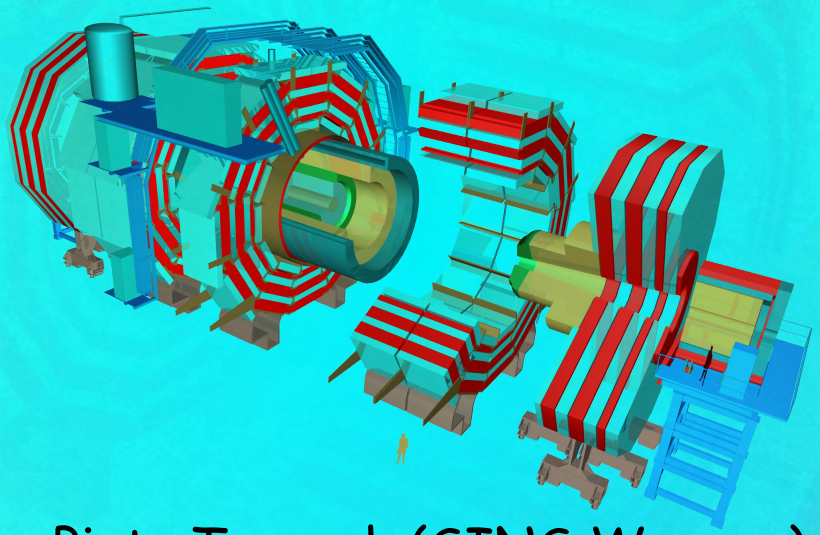
Search for Z-primes and RS gravitons with dimuons in CMS



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for the CMS Collaboration

Physics at LHC

Kraków, July 2006

Outline

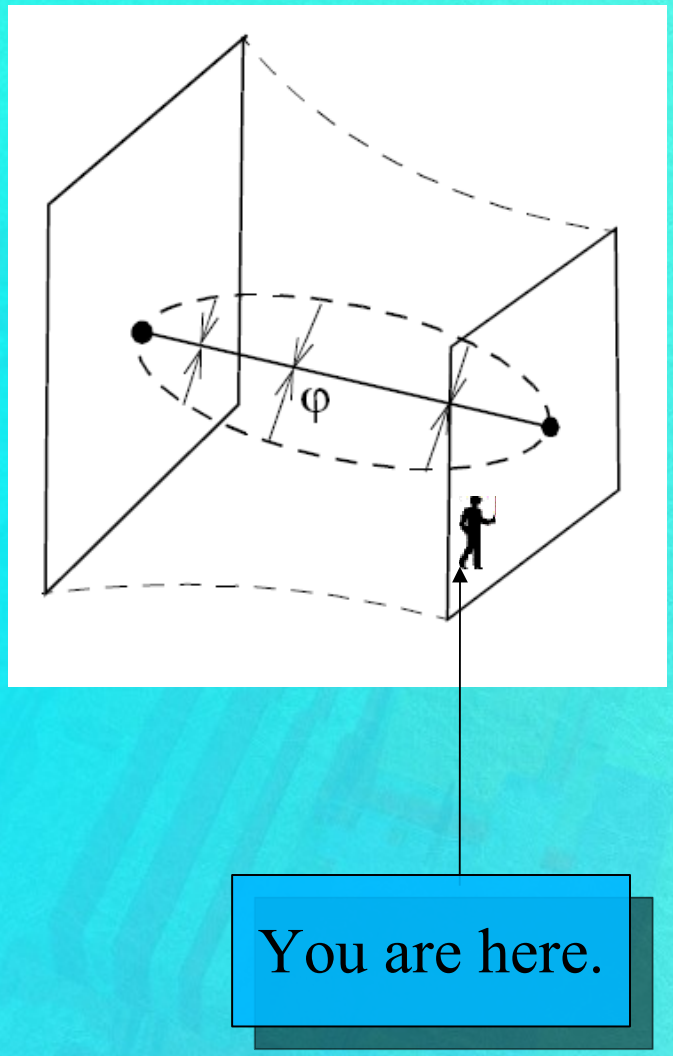
- Overview of models studied
- Signal & Background
- New resonance discovery analysis
- Model discrimination analysis

Z' models

- Z' – generic name for a new neutral gauge boson
- Can arise in various models – GUT's, dynamical symmetry breaking, Little Higgs, extra dimensions
- Models studied here:
  - Z_{SSM} – toy model, essentially a heavy Z^0
  - Z_{LRM}, Z_{ALRM} – left-right symmetric models
  - Z_χ, Z_ψ, Z_η – E_6 and/or SO(10) models

