Autoencoders for Compression in LUX-ZEPLIN

Shawn Dubey, Rick Gaitskell, Woody Hulse
Center for the Fundamental Physics of the Universe
Department of Physics, Brown University

Brown University
CFPU AI Winter School 2025
January 16, 2025

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Introduction

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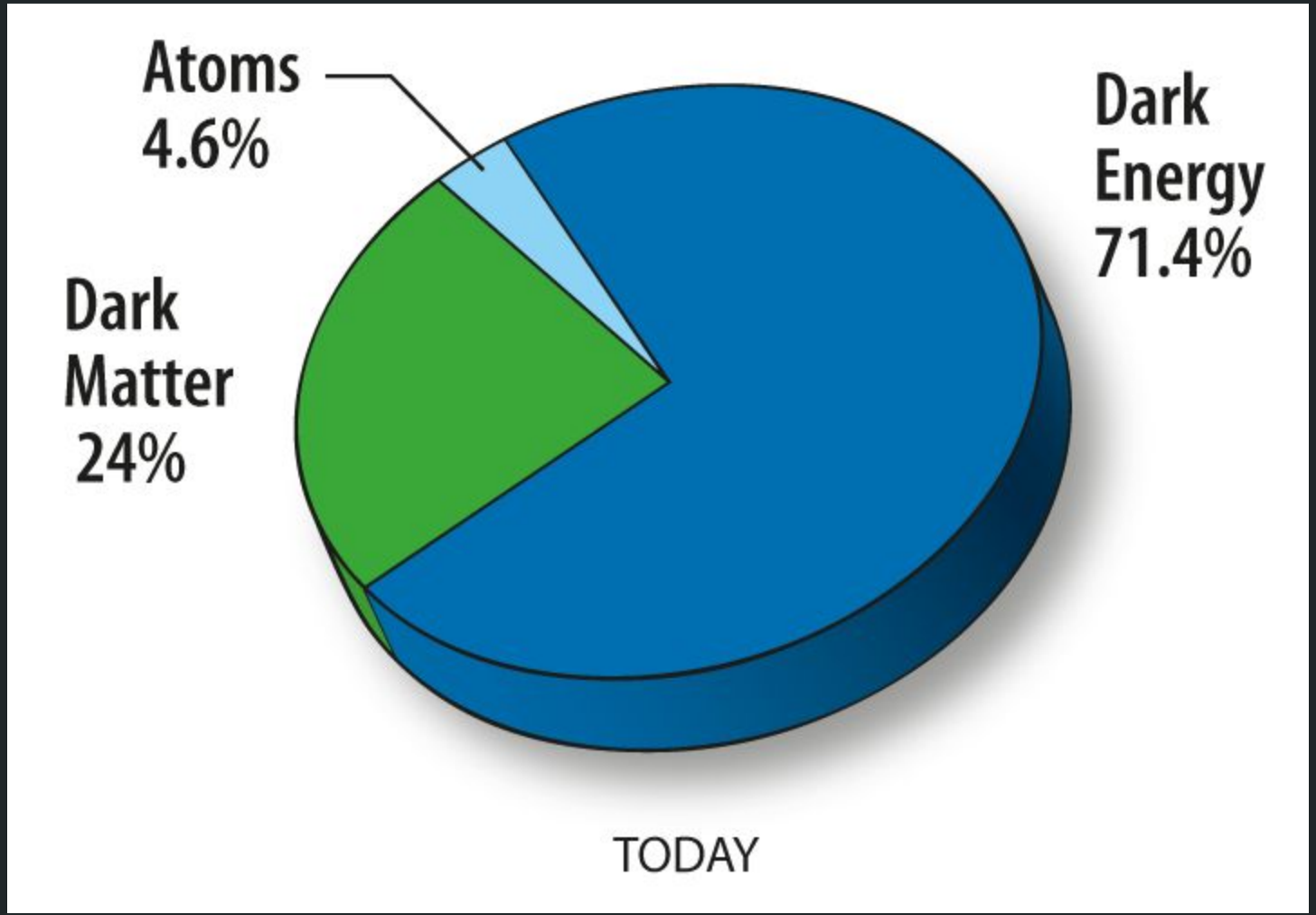

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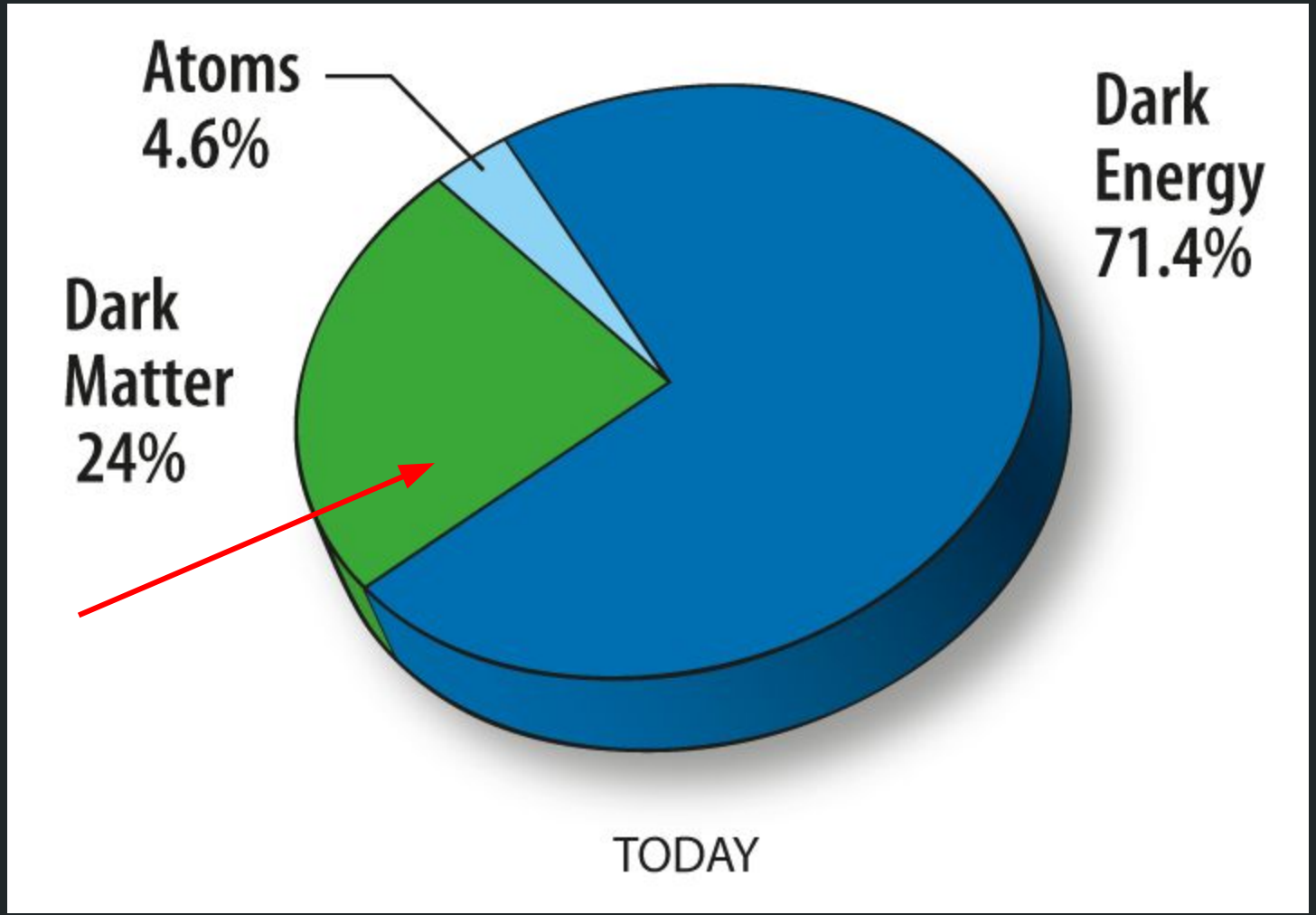
https://wmap.gsfc.nasa.gov/universe/uni_matter.html



