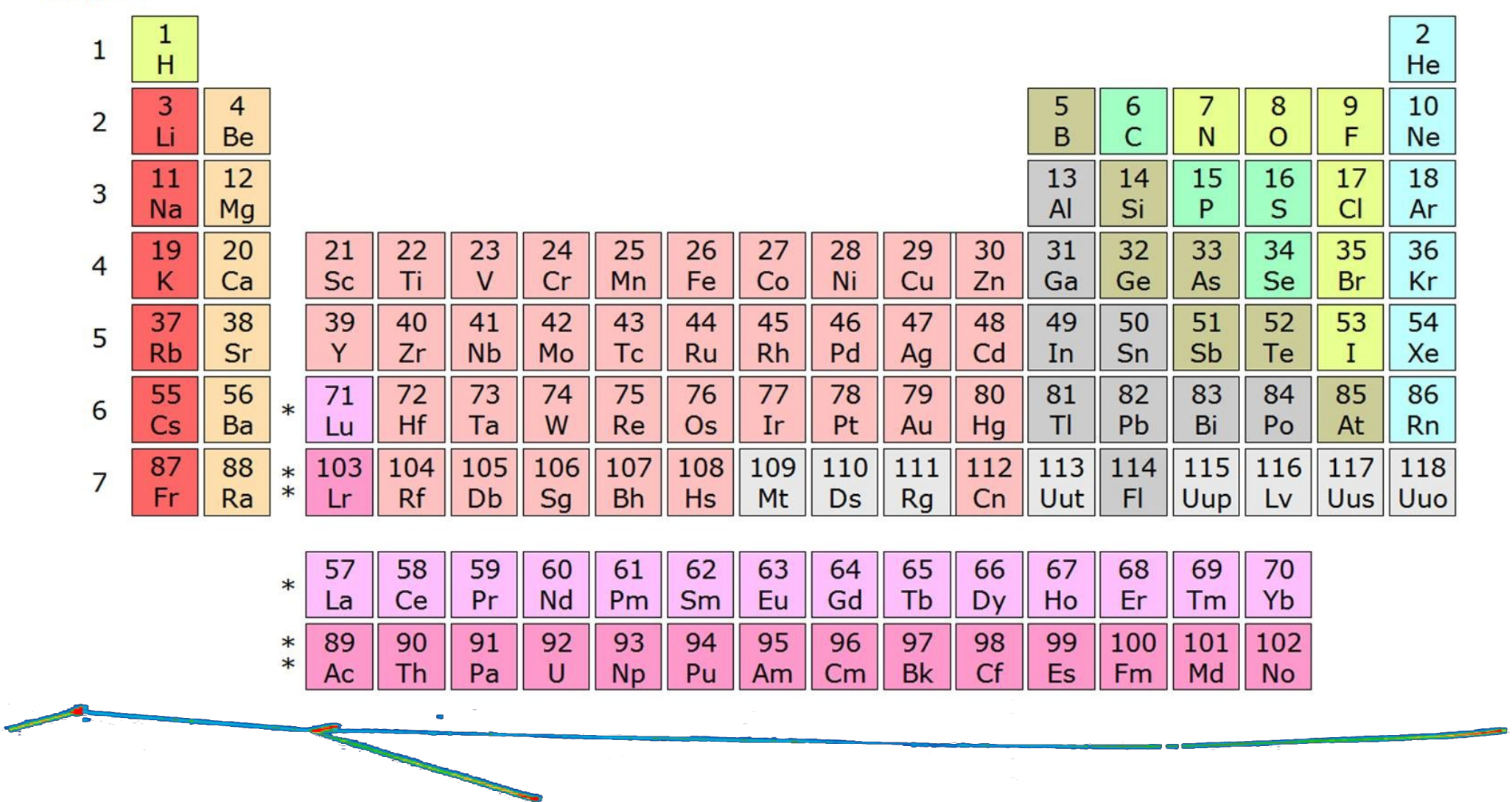
Small Particles, Big Detectors

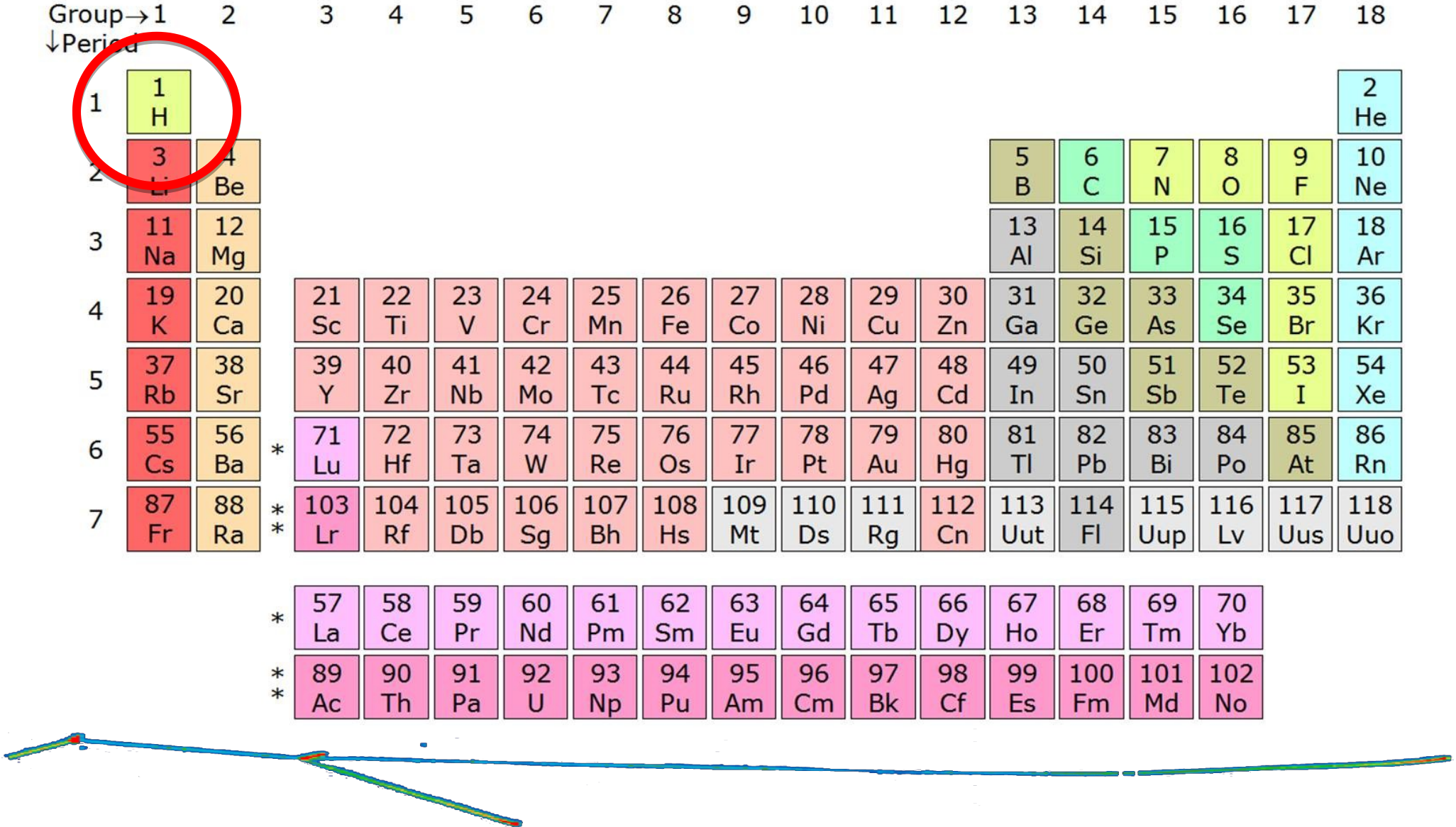
UMN QuarkNet March 2021

Prof. Andrew Furmanski

What is Particle Physics?

- Studying the smallest building blocks of the universe
- Studying how they interact with one another
- Trying to explain why the universe looks the way it does


Group→ 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
↓Period
1 1 H 2 He
2 3 Li 4 Be 5 B 6 C 7 N 8 O 9 F 10 Ne
3 11 Na 12 Mg 13 Al 14 Si 15 P 16 S 17 Cl 18 Ar
4 19 K 20 Ca 21 Sc 22 Ti 23 V 24 Cr 25 Mn 26 Fe 27 Co 28 Ni 29 Cu 30 Zn 31 Ga 32 Ge 33 As 34 Se 35 Br 36 Kr
5 37 Rb 38 Sr 39 Y 40 Zr 41 Nb 42 Mo 43 Tc 44 Ru 45 Rh 46 Pd 47 Ag 48 Cd 49 In 50 Sn 51 Sb 52 Te 53 I 54 Xe
6 55 Cs 56 Ba * 71 Lu 72 Hf 73 Ta 74 W 75 Re 76 Os 77 Ir 78 Pt 79 Au 80 Hg 81 Tl 82 Pb 83 Bi 84 Po 85 At 86 Rn
7 87 Fr 88 Ra ** 103 Lr 104 Rf 105 Db 106 Sg 107 Bh 108 Hs 109 Mt 110 Ds 111 Rg 112 Cn 113 Uut 114 Fl 115 Uup 116 Lv 117 Uus 118 Uuo
* 57 La 58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb
** 89 Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No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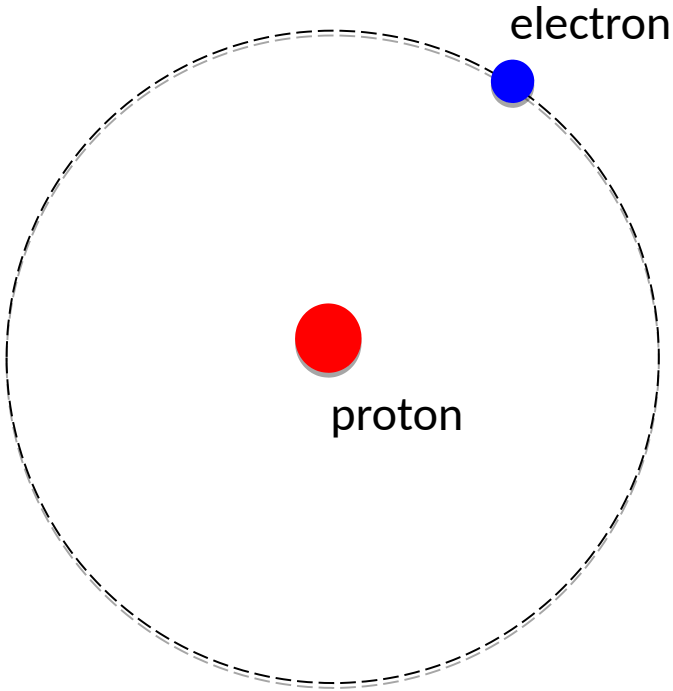
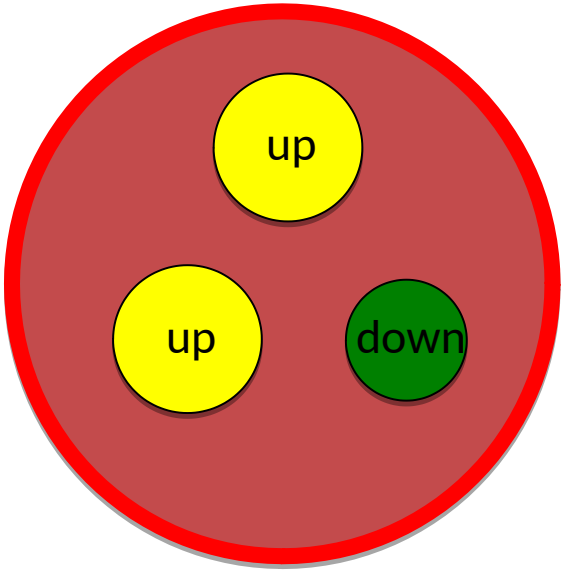
Hydrogen Atom



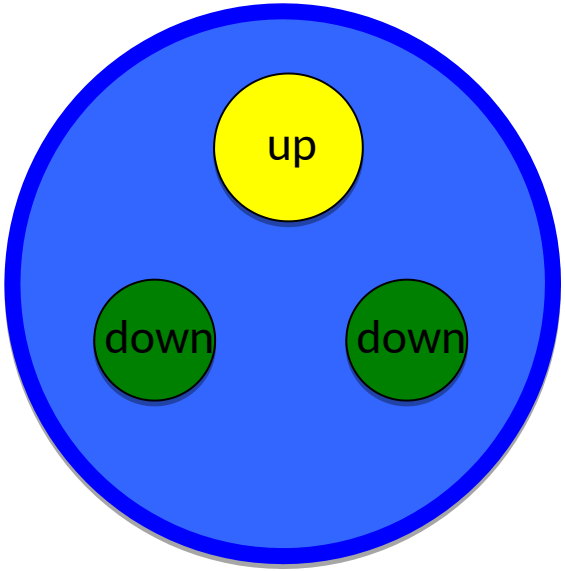
Proton



The proton is made up of quarks!

The strong nuclear force holds the quarks tightly together

Neutron



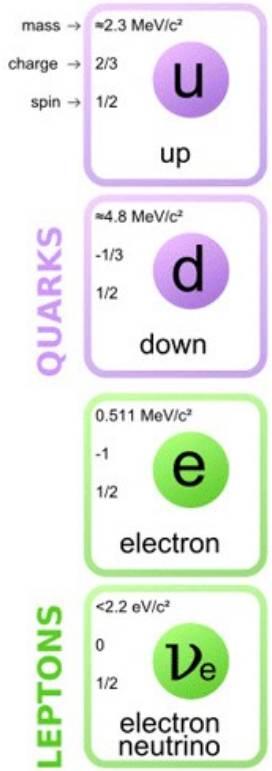
The neutron is also made up of quarks!

Neutrino

- Last particle type*
- Zero electric charge
- Zero magnetic field
- Tiny (but not zero) mass
- Very hard to detect

*Except for force carrier bosons, but they’re for another day!

