Resonances in leptonic channels and llqq contact interactions: CMS

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for the CMS Collaboration

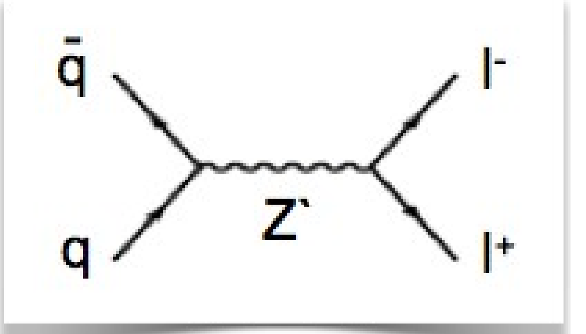
LPCC BSM Jamboree: Status of Higgs and BSM searches at the LHC
11-13 April 2011, CERN

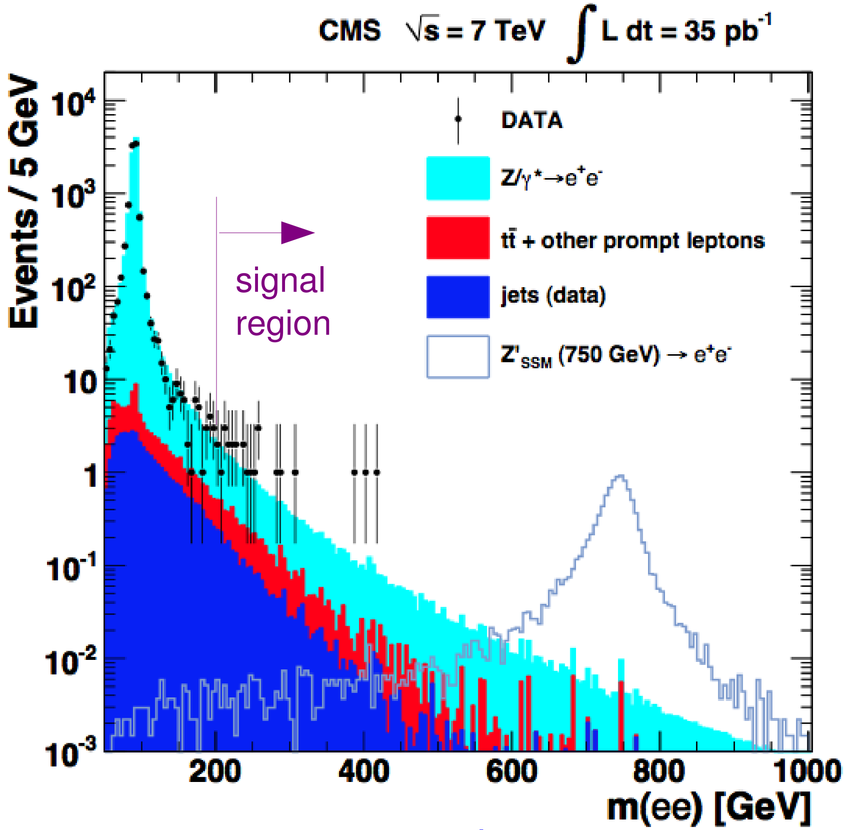
Introduction

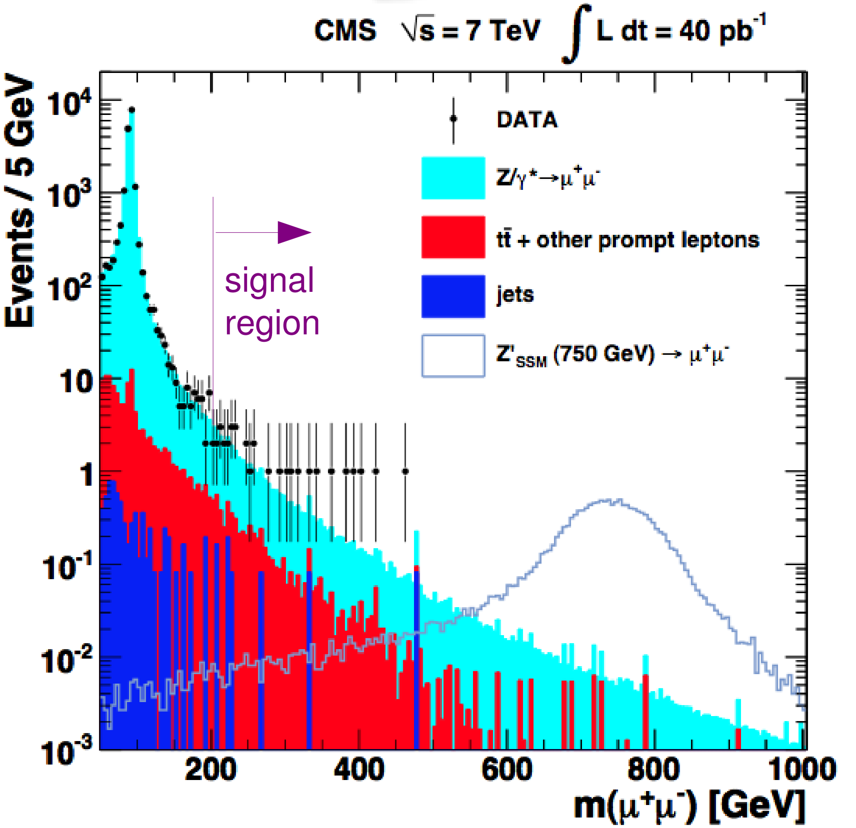
- New resonances foreseen in many SM extension
  - LR symmetric models, Extra Dimensions, GUT, compositeness models, etc...
- In this talk the following searches for exotic signatures in leptonic channels are discussed
  - **Di-lepton resonances (Z'/RS → ee/μμ)**
  - **New heavy charged bosons (W'→eν/μν)**
  - **Excited leptons (e*, μ*)**
  - **Lepton jets**
- All the analyses presented are based on the full 2010 dataset (~35 pb^{-1})
- General strategy:
  - Look for excess in data in the high pT/mass region with respect to the SM expectations
  - no excess is observed → set exclusion limit
- Good description of backgrounds is crucial
  - accurate shape model and normalization
  - use data-driven techniques when MC not fully reliable (e.g. jets misidentified as leptons) or to cross-check MC predictions

Search for Z'/RS graviton to di-leptons

- Select two central, isolated, e(μ) with p^T > 25(20) GeV
- Shape analysis, **look for bump in dilepton mass spectrum**
- **Normalized** to data in window around **Z peak**
- No deviation from SM expectation (dominantly Drell-Yan)
- Set limits on different benchmark models: Z'_{SSM}, Z'_{Ψ}, RS G_{KK}



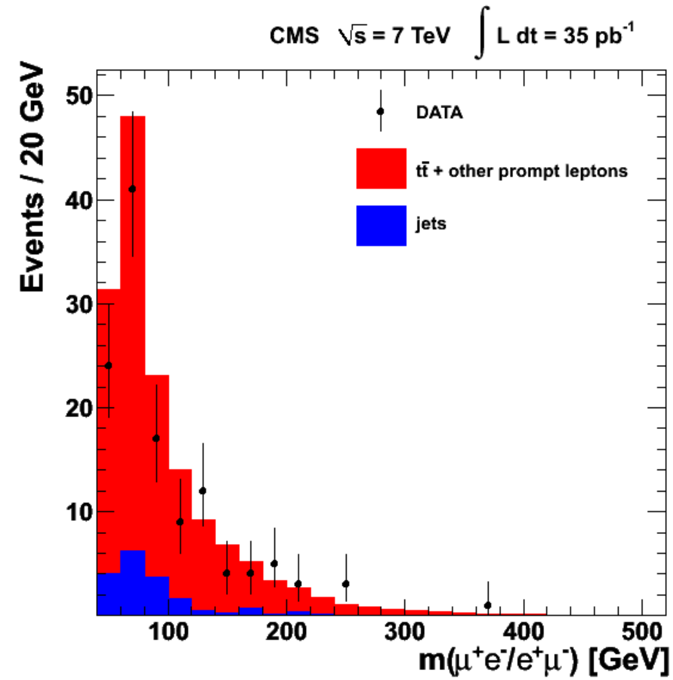




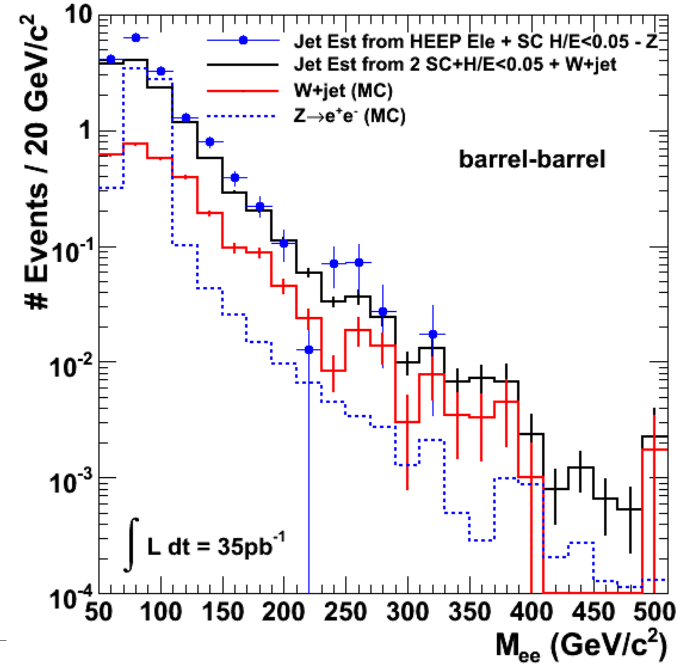
arXiv:1103.0981, submitted to JHEP

Backgrounds estimation

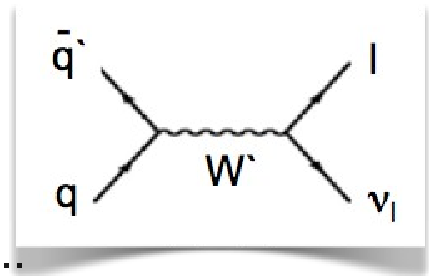
- SM Drell-Yan (irreducible)
  - MC normalized to data at the Z peak
  - uncertainty from QCD h.o. corrections + PDF: 5.7% on the ratio N(high-mass)/N(Zpeak)
- Other backgrounds with prompt leptons (tt, WZ, WW, tW, Z→ττ)
  - cross-check of MC prediction with data-driven approach based on eμ mass spectrum
- Jets faking leptons (W+jet, di-jet)
  - e-channel: fake rate from jets-enriched data samples. Syst. unc. (25% EB, 40% EE) from comparisons between estimates obtained with different samples
  - μ-channel: from non-iso templates
- Cosmic muons
  - Select on impact parameter and opening angle between the two muons
  - Residual contamination from sidebands (0.1 evt)



