Direct Dark Matter Detection with the LUX-ZEPLIN Experiment

Maria Elena Monzani

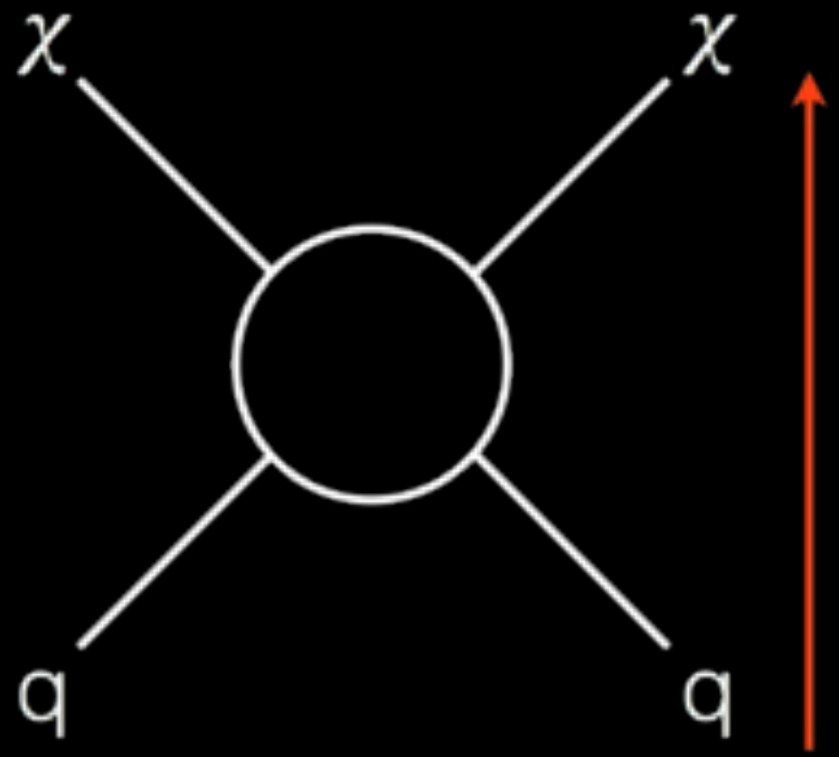
Dark Pollica, 8 June 2022


DARK MATTER IS HIDING IN PLAIN SIGHT!

Three Ways to Look for WIMPs

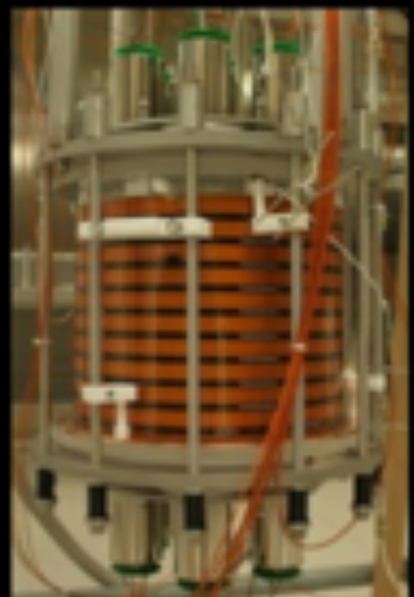
Annihilation

Indirect Detection



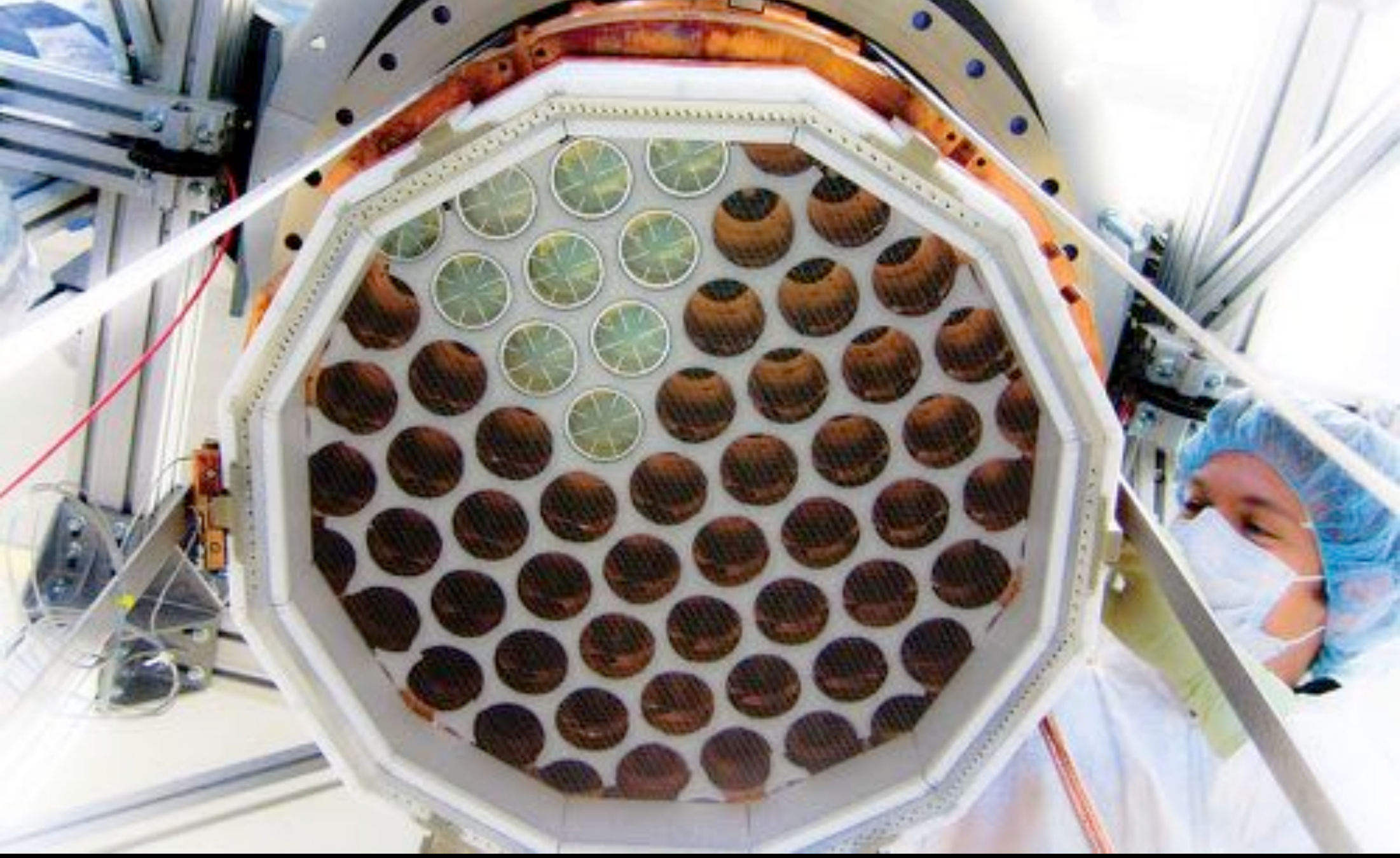
Production

Colliders



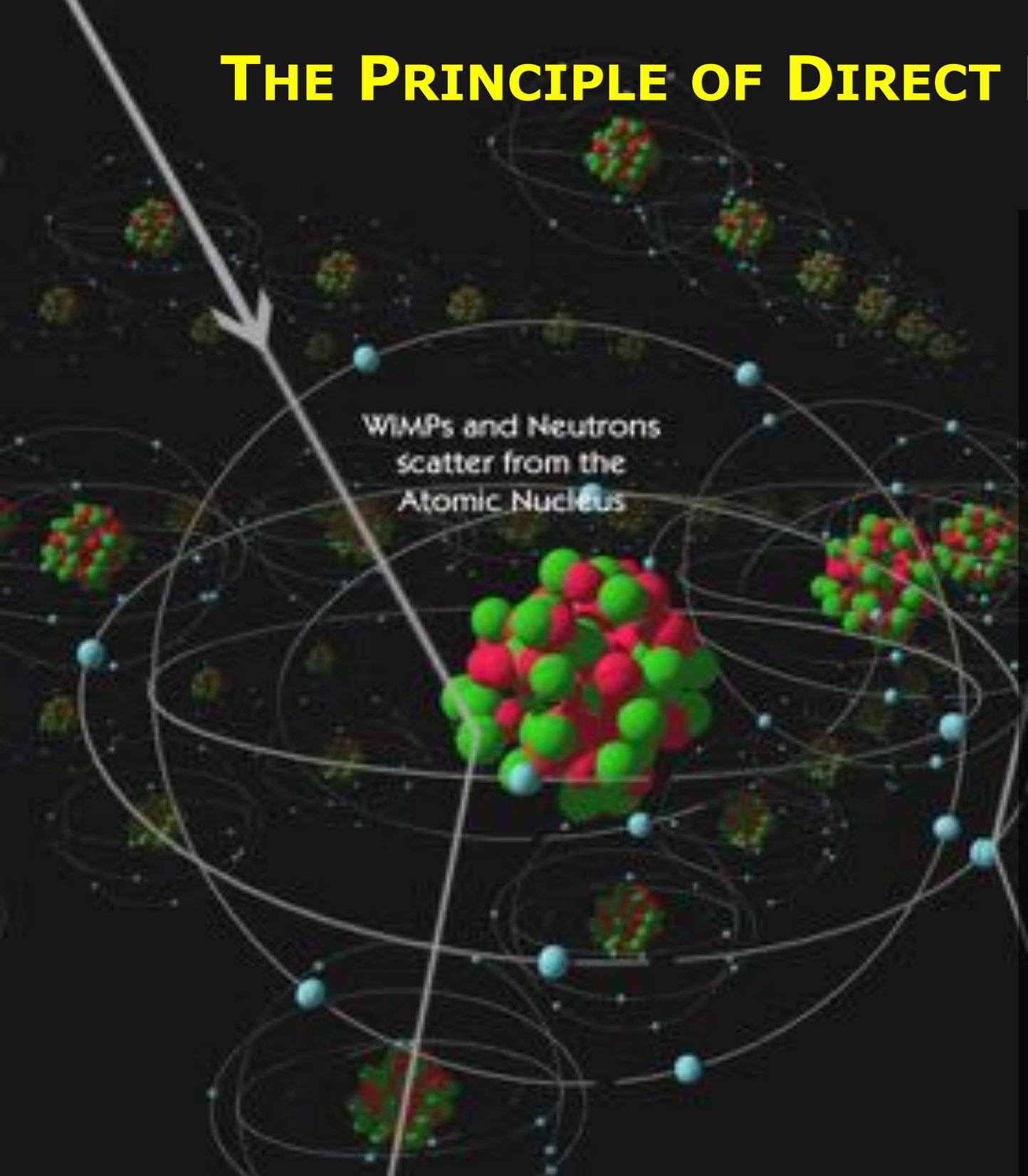
Scattering

Direct Detection



Direct Dark Matter Detection

The Principle of Direct Detection



Build A Massive Tank (or Tower) of Nuclei

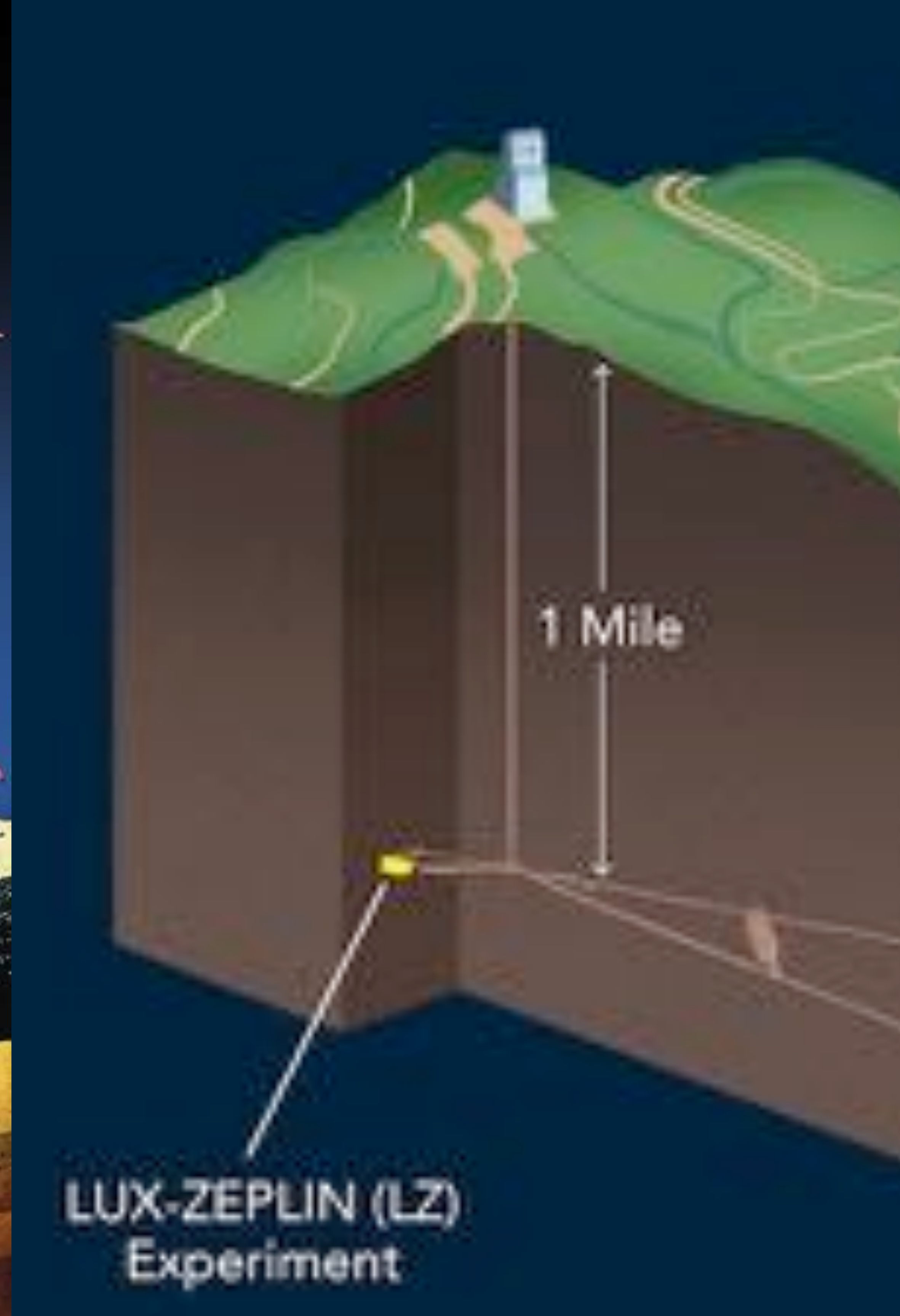
"Hide" it Deep Underground

Wait for Dark Matter Particles to Hit the Nuclei

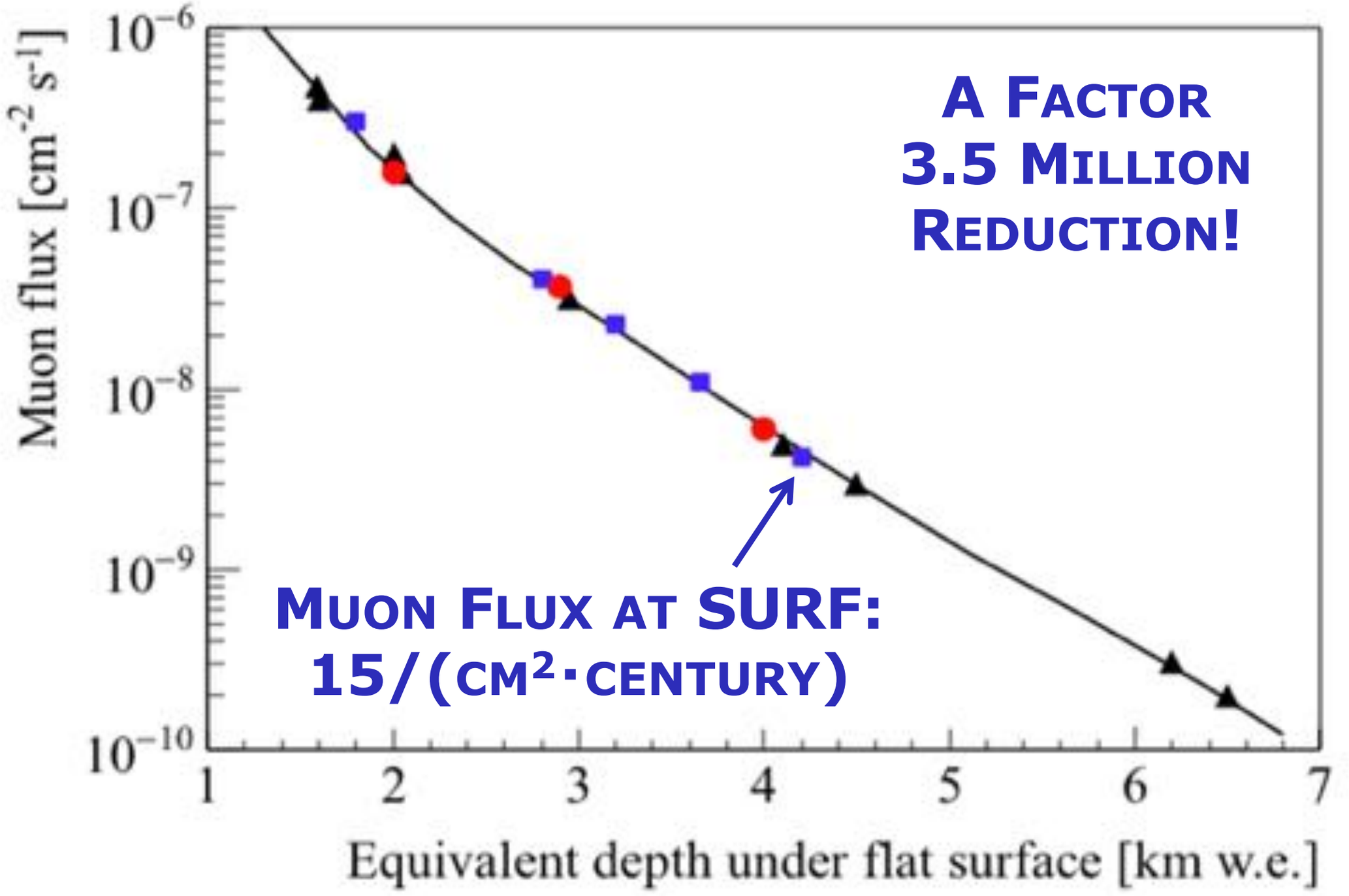
Look for Tiny Vibrations from Nuclei that have been hit by DM

