From atoms to nucleons to quarks - Where is the particle physics going?

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- Introduction
- Particles and interactions
- Discoveries: old and new
- Some thoughts

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Spin Correlations of Strongly Interacting Massive Fermion Pairs as a Test of Bell's Inequality

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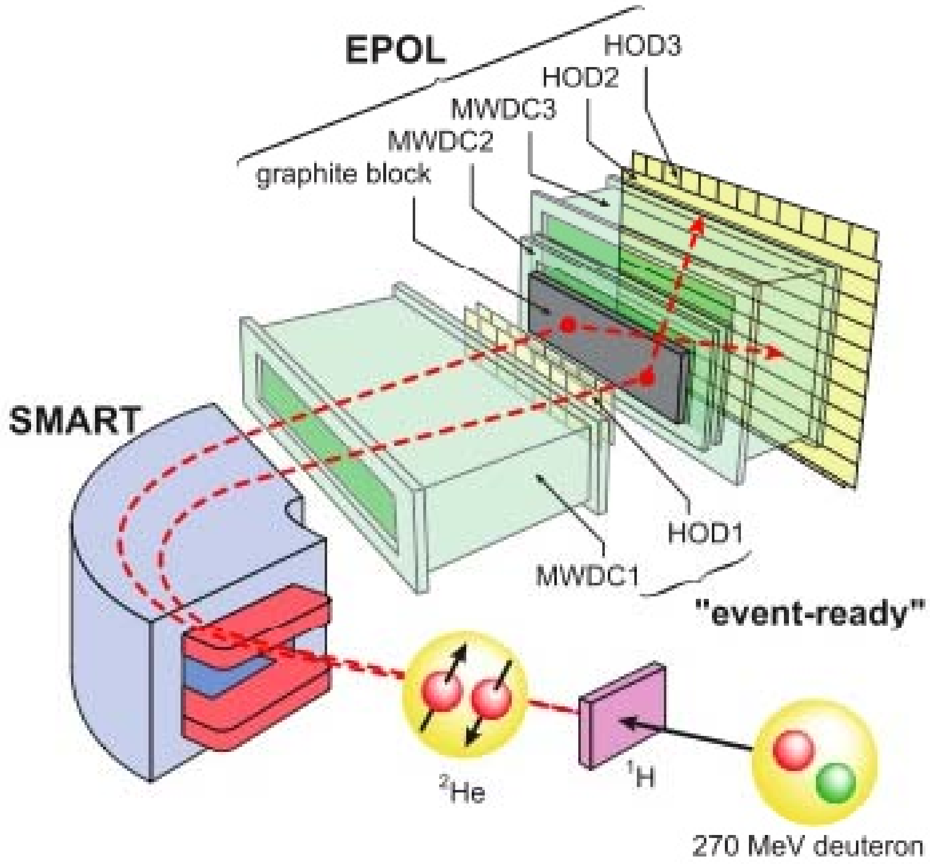


FIG. 1 (color). A schematic diagram of the experimental layout. Deuterons interact with protons in liquid hydrogen (^{1}H) target. The proton pairs (^{2}He) are momentum selected by SMART spectrometer, which are subsequently tracked by the "event-ready" detector (MWDC1 and HOD1). The spin analysis of the protons was then achieved by the EPOL polarimeter, where graphite block is the analyzer and the MWDC2, MWDC3, HOD2, and HOD3 are correlation detectors.

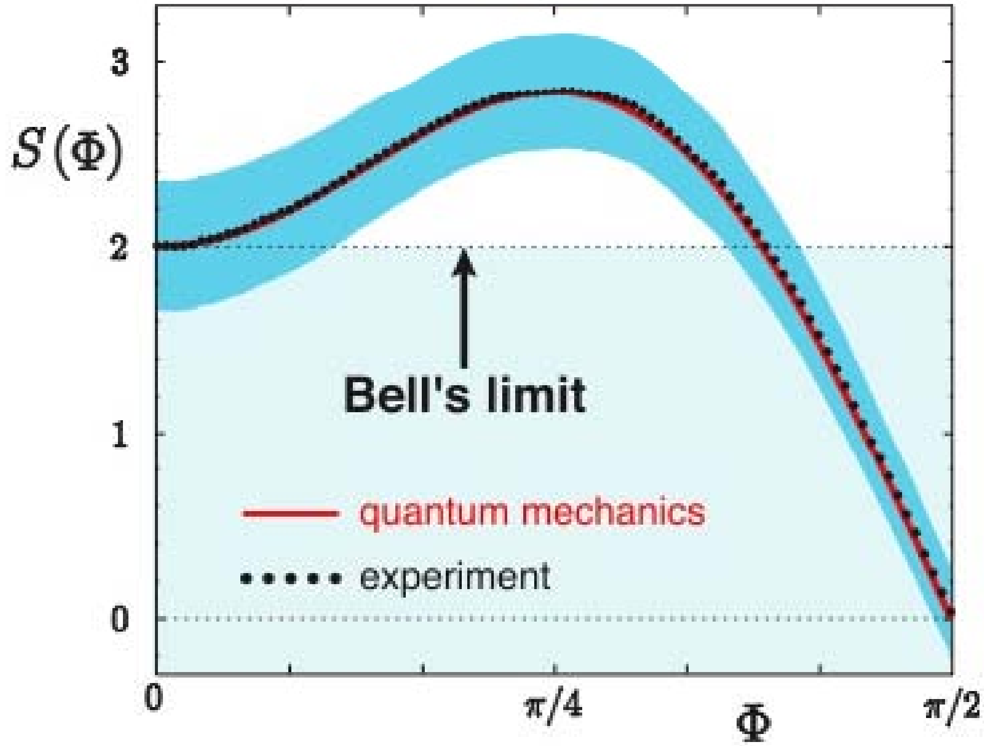


FIG. 4 (color). Plot of the spin-correlation function $S(\Phi)$ vs Φ. Solid circles are the experimental result $S_{\mathrm{exp}}(\Phi)$ derived from the same data set. Each error shown as blue shaded area is correlated. See text for details.

Advice to our undergrads

- Mathematics is the <u>language</u> of physics

- Experiment/observation is the method of physics

Two facets of physics

- Applications-

  Spectacular successes
  The latest: miniaturization of hard-discs
  Giant Magneto Resistance discovery

- Conceptualization and quantification of the dynamics of physical universe -

Two main questions….

- What is the matter made up of ??
- How are the things put together (how do they interact ?)

Are they indeed two separate questions ?

Are the entities (interactants) and interactions clearly distinct?

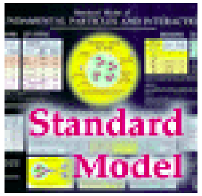
Experimenter "sees" $\langle \psi_f | O | \psi_i \rangle$

Ongoing Enterprise…….

