

# Rottura della simmetria elettrodebole in più di quattro dimensioni

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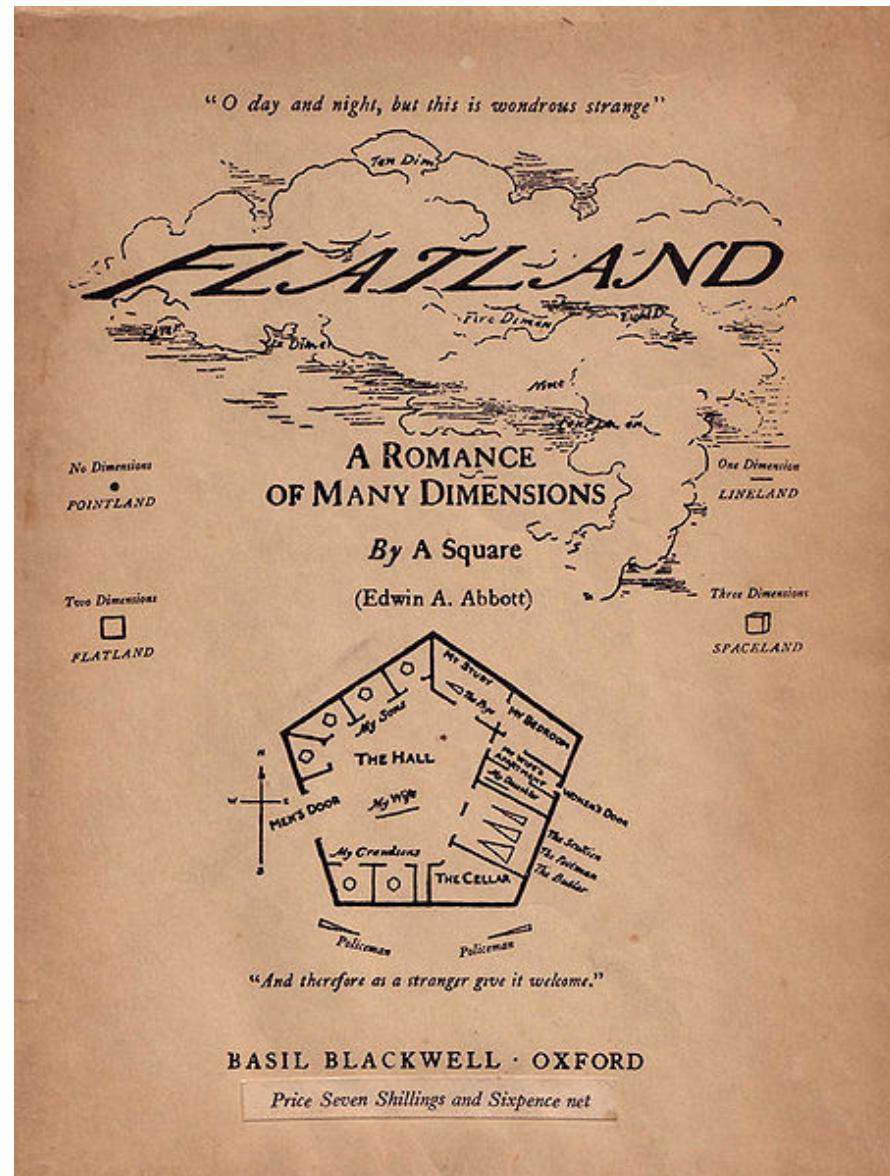
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- Introduction to extra dimensions at the TeV scale
- Invisible Higgs searches at LHC in Large Extra Dimensions
- Higgs searches at LHC in Randall Sundrum model
- New vectors at LHC from extra dimensions

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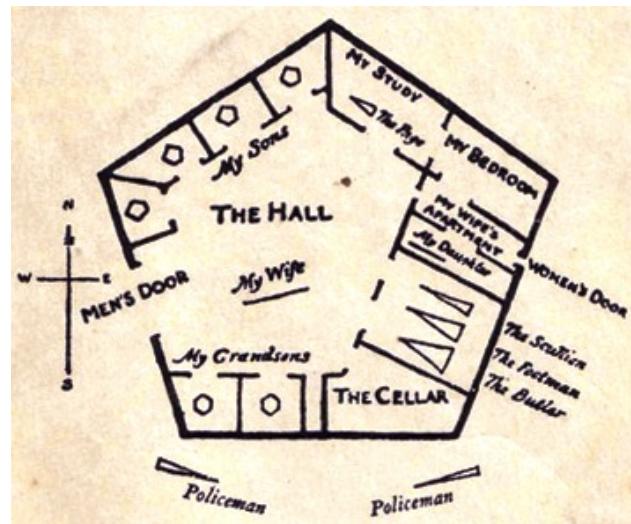
To  
The Inhabitants of SPACE IN GENERAL  
And H.C. IN PARTICULAR  
This Work is Dedicated  
By a Humble Native of Flatland  
In the Hope that  
Even as he was Initiated into the Mysteries  
Of THREE Dimensions  
Having been previously conversant  
With ONLY TWO  
So the Citizens of that Celestial Region  
May aspire yet higher and higher  
To the Secrets of FOUR FIVE OR EVEN SIX Dimensions  
Thereby contributing  
To the Enlargement of THE IMAGINATION  
And the possible Development  
Of that most and excellent Gift of MODESTY  
Among the Superior Races  
Of SOLID HUMANITY

The world is apparently four dimensional. But at distances shorter than those yet probed the universe could be described by a theory with extra dimensions.

Kaluza (1921), Klein (1926), attempts to unify gravity and electromagnetism in a 5 dim theory.

Common wisdom until 1998: size of extra dim  $\sim M_{Pl}$

New idea, branes: ordinary matter (except gravity) confined to 3+1 dimensions embedded in the large extra dim space.



Recent motivation: the hierarchy problem, or why

$$M_W \ll M_{Pl} = G_N^{-1/2} \sim 10^{19} \text{GeV} \sim (10^{-33} \text{cm})^{-1}$$

New ideas:

### Gravity in Large Extra Dimensions

- **Large  $\delta$  extra dimensions** (Arkani-Hamed, Dimopoulos, Dvali, Antoniadis 1998)

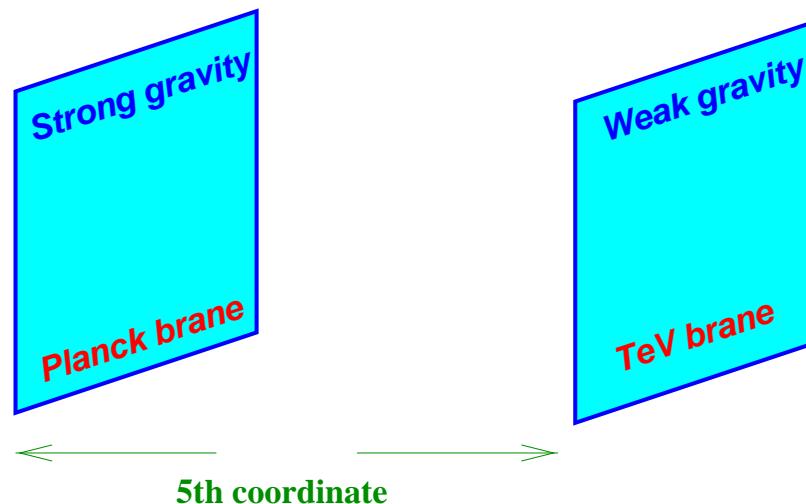
$$G_N^{-1} = M_{Pl}^2 = M_D^{2+\delta} V^\delta$$

$M_D \sim \text{TeV}$  fundamental Planck scale,  $V_\delta$  compactification volume

- Gravity diluted in  $4 + \delta$  dimensions,  $F_{3+\delta} \sim 1/r^{2+\delta}$ . Large distance field weaker by the large  $V_\delta$  in which the field lines can spread,  $F_3 \sim 1/r^2$
- SM interactions live in 4 dims

## Randall-Sundrum: Do we live on the brane?

We generally assume that we live on a brane, but it may not be the brane on which gravity is concentrated. Suppose that gravity is highly concentrated near what I'll call the **Planck brane**. So gravity is concentrated on one brane, the Planck brane, and we live on a **second brane**, not precisely on top of the first brane but a little apart. Gravity on our second brane would appear to be weak. And that's precisely what we wanted to explain: why gravity appears to be so weak. That's the hierarchy problem-why gravity is so weak. (Lisa Randall)



- Branes are assumed separated by a distance  $R$  of the order  $M_5^{-1} \sim M_P^{-1}$ .

- Hierarchy problem is geometrically reformulated: the warping of the fifth dimension brings down the Higgs vev to the weak scale from the Planck mass:

$$\Lambda = \overline{M}_{Pl} \exp(-\pi k R)$$

$$\Lambda \sim \text{TeV}, kR \sim 11\text{-}12$$

- In the original RS setup all SM fields located on the TeV brane
- To solve the hierarchy problem only Higgs has to be localized on the TeV brane, other fields can propagate in the 5D bulk (Davoudiasl, Hewett, Rizzo; Pomarol; Grossman, Neubert)

## Kaluza Klein states

Suppose that the extra-dimension forms, at each point of our four-dimensional space, a **circle** of radius  $R$ . Periodicity condition

$$\Phi(x^\mu, y) = \Phi(x^\mu, y + 2\pi R)$$

It is useful to choose for the KK wave functions the basis

$$\Phi(x^\mu, y) = \sum_{n=1}^{\infty} \Phi^{(n)}(x^\mu) \cos\left(\frac{ny}{R}\right)$$

The 5-dimensional mass-shell condition

$$P_{(5)}^2 = p_0^2 - p_1^2 - p_2^2 - p_3^2 - p_4^2 = m_0^2$$

From the four-dimensional point of view

$$M_n^2 = p_0^2 - p_1^2 - p_2^2 - p_3^2 = m_0^2 + \frac{n^2}{R^2}$$

$M_n \sim n/R$ . Working at fixed energy  $E$  only a limite number of KK can be produced,  $n = ER$ . For  $E < 1/R$  only the zero mode: the model looks 4-dimensional.