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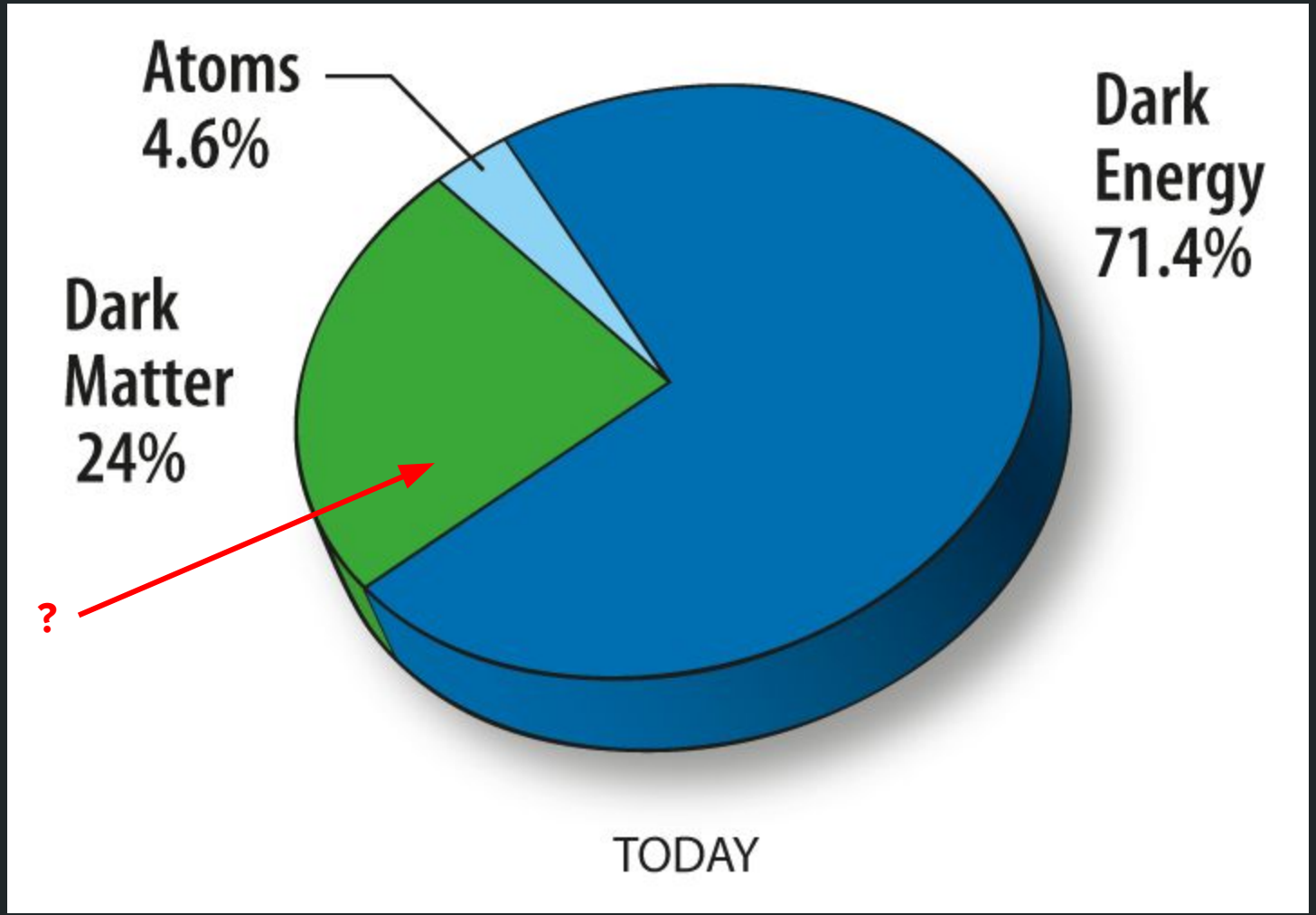

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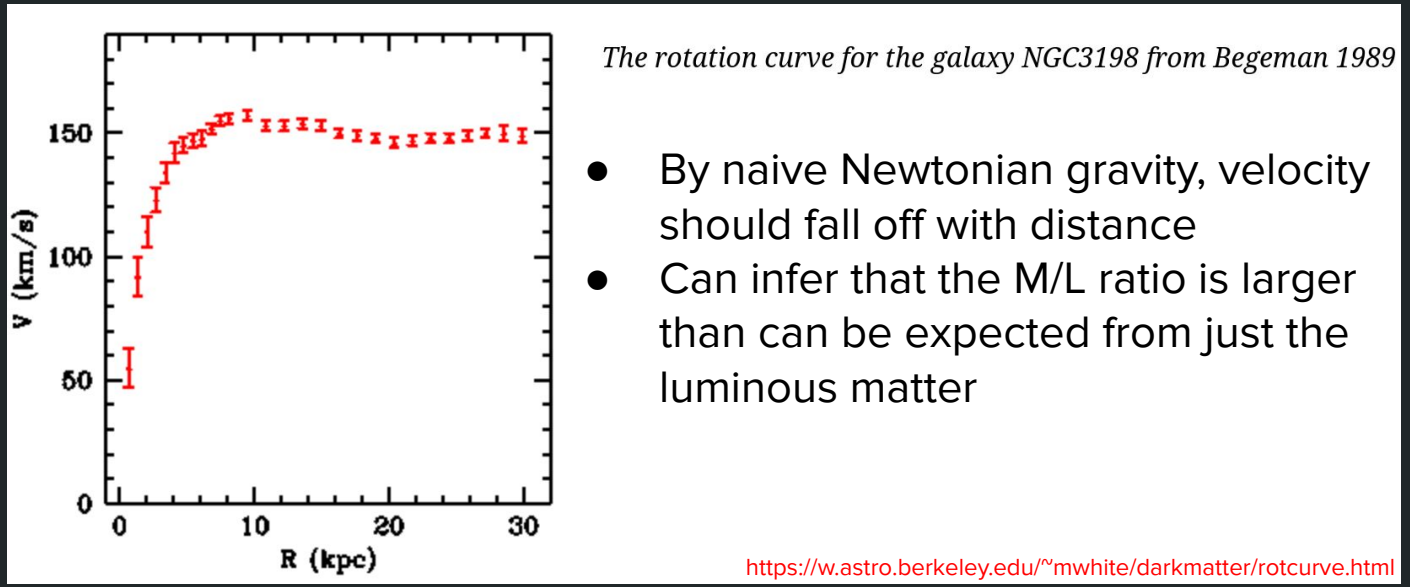

The rotation curve for the galaxy NGC3198 from Begeman 1989

- By naive Newtonian gravity, velocity should fall off with distance
- Can infer that the M/L ratio is larger than can be expected from just the luminous matter

https://w.astro.berkeley.edu/~mwhite/darkmatter/rotcurve.html

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- The universe is made up of
  - “Normal” matter, (mostly) what you see around you
  - Dark Energy (don’t know what it is)
  - **Dark Matter** (don’t know what it is)

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      - Some type of new particle(s)
      - Modified/new theories of gravity

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        - Axions
        - Axion-Like Particles (ALPs)
        - Others

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          - Does not interact with other than gravity and the weak nuclear force.
          - **How do we directly detect particles like these?**

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A BIG VAT OF LIQUID

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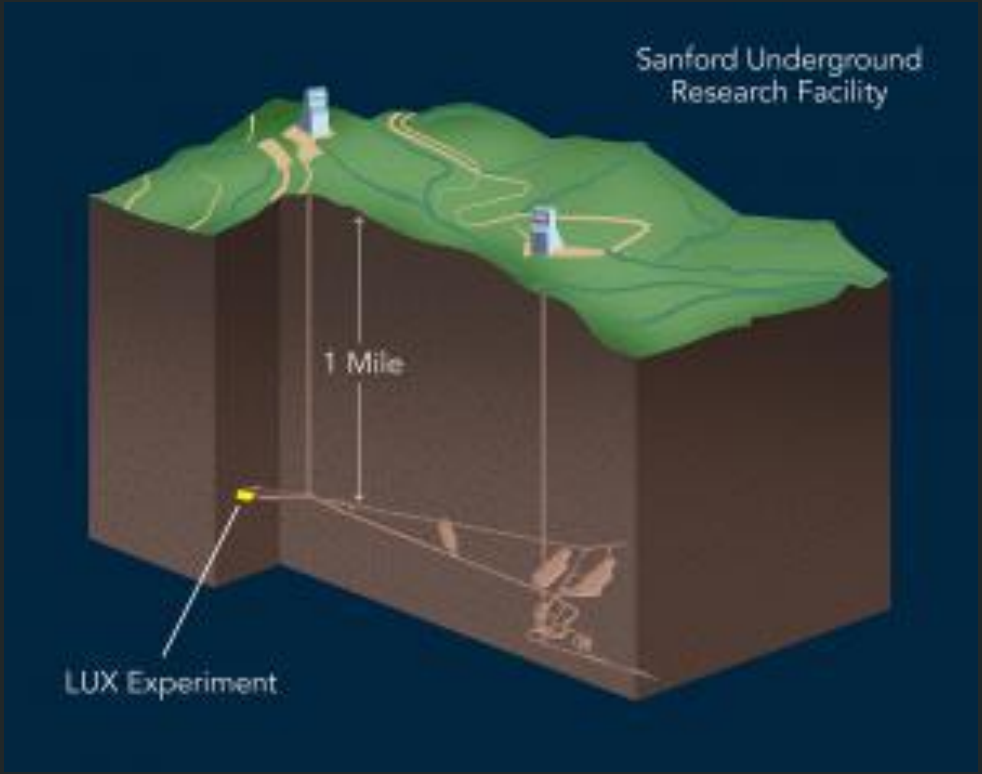
Specifically, liquid xenon

