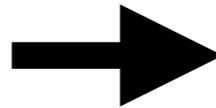
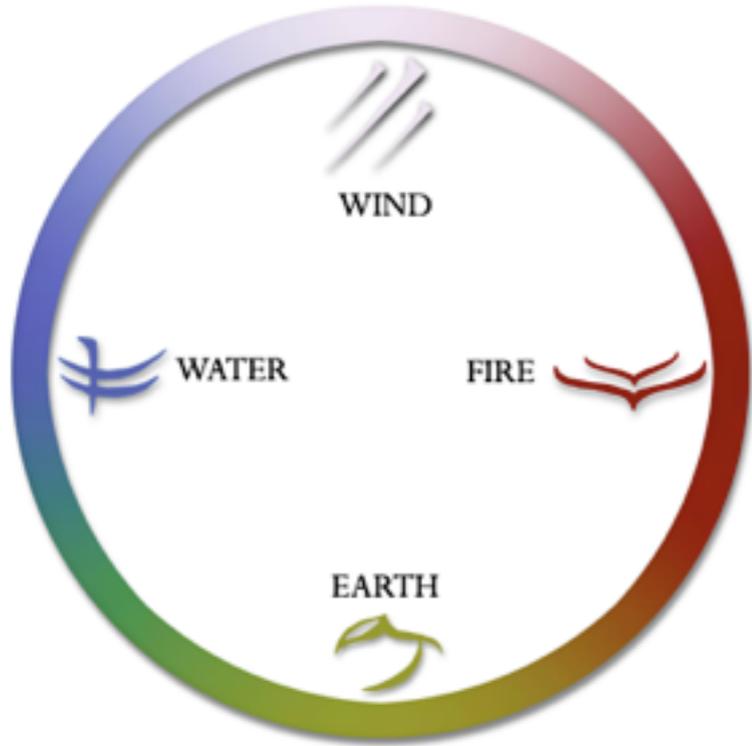


From Quarks to the Cosmos

Patrick Fox

 **Fermilab**

Particles (Fermions)



PERIODIC TABLE OF THE ELEMENTS

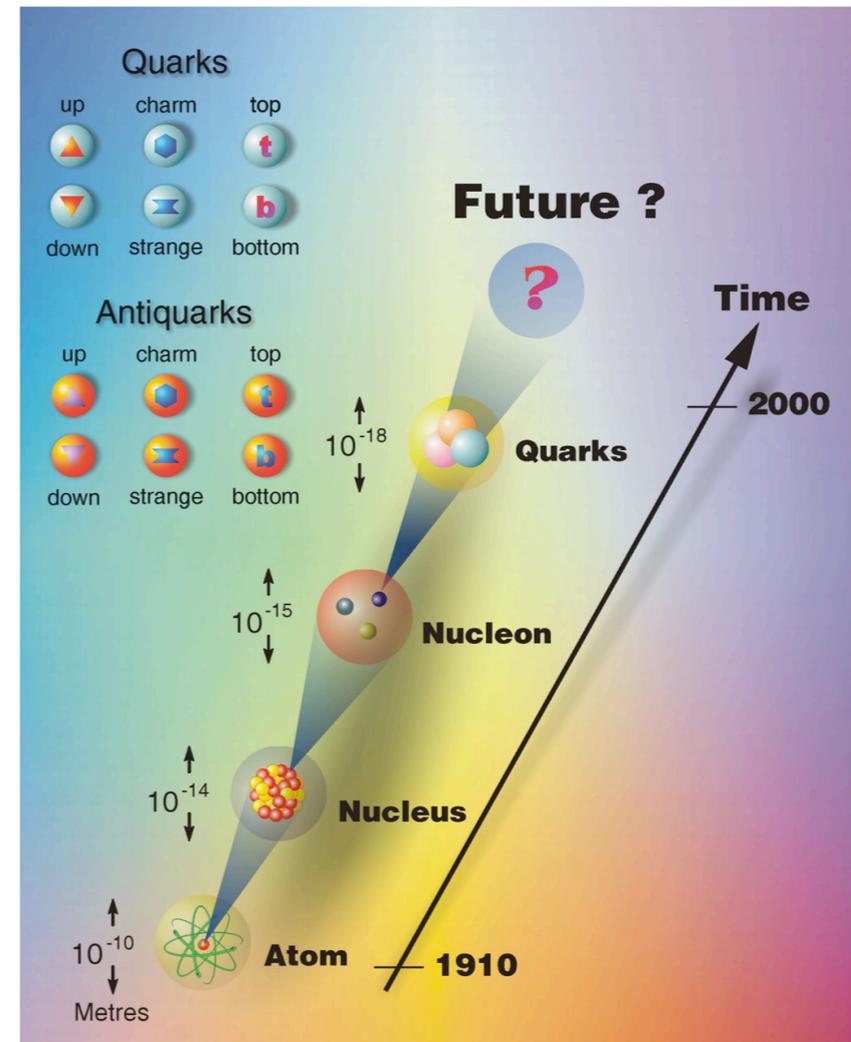
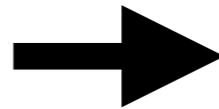
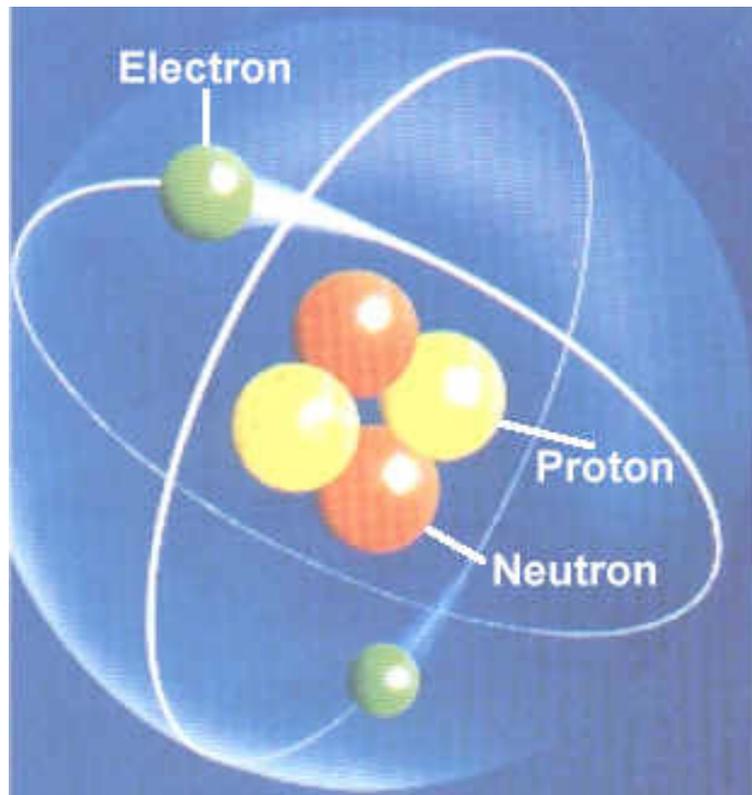
<http://www.ktf-split.hr/periodni/en/>

GROUP	PERIODIC TABLE OF THE ELEMENTS																18											
1	2		10										16		17	18												
IA	IIA	IIIA	IVB	VB	VIB						VII	VIII	IX	X	XIA	XIIA												
1	2	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36			
HYDROGEN	HELIUM																	HELIUM										
3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Li	Be	B	C	N	O	F	Ne	Na	Mg	Al	Si	P	S	Cl	Ar	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	
11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	
Na	Mg	Al	Si	P	S	Cl	Ar	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	
39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba	La-Lu	Hf	Ta	W	Re	Os	Ir	Pt	
55	56	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89-103	104	105	106	107	108	109	110	
Cs	Ba	La-Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Fr	Ra	Ac-Lr	Rf	Db	Sg	Bh	Hs	Mt	Uun	
87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	
Fr	Ra	Ac-Lr	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	
87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	
Fr	Ra	Ac-Lr	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq	Uuq		

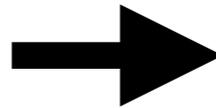
(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001) Relative atomic mass is shown with five significant figures. For elements with no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element. However three such elements (Tl, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (adivar@netlink.com)

For more information and downloads please visit ---> <http://www.periodni.com/en/download.html>



Particles (Fermions)



PERIODIC TABLE OF THE ELEMENTS

<http://www.ktf-split.hr/periodni/en/>

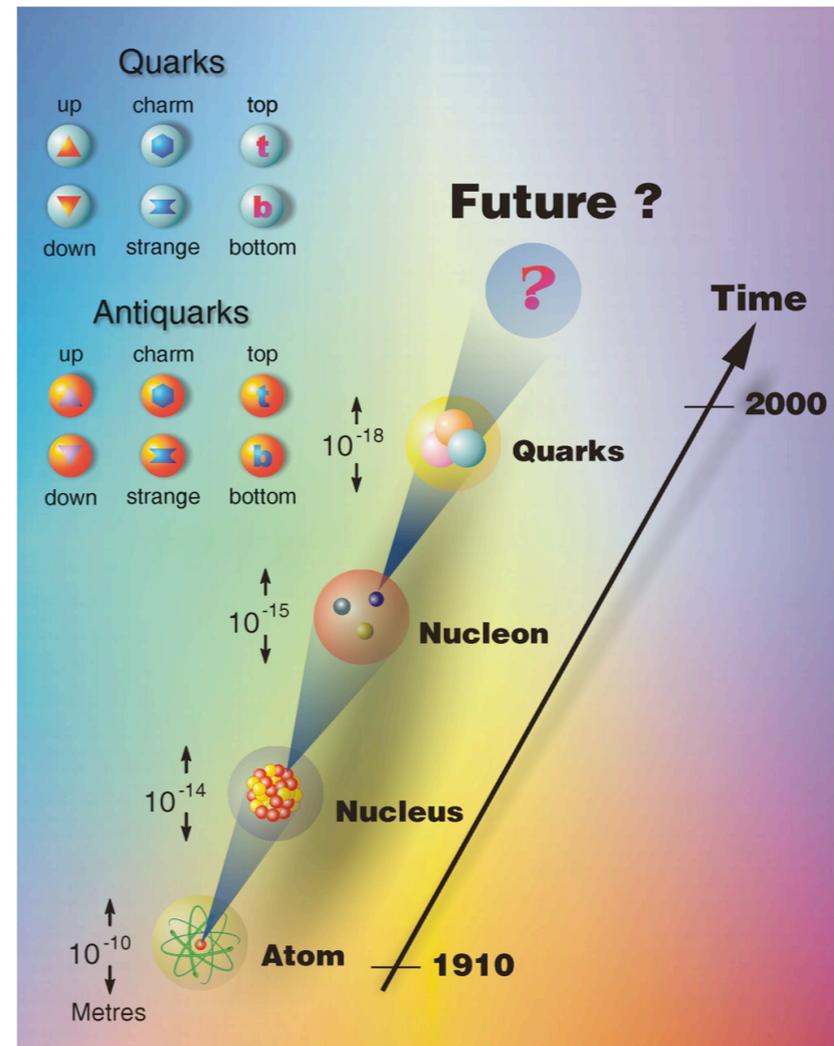
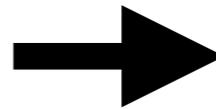
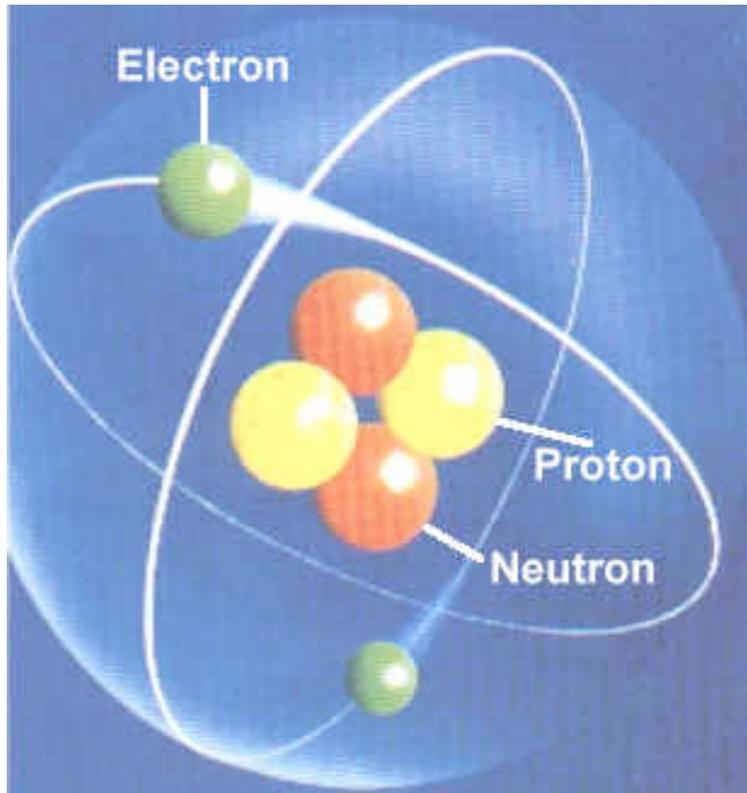
GROUP	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9 VIIIB	10 VIII	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	H																	He
2	Li	Be											B	C	N	O	F	Ne
3	Na	Mg											Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba	La-Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra	Ac-Lr	Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub	Uuq					

Legend:
 Metal: Blue box, Semimetal: Orange box, Nonmetal: Green box.
 1: Alkali metal, 2: Alkaline earth metal, 3: Transition metals, 4: Lanthanide, 5: Actinide.
 16: Chalcogens element, 17: Halogens element, 18: Noble gas.
 STANDARD STATE (25 °C; 101 kPa):
 Ne - gas, Fe - solid, Ga - liquid, others - synthetic.

LANTHANIDE: La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu.
ACTINIDE: Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr.

(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)
 Relative atomic mass is shown with five significant figures. For elements with no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.
 However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.
 Editor: Aditya Vardhan (advvar@netnetlink.com)

For more information and downloads please visit ---> <http://www.periodni.com/en/download.html>



Particles (Fermions)

