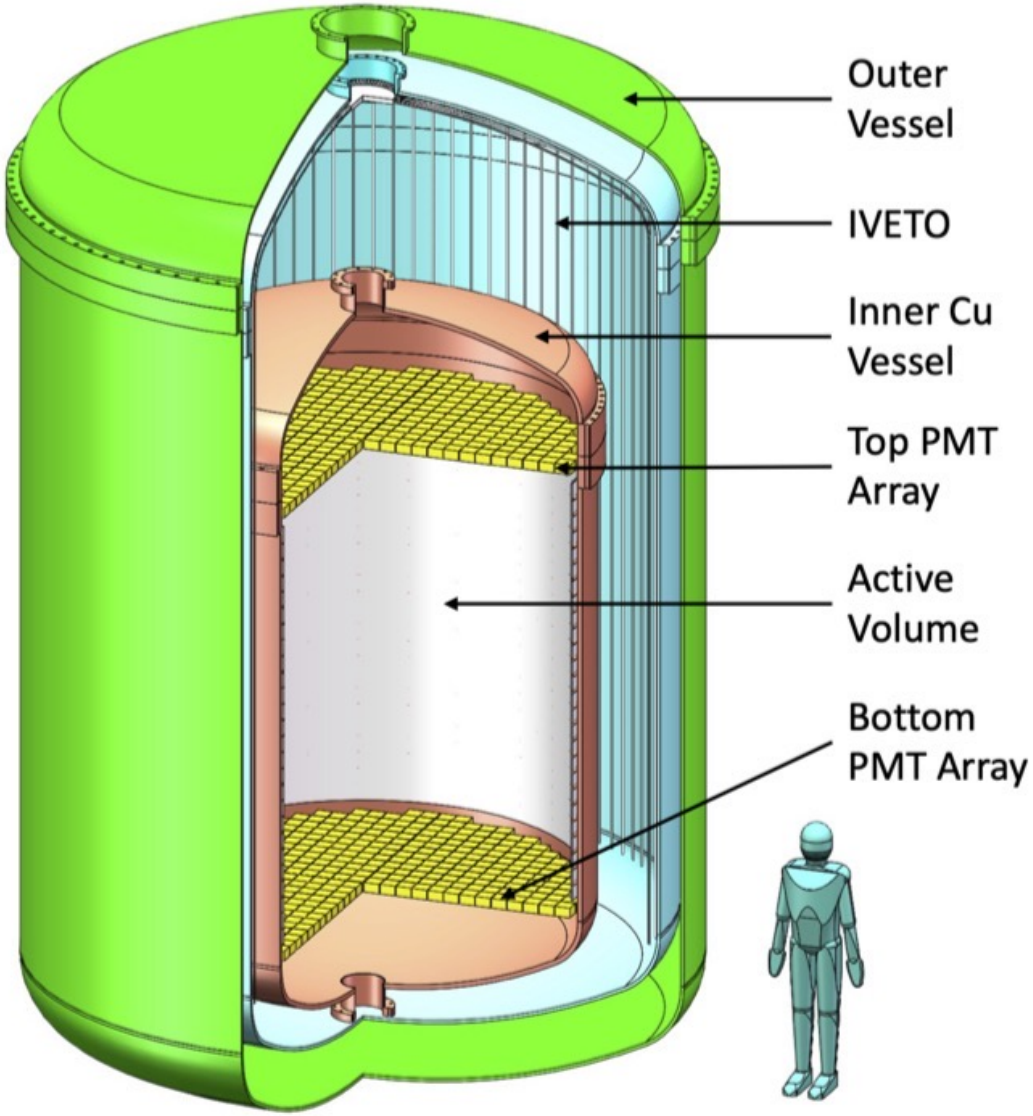

WIMP
Majorana ν
Other DM
Solar ν
Multi-Messenger
Exotic ν property
Nuclear decay
ER/NR
SS/MS
Particle ID
Fiducialization
Coincidence
Energy
Time
3D Position
LXe
TPC



