Art McDonald Had a Farm

EIEIOO

The 2020 QuEen's Summer PartIclE AstrophysIcs WOrkshOp

Benjamin Tam

5 May 2020

Queen's University

Arthur B. McDonald Canadian Astroparticle Physics Research Institute

SNOLAB

Congratulations on your employment!

You’re now one of us

The Golden Rules of Studying Particle Physics

1. Everything is a terribly-constructed made-up acronym.

	5/5 TUESDAY	5/6 WEDNESDAY	5/7 THURSDAY	5/8 FRIDAY	5/11 MONDAY	5/12 TUESDAY	5/13 WEDNESDAY	5/14 THURSDAY
8:00 AM								
8:30 AM								
9:00 AM	[redacted]	Unassigned	Unassigned	Unassigned	Unassigned	Basics of Chi2s & histograms (Phlippe Di Stefano)	Unassigned	Unassigned
9:30 AM		Programming for Beginners (Mark Anderson)	Computing Techniques (Mark Anderson)	Introduction to ROOT (Ian Lam)		Unassigned		
10:00 AM								
10:30 AM					Advanced Computing Tools (Ian Lam)	GePPC/Majorana (Ryan)		
11:00 AM		Lunch	Lunch	Lunch		IceCube & SBC & POne (Ken)	SuperCDMS/CUTE (Serge)	nEXO
11:30 AM							NEWS-G (Marie)	DM Indirect Detection (Aaron)
12:00 PM		Unix-based computing (Thomas McElroy et al)	C++ (Thomas McElroy et al)	ROOT (Thomas McElroy et al)	Lunch	Lunch	Lunch	Lunch
12:30 PM								
1:00 PM	Introduction to the Workshop & Particle Physics (Ben Tam)				Neutrinos(Ryan)	Giving Academic Presentations (Jenna)	Hyper-K (Blair Jamieson)	Break (STEM Stories)
1:30 PM					Dark Matter (Alex)			
2:00 PM		Break	Break	Break	Break	Break	Break	Student Presentations (Ben Tam et al)
2:30 PM	Break	Introduction to C++ (Mark Anderson)	Guided C++ Exercises (Brian Krar)	Guided ROOT Exercises (Brian Krar)	SNO+ (Mark Chen)	PICO (Colin)	KDK (Matt)	
3:00 PM	Setting up the local cluster/setting up accounts/simple UNIX navigation (Ben Tam)				DEAP (Peter)	Di Stefano Lab (Jas)	Supernovae, HALO, & SNEWS (Clarence)	
3:30 PM					Break	Break		
4:00 PM					Guided ROOT Exercises (Brian Krar)	Guided ROOT Exercises (Brian Krar)	Unassigned	
4:30 PM	Unassigned	Unassigned	Unassigned	Unassigned				
5:00 PM								
5:30 PM								

NOTES

Yellow = Tutorial Sessions for Queen's Workshop Participants

Blue = Workshops held by Queen's

Orange = Optional Lectures held by Thomas McElroy et al (McGill, IPP, etc). See sidebar for schedule

Purplish/Lavenderish/Whatever this colour is = Introductory Experiment/Research Talks held by Queen's. Open to all.

Before Starting:

Have a mac or a machine with a linux capability (partition, putty, etc)

Have completed prerequesite safety training with supervisor

All Queen's connections held over Zoom:

https://zoom.us/j/91713705122?pwd=dzBLeXNxeFpTa2NBbHlBZnlWcWhpdz09

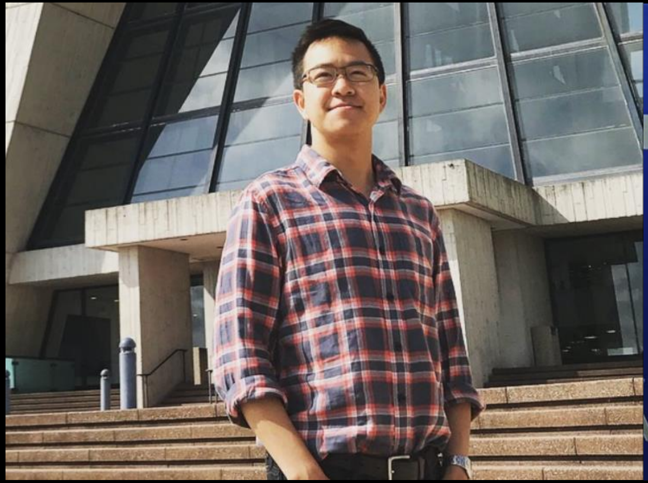
Introductory Talks - Remote Connections

Name	Date/Time	Topic
Ryan Martin	11 May - 1pm	Neutrino Physics
Alex Wright	11 May - 1:30pm	Dark Matter
Mark Chen	11 May - 2:30pm	SNO+
Peter Skensved	11 May - 3:00pm	DEAP
Ryan Martin	12 May - 10:30a	GePPC/Majorana
Ken Clark	12 May - 11am	IceCube/SBC/POne
Jenna Saffin	12 May - 1:00pm	Giving Academic Presentations
Colin Moore	12 May - 2:30pm	PICO
Jasmine Corning	12 May - 3pm	Di Stefano
Serge Nahony	13 May - 11am	SuperCDMS/CUTE
Marie Vidal	13 May- 11:30am	NEWS-G
Blair Jamieson	13 May - 2:30pm	Hyper-K
Matt Stukel	13 May - 2:30pm	KDK
Clarence Virtue	13 May - 2:30pm	HALO/SNEWS
Caio Lucciardi	14 May - 11am	nEXO
Aaron Vincent	14 May - 11:30a	DM Indirect Detection

Thomas McElroy - Optional Parallel Lectures

Lecture	Time	Speaker
UNIX & HPC	6 May 12:00 PM	Thomas McElroy
C++	7 May 12:00 PM	Sumanta Pal
ROOT	8 May 12:00 PM	Chris Jillings
GEANT4	11 May 12:00 PM	Aleksey Sher
Python	12 May 12:00 PM	Pietro Giampa
LabVIEW	13 May 12:00 PM	Chris Chambers
PyROOT	13 May 4:00 PM	TBA
SolidWorks/CAD	14 May 12:00 PM	Xiao Shang
Statistics/Error Analysis	15 May 12:00 PM	Scott Oser

Instructors:



Ben

PhD Candidate
benjamin.tam@queensu.ca

Coronavirus is the only reason he’s not underground

Ian

PhD Candidate
ian.lam@owl.phy.queensu.ca

Rene Brun (ROOT founder) has him on speed dial

Mark

PhD Candidate
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Basically invented machine learning

Brian, M.Eng

MSc Candidate
brian.krar@queensu.ca

Always manages to find other peoples mistakes

Purpose of EIEIOO: The **RADIATE** Goal

1. **RA**mp up to analysis-ready state
2. **D**evelop F**I**eld-specific norms
3. **A**ccumulate Physics Knowledge
4. **T**otally make friends or something idk
5. **E**tc...

Analysis Skills...

1. Linux & Unix-based cluster computing
2. LaTeX
3. Academic Presentations
4. Scientific Cluster Usage
5. C++
6. ROOT
7. Scientific Computing

And others!! (Optional Parallel Sessions)

The Golden Rules of Studying Particle Physics

1. Everything is a terribly-constructed made-up acronym.
2. **Use a Unix-based system**
3. **Make all documents in LaTeX**
    1. **Seriously, don’t use Word**
    2. **Like ever**

Actual Skills…

1. General introduction to background, terminology, etc
2. Don’t try to memorize everything
3. Good to start recognizing the lingo & experiments
4. Get comfortable with potential people to use as resources

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Guest Lecturers...

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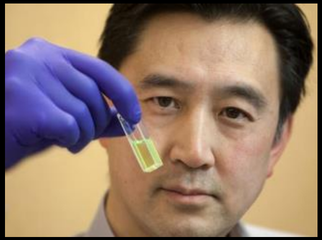











Making the most of this workshop...

1. Wake up in time (hard right now lol)
2. Ask lots of questions. Aim to ask at least 3 questions per day.
   Interrupting the speaker is encouraged
3. Help each other on exercises (nobody is being graded on a curve... or graded)
4. Bug the hell out of instructors/supervisors/guest lecturers/anybody pretending they know what they're doing
5. If you're zoning out, let the instructor know

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5. **Ask lots and lots of questions**
6. **Remember everybody is better at you at something (but you’re better than something compared to each person as well)**

Before you panic about student presentations...

1. Very Casual
2. 3 Slides:
    1. Title Slide
    2. A slide about yourself (2 minutes)
    3. A slide about what you’re working on this summer (2 minutes)
3. As much detail as you want (or know).
4. No Grilling!

Remember...

The Workshop isn’t to access your skills. There is no exams or points or exams. Some people come from no background in coding/physics. The point is to get everybody able to contribute to their experiments as soon as possible.

This isn’t school. Many of you are now part of massive multi-million dollar collaborations with hundreds of professors who rely on you.

The things you do this summer will have lasting impacts on all science. The more you take away this week, the more glory your name will carry for decades to come...

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4. Everybody is extra friendly so it's weird if you're not
5. Ask lots and lots of questions
6. Remember everybody is better at you at something (but you're better than something compared to each person as well)
7. **Giving a shit will get you 80% of the way (this can be hard).**

EIEIOO
Introduction to Particle Physics

Benjamin Tam

5 May 2020

Queen's University

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Particle Physics

The Study of stuff that makes up the Universe

Two types of particle physics...

Collider Physics:

- Create weird particles by smashing boring ones together
- Good for creating heavy particles
- eg. CERN

Particle Astrophyiscs:

- Letting weird particles from space smash into you
- Good for seeing rare stuff we can't make with colliders yet
- eg. SNOLAB

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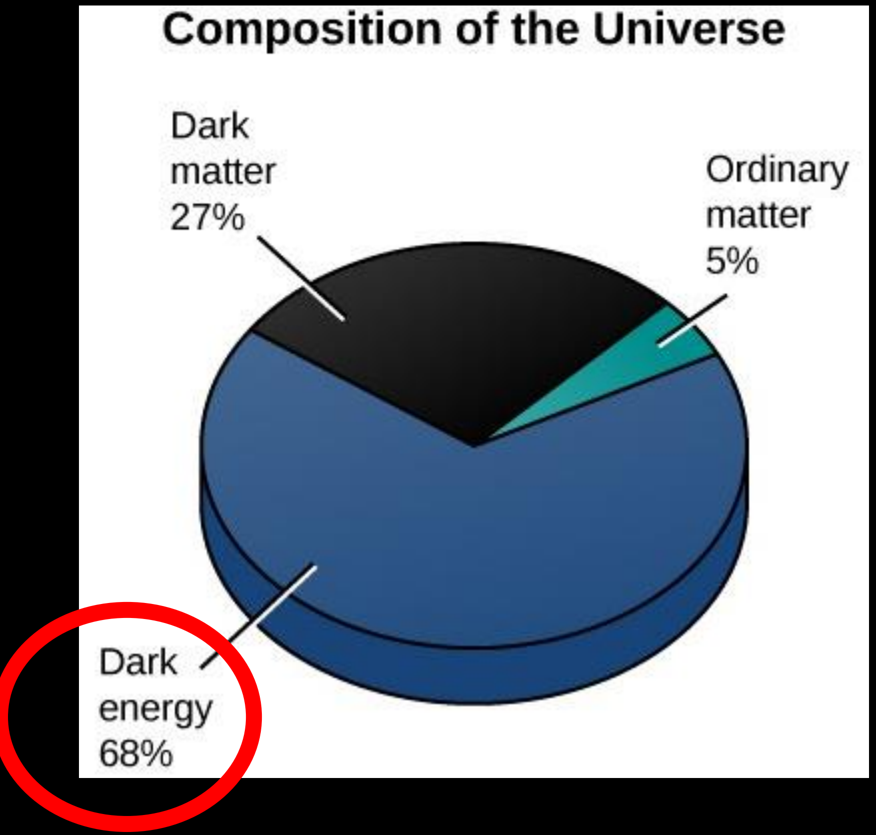
What do we know about the Universe?

