

Xenon Detectors

in Particle, Astroparticle, Nuclear and Medical Physics

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TIDPAN 2026 - Taller de Instrumentación y Detectores en Física de Partículas, Astropartículas y Nuclear

Outline

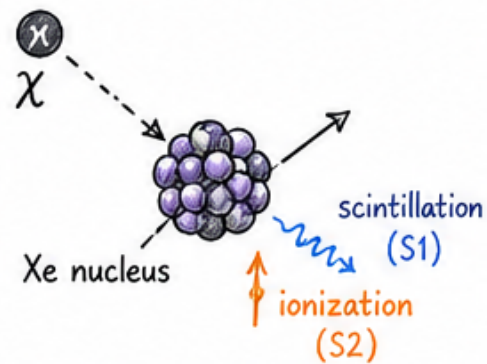
- Why xenon?
- Xenon interaction physics
- Xenon detector concepts
- Xe experiments for dark matter and neutrinoless double beta decay searches

Part I – Why Xenon?

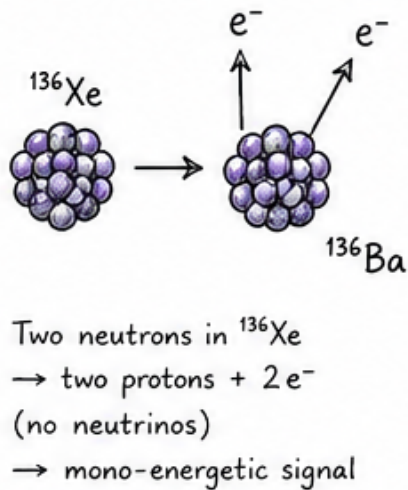
Xenon Detectors: Many Applications!

PARTICLE & ASTROPARTICLE PHYSICS

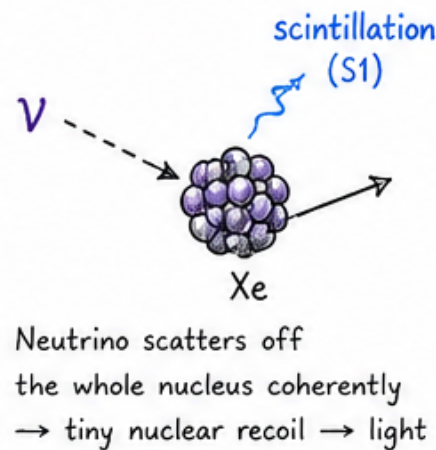
DARK MATTER DIRECT DETECTION



NEUTRINOLESS DOUBLE BETA DECAY ($0\nu\beta\beta$)

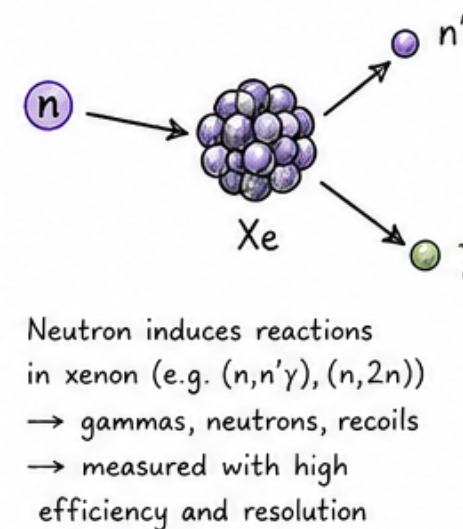


COHERENT NEUTRINO-NUCLEUS ELASTIC SCATTERING (CEvNS)

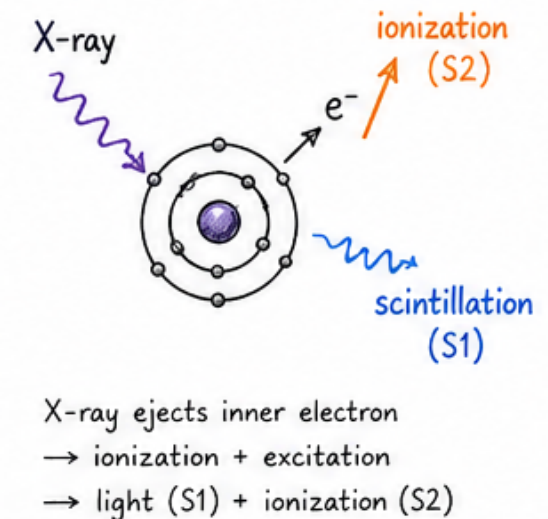


OTHER PHYSICS & TECHNOLOGICAL APPLICATIONS

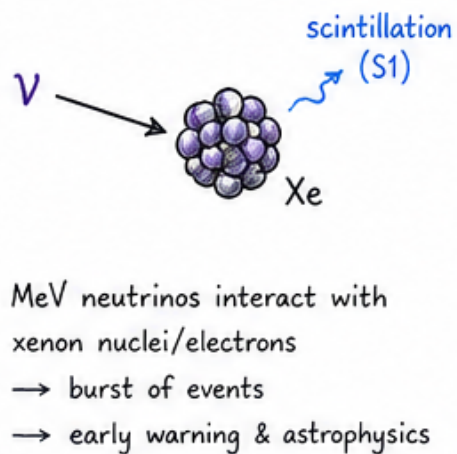
NEUTRON REACTION STUDIES



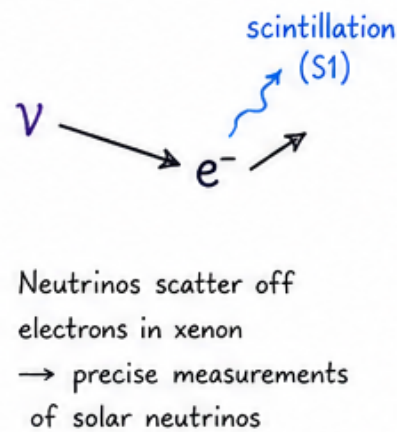
X-RAY DETECTION



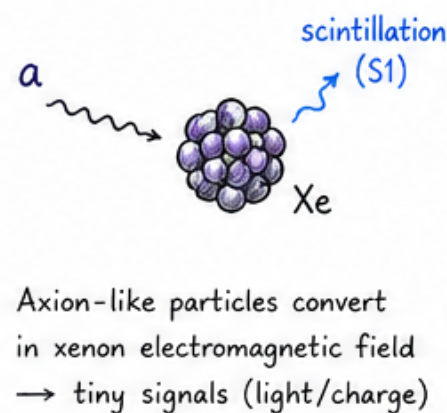
SUPERNOVA NEUTRINOS



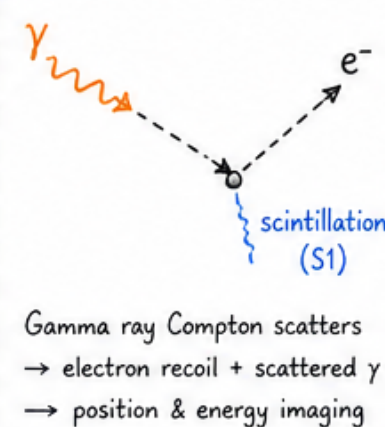
SOLAR NEUTRINOS



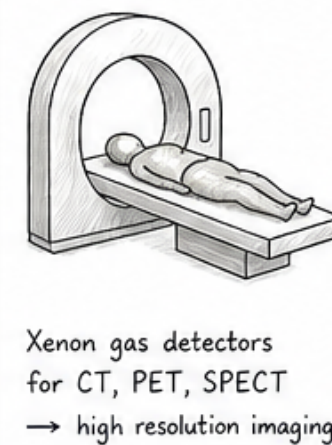
AXION / ALP SEARCHES



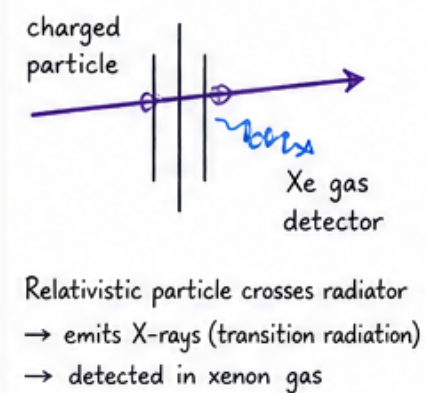
GAMMA-RAY IMAGING



MEDICAL IMAGING



TRANSITION RADIATION DETECTORS (COLLIDERS)



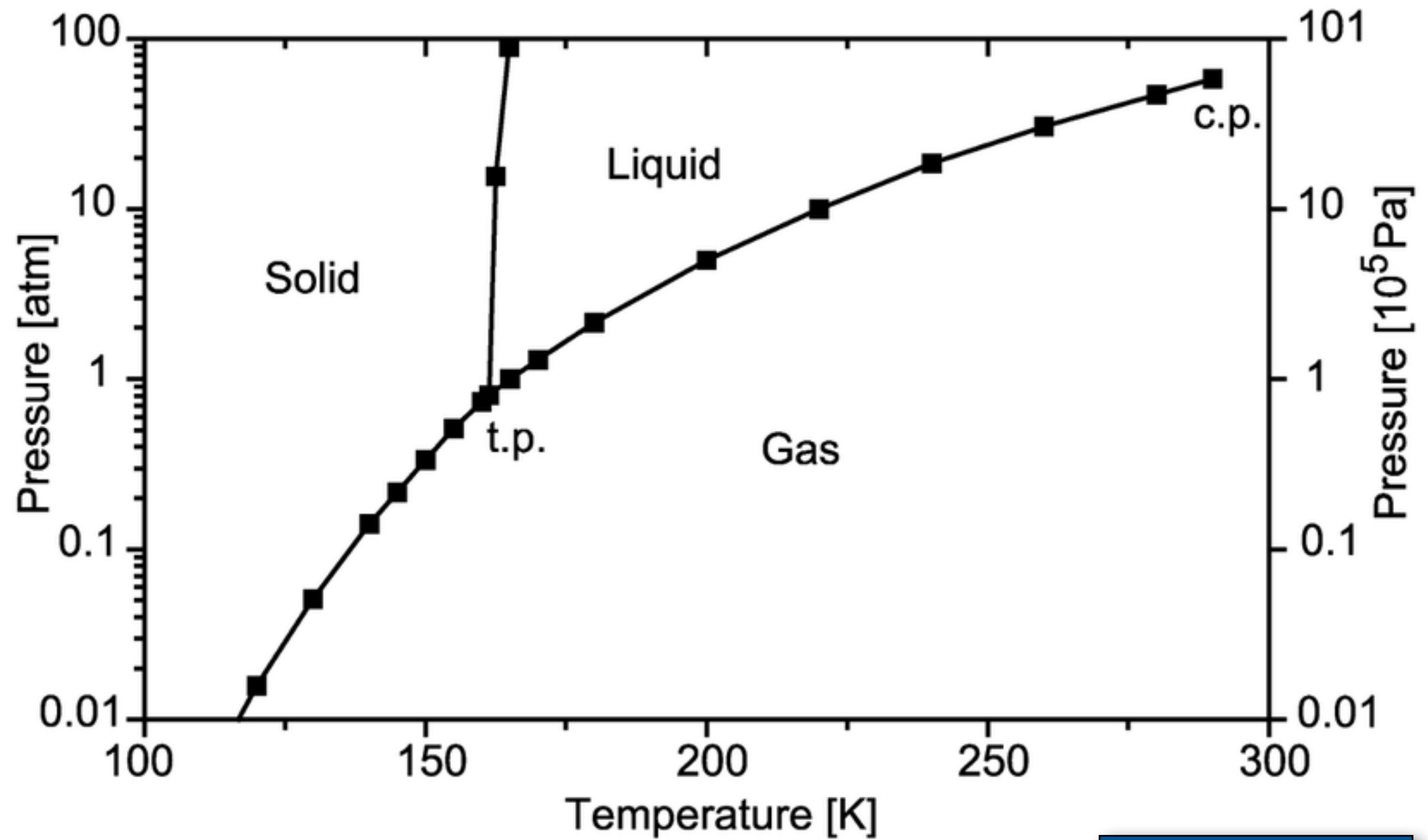
Credit: ChatGPT

Xenon in the Periodic Table

- **Chemistry group:** noble gases → chemically inert, easy purification
- **Atomic number:** $Z = 54 \rightarrow$ high detection efficiencies for X-ray and gamma-rays, good self-shielding
- **Atomic mass:** $A \approx 131 \rightarrow$ heavy nucleus with multiple isotopes, including $\beta\beta$ emitter
- **Density:** $5.5 \times 10^{-3} \text{ g/cm}^3$ (gas, 20 degC and 1 atm), 2.9 g/cm^3 (liquid) → dense in liquid phase, compact detectors with high stopping power
- **Melting and boiling points at 1 atm:** 161.4 K and 165.1 K → Xe is a gas at STP conditions, but easy to liquefy

1																	18	
H	2											13	14	15	16	17	He	
Li	Be											B	C	N	O	F	Ne	
Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	P	S	Cl	Ar	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
Cs	Ba		Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Fl	Uup	Lv	Uus	Uud

Xenon Phase Diagram



Credit: [A. Cherubini et al.](#)

Xenon as a Detection Medium

Liquid Xenon Versus Water and Other Noble Liquids

- Xenon provides very high **ionization** AND **scintillation** yields → ideal for dual-readout (ionization + scintillation) detectors, with good energy resolution and/or low energy threshold
- Xenon scintillation is produced in the vacuum ultraviolet wavelength range (175 nm), posing some challenges for photon detection
- Xenon is not cheap! Cost is main limitation to multi-ton scalability

Element	H2O	He	Ne	Ar	Kr	Xe
Ionization yield [10^4 e/MeV]	-	3.9	4.6	4.2	4.9	6.4
Scintillation yield [10^4 γ /MeV]	0	1.5	0.7	4.0	2.5	4.6
Scintillation wavelength [nm]	-	80	78	128	150	175
Cost [USD/kg]	<0.001	24	240	0.93	290	1800

* https://en.wikipedia.org/wiki/Prices_of_chemical_elements

LXe Versus GXe as Detection Media

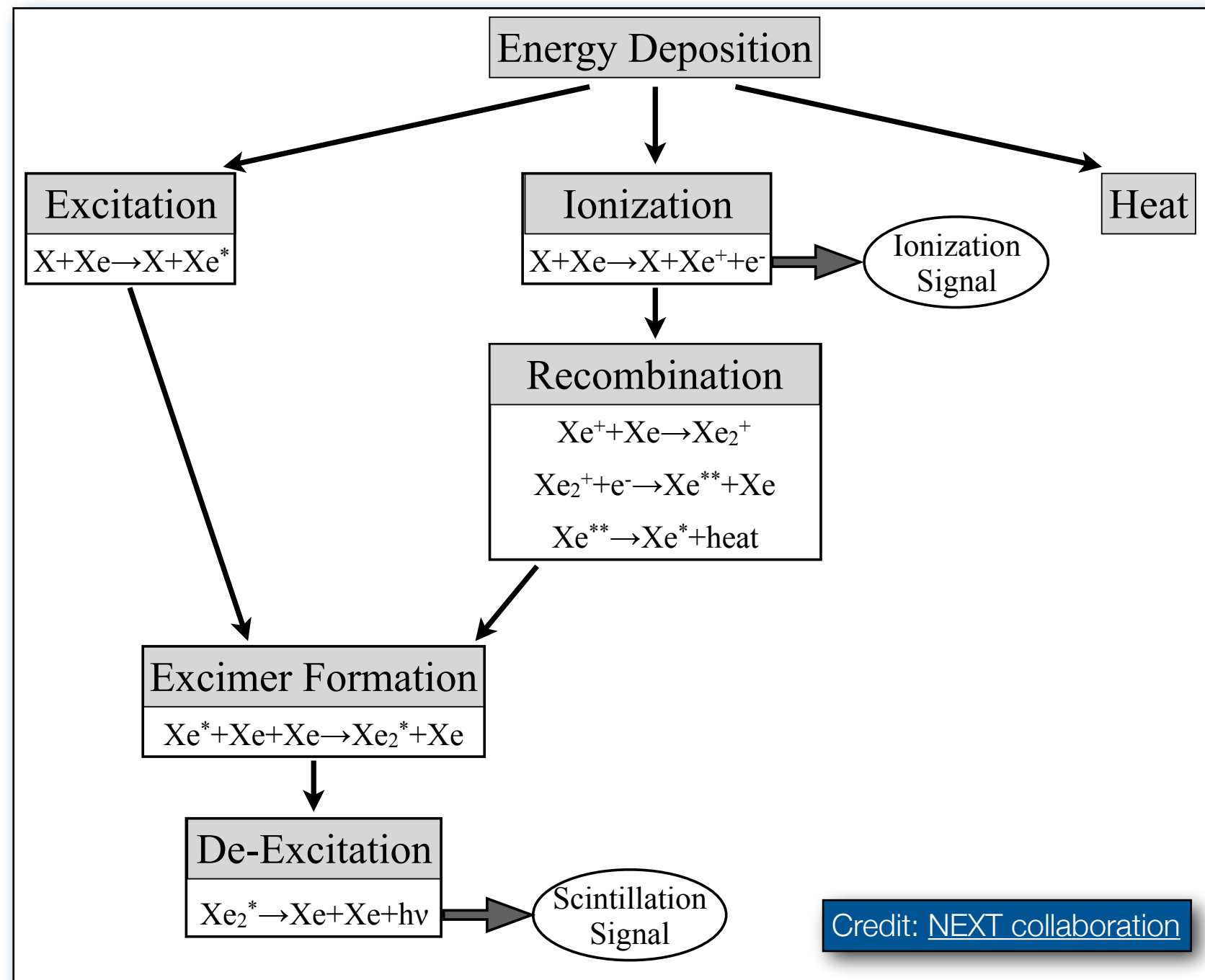
- The 500-fold difference in density is responsible for the huge difference in radiation lengths and Minimum Ionizing Particle (MIP) energy loss
- The ionization and scintillation properties are similar: yields, scintillation wavelengths, scintillation time emission
 - *Both LXe and GXe are fast scintillators*

Property	LXe (165 K)	GGXe (1 bar, 293 K)
Density (g/cm ³)	2.94	5.4×10 ⁻³
Radiation Length (cm)	2.8	1.5×10 ³
MIP Energy Loss (MeV/cm)	3.7	6.9×10 ⁻³
Ionization Yield	6.4	4.5
Scintillation Yield	4.6	2.5
Scintillation Wavelength (nm)	175	175
Scintillation Time Constants	3 ns (fast), 25 ns (slow)	5 ns (fast), 100 ns (slow)

Part II – Xenon Interaction Physics

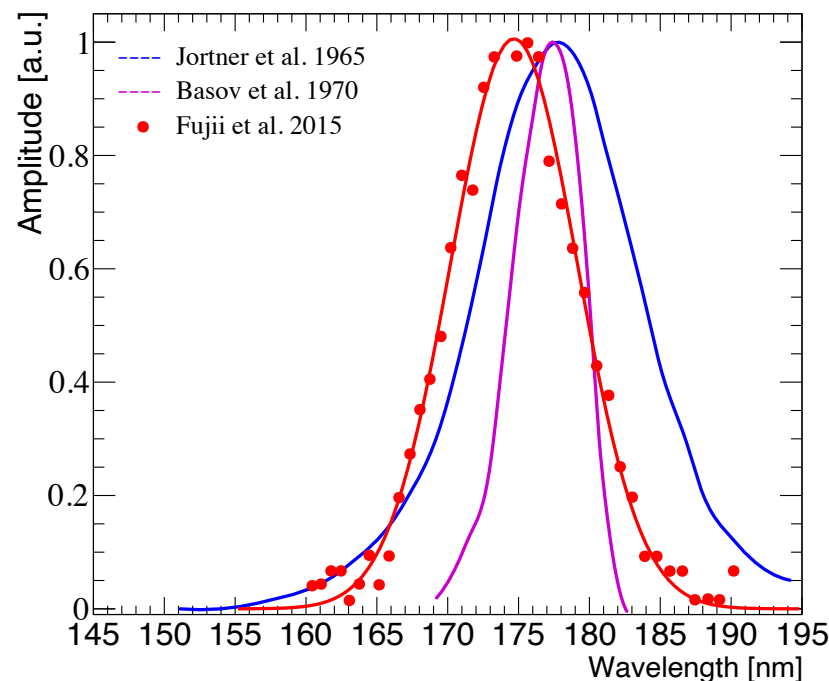
Energy Deposition in Xenon

- Xenon provides both **ionization** (charge) and **scintillation** (light) signals
- The **recombination** of free electrons with Xe_2^+ ions reduce the former and increase the latter
- Scintillation is produced through the radiative decay of excited dimers, or **excimers** (Xe_2^*)

