Particles escaping from our brane

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Background metric of the RSII-n model

T. Gherghetta M. Shaposhnikov 2000.

Consider $(3+n)$ - brane with n compact dimensions, embedded in a $(5+n)$ - spacetime with slice AdS_{5+n} metric:

$$ds^2 = a(z)^2(\eta_{\mu\nu}dx^\mu dx^\nu - \delta_{ij}d\theta^i d\theta^j) - dz^2, \quad (1)$$

z -is the infinite extra-dimension

θ_i - are the compact extra-dimensions $\theta_i \in [0, 2\pi R_i]$, $i = \overline{1, n}$,

n - is a number of compact extra-dimensions,

$a(z) = e^{-k|z|}$ is a warp factor from Randall-Sundrum model.

Peculiar features of the RSII-n model

- Single brane along z direction
- Orbifold geometry of the compact extra-dimensions θ_i,
  Z_2 identification: $\theta_i \to -\theta_i$
- The constant zero modes $A^{(0)} = const$ of the massless fields could be localized due to the presence of the warp-factor in the overlap integral

$$\int dz\, a^n |A^{(0)}|^2 \quad - \text{is finite,}$$

- Kaluza-Klein excitations of the SM particles posses a gapless mass spectrum. Unparticle scenario!

$SU(2) \times U(1)$ bulk sector of the Standard Model

The action of the theory:

$$S = \int d^4x\, dz \prod_{i=1}^{n} \frac{d\theta_i}{2\pi R_i} \sqrt{g}[-\frac{1}{4}\left(F^{\alpha}_{MN}\right)^2 - \frac{1}{4} B^2_{MN} + \left(D_M\Phi\right)^{\dagger} D_M\Phi - \\ -V(\Phi^{\dagger}, \Phi) + \delta(z)\mathcal{L}_F], \quad (2)$$

F^{α}_{MN}, B_{MN}, Φ are the bulk fields.

fermions ψ are localized on the brane and depend only on four-dimensional coordinates x.

$$V(\Phi^{\dagger}, \Phi) = \frac{\lambda}{2}\left(\Phi^{\dagger}\Phi - \frac{v^2}{2}\right)^2 \quad (3)$$

$$D_M\Phi = \partial_M\Phi - i\frac{\widetilde{g}_1}{2}\hat{B}_M\Phi - i\widetilde{g}_2\frac{\sigma_i}{2}A^{\alpha}_M\Phi \quad (4)$$

Equations of motion for bulk photon

$$-p^2\widetilde{A}_5 - ip^\mu\partial_5\widetilde{A}_\mu = 0, \tag{5}$$

$$\left(-\partial_5^2 + (2+n)k\,\mathrm{sign}(z)\partial_5 - \frac{p^2}{a^2}\right)\widetilde{A}_\lambda + \frac{1}{a^2}p^\mu p_\lambda\widetilde{A}_\mu +$$
$$+ip_\lambda\left(\partial_5\widetilde{A}_5 - (2+n)k\,\mathrm{sign}(z)\widetilde{A}_5\right) = 0. \tag{6}$$

We set the gauge $\widetilde{A}_5 = 0$,
the constant solution with respect to fifth z-coordinate
$\widetilde{A}_\mu^{(0)}(p,z) \equiv \widetilde{A}^{(0)} = \mathrm{const}$, is a photon localized on the brane.

$$\int_0^\infty dz\, e^{-nk|z|}\,|\widetilde{A}^{(0)}|^2 = 1 \;\Rightarrow\; \widetilde{A}^{(0)} = \sqrt{\frac{nk}{2}}. \tag{7}$$

$$\mathcal{L}_{int} = e_5\bar{\psi}\gamma_\mu\psi A^\mu(x)\widetilde{A}^{(0)} \quad\Rightarrow\quad e_5 = e_4\sqrt{\frac{2}{nk}}$$

Equations of motion for bulk Z^0 boson.