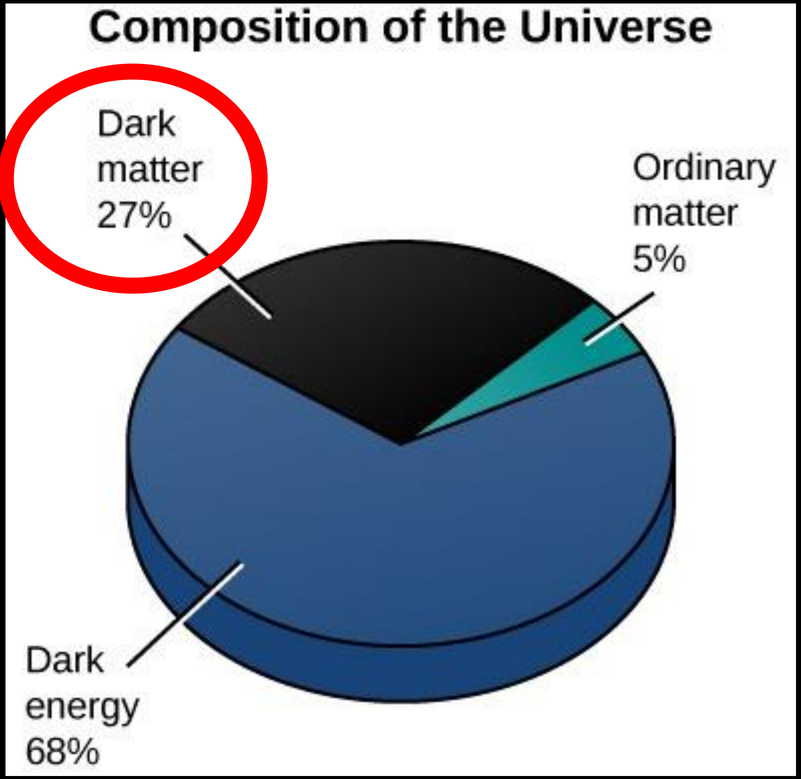


Dark Energy (~68%)

- Universe is expanding at an increasing rate
- The “Energy” responsible for this expansion is called Dark Energy (2011 Nobel Prize)
- We don’t now anything about it.

...yep that’s about it.

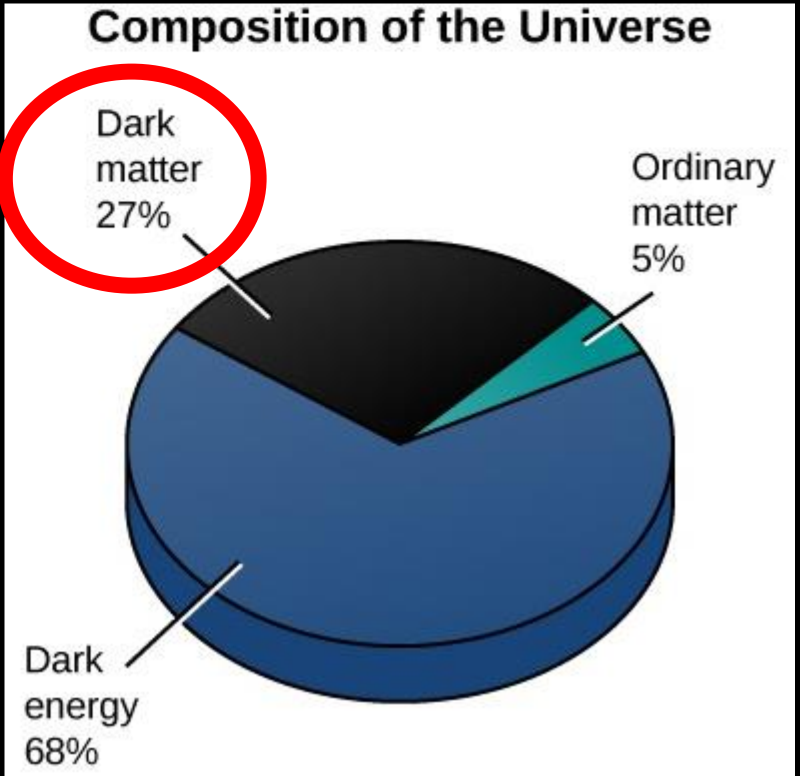
What do we know about the Universe?



Dark Matter (~27%)

- A majority of the galaxy has gravity we can’t account for by regular matter (eg stars, etc)

What do we know about the Universe?

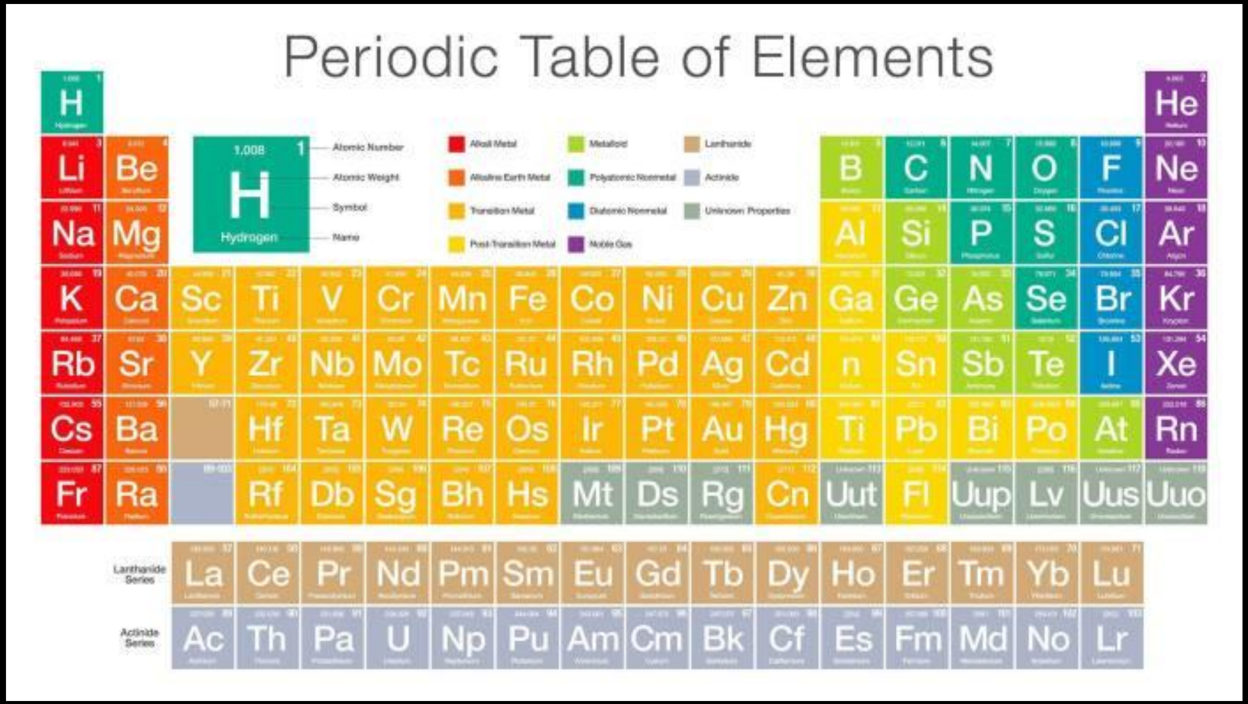


Dark Matter (~27%)

- A majority of the galaxy has gravity we can't account for by regular matter (eg stars, etc)
- idk probably a particle lmao
- On the cusp of figuring this one out (including what some of you will be working on)
- The race is on to find it first...

Ordinary Matter

The most important component because it’s what you’re made of <3
Has been puzzling everybody for millennia



Modern Atomic Theory: The Atom

The Elements are made up of atoms.

Each atom has a nucleus made up of protons and neutrons and has 3 distinctive numbers:

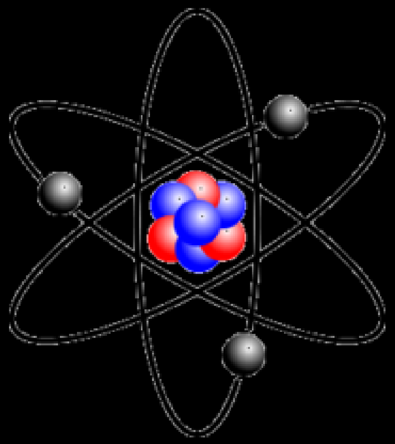
Z = # protons. Unique to each element.

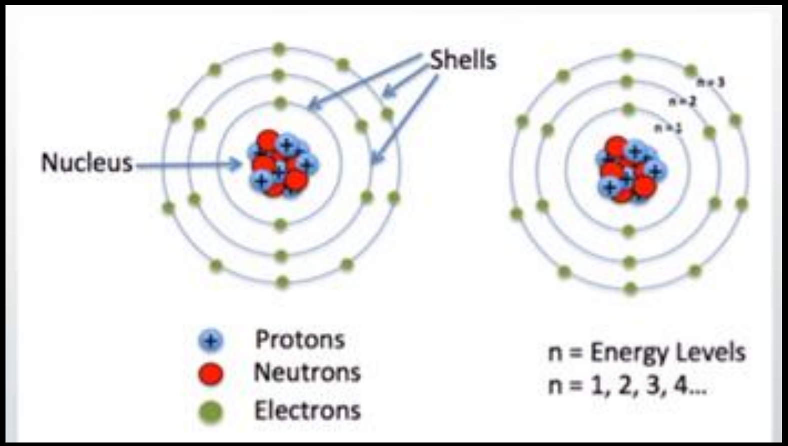
N = # neutrons.

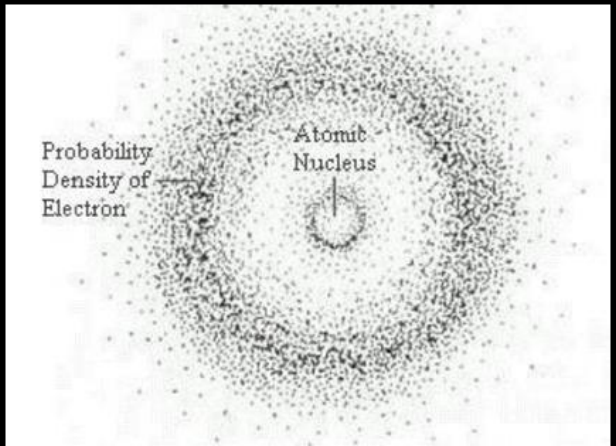
A = Z + N = The Atomic Mass Number

Each element has a unique Z, but may have different Ns (resulting in different As). These differences in mass numbers are the atomic Isotopes.

