



Search for new physics with muons + X at CMS

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Introduction

Search for new physics:

in BSM physics without SUSY

a lot of different analyses :

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO>

→ a small selection of analyses is presented here

In Mu + X:

Leptonic signatures are clear, with low backgrounds

Muon signatures (in CMS) are particularly well reconstructed

X: additional object (MET, photon, ...)

Outline:

- Search for Z'
- Search for W'
- Search for excited muon
- Search for unparticle

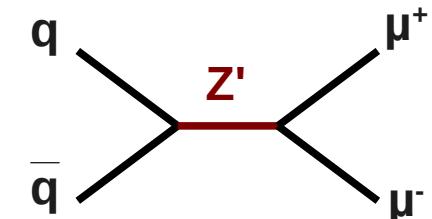
Search for Z'

PAS EXO-12-015

2012 Data, 4fb^{-1} (+ 5fb^{-1})

Models:

- Sequential SM :
 Z'_{SSM} with coupling similar to SM
- Super-string inspired E_6 GUT :
 Z'_{Ψ}
- Other models



Signature and Strategy:

Two isolated opposite charge muons

Using 4.1fb^{-1} of 2012 data ($\sqrt{s}=8\text{TeV}$)

Search for a resonance in the dimuon invariant mass

No excess observed

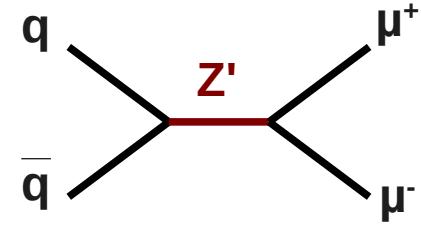
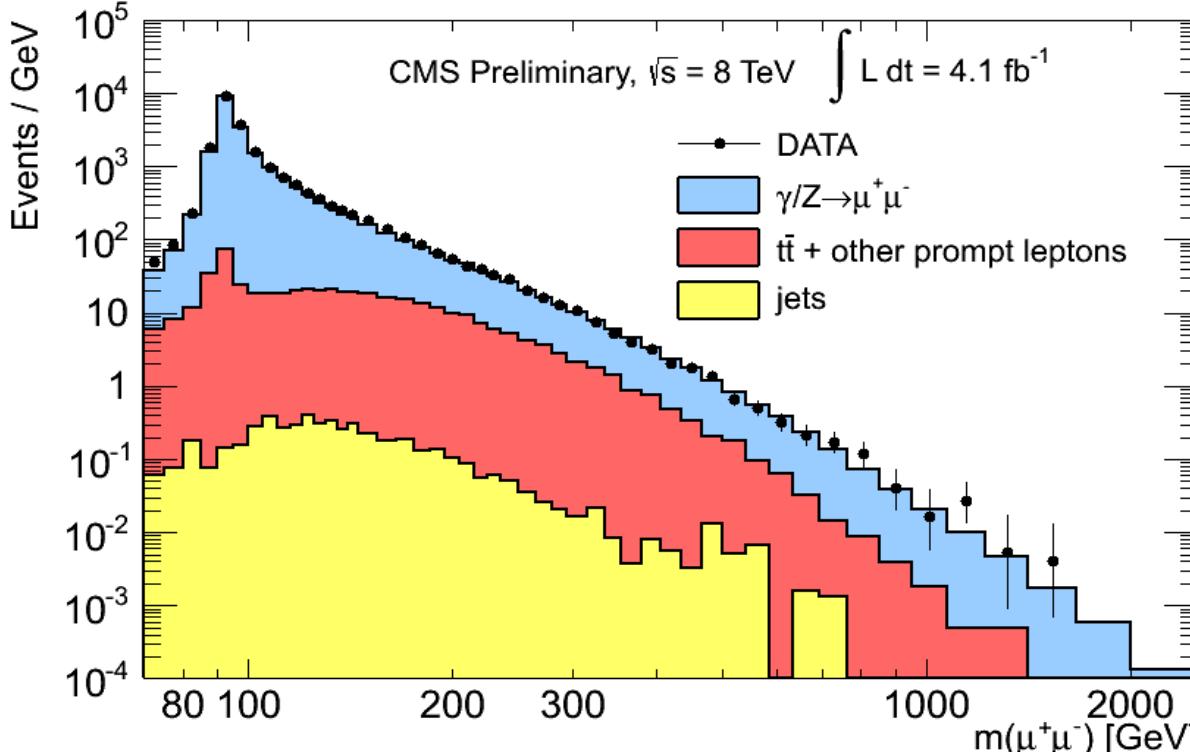
\rightarrow 95% CL exclusion limits, set on $R_\sigma = \frac{\sigma(\text{pp} \rightarrow Z' + X \rightarrow \ell\ell + X)}{\sigma(\text{pp} \rightarrow Z + X \rightarrow \ell\ell + X)}$

Additionally, combination with ee channel, and with 5fb^{-1} 2011 data ($\sqrt{s}=7\text{TeV}$)

Search for Z'

PAS EXO-12-015

2012 Data, 4fb^{-1} (+ 5fb^{-1})



Backgrounds:

Drell-Yan Z/γ^* : irreducible background, from simulation, normalized with the data in the Z peak region

$t\bar{t}$, (tW, diboson) : lower background (factor ~ 0.1 w.r.t. DY), from simulation contribute to $e\mu$ channel, used for cross-check

misid. muons : checked in data to be low

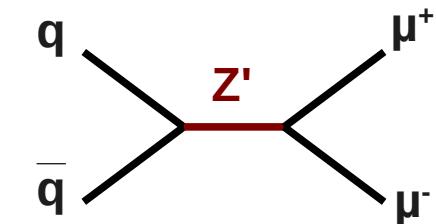
Search for Z'

PAS EXO-12-015

2012 Data, 4fb^{-1} (+ 5fb^{-1})

Limit:

on $R_\sigma = \frac{\sigma(\text{pp} \rightarrow Z' + X \rightarrow \ell\ell + X)}{\sigma(\text{pp} \rightarrow Z + X \rightarrow \ell\ell + X)}$, shape analysis
(unbinned likelihood)



