Physics Beyond SM at the LHC (ATLAS)

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on behalf of the ATLAS collaboration

Why go beyond the Standard Model?

1. Neutrinos have mass Not covered

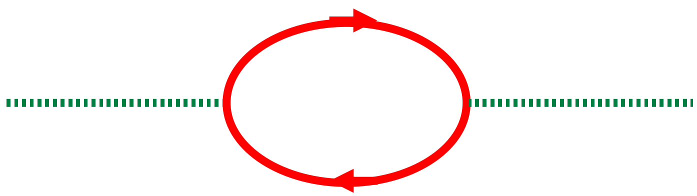
2. Elektroweak symmetry brea Not covered
   - Higgs phenomenology
   - Technicolor
   - other theories with no fundamental scalars…

3. The hierarchy problem
   - Supersym Not covered
   - “Little Higgs” models
   - Theories with more than three spatial dimensions

The hierarchy problem:

assuming the Standard Model is an effective low-energy theory with an ultraviolet cut-off at Λ

The most important radiative corrections to the Higgs-mass comes from loops containing the top-quark, gauge bosons and the higgs itself:



$$\delta m_h^2 = \frac{3}{8\pi^2}\lambda_t^2\Lambda^2$$ from top

$$\delta m_h^2 \propto a_W\Lambda^2$$ from gauge bosons

$$\delta m_h^2 \approx \frac{\lambda}{16\pi^2}\Lambda^2$$ from higgs

So e.g. for Λ = 10 TeV the lowest order contributions are

- ≈ (2 TeV)^2 from top-loops
- ≈ -(750 GeV)^2 from W/Z loops
- ≈ -(1.25 mh)^2 from Higgs loops

=> extreme fine-tuning (at all orders) needed to stabilize the Higgs mass at ≈ 200 GeV

Four ways out:

1 - Learn to live with it: we live in a universe which is fine-tuned to one part in 10^{17}

2 - There is no fundamental scalar
- Technicolor
- ….

3 - Stabilize the Higgs mass through additional symmetries
- Supersymmetry
- Little Higgs

4 - Move the cut-off down
- Extra dimensions

The littlest Higgs Model

- the small Higgs mass results from non-exact symmetry
  $\rightarrow$ pseudoGoldstone boson
  (pions have mass because quark masses and e.m. break chiral symmetry)

- quadratic divergences occur at two-loop level ~ 10 TeV
  $\rightarrow$ model is not complete
  UV completion required at ~ 10 TeV

- Low energy EW constraints rather severe
  - FCNC's at ~ 100 TeV

- New particle content

$$W_H^{\pm}, Z_H, \gamma_H : \sim 1 \ \ \text{TeV}$$

$$T : \sim 1 \ \ \text{TeV}$$

$$\phi^{\pm\pm}, \phi^{\pm}, \phi^{0} : \sim 10 \ \ \text{TeV}$$

New particles

T : heavy top

$M < 2\,\mathrm{TeV} \cdot \left(\frac{M_H}{200\,GeV}\right)^2$

$M_h = 120$ GeV M< 0.2 TeV
$M_h = 200$ GeV M< 2 TeV

$\mathbf{Z_H}$, $\mathbf{W^{\pm}_H}$, $\mathbf{A_H}$: heavy Z , W±, γ

$M < 6\,\mathrm{TeV} \cdot \left(\frac{M_H}{200\,GeV}\right)^2$

$M(Z_H) \approx M(W^{\pm}_H) > M(A_H)$

$M_h = 120$ GeV M< 2.2 TeV
$M_h = 200$ GeV M< 6 TeV

arise from $[SU(2) \otimes U(1)]^2$ symmetry

ϕ^0 , ϕ^+ , ϕ^{++} : triplet of heavy Higgses

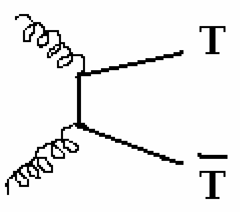
M<10TeV

note: the Standard Model h is still there !

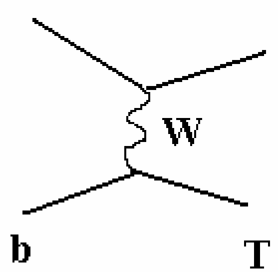
Search for the heavy T quark

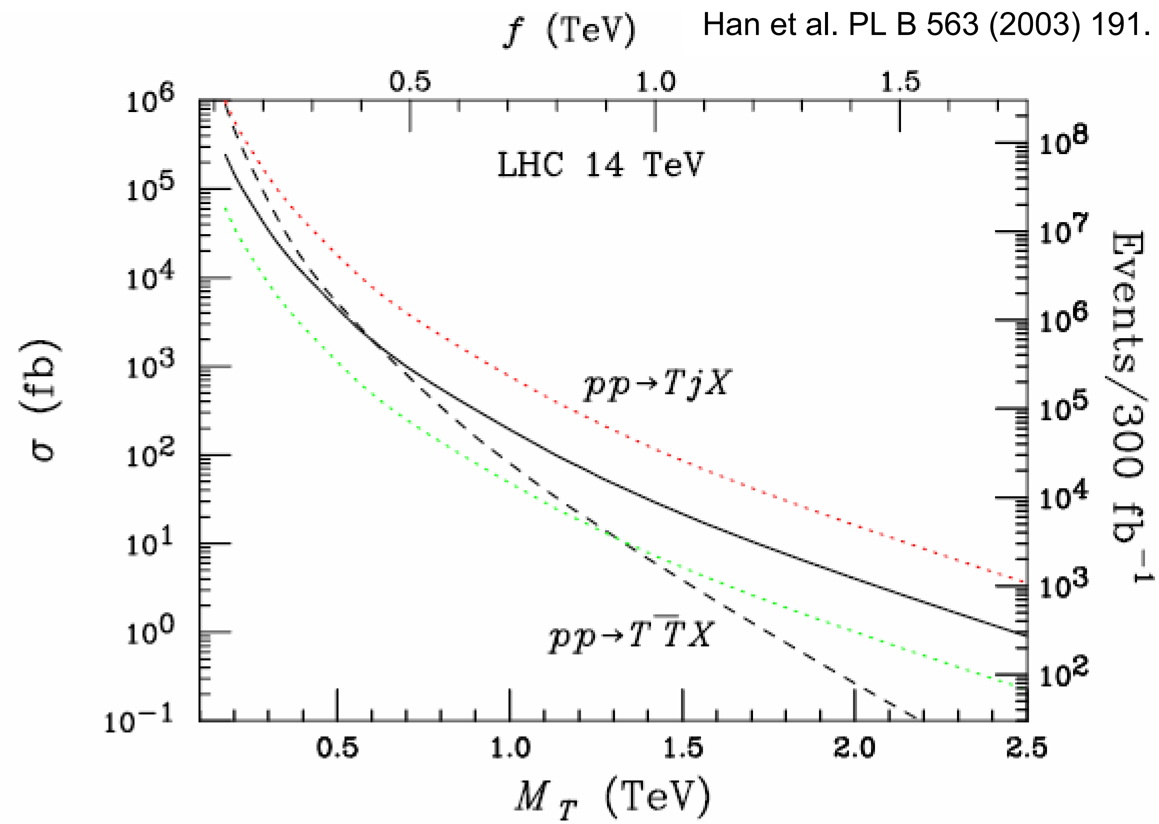
Han et al. PL B 563 (2003) 191.

Pair production



Single production:





So concentrate on single production

Search for the heavy T quark

Couplings: $$\lambda_1\left(iQht_R + fT_L t_R hh^{\dagger}\right) + \lambda_2 f\left(T_L T_R\right)$$

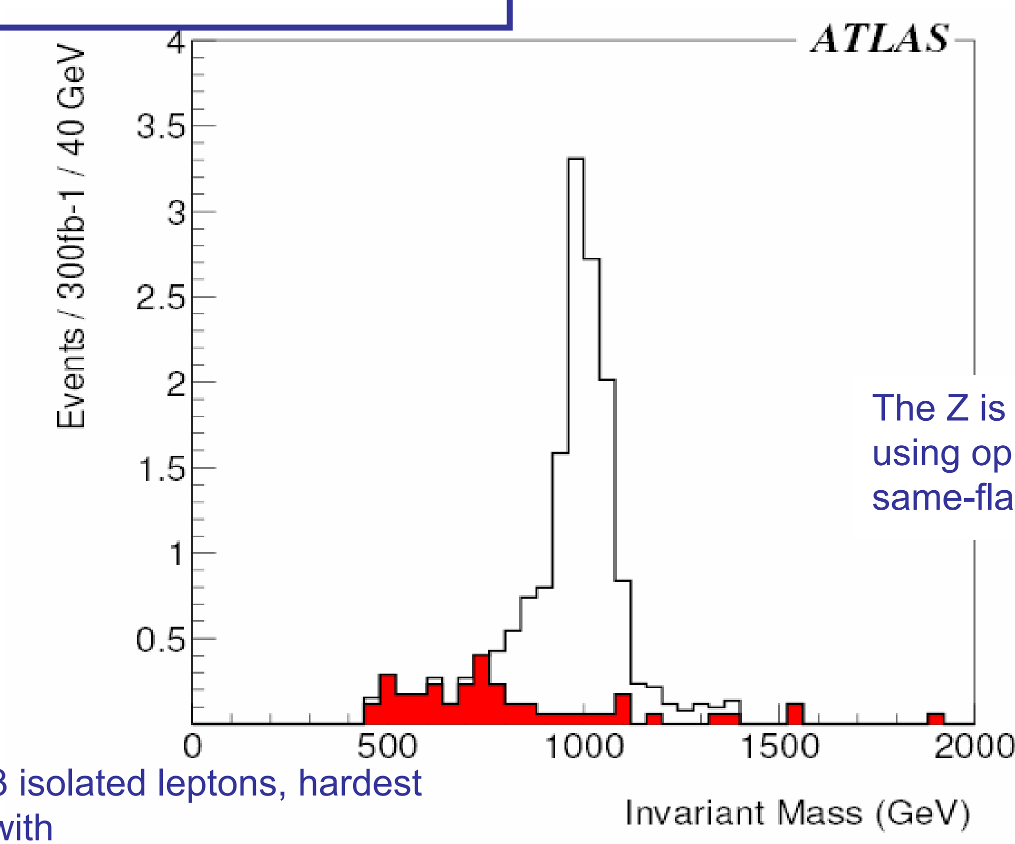
→ **3 free parameters which can be choosen as m_t, m_T, and λ_1/λ_2**

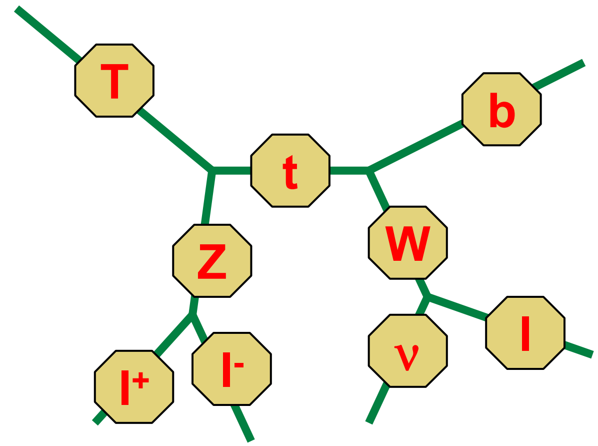
Widths: $$\Gamma(\mathrm{T} \to \mathrm{th}) = \Gamma(\mathrm{T} \to \mathrm{tZ}) = \frac{1}{2}\Gamma(\mathrm{T} \to \mathrm{bW}) = \frac{\kappa^2}{32\pi}M_T$$

$$\kappa = \frac{\lambda_1^2}{\sqrt{\lambda_1^2 + \lambda_2^2}}$$

Search in all three modes!

$T \to Zt \to l^+ l^- l \nu b$





The Z is reconstructed using opposite sign, same-flavour lepton pair.

The W in the top decay is reconstructed assuming $p_T^{\nu} = E_T^{miss}$, and solving for W momentum.

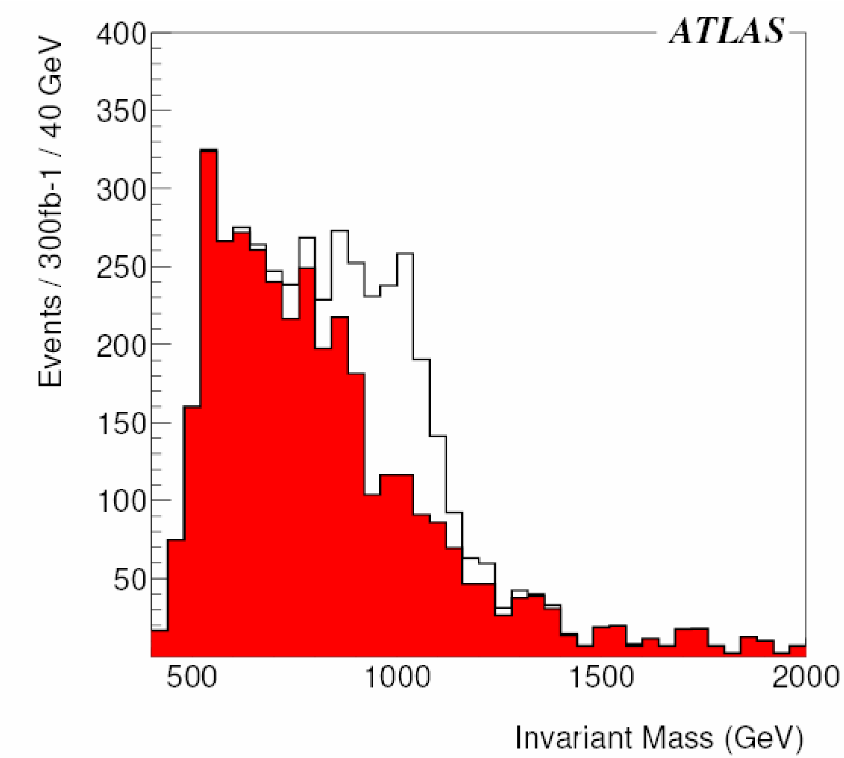
Main background is Ztb and WZ

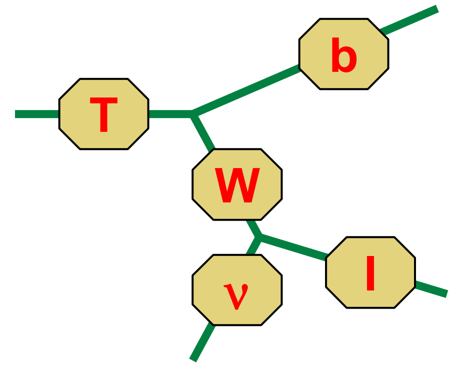
- 3 isolated leptons, hardest with p_T >100 GeV, rest with p_T >40 GeV.
- No other lepton with p_T > 15 GeV
- E_T^{miss} > 100 GeV
- At least one b-tagged jet.

For $\lambda_1/\lambda_2 = 1$ (2) $M_T < 1050$ (1400) GeV is observable (5σ, > 10 events)

G.Azuelos et al.
SN-ATLAS-2004-038
hep-ph/0402037

$T \rightarrow Wb \rightarrow l\,\nu b$





The W is reconstructed assuming $p_T^{\nu} = E_T^{miss}$, and solving for W momentum.

Main background is tt, single t and QCD production of Wbb

- At least one charged lepton with p_T >100 GeV.
- At least one b-tagged jet with p_T > 100 GeV.
- Not more than two jets with p_T > 30 GeV
- Mass of the pair of jets with highest p_T > 200 GeV
- E_T^{miss} > 100 GeV

For λ_1/λ_2 = 1 (2) M_T < 2000 (2500) GeV is observable (5σ, > 10 events)

G.Azuelos et al.
SN-ATLAS-2004-038
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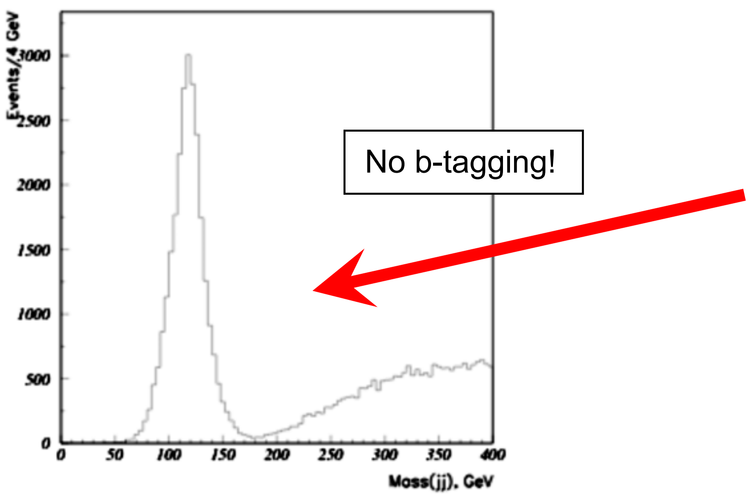
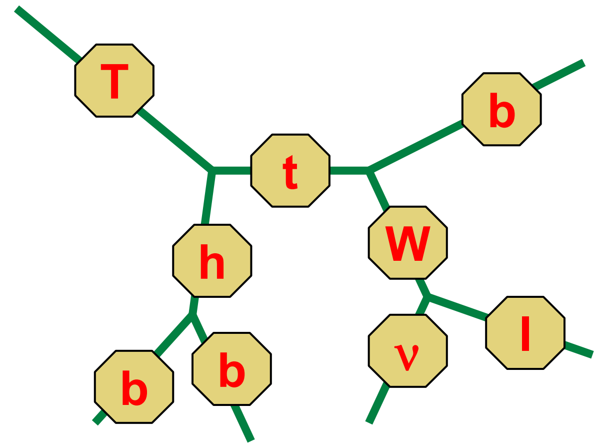
$T \to ht \to bb\, l\, \nu b$

This study assumes that the higgs has been found and its mass determined, here we take m_h = 120 GeV



One di-jet mass combination in 90-130 GeV.



The W is reconstructed assuming $p_T^{\nu} = E_T^{miss}$, and solving for W momentum.

