Search for resonances with leptons (in CMS)

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Introduction

This talk is about:

- Resonances in Exotic physics (= BSM physics without SUSY)
  - → does not include non resonant physics
    does not include subjects of other talks:
    Heavy neutrino, Long-lived particles, ...
- with leptons
  - → does not include taus
    focuses on high energy leptons in the final state

Latest Public CMS Exotica results:

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

Outline:

- Overview of exo models
- Leptons in Exotica
- Z' study
- W' study
- Other studies (ρ_{TC}, boosted Z^0, ℓ^*)
- Summary and conclusion

Search for resonances with leptons

New bosons: motivated by: GUT → additional U(1) or SU(2), Extra dimensions, ...

Z-like:
- Sequential SM : Z'_{SSM} with coupling similar to SM
- super-string inspired E_6 GUT: Z'_{ψ}
- other models (KK Graviton, ...)

W-like:
- Sequential SM : W'_{SSM} with coupling similar to SM (but W' → WZ suppressed)
- split Universal Extra Dimension: W'_{KK} is n=2 KK excited state, for different split-UED parameters (bulk masses μ and radius R of the folded 5th dim)
- Technicolor: ρ_{TC}, which decays in WZ (depending of the masses of ρ_{TC} and π_{TC})
- ...

Compositeness:

General effective Lagrangian, for a compositeness scale Λ

New coupling: f, f', f_S, usually set to $f=f'=1$, $f_S=1$. Final parameters: M and Λ

Excited leptons: ℓ^*, and excited quarks: q^*

Other models (not discussed in this talk):

4th generation, leptoquark, ...

Search for resonances with leptons

Leptonic decay of massive particles → isolated leptons with **high energy**

High energy muons:

- muons with $p_T > 100$ GeV → radiative losses, no longer MIP

  affects the trajectory (and therefore the p_T)

  → *tune P* *(or "cocktail")* algorithm is used for $p_T > 200$:

  affects the isolation → tracker isolation only
- cosmic muons: but easily rejected (di-μ angle, $|d_0|$)

High energy electrons:

For high p_T: resolution of the ECAL > resolution of the Tracker

Track for direction and origin, where the p_T resolution matters less

→ the charge is not always used

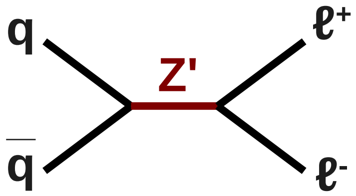
HEEP electrons, based on standard selection but optimized for $p_T > 100$

Z' study

EXO-12-015
PAS Publ.
2012 Data, $4 fb^{-1}$ (+ $5 fb^{-1}$)

Selection:

ee: two isolated electrons ($3.6 fb^{-1}$),
μμ: two isolated opposite charge muons ($4.1 fb^{-1}$)



Main observable: dileptonic invariant mass m(ℓℓ)

Backgrounds:

Drell-Yan Z/γ* : irreducible background,
from simulation, normalized with the data in the Z peak region
m(ℓℓ) shape parametrized for m > 200 GeV

$t\bar{t}$, (tW, diboson) : lower background (factor ~0.1 w.r.t. DY), from simulation (± 15% unc.)
contribute to eμ channel, used to check:
- the MC / data comparison
- misidentification

misid. leptons : from data-driven estimation
μ: low (but can be evaluated with same-sign requirement)
e: (W+jet, γ+jet, multi-jet) misidentification rate (FR) method

Limits:

→ upper limit on

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

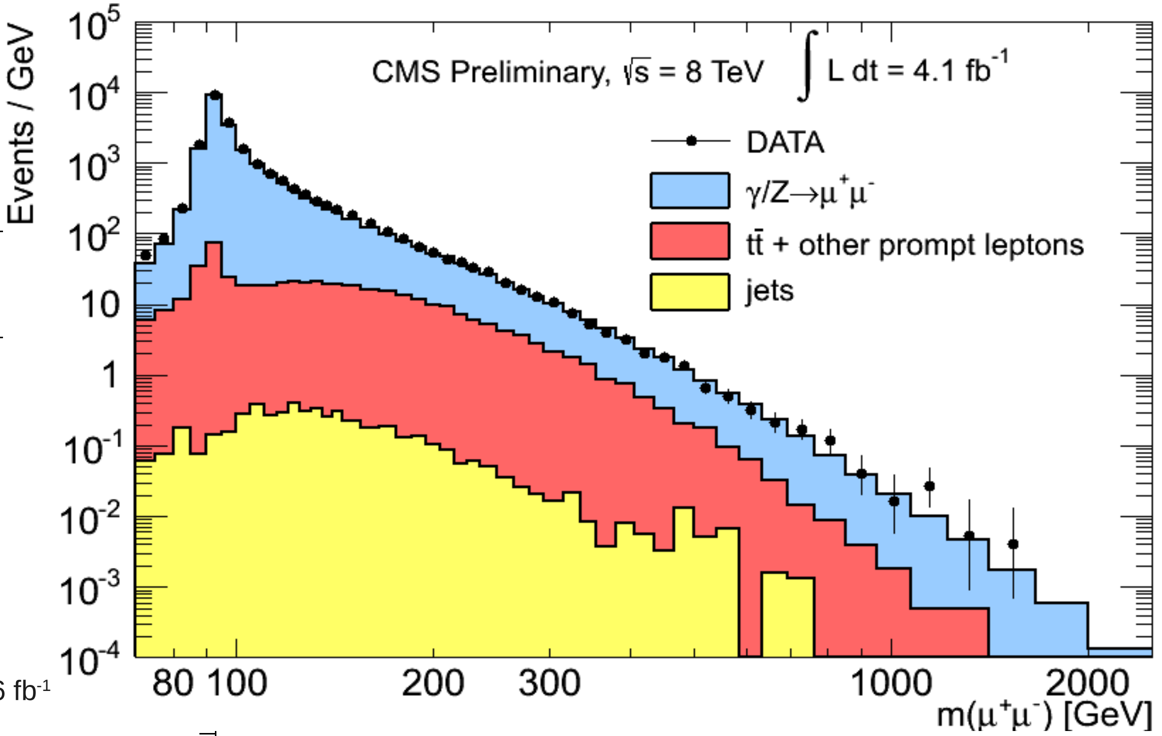
in ee and μμ channels
and √s = 7 + √s = 8

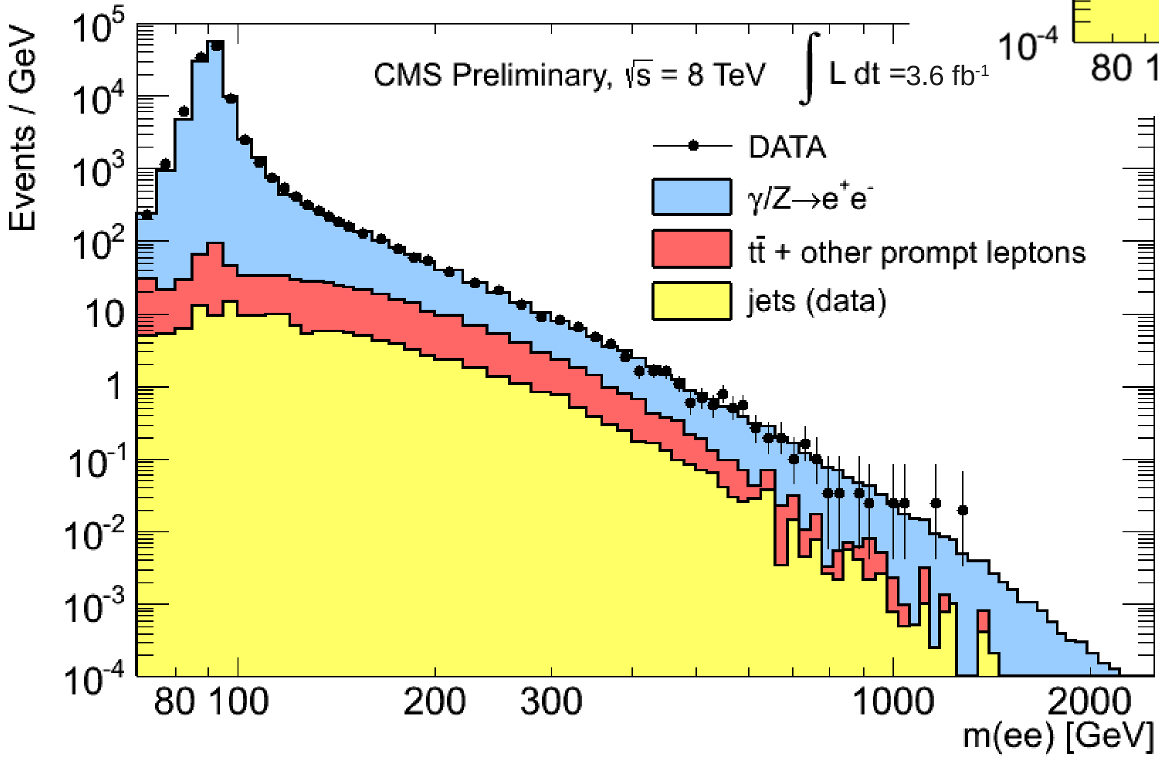
Z' study

EXO-12-015
PAS Publ.
2012 Data, 4fb^{-1} (+ 5fb^{-1})

Yield:

	Dimuon sample	
	(120 – 200) GeV	>200 GeV
Data	13831	3503
Total background	13007 ± 589	3627 ± 160
Z/γ^*	11703 ± 571	2919 ± 139
$t\bar{t}$ + others	1278 ± 146	698 ± 78
jets	26 ± 3	10 ± 1





	Dielectron sample	
	(120 – 200) GeV	>200 GeV
Data	12030	2904
Total background	12241 ± 592	2968 ± 258
Z/γ^*	10657 ± 533	2198 ± 220
$t\bar{t}$ + others	1222 ± 183	557 ± 84
jets	362 ± 181	213 ± 106

Z' study

EXO-12-015
PAS Publ.
2012 Data, $4 fb^{-1}$ (+ $5 fb^{-1}$)

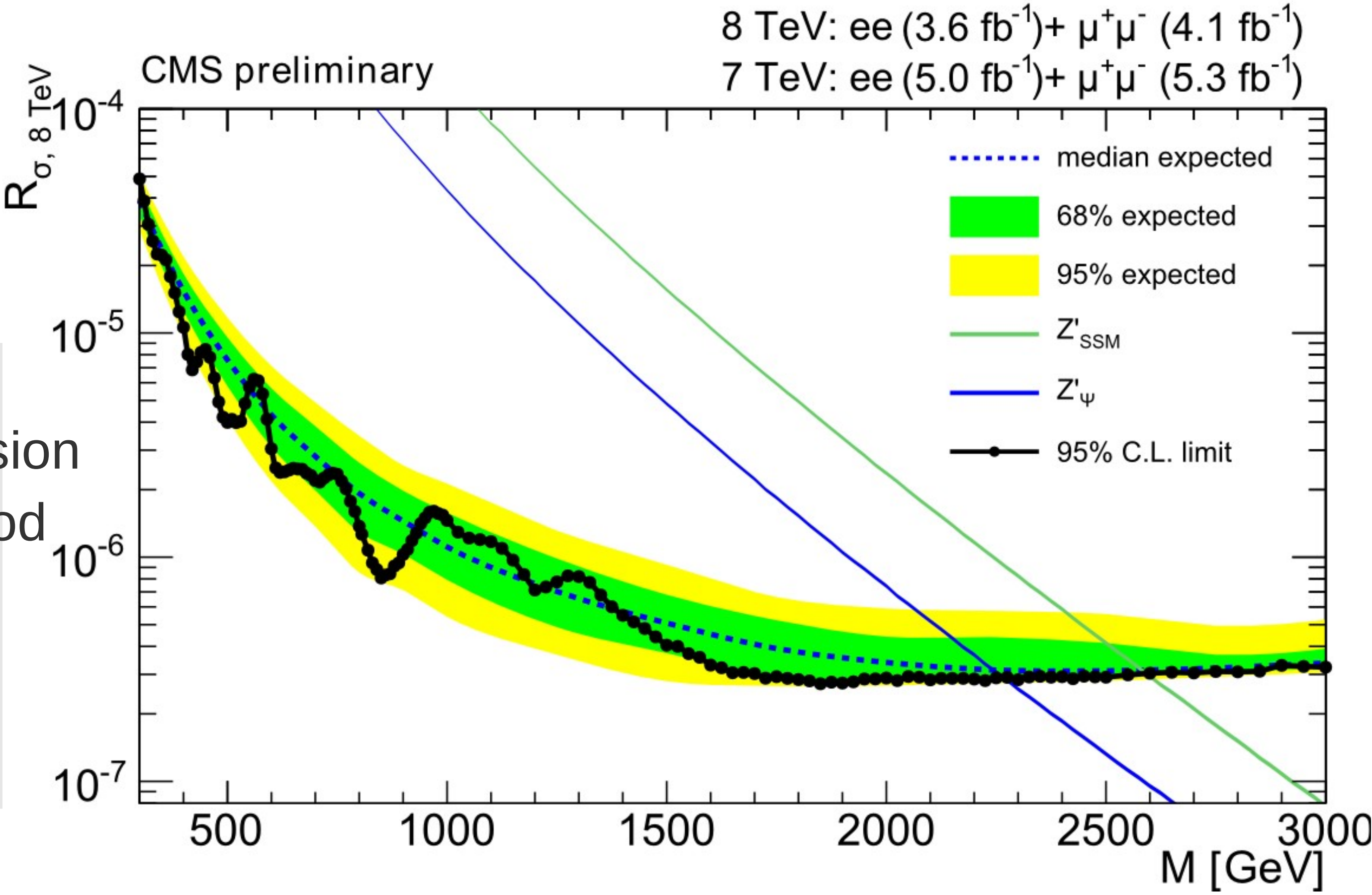
Upper limit:

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

shape analysis, with signal according to Breit-Wigner + Gaussian

Combination:

- ee channel + μμ channel
- 2011 + 2012:
  √s = 7 TeV limits reinterpreted for √s = 8 TeV



Results:

no excess, → 95% CL exclusion

limits from unbinned likelihood function,

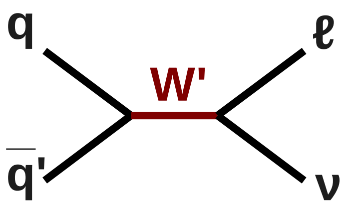
$M(Z'_{SSM})$: > 2.59 TeV

$M(Z'_{\psi})$: > 2.26 TeV

W' study

EXO-12-010
PAS Publ.
2012 Data, $3.7 fb^{-1}$

Selection:



e / µ: one isolated electron / muon,

add. criteria based on missing E_T:

$0.4 < p_T(\ell) / E_T^{miss} < 1.5$ and $\Delta\phi_{\ell,\nu} > 0.8\,\pi$

Main observable: $M_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_T^{miss} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$

Backgrounds:

irreducible $W \to \ell\nu$ + additional lower bkgd: QCD multijet, $t\bar{t}$, DY, diboson

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

method A: fitted in data, based on the $200 < M_T < 600$ sideband

method B: fitted from simulation, but normalized with data in the $200 < M_T < 500$ region

Limits:

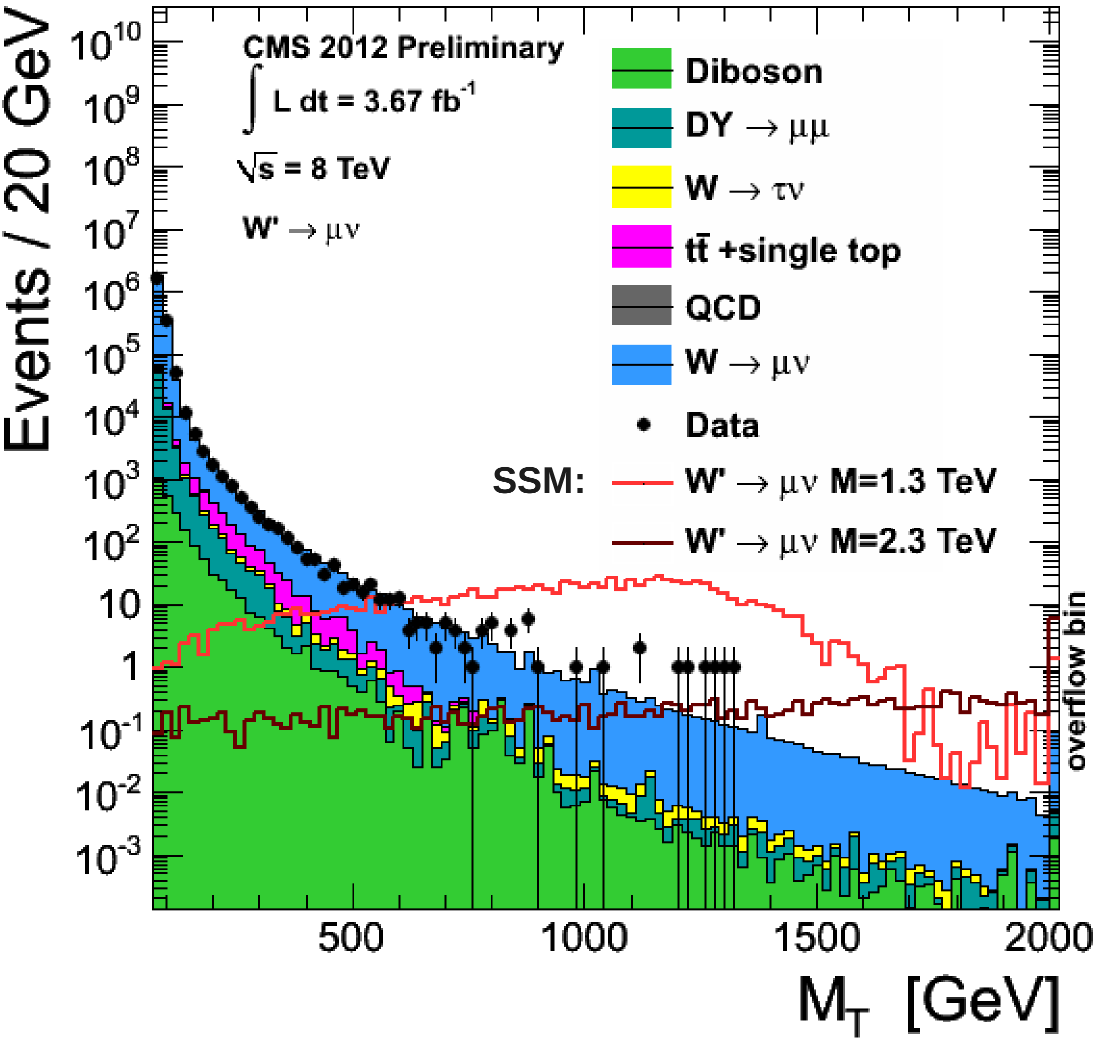
- Limits on σ x BR, for e + µ with $\sqrt{s} = 8$
- Limits on $\sigma_{excl.} / \sigma_{SSM}$, for e + µ with $\sqrt{s}=7$ + $\sqrt{s}=8$ (but does not improve a lot the mass limit)
- → limits on split-UED parameters, for e, µ, e + µ with $\sqrt{s} = 7$

W' study

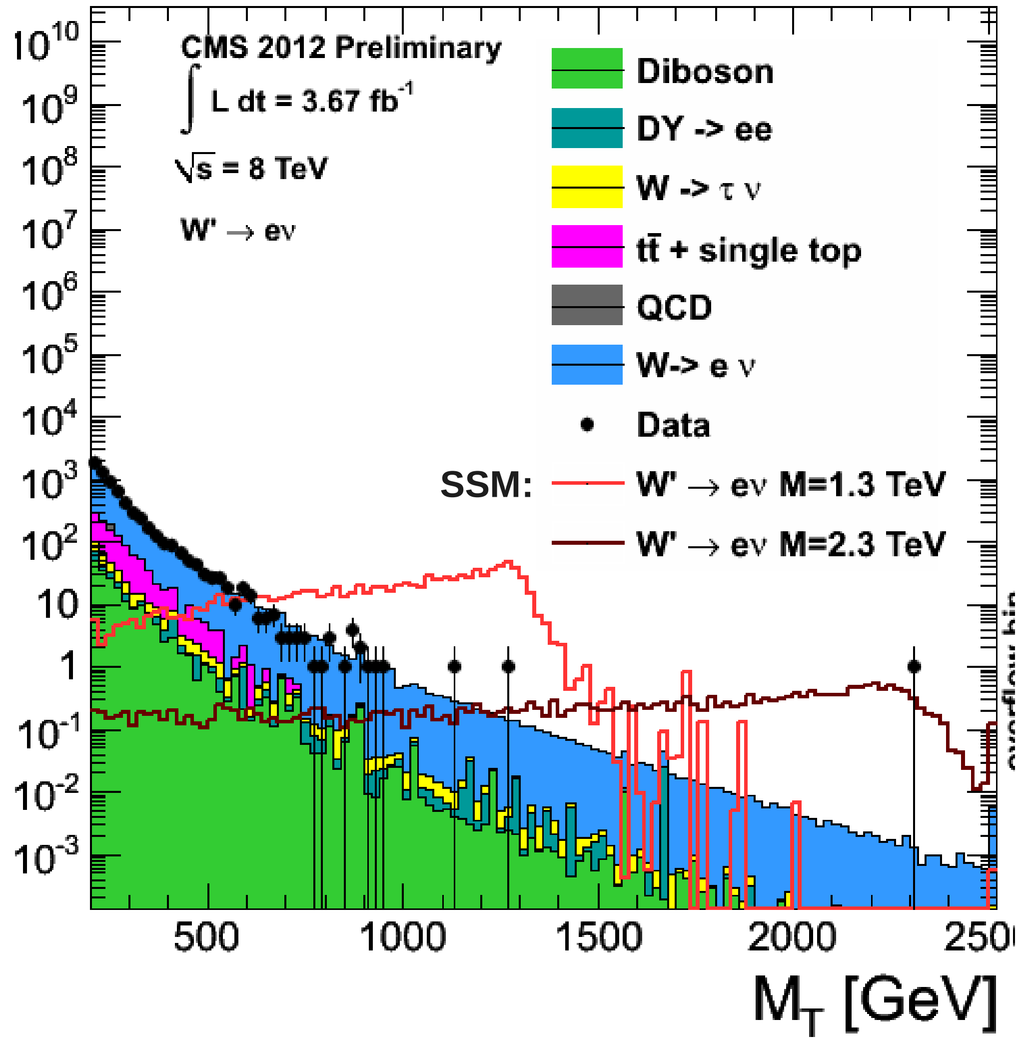
EXO-12-010
PAS Publ.
2012 Data, 3.7fb^{-1}

Yield:

muon channel



electron channel



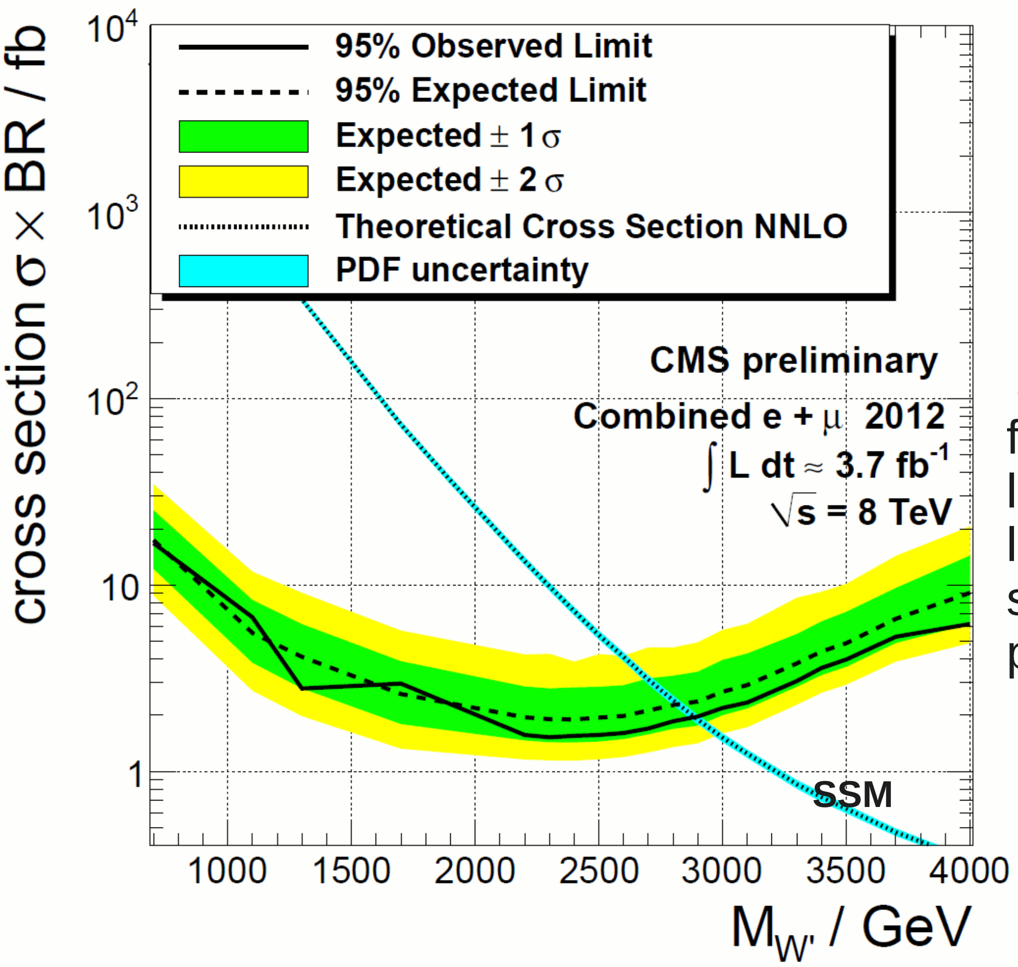
W' study

EXO-12-010
PAS Publ.
2012 Data, $3.7 fb^{-1}$

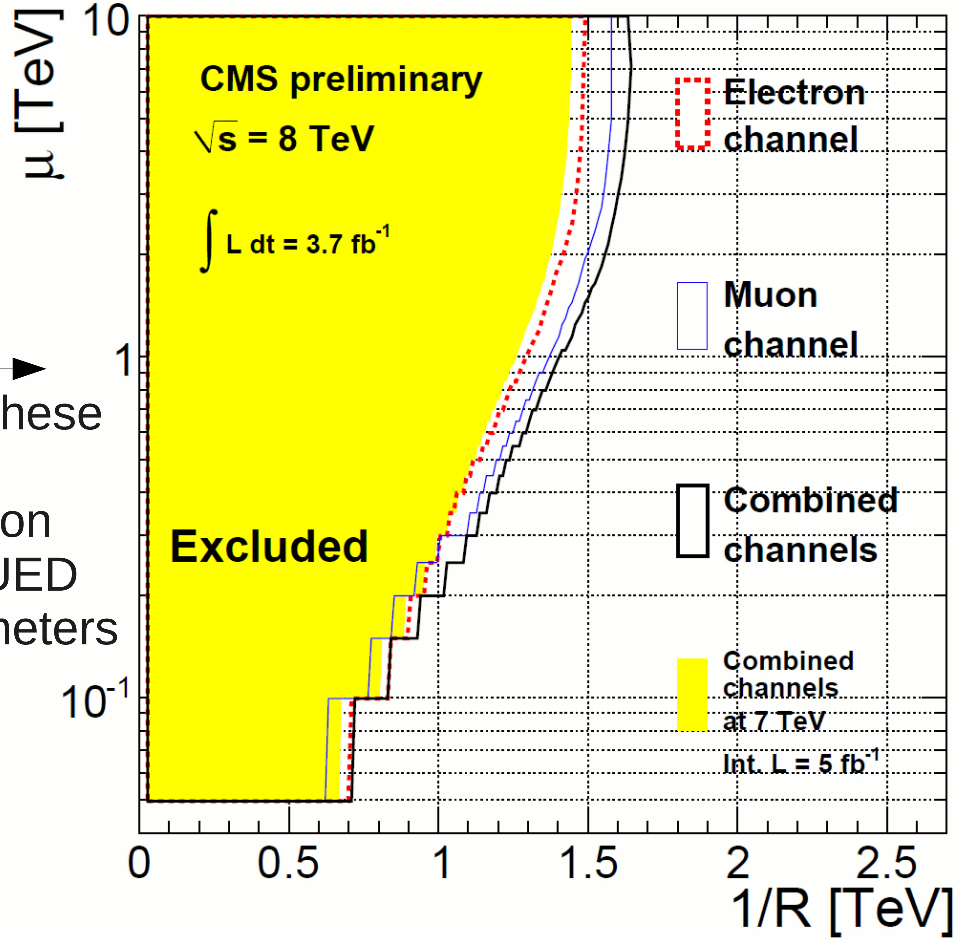
Results:

no excess, →95% CL exclusion
additional optimized cut on M_T
Bayesian limits (counting exp.)

$M(W'_{SSM})$:	> 2.85 TeV
$M(W_{kk})(\mu = 0.05)$:	> 1.4 TeV
$M(W_{kk})(\mu = 10)$:	> 3.3 TeV



from these limits: limits on split-UED parameters



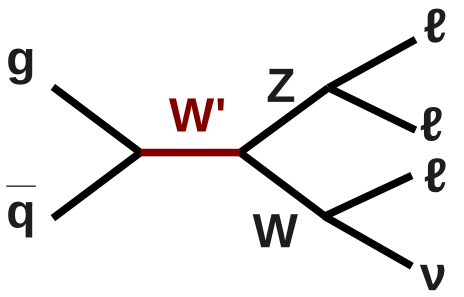
W', $\rho_{TC} \rightarrow WZ$

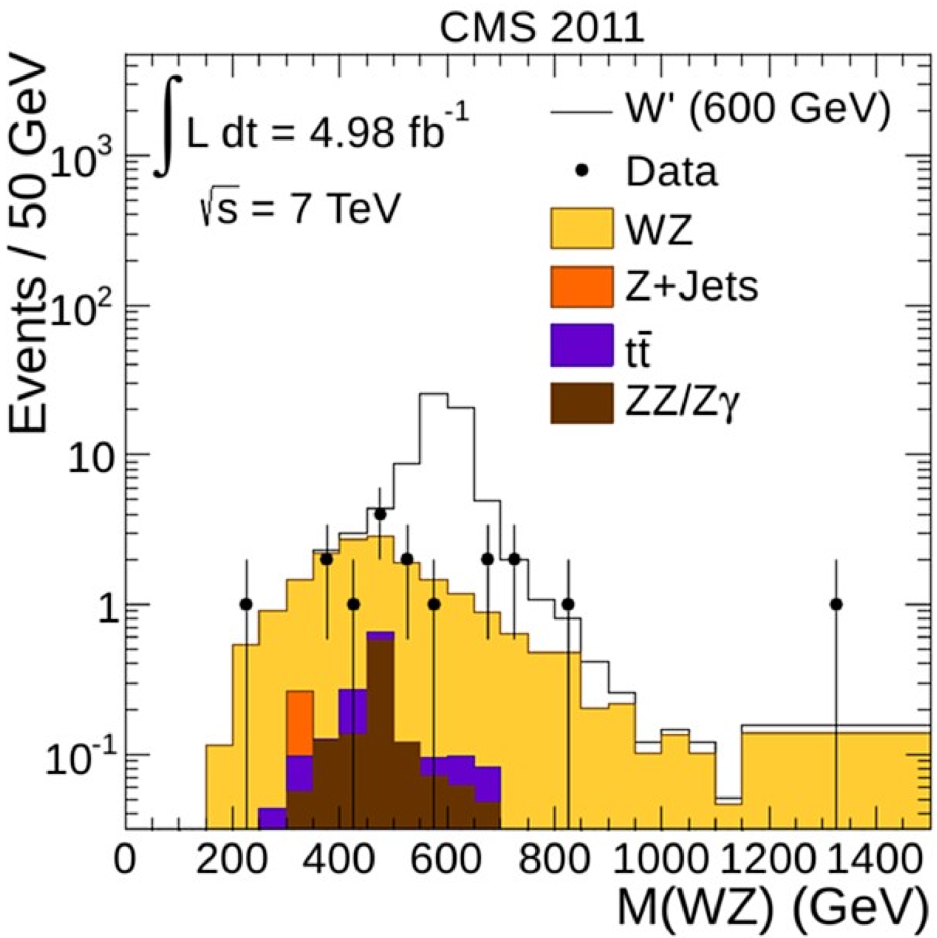
EXO-11-041
going for PRL
2011 Data, $5fb^{-1}$

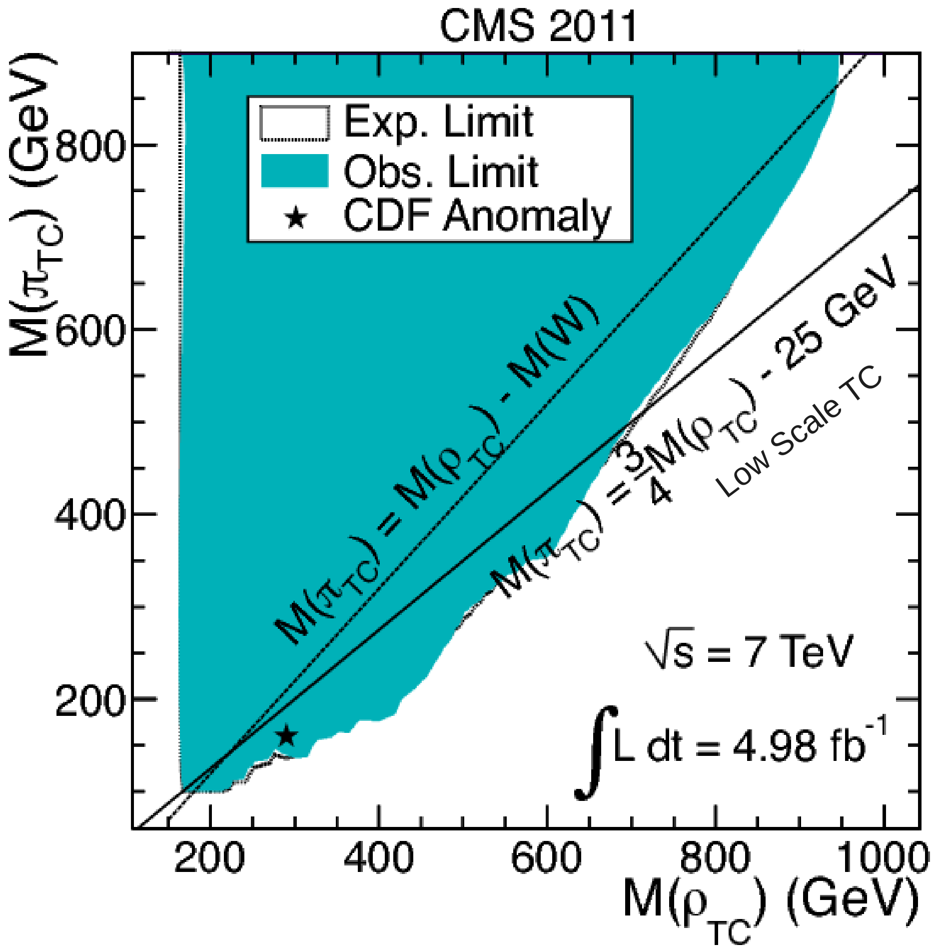
Selection:

2 opp. charge same flavor leptons with $m(\ell\ell) \in [60, 120]$
+ high energy isolated lepton

add. criteria: $E_T^{miss} > 30$ GeV, ZZ veto
cut on scalar sum on the three leptons p_T







W', $\rho_{TC} \rightarrow WZ$

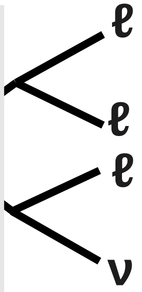
EXO-11-041
going for PRL
2011 Data, $5fb^{-1}$

Selection:

2 opp.