Physically transversal mode of Z boson obeys the equation:

$$\left(-\partial_5^2 + (2+n)k\,\mathrm{sign}(z)\partial_5 + m_Z^2 - \frac{m^2}{a^2}\right) Z_m(z) = 0, \qquad m^2 = p^2, \quad (8)$$

One easily finds:

$$Z_m(z) = \sqrt{\frac{m}{2k}}\, e^{(\frac{n}{2}+1)k|z|} \left[a_m J_\nu\left(\frac{m}{k}e^{k|z|}\right) + b_m N_\nu\left(\frac{m}{k}e^{k|z|}\right)\right],$$

normalization condition:

$$\int dz\, e^{-nk|z|} Z_m(z) Z_{m'}(z) = \delta(m-m'), \qquad a_m^2 + b_m^2 = 1,$$

boundary condition on the brane:

$$\partial_z Z_m(+0) - \partial_z Z_m(-0) = 0.$$

Classical limit and constraints

if $\frac{k}{m} \gg 1$, then $Z_m^2(0)$ tends to the delta function:

$$Z_m^2(0) = \frac{nk}{2} \cdot \frac{1}{\pi} \frac{\Gamma_Z}{2} \frac{1}{(m - M_Z)^2 + \left(\frac{\Gamma_{RS}^Z}{2}\right)^2} \to \frac{nk}{2} \cdot \delta(m - M_Z). \qquad (9)$$

$$\Gamma_{RS}^Z(m) = \frac{2\pi}{n\Gamma^2\left(\frac{n}{2}\right)} m \left(\frac{m}{2k}\right)^n, \quad M_Z = m_Z \sqrt{\frac{n}{n+2}} = 91.3\,\mathrm{GeV} \qquad (10)$$

are the invisible width decay, and the mass of Z^0 boson respectively. Constraints on the parameters k and n are defined by the following condition:

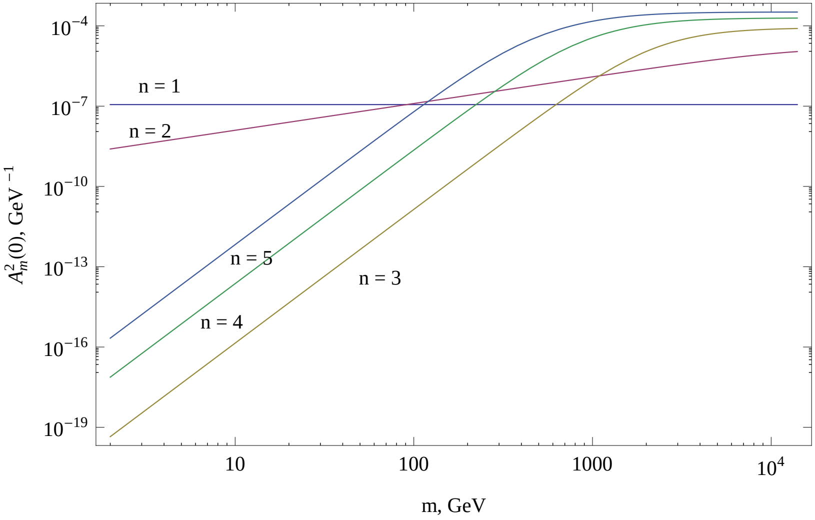
$$\Gamma_{RS}^Z(M_Z) \leq \Delta\Gamma_{invis}^Z \simeq 1.5 MeV \qquad \text{C.Amsler et al. PDG (2008)}$$

$$\Delta\Gamma_{invis}^Z - \text{is the experimental uncertanty.}$$

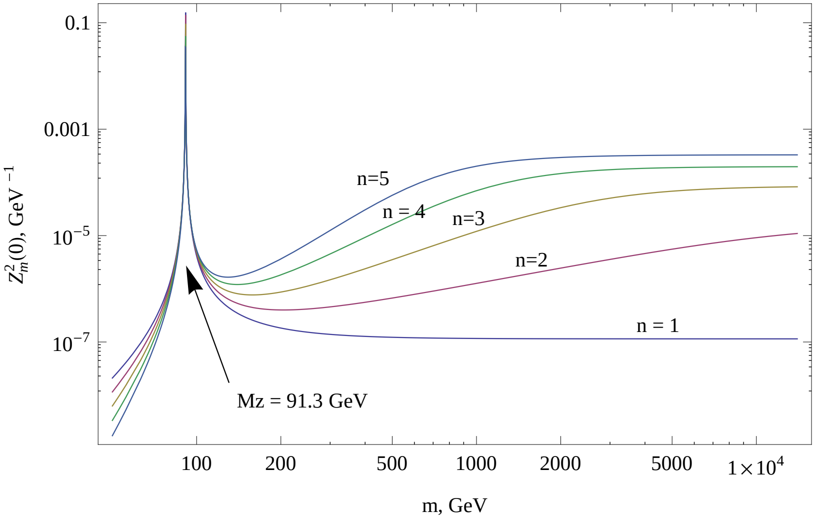
The table of the constraints on n and k

n	$SU(2)_{bulk} \times U(1)_{bulk}$ $k(GeV)$	$SU(2)_{brane} \times U(1)_{bulk}$ $k(GeV)$
1	$5.5 \cdot 10^6$	$1.3 \cdot 10^6$
2	$20 \cdot 10^3$	$10 \cdot 10^3$
3	$2.5 \cdot 10^3$	$1.6 \cdot 10^3$
4	900	600
5	400	300
6	300	200