- At least one isolated e or μ with p_T >100 GeV.
- Three jets with p_T > 130 GeV.
- At least one b-tagged jet
- Reject the event if there is one di-jet combination with 70 < m_{jj} < 90 GeV

Main background is tt

G.Azuelos et al.
SN-ATLAS-2004-038
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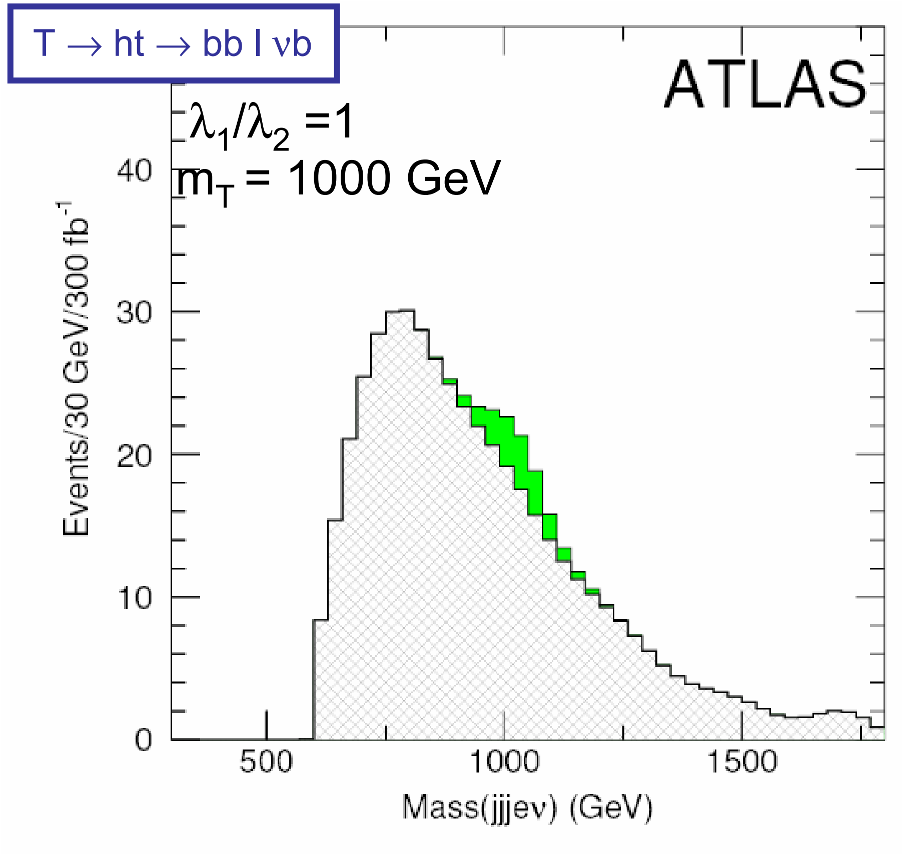

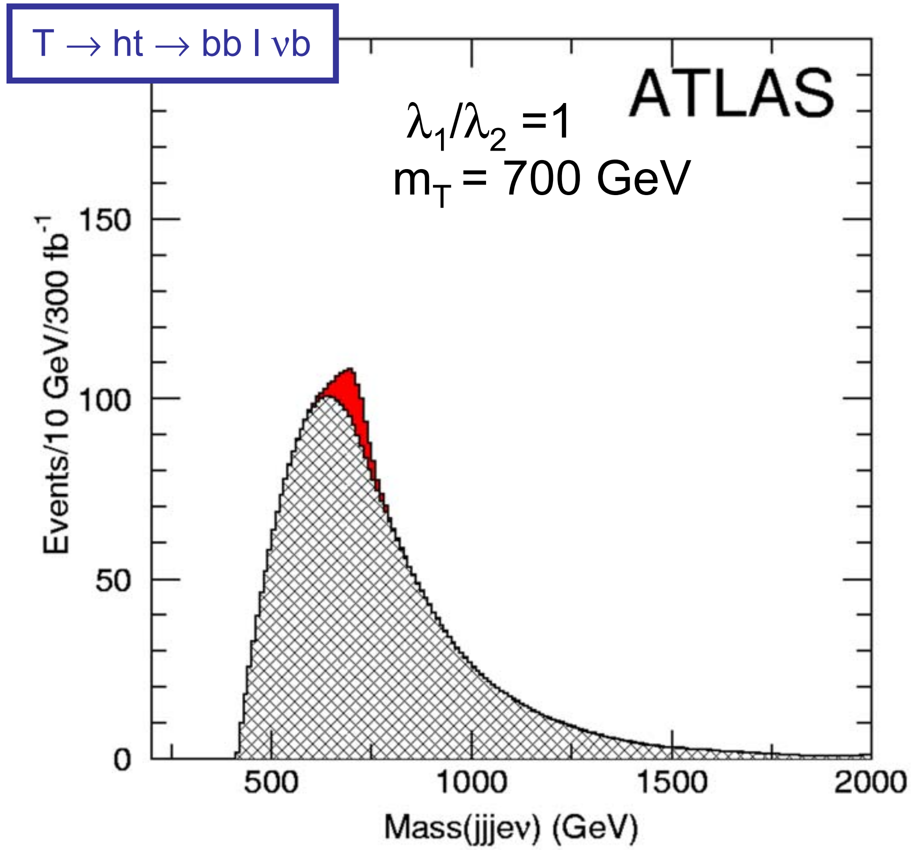

For 300 fb^{-1} the significance is 4σ
- more than enough to perform consistency checks and constraing BR, but marginal for discovery

For lower m_T the kinematics of the signal and tt background become very similar.
Cuts have to be relaxed (70 GeV for lepton and 90 GeV for jets).
For 300 fb^{-1} the significance is 3σ

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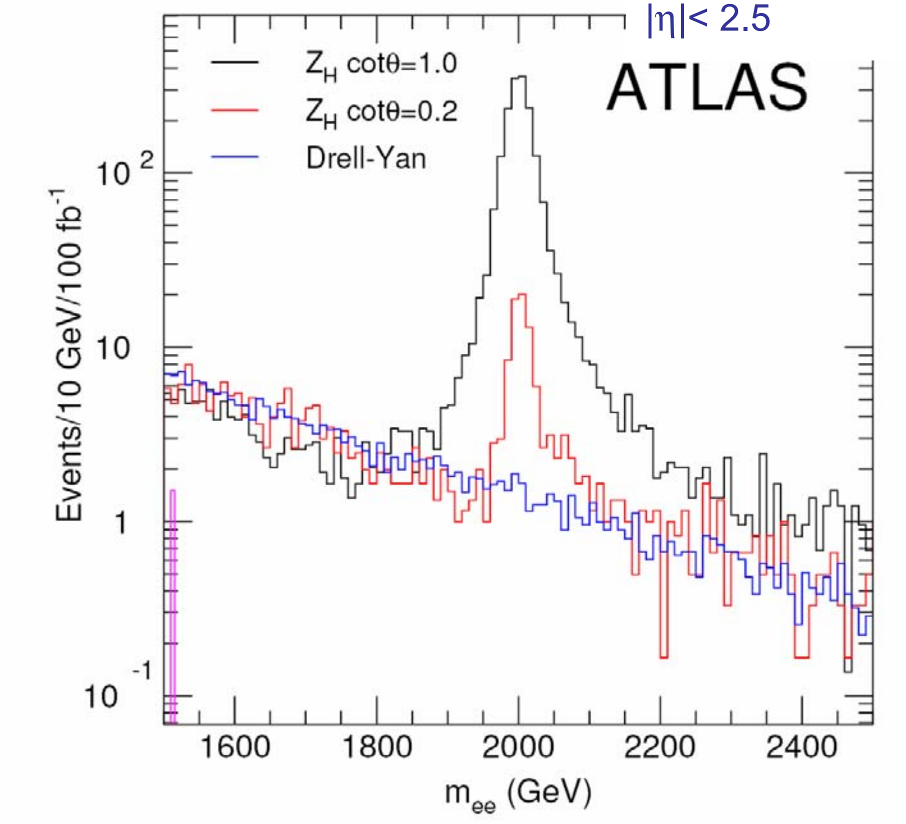
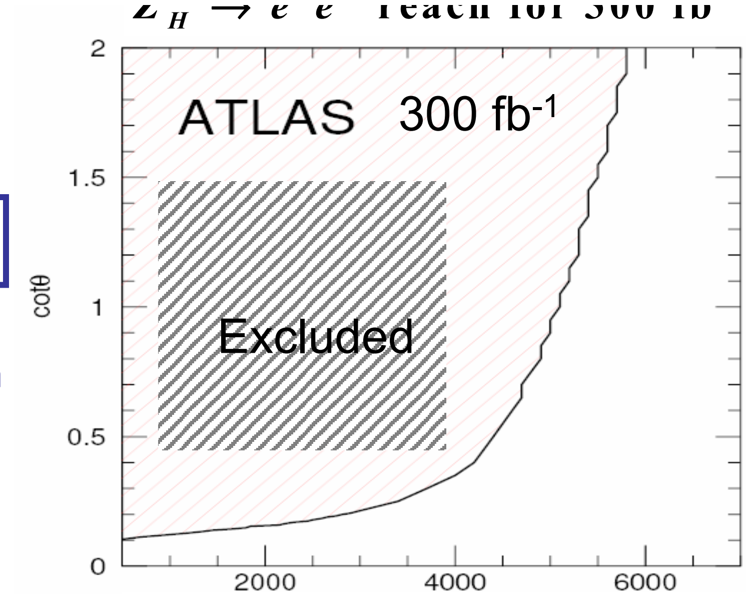
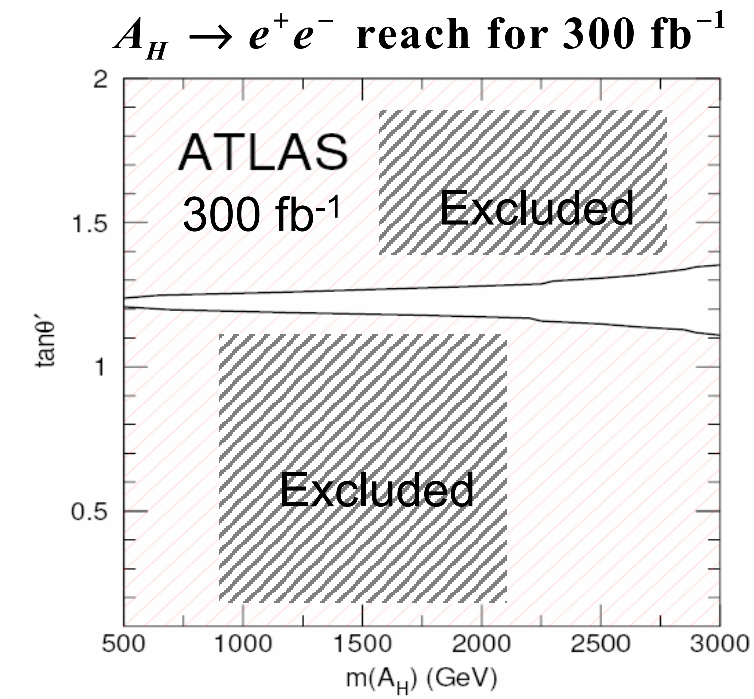
Heavy gauge bosons:

Z_H and $A_H \rightarrow e^+e^-$:

An isolated e^+ and e^- with $p_T > 20$ GeV and $|\eta| < 2.5$







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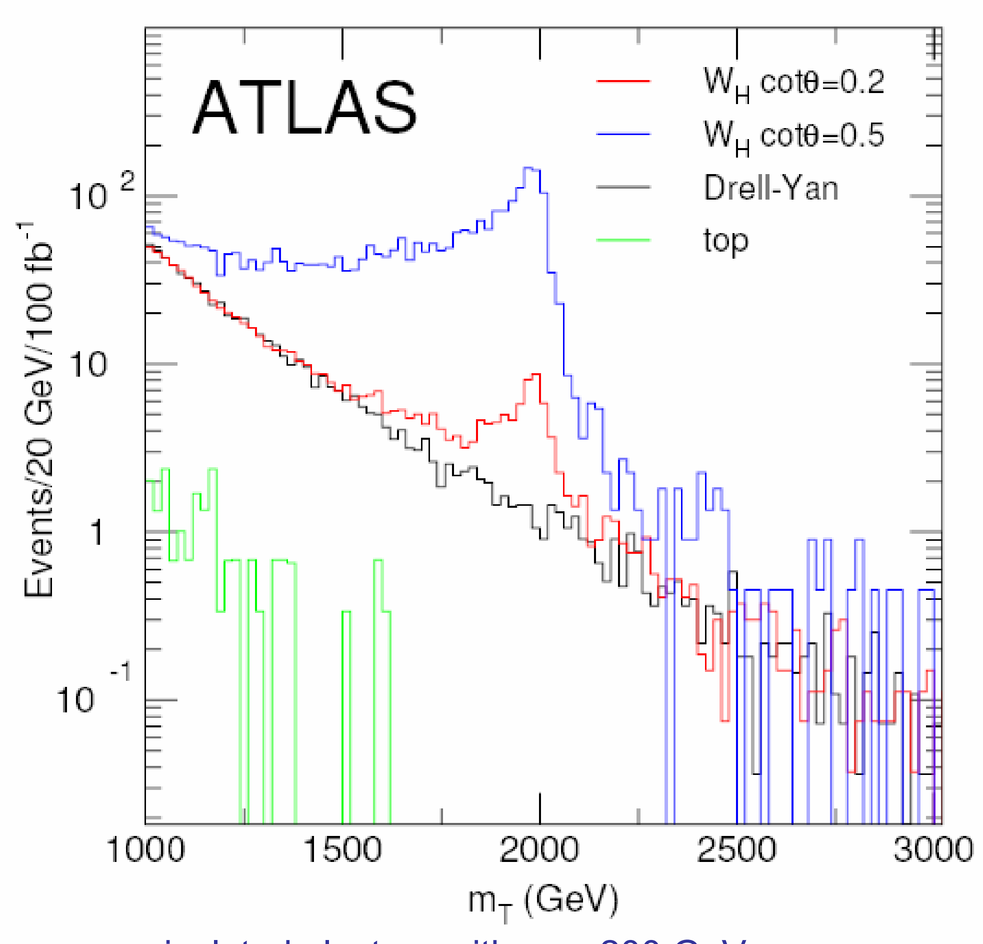
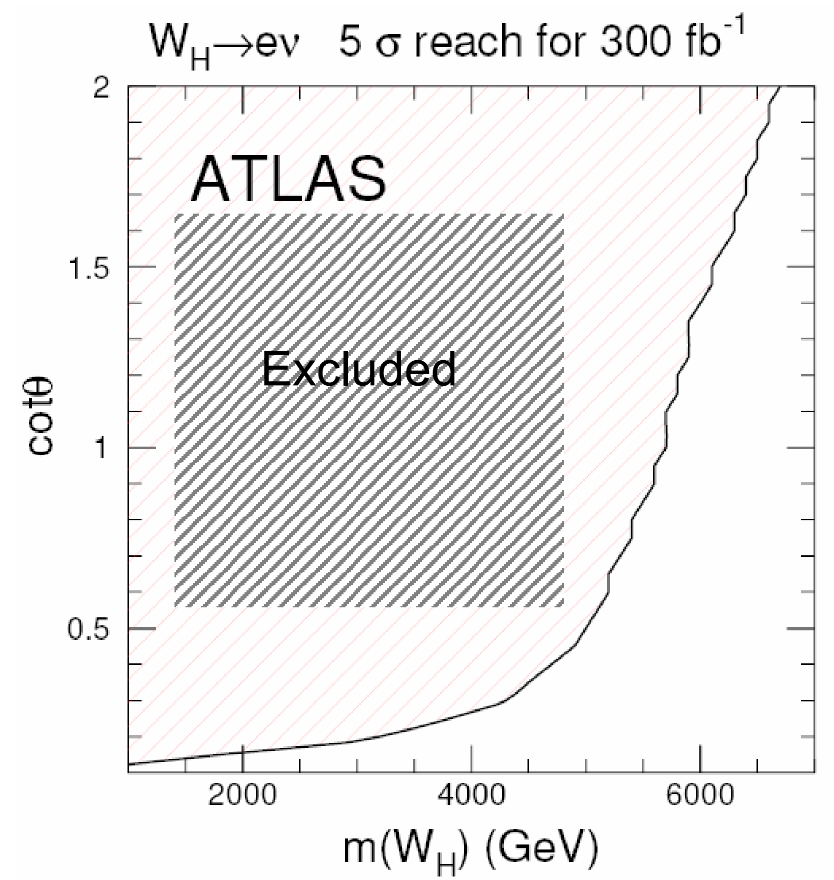
$W_H \rightarrow l\nu$





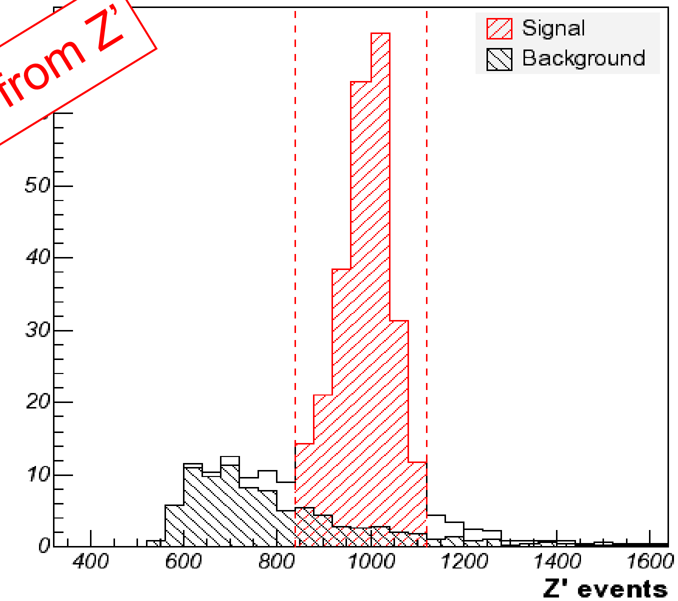
- one isolated electron with p_T > 200 GeV, $|\eta|<2.5$
- E_T^{miss} > 200 GeV

G.Azuelos et al.
SN-ATLAS-2004-038
hep-ph/0402037

$Z_H \to Zh \to l^+l^- bb$

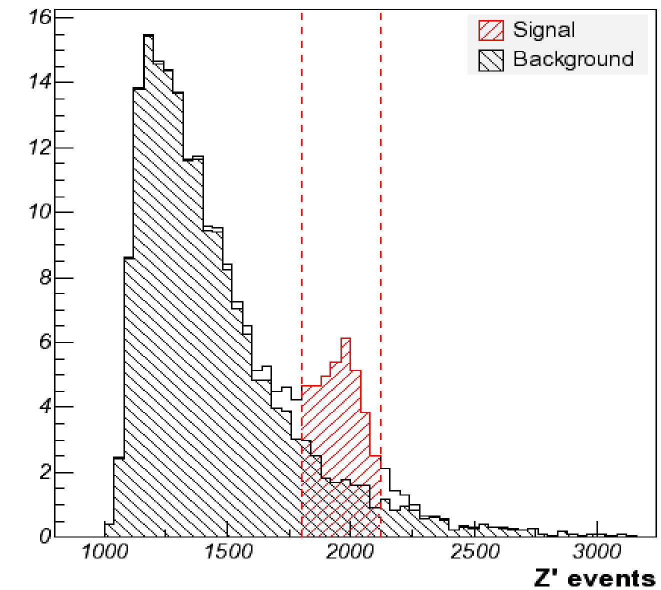
Analysis relies on higgs mass being known (here assumed to be 120 GeV)

Separates Z_H from Z'



- Two leptons with invariant mass between 76 and 106 GeV
- Two b-tagged jets with p_T>25 GeV, $|\eta| < 2.5$, $\Delta R < 1.5$ and invariant mass between 60 and 180 GeV.

(For M=2 TeV the jets from the higgs decay coalesce into one, then use the invariant mass of that one jet)



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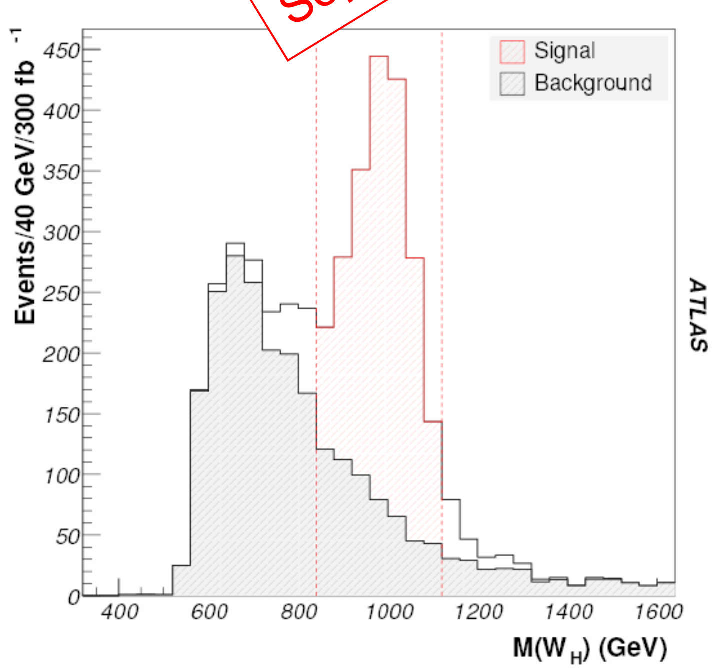
$W_H \to Wh \to l\nu\, bb$

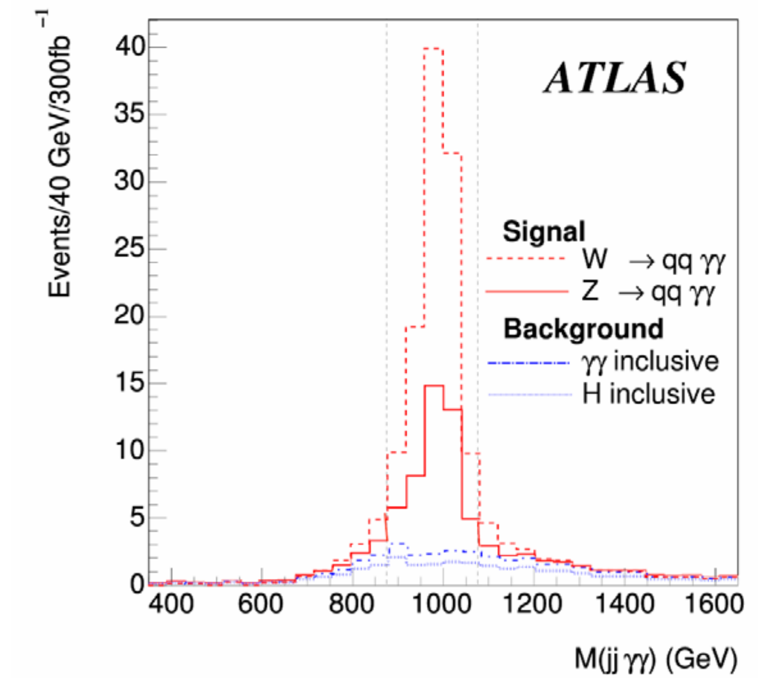
- One isolated lepton with p_T > 25 GeV and $|\eta|$<2.5
- E_T^{miss} > 25 GeV

Separates W_H from W'



