Prospects for New Physics at the LHC (*)

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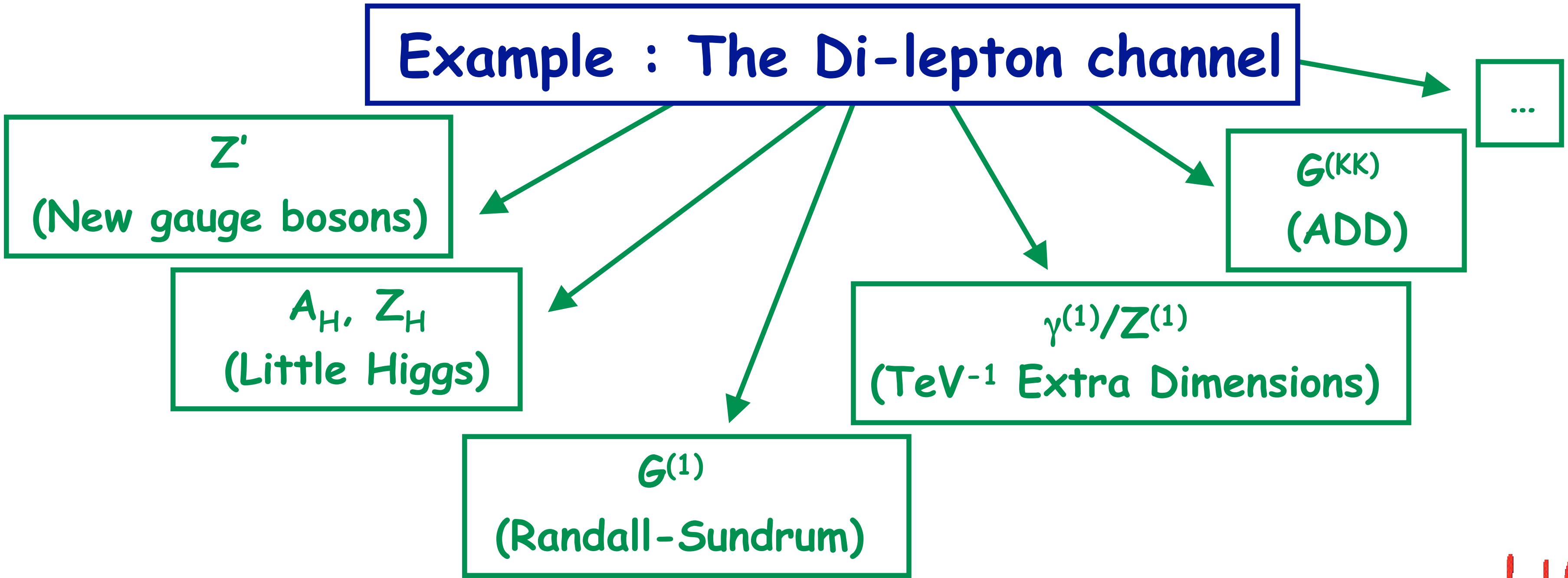
On behalf of the CMS and ATLAS Collaborations

(*): Selected topics (non-Susy)

New physics

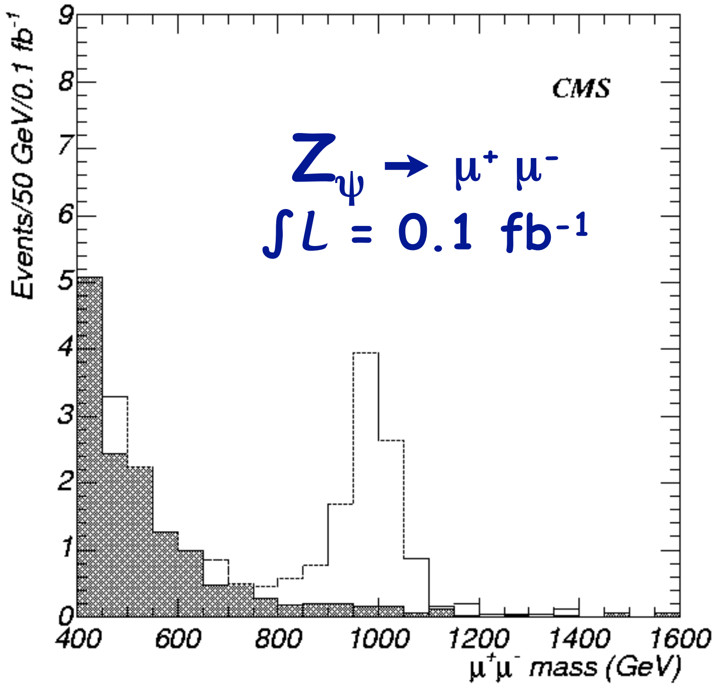
- Large spectrum of models beyond the Standard Model which will be investigated at the LHC
- Need to ask the Delphi's oracle to know which discoveries will be made at the LHC
- Or be prepared with topological approach studies



Z' (New gauge bosons)

Z's arise in many models beyond the Standard Model. The 6 frequently discussed:

- Z_{SSM} in sequential Standard Model (benchmark toy model)
- $Z' = Z_\psi \cos\theta_{16} + Z_\chi \sin\theta_{16}$ in E_6 and/or SO(10) models: Z_ψ, Z_χ and Z_η (θ_{16}=37.78°)
- Z_{LRM} and Z_{ALRM} in left-right symmetric models



$Z_\psi \rightarrow \mu^+ \mu^-$

$\int L$ = 0.1 fb^{-1}

Dominant (and irreducible) background: Drell-Yan production of μ pairs: $pp \rightarrow \gamma/Z^0 \rightarrow \mu^+ \mu^-$

Other sources:
ZZ, WZ, WW, $t\bar{t}$, $b\bar{b}$, pile-up, etc.
(much smaller than Drell-Yan and reducible)

R. Cousins et al, CMS Note 2005/002

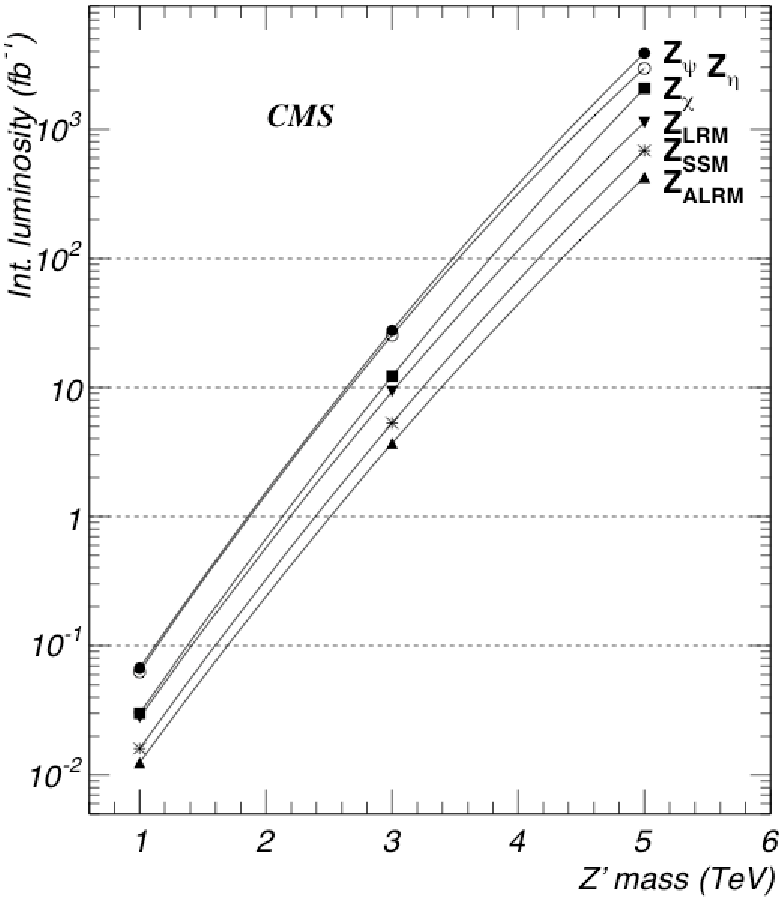
$Z' \rightarrow \mu^+\mu^-$ mass reach

- Cuts: 2 μ of opposite charge sign in $|\eta|<2.4$ + pass the trigger
- Full simulation and reconstruction
- Likelihood-ratio estimator S_L used to calculate the significance of an observed signal

$$S_L = \sqrt{2\ln(L_{S+B}/L_B)}$$

  - L_{S+B} is the maximum likelihood from the signal+background fit
  - L_B is the maximum likelihood from the background-only fit
- Mass reach:
  - > 1TeV with $\int L$ = 0.1 fb^{-1}
  - 2.6-3.4 TeV with $\int L$ = 10 fb^{-1}
  - 3.4-4.3 TeV with $\int L$ = 100 fb^{-1}

