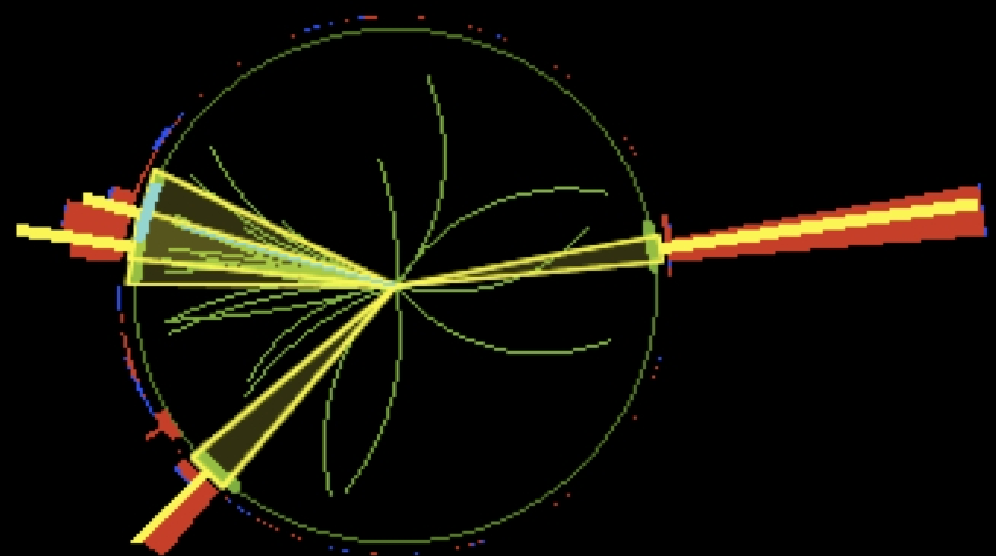
CMS Experiment at LHC, CERN
Data recorded: Thu Oct 28 04:37:39 2010 PDT
Run/Event: 149182 / 239413357
Lumi section: 274

Photon 2011, 22nd - 27th May 2011

# Searches with Photons in CMS

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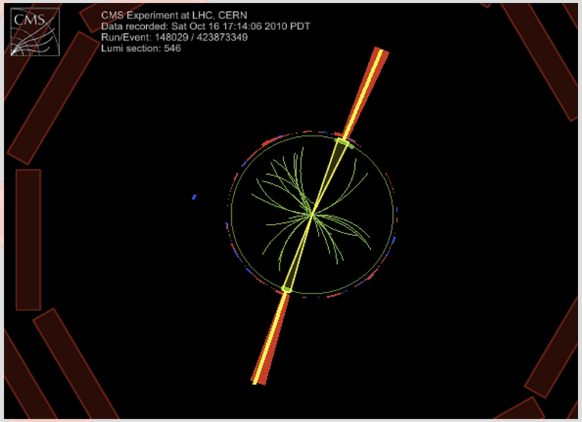
on behalf of CMS Collaboration

# Photons: messangers of new physics

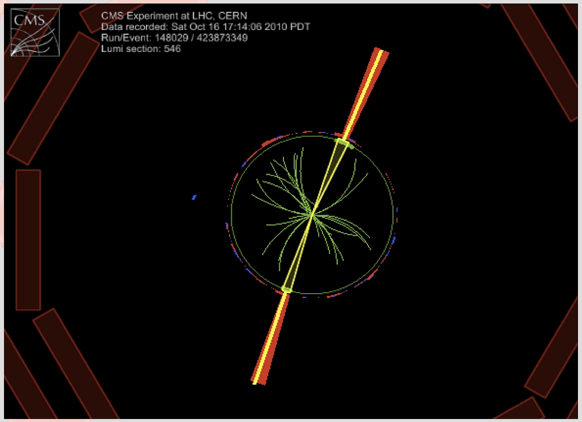
## Many different new physics models predict high-energy photons in the final state




- di-photon from extra-dimension, both RS (resonant) and ADD (non resonant)
- single photon from the decay of excited lepton
- single photon production associated with invisible, stable particle (Graviton, Unparticle...)
- di-photon + missing energy from Universal Extra-Dimension
- displaced photon from the decay of long-lived particles
- GMSB: decay of a neutralino in a photon and gravitino: photon+jets+missing energy
- ...