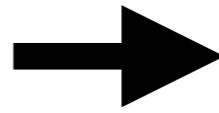
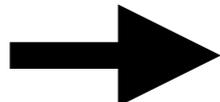
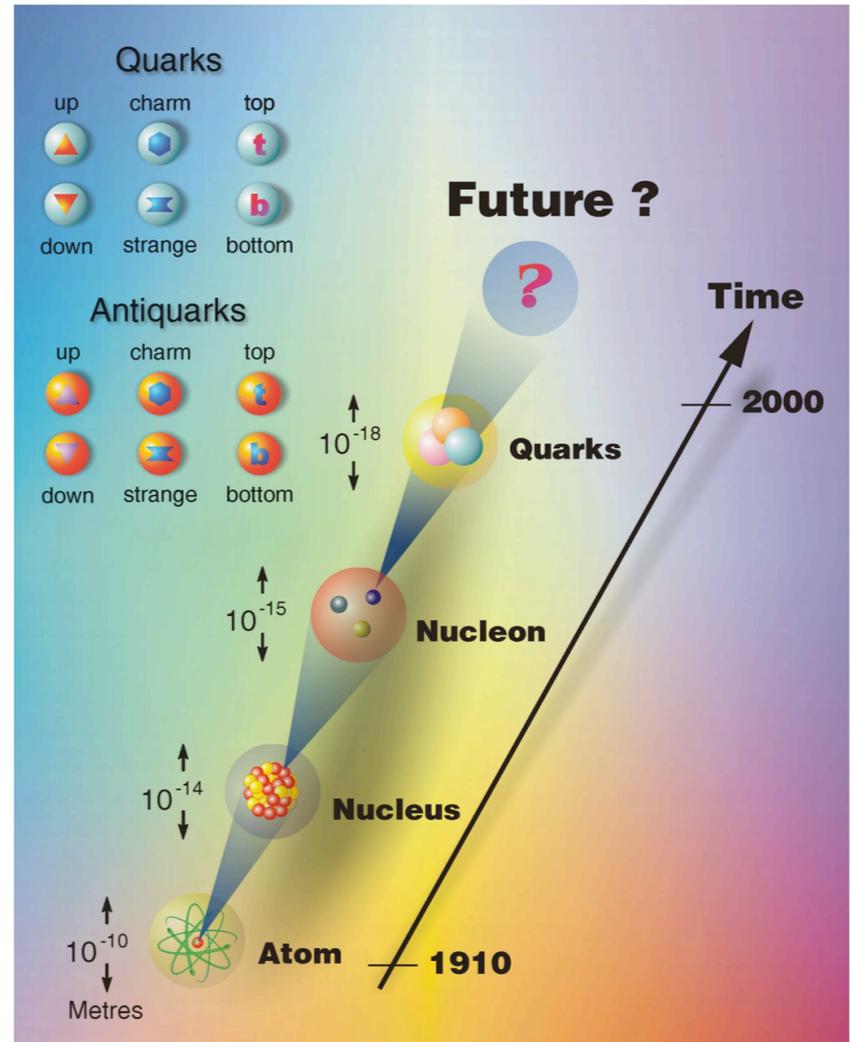
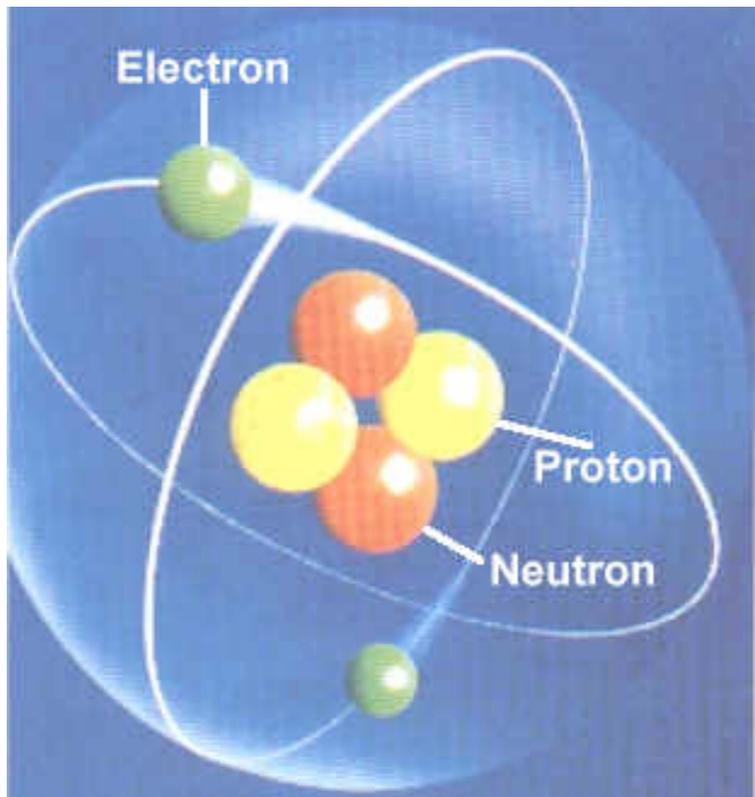
PERIODIC TABLE OF THE ELEMENTS

<http://www.ktf-split.hr/periodni/en/>

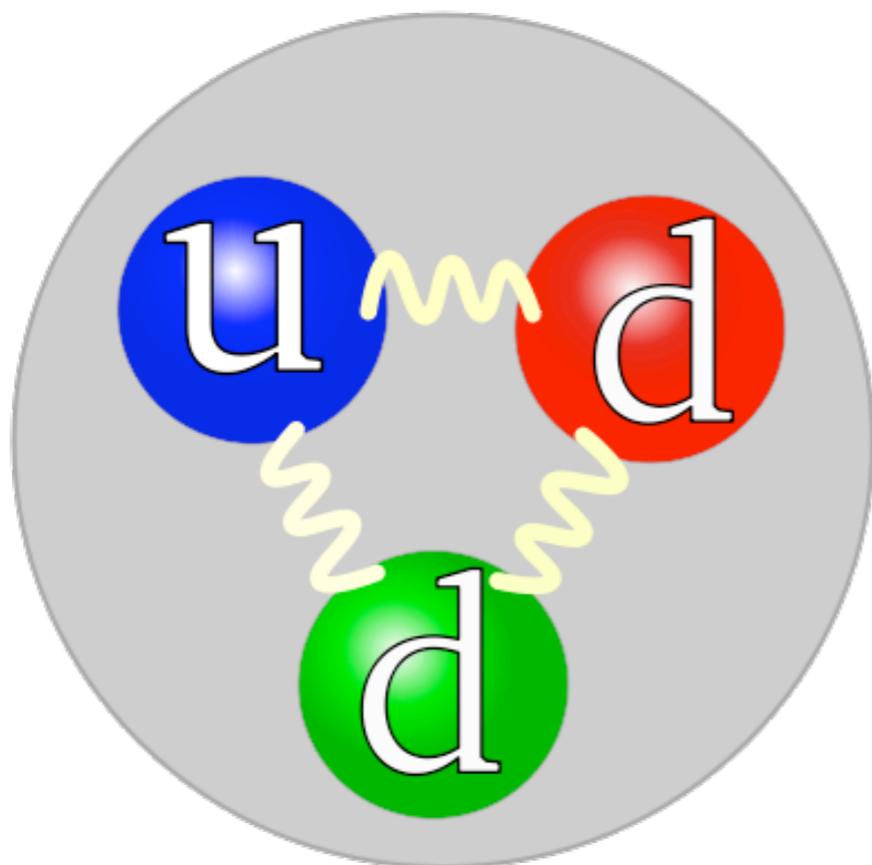
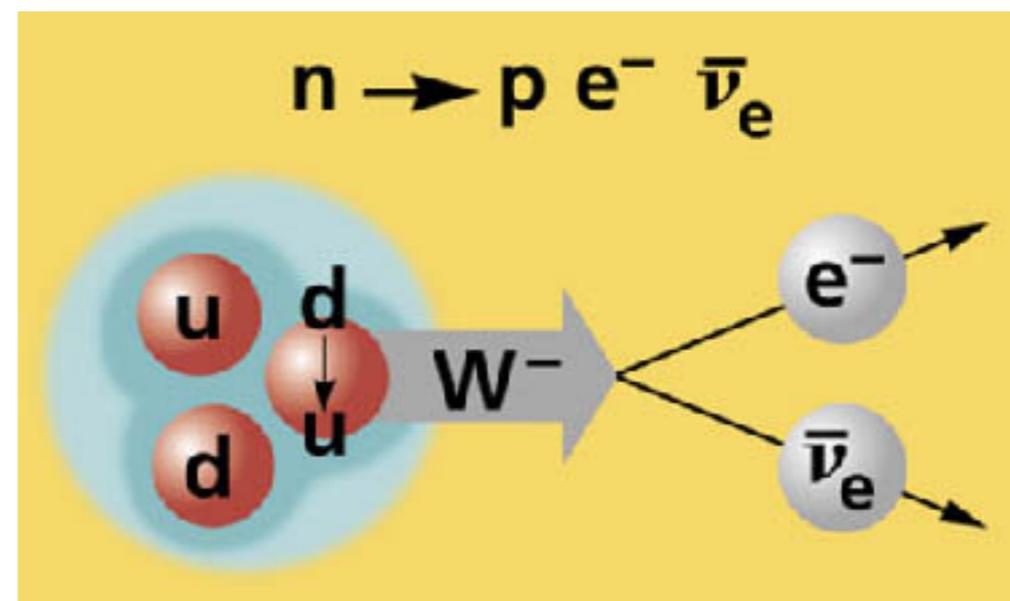
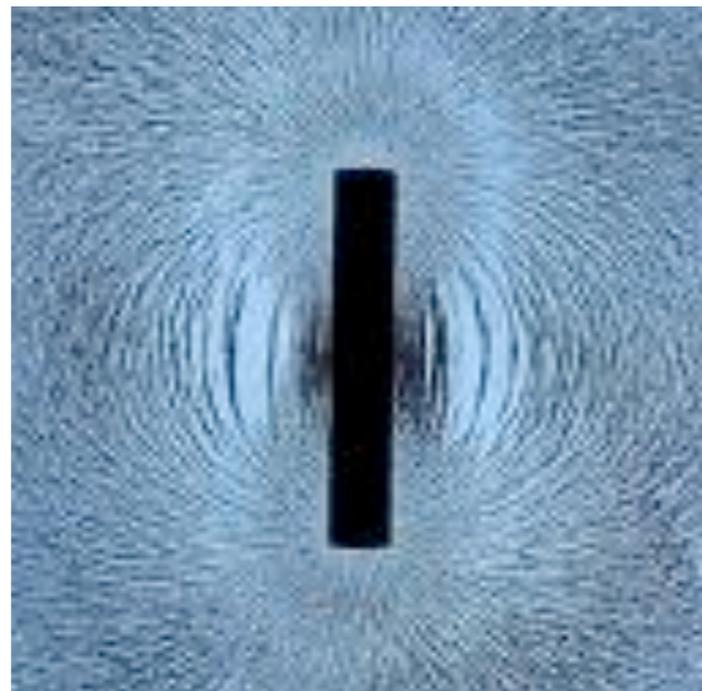
GROUP	PERIODIC TABLE OF THE ELEMENTS																18	
1	2		10										16		17	18		
IA	IIA	IIIA	IVB	VB	VIB	VII	VIII	IX	X	XI	XII	IIIA	IVA	VA	VIA	VIIA	VIIIA	
1 1.0079 H HYDROGEN	2 6.941 Li LITHIUM	4 9.0122 Be BERYLLIUM	5 10.811 B BORON	6 12.011 C CARBON	7 14.007 N NITROGEN	8 15.999 O OXYGEN	9 18.998 F FLUORINE	10 20.180 Ne NEON	11 22.990 Na SODIUM	12 24.305 Mg MAGNESIUM	13 26.982 Al ALUMINIUM	14 28.086 Si SILICON	15 30.974 P PHOSPHORUS	16 32.065 S SULPHUR	17 35.453 Cl CHLORINE	18 39.948 Ar ARGON		
3 39.098 K POTASSIUM	4 40.078 Ca CALCIUM	21 44.956 Sc SCANDIUM	22 47.867 Ti TITANIUM	23 50.942 V VANADIUM	24 51.996 Cr CHROMIUM	25 54.938 Mn MANGANESE	26 55.845 Fe IRON	27 58.933 Co COBALT	28 58.933 Ni NICKEL	29 63.546 Cu COPPER	30 65.39 Zn ZINC	31 69.723 Ga GALLIUM	32 72.64 Ge GERMANIUM	33 74.922 As ARSENIC	34 78.96 Se SELENIUM	35 79.904 Br BROMINE	36 83.80 Kr KRYPTON	
4 85.468 Rb RUBIDIUM	38 87.62 Sr STRONTIUM	39 88.905 Y YTRIUM	40 91.224 Zr ZIRCONIUM	41 92.906 Nb NIObIUM	42 95.94 Mo MOLYBDENUM	43 (96) Tc TECHNETIUM	44 101.07 Ru RUTHENIUM	45 102.91 Rh RHODIUM	46 106.42 Pd PALLADIUM	47 107.87 Ag SILVER	48 112.41 Cd CADMIUM	49 114.82 In INDIUM	50 118.71 Sn TIN	51 121.76 Sb ANTIMONY	52 127.60 Te TELLURIUM	53 126.90 I IODINE	54 131.29 Xe XENON	
5 132.91 Cs CAESIUM	56 137.33 Ba BARIUM	57-71 La-Lu Lanthanide	72 178.49 Hf HAFNIUM	73 180.95 Ta TANTALUM	74 183.84 W WOLFRAM	75 186.21 Re RHENIUM	76 190.23 Os OSMIUM	77 192.22 Ir IRIDIUM	78 195.08 Pt PLATINUM	79 196.97 Au GOLD	80 200.59 Hg MERCURY	81 204.38 Tl THALLIUM	82 207.2 Pb LEAD	83 208.98 Bi BISMUTH	84 (209) Po POLONIUM	85 (210) At ASTATINE	86 (222) Rn RADON	
6 223 Fr FRANCIUM	88 (226) Ra RADIUM	89-103 Ac-Lr Actinide	104 (261) Rf RUTHERFORDIUM	105 (262) Db DUBNIUM	106 (266) Sg SEABORGIUM	107 (264) Bh BOHRRIUM	108 (277) Hs HASSIUM	109 (268) Mt MEITNERIUM	110 (272) Uun UNUNNIUM	111 (272) Uuu UNUNUNIUM	112 (285) Uub UNUNBIUM	114 (289) Uuq UNUNQUADIUM	116 (289) Uuh UNUNHECTIUM	118 (289) Uuo UNUNOCTIUM	119 (289) Uuq UNUNQUADIUM	120 (289) Uuq UNUNQUADIUM	121 (289) Uuq UNUNQUADIUM	122 (289) Uuq UNUNQUADIUM

(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)
 Relative atomic mass is shown with five significant figures. For elements having no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.
 However three such elements (Tl, Po, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.
 Editor: Aditya Vardhan (advard@netlink.com)

For more information and downloads please visit ---> <http://www.periodni.com/en/download.html>



Forces (Bosons)

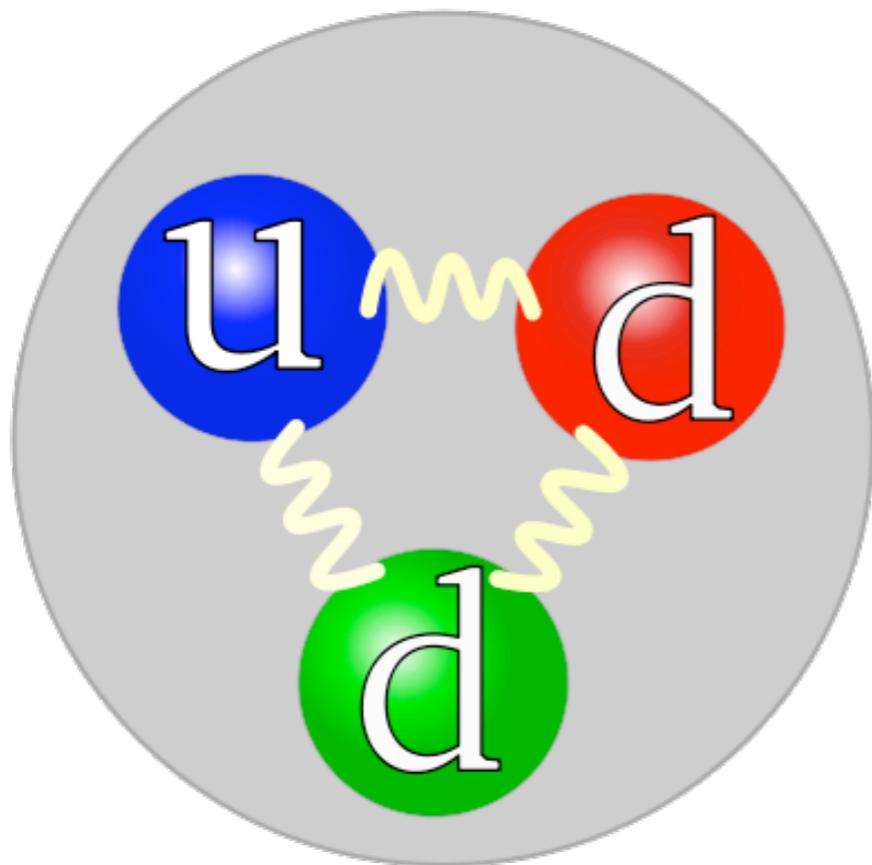
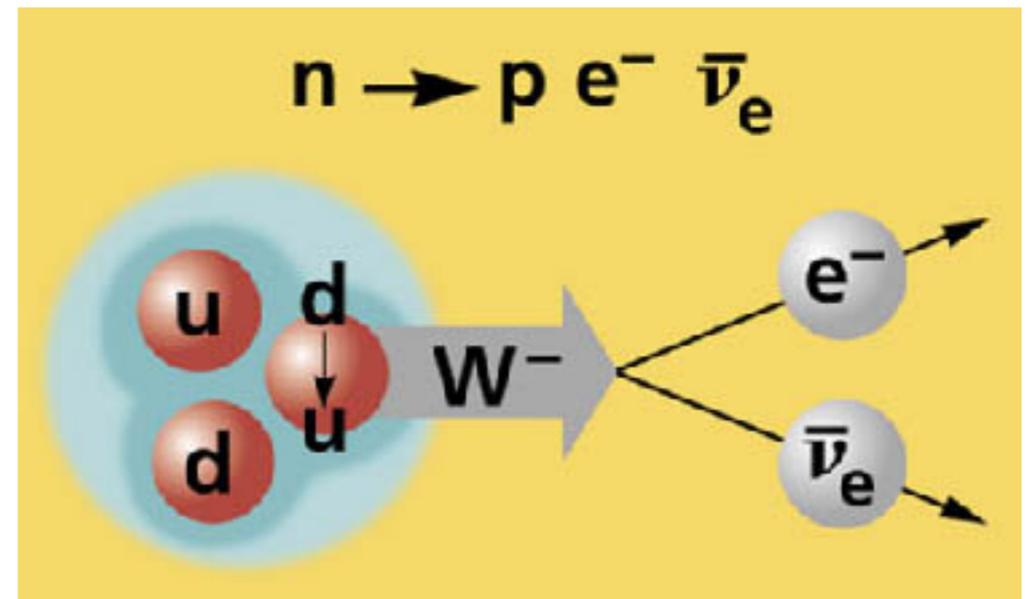
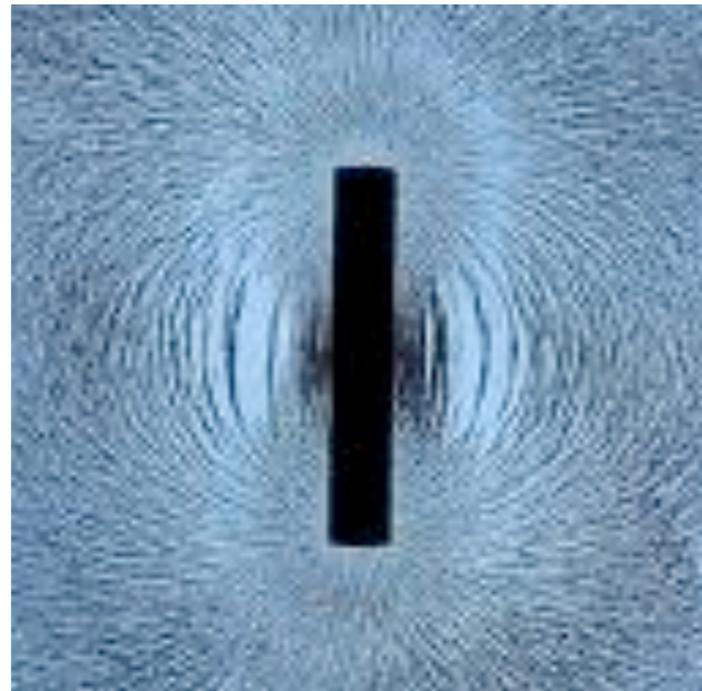