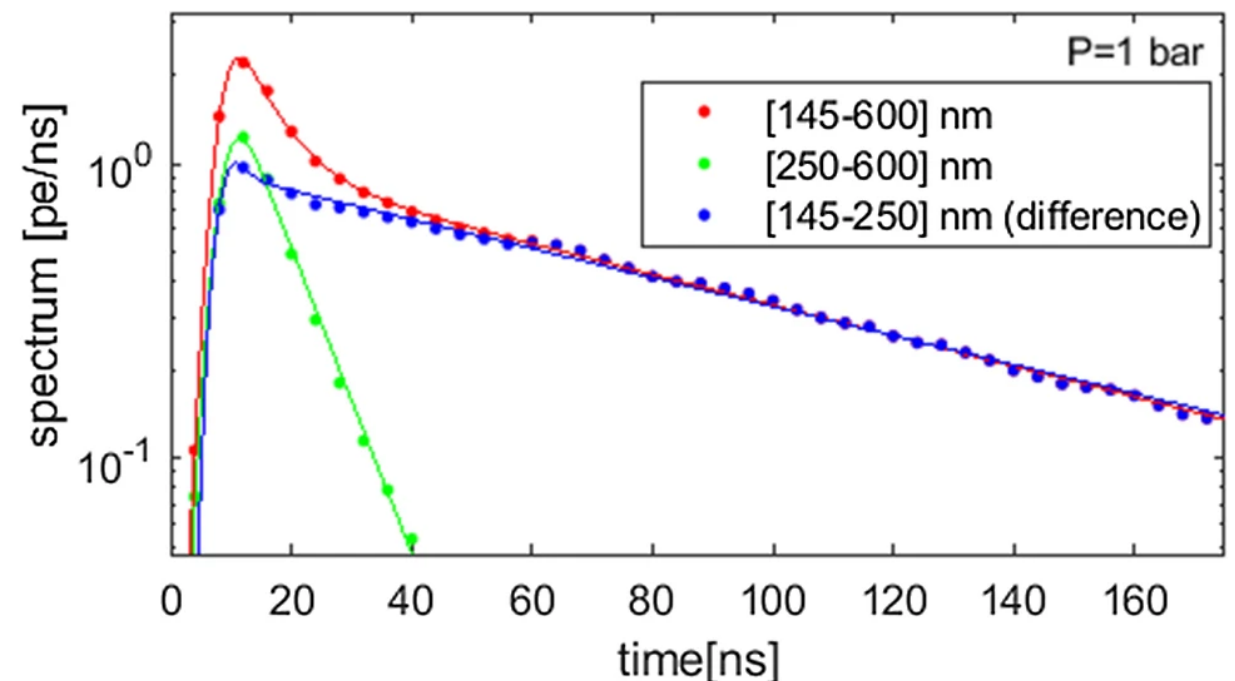


Xenon Scintillation

- The bulk of the scintillation occurs in 2nd continuum region, **(175±10) nm**
 - *Some shorter- and longer-wavelength light also produced (1st and 3rd continua)*
- Different lifetimes for Xe_2^* radiative decay, depending on spin configuration of two electrons participating in excitation and bonding:
 - **Fast** component (~ 5 ns in GXe): two electron spins antiparallel, **singlet** decay
 - **Slow** component (~ 100 ns in GXe): two electron spins parallel, **triplet** decay



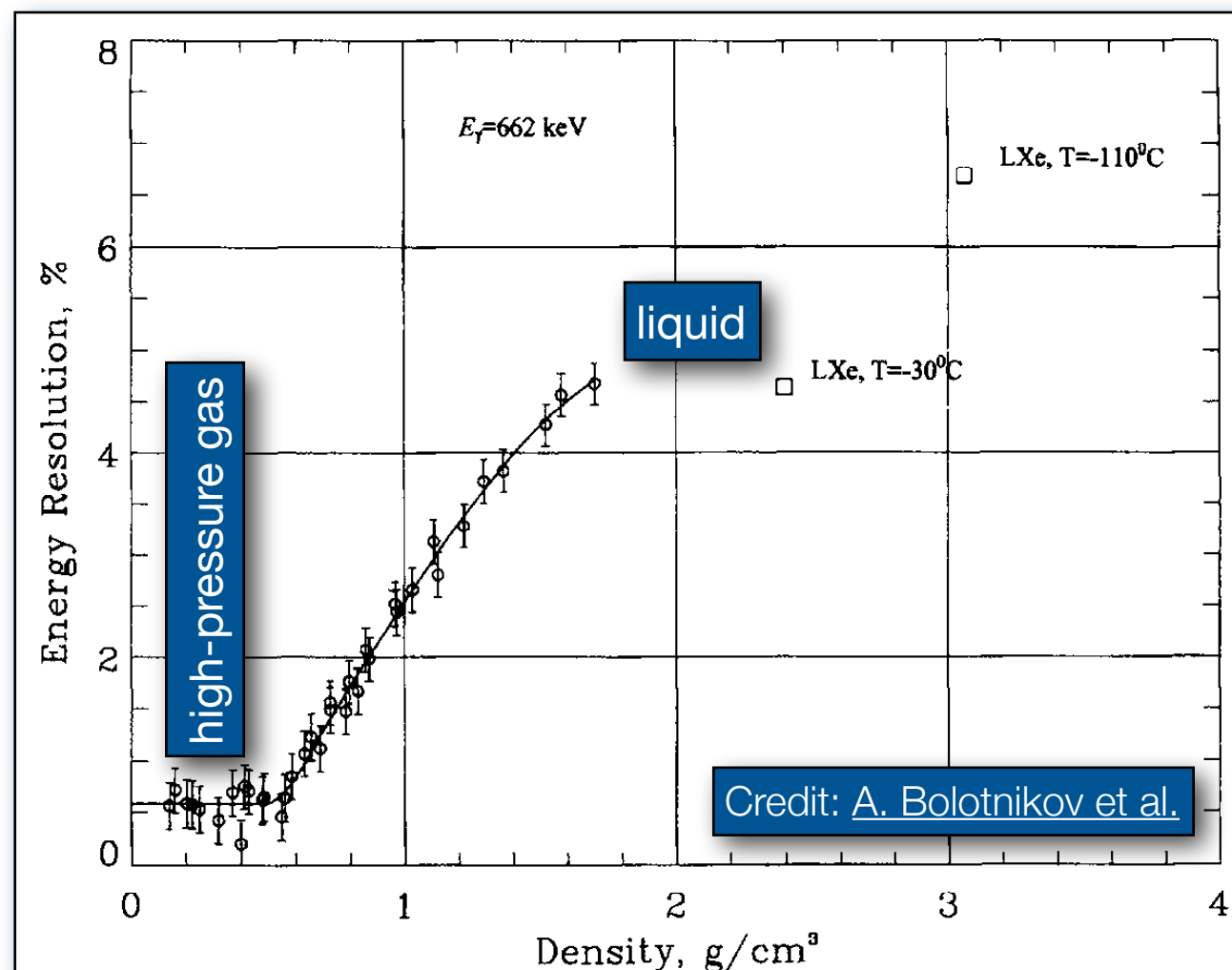
Credit: K. Fujii et al.



Credit: S. Leardini et al.

Xenon Ionization

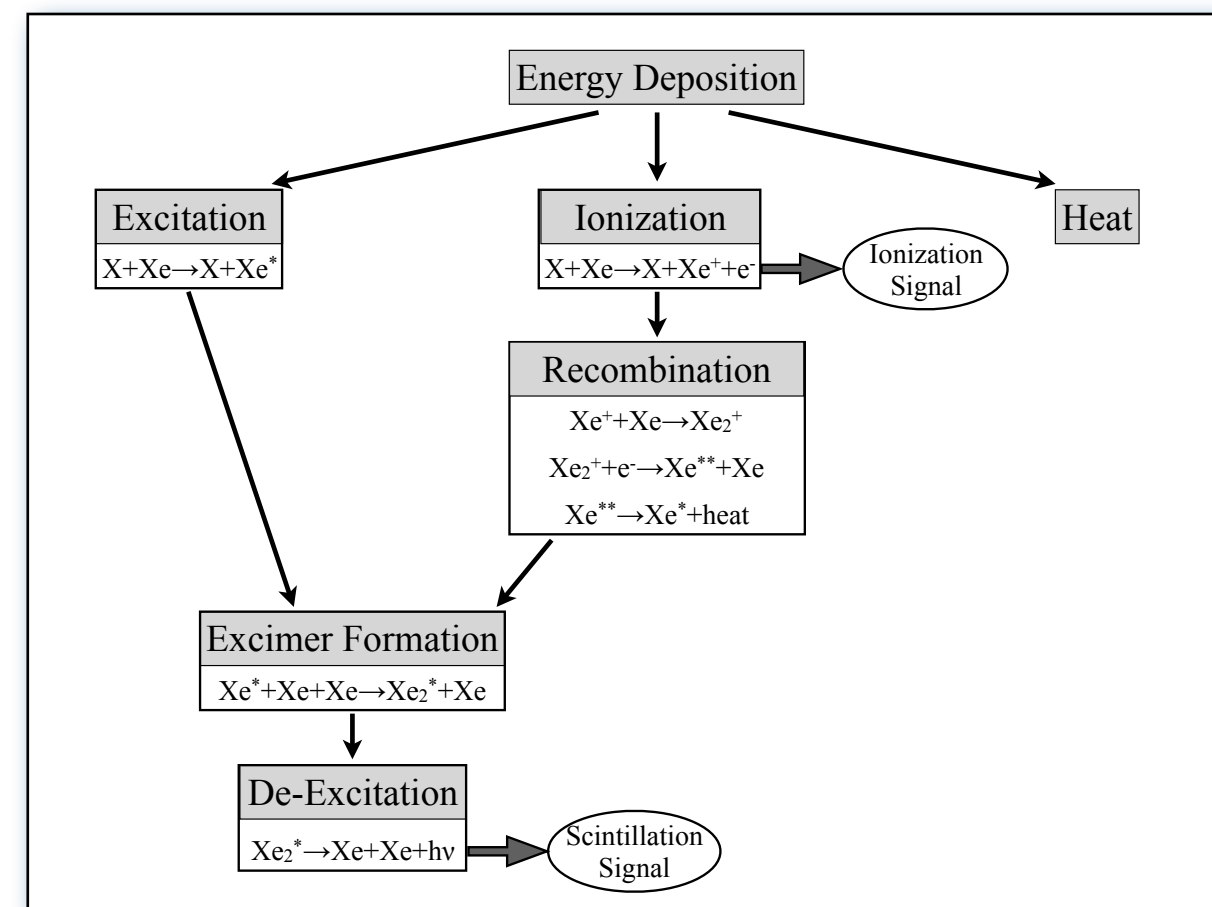
- It only takes $W = 22$ eV to create an electron-ion pair in Xe
 - *Large average number of ionization electrons produced: $N = E / W$*
 - *Percent-level energy resolution. Particularly good for GXe, since fluctuations are sub-Poissonian: $\sigma_N^2 = FN$, with Fano factor $F < 1$*



- Plots shows FWHM energy resolution measured for 662 keV gamma-rays
 - *ionization-only signal*
- Xenon (in gas phase) has very low Fano Factor: **$F = 0.13$**

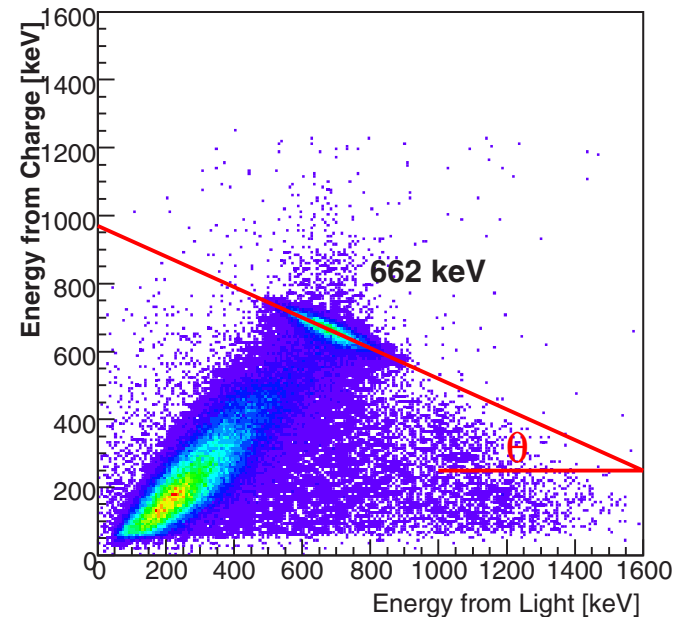
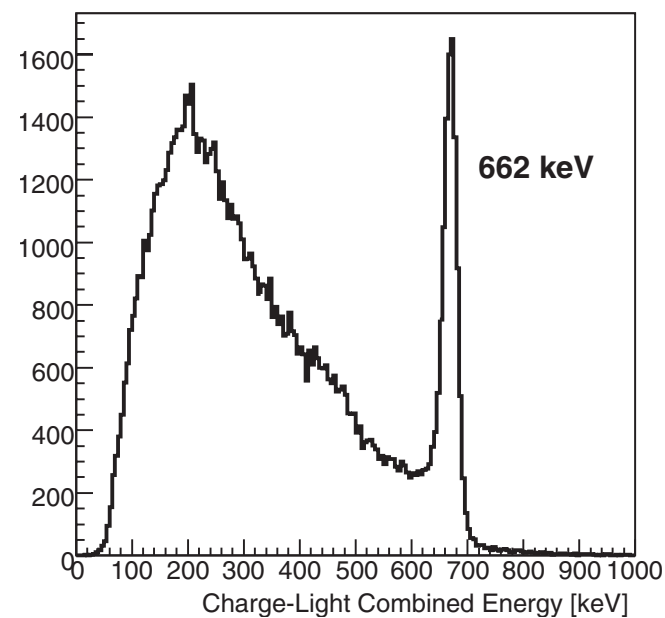
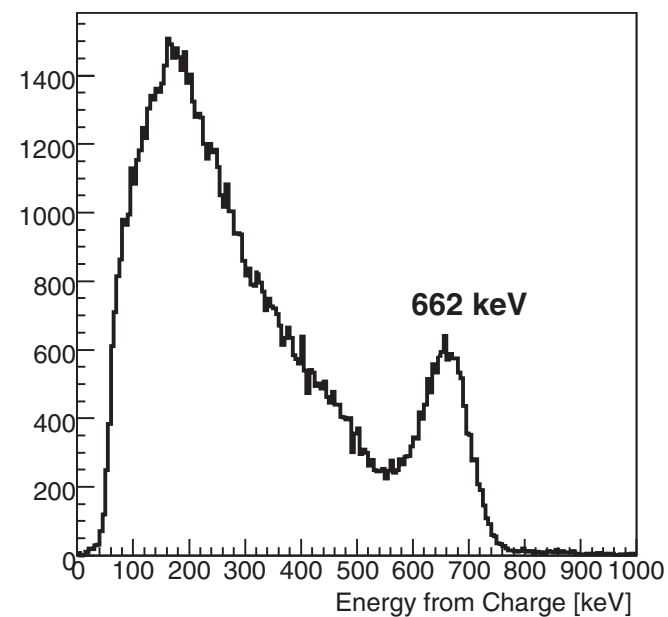
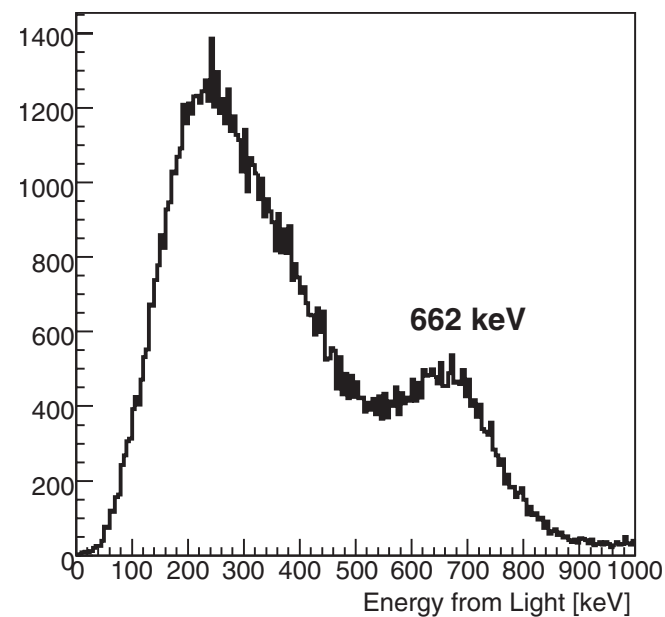
Charge-Light Anti-Correlation

- The recombination of free electrons with Xe_2^+ ions reduce the ionization signal to increase the scintillation one
- Average recombination increases with:
 - *Decreasing drift field*
 - *Increasing $dE/dx \rightarrow$ particle-dependent*
 - *Increasing pressure (in GXe)*
- The recombination also induces an anti-correlation, on an event-by-event basis, between charge and light signals
- Routinely exploited in LXe detectors to improve energy resolution, using a charge+light energy estimator



Charge-Light Anti-Correlation

- Energy spectra of ^{137}Cs 662 keV gamma-rays at 1 kV/cm drift field in LXe:



Credit: E. Aprile et al.

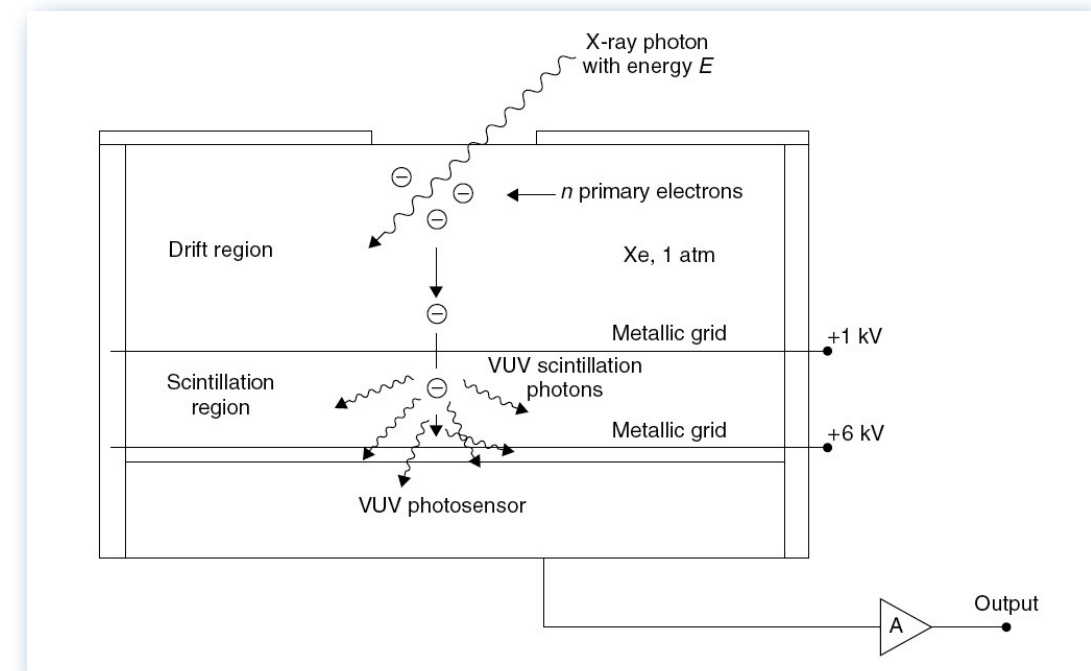
Charge Transport

- Electrons must be drifted from their production point in Xe to anode readouts for their detection, in typical drift fields of order 0.1-1 kV/cm
- For such fields, **drift velocity** is of order 1 mm/ μ s irrespective of phase → charge readout in Xe relatively slow: ~1 ms to drift across 1 m distances
- Along drift, the ionization cloud spreads in 3D, "blurring" energy deposition images. **Diffusion** is much smaller in LXe compared to GXe
- Along drift, some electrons are lost via attachment to electronegative impurities in the Xe. Through recirculation and purification, **electron lifetimes** of order 1-10 ms are accomplished, irrespective of phase

Property	LXe	GXe (1 bar)	HPXe (10bar)
Drift velocity at 500 V/cm (mm/ μ s)	2	1.4	1.0
Transverse diffusion (mm/ $\sqrt{m}$)	3	14	10
Achievable electron lifetime (ms)	$\approx$ 1-10	$\approx$ 1-10	$\approx$ 1-10

Electroluminescence (EL)

- Field in EL region tuned such that accelerated ionization electrons excite, but not ionize, gas atoms
- Excited atoms emit secondary scintillation light, as in primary scintillation process



- **Advantage 1:** read ionization and primary scintillation signals through same photo-sensor array → fully optical readout
- **Advantage 2:** amplification process with high gain (x1000 possible) and small gain fluctuations → good energy resolution
- Practically possible only in gas phase → GXe and dual-phase Xe detectors
- EL field produced either through parallel wire grids or micropattern structures (eg, Micromegas, GEMs)

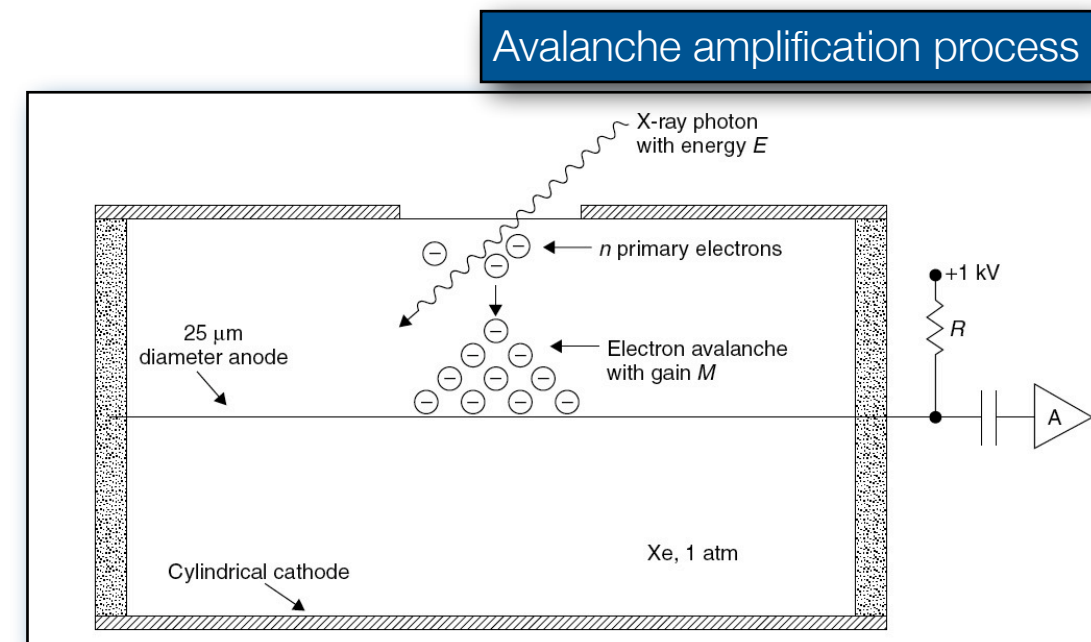
Part III – Xenon Detector Concepts

Taxonomy of Xenon Detectors

- Gaseous Xe detectors:
 - *Proportional counters and multi-wire proportional chambers (MWPCs)*
 - *Drift (straw) tubes*
 - *GXe Time Projection Chambers (TPCs) and EL-TPCs*
- Liquid Xe detectors:
 - *Single-phase LXe TPCs*
 - *Dual-phase (liquid+gaseous) TPCs*
 - *LXe calorimeters*
- Xe doping of other detection media

