

HOW TO PROBE THE  
NATURE OF THE UNIVERSE

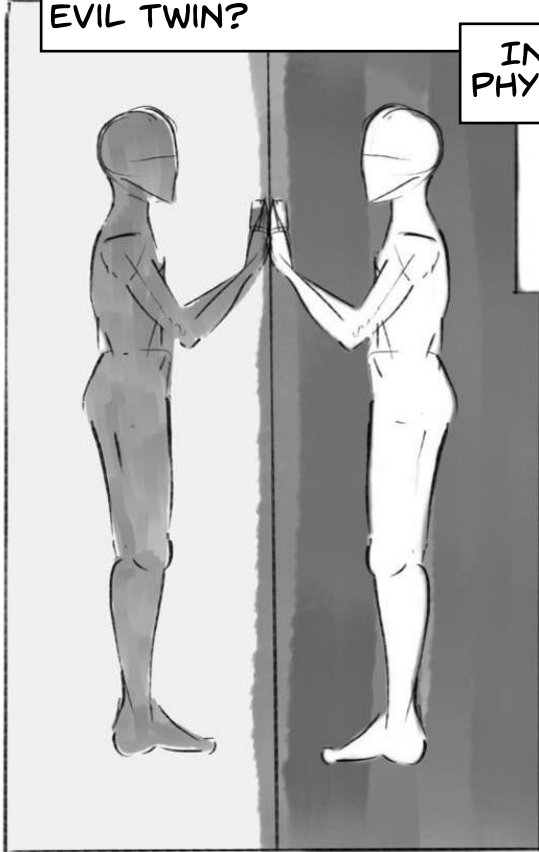


DANIKA WATSON

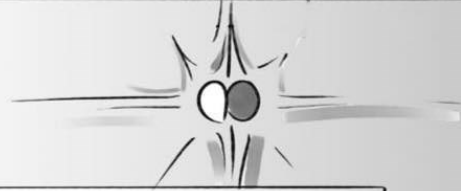
HAVE YOU EVER SEEN A MOVIE WHERE THE PROTAGONIST HAS AN EVIL TWIN?

IN THE WORLD OF PARTICLE PHYSICS, EVIL TWINS ARE REAL.

THEY'RE CALLED ANTIPARTICLES, AND EVERY PARTICLE HAS ONE: A TWIN OF EQUAL MASS BUT OPPOSITE CHARGE.



WHEN THEY COLLIDE,

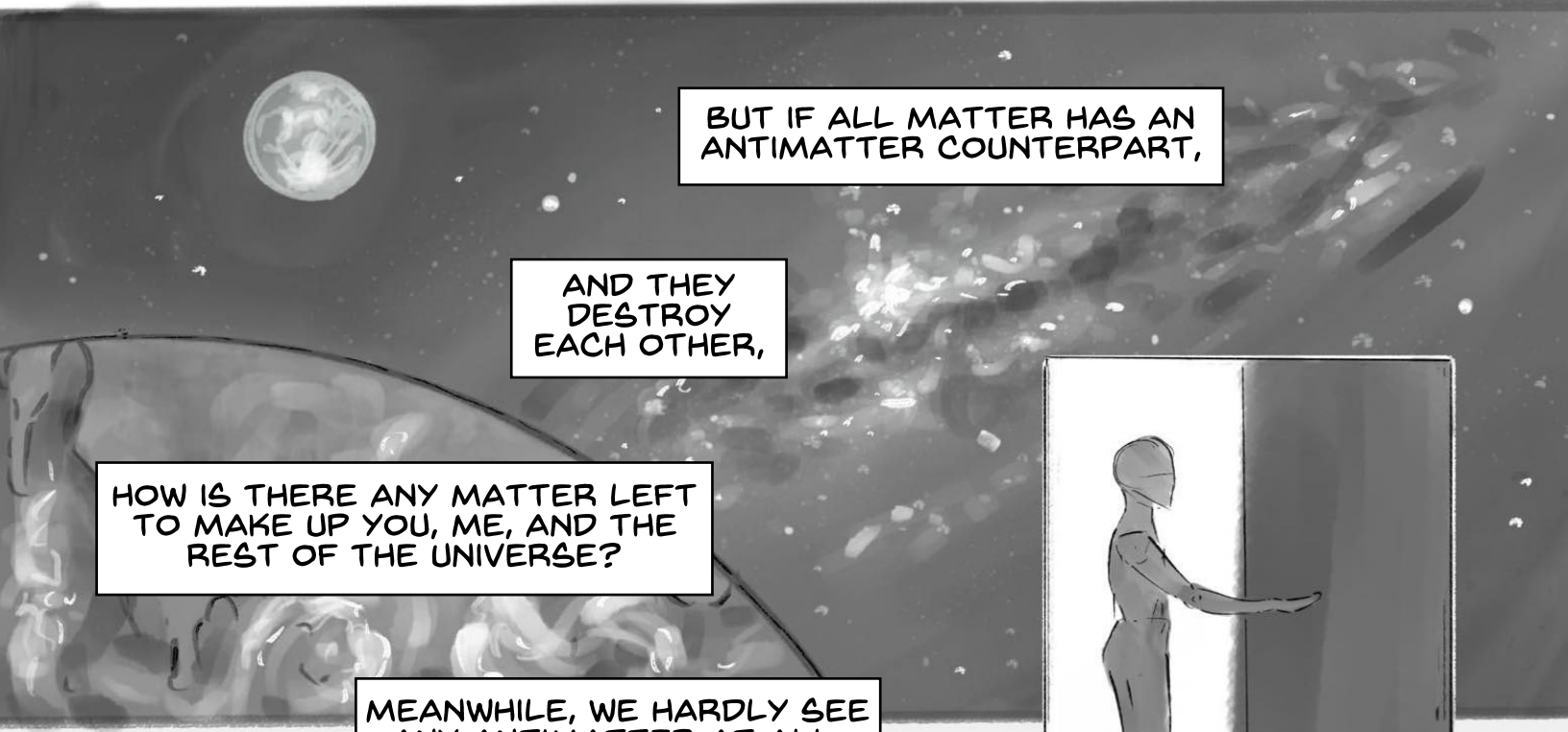


THEY DESTROY EACH OTHER,



ANNIHILATING INTO NOTHINGNESS,

LEAVING ONLY PURE ENERGY BEHIND.