The nucleus is surrounded by a cloud of electrons that can be imagined as shells







Modern Atomic Theory: Special Relativity

Special Relativity Crash Course:

- The speed of light c = 3 x 10^8 m/s is the universal speed limit. When things move near the speed of light, spacetime itself grows to make sure the object doesn’t exceed it.

- If you are stationary on a train moving at 0.9 m/s and throw a baseball at 1 m/s...
  - You see the ball moving at 0.9 m/s
  - An outside observer sees the baseball travelling at 1.8 m/s.

- If you’re stationary on a (very fast) train moving at 0.9c and throw a baseball (very hard) at 0.9c...
  - You see the ball moving at 0.9c
  - An outside observer *does not* see the ball moving at 1.8c.
  - Space and time actually expand such that in every reference frame, the ball is moving at less than 1c.

The math to figure out how space (length) and time change is not challenging – it’s just a factor (The Lorentz Factor) you slap to adjust for the different speeds.

Modern Atomic Theory: Special Relativity

Special Relativity Crash Course:

- Takeaway: when things move near the speed of light, their properties change based on your reference frame.

- Since particles are very light relative to every day objects, they are relativistic – they travel near the speed of light, which warps their properties. Therefore, frames of reference are very important.

- Something neat: the speed of light in a vacuum is *always exactly* c, regardless of the frame of reference.

- The Rest Mass of a particle is $E = mc^2$. This is the mass in a frame of reference that the particle is stationary.

- $E=mc^2$ implies that Mass and Energy are interchangeable! Also, it makes math a lot cleaner if you "re-cast" all of the units such that the speed of light $c = 1$.

Modern Atomic Theory: The Electron Volt

- Masses of elementary particles are small AF compared to every day objects. SI units (kg, J, etc) just don't cut it.
- Makes more sense to.. talk about energies in units of electron-volts (eV). 1 eV is the energy an electron gains by travelling across an electric potential of 1V. 1eV = 1.602×10^{-19} J

eg. The proton has a rest mass of 1.66×10^{-27} kg = 9314940954 eV/c2 = 9.31 MeV/c^2 = 9.31 MeV (c =1)
1 eV = super duper light
511 keV = rest mass of electron
0.8 MeV = The lightest particles the SNO+ detector can reliably see
9.31 MeV =Rest mass of the proton
1-100 GeV = Mass range we think dark matter might be
173 GeV = Rest mass of the heaviest fundamental particle
10^{12} eV = Most energetic particle ever created by humans (Large Hadron Collider)
10^{20} eV = Most energetic particle ever detected. (Rest mass + kinetic energy)

Modern Atomic Theory: Quantum Mechanics

Crash course on Quantum Mechanics:

- Classical (Newtonian) physics is good enough for our size scales, but doesn’t explain a things at the small scale.
- Quantum Mechanics explains nature at both the small and every-day scale.
- Basically, everything is made up of discrete, indivisible units.
    - ie. they’re quantitatively countable
    - ie. they’re quantized.
    - The units are the elementary particles.

- Interactions are governed by exact, never-violated conservation laws.
    - Conservation of mass-energy
    - Conservation of matter
    - Conservation of linear momentum
    - Conservation of angular momentum
    - Conservation of electric charge
    - A few others we’ll worry about later.

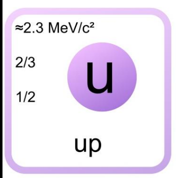
Elementary Particles also have a “spin” - their intrinsic angular momentum.

Modern Atomic Theory: Elemental Constituents

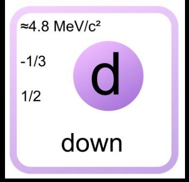
Elements are made of Atoms:

- Protons: Spin = ½, Charge = +1
- Neutrons: Spin = ½, Charge = 0
- Electrons: Spin = ½, Charge = -1

Turns out the Proton and Neutron isn't actually fundamental, but made up of even smaller subatomic particles called Up and Down.

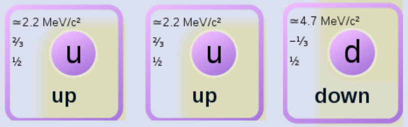


- Up: Spin = ½, Charge = +2/3



- Down: Spin = ½, Charge = -1/3

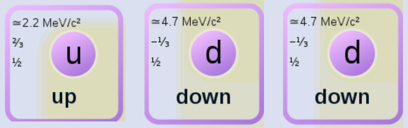
Proton



Charge conservation:

2/3 + 2/3 – 1/3 = +1

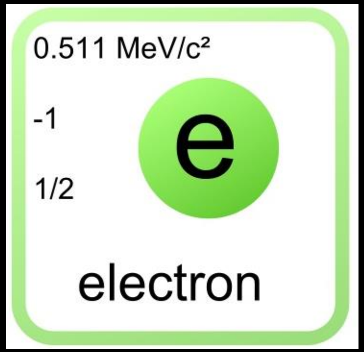
Neutron



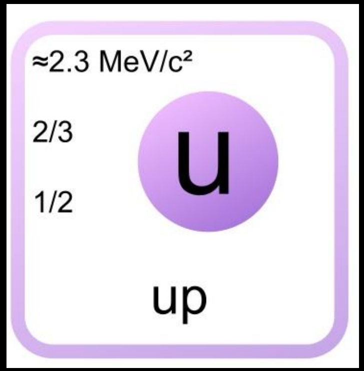
2/3 – 1/3 – 1/3 = 0

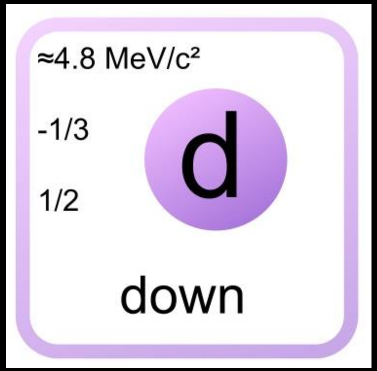
The Elementary Particles

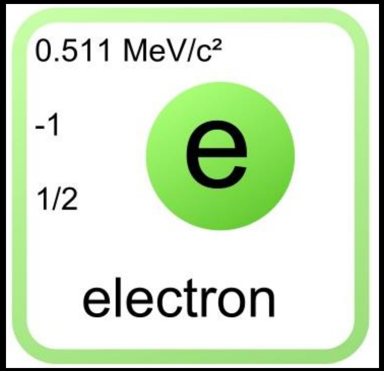
Turns out Electrons are fundamental...



So we have the 3 elementary particles that make up the periodic table of the elements!








MISSION ACCOMPLISHED

Example particle interaction: Beta Decay

Let's turn a neutron into a proton. Since a neutron has a higher mass than the proton, this is a **Spontaneous Decay** – that is, it is energetically allowed.

$$n \rightarrow p$$
$$0 \quad\quad 1$$

Due to **Charge Conservation**, it also has to release an electron

$$n \rightarrow p + e-$$
$$0 \quad\quad 1 \quad -1$$

Electrons used to be called beta particles, hence the name "beta decay".

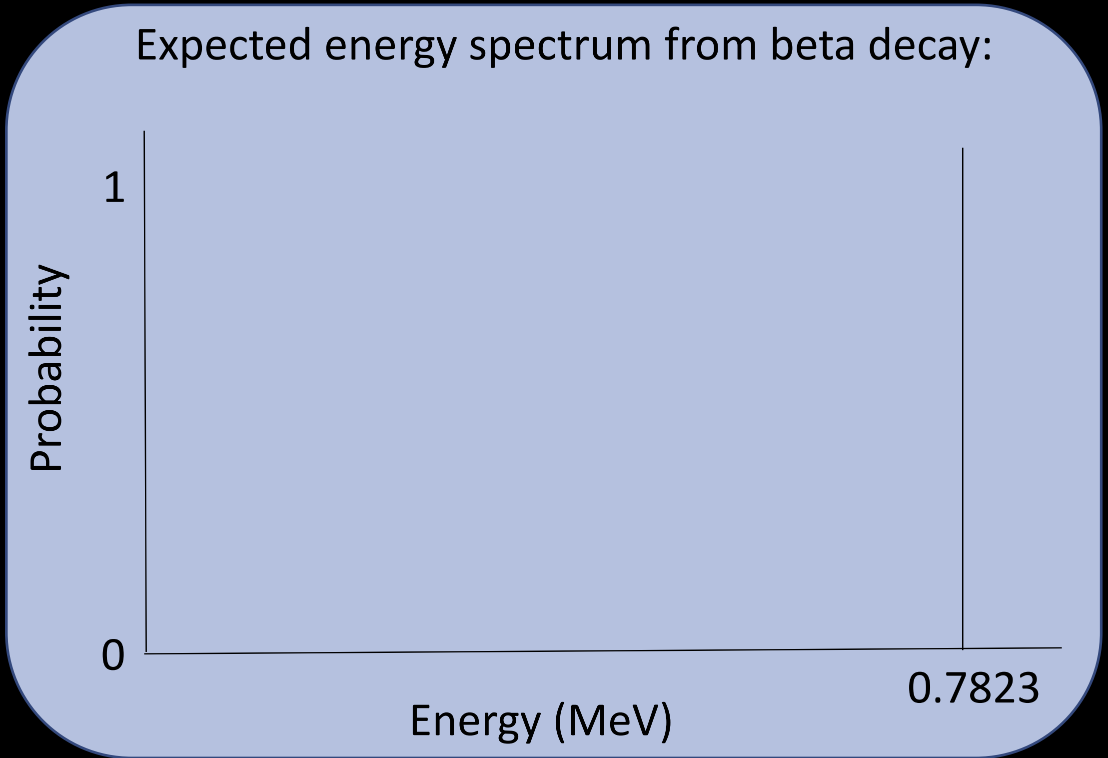
We also need to take into account **mass-energy conservation**, where the before and after mass+energy has to be equivalent.

$$n- \rightarrow p + e^{-} + 0.7823 \text{ MeV}$$

The excess energy is the Q-value – each type of decay has a signature Q-value.

The Q-Value

- The Q Value is unique for each decay. Again, it's the E difference between parent and daughter products.
- The larger the Q value, the more likely the decay is to happen.
- The daughter products of each decay must have exactly the Q value.
- **Beta decay** has a Q Value of 0.7823 MeV. The proton has 2000x the mass of the electron, so virtually all of the energy is carried away by the electron due to **Conservation of Momentum.**
- If we look at many beta decays, we can measure the energy of the electron and build a histogram called the energy distribution of the decay. It should look like this.