# Invisible Higgs searches at LHC in Large Extra Dimensions

Space time is  $\mathcal{M}_4 \times \mathcal{M}_\delta$ ,  $\mathcal{M}_\delta$  compact manifold of volume  $V_\delta$ , Einstein action: (Han, Lykken and Zhang, Giudice, Rattazzi and Wells)

$$S = \frac{\overline{M}_D^{2+\delta}}{2} \int d^D x \sqrt{|g|} R + \int d^4 x \sqrt{-g_{\text{ind}}} \mathcal{L}_{\text{SM}}$$

$$g_{AB} = \eta_{AB} + \frac{2}{\overline{M}_D^{1+\delta/2}} h_{AB}, \quad h_{AB} = \sum_{\vec{n}} \frac{1}{\sqrt{V_\delta}} h_{AB}^{(\vec{n})}(x) e^{-i \sum_{j=1}^\delta n_j y_j}$$

$$(A, B = 0, 1, 2, 3, \dots, 3 + \delta), D = 4 + \delta$$

Ansatz for the metric

$$h_{AB} = V_\delta^{-1/2} \begin{pmatrix} h_{\mu\nu} + \eta_{\mu\nu}\phi & A_{\mu i} \\ A_{\nu j} & 2\phi_{ij} \end{pmatrix}$$

## Interactions of KK gravitons and graviscalars with SM fields

$$-\frac{1}{M_P} h^{(\vec{n})\mu\nu} T_{\mu\nu} + \frac{1}{M_P} \sqrt{\frac{\delta - 1}{3(\delta + 2)}} \phi^{(\vec{n})} T_\mu^\mu$$

- If  $M_D \sim TeV$  KK excitations ( $\delta = 2 - 6$ ) in the range  $10^{-3}$  eV-10 MeV.
- Long life times:  $\tau = 1/\Gamma \sim M_{Pl}^2/m^3$ .
- Gravitons/graviscalars do not decay inside the detector due to their very weak interactions with matter:

⇒signature is missing energy

- Already investigated signals:  
 $e^+e^- \rightarrow \gamma, Z + \text{missing energy, LEP}$   
 $p\bar{p} \rightarrow \gamma, \text{jets} + \text{missing energy, Tevatron}$

Interaction between the Higgs  $H$  and the Ricci scalar curvature of the induced 4-dimensional metric  $g_{ind}$ ,

$$S = -\xi \int d^4x \sqrt{g_{ind}} R(g_{ind}) H^\dagger H$$

After the shift  $H = (\frac{v+h}{\sqrt{2}}, 0)$ , a mixing term

$$\mathcal{L}_{mix} = \epsilon h \sum_{\vec{n} > 0} s_{\vec{n}} \quad \epsilon = -\frac{2\sqrt{2}}{M_P} \xi v m_h^2 \sqrt{\frac{3(\delta - 1)}{\delta + 2}}.$$

This mixing generates an oscillation of the Higgs itself into the closest KK graviscalar levels:  $\Rightarrow$  invisible Higgs.

The mixing invisible width  $\Gamma_{h \rightarrow graviscalar}$  calculated by extracting the imaginary part of the mixing contribution to the Higgs self energy (Giudice, Rattazzi, Wells; Battaglia, Gunion, DD)

$$\langle hh \rangle = \text{---} + \sum_n \frac{\varepsilon}{s_n} \text{---} \dots + \dots$$

$$\begin{aligned}\Gamma_{h \rightarrow graviscalar} &\sim (16 \text{ MeV}) 20^{2-\delta} \xi^2 S_{\delta-1} \frac{3(\delta-1)}{\delta+2} \\ &\times \left( \frac{m_h}{150 \text{ GeV}} \right)^{1+\delta} \left( \frac{3 \text{ TeV}}{M_D} \right)^{2+\delta}\end{aligned}$$

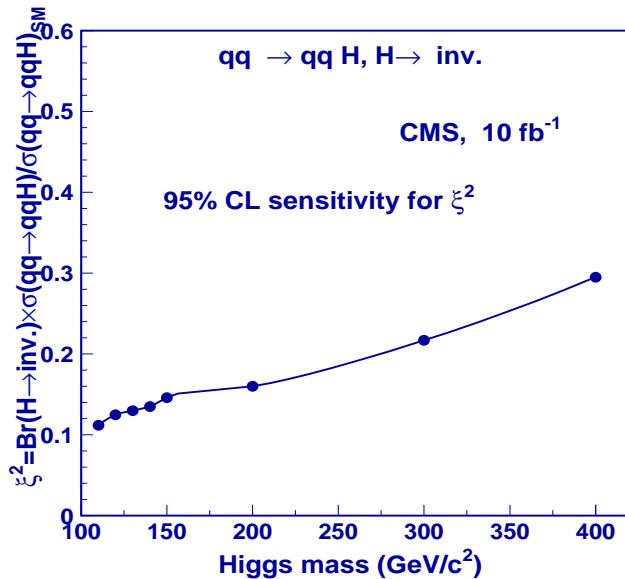
$S_\delta$  denotes the surface of a unit radius sphere in  $\delta$  dimensions.

- For a light Higgs boson ( $\Gamma_{SM}(m_H = 150 \text{ GeV}) \sim 10 \text{ MeV}$ ) the invisible width causes a significant suppression of the LHC rates in the standard visible channels
- There are regions where the invisible Higgs could be the first measured effect from extra dimensions

## Sensitivity to $Br_{inv}$ at LHC

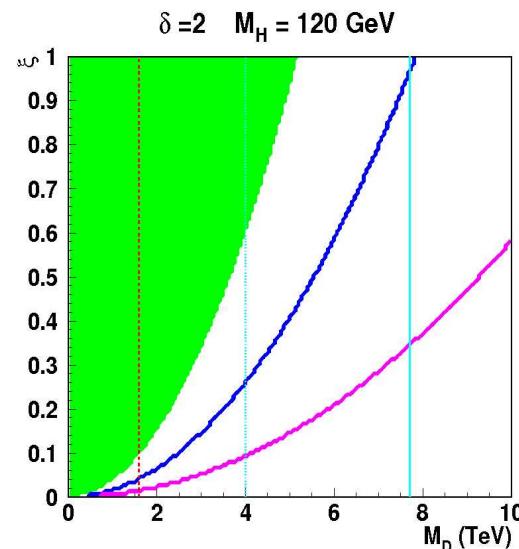
(Fusion channel: Eboli and Zeppenfeld, Di Girolamo et al, Abdullin et al, CMS note)

Higgs production in  $qq \rightarrow qqVV \rightarrow qqH$  and subsequent Higgs invisible decay. Signal characterized by two very energetic forward jets well separated in pseudorapidity. With  $B_{inv} = 1$  and  $10$  ( $100$ )  $\text{fb}^{-1}$  it is possible discover Higgs up to  $480$  ( $770$ )  $\text{GeV}$ .



LHC statistical significance in  $\gamma\gamma$  channel for SM Higgs,  $m_H = 120$  GeV,  $30 \text{ fb}^{-1}$ , is  $\sim 10$ .

The green regions: the Higgs standard signal at the LHC  $< 5 \sigma$  for  $30 \text{ fb}^{-1}$ . The regions above the blue line are the parts where the LHC invisible Higgs signal in the  $WW$ -fusion channel  $> 5 \sigma$ . The cyan line at the largest  $M_D$  value shows the upper limit on  $M_D$  which can be probed at the  $5 \sigma$  by the analysis of jets/ $\gamma$  with missing energy at the LHC. The red dashed line at the lowest  $M_D$  value is the 95% CL lower limit from Tevatron and LEP/LEP2 limits. The regions above the purple line are the parts of the parameter space where the LC invisible Higgs signal will exceed  $5 \sigma$  assuming  $\sqrt{s} = 350$  GeV and  $L = 500 \text{ fb}^{-1}$ . (Battaglia, Gunion, DD)



# Higgs searches at LHC in Randall Sundrum model

Usual 2-brane RS 5D warped space scenario

$$ds^2 = e^{-2kb_0|y|} \eta_{\mu\nu} dx^\mu dx^\nu - b_0^2 dy^2$$

Gravitational fluctuations around the background metric:

$$\eta_{\mu\nu} \rightarrow \eta_{\mu\nu} + \epsilon h_{\mu\nu}(x, y) \quad b_0 \rightarrow b_0 + b(x).$$

The size of the fifth dimension is controlled by a scalar field, the **radion**,  $\phi_0(x)$ :

