Quarks matter

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Abstract:

The Excitement of the last year was the observation of the Higgs particle, but long before this was the prediction of the quarks, so first we explore:

1) how the idea of quarks came about,

2) what is the difference between matter and anti-matter.

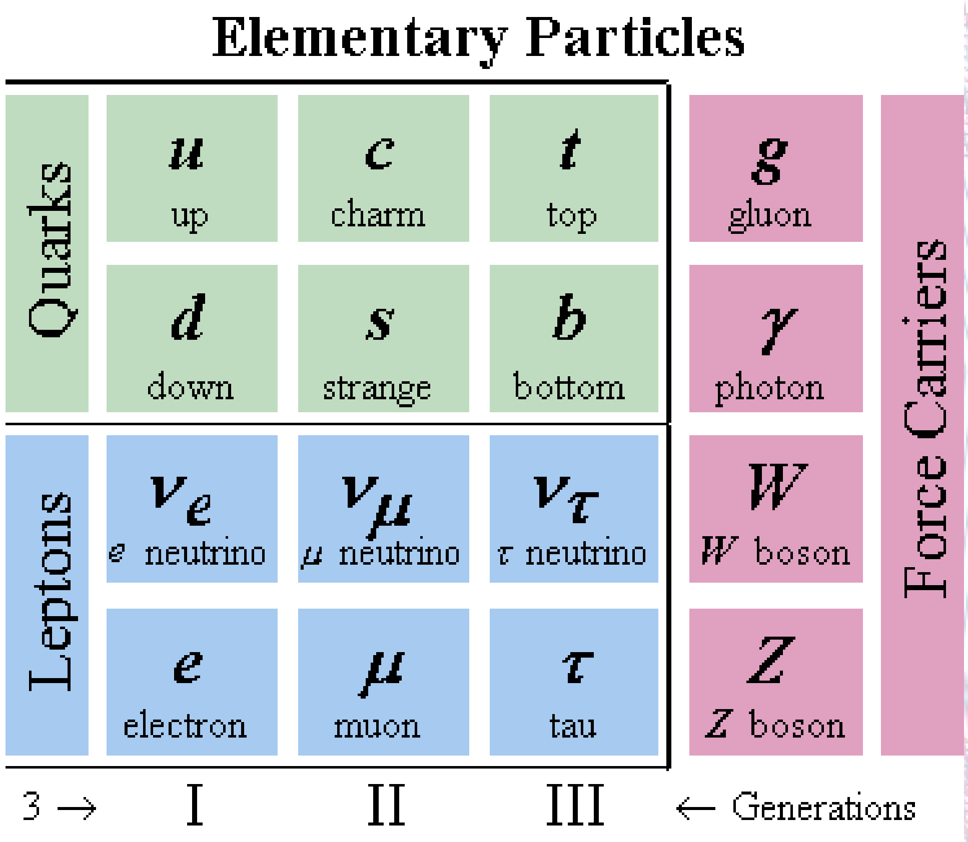
3) explain one very perplexing set of particles that behaved differently in its matter form than when in its anti-mater form.

Could this mechanism be the clue to why the universe is made of matter and not anti-matter? This year, 2014 is the 50th anniversary of this surprising discovery, which many physicists and myself are still working to understand if and how it can solve the matter riddle of the universe.

What are Quarks

Many talks just start by saying here is the table of matter particle and the forces.

I want to explain how it came about and why we know it truly is this way.

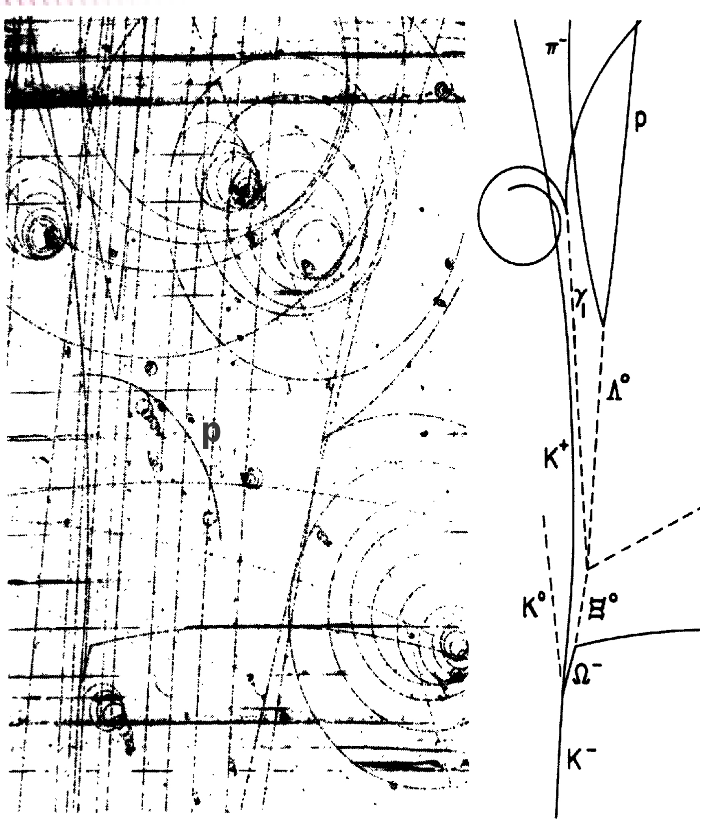


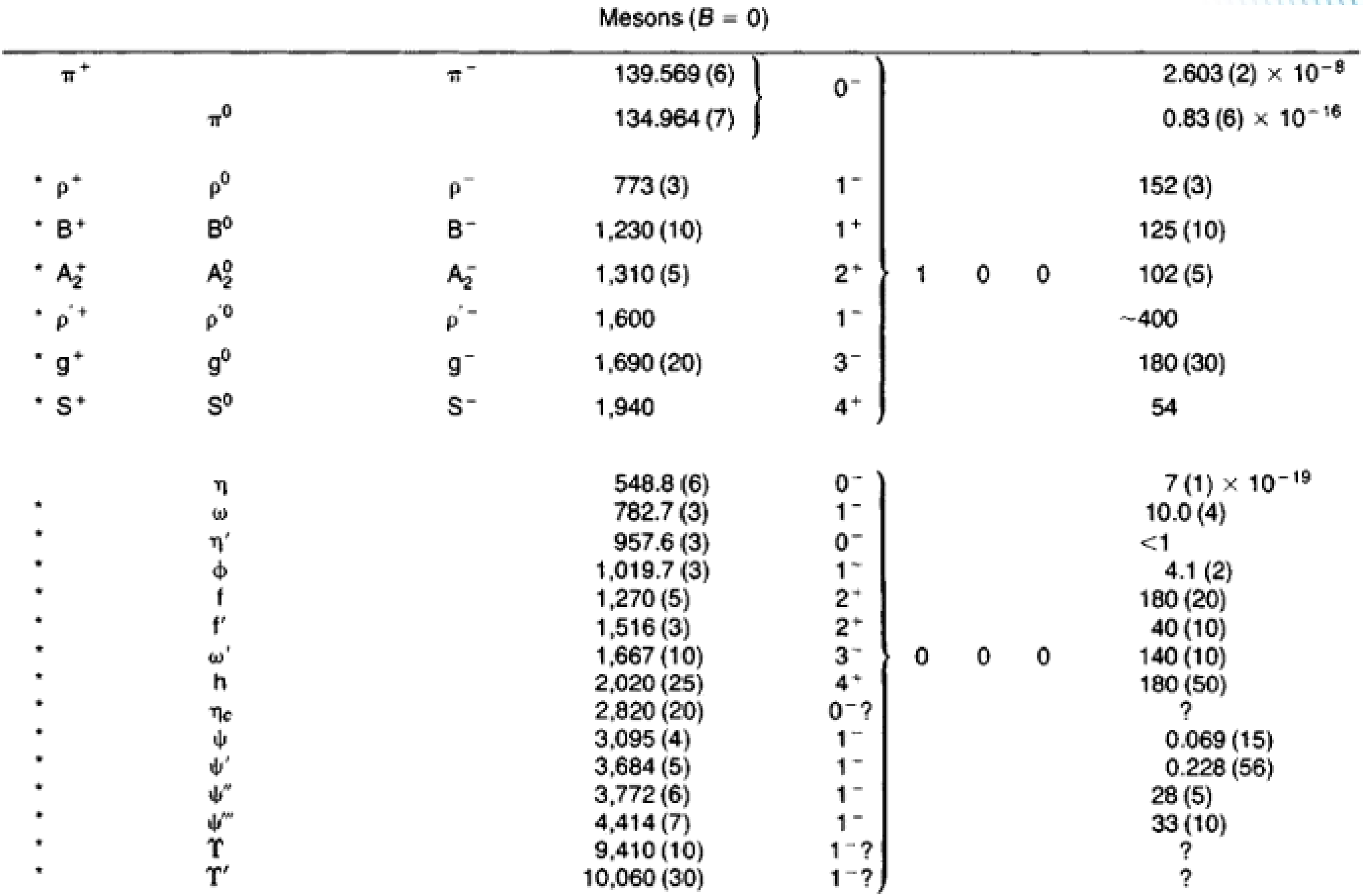
Elementary Particles

Quarks	u up	c charm	t top	g gluon	Force Carriers
	d down	s strange	b bottom	γ photon	
Leptons	ν_e e neutrino	ν_μ μ neutrino	ν_τ τ neutrino	W W boson	
	e electron	μ muon	τ tau	Z Z boson	
3 →	I	II	III	← Generations	

In the early days

In the early days nuclear physics was a unorganized mess, with many particles and little structure.





