FINAL EXAM...

MONDAY,
DECEMBER 11...   12:45 – 2:45 pm

BPS 1415

Problems possibly from
Chapters:

2	Relativity
3	Expt. Basis Quantum Theory
4	Structure of Atom
5	Wave Properties of Matter
6	Quantum Mechanics
7	Hydrogen Atom
12	Atomic Nucleus
13	Nuclear Reactions

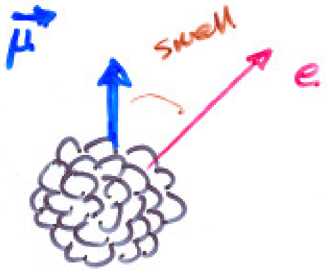
THERMODYNAMICS

"Questions" => famous people & what they did
famous experiments.

Chapters 2, 3, 4, 5, 6, 7, 12, 13, 14

^{60}Co has a net magnetic moment. & β decays

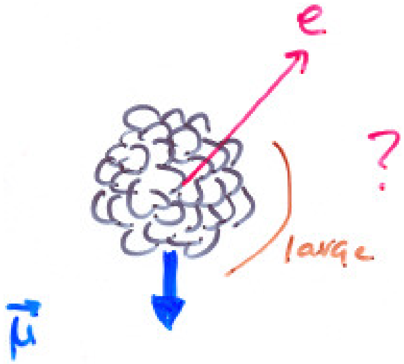
- apply a $\vec{B}$ field .. at cold temperatures



- reverse the field

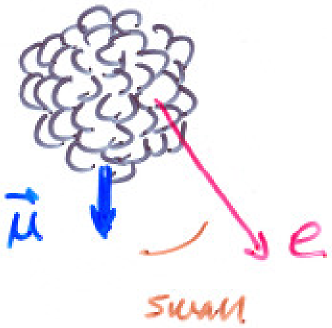
would act like the opposite of a mirror, right?

- Madam C.S. Wu did the experiment – 1957
- suggested by T.D. Lee & C.N. Yang 1956



? NO!

THIS HAPPENS →



terms in the Schrödinger (or really, Dirac) Equation like

$$A(\underbrace{\vec{\mu}\cdot\vec{p}_e}_{\text{small angle}}) \xrightarrow{\text{parity}} A(\underbrace{\vec{\mu}\cdot\vec{p}_e}_{\text{\underline{still} small angle}})$$

⇒ Parity is Violated

The weak interaction violates parity conservation..

no physics had ever done that before.

⇒ a permanent handedness to the
weak interaction.

why? was the universe created un symmetrically?

we don't know!

we would like to know!

working on that!

Then, it got weird.

Jargon and Classification.

4 forces -- already talked about them.

Gravity

weak.

Electromagnetic

strong

Particle Classification & nicknames.

LEPTONS

spin $1/2$ particles

do not "feel" the strong force

electrons, muons, neutrinos

HADRONS

any spin

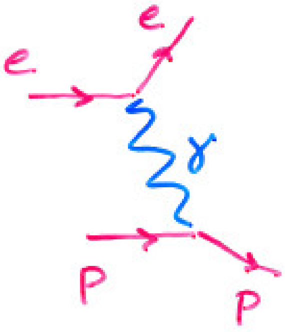
particles which do "feel" the strong force.

Baryons - the spin $1/2$ HADRONS (or $3/2$, $5/2$ ...)

Mesons - the spin 0 HADRONS (or 1, 2 ...)

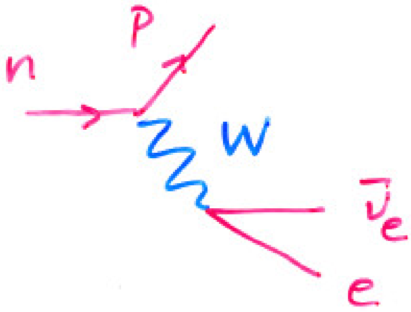
and one more kind...

"Gauge Bosons"

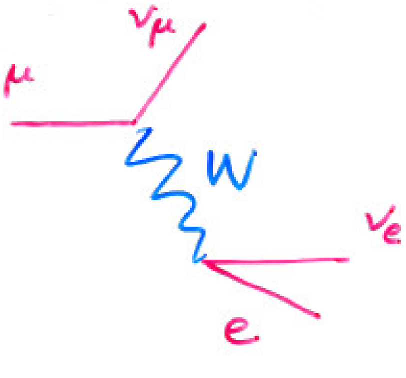


→ we have learned to regard the γ as the propagator of the electromagnetic force

+



the "W" (for "weak") boson was thought to propagate the weak force



Various Conservation rules emerged...

"Baryon Number" $B = 1$ baryons

$= -1$ anti baryons

$e + p \longrightarrow e + p + n + \bar{n}$

B# $0 + 1 = 0 + 1 + 1 + -1$

$\Lambda \longrightarrow p + \bar{\pi}$

B# $1 = 1 + 0$

"Lepton Number" $L = 1$ leptons

$= -1$ anti leptons

$\mu^- \longrightarrow e^- + \nu_\mu + \bar{\nu}_e$

L# $1 = 1 + 1 + -1$

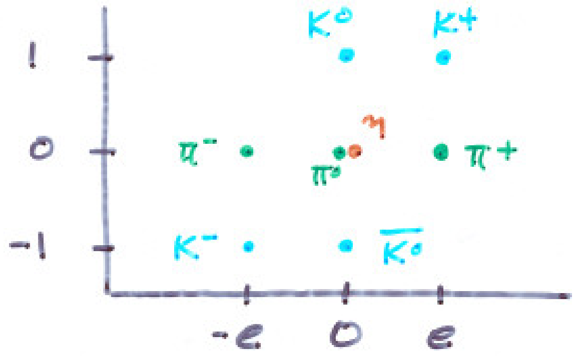
"strangeness"

strange particles seemed to be produced in pairs

suggesting a conservation statement.