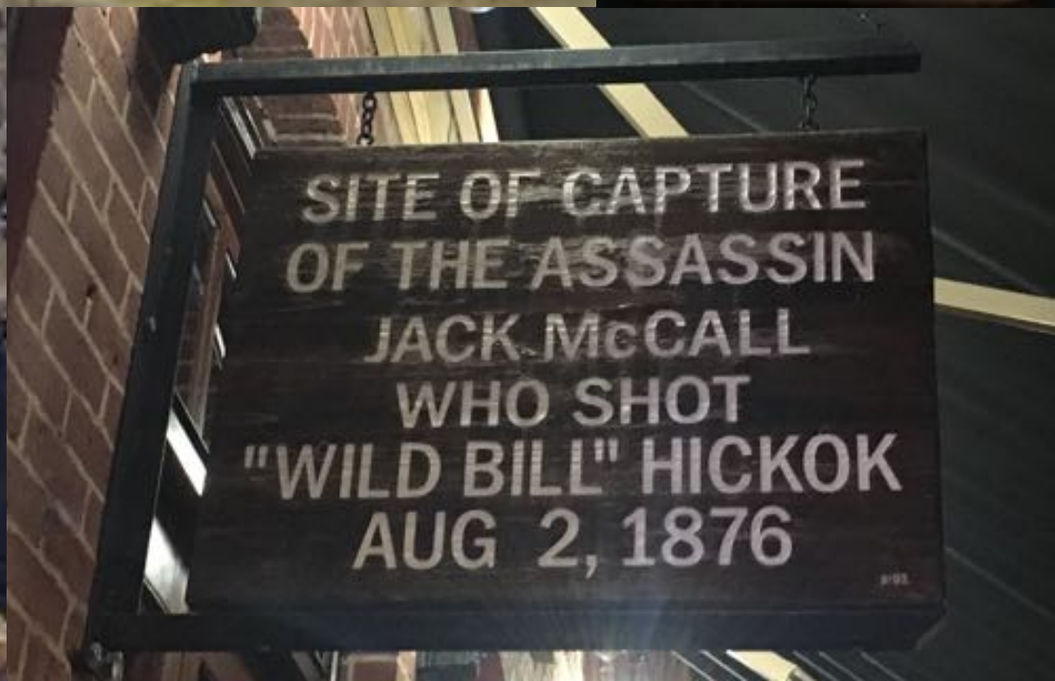
Wait! did you Just say Underground?


Primary cosmic rays
electromagnetic shower
hadron cascade
Mont Blanc (4807 m)
This cosmic ray image is a modified version of an original picture produced by CERN


1 Mile
LUX-ZEPLIN (LZ) Experiment

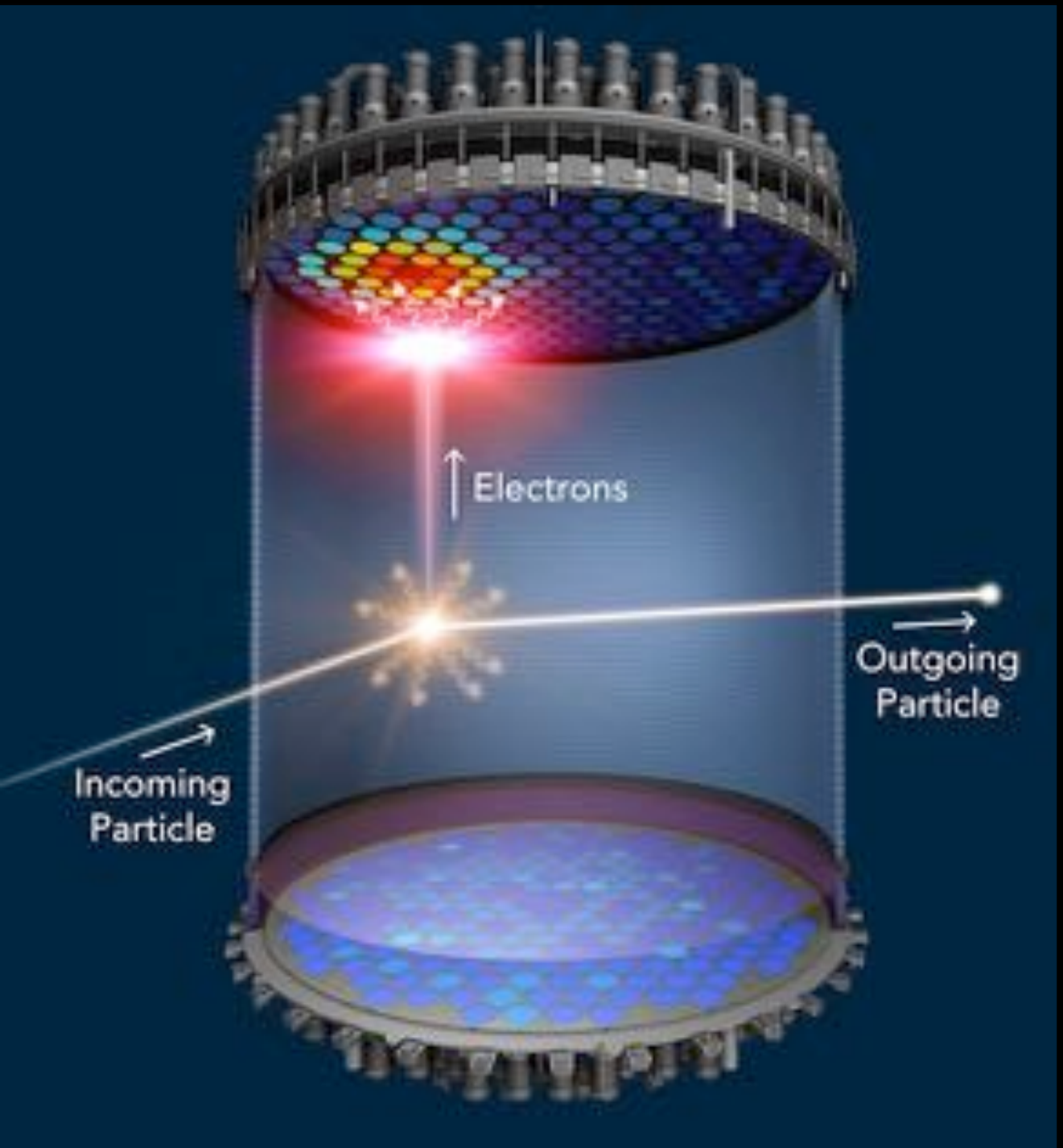
Muon Flux at Earth's Surface: 1/(cm^2·min)





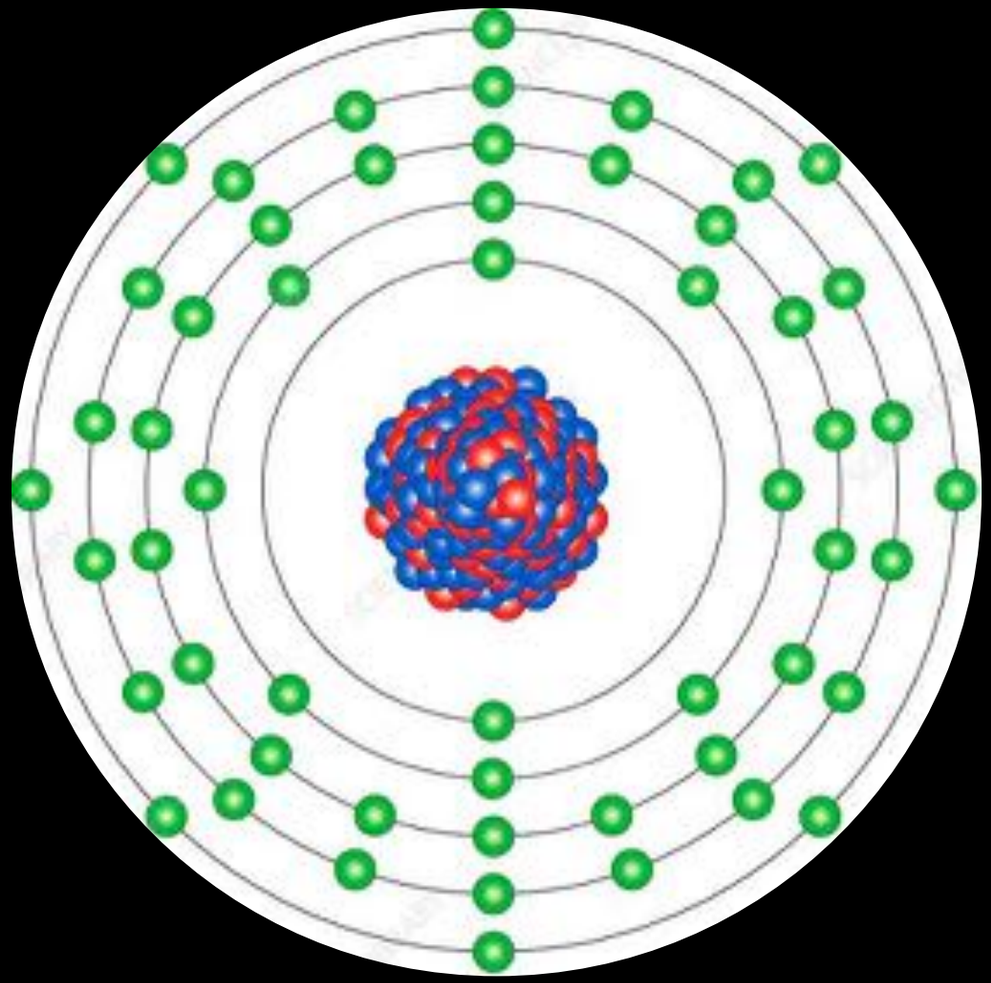
Homestake, South Dakota

The LUX-Zeplin (LZ) Detector



Why Xenon? And why a Liquid?

- Kinematic Matching to DM Particle
- Lots of Nucleons per Atom



Why Xenon? And why a Liquid?

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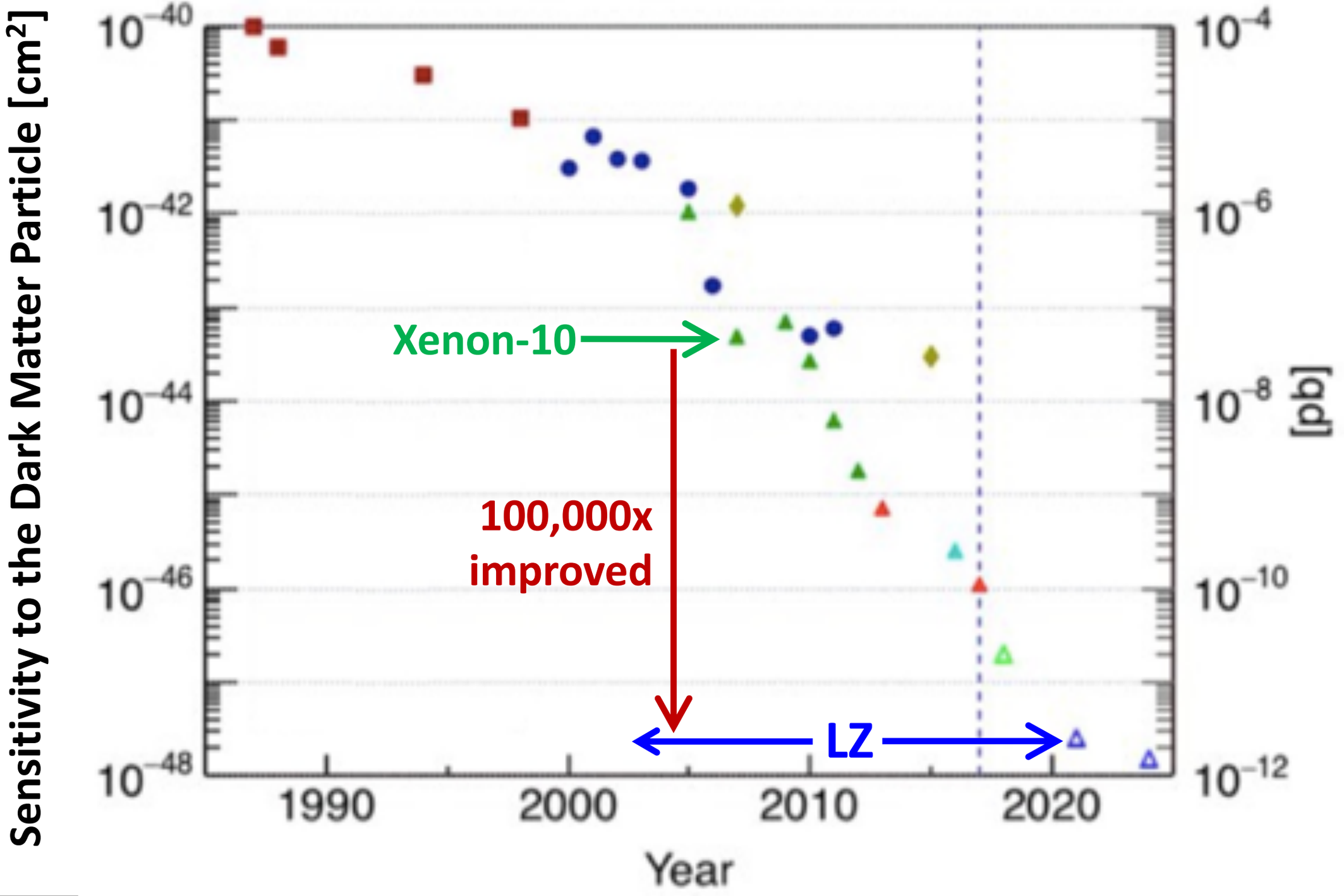
- Transparent to its own Light

Why Xenon? And why a Liquid?

- Kinematic Matching to DM Particle
- Lots of Nucleons per Atom
- Transparent to its own Light
- Very Dense (Self-Shielding)
- Background Rejection (Charge/Light)
- Liquid: can be Purified in a Loop
- "Easy" to Make a Larger Detector