+ Larger
Cleaner
Detector

PandaX-xT: Multi-ten-tonne Liquid Xenon Observatory

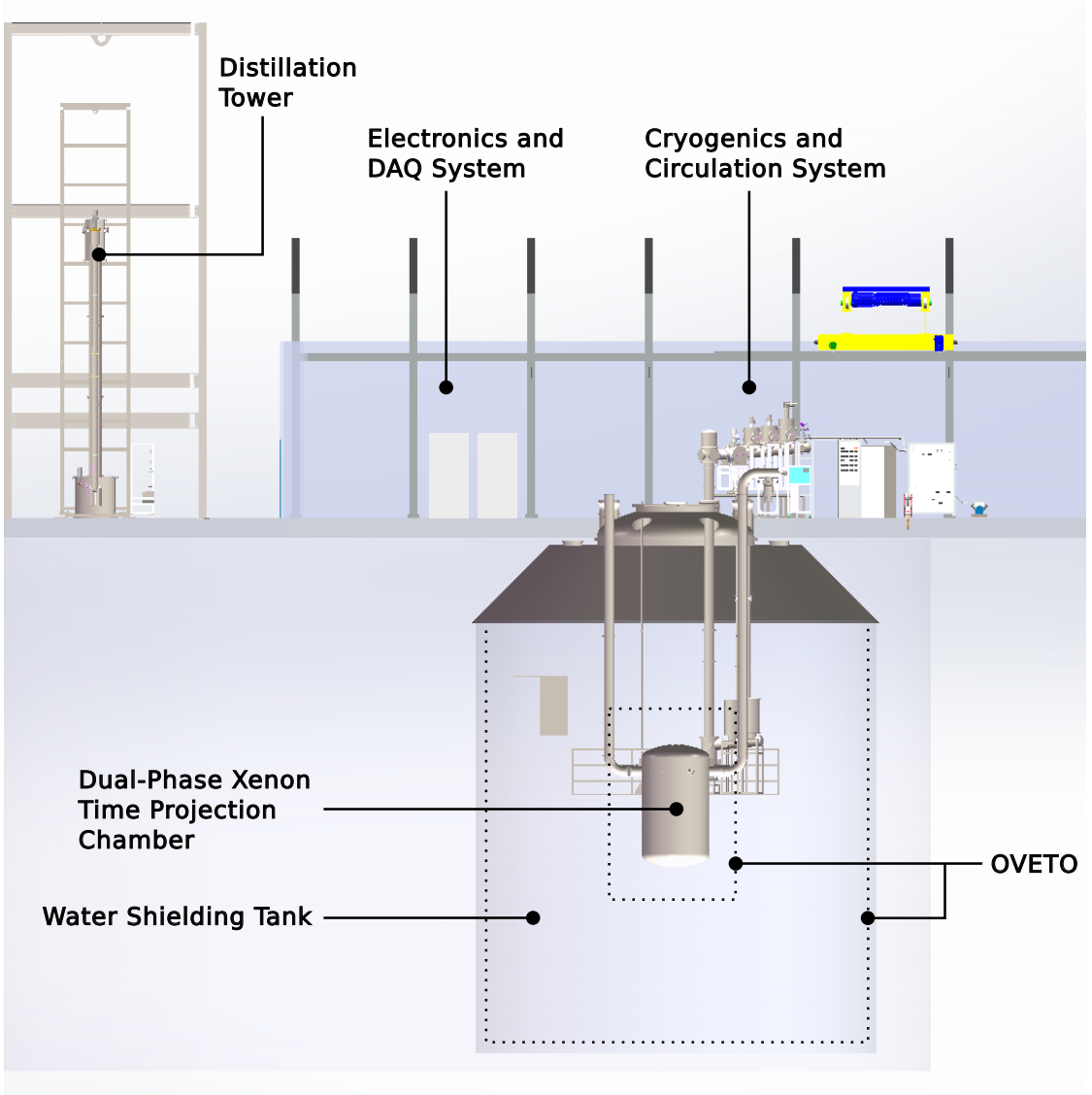
- Active target: 43 ton of Xenon
  - Decisive test to the WIMP paradigm
  - Explore the Dirac/Majorana nature of neutrino
  - Search for astrophysical or terrestrial neutrinos and other ultra-rare interactions
- Notable improvements:
  - High-granularity, low-background 2-in PMT array
  - Cu/Ti vessel for improved radiopurity
  - Inner liquid scintillator veto