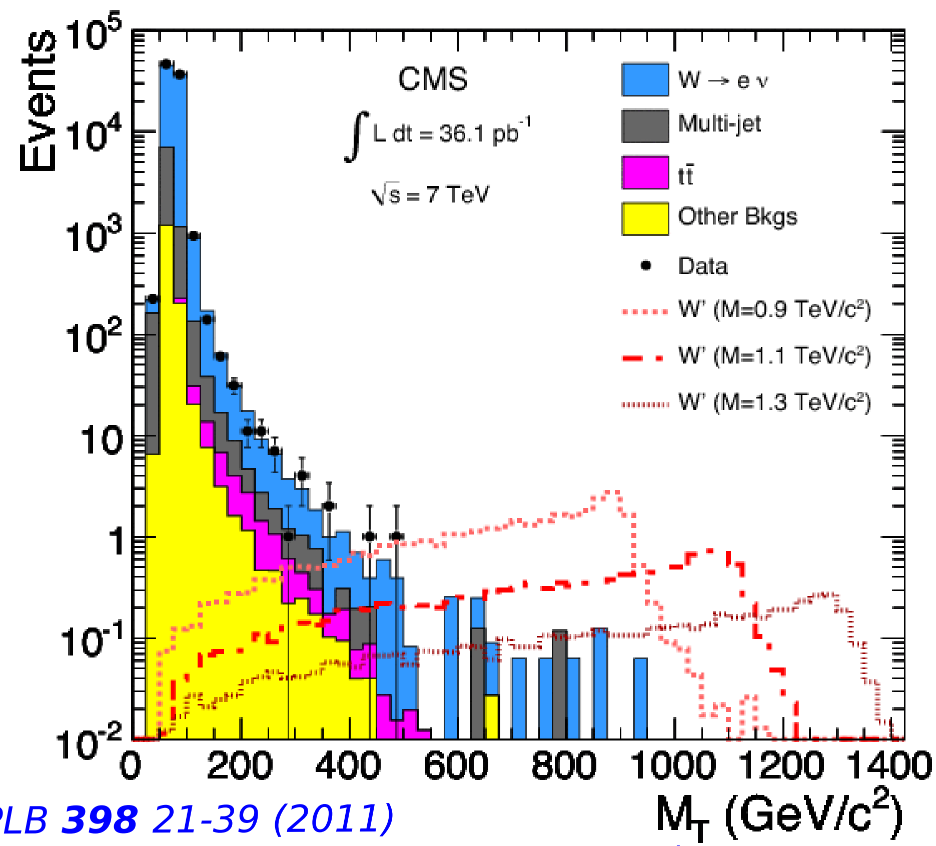
Source	Number of events			
	Dimuon sample		Dielectron sample	
	(120 – 200) GeV	>200 GeV	(120 – 200) GeV	>200 GeV
CMS data	227	35	109	26
Z'_{SSM} (750 GeV)	—	15.0 ± 1.9	—	8.7 ± 1.1
Total background	204 ± 23	36.3 ± 4.3	120 ± 14	24.4 ± 3.0
Z/γ^*	187 ± 23	30.2 ± 3.6	104 ± 14	18.8 ± 2.3
$t\bar{t}$	12.3 ± 2.3	4.2 ± 0.8	7.6 ± 1.4	2.7 ± 0.5
Other prompt leptons	4.4 ± 0.5	1.7 ± 0.2	2.1 ± 0.2	0.8 ± 0.1
Multi-jet events	0.6 ± 0.2	0.2 ± 0.1	6.5 ± 2.6	2.1 ± 0.8

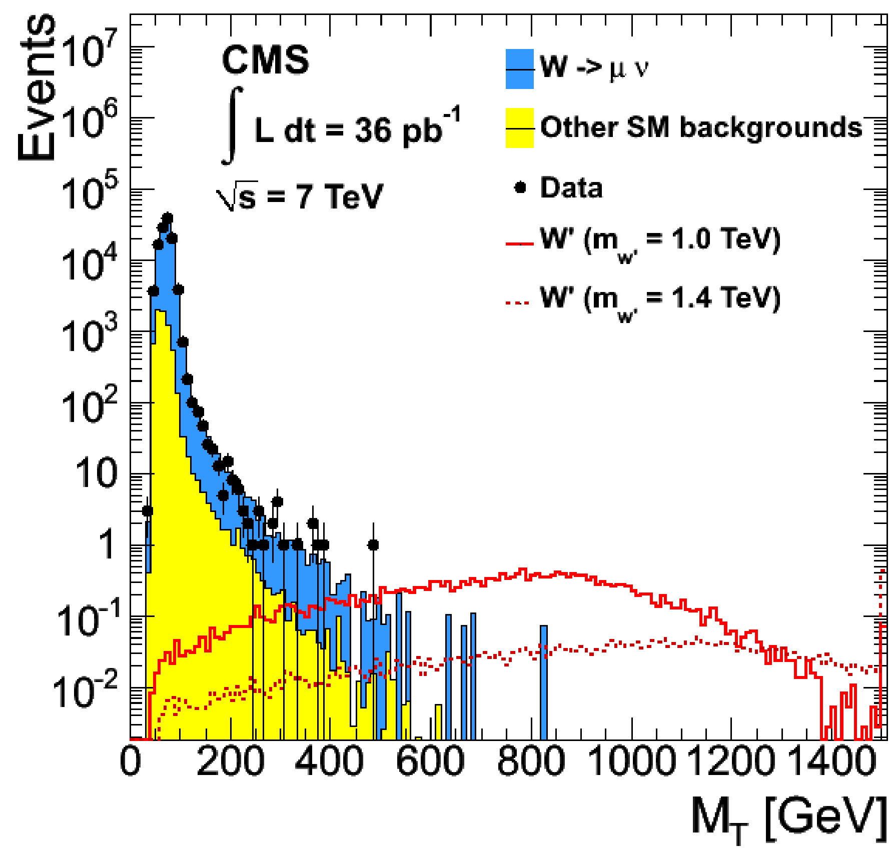


Search for W'→eν and W'→μν



- Select a **central, isolated, e(μ)** with p^T > 30(25) GeV
  - **balanced by E^T_{miss}** : 0.4 < p^T/E^T_{miss} < 1.5 and Δφ(lept-E^T_{miss}) < 2.5
- **Look for Jacobian peak in transverse mass (M^T) distribution**
- Counting experiment in bins of M^T corresponding to M(W') > 600,700,...
- 1-0 evts observed in μ-channel, 2-0 evts in e-channel, consistent with exp bkg
- Reference Model by Altarelli et al. as benchmark model

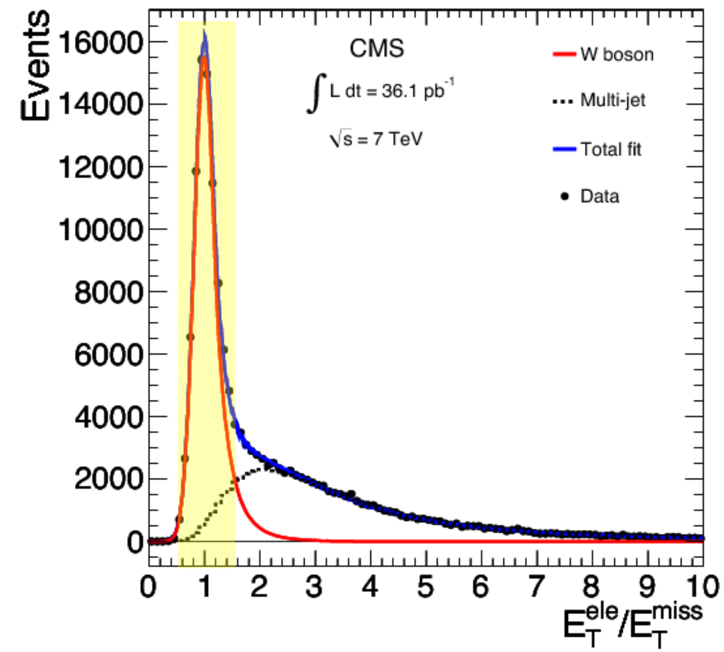




*PLB **398** 21-39 (2011)*
arXiv:1103.0030v1(submitted to PLB)

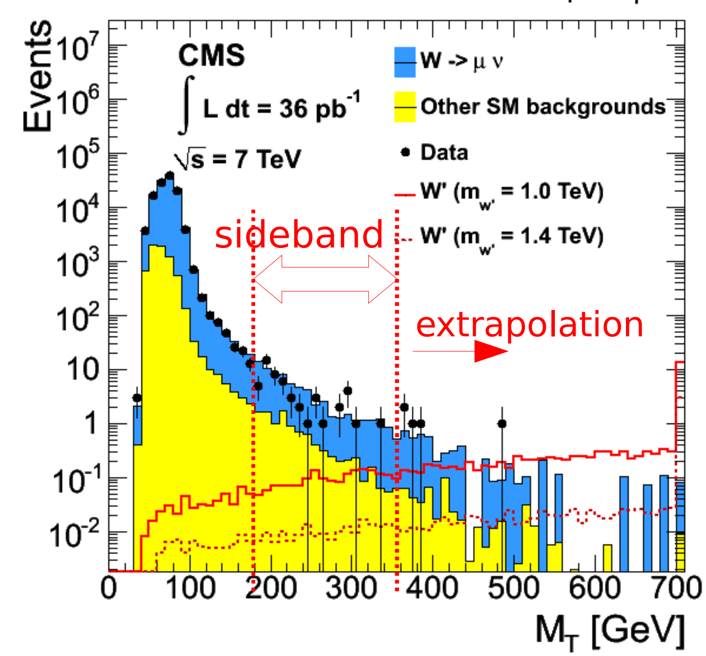
Backgrounds estimation

- Main background: irreducible SM W → lν
- Bkg estimate in the high-MT region: two different approaches for electron and muon channels



Electron channel

- Minor contributions from tt and others from MC
- **W → eν and multi-jet from templates**
  - Fit data E^T/E^T_{miss} distribution with QCD template (from non-iso.) + W template (from MC), leaving the two normalizations as free parameters
  - M^T spectra are normalized to the template area in the region $0.4 < E^T/E^T_{miss} < 1.5$



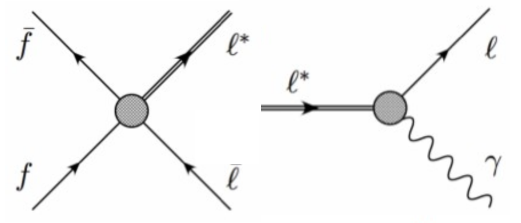
Muon channel:

- **Sideband fit** with Breit-Wigner function in the range 180 GeV < M^T < 350 GeV
- Extrapolation in the high M^T region
- Cross check with MC

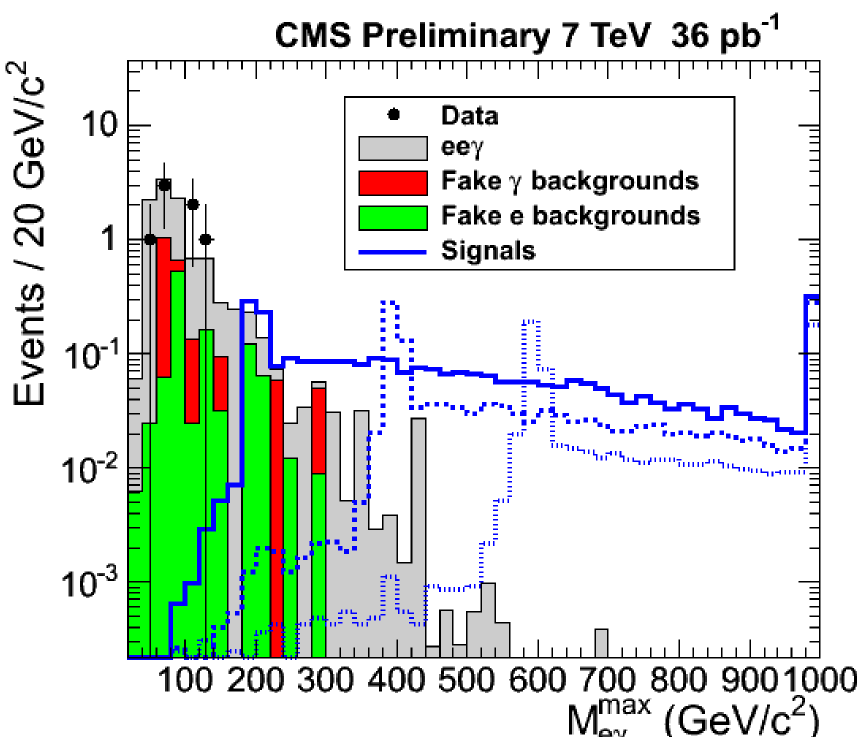
*PLB **398** 21-39 (2011)*
arXiv:1103.0030v1(submitted to PLB)

