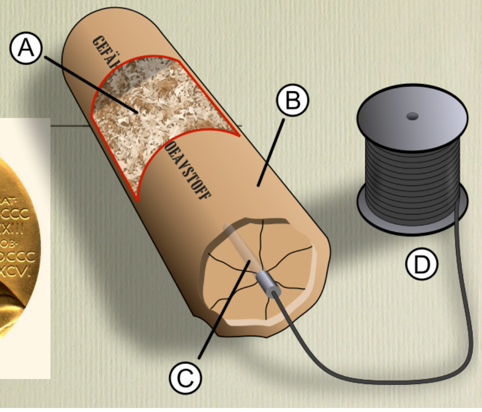
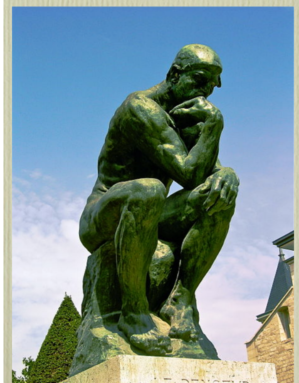
The Nobel Prizes

Peter Watson



Yes they missed me AGAIN



- but now for something completely different;
- the Ig Nobels
- "The Ig Nobel Prizes honour achievements that first make people **laugh**, and then make them **think**."

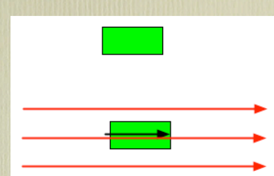
The 2011 Ig Nobel Prize Winners

- **PHYSIOLOGY PRIZE**: Anna Wilkinson (of the UK), Natalie Sebanz (of THE NETHERLANDS, HUNGARY, and AUSTRIA), Isabella Mandl (of AUSTRIA) and Ludwig Huber (of AUSTRIA) for their study "No Evidence of Contagious Yawning in the Red-Footed Tortoise."
- **MEDICINE PRIZE**: Mirjam Tuk (of THE NETHERLANDS and the UK), Debra Trampe (of THE NETHERLANDS) and Luk Warlop (of BELGIUM). and jointly to Matthew Lewis, Peter Snyder and Robert Feldman (of the USA), Robert Pietrzak, David Darby, and Paul Maruff (of AUSTRALIA) for demonstrating that people make better decisions about some kinds of things — but worse decisions about other kinds of things, when they have a strong urge to urinate.
- **BIOLOGY PRIZE**: Darryl Gwynne (of CANADA and AUSTRALIA and the UK and the USA) and David Rentz (of AUSTRALIA and the USA) for discovering that a certain kind of beetle mates with a certain kind of Australian beer bottle
- **MATHEMATICS PRIZE**: Dorothy Martin of the USA (who predicted the world would end in 1954), Pat Robertson of the USA (who predicted the world would end in 1982), Elizabeth Clare Prophet of the USA (who predicted the world would end in 1990), Lee Jang Rim of KOREA (who predicted the world would end in 1992), Credonia Mwerinde of UGANDA (who predicted the world would end in 1999), and Harold Camping of the USA (who predicted the world would end on September 6, 1994 and later predicted that the world will end on October 21, 2011), for teaching the world to be careful when making mathematical assumptions and calculations.

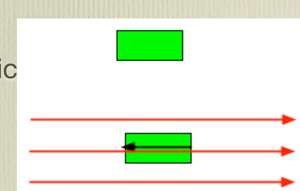
PEACE PRIZE:

- Arturas Zuokas, the mayor of Vilnius, LITHUANIA, for demonstrating that the problem of illegally parked luxury cars can be solved by running them over with an armored tank.

Magnetism



- In practice materials divide into 3:
- Ferromagnetic
- Paramagnetic: increases external field
- Diamagnetic: oppose an external magnetic field
- e.g. water is (weakly) diamagnetic

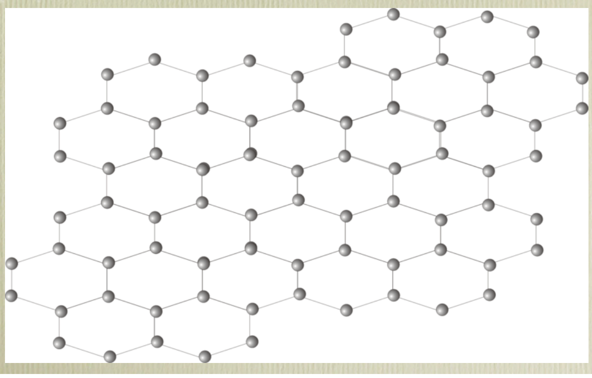


The 2000 Ig Nobel Prize Winners

- **PHYSICS**: Andre Geim of the University of Nijmegen (the Netherlands) and Sir Michael Berry of Bristol University (UK), for using magnets to levitate a frog.

2010 Nobel Prize

- Andre Geim and Konstantin Novoselov used a block of carbon and some Scotch tape to create graphene, a new material with extraordinary properties



- Dung-beetles?

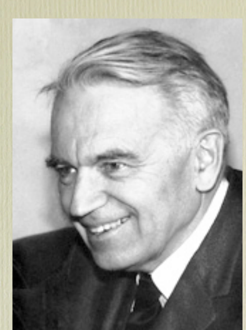
- How do dung beetles find their way?
- By the sun during the day, but by the Milky Way on moonless nights

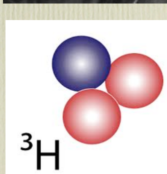
- Moral:
- **If you think you are buried in it, remember to keep your eyes on the stars!**

__2013 Ignobel prizes__

JOINT PRIZE IN BIOLOGY AND ASTRONOMY: Marie Dacke [SWEDEN, AUSTRALIA], Emily Baird [SWEDEN, AUSTRALIA, GERMANY], Marcus Byrne [SOUTH AFRICA, UK], Clarke Scholtz [SOUTH AFRICA], and Eric J. Warrant [SWEDEN, AUSTRALIA, GERMANY], for discovering that when dung beetles get lost, they can navigate their way home by looking at the Milky Way.
REFERENCE: "Dung Beetles Use the Milky Way for Orientation," Marie Dacke, Emily Baird, Marcus Byrne, Clarke H. Scholtz, Eric J. Warrant, Current Biology, epub January 24, 2013. The authors, at Lund University, Sweden, the University of Witwatersrand, South Africa, and the University of Pretoria

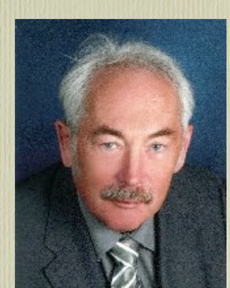
- Gerhard Herzberg
- Nobel Prize in Chemistry 1971
- Free radicals
- but also H_3, identified molecules in space
- Chancellor & adjunct prof at Carleton





Nobel Prize for Physics 2007

Albert Fert

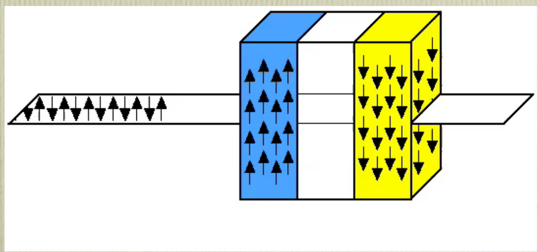


Peter Grünberg

Giant Magneto-Resistance: Why you own it!