$Z' \rightarrow \mu^+\mu^-$: 5σ significance curves



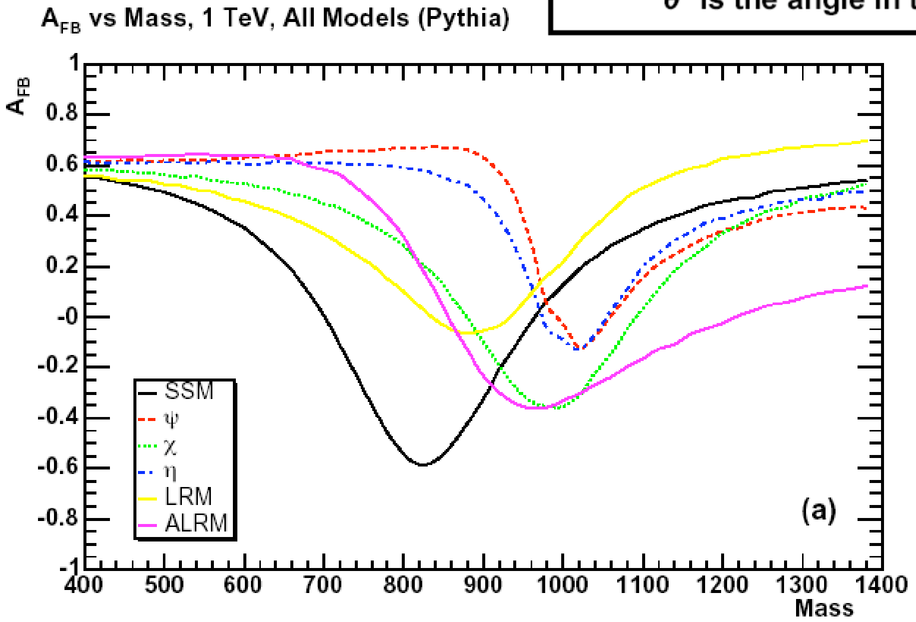
R. Cousins et al, CMS Note 2005/002

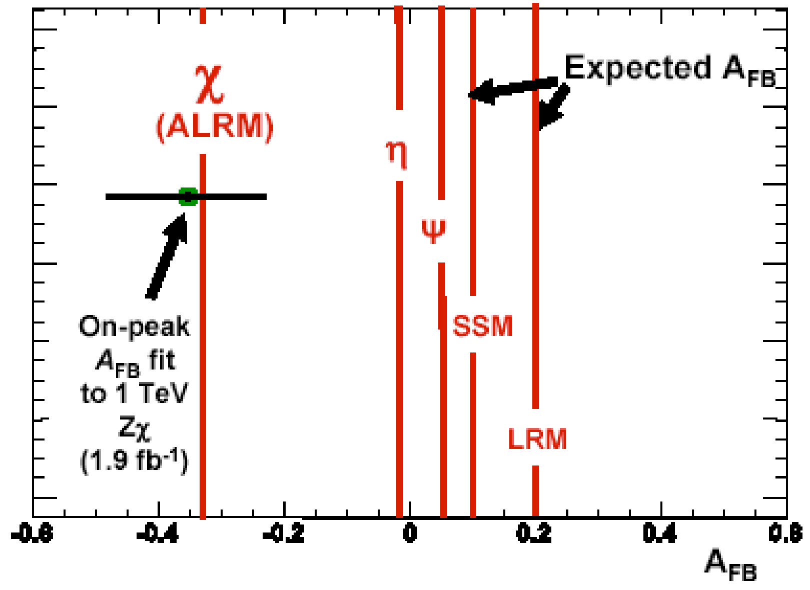
N.B.: systematic uncertainties are not taken into account

Study of the forward-backward asymmetry

$$A_{FB} = \frac{F-B}{F+B}, \quad F = \int_0^1 \frac{d\sigma(q\bar{q} \to \mu^+\mu^-)}{d(\cos\theta^*)} d(\cos\theta^*), \quad B = \int_{-1}^0 \frac{d\sigma(q\bar{q} \to \mu^+\mu^-)}{d(\cos\theta^*)} d(\cos\theta^*)$$

θ^* is the angle in the dimuon CM between the μ^- and the quark.





CMS: R. Cousins et al

With $\int L$ = 400 fb^{-1}:

- Z_ψ, Z_η, Z_{SSM} and Z_{LRM} can be distinguished from each other with $\alpha > 3\sigma$ up to a Z' mass between 1.0-1.5 TeV.
- Z_χ and Z_{ALRM} can be distinguished from any of the other four models up to a Z' mass between 2.0-2.7 TeV (also with $\alpha > 3\sigma$).

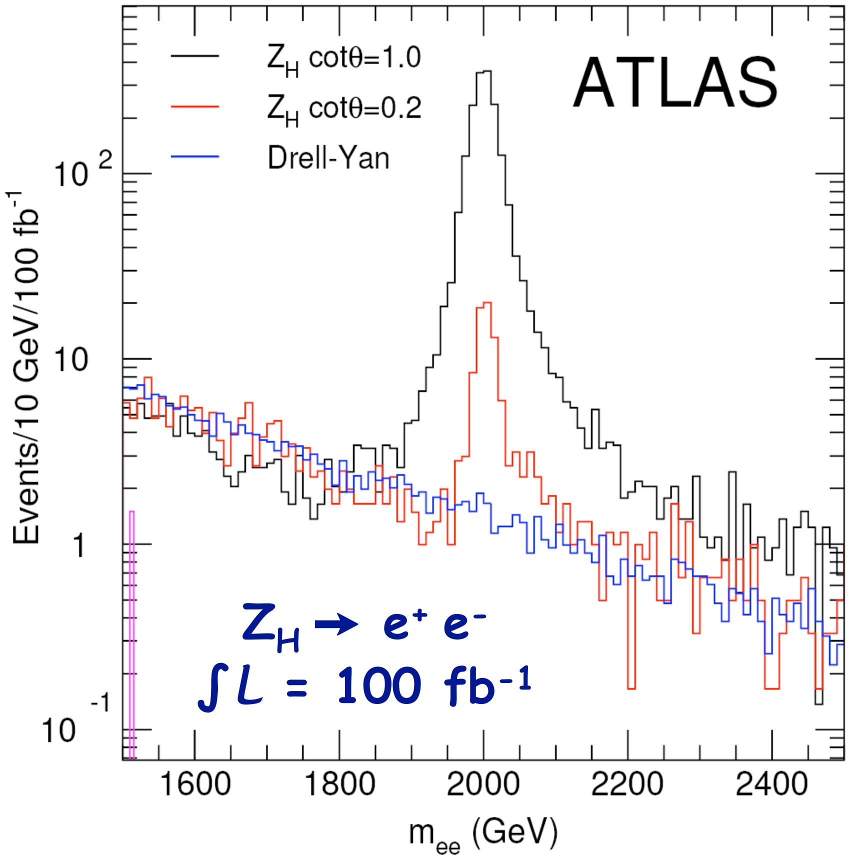
The Little Higgs models

- Answer to the hierarchy problem of the Standard Model: **The Little Higgs models provide just enough new physics to generate cancellations and preserve a light Higgs boson**
- Three main contributions to the radiative corrections to the Higgs mass:
  - From the top loop → New quark T (on a <~TeV scale)
  - From the W/Z loops → New gauge bosons W_H, A_H and Z_H (*) (on a <~5 TeV scale)
  - From the Higgs loops → New Higgs particles ϕ (up to ~10 TeV)

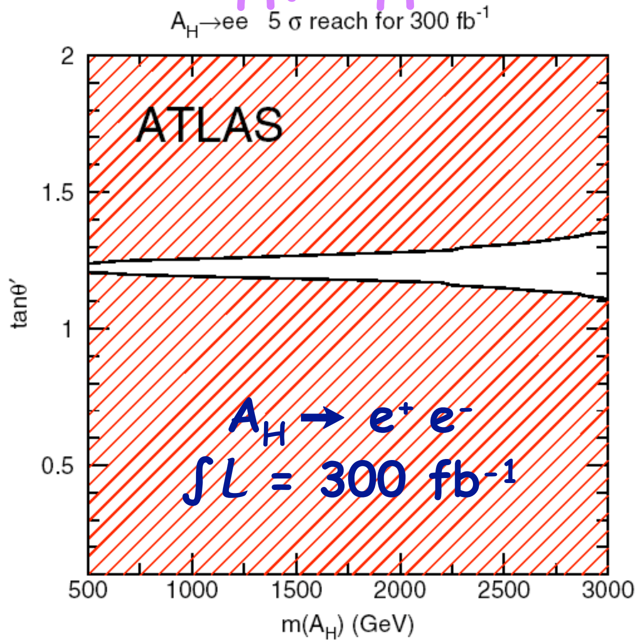
(*) W_H and Z_H almost degenerated in mass and typically heavier than A_H. All these bosons are likely to be discovered via their decays to leptons.

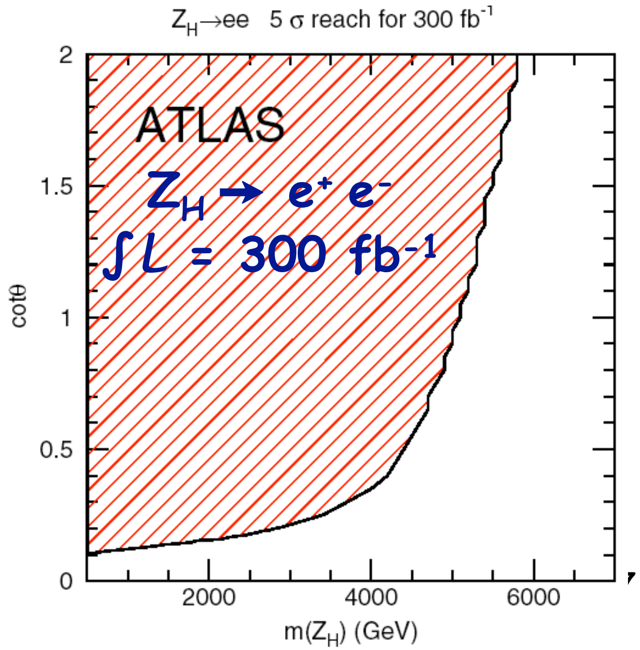
Discovery reach for A_H, Z_H

- **Cuts:** 2 isolated e of opposite charge sign in $|\eta|<2.5$ and $P_t>20$ GeV which provides a trigger
- **Significance:** $S/\sqrt{B}$
- **Fast simulation**



