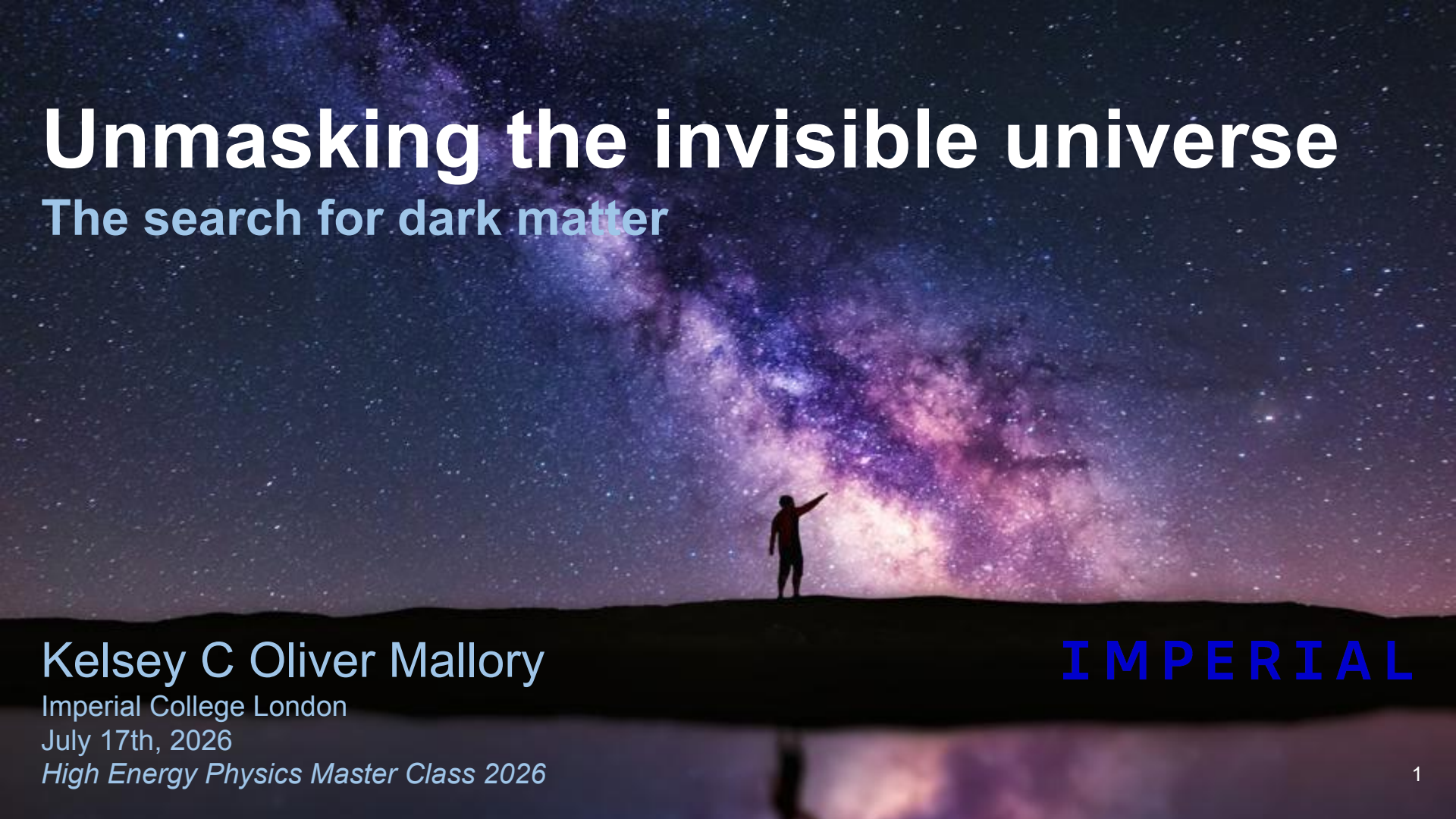


# Unmasking the invisible universe

## The search for dark matter

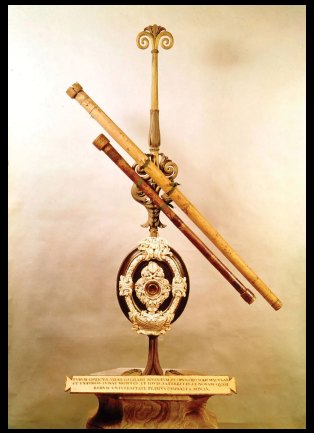
Kelsey C Oliver Mallory
Imperial College London
July 17th, 2026
*High Energy Physics Master Class 2026*

IMPERIAL

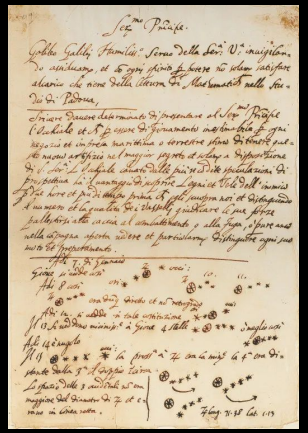

Galileo Galilei

Photograph by John Chumack
www.galacticimages.com

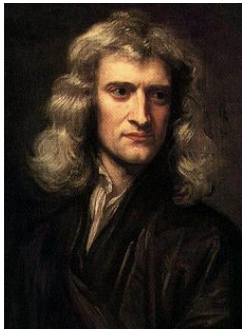
The cosmos may contain matter that is too dark to be perceived through ordinary means.



Two of Galileo's telescopes

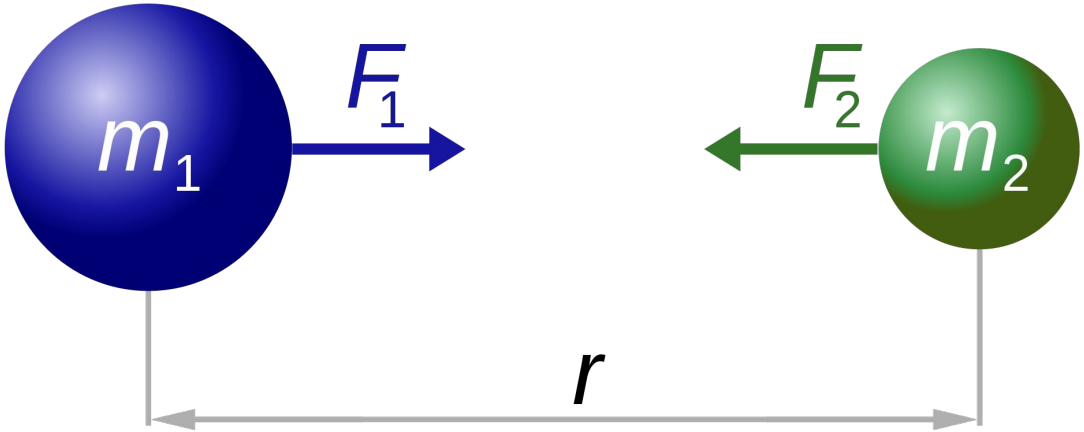


Galileo's notes



Isaac Newton

1687




There are laws of motion and universal gravitation.

$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

Fritz Zwicky

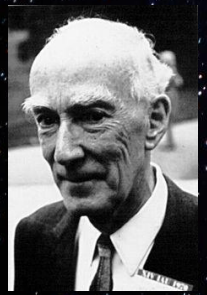
1930s

Why does the Coma cluster not fly apart?

Coined the term “dark matter”

NASA, ESA, and the Hubble Heritage Team (STScI/AURA).
Release ID: 2008-24

# 1930s

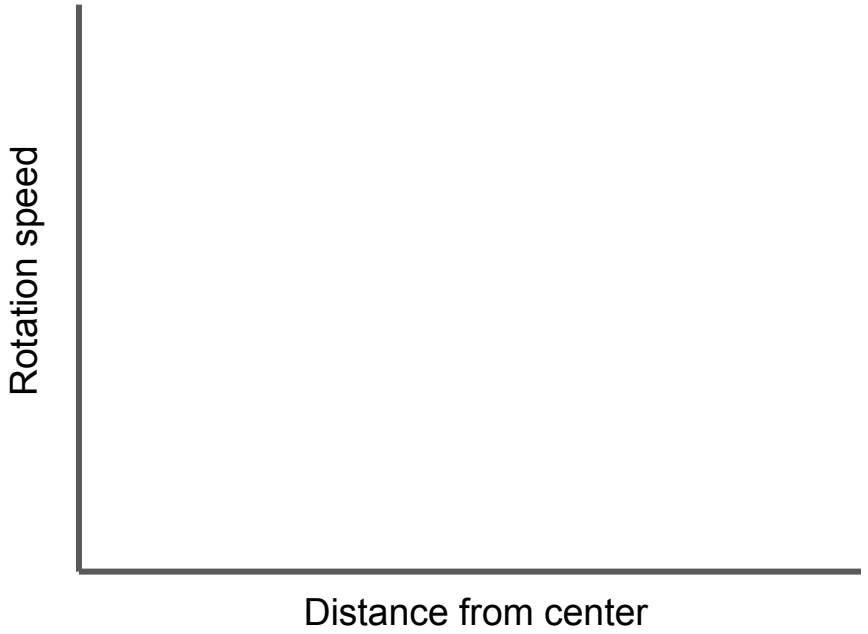


Jan Oort

Why do stars, including our sun, remaining in the spiral arms of galaxies?