$W_H \to Wh \to qq\,\gamma\gamma$ $Z_H \to Zh \to qq\,\gamma\gamma$

- Two photons with p_T > 40, 25 GeV in $|\eta|$<2.5
- $m_{\gamma\gamma}$ within 2σ of m_{higgs}
- jets combined in pairs and closest to m_W selected and constrained to m_W if p_T^W>200 GeV
- Alternatively one jet with mass compatible with m_W used



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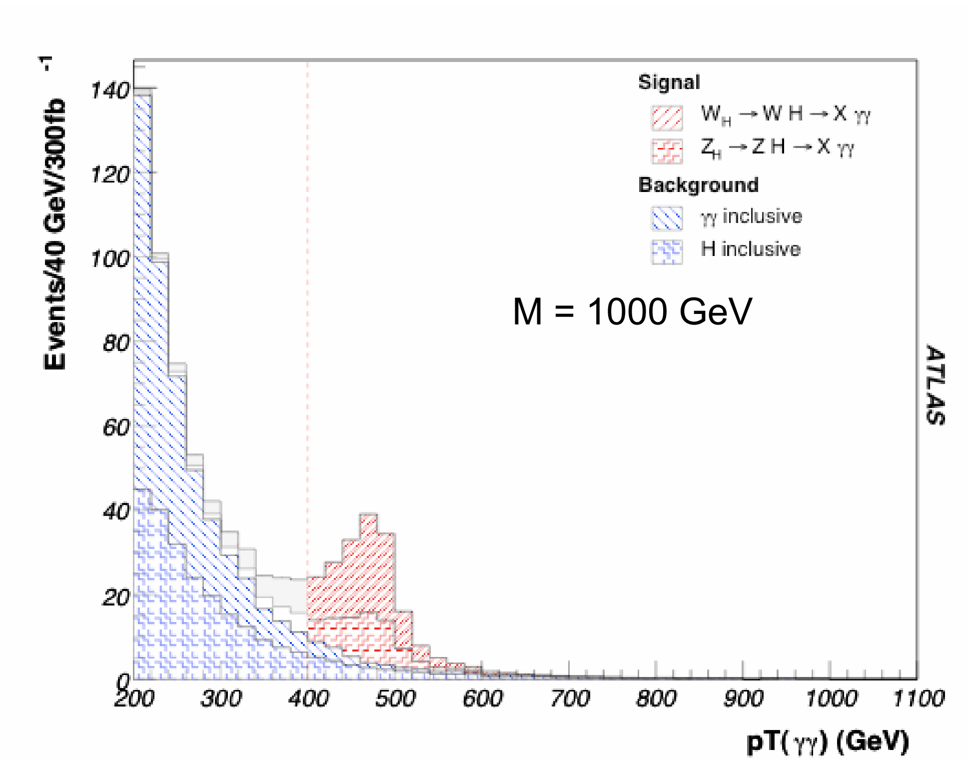
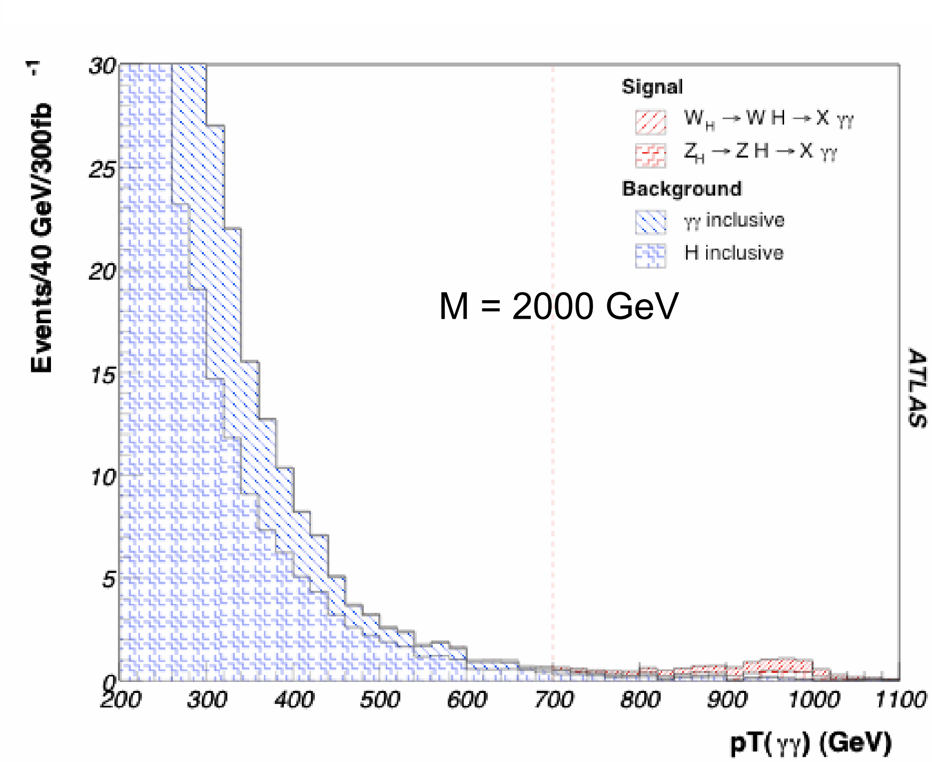
$W_H \to Wh \to qq\ \gamma\gamma$ $Z_H \to Zh \to qq\ \gamma\gamma$

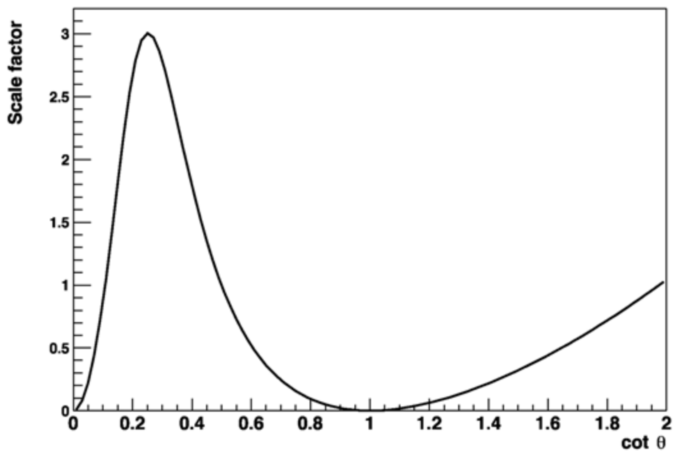
These channels can also be studied without reconstructing the W or Z, the $p_T^{\gamma\gamma}$ distribution displays a "Jacobian peak"



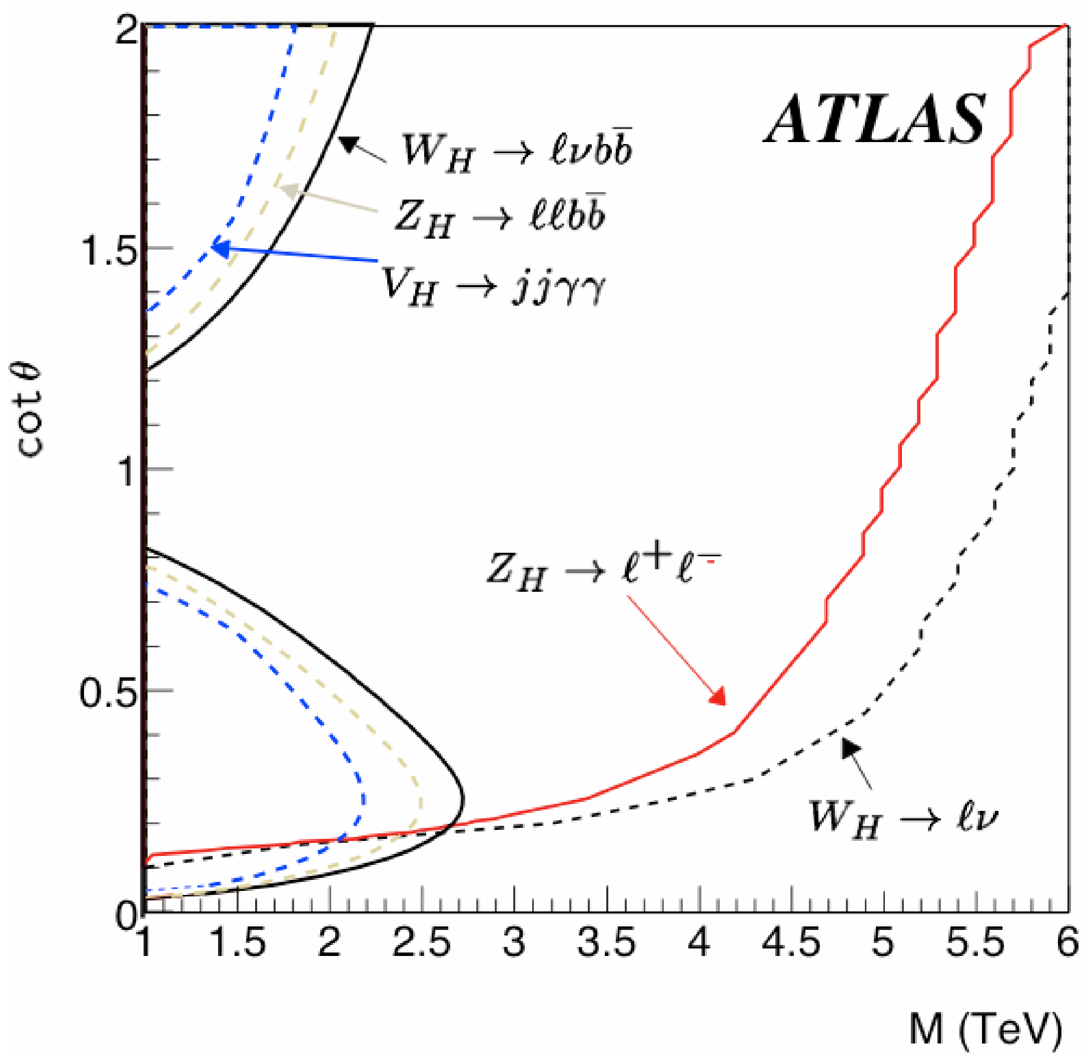


García, J E; Lechowski, M; Ros, E; Rousseau, ATL-PHYS-2004-001

Summary: Discovery range for gauge bosons from little Higgs model



The coupling $Z_H Zh$ is proportional to $\cot(2\theta)$
Folding this with the dependance of the coupling at production give the relative rates (normalised at $\cot(\theta)=0.5$



The regions to the left of the curves are accessible after 300 fb^{-1}

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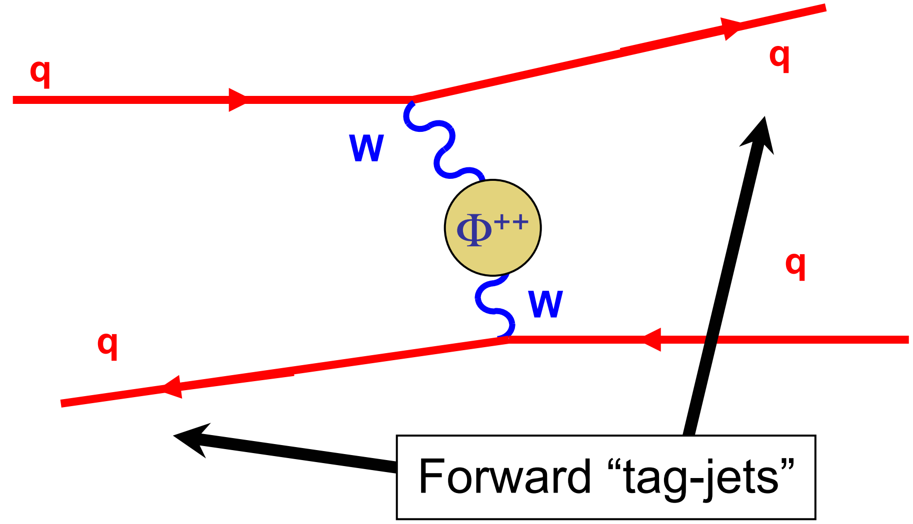
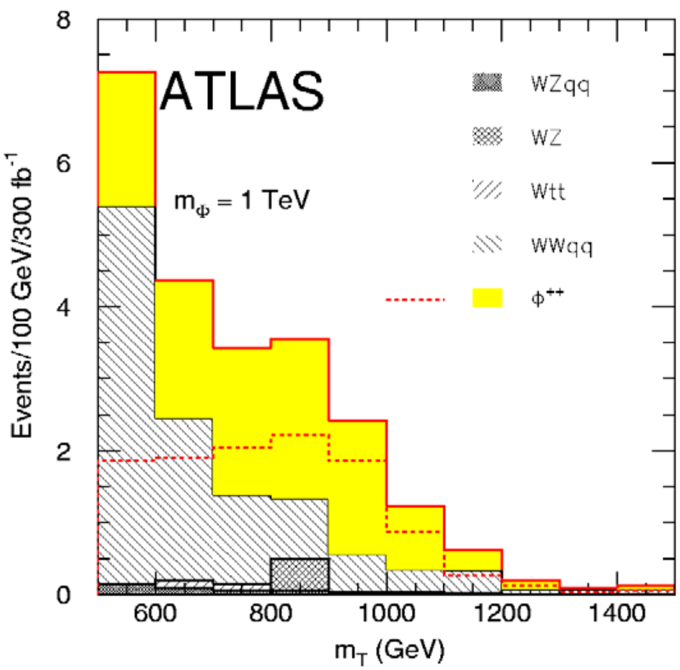
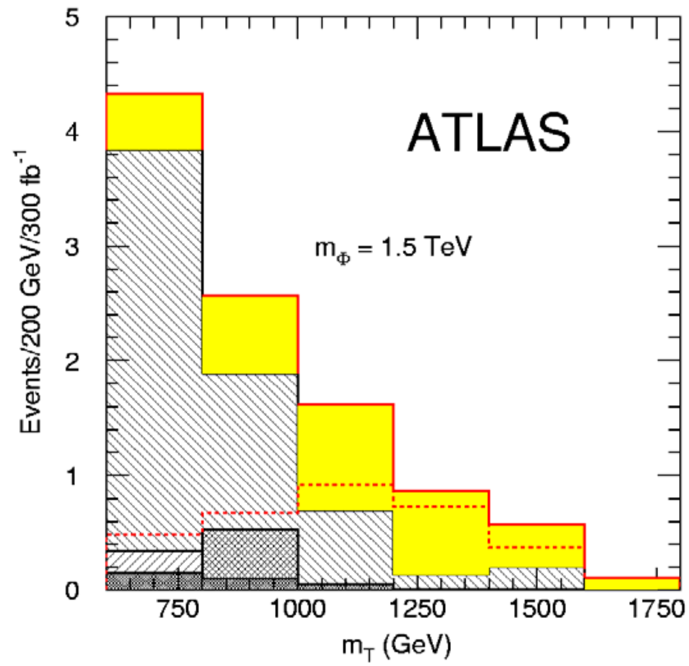
$\Phi^{++} \rightarrow l^+ l^+$

Signal can be extracted from W^+W^+ fusion processes:





- Two positive leptons with p_T> 150, 20 GeV and $|\eta|$<2.5
- $|p_{T1} - p_{T2}|$ > 200 GeV
- $|\eta_1 - \eta_2|$ < 2.0
- E_T^{miss} > 50 GeV
- Two “tag jets”, p_T>15, E > 200, 100 GeV, $|\eta_1-\eta_2]$>5



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The other solution
- bring the cut-off down!

- string theory requires 10 dimensions!
  - the only theoretical approach towards a quantum description of gravity: consistency of quantum mechanics and general relativity
  - includes supersymmetry
- the extra dimensions assumed to be compactified.
  - initially the assumption was that compactification radius was order of M_{PL}^{-1}
  - then it was realised that this could be as large as a millimeter!

3 models studied in some detail (there are more!):

- ADD scenario:

  several compacitfied, but large (>> 1/TeV), dimensions, gravity propagates in bulk, SM in brane.
- Small extra dimensions:

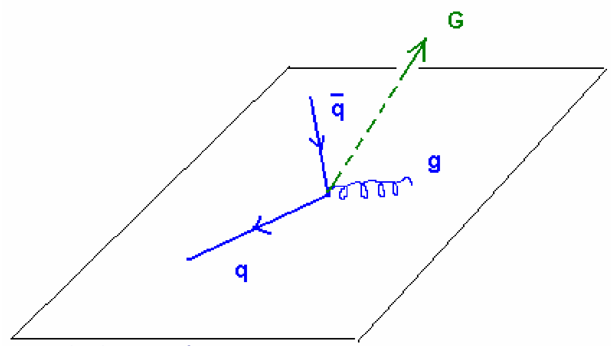
  Only fermions confied to brane, gauge-bosons propagate in a number of small (≈1/TeV) compactified dimensions.
- Randall-Sundrum model:

  1 extra dimension *y* with non-factorizable metric, 5D space of –ve curvature, bounded by 2 branes

  - SM brane (TeV) at $y = \pi r_c$
  - Planck brane at $y = 0$

ADD scenario:

⇒ conjecture:
- SM particles localized in 4D brane
- gravity propagates in the bulk of higher dimension



(1/r² law not verified for dimensions < 0.2 mm)

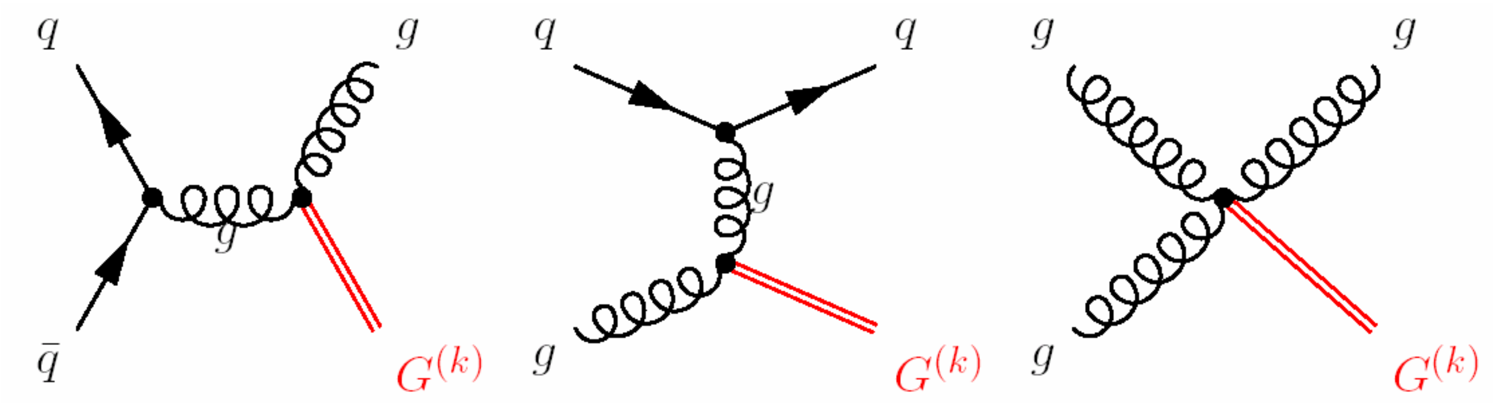
two parameters:
- number of extra (compactified) dimensions: δ
- new fundamental mass scale M_D:

$$M^2_{Pl_{(4)}} = M^{\delta+2}_{Pl_{(4+\delta)}} R^\delta_C \equiv M^{\delta+2}_D R^\delta_C$$

$M_D \sim$ TeV → $R_C \sim$ mm (for $\delta=2$)

