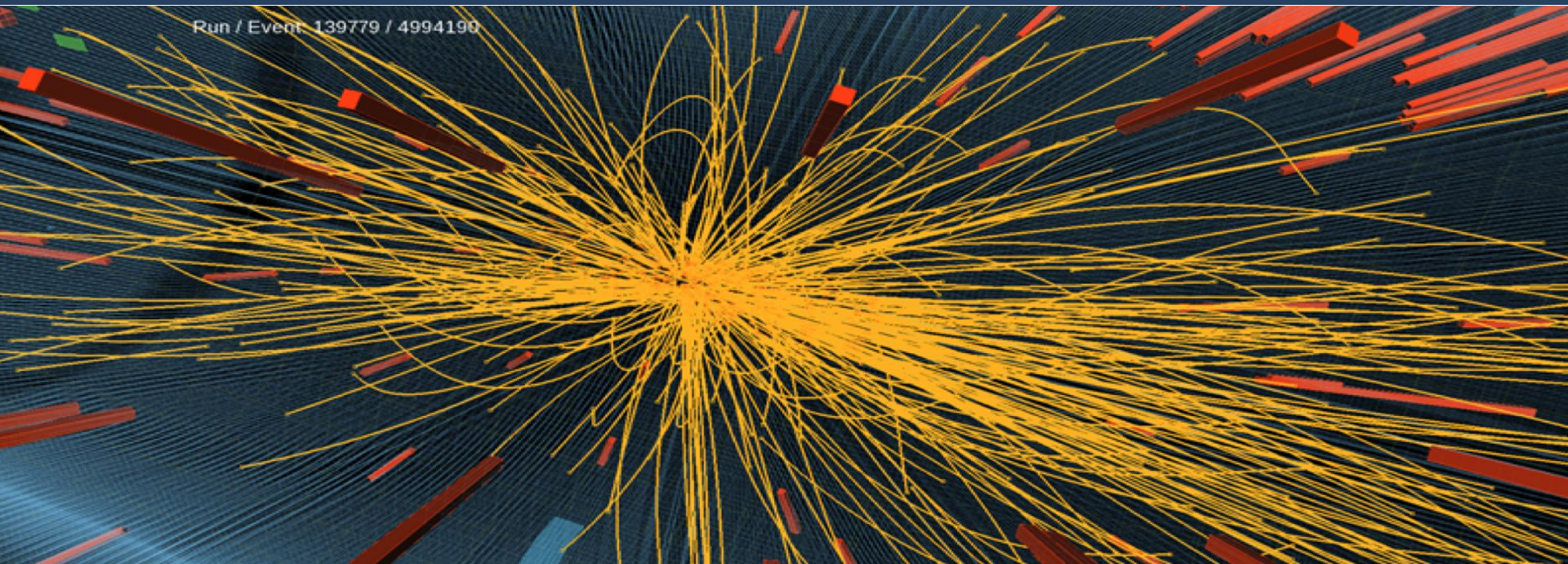
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung
PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Search for Compositeness with CMS

Kerstin Hoepfner, RWTH Aachen, III. Phys. Inst. A
On behalf of the CMS collaboration

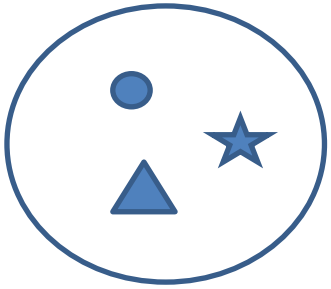
ICHEP Conference July 2012, Melbourne



Theoretical Background

Fermion substructure (Compositeness)

?



May address open questions:

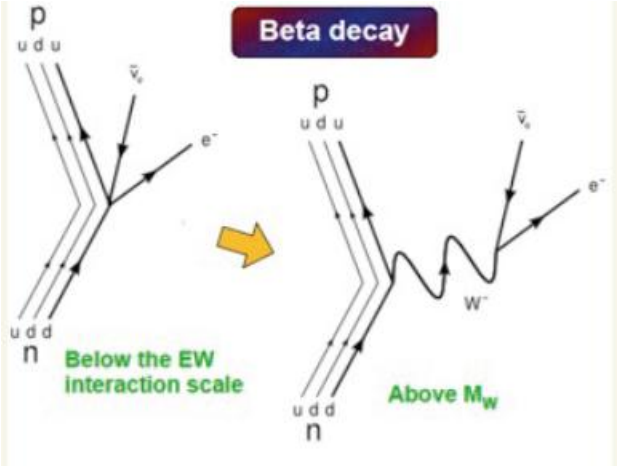
- Replication of SM families
- Their complex pattern of masses and mixing angles
- Large number of fundamental particles

Quarks and leptons are probed to be elementary up to scales of 10^{-15} m or TeV

Maybe substructure? Constituents = "preons". New strong gauge (metacolor) interaction of scale Lambda Λ is introduced.

Pati & Salam, PRD 10 (1974), 2500 citations

Concept similar to Fermi's theory of beta decay

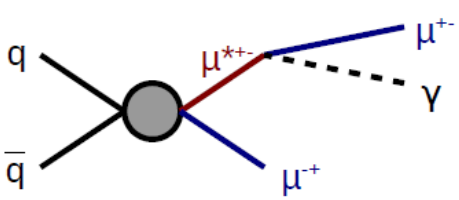


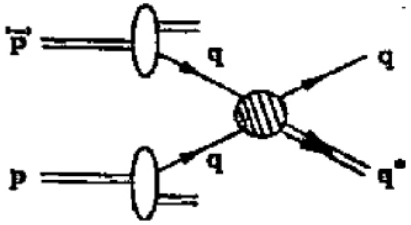
How To Find Compositeness?

Excited leptons and quarks

ℓ, ℓ^*, ℓ^{**} , …. q, q*, q**

- Sort out by mass (or spin), sharing flavor with corresponding SM particle
- Direct evidence for fermion substructure → rich spectrum of excited states
- Known ℓ,q regarded as ground states





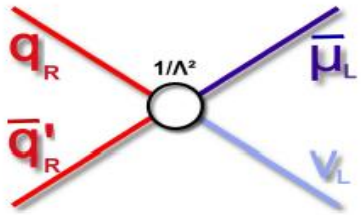
Search channels in CMS

eeγ, μμγ

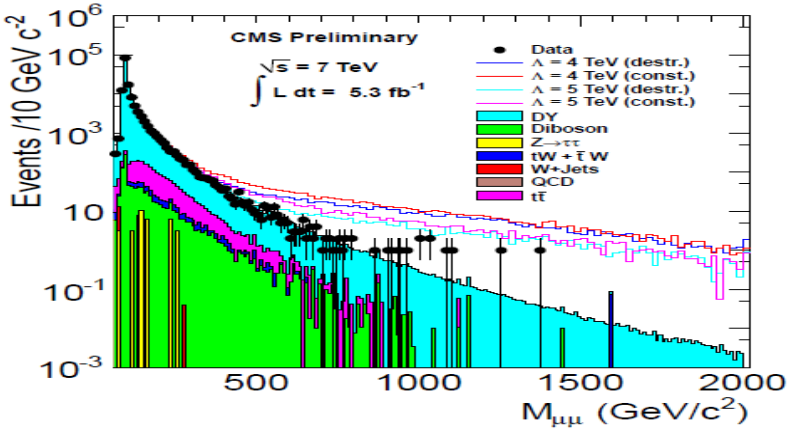
q*→qg (dijet)

q*Z→Z→μμ

4-fermion contact interaction (CI) below compositeness scale Λ



Search channels: μν, μμ, jj



Leads to deviations in well known spectra

Limits being set on masses of excited ℓ,q and the compositeness scale Λ

Search Modes for Compositeness

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

1) Production of excited quarks and leptons

- With leptons = striking signature with good separation from bkgr
- Dijet bumps from generic scan of dijet spectrum