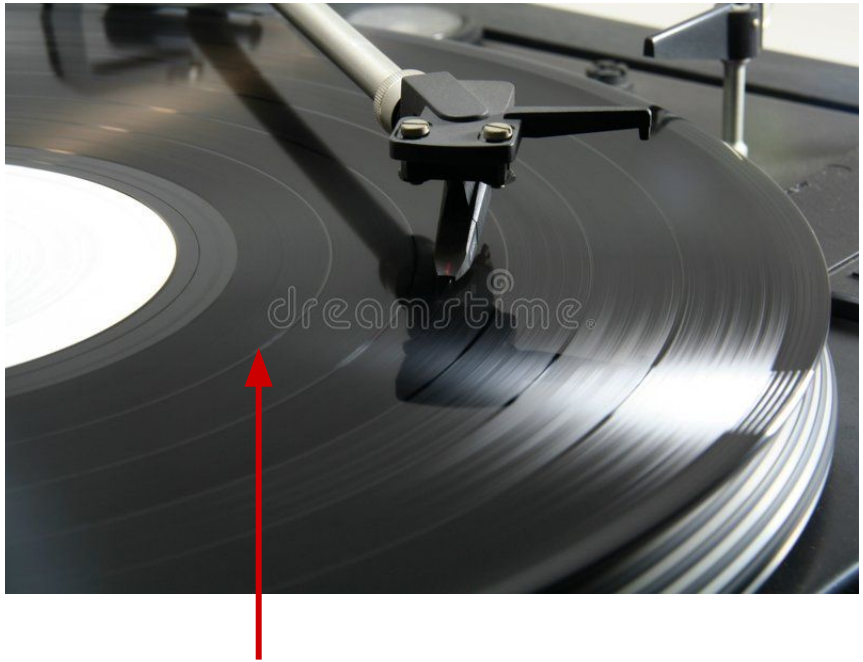
# 1960s & 70s

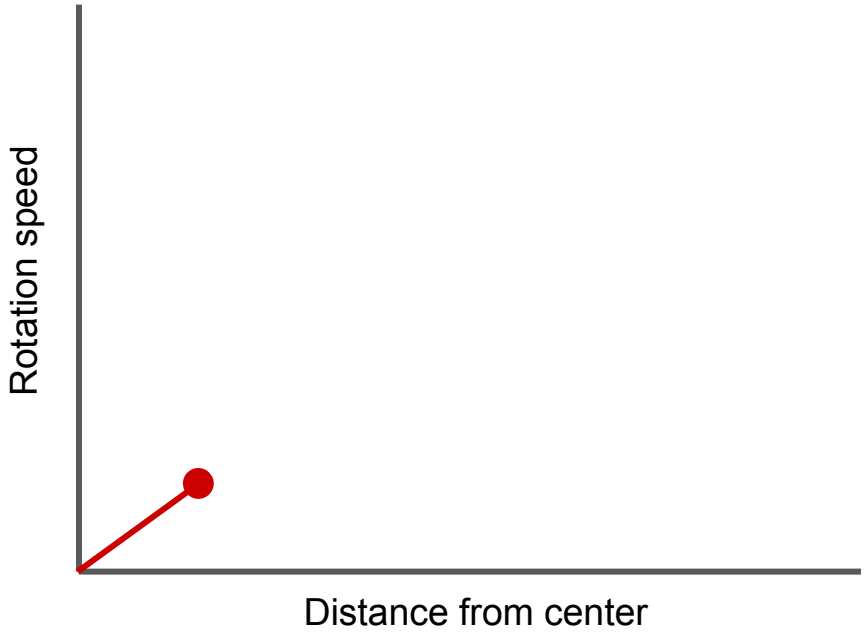
Vera Rubin

# 1960s & 70s

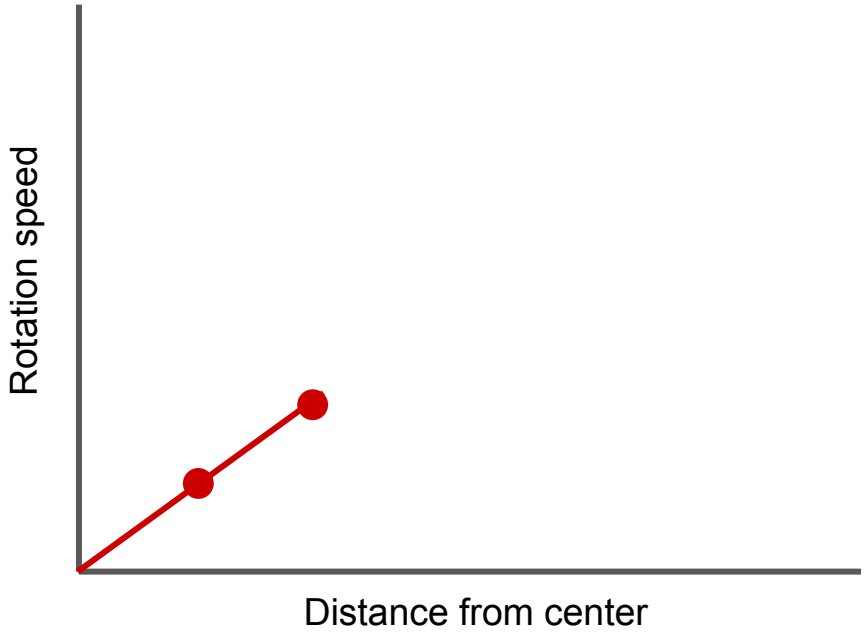
Vera Rubin



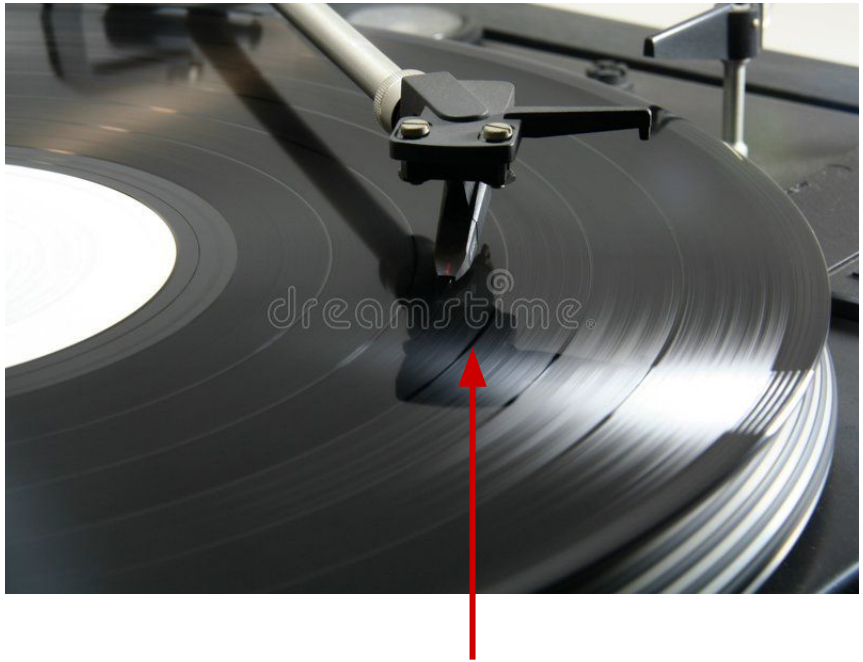
# 1960s & 70s

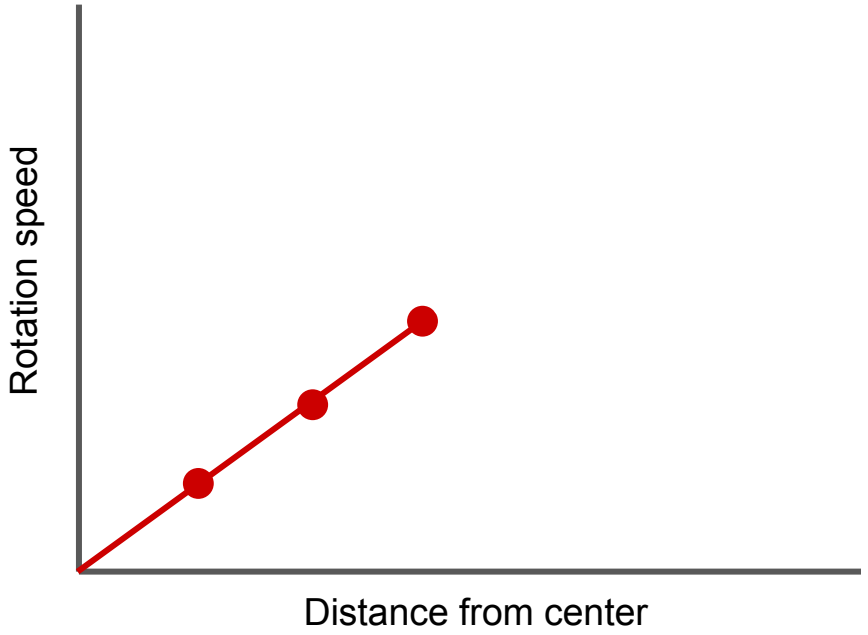
Vera Rubin

# 1960s & 70s

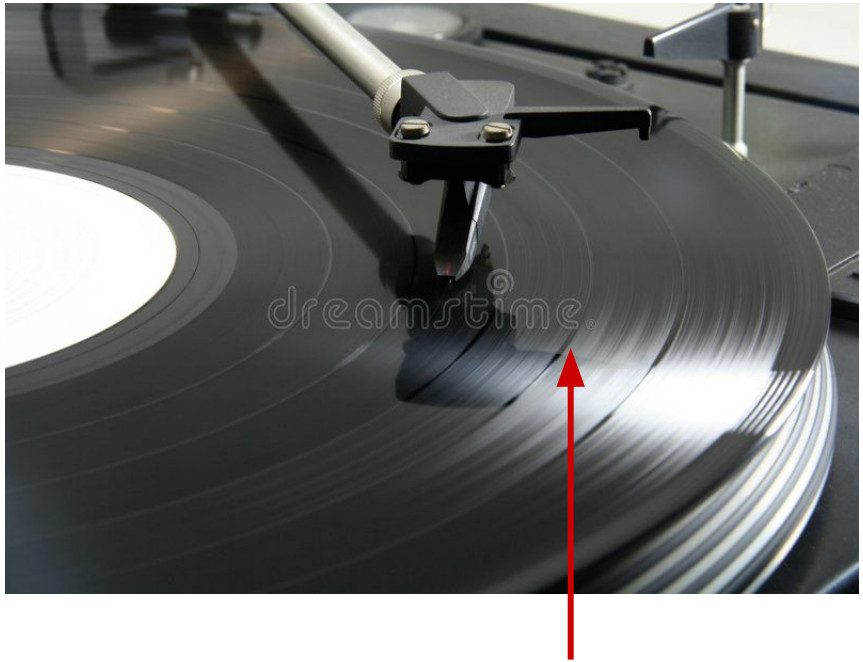
Vera Rubin

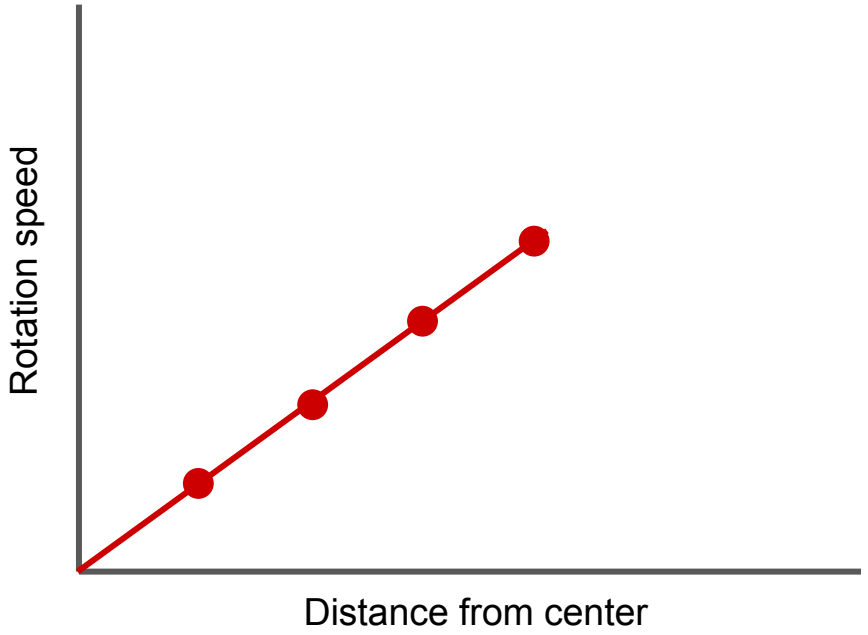


# 1960s & 70s

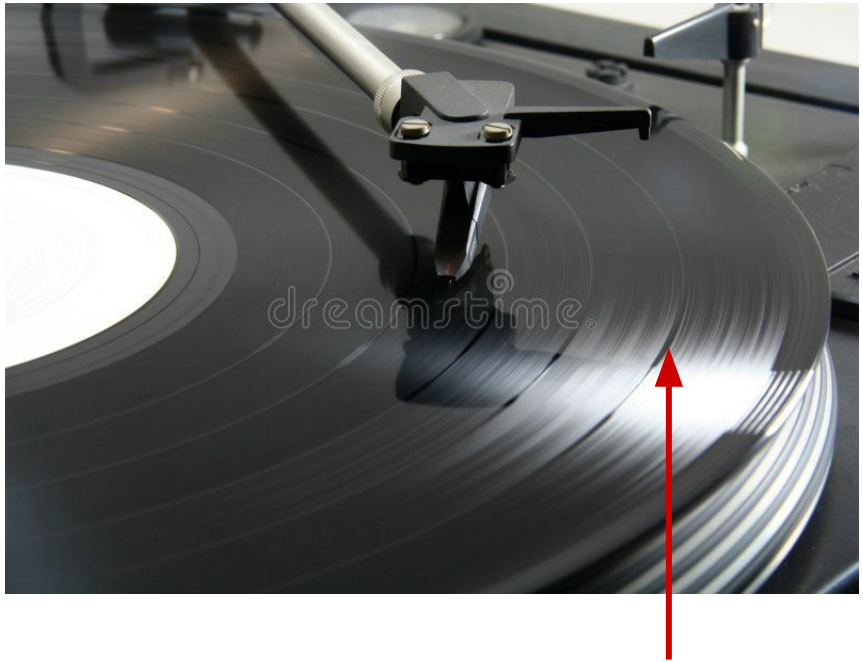
Vera Rubin

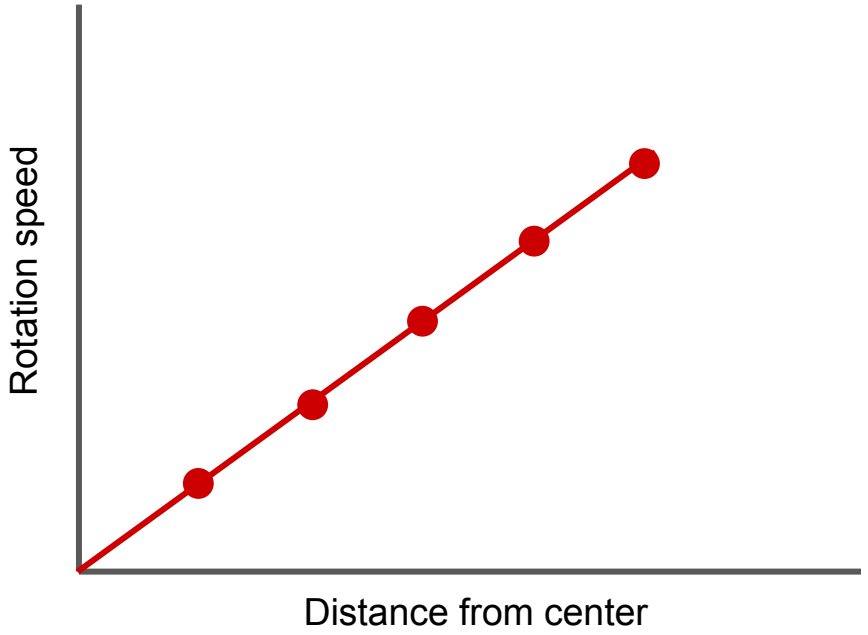


# 1960s & 70s

Vera Rubin



Vera Rubin

Velocity (km $s^{-1}$)