$$W^{\pm} \quad Z^0$$

γ

gluon

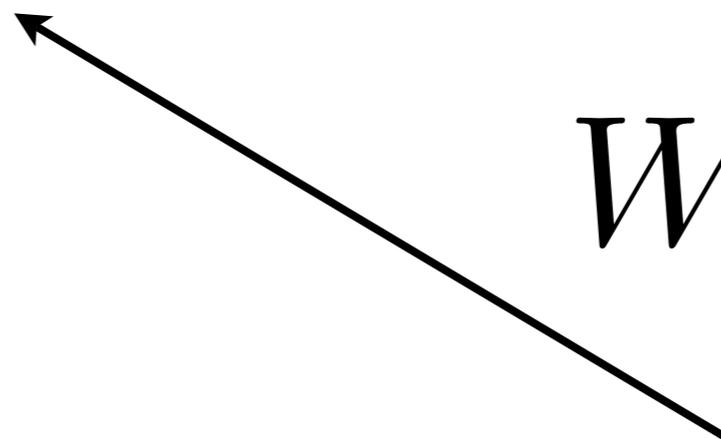
Forces (Bosons)



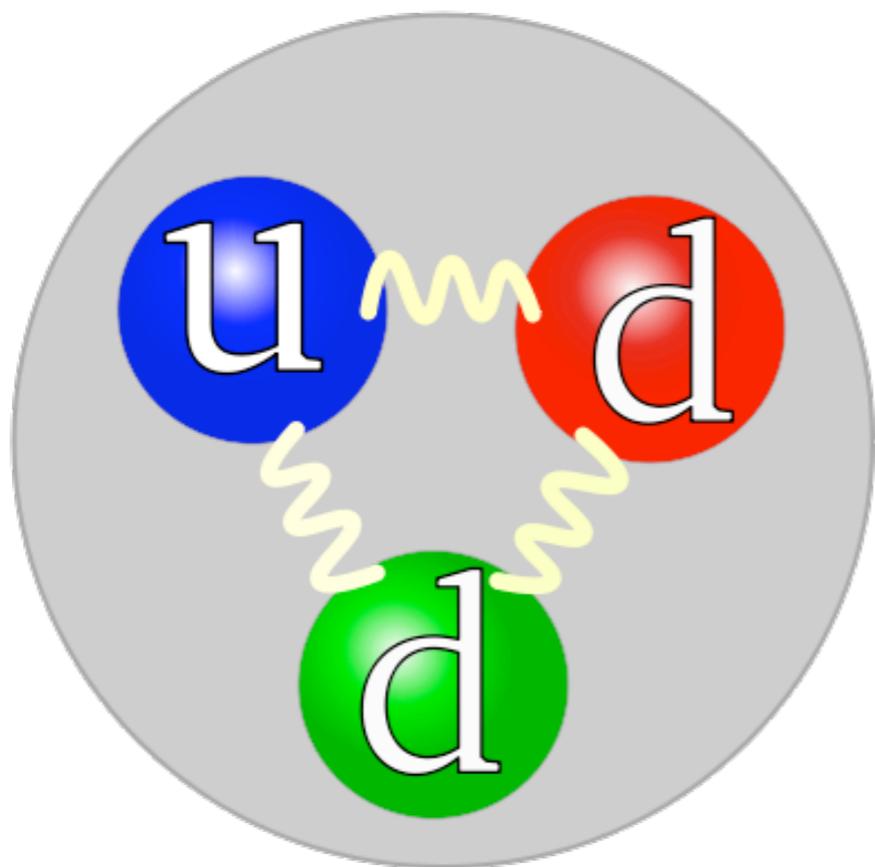
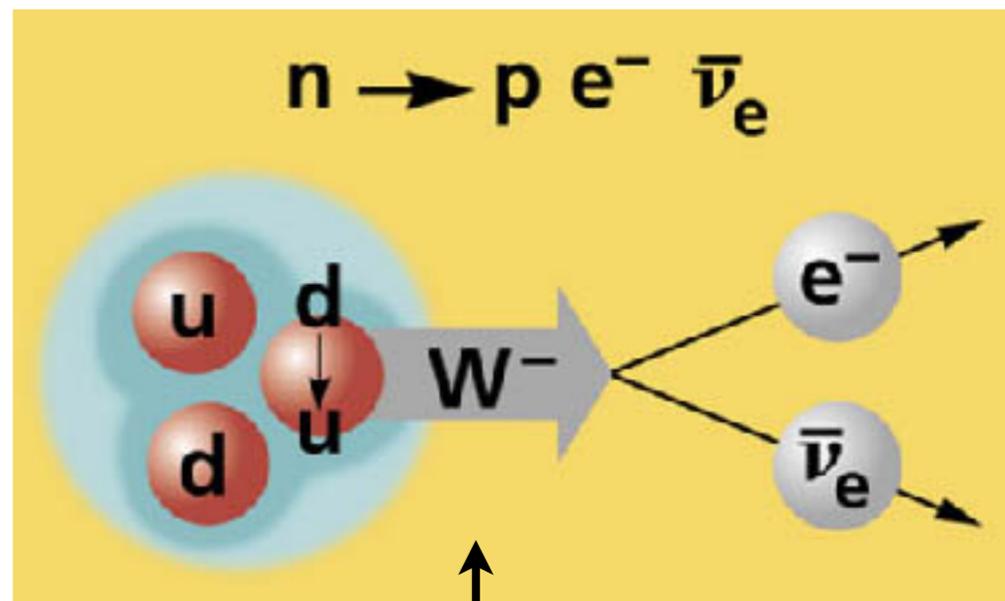
$W^{\pm} Z^0$

γ

gluon



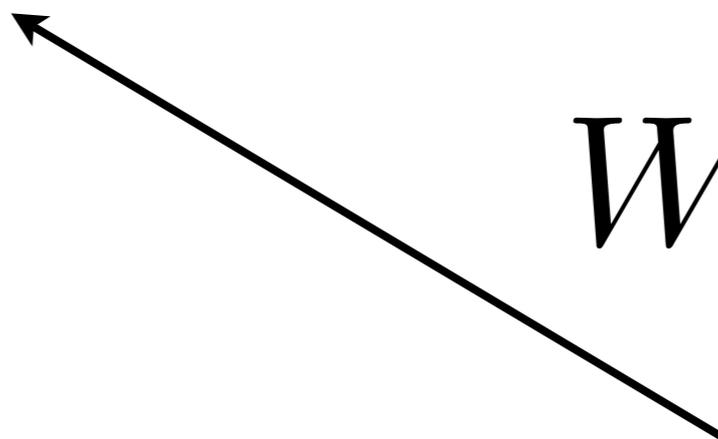
Forces (Bosons)



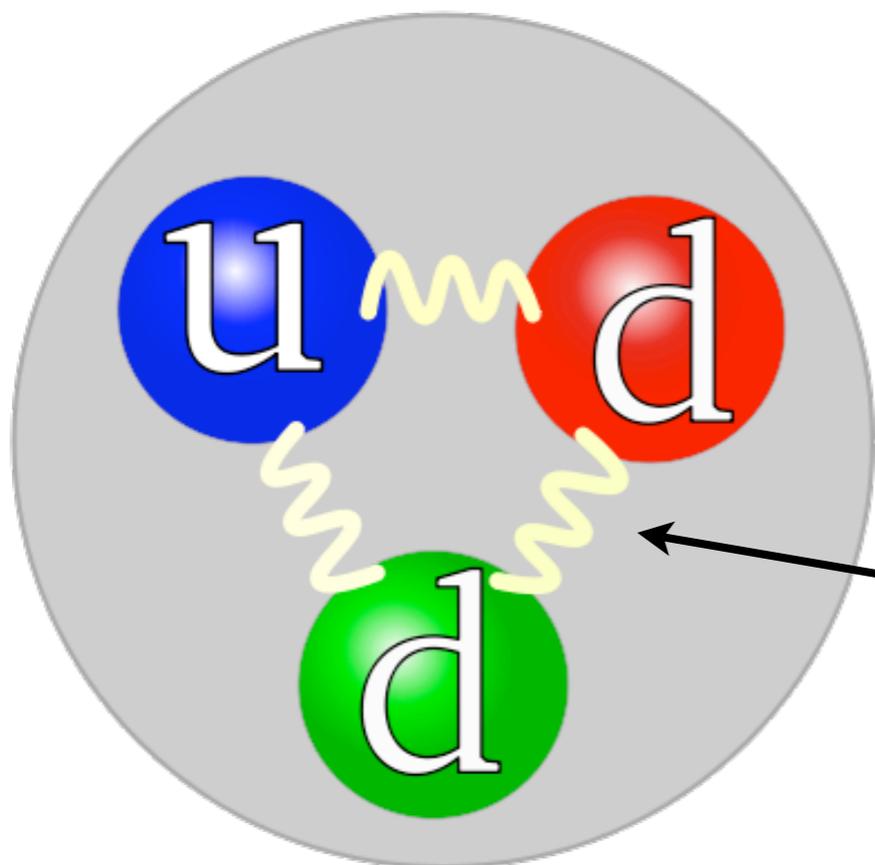
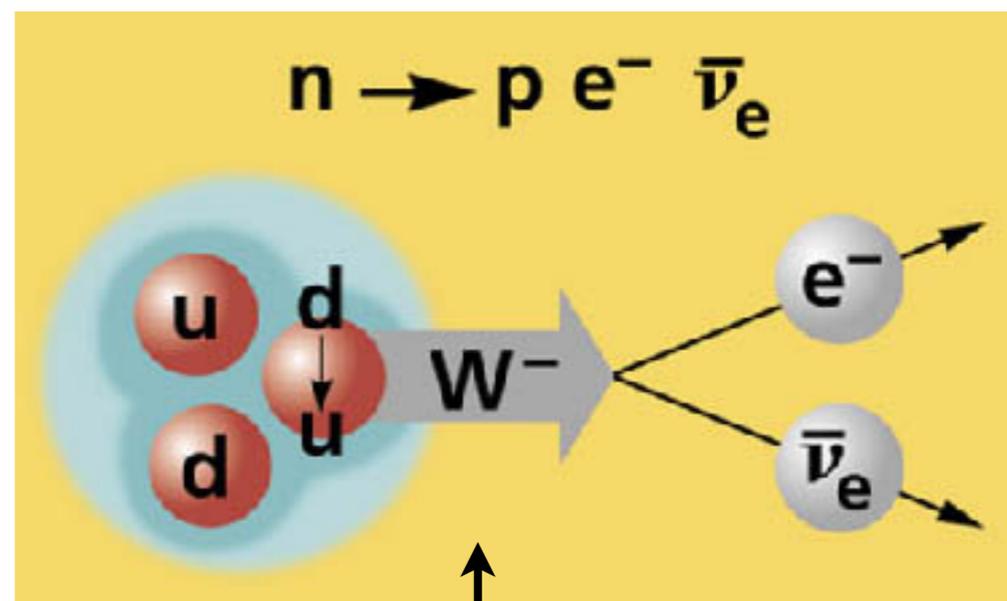
$W^{\pm} \quad Z^0$

γ

gluon



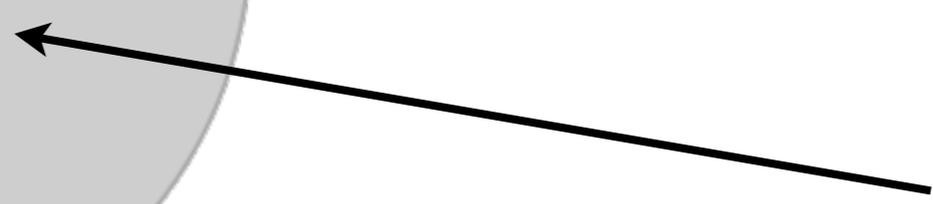
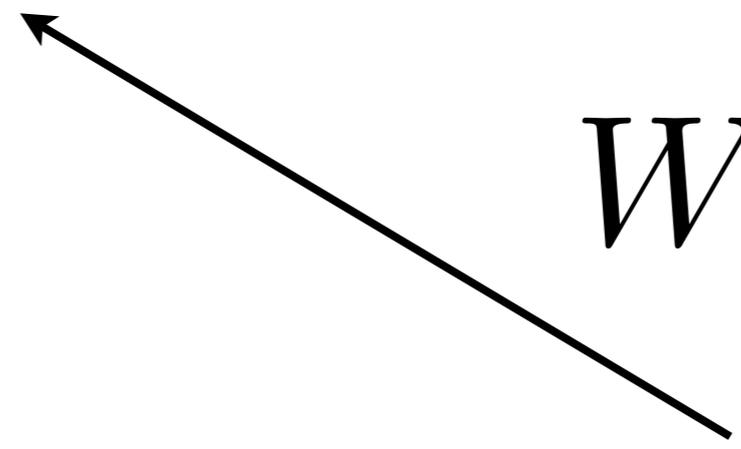
Forces (Bosons)