Xenon Proportional Counters and MWPCs

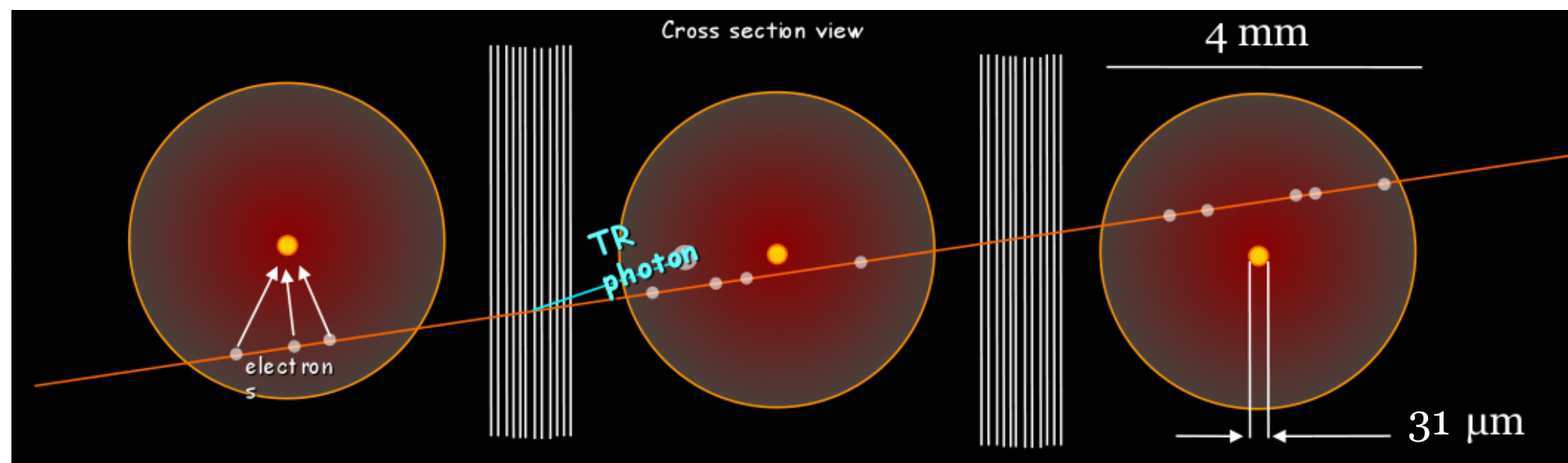
- First Xe-filled radiation detectors (1950s)
- Ionization electrons drift towards a strong electric field region, usually near small diameter (eg, 25 μm) anode wire
- Electrons engage in ionizing collisions that lead to an avalanche with an average multiplication gain of order 10^3 - 10^4



- If space charge effects can be neglected, average number of electrons in the avalanche is **proportional** to the deposited energy, as in EL detector
- Fluctuations in avalanche gain $\rightarrow$ energy resolution not as good as EL gain
- Applications: X-ray spectroscopy, radioactive contamination detection
- If reading multiple, closely-spaced, anode wires $\rightarrow$ **MWPCs**

Drift (Straw) Tubes

- Difference with MWPCs: track position inferred not only from anode wire position, also from **time** it takes for ionization electrons to **drift** to them!
- Straw tube: cylindrical cathode tube filled with gas mixture, with a central anode wire. Drift chamber: collection of many drift cells
- Used for particle tracking applications. Allow for fast (ns-level) readout
- Can also provide particle identification, by detecting transition radiation photons (5-30 keV) → Xe is excellent absorber for those

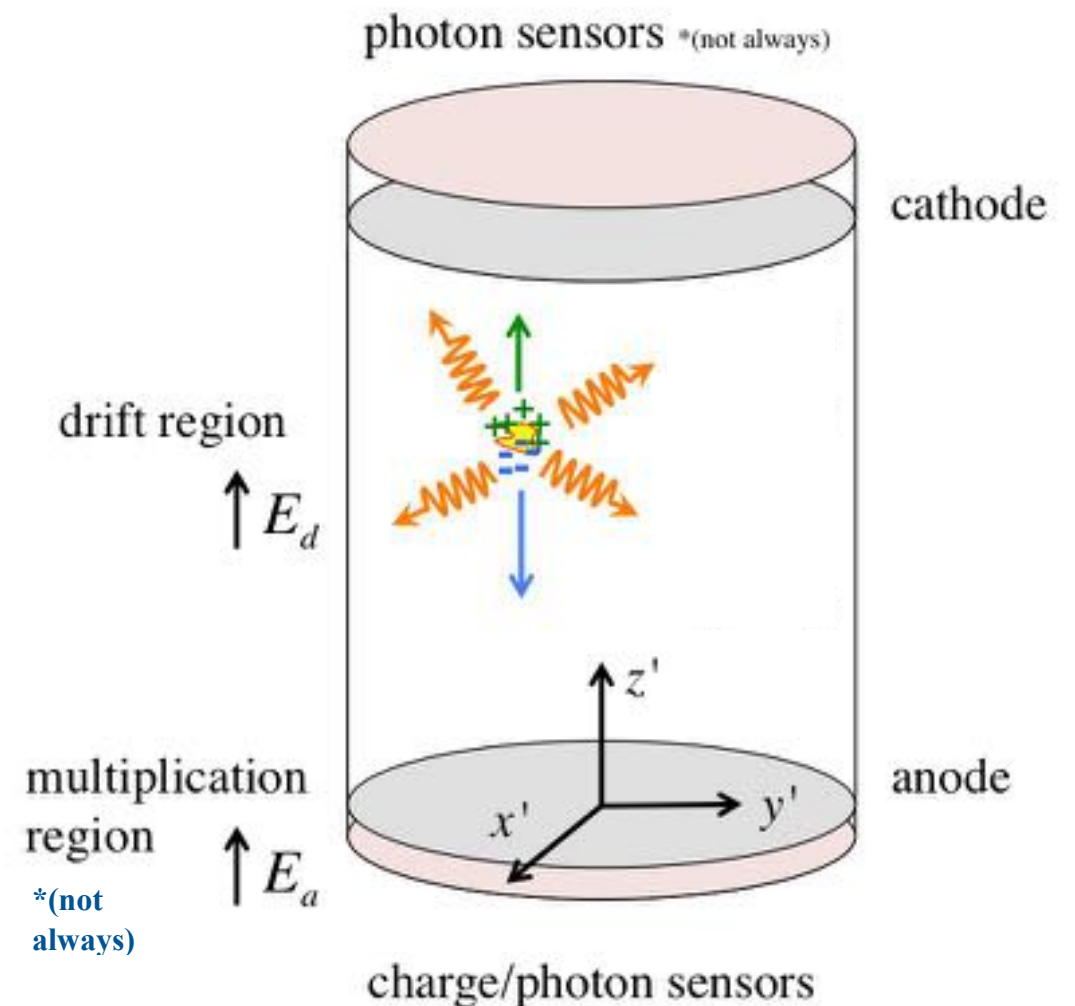


ATLAS Transition
Radiation Tracker
(TRT)

Time Projection Chambers (GXe and LXe)

Working Principle

- TPC invented by David Nygren in 1974. Probably most important detector concept employing noble elements
- Charged particles deposit energy via ionization and scintillation in drift region between cathode and anode readouts
- **TPC principle:** full 3D imaging from 2D image on readout planes as a function of electron drift time (3rd dimension)
- Unlike drift chambers, TPCs have large drift volumes and segmented anodes
- Scintillation light provides event timing
- Single-phase Xe-TPCs widely used for $0\nu\beta\beta$ searches. Examples: EXO-200 (LXe), NEXT-100 (high-pressure GXe)

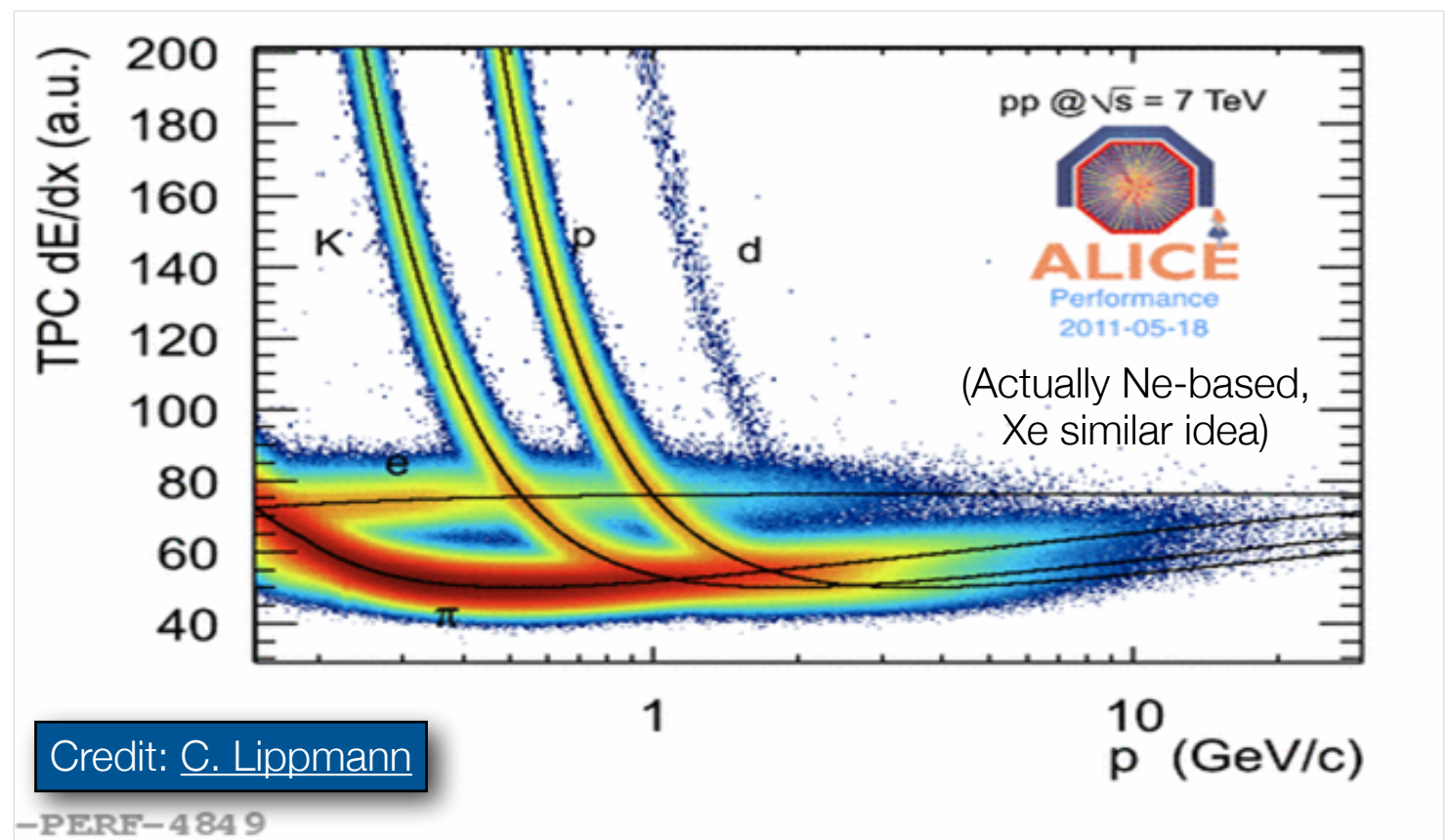


Time Projection Chambers (GXe and LXe)

Advantages and Disadvantages

Advantages

- Excellent **imaging** from mm-scale resolution
- Accurate **calorimetry** from fully active volume and large ionization signal
- **Particle identification** from dE/dx information

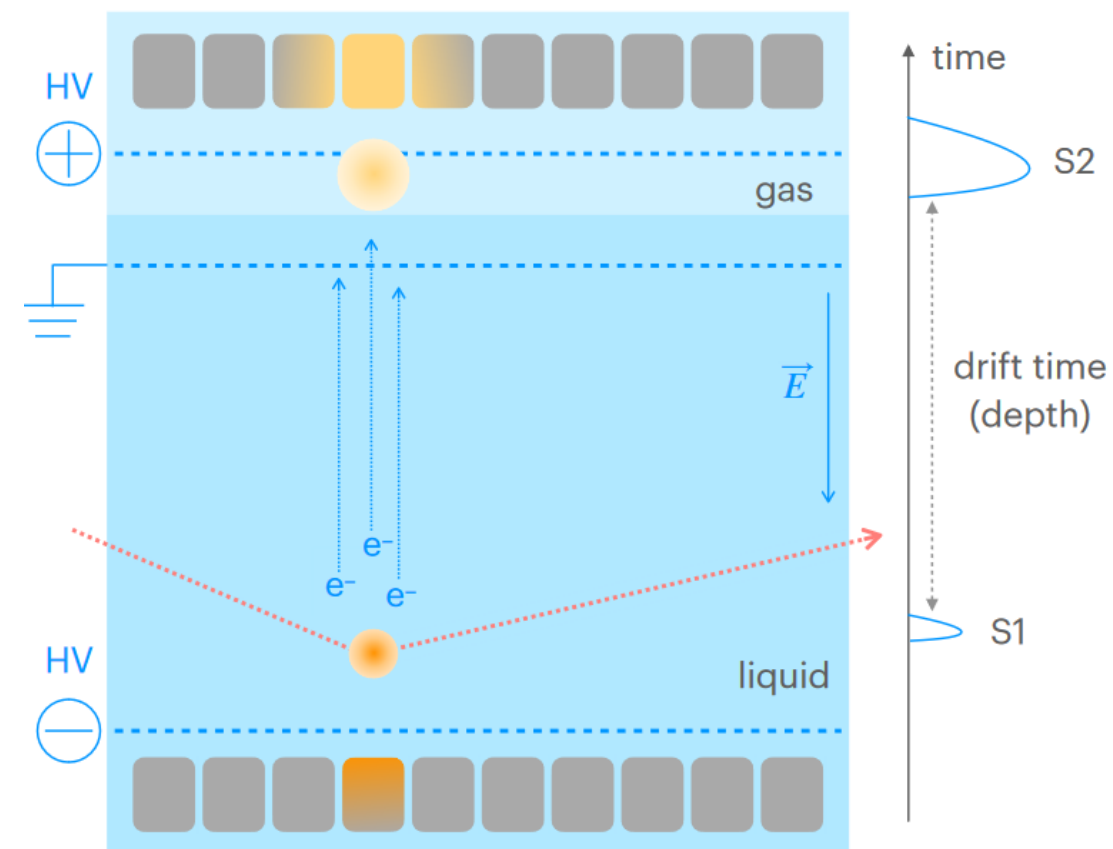


Disadvantages: technically challenging! Requires:

- O(ppm-ppb) impurities (H_2O , O_2 , N_2) at most, very high voltages: O(100 kV)
- Cryogenics for LXe-TPCs, typically operated at 170-180 K
- Vessels for high-pressure GXe-TPCs, typically operated at 10 bar

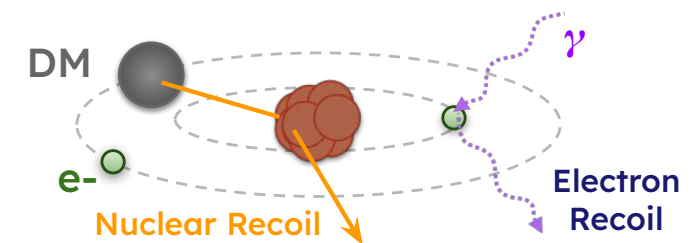
Dual-Phase Xe-TPCs

- Combines large active mass of single-phase LXe with ionization signal amplification of single-phase GXe
- Widely used for WIMP dark matter searches: LZ, XENONnT, PandaX-4T
- **S1**: primary scintillation signal $\rightarrow$ event t_0
- **S2**: optical readout of charge, extracted and amplified in gas $\rightarrow$ low energy threshold and good energy resolution
- If sufficiently segmented, top anode readout provides fine 3D position reconstruction $\rightarrow$ fiducialization
- S1 vs S2 information $\rightarrow$ discrimination between electron and nuclear recoils

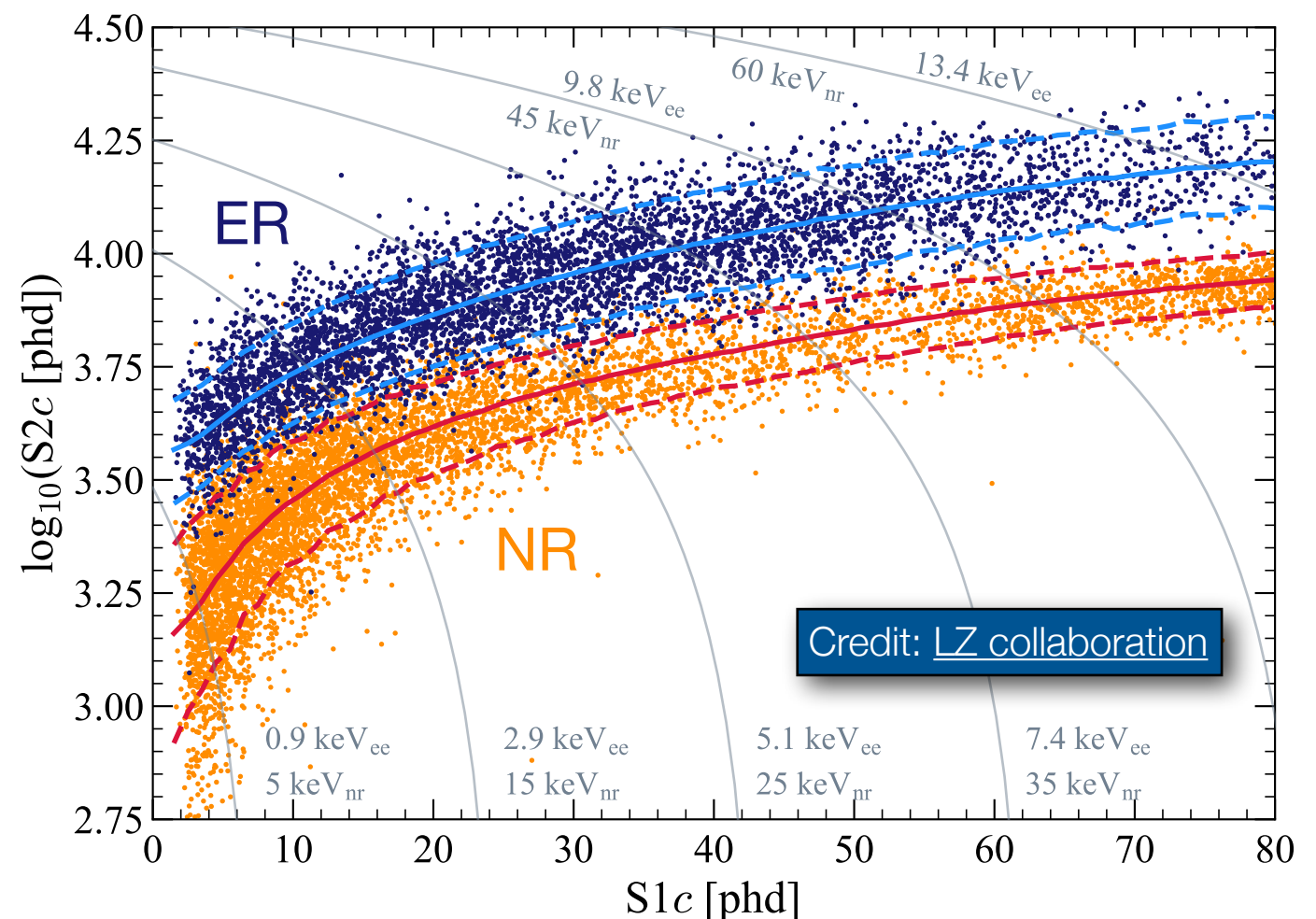


Particle Identification From S1 and S2 Signals

- S1 vs S2 information provides discrimination between electron (ER) and nuclear (NR) recoils
 - Critical for WIMP dark matter searches: signal NR-like, background ER-like*