The first generation



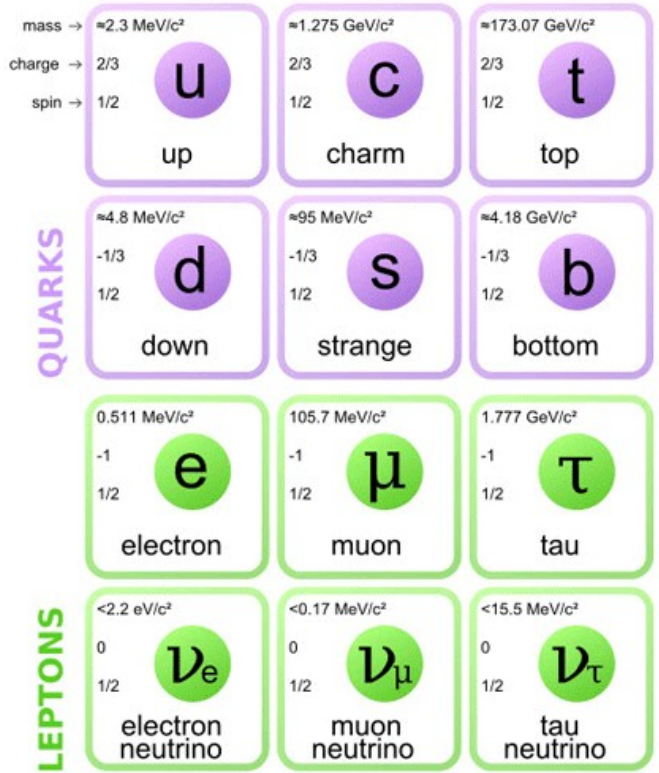
Quarks make protons and neutrons

Electrons form clouds round nuclei in atoms

Everything you can see, touch, taste, and smell, is made of these!

Neutrinos are like electrons shy little brother/sister

The other generations

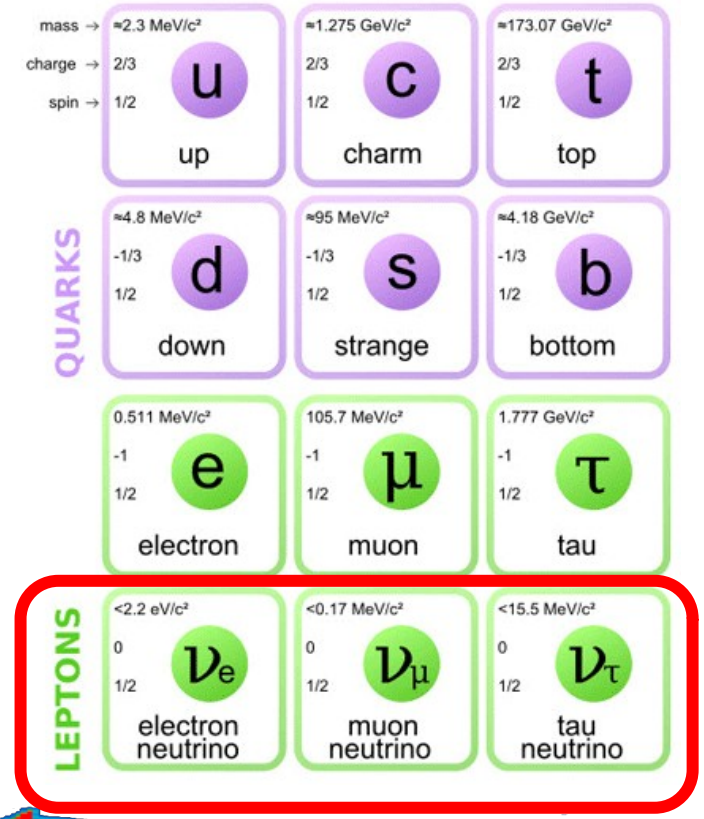


Every particle has two extra copies (which don't usually live very long)

We don't know why there are three generations

The only fundamental difference between them is their mass

The other generations



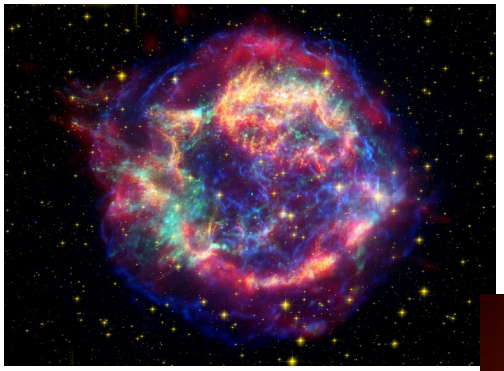
Every particle has two extra copies (which don't usually live very long)

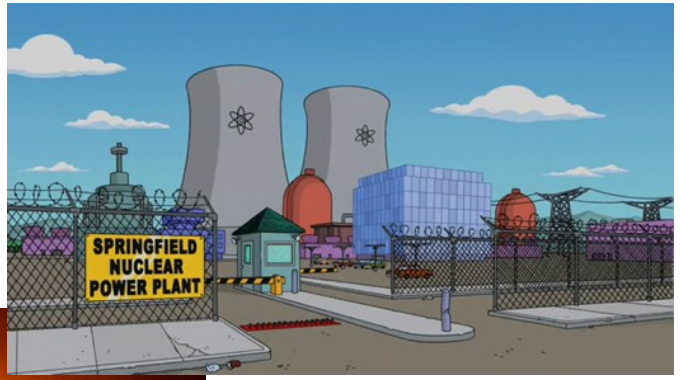
We don't know why there are three generations

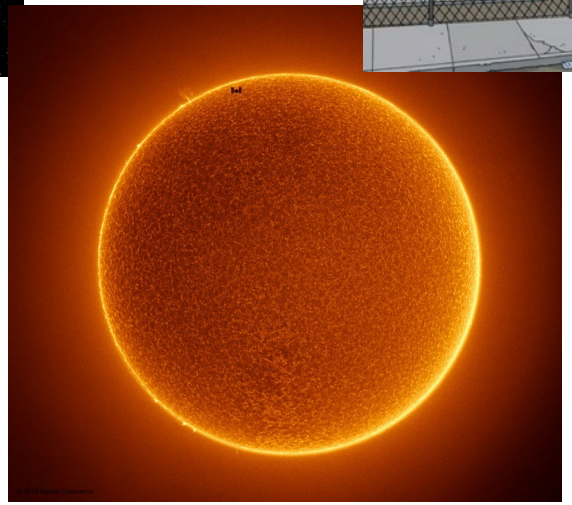
The only fundamental difference between them is their mass

There are three types of neutrino!

Where do Neutrinos Come From?







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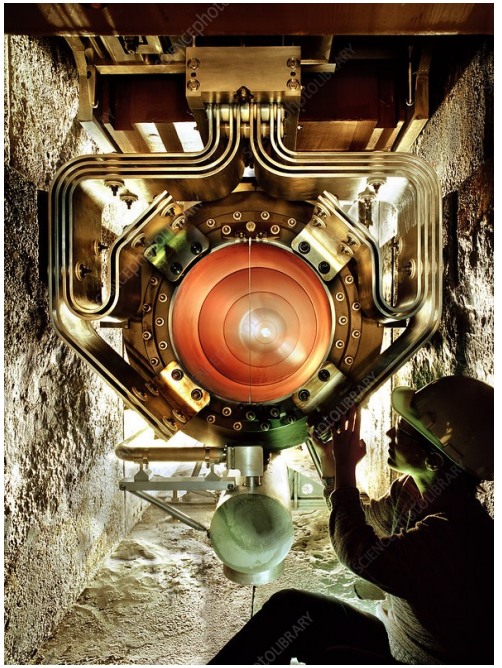


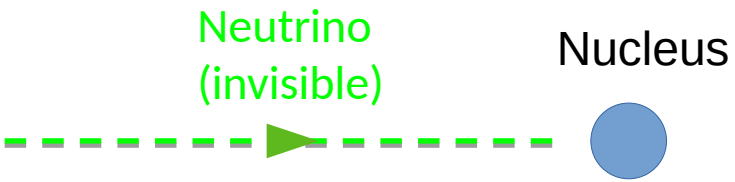
We can also produce beams of neutrinos using proton accelerators

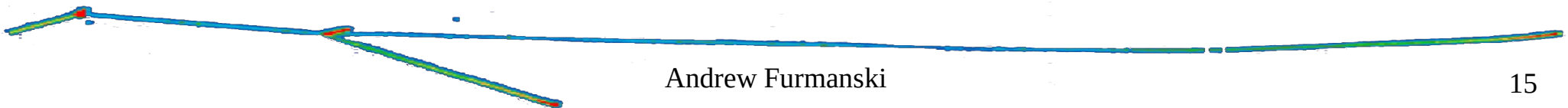
Neutrino Interactions

- Most neutrinos fly straight through you
- Billions each second
- Occasionally, they collide with the nucleus of an atom
- This produces all sorts of charged particles which we can see

65 million each second travel through your thumbnail!

Detecting Neutrinos





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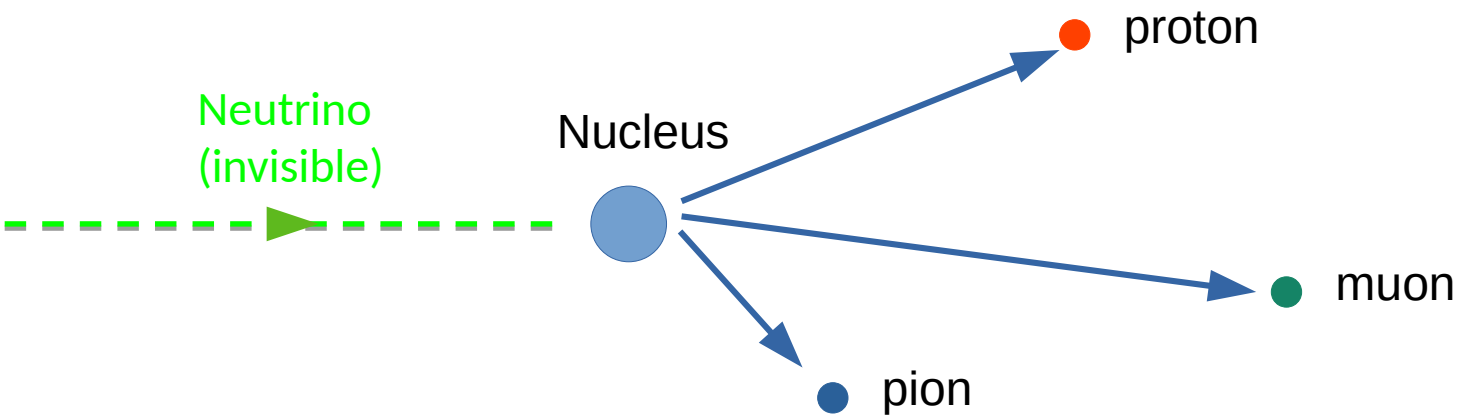
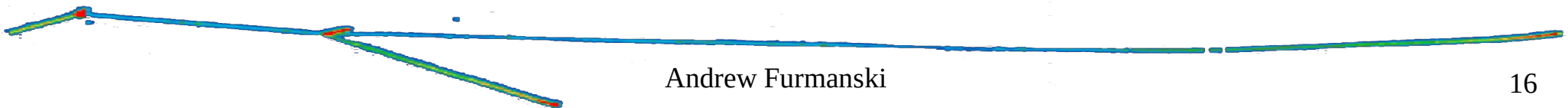
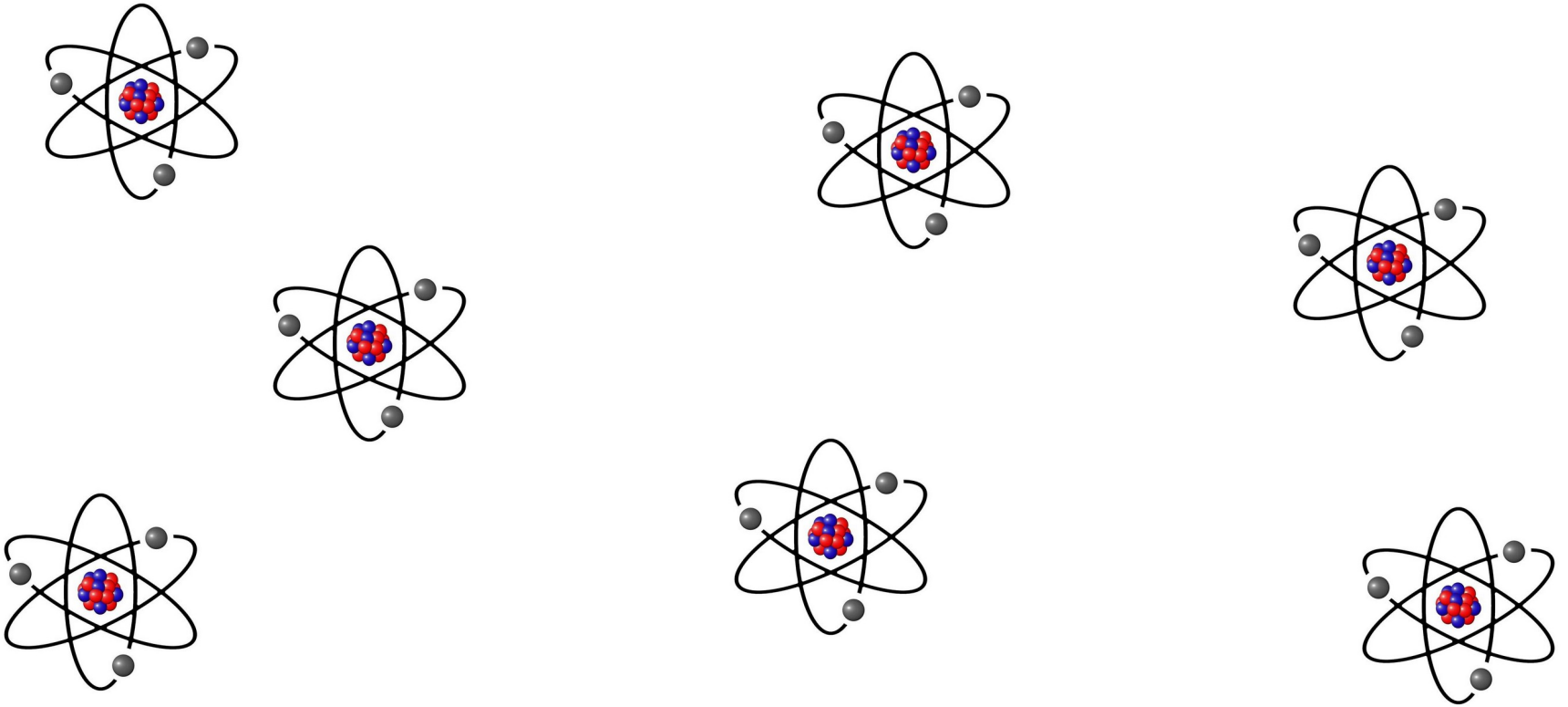


