

Recent results from ATLAS and CMS

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ARC Centre of Excellence for
Particle Physics at the Terascale



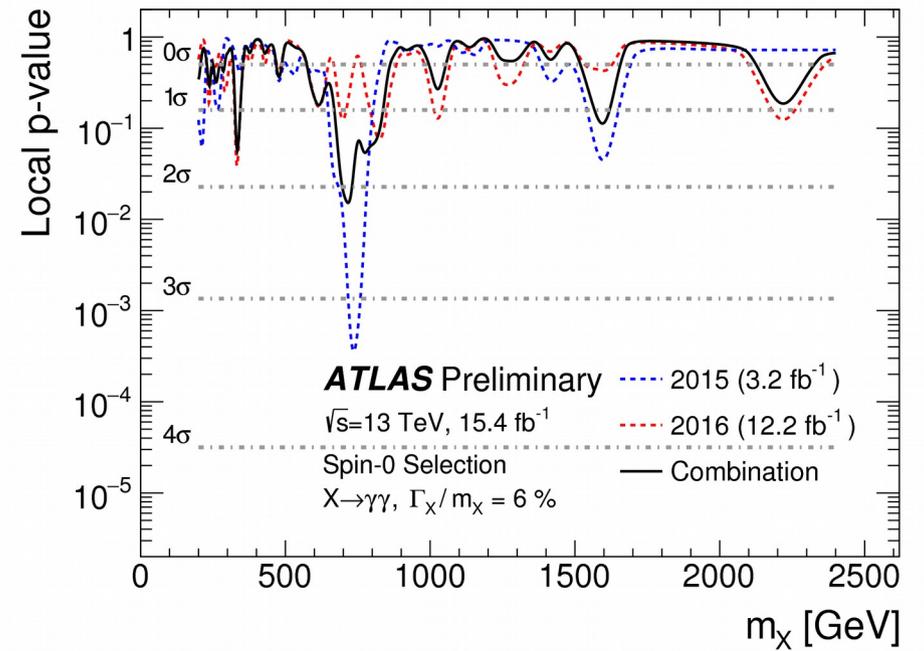
Recent results from ATLAS and CMS (that don't show hints for new phenomena!)