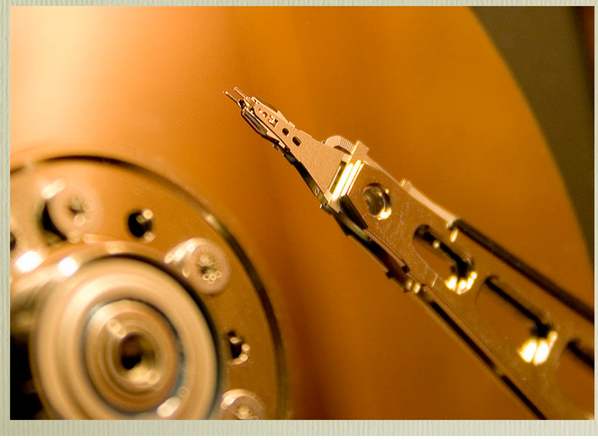
Text

Sandwich magnetic and non-magnetic materials together.
Resistivity changes abruptly (giantly) according to alignment of successive layers
So current changes very rapidly



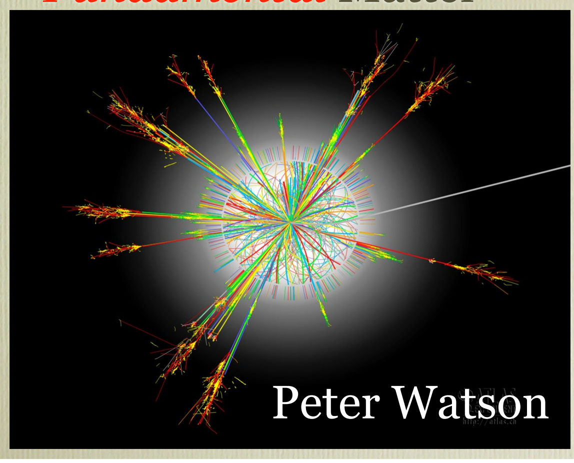
Which can be used to store information at huge density on a hard drive

Ipod would be impossible without it (B$1.9 in 2007!)



Oh, and Peter Grünberg worked at Carleton (in chemistry) for 3 years.

What is *Fundamental* Matter



Are not gross bodies and light convertible into one another; and may not bodies receive much of their activity from the particles of light which enter into their composition? The changing of bodies into light, and light into bodies, is very conformable to the course of Nature, which seems delighted with transmutations.

Newton

It seems probable to me that God, in the beginning, formed matter in solid, massy, hard, impenetrable, moveable particles, of such sizes and figures, and with such other properties, and in such proportions to space, as most conduced to the end for which He formed them; and that these primitive particles, being solids, are incomparably harder than any porous bodies compounded of them, even so very hard as never to wear or break in pieces; no ordinary power being able to divide what God had made one in the first creation.

Newton

How can we see particles?

- Charged particles ionize atoms in gas.
- Ionized atoms can
    1. act as centres for condensation (needs supersaturated gas)
    2. act as centre for boiling (needs superheated liquids)
    3. link up to make a conductor and hence a spark (needs high voltage)
    4. be "drifted" and collected on plates

PW

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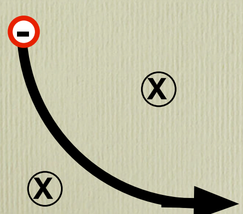
- Add a magnetic field
- an electron in a mag field bends anti-clockwise
- Faster particles bend less



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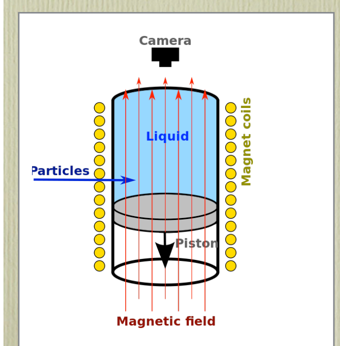
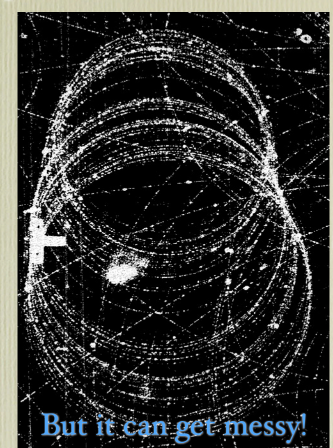
Bubble Chamber

Almost boiling liquid

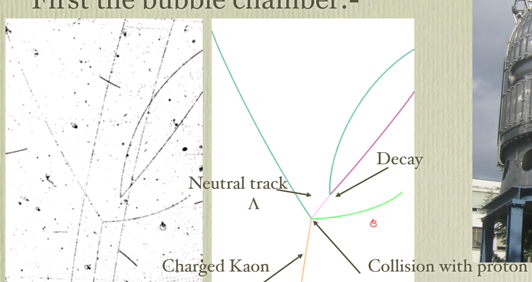




Detectors

How we see the sub-atomic world

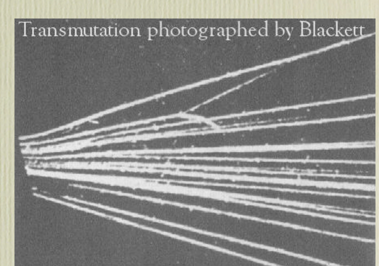
First the bubble chamber:-



CERN

The Proton

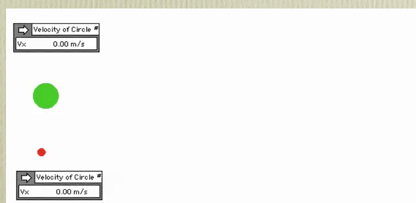
- Discovered as nucleus of H by Rutherford and Blackett (1921) in
- $\alpha + N \rightarrow O + p$
- $q_{proton} = +1 \times 1.6 \times 10^{-19}$
- $m_{proton} = 1.67 \times 10^{-27}$ kg



Blackett

Neutron

- discovered by Chadwick (1932) as penetrating **massive** neutral particle (i.e., not a γ)
- How do we see a particle we can't see?
- Bounce it off one we can!
- compare recoil of proton and nitrogen ($m_N = 14\ m_p$)



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Neutron

- $q_{neutron} = 0$
- $m_{neutron} = 1.68\times10^{-27}$ kg
- since neutrons and protons are so similar in mass, convenient to think of them as the same particle (a nucleon) which comes in two flavours!

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Conservation Laws

- A lot of what happens inside atoms is governed by conservation laws
- e.g. charge must be the same at start and end, so

$n \Rightarrow p\gamma$

- cannot happen ($0\neq1+0$!)

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Most important

- Conservation of energy
- Need to extend our definition of energy to include mass-energy

$$E=mc^2$$

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Usually give particle masses in MeV

- e.g.electron
- $m=9\times10^{-31}$
- $E=mc^2 = .511$ MeV

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State of the game: we have

- Electron (1897) m=.511, q = -1
- Proton (1917) m=938, q = +1
- Neutron (1932) m=939, q = 0
- Photon (1900) m=0, q = 0

Make up Atom

Make up Nucleus

Radiation <u>from</u> atom

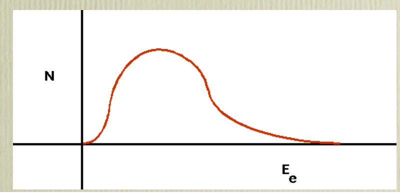
Force <u>inside</u> atom

Isn't it simple!!!

Except we need the neutrino to explain β-decay.....

β-decays

- β particle is just an electron
- an isolated neutron will decay.
- n ➠ p + e^-
- This led to a huge problem:the electron came out with varying energy.



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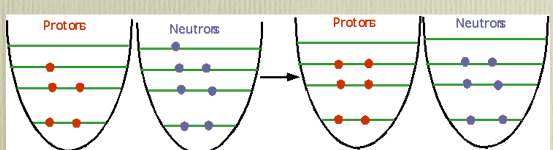
- Fermi (1933) proposed that the missing energy is carried off by an invisible particle, the neutrino (symbol is nu: ν) , so the real reaction is:
- n ➠ p + e^-+ν
- This can also happen in a nucleus if the energies are favorable: e.g. could have



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What is an electron?

- "What is" questions usually require a description ..
- What colour is an electron?
- What shape is an electron?
- Is it soft or hard?
- How big is it?

