Exotic Searches in LHC

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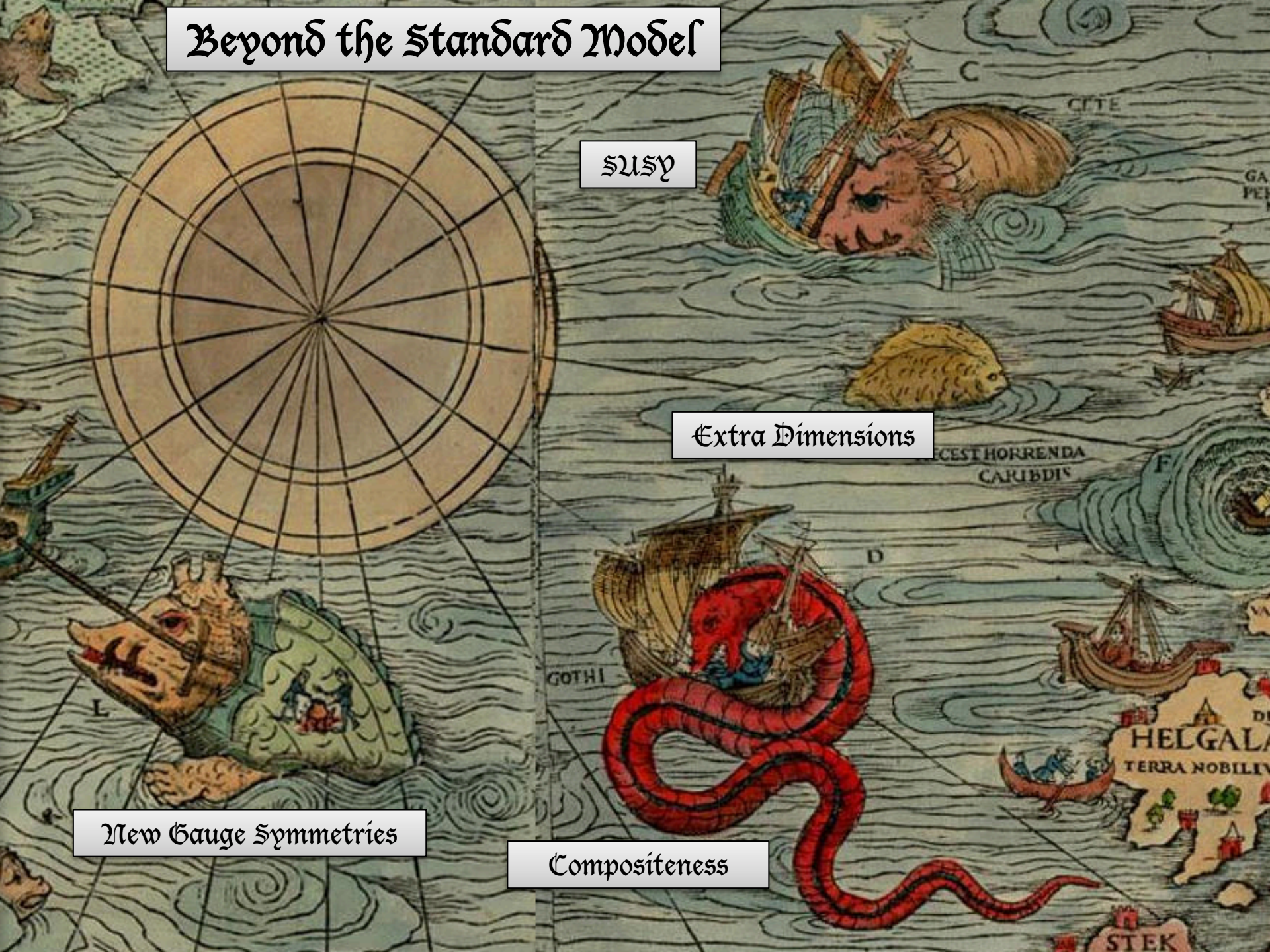
SPRACE – UNESP

For the ATLAS and CMS Collaborations

Beyond the Standard Model



Outline

- General Search for New Phenomena
- Resonant HH → 4b
- Excited Fermions
- Leptoquarks (LQs)
- Vector-like Quarks (VLQs)
- Expectations for Run II

  - Focusing on new results only!
  - **NOT** covered in this talk:
    - SUSY (see talks by P. Bargassa and M. Flowerdew)
    - Boosted Object Searches (see talk by P. Azzi)
    - Dark Matter (see talk by P. Calfayan)
    - BSM Higgs (see talk by P. Thompson)

General Searches

General Search for New Phenomena

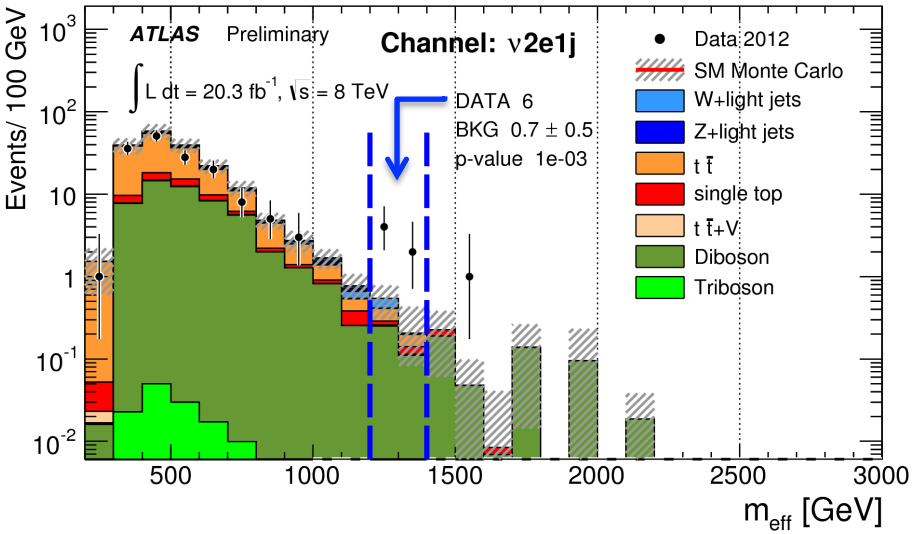
ATLAS-CONF-2014-006

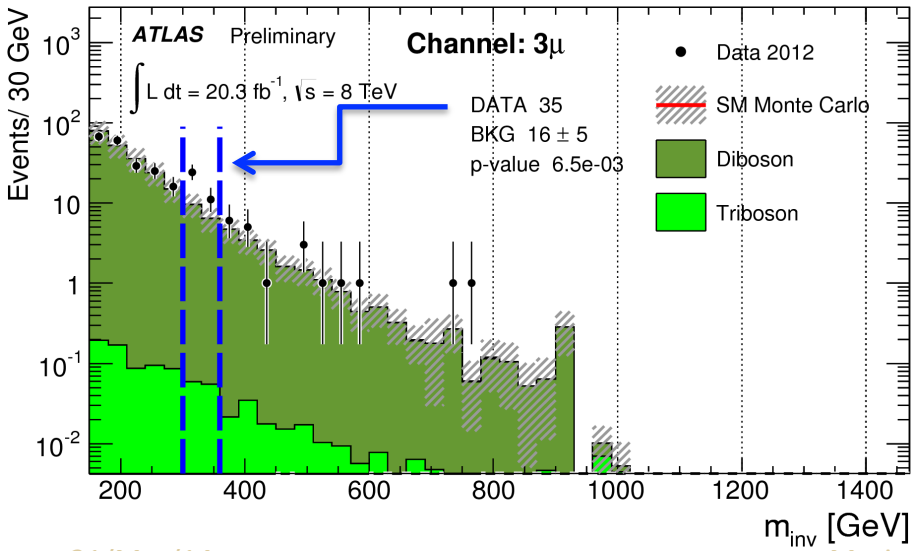
- Model-independent search for NP signals at high p_T
- Division of full dataset into exclusive event classes
  - Number and type of objects with given kinematic characteristics
    - ❑ Electrons
    - ❑ Muons
    - ❑ Photons
    - ❑ Jets
    - ❑ B-jets
    - ❑ Missing transverse energy (MET)

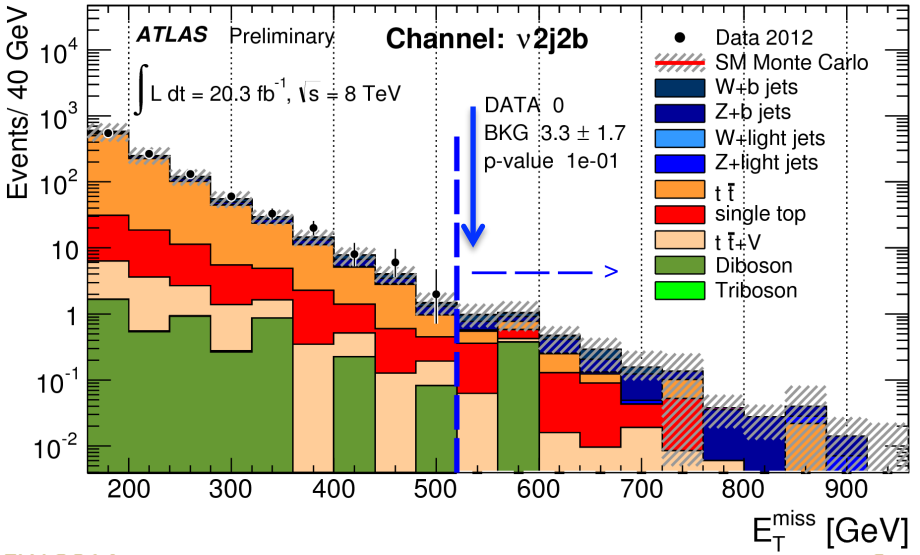
Trigger	Offline Selection
muon:	$p_T > 25$ GeV
electron:	$p_T > 25$ GeV
photon:	$p_T > 140$ GeV
E_T^{miss} :	$E_T^{miss} > 150$ GeV
single jet:	$p_T > 500$ GeV
multijet:	$p_T(jet_{1,\cdots,5}) > 80$ GeV

