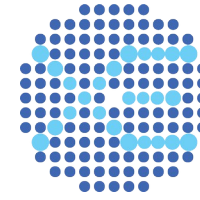




東京大学  
THE UNIVERSITY OF TOKYO



XENON

# XENONnT – Dark Matter

## Direct Detection with Liquid Xenon

Kai Martens

Kavli IPMU, The University of Tokyo

*ETHZ-UZH-UTokyo Strategic Partnership Symposium*

ETH Zürich, 2023.10.17

科研費  
KAKENHI

地下から解き明かす宇宙の歴史と物質の進化

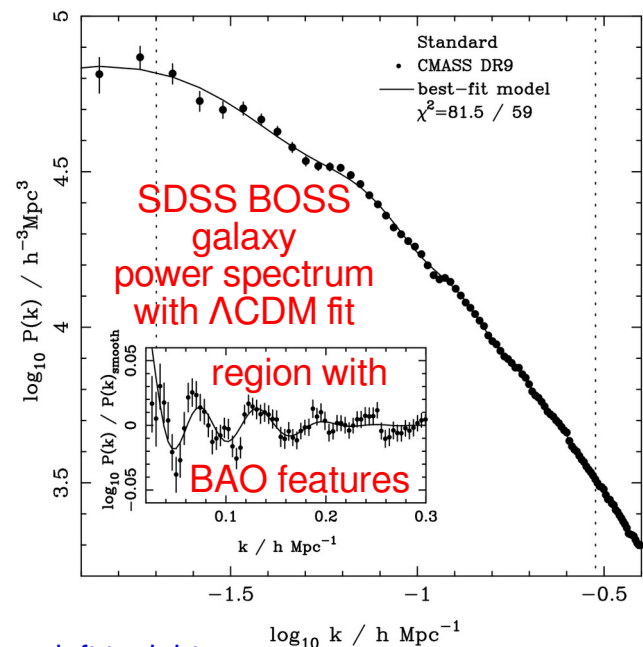
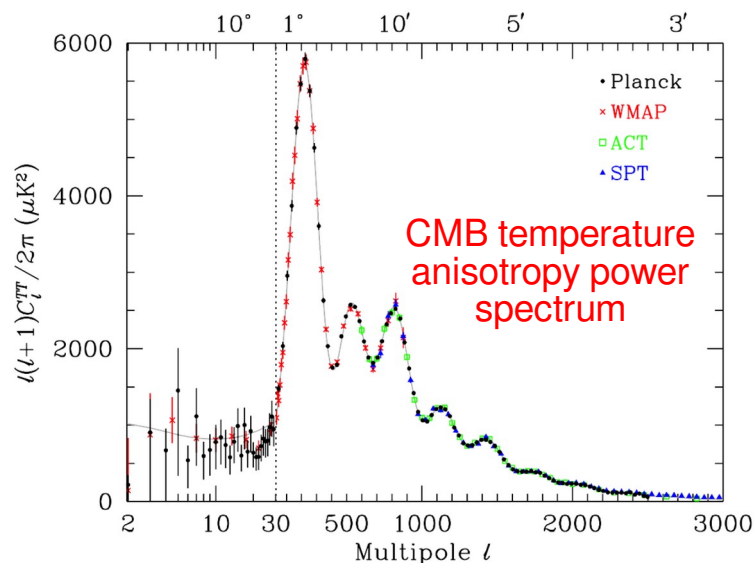
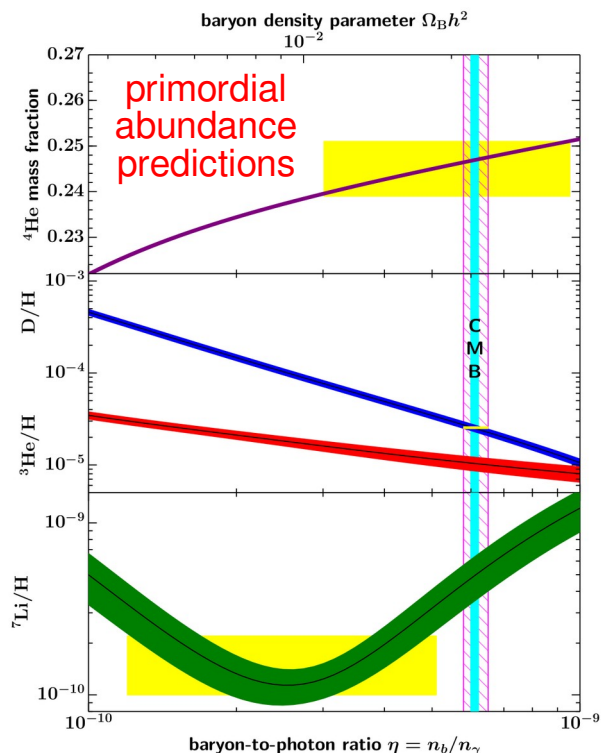
Unraveling the History of the Universe and Matter Evolution with Underground Physics