100

50

Observations from starlight

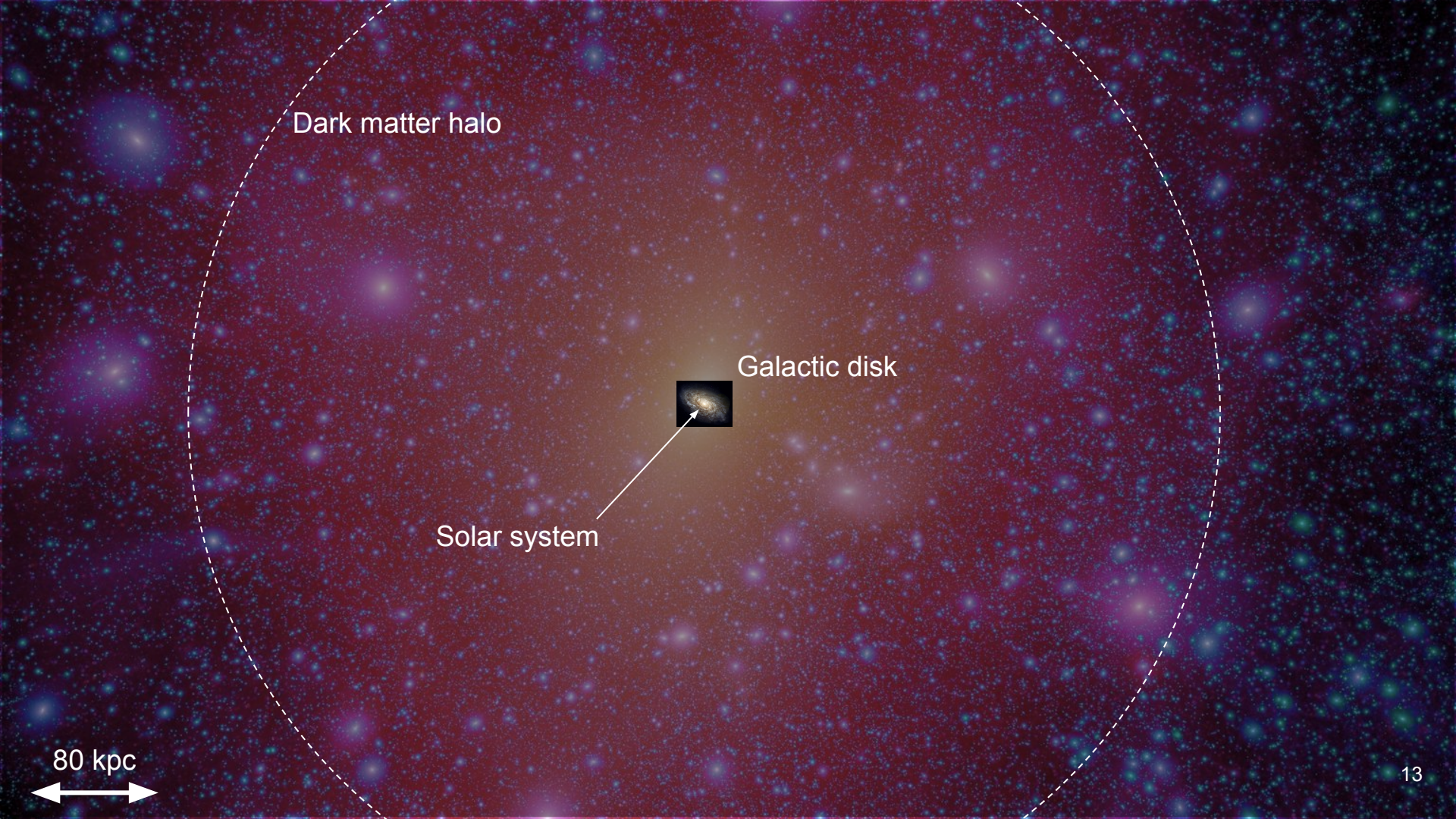
Observations from 21 cm hydrogen

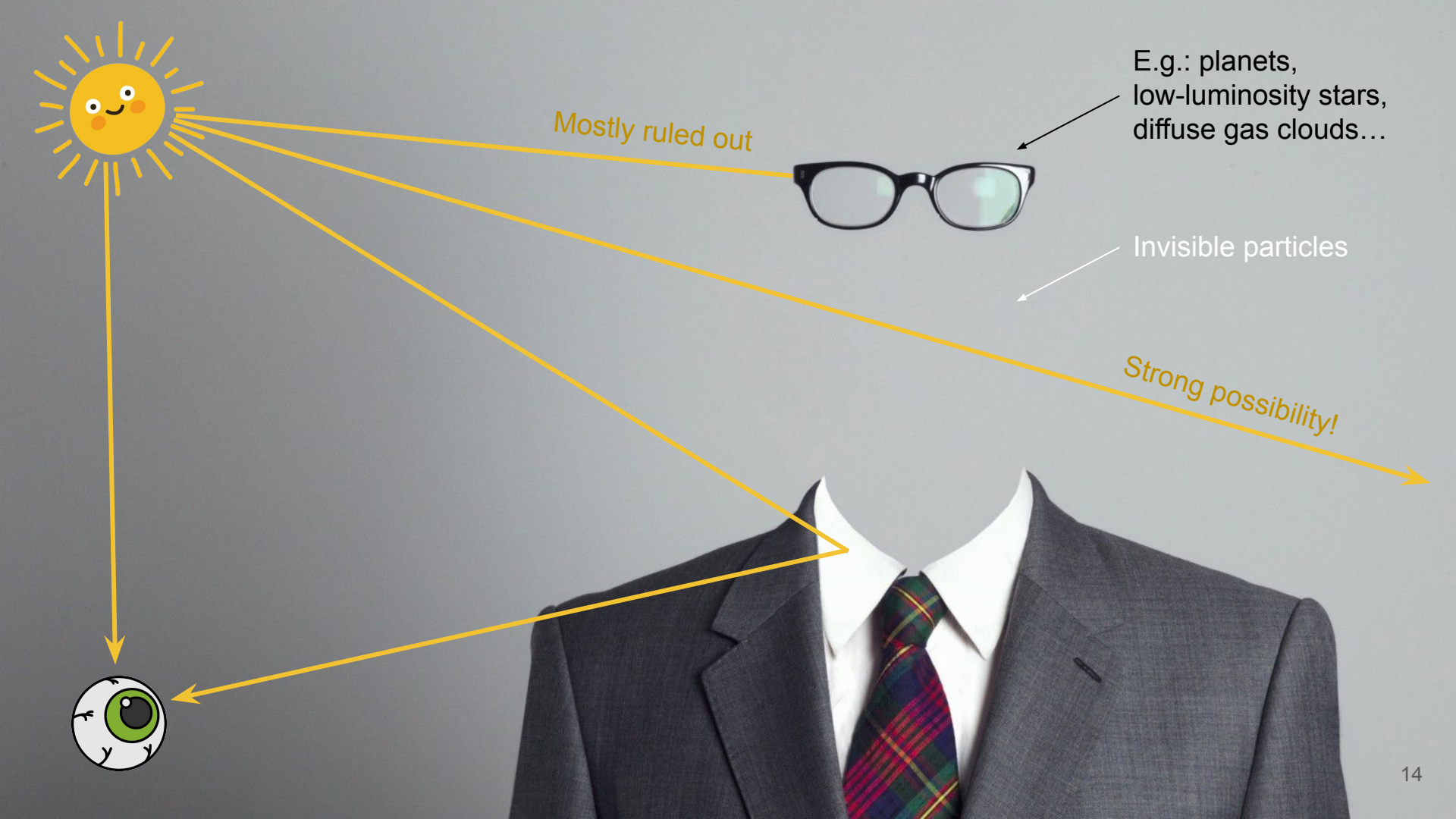
Expected from the visible disk

10,000 20,000 30,000 40,000

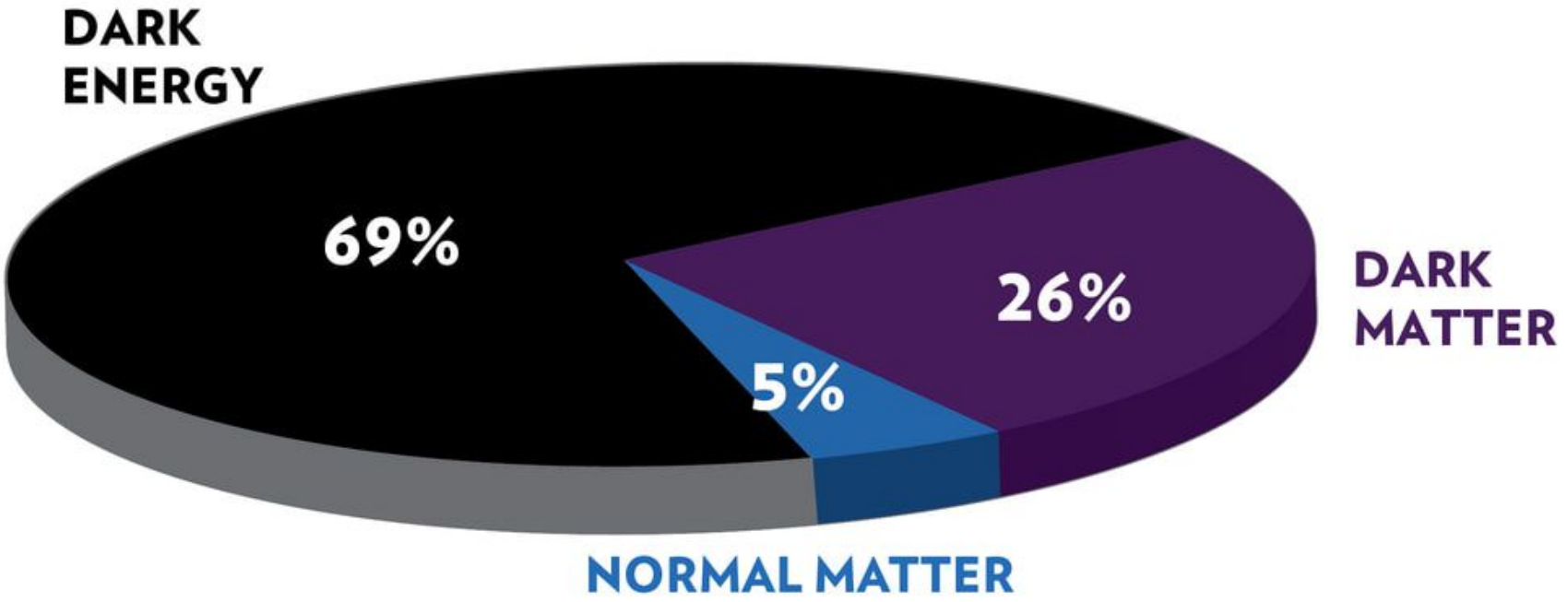
Distance (light years)

Mon. Not. R. Astron. Soc. 311, 441±447 (2000)
By Mario De Leo - Own work, CC BY-SA 4.0

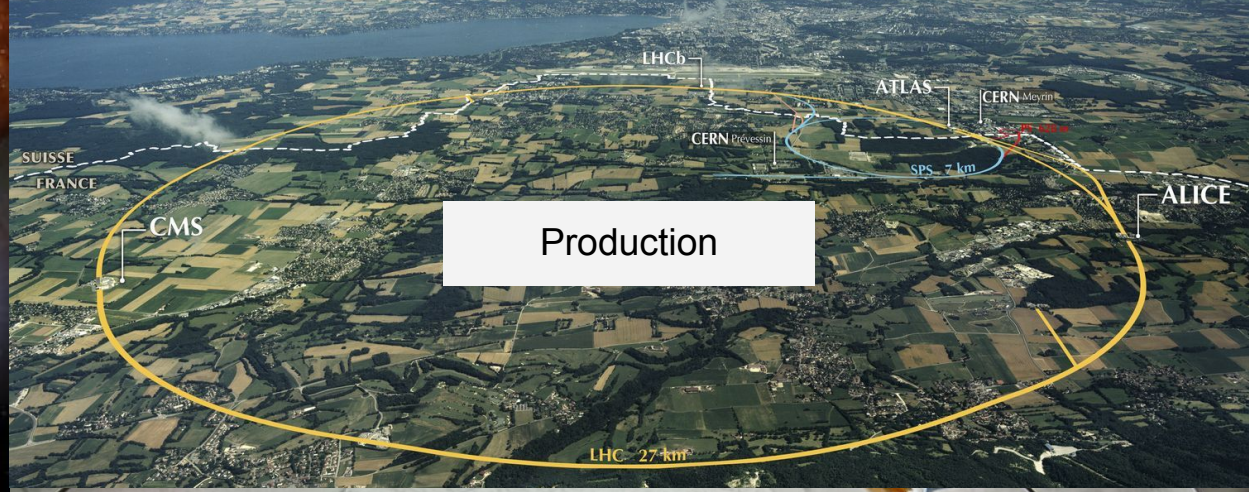

Dark matter halo
Galactic disk
Solar system
80 kpc


E.g.: planets,
low-luminosity stars,
diffuse gas clouds…
Mostly ruled out
Invisible particles
Strong possibility!

# ENERGY DISTRIBUTION OF THE UNIVERSE

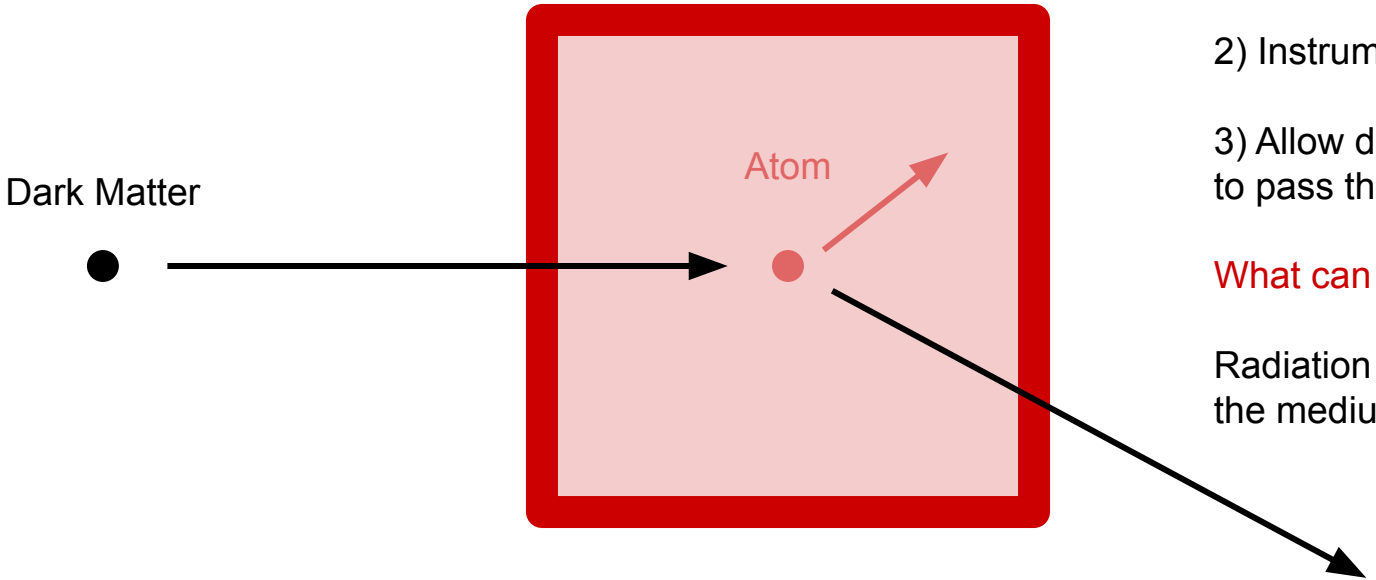


Observation




Production

Direct Detection




How to build a dark matter detector?