- Events selected from different trigger with priority:
  - MET → muon → electron or photon → jet or multijet

- Backgrounds:
  - Most processes: simulation
  - Single fake leptons: data-driven
- Distributions:
  - Scanned for hot spots:
    - m_{eff} (scalar sum of objects' p_T)
    - m_{inv} (visible invariant mass)
    - missing E_T

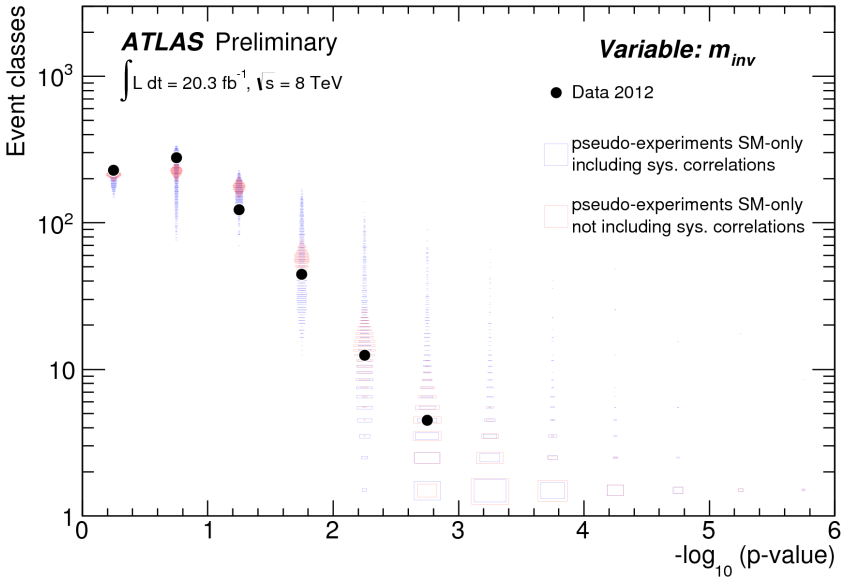


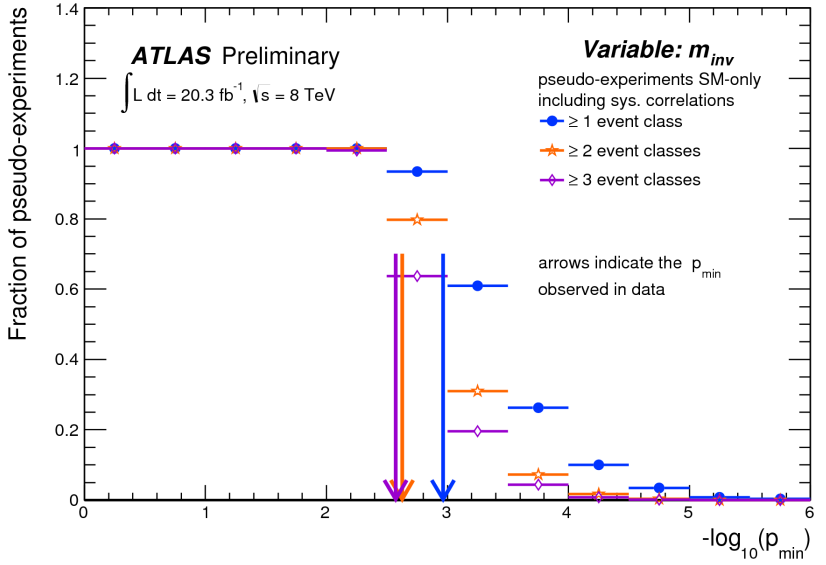




- Results & statistical analysis
  - 573 event classes with data
  - 697 event classes with SM expectation > 0.1
  - Probability of statistical fluctuation in a distribution:
    - Modeled by pseudo-experiments
    - Region of greatest disagreement (smallest p-value) computed

- **No event class is found with a local p-value below 10^{-4}**

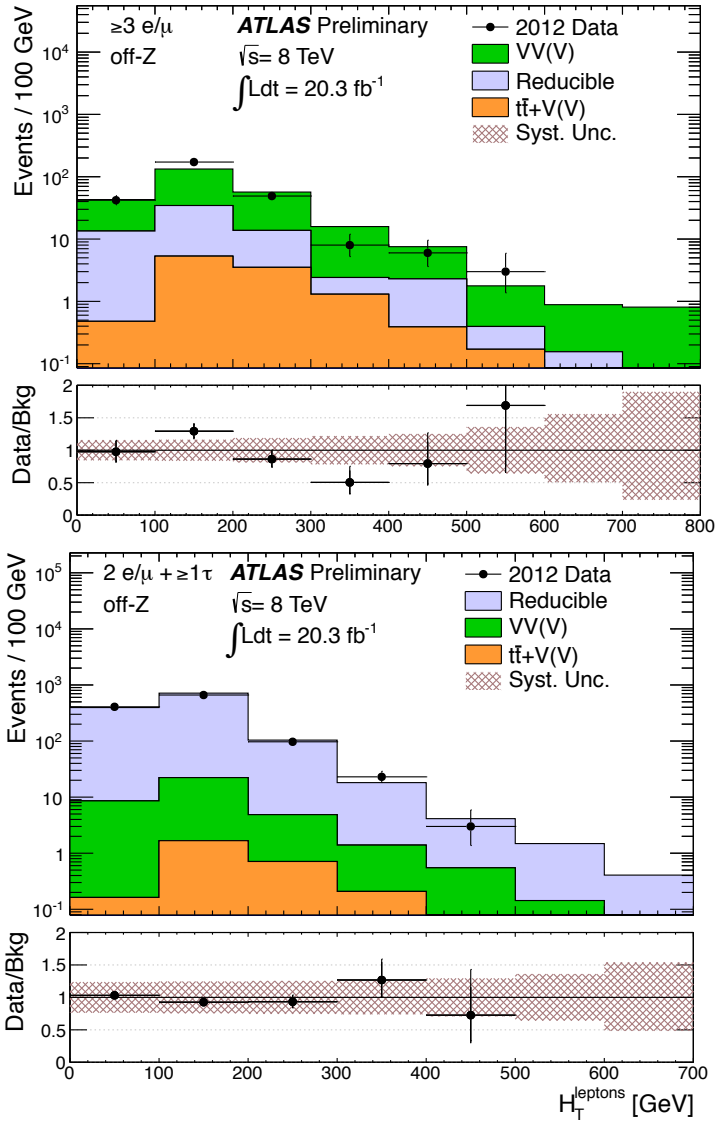


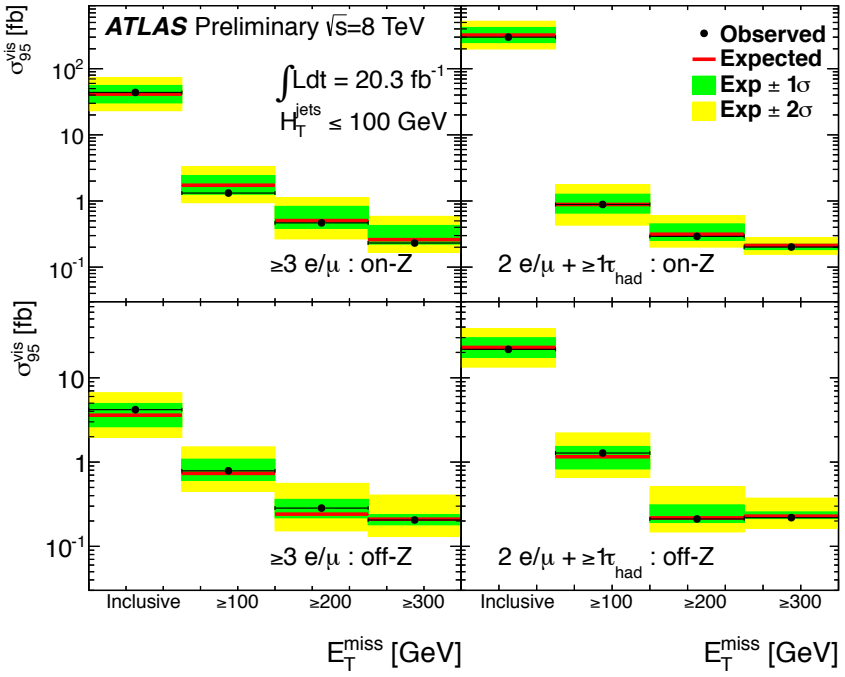


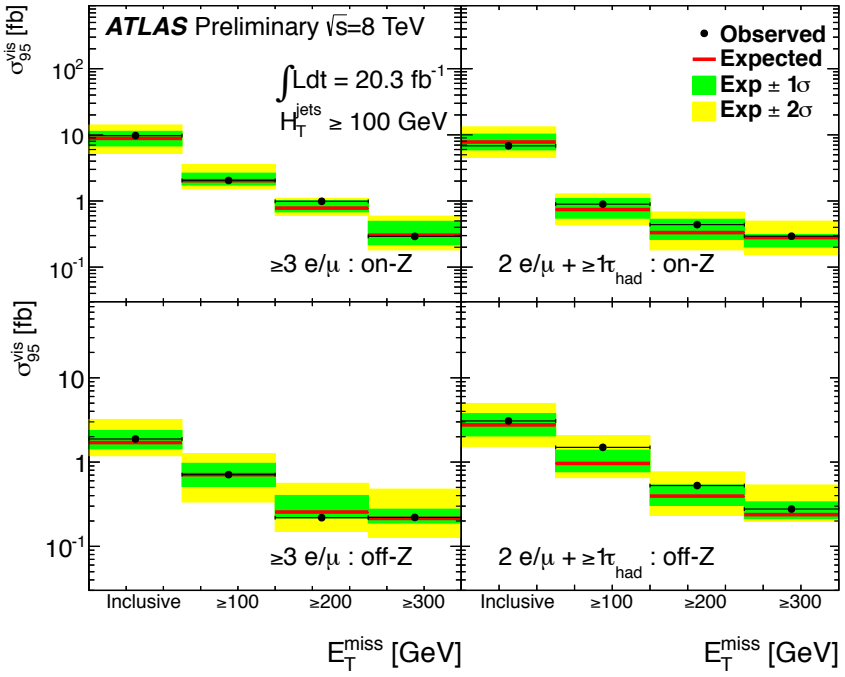
Model-independent multileptons

ATLAS-CONF-2013-070

- A model-independent approach
- Signature:
  - At least three leptons (e, μ, τ_{had})
  - Classifications:
    - ❑ Presence/absence of hadronic τ
      - At least 3 eμ;
      - 2e/μ + at least 1τ_{had}
    - ❑ Presence/absence of Z boson candidate
    - ❑ Number of b-tags
    - ❑ $H_T^{leptons}$, H_T^{jets}, m_{eff}, MET







