SMU

CELEBRATION:

Higgs boson wins Physics Nobel Prize:

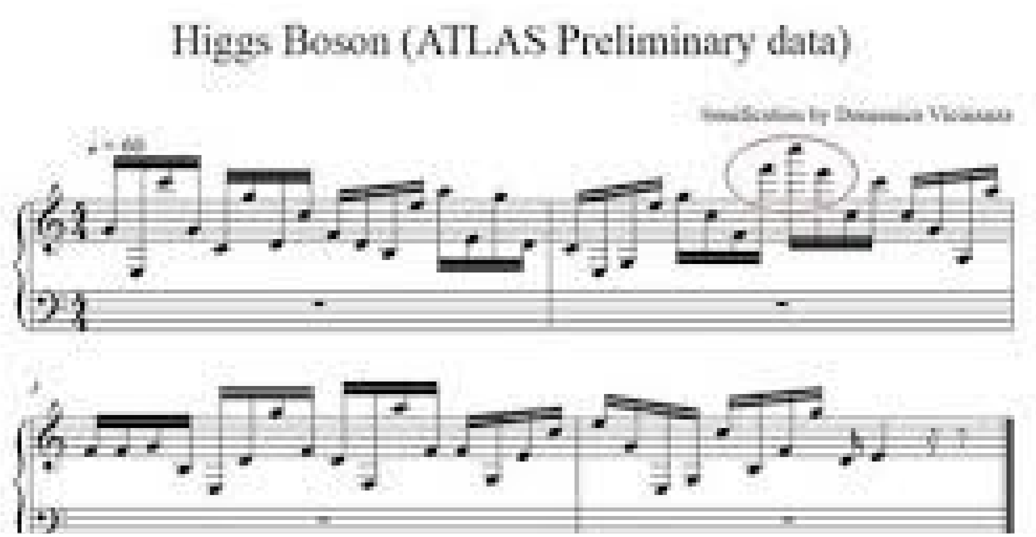
Monday October 21, 2013

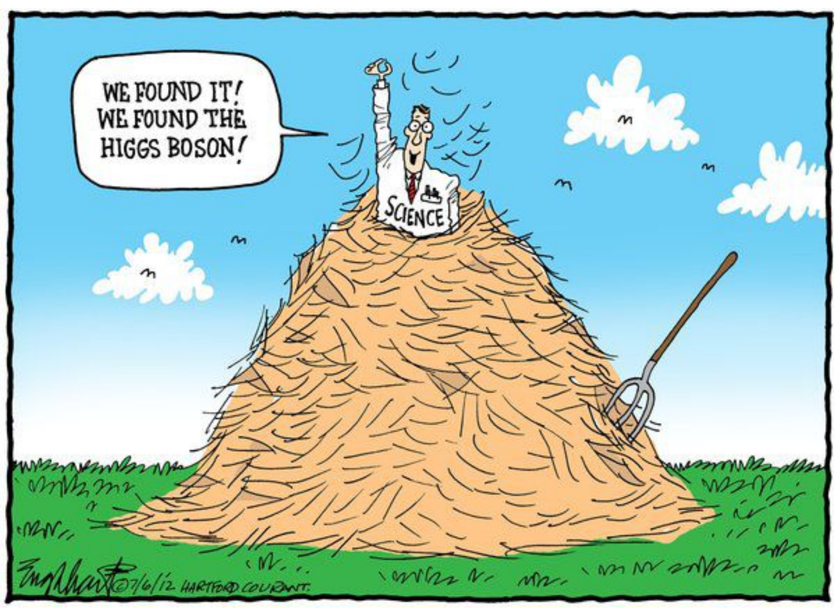
From the official Nobel Prize Press release:

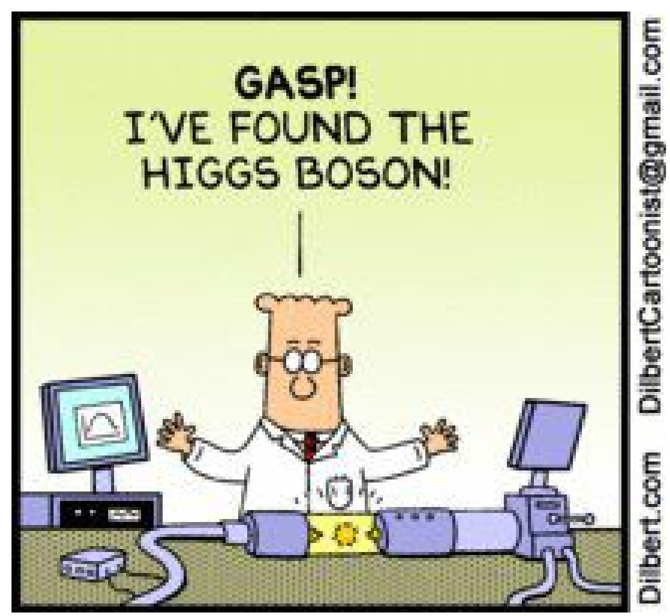
“On 4 July 2012, at the CERN laboratory for particle physics, the theory was confirmed by the discovery of a Higgs particle. CERN’s particle collider, LHC (Large Hadron Collider), is probably the largest and the most complex machine ever constructed by humans. Two research groups of some 3,000 scientists each, **ATLAS** and **CMS**, managed to extract the Higgs particle from billions of particle collisions in the LHC.”

