Review of Exotic Searches at CMS

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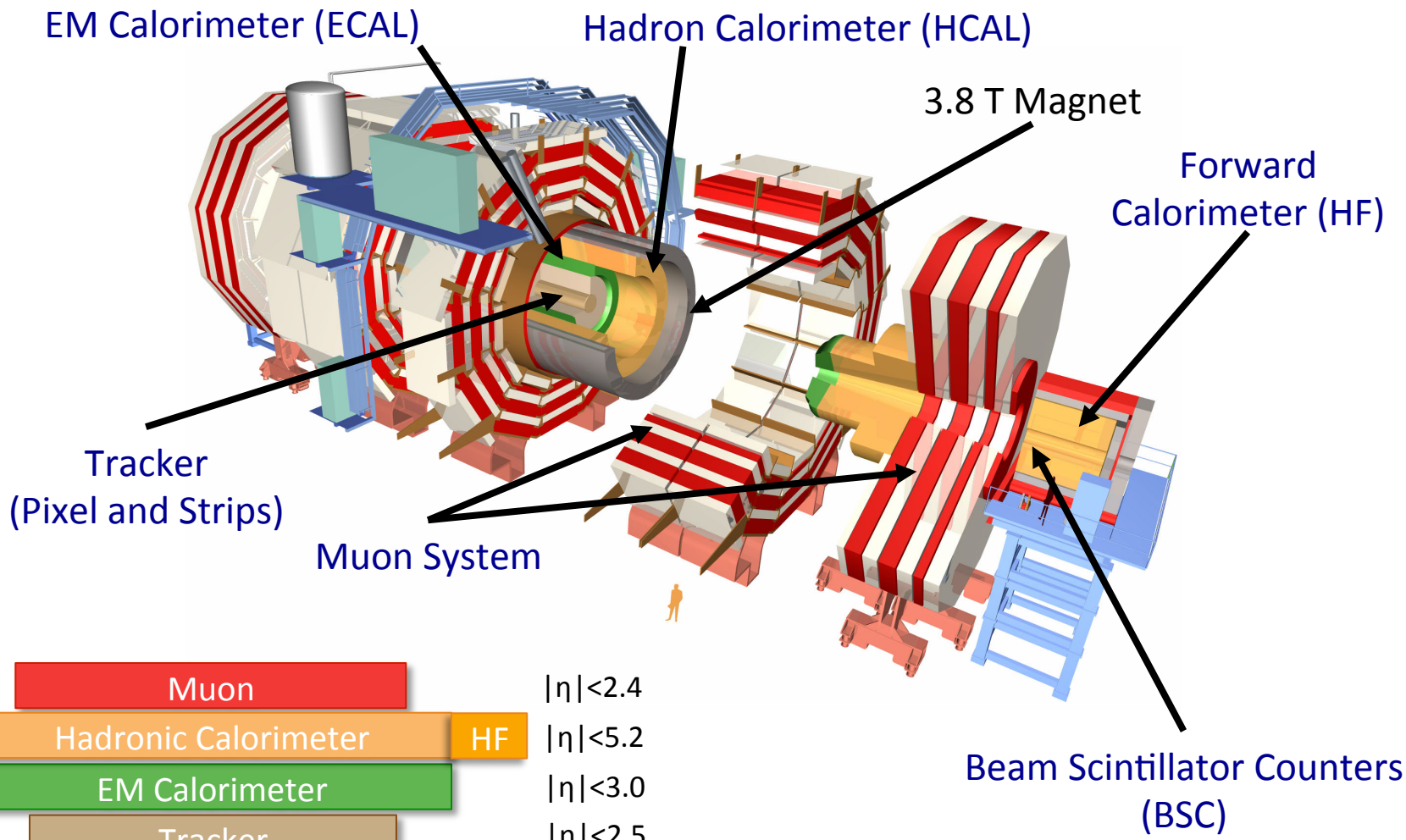
For the CMS Collaboration

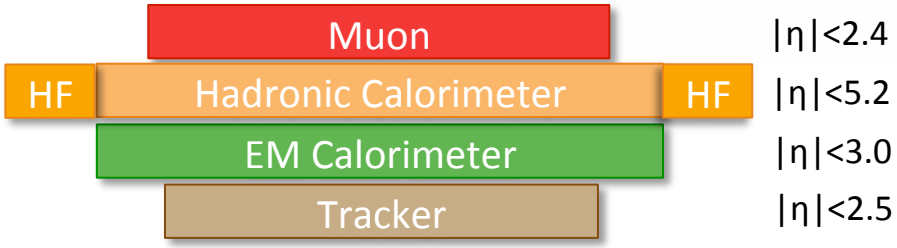
ICTP Workshop “Higgs and BSM Physics at the LHC”
25/Jun/2013

Outline

- Microscopic Black Holes
- Heavy Stable Charged Particles (HSCP)
- 2nd Generation Leptoquarks
- Large Extra Dimensions – Monojet
- Jet extinction
- W'
- Dijet searches
- Dilepton searches
- Ttbar resonances
- Excited tops
- Baryon number violation top decays

The Compact Muon Solenoid

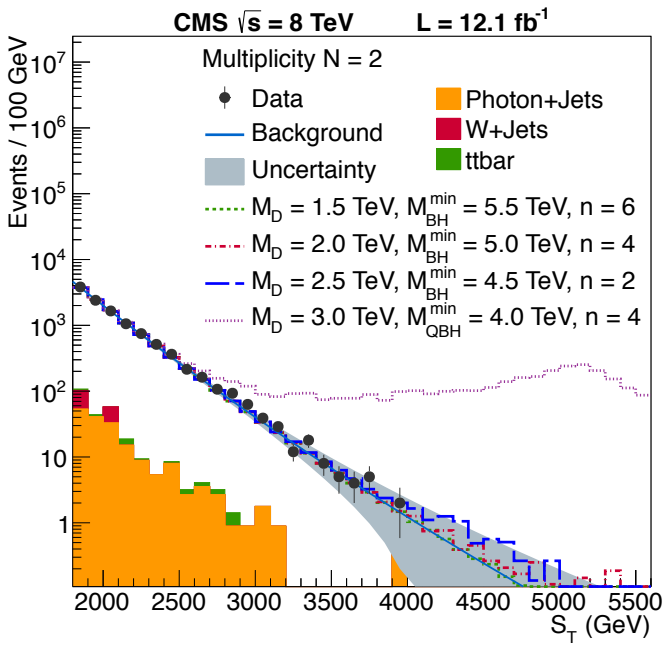


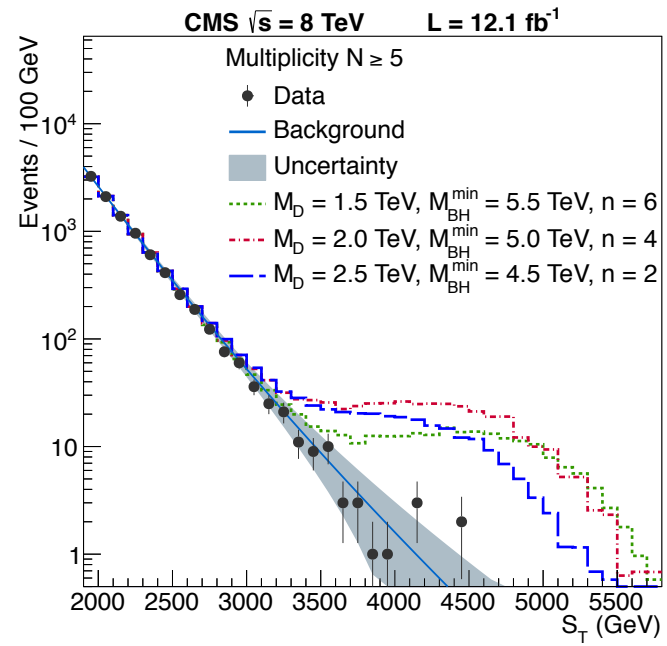


Microscopic Black Holes

CMS-PAS-EXO-12-009
arXiv:1303.5338

- Models:
  - Semiclassical black holes
  - Quantum black holes
  - String balls
- Signature:
  - High total transverse energy ST
  - Presence of multiple energetic jets, leptons, and photons.

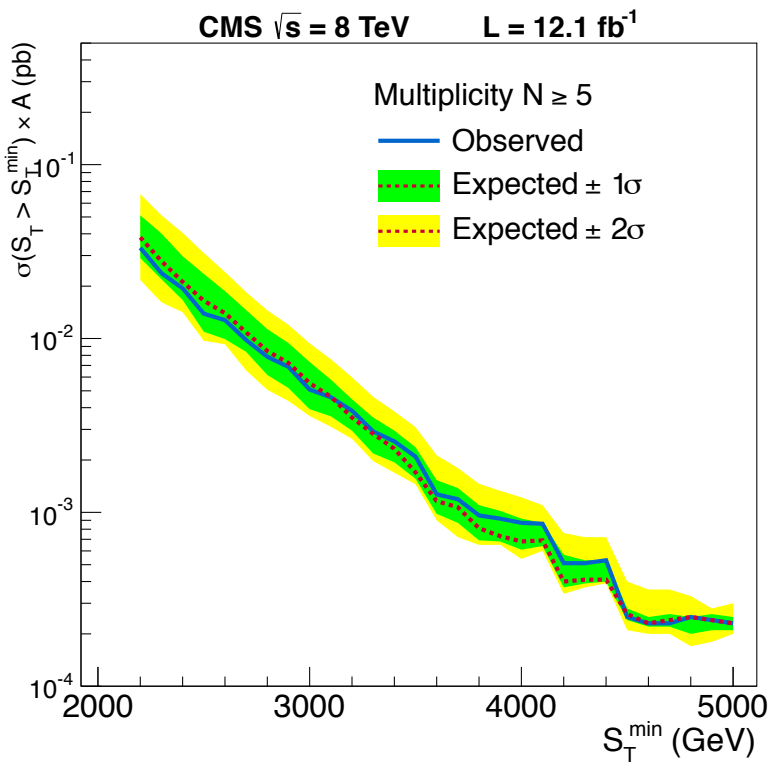


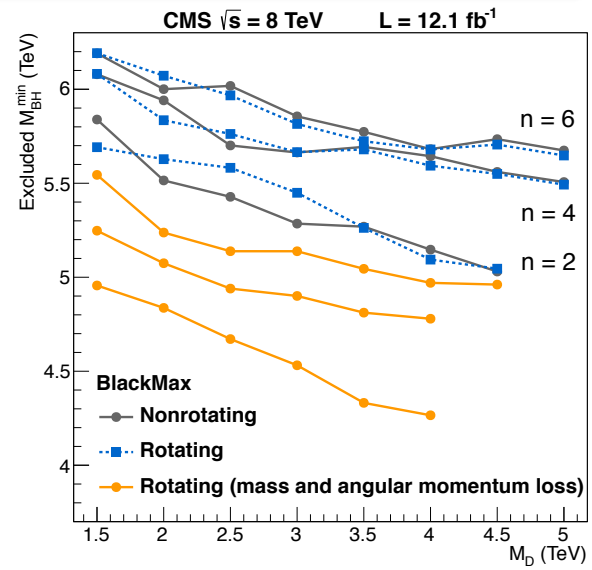


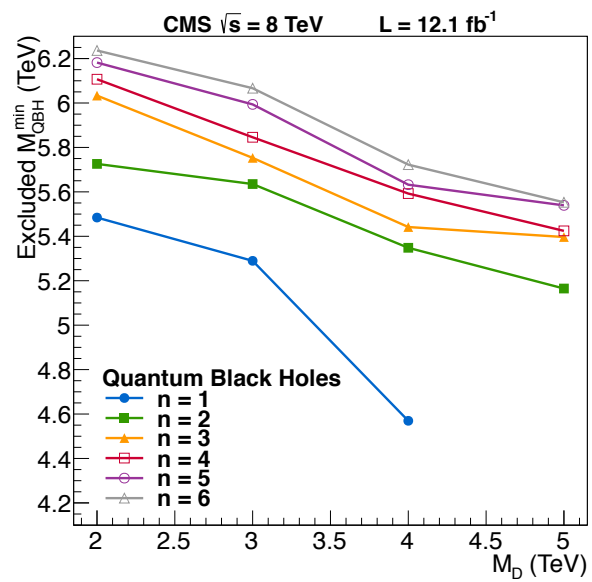
Microscopic Black Holes

CMS-PAS-EXO-12-009
arXiv:1303.5338

- **CMS @ 12/fb**
  - M_{BH} > [4.3 – 6.2] TeV
  - M_{SB} > [5.4 – 5.7] TeV
- Also: model-independent upper limits.