EXO-12-016	q*	bumps in dijet mass spectrum	2012 data
EXO-11-025	q*	in highly boosted Z→μμ	
EXO-11-034	e*, μ*	process e.g. ee*→eeγ , μμ*→ μμγ	

2) Four-fermion contact interaction accessing compositeness scale Λ

- Search for deviations in well known distributions

EXO-11-009	search for excess in Standard Model DY spectrum	
EXO-12-010	excess in μν transverse mass spectrum	2012 data

Bumps in Dijet Spectrum?

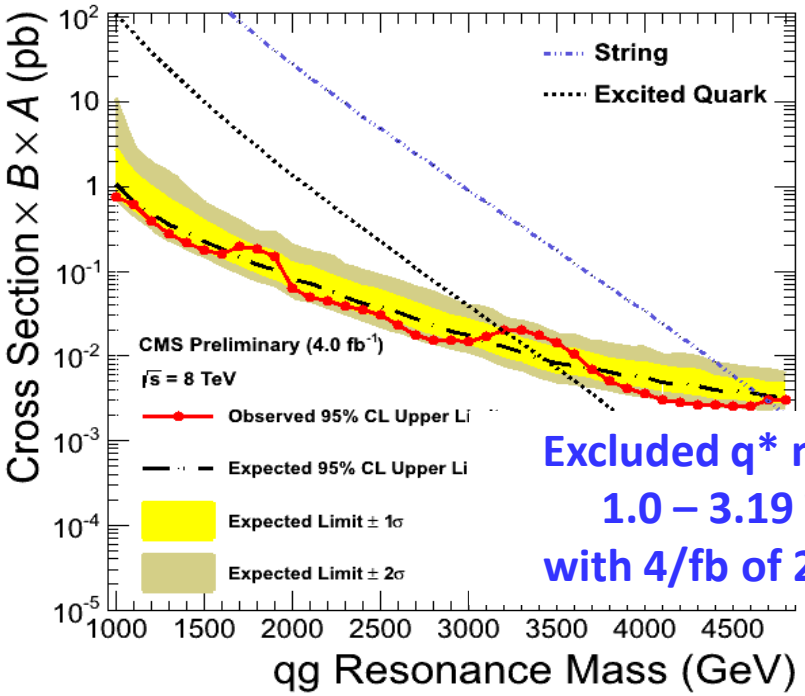
2012 data

CMS-PAS-EXO-11-094, CMS-PAS-EXO-12-016

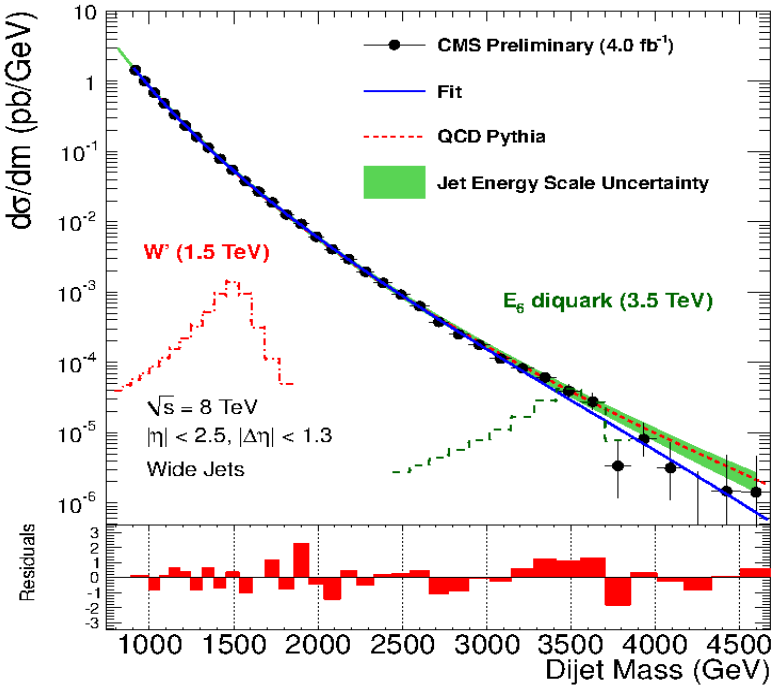
Many theories addressed with dijet analyses:

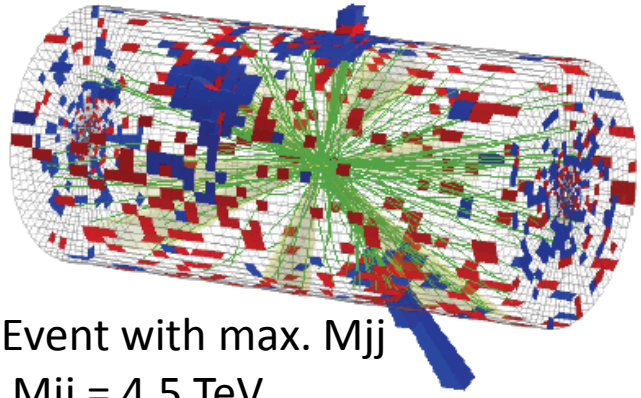
Excited quarks q* from qg fusion would appear as heavy resonance

- Model independent search for **narrow resonances** with res. width < jj mass resol.
- **Bump hunter** systematically looks for "bumps". Varying signal window-



