H. A. TANAKA

PHYSICS 489/1489

INTRODUCTION TO HIGH ENERGY PHYSICS

LOGISTICS

- Instructor: Hirohisa Tanaka
  - “Hiro”
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- Office Hours (MP801A):
  - 1500-1700 Thursday
  - also by appointment (send me an email)
- TA: Vince Pascuzzi
  - vpascuzz@physics.utoronto.ca
  - office hours (MP815) 1600-1700 Wednesday
- No official prerequisites, but I assume you know:
  - Special relativity
  - Lagrangian mechanics
  - Quantum Mechanics:
    - Dirac notation, perturbation theory, uncertainty principle
    - Commutators, spin/angular momentum

MORE LOGISTICS

- Course website:
  - https://sites.physics.utoronto.ca/tanaka/physics-489-1489-2015
  - under construction!
  - Find lectures, problem sets, solutions, posted here.
- Textbook: "Introduction to Elementary Particles" D. J. Griffits, 2nd rev. edition
  - Lecture notes closely follow the text, but are not exhaustive!
  - It is important to read the textbook!
- Grading:
  - 4 problem sets (40%)
  - 1 midterm examination on 12 November (20%)
  - 1 final examination (40%)
- For homework:
  - it is fine (encouraged!) to work together, but each person must fully show their own work.

Class Outline

Date	Lecture	Griffiths Reading	Homework
Tues 15 Sep	1. Course intro and history	1	
Thurs 17 Sep	2. Introduction to elementary particles	2	**PS 1 Assigned**
Tues 22 Sep	3. Particle accelerators and detectors	2	
Thurs 24 Sep	4. Special Relativity	3.1-3.5	
Tues 29 Sep	5. Relativistic kinematics		
Thurs 1 Oct	6. Symmetries in quantum mechanics	4.1-4.2	
Tues 6 Oct	7. Isospin symmetry	4.3	PS 1 due PS 2 assigned
Thurs 8 Oct	8. P, C, CP, and CPT	4.4	
Tues 13 Oct	9. Lifetimes and decay rates	6.1	
Thurs 24 Oct	10. Cross sections and rates	6.2	
Tues 20 Oct	11. Toy theory with Feynman Rules	6.2	PS 2 due PS 3 assigned
Thurs 22 Oct	12. Relativistic wave functions, Dirac equation	7.1-7.4	
Tues 27 Oct	13. Other properties of the Dirac Equation	7.1-7.4	
Thurs 29 Oct	14. Feynman rules for Quantum Electrodynamics	7.5-7.6	
Tues 3 Nov	15. Gamma matrices, spin summation, etc.	7.7-7.8	
Thurs 5 Nov	16. QED examples		PS 3 due PS 4 assigned
Tues 10 Nov	17. Weak interactions: charged-current	9.1-9.3	
Thurs 12 Nov	Midterm		

- Homework policy:
    - submitted in drop box before 1700 on due date
    - solutions will usually be posted at the same time.
    - no credit after solutions are posted
- If you anticipate any issues with turning the assignment in on time, **please let me know in advance.**

HIGH ENERGY PHYSICS

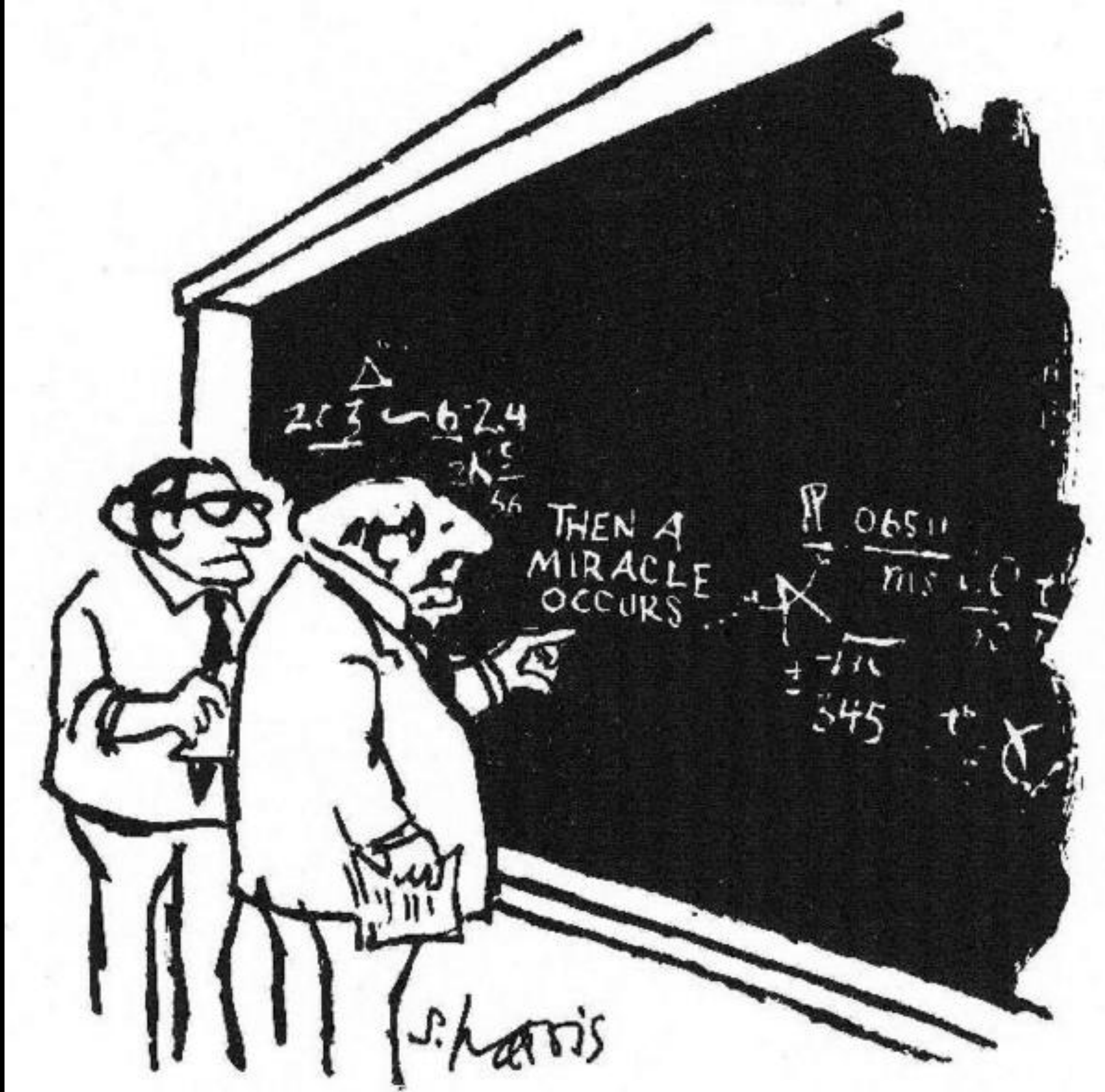
- What is high energy physics? also known as . . . .
  - particle physics
  - elementary particle physics
- Generally speaking:
  - the study of the fundamental (=elementary) constituents and interactions (=forces) of the universe
  - higher energy ~ more fundamental probe of matter
  - some "high energy physics", i.e. study of elementary particles does not involve particularly high energies . . . . .

CLASS OBJECTIVES:

- Learn the “taxonomy” of the elementary particles/interactions
  - what are the fundamental constituents and their interactions?
  - what are the basic properties and rules which govern them? (what is allowed/forbidden)?
  - depict basic processes through Feynman diagrams
- Understand the basic principles of how we produce/detect elementary particles and study their properties
- Kinematics of particle interactions
  - Use special relativity, conservation laws
- Calculate the amplitude of an elementary processes using the Feynman diagrams/rules, and calculate cross sections/decay rates

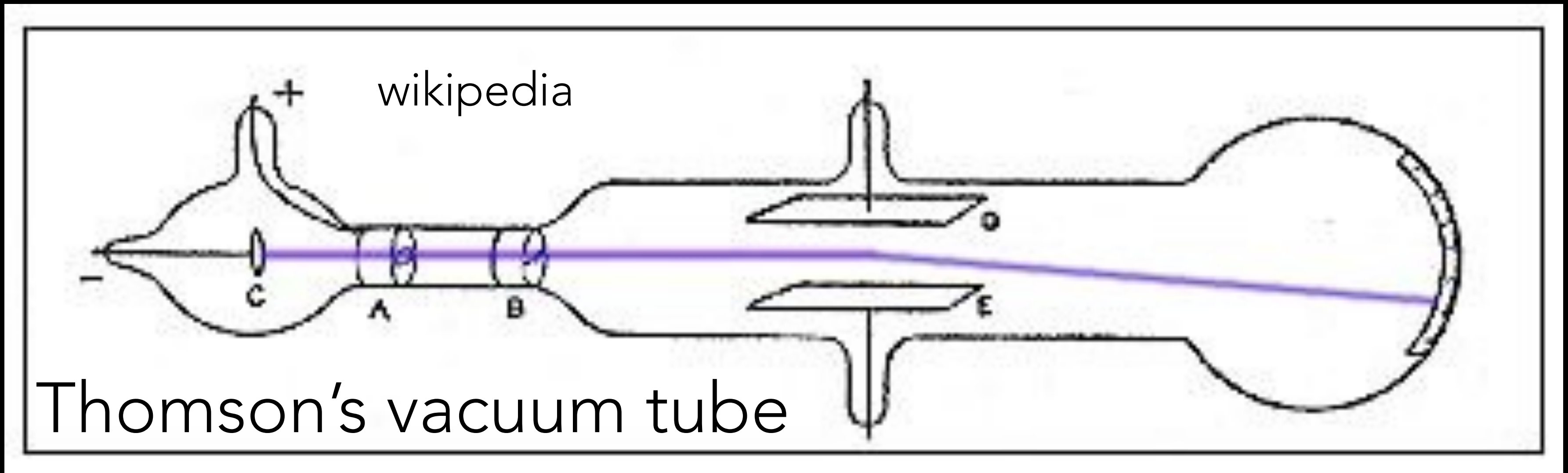
WHAT WE WILL NOT COVER

- In some sense, this class is pedagogically misplaced
- A more logical approach might be to study the fundamental framework of "quantum field theory" first
  - consistent quantum mechanical framework for treating relativistic particles
  - beyonds the scope of this class . . . . .
- We have other fundamental principles (conservation laws, symmetry, etc.) to work with.
- But a large part of the class will come out of nowhere without any fundamental explanation
  - i.e. Feynman rules for calculating the amplitude of a process



"I think you should be more explicit here in step two."