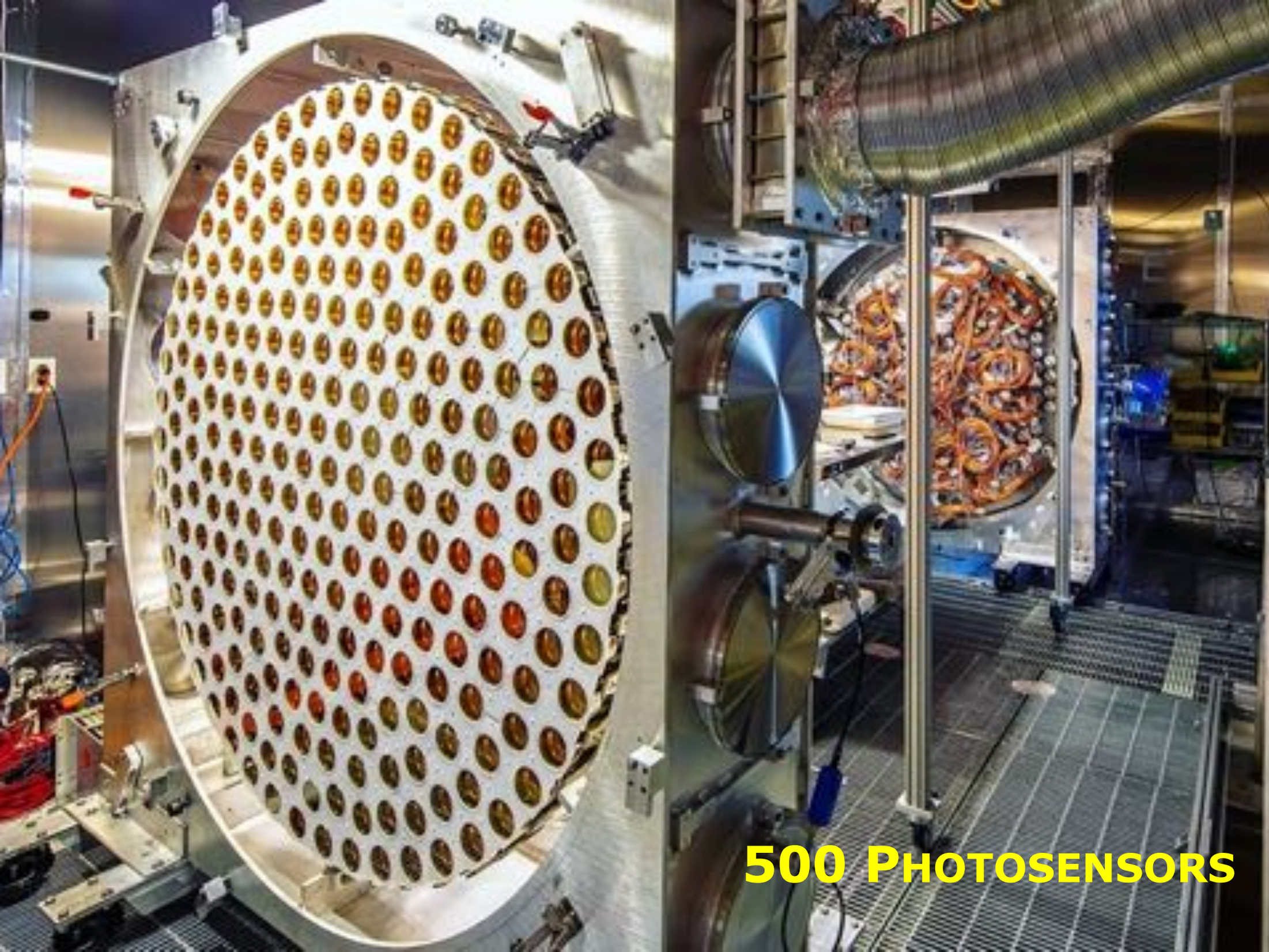

2006
2019

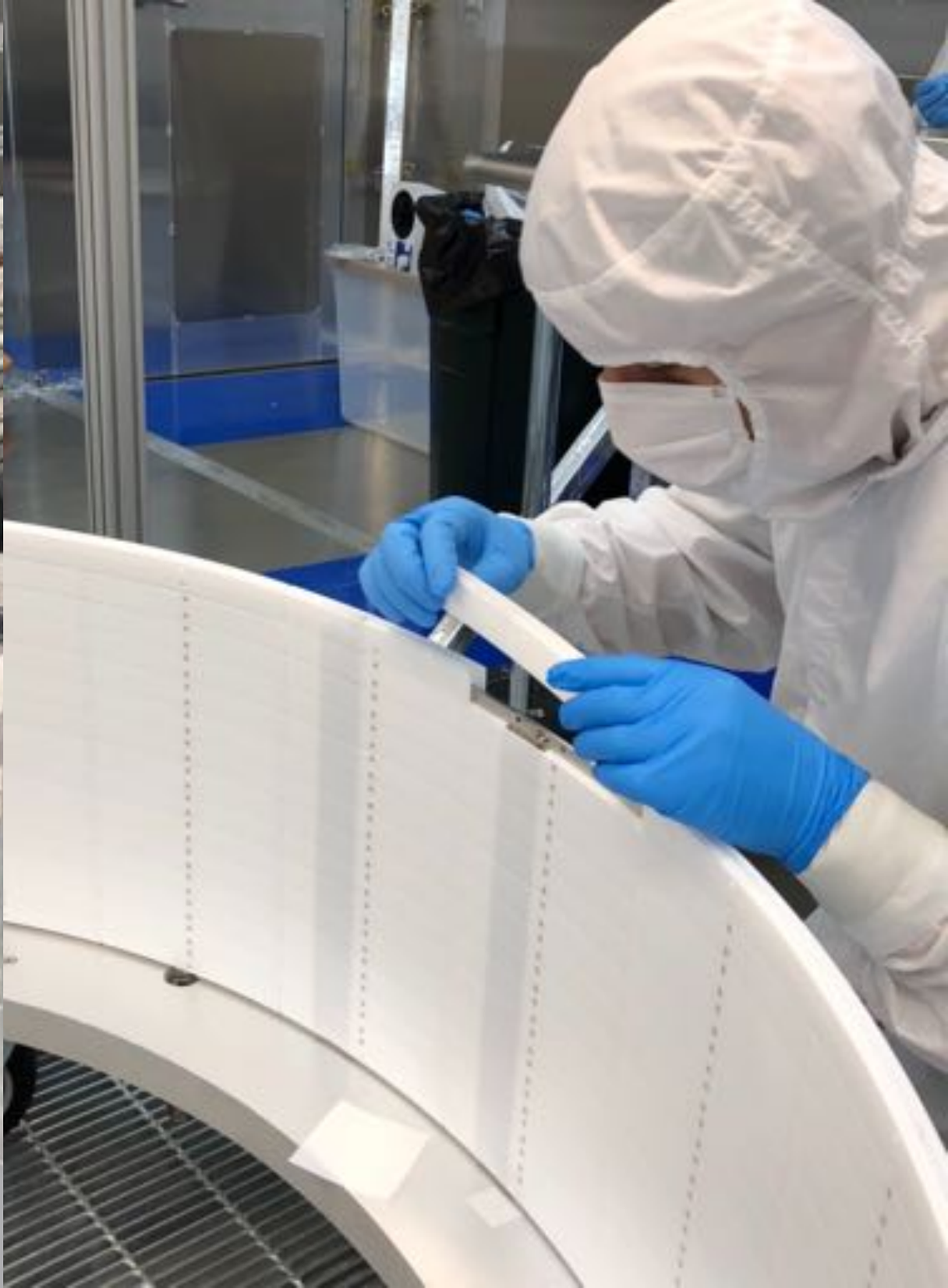
Moore's Law of Dark Matter Detection

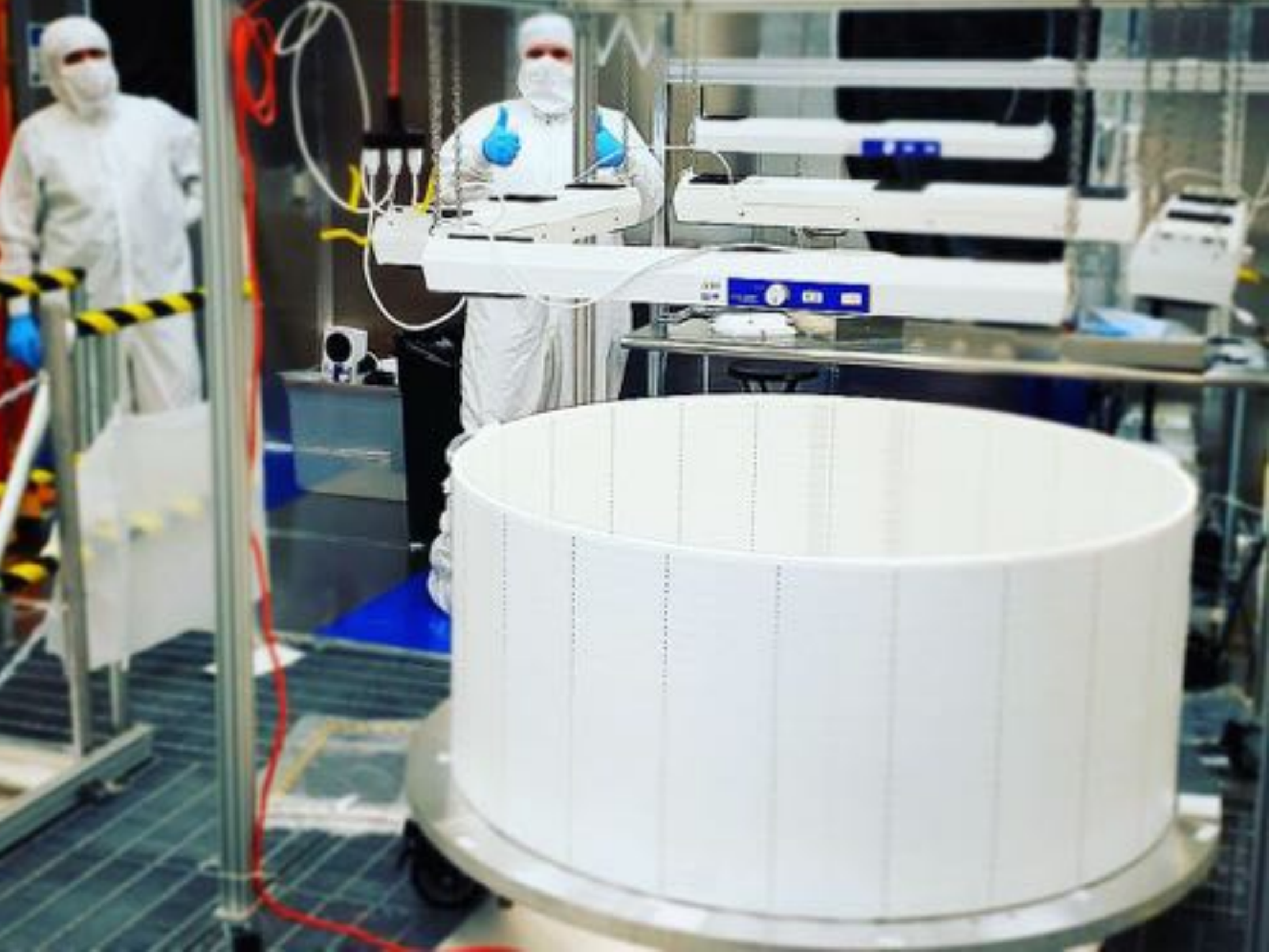


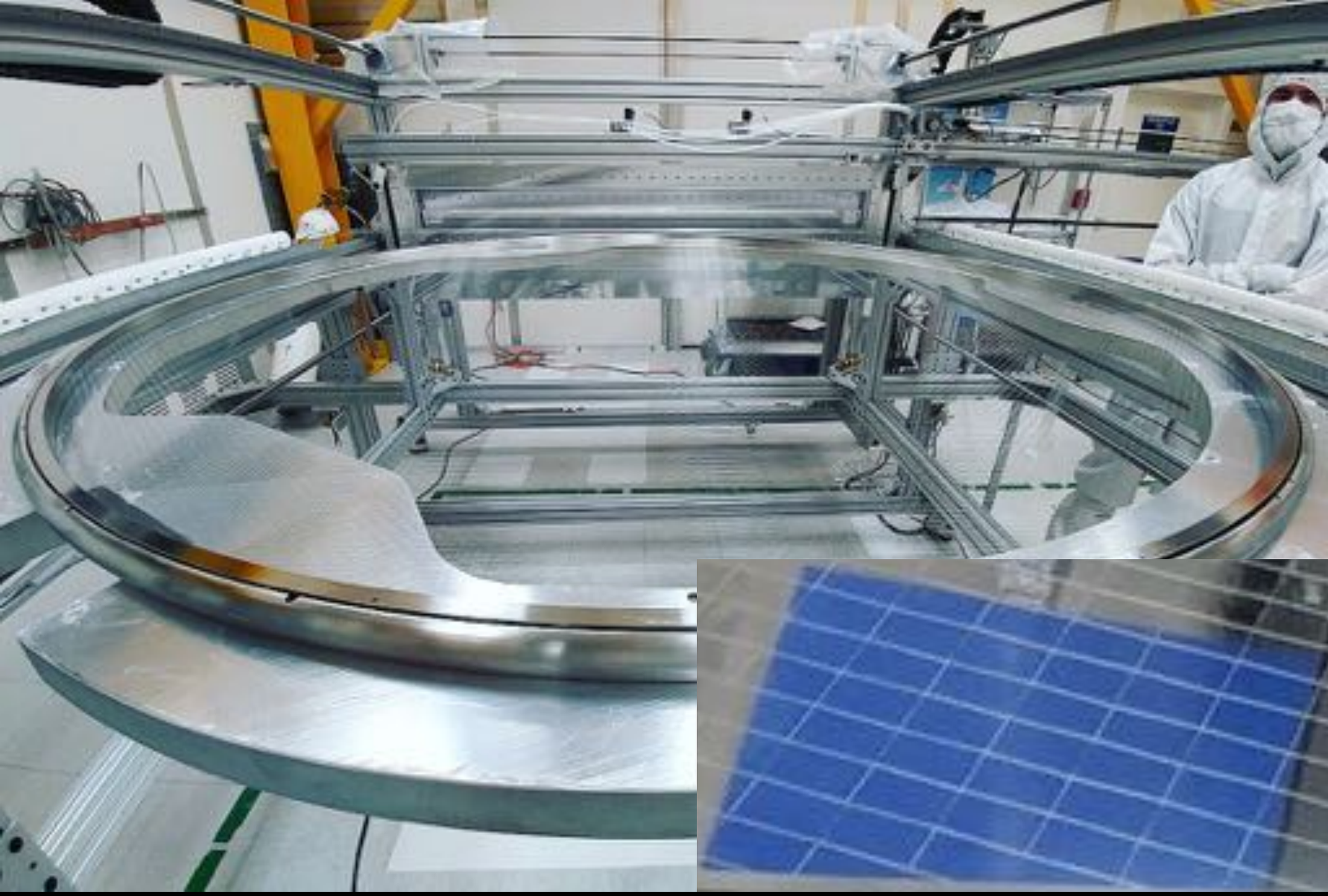
How to Build a Massive Tank of Nuclei

PHOTOSENSORS


500 Photosensors



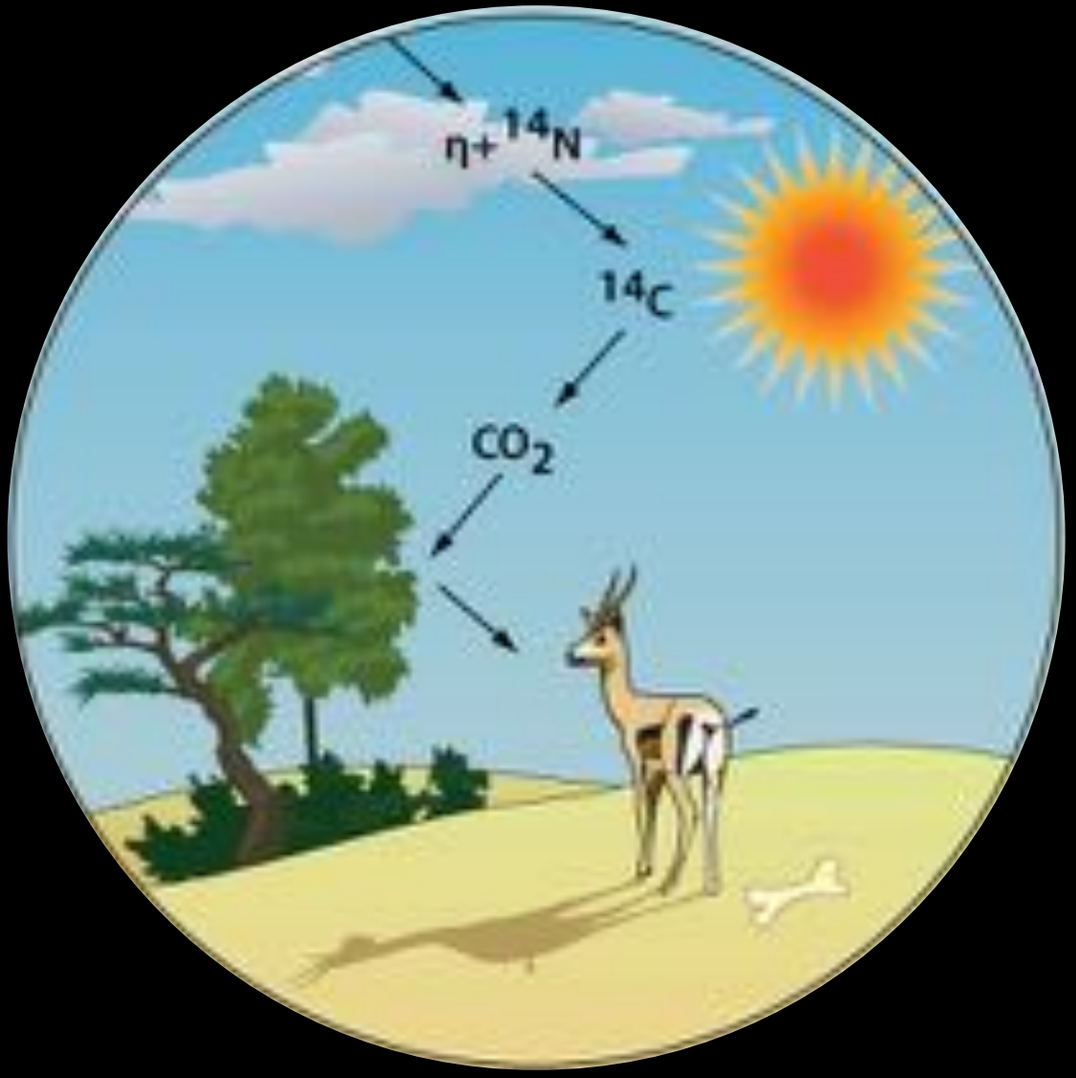




Weave a Bunch of Electrodes (x4)

Halftime: a Few Words about Radioactivity...