1) Build a container to hold medium

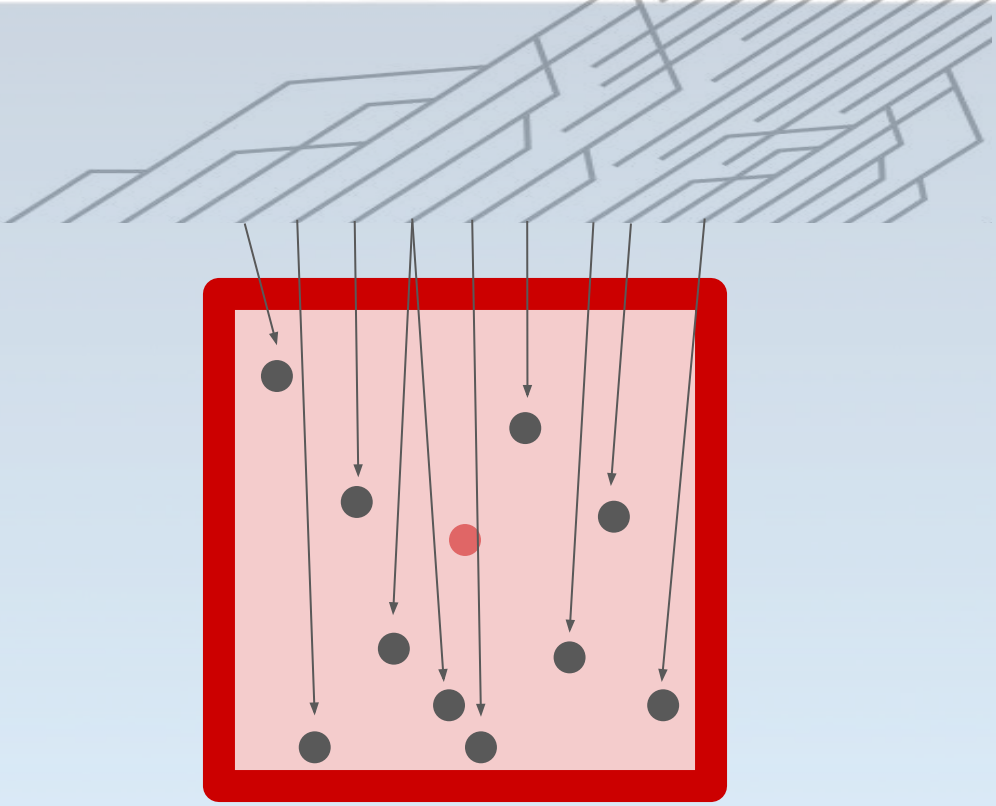
2) Instrument container

3) Allow dark matter from halo to pass through detector

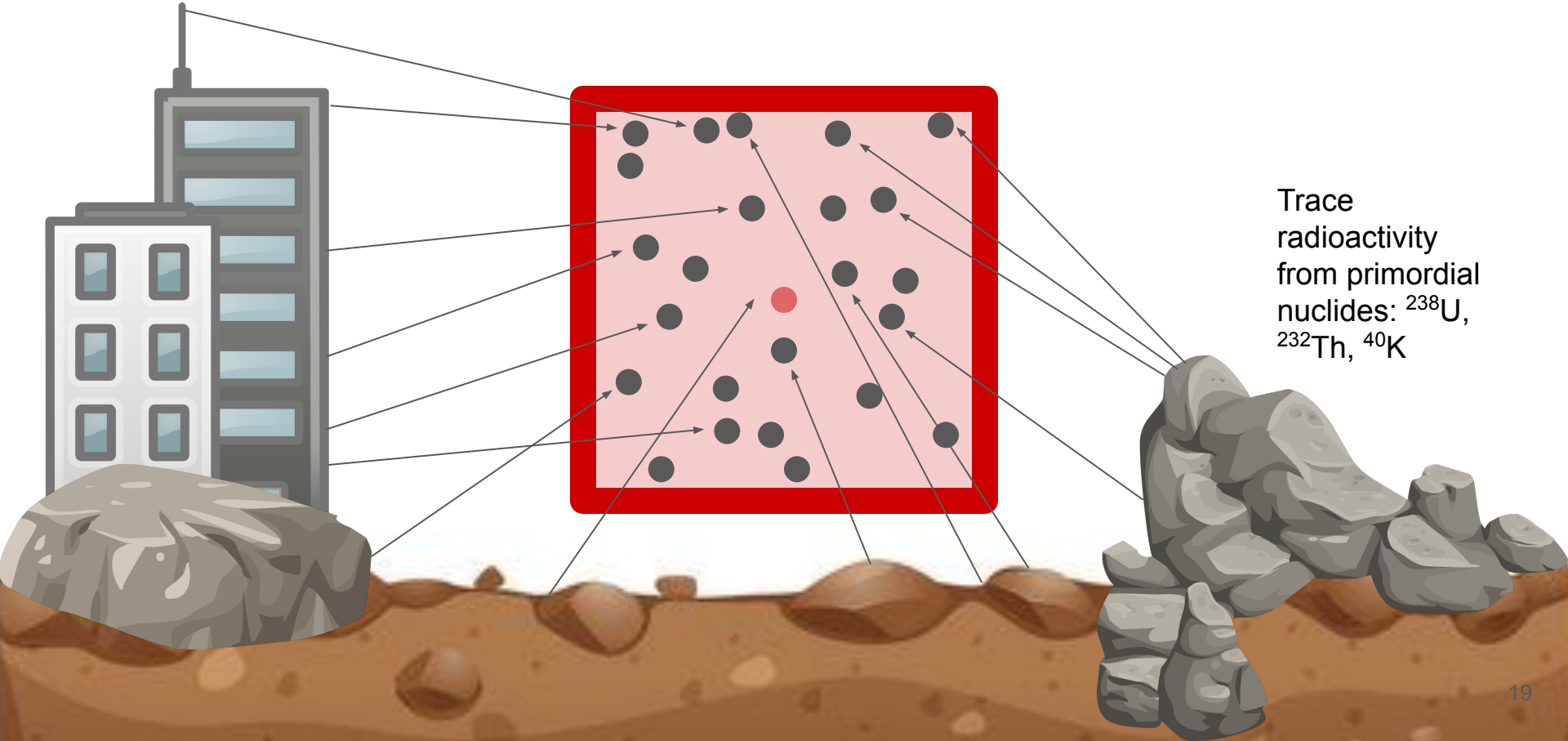
What can go wrong?

Radiation can also scatter in the medium!

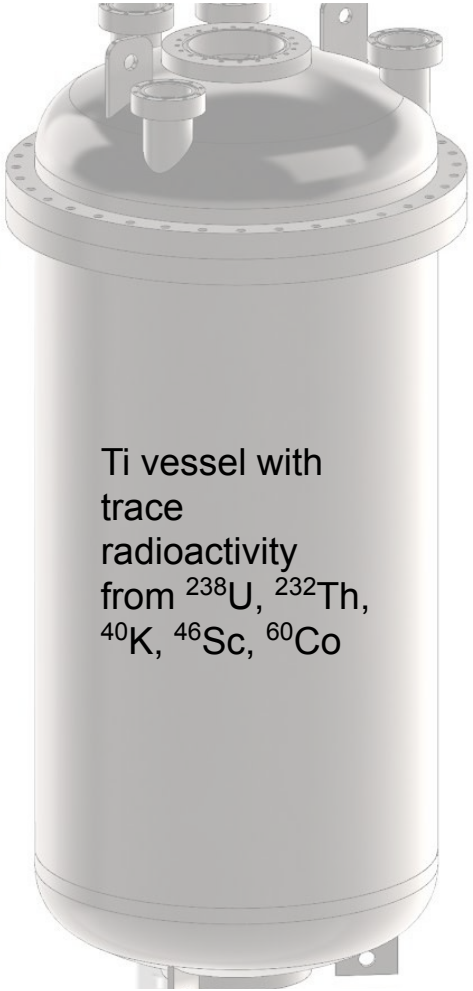
Secondary cosmic rays



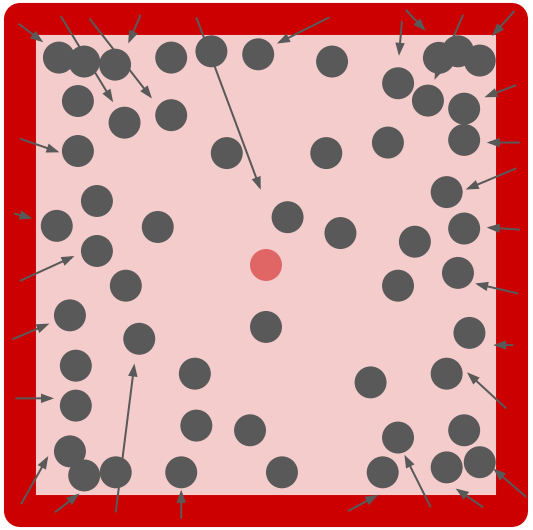
Environment



Trace radioactivity from primordial nuclides: $^{238}U$, $^{232}Th$, $^{40}K$

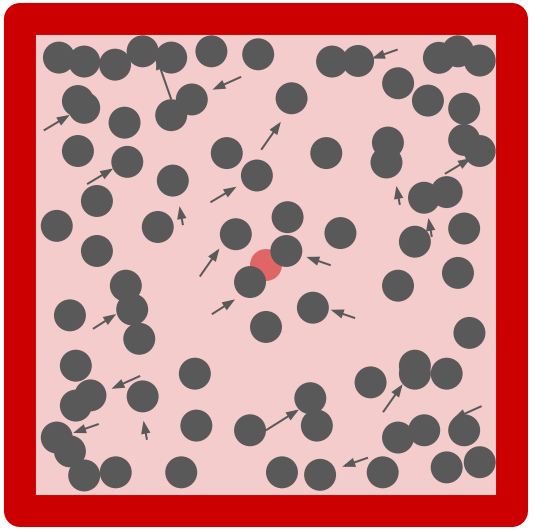


Ti vessel with trace radioactivity from $^{238}U$, $^{232}Th$, $^{40}K$, $^{46}Sc$, $^{60}Co$