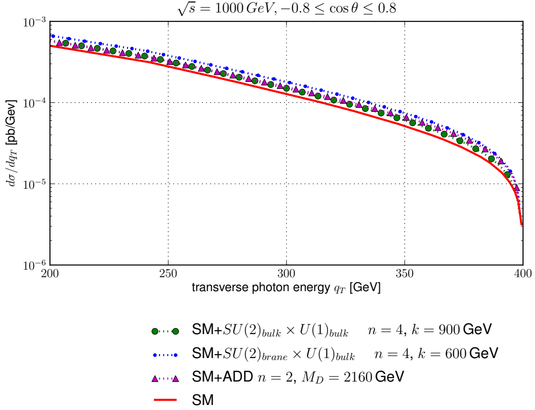
Lower bounds of the parameter k following from invisible Z boson decay



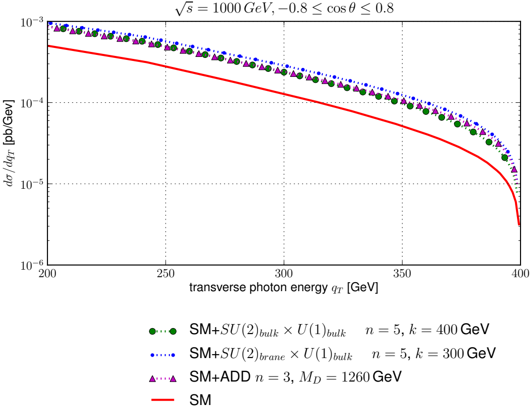
Squared wave function of the bulk photon $A_m^2(0)$ versus energy scale of the theory m



Squared wave function of the bulk Z boson $Z_m^2(0)$ versus energy scale of the theory m



Differential $e^+e^- \to \gamma + Z_{bulk}$ cross-section at $\sqrt{s} = 1$TeV integrated over angle between photon and beam in the range $-0.8 < \cos\theta < 0.8$. We have imposed the cut $q < 400$ GeV for both signal and background $e^+e^- \to \gamma + \bar{\nu}\nu$.



Differential $e^+e^- \to \gamma + Z_{bulk}$ cross-section at $\sqrt{s} = 1$TeV integrated over angle between photon and beam in the range $-0.8 < \cos\theta < 0.8$. We have imposed the cut $q < 400$ GeV for both signal and background $e^+e^- \to \gamma + \bar{\nu}\nu$.

$pp \to$ jet+nothing

To calculate the cross section of the process $pp \to jet + Z_{bulk}$ we consider the subprocess

$$\bar{q}q \to g + Z_{bulk},$$

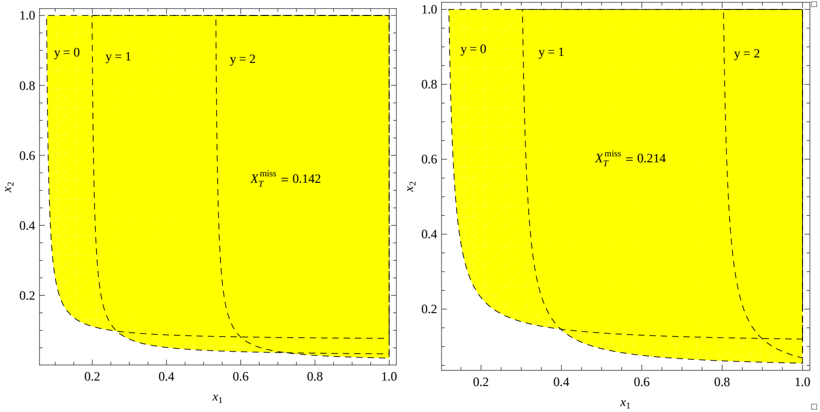
$$qg \to q + Z_{bulk}$$

$$\frac{d^2\sigma}{dy\, p_T\, dp_T} = \int dx_1 dx_2 \sum_{i,j=q,\bar{q},g} \frac{f_i(x_1)}{x_1} \frac{f_j(x_2)}{x_2} \frac{1}{4\pi s\, m} \overline{\sum_k} |\mathcal{M}_{i,j\to k(bulk)}|^2 \tag{11}$$

