BSM searches at the LHC

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on behalf of CMS and ATLAS Collaborations

LFC15: 2015 Linear and Future Colliders Workshop,
7 - 11 September 2015,
Trento, Italy

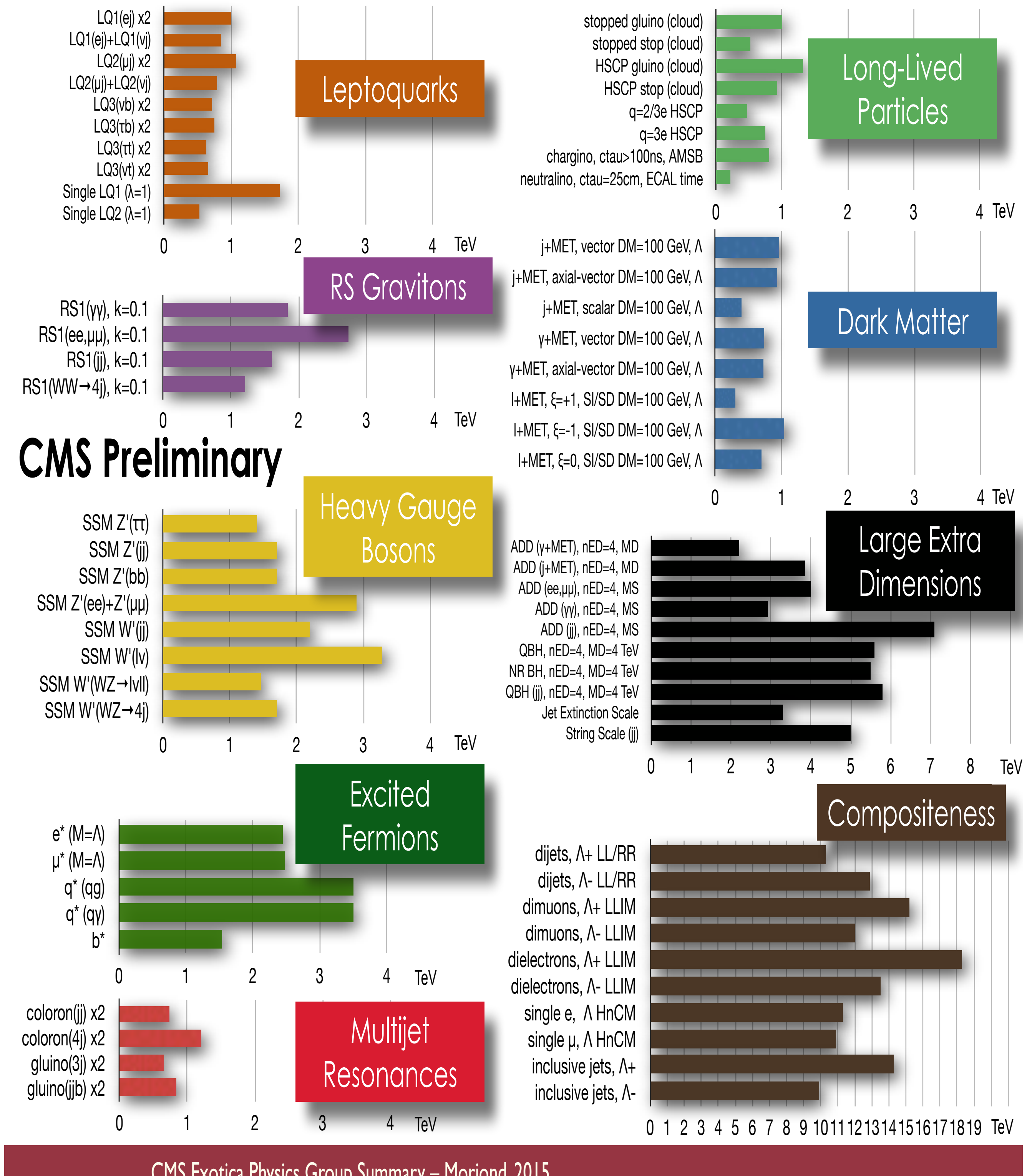
Outline

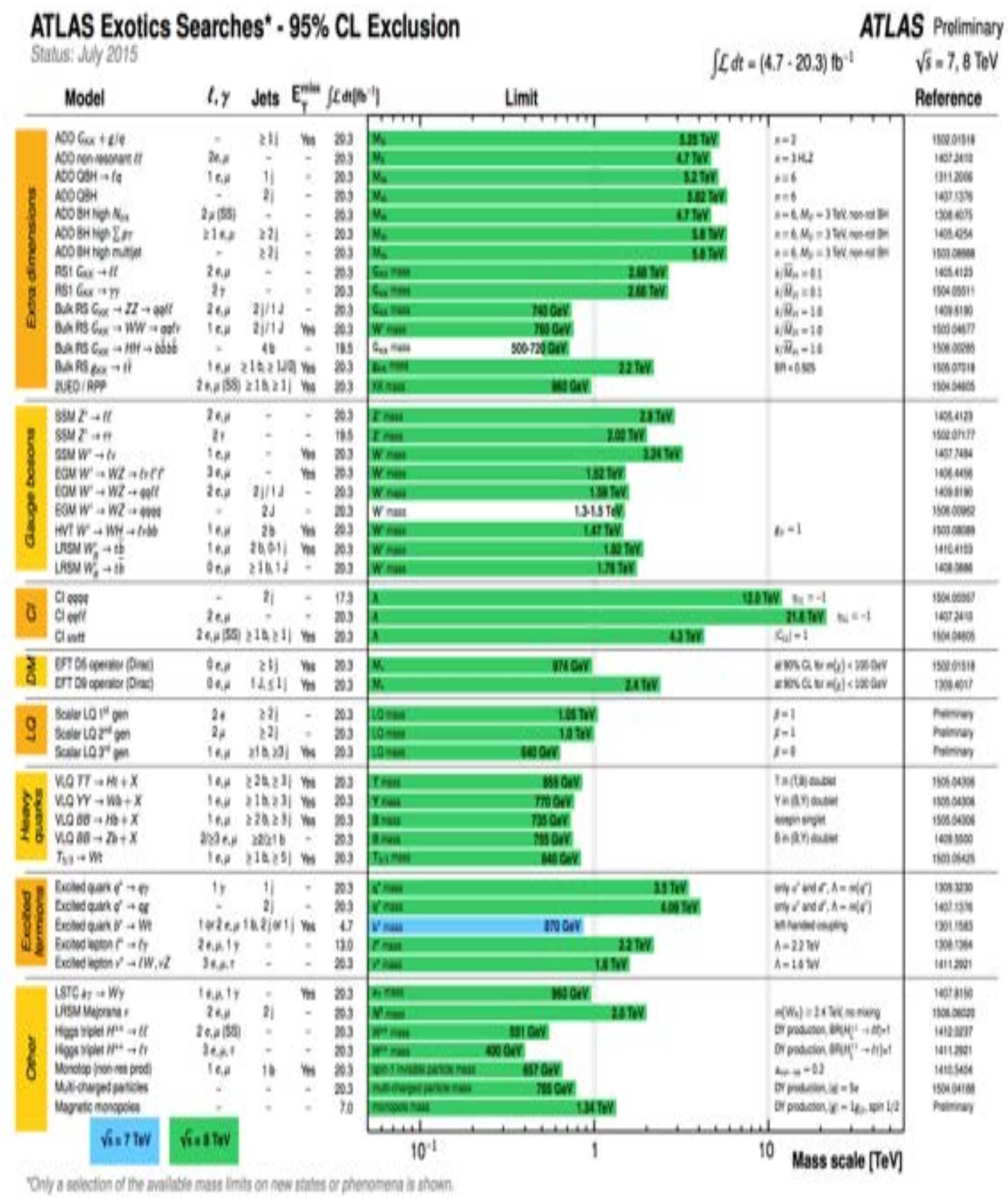
- Exotic searches (with some SUSY interpretations)
  - X+MET interpretations
    - MonoX
    - Razor
    - Higgs Portal
  - Resonance searches
    - Dijet
    - Dilepton
    - Diphoton
  - Long-lived searches
    - Displaced jets
    - Trackless jets
    - Displaced / delayed photons
    - Lepton jets
    - HSCP
- SUSY searches
  - SUSY inclusive searches
    - Hadronic
    - Single/di-[os/ss] lepton
    - Photon
  - SUSY third-generation searches
  - SUSY RPV searches
- Summary

In this talk, introduction to SUSY/EXO will be skipped and all results cannot be covered.

Exotic and supersymmetry searches

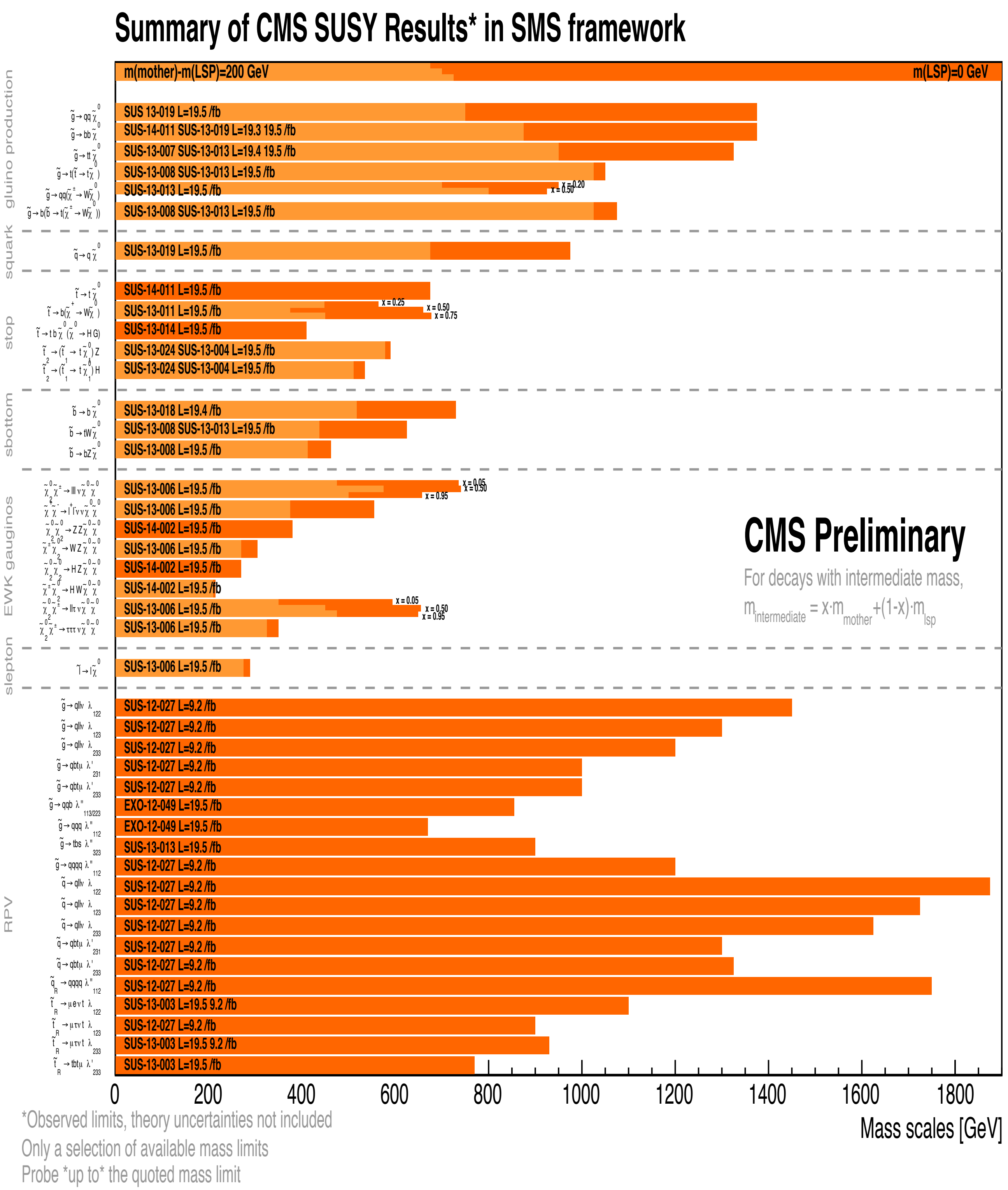
- ATLAS and CMS searches for new phenomena other than Supersymmetry. No evidence yet for the BSM.

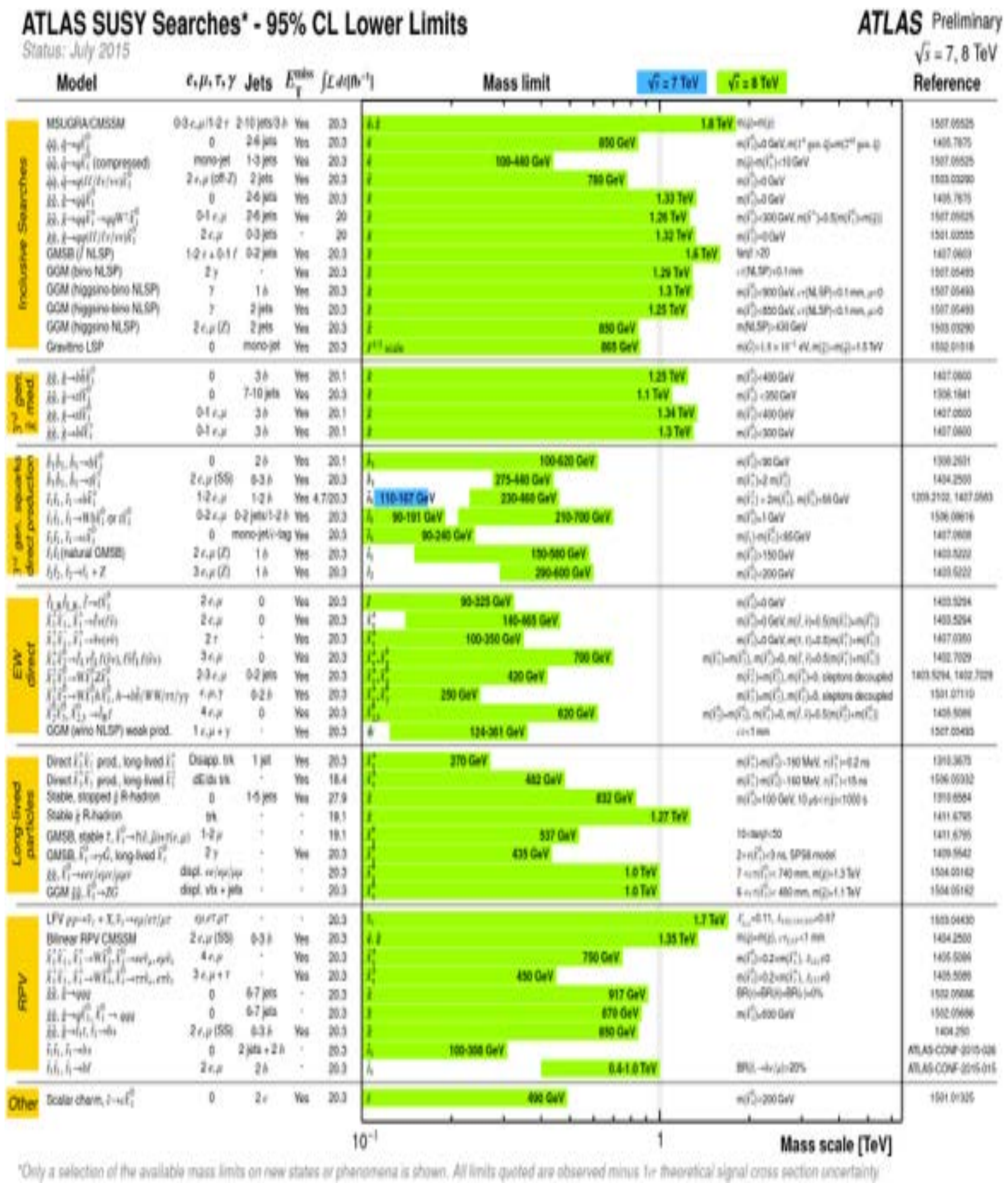




Exotic and supersymmetry searches

- Exclusion limits of CMS and ATLAS SUSY searches.

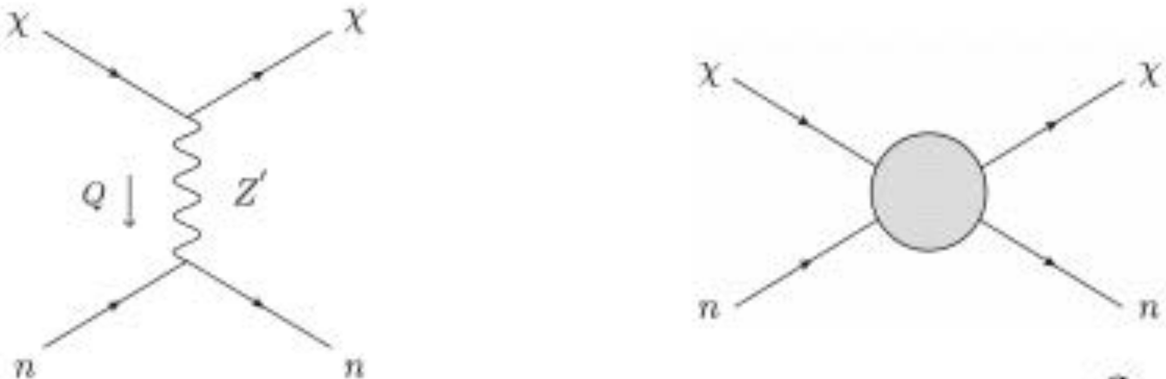




X+MET interpretations

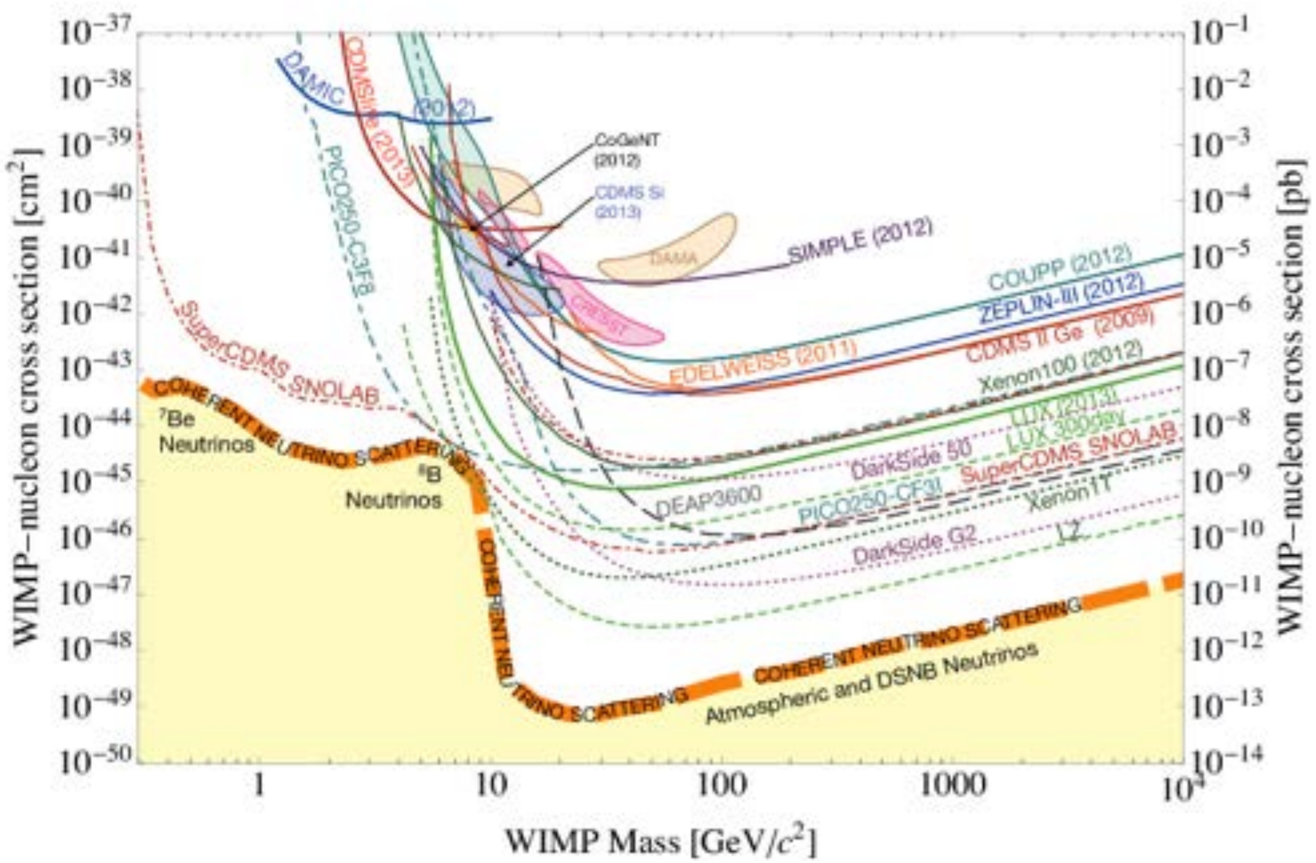
- DM case: limits are quoted in terms of the WIMP-Nucleon cross-section.

Direct detection



Collider

$$\sigma_n \sim \left(\frac{g_n g_\chi}{Q^2 - m_{Z'}^2}\right)^2 \approx \frac{g_n^2 g_\chi^2}{m_{Z'}^4}\left(1 + \frac{Q^2}{m_{Z'}^2} + \cdots\right)^2$$



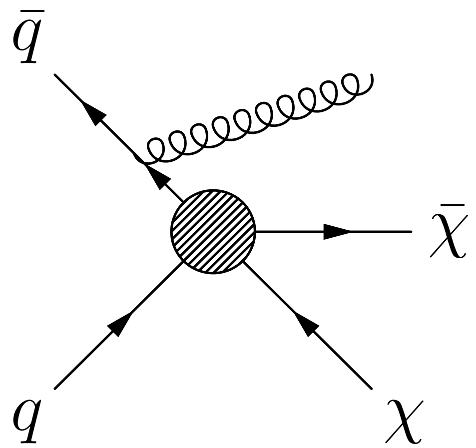
- Contact interaction if

$$m_{Z'} \gg Q = \sqrt{2 m_n E_{\mathrm{R}}} \approx 50\ \mathrm{MeV}$$

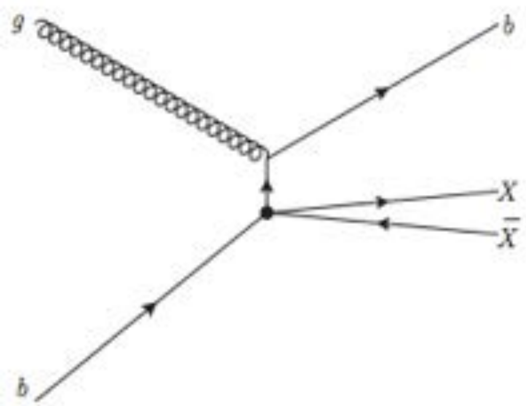
- **Use of effective field theory** (EFT) to place a limit on the contact interaction scale $\Lambda \equiv \frac{m_{Z'}}{\sqrt{g_q g_\chi}}$

- **Use simplified model**

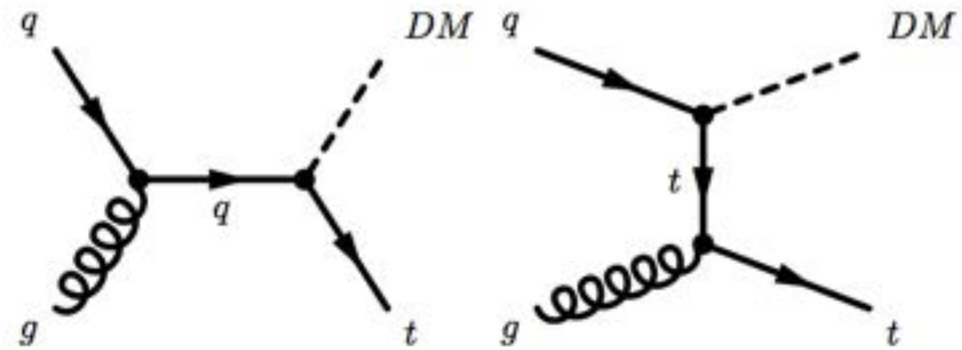
X+MET interpretations



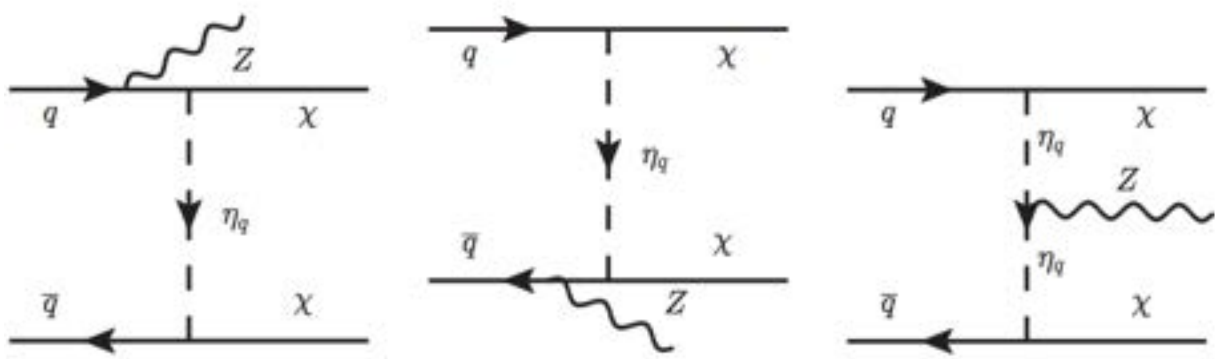
MonoJet / Razor



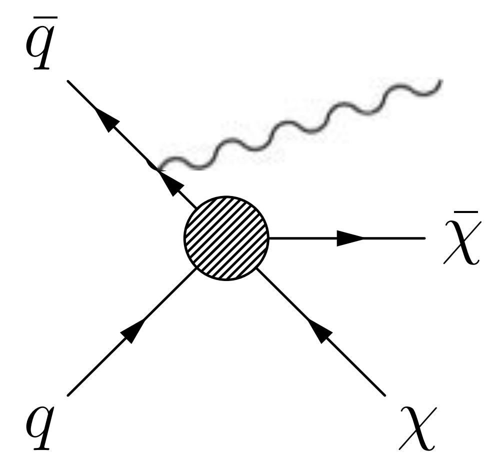
MonoB



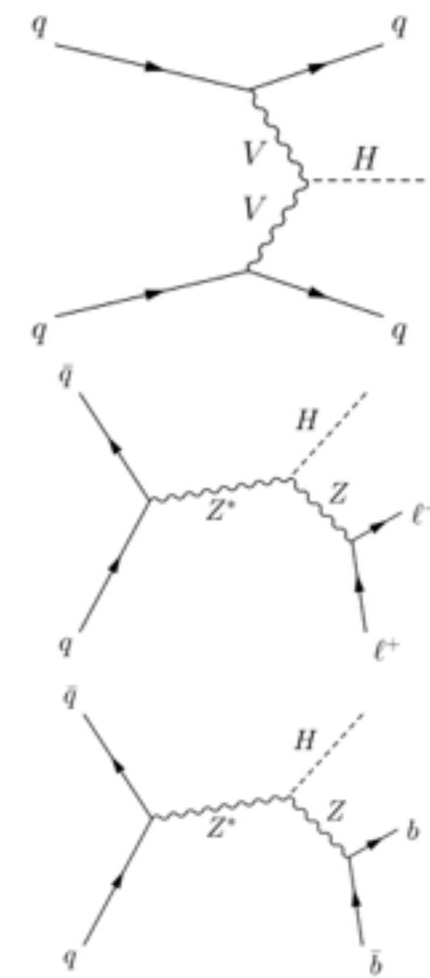
MonoTop



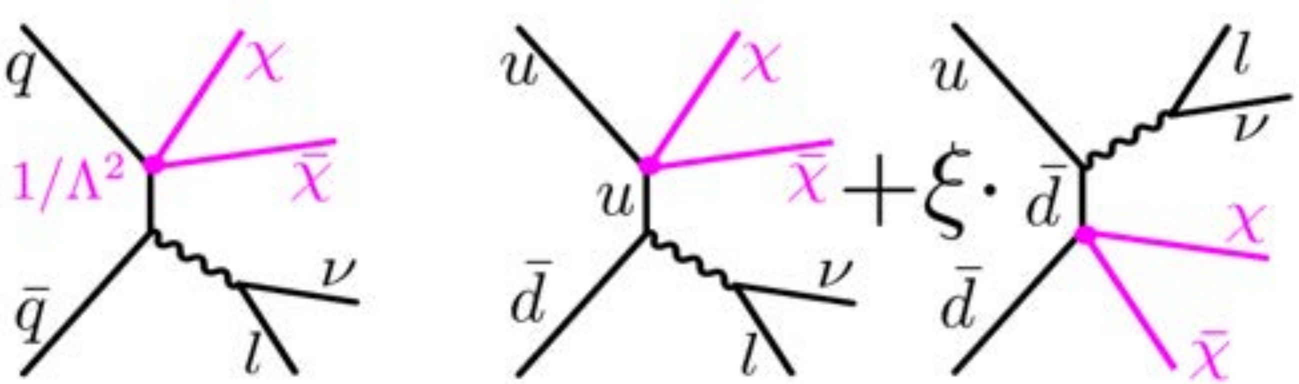
MonoZ



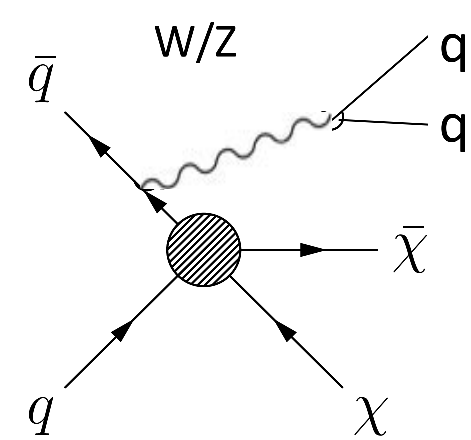
MonoPhoton



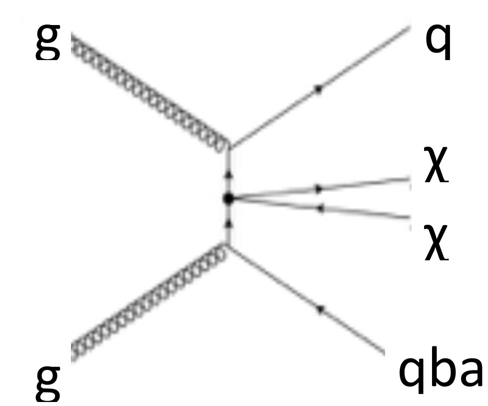
Higgs Portal



MonoW (monoLepton)