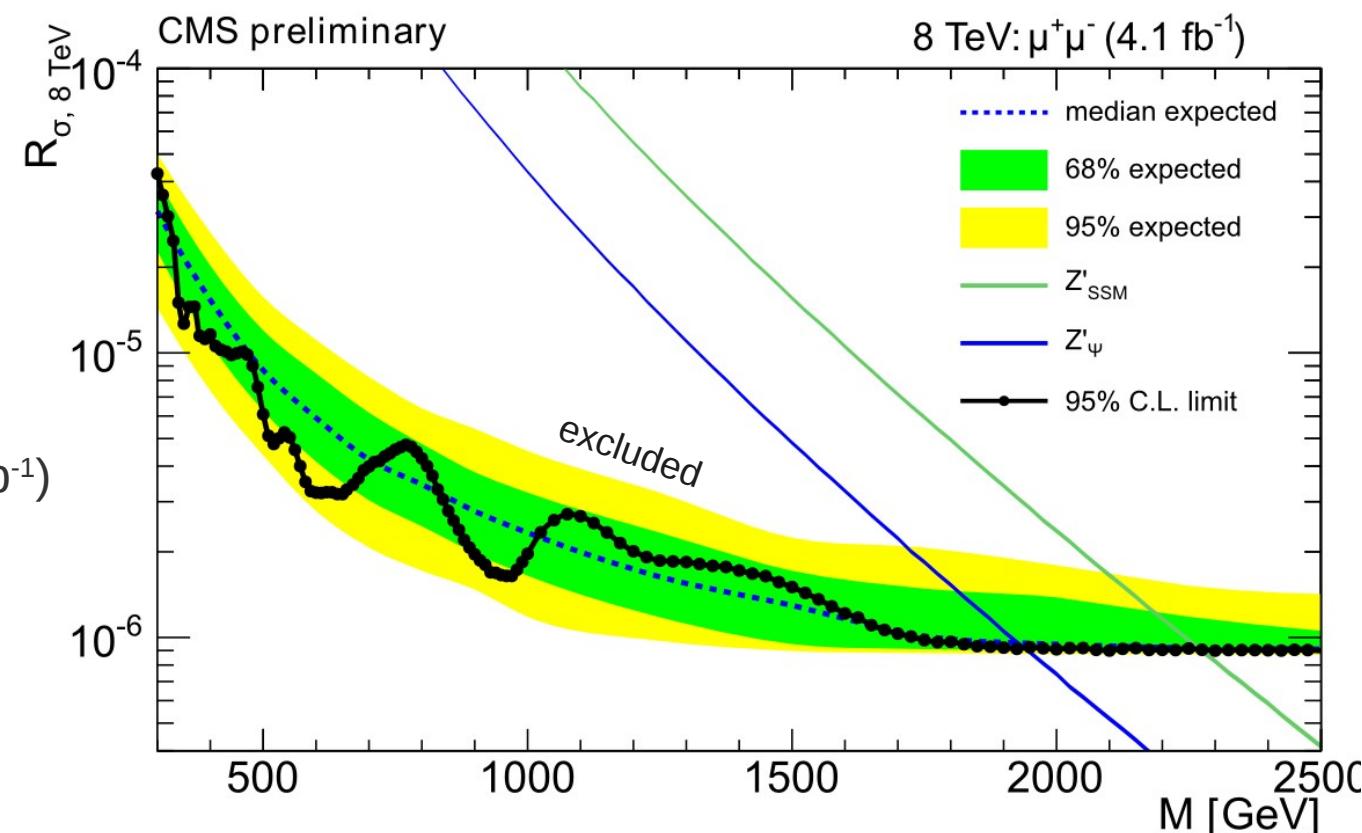
■ Dimuon:

$M(Z'_{\text{SSM}})$: > 2.27 TeV
 $M(Z'_{\Psi})$: > 1.94 TeV

■ Combined :

$e\bar{e} + \mu\bar{\mu}$, 2011(5fb^{-1}) + 2012(4fb^{-1})

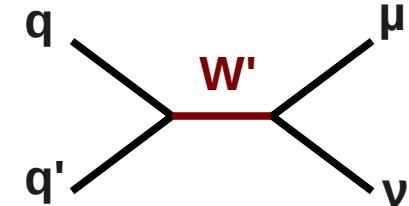
$M(Z'_{\text{SSM}})$: > 2.59 TeV
 $M(Z'_{\Psi})$: > 2.26 TeV



Search for W'

Models:

- Sequential SM :
 W'_{SSM} with SM coupling (no $W' \rightarrow WZ$)
- Split Universal Extra Dimension:
 W'_{KK} is $n=2$ KK excited state,
parameters: μ (Bulk mass) and R (radius of the folded 5th dim)
- Compositeness: 4-fermion Contact Interaction:
no resonance, but same signature
parameter: Λ (binding energy scale)
- Other models



Signature and Strategy:

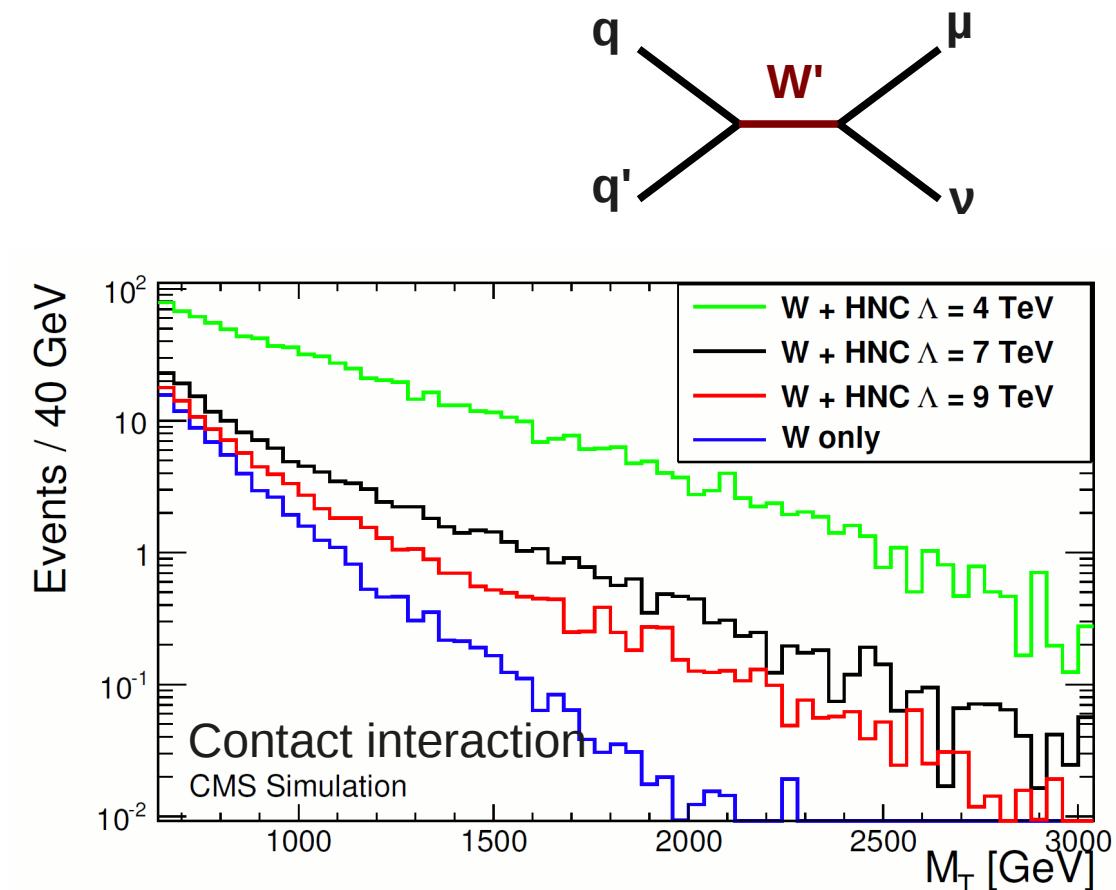
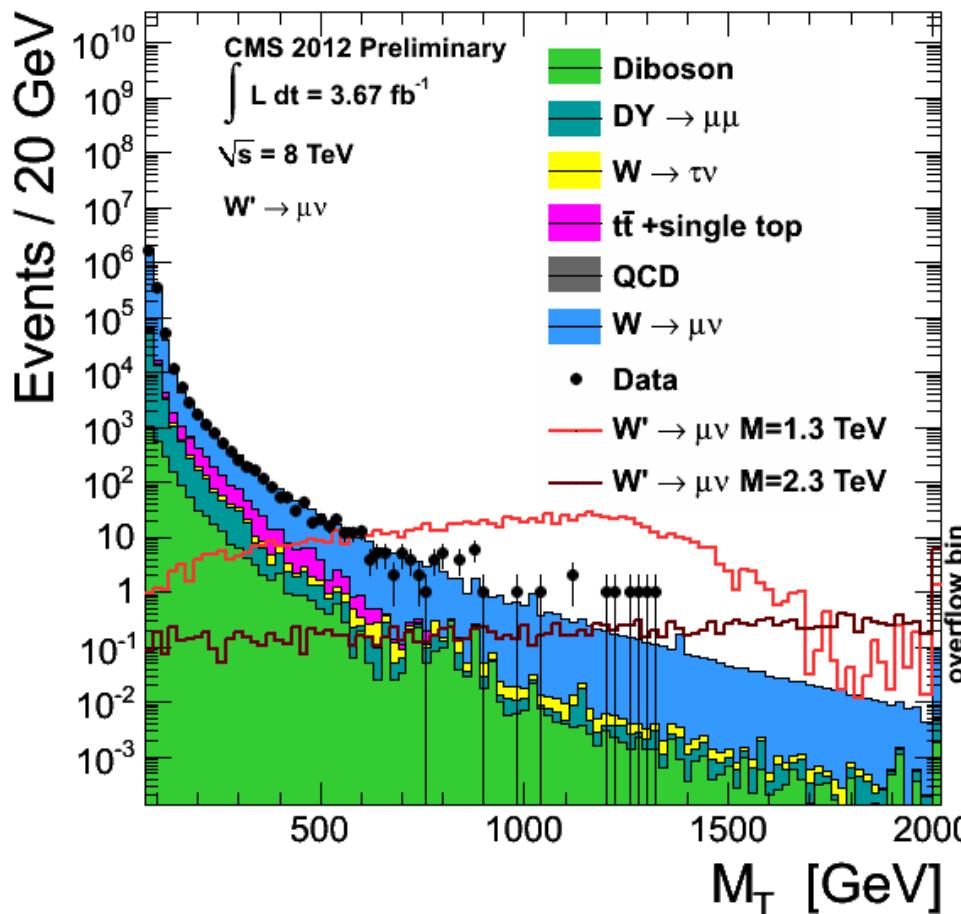
Back-to-back balanced MET and isolated muon