# Dark Matter is what shaped the Universe:

**B**ig  
**B**ang  
**N**ucleosynthesis

**C**osmic  
**M**icrowave  
**B**ackground

**B**aryon  
**A**coustic  
**O**scillations



Figures from respective 2022 Particle Data Group Reviews; left to right: Big Bang Nucleosynthesis, Cosmic Microwave Background, Big-Bang Cosmology

# Dark Matter still rules the Matterverse:

Closer to home: Galactic rotation curves: Gaia satellite catalogue (ESA):

e.g. the Milky Way's **Dark Matter halo**

Strong gravitational lensing maps foreground galaxy cluster's DM:

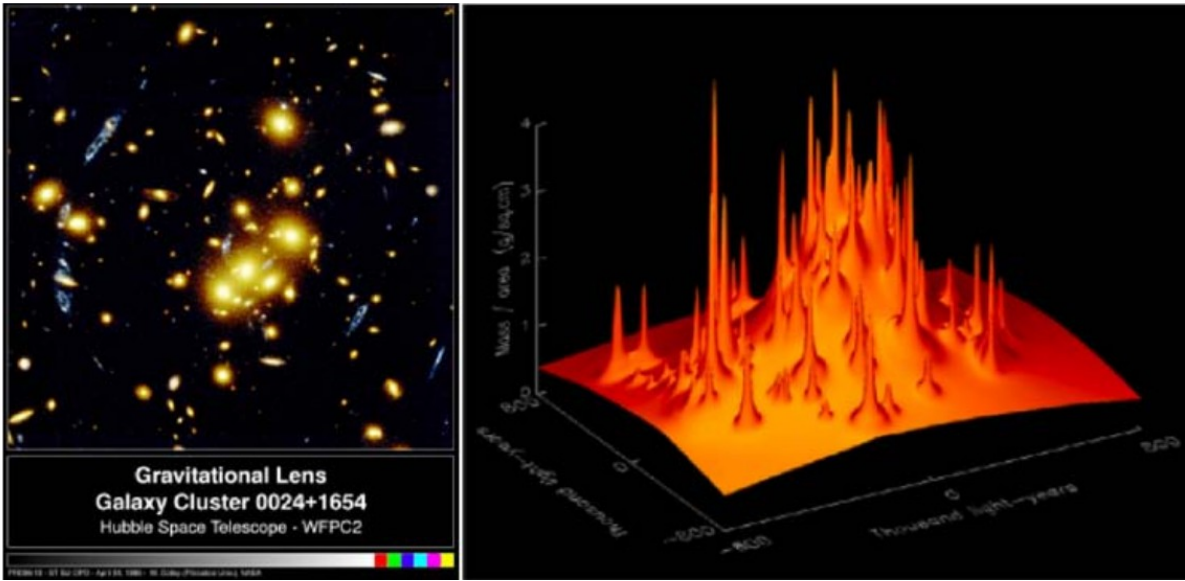
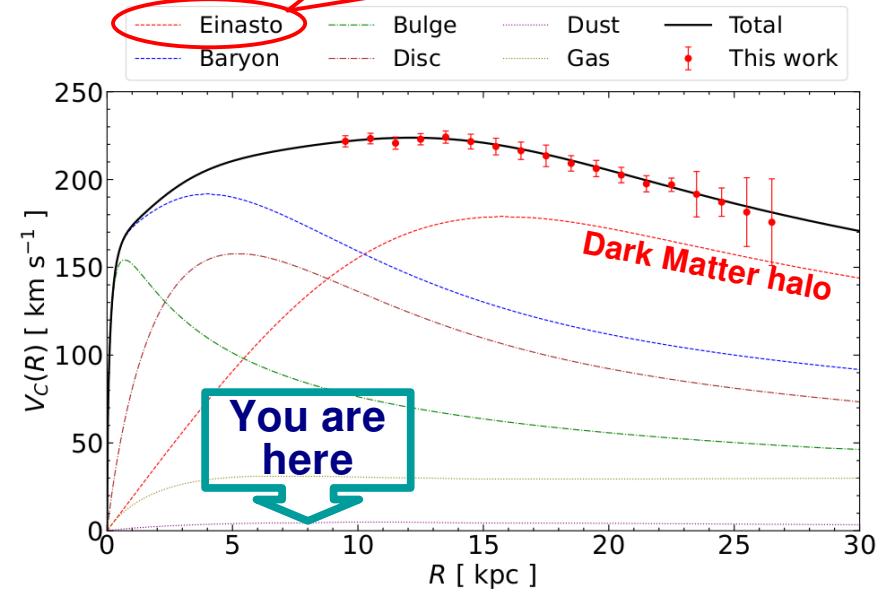