These particles all have **charge**



Charged particles



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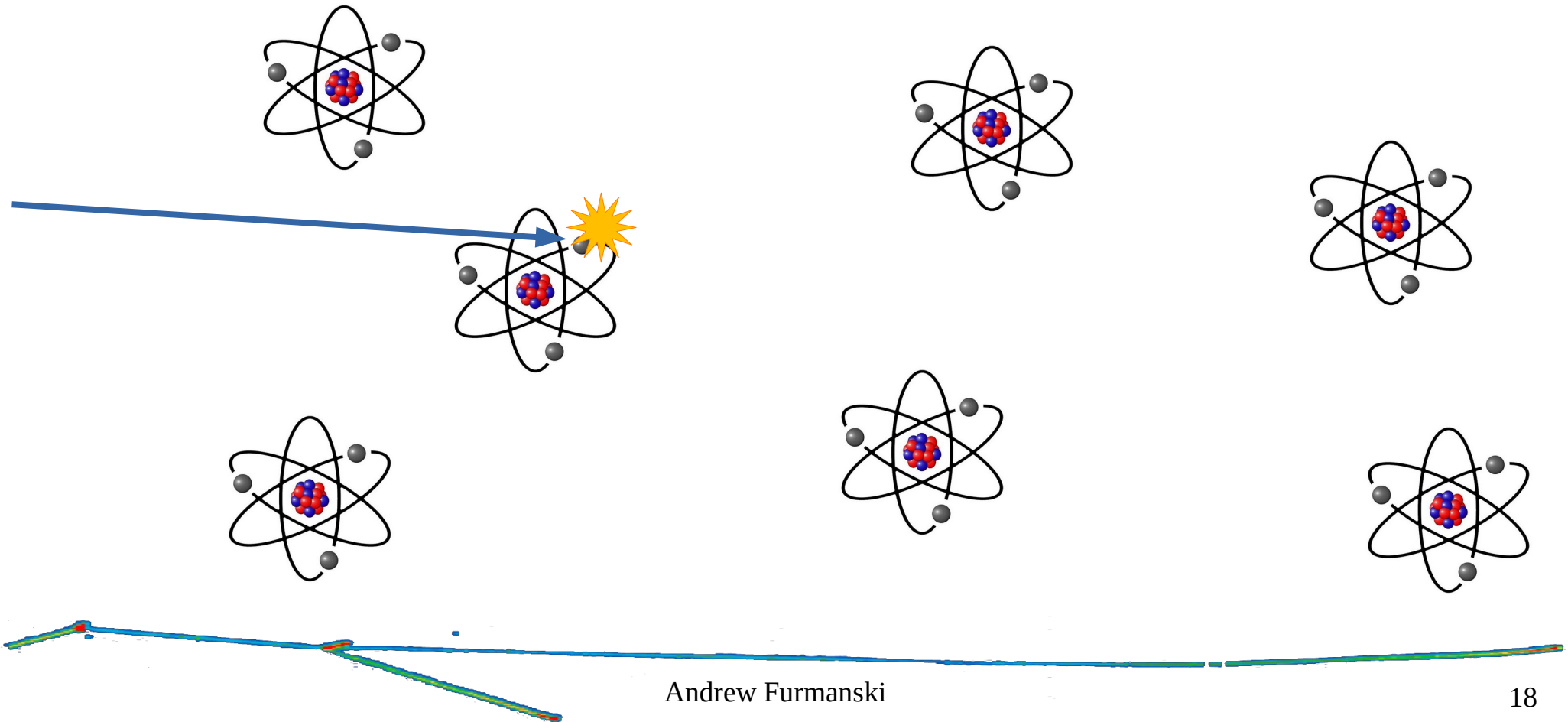

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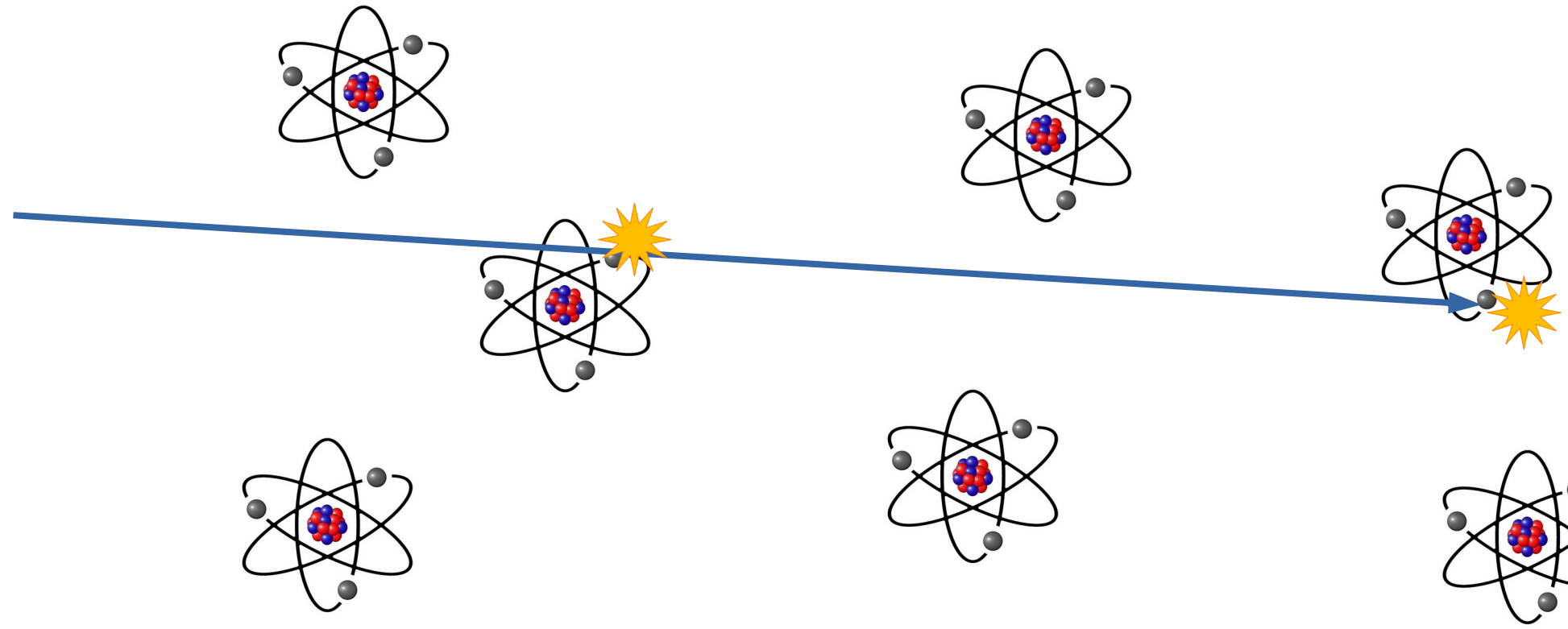

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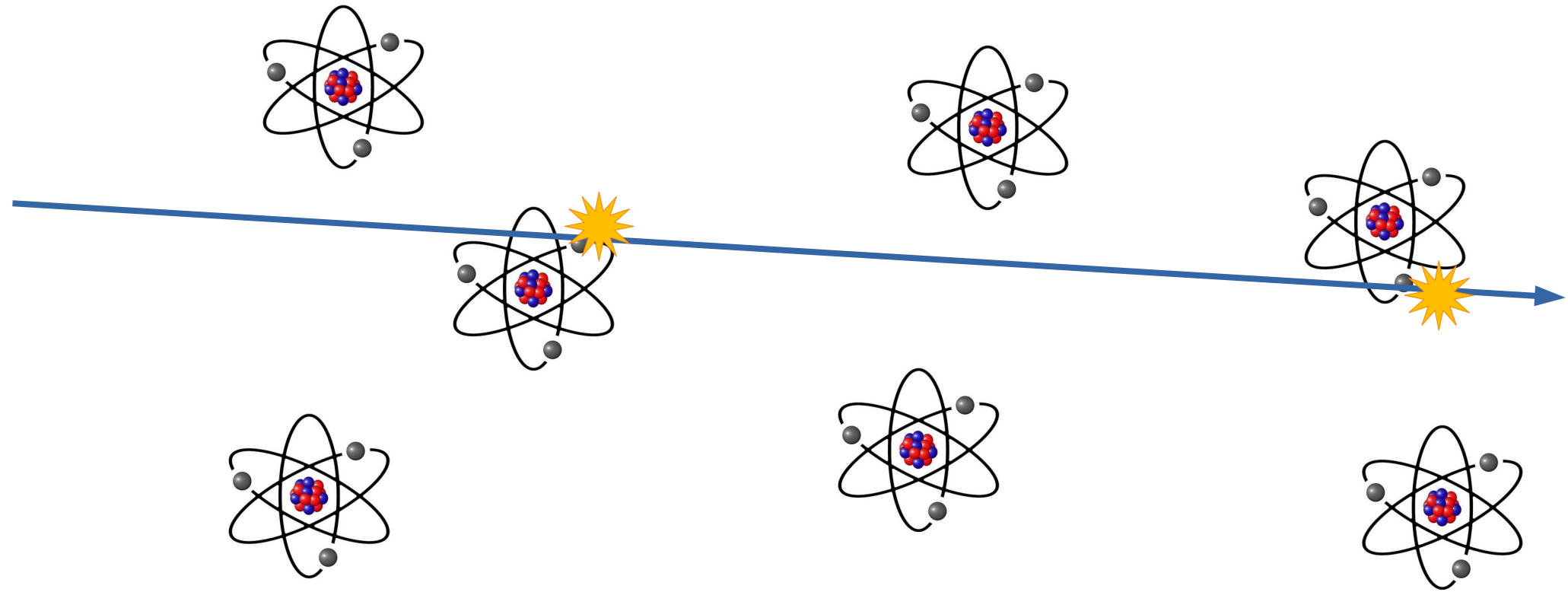

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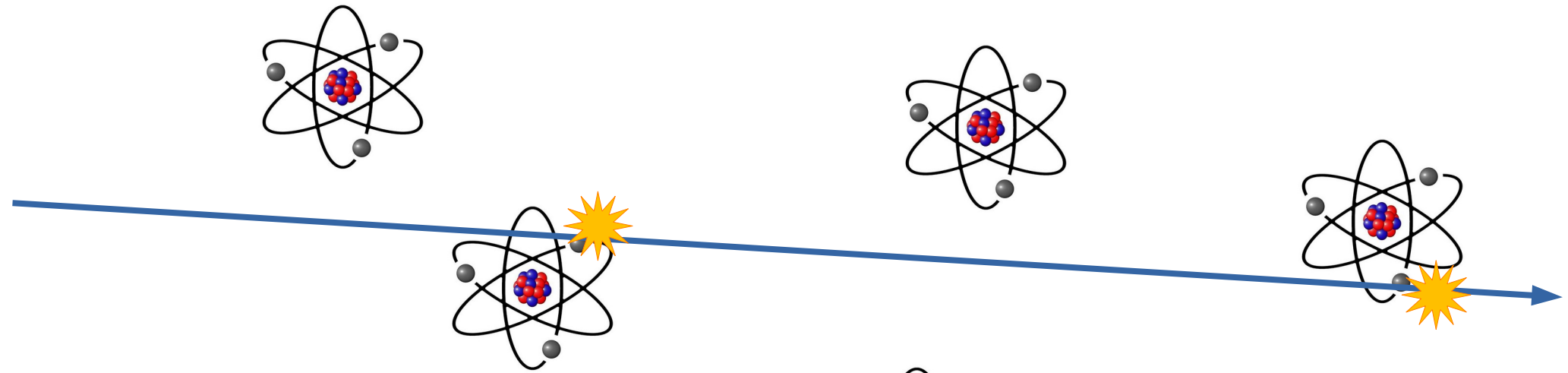
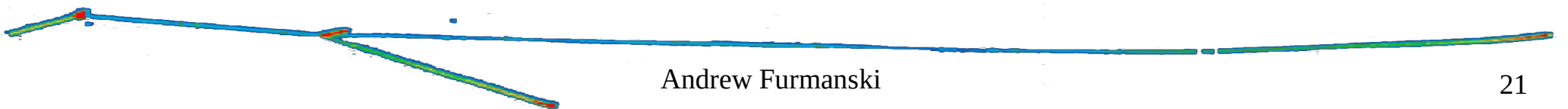
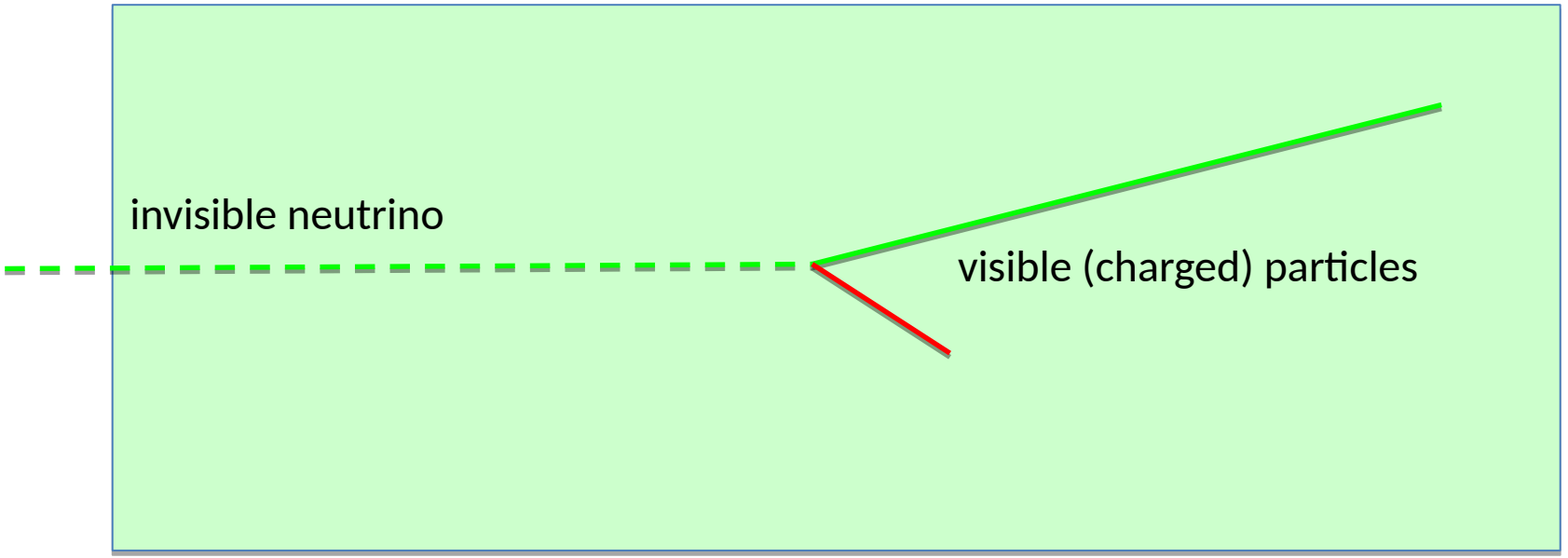
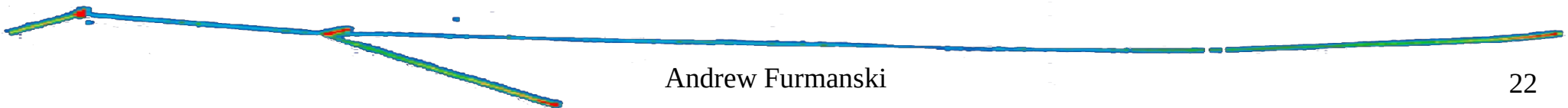