S conserved by strong & electromagnetic not weak.

IF YOU PLOT STRANGENESS VS. Q -- patterns emerge



OR by recognizing <u>another</u> symmetry...

IF we ignore electromagnetism

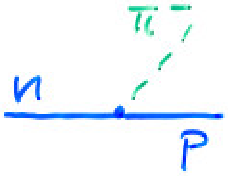
what makes the proton different from the neutron?

– nothing.

we can treat them as identical with respect to the STRONG interaction –

$$N = \begin{pmatrix} p \\ n \end{pmatrix} \longleftarrow \text{arrange them as a } \underline{\text{doublet}}$$

An interaction like



$$\begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}\begin{pmatrix} p \\ n \end{pmatrix} = \begin{pmatrix} n \\ 0 \end{pmatrix}$$

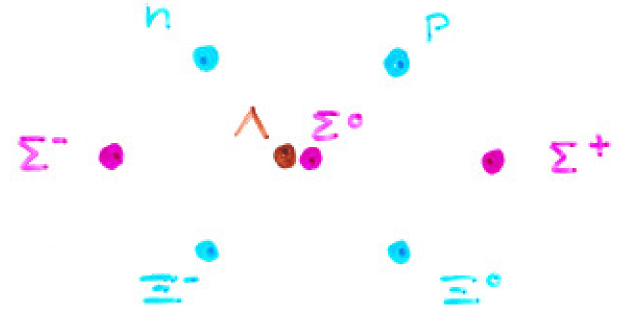
so the π acts like a projection of <u>neutron</u> from an arbitrary N

"ISOSPIN" is the quantum number for nucleons:

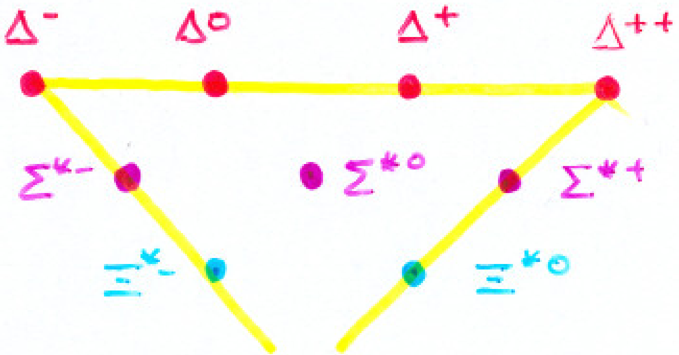
$$I = 1/2 \Rightarrow I_3 = \pm 1/2 \qquad \begin{pmatrix} p \\ n \end{pmatrix} \begin{array}{l} \leftarrow +1/2 \\ \leftarrow -1/2 \end{array}$$

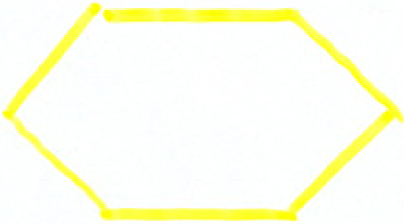
$$I = 1 \Rightarrow I_3 = -1, 0, +1 \qquad \begin{pmatrix} \pi^+ \\ \pi^0 \\ \pi^- \end{pmatrix} \begin{array}{l} \leftarrow 1 \\ \leftarrow 0 \\ \leftarrow -1 \end{array}$$

BARYON OCTET



BARYON
DECUPLET

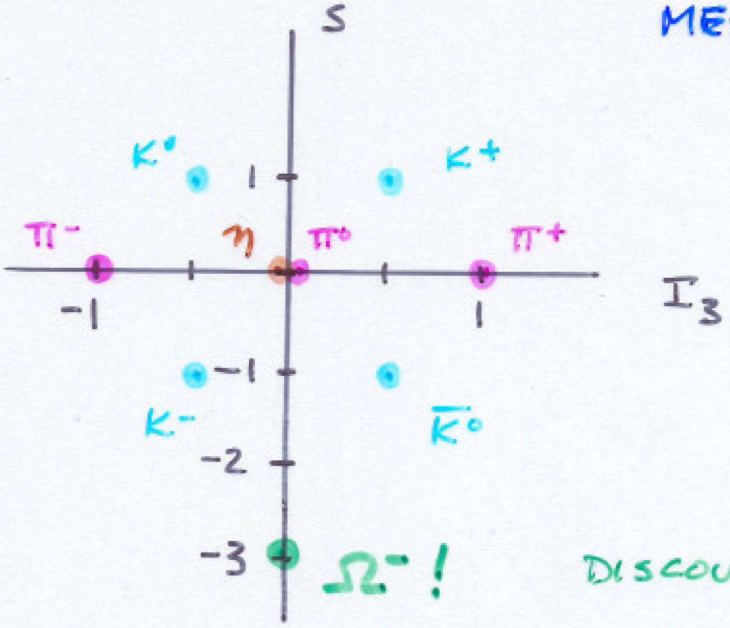




Plotting against I_3 gives famous patterns:

Murray Gell-Mann 1962 & Yuval Ne'eman:

MESON OCTET



DISCOVERED 1964

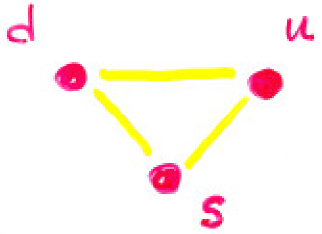
The patterns – those of the "special Unitary Group" in 3 dimensions.._

What's strange -- um, amusing about this is --

The mathematics predicts that each point on the diagram can be produced by combining together, 2 or 3 fundamental representations of SU(3)

Gell-Mann called these fictitious entities

quarks



	Q	S	B	I_3
u	$+\frac{2}{3}e$	0	$\frac{1}{3}$	$\frac{1}{2}$
d	$-\frac{1}{3}e$	0	$\frac{1}{3}$	$-\frac{1}{2}$
s	$-\frac{1}{3}e$	-1	$\frac{1}{3}$	0

And you can build hadrons with them...