arXiv:2402.03596

PandaX-xT: Multi-ten-tonne Liquid Xenon Observatory

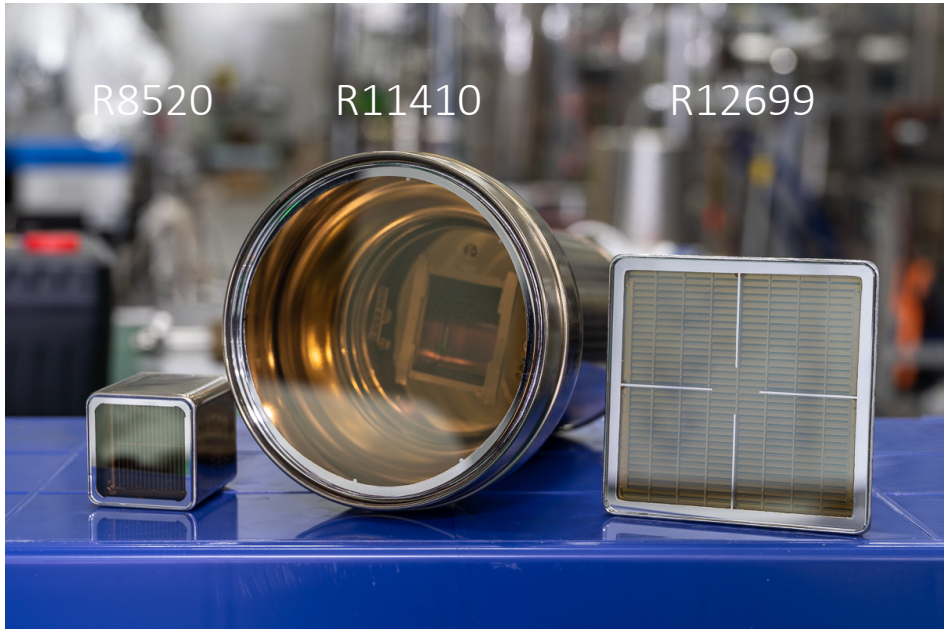
- Active target: 43 ton of Xenon
  - Decisive test to the WIMP paradigm
  - Explore the Dirac/Majorana nature of neutrino
  - Search for astrophysical or terrestrial neutrinos and other ultra-rare interactions
- Notable improvements:
  - High-granularity, low-background 2-in PMT array
  - Cu/Ti vessel for improved radiopurity
  - Inner liquid scintillator veto + outer water veto