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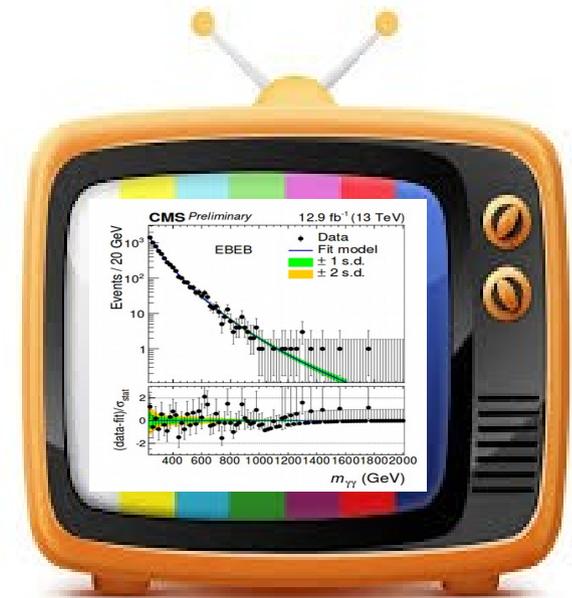
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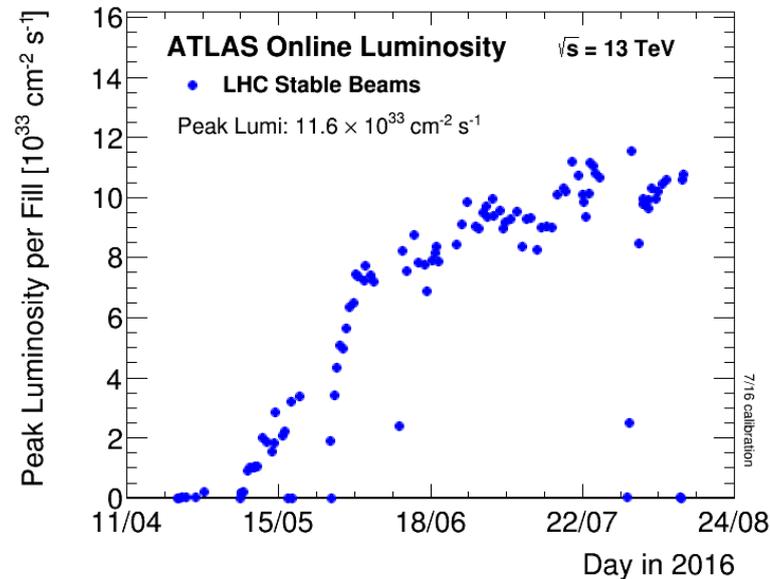
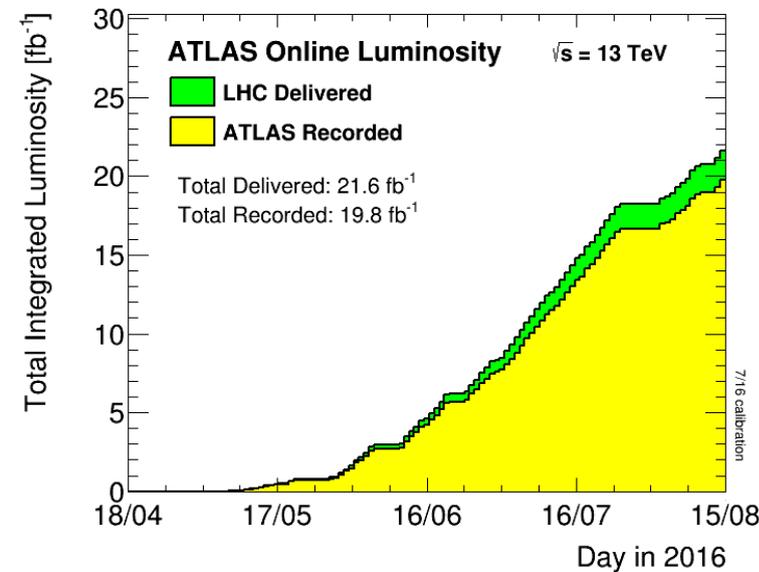
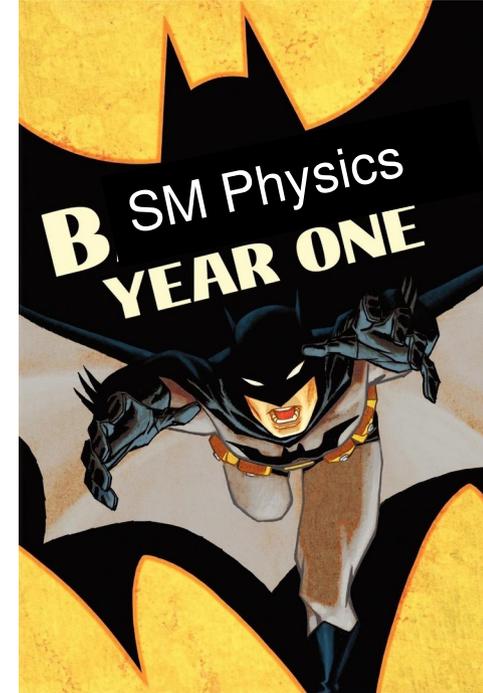
Plan for the next half hour

- It is still true that *new physics could first appear at any time*
- Think of today as a status update from Run II that:
 - tells you what channels you can flick to whilst waiting for interesting discoveries
 - puts the null results in context where possible
- Will give the gist of lots of results
 - details can be found in the relevant CONF notes
 - will try and keep things “astro-friendly”

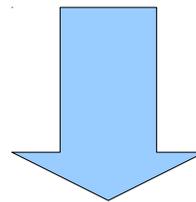
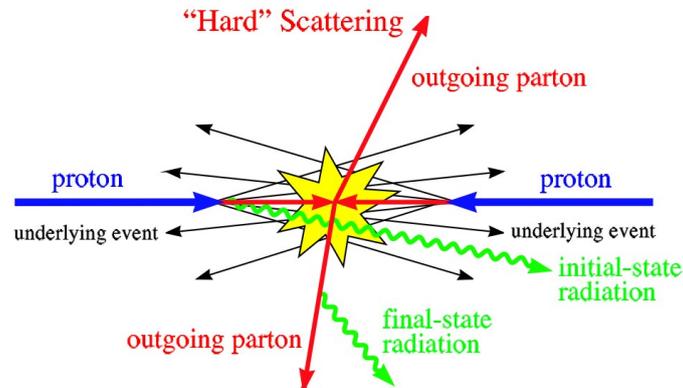