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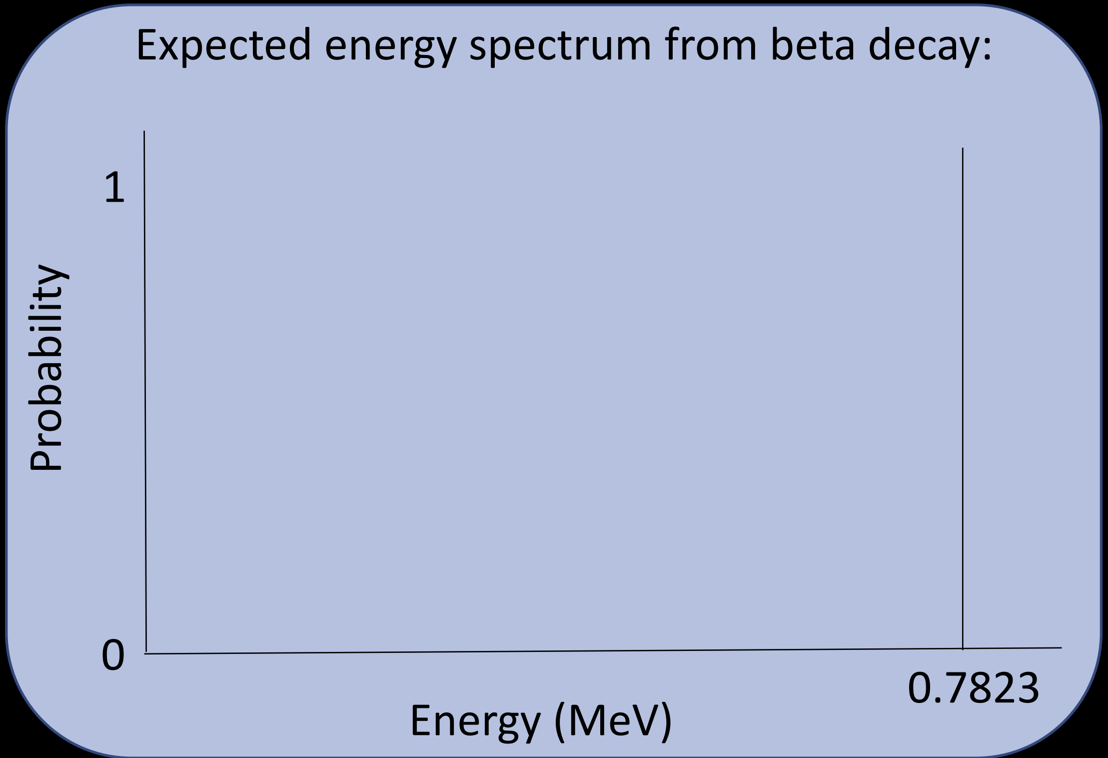
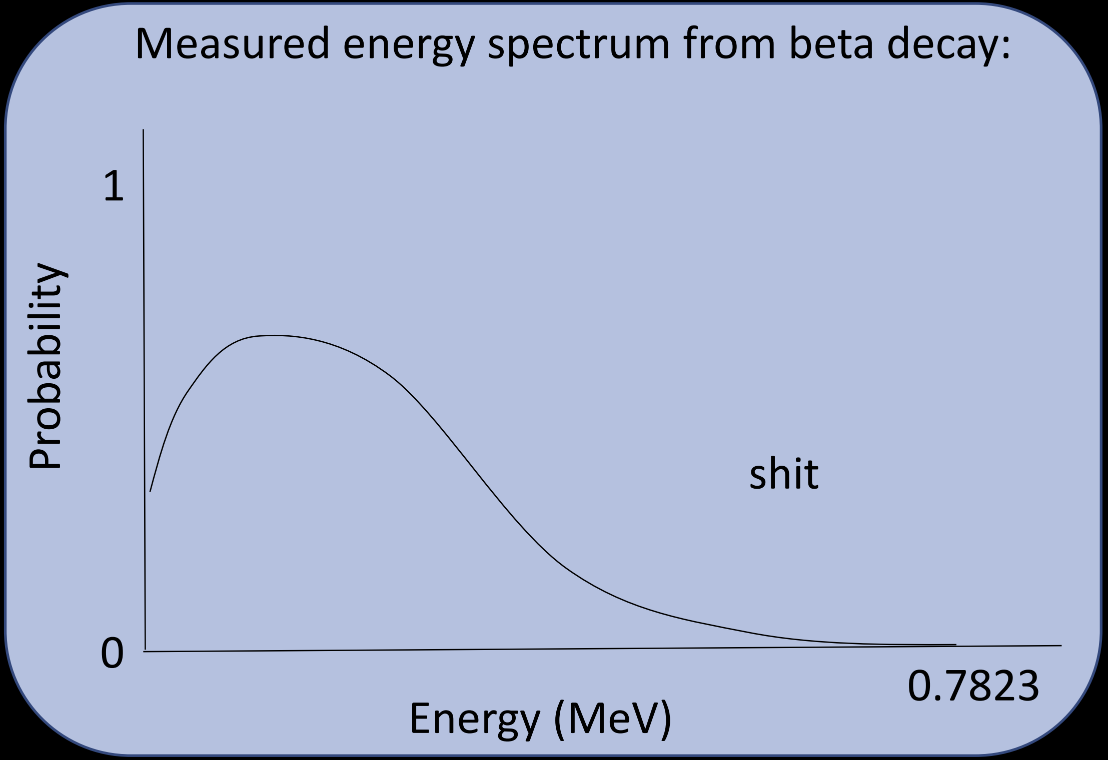




Continuous Energy Distribution???

Wolfgang Pauli: "OK OK OK OK what if we made up a new, impossible to see, ultra tiny particle that rarely if ever interacts with anything, that can carry away excess energy, and be electrically neutral, and solve all of our problems."*

Italians like Enrico Fermi: "Yeah sure whatever if we call it something cute and Italian people won't ask too many questions about this make-belief catch-all problem solving tiny neutron. Like a neutrino."*

*They actually sorta had this conversation

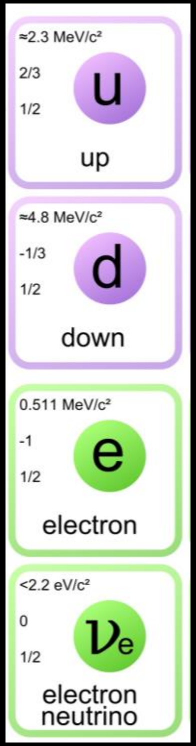
Beta Decay is therefore

$n \rightarrow p + e^- + \nu + 0.7823$ MeV

The made-up particle is also very light, and carries away a random amount of energy in each decay. The electron carries away the rest. Hence why if you measure many beta decays, the electron can take on many energies.

The Elementary Particles (Final)

So we have the ~~three~~ four fundamental elementary particles.

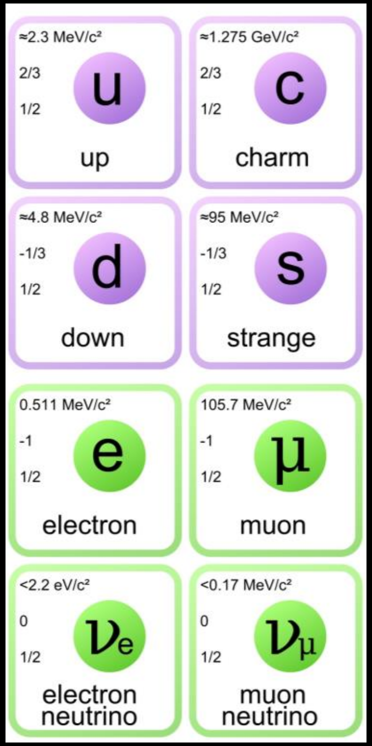


"The Gang discovers more elementary particles"

The Elementary Particles (Final_Final)

- Each particle has a heavier version.
- This “second generation” is heavier and spontaneously decays to the first generation

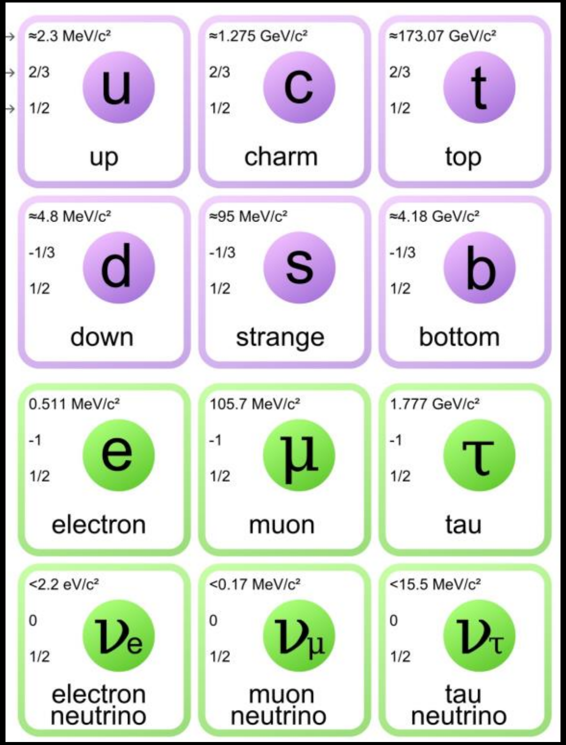
So we have the ~~three~~ ~~four~~ eight fundamental elementary particles.



The Elementary Particles (Final_Final_Actually)

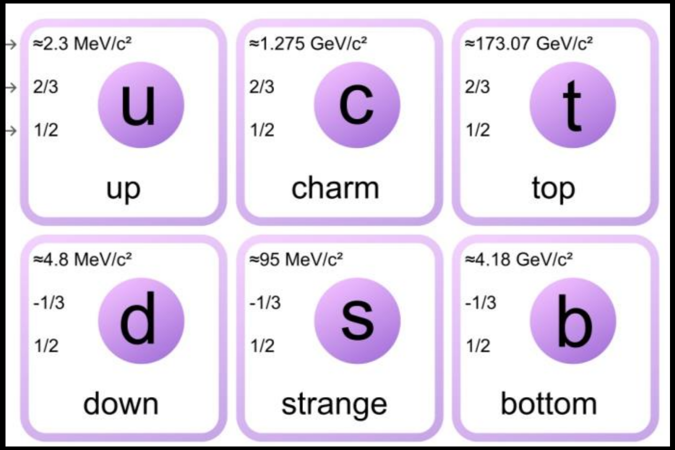
Aaaaand there's also a third generation.

So we have the ~~three~~ ~~four~~ ~~eight~~ nine fundamental elementary particles.



The Quarks

- The particles that make up composite particles (ie proton, neutron) are called Quarks
- The composite particles themselves are called Hadrons
- There are two types of Hadrons.

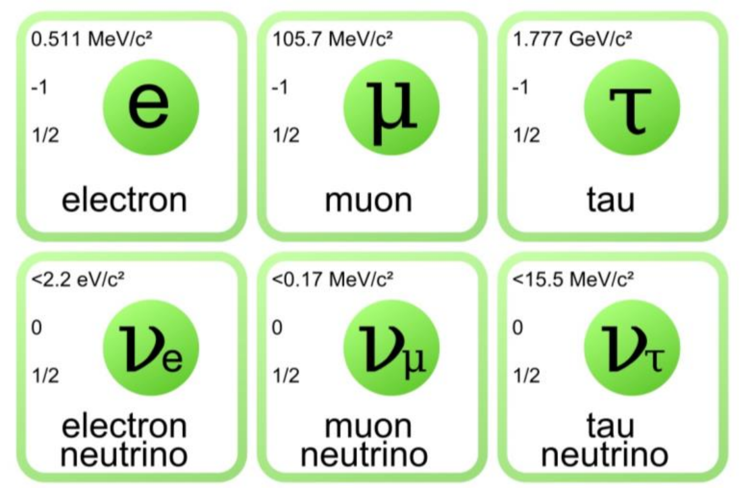


- 3 Quarks = “Baryons”
- 2 Quarks = “Mesons”

- Quarks stick together even if they have like electromagnetic charges
  - This is due to some strong force in the nucleus.
  - It’s called the **nuclear strong force**.