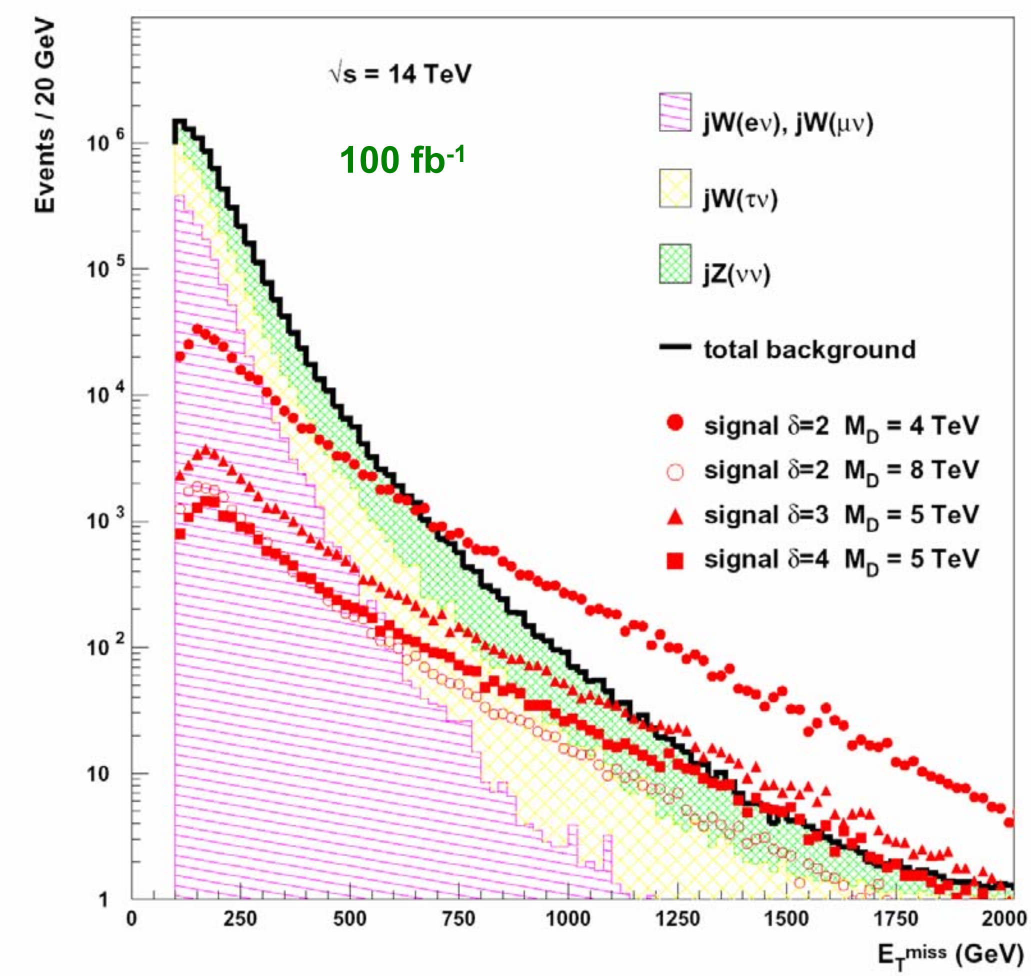
Gravitons & Kaluza-Klein states:
- in the bulk: gravitational interaction → massless G
- in 4D: KK states $G^{(k)}$, $m_k^2 = m_0^2 + k^2/R_C^2$
- coupling: universal & weak ($1/M_{Pl(4)}$), but large # of states

Direct production at LHC:



Signature is high p_T jet and large E_T^{miss}

main backgrounds: jet + Z ($\rightarrow \nu\nu$)
jet + W ($\rightarrow l\nu$)



- require jet and E_T^{miss} above 50 / 100 GeV at high / low L
- no isolated lepton within $|\eta| < 2.5$
- $\delta\Phi$ (ETmiss, jet_2) > 0.5

Minimum of validity

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

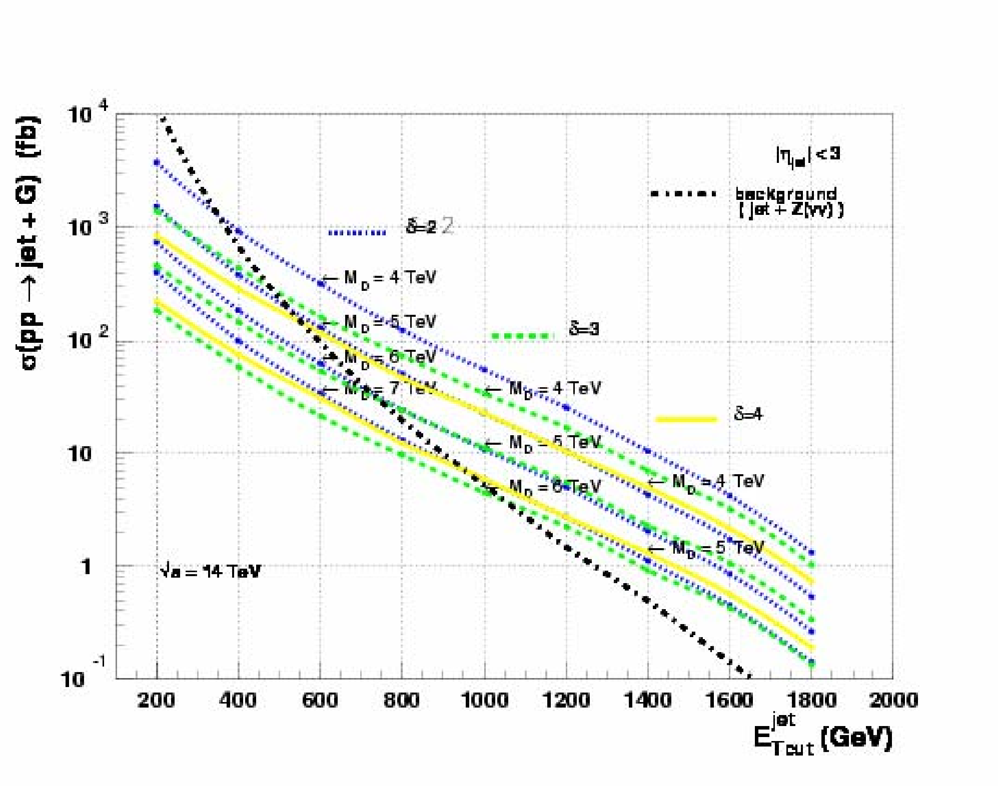
Uncertainty in *σ (Z+jets)* will lower the reach

Reach in M_D for γG

δ	M_D^{max} (TeV) HL, 100 fb^{-1}	M_D^{min} (TeV)
2	4	~ 3.5

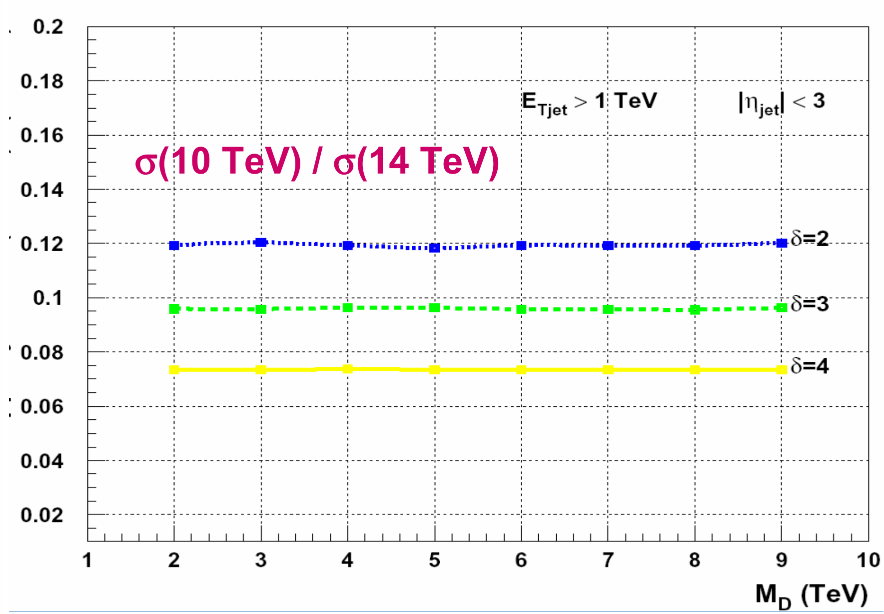
L.Vacavant, I.Hinchliffe
J. Phys. G: Nucl. Part. Phys. 27 (2001) 1839–1850

Characterization of the model:



➔ measure both M_D and δ

Run at a different CME:

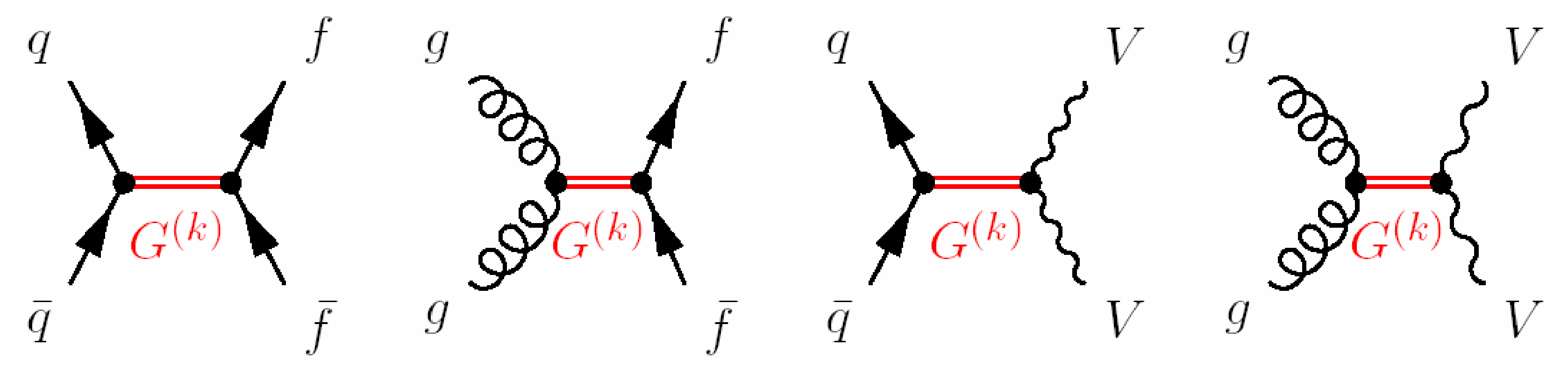


Precise measurement of cross-section:

- difficult:
  case (δ=2, M_D= 5 TeV) very similar to the case (δ=4, M_D= 4 TeV) for instance
- not (yet) investigated in details

- good discrimination if
  - 5% accuracy on $\sigma(10)/\sigma(14)$
  - > 50 fb^{-1} @ 10 TeV
- new CME close to 14 TeV (otherwise small overlap of regions allowed by eff. theory)

Virtual exchange of gravitons at LHC:



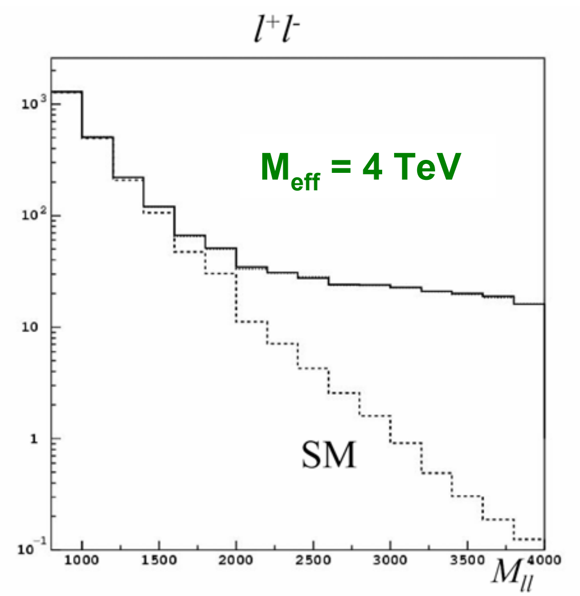
Signatures: deviations from SM in Drell-Yan X-sections, asymmetries
(sensitivity mostly from interference terms, KK exchange $\propto M_s^{-8}$)

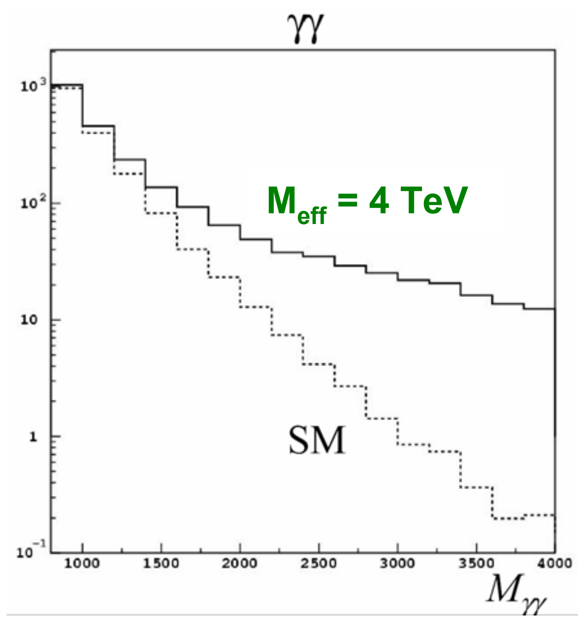
ATLAS study:
- partonic cross-sections
- amplitude divergent for $\delta > 1$: naive cut-off at $M_{ll,\gamma\gamma} < 0.9\ M_S$

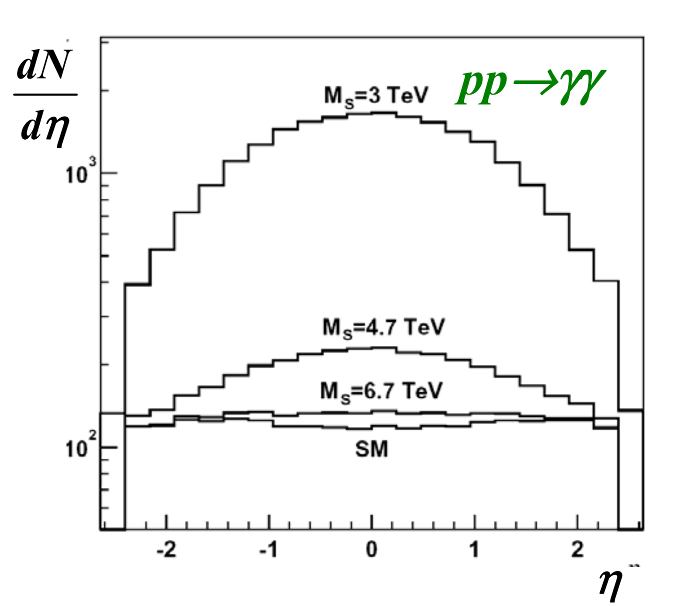
Signatures: qq,gg → γγ, ll, (WW, tt, …)

- excess over DY events in di-lepton, di-photon mass distributions

- some s-channel processes not present at tree-level in SM:
  - ➔ more central production for γγ

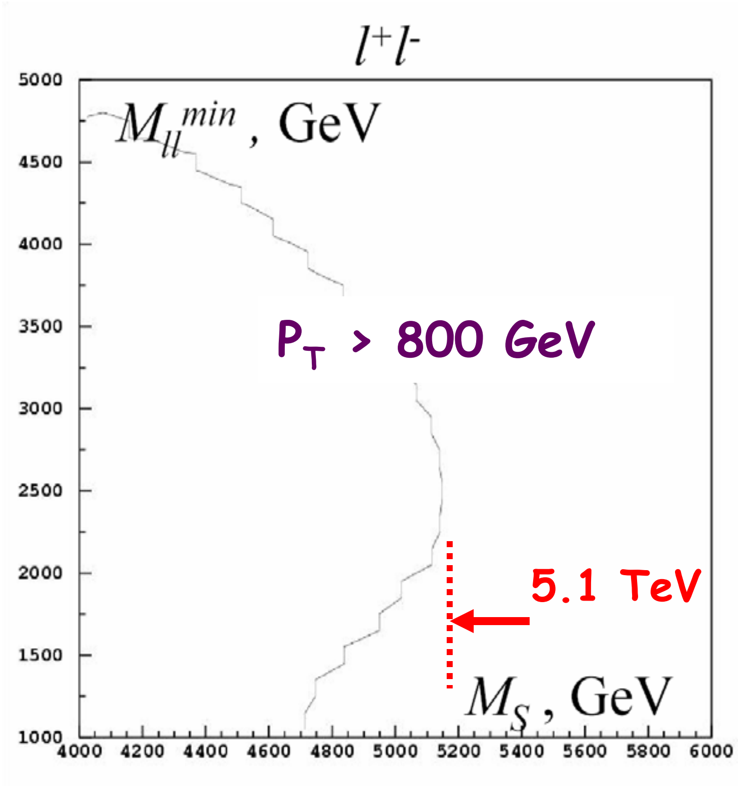


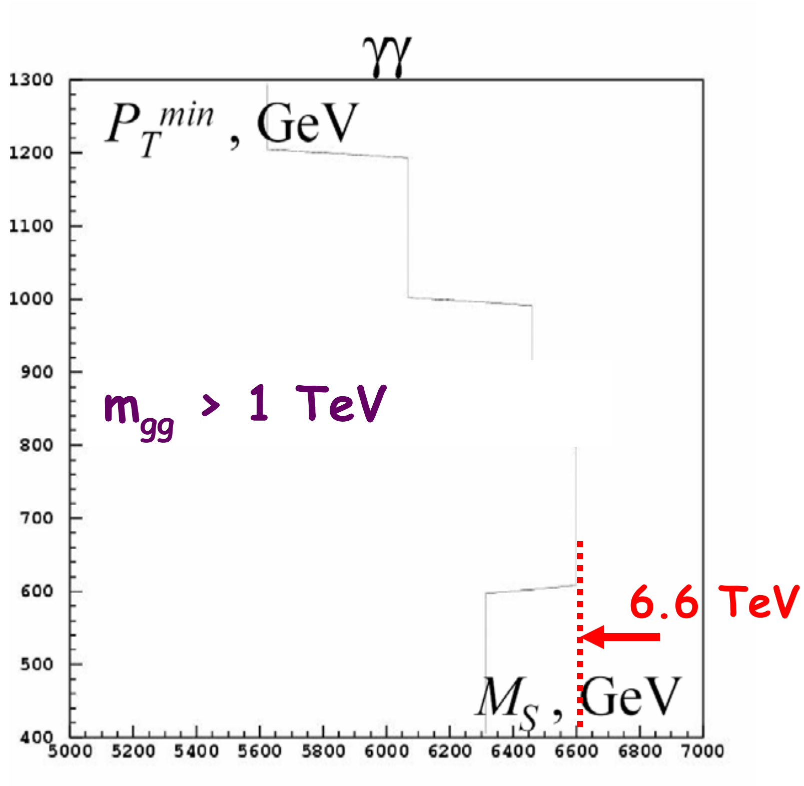




V. Kabachenko, A. Miagkov,
A. Zenin, ATL-PHYS-2001-012

Sensitivity for 100 fb^{-1}:





Mostly a discovery channel:

- no sensitivity on δ
- w/o specifying UV theory, M_s cannot be related to M_D

V. Kabachenko, A. Miagkov,
A. Zenin, ATL-PHYS-2001-012

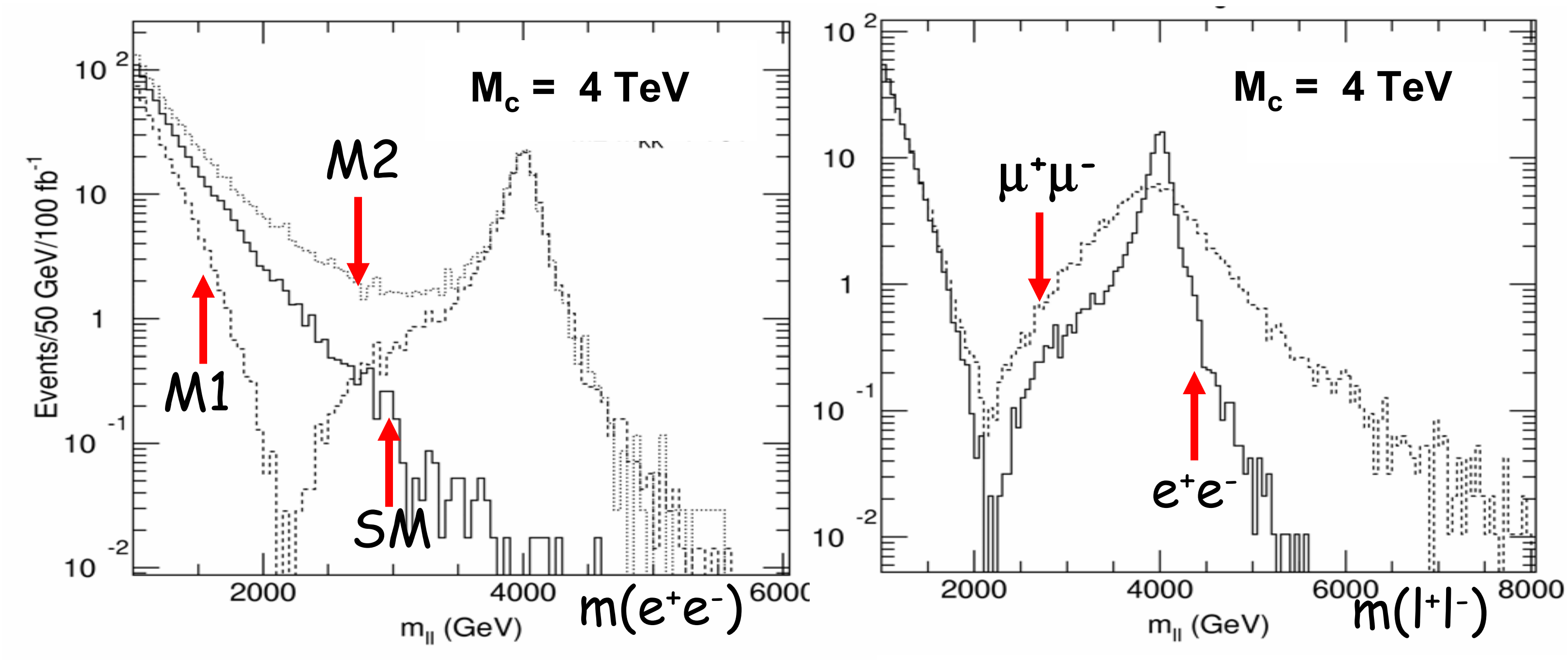
TeV^{-1}-sized extra dimensions

Kaluza-Klein Gauge Bosons

- one extra dimension
- compactified on a S^1/Z^2 orbifold
- radius of compactification small enough ➔ gauge bosons in the bulk
- fermions localized on:
  - — a fixed point (M1 model): invariance under $y \rightarrow -y$
  - — opposite fixed points (M2 model): under $y \rightarrow y + 2\pi R$
- Kaluza-Klein spectra for $Z^{(k)}$, $W^{(k)}$: $m_k^2 = m_0^2 + k^2 M_C^2$
  - – for M_C = 4 TeV: m_1 = 4 TeV, m_2 = 8 TeV

look for $pp \rightarrow \gamma^{(1)}/Z^{(1)} \rightarrow l^+l^-$ on top of SM Drell-Yan