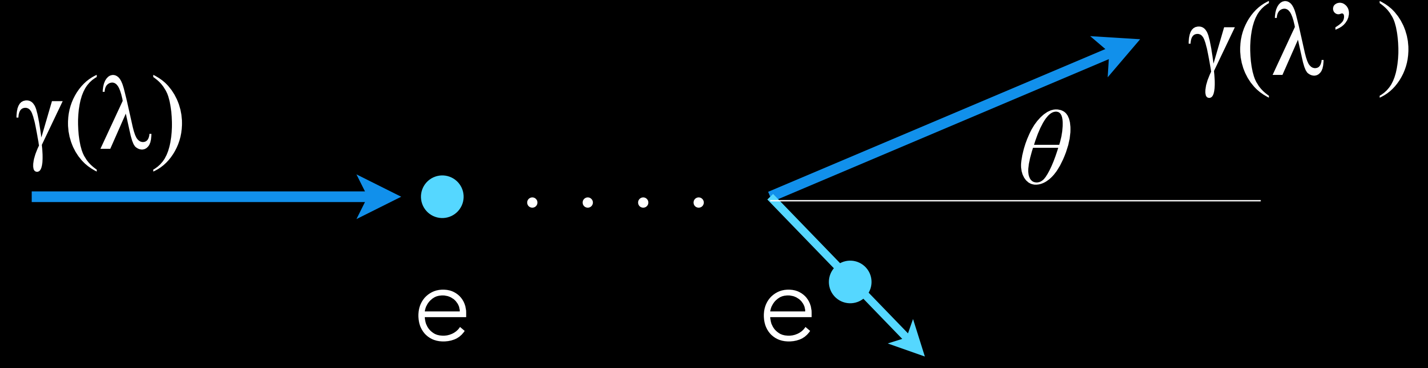
"FIRST" ELEMENTARY PARTICLE



- cathode ray studies:
  - What is a cathode ray? appears to be charged, but what is it?
- Series of experiments:
  - Demonstrated that electric charge follows the cathode ray
  - Deflected by electric field
  - Measured charge/mass ratio:
    - determine velocity by balancing E/B forces
    - Points to particle-nature of the electron

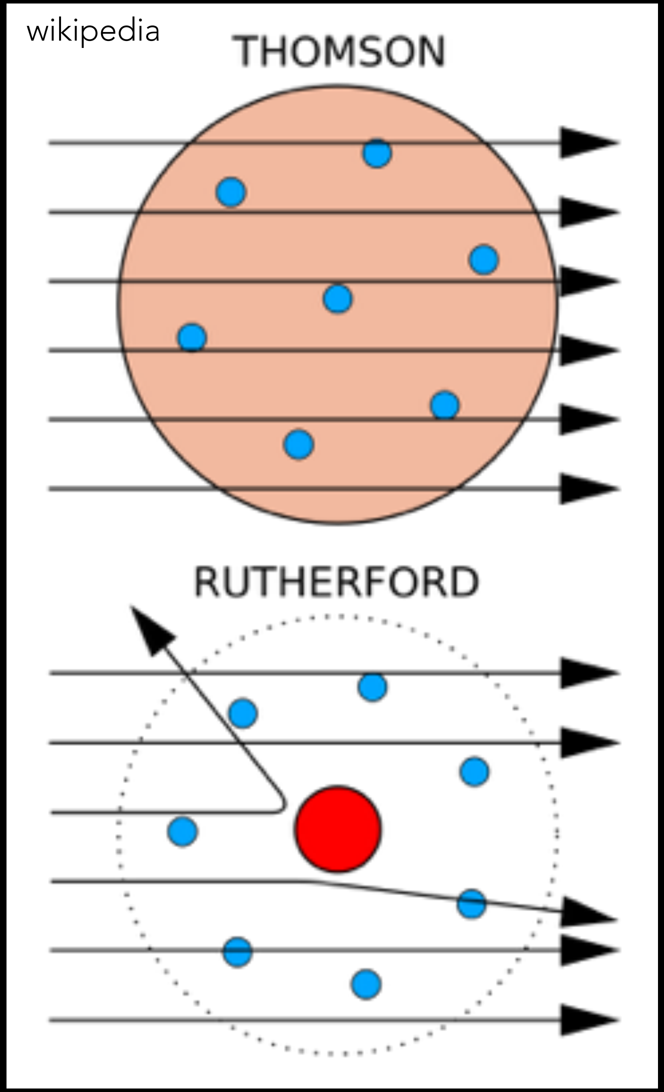
PARTICLE VS. WAVE

- Photon: firmly ingrained belief in wave nature
  - Planck's quantum hypothesis: first clue of particle nature.
  - Photoelectric effect: electrons from a material are liberated only when the wavelength of light is short
    - Einstein (1905): light is composed of particles, whose energy is proportional to frequency (Nobel Prize 1921)
- Compton scattering (1923):
  - Knock-out of electrons by light



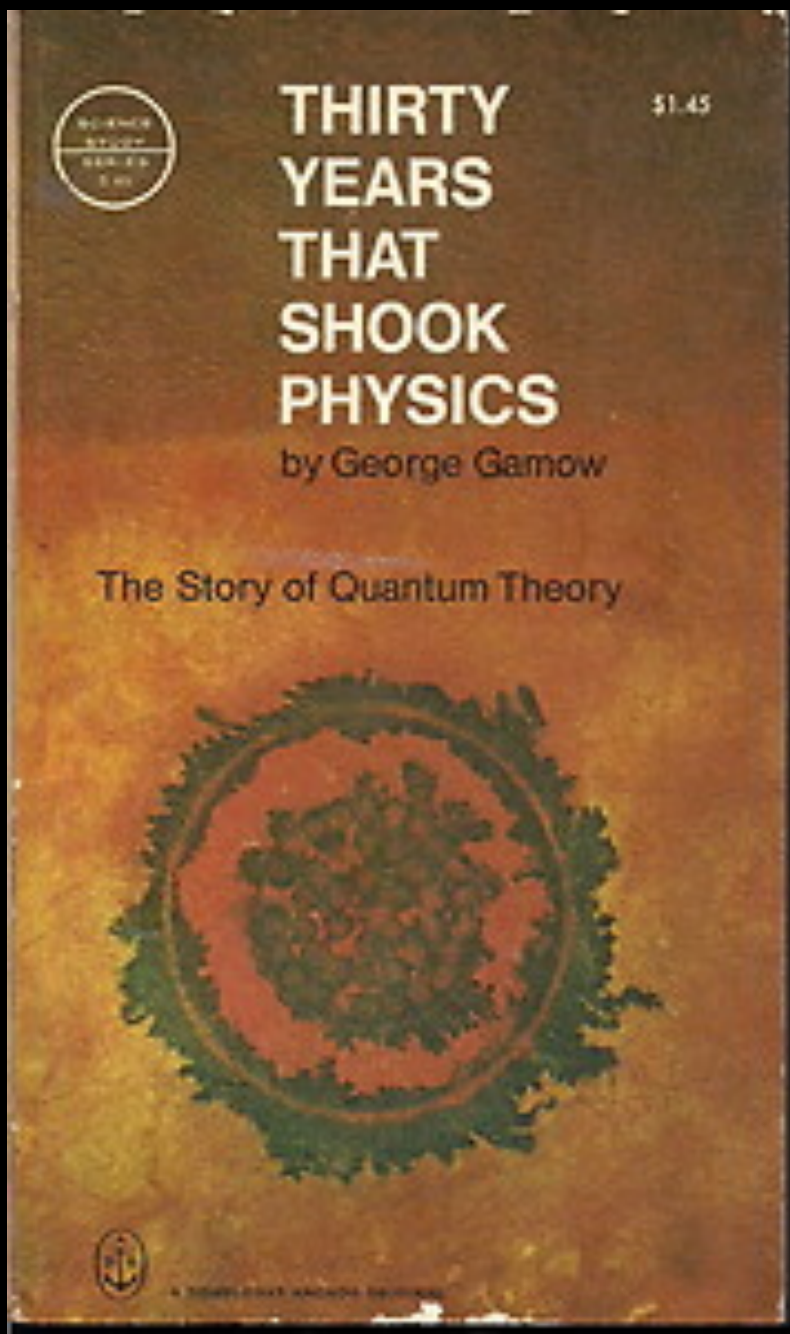
  - Relation between λ, λ' and θ is precisely that of a particle with mass = 0 and energy hc/λ (hc/λ') striking the electron

INTO THE ATOM:



- "High energy physics" in the 1900-1920
- Radioactivity:
  - α (^{4}He nucleus)
  - β (electron)
  - γ (photon/light)
  - transmutation of elements into other elements!
- Discovery of the atomic nucleus:
  - very concentrated charged mass at the center of the atom scattering α particles
- Scattering experiments:
  - $\alpha + {}^{12}N \rightarrow {}^{17}O + {}^{1}H$ (=p)
  - first indication that protons are contained within the nucleus (and = hydrogen nuclei)
  - Rutherford also postulated neutrons . . .

PHYSICS IN THE 1930S



- In the tumultuous era that gave birth to:
  - special/general relativity
  - quantum mechanics

  within ~30 years, the basic building blocks of "ordinary matter" were identified.

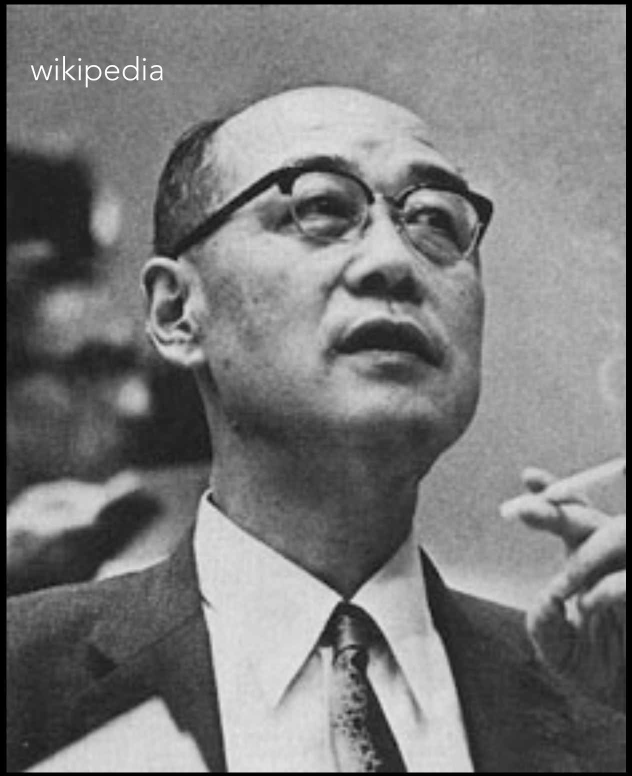
  p e^- γ

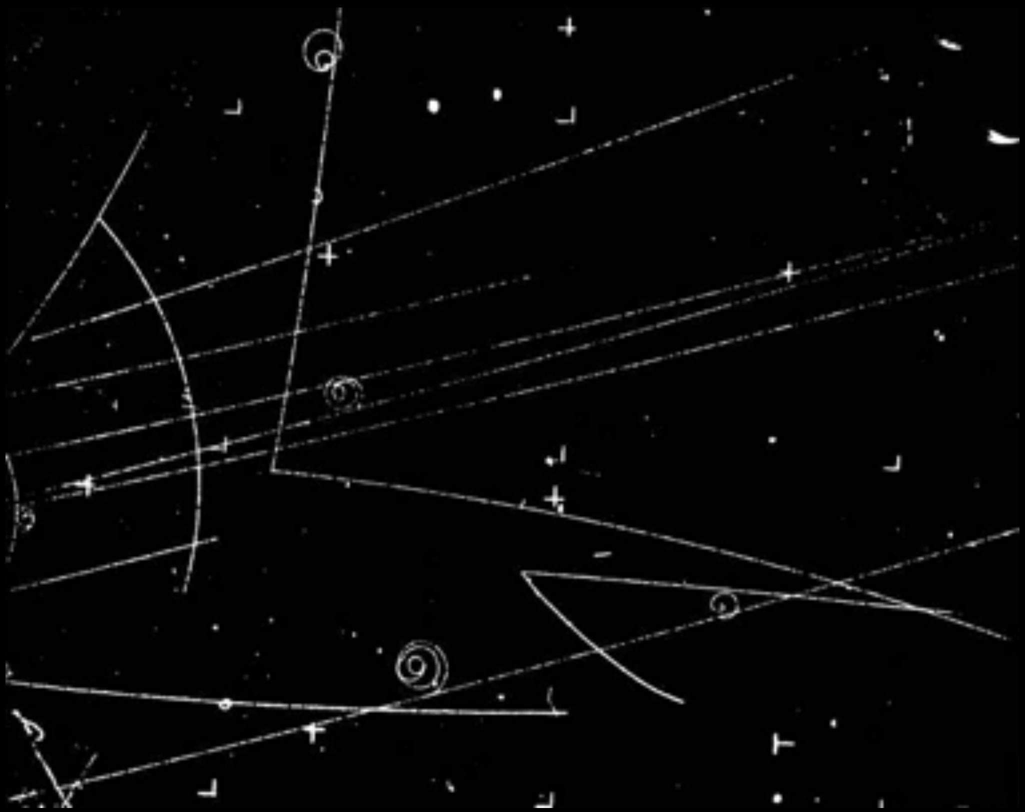
- atoms are some number of protons bound together in the nucleus, with an equal number of electrons bound to them electromagnetically