Figure 2 from International Journal of Modern Physics D  
Vol. 26, No. 6 (2017) 1730012



dashed lines in figure above:  
*mass contributions* at  $R[\text{kpc}]$

Figure 5 from <https://doi.org/10.1051/0004-6361/202347513>

# So now: What really IS that Dark Matter?

It is:

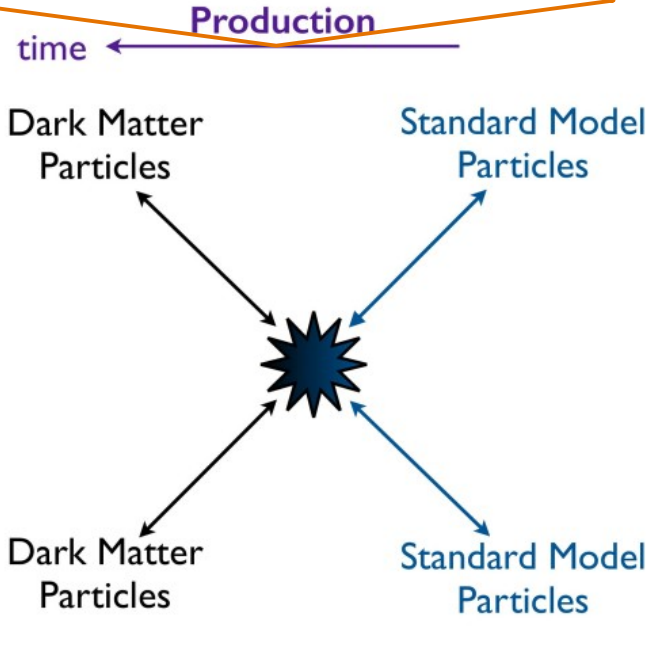
- gravitating (“shaped” the Universe...)
  - “dark” (non-luminous...)
  - “cold” (non-relativistic...) →  $\Lambda$ CDM
  - 85% of all matter in the Universe
- ⇒ *not a standard model particle... !!!*

Then, and only then,  
might it be just what we need  
to tell us how to “complete”  
our supposedly  
**Standard Model**  
of particle physics...

now come along, **dream** with me:  
what if there was an itsy-bitsy-teeny-wheeny  
extra bit of interaction with “**real**” matter???