Earliest times - 1550 AD: The Ancients

1550 - 1900 AD: The Scientific Revolution and Classical Mechanics

1900 - 1964 AD: Quantum Theory



1964 - Present: The Modern View (the Standard Model)

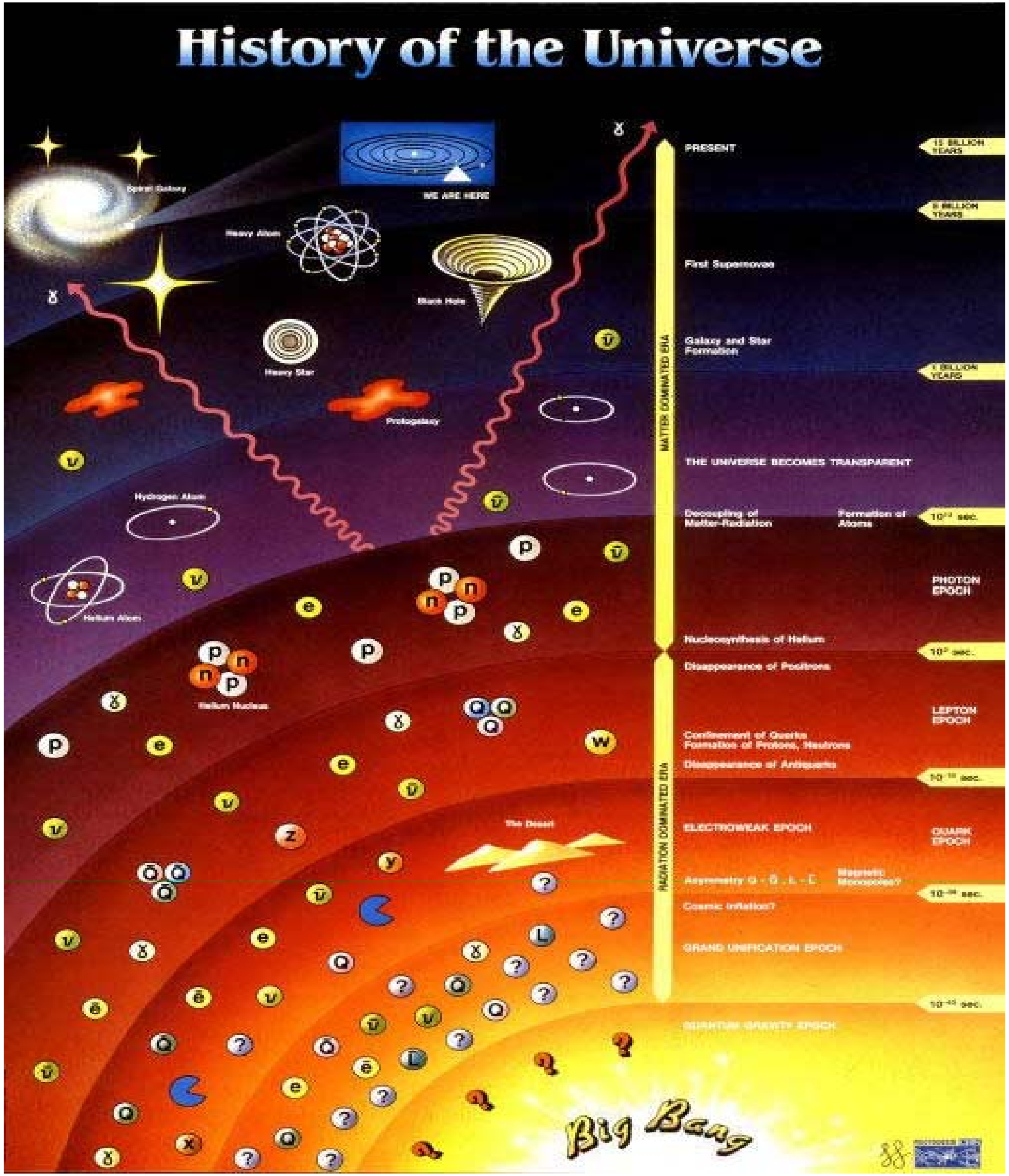
Who needs the particles anyways?

- Particle physicists, particle-astrophysicists, cosmologists,
- Any body who wants to describe the universe away….

History of the universe

- For a good (almost) theologized account of the origins of the universe, please visit

http://www.superstringtheory.com/cosmo/bang0.html



You are here

Galaxies

1by

atoms

12

photon

6

lepton

-12

electroweak

-36

-40 Cosmic inflation

Simple Question(s)

- How did the universe get to its present state?
- Where does it go from here?

To proceed:

- a) Know the fundamental constituents
- b) Know their interactions
- c) Solve the many-body problem

- Exploit symmetries and conservation principles

Interactions?

- Strong
- Electro-weak
- Gravitation

Weak interactions are mischievous brats, not respecting symmetries.

Gravitation is almost ignored by particle physicists.

Many-body problem is a hard nut to crack.

Physics makes strides by not lamenting on short-comings but by circumventing them.

Symmetries are of great help.

Symmetries.....

- Symmetrie, ob man ihre Bedeutung weit oder eng faβt, ist eine Idee, vermöge derer der Mensch durch die Jahrtausende seiner Geschichte versucht hat, Ordnung, Schönheit und Vollkommenheit zu begreifen und zu Schaffen.

Hermann Weyl in Symmetrie

- Symmetry, as wide or as narrow as you may define its meaning, is one idea by which man through the ages has tried to comprehend and create order, beauty, and perfection.

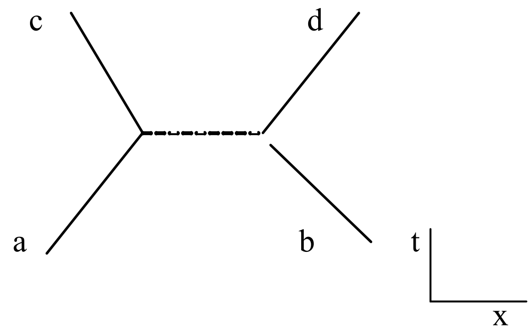
- How do two particles talk to each other?
- They exchange particle(s).
- What are the properties of exchange particles (mass, charge, spin, isospin, color etc.)?

- Relativistic Klein-Gordon equation (Yukawa)

$$\nabla^2\psi - \frac{m^2c^2}{\hbar^2}\psi - \frac{1}{c^2}\frac{\partial^2\psi}{\partial t^2} = 0$$

Range-mass

$$\psi(r) = \frac{g}{r} e^{-r/(\hbar/mc)}$$



Wick:

$$\Delta x \leq R \leq \frac{\hbar}{\Delta t} = \frac{\hbar}{mc}$$

$$used \quad : \Delta E \times \Delta t = \hbar$$

$$R = \Delta t \times c$$

$$E = mc^2$$

Note: This is relativistic mass

Int	range	exchange particle	Mass
Grav	∞	graviton	0?
EM	∞	photon	0?
Weak	$<10^{-18}$	W^{+-}, Z	80 GeV
Strong	10^{-15}	pion	139.5MeV
Strong	$< 10^{-15}$	gluon	0 ?

