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Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

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Search for Dilepton Resonances at CMS

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Search for Dilepton Resonances in CMS

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BSM: Beyond the Standard Model:
results with the 7 TeV LHC Collision Data,
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Outline

- LHC and CMS
- Electron, muon ID and jet background (common to the 2 analyses presented here)
- Search for heavy dilepton resonances (1.1/fb of 2011 data)
- Search for excited leptons (36/pb of 2010 data)
- Conclusion

LHC

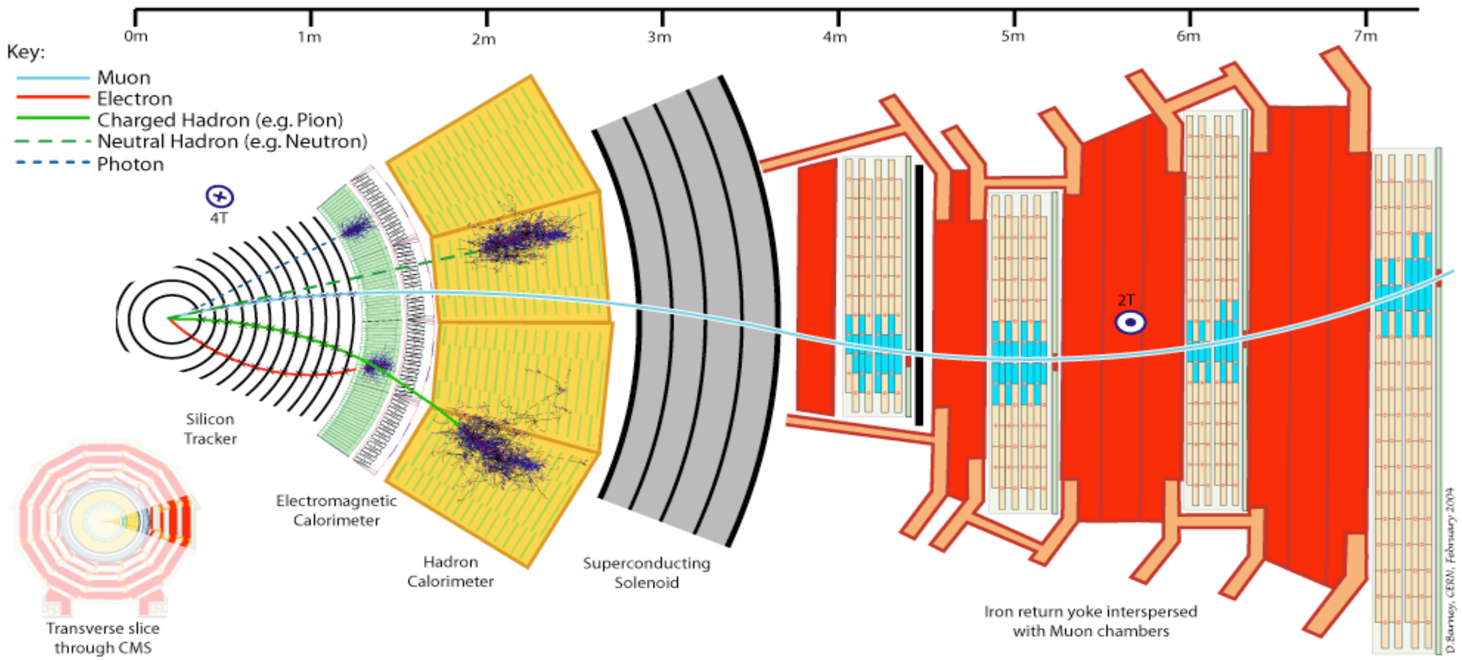
- (Re)Started in Oct 2009 (900 GeV then 2.38 TeV)
- On 30 March 2010, switched to 7 TeV
- 2.7/fb delivered at 7 TeV (as of early September 2011)
- Has already delivered much more than expected for 2011

- Expect to double the integrated luminosity at the end of this year (end of pp run on 30 october)

CMS

- Fine-grained ECAL. $\Delta E/E < 0.5\%$ for $E > 100$ GeV
- Inner tracker in 3.8 T magnetic field, plus muon system for triggering, id, and to improve high-pT measurement. $\Delta p_T/p_T < 10\%$ at $p_T \sim 1$ TeV.