+

add. cr



Results:

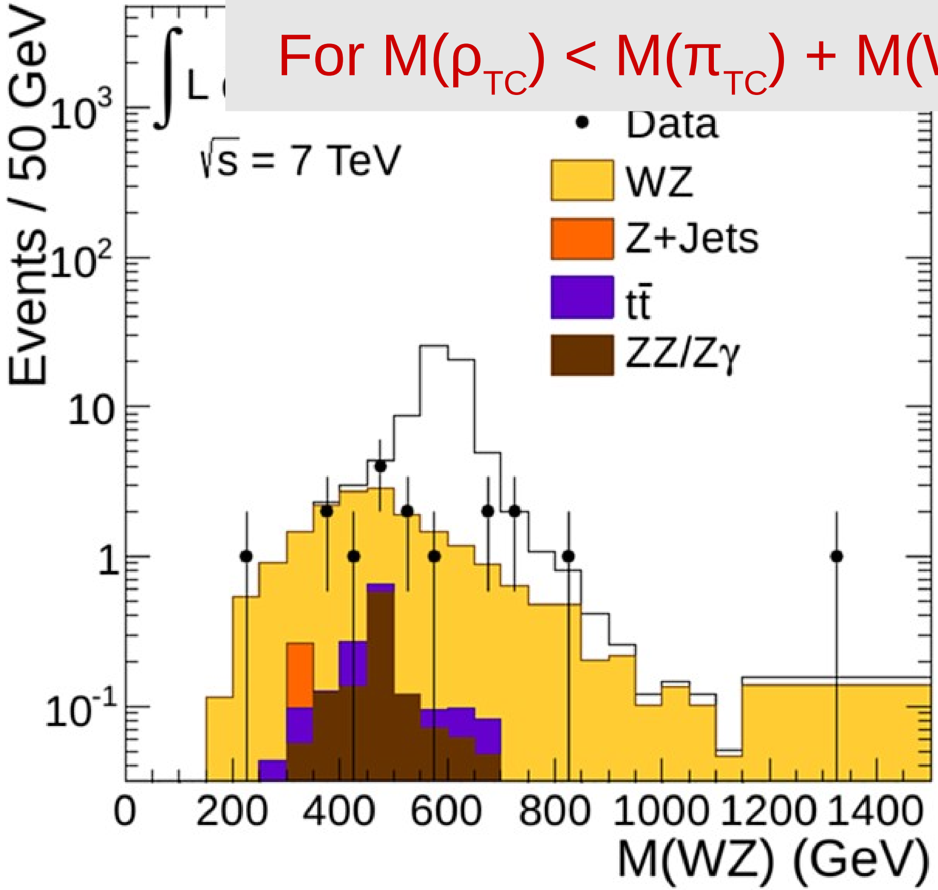
no excess, →95% CL exclusion

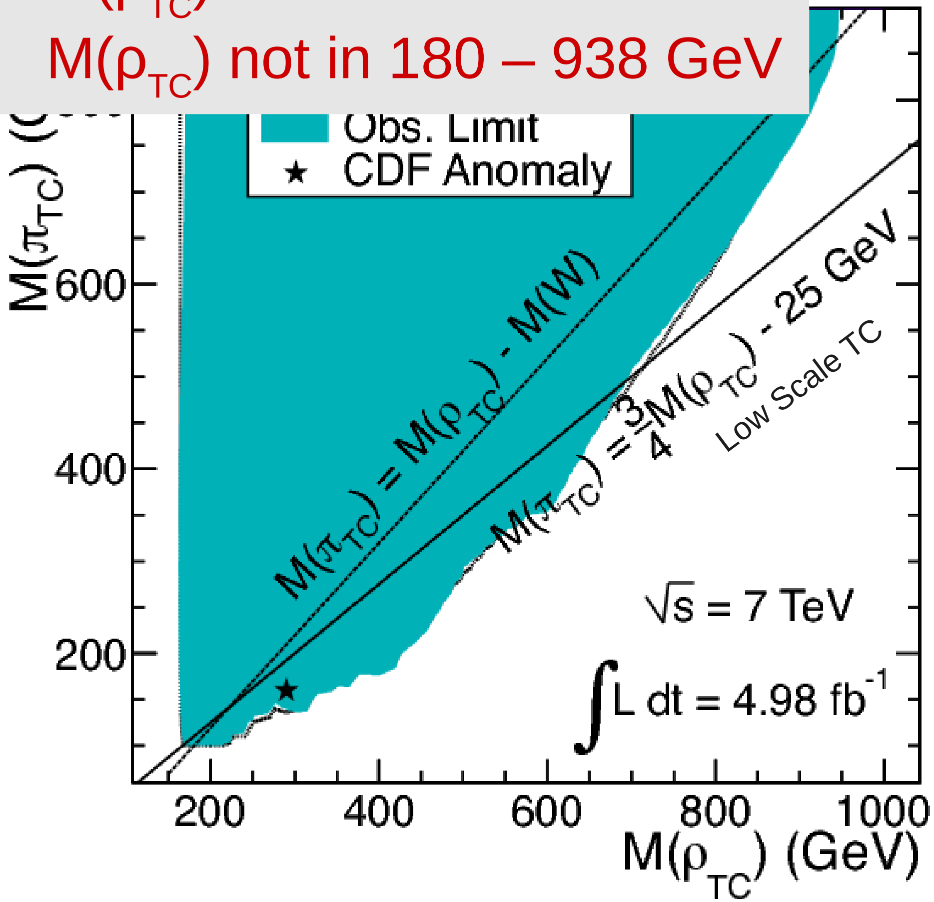
CLs limits (counting exp.),

SSM M(W') > 1143 GeV

low-scale TC: $M(\rho_{TC})$ not in 167 – 687 GeV

For $M(\rho_{TC}) < M(\pi_{TC}) + M(W)$: $M(\rho_{TC})$ not in 180 – 938 GeV





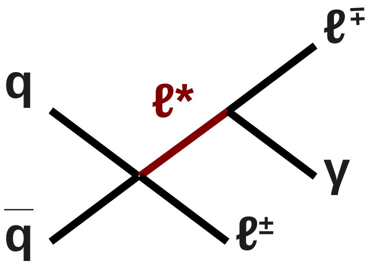
Excited lepton

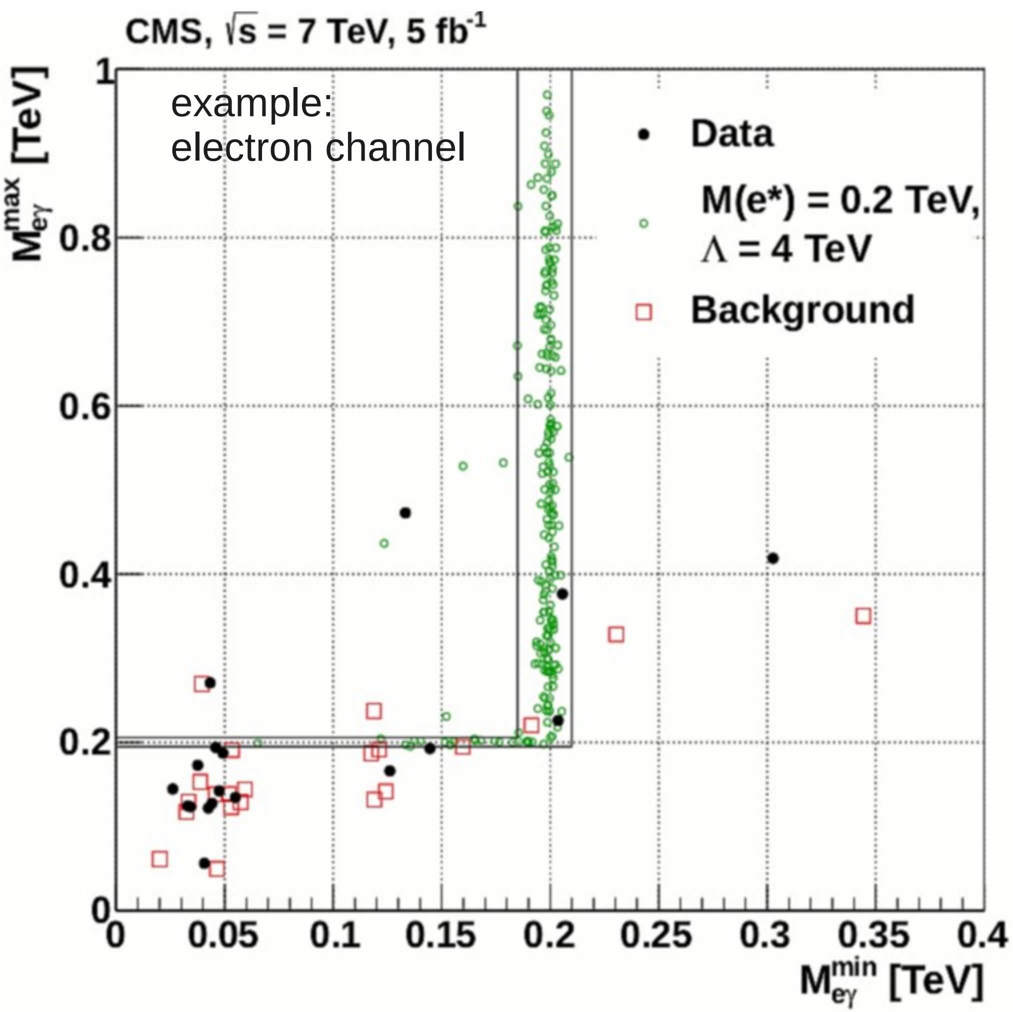
EXO-11-034
going for PLB
2011 Data, $5fb^{-1}$

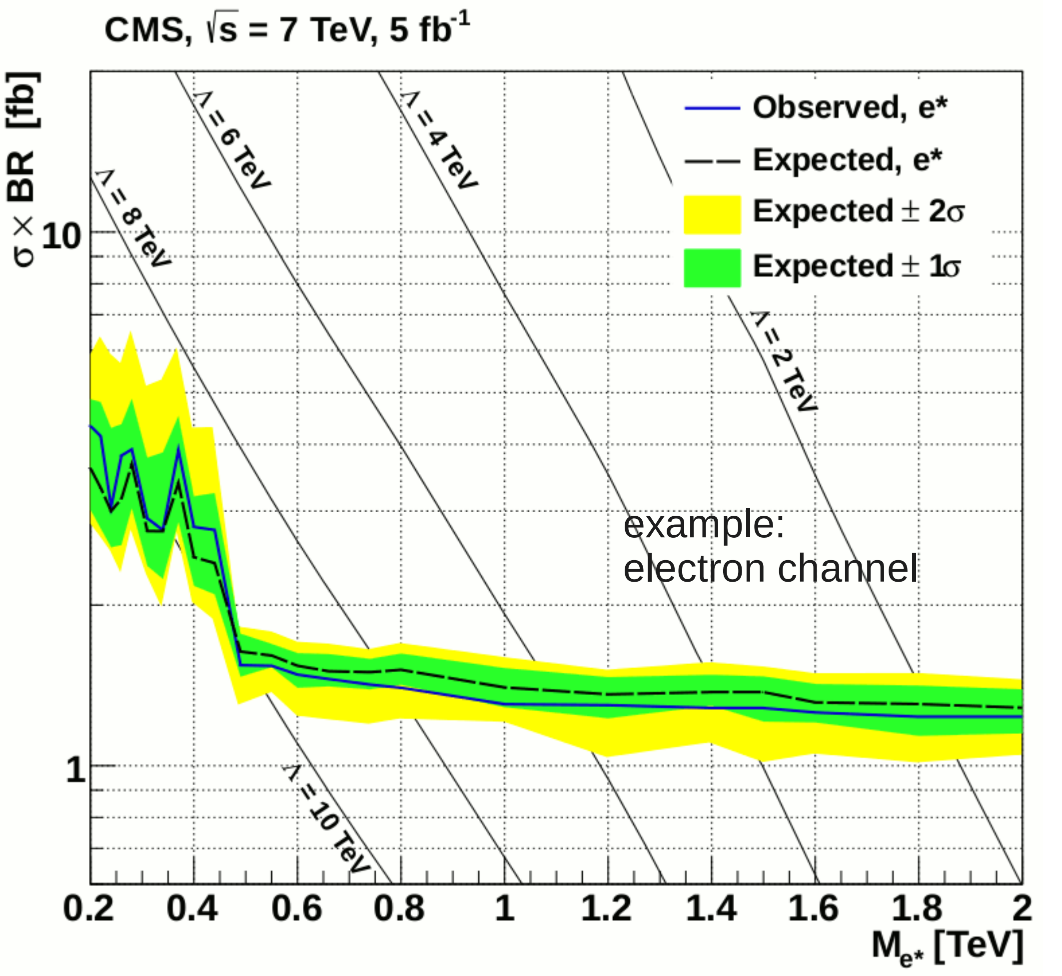
Selection:

e / μ: two opposite charge isolated electron / muon,
+ high energy photon

add. criteria: Z veto,
selection in the min-max lepton-photon inv. mass plane







Excited lepton

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

Selection:

e / μ: two c
+ hig

add. criteria
sele

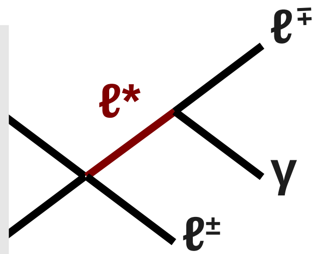
Results:

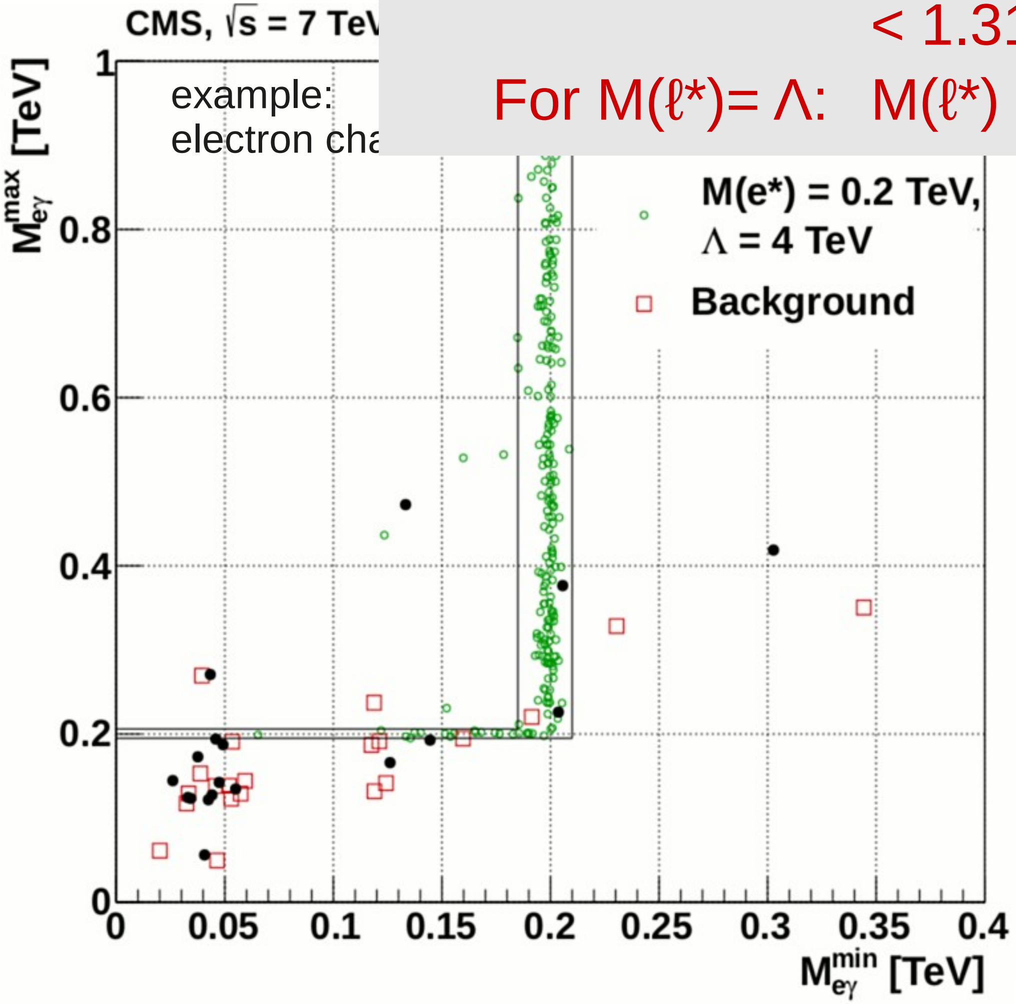
no excess, → 95% CL exclusion

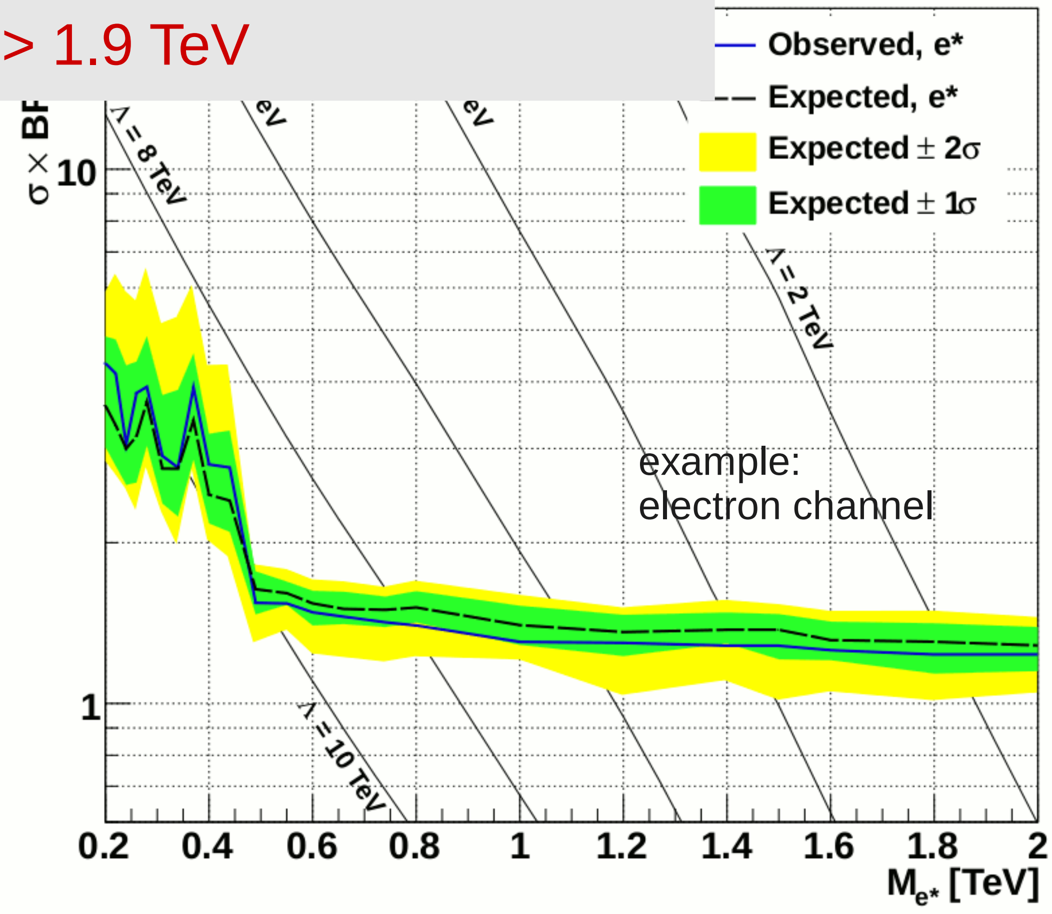
CLs limits (counting exp.),

σ x BR: < 1.48 – 1.24 fb for m(e*)>0.2 TeV
< 1.31 – 1.11 fb for m(μ*)>0.2 TeV

For M(ℓ*)= Λ: M(ℓ*) > 1.9 TeV







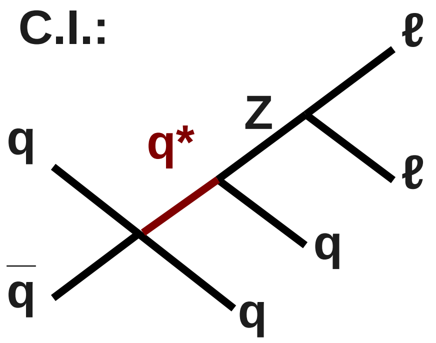
Boosted Z^0

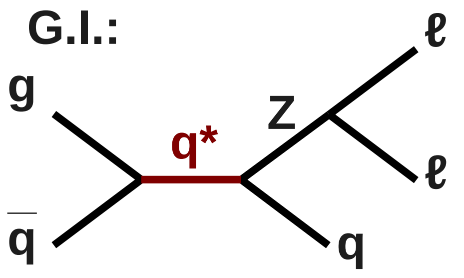
EXO-11-025
going for PLB
2011 Data, $5fb^{-1}$

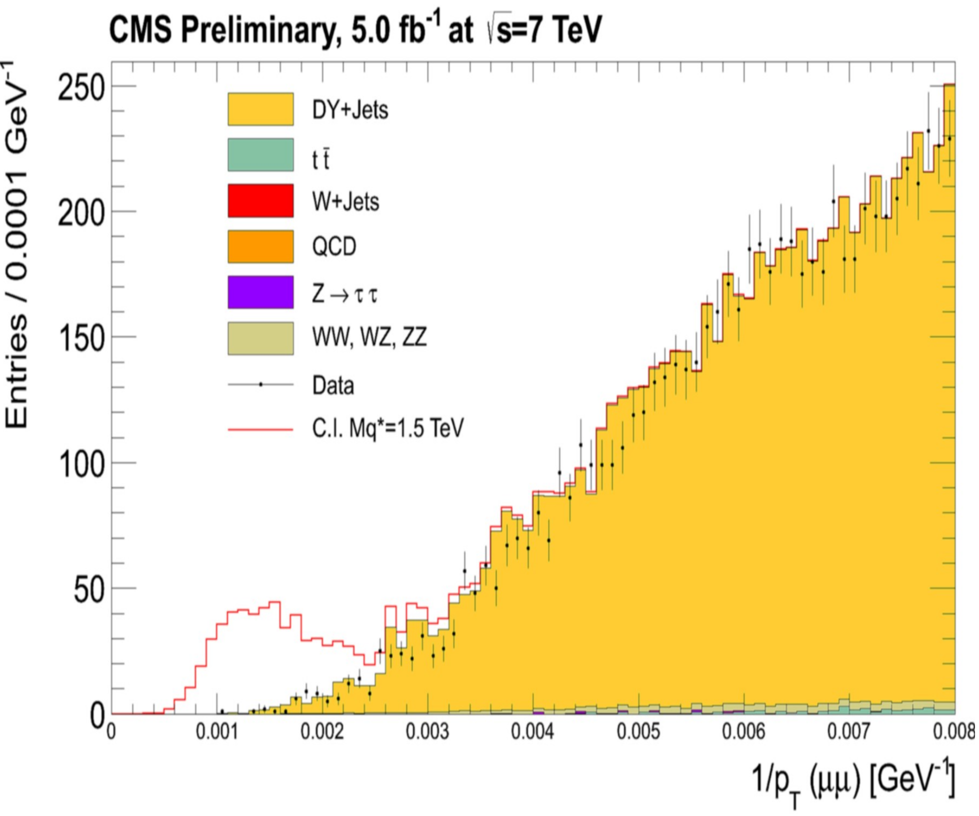
Several model predicts boosted Z^0. Here, the analysis focuses on q*

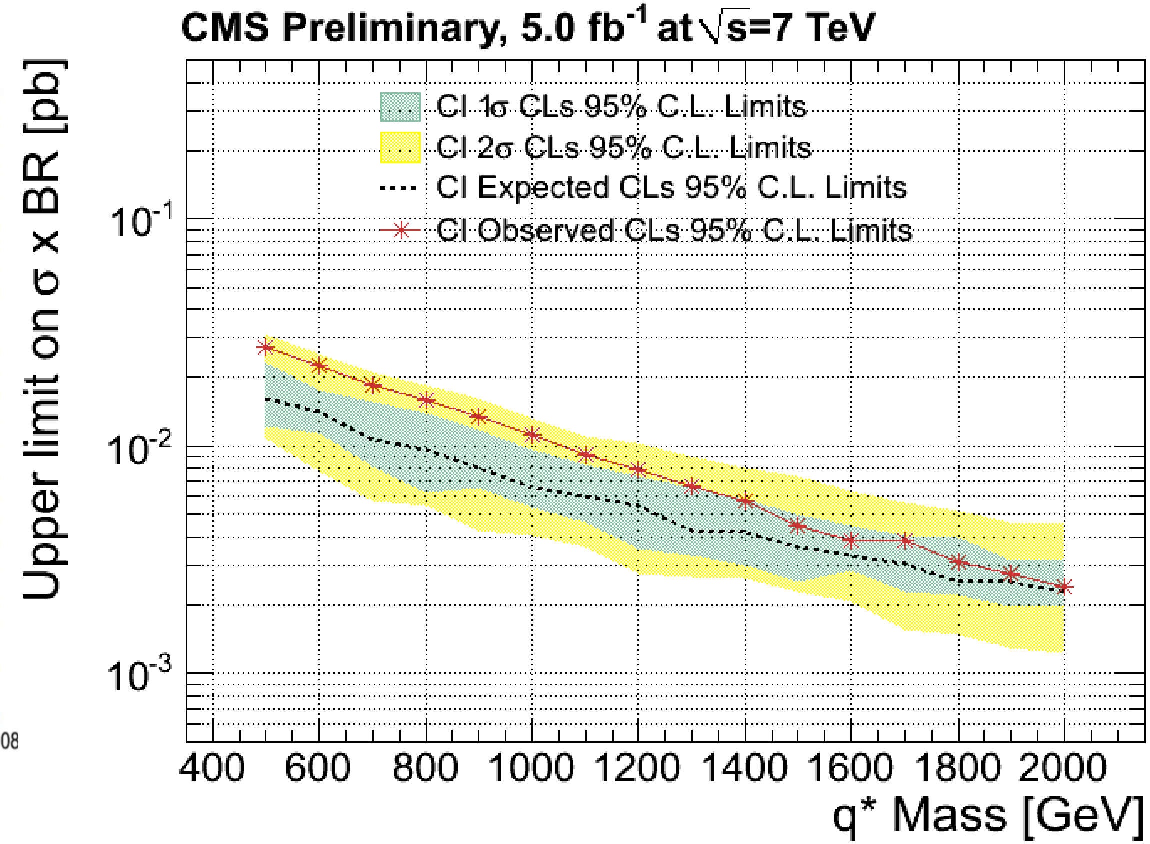
Selection:

2 opp. charge isolated
muons with m(μμ) ϵ [60, 120]









Boosted Z^0

EXO-11-025
going for PLB
2011 Data, $5fb^{-1}$

Several model predicts boosted Z^0. Here, the analysis focuses on q*

Selection:

2 opp. charg
muons with

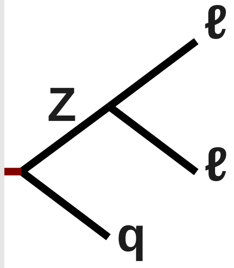
Results:

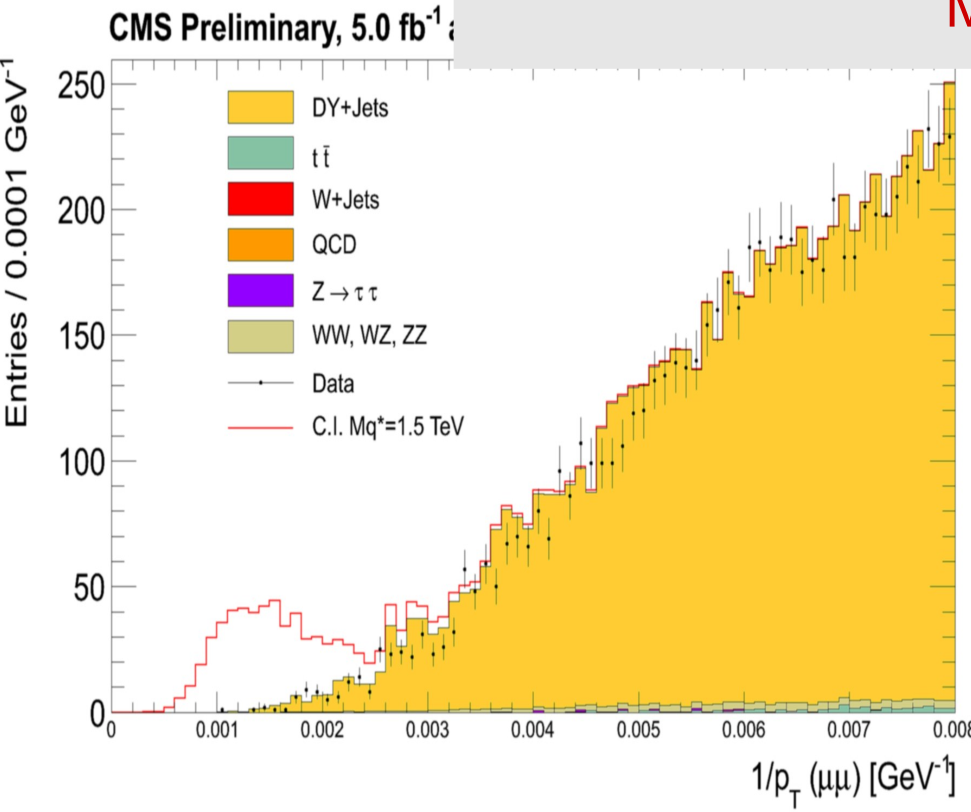
no excess, → 95% CL exclusion

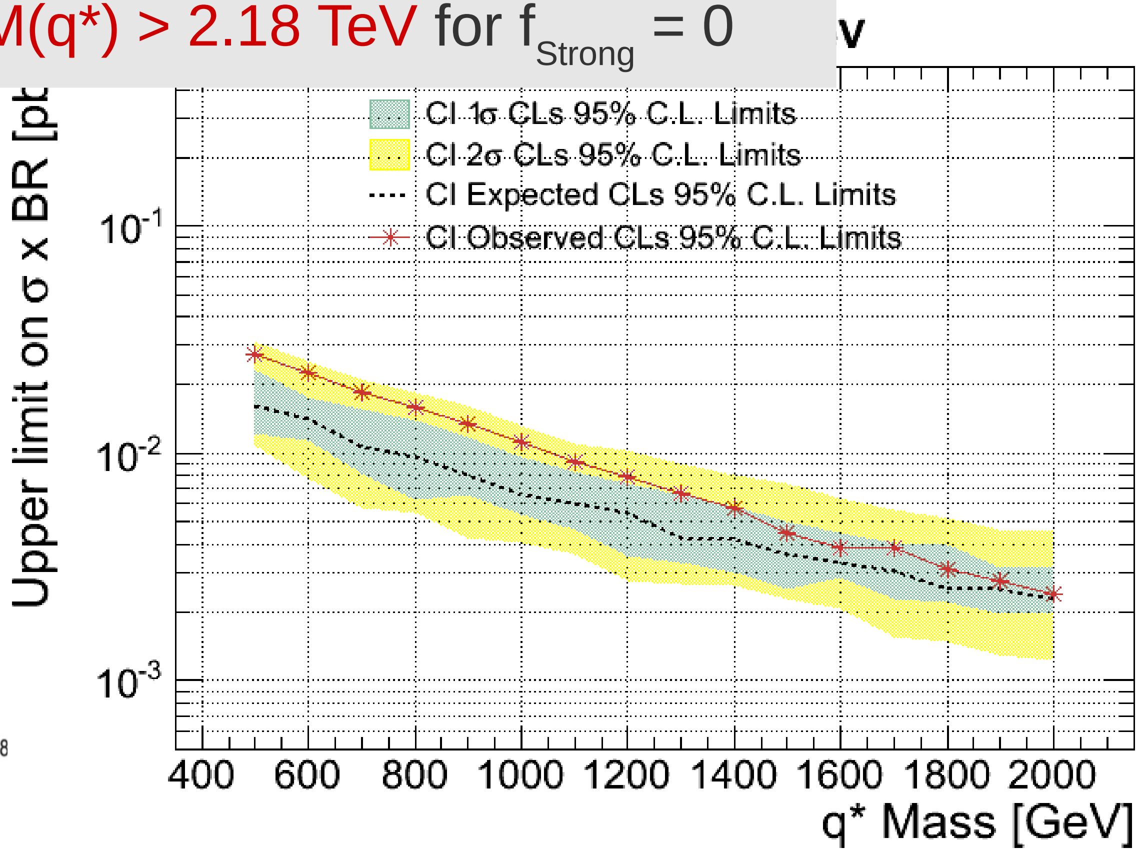
CLs limits (shape analysis),

For M(q*)= Λ: M(q*) > 1.94 TeV for G.I
M(q*) > 2.14 TeV for C.I

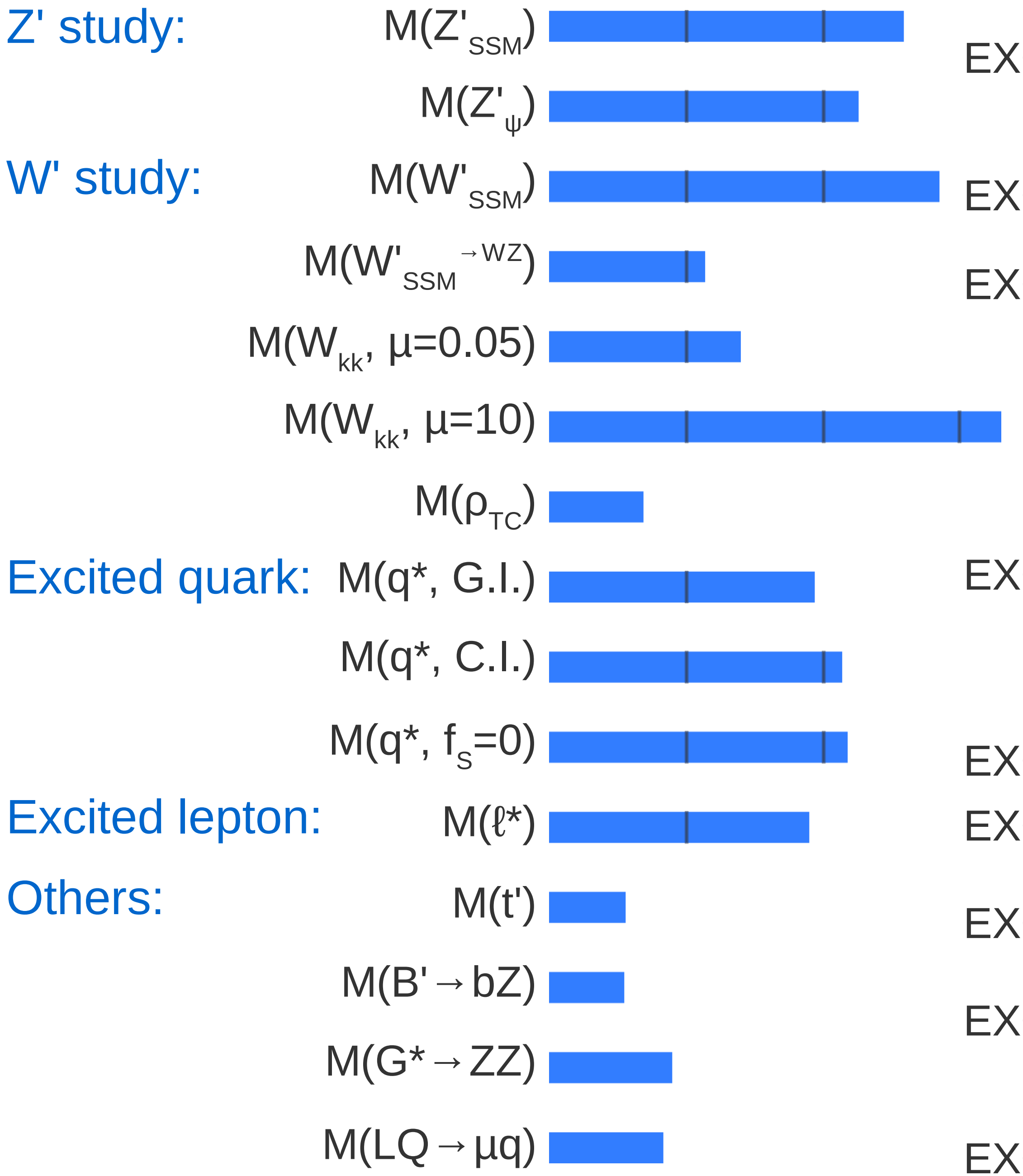
M(q*) > 2.18 TeV for f_{Strong} = 0







Summary



*: 2012 data

EXO-12-015*: *“Search for Resonances in Dilepton Mass Spectra...”*

EXO-12-010*: *“Search for leptonic decays of W' bosons...”*

EXO-11-041: *“Search for a W or ρ_{TC} decaying to WZ ...”*

EXO-11-025: *“Updated Search for New Physics in Highly Boosted Z^0 Decays to Dimuon...”*

EXO-11-034: *“Search for Excited Leptons ...”*

EXO-11-050: *“Search for heavy, top-like quark pair production in the dilepton final state...”*

EXO-11-066: *“Search for a vector-like quark of charge -1/3 and decaying to bZ...”*

EXO-11-102: *“Search for a narrow spin-2 resonance decaying to Z vector bosons in the semileptonic final state”*

EXO-11-028: *“Search for Second Generation Scalar Leptoquarks”*

Conclusion

Numerous exotica analyses with leptonic final state

Leptonic final states
- are well reconstructed in CMS (robust against pu, ...)
- are clear signatures, with low background
- give the best limits for Z' and W'
- are complementary to hadronic final states (q*)

No excess has been observed, but limits have been stated

LHC: current public results: 2011, ~5fb^{-1}
2012, ~5fb^{-1}
expected: ~25fb^{-1}

Backup slides

Leptons reconstruction and selection

Usual selection (mainly based on Z' study):