$W^{\pm} \quad Z^0$

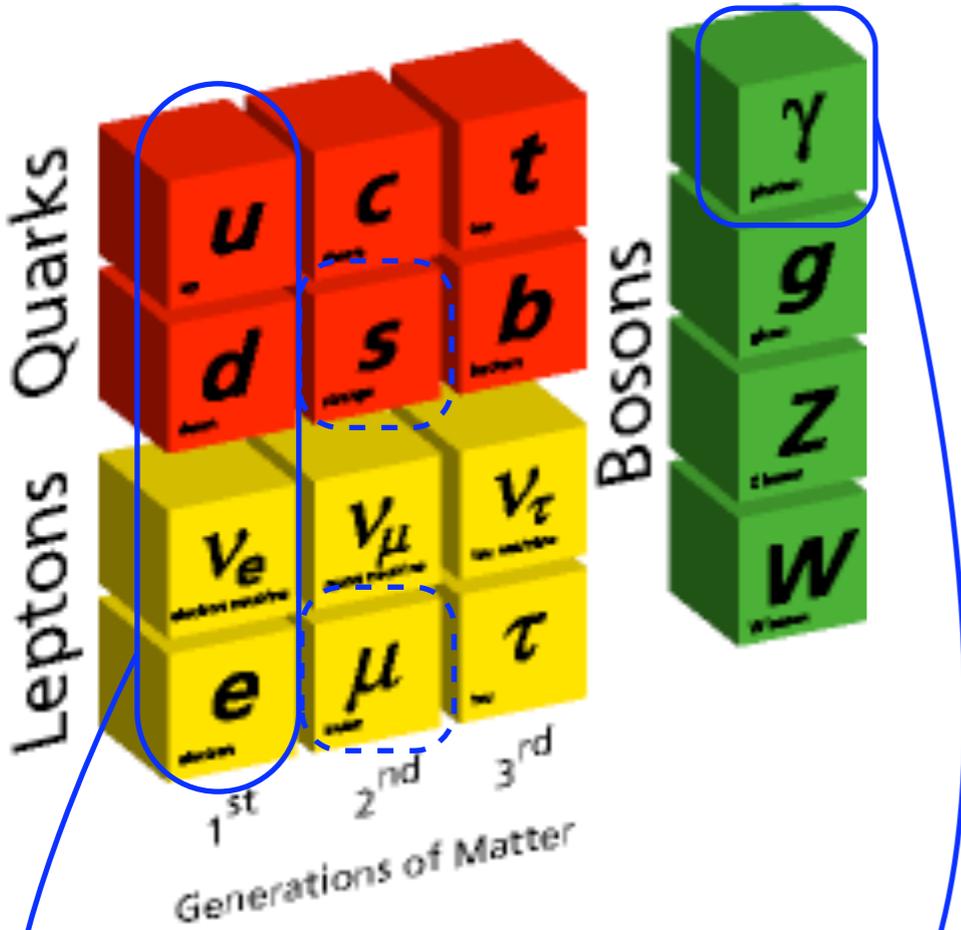
γ

gluon



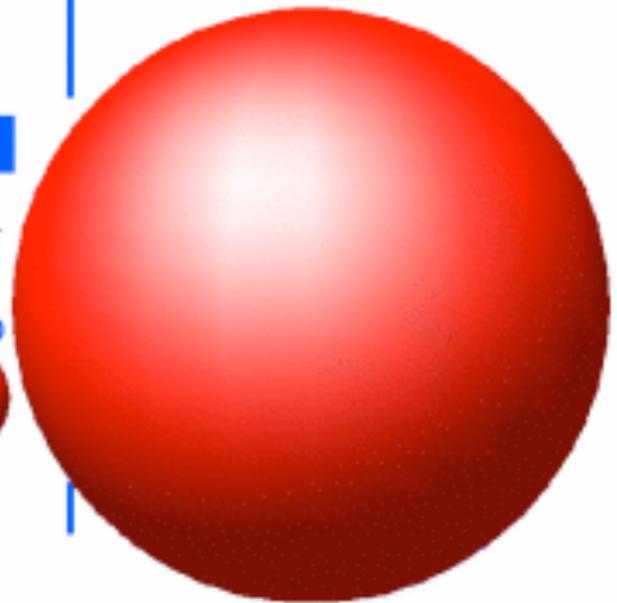
Finally arrive at the Standard Model

Elementary Particles

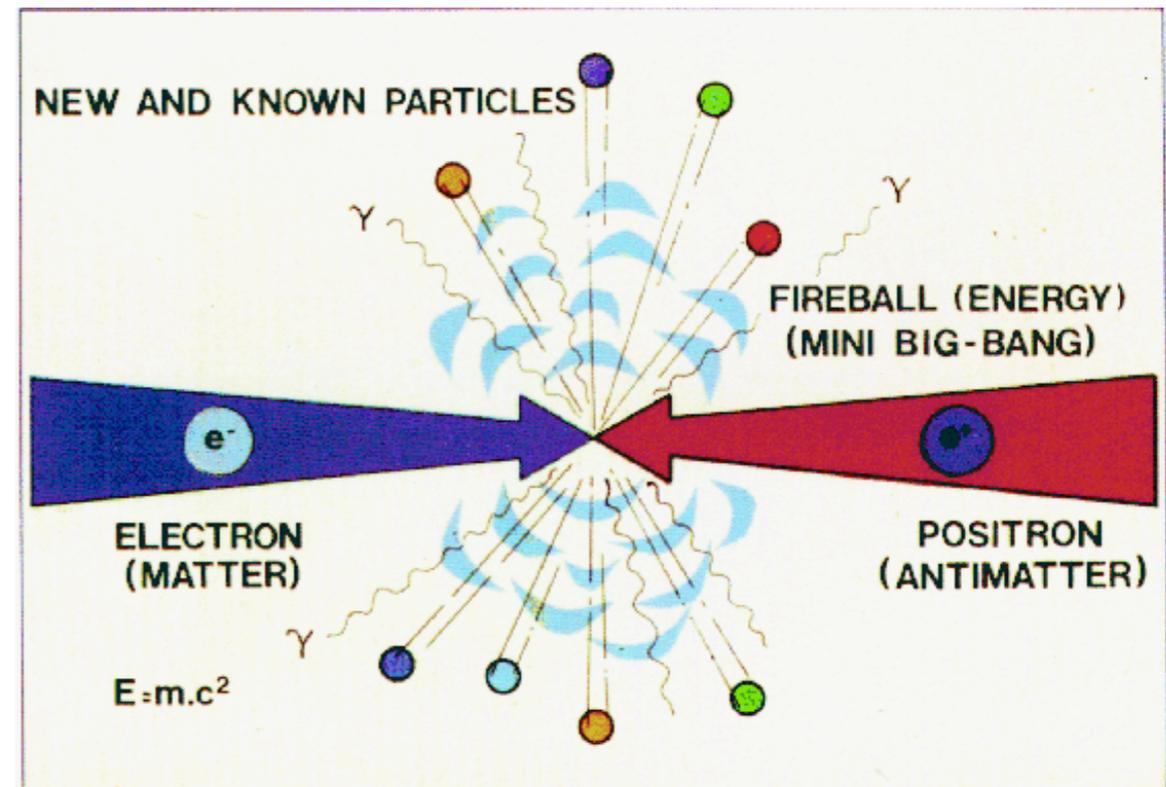
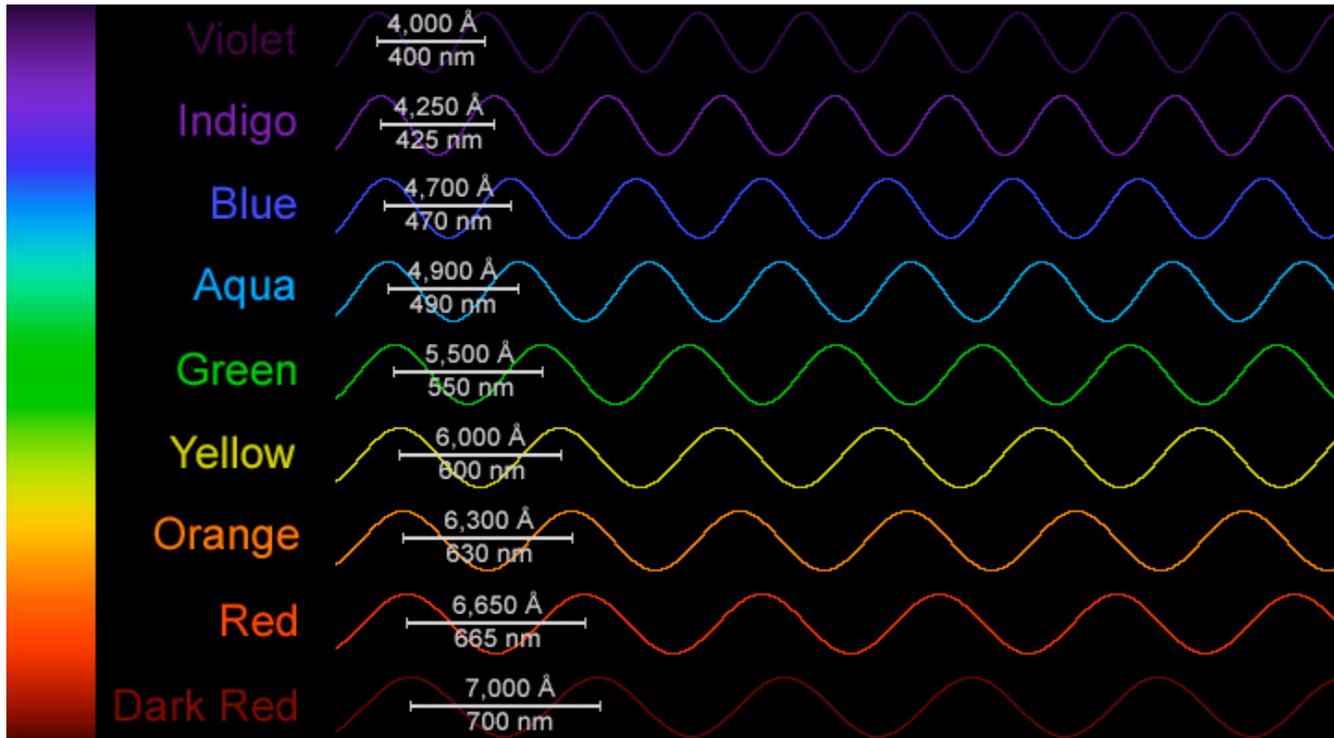
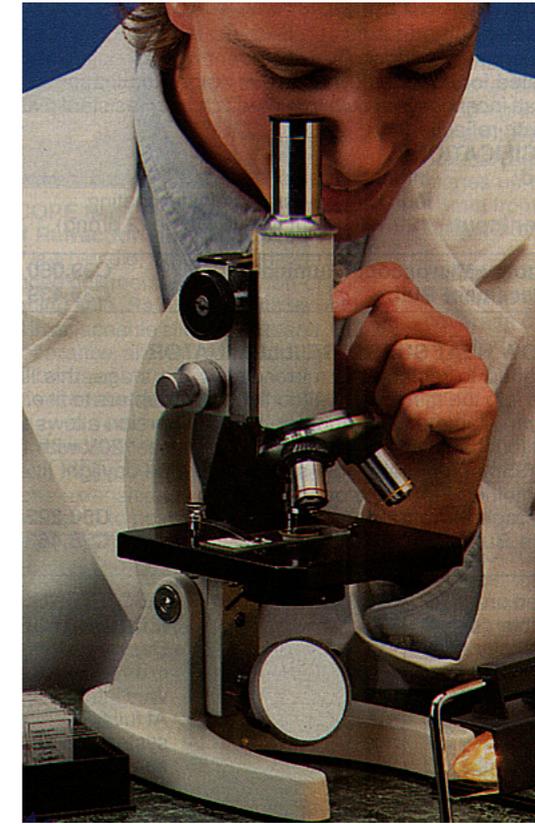
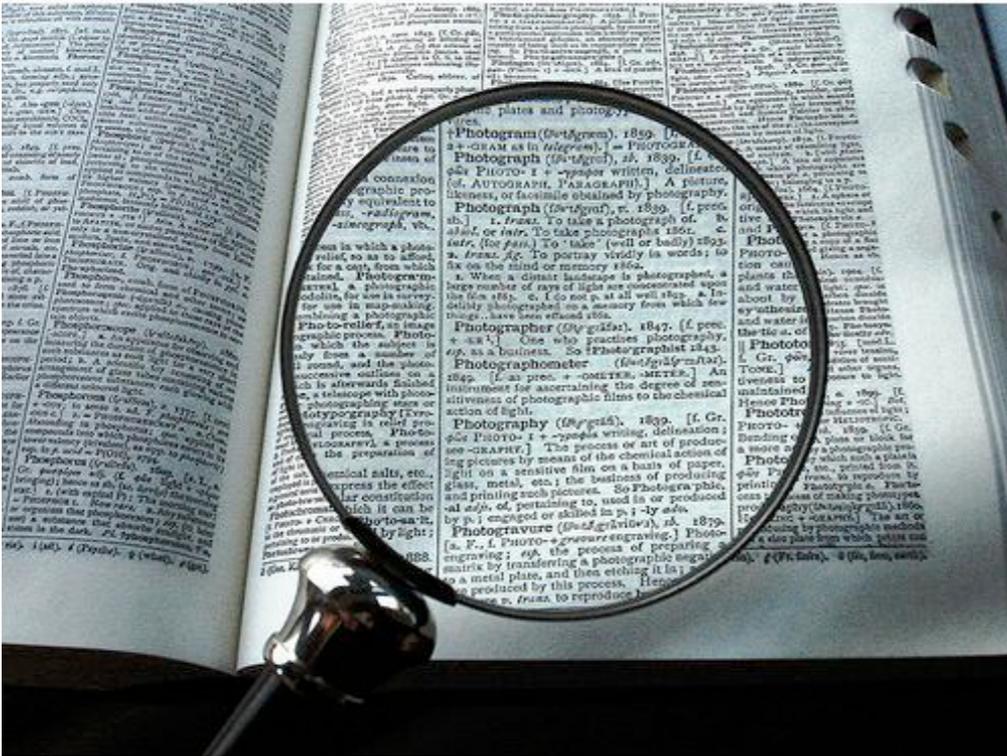


“Everyday” stuff

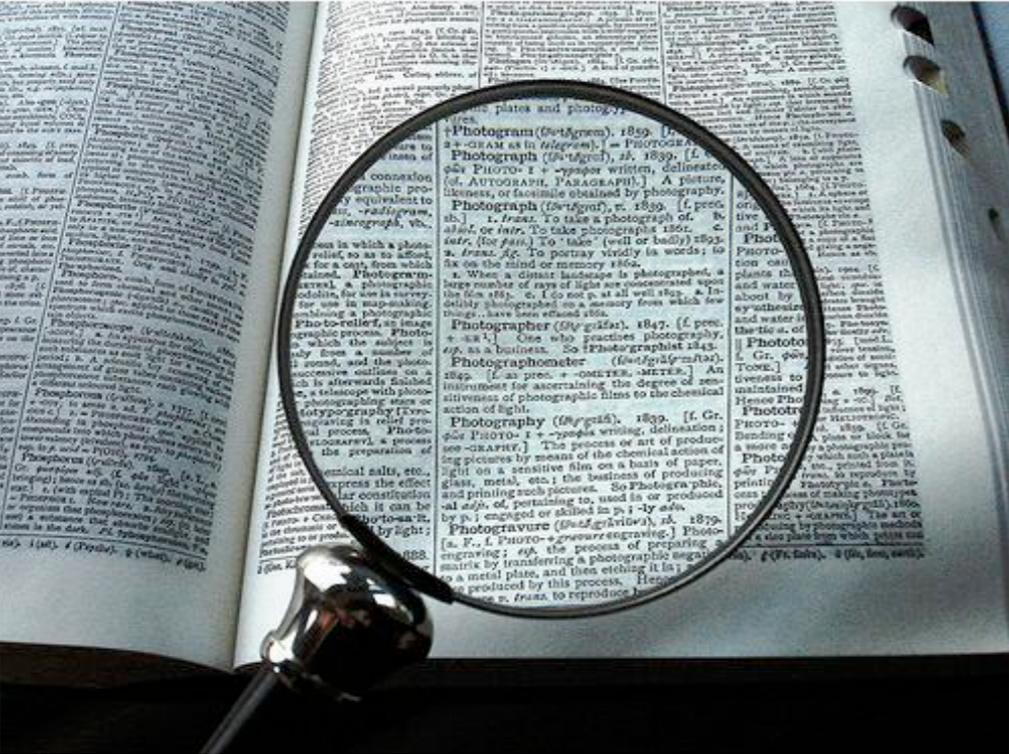
LEPTONS		
Electron Neutrino Mass -0	Muon Neutrino -0	Tau Neutrino -0
Electron .511	Muon 105.7	Tau 1 777
QUARKS		
Up Mass: 5	Charm 1 500	Top ~180 000
Down 8	Strange 160	Bottom 4 250



