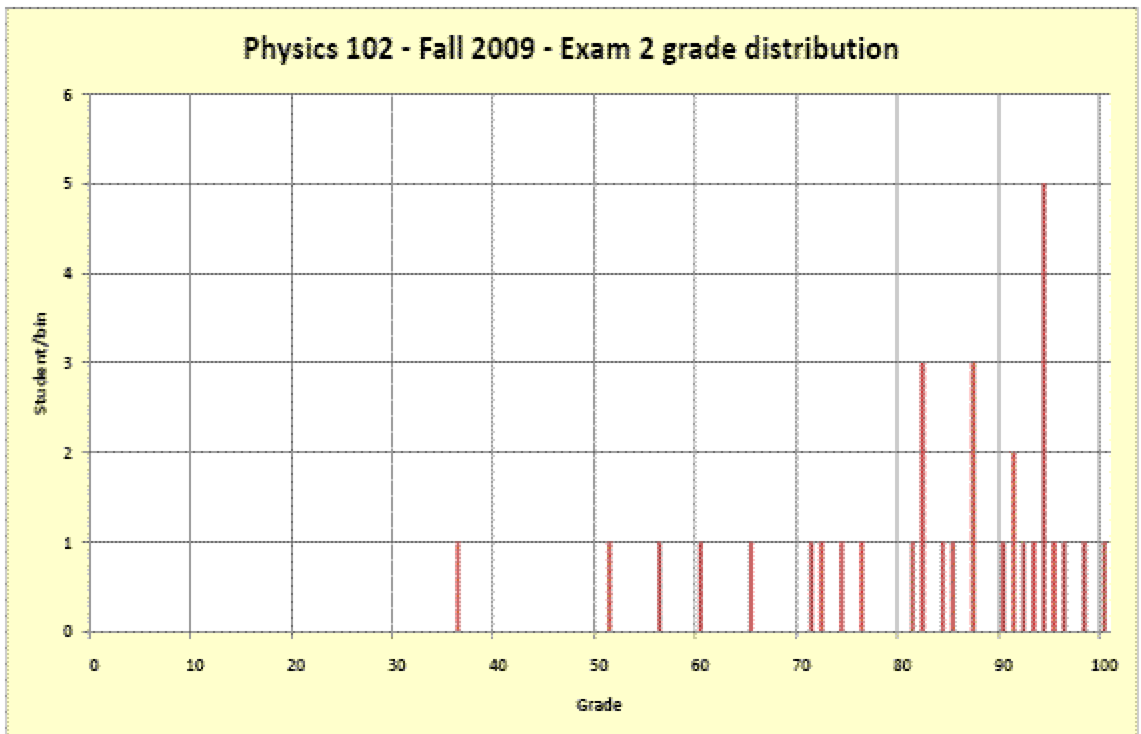
Physics 102 - December 2, 2009

- Exams
- Projects

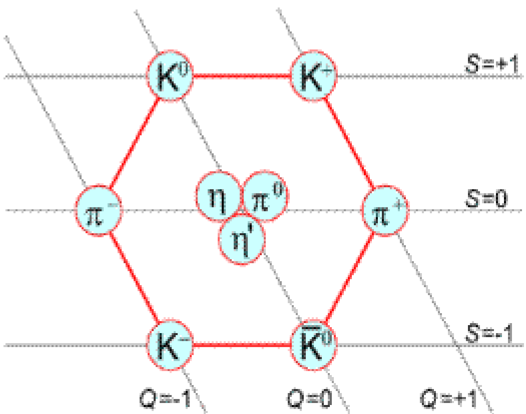


The Dark Matter pseudomultiverse . . .