LHC: Year One

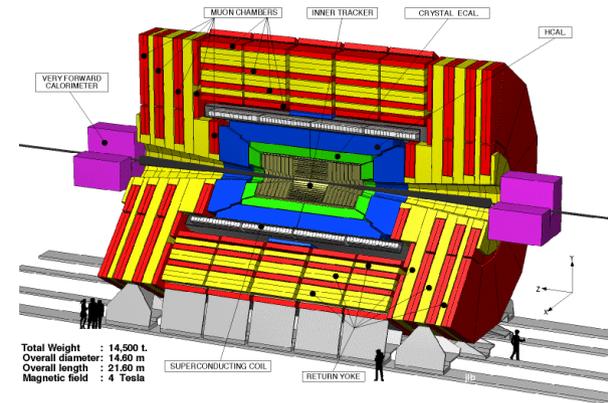
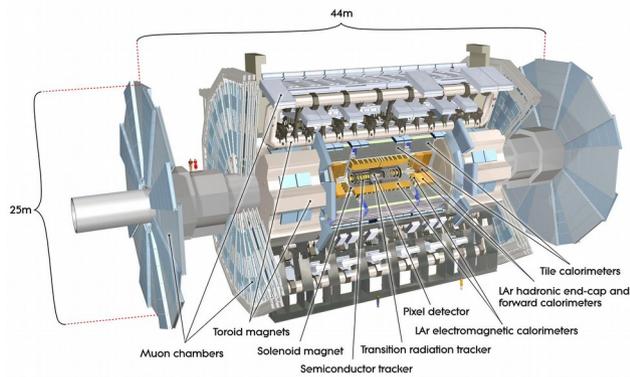
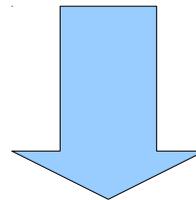
- Don't forget that the original plan was to run the LHC at 14 TeV
 - collect 10 fb^{-1} per year at low luminosity ($L = 1 \times 10^{33}$)
 - bump up the luminosity and take 100 fb^{-1} per year ($L = 1 \times 10^{34}$)
- This year we are on course to get $> 30 \text{ fb}^{-1}$ at 13 TeV (close enough)
 - this is an extremely exciting year for particle physics
 - you might even think of this as ***BSM: Year One***



LHC physics for non-collider physicists (1)



or



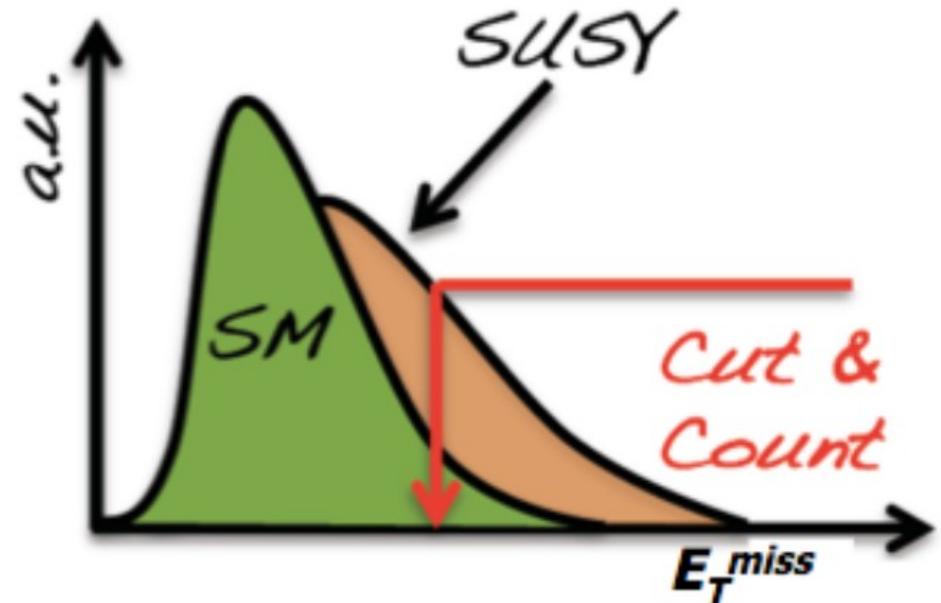
Four vectors of particle decay products, plus particle ID (electrons, muons, jets, photons, b-jets, tau leptons)

LHC physics for non-collider physicists (2)

- There are two main ways to uncover evidence for new physics

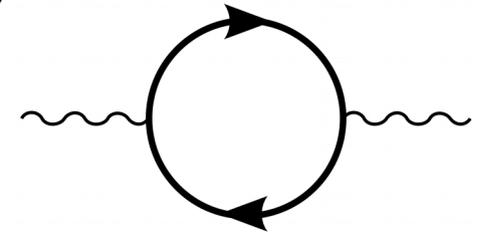
1) Search *directly*: look for new particles being produced

- Look for functions of four vectors that discriminate between SM and SUSY
- Cut away the SM background as much as possible without hurting the expected signal
- Or look for bumps over SM expectation