# Three ways to look for it:

## accelerators (LHC)



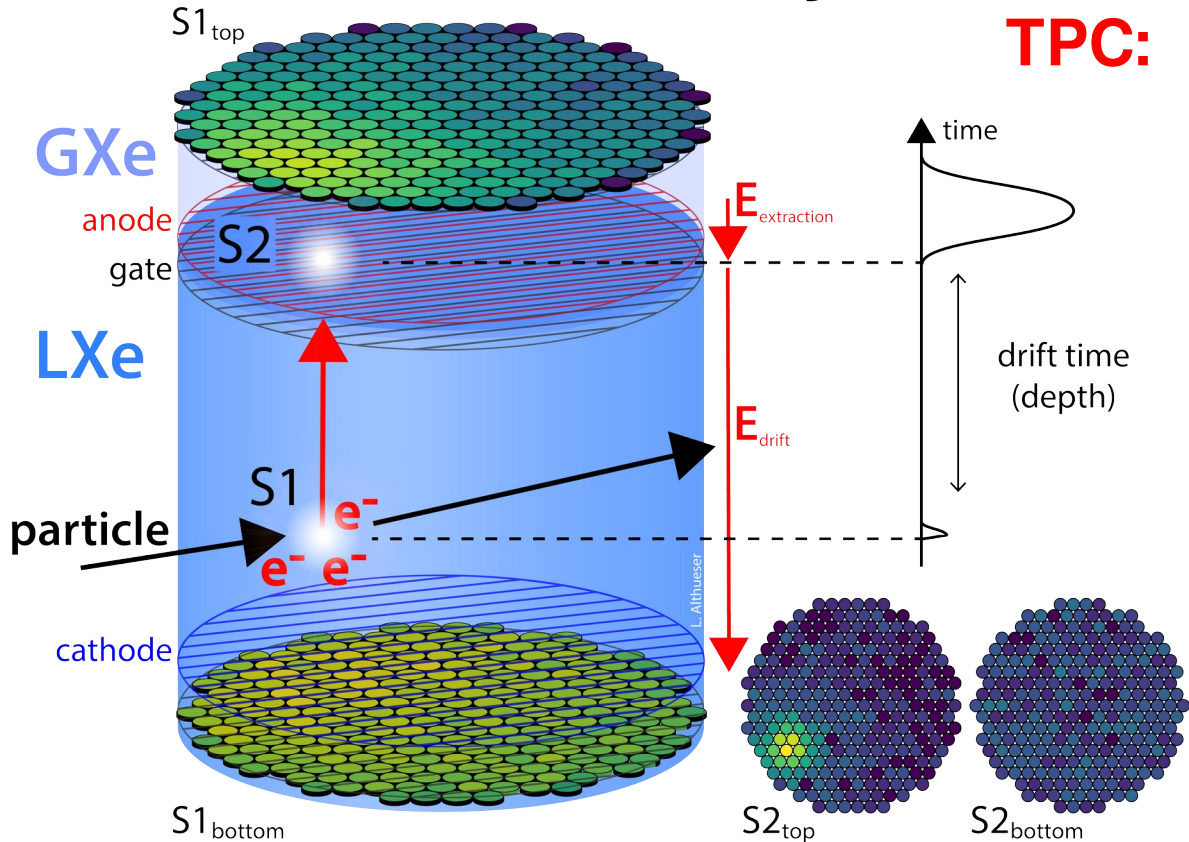
## cosmic rays/gammas

## background sources:

- **cosmic rays:**
  - go underground !!!
- **external gammas neutrons**
  - materials' radioactivity: intrinsic & cosmogenic
- **target radiopurity:**
  - liquid: argon (LAr)  $^{39}\text{Ar}$   
xenon (**LXe**)  $^{136}\text{Xe}$
  - solid: Ge, Si, NaI
- **neutrinos** (irreducible):
  - solar
  - (- supernovae)

ultra-low  
background  
(BG)  
experiment

# LXe Time Projection Chamber (TPC):



**TPC: one recoil  $\Rightarrow$  two signals**

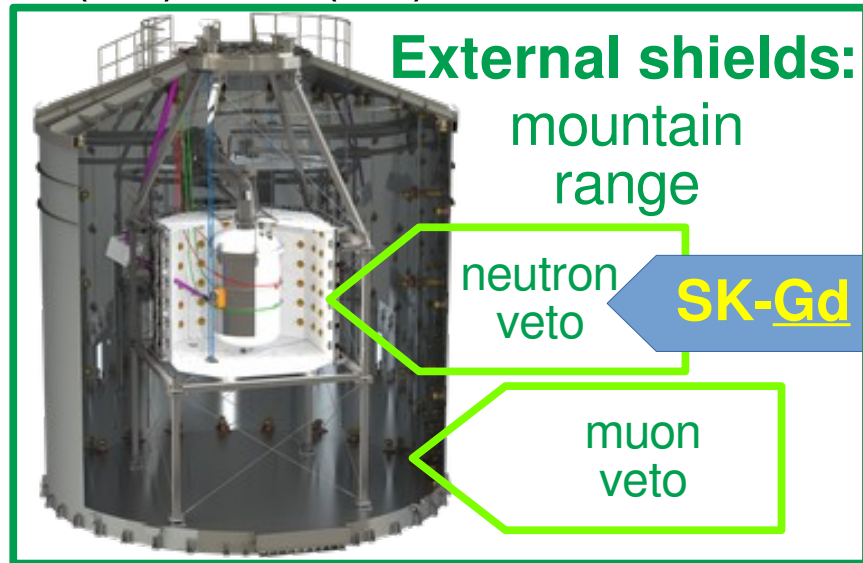
**S1**  $\leftarrow$  scintillation in liquid phase

**S2**  $\leftarrow$  scintillation from electrons

in gas phase *after drift*:

$\text{time}(\mathbf{S2}) - \text{time}(\mathbf{S1}) = \mathbf{z\text{-coordinate}}$

**LXe target: high density**  $\Rightarrow$  “self-shielding”  
**scintillation + charge: nuclear**  $\leftrightarrow$  **electron recoil discrimination!!!**