TEN MYTHS ABOUT RUSSIA
JAPAN: HOT GREEN CARS
Newsweek
The Biggest Experiment Ever
(And It's European)
The Economist
A giant leap for science
Science
BREAKTHROUGH of the YEAR
The HIGGS BOSON
DER SPIEGEL
DAS TOR ZU EINER ANDEREN WELT
Physiker entschlüsseln das Geheimnis der Anti-Materie
Volume 716, Issue 1, 17 September 2012
ISSN 0370-2693
ELSEVIER
PHYSICS LETTERS B
Available online at www.sciencedirect.com
SciVerse ScienceDirect
CMS
ATLAS
2011-12
TIME
Nº5
PARTICLE PHYSICIST
FABIOLA GIANOTTI

… like it or not, Higgs Boson is in the public lexicon







Past & Present Discoveries

Discovery of Charm: 1976 Nobel Prize

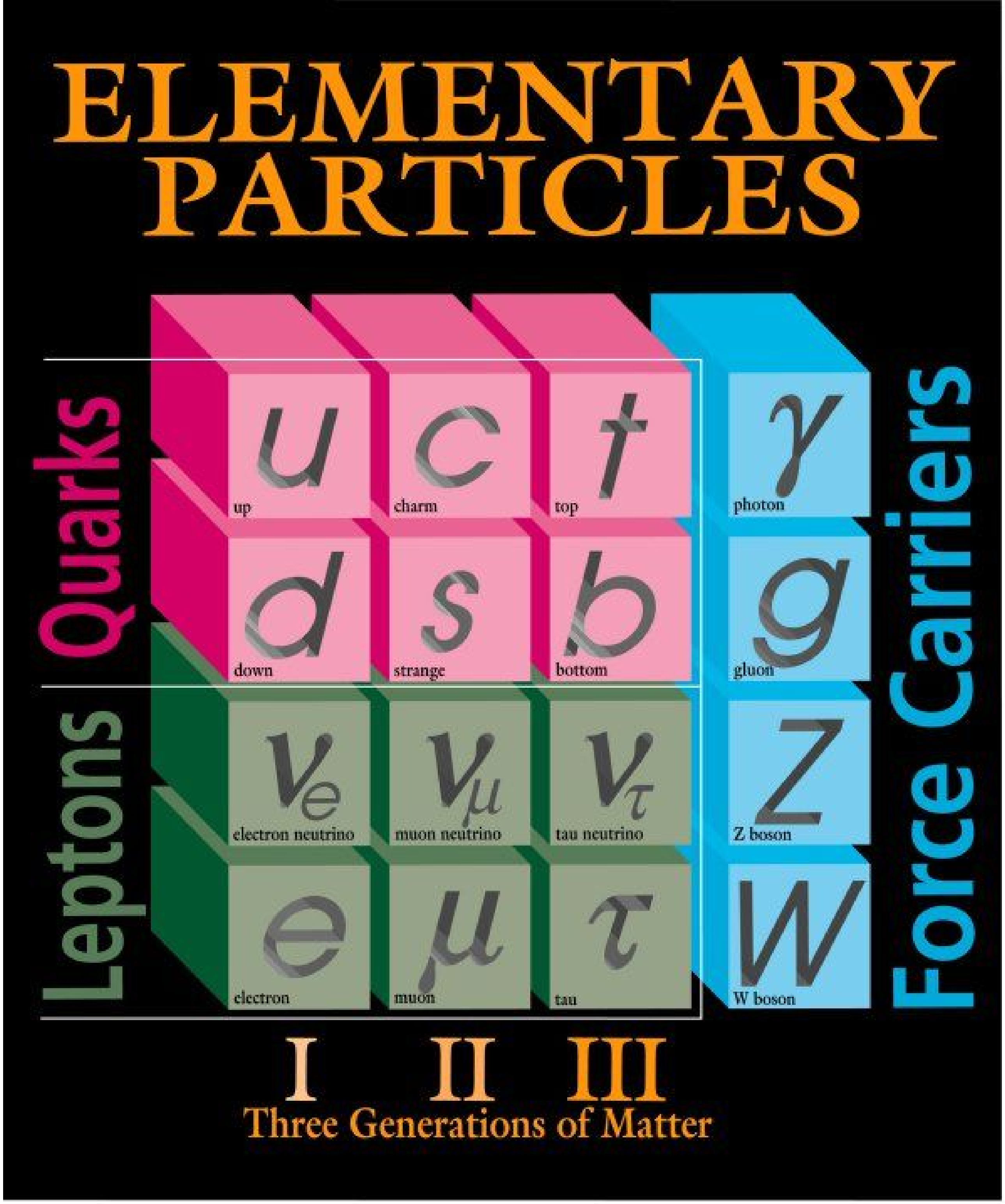
- November 1974 Revolution
- Mechanism for CKM and CP violation

Discovery of W/Z Boson: 1984 Nobel Prize

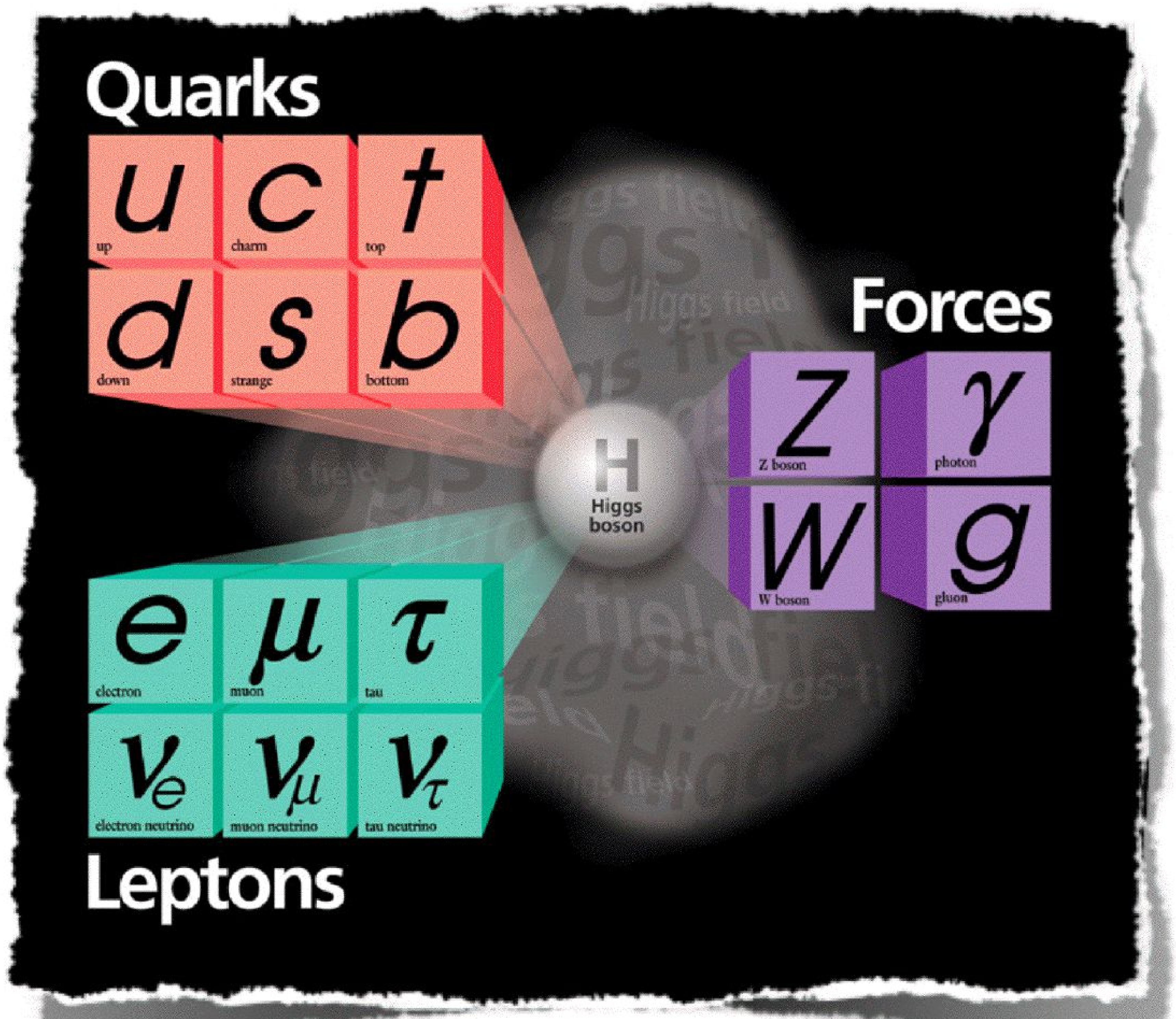
- Discovery in 1983 w/ proton anti-proton collider
- Set the stage for the Higgs