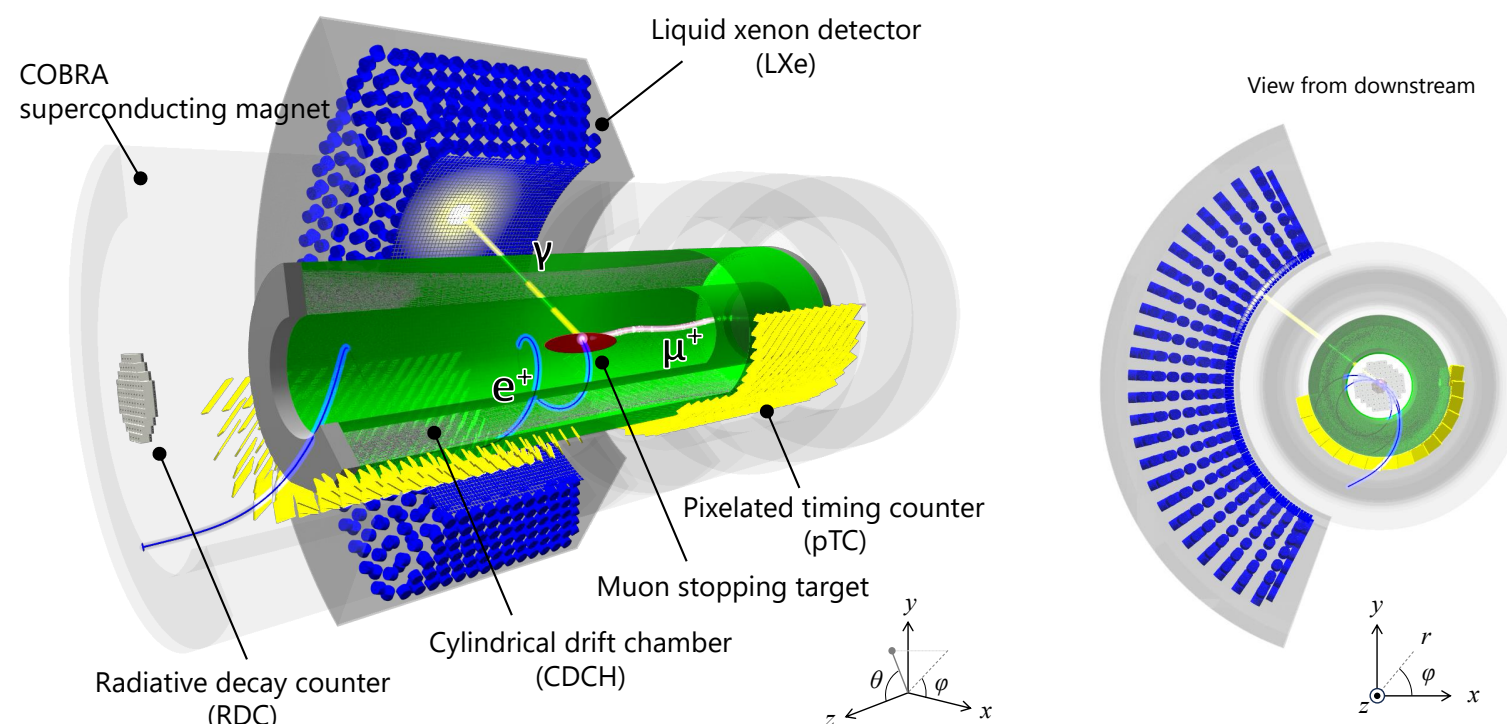


- Example from LZ detector:
 - Calibration ER data from tritium (CH_3T) source mixed with Xe, producing 0-18.6 keV electrons via ${}^3\text{H} \rightarrow {}^3\text{He} + e^- + \bar{\nu}_e$*
 - Calibration NR data from deuterium-deuterium generator outside cryostat, producing 2.45 MeV neutrons via $d + d \rightarrow {}^3\text{He} + n$*



LXe Calorimeters

- LXe can be operated as a pure scintillation detector, without any drift field
- At zero field, primary scintillation has even higher yield (40,000 photons/MeV produced) because of full recombination, and is fast
- Useful for applications requiring compact calorimeters for gamma-ray detection, with few-percent energy resolution and sub-ns time resolution
- Example: LXe detector of MEG II experiment ($\mu^+ \rightarrow e^+ \gamma$ search)

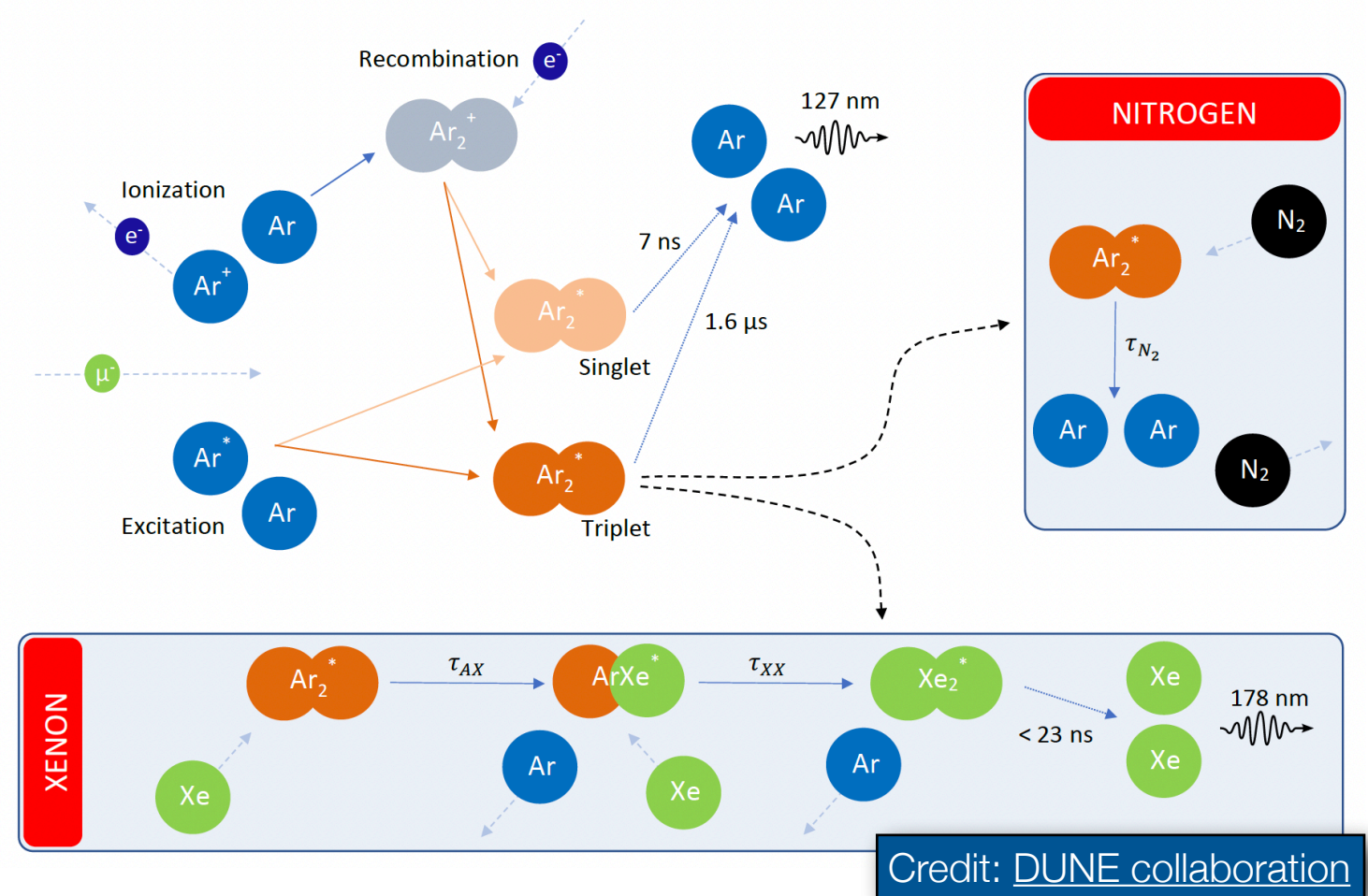


Credit: MEG II collaboration

Xenon Doping of Other Detection Media

- **In liquid argon:** efficient conversion of 127 nm Ar light into 178 nm Xe light by doping Ar with only 9(10 ppm) of Xe

- Advantages: much reduced Rayleigh scattering, faster time response, reduced light absorption by N_2 impurities
- Examples: DUNE (ν detection), LEGEND ($0\nu\beta\beta$)

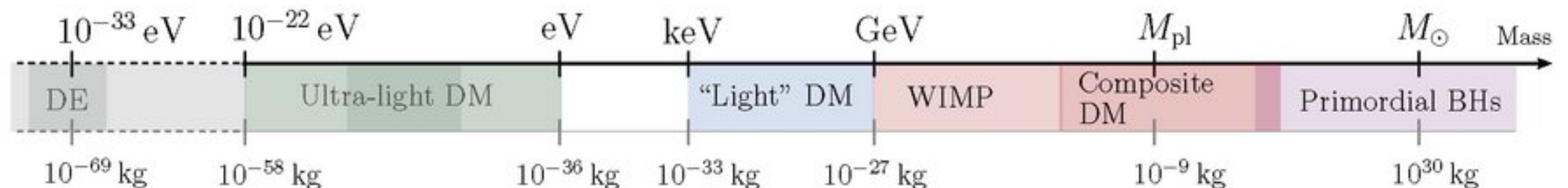
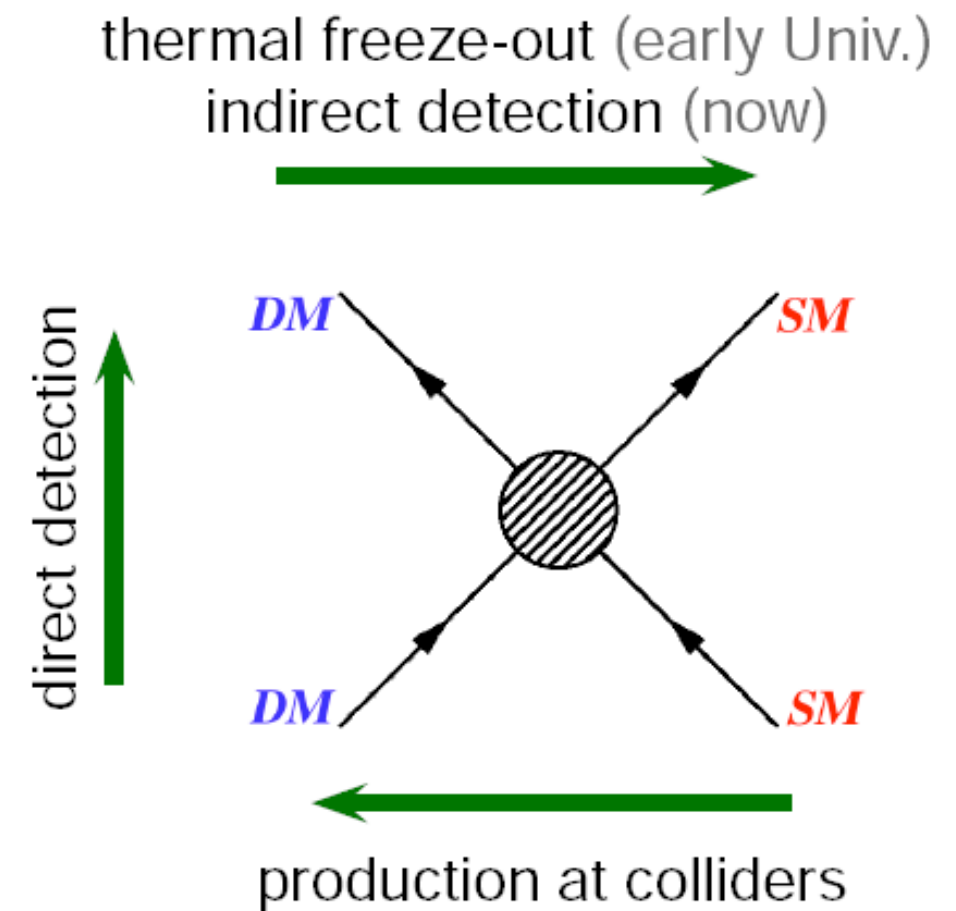


- **In liquid scintillators:** Xe added NOT to improve scintillation performance, but to provide a target isotope (^{136}Xe) for $0\nu\beta\beta$ searches. Example: KamLAND-Zen

Part IV – Xe Experiments for Dark Matter and Neutrinoless Double Beta Decay Searches

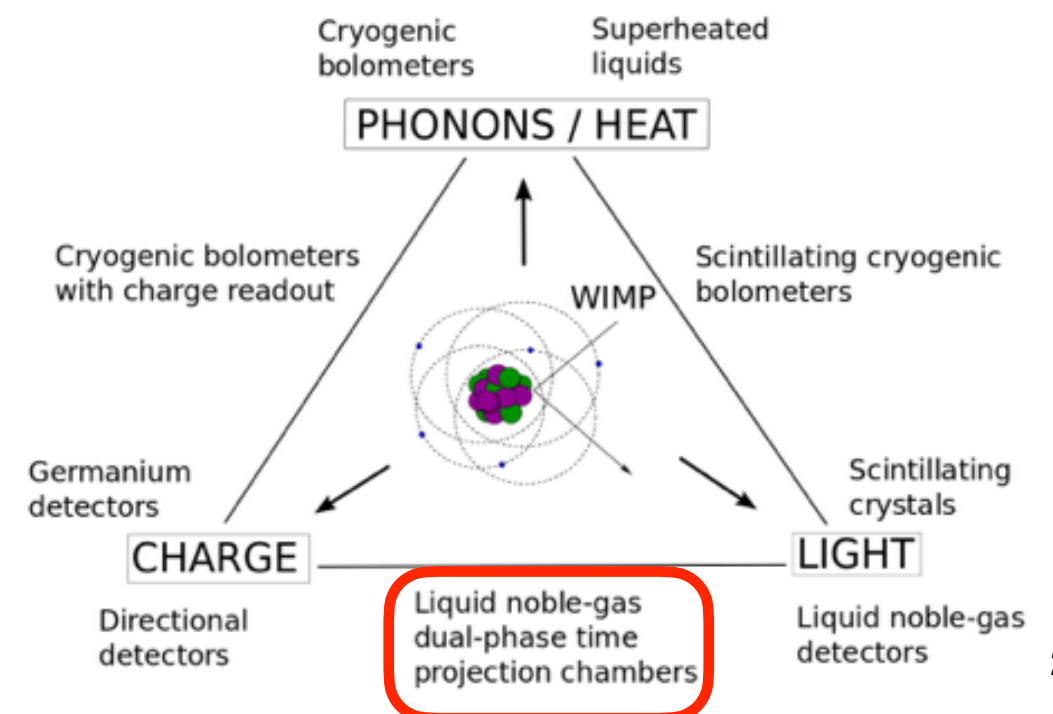
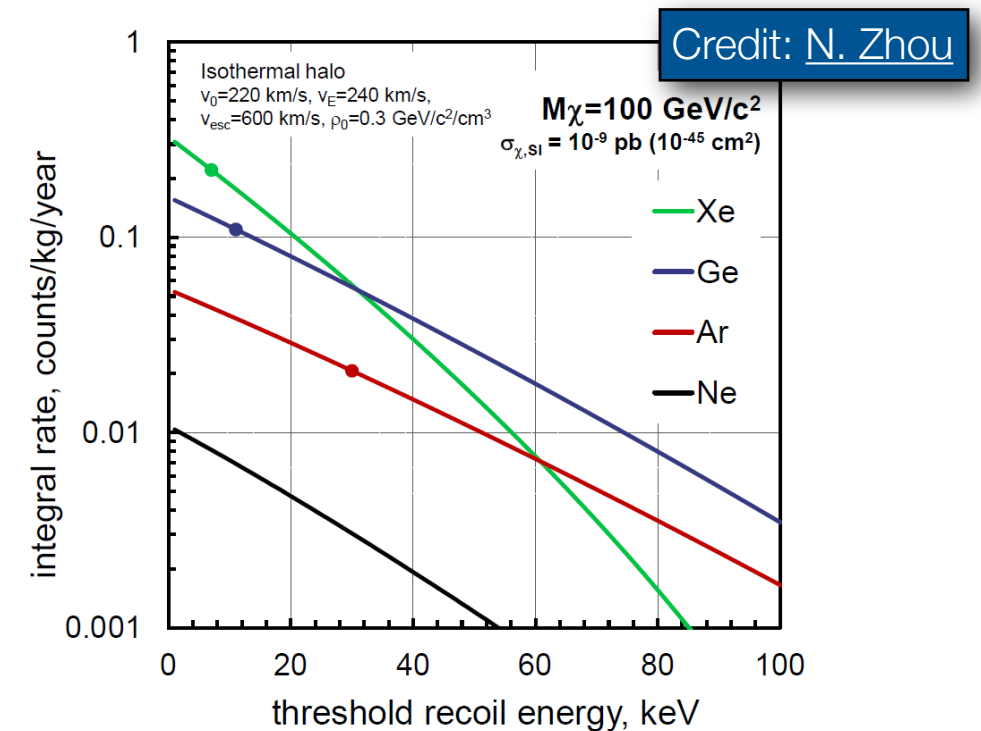
Dark Matter

- Necessary and very abundant component in our Universe
- Can be searched for in different ways, direct detection of nuclear recoils from DM-SM scattering being one way
- Particle candidates for DM span many orders of magnitude in mass
- WIMPs leading candidates, as they naturally produce the observed dark matter abundance

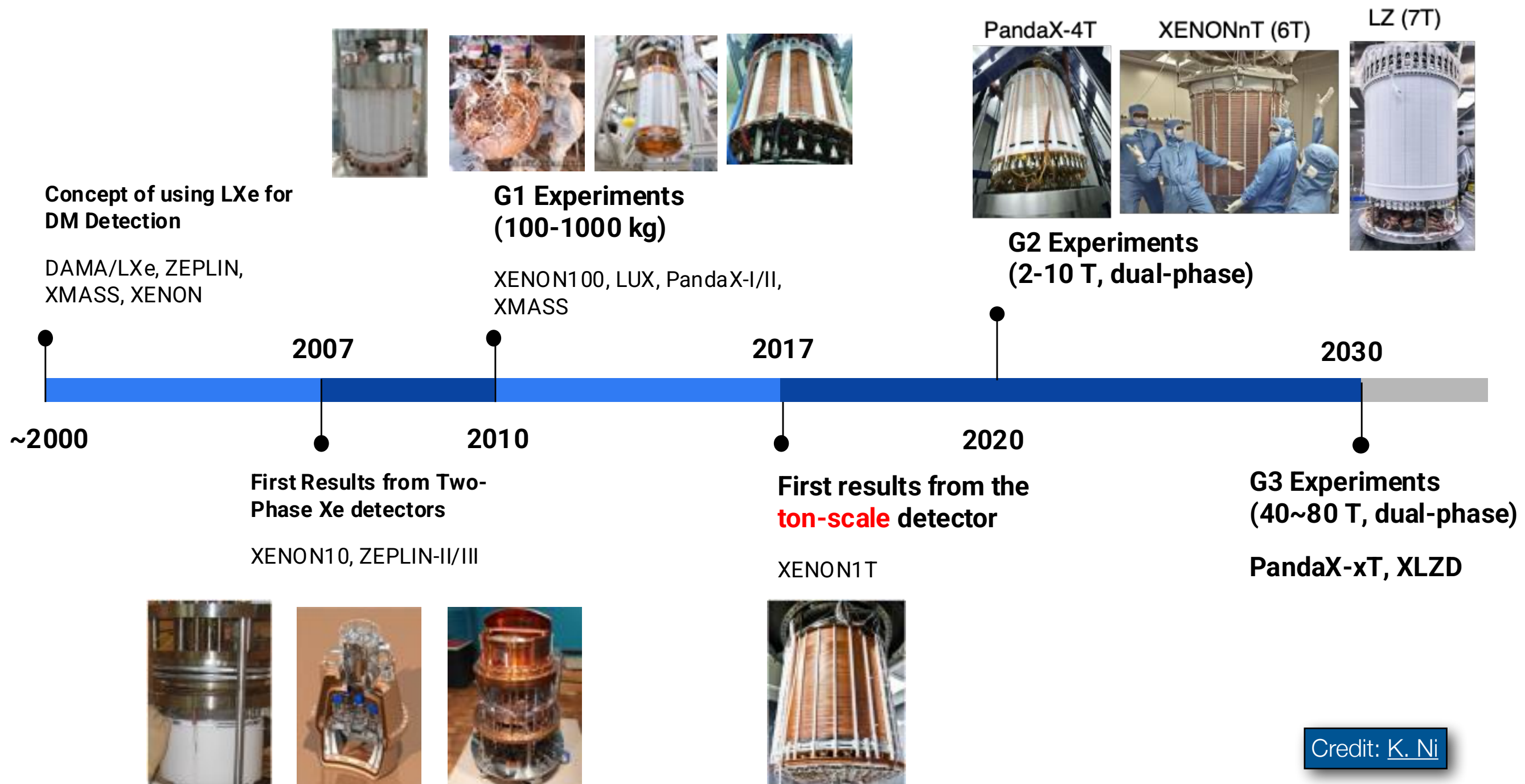


Why Xenon Dominates WIMP Dark Matter Direct Searches?