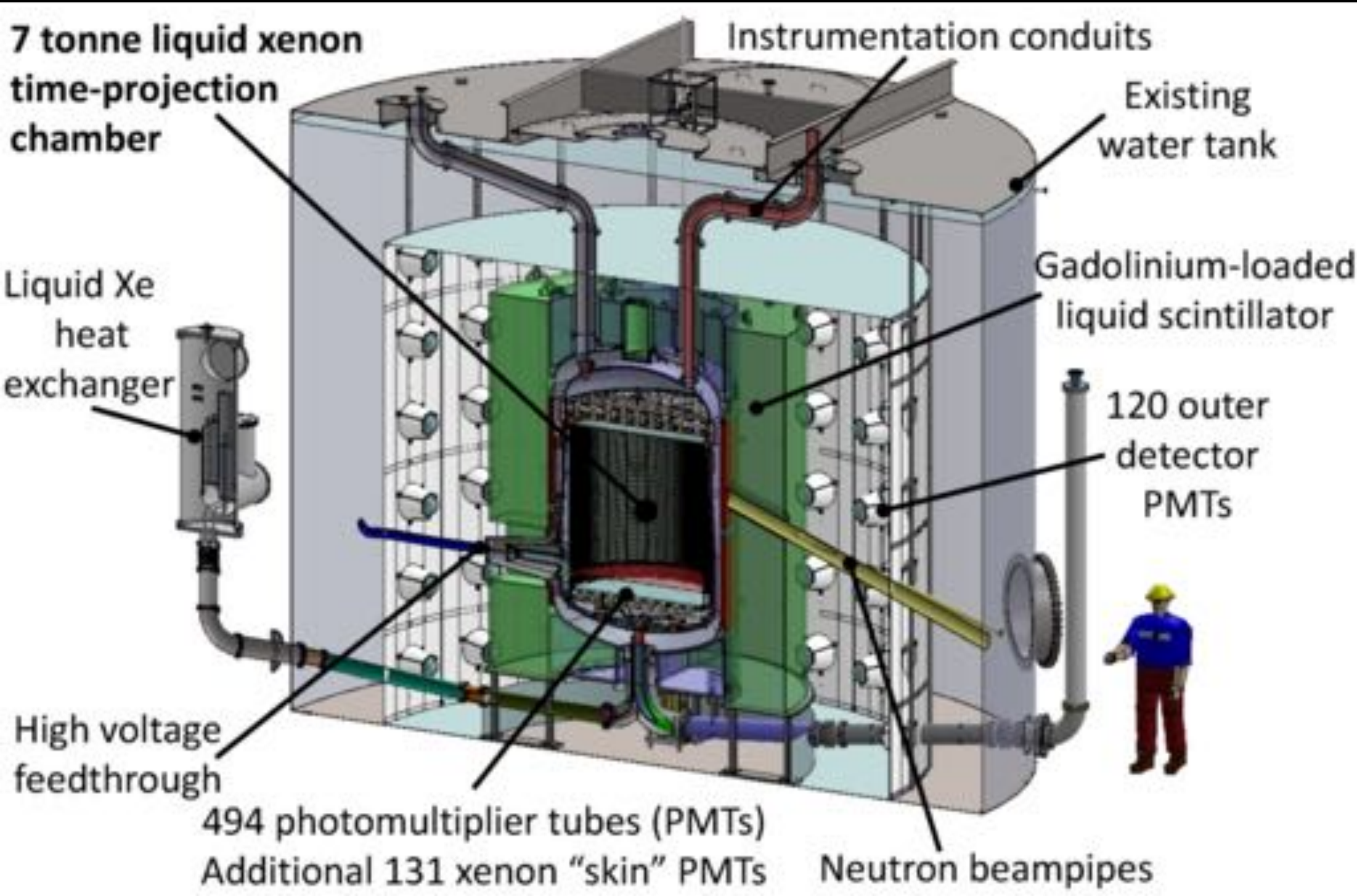
Everything is Radioactive!



Everything is Radioactive!

- Dark Matter: Extremely Rare Interactions
- Must Control the Radioactivity of Detectors!
- Humans: 100,000x more Radioactive than LZ
- Commercial Steel: 200,000x more radioactive than Titanium in LZ Cryostat
- But: we don't get Choose the Rock In the Homestake Mine

LZ within its Shielding Detectors




CAUTION

Dark Matter is Extremely Elusive!

- There are ~3 DM Particles per Liter on Earth
- Streaming through the Earth at 230 km/sec
- Almost 10,000 Particles inside LZ at any Time, Crossing the LZ Volume in ~10 microseconds
- 1 Billion Particles go through LZ every Second!
- Of those Dark Matter Particles, we are Hoping to Detect ~a Handful per Year (If we Are Lucky)!

How does That Compare to Background?

Needle in a Haystack

- Underground Laboratory: 3.5 Million Reduction in Cosmic Rays than Surface
- Low Radioactivity Materials + Clean Assembly: 100,000 – 1 Million Cleaner Than "Regular"
- Residual Expected Particles: ~5 Billion over the Life of the Experiment (50/second)
- Expected Dark Matter Particles: a few Dozens? in the same Timeframe (if Nature Cooperates)!

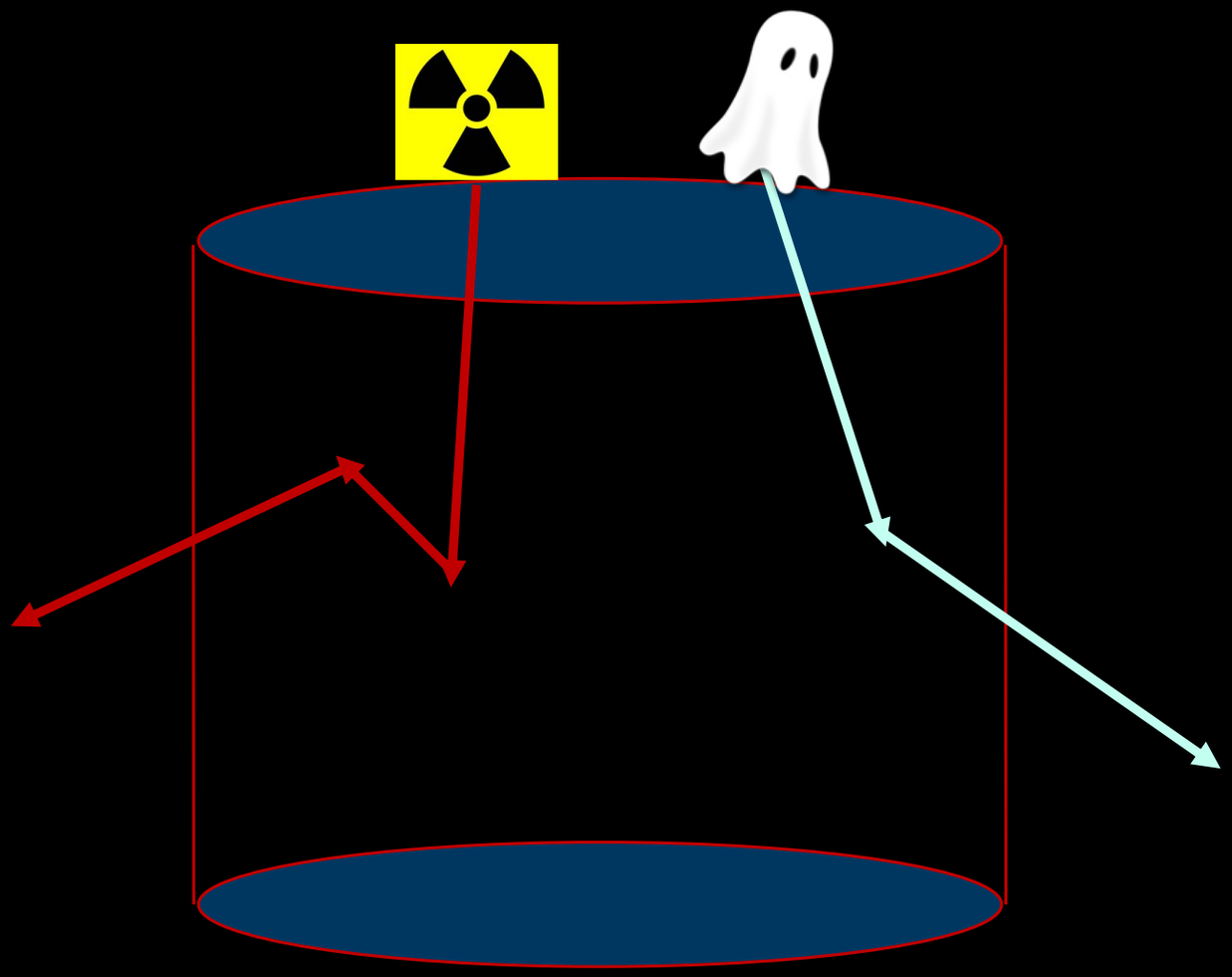
How do we find those Few Particles?!?

Needle in a Haystack

How do we find those Few Particles?!?

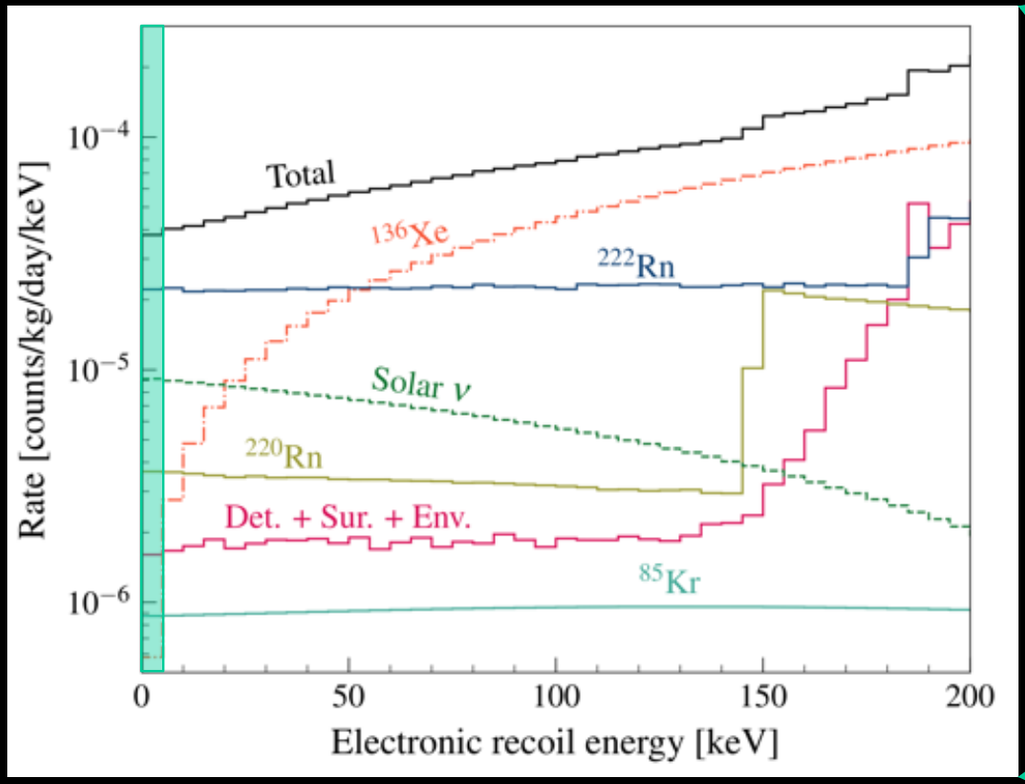
Needle in a Haystack

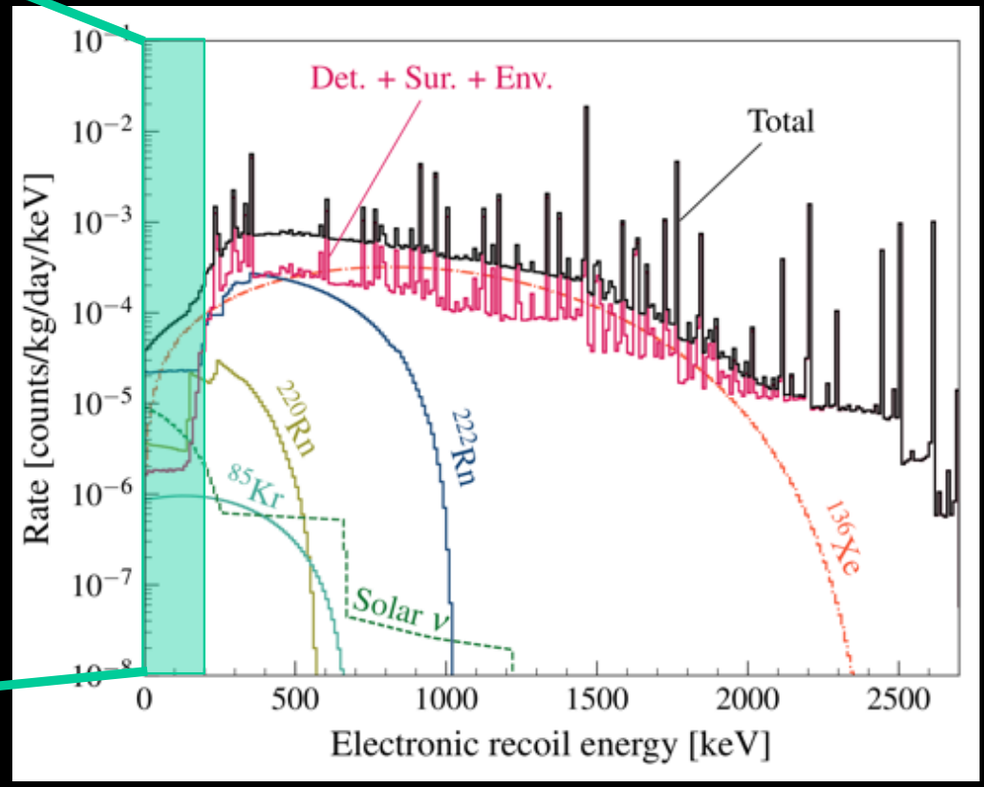
Total Collected Particles	100%	5 Billion
Single Site Interactions	5%	250 Million



Needle in a Haystack

Total Collected Particles	100%	5 Billion
Single Site Interactions	5%	250 Million
Low Energy Transfer	0.4%	1 Million





Needle in a Haystack

Total Collected Particles	100%	5 Billion
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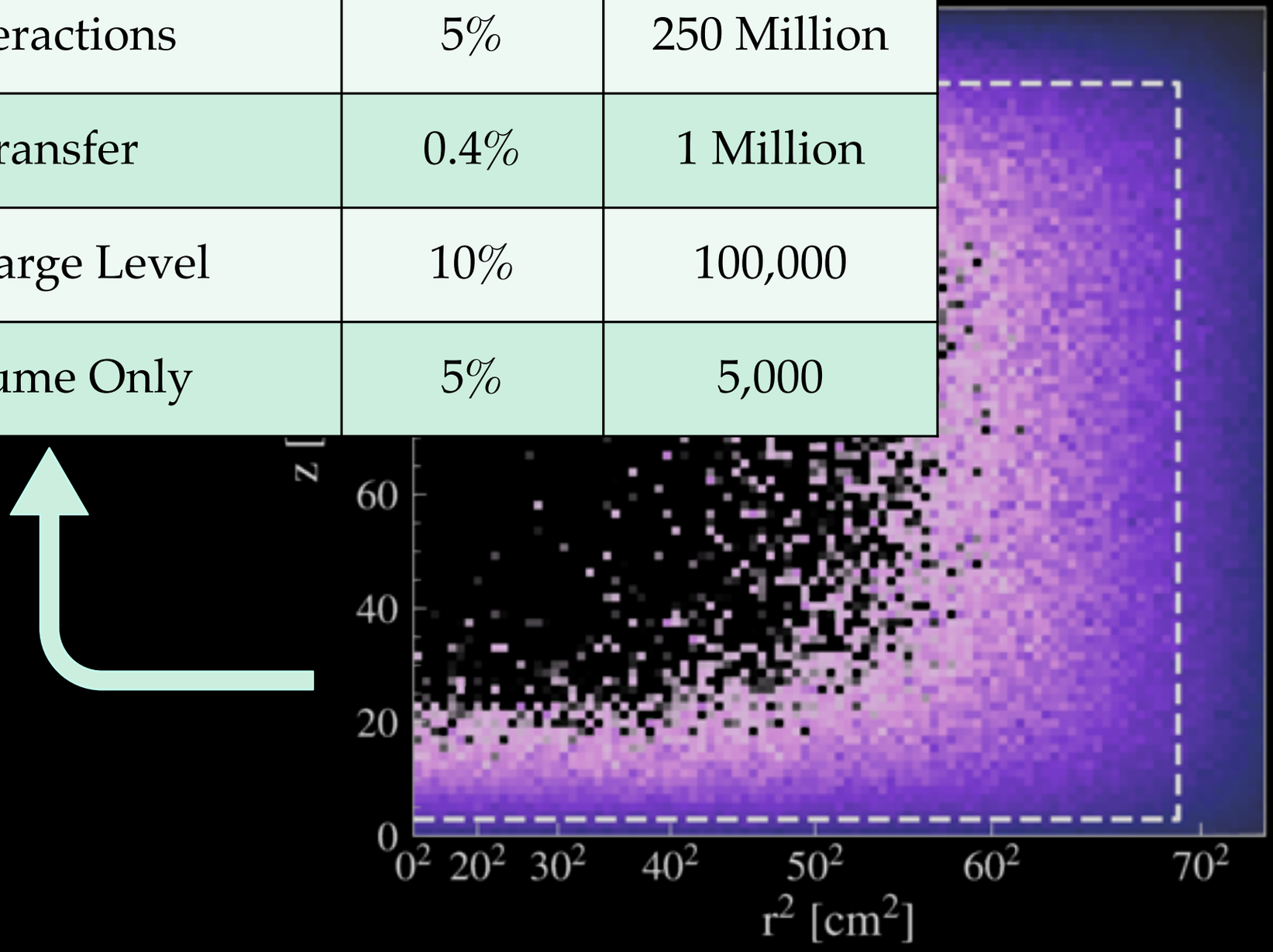
Low Energy Transfer	0.4%	1 Million
Detectable Charge Level	10%	100,000
Use Inner Volume Only	5%	5,000