Excluded q* masses
1.0 – 3.19 TeV
with 4/fb of 2012 data



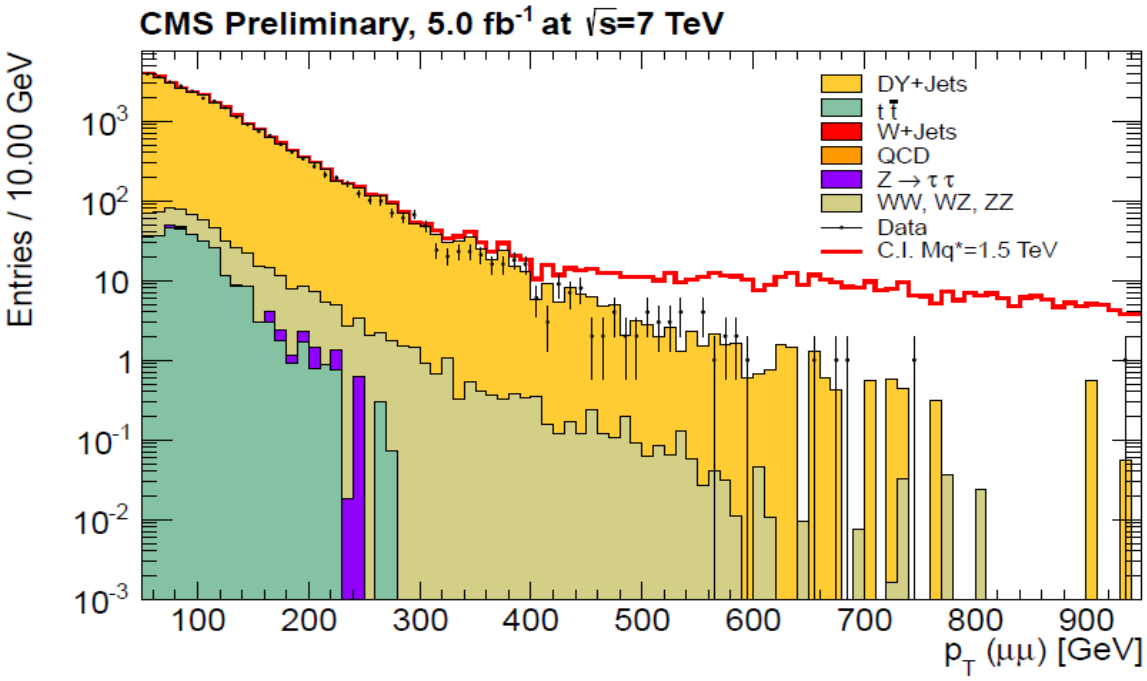


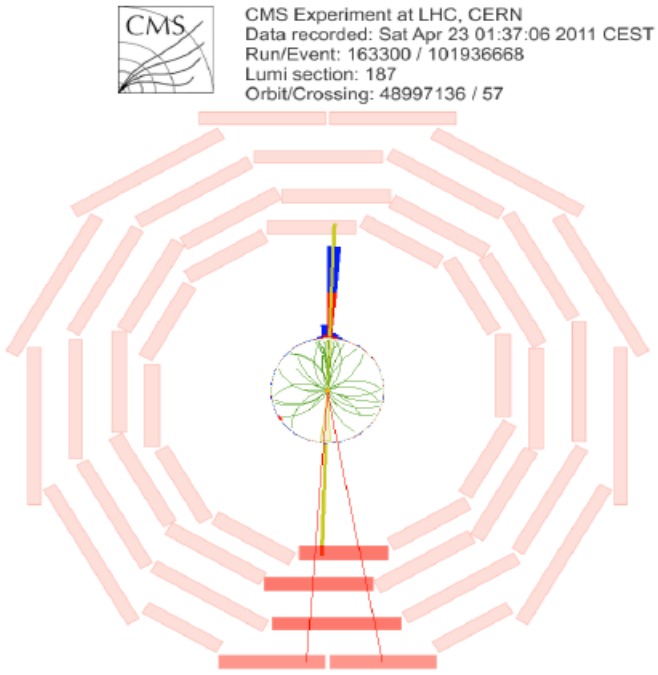
Event with max. Mjj
Mjj = 4.5 TeV

Search for q* in highly boosted Z→μμ

CMS-PAS-EXO-11-025

Search channel: q*→qZ → qμ⁺μ⁻. q* produced via 4-fermion CI or gauge boson exchange. Signal: Two boosted (nearby) muons opposite a jet → flat excess in μμ





Search performed in 1/pT(μμ)

Main background are DY+jets

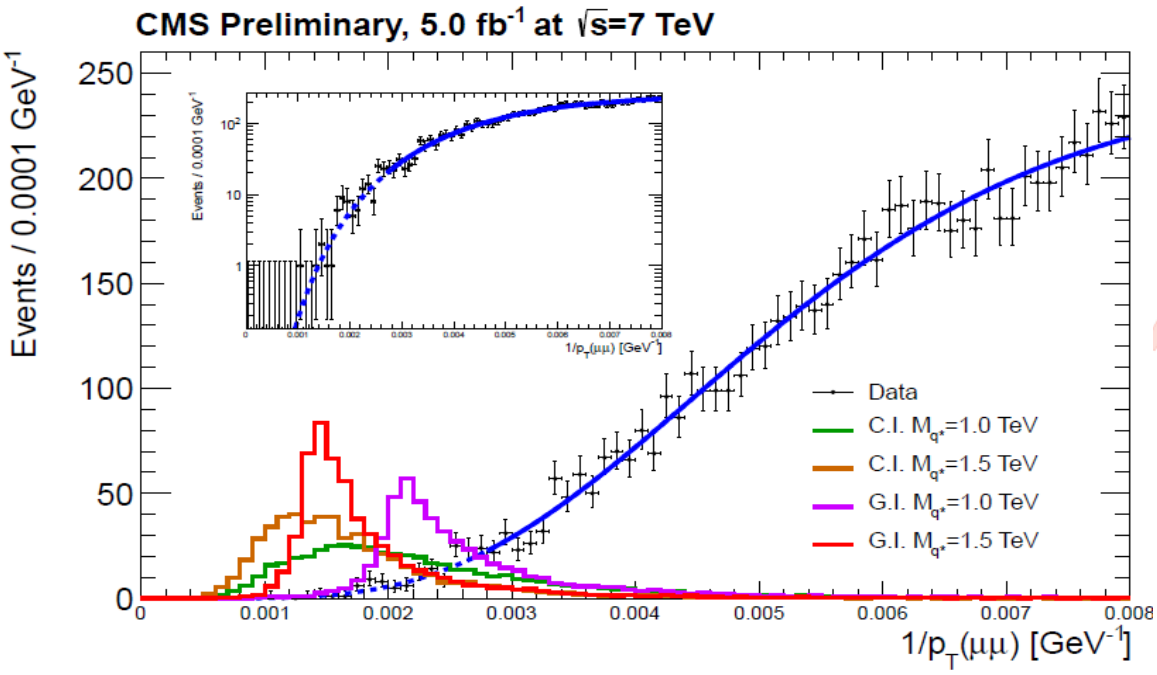
Background determination: Template fit to high statistics, signal-free region of 1/pT, corresponding to pT 125-360 GeV. Extrapolation to high pT

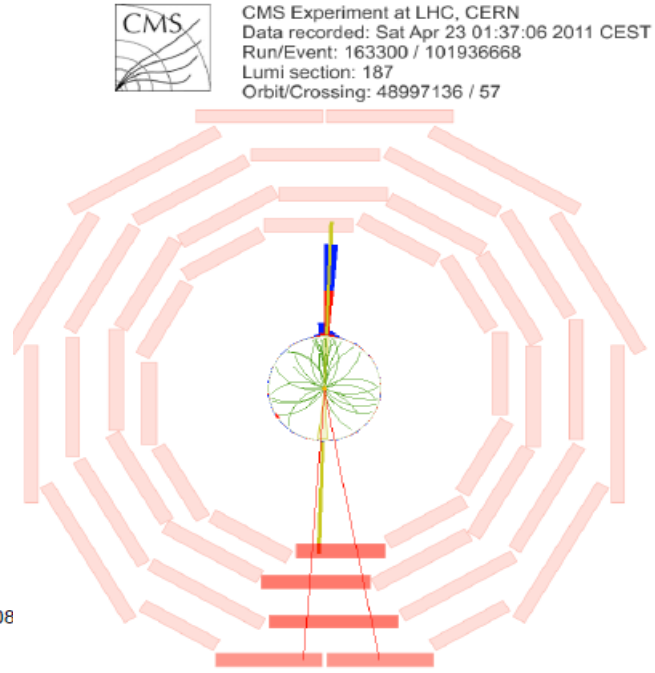
Signal efficiency x acceptance 50-70% (increasing with q* mass)

