Search for narrow high-mass resonances in the dielectron + dimuon final states at CMS

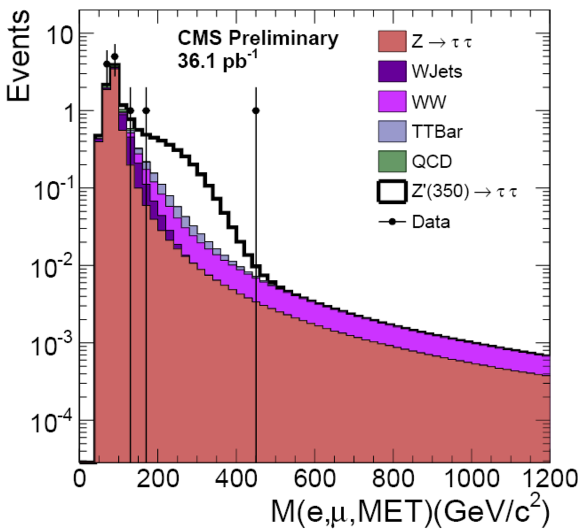
(CMS-PAS-EXO-11-019)

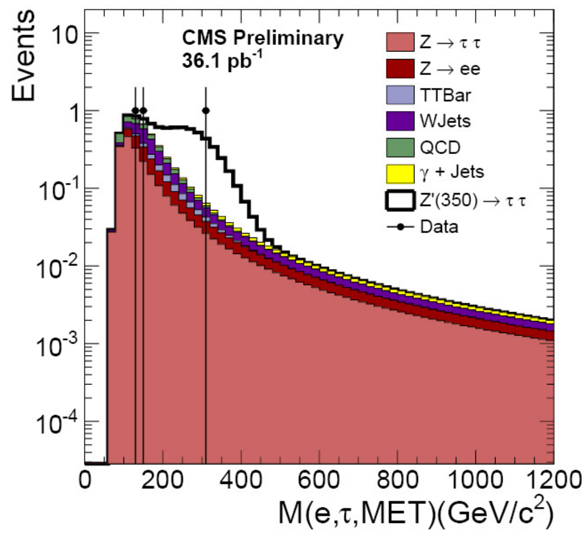
Jordan Tucker, *UCLA*

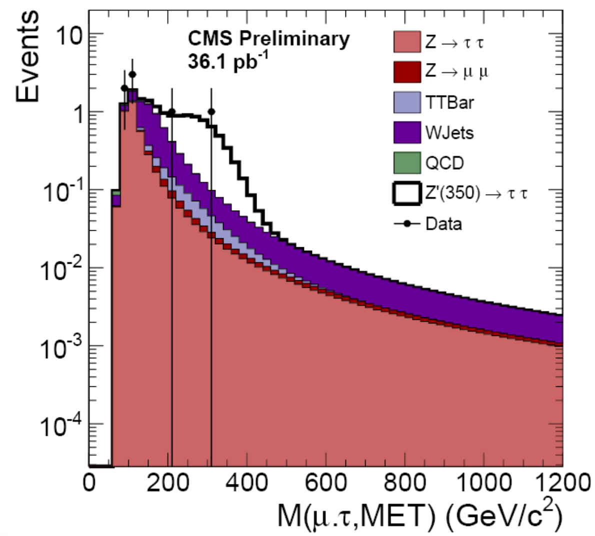
For the CMS Collaboration

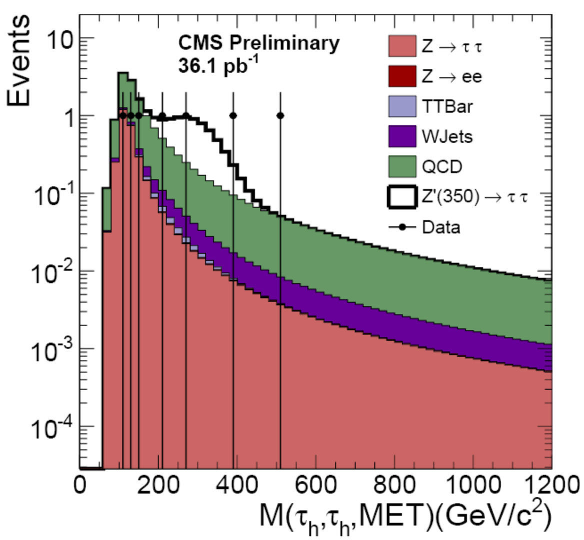
EPS-HEP July 21, 2011

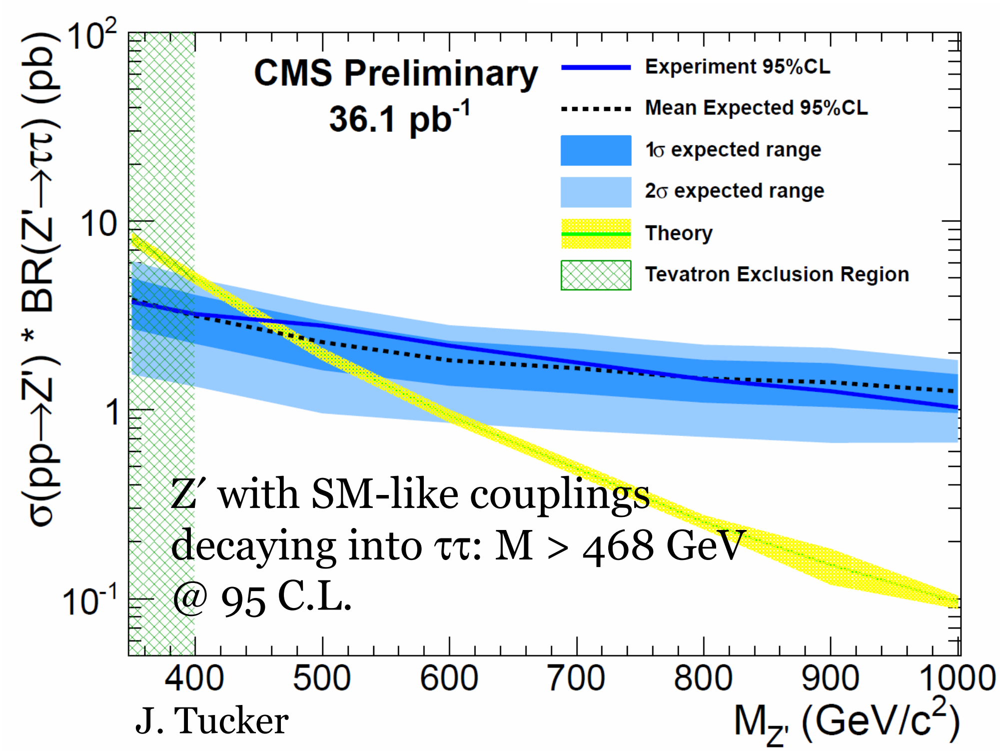
But first… Z′ →ττ search with 36 pb^{-1}











Z′ with SM-like couplings decaying into ττ: M > 468 GeV @ 95 C.L.