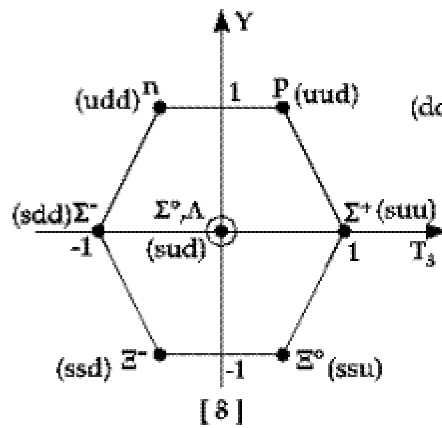
String Theory

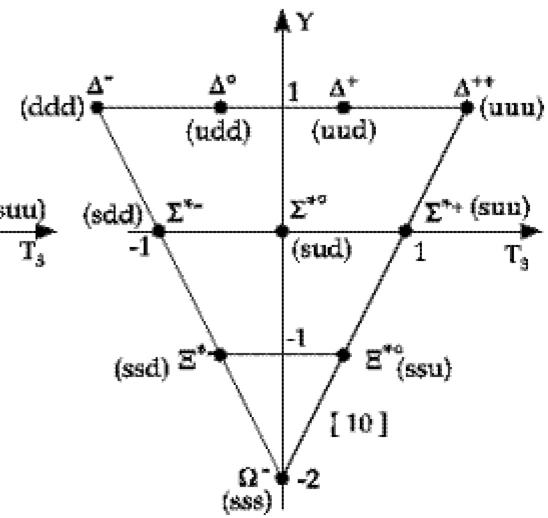
Before
quarks established
Before QCD

Spin 0 mesons

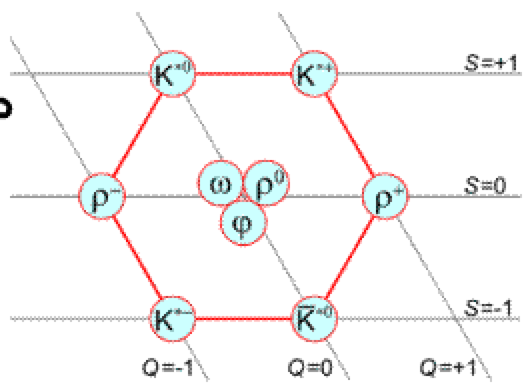


Baryons





Spin 1 mesons



Particle	Rest mass MeV	Average lifetime s	Most frequent type of decay %
Photon			
γ	0 ($< 2\cdot10^{-22}$)	stable	stable
Leptons			
ν_e	0 ($< 3\cdot10^{-6}$)	stable	stable
ν_μ	0 (< 0.19)	stable	stable
ν_τ	0 (< 18.2)	stable	stable
e	0.510998890	stable ($> 4.2\cdot10^{24}$ a)	stable
μ	105.658357	$2.19703\cdot10^{-6}$	$e^- \bar{\nu}_e \nu_\mu$ 98.6 $e^- \bar{\nu}_e \nu_\mu \gamma$ 1.4
τ	1777.03	$2.906\cdot10^{-13}$	$e^- \bar{\nu}_e \nu_\tau$ 17.83 $\mu^- \bar{\nu}_\mu \nu_\tau$ 17.37
Mesons			
π^0	134.9766	$8.4\cdot10^{-17}$	$\gamma\gamma$ 98.8 $\gamma e^+ e^-$ 1.2
$\pi^\pm$	139.57018	$2.6033\cdot10^{-8}$	(for π^+) $\mu^+ \nu_\mu$ 99.98 $e^+ \nu_e$ 0.01 $\mu^+ \nu_\mu \gamma$ 0.01
η	547.305		$\gamma\gamma$ 389.3 $\pi^0 \pi^0 \pi^0$ 312.2 $\pi^+ \pi^- \pi^0$ 23.0 $\pi^+ \pi^- \gamma$ 4.9
$K^\pm$	493.677	$1.2386\cdot10^{-8}$	(for K^+) $\mu^+ \nu_\mu$ 63.51 $\pi^+ \pi^0$ 21.16 $\pi^+ \pi^+ \pi^-$ 5.59 $e^+ \nu_e \pi^0$ 4.82 $\mu^+ \nu_\mu \pi^0$ 3.18 $\pi^+ \pi^0 \pi^0$ 1.73
K^0	497.672	K_S $8.935\cdot10^{-11}$ K_L $5.17\cdot10^{-8}$	$\pi^+ \pi^-$ 68.61 $\pi^0 \pi^0$ 31.39 $\pi^\pm e^\mp \nu_e$ 38.78 $\pi^\pm \mu^\mp \nu_\mu$ 27.18 $\pi^0 \pi^0 \pi^0$ 21.13 $\pi^+ \pi^- \pi^0$ 12.55 $\pi^\pm e^\mp \nu_e \gamma$ 0.36
D^0	1864.6	$0.4126\cdot10^{-12}$	
$D_s^\pm$	1968.6	$0.496\cdot10^{-12}$	
$D^\pm$	1869.3	$1.051\cdot10^{-12}$	
$B^\pm$	5279.0	$1.653\cdot10^{-12}$	
B^0	5279.4	$1.548\cdot10^{-12}$	
B_s^0	5369.6	$1.493\cdot10^{-12}$	
Baryons			
p	938.27200	stable ($> 1.6\cdot10^{25}$ a)	stable
n	939.56533	886.7	$p e^- \bar{\nu}_e$ 100
Λ^0	1115.683	$2.632\cdot10^{-10}$	$p \pi^-$ 63.9 $n \pi^0$ 35.8
Σ^+	1189.37	$8.018\cdot10^{-11}$	$p \pi^0$ 51.6 $n \pi^+$ 48.3
Σ^0	1192.642	$7.4\cdot10^{-20}$	$\Lambda^0 \gamma$ 100
Σ^-	1197.449	$1.479\cdot10^{-10}$	$n \pi^-$ 99.9
Ξ^0	1314.83	$2.90\cdot10^{-10}$	$\Lambda^0 \pi^0$ 99.5
Ξ^-	1321.31	$1.639\cdot10^{-10}$	$\Lambda^0 \pi^-$ 99.9
Ω^-	1672.45	$8.21\cdot10^{-11}$	$\Lambda^0 K^-$ 67.8 $\Xi^0 \pi^-$ 23.6 $\Xi^- \pi^0$ 8.6

