The Music in the Atom

physics For All
Music For All?

Star No Match for Black Hole

In this illustration, an arrow points to the doomed star. Part of its mass, shown by the white stream, was swallowed by the black hole.
Physics for All, NYC, 8 Nov 2005

The Music in the Atom

K. Goulianos

3
In the beginning…
Blow-hole at Grand Cayman
Energy Budget of the Universe

Composition of the Cosmos

- Heavy elements: 0.03%
- Ghostly neutrinos: 0.3%
- Stars: 0.5%
- Free hydrogen and helium: 4%
- Dark matter: 30%
- Dark energy: 65%
Dark Matter

Use light as a guide for mass

Expect \( v^2 = G \frac{M}{R} \left( m \frac{v^2}{R} = G \frac{M \cdot m}{R^2} \right) \)

Is there mass where there is no light? …Dark Matter!

• Photo courtesy of Blas Cabrera
§ Rotation curve for the galaxy NGC3198 from Begeman 1989

(slide from Clarence Chang, Aspen 2004 Winter Conference on Particle Physics)
\( \mu = 1.00115965219 \pm 0.000000000001 \)

\( \mu = 1.00115965219 \pm 0.000000000003 \)
Elementary Particles

Aristotle (450 BC)
- earth
- water
- air
- fire

Demokritos
- atom

Mendeleyev (1869)
- periodic table

Thomson (1897)
- electron

Rutherford (1910)
- nucleus

Gell-Mann (1962)
- quarks

Rutherford Experiment
- Source $\rightarrow$ $\alpha$-particles
- Large angle scattering $\rightarrow$ atoms have nuclei
SU3: Law and Order in the Particle Zoo

\[ \Sigma^+ (1193) \]
\[ \Sigma^0, \Lambda^0 \]
\[ \Sigma^- (1384) \]
\[ \Xi^- (1533) \]
\[ \Xi^0 (1318) \]

Strangeness: \( S \)
- \( u : I_3 = 1/2 \) \( S = 0 \) \( Q = 2/3 \)
- \( d : I_3 = -1/2 \) \( S = 0 \) \( Q = -1/3 \)
- \( s : I_3 = 0 \) \( S = -1 \) \( Q = -1/3 \)

Isotopic spin: \( I_3 = Q - (B + S)/2 \)
The Standard Model
Glashow, Salam, and Weinberg

Elementary Particles

<table>
<thead>
<tr>
<th>Quarks</th>
<th>$u$ (up)</th>
<th>$c$ (charm)</th>
<th>$t$ (top)</th>
<th>$g$ (gluon)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$d$ (down)</td>
<td>$s$ (strange)</td>
<td>$b$ (bottom)</td>
<td>$\gamma$ (photon)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leptons</th>
<th>$\nu_e$ (electron neutrino)</th>
<th>$\nu_\mu$ (muon neutrino)</th>
<th>$\nu_\tau$ (tau neutrino)</th>
<th>$W$ (W boson)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$e$ (electron)</td>
<td>$\mu$ (muon)</td>
<td>$\tau$ (tau)</td>
<td>$Z$ (Z boson)</td>
</tr>
</tbody>
</table>

$3 \rightarrow I \quad II \quad III \quad \leftarrow$ Generations

$M_\gamma, g = 0 \quad M_W, Z \sim 100 \quad M_p \quad M_{\text{top}} \sim M_{\text{gold}}$

Higgs field generates Mass!
Unification of forces

**STRONG ~ 1**
\[ q \xrightarrow{\alpha_s} e \]
\[ q \xrightarrow{\alpha_s} \]  

**ELECTROMAGNETIC ~ 10^{-2}**
\[ e \xrightarrow{\alpha} \gamma \]
\[ e \xrightarrow{\alpha} \]  

**WEAK ~ 10^{-14}**
\[ \nu_e \xrightarrow{\alpha_W} e^- \]
\[ d \xrightarrow{w^-} u \]  

**charged current**
\[ \nu_e + n \rightarrow p + e^- \]
\[ v \xrightarrow{Z^0} v \]
\[ d \xrightarrow{d} \]  

**neutral current**
\[ \nu_e + p \rightarrow \nu_e + p \]
A good theory should fit on a T-shirt!

But what about interactions?