# Team XENON - the collaboration:



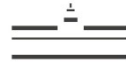
Columbia



KIT



Nikhef



Muenster



WWU MÜNSTER



Mainz



MPIK, Heidelberg



Stockholm



Freiburg



University of Zurich

Zurich



清华大学  
Tsinghua University

Tsinghua



Tokyo



Chicago

UC San Diego

UCSD



Rice



Purdue



NAGOYA UNIVERSITY

Nagoya



Kobe



Westlake



CUHK, Shenzhen

12 countries, 30 institutions, ~180 scientists



Subatech



Coimbra



LPNHE



Torino



Bologna



L'Aquila



LNGS



Napoli



Weizmann

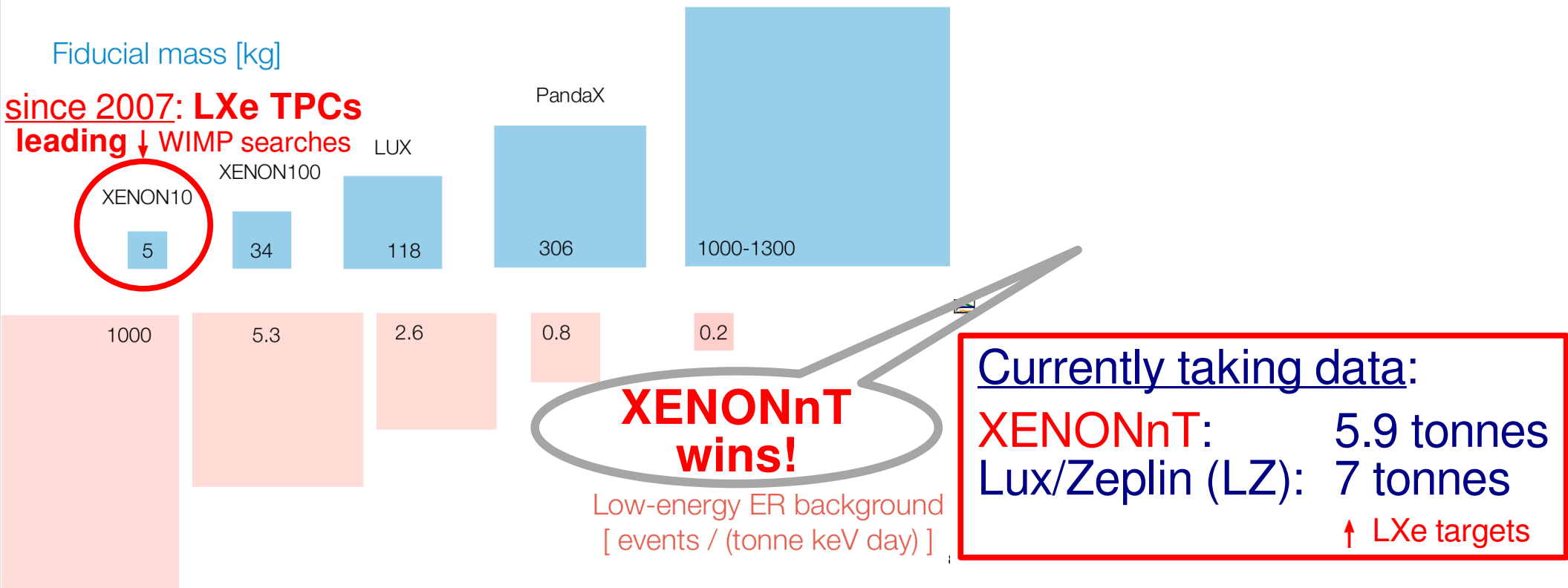


NYUAD

# Background (BG): The fight is on!

LXeTPCs as WIMP detectors from 2006 to 2018

Elena's favorite plot with good reason: XENONnT





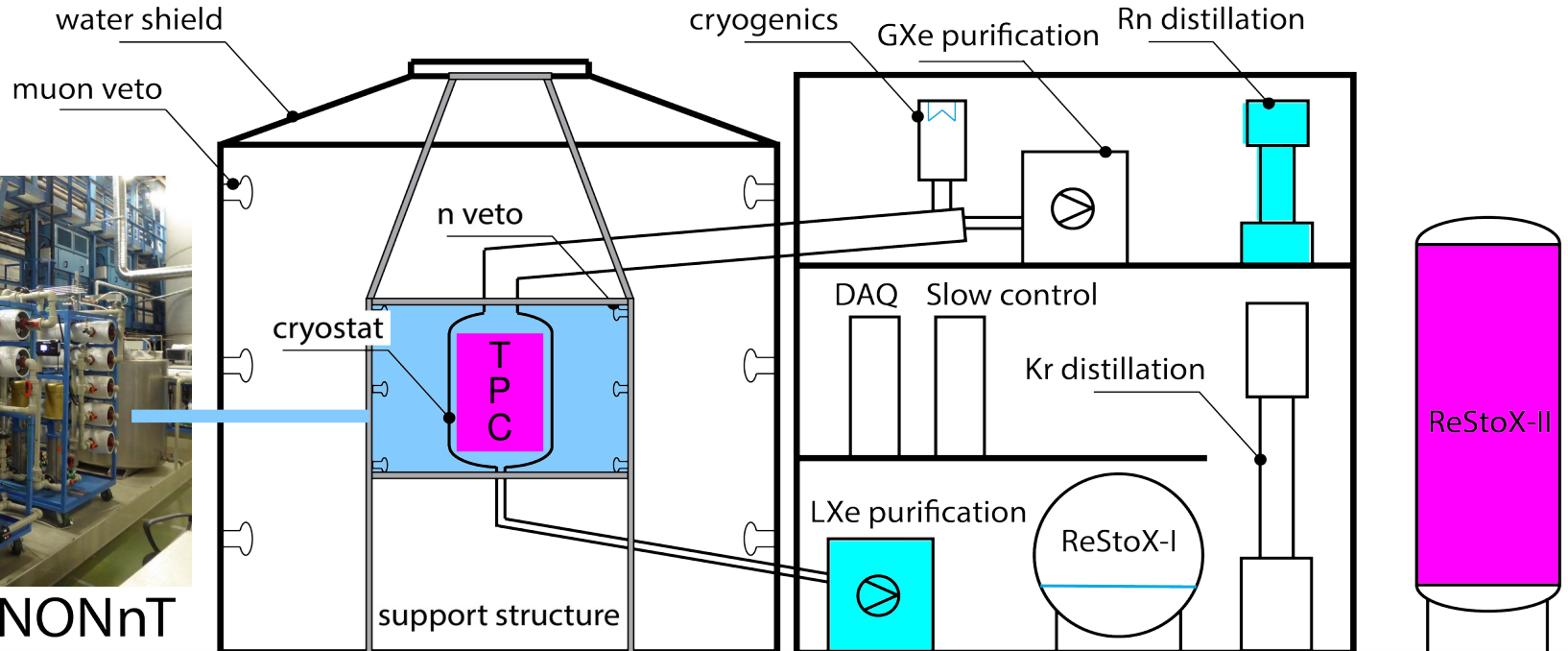
# XENONnT: How did we do it?

- Upgrade XENON1T:**
- bigger **TPC** (LXe target)
  - lower intrinsic **BG**
  - **neutron** tagging