Interactions with electrons in the atoms in your detector produce **charge** and **light** signals



Liquid Argon Detectors





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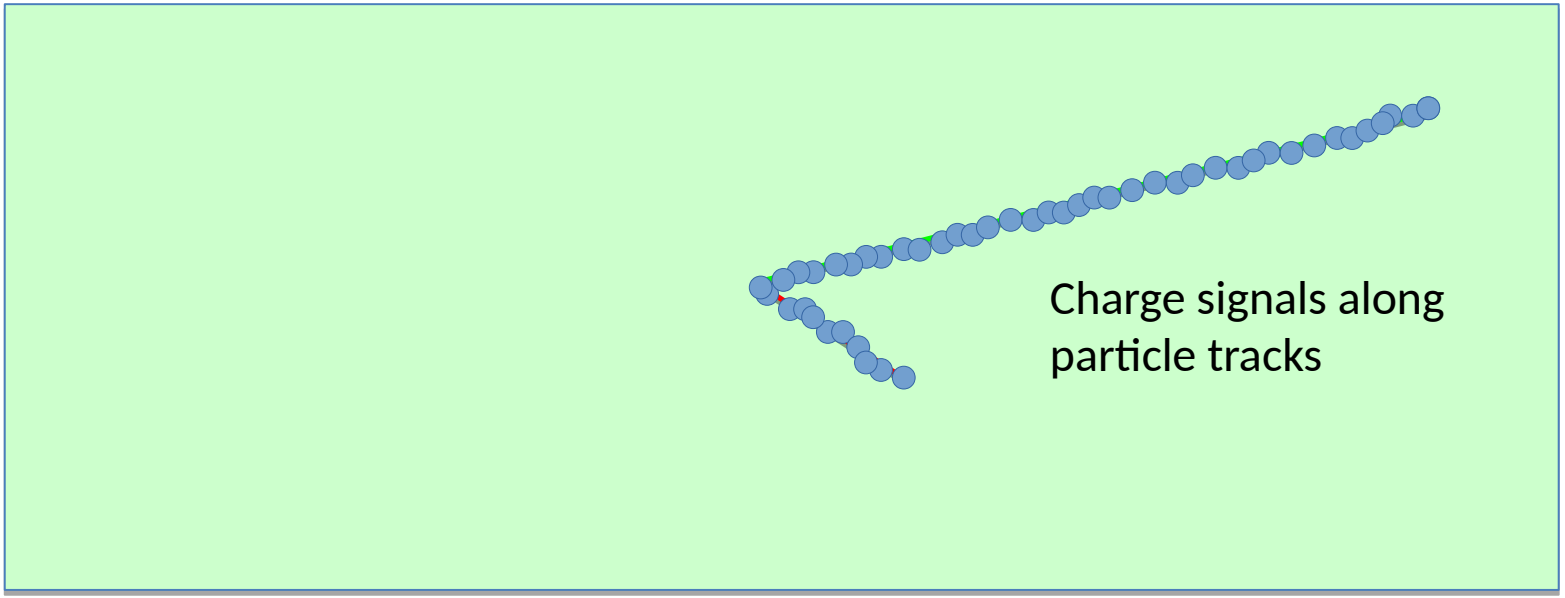

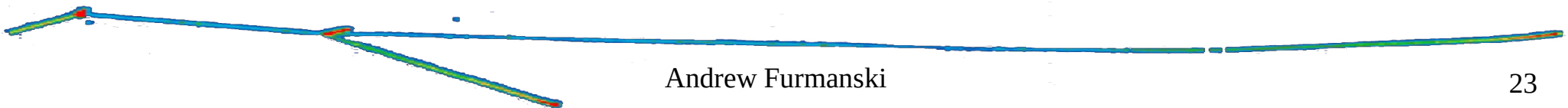

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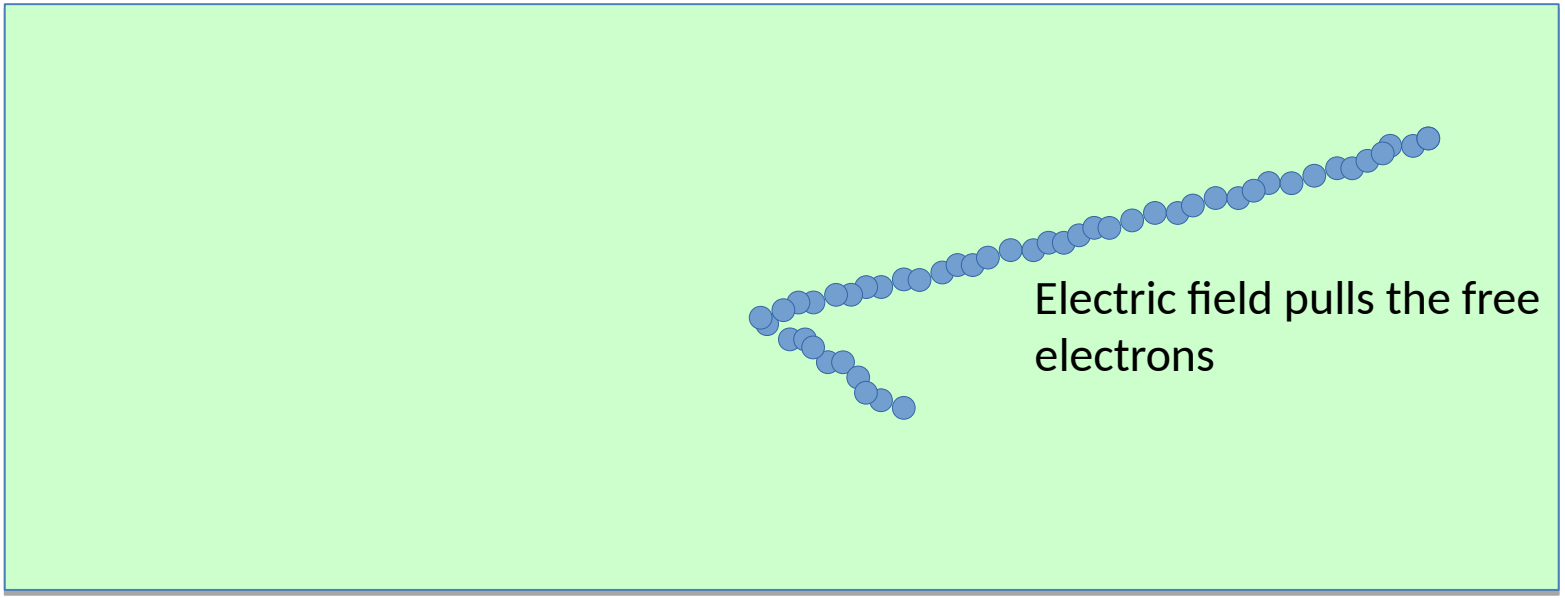

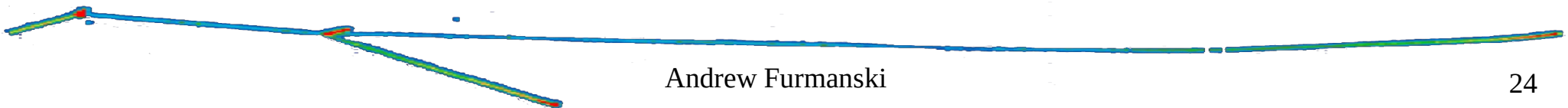

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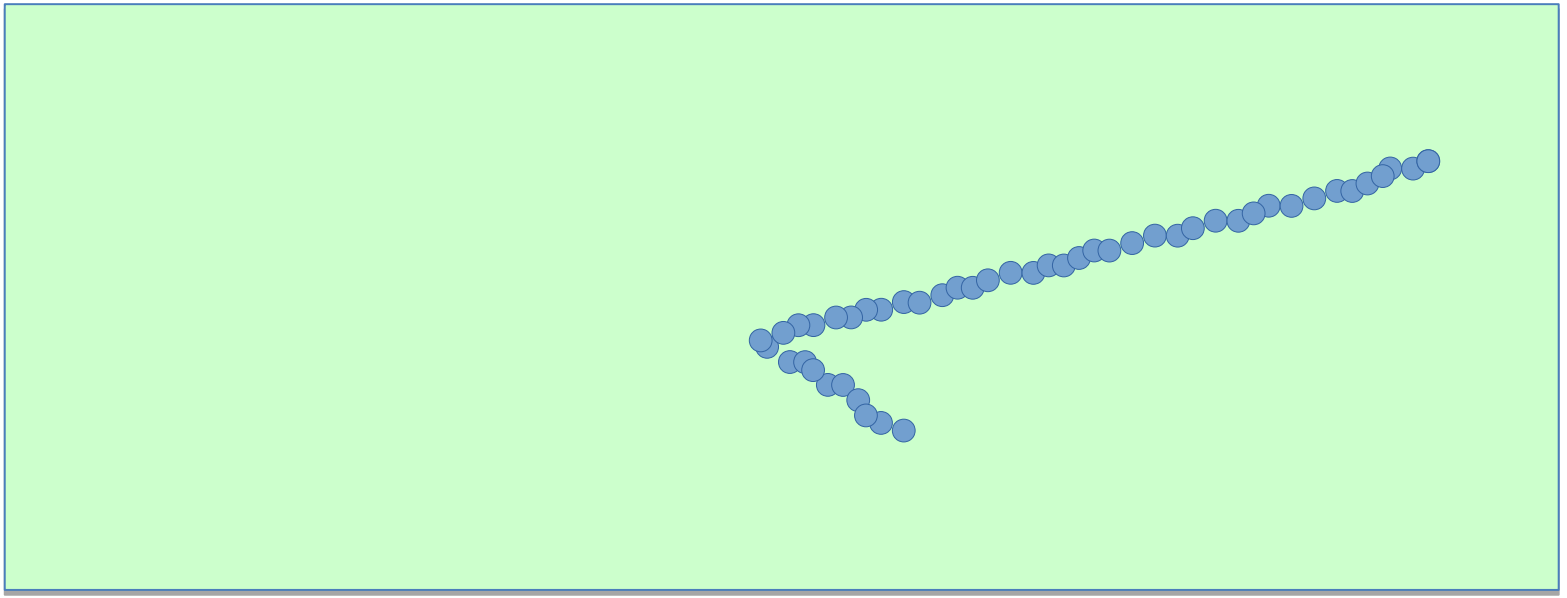

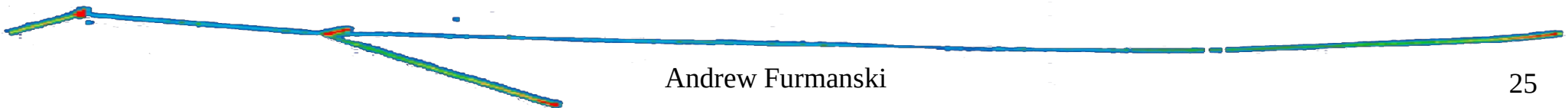

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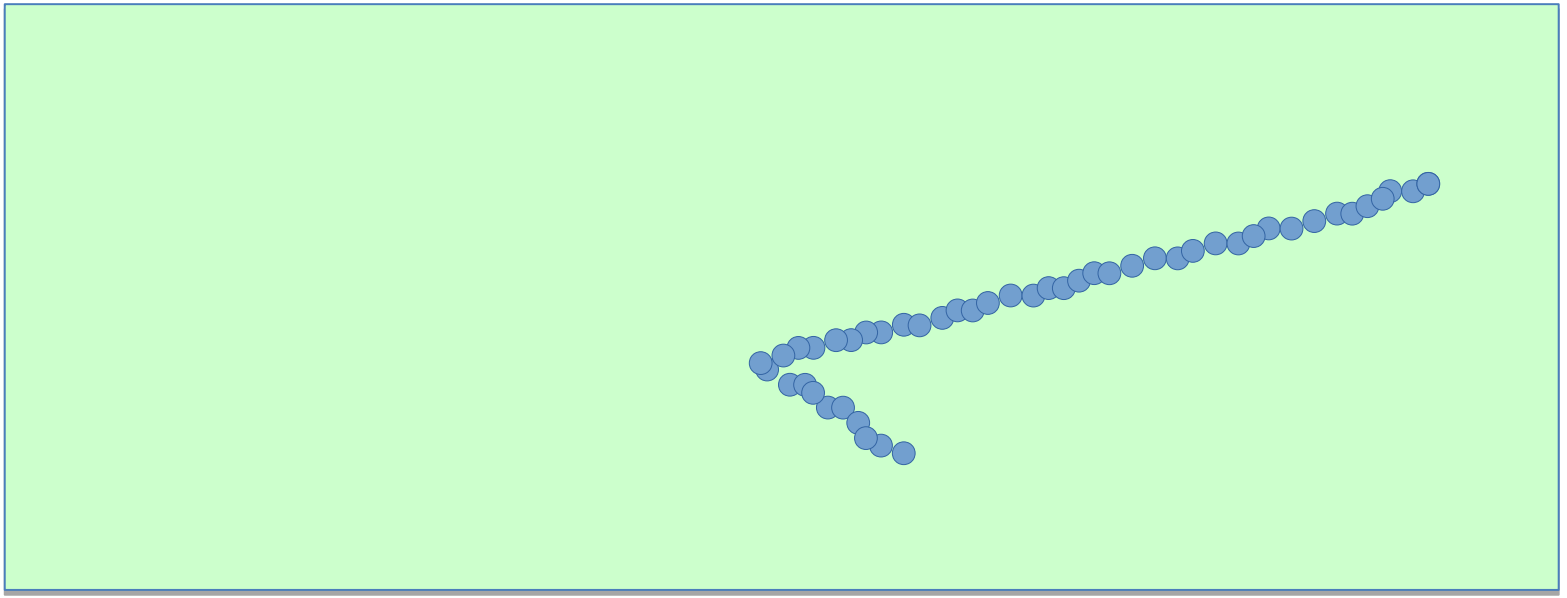

