Extra Dimensions

Gela Devidze

High Energy Physics Institute,

Tbilisi State University

Content

- *Gunnar Nordström*
- *Theodor Kaluza*
- *Oskar Klein*

- Nordstrom G, Phys. Ztsch., 1914, Bd. 15, S.504.
- Th. Kaluza**.** Sitzungsber. Preuss. Akad. Wiss. Berlin (Math.Phys) 1921 (1921) 966.
- O. Klein. Z.Phys.37 (1926) 895.

Nordström showed that gravitation and electromagnetism could be understood as two different faces of a five dimensional electromagnetism.

In other words, Nordström formulated first five dimensional electrodynamics, while Kaluza and Klein created first 5D gravity.

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- Th. Kaluza**.** Sitzungsber. Preuss.Akad.Wiss.Berlin(Math.Phys) 1921 (1921) 966.
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The discovery of new interactions, other than electromagnetizm and gravitation, complicated more the overall picture . In the next years the interpretation of the extra dimensions changed, in the sense that they were given a physical meaning. It was due to the development of new theories; supergravity and string theory, where the extra dimensions played a key role. The natural energy scale for these theories is the Planck mass, that is completely out of reach for current particle accelerators.

1. ADD model of Arcani-Hammed, Dimopoulos and Dvali

2. RS model of Randal and Sundrum with warped 5-dimensional space-time and nonfactorized geometry

3. ACD models of Appelquist, Cheng and Dobrecu (so called Universal Extra Dimensional Model (UED)), where all the particles move in the whole Bulk.

1. Phys.Lett. B429, 263-272 (1998), hep- ph/9803315.
   Phys. Lett. B436, 257-263 (1998), hep-ph/9804398.
2. Phys. Lett. 83, 3370-3373 (1999), hep-ph/9905221.
   Phys. Lett. 83, 46090-4693 (1999), hep-th/9906064.
3. Phys. Rev. D64, 035002 (2001), hep- ph/0012100.

V.A.Rubakov, M.E.Shaposhnikov, “Do We Live Inside A Domain Wall”, Phys. Lett. B125 (1983) 136

K.Akama, “An Early Proposal Of’Brane World”, Lect.Notes Phys. 176, 267 (1982) [hep-th/0001113]

I.Antoniadis, « A POSSIBLE NEW DIMENSION AT A FEW TEV « Phys. Lett. B246 (1990) 377

A.Barnaveli, O.Kancheli, Sov.J.Nucl.Phys. 52 (1990) 576.

The main ingredients of a simplest ADD scenario are :

- Standard Model particles are localized on a3-d brane, while gravity spreads to all 4+N dimensions
- The fundamental scale of gravity M are around a few Tev
- N extra dimensions are compactified

Technical simplifications:

- The Brane width is taken to be zero (generally, the natural scale for the Brane width could 1/M).

- Brane fluctuation are neglected

- All extra dimensions have equal sizes (in general, different extra dimensions could have different sizes)

- Only gravity can propagate in the bulk (in general, other fields could also live in the bulk)

Selected topics of the ADD phenomenology

- Gauge coupling unification.
- Missing energy signals in accelerator experiments.
- Energy loss by stars via emission of light KK gravitons.
- Cosmological implications

$$\frac{M^{2+n}}{2}\int d^4x\int_0^{2\pi} d^n y\sqrt{G}R_{(4+n)} \rightarrow \frac{M^{2+n}(2\pi r)^n}{2}\int d^4x\sqrt{g}R$$