Using 3.7fb^{-1} of 2012 data ($\sqrt{s}=8\text{TeV}$)

Search for an excess in $M_T = \sqrt{2 \cdot p_T^\ell \cdot E_T^{\text{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$

No excess observed → 95% CL exclusion limits

Search for W'



Backgrounds:

irreducible $W \rightarrow \mu\nu$ + additional lower bkgd (QCD multijet, $t\bar{t}$, DY, diboson)

background M_T parametrized as $f(m; a, b, c) = a / (m + b)^c$

fitted from simulation, but normalized with data

Search for W'

Limit:

counting experiment, Bayesian method

$M(W'_{\text{SSM}})$: $> 2.75 \text{ TeV}$

$M(W'_{kk})(\mu = 0.05)$: $> 1.5 \text{ TeV}$

$M(W'_{kk})(\mu = 10)$: $> 3.4 \text{ TeV}$

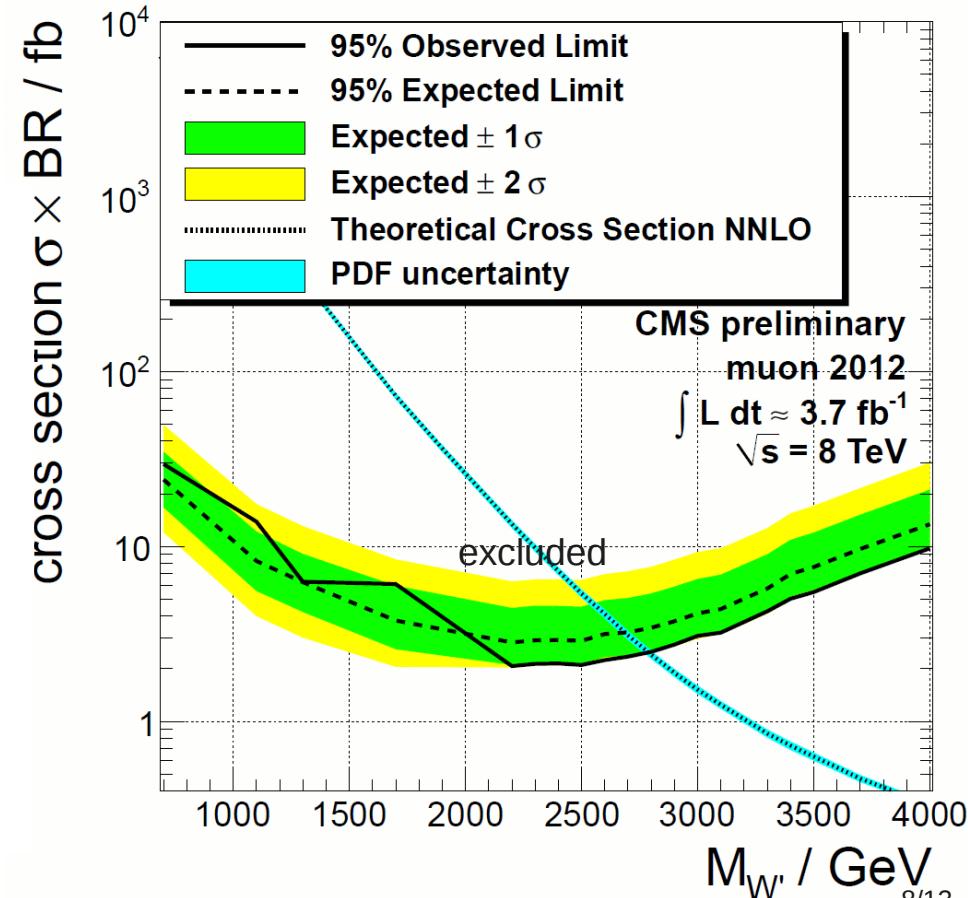
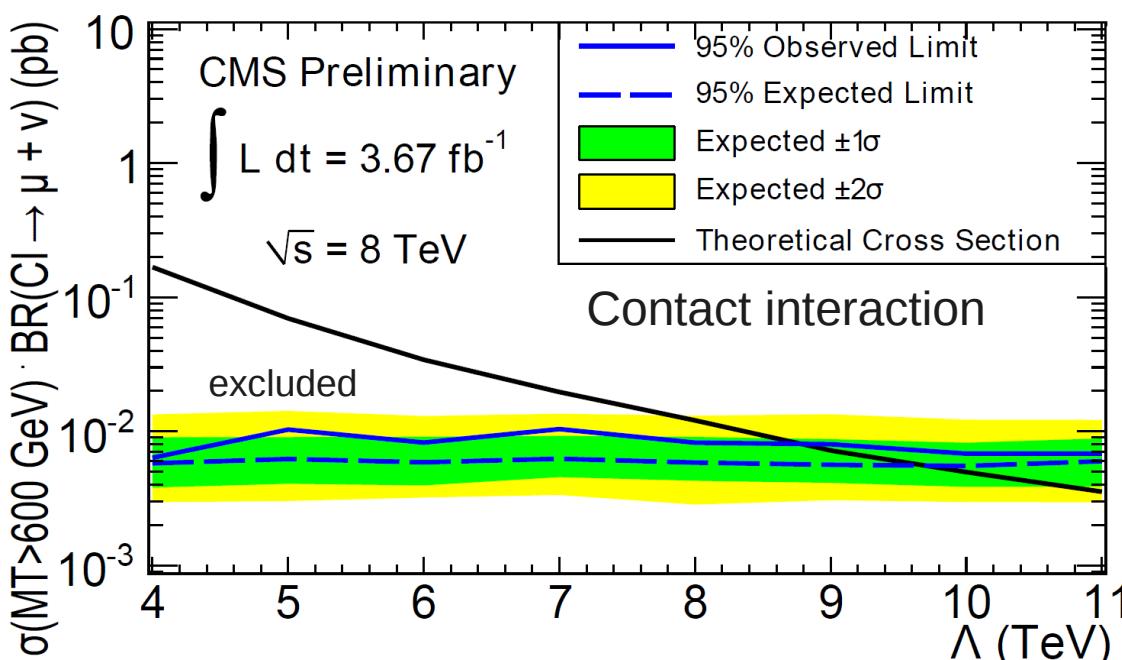
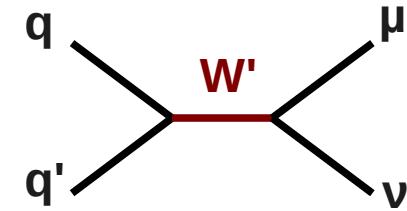
CI: Λ $> 8.8 \text{ TeV}$