$p \quad uud = \frac{2}{3} + \frac{2}{3} - \frac{1}{3} = 1\,e \quad Q$

$\frac{1}{3} + \frac{1}{3} + \frac{1}{3} = 1 \quad B$

$n \quad udd = \frac{2}{3} + -\frac{1}{3} - \frac{1}{3} = 0\,e \quad Q$

$\pi^+ \quad u\bar{d} = \frac{2}{3} + (--\frac{1}{3}) = 1\,e$

$K^+ \quad u\bar{s} = \frac{2}{3} + \frac{1}{3} = 1\,e$

⋮

and so on... <u>all</u> of them

Nobody believed they were real

until they showed up!

"Mott scattering"

~ relativistic Rutherford scattering

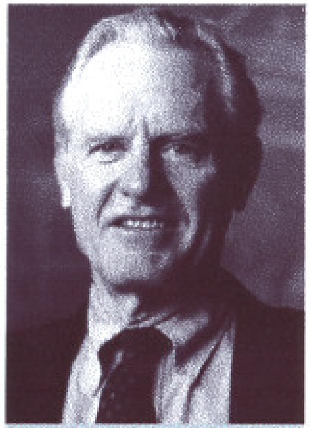
Jerome I. Friedman

1/3 of the prize

USA

Massachusetts Institute
of Technology (MIT)
Cambridge, MA, USA

b. 1930



Henry W. Kendall

1/3 of the prize

USA

Massachusetts Institute
of Technology (MIT)
Cambridge, MA, USA

b. 1926
d. 1999

Photo: T. Nakashima

Richard E. Taylor

1/3 of the prize

Canada

Stanford University
Stanford, CA, USA

b. 1929

716 *Physics 1990*

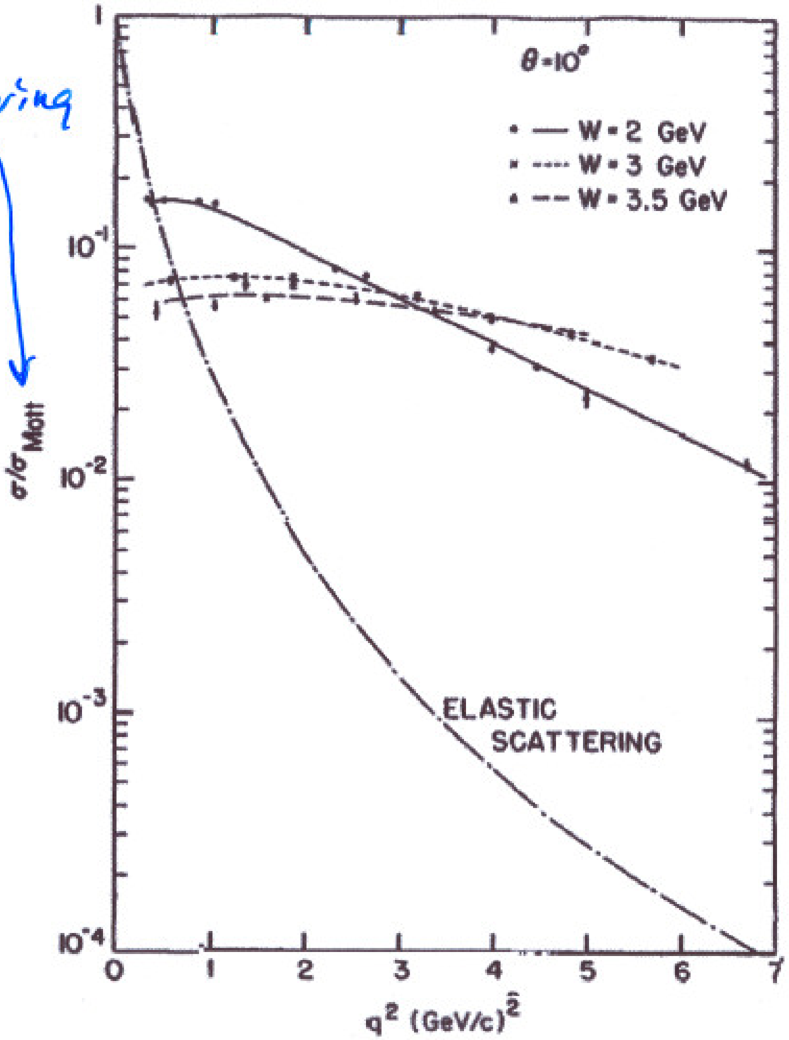


Fig. 1: $(d^2\sigma/d\Omega dE')/\sigma_{Mott}$, in GeV^{-1}, vs. q^2 for W = 2, 3 and 3.5 GeV. The lines drawn through the data are meant to guide the eye. Also shown is the cross section for elastic e-p scattering divided by σ_{Mott}, $(d\sigma/d\Omega)/\sigma_{Mott}$, calculated for θ = 10°, using the dipole form factor. The relatively slow variation with q^2 of the inelastic cross section compared with the elastic cross section is clearly shown.

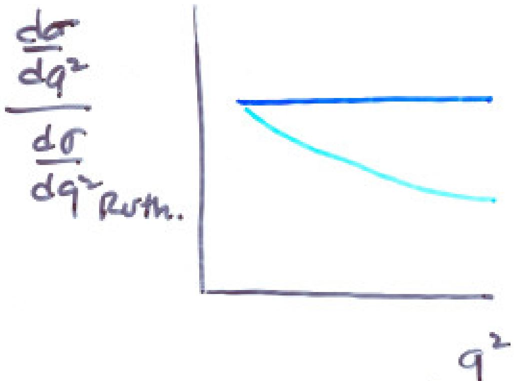
Then it got weird.

