Probing Large Extra Dimensions in Collider Experiments

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APS 2000 Long Beach Meeting
May 1, 2000

http://www-d0.fnal.gov/~gll
Standard Model: Beauty and the Beast

...beauty:

Moriond 2000

<table>
<thead>
<tr>
<th>Measurement</th>
<th>m_Z [GeV]</th>
<th>( \pm 0.0021 )</th>
<th>Pull</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Gamma_Z [\text{GeV}] )</td>
<td>2.4944 \pm 0.0024</td>
<td>-0.62</td>
<td></td>
</tr>
<tr>
<td>( \sigma_{\text{hadr}} [\text{nb}] )</td>
<td>41.544 \pm 0.037</td>
<td>1.72</td>
<td></td>
</tr>
<tr>
<td>( R_b )</td>
<td>20.768 \pm 0.024</td>
<td>1.19</td>
<td></td>
</tr>
<tr>
<td>( A_{tb}^{0,e} )</td>
<td>0.01701 \pm 0.00095</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>( A_{t} )</td>
<td>0.1483 \pm 0.0051</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>( A_{t} )</td>
<td>0.1425 \pm 0.0044</td>
<td>-1.16</td>
<td></td>
</tr>
<tr>
<td>( \sin^2 \theta_{\text{eff}} )</td>
<td>0.2321 \pm 0.0010</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>( m_W [\text{GeV}] )</td>
<td>80.401 \pm 0.048</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>( R_b )</td>
<td>0.21642 \pm 0.00073</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>( R_c )</td>
<td>0.1674 \pm 0.0038</td>
<td>-1.27</td>
<td></td>
</tr>
<tr>
<td>( A_{tb}^{0,b} )</td>
<td>0.0988 \pm 0.0020</td>
<td>-2.34</td>
<td></td>
</tr>
<tr>
<td>( A_{tb}^{0,c} )</td>
<td>0.0692 \pm 0.0037</td>
<td>-1.29</td>
<td></td>
</tr>
<tr>
<td>( A_{b} )</td>
<td>0.911 \pm 0.025</td>
<td>-0.95</td>
<td></td>
</tr>
<tr>
<td>( A_{c} )</td>
<td>0.630 \pm 0.026</td>
<td>-1.47</td>
<td></td>
</tr>
<tr>
<td>( \sin^2 \theta_{\text{eff}} )</td>
<td>0.23096 \pm 0.00026</td>
<td>-1.87</td>
<td></td>
</tr>
<tr>
<td>( \sin^2 \theta_W )</td>
<td>0.2255 \pm 0.0021</td>
<td>1.17</td>
<td></td>
</tr>
<tr>
<td>( m_W [\text{GeV}] )</td>
<td>80.448 \pm 0.062</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>( m_t [\text{GeV}] )</td>
<td>174.3 \pm 5.1</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>( \Delta \alpha^{(5)}(m_Z) )</td>
<td>0.02804 \pm 0.00065</td>
<td>-0.20</td>
<td></td>
</tr>
</tbody>
</table>

The Standard Model, based on just three parameters, is extremely successful in calculating dozens of physics quantities to a very high precision.

...and the beast:

- Standard Model accommodates, but does not explain:
  - EWSB
  - CP-violation
  - Fermion masses
- In order for the SM to be an ultimate theory to the highest energies an extremely precise fine tuning of the parameters is required.

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Life in the Bulk Space

Standard picture of universe: all forces unify at very high energy, $10^{16}$ GeV, and gravity catches up at the Planck mass of $10^{19}$ GeV

Arkani-Hamed, Dimopoulos, Dvali (ADD) (1998): what if the scale of unification is only $\sim 1$ TeV?!!

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Bringing unification scale to 1 TeV allows for a very rich physics, possibly filling in the gaps left by the Standard Model.

First alternative to the “established” post-Standard-Model theories in 25 years! – What took us so long?

A significant theoretical interest to the subject ensures rapid development of this field.

Close to 300 theoretical papers on this subject over the past two years – truly a topic du jour.

This new theory, if proved right, could be the most significant discovery of human mind since we managed to realize that the Earth is not flat.