Sanford Underground Research Facility (SURF)
Lead, South Dakota, USA



- 4850 ft (1478.28 m)
- 4300 meter water equivalent rock

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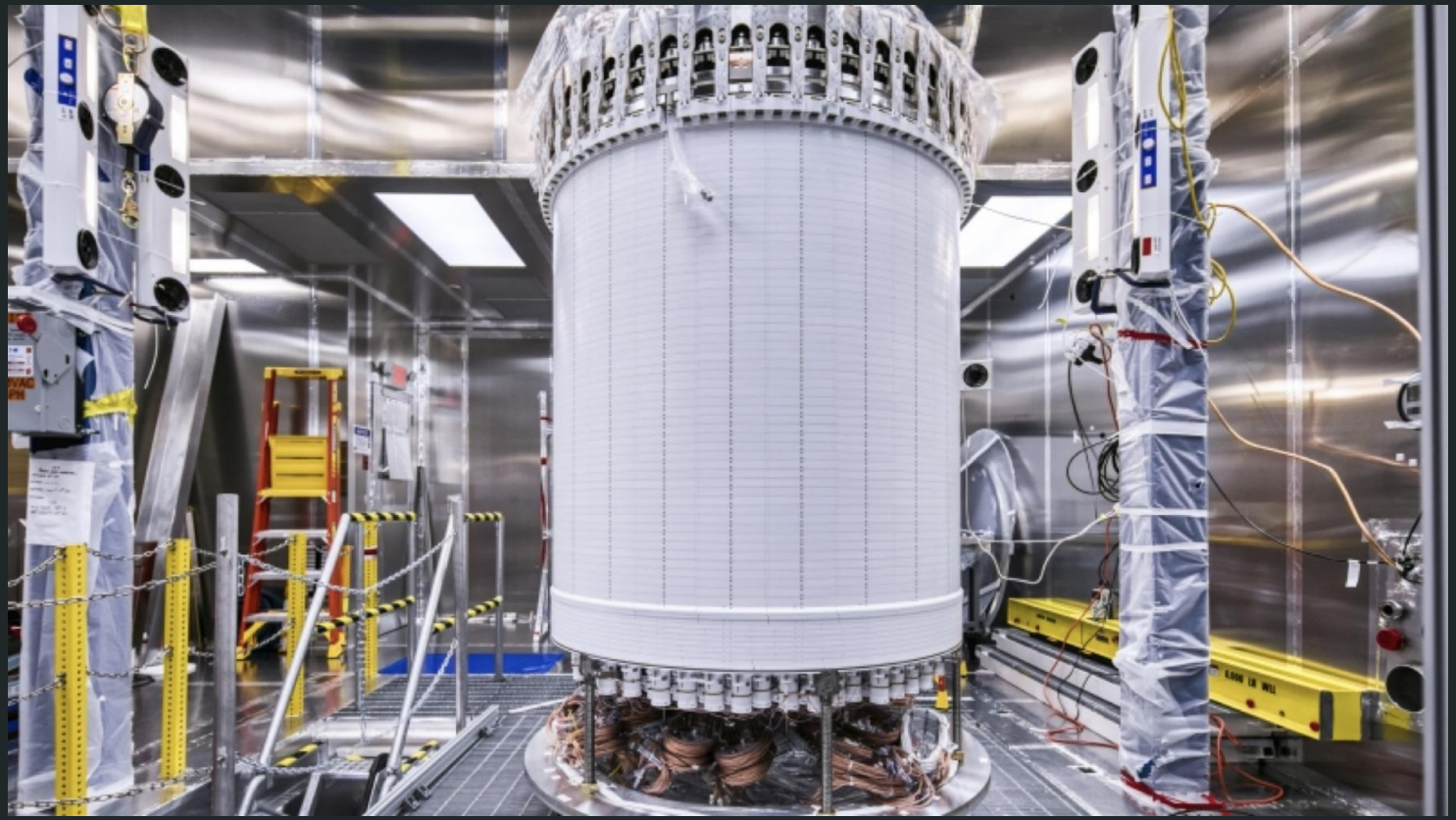
https://lz.slac.stanford.edu/our-research/lux-research

Large Underground Xenon-ZonEd Proportional scintillation in LIquid Noble gases LUX-ZEPLIN (LZ) https://lz.lbl.gov/



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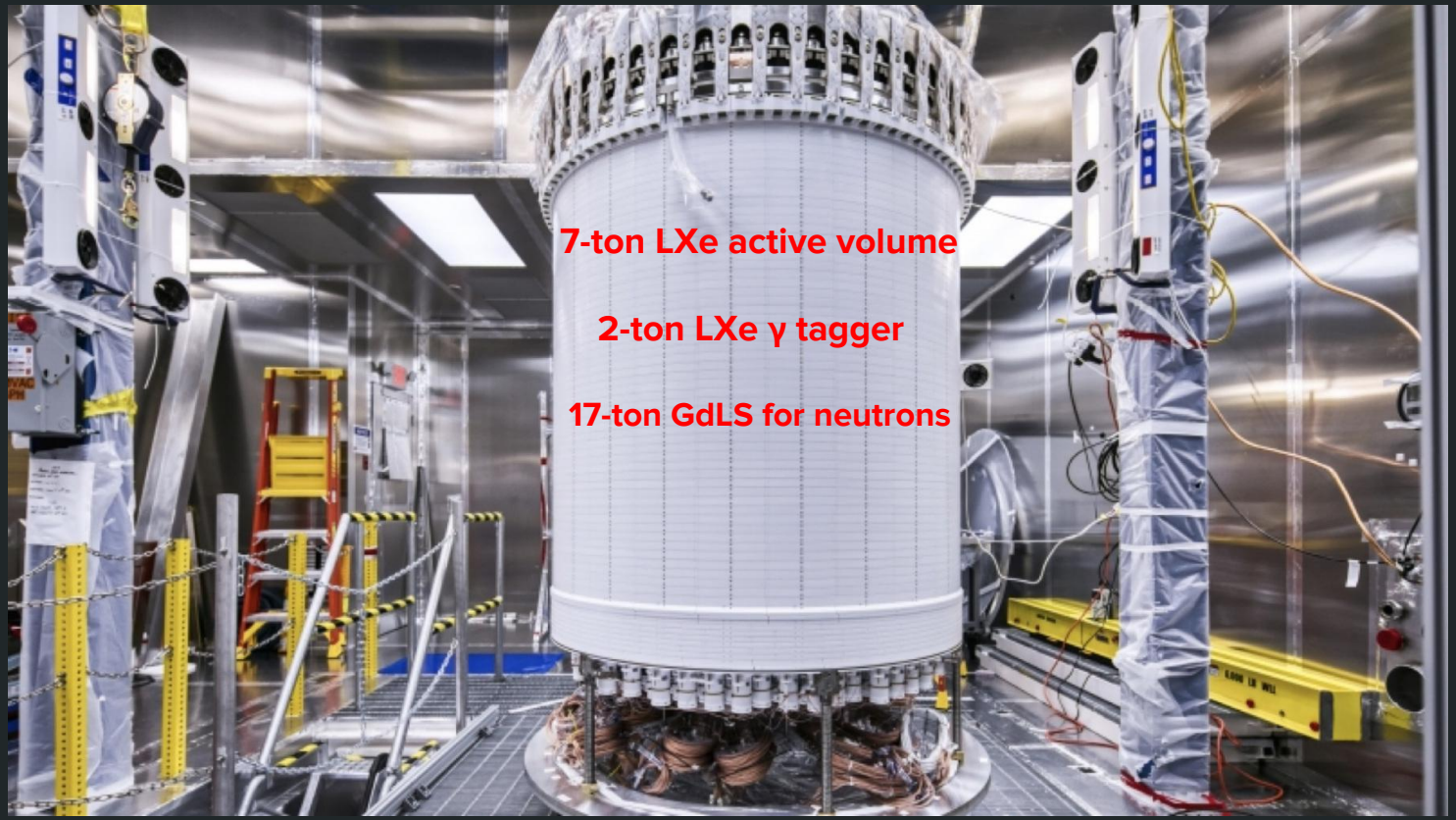