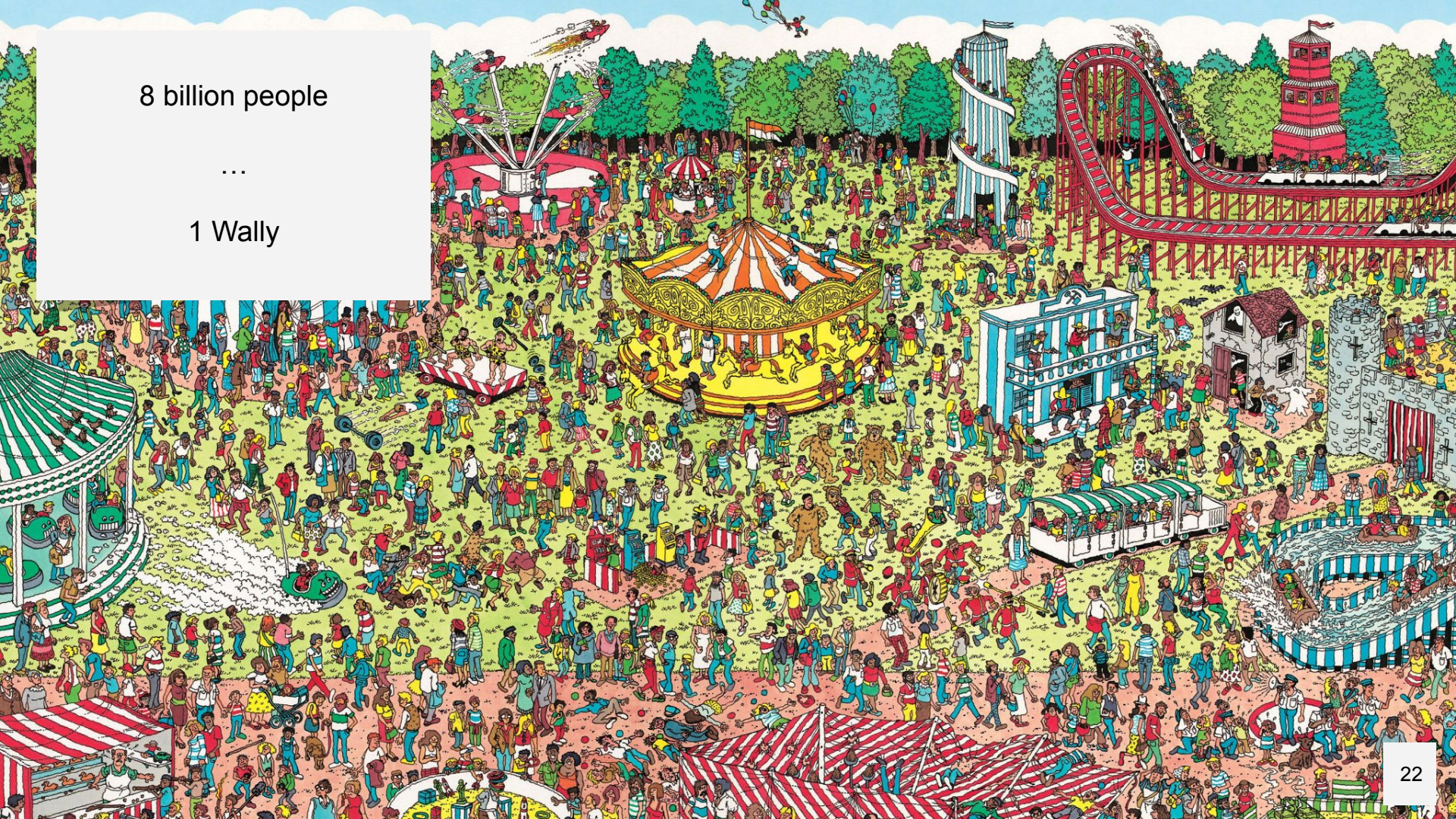


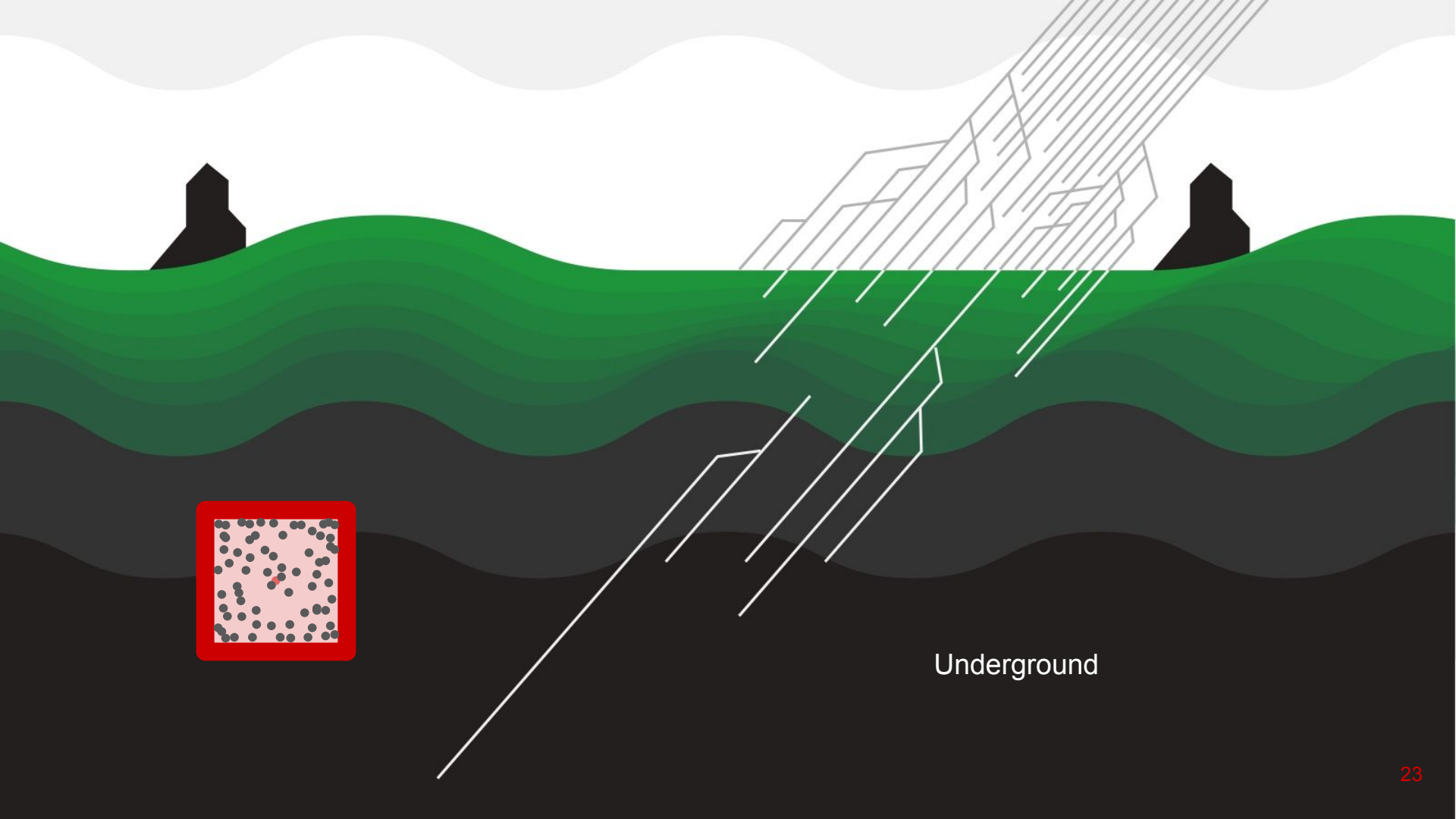
Detector materials

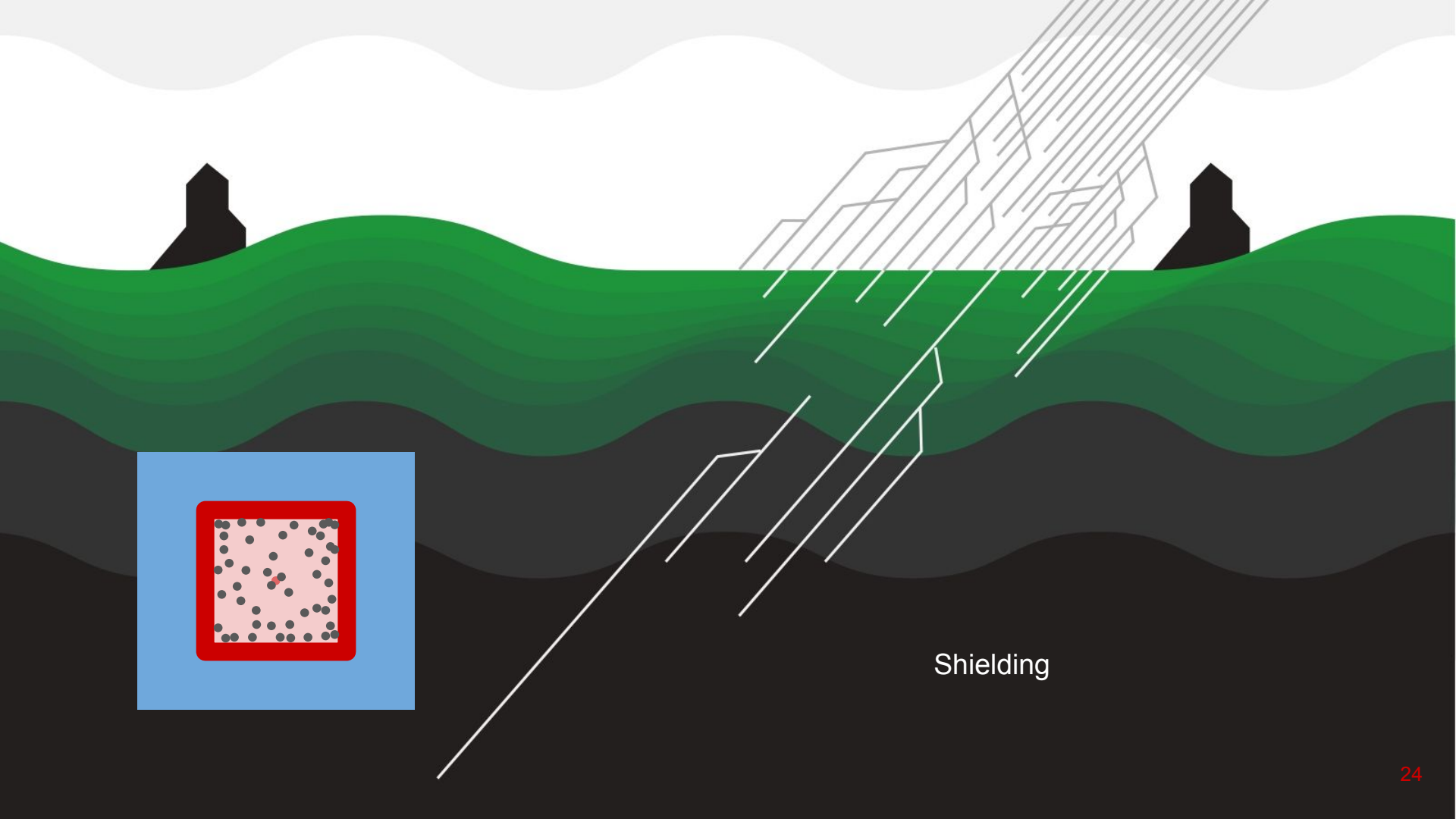

Absorbs $^{222}Rn$, $^{220}Rn$ and contains trace amounts of $^{85}Kr$

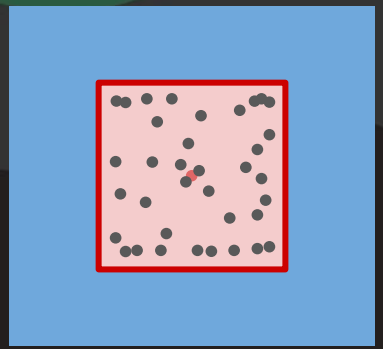


Target Medium


8 billion people
…
1 Wally

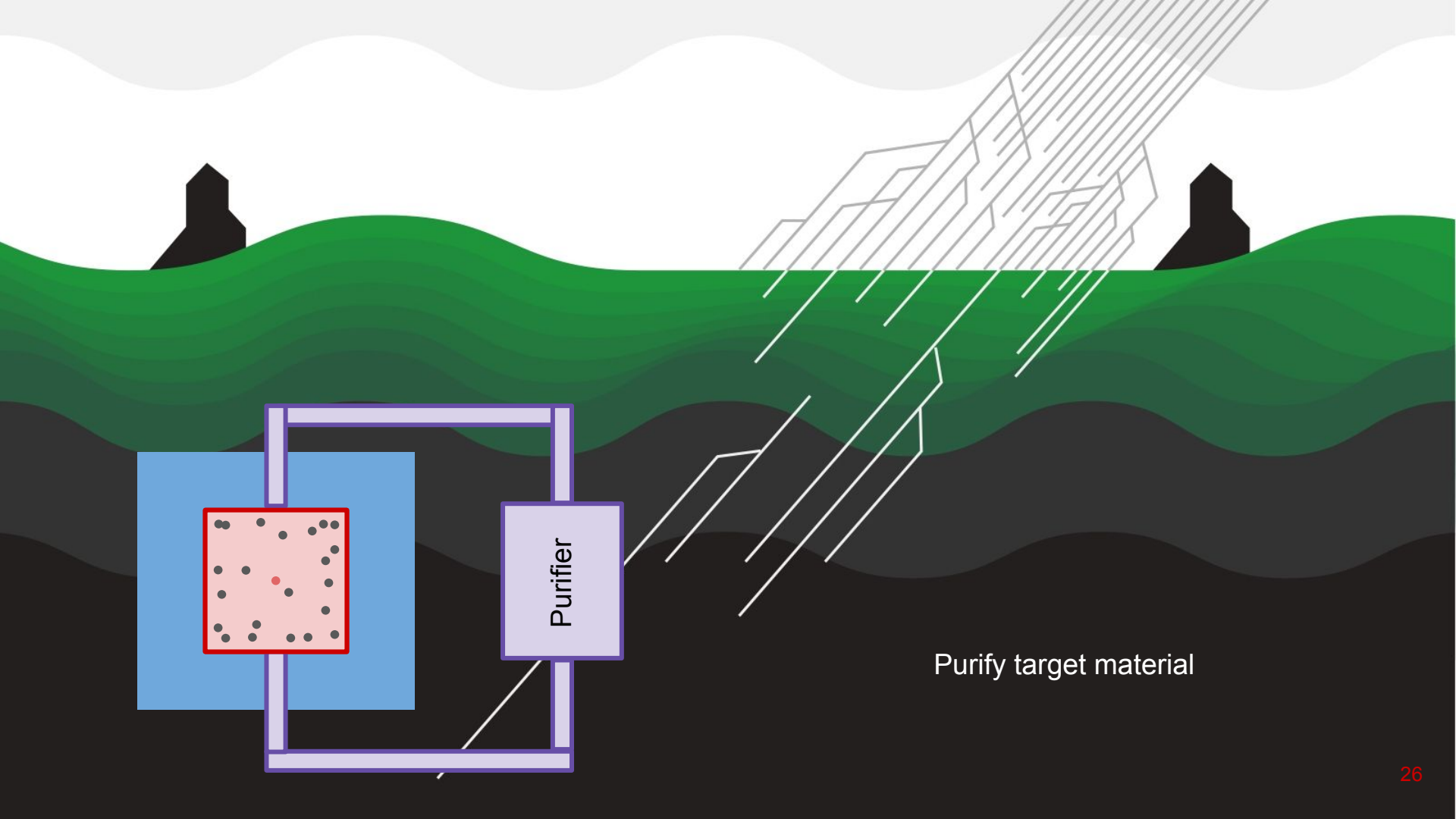

Underground


Shielding

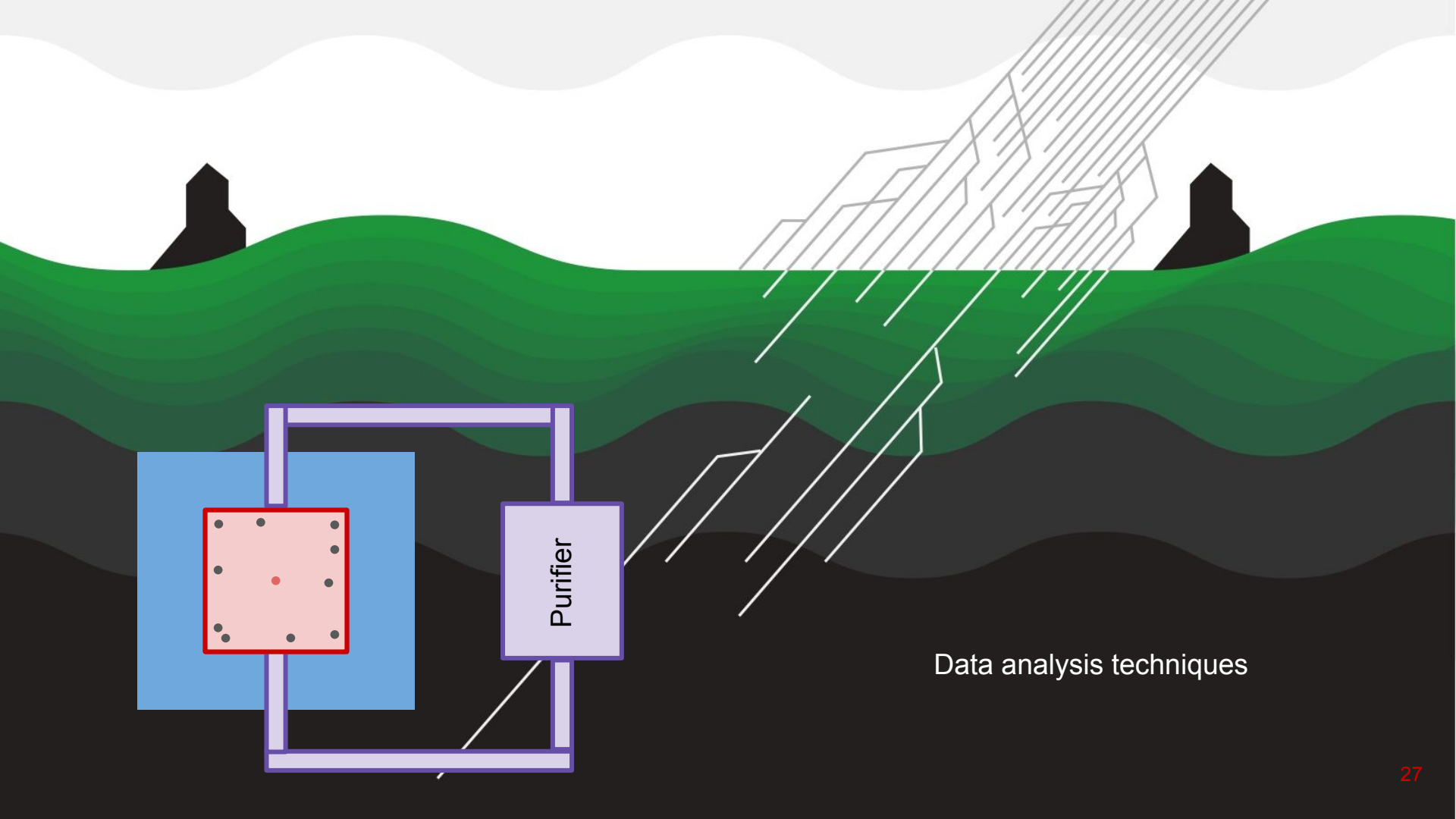


Reduce detector mass

Use radiopure materials



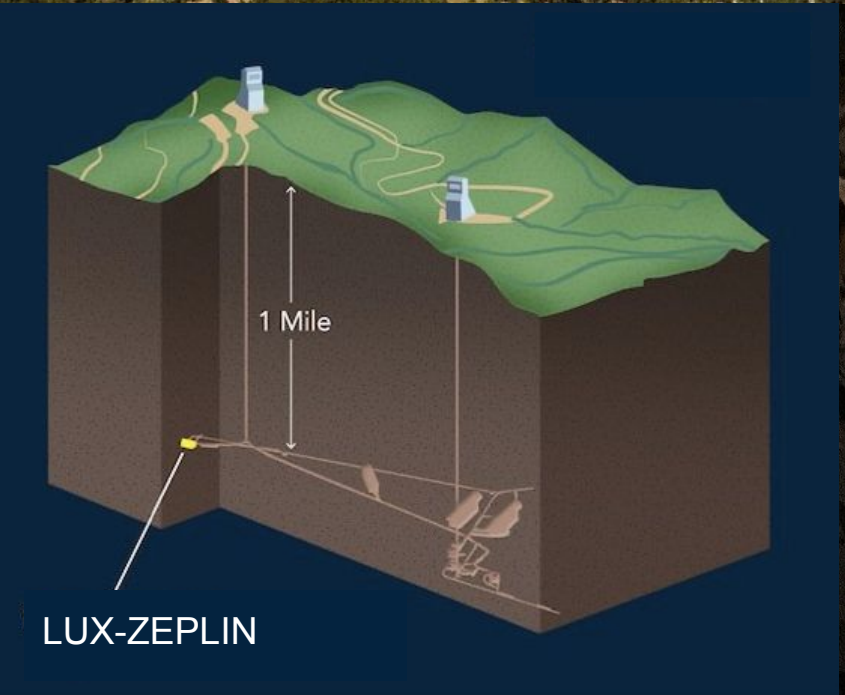

Purify target material




Data analysis techniques


Lead
