From Rutherford scattering to QCD

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Guest lecture in Professor Yu's class

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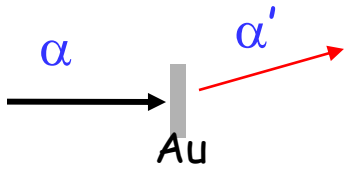
Please interrupt and ask questions.

It is much more fun that way

Intro

Rutherford scattering……. The start of it all

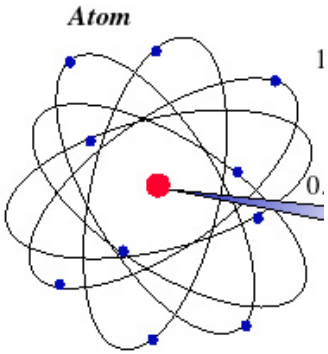


Observe anular distribution of scattered alpha'

Anular distribution of alpha' gives tells us structure of Au atom

Small inner core (nucleus) ---surrounded by "empty" space

Long time ago ….. Early 1900's ….



History

For long time scattering technique was not used…. (trying to remember)

Science/physics busy with atomic/nuclear phyiscs

Nuclear decays (alpha, beta, gamma)

Strong, Weak and EM interactions establish

β-decay: n-> p e ν

Establish weak interaction
Mystery of "missing energy" – still today
Explanation by Pauli: postulate neutrino

Occupied with nuclear processes
Shell model developed→ nuclear energy

Reactors
Bombs

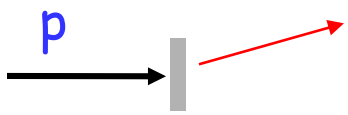
Some time after WWII….. Peace was back……

Start accelerating protons……Berkeley (cyclotron invented)

Serious proton accelerators at CERN, Argonne, Brookhaven

Scattering I

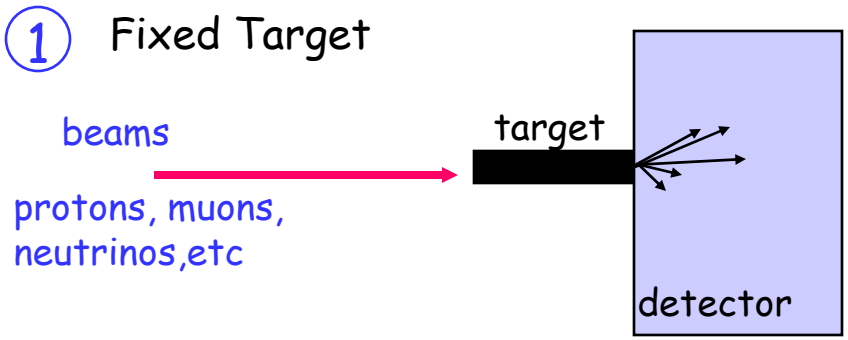
In 1950's (I was born) & 60's back to scattering, either nuclei or protons

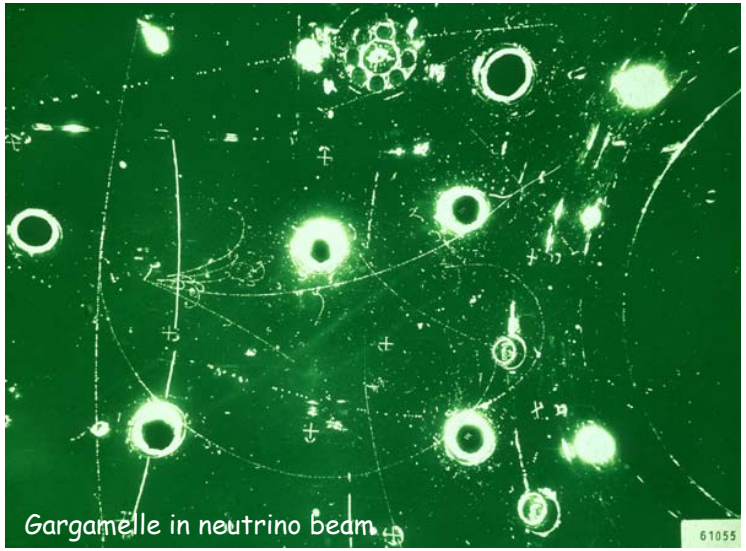


Did this in bubble chambers (see event)

Mainly: p+p/n → X + Y +....