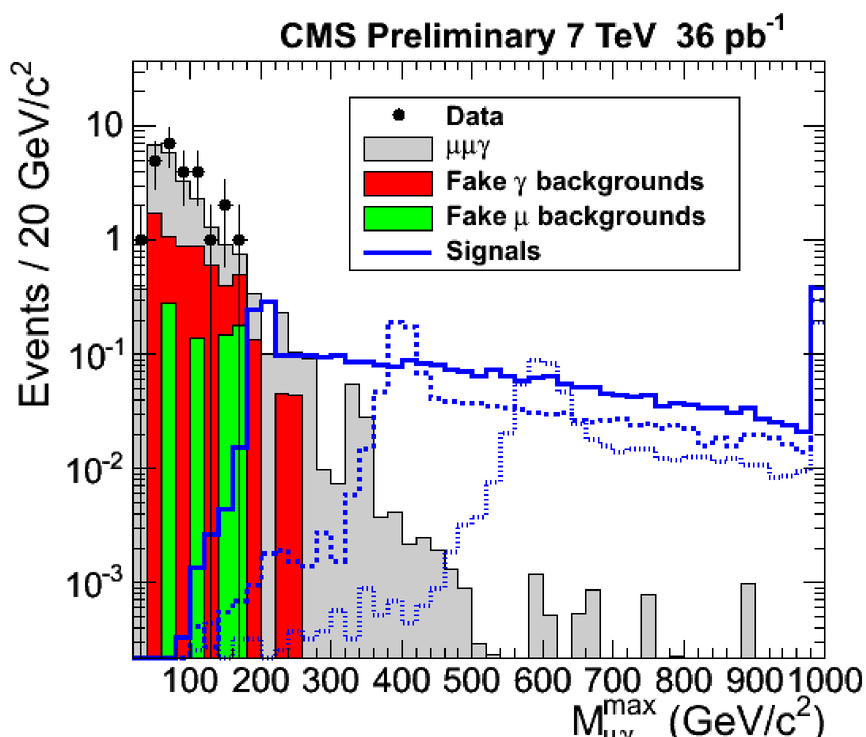
Excited leptons

- 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)
  - **qq→μμ*→μμγ , qq→ee*→eeγ**
- Two isolated e(μ) with p^T > 20(25) GeV
- isolated photon with E^T > 20 GeV and $\Delta R(\gamma,\ell)>0.5$
- Look for an excess in $M(\ell$-$\gamma)$ distribution
- 0 events observed at high M(μγ), M(eγ)



$$\mathcal{L}_{CI} = \frac{g^2}{2\Lambda^2} j^\mu j_\mu$$

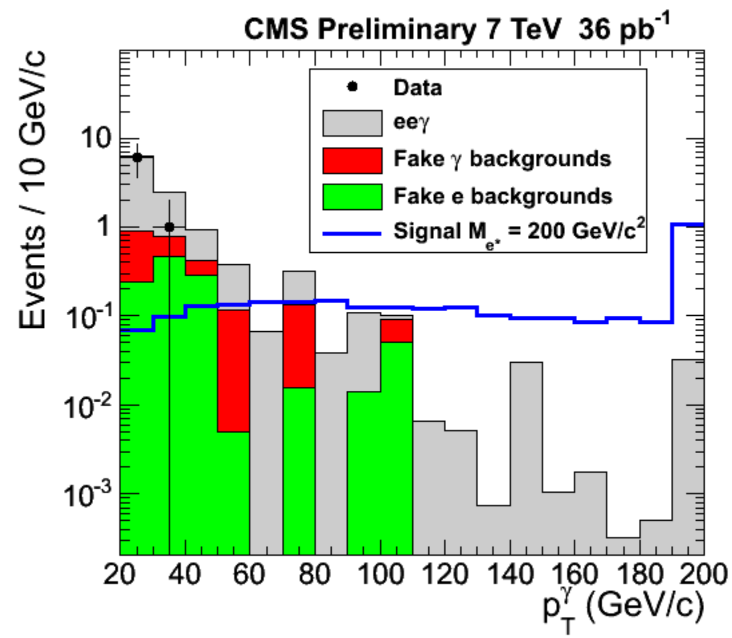


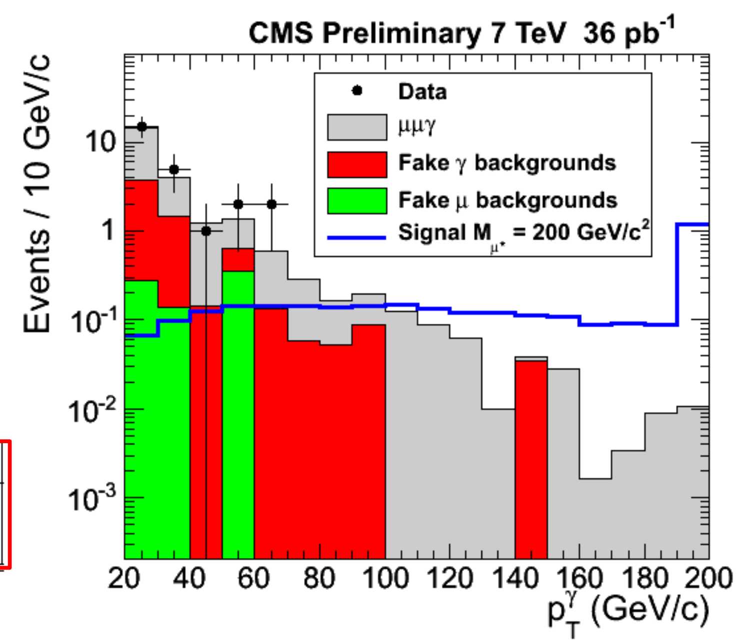


CMS EXO-10-16

Backgrounds estimation

- Contamination from SM processes (mainly $Z/\gamma^* \to \ell\ell$) with real lepton and photons from MC
- Backgrounds with jets misidentified as leptons (mainly $W \to \ell\nu + \gamma$) or photons (mainly $Z/\gamma^*(\ell\ell)$+jets) from data samples containing jets
  - Photon fake rate from sample failing isolation or shower shape requirements
  - Electron fake rate from e.m. clusters
  - Muon fake rate = number of identified muons / number of tracker muons
- Modeling tested in several control regions, with looser selections and after final event selection



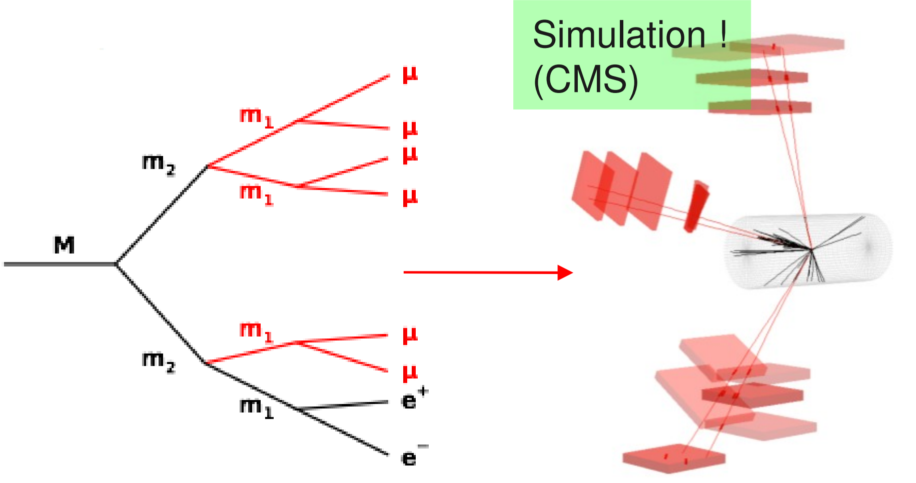


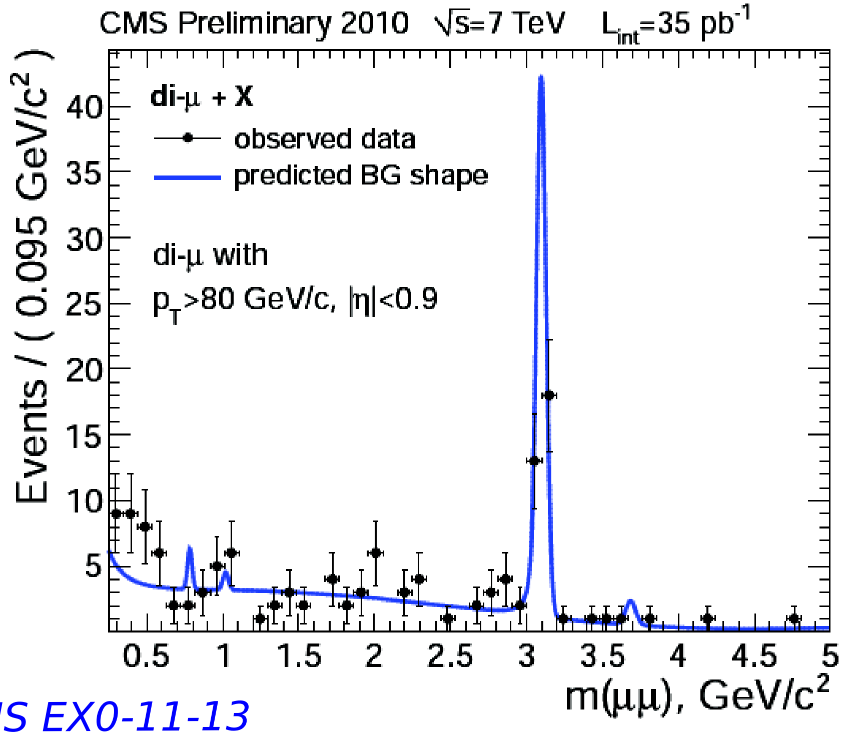
Final State	$\ell^+\ell^-\gamma$	$\ell^+\ell^- + jet(s)$	$\ell\gamma + jet(s)$	Total	Observed
$\mu^+\mu^-\gamma$	16.3 ± 1.3	5.5 ± 2.1	0.7 ± 0.9	22.6 ± 2.6	25
$e^+e^-\gamma$	8.3 ± 0.9	1.4 ± 0.8	1.0 ± 0.4	10.7 ± 1.3	7