A few developments then completely disrupted this simple picture

THE YUKAWA HYPOTHESIS

- EM (photon) binds electron to nucleus
- Yukawa: some force (=particle) must bind the nucleus together
  - short range = massive
  - He called this the π particle (300 x m_e)





The π is sought in cosmic rays using photographic emulsions
Several things are discovered

- the μ "meson"
- the π meson
- "strange" particles K, Λ, Σ

What are these things?

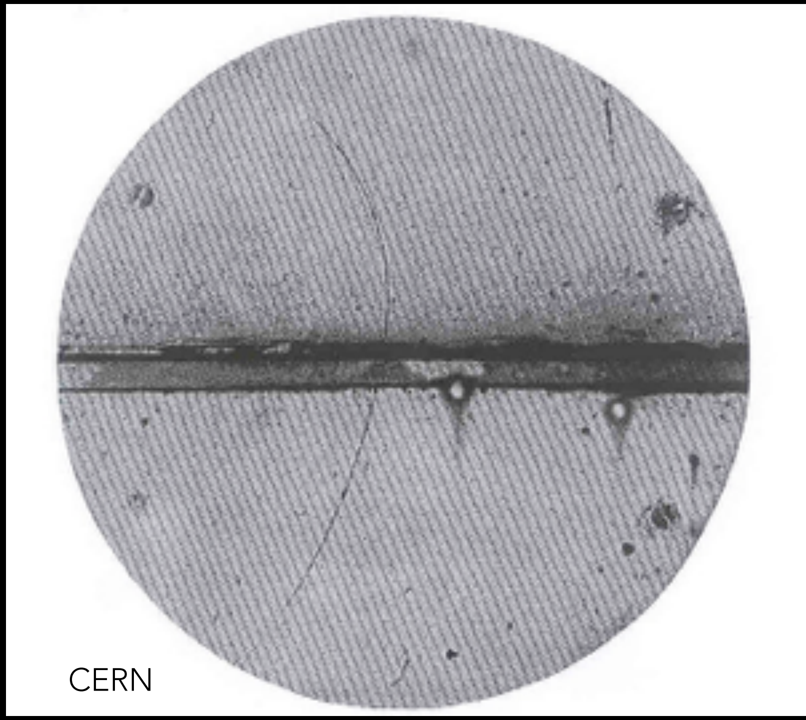
ANTIPARTICLES

- In the 1920's, physicists try to put together:
  - Quantum Mechanics
  - Special Relativity
- Dirac's attempt at this leads to the need for:
  - positively charged counterpart of the electron

Such a particle is actually observed

- just like the electron, but positively charged
- in due course, find every particle has an antiparticle
- (In some cases, e.g. γ, it is itself)

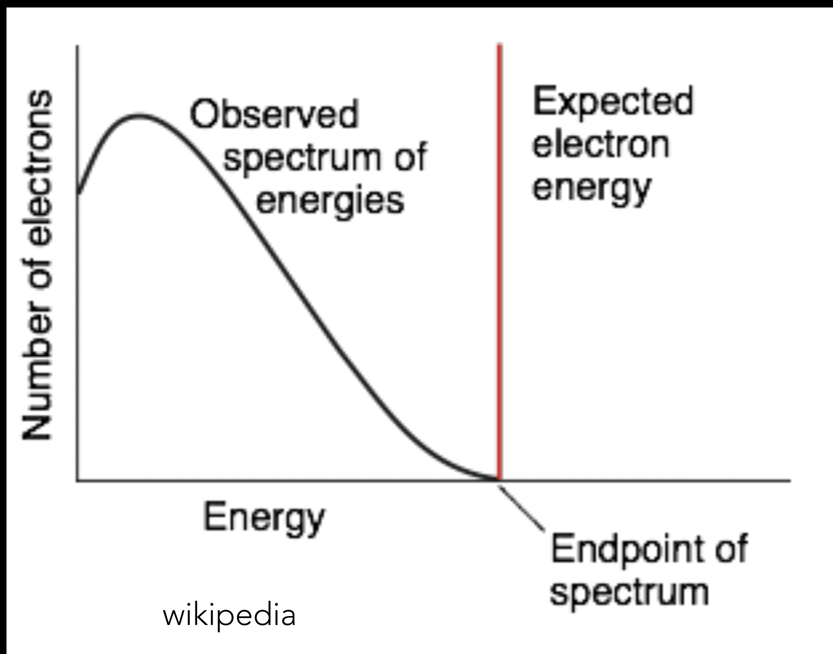
antiparticles are denoted by a "bar"



ASIDE:

- Reporter: “Professor Dirac, how did you find the Dirac equation?”
- Dirac: “I found it beautiful.”

NEUTRONS AND NEUTRINOS



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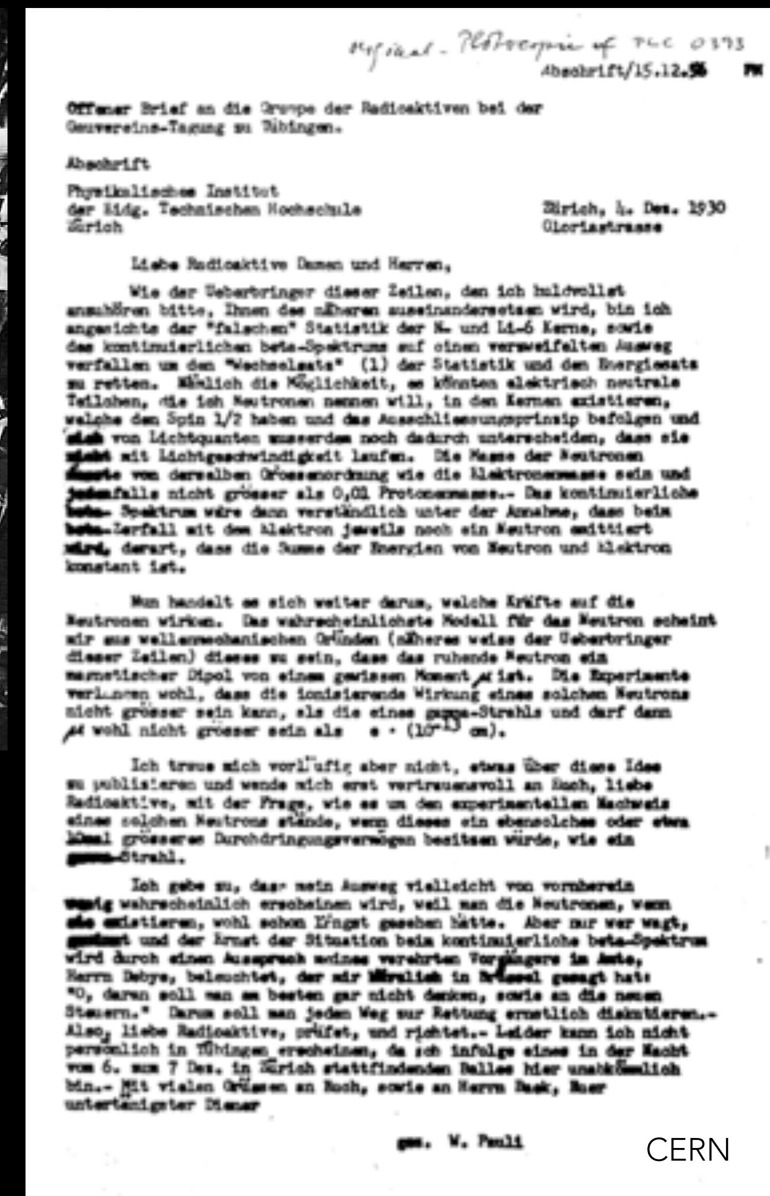

Abschrift/15.12.56 PM

Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen dürfte von derselben Grössenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

Nun handelt es sich weiter darum, welche Kräfte auf die Neutronen wirken. Das wahrscheinlichste Modell für das Neutron scheint mir aus wellenmechanischen Gründen (näheres weiss der Ueberbringer dieser Zeilen) dieses zu sein, dass das ruhende Neutron ein magnetischer Dipol von einem gewissen Moment μ ist. Die Experimente verlangen wohl, dass die ionisierende Wirkung eines solchen Neutrons nicht grösser sein kann, als die eines gamma-Strahls und darf dann μ wohl nicht grösser sein als $e \cdot (10^{-13}$ cm).

Ich traue mich vorläufig aber nicht, etwas über diese Idee zu publizieren und wende mich erst vertrauensvoll an Euch, liebe Radioaktive, mit der Frage, wie es um den experimentellen Nachweis eines solchen Neutrons stände, wenn dieses ein ebensolches oder etwa 10mal grösseres Durchdringungsvermögen besitzen würde, wie ein gamma-Strahl.