J. Tucker

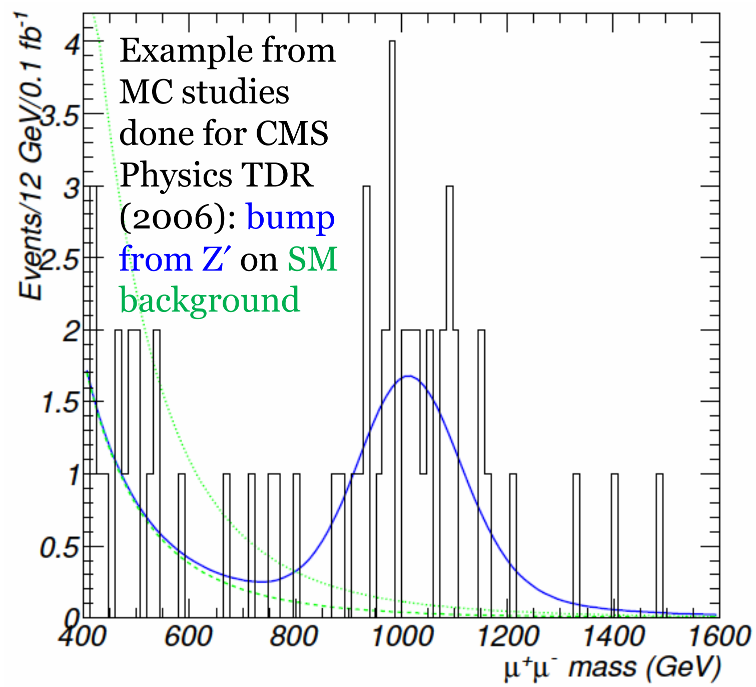
Introduction

- Search for new physics: extra narrow high-mass resonances.
  - E.g. new gauge bosons Z′ or Randall-Sundrum gravitons G_{KK}.
- Generic shape-based search: no assumptions on absolute background rate.
- Results normalized to the Z^0 peak:

$$\frac{\sigma \times BR(Z')}{\sigma \times BR(Z^0)} = \frac{N(Z')}{N(Z^0)} \times \frac{A(Z^0)}{A(Z')} \times \frac{\epsilon(Z^0)}{\epsilon(Z')}$$

Benefits:

- Luminosity uncertainty irrelevant
- Other systematic effects cancel or are reduced



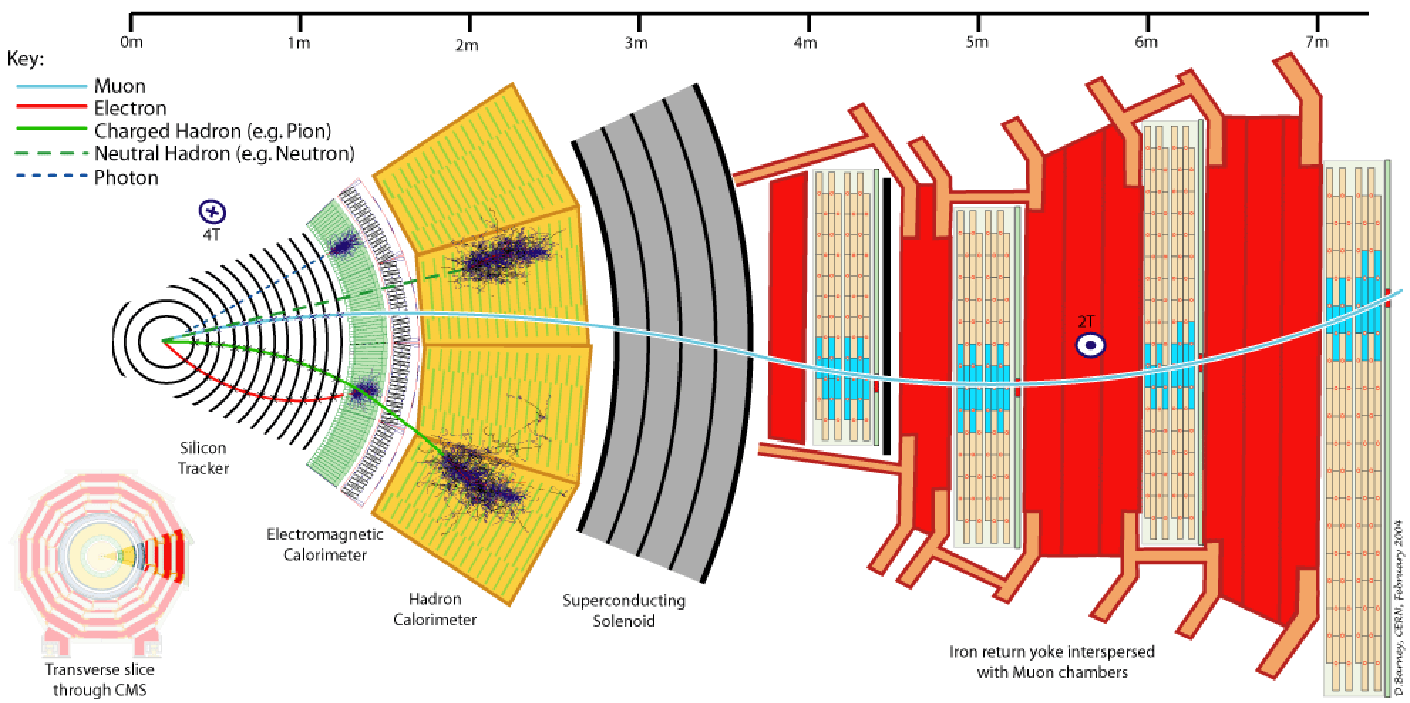
CMS: the Compact Muon Solenoid

Fine-grained ECAL for precise measurement of EM energies – ultimately, $\Delta E/E < 0.5\%$ for $E > 100$ GeV.

→ Excellent m_{ee} resolution, but challenge is on id of electrons vs. jets!

Inner tracker in 3.8 T magnetic field, plus muon system for triggering, id, and to improve high-p_T measurement – $\Delta p_T/p_T < 10\%$ at $p_T \sim 1$ TeV.

→ Muon id much easier than electron id, $m_{\mu\mu}$ resolution is the challenge!



Dilepton selection

- As in Z^0 cross section measurement, adapted for high E_T or p_T.
  - Differences → small extra systematic uncertainties.
- Trigger: double EM clusters with $E_T > 33$ GeV, single muons with $p_T > 30$ GeV.
- Offline: require two isolated leptons with E_T or p_T above trigger turn-on, with further quality cuts.
- Total efficiency in simulation is >85% for $m_{ll} > 1$ TeV.
  - Checked lepton efficiency in data using Z^0 tag+probe up to $p_T \sim 100$ GeV; for muons, also use cosmic-ray events.
  - Ratio of efficiencies from low to high mass, rather than absolute efficiencies, is important in this analysis.

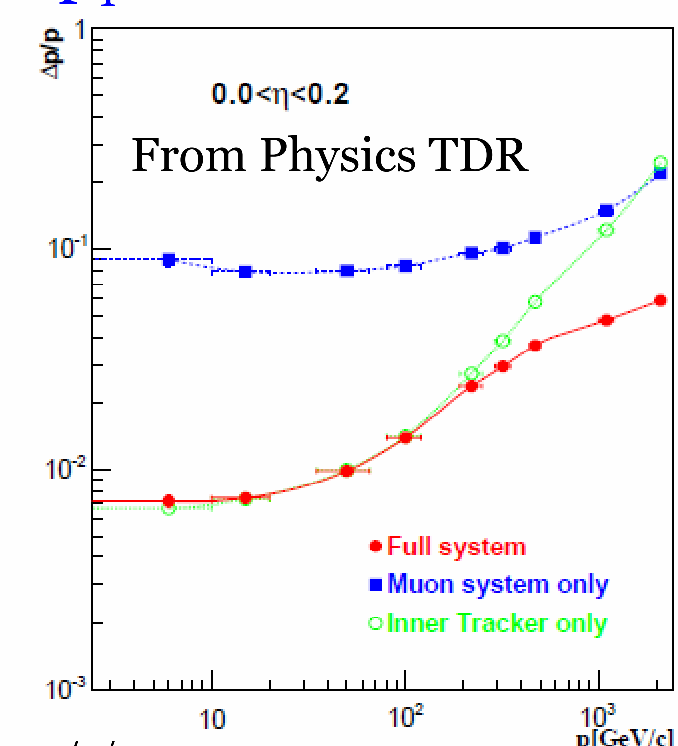
Dielectron/dimuon differences

- Looser muon selection: smaller background from jets for muons.
- Smaller dielectron acceptance: no endcap-endcap electron pairs allowed, gap between ECAL barrel and endcap.
- Opposite charges required for dimuons, but not for dielectrons.
- Cosmic-ray muons used to aid in understanding high-p_T collision muons.

Muon momentum/dimuon mass resolution

Narrow peak broadened by mass/momentum resolution.