MonoW/Z (Hadronic)

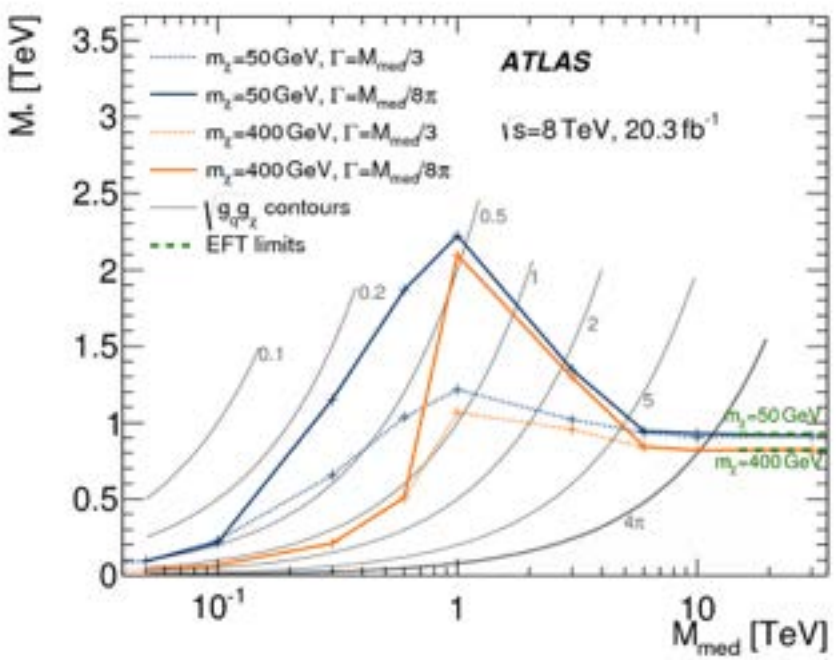


BBbar /TTbar

Jet+MET interpretations

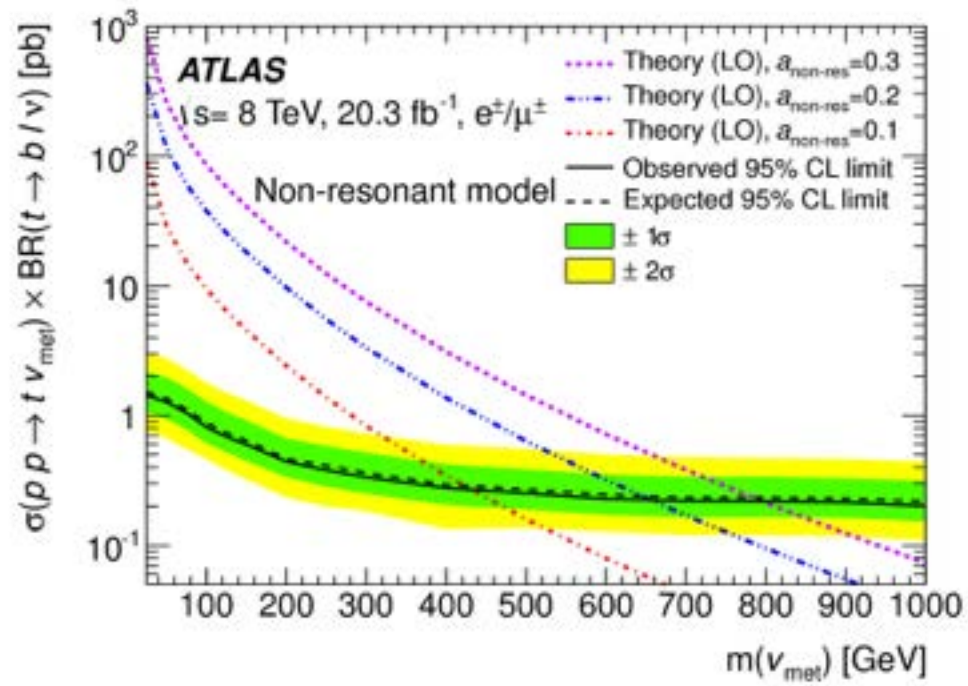
Monojet

ATLAS, Eur. Phys. J. C 75 (2015) 299



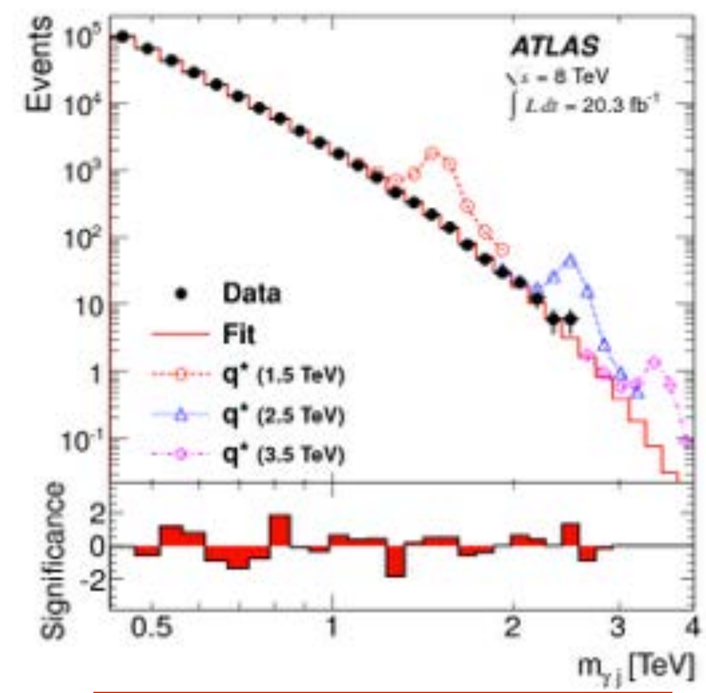
Monotop (leptonic/hadronic)

ATLAS, Eur. Phys. J. C 75 (2015) 79

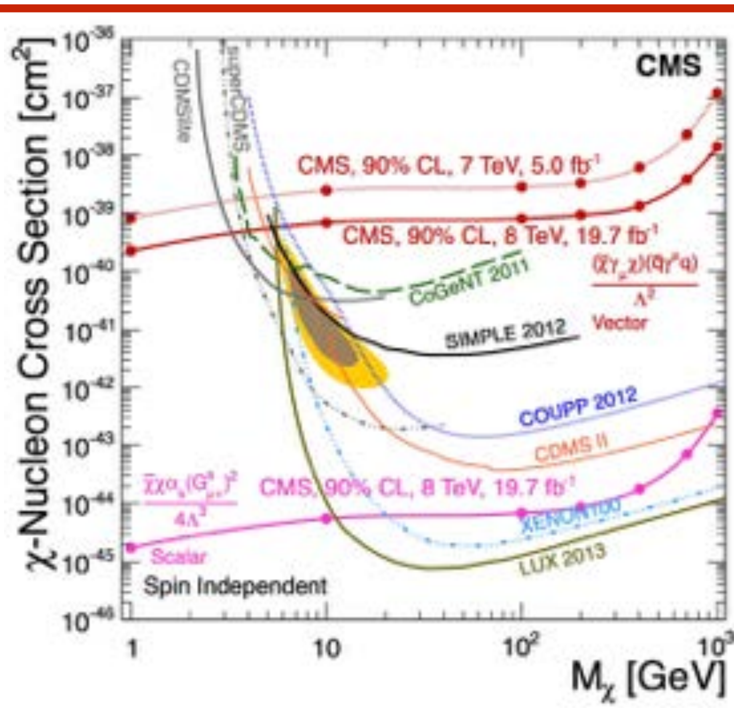


Monophoton

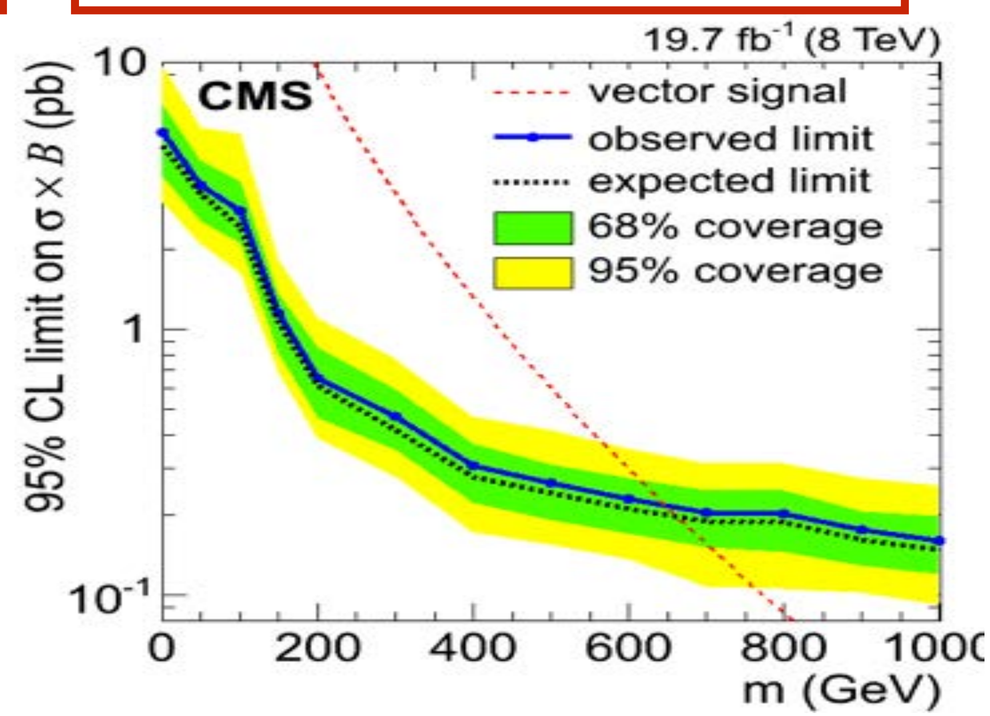
ATLAS, Phys. Lett. B 728 C (2014) 562



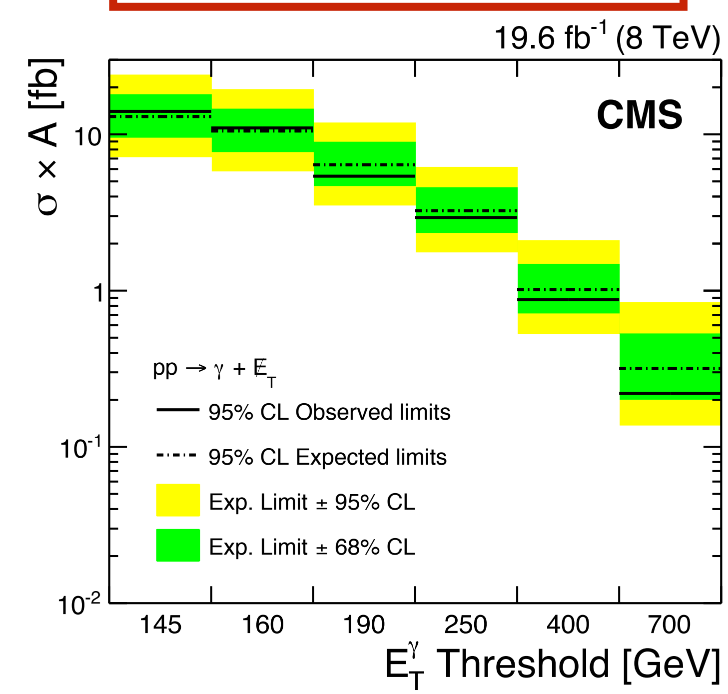
CMS, Eur. Phys. J. C 75 (2015) 235



CMS, Phys. Rev. Lett. 114, 101801

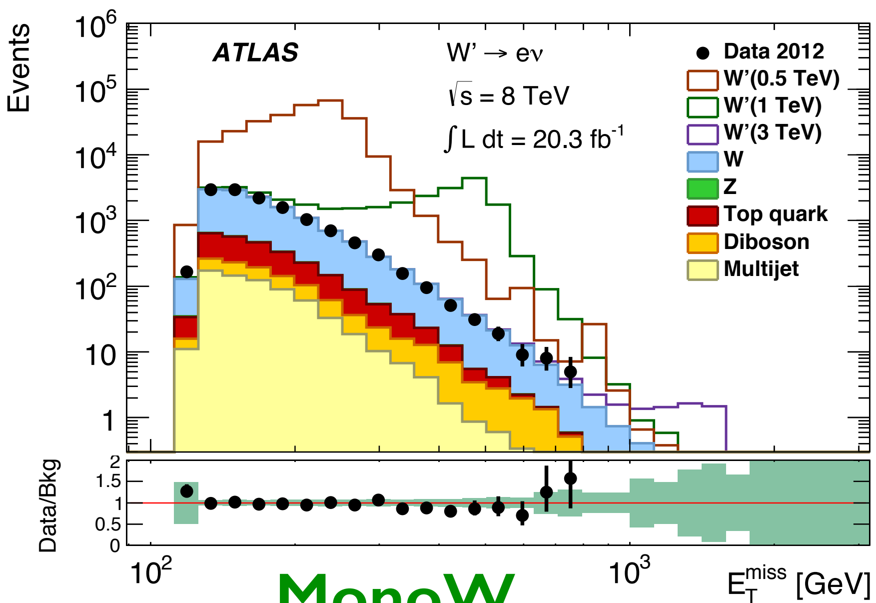


CMS, arXiv:1410.8812



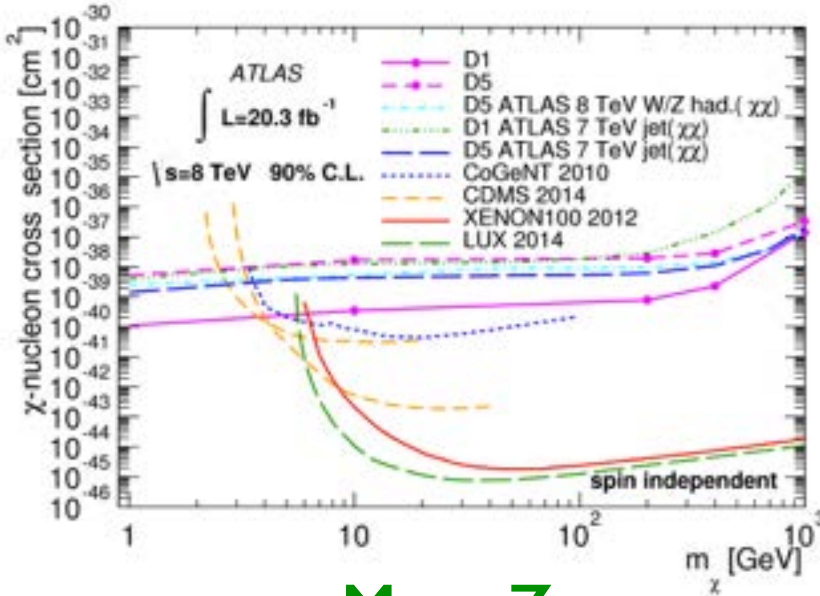
Boson+MET interpretations

ATLAS, JHEP09 (2014) 037



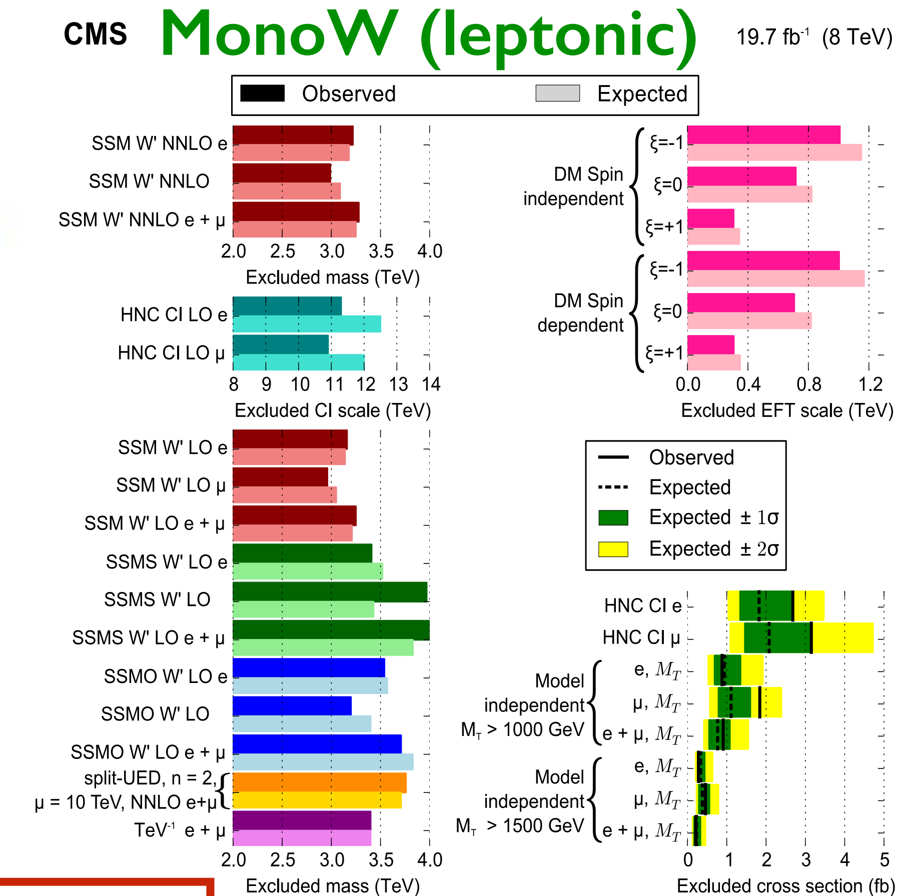
MonoW (leptonic)

ATLAS, Phys. Rev. D. 90, 012004

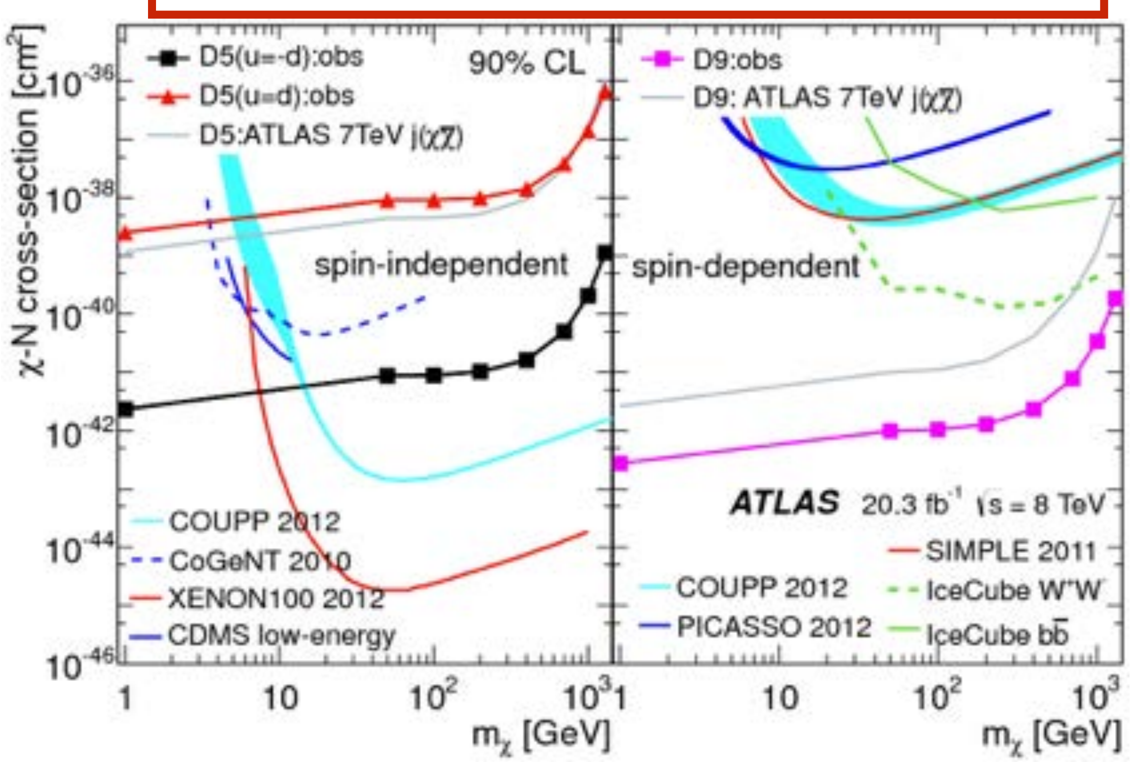


MonoZ (leptonic)

CMS, JHEP09 (2014) 037

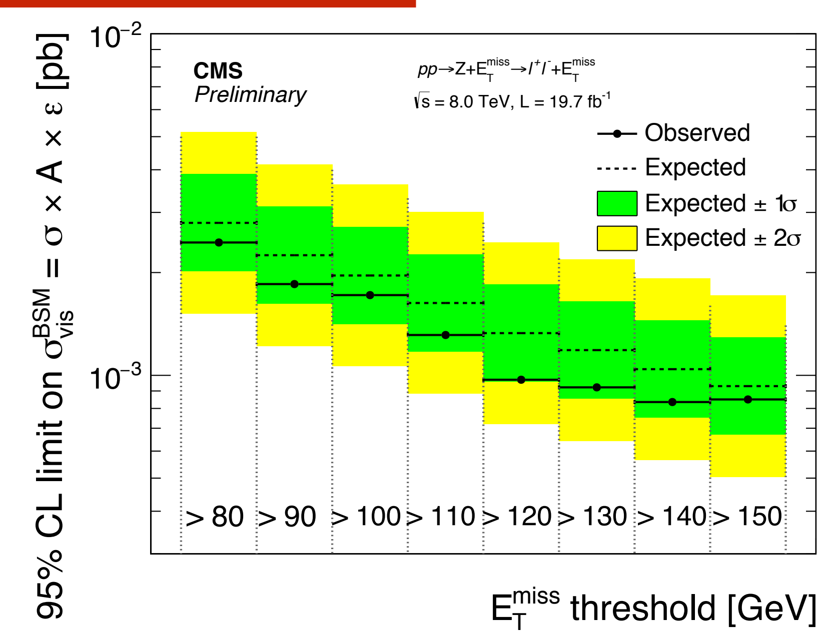


ATLAS, Phys. Rev. Lett. 112, 041802



MonoW,Z (Hadronic)

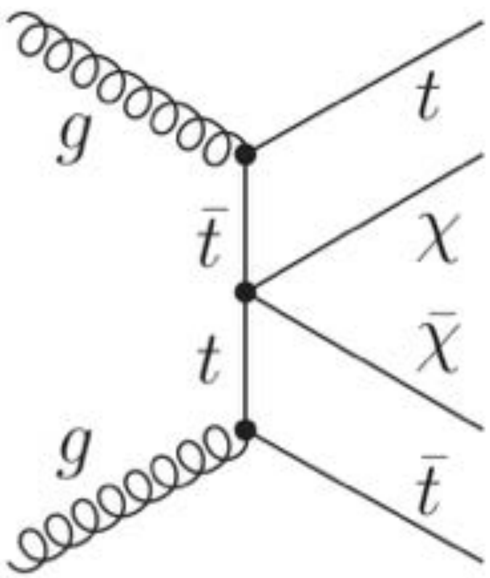
CMS, CMS-PAS-EXO-12-054

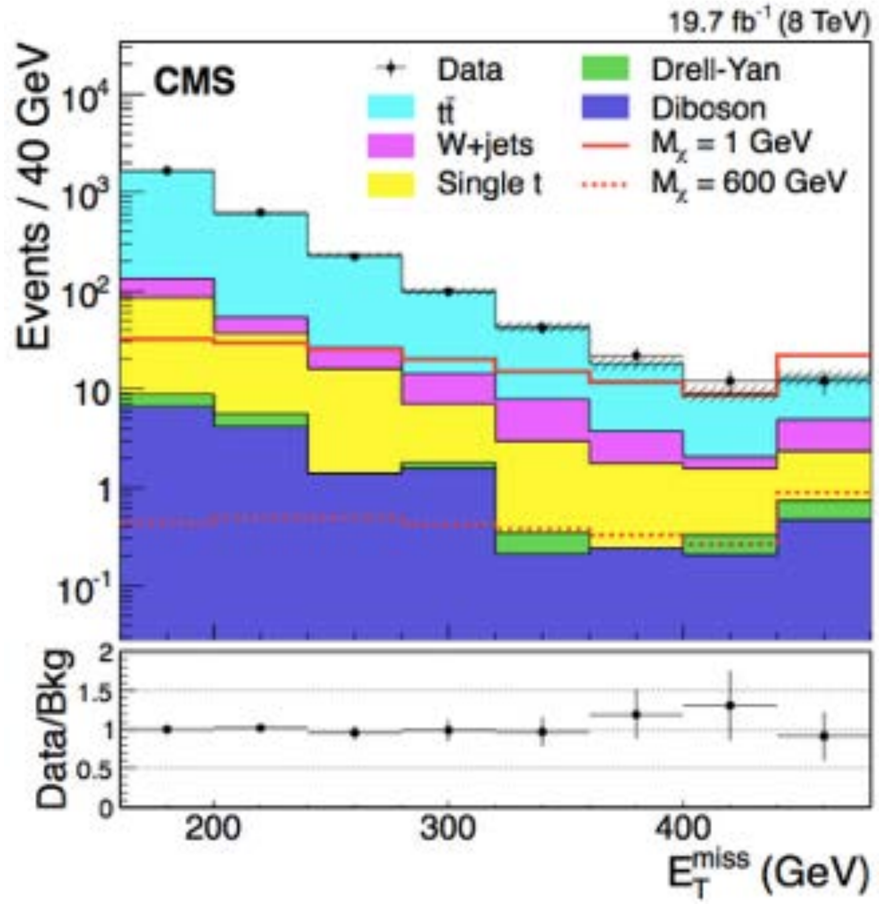


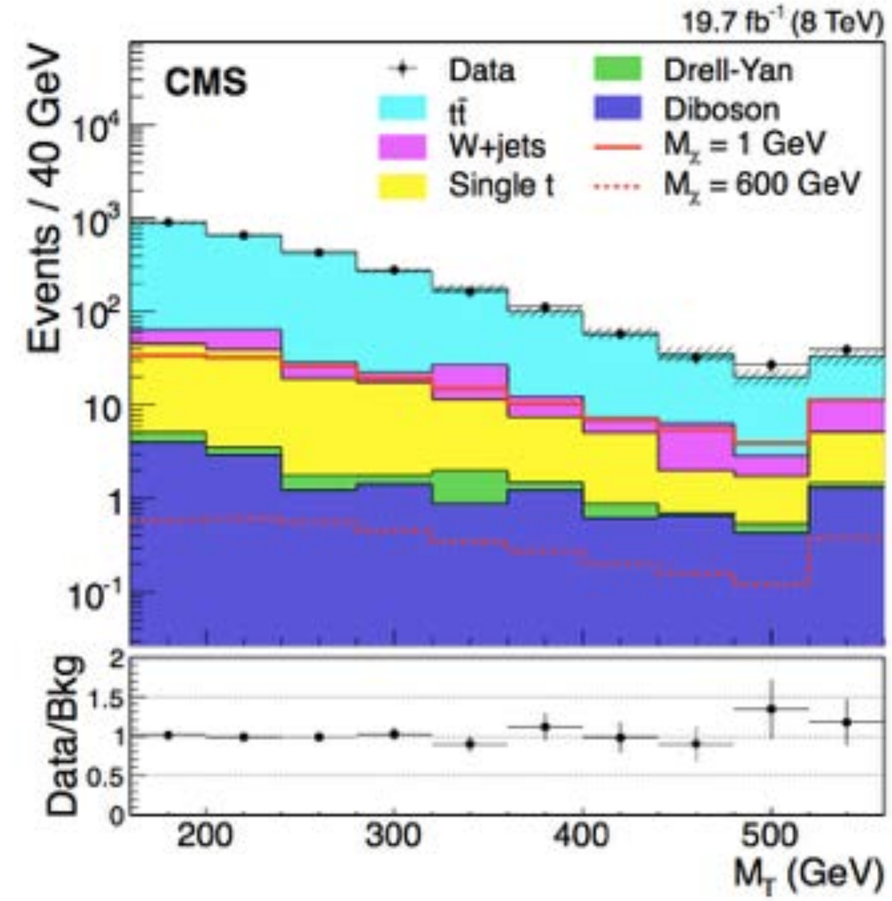
MonoZ (leptonic)