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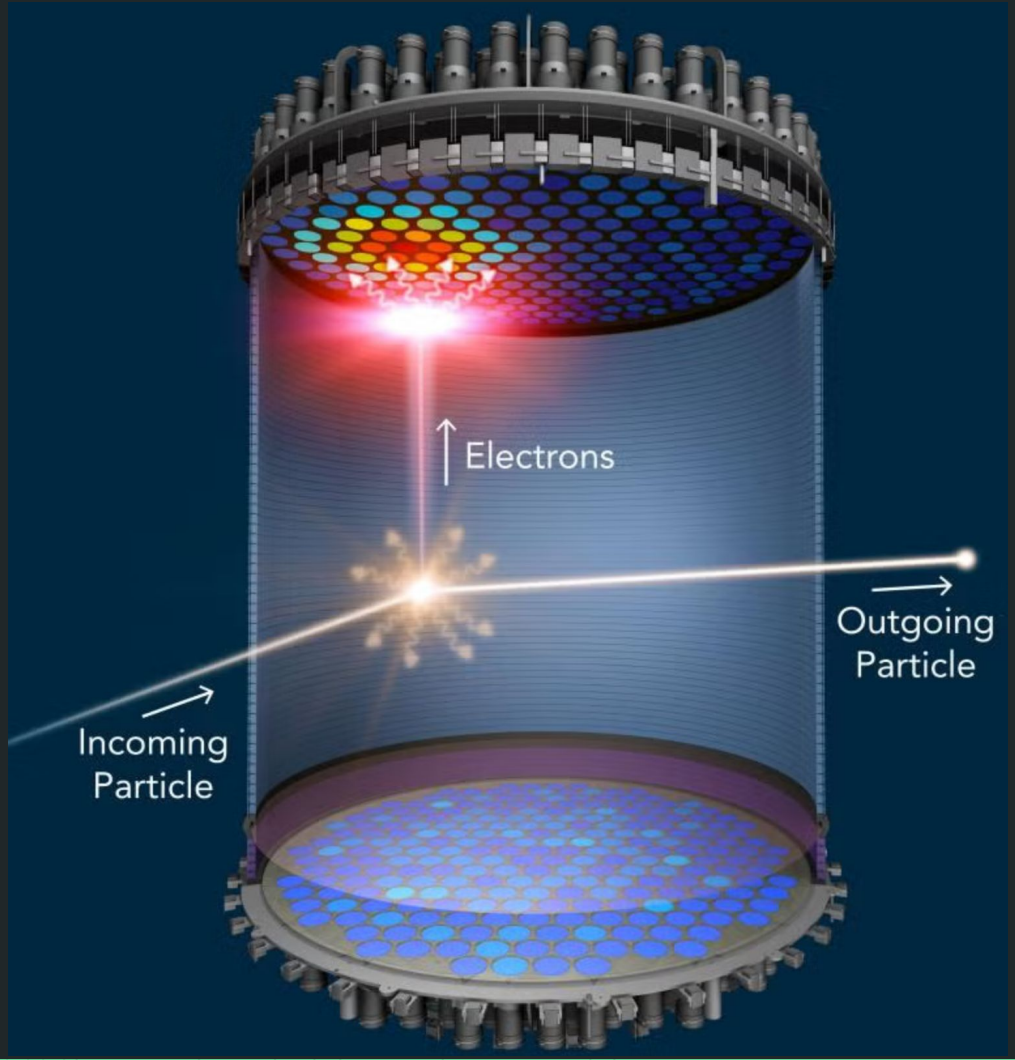

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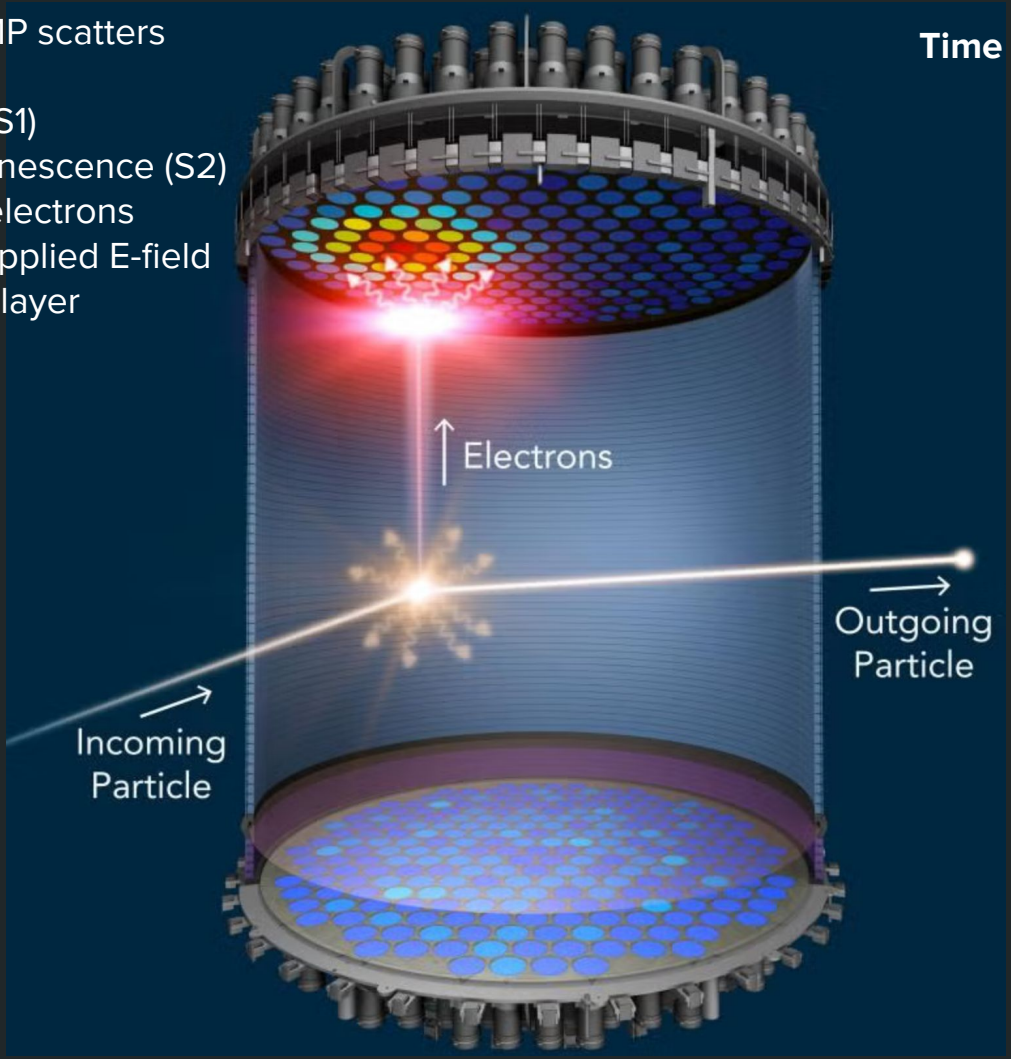
https://www6.slac.stanford.edu/news/2016-06-01-prototype-lux-zeplin-dark-matter-detector-tested-slac

When a particle like a WIMP scatters

- Prompt UV photon (S1)
- Delayed electroluminescence (S2)
  - Produced by electrons drifting in an applied E-field through a gas layer

Time Projection Chamber (TPC)