Ich gebe zu, dass mein Ausweg vielleicht von vornherein wenig wahrscheinlich erscheinen wird, weil man die Neutronen, wenn sie existieren, wohl schon längst gesehen hätte. Aber nur wer wagt, gewinnt und der Ernst der Situation beim kontinuierliche beta-Spektrum wird durch einen Ausspruch meines verehrten Vorgängers im Amte, Herrn Debye, beleuchtet, der mir kürzlich in Brüssel gesagt hat: "O, daran soll man am besten gar nicht denken, sowie an die neuen Steuern." Darum soll man jeden Weg zur Rettung ernstlich diskutieren.- Also, liebe Radioaktive, prüfet, und richtet.- Leider kann ich nicht persönlich in Tübingen erscheinen, da ich infolge eines in der Nacht vom 6. zum 7. Dez. in Zürich stattfindenden Balles hier unabkömmlich bin.- Mit vielen Grüssen an Euch, sowie an Herrn Back, Euer untertänigster Diener

gez. W. Pauli

CERN

- Evidence of a "weak interaction"
  - transmutes nuclei via emission of electron

$$^{A}_{Z}\mathrm{X}_N \rightarrow \ ^{A}_{Z+1}\mathrm{Y}_{N-1} + e$$

  - Meitner and Hahn observe unexpected continuous spectrum
  - Pauli hypothesizes that unseen neutral particle is emitted along with electron

$$^{A}_{Z}\mathrm{X}_N \rightarrow \ ^{A}_{Z+1}\mathrm{Y}_{N-1} + e + n$$

Fermi: underlying reaction is:

$$n \rightarrow p + e + \bar{\nu}_e$$

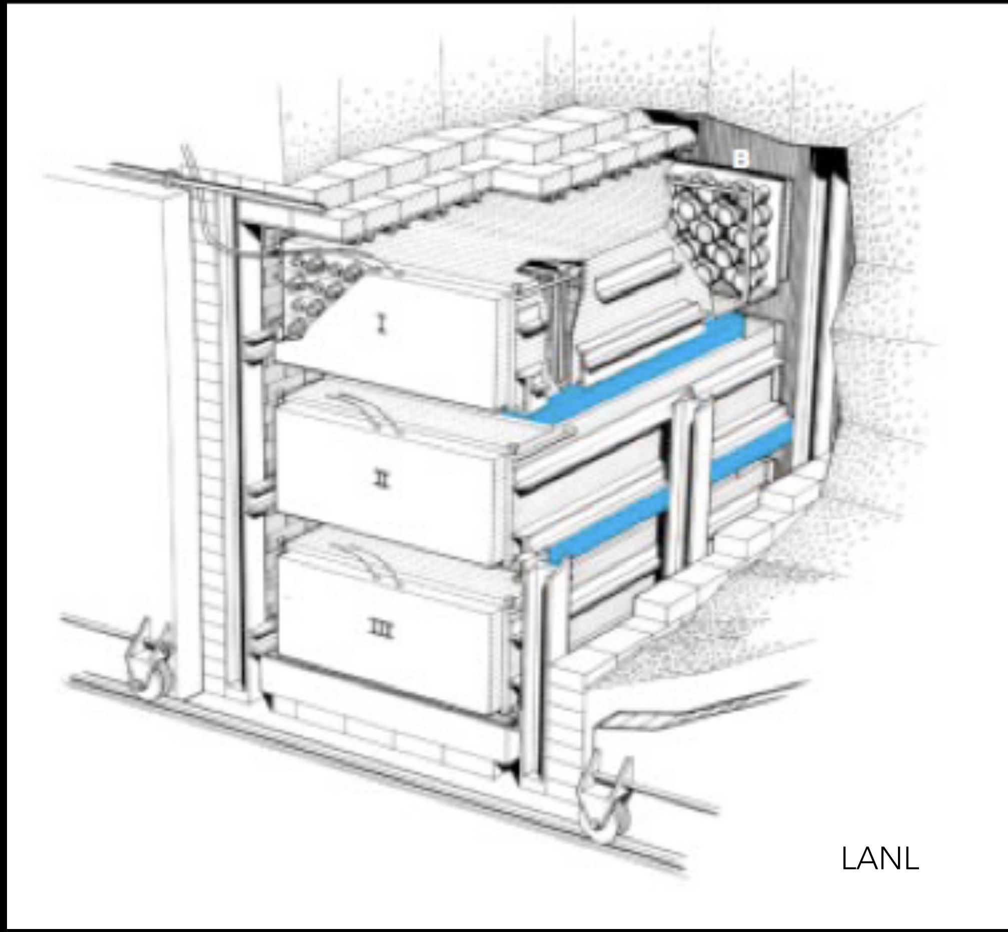
ASIDE:

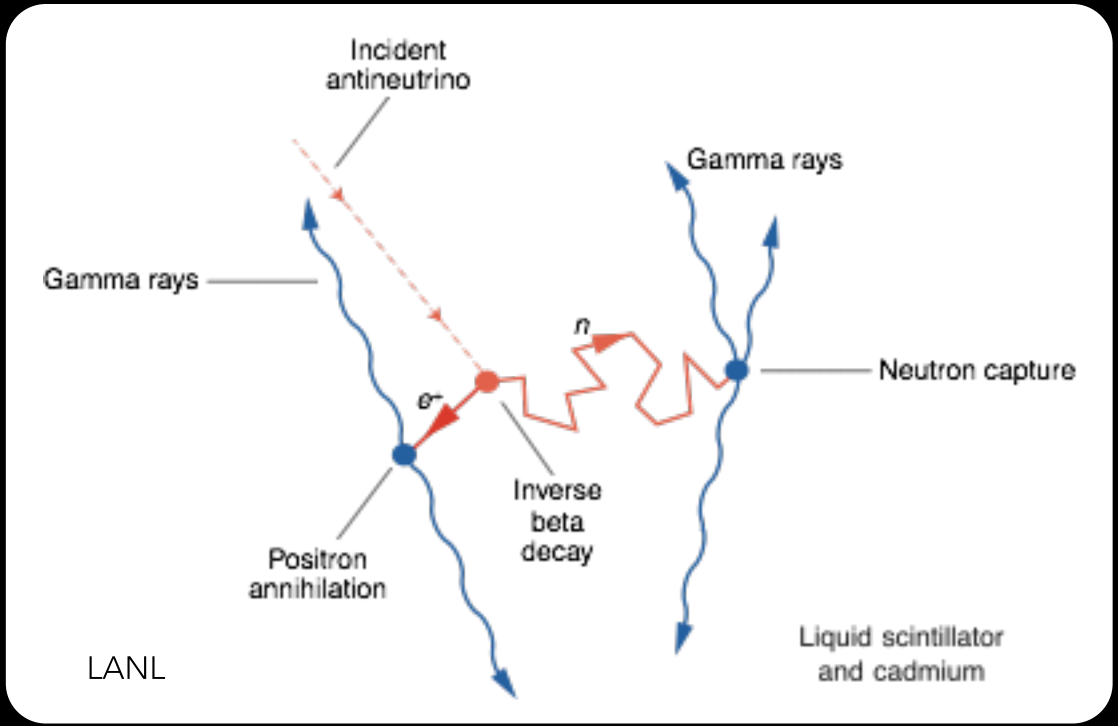
- Bohr: “We are all agreed that your theory is crazy. The question which divides us is whether it is crazy enough to have a chance of being correct. My own feeling is that it is not crazy enough.”
- Pauli: “I have done a terrible thing, I have postulated a particle that cannot be detected.”

PROJECT POLTERGEIST

Overcome the superlative shyness of neutrinos by:

- Intense neutrino source
  - atomic bomb ✕ (original plan)
  - nuclear reactor✓
- Large detector (many targets)
- Way to reduce backgrounds:
  - shielding from cosmic rays
  - cleanliness (low radioactivity)
  - coincidence signature.





$$\overline{\nu}_e + p \rightarrow e^+ + n$$
$$n + \mathrm{Cd} \rightarrow \mathrm{Cd}' + \gamma(9\mathrm{MeV})$$

- The Reactor:
  - Savannah River, SC (10^{13} $\nu/\mathrm{cm}^2/\mathrm{sec}$)
- The Detector:
  - Water with Cd to enhance n capture
  - Photons/$e^{\pm}$ detected in liquid scintillator

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PROFESSOR W PAULI

ZURICH UNIVERSITY ZURICH

Per Post

(1)

NACHLASS
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NACHLASS
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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

FREDERICK REINES AND CLYDE COWAN

BOX 1663 LOS ALAMOS NEW MEXICO

NOTE ON UNITS

- Standard unit of energy in particle physics is eV
  - keV, MeV, GeV, TeV, ...
  - 1 eV ~ 1.6×10^{-19} J
- Recall $E=mc^2$
  - Mass can be expressed in units of $[E]/c^2 \Rightarrow eV/c^2$
  - For reference, m_p = 938.272 MeV/c^2 = 1.672×10^{-27} kg
- $\mathbf{p} = (\gamma)m\mathbf{v}$
  - momentum can be expressed in units of $[m]c \Rightarrow eV/c$
- Sometimes we will be “sloppy” and set c=1
  - Use eV as the units for mass, momentum, energy

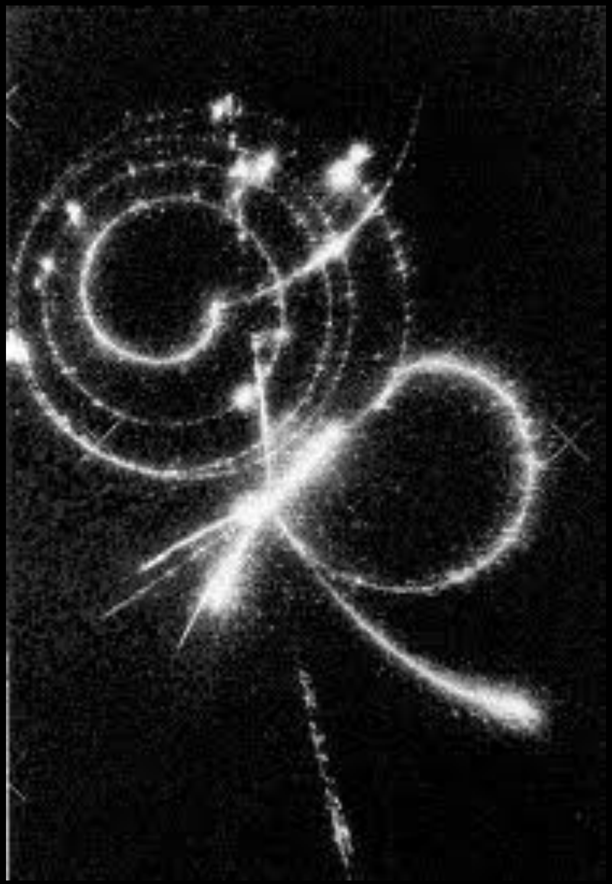
DECAY AND SCATTERING

- Processes can be roughly categorized into two classes:
- "Decays": spontaneous disintegration of a particle into other particles:
  - $A \rightarrow B + C + D + \ldots$
  - Examples: radioactive emission of α, β,γ rays
  - E/p conservation can tell us the **mass** of A based on B, C, D, . . .
    - mass is a fundamental property that identifies a particle
    - decay reactions are also limited by the mass of A
  - "strength" of the underlying interaction related to the decay rate
  - A may have several modes of decay
    - what kind of particles B, C, D . . . emerge, and which decays modes are preferred can tell us about the properties of A.
- Note: information goes in both ways: we can use decays to
  - tell us about the particles involved
  - tell us about the underlying interaction

"SCATTERING":

- "Scattering": interaction of two (or more) particles
  - A + B (+ C . .) -> X + Y + Z . .. . . .
  - note: initial state may be the same as final
  - Examples:
    - Compton scattering
    - Rutherford scattering
    - "inverse beta decay"
    - bound states can also be viewed as "scattering"
  - Extra energy is available from kinetic energy of the incident particles

PARTICLE PHYSICS C. 1930



ν No electromagnetic or strong interaction

$e^{\pm}$ Interacts electromagnetically
No strong interaction

p, n Bound in nucleus by strong interaction
Interacts electromagnetically

$\mu^{\pm}$ Interacts electromagnetically
No strong interaction

γ Mediator of EM interaction

π Mediator of strong interaction

Who ordered that?

HADRON VS. LEPTON, ETC.

