BERKELEY LAB

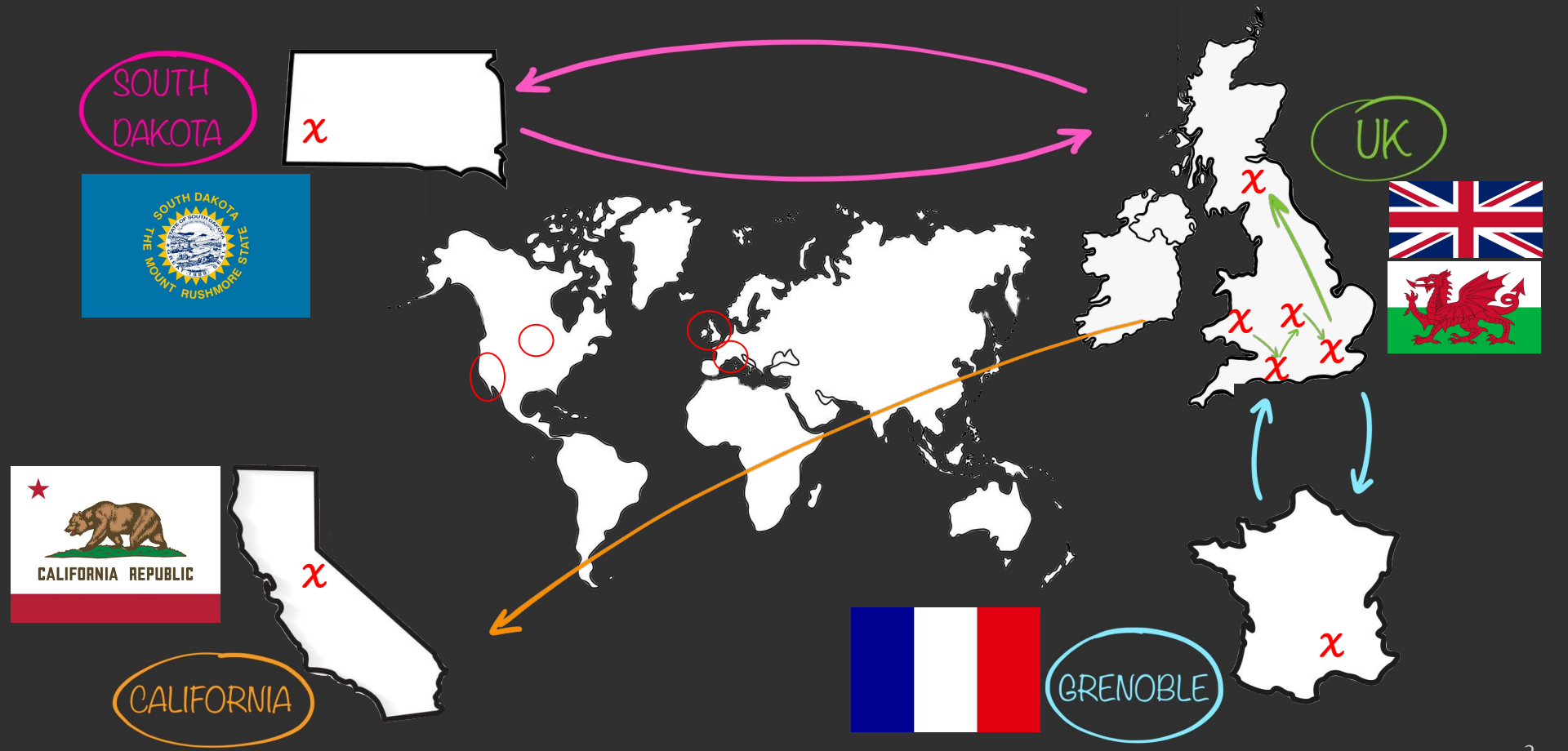
TOWARDS THE DISCOVERY OF GALACTIC DARK MATTER

Emily Perry

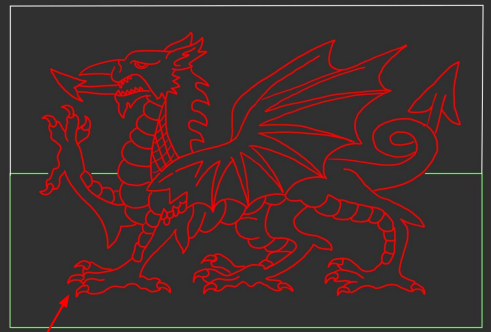
QuarkNet - Physics in and Through Cosmology

June 17th 2025

My Journey to Physics - Around the World



My Journey to Physics - Welsh Roots



- Born and raised in Barry, Wales
- Wales is a country known for its coastlines, landscapes, celtic history, unique cultural identity, poetry, music and rugby!

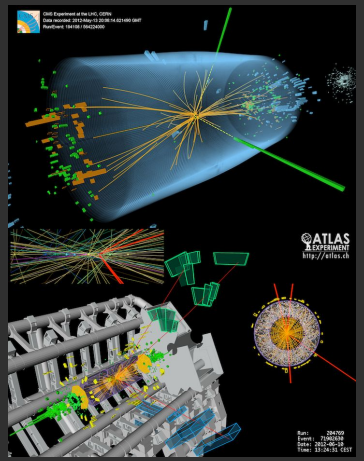
WELSH PHRASES

- Shw Mae: Hi (*Pronounced: shue-my)*
- Iechyd da: Good health, cheers (*Pronounced: yech-ed dah*)
- Sut wyt ti? / Shw mae? How are you? (*Pronounced: Sit-oit-ti*)
- Na, dydyn ni ddim wedi dod o hyd i fater tywyll eto: No, we have not found dark matter yet (*Pronounced: Na, deth-n ne dim wedy dod o hed e fater toy-oll eto*)

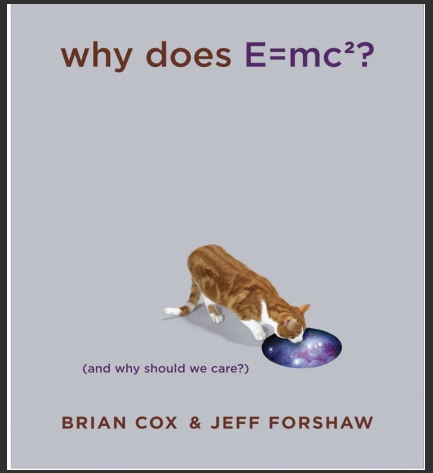
My Journey to Physics - From Wales to the Cosmos

I left Wales to study math and physics at the University of Bath, England after developing an interest in popular physics. I quickly realized math wasn't my strong suit and switched to physics.

I chose Bath for its year-long industry placements and a master's project abroad, which felt like a good idea since I wasn't sure what I wanted to do.



Discovery of Higgs Boson 2012



My Journey to Physics - Year of Diamonds (& Pressure)

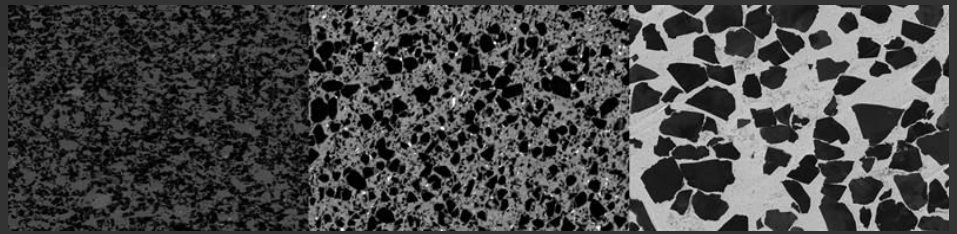
elementsix™ DE BEERS GROUP

1-year industry placement. Manufactured synthetic diamonds used in various industries, including oil & gas and water purification

Key skills gained: working in a lab, using material diagnostic methods,

First international exposure: opportunity to travel to company sites in Germany.

Confirmed interest in R&D: The experience solidified my strong interest in the research and development aspect of scientific work.



Synthetic diamond microscopic images

Images form E6 website: https://www.e6.com/en

High-pressure-high-temperature diamond synthesis hall

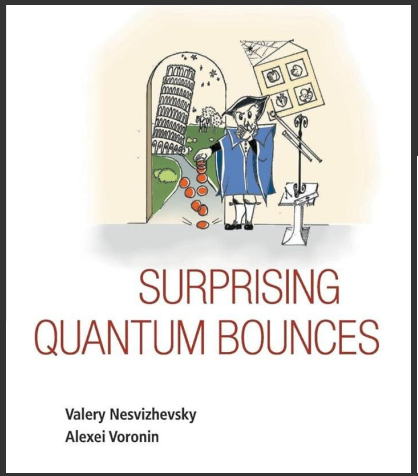
My Journey to Physics - Emily in ~~Paris~~ Grenoble

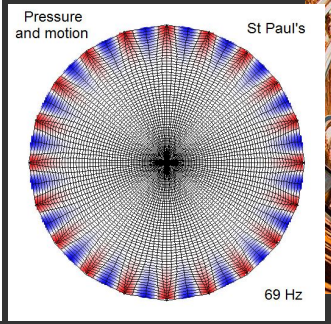
GRENOBLE

6-month master's project at the ILL neutron reactor, using ultracold neutrons to study the whispering gallery effect.

First experience in a **research environment** : involved **deep-dive analysis** , **writing scientific papers** and **giving talks** .

My time also provided unique insight into life at a **nuclear reactor** , surrounded by specialized equipment and a diverse community of scientists.





My Journey to Physics - Accidental Journey to the Dark Side*

*(of matter)

- After returning to the UK to finish my degree, I decided a PhD was next.
- I initially aimed for a project in proton beam therapy, but due to funding changes, I ended up taking a PhD in **dark matter** at the **University College London (UCL)**
- Dark matter wasn't even on my radar until then, but the day-to-day work sounded really appealing.
- And just like that, five years ago, I found myself diving into one of the biggest mysteries of the universe!

UCL

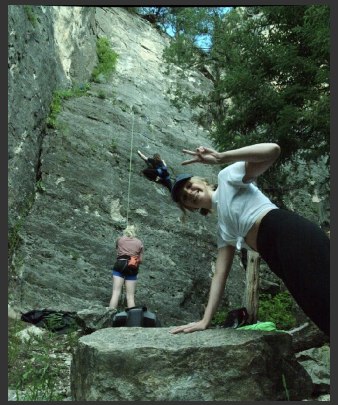
Bath graduation with my sister

My Journey to Physics - Diving into the Dark

UCL

I did my PhD at University College London, focusing on the **LUX-ZEPLIN (LZ) dark matter detector** , alongside a smaller research and design experiment—more on that later!

Though PhDs are hard, life exists outside of physics



My Journey to Physics - Stint in South Dakota

SOUTH DAKOTA

PhD included time working for LZ at Sanford Underground Research Facility in SD

My Journey to Physics - Outreach Interest

SCIENCE MUSEUM LATES

Case Study: Studying high energy physics

My name is Emily, and I am a second year PhD student in the High Energy Physics department at University College London. My time is spread ove
projects.