Mesons ($B = 0$)

	π^+		π^-	139.569 (6)	0^-	1	0	0	$2.603 (2) \times 10^{-8}$
		π^0		134.964 (7)					$0.83 (6) \times 10^{-16}$
*	ρ^+	ρ^0	ρ^-	773 (3)	1^-				152 (3)
*	B^+	B^0	B^-	1,230 (10)	1^+				125 (10)
*	A_2^+	A_2^0	A_2^-	1,310 (5)	2^+				102 (5)
*	ρ'^+	ρ'^0	ρ'^-	1,600	1^-				~400
*	g^+	g^0	g^-	1,690 (20)	3^-				180 (30)
*	S^+	S^0	S^-	1,940	4^+				54
		η		548.8 (6)	0^-	0	0	0	$7 (1) \times 10^{-19}$
*		ω		782.7 (3)	1^-				10.0 (4)
*		η'		957.6 (3)	0^-				<1
*		ϕ		1,019.7 (3)	1^-				4.1 (2)
*		f		1,270 (5)	2^+				180 (20)
*		f'		1,516 (3)	2^+				40 (10)
*		ω'		1,667 (10)	3^-				140 (10)
*		h		2,020 (25)	4^+				180 (50)
*		η_c		2,820 (20)	0^-?				?
*		ψ		3,095 (4)	1^-				0.069 (15)
*		ψ'		3,684 (5)	1^-				0.228 (56)
*		ψ''		3,772 (6)	1^-				28 (5)
*		ψ'''		4,414 (7)	1^-				33 (10)
*		Υ		9,410 (10)	1^-?				?
*		Υ'		10,060 (30)	1^-?				?

Unexplained anomalies

Many great advances in Physics are proceeded by a mystery that was unexplainable with the current knowledge.

In optics from 1805 to 1920 there were nine experimental unexplained anomalies.

Foucault's 1861 rotating mirrors (seen as far back as 1801)

Fizeau's 1851 moving water column experiment

Sagnac's 1892 rotating platform interferometer

Eventually all of the proper explanations for these unusual physics phenom were explained by Einstein's Special Theory of Relativity

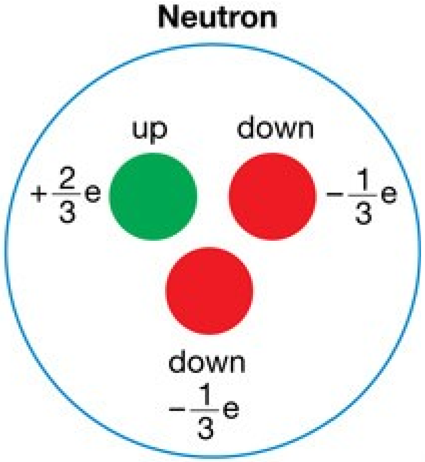
In particle physics of the early days there were unexplained observations, that did not make any sense with the understanding of the time.

Simon Altshuler and Igor Tamm of Russia in 1934 demonstrated that the neutron had a non-zero magnetic moment.

How could a particle with no charge produce a magnetic moment, when magnetic moments only come from charged particles in motion?

Introduction of quarks

Murray Gell-Mann and George Zweig introduced the idea of quarks. The quarks are sub-entities within an elementary particle, that forms part of the elementary particle.



Enlightenment

After a major new theory is introduced it has to explain the past anomalies, but also must be tested by new unobserved results.

For Einstein's Special Theory of Relativity ideas published in 1905:

The optics experiment anomalies are all explained

New experimental results like, relative motion between clocks, time dilation in cosmic-rays and the 1919 solar eclipse observation of the bending of light rays around the sun further confirms his new idea was correct.

Further understanding gained leads to even more changes to the Physics, such as the General Theory of Relativity.

In particle physics once quarks are introduced then.

Neutron's non-zero magnetic moment is understood.

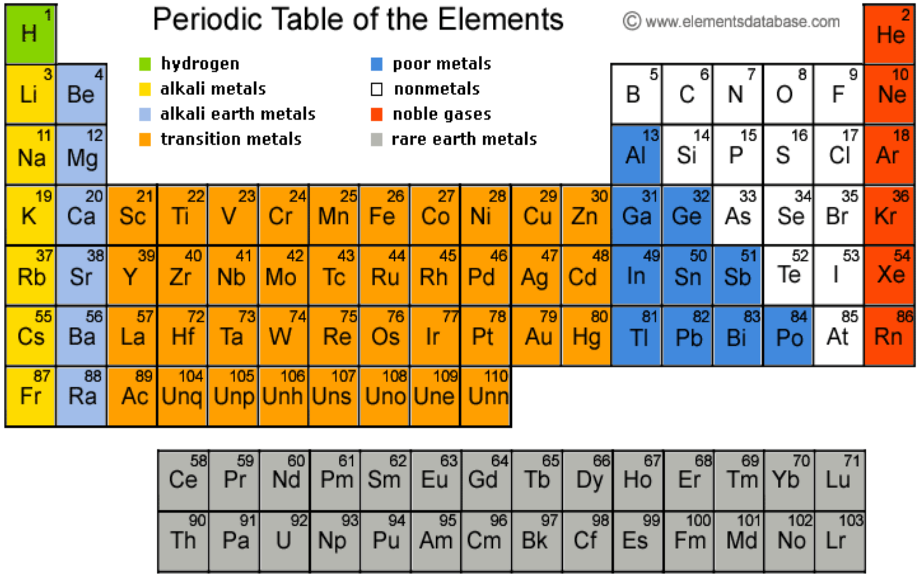
Furthermore, the many particles of nuclear physics could be organized.

The Tau-Theta puzzle, two particles with same mass but they decay differently with different lifetimes

Eventually particle physics understanding advanced further.

Particle Organization

Just like the Periodic table organized the nuclei, graphs using quark structure organize the observable elementary particles.



Periodic Table of the Elements

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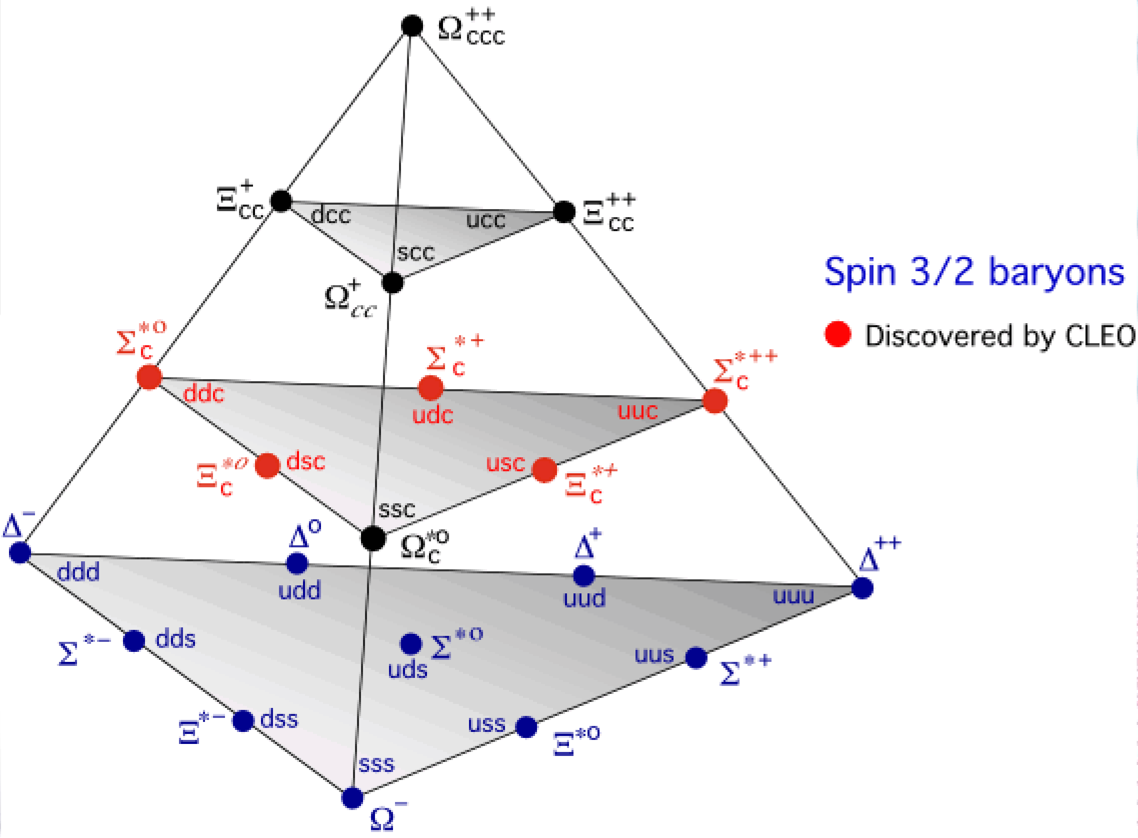
- 🟩 hydrogen
- 🟨 alkali metals
- 🟦 alkali earth metals
- 🟧 transition metals
- 🟦 poor metals
- ☐ nonmetals
- 🟥 noble gases
- ⬜ rare earth metals

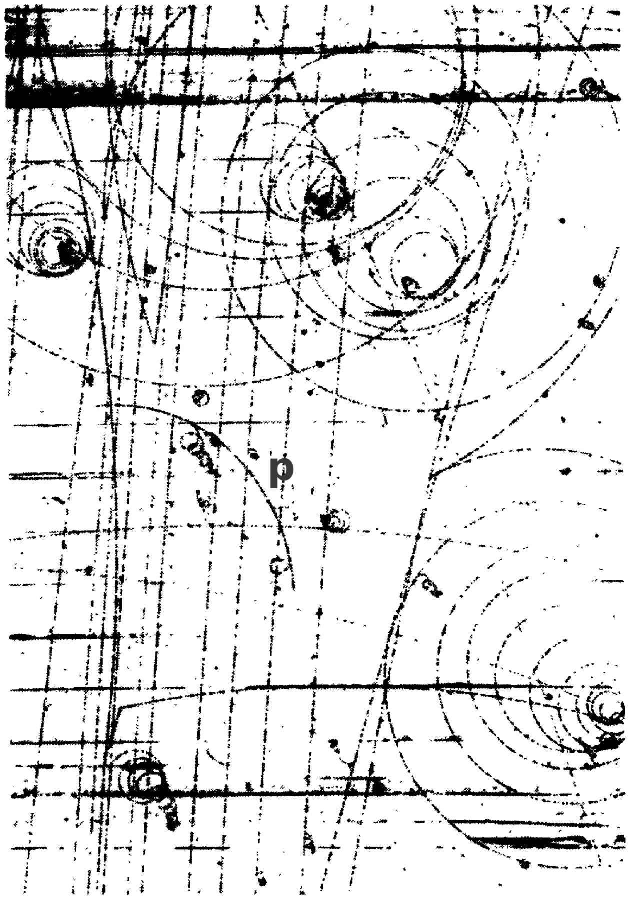
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	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
87 Fr	88 Ra	89 Ac	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Unn								