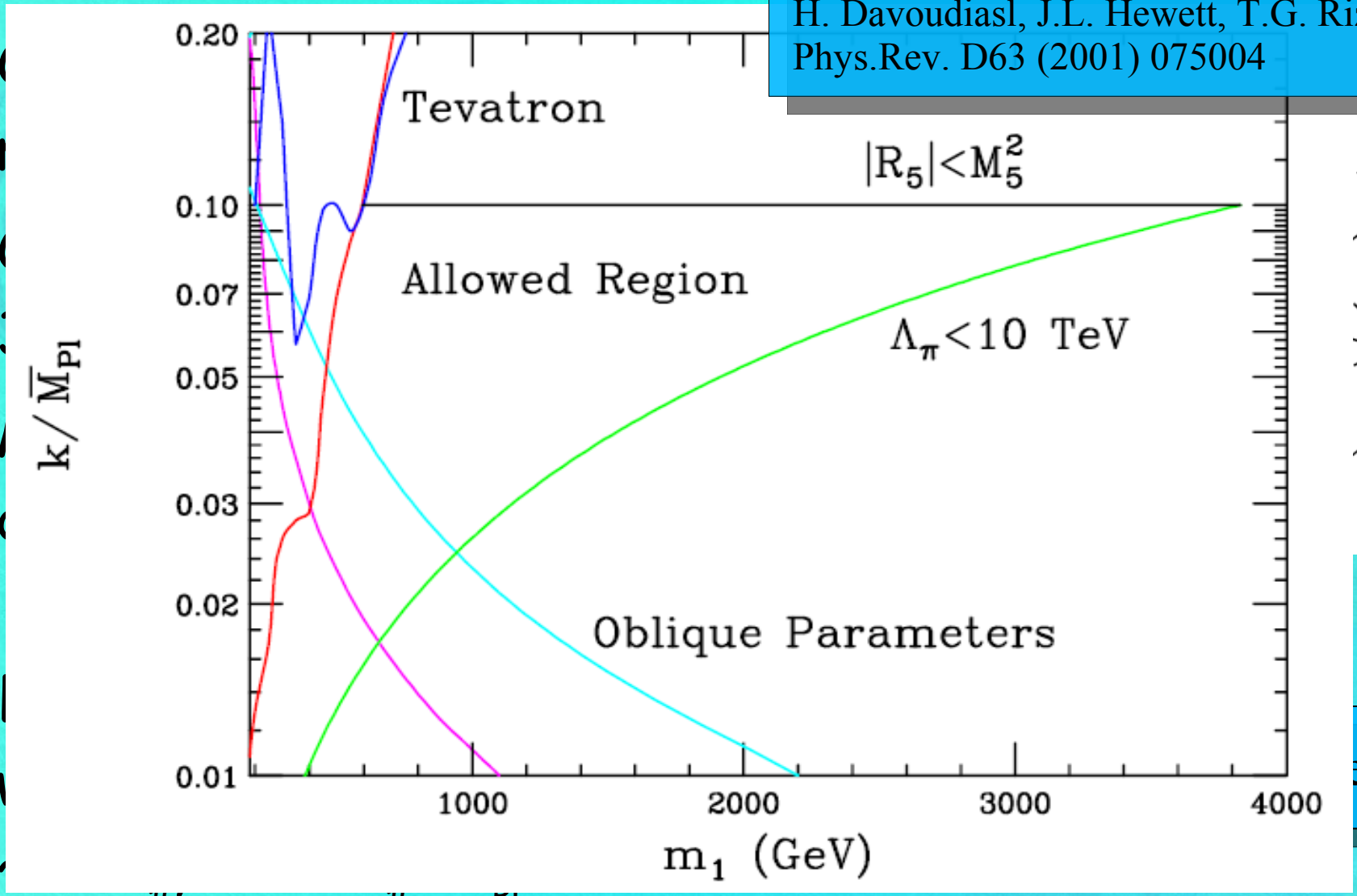
The Randall-Sundrum model

- One extra dimension φ with radius r, seen only by gravity
- Our universe on one of two 3-branes
- Metric:
  $ds^2=e^{-2kr|\phi|}\eta_{\mu\nu}dx^\mu dx^\nu+r^2d\phi^2$
  k ~ M_{Pl} - mass scale parameter of the theory
- Kaluza-Klein graviton excitations with ~TeV masses and couplings ~ $1/\Lambda_\pi$, with $\Lambda_\pi=M_{Pl}e^{-kr\pi}$ ~TeV



The Randall-Sundrum model

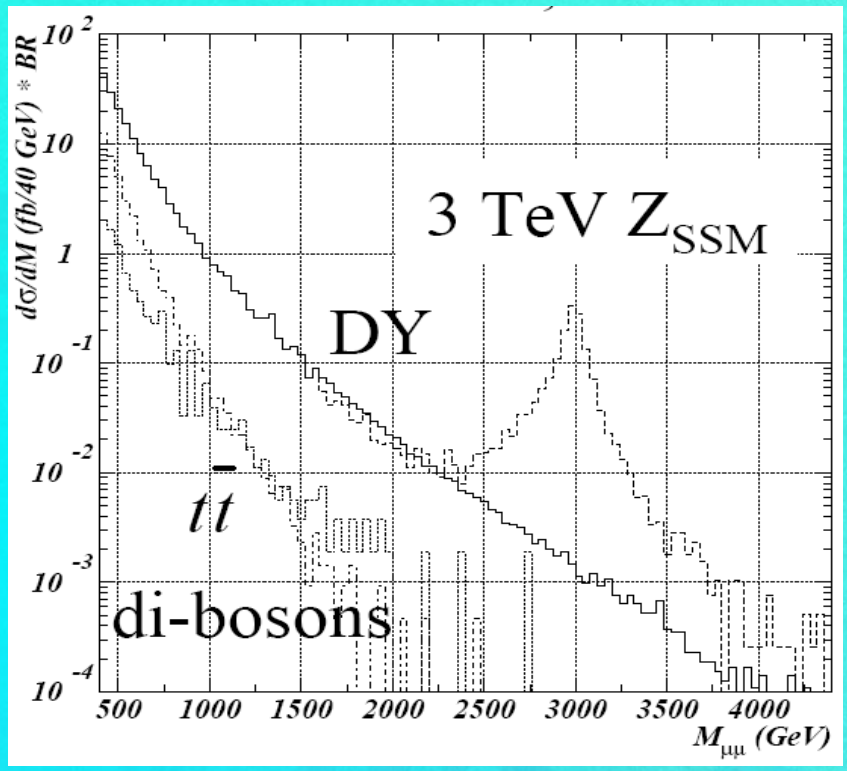
H. Davoudiasl, J.L. Hewett, T.G. Rizzo, Phys.Rev. D63 (2001) 075004



Signal and background generation

Signal

- Z': masses 1,3,5 TeV, 6 models (Z_{SSM}, Z_{LRM}, Z_{ALRM}, Z_{χ}, Z_{ψ}, Z_{η})
- G*: masses 1-5 TeV, k/M_{Pl}=0.01, 0.02, 0.05, 0.10