# Photons: messangers of new physics

## Some of them have been addressed by CMS with 2010 data (33-36 pb$^{-1}$)




- di-photon from extra-dimension, both RS (resonant) and ADD (non resonant)
- single photon from the decay of excited lepton

- no evidence of new physics has been observed
  - → improved limits on some models
  - → model-independent limits
- Standard Model background processes well under control
  - → techniques for measuring background and fake rate with data
- put the basis for the 2011-2012 discovery campaign

# How to reconstruct a high-$E_T$ $\gamma$?

## CMS must be able to reconstruct photons with $E_T$ larger than ~ 100 GeV

*To reconstruct photons:*

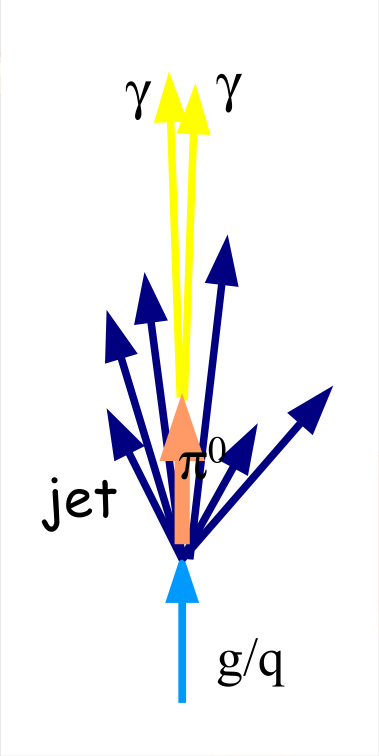
- Clusters in the Electromagnetic Calorimeter (ECAL)
- Supercluster (SC) (5 crystals in $\eta$, variable length in $\phi$) to collect all EM energy
- rejection if a track compatible with electron is found (from hits in the fist 2 layers of Pixel detector)

*To separate photons from jets:*

Jets can be misidentified as $\gamma$, when they fragment in a hard $\pi^0$ or $\eta$.

To reduce misidentification:

- hadronic energy within $\Delta R<0.15$ from SC must be <5% of its EM energy
- in the $0.04<\Delta R<0.40$ cone around the SC: $\Sigma p_T$ of tracks from the associated primary vertex must be $2.0+0.001\ E_T$ GeV
- in the $0.06<\Delta R<0.40$ cone around the SC: $\Sigma E_T$ of energy deposit in ECAL must be $4.2+0.006\ E_T$ GeV
- in the $0.15<\Delta R<0.40$ cone around the SC: $\Sigma E_T$ of energy deposit in hadronic calorimeter (HCAL) must be $2.2+0.0025\ E_T$ GeV
- shower shape $\sigma_{\eta\eta}$ consistent with a $\gamma$



# How to reconstruct a high-$E_T$ $\gamma$ ?

*In order to suppress noise and anomalous signal in ECAL:*

- shower shape
- pulse timing information

*Preselection and trigger:*

- single photon trigger ($E_T(\gamma)$> 20 GeV or lower, depending from the stage) OR double photon trigger ($E_T(\gamma_{1,2})$> 22 GeV or lower, depending from the stage)
- $E_T(\gamma)$> 20-30 GeV depending from the analysis

*Reconstruction and identification efficiency* (1103.4279 (hep-ex)):

→ single-$\gamma$: 87.8 ± 2.3 %

→ double-$\gamma$: 77.1 ± 4.5 %

constant with $E_T$ , $\eta$ within the uncertainty

# How to estimate the fake rate

The remaining rate of jet faking $\gamma$ controls the amount of background, and has to be evaluated from data

*measure fake rate:*

(# isol. $\gamma$) /( # $\gamma$ failing one isol. or $\sigma_{\eta\eta}$ requirement)

→ 28% - 2% in a 30-120 GeV range

*measure fake rate syst error:*

from real isolated $\gamma$ in the numerator:

→ ~ 20%

*apply the fake rate to sample with non-isolated photons:*

→ get a prediction for di-jet and $\gamma$+jet background

# Di-γ from ADD Graviton

*Large Extra-Dimension model* (Phys. Lett. B429 (1998) 263):

- there's a number $n_{ED}$ of extradimensions, compactified over a torus with radius r
- Standard Model is confined in the torus surface, gravity can propagate in the bulk
- there's a $M_D$ scale related to Planck mass $M_{Pl}$ : $M_D^{n_{ED}+2} = M_{Pl}^2 / r^{n_{ED}}$

→ Gravitons appears as continuum (spaced < 100 MeV) spectrum of Kaluza-Klein excitations, extended up to a $M_S$ scale