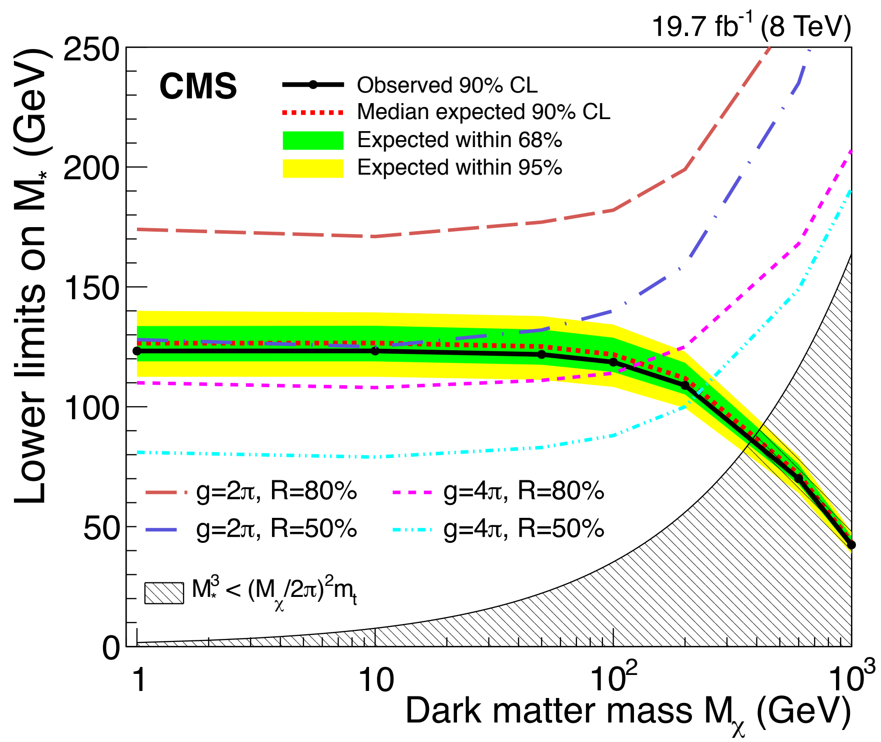
Top pair+MET interpretations

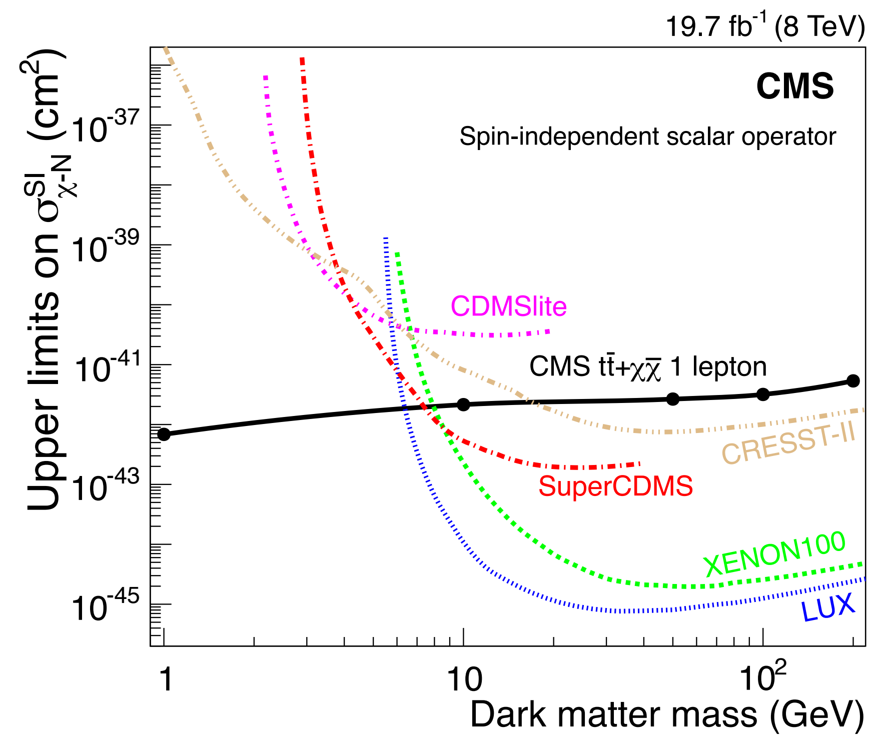
CMS, JHEP 06 (2015) 121



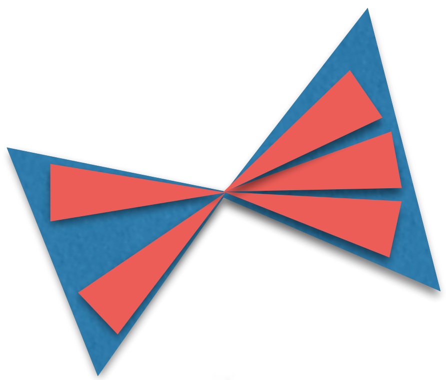








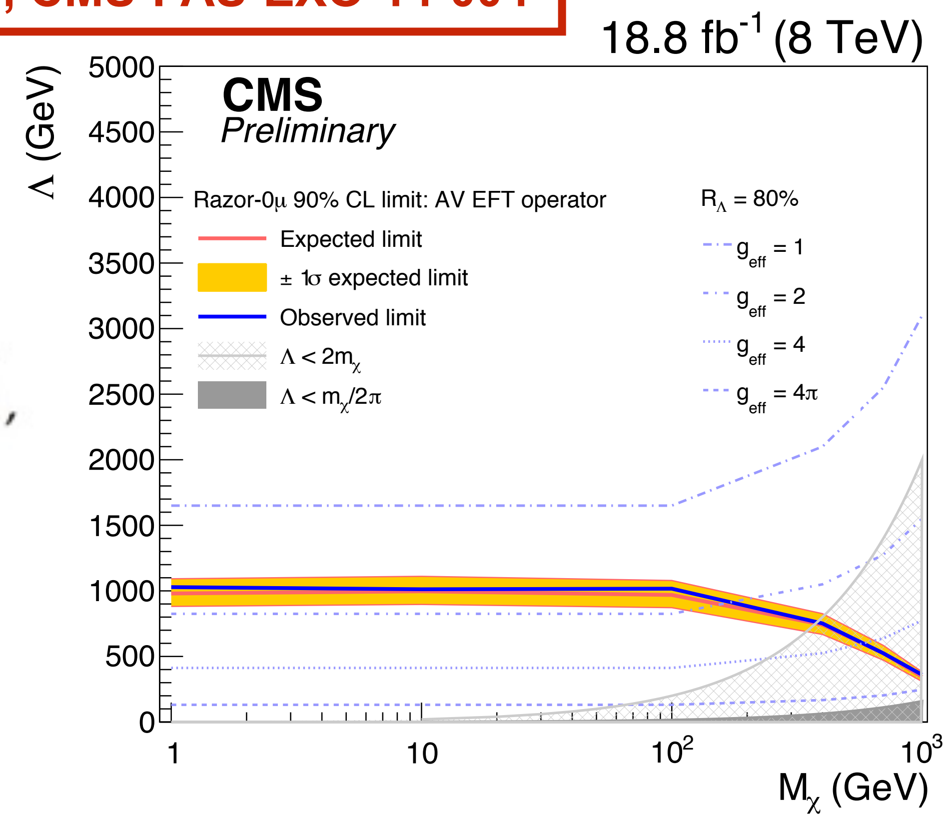
Dark matter interpretations: Razor variables

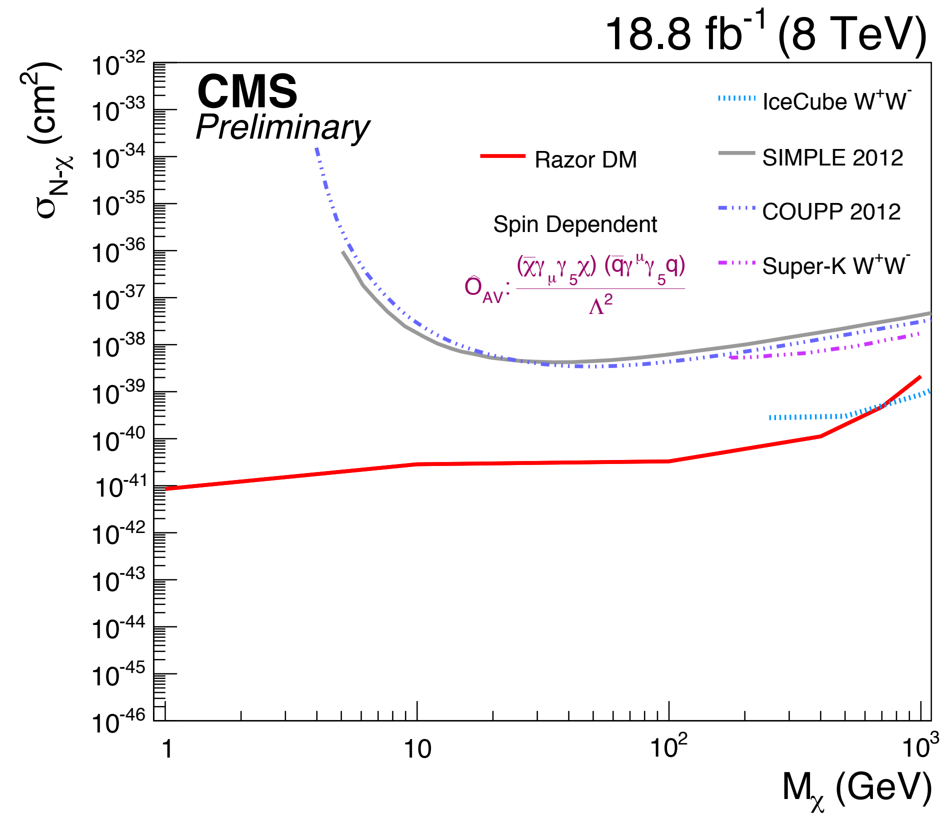


CMS, CMS-PAS-EXO-14-004

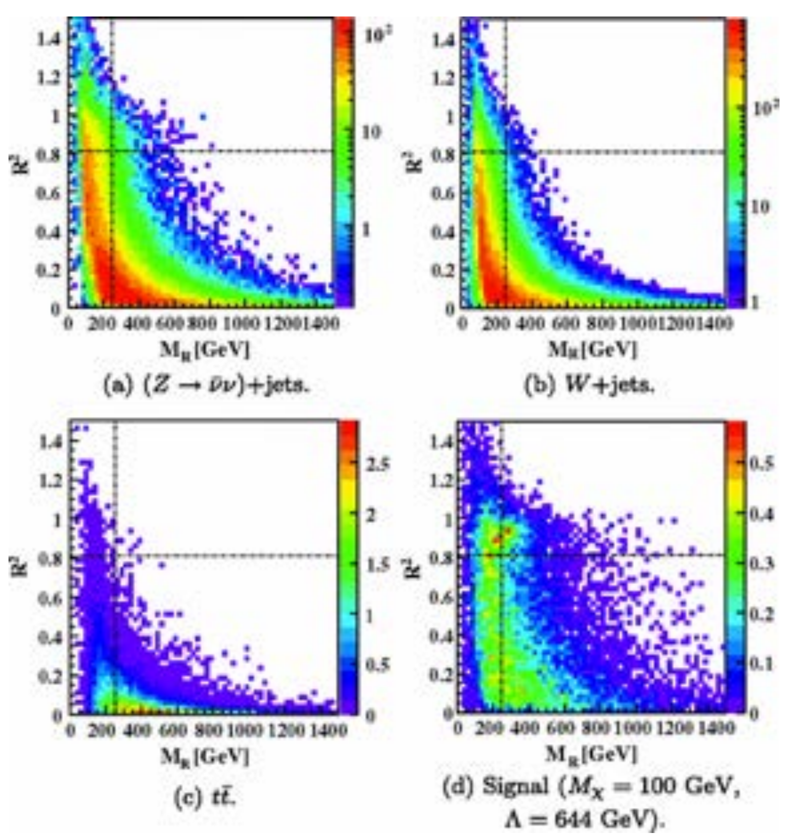
$$M_R \equiv \sqrt{(|\vec{p}_{J_1}| + |\vec{p}_{J_2}|)^2 - (p_z^{J_1} + p_z^{J_2})^2}\,,$$

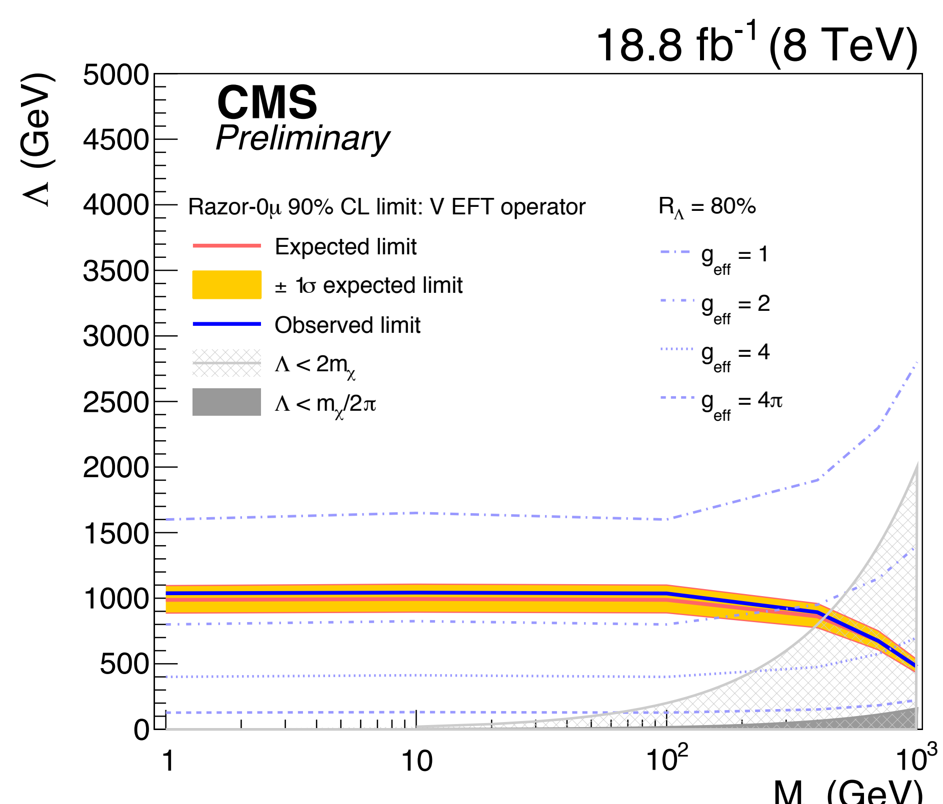
$$R \equiv \frac{M_T^R}{M_R}\,,$$

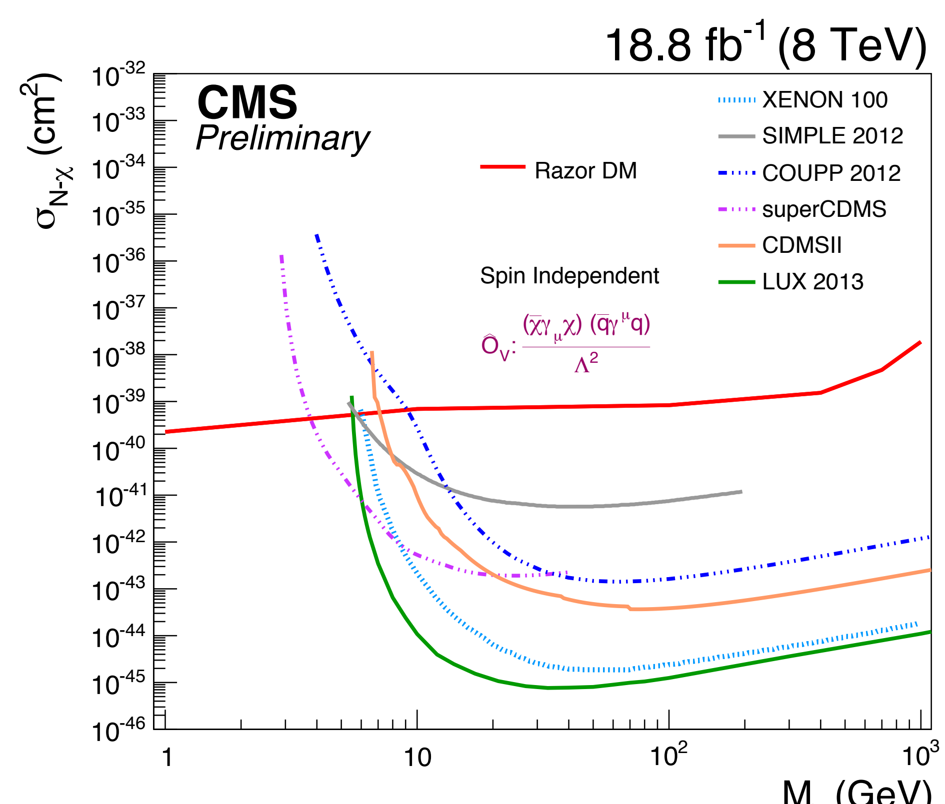




Phys. Rev. D 86, 015010







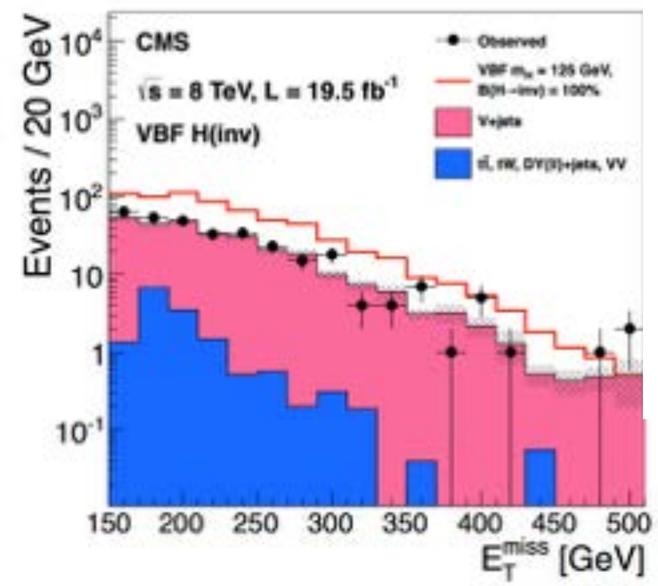
Dark matter interpretations: Higgs Portal

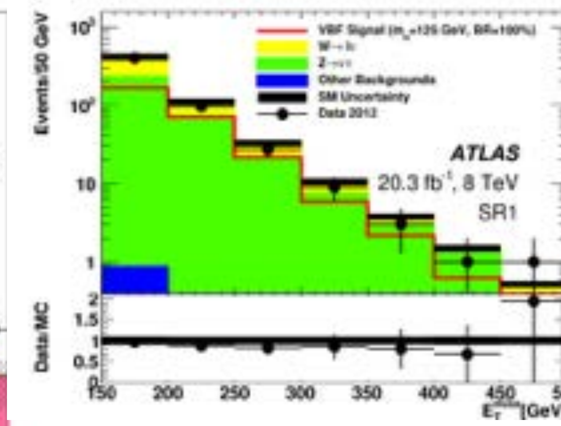
CMS, Eur. Phys. J. C 74 (2014) 2980

ATLAS, arXiv:1508.07869

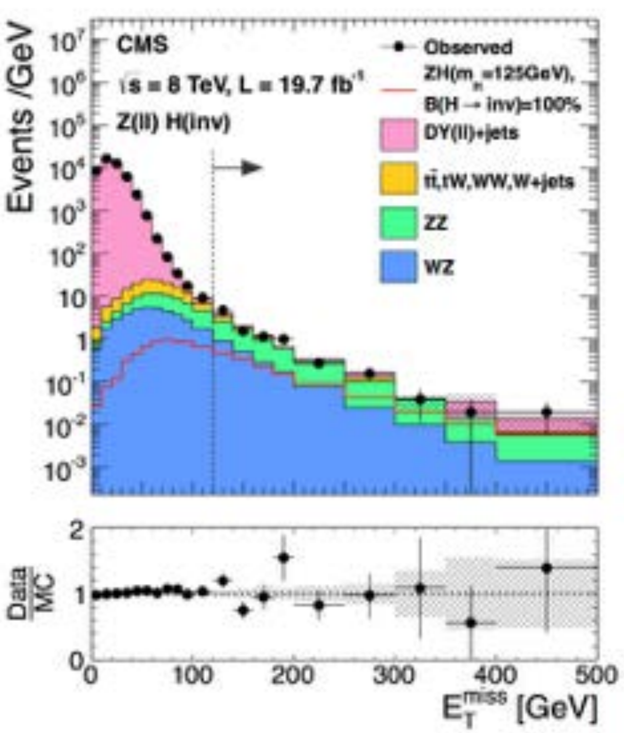
DM particles have the direct couplings to the SM Higgs sector, $H \to \chi\chi$

- Limits on branching fraction of Higgs to "invisible" particles used for limits on DM
- Can be scalar, vector or fermionic couplings
- Limits only up to DM mass $M_\chi < M_H/2$

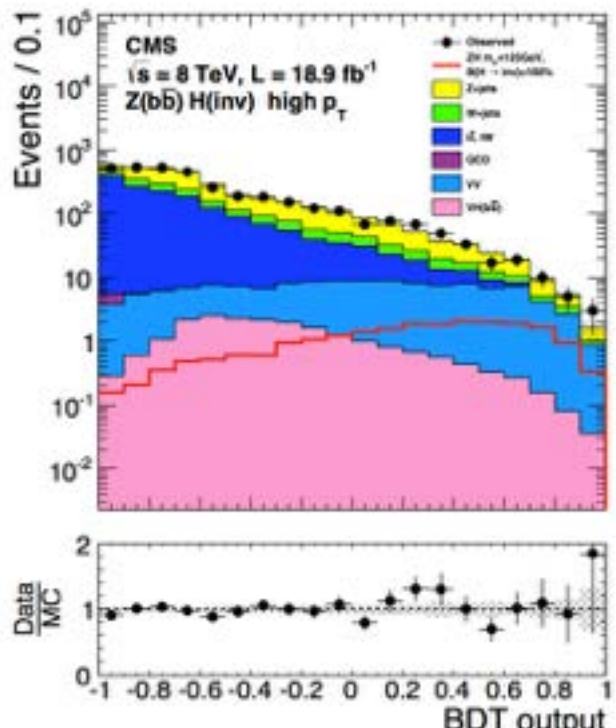




VBF Hinv

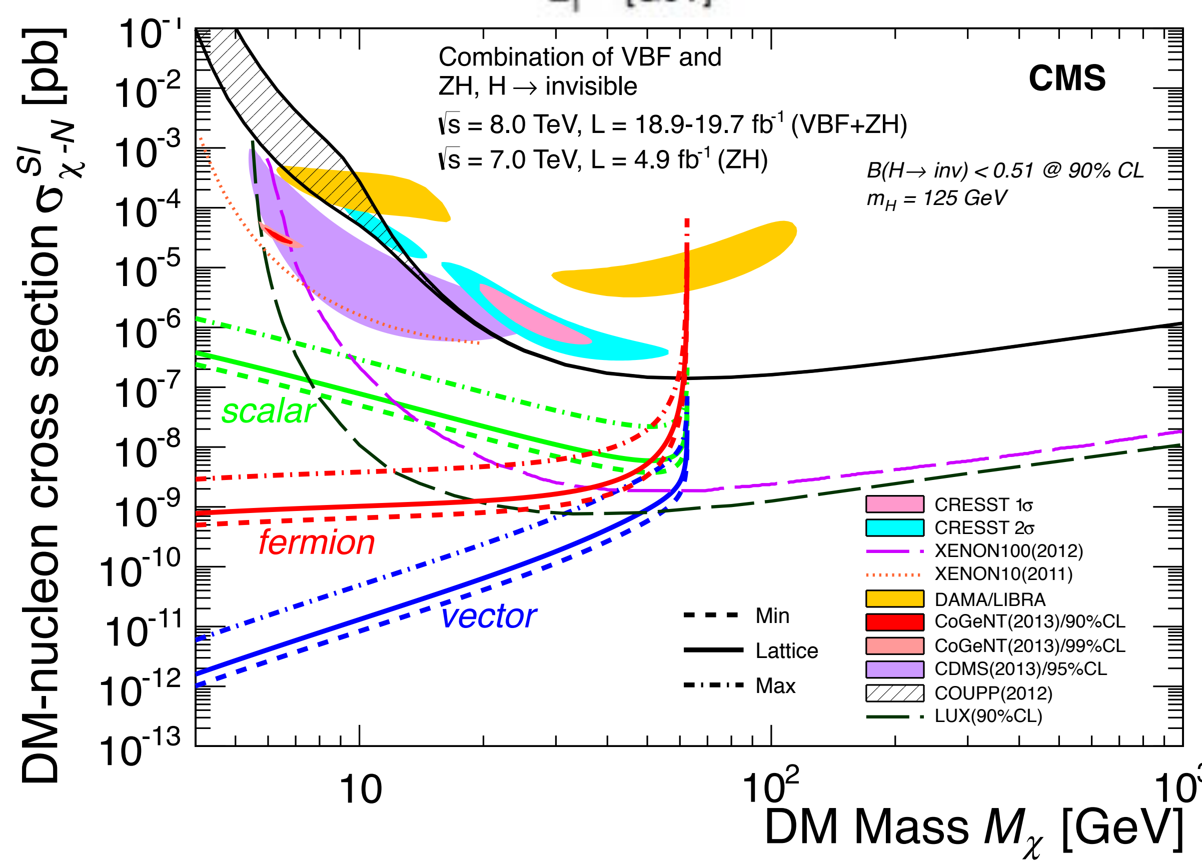


Z(ll)Hinv



Z(bb)Hinv

mH=125GeV, and B(H→inv) < 0.51 at 90% CL, as a function of the DM mass.