Discovery of Higgs Boson: 2013 Nobel Prize

- Discovery in 2012 w/ LHC proton-proton collider
- Set the stage for the ______???



Fermilab 95-759


Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
H
Higgs boson
e
electron
μ
muon
τ
tau
νe
electron neutrino
νμ
muon neutrino
ντ
tau neutrino
Leptons

Standard Model of

FUNDAMENTAL PARTICLES AND INT[...]CTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (... QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactio... the "Standard Model."

TO BE UPDATED

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

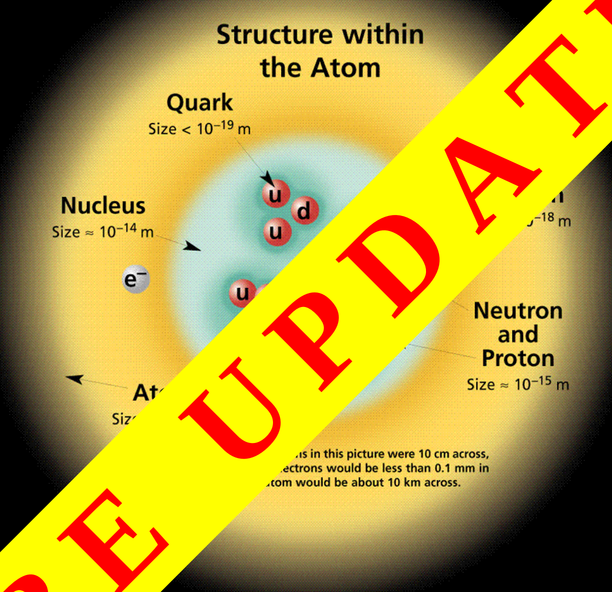
Leptons spin = 1/2		
Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	–1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	–1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	–1

Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of ħ, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $= 1.05\times10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$), where 1 GeV $= 10^9$ eV $= 1.60\times10^{-10}$ joule. The mass of the proton is 0.938 GeV/c^2 $= 1.67\times10^{-27}$ kg.



BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1		
Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	–1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Color Charge
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and ***W*** and ***Z*** bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons
One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq.

Residual Strong Interaction
The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

[...]TIES OF THE INTERACTIONS

Property	[...]avitational	Weak (Electroweak)	Electromagnetic	Strong Fundamental	Strong Residual
	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
[...]:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength rela[...]mag for two u qua[...]: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$
Baryons are fermionic hadrons.
There are about 120 types of baryons.

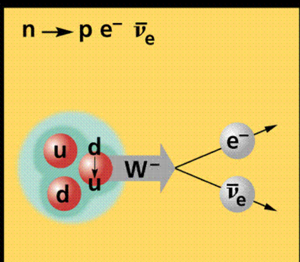
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	–1	1.672	3/2

Mesons $q\bar{q}$
Mesons are bosonic hadrons.
There are about 140 types of mesons.

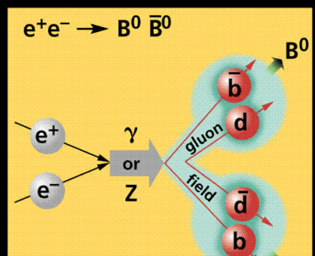
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	–1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

Matter and Antimatter
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or – charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

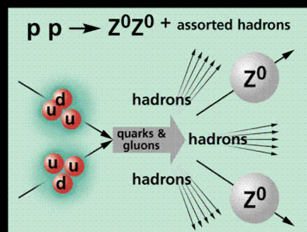
Figures
These diagrams are an artist's conception of physical processes. They are ***not*** exact and have ***no*** meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.



A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β decay.



An electron and positron (antielectron) colliding at high energy can annihilate to produce B^0 and $\bar{B}^0$ mesons via a virtual Z boson or a virtual photon.



Two protons colliding at high energy can produce various hadrons plus very high mass particles such as Z bosons. Events such as this one are rare but can yield vital clues to the structure of matter.

