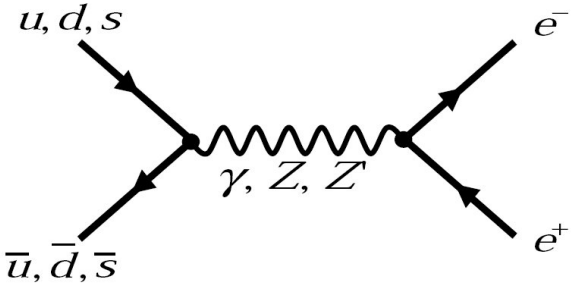
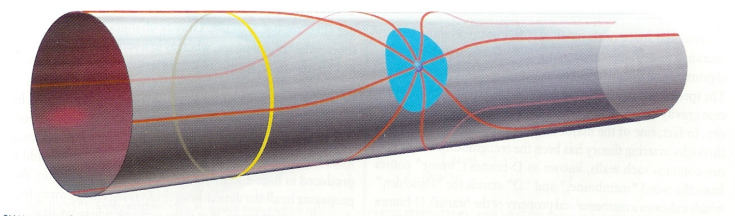
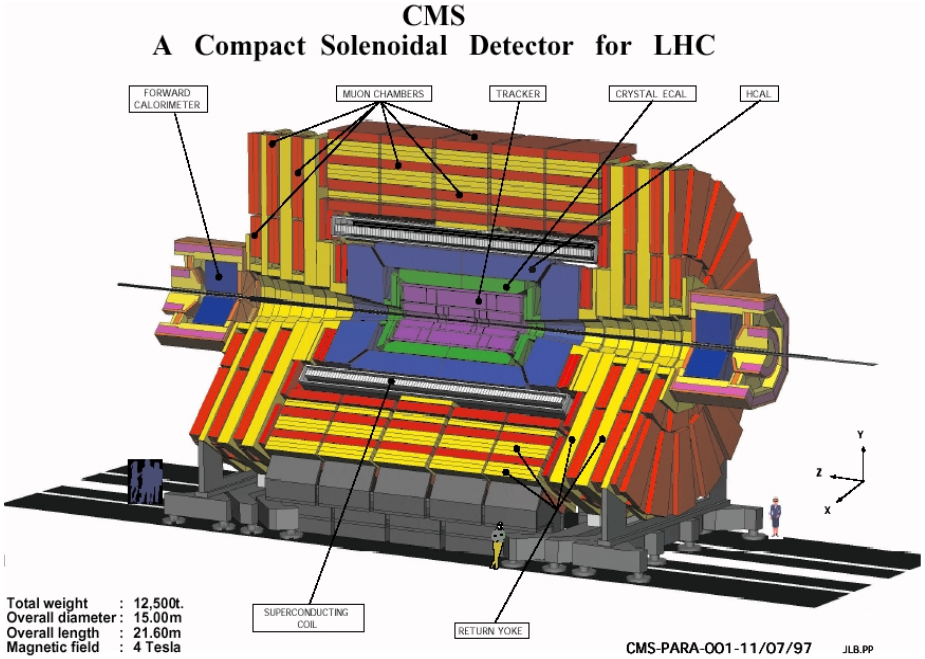


CMS discovery potential for Z'/ED and spin discrimination

Barbara Clerbaux
ULB, Brussels





Models considered

If $\sqrt{s} < M_D$: (1) Large flat Extra Dimension (ADD)

Extra dimensions are flat and could be as large as a few μm
SM particles restricted to 3D brane - bulk: only accessible to gravity
→ direct production of KKG
→ virtual effect of KKG

Size of the ED

(2) TeV^{-1} size ED

if ED small enough R<= TeV^{-1}
SM fields are allowed to propagate in the bulk
→ KK excitation of gauge bosons

(3) Randall, Sundrum (RS1 – two branes)

Small extra spatial dimensions
Curved bulk space (AdS5 - slice)
→ narrow resonance of KKG
free parameter: coupling c

In all cases: $M^2(i) \sim i^2/R^2$ - free parameter: m(1)
in ADD: n = number of ED

$$M^2_{\text{Planck}} = M_D^{2+n}\, R^n$$

If $\sqrt{s} > M_D$: TransPlanckian physics

Models considered

Additional heavy neutral gauge boson are predicted in many models BSM:
superstring-inspired and GUT theories - L-R models - little Higgs
No reliable prediction on the Z' mass scale (free paramete)

Consider 6 Z' models, representative of a broad class of models:
- Sequential Standard Model (SSM): same coupling as SM Z
- Z(ψ), Z(η) and Z(χ), arising from E6 and SO(10) GUT groups differ from couplings to quark and leptons
- Z_LRM and ZALRM, arising from the framework of the so-called “left-right” and “alternative left-right” models.

Current limits on Z' mass: from 600-900 GeV depending on models
Tevatron: expected to cover up to masses ~1 TeV

Topologies

CMS searches in the following topologies:

Di-electron, di-photon, di-muon and di-jets resonance states
(new particles)
in GUT models (Z'), RS1-model (G) and TeV^{-1} extra dimension model (KKZ)

(how to distinguish between models)

Single Leptons + missing ET
in R-L models (W' production)

Di-muon continuum modifications
(virtual graviton production in ADD)

Single Photons + Missing ET
(direct graviton production in ADD)

High mass di-electrons

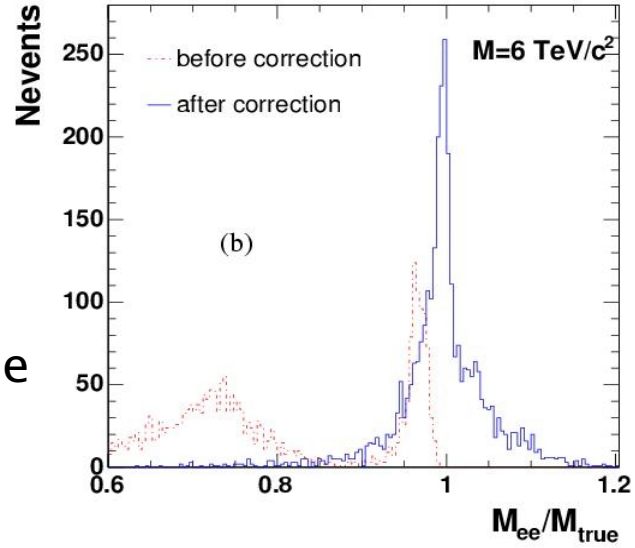
B. Clerbaux et al. CMS NOTE 2006/083

pp → HR → ee

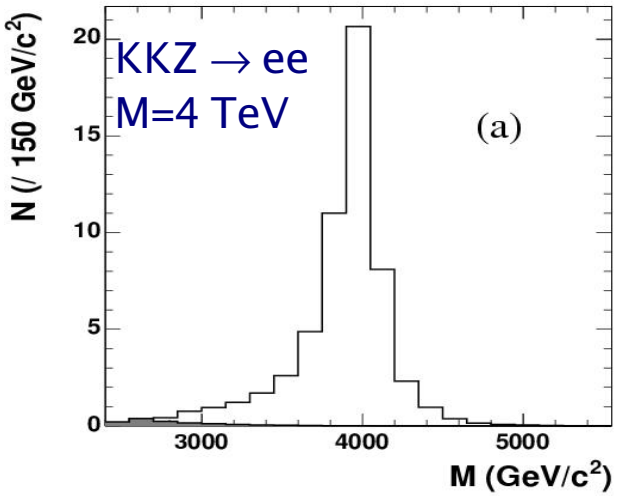
Heavy Resonance: from TeV^{-1} ED (KKZ), GUT (Z') and RS(G)