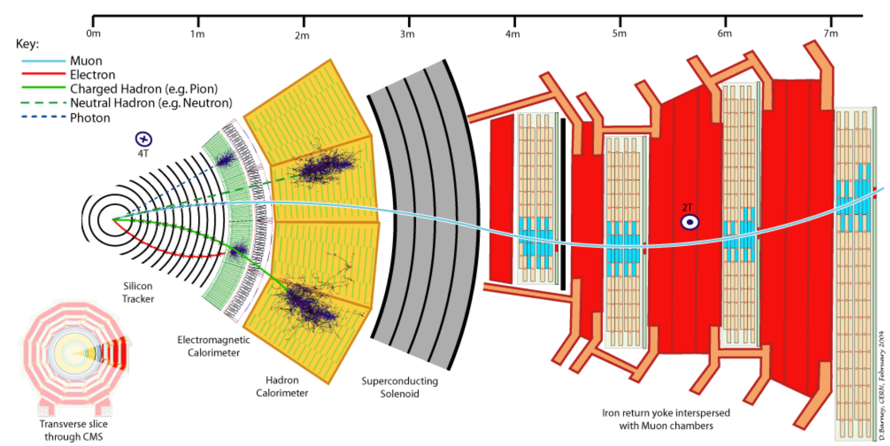
Adding muon system hits to tracker-only fit helps for p_T > ~200 GeV:



But:

High-p muons' E loss in steel yoke + showers in muon chambers can spoil fit.

→ Use muon hits selectively: e.g. take only first station with hits, drop incompatible hits in chambers flooded by showers.



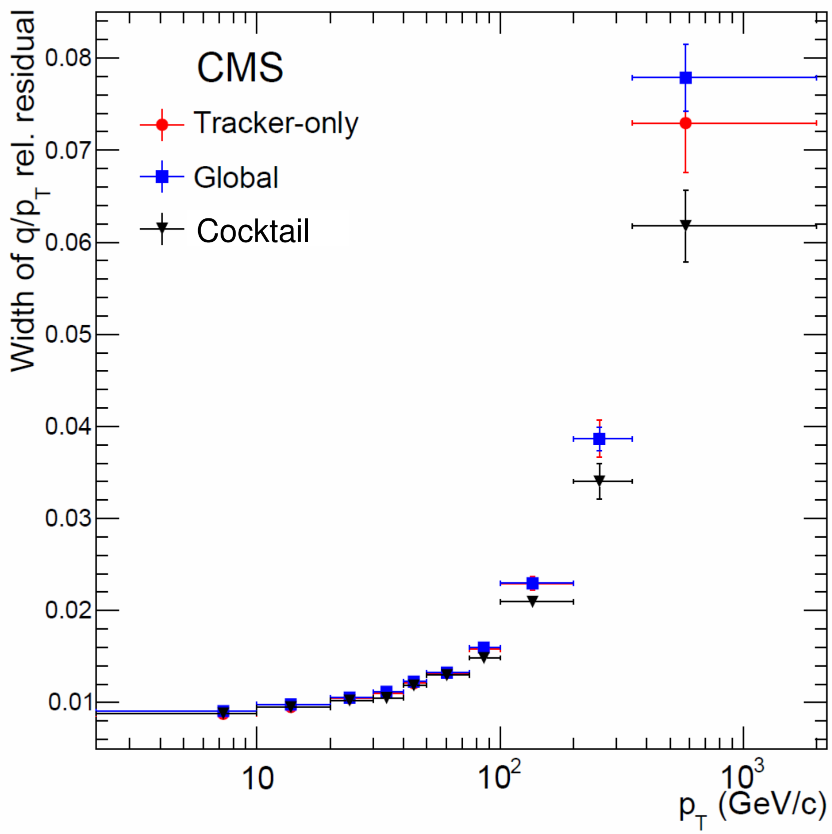
3.8 T in Si tracker, 2 T in muon system

High-p resolution ~ $1/(BL^2)$

Optimizing measurement of high-p_T muons

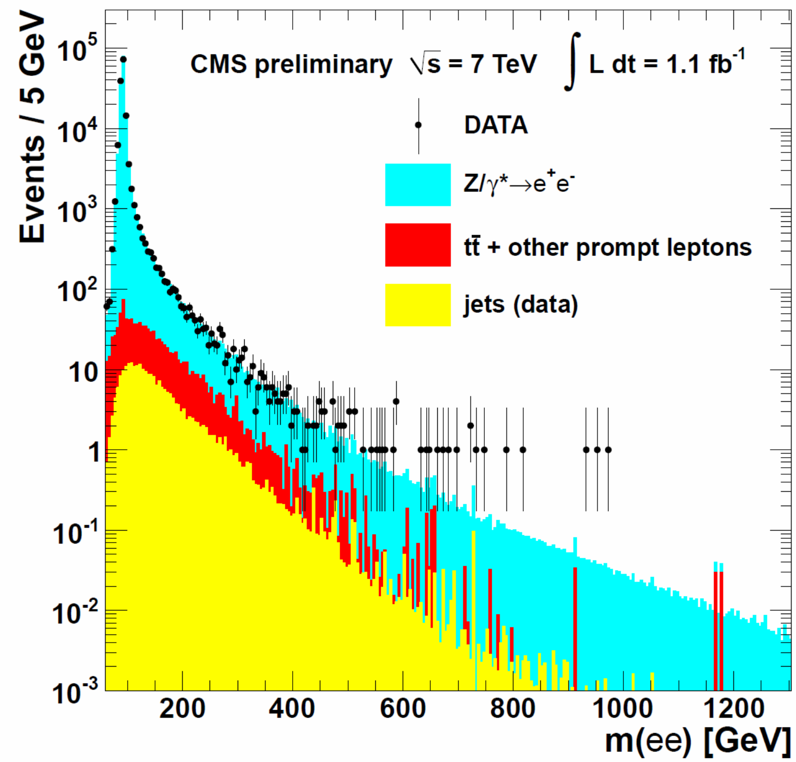
- Improve on these algorithms by making "cocktail" of fits: for each muon, choose based on e.g. goodness-of-fit criteria.
- Gauge impact in data using cosmic-ray muons: reconstruct the same muon separately in opposite halves of CMS then compare results.

$$R(q/p_T) = \frac{(q/p_T)^{\text{upper}} - (q/p_T)^{\text{lower}}}{\sqrt{2}(q/p_T)^{\text{lower}}}$$



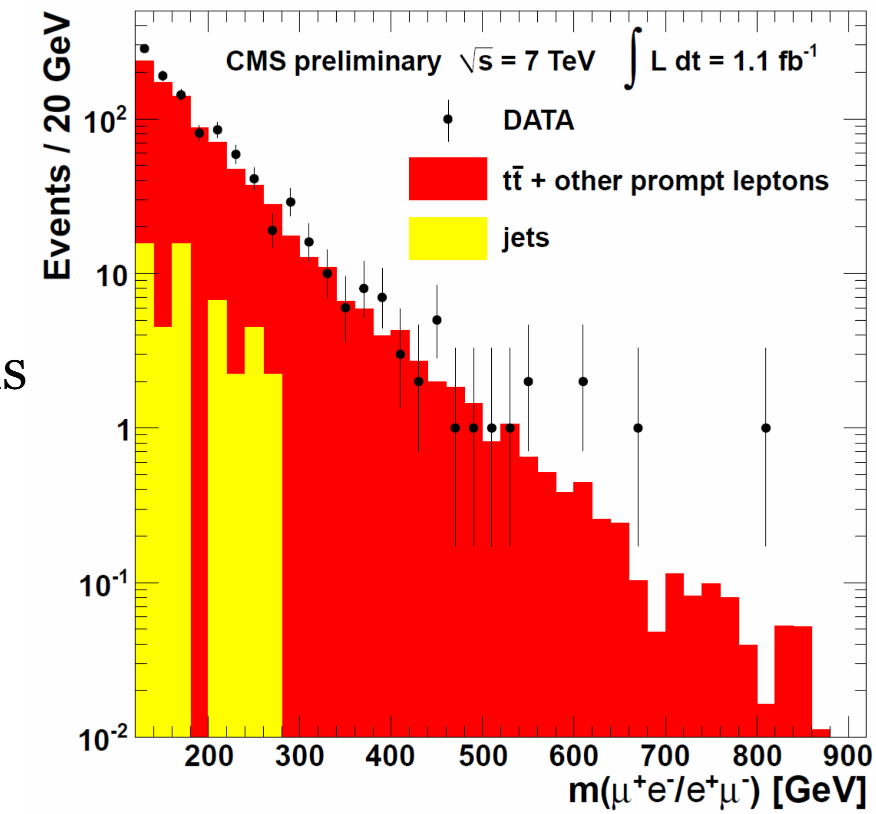
Dilepton backgrounds

- Dominant: irreducible Drell-Yan (DY) production – use DY shape from sim. in search.
- Next biggest (10% of DY above 120 GeV): ttbar and other sources of "prompt" leptons – check in data using eμ events.
- Dileptons from misidentified jets:
  - For dimuons, negligible (<1% of DY rate above 120 GeV).
  - Dielectrons suffer more: about 5% of the DY rate above 120 GeV.
  - Estimate in data by loosening cuts (e.g. isolation).
- Cosmic-ray muons: using sidebands, estimate less than 0.1 remaining dimuon event above 120 GeV.