The Leptons

- The other elementary particles can't interact through the Strong Nuclear Force
- They can't make composite particles and are lept behind.
    - That's definitely why they're called Leptons.



- They interact through a nuclear force that is weaker than the Strong Nuclear Force
- It's called the **Weak Nuclear Force**

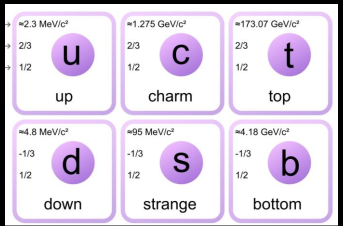
Anti-matter

- Each of the 12 particles have an anti-version of itself
- The anti-version is the exact same in every way except with an opposite electric charge

- When a particle and anti-particle interact, they destroy itself (pair annihilation)
- When a particle is created, its antiparticle is also created.

- An antiparticle is symbolized using an overhead dash:

Up Quark:	Particle	u
Anti-Up Quark	Anti-Particle	$\bar{u}$



Baryon Number Conservation

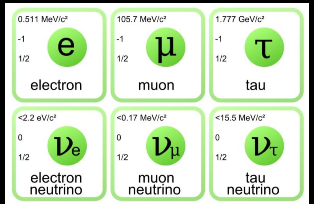
- Baryons (3-quark composites) are assigned a value per particle.

Baryon = 1
Anti-baryons = -1

This is the Baryonic Number. The Baryon number is conserved.

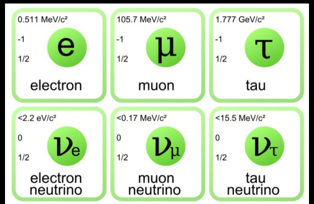
“Baryon Number Conservation”

Third Grader: Matter cannot be created or destroyed
Big Brain You: Uhm acktually, Net Baryonic matter cannot be created or destroyed.



Lepton Number Conservation

- Here’s an interesting thought: if neutrons have 0 charge, what’s the difference between neutrinos and anti-neutrinos?



Lepton Number Conservation

- Here's an interesting thought: if neutrons have 0 charge, what's the difference between neutrinos and anti-neutrinos?

- Uhm uhhh ummmm okay if baryon number is conserved, lepton number is probably also conserved.
- All leptons have a lepton number of 1, anti-leptons have a lepton number of -1
- This totally legitimate and 100% believable line of logic gives us

"Lepton Number Conservation"

So back to beta decay:

$$n \rightarrow p + e^- + \nu_e + 0.7823 \text{ MeV}$$

0 0 1 1

Should really be

$$n \rightarrow p + e^- + \overline{\nu}_e + 0.7823 \text{ MeV}$$

0 0 1 -1

The Fermions

- The fundamental particles obey Fermi-Dirac Statistics because they have half-integer spins
- You can picture spin as its inherent angular momentum.
- Quarks and Leptons collectively called the Fermions (lol Dirac got shafted)

$$F(E) = \frac{1}{e^{(E-E_f)/kT} + 1}$$

Quantum Properties described by the Dirac Equation

$$i\partial\psi - m\psi = 0$$

It’s math mumbo jumbo, let’s move on (sorry theorists)

The Fundamental Forces

The Fermions interact with each other through the fundamental forces...

1. The Electromagnetic Force
2. The Strong Nuclear Force -> Quarks Only
3. The Weak Nuclear Force -> Leptons Only

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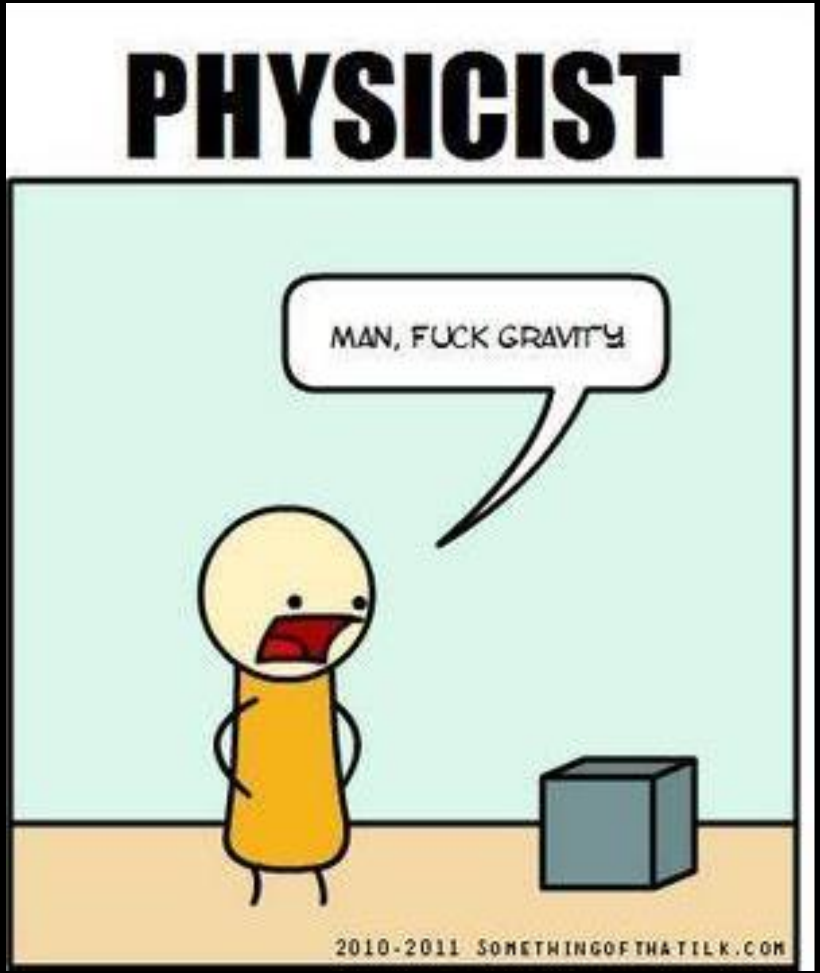


But they were all of them deceived, for a 4th force exists

4. Gravity

We have no idea how Gravity works.

The Bosons

Forces are transfers of information. This information is carried through messenger “mediator” particles.

- The Electromagnetic Force mediator is the **Photon**
- The Strong Force mediator is the **Gluon**
- The Weak Force has 3 mediators, since they can affect the charges of particles
    - The **Z** (neutral)
    - The **W+** (Charge = +1)
    - The **W-** (Charge = -1)

These particles have whole-integer spins and obey Bose-Einstein statistics
Called the **Bosons** because Einstein has enough time in the spotlight already.

Other Bosons

The Higgs Boson mediates mass Interactions between particles

It’s very heavy and therefore decays very quickly, making it hard to find

The Graviton: Probably what we’d call the mediator for Gravity. If it exists it’ll probably be massless since gravity exchanges information at the speed of light.

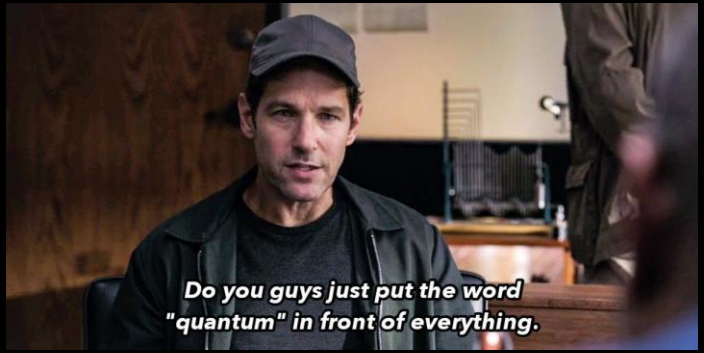
Jedi Business

Three fields of study investigate the fundamental Forces...

Quantum Electrodynamics (QED)is the study of the EM Force

Quantum Chromodynamics (QCD) is the study of the gluon

Quantum Flavourdynamics (QFD) is the study of the weak force



At certain energy levels, the forces merge into one.

The EM and Weak forces merge into the Electroweak force at about 250 GeV

The EM, Weak, and Strong force hopefully merge at (probably) around 10^{25} eV

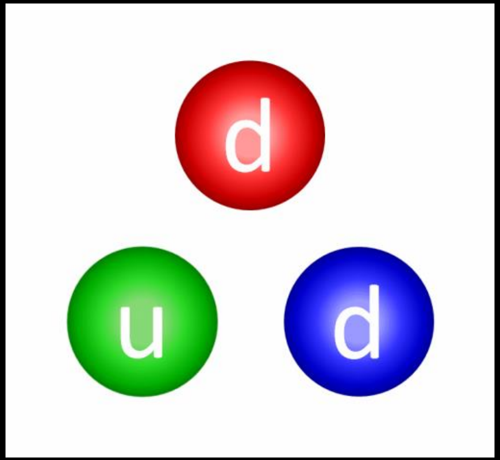
“Grand Unification”

...This is a work in progress.

Quantum Chromodynamics

The Gluon comes in 3 varieties (and anti-varieties), named after the 3 primary colours

- Red (anti-red)
- Green (anti-green)
- Blue (happiness)



The colour of each gluon is the "Colour Charge"
Particles with a net colour charge of 0 (equal red, green, blue) are stable
Colour is conserved in the **Conservation of Colour**.

The Great Symmetries

Symmetries are physical features that are unchanged when a system undergoes some operation or transformation.
Symmetries are assigned a property of “1”. If the symmetry is reversed (‘flipped’), the symmetry property goes from 1 to -1.

Particle Physics has three great symmetries: CPT

- **C**harge Conjugation: When a particle flips to their antiparticle, their charge must also flip
- **P**arity: When a particle is reflected, their positions are also flipped
- **T**ime Reversal: Regardless if a particle goes forwards or backwards in time, it stays the same.

Symmetry Violations

The Weak Nuclear Force violates C and P

Products of conservation laws may also be considered...

CP is not conserved: Quarks can change from one flavour (aka type) to another.
They “mix” – governed by a matrix called the CKM matrix.