→ Gravitons decay in di-photon

The total cross-section for di-γ production is: $\sigma_{ADD} = \sigma_{SM} + A\eta_G\,\sigma_{int} + B\eta_G^2\,\sigma_{ED}$
where $\eta_G = \mathcal{F}/M_S^4$, and:

$$\mathcal{F} = 1 \quad \text{(Guidice, Rattazzi, and Wells, GRW [5])},$$

$$\mathcal{F} = \begin{cases} \log\left(\frac{M_S^2}{\hat{s}}\right) & \text{if } n_{ED} = 2 \\ \frac{2}{(n_{ED}-2)} & \text{if } n_{ED} > 2 \end{cases} \quad \text{(Han, Lykken, and Zhang, HLZ [6])},$$

$$\mathcal{F} = \pm\frac{2}{\pi} \quad \text{(Hewett [7])},$$

**Previous limits (95% C.L.):**
**D0 (Rev. Lett. 102 (2009) 051601):**
**$M_S$ excluded below 1.3-2.1 TeV depending from $n_{ED}$**

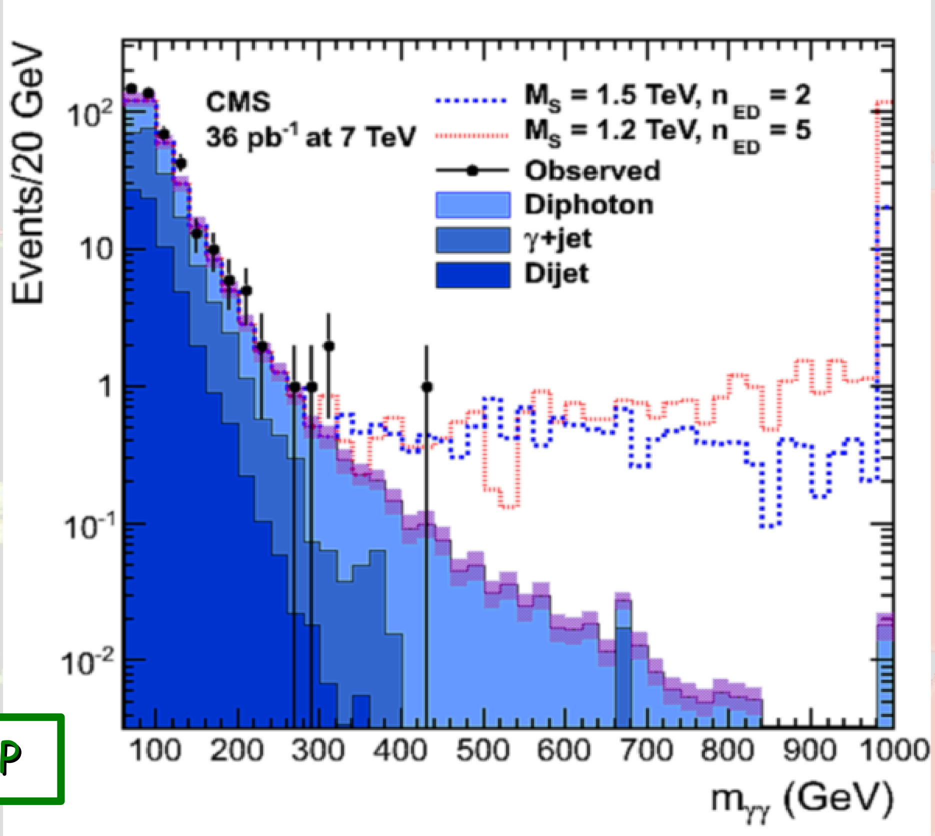
# Di- γ from ADD Graviton

look for excess in the tails of the M(γγ) distribution
→ *good agreement between the data and the Standard Model*

*Main systematic effects:*

- Luminosity uncertainty : 11%
- $K_{NLO}$ for signal =1.3±0.1
- $K_{NLO}$ for background =1.3±0.3
- fake rate uncertainty

1103.4279 (hep-ex), accepted by JHEP




| Process | $60 < M_{\gamma\gamma} < 200$ GeV | $200 < M_{\gamma\gamma} < 500$ GeV | 500 GeV$< M_{\gamma\gamma}$ |
|---|---|---|---|
| Dijets | $70 \pm 28$ | $0.5 \pm 0.2$ | $0.0009 \pm 0.0004$ |
| $\gamma +$Jets | $145 \pm 7$ | $2.3 \pm 0.3$ | $0.016 \pm 0.003$ |
| Diphotons | $150 \pm 35$ | $6.2 \pm 1.4$ | $0.29 \pm 0.07$ |
| Total Backgrounds | $365 \pm 49$ | $9.0 \pm 1.5$ | $0.30 \pm 0.07$ |
| Observed | 428 | 12 | 0 |