→Muon id much easier than electron id, but m_{ee} resolution much better than $m_{\mu\mu}$



Lepton ID

- Both analyses use official CMS high energy electron and muon ID

  - Selection optimized for high efficiency at high energy
  - Lowest E_T unprescaled diphoton and single-muon trigger
  - Offline E_T cut above trigger turn-on:
    - Electron: E_T > 25 GeV (2010), E_T > 35-40 GeV (2011)
    - Muon: E_T > 20 GeV (2010), E_T > 35 GeV (2011)
  - Energy scale correction applied (important for endcap electrons)
  - ID and trigger efficiencies measured with the tag-and-probe method
  - Scale factor to account for data-MC efficiency difference applied

Jet Background

- A jet can fake an electron, a muon or a photon

- Measure this contamination with « Fake Rate » method
  - Measure probability for a jet reconstructed as a lepton/photon (with loosened cuts) to pass rest of selection.
  - Apply to get mass spectrum from jets and compare to MC
  - Different methods/jet trigger thresholds give systematic uncertainty.

Search for heavy dilepton resonances

Introduction

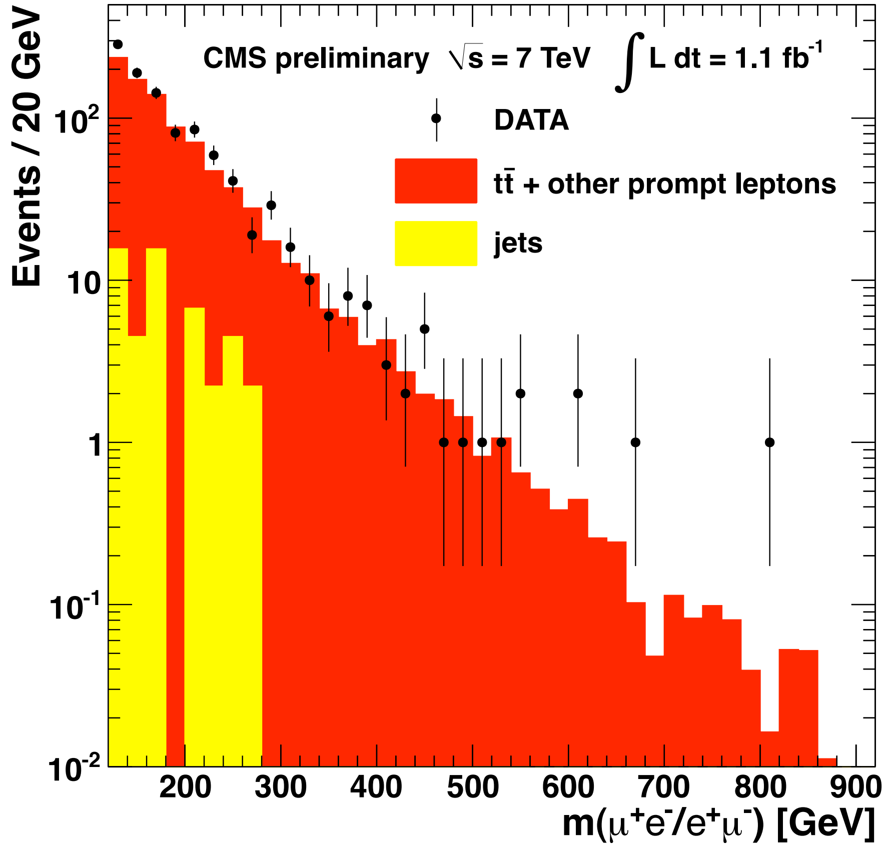
- New gauge bosons Z' or Randall-Sundrum gravitons G_{KK}
  - new narrow high-mass resonances.
- Generic shape-based search:
  - no assumptions on absolute background rate.
- Results normalized to the Z^0 peak:
  - luminosity uncertainty and other systematic effects cancel or are reduced.
- Dielectron and dimuon channels are actually quite different:
  - muon selection looser (less background from jets)
  - dielectron acceptance smaller (endcap-endcap pairs rejected and gap between barrel and endcap)
  - requirement on charges only for muons
  - cosmic rays useful to understand high pt muons and test special algorithms (and are also a source of bakground)