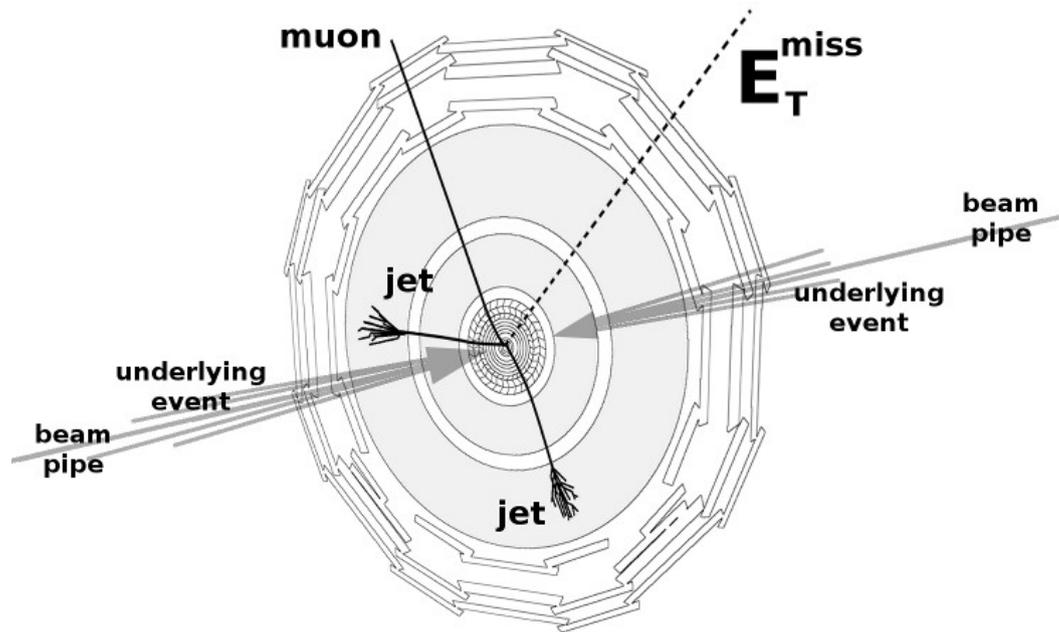


2) Measure SM processes *very precisely*

- New physics can enter via loop diagrams
- Measuring SM processes checks consistency but also reveals new physics at high scales



LHC physics for non-collider physicists: One more thing



- Missing transverse energy is a key feature of dark matter production
 - only real SM source is neutrinos (whose kinematics are known)
 - also get a fake contribution from mismeasurements
 - loads of missing energy would indicate BSM physics...

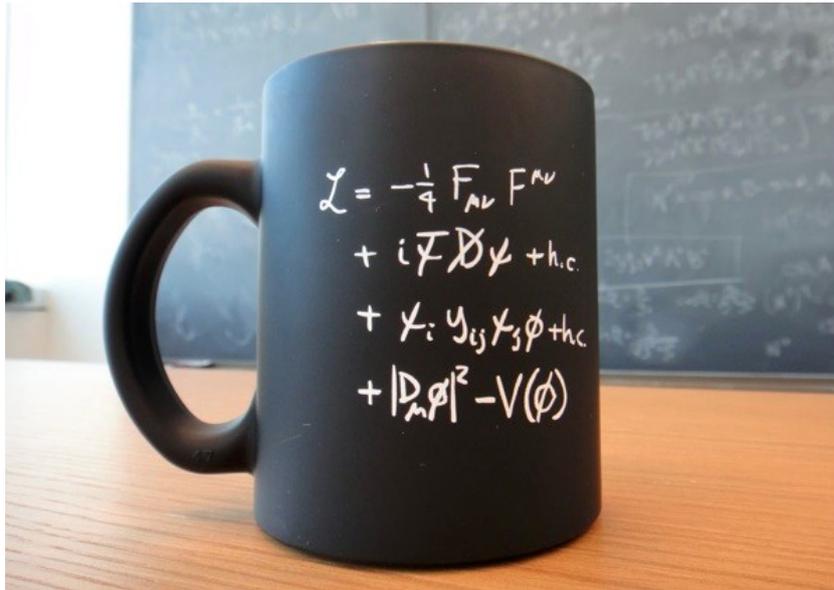
Run I Higgs summary

• Run I of the LHC gave us the Higgs discovery and then:

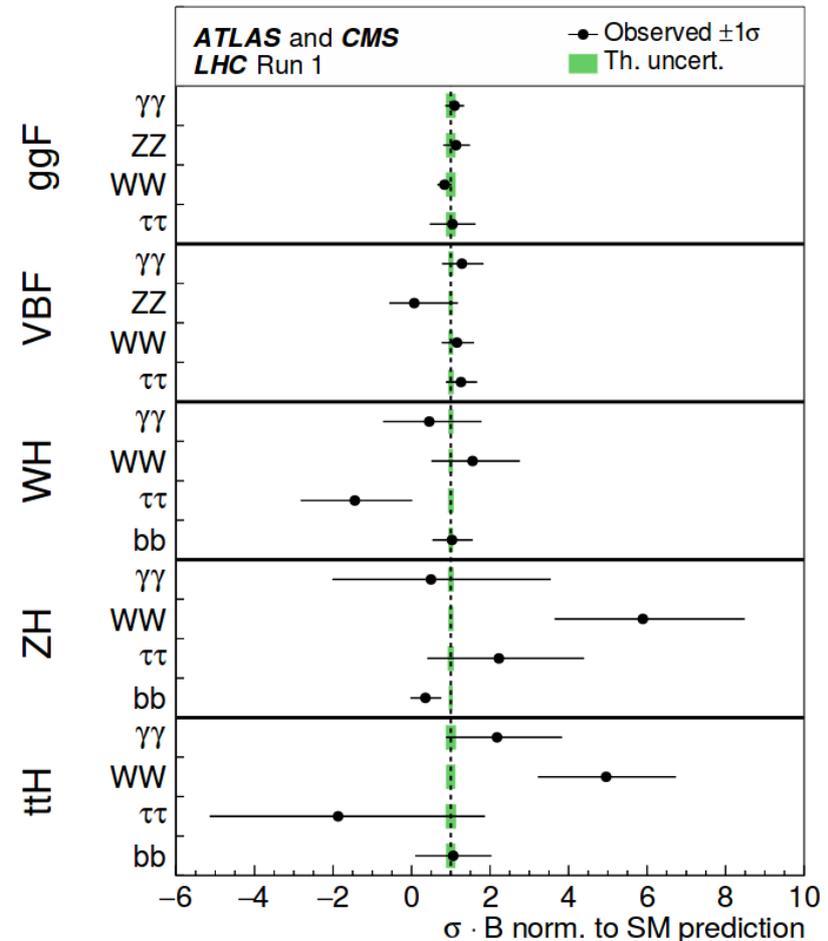
- mass measurement to high precision ($m_H = 125.09 \pm 0.24 \text{ GeV}$)
(independent of SM coupling assumptions)
- measurements of decay rates in different channels
- spin measurement
- parity measurement

arXiv:1606.02266
Phys. Rev. Lett. 114, 191803

ATLAS+CMS



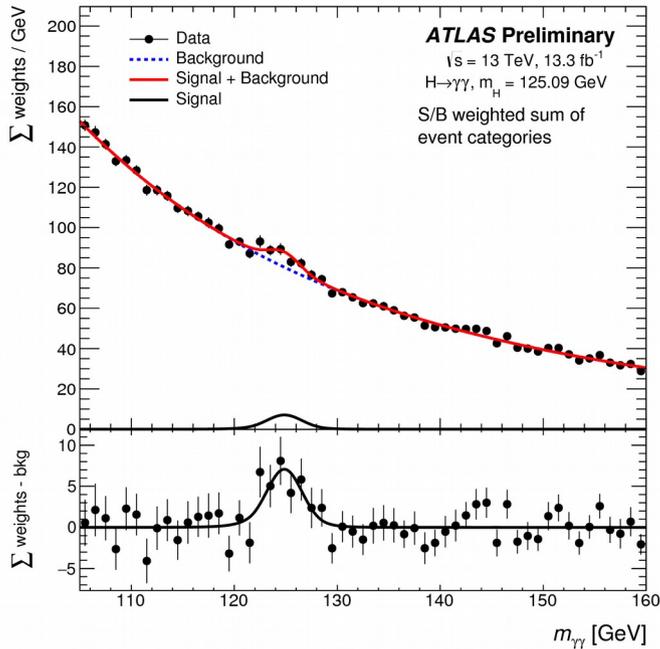
All measurements so far are consistent with the SM



