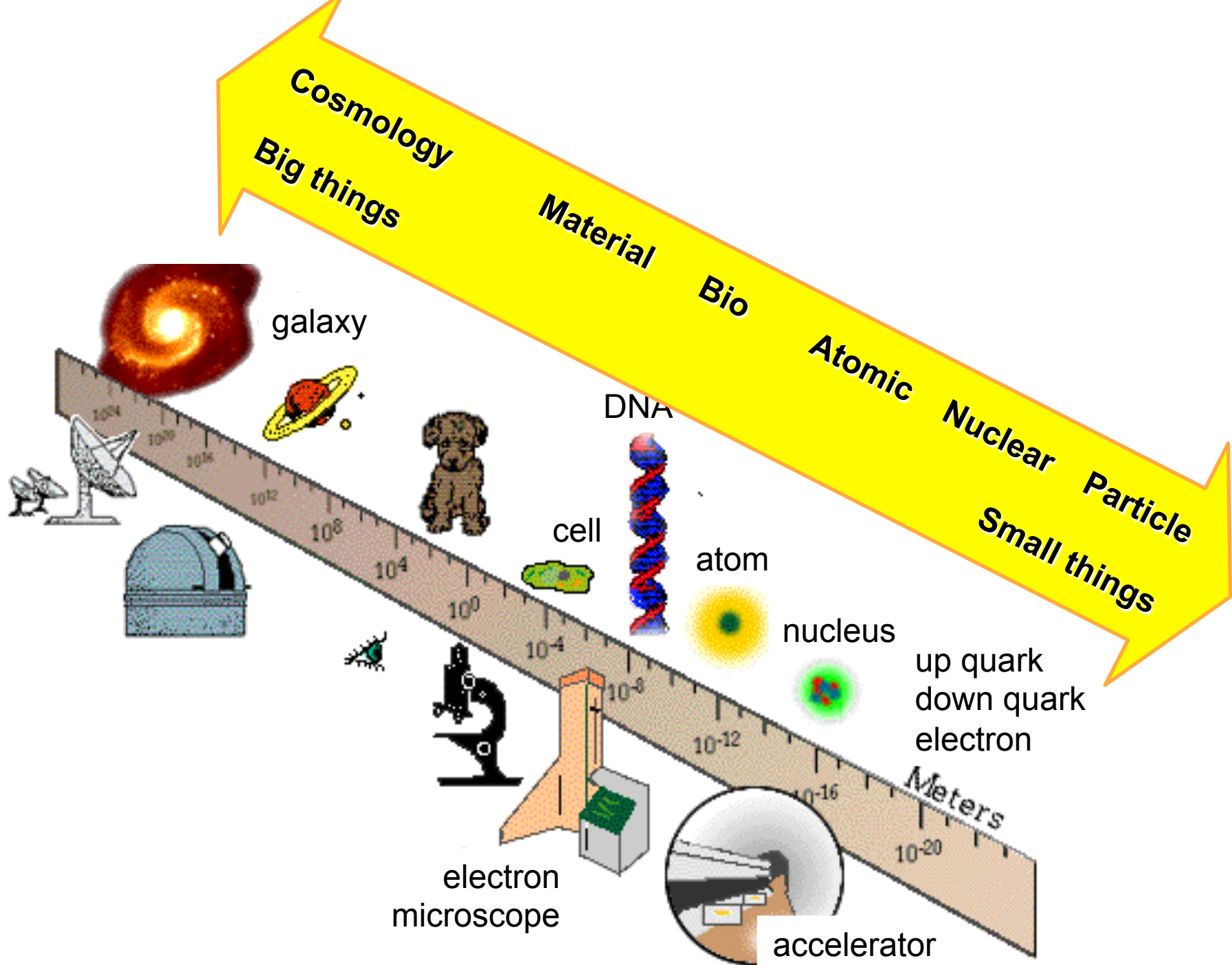


Higgs

What's it all about?

August 25, 2015

*Young-Kee Kim
Department of Physics and Enrico Fermi Institute
The University of Chicago*



Cosmology

Big things

Material

Bio

Atomic

Nuclear

Particle

Small things

galaxy

DNA

cell

atom

nucleus

up quark

down quark

electron

electron microscope

accelerator

Meters



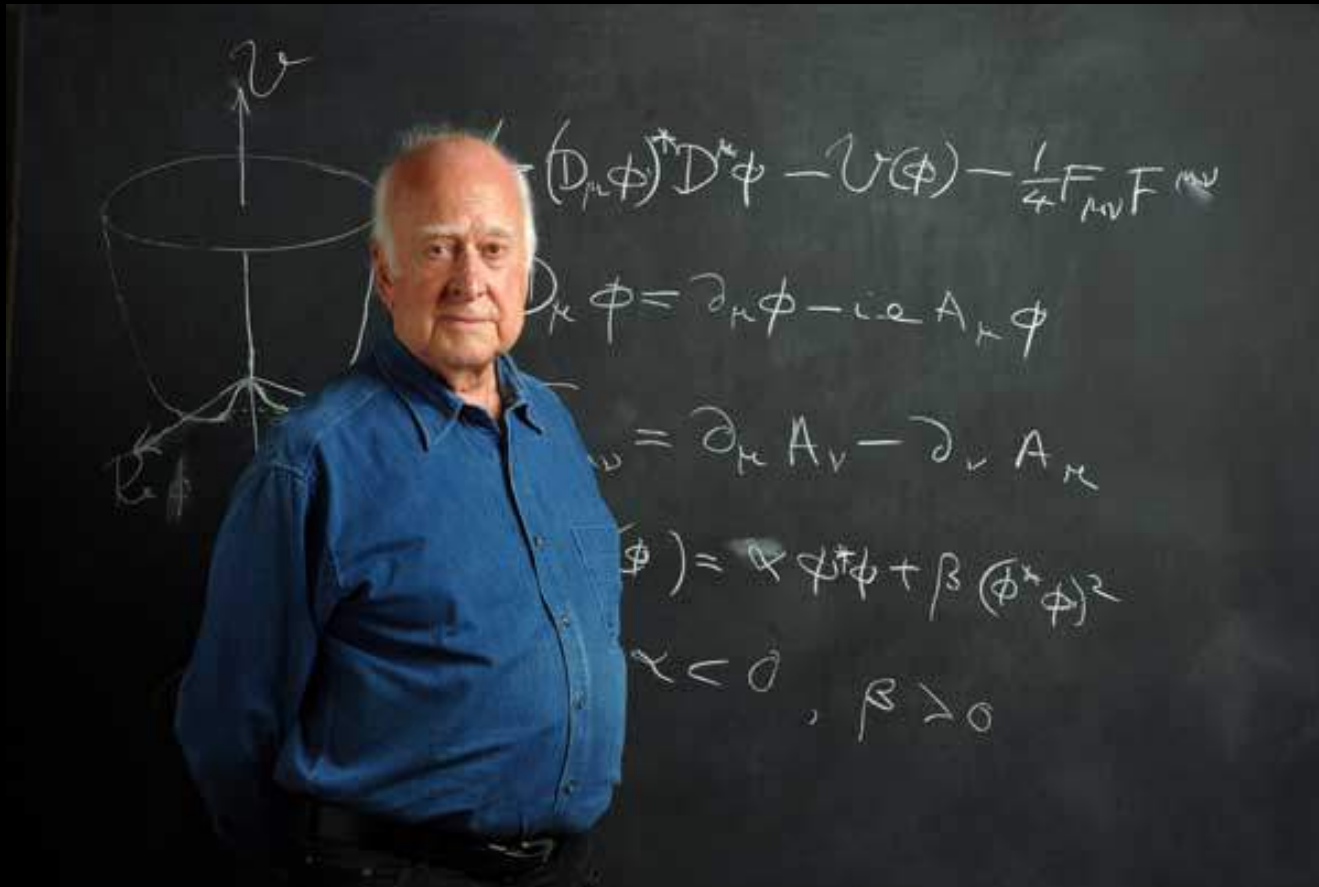
The July 4th 2012 announcement (experiments at LHC, Large Hadron Collider) caused global sensation !!

Press coverage after July 4th seminars at CERN

Time magazine called the Higgs particle
“Particle of the Year”.

<http://poy.time.com/2012/12/19/the-higgs-boson-particle-of-the-year/>

Peter Higgs



BEGHHK Particle



Robert Brout
Universite Libre de Bruxelles
Belgium



Carl R. Hagen
University of Rochester
U.S.A.



Francois Englert
Universite Libre de Bruxelles
Belgium



Peter W. Higgs
University of Edingurgh
U.K.



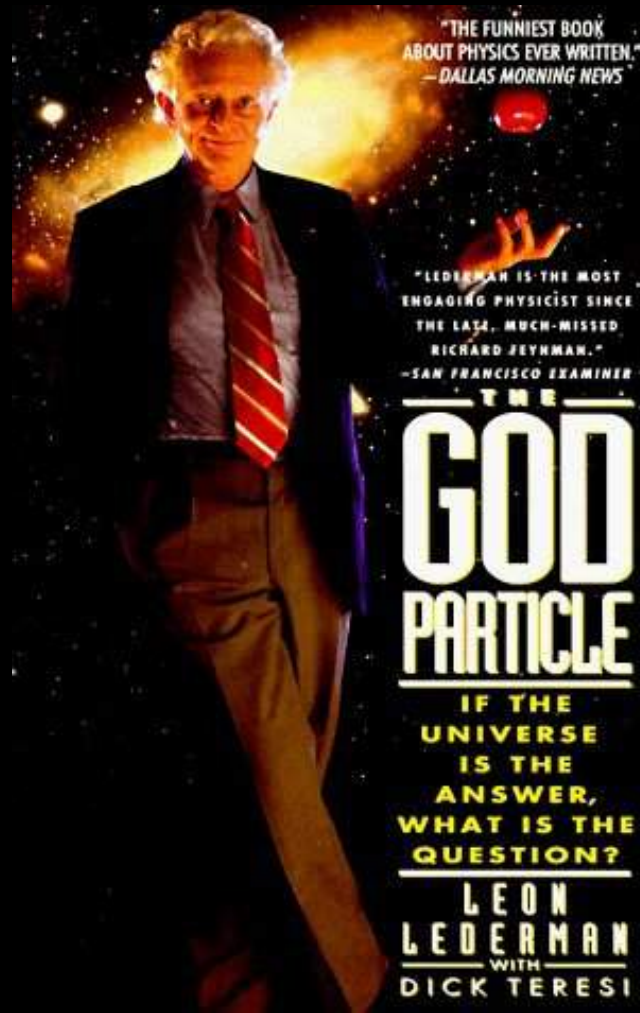
Gerald S. Guralnik
Brown University
U.S.A.



T.W.B. Kibble
Imperial College
U.K.

2013
Nobel Prize
in Physics

The Higgs particle has been given another misnomer.