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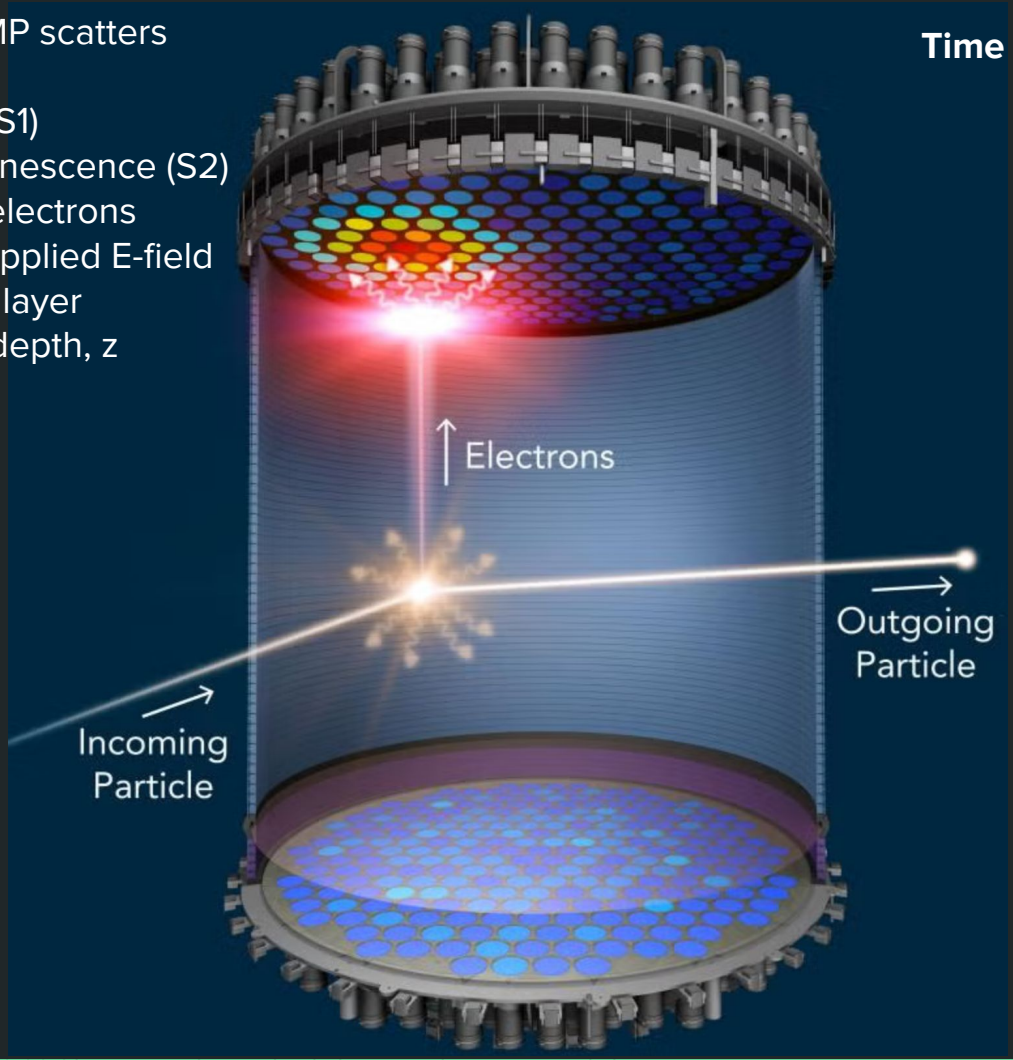

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- Signals from WIMP-N recoils are single scatter (SS), backgrounds are multiscatter (MS)

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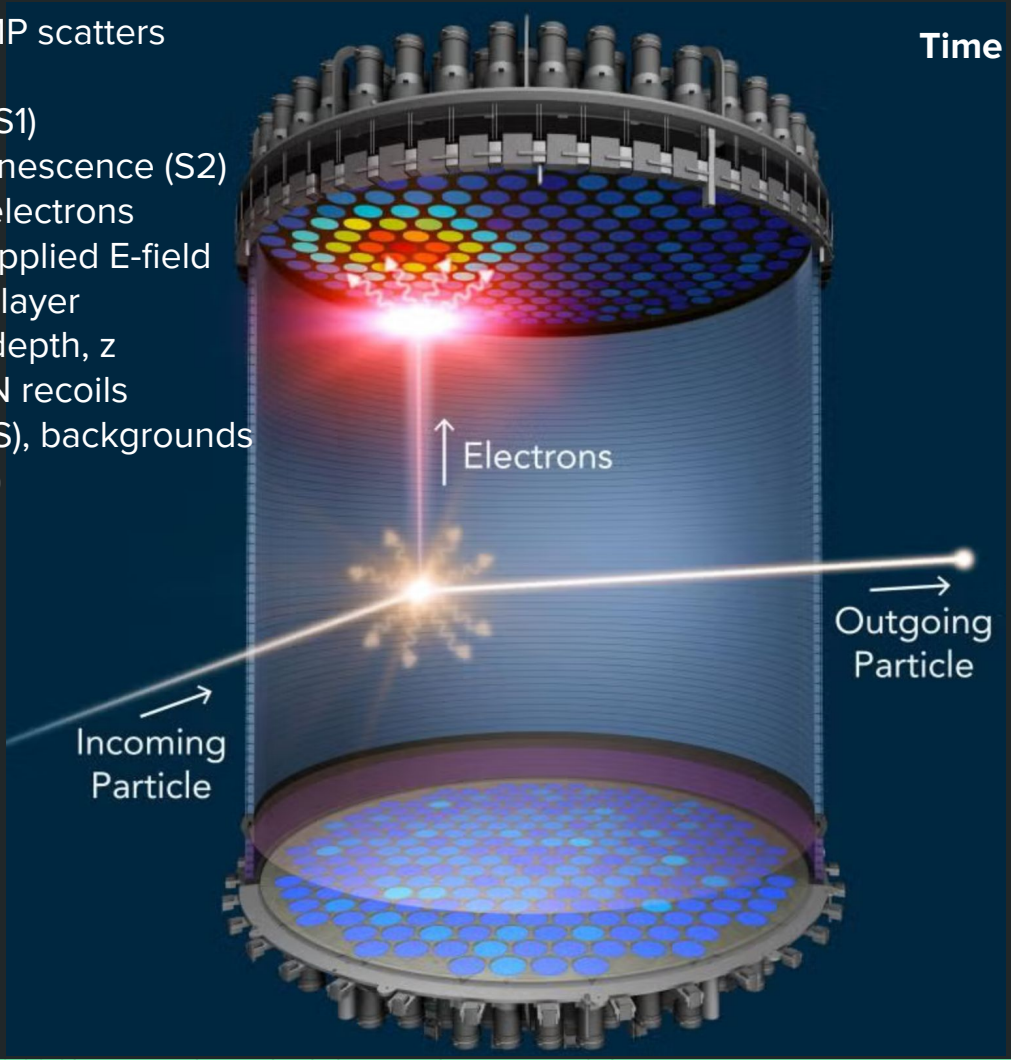

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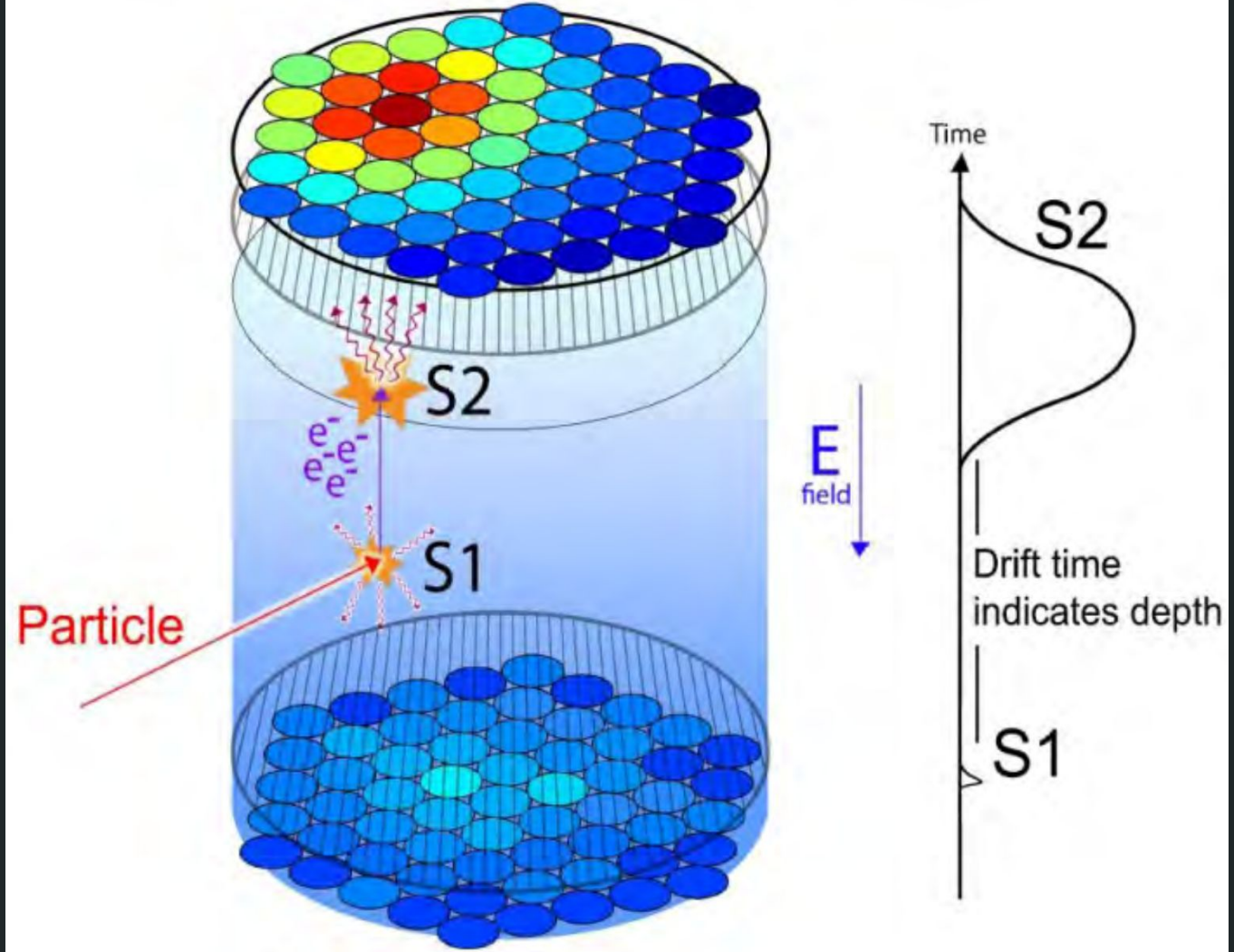
Time
S2
S2
e-
e-
e-
e-
E
field
S1
Particle
Drift time
indicates depth
S1