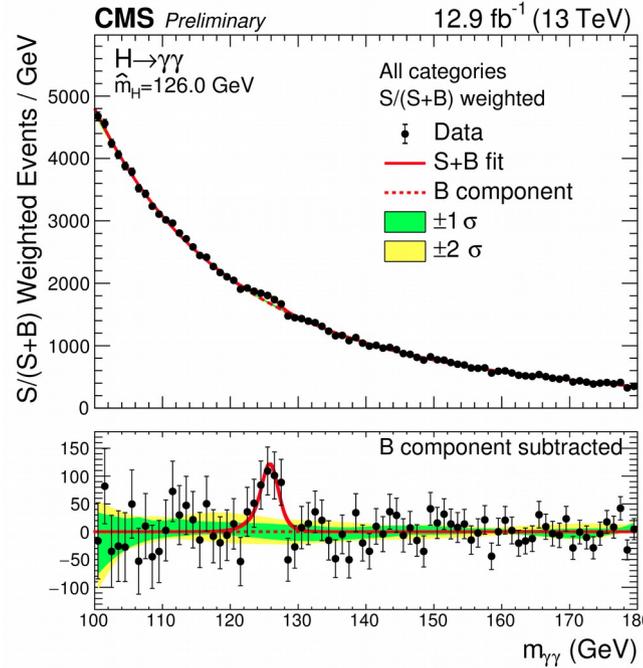
What's next?

- We still have no idea what the dynamical origin of the Higgs mechanism is
- Is the Higgs boson fully responsible for EW symmetry breaking as in the SM
 - need to measure Higgs couplings (and self-coupling)
- Is the Higgs sector natural?
 - precision branching ratio measurements are one way to answer this question
 - e.g. measurements of Higgs coupling to fermions compete with top partner searches in constraining the fine tuning of Minimal Composite Higgs scenarios (arXiv:1507.02332)
- Does the Higgs mediate interactions with a dark sector?
 - this is arguably the simplest WIMP model of all (UV complete for scalar DM)
 - invisible width measurements constrain Higgs portal DM (e.g. arXiv:1512.06458)
 - Higgs properties also affect indirect and direct DM searches
- Are Run II LHC results consistent with Run I results at low CoM energy?
 - does the cross-section match the SM prediction?
- Are there extra Higgs bosons?

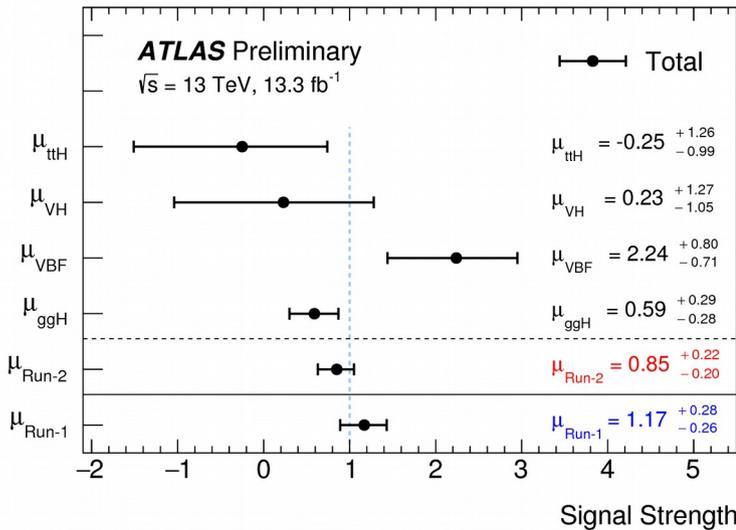
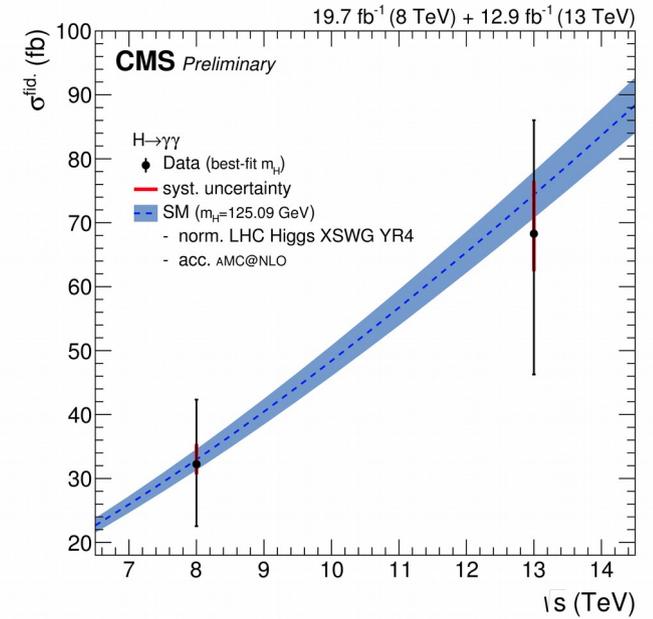
Rediscovering the Higgs (1): $\gamma\gamma$