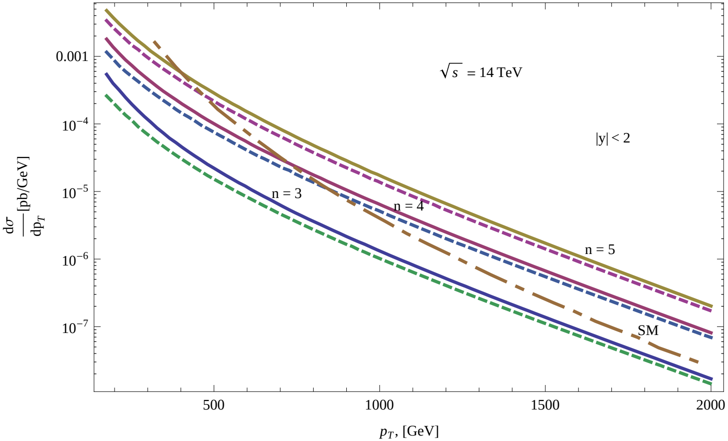
$p_T -$ is the transversal momentum of a jet.

$y -$ is the rapidity of a jet.

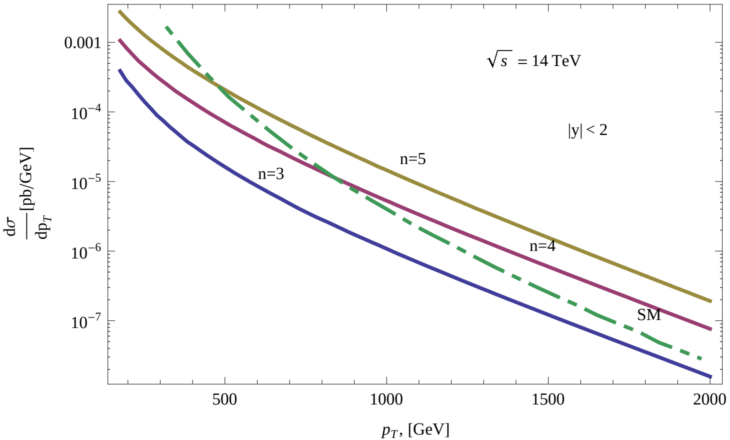
$m^2 = x_1 x_2 s \left(1 - \frac{p_T}{x_1\sqrt{s}} e^{-y} - \frac{p_T}{x_2\sqrt{s}} e^{y}\right) > 0$ is the invariant bulk mass of Z_{bulk}



Allowed area for longitudinal momentum of a partons, x_1 versus x_2 The rapidity of a jet $y = 0, 1, 2$, $X_T^{miss} = 2p_T/\sqrt{s}$ is the transversal portion of missing energy. The center mass energy is $\sqrt{s} = 14\,TeV$, the transversal momentum of a jet are $p_T = 1.5\,TeV$ and $p_T = 1\,TeV$



Comparison of differential cross-sections for the processes $pp \longrightarrow jet + Z_{bulk}$(solid line) and $pp \longrightarrow jet + \gamma_{bulk}$ (dotted line) at LHC for $\sqrt{s} = 14$ TeV versus transversal momentum p_T of a jet. The background signal of the SM comes from $pp \longrightarrow jet + \bar{\nu}\nu$ (dash-and-dot line)



Differential cross-sections for the processes $pp \longrightarrow jet + Z_{bulk} + \gamma_{bulk}$(solid line) at LHC for $\sqrt{s} = 14$ TeV versus transversal momentum p_T of a jet. The background signal of the SM comes from $pp \longrightarrow jet + \bar{\nu}\nu$ (dash-and-dot line)

Summary and conclusion

- From invisible decay of Z boson into the additonal dimensions we obtain a viable experimental constraints on numbers of extra dimension n and AdS curvature k. For $n = 3$, $k \geq 2,5$ TeV for $n = 4$, $k \geq 900$ GeV and for $n = 5$, $k \geq 400$ TeV.
- We represent a cross-section for the signal $pp \rightarrow jet +$ "nothing" in the RSII-n brane world model. There is a hope of detection particle escaping from our brane if the numbers of compact extra dimensions equal 4 and 5.
- The things to be done: the processes $pp \rightarrow jet + W^{\pm}_{bulk}$