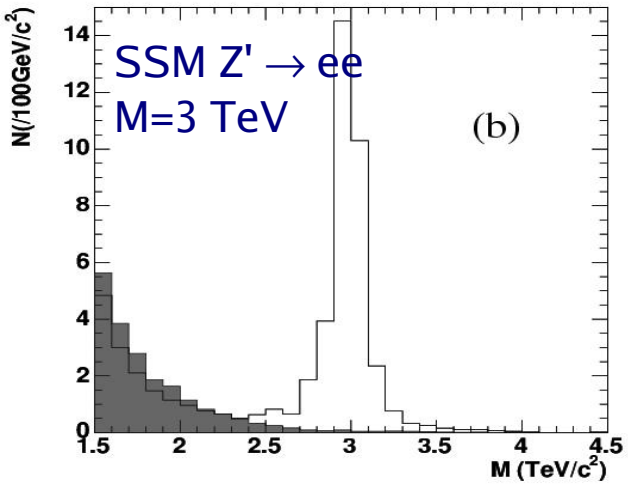
Dominant and irreducible bg: DY: pp → γ/Z → ee
others: ZZ,ZW,WW, tt: few % of DY bg

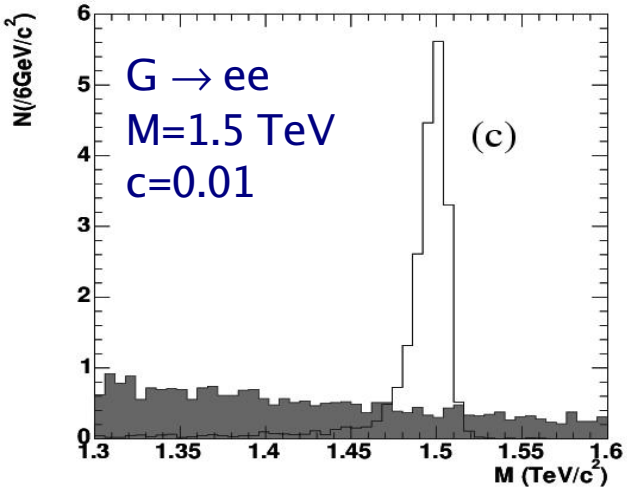
Selection: 2 electrons: Et>100 GeV in ECAL + track,
+ FSR recovery, H/E, isolation
Reconstruction: saturation of ECAL readout electronic because of limited dynamical range of the Multi-Gain- Pre-Amplifier: if E1>1.7 TeV (in barrel) and 3.0 TeV in Endcap



Mass resolution: ~0.6 % for non saturated events and ~7% for saturated events







High mass di-photons

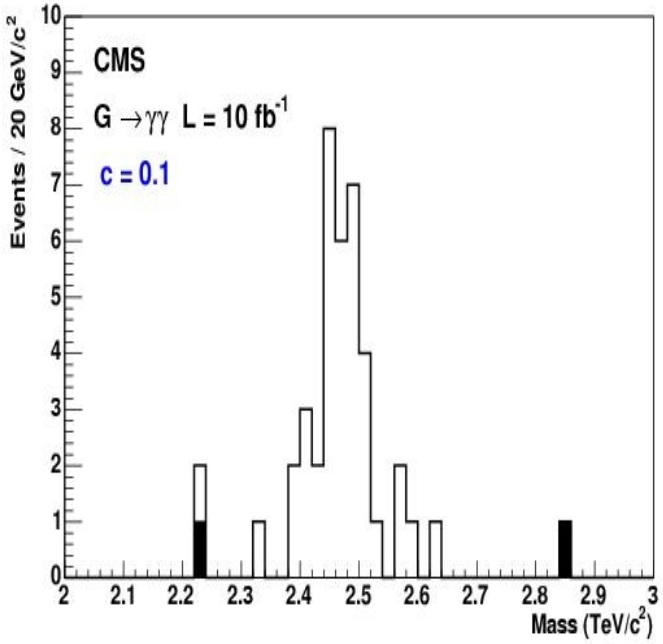
M.-C. Lemaire et al. CMS NOTE 2006/051

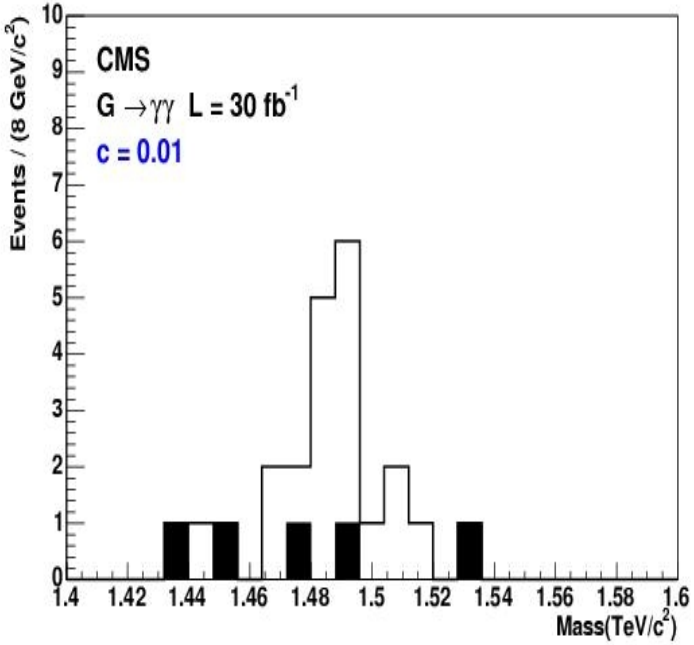
$pp \rightarrow G \rightarrow \gamma\gamma$

Important channel: Identify a graviton: $G \rightarrow \gamma\gamma$, distinguish to Z'

Main bg: prompt diphoton (irreducible)
(γ+ jets, QCD jets, DY(ee))

Selection: 2 electrons Et>150 GeV in ECAL, H/E, isolated in ECAL/tracker
Reconstruction: saturation correction





High mass di-muons

R. Cousins et al. CMS NOTE 2005/002
CMS NOTE 2006/062

$pp \rightarrow HR \rightarrow \mu\mu$
Heavy Z from GUT (Z') and RS(G)

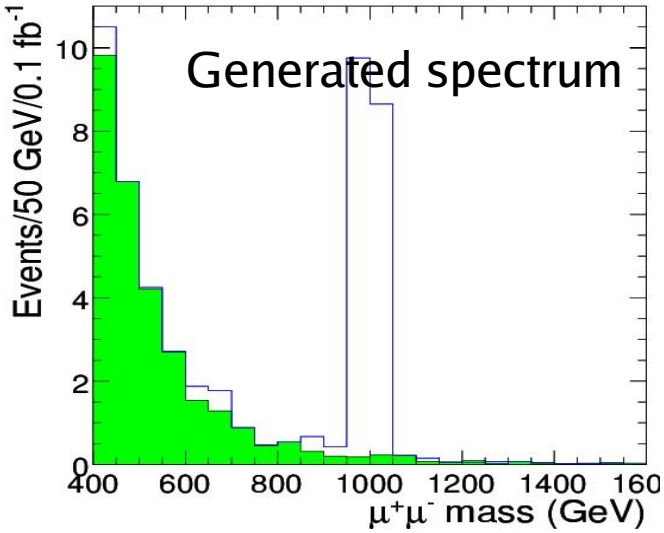
Dominant and irreducible bg: DY: $pp \rightarrow \gamma/Z \rightarrow \mu\mu$
others: ZZ,ZW,WW tt: few % of DY bg