$$\phi_0(x) = \Lambda_\phi e^{-kb(x)/2}$$

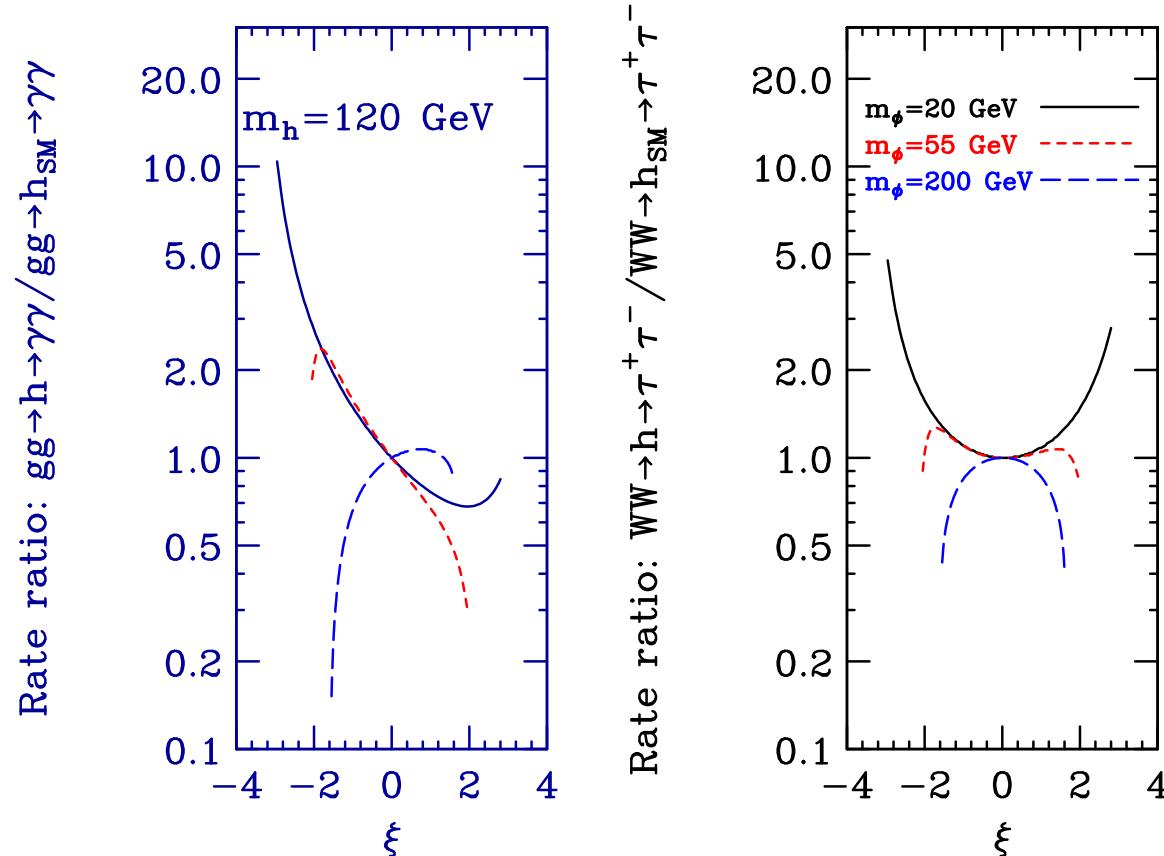
with  $\Lambda_\phi = \sqrt{6} M_{Pl} e^{-kb_0/2} \sim \text{TeV}$ .

A mixing among the radion and the Higgs  $H$  is induced by  
(Giudice, Rattazzi, Wells)

$$S_\xi = \xi \int d^4x \sqrt{-g_{\text{vis}}} R(g_{\text{vis}}) H^\dagger H,$$

## Prospects for Higgs searches at LHC in RS

The ratio of the rates for  $gg \rightarrow h \rightarrow \gamma\gamma$  and  $WW \rightarrow h \rightarrow \tau^+\tau^-$  to the corresponding rates for the SM Higgs boson for  $m_h = 120$  GeV and  $\Lambda_\phi = 5$  TeV for  $m_\phi = 20, 55$  and  $200$  GeV. (DD, B. Grzadkowski, J. Gunion, M. Toharia)



## New vectors at LHC from extra dimensions

In the original RS only gravity in 5 D. However to explain the hierarchy problem it is sufficient only Higgs in 4D.

Models with gauge bosons in the bulk have been studied in 5 dimensions but also discretizing the fifth dimension

(Hill, Pokorski, Wang; Randall, Shadmi, Weiner; Georgi)

$$S = -\frac{1}{2} \int d^4x \int_0^{\pi R} dy \frac{1}{g_5^2} [\text{Tr}[F_{MN}F^{MN}]] , \quad M, N = 0, 1, \dots, 4$$

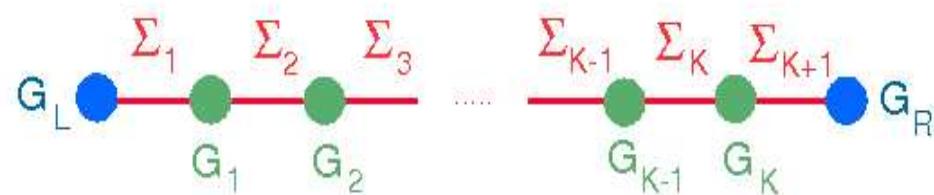
$$= -\frac{1}{2} \int d^4x \int_0^{\pi R} dy \frac{1}{g_5^2} [\text{Tr}[F_{\mu\nu}F^{\mu\nu}] + 2\text{Tr}[F_{\mu 5}F^{\mu 5}]]$$

↓ discretization on a lattice

$$S_{\text{moose}} \sim -\frac{1}{2} \int d^4x \frac{a}{g_5^2} \sum_j \left[ \text{Tr}[F_{\mu\nu}^j F^{\mu\nu j}] + \frac{2}{a^2} \text{Tr}[(D_\mu \Sigma^j)^\dagger (D^\mu \Sigma^j)] \right],$$

where

$$\Sigma^j \sim 1 + i \int_{y_j}^{y_j+a} dy A_5(x, y)$$

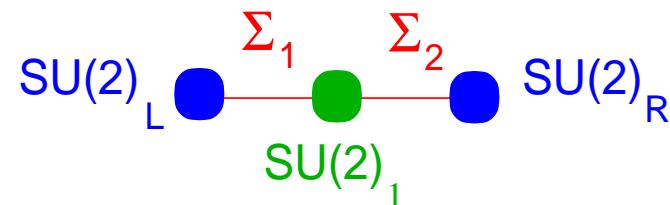


(Casalbuoni, De Curtis, DD, Bechi, Coradeschi, Dolce, Fedeli)