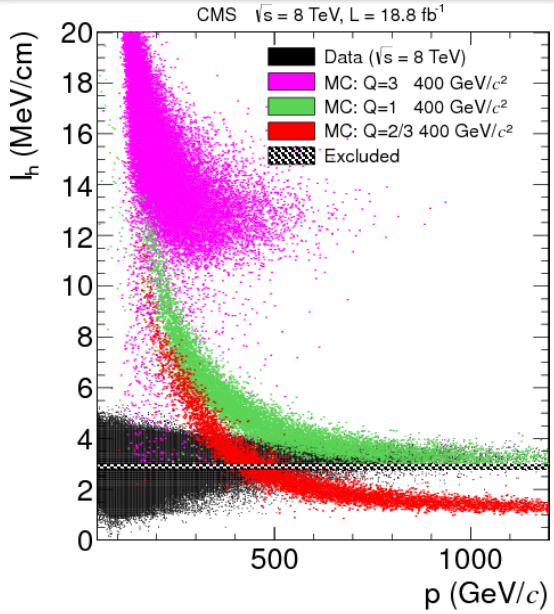


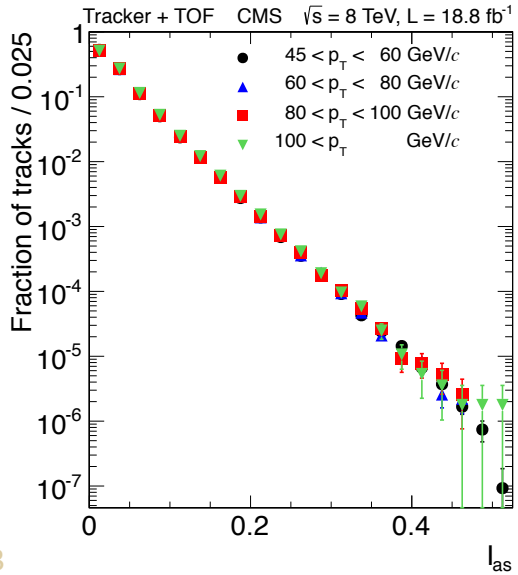




Heavy Stable Charged Particles

CMS-PAS-EXO-12-026
arXiv:1305.0491



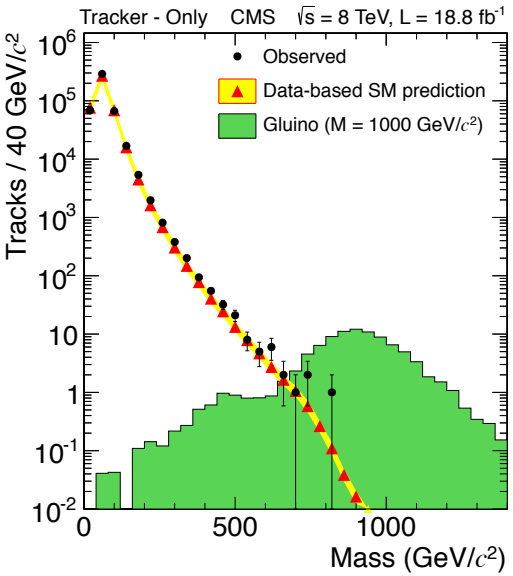


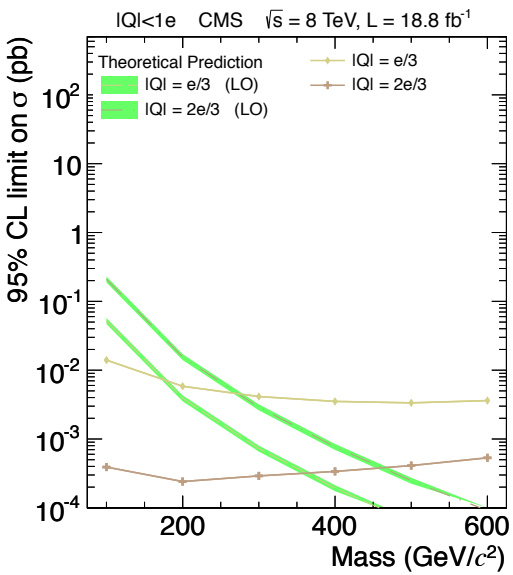
- Leptons with an electric charge between e/3 – 8e
- Bound states that can undergo charge exchange with the detector material.
- Signatures:
  - long time-of-flight to the outer muon system.
  - anomalously high (or low) energy deposition in the inner tracker.

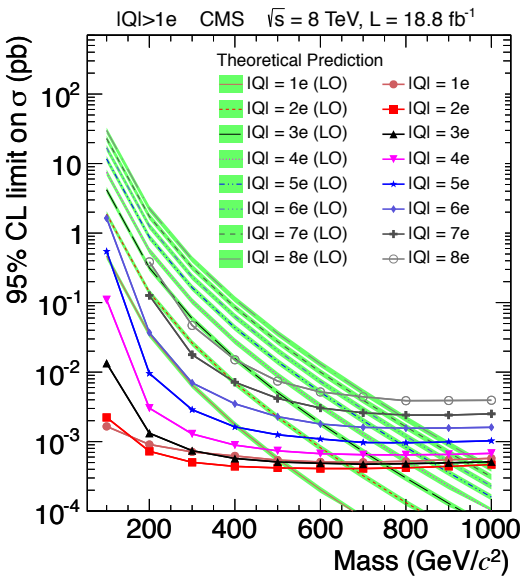
Heavy Stable Charged Particles

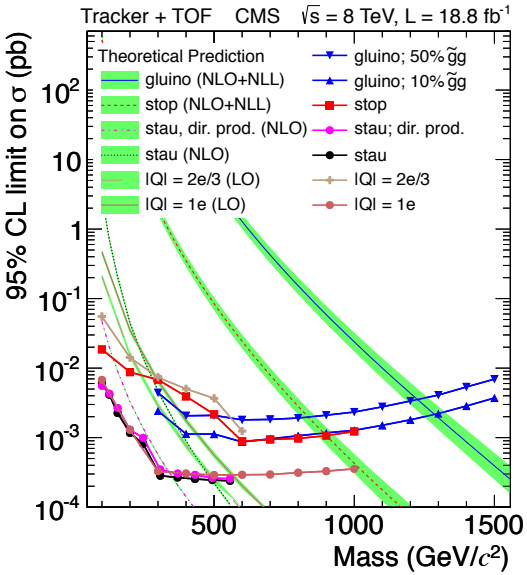
CMS-PAS-EXO-12-026
arXiv:1305.0491

- **CMS @ 20/fb**
  - Gluino, f=0.1, charge-suppressed model: M > 1233 GeV
  - Gluino, f=0.1, cloud-interaction model: M > 1322 GeV
  - Gluino, f=0.5: M > 1276 GeV
  - Gluino, f=1.0: M >1250 GeV
  - Stop, cloud model: M > 935 GeV
  - Stop, charge-suppressed model: M > 818 GeV
  - Stau, direct+indirect production: M > 435 GeV
  - Stau, direct production only: M > 339 GeV





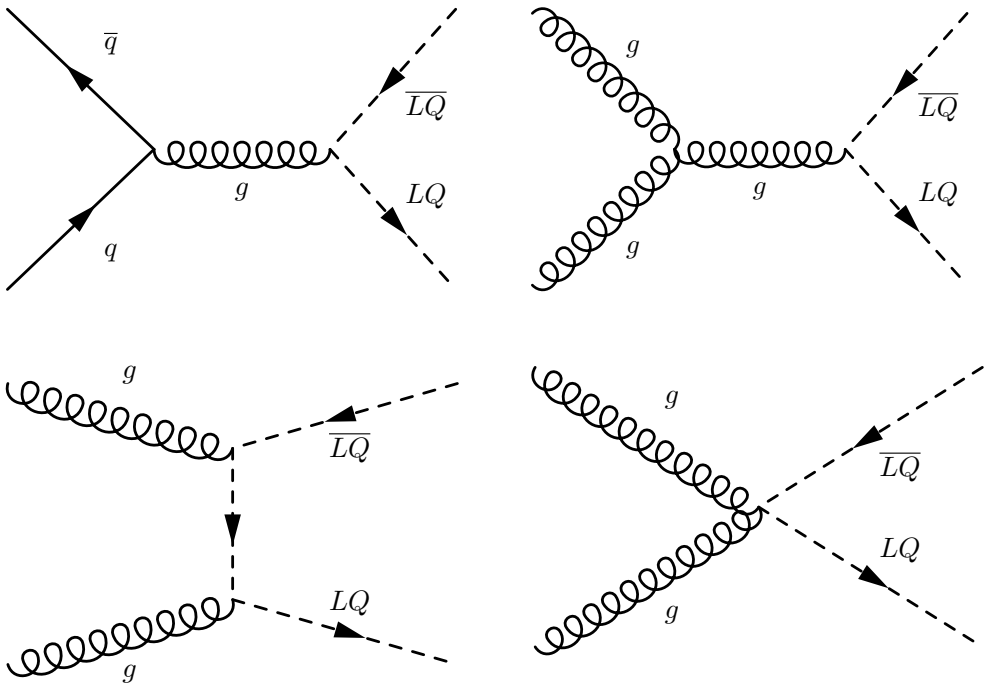




2nd Generation Leptoquarks

CMS-PAS- EXO-12-042

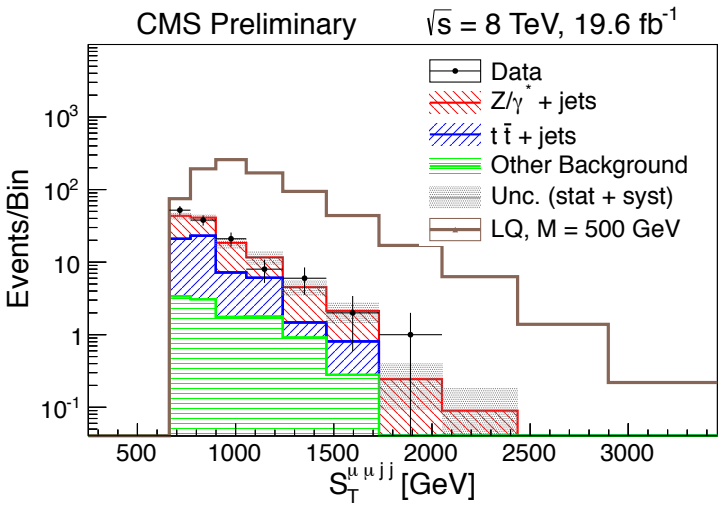
- Color-triplet bosons with fractional electric charge
  - couple to leptons and quarks
  - no inter-generational mixing
- Produced in pairs or with associated lepton.
- Signature:
  - high p_T muons,
  - high E_T jets
  - missing E_T
- Masses at GUT scale, some models predict LQ at TeV scale .