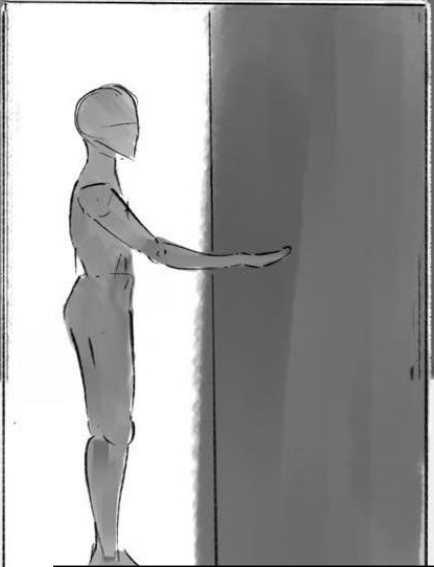
BUT IF ALL MATTER HAS AN ANTIMATTER COUNTERPART,

AND THEY DESTROY EACH OTHER,

HOW IS THERE ANY MATTER LEFT TO MAKE UP YOU, ME, AND THE REST OF THE UNIVERSE?

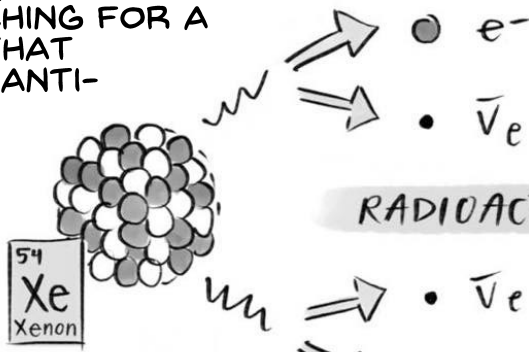
MEANWHILE, WE HARDLY SEE ANY ANTIMATTER AT ALL.

WHY DOES THIS IMBALANCE EXIST?



WHERE DID MOST OF THE ANTIMATTER GO?

TO ANSWER THESE QUESTIONS, SCIENTISTS ARE SEARCHING FOR A PROCESS THAT DESTROYS ANTI-MATTER.



ONE CANDIDATE IS DOUBLE BETA DECAY,

A PROCESS WHICH PRODUCES TWO ELECTRONS AND TWO ANTINEUTRINOS.

SCIENTISTS WONDER:

WHAT IF NEUTRINOS AND ANTINEUTRINOS

WERE ONE AND THE SAME?

IN OTHER WORDS, WHAT IF NEUTRINOS WERE THEIR OWN ANTI PARTICLES?

THEN, THOSE TWO ANTINEUTRINOS COULD ANNIHILATE EACH OTHER,

MEANING THE PROCESS WOULD SELECTIVELY DESTROY ANTIMATTER.

IF THIS "NEUTRINOLESS" DOUBLE BETA DECAY PROCESS IS REAL, IT COULD POINT US TO WHERE THE MISSING ANTIMATTER WENT.

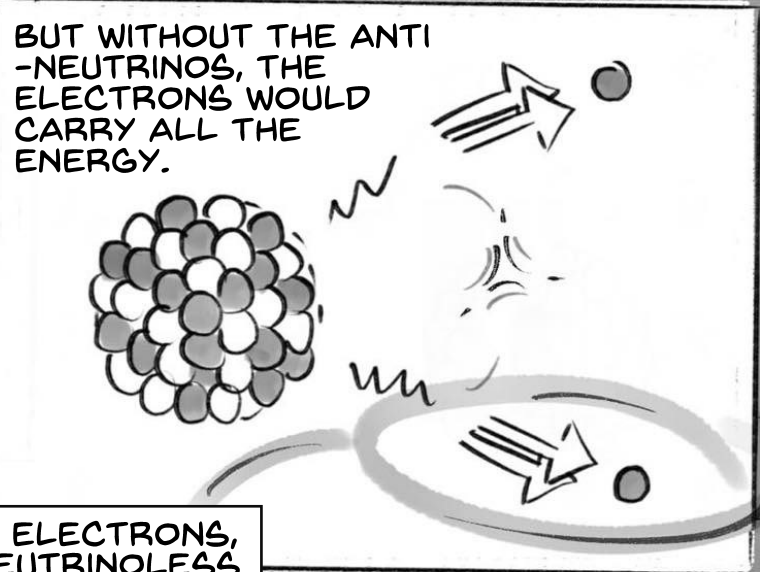
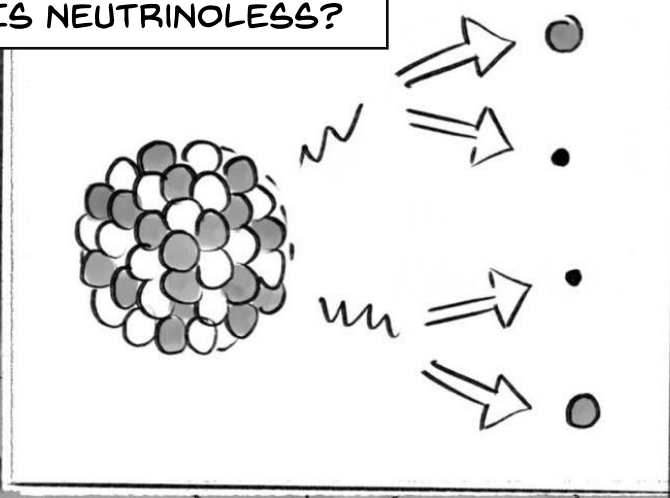
NOT ONLY THAT, IT WOULD ALSO BREAK THE STANDARD MODEL OF PARTICLE PHYSICS,

FUNDAMENTALLY ALTERING OUR UNDERSTANDING OF THE UNIVERSE.