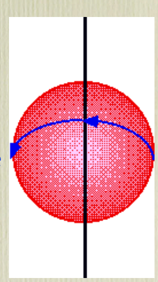
- What colour is an electron?
- Colour comes from reflected light: an electron is too small (actually, it reflects light of all colours, so ....)
- What shape is an electron?
- To decide what shape something is, we need to "see' it
- Is soft or hard?
- What can we "poke" it with?
- How big is it?
- Depends on how you measure size; best assumption is that it's a point.

- "What is an electron?" is not a good question
- "How does an electron behave?" is, but .....
- You're not going to like the answer (Marvin, in the Hitchhiker's Guide to the Galaxy)
- It behaves like a solution of the Dirac Equation

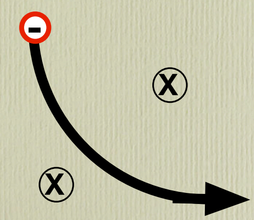
$$i\hbar\left[\gamma_0\frac{\partial}{\partial t}-\gamma_1\frac{\partial}{\partial x}-\gamma_2\frac{\partial}{\partial y}-\gamma_3\frac{\partial}{\partial z}-\frac{e}{cr}-mc^2\right]\Psi(r)=0,\gamma_0=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&-1&0\\0&0&0&-1\end{bmatrix}etc$$

But for a model of an electron

- a spinning ball of negative charge
- Note: this is not reality, but a convenient crutch for thinking!!!!
- ..Any picture of the atom that our imagination is able to invent is for that reason defective. An understanding of the atomic world in that primary sensuous fashion ..is impossible. Heisenberg



- The Dirac equation has a solution for an electron in a mag field
- bends anti-clockwise



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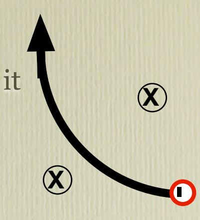
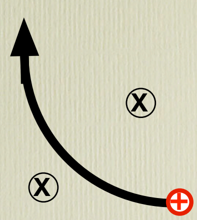
- Also one for an electron going backwards in time! In a mag field it would go clockwise



But this looks exactly like a positively charged particle going forwards in time!



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I.e. The Dirac equation predicts anti-matter!!!!!!

- This result is too beautiful to be false; it is more important to have beauty in one's equations than to have them fit experiment. Paul Dirac
- It predicts a particle identical to the electron but opposite in charge: the positron

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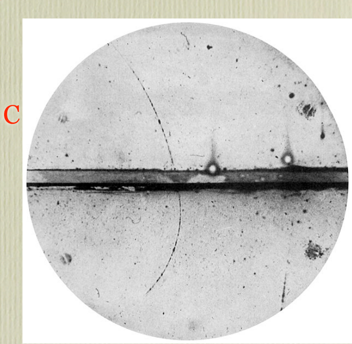
Antiparticles

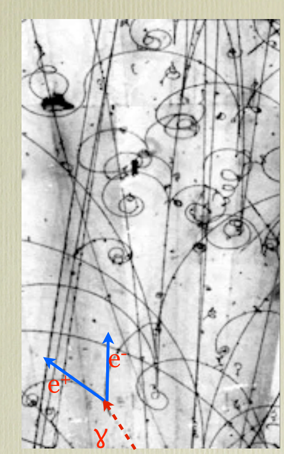
- For every particle with given quantum numbers, there is a corresponding anti-particle with the properties flipped:
- e.g. electron has charge $q = -1.6\times10^{-19}$ C
- positron has same mass,
- charge = $q = +1.6\times10^{-19}$ C
- predicted by Dirac
- Found by Anderson



- Picture shows many pairs created in a hydrogen bubble chamber.
- process is

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

Note we are creating matter from energy



Fermilab

However we must have enough energy

- $E = mc^2$ tells us we must have
- .5 MeV + .5 MeV = 1 MeV of energy: needs to be very energetic photon
- If we can make a positron, it will annihilate with an electron and give 2 photons

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Positron-Emission Tomography

- Positron in matter will annihilate

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

- Some isotopes decay emitting positron, e.g.
- $^{18}F \rightarrow {}^{18}O + e^+ + \nu$
- e^+ immediately annihilates and γ's come out back-to back with energy of 511 keV

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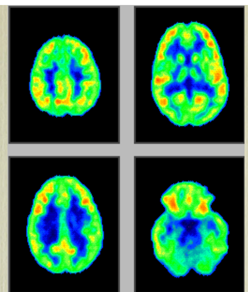
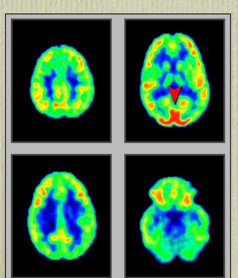
- This shows a resting brain





- Here the brain is being stimulated by colour and patterns: the stimulated area is the visual cortex.

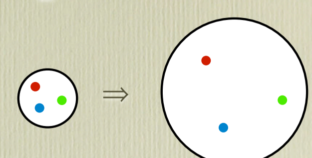
Crump Institute for Molecular Imaging
UCLA School of Medicine

Forces	Proton	Neutron	Electron	Photon	N
Gravitational	√	√	√	√	
Weak	√	√	√	x	
Electromagnetic	√	√ via magnetism	√	√	
Strong	√	√	x	x	

	Proton	Neutron	Electron	Photon	Neutrino
Grav.	√	√	√	√	√
Weak	√	√	√	x	√
E.M.	√	√	√	√	x
Strong	√	√	x	x	x
Mass	938.27	939.57	.511	0 ($<10^{-33}$)	0 ?
Charge	+1	0	-1	0	0
Baryon #	1	1	0	0	0
Lepton #	0	0	1	0	1
Spin	1/2	1/2	1/2	1	1/2

Magnifying proton seems not to change it (!)

Quarks



Suggests that proton has substructure of point-like particles

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Quarks

- postulated to explain patterns seen
- up quark (u) has charge +2/3
- down quark (d) has charge -1/3
- baryons (heavy particles) consist of 3 quarks
- proton is uud: charge Q = 1 √
- neutron is udd: charge Q = 0 √

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- maximum is uuu: Q = +2 √
- minimum is ddd: Q = -1 √
- mesons (lighter particles) are quark-antiquark
- e.g. $u\bar{d}$ has Q = +1 √
- no Q = 2 or Q= -2 √

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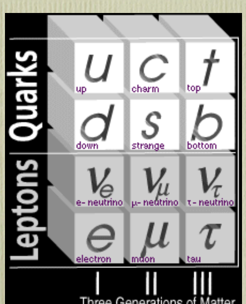
What we know so far: The building blocks of the universe

Particles



Forces

Gravity ***(Graviton)***
(Keeps us stuck on the ground)

Weak ***(W and Z)***
(Related to radioactivity)

Electro-Magnetic ***(photon γ)***
(Electronics, radio waves)

Strong ***(gluons)***
(holds nuclei of atoms together)

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Gravity ***(Graviton)*** (massless)
Weak ***(W and Z)*** (mass of ~90 GeV)
Electro-Magnetic ***(photon γ)*** (massless)
Strong ***(gluons)*** (massless)

Why?

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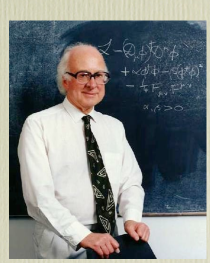
Quarks and gluons: The standard model

- This picture of our world works very well.
- But there are some problems ...
- Why are the particle masses so different?
- Why do they have mass at all?
- Something is missing!
- Add one particle: the Higgs boson.

Mr Higgs:-



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David Millers explanation of the Higgs

- Suppose you have a room full of (vacuous) political workers...

David Miller

and an important politician enters

David Miller

She will acquire mass by interaction with the vacuum

But suppose we hear a rumour....