\[
L = -\frac{1}{4} W_{\mu\nu} W^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} \\
+ \bar{L}^\mu \left( i \dot{\phi}_\mu - g \frac{1}{2} \tau \cdot W_{\mu} - g' \frac{Y}{2} B_{\mu} \right) L \\
+ \bar{R}^\mu \left( i \dot{\phi}_\mu - g' \frac{Y}{2} B_{\mu} \right) R \\
+ \left[ \left( i \dot{\phi}_\mu - g \frac{1}{2} \tau \cdot W_{\mu} - g' \frac{Y}{2} B_{\mu} \right) \phi \right]^2 - V(\phi) \\
- \left( G_1 \bar{\phi} R + G_2 \bar{\phi} R + \text{hermitian conjugate} \right)
\]

AND WHAT ABOUT GRAVITY?
String Theory, then?

Particles correspond to the vibration modes of a string in 10 dimensions.

Pythagoras applied it to music in 400 BC: $1+2+3+4=10$

Gravity is included!

It surely makes an interesting T-shirt!

http://www.aboutscotland.com/harmony/prop.html
The Tevatron $\bar{p}-p$ Collider
Collider Detector at Fermilab
CDF event in central tracker

10^6 electronic channels
10^6 collisions/sec

Trigger:
L1: 100 K/sec
L2: 1 K/sec
L3: 100/sec

Superconducting solenoid
15 K gauss
3 m diameter
5 m long
Selecting the information of interest
The Top Quark
Top Quark Discovery

The top quark was co-discovered in 1995 by the CDF and D0 Collaborations at Fermilab

One of the discovery tools was the expected high value of the sum of the transverse energy in an event

\[ H = \Sigma E_T \]
http://www.fnal.gov/pub/news05/TopTurnsTen.html
QCD - Quantum Chromo-Dynamics

The Theory of Strong Interactions

COLOR FORCE

proton (colorless)

asymptotic freedom

Strong coupling

0 1 fermi

Distance

confinement

Strong coupling

$\alpha_s$
David Politzer

2004 Nobel Prize in Physics
w/ David Gross and Frank Wilczek
The MiniPlug @ CDF
About 1500 wavelength shifting fibers of 1 mm dia. are 'strung' through holes drilled in 36 lead plates sandwiched between reflective Al sheets and guided into bunches to be viewed individually by multi-channel photomultipliers.
An Event in the MiniPlug
The Higgs Mechanism for generating Mass

The vacuum is filled with the Higgs field, the quanta of which are Higgs particles - named after Peter Higgs.
Search for the Higgs

\[ H \rightarrow b\bar{b} \text{ jet} \text{ jet} \]

\[ M_H \]

<table>
<thead>
<tr>
<th>Theory uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>80.1</td>
</tr>
<tr>
<td>80.2</td>
</tr>
<tr>
<td>80.3</td>
</tr>
<tr>
<td>80.4</td>
</tr>
<tr>
<td>80.5</td>
</tr>
<tr>
<td>80.6</td>
</tr>
</tbody>
</table>

Higgs Boson Mass [GeV/c^2]

\[ \Delta \chi^2 \]

All data, with old world-average \( M_{\text{top}} \)

All data, with new world-average \( M_{\text{top}} \)

TEVATRON

LEP2

MW-Mtop contours : 68% CL
The Large Hadron Collider

ATLAS

Physics for All, NYC, 8 Nov 2005  The Music in the Atom  K. Goulianos  29
Many thanks to my Colleagues!
The Rockefeller University and
The Ensemble Studio Theatre/Alfred P. Sloan Foundation Science & Technology Project
Present a staged reading of

String Fever

Wednesday, January 15, 2003

Staged reading of String Fever — a comedy about a woman turning 40 and turning to string theory for answers

Q&A led by Rockefeller University professor and physicist Konstantin A. Goulianos