FROM ELECTRONS TO QUARKS

What is the world really made of?

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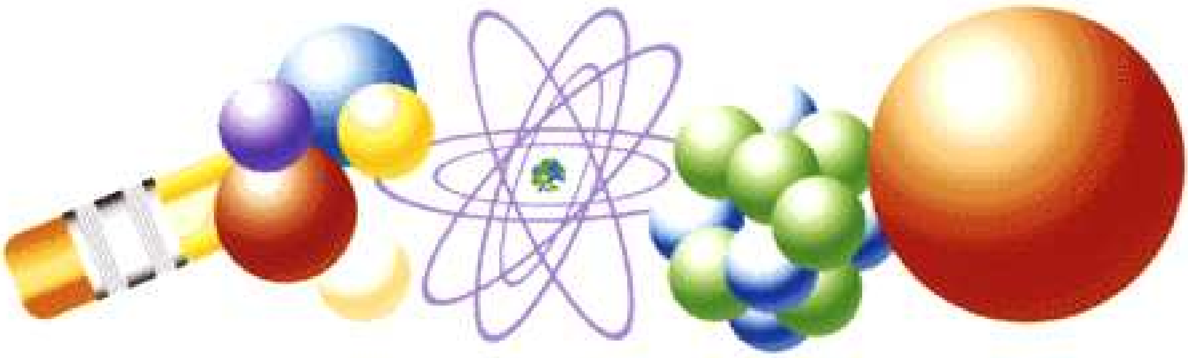
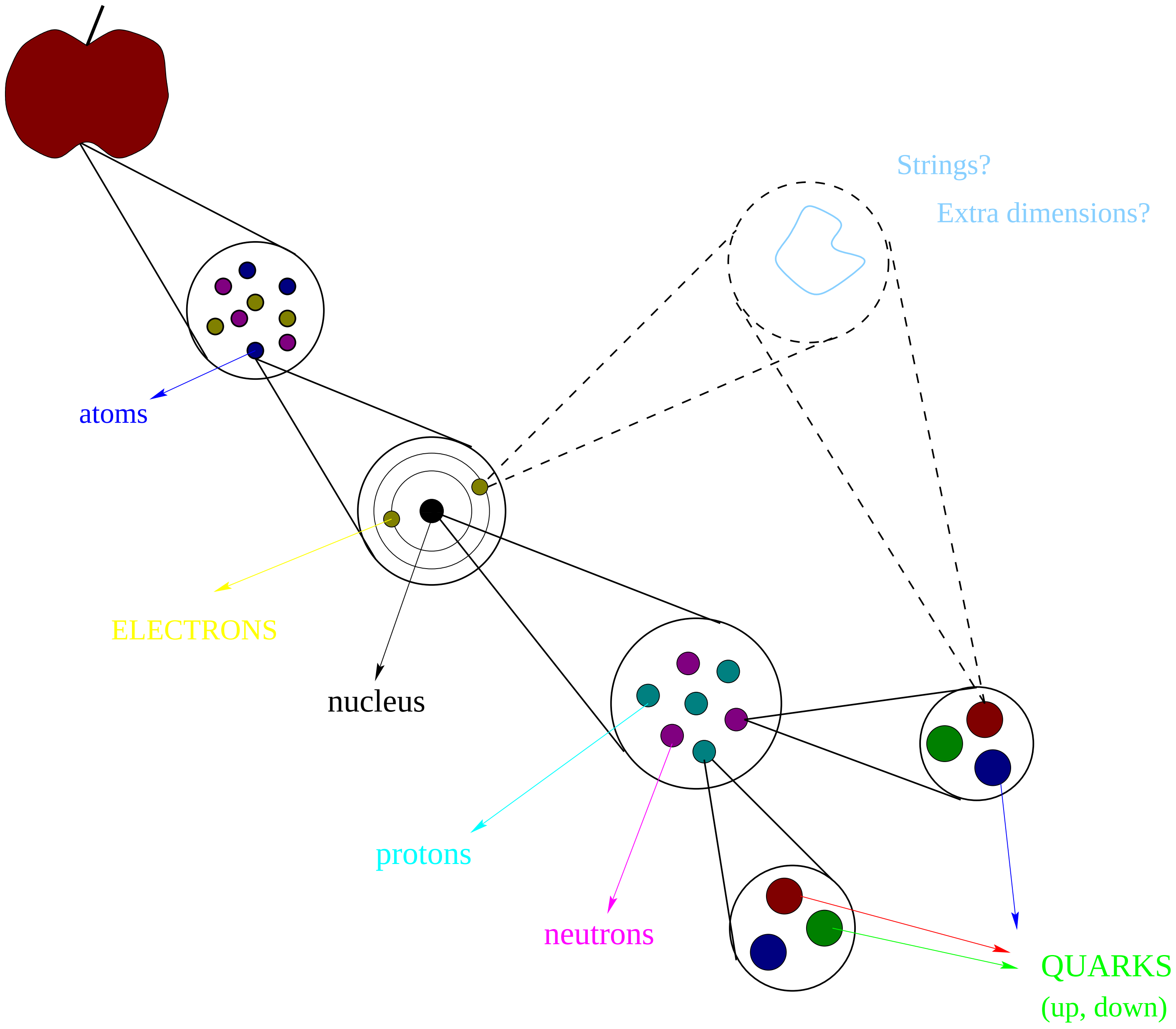