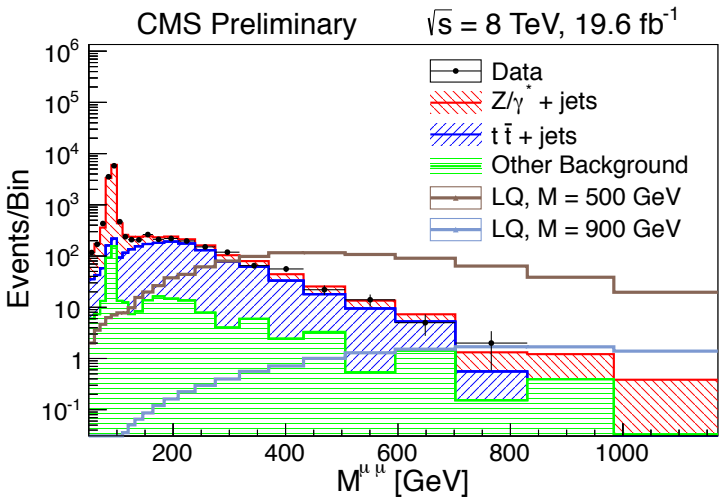


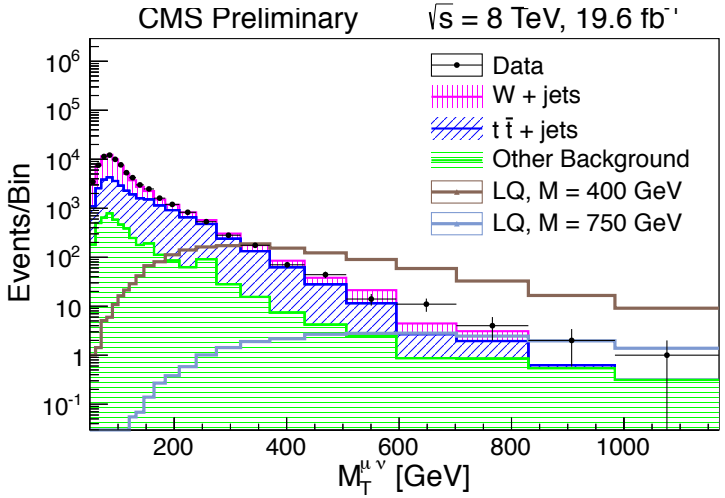
2nd Generation Leptoquarks

CMS-PAS- EXO-12-042

- Two primary channels studied: μμjj and μνjj



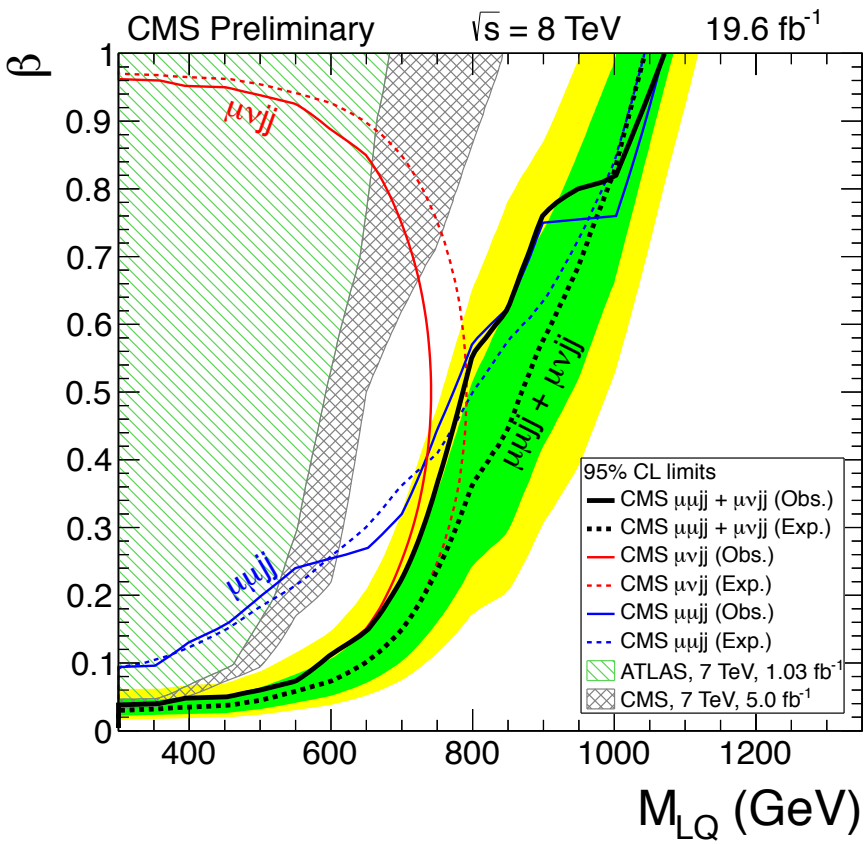


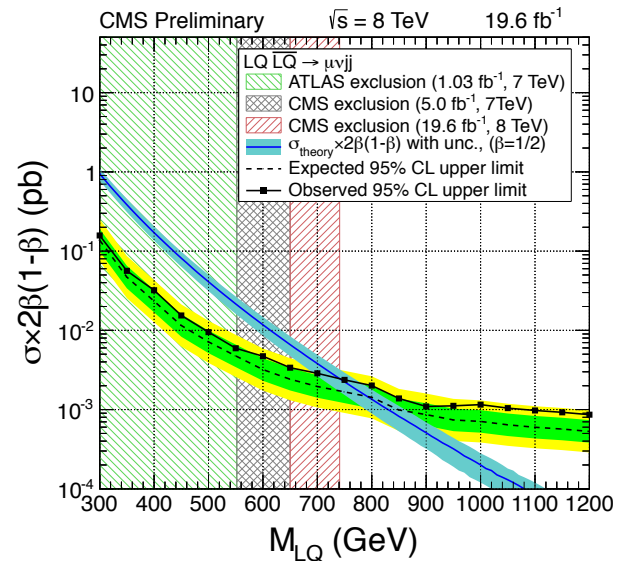


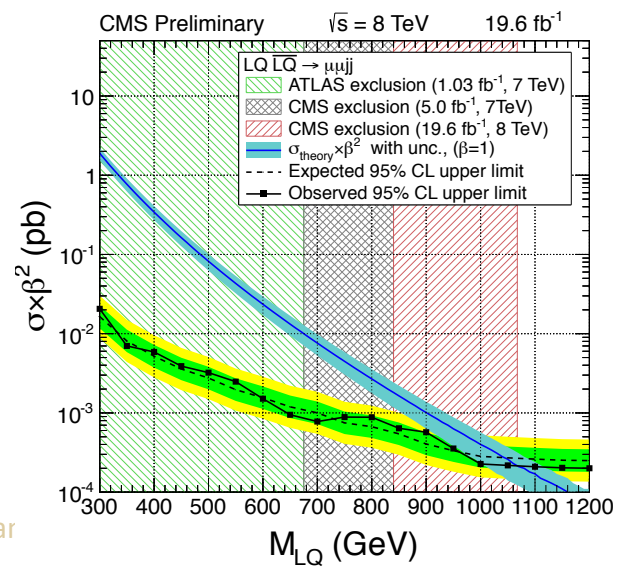
2nd Generation Leptoquarks

CMS-PAS- EXO-12-042

- **CMS @ 20/fb:**
  - Exclude M_{LQ} < 1070 GeV for β =1
  - Exclude M_{LQ} < 785 GeV for β =0.5.



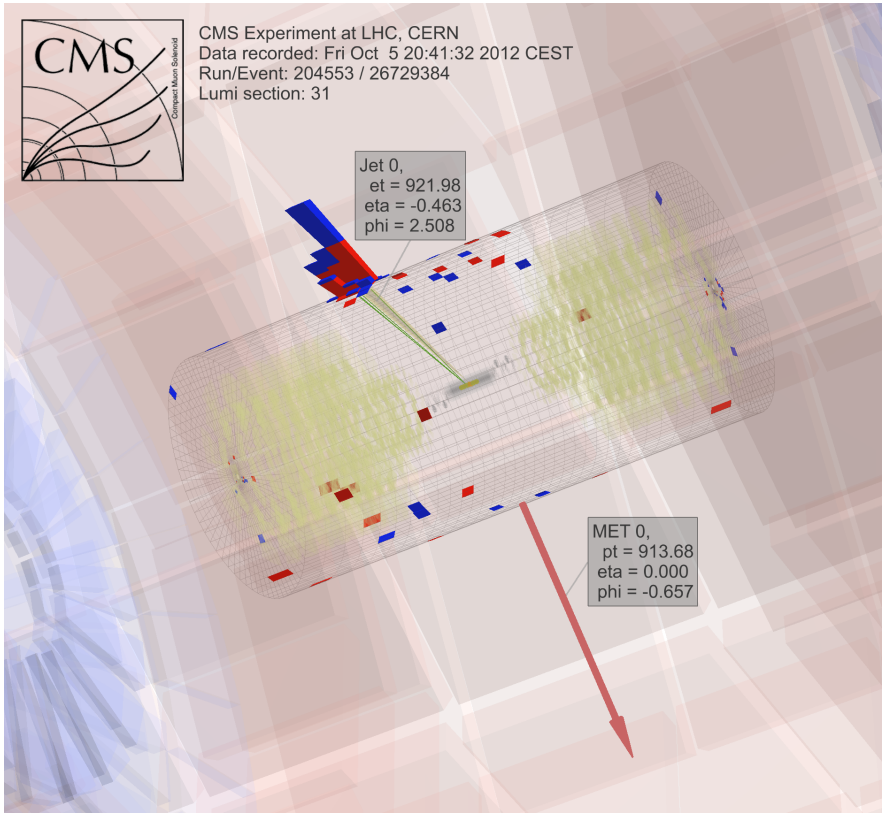


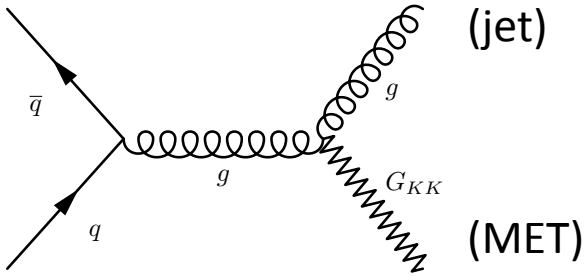


Large Extra Dimensions – Monojets

CMS-PAS-EXO-12-048

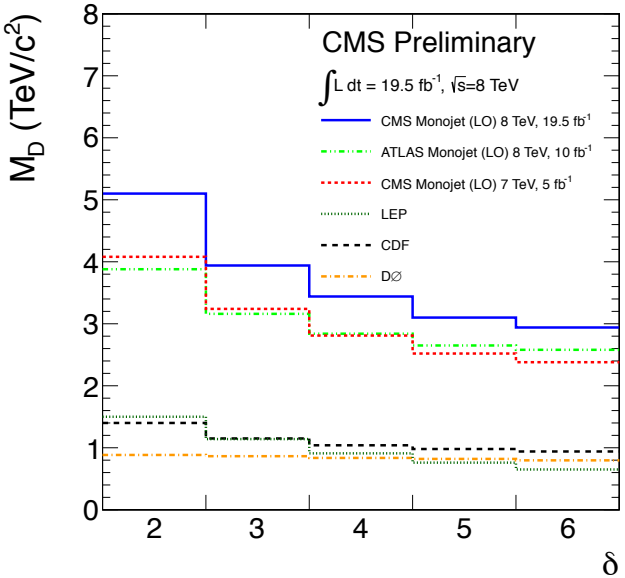
- ADD Model (Arkani-Hamed, Dimopoulos, and Dvali)
  - n extra dimensions of size *R*
  - For gravity only
    - weakens gravitational coupling to SM particles
  - Reduced Planck scale in 4+n dimensions assumed at O(TeV)
- Signatures:
  - Direct KK graviton emission plus g/γ
    - MET and single jet or photon
  - Virtual KK graviton exchange, (continuous spectrum)
    - Dilepton, diphoton final states, broad excess over SM (see dileptons section)

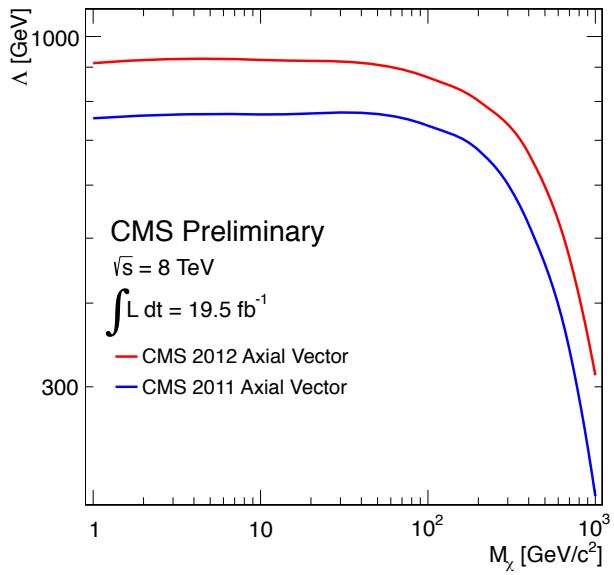


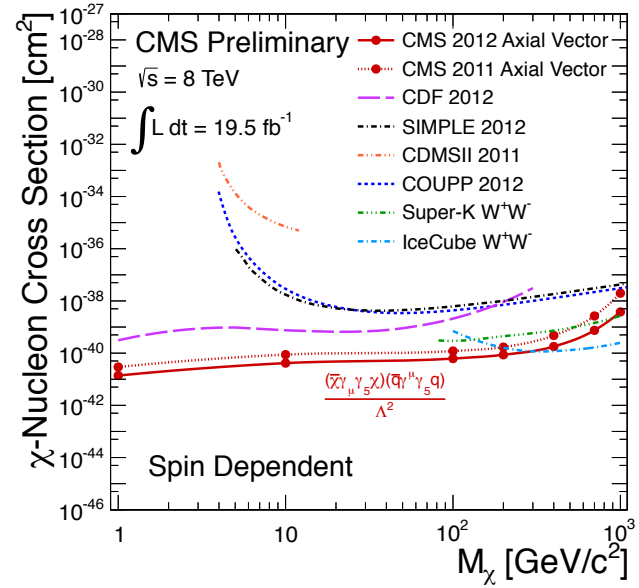


Large Extra Dimensions – Monojets

CMS-PAS-EXO-12-048





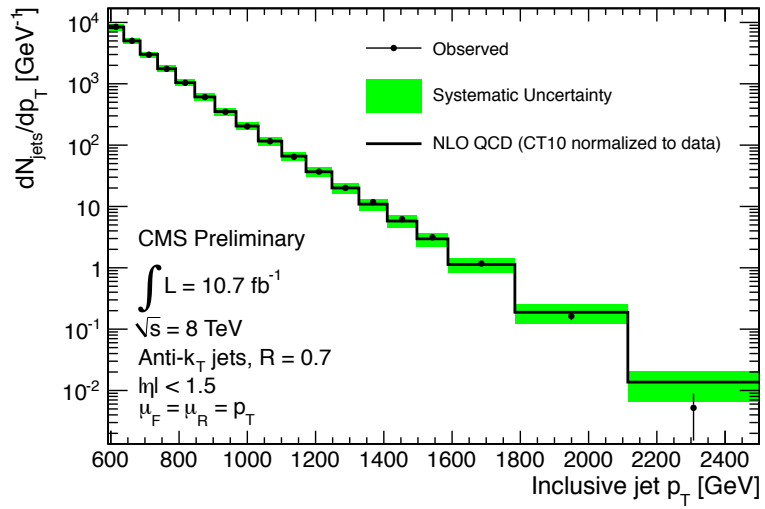


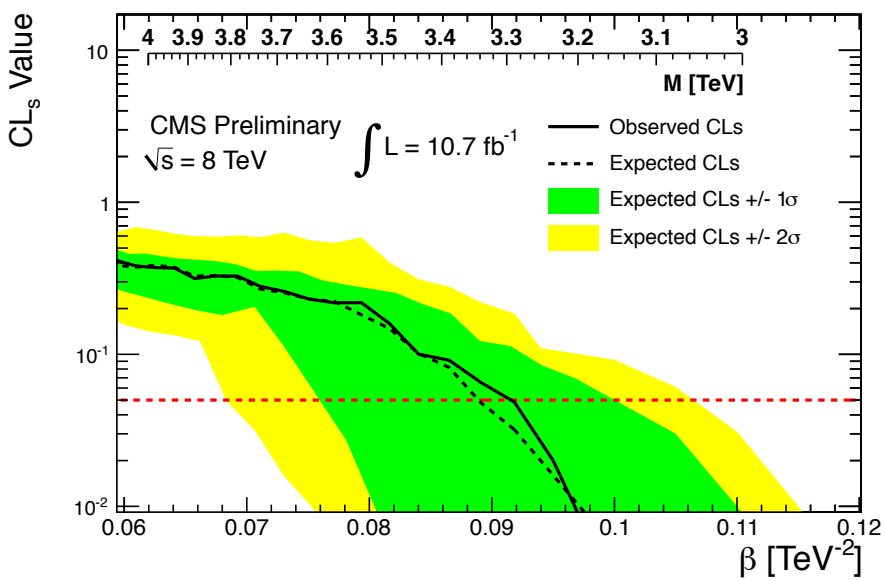
- Interpret results in several models:
  - ADD extra dimensions
  - Constraints on dark matter nucleon scattering cross sections
  - Unparticles