- Enhanced WIMP sensitivity thanks to heavy nucleus
- Spin-independent and spin-dependent sensitivity
- Simultaneous scintillation and ionization signals → background discrimination
- Excellent self-shielding and ultra-high purity
- Scalable to multi-ton detectors
- No long-lived radioactive isotopes



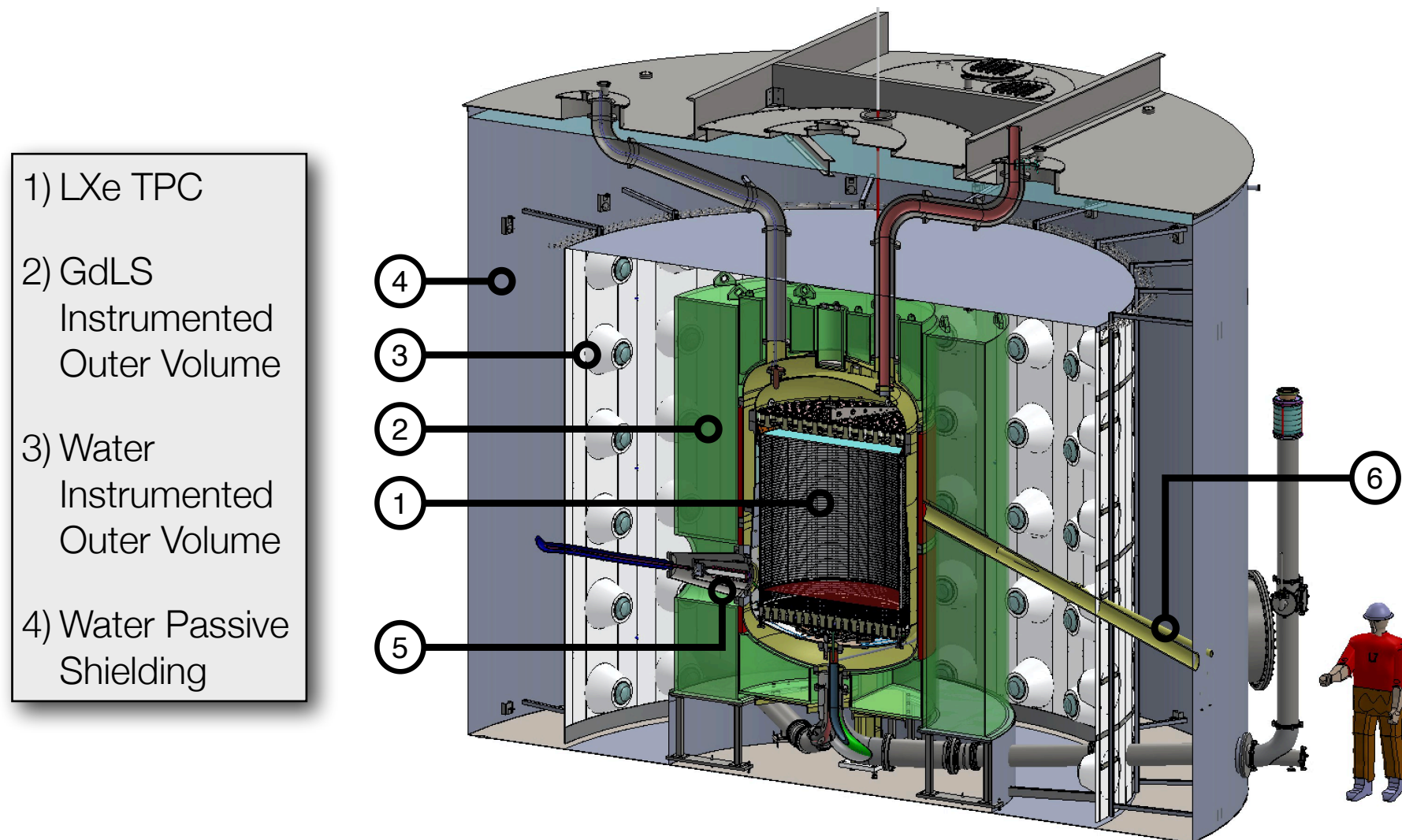
The Evolution of Dark Matter Detectors With LXe



Credit: [K. Ni](#)

LUX-ZEPLIN (LZ)

- Merger of LUX and ZEPLIN collaborations. 7-ton (active mass) detector
- Operating since 2021 at SURF (USA)



Credit: LZ collaboration

XENONnT

- Operating since 2020 at LNGS (Italy)

Credit: [M. Pierre](#)

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

1 Muon Veto

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

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

84 8" high-QE PMTs

[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. Phys. 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

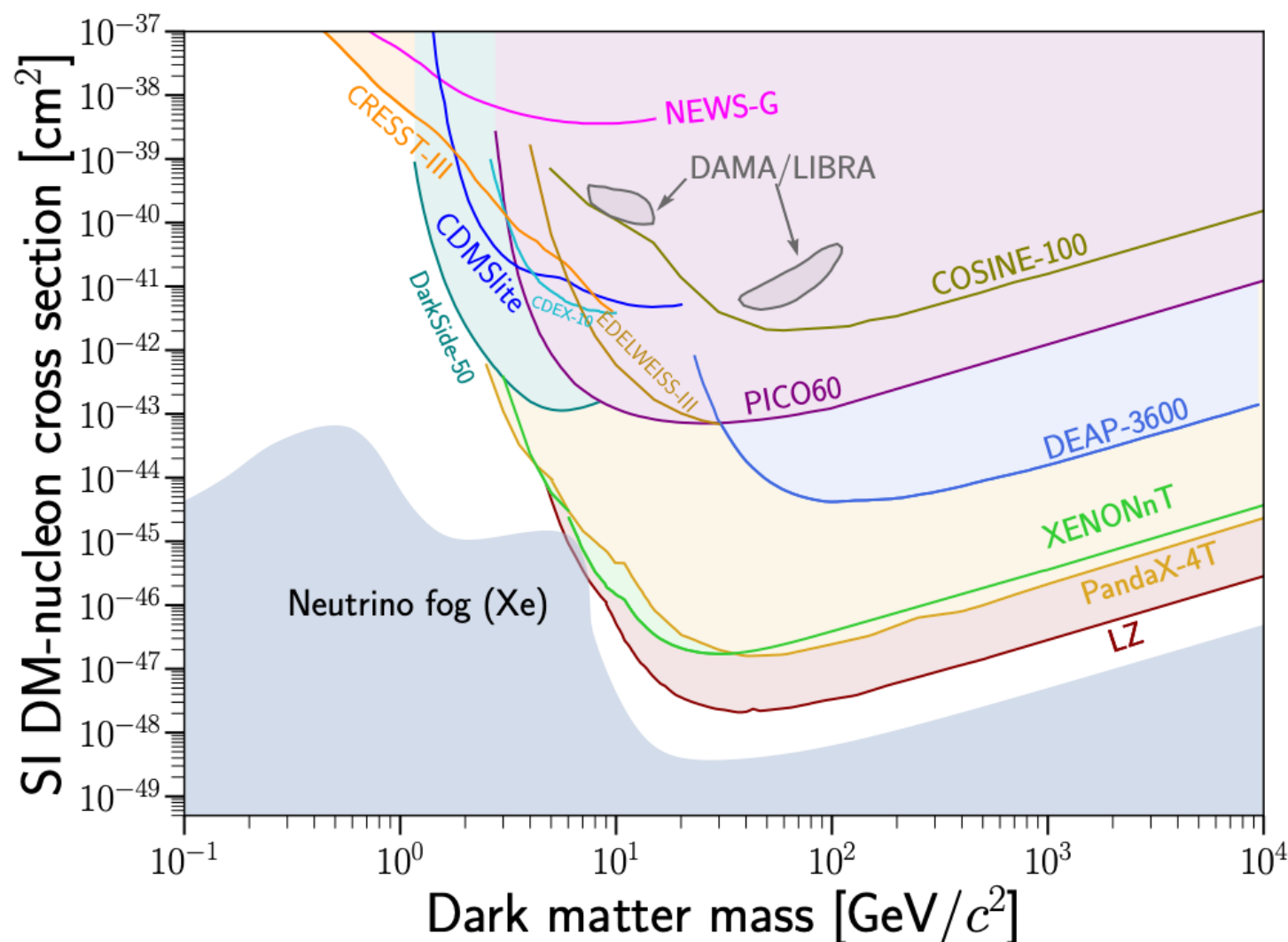
494 3" PMTs

[Eur. Phys. J. C 84 \(2024\) 784](#)



Current WIMP Limits and Coherent Elastic Neutrino-Nucleus Scattering

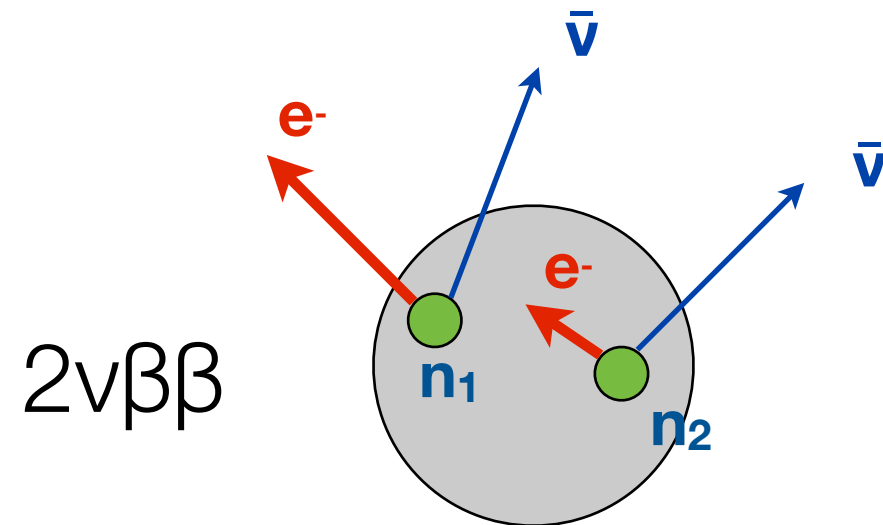
- Limits on spin-independent WIMP cross section versus DM mass
- Xe experiments reaching "neutrino fog" for WIMP masses ~ 5 GeV
 - *Neutrino fog: Irreducible background from Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) $\rightarrow$ LXe TPCs also ^8B solar neutrino detectors through CEvNS*



Credit: Q. Xia

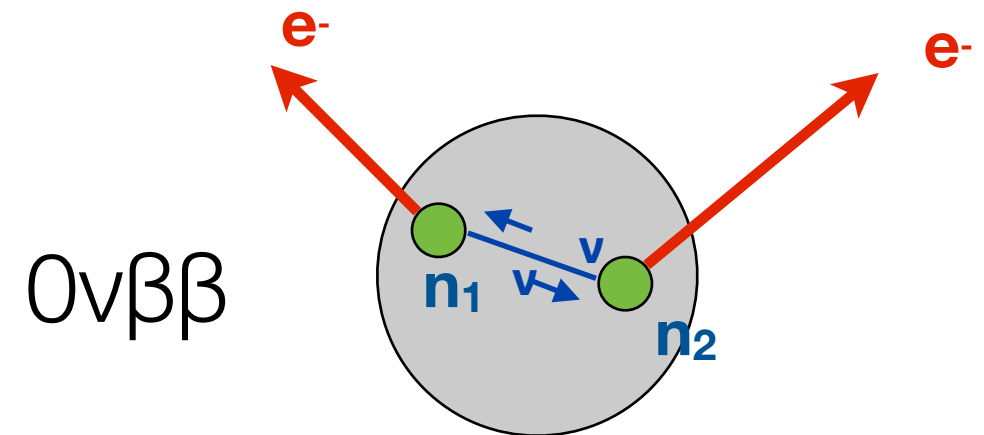
Double Beta Decay

- Rare $(Z,A) \rightarrow (Z+2,A)$ nuclear transition, with emission of two electrons
- Two basic decay modes



Two neutrino mode

- Observed in several nuclei
- $10^{19} - 10^{21}$ yr half-lives
- Standard Model allowed



Neutrinoless mode

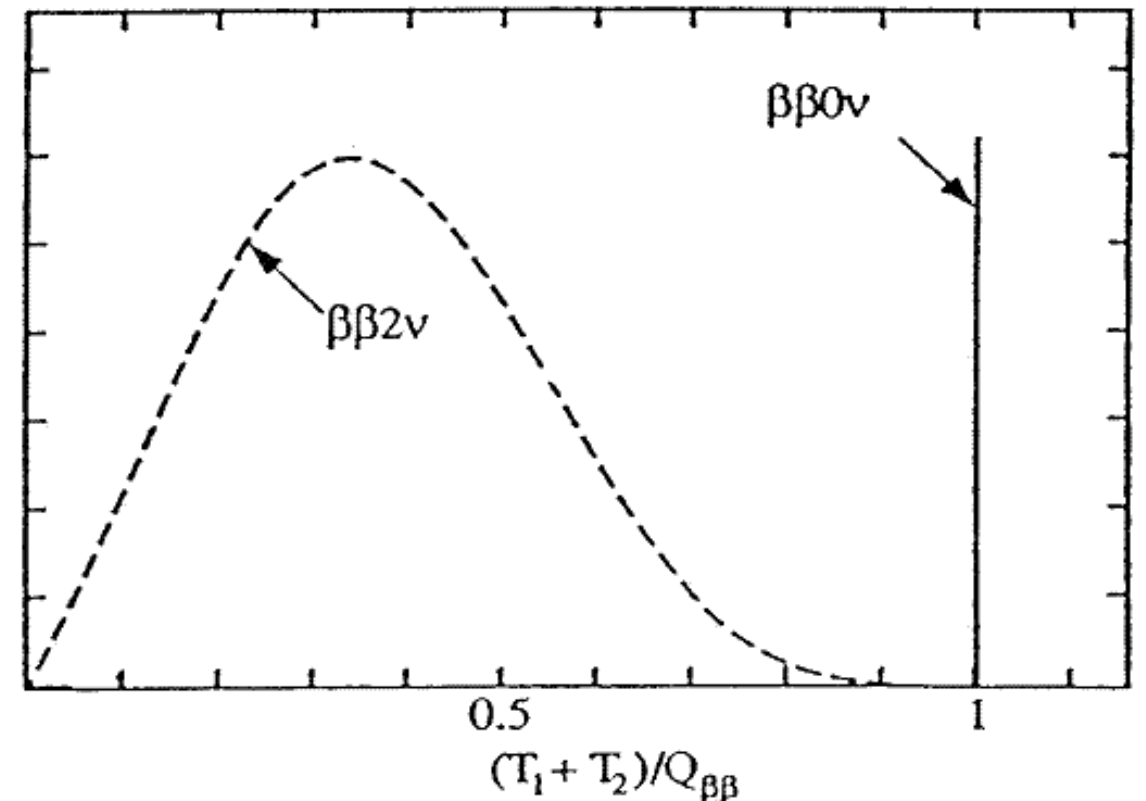
- Not observed yet in Nature
- $>10^{26}$ yr half-lives
- Would signal Beyond-SM physics

$\beta\beta 0\nu$ Experimental Signature

Rare Process To Be Isolated in Radio-Pure Detector Underground

1. Calorimetry (A MUST):

- 2 ν mode: continuous spectrum for sum electron kinetic energy T_1+T_2
- 0 ν mode: mono-energetic line at $Q_{\beta\beta}$ for T_1+T_2 spectrum



2. Topology of decay electrons (AN ADDITIONAL HANDLE):

- Single energy deposit in liquid / solid detectors
- Two electron tracks from common vertex in gaseous detectors

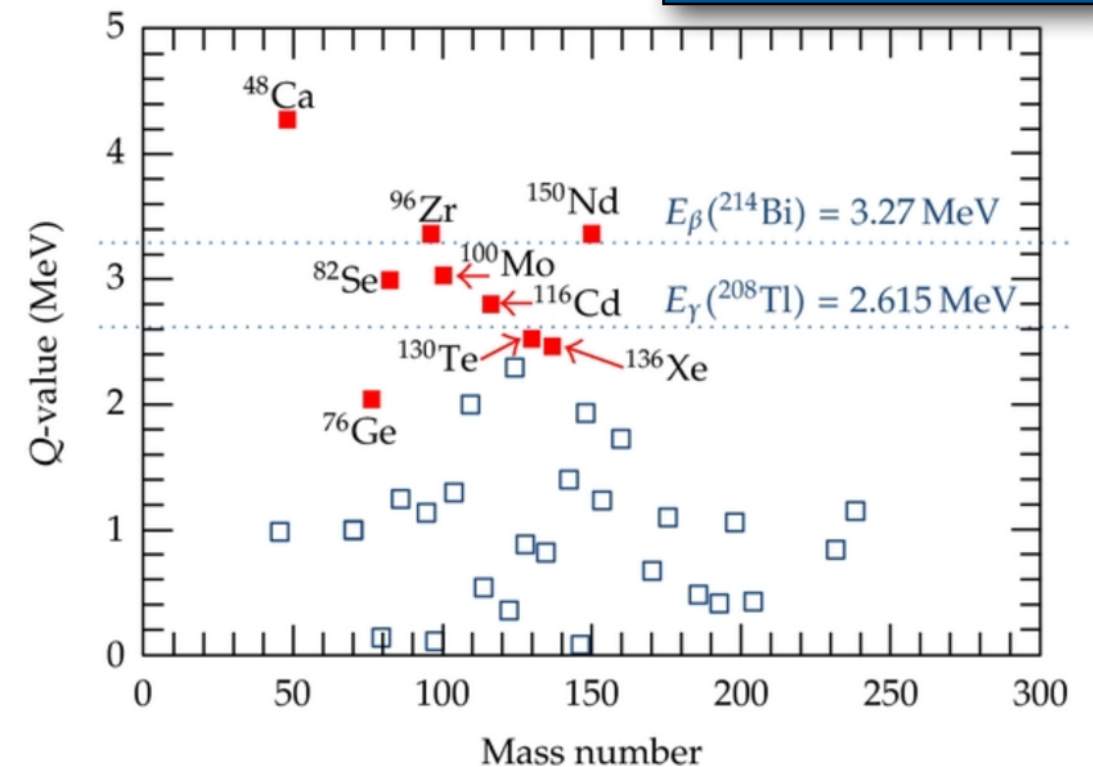
3. Daughter ion tagging (A DREAM):

- Observe ion produced in the decay

Why Xenon Detectors Are Leading Technologies for $0\nu\beta\beta$ Searches?

- Xenon contains a $\beta\beta$ isotope, ^{136}Xe
 - *8.9% natural abundance. Isotopic enrichment to ~90% is "cheap"*
 - *High Q-value (2458 keV) and slow $2\nu\beta\beta$ mode (2.17×10^{21} yr half-life)*
- Source = detector possible, scalable to ton-scale masses. Xe is recoverable
- Xenon TPCs:
 - *Excellent energy resolution*
 - *Excellent self-shielding in liquid xenon*
 - *Event topology in gaseous xenon*
 - *Possibility of daughter tagging: $^{136}\text{Xe} \rightarrow ^{136}\text{Ba}^{++} + 2e^-$*

Credit: A. Giuliani et al.