Signatures: $\gamma^{(1)}/Z^{(1)} \rightarrow e^+e^-, \mu^+\mu^-$



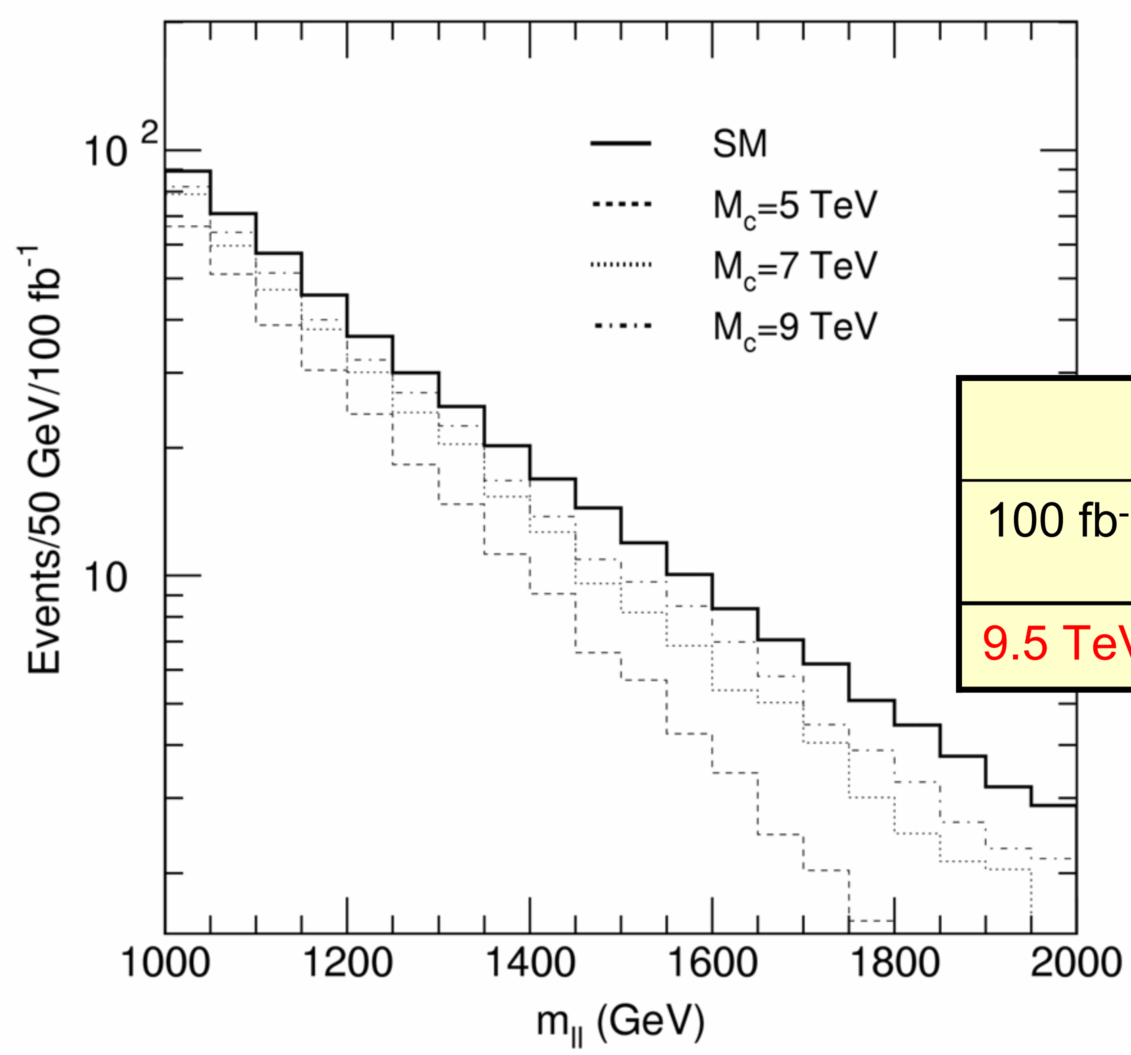
Sensitivity from peak region:

for 100 fb^{-1}, $S/\sqrt{B} > 5$, $S > 10$:

M_C^{max} = 5.8 TeV

G.Azuelos, G.Polesello
SN-ATLAS-2003-023
EJP Direct

Optimal reach (using interferences in tail region):



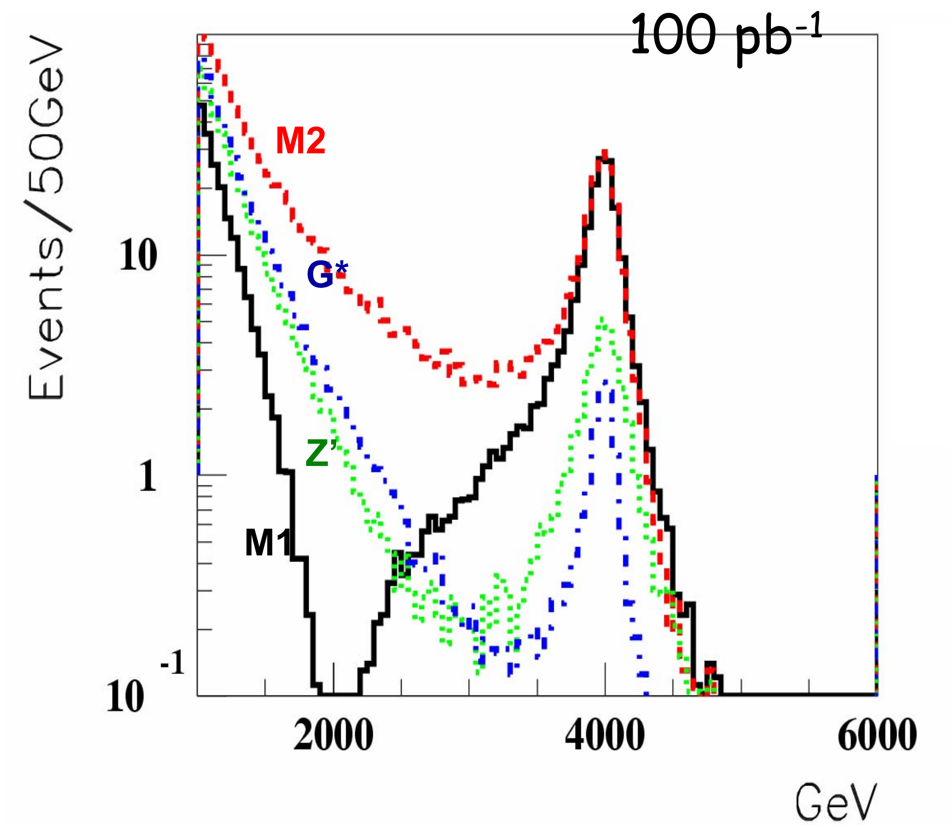
likelihood fit analysis w/
MC experiments

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

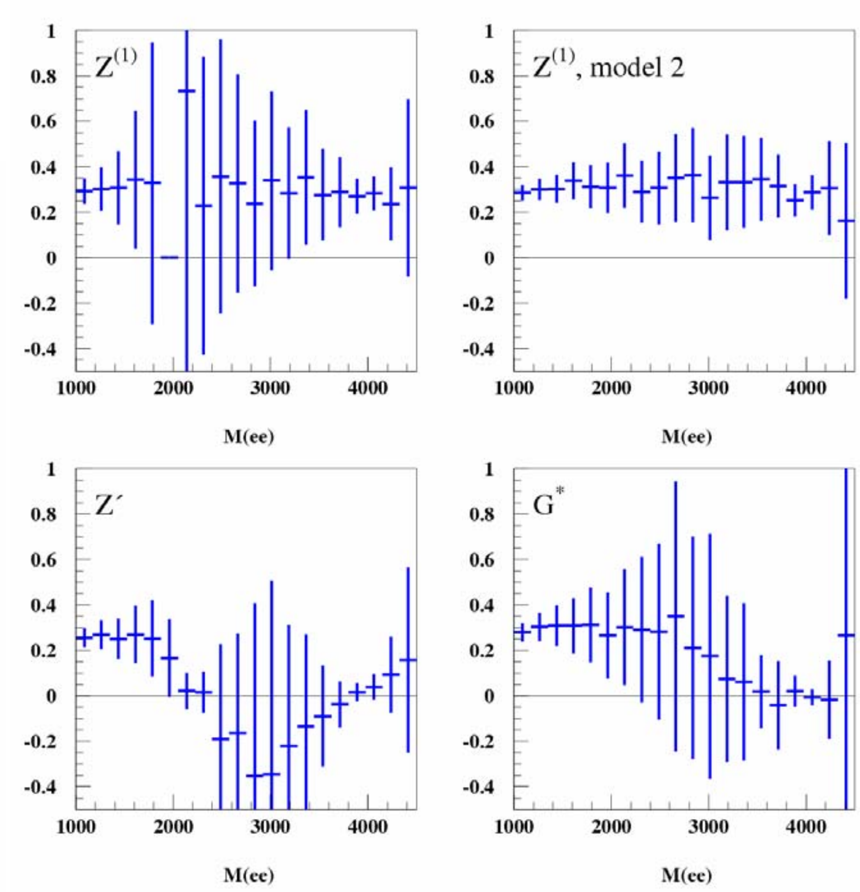
G.Azuelos, G.Polesello
SN-ATLAS-2003-023
EJP Direct

Characterization of the model:

$Z^{(1)}$ or Z ' or RS graviton ??

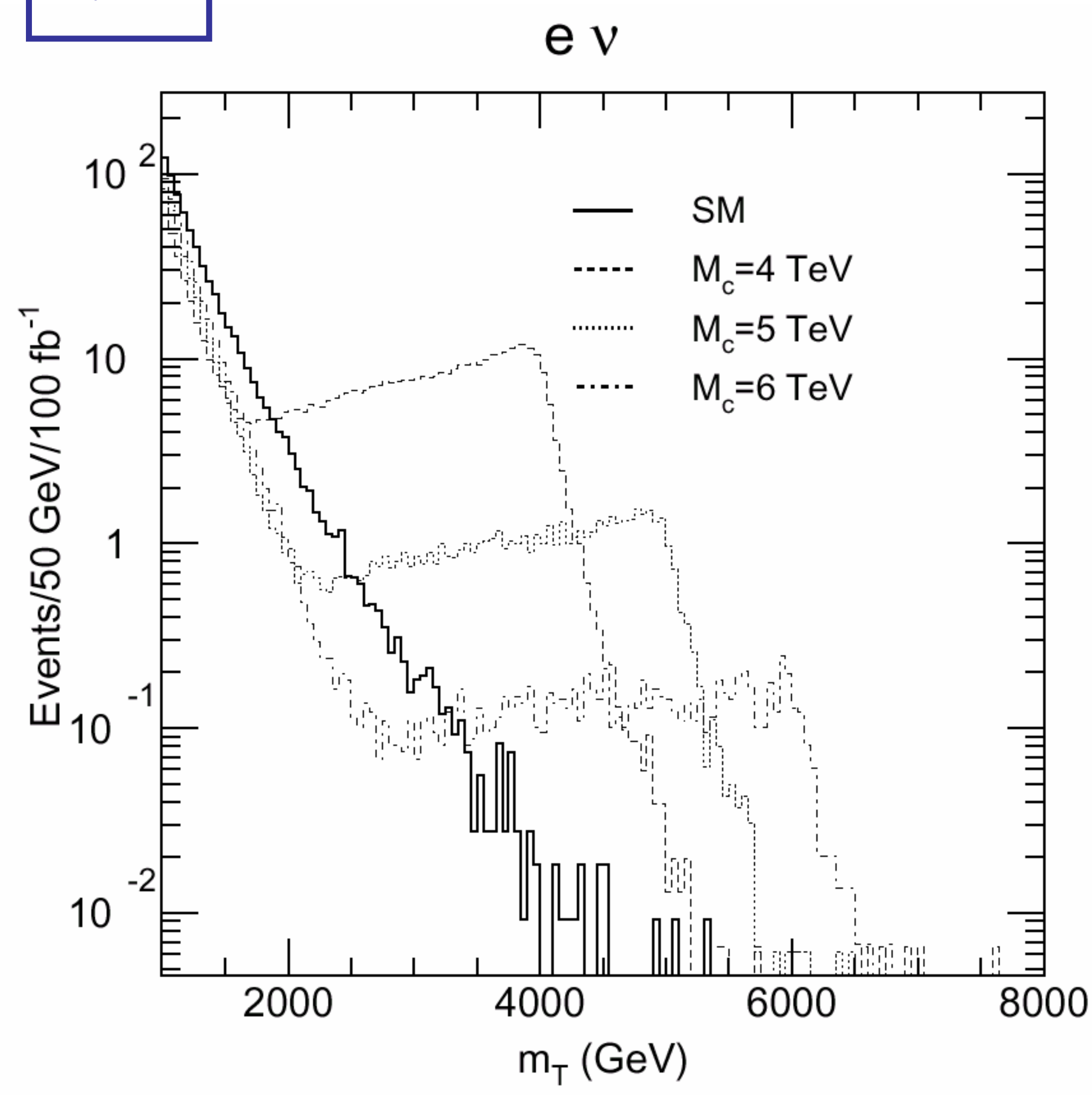


Forward-backward asymetries:



G.Azuelos, G.Polesello
SN-ATLAS-2003-023
EJP Direct

$W^{(1)}$:



Sensitivity for 100 fb^{-1}:

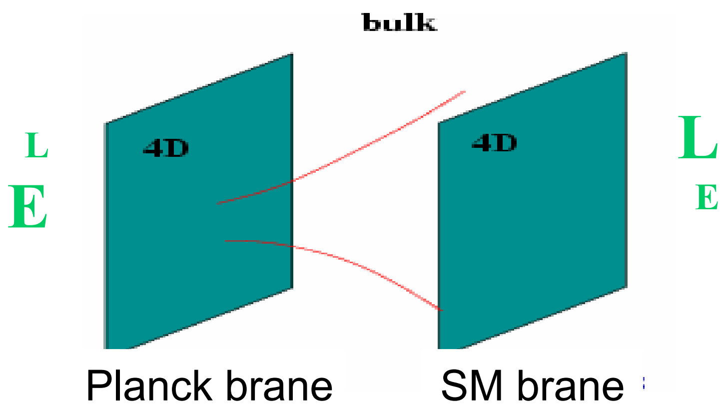
from peak	optimal
~ 6 TeV	~ 9 TeV

Discrimination from W ‘:

- more difficult
- under study

G.Polesello, M. Prata,
ATLAS SN 2003-036

Randall-Sundrum model



KK graviton excitations $G^{(k)}$

- scale Λ_π
- coupling & width determined by:
  $c = k/M_{Pl}$
- $0.01 < k/M_{Pl} < 0.1$
- mass spectrum:
  $m_n = k\, x_n \exp(-k\pi r_c)$

Golden channel: $G^{(1)} \rightarrow e^+e^-$

- good acceptance
- good energy resolution
- good angular resolution
- also $G^{(1)} \rightarrow \gamma\gamma$

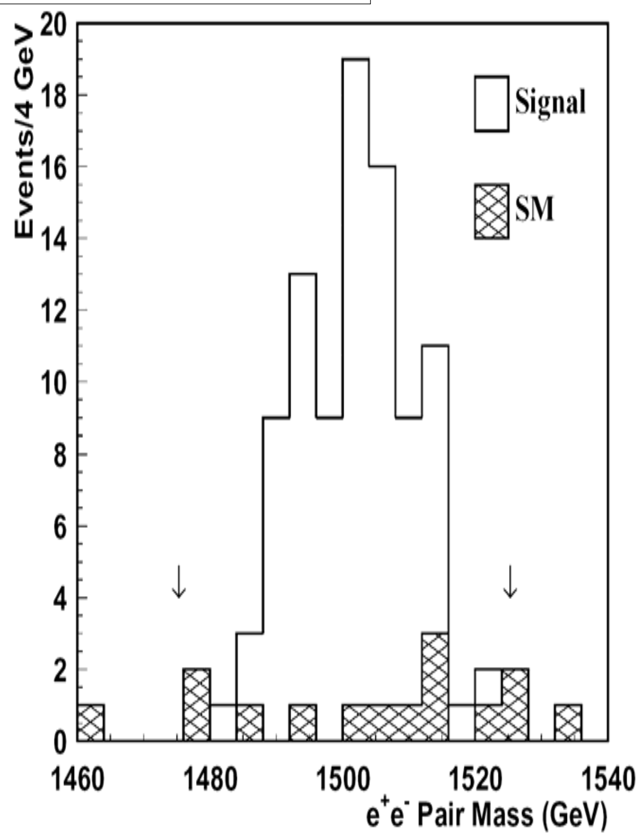
Main features to check:

- universal couplings:
  $G^{(1)} \rightarrow \mu^+\mu^-$, WW, ZZ, jj
- spin 2
- measure r_c ?