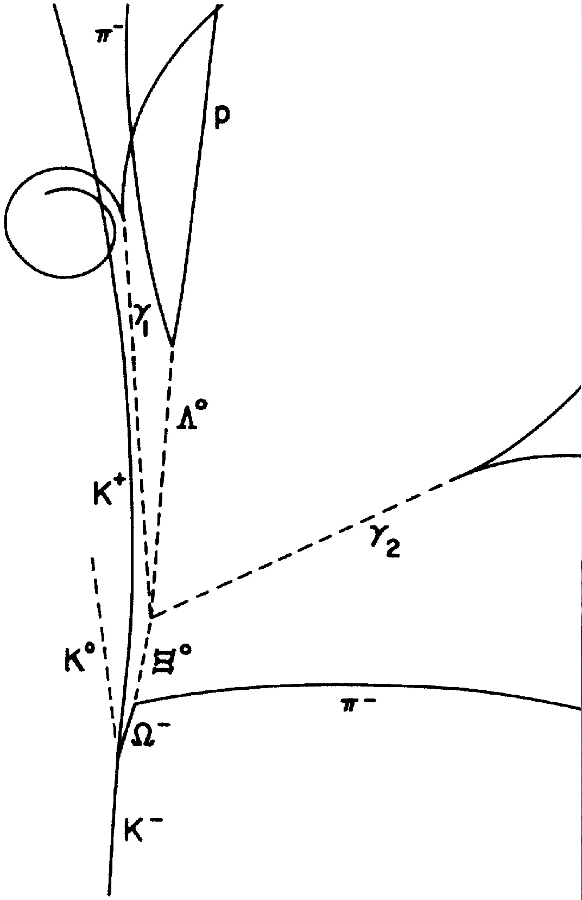
58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr



Predicted New particle discovered

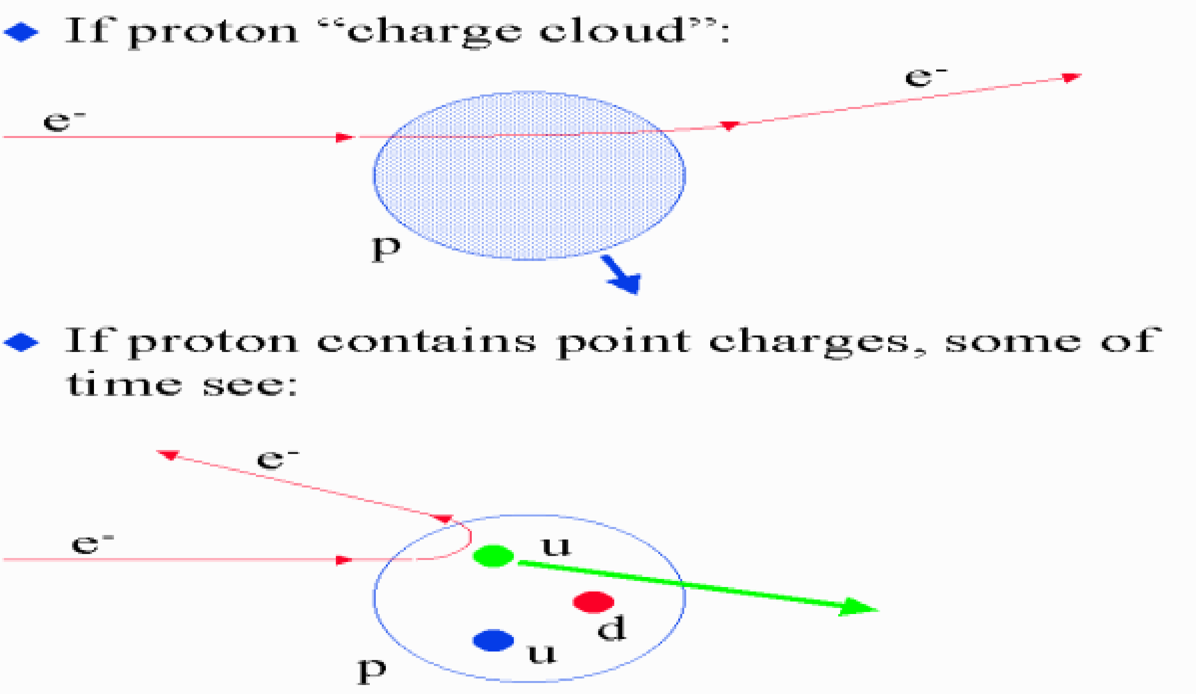
The Ω^- predicted by this new quark theory was searched for and found.



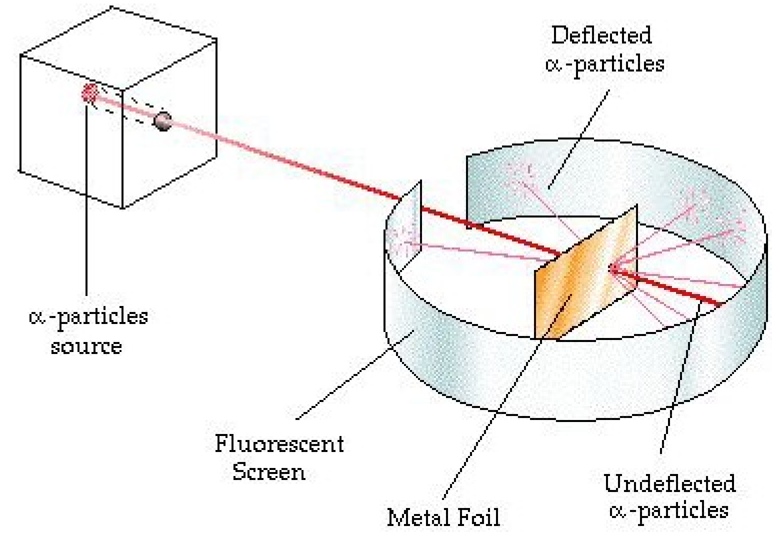


Directly Observing Quarks

Rutherford in England showed that the nuclear structure was a proton core by firing alpha particles at atoms, at Stanford Accelerator they used electrons to prove the quarks were really there, able to scatter incoming particles, resulting in the 1990 Nobel Physics prize.



- If proton "charge cloud":
- If proton contains point charges, some of time see:



Anti-Matter

PAM Dirac in 1930 formulated a relativistic theory of quantum electrodynamics, using Einstein's new theory of relativity. This formulation of motion predicted both negative electrons and positive electrons (anti-electrons are called positrons for their positive charge).

In 1982 I had interactions with Dirac when he tried to recruit me to be a Physics PhD graduate student in high energy theory at Florida State University, he made a comment very close to: ***"It is very easy only to see what one is told to look for"*** *when we discussed the positron discovery, which knowing he was a very important person in the history of Physics I wrote down his comment.*

In 1933 Carl Anderson discovered the positive electron using old photographs of cosmic ray tracks.

Anti-Proton

Knowing that anti-electrons exist did not assure us that the anti-proton was real. A 1955 experiment at the Berkeley accelerator was created by Chamberlain, Segre, Wiegand and Ypsilantis.