Break up of nucleon---somethig inside



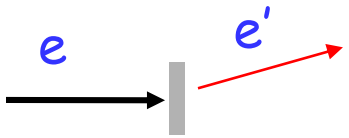


Spent a whole year trying to understand this.....

Scattering II

End of 1960's SLAC developed linear accelerator for electrons. Big deal

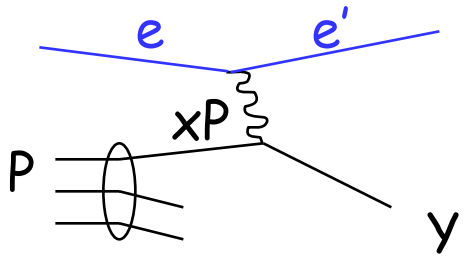
Redo Rutherford scattering from nuclei, use electrons (no internal structure)



Build the first large spectrometer….. Detect e' by moving detector on circular rail system

Define Lorentz invariant variables: Q and x.

Q is momentum transfer from e to nucleon (defines distance scale)
x is the fraction of nucleon momentum carried by scattering constituent



Know incoming "e" and measure outgoing "e'"

EM interaction, photon exchange, photon momentum is Q, Q>> wavelength small, probe small distances

Scattering II

If proton consistents of hard constituents, lets say three quarks, with no internal structure and "free" ➔ distribution of x should a delta function st x=1/3.

Not that simple….

Observed:

Also observe that distribution only varies slightly with incoming energy and Q.

"Scaling "

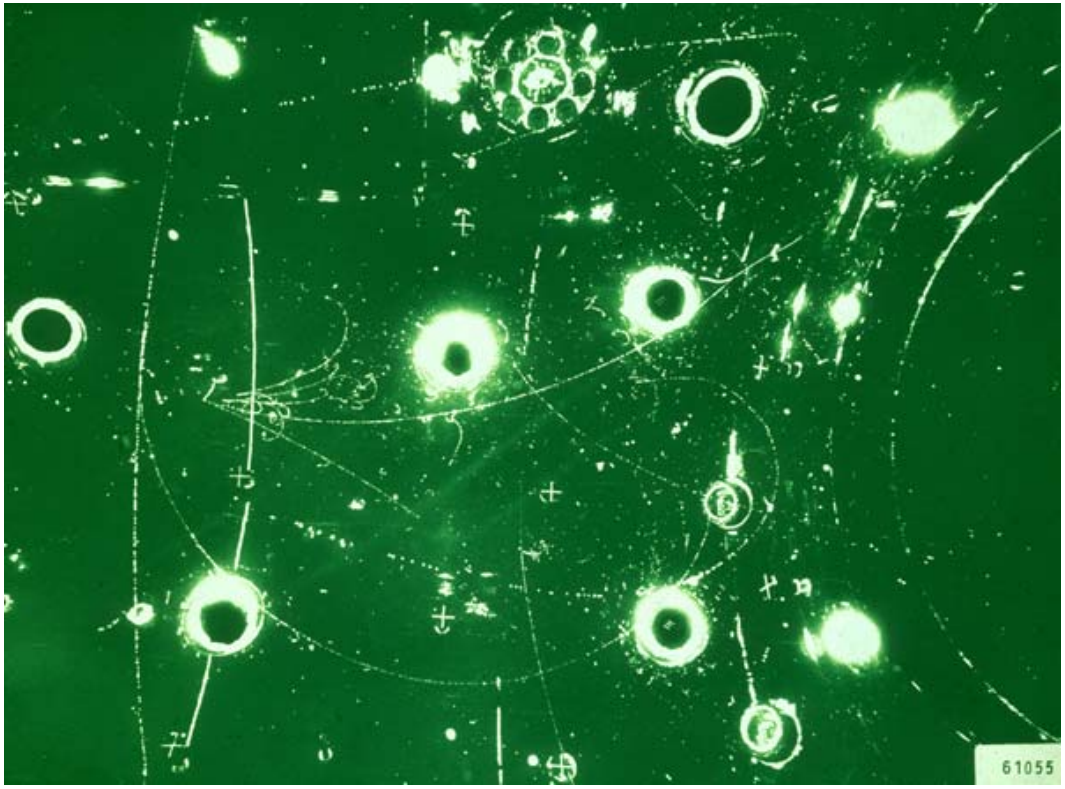
If above "picture" is correct, then expect scaling….i.e. dN/dx should not change if constituents are "free".