Background

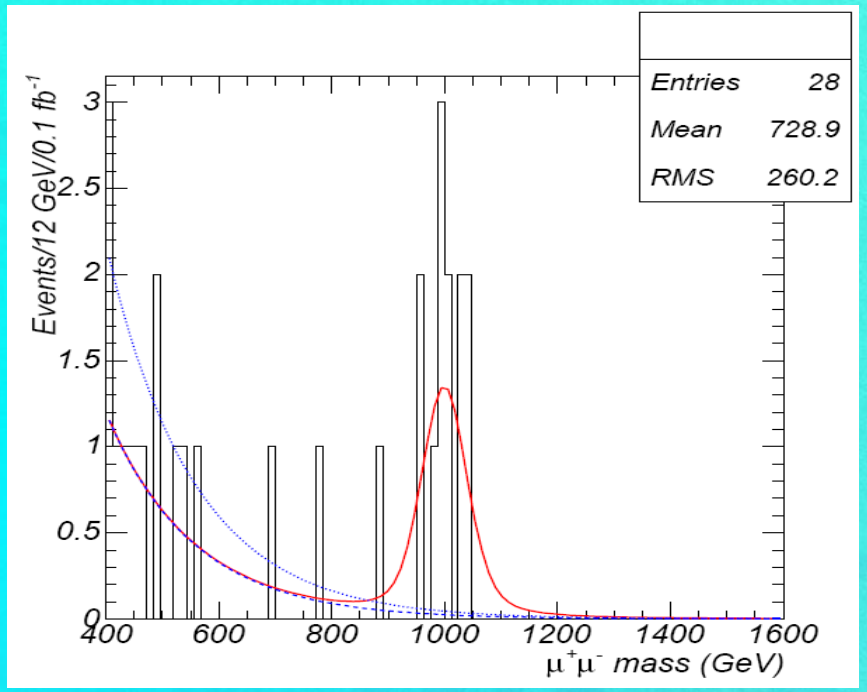
- Drell-Yan – dominant, irreducible
- Other backgrounds – dibosons, tt, bb - smaller than 10% DY, reducible

Simulation and reconstruction

- PYTHIA 6.227; CTEQ6L/6M
- K-factor 1.35 for both signal and background
- Full detector simulation & reconstruction (CMS OSCAR+ORCA software)
- TeV muon reconstruction
  - Optimized track reconstruction
  - Recovery of photons radiated by the muons (mostly internal bremsstrahlung)

Search for a resonance

- Discovery significance estimated from likelihood ratio $S_{\mathcal{L}} = \sqrt{2\ln\left(\mathcal{L}_{s+b}/\mathcal{L}_{b}\right)}$



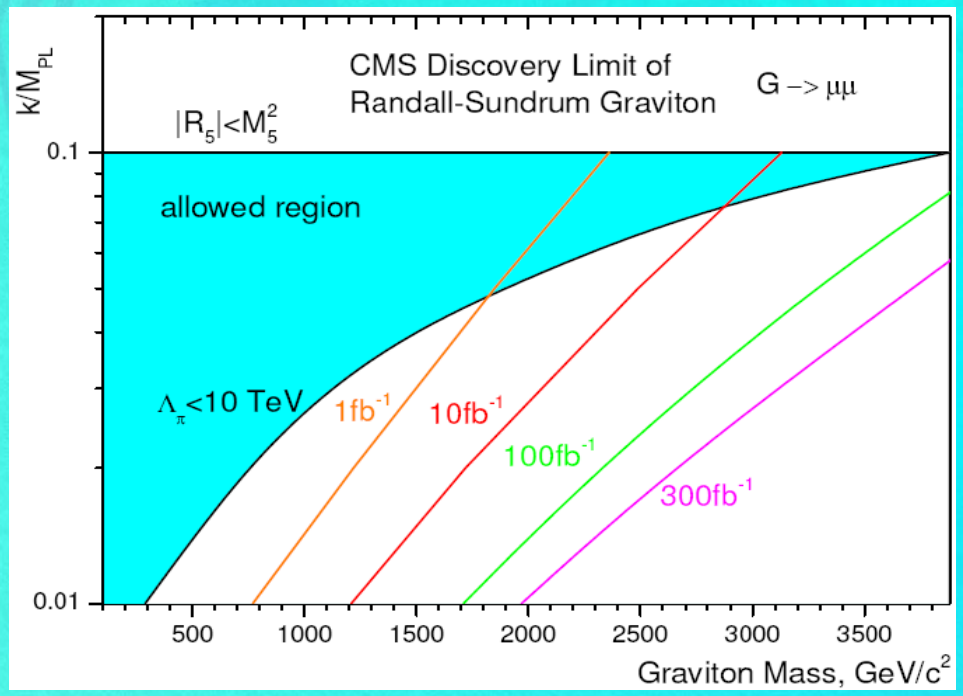
- L_{s+b} and L_b - maximum likelihood values for signal+background and background only fits.
- pdf used in the fit:

$$p(M_{\mu\mu}; N_S, M_G, \Gamma, k) = N_S \cdot p_G(M_{\mu\mu}; M_G, \Gamma) + N_B \cdot p_{DY}(M_{\mu\mu}; k)$$