Postgraduate school
Hometown
WA
OR
CA
ID
NV
MT
WY
UT
AZ
CO
NM
ND
SD
NE
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MS
MI
IN
KY
TN
AL
OH
WV
GA
FL
SC
NC
VA
PA
NY
MD
DE
NJ
CT
RI
MA
VT
NH
ME
AK
HI
United States
0 500 Miles
0 500 Km
0 100 Miles
0 100 Km
0 500 Miles
0 500 KM

# Sanford Underground Research Facility



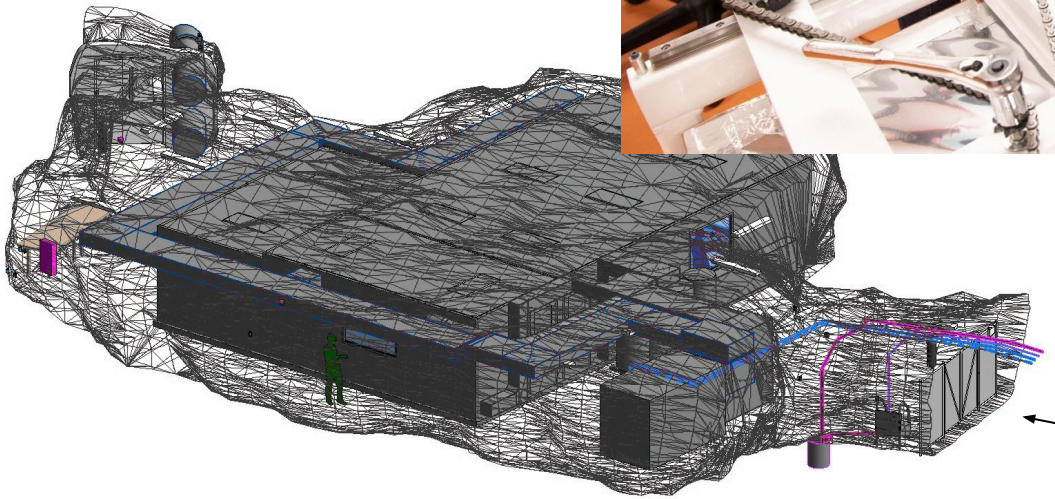

## Black Hills Underground Campus

Built in another cavern

Measure radioactivity in many materials

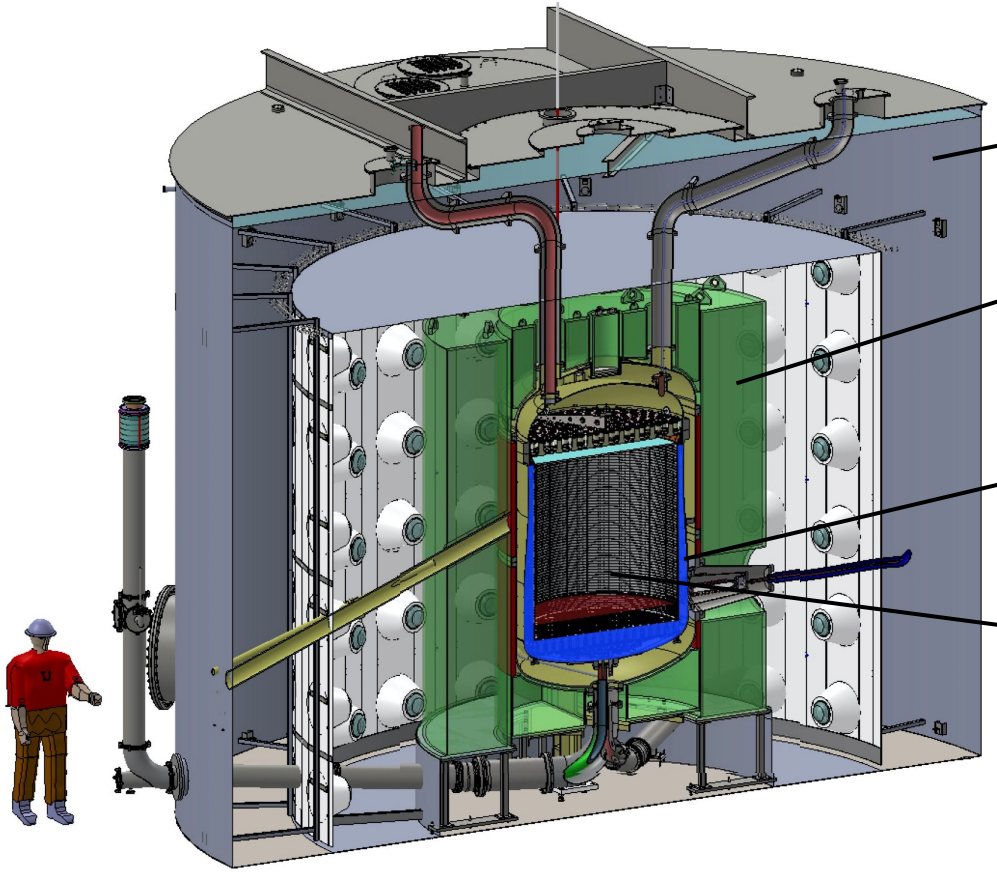
Choose the most radiopure to build the dark matter detector