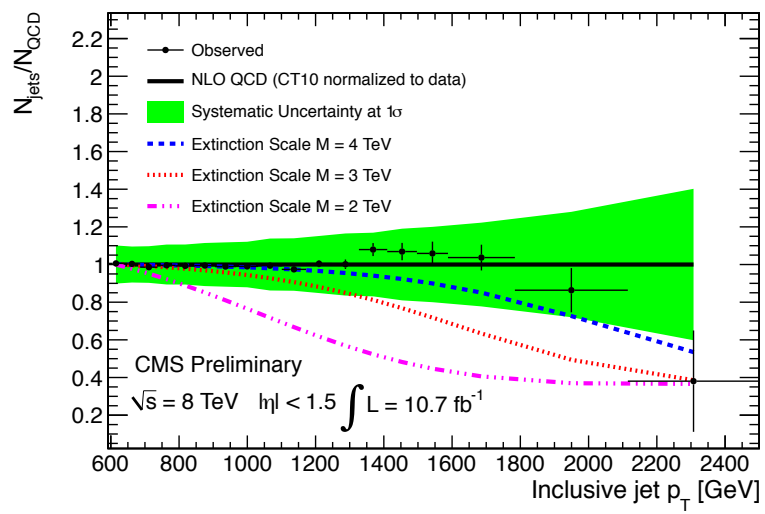
Jet Extinction

CMS-PAS-EXO-12-051

- Motivated by search for signatures of TeV scale gravity.
- Assumes the existence of string couplings at the strong coupling limit.
  - Suppression of all high p_T SM processes (including jet production) beyond a certain energy scale
- Perform shape comparison between measured jet p_T spectrum and theoretical prediction.
  - CLs scan in the extinction scale, $\beta = M^{-2}$
    - **M: extinction scale**
- **CMS @ 11/fb: M > 3.3 TeV**





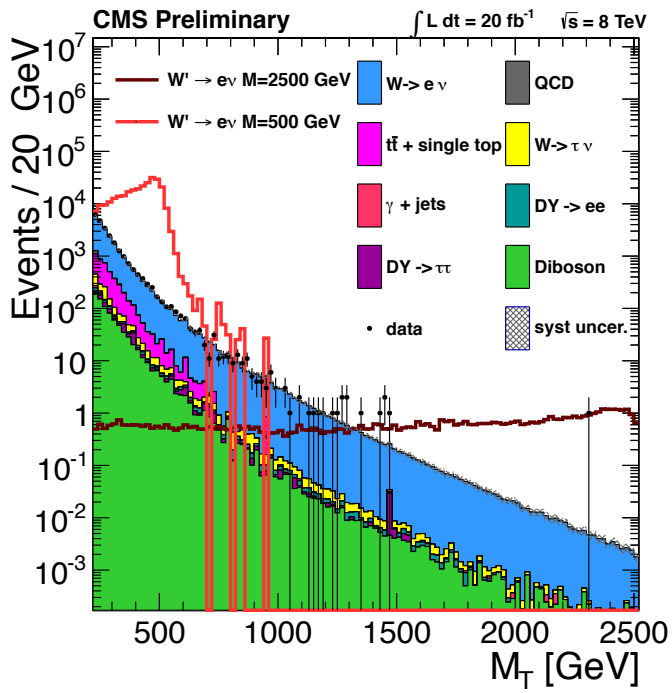


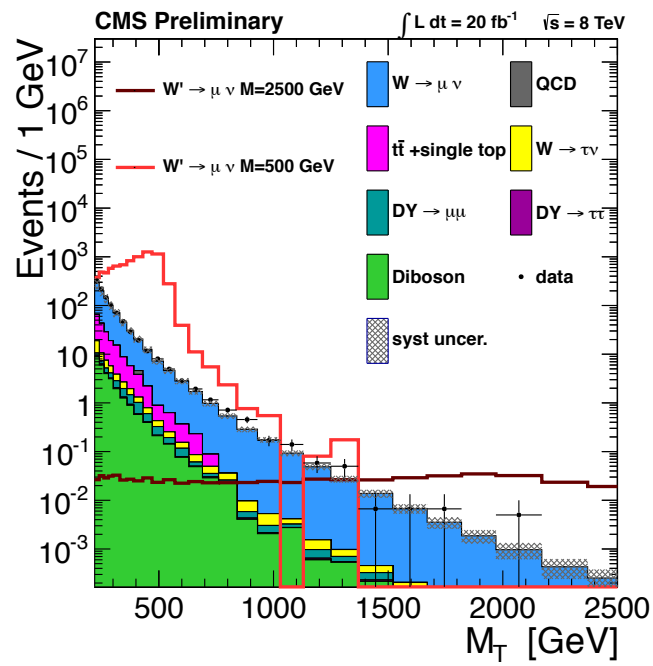
W' in Leptonic Decay

CMS-PAS-EXO-12-060

- Baseline: Sequential Standard Model
  - "Reference model" (G. Altarelli et al.)
- W' boson is a copy of the SM W
- Neutrino is light & stable
- WZ channel is suppressed

- Consider W-W' interference
- Signature:
  - High p_T lepton (μ,ν) + MET
- Provide model independent results
  - Also results for SSM, Split UED and Contact Interactions

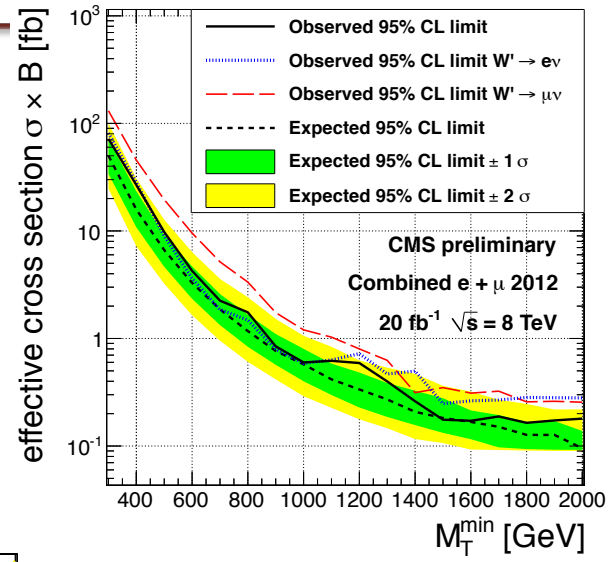


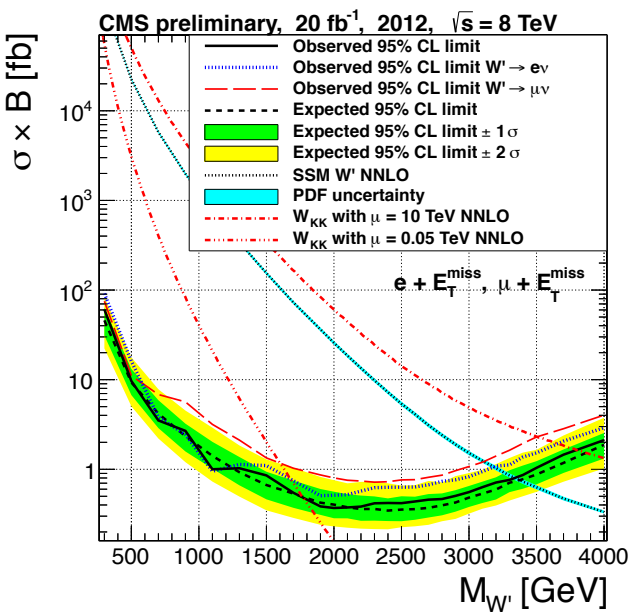


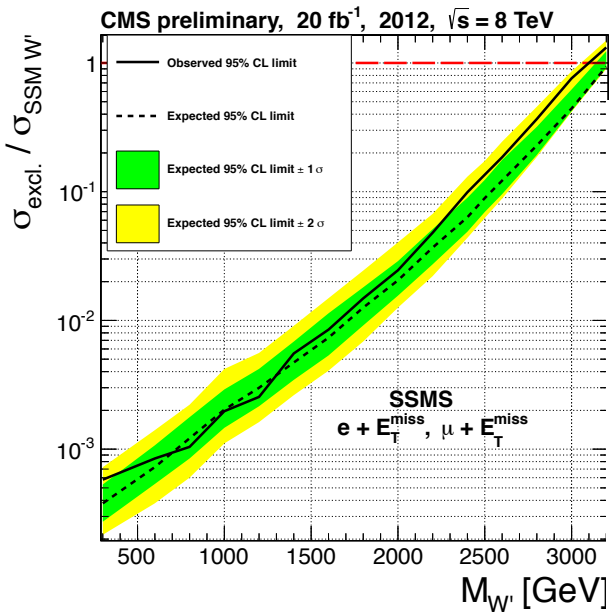
W' in Leptonic Decay

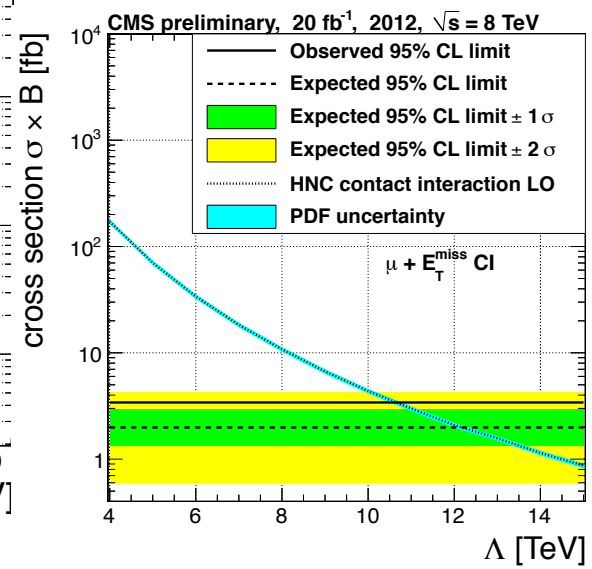
CMS-PAS-EXO-12-060

- **CMS @ 20/fb exclusion limits:**
  - SSM W':
    - 3.35 TeV;
    - 3.6 TeV [constr],
    - 3.1 TeV [destr]
  - W_{KK}:
    - 1.7 TeV [μ=0.05],
    - 3.7 TeV [μ=10.0]
  - HNC (C.I.)
    - 13.0 TeV (electrons)
    - 10.9 TeV (muons)





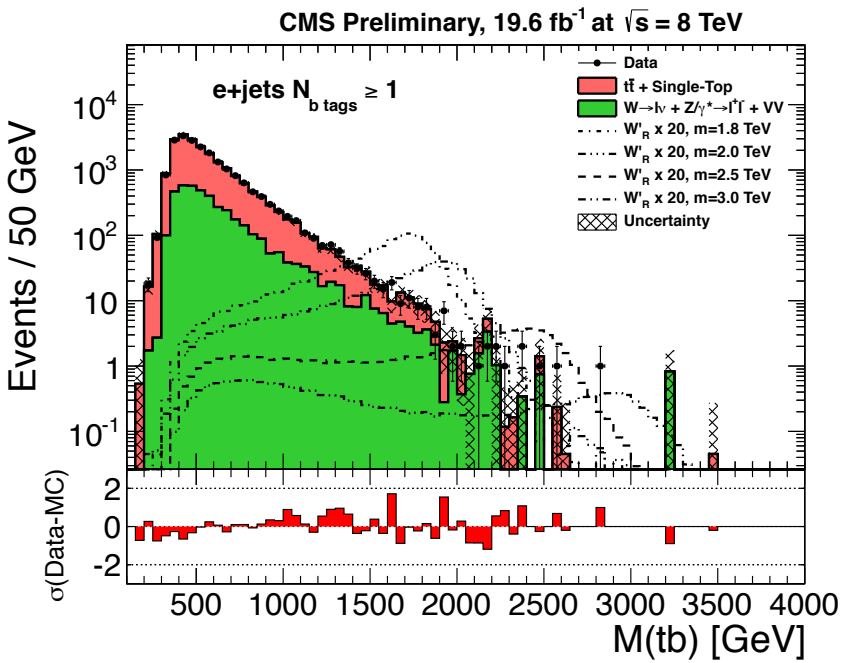


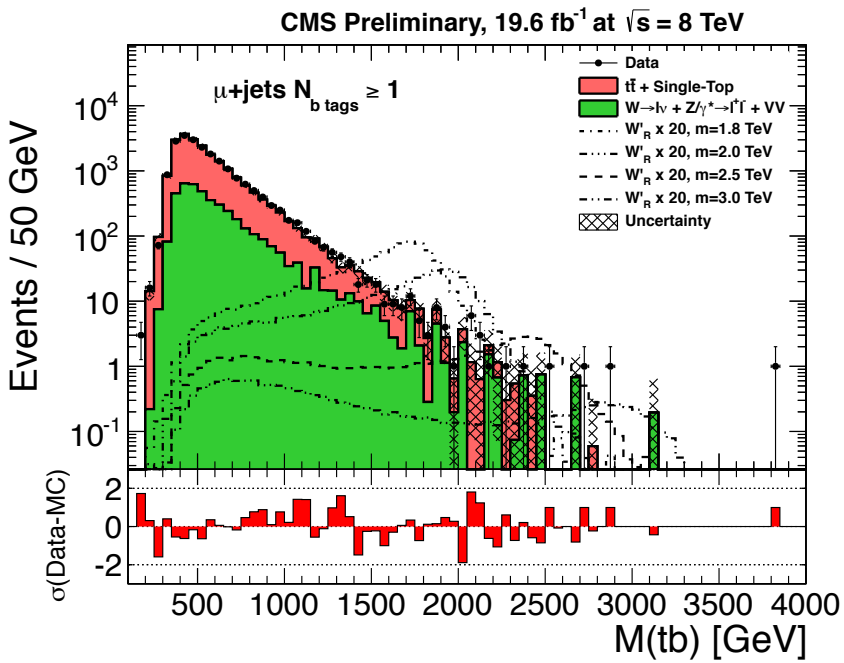


W' → tb

CMS-PAS-B2G-12-010

- Option for W' that interacts hadronically
  - Consider right-handed W_R' with SM-like couplings as a benchmark model
  - Complementary to W' → lν searches
    - ❑ If right-handed neutrino is heavy enough, W' → lν is suppressed!
- Signature:
  - One lepton (e,μ), p_T > 50 GeV
  - At least two jets, p_t > 120, 40 GeV
  - At least one b-tagged jet
  - MET > 20 GeV