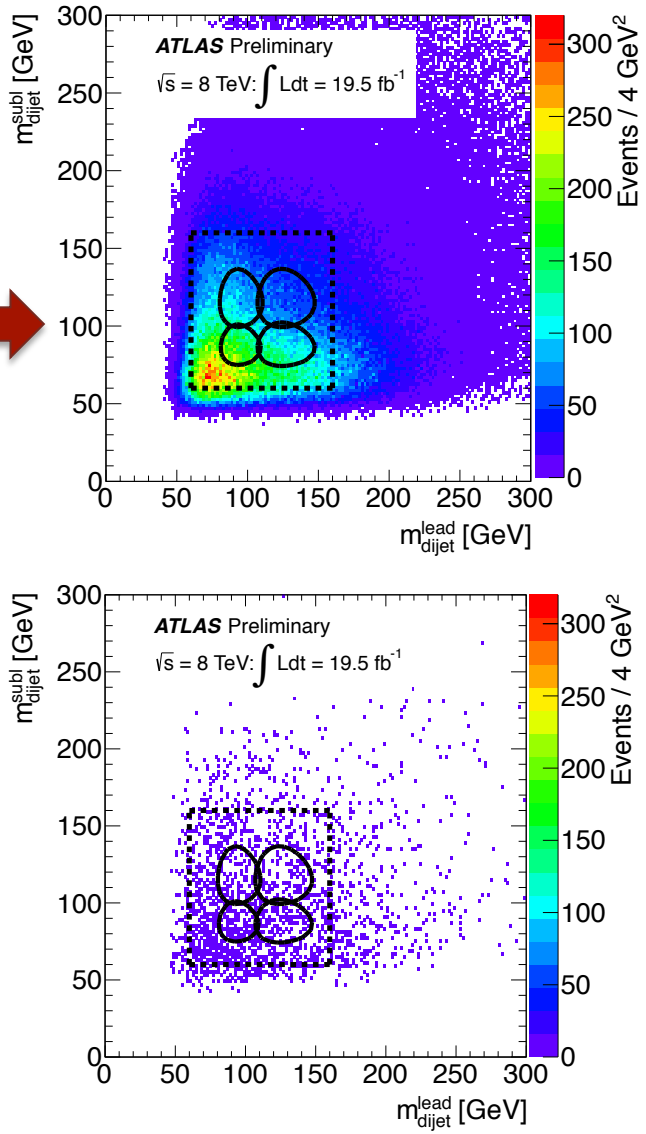
- Limits in terms of pure visible cross-section as function of a given variable.
  - Tables of fiducial efficiencies as function of lepton kinematics.
  - Easy for theorists to plugin their own models.

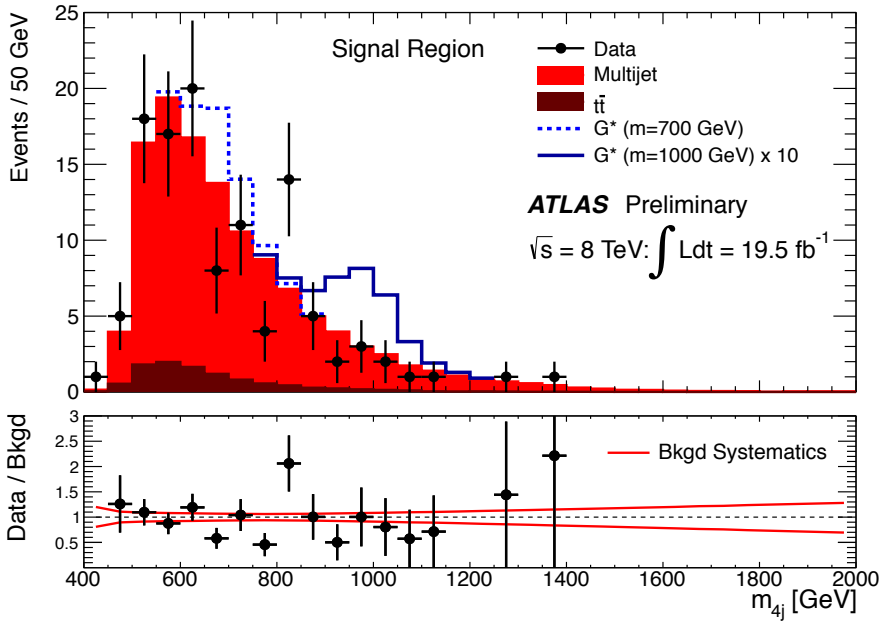
HH → 4b Resonant Production

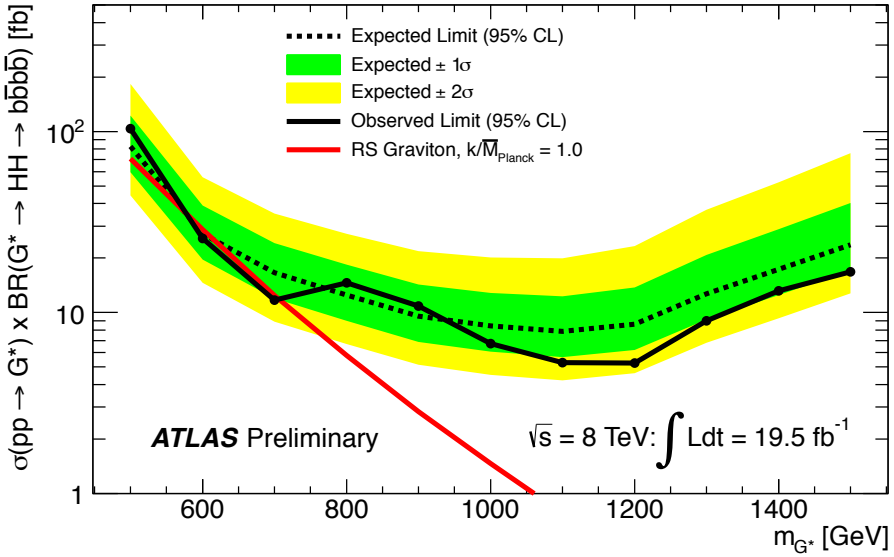
ATLAS-CONF-2014-005

- Signature:
  - 4 resolved b-tagged jets
  - Dijet mass around 125 GeV
- Main backgrounds:
  - Multijet (~90%)
  - ttbar
- Control / Signal region:
  - Dijet invariant mass windows
- Benchmark model:
  - Randall-Sundrum bulk warped extra dimension model
    - $G_{KK} \rightarrow HH$

ZZ / ZH / HH windows







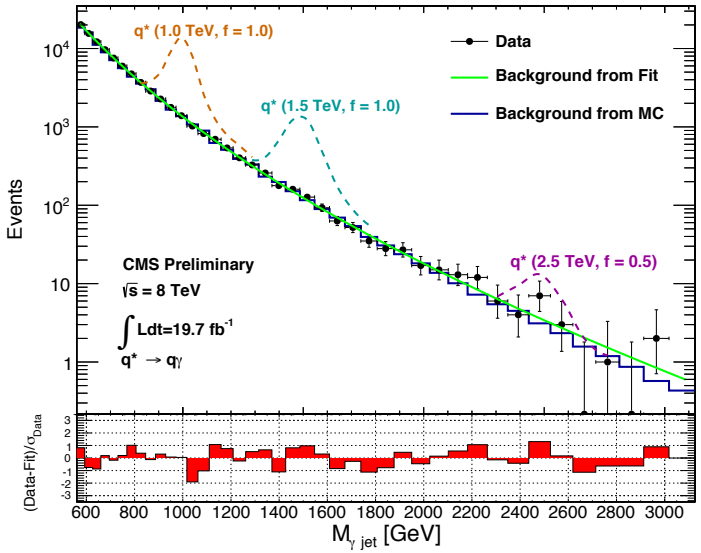
- 95% C.L upper limit on cross-section of Bulk Graviton:
  - Observed limit:
    - $\sigma < 7$ fb for 1 TeV G*
  - Expected limit:
    - Rises with higher values of M_{G^*}
    - Expected behavior due to jet merging.
- Benchmark model is excluded at the 95% C.L for M_{G^*} in 590 – 710 GeV range