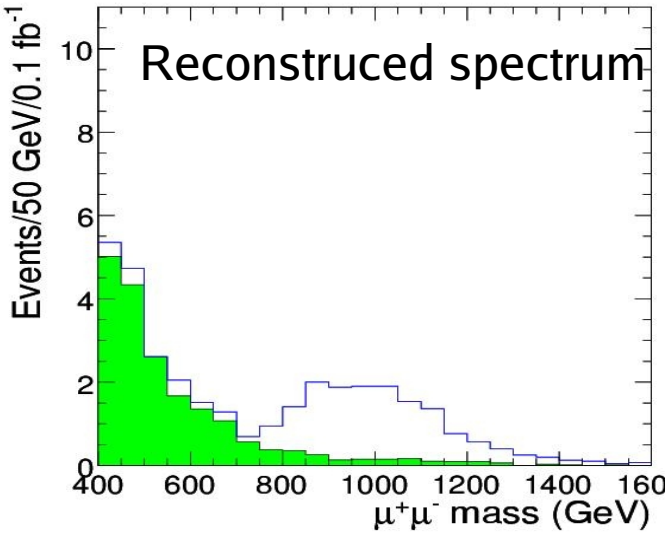
Selection:
- muon acceptenace |eta| <2.4
- at least 2 muons of opposite charge + FSR recovery
- overall acceptance ~75-85 %

Reconstruction: misalignment of tracker + muon system:
"first data" (0.1 fb^{-1}) and "long term" (1 fb^{-1}) scenarios

Mass resolution: 4.2 (1TeV) to 9% (5TeV) - long term
12.5 % (1 TeV) first data

Example: mass spectrum for 1TeV Z'(η) signal and DY bg
(L=0.1 fb^{-1}, and using "first data" misalignment).





Significance

Significance:

- for ee and $\gamma\gamma$: $S = \sqrt{(2\,(Ns+Nb)\,\ln(1+Ns/Nb)-Ns)}$
- for $\mu\mu$: signal observability: used an unbinned maximum likelihood fit to $\mu\mu$ spectrum over range peak+bg tail.

$S=\sqrt{\ (2\ln\,(L(s+b)/L(b)\ )}$

L(s+b) is the maximum likelihood value obtained in the full (signal + bg) fit

Discovery limit is defined S>5

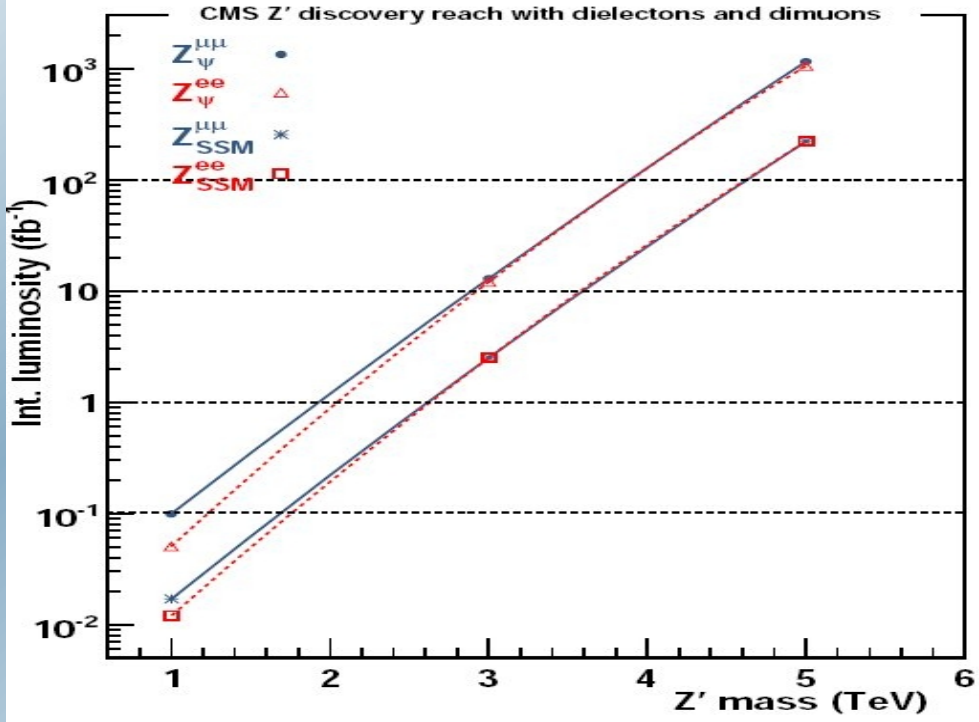
Cross section: use pythia LO

K factor (for NNLO QCD correction) - K = 1.3 for signal and bg

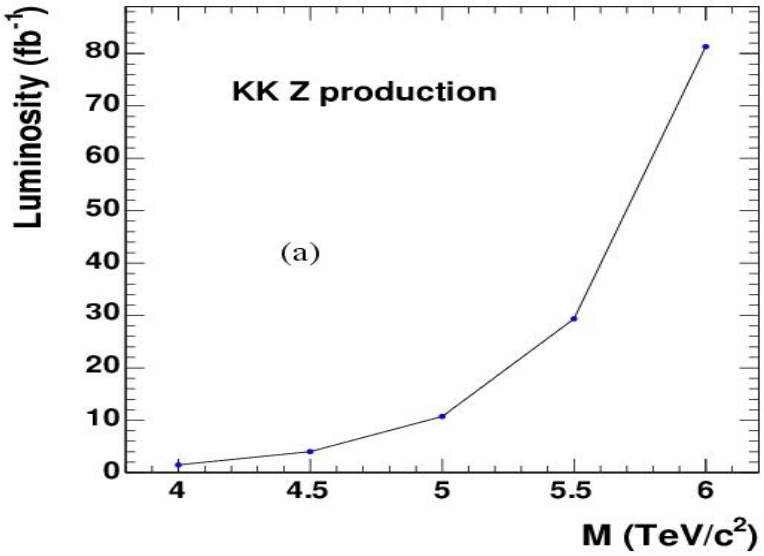
Discovery limits

CMS PTDR(volII) CERN/LHCC 2006-021

For Z' production:



For KKZ production:



Reach: Z' mass up to 1 (3) (5) TeV with L<~ 0.1 (10) (1000) fb^{-1}

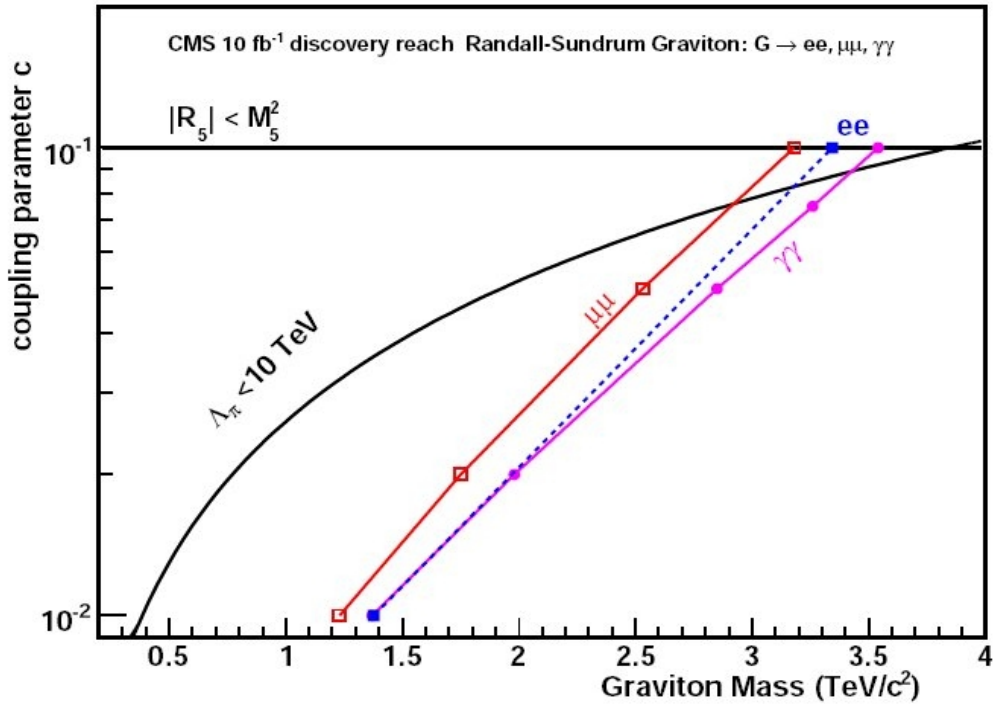
Reach: KKZ mass up to 5 (5.5) (5.9) TeV with L=10 (30) (60) fb^{-1}