Why Strings?

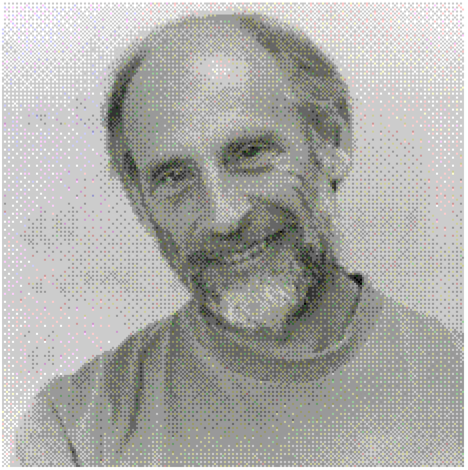
Try to understand what is structure of Mesons + barons

Hadrons

Point particles give troubles

$F \sim \frac{1}{r^2} \to \infty$ as $r \to 0$

Leonard Susskind



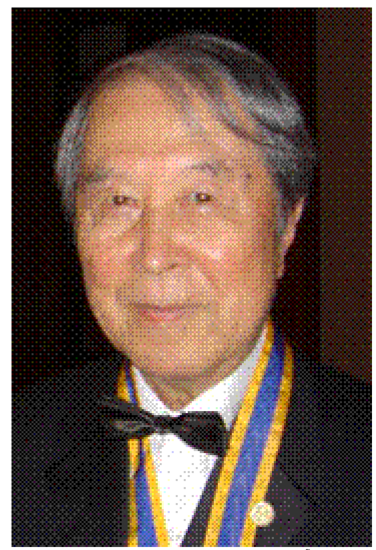
Stanford Univ.

Discovered that excitations of relativistic strings have a correspondance to particle states

Also publ. recently controv. work about future affecting LHC

Holger Bech Nielsen

Niels Bohr Inst.



2008 Nobel Prize in physics

Yoichiro Nambu

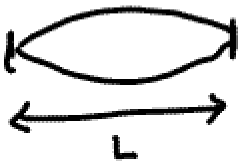
Univ. of Chicago

Travelling wave on string

$y = A \sin(kx \pm \omega t)$

Standing waves: non-relativistic string w/ fixed ends
Length L

Music



0 nodes

$L = \frac{1}{2}\lambda$

$v = \lambda \nu$

$\lambda = v/\nu$

$L = \frac{1}{2}\frac{v}{\nu} \rightsquigarrow \nu = \frac{1}{2}\frac{v}{L}$

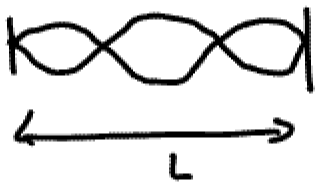
1 node

$L = \lambda$

$\nu = \frac{2}{2}\frac{v}{L}$

$L = \frac{v}{\nu}$

Illustration of how quantized states can come from strings (not for you to do on a test)



2 nodes

$$L = \frac{3\lambda}{2} \qquad \nu = \frac{3}{2}\frac{v}{L}$$

$$L = \frac{3}{2}\frac{v}{\nu}$$

⋮

$$\boxed{\nu_n = \frac{n}{2}\frac{v}{L}}$$

frequencies that will resonate on string of length L

$n = 1, 2, 3 \ldots$

$v \equiv$ velocity of wave propagation
Depends on string tension and mass / length