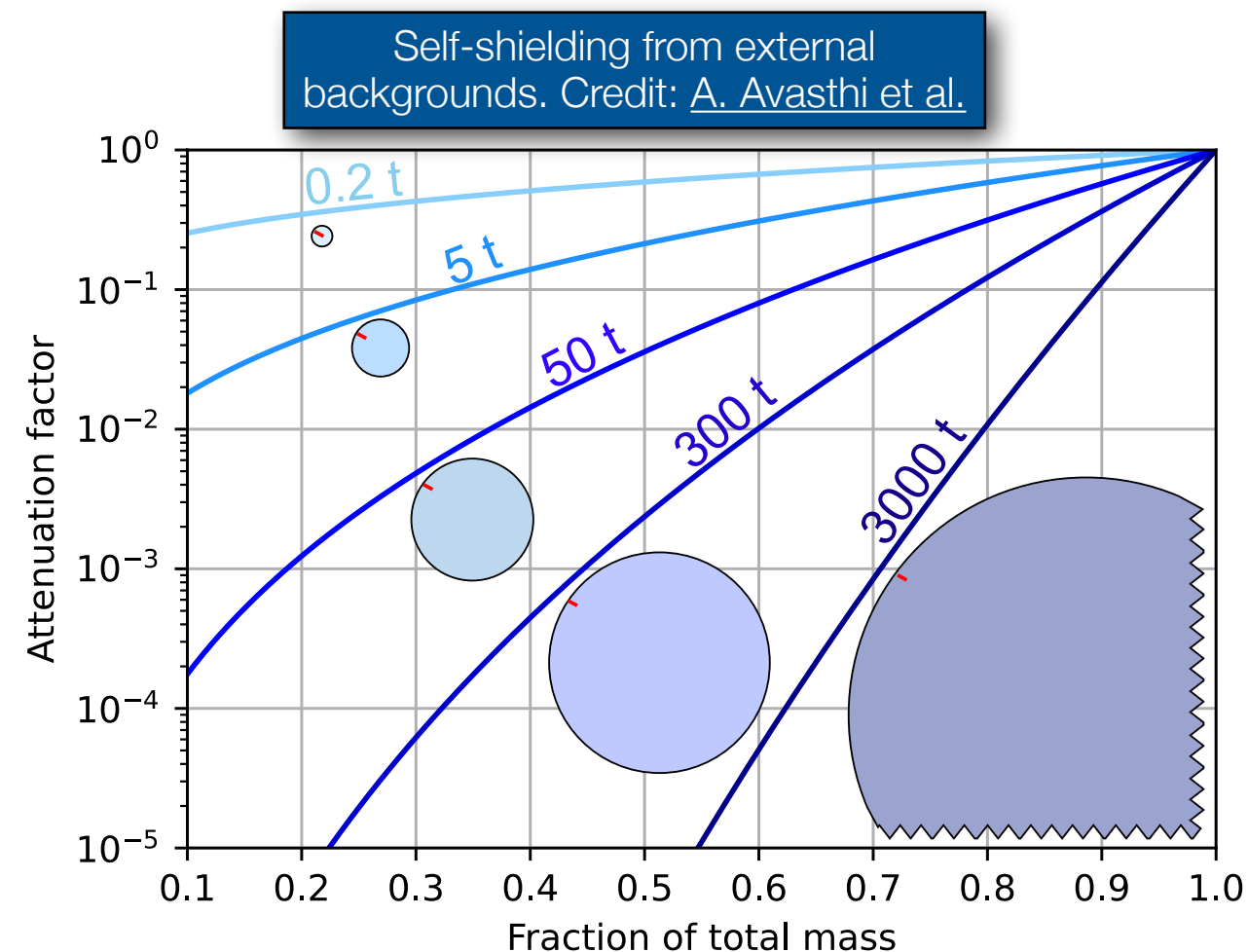


Isotope	Natural Abundance (%)
^{76}Ge	7.8
^{100}Mo	9.6
^{130}Te	34
^{136}Xe	8.9

Liquid Xenon TPCs (Single-Phase) for $0\nu\beta\beta$

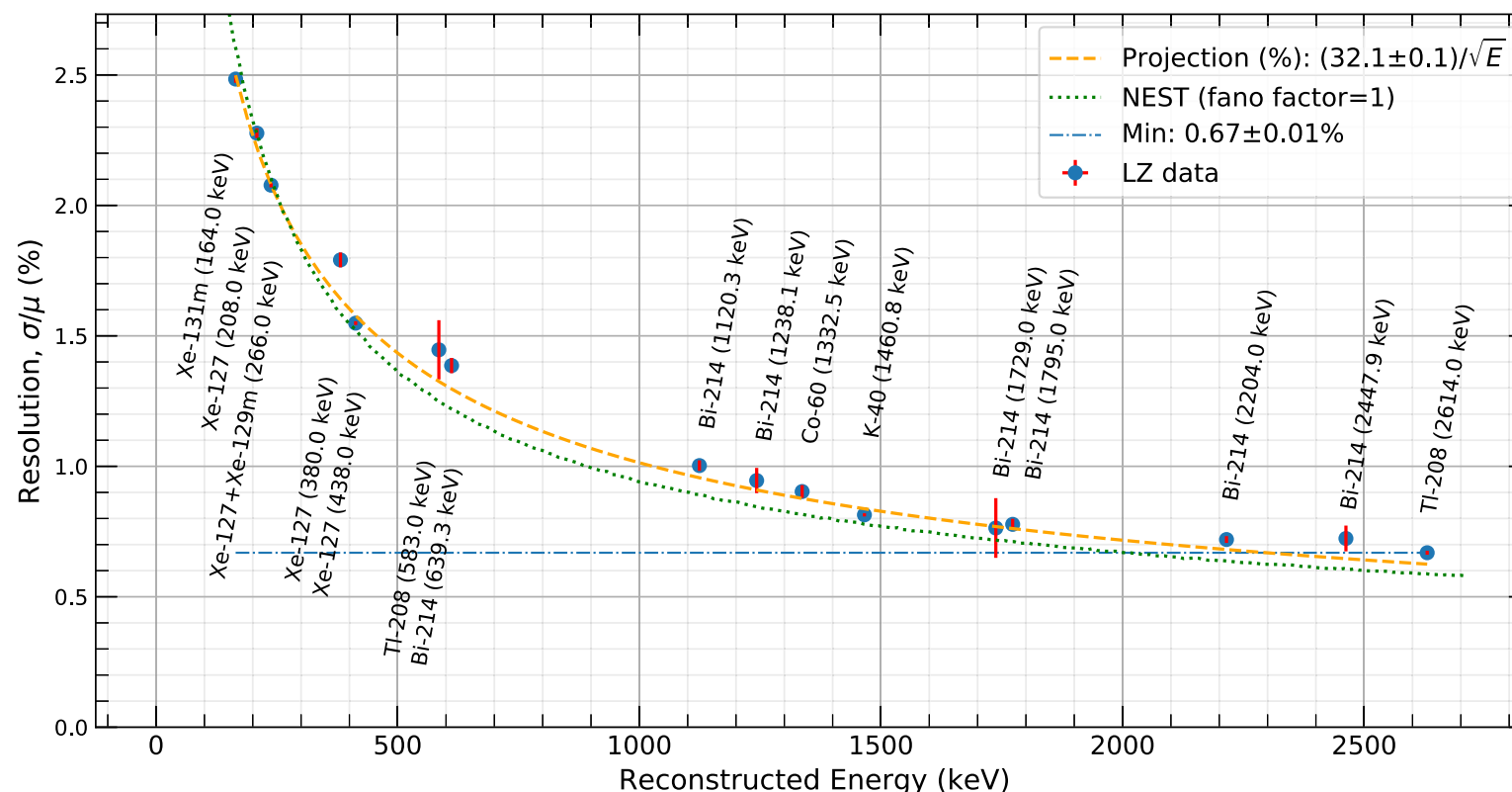
- Excellent self-shielding capabilities, particularly for larger detectors
 - *8.5 cm attenuation length for 2.5 MeV external gamma-rays*
- Excellent mass scalability, demonstrated in both LXe dark matter and LAr ν communities
- Some topological information, discriminating single-site versus multi-site energy deposits
- "Simple" engineering: no need to control liquid level, no extraction fields (and no loss of electrons due to incomplete extraction efficiency)

Mass (t)	Linear dimensions (m)
0.2	~0.3
5	~1
1000	~7



Dual-Phase Xenon TPCs for $0\nu\beta\beta$

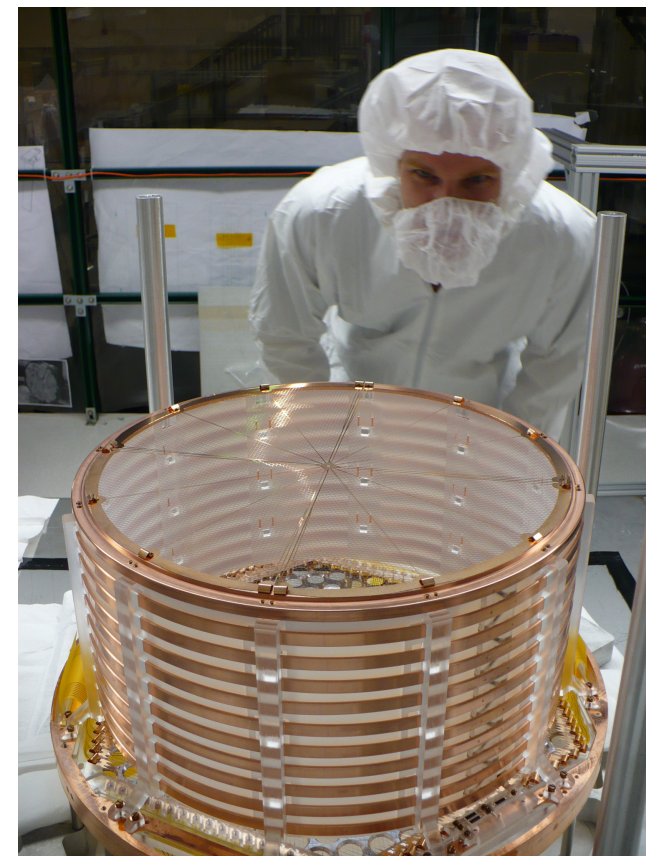
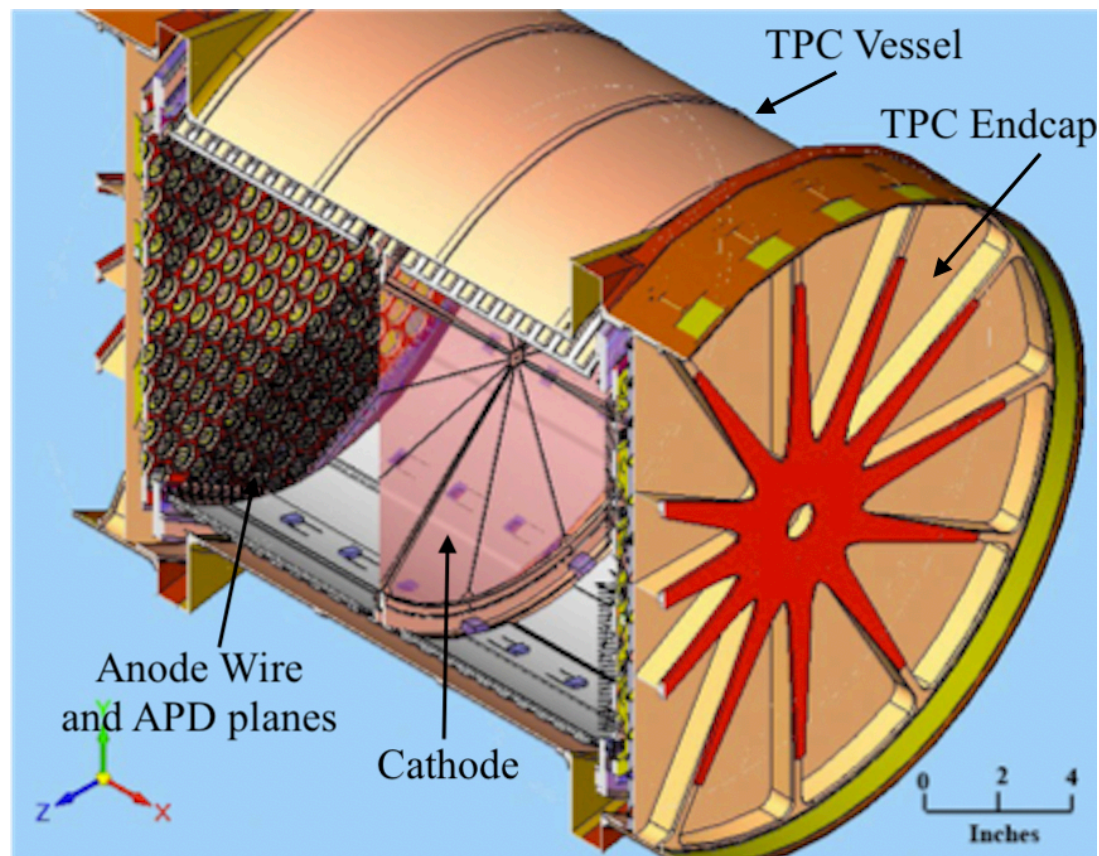
- Same self-shielding, mass scalability and topological discrimination capabilities as single-phase LXe TPCs
 - Amplification of charge signals possible. Compared to single-phase LXe:
 - *Better energy resolution: **1.6-1.8% FWHM** versus 2.8% FWHM at 2.6 MeV*
 - *Much lower energy threshold ($\sim$ keV)*
- $^{\text{nat}}\text{Xe}$ experiments (eg, XLZD) considered for joint DM and $0\nu\beta\beta$ searches



Credit: [LZ collaboration](#)

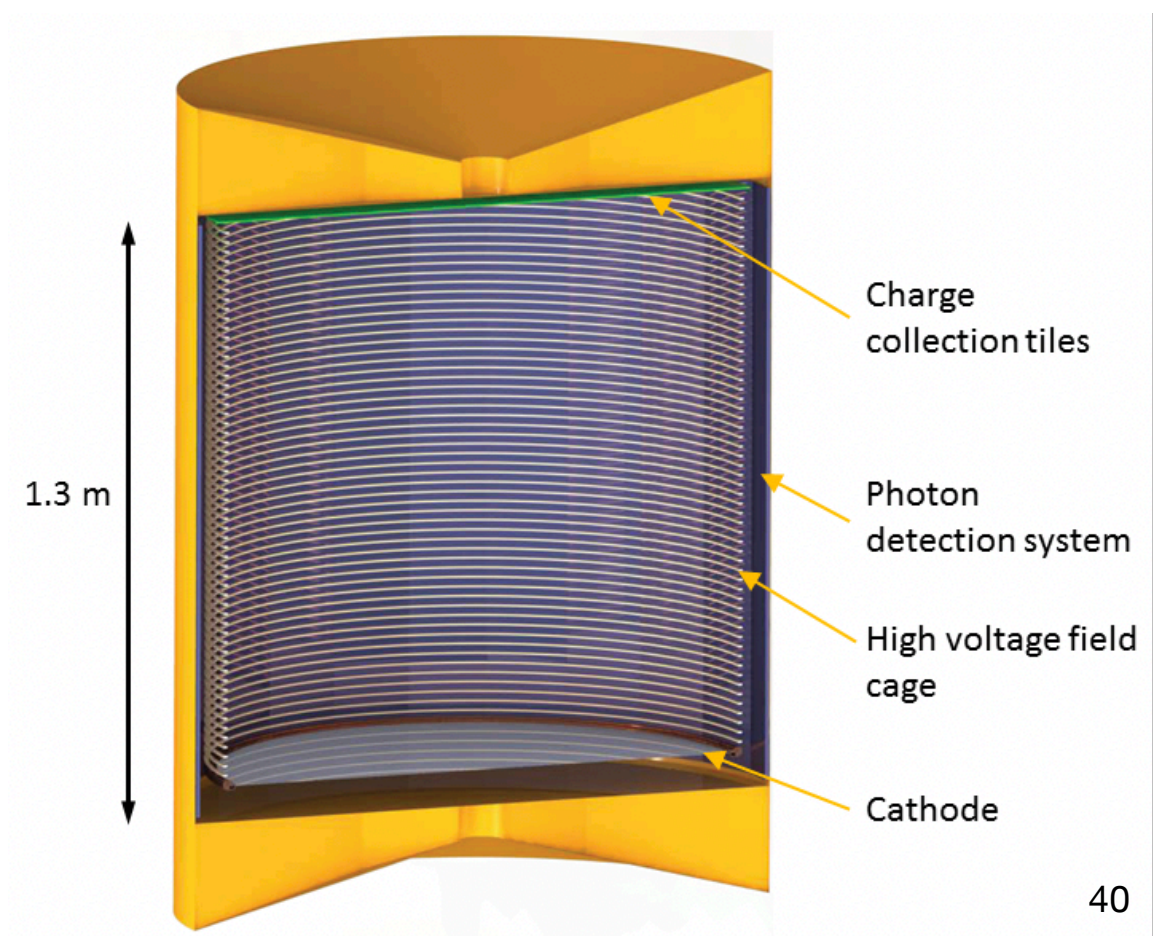
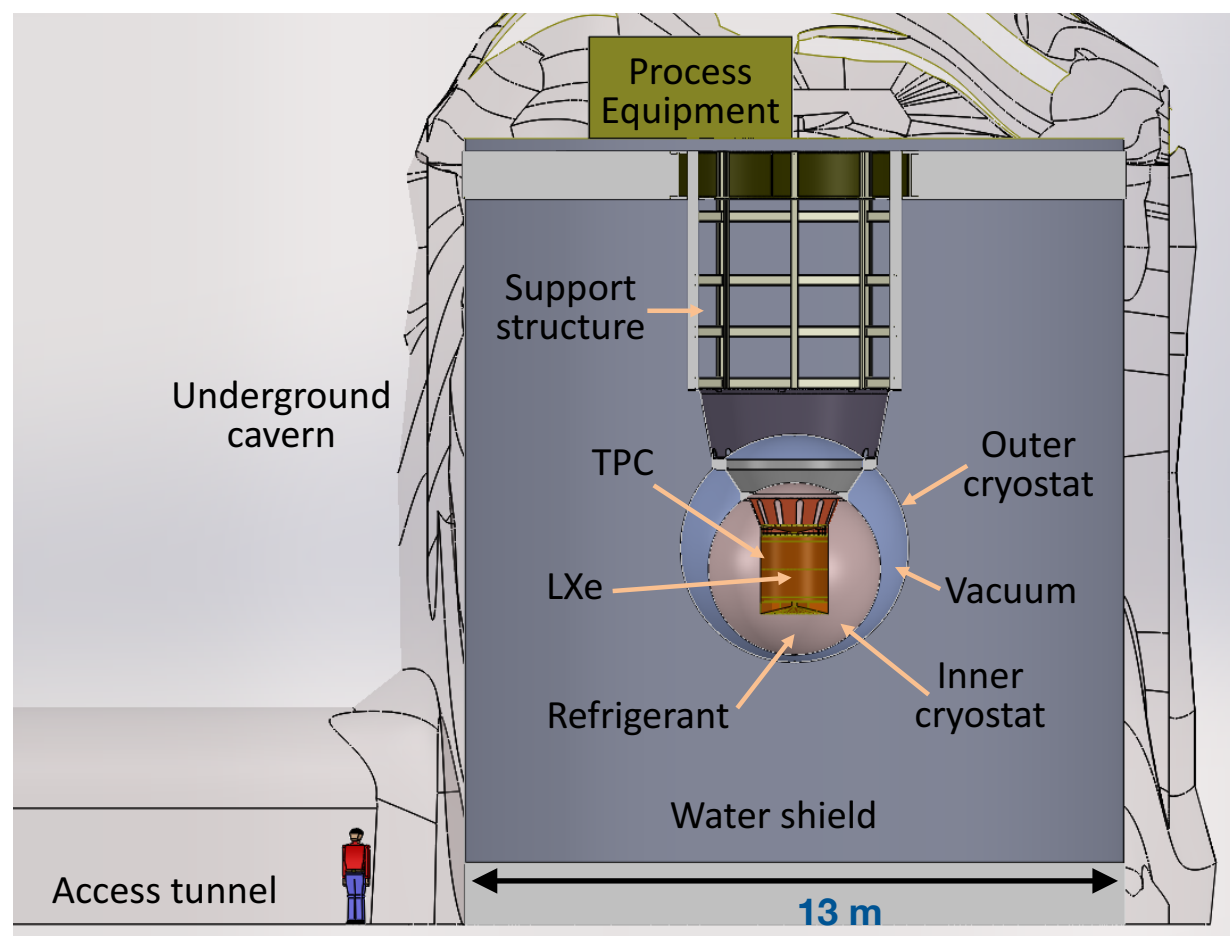
EXO-200

- Cryogenic time projection chamber filled with 110 kg (active) liquid xenon. Operated during 2011-2018 at WIPP (USA)
- TPC: two drift volumes with central cathode
- Charge readout: induction and collection wire grids, warm electronics
- Light readout: APDs behind anodes



nEXO

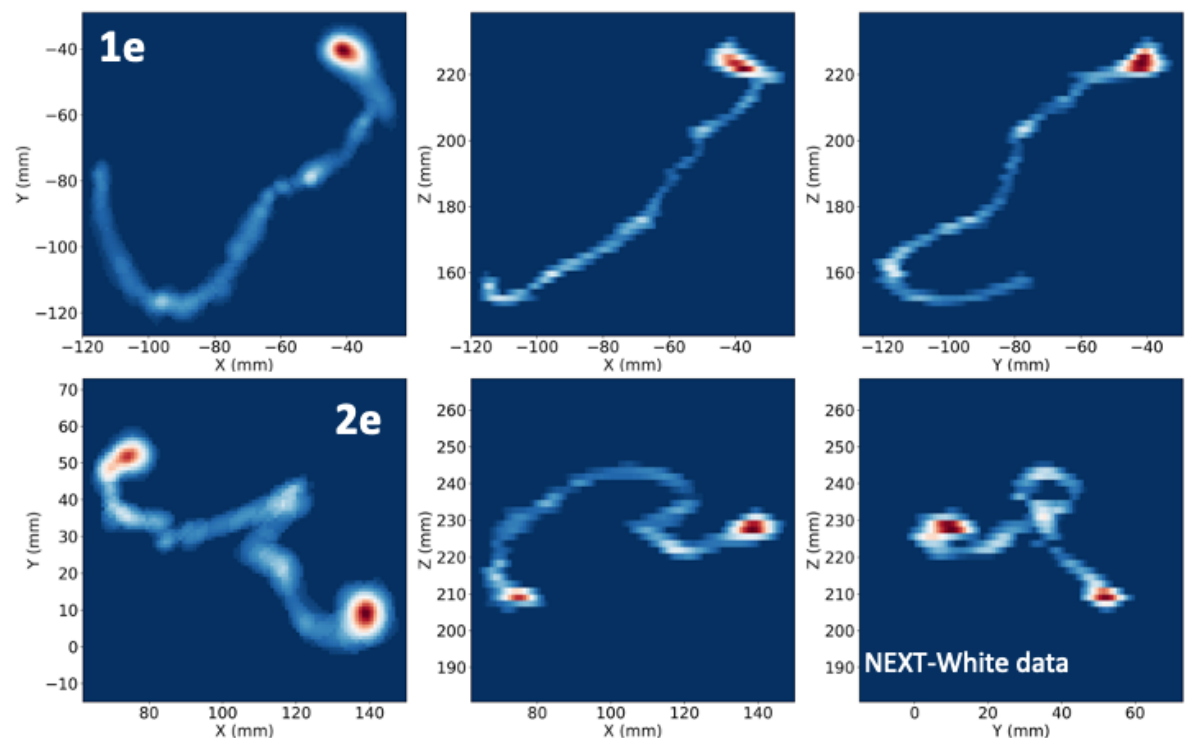
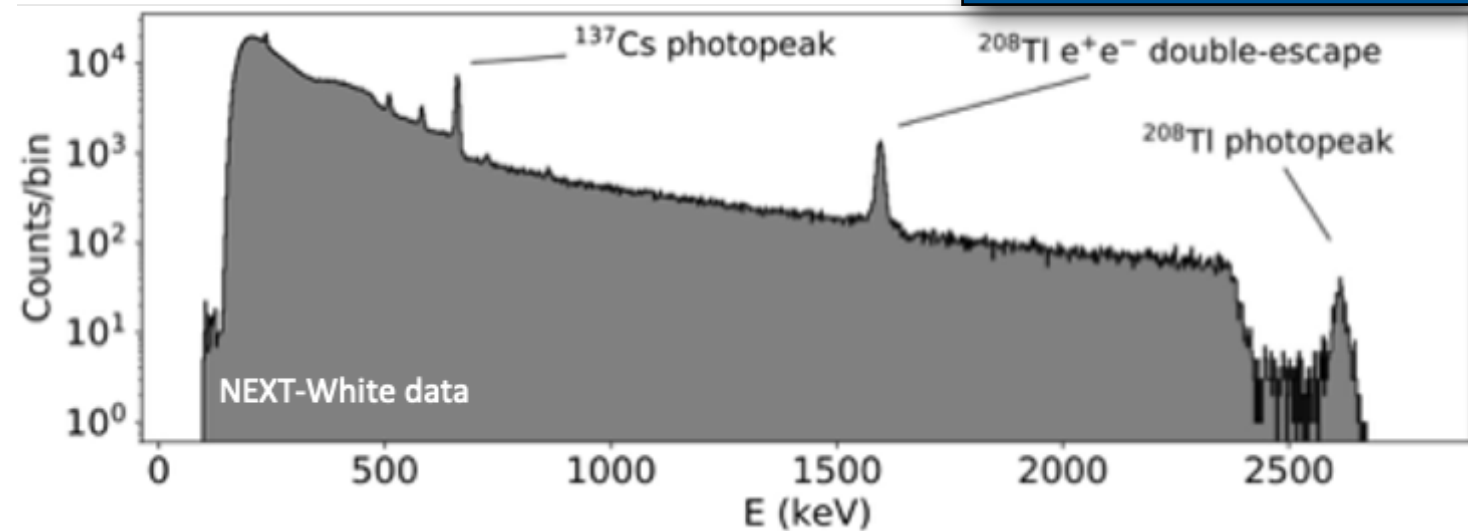
- Cryogenic TPC to be filled with 5 tons of LXe in active volume. Future project, Pre-Conceptual Design Report in 2018
- TPC: one drift volume (cathode at the bottom)
- Charge readout: wire-free design with charge tiles, electronics in LXe
- Light readout: VUV-sensitive SiPMs along barrel region