WIN



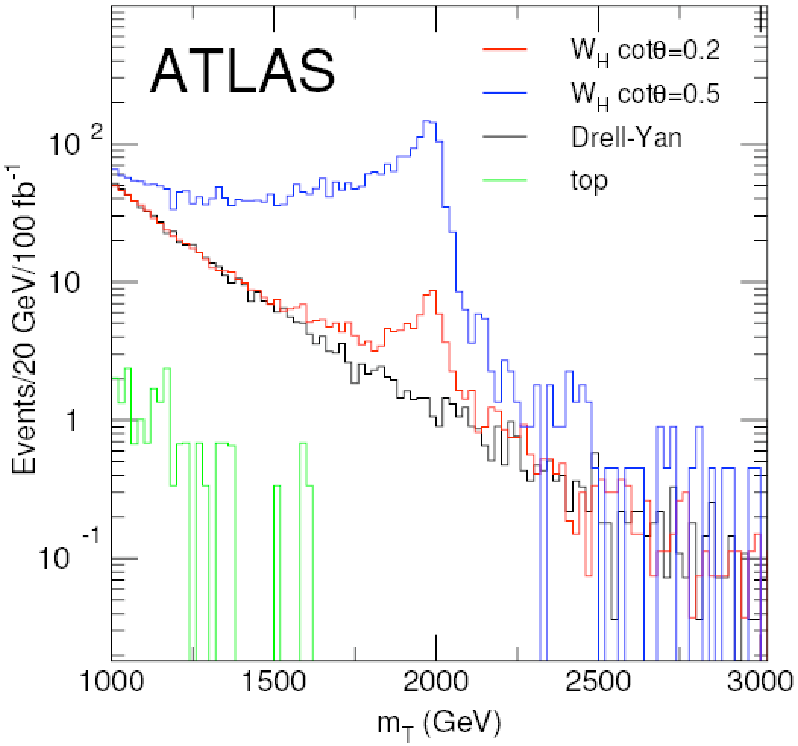


ATLAS: Azuelos et al, EPJ C Vol 39 (2005), Suppl 2, 13 - 24

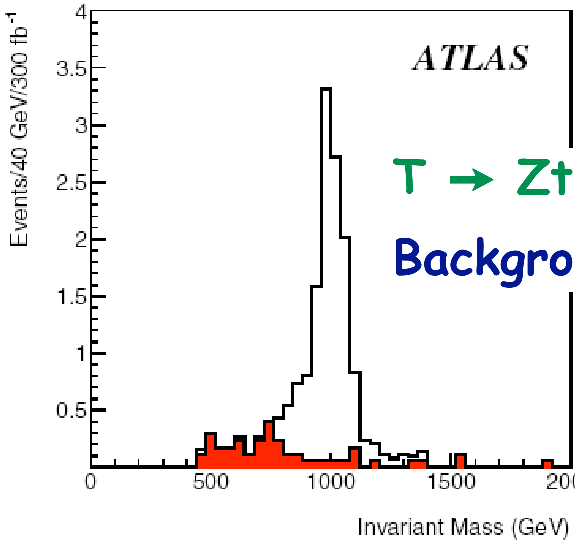
Other signatures of the Little Higgs

$W_H \rightarrow e\upsilon$

Background: $l\upsilon$ via virtual W, labeled Drell-Yan



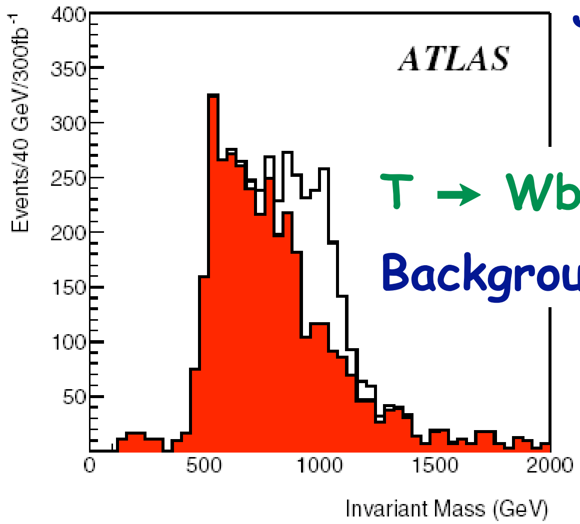
M_{WH} = 2 TeV, $\int L$ = 100 fb^{-1}



$T \rightarrow Zt \rightarrow l^+l^-l\upsilon b$

Background: tbZ, WZ

M_T = 1 TeV, $\int L$ = 300 fb^{-1}



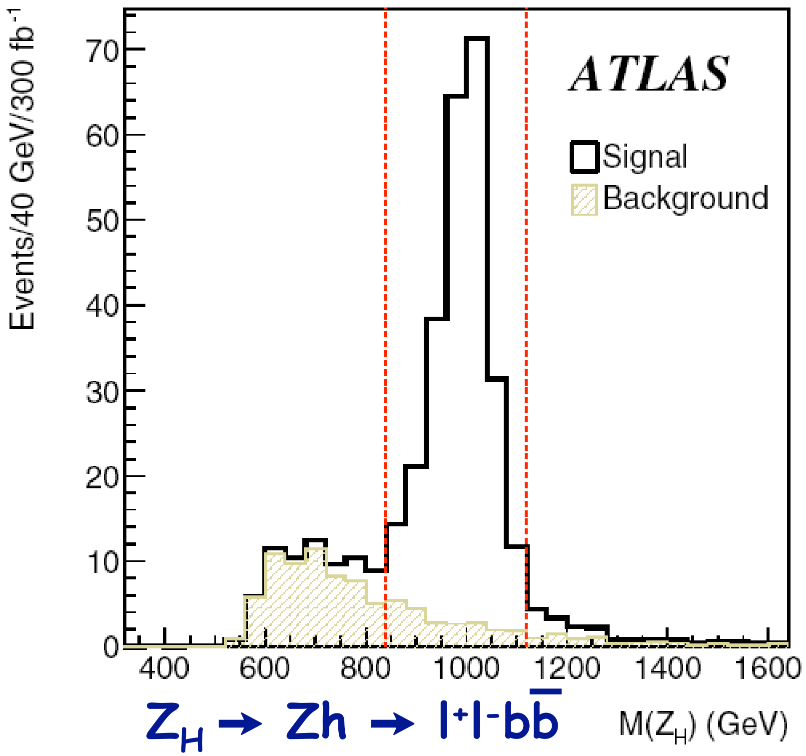
$T \rightarrow Wb \rightarrow l\upsilon b$

Background: single t, $t\bar{t}$

ATLAS: Azuelos et al, EPJ C Vol 39 (2005), Suppl 2, 13 - 24

Test of the Little Higgs model

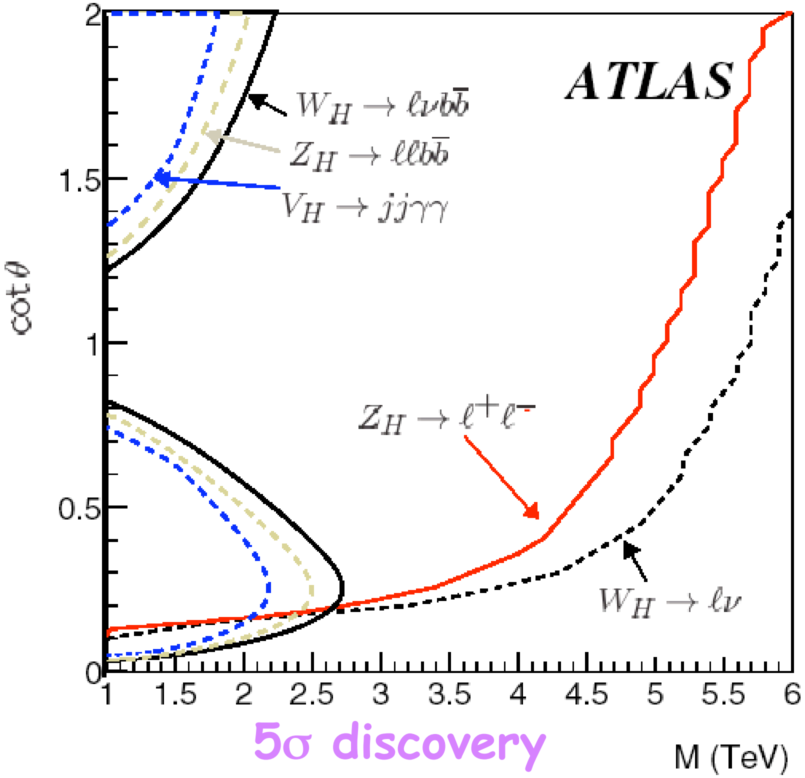
Observation of the cascade decays $Z_H \rightarrow Zh$, $A_H \rightarrow Zh$ and $W_H \rightarrow Wh$ provides crucial evidence that an observed new gauge boson is of the type predicted in the Little Higgs Models.



$Z_H \rightarrow Zh \rightarrow l^+l^-b\bar{b}$

Background: Z+jet

$\int L$ = 300 fb^{-1}



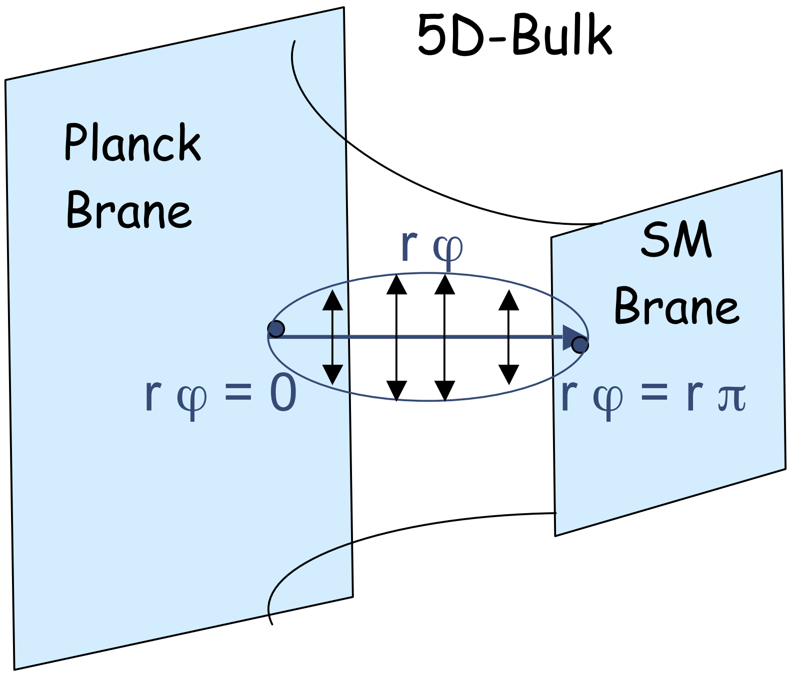
5σ discovery

$\int L$ = 300 fb^{-1}

ATLAS: Azuelos et al, EPJ C Vol 39 (2005), Suppl 2, 13 - 24

The Randall-Sundrum model

Model with one Warped Extra Dimension = Answer to the Hierarchy Problem



5D Anti-de-Sitter space-time with 2 3-branes (of 4D):

$$e^{-2kr\varphi}\,\eta_{\mu\nu}\,dx^{\mu}\,dx^{\nu} + r^2\,d\varphi^2$$

k = curvature of the space and r = compactification radius of the extra dimension (φ: new coordinate)