- Some initial categories of particles:
  - leptons: do not experience the strong interaction
    - electron, muon, neutrinos
  - hadrons: do experience the strong interaction
    - protons, neutrons
    - pions, kaons, etc.
- Within the hadrons:
  - baryons: "heavy" protons, neutrons, Λ, Σ, etc. (≳ 1 GeV/c2)
  - mesons: "medium": π (~0.1 GeV/c^2), K (~0.5 GeV/c2)
    - baryon "number" is conserved, mesons are not.
  - "strange": mesons and baryons that are produced copiously in strong interactions but decay slowly.

FLAVOR

"all is permitted that is not explicitly Forbidden"

- Recall (electric) charge conservation:
  - In any process, the total charge before and after must be the same.
  - Charged objects may be created or disappear in the process, but the sum of the charge must be the same
- It appeared that their were other forms of "charge"

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \quad \longrightarrow \quad \nu + n \rightarrow \mu^- + p$$
$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu \quad \longrightarrow \quad \nu + p \rightarrow \mu^+ + n$$

  - neutrinos produced with muons produce muons later
  - neutrino has "muoness" opposite to the muon it was created with in the π decay, assuming π have 0 "muonness".
  - antiparticles have opposite "muonness" from particle
- Likewise in the decays of the muon, we can introduce "electronness"

$$\mu^- \rightarrow e^- + \nu + \nu \quad \longrightarrow \quad \mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$
$$\mu^+ \rightarrow e^+ + \nu + \nu \quad \longrightarrow \quad \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Note "reversibility"

FLAVOR CONSERVATION

- Consequence of "electron number" and "muon number" conservation:

$\mu^- \rightarrow e^- + \gamma$ **doesn't happen**

$\bar{\nu}_\mu + p \rightarrow \mu^+ + n$ **does happen**

$\bar{\nu}_\mu + p \rightarrow e^+ + n$ **doesn't happen**

$\bar{\nu}_\mu + n \rightarrow \mu^- + p$ **doesn't happen**

- What about:

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

$\bar{\nu}_e + n \rightarrow e^- + p$

$\bar{\nu}_e + p \rightarrow e^+ + n$

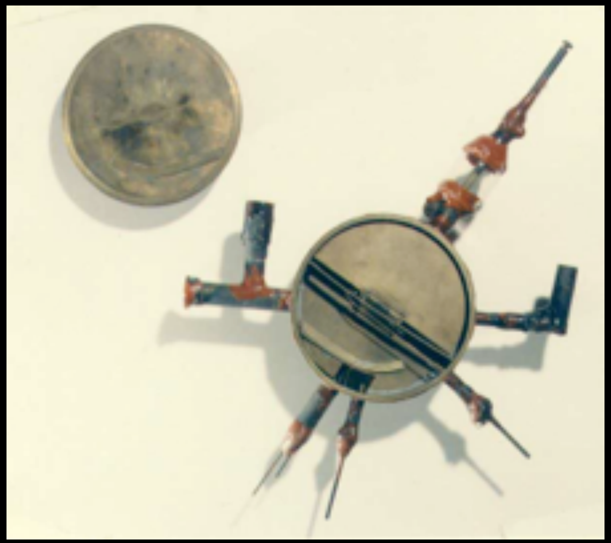
$\bar{\nu}_e + p \rightarrow \mu^+ + n$

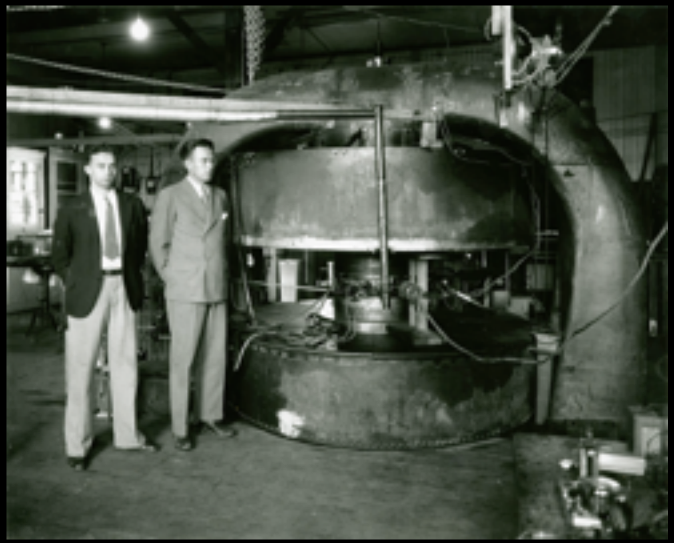
$\bar{\nu}_e + n \rightarrow e^+ + p$

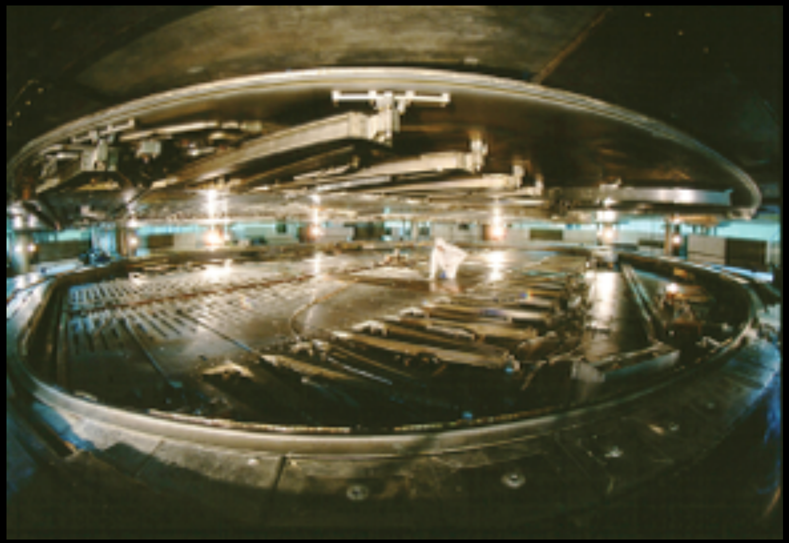
ACCELERATORS

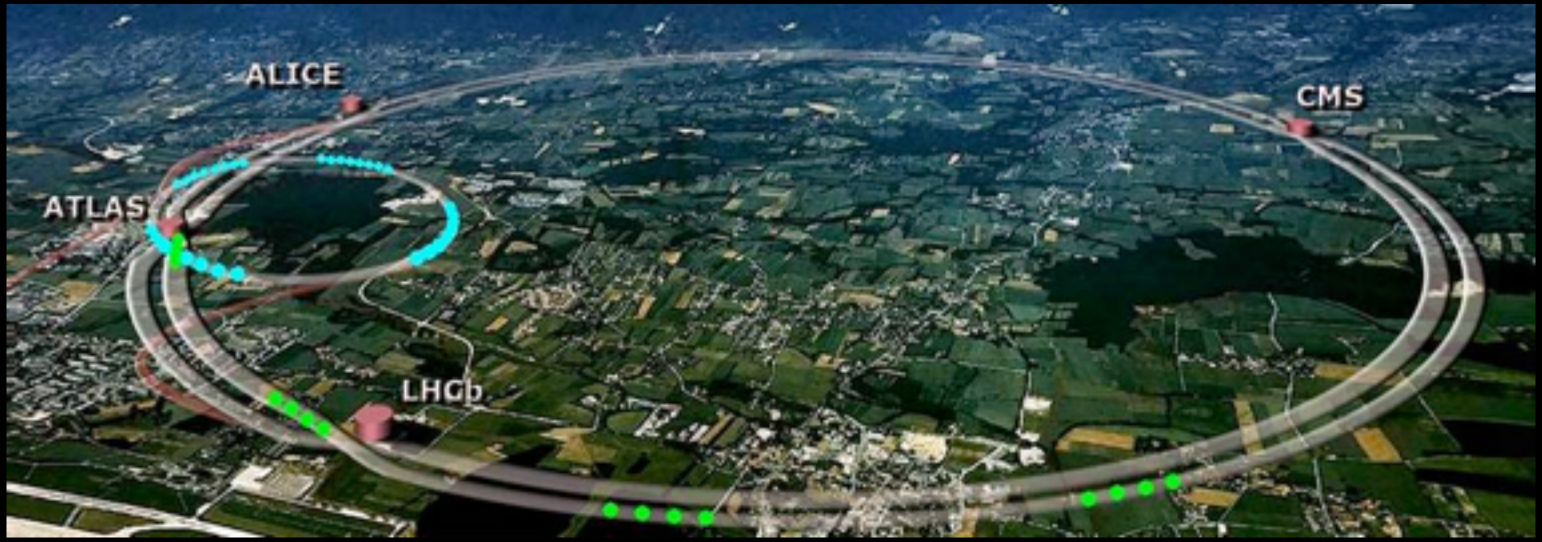
- Why higher energies?
  - Create particles (mass) from energy
  - More energy (usually) means more mass can be created
- Basic principle:
  - alternating electric field can “push” a charged particle
  - Two options for acceleration:
    - Accelerate them in a straight line (LINAC)
    - Use magnetic fields to circulate the particles and push them repeatedly (cyclotron/synchrotron)
  - Two options for collisions:
    - Collide on a fixed target (“fixed target”)
    - Collide two counter-moving beams (“collider”)

ACCELERATORS:









THE HADRON ZOO

- As energies of accelerators increased, a proliferation of new particles (hadrons) were discovered:
  - Mesons:
    - "pseudoscalar" mesons: π^+, π^0, π^-, η, η', K^+, $\bar{K}^-$,K^0, $\bar{K}^0$
    - "vector" mesons: ρ^+, ρ^0, ρ^-, ω, φ, K^{*+}, K^{*-}, K^{*0}, $\bar{K}^{*0}$
  - Baryons
    - p, n, Λ, Σ^+, Σ^0, Σ^-, Ξ^+, Ξ^0, Ξ^-
    - Δ^{++}, Δ^+, Δ^0, Δ^{--}, Σ^{*+}, Σ^{*0}, Σ^{*-}, Ξ^{*0}, Ξ^{*-}, Ω^-
    - and many more . . . .
  - what are all these particles?
  - "Strange" = copiously produced, but long lifetime

"strange particles"

ASIDE

- Willis Lamb (1955): “the finder of a new elementary particle used to be rewarded by a Nobel Prize, but such a discovery now ought to be **punished by a $10,000 fine.**”

"STRANGENESS"

- A class of "strange" particles that live for a long time and decay.
- Observe that strange particles:
  - are produced in pairs
  - never by themselves

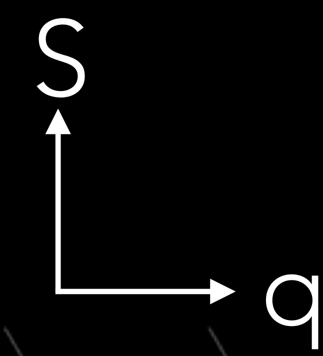
$$\pi^- + p \to \boxed{K^+ + \Sigma^-}$$
$$\pi^- + p \not\to \boxed{\pi^+ + \Sigma^-}$$

- This lead to the concept of "strangeness conservation"
  - the net strangeness (S) is the same before and after

