Probing Large Extra Dimensions in Collider Experiments

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APS 2000 Long Beach Meeting

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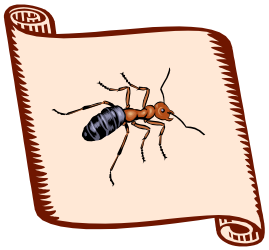
http://www-d0.fnal.gov/~gll

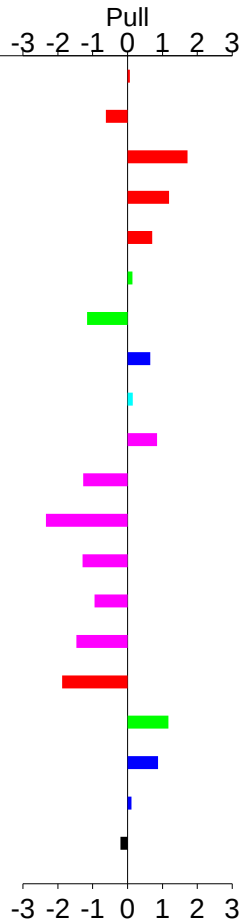


Standard Model: Beauty and the Beast

- ...beauty:

Moriond 2000

	Measurement	Pull
m_Z [GeV]	91.1871 ± 0.0021	.07
Γ_Z [GeV]	2.4944 ± 0.0024	-.62
σ^0_{hadr} [nb]	41.544 ± 0.037	1.72
R_e	20.768 ± 0.024	1.19
$A^{0,e}_{fb}$	0.01701 ± 0.00095	.70
A_e	0.1483 ± 0.0051	.13
A_τ	0.1425 ± 0.0044	-1.16
$\sin^2\theta^{lept}_{eff}$	0.2321 ± 0.0010	.65
m_W [GeV]	80.401 ± 0.048	.15
R_b	0.21642 ± 0.00073	.85
R_c	0.1674 ± 0.0038	-1.27
$A^{0,b}_{fb}$	0.0988 ± 0.0020	-2.34
$A^{0,c}_{fb}$	0.0692 ± 0.0037	-1.29
A_b	0.911 ± 0.025	-.95
A_c	0.630 ± 0.026	-1.47
$\sin^2\theta^{lept}_{eff}$	0.23096 ± 0.00026	-1.87
$\sin^2\theta_W$	0.2255 ± 0.0021	1.17
m_W [GeV]	80.448 ± 0.062	.88
m_t [GeV]	174.3 ± 5.1	.11
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02804 ± 0.00065	-.20

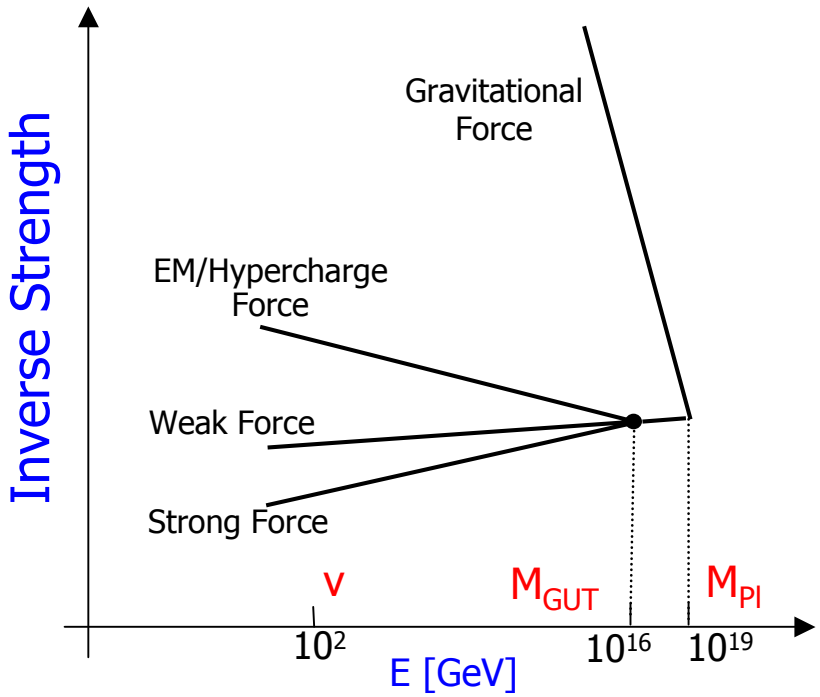


The Standard Model, based on just three parameters, is extremely successful in calculating dozens of physics quantities to a very high precision