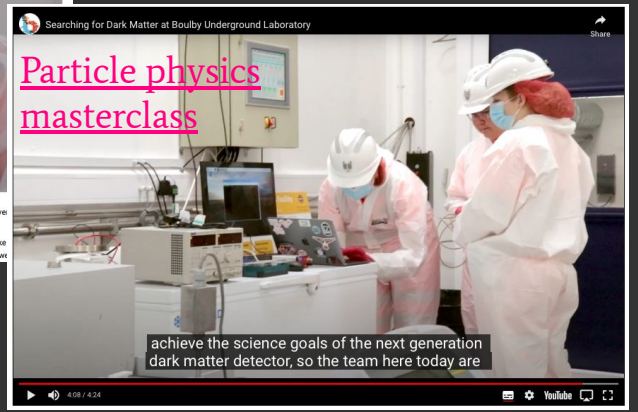
Firstly, I am a member of the Lux Z
h we believe make
majority of our universe. The LZ de
with the xenon, we

Binding Blocks
Building the Universe one nucleus at a time

Science and Technology Facilities Council

STFC outreach video March 2022

Particle physics masterclass



Some Takeaways from My Journey to Physics

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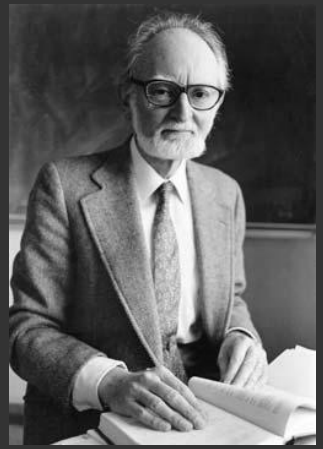
- **Define your own path:** It's fine not to fit a stereotypical mold of a physicist.
- **Find your balance:** Remember that life extends beyond your research. Maintaining a healthy work-life balance is crucial.
- **It's okay to not have your entire career path figured out**

My Journey to Physics - Current Day

Now working at Lawrence Berkeley National Laboratory as a Chamberlain Postdoctoral Fellow, since September 2024

- Part of the dark matter group in the physics division
- Working within the LZ collaboration, which is a collaboration of ~200 international scientists
- Also work on R&D on LZ upgrades and next-generation dark matter experiments
- Dark matter searches using quantum sensors

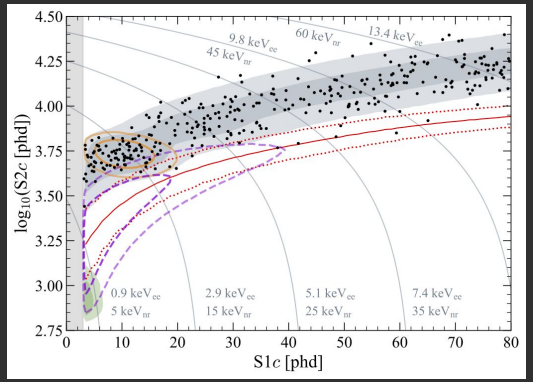
Owen Chamberlain (July 10, 1920 – February 28, 2006) shared Nobel Prize in Physics for the discovery of the antiproton.



LIFE OF AN EXPERIMENTAL PHYSICIST

ANALYSIS

- LZ experiment generates **1 terabyte of data every day**
- To make sense of this massive dataset, we use programming languages like **Python, C++, and ROOT** .
- Continuous analysis helps us understand exactly **what's happening inside our detectors!**



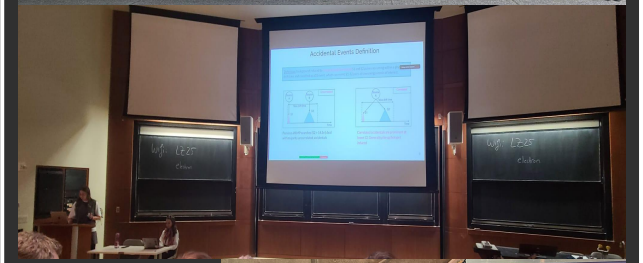
PRACTICAL WORK

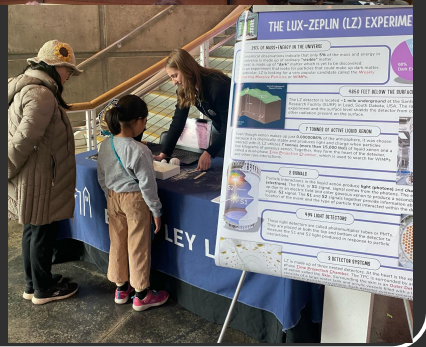
Design, Build, and Test new detectors experiments

Build Small-scale tests of upgrade to current LZ detector

COMMUNICATION

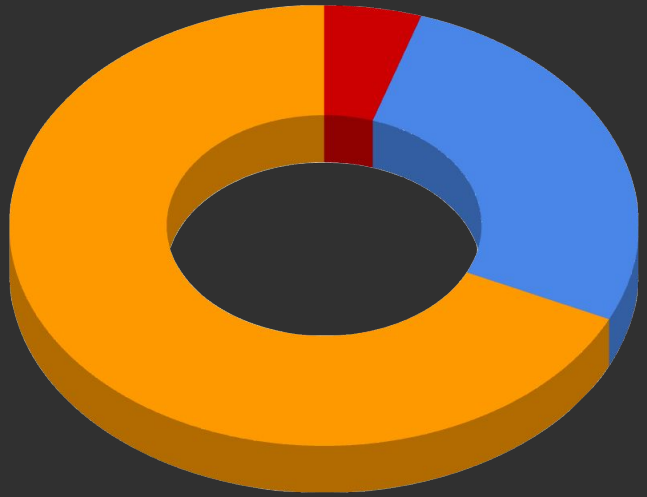
Talks, paper writing, public outreach events + more





Break

What is Matter?



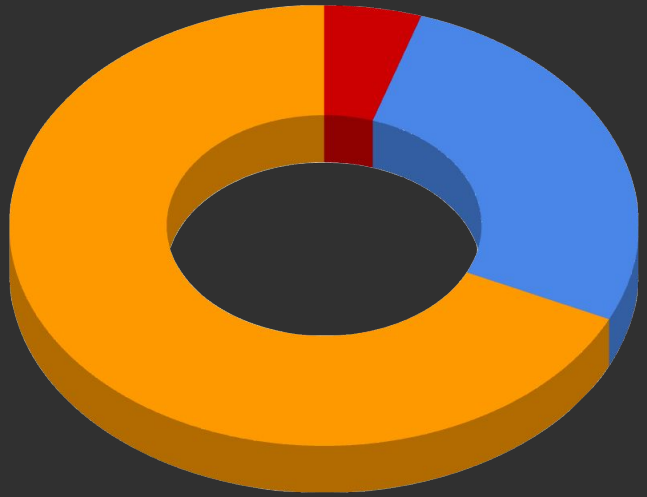
5% VISIBLE MATTER

27% DARK MATTER

68% DARK ENERGY

What is Matter?

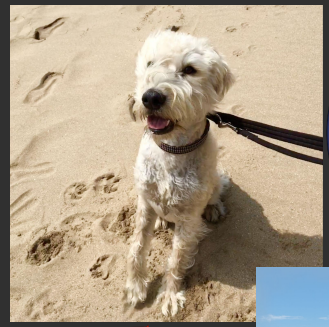
5% VISIBLE MATTER



27% DARK MATTER

FOCUS FOR THIS TALK!

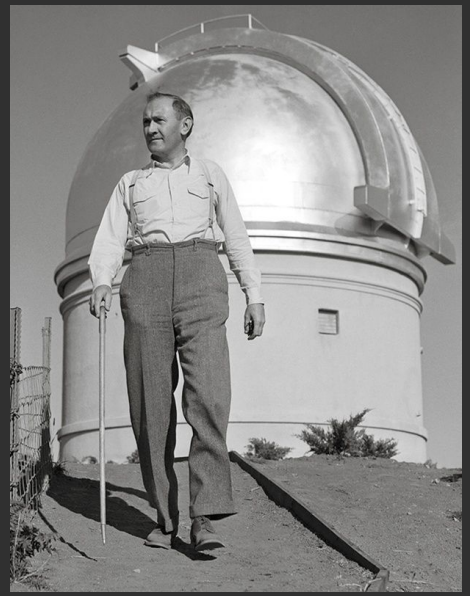
~~68% DARK ENERGY~~



Where is Dark Matter?

1930s

Fritz Zwicky performed measurements of velocities of galaxies within the Coma Cluster

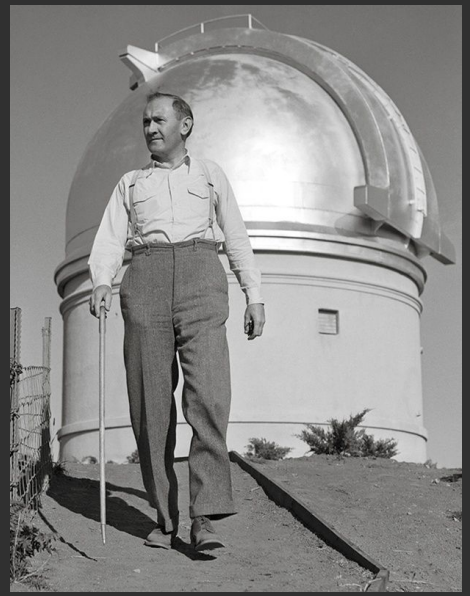


PREDICTION : AMOUNT OF LIGHT $\propto$ MASS

Image from NASA: https://science.nasa.gov/asset/hubble/coma-cluster-full-mosaic/

Where is Dark Matter?

1930s



Zwicky measured galaxy clusters, but here's an analogy with 1 galaxy...

OBSERVATION PREDICTION

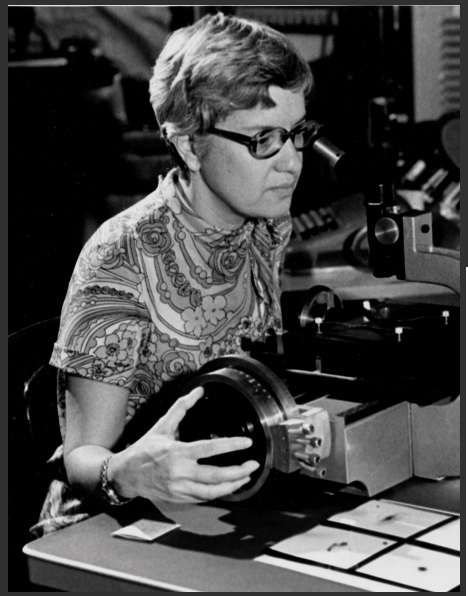
Too fast for visible stars → clusters should fly apart....

Either stars and physics are different or there is a missing dark matter!