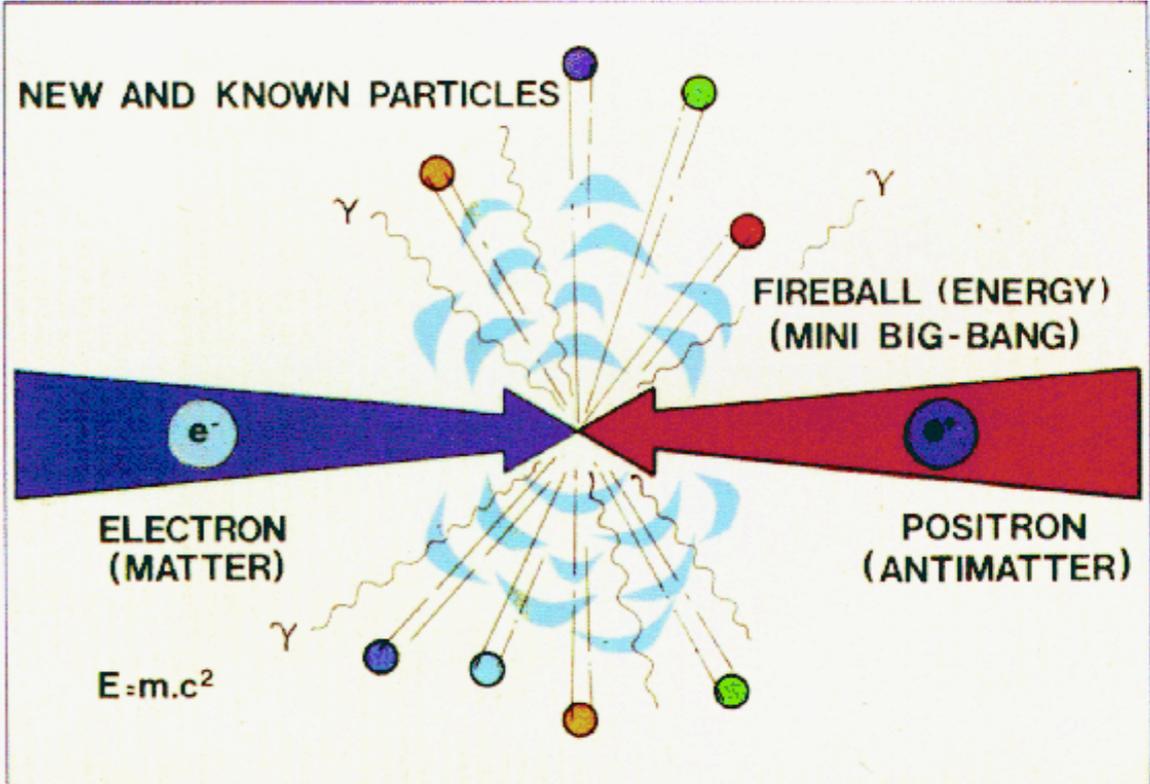
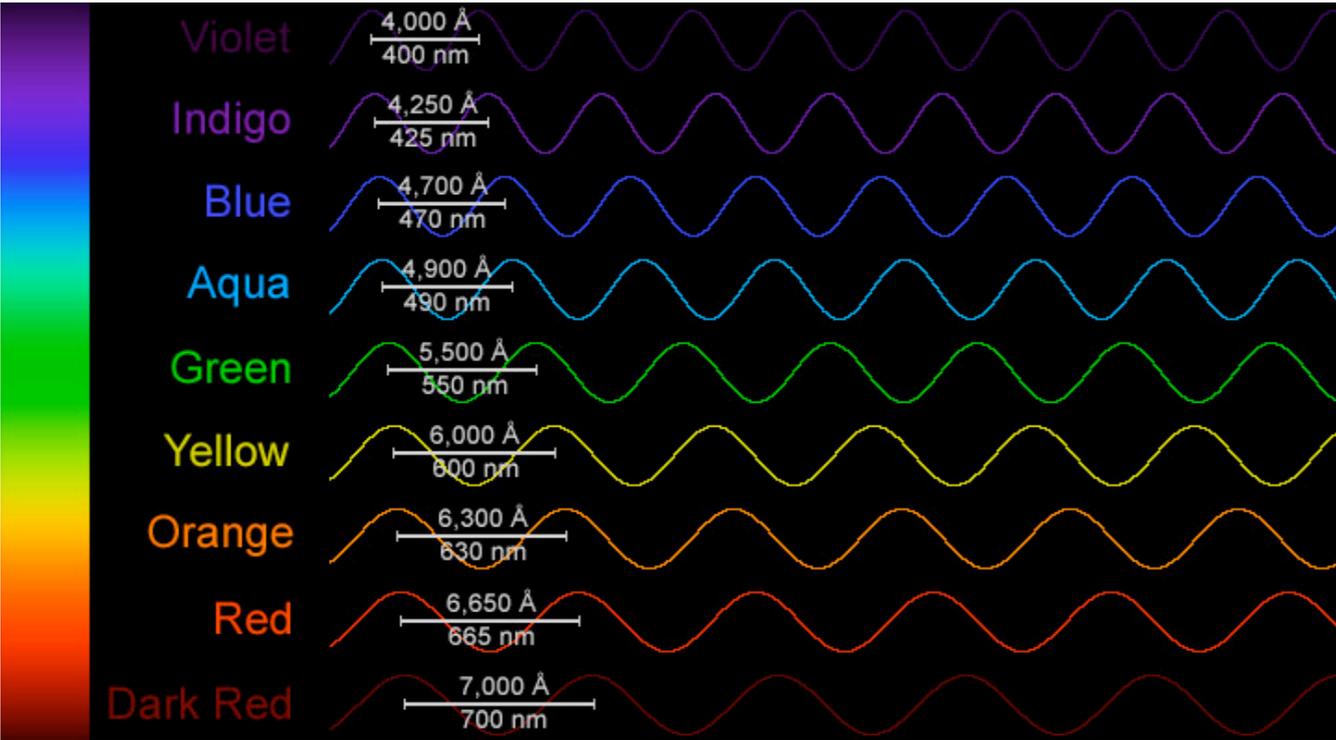
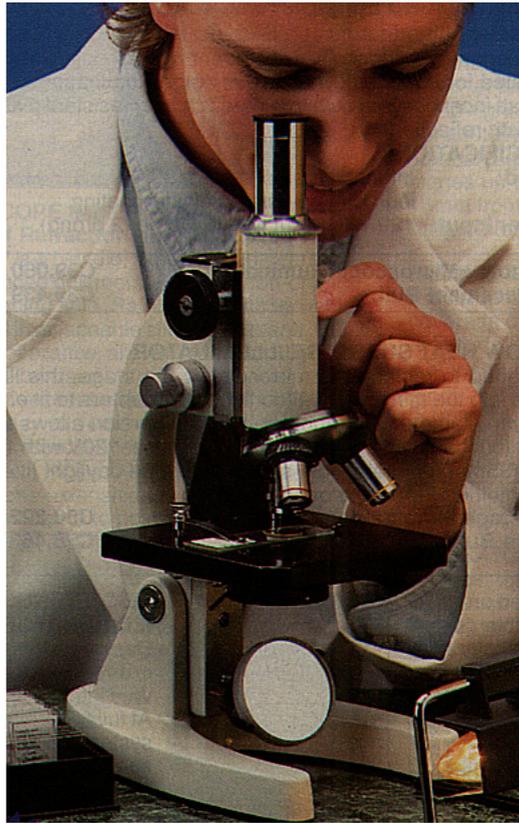
How do we find all these particles?



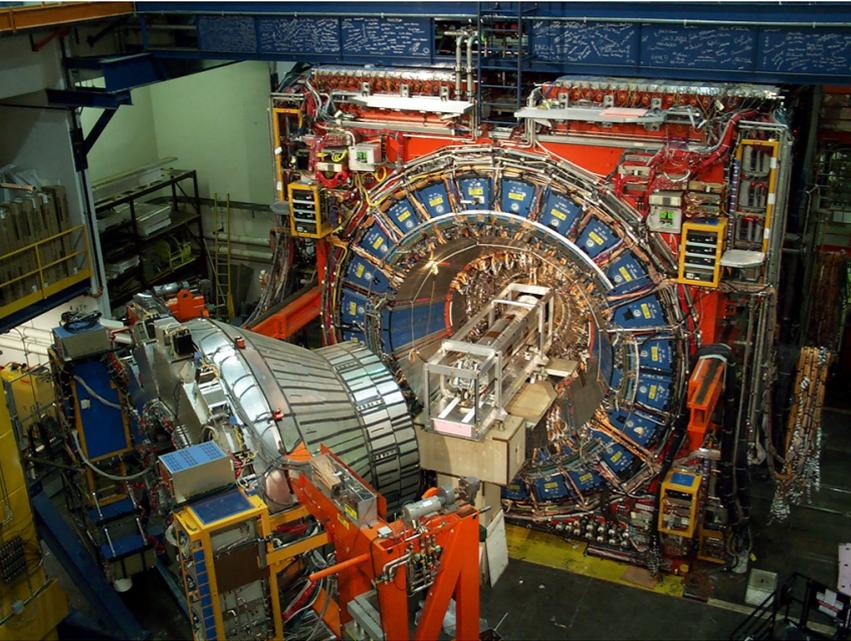
How do we find all these particles?



Experimental physicist in the lab →



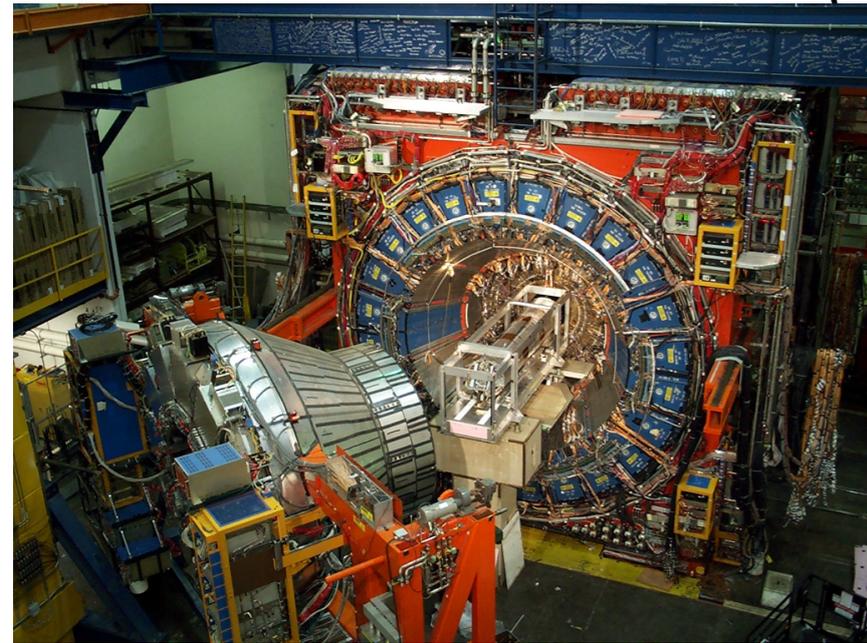
The Tevatron



Discovered the top quark, 1995

The Tevatron

I work here



Discovered the top quark, 1995

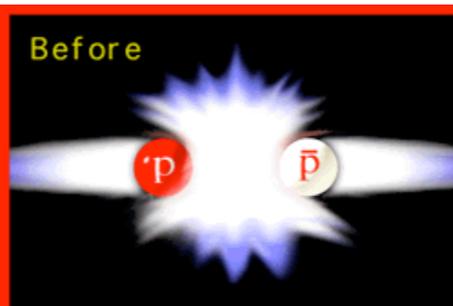
The Tevatron



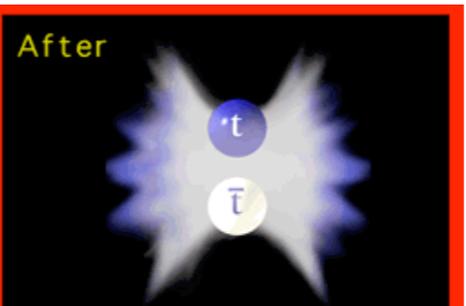
- 4 miles around
- Collides protons and anti-protons
- World's highest energy machine, ~ 2 TeV
- Two experiments: D0, CDF
- Superconducting magnets
- Running brilliantly, delivering new results all the time e.g. $\Omega_b B_s$

Top quark (~170 x proton mass!)

Before

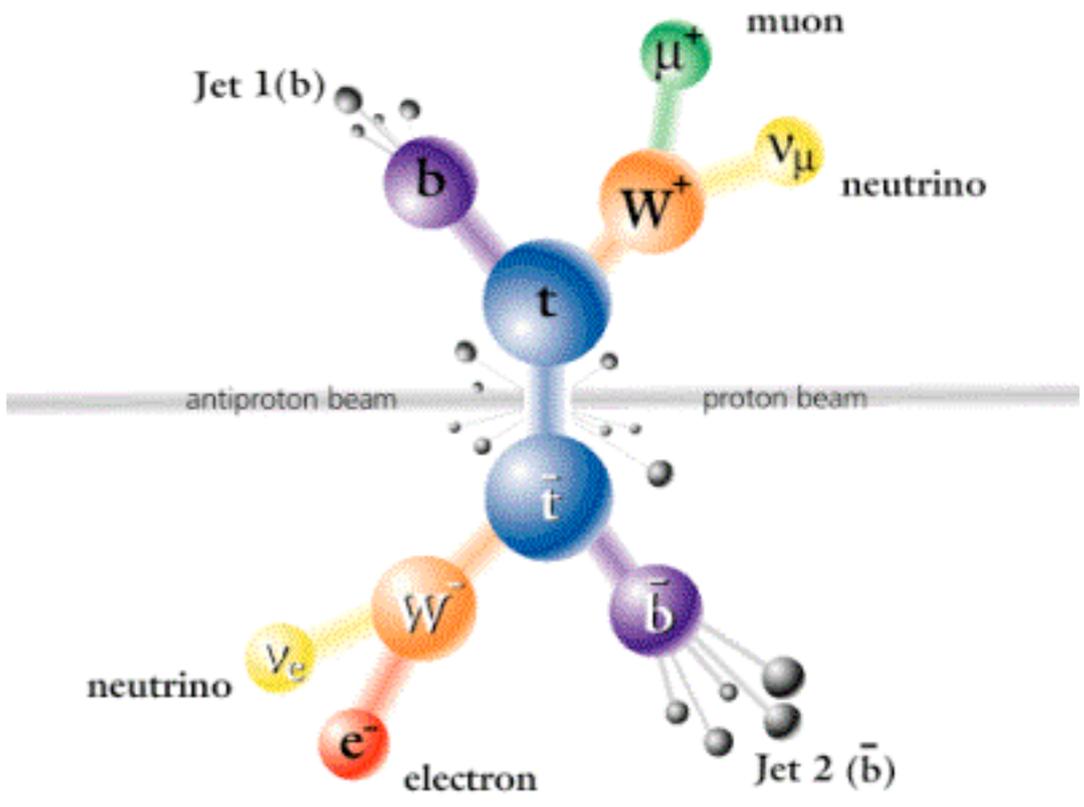
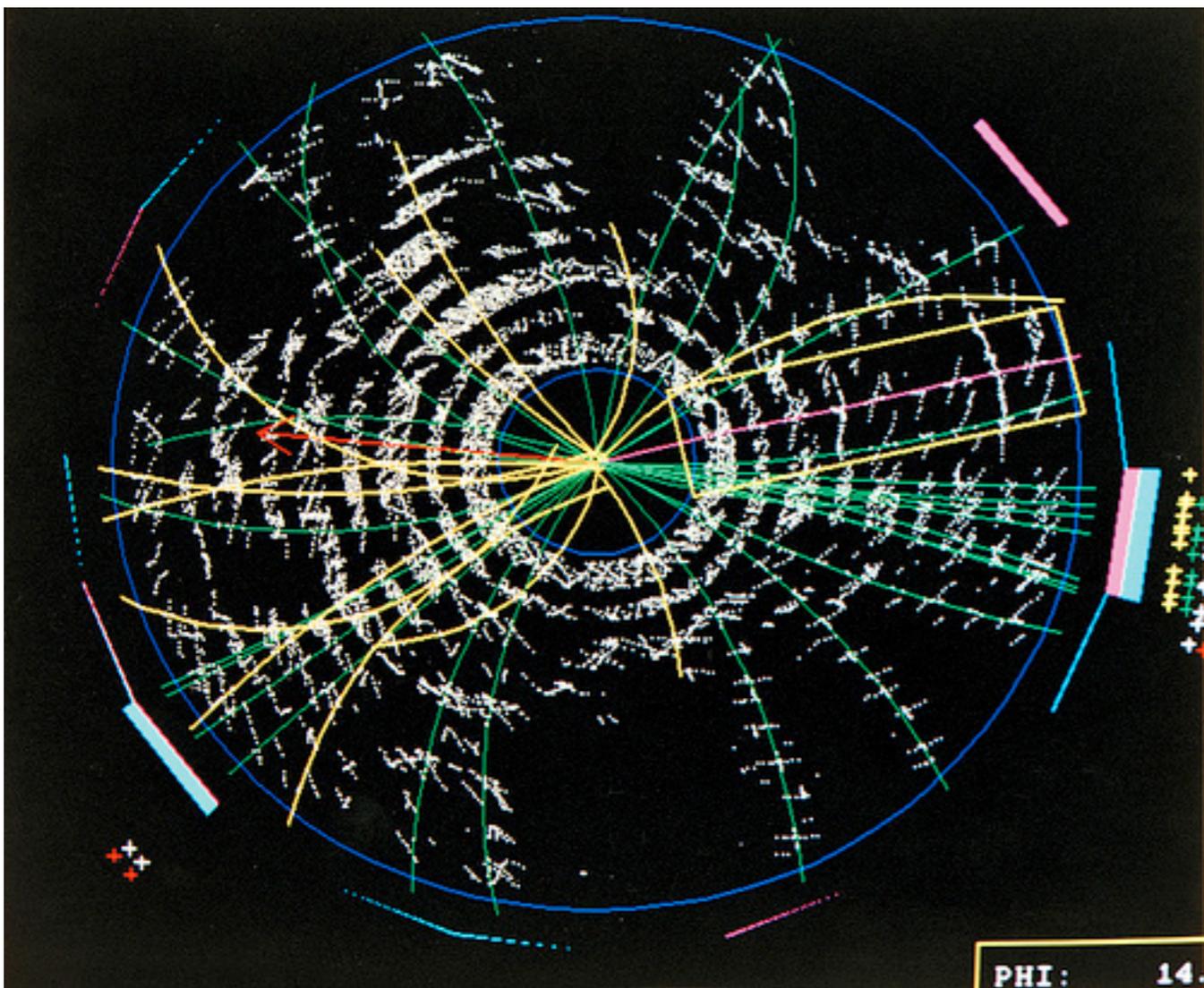