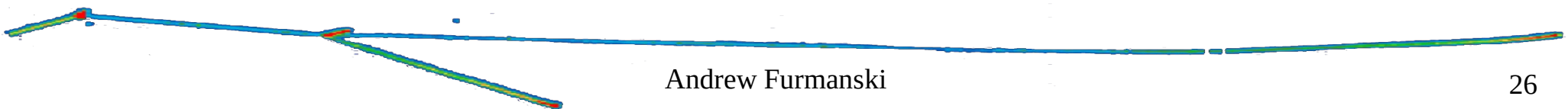

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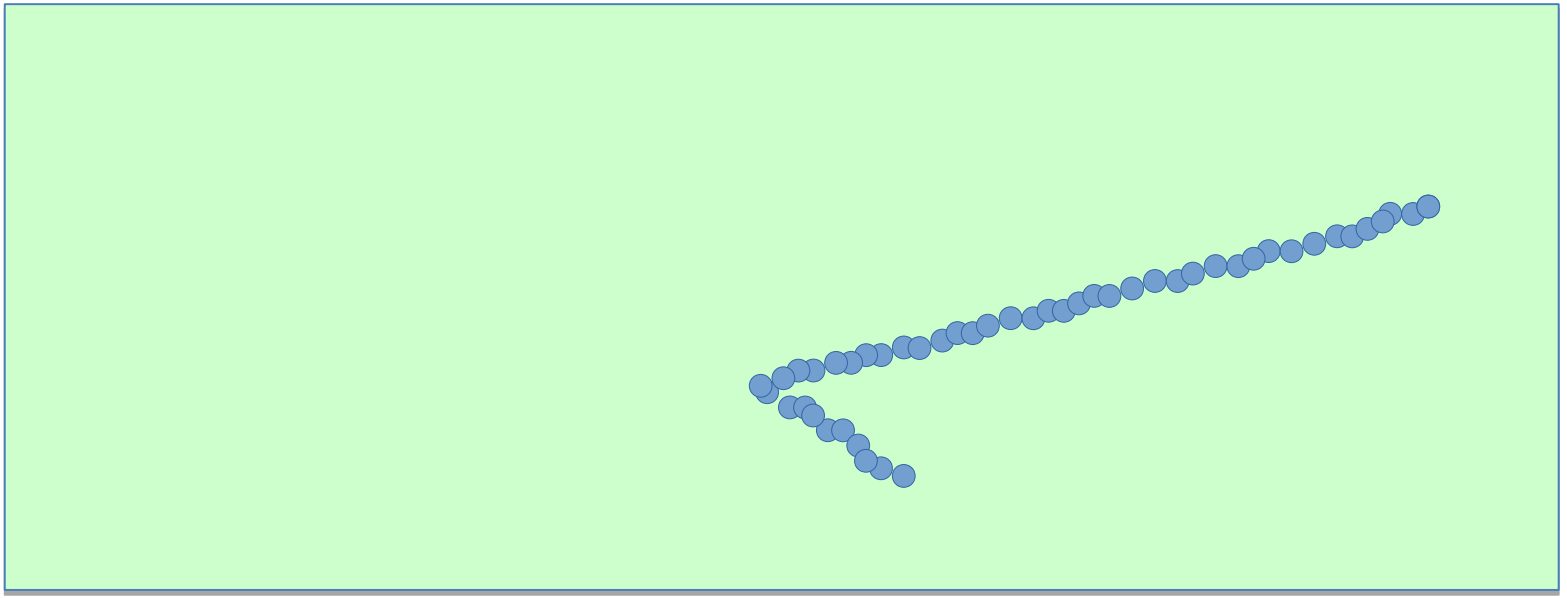

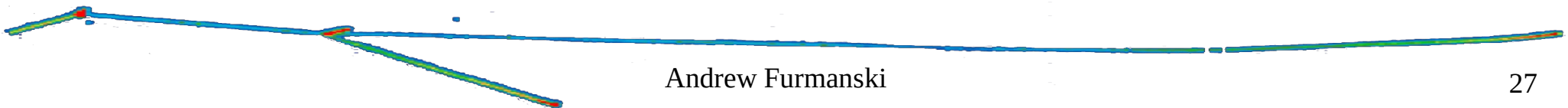

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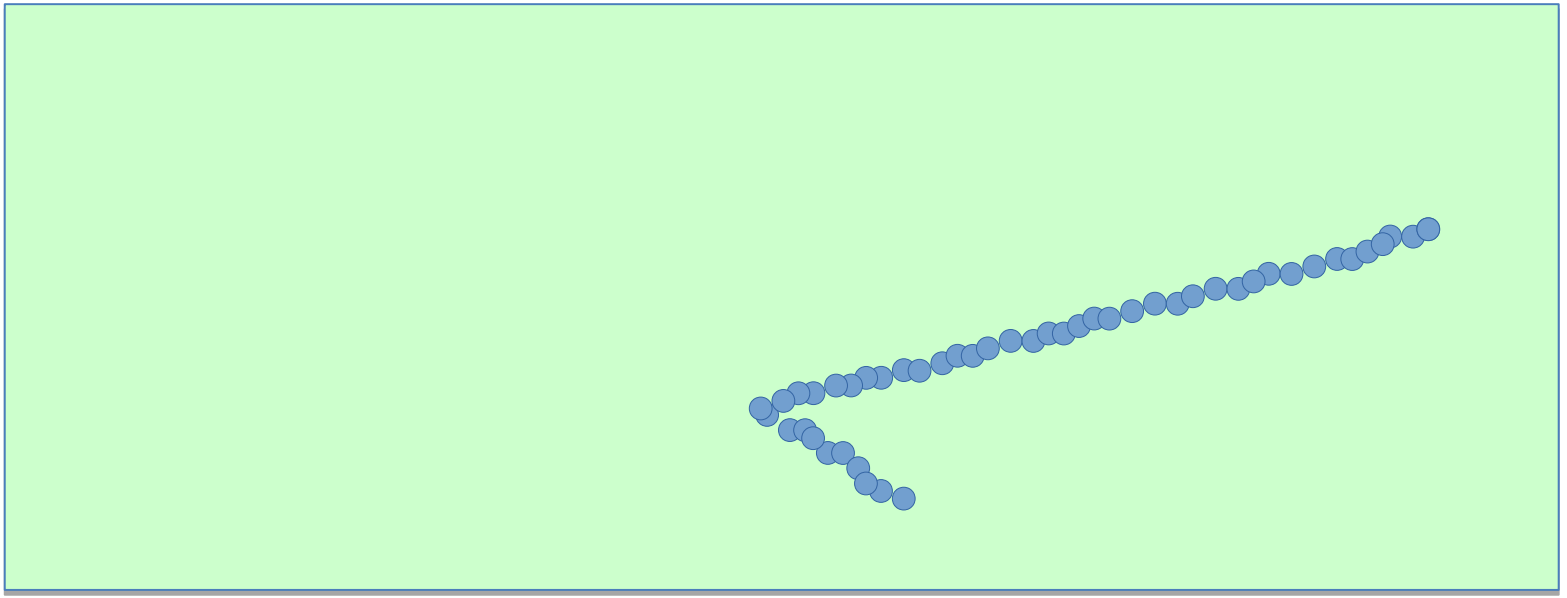

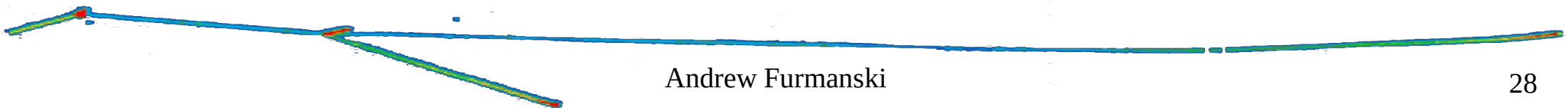

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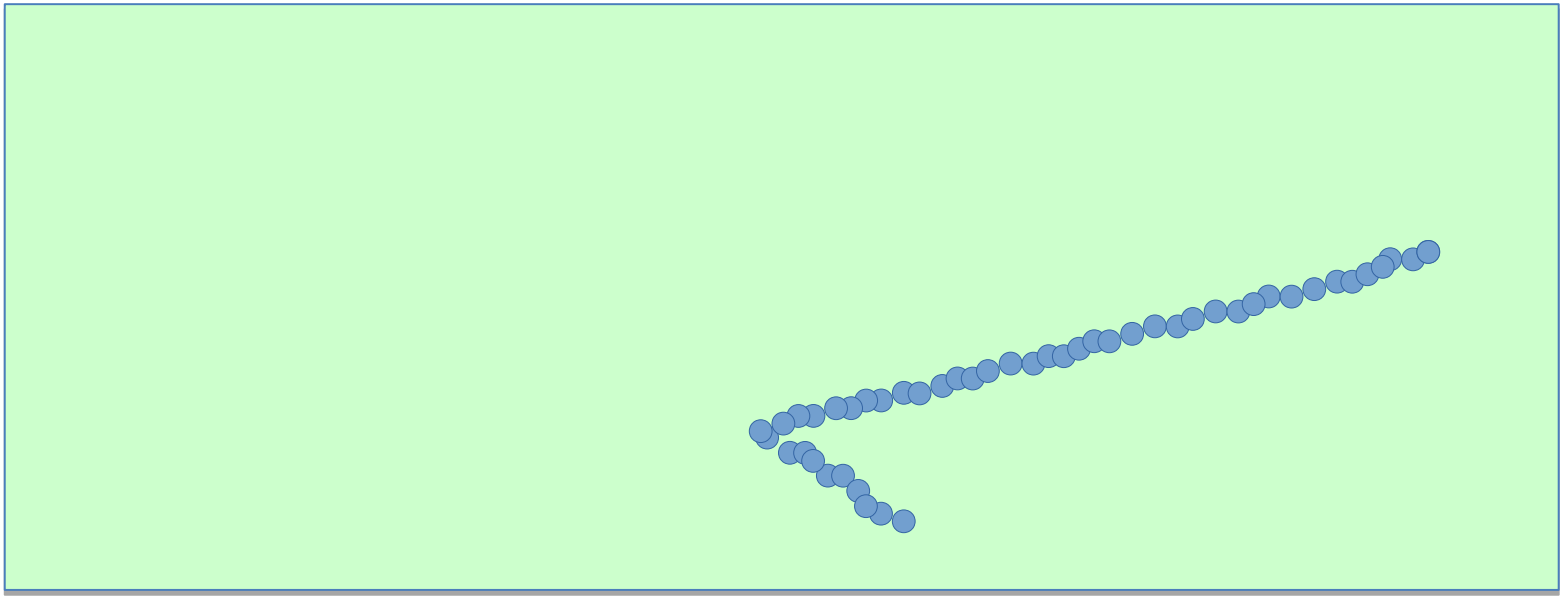

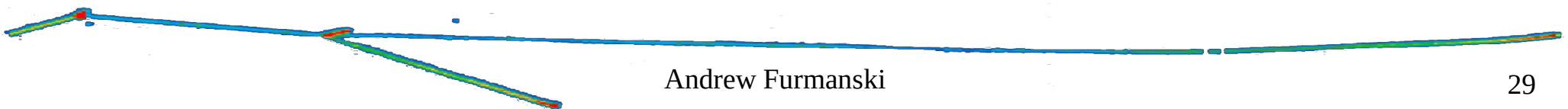

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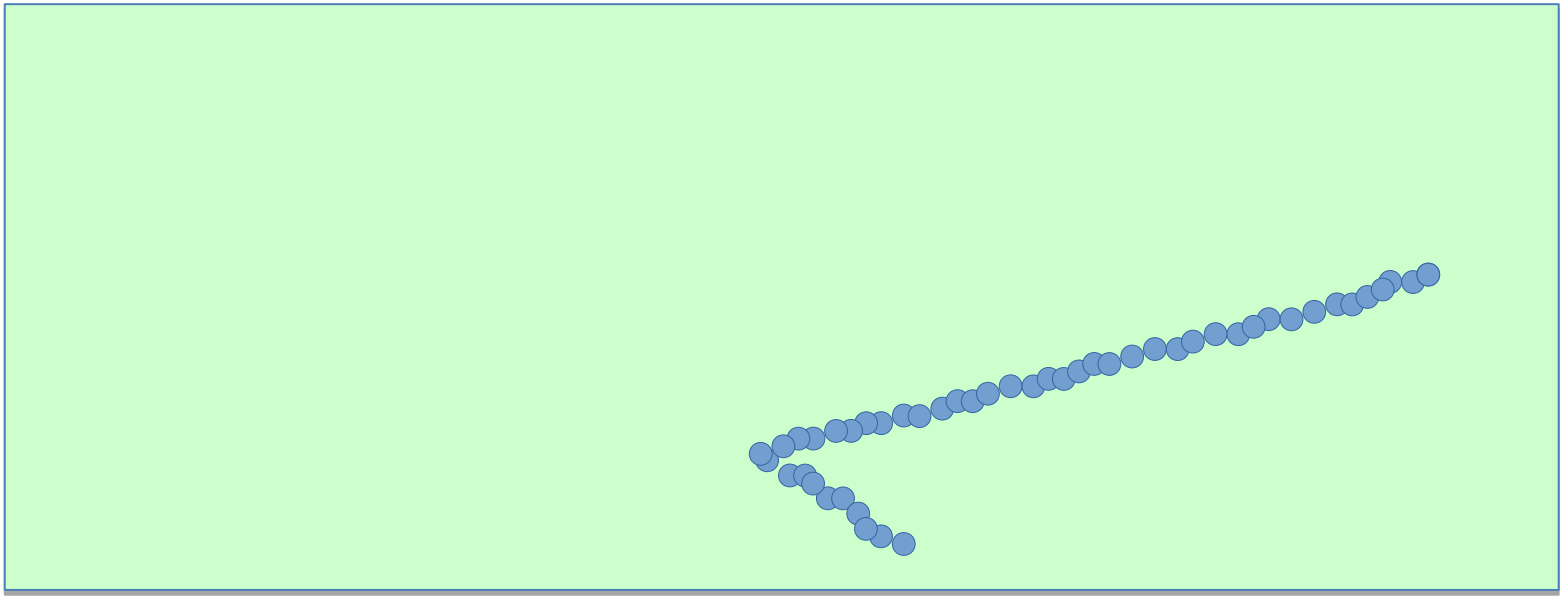