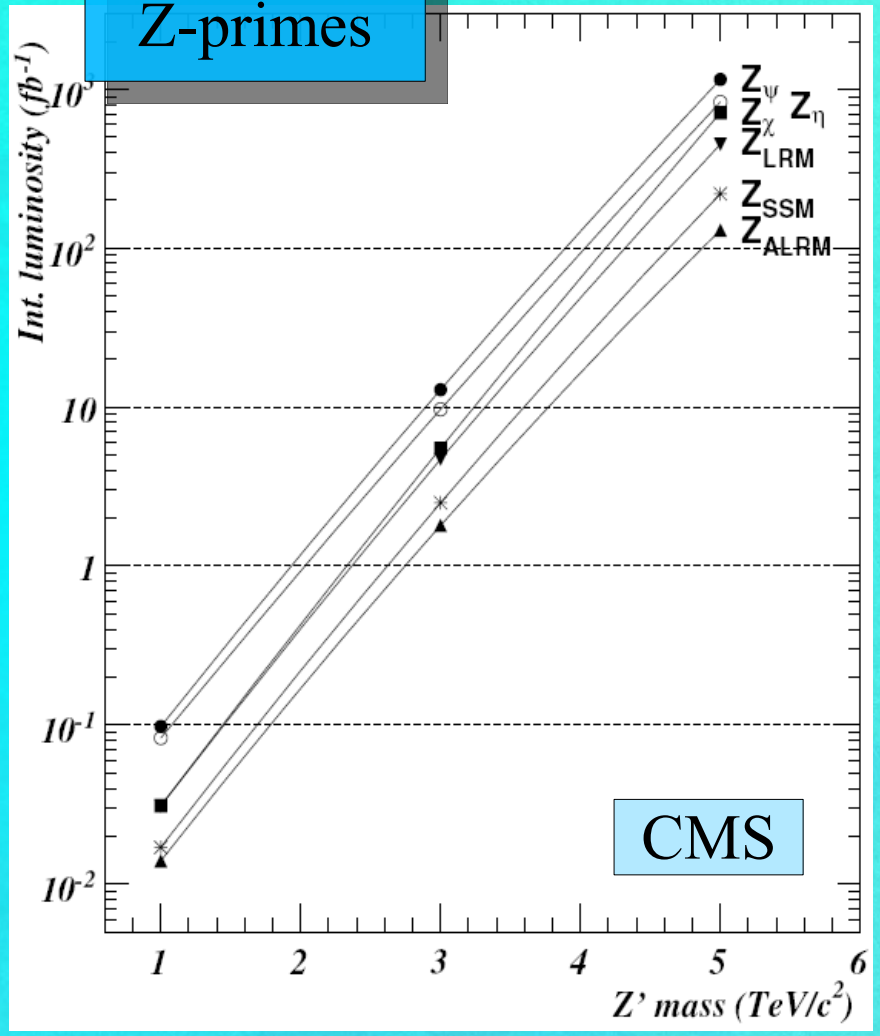
(N_s=0 for "background-only")

Results for 5σ discovery

Randall-Sundrum Gravitons



Z-primes



Systematics

- Theoretical uncertainties
  - QCD and EW higher order corrections
  - pdf uncertainty
  - Hard process scale
- Experimental uncertainties
  - tracker and muon system misalignment
  - Drift Tube calibration, magnetic field uncertainty

Systematics

- Theoretical uncertainties
  - QCD and EW higher order corrections
  - pdf uncertainty
  - Hard process scale

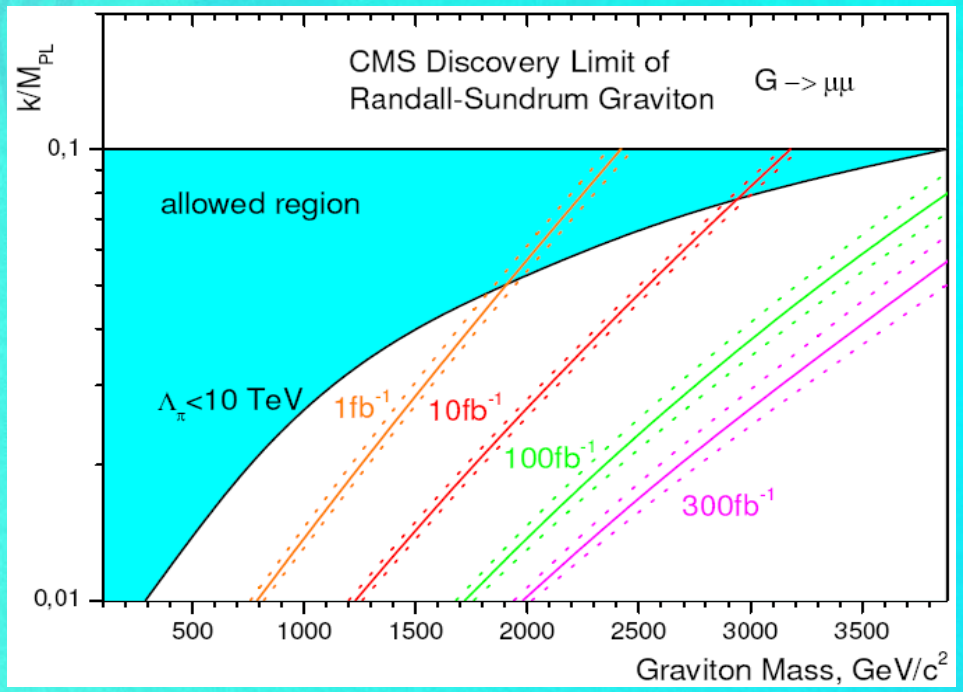
added in quadrature

- Experimental uncertainties
  - tracker and muon system misalignment - simulated
  - ~~Drift Tube calibration, magnetic field uncertainty~~