~~TOTAL LEPTON NUMBER CONSERVATION~~

HOW DO WE MEASURE WHETHER A DOUBLE BETA DECAY PROCESS IS NEUTRINOLESS?

IN REGULAR DOUBLE BETA DECAY, BOTH THE ELECTRONS AND ANTINEUTRINOS CARRY AWAY ENERGY.



BUT WITHOUT THE ANTI-NEUTRINOS, THE ELECTRONS WOULD CARRY ALL THE ENERGY.

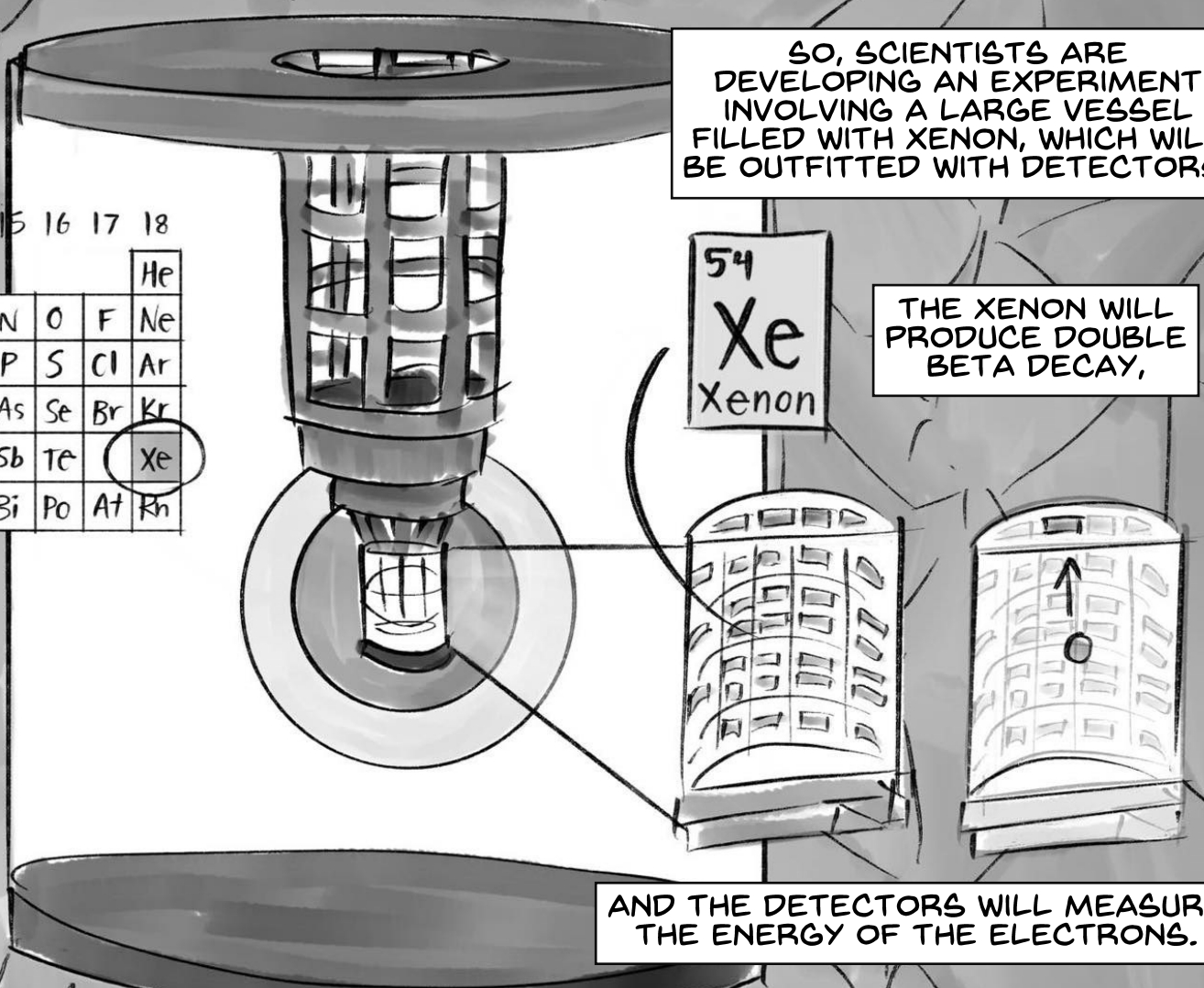
BY MEASURING THE ENERGY OF THE ELECTRONS, WE CAN SEE IF THE PROCESS WAS NEUTRINOLESS.

SO, SCIENTISTS ARE DEVELOPING AN EXPERIMENT INVOLVING A LARGE VESSEL FILLED WITH XENON, WHICH WILL BE OUTFITTED WITH DETECTORS.

13	14	15	16	17	18
					He
B	C	N	O	F	Ne
Al	Si	P	S	Cl	Ar
Ga	Ge	As	Se	Br	Kr
In	Sn	Sb	Te	<b>Xe</b>	Rn
Tl	Pb	Bi	Po	At	Rh

<sup>54</sup>Xe  
Xenon

THE XENON WILL PRODUCE DOUBLE BETA DECAY,



AND THE DETECTORS WILL MEASURE THE ENERGY OF THE ELECTRONS.

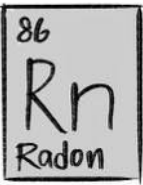
HOWEVER, DOUBLE BETA DECAY IS RARE--ONLY A FEW DECAYS WILL HAPPEN IN AN ENTIRE DECADE!

THE EXPERIMENT MUST BE CAREFULLY CRAFTED. THESE RARE EVENTS ARE EASY TO MISS...