Search for q* in highly boosted Z→μμ

CMS-PAS-EXO-11-025

Search channel: q*→qZ → qμ⁺μ⁻. q* produced via 4-fermion CI or gauge boson exchange. Signal: Two boosted (nearby) muons opposite a jet → flat excess in μμ





Search performed in 1/pT(μμ)

Main background are DY+jets

Background determination: Template fit to high statistics, signal-free region of 1/pT, corresponding to pT 125-360 GeV. Extrapolation to high pT

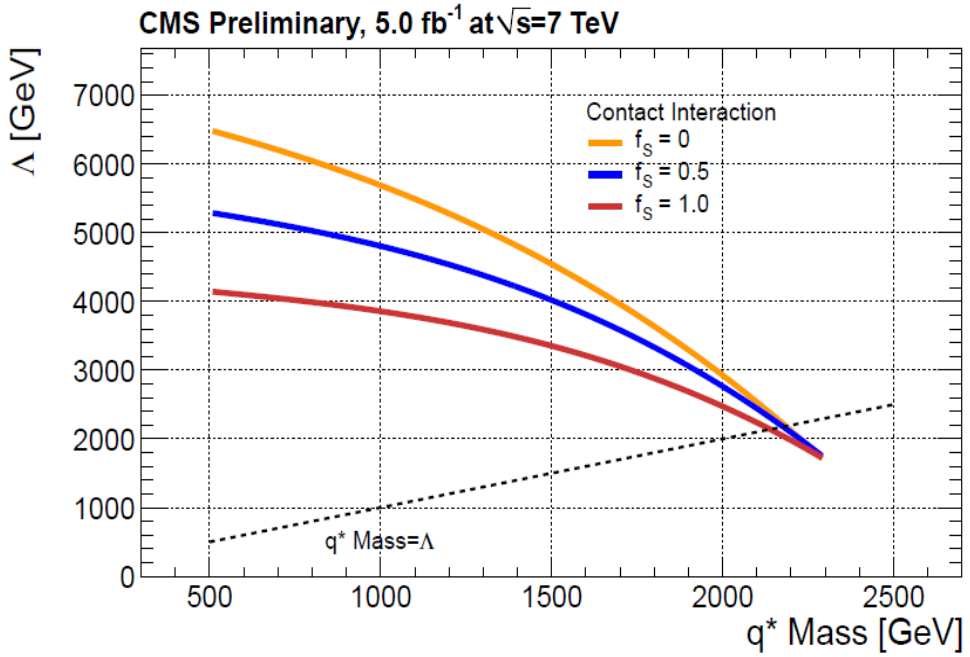
Signal efficiency x acceptance 50-70% (increasing with q* mass)

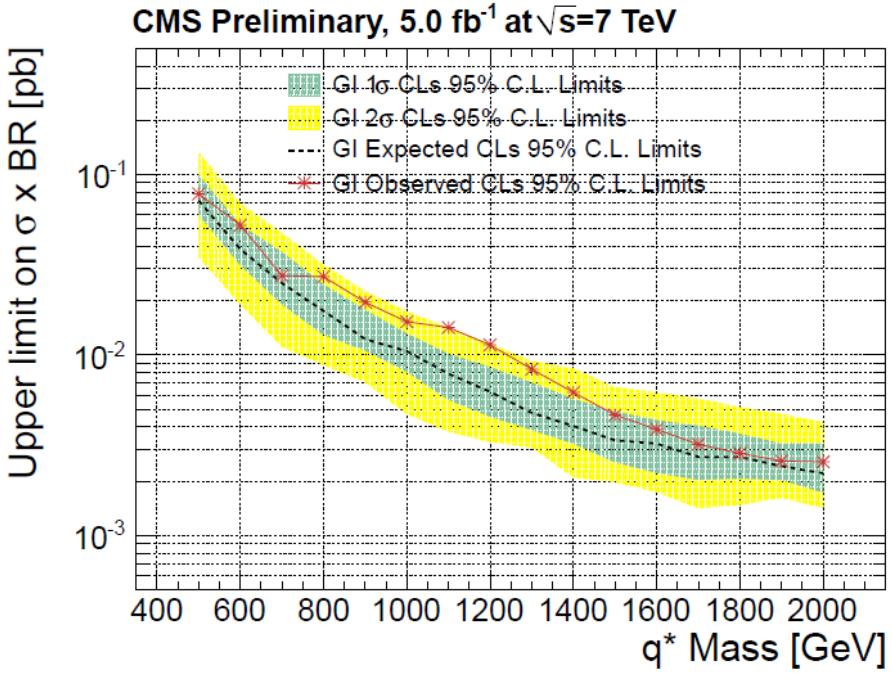
Limits on Excited Quarks

CMS-PAS-EXO-11-025

- Shape analysis, unbinned maximum likelihood fit L_{s+b} and L_b
- Interpretation in terms of **excited quarks q*Z→q μ^+ μ^-** different production mechanism. Assuming $M_{q^*} = \Lambda$ and $f = f' = f_s = 1$

4-fermion contact interaction	via gauge boson exchange
$M_{q^*} < 2.14$ TeV	$M_{q^*} < 1.94$ TeV