eμ method for ttbar, other prompt leptons

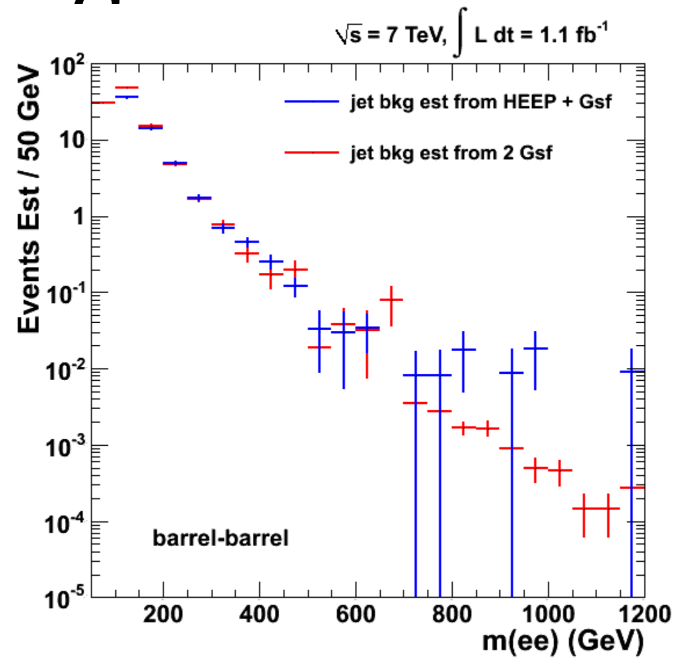
- Expect two eμ events for every ee or μμ event, then scale by different e,μ efficiencies.
- Extract scale factor N(ee, μμ)/N(eμ) from MC in bins of dilepton mass.
- Currently just a cross-check – but good agreement between data and MC.

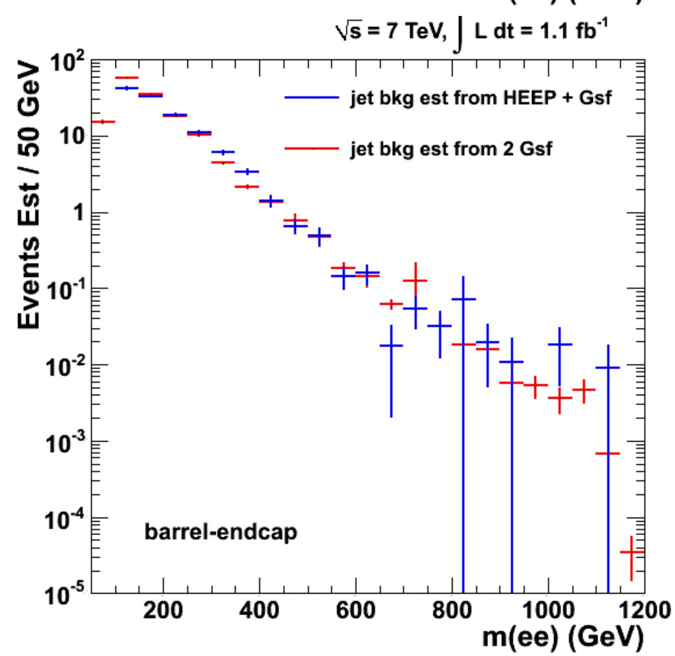


Mass range	N(eμ), data	eμ-predicted N(ee)	MC-predicted N(ee)	eμ-predicted N(μμ)	MC-predicted N(μμ)
> 120 GeV	999	420 ± 14	400 ± 64	578 ± 25	560 ± 71
> 200 GeV	300	139 ± 8	124 ± 20	194 ± 15	171 ± 22

Dielectron jet background

- Measure probability for jet reconstructed as an electron (with loosened cuts) to pass rest of selection.
  - Require exactly one reconstructed electron to remove $Z^o \to ee$ events.
  - Use simulation to subtract W+jet, γ+jet, $Z^o \to ee$ contamination.
- Apply to ee events to get dielectron-from-jets spectrum – compatible with simulation within target uncertainty.
- Similar strategy in dimuon channel using isolation cut.