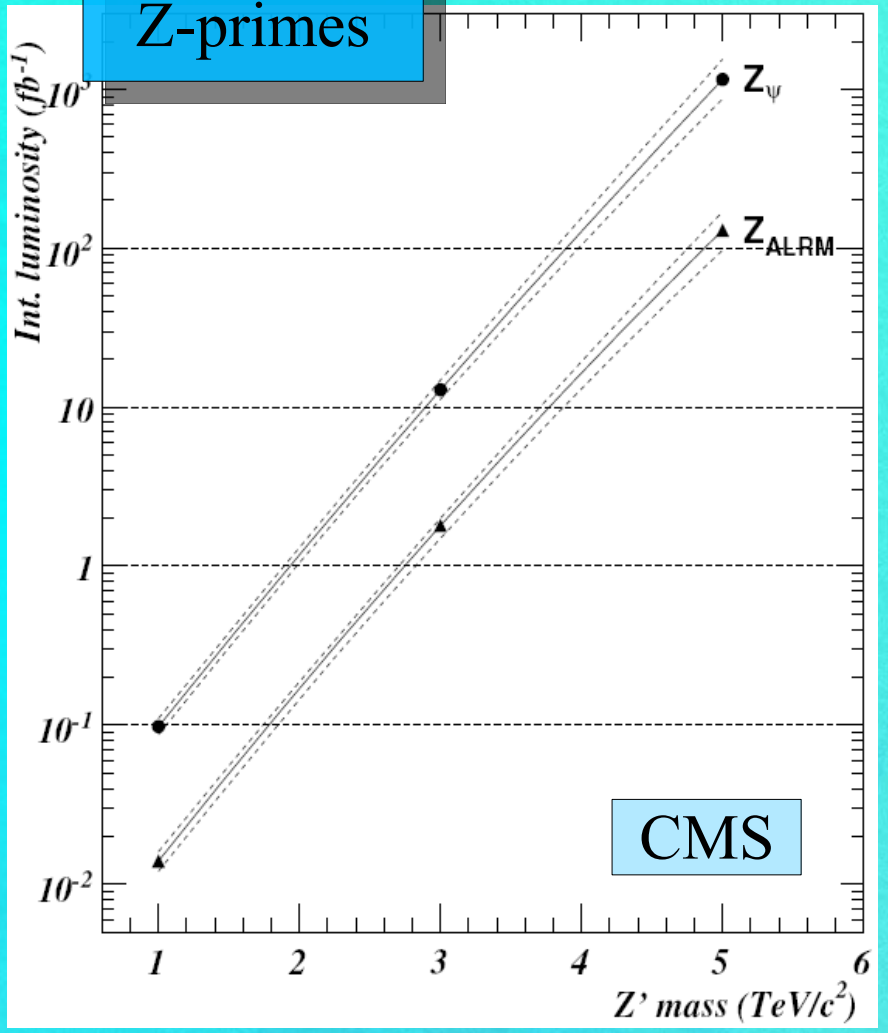
negligible

Discovery results (with systematics)

Randall-Sundrum Gravitons



Z-primes



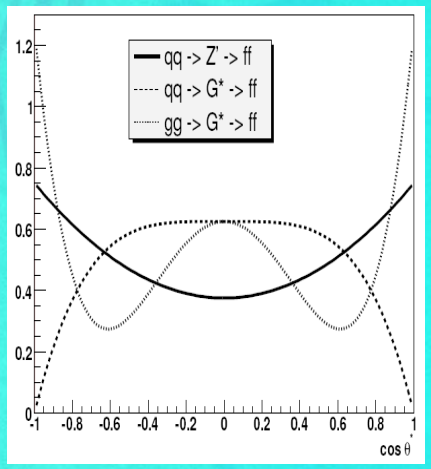
Reach prediction modified

Model discrimination

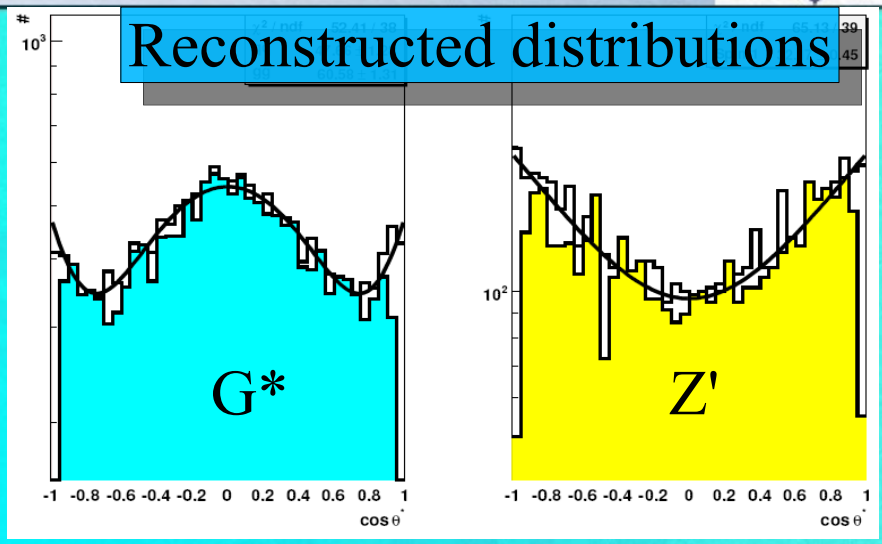
- First question after the discovery of a heavy resonance:
  - Is it a graviton or a Z'?
  - What kind of a Z'?
- Answer: Check angular distributions of final state muons
  - Graviton is spin-2, Z' is spin-1. Check even terms in $\cos\theta^*$
  - Use forward backward asymmetry (odd terms in $\cos\theta^*$) to distinguish between Z' models