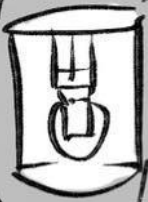
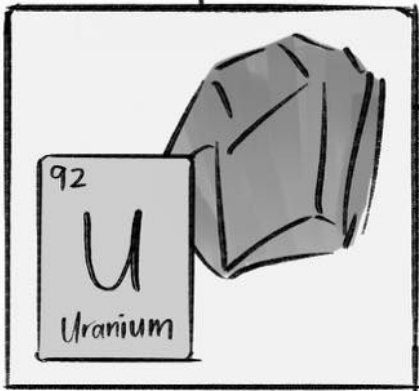
FOR ONE, RADIATION CAN COME FROM BACKGROUND SOURCES,

CREATING FALSE SIGNALS.



THE XENON VESSEL WILL BE BURIED UNDERGROUND

AND SHIELDED UNDER MANY LAYERS,

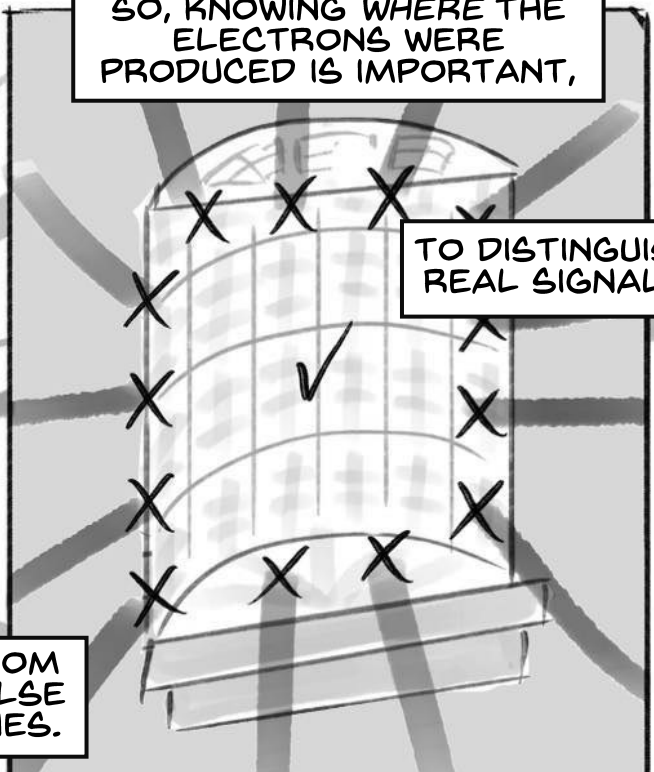
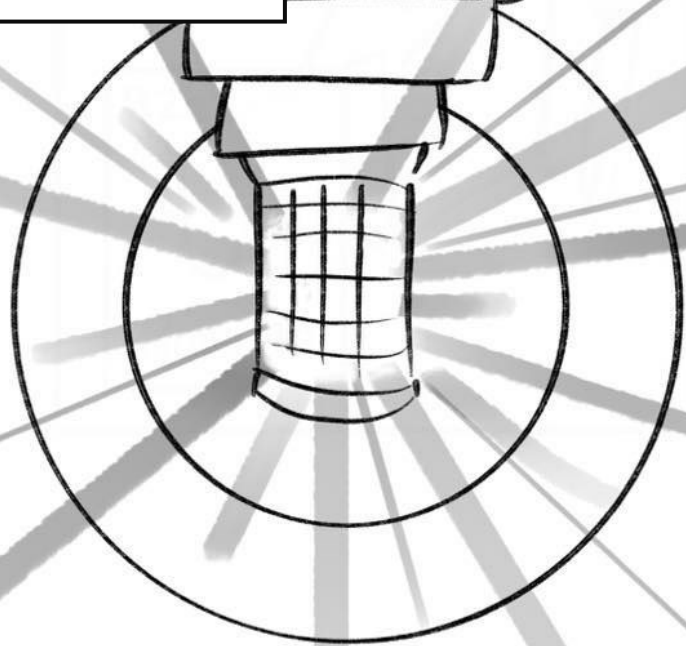


BUT FALSE SIGNALS MAY STILL MAKE IT IN,

MOSTLY NEAR THE EDGES OF THE VESSEL.

SO, KNOWING WHERE THE ELECTRONS WERE PRODUCED IS IMPORTANT,

TO DISTINGUISH REAL SIGNALS



FROM FALSE ONES.

HOW CAN WE PINPOINT THE ELECTRONS' COORDINATES?

AN ELECTRIC FIELD WILL PULL THE ELECTRONS TOWARDS DETECTORS AT THE TOP OF THE VESSEL.

SO, THE POINT WHERE THE ELECTRONS LAND WILL GIVE TWO OF THEIR ORIGINAL COORDINATES.