SK/EGADS  
based  
Gd-water  
system

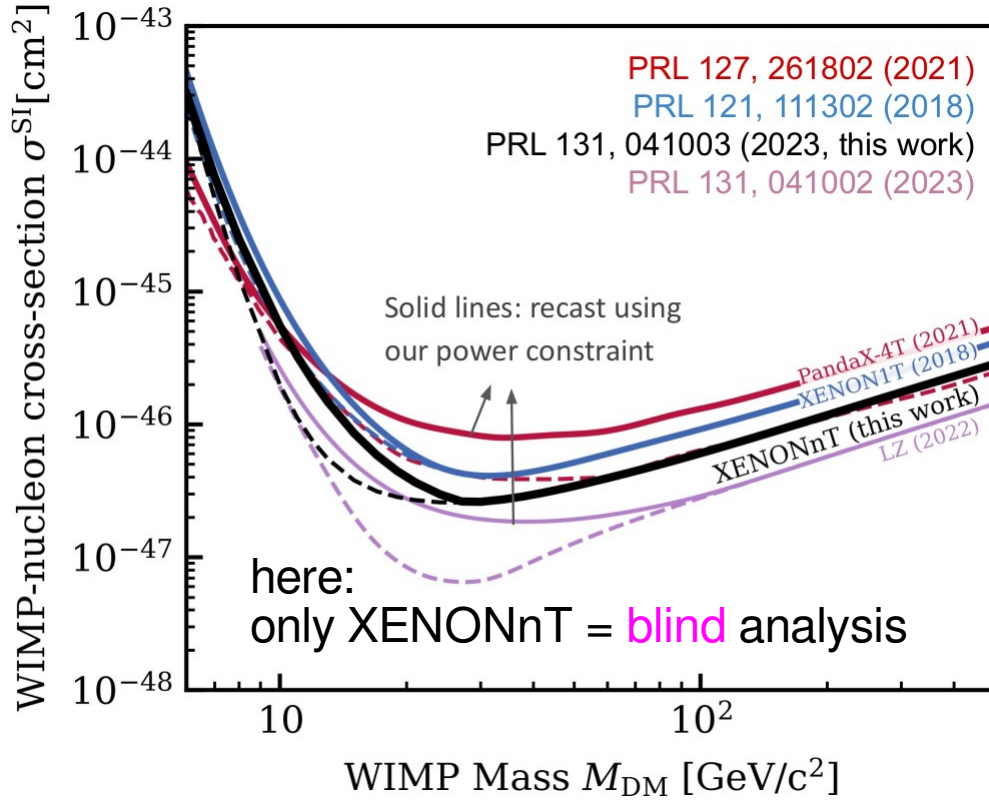


XENONnT

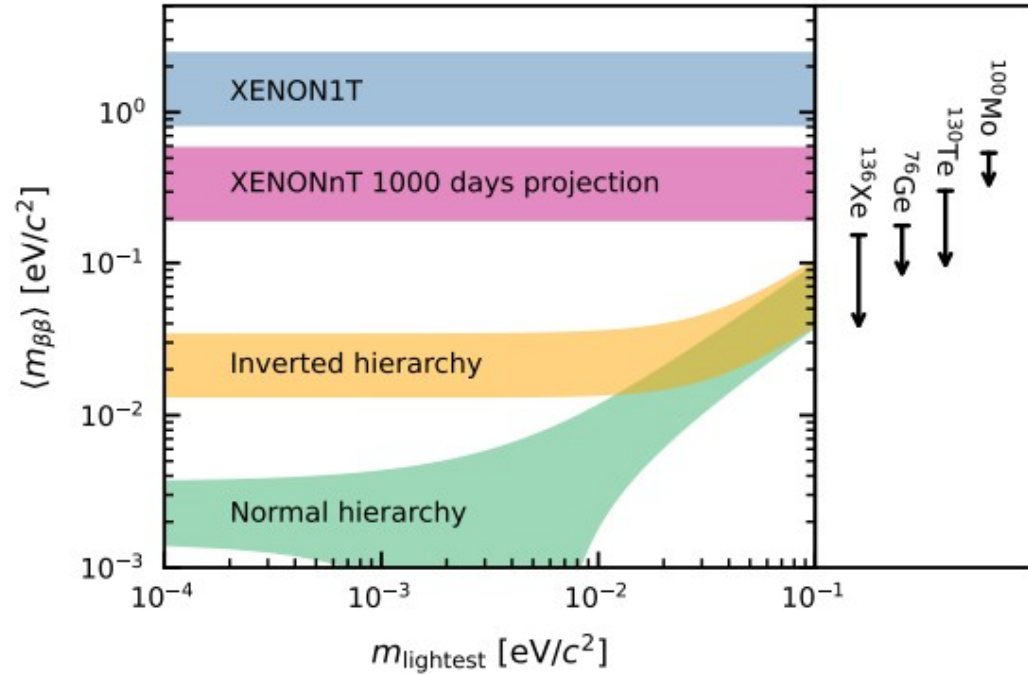


given limited time,  
two highlights:

# What did it get us?



$^{136}\text{Xe}$  neutrinoless double beta decay:



key ingredients: proper statistical inference from blind analysis

# Heading for the Neutrino Fog: XLZD



**X**ENON, **LUXZ**EPLIN, **D**ARWIN

- July 2021: MoU signed by 104 individual research group leaders
- June 2022: first in-person meeting and founding of the XLZD Consortium  
currently discussing when to transition to formal collaboration:  
**XLZD** is on its way!