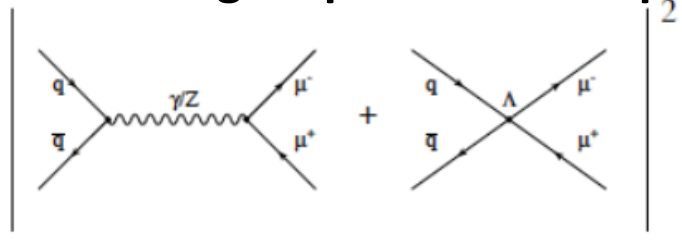




Contact Interactions → μμ

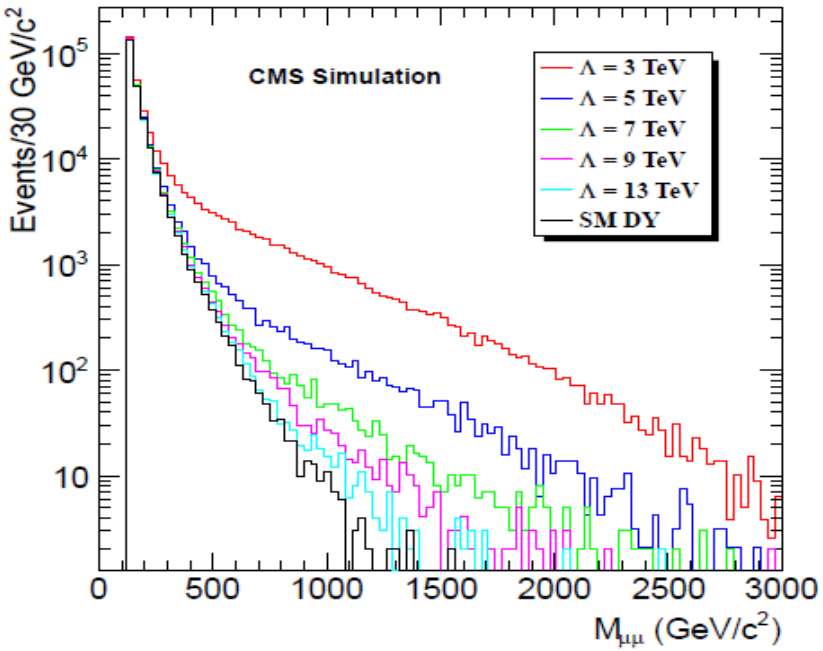
CMS-PAS-EXO-11-009

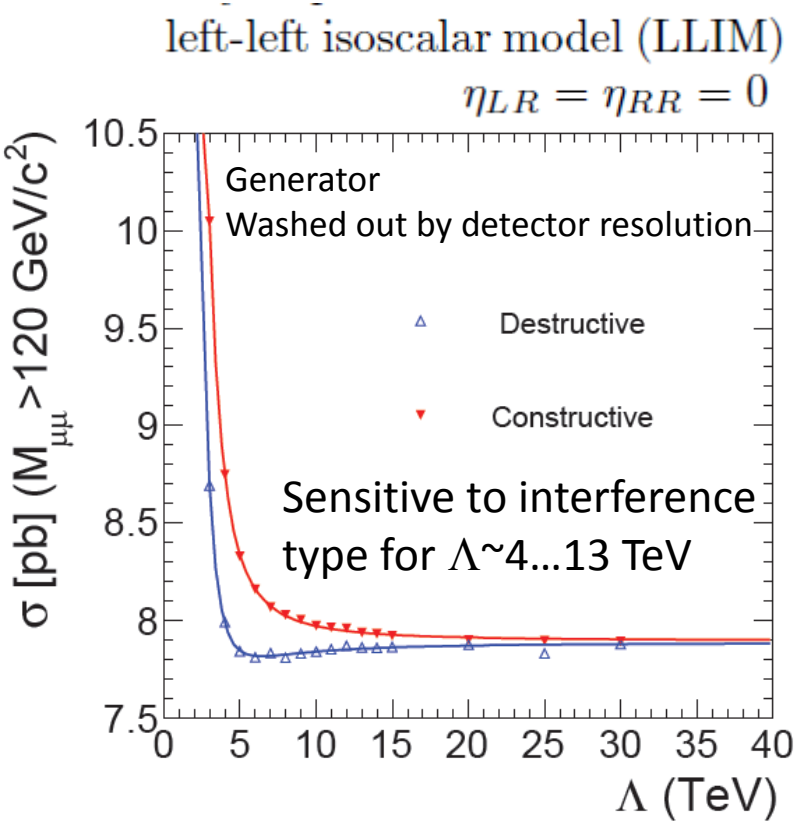
Signal manifested as broad excess in $M_{inv}(\mu\mu)$ SM DY has same dimuon final state → scattering amplitudes add up



$\eta_{LL} = -1$ → Constructive interference

$\eta_{LL} = +1$ → Destructive interference

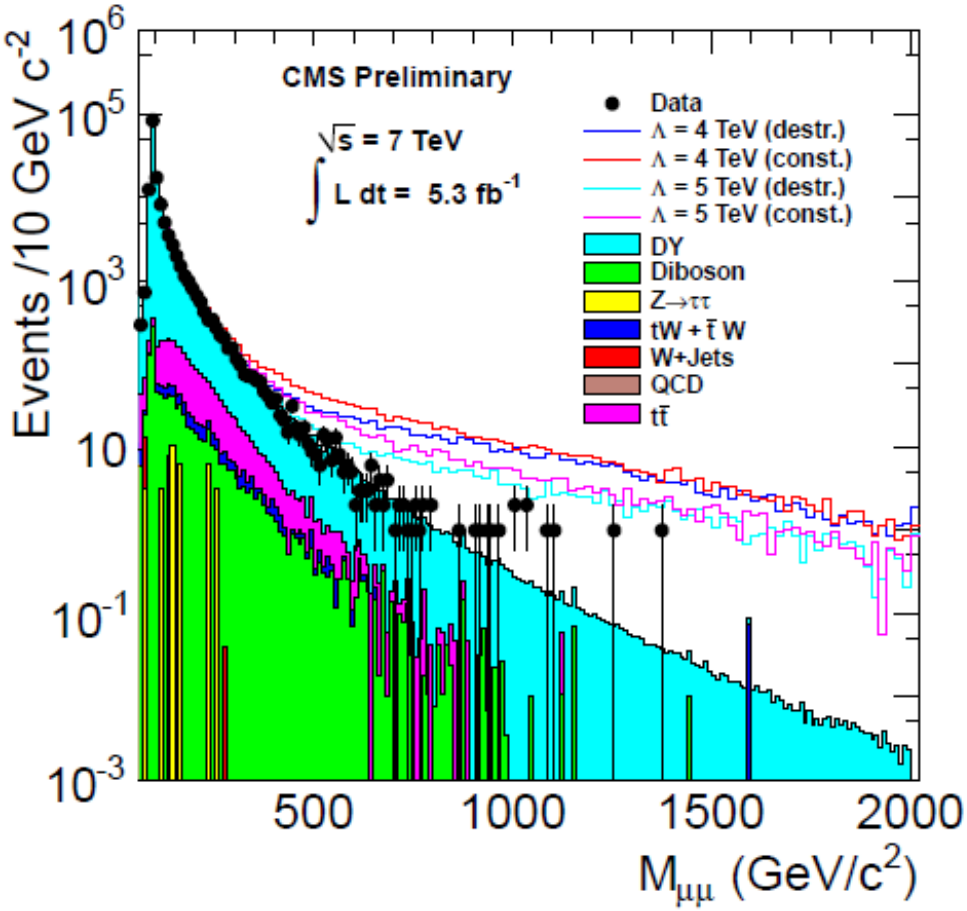




Signal would manifest itself as excess in dimuon spectrum, depending on Λ
Example of constructive interference

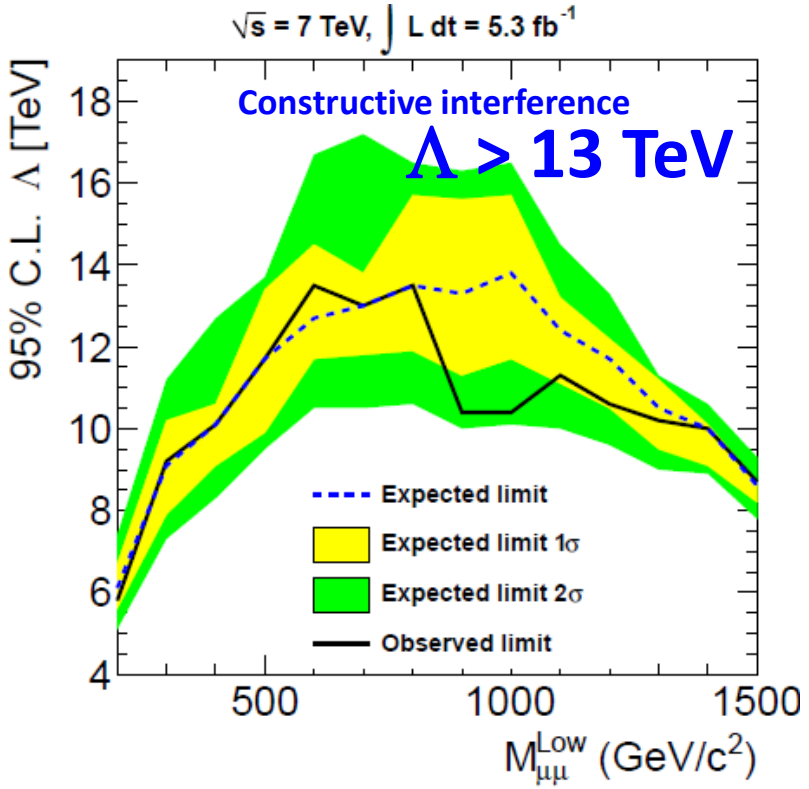
CI →μμ with 5/fb 2011 data

CMS-PAS-EXO-11-009



Single bin counting

95% C.L. Bayesian limit



Background dominated by DY→μμ, also contributions from ttbar and VV. W is rejected by requiring two muons. QCD by requiring muon to be isolated.