"THE FUNNIEST BOOK
ABOUT PHYSICS EVER WRITTEN."
—DALLAS MORNING NEWS

"LEDERMAN IS THE MOST
ENGAGING PHYSICIST SINCE
THE LATE, MUCH-MISSED
RICHARD FEYNMAN."
—SAN FRANCISCO EXAMINER

THE
**GOD
PARTICLE**

IF THE
UNIVERSE
IS THE
ANSWER,
WHAT IS THE
QUESTION?

LEON
LEDERMAN
WITH
DICK TERESI



dreamstime.com



Why has the Higgs boson caused such a stir around the world?



Press coverage after July 4th seminars at CERN

Particle Physics:

What is the universe made of ?
What holds it together ?
Where did we come from ?



Accelerators are **Ultimate Microscopes**.

What is the world made of?



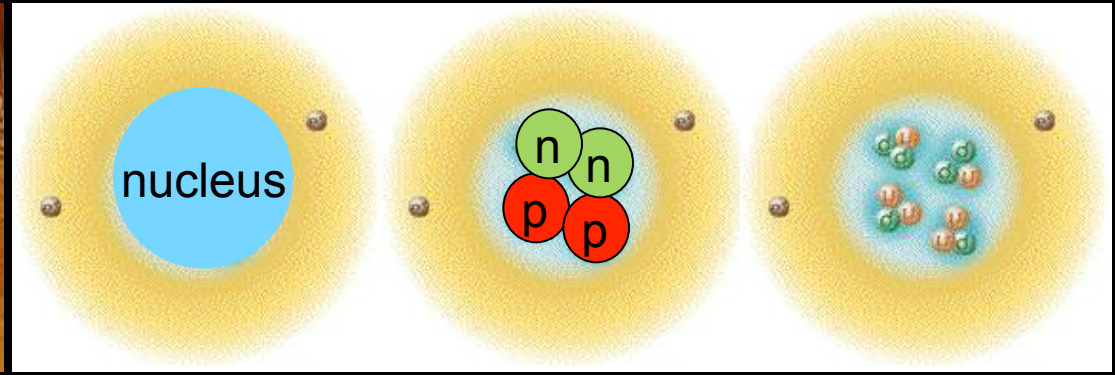
up, down quarks, electrons



Gravitational force



Electromagnetic force



Weak and Strong forces

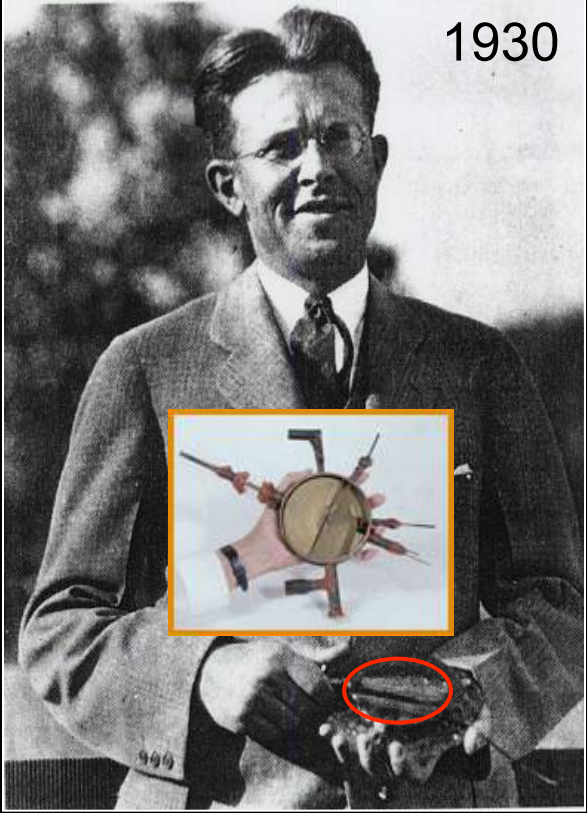


What holds it together?



1930

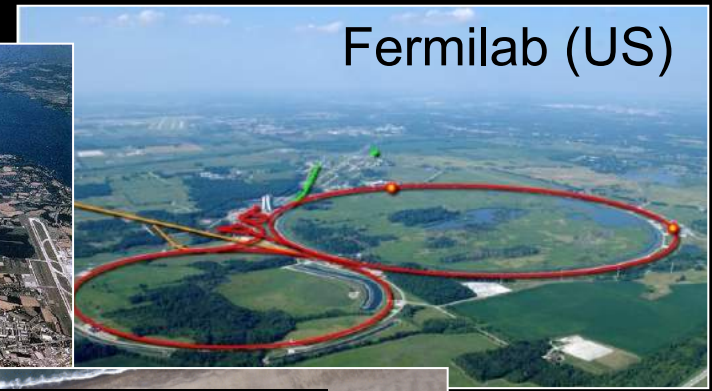
Today's accelerators for particle physics



Ernest Lawrence
(1901-1958)



CERN (Europe)



Fermilab (US)



KEK/J-PARC (Japan)

Today, ~30,000 accelerators are in operation around world

- Discovery science



- Manufacturing and material science



- National security



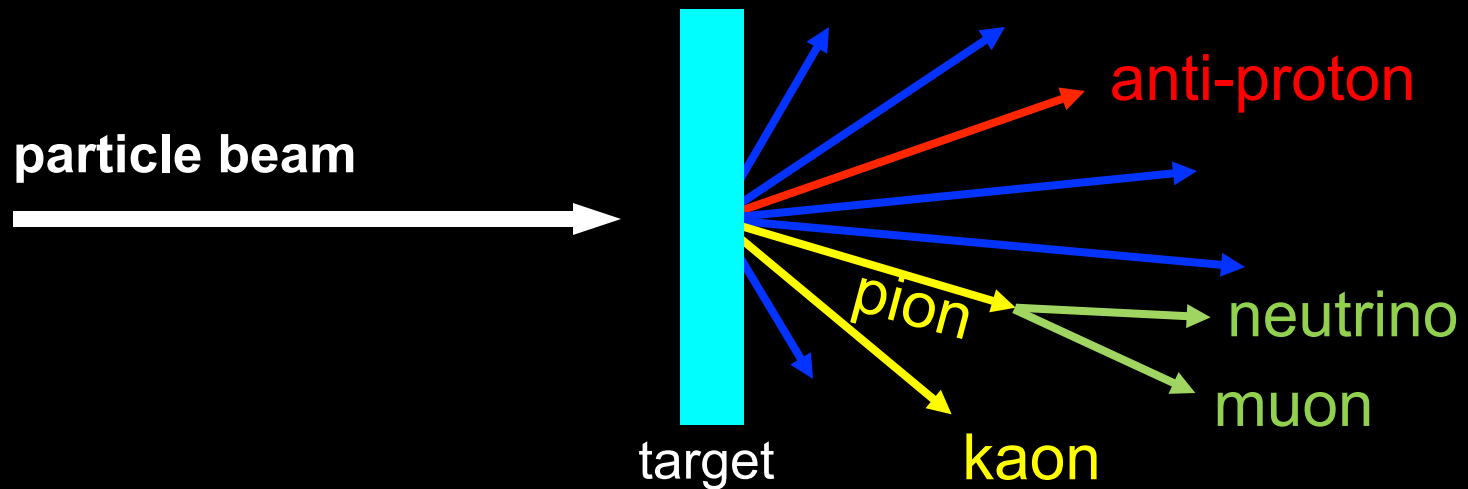
- Energy and the environment

- Medical diagnostics / treatments



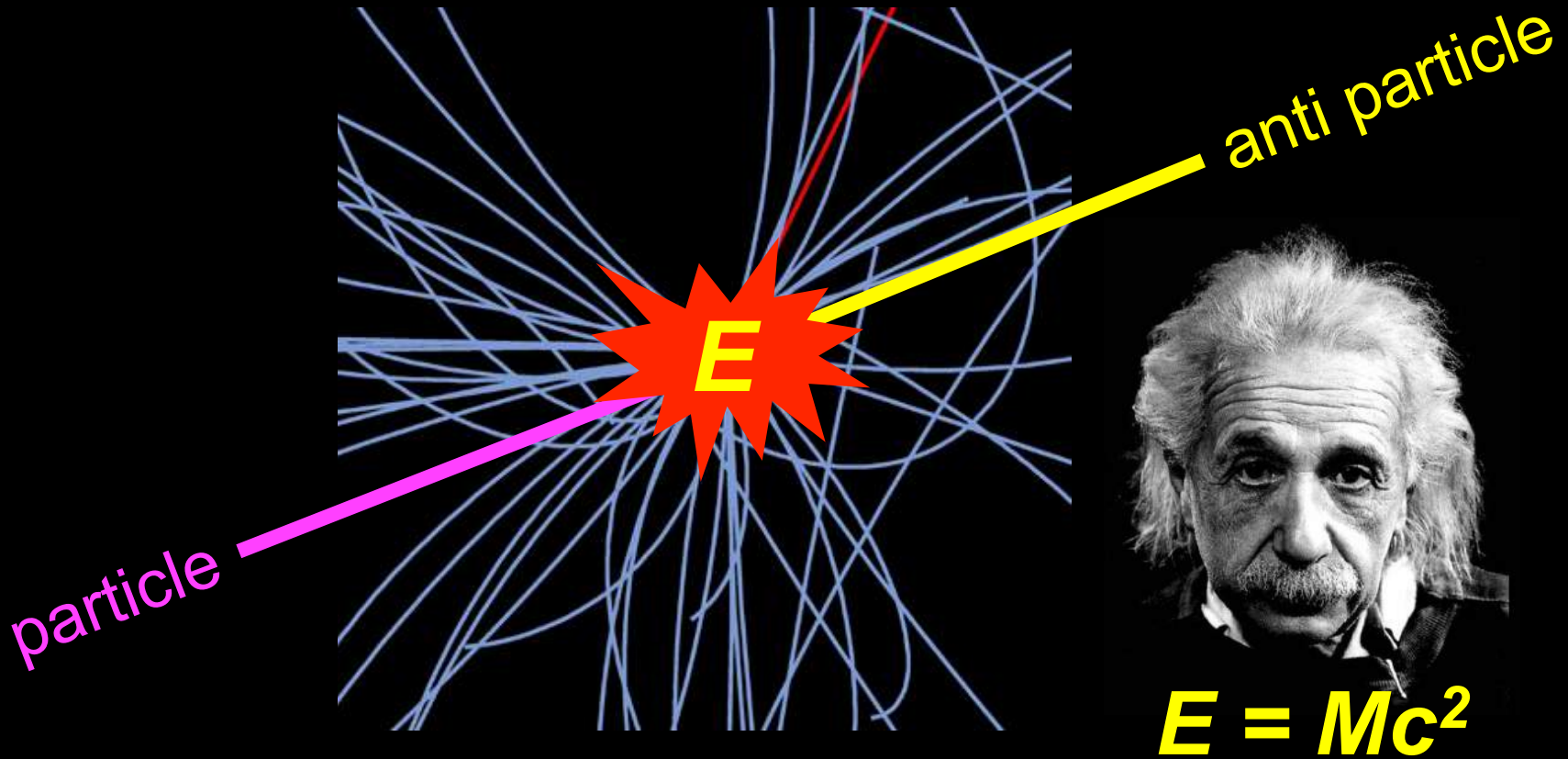
Accelerators are like **Time Machines**.