Other experiments followed (but not as precise), with neutrino and muon beams

Muon similar to electrons, but higher energy.
Neutrinos….. more complicated: $\nu_\mu + p \rightarrow \mu + Y$

Scattering IV

Neutrino nucleon scattering



Many lepton nucleon scattering experiments

Called: deep inelastic experiments or DIS.

Understand how proton is build and held together. So use Em and weak interaction to probe strong interaction (holds proton together)….

"Scaling" was never observed, but well defined scaling violations were measured and they were consistent in different eperiments

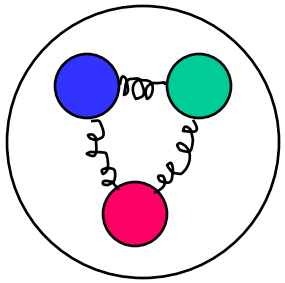
QCD

On theory side Quantum Chromo Dynamics had been suggested as the theory describing dynamics of strong interaction between quarks.

Proton consists of quarks (nominally 3), held together by gluons. Quarks carry color and gluons couple to color. Gluons also carry color combinations and couple to each other.

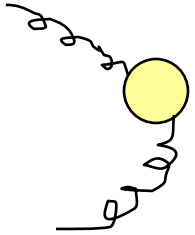
Colors: red, blue and green

(they are not really green…..)