Video: European Southern Observatory (ESO) YouTube channel

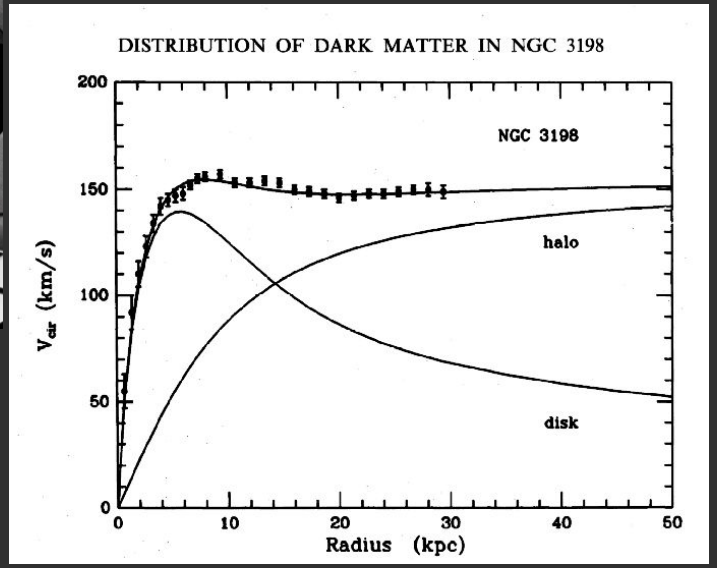
Where is Dark Matter?

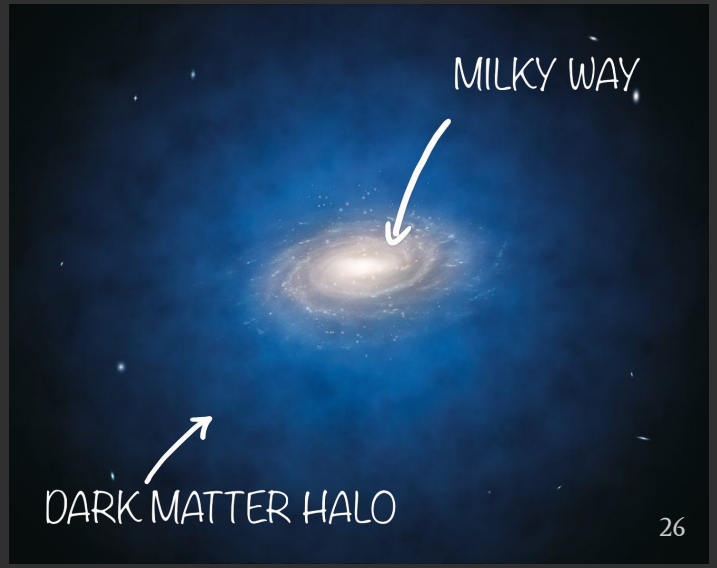
1970s



Vera Rubin performed measurements of the rotation curves of galaxies with hydrogen lines being emitted from stars

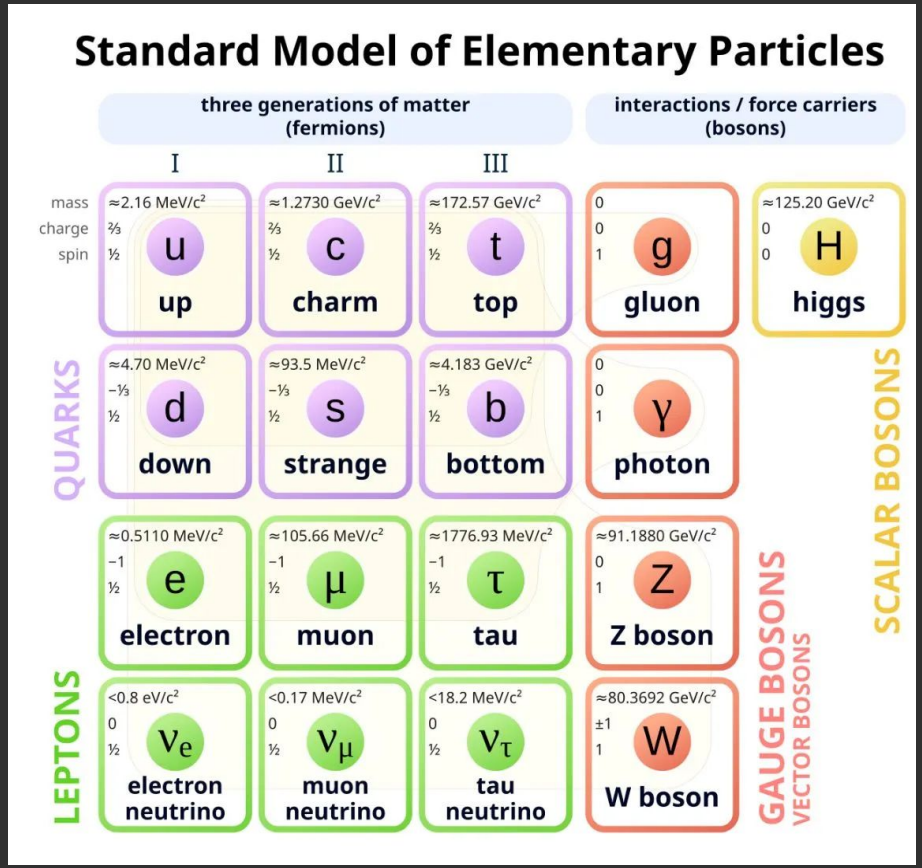
Observations form the basis of how we think of galaxy structures today





Rotation curve of the spiral galaxy NGC 3198 (van Albada et al. 1985)

What is Dark Matter?



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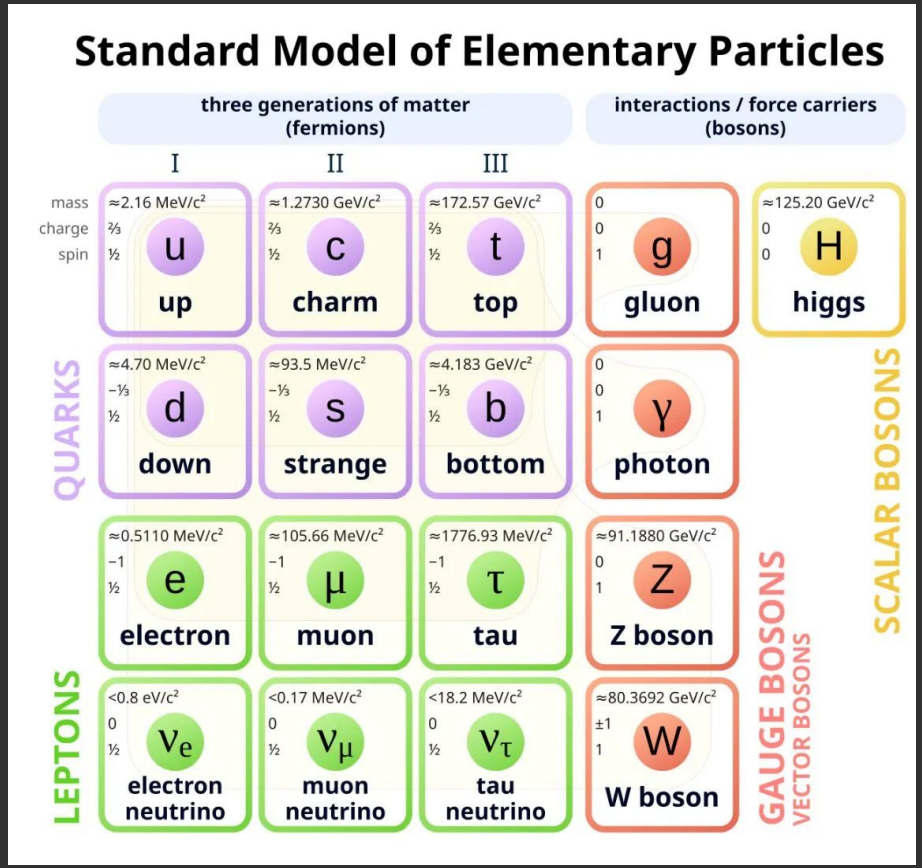
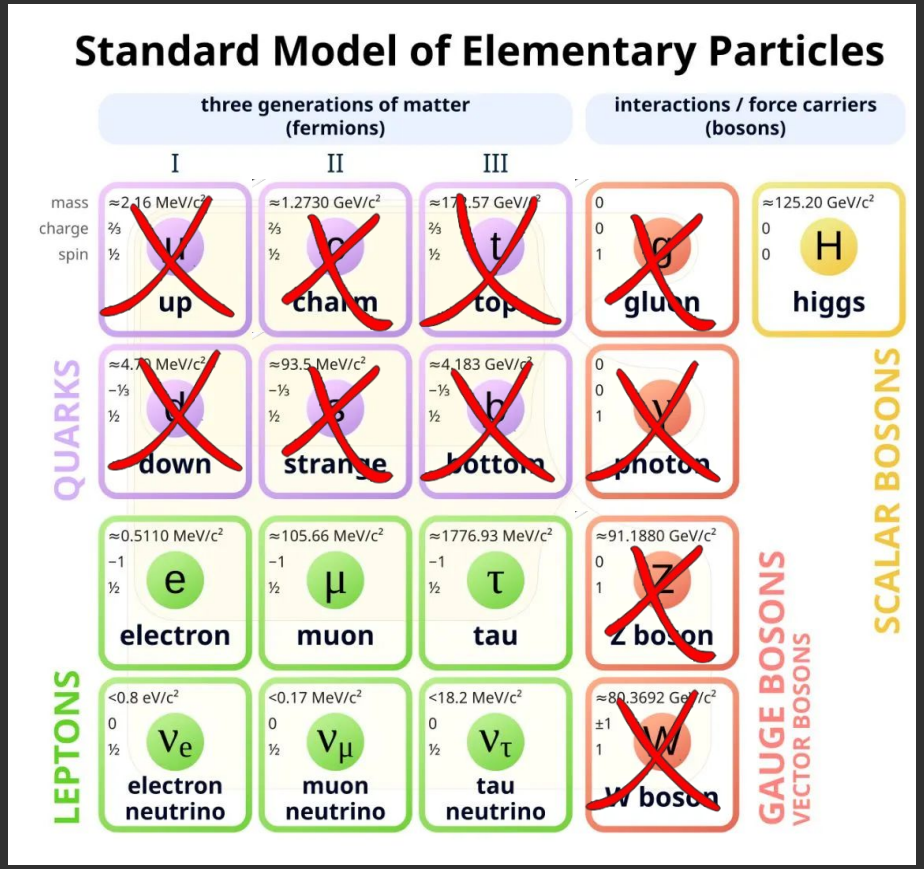
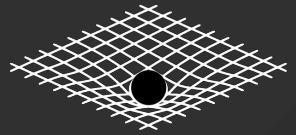


We don't know!

But we can start to narrow down our options using things we do know about dark matter....

What is Dark Matter?