Electron Scattering

got more and more energetic

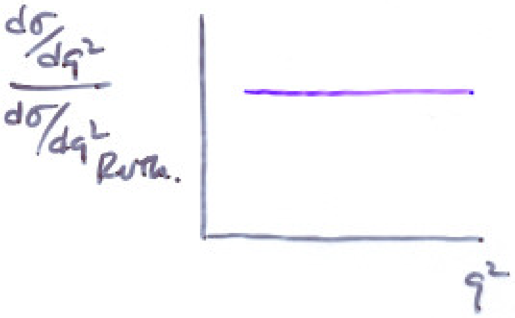
$$\Delta x \sim \frac{\hbar}{\Delta p}$$

more momentum transferred to target, the <u>shorter</u> the distance probed.

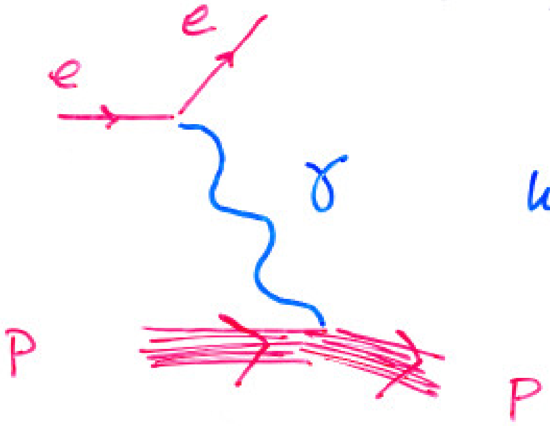


standard momentum transfer name

at high energy



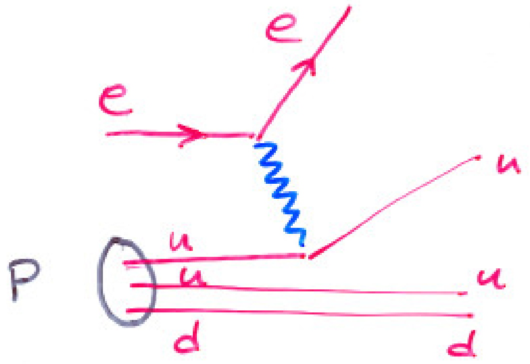
Electron scattering went from



low frequency, long λ

$\Rightarrow$ low E

to



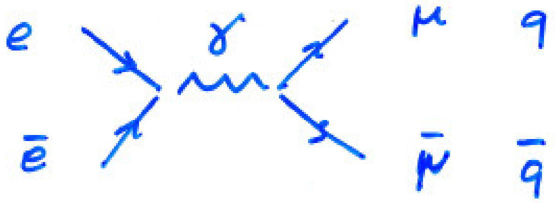
+ other combinations.

& Rutherford scattering emerges as quarks are too small to be resolved...

Early "colliding beam" accelerators were

electron - positron

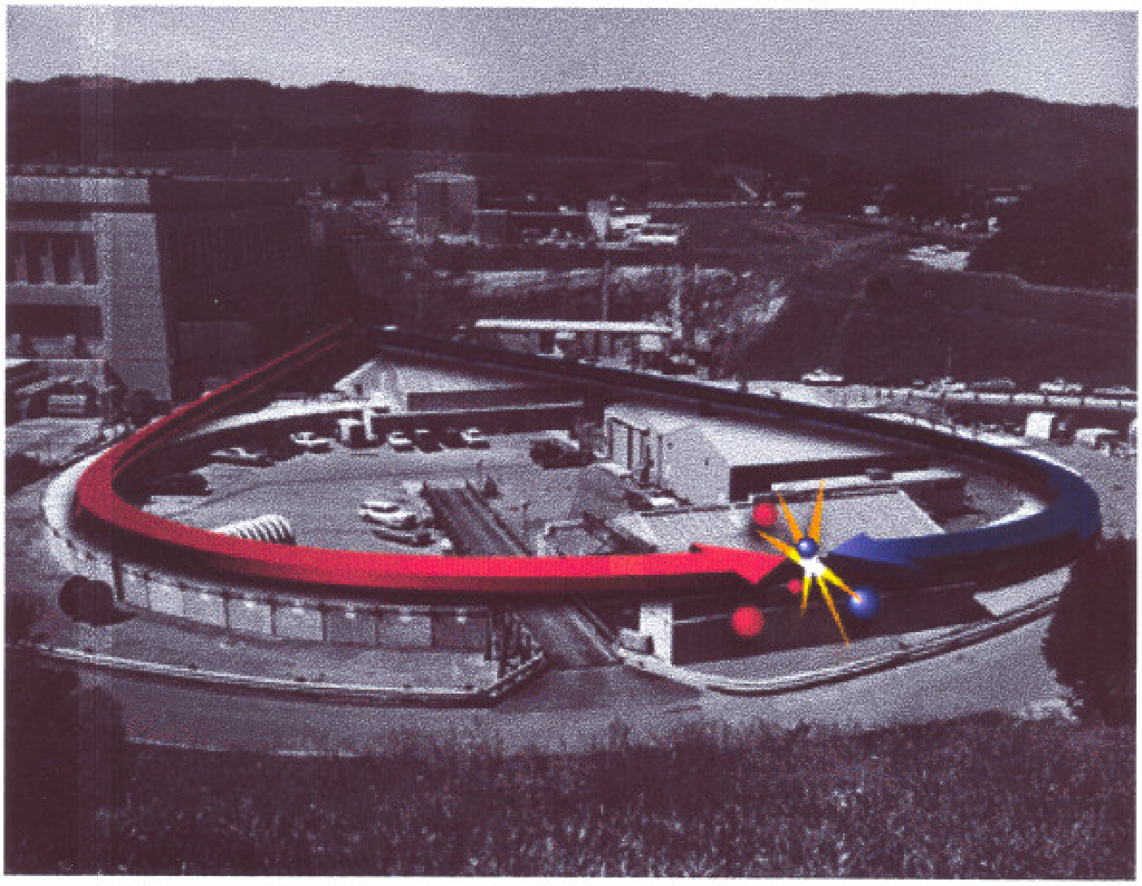
(more on this later)