# Di- $\gamma$ from ADD Graviton

## *Model-independent limit:*

→ CMS can exclude any excess in $M(\gamma\gamma)>500$ GeV (with $E_T(\gamma)>30$ GeV, $\eta(\gamma)<1.442$) down to 0.118 pb

## *Model-dependent limit:*

| | GRW | Hewett | | HLZ | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Pos. | Neg. | $n_{ED}=2$ | $n_{ED}=3$ | $n_{ED}=4$ | $n_{ED}=5$ | $n_{ED}=6$ | $n_{ED}=7$ |
| Full | 1.94 | 1.74 | 1.71 | 1.89 | 2.31 | 1.94 | 1.76 | 1.63 | 1.55 |
| Trunc. | 1.84 | 1.60 | 1.50 | 1.80 | 2.23 | 1.84 | 1.63 | 1.46 | 1.31 |

1103.4279 (hep-ex), accepted by JHEP

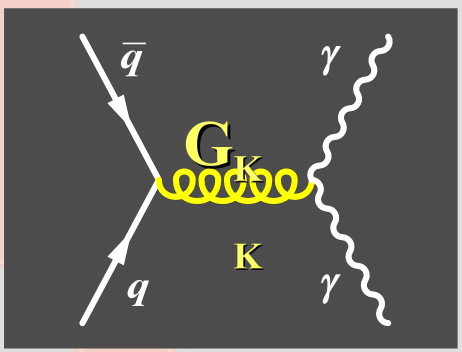
# Di- $\gamma$ from RS Graviton

*Randall-Sundrum model* (Phys. Rev. Lett. 83 (1999) 3370-3373):

- there's a 5th dim that is "warped"
- the 4-dimensional metric depends on the extra-dimension coordinate y:

$$ds^2 = e^{-2kr_c y}\eta_{\mu\nu}dx^\mu dx^\nu - r_c^2 dy^2$$

- RS-1: there's a brane (IR) where Standard Model is localized, and a brane (UV) where graviton lives mostly
- scale of the IR brane is "red-shifted" wrt UV brane: $\Lambda_\pi = M_{Pl}e^{-kr_c\pi}$
- we can assume $\Lambda_\pi \sim M_{EW}$ , so to have $kr_c \sim 11\text{-}12$

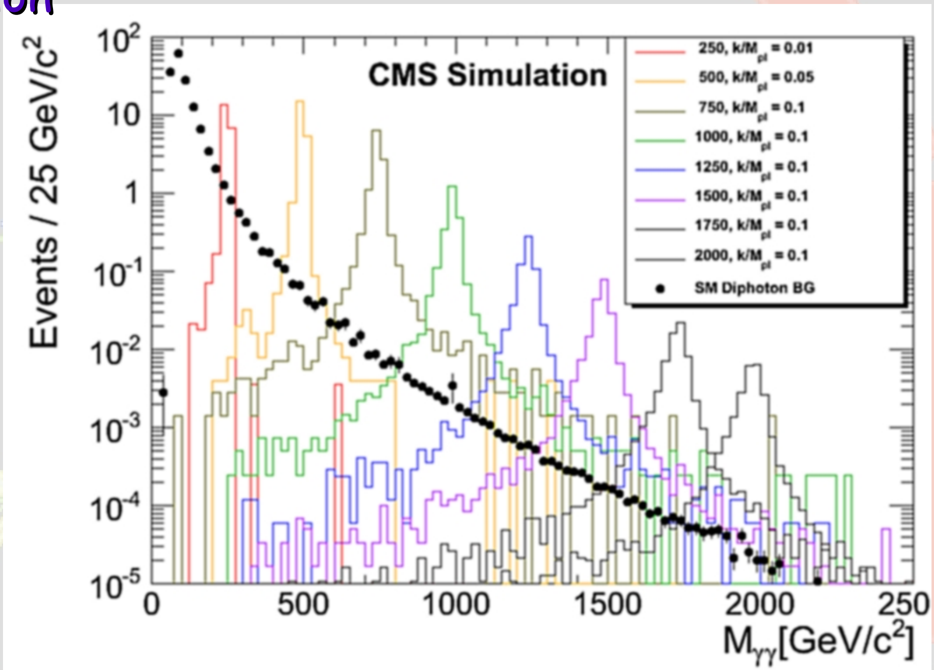



→ Gravitons appears as well separated (~1 TeV) resonances
→ resonances decay in di-photon
→ parameters: first excitation $M_1$ and $\tilde{k} \equiv k/\bar{M}_{Pl}$