Specificity of this model: the exponential factor ("warp factor")

Gravity :

$$\Lambda_{\pi} = M_{PL}\,e^{-kr\pi} \sim 1\,\text{TeV}$$

i.e. no hierarchy if $kr \approx 11\text{-}12$ which can be stabilized with the introduction of the Radion field

The Randall-Sundrum Model

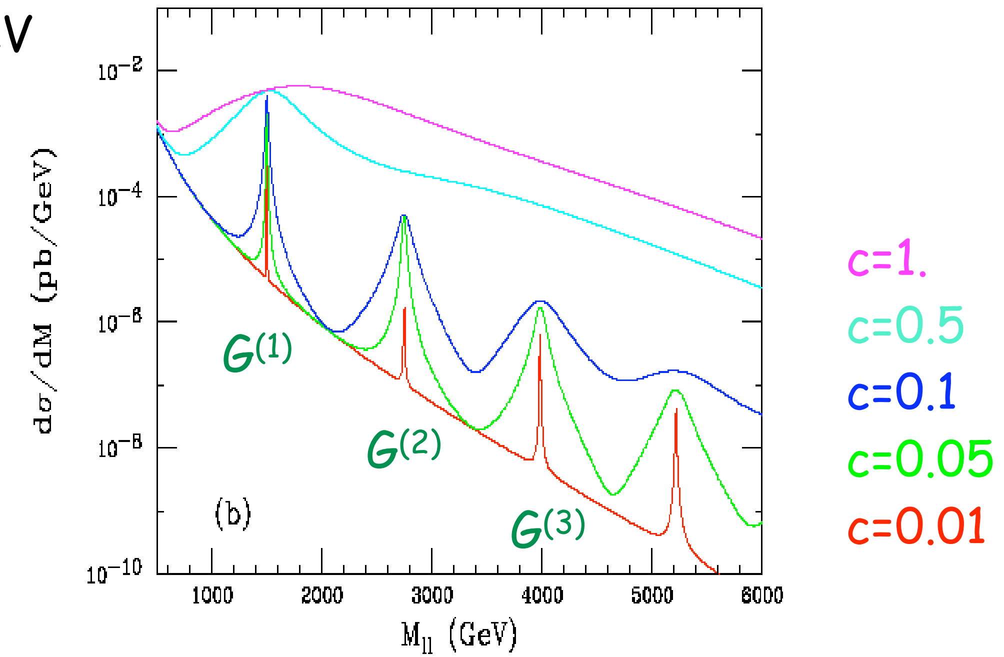
Only the graviton can propagate in 5D. On the 4D branes, Kaluza-Klein excitations of the graviton can be observed:

$$M_n = k\, x_n\, e^{-kr\pi} \quad \text{avec } J_1(x_n)=0$$

$$\Gamma_n = \rho\, M_n\, x_n^2\, c^2$$

with two free parameters in the model: $M_G=M_1$ and $c=k/M_{PL}$

Example: if M_1=1.5 TeV

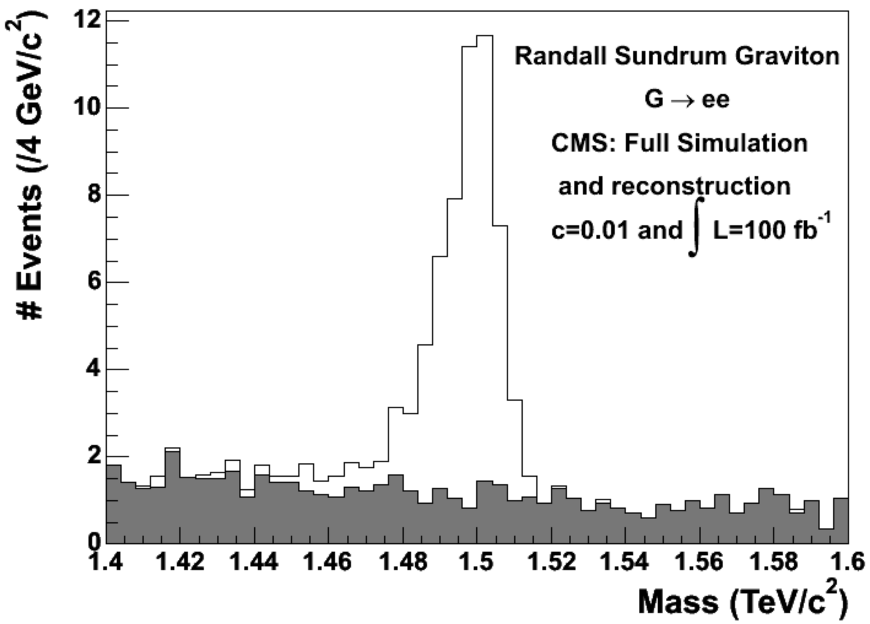


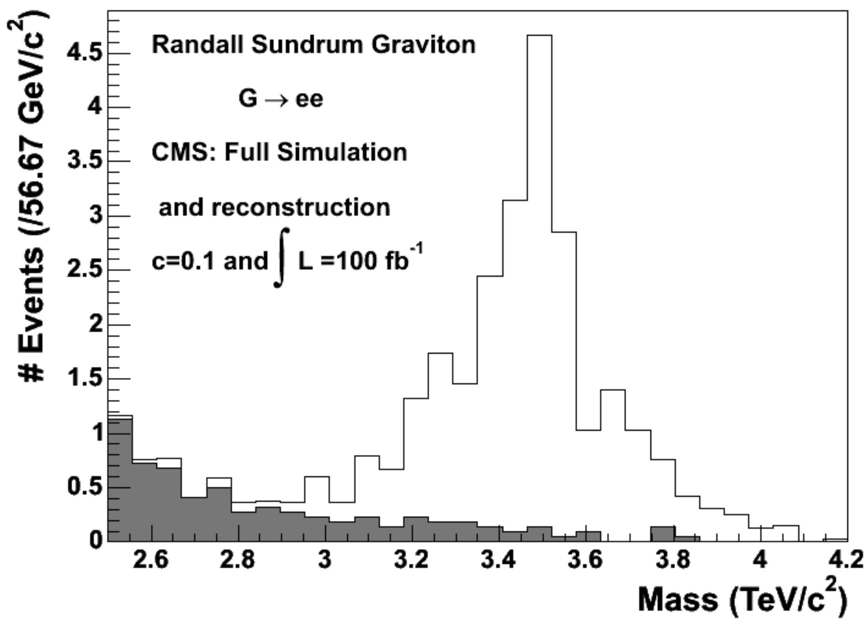
H.Davoudiasl, J.Hewett, T.Rizzo, hep-ph/0006041

Look for the 1st KK graviton (resonance @ M_G~ TeV)

Search for $G^{(1)}$

- Cuts: 2 isolated e in $|\eta|<2.5$ and $P_t>100$ GeV + pass the trigger
- Significance: $2*(\sqrt{S+B}-\sqrt{B})$
- Full simulation and reconstruction