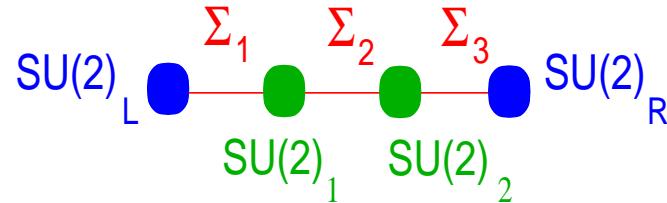
$$G_1 = G_2 = \dots = G_K = SU(2)$$

$$G_1 = G_2 = \dots = G_K = SU(2)_L \times SU(2)_R$$

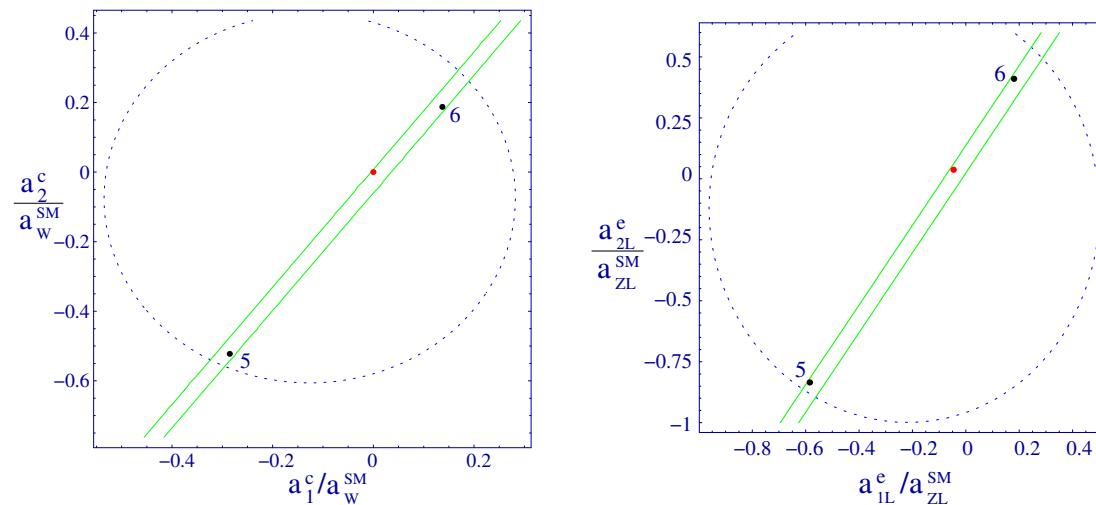
**Generalizations of old BESS model:**



## Foursite Model (E. Accomando, S. De Curtis, DD, L. Fedeli)

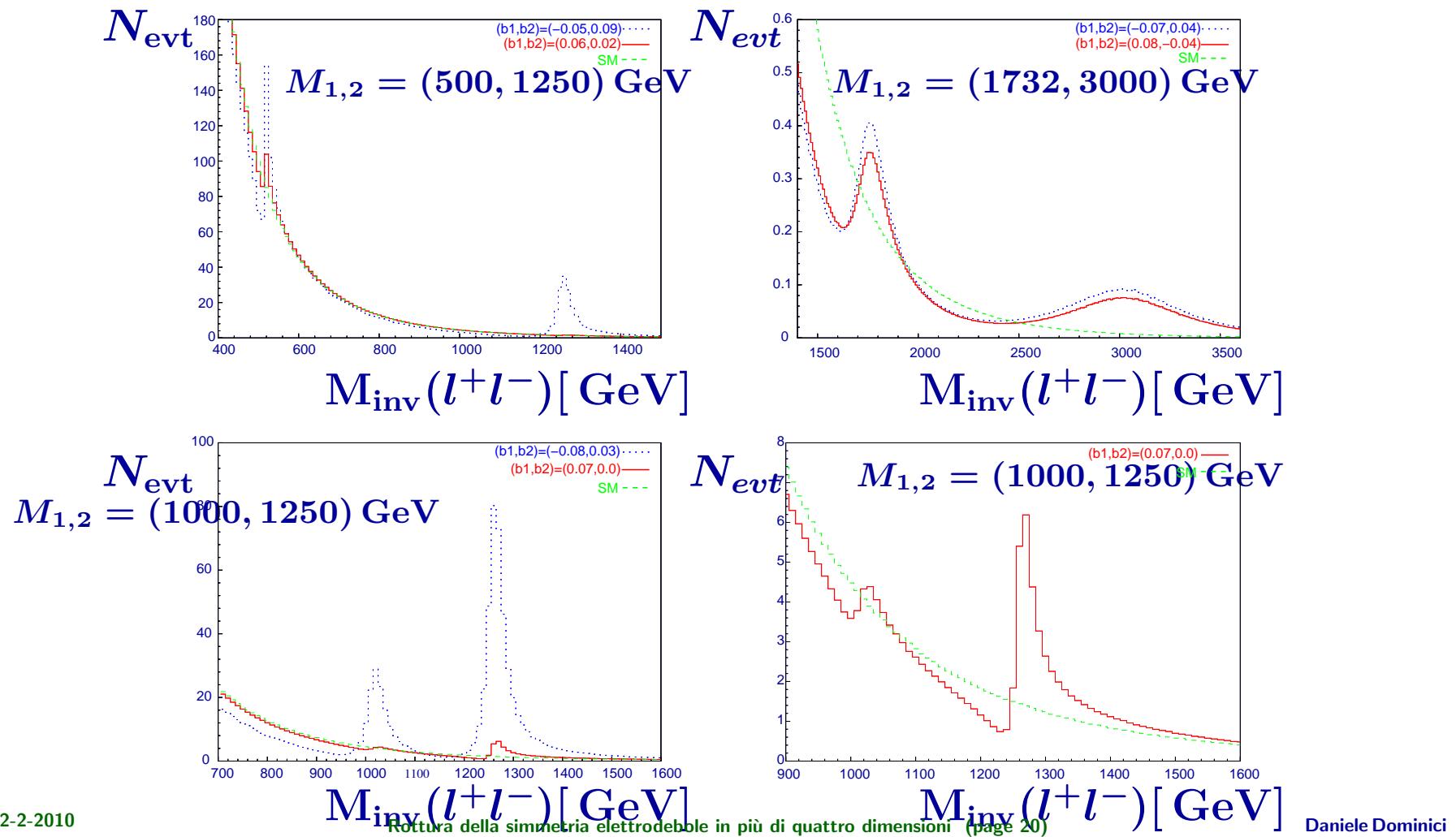


- New particles: first 2 levels of KK excitations of  $W$ ,  $Z$   
Electroweak precision tests imply strong bounds:



95% C.L. bounds from  $\epsilon_1$  (dashed line) and  $\epsilon_3$  (solid line), for  $M_1 = 1 \text{ TeV}$  and  $z = 0.8$  ( $M_2 = M_1/z$ ).

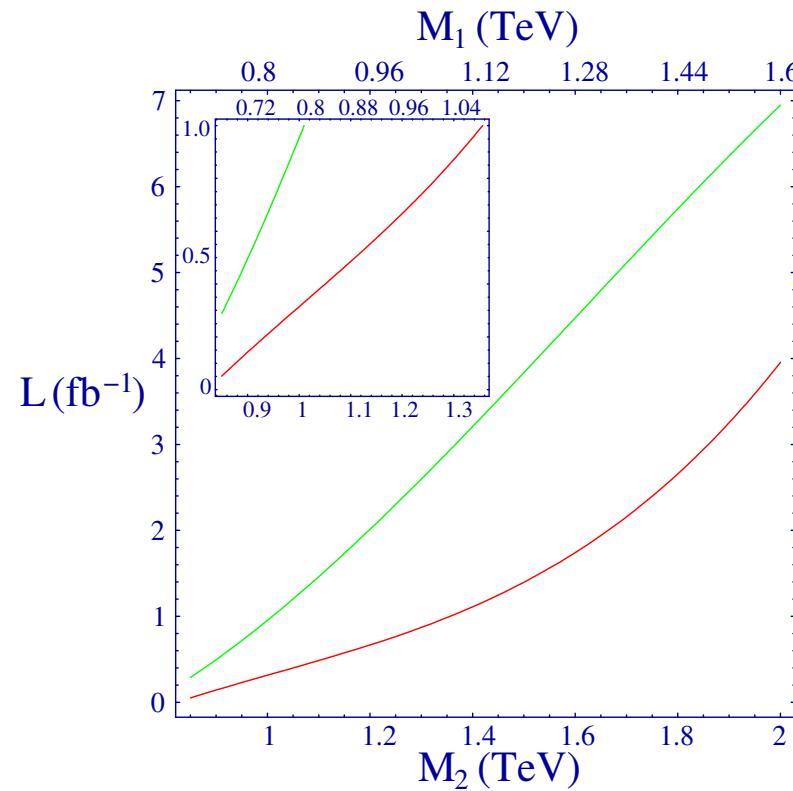
**Total number of events in a 10 GeV-bin versus the dilepton invariant mass,  $M_{\text{inv}}(l^+l^-)$ , for the process  $\text{pp} \rightarrow l^+l^-$  for  $L = 10 \text{ fb}^{-1}$ ,  $E = 14 \text{ TeV}$ .**



**Signal and total (including the SM background) event number  
for the  $Z_1$  production, and the statistical significance  
 $\sigma = N_{\text{evt}}^S / \sqrt{N_{\text{evt}}^{\text{tot}}}$  for an integrated luminosity  $L=10 \text{ fb}^{-1}$ ,  
 $E = 14 \text{ TeV}$ . The last three columns show the same results  
for the  $Z_2$  production.**

$M_{1,2} (\text{GeV})$	$N_{\text{evt}}^S(Z_1)$	$N_{\text{evt}}^{\text{tot}}(Z_1)$	$\sigma(Z_1)$	$N_{\text{evt}}^S(Z_2)$	$N_{\text{evt}}^{\text{tot}}(Z_2)$	$\sigma(Z_2)$
500,1250	47	154	3.8	134	143	11.2
500,1250	11	123	1.0	0	9	0.0
1732,3000	7	10	2.2	7	8	2.5
1732,3000	5	9	1.7	6	6	2.4
1000,1250	108	119	9.9	291	302	16.7
1000,1250	3	28	0.0	15	22	3.2

**Luminosity vs  $Z_2$  mass needed for a  $5\sigma$ -discovery for  $z = 0.8$ .  
 We assume the maximum value for the fermion-boson  
 couplings allowed by EWPT. We sum over  $e, \mu$  and apply  
 standard cuts.**



**...while waiting for LHC, let us hope that LHC will be....**

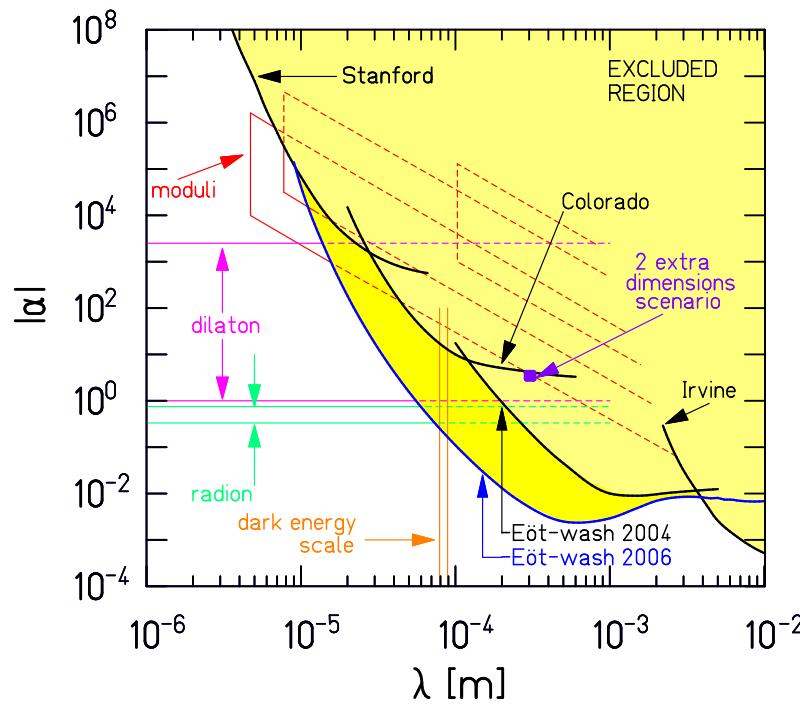


## Conclusions

- Extra dimensions offer new tools for model building, new ideas for symmetry breaking, fermion masses, hierarchy problem.

### Extra dimension phenomenology at LHC

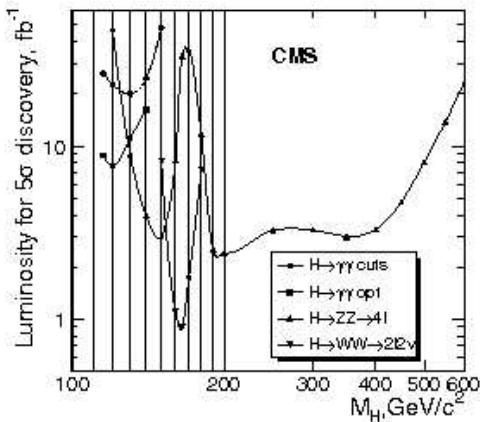
- ADD, RS: Higgs boson detectability could change, new phenomena, invisible Higgs, radion production.
- 5D extensions of SM: Extra dimensions could manifest at LHC with replicas of the SM gauge bosons with masses in the TeV range.



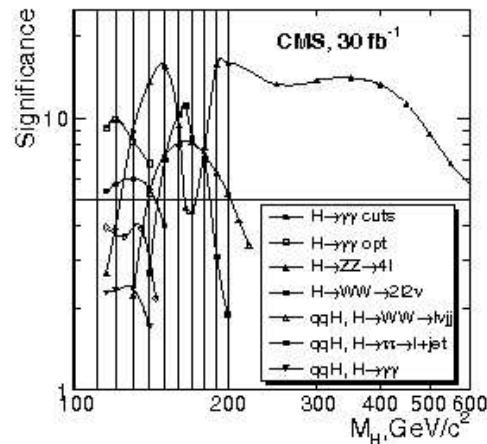
From Kapner et al , 2009. For  $\delta = 2$   $M_D \geq 3.6$  TeV (From LEP,  $M_D \geq 1.6$  TeV).

$$V(r) = - \int dr_1 \int dr_2 \frac{G \rho_1(r_1) \rho_2(r_2)}{r_{12}} [1 + \alpha \exp(-r_{12}/\lambda)]$$

For  $\delta = 2$ ,  $\alpha = 3, (4)$ , compactifying over a sphere (torus),  $\lambda \sim L = 2\pi R$