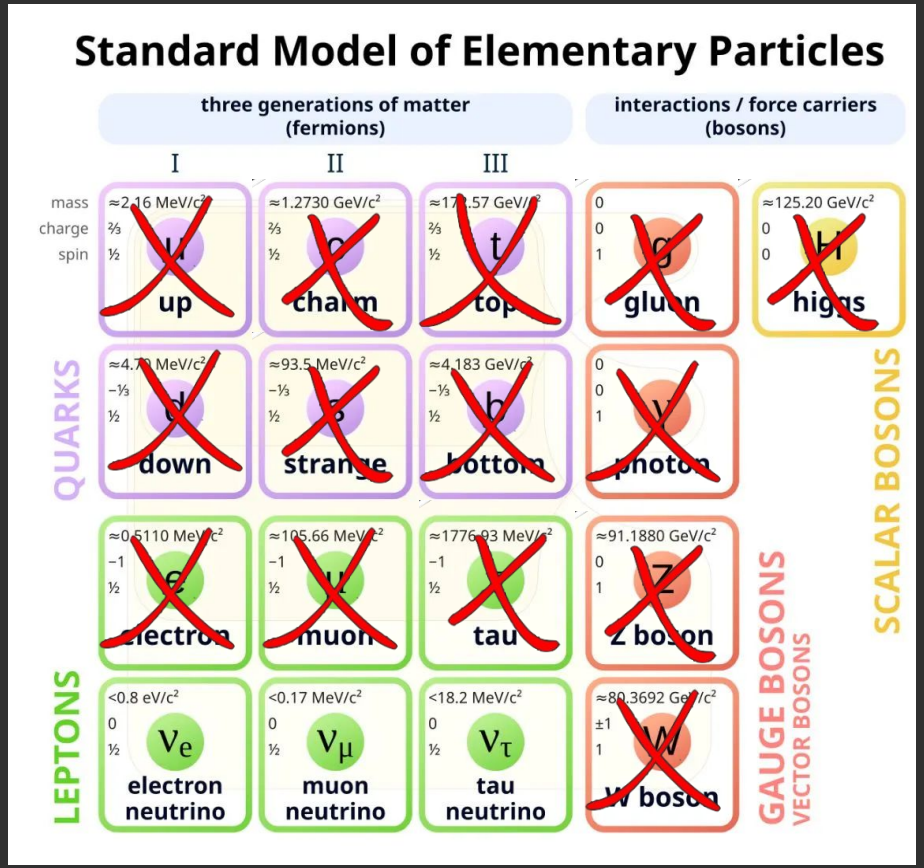


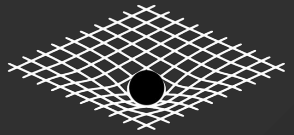


Interacts through gravity but is dark (no light or electric charge)

PROPERTIES OF DARK MATTER

What is Dark Matter?





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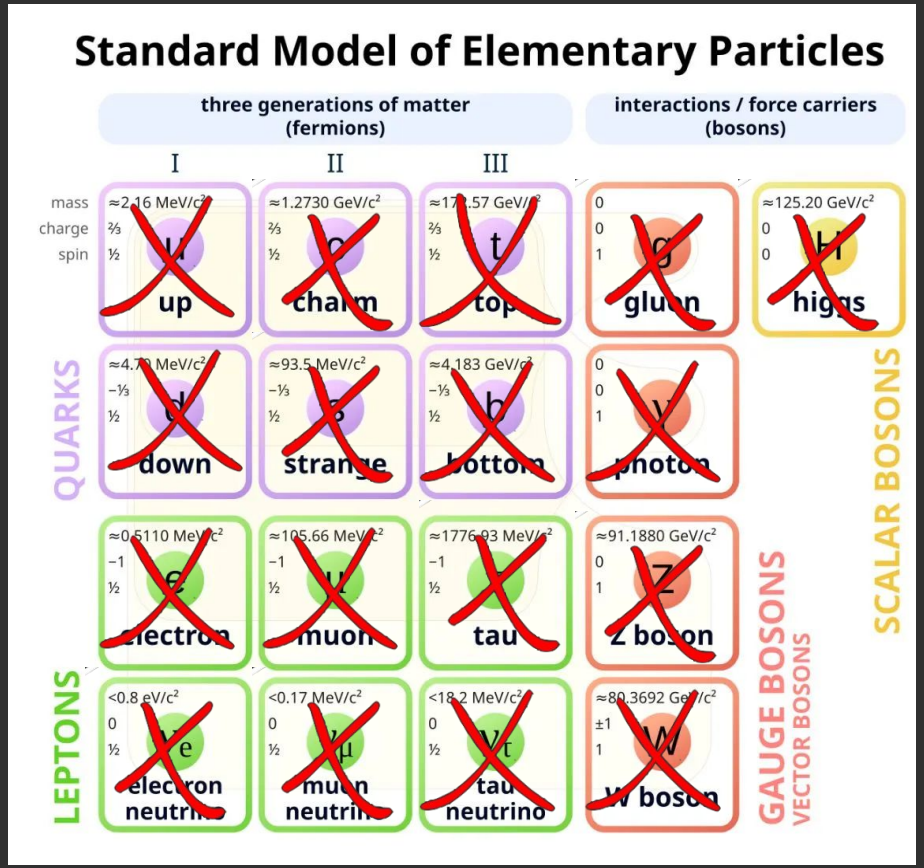
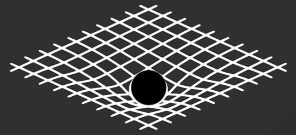
PROPERTIES OF DARK MATTER

Dark matter must be long lived, it can't decay

What is Dark Matter?





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Neutrinos are too light and move too fast for galaxy formation

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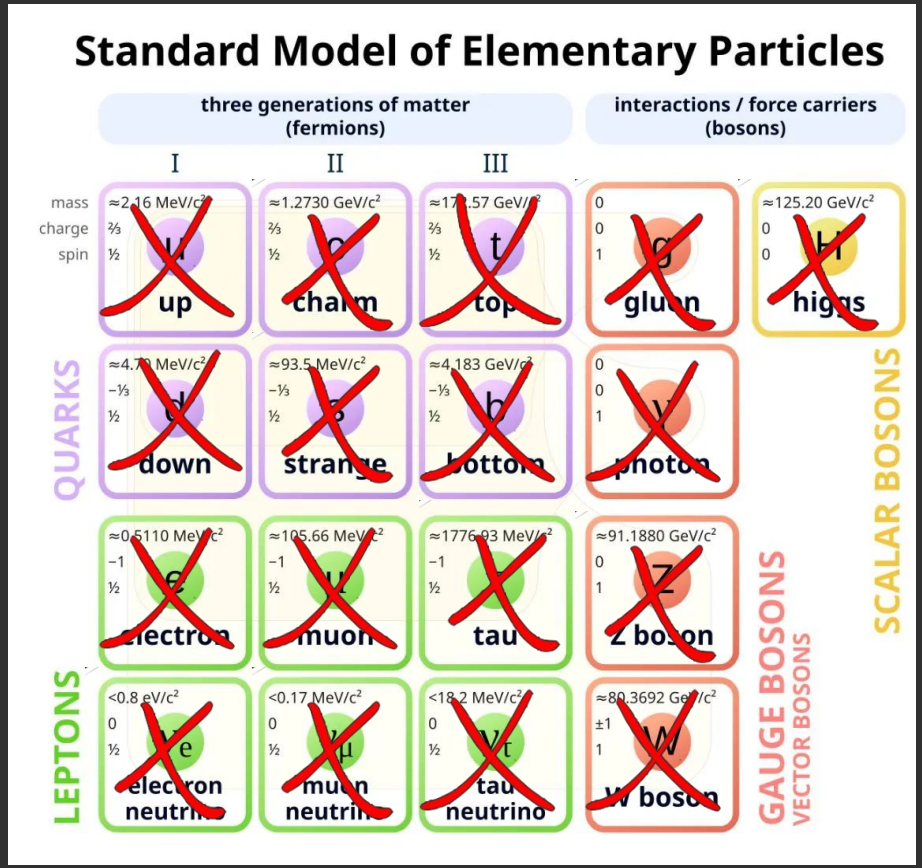

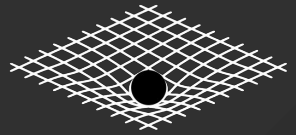

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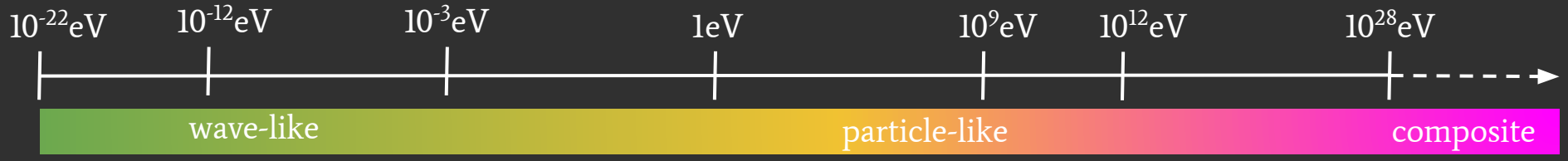
What is Dark Matter?

Turns out dark matter could be many things....

What is Dark Matter?

Most popular candidates:



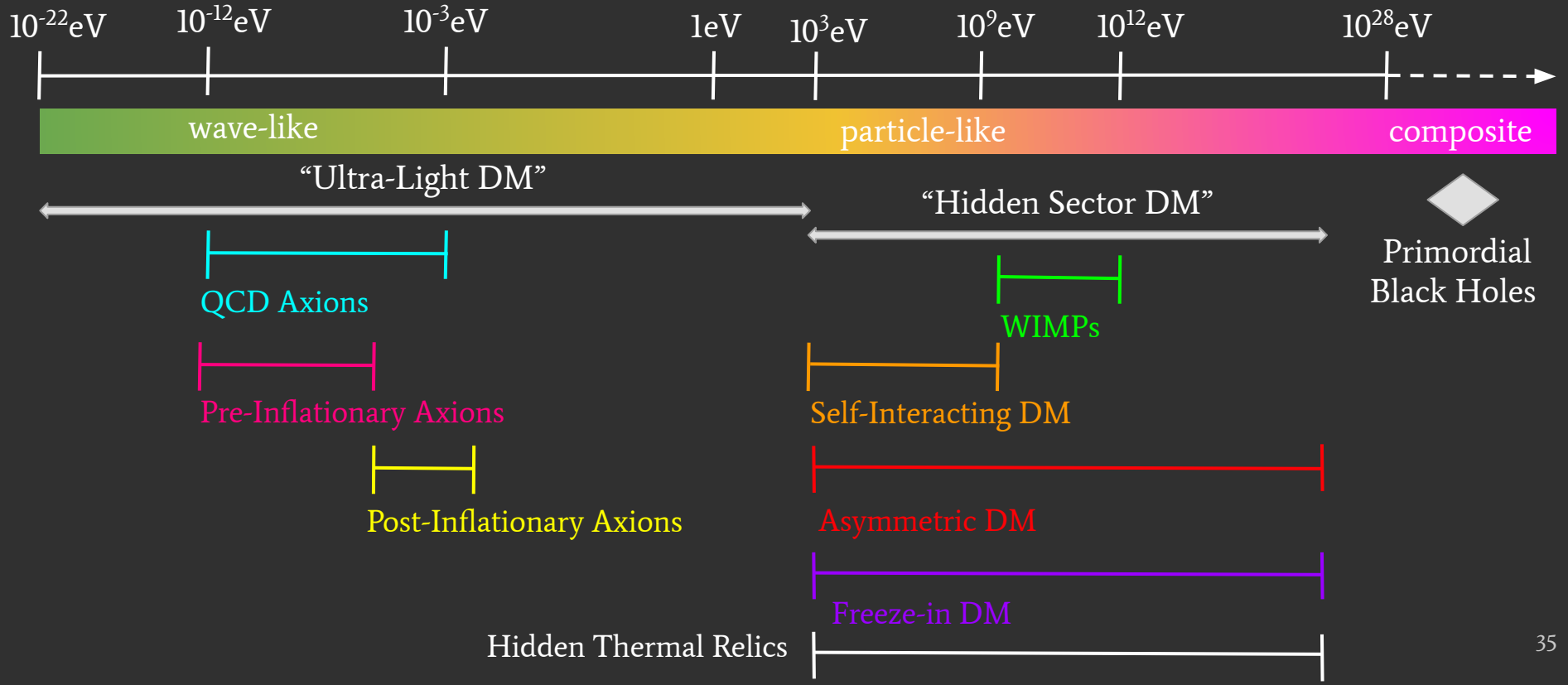
QCD Axions (peV-meV):
Related to things we don't understand about the Strong nuclear interaction

WIMPs (10-1000 GeV):
Related to things we don't understand about the Electroweak symmetry

Would help solve problems in physics on the smallest and largest scales simultaneously!