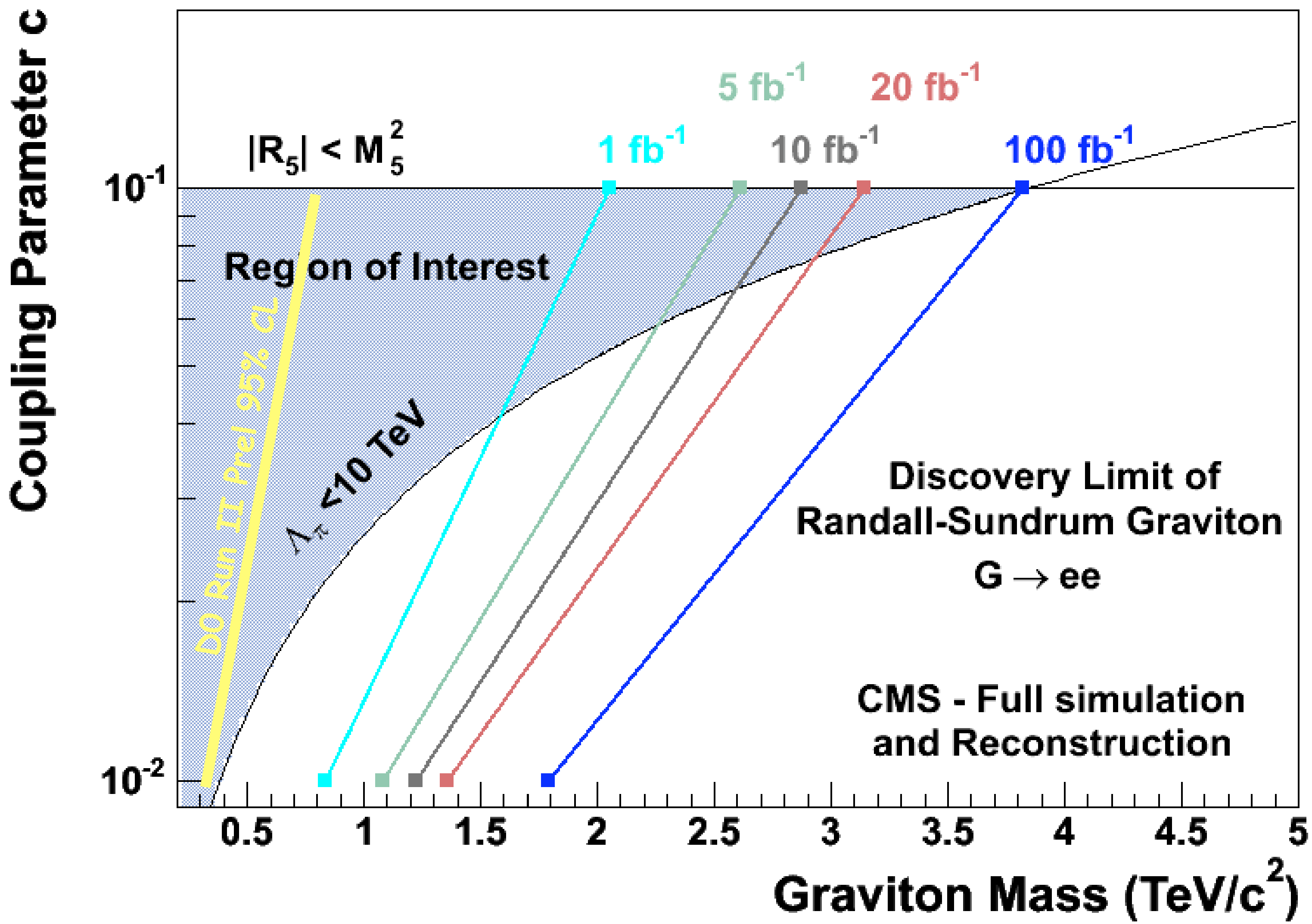




K factor =1 for signal and 1.3 for Drell-Yan

CMS: Collard and Lemaire, EPJ C Vol 40 (2005), Num 5, 15 - 21

Discovery reach for $G^{(1)}$

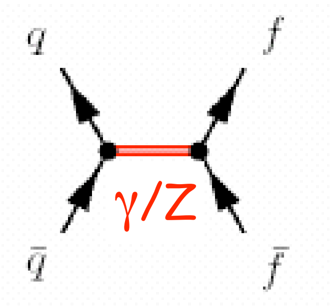


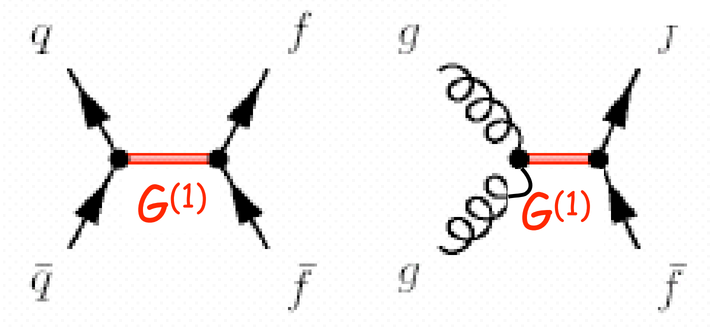
CMS: Collard and Lemaire, EPJ C Vol 40 (2005), Num 5, 15 - 21

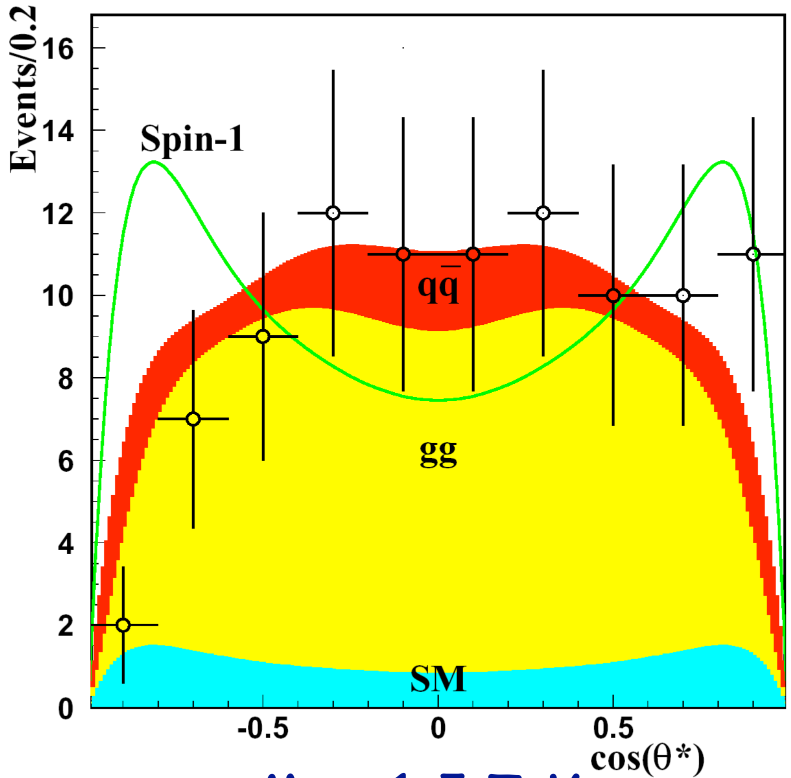
Identification of the graviton nature

Other decay channels: $G^{(1)} \to \gamma\gamma$ vs. $Z' \to \gamma\gamma$ not allowed

Angular distribution: spin 2 vs. spin 1







M_G = 1.5 TeV

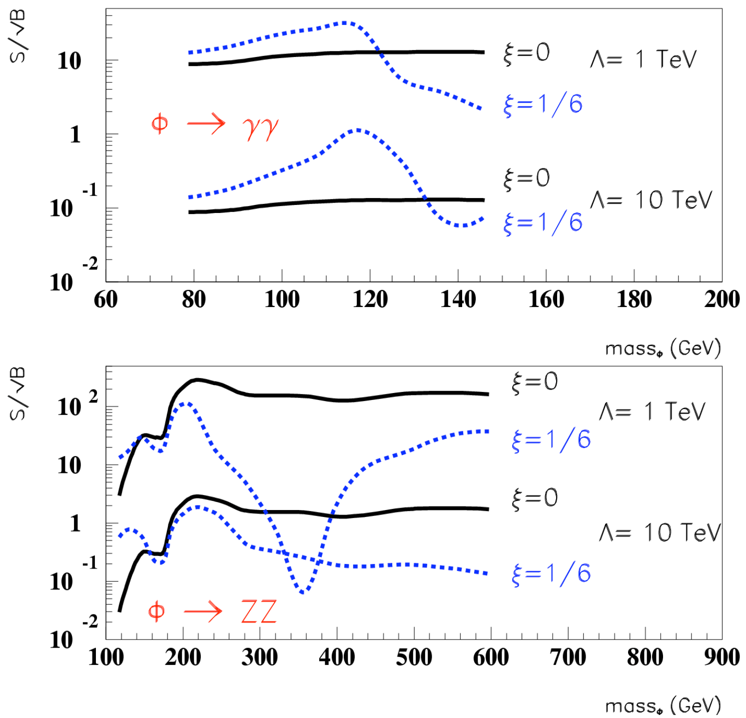
$\int L$ = 100 fb^{-1}

ATLAS: Allanach et al, JHEP-09(2000)019

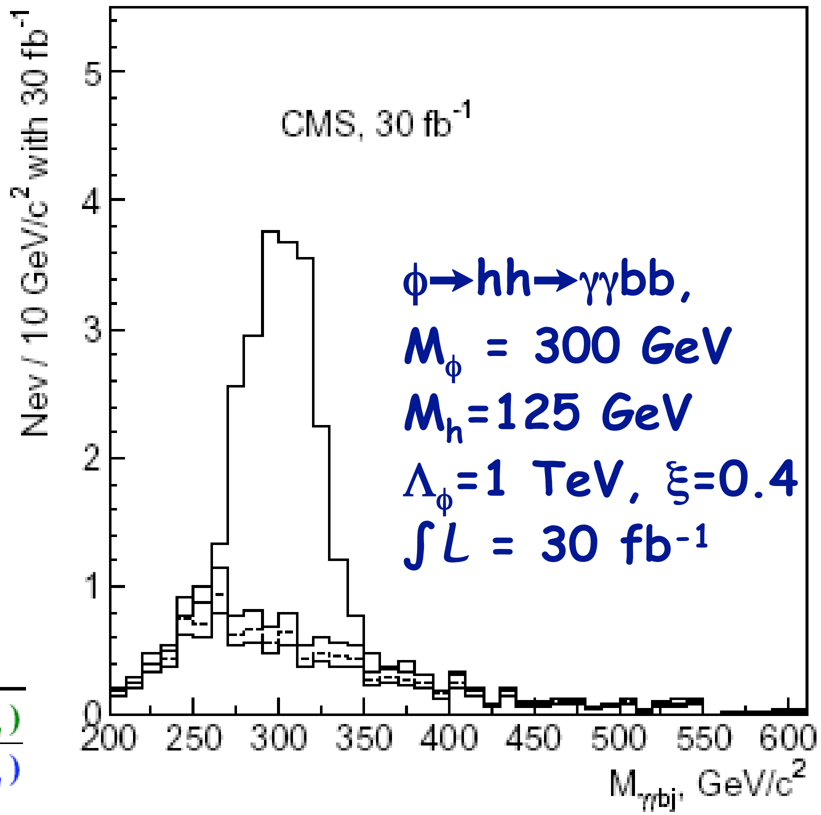
Other signature of the RS model

- **Radion:** scalar field responsible for the brane stabilization.
- Couplings similar to the Higgs, with a more important coupling to gluons. Interference with the Higgs.