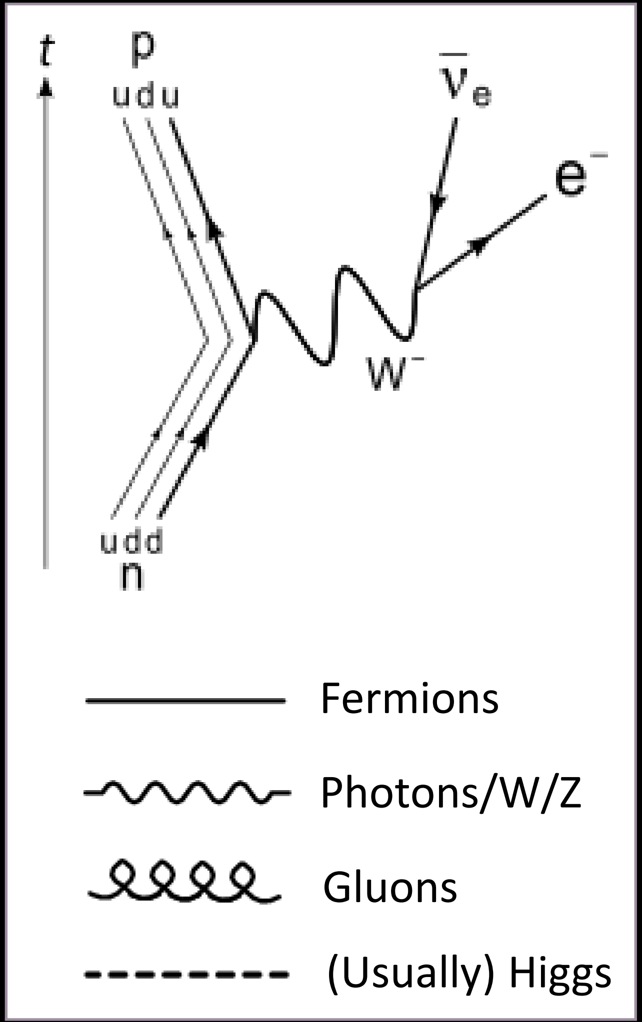
The only exact conservation law is CPT Conservation

Feynman Diagrams

Feynman Diagrams are the standard way to illustrate particle interactions
It shows the point of interactions, the original/final products, the boson that mediates the interaction, and visibly demonstrates preservation of conservation laws.

eg Back to Beta Decay: $n \rightarrow p + e^- + \bar{\nu}_e + 0.7823$ MeV

- Every vertex preserves charge, charge, colour, lepton/baryon number, etc
- Typically time goes from bottom to top, or from left to right
- Antiparticles go backwards in time
- Bosons are squiggly lines (different squiggles based on boson)
- Good form: draw diagrams with maximum 3 lines per vertex.



e.g. Pair Annihilation

$e^- + e^+ \rightarrow 2\gamma$

Note: e^+ is a positron (aka anti-electron)

e.g. Pair Annihilation

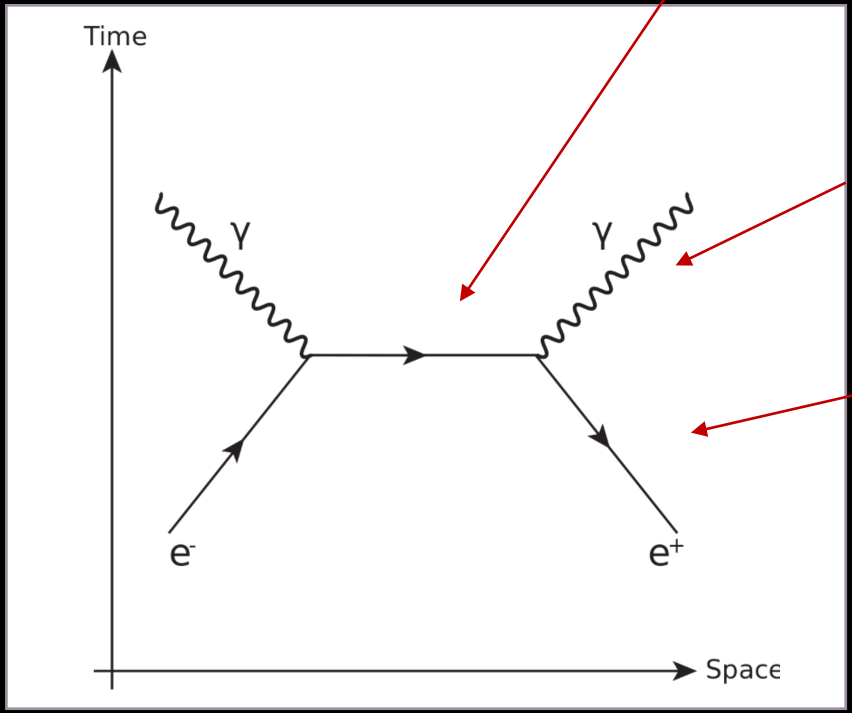
$e^- + e^+ \rightarrow 2\gamma$

Note: e^+ is a positron (aka anti-electron)

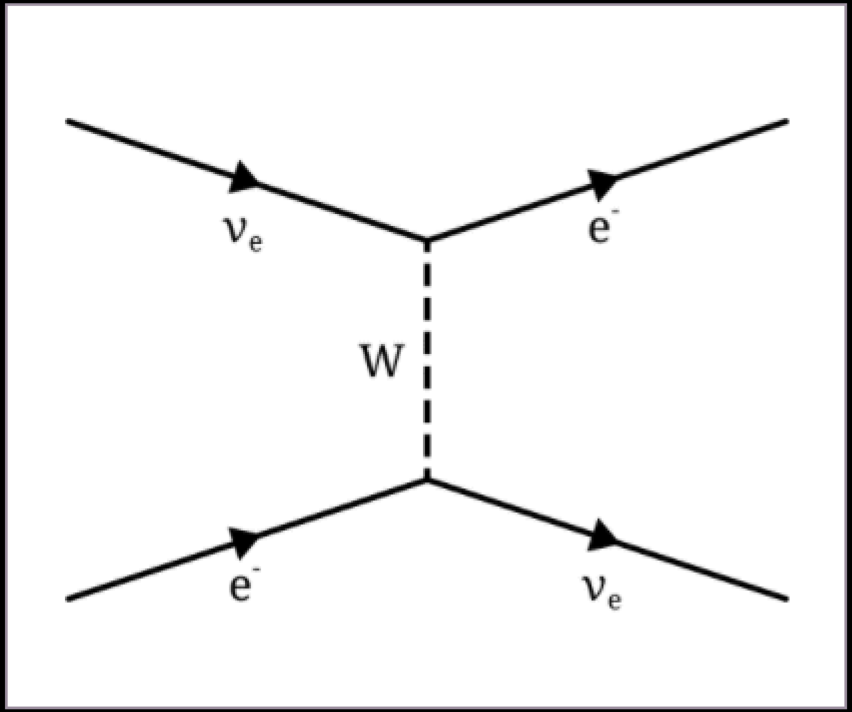
This is a virtual particle – it only exists as a 'ripple' during the interaction

Photons (aka EM radiation aka light) released in this interaction

Antielectron goes backwards in time



e.g. What's going on here?



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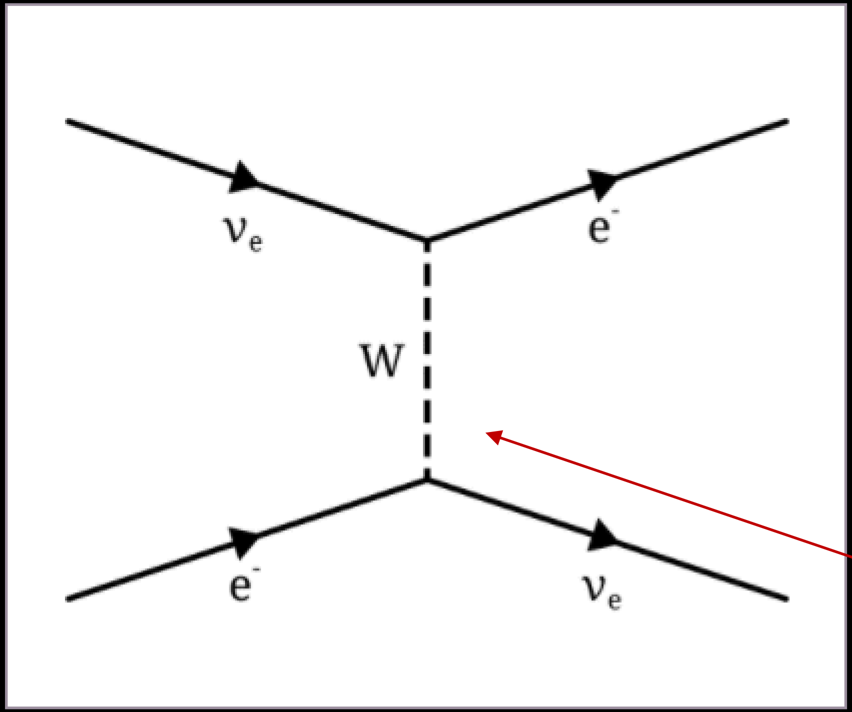


$e^- + \nu_e \rightarrow e^- + \nu_e$

This is Elastic Scattering!

Equal probability W^+ and W^-, so W is sufficient

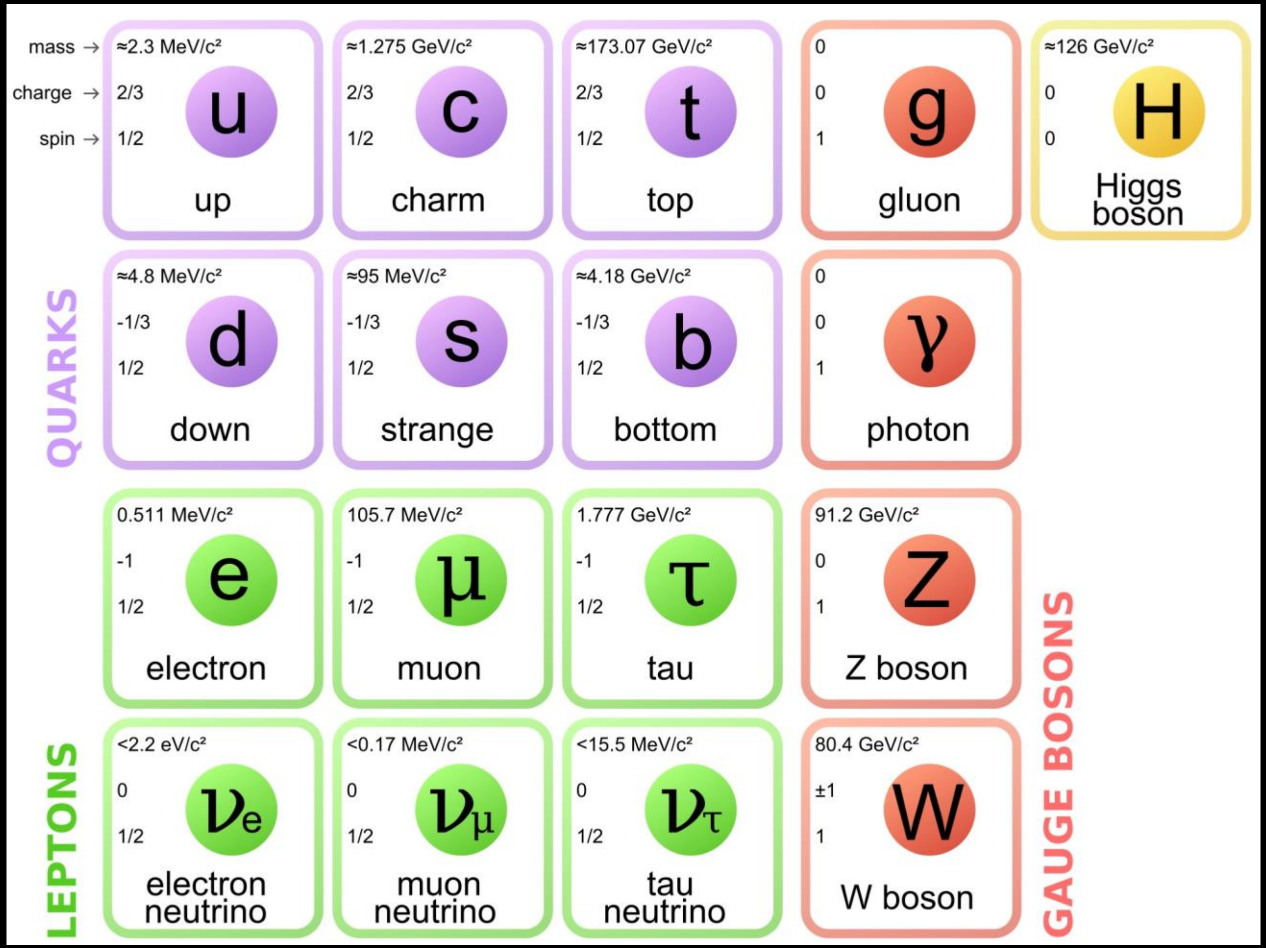
W^+ Case: The boson goes downwards to preserve charge at each vertex