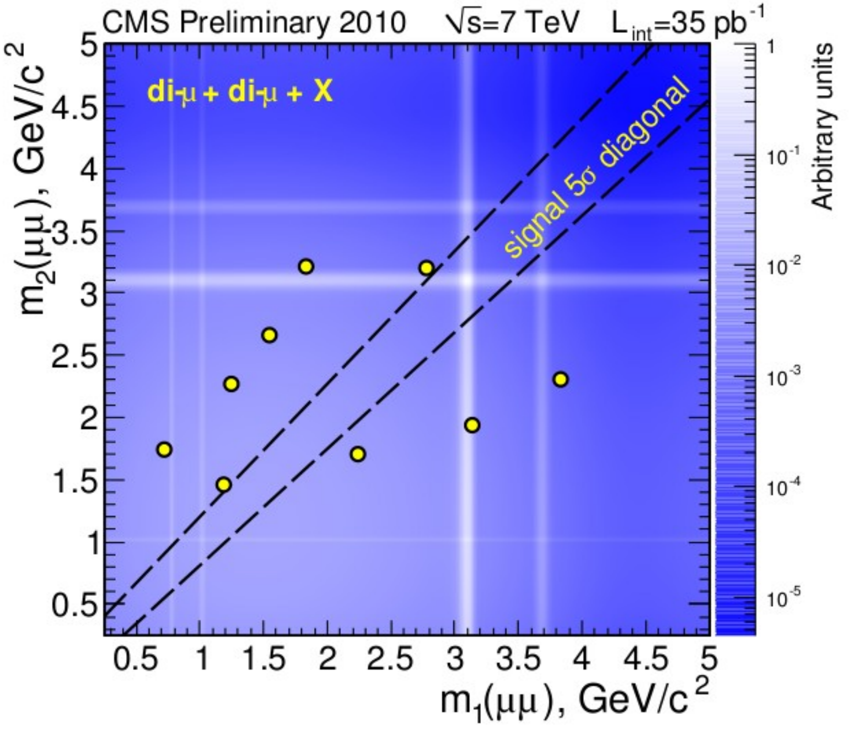
CMS EXO-10-16

Lepton jets

- Hidden-valley picture: predicts new low-mass (few GeV), high-momentum particles decaying to Standard Model pairs like μμ
- Search for **collimated** groups of **di-muons**
  - Opposite charge, m(μμ) < 9 GeV, same vertex
  - Different topologies: [μμ],[μμ][μμ],[μμμμ]
- Perform *inclusive* search





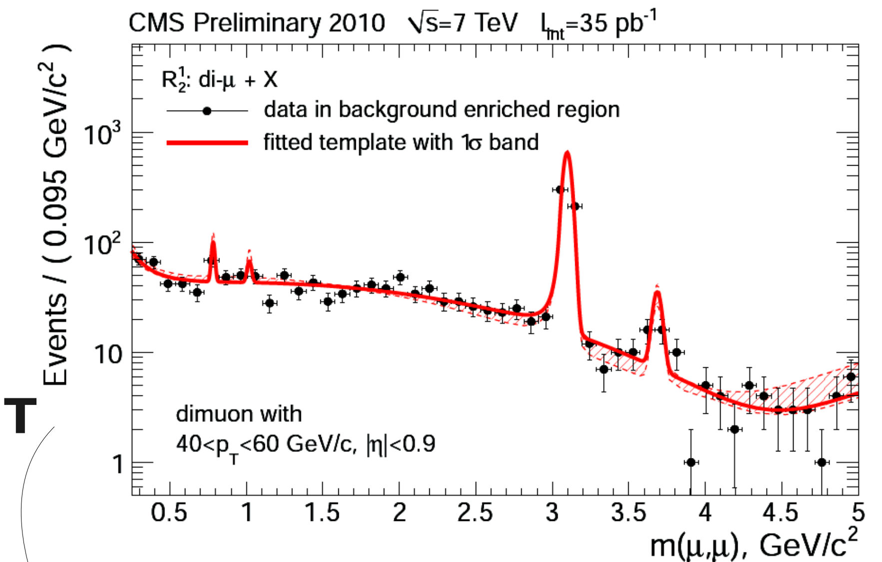


CMS EX0-11-13

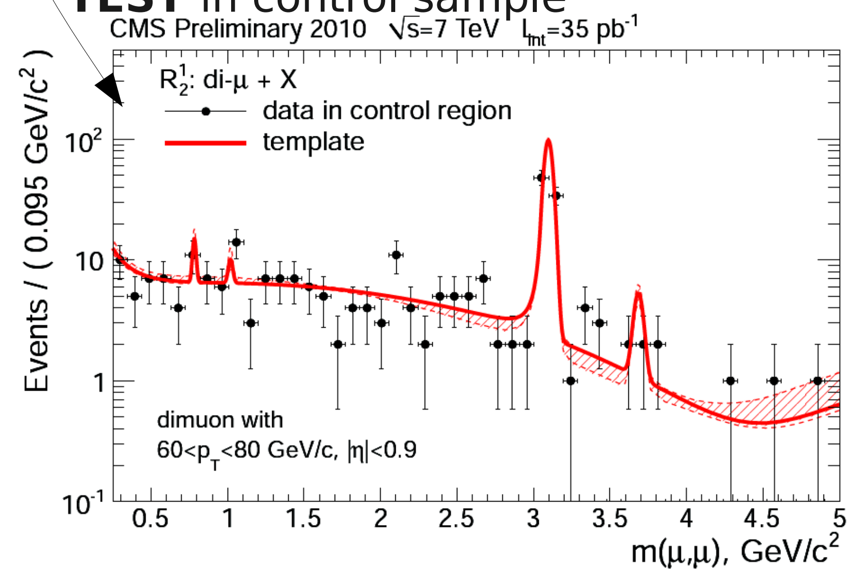
Background estimation

- **Background shape templates from data,** check composition from MC
- Use **SM narrow resonances to model the detector resolution**, use MC to extrapolate with p^T
- General strategy:
  → set templates with high statistics bkg enriched data sample
  → test on control samples
  → apply to signal search region

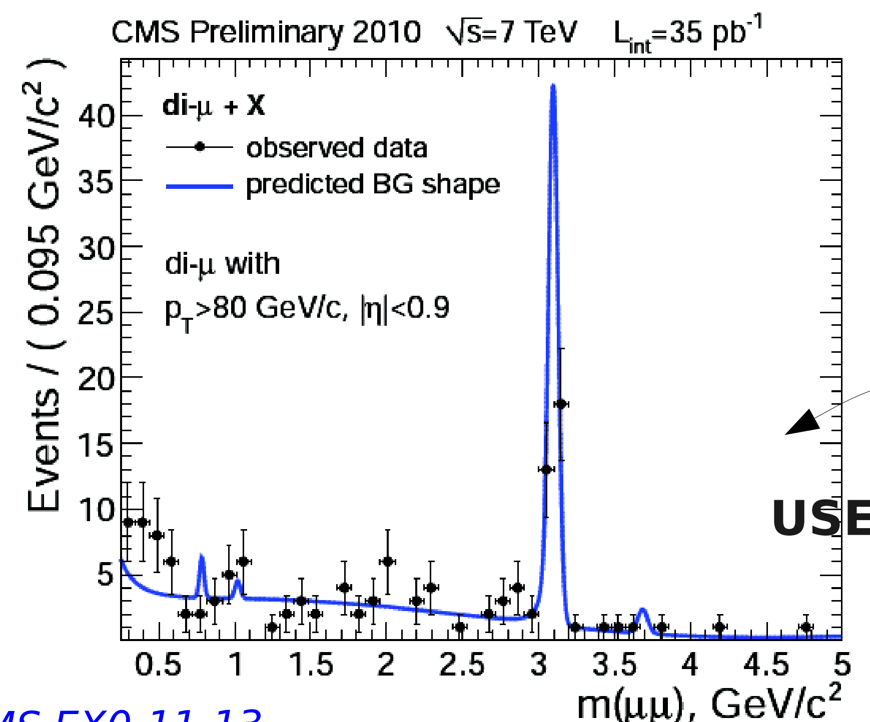
FIT



TEST in control sample



USE



CMS EX0-11-13

Overview of main systematics (I)

Systematic uncertainties arise from detector performance and theoretical uncertainties on background and signal modeling

Luminosity:

- 11% uncertainty (recently improved to 4%)

Trigger and lepton reconstruction/identification efficiency

- use Z Tag&Probe method
- measured within few % uncertainty
- extrapolation with MC for very high p^T range
  - main contribution (8%) to systematic uncertainty on Z' to Z efficiency ratio in the e-channel

Energy scale/resolution

- Electrons/photons
  - ECAL scale from Z→ee and low mass $\gamma\gamma$ resonances (1%-3% accuracy)
  - extrapolation to high pT exploiting ECAL linearity, MC, cross-check in data exploiting electron shower shape
- Muons
  - from Z→$\mu\mu$
  - cosmics provide validation at high pT

Overview of main systematics (II)

Missing transverse energy

- model hadronic recoil from Z→ee/Z → μμ events
  - along with energy scale and eff. uncertainty affects the bkg estimation in W' → eν searches (total ~28% uncertainty for MT > 500 GeV)

Electron/muons/photon fake rates

- Uncertainty estimated comparing results with different datasets/selections, and applying to control samples. Large uncertainties (25%-50%) but marginal impact in the high mass/pt region

Theoretical uncertainties

- PDF uncertainties – reweighting PDF sets
- QCD higher order corrections estimated varying factorization and renormalization scales

*SETTING **UPPER LIMITS:***

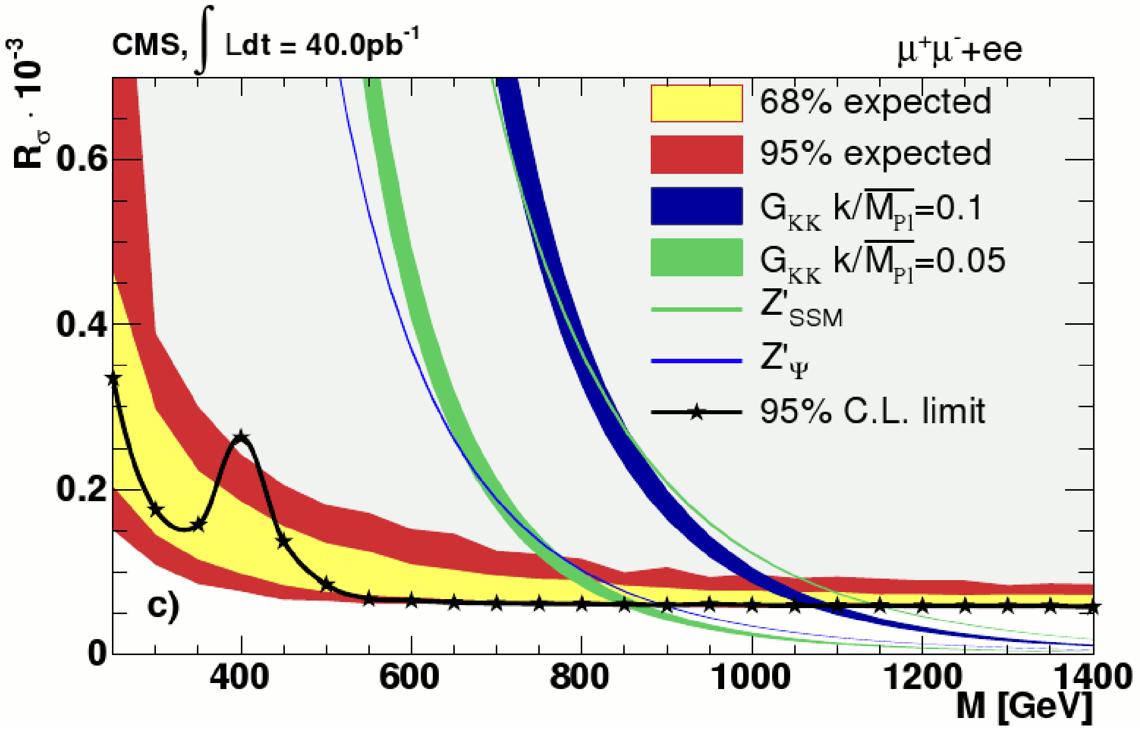
- *Simple **Bayesan approach** to set 95% C.L. Exclusion limit*
- *Flat prior for signal cross section*
- *Systematic uncertainties treated as nuisance parameters with log-normal prior distribution*