The Particle Adventure
Visit the award-winning web feature *The Particle Adventure* at
http://ParticleAdventure.org

This chart has been made possible by the generous support of:
U.S. Department of Energy
U.S. National Science Foundation
Lawrence Berkeley National Laboratory
Stanford Linear Accelerator Center
American Physical Society, Division of Particles and Fields
BURLE INDUSTRIES, INC.

http://CPEPweb.org

Symmetries: A brief history

Einstein's Special Relativity: 1905

- All inertial reference frames are created equal
- Light travels with speed *c* in all frames

Gauge Symmetry (and Gauge Invariance) 1954

- Physics is independent of gauge (~ coordinate system)
- Higgs Mechanism respects gauge invariance

SUSY: SuperSymmetry 1976 *(7202 Theory Papers; 0 Data)*

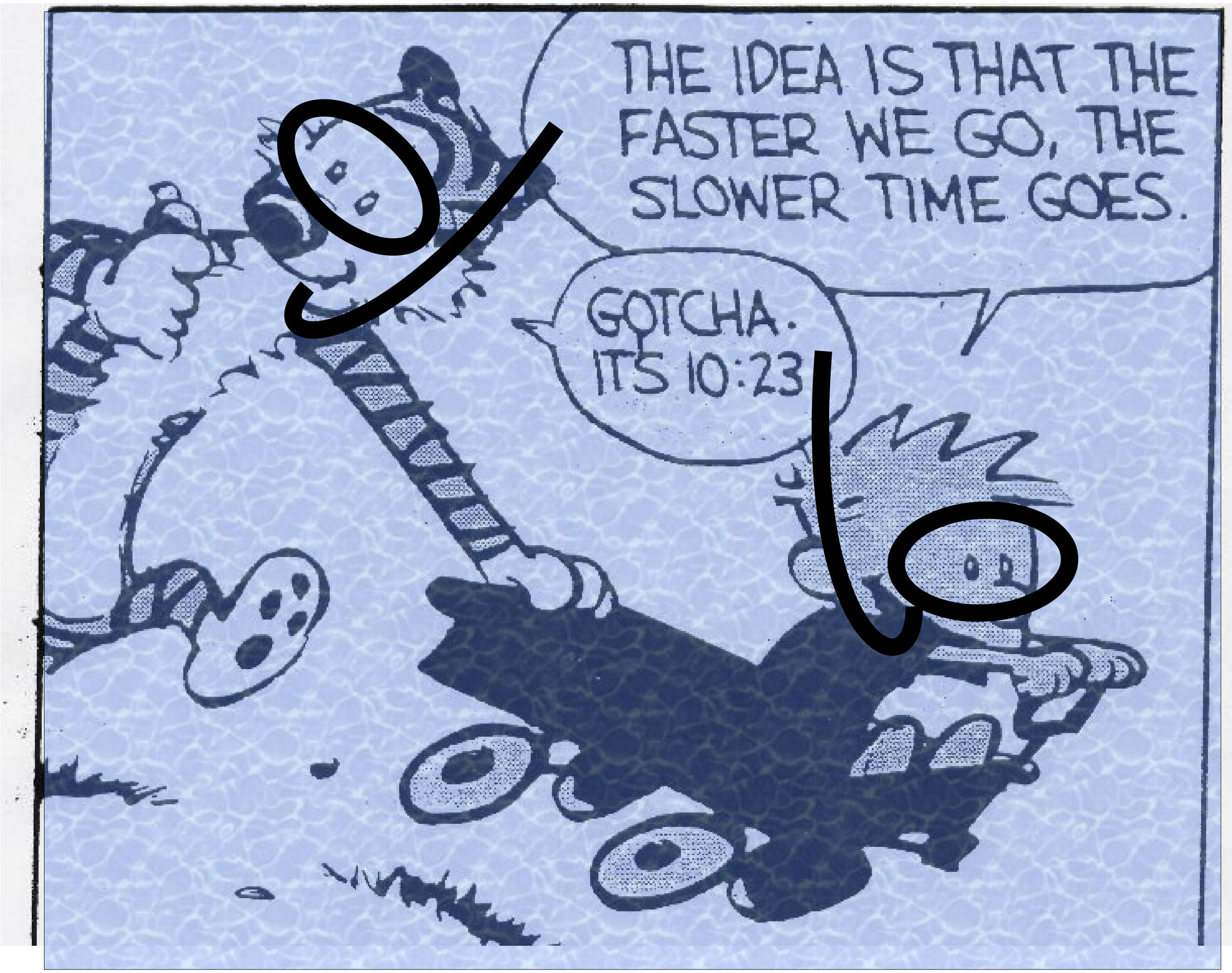
- There exists a symmetry between Fermions and Bosons
- Previously:
  - Fermions (s=1/2: building blocks)
  - Bosons (s=0,1, ... : forces)

Mathematical String Theology: 1974 *(12533 Theory Papers; 0 Data)*

- Things are simple in 11 dimensions

Higgs Bosons Over-Simplified ...

Underwater!!!