Loading sample into high purity germanium detector



Cavern

# Layered shielding

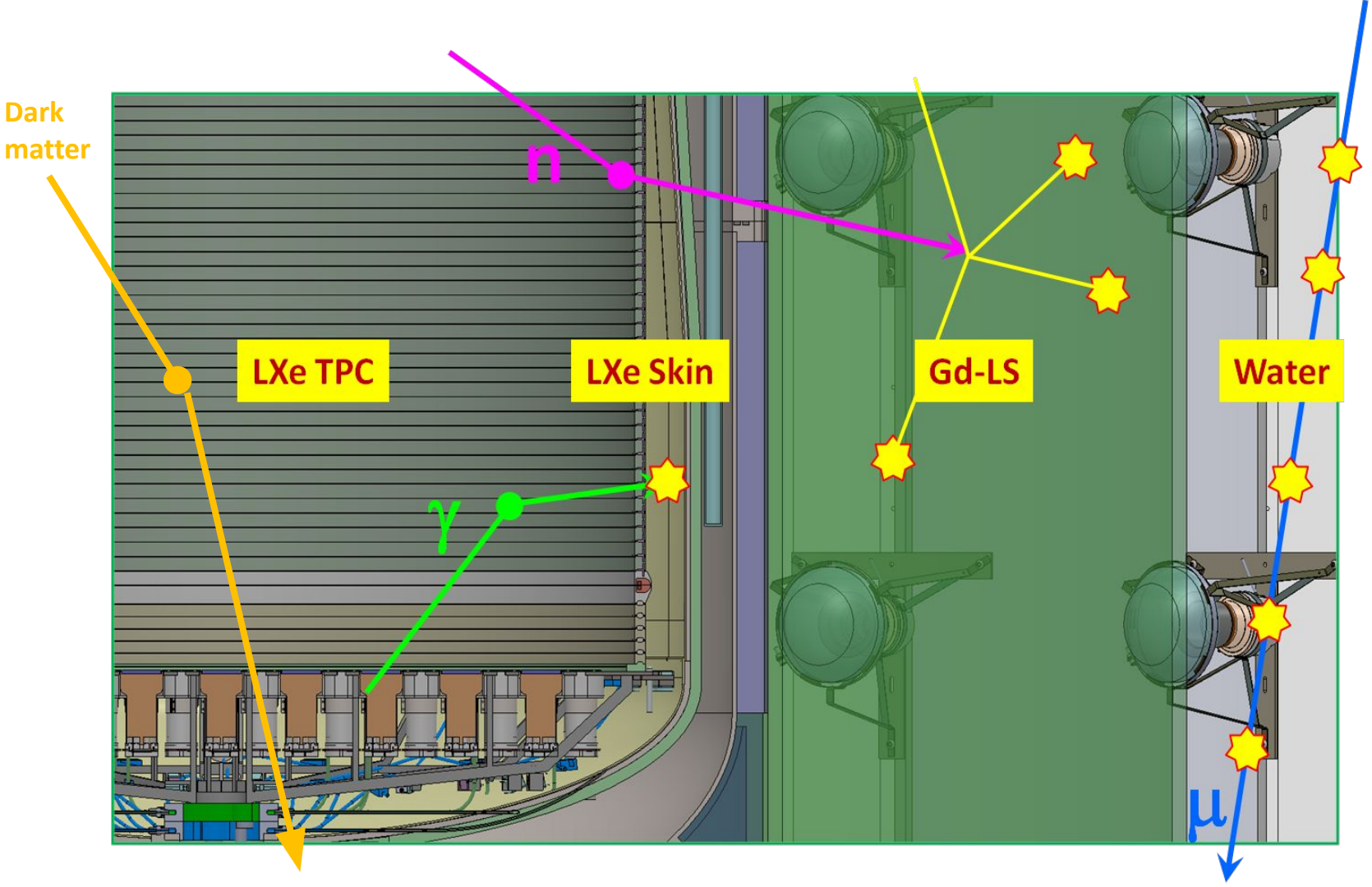


Tank
- High purity water

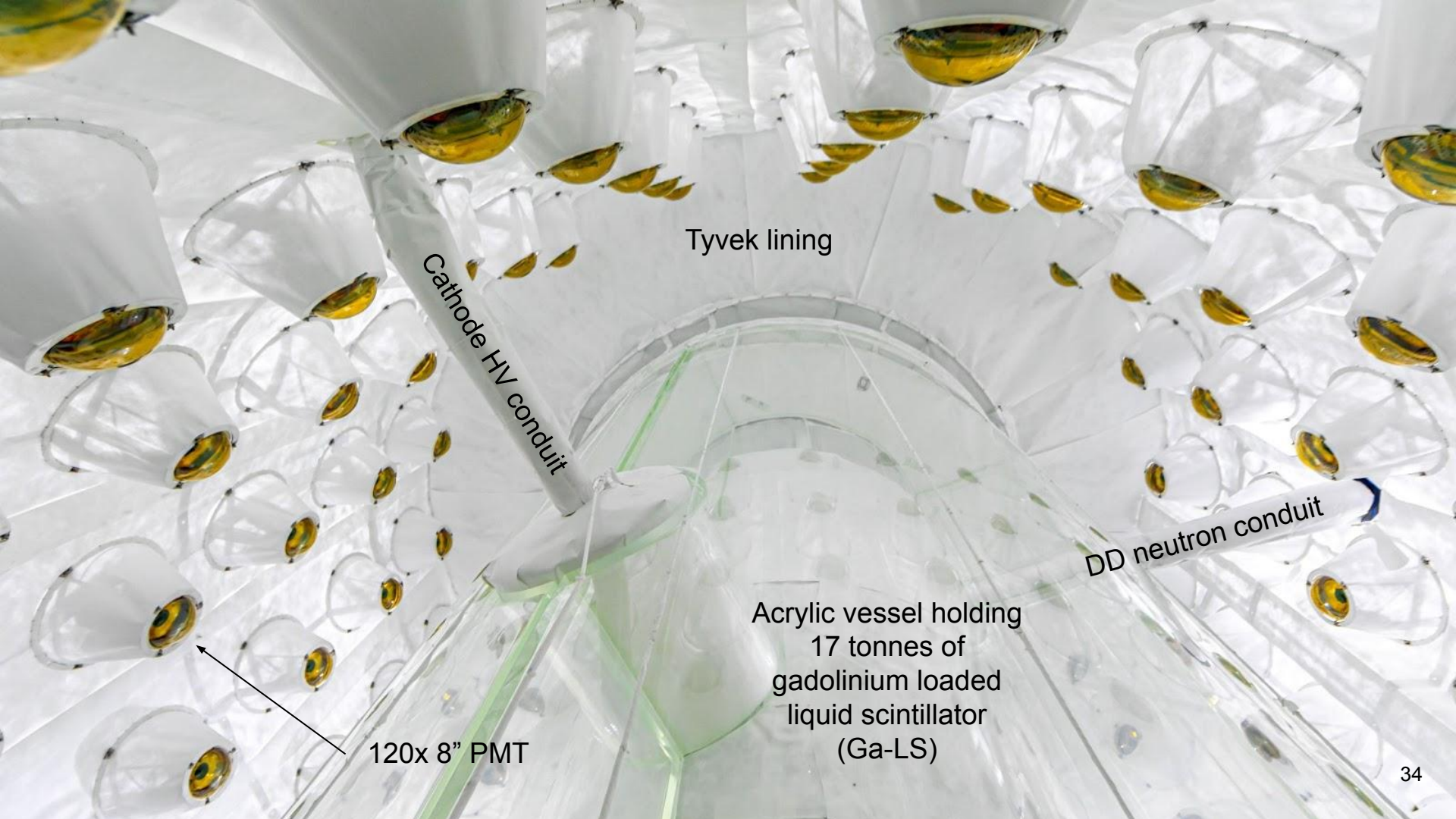
Outer detector
- 17 T gadolinium loaded liquid scintillator
- 120x 8” photomultiplier tubes

Skin
- 2 T liquid xenon
- 93x 1” and 38x 2” PMTs

Liquid-gas time projection chamber
- 7 T liquid xenon
- 494 3” PMTs


Dark matter
n
LXe TPC
LXe Skin
Gd-LS
Water
γ
μ

Construction

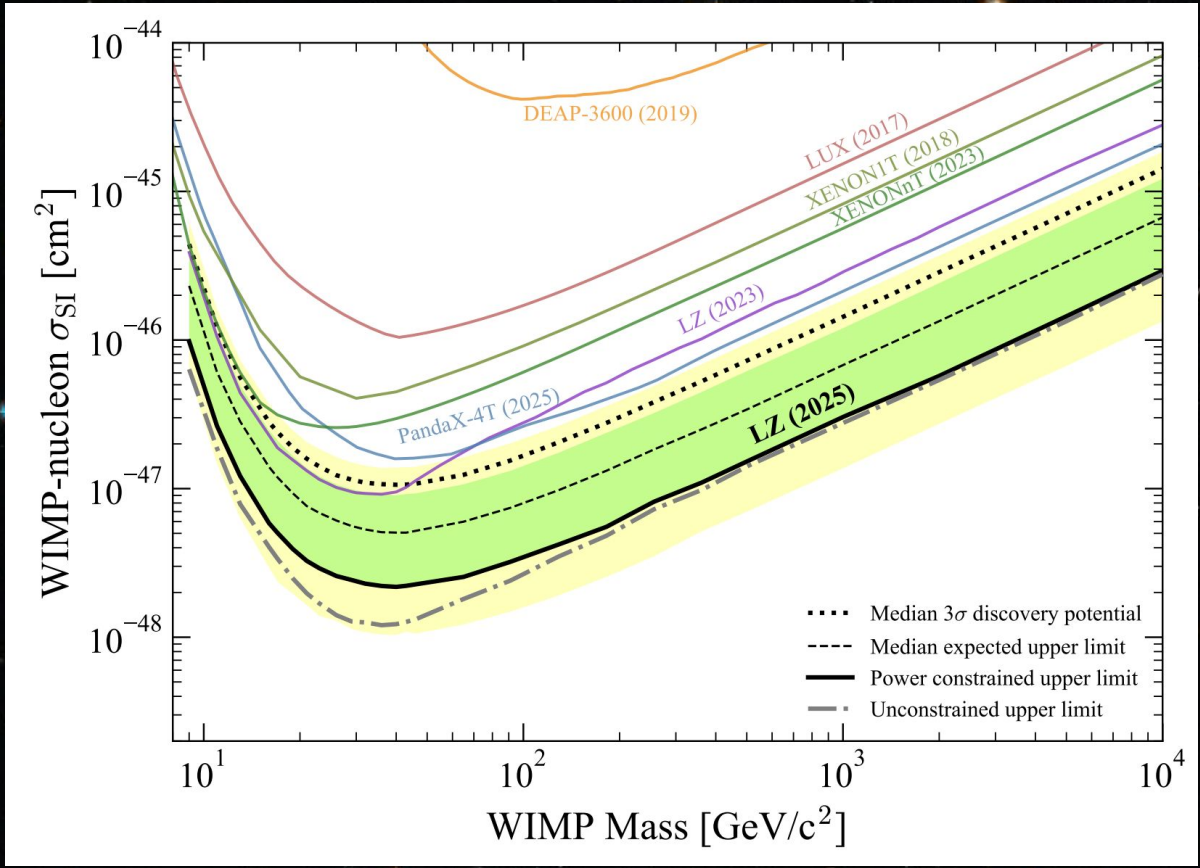

Tyvek lining
Cathode HV conduit
DD neutron conduit
Acrylic vessel holding
17 tonnes of
gadolinium loaded
liquid scintillator
(Ga-LS)
120x 8” PMT

# Results of LUX-ZEPLIN

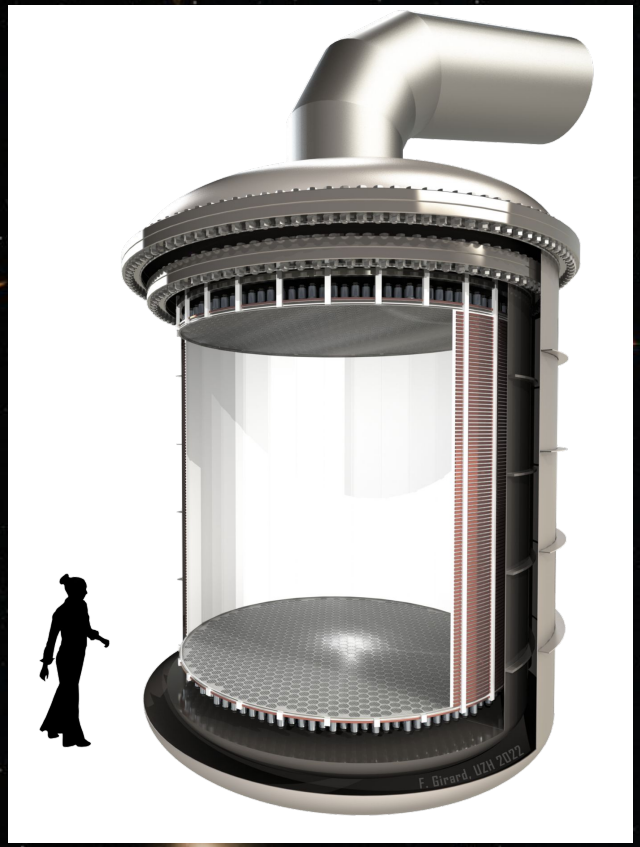
First and second results are world leading!