PARTICLE	year	method	physical	comments
electron	1897	cathode rays	yes	unexpected
atomic nucleus	1911	scattering	yes	unexpected
proton	1911-18	?	yes	anticipated
neutron	1932	scattering	yes	anticipated
muon	1937	cosmic rays	yes	anticipated
pion	1947	cosmic rays	yes	anticipated
neutrino	1955	reactor	yes	sought after
quark	1964-1995	production	no	sought after
W+-, Z	1983	production	no	sought after
Higgs	2009?	production	no	sought after
SuSy particles	2010?	production	no	sought after

What constitutes discovery of a particle?

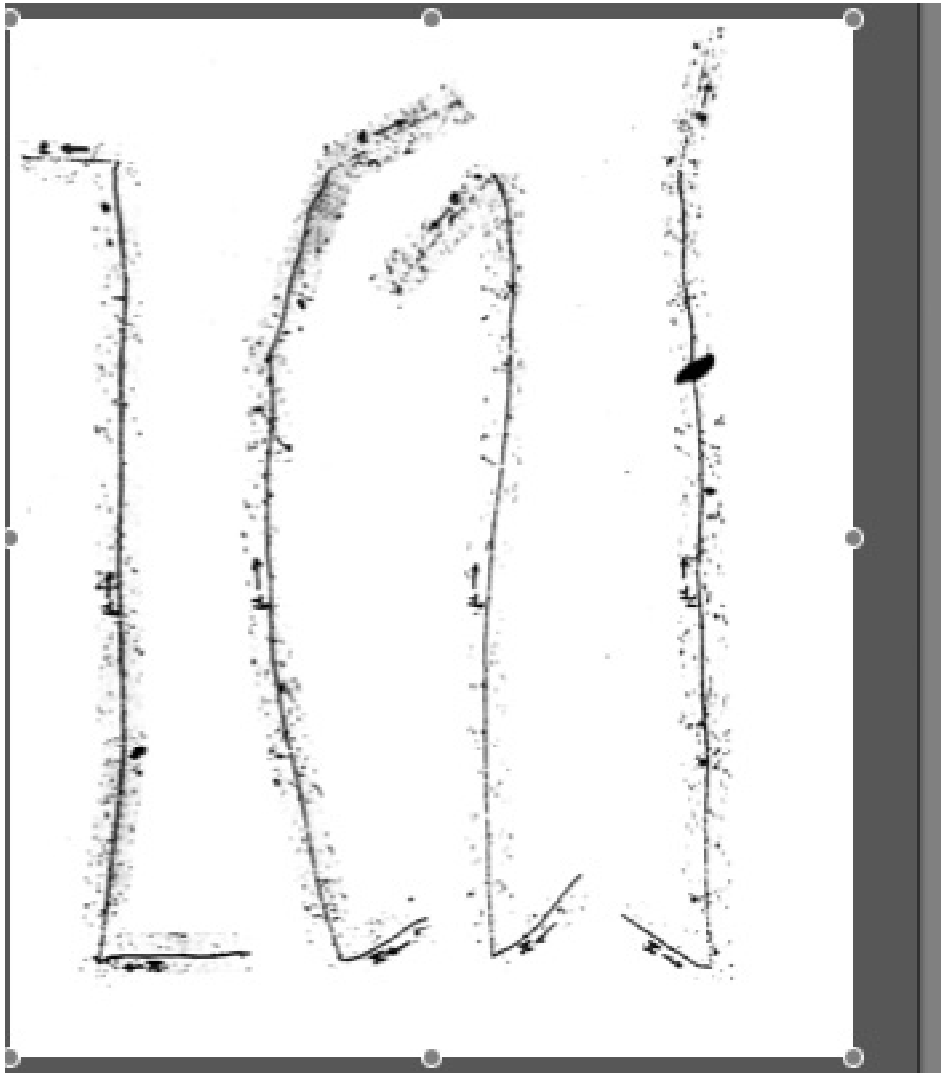
- Ionization trails: π,μ etc.
- Scattering, production processes
  - Conservation principle:
  - characteristic emissions
    - cascade photons: $\nu + p \rightarrow n + \beta^+$
    - $W^{+-} \rightarrow e^{+-} \nu$

$$M^2 = \sum E_i^2 - \sum \vec{p}_i^{\,2}$$

- Excess events in phase space

top-quark, Higgs, SuSy(?)

$\pi - \mu$-e tracks in Cloud chamber



Neutrino discovery $\nu + p \to n + \beta^+$
$\beta^+ e^- \to 2\gamma$; $\nu Cd \to Cd\ n\gamma$

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Quarks and Leptons

$$\begin{pmatrix} up \\ down \end{pmatrix} \quad \begin{pmatrix} \nu_e \\ e \end{pmatrix}$$

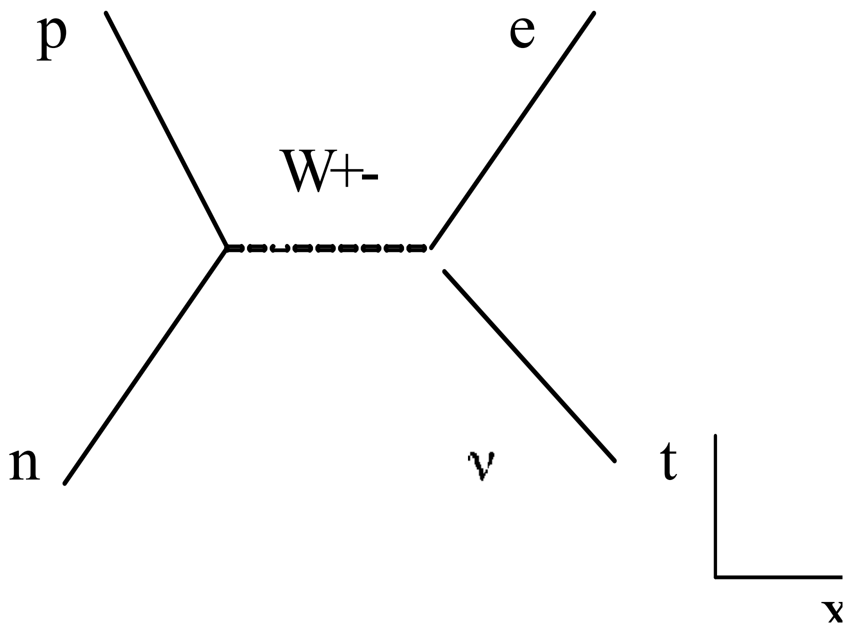
$$\begin{pmatrix} charm \\ strange \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}$$

$$\begin{pmatrix} top \\ bottom \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$$