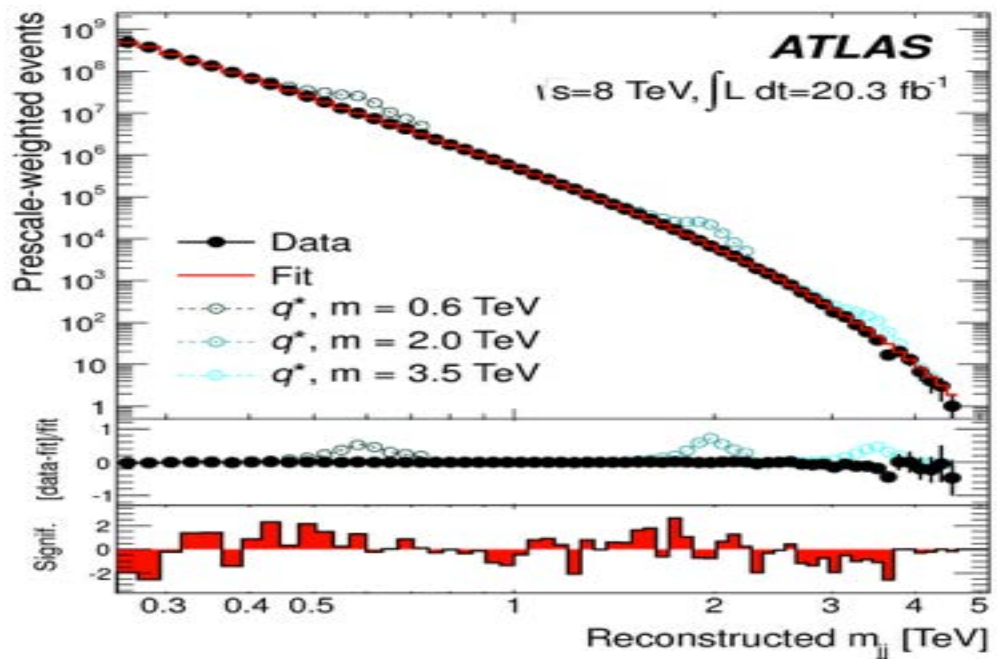


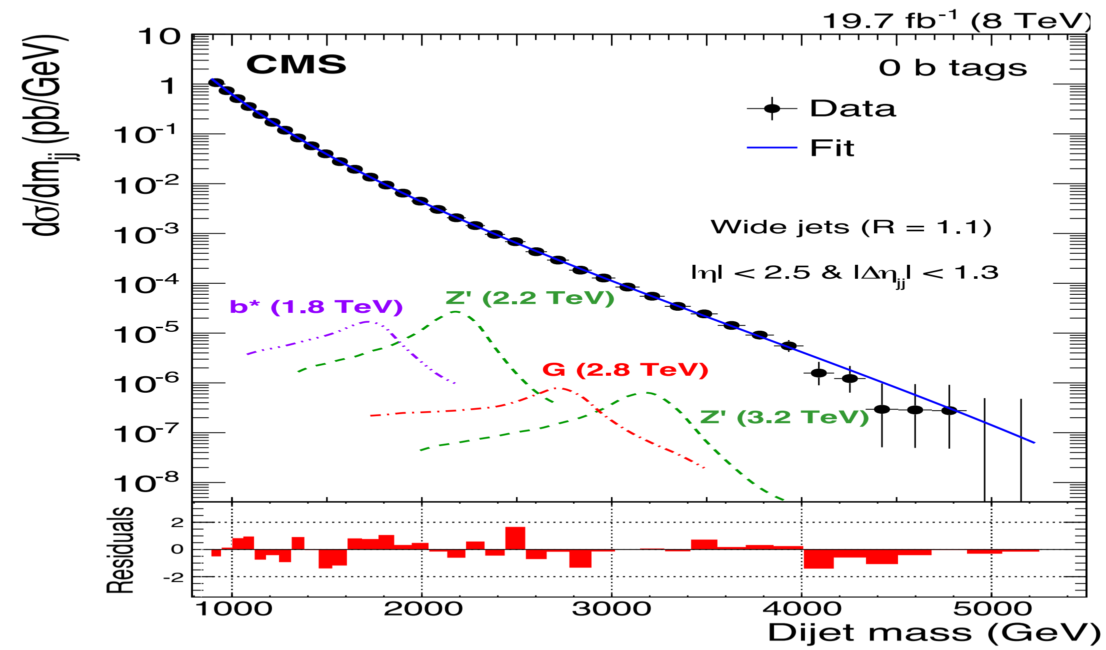
Resonance searches: Dijet resonances

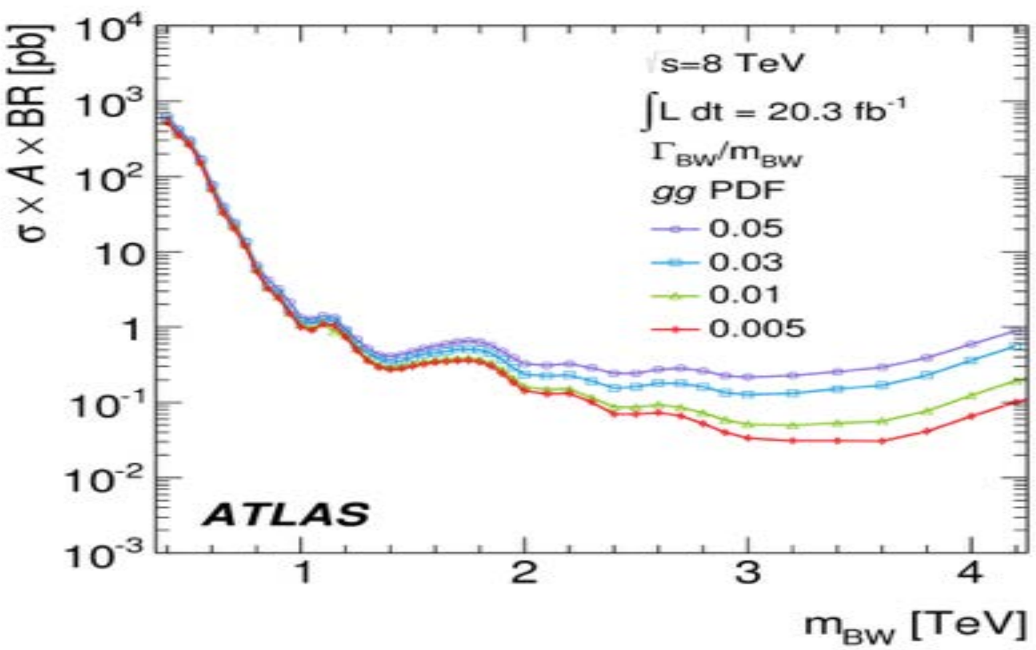
- Almost fully data driven: assuming a smooth background and narrow bumps.
- Limits are interpreted to resonances (string, excited quarks, scalar diquark, W', Z', RS gravitons) and quantum black holes.

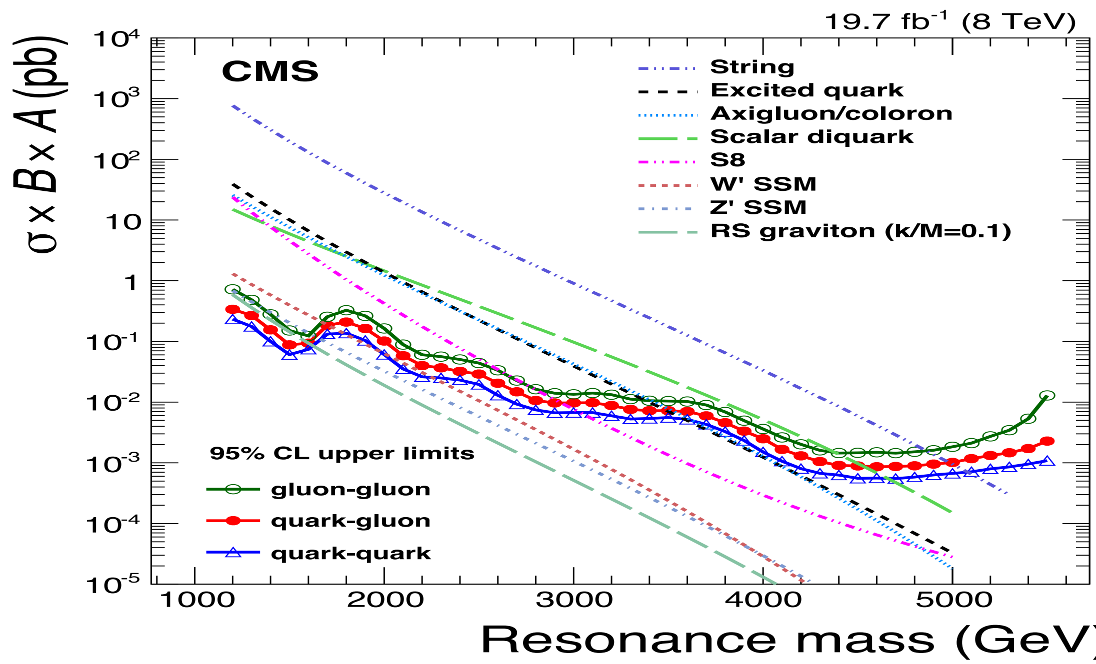
ATLAS, Phys. Rev. D 91, 052007

CMS, Phys. Rev. D 91, 052009



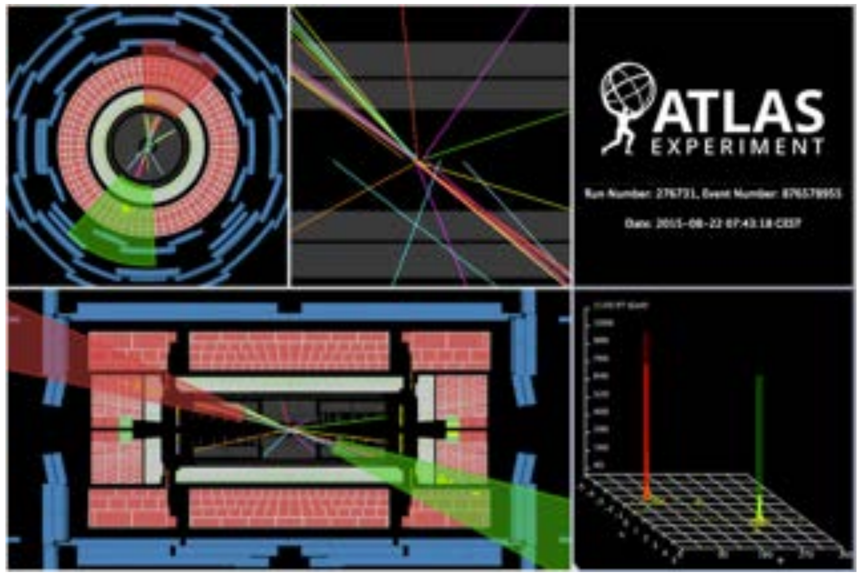


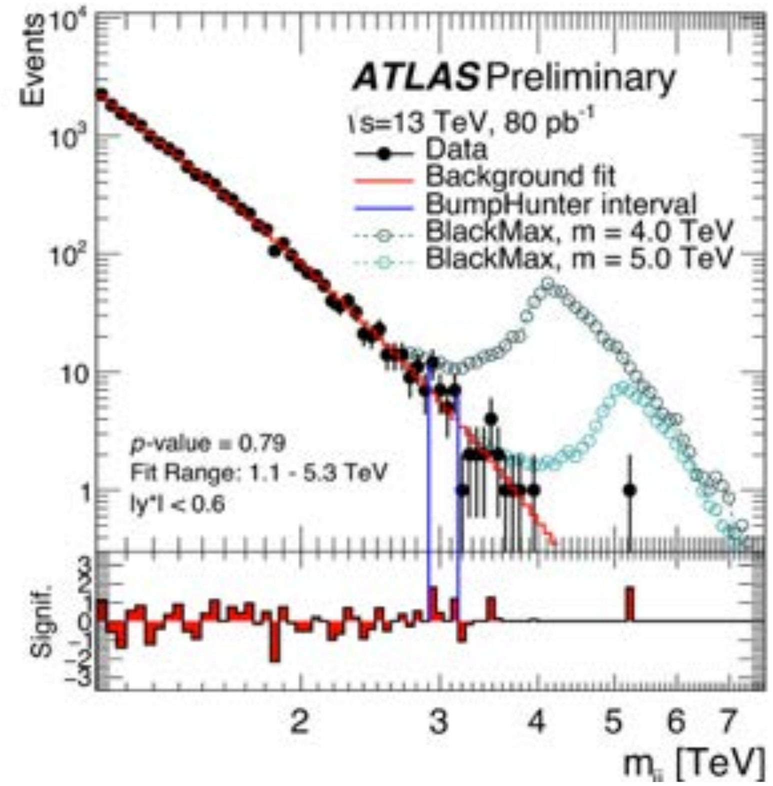


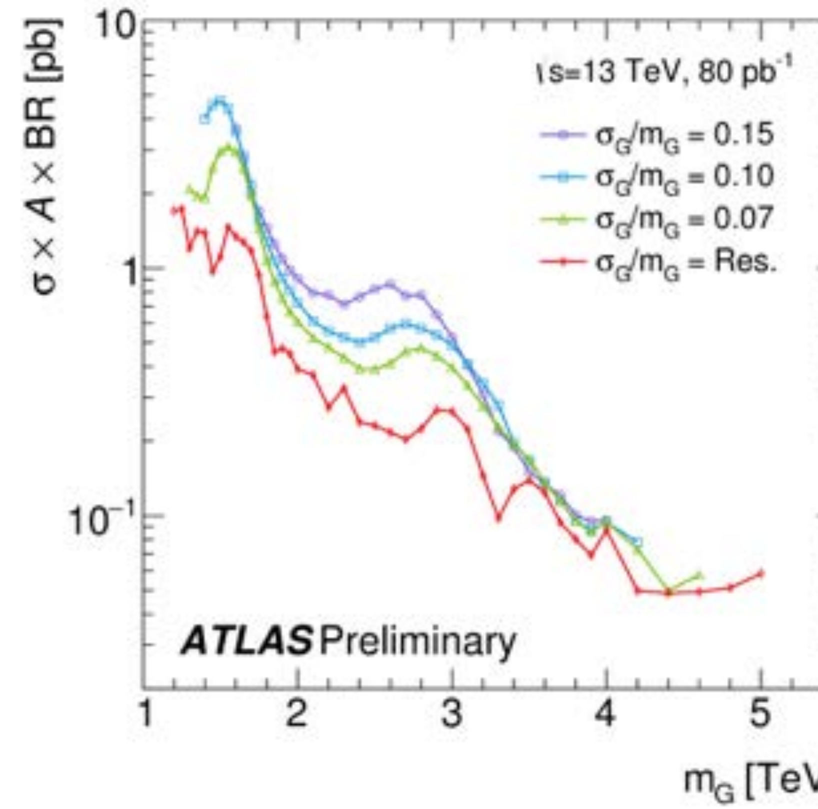


Resonance searches: Dijet resonances (13 TeV)

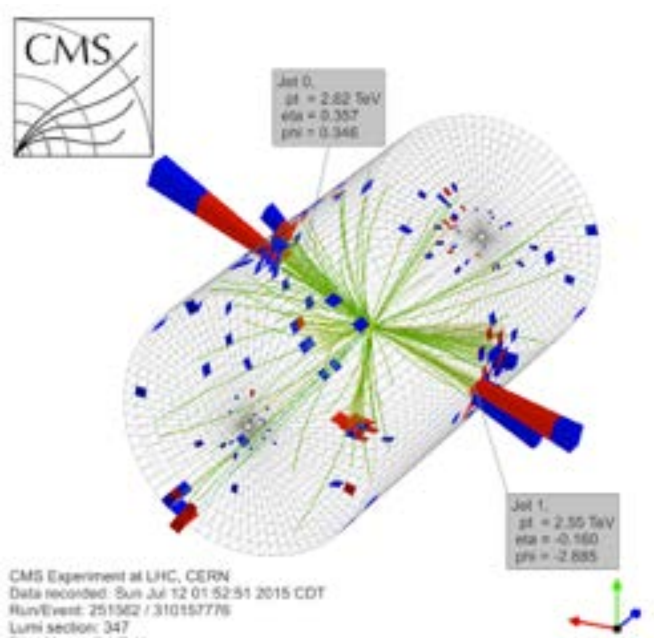
ATLAS, https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2015-042/

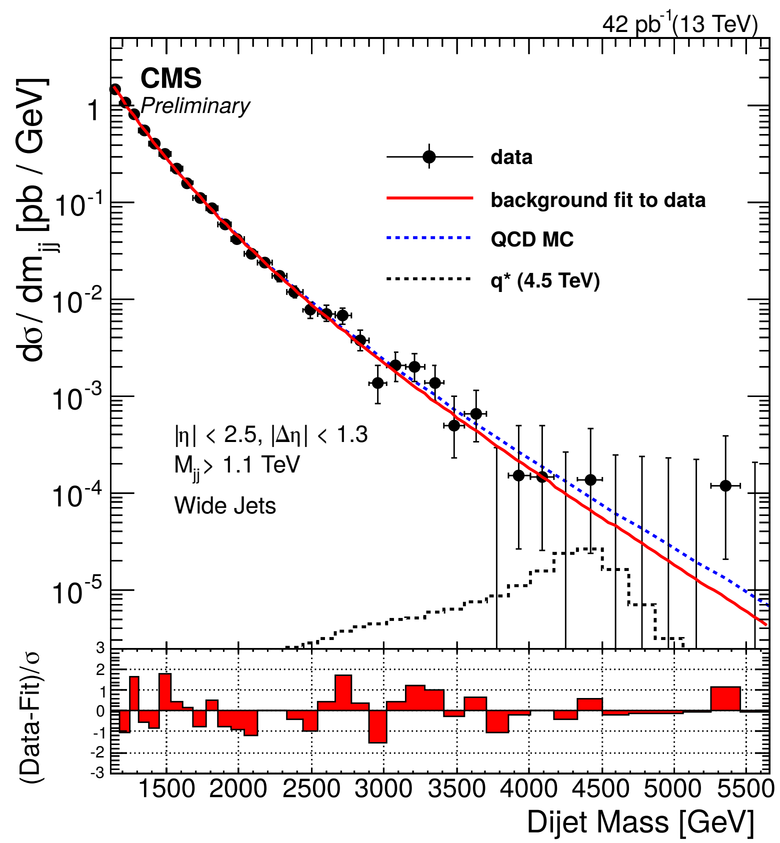


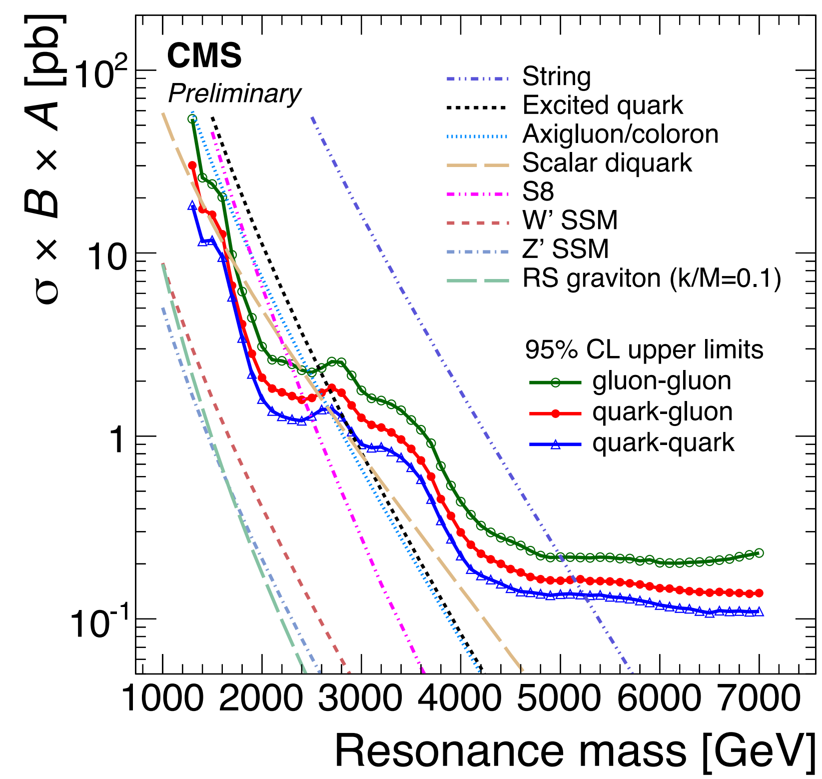




CMS, https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO15001

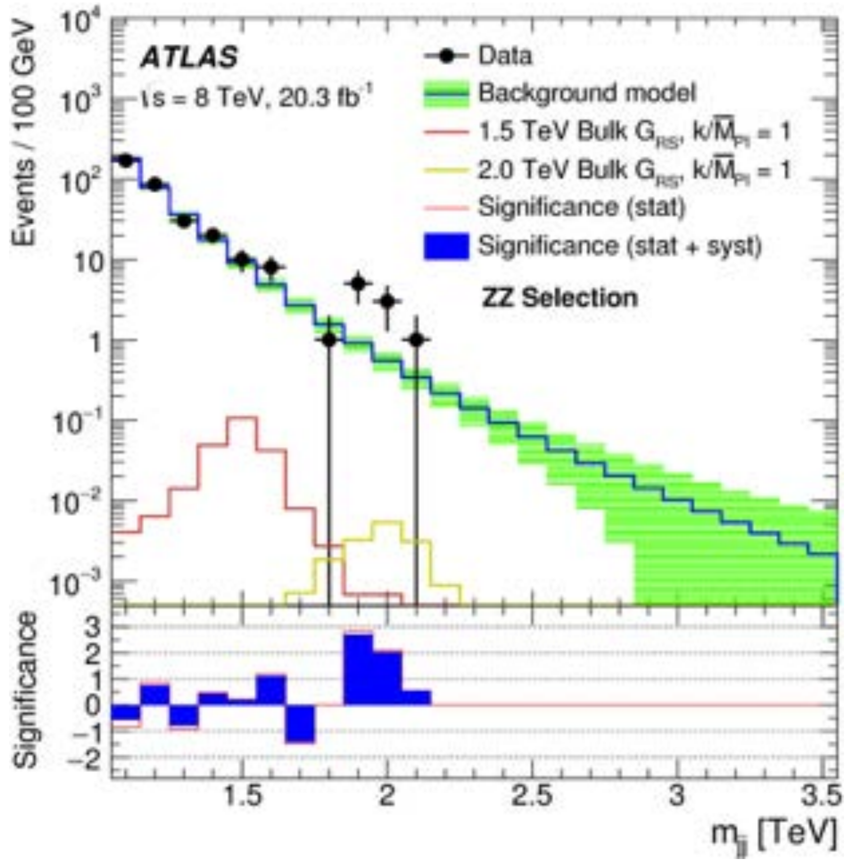


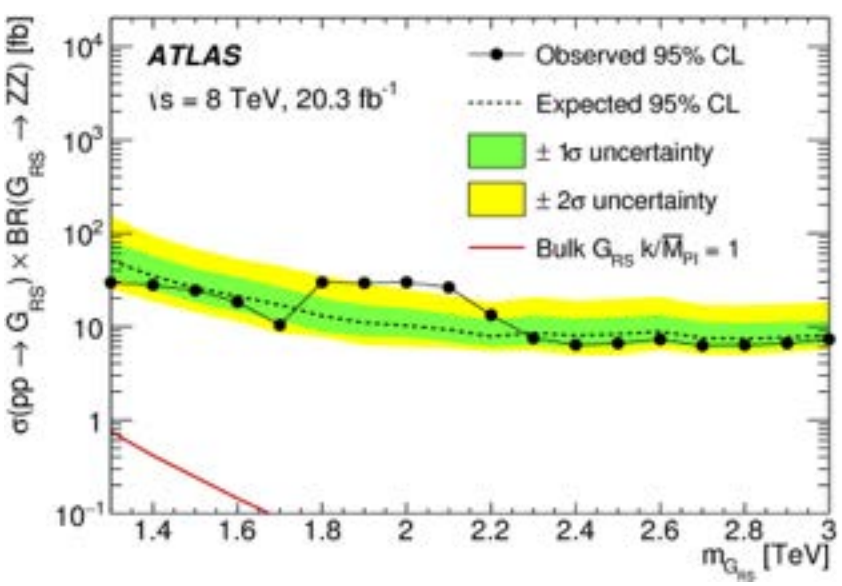




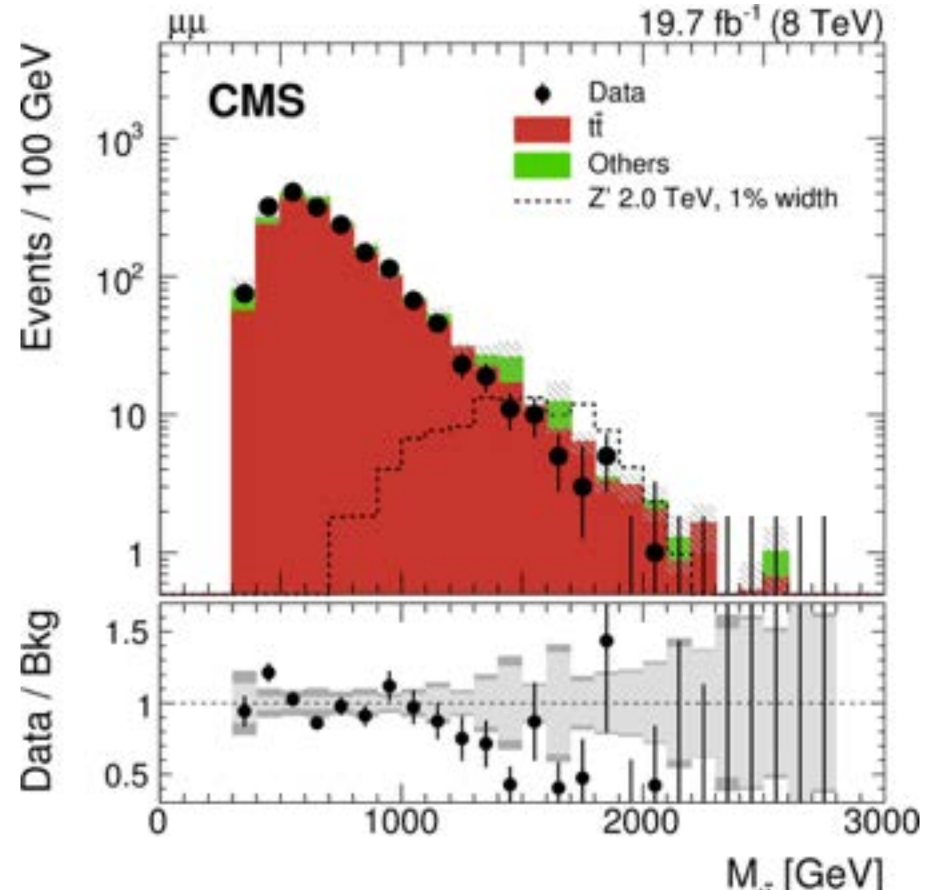
Resonance searches: Tagged jets resonances

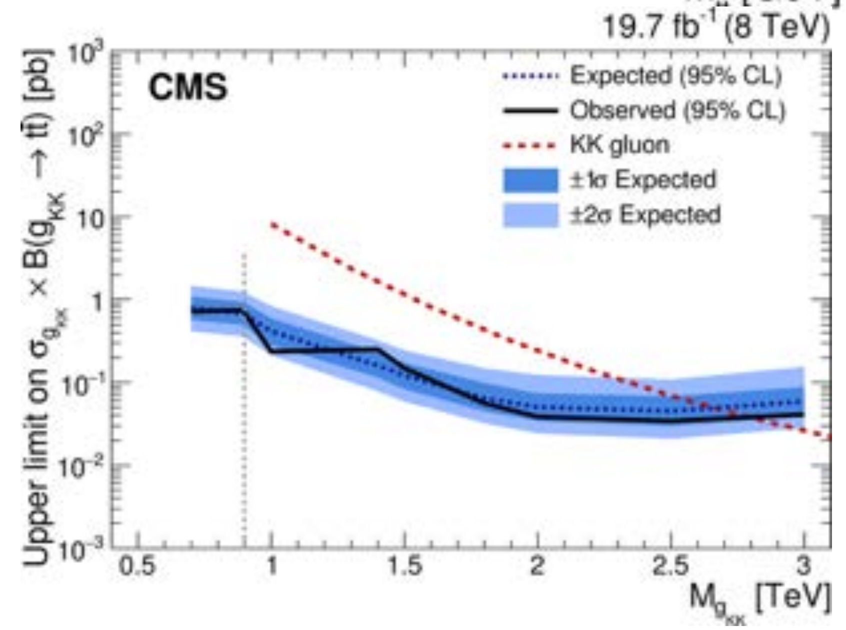
ATLAS, arXiv:1506.00962 **Boson-tagged jet**





CMS, arXiv:1506.03062 **Top-tagged jet**

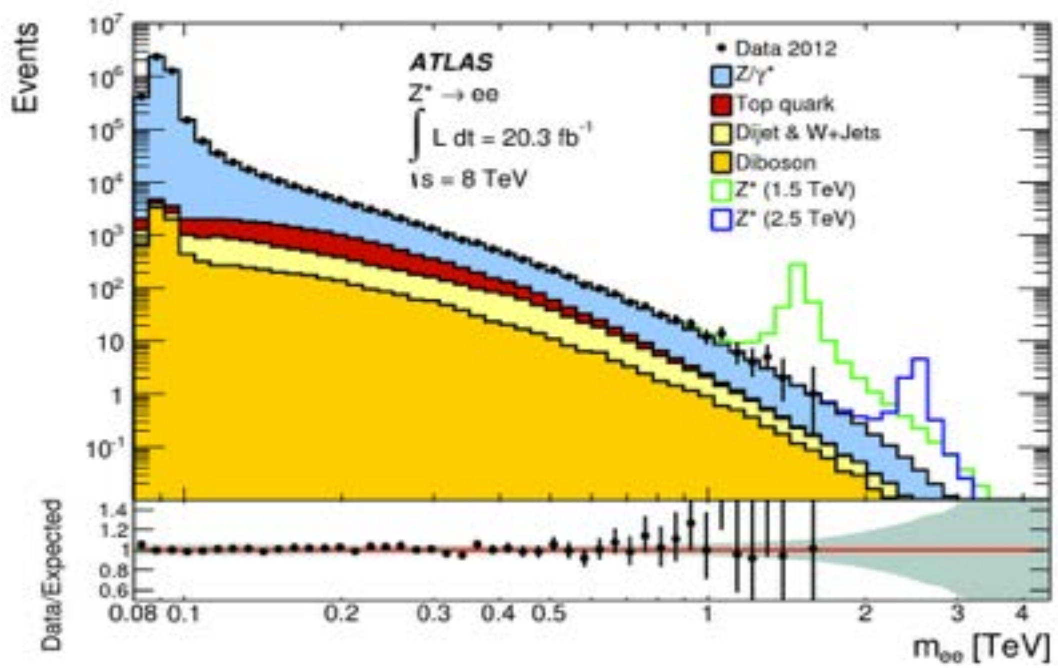


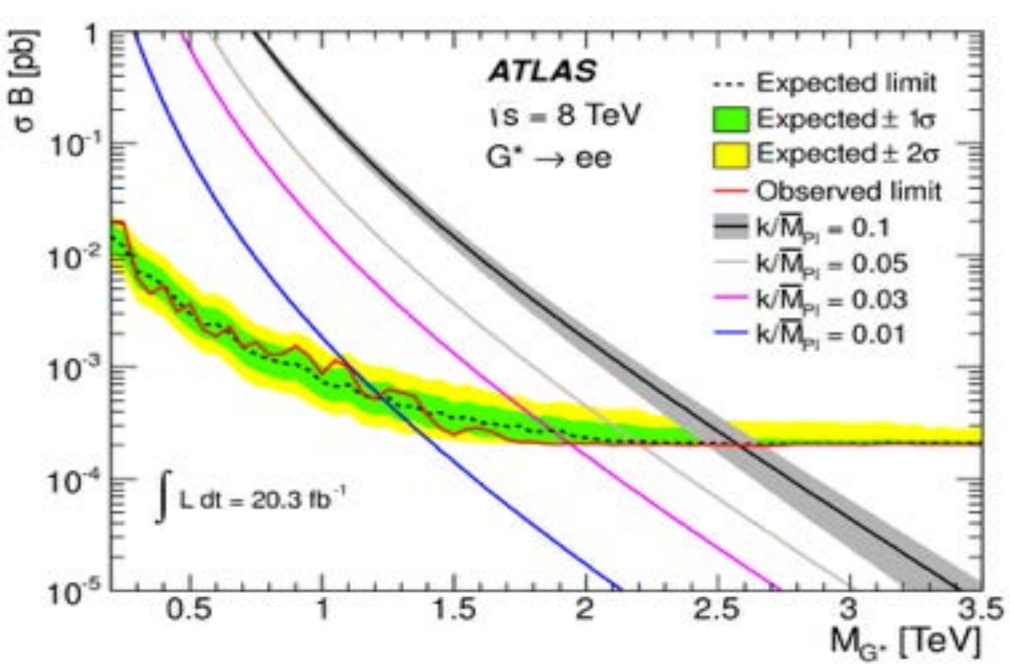


Resonance searches: Dilepton resonances

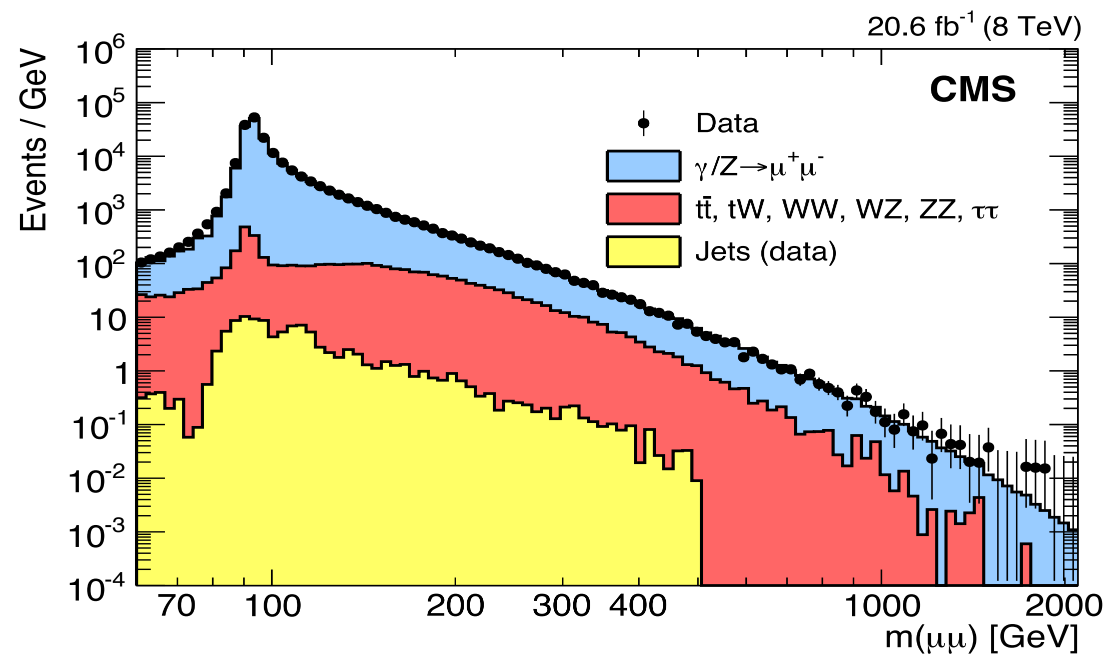
- Clean and excellent resolution even at higher masses.
- Limits can be interpret in various models, e.g. Z' models, spin-2 graviton.