e+μ comb.
↓

$> 2.85 \text{ TeV}$

$> 1.4 \text{ TeV}$

$> 3.3 \text{ TeV}$



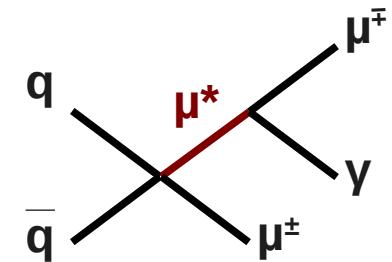
Search for excited muon

EXO-11-034
going for PLB
2011 Data, 5fb^{-1}

Models:

Compositeness \rightarrow excited state

General effective Lagrangian,
parameters: Λ (compositeness scale) and M (mass)



Signature and Strategy:

2 muons + 1 high energy photon

Using 5fb^{-1} of 2011 data ($\sqrt{s}=7\text{TeV}$)

Signal in min-max $M(\mu\gamma)$ plane

No excess observed

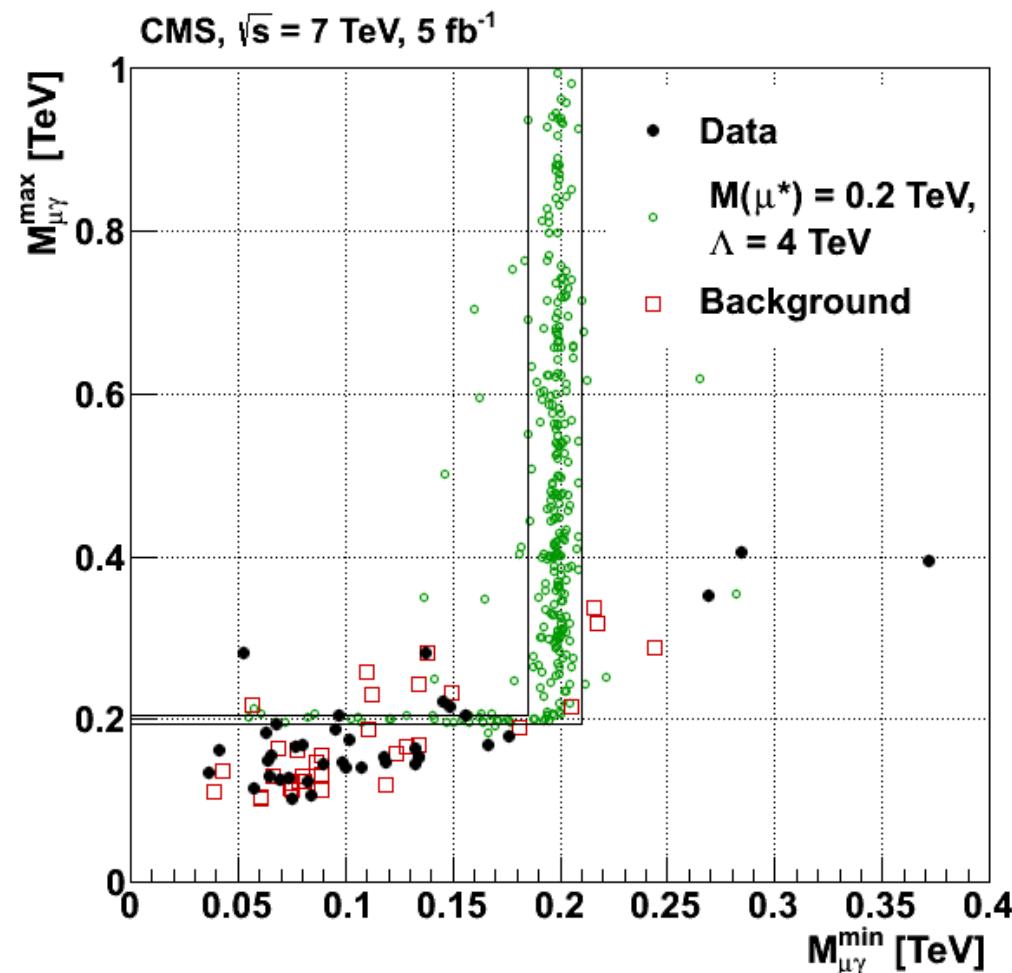
\rightarrow 95% CL exclusion limits

Backgrounds:

$Z\gamma \rightarrow \mu\mu\gamma$: irreducible background,
from simulation

others ($t\bar{t}$, diboson, ...) : low,
from simulation

misid. photons : data driven estimation



Search for excited muon

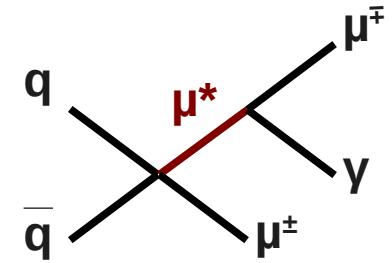
EXO-11-034
going for PLB
2011 Data, 5fb^{-1}

Limit:

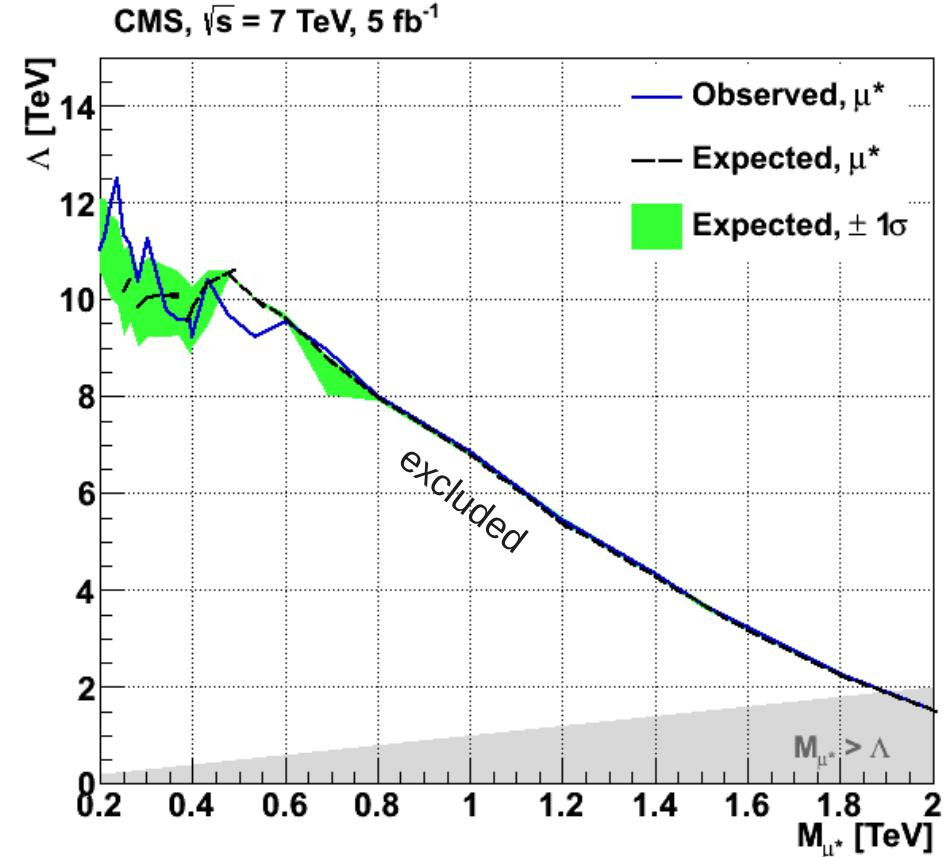
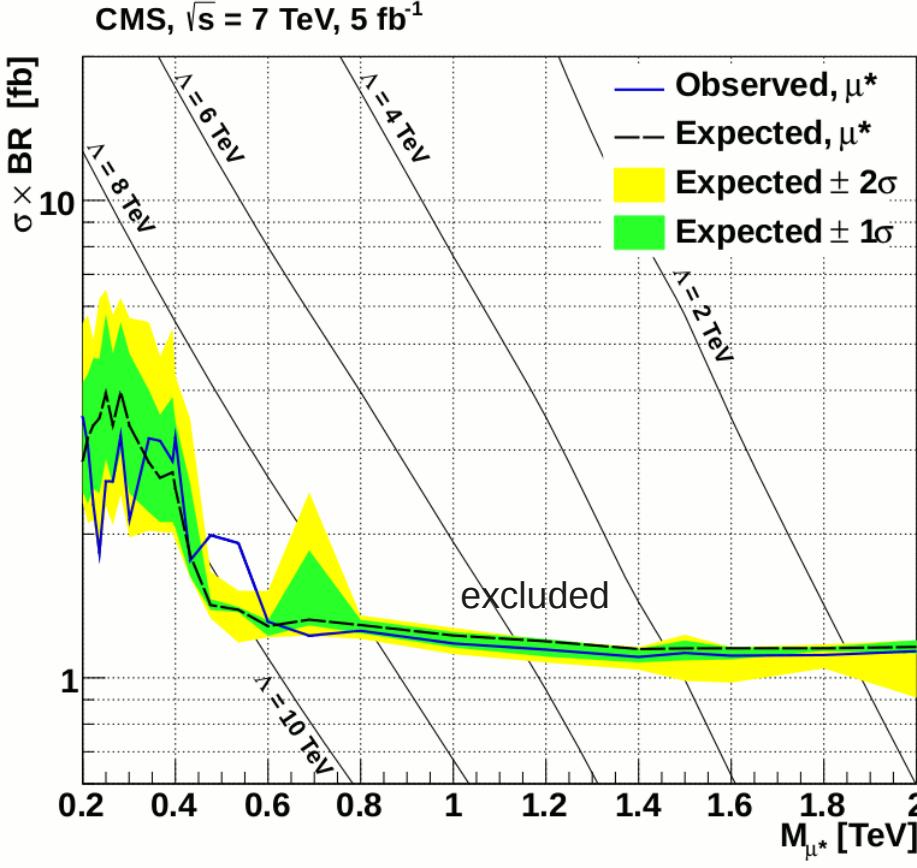
counting experiment, CLs method

$\sigma \times \text{BR}$: $< 1.31 - 1.11 \text{ fb}$ for $m(\mu^*) > 0.6 \text{ TeV}$

For $M(\mu^*) = \Lambda$: $M(\mu^*) > 1.9 \text{ TeV}$



(e channel similar)



Search for unparticle

Models:

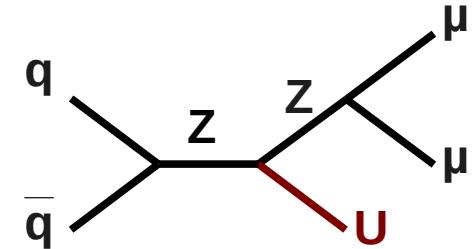
Scale-invariant conformal field at high energy (H. Georgi 2007),

→ continuous mass spectrum

assumptions: scalar with no FCNC

parameters: Λ_u (ultraviolet cut-off), λ (coupling constant),

d_u (unparticle dimension (non integer))



Signature and Strategy:

2 muons from $Z + \text{MET}$ (and nothing else)

Using 5fb^{-1} of 2011 data ($\sqrt{s}=7\text{TeV}$)

Excess in high MET

No excess observed

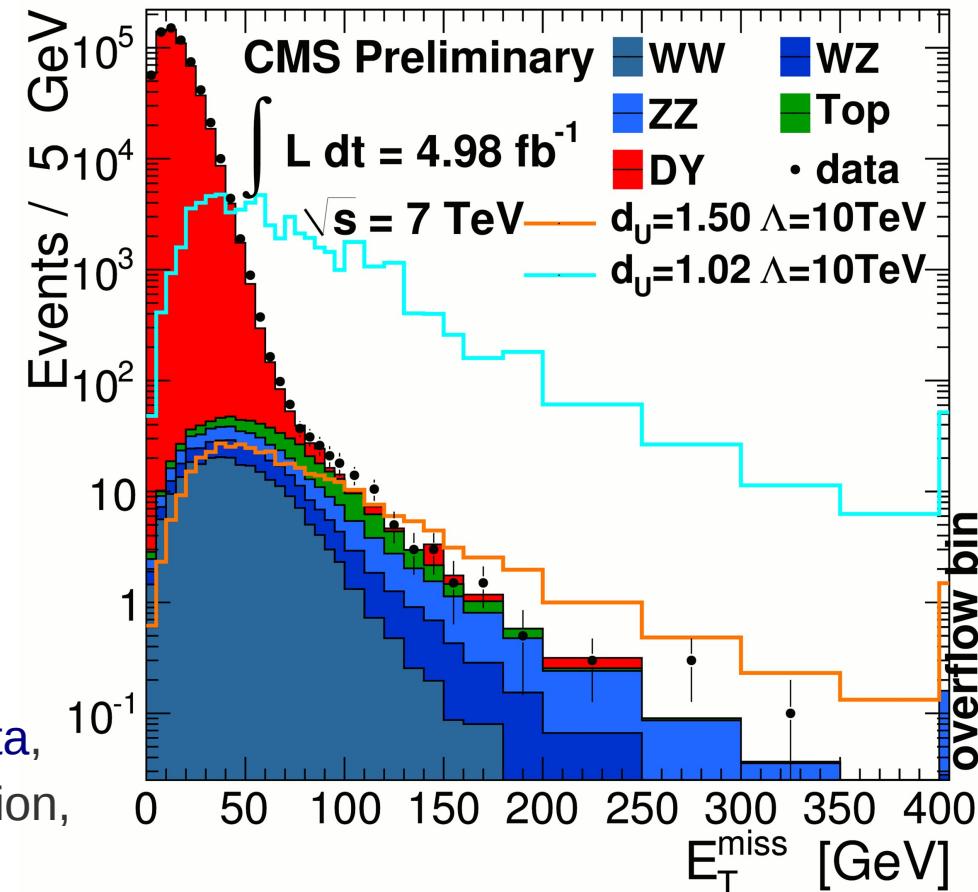
→ 95% CL exclusion limits

Backgrounds:

$ZZ \rightarrow 2\mu 2\nu$: irreducible background,

Drell-Yan + fake MET : MET studied in data,

others (diboson, $t\bar{t}$, ...) : reduced by the selection,
control region ($e\mu$)



Search for unparticle

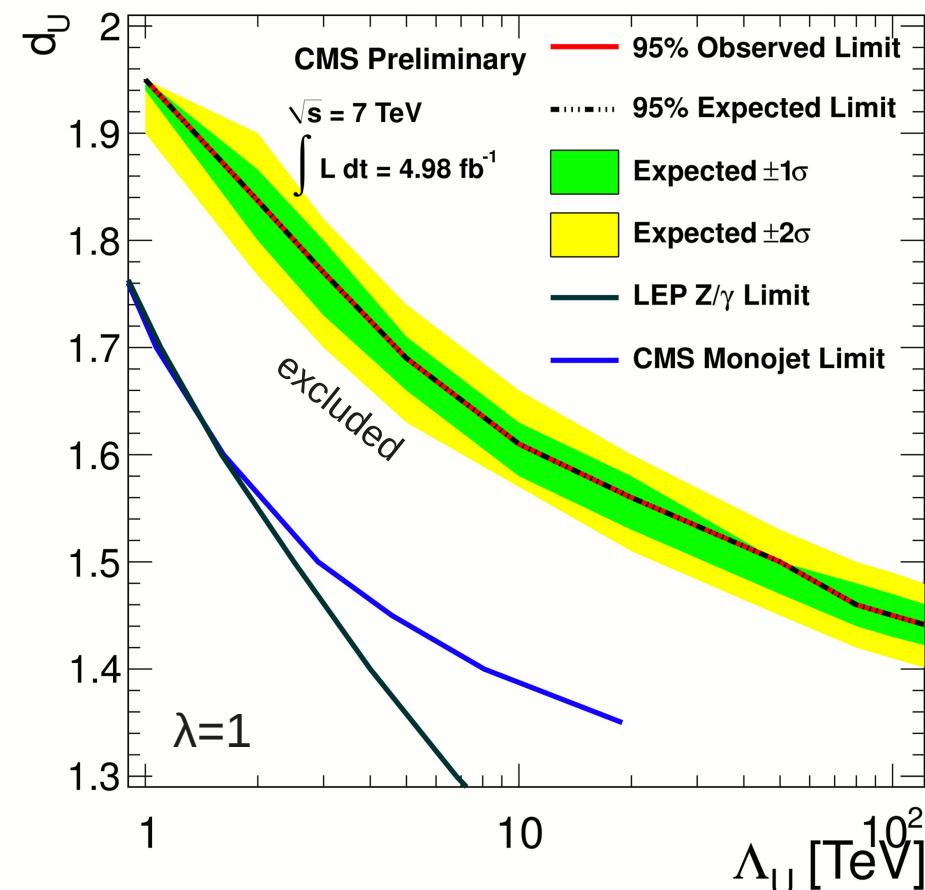
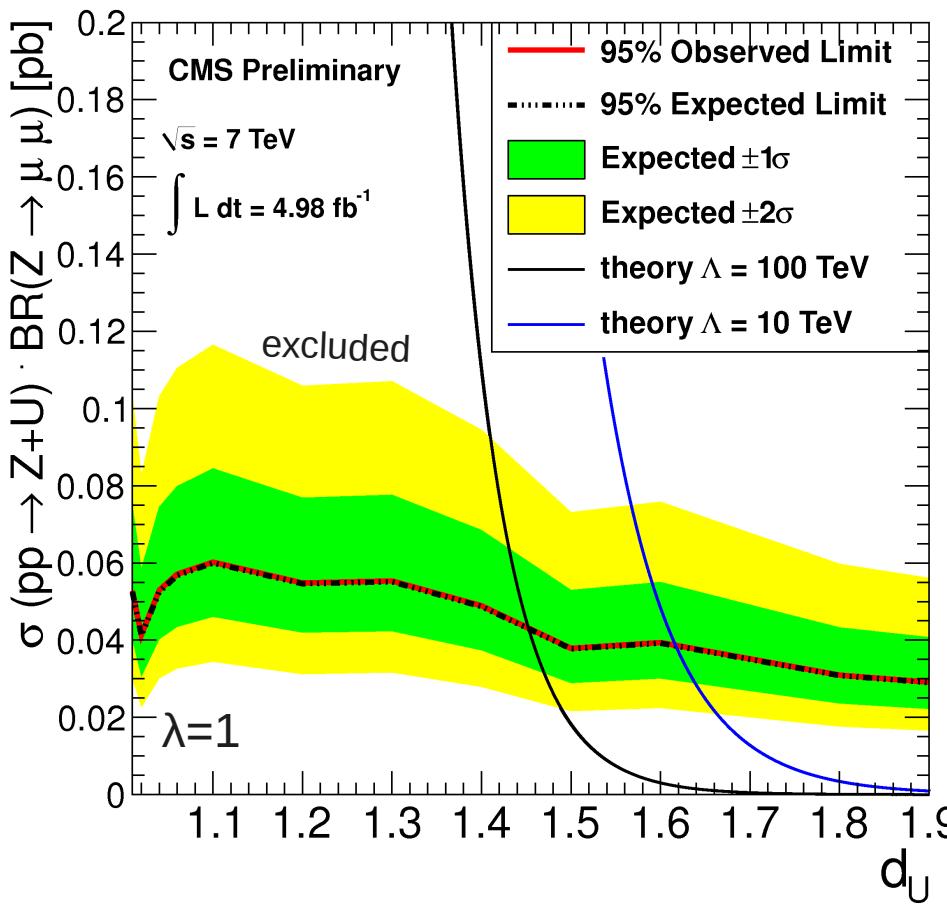
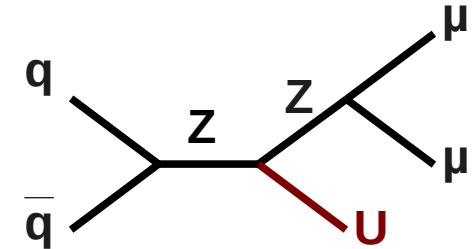
Limits:

counting experiment, CLs method

$\sigma \times \text{BR}$: $< 0.03 - 0.06 \text{ pb}$ for d_U in $[1, 1.9]$, $\lambda=1$

For $\lambda=1$: exclusion up to $\Lambda_U > 100 \text{TeV}$ (for $d_U=1.45$)

For $\Lambda_U=3 \text{TeV}$: exclusion up to $\lambda < 8 \cdot 10^{-4}$ (for $d_U=1.04$)