ATLAS-CONF-2016-067

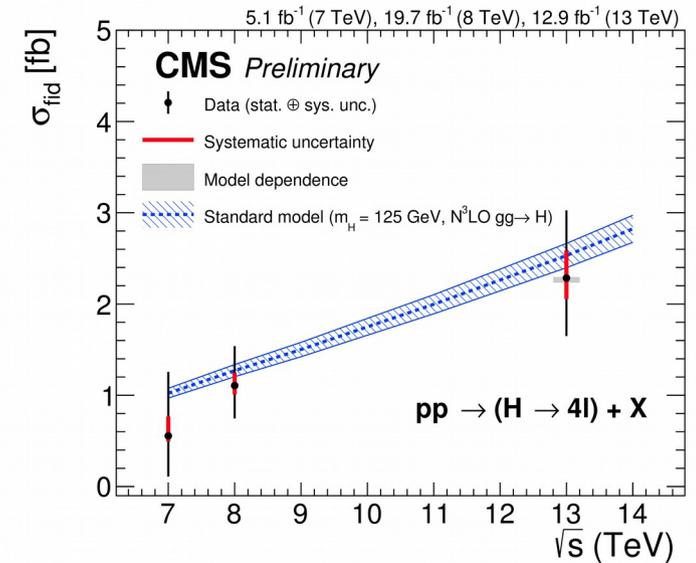
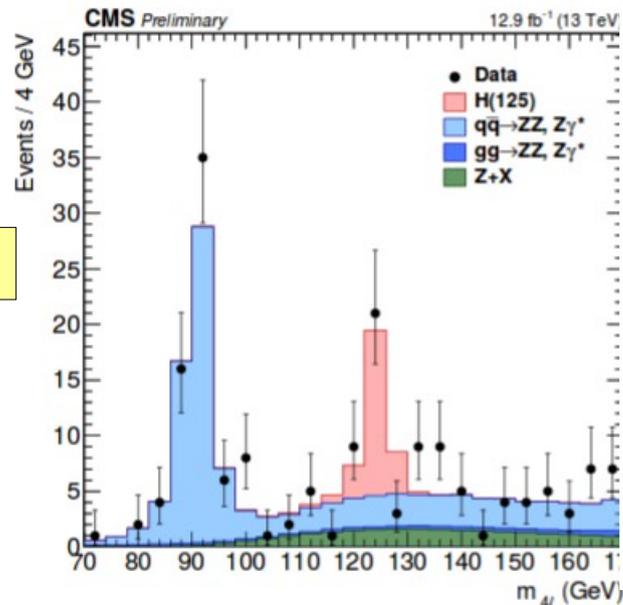
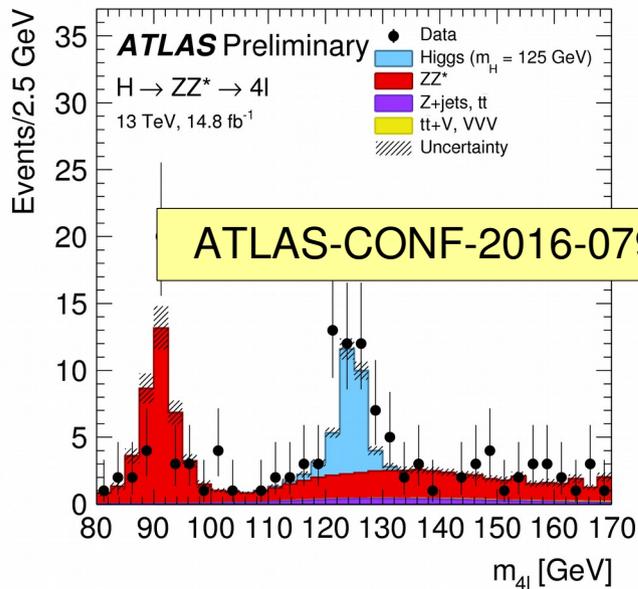


CMS-PAS-HIG-16-020



| 13 TeV | Fiducial σ (fb) | SM prediction (fb) |
|----------------------------------|--|--|
| ATLAS (13.3 fb^{-1}) | $43.2 \pm 14.9(\text{stat}) \pm 4.9(\text{syst})$ | $62.8^{+3.4}_{-4.4} (\text{N}^3\text{LO}+\text{XH})$ |
| CMS (12.9 fb^{-1}) | $69^{+16}_{-22}(\text{stat})^{+8}_{-6}(\text{syst})$ | 73.8 ± 3.8 |