$\mu\mu$: low Land low mass: suffers from misalignment effects (recover for L>10 fb^{-1})
ee: high mass: suffers from ECAL electronic saturation, degrade the mass resolution

Discovery limits

CMS PTDR(volII) CERN/LHCC 2006-021

For G production:



Reach: Most of the interesting plane in (M, c) for L<10 fb^{-1}

- BR for G → γγ is ~twice the one for ee or μμ
- Low c and mass: γγ channel suffers from QCD and prompt photon bg

High energy single lepton

C. Hof et al. CMS NOTE 2006/117

$W' \rightarrow \mu\nu$

Search for heavy W' :
L-R models , composite models, little Higgs model

Use “reference model”: generic W' (same coupling as W, except opening tbbar for M(W')>180 GeV))

Topology: μ + missing Et
bg:$W\rightarrow\mu\nu$, $Z\rightarrow\mu\mu$, WW incl., ZZ incl., ZW incl., tt.

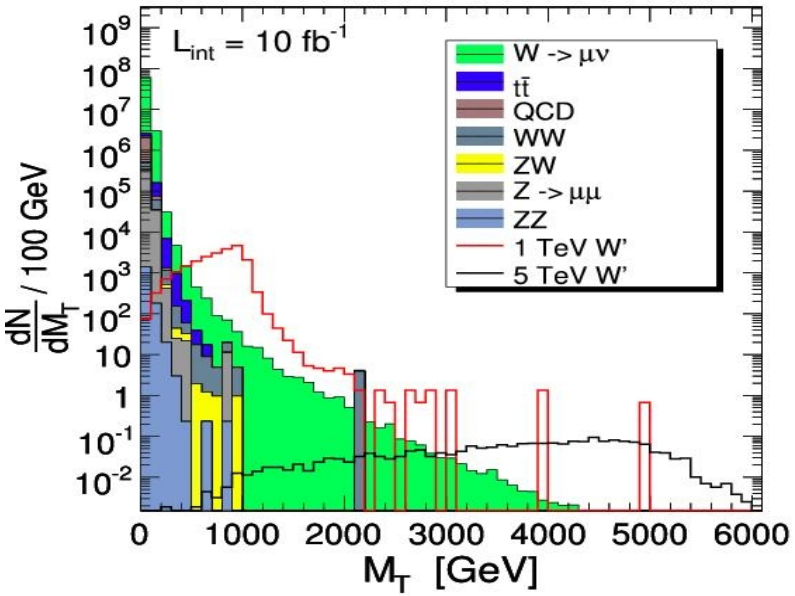
Selection: single muon (good quality fit) + isolation

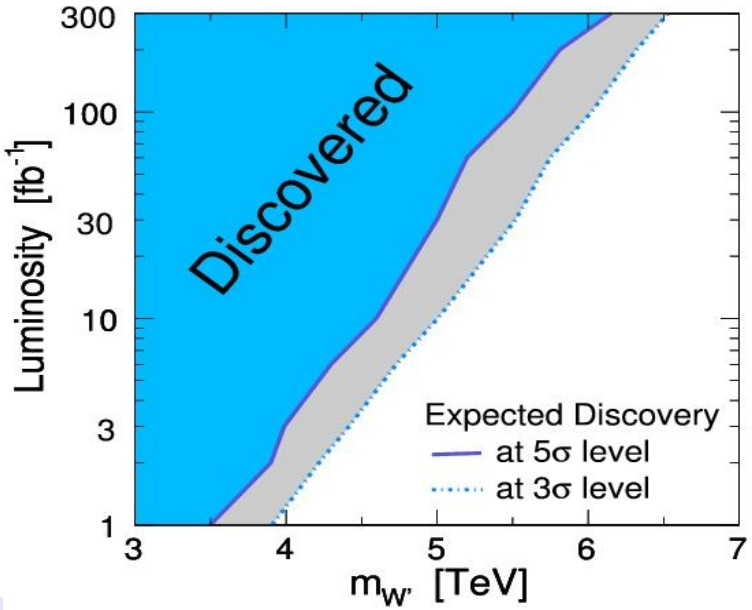
Transverse mass: $M_T = \sqrt{\ (2 pt(\mu)\ Et(miss)\ (1-\cos\Delta\Phi)\ )}$

Peak is spread at large M_T due to detector resolution

CLs method applied, based on likelihood ratio, calculated for all bins of the M_T distribution.

Expected discovery: M(W')<5TeV for L=10 fb^{-1}





Theoretical uncertainties

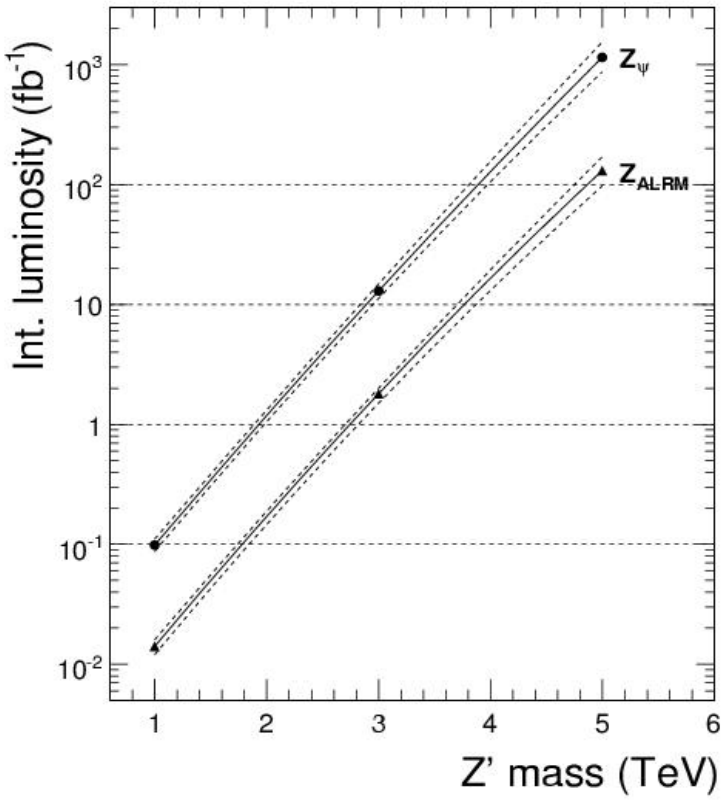
QCD and EW high-order corrections (K factors)

Parton Distribution Functions (PDF)

Hard process scale (Q2)

Cut efficiency, significance estimators..