Conclusion

Numerous BSM analyses have been performed in CMS (even without SUSY).
Four of them have been presented here:

- Search for Z'
- Search for W'
- Search for excited muon
- Search for unparticle

The leptonic final states, and in particular the **muon channels**, are particularly efficient: well reconstructed in CMS, with low background

No excess has been observed, but limits have been stated
→ useful to exclude models

LHC: results shown here: 2011, $\sim 5\text{fb}^{-1}$
2012, $\sim 5\text{fb}^{-1}$

expected: $\sim 25\text{fb}^{-1}$ → stay tuned for new results

Backup slides

Muons in Exotic searches

Muon detection in CMS:

3 detectors: Drift Tubes,
Cathode Strips,
and RPC (for trigger)

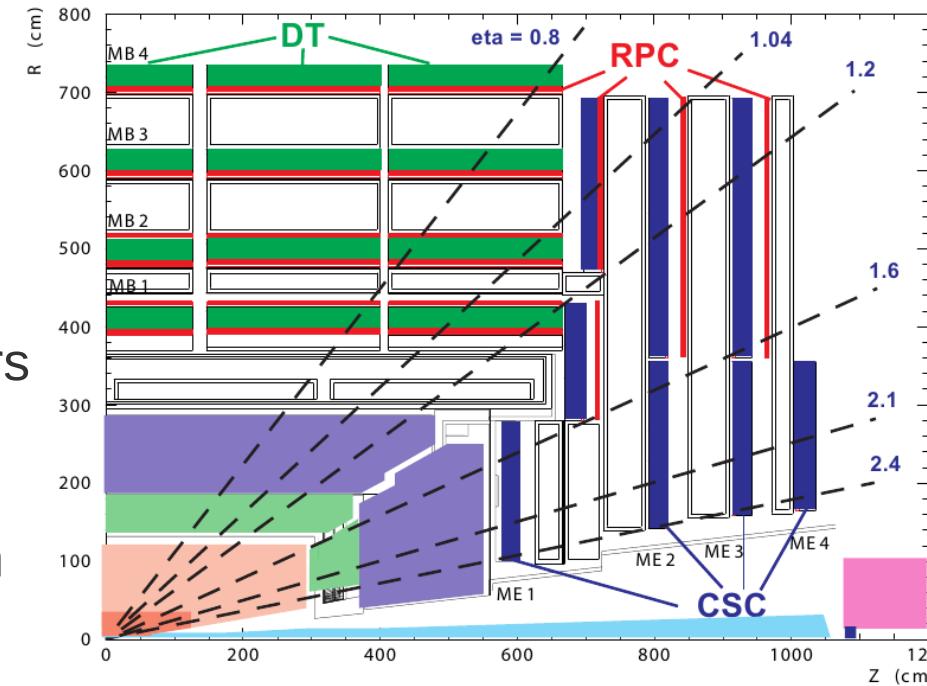
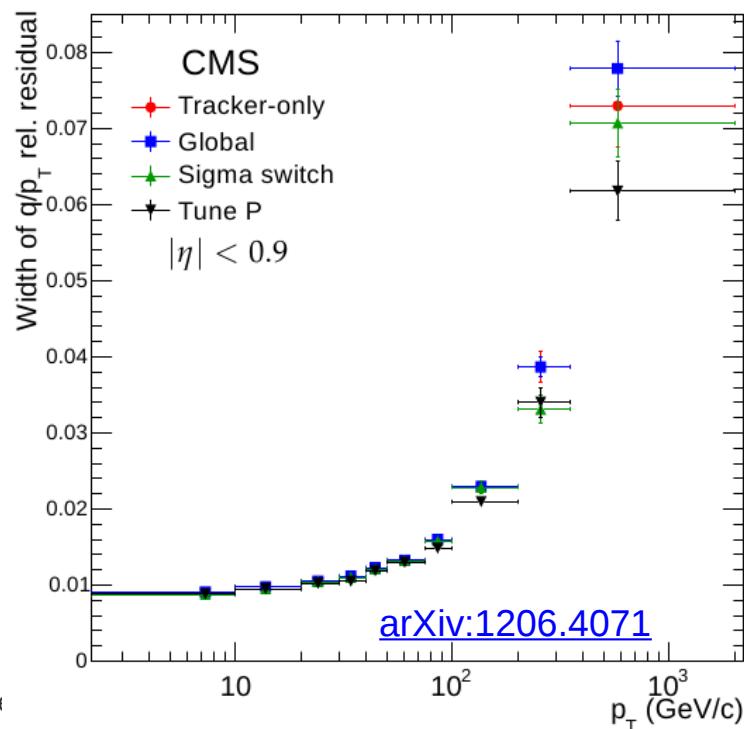
Muon reconstruction:

Segments are reconstructed in each chambers

From these segments → **standalone track**

From this track + tracker info → **global track**

→ Very high reco / id efficiency and resolution



High energy muons:

- muons with $p_T > 100$ GeV
→ radiative losses, no longer MIP
- affects the p_T
→ *tune P* (or “cocktail”) algorithm
- affects the isolation → tracker iso only
- cosmic muons: easily rejected (di- μ angle, $|d_0|$)

Leptons reconstruction and selection

Usual selection (mainly based on Z' study):

- Triggers:**
- For muon: Single muon trigger (maximum: $p_T > 40 \text{ GeV}$, $|\eta| < 2.1$)
 - For dielectron: Double electron trigger ($E_T(\text{cluster}) > 33 \text{ GeV}$)
 - For single electron: Single electron trigger ($E_T(\text{cluster}) > 85 \text{ GeV}$)

Kinematics: ▪ p_T and $|\eta|$ consistent with triggers

(muon: $p_T > 45 \text{ GeV}$, $|\eta| < 2.1$, electron: $p_T > 35 \text{ GeV}$, $|\eta| < 2.4$ without [1.442,1.560])

Identification:

- Track of the lepton consistent with the collision point ($|d_0| < 0.2 \text{ cm}$)
- For muon:
 - cosmic muon rejection (dimuon: angle $< \pi - 0.02 \text{ rad}$, single muon: stronger $|d_0|$ cut)
 - good track quality (≥ 1 hit in pixel tracker, ≥ 9 hits in silicon tracker, ≥ 2 segment in muon stations)
- For electron:
 - good correspondence track - ECal cluster ($\Delta\eta$, $\Delta\phi$)
 - energy deposit electron-like ($E_{\text{ECal}}/E_{\text{HCal}}$, shower shape variables)

Isolation:

- For muon: relative isolation in the tracker in a 0.3 cone (robust again Pile-Up)
- For electron: isolation in the tracker and the calorimeter in a 0.3 cone (corrected for Pile-Up)