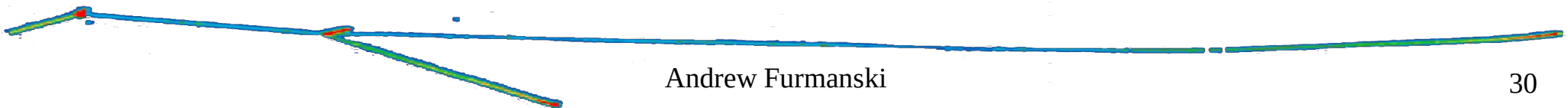

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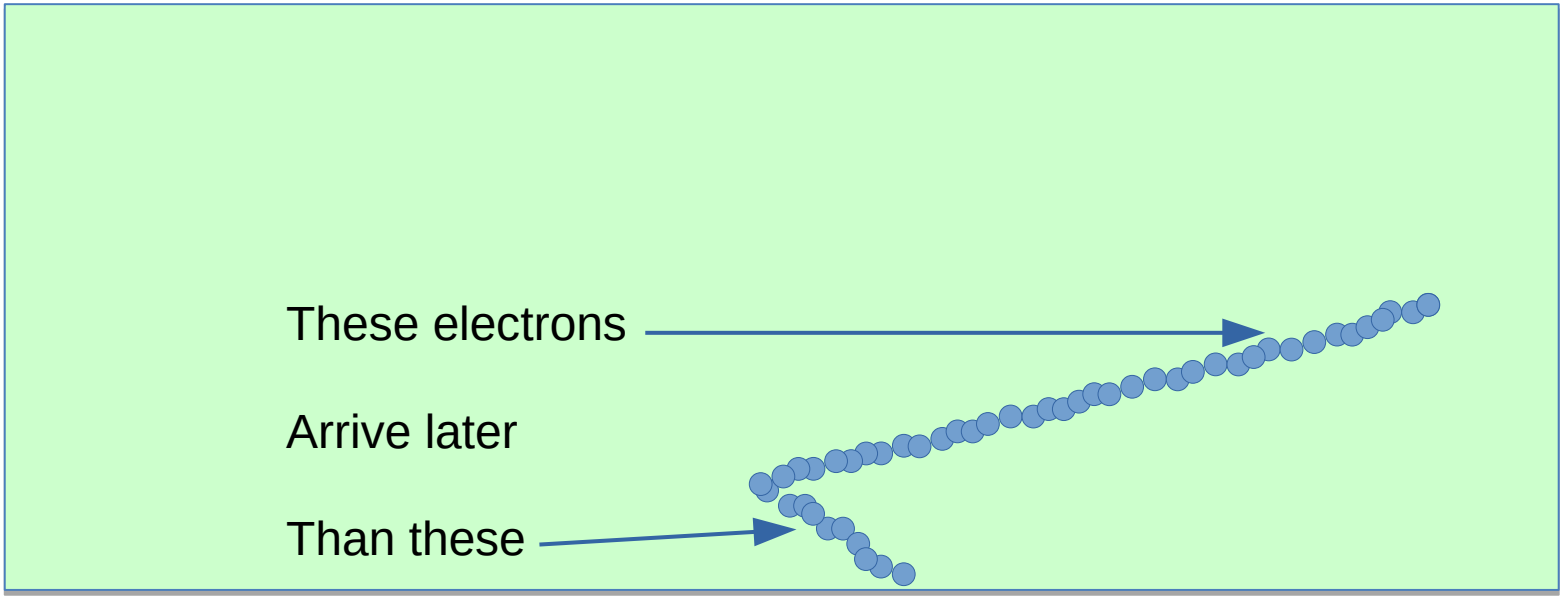


Liquid Argon Detectors

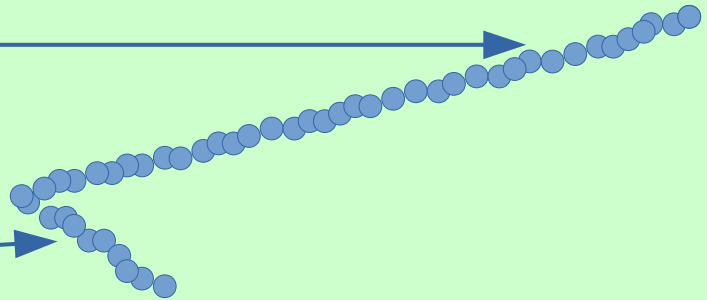
speed = distance / time
distance = speed x time

If we know the speed they move, we can work out where the electrons came from

These electrons

Arrive later

Than these



In Real Life

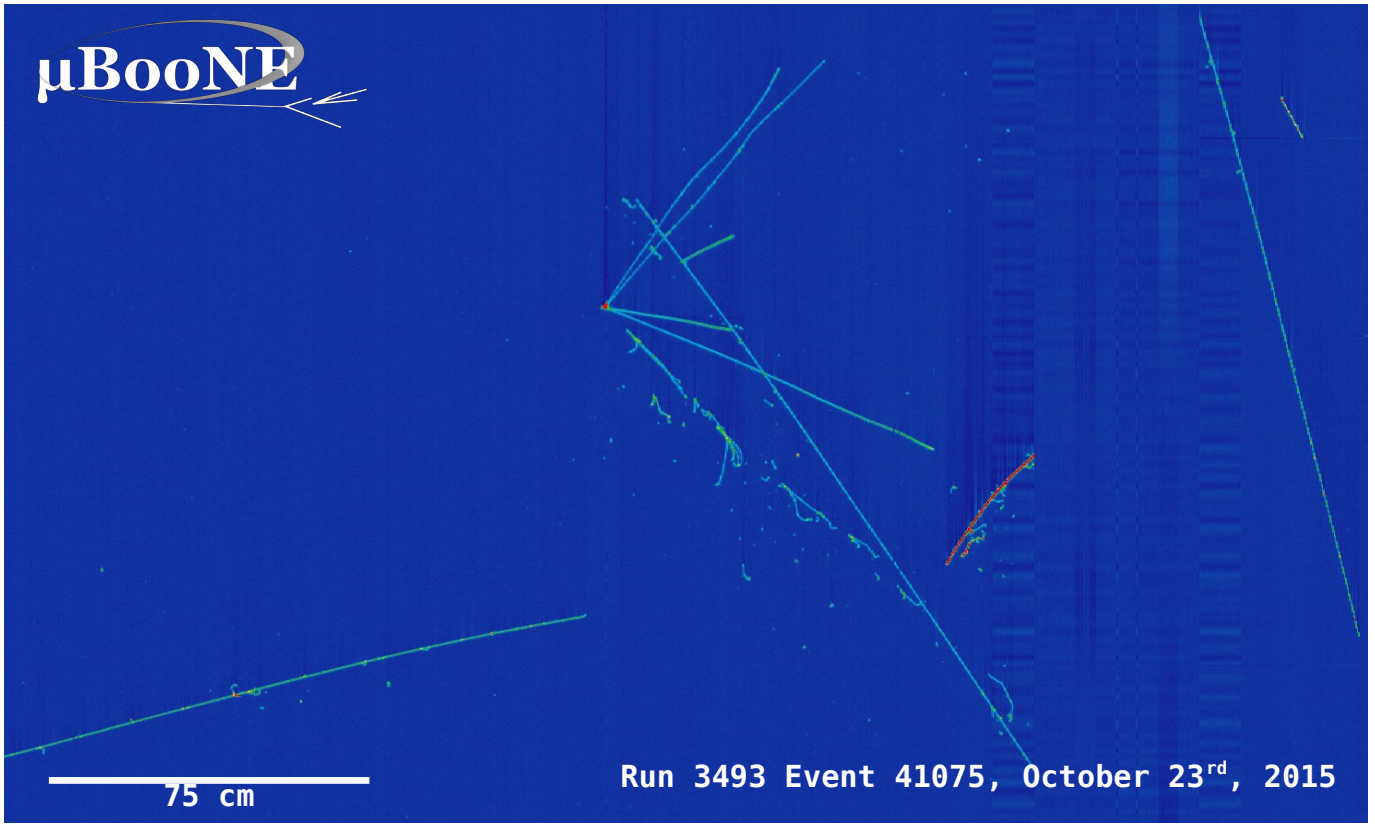
New technology improving neutrino measurements

Detector filled with **liquid argon** (89K / -184C / -300F)

In this detector, the **charge** is detected by a series of wires

Very high voltages required (up to 300,000 volts!)

Also detect **light** with photon detectors around the edges



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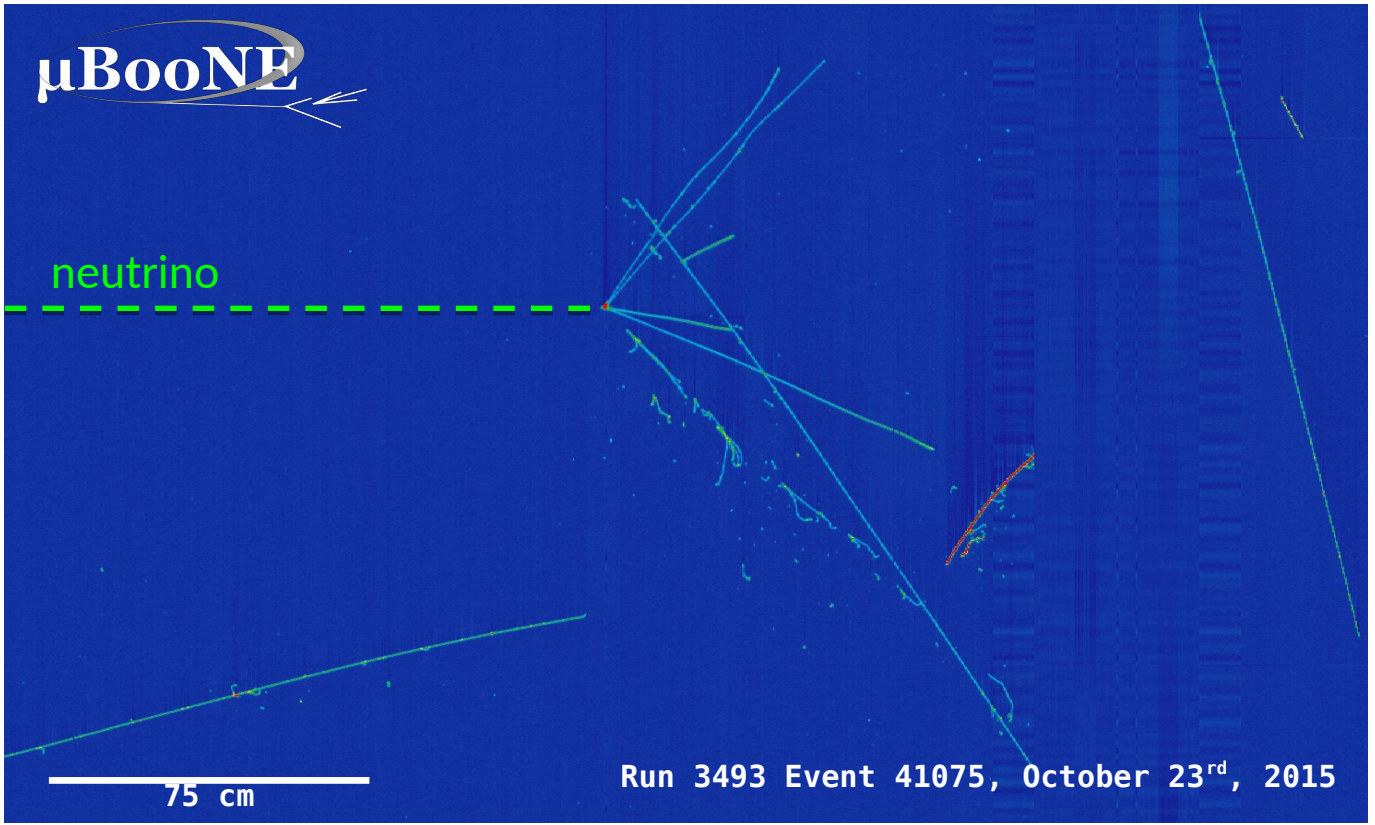
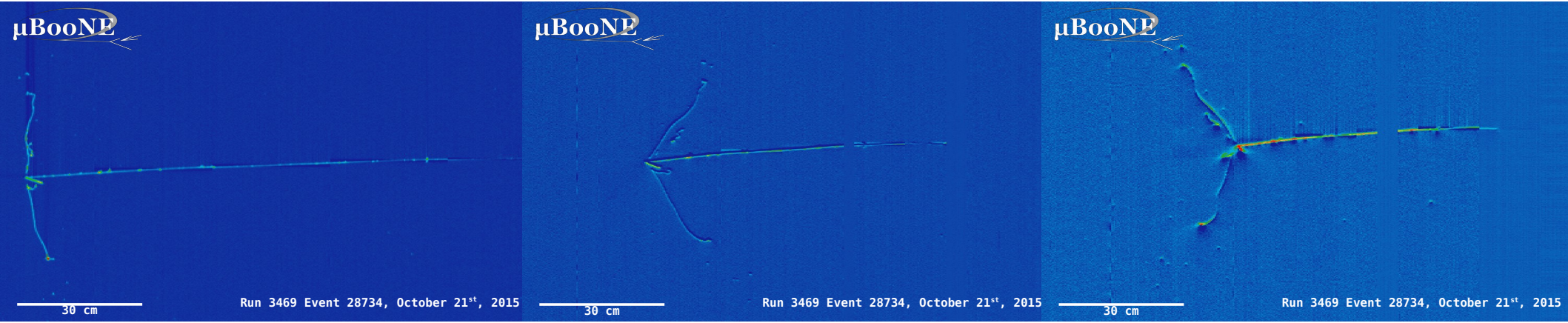
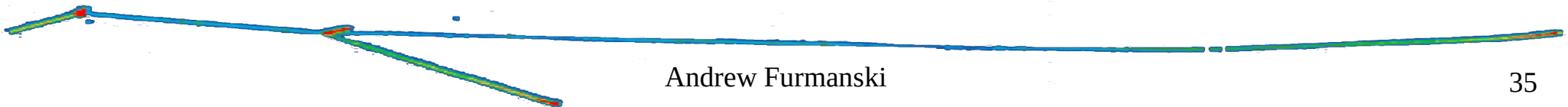