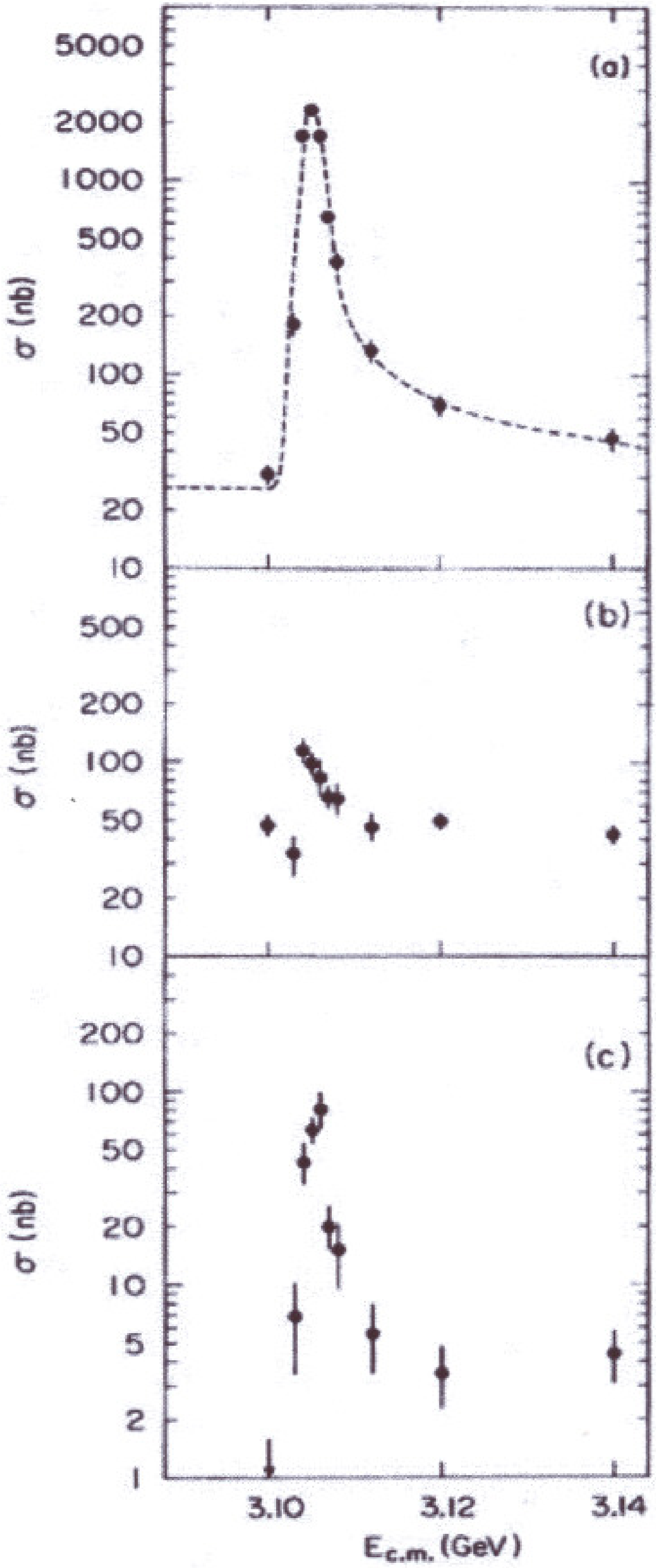


The SLAC facility was one of the first and most energetic.

www.slac.stanford.~~gov~~ edu !

In 1974 they initiated the "November Revolution"





@ $E_{cm} = 3.105$
± 0.003
GeV

a narrow

⇒ long-lived

massive

state

This had to be a bound state of fermion-antifermion

with mass $m \simeq 1.5\ \mathrm{GeV}/c^2$

Quickly, it was found to have a non-relativistic SPECTROSCOPY

A different kind of experiment simultaneously found the same thing at Brookhaven National Lab

SLAC called the state ψ

BNL called it J

now, we call it "J/ψ"

a bound state of the charm quark

In October, 1974, the community was split about the existence of quarks.

By December, 1974 – everyone believed in quarks.

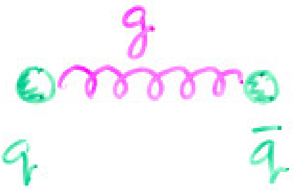
"Charmonium" spectroscopy...

Schrödinger equation $V(r) \propto r$

!!