Results - Dileptons

- Set limits on ratio of production cross sections (uncertainty form luminosity canceled)

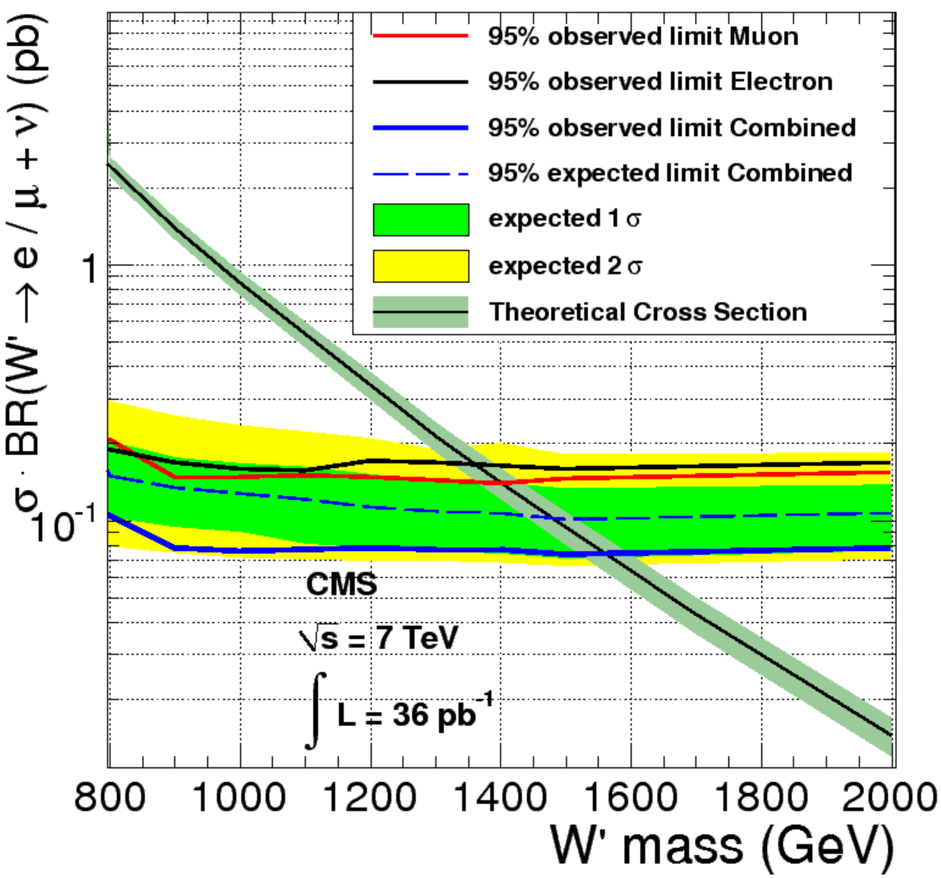
$$\frac{\sigma \times BR(Z')}{\sigma \times BR(Z^0)} = \frac{N(Z')}{N(Z^0)} \times \frac{A(Z^0)}{A(Z')} \times \frac{\epsilon(Z^0)}{\epsilon(Z')}$$

Channel	μμ	ee	Combined
Z_{SSM}	1027 GeV	958 GeV	1140 GeV
Z_ψ	792 GeV	731 GeV	887 GeV
G_{KK}, k/M_{Pl} = 0.05	778 GeV	729 GeV	855 GeV
G_{KK}, k/M_{Pl} = 0.10	987 GeV	931 GeV	1079 GeV



For comparison:
Published CDF/D0 limits
D0, Z' → ee, G → 5.4 fb^{-1}:
$M(Z`_{SSM}) > 1023$ GeV
$M(G_{KK},^{k/M=0.1}) > 1050$ GeV
CDF, μμ, 2.3 fb^{-1}:
$M(Z`_{SSM}) > 1030$ GeV
$M(G_{KK},^{k/M=0.1}) > 921$ GeV
CDF, ee , 2.5 fb^{-1}:
$M(Z`_{SSM}) > 963$ GeV
$M(G_{KK},^{k/M=0.1}) > 848$ GeV

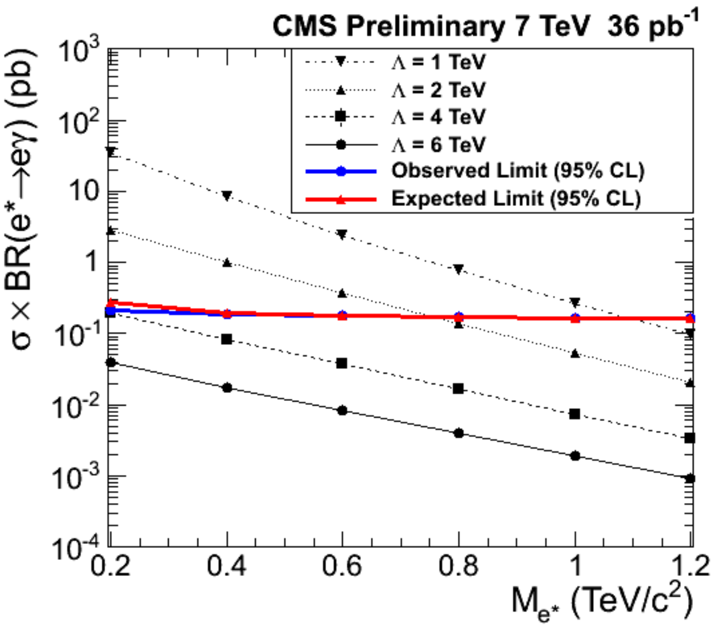
Results – W'

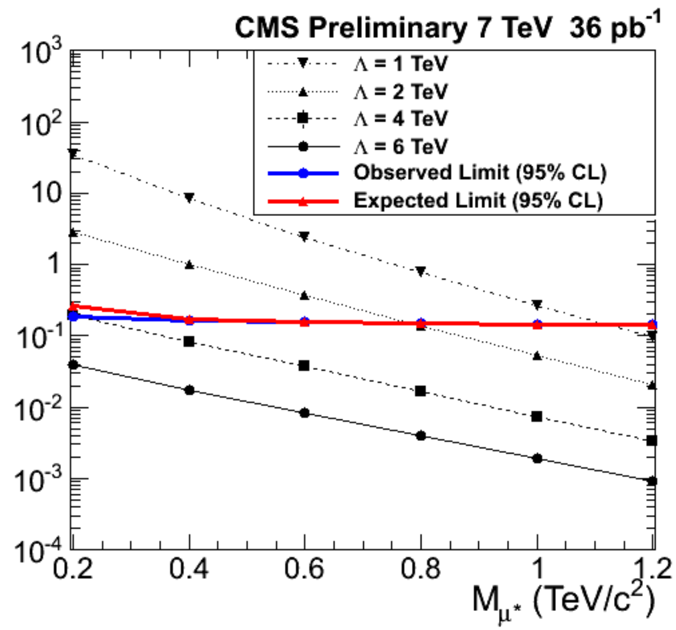


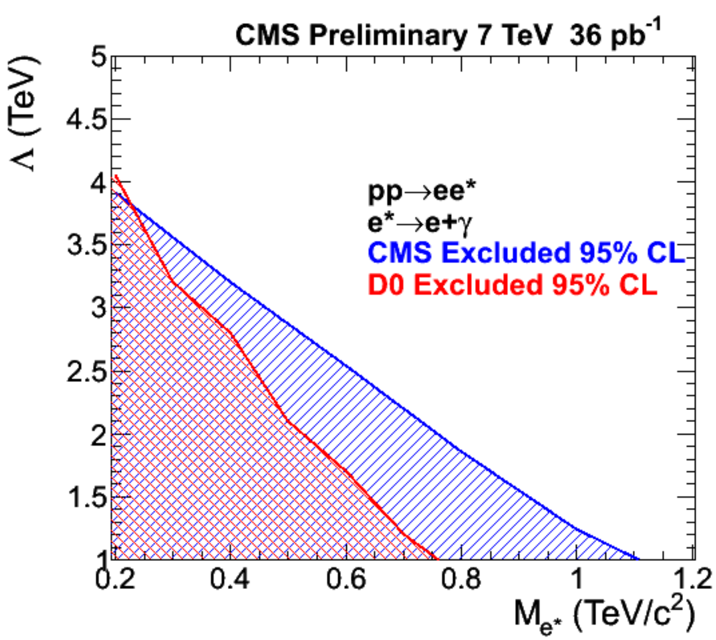
- **Reference Model as benchmark**
- Exclusion limits
  - e-channel M(W') > 1.36 TeV
  - μ-channel M(W') > 1.4 TeV
  - **combined M(W') > 1.58 TeV**

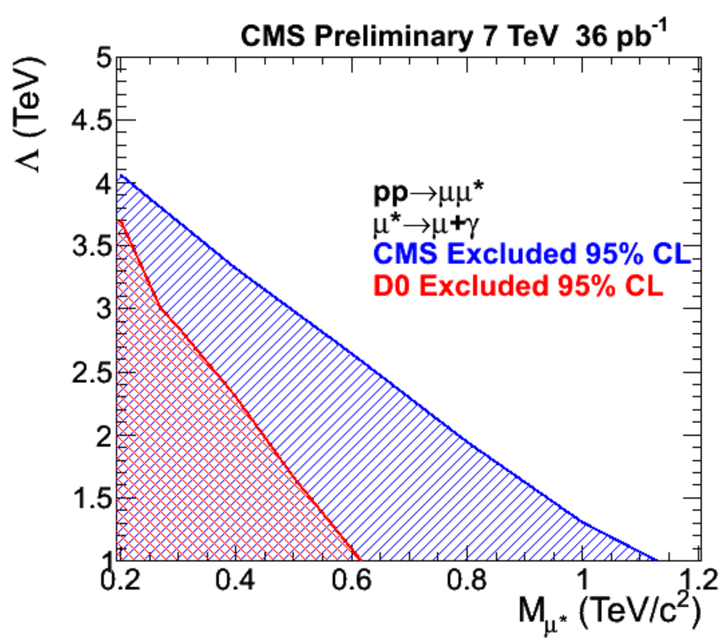
- Superseded TeVatron limits (CDF, 1.1 TeV)