Dilepton background

- Dominant: irreducible Drell-Yan (DY) production
  - use DY shape from simulation in search.
- Next biggest (10% of DY above 120 GeV): ttbar and other sources of prompt leptons
  - check in data using « $e\mu$ method » (see next slide).
- Dileptons from misidentified jets:
  - Use « fake rate » method (see slide 6)
  - For dimuons, negligible (<1% of DY rate above 120 GeV)
  - More important for dielectrons : about 5% of the DY rate above 120 GeV.
- Cosmic-ray muons:
  - using sidebands, estimate less than 0.1 remaining dimuon event above 120 GeV.

emu method

- Expect two $e\mu$ events for every ee or $\mu\mu$ event, then scale by different e,μ efficiencies.
- Extract scale factor N(ee,$\mu\mu$)/ N($e\mu$) from MC in bins of dilepton mass.
- Currently just a cross-check – but good agreement between data and MC.

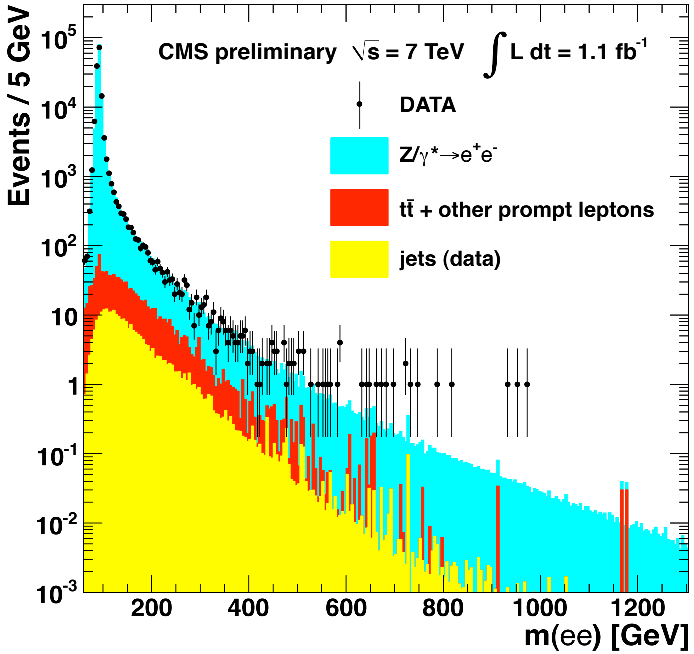


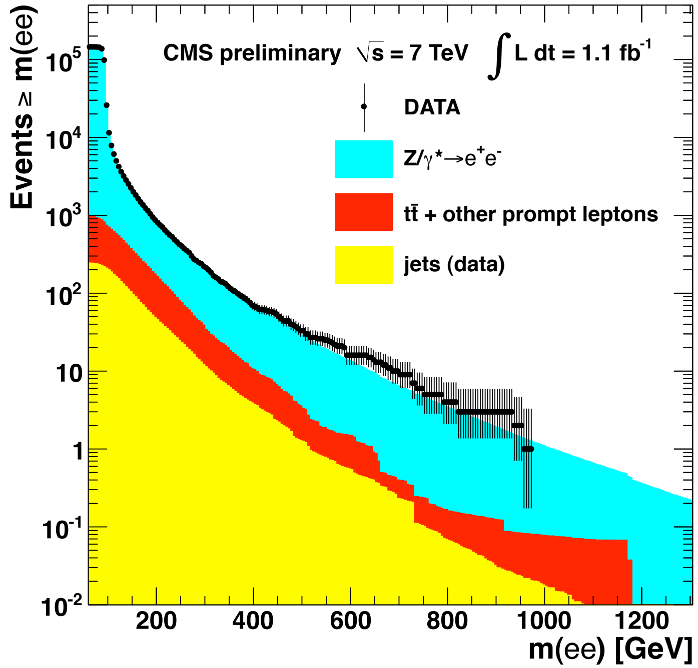
Dielectron mass spectrum

MC distributions normalized to NLO cross sections, then overall to the data at Z peak in 60-120 GeV.