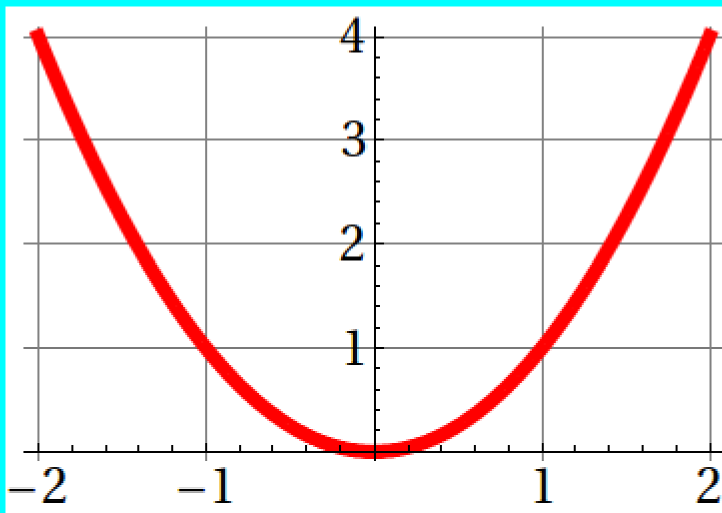
$$F = m a$$

$$m = F/a$$

Enables the theory to have a mass term AND respect gauge invariance

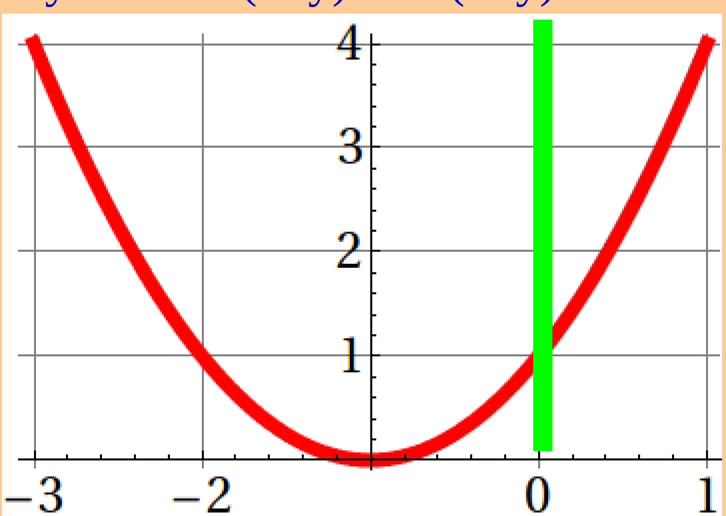
$$f(x) = x^2$$

symmetric $x \longrightarrow -x$

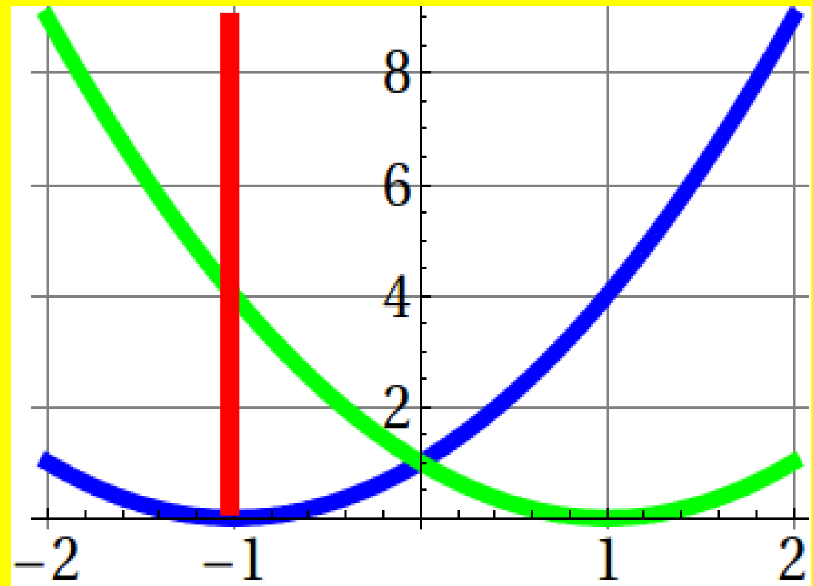


$$f(y) = y^2 + 2\,y + 1$$

symmetric $(1+y) \longrightarrow -(1+y)$



$$x \longrightarrow (1+y)$$



An inelegant truth ...

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Mathematical String Theology: 1974 *(20.643+ Theory Papers; 0 Data)*

- Things are simple in 11 dimensions

Perspective

The world: Pre-Columbus

Impact on other fields

The New York Review of Books

Physics: What We Do and Don't Know

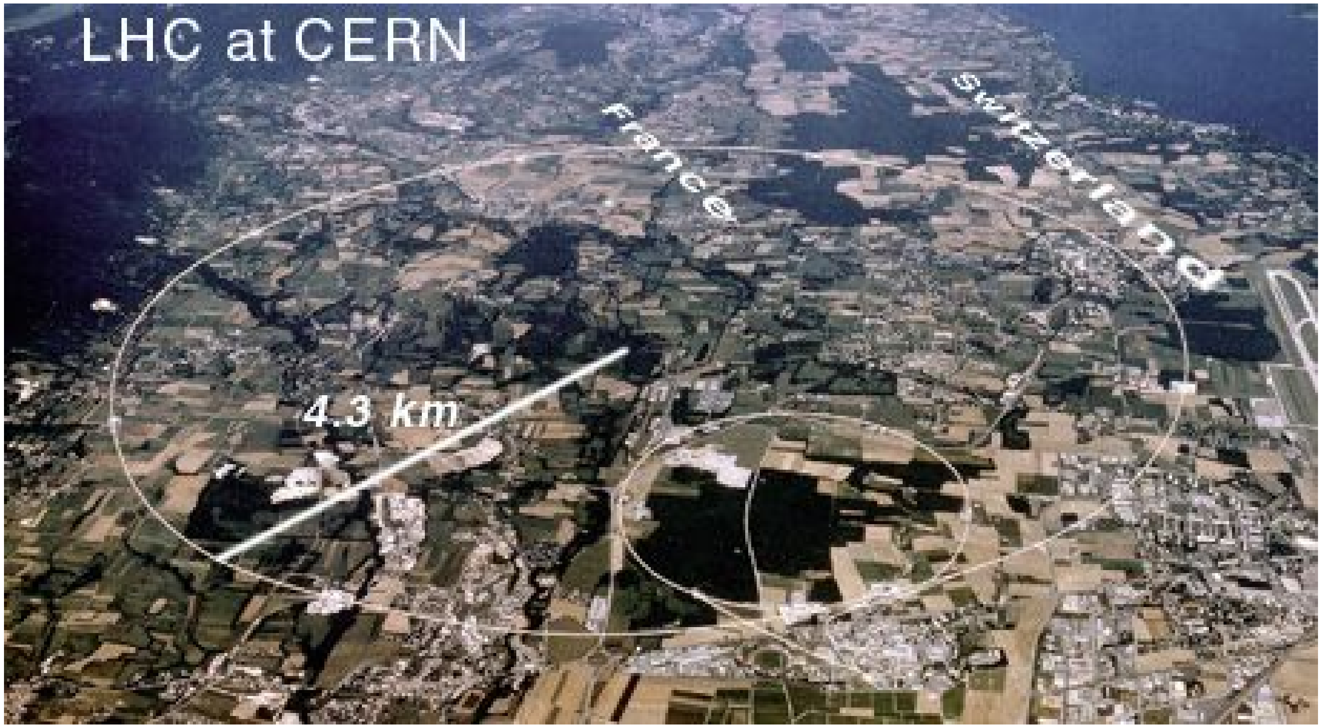
Steven Weinberg

In the past fifty years two large branches of physical science have each made a historic transition. I recall both cosmology and elementary particle physics in the early 1960s as cacophonies of competing conjectures. By now in each case we have a widely accepted theory, known as a "standard model." …