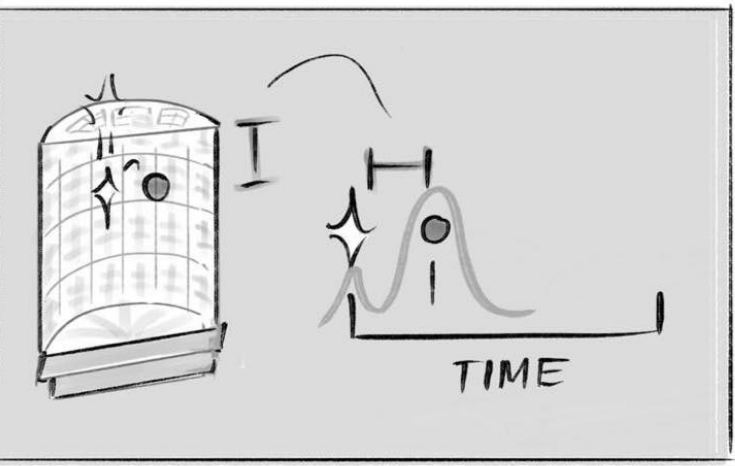
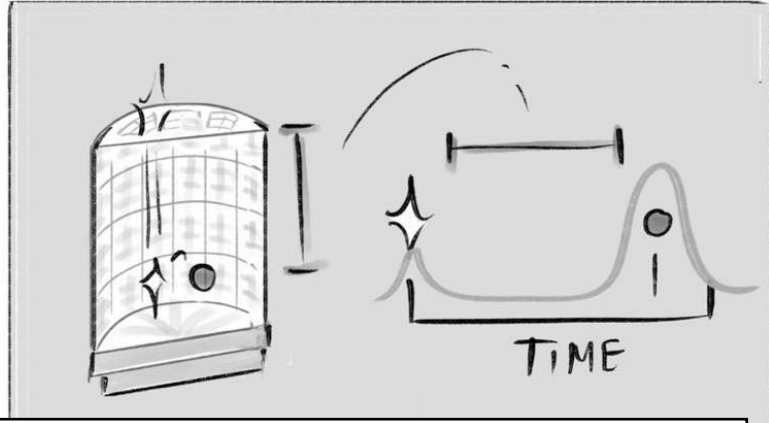
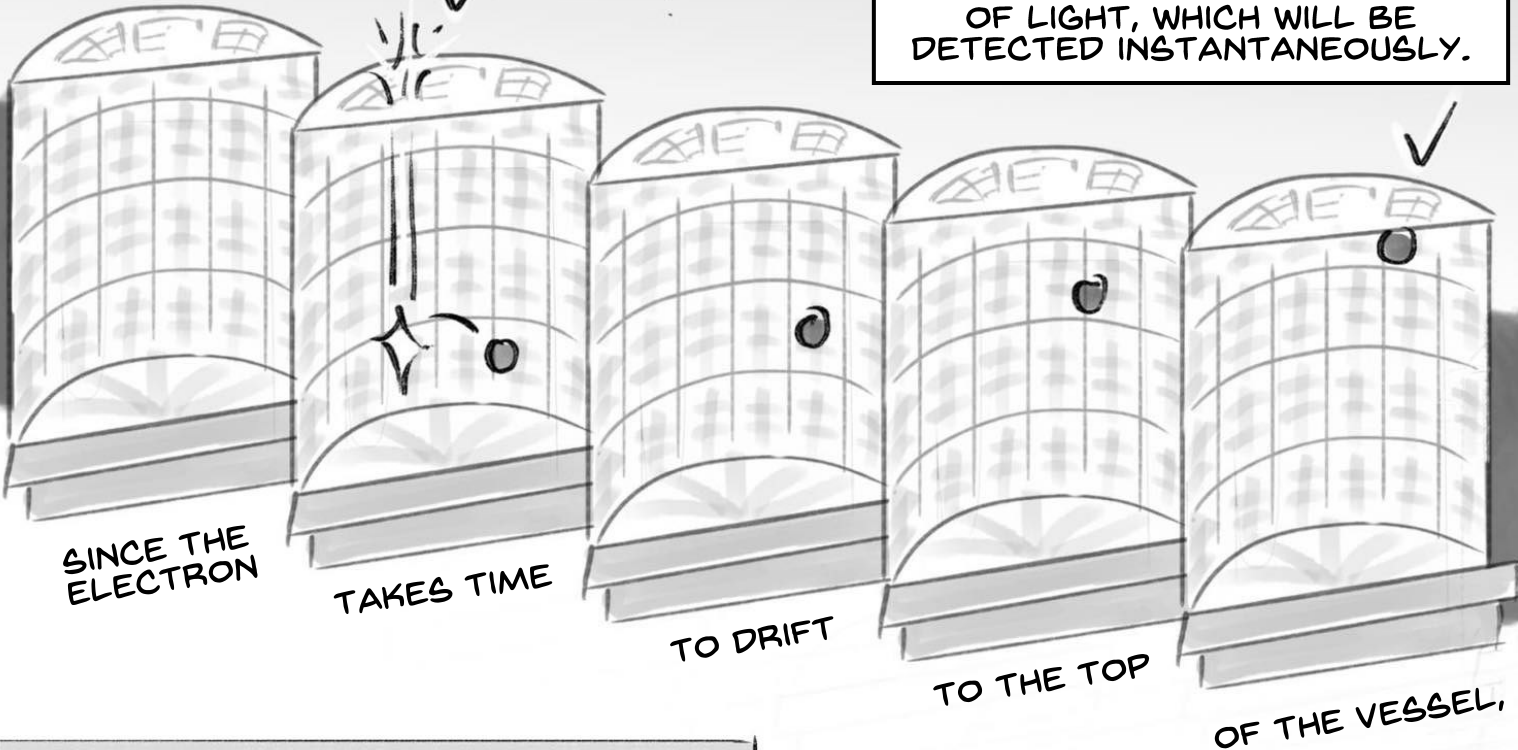
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WHAT ABOUT THE THIRD COORDINATE?

LUCKILY, DOUBLE BETA DECAY IN XENON ALSO PRODUCES A FLASH OF LIGHT, WHICH WILL BE DETECTED INSTANTANEOUSLY.



THE DIFFERENCE IN TIMING BETWEEN THE DETECTION OF THE ELECTRONS AND THE FLASH OF LIGHT TRANSLATES INTO THE THIRD COORDINATE.

HOWEVER, THAT FLASH OF LIGHT WILL BE EXTREMELY DIM--IT MIGHT JUST BE A SINGLE PHOTON.

SO, THE DIM LIGHT OF THAT SOLITARY PHOTON WILL HAVE TO BE AMPLIFIED INTO AN ELECTRICAL SIGNAL LARGE ENOUGH TO DETECT.