David Miller

The rumour takes time to cross the room....

this is the Higgs boson

David Miller

OK, how do we really see it?

- Need lots of energy to create it
- Need to know how it decays
- Need to see its decay with a detector

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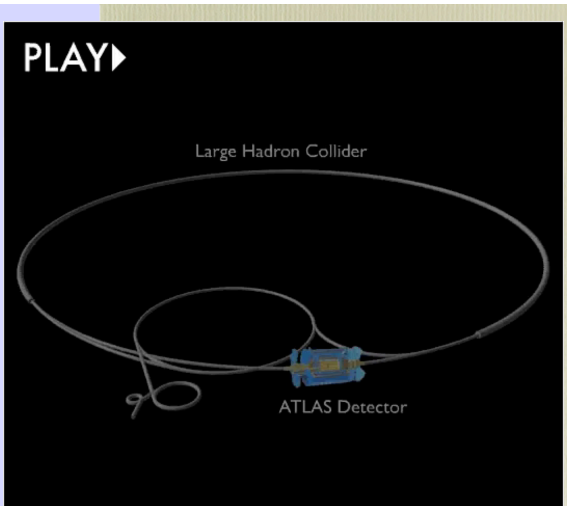
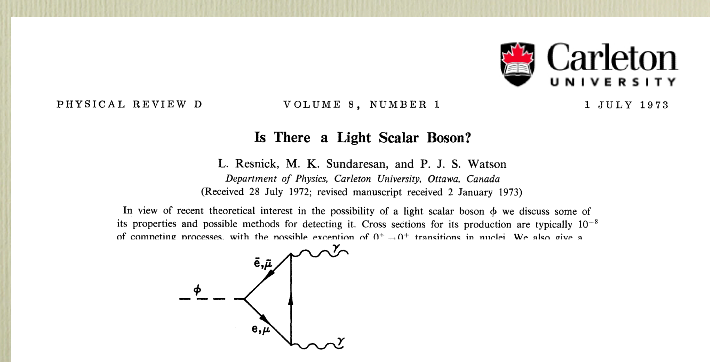


The Large Hadron Collider (LHC) in CERN (Geneva)

How do we see it?

- Sometimes it can decay into 2 photons



PHYSICAL REVIEW D VOLUME 8, NUMBER 1 1 JULY 1973

Is There a Light Scalar Boson?

L. Resnick, M. K. Sundaresan, and P. J. S. Watson
Department of Physics, Carleton University, Ottawa, Canada
(Received 28 July 1972; revised manuscript received 2 January 1973)

In view of recent theoretical interest in the possibility of a light scalar boson ϕ we discuss some of its properties and possible methods for detecting it. Cross sections for its production are typically 10^{-8} of competing processes, with the possible exception of $0^+ \rightarrow 0^+$ transitions in nuclei. We also give a

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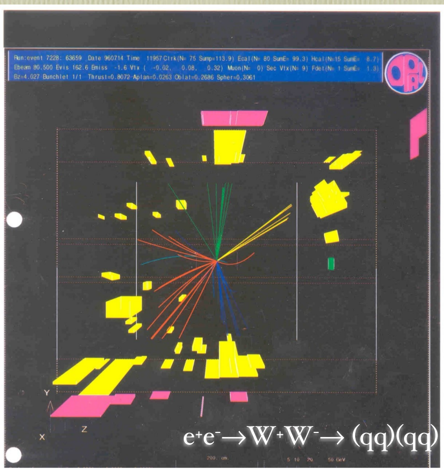
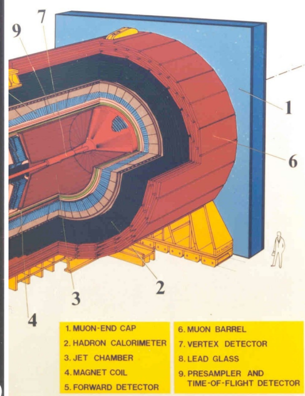
Electronic detectors

Example ATLAS:CERN





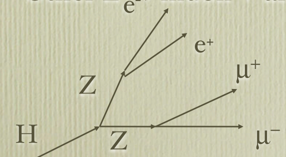
How we see the Higgs particle

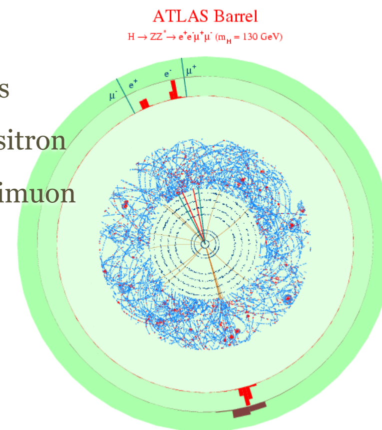
One possibility:

Higgs → two Z particles

One Z → electron + positron

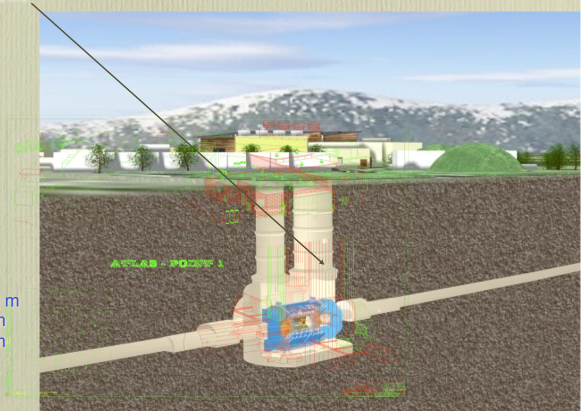
Other Z → muon + antimuon



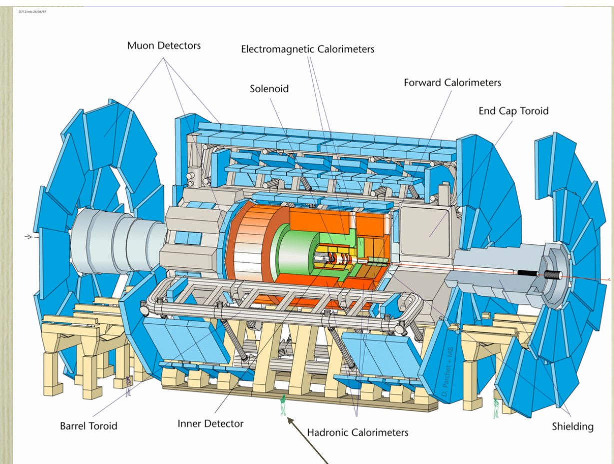


Access shafts for detector

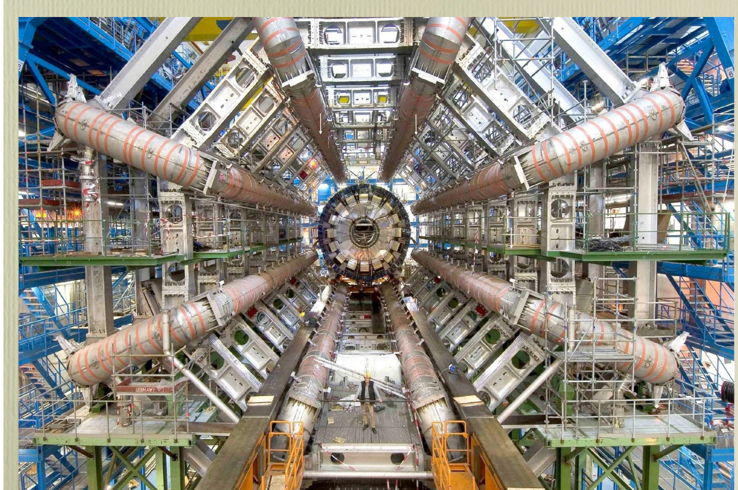
The Underground Cavern at Pit-1 for the ATLAS Detector



Length = 55 m
Width = 32 m
Height= 35 m



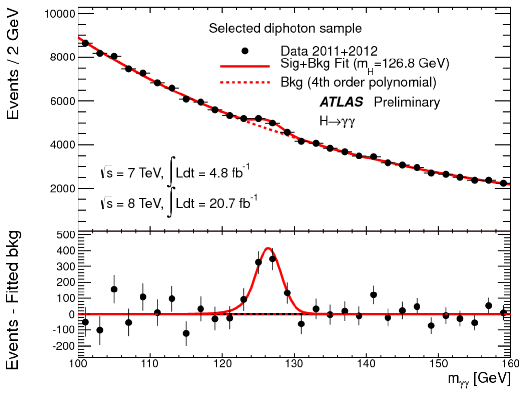
A physicist!