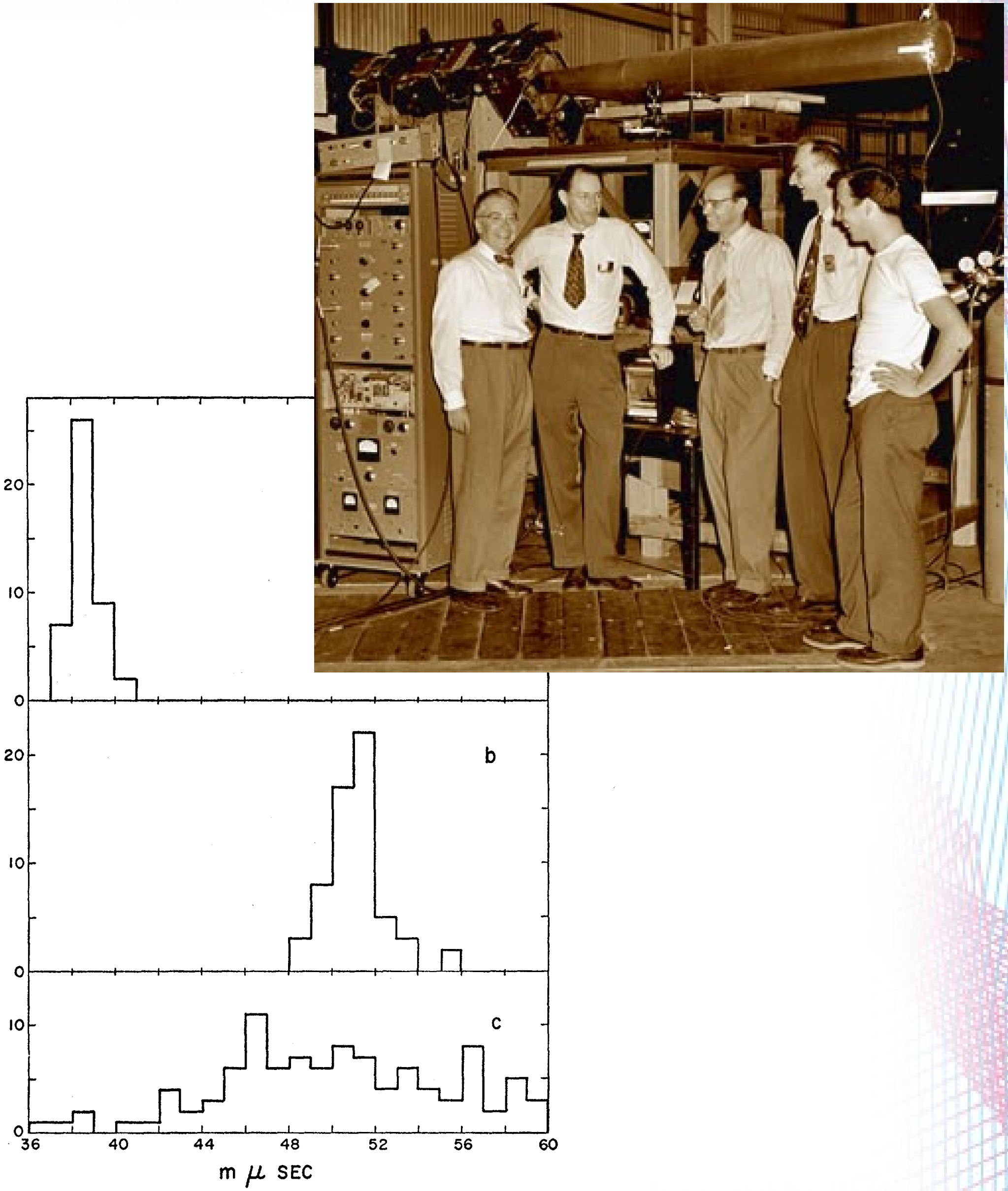
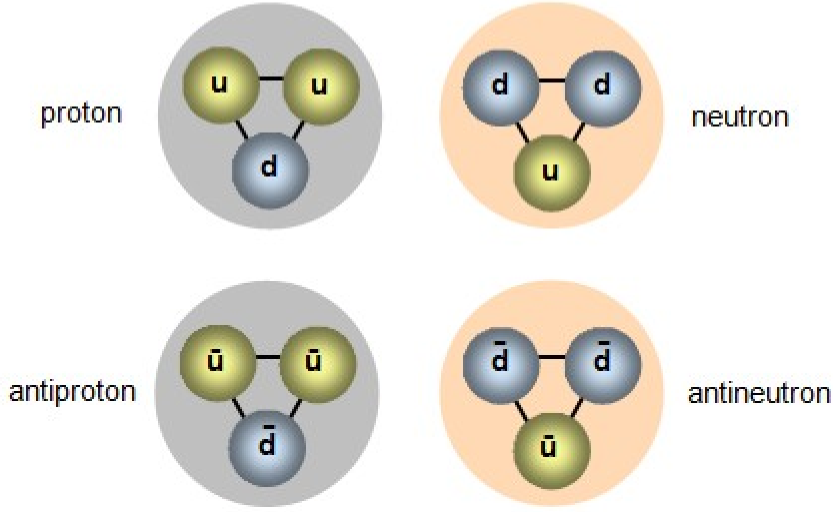


Fig. 3. (a) Histogram of meson flight times used for calibration. (b) Histogram of antiproton flight times. (c) Apparent flight times of a representative group of accidental coincidences. Times of flight are in units of 10^{-9} sec. The ordinates show the number of events in each 10^{-10}-sec intervals.

Anti-quarks

Since the electron has an anti-particle the positron

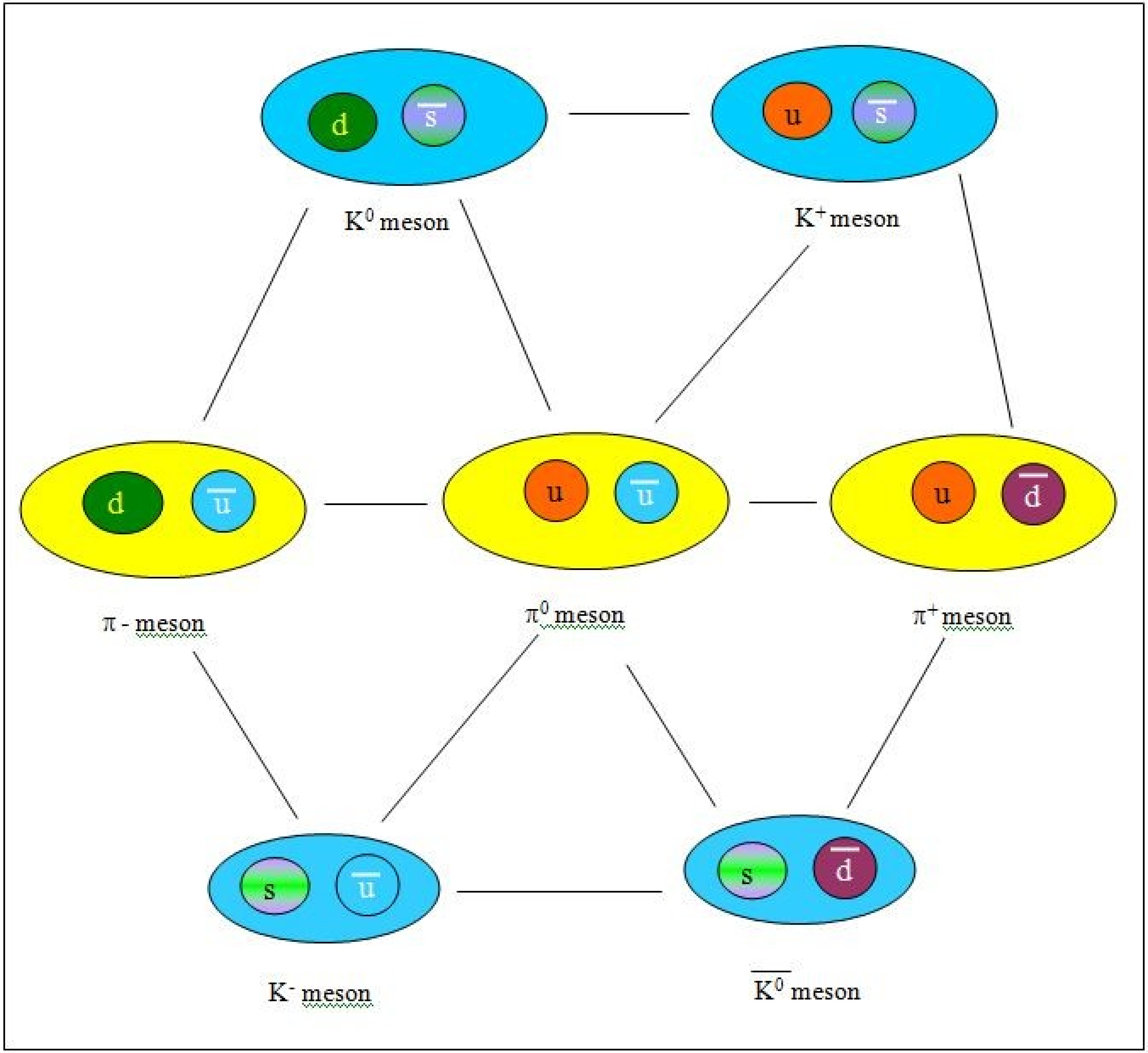
We now know the anti-proton exists, and since protons are made of quarks, it followed that the anti-proton should be made of anti-quarks.



Mesons and Strange Quarks

Other particles can be made of quarks and anti-quarks bound together; examples of these are the Pions.

A 3rd type of quark, called strange, allows us to have even more combinations producing Kaons.



Tau-Theta Puzzle

The two particles Tau and Theta had the same mass, but one decayed into two Pions and the other into three Pions.

Today these particles are known as the K^0 short and the K^0 long, identical in mass because they are constructed of the same quarks, but in two different parity states. One is the mirror image of the other, right handed and left handed for example.

Parity

The laws of physics should be the same when observed directly or in a mirror.

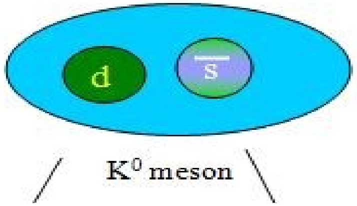
However, some particles exhibited parity violation in certain type of nuclear decays.

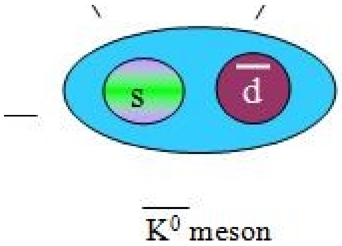
CP

However, if you change the charge: all positive to negative and all negative to positive charges, then the combination of Charge and Parity (CP) was an apparent good symmetry for elementary particle decays and interactions.