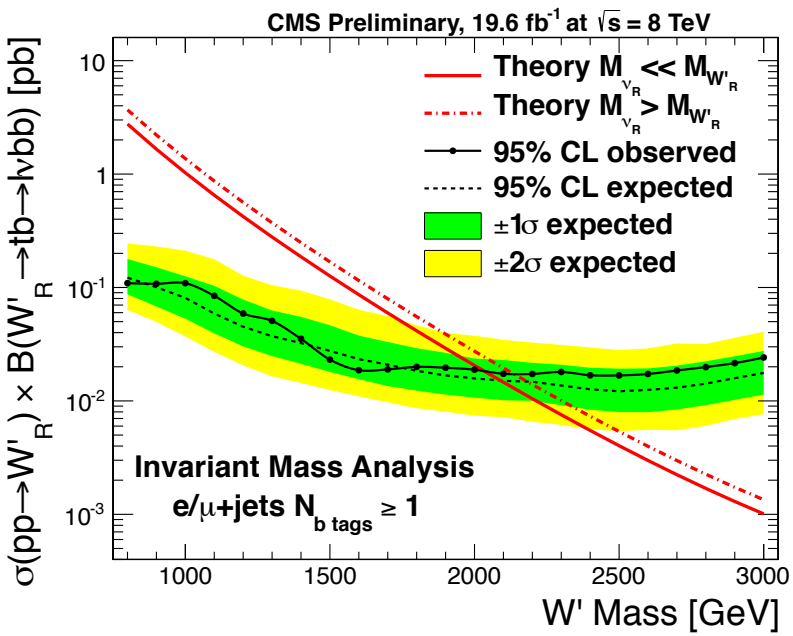


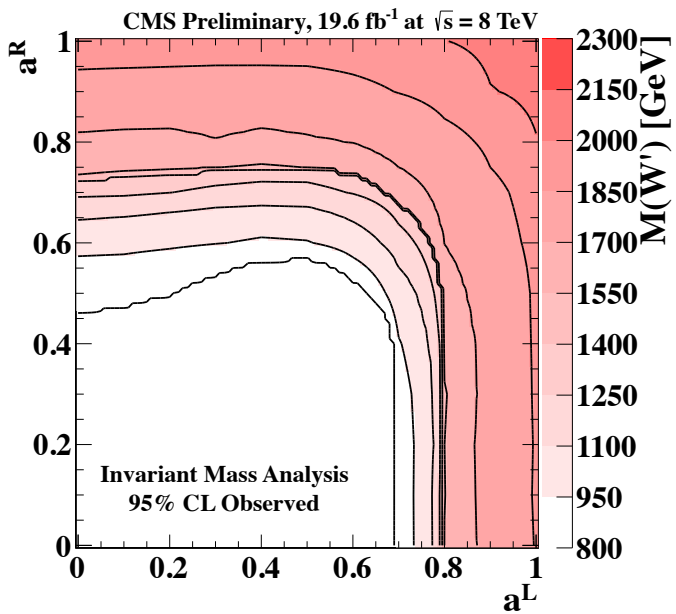


W' → tb

CMS-PAS-B2G-12-010

- Analyze in terms of right handed, left-handed & mixed gauge couplings
  - Right-handed W_R' with SM-like couplings as a benchmark model
  - Also consider arbitrary combination of left and right- handed couplings to fermions.
- **CMS @ 20/fb: $M_{W'}$ > 2.03 TeV**

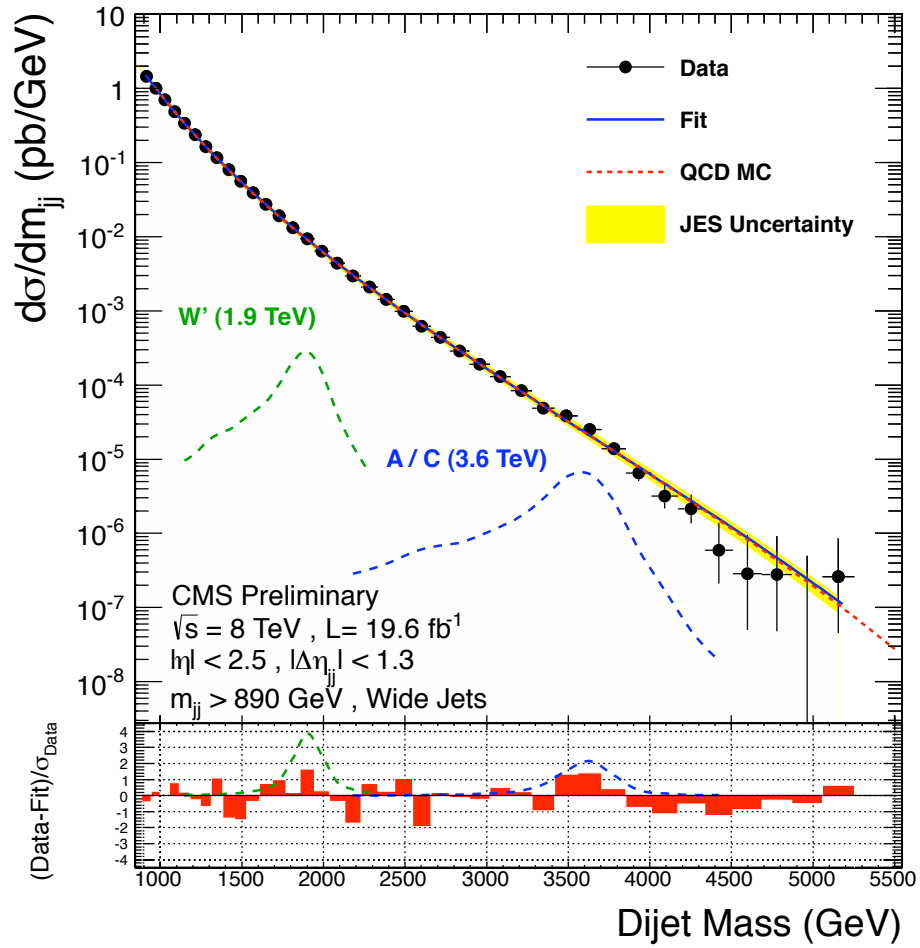




Dijet Searches

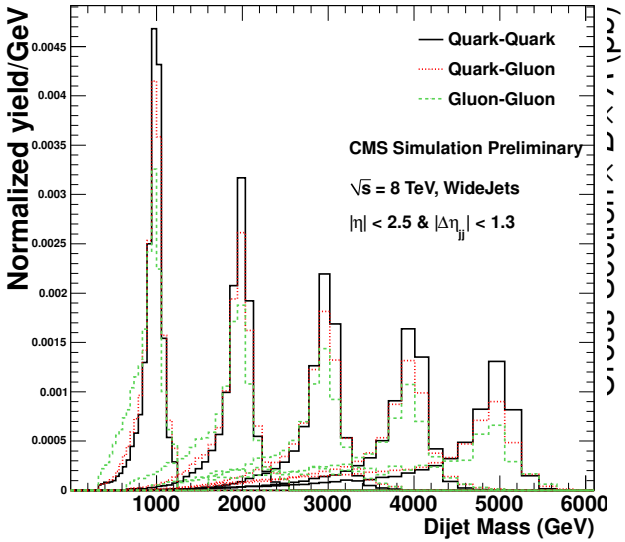
CMS-PAS-EXO-12-059

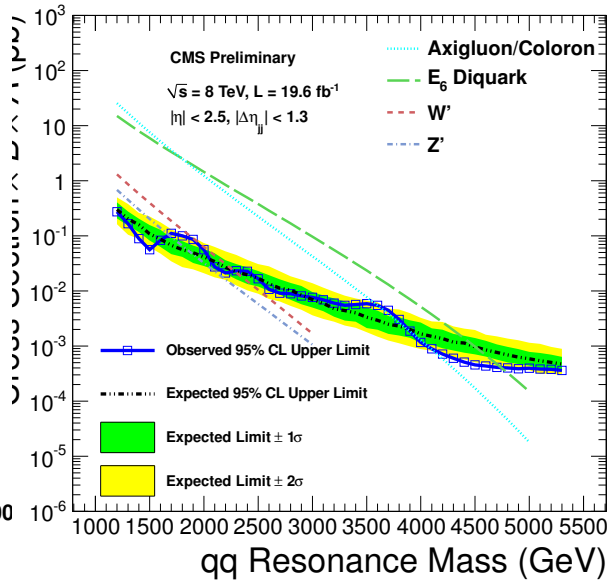
- Different Models:
  - string resonances
  - excited quarks q*
  - Axigluons
  - colorons
  - s8 resonances
  - E_6 diquarks
  - SSM W'/Z' and RS graviton
- Signature:
  - 2 jets with $|\eta| < 2.5$
  - $|\Delta\eta_{jj}| < 1.3$
  - Structures (bumps) on top of falling QCD m(jj) spectrum
  - In comparison with dilepton channel:
    - Larger background
    - Lower resolution
    - All-hadronic trigger threshold issues