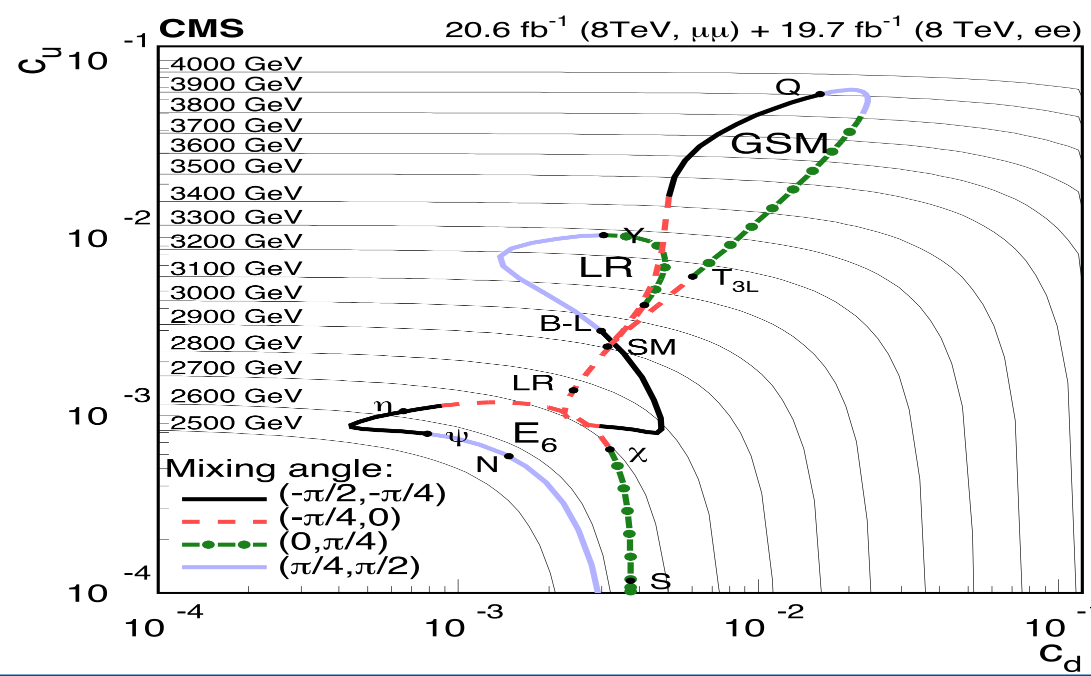
ATLAS, Phys. Rev. D 90, 052005





CMS, JHEP 04 (2015) 025

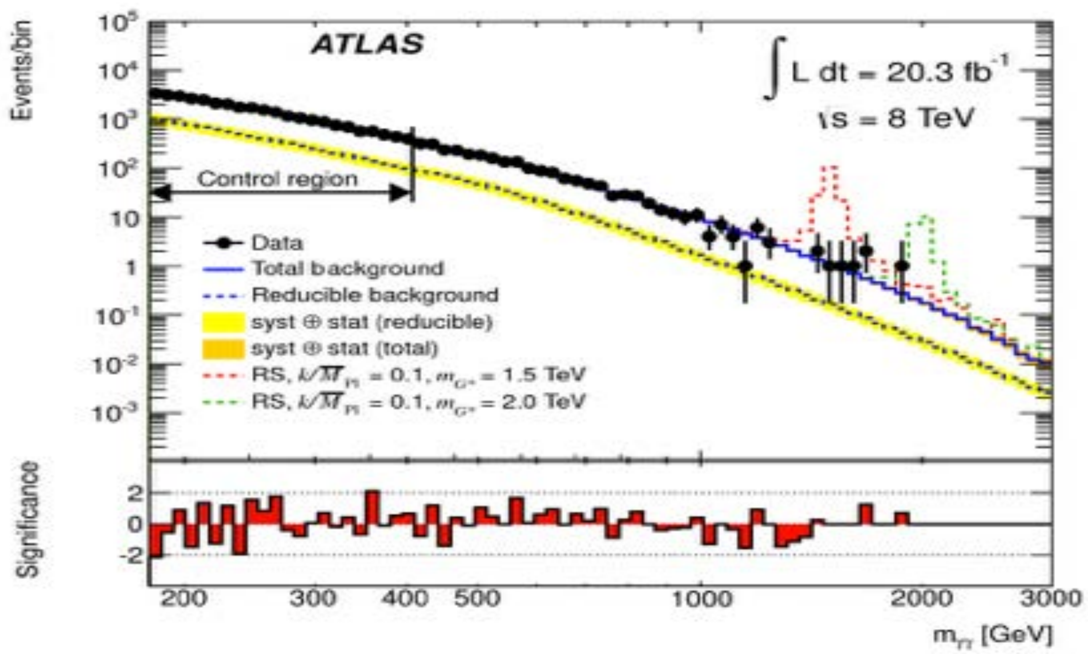


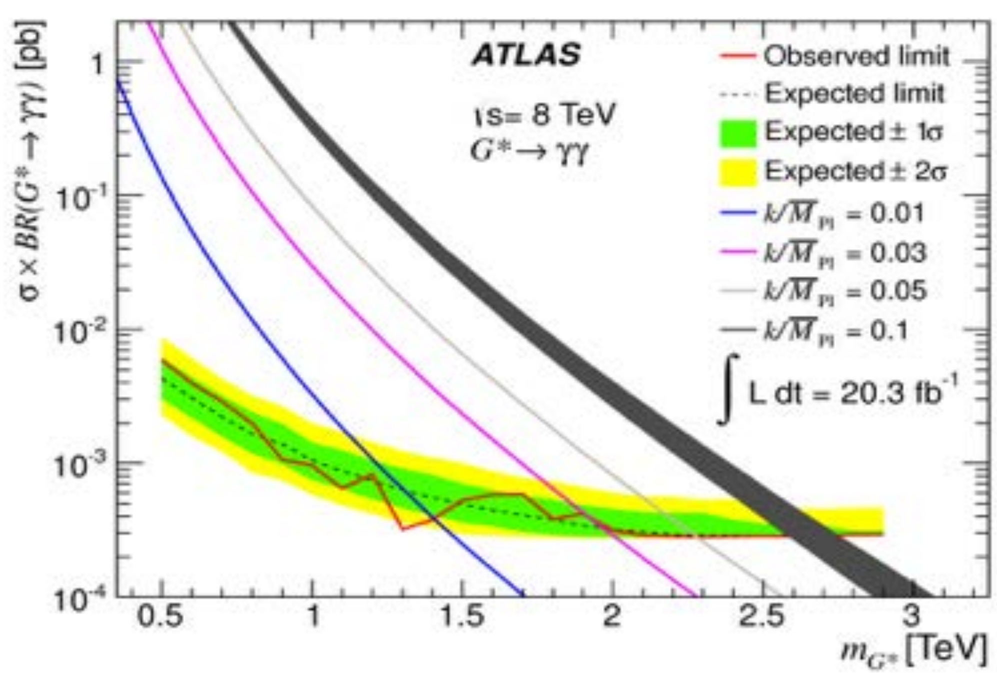


Resonance searches: Diphoton resonances

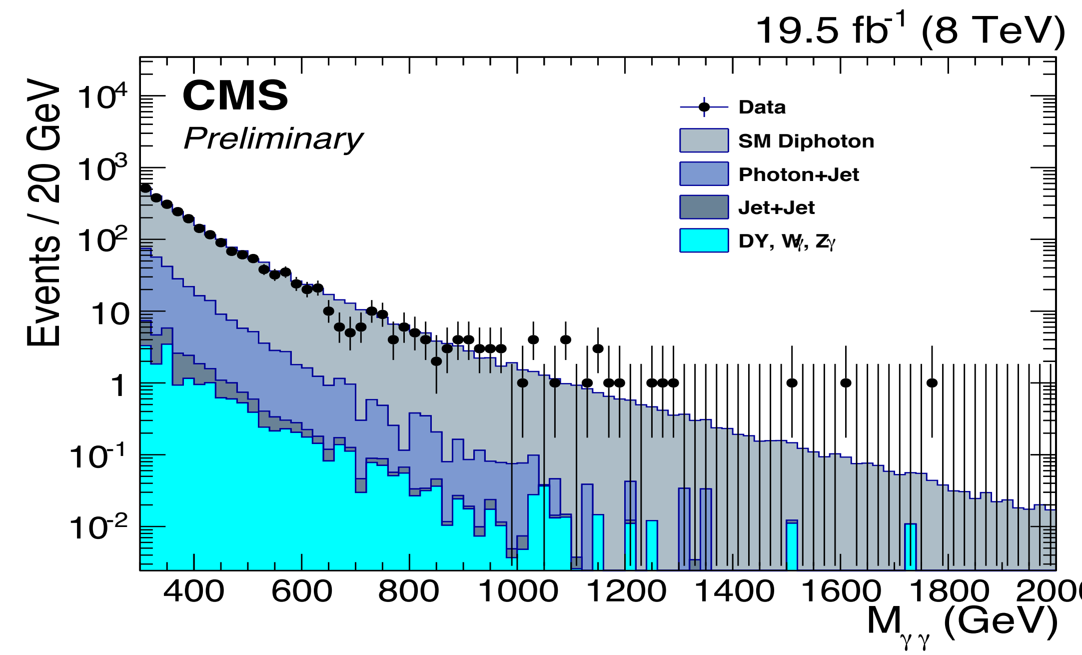
- Clean and sensitive to scalar and particularly to spin-2 (RS-Graviton) resonances.
- Limits are set on the mass of lightest graviton for couplings of $0.01 \leq k/\bar{M}_{PL} \leq 0.1$.

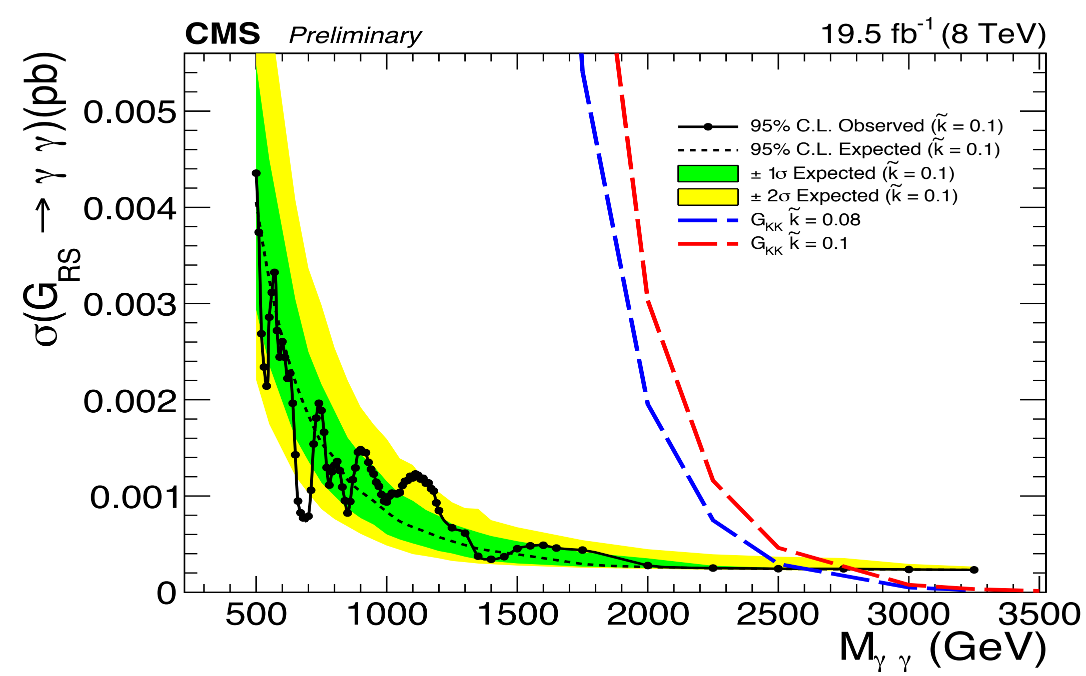
ATLAS, Phys. Rev. D 92, 032004





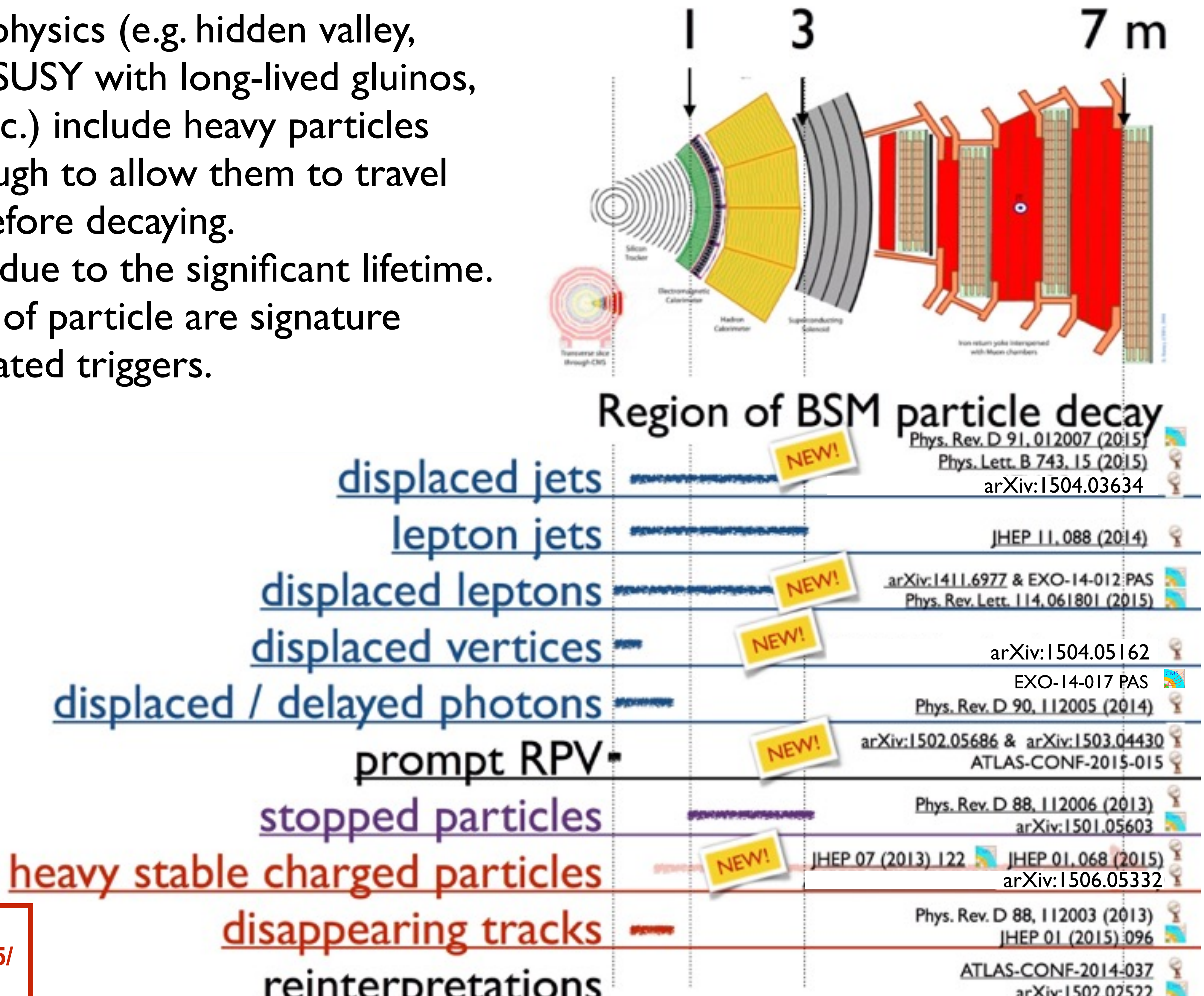
CMS, CMS-PAS-EXO-12-045





Long-lived searches

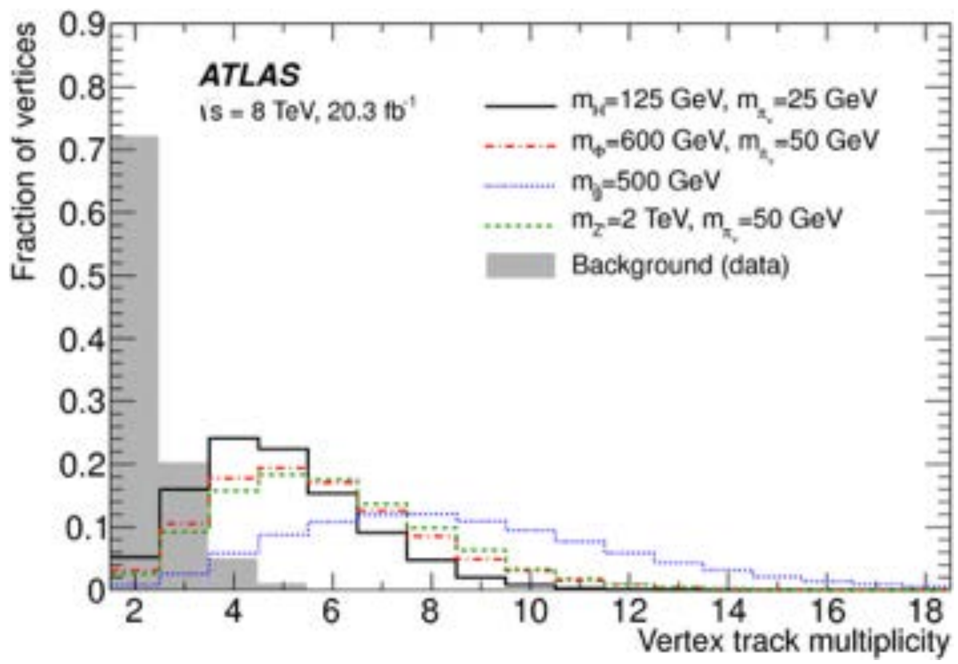
- Many models of new physics (e.g. hidden valley, weakly RPV SUSY, split SUSY with long-lived gluinos, Z' decays, little Higgs, etc.) include heavy particles with lifetimes large enough to allow them to travel measurable distances before decaying.
- Small SM background due to the significant lifetime.
- Searches for this kind of particle are signature driven. They need dedicated triggers.

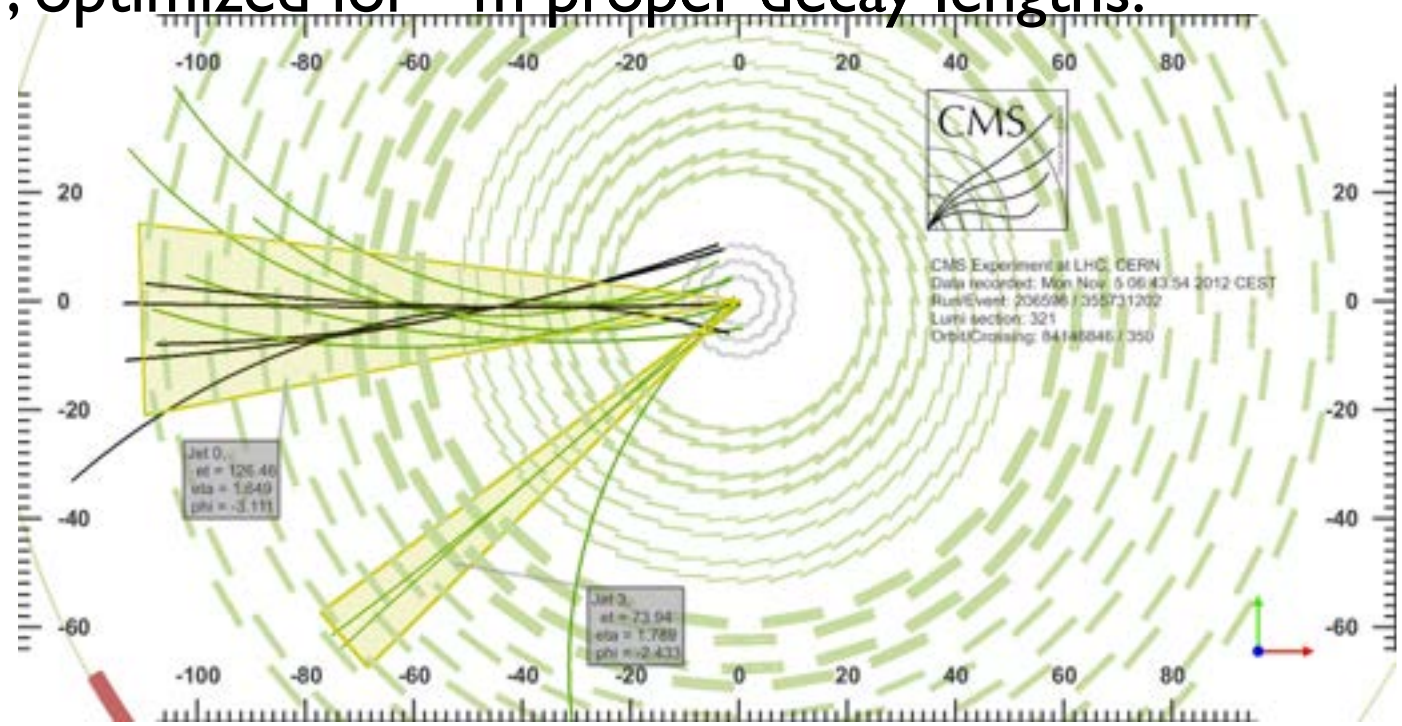


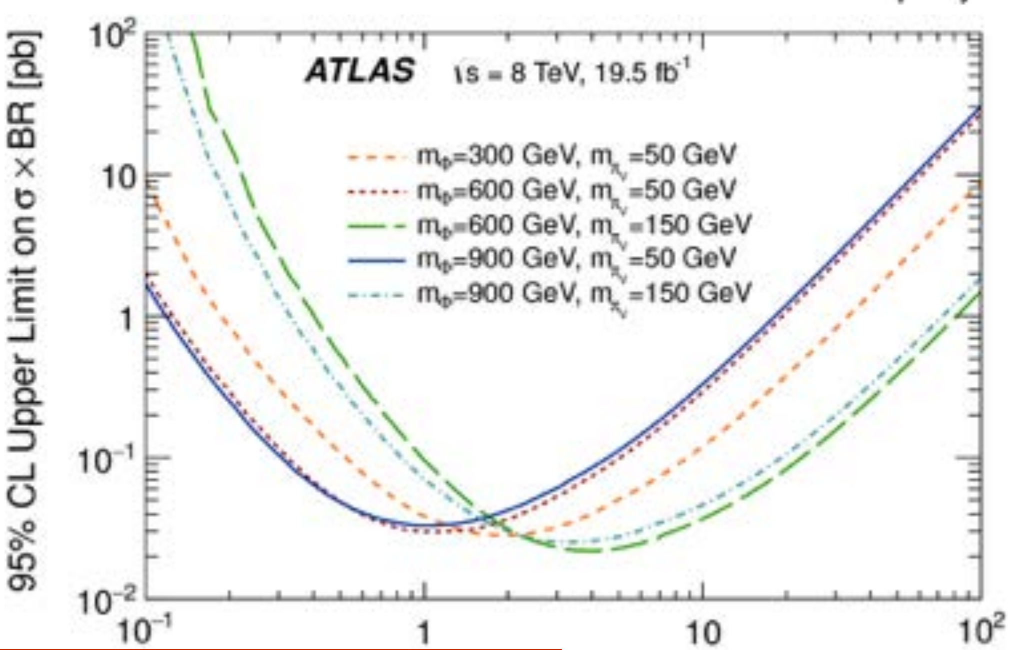
Update from http://moriond.in2p3.fr/QCD/2015/WednesdayMorning/Wulsin.pdf

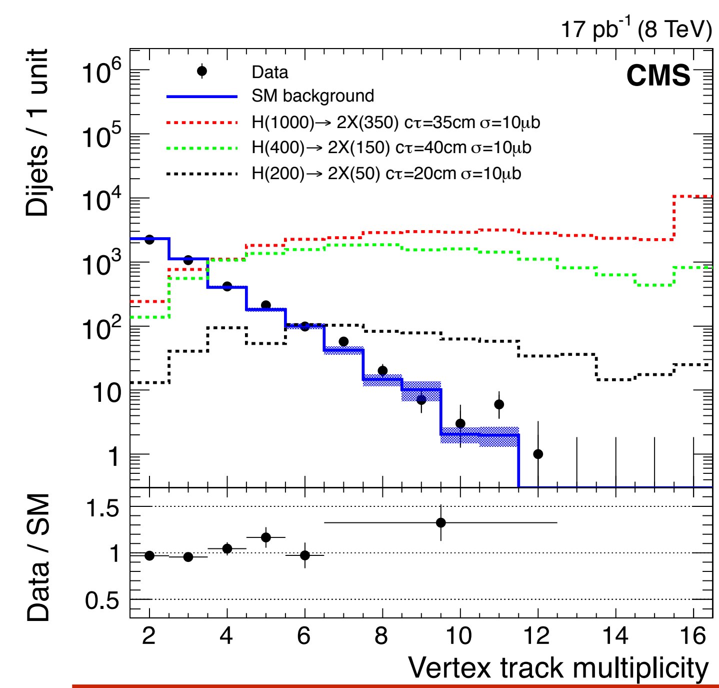
Displaced jets / Displaced dijets

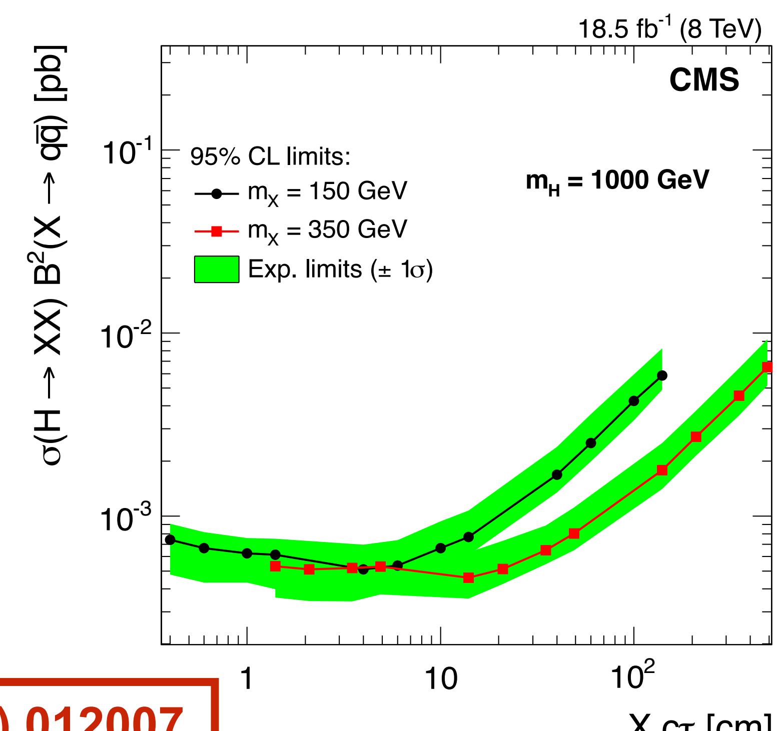
- Dedicated triggers are needed:
  - CMS: Total CAL trigger, optimized to ~cm proper decay lengths.
  - ATLAS: Muon chamber vertexing trigger, optimized for ~m proper decay lengths.