$$M_{Pl}^2 \sim M^{2+n} r^n$$

$$M \sim 1TeV$$

$$r = 10^{\frac{30}{n}-17} cm$$

$n=1$	$r=10^{13}\,cm$
$n=2$	$r=10^{-2}\,cm$
$n=3$	$r=10^{-7}\,cm$

$$V(R) = G\frac{m_1 m_2}{R}$$

$$V(R) = G_N \frac{m_1 m_2}{R^{1+n}}$$

$R >> r$ $\qquad$ $R << r$

$r \sim R$ $\qquad$ $G_N = Gr$ $\qquad$ $G_N = 1/M^{2+n}$

$$M_{Pl}^2 = M^{2+n} R^n$$

$M \sim 1 TeV$

$n = 1$ $\qquad$ $r = 10^{13}\, cm$

$$r = 10^{\frac{30}{n} - 17}\, cm$$

$n = 2$ $\qquad$ $r = 10^{-2}\, cm$

$n = 3$ $\qquad$ $r = 10^{-7}\, cm$

$$Br(\mu \to e\gamma)_{SM} < 10^{-50} \qquad Br(\mu \to e\gamma)_{\exp} < 1.2 \cdot 10^{-11}$$

$$\left(\frac{m^2(\nu_a) - m^2(\nu_b)}{M_W^2} \right)^2$$

$$Br(\mu \to e\gamma) \; < 1.2 \cdot 10^{-13} \div 10^{-14}$$

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http://meg.web.psi.ch

Collider signatures

$e^+ + e^- \rightarrow \gamma + G$ $\sigma \sim s^{n+2}/M^{n+2}$

8 Tev (n=2) ---------- 3 Tev (n=6) LHC

10^{-3} cm (n=2) < R < 10^{-13} cm (n=6)

Indirect detection

$M_W, \Gamma_{ll}, \Gamma_{had}, \ldots$ $\qquad Z^{(n)}, \gamma^{(n)}$

$1/R \sim O(\text{TeV})$

Direct detection

ff KK

	LEP2	Tevatron	LHC
1/R (TeV)	1.9	1.2	6.7

Current constraints on M

- $e^+ + e^- \rightarrow \gamma + G$ LEP

M (TeV)	1.43	1.1	0.87	0.72	0.62	
n	2	3	4	5	6	

.

- Neutrinos detection from SN1987A requires

  $M > 12.5$ TeV $(n=2)$, $M > 1.5$ TeV $(n=3)$

- EGRET

  $M > 34$ TeV $(n=2)$, $M > 3.8$ TeV $(n=3)$

- Pulsars

  $M > 670$ TeV $(n=2)$, $M > 30$ TeV $(n=3)$

Charged Lepton Radiative and B-meson Double Radiative Decays in Models with Universal Extra Dimensions

I.I.Bigi, G.Chiladze, G.Devidze, Ch.Hanhart, A.Liparteliani, Ulf-G.Meissner

hep-ph/0603160

MEGA Collab., a research proposal PSI-R-9905
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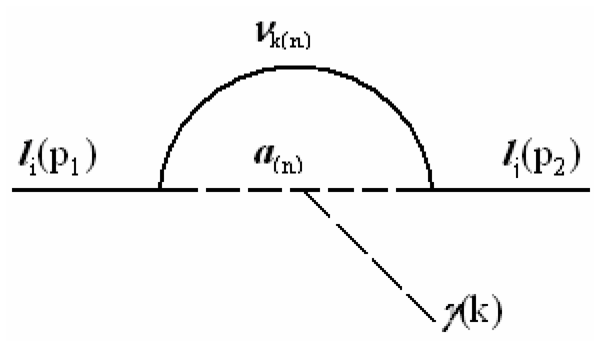
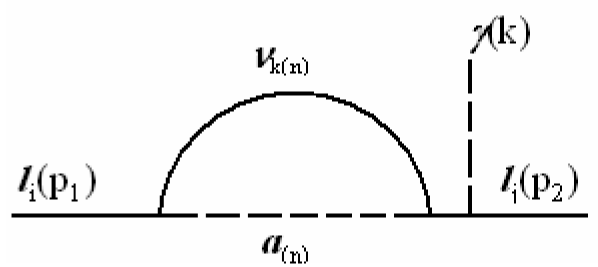
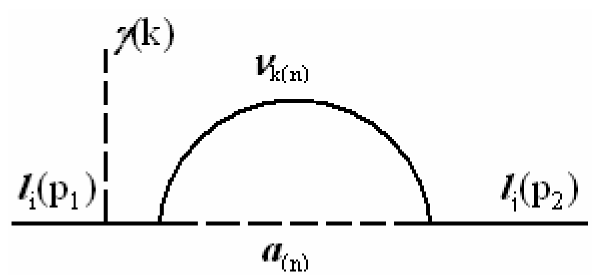