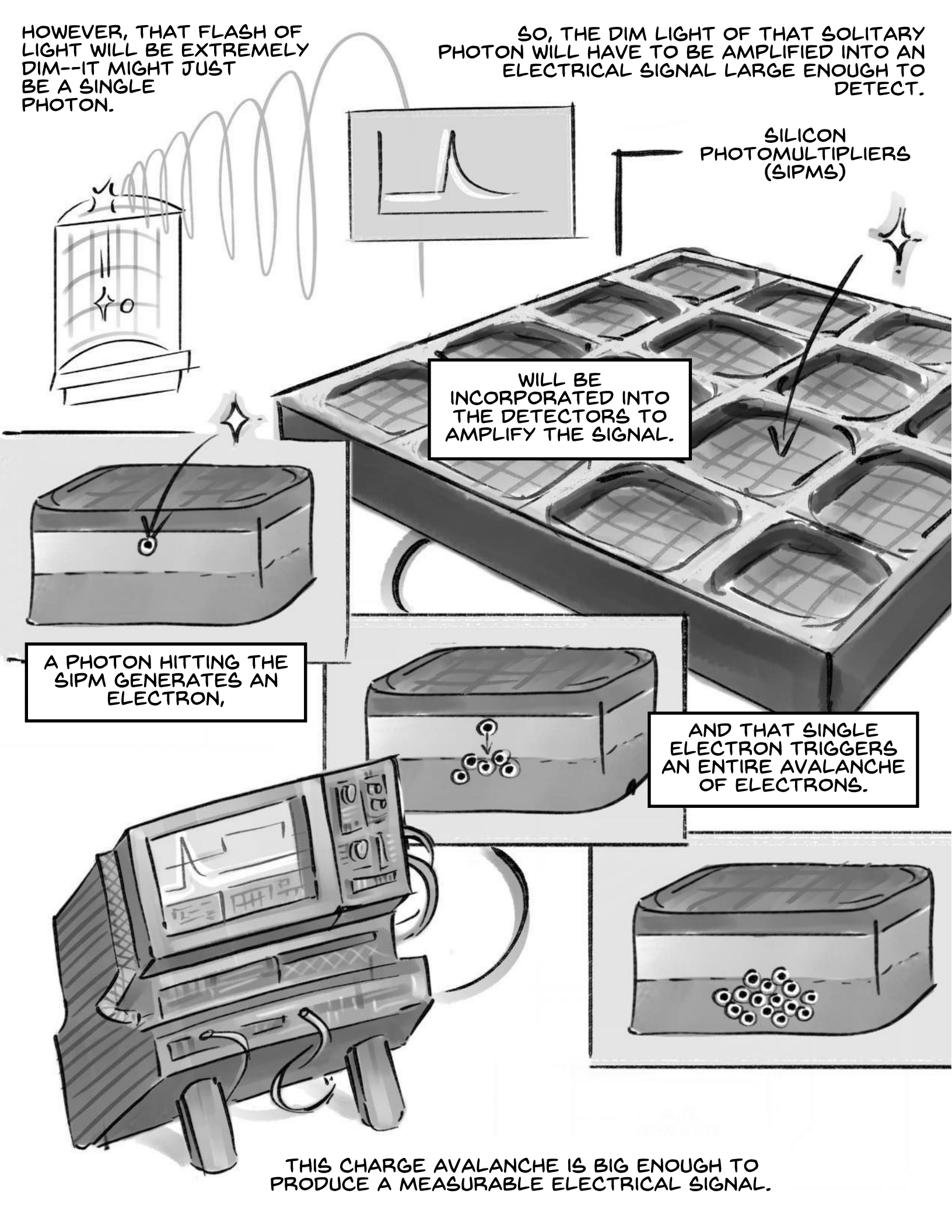
SILICON PHOTOMULTIPLIERS (SIPMS)

WILL BE INCORPORATED INTO THE DETECTORS TO AMPLIFY THE SIGNAL.

A PHOTON HITTING THE SIPM GENERATES AN ELECTRON,

AND THAT SINGLE ELECTRON TRIGGERS AN ENTIRE AVALANCHE OF ELECTRONS.

THIS CHARGE AVALANCHE IS BIG ENOUGH TO PRODUCE A MEASURABLE ELECTRICAL SIGNAL.



LIKE ANY DETECTOR, THE SIPMS ARE SUBJECT TO BACKGROUND NOISE.

THEY CAN EVEN GENERATE FALSE SIGNALS WITHIN THEMSELVES;