Uncertainties in table: statistical ⊕ systematic.

Source	Number of events	
	(120 − 200) GeV	>200 GeV
CMS data	3410	809
Total background	3375 ± 161	787 ± 67
Z/γ^*	2992 ± 149	622 ± 62
$t\bar{t}$ + other prompt leptons	275 ± 41	118 ± 17
Multi-jet events	107 ± 43	46 ± 18



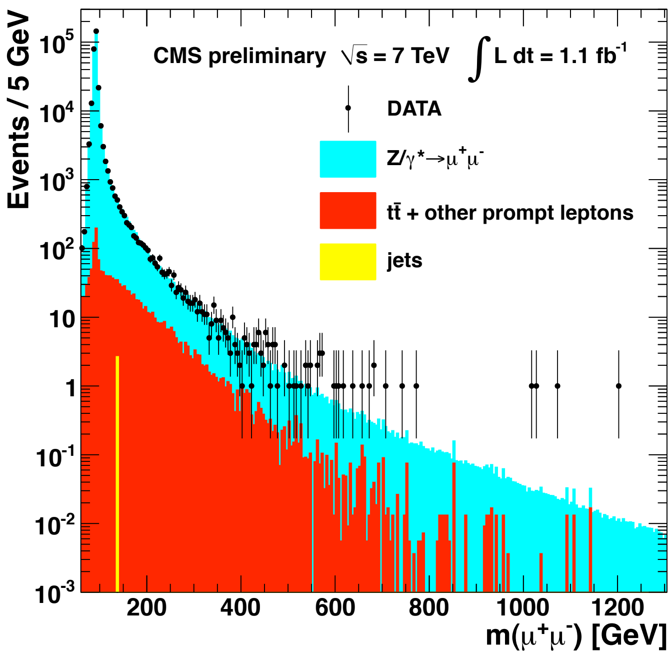


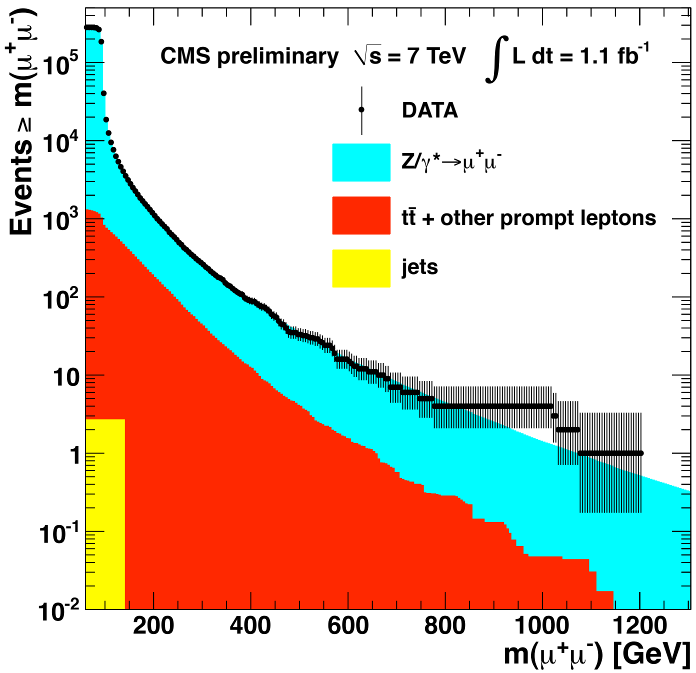
Dimuon mass spectrum

MC distributions normalized to NLO cross sections, then overall to the data at Z peak in 60-120 GeV.

Uncertainties in table: statistical ⊕ systematic.