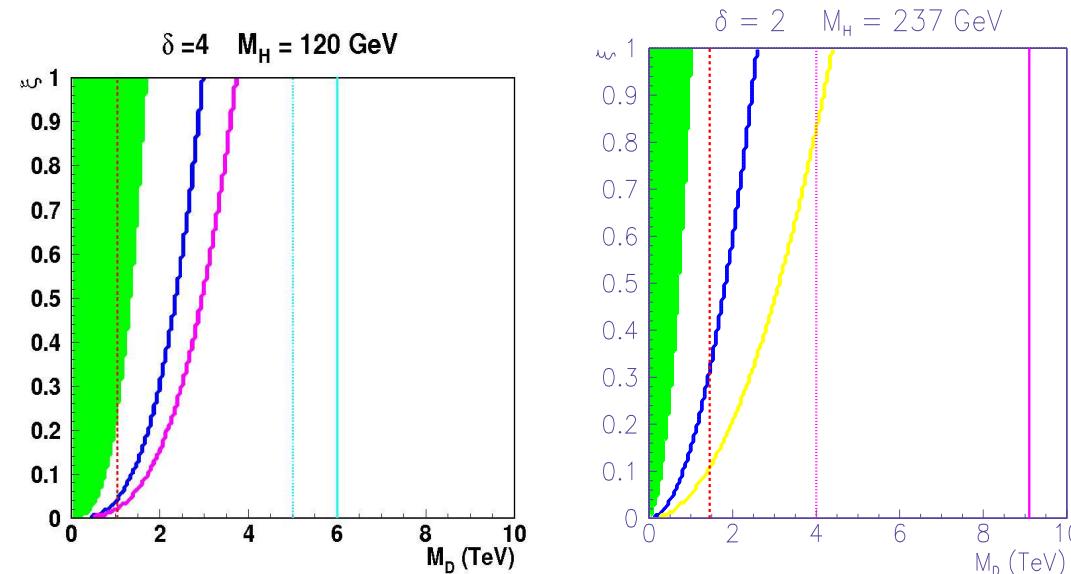


**Figure 10.38.** The integrated luminosity needed for the  $5\sigma$  discovery of the inclusive Higgs boson production  $pp \rightarrow H + X$  with the Higgs boson decay modes  $H \rightarrow \gamma\gamma$ ,  $H \rightarrow ZZ \rightarrow 4\ell$ , and  $H \rightarrow WW \rightarrow 2\ell 2\nu$ .



**Figure 10.39.** The signal significance as a function of the Higgs boson mass for  $30 \text{ fb}^{-1}$  of the integrated luminosity for the different Higgs boson production and decay channels.

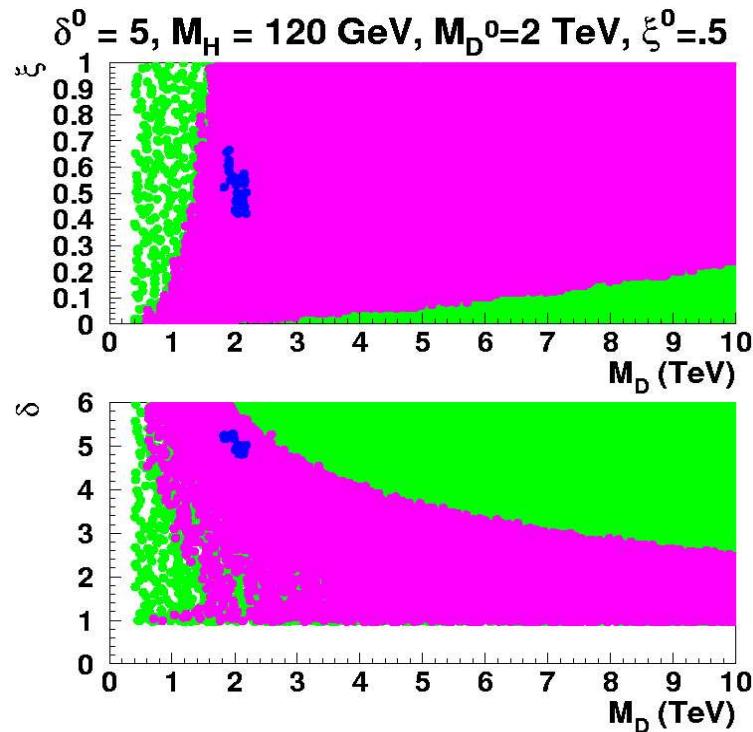
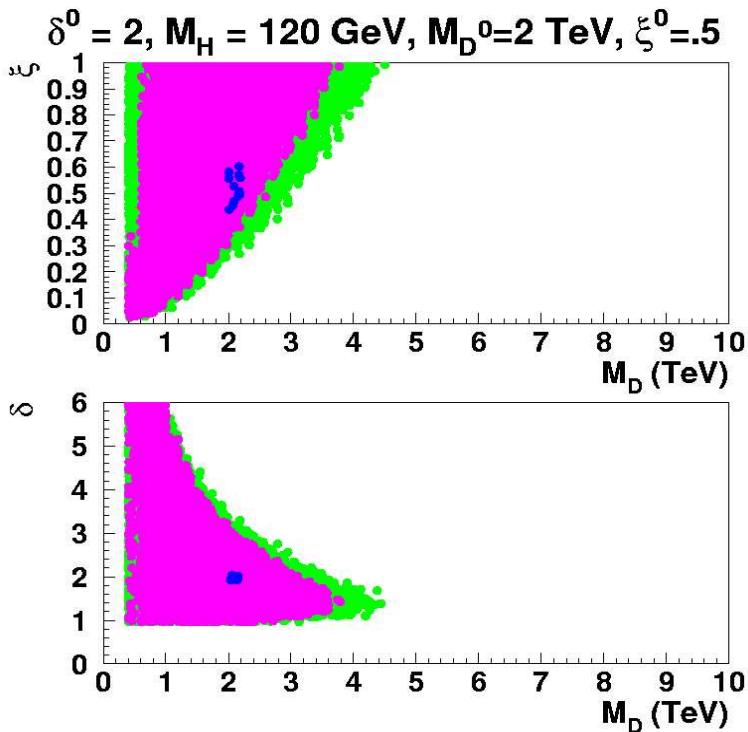
The green regions: the Higgs standard signal at the LHC  $< 5 \sigma$  for  $100 fb^{-1}$ . The regions above the blue line are the parts where the LHC invisible Higgs signal in the  $WW$ -fusion channel  $> 5 \sigma$ . The cyan line at the largest  $M_D$  value shows the upper limit on  $M_D$  which can be probed at the  $5 \sigma$  by the analysis of jets/ $\gamma$  with missing energy at the LHC. The red dashed line at the lowest  $M_D$  value is the 95% CL lower limit from Tevatron and LEP/LEP2 limits. The regions above the purple line are the parts of the parameter space where the LC invisible Higgs signal will exceed  $5 \sigma$  assuming  $\sqrt{s} = 350$  GeV and  $L = 500 fb^{-1}$ . (Battaglia, Gunion, DD)



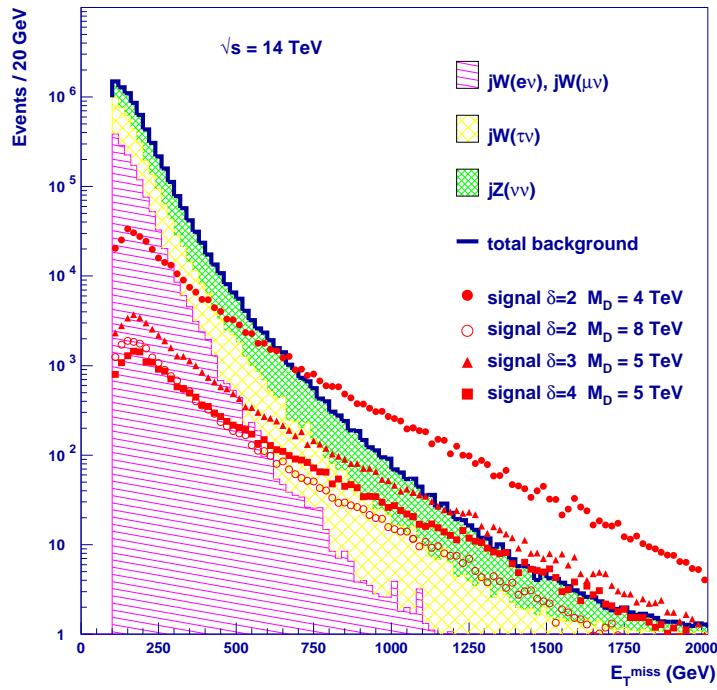
# Determining ADD parameters from LHC and LC data

- For LHC we employed the visible and invisible Higgs signal assuming SM production rate for  $30 \text{ fb}^{-1}$  and  $100 \text{ fb}^{-1}$ .
- For LC we have used measurements of the visible ( $WW^*$ ,  $b\bar{b}$ ) and the invisible branching ratio at  $\sqrt{s} = 350 \text{ GeV}$ .
- For LC we have also used the measurements of  $\gamma + \text{missing } E_T$  signal at two different energies: the ratio of the two cross sections gives a strong constraint on  $\delta$ . We have considered measurements performed at  $\sqrt{s} = 500 \text{ GeV}$  and  $\sqrt{s} = 1000 \text{ GeV}$  of either  $500 \text{ fb}^{-1}$  and  $1000 \text{ fb}^{-1}$ , respectively, or  $1000 \text{ fb}^{-1}$  and  $2000 \text{ fb}^{-1}$ , respectively.