They make particles last seen
in the earliest moments of the universe.

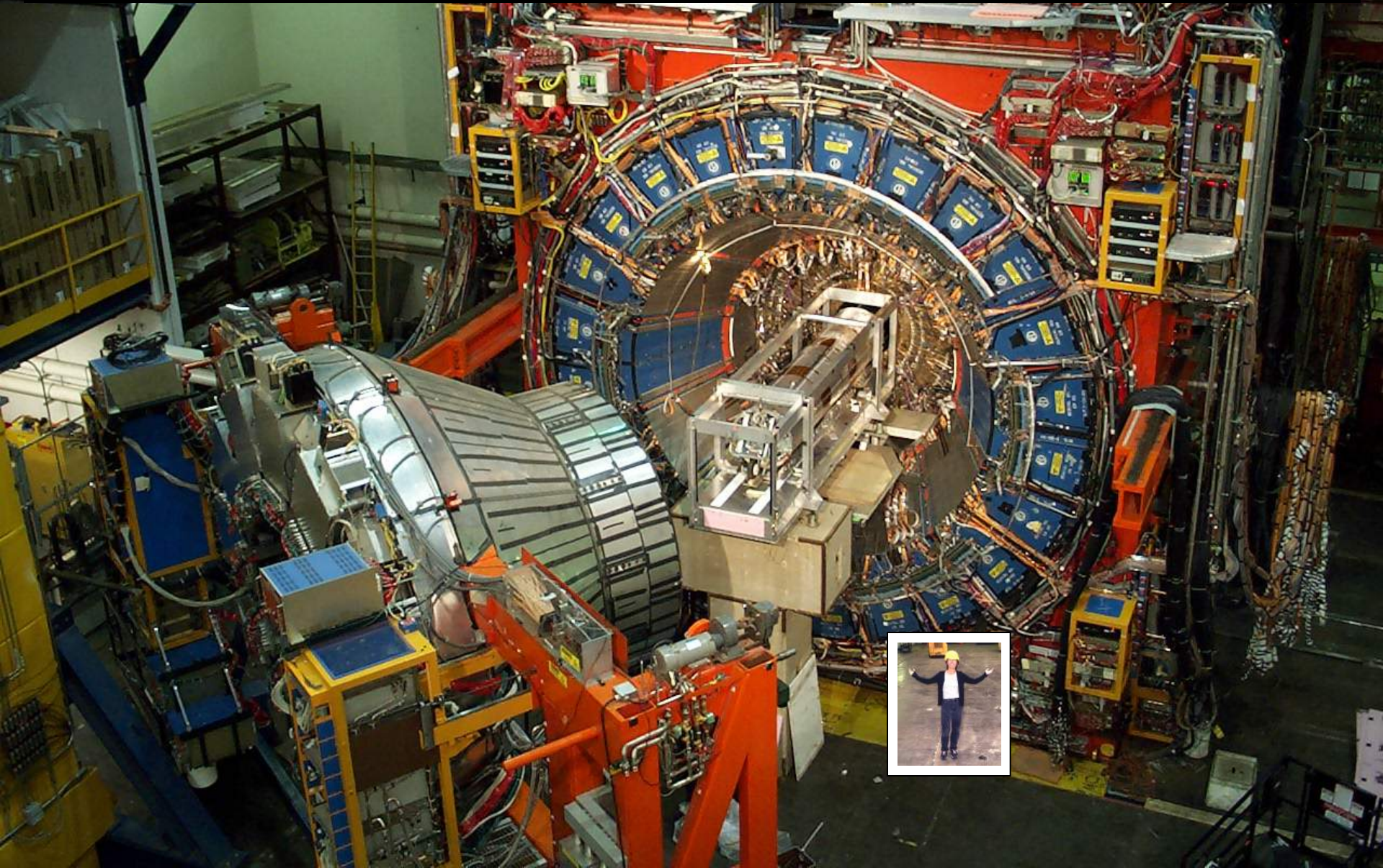


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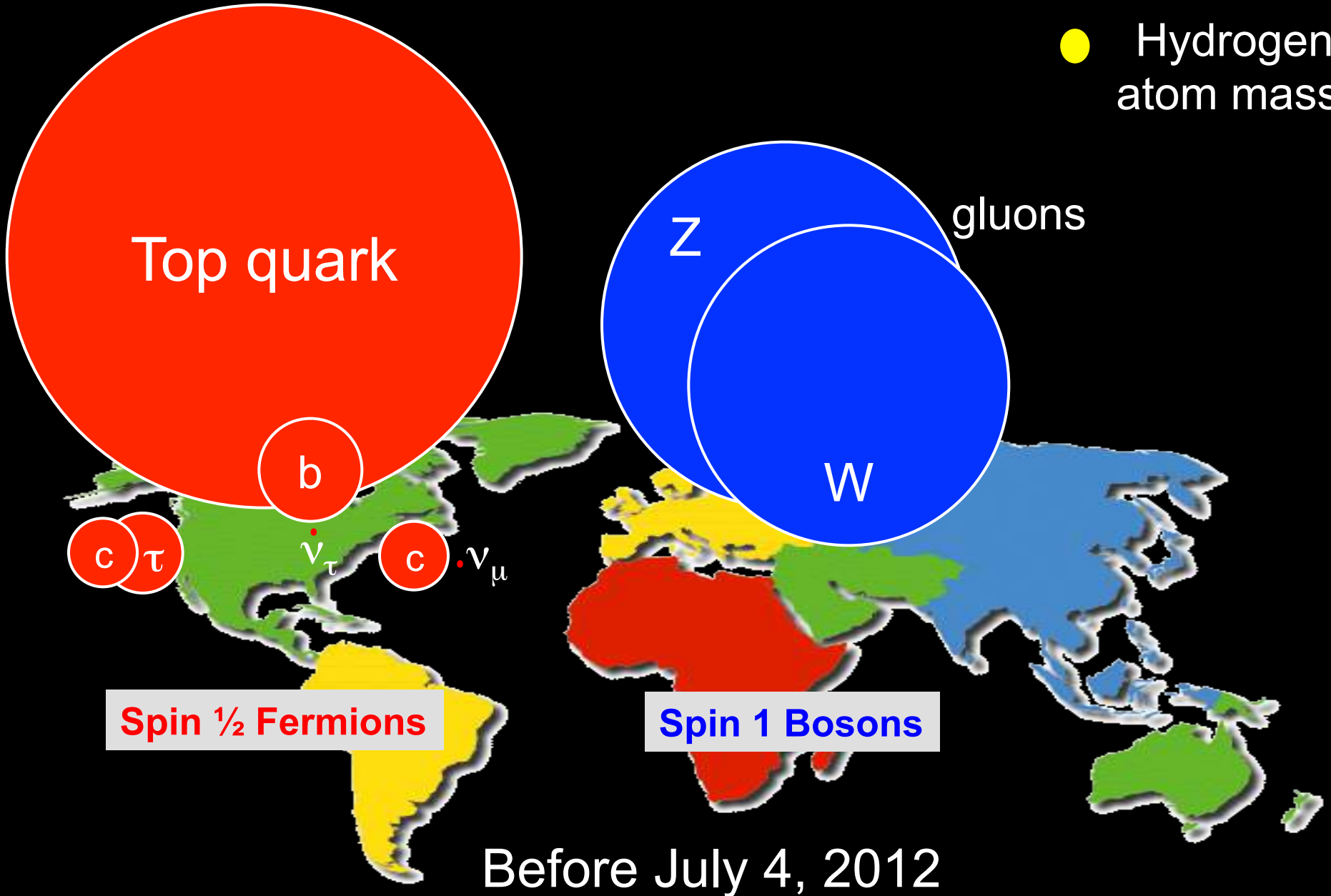


Experiments at the Tevatron accelerator (1985 – 2011) Fermilab in Chicago



Discovering elementary particles

● Hydrogen atom mass



Accomplishment of the 19th Century

Periodic Table of Elements

■ Alkali Metals E Gaseous State
■ Alkaline Earth Metals E Liquid State
■ Transition Metals E Solid State
■ Other Metals E Synthetically Prepared
■ Nonmetals
■ Noble Gases
■ Inner Transition Metals

1 H 1.0079																	2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.179
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.06	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.941	24 Cr 51.996	25 Mn 54.938	26 Fe 55.847	27 Co 58.933	28 Ni 58.71	29 Cu 63.546	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 106.4	46 Pd 107.87	47 Ag 112.41	48 Cd 112.41	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.30
55 Cs 132.91	56 Ba 137.33	57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04		
87 Fr (223)	88 Ra (226)	89 Ac (227)	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (254)	100 Fm (257)	101 Md (258)	102 No (259)		

*Name Not Officially Assigned
 Lanthanide Series: La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb
 Actinide Series: Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No

Accomplishment of the 20th Century

Table of Elementary Particles

Standard Model

Quarks

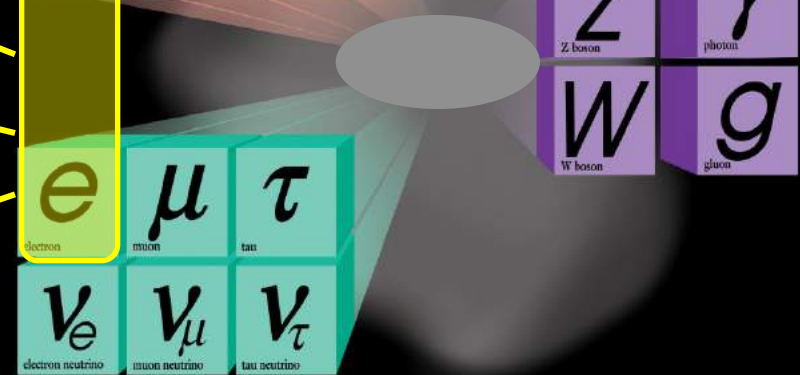
<i>u</i> up	<i>c</i> charm	<i>t</i> top
<i>d</i> down	<i>s</i> strange	<i>b</i> bottom