Results – excited leptons



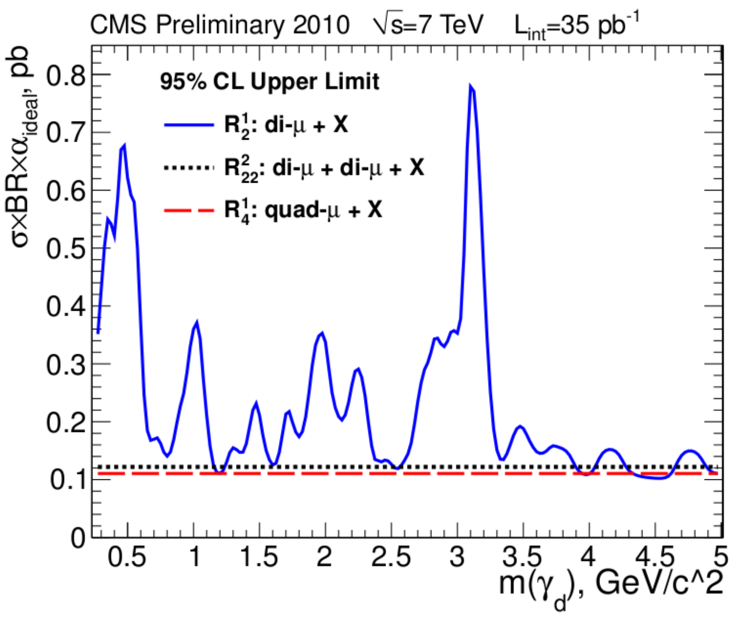




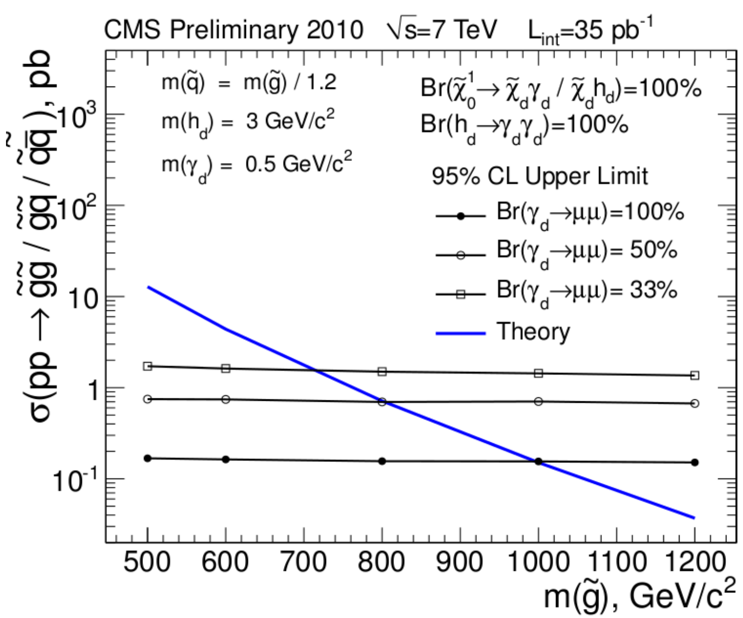


Significant improvement over current D0 limits

Results – lepton jets



- Upper limit on cross-section x branching fraction x acceptance, where acceptance must be supplied by the model in question



- Example of application to model of SUSY dark matter with a ~1 GeV/c^2 dark photon, inspired by the PAMELA interstellar positron excess (PRL 103 (2009) 051801)

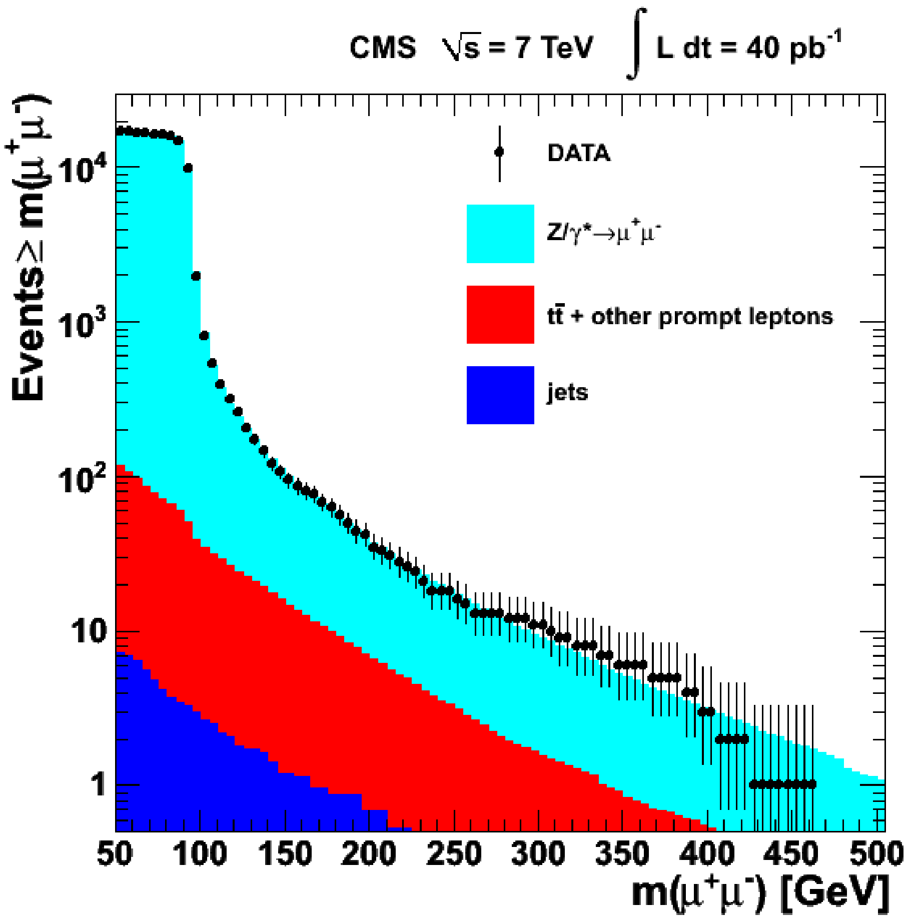
Summary

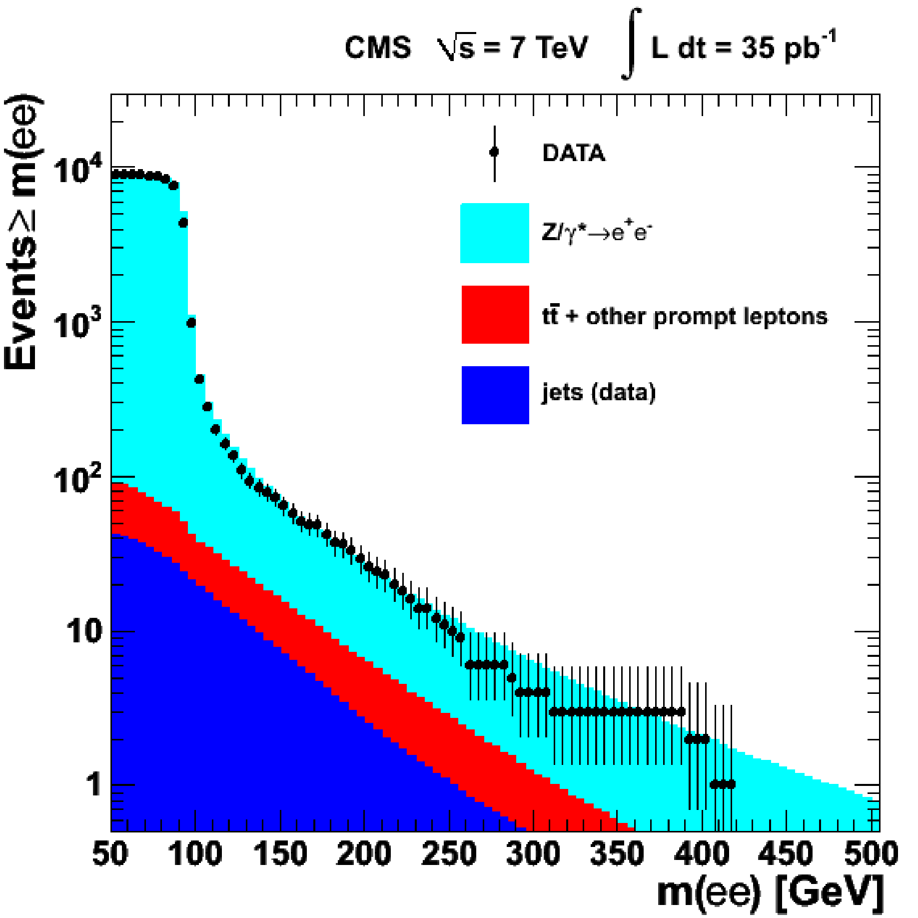
- Searches for leptonic resonances with 2010 pp collision data shown
- No significant excess found in data
- Good understanding of detector and backgrounds
  - Data-driven background estimation in most cases
- We exceed the exclusion limits previously set by Tevatron experiments
- These results are the basis for searches with much larger datasets expected in 2011

BACKUP SLIDES

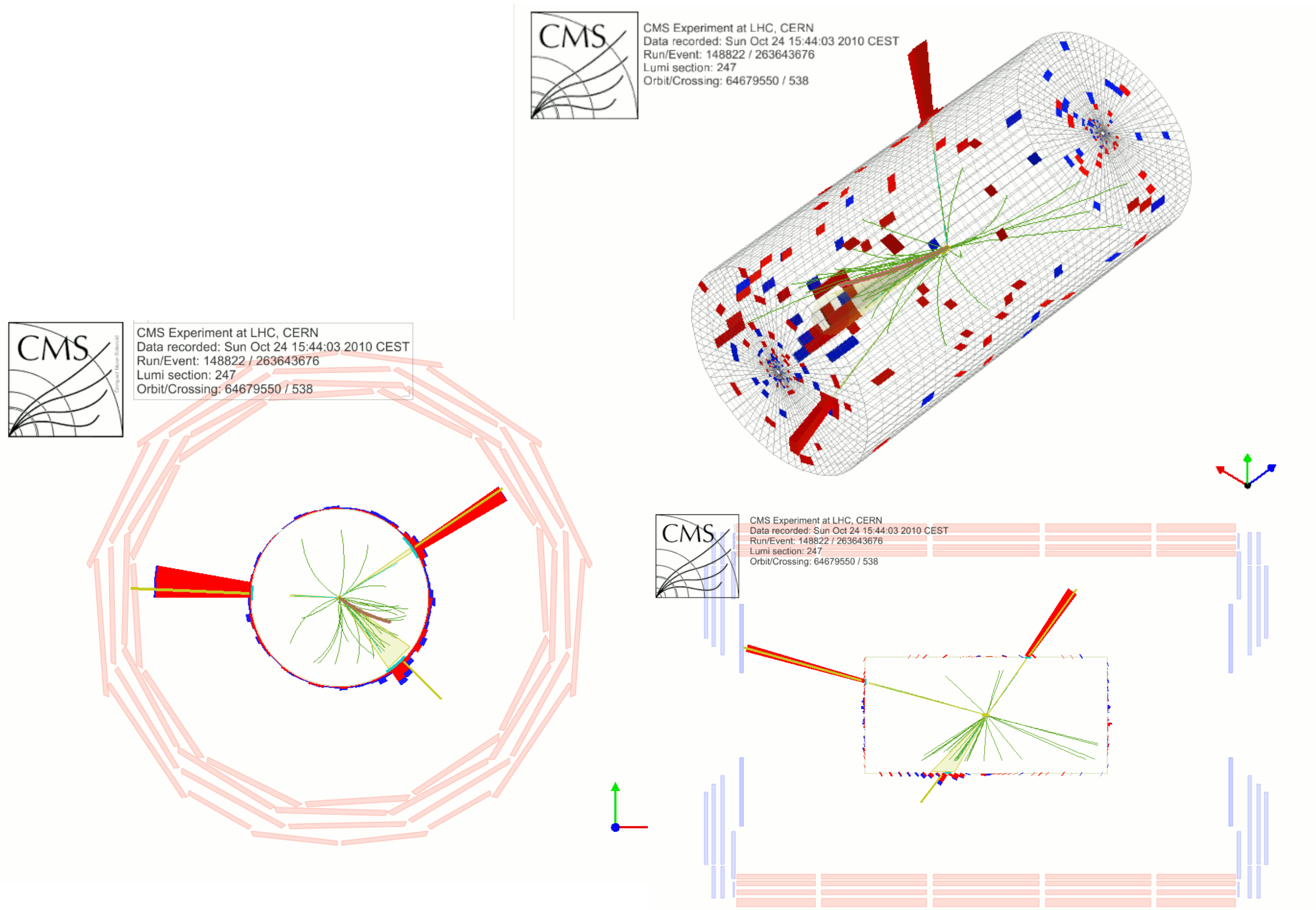
Z'