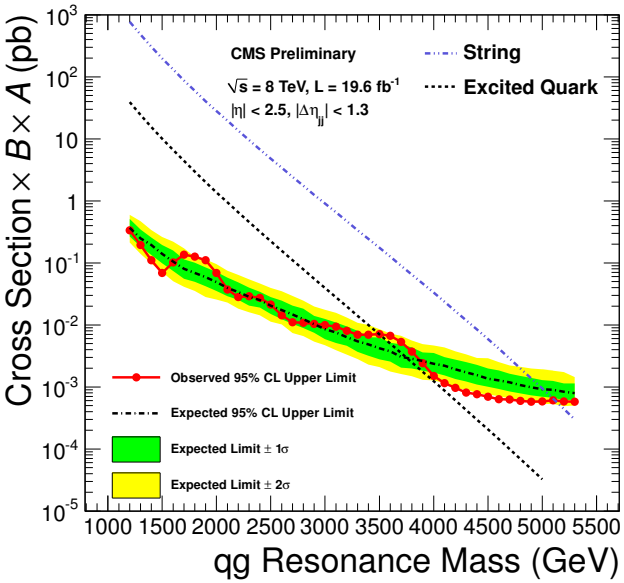


Dijet Searches

CMS-PAS-EXO-12-059

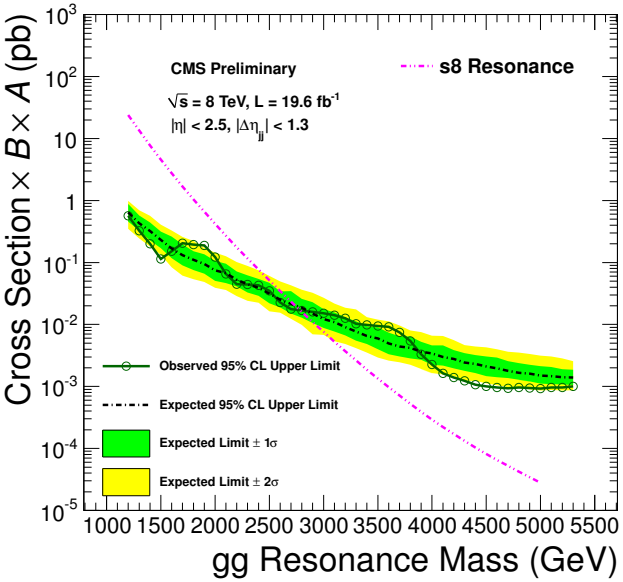






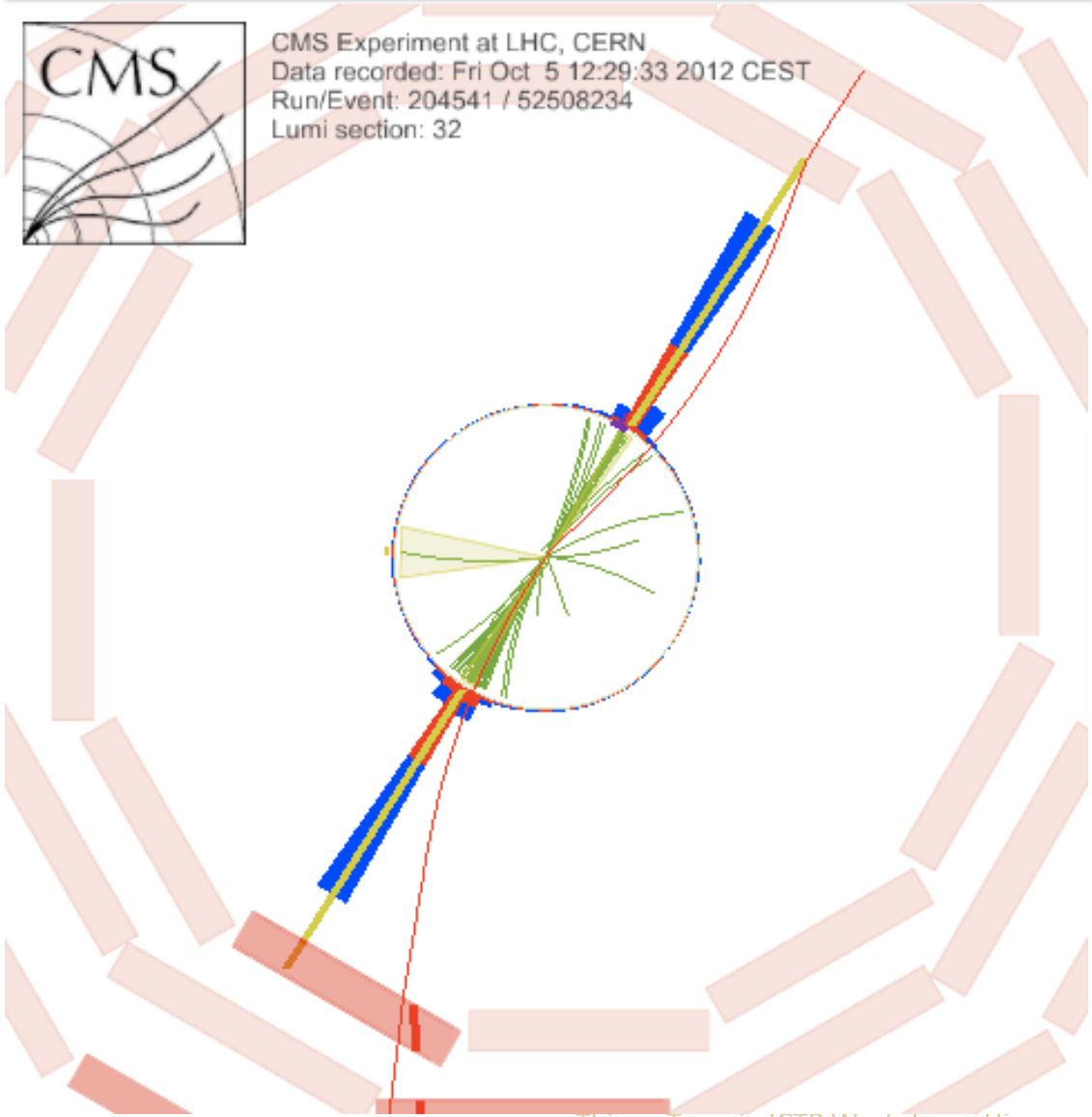
CMS @ 20/fb:

Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.20,5.08]	[1.20,5.00]
Excited Quark (q*)	qg	[1.20,3.50]	[1.20,3.75]
E_6 Diquark (D)	qq	[1.20,4.75]	[1.20,4.50]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.20,3.60] + [3.90,4.08]	[1.20,3.87]
Color Octet Scalar (s8)	gg	[1.20,2.79]	[1.20,2.74]
W′ Boson (W′)	$q\bar{q}$	[1.20,2.29]	[1.20,2.28]
Z′ Boson (Z′)	$q\bar{q}$	[1.20,1.68]	[1.20,1.87]
RS Graviton (G)	$q\bar{q}$+gg	[1.20,1.58]	[1.20,1.43]



Dijet Searches

CMS-PAS-EXO-12-059

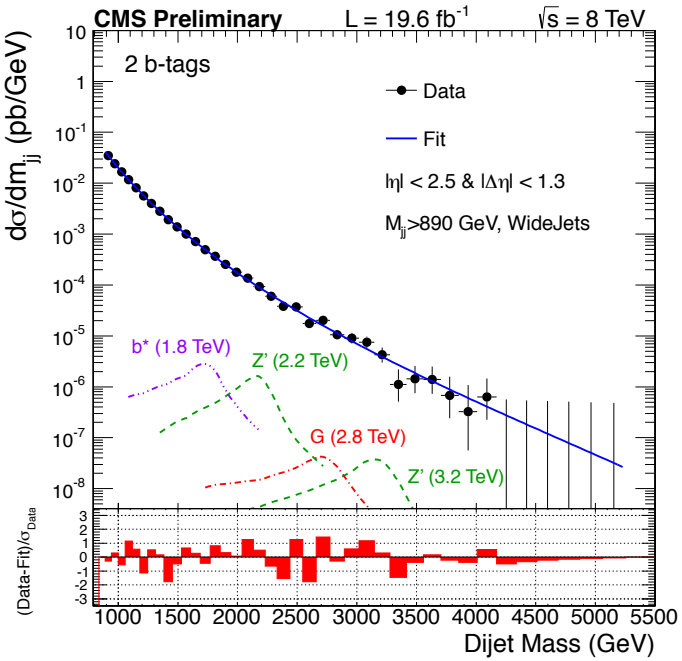


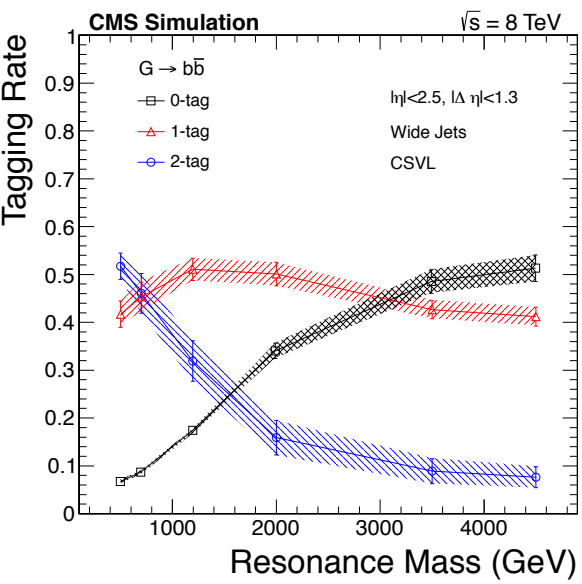
- Our most energetic dijet event to date!
  - M_{JJ} = 5.15 TeV
  - Wide (R = 1.1) jets

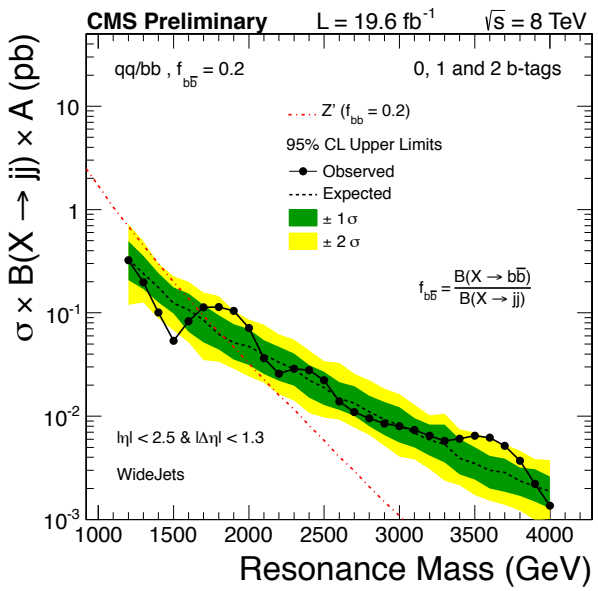
Dijet Searches With b-tag

CMS-PAS-EXO-12-023

- **CMS @20/fb**
  - Z' (f_{bb}=0.2):
    - exclude M in [1.20, 1.68] TeV
  - RSG (f_{bb}=0.1) k/M_{Pl}=0.10:
    - exclude M in [1.42, 1.57] TeV
  - b*→bg:
    - exclude M in [1.34, 1.54] TeV







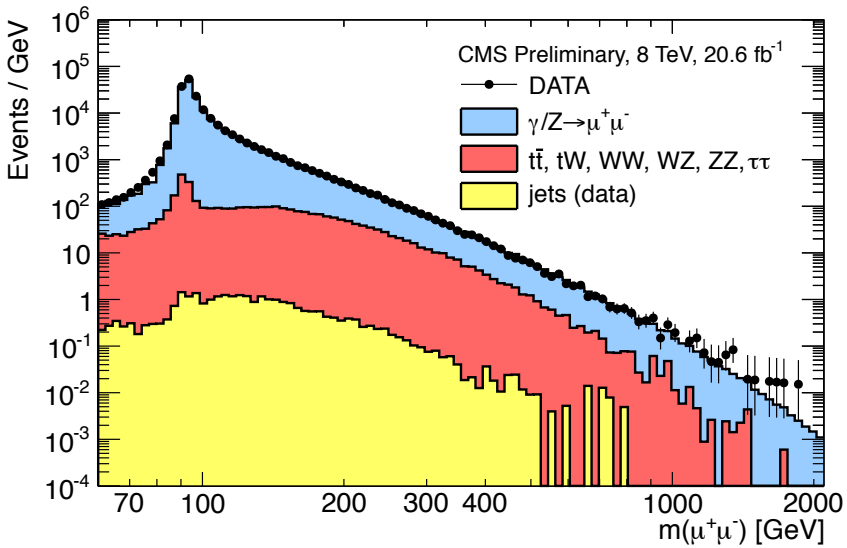
Dilepton Searches

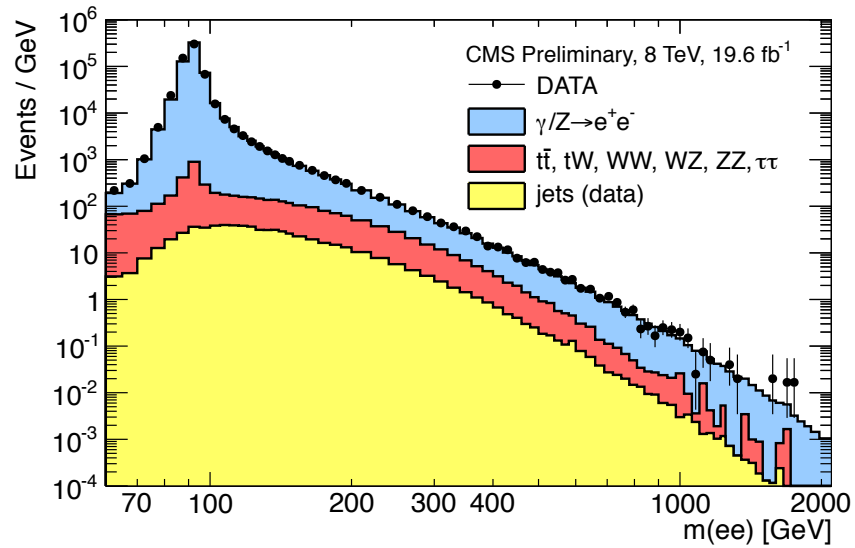
CMS-PAS-EXO-12-027
CMS-PAS-EXO-12-031
CMS-PAS-EXO-12-061

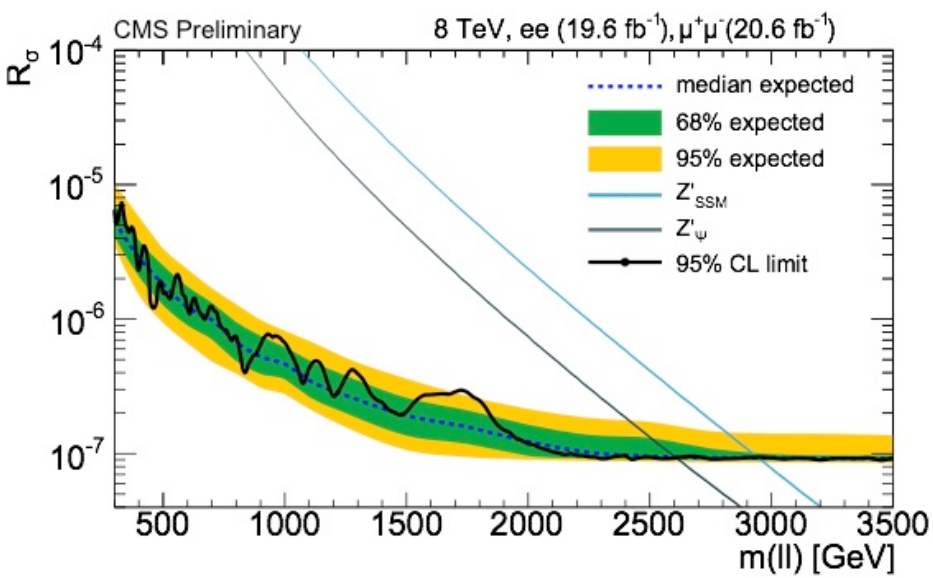
- $X \rightarrow \mu\mu$:
  - Single muon triggers
  - $p_T > 45$ GeV, $|\eta| < 2.1$
  - Combined μ
    - Tracker + muon stations
  - Quality cuts
  - Muon track isolation
  - Search for structure in dimuon mass spectrum.
    - 2 muons of opposite charge
- $X \rightarrow ee$
  - Double electron trigger
  - $E_T > 45$ GeV, $|\eta| < 2.5$
  - Combined e
    - Tracker + ECAL
  - Quality cuts
  - Electron track isolation
  - Search for structure in dielectron mass spectrum.
    - No charge requirement