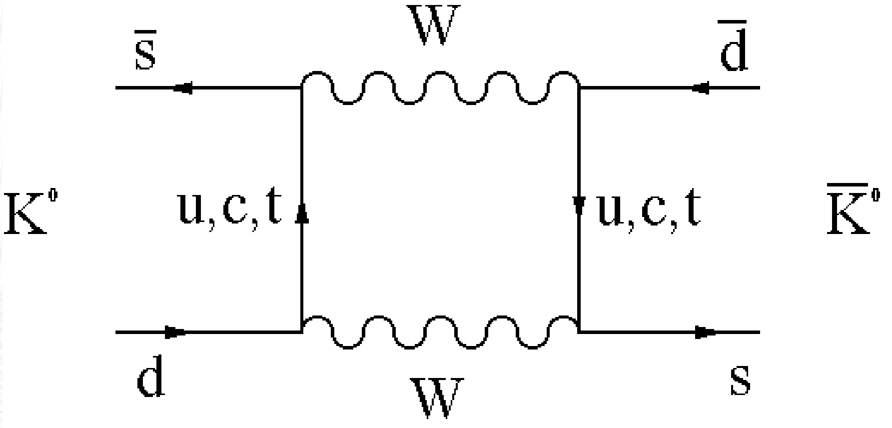
Neutral Kaon

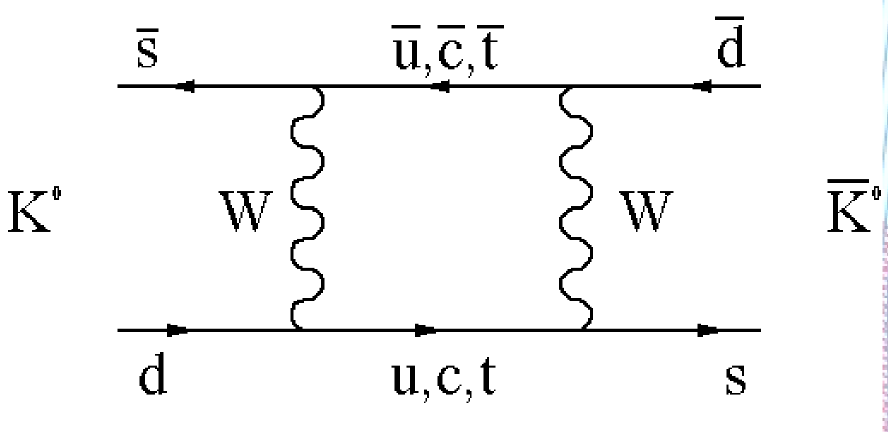
The neutral Kaon is a very mysterious particle





Since quarks are not free we see it as almost the same particle, but it should be the anti-particle.





The neutral Kaon can oscillate between matter and anti-matter as it propagates through space.

Observe K_{long} and K_{short}

The two ways to assemble the quarks positive and negative parity states, and that it can go from matter to anti-matter form as it travels results in us only able to observe:

K_{short} 8.9×10^{-11} s lifetime, 2 Pion decay

K_{long} 5.12×10^{-8} s lifetime, 3 Pion decay

CP Violation

Jim Cronin, Val Fitch and Rene Turlay observed in 1964 that sometimes

K_{long} can decay into 2 Pions!

(also much later others showed K_{short} can decay into 3 Pions)

This showed that the initial and final states had different CP states, and hence they observed CP-violation.

Types of CP violation

There are 2 types of CP violation involved

1st There is the indirect CP violation because the K^0 and anti-K^0 are mixing.

2nd There is direct CP violation which is occurring at the instant of decay, through a modified decay process.

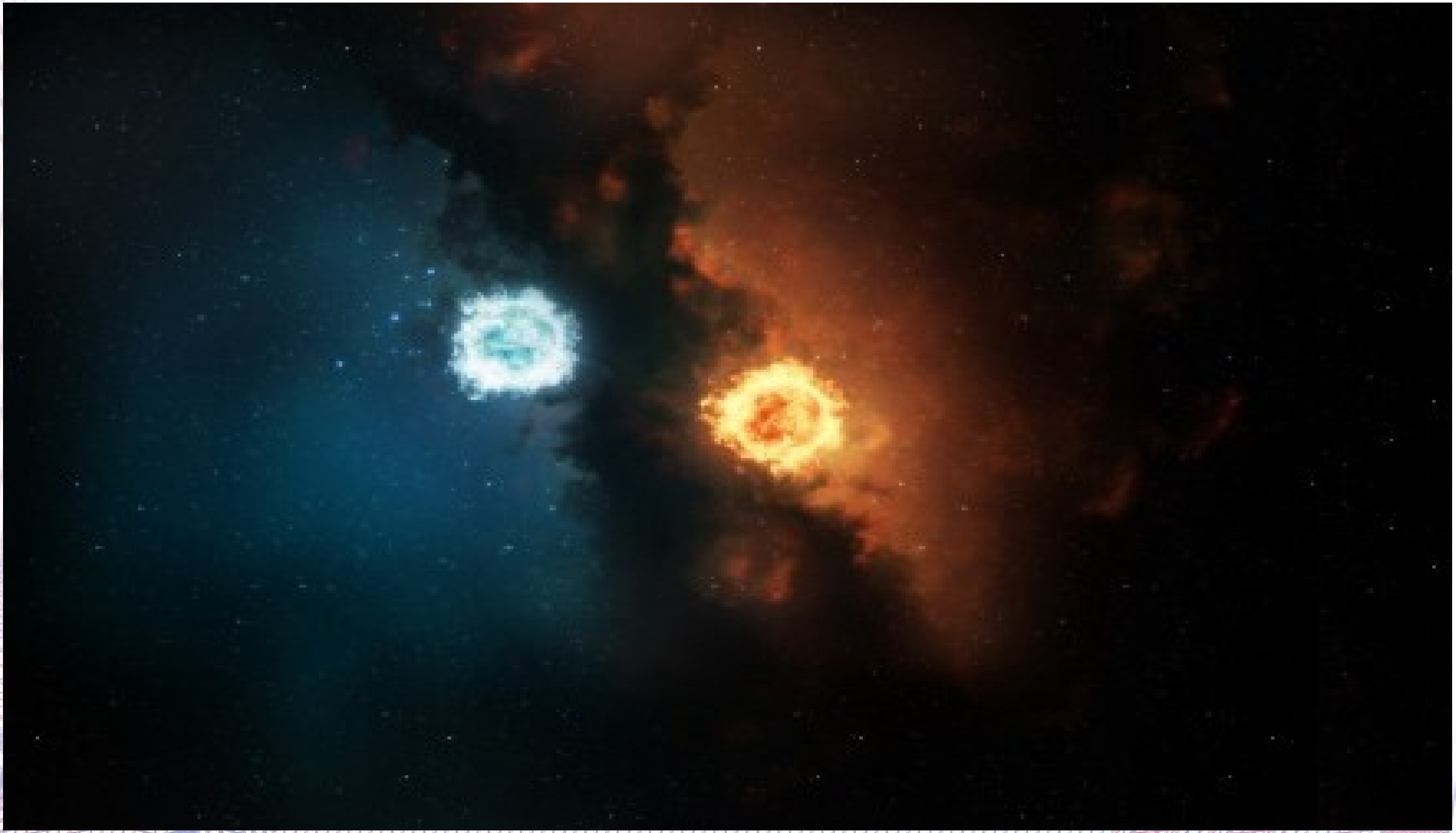
This might mean there is a difference between matter and anti-matter!

The Universe

When we look anywhere in the Universe with our eyes we are seeing matter.

Anti-matter Universe

We would expect that if some of the Universe is anti-matter then where they touch we would see matter anti-matter annihilation, but we do not.



Anti-matter mystery

This leads us to the question of where is the anti-matter in the Universe.

If in the beginning at the Big Bang, matter and anti-matter where created equally, then why only matter has survived for us to see today?

The answer to this matter riddle of the Universe might lay with the properties of elementary particles and their decays.

Anti-Matter

We think that Matter and Anti-Matter were created equally in the Big Bang.

Around us we see no sign of Anti-Matter.

The Universe today is made of cold matter such as electrons, protons and neutrons, not excited matter.

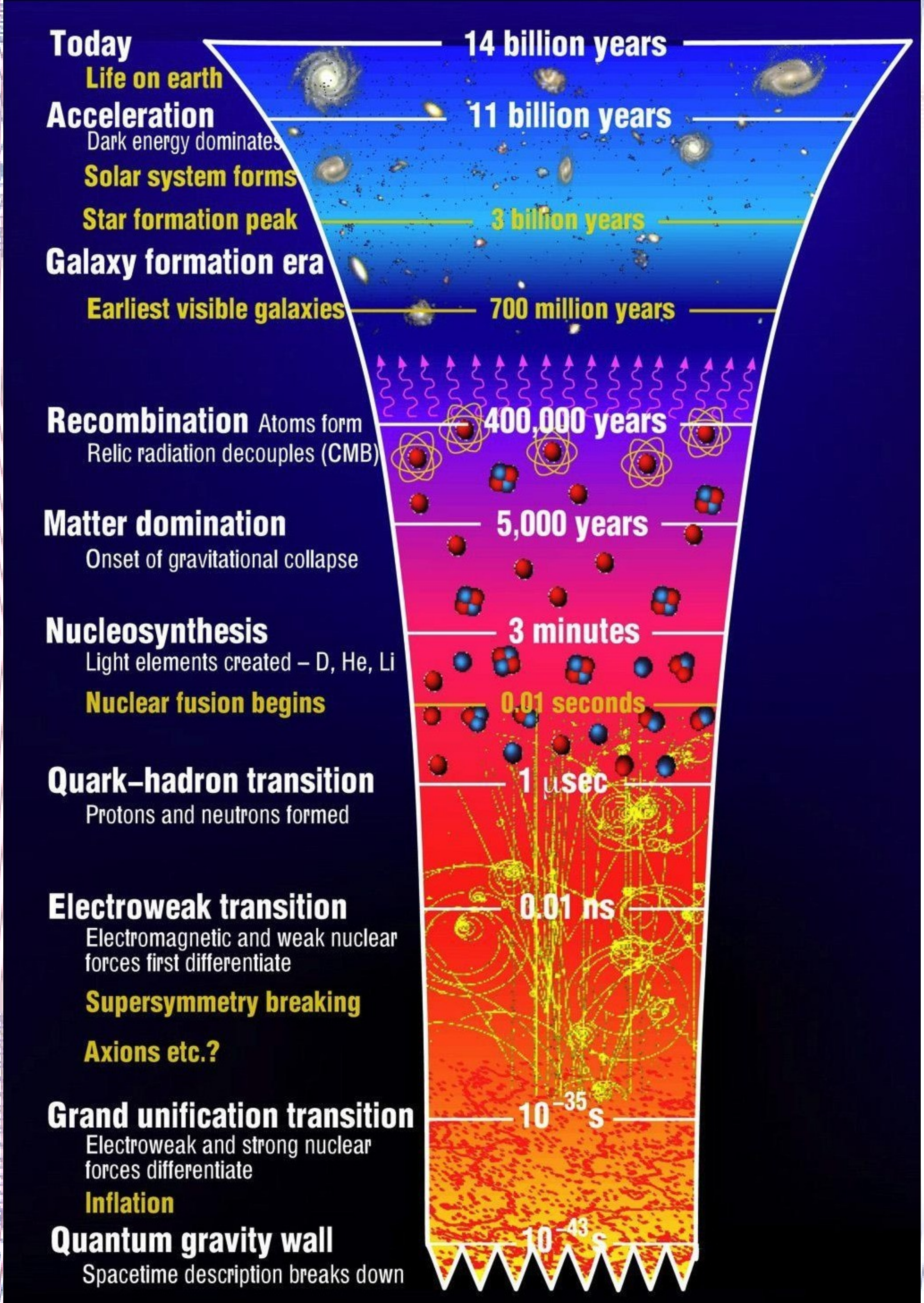
It could be that the excited matter we make in accelerators had matter behaving differently than anti-matter?