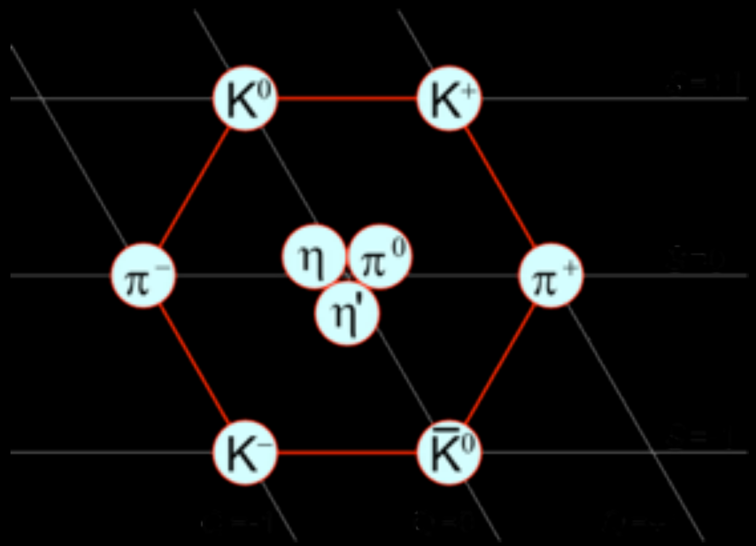
S	-2	-1	0	+1	+2
MESON		K^-, $\bar{K}^0$ K^{*-}, K^{*0}	π^-, π^0, π^+ η	K^+, K^0 K^{*+}, K^{*0}	
BARYON	Ξ^0, Ξ^-	Λ, Σ^+, Σ^0, Σ^-	p, n Δ^-, Δ^0, Δ^+, Δ^{++}	$\bar{\Lambda}$, $\bar{\Sigma}^+$, $\bar{\Sigma}^0$, $\bar{\Sigma}^-$	$\bar{\Xi}^0$, $\bar{\Xi}^+$

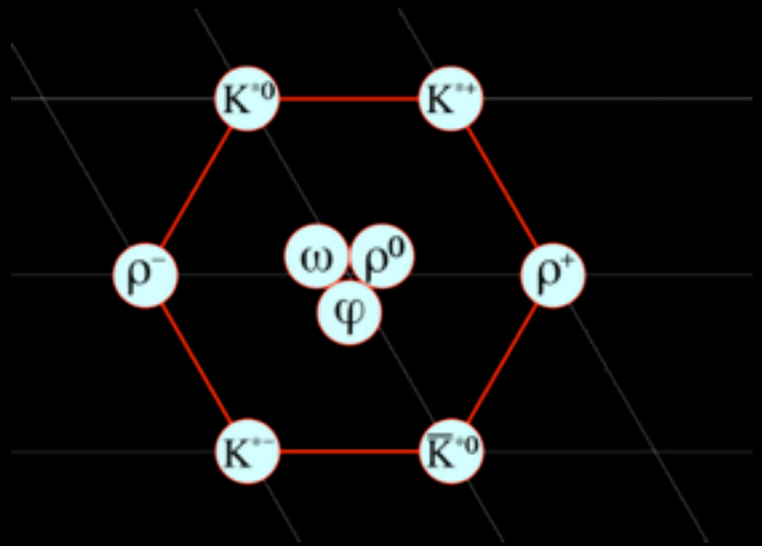
- Note that strangeness is not conserved in weak interactions
  - this "explains" the "strange" property of strange particles

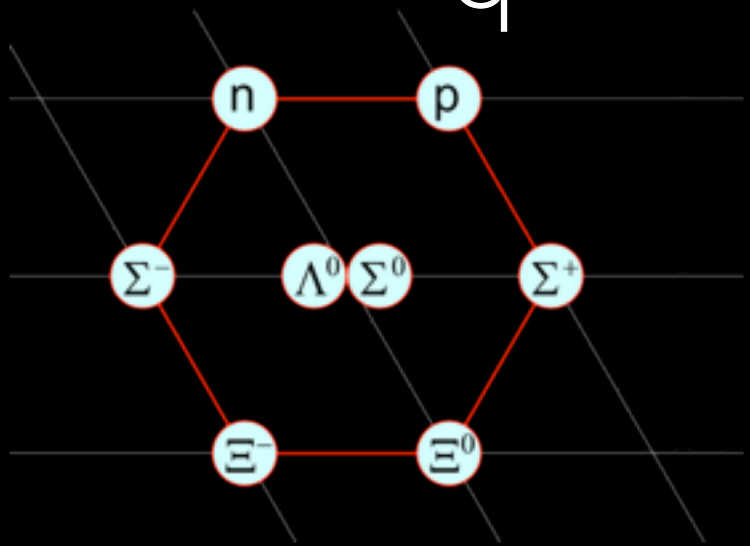
PATTERNS:



- Arrange particles by strangeness and charge:



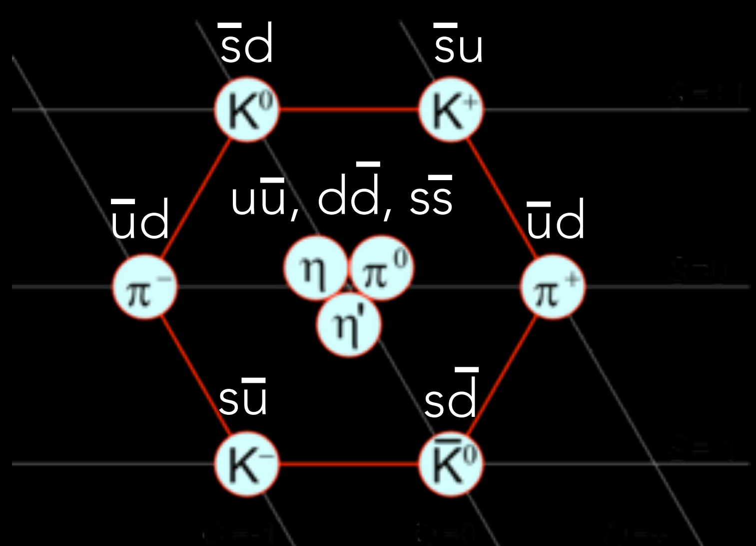


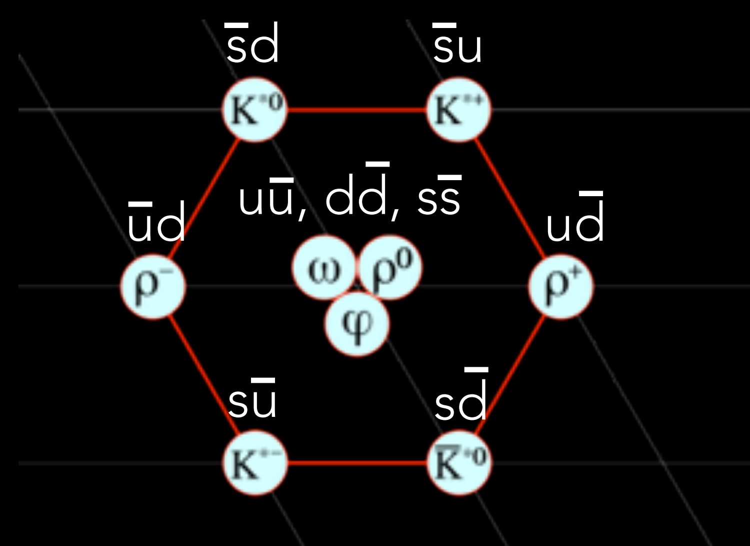


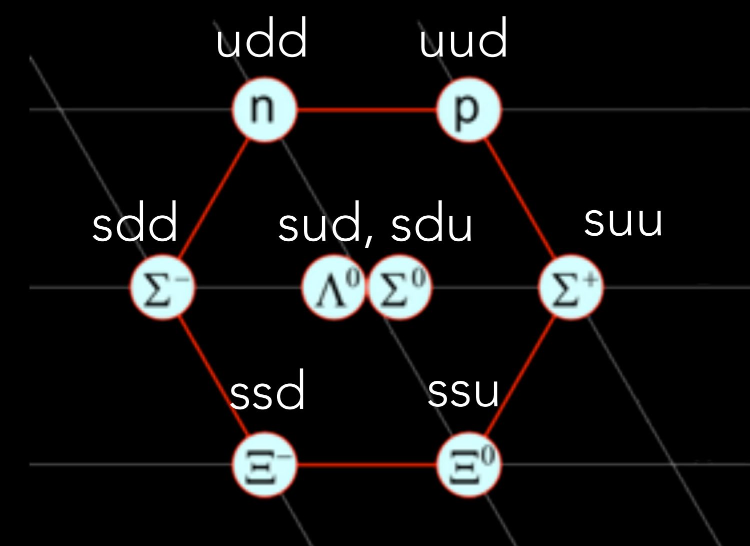
- this lead Gell-Mann to hypothesize that there are underlying elements responsible for the pattern:
  - Could explain the pattern with constituents ("quarks")
    - "up" with (electric) charge + 2/3
    - "down" and "strange" with charge -1/3
  - Mesons are composed of a quark + antiquark
  - Baryons are composed of three quarks
  - the "eight-fold way"

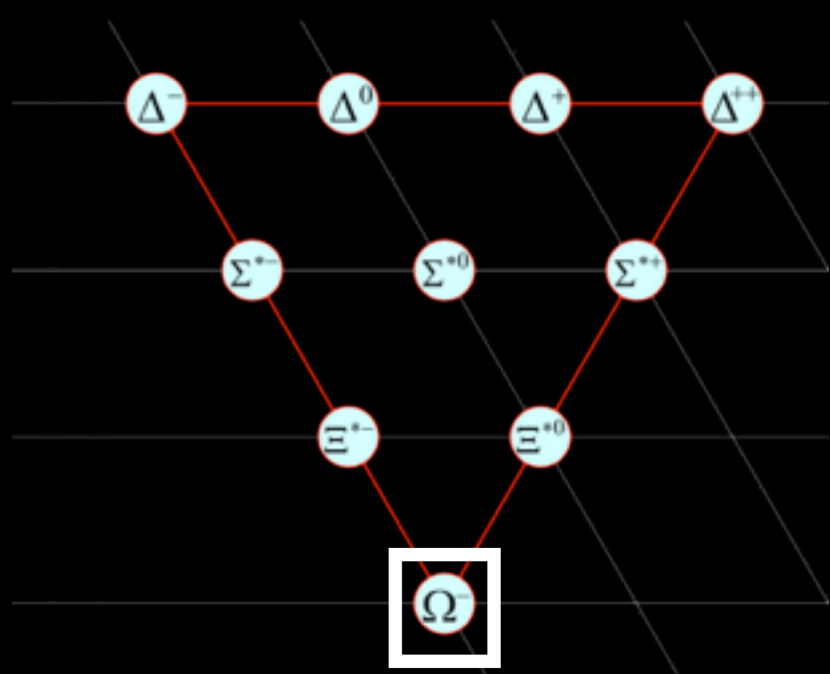
IN TERMS OF QUARKS . . .

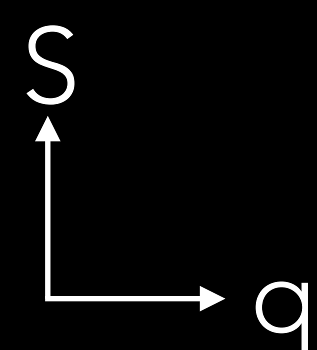
- Gell-mann predicts the existence of sss (Ω^-) and it is found!