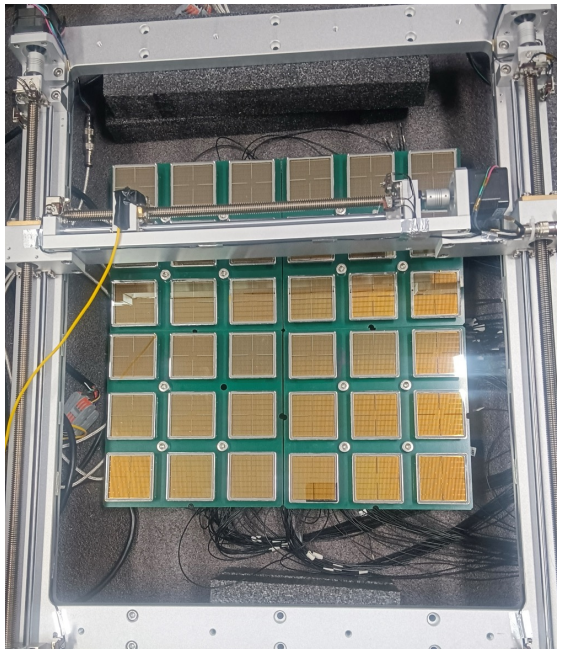


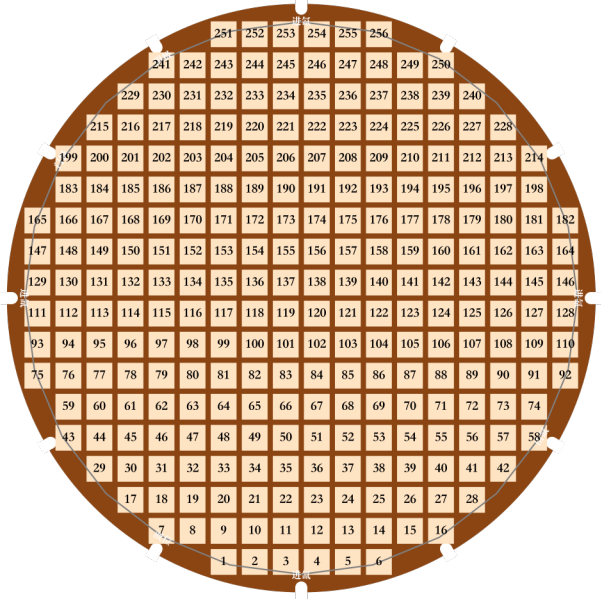
arXiv:2402.03596

New 2” multi-anode R12699 PMT for LXe TPC

- Higher granularity while maintaining low dark noise: best of both large PMT and SiPM
  - Improved position reconstruction for better event topology
  - 2” array has an effectively wider dynamic range for DM and DBD simultaneously
  - Faster timing for possible pulse shape analysis or Cerenkov/Scintillation seperation
- Collaboration between PandaX and Hamamatsu for a low-radioactivity version of R12699