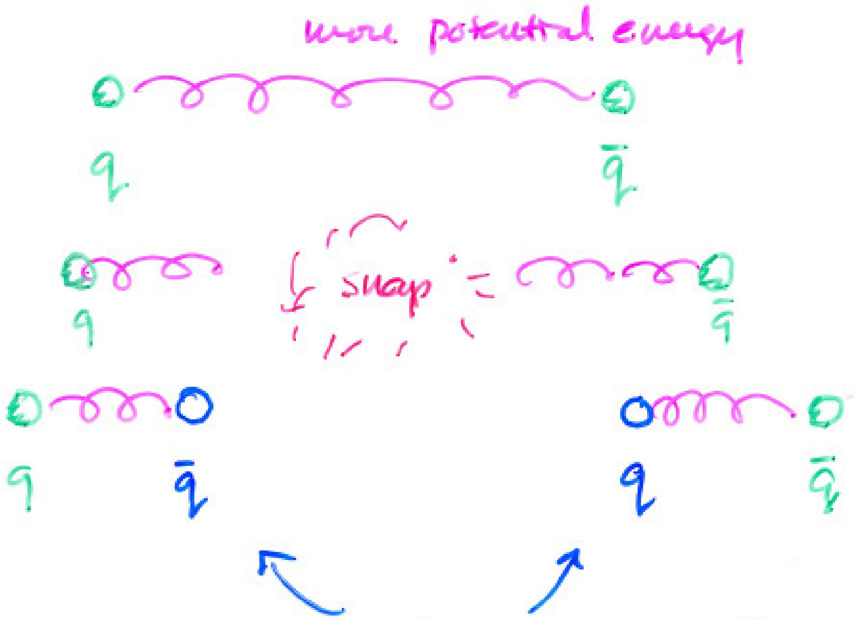
gets stronger the FURTHER apart 2 quarks get!

yup

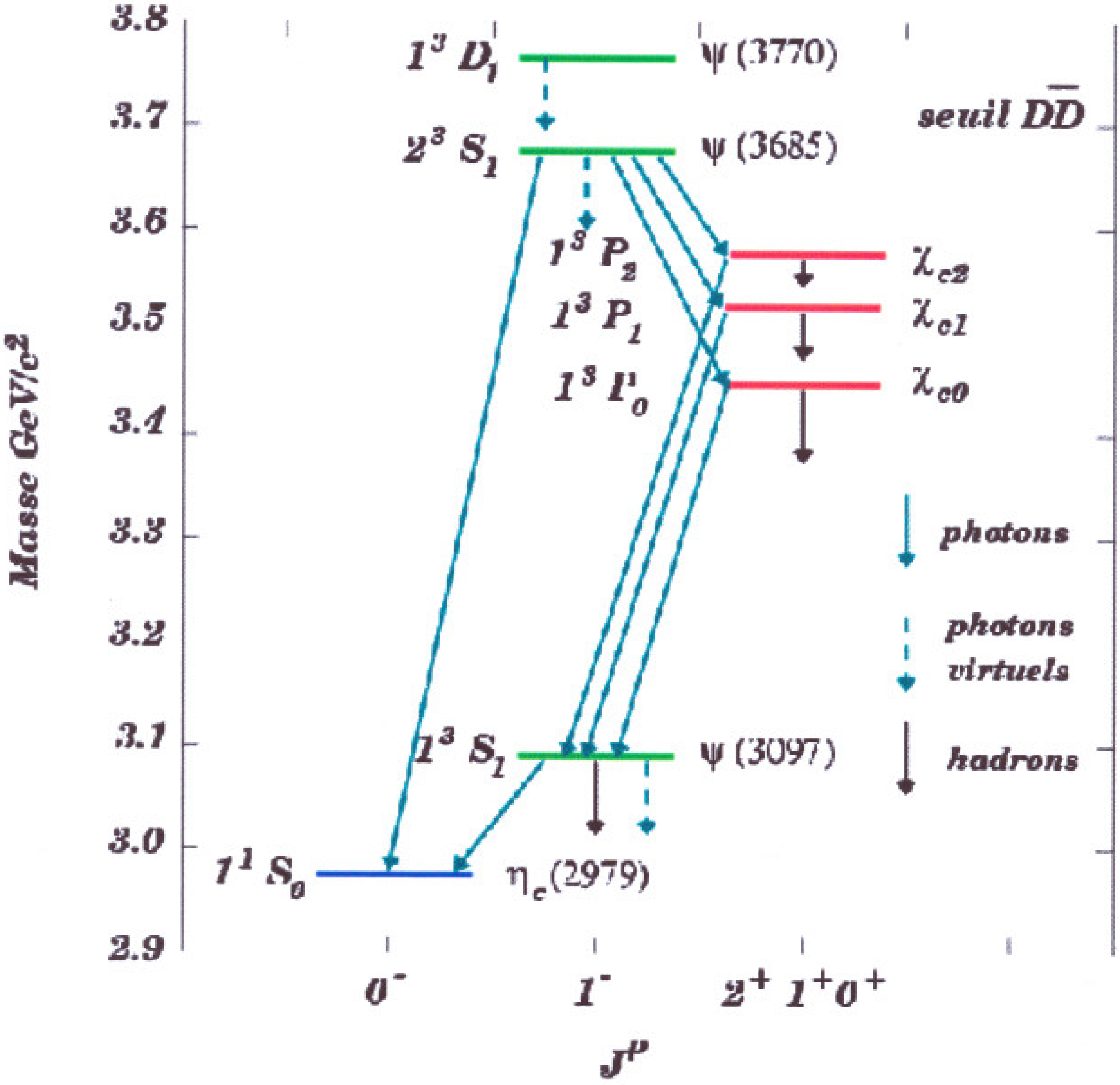


"gluon" is the vector boson, "gauge boson" of the strong force

joining W, and γ



creates new quark-antiquark pairs


Masse GeV/c²
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
$1^3 D_1$
ψ (3770)
seuil $D\bar{D}$
$2^3 S_1$
ψ (3685)
$1^3 P_2$
χ_{c2}
$1^3 P_1$
χ_{c1}
$1^3 P_0$
χ_{c0}
photons
photons virtuels
$1^3 S_1$
ψ (3097)
hadrons
$1^1 S_0$
η_c(2979)
0^-
1^-
2^+ 1^+ 0^+
J^P

Burton Richter
Born 1931

Samuel C.C. Ting
Born 1936

Patterns now were apparent:

Quarks:

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \qquad \begin{array}{cc} I_3 & Q \\ 1/2 & +2/3\,e \\ -1/2 & -1/3\,e \end{array}$$

Leptons:

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \qquad \begin{array}{c} Q \\ 0 \\ -1 \end{array}$$

Then... you guessed it...