Strings?
Extra dimensions?
atoms
ELECTRONS
nucleus
protons
neutrons
QUARKS
(up, down)

1940's $\rightarrow$ 1950's

A plethora of particles is discovered

(mainly in cosmic rays)

e^-, p, n, ν_e, μ^-, $(\pi^\pm, \pi^0)$, e^+

plus

$(K^\pm$, K^0, $\bar{K}^0)$, Λ^0, $\bar{p}$, (Σ^+, Σ^0), Ξ, ...

NATURE CANNOT BE SO MESSY!

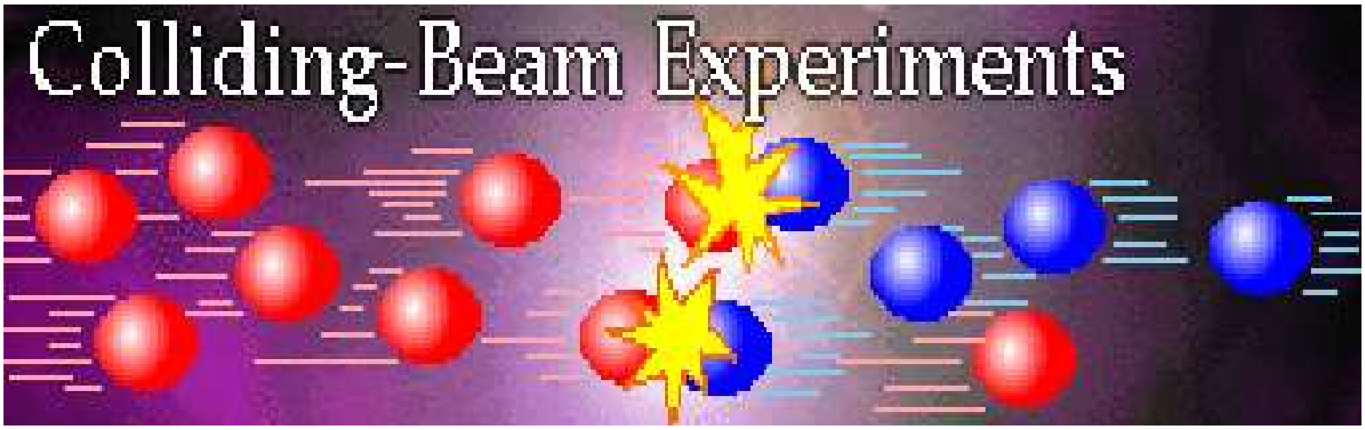
$\Downarrow$

- Are all these particle intrinsically different?

OR

- Can we recognize patterns in their nature (charge,mass) and the way they behave (decays)?