Graviton or Z'? Spin discrimination

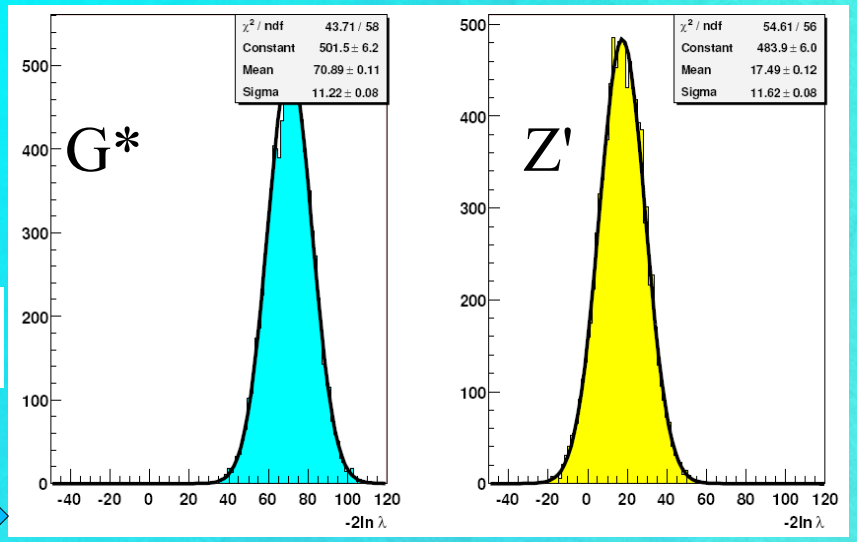
- cosθ* measured in the Collins-Soper frame



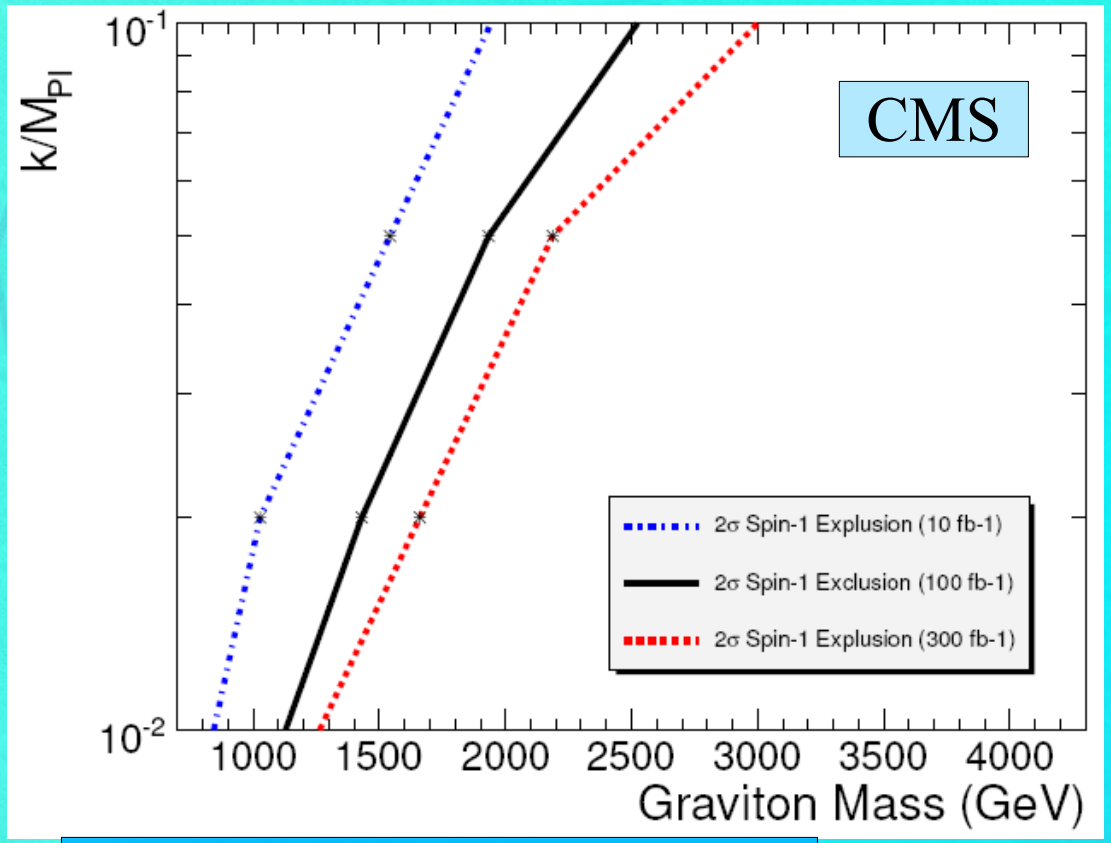
$$q\bar{q} \to \gamma/Z^0/Z' \to f\bar{f} \qquad \frac{3}{8}(1+\cos\theta^{*2})$$
$$q\bar{q} \to G^* \to f\bar{f} \qquad \frac{5}{8}(1-3\cos\theta^{*2}+4\cos\theta^{*4})$$
$$gg \to G^* \to f\bar{f} \qquad \frac{5}{8}(1-\cos\theta^{*4})$$



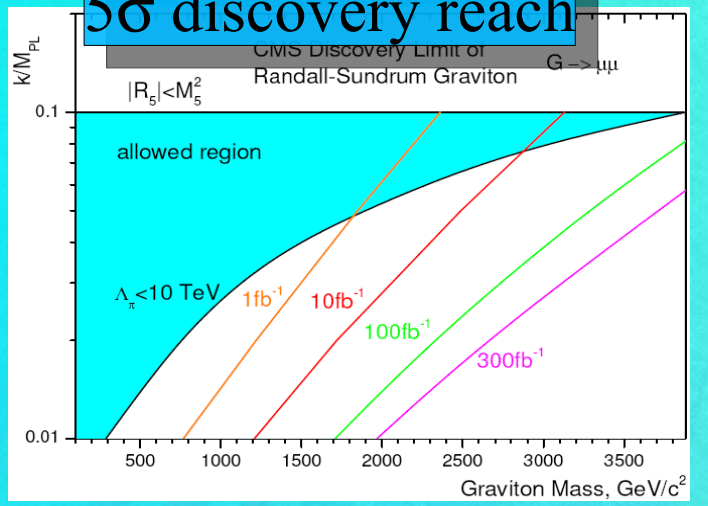
- Calculate the likelihood ratio $-2\ln\lambda = 2\ln\mathcal{L}_1 - 2\ln\mathcal{L}_2$
- To separate the two hypotheses