Previous limits (95% C.L.):
CDF (Phys. Rev. D83 (2011) 011102):
$M_1 > 604$ (1055) GeV for $\tilde{k}$=0.01 (0.1)

# Di- γ from RS Graviton

look for resonances in the M(γγ) distribution
→ *good agreement between the data and the Standard Model*




*Main systematic effects:*

- Luminosity uncertainty: 11%
- $K_{NLO}$ for signal =1.3±0.1
- $K_{NLO}$ for background =1.3±0.1
- di-γ efficiency: 2%
- PDF uncertainty on signal: 1.5%
- fake rate uncertainty: ~20%
- background parametrization: 10%

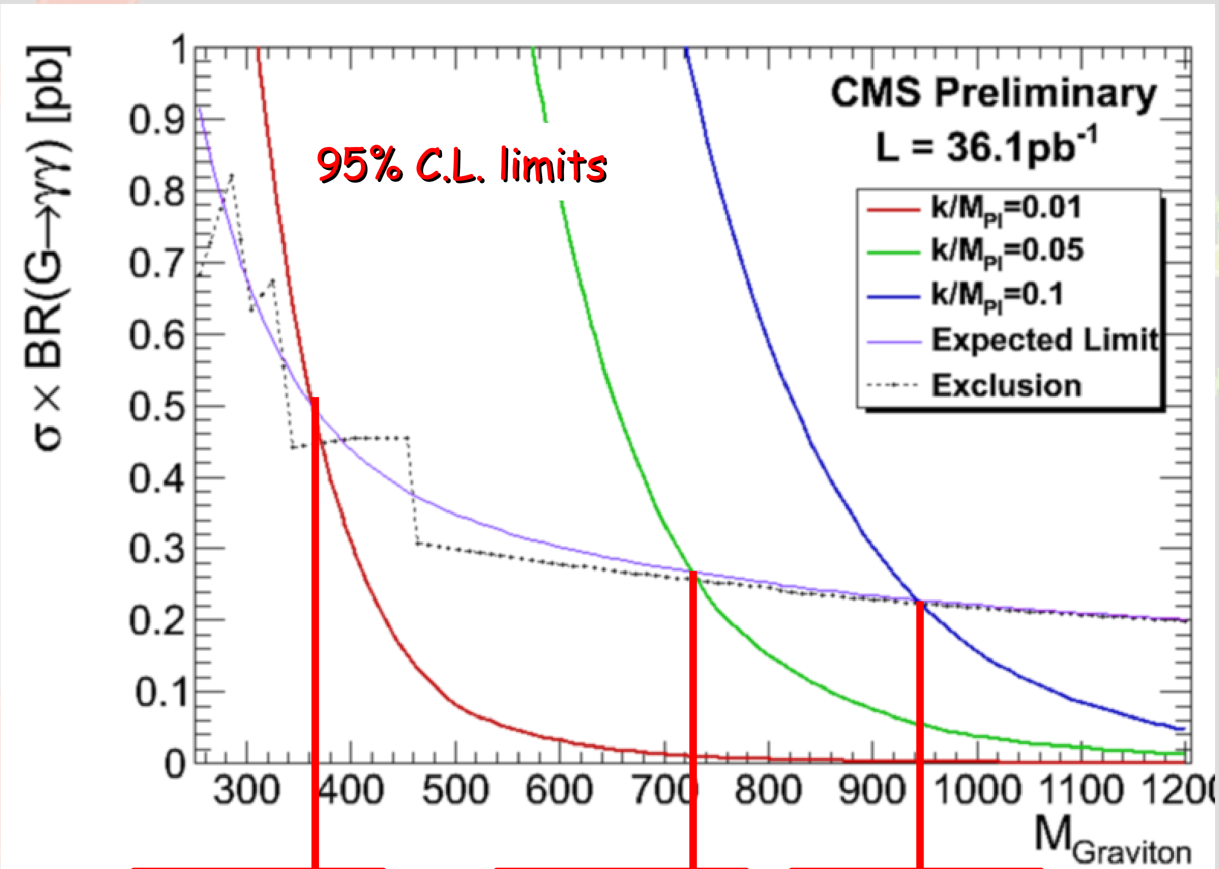
CMS-PAS-EXO-10-019

| Sample | $0 < M_{\gamma\gamma} < 60$ GeV/c² | $60 < M_{\gamma\gamma} < 200$ GeV/c² | $200 < M_{\gamma\gamma} < 500$ GeV/c² | $500 < M_{\gamma\gamma} < 1000$ GeV/c² |
|---|---|---|---|---|
| Diphoton | 0.6 ± 0.04 ± 0.1 | 148.0 ± 0.4 ± 34.2 | 6.1 ± 0.1 ± 1.4 | 0.27 ± 0.01 ± 0.06 |
| QCD Jets | 3.0 ± 0.3 ± 0.8 | 69.1 ± 1.4 ± 19.5 | 0.5 ± 0.04 ± 0.1 | 0.001 ± 0.001 ± 0.0003 |
| γ+Jet | 18.3 ± 4.3 ± 5.1 | 144.8 ± 7.1 ± 68.8 | 2.3 ± 0.5 ± 0.7 | 0.02 ± 0.02 ± 0.004 |