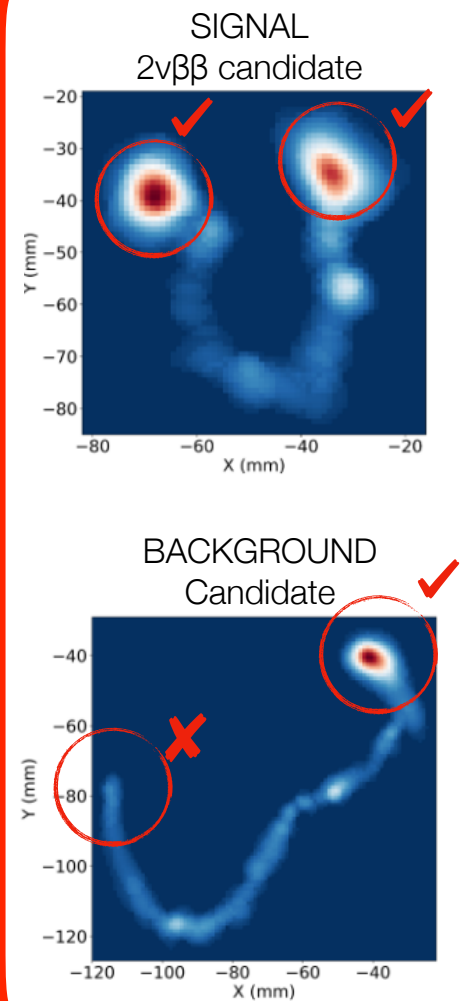
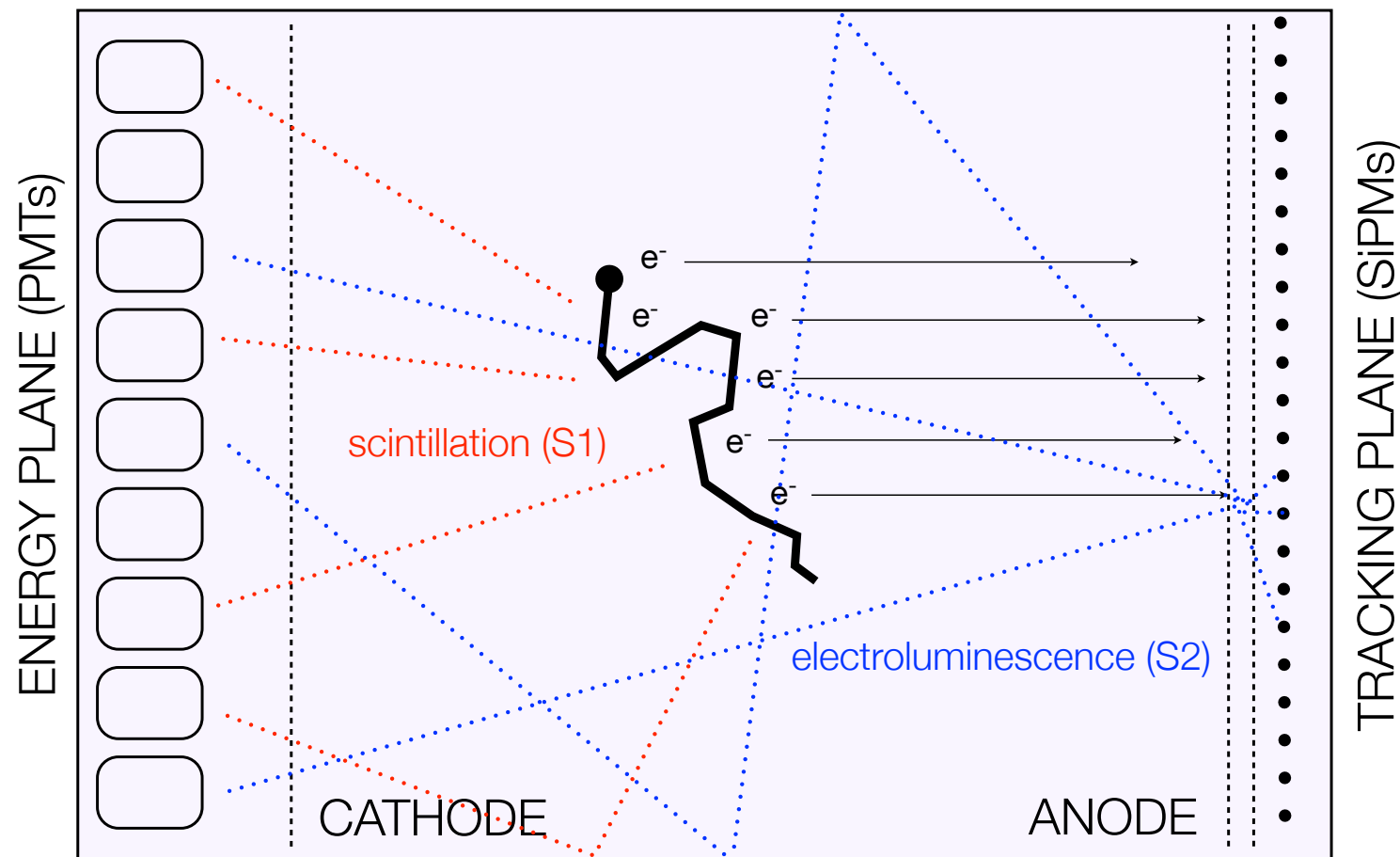
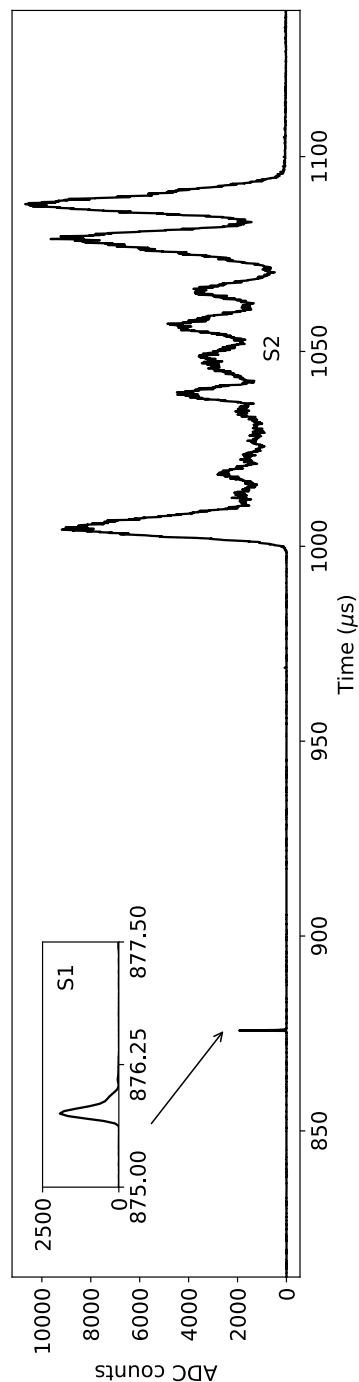
High-Pressure Xenon Gas TPCs for $0\nu\beta\beta$

- Precise energy resolution of 1% FWHM at $Q_{\beta\beta}$ achievable in xenon gas.
 - *Better than both single-phase LXe and dual-phase Xe*
- Topological event ID in xenon gas distinguishes 2e from 1e events
- Capabilities shared with LXe TPCs:
 - *scalability (but LXe better)*
 - *possibility of daughter ion tagging (better in gas?)*

Credit: [NEXT collaboration](#)



NEXT Detection Concept

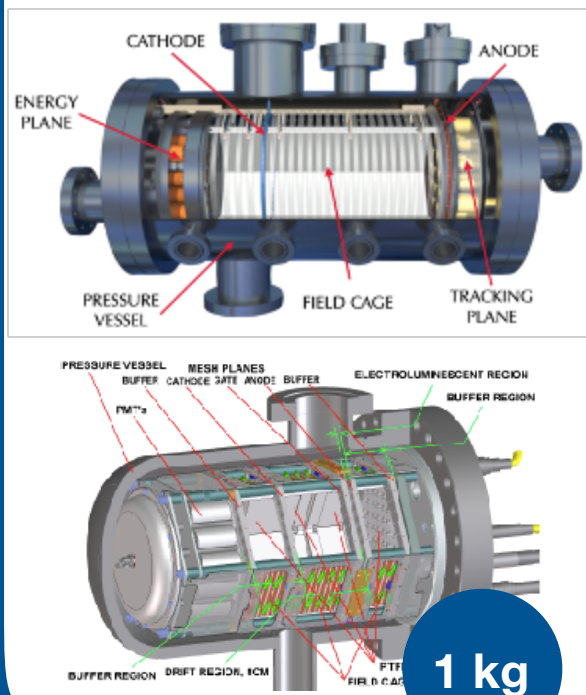


NEXT Experimental Program

Prototypes

2008-2015

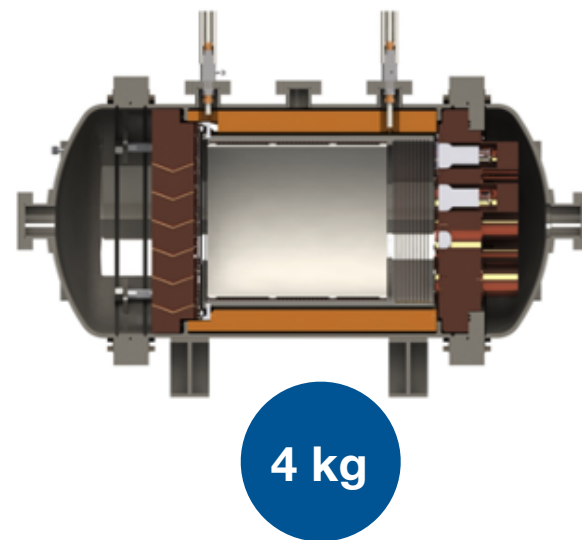
- Demonstration of detector concept



NEXT-White

2016-2021

- Performance at $Q_{\beta\beta}$
- Background meas.
- $2\nu\beta\beta$ measurement



NEXT-100

2024-2029

- Background meas.
- $0\nu\beta\beta$ search



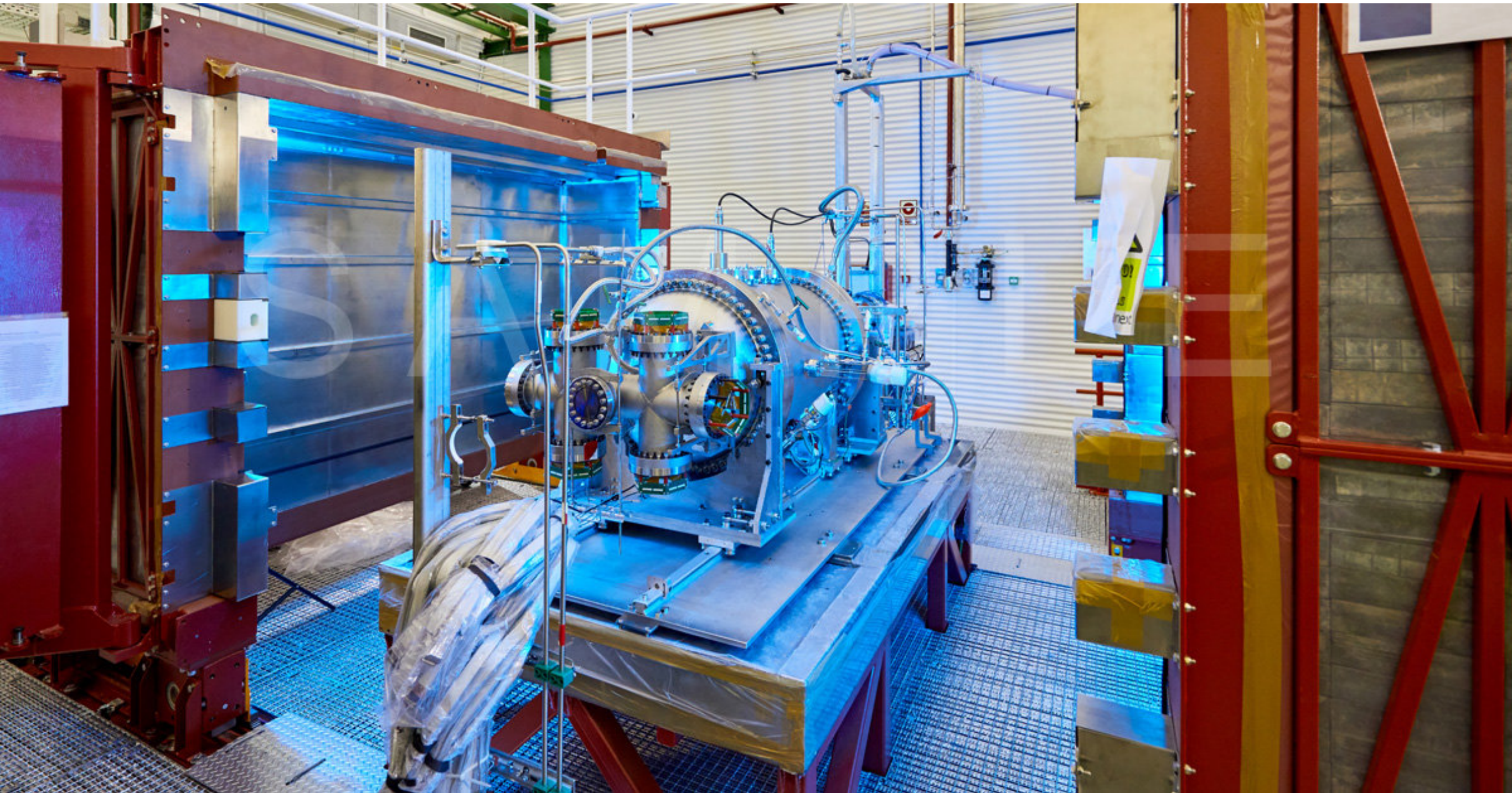
NEXT-HD / NEXT-BOLD

2030s

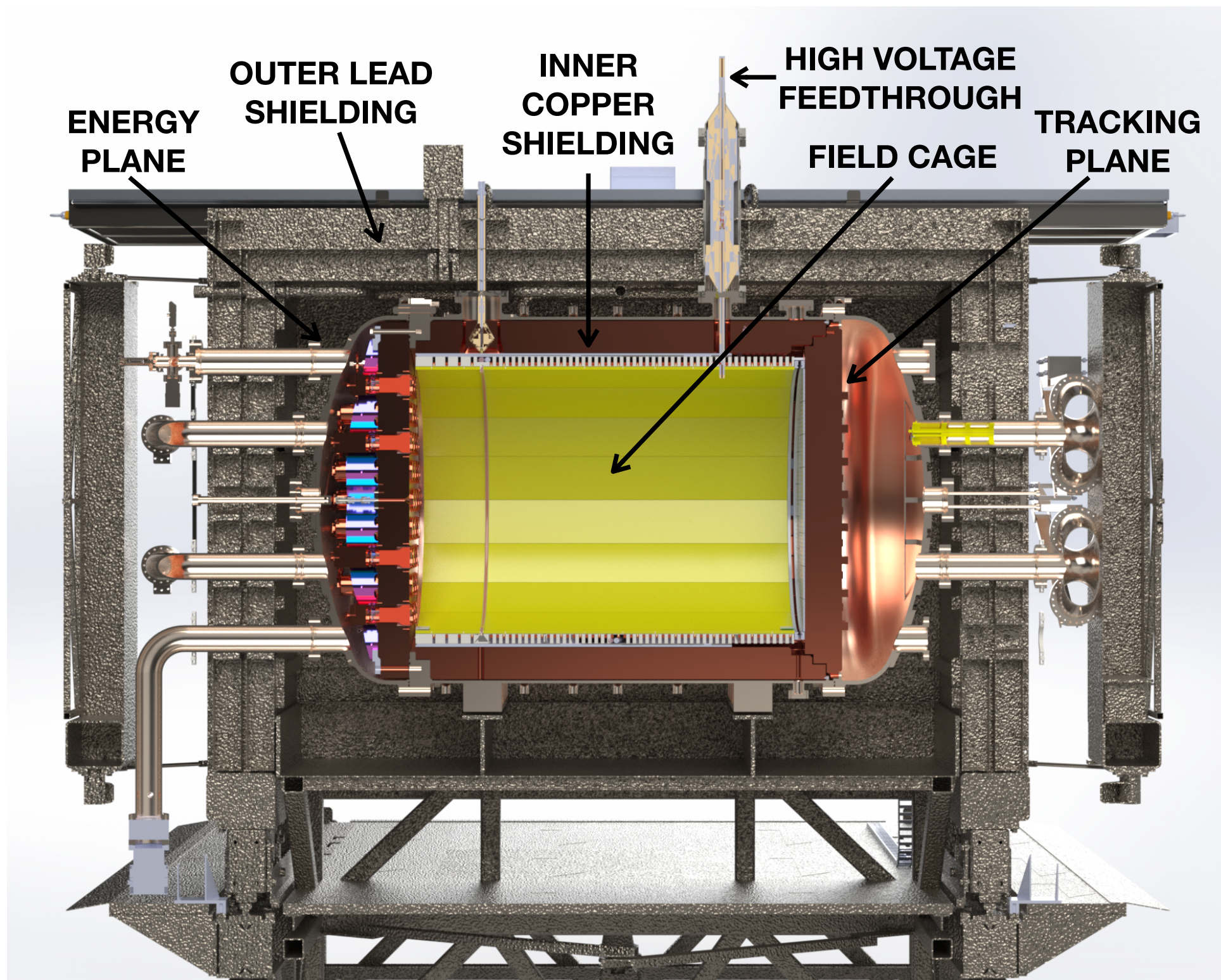
- $0\nu\beta\beta$ at inverted ν mass ordering
- Ba^{++} tagging