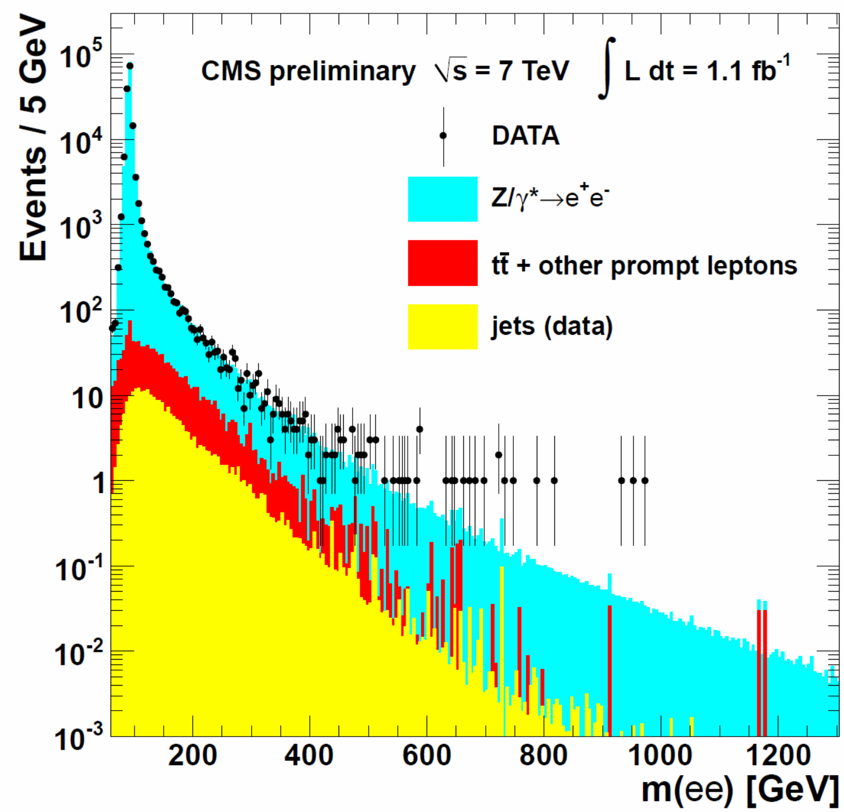
Dielectron mass spectrum

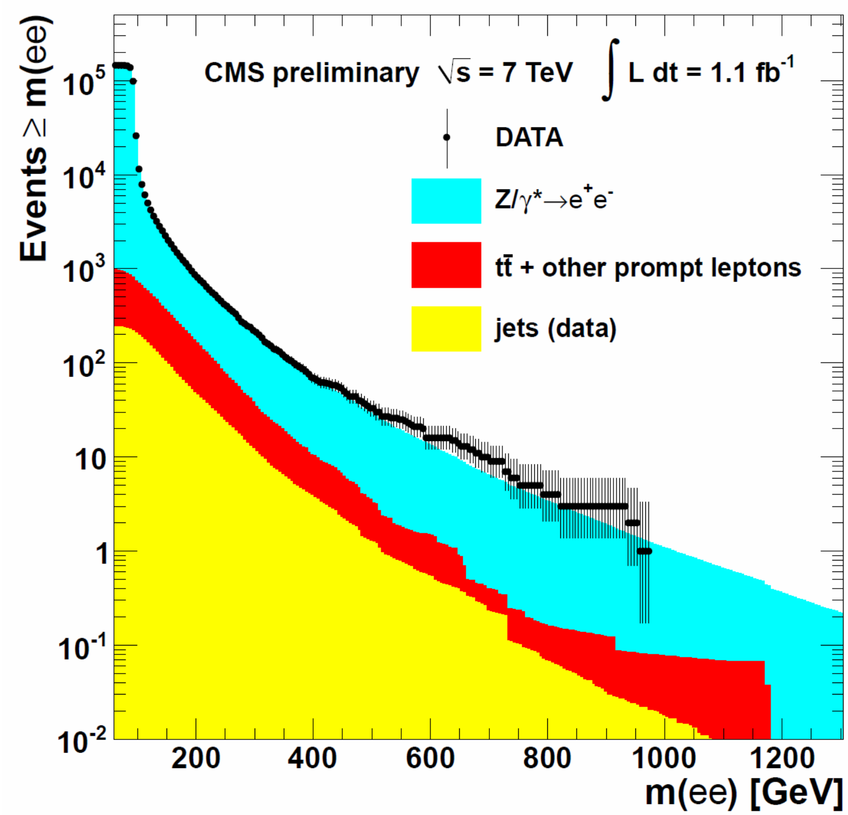
Other prompt leptons: VV, tW, Z→ττ.
Jets: QCD dijets, W+jets.

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	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





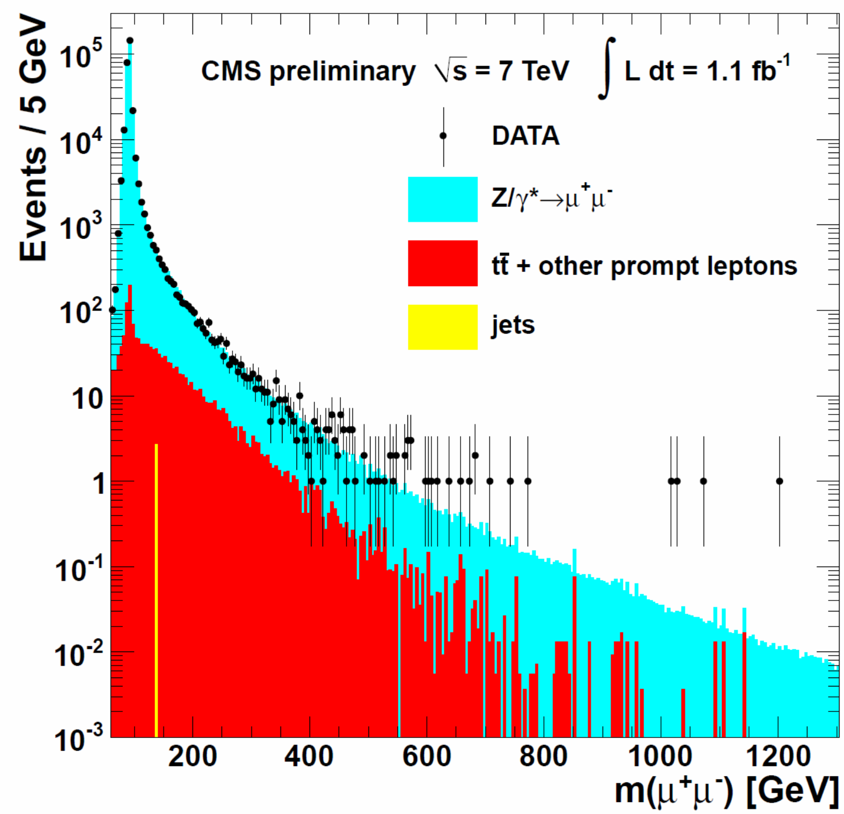
Opposite-sign dimuon mass spectrum

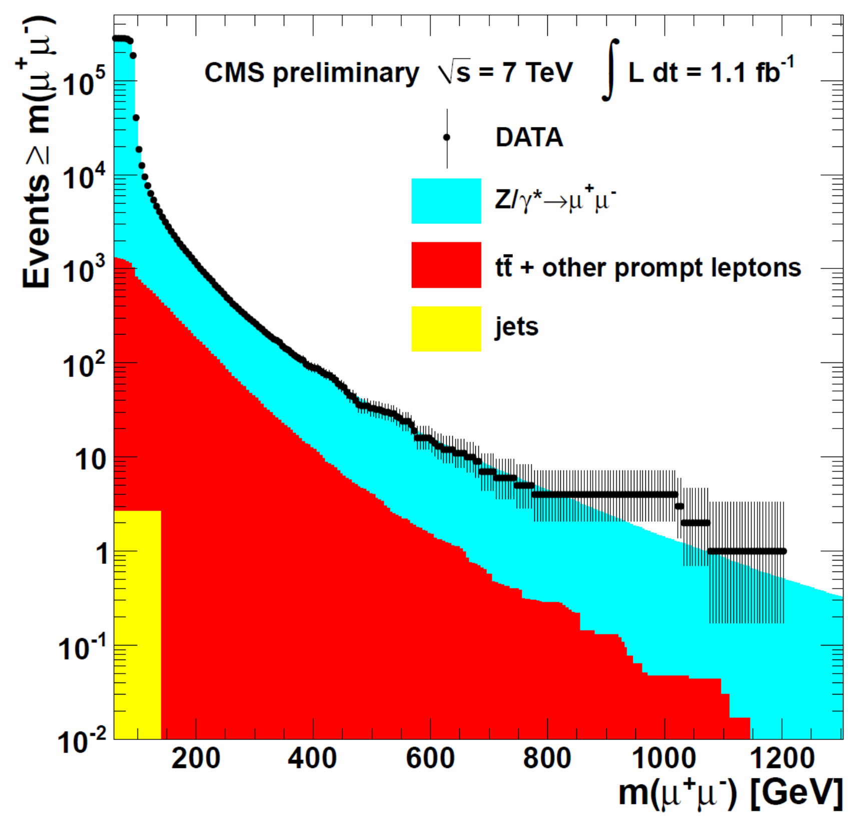
Other prompt leptons: VV, tW, Z→ττ.
Jets: QCD dijets, W+jets.

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	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: bump hunt

- Simple signal + background pdf, with shape parameters from MC; fit explores the difference in shapes.
- Use likelihood ratio to calculate uncorrected significance S_L as a function of the dimuon mass M.
- Correct for probability of getting at least as extreme of a fluctuation from background-only ("look-elsewhere effect", LEE) in the range 600-2000 GeV.

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

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

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

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

Channel	Most sig. bump at M (GeV)	Local Z (σ)	LEE-corrected Z (σ)
ee	950	2.2	0.2
μμ	1080	1.7	0.3
Combined	970	2.0	0.2

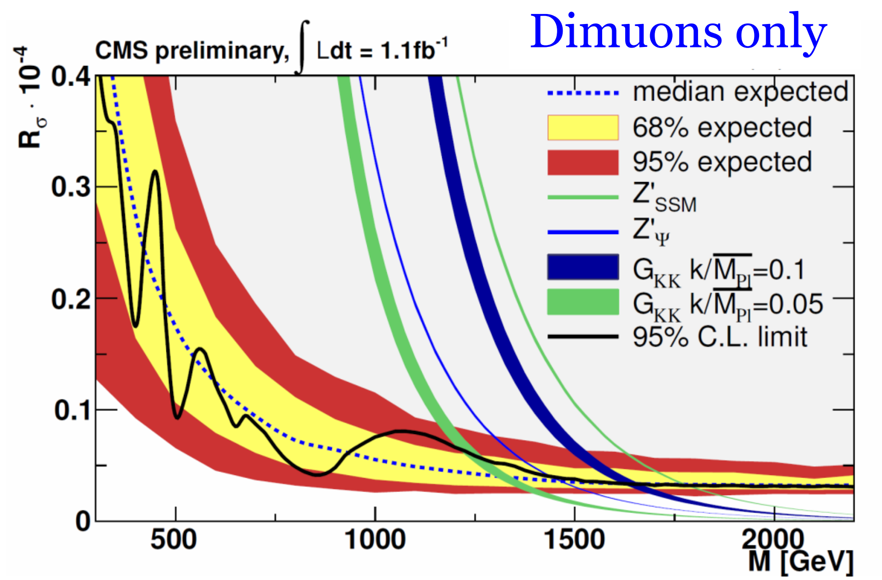
Dilepton mass limits on benchmark models