Annihilation

So if Anti-matter could oscillate faster into Matter we could explain the dominance of Matter.

This is because shortly after the Big Bang all the matter and anti-matter annihilated, creating a photon dominated Universe and any imbalance of matter converting into anti-matter slower than anti-matter could convert into matter would explain the imbalance at the time of the matter anti-matter annihilation, about 1 μs to 5000 years after the Big Bang.

After the Big Bang



This graph shows some of the major steps the Universe went through after the Big Bang and when stable matter could dominate.

CP violation

CERN's NA31 experiment discovered the first hint of direct CP violation, and both the KTeV at Fermilab and NA48 at CERN finally confirmed it in 1999. However, the value observed is far to small to account for the Matter Anti-Matter imbalance of the early Universe.

Other even smaller forms of CP violation in the b-quark mesons were observed.

Messengers from the Big Bang

There is another particle from the Big Bang that survives until today.

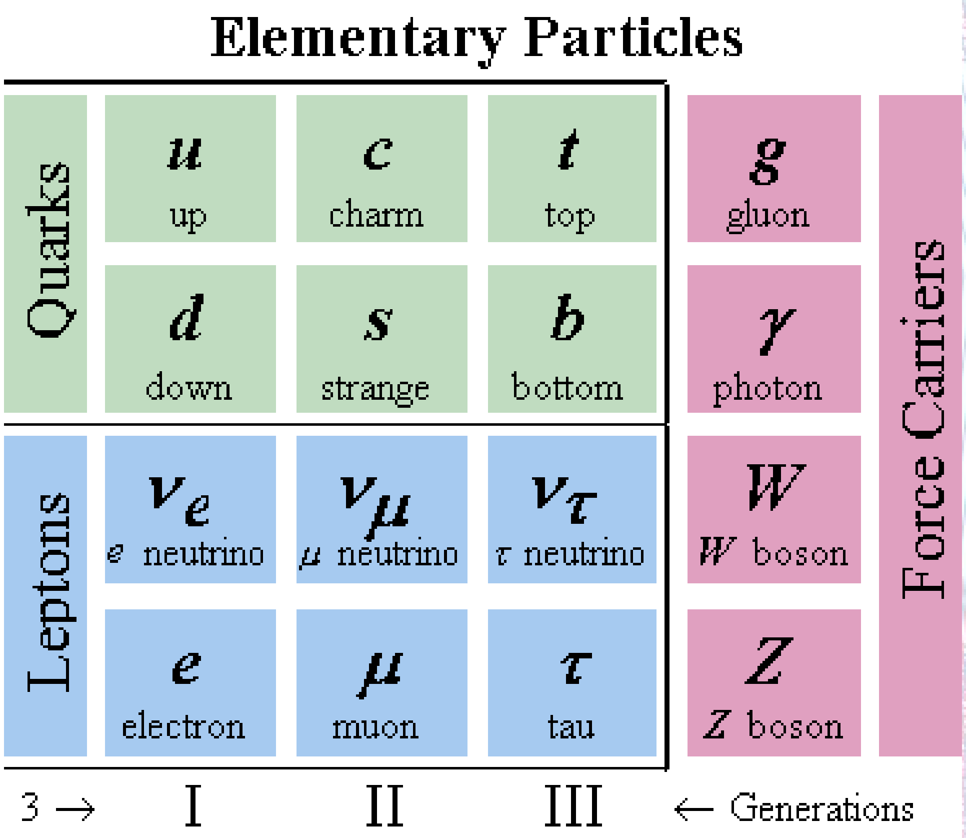
Neutrinos created in the Big Bang and early Universe could have a CP violation that could account for the Matter Anti-Matter imbalance

What are neutrinos and how to measure if this Elusive Particle could hold the ultimate key to understanding the Universe.

Fundamental Particles

Just like the quarks, the leptons are fundamental particles with charge electrons and neutrinos.

But, the neutrino has a very special property, it hardly interacts at all and could go through light years of lead walls.



Elementary Particles

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Leptons	ν_e e neutrino	ν_μ μ neutrino	ν_τ τ neutrino	W W boson	
	e electron	μ muon	τ tau	Z Z boson	
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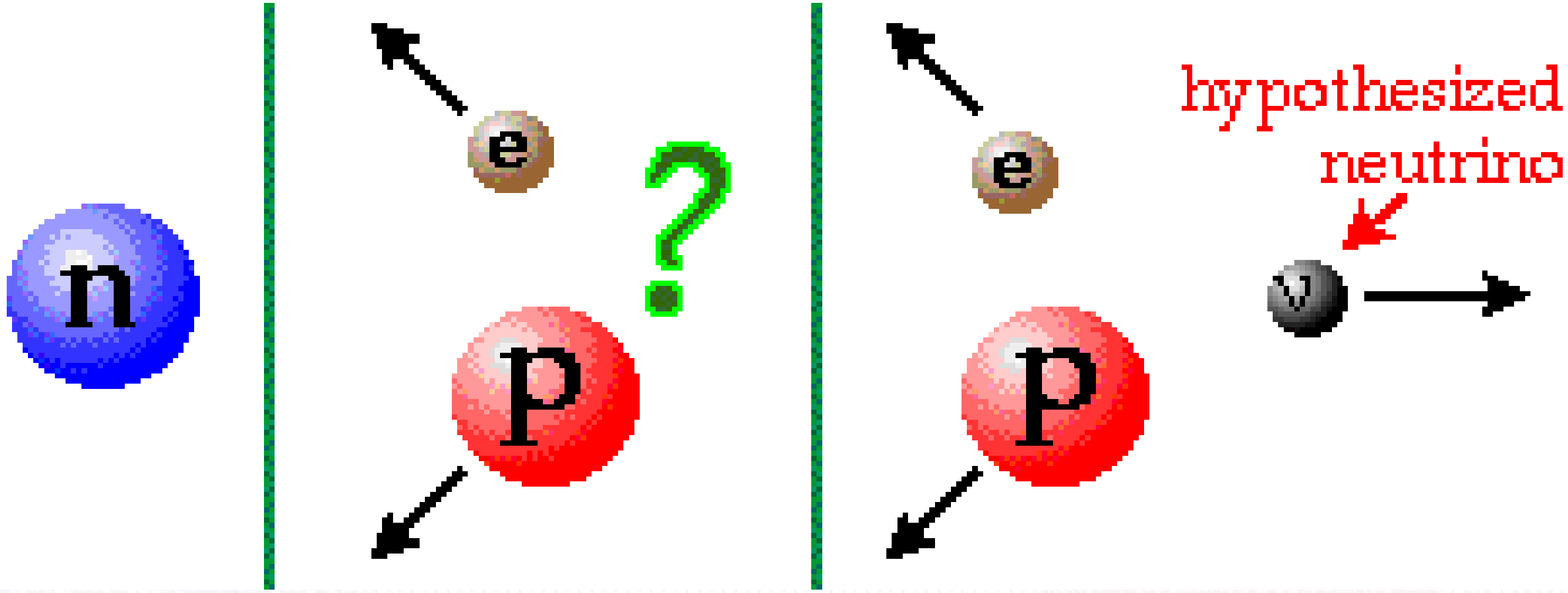
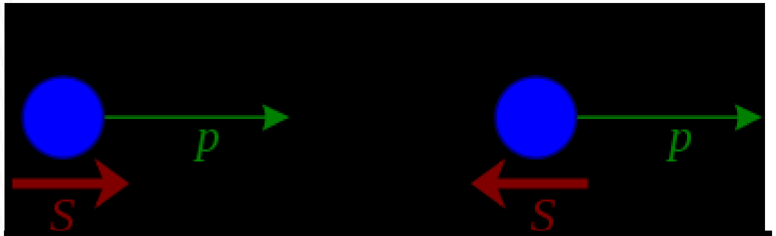
Missing Energy

Neutrino speculated by W. Pauli to explain the missing energy from Beta decay.

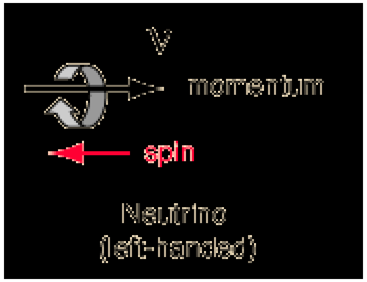


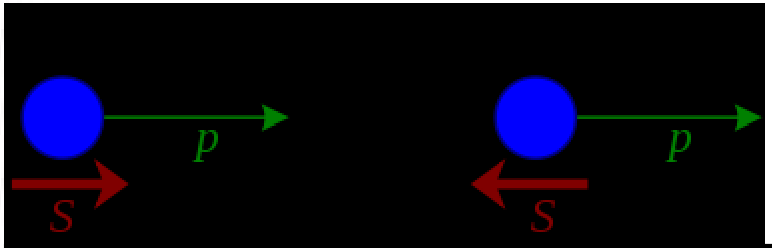
Missing states

Neutrino has only one spin state while the electron has both, and the same for the anti-particle.