ATLAS: Azuelos et al, EPJdirect C4:16,2002



$$\frac{S/\sqrt{B}\,(\phi)}{S/\sqrt{B}\,(h)} = \frac{\Gamma(\phi \to gg)BR(\phi \to \gamma\gamma, ZZ)}{\Gamma(h \to gg)BR(h \to \gamma\gamma, ZZ)} \sqrt{\frac{\max(\Gamma^{h}_{tot}, \sigma_m)}{\max(\Gamma^{\phi}_{tot}, \sigma_m)}}$$



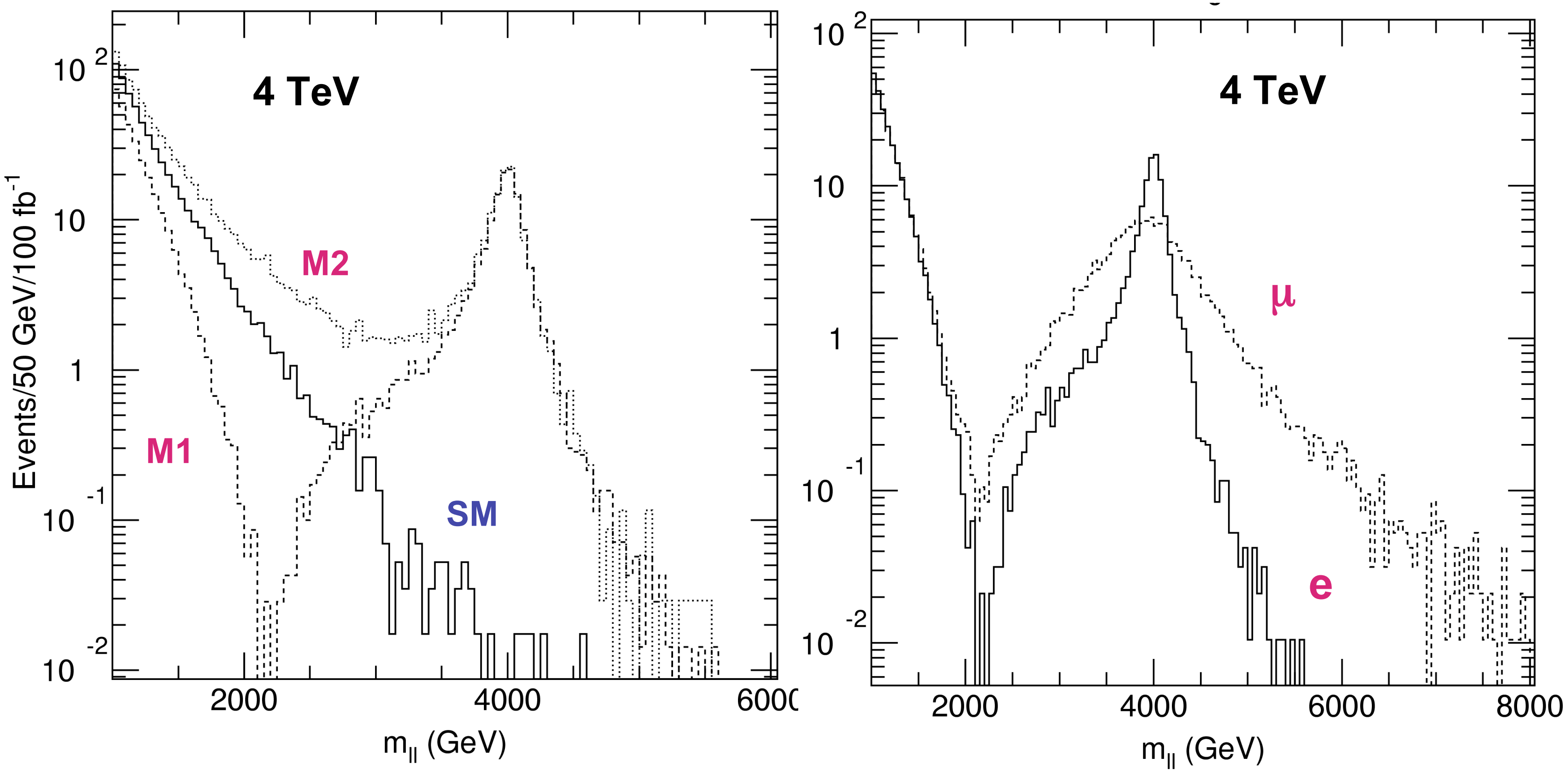
CMS: D. Dominici et al, CMS Note 2005/007

The TeV^{-1} extra dimension model

- Model with one "small" extra dimension
  - Compactification radius R ~ 1/TeV
  - Free parameter : compactification scale = M_c
- Only the gauge bosons propagate in the extra dimension → Appearance of Kaluza-Klein excitations for each gauge field in the bulk
  - $M_n^2 = (n\ M_c)^2 + M_0^2$
  - Couplings like SM (* √2)
- Fermions are confined on 3-branes
  - Model M_1 : all SM fermions on the same orbifold point
  - Model M_2 : quarks and leptons are at opposite fixed points
- EW constraints on the TeV^{-1} model: M_c > 4 TeV

$\gamma^{(1)}, Z^{(1)}$

- **Cuts:** 2 isolated e in $|\eta|<2.5$ and $P_t>20$ GeV, $M_{ll}>1$ TeV
- **Significance:** $S/\sqrt{B}$
- **Fast simulation**
- **Resonance observable** up to ~5.8 TeV with $\int L$ = 100 fb^{-1}

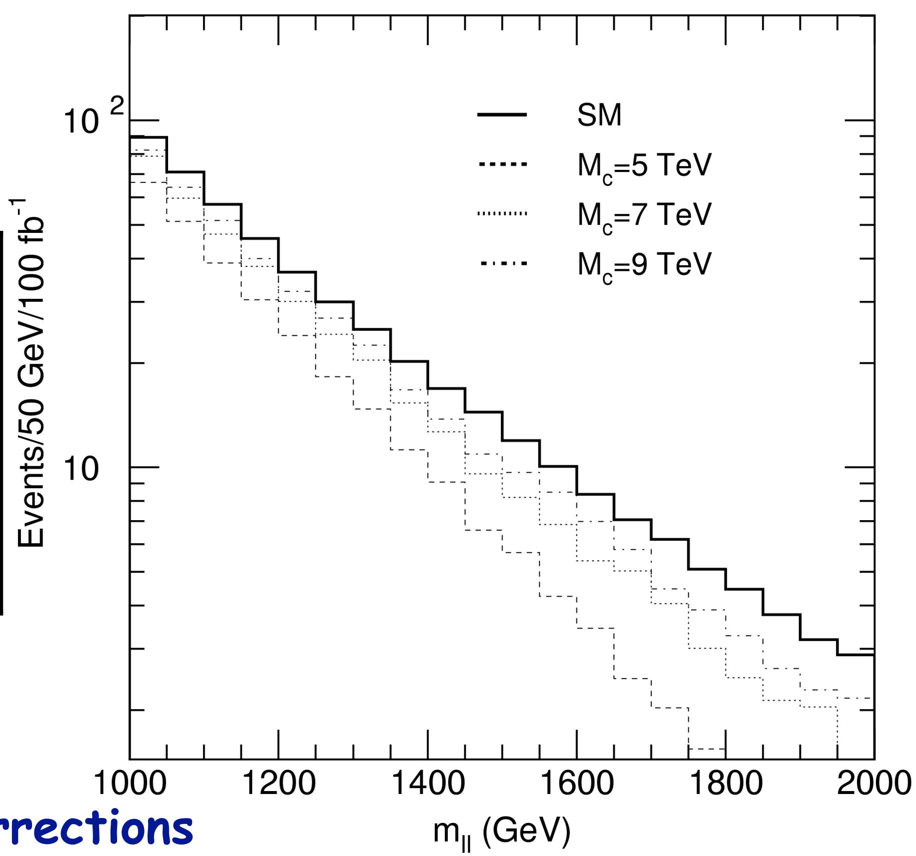


ATLAS: Azuelos and Polesello, EPJ C Vol 39 (2005), Suppl 2, 1 - 11

Look off-peak: interference effect

- Optimal analysis of mass from tail
  - Uses full information
  - Unbinned max. likelihood

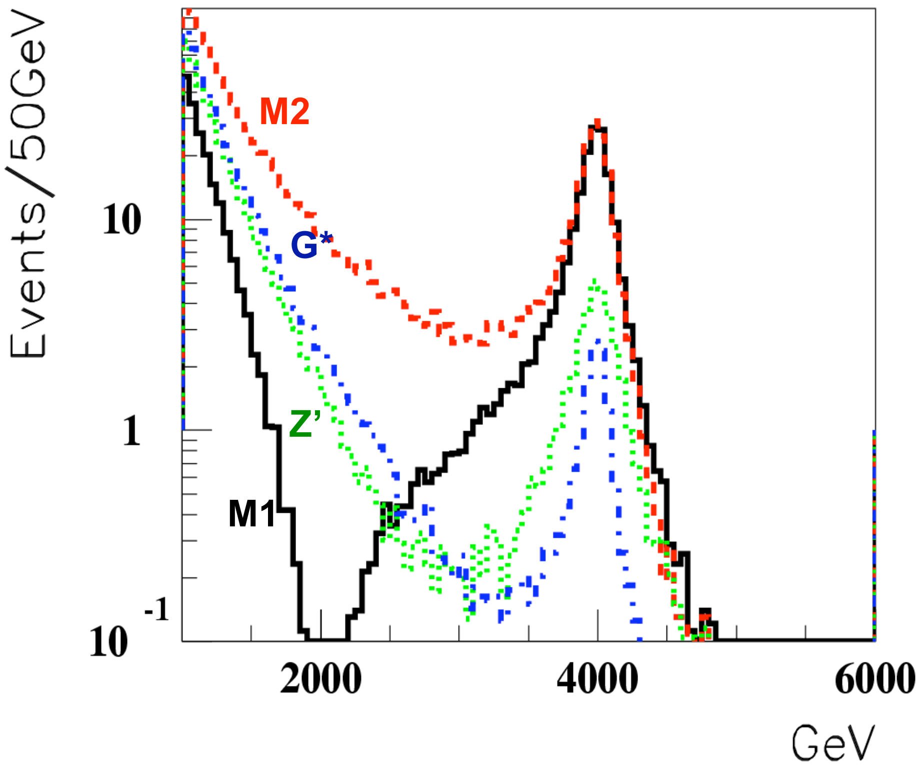
electrons			e+μ
100 fb^{-1}	200 fb^{-1}	300 fb^{-1}	300 fb^{-1}
9.5 TeV	11 TeV	12 TeV	13.5 TeV