Or put slightly differently....

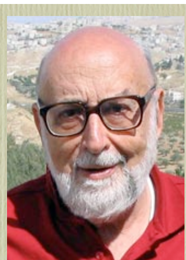
Text

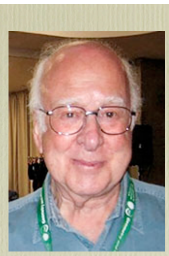
Higgs boson discovery



ATLAS results (CMS has similar plots)

PW





The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

The Carleton Connection:
Manuella Vinctner, Gerald Oakham, Thomas Koffas and several others work on Atlas

Heather Logan and others work on theoretical aspects

The cost

- **Total expenditure on CERN in 2007**
- **986.9 MCHF**
- Total LHC
- B$5-B$8

PW

With $8,000,000,000 we could

- Fight 2 weeks of a war in Iraq
- Supply vaccine for HPV, meningitis, MMR for every child in Africa
- Rescue one very small bank
- Discover the Higgs

PW

How well does undirected research pay off?

- E.g. detecting cancer
- Nuclear magnetic moment measured by Rabi in 1938
- MRI invented 1973
- Now only method for detection of many tumours

How about CERN?

- World Wide Web invented by Tim Berners-Lee at CERN in 1988
- Not copyrighted or patented
- Google worth B$340 : it has indexed 1 trillion pages
- 0.001 ¢/page license would pay annual budget of CERN!

Conclusions

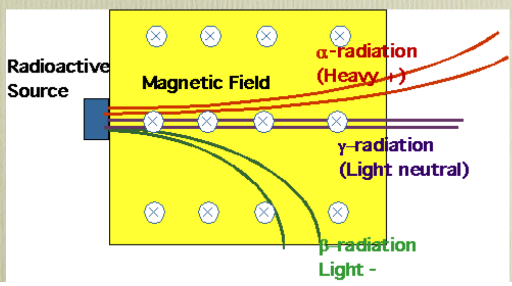
- ATLAS gives us best check of our theories ever
- Good science costs money
- Good science requires commitment
- We don't know what it's going to produce (That's research!)
- The spinoffs may take 50 years to arrive

Something Nu Under the Sun

Art McDonald,
Queens U
Nobel Prize for Physics
2015

Radioactivity and Decays Becquerel (1896)

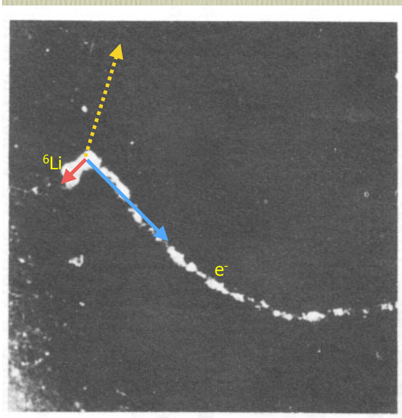
- (alpha) α-rays ~heavy, positively charged
- (beta) β-rays ~ light, negatively charged
- (gamma) γ-rays ~ neutral, light



Radioactive β-decays

- β particle is just an electron
- e.g. an isolated neutron will decay.
- $n \rightarrow p + e^-$

β-Decay and Momentum Conservation



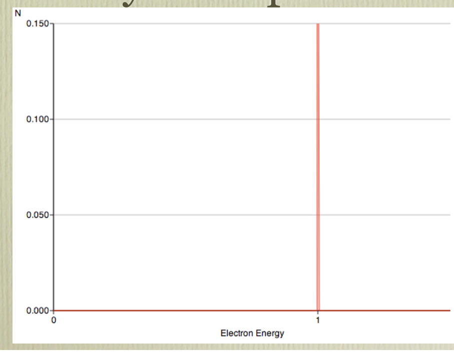
$^{6}He \rightarrow {}^{6}Li + e^{-}$

Appears to violate Momentum Conservation

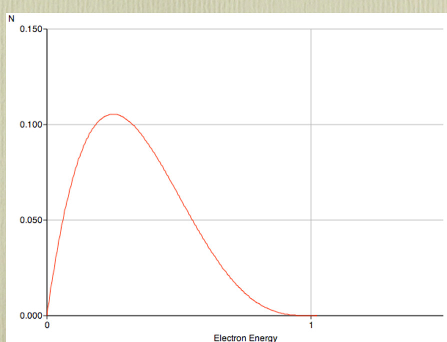
---

e.g. a neutron can decay: n ➠ p + e^-

Energy of Electron: What you expect..



Energy of Electron: What you get..



Wolfgang Paul… Neu…

- 1930 – Neutral part… carry off missing… momentum
- Shortly a… discov… (mu…

I have done a terrible thing, I have postulated a particle that cannot be detected.

Wikipedia

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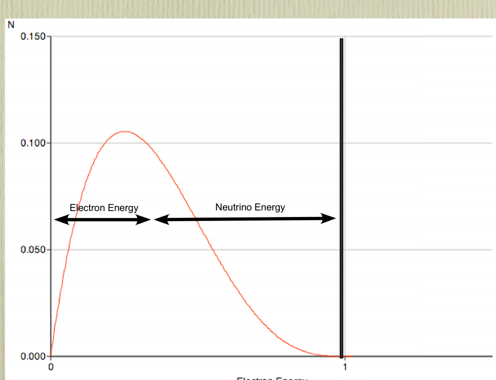
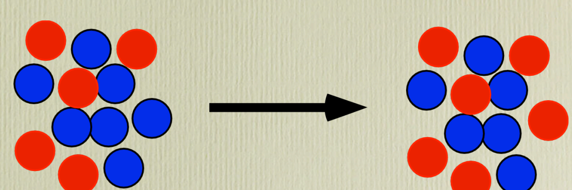
e^- and ν (nu)split the energy

e.g. a neutron can decay: n ➠ p + e^-+ν



- This can also happen in a nucleus if the energies are favorable: e.g. could have



$^{12}B \rightarrow {}^{12}C + e^{-} + \nu$

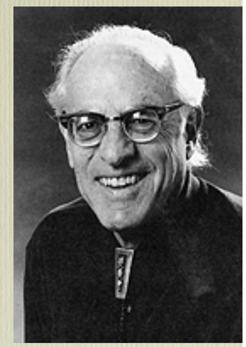
Nuclear Reactors are also (anti-) neutrino sources

- In a reactor uranium fissions to form lighter fragments
- Fragments are very neutron rich
- Neutrons decay to protons to form more stable nuclei giving neutrinos

PW

Neutrinos Finally Found

- Reines and Cowan (1957)
- Detected neutrinos from a reactor
- Efforts at Chalk River by John Robson ended due to reactor problem