Source	Number of events (120 – 200) GeV	Number of events >200 GeV
CMS data	5216	1095
Total background	5537 ± 250	1100 ± 48
Z/γ^*	5131 ± 246	922 ± 44
$t\bar{t}$ + other prompt leptons	404 ± 46	178 ± 20
Multi-jet events	3 ± 3	0





Resonance search

- Simple signal and background pdf, with shape parameters from MC.
- Use likelihood ratio to calculate uncorrected significance S_L as a function of mass M.
- Correct for Look Elsewhere Effect

$$\mathcal{L} \sim \prod_i f_{\text{signal}} + f_{\text{background}}$$

$$f_{\text{signal}} \sim \text{Breit-Wigner}(m|M,\Gamma) \otimes \text{Gaussian}(m|M,w)$$

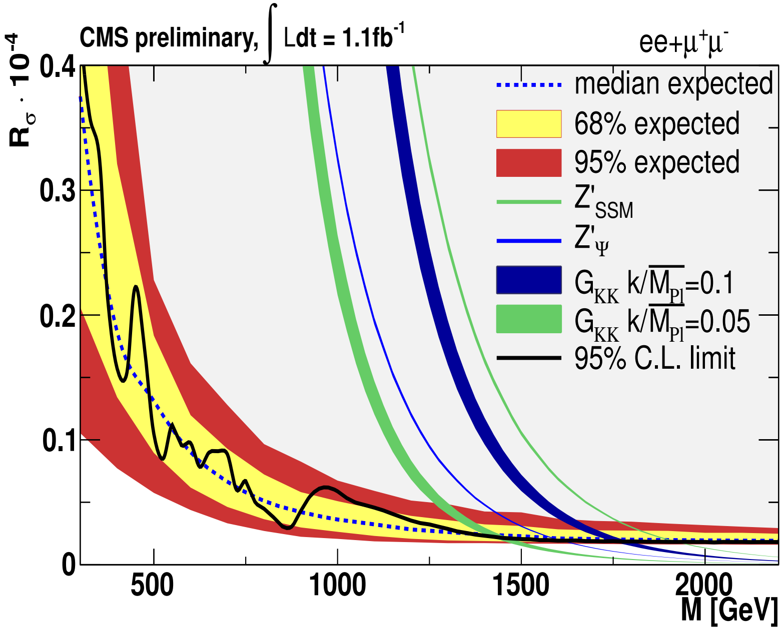
$$f_{\text{background}} \sim \exp(-am)/m^b$$

$$S_L = \sqrt{2 \ln \frac{L_{S+B}^{\max}(f_s)}{L_B}}$$

Channel	Most significant bump mass	Local Z(σ)	LEE-corrected Z(σ)
ee	950 GeV	2.1	0.2
μμ	1080 GeV	1.8	0.3
ee+μμ combined	970 GeV	2.1	0.2

Limits

- Limits (95% CL) on ratio of cross sections times branching fractions (R_σ) using a Bayesian method



channel	μμ	ee	μμ + ee
Z'_{SSM}	1780 GeV	1730 GeV	1940 GeV
Z'_ψ	1440 GeV	1440 GeV	1620 GeV
G_{KK}, c=0.05	1240 GeV	1300 GeV	1450 GeV
G_{KK}, c=0.1	1640 GeV	1590 GeV	1780 GeV

Search for excited leptons

Introduction

- The Standard Model's lepton mass hierarchy can be explained by the existence of lepton substructure

  - Leptons made up of bound states of 3 fermions or a fermion and a boson that can be excited and then decay to ordinary leptons
- Here, search for the production of an excited lepton (e^*/μ^*) in association with a SM lepton via novel contact interactions (scale determined by parameter Λ)
- The excited lepton then decays via the electroweak interactions resulting in a final state of two high E_T leptons (ee or μμ) and one high E_T photon
- The decay width for other decay modes taken into account:

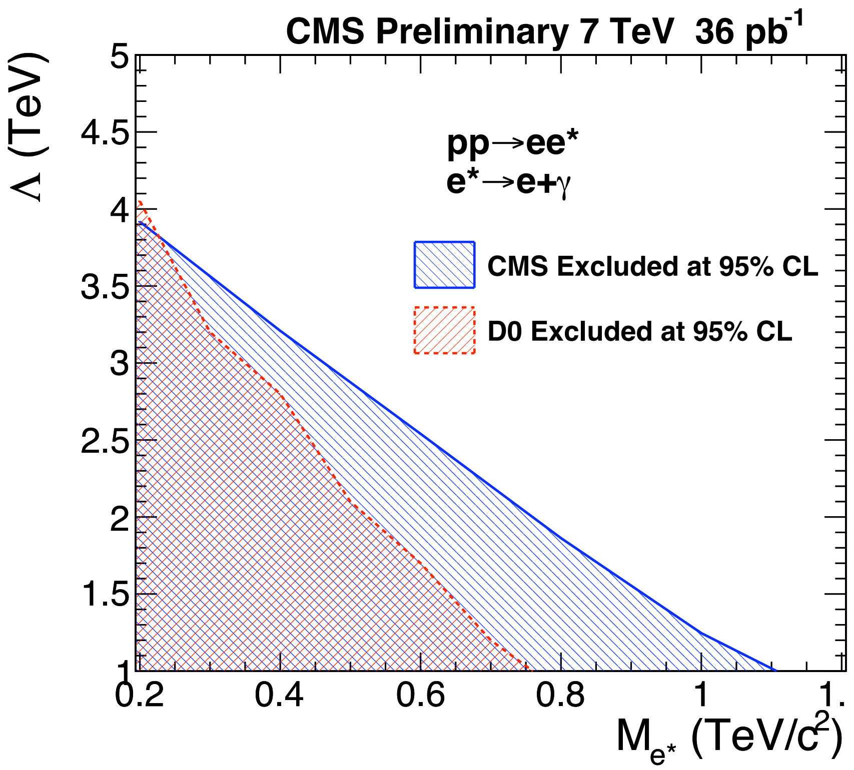
  $BR(l^* \rightarrow l+\text{photon})=25\%$ for low M^*/Λ
- Two theory parameters: Λ and excited lepton mass (M^*)