Cf. Edwin Abbot’s “Flatland” (1884)
An Importance of Being Compact

- What about Newton’s Law?
  - \( n=3 \): \( F \sim 1/r^2 \)
  - \( n=3+\delta \): \( F \sim 1/r^{2+\delta} \)
- This is only true for “flat” or infinite dimensions!
- If extra dimensions are curled-up, or compactified, with the radius \( R \), the \( 1/r^{2+\delta} \) law works only for distances \( r \ll R \)
- For \( r \gg R \) we still have usual \( 1/r^2 \) law

Compactified dimensions offer a way to increase tremendously gravitational interaction due to a large number of the available “winding” modes

- This tower of excitations is known as Kaluza-Klein modes, and such gravitons propagating in the compactified extra dimensions are called Kaluza-Klein gravitons, \( G_{KK} \)
- The higher the energy is, the more turns a graviton can make, and the stronger gravity becomes
Examples of Compactified Spatial Dimensions

M.C. Escher, Mobius Strip II (1963)

M.C. Escher, Relativity (1953)

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Particle accelerators (colliders) are the finest microscopes we have ever built. While tabletop experiments are important tests of Newton’s law at short distances, collider experiments are complementary as they are capable of probing gravity at much shorter range.
Modern Collider Experiments

- **LEP2**: electron-positron collider at CERN, near Geneva, Switzerland
  - Colliding beams have energy of about 100 GeV each
  - Four experiments: ALEPH, DELPHI, L3, and OPAL
- **Tevatron**: proton-antiproton collider at Fermilab, near Chicago, U.S.
  - Colliding beams are accelerated to nearly 1000 GeV
  - Highest energy man-made accelerator to date
  - Two experiments: CDF and DØ
Looking for Extra Dimensions at Colliders

Graviton produced in high-energy collisions could leave our world forever, resulting in an apparent energy non-conservation...

Computer simulation of how such an event would've looked like in a collider detector (courtesy M.Spiropulu)

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Looking for Extra Dimensions at Colliders

Graviton leaves our world for a short moment, just to reappear again and decay...

\[ M_{\gamma\gamma} = 574 \text{ GeV} \]

Unfortunately, the topology of this event makes it very unlikely candidate in graviton decay. Most likely it is due to well-established physics processes.

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Recent Results from Colliders

- LEP2 Collaborations looked at both processes and have not seen any characteristic events due to strong gravity
  - Current limits on the unification scale from LEP2 is ~1 TeV
- The DØ experiment at Fermilab has just finished search for pairs of photons and electrons; no events typical of strong gravity have been seen
  - Current limits from DØ are similar to those from LEP2, although slightly higher
- Higher energy of the Tevatron, compared to LEP2, allows to increase the sensitivity by a factor of 2-3 in the next Tevatron run, just due to higher number of proton-antiproton collisions that we will collect
- This puts Tevatron in the unique position of finding extra dimensions in the next few years or significantly constrain the new model
- Both CDF and DØ are working on search for “monojets” due to graviton emission in the extra dimensions
- Further generation of colliders (LHC, NLC ?) will be able to probe unification scale up to 8-10 TeV, and thus allow for ultimate test of theory of extra dimensions

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Black Hole Production at Future Colliders?

- If the energy of the collider exceeds the unification scale, gravity becomes so strong that colliding particles will form a microscopic black hole.
- Not to worry: it lives for just a tiny moment and can not possibly interact with matter around it!
- The best prove is our own existence, since such black holes would be constantly produced by high energy cosmic rays.
- These decaying black holes could produce spectacular events in future collider experiments, and we are looking at this possibility in more details.
- Black hole production in the lab would be a unique achievement, helping us to solve the ultimate puzzle: origin of the universe and our very existence.
Conclusion: WWW Search for Extra Dimensions

http://www.extradimensions.com

On 2/15/00 patent 6,025,810 was issued to David Strom for a "hyper-light-speed antenna." The concept is deceptively simple: "The present invention takes a transmission of energy, and instead of sending it through normal time and space, it pokes a small hole into another dimension, thus sending the energy through a place which allows transmission of energy to exceed the speed of light." According to the patent, this portal "allows energy from another dimension to accelerate plant growth."

- from APS “What’s New”, 3/17/00

Stay tuned – next generation of collider experiments has a good chance to solve the mystery of large extra dimensions!

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