It happened that inside of the SLAC $c\bar{c}$ data:

a new lepton, τ $\quad M_\tau \sim 1.8\ \mathrm{GeV}/c^2$

$$\begin{pmatrix} \\ \tau \end{pmatrix}$$

the neutrino not discovered until 2000 at Fermilab

so: $\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$

Then … it happened again

another $q\bar{q}$ state, this time even more massive

called the bottom quark $m_b \simeq 4.5\ \mathrm{GeV}/c^2$

$$\begin{array}{ccc} & I_3 & Q \\ \left(b \right) & -\tfrac{1}{2} & -\tfrac{1}{3}e \end{array}$$

obviously…
something missing

Also – masses are out of line.

$m(u) \simeq 1.5 - 3.0\ \mathrm{MeV}/c^2$

$m(d) \simeq 3 - 7\ \mathrm{MeV}/c^2$

$m(s) \simeq 95\ \mathrm{MeV}/c^2$

$m(c) \simeq 1500\ \mathrm{MeV}/c^2$

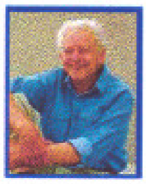
$m(b) \simeq 4500\ \mathrm{MeV}/c^2$

we don't understand this!

wait.. how do you make a proton?
$m(p) = 938\ \mathrm{MeV}/c^2$

$$E = m_p c^2 = \sqrt{\underset{\substack{\uparrow \\ \text{LARGE} \\ p_q \,\&\, p_g}}{p_q^2 c^2} + \underset{\substack{\uparrow \\ \text{tiny } m_q}}{m_q^2 c^4}}$$