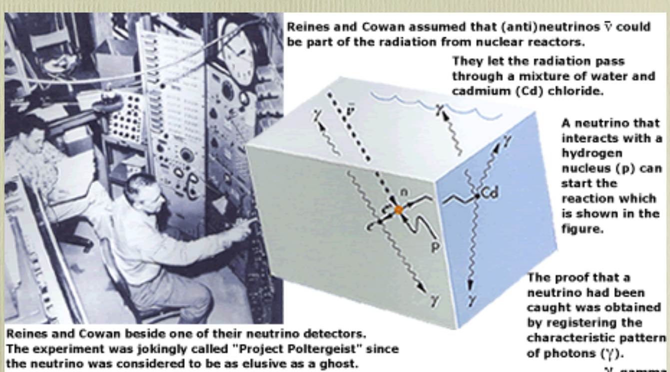


if a neutron can decay: $n \rightarrow p + e^- + \nu$

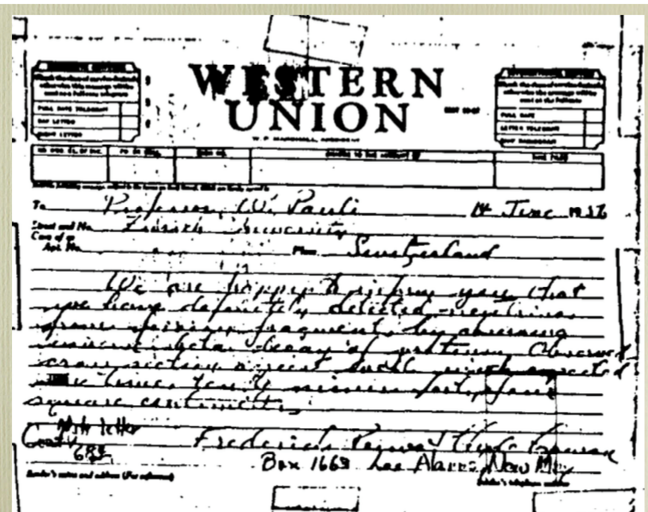
then we can reverse it $\nu + p \rightarrow n + e^+$

Fred Reines

Neutrinos meet Experiment



Savannah River


WESTERN UNION

To Professor W. Pauli 14 June 1956

Zurich University

Switzerland

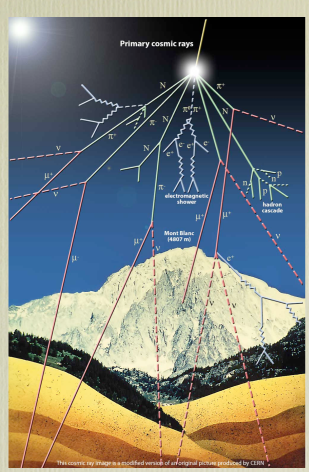
We are happy to inform you that we have definitely detected neutrinos from fission fragments by observing inverse beta decay of protons. Observed cross section agrees well with expected six times ten to minus forty four square centimeters.

Night letter

Frederick Reines Clyde Cowan

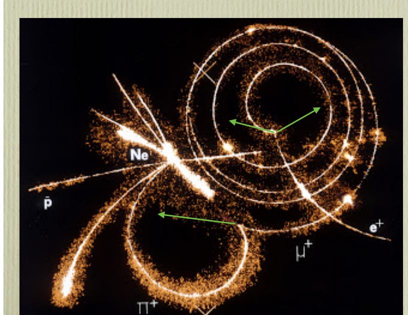
Box 1663 Los Alamos New Mex

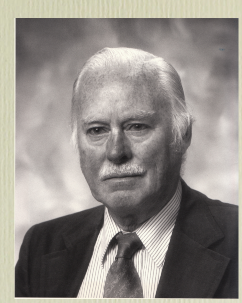
Muons



- Muons (μ) are particles like heavy electrons produced by cosmic rays
- One goes through you each minute on average)!
- Lifetime ~ 2 μs

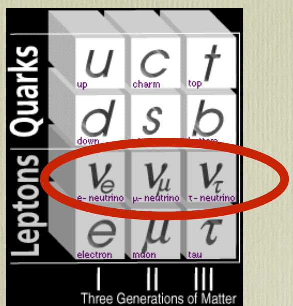
Pontecorvo/Hincks (Chalk-River/ NRC/Carleton) study muons





Muon decays to electron and 2 different neutrinos

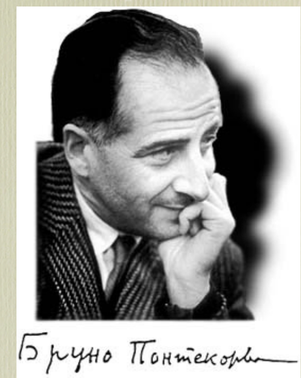
What we know so far (2016): The building blocks of the universe



PW

Pontecorvo Questions Neutrino Stability

- Perhaps neutrinos 'oscillate': a neutrino created as electron type *might* change to muon type and back again



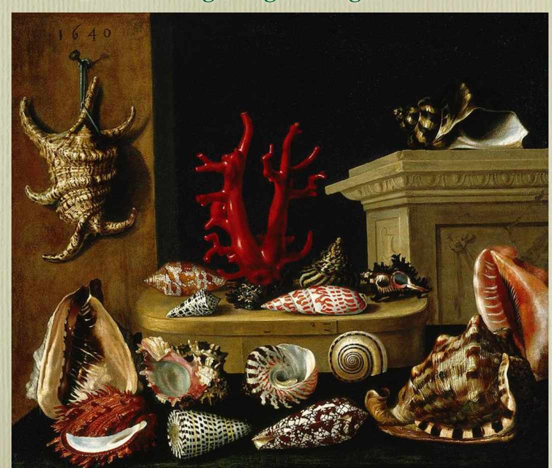
Bruno Pontecorvo

What Are Neutrinos?

- Neutral particles
- Very weakly interacting with matter
- If 100,000,000,000 neutrinos strike the earth, all but 1 will pass right through
- Must have very little mass, if any
- Seem to come in 3 distinct types – electron, muon, tau

PW

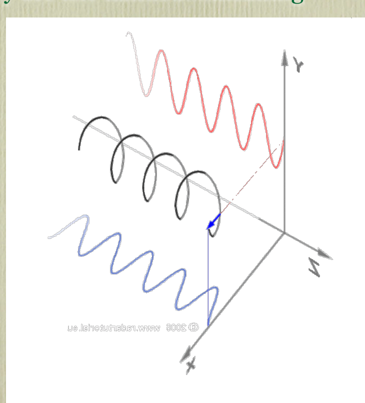
- Most living things are right-handed



Jacques Linard, early 17th, c

What Are Neutrinos?

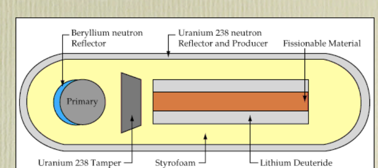
And they are left-handed....meaning



Wikipedia

So how does the sun work?

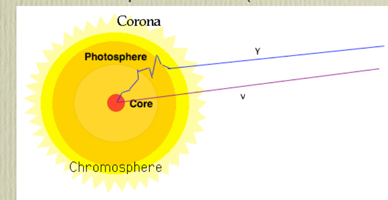
- Sun is ~ 90% hydrogen,
- ~9% Helium
- ~1% everything else
- It "burns" Hydrogen to Helium (almost the same reaction as a hydrogen bomb!)



Every second the sun converts 4 million tons of matter into energy!