$\nu_{k(n)}$
$l_i(p_1)$
$a_{(n)}$
$l_i(p_2)$
$\gamma(k)$



$\gamma(k)$
$\nu_{k(n)}$
$l_i(p_1)$
$l_i(p_2)$
$a_{(n)}$



$\gamma(k)$
$\nu_{k(n)}$
$l_i(p_1)$
$l_i(p_2)$
$a_{(n)}$

In the paper [*] mainly model independent analysis of $\mu \to e\gamma$ and $\tau \to \mu\gamma$ is performed. Important statement is that when intermediate scalar particle and fermion masses are comparable, considerable enhancement of the amplitude has the place. The authors declare that such a situation is realizable in theories with universal extra dimensions.

* Bo He, T.P. Cheng and Ling-Fong Li, Phys. Lett. **B553**, 277 (2003).

$$m^2(\nu_{k(n)}) = m^2(\nu_k) + \frac{n^2}{r^2}$$

$$m^2(a_{(n)}) = M_W^2 + \frac{n^2}{r^2}$$

$$x_k = \frac{m^2(\nu_{k(n)})}{m^2(a_{(n)})} = \frac{m^2(\nu_k) + \frac{n^2}{r^2}}{M_W^2 + \frac{n^2}{r^2}}$$

$$0.9 < x_k < 1$$

$$F_{2V} \sim V_{ik} V_{jk}^{*} \left\{ \frac{n}{rM_W} \frac{m(\nu_{k(n)})}{M_W} \left(-\frac{1}{4} + \frac{x_k}{12} \right) + \frac{x_k}{60} \right\}$$

$$\frac{n}{rM_W} V_{ik} V_{jk}^{*} \frac{m(\nu_{k(n)})}{M_W} = \frac{n}{rM_W} V_{ik} V_{jk}^{*} \left(\frac{n}{r} + \frac{rm^2(\nu_k)}{2n} \right) \frac{1}{M_W} = V_{ik} V_{jk}^{*} \frac{m^2(\nu_k)}{2M_W^2}$$

$$Br(l_i \to l_j\gamma) = \frac{3\alpha}{32\pi}\frac{M_W^8}{M_{W(n)}^8}\left(V_{ik}V_{jk}^*\frac{m^2(\nu_k)}{M_W^2}\right)^2$$

$$Br(l_i \to l_j\gamma)_{SM} = \frac{3\alpha}{32\pi}\left(V_{ik}V_{jk}^*\frac{m^2(\nu_k)}{M_W^2}\right)^2$$

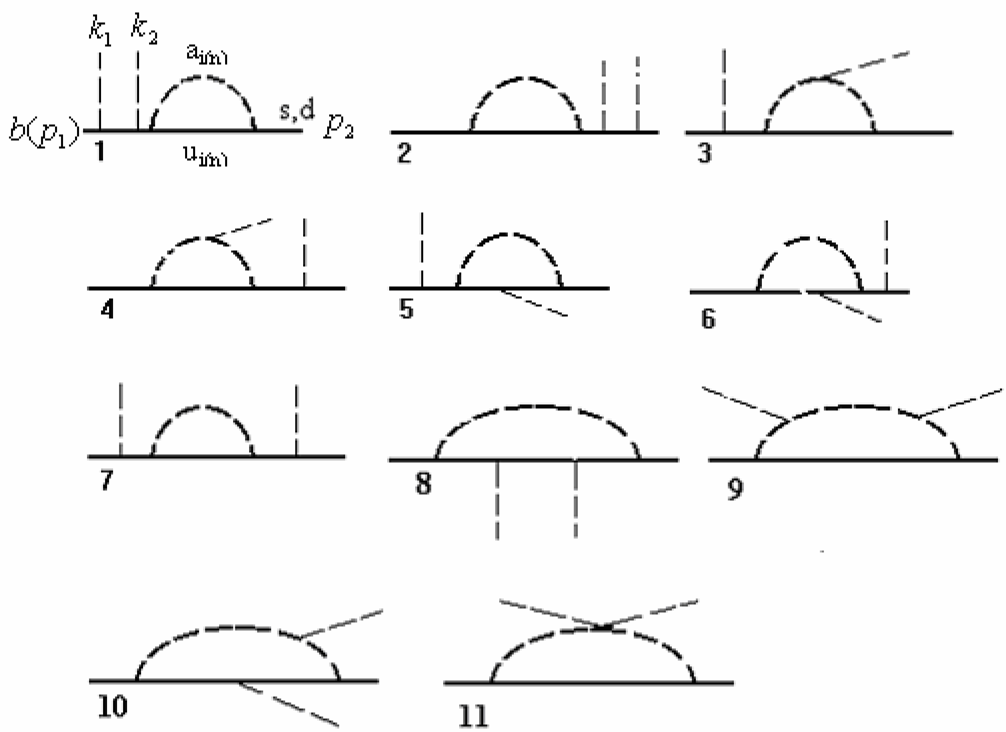
$B \rightarrow \gamma\gamma$ decay in the theory with one universal extra dimension