| TOTAL | 21.9 ± 4.4 ± 4.9 | 362.0 ± 7.2 ± 68.9 | 8.9 ± 0.5 ± 1.6 | 0.29 ± 0.03 ± 0.06 |
| Data | 35 | 428 | 12 | 0 |

# Di- γ from RS Graviton

*Limits extraction:*

- resonant signal is parametrized with a Gaussian+Crystal Ball function
- background shape is parametrized with an exp(pol4), fitted in the 220-1000 GeV region and normalized in the 100-220 GeV region




371 GeV | 731 GeV | 945 GeV

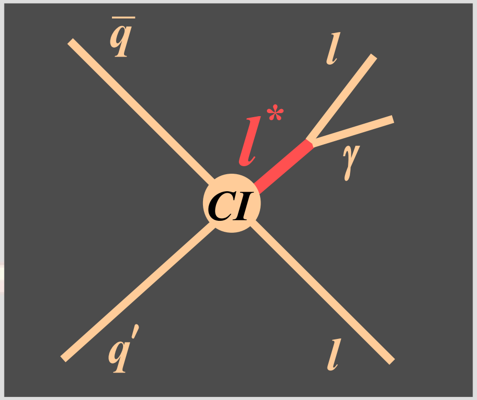
CMS-PAS-EXO-10-019

# $\gamma$ from excited leptons

*Compositness model* (Phys. Lett. B112 (1982) 387):

- leptons and quarks are bound states of 3 fermions (or fermion-boson pair)
- novel, strong interaction couple quarks and leptons with a scale $\Lambda$:

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




- namely, a "charge current" l*l can couple with $\bar{q}$q
- the l* may decay as l* → l + $\gamma$

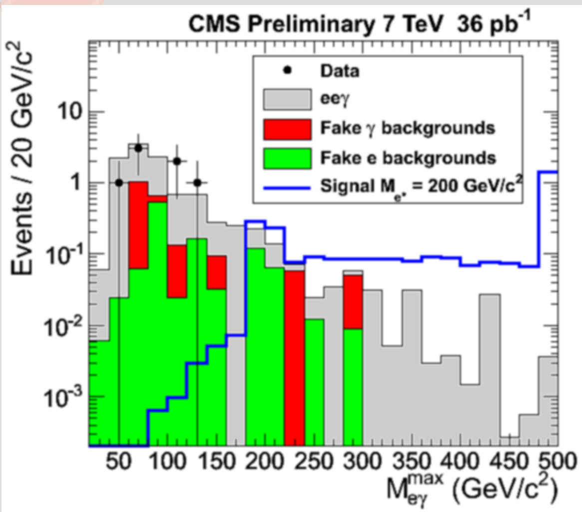
→ excited leptons may be searched in the $l^+l^-\gamma$ final state

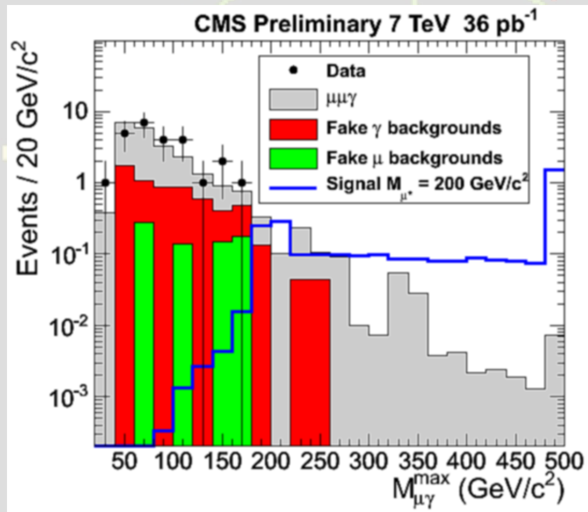
→ they correspond to resonances l $\gamma$