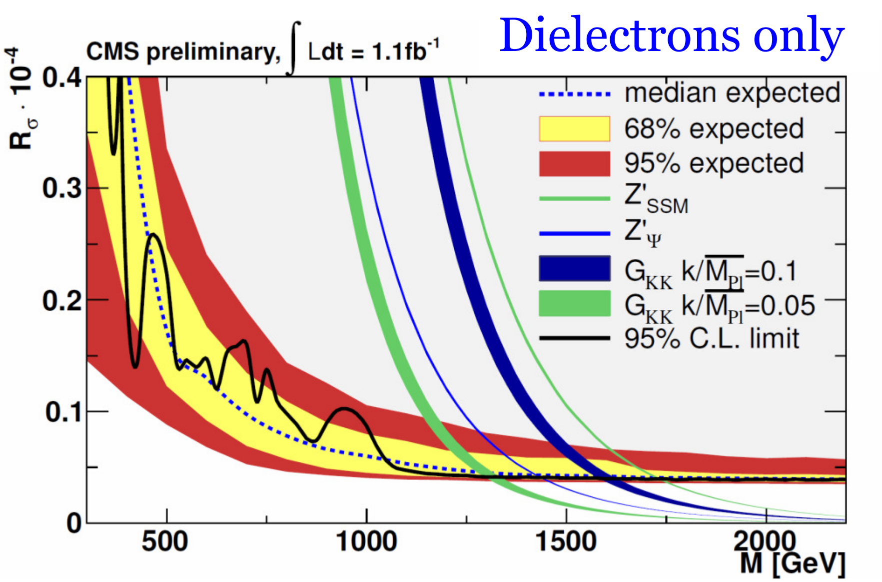
Set limits on ratio of cross sections

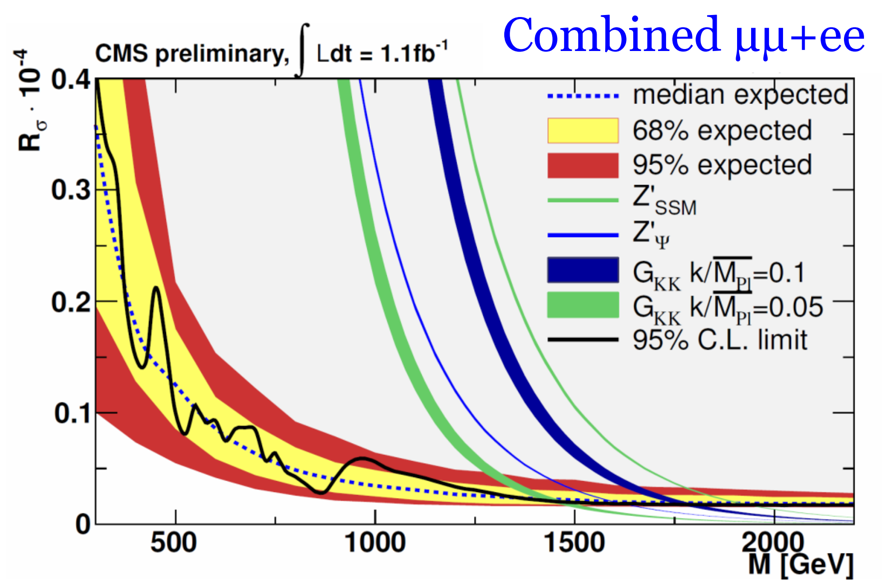
$$R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$$

using a Bayesian method. 95% CL limits:

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







Conclusions

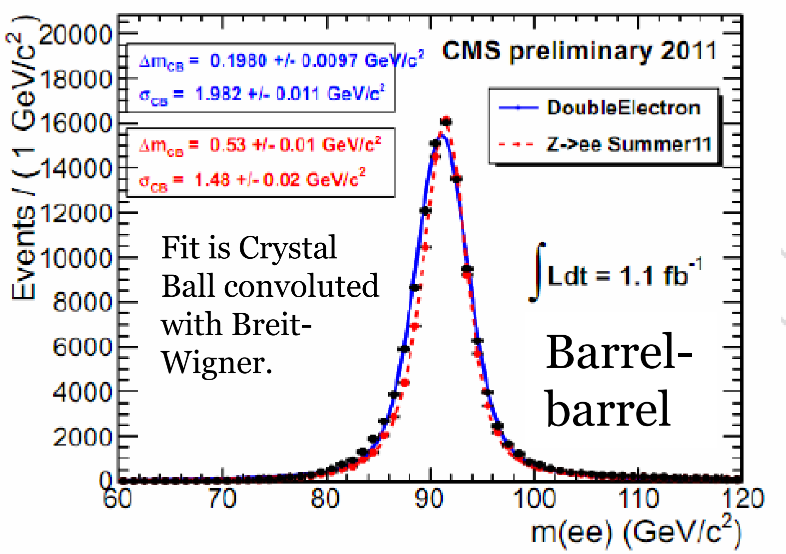
- Data/MC agreement is good – still waiting for a bump.
- Cross-checks/systematic studies show backgrounds are under control.
- 2011 data has piled in fast – expecting to have 400% more by the end of the year.
- Thanks to CMS and the LHC, and…
- Thanks to you for listening!