PW

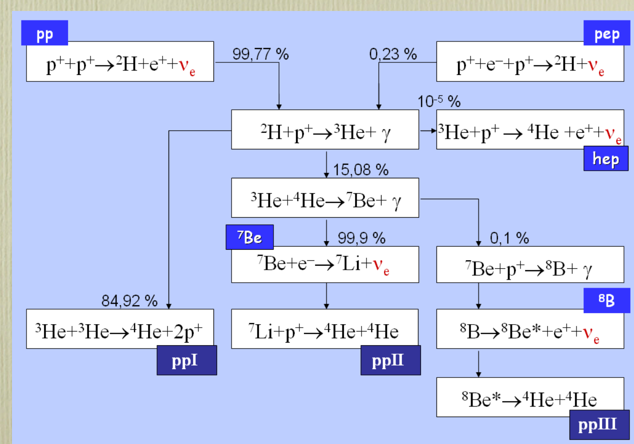
- And this is what keeps us warm!
- How do we know it's true?
- What really goes on in the core is a bit more complicated
- 4 protons become helium + 2 positrons (anti-electrons) + 2 neutrinos



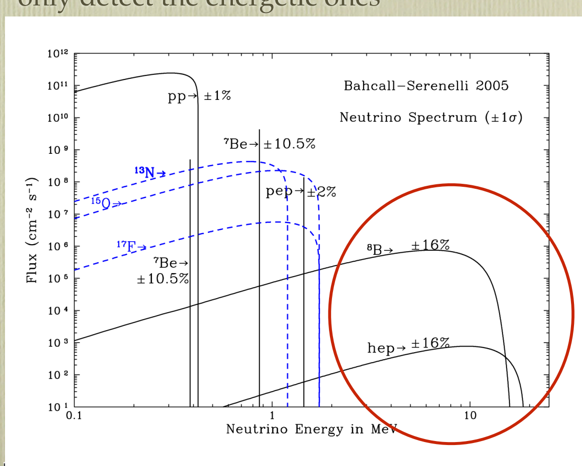
The neutrinos produced at the centre make it to earth in 8 minutes

- One Trillion (roughly) go through your thumbnail each second
- you hadn't noticed?
- tsk tsk!
- If we could see the neutrinos, we can see the centre of the sun, but they have almost no interactions!

It's a bit more complicated….Proton-Proton Chain



- neutrinos come with different energy: we can only detect the energetic ones



37-Chlorine Experiment Ray Davis (Nobel 2002)

- 100,000-gallon tank of perchloroethylene
- 4800 feet underground in the Homestake Gold Mine

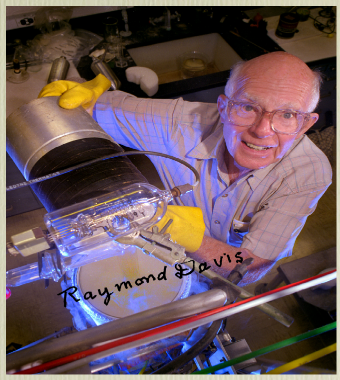
37-Chlorine Experiment

- A solar neutrino interacts with ^{37}Cl to produce Argon and an electron

$^{37}Cl + \nu_e \rightarrow {}^{37}Ar + e^-$

- Argon decays after 35 days: detect the electrons

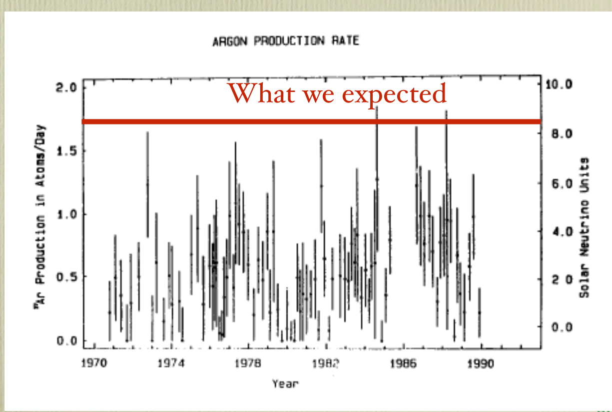
$^{37}Ar \rightarrow Cl + e^-$



PW

Ray Davis tells me that the experiment is simple ('only plumbing') and the chemistry is 'standard.' I suppose I must believe him, but as a non-chemist I am awed by the magnitude of his task and the accuracy with which he can accomplish it. –John Bahcall 1969

PW



PW

Results of th... Chlorine Exp... ...ment

- Look for Cl ... > A...
- First d... 196...
- P...ctio... rgon ... rate

Experiment may be wrong

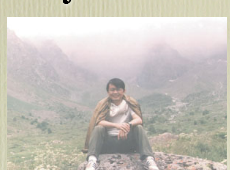
Model of Sun may be wrong

Model of neutrino may be wrong

PW

Neutrino Detection in Heavy Water

Suggested by Herb Chen d. 1987



- Heavy water is D_2O – D is Deuterium
- Deuterium nucleus is weakly bound proton and neutron
- **allows us to detect ν_e's (electron nu's) and ν_x's (all nu's) simultaneously**

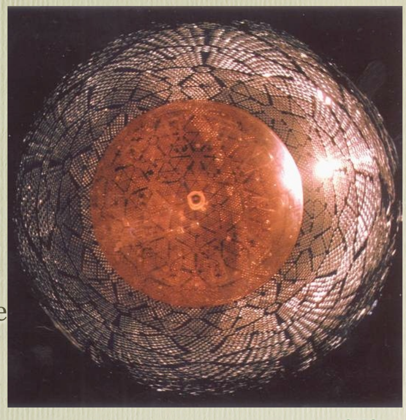
Sudbury Neutrino Observatory (SNO)

- Patience: idea formulated in 1985, construction started in 1990, First results in Fall 2000
- Money: (depending on what you include) M$40 - M$150
- Skill: meant constructing a device that has never existed before

PW

- Luck: Could only be built in Canada because of a political boondoggle, but more seriously:

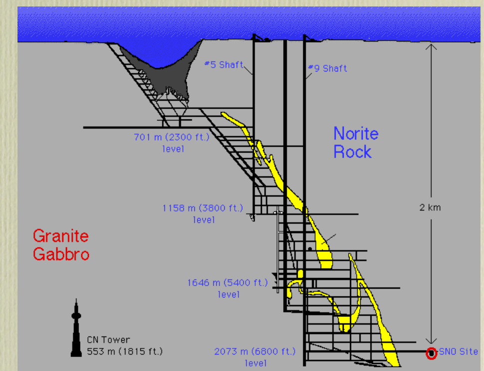
- **if** we are lucky (we were!), we could
  1. Understand how the sun works
  2. Understand how neutrinos work
- **If** we had been unlucky, would just have found the previous experiments were wrong!



SNO

Sudbury Neutrino Observatory

- Let's look at the sun through 2 kilometres of rock!!
- And use 1000 tons of heavy water as our detector



Sudbury Neutrino Observatory (SNO)

NEUTRINO

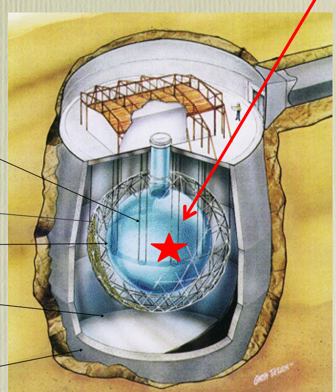
1000 tonnes of heavy water: D_2O \$ 300 million on Loan for \$1.00

9500 light sensors

12 m Diameter Acrylic Container

Ultra-pure Water: H_2O.

Urylon Liner and Radon Seal



34 m or ~ Ten Stories High!