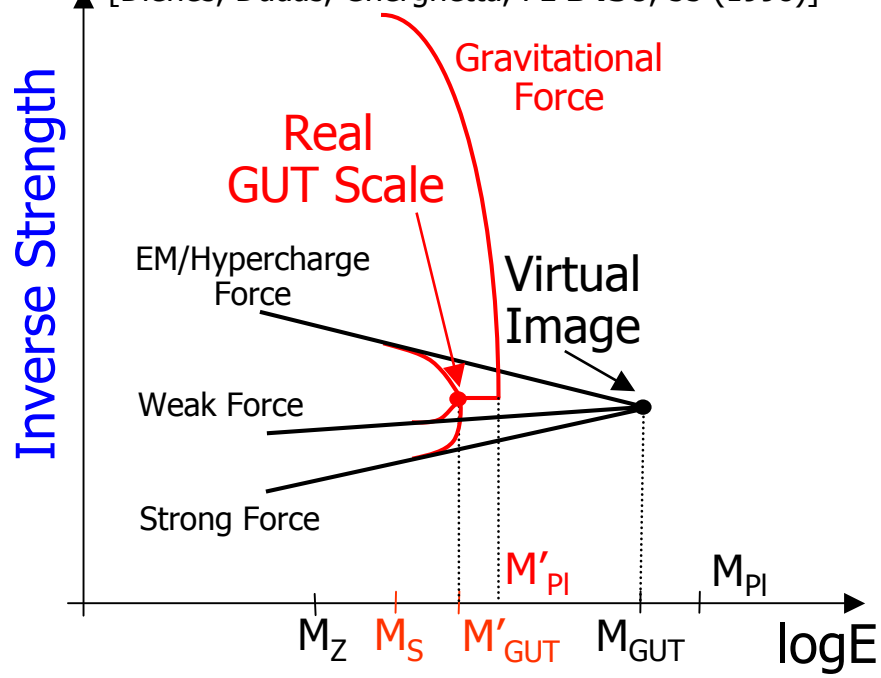
- ...and the beast:
  - Standard Model accommodates, but does not explain:
    - EWSB
    - CP-violation
    - Fermion masses
  - In order for the SM to be an ultimate theory to the highest energies an extremely precise fine tuning of the parameters is required

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 ~ 1 TeV?!!