Dilepton Searches (Resonant)

CMS-PAS-EXO-12-061





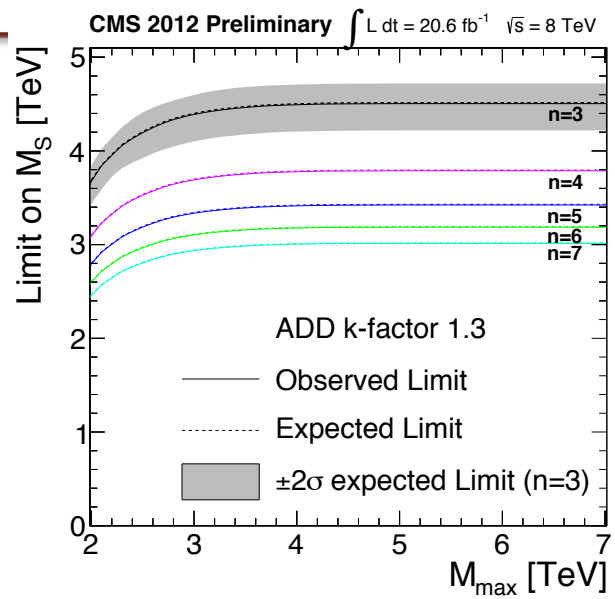


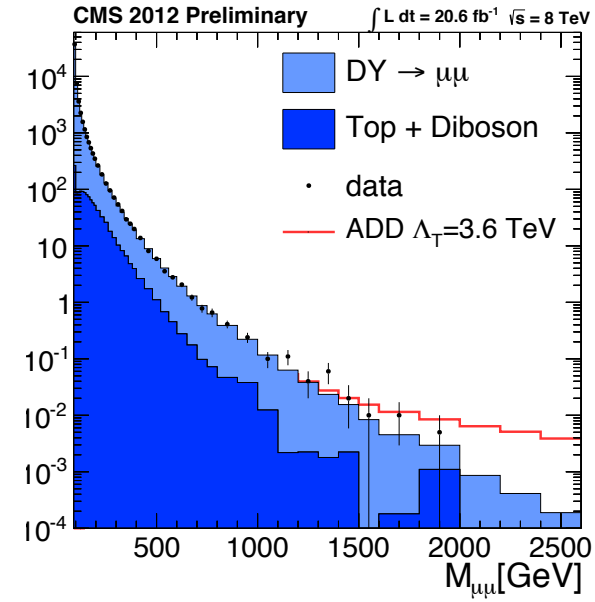
- **CMS @ 20/fb:**
  - Z'_{SSM}: M > 2.96 TeV
  - Z'_{ψ}: M > 2.6 TeV

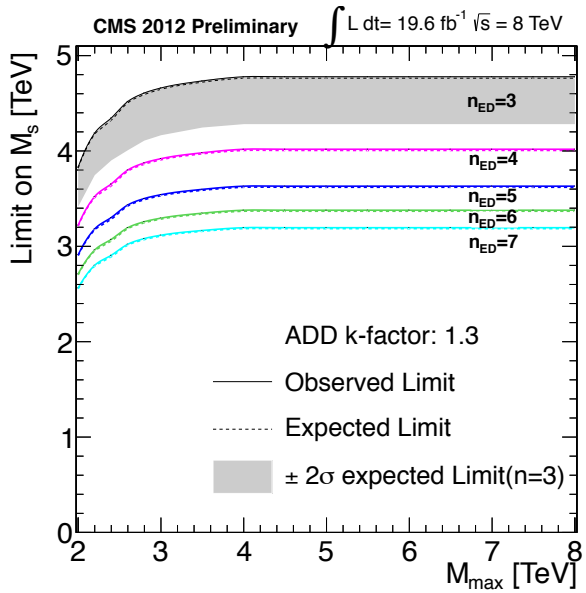
Dilepton Searches (Non-resonant)

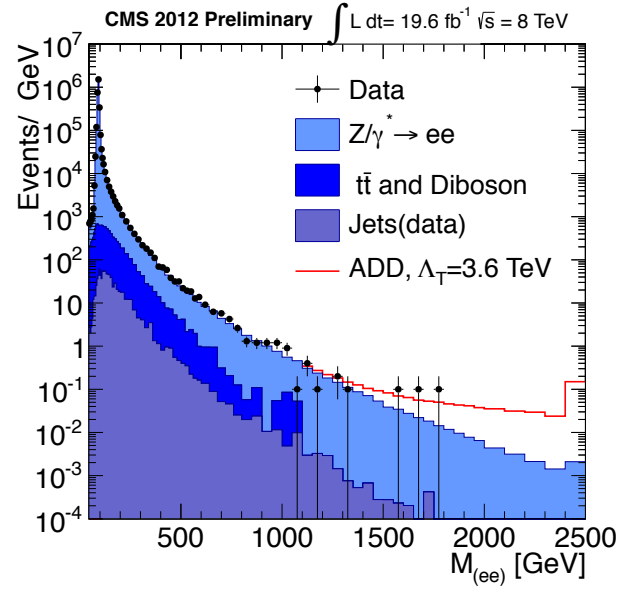
CMS-PAS-EXO-12-027
CMS-PAS-EXO-12-031

- ADD searches are also possible with the dilepton spectra.
- **CMS @ 20/fb:**
  - Muons:
    - M_S > 4.49 TeV (HLZ, n=3)
    - Λ_T > 3.77 TeV (GRW)
  - Electrons:
    - M_S > 4.49 TeV (HLZ, n=3)
    - Λ_T > 3.77 TeV (GRW)
  - Combination:
    - M_S > 4.94 TeV (HLZ, n=3)
    - Λ_T > 4.15 TeV (GRW)





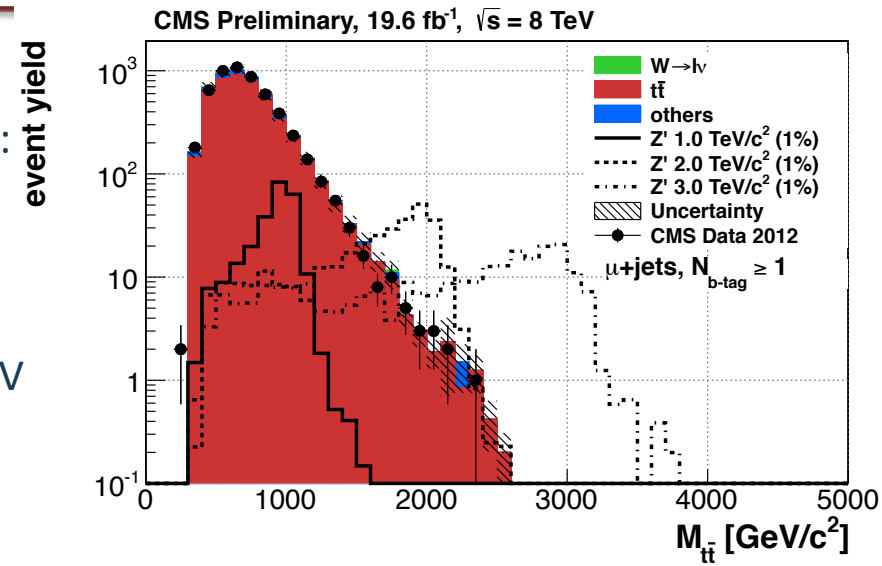


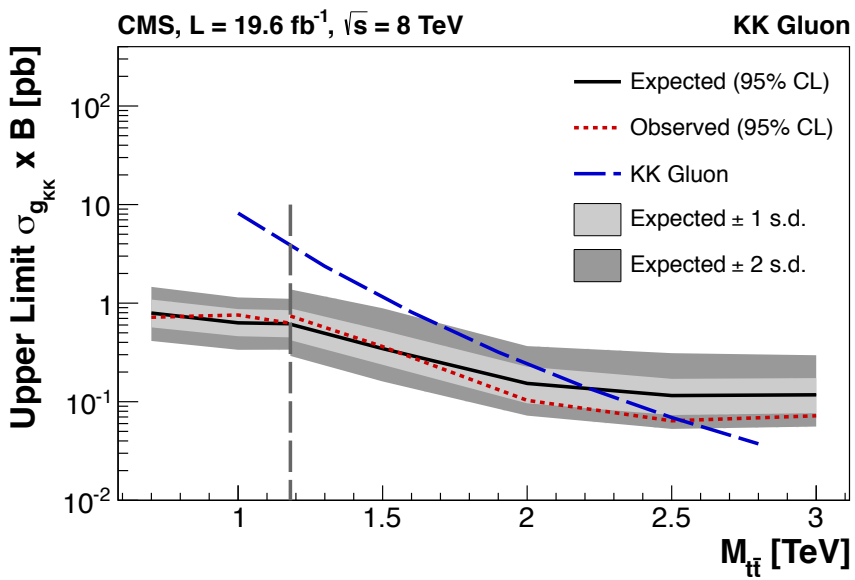


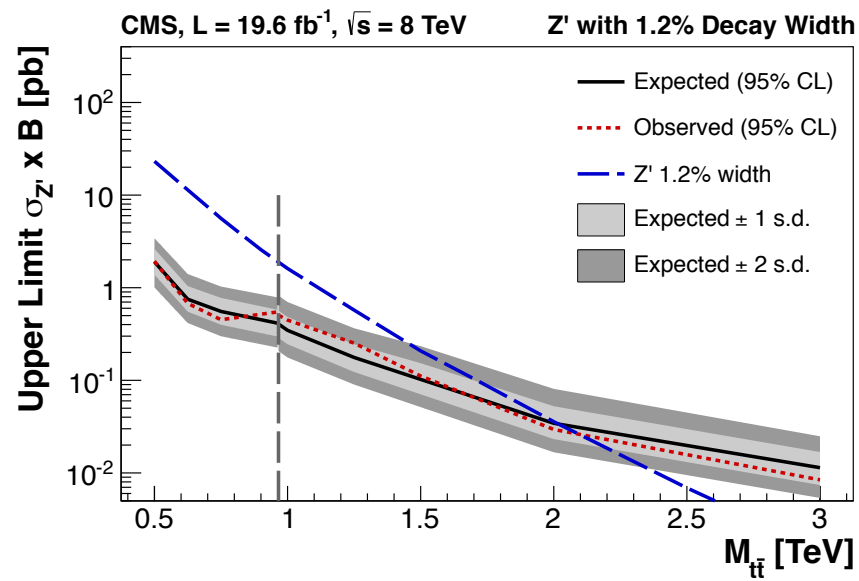
Ttbar Resonances – Semileptonic

CMS-PAS-B2G-12-006

- Models
  - Topcolor Z'
  - Gluon KK
- Signature:
  - 1 lepton (muon or electron)
  - 2 jets
    - 0/1 b-tags
- **CMS @ 20/fb:**
  - Z', width = 1.2%: M > 2.10 TeV
  - Z', width = 10%: M > 2.68 TeV
  - g_{KK}: M > 2.69 TeV