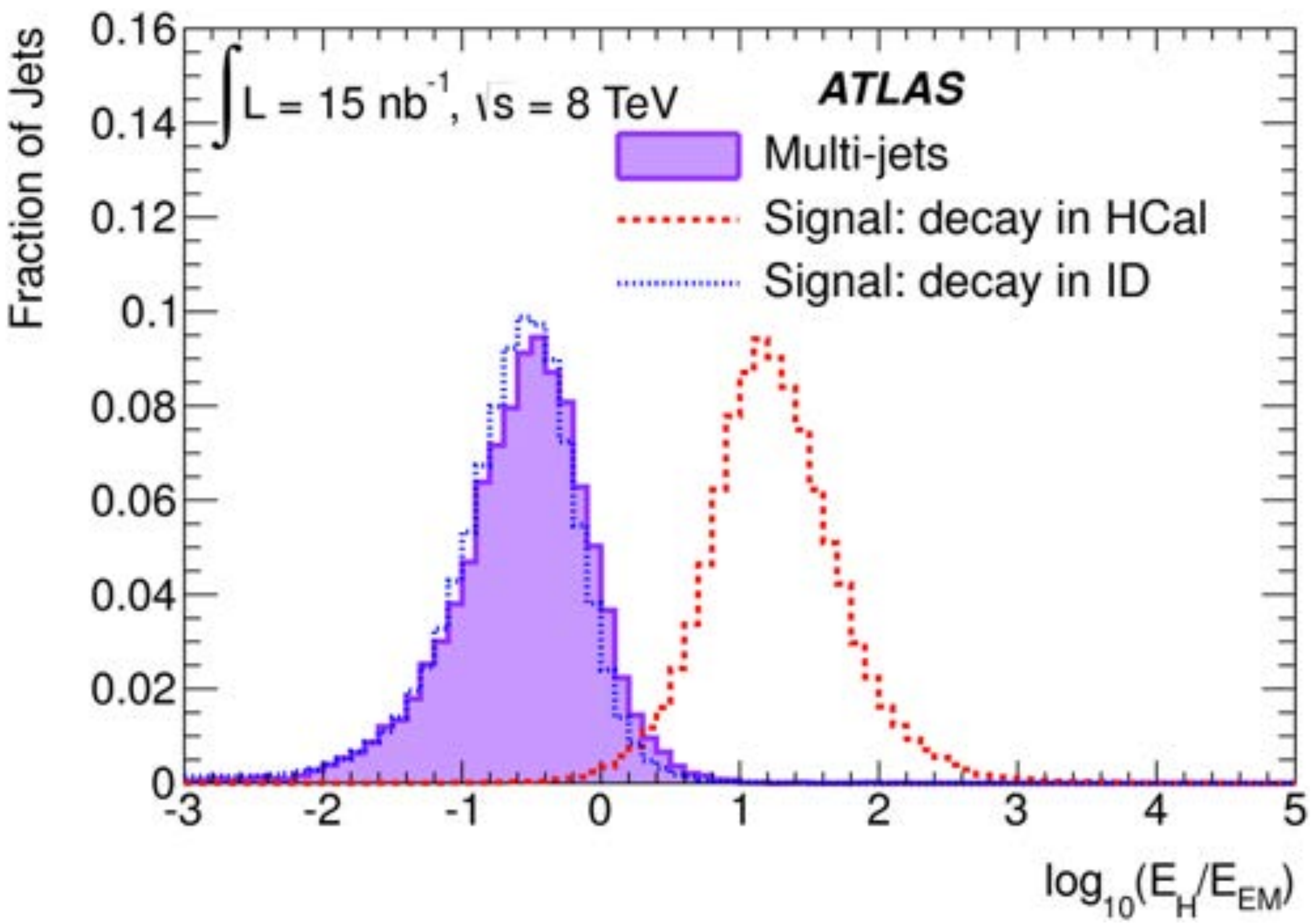
ATLAS, arXiv:1504.03634

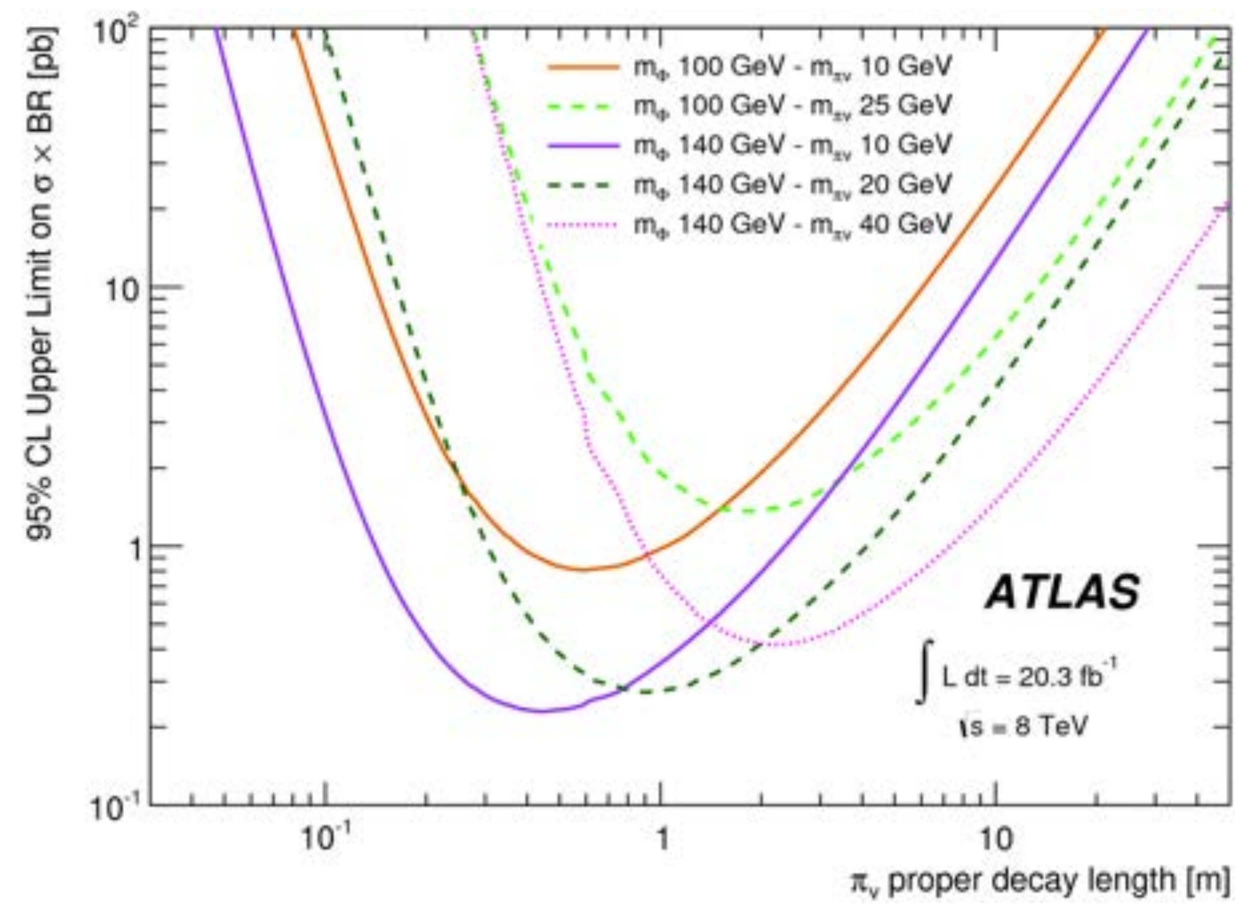
CMS, Phys. Rev. D 91 (2015) 012007

Trackless jets

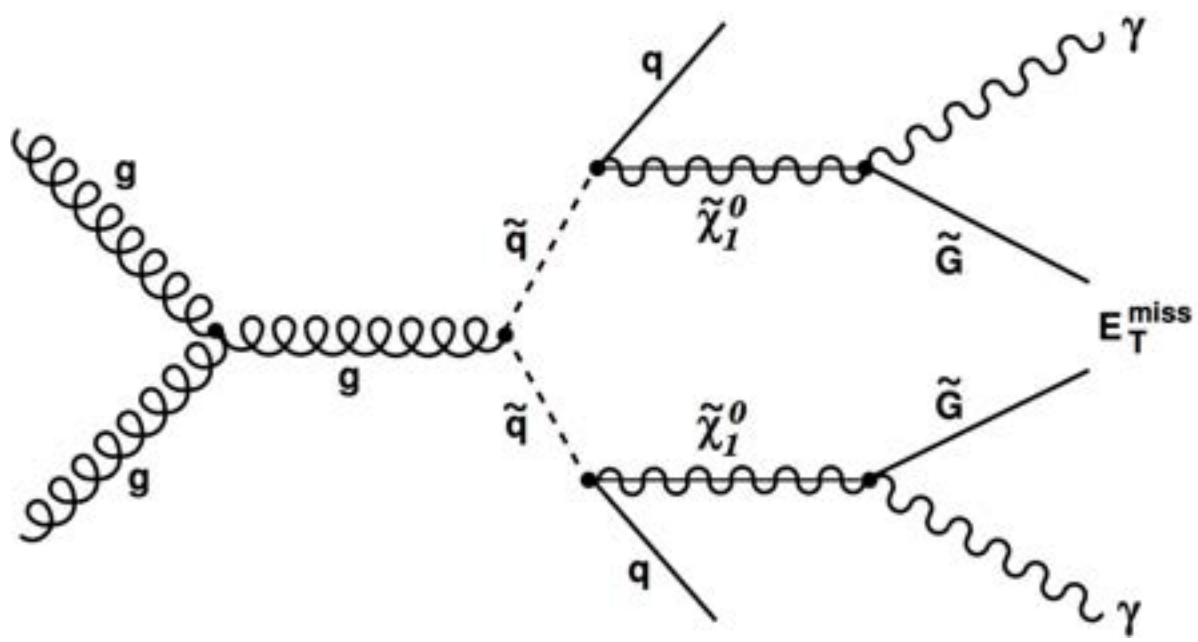
ATLAS, Physics Letters B 743 (2015) 15-34

- Long-lived particles that decay to SM particles producing jets at the outer edge of the electromagnetic calorimeter or inside the hadronic calorimeter.
- Limits on the product of the scalar boson production cross section times branching ratio into long-lived neutral particles as a function of the proper lifetime of the particles.

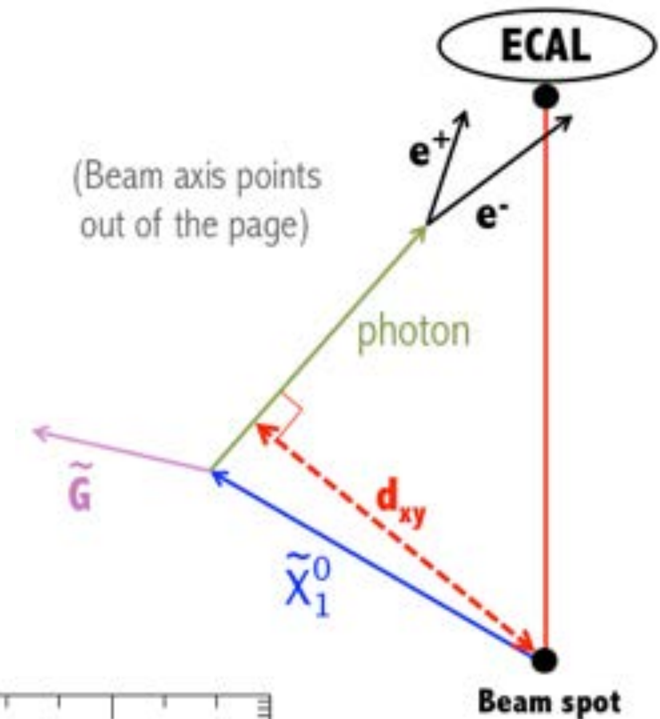




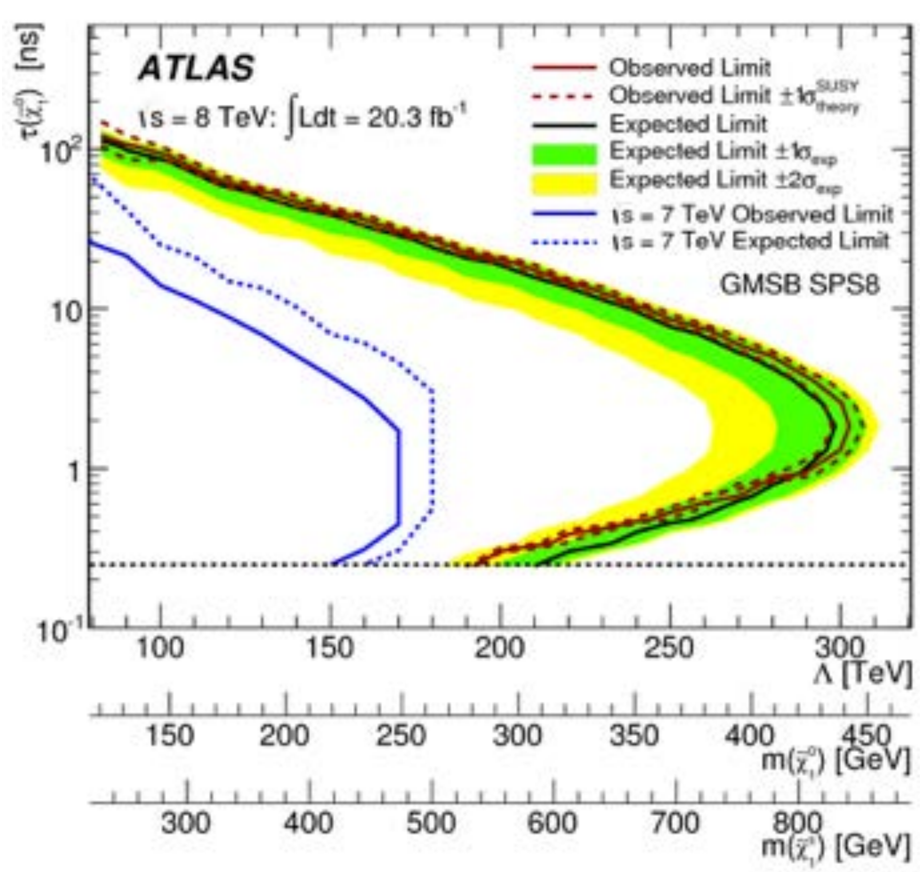
Displaced / delayed photons



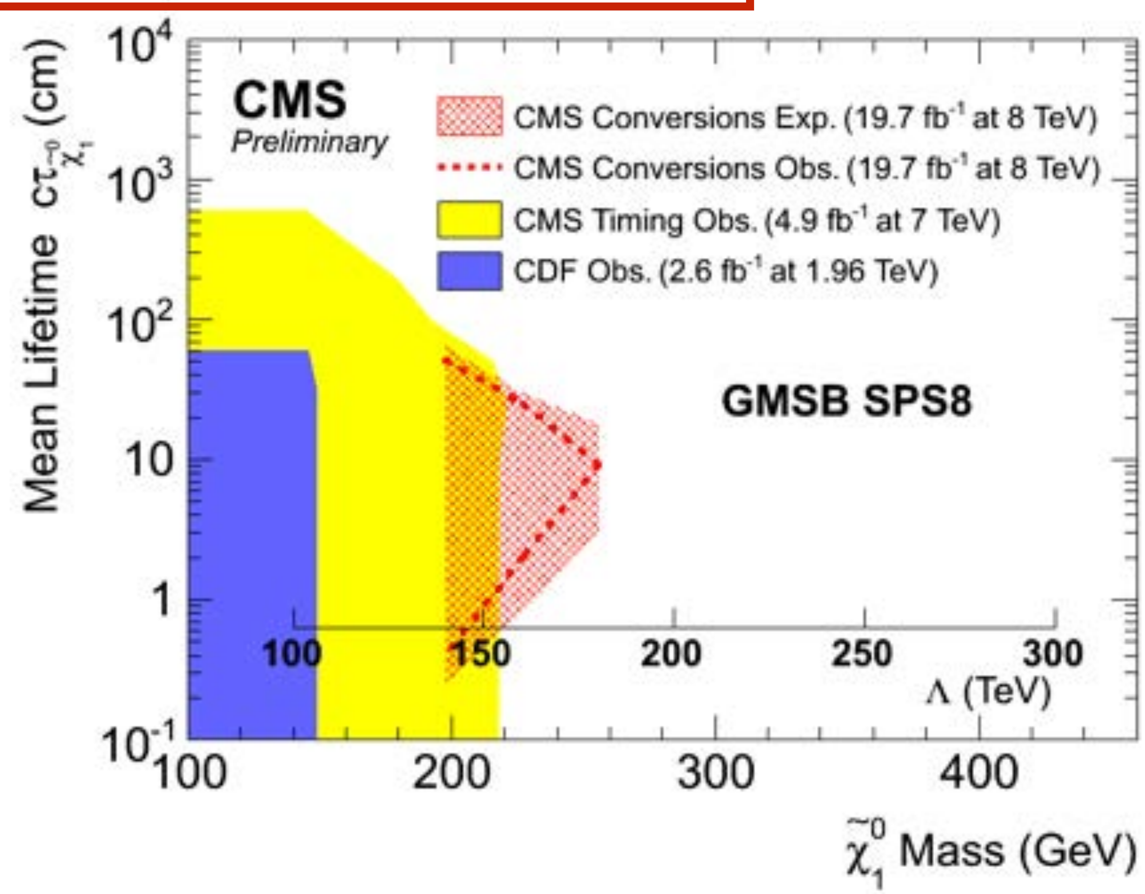
- Ex. lightest neutralino with nonzero lifetime into a gravitino and a photon.
- Look for photons that do not point back to PV.
  - ATLAS: intrinsic photon pointing capabilities.
  - CMS: back-tracking photon conversion.



ATLAS, Phys. Rev. D 90, 112005

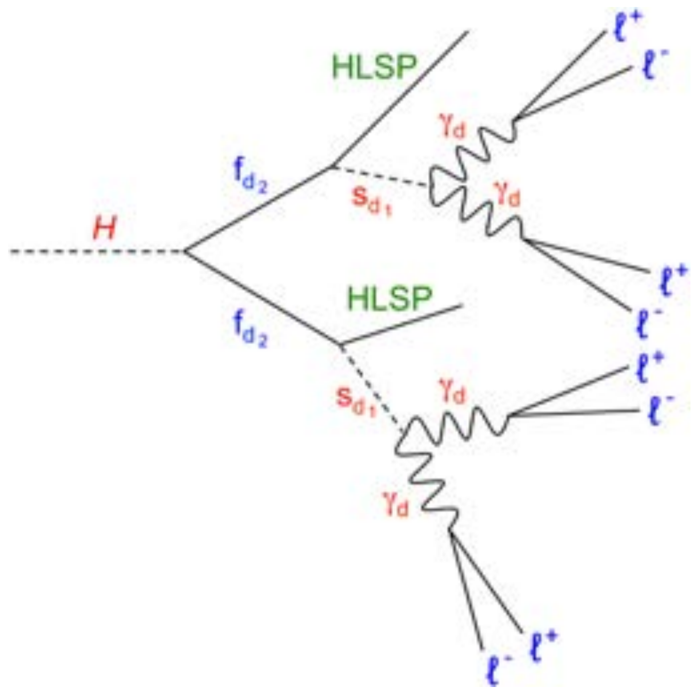


CMS, CMS-PAS-EXO-14-017

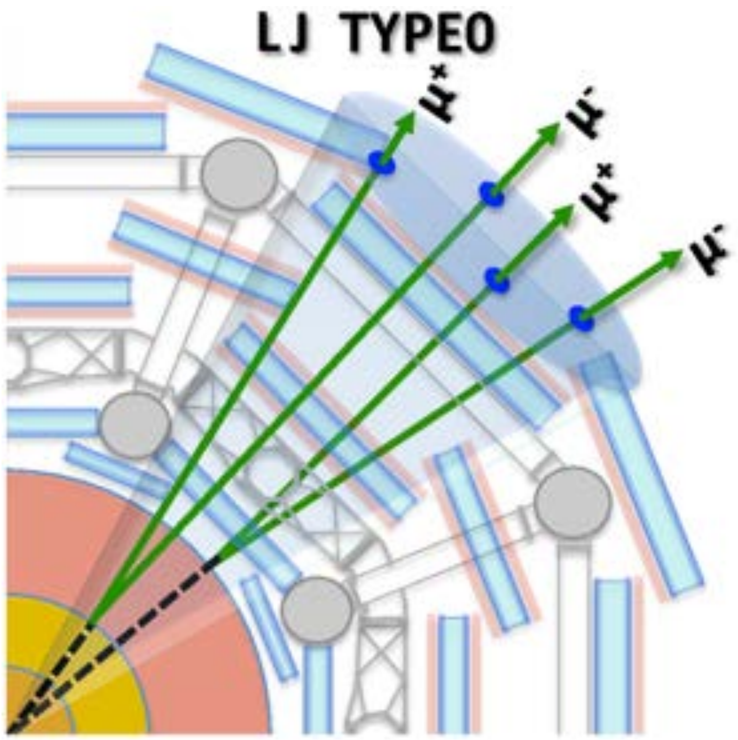


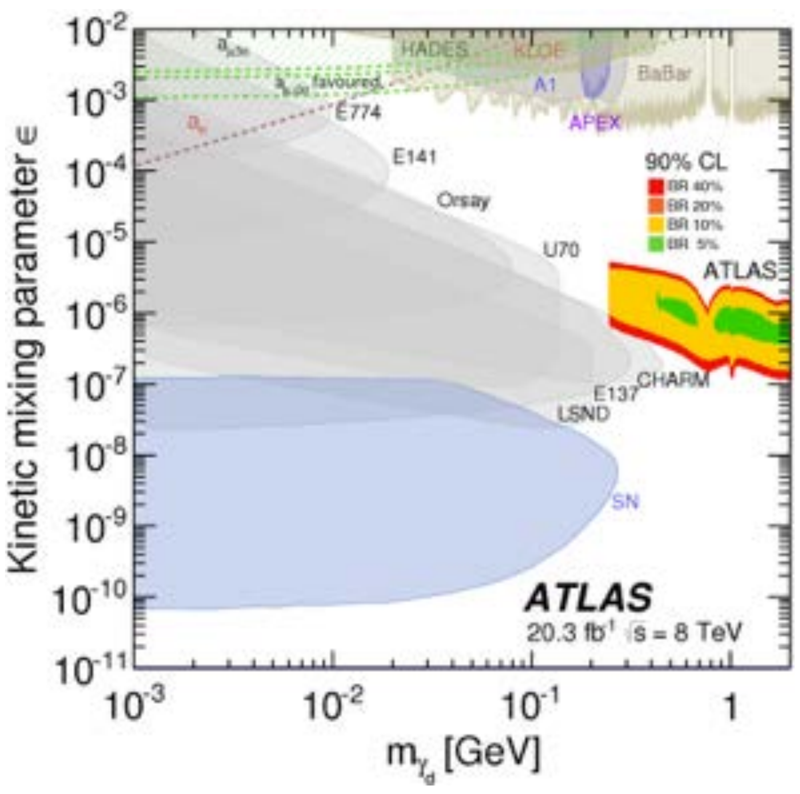
Lepton jets

ATLAS, JHEP 11 (2014) 088



- Collimated jets of electrons/muons
- Sensitive to low mass dark matter photon scenarios with very weak coupling to the SM sector

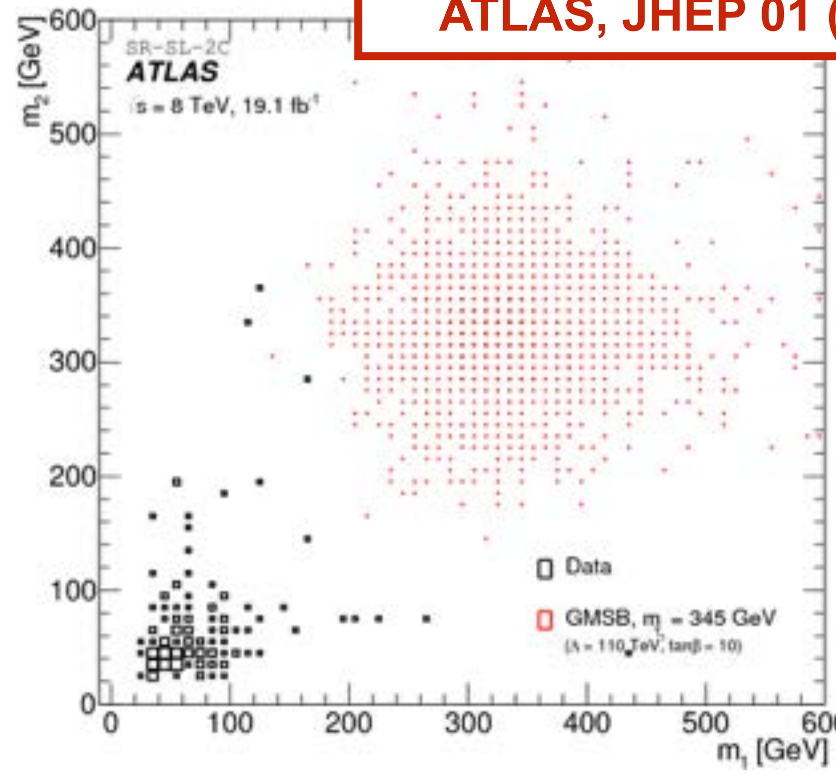




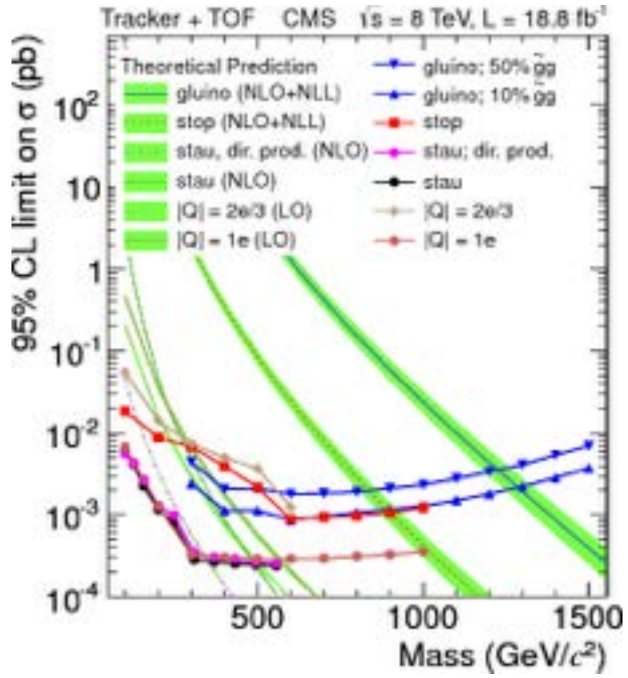
Heavy stable charged particles

- Identify slow (β<1) particles by (i) large dE/dx from pixel tracker and (ii) late timing on calorimeter and muon systems.
- Reconstructed mass, $m_\beta = p/(\gamma\beta)$
- Main background is muons with mismeasured timing or de/dx