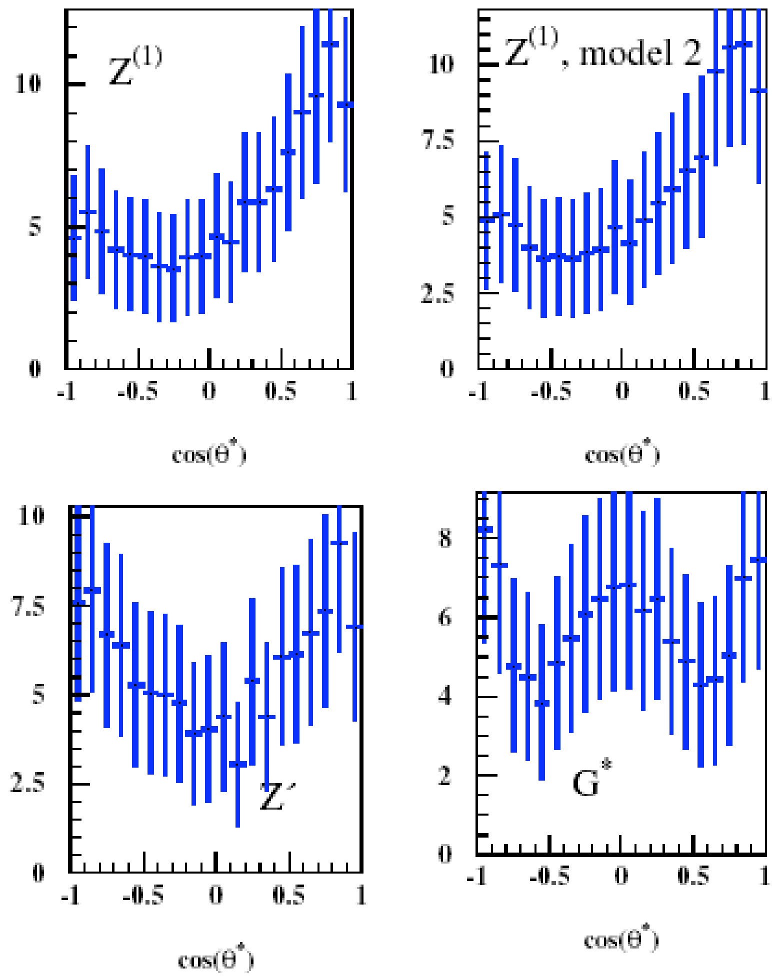
ATLAS: Azuelos and Polesello, EPJ C Vol 39 (2005), Suppl 2, 1 - 11

- Systematics:
  - Linearity in energy calibration
  - QCD and EW higher order corrections
  - Structure functions

Angular distribution

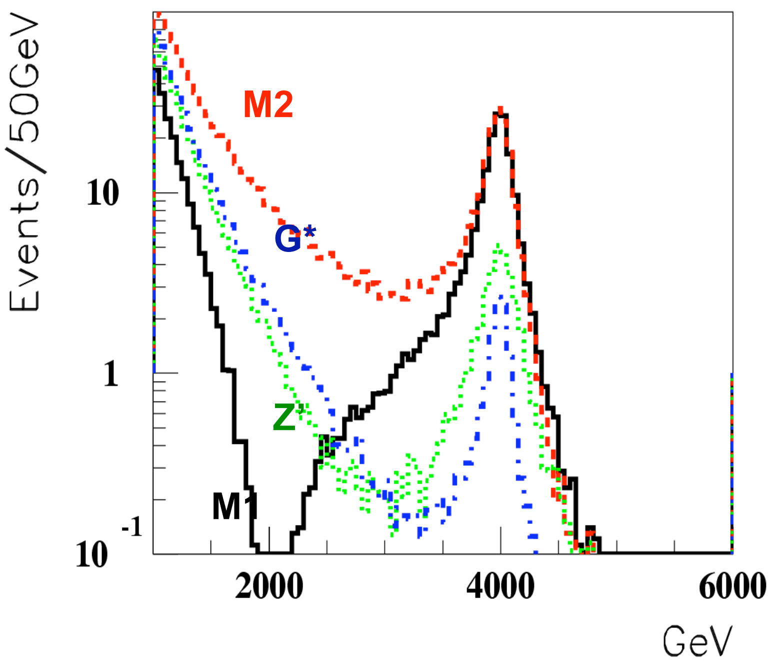


In the resonance peak

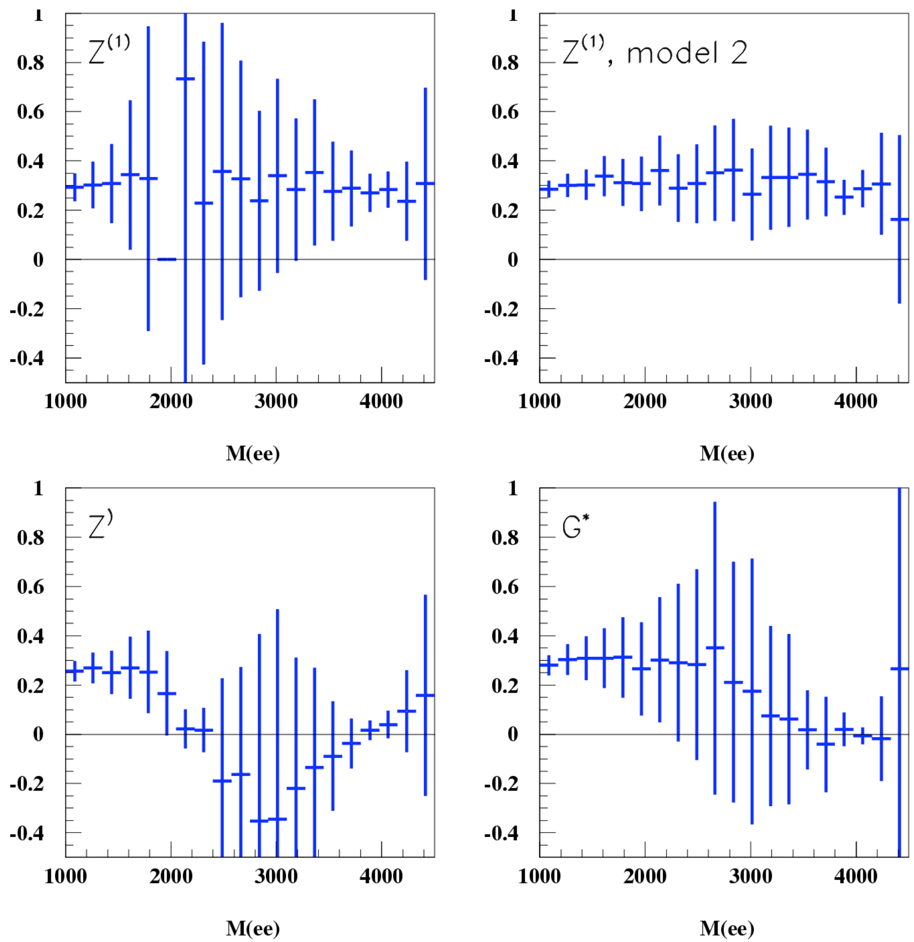


ATLAS: Azuelos and Polesello, EPJ C Vol 39 (2005), Suppl 2, 1 - 11

Forward-Backward asymmetry



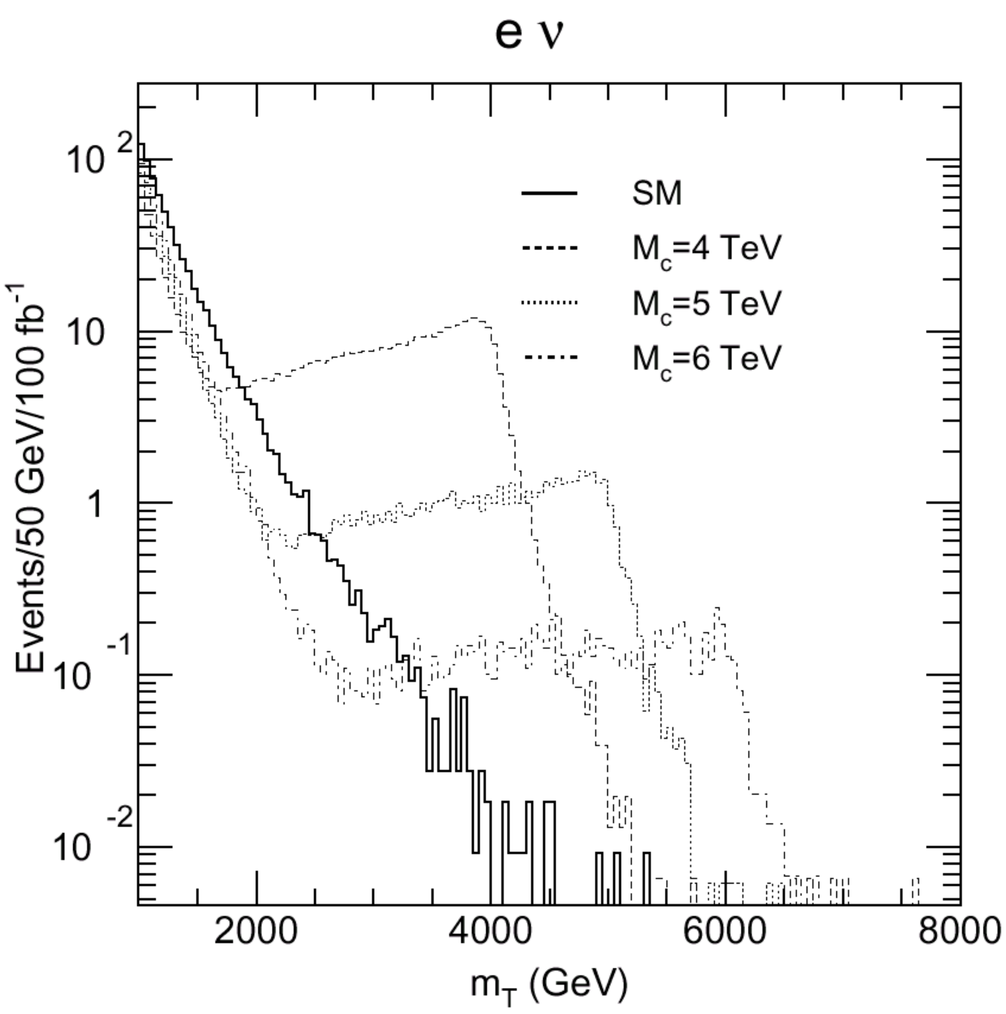
As a function of the mass M_{ee}



ATLAS: Azuelos and Polesello, EPJ C Vol 39 (2005), Suppl 2, 1 - 11

Other signature of the TeV^{-1} model

- Same for $W^{(1)}$
  - Direct observation up to 6 TeV
  - Indirect up to ~9 TeV
- More difficult to distinguish from a W'