Backup information

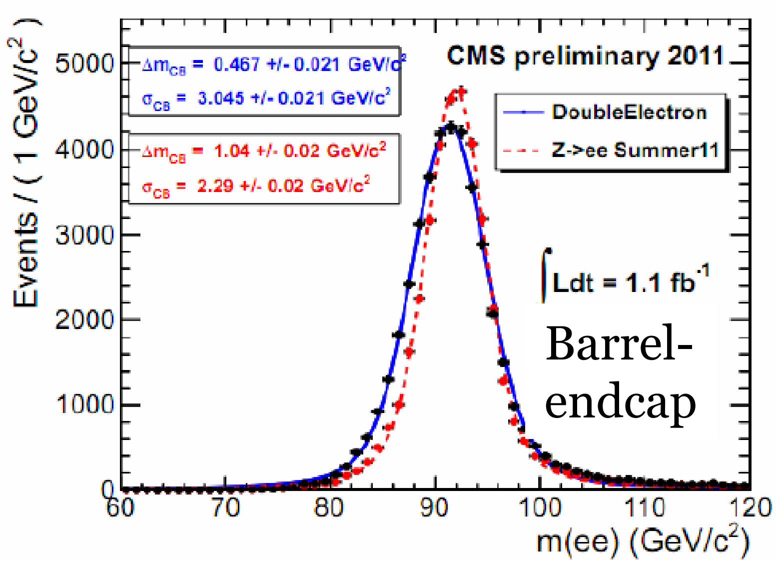
Electron selection

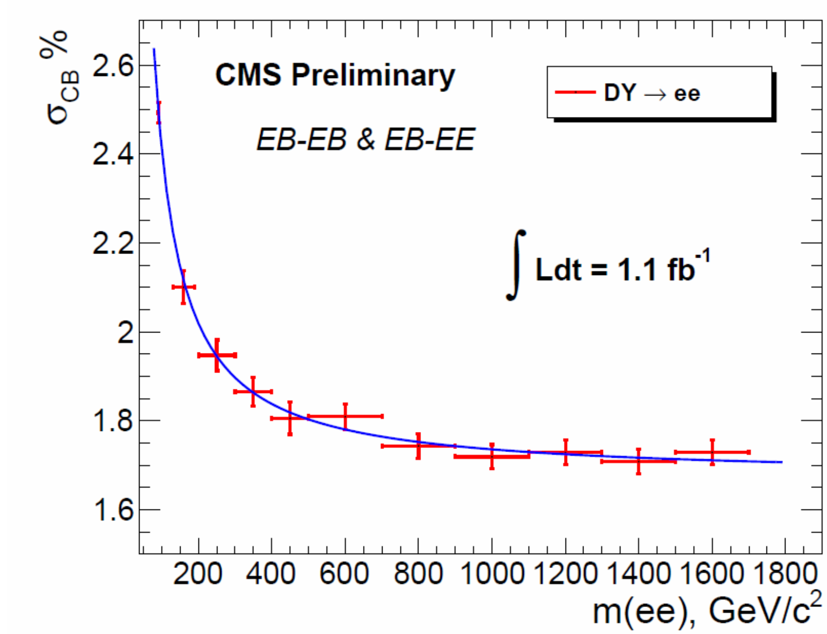
variable	barrel	endcap
E_T	> 35 GeV	> 40 GeV
$\lvert\eta_{SC}\rvert$	< 1.442	$1.56 < \lvert\eta\rvert < 2.5$
seed	ECAL seeded	ECAL seeded
missing hits	=0	=0
$\Delta\eta_{in}$	< 0.005	< 0.007
$\Delta\phi_{in}$	< 0.09	< 0.09
H/E	< 0.05	< 0.05
E^{2x5} / E^{5x5}	> 0.94 OR $E^{1x5} / E^{5x5} > 0.83$	-
$\sigma_{i\eta i\eta}$	-	< 0.03
isol Em + Had Depth 1	$< 2 + 0.03 \times E_T$ GeV	< 2.5 GeV for $E_T < 50$ GeV $< 2.5 + 0.03 \times (E_T - 50)$ GeV
isol Had Depth 2	-	< 0.5 GeV
isol Pt Tracks	< 7.5 GeV/c	< 15 GeV/c

Dielectron energy scale/resolution



- Fit $Z^o \rightarrow ee$ peak in data and simulation and compare.
- Take resolution at high mass from simulation, applying additional smearing derived at Z^o peak:





Dielectron eff. scale factor

Data/simulation scale factor, measured at Z^0:

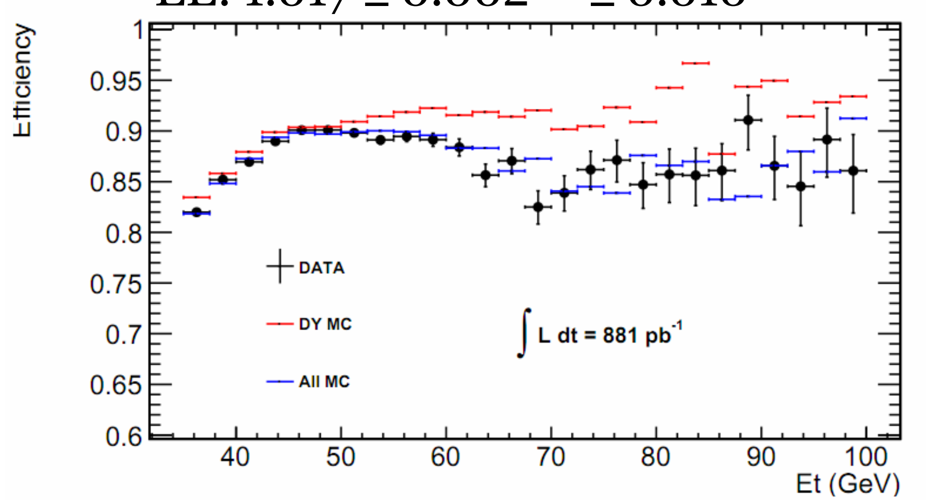
EB: $1.008 \pm 0.001^{stat} \pm 0.011^{sys}$

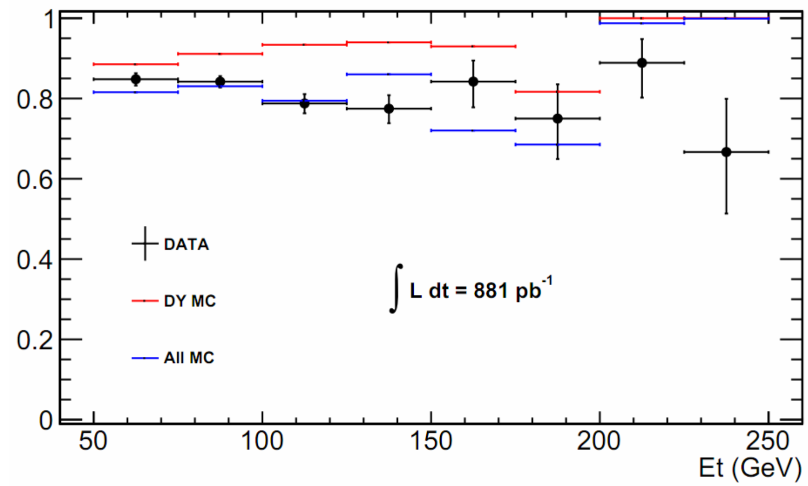
EE: $1.017 \pm 0.002^{stat} \pm 0.010^{sys}$

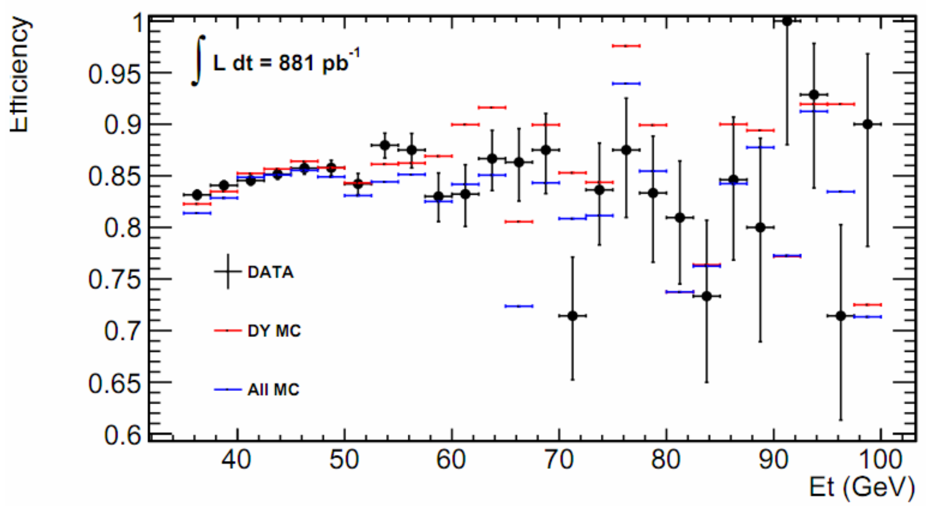
Extrapolate to high mass:

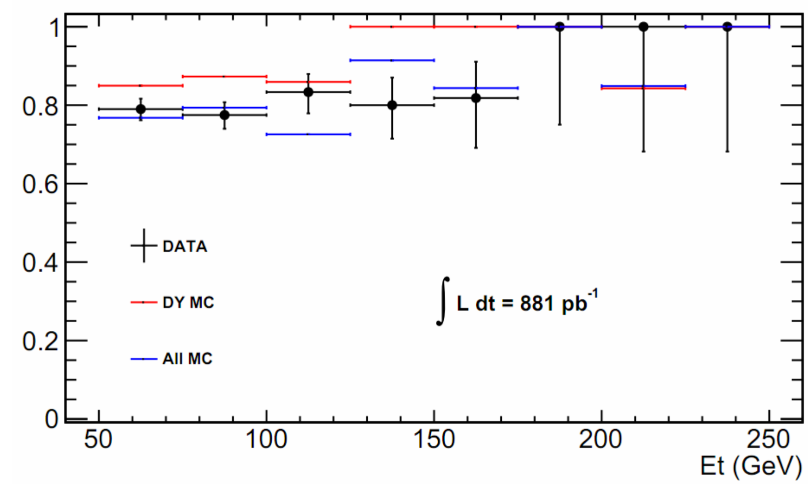
EB: $1.002 \pm 0.011^{stat} \pm 0.018^{sys}$