Source	COM (TeV)	L (/fb)	Dest. Λ (TeV)	Const. Λ (TeV)
PDG (CDF 1999)	1.8	0.11	2.9	4.2
PRD (ATLAS 2010 data)	7.0	0.042	4.5	4.9
ATLAS 2011 (submitted to PRX)	"	1.2	7.0	8.0
This analysis	"	5.3	9.5	13.0

Single Muon Spectrum

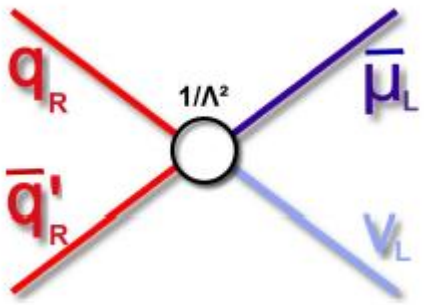
2012 data

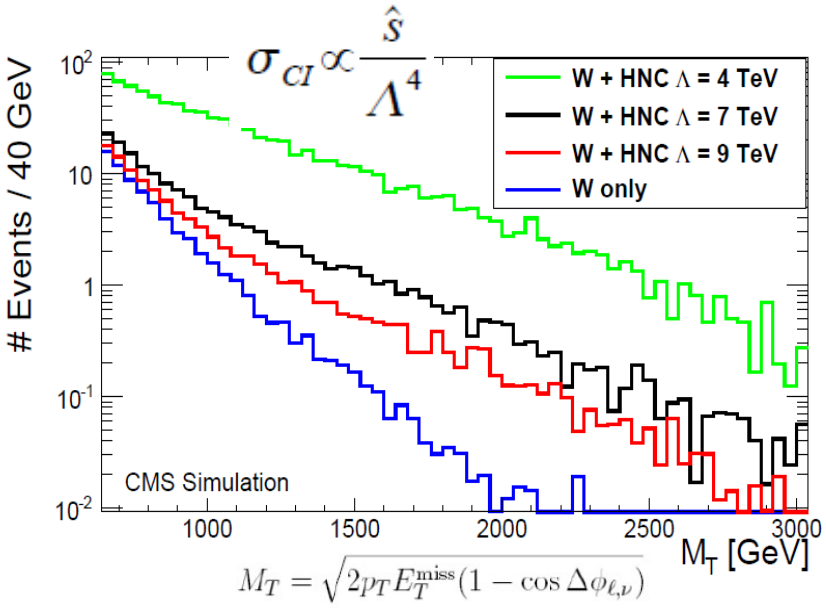
CMS-PAS-EXO-12-010

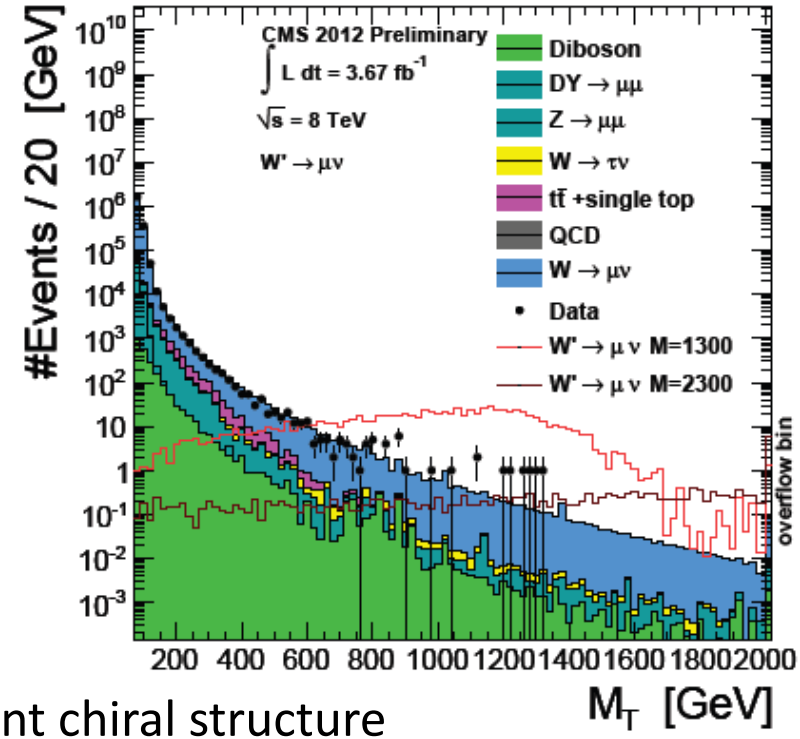
"Helicity Non-Conserving Model" (HNC) ad-hoc model predicting excess in lν transverse mass spectrum → same final state as W'→lν but different structure of excess

- PDG limit for electron channel Λ>2.81 TeV

Phys. Rev. Lett. 87, 231803







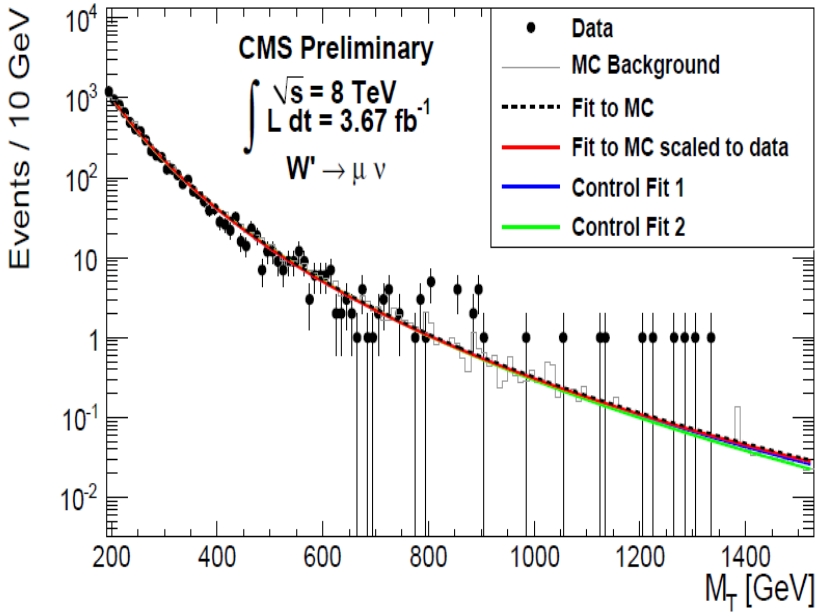
No interference with SM W, due to different chiral structure