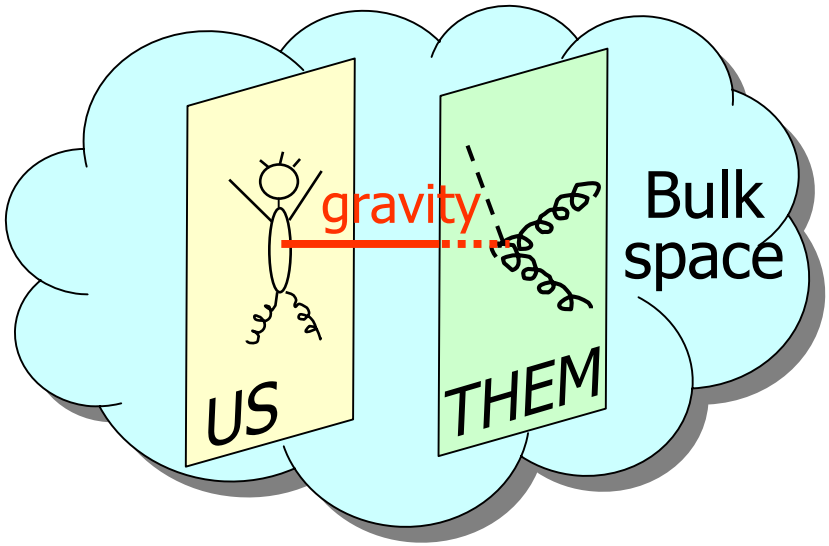


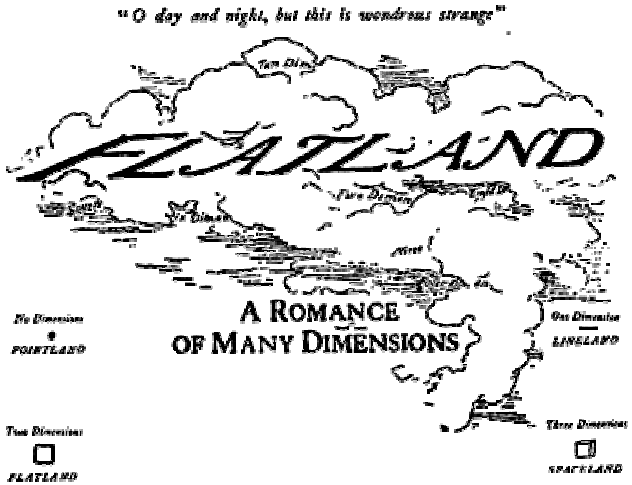
[Dienes, Dudas, Gherghetta, PL **B436**, 55 (1998)]



Physics of Large Extra Dimensions

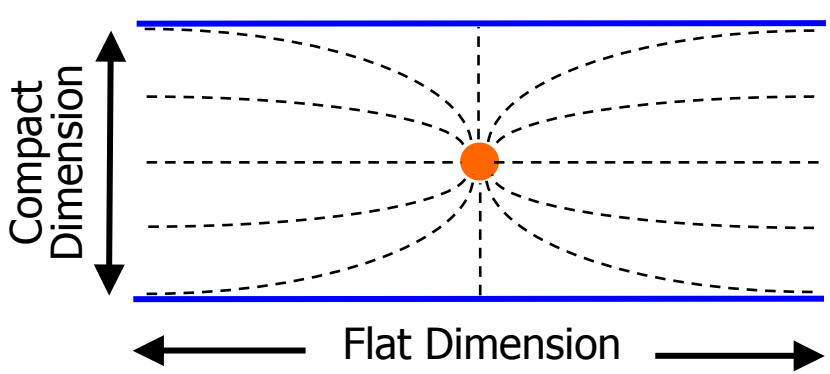
- Bringing unification scale to 1 TeV allows for a very rich physics, possibly filling in the gaps left by the Standard Model
- First alternative to the "established" post-Standard-Model theories in 25 years! – What took us so long?
- A significant theoretical interest to the subject ensures rapid development 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)