Neutron decay

$$n \rightarrow pe^{-}\overline{\upsilon}$$

$$d \rightarrow ue^{-}\overline{\upsilon}$$



E_i~E_f~ 1GeV, W mass 81 GeV

W discovery

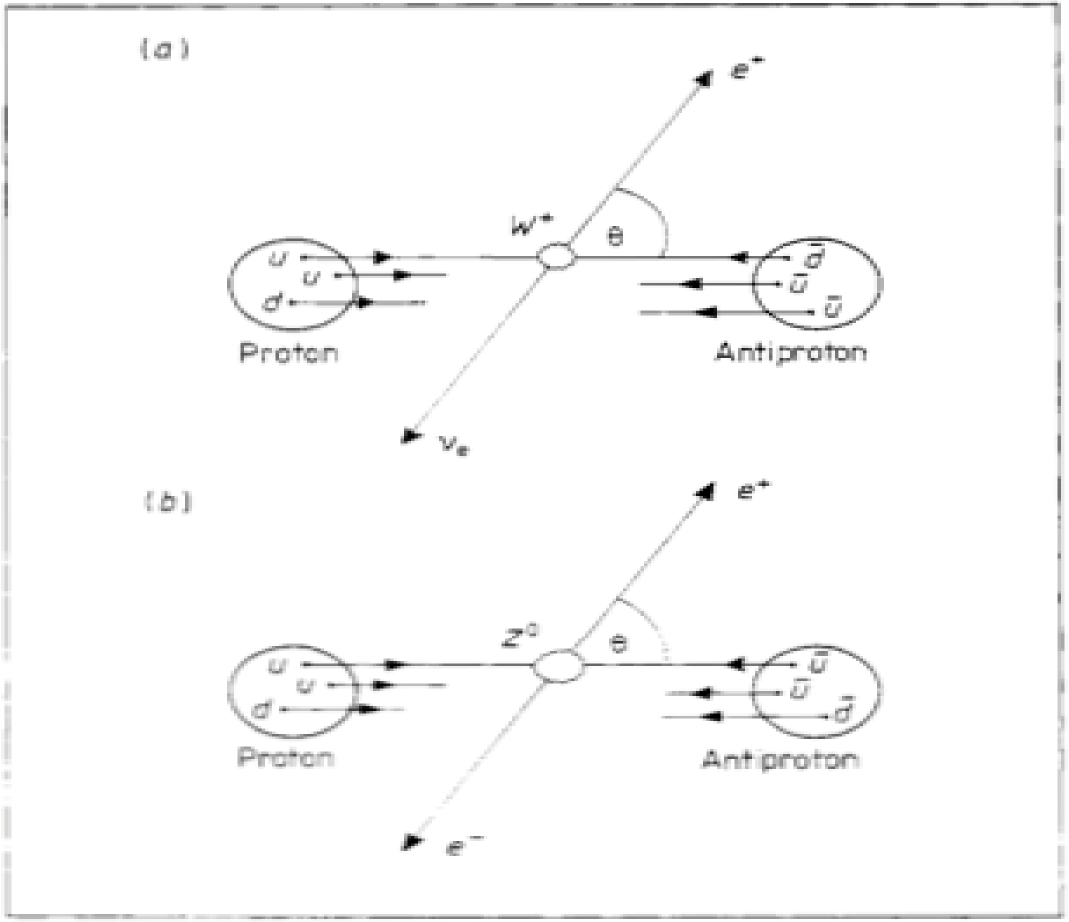


Figure 4 (a). Production of a W^+ boson by the annihilation of a u quark from a proton and a $\bar{d}$ quark from an antiproton and its subsequent decay to a positron and neutrino (W^- production would require $d\bar{u}$ annihilation). (b). Production of a Z^0 boson by $u\bar{u}$ annihilation and subsequent decay to an electron positron pair.

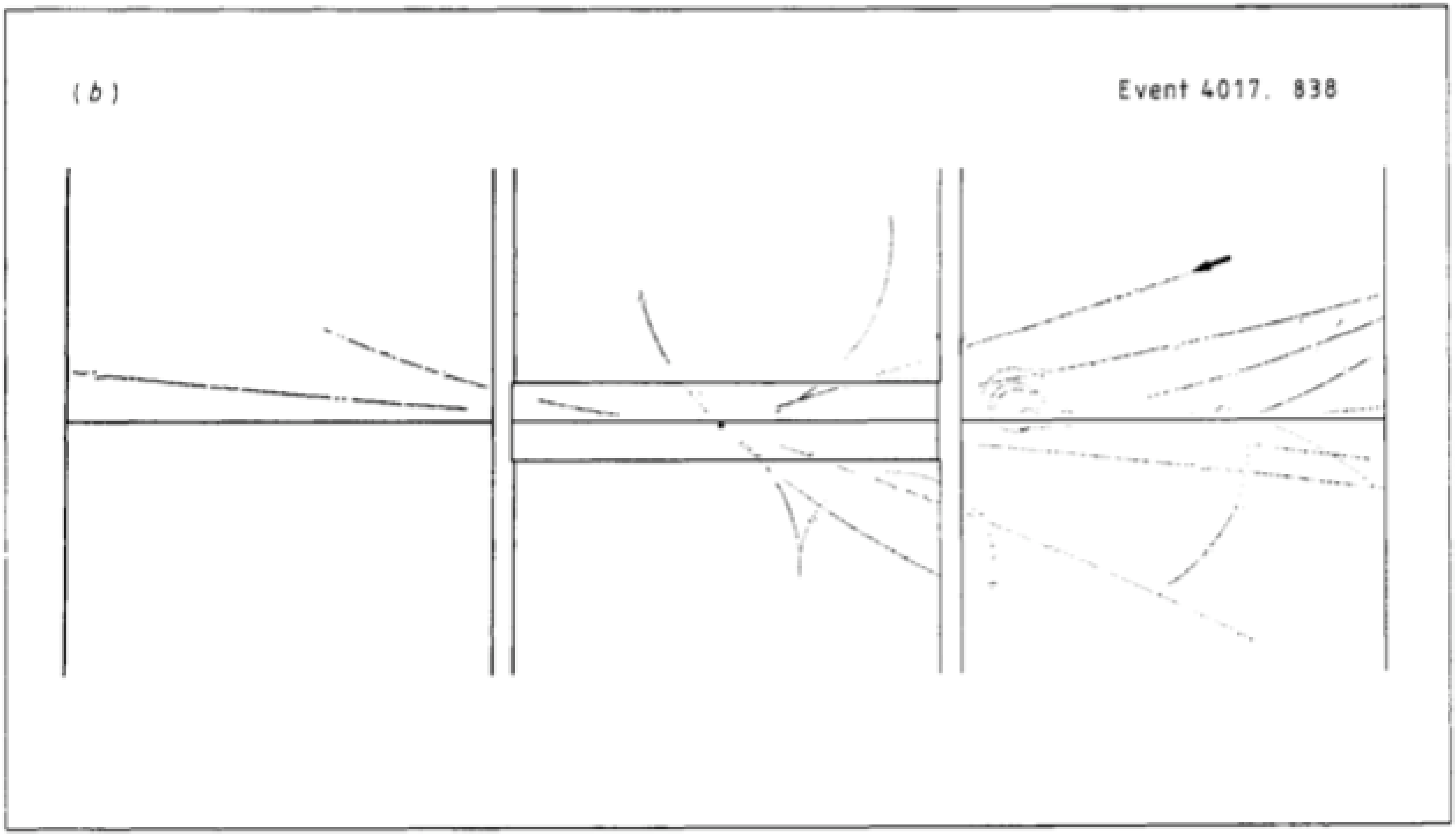


Figure 7 Reconstructions from the drift time information tracks of charged particles in the central detector. The effect of the magnetic field in curving the trajectories is evident. Both (*a*) and (*b*) are examples of W production and decay $W \rightarrow e + \nu$ with the electron arrowed. One event had high charged particle multiplicity (65 tracks) and the other had low multiplicity (14 tracks).