Discovery plane for Z' :
1 σ band



systematics on signal W' production cross section:

Systematic Uncertainties					
Type	1 TeV W'	2 TeV W'	3 TeV W'	4 TeV W'	5 TeV W'
PDF $\Delta\sigma/\sigma$	$^{+3.6}_{-4.3}$	$^{+6.8}_{-5.9}$	$^{+6.2}_{-8.3}$	$^{+17.1}_{-10.6}$	$^{+33.7}_{-18.9}$
Hard Scale $\Delta\sigma/\sigma$	$^{+4.1}_{-4.1}$	$^{+7.5}_{-6.9}$	$^{+10.4}_{-9.2}$	$^{+13.1}_{-10.3}$	$^{+14.8}_{-12.7}$
Luminosity $\Delta\mathcal{L}/\mathcal{L}$	$\pm 5\%$	$\pm 5\%$	$\pm 5\%$	$\pm 5\%$	$\pm 5\%$

Distinguishing among Z' models

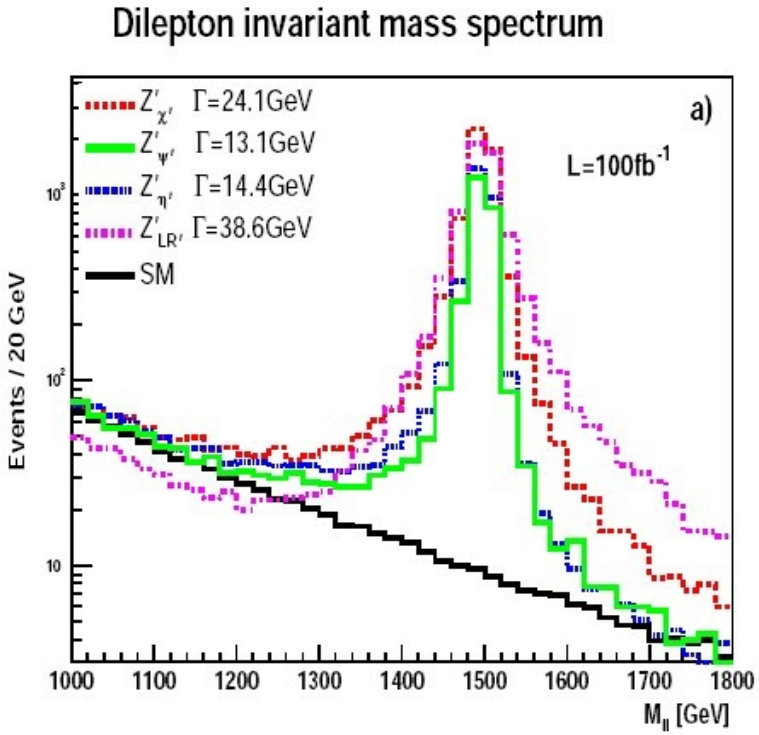
R. Cousins et al. CMS NOTE 2005/022

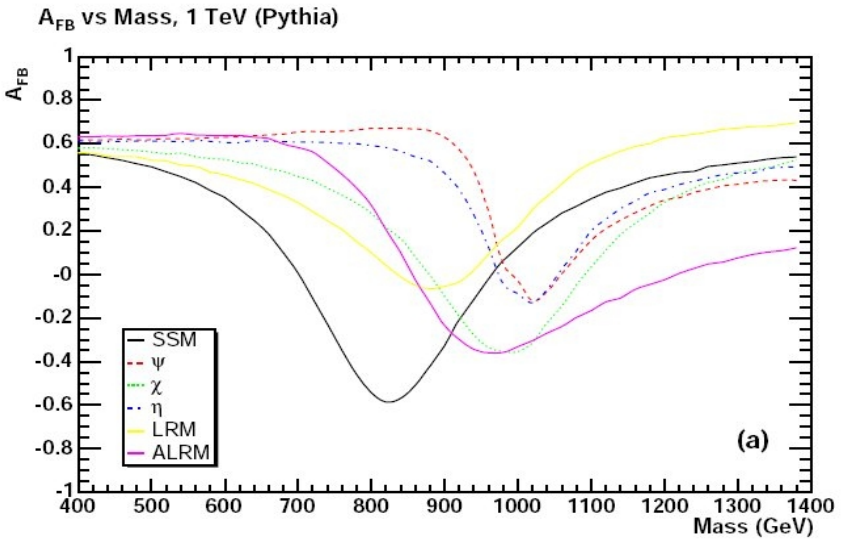
If new Z' resonance is discovered

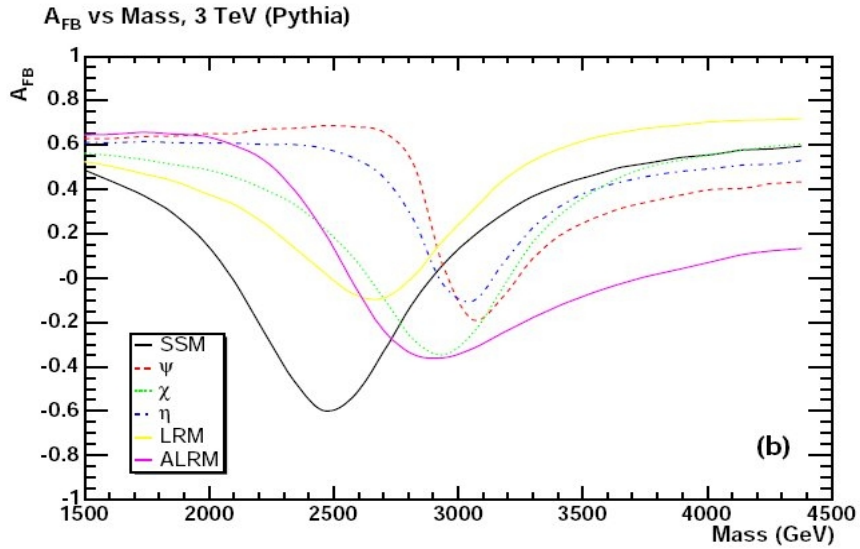
characterisation of its coupling using:

- production and decay distributions
- measurement of forward-backward asymmetries of leptonic decay product at the resonance peak and off-peak

-> info on parity violating couplings (can distinguish between Z' models)







Distinguishing among Z' models

- The forward-backward asymmetry:

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

$$\sigma_F \equiv \int_0^1 \frac{d\sigma(q\bar{q} \to \mu^+\mu^-)}{d\cos\theta^*} d\cos\theta^*$$

$$\sigma_B \equiv \int_{-1}^0 \frac{d\sigma(q\bar{q} \to \mu^+\mu^-)}{d\cos\theta^*} d\cos\theta^*$$

qq $\to$ μ+μ−

θ∗: angle between quark direction and μ− in μ−μ+ CM

For spin 1 (γ/Z/Z') propagators:

$$P(\cos\theta^*; A_{\rm FB}, b) = \frac{3}{2(3+b)}(1 + b\cos^2\theta^*) + A_{\rm FB}\cos\theta^*$$

A_{FB}: depends on left- and right- handed couplings of γ/Z/Z' to u and d quarks and charged leptons.