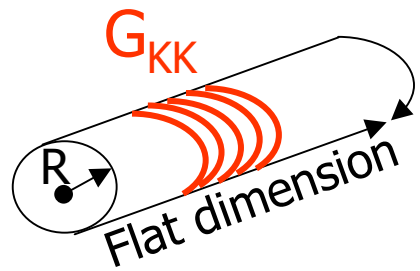




An Importance of Being Compact

- 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



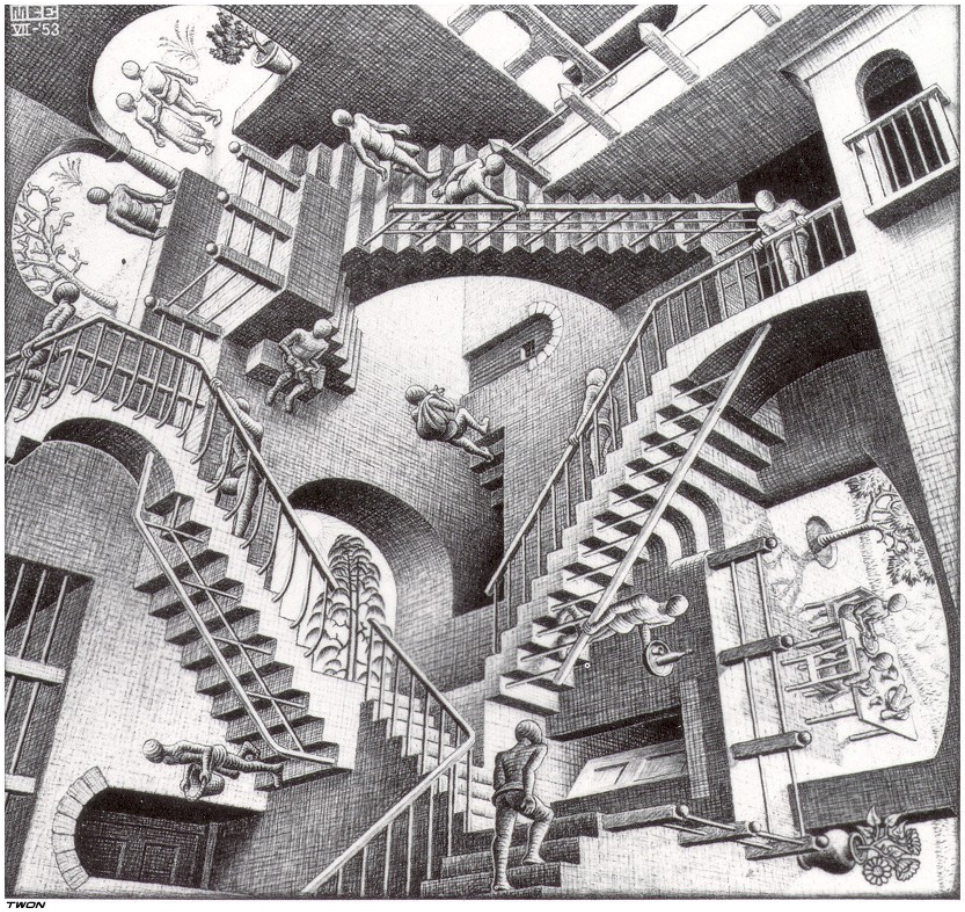


Compactified dimension

- 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

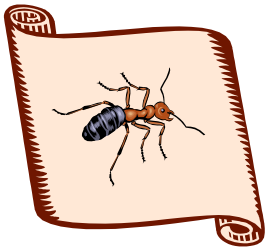
Examples of Compactified Spatial Dimensions

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



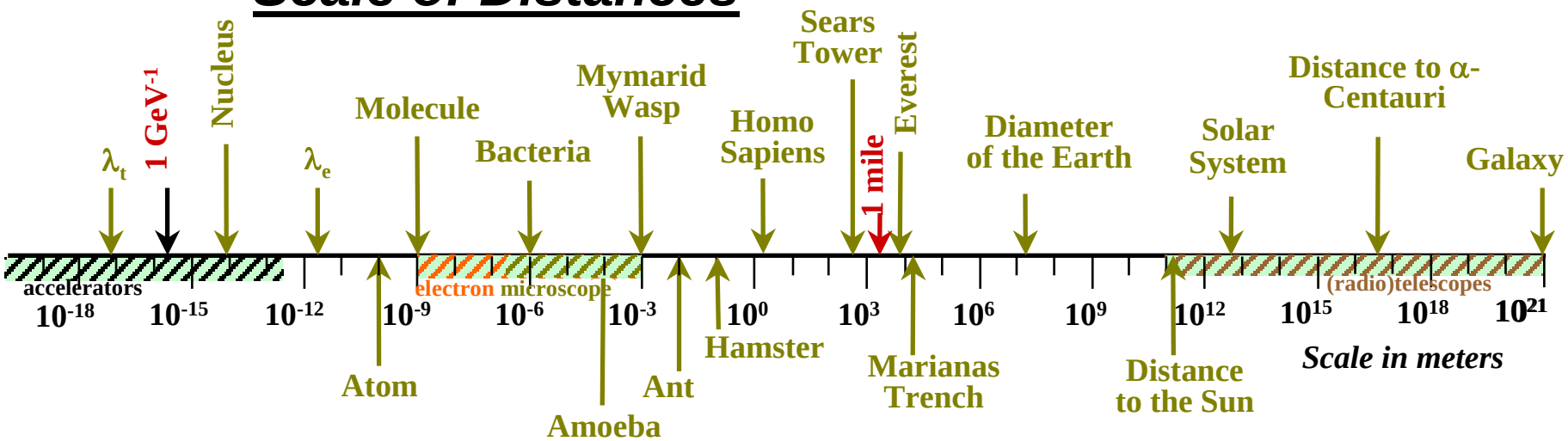
M.C.Escher, Relativity (1953)

[All M.C. Escher works and texts copyright © Cordon Art B.V., P.O. Box 101, 3740 AC The Netherlands. Used by permission.]