2 more years until final result

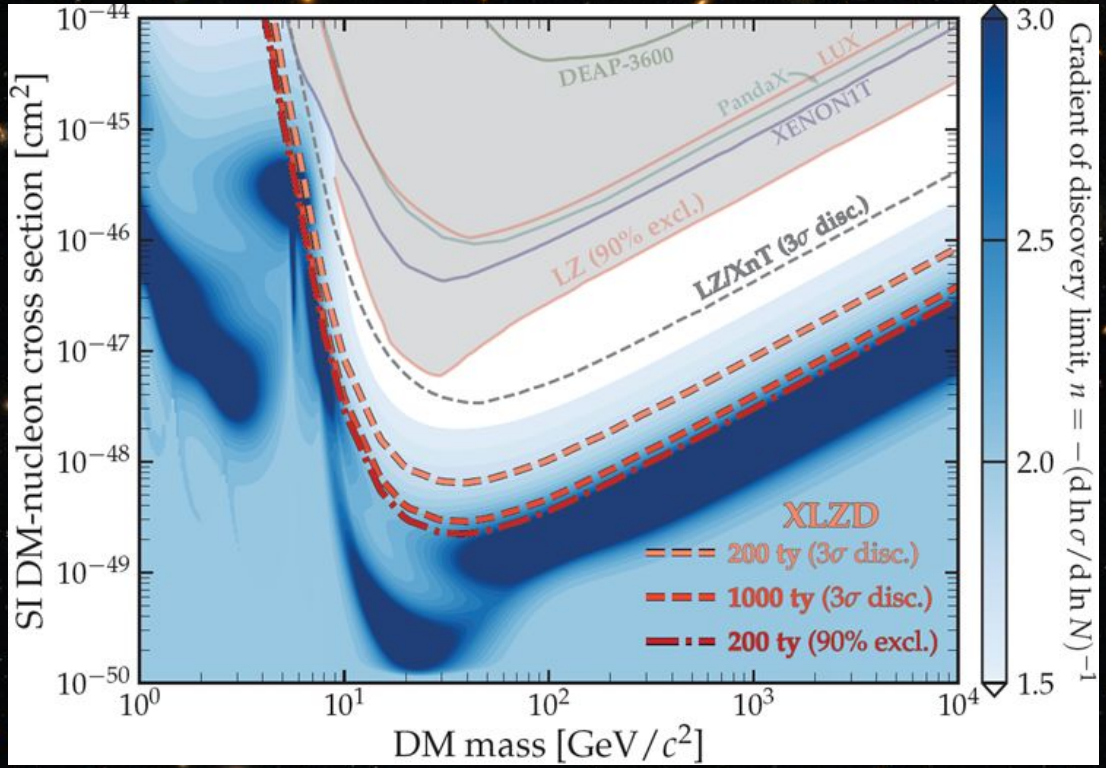
Phys. Rev. Lett. 135, 011802



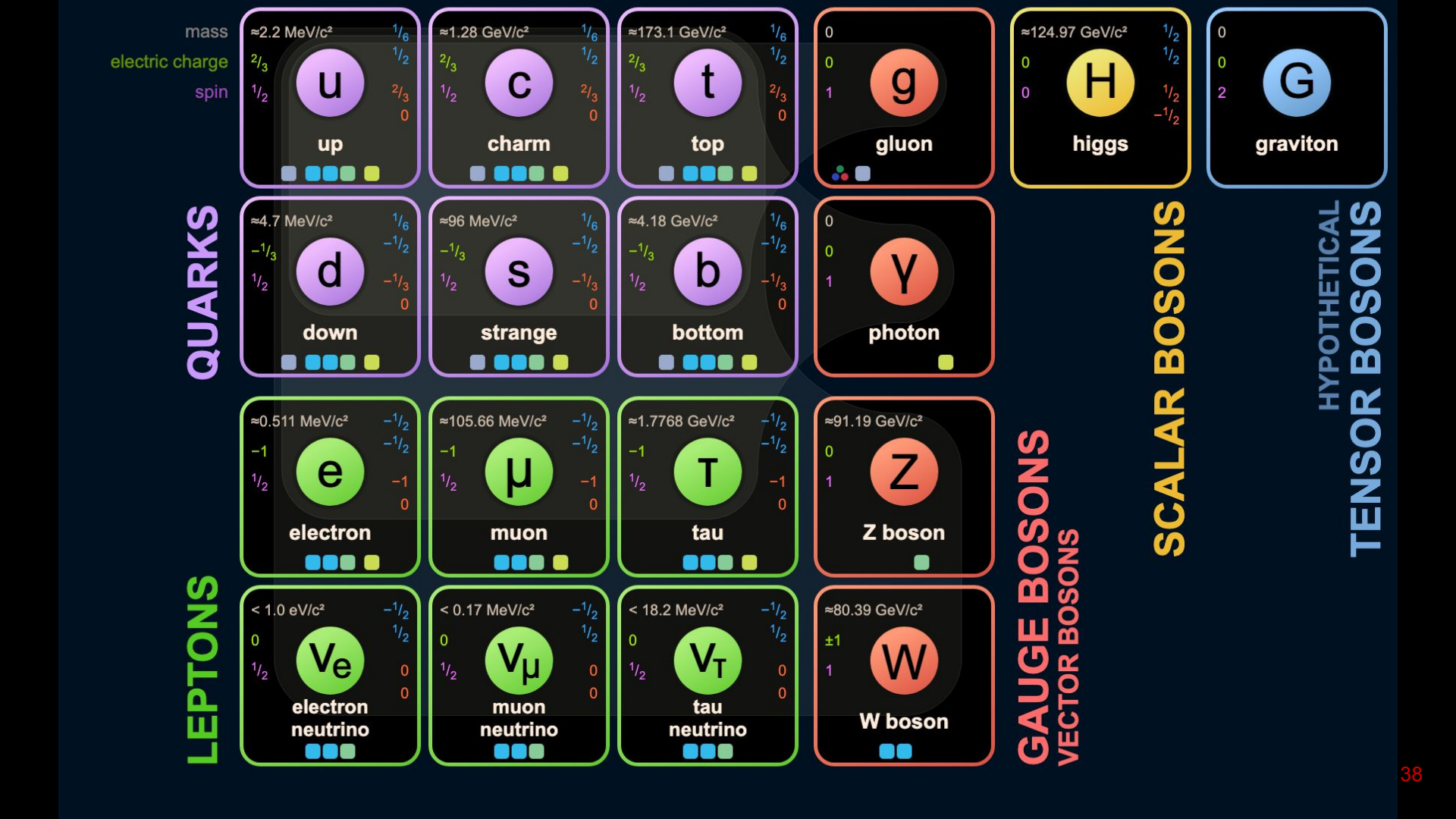
# The Future: XLZD




J. Phys. G: Nucl. Part. Phys. 50 013001 (2023)
Phys. Rev. Lett. 127, 251802



Thanks you!

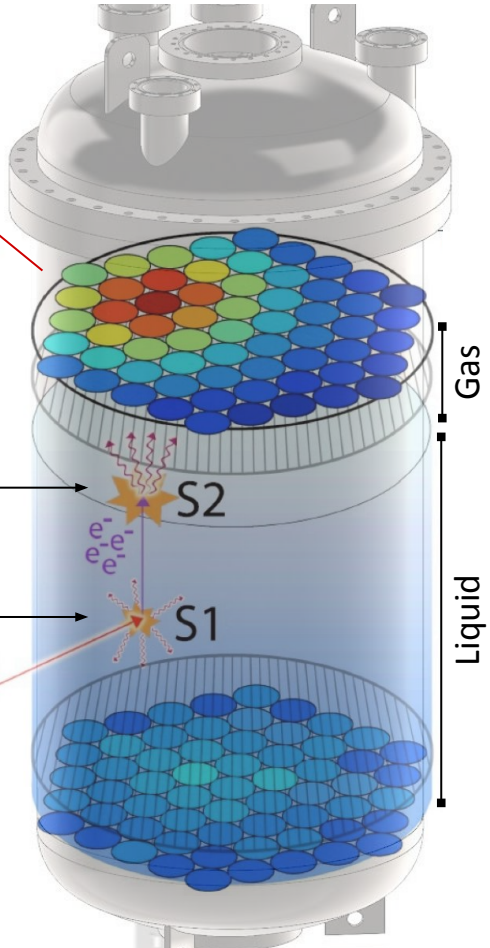

mass
electric charge
spin
QUARKS
LEPTONS
GAUGE BOSONS
VECTOR BOSONS
SCALAR BOSONS
HYPOTHETICAL
TENSOR BOSONS
≈2.2 MeV/c²
u
up
≈1.28 GeV/c²
c
charm
≈173.1 GeV/c²
t
top
g
gluon
≈124.97 GeV/c²
H
higgs
G
graviton
≈4.7 MeV/c²
d
down
≈96 MeV/c²
s
strange
≈4.18 GeV/c²
b
bottom
γ
photon
≈0.511 MeV/c²
e
electron
≈105.66 MeV/c²
μ
muon
≈1.7768 GeV/c²
τ
tau
≈91.19 GeV/c²
Z
Z boson
< 1.0 eV/c²
νe
electron neutrino
< 0.17 MeV/c²
νμ
muon neutrino
< 18.2 MeV/c²
ντ
tau neutrino
≈80.39 GeV/c²
W
W boson

X, Y coordinates are calculated from localized S2 light pattern in top PMTs

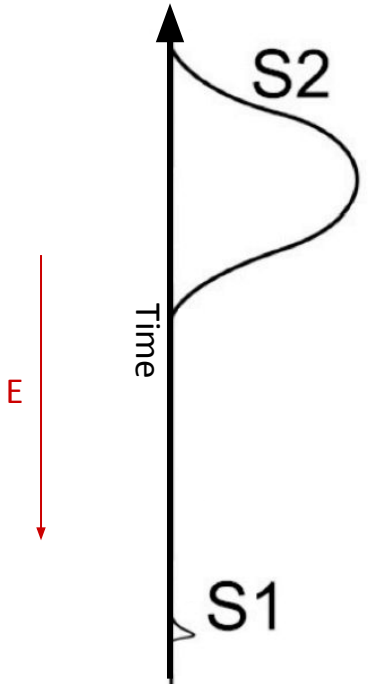
Delayed electroluminescence (S2)

Prompt scintillation (S1)

Particle

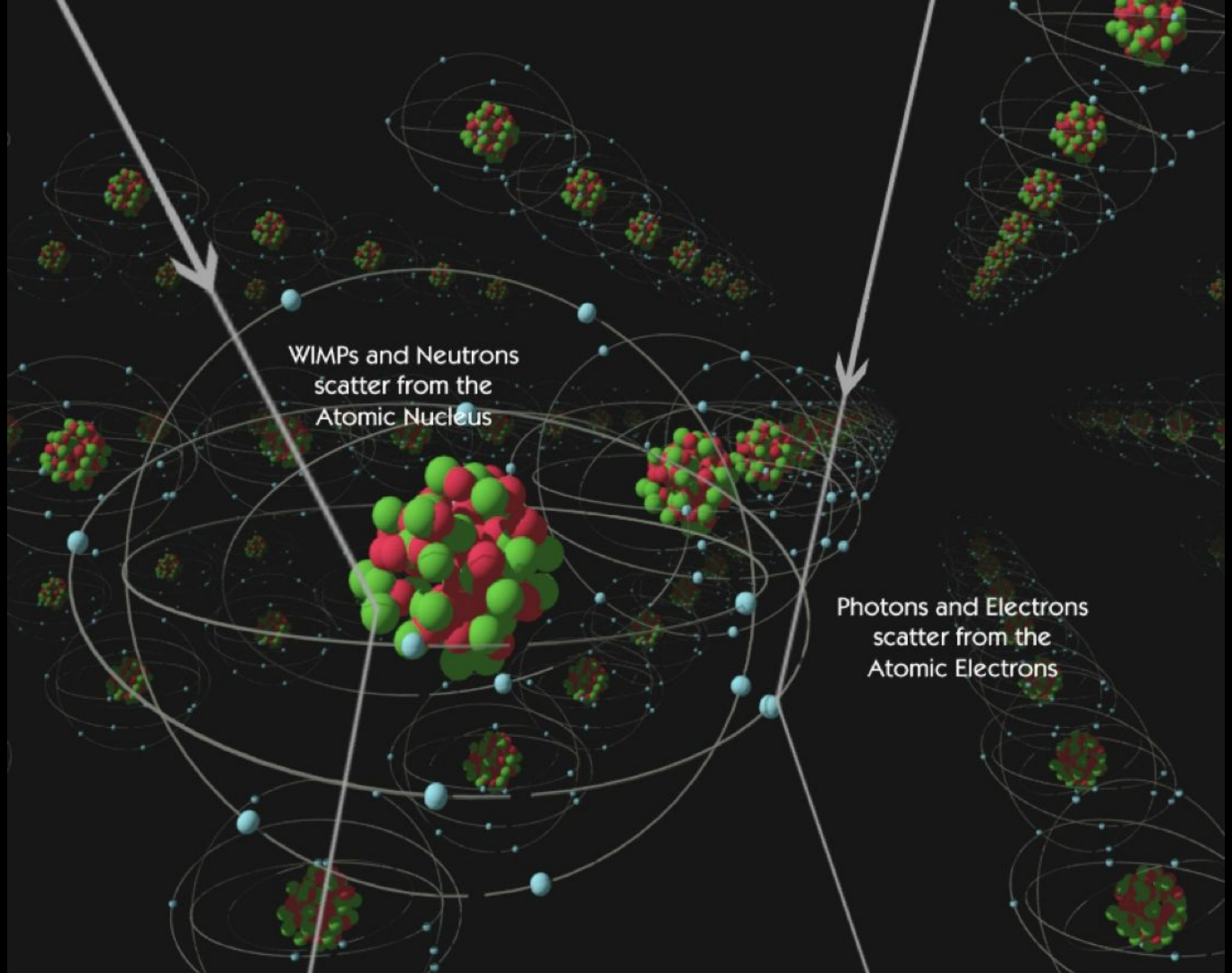


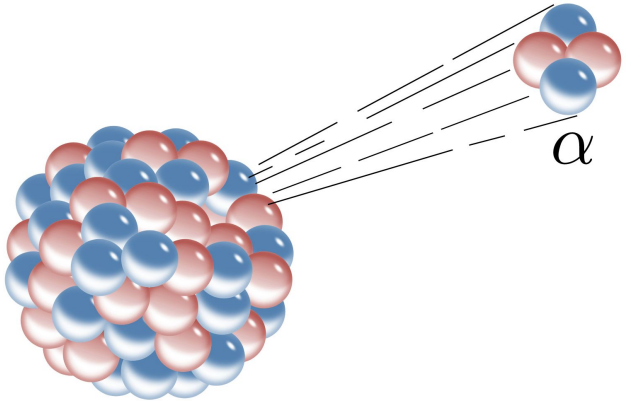

## Liquid/gas Xe time projection chamber (TPC)

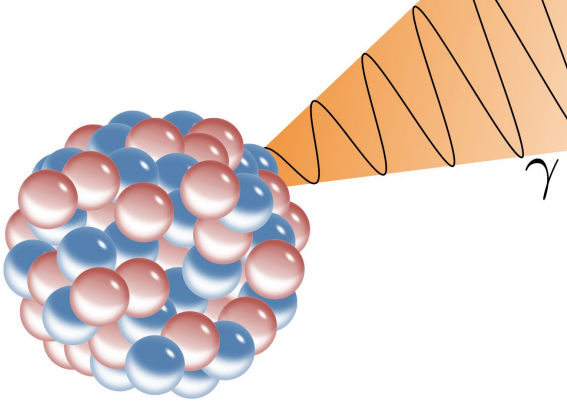


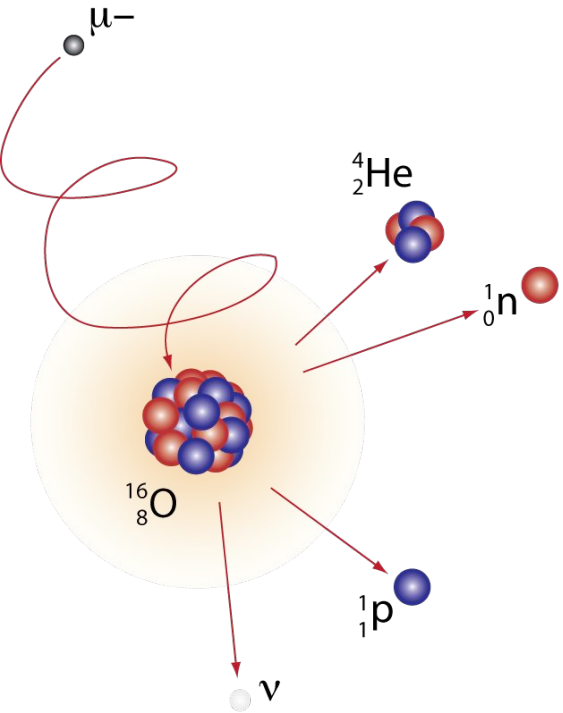

E

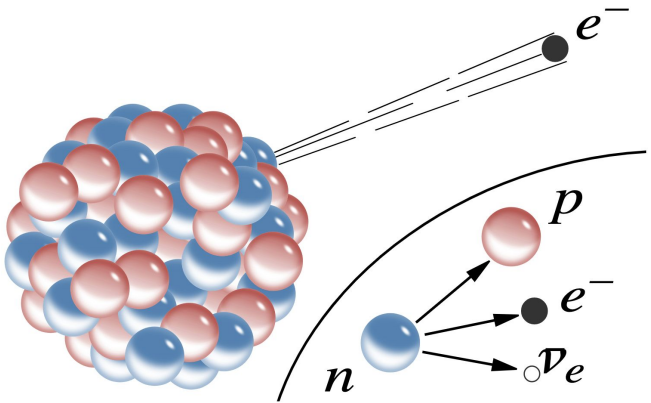
Z coordinate is calculated from Δt


WIMPs and Neutrons
scatter from the
Atomic Nucleus
Photons and Electrons
scatter from the
Atomic Electrons


α


γ


μ−
$^{4}_{2}$He
$^{1}_{0}$n
$^{16}_{8}$O
$^{1}_{1}$p
ν


e−
p
e−
n
ν̄e