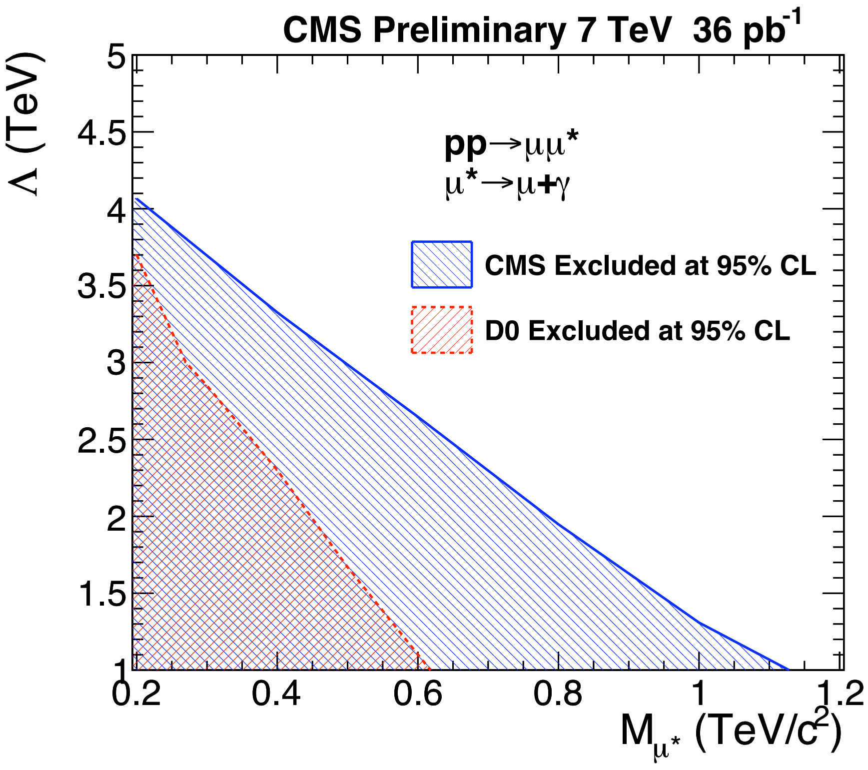
Analysis

- Background:
  - $Z\gamma \rightarrow l^+l^+ \gamma$: Estimated from simulation.
  - Fake γ: dominated by Z + jets : Use Photon fake rate
  - Fake l: dominated by $W\gamma$ + jets: Use lepton fake rate
  - $Z\rightarrow\tau\tau$, ttbar, WW, WZ, ZZ, $W\rightarrow l\nu$, diphoton (e*) taken into account.
- Event Selection
  - Require two muons/electrons. Require one photon with E_T> 20 GeV in ECAL barrel ($|\eta|$ < 1.4) , with ΔR to the nearest lepton above 0.5
  - Require M(ll)>60 GeV (eliminates low-mass Drell-Yan).
  - Lower mass cut (value depends on M* hypothesis) made on the maximum $l\gamma$ invariant mass
- No signal candidates observed in data.
- Perform a counting experiment and set 95% CL limits using the standard Bayesian method.

Limits

Data (M*=200 GeV)	0 (e*)	0 (mu*)
Expected Bkg	0.68 ± 0.20	0.98 ± 0.22
Z γ	0.36 ± 0.12	0.75 ± 0.15
Fake γ	0.10 ± 0.07	0.22 ± 0.14
Fake e (mu)	0.22 ± 0.11	0.00 ± 0.06





Conclusion

- Both LHC and CMS are performing very well
- Dilepton resonances are a good handle to new physics.
- Here, search for excited leptons, Z' and Randall sundrum gravitons G_{KK}
  - there is also a Z' to ττ search: M > 468 GeV @ 95% C.L. (assuming SM-like couplings, with 36/pb)
- No significant excess so far, everything agrees with SM
- A lot more data to be accumulated this and next year.

BACKUP SLIDES

Dilepton systematics

- 3% (8%) on the acceptance times efficiency ratio evolution from low to high mass for dimuons (dielectrons), which includes PDF uncertainties (relevant to the acceptance) and the mass dependence of K-factors.
- For dimuons, sensitivity study to mass scale uncertainty (affecting only the region below 1250 GeV where there are events) showed negligible impact up to the maximum possible from alignment effects; for dielectrons, study at Z0 peak results in 1% for barrel and 3% for endcap.
- For dimuons, effect of possible $\chi 2$-invariant "weak mode"in alignment, which corresponds to a muon tracking curvature bias, folded into estimate of Gaussian width for signal pdf.
- Shape systematics explored:

  – include an extra background shape representing the ttbar component and varying its amplitude;

  – trying a different functional form for the background pdf;

  – and changing the low-mass cut-off point for the DY shape fit from 200 GeV down to 150 GeV, which changes the background shape parameters.