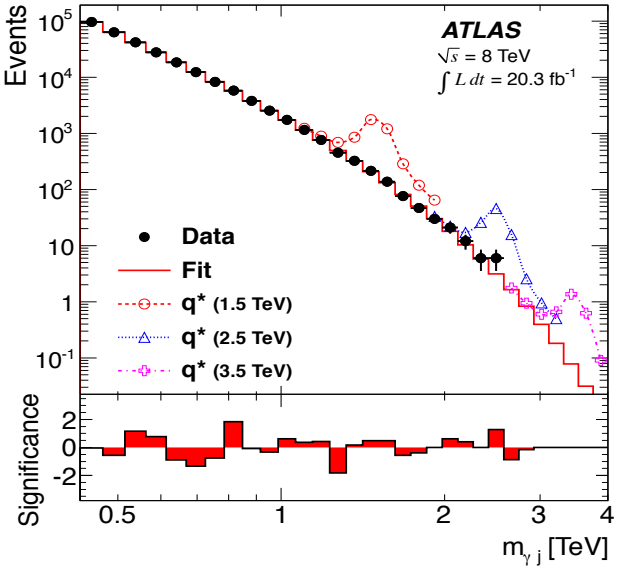
Excited Fermions

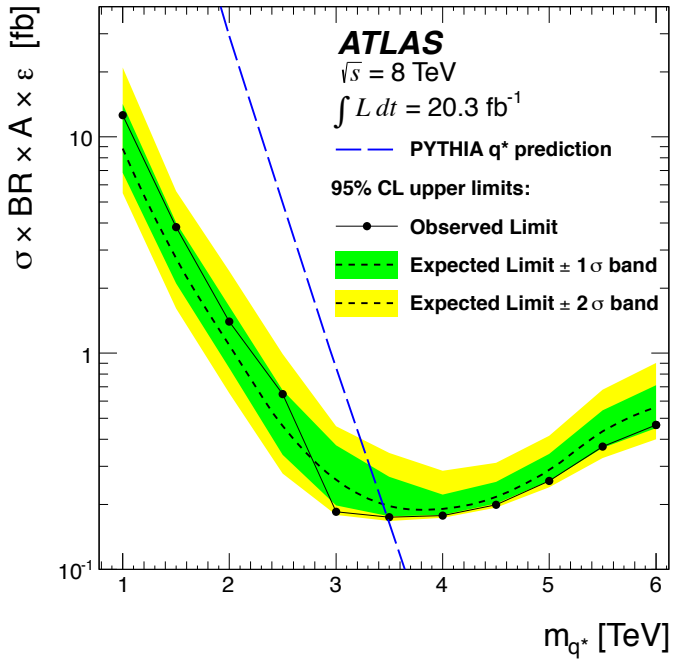
Excited Quarks

ATLAS: Phys. Lett. B 728C (2014) 562-578
CMS-PAS-EXO-13-003

- Signature: excited quark q* → q + γ
  - Search for excess of events (“bump”)over parameterized shape of (qγ) distribution.
- Main backgrounds:
  - Irreducible:
    - q g → q + γ,
    - qqbar → g + γ
  - Fakes:
    - dijet events with jet faking a photon
- ATLAS also presents results of search in terms quantum black-holes model.

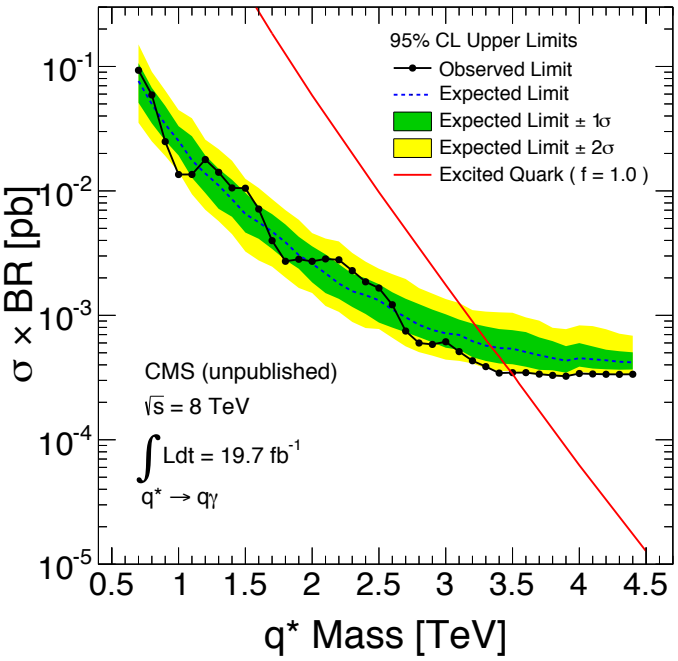


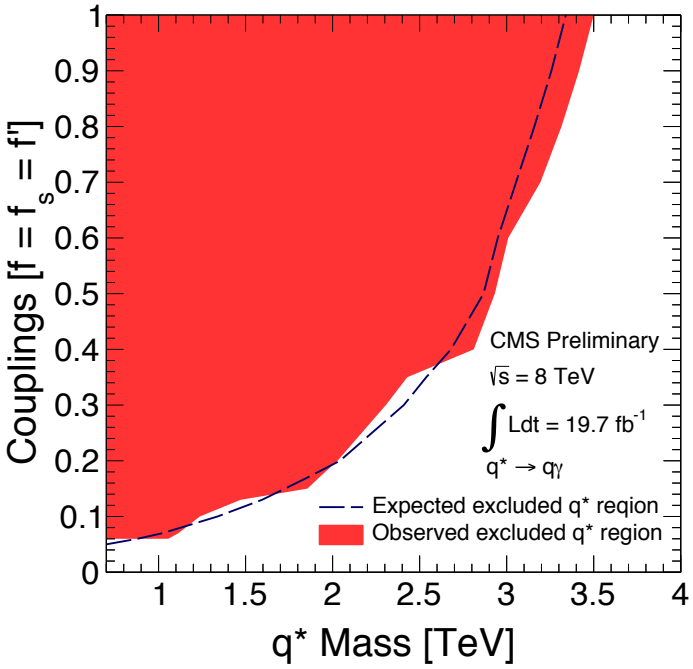




- **ATLAS results (20/fb):**
  - $M_{QBH} > 4.6$ TeV
  - $M_{Q^*} > 3.5$ TeV

- **CMS results (20/fb)**
  - $M_{Q^*} > 3.5$ TeV

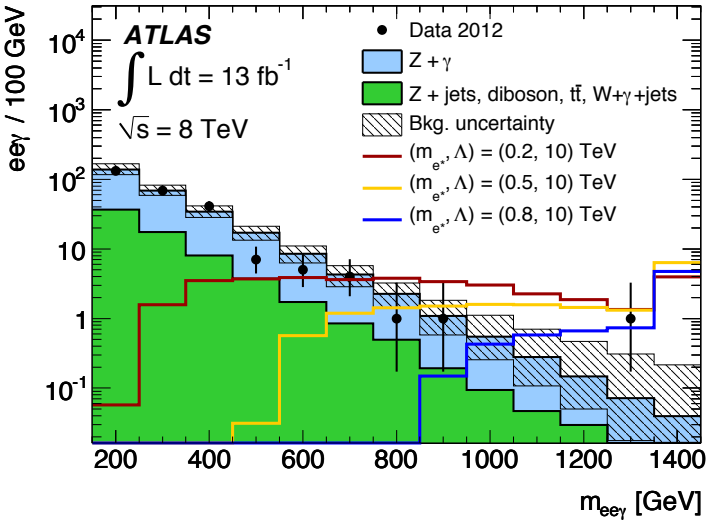


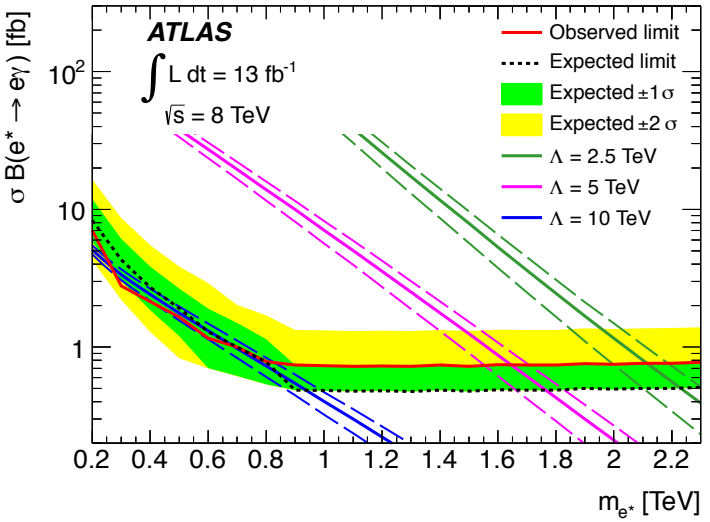


Excited Leptons

ATLAS Collab.
NJP 15 (2013) 093011

- Search for excess in the M(llγ) distribution
  - Lepton-photon pair ambiguity.
  - Natural resonance width.
- Two main analysis requirements:
  - Z-veto: M(ll) > 110 GeV
  - Signal window:
    - M(llγ) lower threshold.
- **ATLAS results (13/fb):**
  - $\sigma \times B < 0.75$ fb (e* search)
  - $\sigma \times B < 0.90$ fb (μ* search)
  - For special case $\Lambda = m_{l^*}$:
    - $m_{l^*} > 2.2$ TeV