ATLAS: Azuelos and Polesello, EPJ C Vol 39 (2005), Suppl 2, 1 - 11

The ADD model

- Model with n "large" extra dimensions
  - M_{PL} is an effective scale, restricted to 4 dimensions. The real Planck mass in n+4 dimensions is $M_D = M_{PL}^{[n+4]}$ related to M_{PL} by

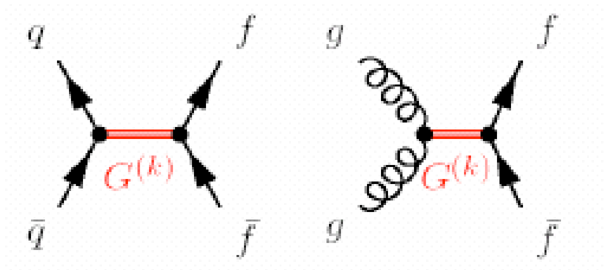
$$G_N \frac{m_1 m_2}{r^2} = G' \frac{m_1 m_2}{r^2 (2\pi r)^n}, \quad \text{for} \quad r = R \quad \Rightarrow \quad G' = G_N (2\pi R)^n$$

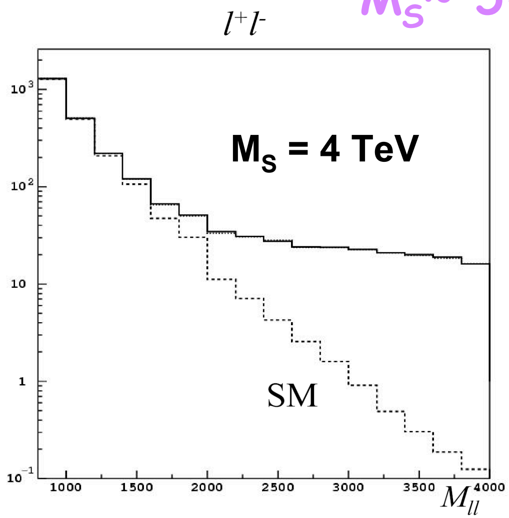
$$M_D^{2+n} = \frac{M_{Pl}^2}{8\pi (2\pi R)^n} \quad \Rightarrow M_D \sim \text{TeV for values of } R \leq \text{mm}$$

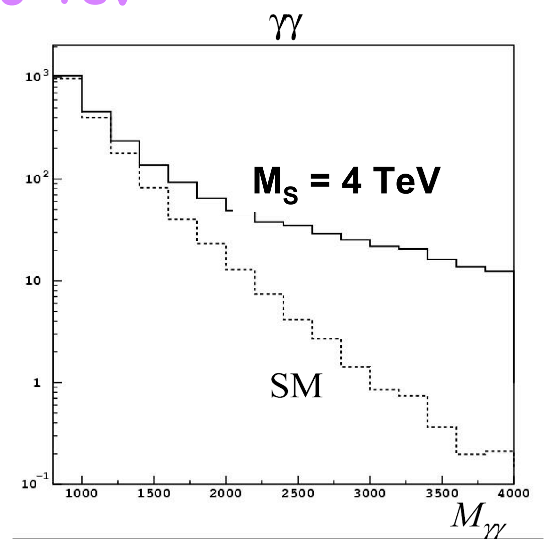
  - Compactification radius R < 0.2 mm (from gravity experiment)
- Only the gravitons propagate in the extra dimensions→ Appearance of Kaluza-Klein excitations for the graviton
  - Mass: $M_n^2 = M_0^2 + n^2/R^2$
  - Coupling to the SM particles: $L = 1/M_{PL}\, G_{\mu\nu}^{(n)}\, T^{\mu\nu}$
  - The large number of states (degenerated in mass) compensate the weak coupling ($1/M_{PL}$): $\sigma \sim (\sqrt{s}/M_D^2)^n$

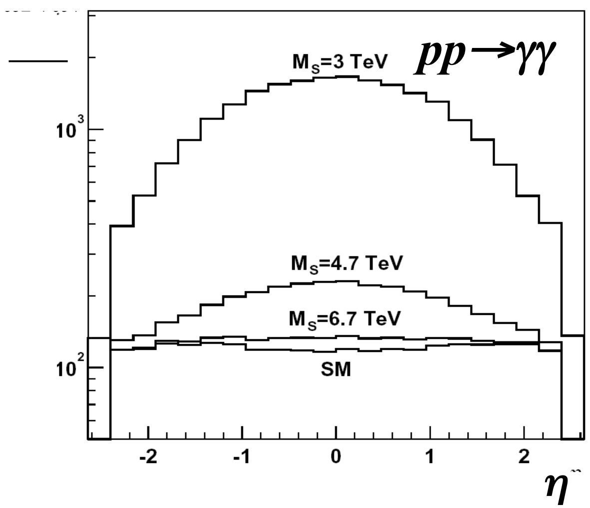
$G^{(KK)}$: virtual exchange

- Cuts: 2 isolated l or γ in $|\eta|<2.5$ and $P_t>50$ GeV, $M_{ll/\gamma\gamma} > 0.8$ TeV
- No resonance anymore, but a continuum of $G^{(KK)}$ states. Excess in di-leptons mass distribution (same for di-photons), event distribution of $\gamma\gamma$ (s-channel) more central than in SM (t and u channels), FB asymmetry can be measured
- Significance: $S/\sqrt{S+B}$
- Fast simulation
- Sensitivity for $\int L$ = 100 fb^{-1}:
  $M_S \sim$ 5-6 TeV





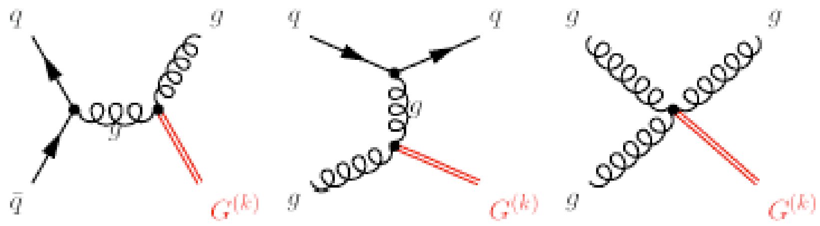


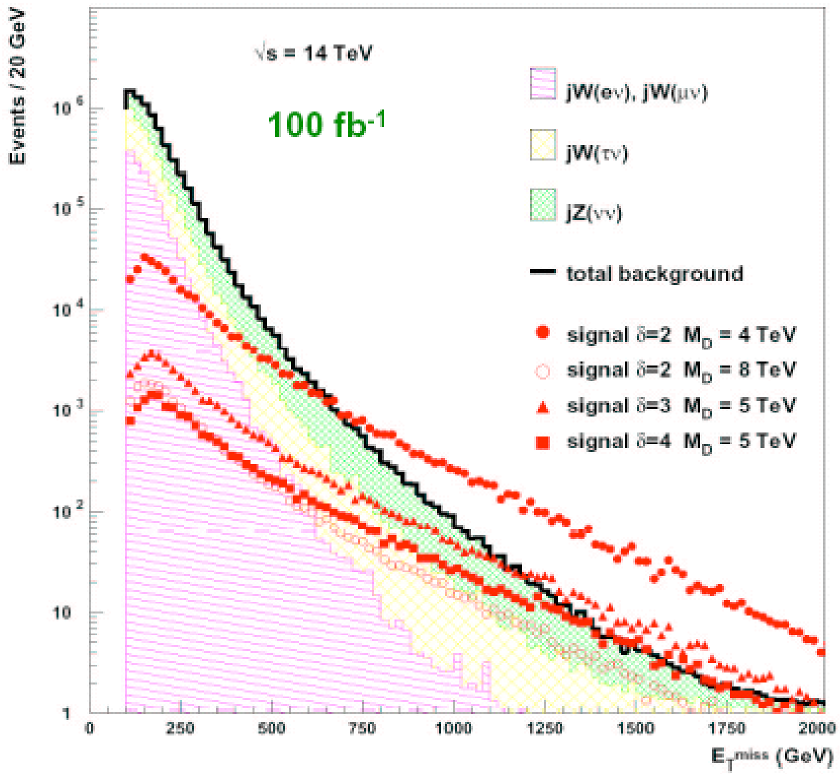


V. Kabachenko et al, ATL-PHYS-2001-012,
O.J.P. Éboli et al, Phys. Rev. D61 094007 (2000)

Other signature in the ADD model

- **Direct Search:** Monojet with a large missing transverse energy (stable non detected G^{KK})





δ	M_D^{max} (TeV) LL, 30 fb^{-1}	M_D^{max} (TeV) HL, 100 fb^{-1}	M_D^{min} (TeV)
2	7.7	9.1	~ 4
3	6.2	7.0	~ 4.5
4	5.2	6.0	~ 5

Limit on M_D^{min}:

Validity of the effective theory: $\sqrt{s} < M_D$. Above this limit: sensitivity to new physics. → Truncation of σ when $\sqrt{s} > M_D$.

ATLAS: Vacavant and Hinchliffe, J. Phys. G: Nucl. Part. Phys. 27 (2001) 1839

Conclusions

A lot of prospects for Physics Beyond the Standard Model

Example : The Di-lepton channel

$\int L$ = 100 fb^{-1}

- Z' (New gauge bosons) — $M_{Z'}$~3.4-4.3 TeV
- A_H, Z_H (Little Higgs) — 300 fb^{-1}: M_Z~0.5-5.7 TeV (cotθ=0.1-2); M_A full range except for tanθ'~1.3
- $G^{(1)}$ (Randall-Sundrum) — M_G~1.8 -3.8 TeV (c=0.01-0.1)
- $\gamma^{(1)}/Z^{(1)}$ (TeV^{-1} Extra Dimensions) — M_c~5.8 TeV (9.5 TeV off-peak)
- $G^{(KK)}$ (ADD) — M_S~5-6 TeV
- ...

Web pages with BSM results:

CMS: http://cmsdoc.cern.ch/cms/PRS/results/susybsm/susybsm.html

ATLAS: http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/EXOTICS/