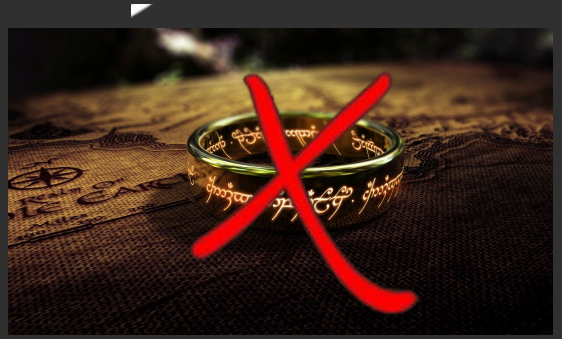
What is Dark Matter?

And lots more...



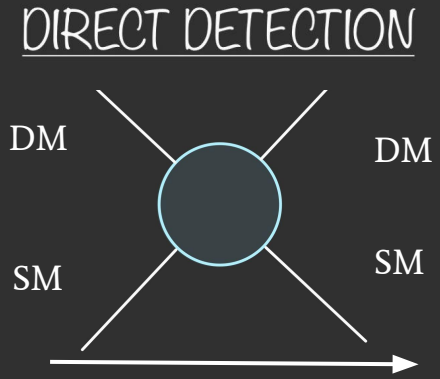
How Can We Look for Dark Matter?

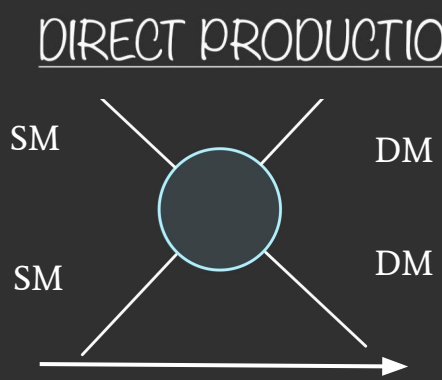
It isn't possible to build one experiment that can search for *any* type of DM

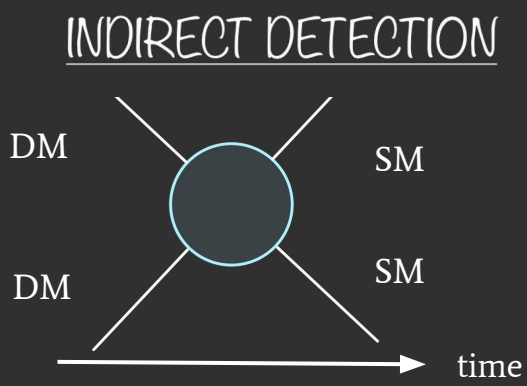


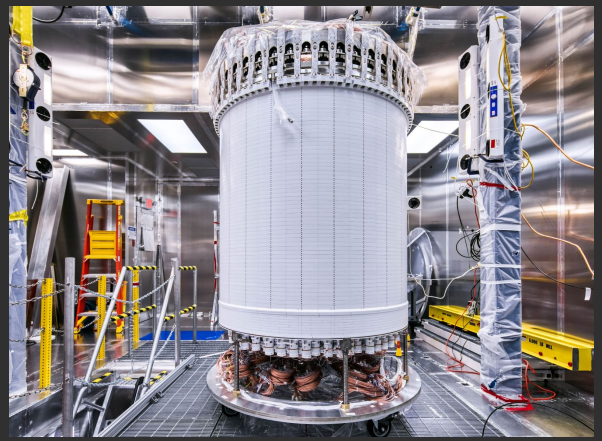
How Can We Look for Dark Matter?

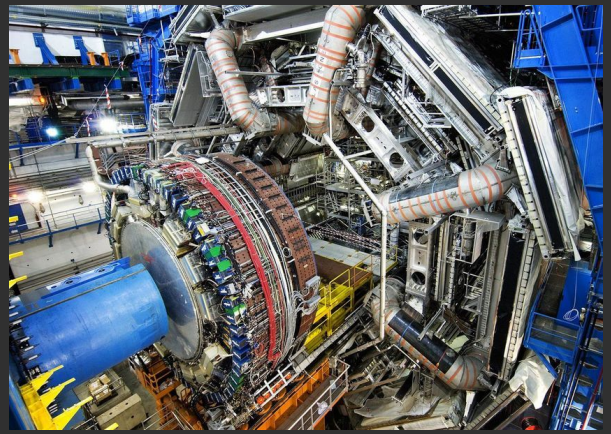
Detectors can be separated into 3 types:

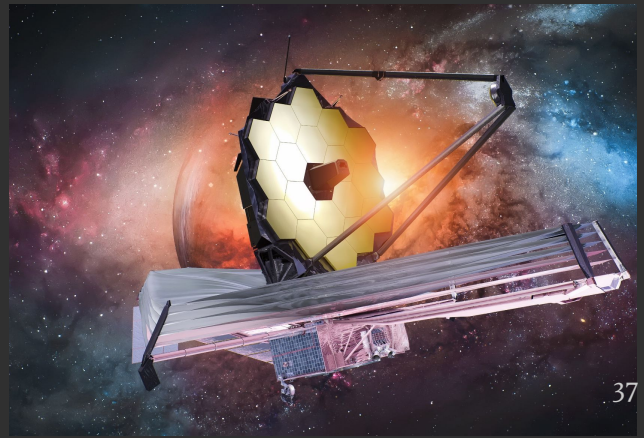




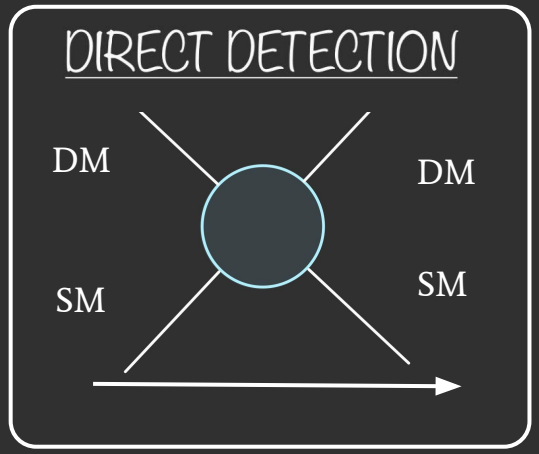






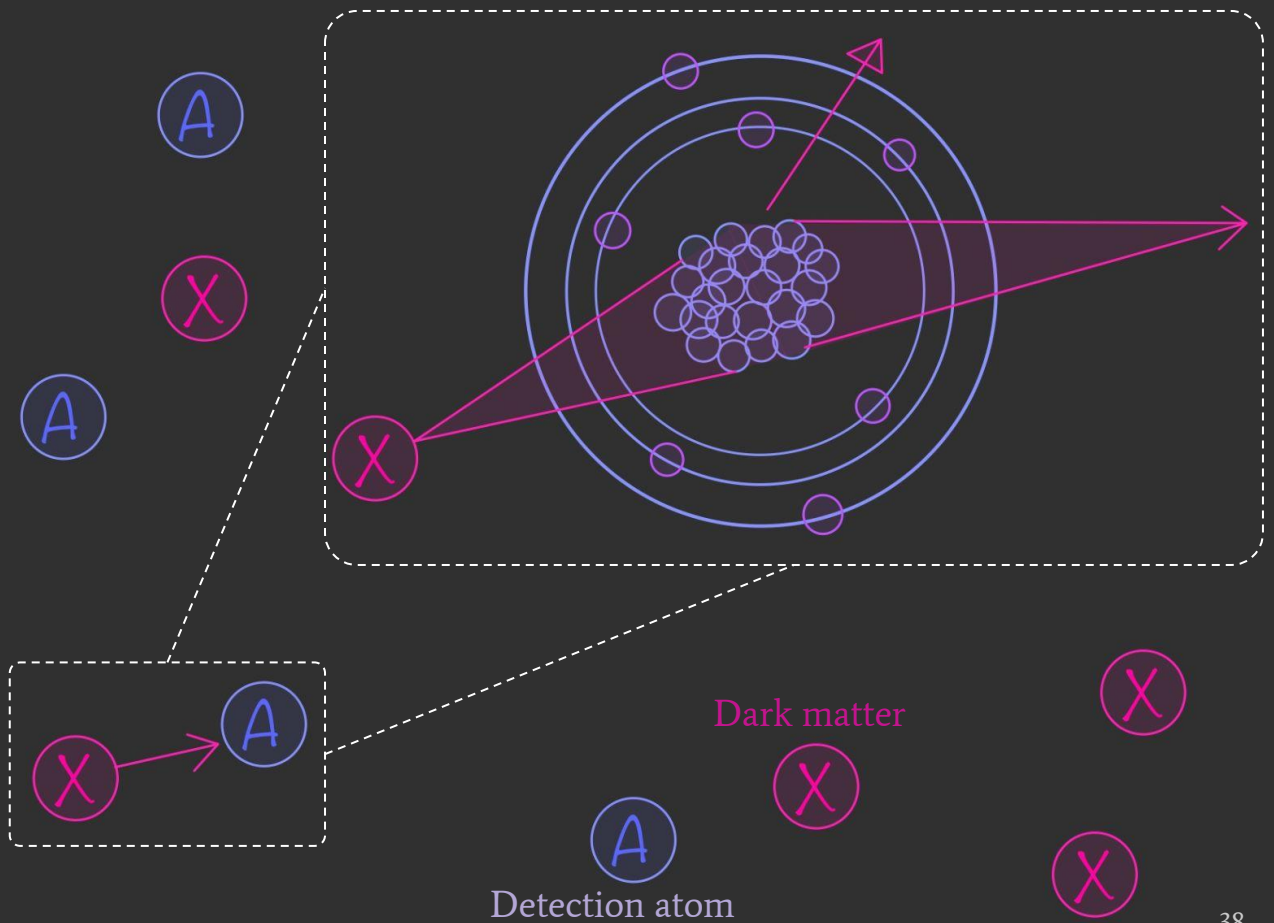


How Can We Look for Dark Matter?