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

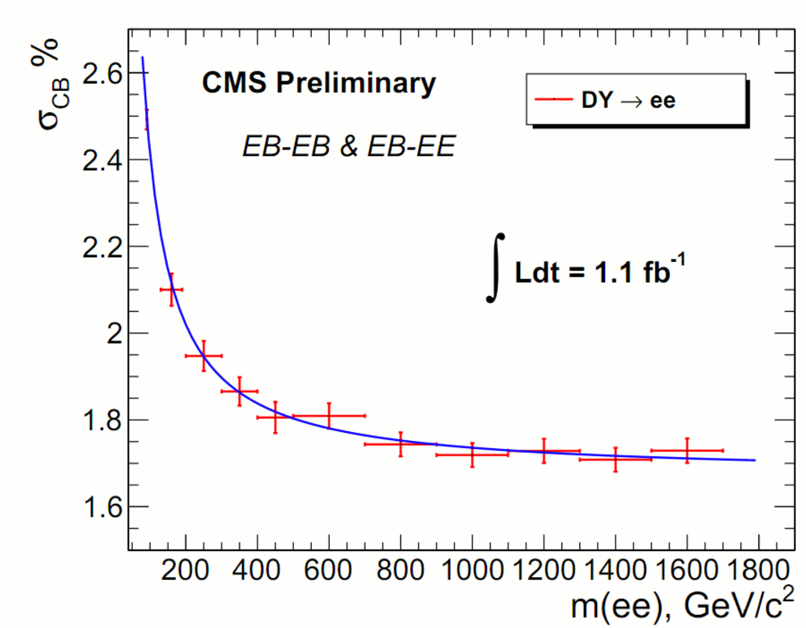
Kinematics:
- p_T and $|\eta|$ consistent with triggers

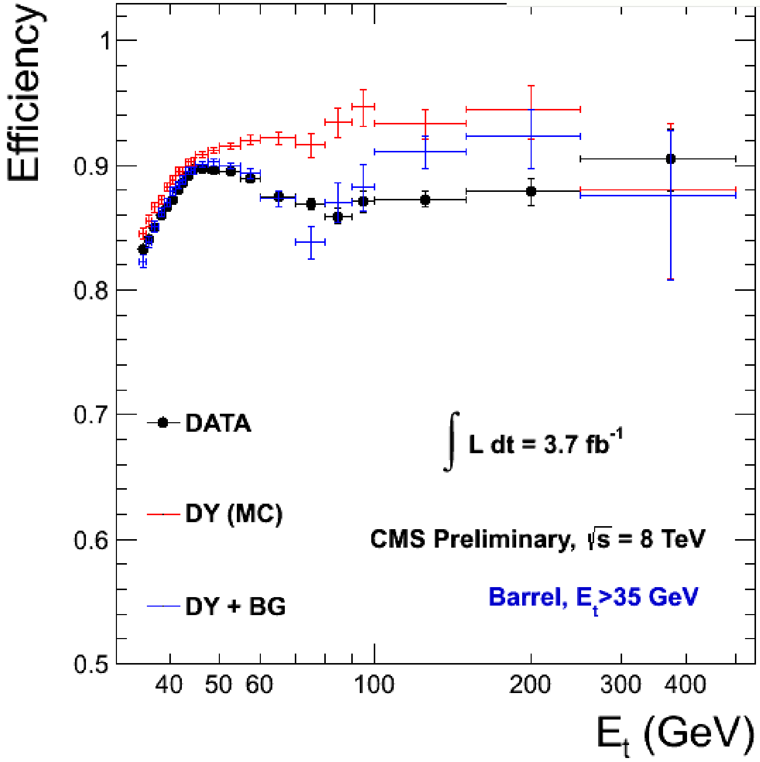
(muon: $p_T > 45$ GeV, $|\eta| < 2.1$, electron: $p_T > 35$ GeV, $|\eta| < 2.4$ without [1.442,1.560])

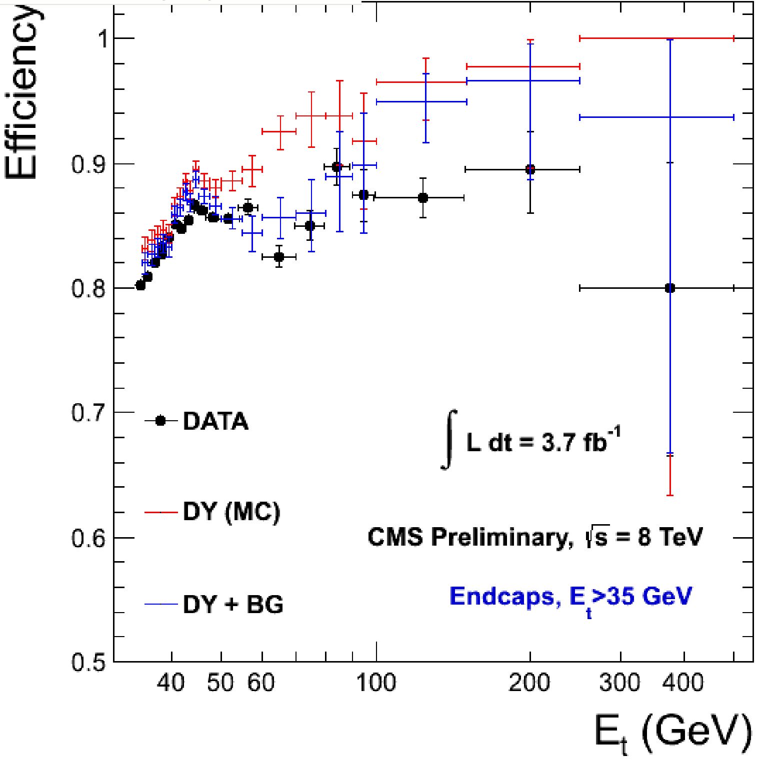
Identification:
- Track of the lepton consistent with the collision point ($|d_0| < 0.2$ cm)
- For muon:
  - cosmic muon rejection (dimuon: angle < pi-0.02 rad, single muon: stronger $|d_0|$ cut)
  - good track quality (≥1 hit in pixel tracker, ≥9 hits in silicon tracker, ≥2 segment in muon stations)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

Electrons efficiency and resolution

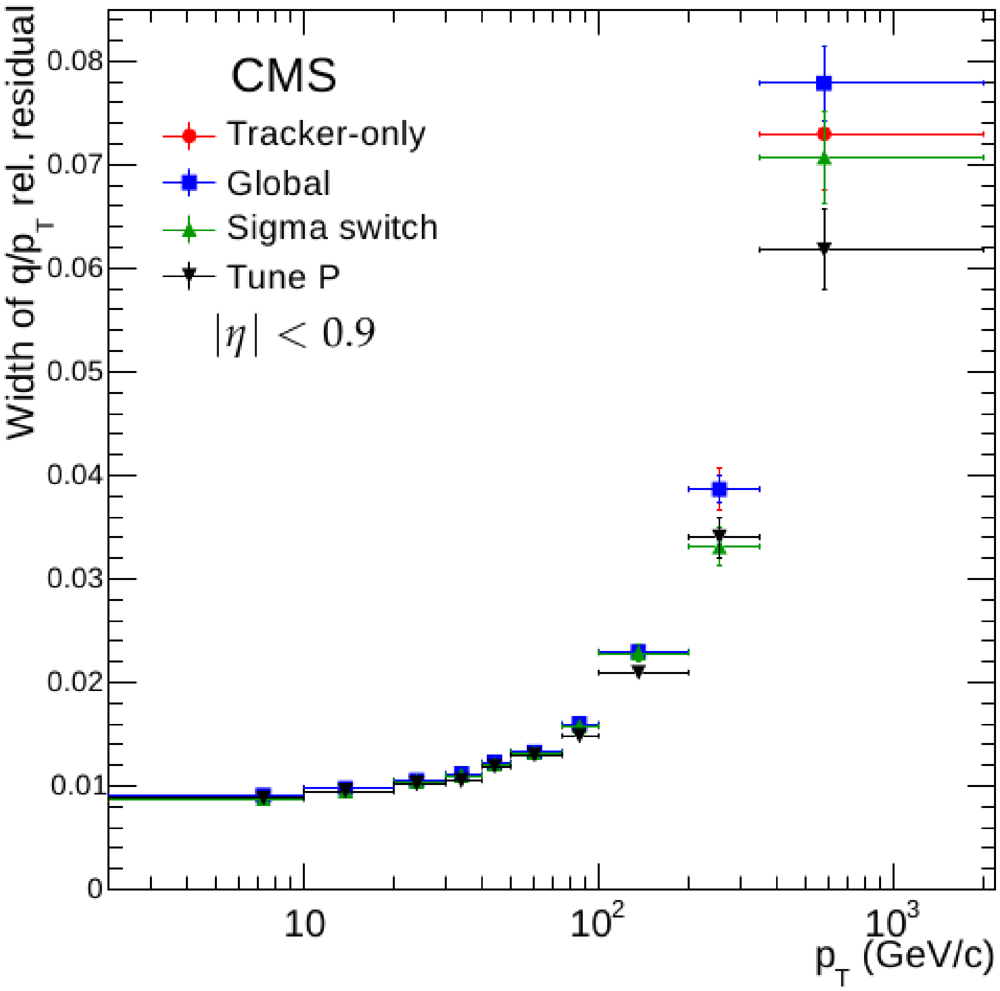






Muons performances

arXiv:1206.4071



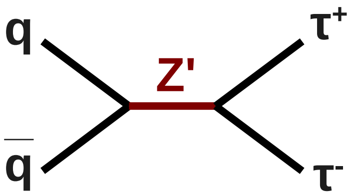
Z' to taus

EXO-11-031
going for PLB
2011 Data, 5fb^{-1}

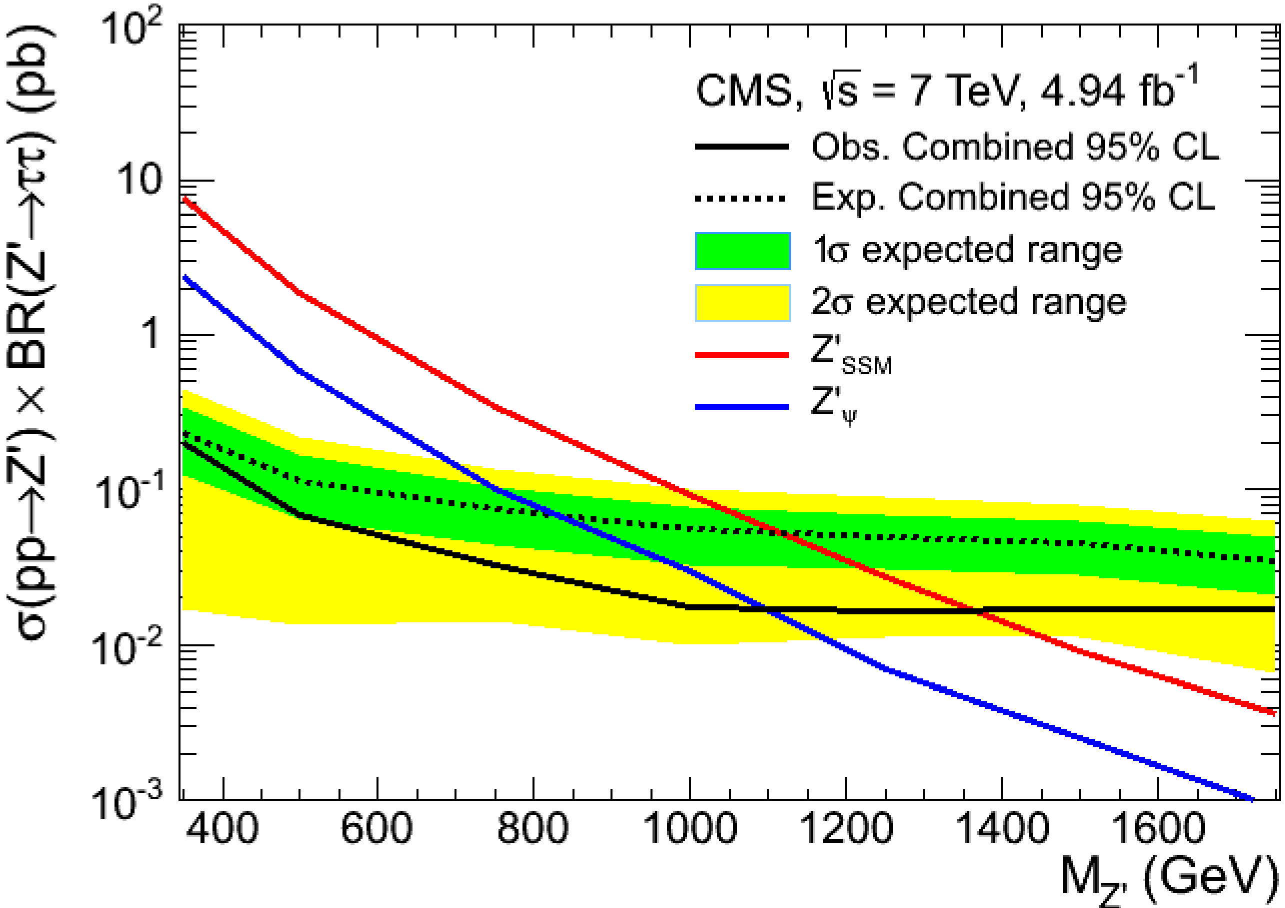
Selection:

two taus in 4 channels: hh, he, hμ, eμ

add. criteria: back-to-back taus, E_T^{miss} cut,
no b-jets, projection variables cut> 50 GeV



$$M(\tau_1,\tau_2,E_T^{miss}) = \sqrt{(E_{\tau_1}+E_{\tau_2}+E_T^{miss})^2 - (\overrightarrow{p_{\tau_1}}+\overrightarrow{p_{\tau_2}}+\overrightarrow{E_T^{miss}})^2}$$