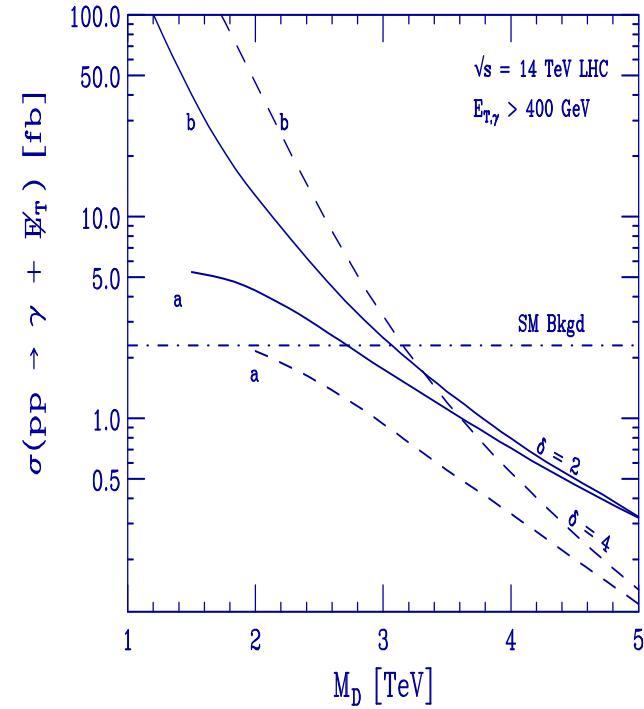
# Determining ADD parameters from LHC and LC data



(Battaglia, Gunion, DD)



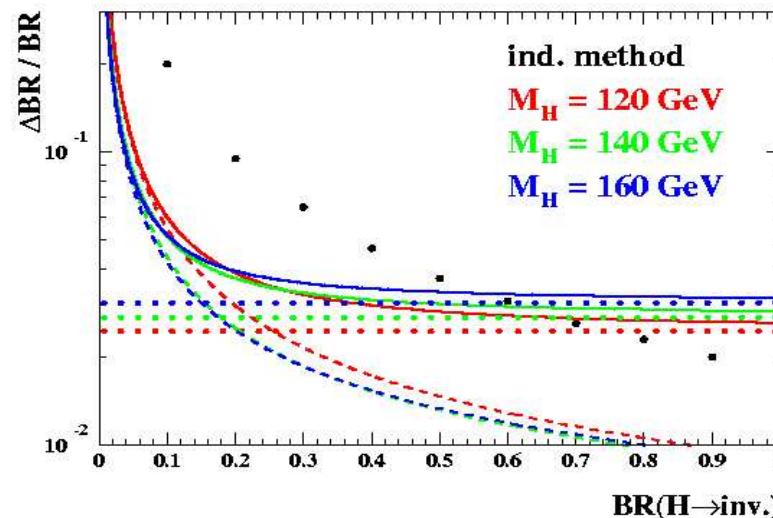
(Hinchliffe, Vacavant)



(Giudice, Rattazzi, Wells)

## Sensitivity to ADD $\Gamma_{inv}$ at the LC

Relative accuracy of the measurement of the invisible branching as a function of the branching ratio, for  $m_H = 120, 140, 160$  GeV for  $500 \text{ fb}^{-1}$  at  $\sqrt{s} = 350$  GeV. (Schumacher).



Signal process:  $e^+e^- \rightarrow ZH \rightarrow \text{two jets + miss. } E_T$ . Invisible Higgs discovered down to  $B \sim 0.02$  for masses 120-160 GeV.

The bulk space time is  $D > 4$  dimensional and the SM is confined to a 3+1 hypersurface. Gravity can propagate in the extra dims, provided these are compactified ( $R < mm$ )

### Relating Planck Scales

A  $4 + \delta$  theory compactified to 4 dims

$$F_{(4+\delta)}(r) = G_{N(4+\delta)} \frac{m_1 m_2}{r^{\delta+2}}$$

$$\Rightarrow F_{(4)}(r) = G_{N(4)} \frac{m_1 m_2}{r^2}$$

Compactify  $\delta$  dimensions  $y_\alpha$  with the periodic conditions

$\Phi(y_\alpha, x) = \Phi(y_\alpha + L, x)$ . Suppose that a mass  $m$  is placed at the origin: one can reproduce this situation in the uncompactified theory by placing mirror masses periodically in all the new dims.

- ❖ For  $r \ll L$  4 +  $\delta$  dim force
- ❖ For  $r \gg L$  mirror masses look like an infinite  $\delta$  line with uniform density. Gauss theorem to the cylinder  $C = S_3 \times \delta - \text{line} \Rightarrow$

$$M_P^2 \sim L^\delta M_{4+\delta}^{(\delta+2)}$$

$$G_{N(4+\delta)} \sim (M_{4+\delta})^{-\delta-2}$$

$$L = 2 \cdot 10^{31/\delta - 16} \text{ mm} \left( \frac{1 \text{ TeV}}{M_{4+\delta}} \right)^{1+2/\delta}$$

- ❖  $\delta = 1$     $M_5 = 1 \text{ TeV}$       $L \sim 10^{15} \text{ mm}$    excluded
- ❖  $\delta = 2$     $M_6 = 1 \text{ TeV}$       $L \sim \text{mm}$    excluded
- ❖  $\delta = 6$     $M_{10} = 1 \text{ TeV}$      $L \sim 10^{-11} \text{ mm}$

**Astrophysical constraints from SN cooling and cosmological constraints from  $\gamma$  diffuse radiation imply  $\delta \geq 2$  (Cullen and Perelstein, Hall and Smith)**

**From  $\gamma$  flux limits from nearby neutron stars for  $\delta = 2$   $M_{P6} \geq 500 \text{ TeV}$  (Hannestad and Raffelt)**

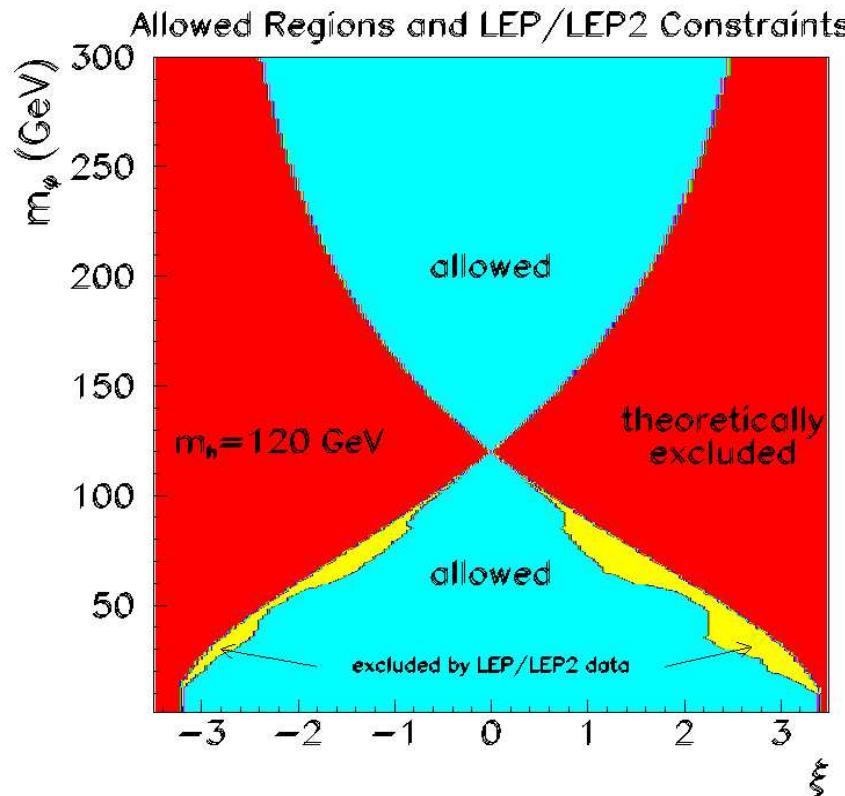
**The limit  $\delta \geq 2$  can be evaded in new scenarios with  $q$  large and  $p$  extra large dims (Lykken and Nandi)**

$$M_P^2 = M_*^{p+2} R^p = M^{p+q+2} R^p r^q$$

$p = 1, q = 5, R \sim \text{mm}$  ( $R^{-1} \sim 10^{-4} \text{ eV}$ ),  $1/r \sim \text{TeV}$ ,  $M = 137 \text{ TeV}$ ,  $M_* = 5 \times 10^5 \text{ TeV}$

**Also the limit  $\delta \geq 1$  can be avoided by allowing for a small warping of the metric (Giudice, Plehn and Strumia).**

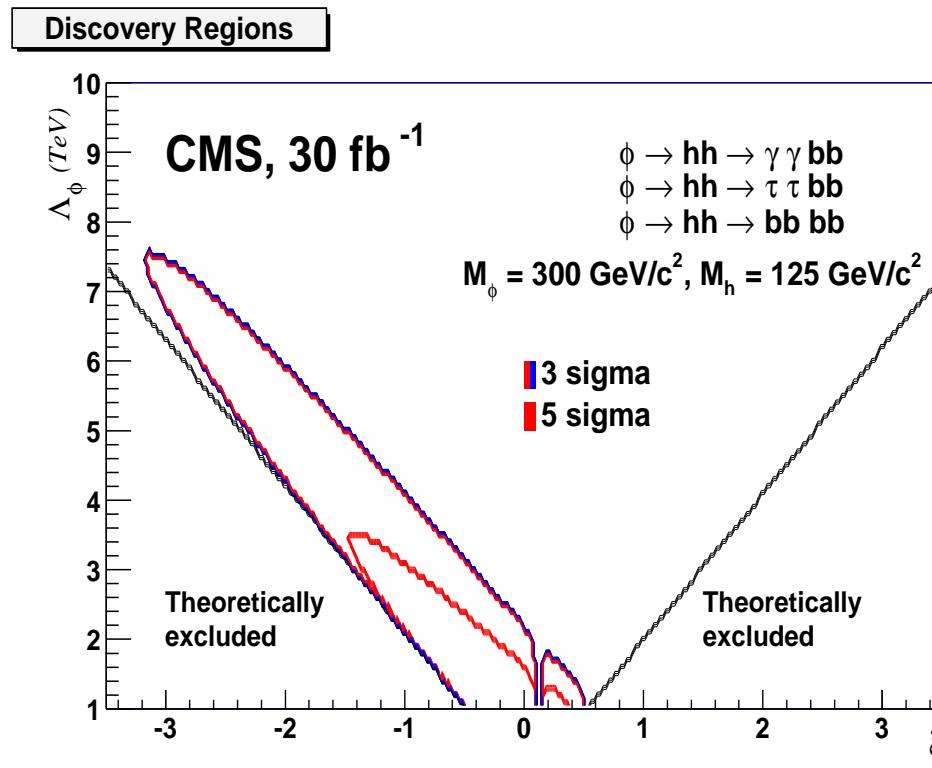
**Allowed regions for  $\Lambda_\phi = 5$  TeV and  $m_h = 120$  GeV. The light yellow portion is eliminated by LEP/LEP2 constraints on  $g_{ZZs}^2$  (un-tagged hadronic events) or on  $g_{ZZs}^2 BR(s \rightarrow b\bar{b})$ , with  $s = h$  or  $s = \phi$  (DD, B. Grzadkowski, J. Gunion, M. Toharia).**