**Previous limits (95% C.L.):**
CDF (Phys. Rev. Letters, 97 (2006) 191802): 107 < M($\mu\gamma$) < 853 GeV, $\Lambda$ = M($\mu\gamma$)
CDF (Phys. Rev. Letters, 94 (2005) 101802): 132 < M($e\gamma$) < 879 GeV, $\Lambda$ = M($e\gamma$)

# $\gamma$ from excited leptons

- use a single-$\mu$ or di-$\gamma$ trigger
- select high-quality, isolated, $p_T$> 20 GeV, $|\eta|$<2.4 muons
- select high-quality, $p_T$> 25 GeV, $|\eta|$<1.44 + 1.56<$|\eta|$<1.25 electrons
- accept events with 1 $\gamma$ and 2 e/$\mu$, $\Delta R(l,\gamma)$ > 0.5
- look for resonances in the distribution of the largest $M(l\gamma)$




Here also the *μ/e fake rates* have to be measured:

- muon: (# good $\mu$)/(# $\mu$ tracks with $|\eta|$<2.4)
- electron: (# good e)/(# energy deposit with Had/EM energy < 0.05 and $E_T$> 20 GeV)

**CMS-PAPER-EXO-10-016**

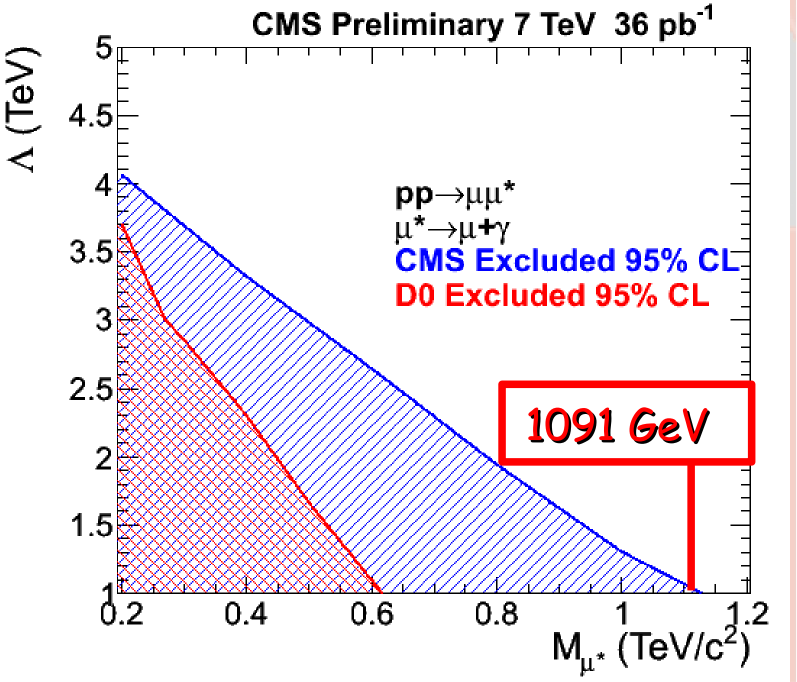
| Final State | $\ell^+\ell^-\gamma$ | $\ell^+\ell^- + jet(s)$ | $\ell\gamma + jet(s)$ | Total | Observed |
|---|---|---|---|---|---|
| $\mu^+\mu^-\gamma$ | $16.3 \pm 1.3$ | $5.5 \pm 2.1$ | $0.7 \pm 0.9$ | $22.6 \pm 2.6$ | 25 |
| $e^+e^-\gamma$ | $8.3 \pm 0.9$ | $1.4 \pm 0.8$ | $1.0 \pm 0.4$ | $10.7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

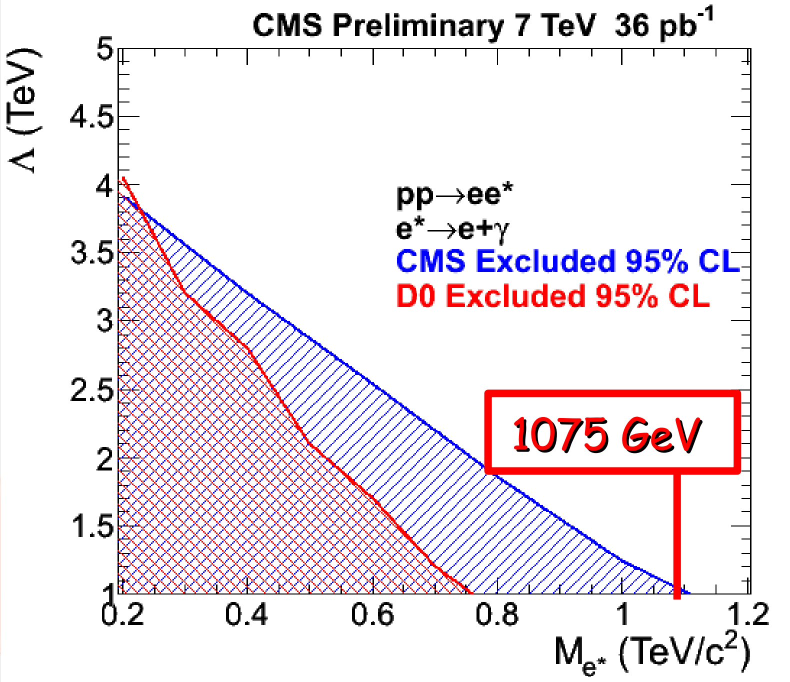
→ *good agreement between the data and the Standard Model*