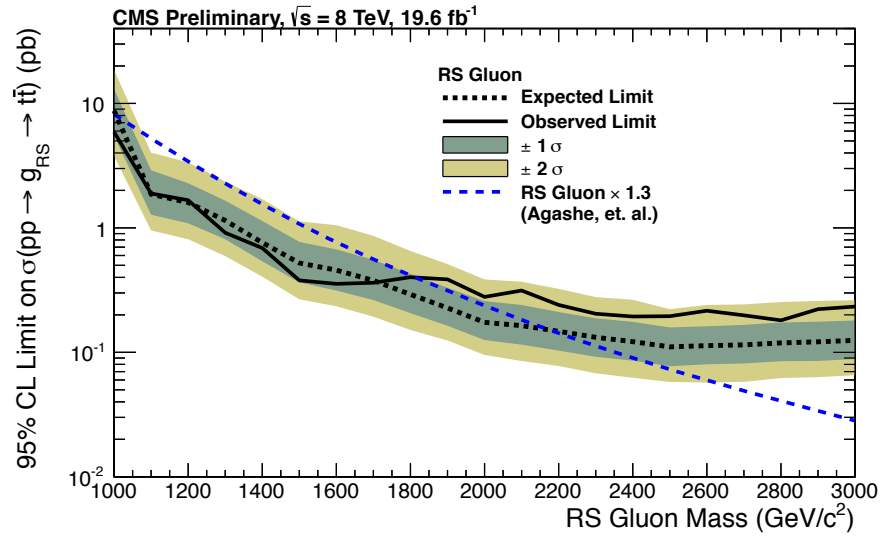


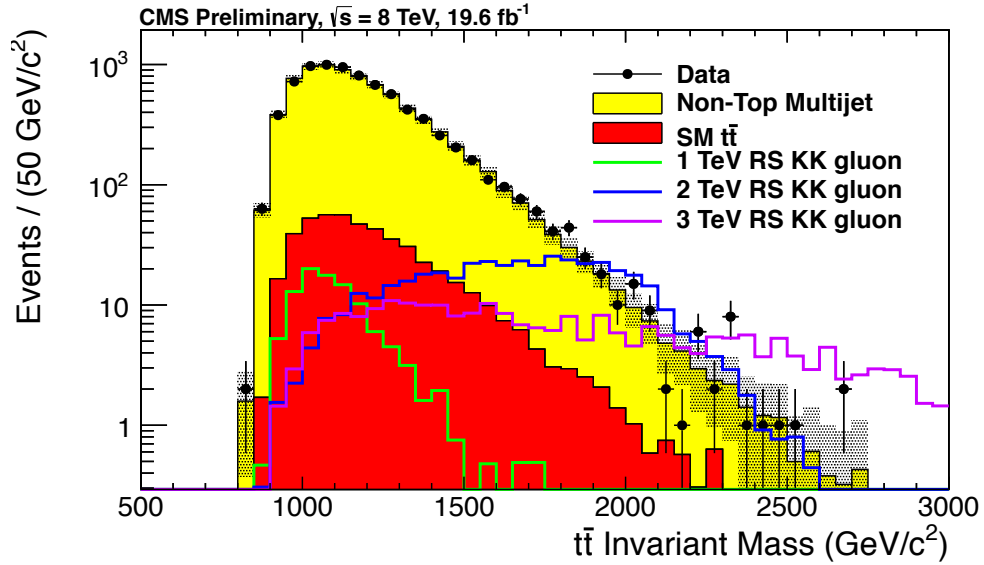


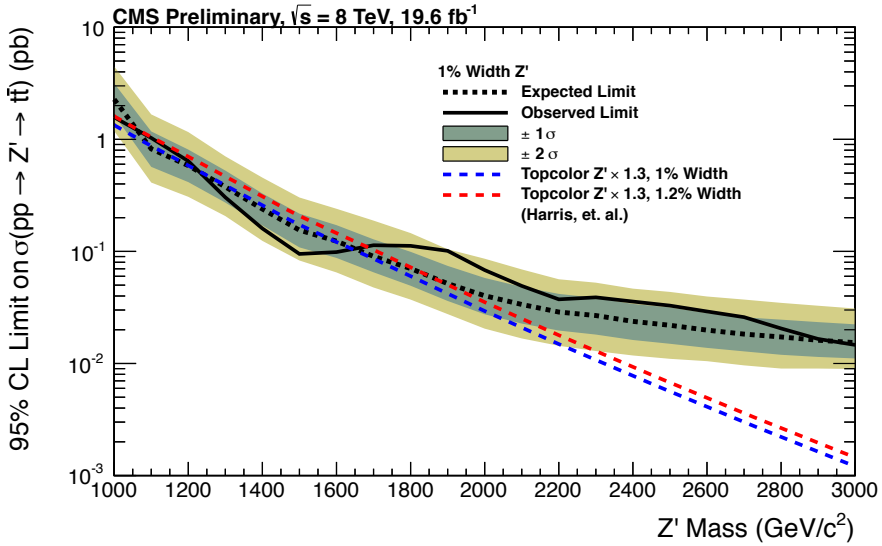


Ttbar Resonances – Hadronic

CMS-PAS-B2G-12-005





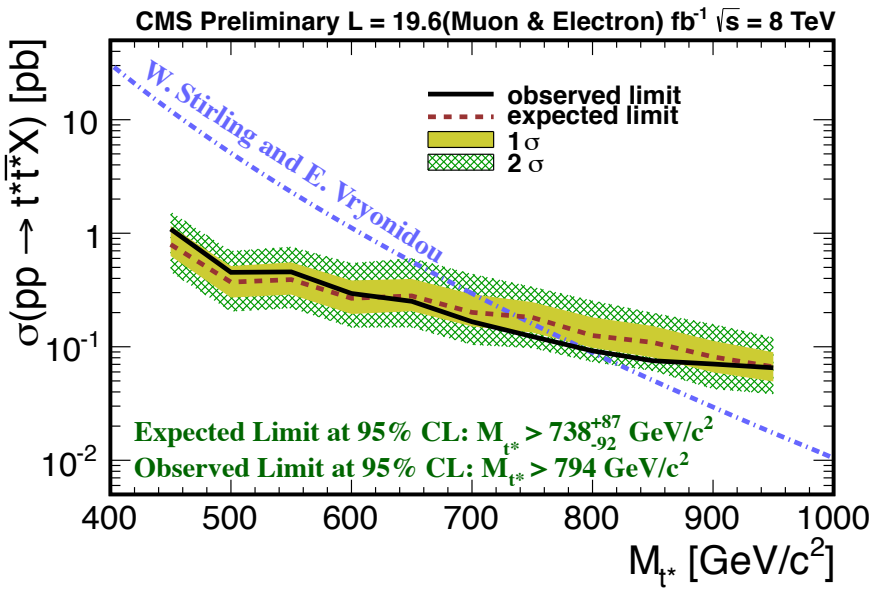


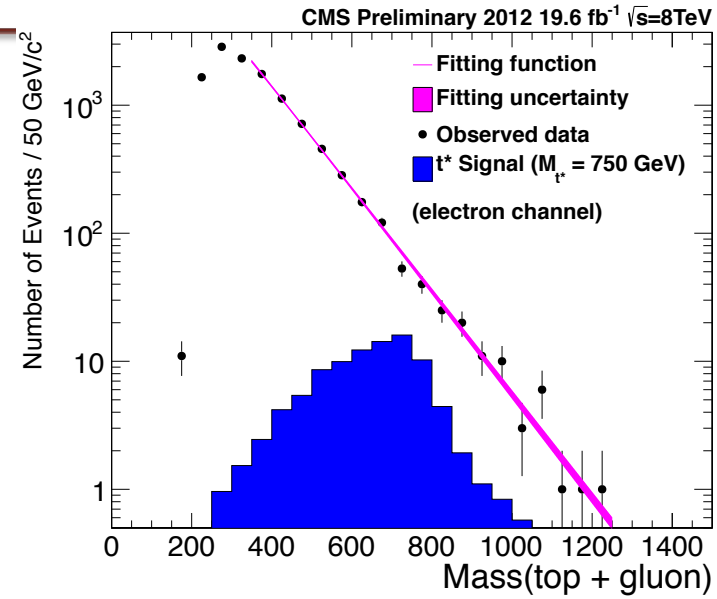
- Hadronic channel:
  - Top tagging algorithm
  - Signal region: fully merged (1+1) top jets
  - Control region: fully (1+1) and partially (1+2) merged with muon +jets sample.
- **CMS @ 20/fb:**
  - g_{KK}: M > 1.8 TeV
  - Topcolor Z': M > 2.5 TeV

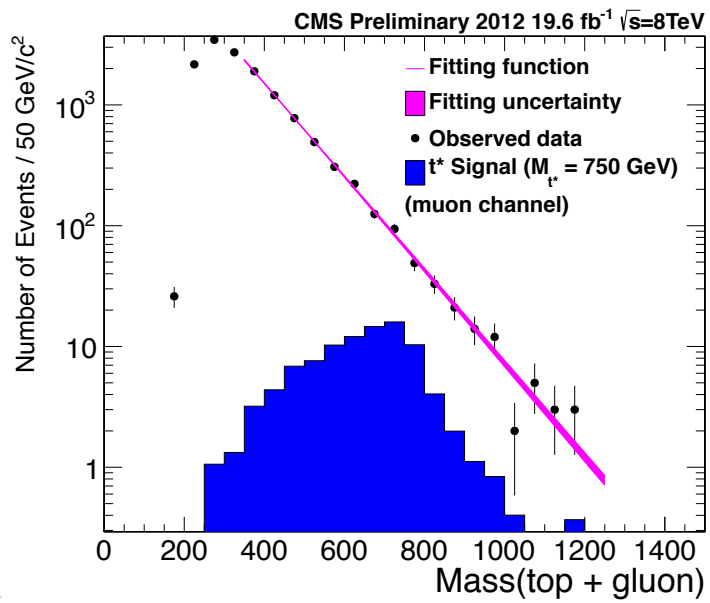
t* → Top Quark + Gluon

CMS-PAS-B2G-12-014

- Signature:
  - One isolated muon or electron
  - At least six hadronic jets
  - At least one b-tagged jet.
- **CMS @ 20/fb:**
  - M_{t*} > 794 GeV





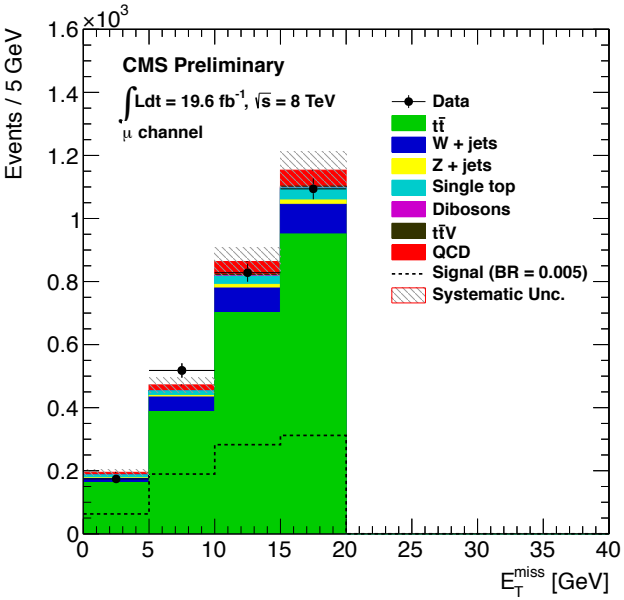


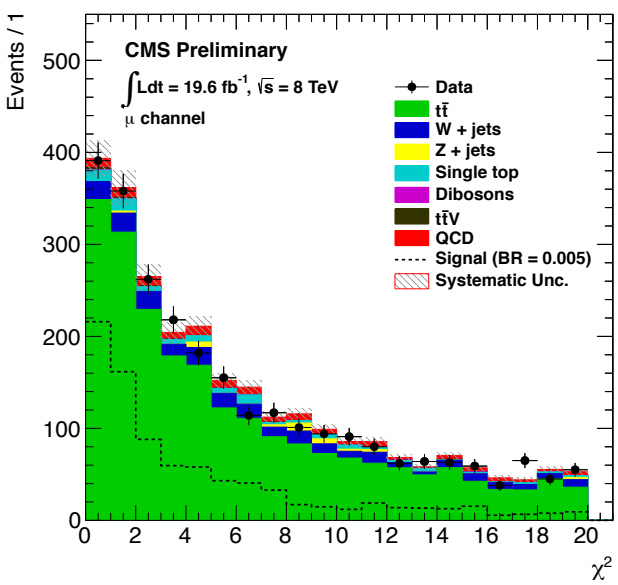
Baryon Number Violation in Top Decays

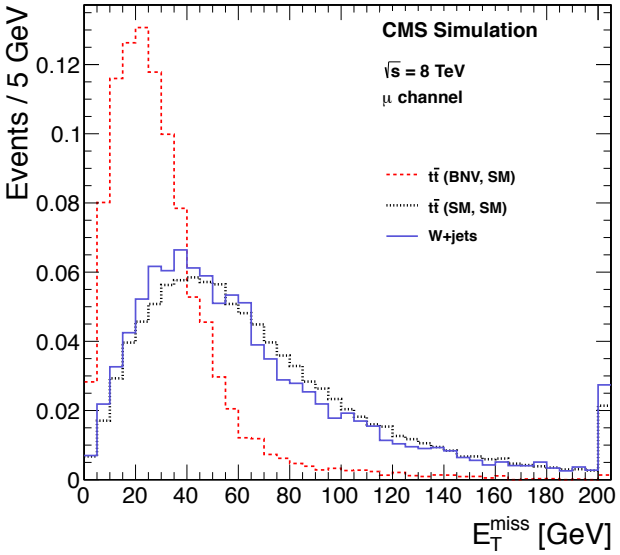
CMS-PAS-B2G-12-023

- Signature:
  - One electron or muon
  - At least five hadronic jets
  - At least one b-tagged jet
  - **no neutrino in the final state**
    - MET < 20 GeV
    - kinematical compatibility with
    - SM-BNV decay.

- **CMS @ 20/fb:**
  - BR of top BNV decay:
    - $BR_{(BNV)} < 0.0016$ (muon)
    - $BR_{(BNV)} < 0.0017$ (electron)







Summary and Conclusions

- Wide range of searches for Standard Model are being performed with the data collected by the CMS Experiment.
- Many of the searches present model-independent results.
- Also, results can be interpreted in terms of a large amount of popular models.
  - Sequential Standard Model
  - Topcolor Z'
  - Extra Dimensions (in all its flavours)
  - Contact Interactions
  - TeV gravity
  - Unparticles
- More and more results using the full 2012 dataset are becoming available
  - Theory predictions are already being tested.
  - Stay tuned for more new results later this year, put the following in your bookmarks!
  - **https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO**
  - **https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G**