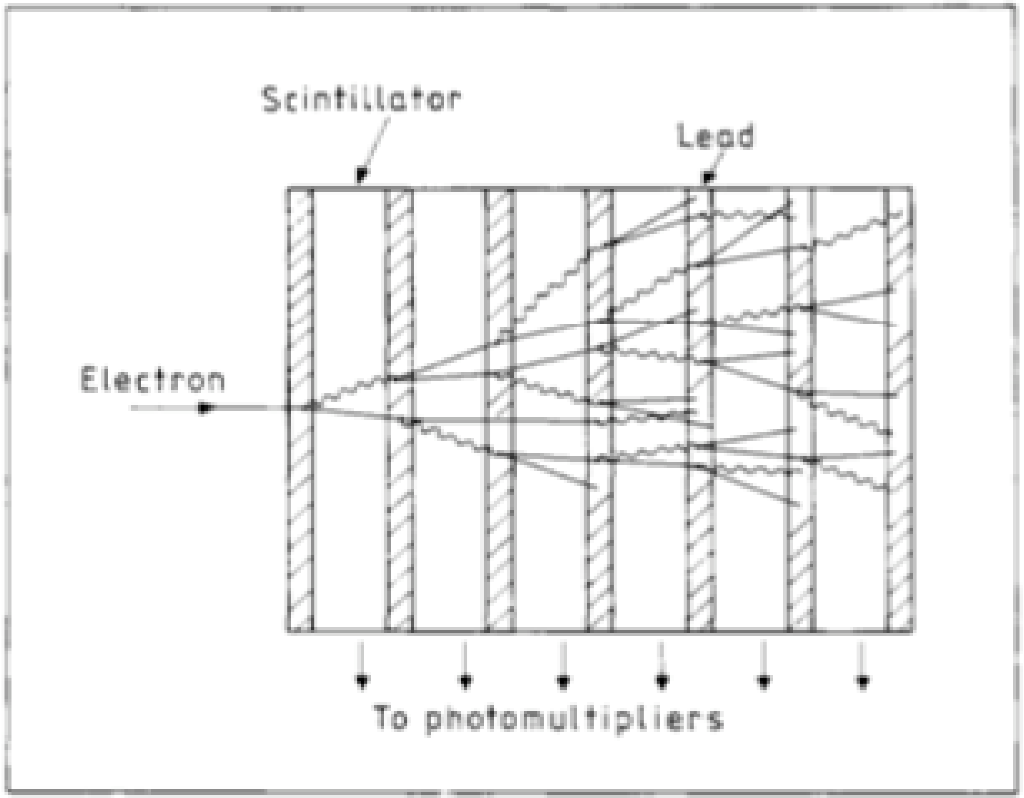
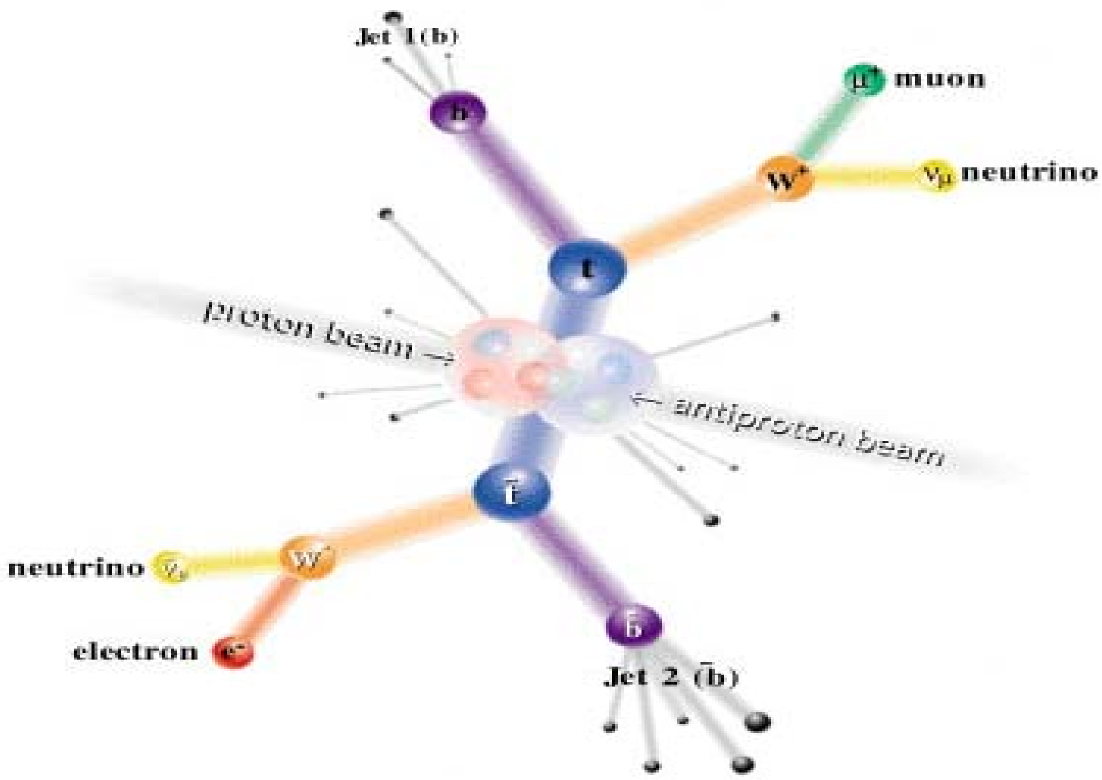
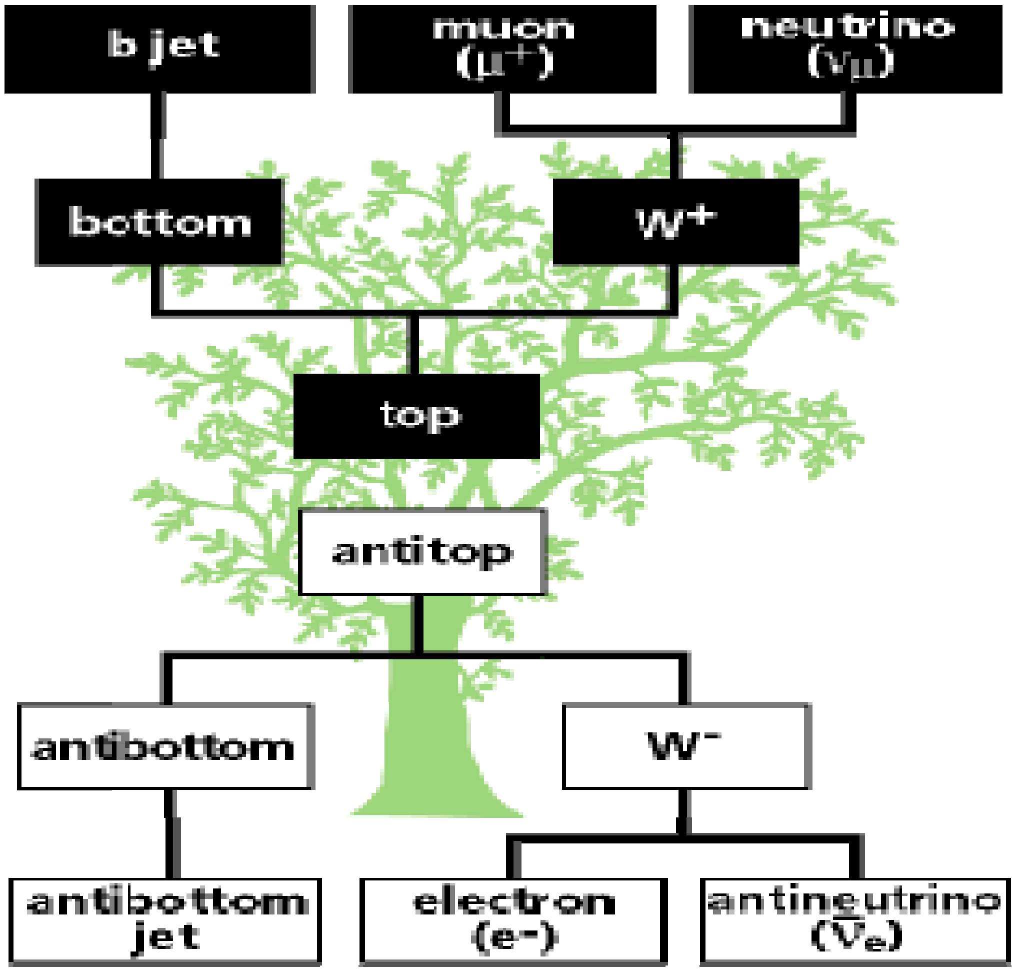