The proton: mostly energy of motion of quarks/gluons



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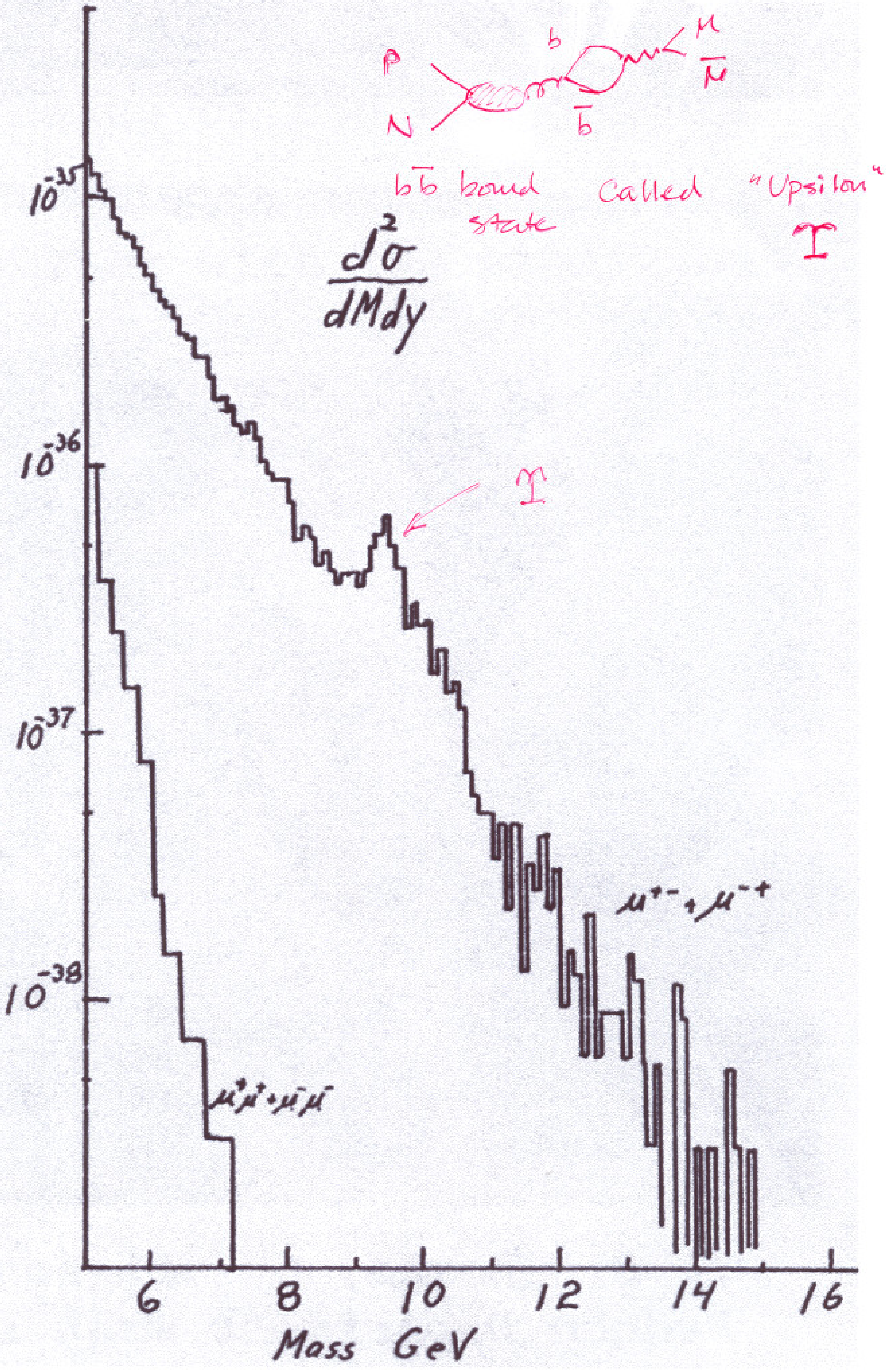
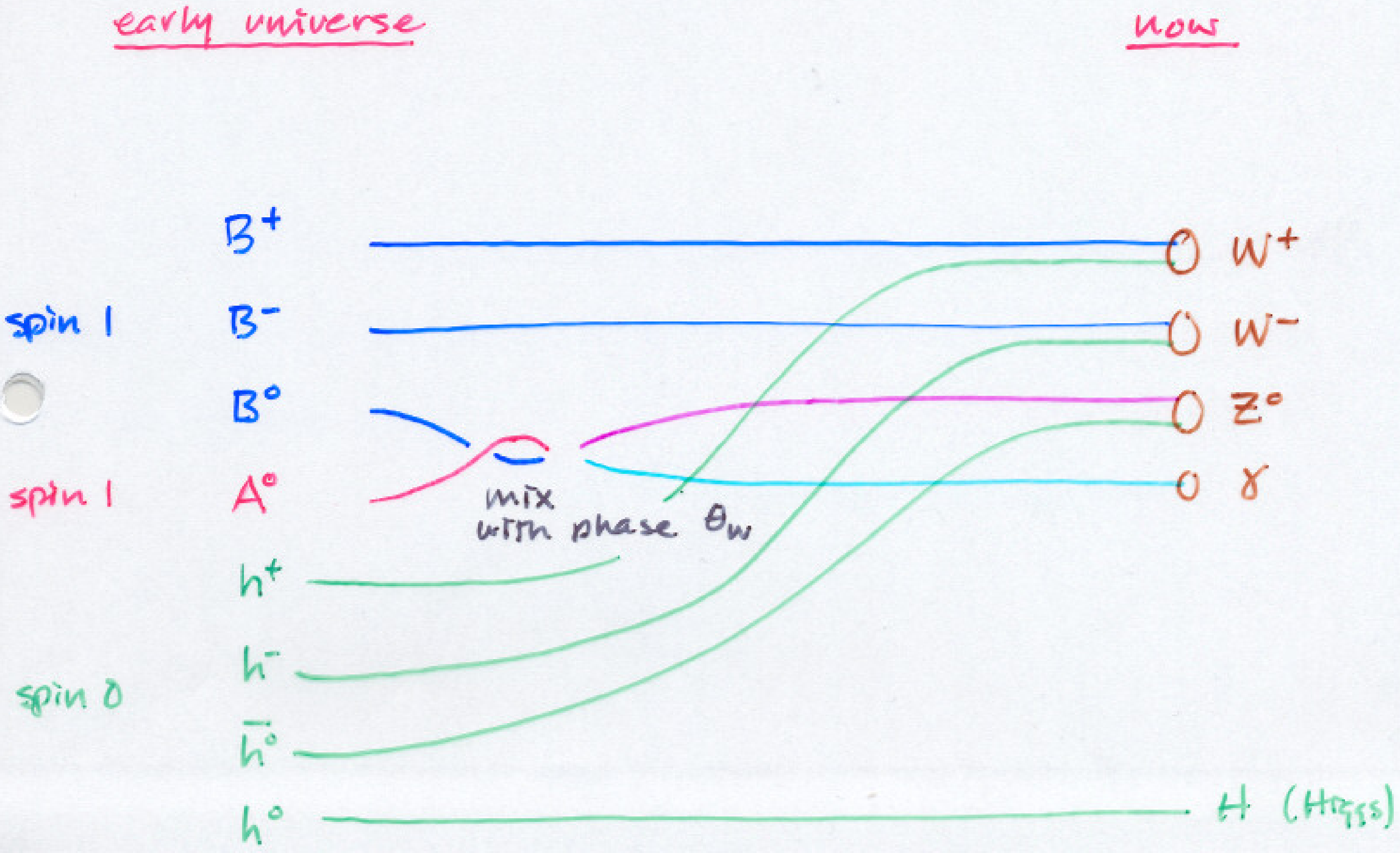


$b\bar{b}$ bound state called "Upsilon" Υ

1967 Stephen Weinberg writes a 3 page paper describing a model for elementary particles

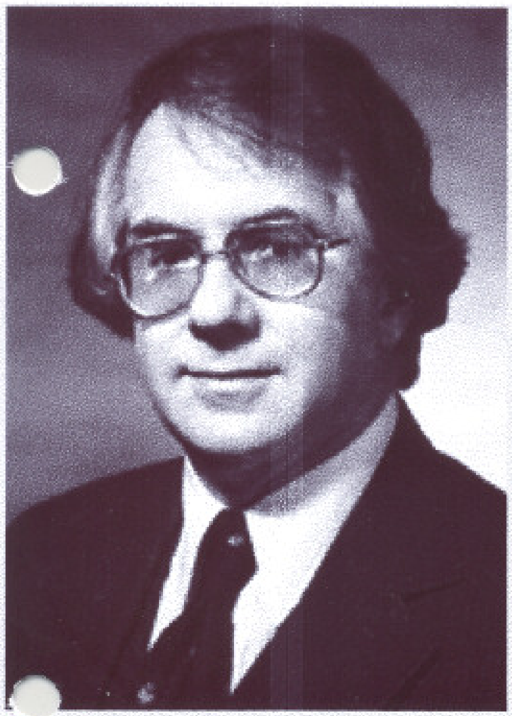
A model of phase transitions of the universe.

... um... I guess a model of phase TRANSITION



Massless spin 1 particles have 2 dof -- γ polarizations

MASSIVE spin 1 particles must have 3 dof.



Sheldon Glashow
Born 1932

Abdus Salam
Born 1926
Died 1996

Steven Weinberg
Born 1933