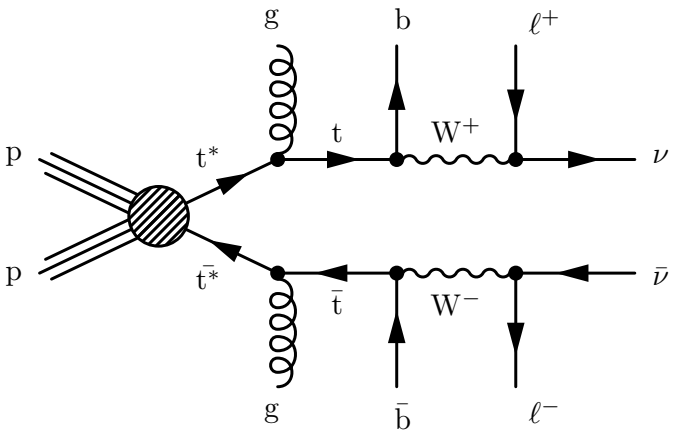


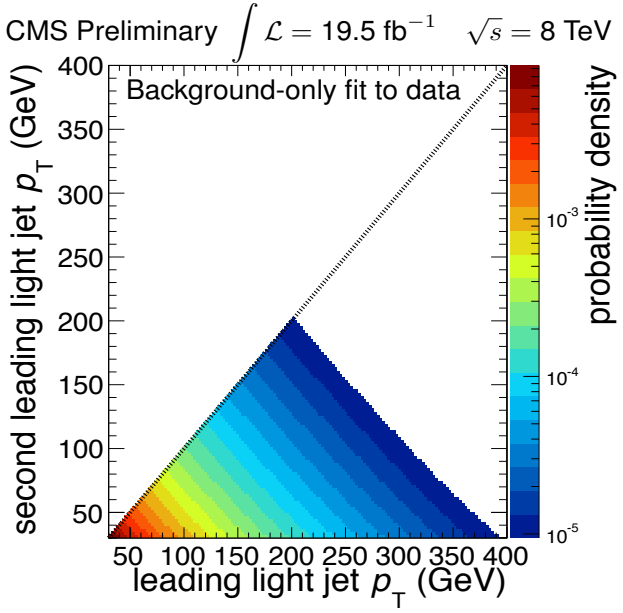


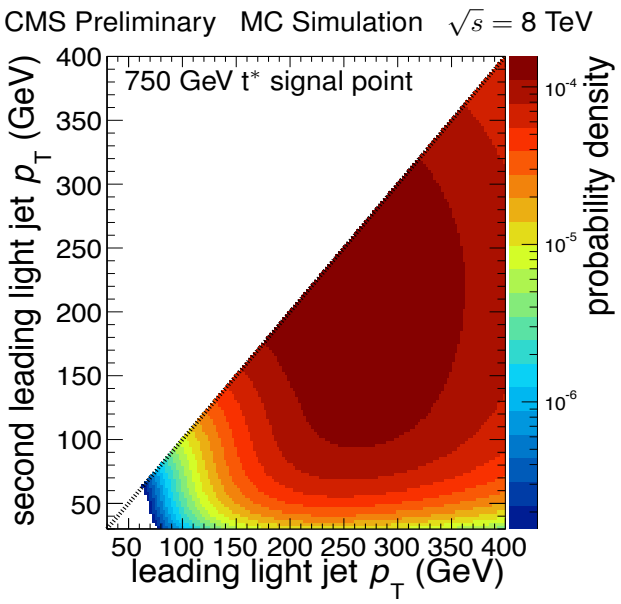
Resonance pair to top + j

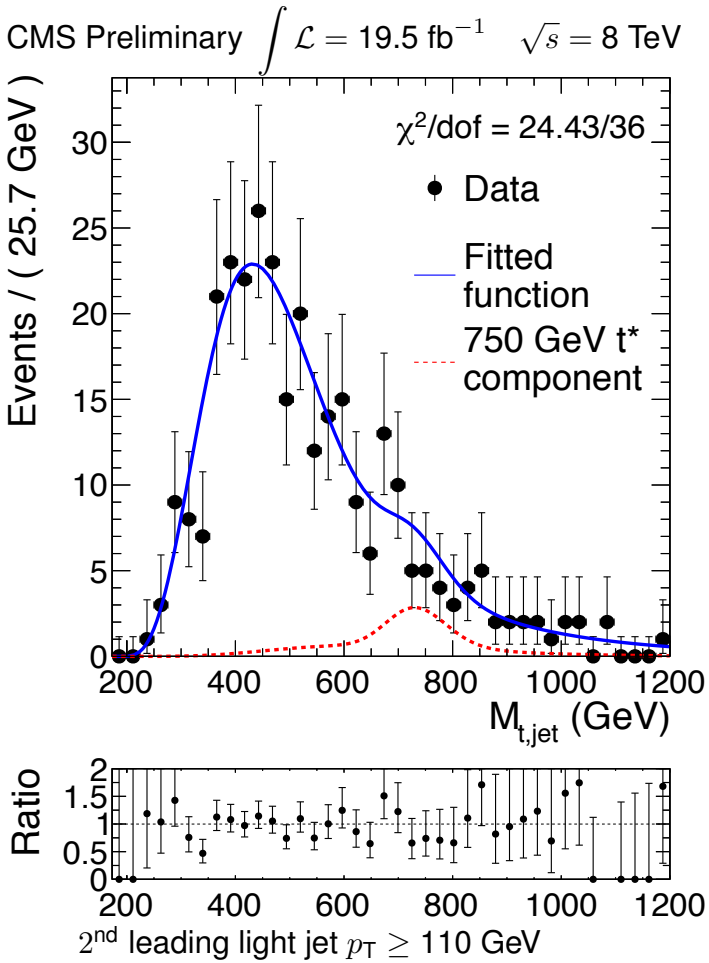
CMS-PAS-B2G-12-008

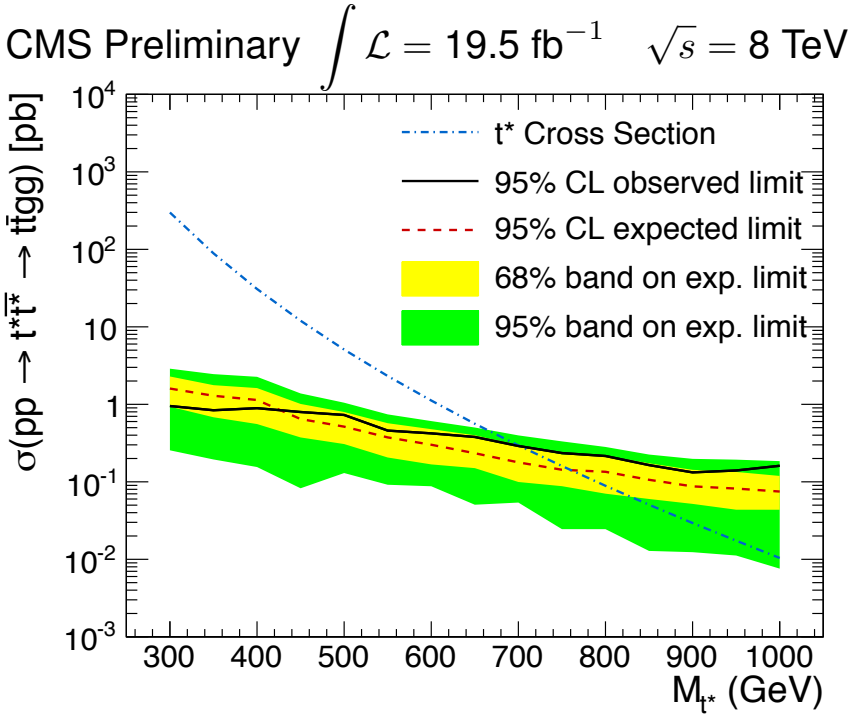
- Two benchmark models:
  - Spin 3/2 excited top quark
  - RPV bottom squark
- Signature:
  - Two leptons (e/mu)
  - 4 jets, with 2 b-tags
- Control / Signal regions:
  - Defined in second leading light jet p_T











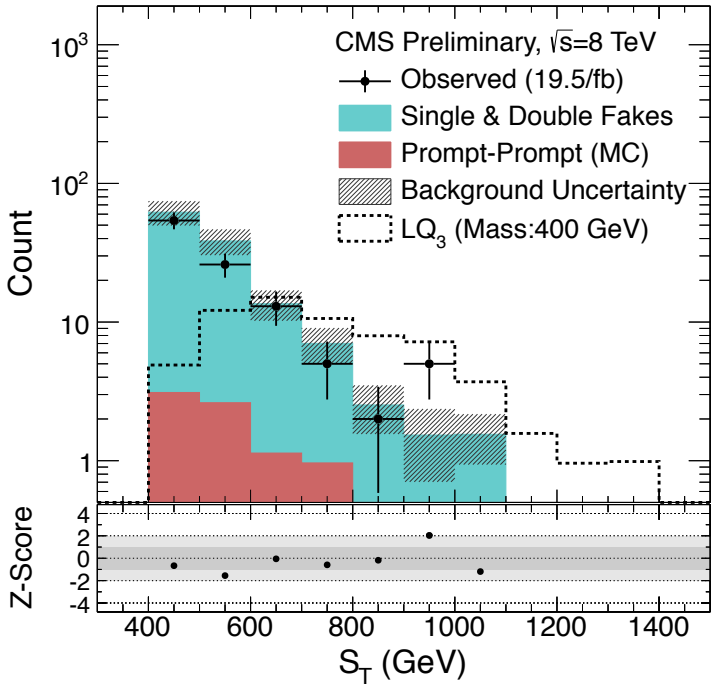
- **CMS results (20/fb):**
  - **M_{t^*} 95% C.L. excluded in range 300 – 703 GeV.**
  - **$M_{b^\sim}$ 95% C.L. excluded in range 250 – 326 GeV.**

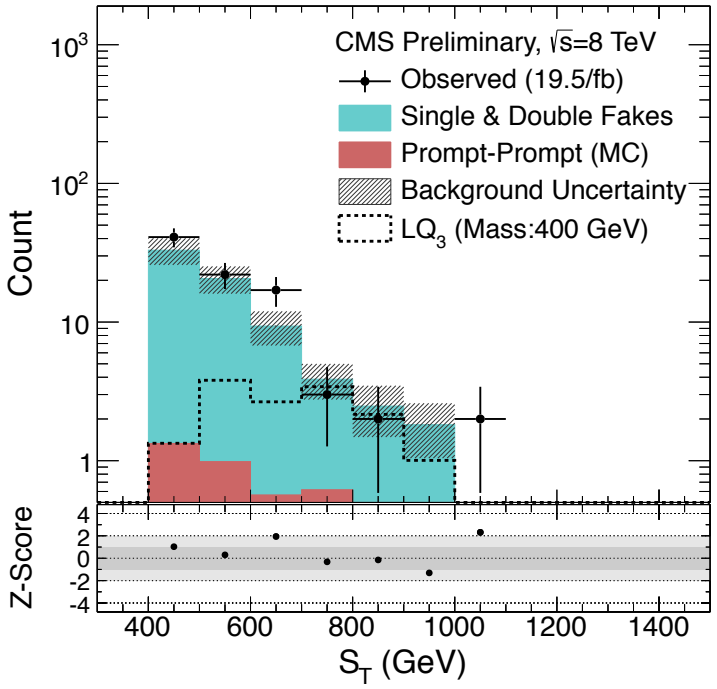
Leptoquarks

3rd Gen Leptoquarks (τ + top)