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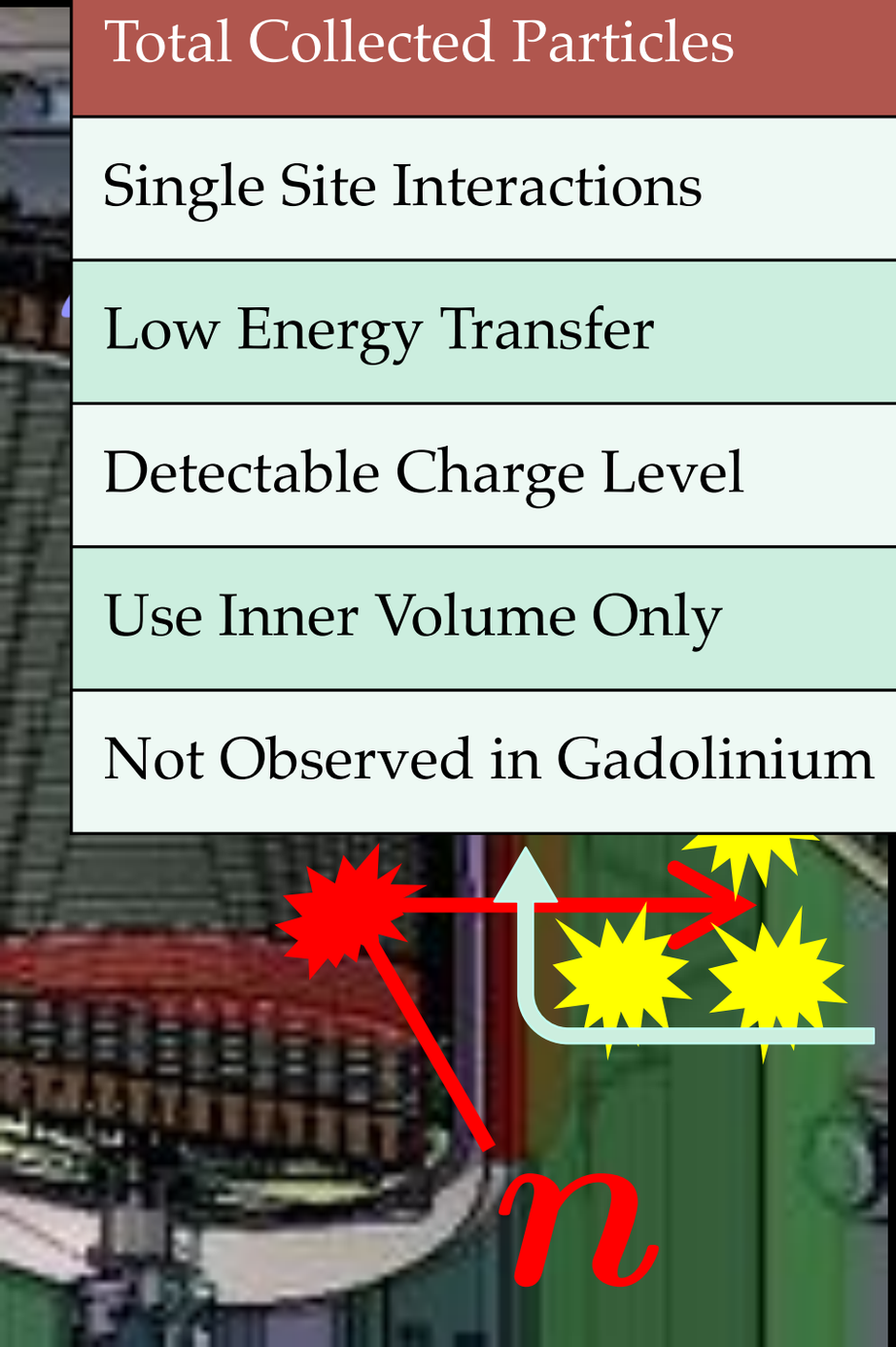

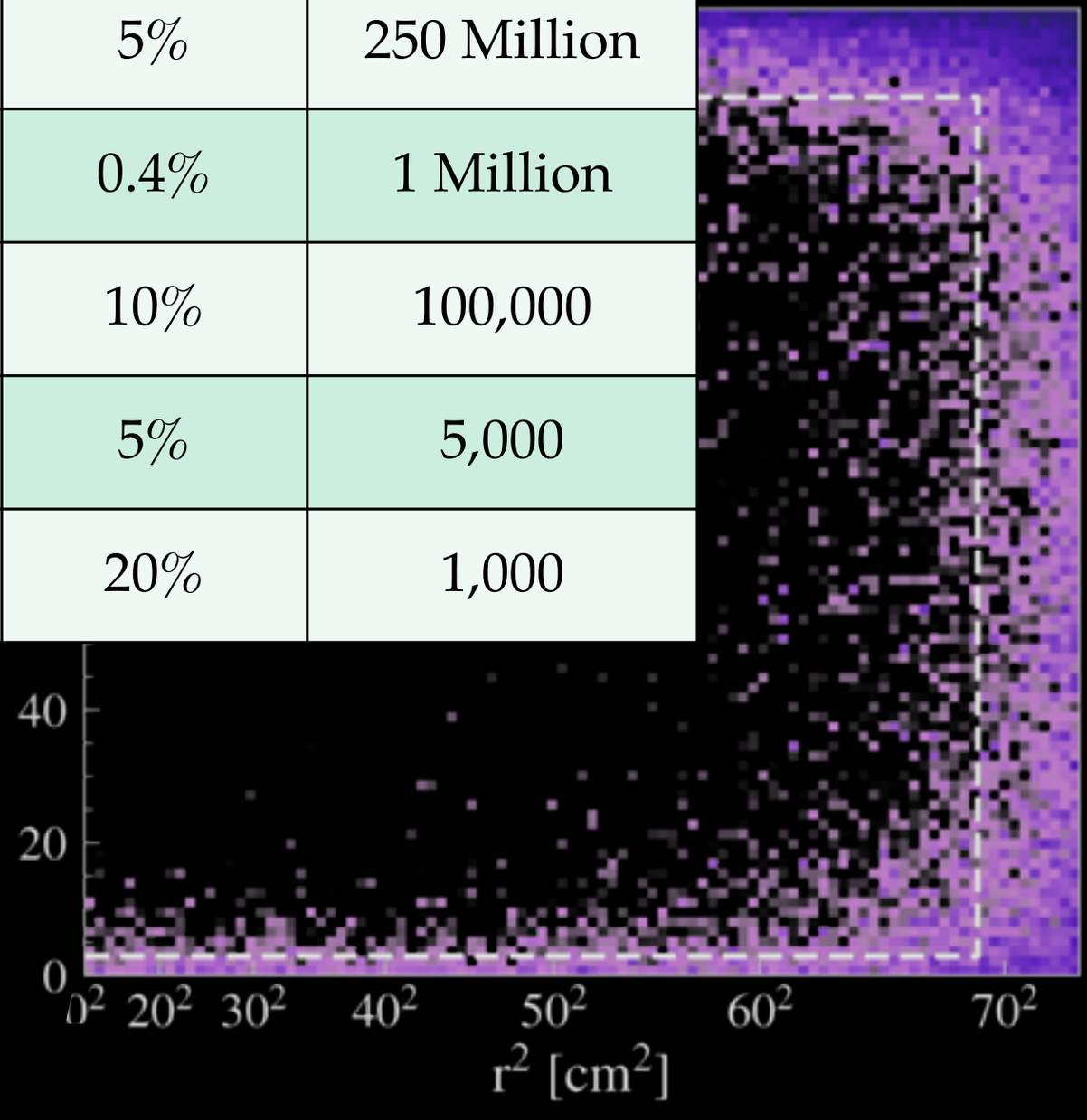

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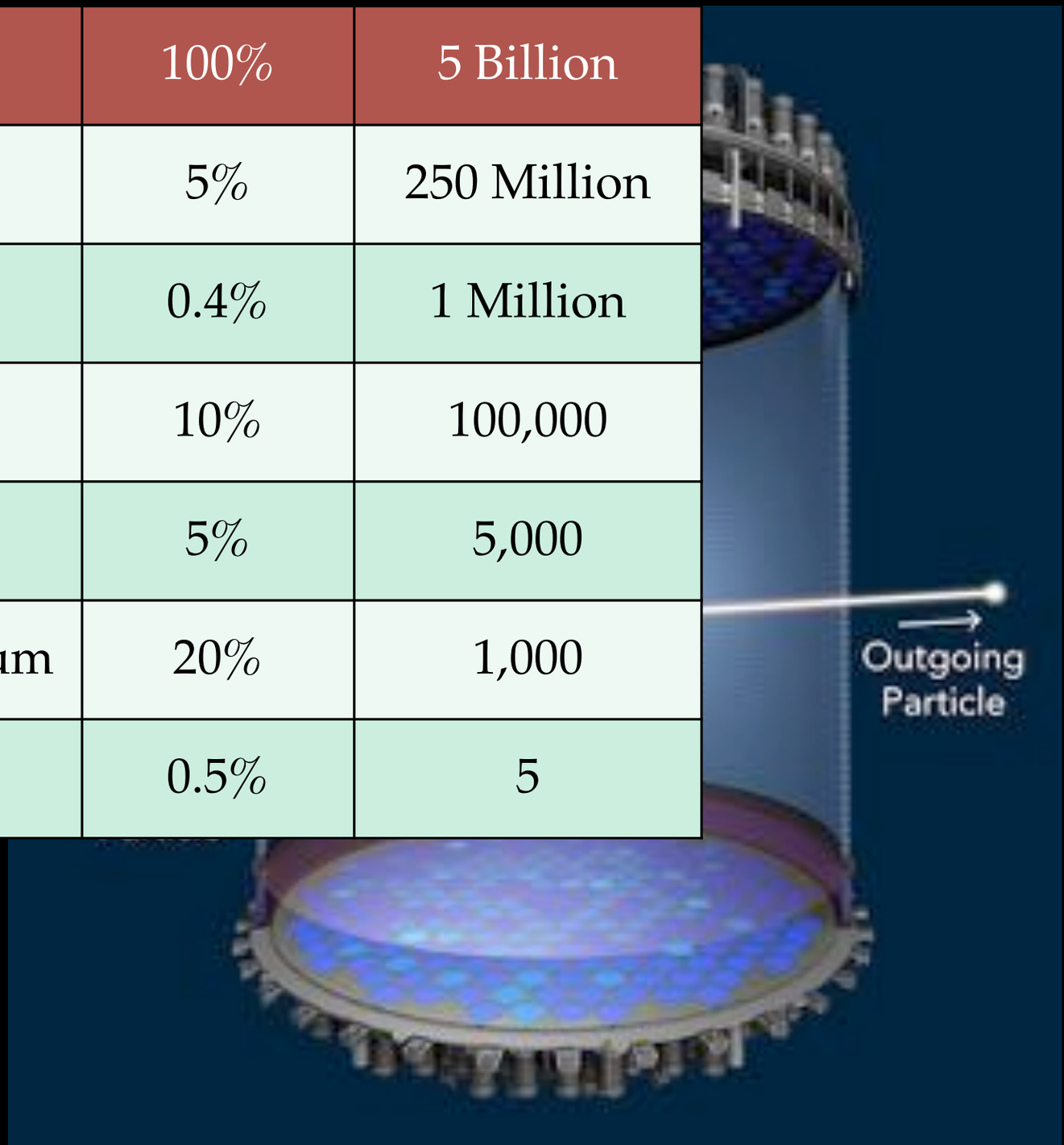
Not Observed in Gadolinium	20%	1,000
Low Charge/Light Ratio	0.5%	5

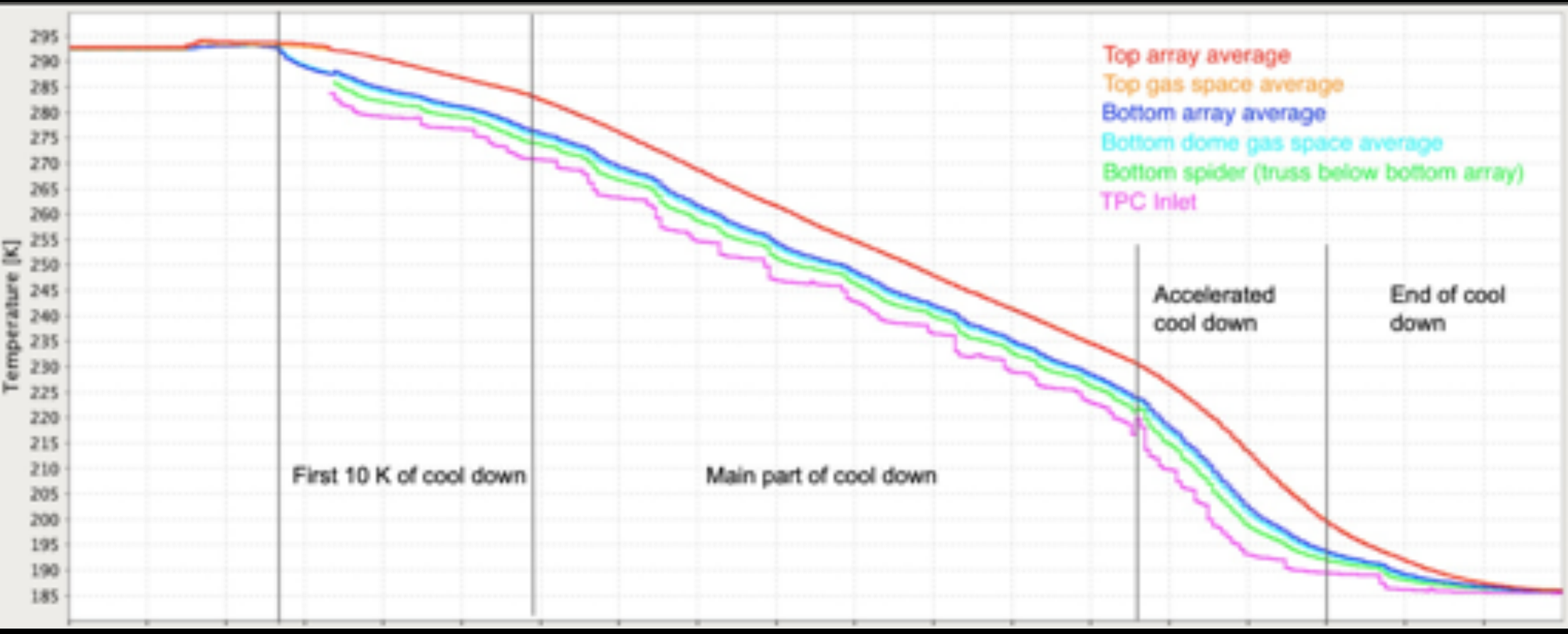


Needle in a Haystack: Computing

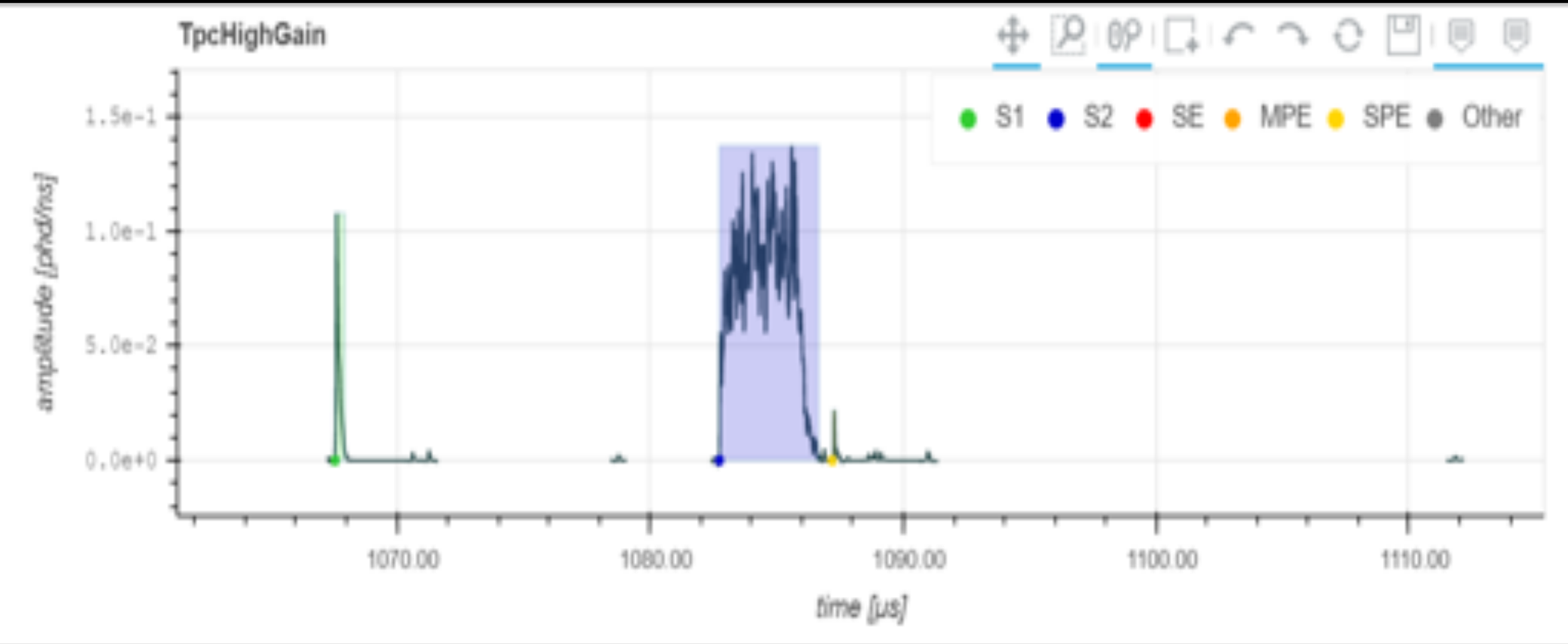
Commissioning 2 Machines at Once!

New NERSC Supercomputer:
64.6 PFlops! CPUs + GPUs!