Three Wire Planes – Three views

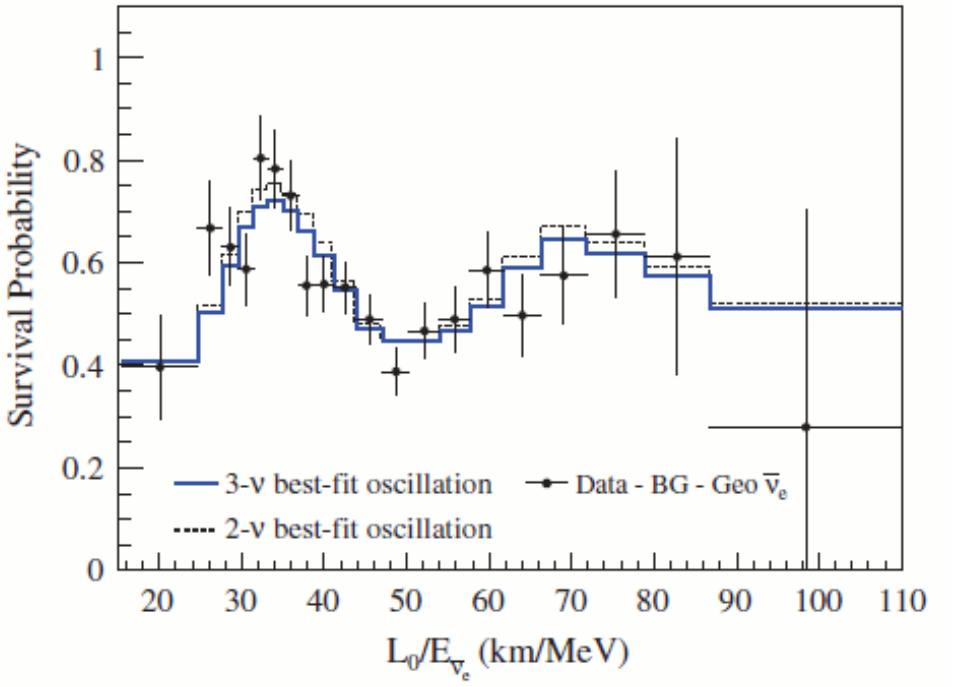


Three views of the same event can be combined to make a 3D image

You can tell how far away something is because you have two eyes – same thing!



Neutrino Oscillations



Three types (flavors) of neutrino

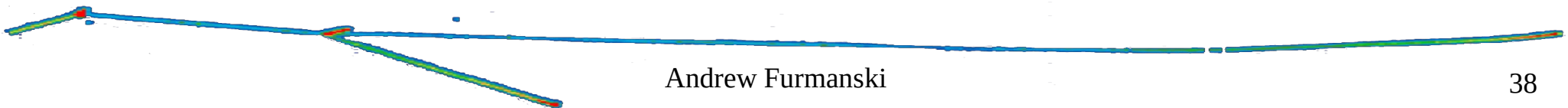
Change back and forth as they travel

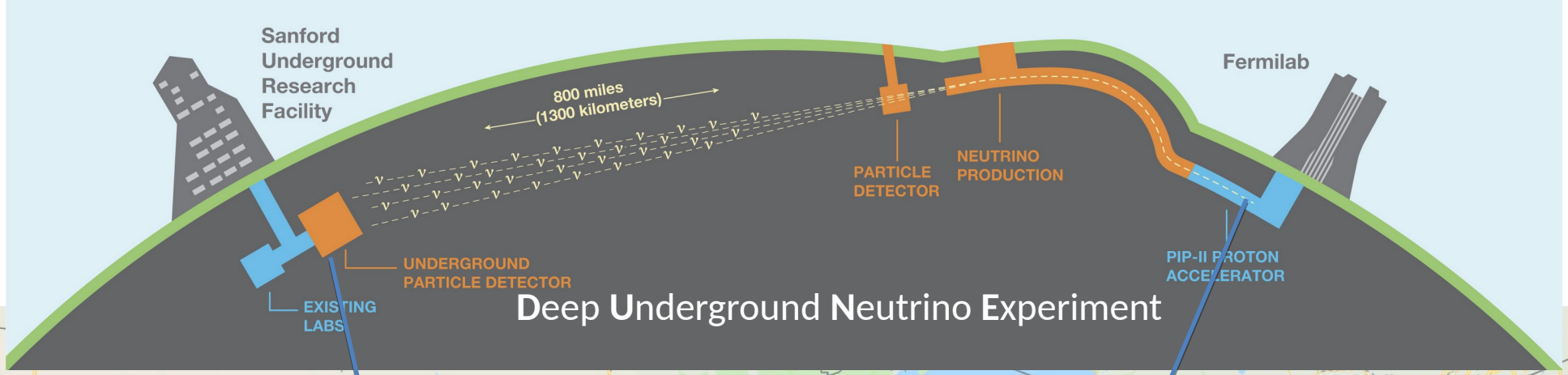
Known as “oscillations”

This is very weird

What we need

- Lots of neutrinos
- A big detector
- A sensitive detector
- No external noise
- Enough distance to observe the oscillation effects




Sanford
Underground
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Facility
800 miles
(1300 kilometers)
PARTICLE
DETECTOR
NEUTRINO
PRODUCTION
Fermilab
UNDERGROUND
PARTICLE DETECTOR
EXISTING
LABS
PIP-II PROTON
ACCELERATOR
Deep Underground Neutrino Experiment

MONTANA
NORTH
DAKOTA
MINNESOTA
SOUTH
DAKOTA
WYOMING
NEBRASKA
IOWA
WISCONSIN
MICHIGAN
ILLINOIS
INDIANA
OHIO
KENTUCKY
VIRGINIA
PENNSYLVANIA
NEW YORK
VERMONT
MASSACH
CT
NJ
DE
UTAH
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KANSAS
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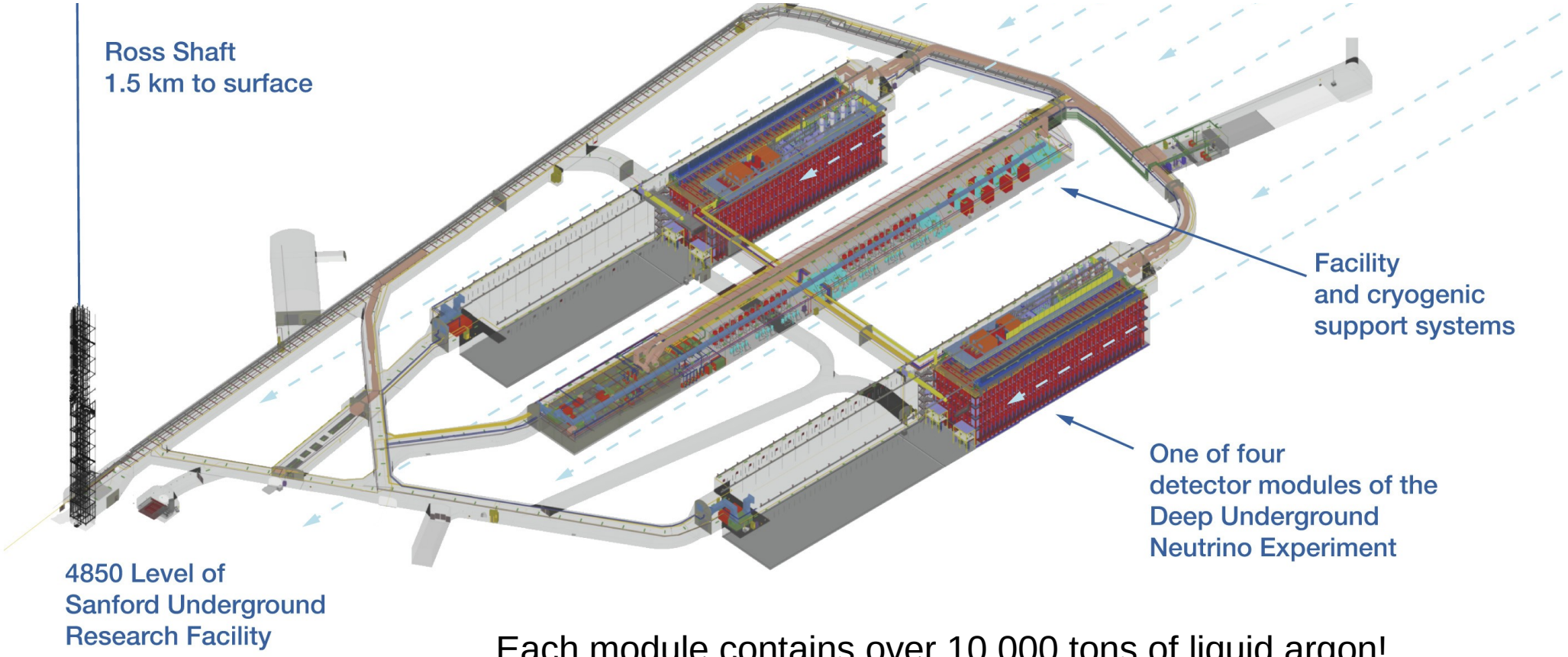
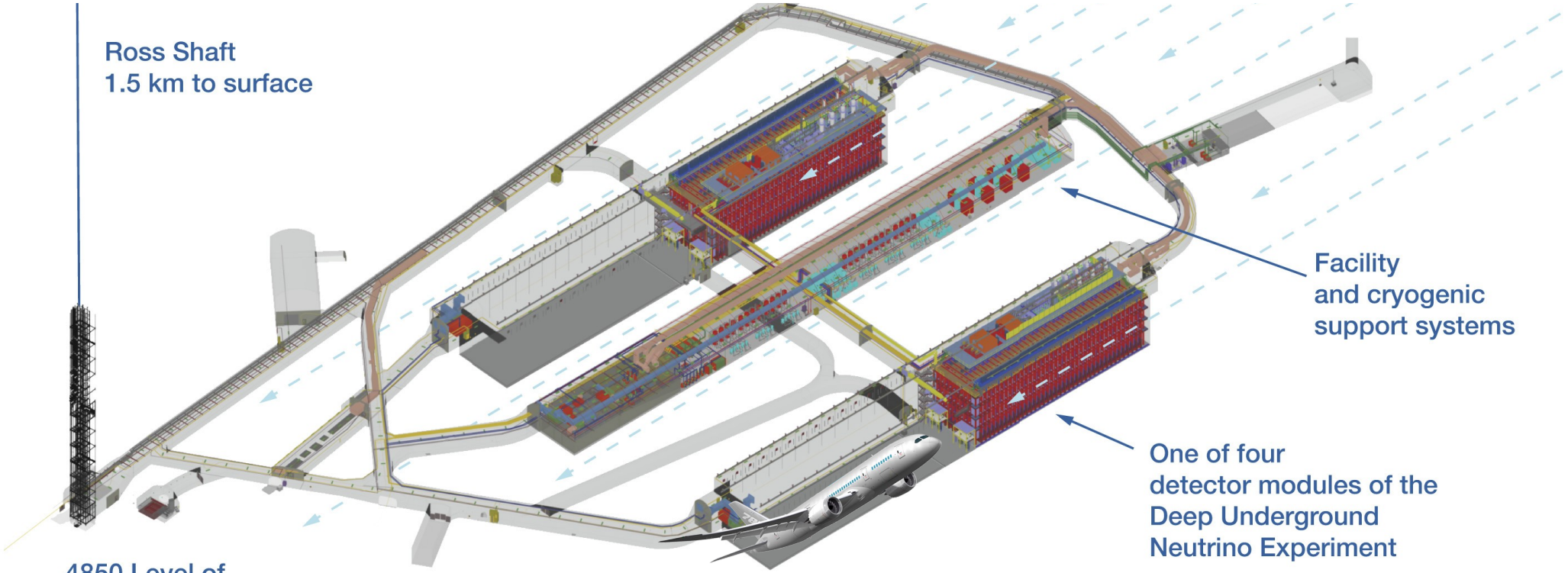
Indianapolis
Kansas City



Each module contains over 10,000 tons of liquid argon!