60's, early 70's

Susskind, Nielsen, Nambu independently discovered that the mathematical description of relativistic string vibrations/rotations is similar to that for particles with different masses/spins in quantum field theory

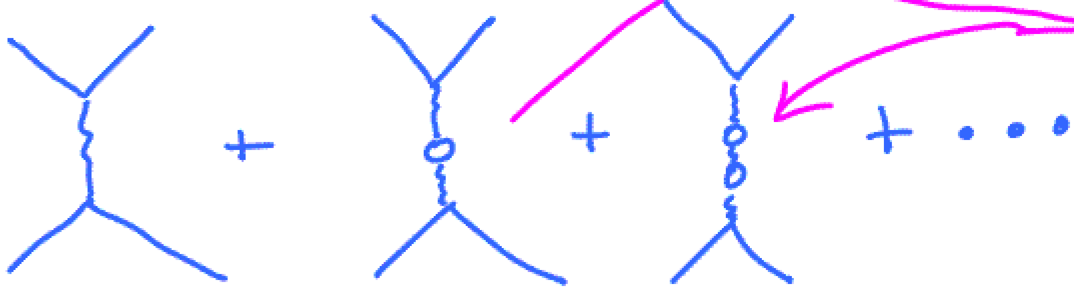
→ Birth of String theory

Quantum Mechanics + Gravitation → quantum gravity

Add "graviton" to quantum field theory

Ad hoc Addition (NOT Natural)

two interacting particles (Feynman diagrams)



quantum loops of virtual particles

must sum over all possibilities at all Momenta

graviton at ∞ momentum

↳ zero DISTANCE

→ Causes calculation to Misbehave badly

Quantum Gravity + String theory

massless spin 2 graviton state
unavoidable + Natural in String theory

Short distance behavior problem goes away

Quantum Gravity is natural and well-behaved in String theory

String theory
Bosons only
misbehaves
(ghost particles)
unless done in
26 dimensions mathematically

Not like the real world

String theory
Bosons + Fermions
misbehaves
(ghost particles)
unless done in
10 dimensions mathematically
plus
Supersymmetry