Spin discrimination results



Reminder: 5σ discovery reach



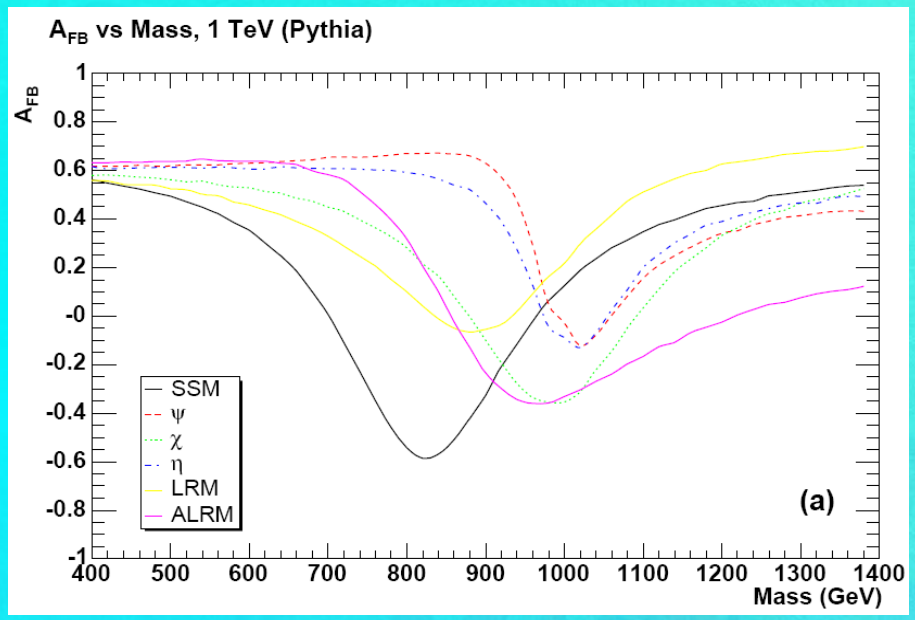
Mass reach for 2σ exclusion

Integrated luminosity	$10\ \mathrm{fb}^{-1}$	$100\ \mathrm{fb}^{-1}$	$300\ \mathrm{fb}^{-1}$
$c = 0.01$	843	1128	1264
$c = 0.1$	1946	2524	3000

Which Z'? A_{FB} measurement

- Need knowledge of incident quark direction
- Assumed equal to the direction of the dimuon system
- Probability of "mistag" taken into account in a multi-dimensional fit

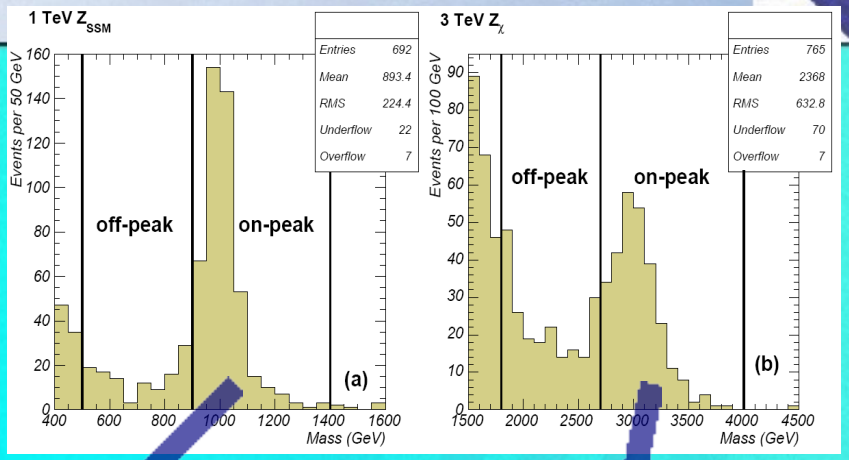
$$A_{\mathrm{FB}} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$