- Uncertainty in the sign of cosθ∗ in pp collision:

quark direction is ambiguous experimentally since the quark can come from either p

assume: longitudinal motion of the dimuon system gives the quark direction

$\to$ exist "mistagging probability" - high at low y value – low at high y value

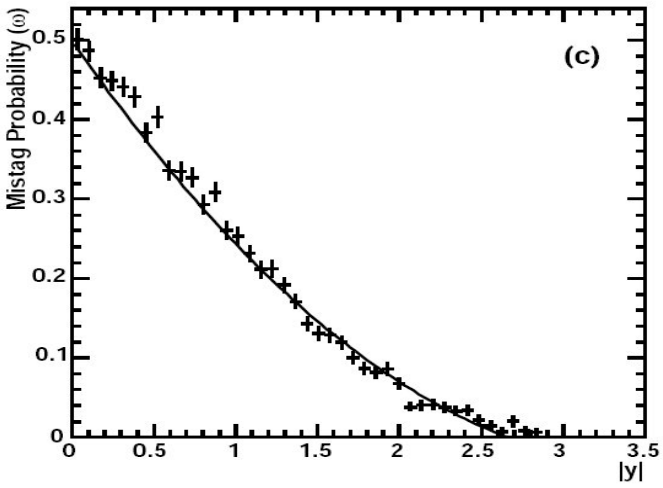
$\to$ dilute the A_{FB} if not corrected for

Use the Collins-Soper reference frame (pt effect)

To correct for mistag: y cut, A_{FB} in y bin or mistagging probability on an event by event basis (using all event)

Distinguishing among Z' models

Define a mistagging probability function: W(y, M)
unbinned likelihood fit on P(cosθ*) after mistag correction
→ nominal uncertainty on A_{FB}
= 0.09 in a fit of 400 events for 1 TeV Z'
0.08 400 3



Significance level (in term of sigma's)
for pairwise comparisons of Z' models:

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	–

at M=1 TeV, L=10 fb^{-1}

Model	Z_{ALRM}	Z_χ	Z_η	Z_ψ	Z_{SSM}	Z_{LRM}
Z_{ALRM}	–	0.3	2.5	3.0	3.2	4.2
Z_χ	0.2	–	1.4	1.7	1.8	2.4
Z_η	1.2	1.0	–	0.3	0.4	0.8
Z_ψ	1.4	1.3	0.3	–	0.1	0.5
Z_{SSM}	2.7	2.5	0.6	0.2	–	0.8
Z_{LRM}	2.8	2.6	1.1	0.8	0.6	–

at M=3 TeV, L=400 fb^{-1}

Spin discrimination

I. Belotelov et al. CMS NOTE 2005/104

If new resonance is discovered

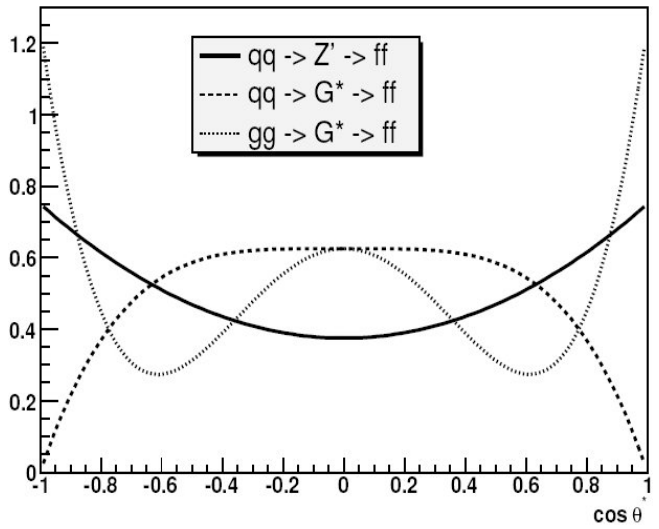
Characterisation of its spin and coupling using:

- Production and decay probabilities and distributions: for example $G \to \gamma\gamma$
- Angular distribution of the decay product : useful for spin discrimination

Spin-1 States: Z from extended gauge models, ZKK
Spin-2 States: RS1-graviton

Method: unbinned likelihood ratio statistics incorporating the angles in of the decay products the Collins-Soper frame consider only the even term in $\cos\theta^*$ (sign of $\cos\theta^*$ is random)

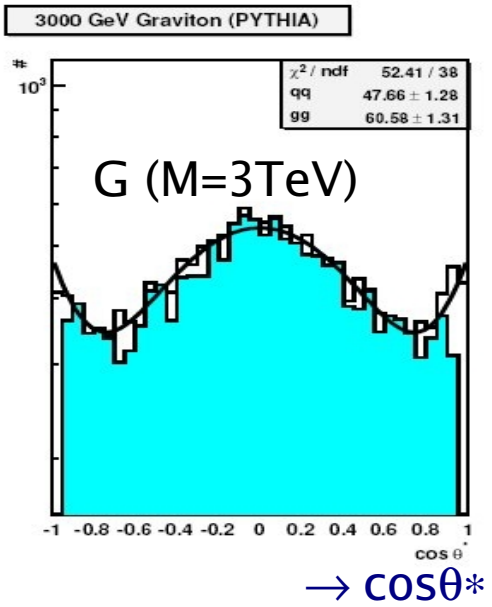
subprocess	angular distribution
$q\bar{q} \to \gamma/Z^0/Z' \to f\bar{f}$	$\frac{3}{8}(1+\cos\theta^{*2})$
$q\bar{q} \to G^* \to f\bar{f}$	$\frac{5}{8}(1-3\cos\theta^{*2}+4\cos\theta^{*4})$
$gg \to G^* \to f\bar{f}$	$\frac{5}{8}(1-\cos\theta^{*4})$



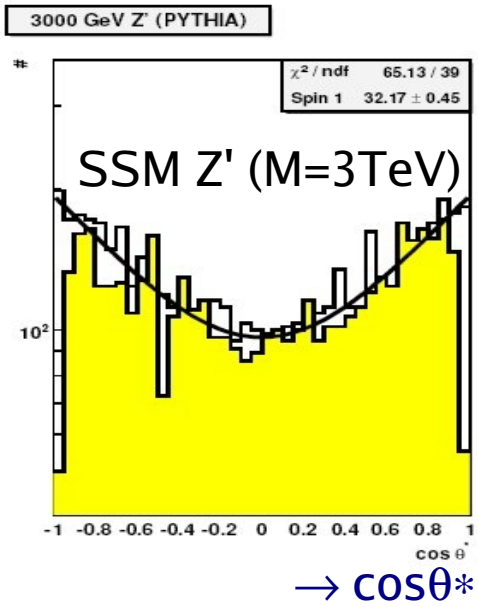
→ $\cos\theta^*$

Spin discrimination

The statistical technique has been applied to fully simu/reco events:



→ cosθ*



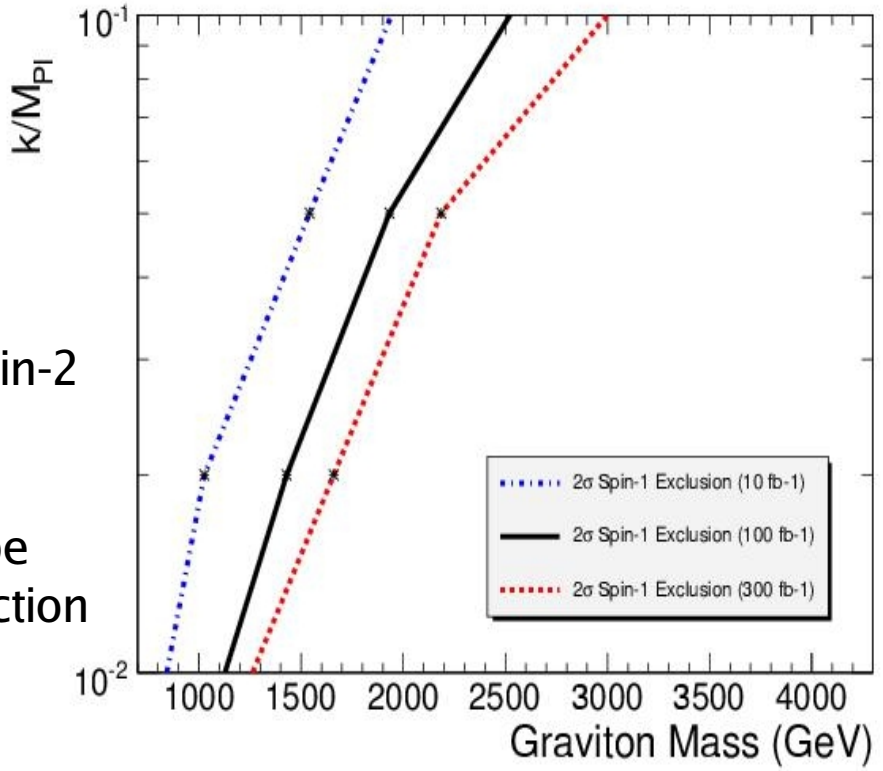
→ cosθ*

$\sqrt{s}$, TeV	c	$\int \mathcal{L} dt$, fb^{-1}	N_s	N_b
1.0	0.01	50	200	87
1.0	0.02	10	146	16
1.5	0.02	90	174	41
3.0	0.05	1200	154	22
3.0	0.10	290	148	6