Looking at color from far away: well defined

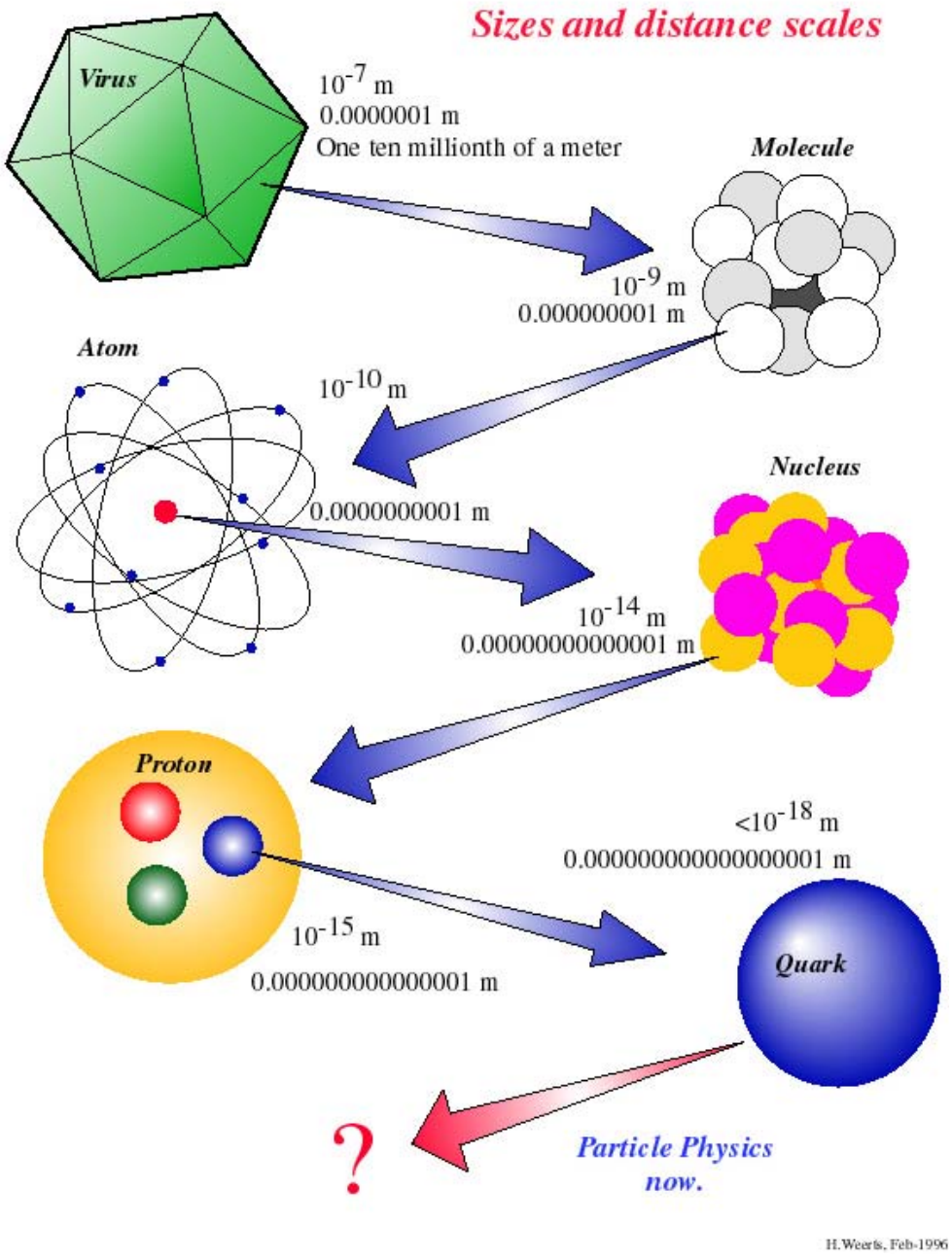
Looking at color close by: not well defined



See cloud of gluons→ color changes

"asymptotic freedom"