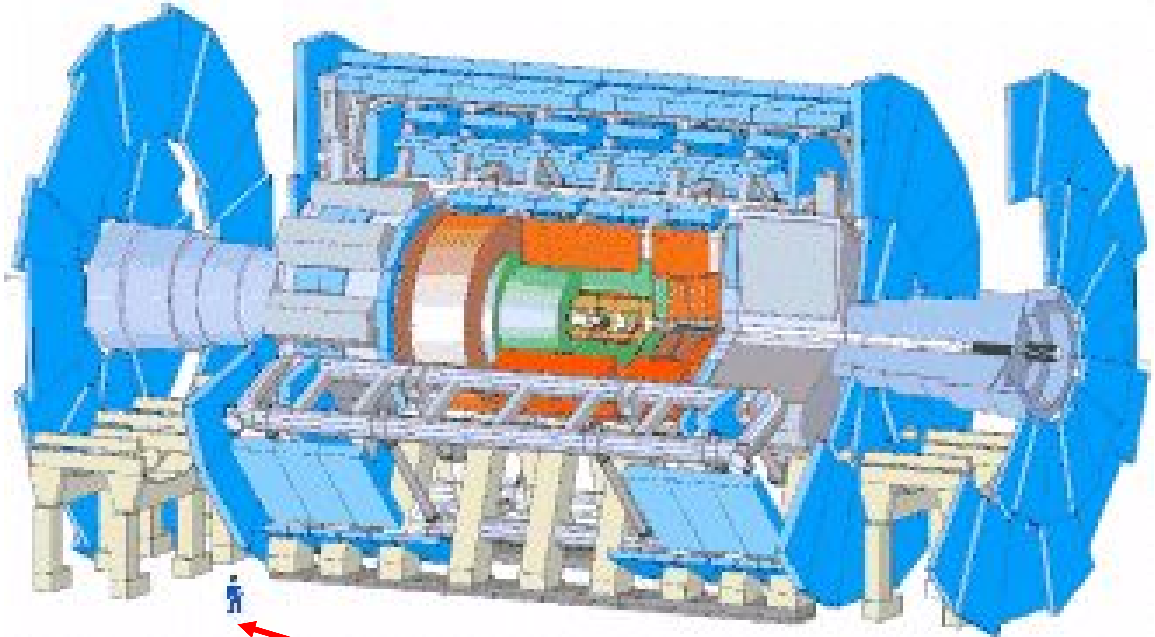
The eXtreme Deep Field photo combines 10 years of NASA Hubble Space Telescope photographs taken at the center of the original Hubble Ultra Deep Field