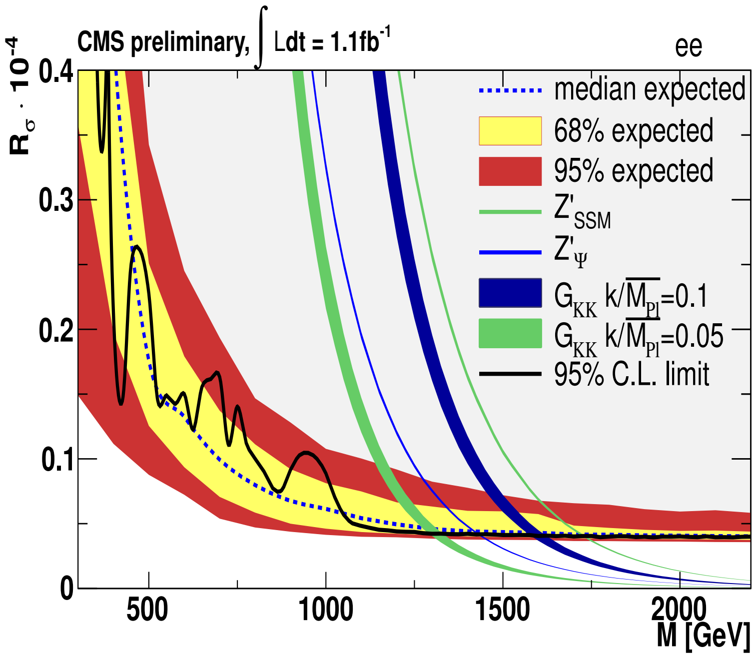
Likelihood function

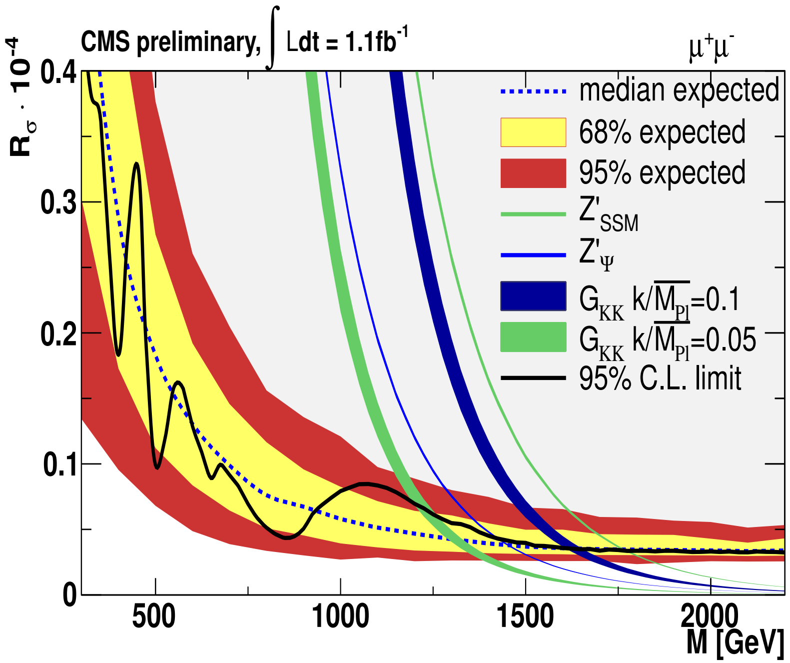
$$\mathcal{L}(\boldsymbol{m}|R_\sigma, M, \Gamma, w, \alpha, \kappa, \mu_B) = \frac{\mu^N e^{-\mu}}{N!} \prod_{i=1}^{N} \left(\frac{\mu_S(R_\sigma)}{\mu} f_S(m_i|M,\Gamma,w) + \frac{\mu_B}{\mu} f_B(m_i|\alpha,\kappa) \right)$$

with:

- m_i = observed mass spectrum;
- $f_S(m_i|M,\Gamma,w)$ = signal pdf, Breit-Wigner of width Γ and mass M, convoluted with Gaussian with width w;
- $f_B(m_i|\alpha,\kappa) \sim \exp(-\alpha m) m^{-\kappa}$ = background pdf;
- $R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$ = the cross section ratio, which goes into the likelihood function as part of the signal Poisson mean $\mu_S = R_\sigma \cdot \mu_Z \cdot R_\epsilon$, where μ_Z is the Poisson mean number of $Z^0 \to$ ee or μμ events, and R_ϵ is the ratio o total efficiency for Z′ and Z^0 decays;
- μ_B is the Poisson mean of the total background yield, $\mu = \mu_S + \mu_B$, and N is the total number of events with mass above 600 GeV.

Limits in individual channels





Photon ID

Photon ID Variable	Cut Threshold
$\|\eta\|$	< 1.4442
E_T	$> 20.$ GeV/c
H/E	< 0.05
Tracker Isolation	$< 2.0 + 0.001 * E_T$
ECAL Isolation	$< 4.2 + 0.006 * E_T$
HCAL Isolation	$< 2.2 + 0.0025 * E_T$
$\sigma_{i\eta i\eta}$	0.013
hasPixelSeed	No Requirement

- Tight ID
- Only ECAL barrel photons
- Data/MC scale factor applied to account for the difference between data and MC: 0.967 ± 0.025

Excited leptons systematics

Source	Magnitude	Error on signal efficiency (%)	Error on bkgd. expectation (%)
Luminosity	11%	-	8.5
Photon Fake Rate	46%	-	10
Muon Fake Rate	50%	-	6.2
Ecal Energy Scale	1.3%	0.1	0.4
Photon ID	0.025	2.6	1.9
Muon ID	0.01	2.1	1.6
PDF and scales	-	0.8	3