Science and particle physics



Biology ++

Chemistry ++

Atomic physics

Nuclear Physics

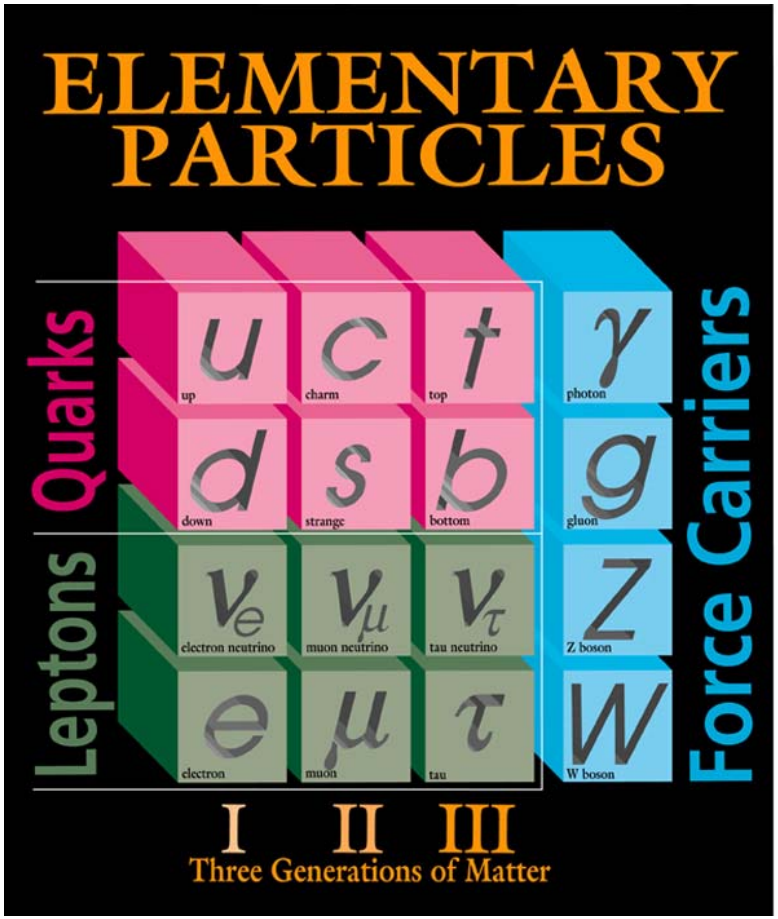
Particle Physics

"Missing" on list Universe

Astrophysics

Come back later to this

View of world from particle physics



Ordinary matter (we):

Made of u,d and e
Held together by γ and g

All other particles predicted
by theory
"Standard Model"
and observed experimentally

Constituents and Forces

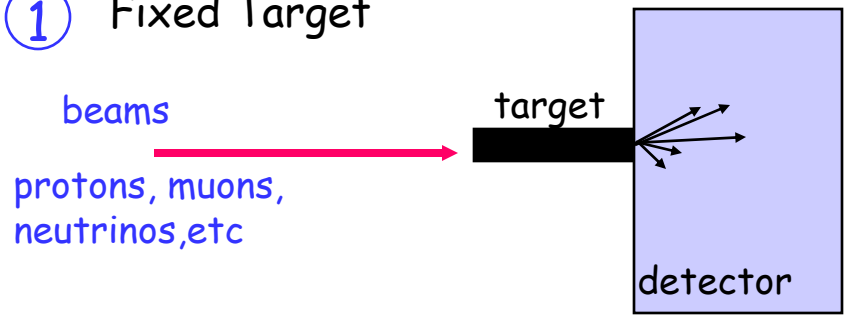
Learned from theory & experiments.

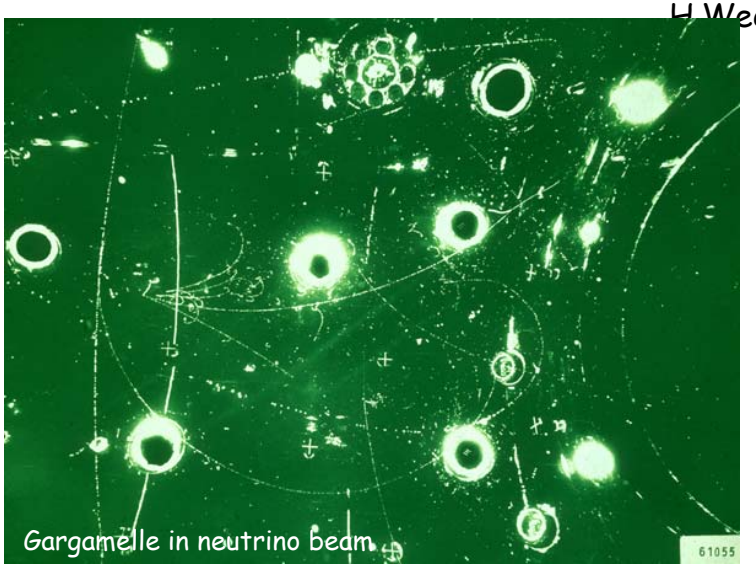
Experimental efforts nearly all done at particle accelerators