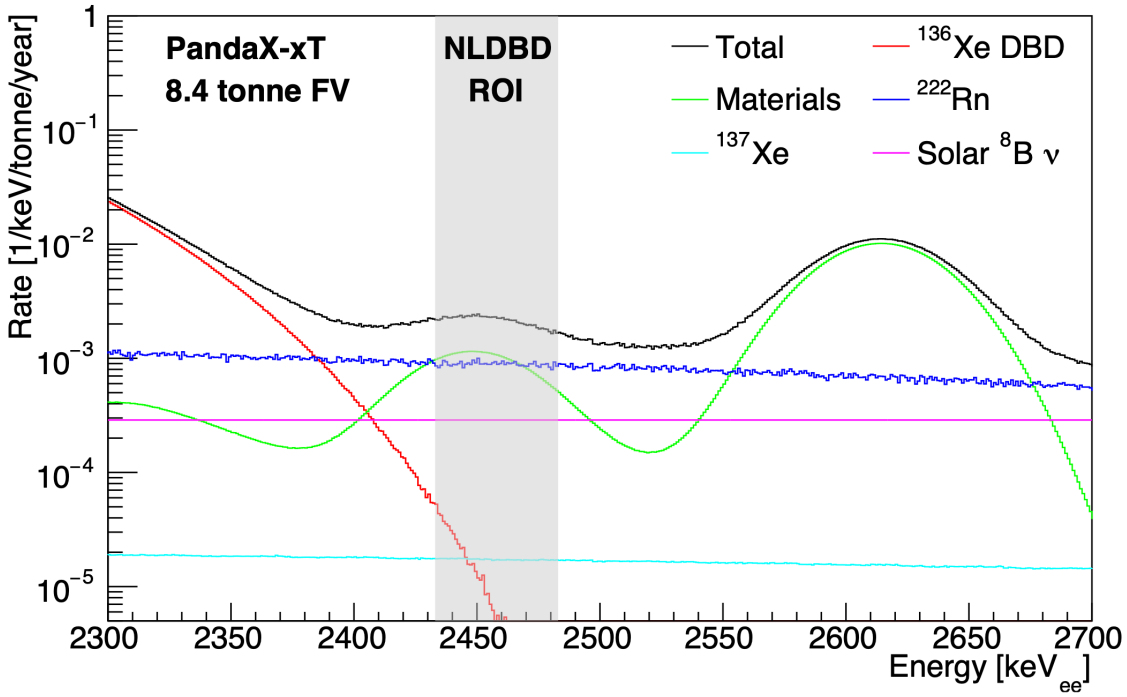


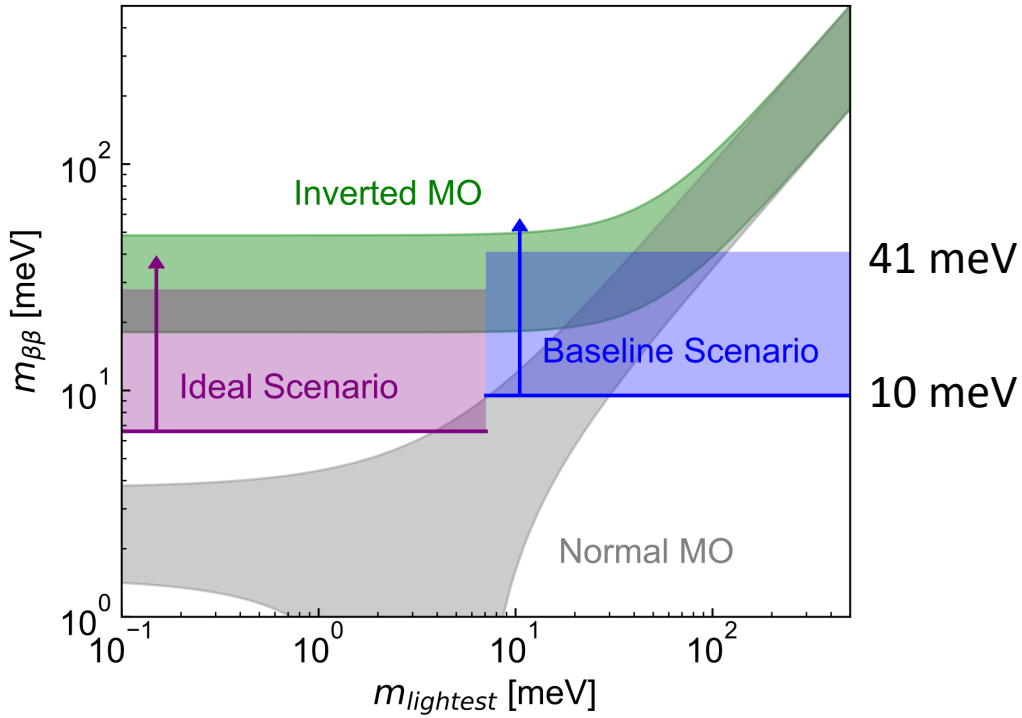
Conceptual array for a PandaX-4T-sized TPC

PandaX-xT for NLDBD

- 4 ton of ^{136}Xe: one of the largest DBD experiments
- Effective self-shielding: Xenon-related background dominates in the 8.4-tonne center FV

	Baseline (1/tonne/year)	Ideal (1/tonne/year)
Photosensors	1.4×10^{-2}	2.8×10^{-3}
Copper vessel	3.2×10^{-2}	6.3×10^{-3}
^{222}Rn	4.5×10^{-2}	-
^{136}Xe DBD	5.2×10^{-4}	5.2×10^{-4}
^{137}Xe	8.7×10^{-4}	8.7×10^{-4}
Solar ^{8}B ν	1.4×10^{-2}	1.4×10^{-2}
Total	$\mathbf{1.1\times10^{-1}}$	$\mathbf{2.4\times10^{-2}}$