2 km below the ground

Bursts of light from radioactivity were reduced to ~10 times less frequent than neutrinos

SNO

Excavating the Cavity

as large as a 10 story building

Largest cavity excavated at this depth

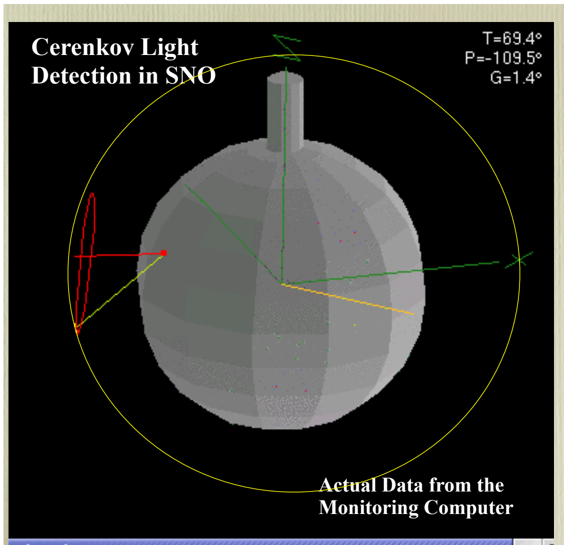
SNO

A part of the Heavy Water Purification System (Basement of Herzberg)

SNO

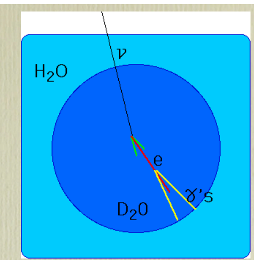
Detector partially filled

SNO

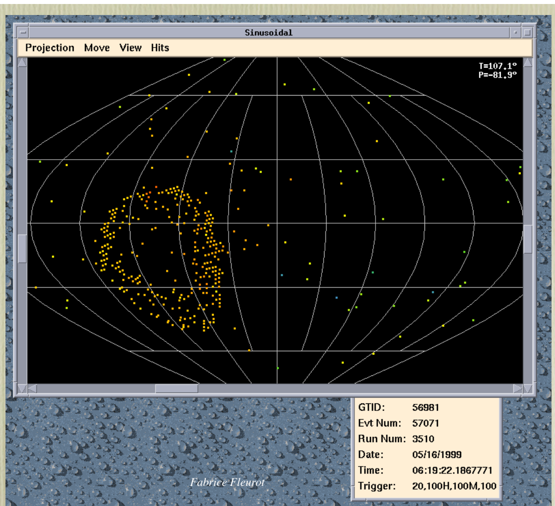


Cone of light emitted when neutrinos hit atoms in water

- Once every 3 hours a neutrino will hit an atom and produce light



- Which we can detect



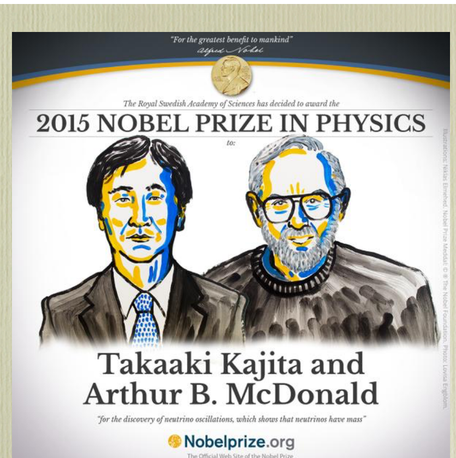
The Basic SNO Result

- Flux of Electron type Neutrinos ~ 1 million/sec
- Flux of All Neutrinos ~ 5 million/sec
- (note: these are just the high energy ones)

These numbers are different
Electron neutrinos must change into another kind

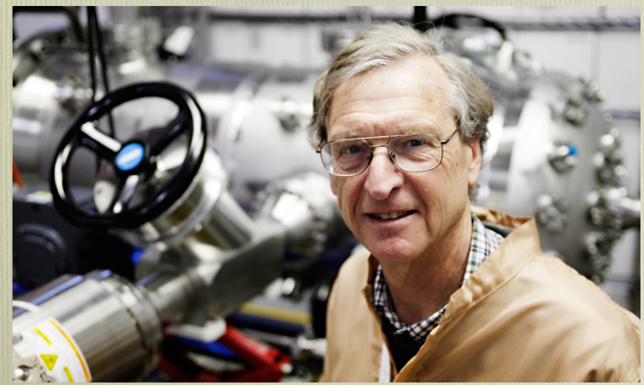
So neutrinos really come from the core of the sun, but they change into another kind on the way over

Why?

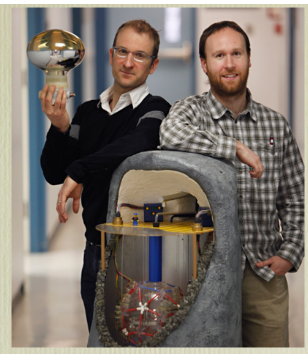


The Carleton Connection:

David Sinclair (Inaugural CAP-TRIUMF Vogt Medal) for Outstanding Experimental or Theoretical Contributions to Subatomic Physics.



- Alain Bellerive
- Etienne Rollin
- and about 20 others

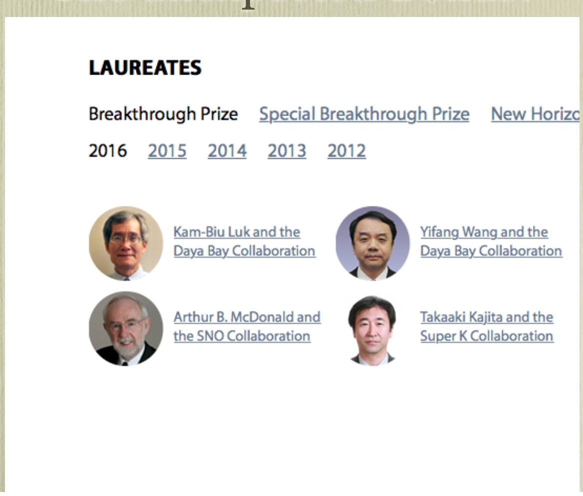


I will be with you in spirit (if I ever get off the phone today). Thanks to everyone from SNO for all they have done to create this success.
Way to go colleagues!!!
Art

The unexpected Bonus!

SAN FRANCISCO – November 3, 2015 – The Breakthrough Prize today announced that ten-time Grammy Award winner Pharrell Williams will perform at its third annual Breakthrough Prize ceremony, held to honor the world's top scientists and mathematicians, on Sunday, November 8 in Silicon Valley. Williams will be joined at the exclusive ceremony by a star-studded lineup of presenters, including Academy Award winner Russell Crowe, Academy Award winner Hilary Swank, Lily Collins, and Thomas Middleditch and Martin Starr of HBO's Silicon Valley. As previously announced, Emmy-nominated Cosmos executive producer and Family Guy creator Seth MacFarlane will serve as the ceremony's host.
The Breakthrough Prize ceremony is hosted by co-founders Sergey Brin (Google) and Anne Wojcicki (23andMe), Jack Ma (Alibaba) and Cathy Zhang, Yuri Milner (DST Global) and Julia Milner, and Mark Zuckerberg (Facebook) and Priscilla Chan, along with Vanity Fair

The unexpected Bonus!

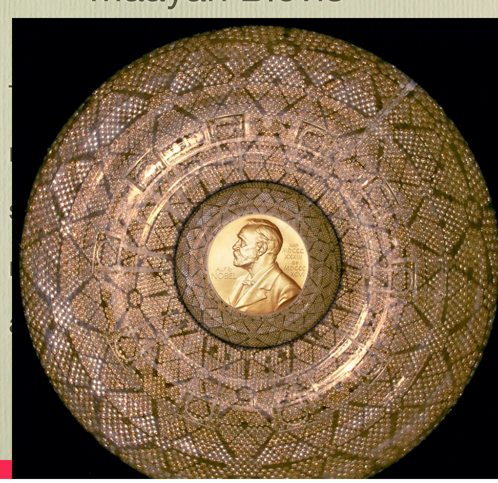

LAUREATES

Breakthrough Prize   Special Breakthrough Prize   New Horiz

2016   2015   2014   2013   2012

Kam-Biu Luk and the Daya Bay Collaboration
Yifang Wang and the Daya Bay Collaboration
Arthur B. McDonald and the SNO Collaboration
Takaaki Kajita and the Super K Collaboration

And finally, written and performed by Maayan Blevis



So the Higgs boson exists!

- Do we understand everything?
- Not by a long way!!!!!!!!!!!
- We don't know why there are 3 generations of quarks, what the missing matter in the universe is, whether there is only one Higgs............