# γ from excited leptons

***Main systematic effects:***

- Luminosity uncertainty: 4%
- PDF and scale uncertainty on background: 4%
- photon fake rate uncertainty: 10%
- lepton fake rate uncertainty: 10%
- l and γ reconstruction efficiency uncert.: 2.5%
- EM energy scale: 0.5%




***95% C.L. limits:***

- cross-sections excluded: 0.16-0.21 pb for e*, 0.14-0.19 for μ*
- excluded region in Λ-M* space is much larger than previous one

**CMS-PAPER-EXO-10-016**

# Conclusions

- *several new physics models predict final states with photons*

→ di-$\gamma$ from RS model, di-$\gamma$ from ADD model, ll$\gamma$ from compositeness model have been searched by CMS with 2010 data

- *simple analysis for simple final states*

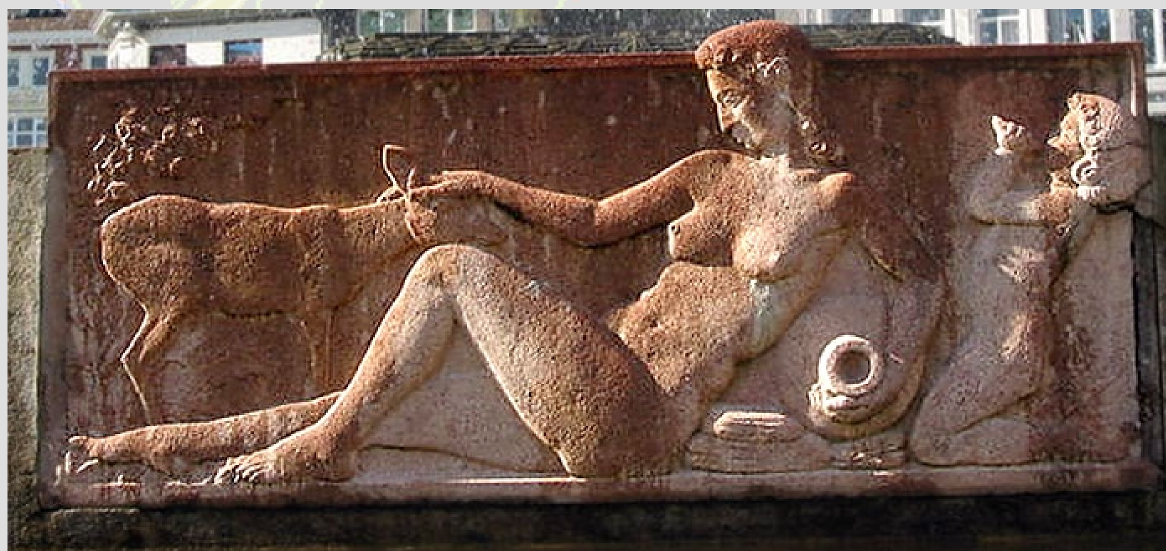
→ no evidence of new physics have been found
→ new limits on the models established and in the process to be published

- *search with photons is mature to afford more complex final state... and discoveries*

→ promising future!

# Conclusions

***CMS in 2010...***



# Conclusions



***CMS in 2011 and beyond***

***CMS in 2010...***


(Casino fountain in Spa-Belgium)

# Backup

# Backup

- Shower Shape ($\sigma_{i\eta i\eta}$): $\sigma_{i\eta i\eta}$ is the second moment of the cluster about its average $\eta$ position, $\sigma^2 = \Sigma_i w_i(\eta_i - \bar{\eta})^2/\Sigma_i w_i$, where $w_i = \max(0, 4.7 + \ln(\mathrm{E_i}/\mathrm{E}))$ and $i$ is the index of a crystal in a $5 \times 5$ array centered on the highest energy crystal [16]. We require $\sigma_{i\eta i\eta} < 0.013$.