Limits:

M(Z'$_{SSM}$): > 1.4 TeV
M(Z'$_\psi$): > 1.1 TeV

Limits for Z' → ℓℓ:

M(Z'$_{SSM}$): > 2.6 TeV
M(Z'$_\psi$): > 2.3 TeV

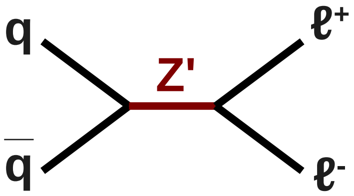
Z' 2011

EXO-11-0

2011 Data, 5fb^{-1}

Selection:

similar to 2012 analysis

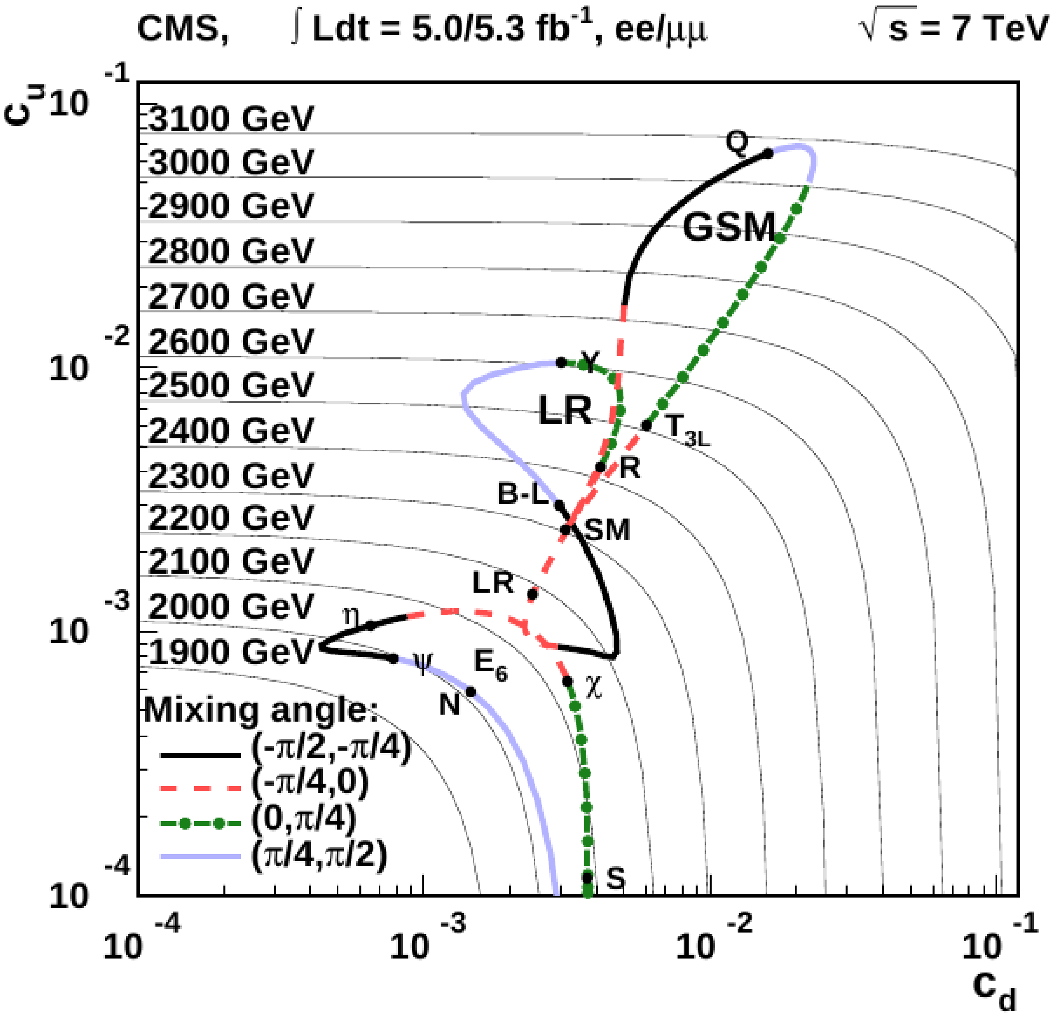


Limits in 2011:

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

Limits in 2012:

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



rough comparison

	cms with leptons	cms with hadrons	atlas
$M(Z'_{SSM})$:	> 2.59	excl [1.0, 1.45]	> 2.49
$M(Z'_{\psi})$:	> 2.26		> 2.09
$M(G_{KK})$ (c=0.10):	> 2.14		> 2.16
M(W')	> 2.85	excl [1.0, 1.9]	> 2.55
$M(\rho_{TC})$	excl [0.18, 0.94]		> 0.85
M(q*), f_S != 0	> 1.94	excl [0.6, 3.27]	> 3.7 (had)
M(q*), f_S = 0	> 2.18	-	
M(l*)	> 1.9		> 1.9-2.0
M(t')	> 0.56	> 0.69	> 0.66
M(b')		> 0.61	

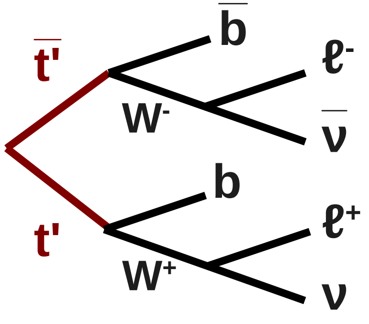
dileptonic $\bar{t}'t'$ study

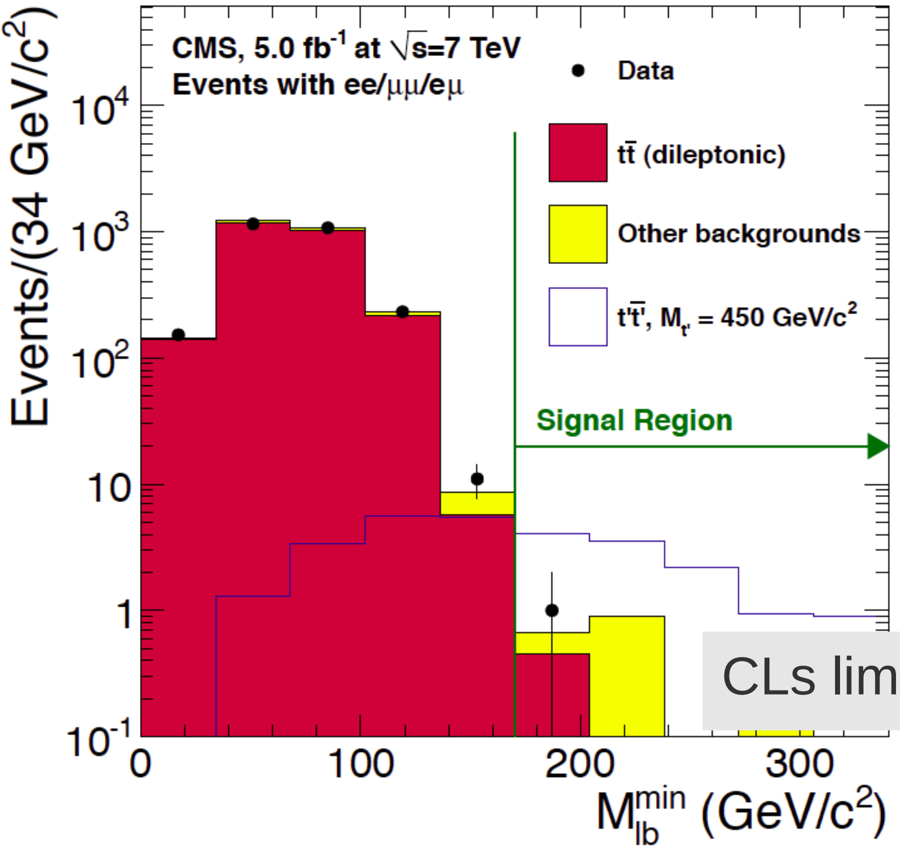
EXO-11-050
10.1016/j.physletb.2012.07.059
2011 Data, $5 fb^{-1}$

Selection:

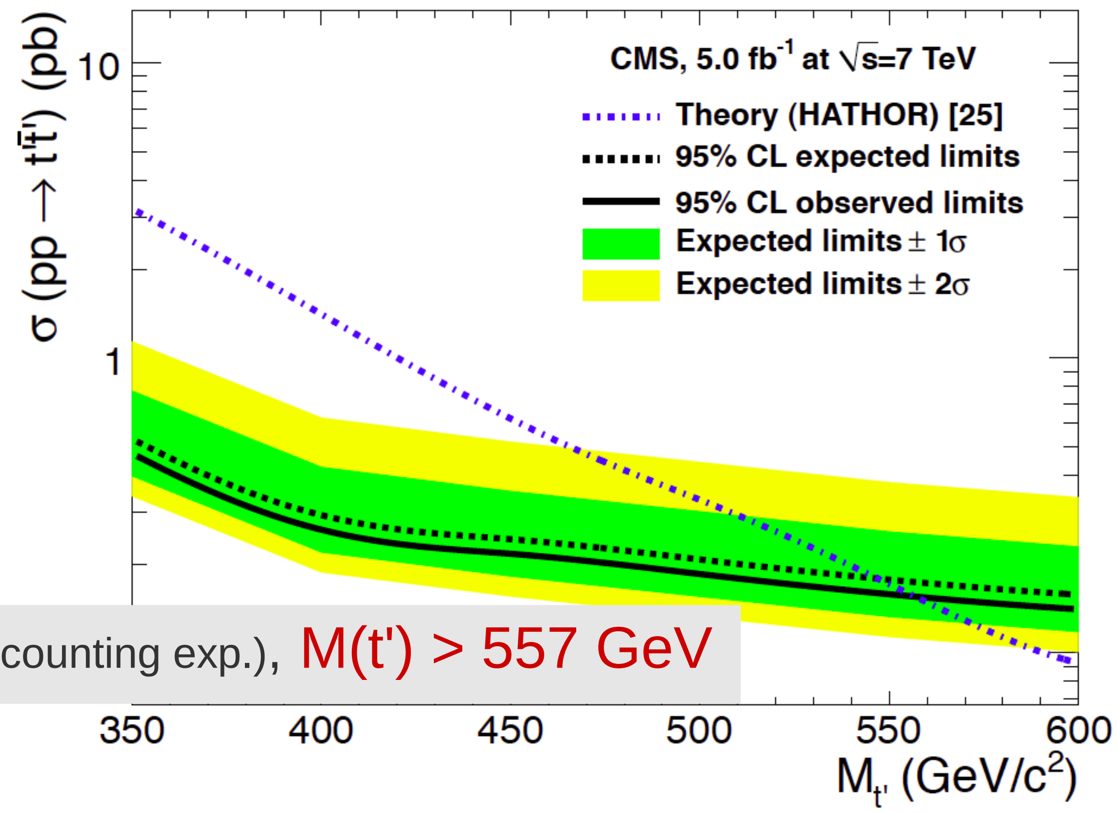
two opp. charge isolated leptons (ee, μμ, eμ)

add. criteria: Z veto, $E_T^{miss} > 50$ GeV,
at least 2 b-jets,
min. of the 4 lept.–b-jet inv. mass (M_{lb}^{min}) > 170 GeV





t'→bW assumed to be 100%



CLs limits (counting exp.), M(t') > 557 GeV