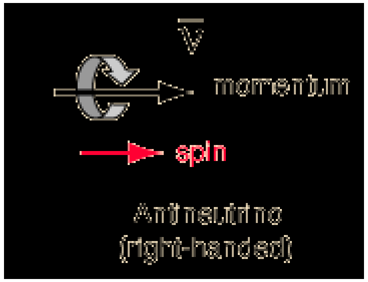


electron





positron



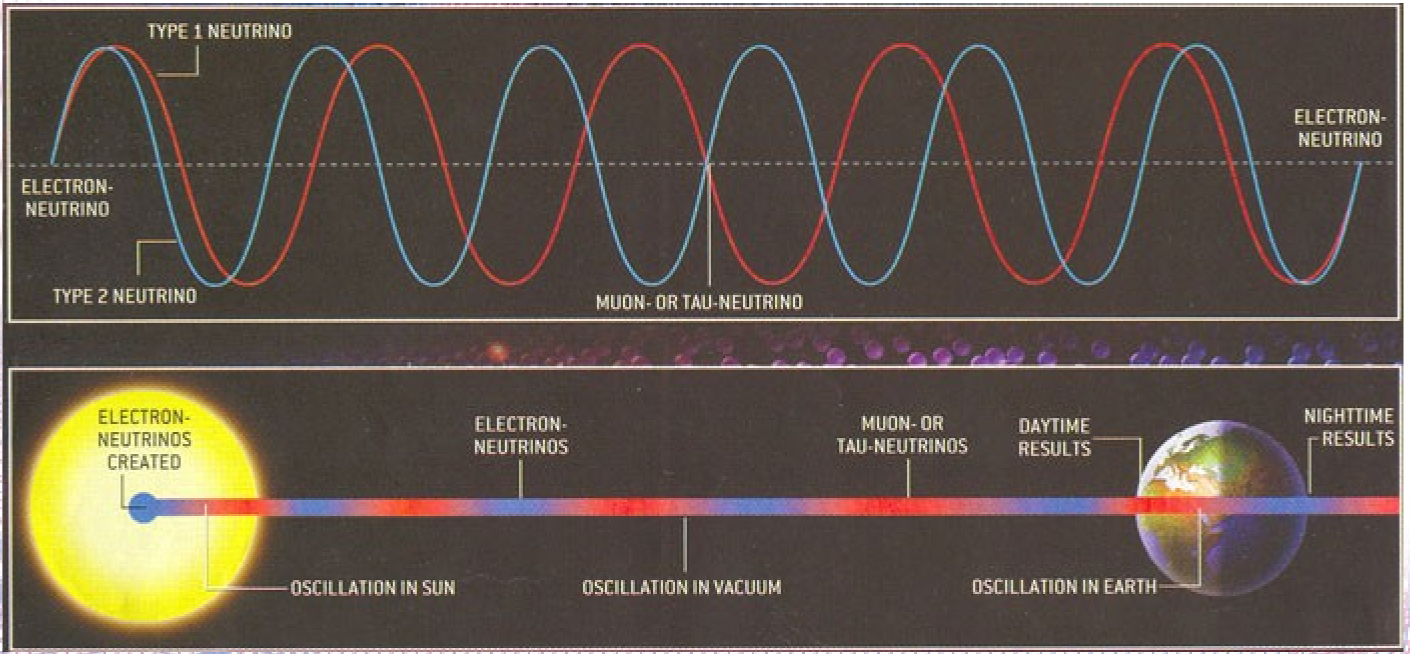
From the beginning it was clear that the neutrino is very different than the electron, although they are both leptons.

Neutrino properties

Neutrino is nearly mass-less, and far lighter than electron

Neutrino might be is own anti-particle

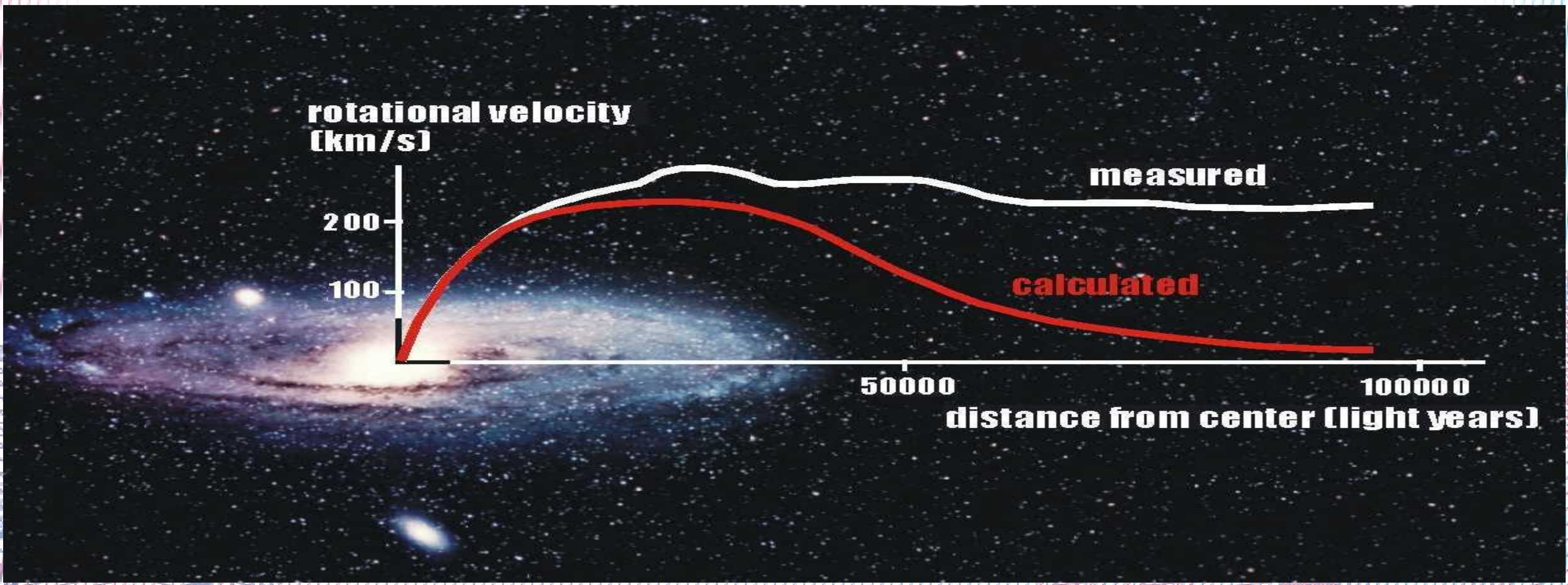
Neutrinos oscillate between the flavours



Dark Matter

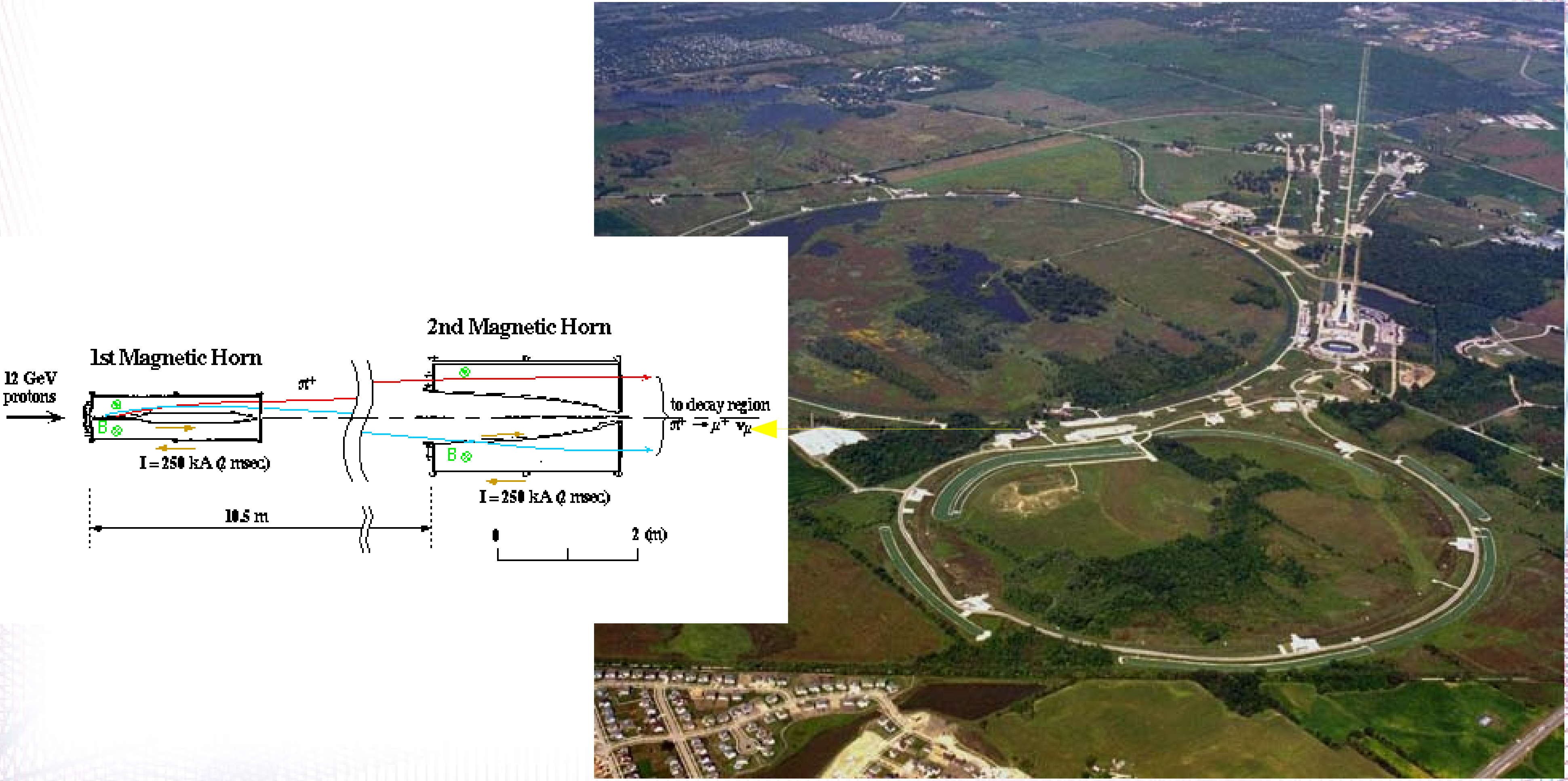
Recently we have understood there is far more matter we do not see that is controlling the Universe, what is it?