- Cumulative distributions

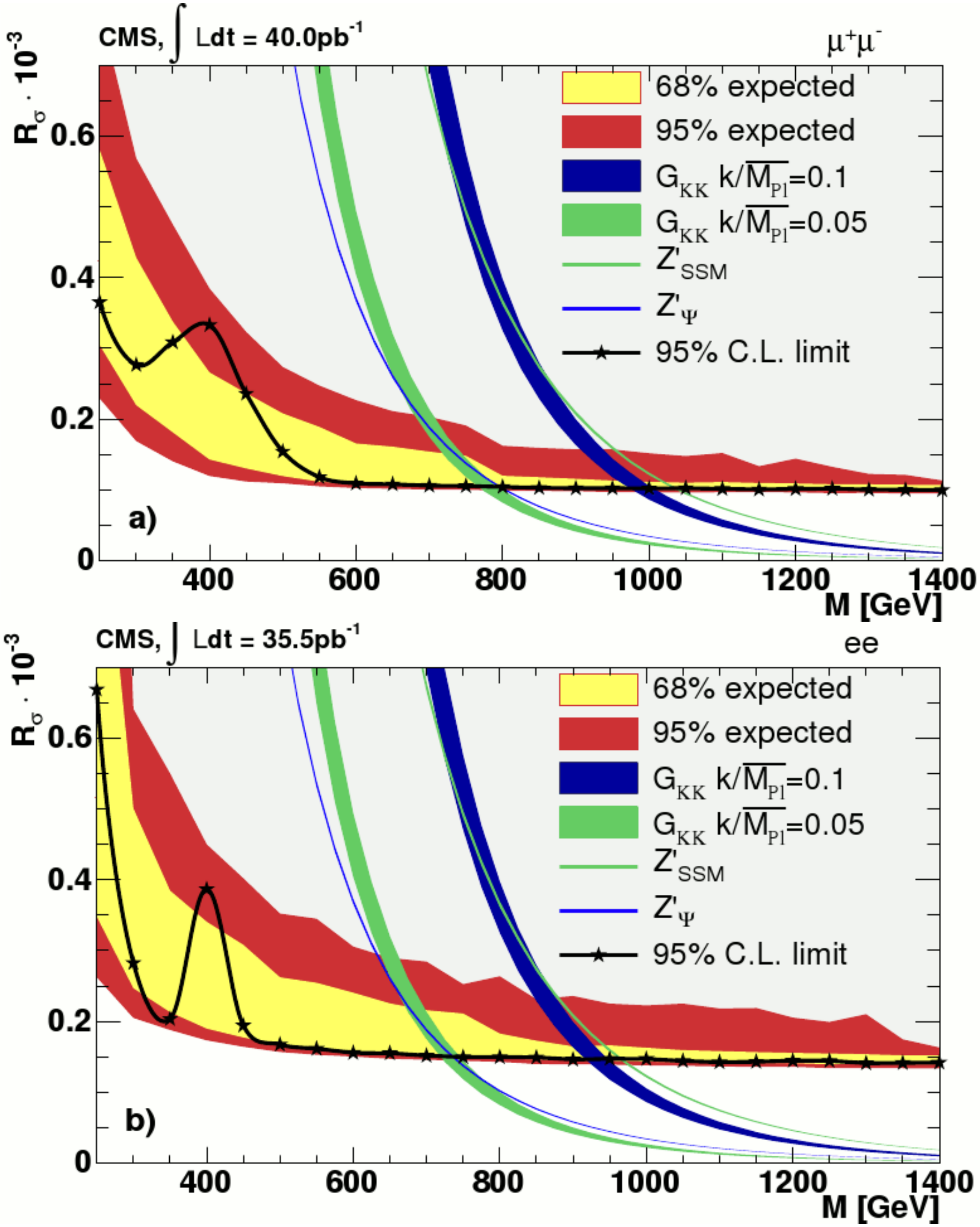




Highest mass event display

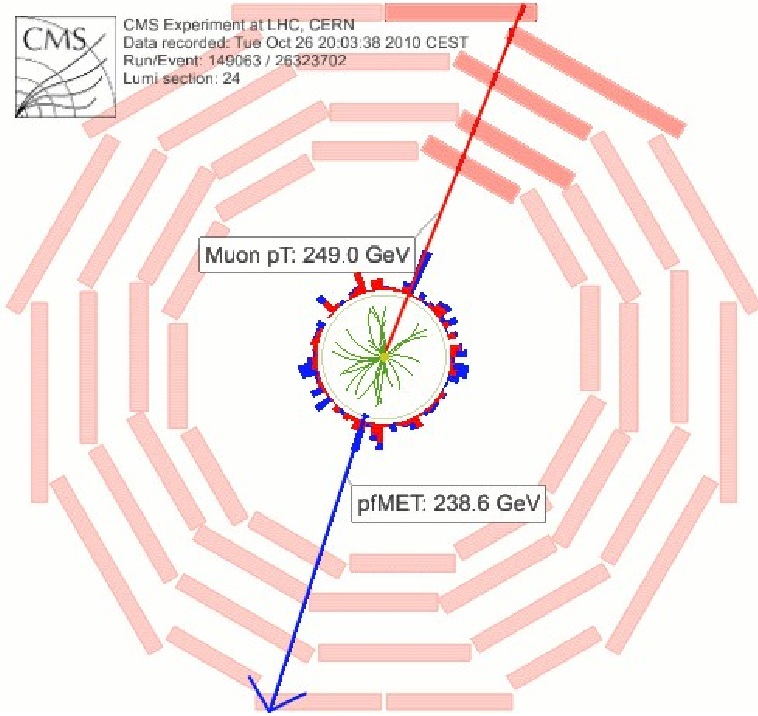


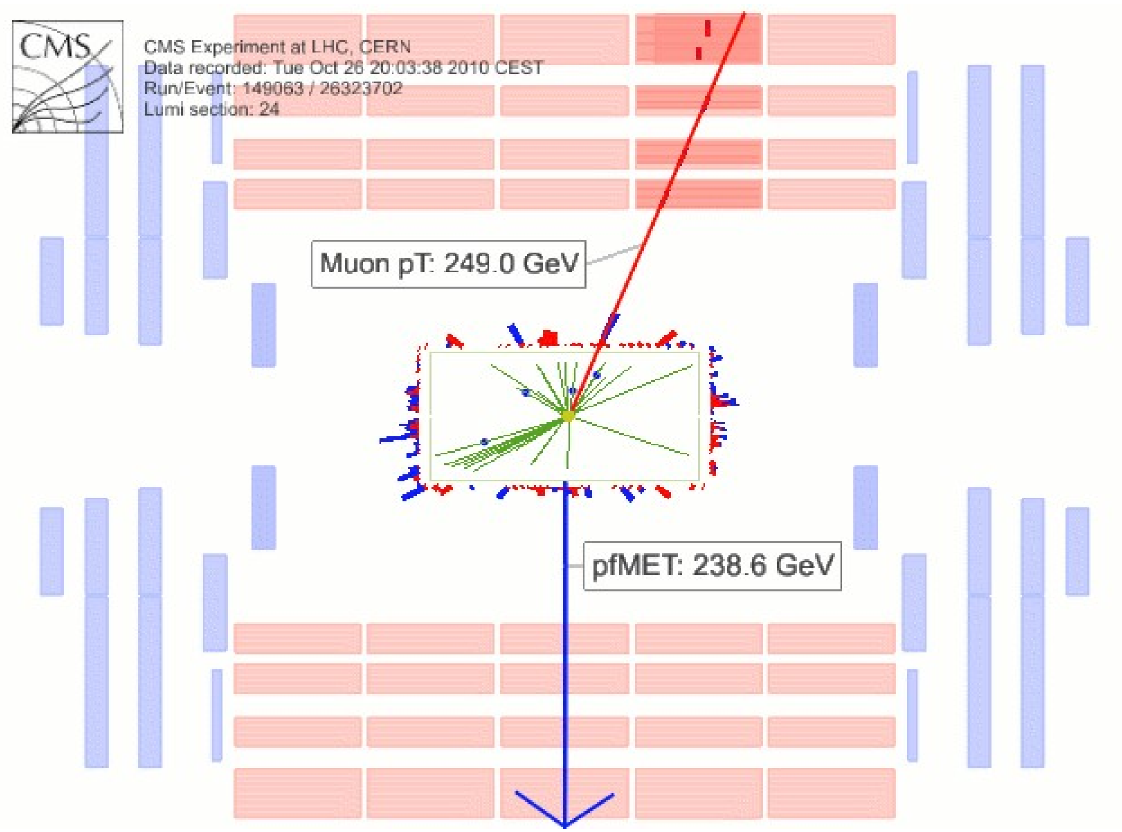
Z' results



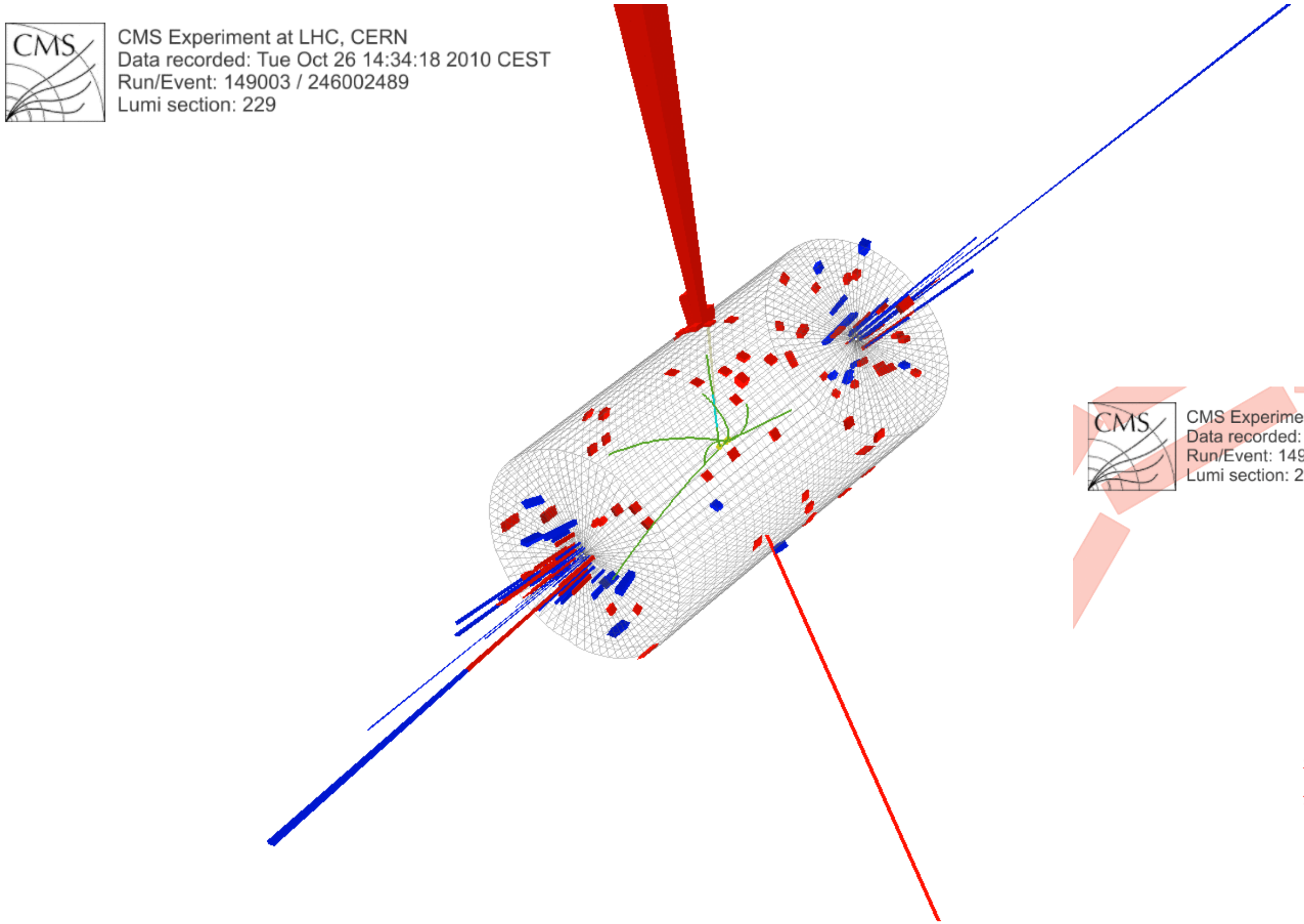
CMS, ∫ Ldt = 40.0pb⁻¹
μ⁺μ⁻
$R_\sigma \cdot 10^{-3}$
68% expected
95% expected
G_{KK} $k/\overline{M}_{Pl}$=0.1
G_{KK} $k/\overline{M}_{Pl}$=0.05
Z'_{SSM}
Z'_ψ
95% C.L. limit
a)
M [GeV]
CMS, ∫ Ldt = 35.5pb⁻¹
ee
$R_\sigma \cdot 10^{-3}$
68% expected
95% expected
G_{KK} $k/\overline{M}_{Pl}$=0.1
G_{KK} $k/\overline{M}_{Pl}$=0.05
Z'_{SSM}
Z'_ψ
95% C.L. limit
b)
M [GeV]

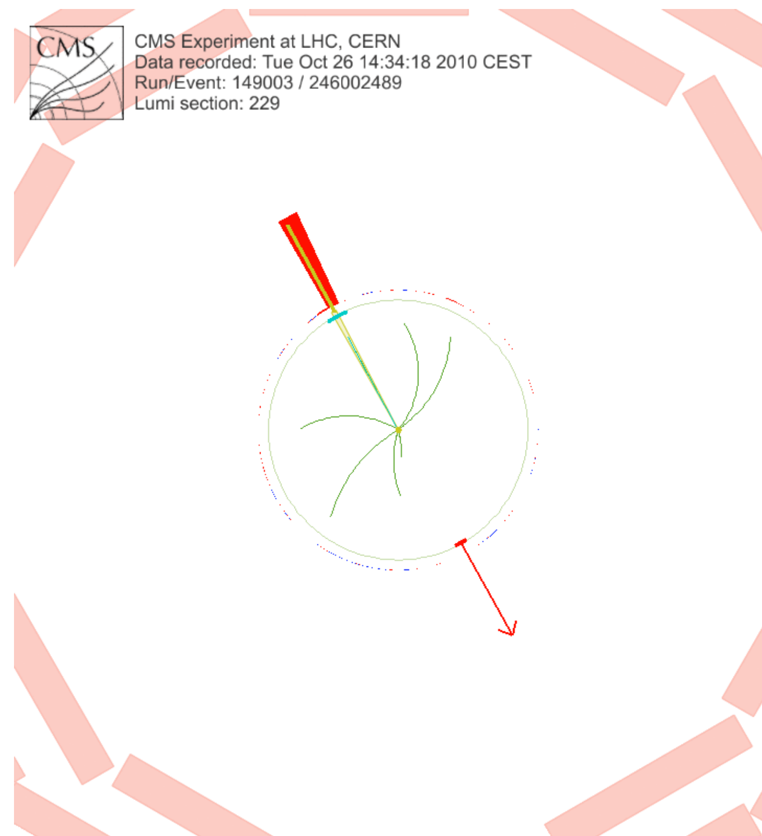
W' → μν highest MT event



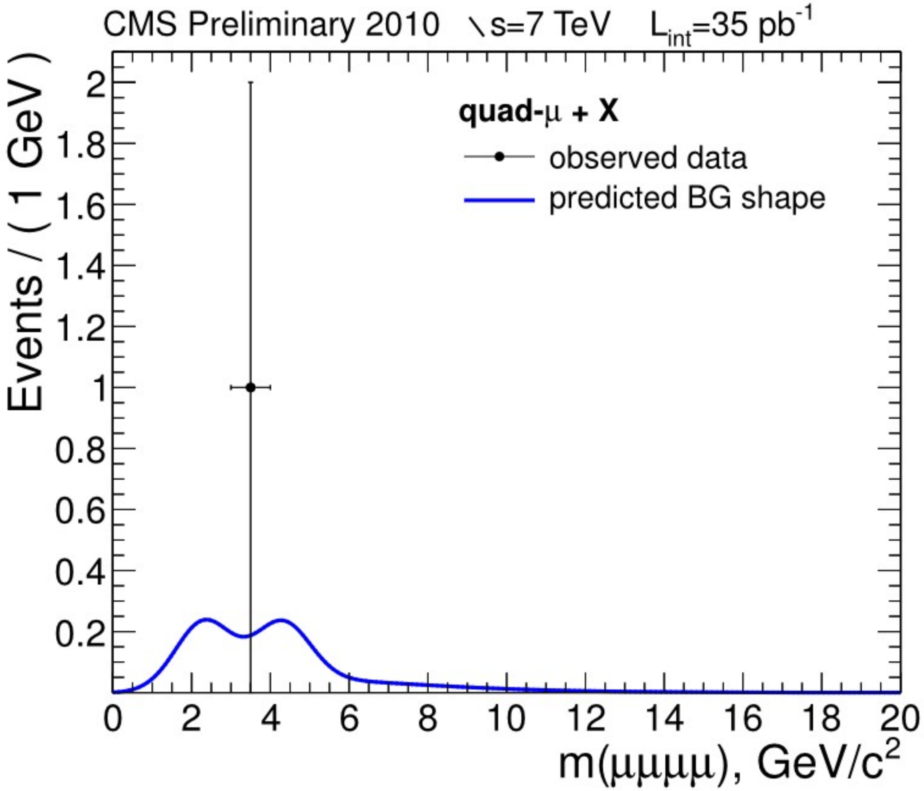


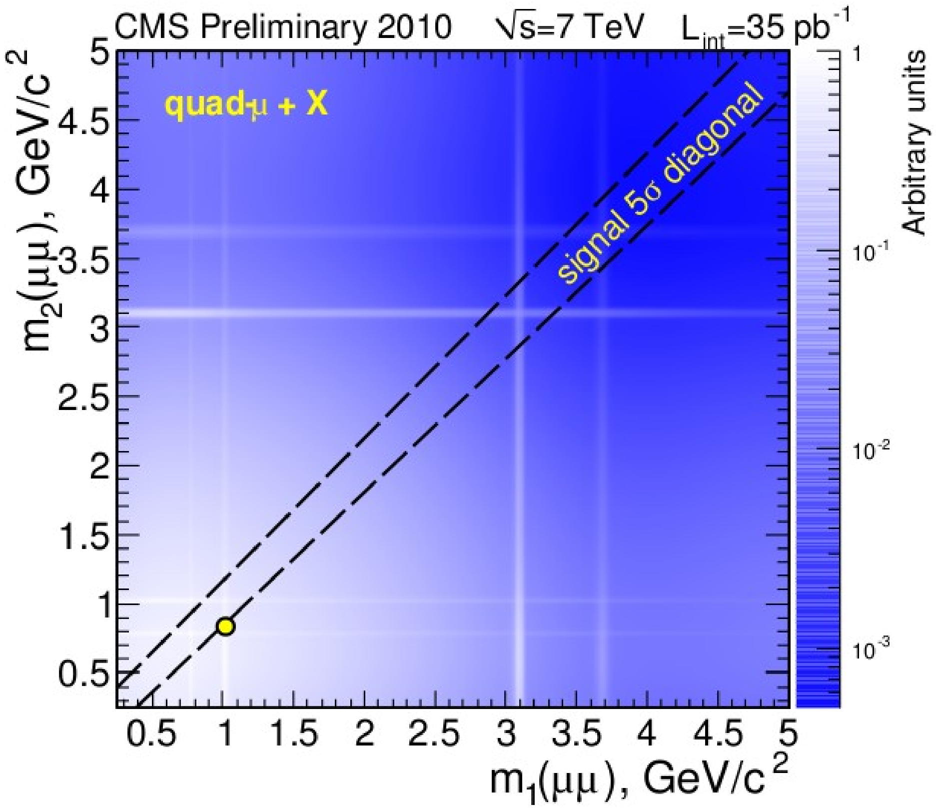
W' → eν highest MT event





Lepton jets - 4 muons event





Bayesian upper limit

- Bayesian approach to set 95% C.L. upper limits