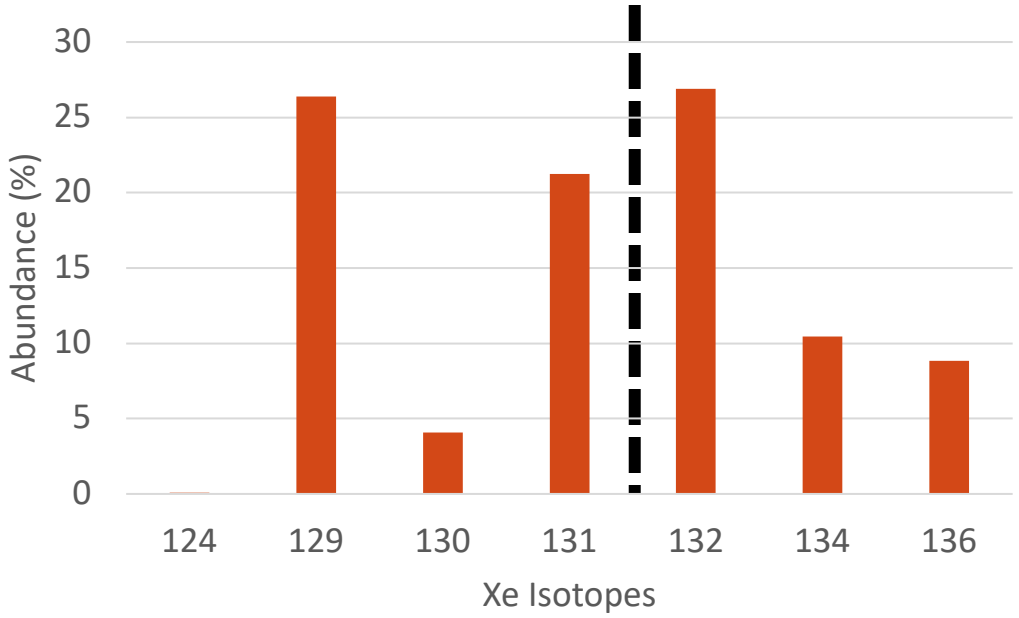
Head-to-head with other DM/DBD experiments

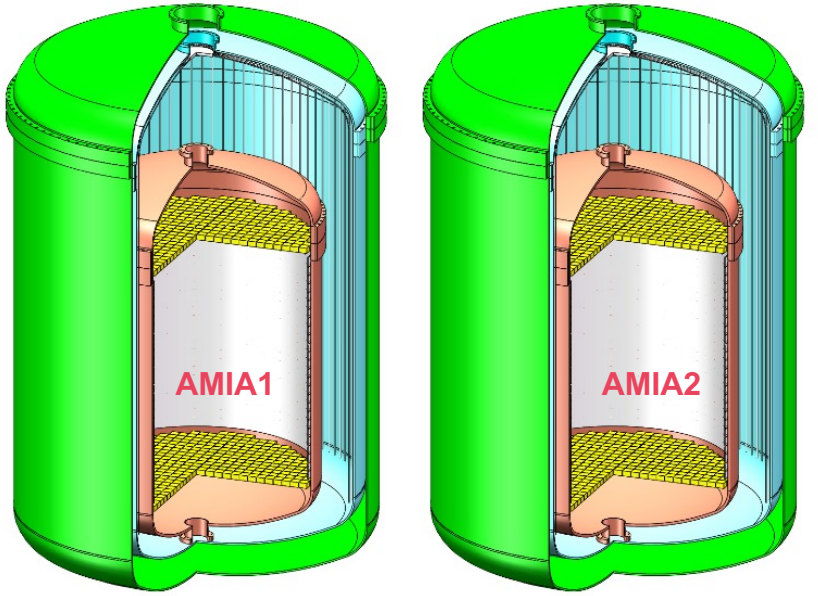
	Bkg rate (/keV/ton/y)	Energy resolution	Mass (ton)	Run time	Sensitivity/Limit (90% CL, year)
PandaX-4T	6	1.9%	4	94.9 days	$> 10^{24}$
XENONnT	1	0.8%	6	1000 days (expected)	2×10^{25}
LZ	0.3	1%	7	1000 days (expected)	1×10^{26}
KamLAND-ZEN	0.002	5%	0.8 (^{136}Xe)	1.5 years	2.3×10^{26}
nEXO	0.006	1%	5 (^{136}Xe)	10 years	1.35×10^{28} **
DARWIN	0.004*	0.8%	40	10 years	2×10^{27}
PandaX-xT	0.002*	1%	43	10 years	3×10^{27}

* Major difference from cosmogenic ^{137}Xe; ** $\frac{S}{\sqrt{B}}$ sensitivity is 6×10^{27} yr, for detector performance comparison in the table.