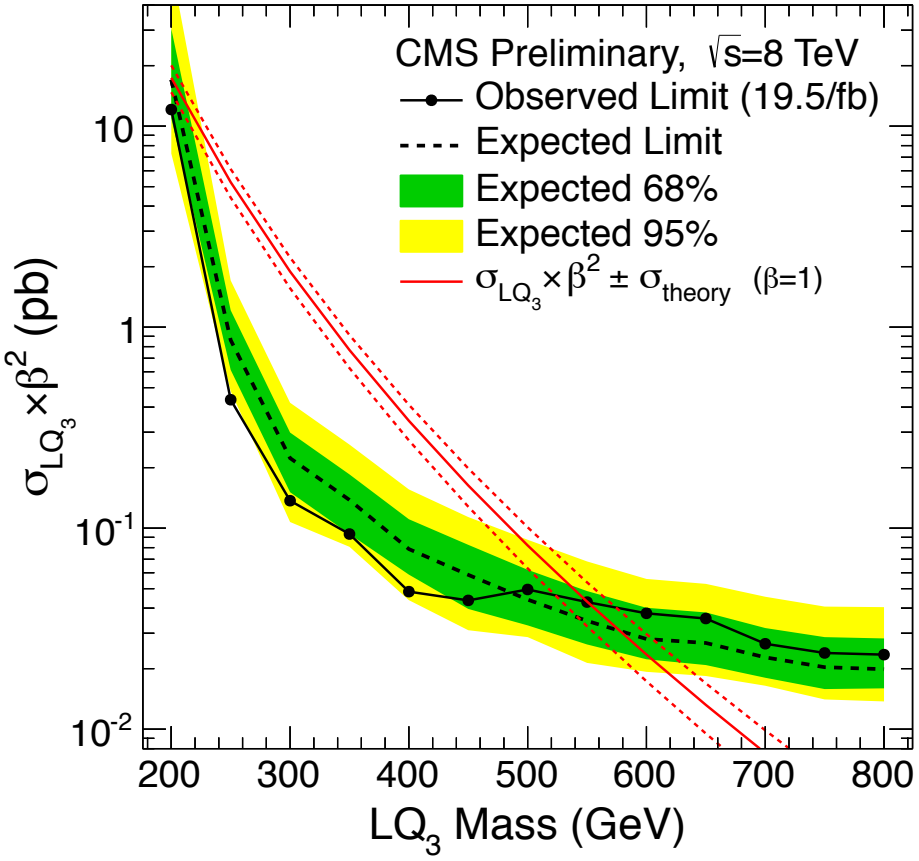
CMS-PAS-EXO-12-030

- LQ → top + tau Analysis:
  - Same sign μ + τ_{had}
  - Two or more jets
  - $S_T > 400$ GeV
- Main backgrounds:
  - Fake leptons (50-90%)
    - Especially fake jets.
  - Z + jets, ttbar + jets
- Analysis in central and forward regions





3rd Gen Leptoquarks (τ + top)

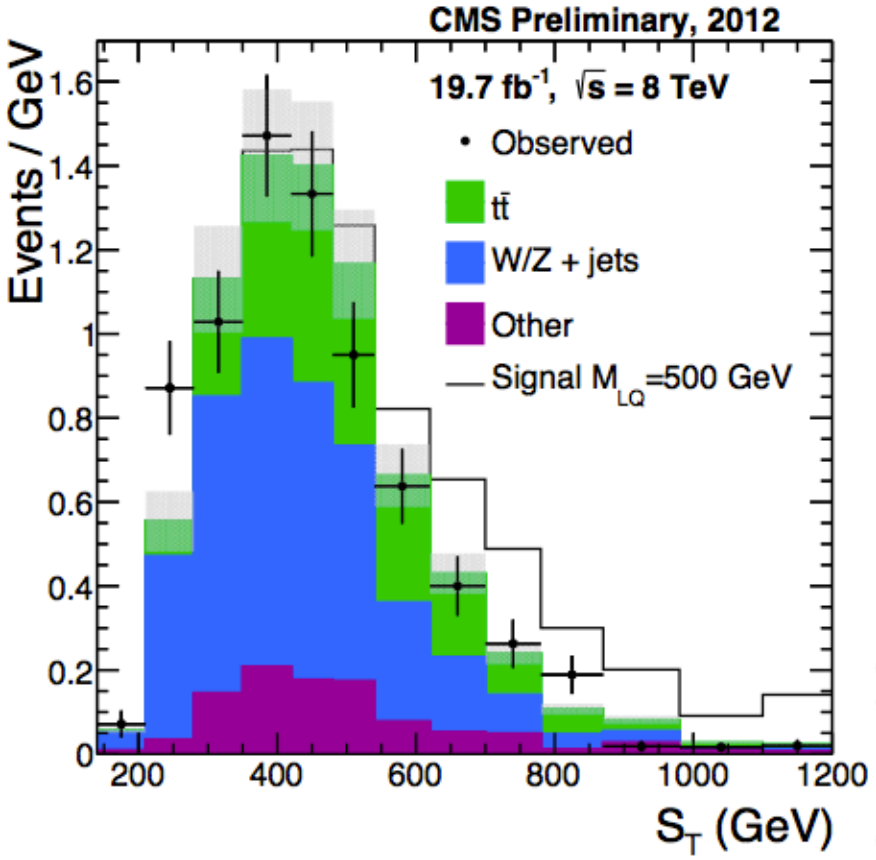


- **CMS results (20/fb):**
  - **M_{LQ3} > 550 GeV at 95% C.L.**

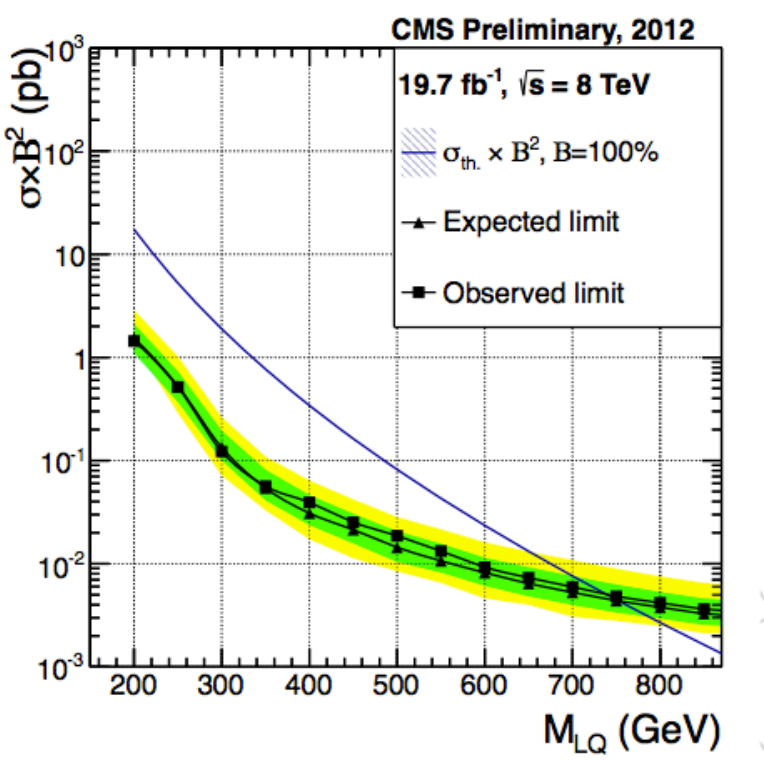
3rd Gen Leptoquarks (τ + bottom)

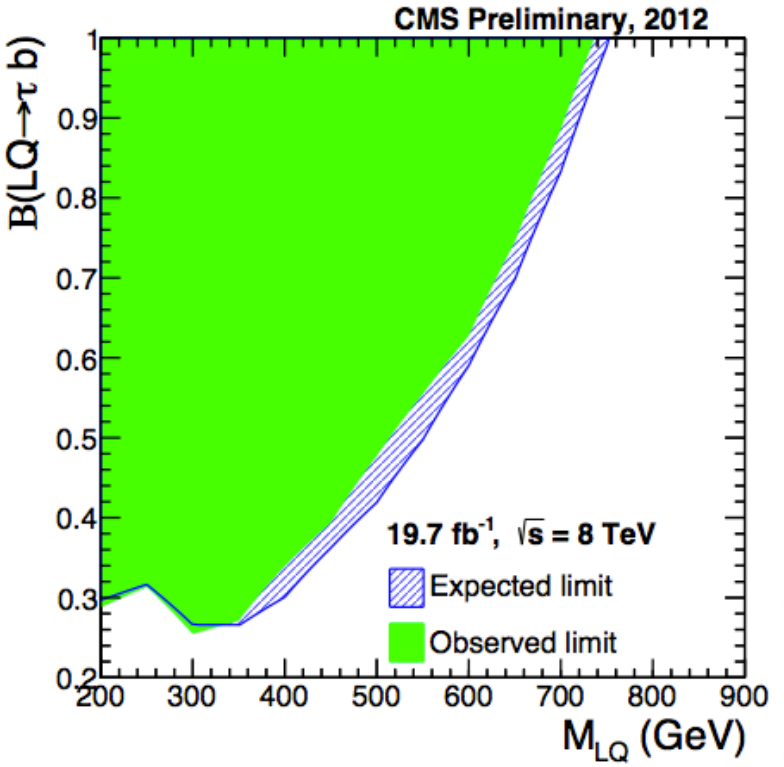
CMS-PAS-EXO-12-032

- LQ → bottom + tau analysis:
  - $\mu/e + \tau_{had}$
  - Two or more jets
  - At least one b-tag
  - $M(l,\tau_{had}) > 250$ GeV
- Main backgrounds:
  - W/Z + jets
  - Inclusive ttbar
- Search performed in S_T variable.
- Analysis also puts limits in light stops.