After



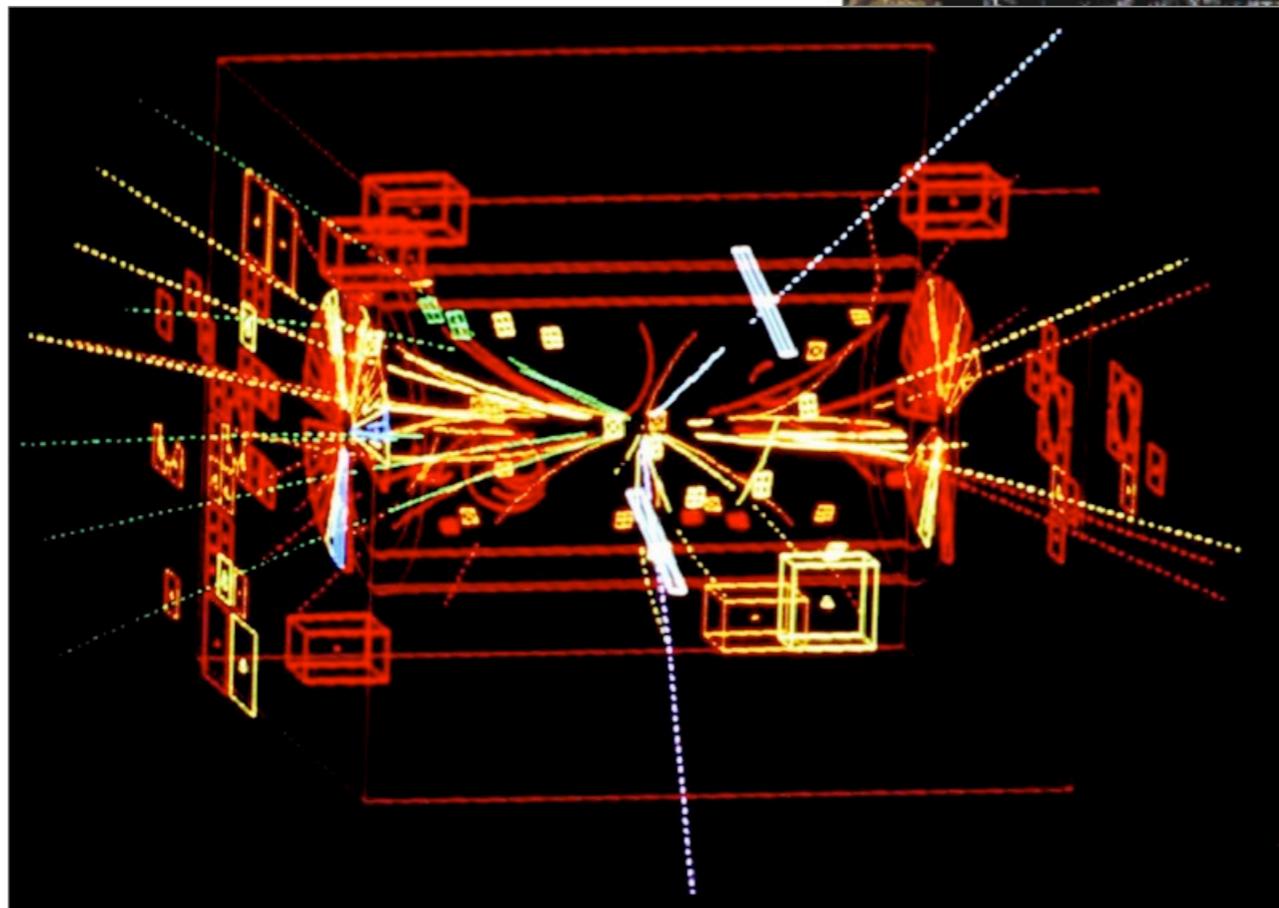
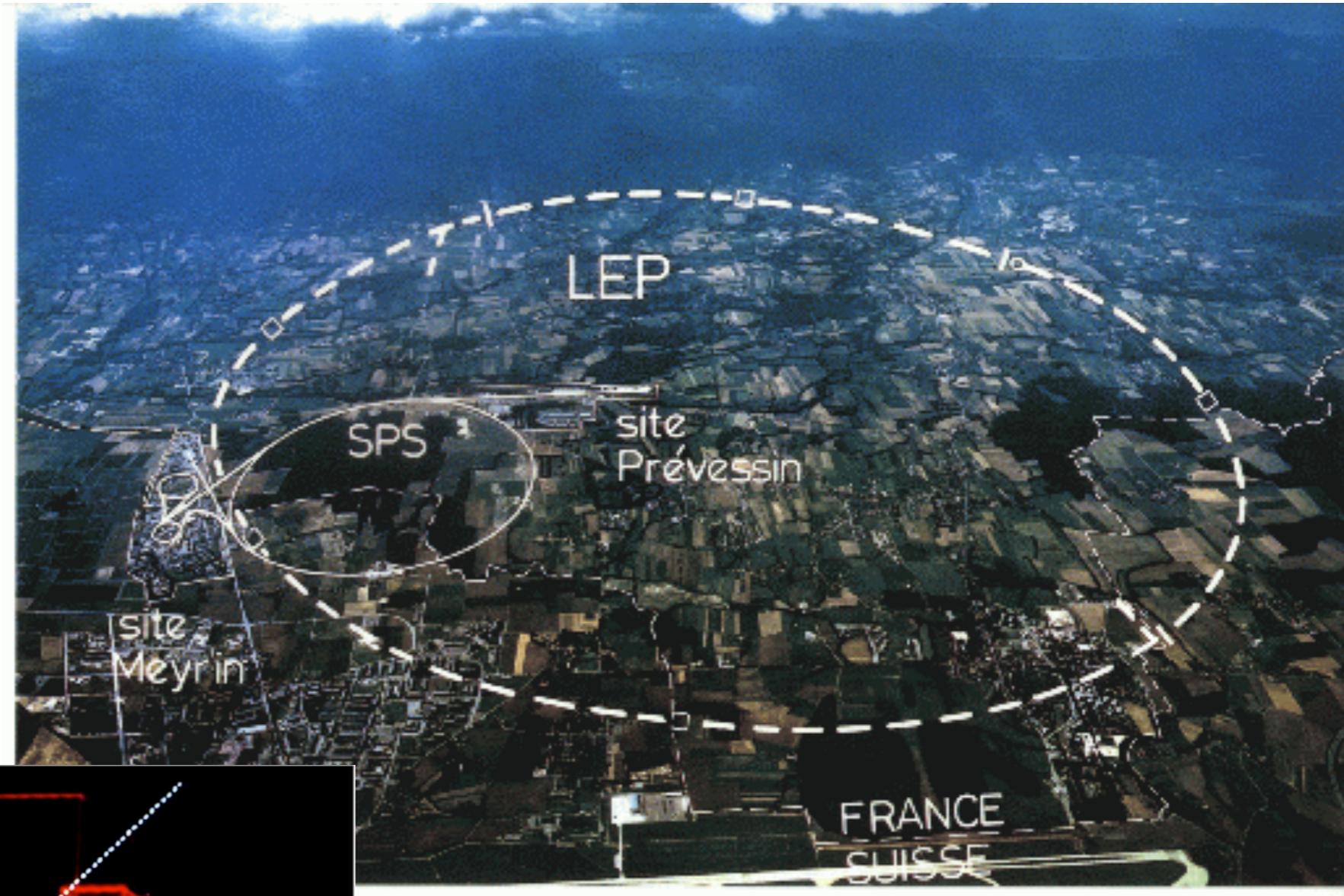
$E=mc^2$

The energy of the colliding proton and antiproton is transformed into the masses of the much more massive top and antitop quarks.



CERN

Discovered the
W and Z,
1983



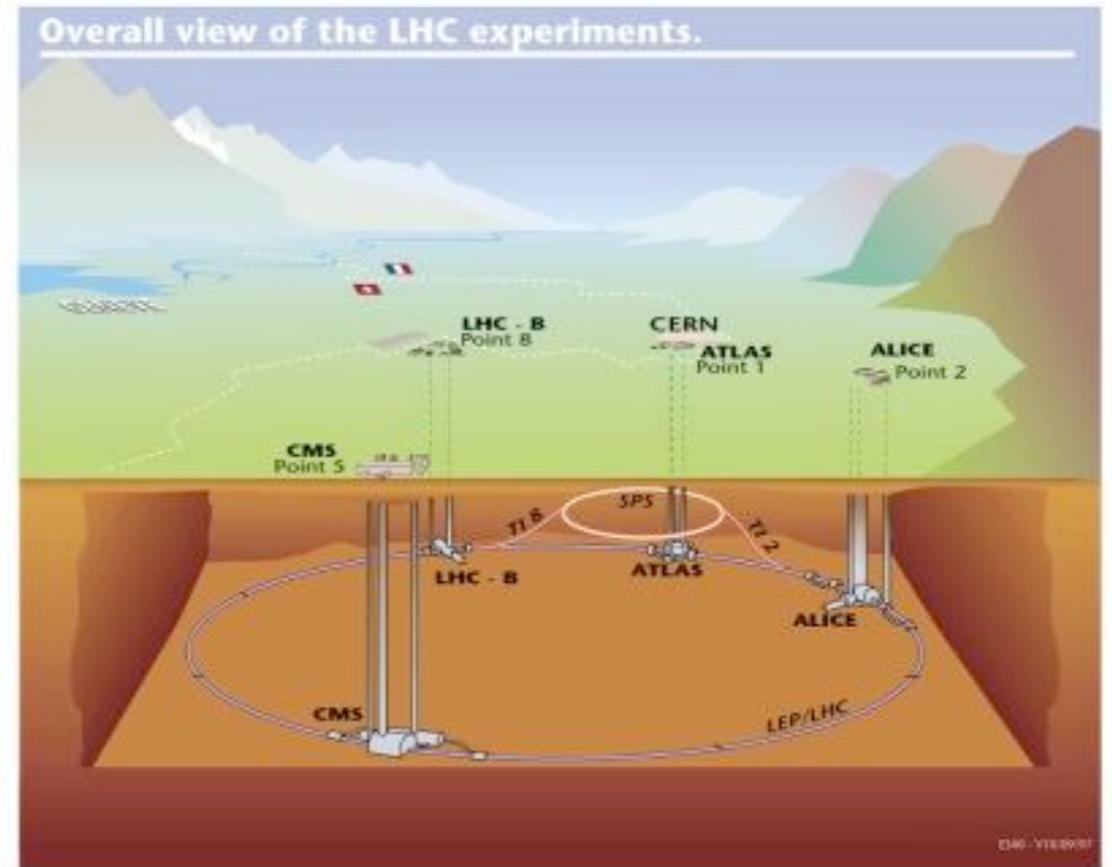
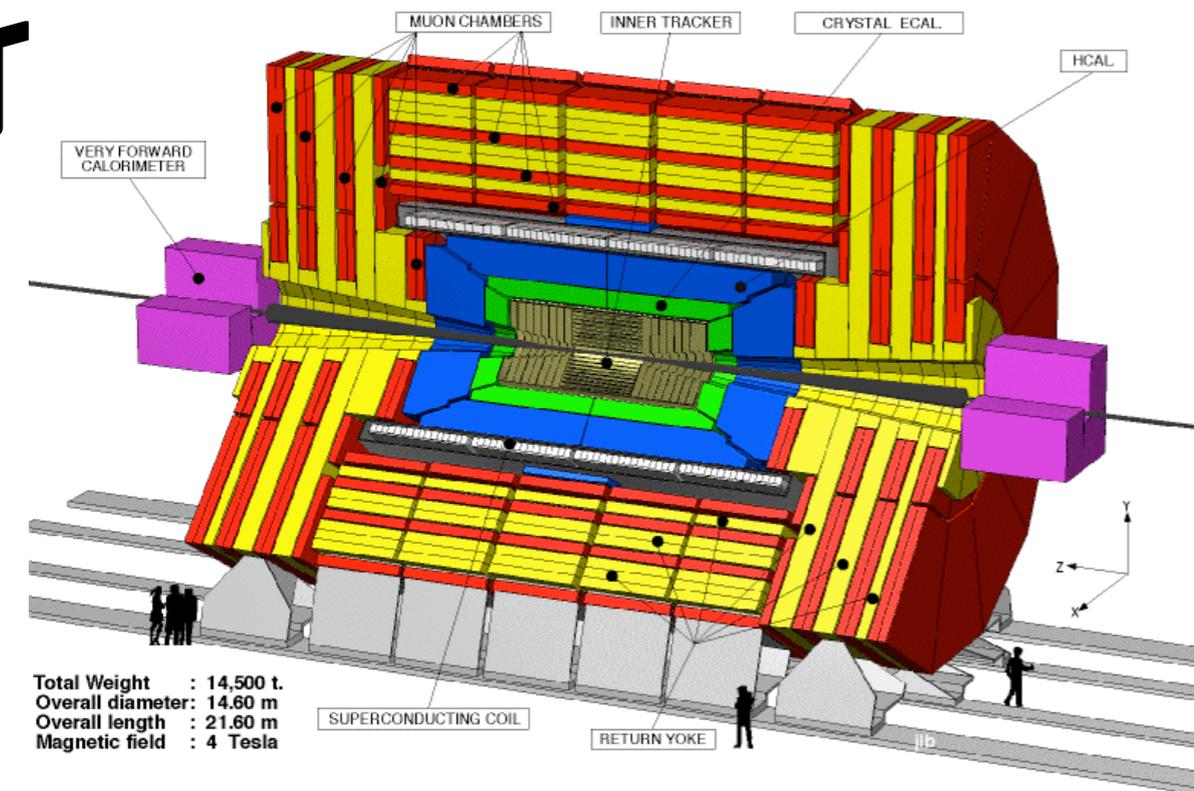
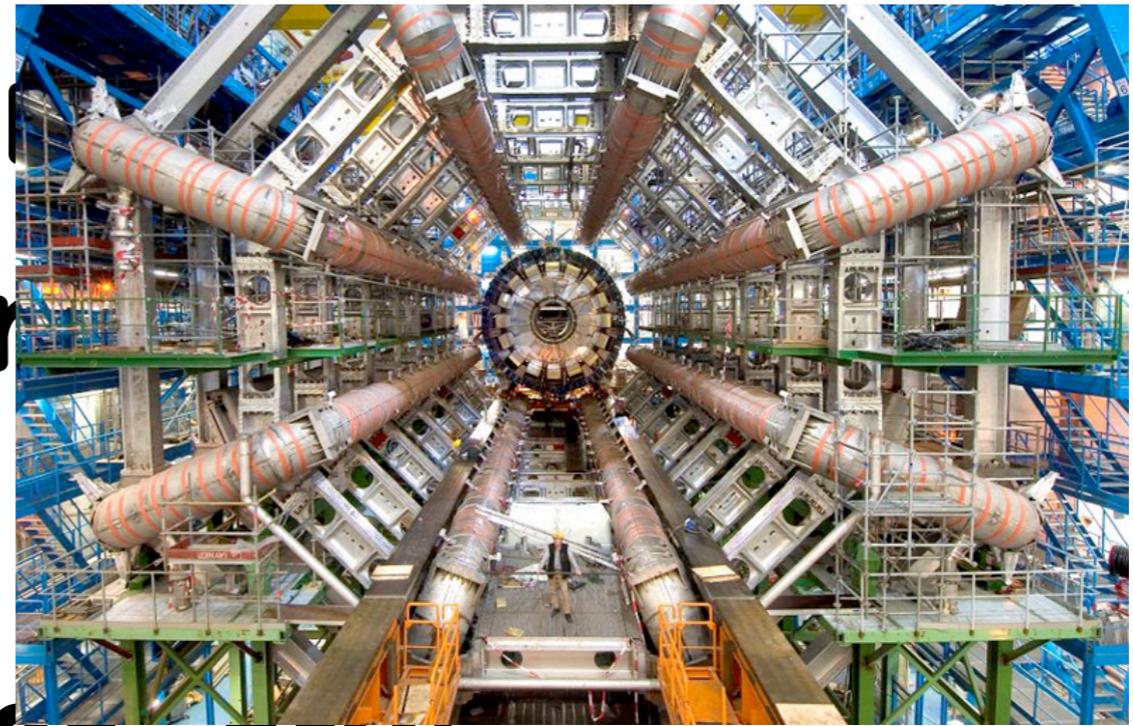
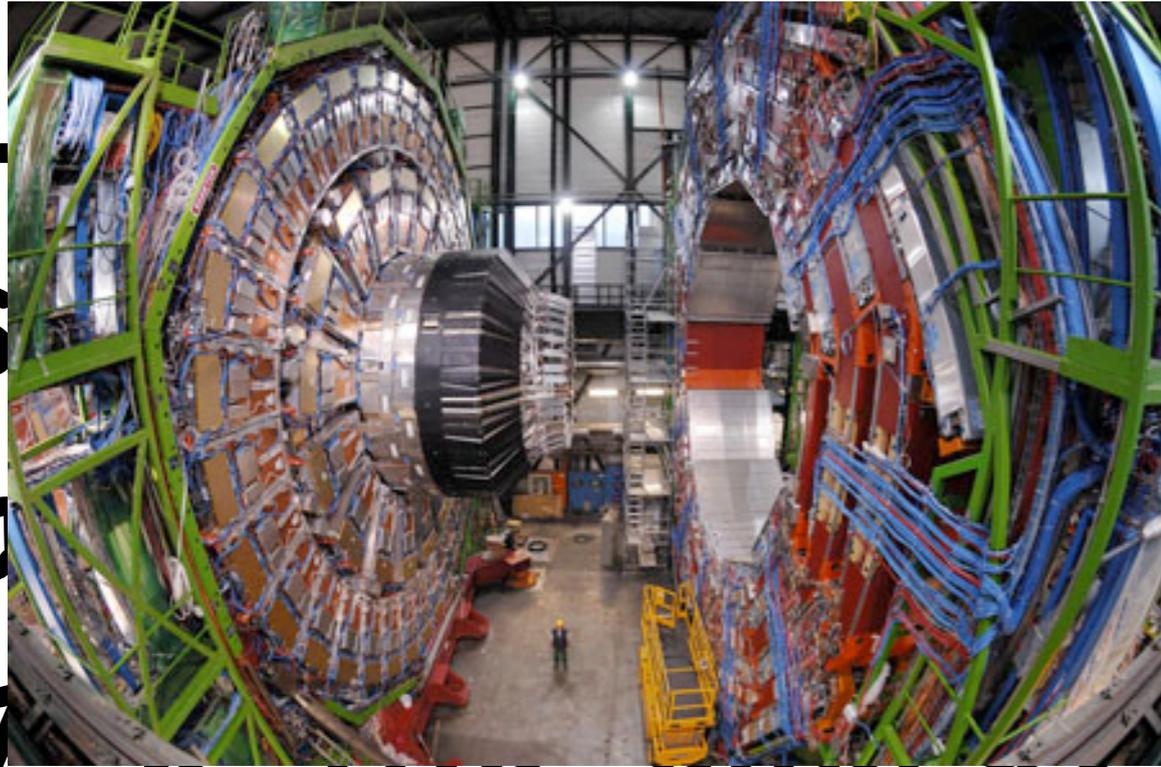
LEP → LHC