$$\int_{-\infty}^{\sigma_{\rm up}(n)} p(\sigma|n,A,\mathcal{L},b)\mathrm{d}\sigma = \frac{\int_{-\infty}^{\sigma_{\rm up}(n)} L'(n|\sigma,A,\mathcal{L},b)\pi(\sigma)\mathrm{d}\sigma}{\int_{-\infty}^{+\infty} L'(n|\sigma,A,\mathcal{L},b)\pi(\sigma)\mathrm{d}\sigma} = 0.95$$

$$L'(n|\sigma,A,\mathcal{L},b) = \int_0^{+\infty}\int_0^{+\infty}\int_0^{+\infty} L(n|\sigma,A',\mathcal{L}',b')\,\underbrace{g(A')h(\mathcal{L}')f(b')}\,\mathrm{d}A'\mathrm{d}\mathcal{L}'\mathrm{d}b'$$

Flat prior

$$\pi(\sigma) = \begin{cases} 0 & \sigma < 0 \\ 1 & \sigma \geq 0 \end{cases}$$

$g(A'),\ h(\mathcal{L}'),\ f(b')$ **Log-normal distributions describing** uncertainties in A', $\mathcal{L}'$, b'

Poisson distribution

$$L(n|\sigma,A',\mathcal{L}',b') = \frac{(\sigma A'\mathcal{L}' + b')^n}{n!} e^{-(\sigma A'\mathcal{L}'+b')}$$

Expected upper limit

$$<\sigma_{\rm up}> = \sum_{n=0}^{+\infty} \sigma_{\rm up}(n) L(n|\sigma=0,A,\mathcal{L},b)$$

n = number of observed events
A = acceptance×efficiency
$\mathcal{L}$ = integrated luminosity
b = expected number of background events