G.Devidze, A.Liparteliani, Ulf-G. Meißner

Phys. Lett. B634 (2006) 59-62

$$Br(B_s \to \gamma\gamma) \sim 10^{-7} \qquad Br(B_d \to \gamma\gamma) \sim 10^{-9}$$

$$Br(B_s \to \gamma\gamma) \sim 10^{-6}$$



k_1
k_2
$a_{i(n)}$
$b(p_1)$
s,d
p_2
1
$u_{i(n)}$
2
3
4
5
6
7
8
9
10
11

Our analyses show that in case of $B_s \rightarrow \gamma\gamma$ decay we can get the difference from SM-result as much as 3%, while the same difference for the case of $B_d \rightarrow \gamma\gamma$ is 6% .

Theoretical estimates of double radiative decays in the framework of the Standard Model and along with the upper experimental limits permits us to hope that in the not to far future these decays will be observed (say, by BaBar collaboration or at CERN B physics facility).

In this case we hope that there is not far the time when the differences of will be accessible for experimental analysis as well

We have investigated charged leptons radiative decays $l_i \rightarrow l_j \gamma$ and B mesons double photon decays $B \rightarrow \gamma\gamma$ in frame of UED model.

•In the SM with massive neutrinos lepton flavor violating processes are extremely suppressed. As it is seen from our analyses there is no enhancement of this process in the universal extra dimension model over the SM. As present analysis shows, if forthcoming search for $l_i \rightarrow l_j \gamma$ gives us the flavor violation effect, one should look it in kind of sources of lepton flavor violation, other than the UED model with only additional spatial dimension is.

• Our analyses show that in case of $B_s \rightarrow \gamma\gamma$ decay we can get the difference from SM-result as much as 3%, while the same difference for the case of $B_d \rightarrow \gamma\gamma$ is 6% .
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$M_{BH} \sim 1TeV$

Mini BH

- $M_{BH} \sim 1TeV$ $\sigma \sim \pi R^2$

$$R = \frac{1}{\pi M}\left(\frac{M_{BH}}{M}\right)^{\frac{1}{n+1}}\left[\frac{8\Gamma((n+3)/2)}{n+2}\right]^{\frac{1}{n+1}}$$

Mini Bh phenomenology

- Proton decay
- Lepton number violation
- Top decay
- Meson decay

- The predicted B and L non-conserving decay rates are interestingly close to the existing experimental bounds.

Conclusion

- Large Extra Dimensions are well motivated theoretically.
- Large Extra Dimensions and low scale quantum gravity effects are at reach at present (Tevatron) and future colliders (LHC).
- Large Extra Dimensions have unambiguous experimental signatures.
- Large Extra Dimensions can also help to solve theoretical Particle Physics problems
- If Large Extra Dimensions are found at LHC or somewhere else it would possibly constitute the most important revolution in the History of Particle Physics