Opto-electronics Laboratory

The Large Hadron Collider (LHC) at the CERN Laboratory

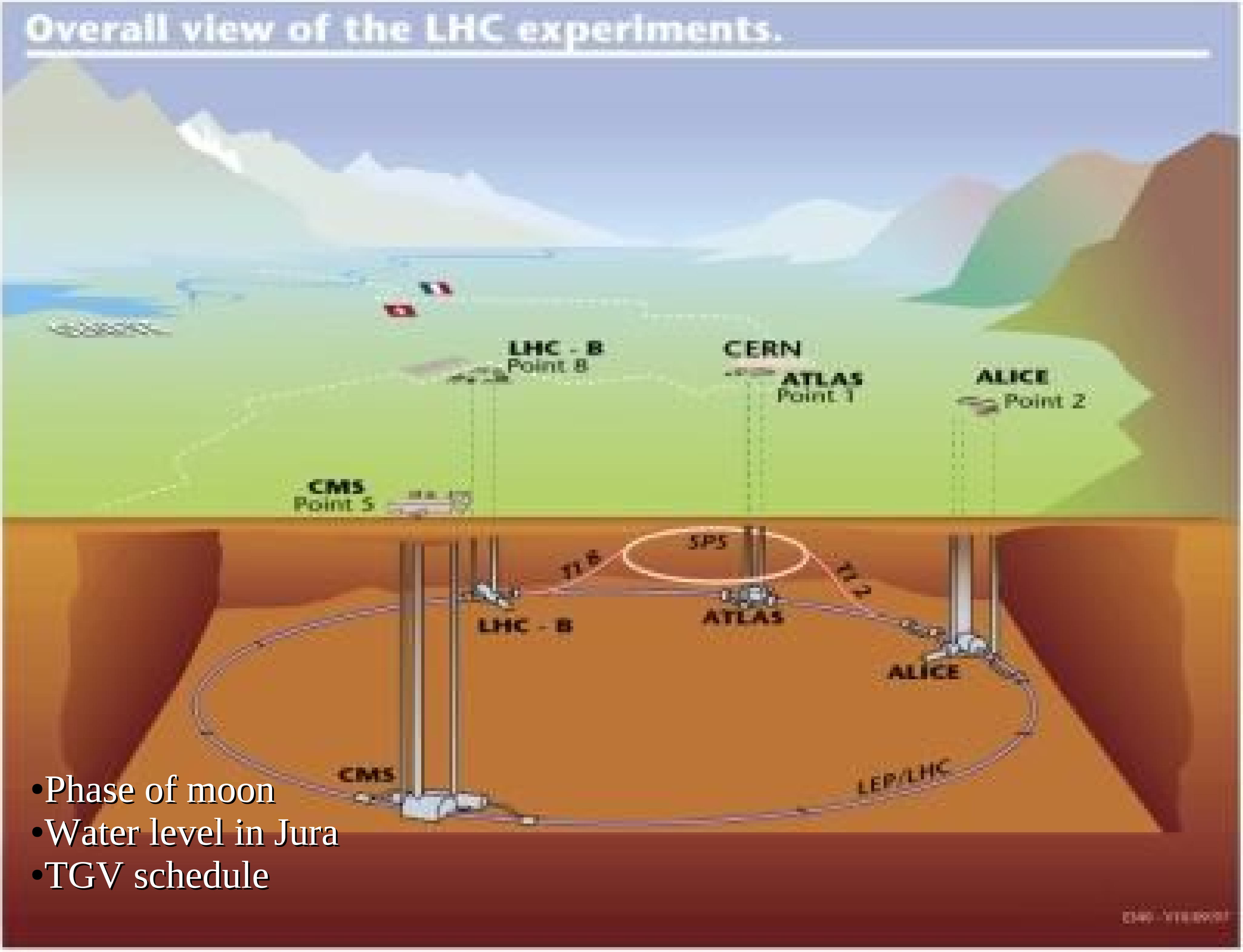


The ATLAS detector



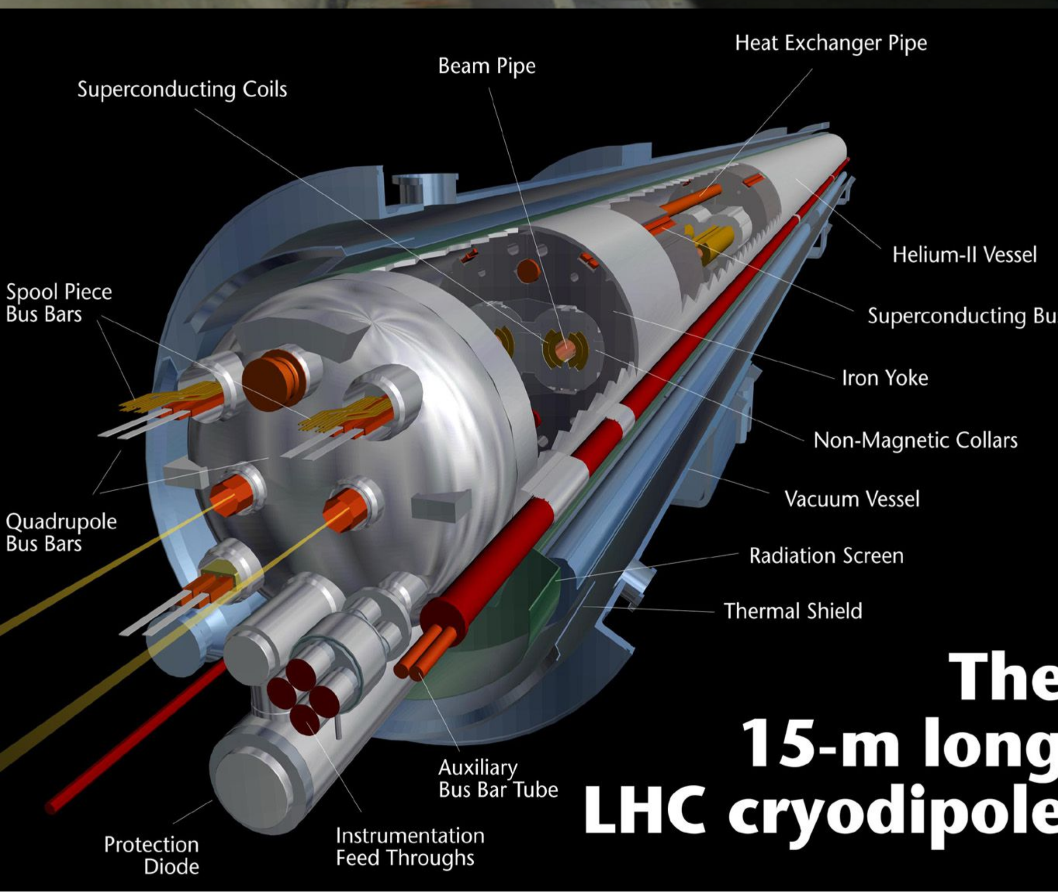
Size of a person

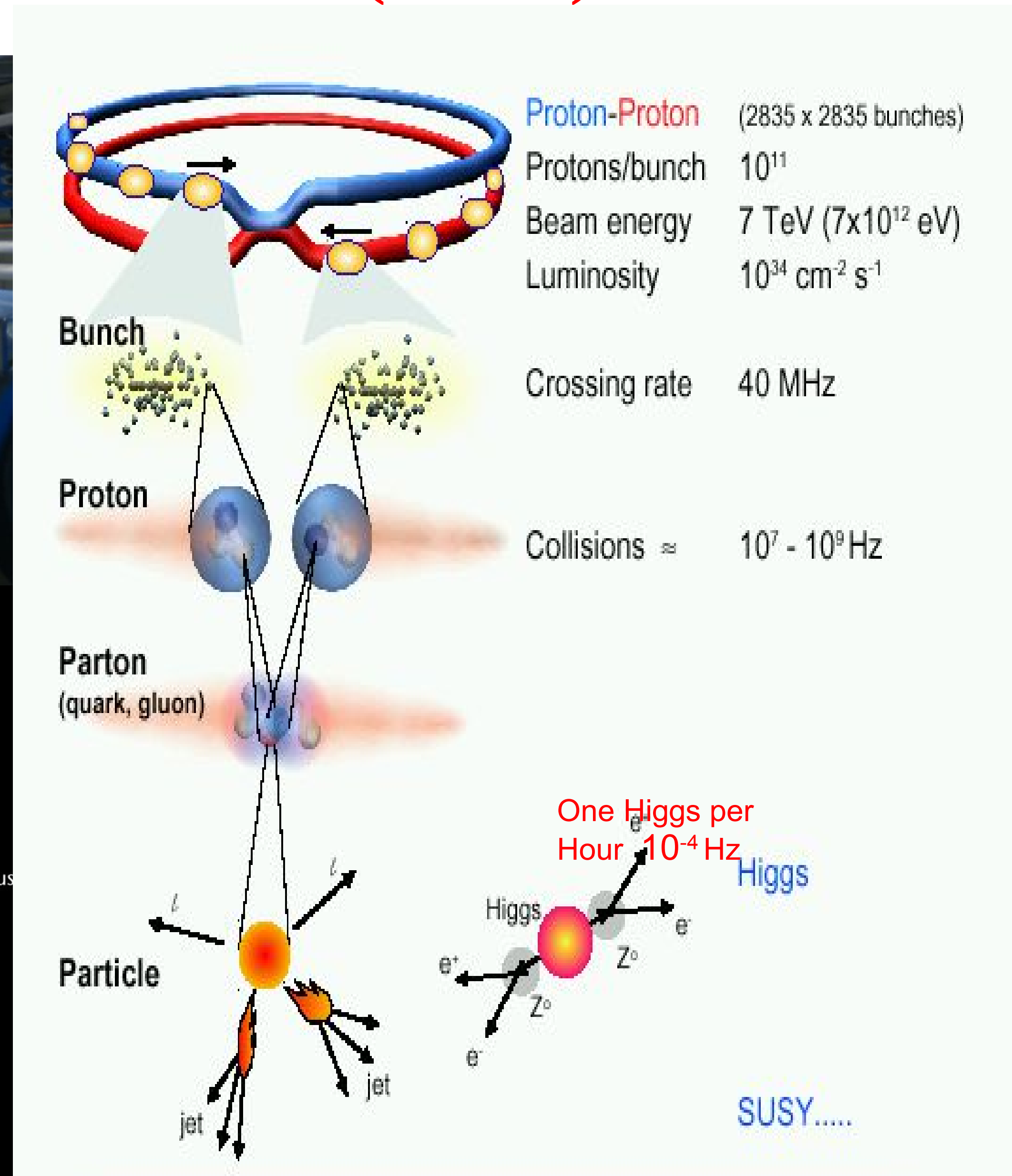
Caveat: Physics is data driven while music is subjective