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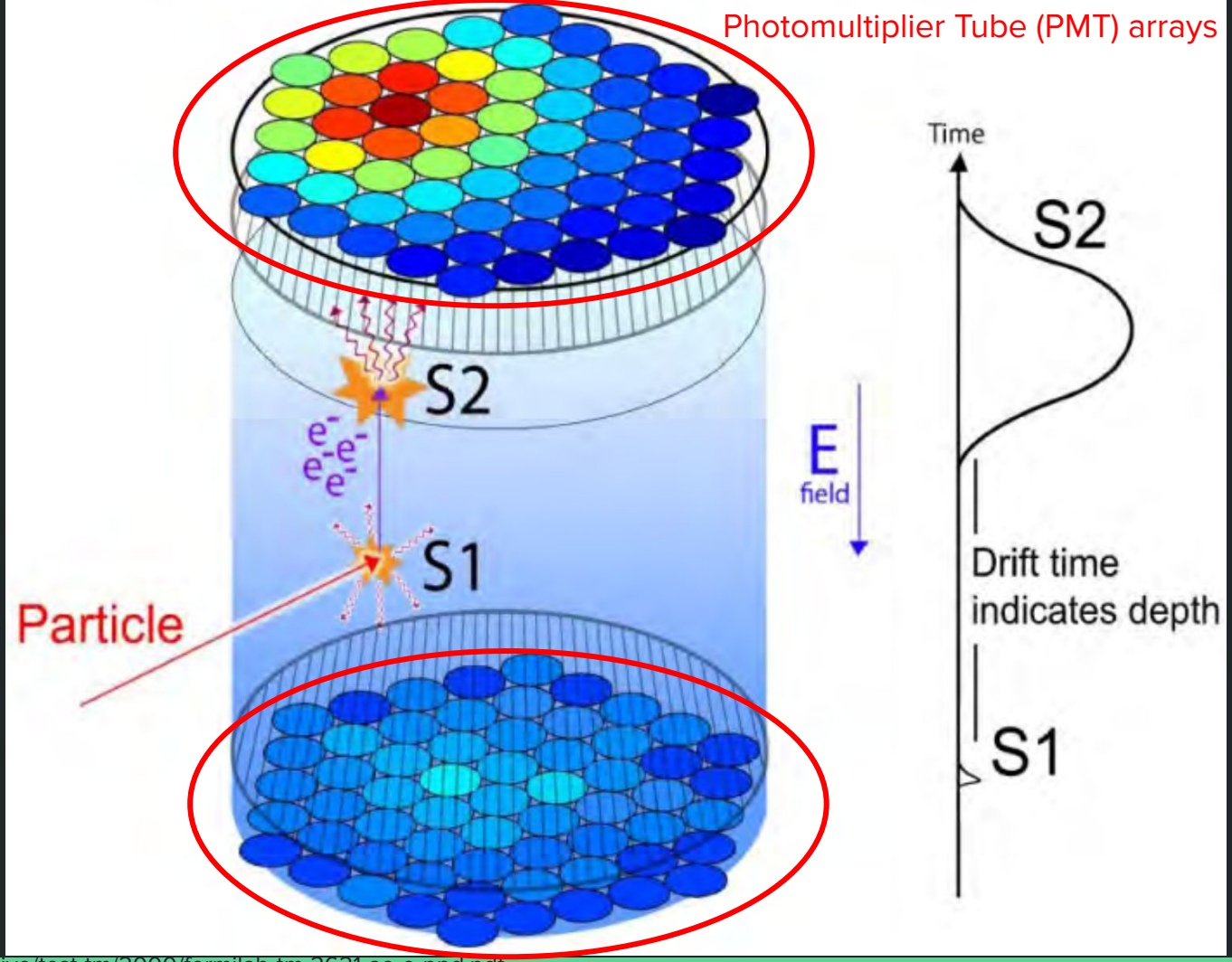
Photomultiplier Tube (PMT) arrays
Time
S2
S2
e-
e-
e-
e-
E
field
S1
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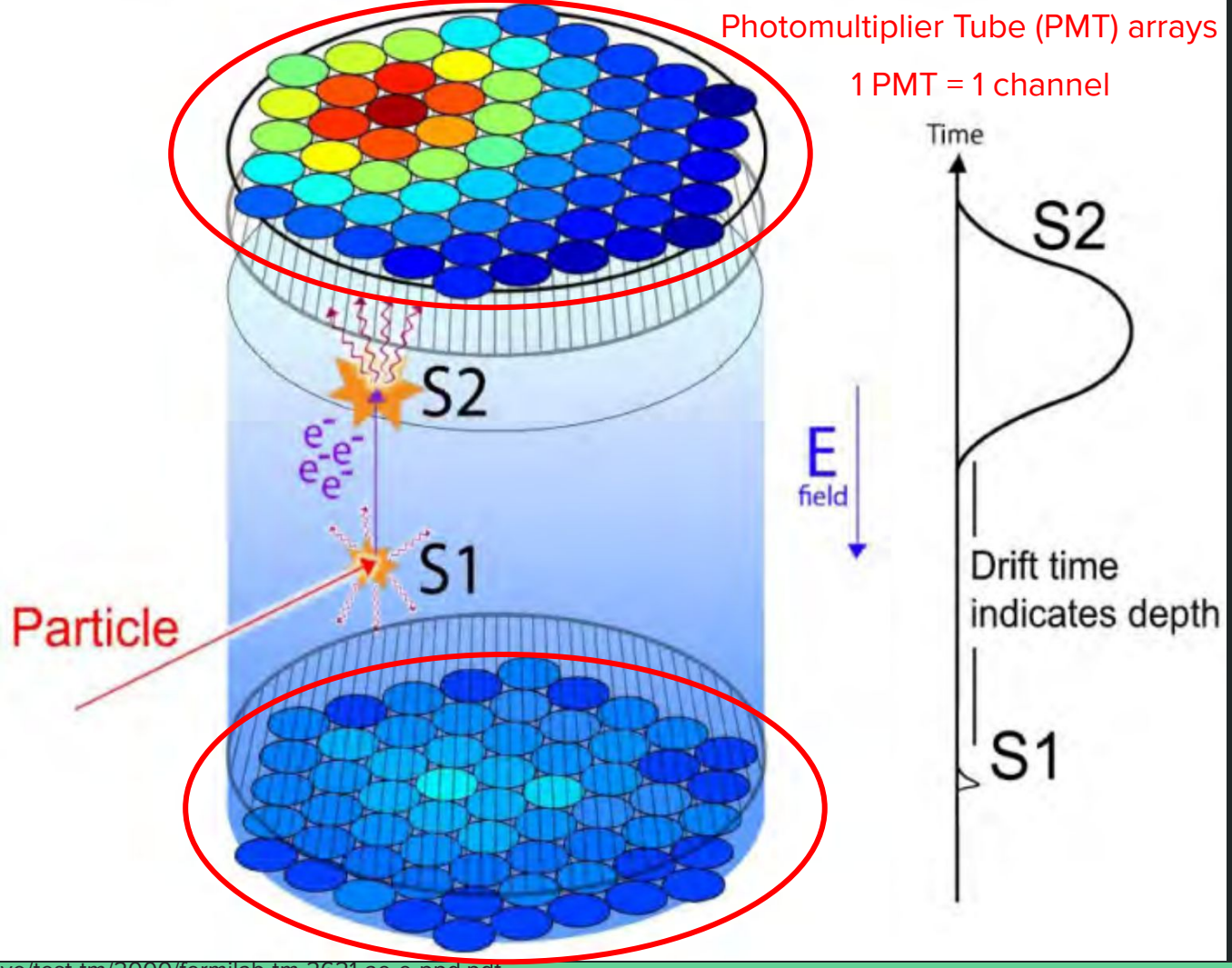
S1