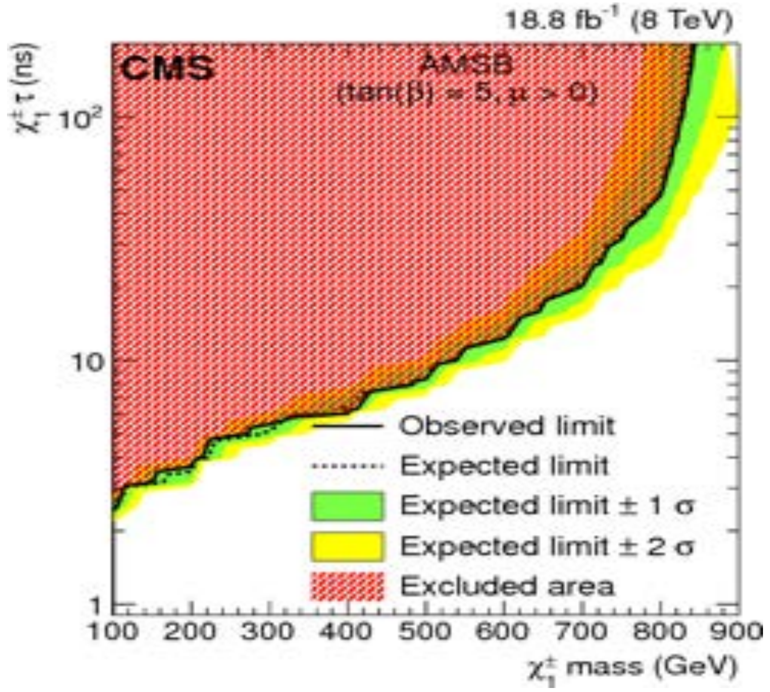
ATLAS, JHEP 01 (2015) 068



CMS, JHEP 07 (2013) 122

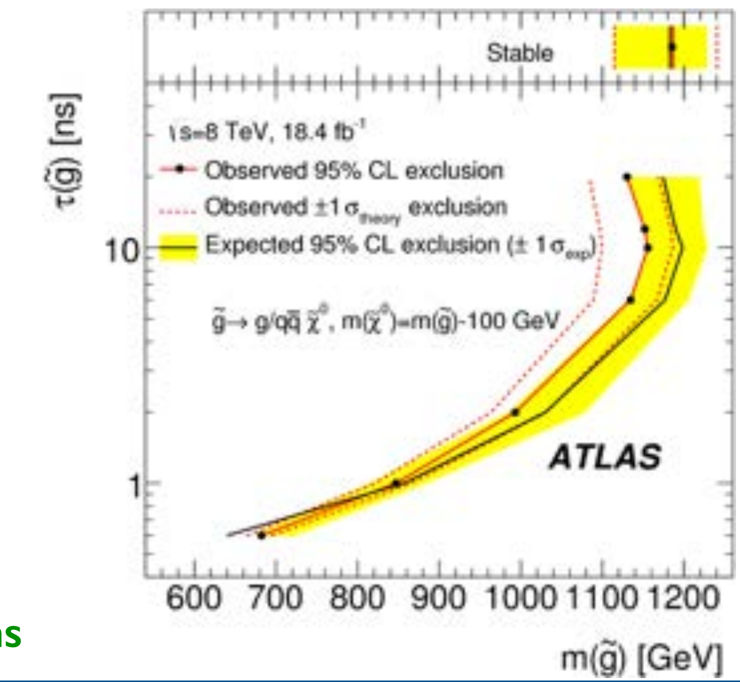


CMS, EPJC 73 (2015) 325



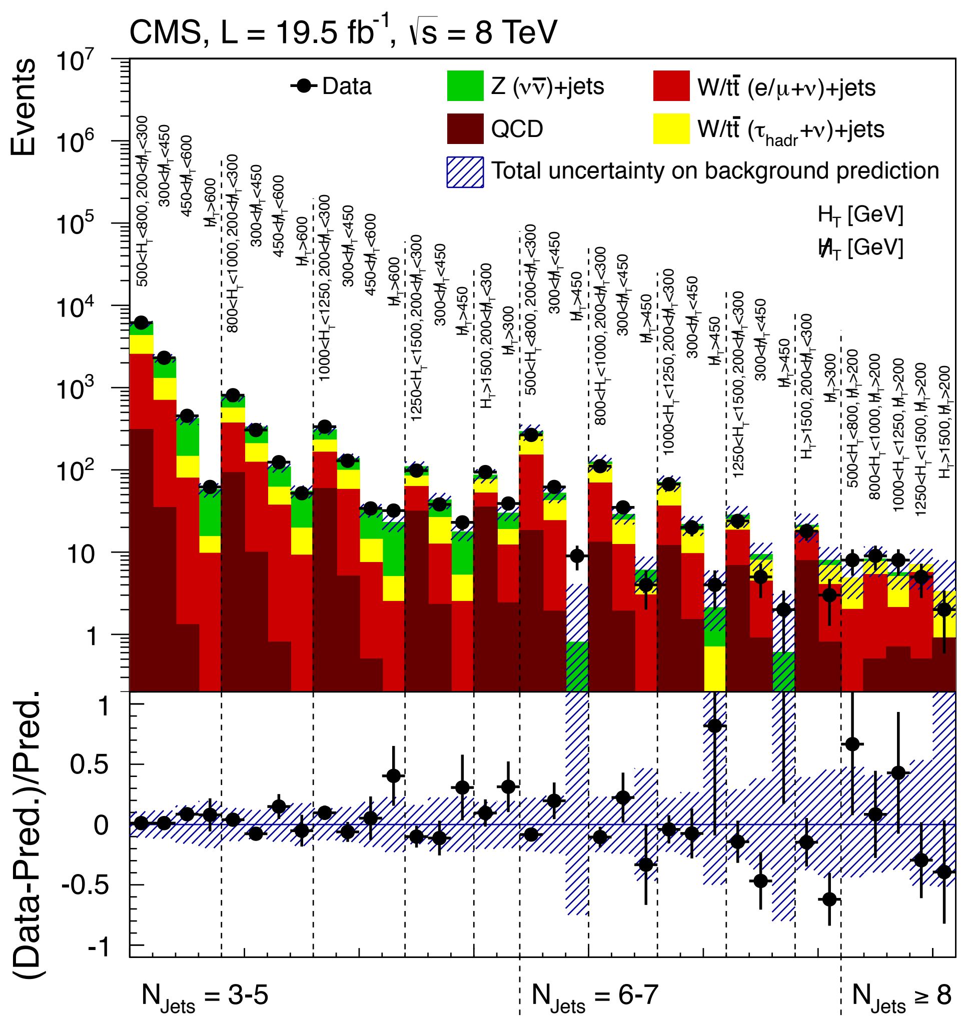
pMSSM, AMSB Reinterpretations

ATLAS, arXiv:1506.05332

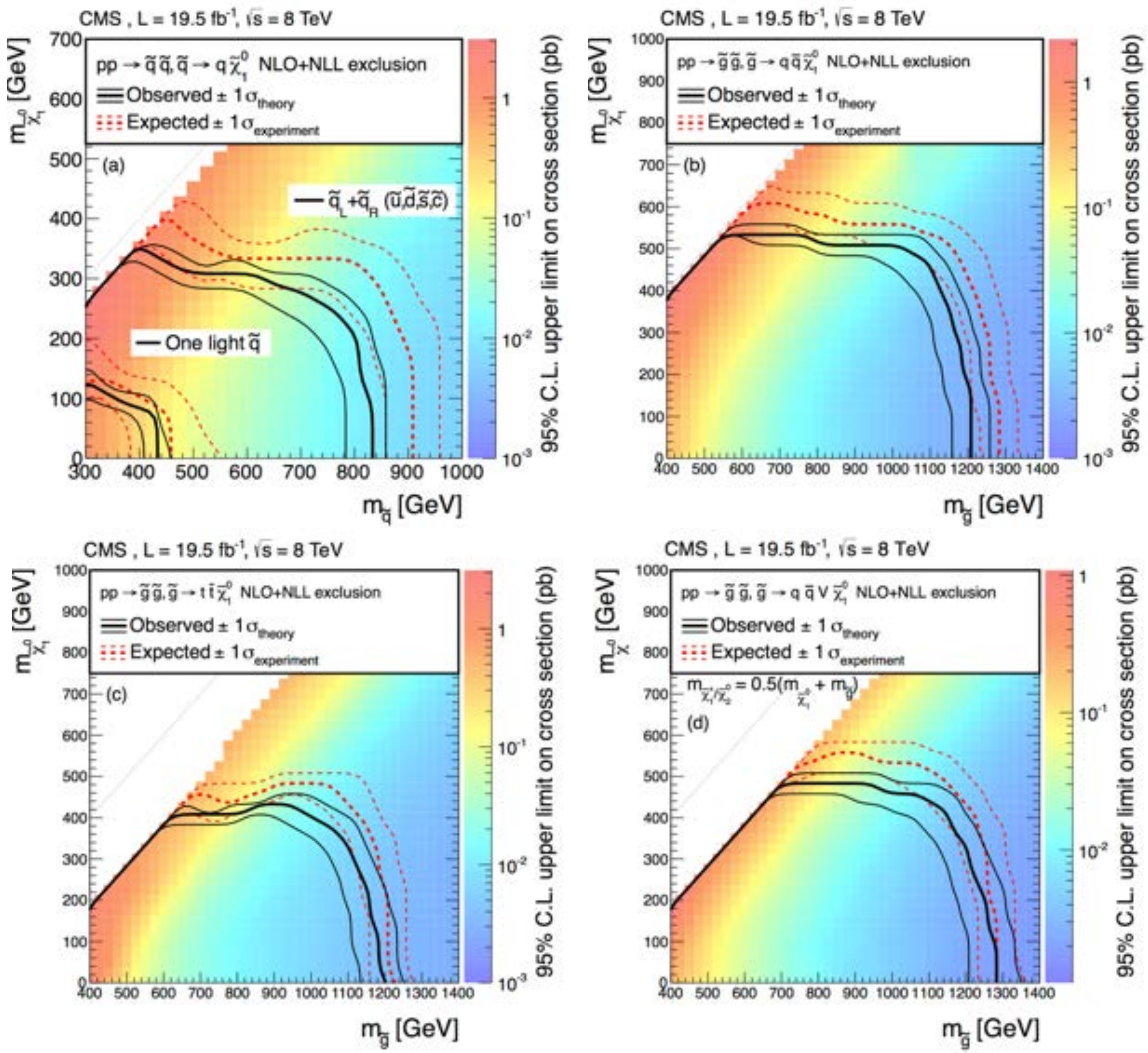


SUSY: Inclusive hadronic searches

- 36 signal regions were defined based on
  - jet multiplicity (>=3)
  - HT and missing HT
  - DeltaPhi between leading jets and missing HT
  - lepton vetos



CMS, JHEP 06 (2014) 055

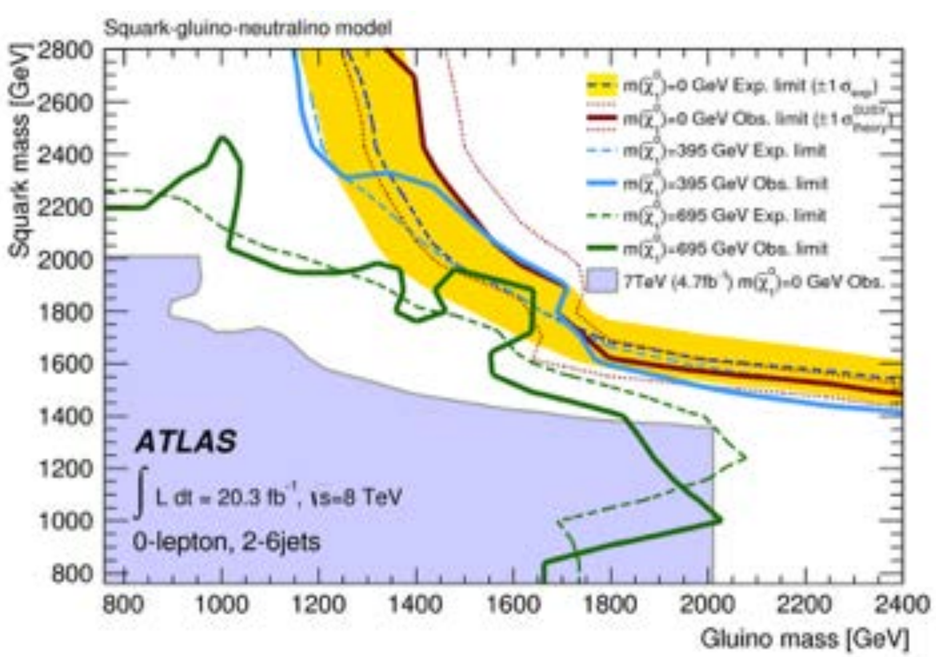


Exclusion limits in simplified supersymmetric models of squark or gluino pair production.

SUSY: Inclusive hadronic searches

ATLAS, JHEP 09 (2014) 176

- 15 signal regions were analysed based on
  - 2-6 jet multiplicity
    - ➡ m_{eff}
  - Level of background rejection
  - Etmiss > 160 GeV
  - Etmiss/m_{eff} or Etmiss/sqrt(HT)



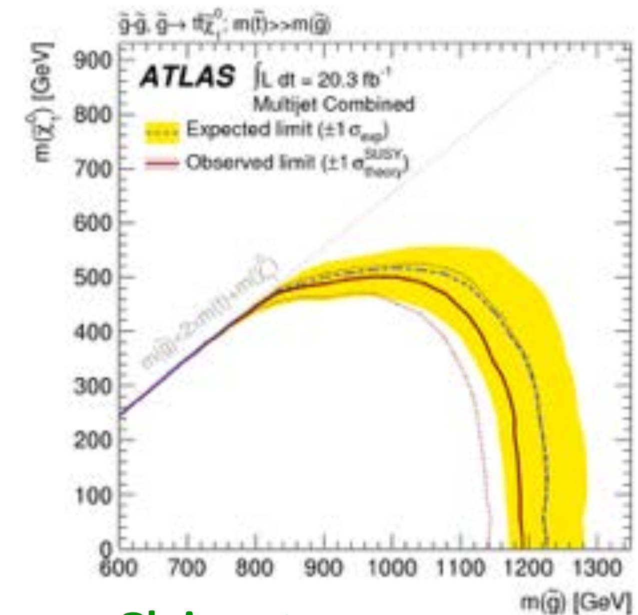
Strong production of gluinos and first- and second-generation squarks with direct decays to quarks and lightest neutralinos

ATLAS, JHEP 10 (2013) 130

- Consider long cascade decays, i.e.

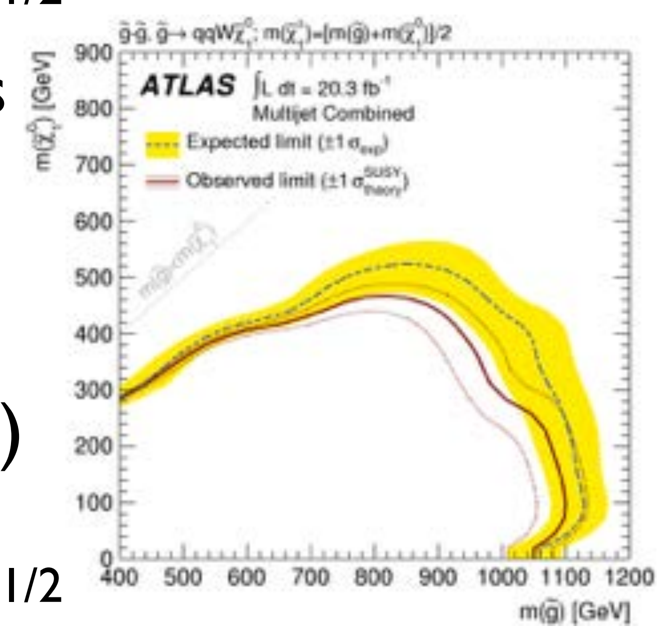
$$\tilde{g} \to \tilde{t} + \bar{t}$$
$$\downarrow$$
$$\tilde{t} \to t + \tilde{\chi}_1^0$$

- 19 signal regions were analysed
  - Multi-jet + flavour
    - ➡ 7,8,9,10 jets
    - ➡ Jet p_T > 50 or 80 GeV
    - ➡ Jet |eta| < 2.0
    - ➡ 0,1,2 b-tagged jets
    - ➡ Etmiss/sqrt(HT) > 4 $GeV^{1/2}$
  - Multi-jet + Sum of jet masses
    - ➡ 8,9,10 jets
    - ➡ Jet p_T > 50 GeV
    - ➡ Jet |eta| < 2.8
    - ➡ Sum of jet masses (R=1.0) > 340 or 420 GeV
    - ➡ Etmiss/sqrt(HT) > 4 $GeV^{1/2}$



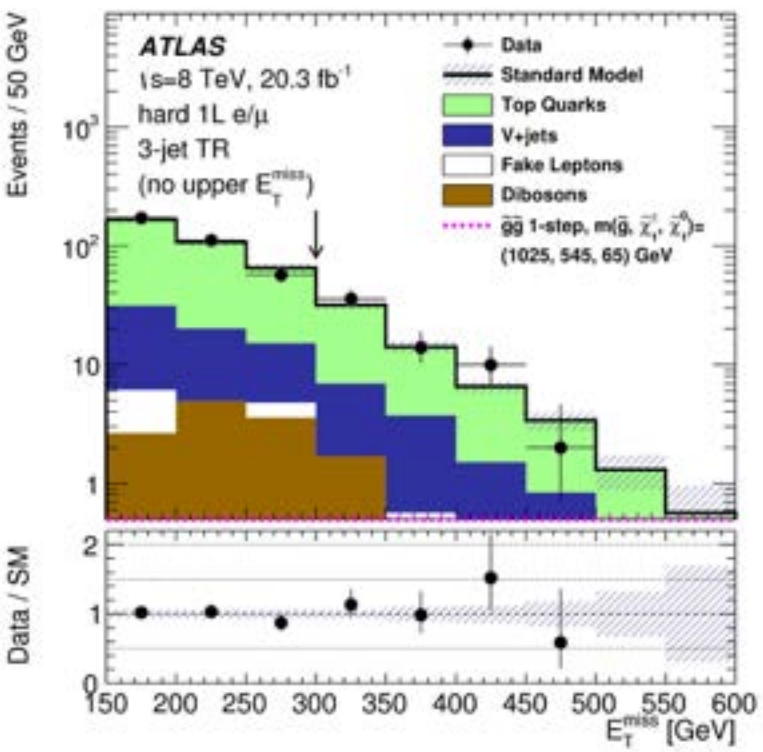
Gluino-stop

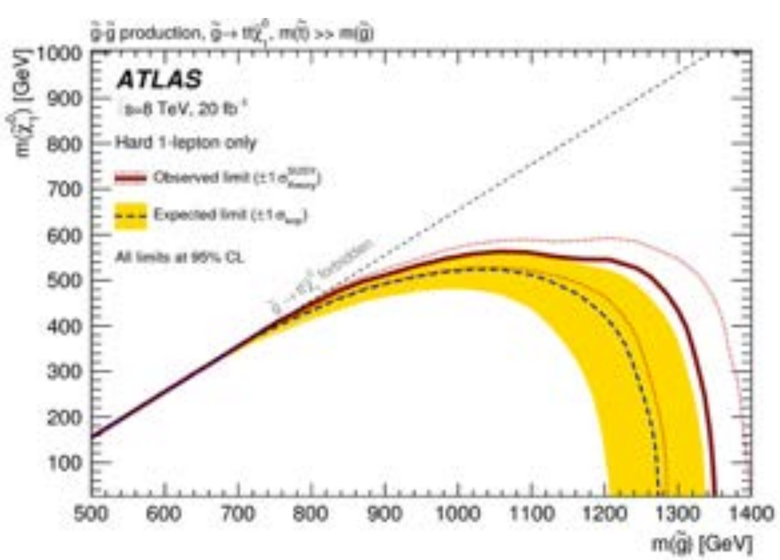
Gluino-squark (via chargino)



SUSY: Inclusive single/di-[os/ss] lepton searches

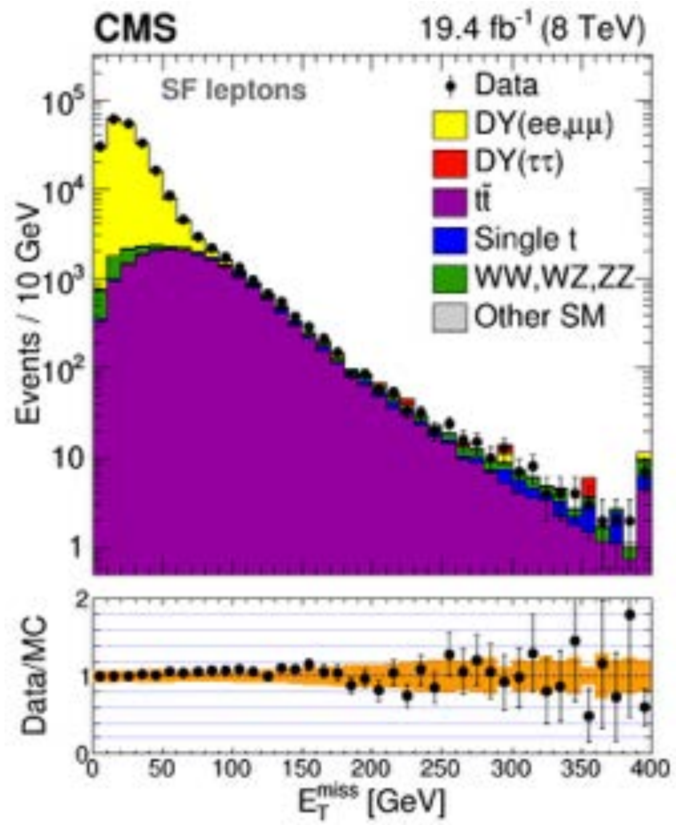
At least one isolated lepton (electron or muon), jets and MET

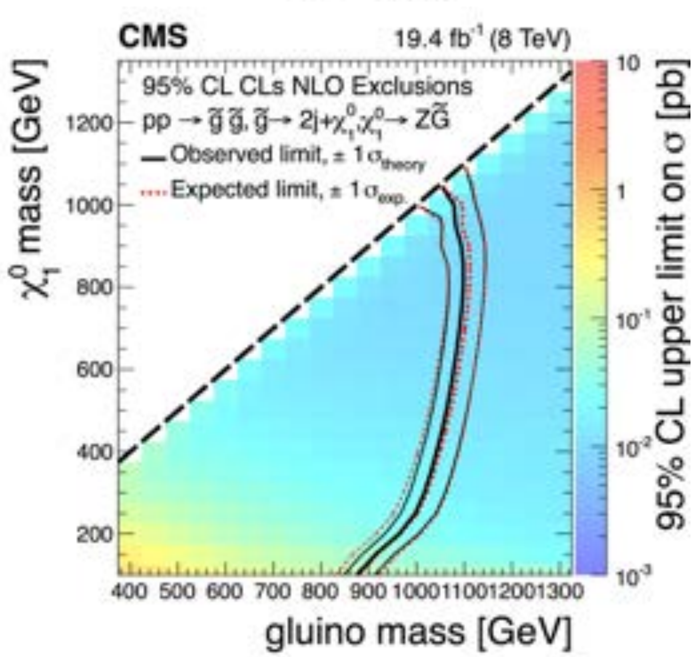




ATLAS, JHEP 04 (2015) 116

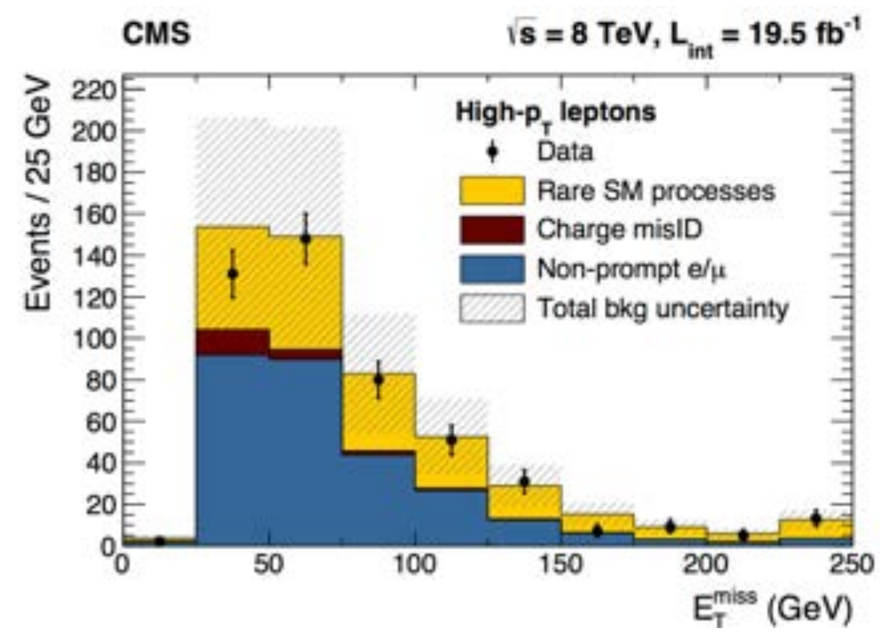
Two opposite-sign same-flavor leptons, jet, MET

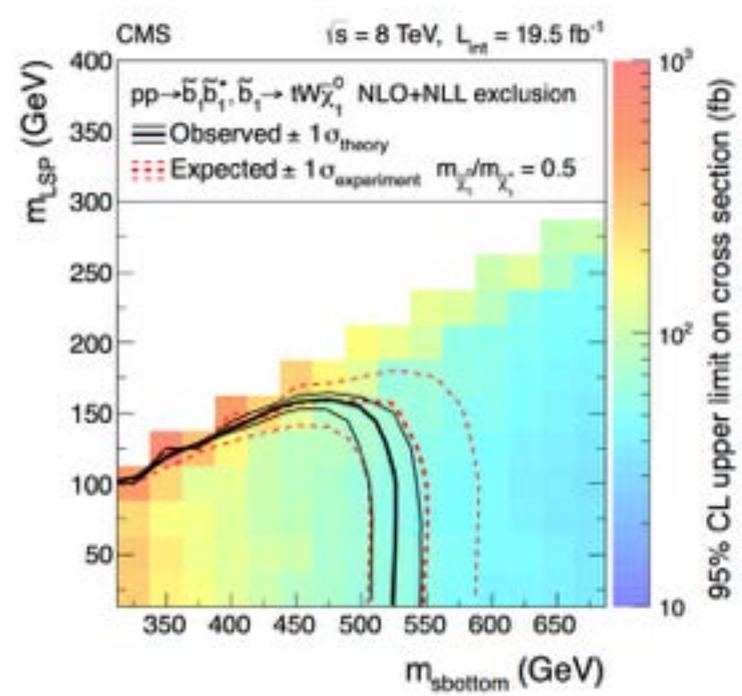




CMS, JHEP 04 (2015) 124

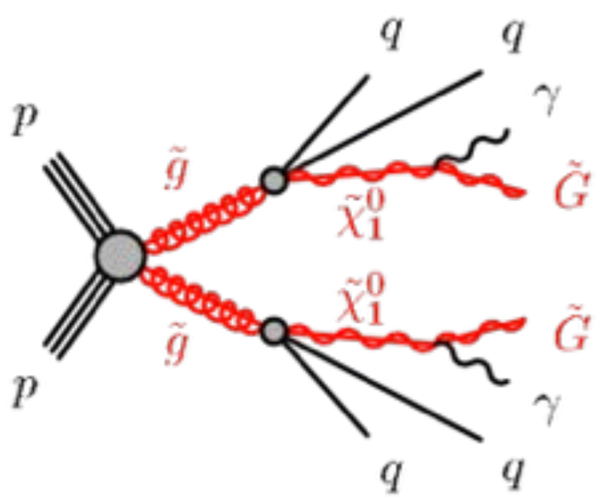
Same-sign leptons
Bins with low/high MET, HT, nJets, and nB