- Phase of moon
- Water level in Jura
- TGV schedule

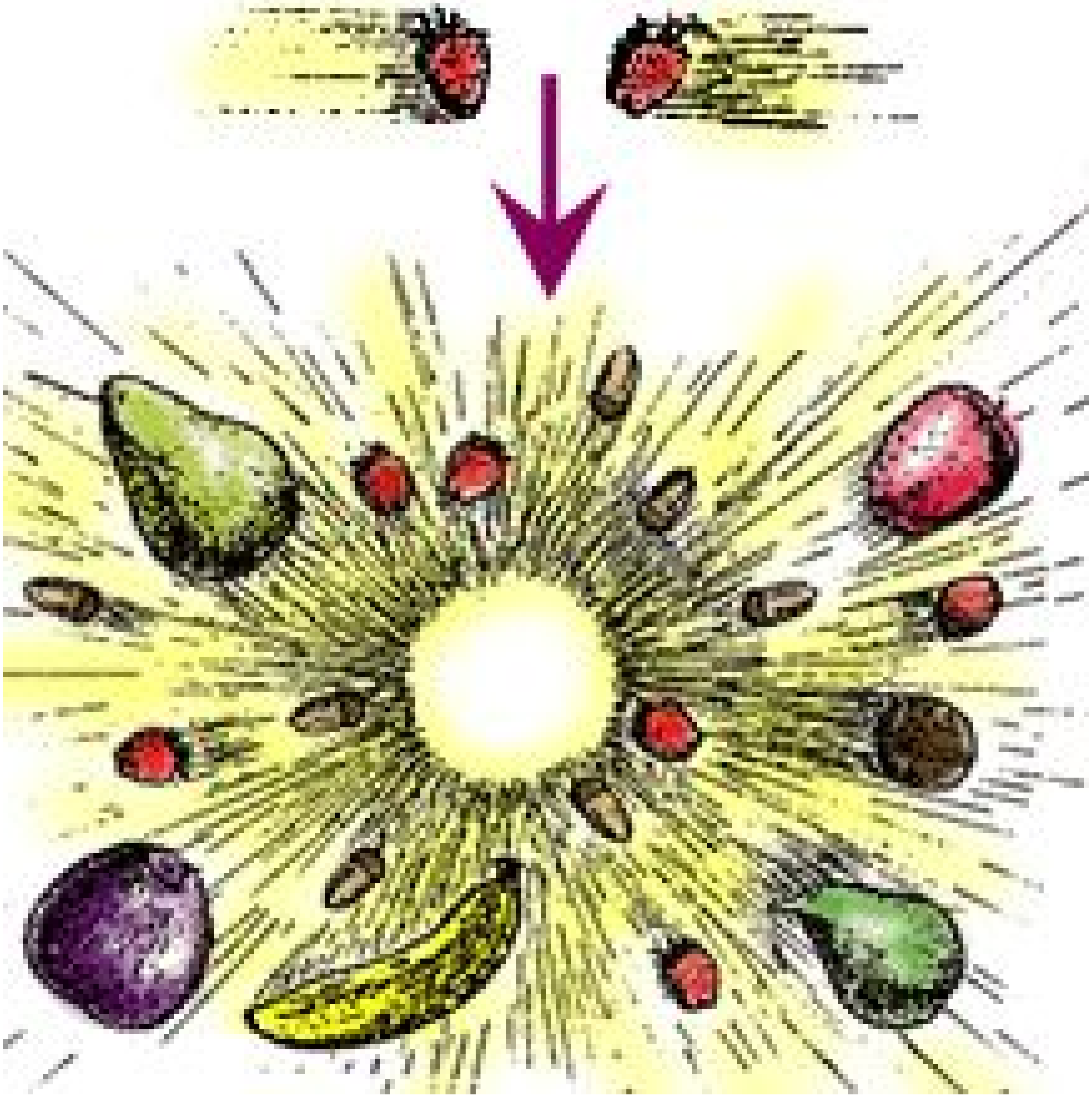
The Large Hadron Collider (LHC)





Selection of 1 in 10,000,000,000,000

One interpretation of a hadron-hadron collision



SMU Opto-electronics Laboratory

- The opto-electronics lab was established in 1998 for the ATLAS experiment and has since been built into a state-of-the-art facility for the department of physics.
- Faculties, postdocs and students (graduate and undergraduate, even high school students) are conducting research projects that are in leading positions in particle physics.
- The optical link system SMU delivered from this lab is the one that reads out the ATLAS Liquid Argon Calorimeter and contributed to the discovery of the Higgs particle. This optical link is still the leader in particle physics in terms of speed and data bandwidth, the #1 in all readout systems.
- The integrated circuits that are being developed in the lab for the ATLAS upgrade projects are the fastest, smallest in our field, #1 in many sense in particle physics around the World. Because of these achievements, this lab is well recognized nationally and internationally.
- SMU works with Columbia University, Brookhaven National Lab, Oxford University (UK), CERN and many other schools and labs and in all these collaborations and R&D projects. SMU leads: In terms of speed, SMU achieved 8 Giga-bit-per-second this year.
- SMU designed and prototyped the (TOSA based) smallest optical transmitter in the World, beating the industry counterpart by a factor of two in volume.
- The module developed by SMU will be produced in thousands in the coming years and will be used in ATLAS. With the hard work from people in the lab, SMU is now firmly established as #1 laboratory in optical link and serial data transmission for particle physics.
- All these achievements in detector instrumentation contributed to discoveries and precision measurements in physics. SMU's laboratory will continue to play leading roles in future experiments.

SMU®

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