CI signals generated in LO (Pythia)

CI→μν Limit

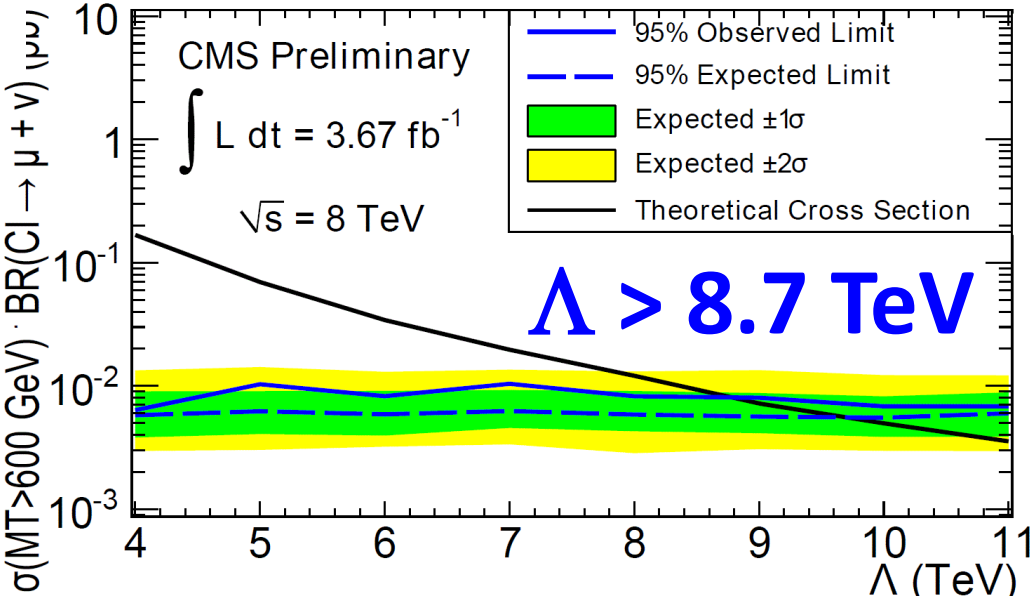
2012 data

CMS-PAS-EXO-12-010



- Main background is SM W. Total background from fit to simulated M_T spectrum
- Search in M_T spectrum. Single bin counting above M_{Tmin} threshold optimized for best expected limit.

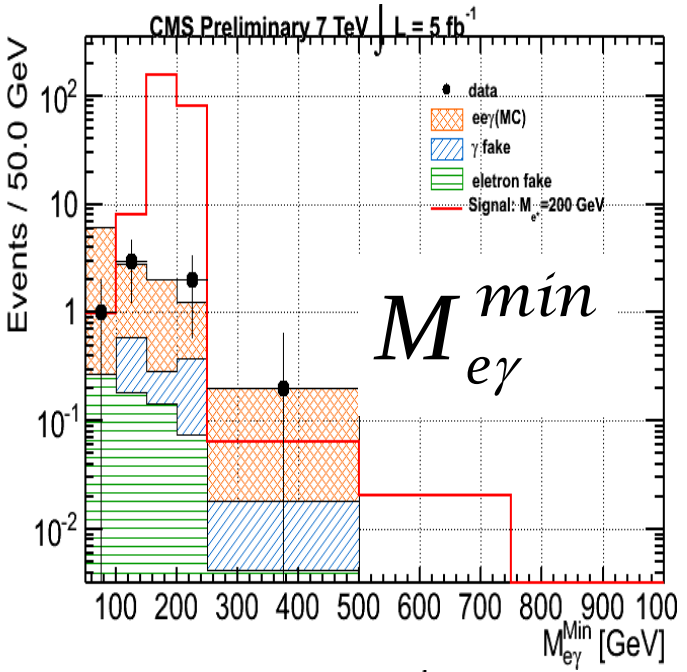
- Signal efficiency times acceptance ~78%
- Bayesian limit at 95% C.L.

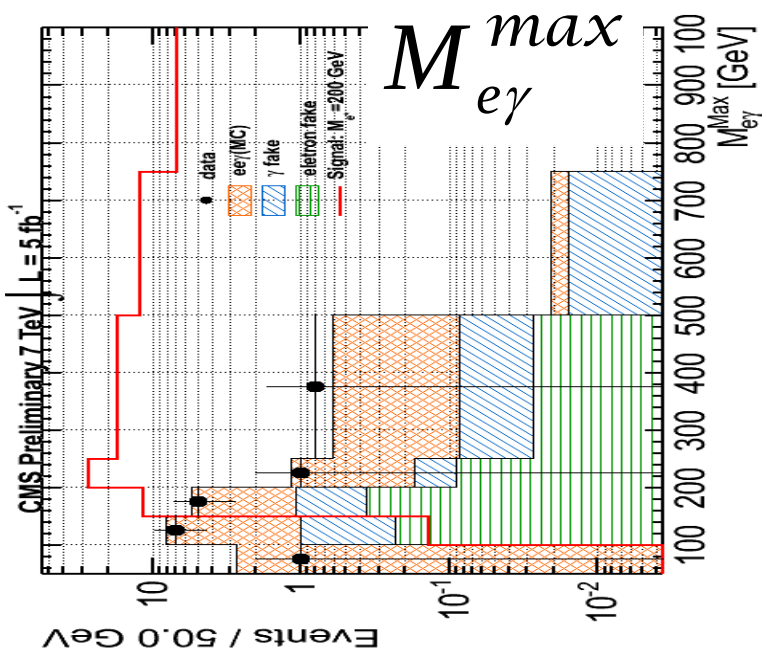


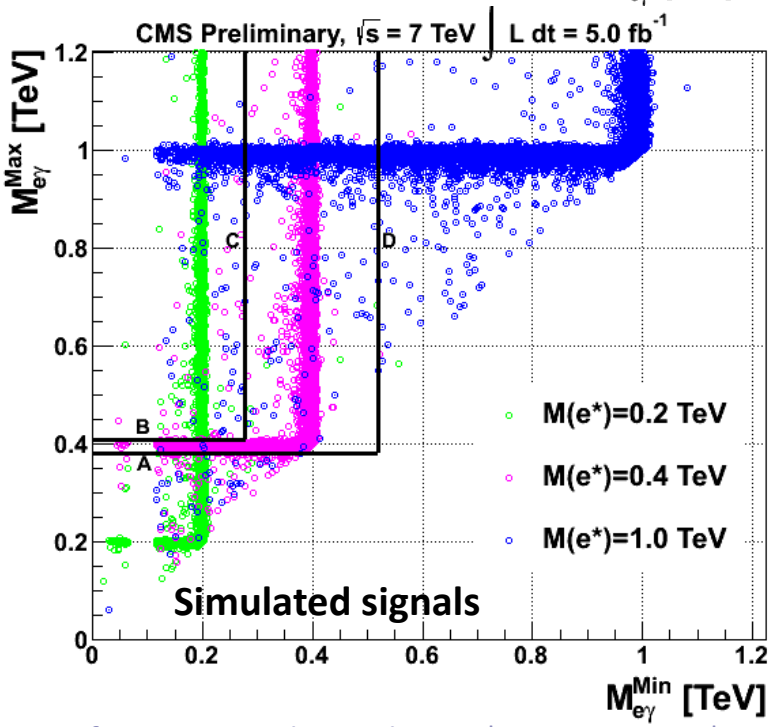
e* and μ*

CMS-PAS-EXO-11-034

- Triggers: single-μ, di-e, di-γ
- Two oppositely charged leptons
- $M_{\ell\ell} > 60$ GeV
- Photon separated from lepton
- Veto Z-peak 91+-25 GeV
- Two highest p_T leptons, pairing with photon → min and max $M_{\ell\gamma}$
- L-shape search region → ABCD