Large Hadron Collider (LHC)

Largest, most complicated
science experiment ever
attempted.

7 x the energy of the
Tevatron (14 TeV)

Large Hadron Collider (LHC)



Large Hadron Collider (LHC)

- 17 miles around, cooled to 1.9K
- 120 ton of liquid He (1% annual production)
- Collides protons and protons
- Very high energy (14 TeV)
- Equivalent to 737 at landing (60kg TNT)
- 40M collisions/sec -> record 200/sec = 2MB/s

30-40 countries



3000-4000 people



LHC pyjama party: 1am Sep 10, 2008



LHC will start-up again Oct, 09

The **BIG** questions

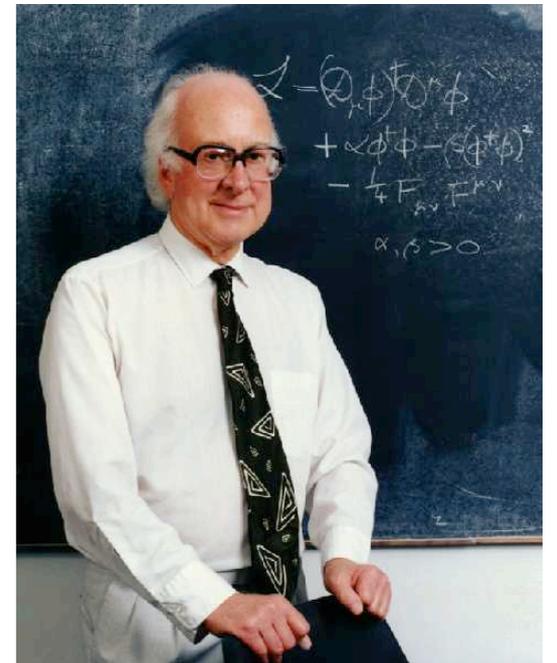
- What gives the particles their mass?
- Why 3 generations?
- Why is gravity so weak?
- Why 3 forces, are they really the same?
- Why do they have the masses they have?
- Why is there matter and no antimatter?
- What makes up the Universe?
-?

The hunt for the Higgs boson

Higgs is responsible for mass of all the standard model particles

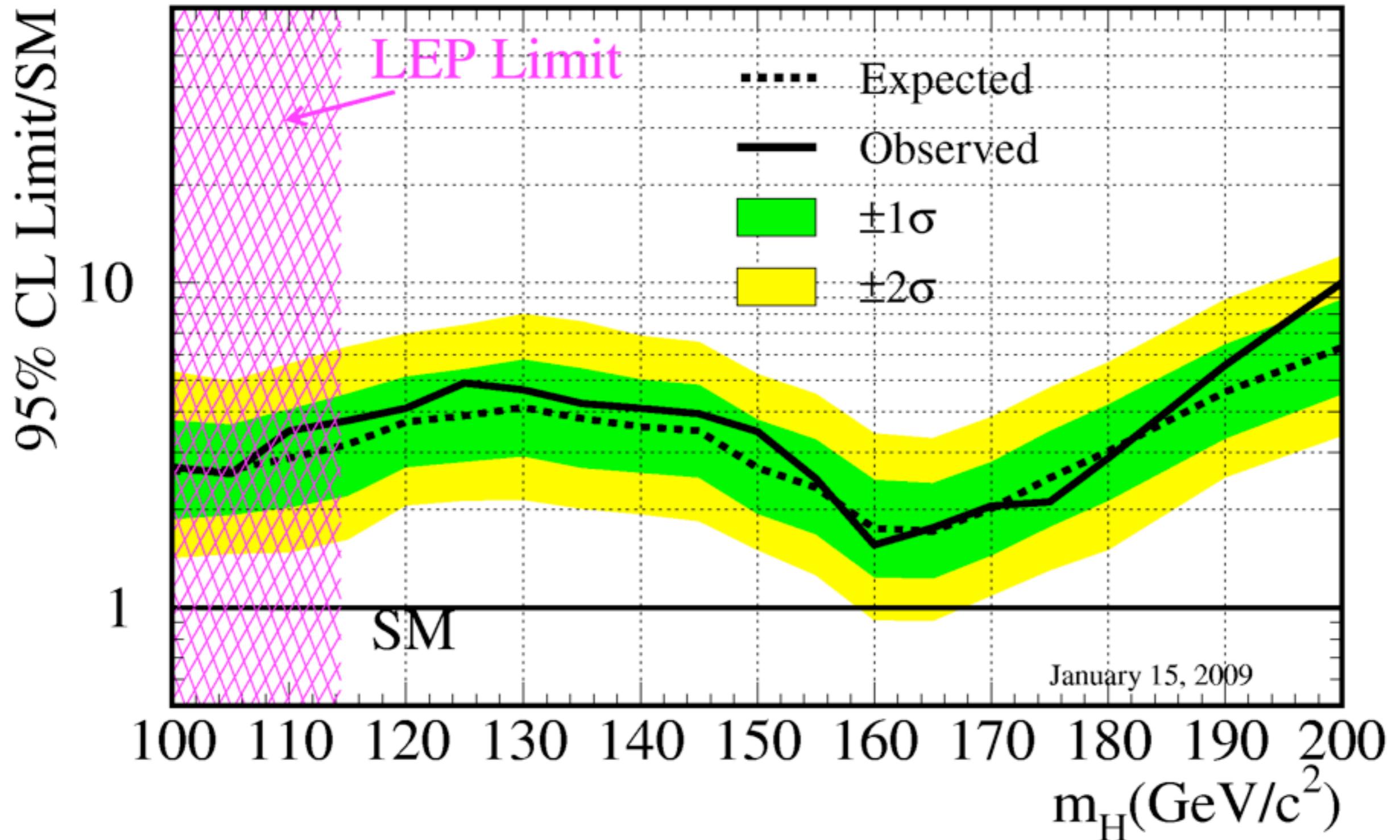
Still not seen

Higgs cocktail party analogy:



The Tevatron is getting close....

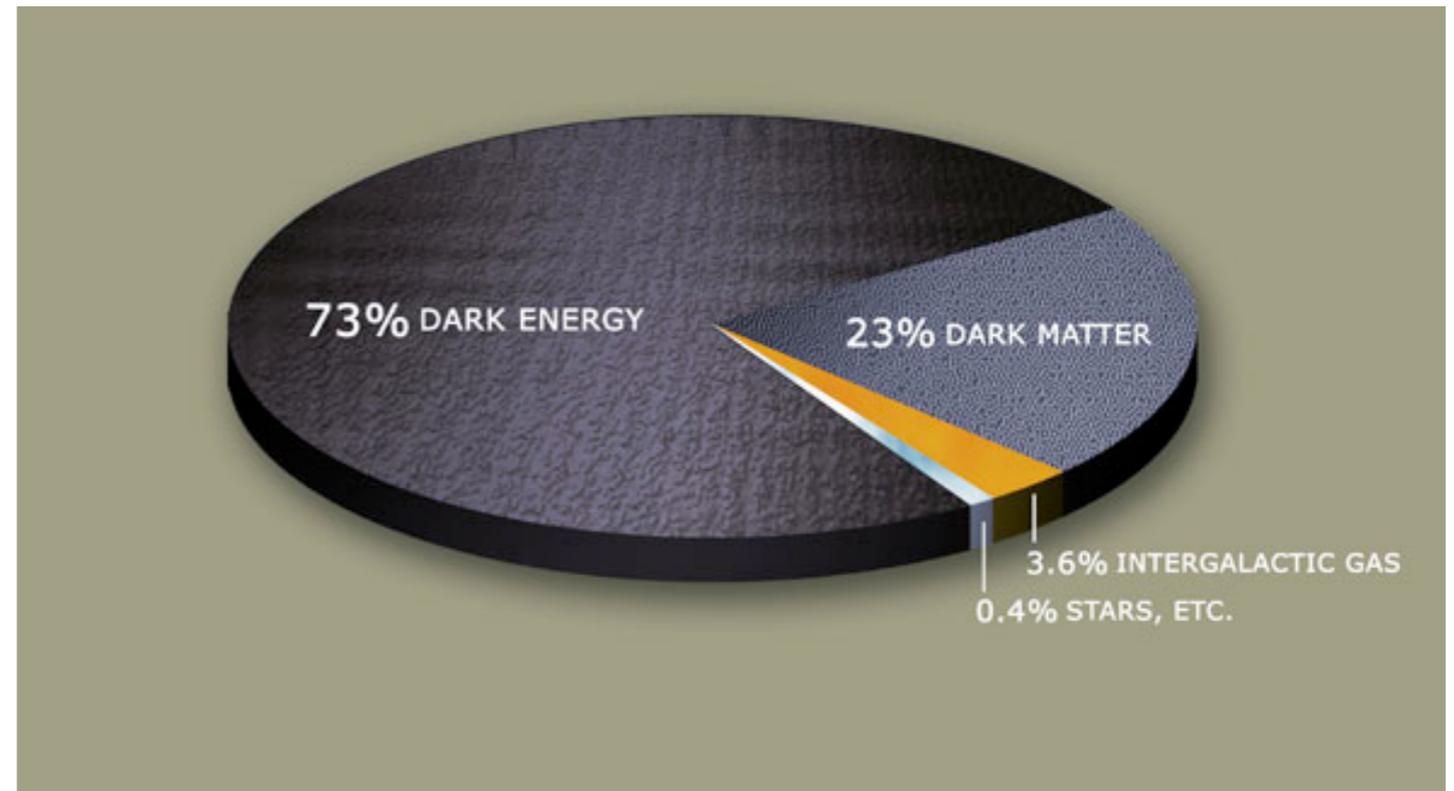
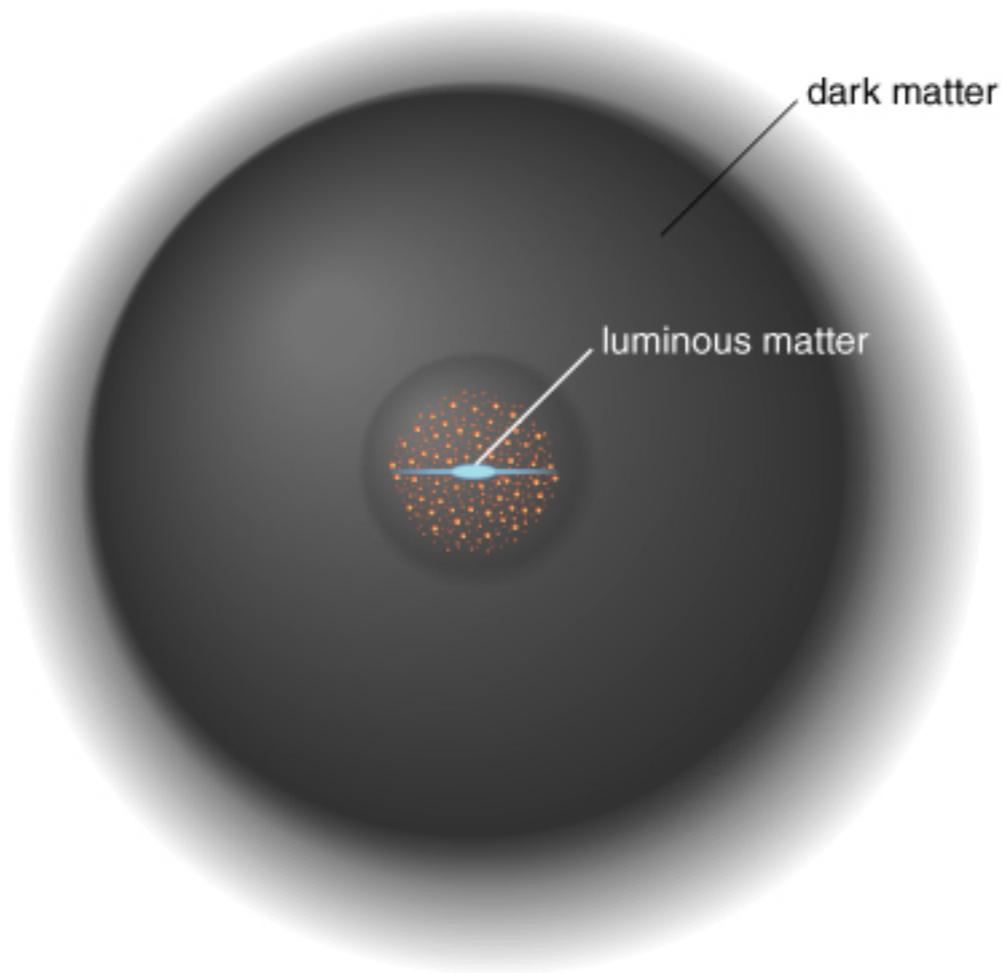
CDF Run II Preliminary, $L=2.0-3.0 \text{ fb}^{-1}$