Possible isotope seperation/enrichment

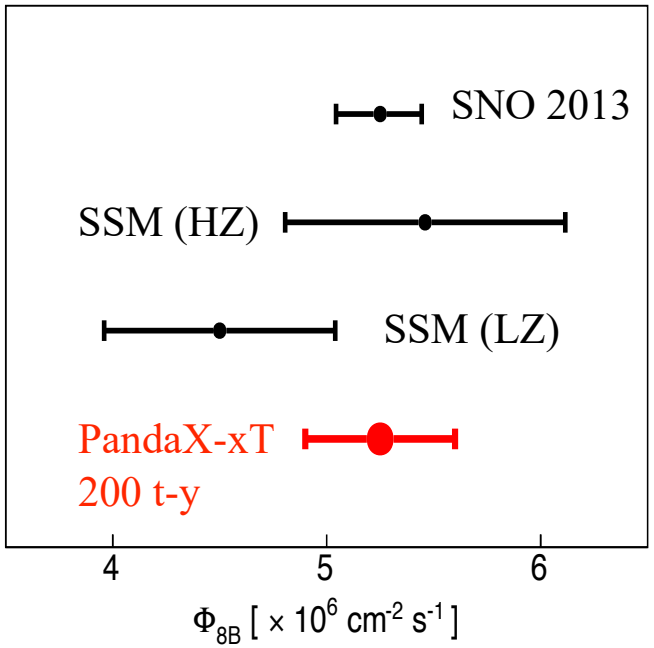
- Xenon with artificially modified isotopic abundance (AMIA) for smoking gun discovery
  - A split of odd and even nuclei
  - Further enrichment of ^{136}Xe
  - to improve sensitivity to spin-dependence of DM-nucleon interactions and NLDBD