Forces

<i>Z</i> Z boson	γ photon
<i>W</i> W boson	<i>g</i> gluon

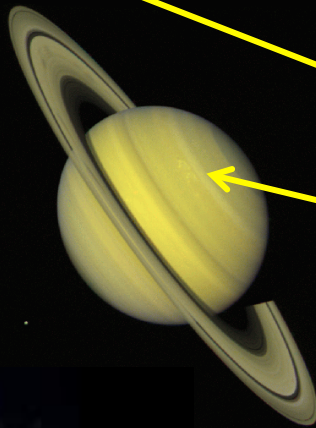
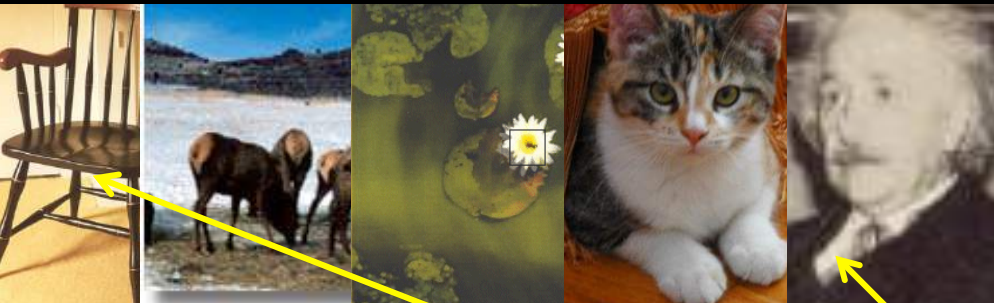
<i>e</i> electron	μ muon	τ tau
ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino

Leptons



Accomplishment of the 20th Century

Table of Elementary Particles Standard Model



Quarks

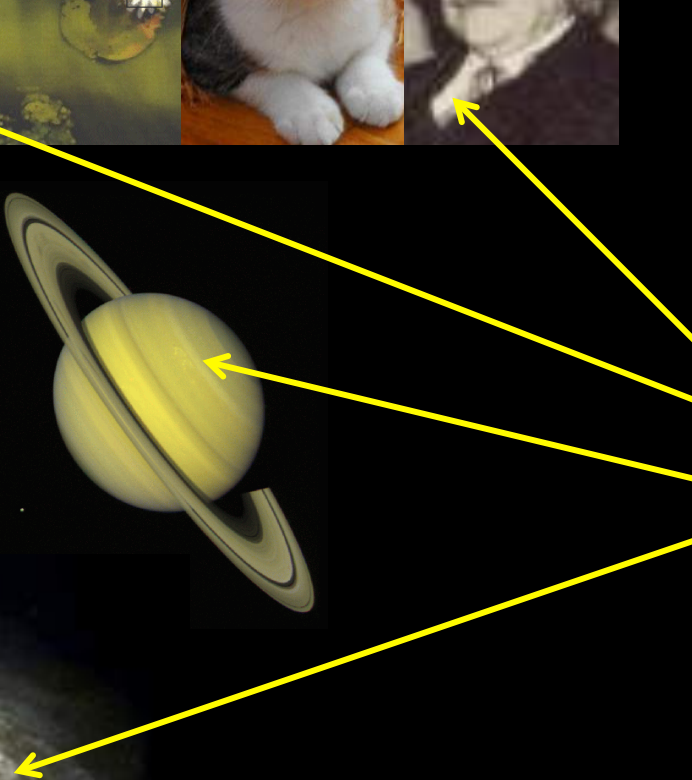
u up	c charm	t top
d down	s strange	b bottom

Forces

Z Z boson	γ photon
W W boson	g gluon

e electron	μ muon	τ tau
ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino

Leptons

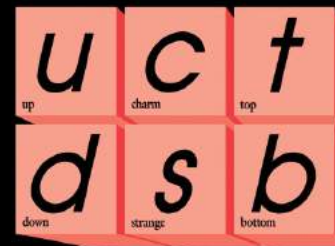


The triumphs.....

- The present theory is a remarkable intellectual construction
- Particle experimental results beautifully fit in this framework

Standard Model

Quarks



Forces



Higgs

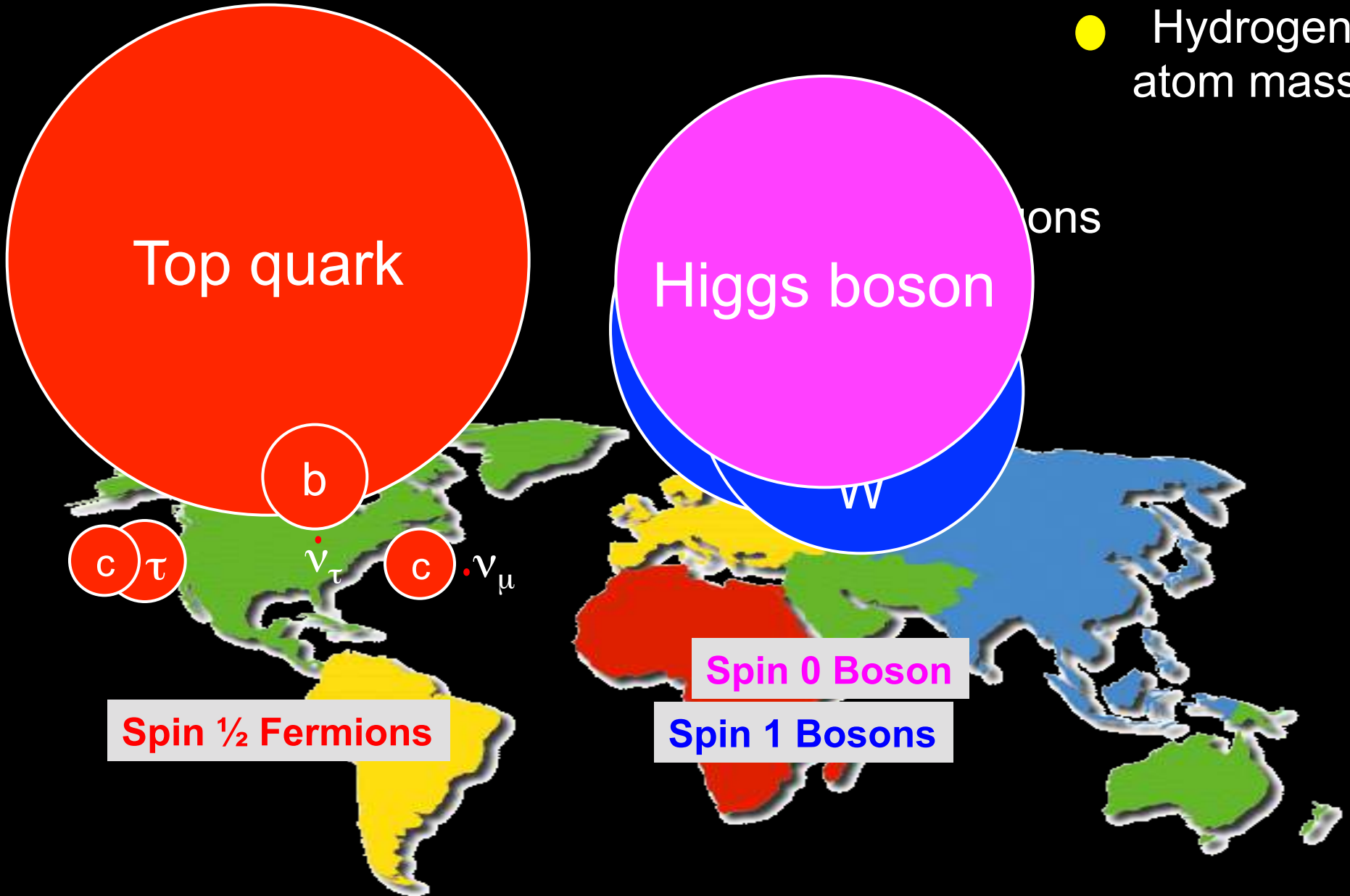


Leptons

What is the origin of mass for elementary particles?

Discovering elementary particles

● Hydrogen atom mass



Origin of Mass:

There might be something (new particle?!) in the universe that gives mass to particles

Nothing in the universe

Something in the universe

Higgs Particles:

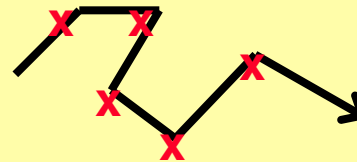
Electron



mass



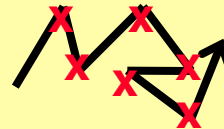
Z,W Boson



W



Top Quark



Top



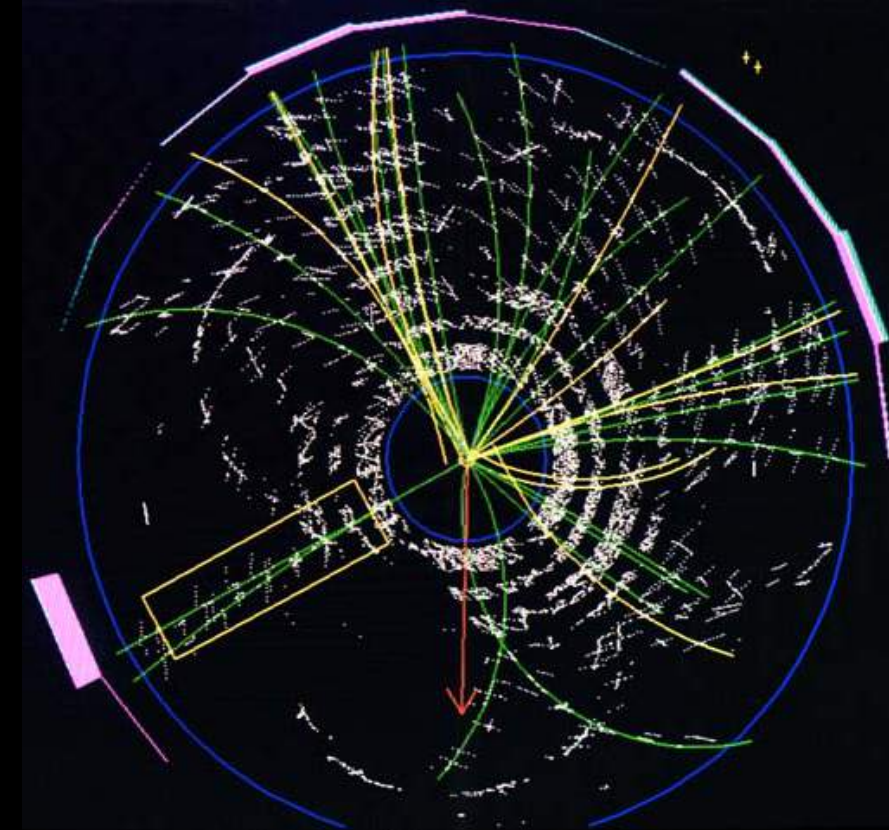
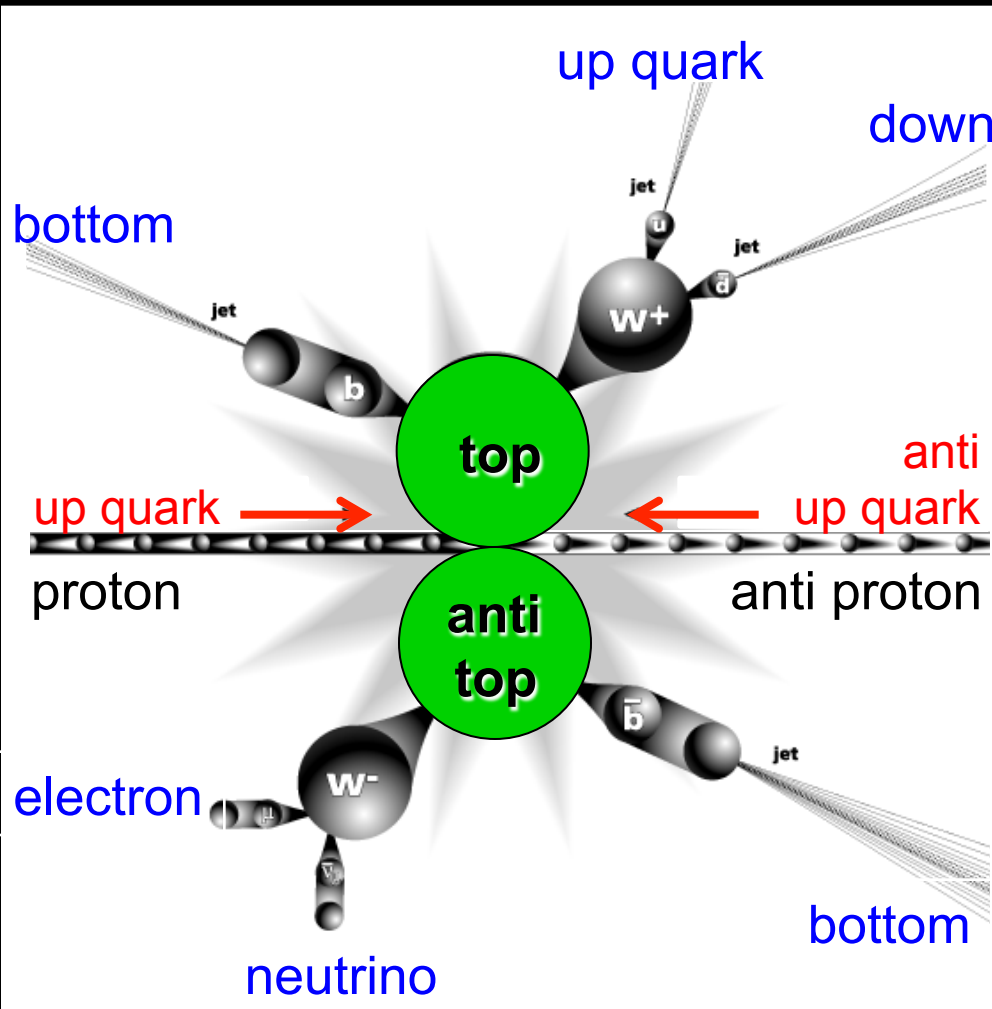
Mass

∞

coupling strength to Higgs

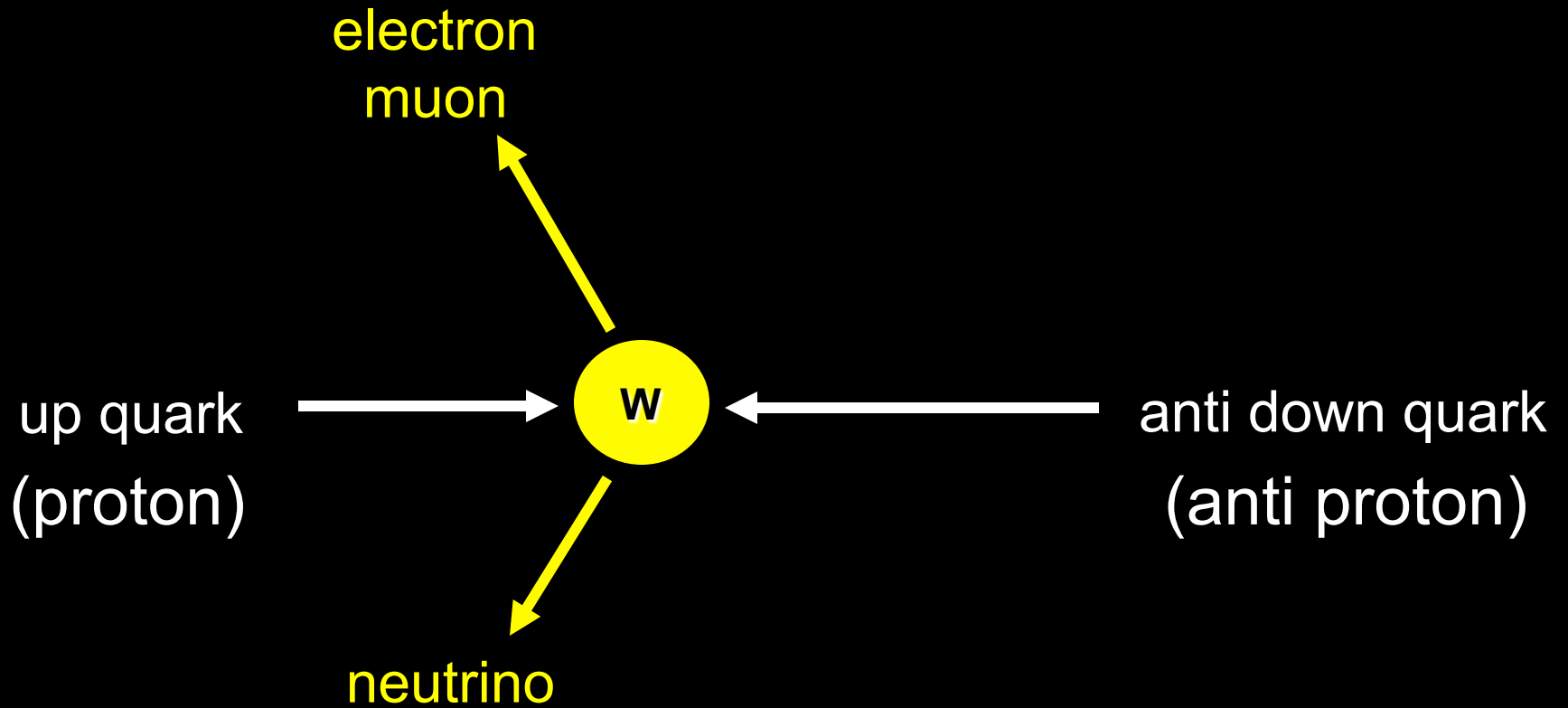
Top quark and W boson
carry information
about mass of Higgs boson

Top Quark Mass (Tevatron)



about 0.5 % Accuracy

W Boson Mass (Tevatron)



0.02 % Accuracy

Top quark and W boson
carry information
about mass of Higgs boson

114 x proton mass < Higgs mass < 150 x proton mass
(top quark mass = 175 x proton mass)

Expect:

W
80

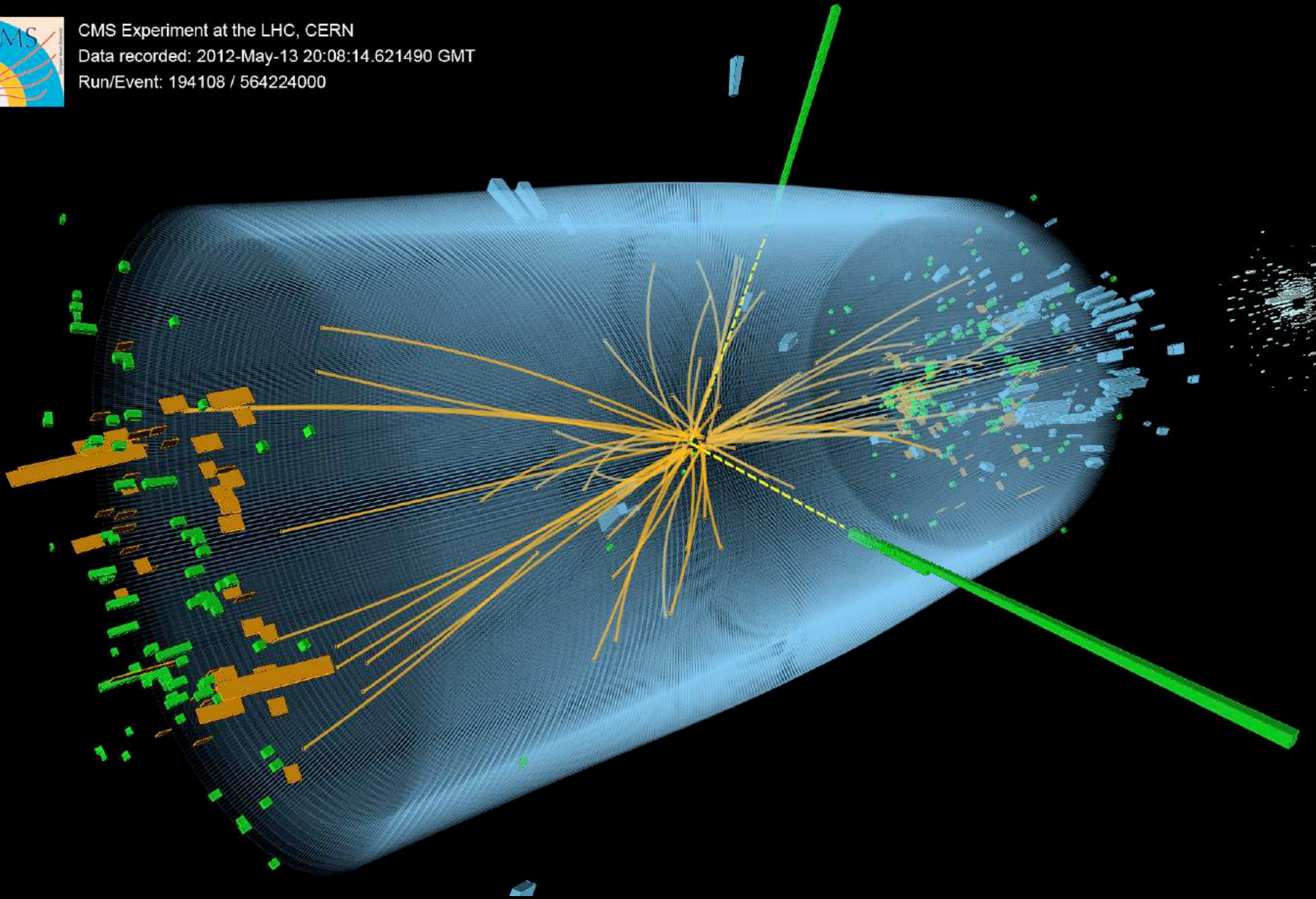
Higg

top
175

Discovered: Higgs mass = 125 x proton mass



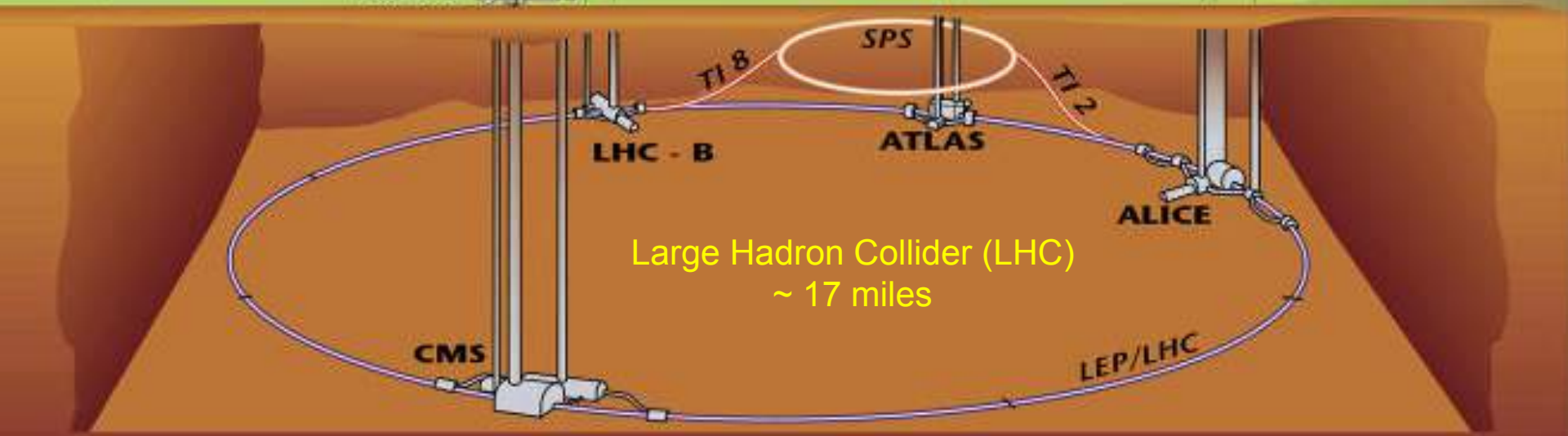
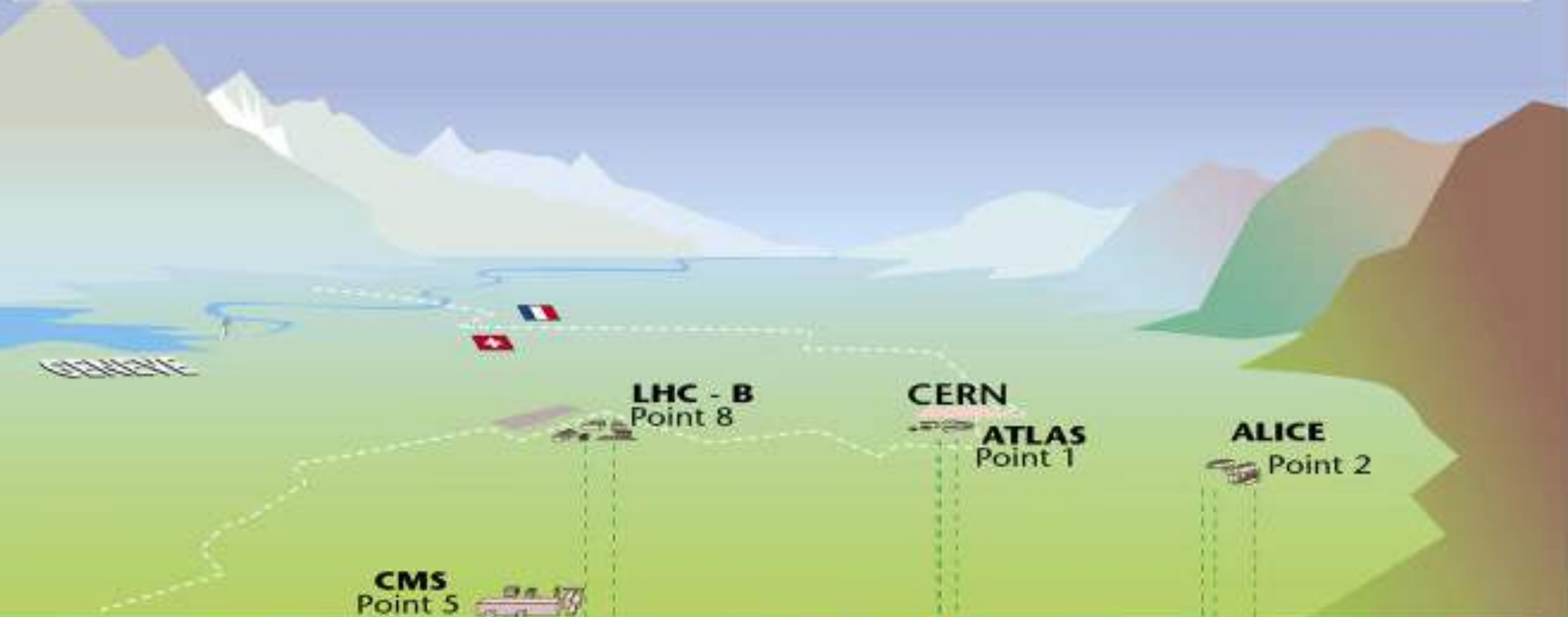
CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000



CERN: the European Organization for Nuclear Research

Particle

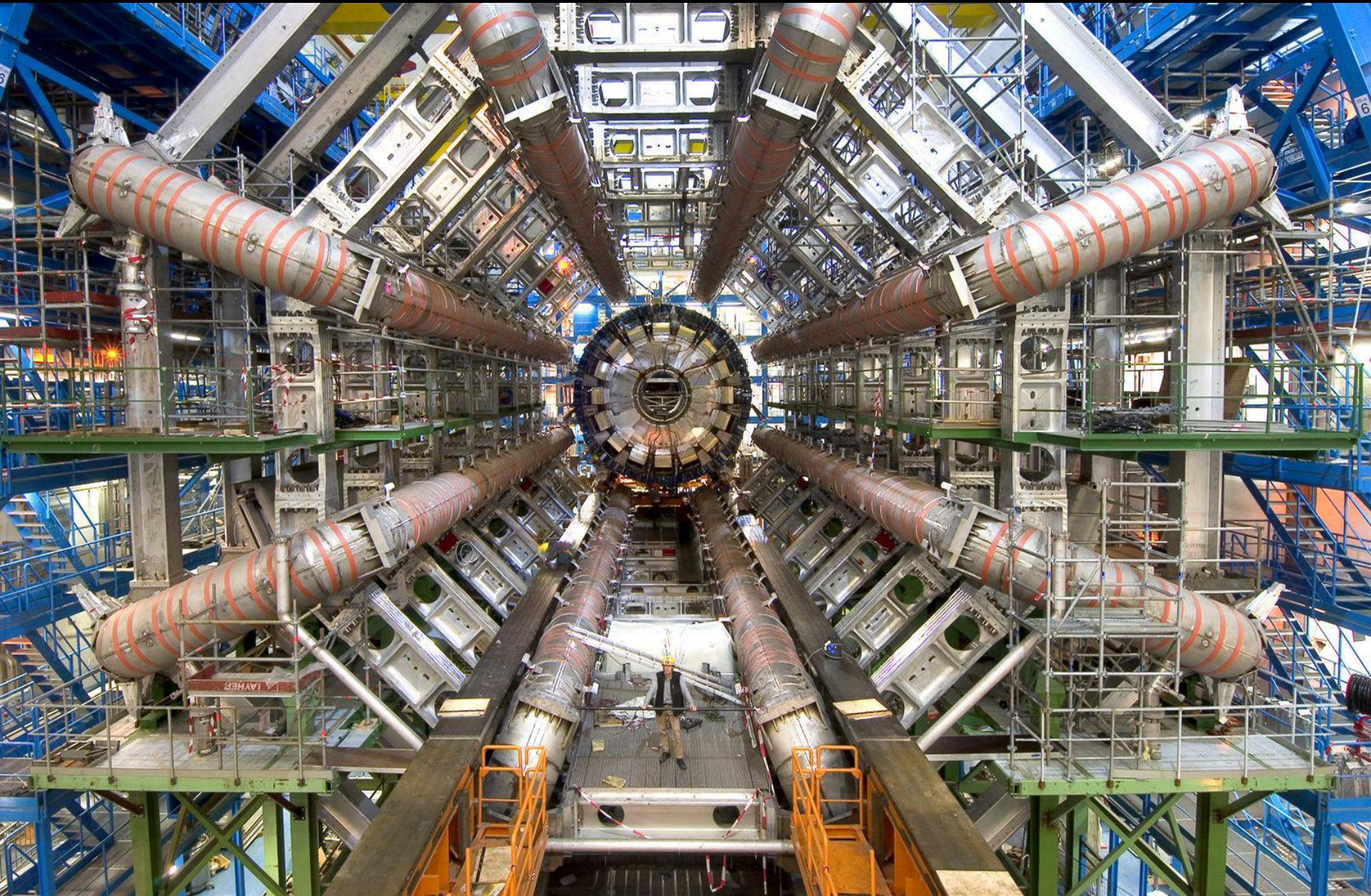






Large Hadron Collider

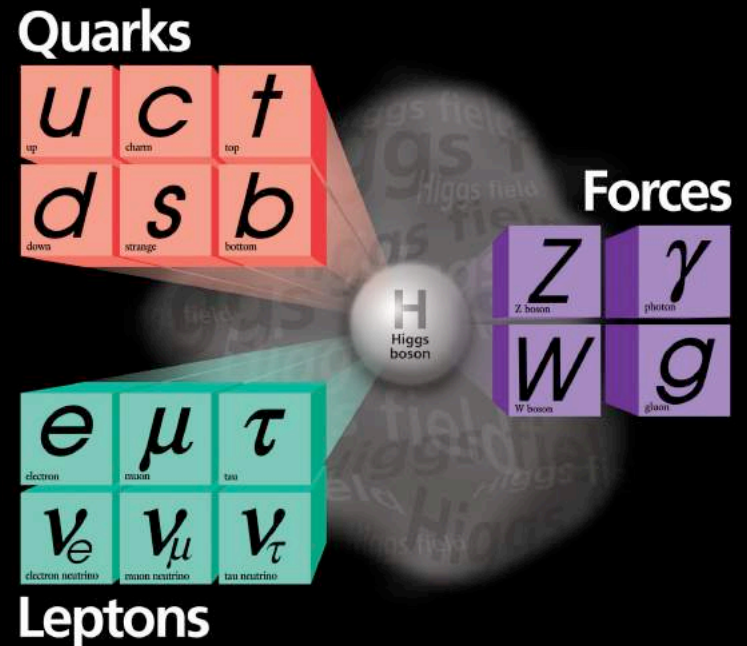
ATLAS experiment at LHC



Are we done now?