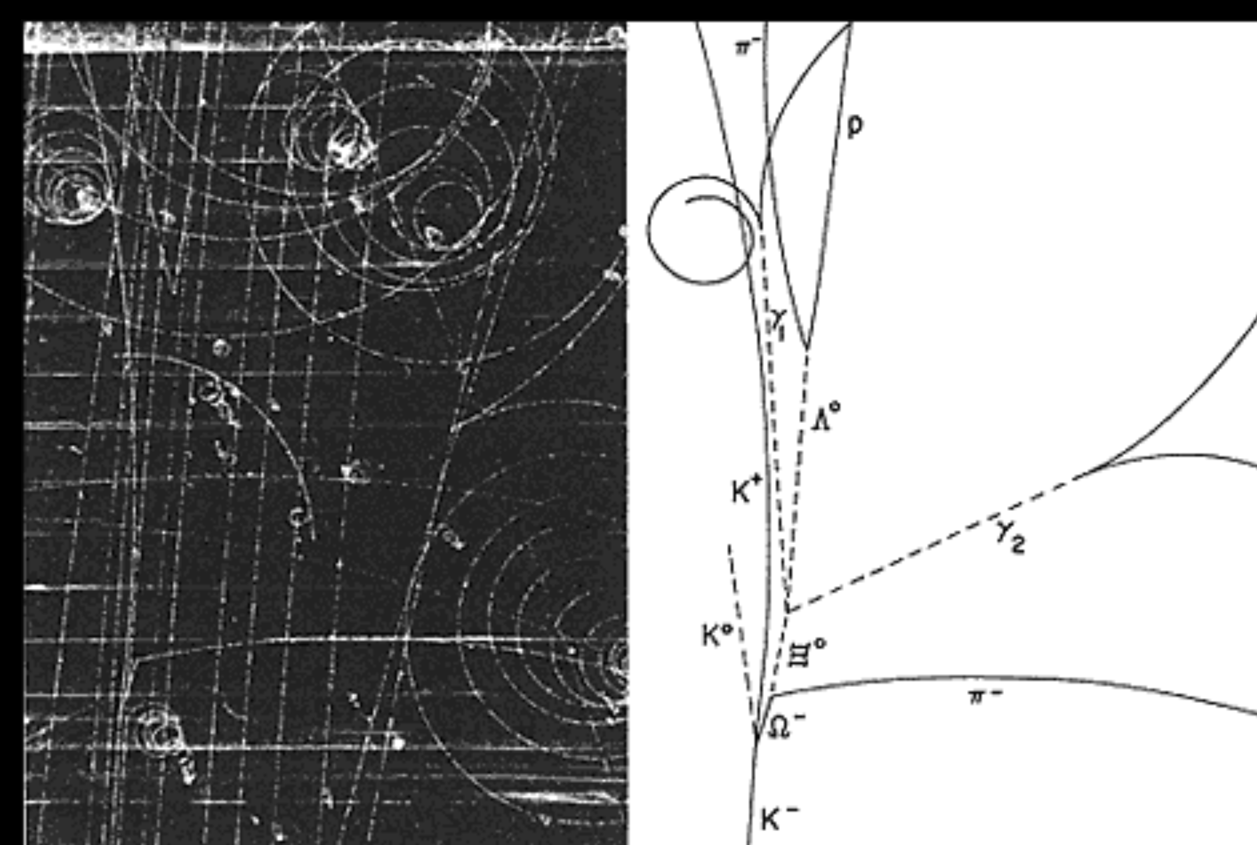




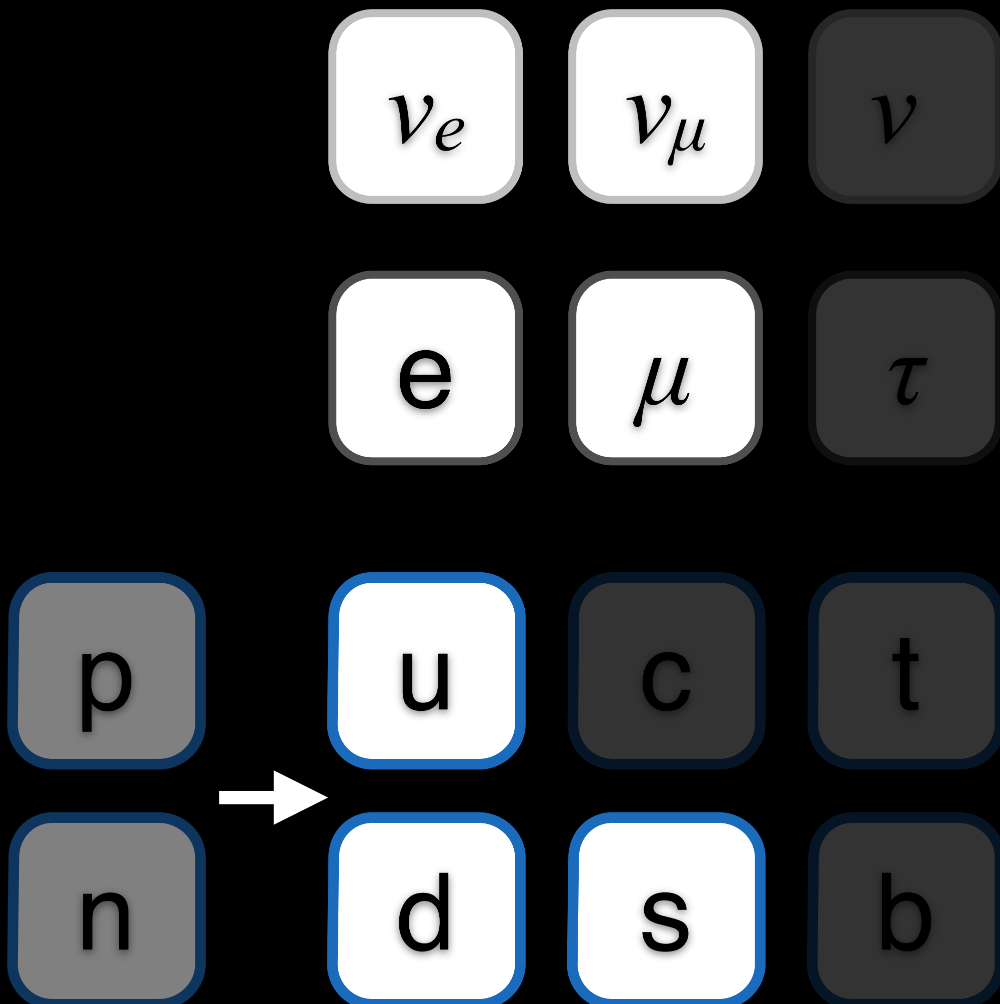








PARTICLE PHYSICS IN THE 1970S

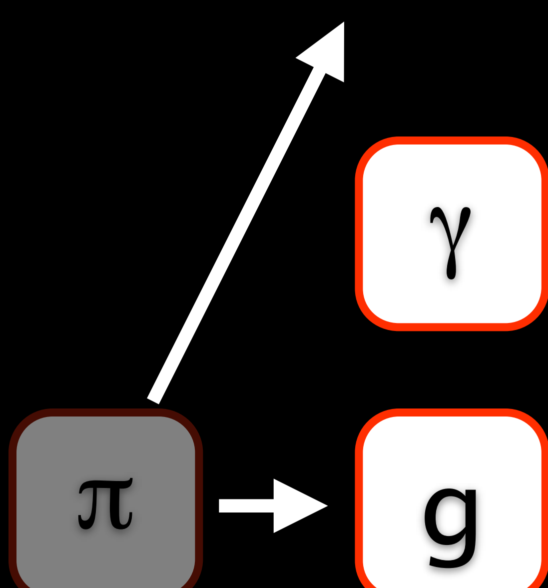


weak interactions
No EM/strong interaction

EM and weak interactions
No strong interaction

EM and weak interactions
strong interactions

EM and weak interactions
strong interactions

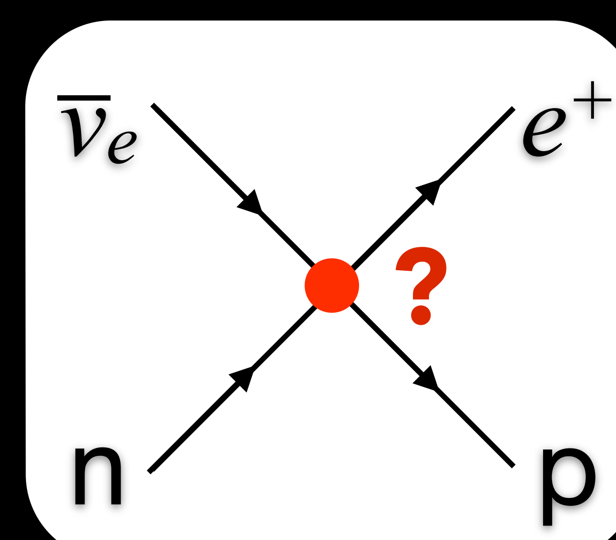


Mediator of EM interaction

Mediator of strong interaction?

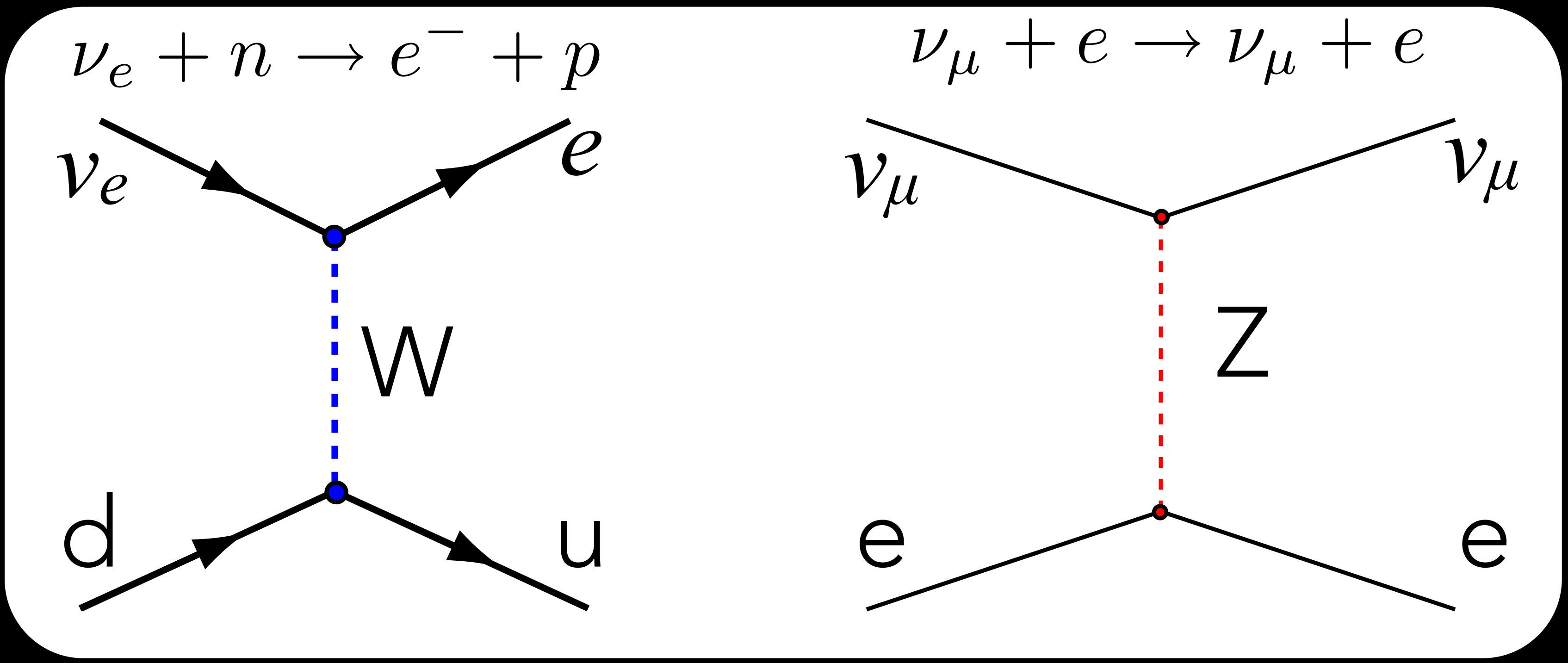
- Somehow, weak interactions preserve lepton flavour but allow quark flavour change