3rd Gen Leptoquarks (τ + bottom)





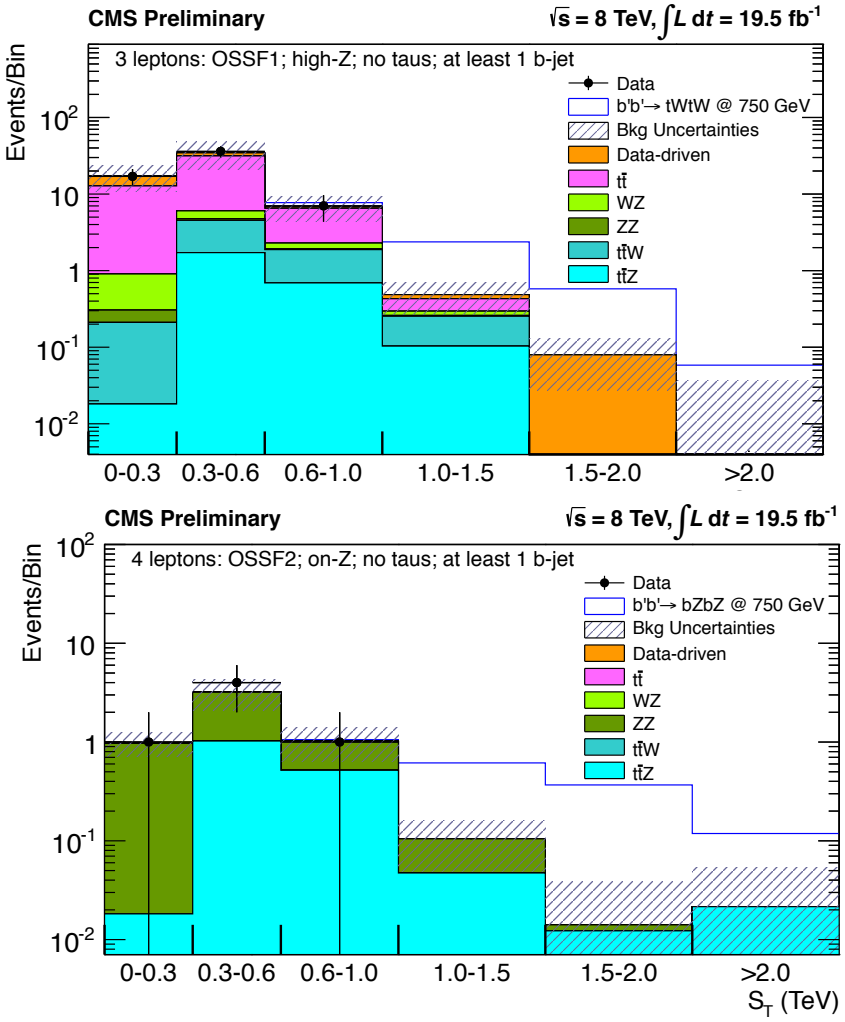
- **CMS results (20/fb):**
  - M_{LQ} > 740 GeV at C.L = 95% (B=1)
  - Excluded region also in (M_{LQ}, B) plane.

Vector-like Quarks

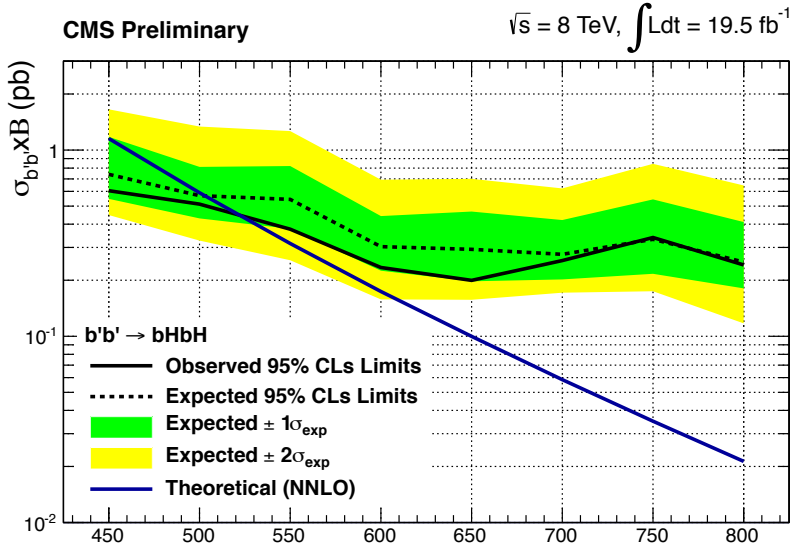
Vector-like quarks: Multileptons

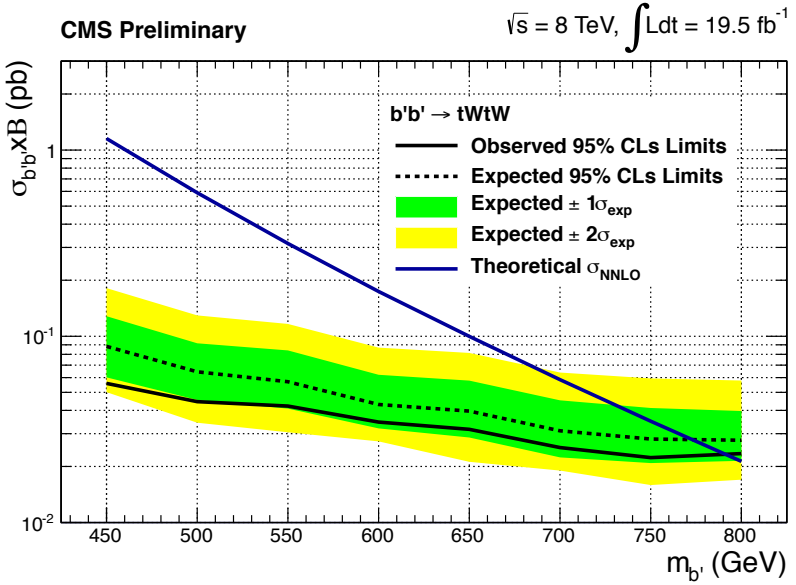
CMS-PAS-B2G-12-020
CMS-PAS-B2G-13-003

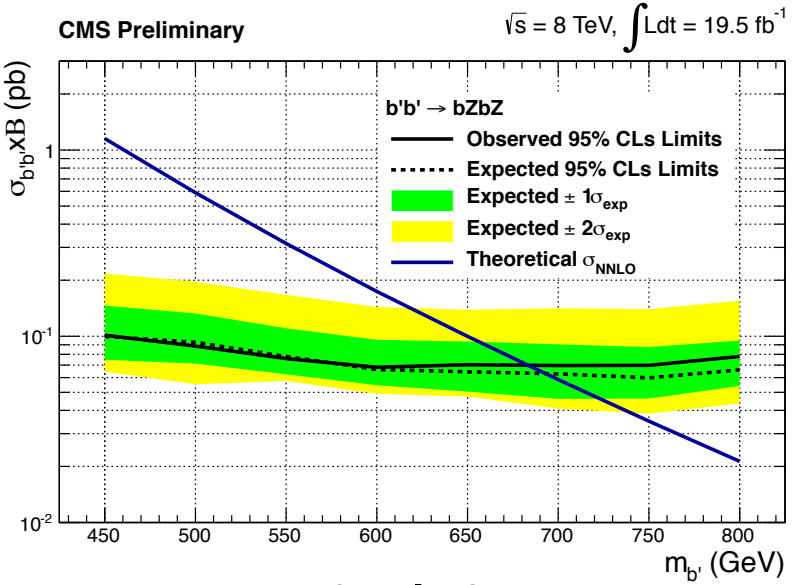
- Pair production of b' → bZ, tW, bH.
  - Remember: not the 4-th generation chiral quark.
- Signature:
  - At least three leptons (e, μ, τ_{had})
  - Classifications:
    - Number of b-tags (0,1+)
    - Multiplicity of OSSF pairs
    - S_T variable
- Backgrounds:
  - 3-lepton channel: mainly ttbar
  - 4-lepton channel: mainly ZZ

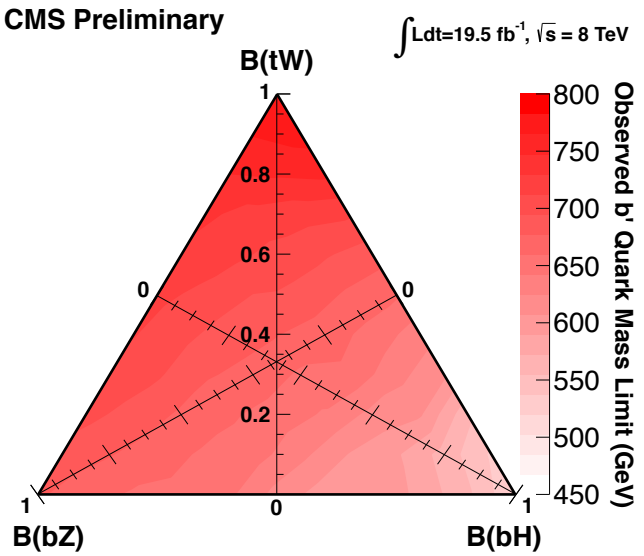


- This talk is about non-boosted results only.
  - For boosted results see P. Azzi's talk!