Beyond the Standard Model

The SM (with Higgs) is **not** complete

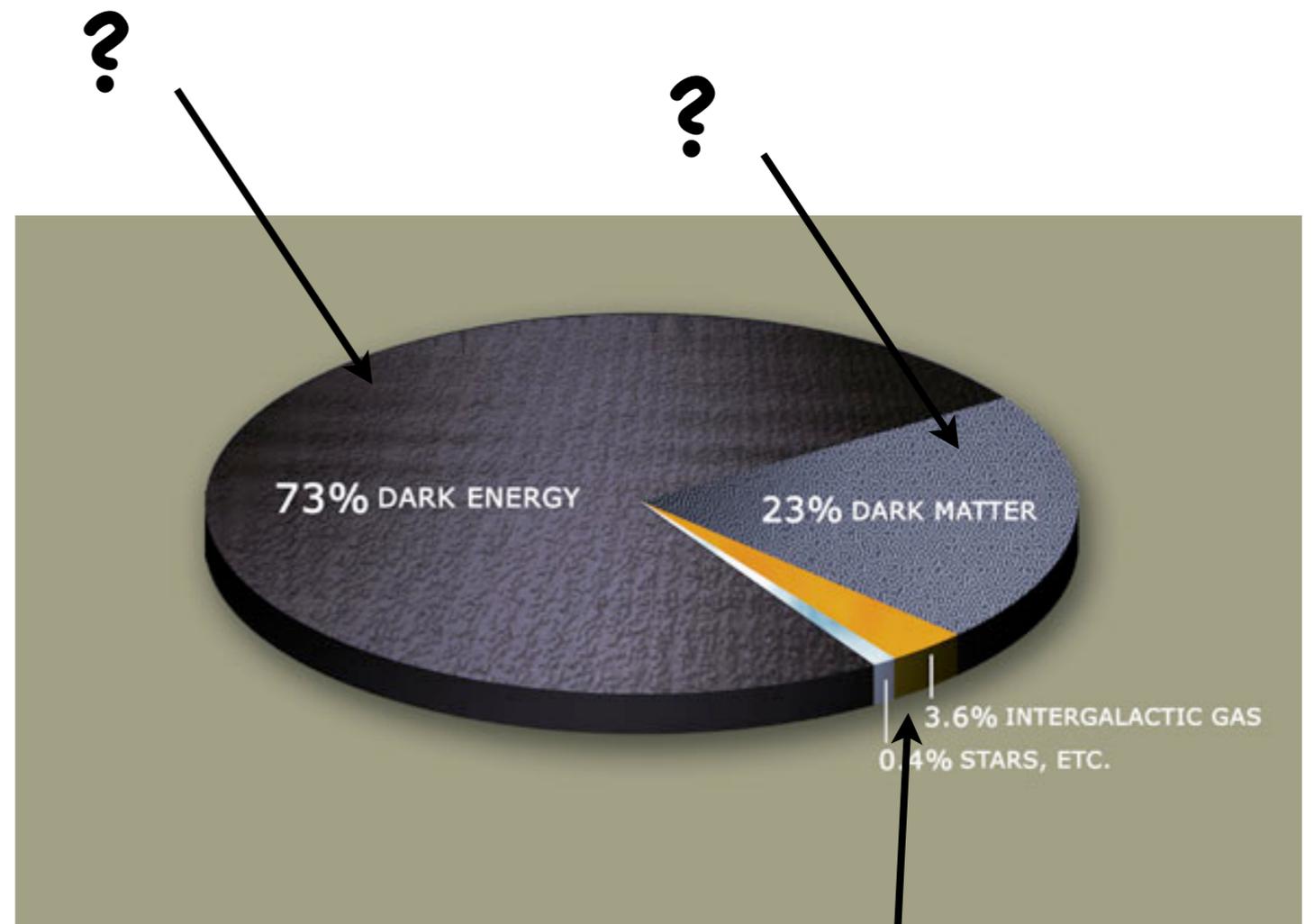
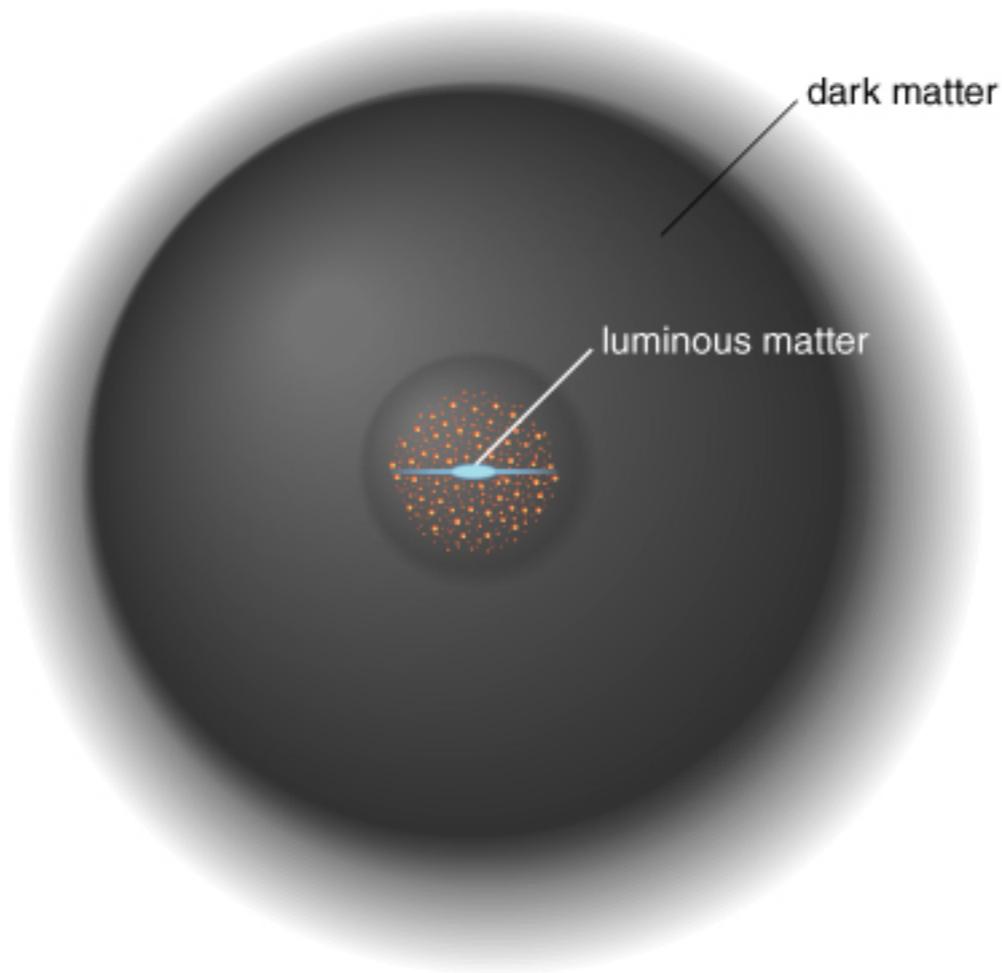
Observations of galaxies tell us



Beyond the Standard Model

The SM (with Higgs) is **not** complete

Observations of galaxies tell us



Standard Model

Beyond the Standard Model

The SM (with Higgs) is **not** complete

Observations of

?

?

gal **Session NA: AAPT Plenary – Dark Matter in the Laboratory**

Location: H-Grand Ballroom EF
Sponsor: AAPT
Date: Monday, Feb. 16
Time: 11:30 a.m.–12:30 p.m.
Presider: David Cook

*Joseph D. Lykken, Fermilab, 1707 E. Thomas Rd.,
Wheaton, IL 60187; lykken@fnal.gov*



Joseph D. Lykken

Most of the universe is dark matter, whose composition is entirely unknown and may involve new forces or principles of nature. Using ultra-sensitive detectors deep underground, physicists are attempting to detect dark matter particles streaming in from space. At the Large Hadron Collider, physicists hope to manufacture large numbers of dark matter particles and study their properties in the laboratory. I will describe these efforts and how impending discoveries may change our fundamental understanding of physics and the universe.

Standard Model

Beyond the Standard Model

Other reasons to believe in new physics

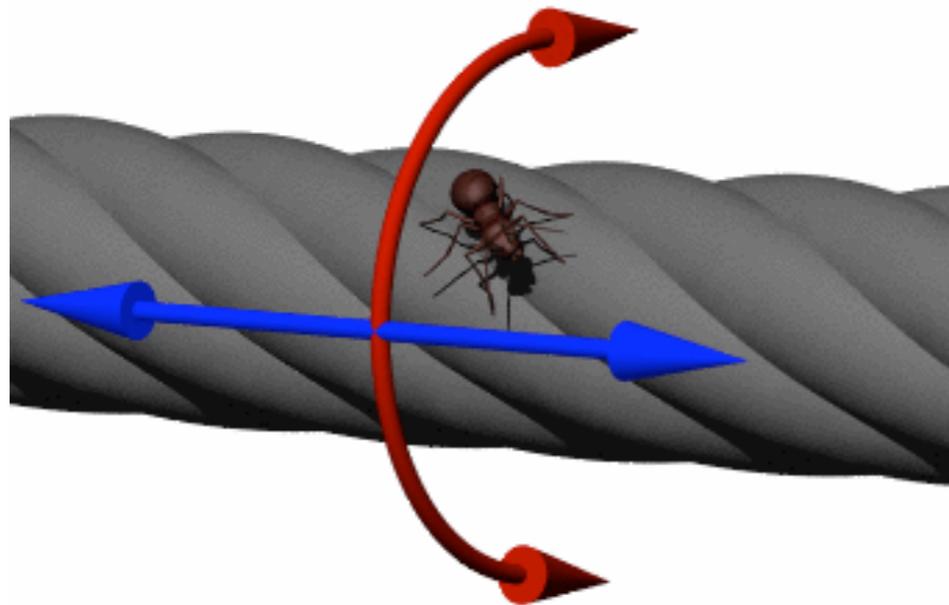
e.g.

- Extra dimensions of space
- Second copy of SM - **supersymmetry**

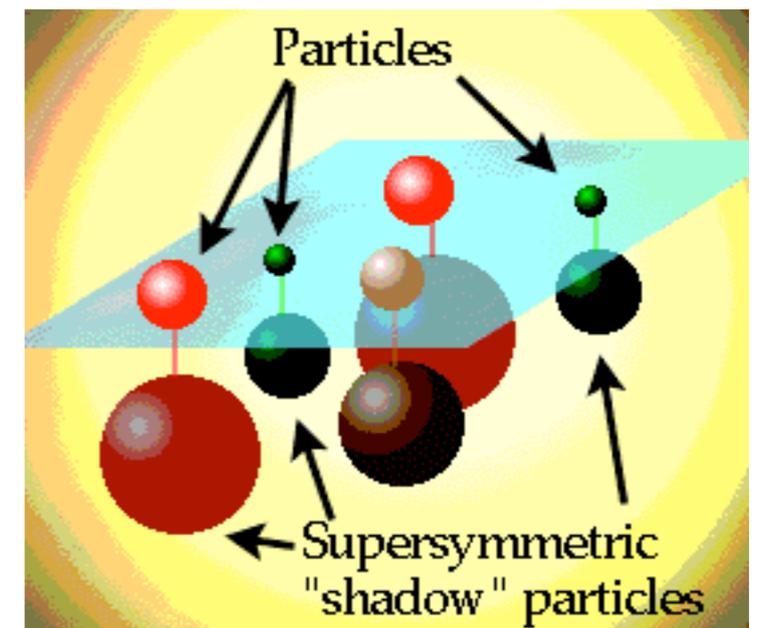
Both predict new particles and Dark Matter possibilities

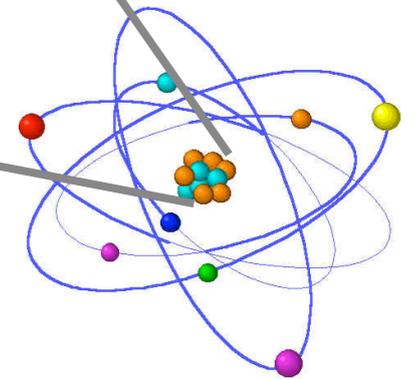
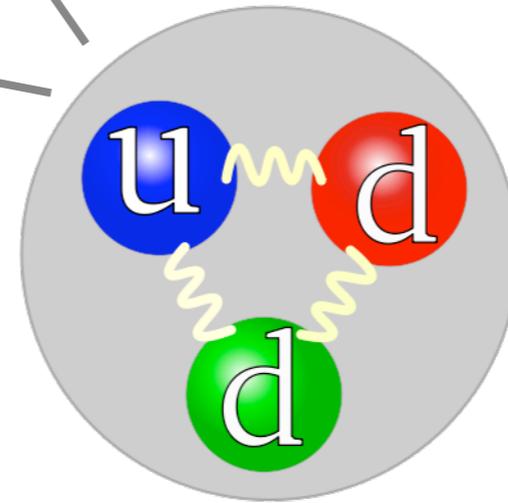
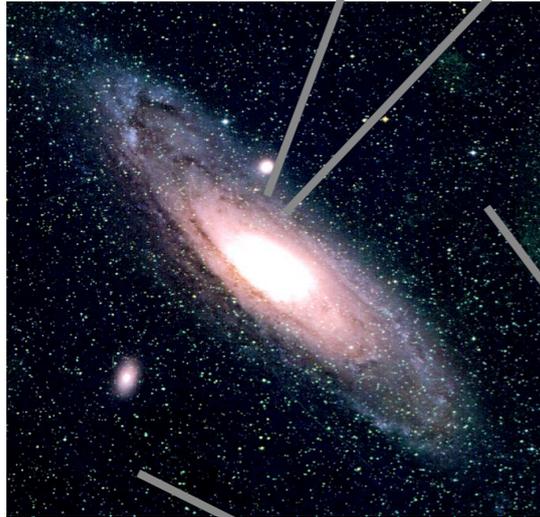
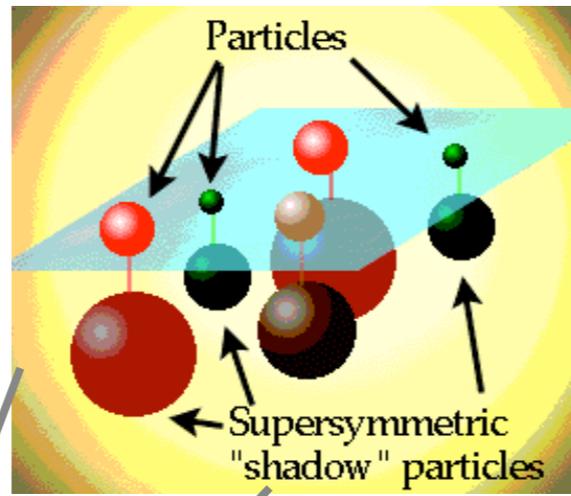
Colliders and **Cosmos**
probing the same physics!

Extra dimensions of space, curled up very small
May be able to see them at Tevatron/LHC!



Supersymmetry is a new symmetry of nature, only noticeable at short distances.
New particles made in collisions





Keep your eye on the headlines!

- Very exciting times ahead
- Expect important discoveries impacting microscopic and macroscopic physics
- Many long standing mysteries may be solved:

Origin of mass, source of most of universe's matter, why not antimatter, unification of forces....

The **BIG** questions

- What gives the particles their mass?
- Why 3 generations?
- Why is gravity so weak?
- Why 3 forces, are they really the same?
- Why do they have the masses they have?
- Why is there matter and no antimatter?
- What makes up the Universe?
-?