Table: Integrated luminosity and numbers of signal and bg events required to distinguish spin-1 and spin-2 hypothesis (2σ)

Region in the (M, c) plane where RS graviton can be distinguisg from Z' (2σ) – having an equal cross section

Z' vs RS-graviton



High mass dijets

K. Gumus et al. CMS NOTE 2006/070

Search for dijet resonance (pp → X → jet+jet)

Sensitivity to observing narrow resonance signal on a high QCD bg - Challenging channel: large QCD bg and often limited dijet mass resolution

Goal: as generic an analysis as possible

Give the CMS cross section sensibility for 95% CL and 5 σ discovery

Compare to 8 benchmark models:

First five: produced via strong interactions

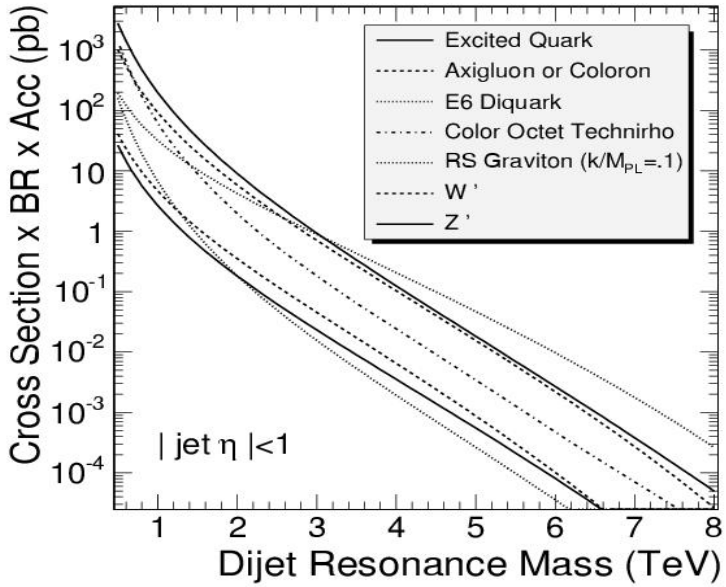
last three:electro-weak coupling – lower cross-section

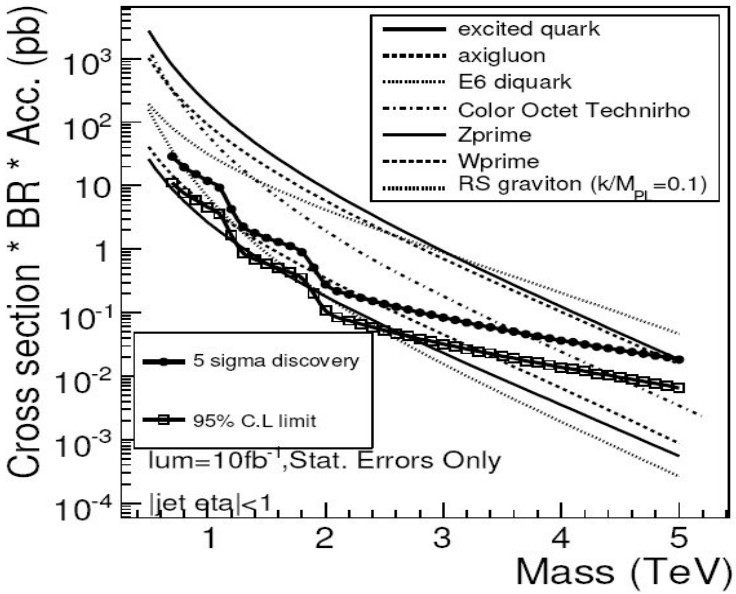
no 5σ discovery potential

but exclusion at 95%CL

|η|(jet)<1

Resonance Model	95% CL Excluded Mass (TeV/c^2)			5σ Discovered Mass (TeV/c^2)		
	100 pb^{-1}	1 fb^{-1}	10 fb^{-1}	100 pb^{-1}	1 fb^{-1}	10 fb^{-1}
Excited Quark	0.7 - 3.8	0.7 - 4.8	0.7 - 5.8	0.7 - 2.9	0.7 - 3.9	0.7 - 5.0
Axigluon or Coloron	0.7 - 3.6	0.7 - 4.6	0.7 - 5.6	0.7 - 2.6	0.7 - 3.8	0.7 - 4.8
E_6 diquark	0.7 - 4.1	0.7 - 5.6	0.7 - 7.0	0.7 - 2.8	0.7 - 4.5	0.7 - 6.0
Color Octet Technirho	0.7 - 2.4	0.7 - 3.4	0.7 - 4.5	0.7 - 1.8	0.7 - 2.6	0.7 - 3.6
Randall-Sundrum Graviton	0.7 - 1.1	0.7 - 1.7	0.7 - 1.7 1.9 - 2.4	0.7 - 0.8	0.7 - 0.8	0.7 - 0.8
W′	0.7 - 1.0	0.7 - 1.0 1.2 - 2.1	0.7 - 1.0 1.2 - 3.4	N/A	N/A	2.0 - 2.3
Z′	N/A	1.2 - 1.5	1.3 - 1.5 1.9 - 2.6	N/A	N/A	N/A