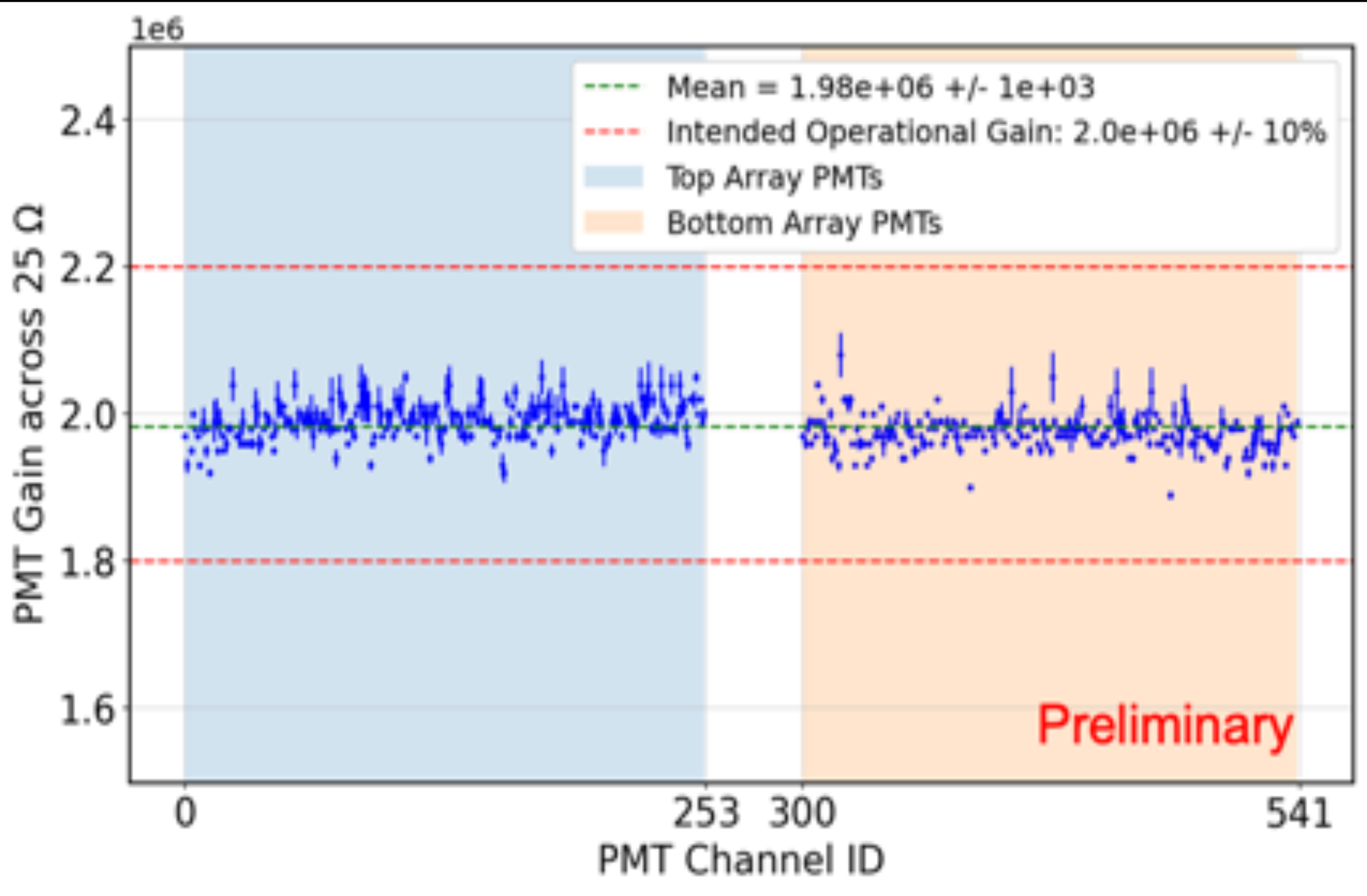
LZ Commissioning: Cooldown!



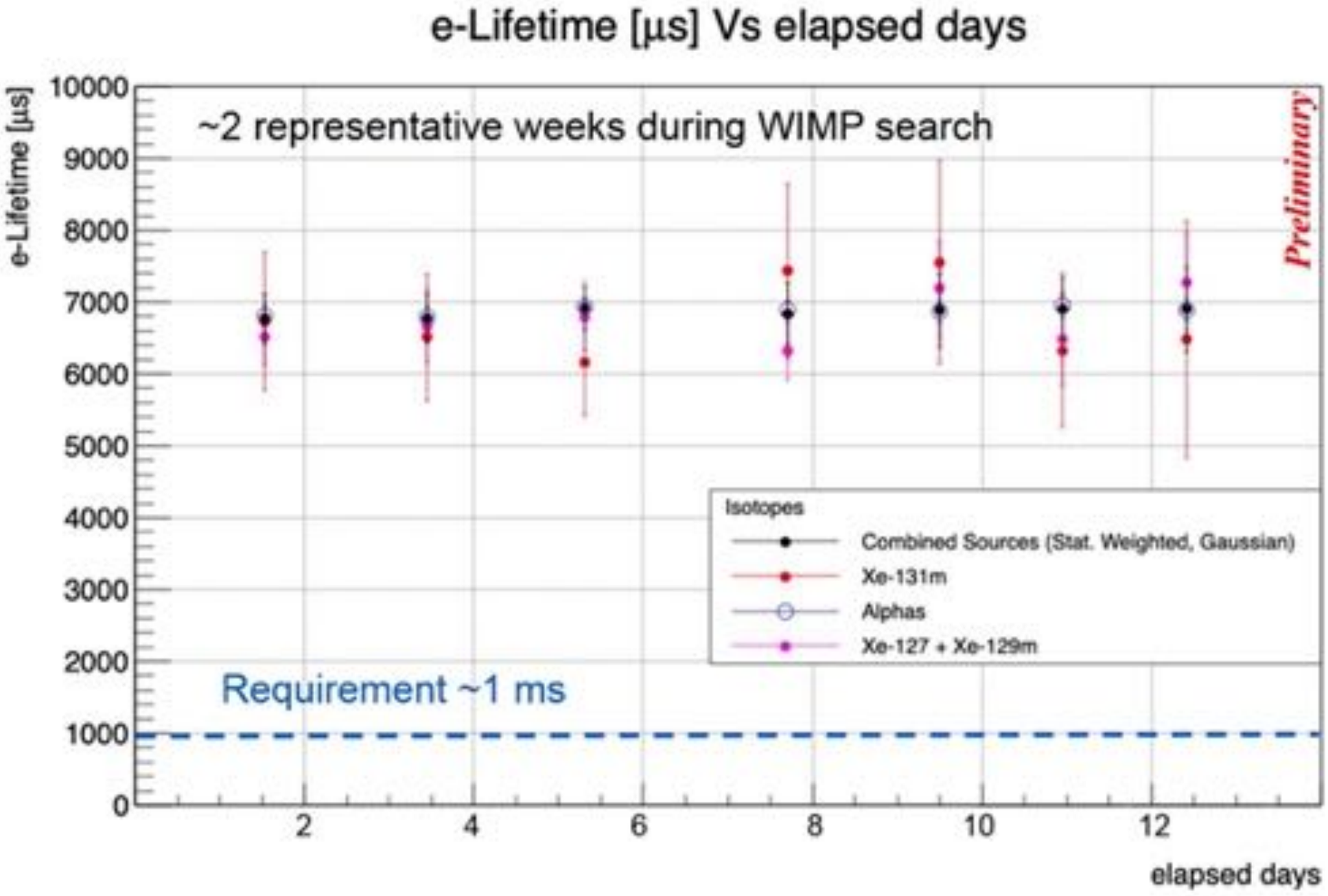
LZ Commissioning: First Light!



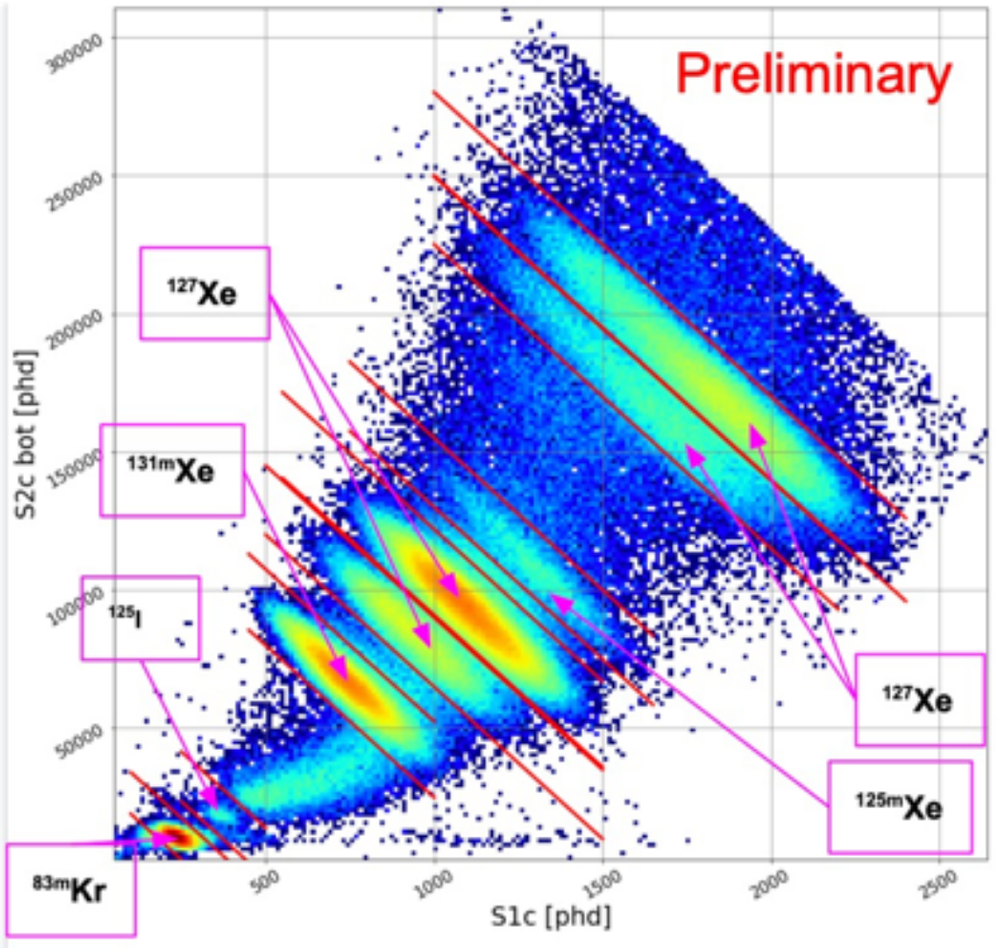
LZ Commissioning: PMT Gain Matching!