Scales, Scales, Scales…

Scale of Distances

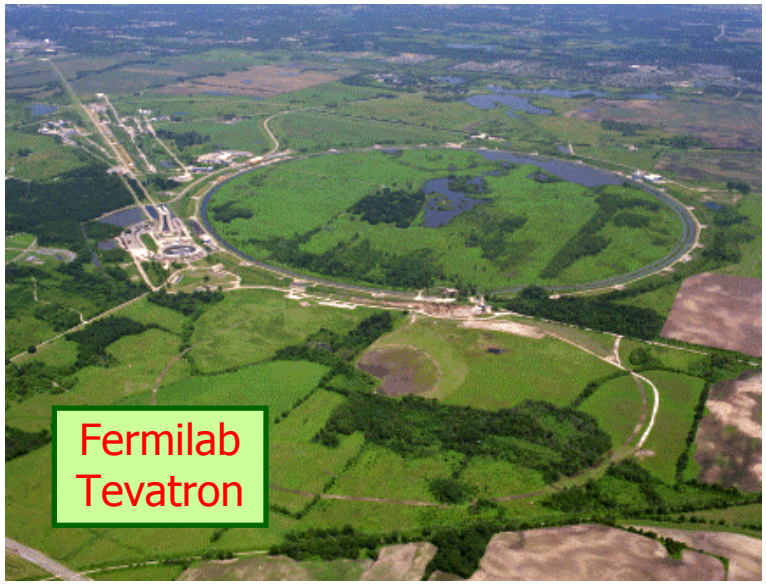


- Particle accelerators (colliders) are the finest microscopes we have ever built
- While tabletop experiments are important tests of Newton's law at short distances, collider experiments are complementary as they are capable of probing gravity at much shorter range

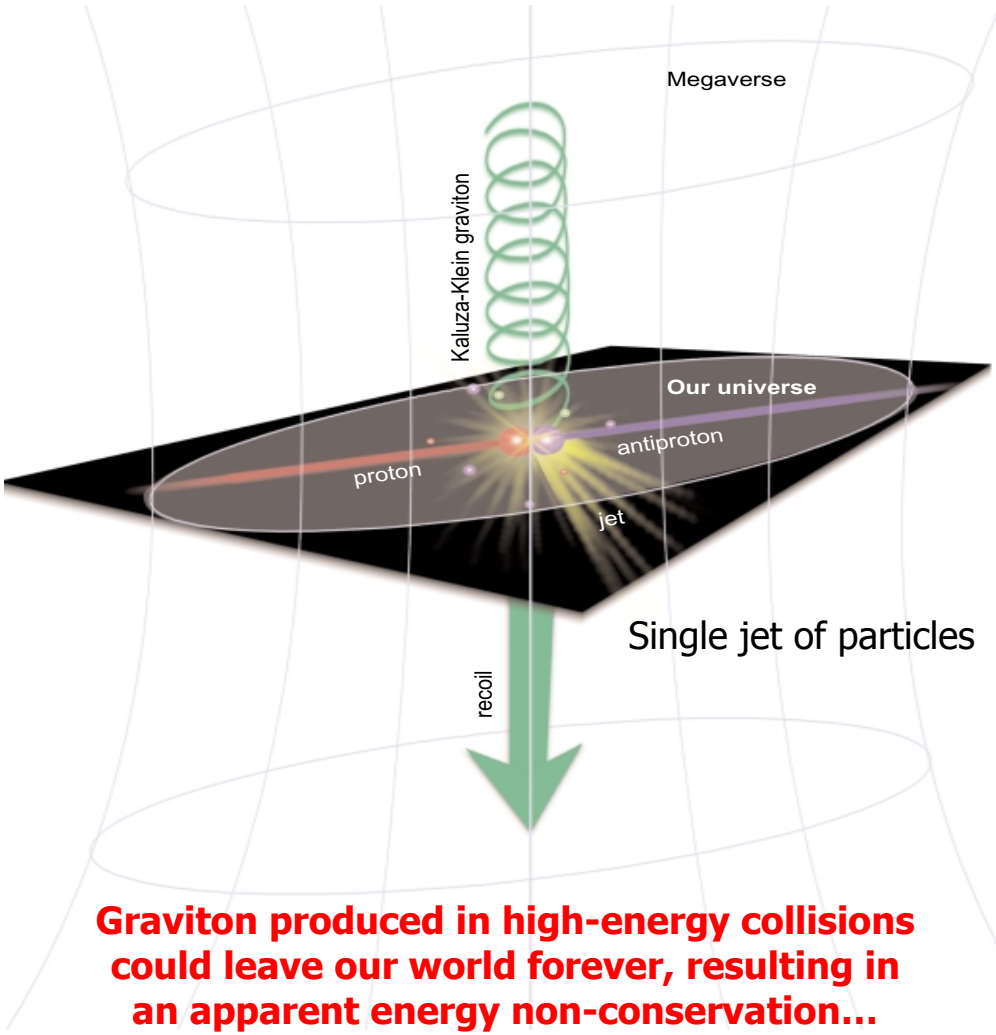
$$R \propto \begin{cases} 8\times10^{12}\,m, & n=1 \\ 0.7\,mm, & n=2 \\ 3\,nm, & n=3 \\ 6\times10^{-12}\,m, & n=4 \end{cases}$$