- What is the mediator for the weak interaction?
- why is it "left handed"



THE WEAK INTERACTION

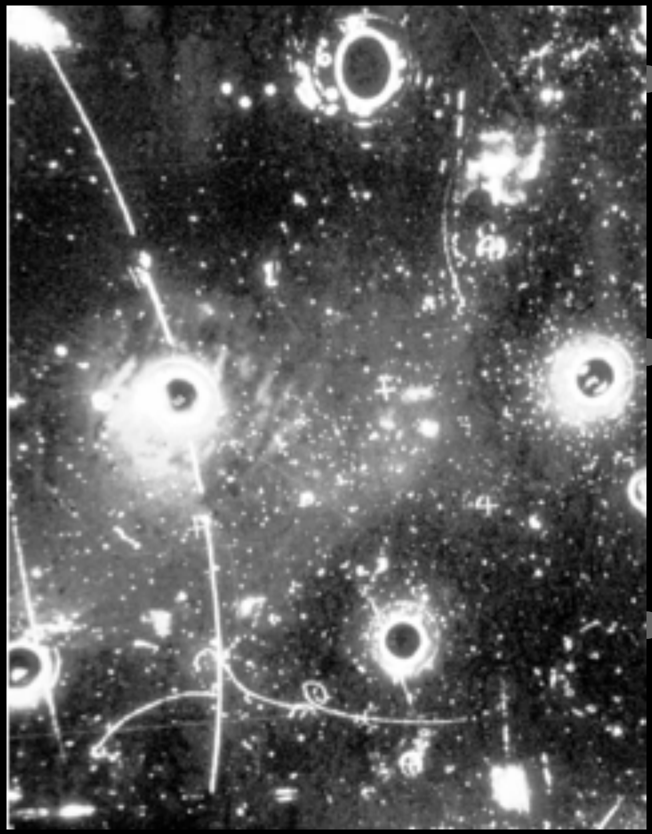
- Why is the weak interaction weak?
  - weak decays have very long lifetimes
  - neutrinos (which interact only weakly) do not interact often
- If the photon mediates the EM interaction, what mediates the weak interaction? (recall Yukawa's hypothesis)
  - It must be a charged, since it couples neutrinos to e/μ
  - Is there a neutral mediator (NC)?



The weak NC interaction is closely related to the electromagnetic reaction (i.e. γ and Z) but differs in "structure" and "strength". Every interaction via γ can in principle also happen with Z

Note that neutrinos can also interact via Z (but not the γ)

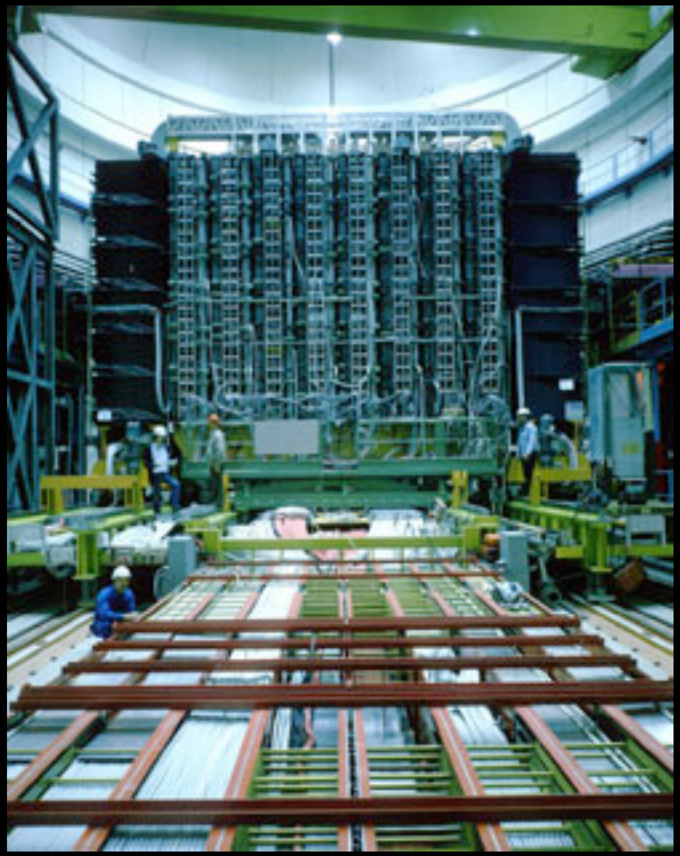
DISCOVERY OF NC, W, Z

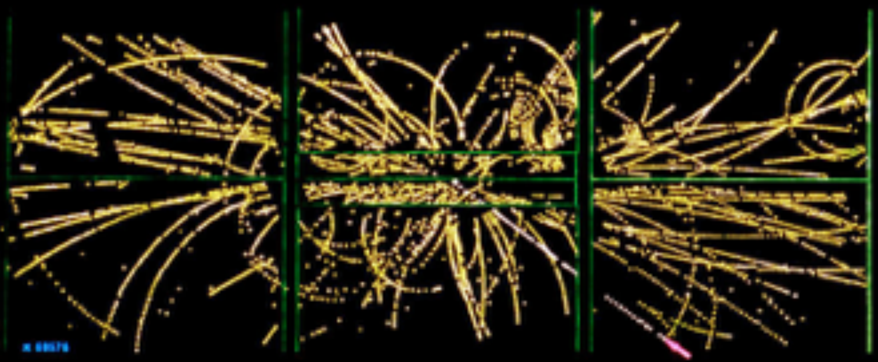


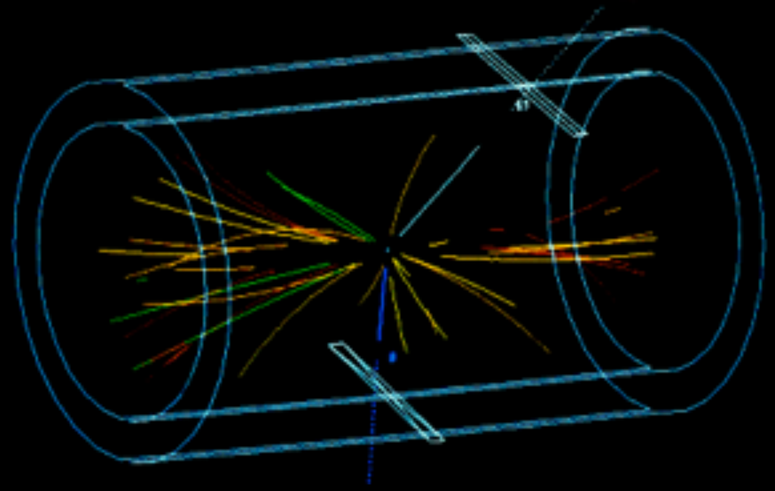
- NC reaction of neutrinos in bubble chamber

$$\nu_\mu + e \to \nu_\mu + e$$

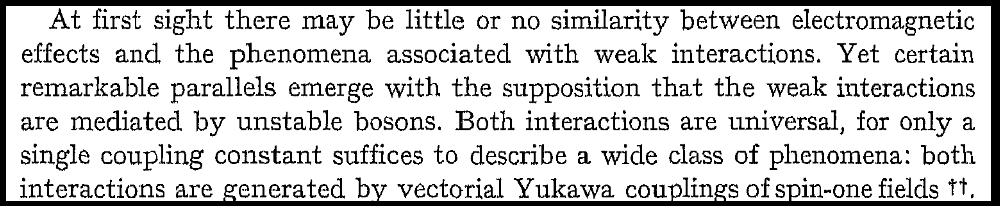
- W production in pp collisions.
  - Observe W → e + ν_e
- Z particle by observing Z → e + e







W, Z are extremely massive
W ~ 80 GeV/c^2
Z ~ 91 GeV/c^2
See later that this is responsible for the "weakness" of the weak interaction


At first sight there may be little or no similarity between electromagnetic effects and the phenomena associated with weak interactions. Yet certain remarkable parallels emerge with the supposition that the weak interactions are mediated by unstable bosons. Both interactions are universal, for only a single coupling constant suffices to describe a wide class of phenomena: both interactions are generated by vectorial Yukawa couplings of spin-one fields ††.

S.L. Glashow, 1960

ELECTROWEAK THEORY

- Concurrently, a few major theoretical developments were happening:
  - introduction of "gauge" theories
    - based on a mathematical structure (groups) that describe a symmetry
    - Simplest example: Electromagnetism a "U(1) gauge theory"
    - Extension to more complicated groups ("SU(N)", "SO(N)")
    - Naturally introduces **massless** mediators as a requirement of symmetry
  - Electroweak unification:
    - EW and EM are inextricably linked together by "mixing" of two gauge theories "SU(2) x U(1)"
    - Issue: how does W, Z gain mass? Why is the photon massless?
  - Strong interactions also incorporated as a "SU(3)" gauge theory (QCD)
  - Solution:
    - The Higgs mechanism!

> The mass of the charged intermediaries must be greater than the K-meson mass, but the photon mass is zero — surely this is the principal stumbling block in any pursuit of the analogy between hypothetical vector mesons and photons. It is a stumbling block we must overlook. To say that the decay intermediaries

TURN KEY THEORY?

- "A local wag posted a sign of my door that went something like this:
  - Algorithm for constructing weak interaction models
    1. Choose symmetry group
    2. Choose particle representation of symmetry
    3. Break symmetry spontaneously
    4. Calculate particle masses
    5. Identify weak interaction and find neutral current effects
    6. Write paper
    7. Go to Step 1"
- *S.L. Glashow in "The New Physics" by Paul Davies*

SUMMARY:

- Introduced to the fundamental constituents:
  - quarks (strong, weak, EM interactions)
    - mesons and baryons are bound states of quarks
  - leptons (weak, EM interactions)
    - no strong interaction
    - for neutrinos, no electric charge either
- Introduced to the fundamental interactions
  - electromagnetic, weak, strong
  - some basic properties:
    - electric and lepton flavor conservation in all interactions
    - flavor conservation in strong interactions
    - quark flavor change can only happen with weak interaction
- Decay and Scattering processes
- Units
- First Feynman diagram