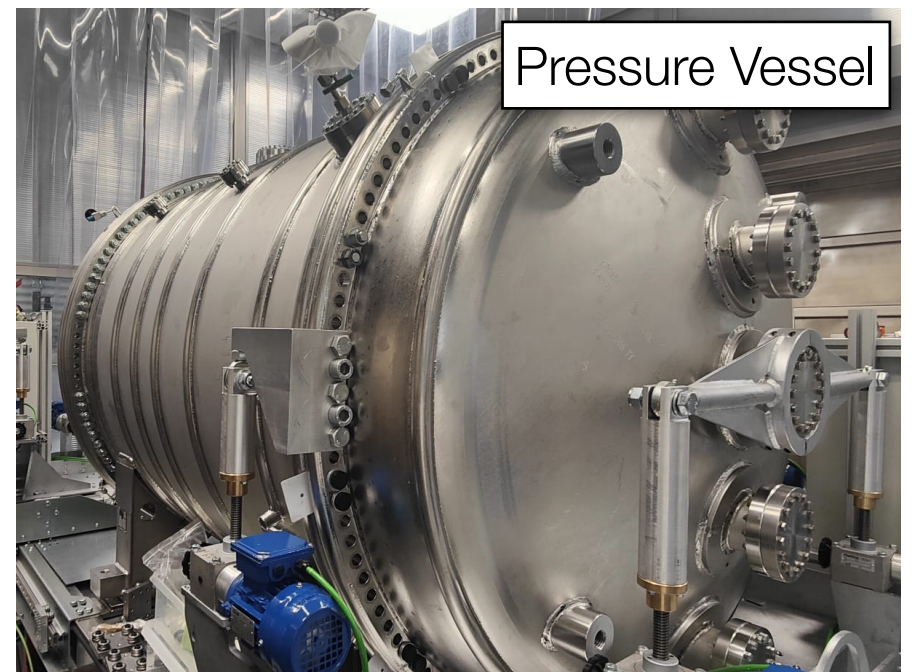
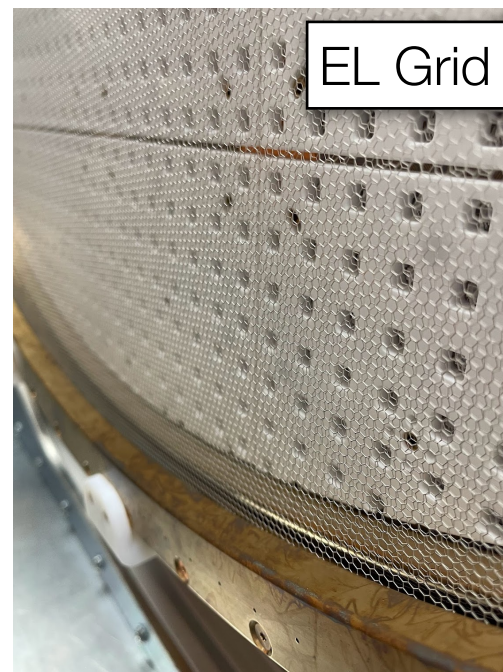
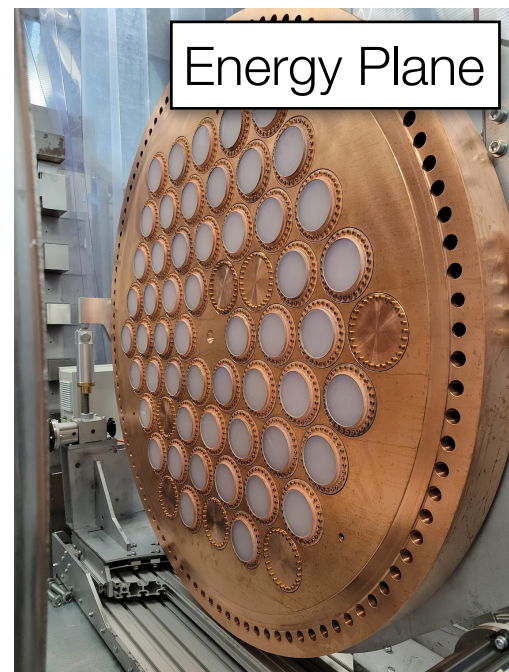
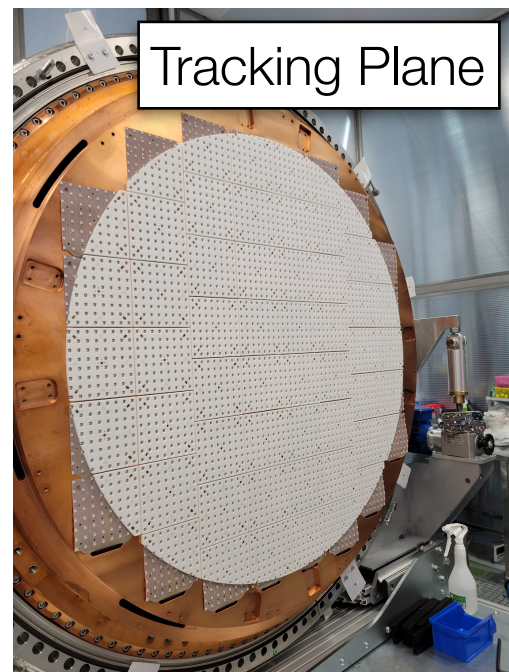
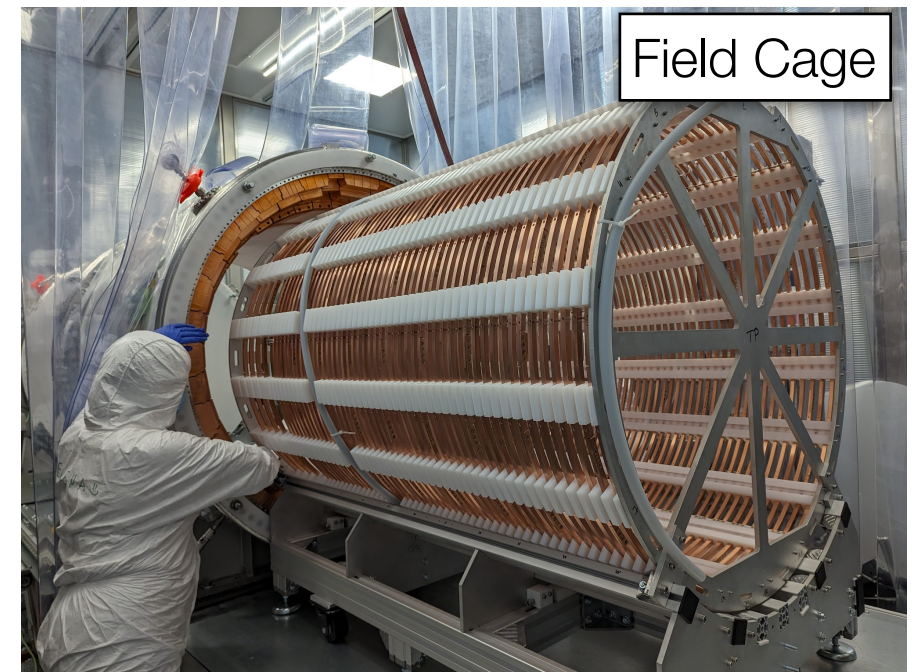
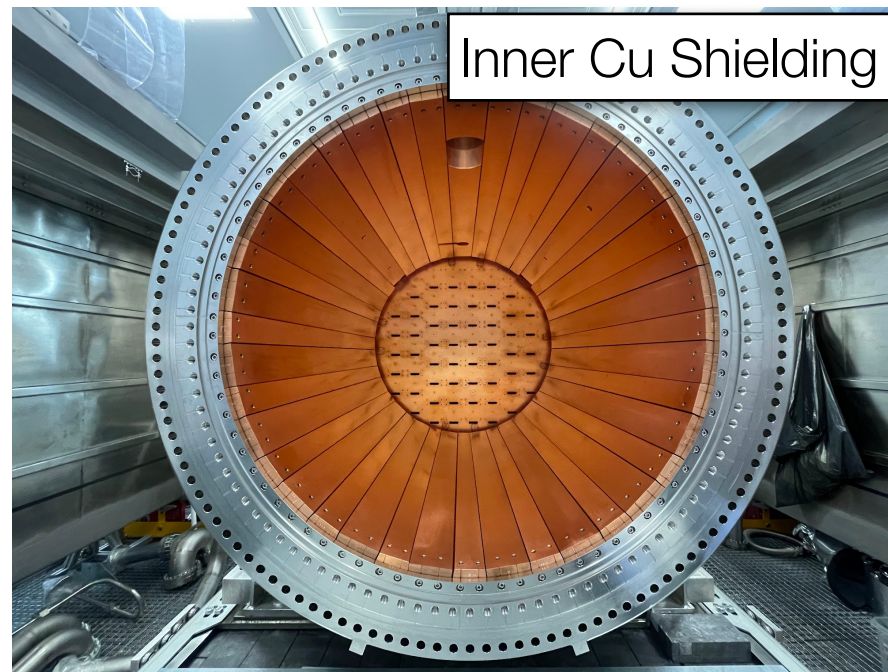
NEXT-White at the Laboratorio Subterraneo de Canfranc (2016-2021)



NEXT-100 (2024-present)

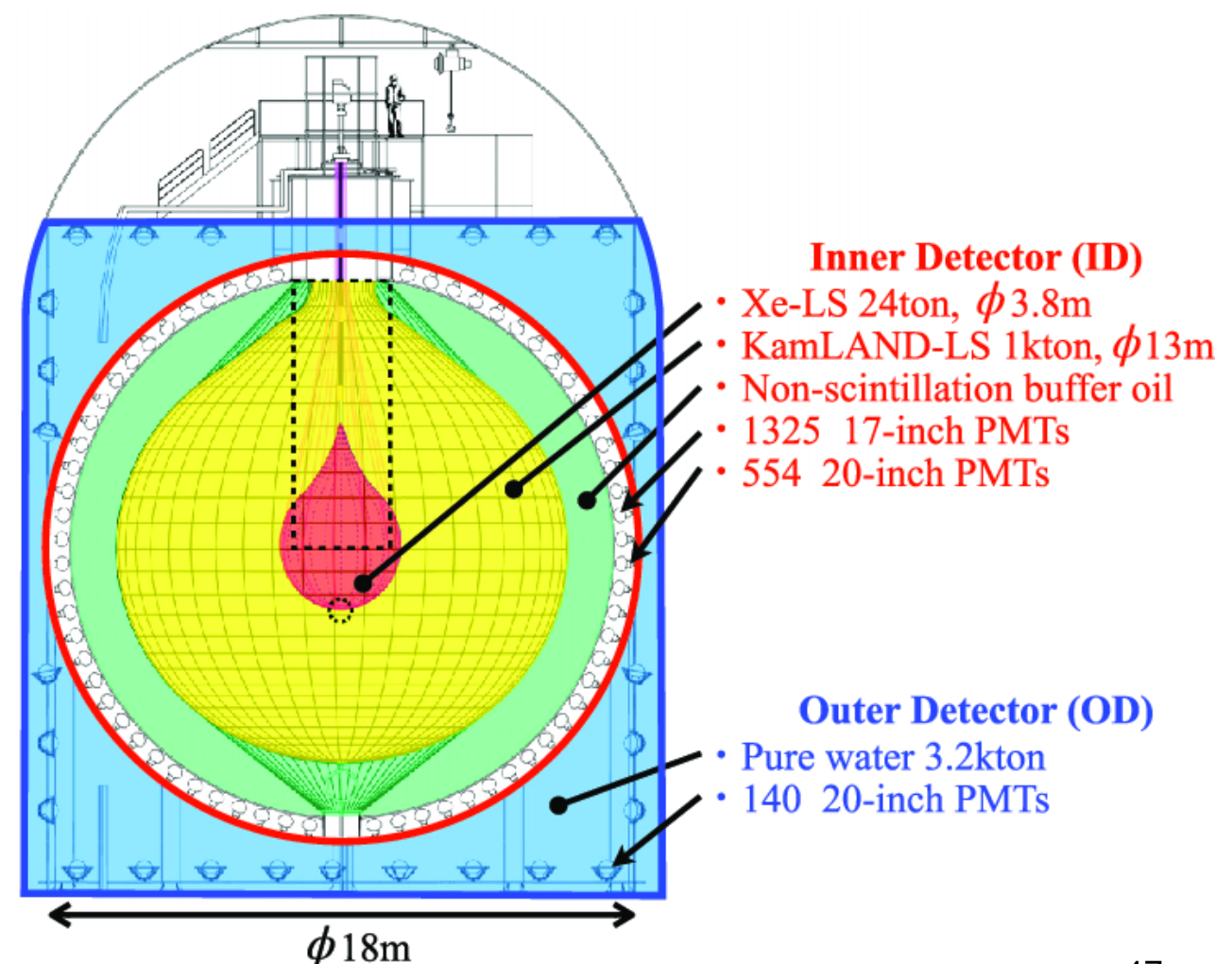
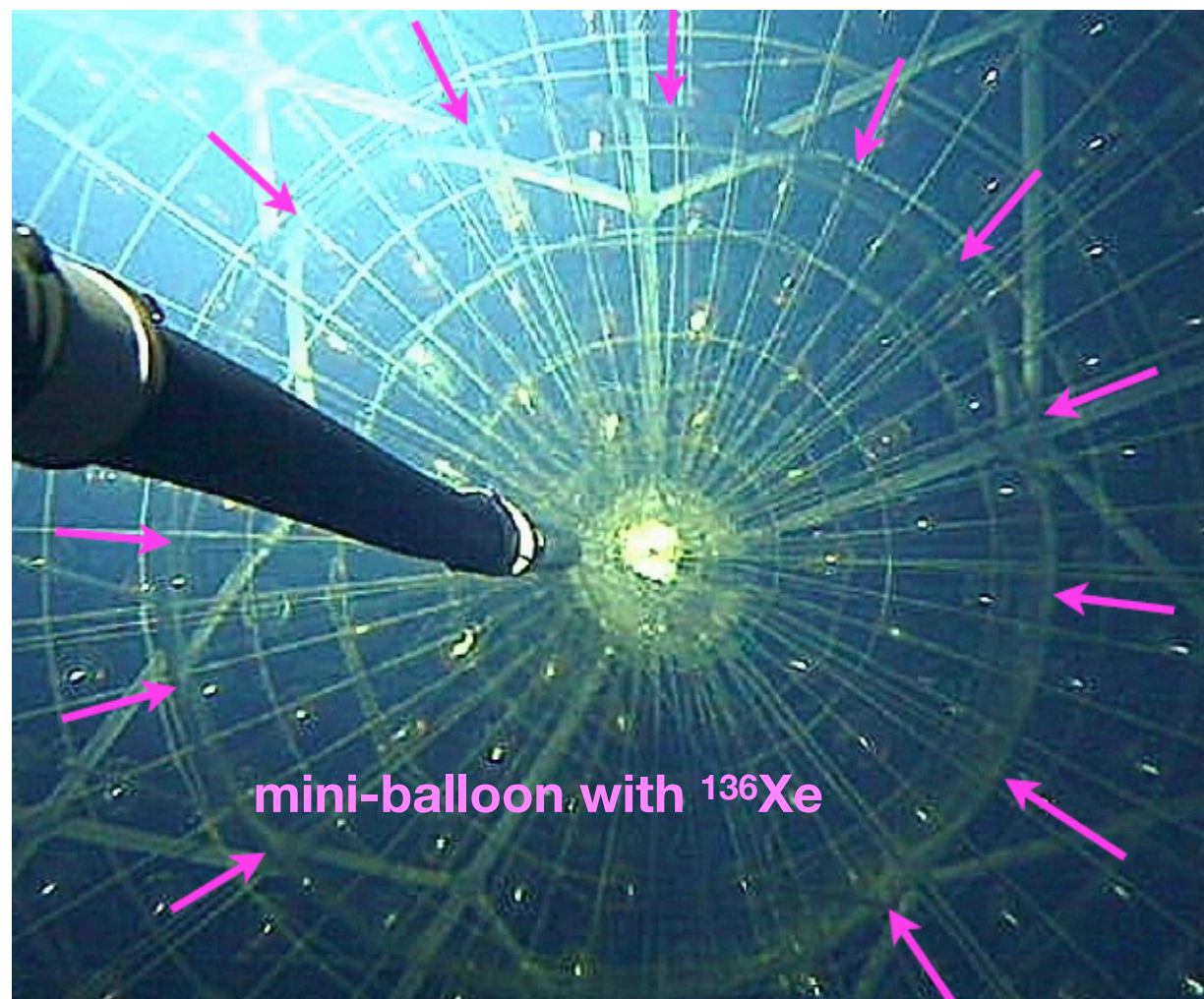


NEXT-100 Building Blocks



KamLAND-Zen Experiment

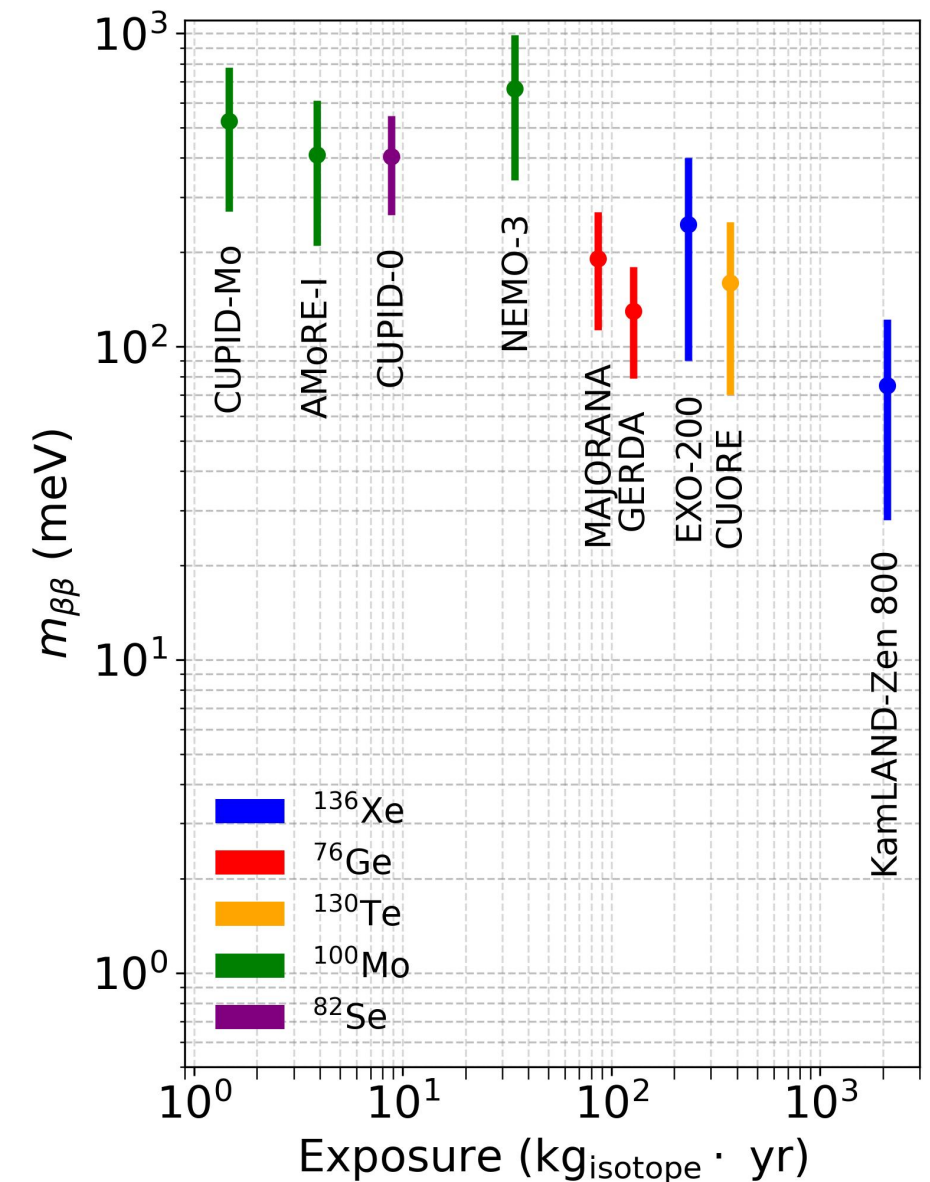
- Onion-like structure. Inner: liquid scintillator doped with **750 kg** of ^{136}Xe
- Advantages: mass scalability, radiopurity, veto region
- Operating since 2011 at Kamioka Underground Observatory (Japan)



Current $0\nu\beta\beta$ Limits

- No evidence for $0\nu\beta\beta$ in any isotope so far
- Xenon experiments provide the most stringent constraints on both:
 - *the direct observable: the half-life $T_{1/2}$ of the decay*
 - *its interpretation in terms of neutrino properties: the Majorana neutrino mass $m_{\beta\beta}$. Directly comparable across different isotopes*

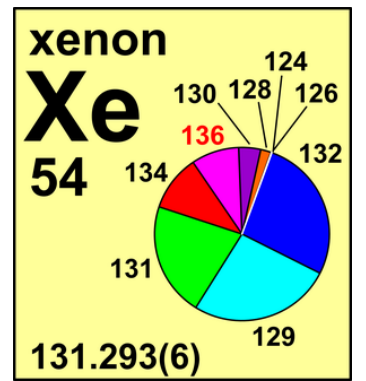
Experiment	Isotope	Exposure [kg·yr]	$T_{1/2}^{0\nu}$ Limit [y]	$m_{\beta\beta}$ Range [meV]
KamLAND-Zen 800	^{136}Xe	~2100	$> 3.8 \times 10^{26}$	28–122
CUORE	^{130}Te	372	$> 3.4 \times 10^{25}$	70–250
GERDA	^{76}Ge	127	$> 1.8 \times 10^{26}$	79–180
EXO-200	^{136}Xe	234	$> 3.5 \times 10^{25}$	93–286
MAJORANA Demonstrator	^{76}Ge	~86	$> 8.3 \times 10^{25}$	113–269
AMoRE-I	^{100}Mo	3.89	$> 2.9 \times 10^{24}$	210–610
CUPID-0	^{82}Se	8.82	$> 4.6 \times 10^{24}$	263–545
CUPID-Mo	^{100}Mo	1.47	$> 1.8 \times 10^{24}$	280–490
NEMO-3	^{100}Mo	34.3	$> 1.1 \times 10^{24}$	330–620



Credit: [A. Giuliani](#)

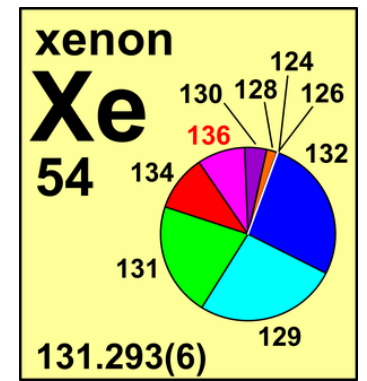
Summary

Summary



- Xenon provides both scintillation and ionization signals
- Percent-level energy resolutions and keV energy thresholds are achievable
- Gas and liquid phases enable very different detector concepts
- Xenon detectors dominate WIMP dark matter searches and play a major role in neutrinoless double-beta decay searches
- New applications continue to emerge in fundamental and medical physics:
 - *Xe TPCs for the detection of solar, reactor and spallation neutrinos through coherent elastic scattering with Xe nuclei*
 - *LXe Compton telescopes for gamma-ray astronomy and positron emission tomography*
 - *Optical TPCs, pixelated charge readouts, low-diffusion gas mixtures, VUV sensors,...*
 - *TPCs integrating the tagging of $^{136}\text{Ba}^{++}$ daughter ions in ^{136}Xe decays*
 - *AI/ML reconstruction of Xe-TPC images*

For More Details...



- See related lectures at this school!
 - *Radiopurity (Roberto Santorelli, 22/06)*
 - *Instrumentation for WIMP detection (Nuria Castello-Mor, 23/06)*
 - *Argon detectors (Inés Gil Botella, 26/06)*
- Essential bibliography:
 - *E. Aprile and L. Baudis, 'Liquid noble gases' chapter in 'Particle dark matter' book*
 - *E. Aprile and T. Doke, 'Liquid Xenon Detectors for Particle Physics and Astrophysics' review article*
 - *E. Aprile, A. Bolotnikov, A. Bolozdynya, T. Doke, 'Noble gas detectors' book*