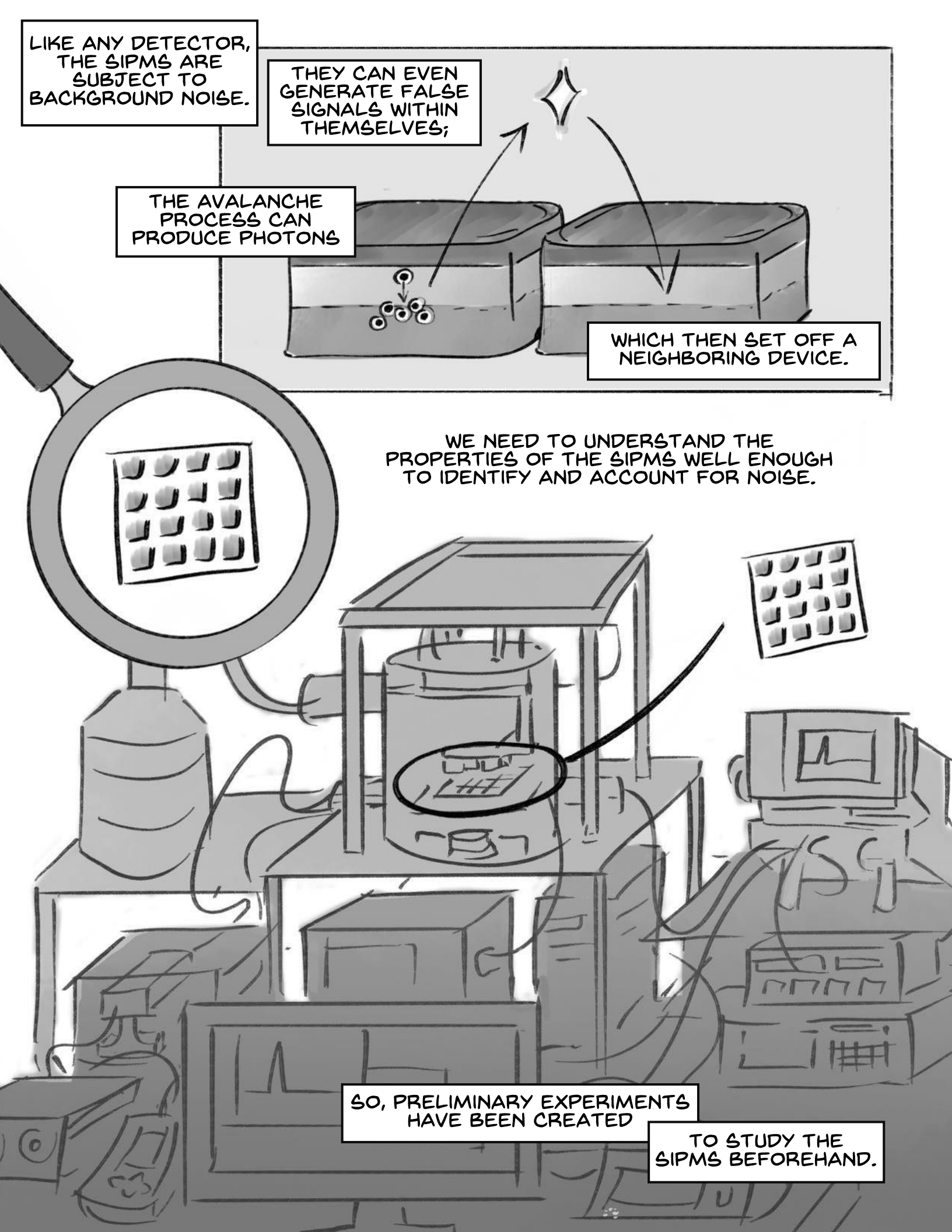
THE AVALANCHE PROCESS CAN PRODUCE PHOTONS

WHICH THEN SET OFF A NEIGHBORING DEVICE.

WE NEED TO UNDERSTAND THE PROPERTIES OF THE SIPMS WELL ENOUGH TO IDENTIFY AND ACCOUNT FOR NOISE.

SO, PRELIMINARY EXPERIMENTS HAVE BEEN CREATED

TO STUDY THE SIPMS BEFOREHAND.





THIS IS WHERE MY OWN RESEARCH COMES IN. IN THIS EXPERIMENT,

A LASER

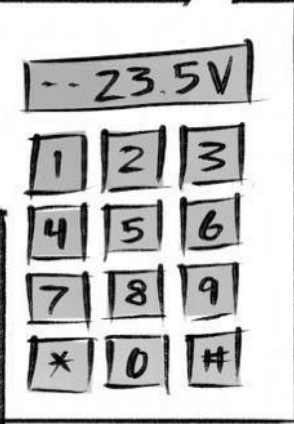
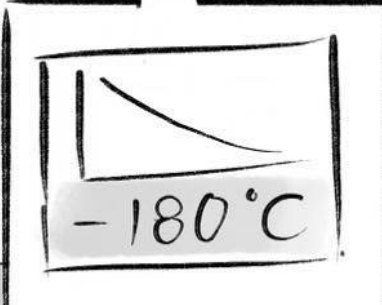
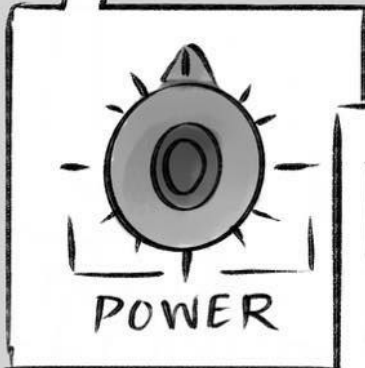
AND PRODUCING A SIGNAL

AT A  
SIPM,

TRIGGERING  
AVALANCHES

FIRES PHOTONS

THAT IS READ  
OUT BY AN  
OSCILLOSCOPE.