Photomultiplier Tube (PMT) arrays
1 PMT = 1 channel
Time
S2
S2
e-
e-
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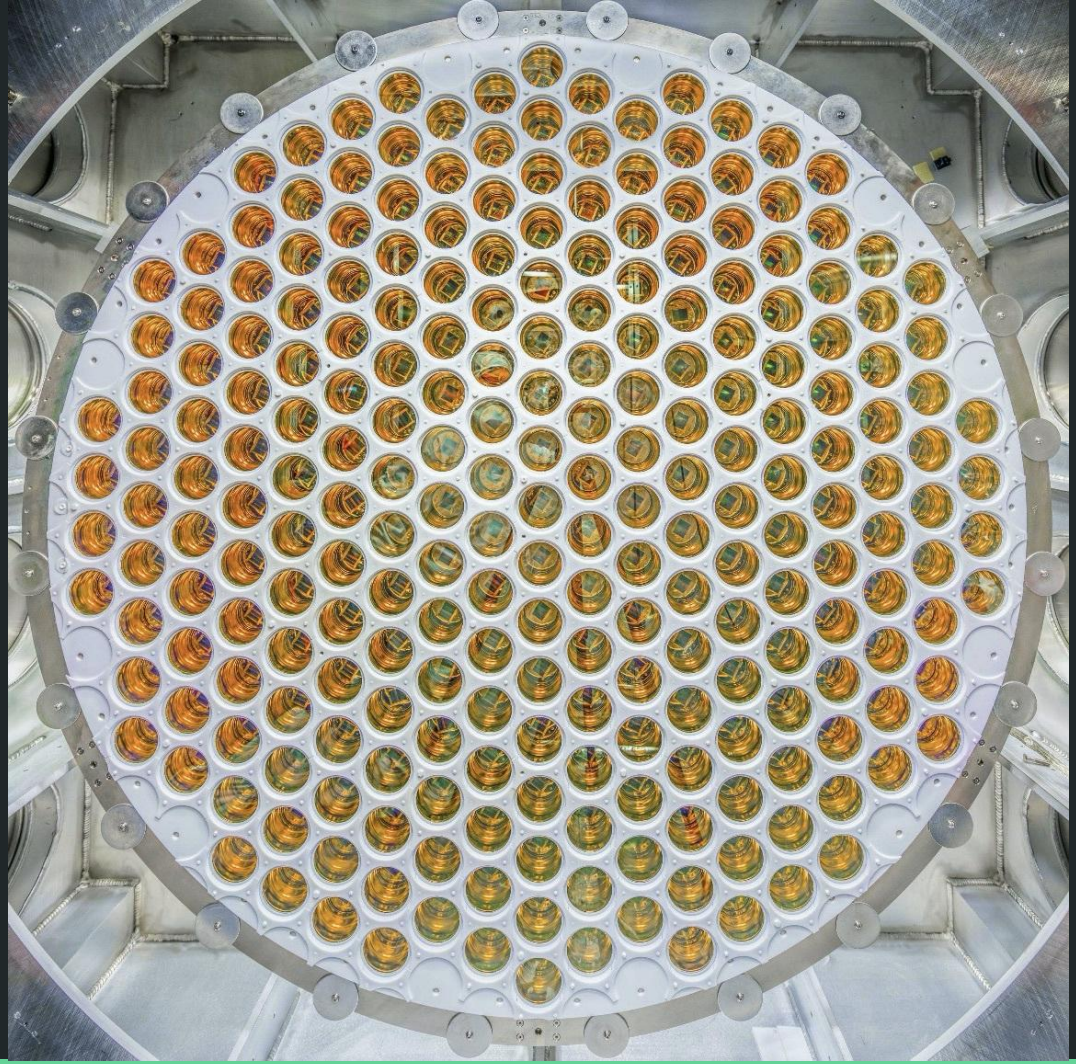

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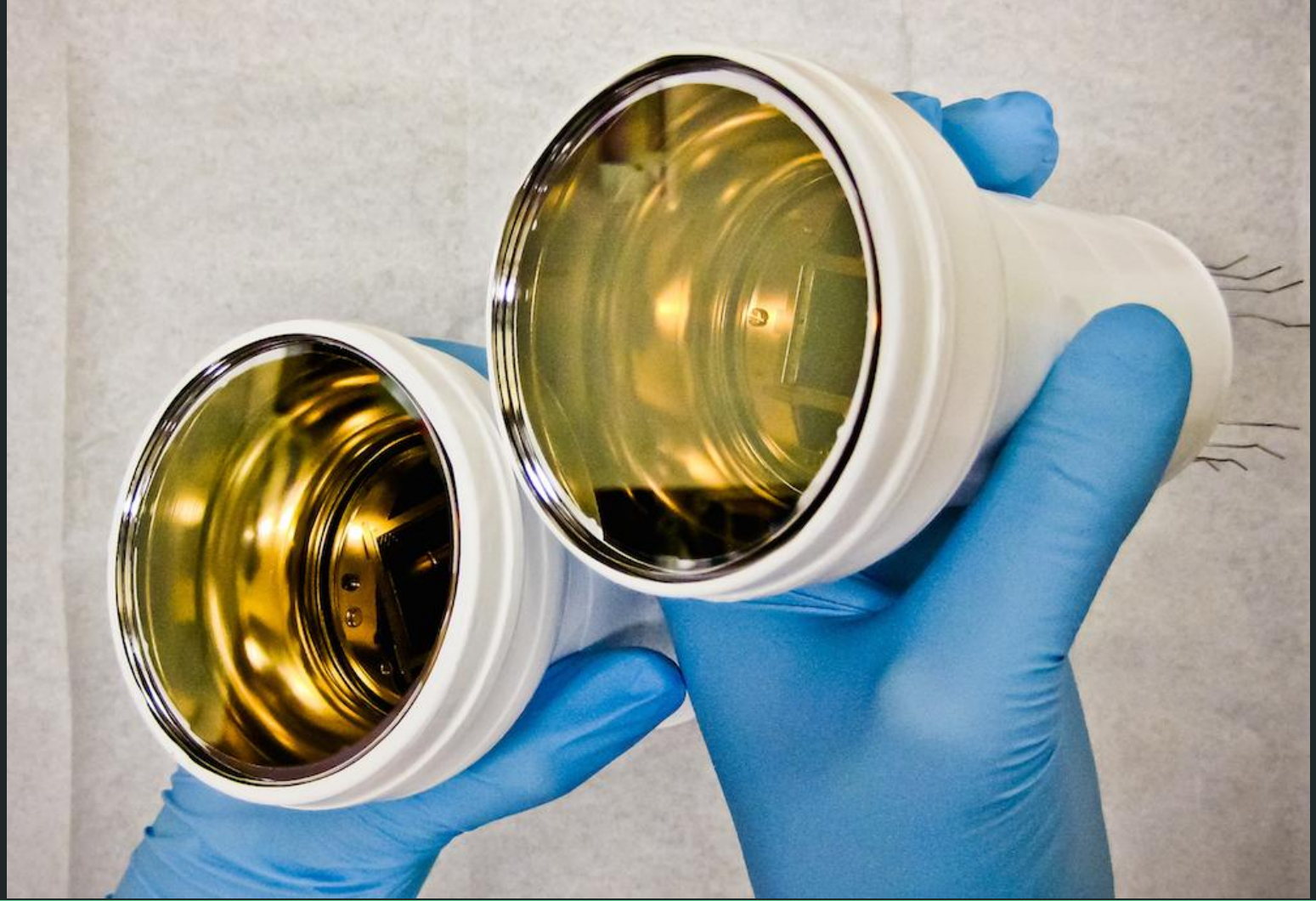

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- Data from these PMTs are recorded by the readout electronics
- Data is stored on disk for further analysis
- Large quantities of of data (1 PB/year)
    - Not all of the data, or features of the data, are necessarily useful to perform physics analyses that search for dark matter candidates, e.g. WIMPs
    - Can the amount of data that is saved be reduced while still having high-fidelity physics searches?