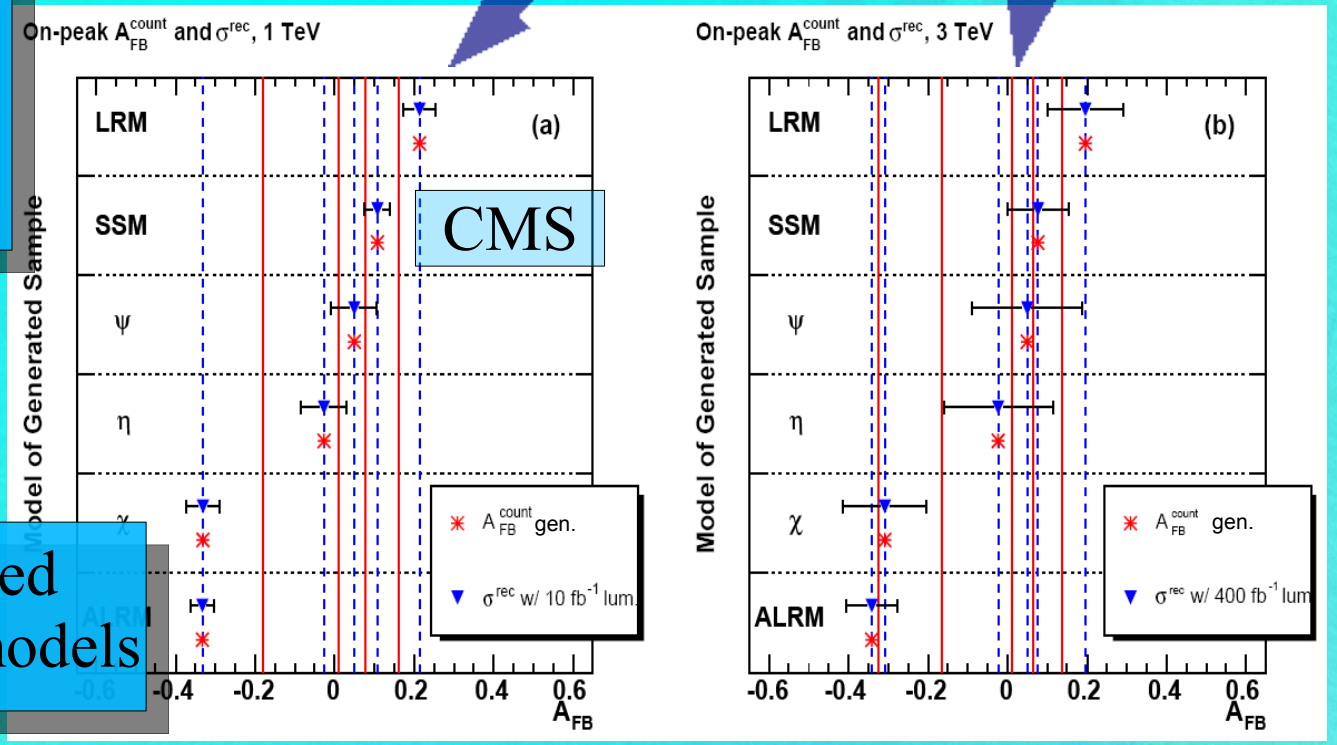
$$\begin{aligned}
&P(p_{\mathrm{T}}, y, \phi, M_{\mu\mu}, \cos\theta^*_{\mathrm{CS}}, \phi^*_{\mathrm{CS}}; A_{\mathrm{FB}}, b) = \\
&\quad [(1-\omega(y, M_{\mu\mu}))P(\cos\theta^*_{\mathrm{CS}}; A_{\mathrm{FB}}, b) + \omega(y, M_{\mu\mu})P(-\cos\theta^*_{\mathrm{CS}}; A_{\mathrm{FB}}, b)] \\
&\quad \times \Omega(p_{\mathrm{T}}, y, \phi, M_{\mu\mu}, \cos\theta^*_{\mathrm{CS}}, \phi^*_{\mathrm{CS}}) \\
&\quad \times P_{p_{\mathrm{T}}}(p_{\mathrm{T}}, M_{\mu\mu})\, P_y(y, M_{\mu\mu})\, P_{M_{\mu\mu}}(M_{\mu\mu})\, P_{\phi^*_{\mathrm{CS}}}(\phi^*_{\mathrm{CS}}, M_{\mu\mu}),
\end{aligned}$$

A_{FB} measurement results

Model	Z_{ALRM}	Z_χ	Z_η	Z_ψ	Z_{SSM}	Z_{LRM}
Z_{ALRM}	–	0.0	5.3	6.6	7.6	9.4
Z_χ	0.0	–	3.7	4.6	5.3	6.6
Z_η	2.7	2.6	–	0.7	1.2	2.1
Z_ψ	3.3	3.3	0.7	–	0.5	1.4
Z_{SSM}	6.8	6.8	2.1	0.9	–	1.6
Z_{LRM}	6.8	6.8	3.0	2.1	1.3	–



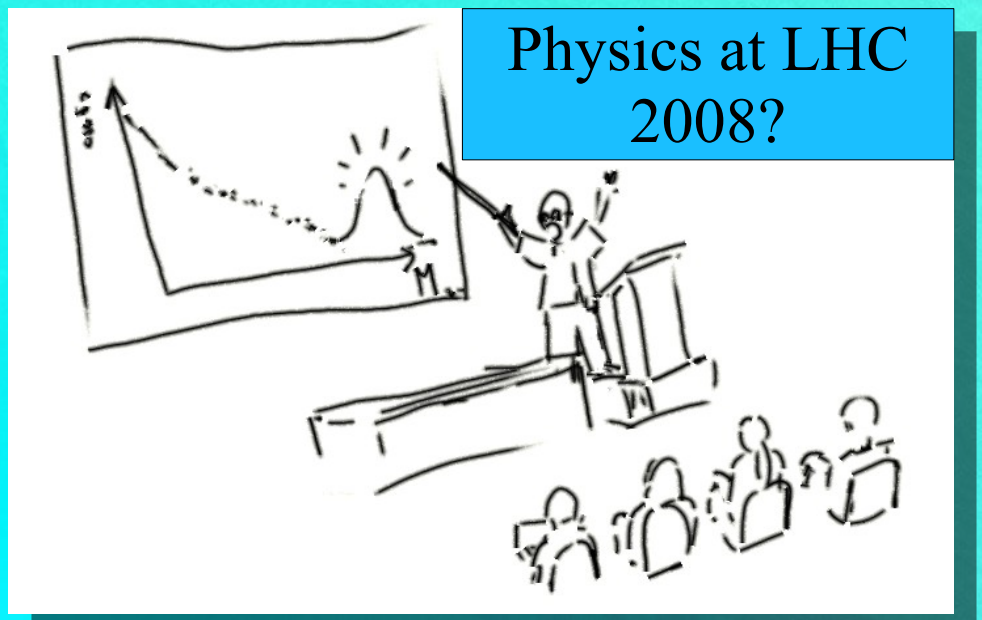
Pair-wise model discrimination for 10 fb^{-1}, $M_{Z'} = 1$ TeV (in sigma's)



Errors on reconstructed A_{FB} for different Z' models

Conclusions

- Dimuon channel promising for new heavy boson discovery.
- Full analysis with systematics done.
- 5σ discovery for masses up to 1.7-4.9 TeV
- 2σ spin discrimination for masses up to 1-2.5 TeV



Details in: CMS NOTE-2006/062, CMS NOTE-2006/104, CMS NOTE-2005/022, JHEP 11 (2005) 047, CMS Physics TDR