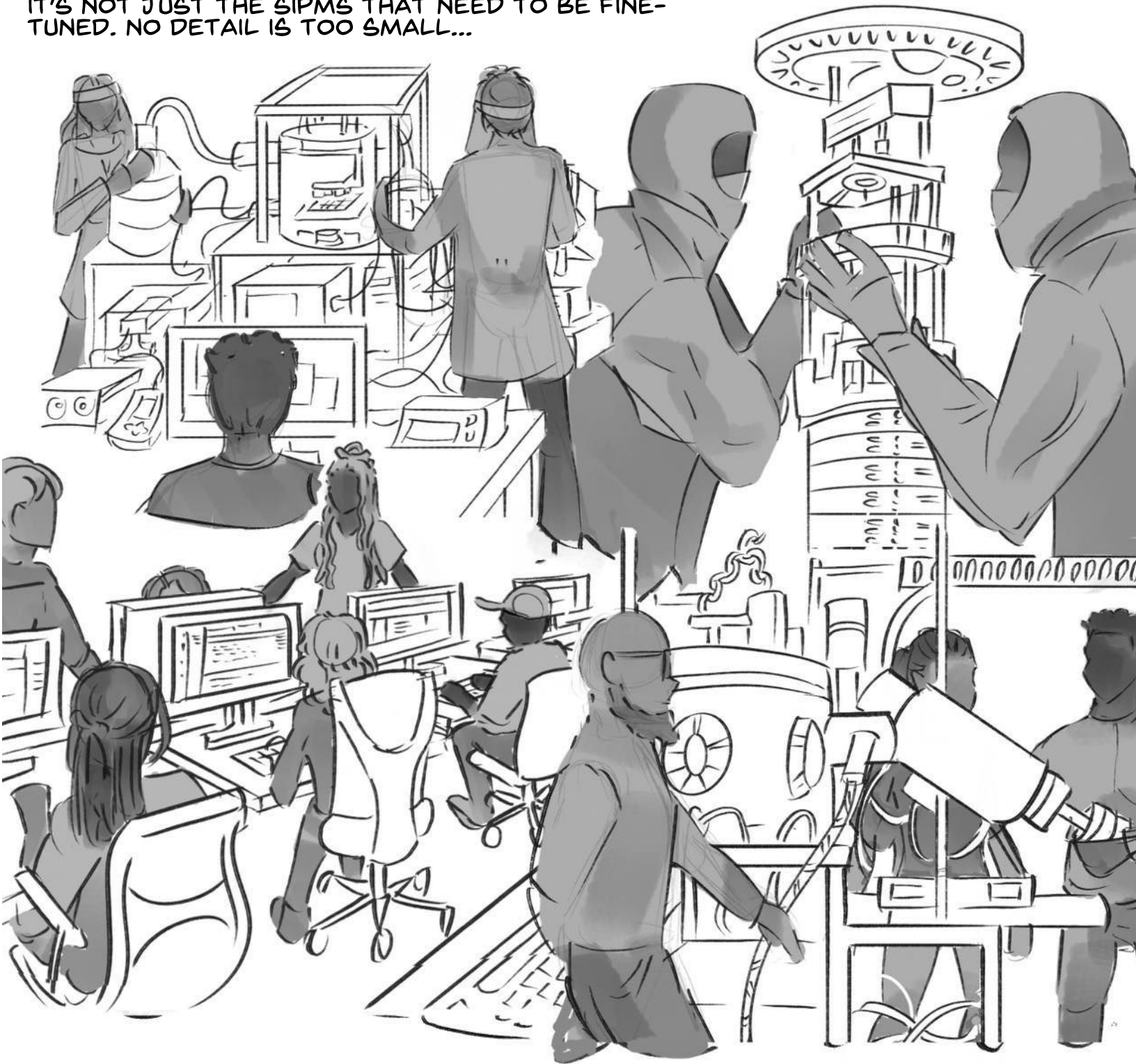


BASED ON MEASUREMENTS LIKE THESE, SCIENTISTS ARE BUILDING COMPUTER MODELS OF THE SIPMS TO SIMULATE DETECTION EVENTS, SO THEY KNOW WHAT TO EXPECT.

BY ALTERING SETTINGS AND MEASURING HOW THE SIGNAL RESPONDS, I CAN IMPROVE MY UNDERSTANDING OF NOISE IN THE SIPM.

ALL THIS RESEARCH WILL BE USED TO FINE-TUNE THE SETTINGS OF THE SIPMS FOR THE FINAL EXPERIMENT.

IT'S NOT JUST THE SIPMS THAT NEED TO BE FINE-TUNED. NO DETAIL IS TOO SMALL...



... WHEN YOU'RE SEARCHING FOR A PROCESS THAT HAS NEVER BEEN OBSERVED BEFORE. IF YOU MISS IT, YOU MAY NOT GET ANOTHER CHANCE.

EVENTUALLY, THROUGH THE COLLECTIVE EFFORTS OF HUNDREDS OF PEOPLE AROUND THE WORLD, THE FINAL EXPERIMENT WILL COME TOGETHER.

WHAT WILL IT TELL US ABOUT THE NATURE OF THE UNIVERSE?

## ACKNOWLEDGEMENTS

THANK YOU TO KURTIS RAYMOND, DUNCAN MCCARTHY AND DR. FABRICE RETIERE FOR MAKING THIS PROJECT POSSIBLE.

INSPIRATION TO 'THINK IN COMICS' WAS DRAWN FROM THE LECTURES AND WORK OF NICK SOUSANIS.

THIS RESEARCH WAS UNDERTAKEN THANKS IN PART TO FUNDING FROM THE CANADA FIRST RESEARCH EXCELLENCE FUND THROUGH THE ARTHUR B. MCDONALD CANADIAN ASTROPARTICLE PHYSICS RESEARCH INSTITUTE.

## REFERENCES

- 1) NEXO. [HTTPS://NEXO.LLNL.GOV/](https://nexo.llnl.gov/)
- 2) BREWSTER, S. (2016). IS THE NEUTRINO ITS OWN ANTIPARTICLE?. SYMMETRY.
- 3) WAGENPFEIL, M., ET AL. (2021). REFLECTIVITY OF VUV-SENSITIVE SILICON PHOTOMULTIPLIERS IN LIQUID XENON. JOURNAL OF INSTRUMENTATION, 16 (08), P08002.
- 4) SLAC (2016). PROTOTYPE OF LUX-ZEPLIN DARK MATTER DETECTOR TESTED AT SLAC. SLAC

## ABOUT ME

I AM A MASTER'S STUDENT IN PHYSICAL GEOGRAPHY WITH A BACHELOR'S IN CHEMISTRY. I LOVE ART AND SCIENCE COMMUNICATION, SO I ENJOY FINDING WAYS TO COMBINE THEM... LIKE THIS COMIC!

I PUT TOGETHER THIS COMIC AFTER A CROSS-DISCIPLINARY INTERNSHIP (THROUGH THE ARTHUR B. MCDONALD CANADIAN ASTROPARTICLE PHYSICS RESEARCH INSTITUTE) AT TRIUMF IN VANCOUVER, BC.

BROADLY, THE RESEARCH I WORKED ON DURING THE INTERNSHIP WAS AIMED TOWARDS THE DEVELOPMENT OF NEXO, THE EXPERIMENT THAT WAS DISCUSSED IN THE COMIC.

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