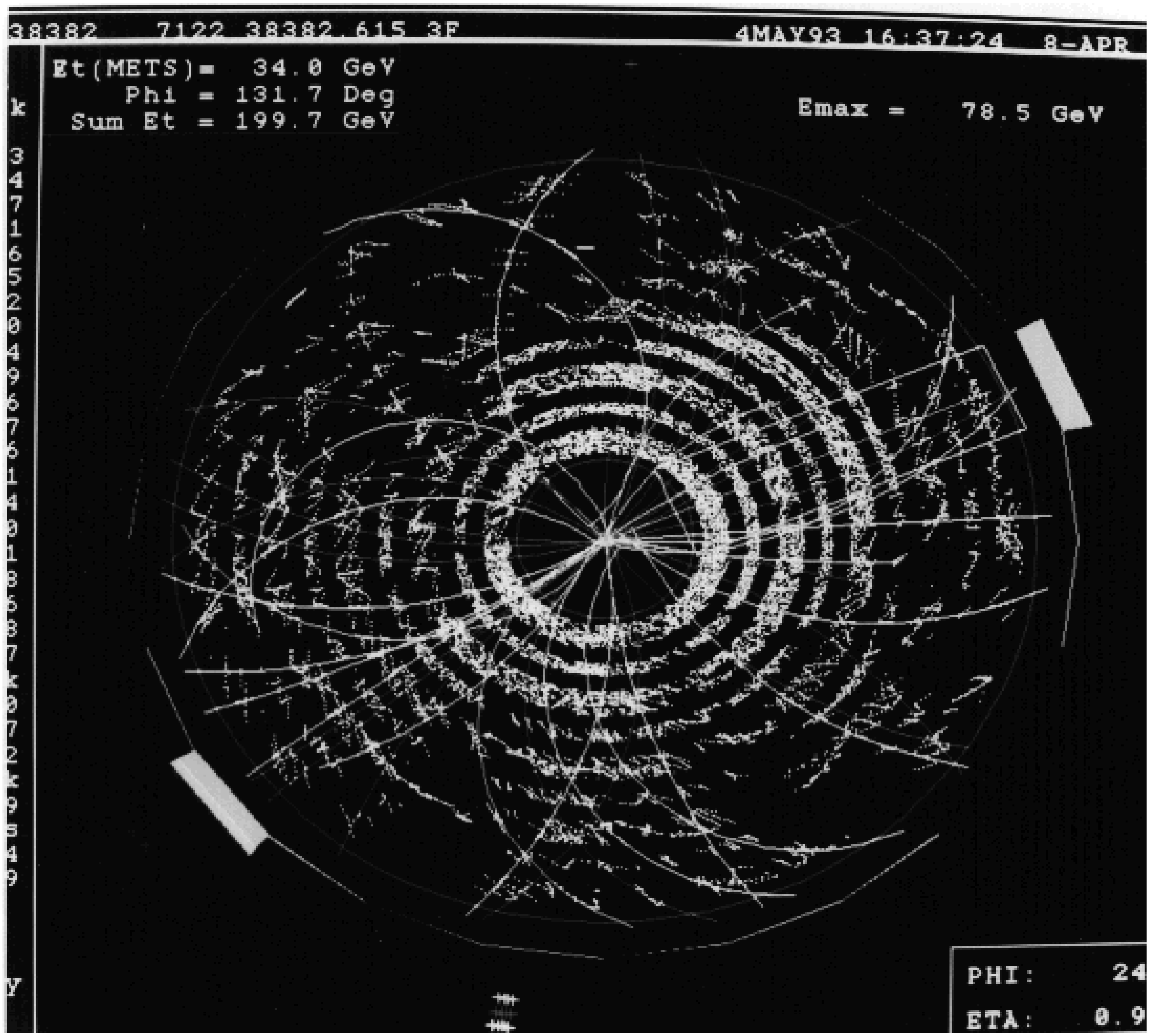
Figure 8 The principle of an electromagnetic calorimeter. An incident electron loses energy in the lead plates, emitting photons which can create electron–positron pairs which then give further photons. An electron–photon cascade or shower builds up. Charged particles cause the scintallator sheets to emit light which is directed to photomultipliers giving a pulse proportional to the energy of the original electron.