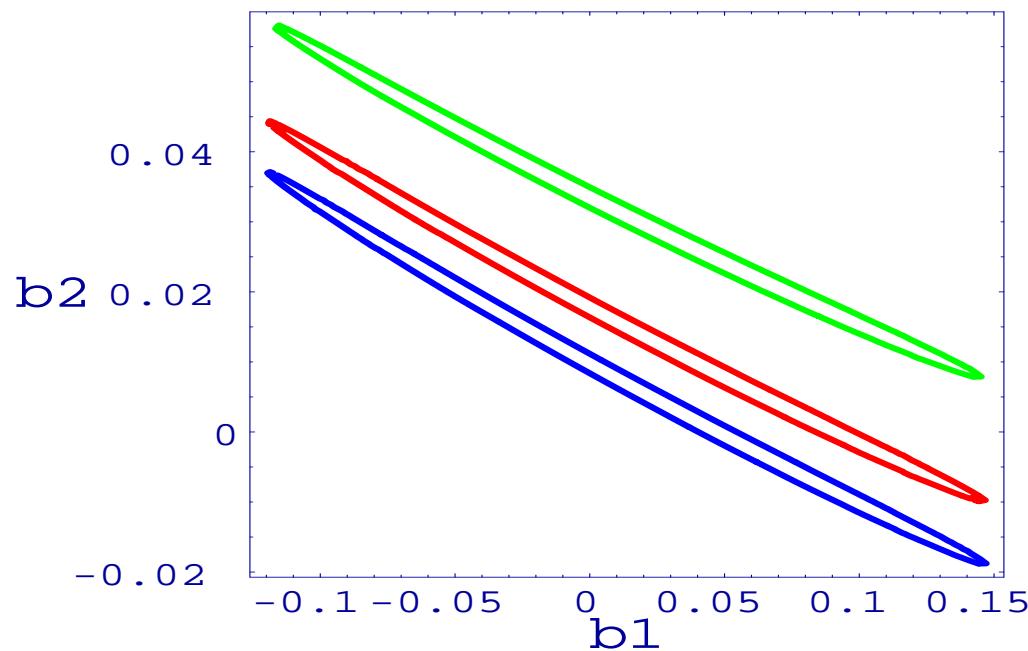
**For  $m_h = 112$  GeV, almost all excluded. For  $\Lambda_\phi = 1$  TeV light radion much more constrained.**

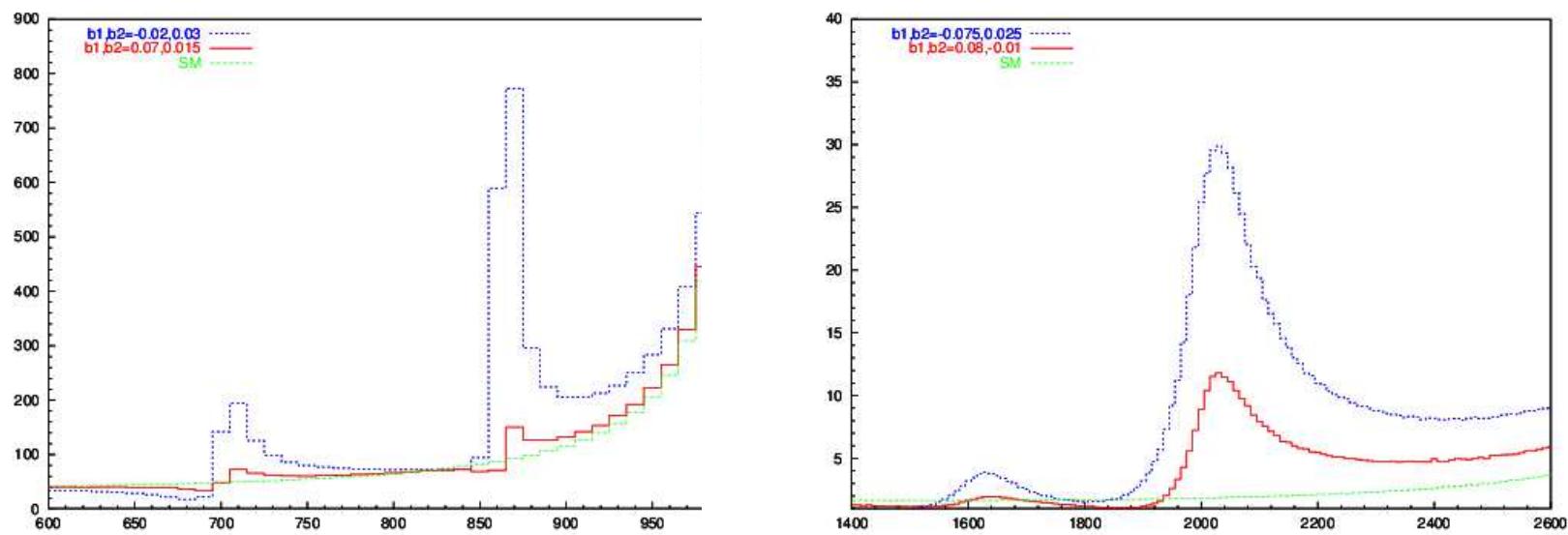
# Prospects of $\phi \rightarrow hh$ discovery at CMS

(Dewhurst, DD, Fano, Gennai, Nikitenko).

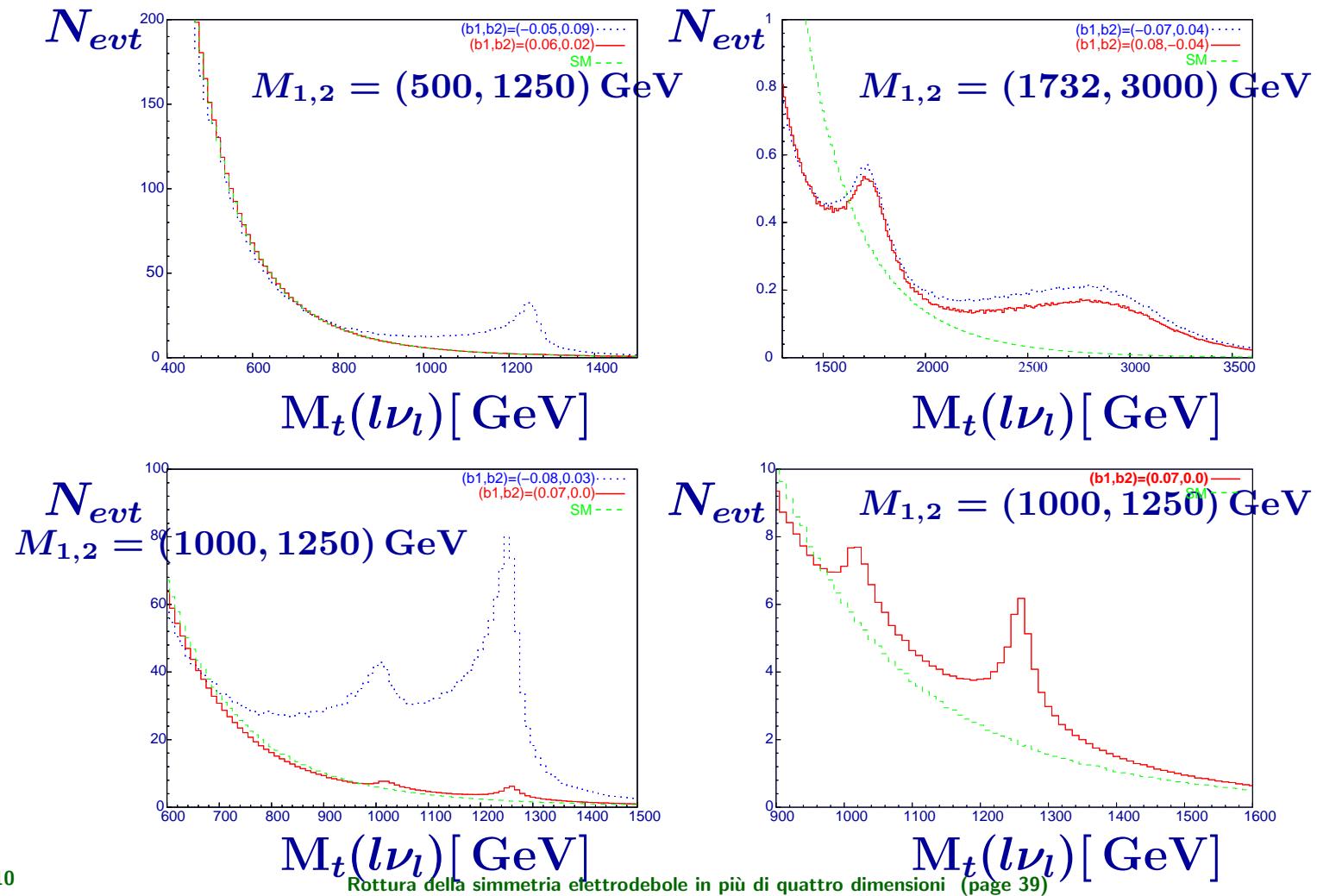


5  $\sigma$  discovery potential in the  $(\xi, \Lambda_\phi)$  plane.  
The  $\gamma\gamma\bar{b}b$  topology provides the best discovery potential.