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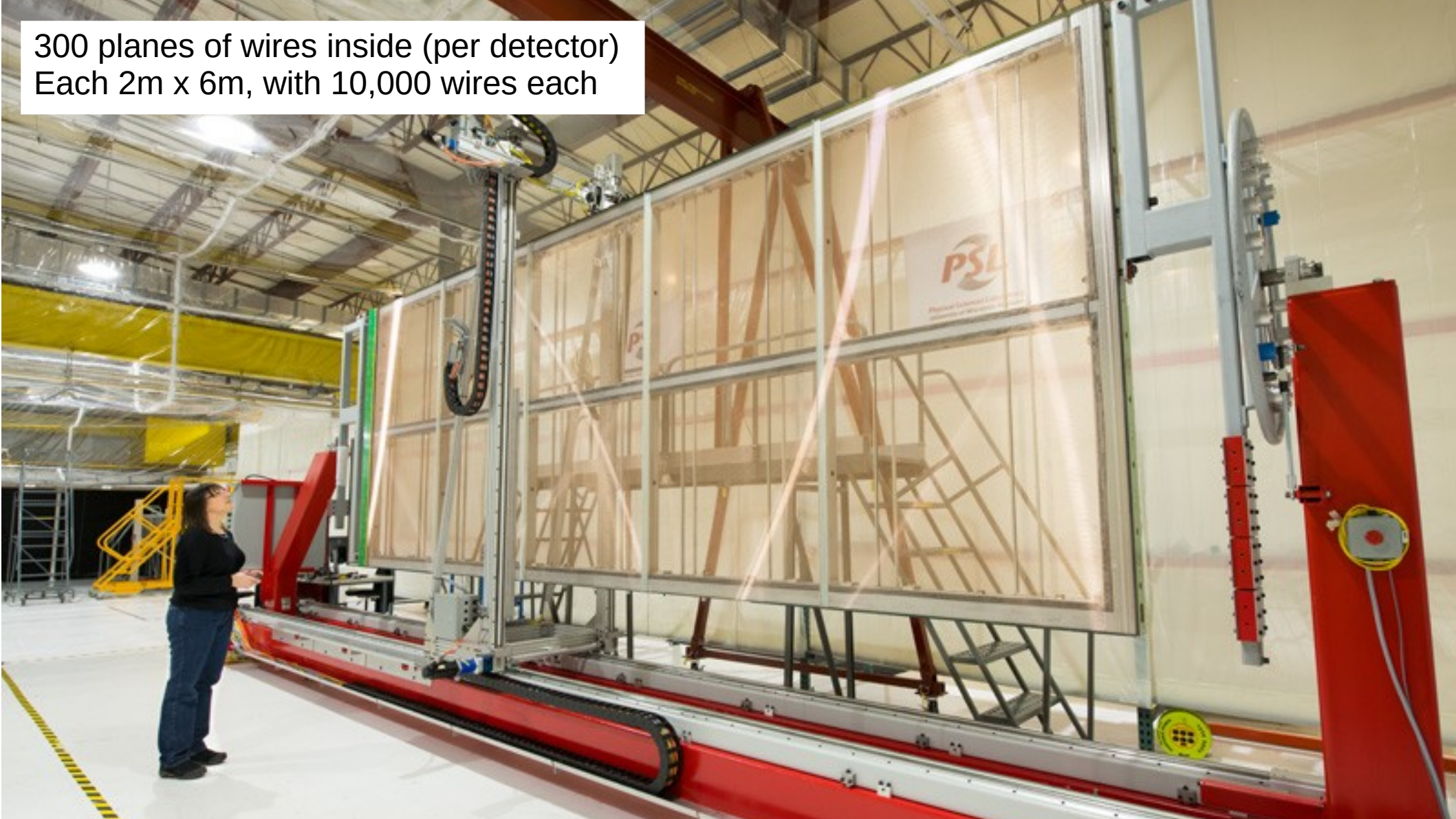
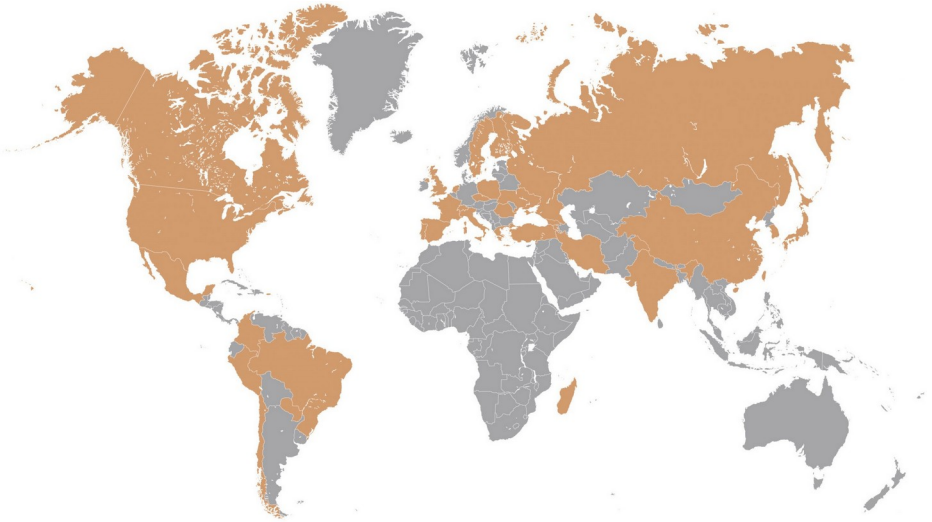
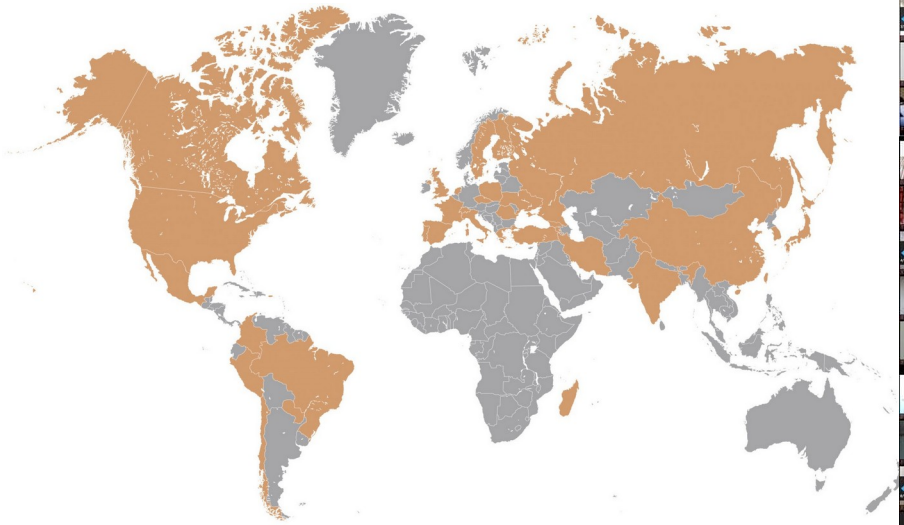
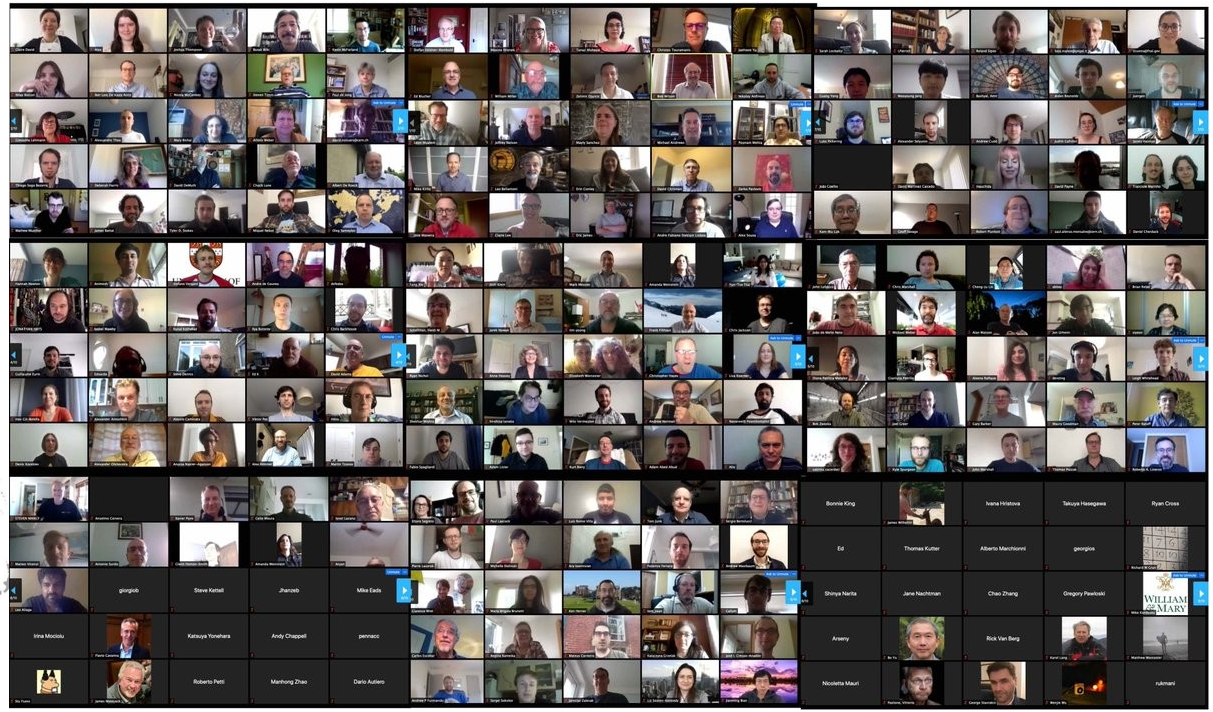

300 planes of wires inside (per detector)
Each 2m x 6m, with 10,000 wires each

The Collaboration

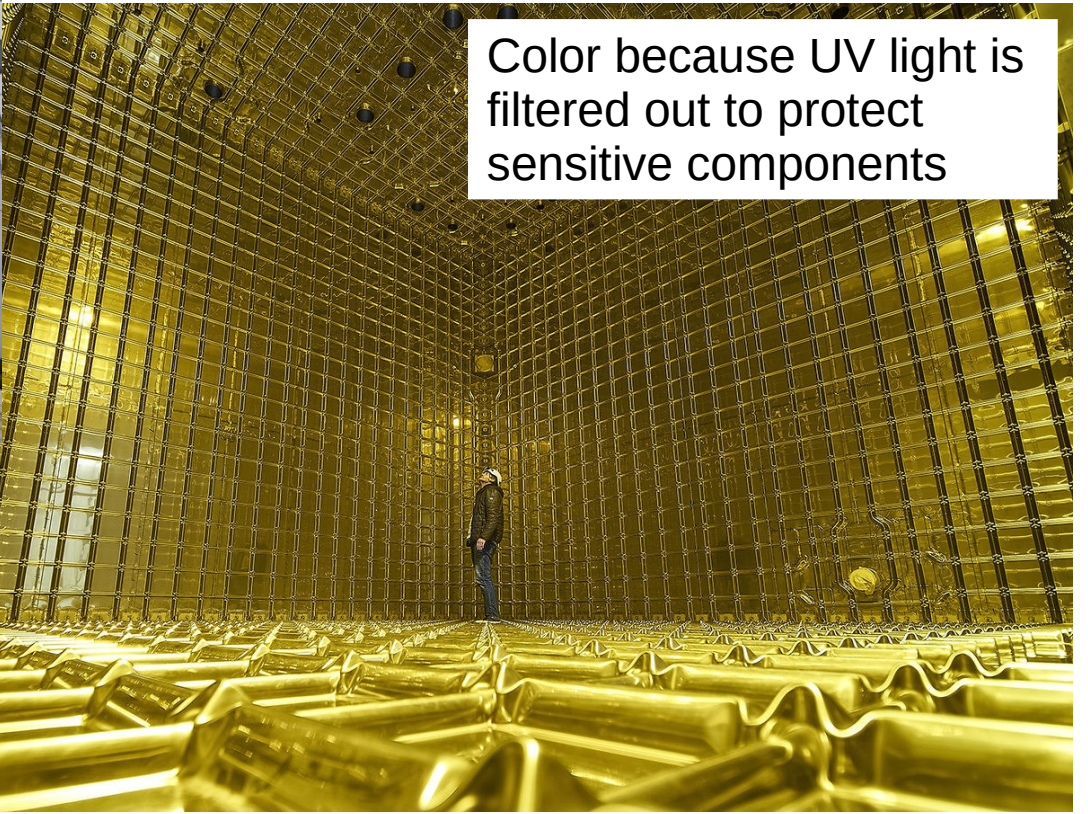


The Collaboration





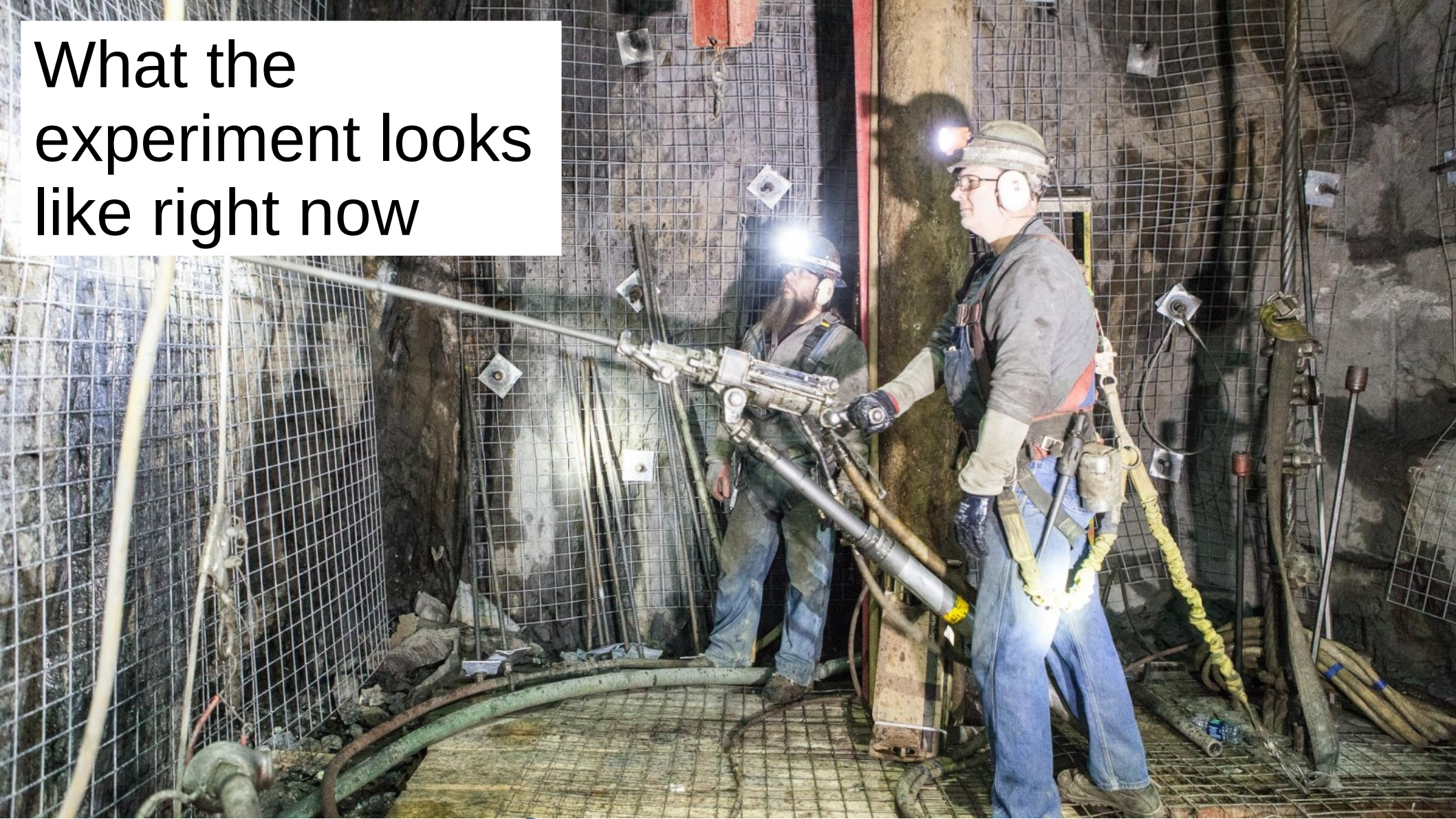
Prototyping



Color because UV light is filtered out to protect sensitive components

Prototypes built at CERN
1,000 tons each

Even the protoype detector is **huge!**


What the experiment looks like right now

DUNE in Numbers

- **40 million kg** of liquid argon
  - Created from 2.5 billion cubic meters of air!
- **1 mile** underground
- **800 miles** from the neutrino beam source
- **1000 scientists** from **180 universities and labs** in **30 countries**, covering **5 continents**!
- Turning on in **2026,** minimum **10 year** run