..... and the mysteries

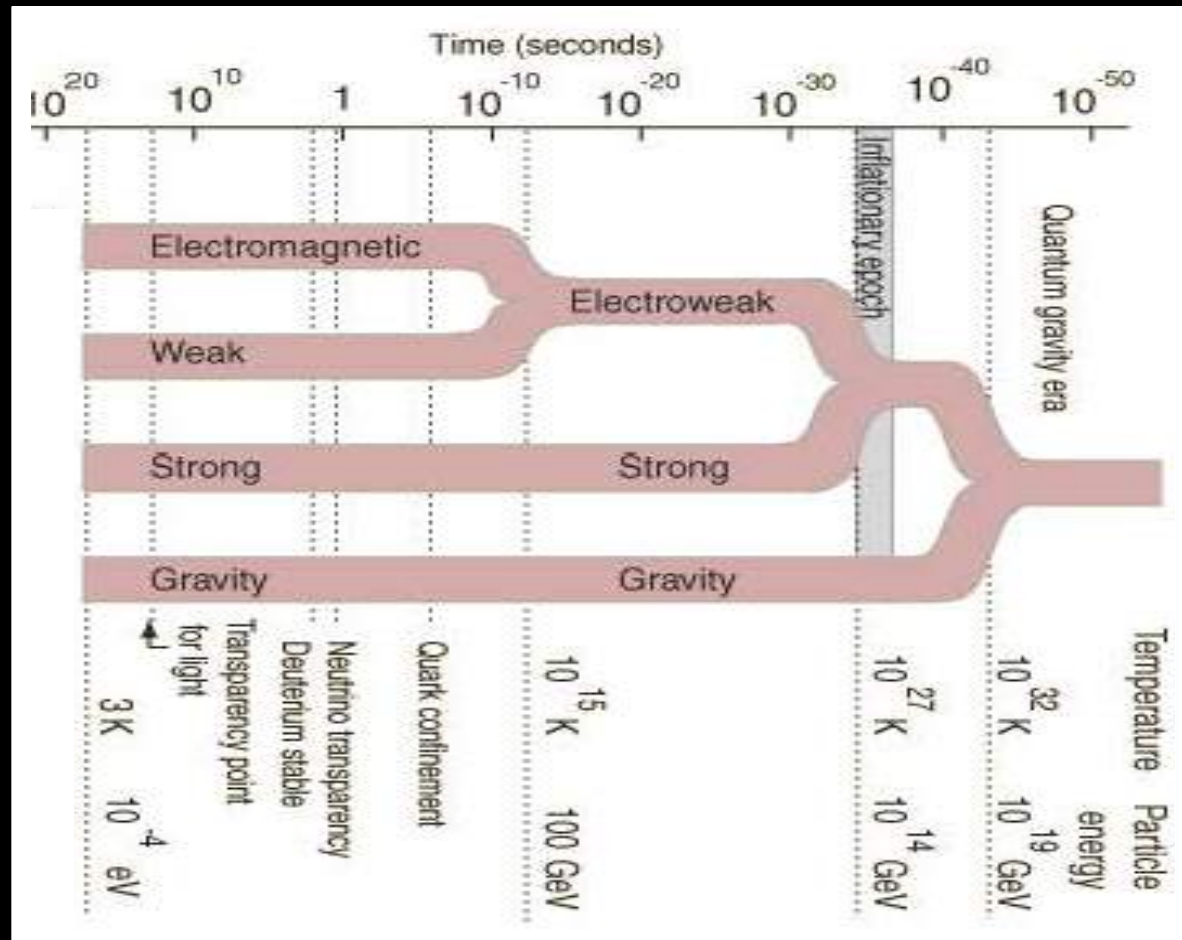
- Origin of mass?
 - Discovery of Higgs is the only beginning
- Why so many kinds of particles? Why three families?



..... and the mysteries

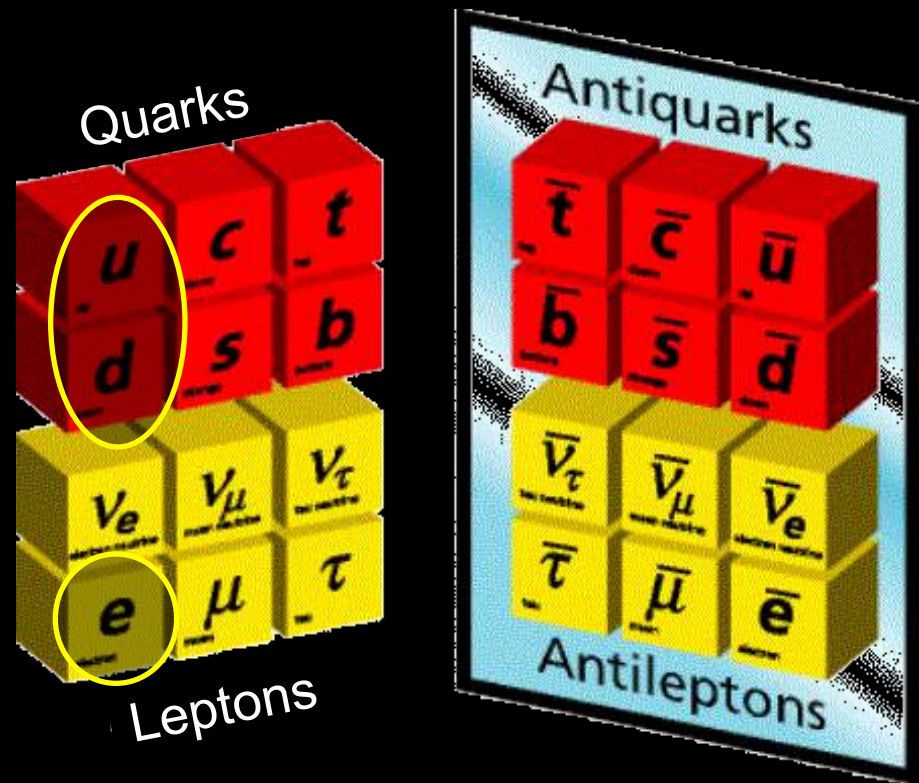
energy →
← age of the universe

- Do all forces become one?
 - Super symmetry
 - Proton decay
 -



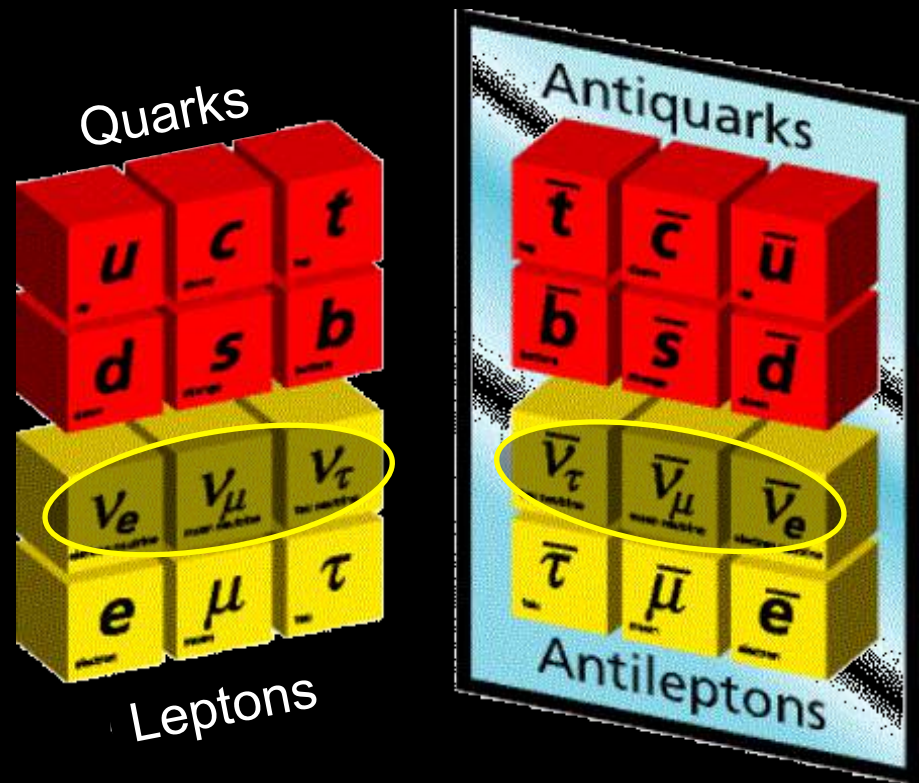
..... and the mysteries

- Where did antimatter go?



..... and the mysteries

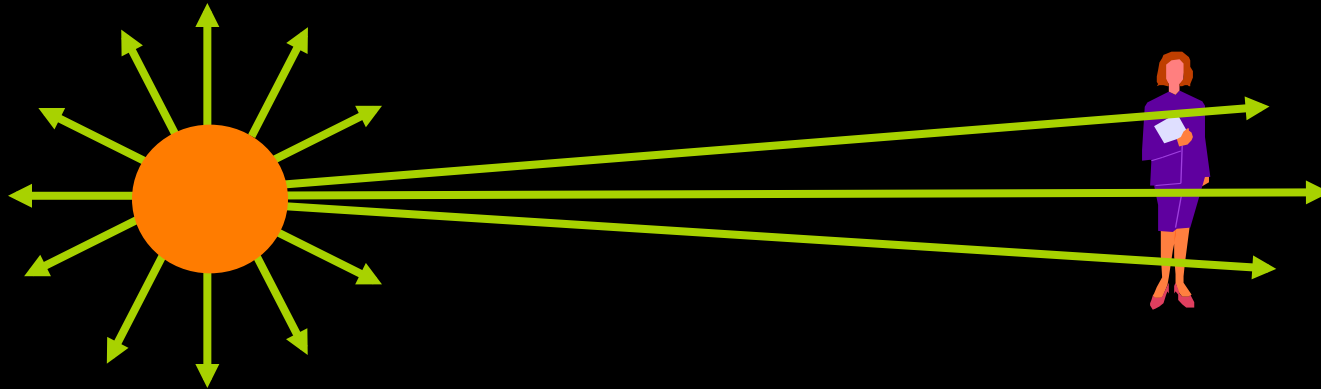
- What are neutrinos telling us?
- Origin of neutrino mass?



..... and the mysteries

Neutrinos are under our skin

~100 trillion neutrinos zip through each person every second.