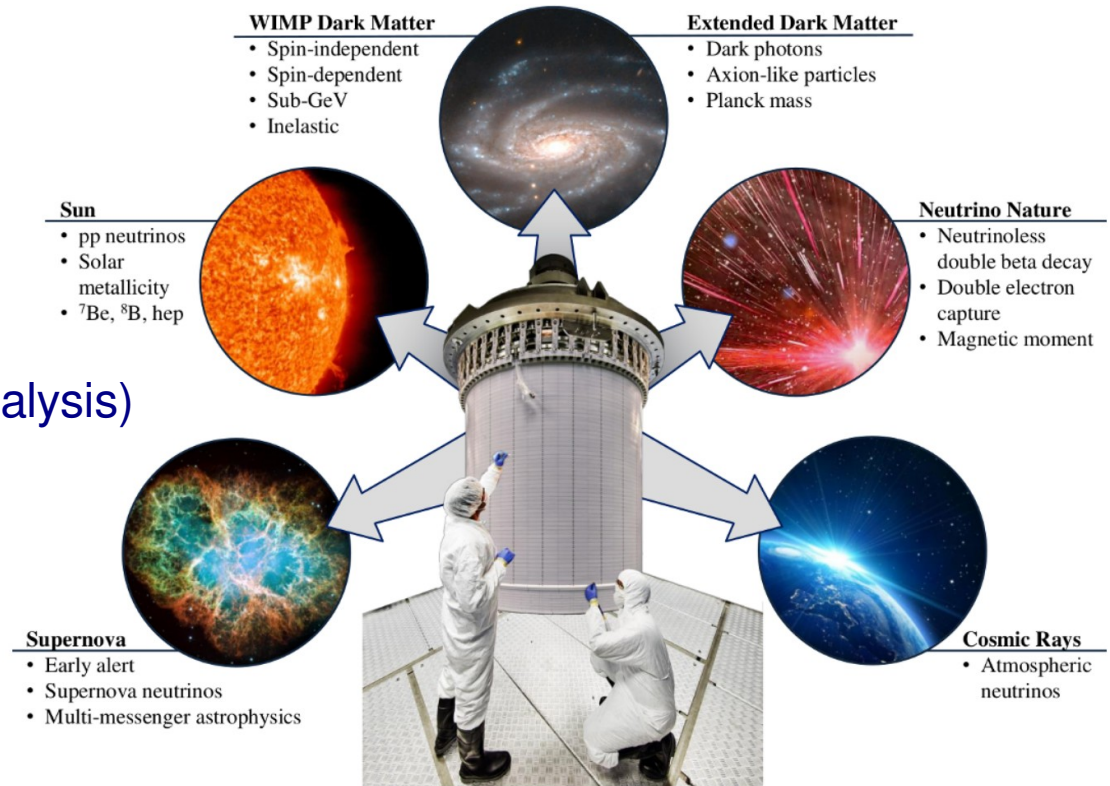
# Whitepaper Details the Physics:

of a 50-100 tonne LXe detector,

ordered by sections:

- DM WIMPs
- broadening DM reach  
(improving the detector physics and analysis)
- double beta processes
- neutrino and astrophysics
- other physics channels

... a lot to do and learn!



**J. Phys. G 50 (2023) 013001**

# Concluding remarks:

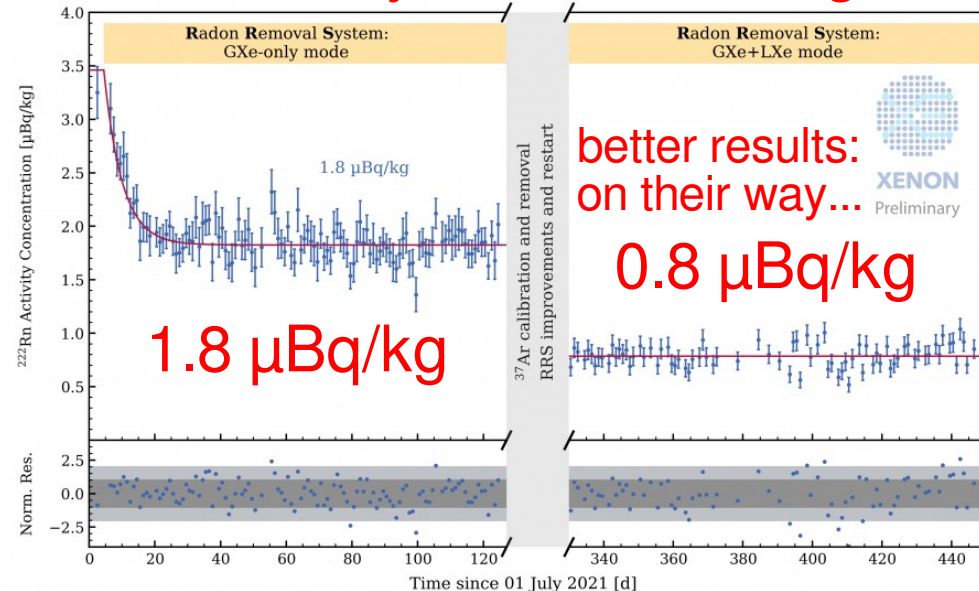
LXe TPCs led WIMP DM searches  
LXe TPCs lead WIMP DM searches  
LXe TPCs will continue to lead.

LXe TPCs also are:

- neutrino observatories
- supernova explosion recorders
- nuclear physics laboratories
- challenging our imagination:
  - background reduction
  - analysis innovation
  - physics reach expansion

Research is fun and exciting:  
← *the lesson for us to teach!*

Rn decay rate in LXe target:



For **publications** have a look at:  
<https://xenonexperiment.org>  
For a **glimpse of the future** have a look at:  
<https://xlzd.org>