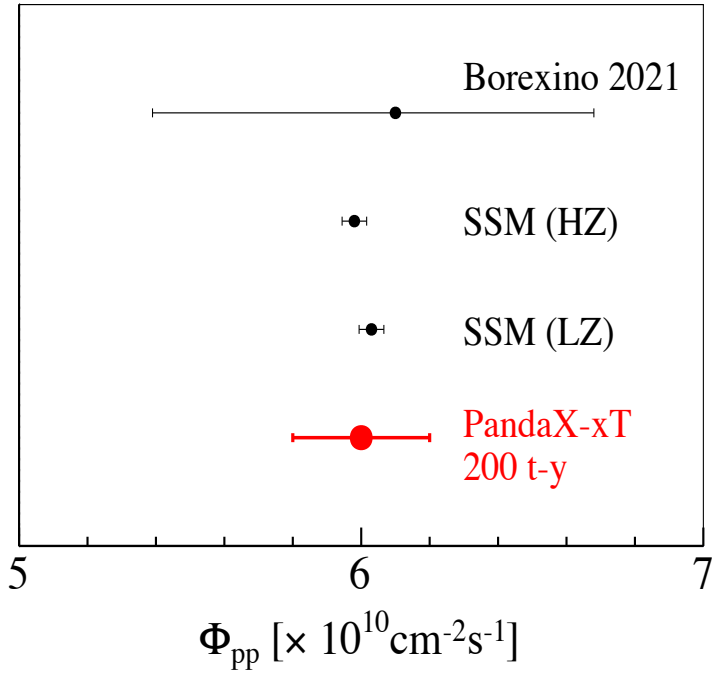


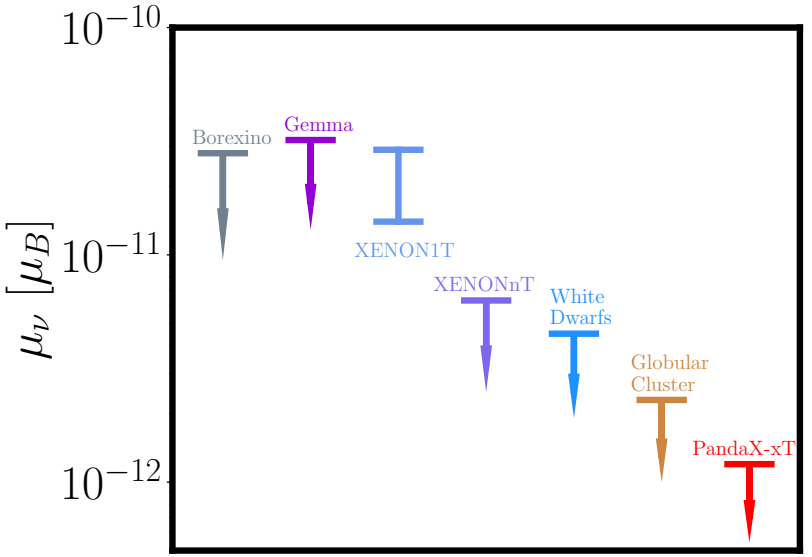


Competitive in other neutrino physics topics as well

- Coherent scattering of solar ^{8}B neutrino: from a first observation in LXe TPC to precision measurement
- Electron scattering of solar pp neutrino: competitive precision at a wider energy range
- Neutrinos with abnormal magnetic moments: a better sensitivity than astrophysical observations

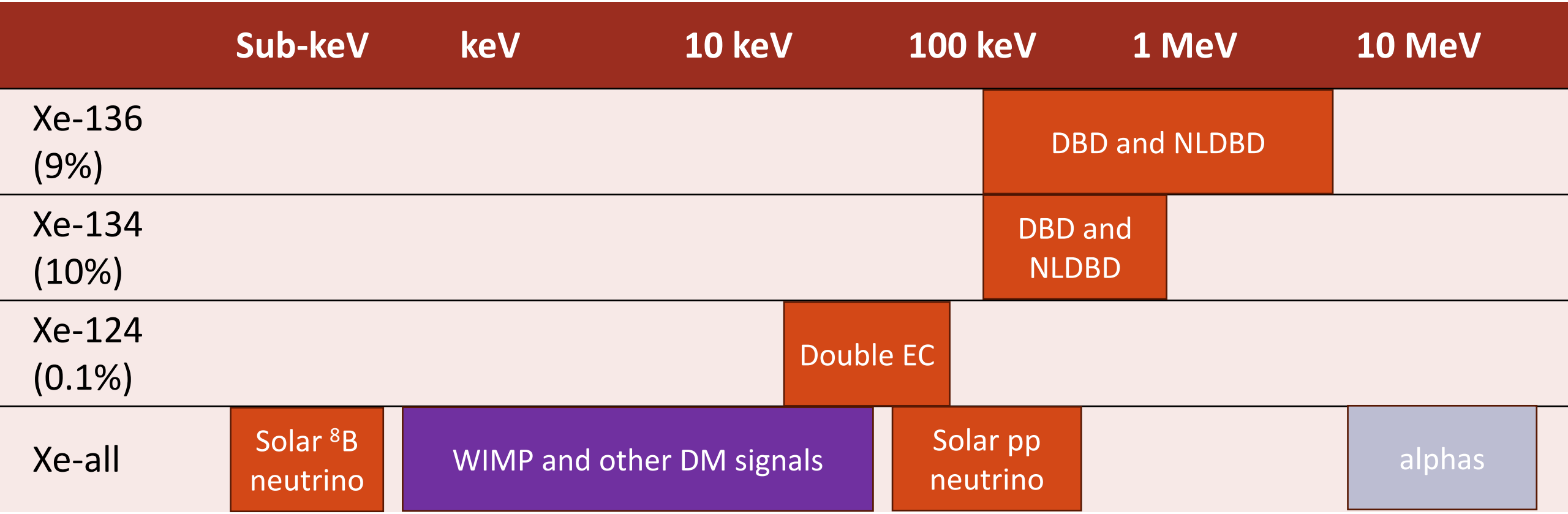






arXiv:2402.03596

Neutrino physics program at PandaX



- Re-think the LXe TPC as a Total-Absorption 5D Calorimeter
- Fully exploit the entire energy range of LXe TPC
- Fully utilize the multiple isotopes of natural xenon for rich physics


PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC
Thank you very much
We welcome new collaborators
at PandaX-xT

The 7th International Workshop on Application of Noble Gas Xenon to Science and Technology

XeSAT 2024

Scientific Program

- Noble gas properties for radiation detection
- Applications to dark matter, double beta decay, and other physics
- Imaging in medicine, astrophysics, and nuclear engineering
- Novel techniques in noble gas detector R&D
- Gas and liquid handling; industrial supplies
- Background reduction and shielding technology

www.xesat2024.cn

May 24~27,2024

Tsung-Dao Lee Institute

Shanghai,China