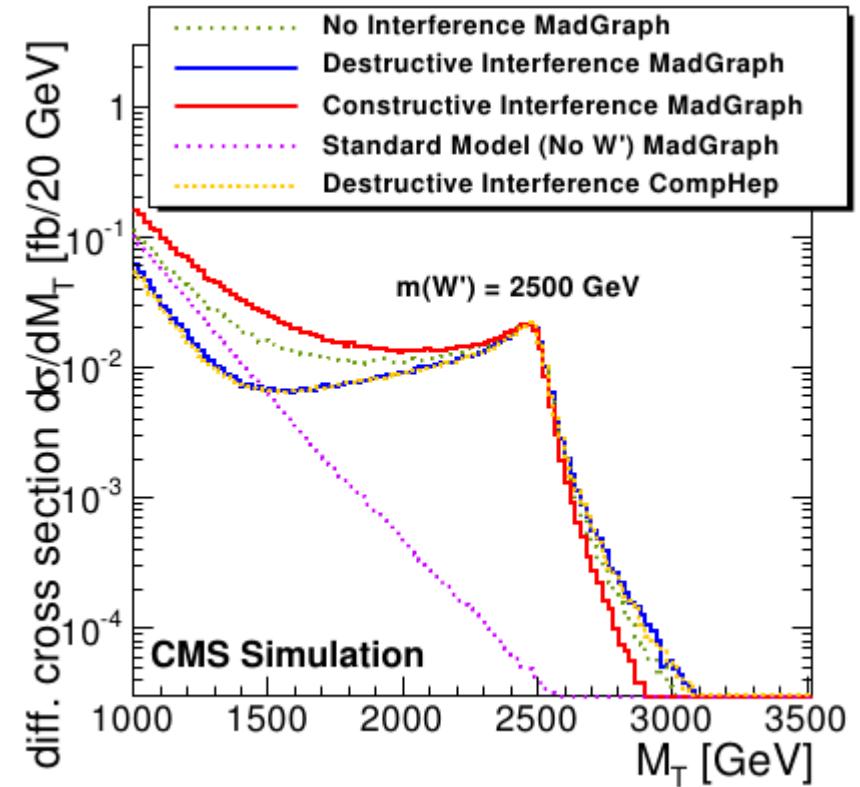
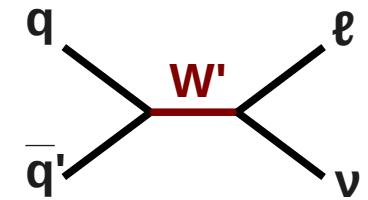
W' study

Interference:

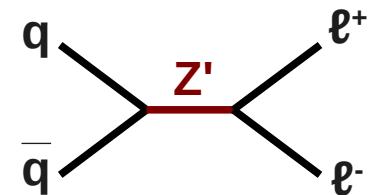
If W' is left-handed \rightarrow interference with W

The destructive (constructive) interference will reduce (increase) the limit

EXO-11-024, with 2011 Data, 5.0 fb^{-1}
 10.1007/JHEP08(2012)023
 arXiv:1204.4764



Selection:
similar to 2012 analysis

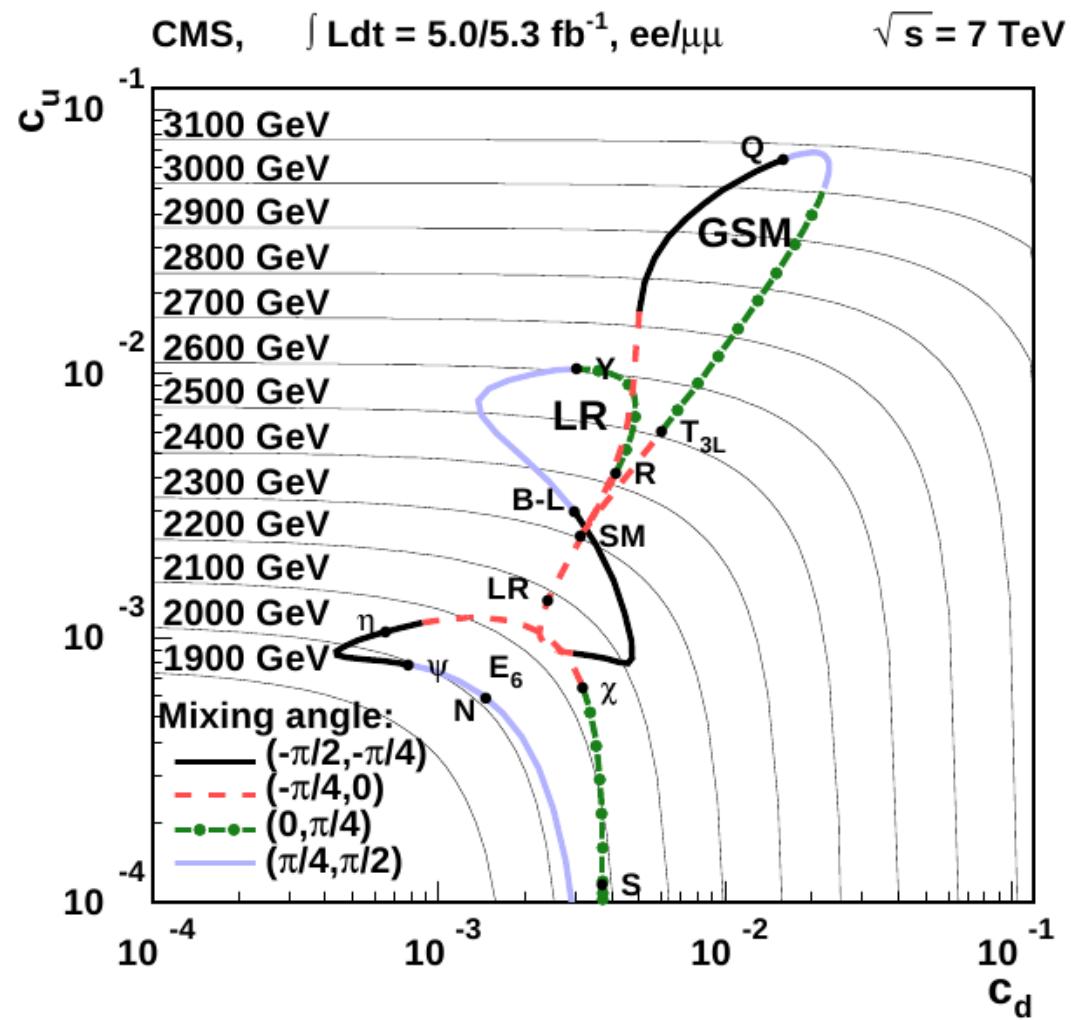


Limits in 2011:

$M(Z'_{\text{SSM}})$:	$> 2.33 \text{ TeV}$
$M(Z'_{\Psi})$:	$> 2.00 \text{ TeV}$
$M(Z'_{\text{St}})$ ($\epsilon=0.06$):	$> 0.89 \text{ TeV}$
$M(Z'_{\text{St}})$ ($\epsilon=0.04$):	$> 0.54 \text{ TeV}$
$M(G_{KK})$ ($c=0.10$):	$> 2.14 \text{ TeV}$
$M(G_{KK})$ ($c=0.05$):	$> 1.81 \text{ TeV}$

Limits in 2012:

$M(Z'_{\text{SSM}})$:	$> 2.59 \text{ TeV}$
$M(Z'_{\Psi})$:	$> 2.26 \text{ TeV}$



Search for unparticle

Limit:

counting experiment, CLs method

$\sigma \times \text{BR}$: $< 0.03 - 0.06 \text{ pb}$ for d_U in $[1, 1.9]$, $\lambda=1$

For $\lambda=1$: $d_U > 1.45$ for $\Lambda_U = 100 \text{ TeV}$, $d_U > 1.95$ for $\Lambda_U = 1 \text{ TeV}$,

For $\Lambda_U = 3 \text{ TeV}$: $\lambda < 8 \cdot 10^{-4}$ for $d_U = 1.04$, $\lambda < 0.19$ for $d_U = 1.6$