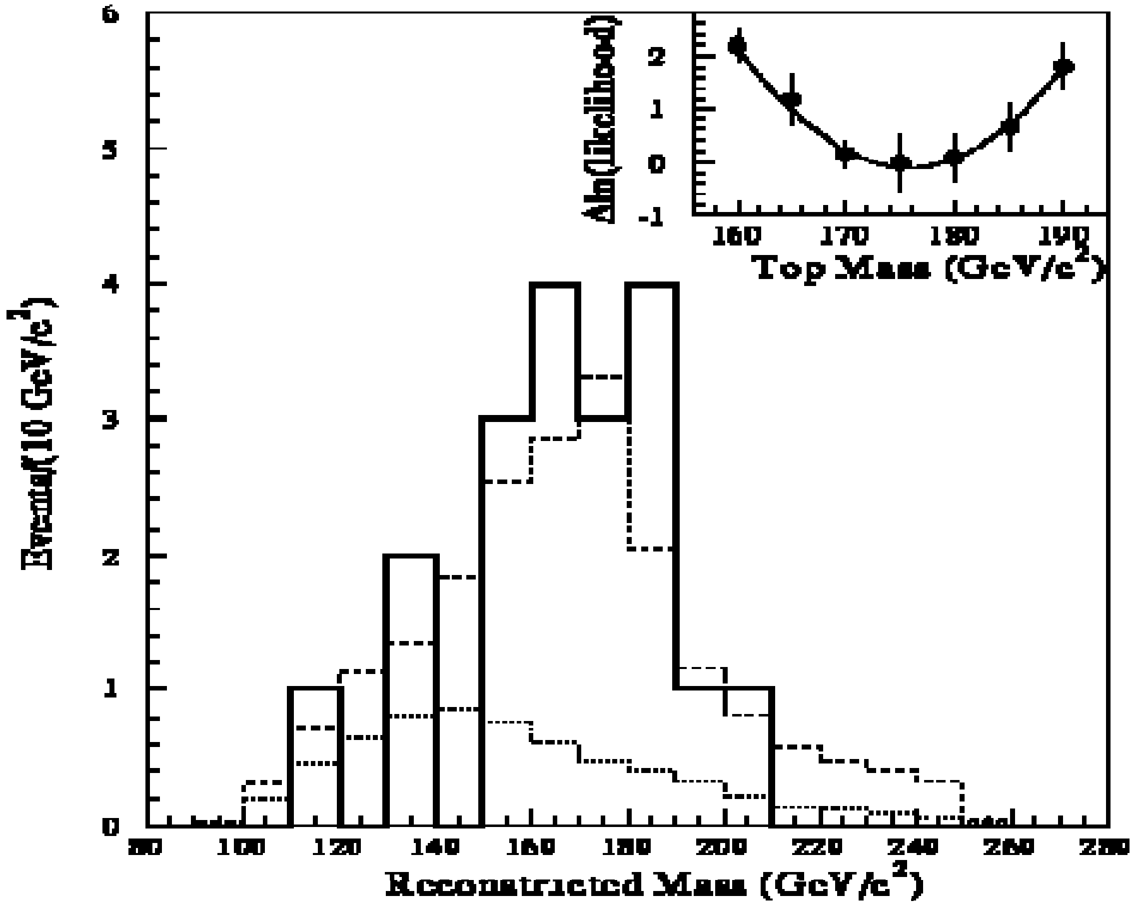
- Up and down hypothesized, never seen in the lab.
- Charm quark J/psi resonance: 3.2 GeV so, charm quark mass 1.6 GeV
- B-quark : Uppsilonium resonance: 10 GeV, b quark ~ 5GeV

Top-quark topology




b jet
muon
(μ+)
neutrino
(νμ)
bottom
W+
top
antitop
antibottom
W-
antibottom
jet
electron
(e-)
antineutrino
(ν̄e)


38382 7122 38382.615 3F
4MAY93 16:37:24 8-APR
Et(METS)= 34.0 GeV
Phi = 131.7 Deg
Sum Et = 199.7 GeV
Emax = 78.5 GeV
PHI: 24
ETA: 0.9



Events/(10 GeV/c^2)
Reconstructed Mass (GeV/c^2)
0
1
2
3
4
5
6
80
100
120
140
160
180
200
220
240
260
280
Δln(likelihood)
Top Mass (GeV/c^2)
-1
0
1
2
160
170
180
190

- Strong interactions mediated by gluons, They are massless - hadron jets are Signatures.

Higgs - who needs it?

- Why are W, Z massive ?
- Higgs mechanism of spontaneous symmetry breaking. Introduce a mass term, which pushes the system from vacuum state of zero energy.
- Still divergencies - postulate super symmetry (SuSy) [For each Fermion a Bose partner and vice versa]   squarks, sleptons, ….

Higgs production

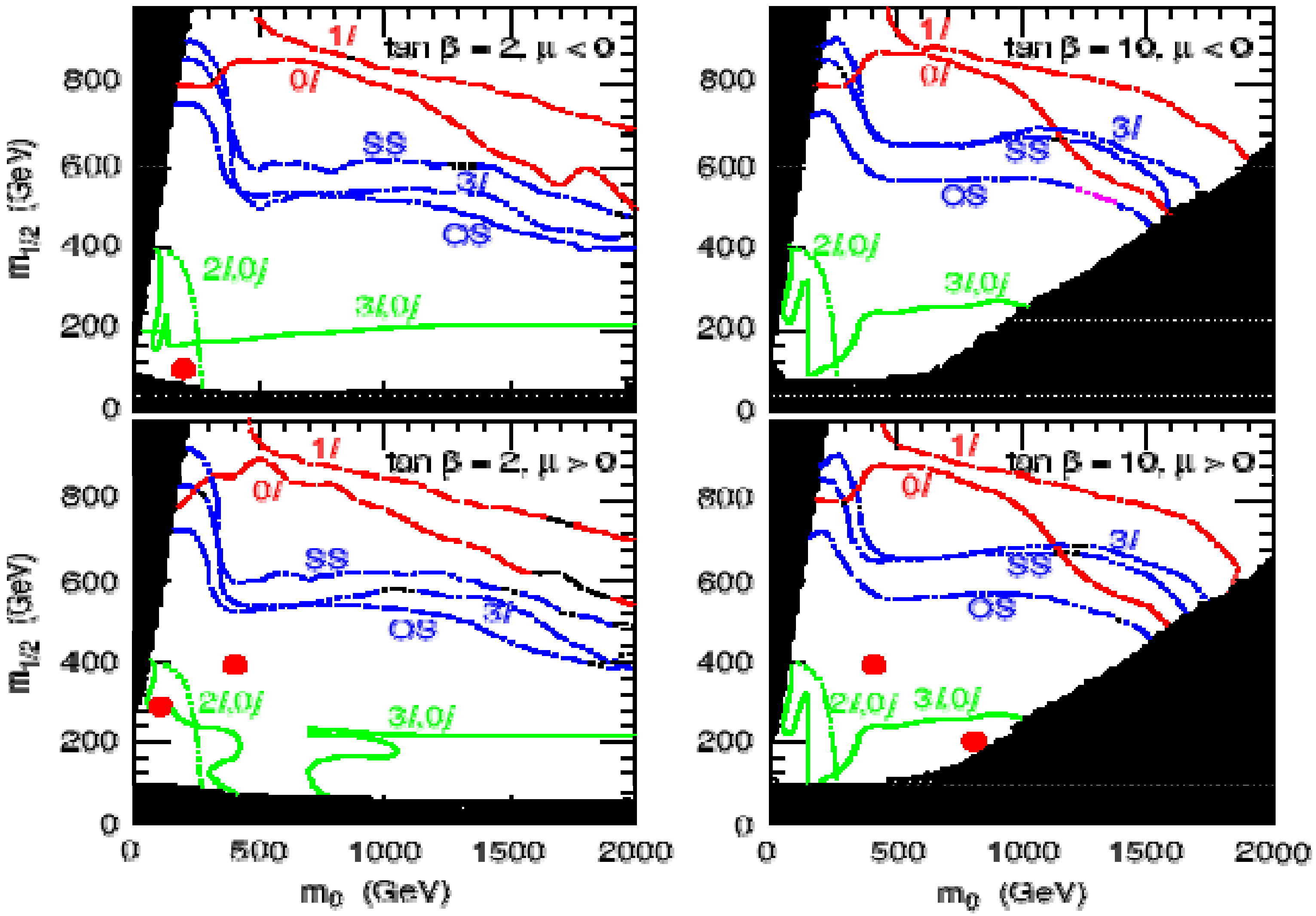
QuickTime™ and a
decompressor
are needed to see this picture.