Modern Collider Experiments

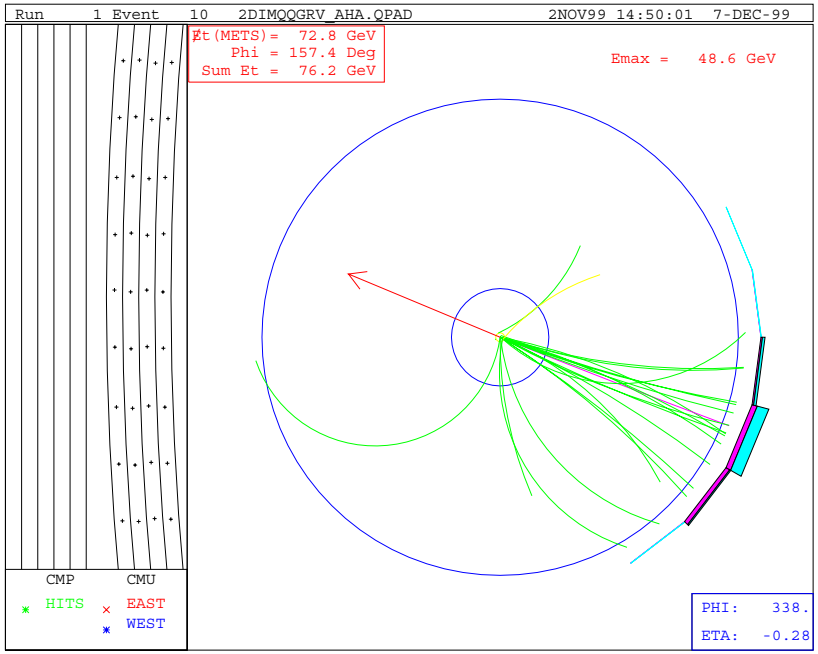
- LEP2: electron-positron collider at CERN, near Geneva, Switzerland
  - Colliding beams have energy of about 100 GeV each
  - Four experiments: ALEPH, DELPHI, L3, and OPAL
- Tevatron: proton-antiproton collider at Fermilab, near Chicago, U.S.
  - Colliding beams are accelerated to nearly 1000 GeV
 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