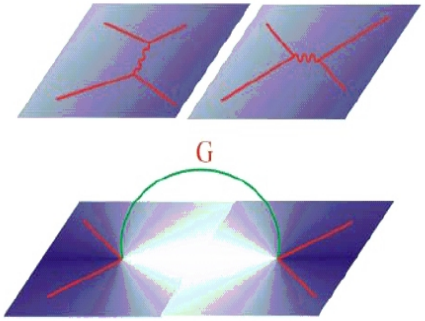




ADD virtual Graviton

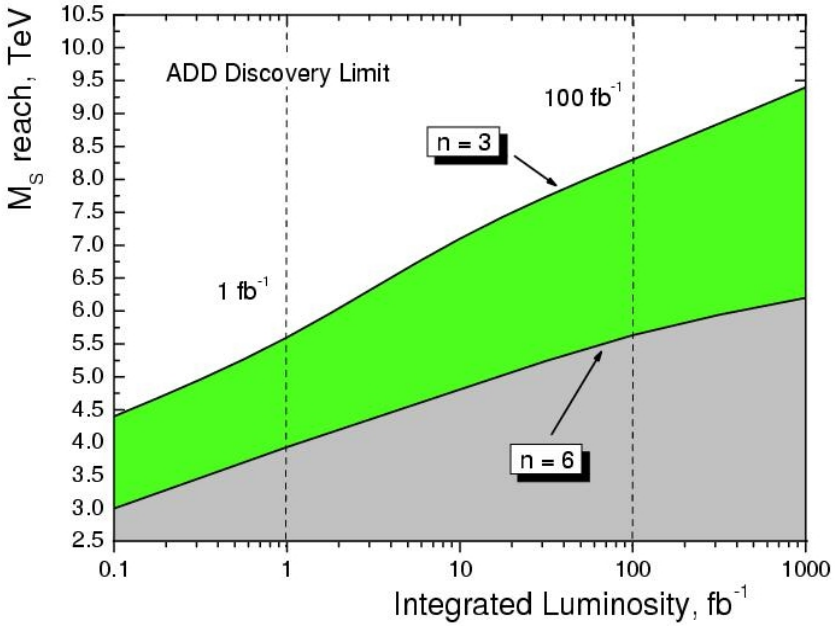
I. Belotelov et al. CMS NOTE 2006/076

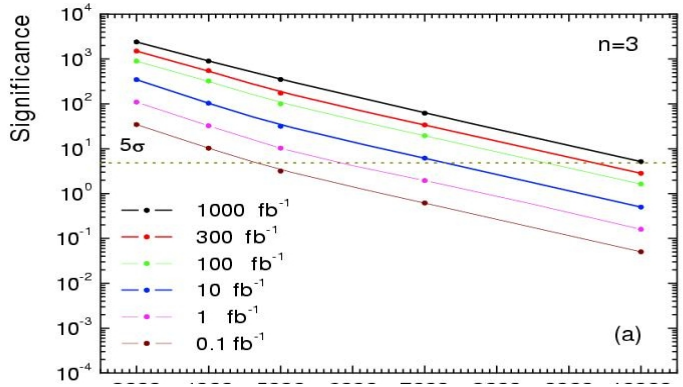
Search for deviation of the μμ DY spectrum due to virtual graviton exchange (KK mode of G) - in ADD ED framework
Planck scale: $3<M_S<10$ TeV and n=3 to 6.

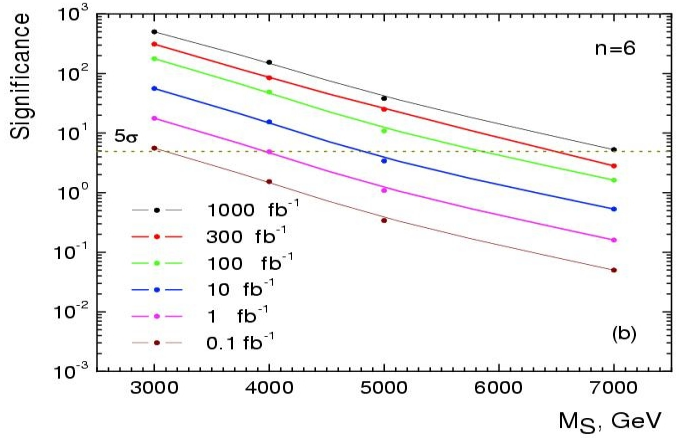


Similar selection/bg as for μμ resonance search
Significance (only statistical error) →

Discovery limits: includes systematics: misalignment, K factor (1.3 +-0.05), hard scale and PDF, trigger





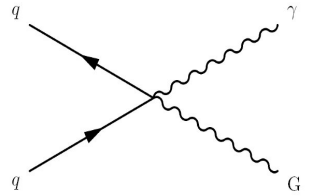


ADD direct Graviton

J. Weng et al. CMS NOTE 2006/129

Search for direct graviton emission in ADD type of ED framework
(KK mode of G)

Topology of single photon events: high pt photon in central η region
+ high missing pt back to back in ϕ

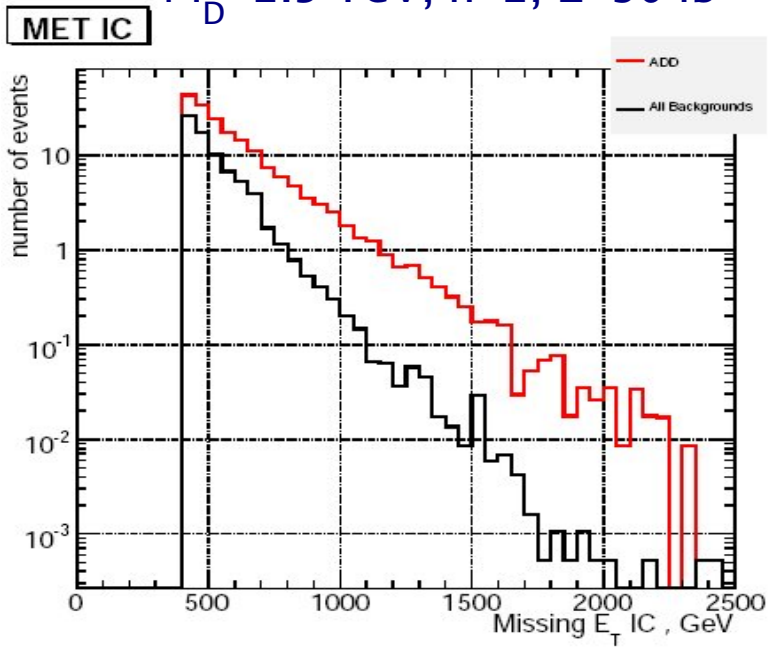


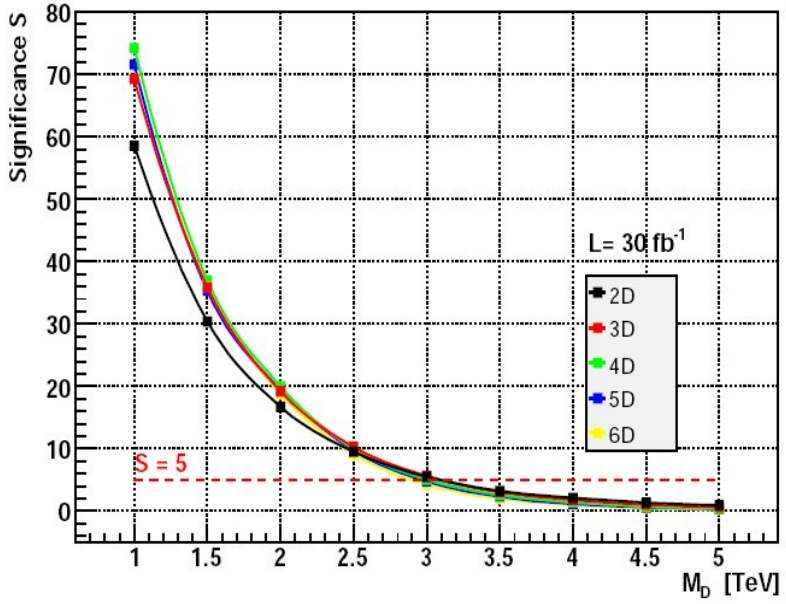
Selection: Et(miss)>400GeV and pt(γ)>400 GeV, |η|(γ)<2.4, Δϕ>2.5, track veto (pt>40GeV), isolated photon (veto jets)

Largest irreducible bg: $Z/\gamma \rightarrow \nu\nu + \gamma$ (also $W^{+-}\gamma$)

Reach: M_D<2.5 TeV (n=2-6)
M_D<3.0 TeV (n=2-4)

M_D=2.5 TeV, n=2, L=30 fb^{-1}





Conclusions

- Discovery potential of various Z' and ED scenarios at the TeV scale:
  Various Z' models and W'
  Randall-Sundrum model
  TeV^{-1} extra dimension model
  Large extra dimension

- High detector performance → search in different channels / topologies
  - resonant peak: lepton/photon/jet final state
  - deviation to continuum
  - large Et(miss) final state

  allows: - confirmation of the signal
  - identification of the signal
  + model and spin discrimination

→ **Rich potential at the LHC**
in particular *already* at the LHC start up: luminosity < few fb^{-1}