One billion neutrinos for each proton or electron in the universe.
If we wish to understand the universe, must understand neutrinos

..... and the mysteries

- What is dark matter?
- It is everywhere, it is five times more abundant than matter.

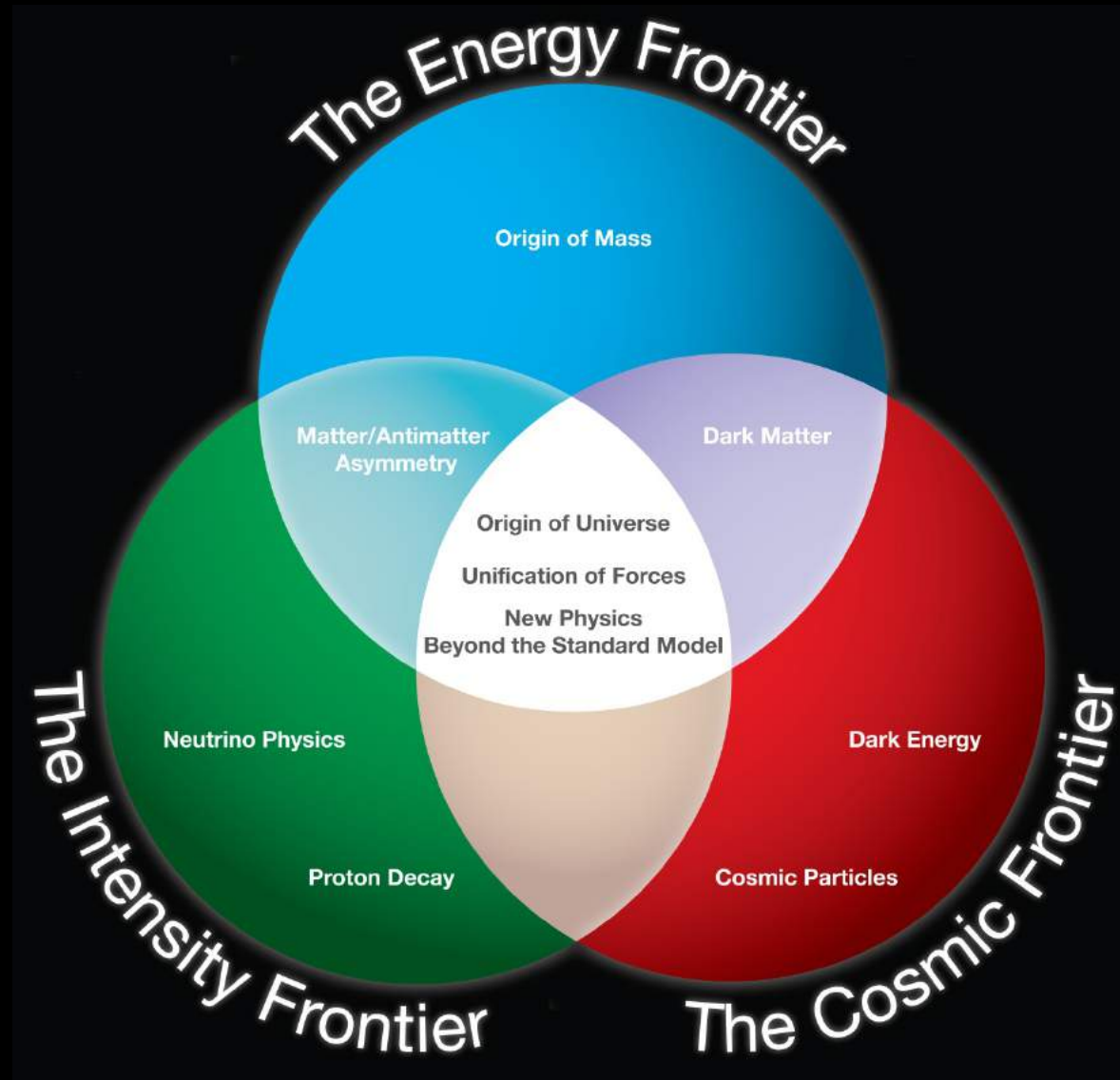


..... and the mysteries

- Not only is the universe expanding, it is accelerating.
- What is dark energy?
Not a clue!



Tools: three frontiers



Top quark discovery

Higgs discovery + ??
(Higgs as a tool to discover new physics)



Fermilab ★

★ CERN



Tevatron

$p\bar{p}$: 2 TeV

LHC

pp : 7,8 TeV \rightarrow 13 TeV

★
(decision)

Lepton collider

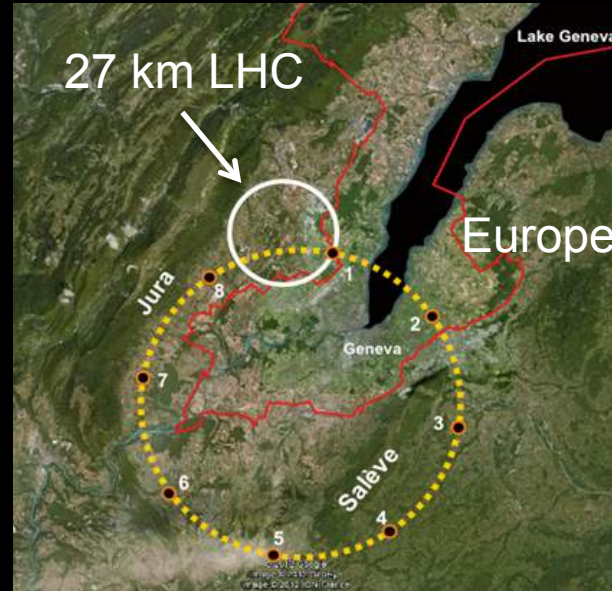
Hadron collider

Future Energy Frontier Facility Candidates

Global projects



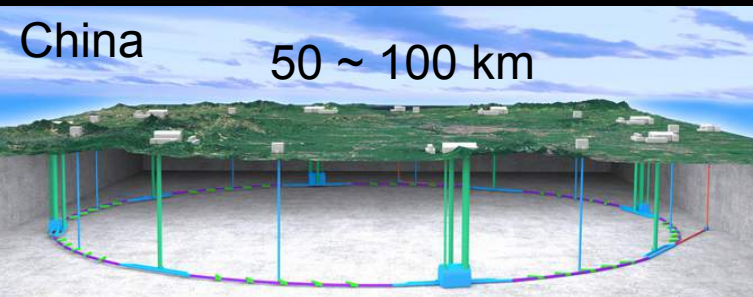
30 – 50 km
 e^+e^- linear collider (ILC)
 Higgs factory $\rightarrow \sim 1$ TeV



80 km circular collider
 $\rightarrow \sim 100$ TeV pp collider

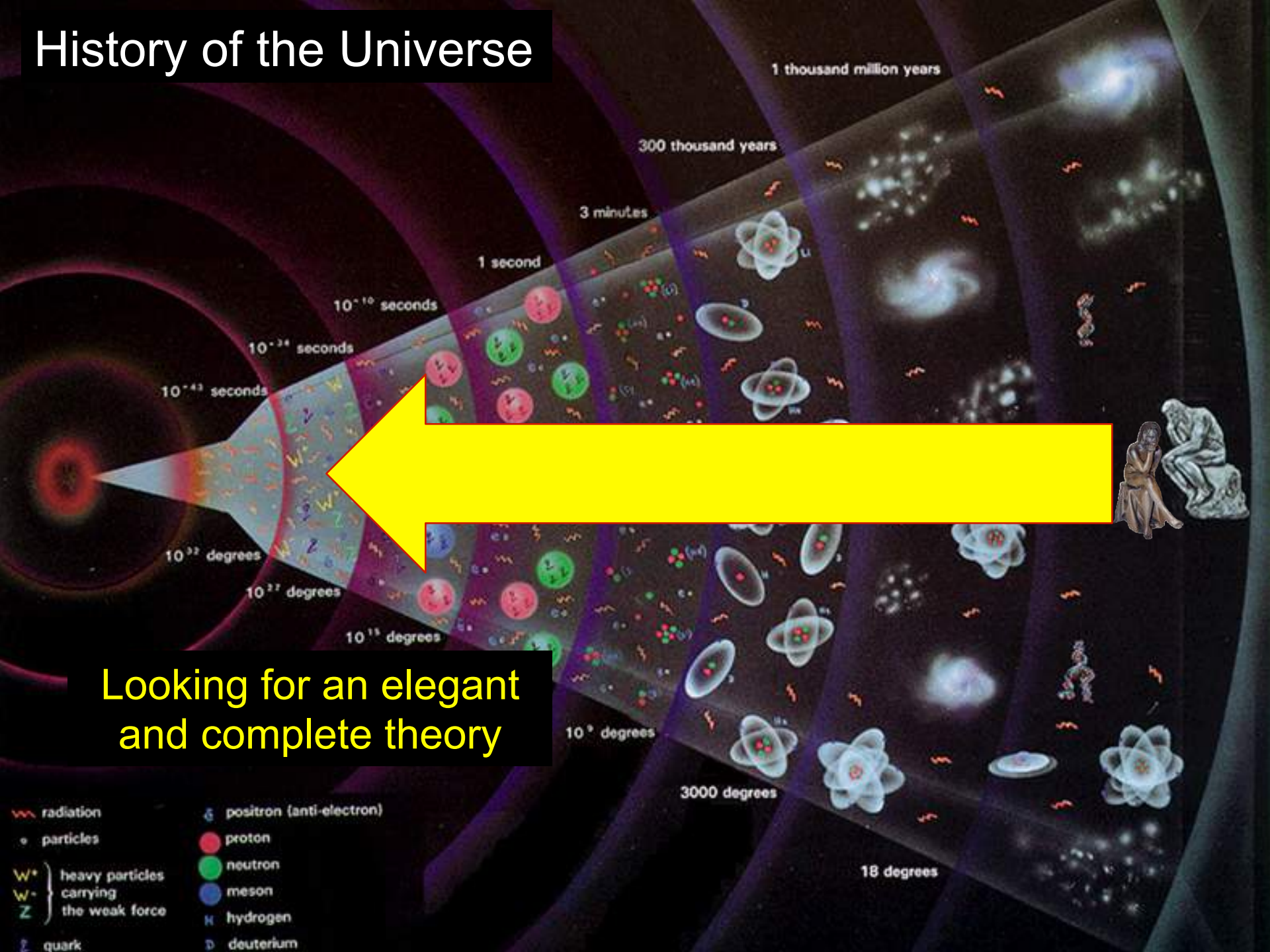


~ 10 km $\mu^+\mu^-$ collider
 Higgs factory $\rightarrow \sim 3$ TeV



e^+e^- circular collider (Higgs factory)
 pp circular collider (50 ~ 100 TeV)

History of the Universe



History of the Universe