Looking for Extra Dimensions at Colliders



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

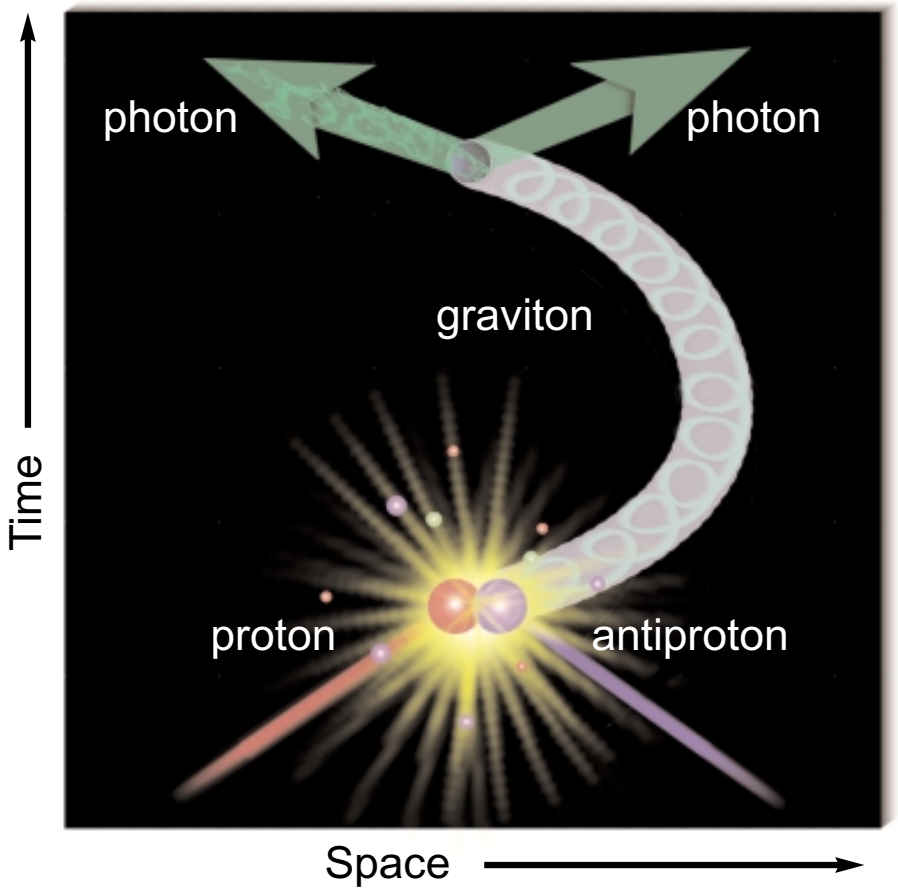


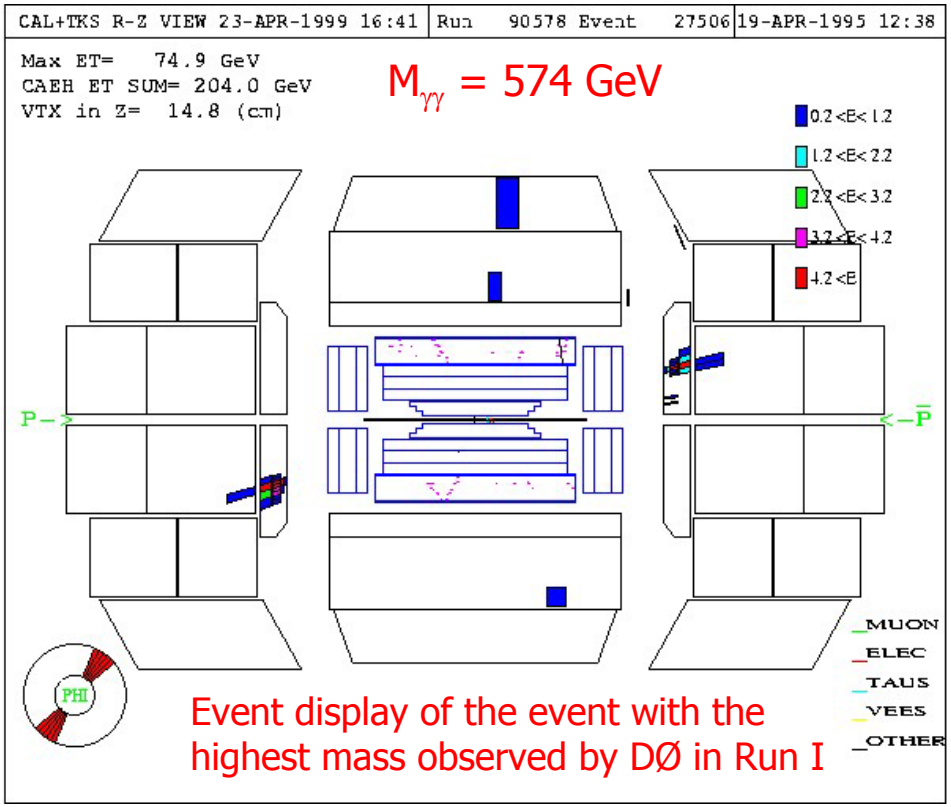
[Detector slice transverse to the colliding beams]