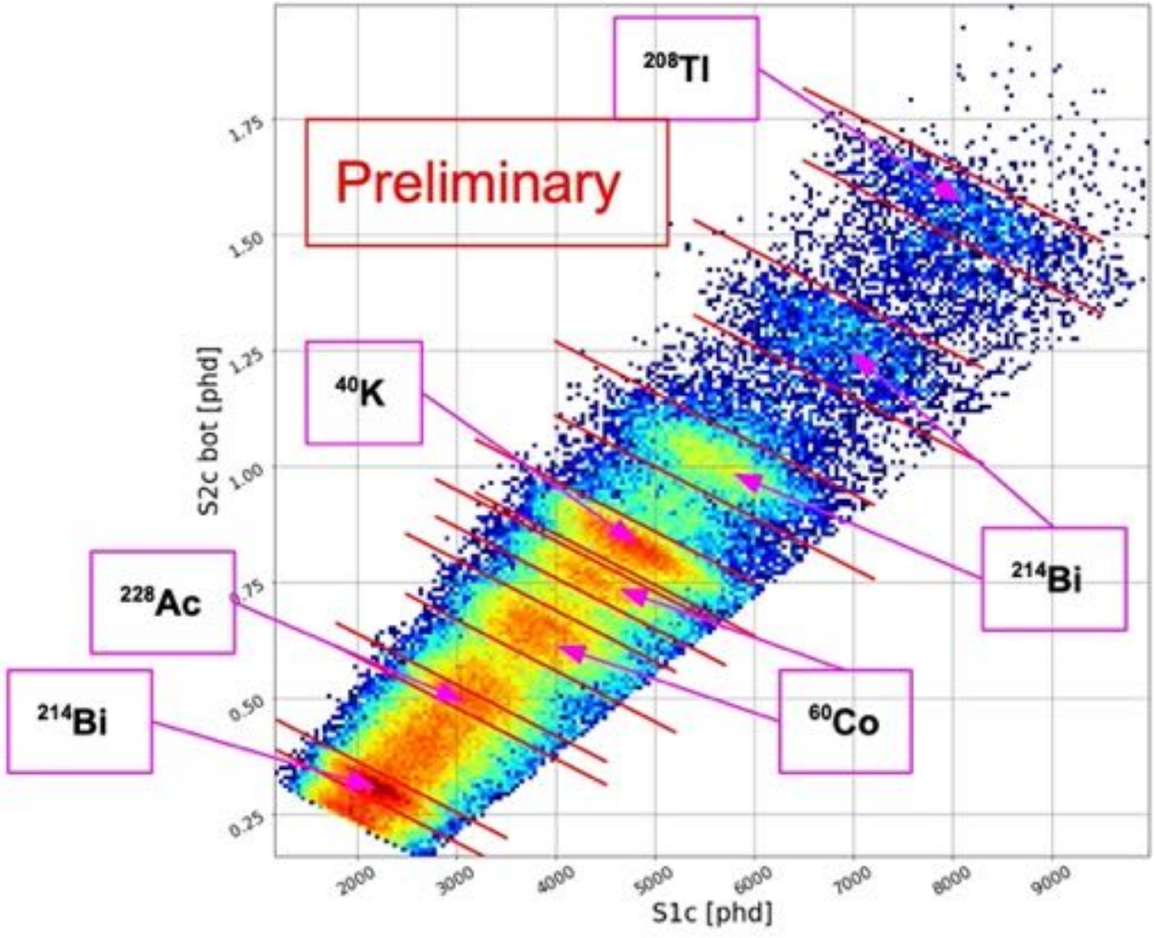


LZ Commissioning: LXe Purity



LZ Commissioning: ER Calibrations

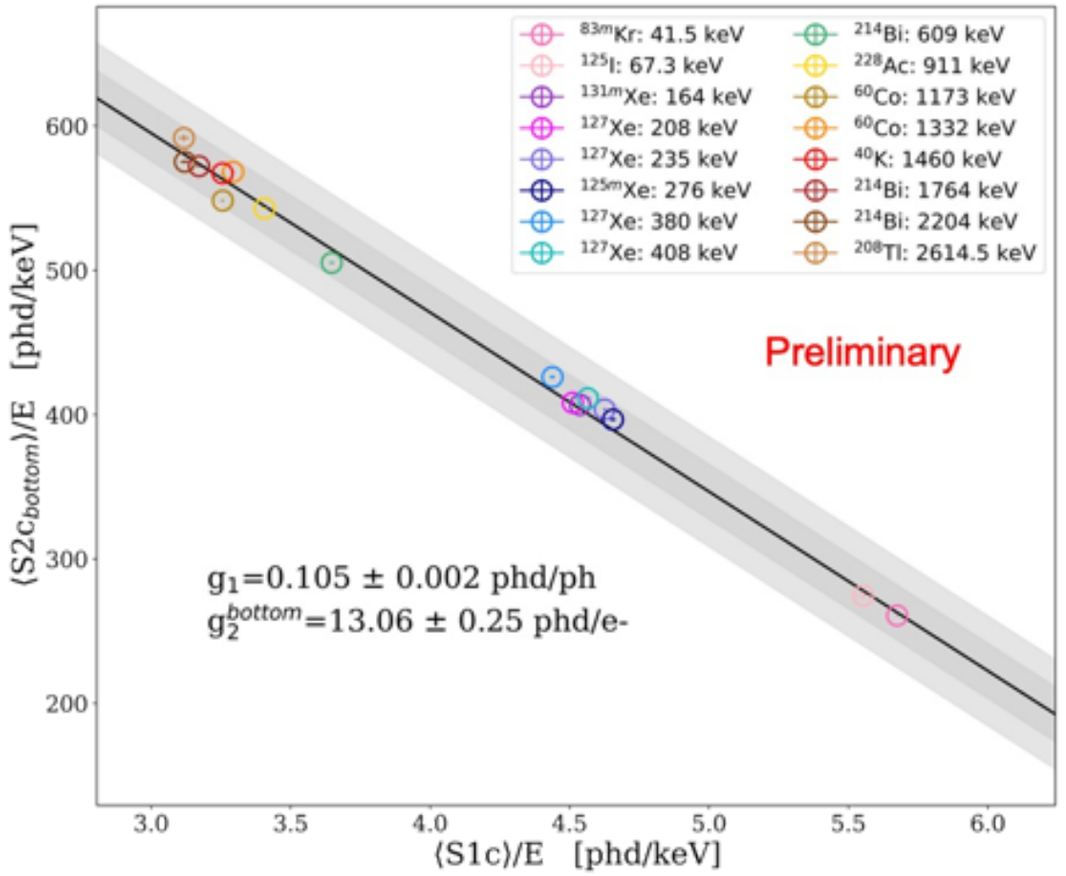




LZ Commissioning: ER Calibrations

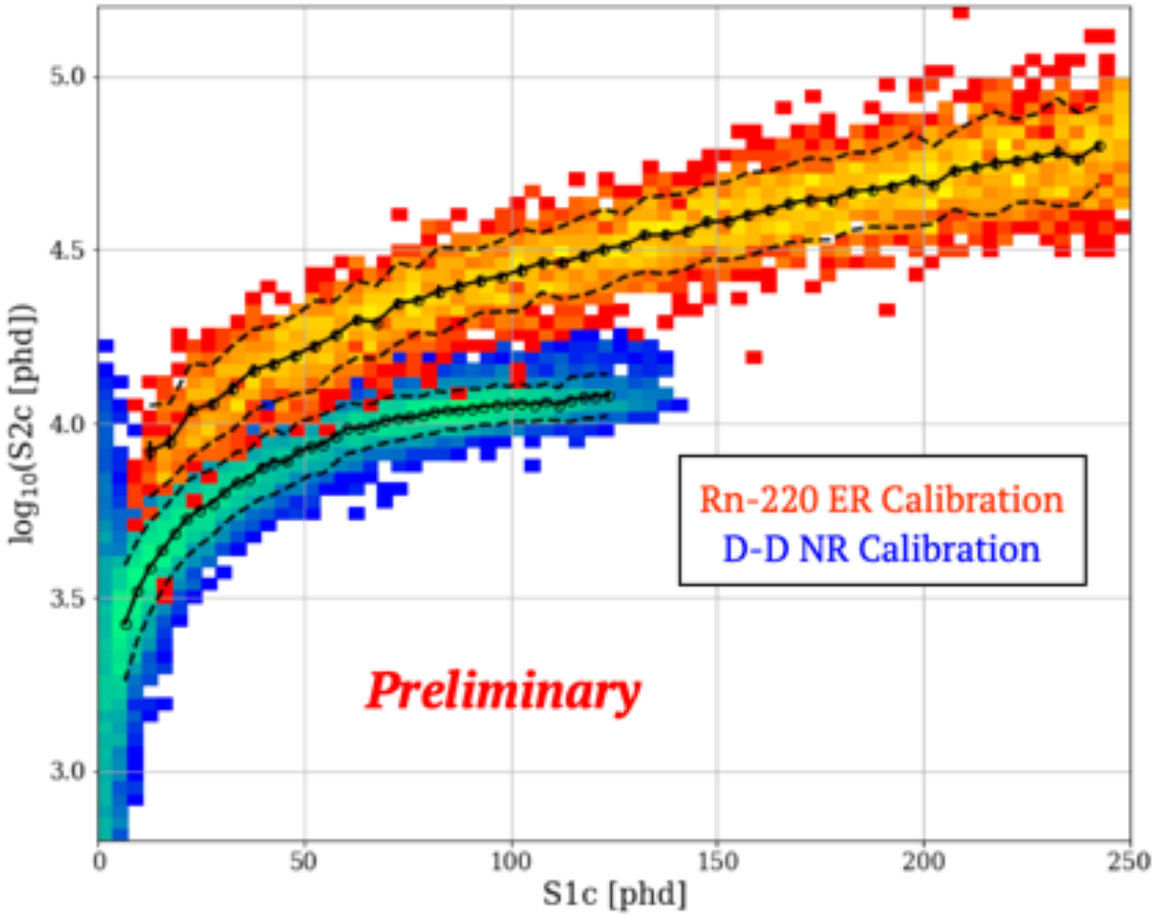
- Mono-energetic ER peaks used to find:
  - g1, photons detected (phd) per prompt scintillation photon
  - g2, phd per ionisation electron

$$E = W\left(\frac{S1_c}{g_1} + \frac{S2_c}{g_2}\right)$$



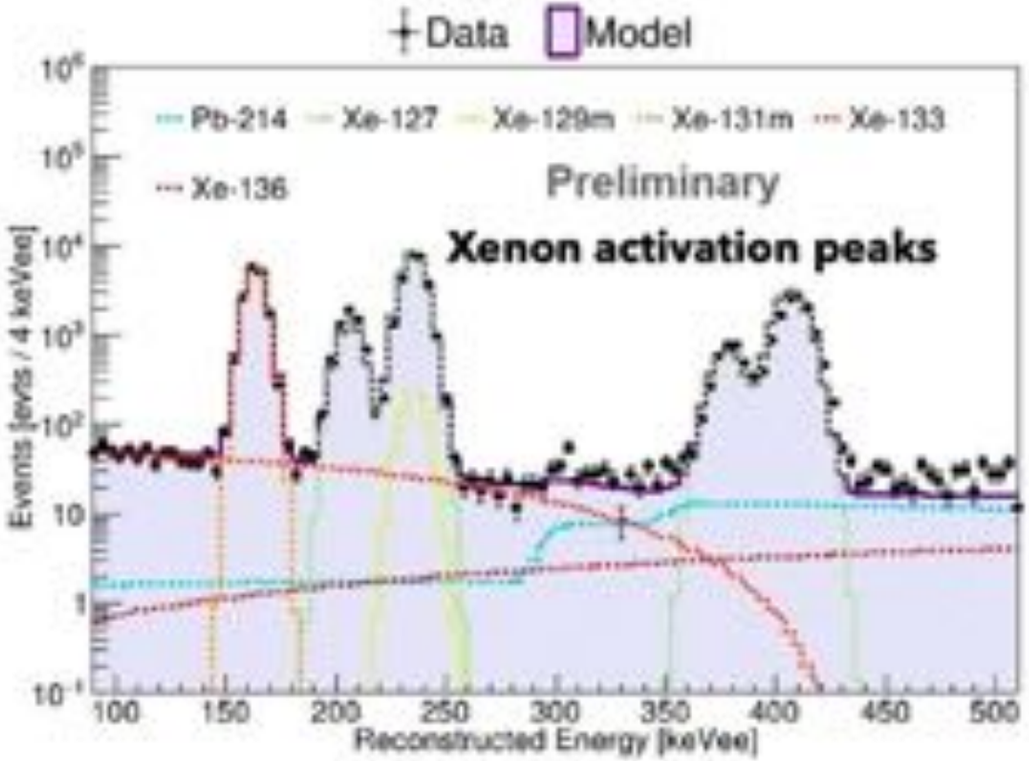
LZ Commissioning: NR Calibrations

- Neutrons from DD source in **3 modes**
  - Direct mode: 2.45 MeV
  - D-reflector: 350 keV
  - H-reflector: 10-200 keV
- Direct mode
  - Max Xe recoil: **74 keVnr**
  - **Minimal ER rate** due to low γ emission
- Observed data **agrees with NEST** simulations

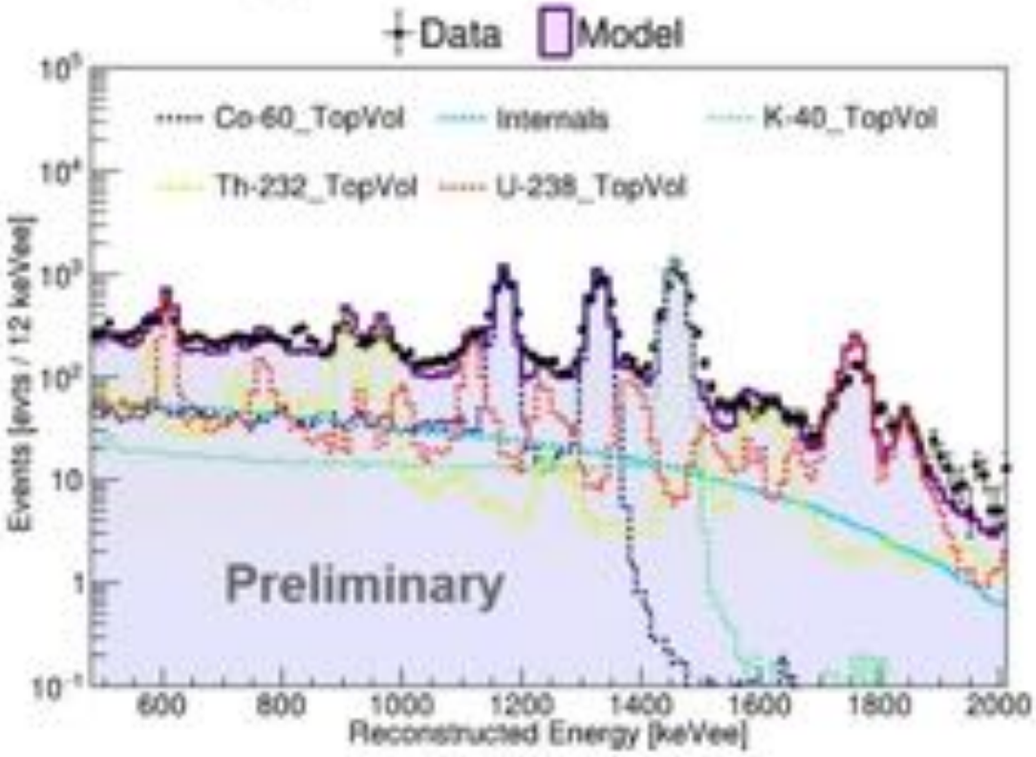


LZ Commissioning: Backgrounds

- Can fit simulated background models to data



- Fitted to detector sub-volume near top



Expected Backgrounds, full Exposure

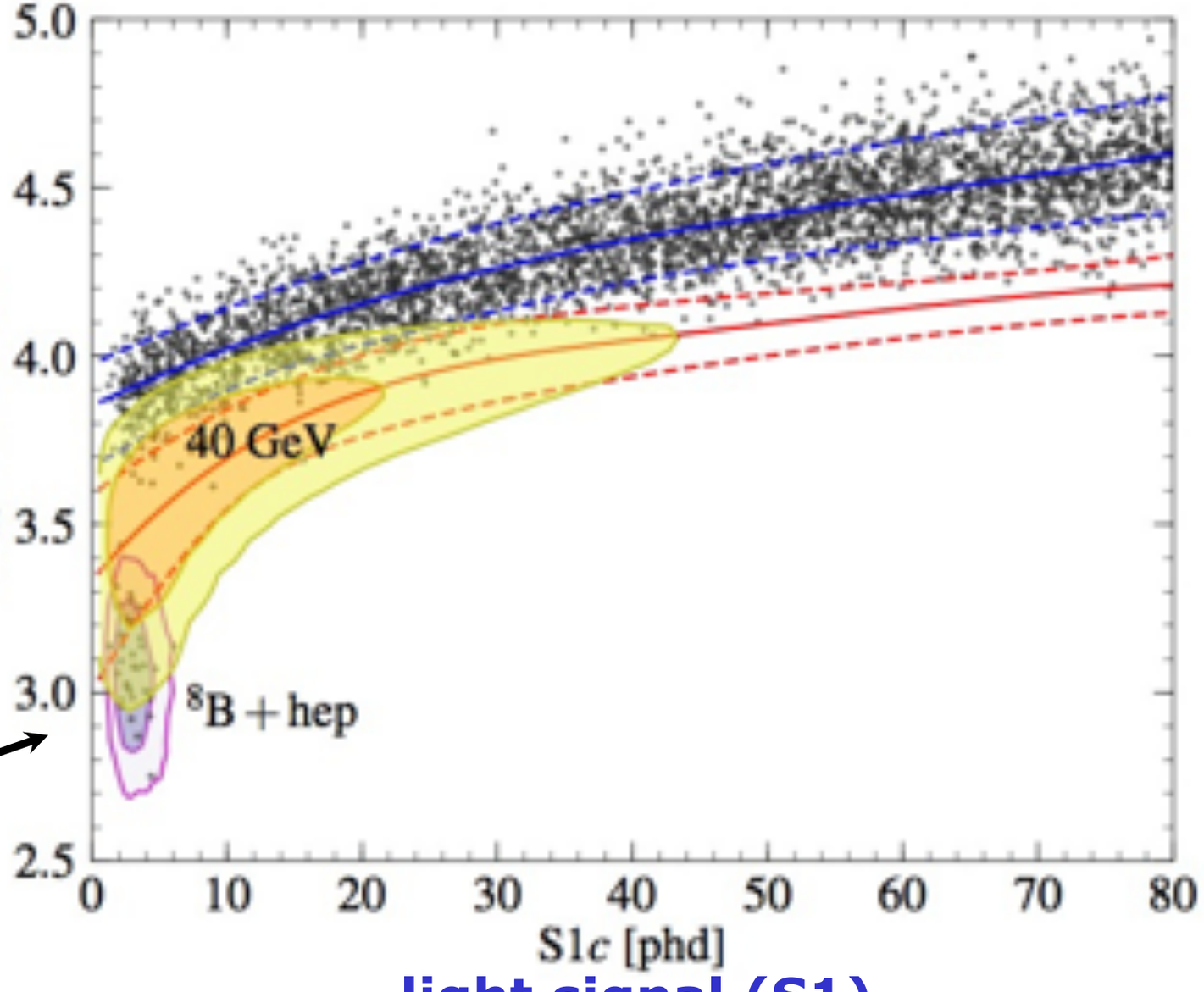
Nominal: 5.6 ton fiducial, 1000 live-days
~1.5 - 6.5 keV, single scatters, no coincident veto

Background Source	ERs	NRs
Detector Components	9	0.07
Dispersed Radionuclides — Rn, Kr, Ar	819	—
Laboratory and Cosmogenics	5	0.06
Surface Contamination and Dust	40	0.39
Physics Backgrounds — 2β decay, neutrinos*	322	0.51
Total (after 99.5% ER discrimination, 50% NR efficiency)	**5.97**	**0.52**

Phys. Rev. D 101, 052002 (2020)

Simulated Signal & Background

Nominal: 5.6 ton fiducial, 1000 live-days



charge signal (S2)

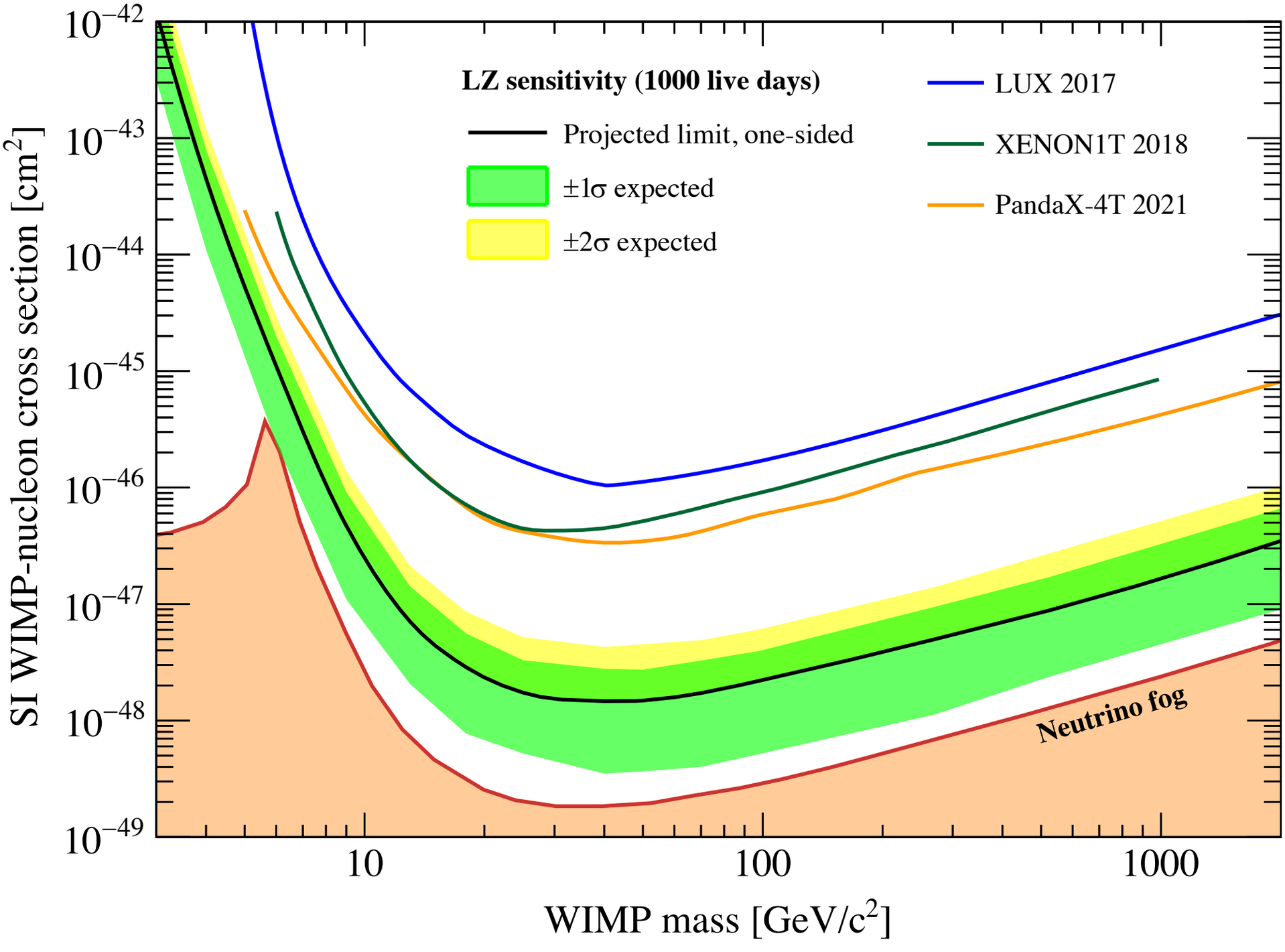
light signal (S1)

Expected ~ 36 NR from ν CNS

→ low-energy calibrations!!!