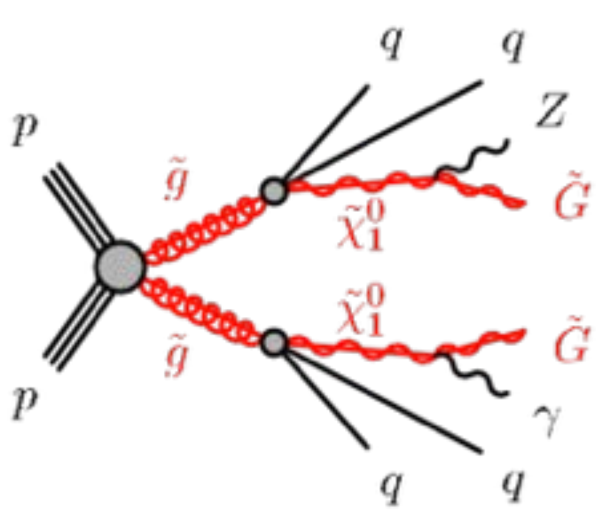




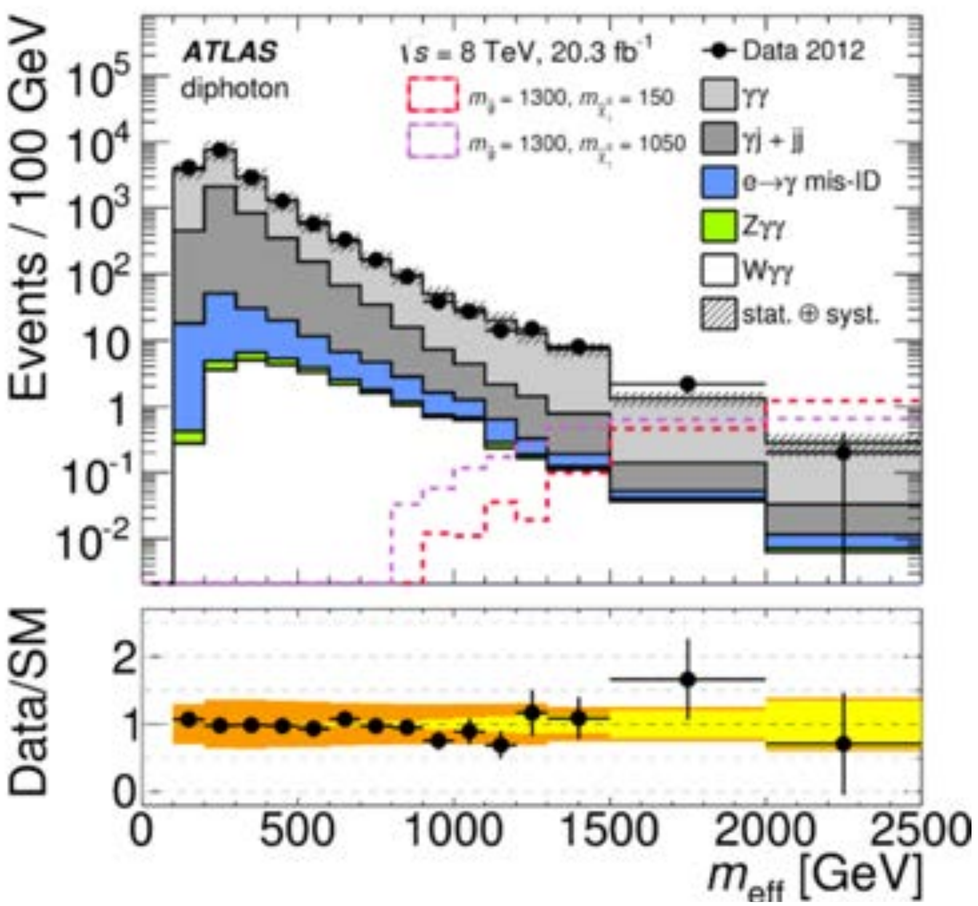
CMS, JHEP 01 (2014) 163

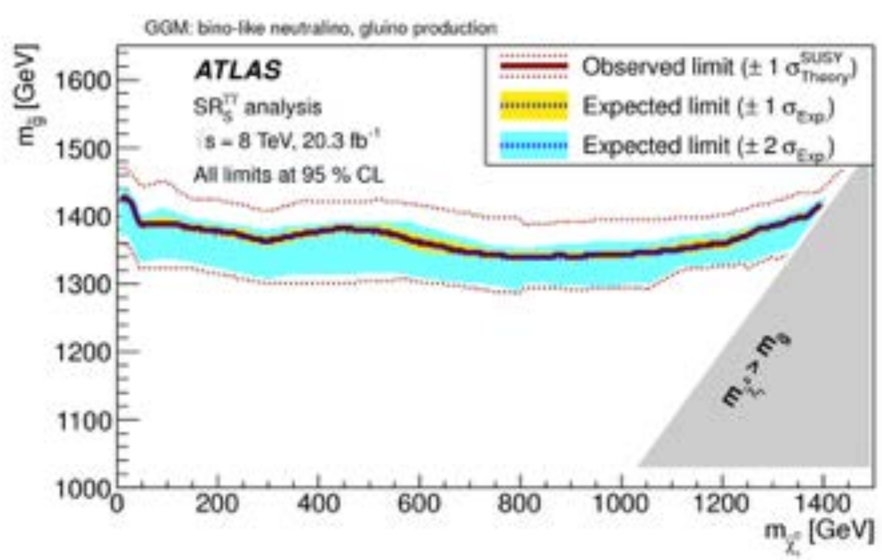
SUSY: Inclusive photon searches



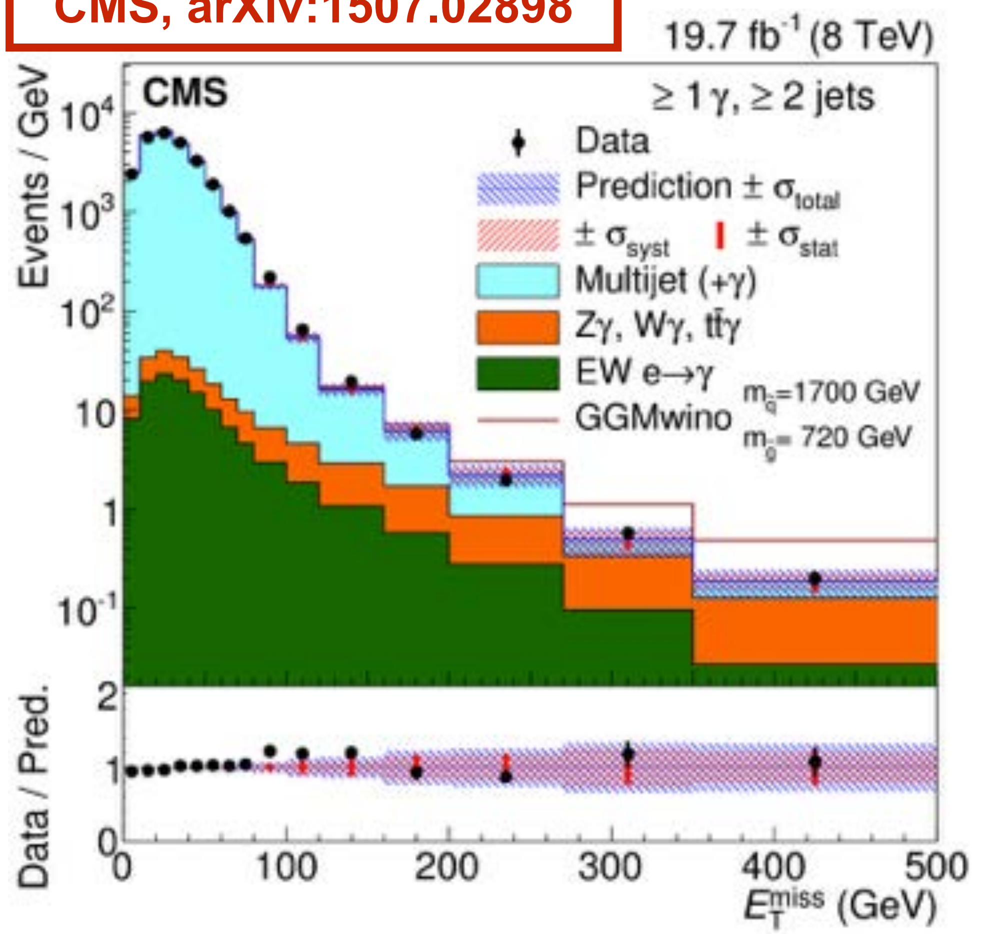


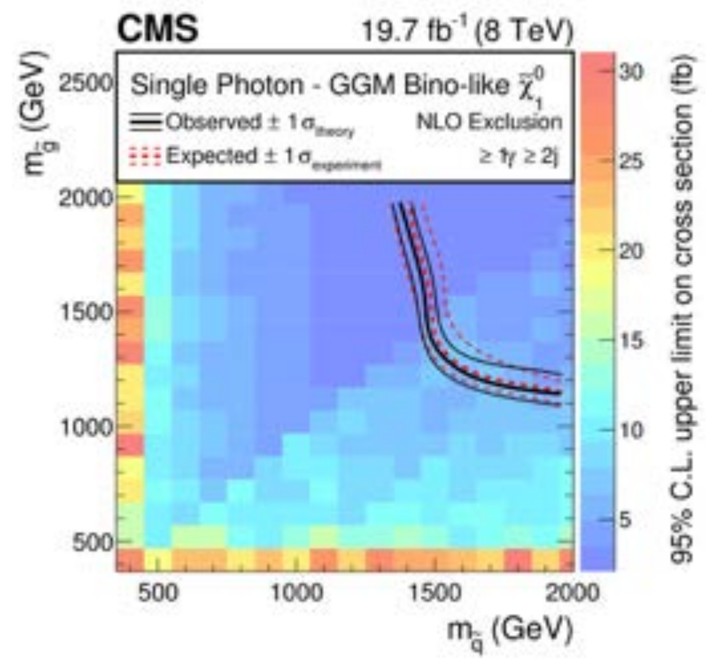
ATLAS, arXiv:1507.05493



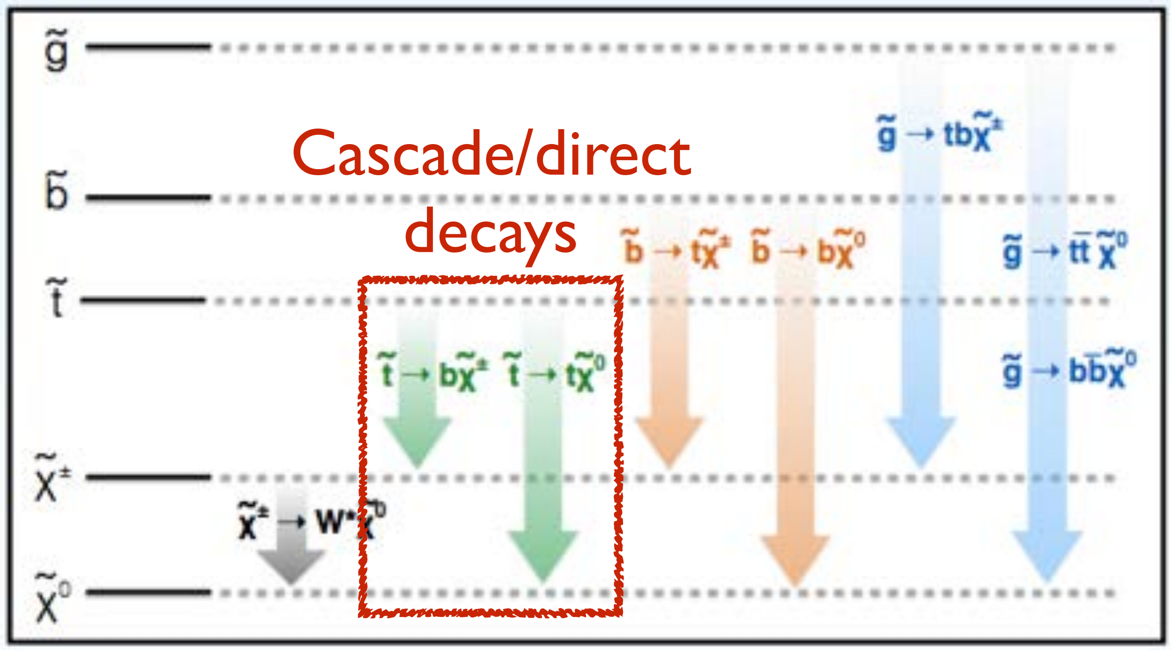


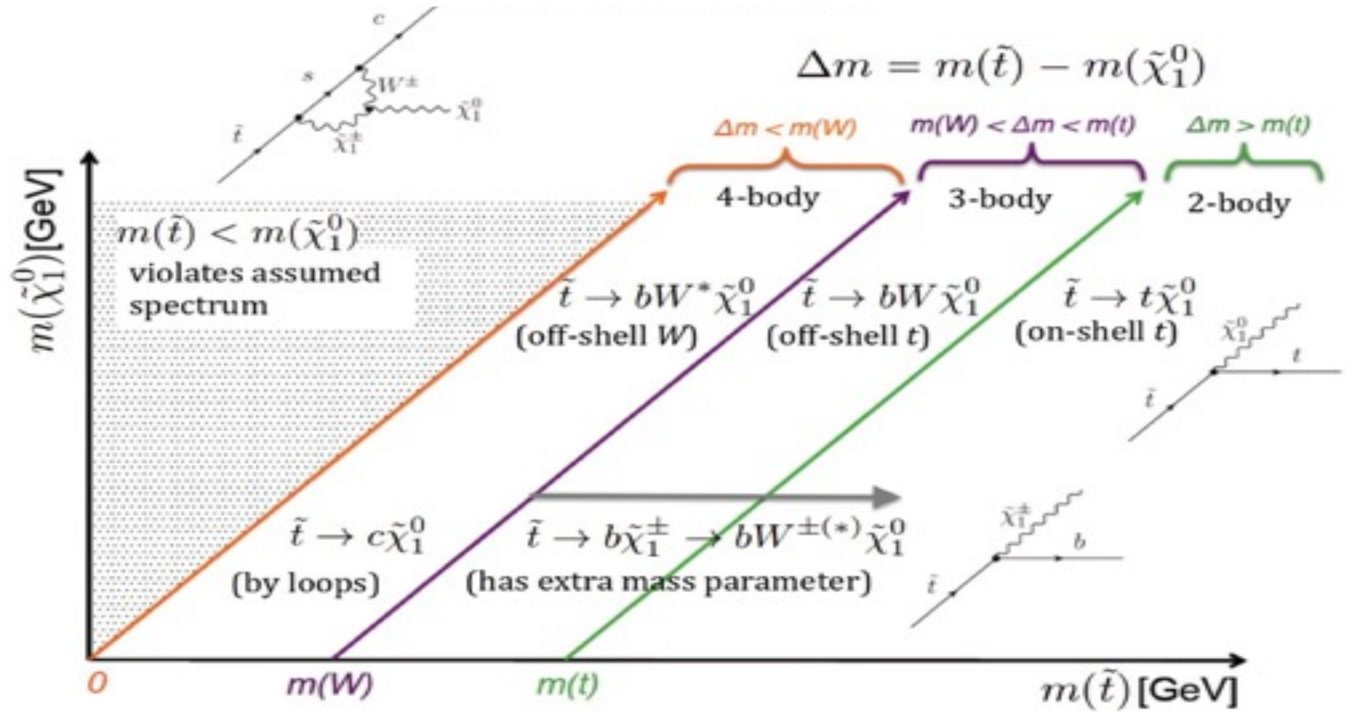
CMS, arXiv:1507.02898

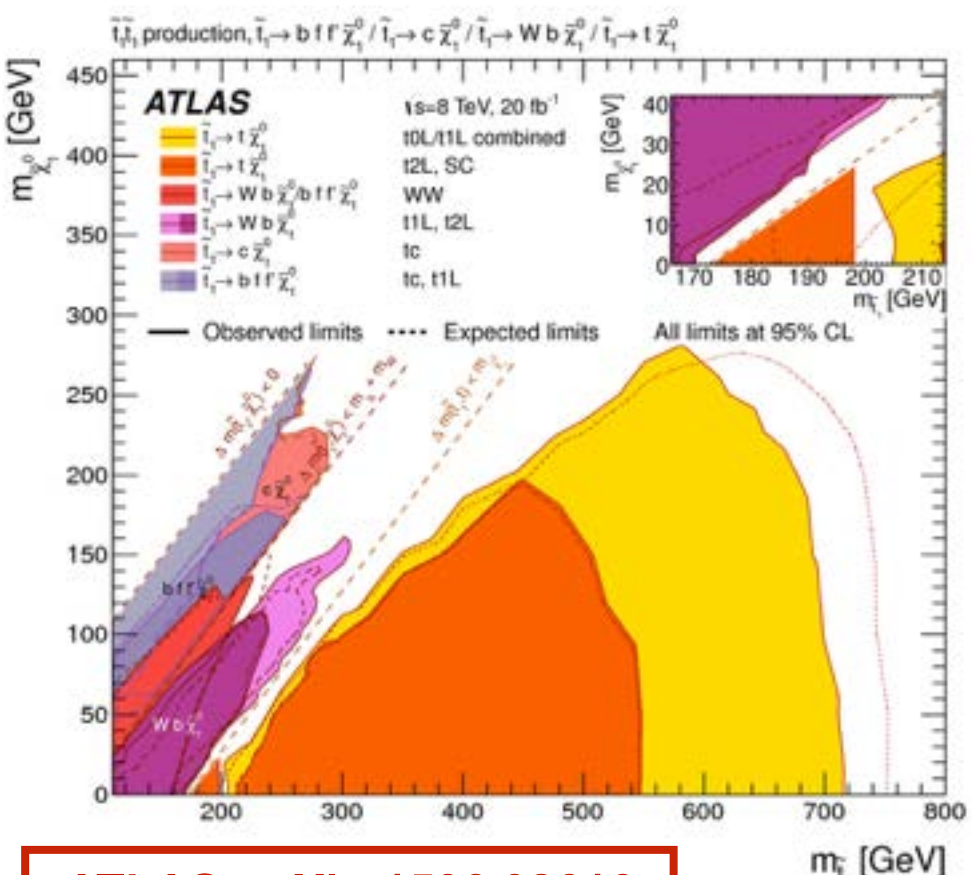


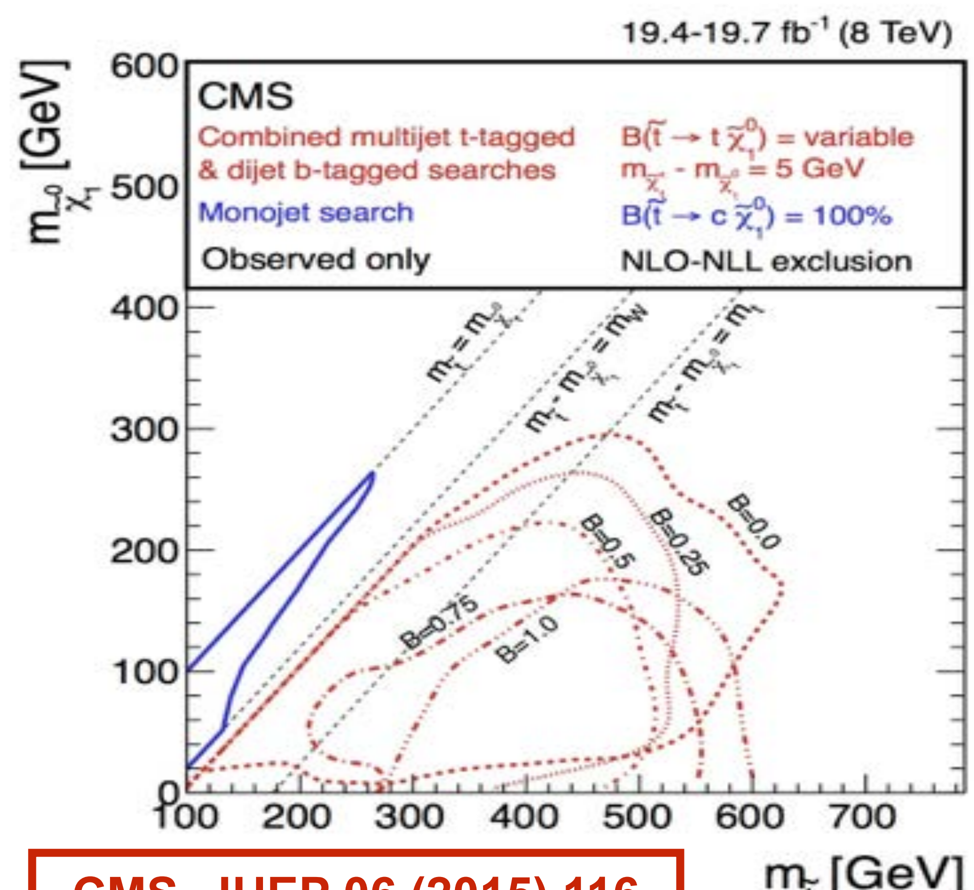


SUSY: Third generation squark









ATLAS, arXiv:1506.08616

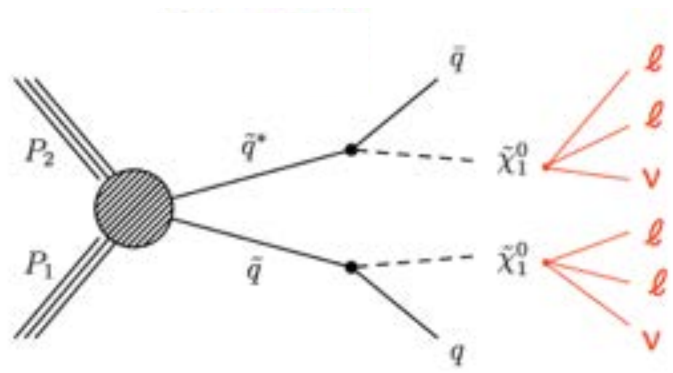
CMS, JHEP 06 (2015) 116

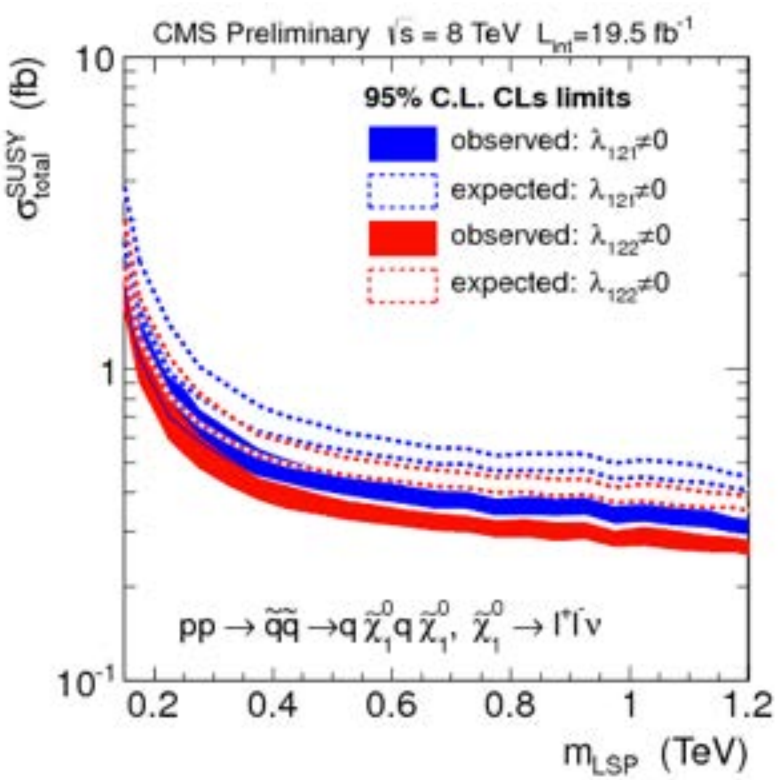
SUSY: R-parity violation

$$W_{\mathrm{RPV}} = \boxed{\mu_i' H_u L_i + \frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \frac{1}{2}\lambda'_{ijk} L_i Q_j \bar{D}_k} + \boxed{\frac{1}{2}\lambda''_{ijk}\bar{U}_i \bar{D}_j \bar{D}_k}$$

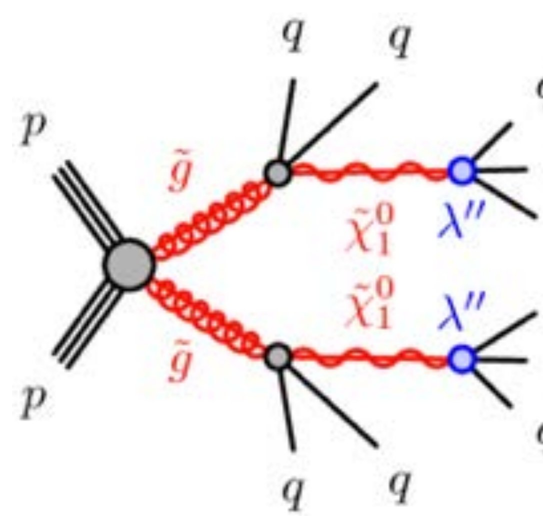
L-number violation

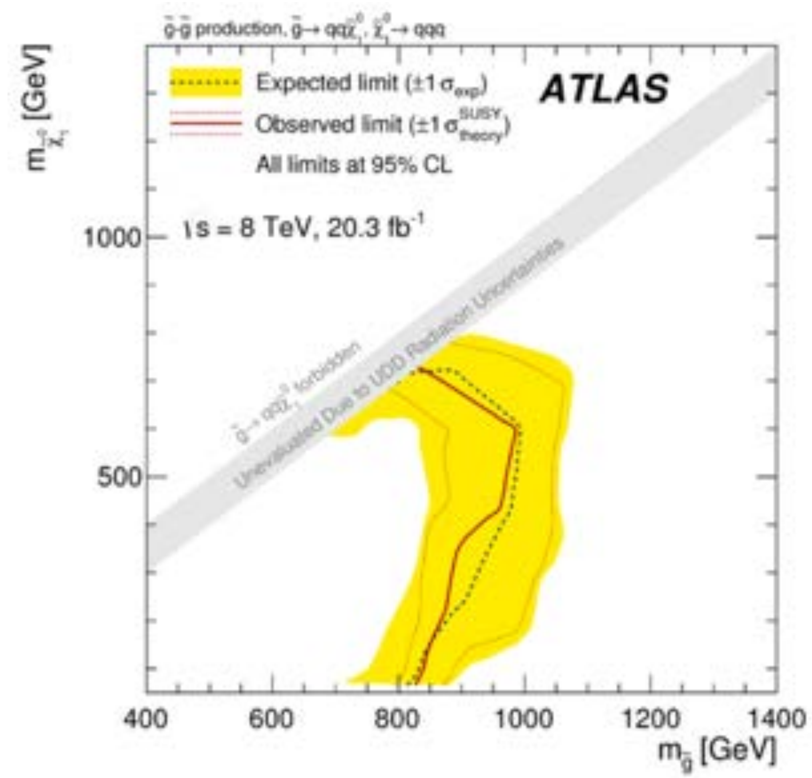
B-number violation



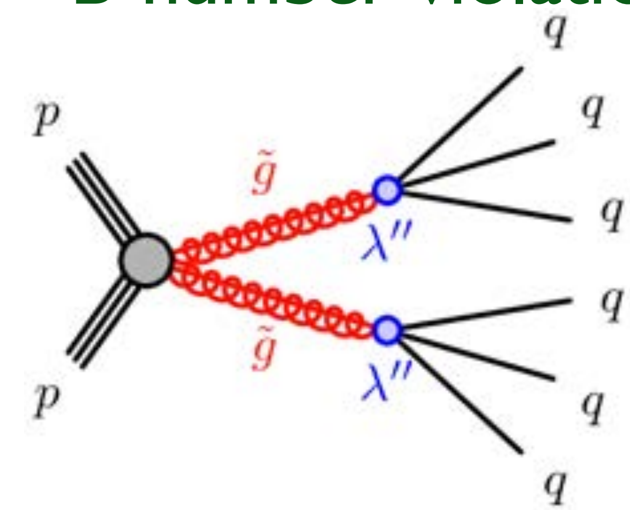


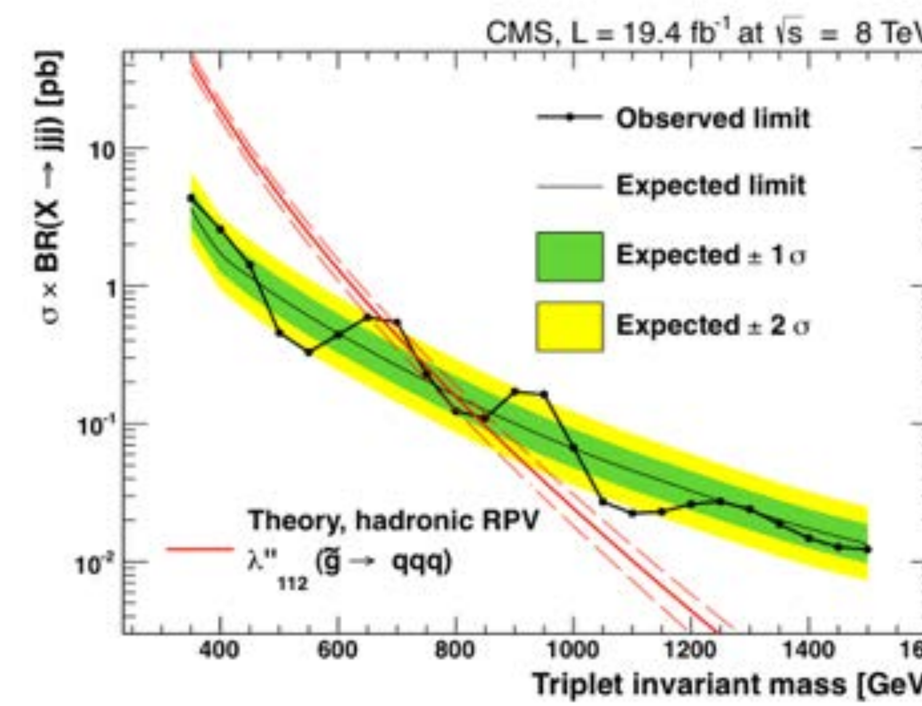
CMS, CMS-PAS-SUS-13-010





ATLAS, Phys. Rev. D 91, 112016





CMS, Phys. Lett. B 730 (2014) 193

Summary

- Search for physics beyond the standard model, SUSY and non-SUSY, is one of the main motivations for the LHC experiments

- ATLAS and CMS cover a large phase space to cover possible final states.

- Most SUSY and non-SUSY searches do not see significant excess from SM. Few "significant" deviations from SM which are needed to follow.

- For update results, specially for 13 TeV,
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
  - 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