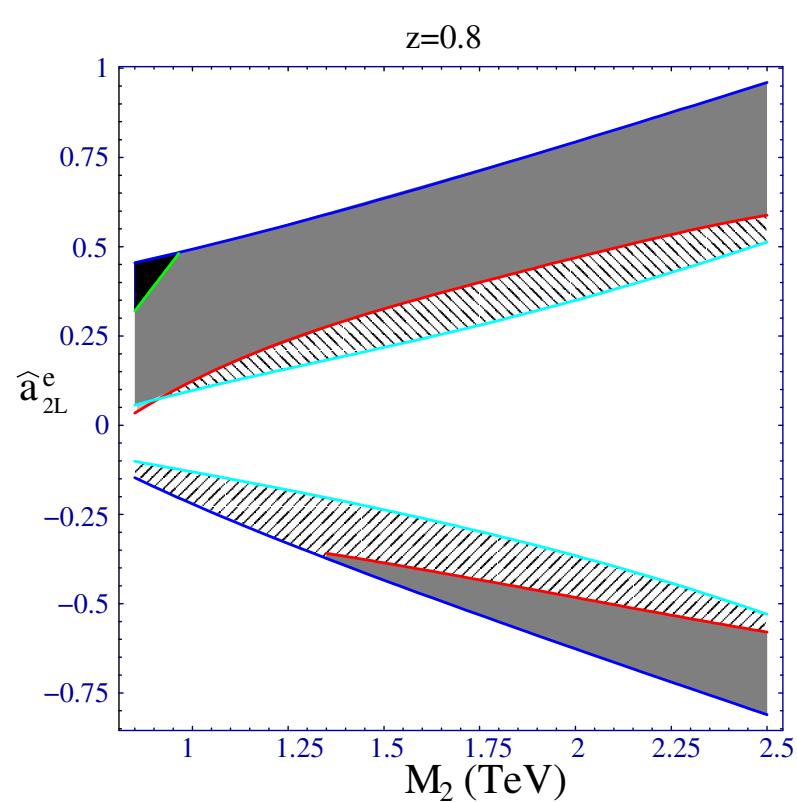
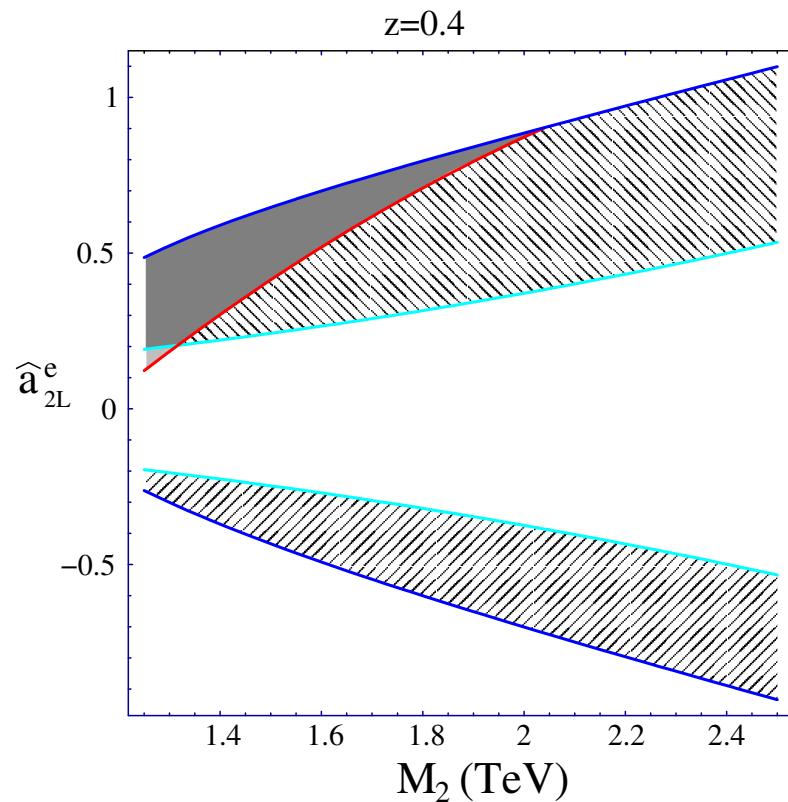
**Total number of events in a 10 GeV-bin versus the lepton transverse mass,  $M_t(l\nu_l)$ , for the process  $\text{pp} \rightarrow l\nu_l$  for  $L = 10 \text{ fb}^{-1}$ . We sum over  $e, \mu$  and charge conjugate channels.**

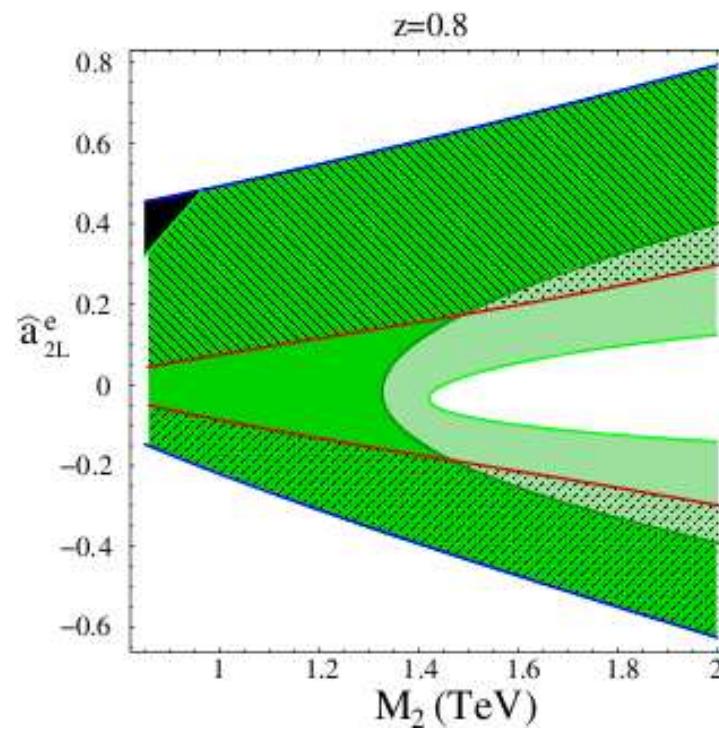


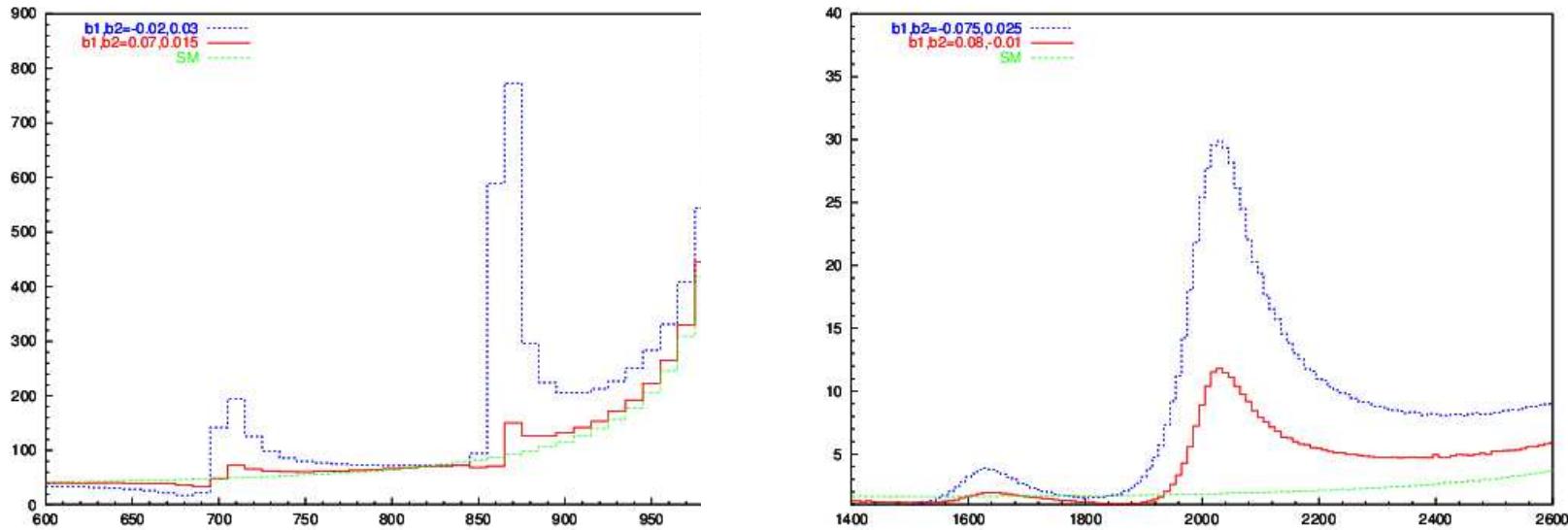
The second column shows the cut on the dilepton transverse mass  $M_t(l\nu_l)$ . The next three columns give signal and total (including the SM background) event number for the  $W_1^\pm$  production, and the statistical significance  $\sigma = N_{\text{evt}}^S / \sqrt{N_{\text{evt}}^{\text{tot}}}$  for an integrated luminosity  $L=10 \text{ fb}^{-1}$ . The last three columns give the corresponding results for  $W_2^\pm$  production.

$M_{1,2} (\text{ GeV})$	$N_{\text{evt}}^S(W_1)$	$N_{\text{evt}}^{\text{tot}}(W_1)$	$\sigma(W_1)$	$N_{\text{evt}}^S(W_2)$	$N_{\text{evt}}^{\text{tot}}(W_2)$	$\sigma(W_2)$
500,1250	36	2435	0.7	776	2214	16.5
500,1250	0	2609	0	1	1807	0
1732,3000	10	18	2.4	24	26	4.7
1732,3000	9	14	2.4	22	24	4.5
1000,1250	808	1230	23.0	1112	1189	32.3
1000,1250	12	443	0.6	17	88	1.8

**$5\sigma$  discovery for  $L = 100 \text{ fb}^{-1}$ . The upper and lower parts are excluded by EWPT, the black triangle in the right panel is the region excluded by the direct search at the Tevatron. Inside the grey regions both  $Z_{1,2}$  are visible; inside the dashed ones only  $Z_2$  can be detected. ( $M_1 = zM_2$ )**







**Invariant mass distribution of  $\mu^+\mu^-$  pairs, E=1 (3) TeV,  
 $M_1 = 680(1600)$  GeV,  $M_2 = 850(2000)$  GeV**