W^- Case: The boson goes upwards

The Standard Model of Particle Physics

- Fermions: Every fundamental constituent of ordinary matter
- Bosons: How the fermions interact with each other
- Conservation Laws
- Works at micro and macro scales
- Speak the language of Quantum Physics
- Relationship between EM, Strong, Weak
- Fuck Gravity

Final "current" form finalized between 50s-70s, experimentally completed in 2012 with discovery of the Higgs Boson



"The Standard Model is the most complete, well-tested, and well-understood framework in all of science"

- Probably People who worked on the Standard Model

The Solar Neutrino Problem...

Few minor outstanding problems with the Standard Model

A major one:

- Thermonuclear reactions that power the Sun should only be able to produce electron neutrinos.
- We have a pretty good idea of how many electron neutrinos should be produced.
- When measuring the flux of electron neutrinos from the sun, we found that there were only 1/3 of the amount we predicted...

This is the Solar Neutrino Problem

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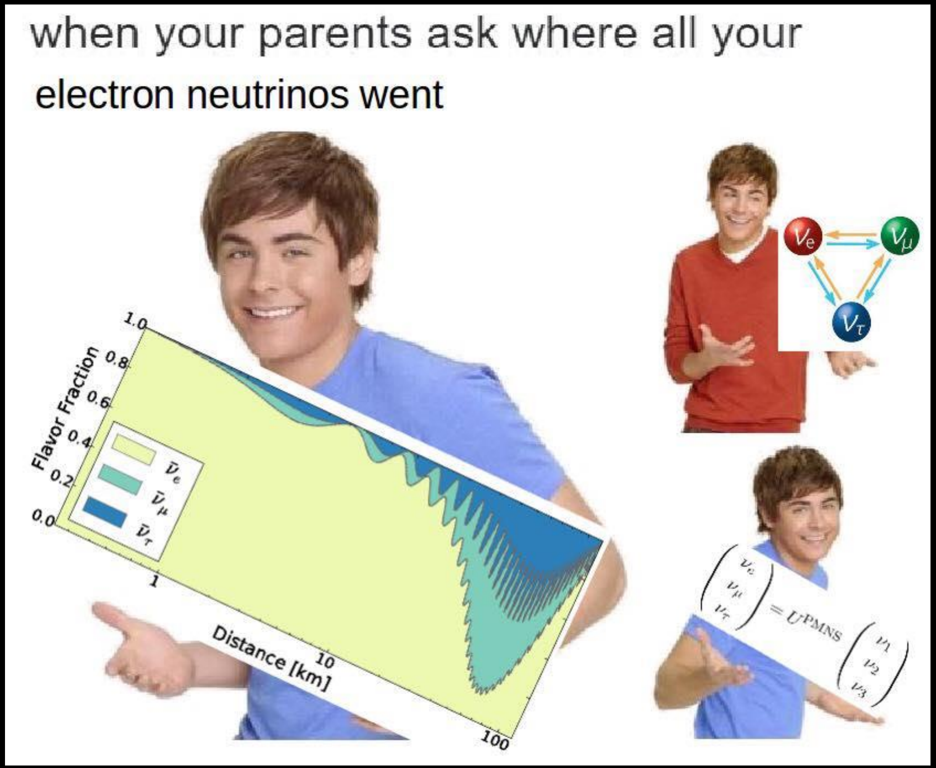
This is the Solar Neutrino Problem

The Sudbury Neutrino Observatory

- The Japanese Experiment Super-Kamiokande found out that neutrinos in the atmosphere flip between flavours (aka types).
- The first experiment to be sensitive to all types of neutrinos was the Sudbury Neutrino Observatory (SNO).
- SNO showed that neutrinos arriving from the sun came in all 3 flavours with equal quantities.
- Just like Quarks, it seems like Neutrinos can also oscillate between flavours as they propagate through space.
  - Quarks: CKM Matrix
  - Neutrinos: PMNS Matrix




ALFR.
NOBEL

Beyond the Standard Model

- Neutrino Oscillations requires neutrinos to have mass
- Problematic, since the Standard Model predicted neutrinos to have zero mass...

This opens up a whole bunch of problems.

- What are the neutrino masses?
- What order are the neutrino masses? (The Mass Hierarchy Problem)
- Why is there an asymmetry in matter and anti-matter?
- **Can neutrinos be their own antiparticles? (The Majorana Paradigm)**

We need bigger, better, broader, bolder neutrino detectors to answer these questions.

The Era of Particle Astrophysics

- SNO and Super-K were among the first megalithic underground particle detectors.
- The implications of Neutrino Oscillations necessitates a new generation of underground experiment: the coming of age of Particle Astrophysics.
- . This second generation is now maturing.

SNO → SNO+	(Next Monday)
GERDA/MAJORANA -> LEGEND	(Next Tuesday)
IceCube	(Next Tuesday)
Super-K → Hyper-K	(Next Wednesday)
HALO	(Next Wednesday)
EXO → nEXO	(Next Thursday)

- Many of the techniques are among the best ways to directly detect Dark Matter

DEAP (Next Monday)	Bubble Chambers (Next Tuesday)	PICO (Next Tuesday)
SuperCDMS (Next Thursday)	NEWS-G (Next Thursday)	DAMA/KDK (Next Wednesday)

“The World is sailing beyond a new horizon in physics.” – Cool quote I heard at the opening talk of a conference

EIEIOO
Introduction to Unix, Clusters, and LaTeX

Benjamin Tam

5 May 2020

What is Unix?

- Unix is a family of computer operating systems (OS)
    - Based off of AT&T Unix, the OG OS
- Designed for total control of your machine (could be dangerous...)
- Meant to be operated entirely from a command line

- These days, graphical interfaces are becoming common
- Modern evolution of unix is still the most universal operating system
- Basically the entire world has been designed on unix

All of physics and physics research runs on unix.
Apple machines are unix-based
PCs aren’t... hopefully at this point you’ve hacked it to work, though.

Computing Clusters

- A majority of physics analysis requires much more processing power, computer cores, graphics processing, memory, etc, than hardware available or affordable for consumer use.
- Even if you could run it on your computer...why would you?

Computer Clusters

- Instead, we use supercomputers (aka clusters if you don’t feel like living in a sci-fi) built by governments, universities, or other major institutions.
- Compute Canada is the Canadian flagship advanced computing organization that manages and runs the most powerful machines in the country.
- Compute Canada is powerful, but very popular. Your limitations will be related to your position in the “queue” than processing power. Sometimes, it may be desirable to use local supercomputers instead, or to run stuff on a machine you have more control over.

Local Resources

- The most powerful supercomputer at Queen’s is the “Neutrino” cluster, built and maintained by Ryan Martin and Mark Anderson for the SNO+ research group.
- Many of you will have accounts on your own experiments computing clusters.

schrrk I'm in.

- You're now in the **home directory**. The symbol ~ always indicates your home directory.
- The cluster has many accounts, each belonging to a different person.
- You can imagine each account as a folder (aka directory) on the computer, located at /home/

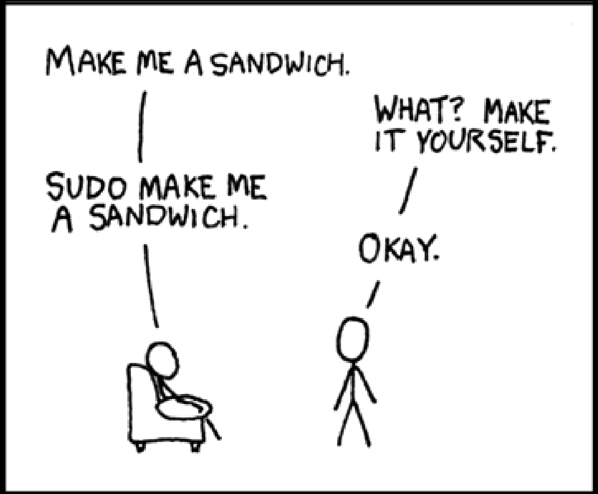
For example, the nuguest user has an account folder /home/nuguest/
Your account folder is your home directory.
If you're logged in as nuguest, ~ is a shortcut that means /home/nuguest/

- You have virtually full control over your own directory and the thigns in it, unless it affects the machine and other people (ie installing software)
- You might be able to see or even take things from other peoples directories – you can set these permissions yourself for your own account.

The root user

- The root user is the super boss-man administrator of the device. For the neutrino cluster, this is Ryan Martin and Mark Anderson.
- For your computer, you're likely the root user.

- The root user can see, move, and change everything.
- Unix automatically protects sensitive directories/dangerous commands.
- If you are the root user, you use the "Super User Do!" (sudo) command to force your computer to do something.



ls

- The LiSt (ls) command is how to see what is in your home directory.

- There are variations of it, too, like

  - ls –al (which lists hidden files)
  - ls –t (which lists files based on modification time)

  And many more.

  - Unix navigation has been the staple of the modern world for decades now, so almost everything should be googlable even to a very advanced level.
  - I still google how to do things every 3 minutes.

cd

- How do you move around?
- Use the Change Directory (cd) command.

Change your directory using

```
cd [directoryname]
```

You can only do this to directories that are inside the directory you're currently in. If you want to go somewhere specific, you just need to type

```
cd [path]/[directoryname]
```

If you just type

```
cd
```

This will bring you immediately to your home directory.

Making sub-directories

- Throwing things into your home directory is bad form
- It’s also embarrassing, people can see what’s in there.
- You make a sub-directory (folder) using the Make Directory (mkdir) command

Make a directory where you are by typing

```
mkdir [new_directory_name]
```

If you are in nuguest, make a subdirectory in your home directory called xyyyy
where x is your first name initial and y is your last time. For example, I, Ben Tam, would type

```
mkdir btam
```

If you’re on nuguest, this will be your pseudo-home directory for the week.
Don’t put stuff in the nuguest home directory, that will be confusing for everybody.