Search for Excited Leptons

CMS-PAS-EXO-11-034

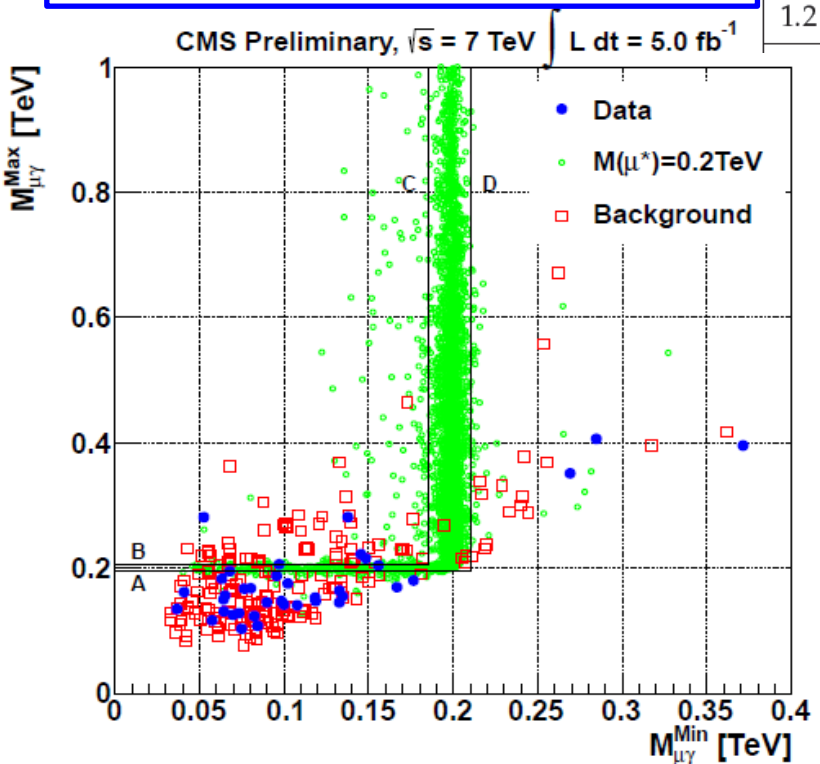
95% C.L. **excluded cross sections** for 0.6 TeV < M(l*) < 2 TeV

e* 1.6 fb – 1.3 fb

μ* 1.3 fb – 1.1 fb

For Λ = M(l*) m_{l^*}<1.9 TeV are excluded

$m(\ell^*)$ (TeV)	$M_{\ell\gamma}^{Min}$ (TeV)	$M_{\ell\gamma}^{Max}$ (TeV)	Muon channel ϵ_{signal} (%)	Muon channel N_{bkgd}	Muon channel N_{data}	Electron channel ϵ_{signal} (%)	Electron channel N_{bkgd}	Electron channel N_{data}
0.2	0.19	0.20	28.2 ± 1.3	$1.16^{+1.67}_{-0.65}$	2	24.8 ± 1.8	$0.97^{+1.17}_{-0.54}$	2
0.4	0.28	0.38	39.1 ± 1.8	$1.61^{+1.95}_{-0.93}$	3	32.7 ± 2.4	$0.09^{+1.36}_{-0.08}$	1
0.6	0.42	0.55	45.4 ± 2.0	$0.02^{+1.41}_{-0.01}$	0	36.6 ± 2.6	$0.00^{+1.36}_{-0.00}$	0
0.8	0.56	0.75	45.3 ± 2.0	$0.00^{+1.41}_{-0.00}$	0	37.8 ± 2.7	$0.00^{+1.36}_{-0.00}$	0
1.0	0.70	0.75	48.5 ± 2.1	$0.00^{+1.41}_{-0.00}$	0	40.4 ± 2.8	$0.00^{+1.36}_{-0.00}$	0
1.2	0.84	0.75	50.0 ± 2.2	$0.00^{+1.41}_{-0.00}$	0	41.1 ± 2.9	$0.00^{+1.36}_{-0.00}$	0



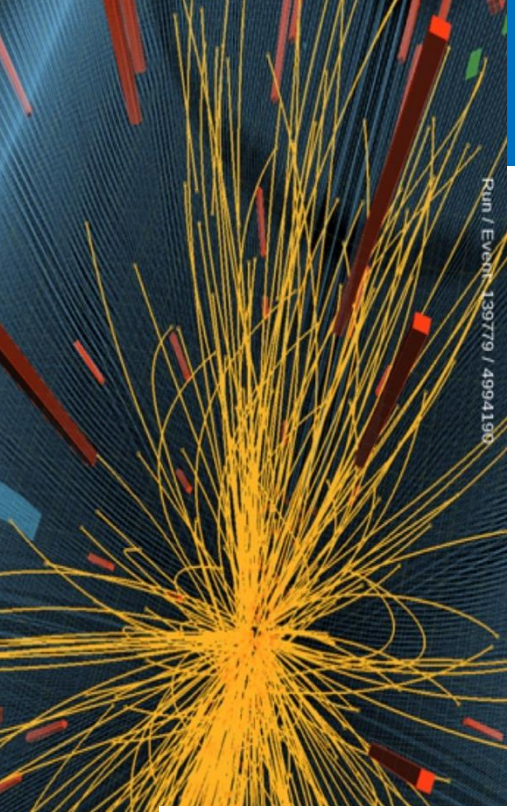
Thresholds increase with l* mass

Signal acceptance x efficiency 30-50%

Main background Zγ and fake photons (<10%)

For high l* masses nearly background free

Both channels no data point for M > 400 GeV



Summary

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

- Many searches for compositeness and contact interaction in CMS ongoing
- First results already with 2012 data at sqrt(s)=8 TeV
- No indications for compositeness yet. Limits on excited fermions up to 3 TeV. Limits on CI up to 13 TeV (depending on model & mode).

95% C.L. Exclusion Limits

	Excluded m / Λ		
Excited fermions			
e* -> eeγ	m < 1.9 TeV	eeγ	5/fb @ 7TeV
μ* -> μμγ	m < 1.9 TeV	μμγ	5/fb @ 7TeV
q* -> qg (dijet)	1TeV - 3.2TeV	dijets	4/fb @ 8TeV
q*Z -> jμμ	m < 1.9 TeV	boosted dimuons	5/fb @ 7TeV
Compositeness scale			
CI -> μμ constr	Λ < 13 TeV	dimuon spectrum	5/fb @ 7TeV
CI -> μμ destr	Λ < 9.5 TeV	dimuon spectrum	5/fb @ 7TeV
Single μ	Λ < 8 TeV	Muon-MET transverse mass	3.7/fb @ 8TeV