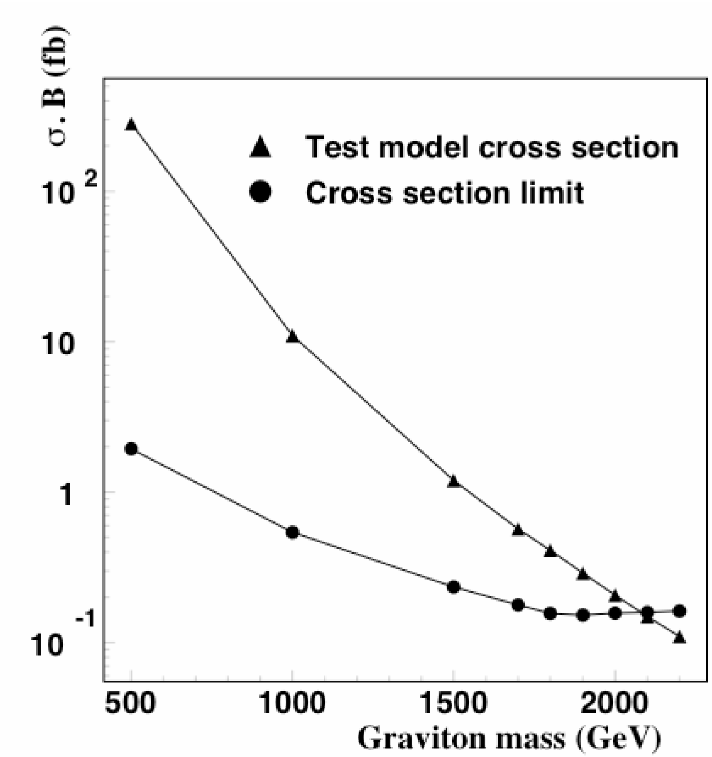
B.C. Allanach, K.Odigari, A. Parker, B. Webber JHEP **9** 19 (2000),
ditto + M.J.Palmer, A. Sabetfakhri hep-ph/0211205

Signature: $G^{(1)} \rightarrow e^+e^-$

ATLAS, e^+e^-
m_G= 1.5 TeV, c = 0.01
100 fb-1



Sensitivity



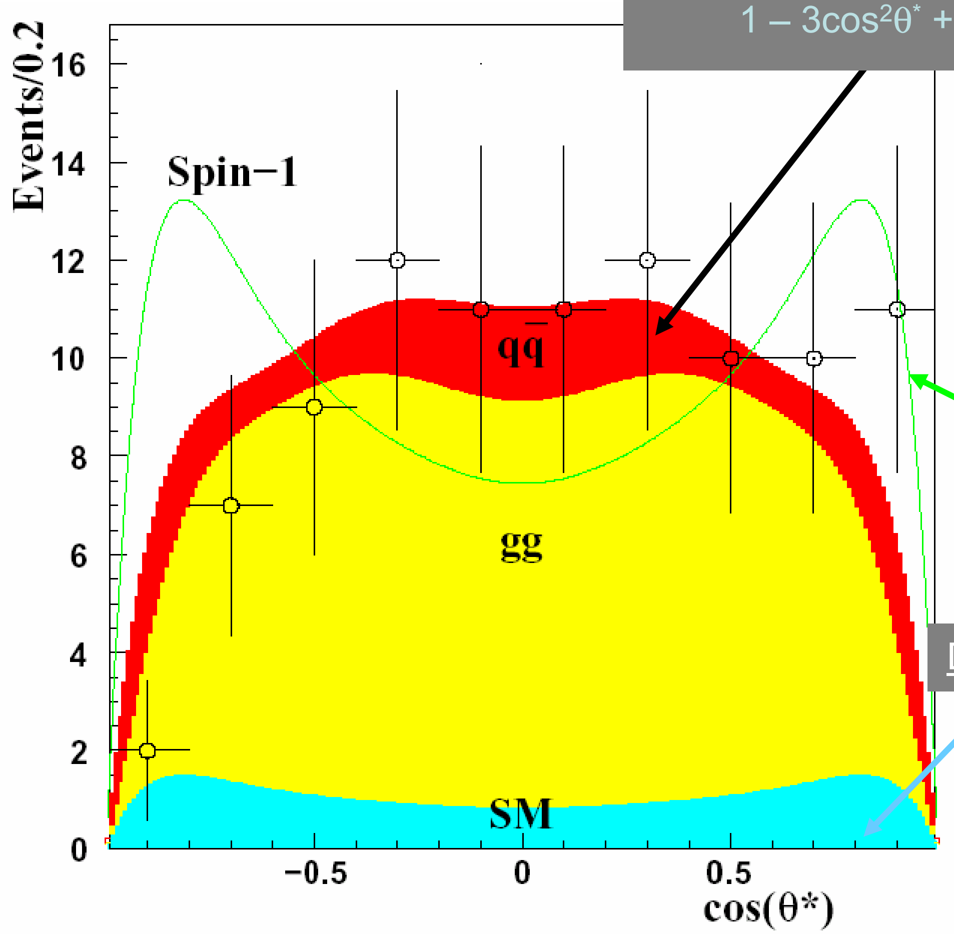
➔ LHC covers completely the interesting regior

B.C. Allanach, K.Odigari, A. Parker, B. Webber JHEP **9** 19 (2000), ditto + M.J.Palmer, A. Sabetfakhri hep-ph/0211205

Spin determination:

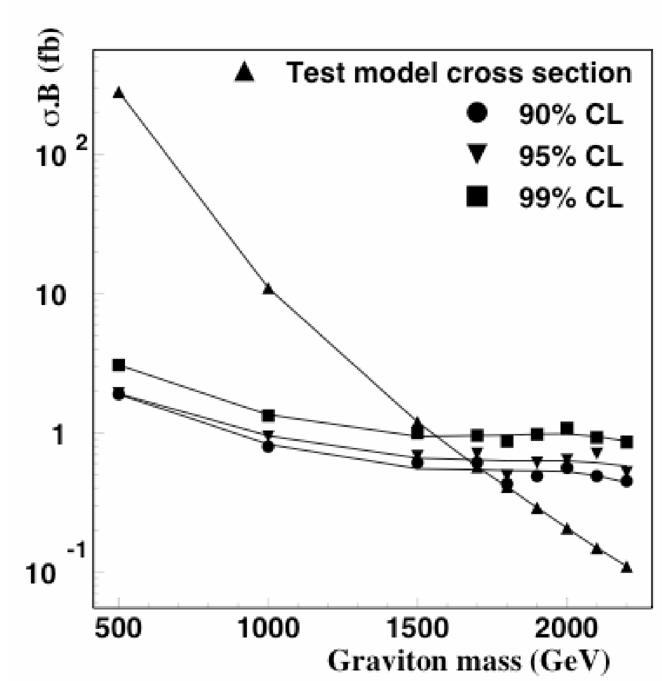
ATLAS, e^+e^-, 100 fb^{-1}
m_G= 1.5 TeV, c = 0.01

<u>Signal:</u>
- from gluon fusion
  $1 - \cos^4\theta^*$
- from quark annihilation
  $1 - 3\cos^2\theta^* + 4\cos^4\theta^*$



<u>Spin-1</u> (Z '):
$1 + \cos^2\theta^*$

<u>Drell-Yan SM</u>

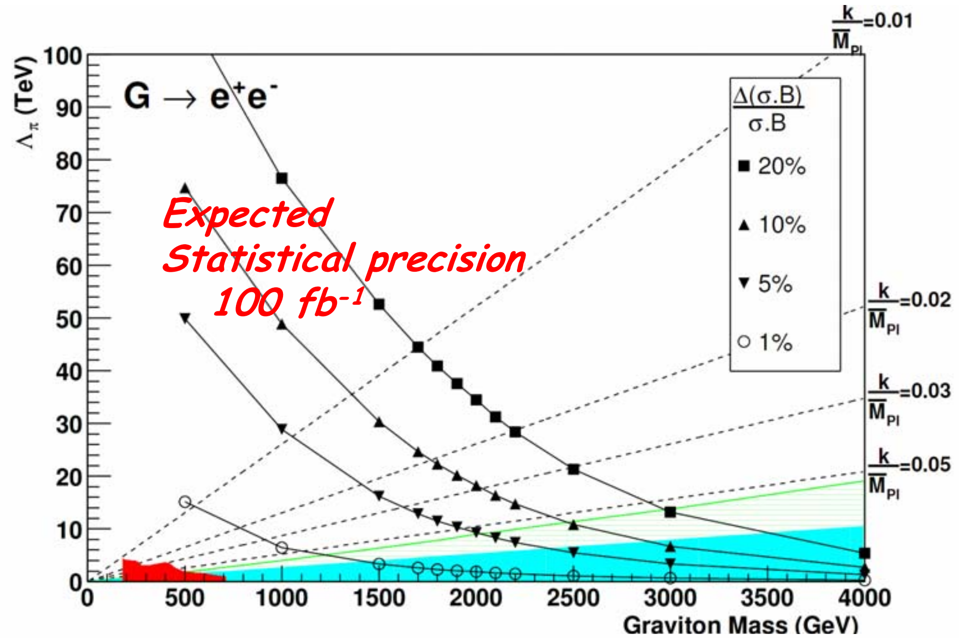


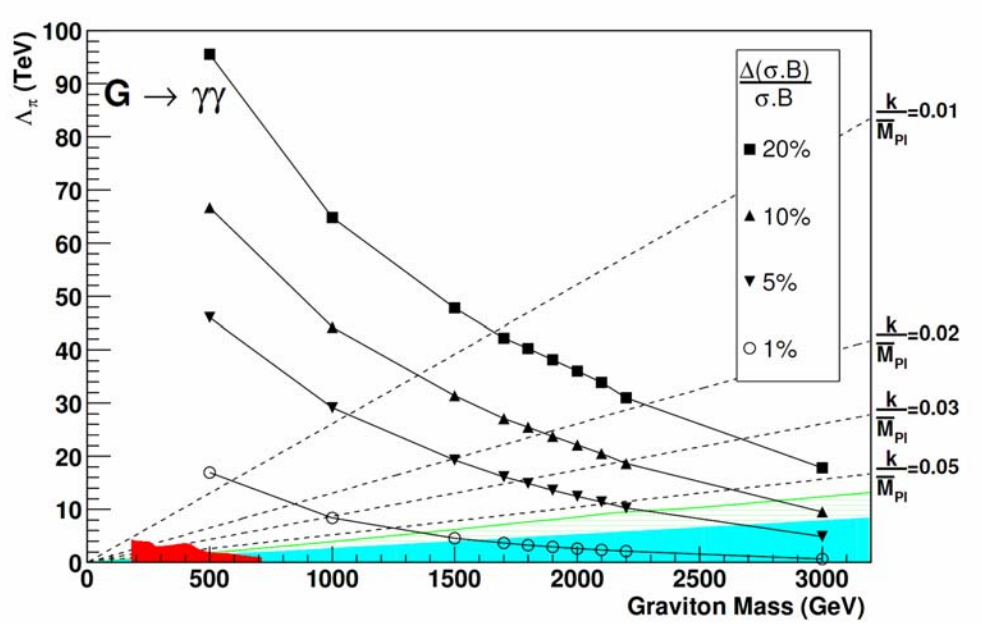
spin-2 could be determined (spin-1 ruled out) with 90% CL up to graviton mass of 1720 GeV

NB: acceptance at large η
- coverage to 2.4-2.5 is essential
- almost no discrimination spin 1/spin 2 for |η| < 1.5

B.C. Allanach, K.Odigari, A. Parker, B. Webber JHEP **9** 19 (2000),
ditto + M.J.Palmer, A. Sabetfakhri hep-ph/0211205

also G → WW , ZZ, jj, mm, tt, hh





e.g.: for a resonance observed at
m_G = 1.5 TeV in ee channel
Δm_G < 10.5 GeV (energy scale error)
$\Delta\sigma.B \sim 18\%$
if $k/r_c = 0.01$ (pessimistic)
$\Rightarrow r_c = (82\pm7) \times 10^{-33}$ m !!

Allanach et al., ATL-PHYS-2002-031

Stabilize $kr_c\pi \sim 35$ ($kr_c \sim 12$)

Goldberger and Wise (PRL 83 (1999) 4922)

Goldberger and Wise proposed a mechanism which stabilizes $kr_c\pi$

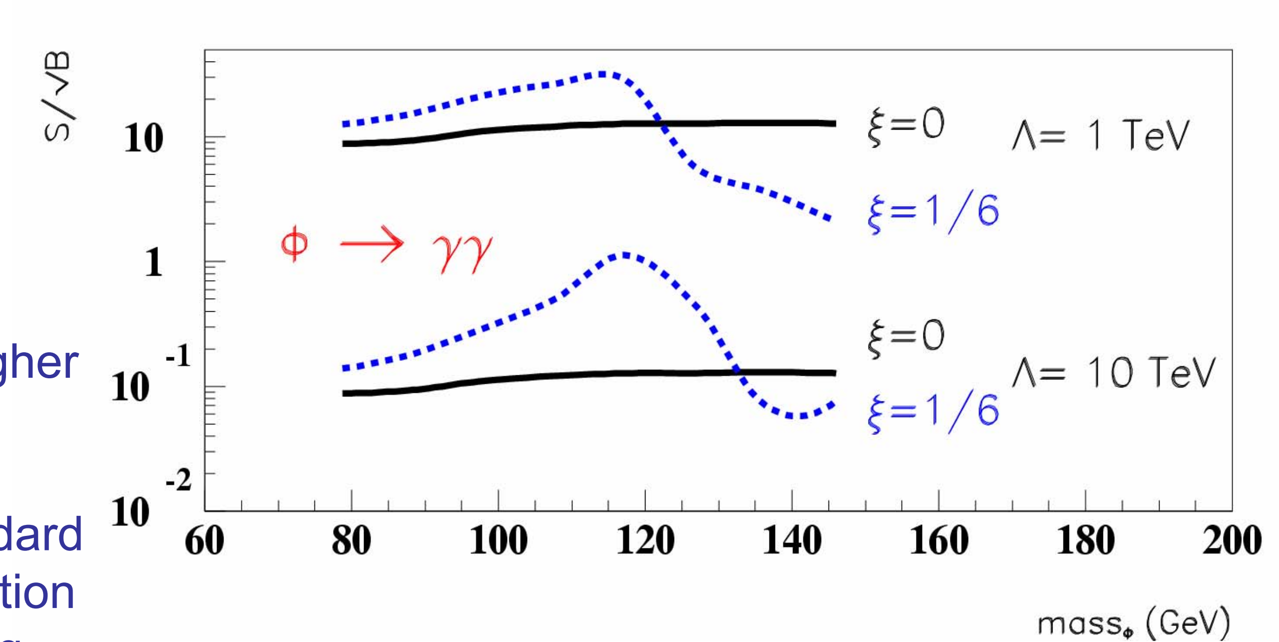
- introduce a radion: a scalar field representing fluctuations of the distance between the two branes
- radion has mass: $m_f < m(KK=2)$

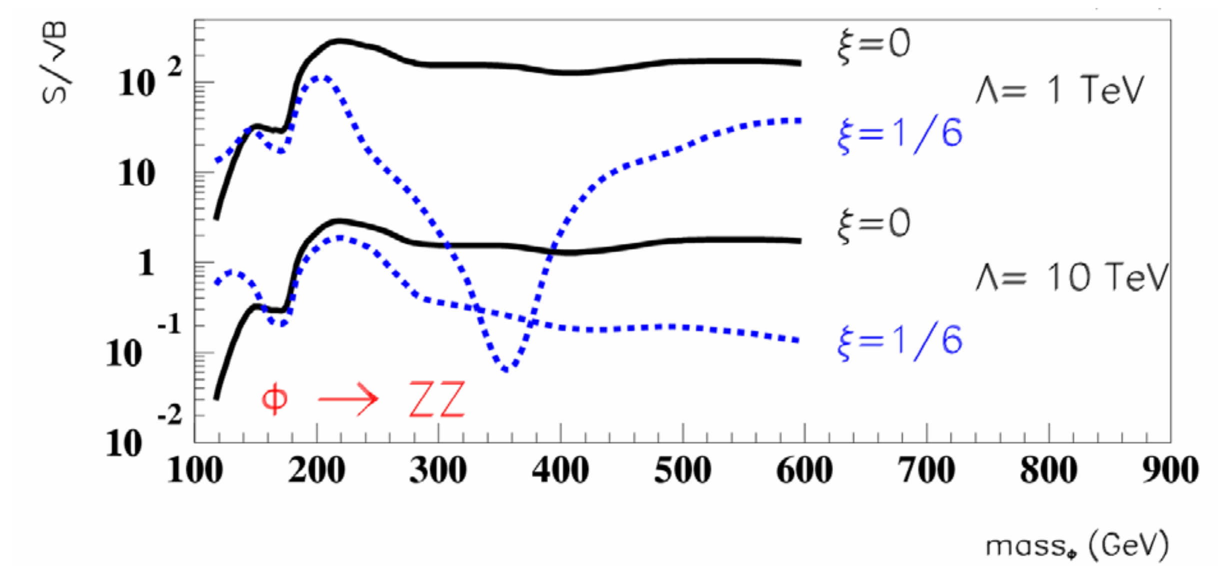
- higgs-like couplings $\Rightarrow$ mixes with Higgs
- reinterpreting SM Higgs search studies…

For $m_\Phi < 2 \cdot m_h$:

"easy" to see if Λ=1, but higher Λ very difficult.

discrimination against standard higgs need study of production cross-section and branching ratios





George.Azuelos., D. Cavalli, H. Przysiezniak, L. Vacavant *SN-ATLAS-2002-019*

For $m_\Phi < 2 \cdot m_h$: $\Phi \to hh \to \gamma\gamma\, bb$

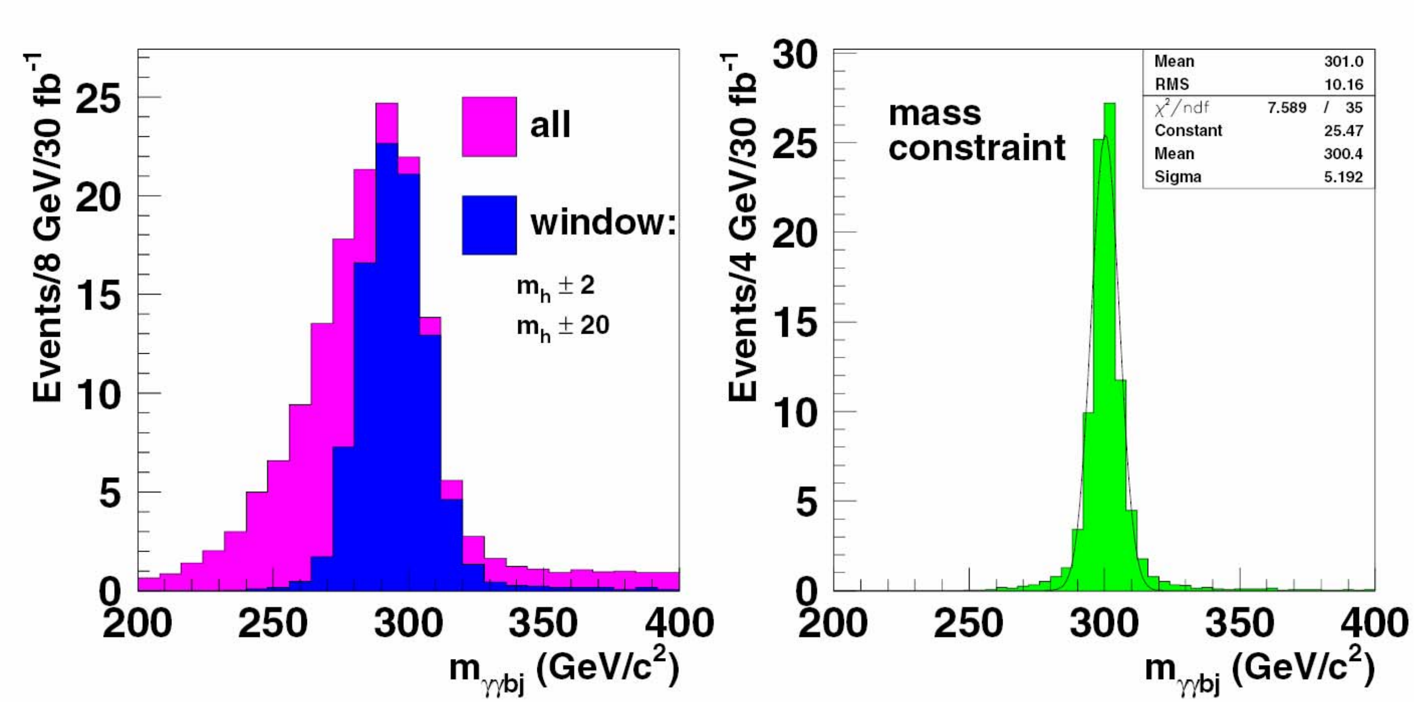
signal:

- similar to MSSM, but with appropriate corrections for width and branching ratios
- consider cases: $m_\phi = 300, 600$ GeV, $m_h = 125$ GeV

backgrounds negligible

- $\gamma\gamma$, with QCD radiation
- γj, with jet misidentified as photon

reach: 2.2 TeV or 0.6 TeV for $m\phi$ = 300 or 600 GeV, respectively, with 30 fb^{-1}



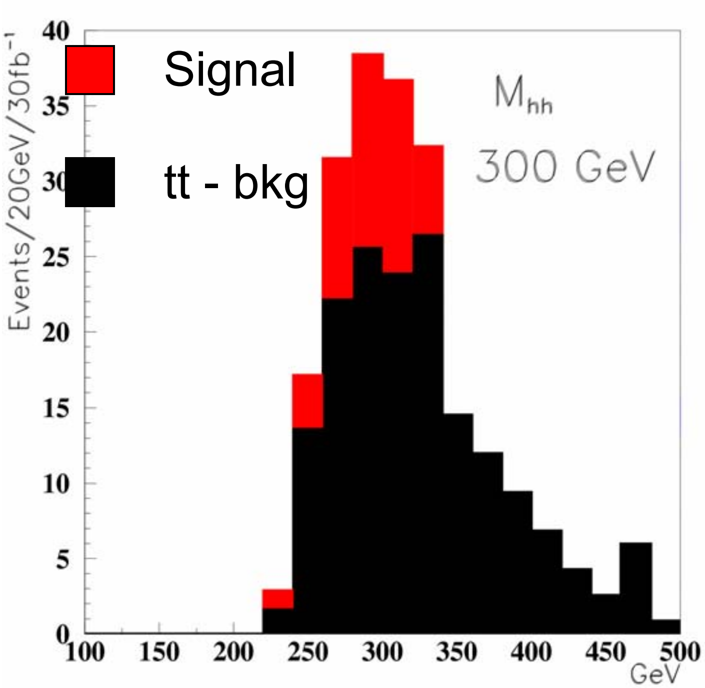
George.Azuelos., D. Cavalli, H. Przysiezniak, L. Vacavant *SN-ATLAS-2002-019*

For $m_\Phi < 2 \cdot m_h$: $\Phi \to hh \to \tau\tau\, bb$, one τ decaying leptonically , other hadronically

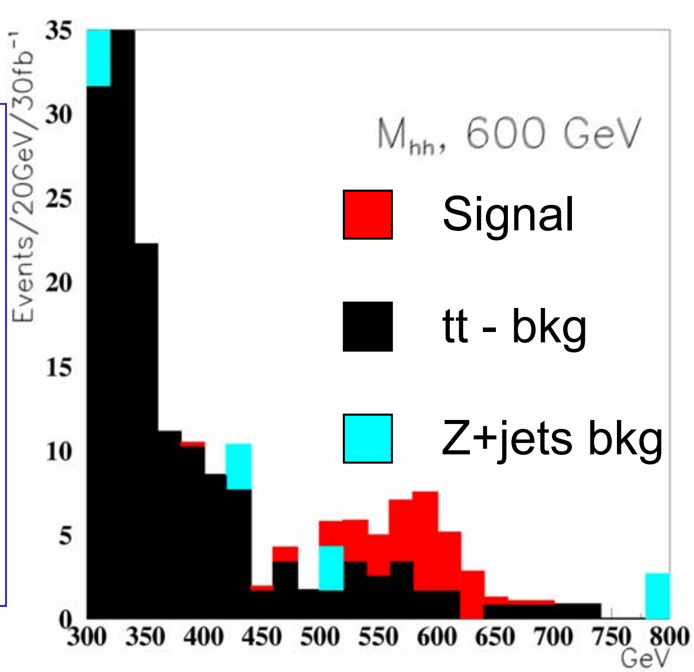
Main backgrounds:

- tt $\to$ bW bW, one W decaying leptoincally, other hadroncially
- Z + jets followed by Z $\to$ tt
- W + jets with W decaying leptonically

reach: 1.0 TeV for m_ϕ = 600 GeV, with 30 fb^{-1}



- a lepton with p_T> 25 GeV and $|\eta|$<2.5
- transverse mass of lepton and missing E_T > 40 GeV
- m(tt) from lepton and a τ-tagged jet with p_T> 55 GeV and $|\eta|$<2.5 (if more than one, the pair with mass closest to m_h choosen)
- a pair of b-tagged jets with p_T> 55 GeV and $|\eta|$<2.5 selected, if more than one pair chose pair with mass closest to m_h
- cuts on reconstructed h-mass



George.Azuelos., D. Cavalli, H. Przysiezniak, L. Vacavant *SN-ATLAS-2002-019*

Conclusions:

- There are a number of reasons why we want to extend the Standard Model.
- There is no lack of theoretical suggestions on how to do this, some more contrieved than others.
- Initial studies in ATLAS show that many of the “main-stream” scenarii can be discovered.
- Not less important - specific characteristics of each model can be determined in many cases.