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    - Specifically, we want to use **autoencoders**

Autoencoders

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Autoencoders

- Types of ANNs that perform an *unsupervised* learning task to learn representations of the data called **latent representations**
  - This *latent space* typically has a lower dimensionality than the original data
- Learns by trying trying to copy the input to the output
  - I.e., tries to learn the identity function
  - But this done under some constraints, e.g. forcing the latent space to be of smaller dimension or adding some noise
  - Forces the model to learn efficient representations of the input data

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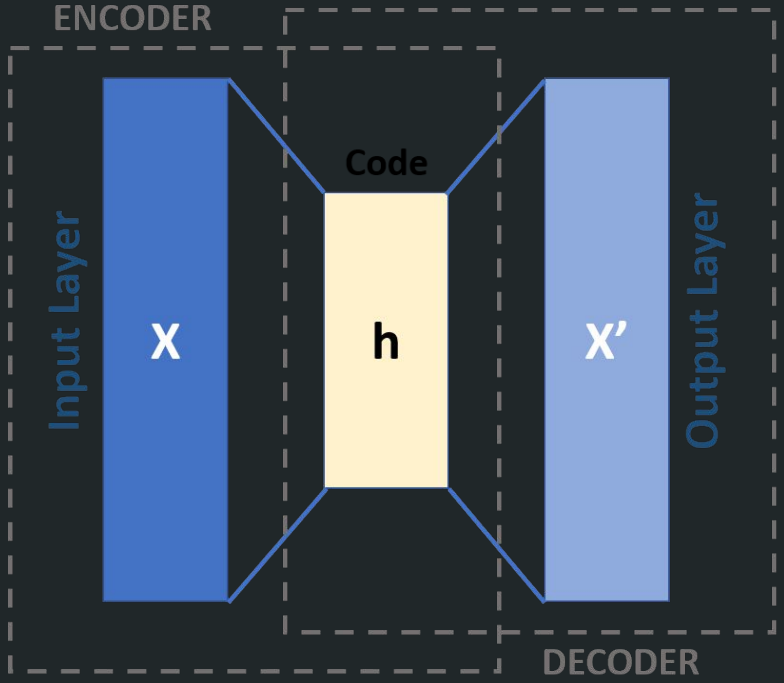

Application of Autoencoders to LZ Channel Data

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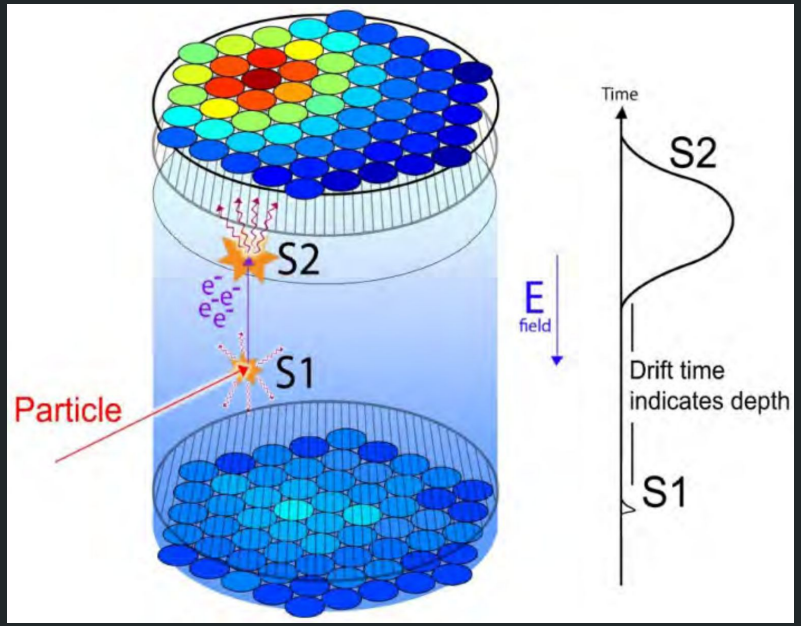

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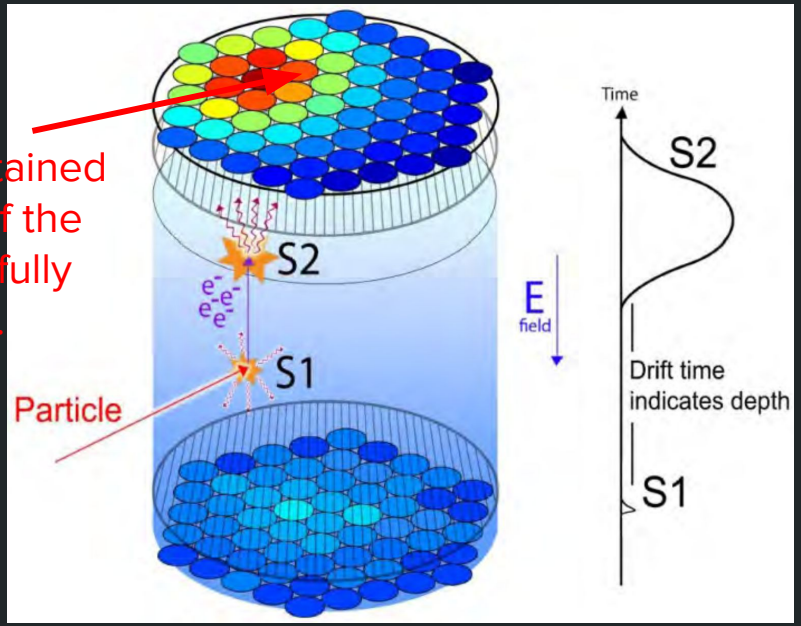
Want to compress the data obtained from simulated PMTs and see if the compressed data can still faithfully represent the the original data.



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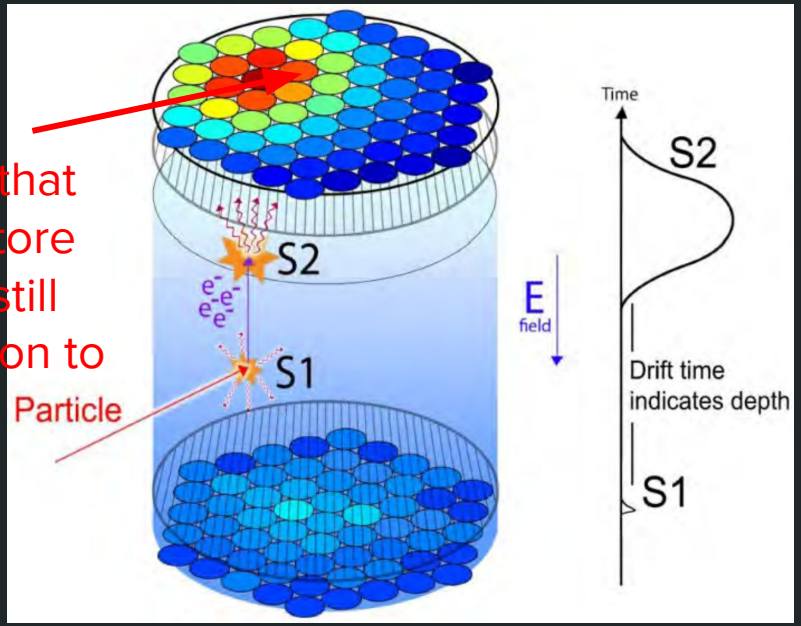
If we can, then we have demonstrated a technique that can be used to efficiently store data, reducing costs while still providing enough information to search for dark matter.



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For this hands-on we will use *simulated*, LZ-like events, not real LZ data.

Summary and Conclusion

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- Have observed astrophysical phenomena, such as seen in galaxy rotation curves, of unknown origin, called “Dark Matter”
- Hypothesize that a new class of particle exists to try and explain the phenomena
  - WIMPs
- Built a large LXe detector to try and detect these particles coming from outer space
- Want to use machine learning, specifically autoencoders, to compress the detector data to perform efficient searches for DM
  - Generally applicable technique

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References

1. https://wmap.gsfc.nasa.gov/universe/uni_matter.html (energy content of the universe)
2. https://w.astro.berkeley.edu/~mwhite/darkmatter/rotcurve.html (galaxy rotation curves)
3. LZ Sites
    a. https://lz.lbl.gov/
    b. http://lz.ac.uk/
    c. https://lz.slac.stanford.edu/
4. https://arxiv.org/abs/2410.17036 (latest results)
5. Non-LZ direct detection experiment websites
    a. https://xenonexperiment.org, http://xenon.astro.columbia.edu/XENON10_Experiment/
    b. https://depts.washington.edu/admx/