The neutrino might be one form of missing Dark Matter of the Universe.



Producing a Neutrino Beam

The neutrino horn was first invented by Val Talegdi and Roland Winston, it uses a sheet of current to de-focus a pion beam that decays producing a parallel beam of neutrinos.



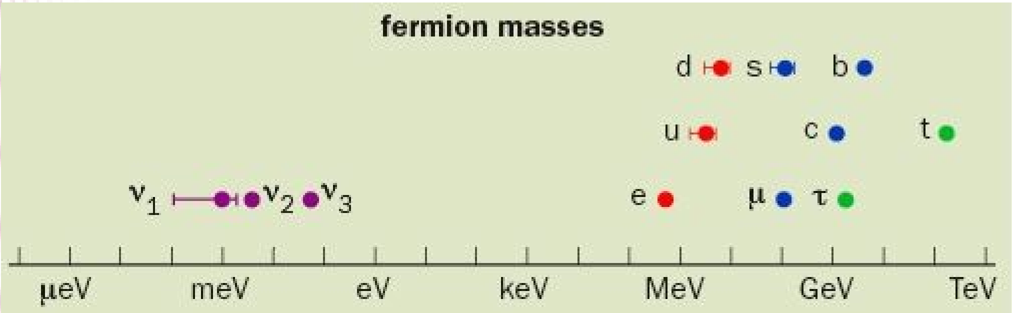
Studying the Neutrino

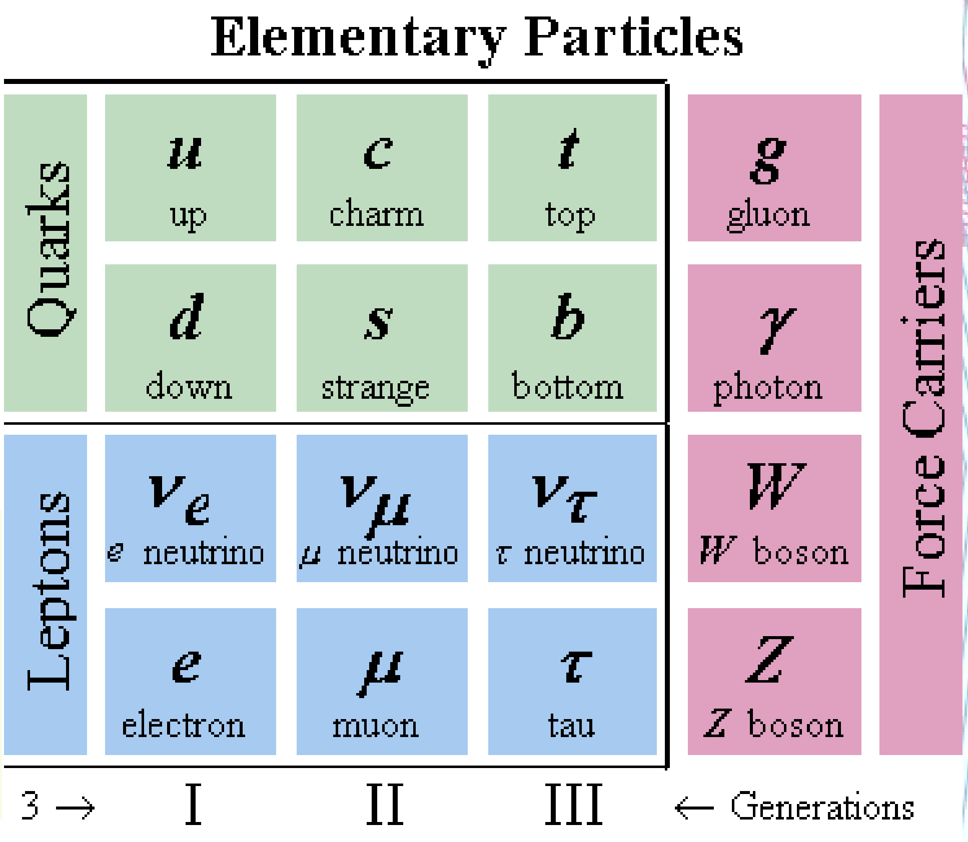
Fermilab has had a neutrino beam that can produce neutrinos or anti-neutrinos to a far distant lab. Experiments such as MINOS and NOvA are able to study neutrinos and anti-neutrinos, these experiments might see the first hint at Neutrino CP violation.

Fermilab is planning for a long term future of neutrino studies with the LBNE experiment to expand this neutrino program to gain more insight into the Neutrinos, studying CP violation and its implication to the early Universe.

Mass of the Elementary Particles

Why do these fundamental particles have such a great range of masses.

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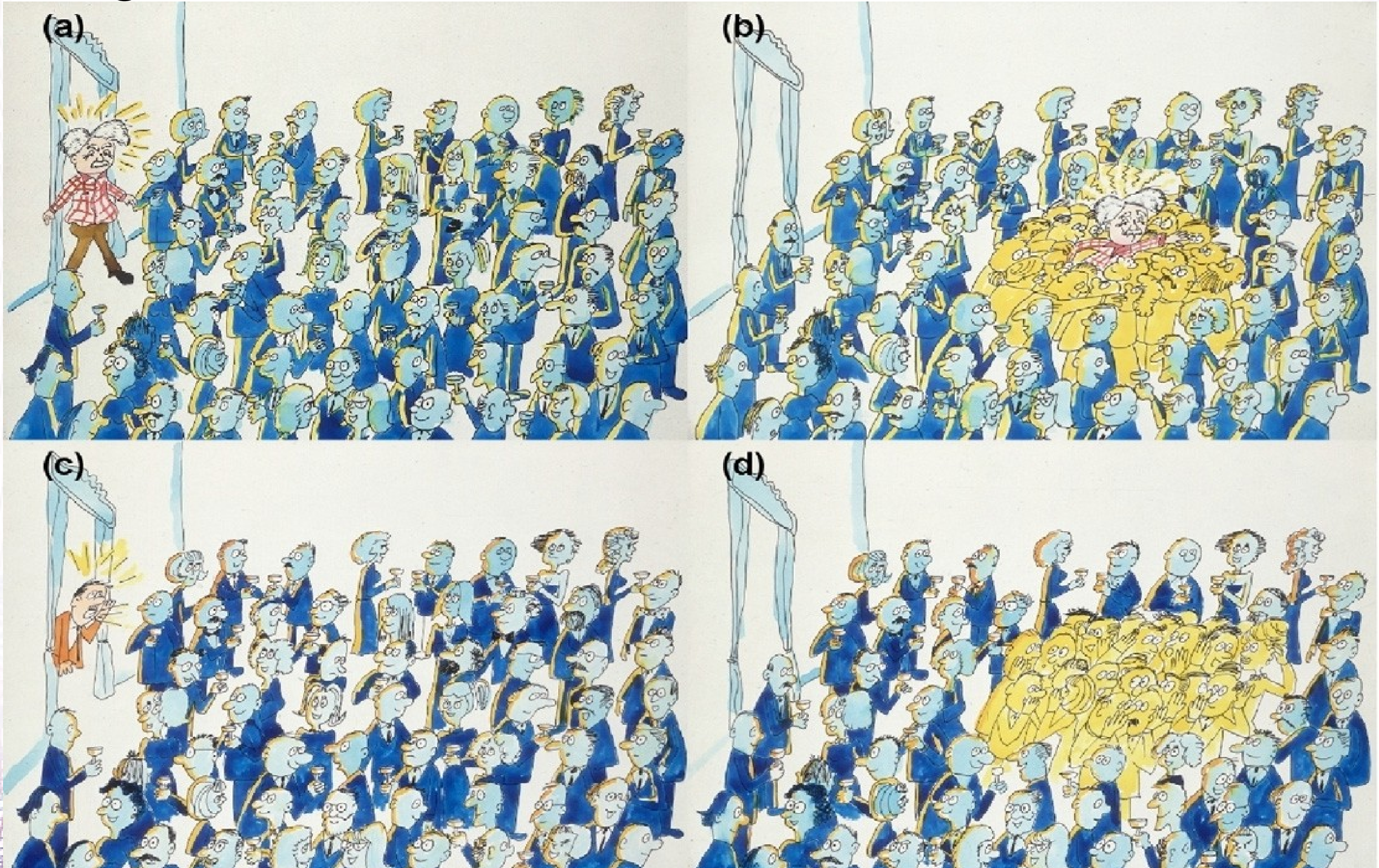
We think all of these masses can be explained by the Higgs particle, and that the mass of each particle depends upon how strong this particle feels the Higgs field.

Higgs mechanism

Depending upon the popularity of the person it could take them no time or a long time to walk through a crowd of admirers.



Conclusion

We saw a brief glimpse into the world of particle physics, from its early days of many unexplained particles, to the advanced studies of today of the Higgs, Quark Physics, and the Neutrino.

The idea of the Quarks was truly important and this has gained us much knowledge about the what the Universe is made of and how it interacts. It is always amazing to see how the very small can influence the amazingly large as with particle physics and the Universe.

But there are still many more questions unanswered that we continue to study.

Any science investigation is like a detective story, it takes time to discover and put all the pieces together.

Thank you

I wish to thank you for your attendance and patience while I tried to explain the story of particle physics.

It was my pleasure to give this talk and I hope I inspired some younger students, gave the public some sense of why the subject of particle physics is exciting, and that you enjoyed the talk.

For those that came with a particle physicists, they will tell you and as I know, my story was very incomplete, but now you can spend a few days asking them many questions.