Higgs' Decay modes

QuickTime™ and a
decompressor
are needed to see this picture.

LHC-ATLAS will see it in two years from now.

SuSy at ATLAS



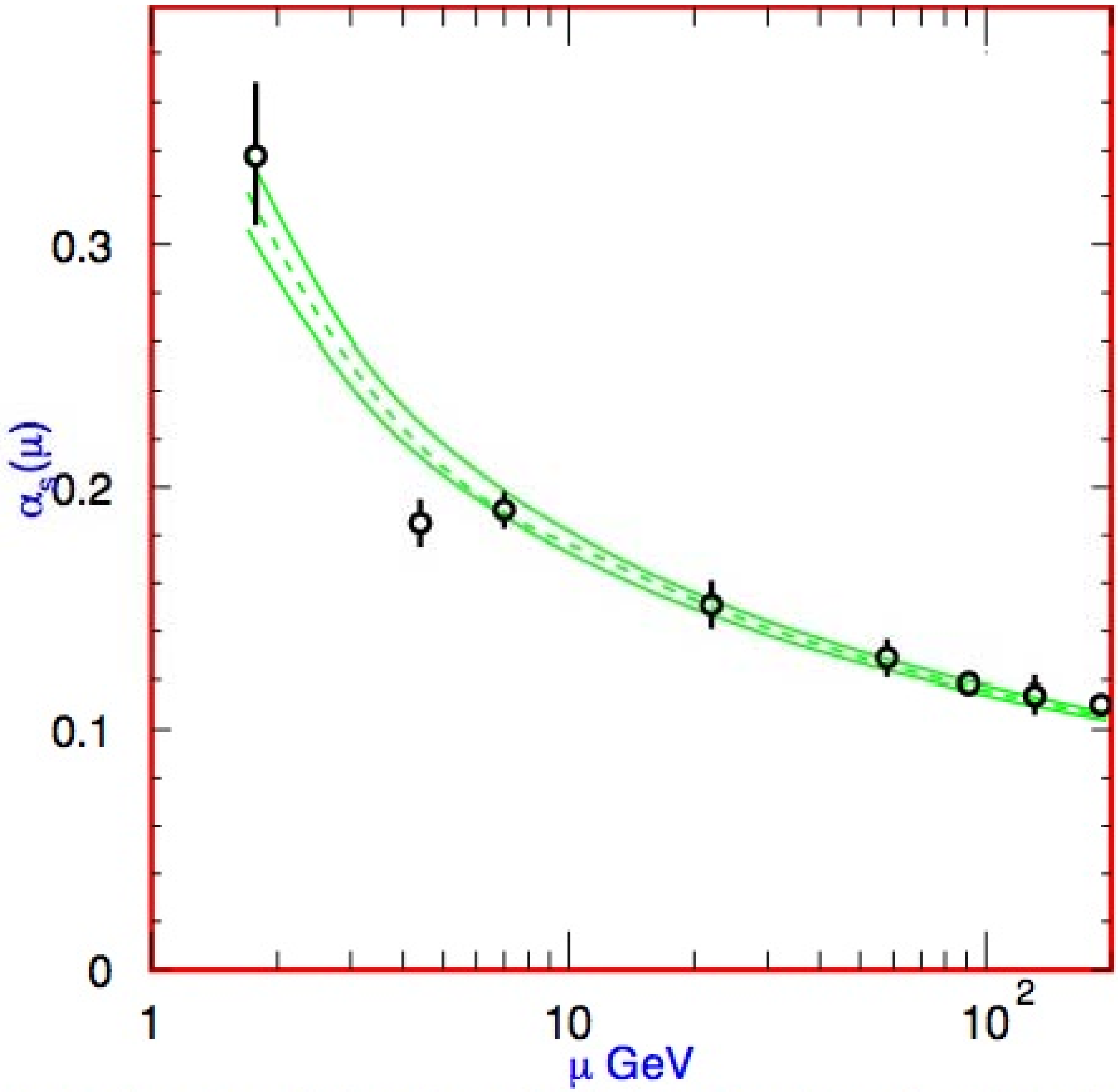


Figure 9.2: Summary of the values of $\alpha_s(\mu)$ at the values of μ where they are measured. The lines show the central values and the $\pm 1\sigma$ limits of our average. The figure clearly shows the decrease in $\alpha_s(\mu)$ with increasing μ. The data are, in increasing order of μ, τ width, Υ decays, deep inelastic scattering, e^+e^- event shapes at 22 GeV from the JADE data, shapes at TRISTAN at 58 GeV, Z width, and e^+e^- event shapes at 135 and 189 GeV.

- The search continues….
- Are we close to discovering physical reality?
- I am afraid NOT.
- A few somber thoughts….

Have we forgotten O'ckam's razor?

- In formulating hypotheses, keep the number of assumptions to the minimum. *Ruthlessly cut off gratuitous ingredients*.

- Physics knows no absolute truths

  » Pierre Duhem

Does nature design all its experiments to be amenale to Mathematical description - a human logic ??

Heisenberg ?

- *As every physicist knows, or is supposed to have been taught, physics does not deal with physical reality. Physics deals with mathematically describable patterns in our observations.*

Henry Stapp, Foundations of Physics,21(1991)1

Alfred North Whitehead (1933)

- *The intimate timidity of professionalized scholarship circumscribes reason by reducing its topics to triviality, for example, to bare sensa and to tautologies. It then frees itself from criticism by dogmatically handing over the remainder of experience to an animal faith or religious mysticism, incapable of rationalization.*

- *The transitions to new fruitfulness of understanding are achieved by recurrence to the utmost depths of intuition for the refreshment of imagination.*

I will end an optimistic note that the crisis of physics is serious enough that it will reinvent itself in not too long future.