Build a detector from your choice of atom* and wait for the dark matter to come to you.

**turns out there's obvious choices*



How Can We Look for Dark Matter?

...with the LUX ZEPLIN (LZ) direct dark matter detector!

LZ collaboration meeting @ UCLA, March 2025

LZ collaboration is made up of 250 scientists, engineers and technical staff from across the UK, Europe, US, Asia and Oceania

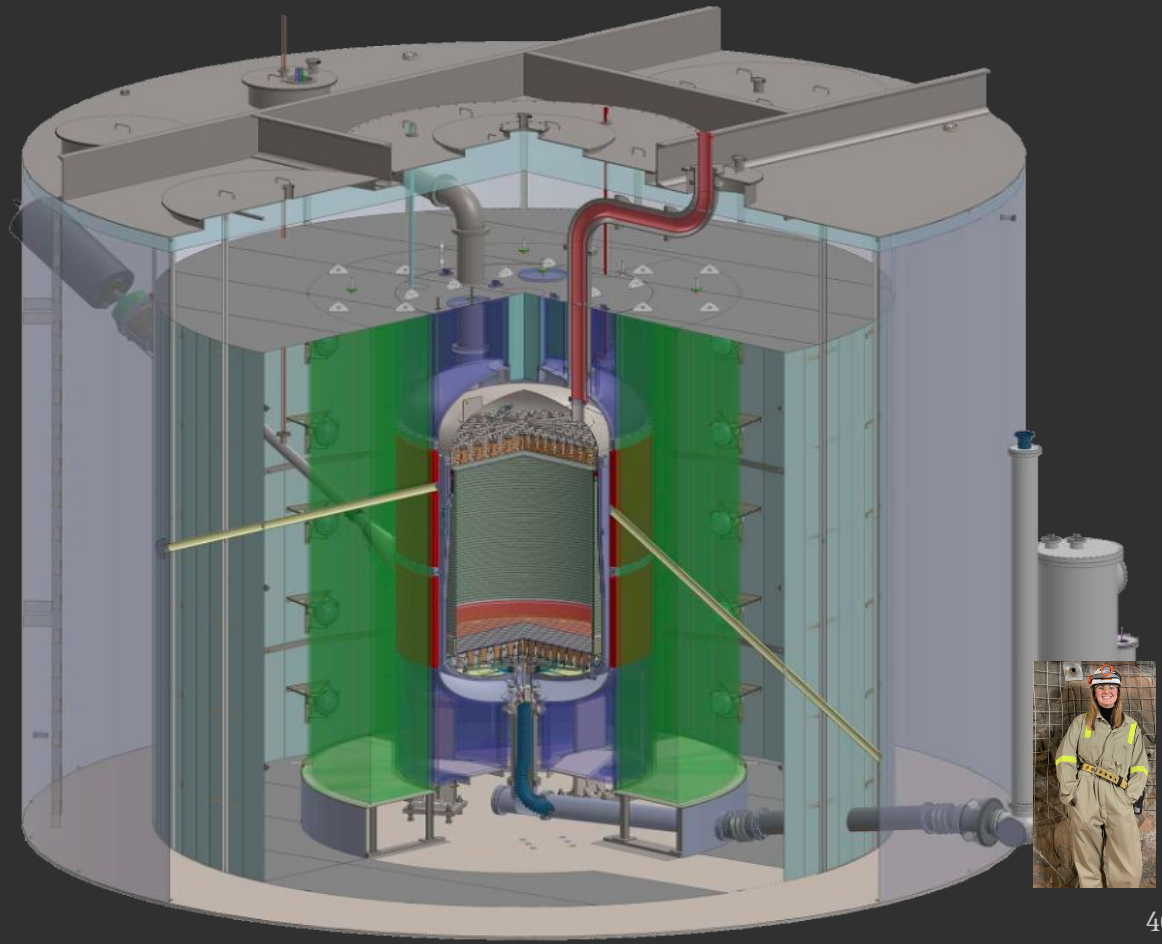
The LUX ZEPLIN (LZ) Dark Matter Detector

7 tonnes of xenon used to detect dark matter

Xenon based detectors have been leading the search for WIMP dark matter for the best 20 years!

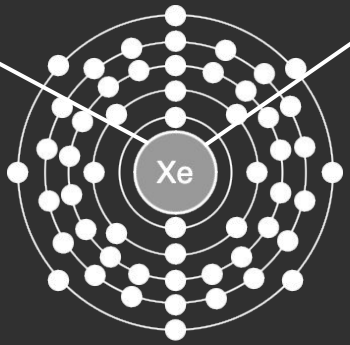
LZ is an onion of detectors:

- Outer detector
- Liquid Xe skin detector
- Central Xe time projection chamber (TPC)

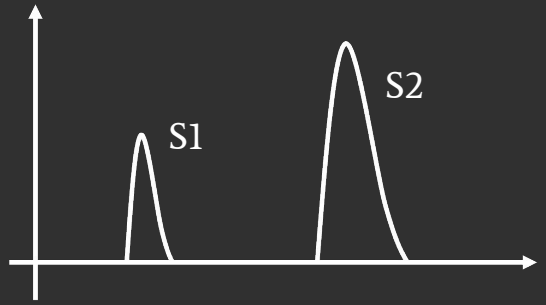


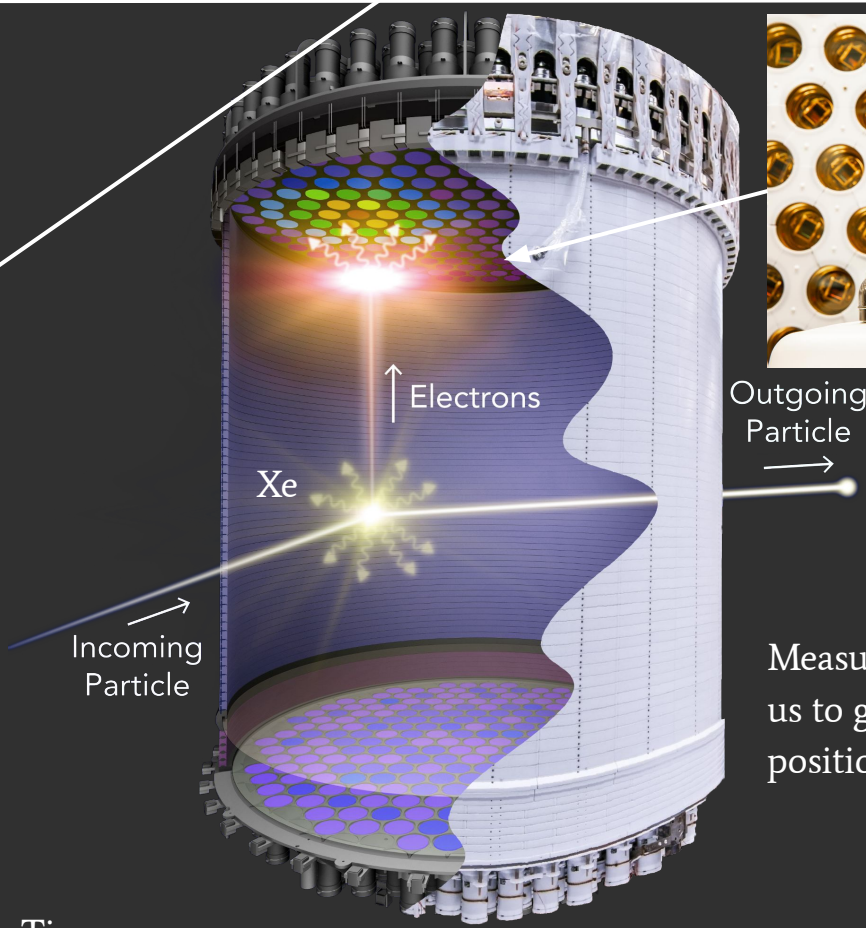
The LZ Detector (TPC)

Try to measure dark matter hitting Xenon particles



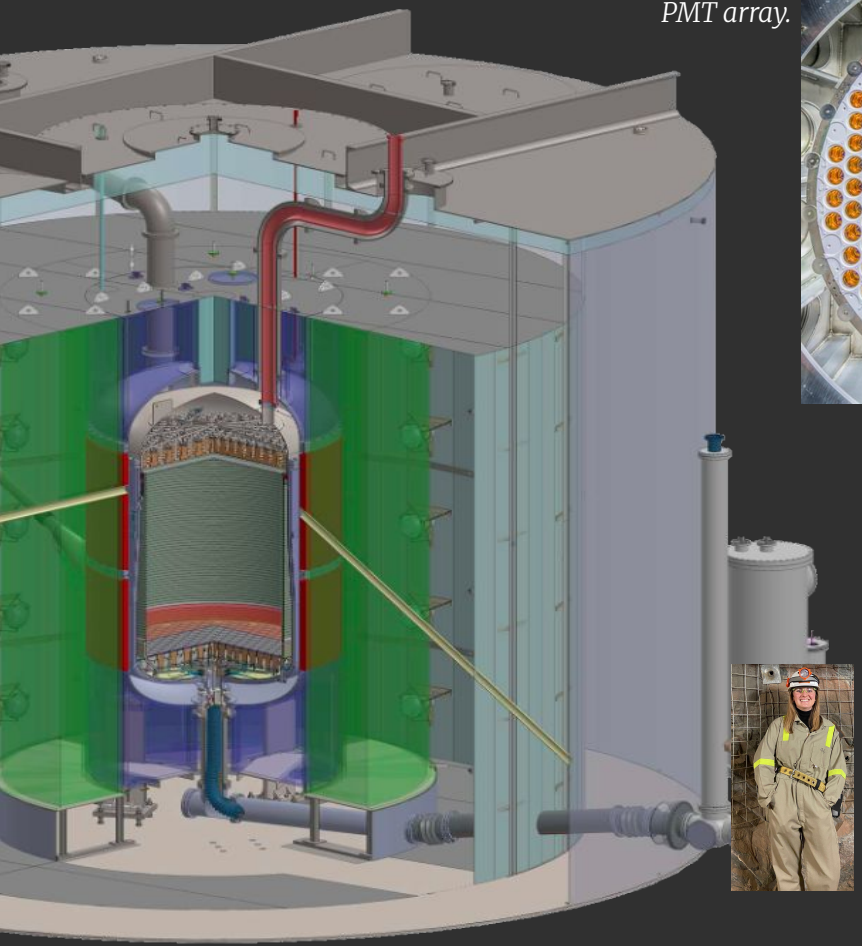
Nuclear Recoil (NR) = Signal like



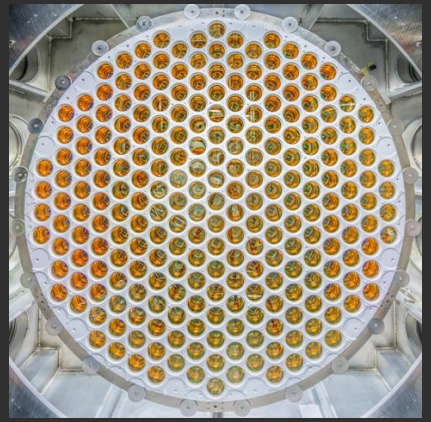


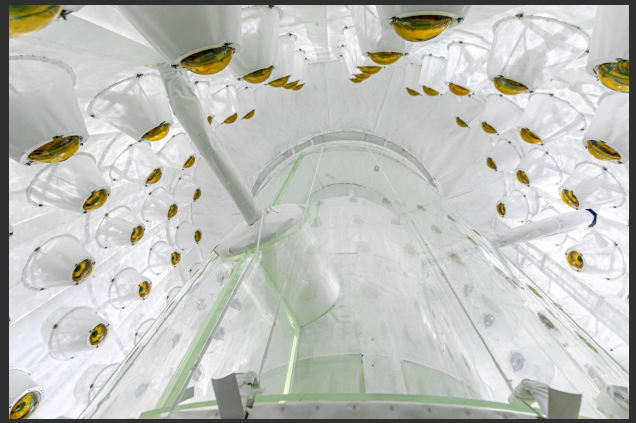
Measuring 2 signals allows us to get energy and position information