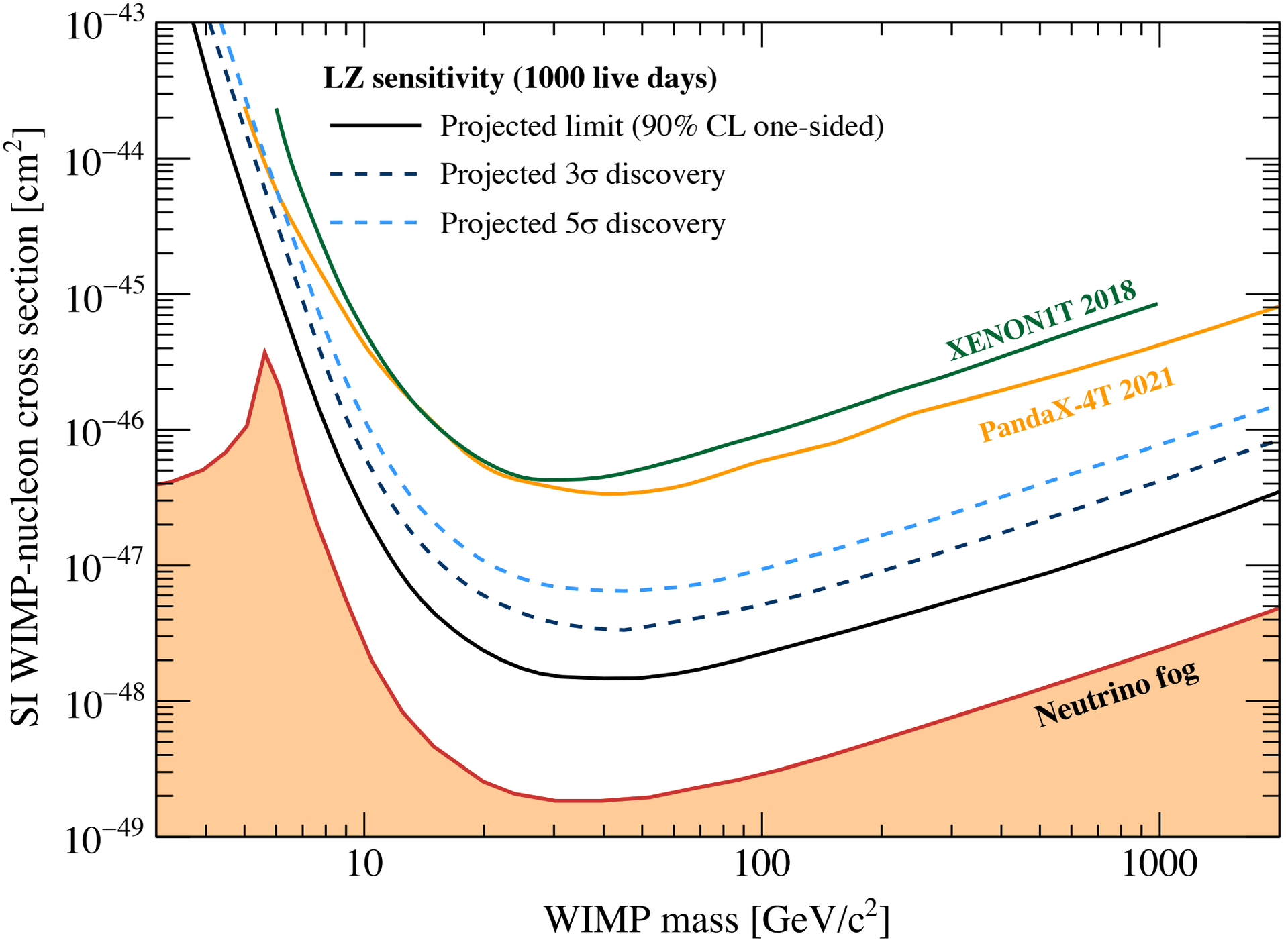
Phys. Rev. D 101, 052002 (2020)

Proj. WIMP Sensitivity: Spin-Independent



Phys. Rev. D 101, 052002 (2020)

S.I. WIMP Sensitivity: Discovery?



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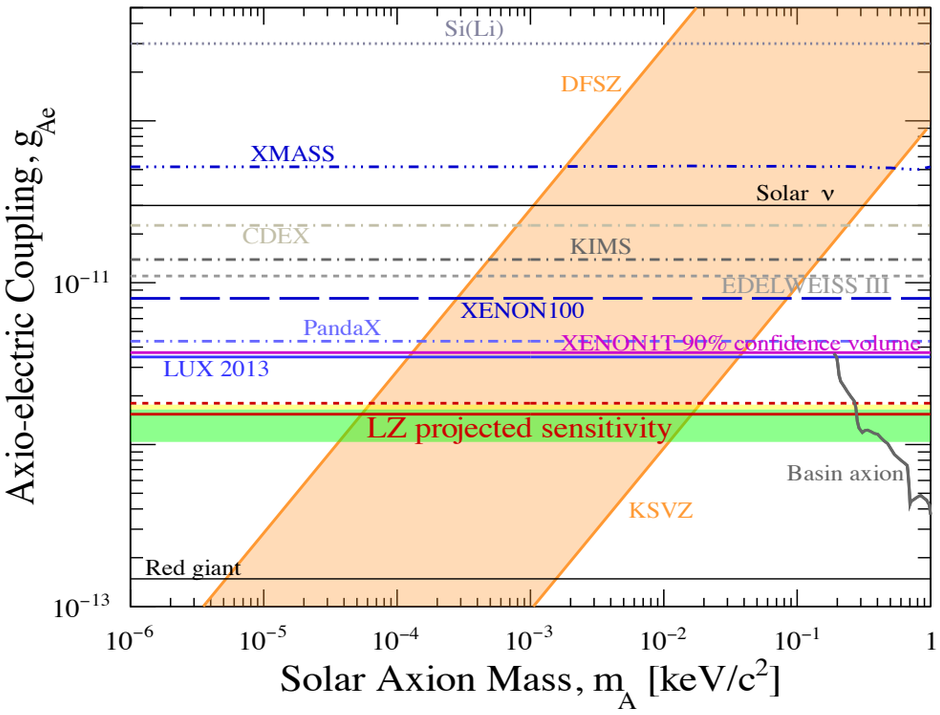
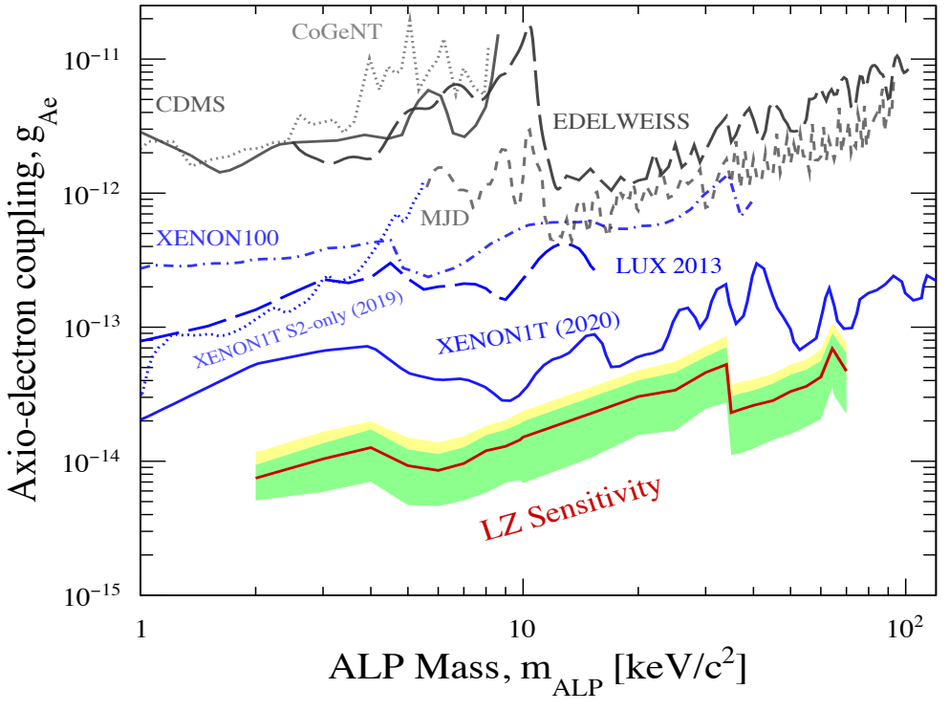
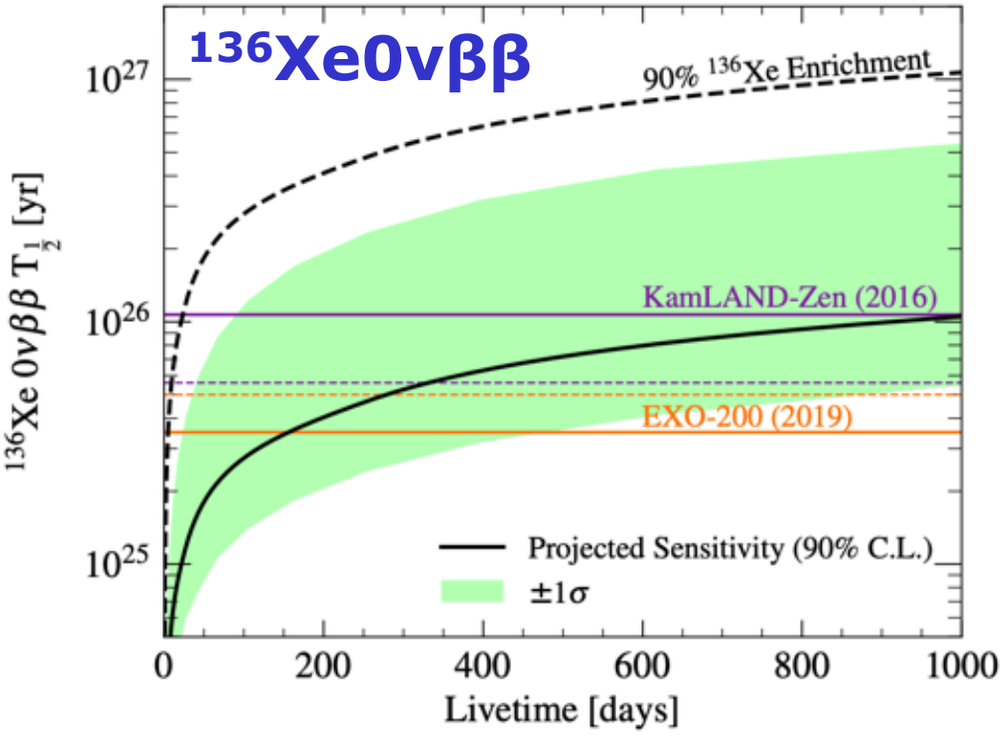
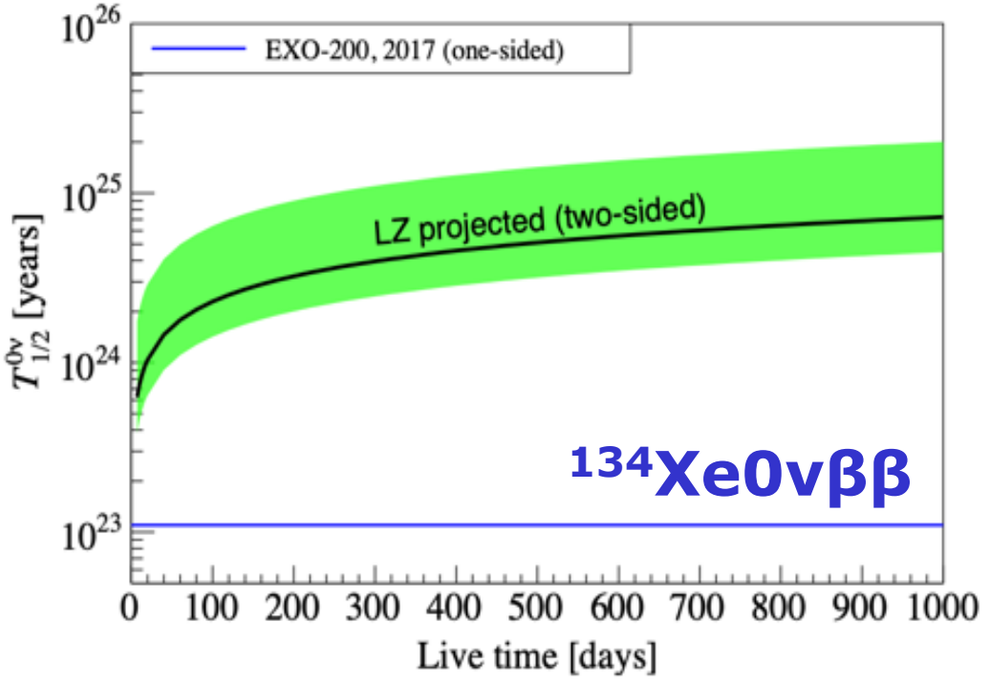
LZ Physics Reach: non-WIMPs





Phys. Rev. D 104, 092009 (2021)





Phys. Rev. C 104, 065501 (2021) Phys. Rev. C 102, 014602 (2020)

A Team Effort! the LZ Collaboration

Black Hills State University
Brandeis University
Brookhaven National Laboratory
Brown University
Center for Underground Physics
Edinburgh University
Fermi National Accelerator Lab.
Imperial College London
Lawrence Berkeley National Lab.
Lawrence Livermore National Lab.
LIP Coimbra
Northwestern University
Pennsylvania State University
Royal Holloway University of London
SLAC National Accelerator Lab.
South Dakota School of Mines & Tech
South Dakota Science & Technology Authority
STFC Rutherford Appleton Lab.
Texas A&M University
University of Albany, SUNY
University of Alabama
University of Bristol
University College London
University of California Berkeley
University of California Davis
University of California Los Angeles
University of California Santa Barbara
University of Liverpool
University of Maryland
University of Massachusetts, Amherst
University of Michigan
University of Oxford
University of Rochester
University of Sheffield
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FCT Fundação para a Ciência e a Tecnologia
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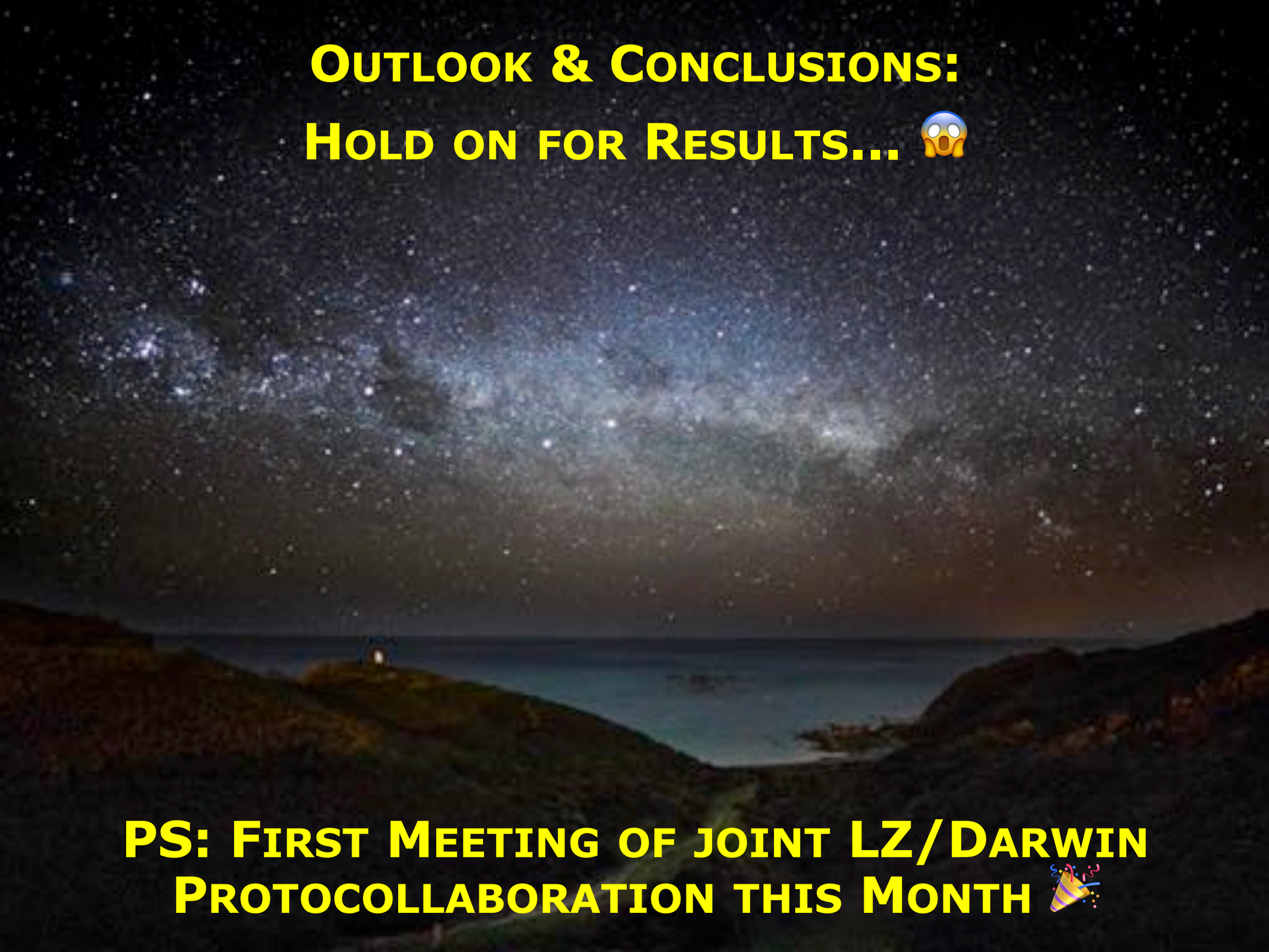
ibs Institute for Basic Science


Outlook & Conclusions:
Hold on for Results... 😱
PS: First Meeting of joint LZ/Darwin
Protocollaboration this Month 🎉