EE: $1.030 \pm 0.024^{stat} \pm 0.021^{sys}$

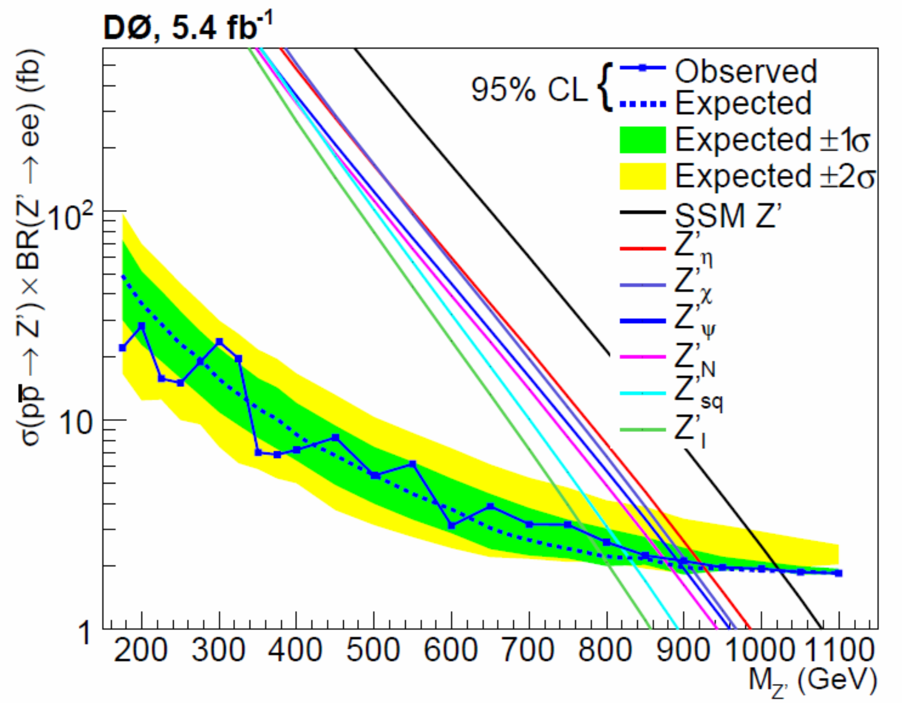


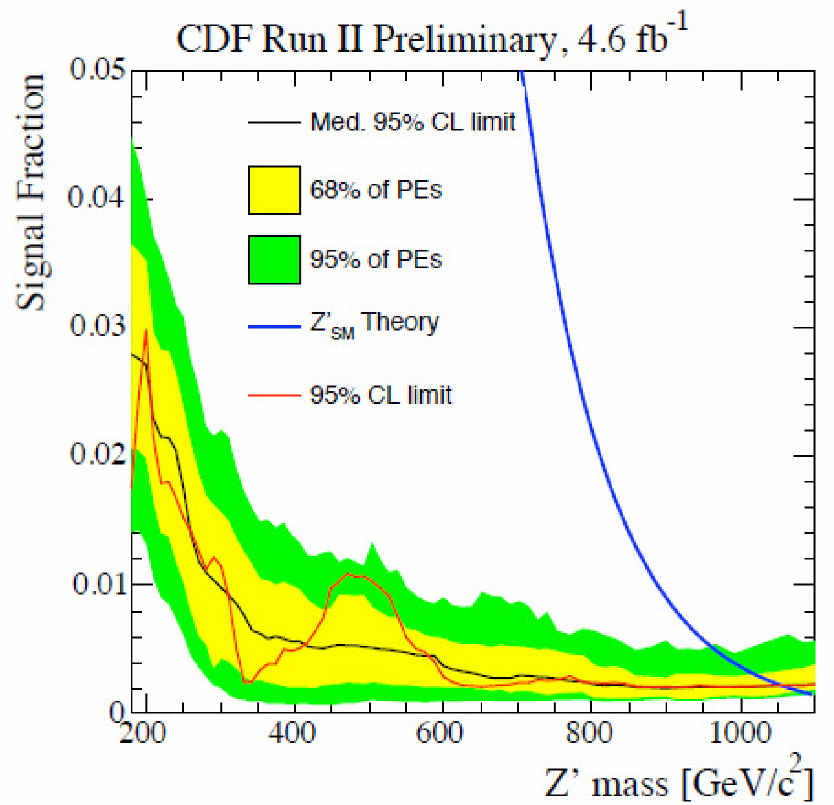


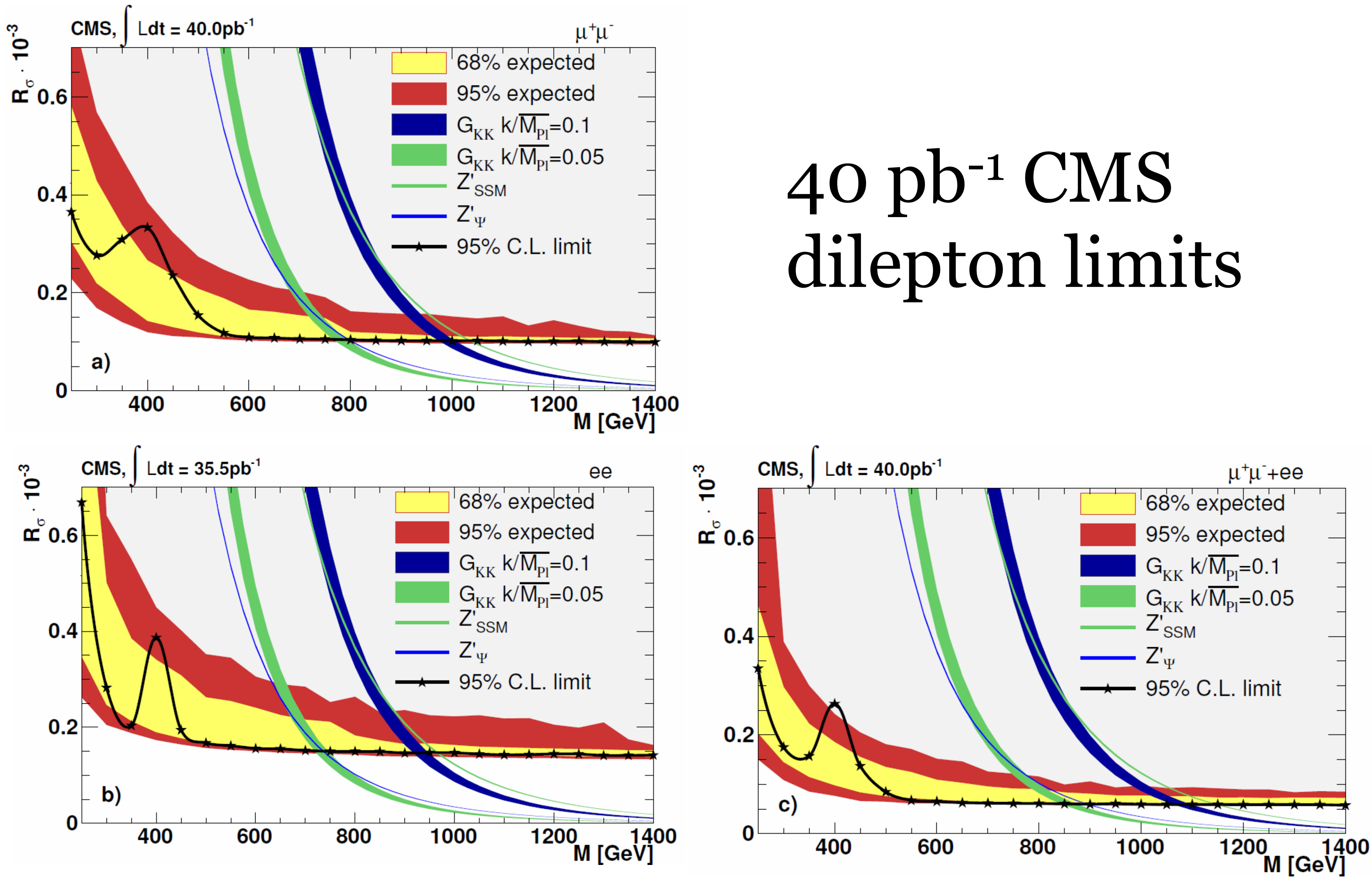




Example Tevatron dilepton limits







40 pb^{-1} CMS dilepton limits

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

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 $\mu\mu$ events, and R_ϵ is the ratio of 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.

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 Z^0 peak results in 1% for barrel and 3% for endcap.
- For dimuons, effect of possible χ^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.

RSG diphoton search with 36 pb^{-1}