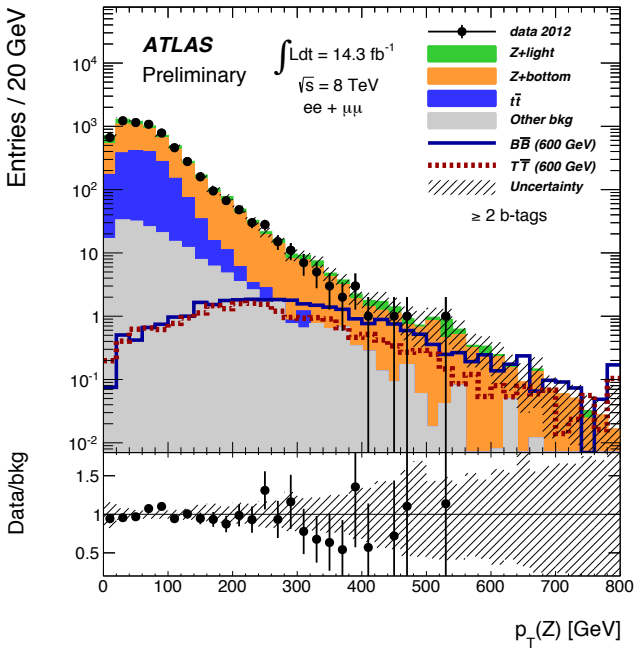


- **CMS results (20/fb):**
  - Limits in function of the different branching ratios.
  - **Exclusion of b' lightest than 520—785 GeV, at 95% C.L.**

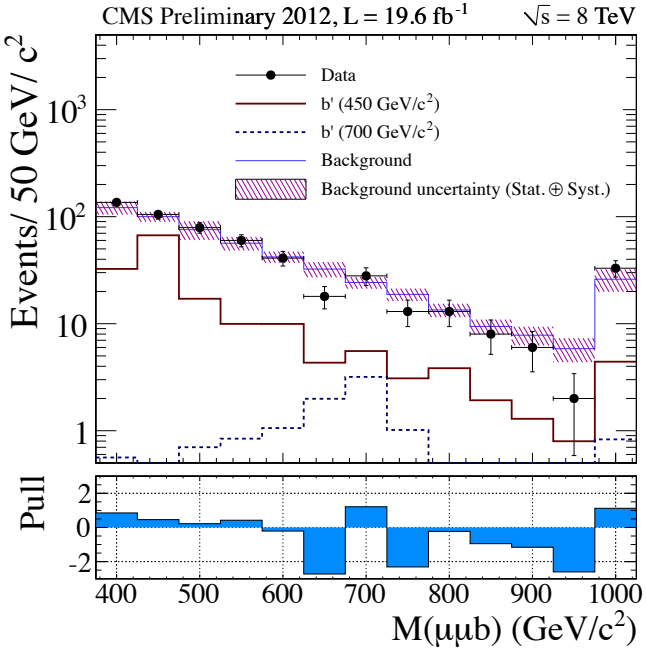
Vector-like quarks: Zb + X

ATLAS-CONF-2013-051
ATLAS-CONF-2013-056
CMS-PAS-B2G-12-021

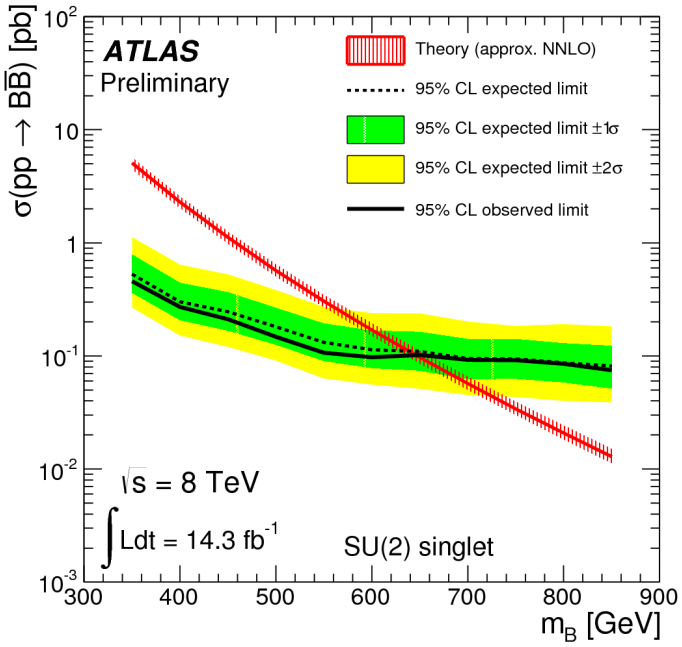
- Common strategy:
  - Z → ee, mumu
  - p_T Z > 150 GeV
- ATLAS analysis (14.3/fb)
  - Single lepton triggers
  - HT (jets) > 600 GeV
  - N btags >= 2

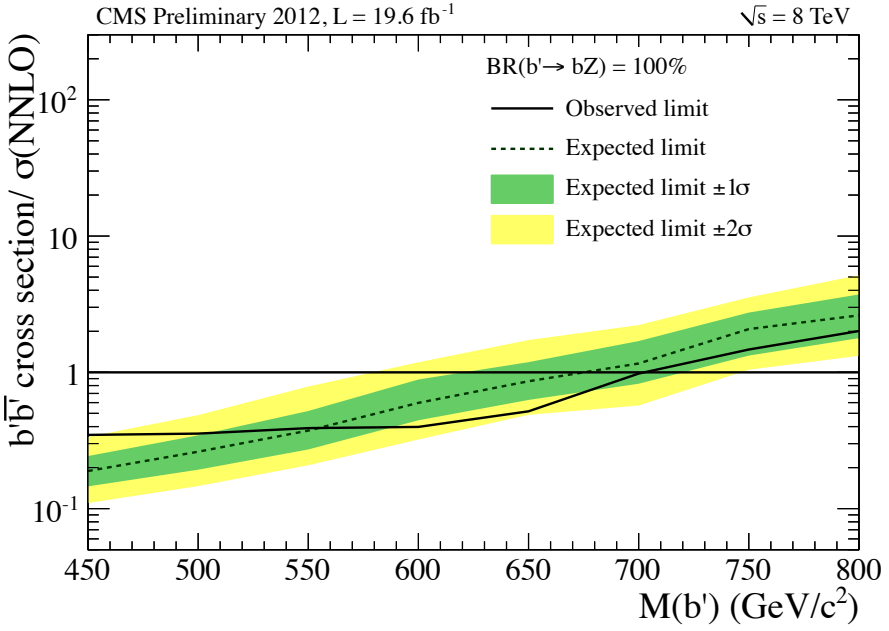


- CMS analysis (19.6/fb)
  - Double lepton triggers
  - N btags >= 1
  - p_T (bjet) > 80 GeV
  - M(llb) > 375 GeV

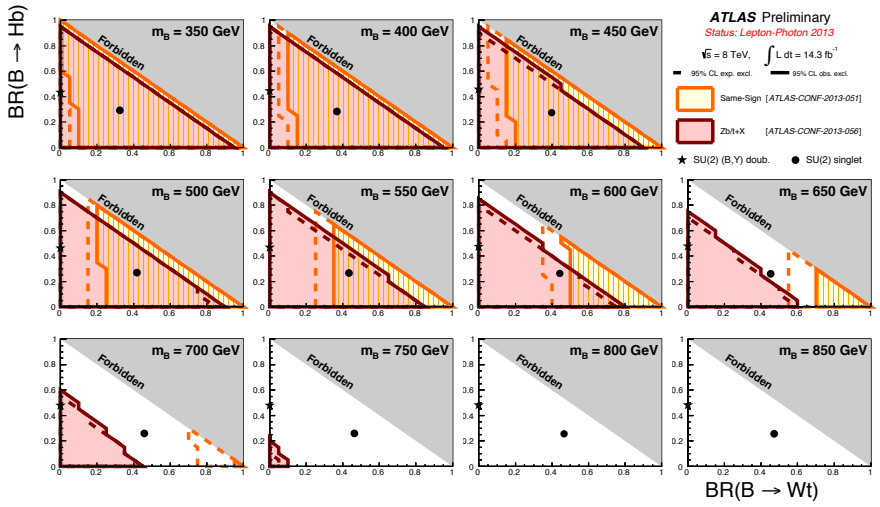


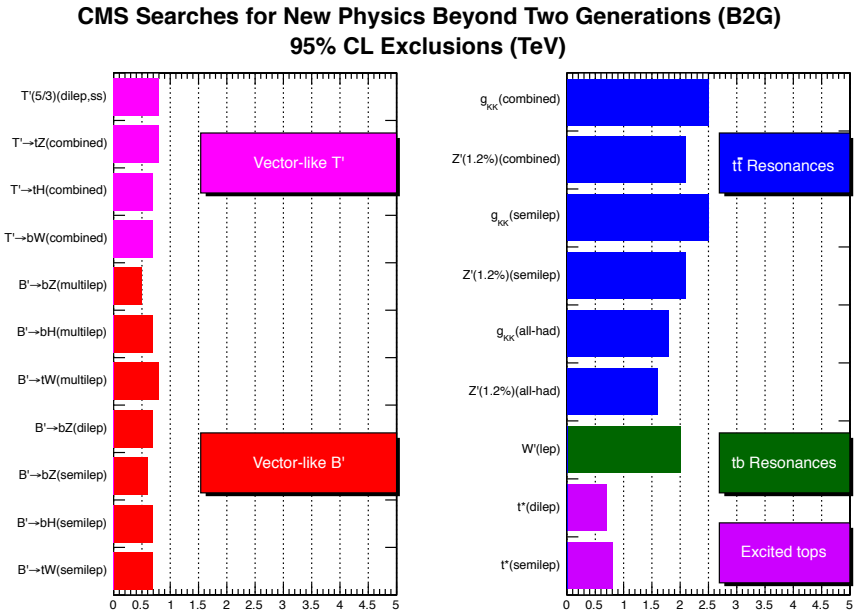
- **ATLAS results (14/fb):**
  - M(b') > 645 GeV for b' singlet (BR b' → Zb = 1/3)
  - M(b') > 725 GeV for (b',Y) doublet (BR b' → Zb = 2/3)
- **CMS results (20/fb).:**
  - M(b') > 700 GeV for BR(b' → bZ) = 100%
  - BR(b' → bZ) smaller than [0.3, 1.0], as function of b' mass.





Vector-like quarks: Summary





ATLAS 95% C.L. Exclusions

CMS 95% C.L. Exclusions

Conclusions and Outlook

Expectations for Run II

- Standard searches (resonances in dileptons, diphotons, dijets) will continue to be performed.
  - These searches are usually at the forefront of reconstruction techniques, due to the pushing the p_T boundary.
- Model-independent searches: liaison to theorists.
  - Both the "event classes" kind of analysis and recasts of existing searches.
- Searches with final states with 3rd generation and Higgs Bosons
  - Moving to the forefront.

Conclusions

- Searches for Physics Beyond the Standard Model
  - One of the more active areas of both ATLAS and CMS Collab.
- Efforts are being made in order to
  - Address more benchmark models
  - Give model-independent results to theorists.
- 2012 was the year of the Higgs
  - Now Higgs channels are signatures in the BSM search!
- 2015 will be (hopefully) the year of BSM! ☺

  - Please always check our latest results:
    - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
    - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
    - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G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