LZ Detector in Pictures

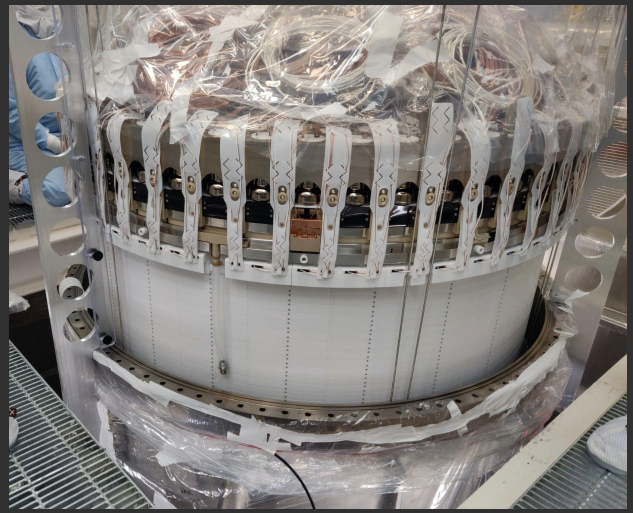


PMT array.





Outer detector.



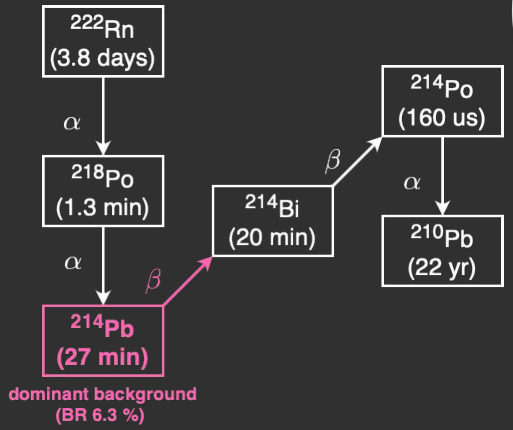
The LZ TPC being lowered into the cryostat.

LZ is based 4850 ft underground at the Sanford Underground Research Facility (SURF) in Lead, SD

Going Underground

Why Go Underground?

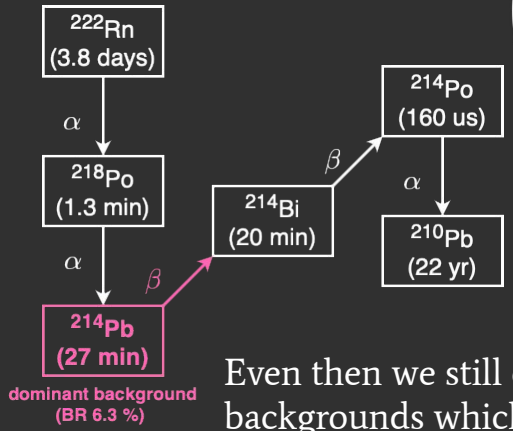
We need to shield our detector from cosmic rays and radiation



LZ'ers checking the detector for dust contamination during detector construction

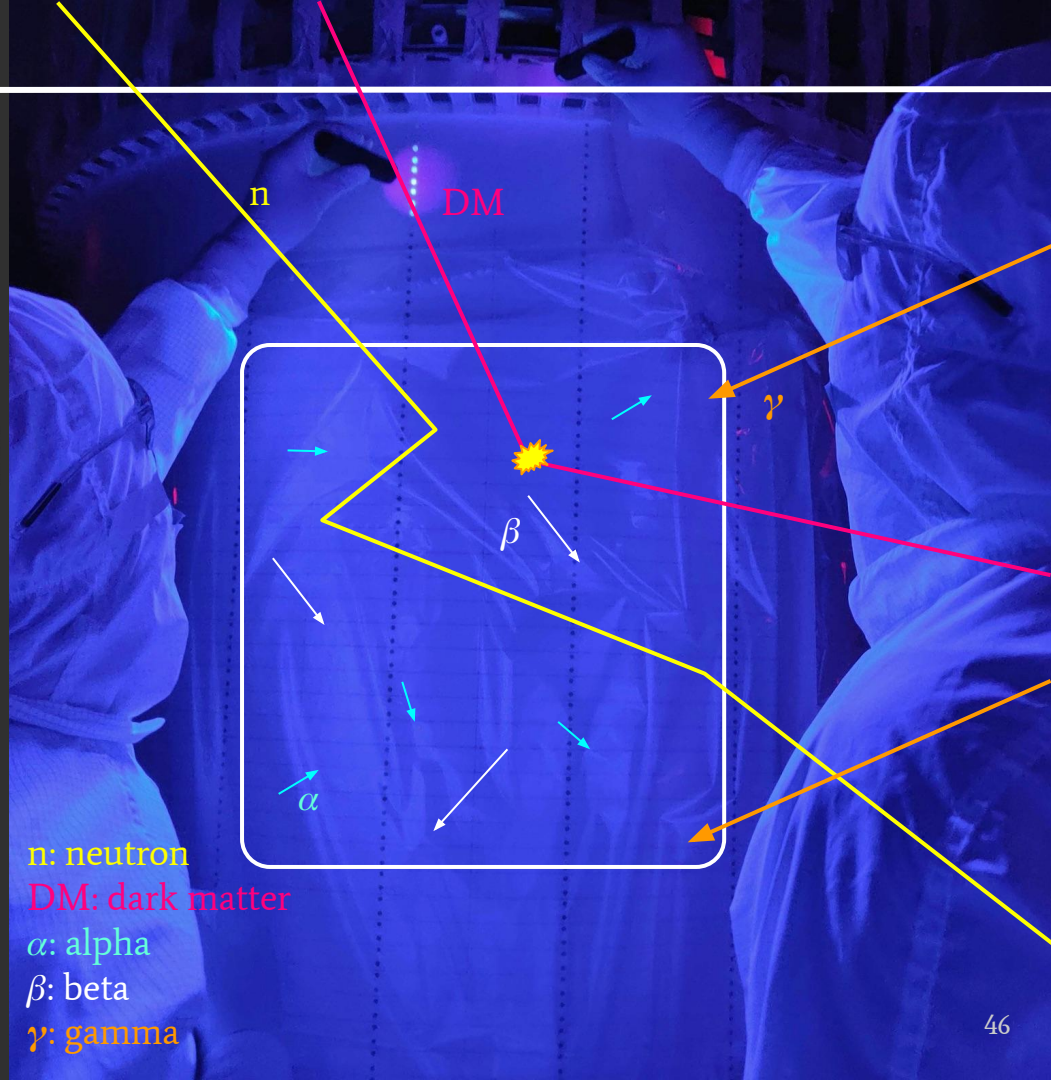
Why Go Underground?

We need to shield our detector from cosmic rays and radiation



Even then we still can see lots of backgrounds which look like WIMPs.

My current jobs involves modelling these and removing them from data.

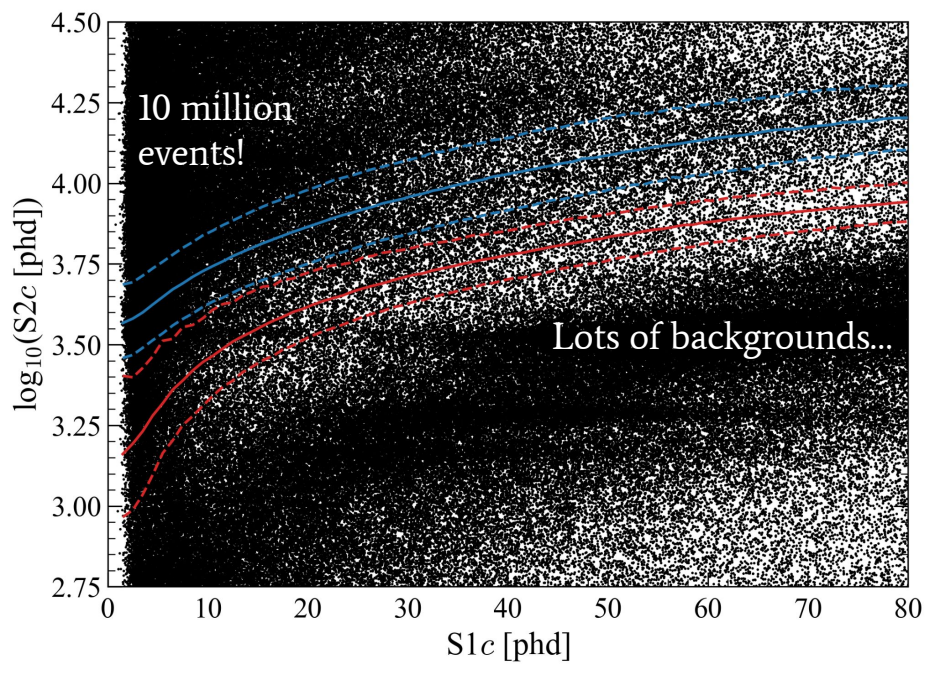


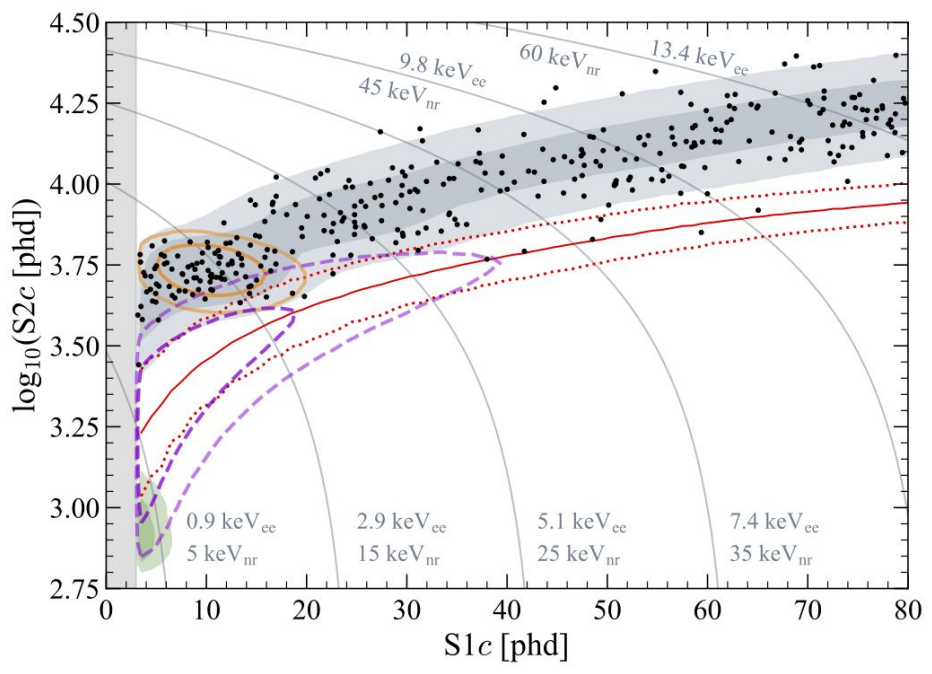
n: neutron
DM: dark matter
α: alpha
β: beta
γ: gamma