Still….

only experiments will tell - the truth is out there !!

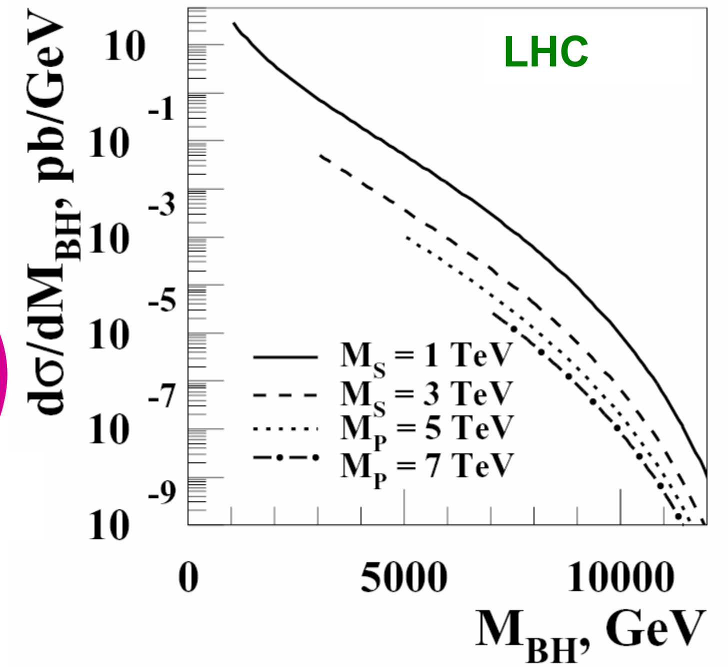
Black Holes

- definition
  - object confined in a volume of radius $R < R_S$

For n+3 dim., $R_S^{(n)} = \frac{1}{\sqrt{\pi} M_P} \left[\frac{M_{BH}}{M_P} \left(\frac{8\Gamma(\frac{n+3}{2})}{n+2} \right) \right]^{\frac{1}{n+1}}$

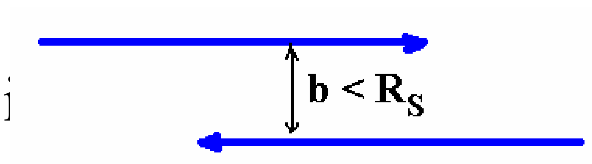
$$M_P \sim \text{TeV} \quad \Rightarrow \quad \pi R_S^2 \sim \mathrm{O}(100\,\text{pb})$$

(**This approximation is contested:**
- M. B. Voloshin, *PL B518 (2001) 137, PL B524 (2002) 376*
- V. S. Rychkov, *hep-ph/0401116*)



Dimopoulos et Landsberg, hep-ph/0106295

- Production at the LHC $b < R_S(\sqrt{s})$
  - For i



« The end of short-distance physics »
Giddings and Thomas, hep-ph/0106219

› formation of black holes

Black Holes

- Theoretical Uncertainties
  - production cross section
  - disintegration
    - emission of gravitational radiation (balding phase)
    - main phase ? = Hawking radiation, or evaporation
      - spin-down phase: loss of angular momentum
      - Schwarzschild phase: emission of particles
        - » quantum numbers conserved?
    - Planck phase: impossible to calculate

⇒ new generator, CHARYBDIS

CM Harris, P. Richardson and BR Webber, JHEP 0308 (2003) 033 (hep-ph/0307305)

- Characteristics
  - temperature: depends on the mass

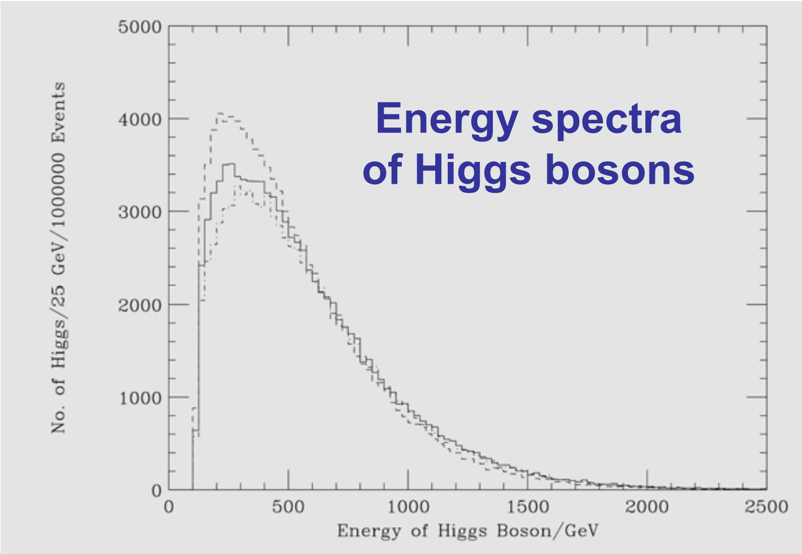
$$T_H(M_P, n, M_{BH}) = M_P \frac{n+1}{4\sqrt{\pi}}\left(\frac{M_P}{M_{BH}}\frac{n+2}{8\Gamma\left(\frac{n+3}{2}\right)}\right)^{\frac{1}{n+1}} = \frac{n+1}{4\pi R_S^{(n)}}$$

  - black body radiation: emission of particles
    - high multiplicity
    - “democratic” emission

Black Holes in ATLAS

– development of a Monte Carlo generator: CHARYBDIS
CM Harris, P. Richardson and BR Webber, JHEP 0308 (2003) 033 (hep-ph/0307305:

- evaporation
- time evolution
- "grey body" factors (transmission of particles through curved space-time outside horizon)
- planck phase: few hard jets
- …

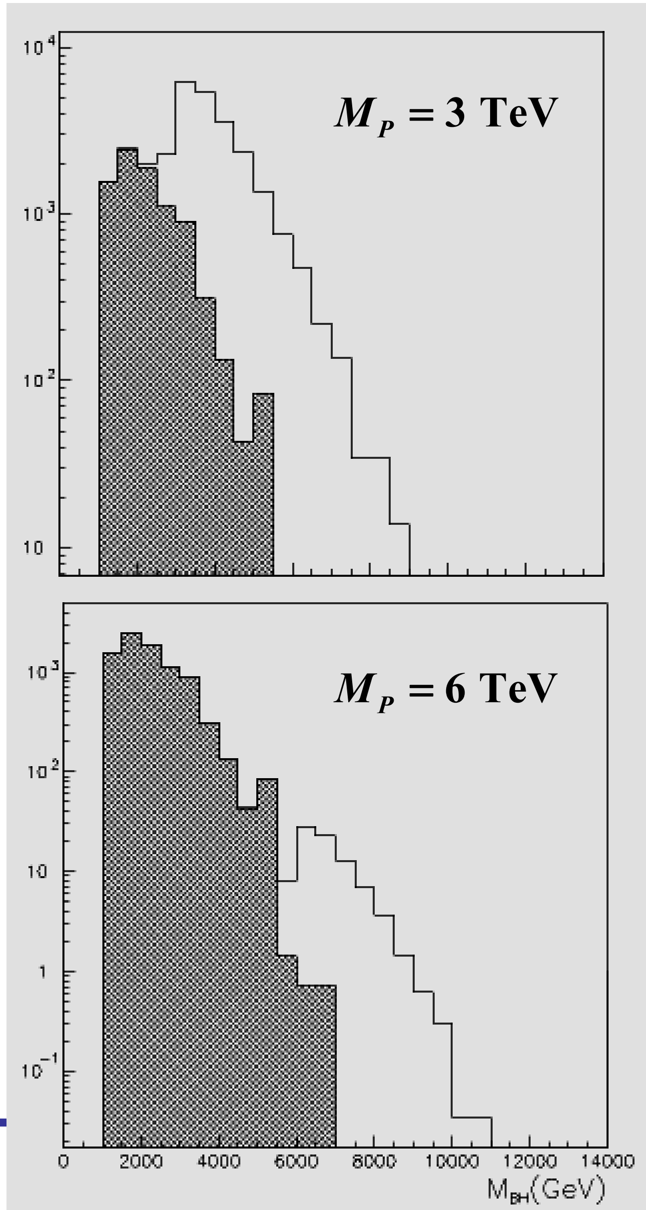


– simulation in ATLAS
Japanese group (T. Yamamura, J. Tanaka, et al.)

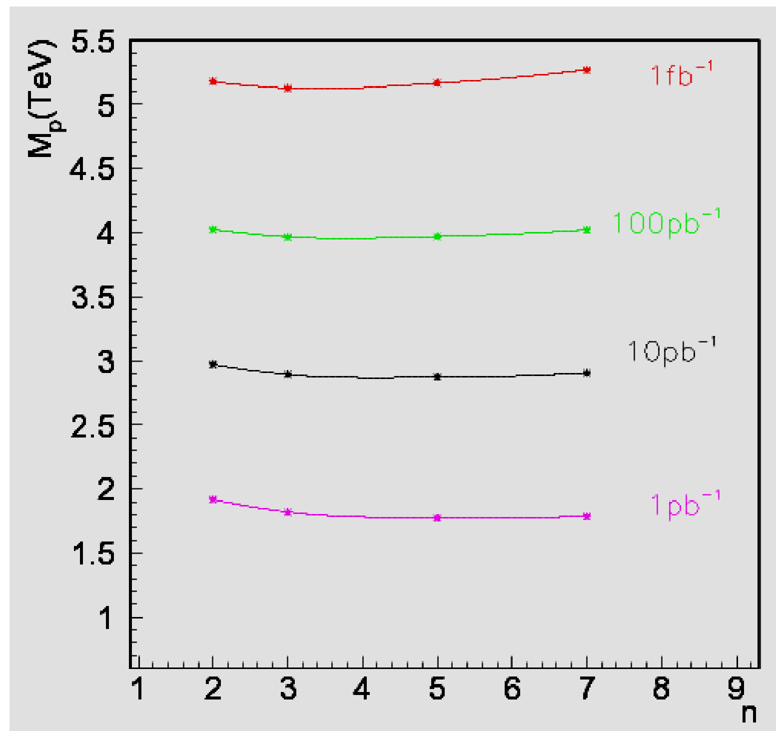
- selection of spherical events
- $\mathbf{M_{BH}}$ reconstructed for each event
- reconstruction of $\mathbf{M_P}$ from the cross section $\mathbf{d\sigma/dM_{BH}}$
  – given the energy distribution for M_{BH} $\Rightarrow$ $\mathbf{T_H}$
    » **n** deduced from T_H, M_{BH} and M_P (Hawking radiation formula)

Black Holes

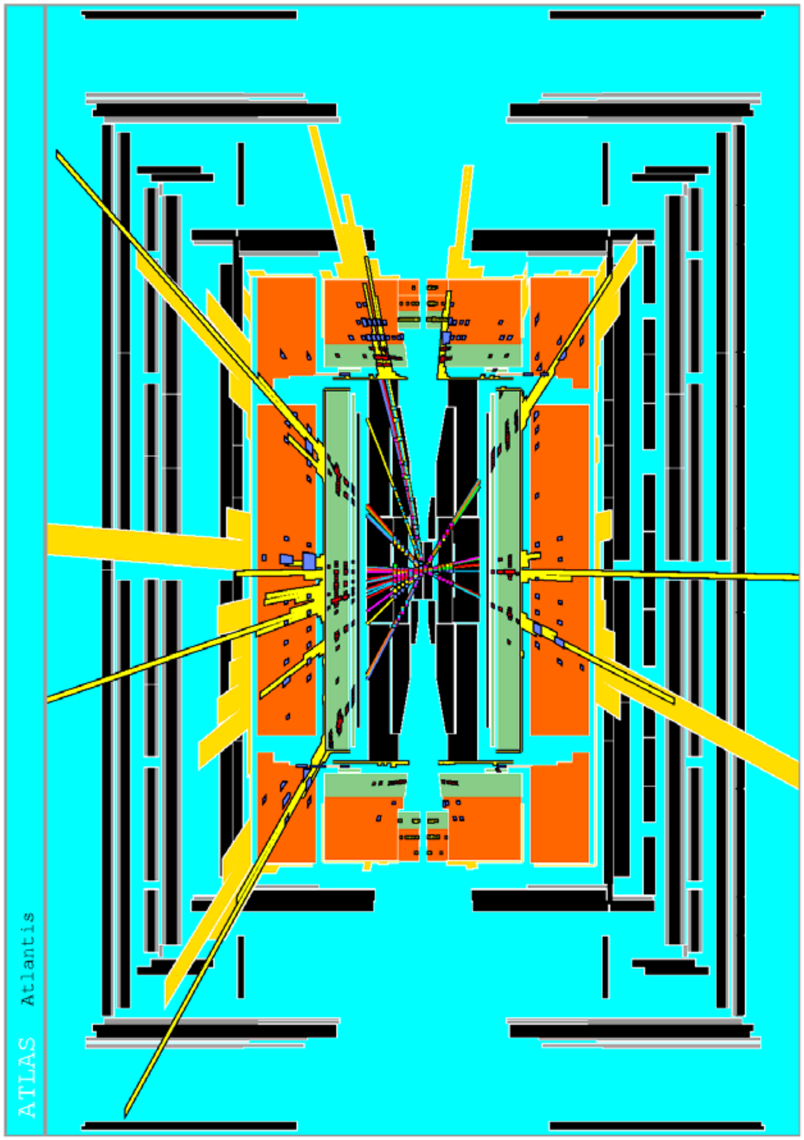
J. Tanaka et al.,
ATL-PHYS-2003-037

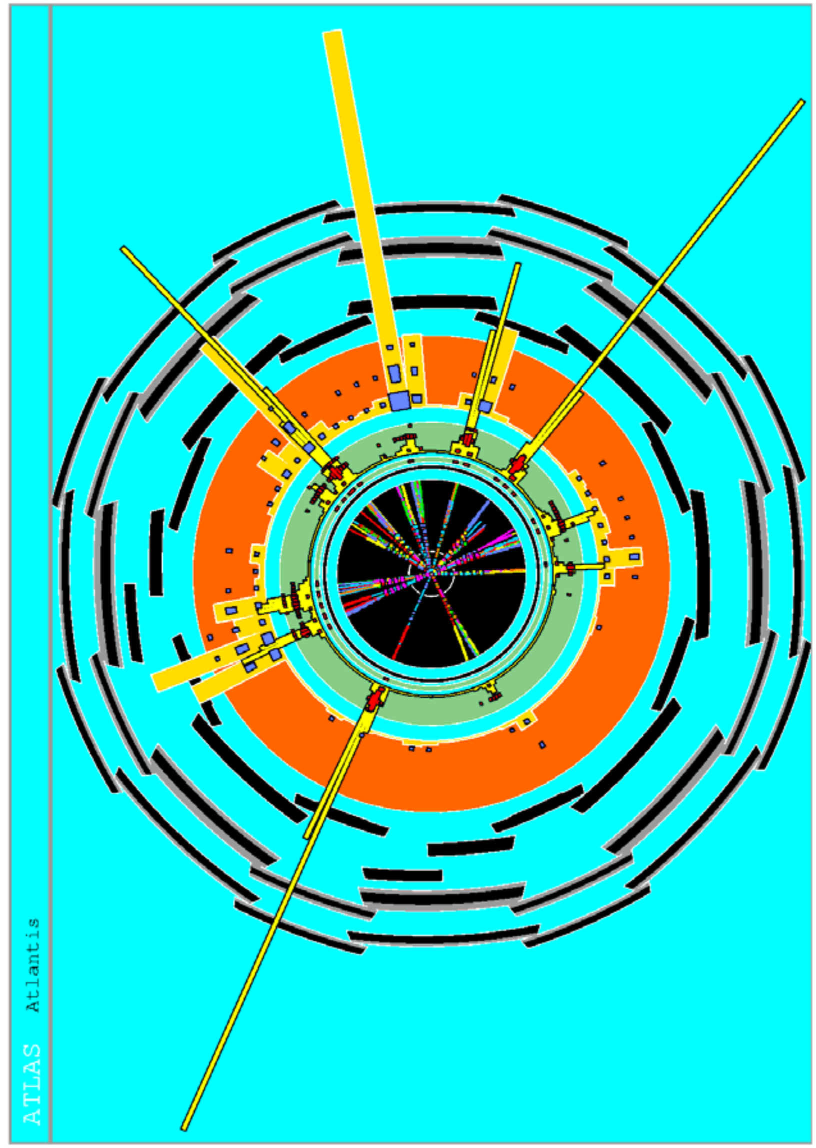


M_{BH}



es





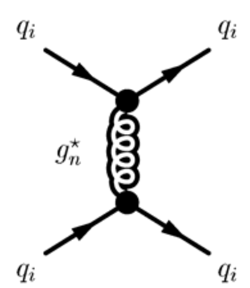
an, S

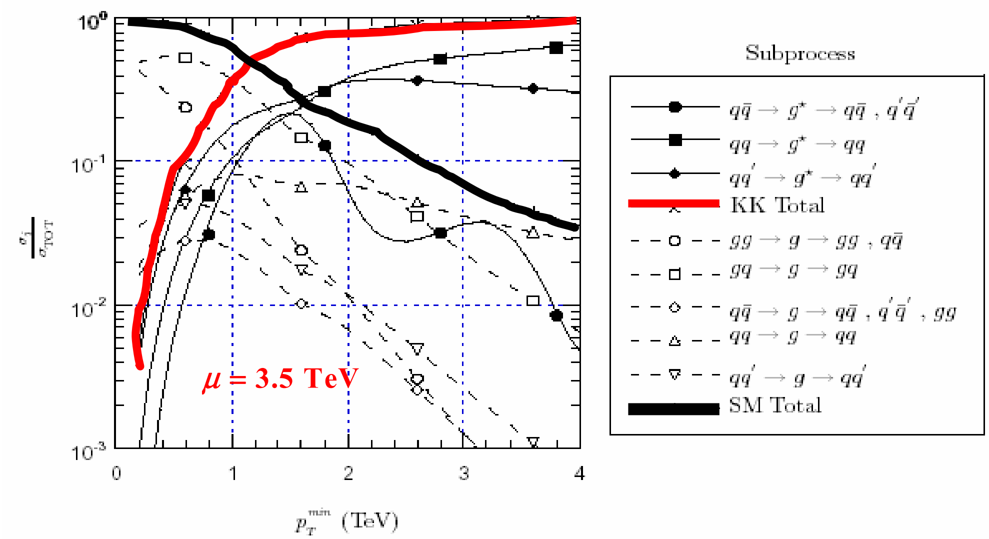
Other models and ideas…

- TeV^{-1}-size:

DA Dicus, CD McMullen and S. Nandi hep-ph/0012259

  - virtual g* excitation ⇒ enhanced di-jet cross section





ATLAS study in progress…

T. Appelquist, HC Cheng and BA Dobrescu, PR D64 (2001) 035002

- Universal Extra dimensions
  - All SM particles in bulk

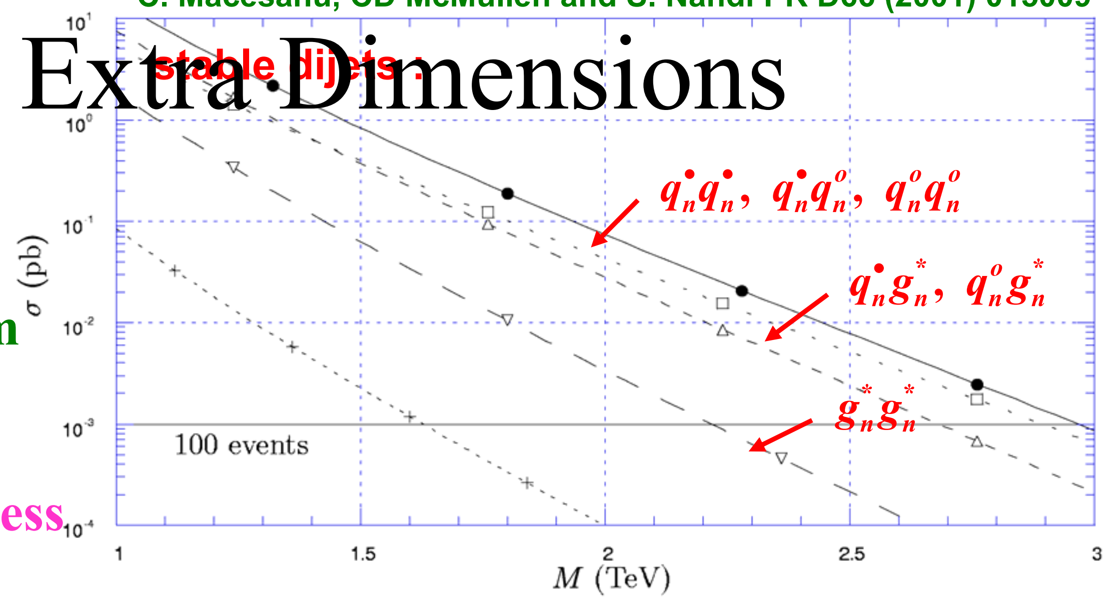
    ⇒ conservation of momentum in extra dimensions

    ⇒ conservation of KK number

Universal Extra Dimensions

– **dijet signals**
  - **stable**
  - **unstable:**
    fat brane absorbs unbalanced momentum from KK number violation
  - **ATLAS study in progress**

C. Macesanu, CD McMullen and S. Nandi PR D66 (2001) 015009



– **LKP:**

γ^*

$q_1^\bullet q_1^\bullet \rightarrow (...+\gamma^*)(...+\gamma^*)(\rightarrow \gamma G + \gamma G + X)$

C. Macesanu, CD McMullen and S. Nandi
Phys.Lett. B546 (2002) 253

  - **can be fooled by SUSY**

HC Cheng, KT Matchev, and M Schmaltz
Phys.Rev. D66 (2002) 056006 (hep-ph/0205314)

  - **ATLAS study in progress**

b-tagging

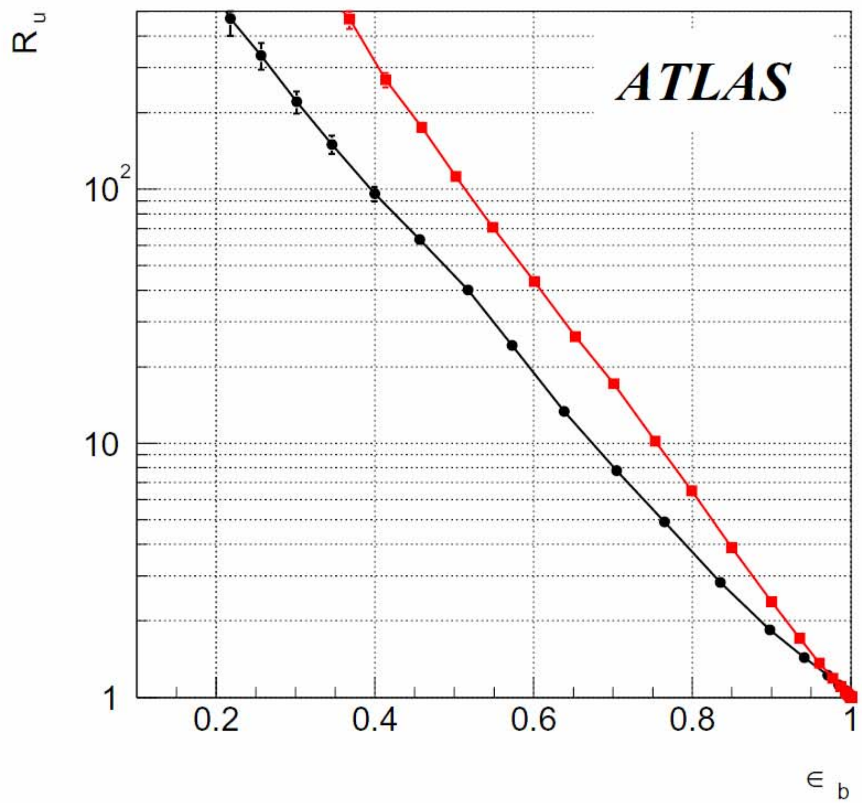


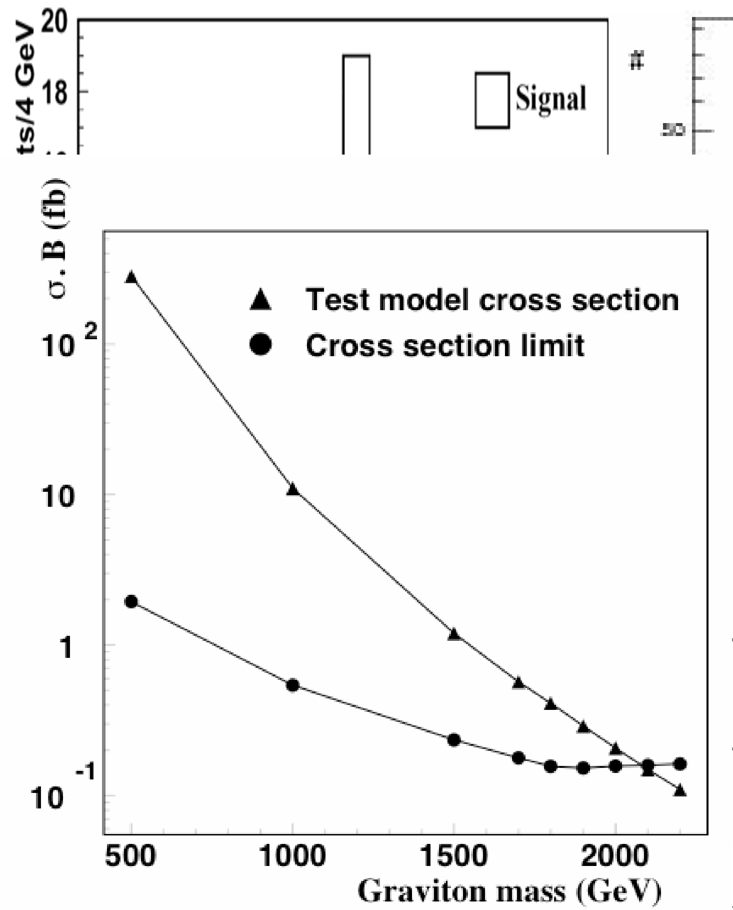
Figure 13: Plot showing the tagging efficiency for $b-$jets as a function of the rejection factor against light quark jets. The upper curve shows the result from the benchmark ATLAS sample of bottom quarks from a Higgs decay of mass 400 GeV produced in association with a W [13]. The lower curve shows the result from the higher energy $b-$quarks from the $Z_H \to Zh$ sample.

Signature: $G^{(1)} \rightarrow e^+e^-$

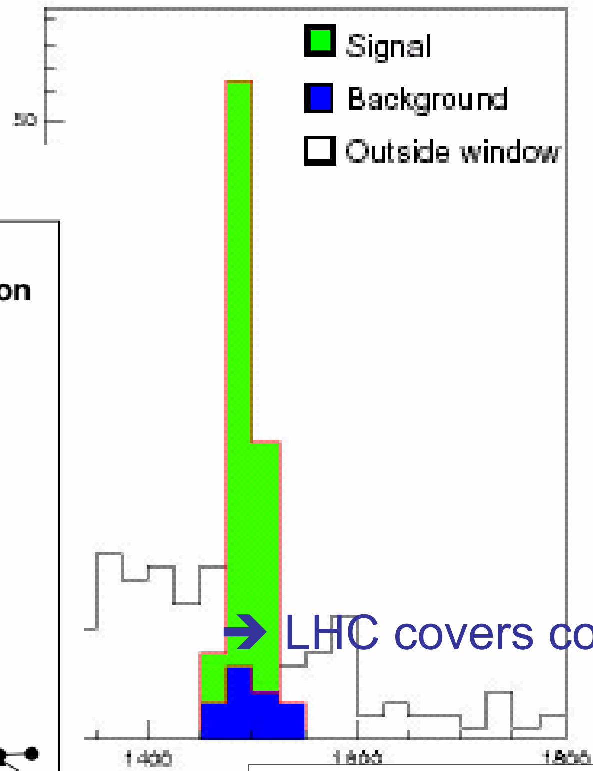
Sensitivity

discovery

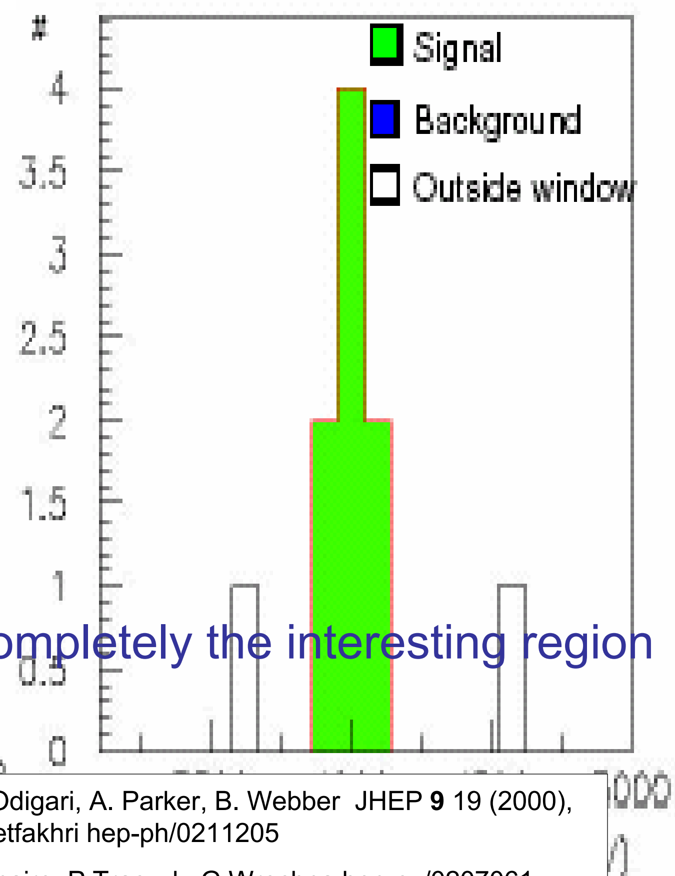
ATLAS, e^+e^-
m_G = 1.5 TeV, c = 0.01



CMS, e^+e^-
m_G = 1.5 TeV, c = 0.01



CMS, e^+e^-
m_G = 4 TeV, c = 0.1



→ LHC covers completely the interesting region

10

ATLAS: B.C. Allanach, K.Odigari, A. Parker, B. Webber JHEP **9** 19 (2000), ditto + M.J.Palmer, A. Sabetfakhri hep-ph/0211205

CMS: C.Collard, M.-C. Lemaire, P.Traczyk, G.Wrochna hep-ex/0207061; I. Golutvin, P.Moissenz, V.Palichik, M.Savina, S.Shmatov

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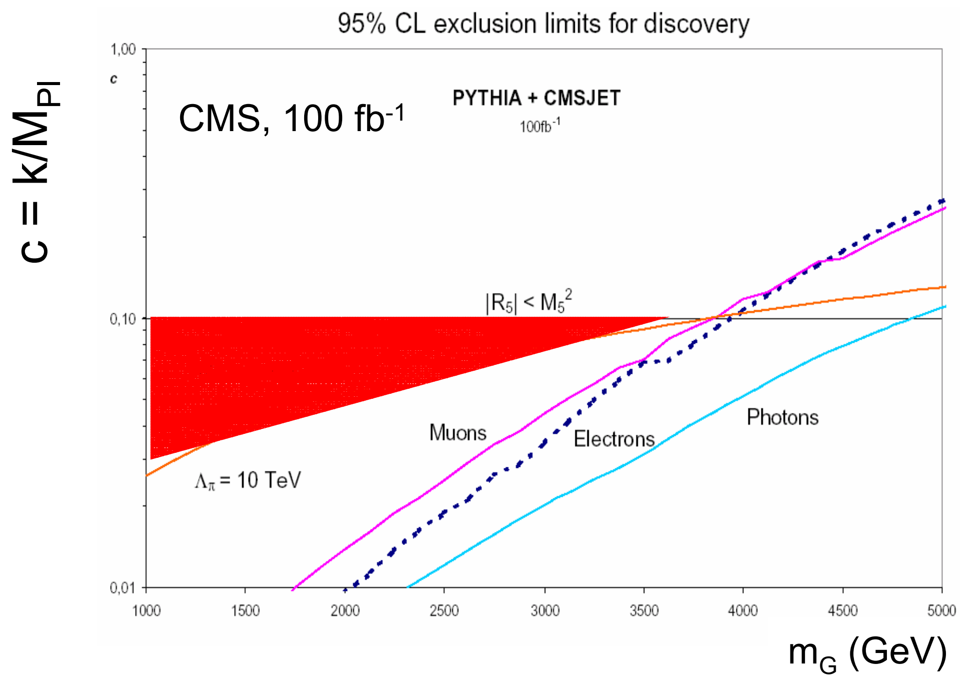
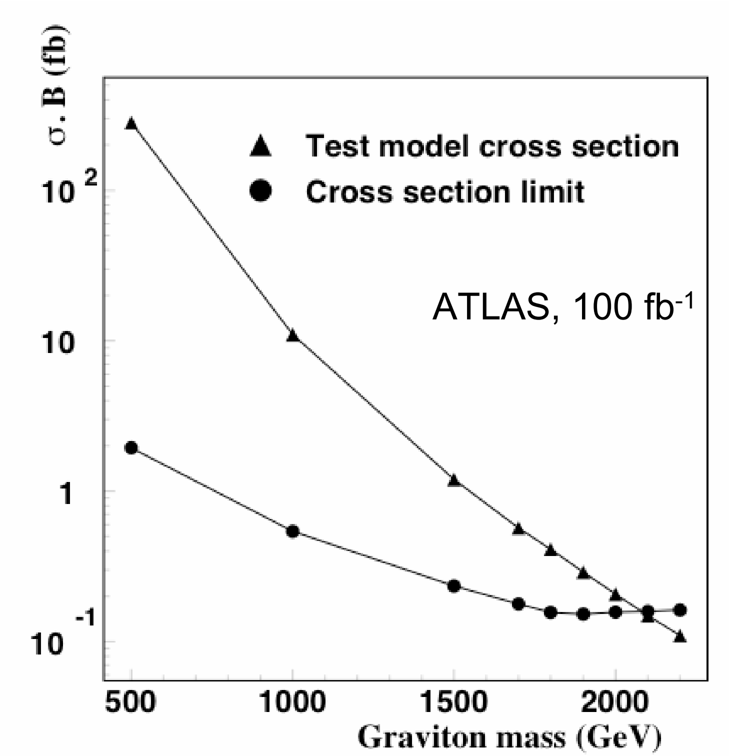
Sensitivity



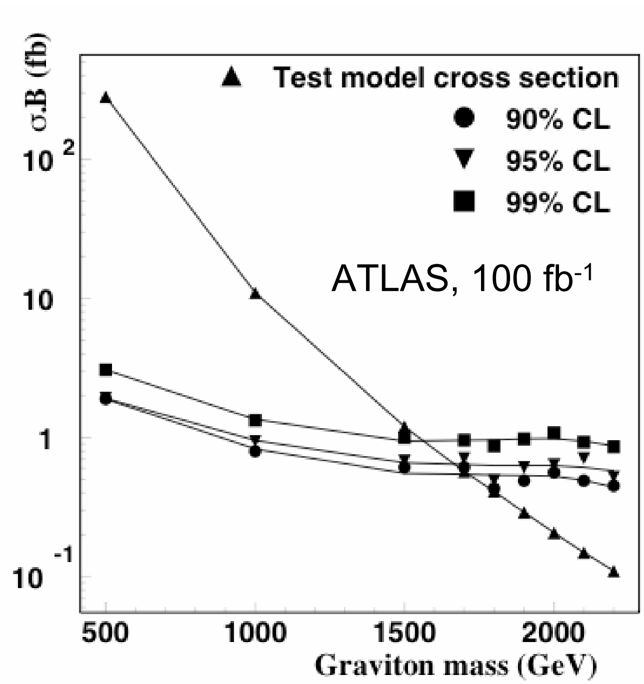


➔ LHC covers completely the interesting region

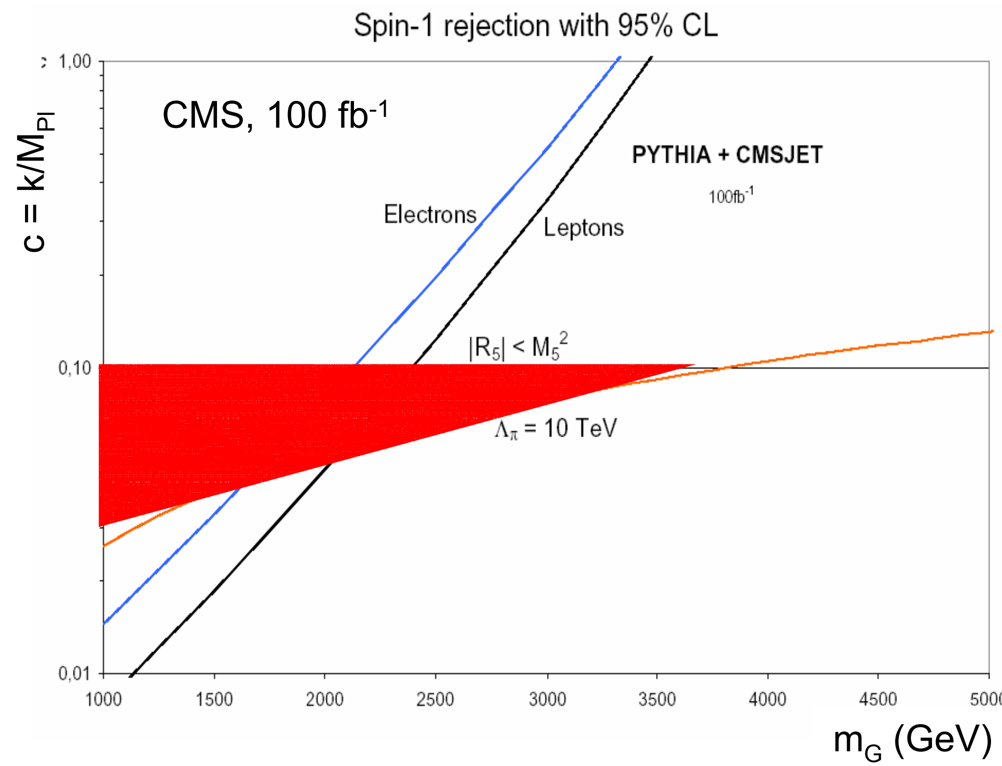
ATLAS: B.C. Allanach, K.Odigari, A. Parker, B. Webber JHEP **9** 19 (2000), ditto + M.J.Palmer, A. Sabetfakhri hep-ph/0211205

CMS: C.Collard, M.-C. Lemaire, P.Traczyk, G.Wrochna hep-ex/0207061; I. Golutvin, P.Moissenz, V.Palichik, M.Savina, S.Shmatov

Spin-1 hypothesis rejection:



spin-2 could be determined (spin-1 ruled out) with 90% CL up to graviton mass of 1720 GeV



large fraction of interesting region covered by LHC.

ATLAS: B.C. Allanach, K.Odigari, A. Parker, B. Webber JHEP **9** 19 (2000), ditto + M.J.Palmer, A. Sabetfakhri hep-ph/0211205

CMS: C.Collard, M.-C. Lemaire, P.Traczyk, G.Wrochna hep-ex/0207061; I. Golutvin, P.Moissenz, V.Palichik, M.Savina, S.Shmatov