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

Looking for Extra Dimensions at Colliders

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





Event display of the event with the highest mass observed by DØ in Run I

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

Recent Results from Colliders

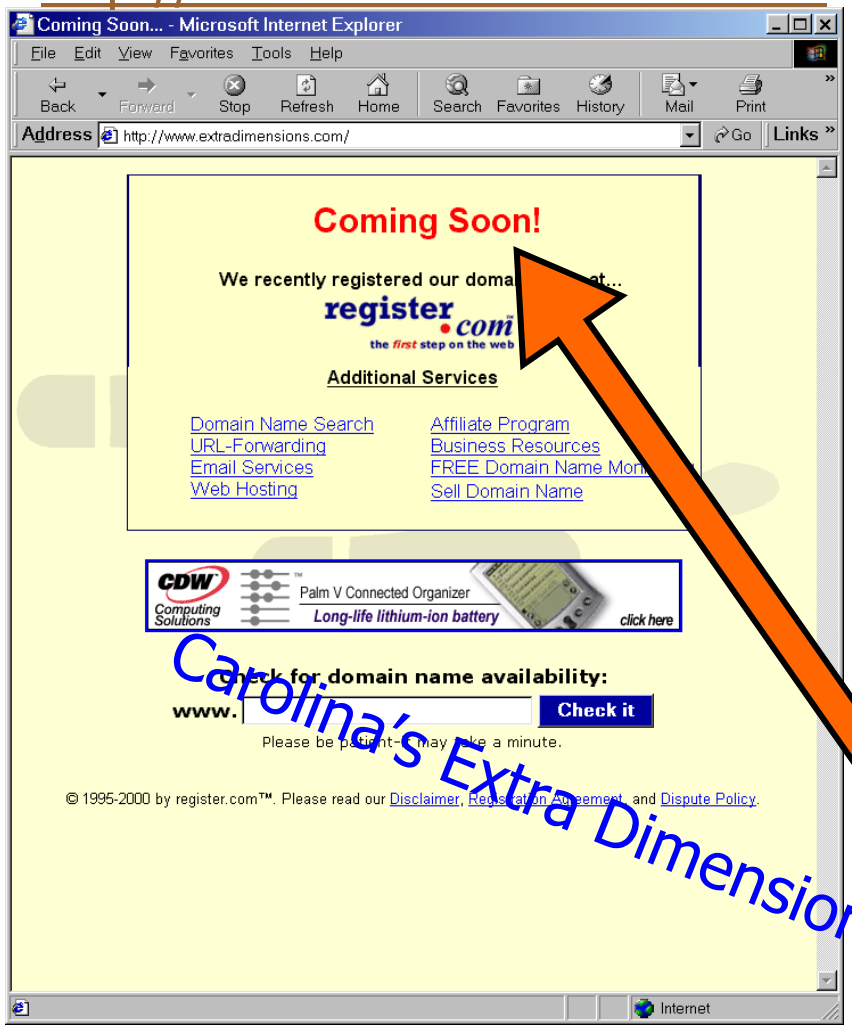
- LEP2 Collaborations looked at both processes and have not seen any characteristic events due to strong gravity
  - Current limits on the unification scale from LEP2 is ~1 TeV
- The DØ experiment at Fermilab has just finished search for pairs of photons and electrons; no events typical of strong gravity 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

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

Carolina's Extra Dimensions

Extra Dimensions TV Show

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