Labs around world build around them

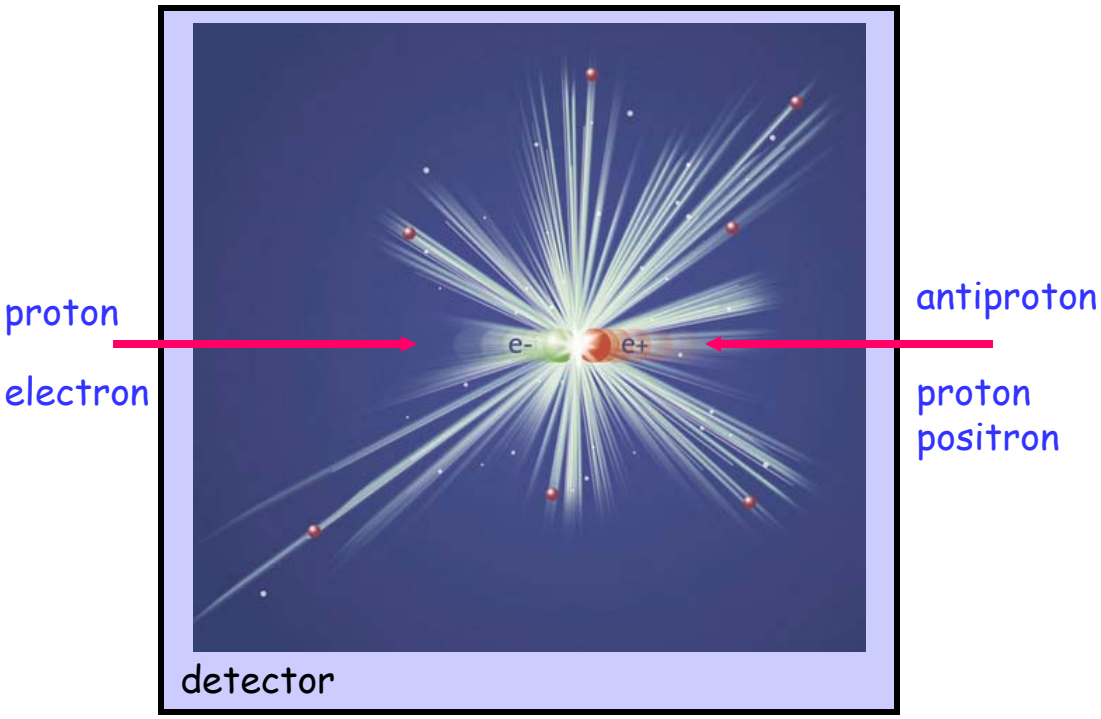
How did we learn this…

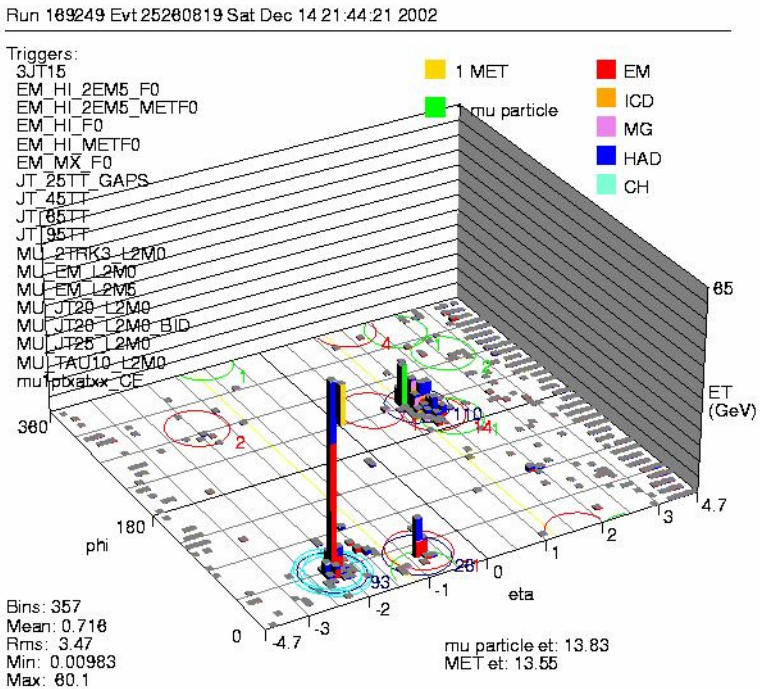
① Fixed Target





② Colliding beams





Dzero event at Tevatron

Increasing energy probes smaller and smaller distances