Now Run LZ

Phys. Rev. Lett. 131, 041002 (2023)

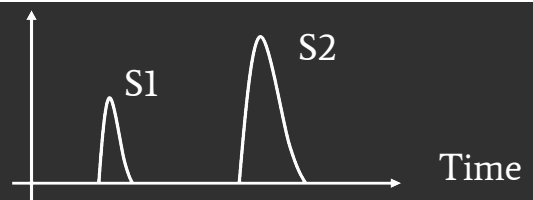
BEFORE ANALYSIS → AFTER ANALYSIS





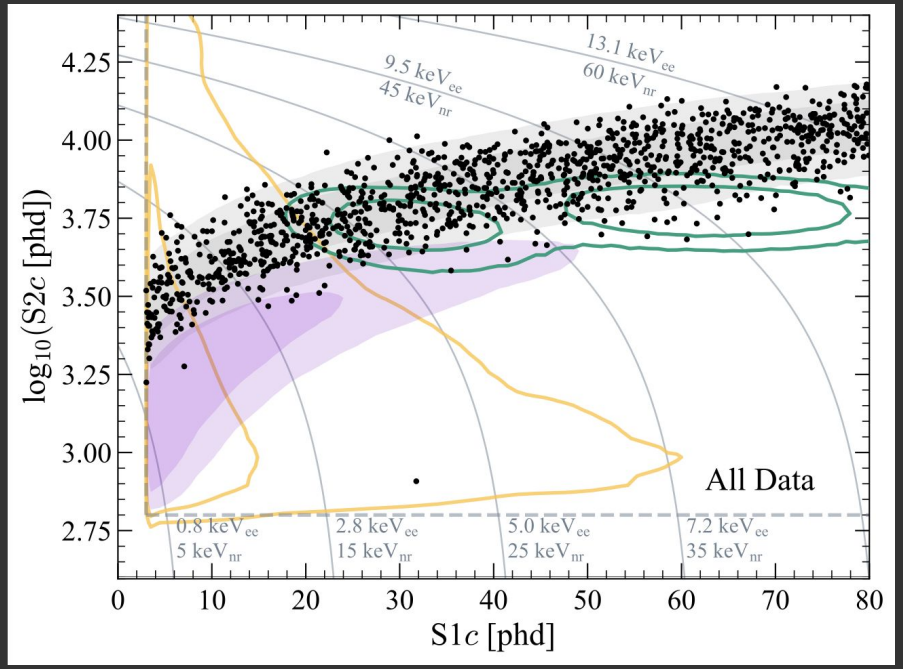
Analysis involves removing events we know are not dark matter

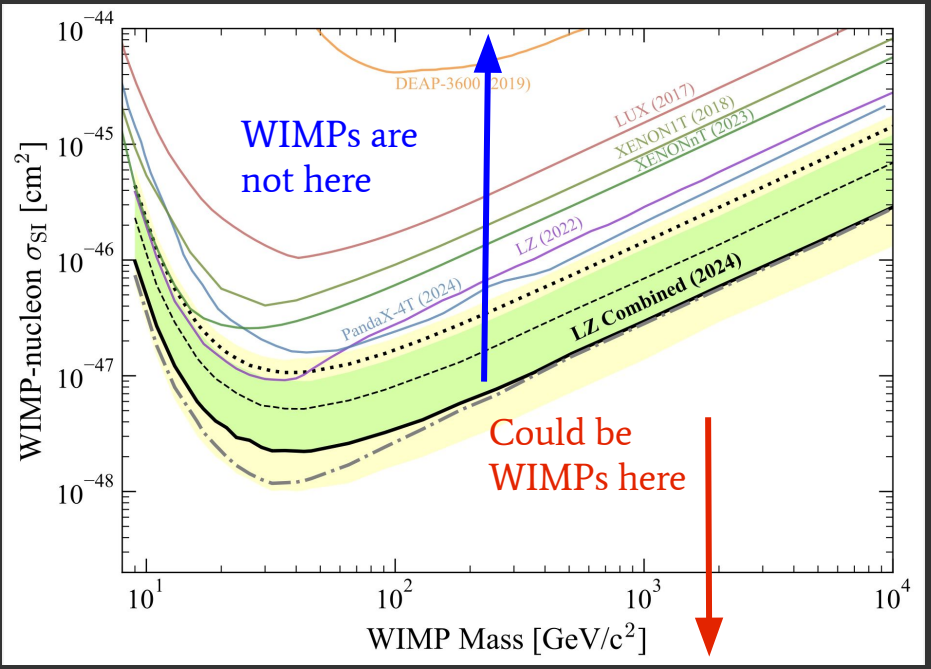
Data from first 60 live days of running



World Leading Results

arXiv:2410.17036





LZ will continue running for the next few years

PAST, PRESENT & FUTURE OF DARK MATTER

It's almost 100 years since evidence for DM was seen!

In that time huge progress has been made towards its discovery with xenon detectors at the forefront

But what's next?

1930s : Fritz Zwicky : Coma Cluster

1970s : Vera Rubin : Andromeda Galaxy

2000s : Rise of LXe Detectors : ZEPLIN III, XENON100

2010s : LUX, XENON1T, DEAP3600 (LAr)

2020s : LUX ZEPLIN, XENONnT, PandaX

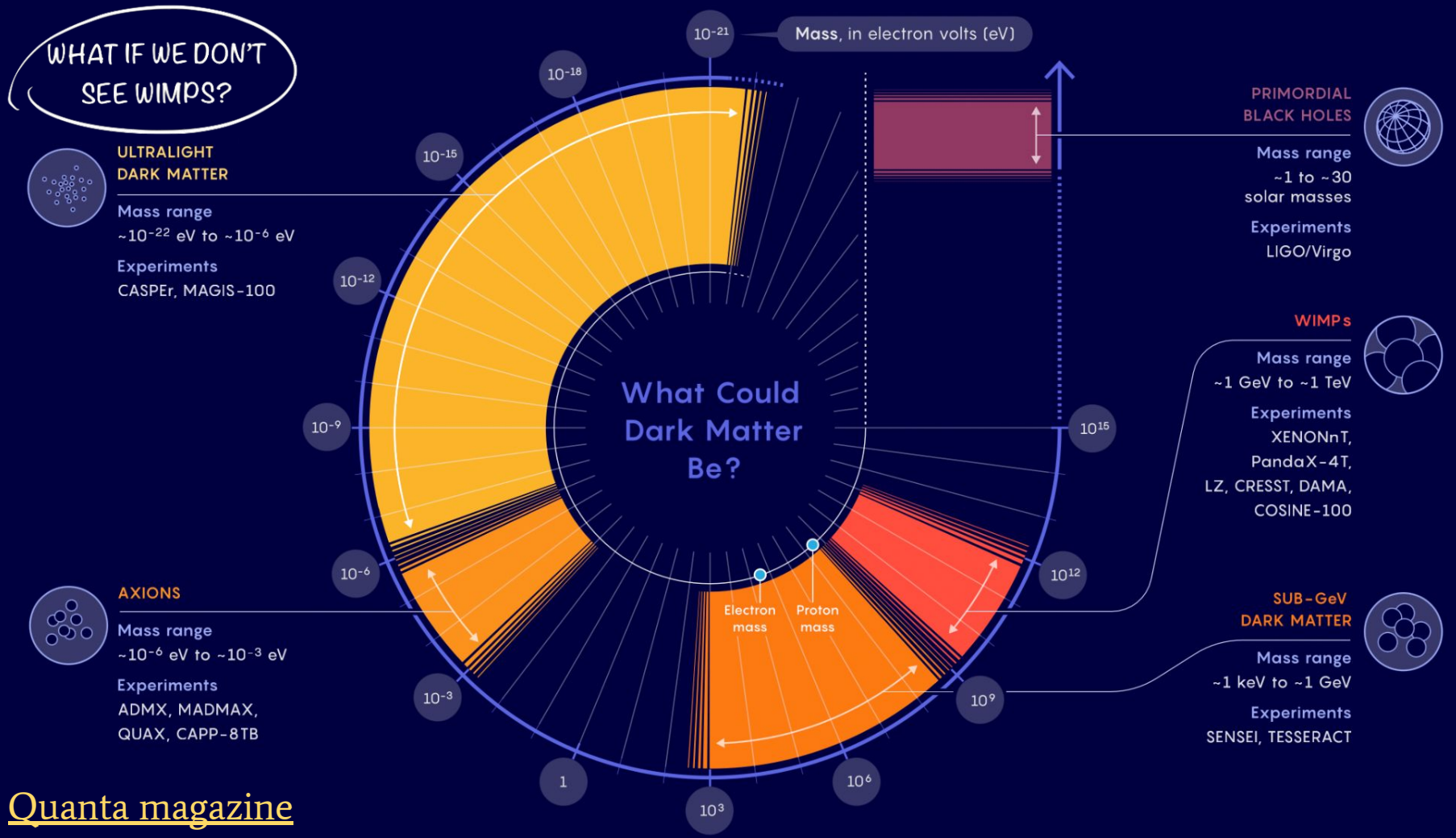
2030s : XLZD - observe DM ?

XLZD: the coming together of the LUX-ZEPLIN, XENON and DARWIN collaborations.

Would be the most sensitive DM detector to date! But can also look for so much more..

- *Neutrinoless double beta decay; low-energy solar neutrino flux; solar axions; galactic axion like particles: supernovae; sterile neutrinos; ...*

First in-person meeting. KIT, June 2022



Quanta magazine

Thank you!