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Don’t put stuff in the nuguest home directory, that will be confusing for everybody.

Making sub-directories

In your pseudo-home, make a directory called eieioo, then navigate to it.

In general, you want to keep things lower-case and with absolutely no spaces. This will make it faster to navigate around later since everything is case-sensitive.

Important Shortcuts

Again, typing

```
cd
```

This will bring you immediately to your home directory.

The shortcut of your current directory is always "."
Typing

```
cd [directory]/[subdirectory]
```

is the same as typing

```
cd ./[directory]/subdirectory]
```

BUT typing

```
cd /blah/blah/
```

is NOT the same as typing

```
cd ./blah/blah
```

That first "/" is important! It implies you're manually inputting the path.

Important Shortcuts

Again, ~ is your home directory.

```
cd ~/blah/blah
```

will navigate to that subdirectory in your home directory

While "." is your current location within the cluster,
".." is always 1 level up. So if you want to exit your subdirectory and go to the directory that holds that subdirectory, type

```
cd ..
```

This also works for other commands such as ls

Are you lost? If you don't know where you are, use the Print Working Directory (pwd) command. This gives you the filepath to where you are right now. Or just go back to the home directory with cd if you are panicking.

cp, mv

The copy (cp) command lets you copy stuff from one place to the next.

```
cp [original_filepath/filename] [destinationfilepath]
```

You must include the extensions (eg .txt, .ppt).

You can move files by using the move (mv) command.

```
mv [original_filepath/filename] [destinationfilepath]
```

You rename files by using the mv command:

```
mv [filepath/filename] [filepath/newfilename]
```

cp, mv

These slides are in btam. You can find them at

/home/btam/talks/intro_particle_2020.pdf

Copy this to /home/nuguest/YourDirectory/eieioo/

Rename the slides to standardModel.pdf

Logging out

Controlled logouts are always better than alt+f4. Log out by typing

```
logout
```

or

```
exit
```

Transferring Files

To transfer files between machines, use the Secure Copy (scp) command.
This is how you upload/download things between the cluster and your computer.

```
scp [filepath]/[filename] [destinationpath]
```

If you're trying to upload something, you need to type
[account@hostname:] before the destination path. For example, if I was trying to upload a file called blah.txt to the nuguest pseudo-home directory, I would type.

```
scp ./blah.txt nuguest@neutrino.phy.queensu.ca:~/btam/
```

Similarly, if you're trying to download something, you need to put the server name before the original filename. Download the slides to your computer now.

If you're trying to download an entire folder, you'll need to tell the computer to recursively run the command with –r

```
scp –r [filepath]/[directory] [destinationpath]
```

OK, let’s log back onto neutrino.

Removing Files

You don’t need the slides on neutrino anymore. You can remove the file with the remove (rm) command.

```
rm [path]/[filename]
```

In fact, why not delete the whole eieioo folder.
To delete folders, you’ll need to also do this recursively

```
rm -rf [path]
```

Notice how you didn’t get a warning?
Unix is built for efficiency, but this is one easy way to fuck up your day.

The Hacker Screen

- Type “top” and see what happens
- When a hacker is on TV, 99% of the time it’s on this screen.
- Use top to monitor processes on the cluster.
- This is used to make sure you’re not slowing down the machine for everybody because your code sucks.
- Don’t be creepy.

- Neutrino has multiple cores, so using 100% of CPU just means you’re using 100% of a single core. This is fine.
- Pay attention to MEM (RAM) usage. Anything more than 10% is a crazy intense program. Anymore more and you probably have some major problem in your code, such as a memory leak.
- A Memory Leak is something that borrows memory from the cluster temporarily but forgets to return it.

Neutrino is set up to auto-kill any process using more than 70% MEM.
It’s really really bad form to slow down the cluster by sucking up RAM.

Killing Processes

- Is something you're doing sucking up MEM like crazy?
- No problem, this is going to happen for sure.

- Kill a running program with Ctrl+C. Have fun accidentally killing a lot of things by accident when you try to copy stuff with that shortcut. Happens to everybody.
- If you can't destroy the program normally (eg its causing so many problems its lagging like crazy, or you set it to run in the background), you need to kill it with... uh, the kill command (kill)
- First, use top to determine the program identification (PID). It's the one sucking up all the MEM.
- Then type

```
kill -9 [PID]
```

Look over your shoulder. Hope nobody noticed. Change your code before moving on.

Cluster Etiquette

- Keep your home directories very neat and tidy. Don’t just dump a whole bunch of random crap in directories.
- Future collaborators may need to comb through your stuff. Also, it just looks terrible.
- Most clusters are huge, so if you’re overusing resources, it’s definitely because your code sucks. Check top frequently and kill offenders immediately!!

Some clusters may be running critical processes for people or experiments 24/7. Never brick a cluster “even for a little”.

Programming on a Cluster

- OK, so make another eieioo directory in your pseudo-home directory.
- Code is written in text editors.
- In the modern day, there are 2 main ones.
  - People are very aggressive about which one they like more
  - Seriously, they probably won't like you if you use the other one.

Vim:
- In-terminal
- Very resource efficient, useful if your connection sucks
- Much faster and much more powerful once you learn the shortcuts
- Huge learning curve
- Seriously, remembering how to save is a challenge.

Emacs:
- Pop-up GUI interface which makes it easy to get started.
- Very slow/laggy if your connection isn't stable
- Shortcuts are similar but not the same as Windows ones, leading to a strange unlearning-learning curve

You decide…

- You might not get the chance, some collaborations are insistent about which one to use
- Honestly, people are strangely religious about this. It’s weird.

Let’s try both. To open a text file in vim, type

```
vim [filename]
```

- If the filename doesn’t exist, it will automatically create a file with that name (same with emacs). Create a file called snolab.txt
- Currently, you’re only viewing the (blank) document. Type “i” (for insert) to start writing.
- When you’re done writing, press esc to leave insert mode.

Basics (when in view mode, NOT in insert mode):

- “:w” saves
- “:q” quits without saving
- “:wq” save and quits. More commands are googleable.

List all of the fermions and bosons in the standard model, then quit.

You decide…

- Open the same text file in emacs

```
emacs [filename]
```

After each fundamental particle, list their symbol, mass (with units), electric charge, and spin.

Save and quit.

"Ctrl-X Ctrl-W" saves
"Ctrl-X Ctrl-C" exits.

Again more commands are googleable.

Code

- This workshop will concentrate on C++ and ROOT, the two most widespread in particle astrophysics
- Python is also a very good and widespread language – I highly recommend everybody to learn it as well.
- Let’s try some now.

Type “python” to start python. Try the following:

```
print “Hello World”
1+1
2**5
```

Do you understand what happened at each stage?

Python Crash Course

- Python relies on external libraries that you need to import. These libraries allow python to run features. This way, your code can be very efficient as you only import features you need.

For example, if we want to use pi in our calculations, you'll want to import the math library. Try the following:

```
import math
math.pi
```

Let's create a **variable**. Variables are basically temporarily addressed you name that you can store data into. For example, if you want to store the value 5 at a place called x, type

```
x=5
```

OK, now try typing

```
x
```

Python Crash Course

- Now try the following:

```
y = 0.03*x
z = 0.05*z
```

Now get python to calculate $(\cos(z*pi)+\sin(y*pi))^3$
Hint: math.cos(x) is how you calculate cos(x)

What if you decide that you want x to be 6?
It sure would be annoying to type everything over again.

Quit python by typing

```
quit()
```

Scripts

Instead of retyping everything, we want to send the computer a pre-determined list of instructions. This list of instructions is called a script.

- Scripts are just text files! Python scripts have a .py extension.
- Using your favourite file editor, make a text file called file.py (or a more creative name idk)
- Put all of the commands from before in the script. Remember to import math!

When you’ve saved the document, run the script by typing

```
python file.py
```

- If there’s a bug, debug by reading the error message.
- If there wasn’t an error but nothing printed, figure out why. Hint: how did we get the computer to say “hello world”?

Plotting

Making plots is the physics bread and butter. Let’s make a simple graph in a script called, uh, plot.py

You’ll need to import a module with

```
import matplotlib.pyplot as plt
```

the “as plt” is so you can use plt as a shortcut for matplotlib.pyplot.

Let’s plot 3 points: (1,2), (2,4), 3,1)
Turn the x and y values into an array (matrix):

```
x = [1,2,3]
y = [2,4,1]
```

Then plot the points with

```
plt.plot(x,y)
```

and display the plot with

```
plt.show()
```

Because you’re a good physicist, add axis labels. For example,

```
plt.xlabel(“This is the x-axis”)
```

Try `plot.scatter(x,y)` instead of plt.plot to see what happens.

More Python…

Using python extensively this summer? Check out the python parallel lectures run by our colleagues at McGill next week.

Not using python? Learn it in your spare time. It is one of the most valuable skills to have right now for every field of science and engineering. I learned using the guide, Learn Python the Hard Way. I’ve put a copy of the guide on neutrino:

/home/btam/public/books

And oh yeah, feel free to access our library of textbooks at /media/p1/library/
Who knows, maybe you’ll need one for a class coming up soon.

LaTeX

Pronounced "Lah-Teck" but everybody gets it wrong (including me). Depends on how condescending you feel like being.

This is how all documents in physics are created.
After using LaTeX for 30 minutes, you too will look down on the lesser beings
Seriously, if you use word, people will probably just ignore you (at best) and loudly mock you (also one of the better case scenarios)

LaTeX compiles code in a text file with a .txt extension. There are lots of software that compiles it for you. I recommend **texmaker**.

Overleaf is an online version you can use too. You need to be connected to the internet, but it also allows for multiple editors. It can also be slow/laggy/clunky compared to a local copy (pros/cons analogous to using google sheets vs excel)

Tasks for Today:

Step One: Get LaTeX to work

1. Install a LaTeX compiler on your personal device. I recommend texmaker – I use it on both windows and linux. Macs have a built-in LaTeX compiler which I was always a big fan of too.
2. I have a directory on neutrino called btam/public/latex_template. Copy the whole directory to your computer and try to create the pdf.
3. Do you understand how the source code works? Mess around with it to change things up.

Step Two: Start cutting edge physics immediately

1. The Q value is not just a difference in total masses of just the neutrons and protons. Many different nuclear effects go into the atomic masses as well. They are approximated by the Liquid Drop Model (aka Semi-empirical mass formula). State the formula, and describe the various terms.
2. What is a mass parabola, and how do you create it?
3. Some heavy nuclei may be energetically forbidden to undergo a beta decay, but can undergo two beta decays simultaneously. How is this possible? Explain by referring to mass parabolas.
4. What is the natural abundance of an isotope?
5. Find a list of all isotopes capable of undergoing double beta decay, their respective Q-values, and the natural abundance of the isotope. Create a scatterplot on python. with Q value on the y axis and natural abundance on the x axis.
6. If you're making an experiment to look for double beta decay, (a) Is it better to have a higher or lower Q value? (b) Is it better to have a higher or lower natural abundance? (c) Which isotope would you choose and why?