like real world ?
maybe

Supersymmetry

$$\psi(x_1, x_2) \rightarrow \pm \psi(x_2, x_1)$$

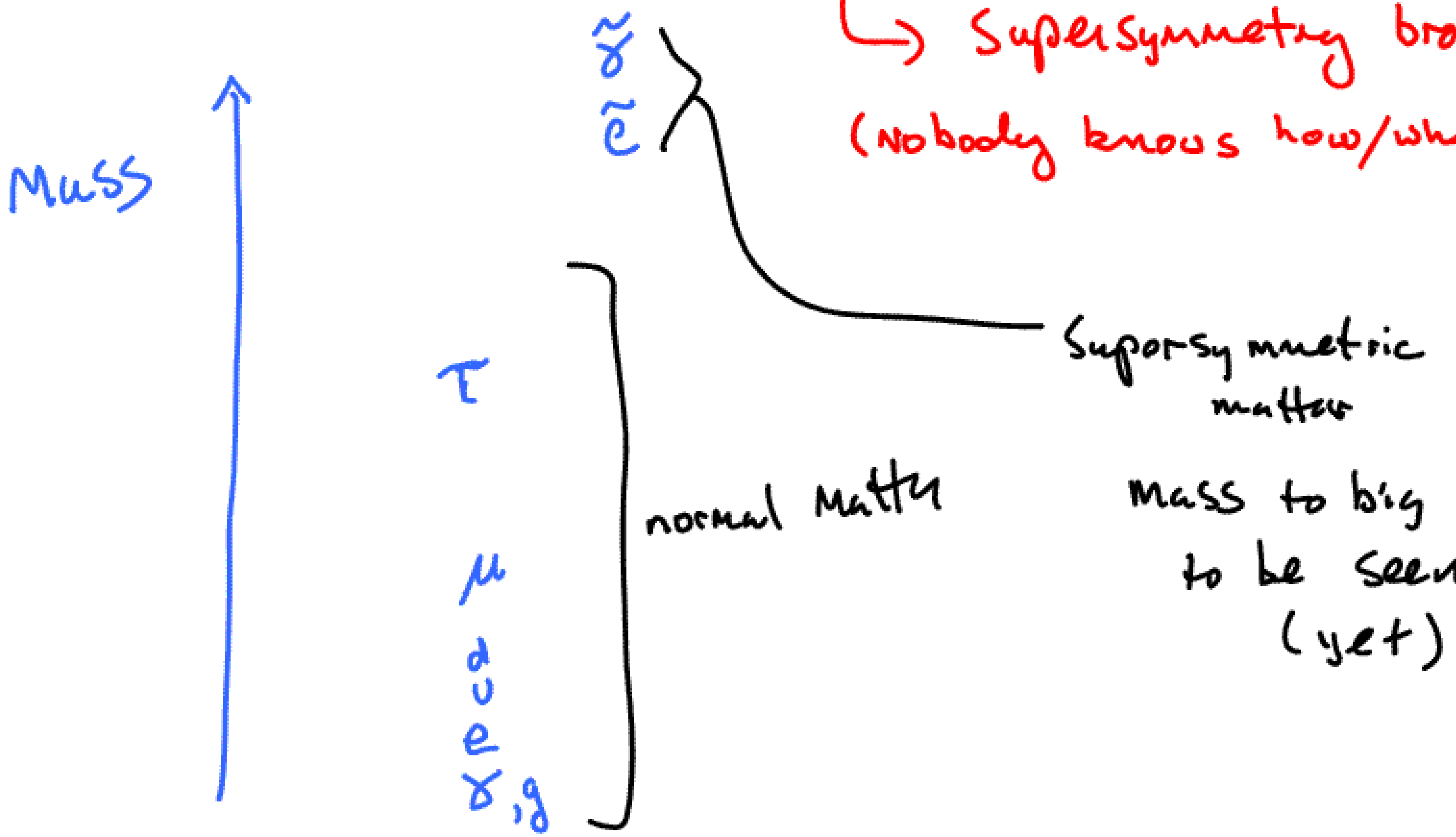
Bosons → + ; Fermions → −

normal matter		supersymmetric matter	
Spin ½	electron →	selectron	spin 0
Spin 1	photon →	photino	spin ½

Super symmetry predicts doubling of particle spectrum

↳ NOT observed

↳ Supersymmetry broken (Nobody knows how/why yet)



Extra Dimensions

General Relativity

Einstein 1915
Gemetrical theory
4 dimensions

Theodor Kaluza

(German 1885-1954)

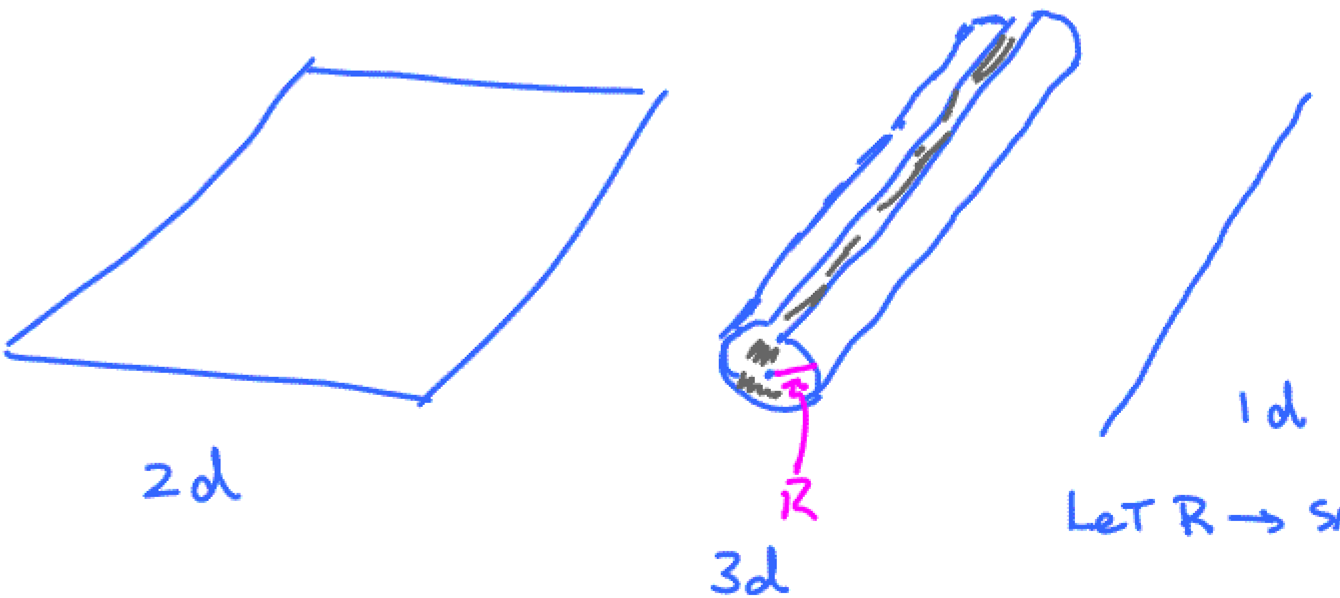
Can unify fundamental forces using extra dimensions

1919-1921 Showed that if you solve Einsteins GR equations in 5-d get Electromagnetism + Gravitation !