1950's → .....
A new era for particle physics



We can convert energy into particles

$$E^2 = p^2c^2 + m^2c^4$$

and reproduce the primordial stages of our universe (almost...)

$\Downarrow$

Collider Physics

$$e^+e^- \;,\; p\bar{p} \;,\; \ldots.$$

With High Energies we can:

→ make objects of large mass
→ resolve structure at small distances

First Great Discoveries....

• $e^{\pm}, \mu^{\pm}, \tau^{\pm}$ and their neutrinos (we call them *Leptons*) are fundamental particles and interact electromagnetically and "*weakly*"

while

• p, n, $(\pi^{\pm}, \pi^{0})$, $(K^{\pm}, K^{0}, \bar{K}^{0})$, Λ^{0}, (Σ^{+}, Σ^{0}), Ξ, ... (we call them *Hadrons*) are not fundamental particles!

$\Downarrow$

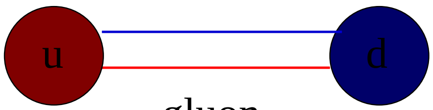
They are made of QUARKS!
named up, down, and strange

and they interact electromagnetically, "*weakly*", and "*strongly*".

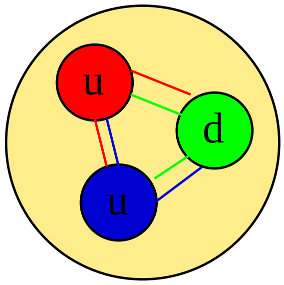
Quarks carry a COLOR charge

un UP quark can be $\begin{cases} up & (green) \\ up & (red) \\ up & (blue) \end{cases}$

and interact exchanging GLUONS, the carriers of the STRONG FORCE



gluon



proton

Barions	Mesons
(qqq)	$(\bar{q}q)$
$p \rightarrow uud$	$\pi^{\pm} \rightarrow u\bar{d}(\bar{u}d)$
$n \rightarrow ddu$	$\pi^{0} \rightarrow u\bar{u} + d\bar{d}$
$\Sigma^{+} \rightarrow uus$	$K^{\pm} \rightarrow u\bar{s}(\bar{u}s)$
$\Sigma^{0}, \Lambda^{0} \rightarrow uds$	$K^{0}(\bar{K}^{0}) \rightarrow \bar{s}d(s\bar{d})$
$\Xi^{0} \rightarrow uss$	$\rho \rightarrow u\bar{d}$
$\ldots$	$\ldots$

More Quarks coming along .....

1974 $\rightarrow$ Discovery of the charm quark ($\psi = c\bar{c}$, D mesons) (BNL, SLAC)

1977 $\rightarrow$ Discovery of the bottom quark ($Y = b\bar{b}$, B mesons) (FERMILAB, DESY)

1995 $\rightarrow$ Discovery of the top quark (no bound state) (FERMILAB)

And more Forces .....

1983 $\rightarrow$ Discovery of the $W^{\pm}$ and Z bosons, carriers of the WEAK FORCE (CERN)

Open Problems .....

- What is the origin of mass??

$$\Downarrow$$

the Higgs boson

a very elusive particle.....

- Do forces unify??

- Are there more fundamental objects than just leptons and quarks??

- Are there extra dimensions?? i.e. are four dimensions enough??

Why all these particles and forces??

Who ordered it? (Rabi)

- Most of the particle the world is made of are : electrons, protons, and neutrons (e^+, u, and d quarks).

- This is because our world lives at very low energy.

- All other particles were created at the high energies of the very early stages of our universe and we can nowadays recreate some of them in our laboratories, even if for very short time

$\rightarrow$ Tevatron ($p\bar{p}$), Fermilab (Chicago) (2001)
$\rightarrow$ B-factories (SLAC, KEK) (e^+e^-)(1999)
$\rightarrow$ LHC (pp), CERN (Geneva, CH) ($\sim$ 2006)
$\rightarrow$ NLC/Tesla (e^+e^-) ($\sim$ 2020?)

We may have to look back at the universe to know more and try to unify the very large with the very small!