Where is this extra dimension?

1926 → Compactification

Oskar Klein
(1894 - 1977)



Let $R \to$ small

Superstring Theory in Mid-80's

5 consistent theories known

hoped one might prove to be the

Theory of Everything

I

IIA

IIB

Heterotic $E_8 \times E_8$

Heterotic $SO(32)$

Duality discovered – Deep relationships among the 5 theories

Strong

I

large

II A

T-Duality

S-duality

II B

small

Heterotic $E_8 \times E_8$

large

T-duality

Weak

Heterotic SO(32)

small

1995 – All 5 Superstring theories in 10-d Come from Single 11-d Theory

M-Theory

is this the T.O.E.?

Inst. for Advance Study (Princeton)

Edward Witten
(1951 –   )

Other structures in String theory

P-Branes

0-Brane	Point
1-Brane	String
2-Brane	Membrane
3-Brane	
⋮	
9-Bran	

D-Brane (Dai, Leigh Polchinski + indep by Horava)
1989

P-Brane where on end of an open string is attached.

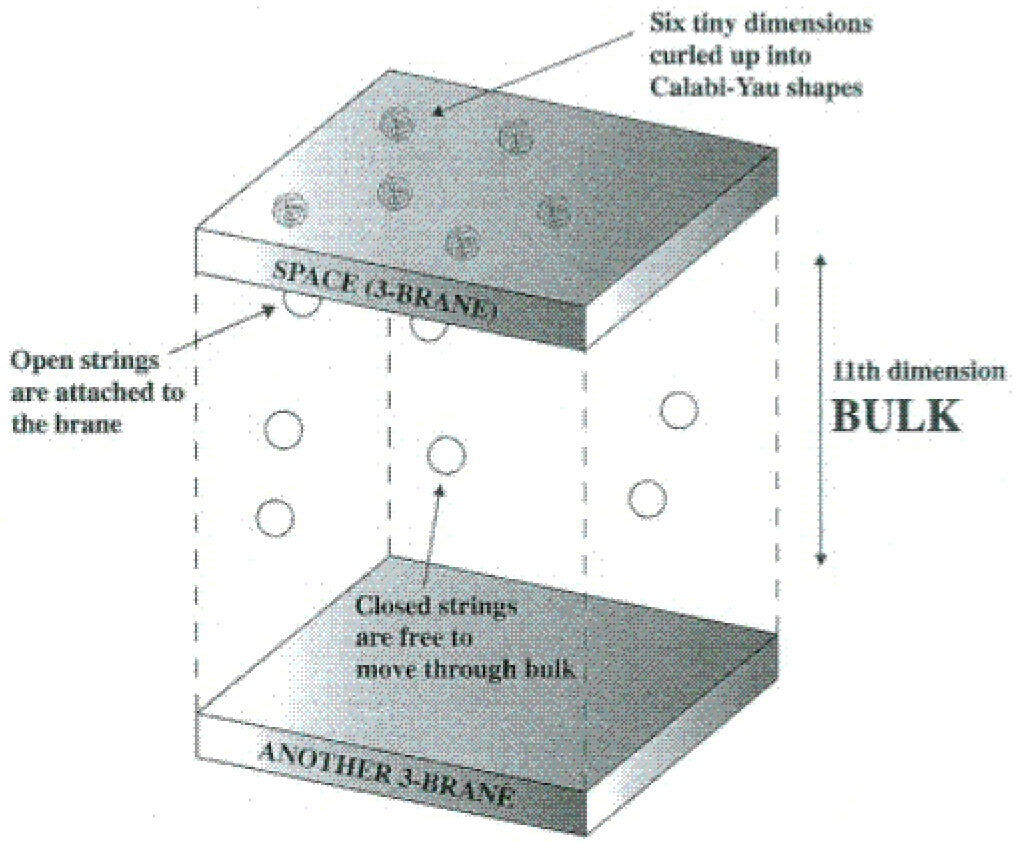


image from http://abyss.uoregon.edu/~js/qc/qc.html

Extra dimensional pseudomultiverse

Ekpyrotic multiverse (cyclic Brane collisions)