Rediscovering the Higgs (2): ZZ^*

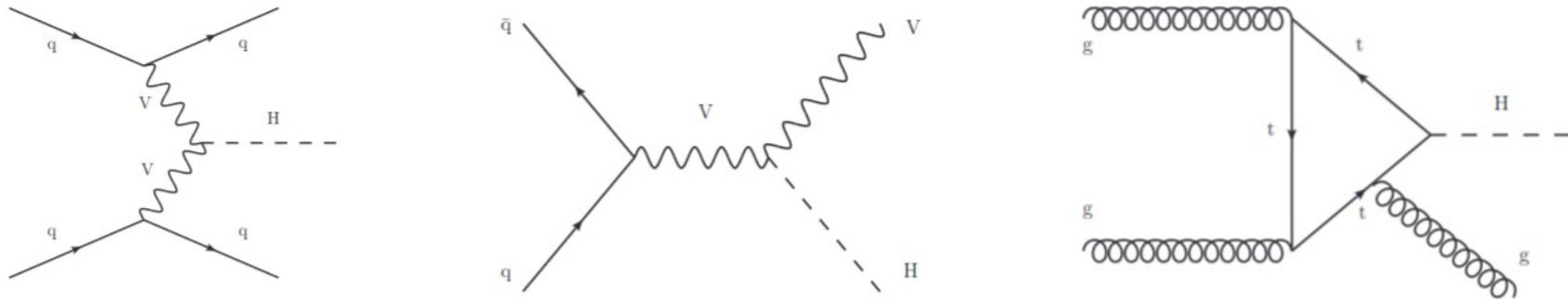


CMS-PAS-HIG-16-033

- Select two pairs of same flavour opposite sign leptons
 - impose kinematic requirements to reject, e.g. one Z and one low mass resonance
- Extract signal (for fiducial cross-section measurement) through fit of m_{4l}
- Results include separate studies of each production mode
 - CMS uses kinematic discriminants to enhance purity of various production modes
 - ATLAS uses BDT approach, plus simple counting and kinematics

See also: ATLAS $\gamma\gamma$ and ZZ^* combination (ATLAS-CONF-2016-081)

Higgs: Invisible width: CMS-HIG-16-016

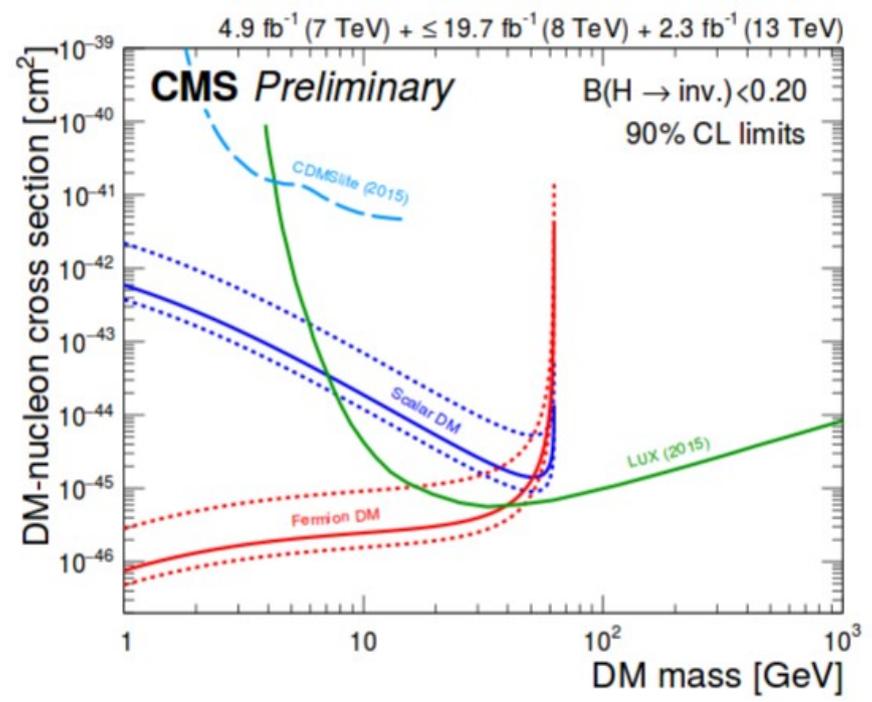


- Perform search for the above production modes
 - basic signature: MET recoiling against other objects
 - can look for hadronic or leptonic $V=Z$ decays

- Limits set in a Higgs-portal scenario

$BR(H_{inv}) < 0.24$ (0.23) at 95% CL

- See also ATLAS-CONF-2016-056
 - search for $Z(->ll)H$
 - used to set $BR(H_{inv}) < 0.98$ at 95% CL

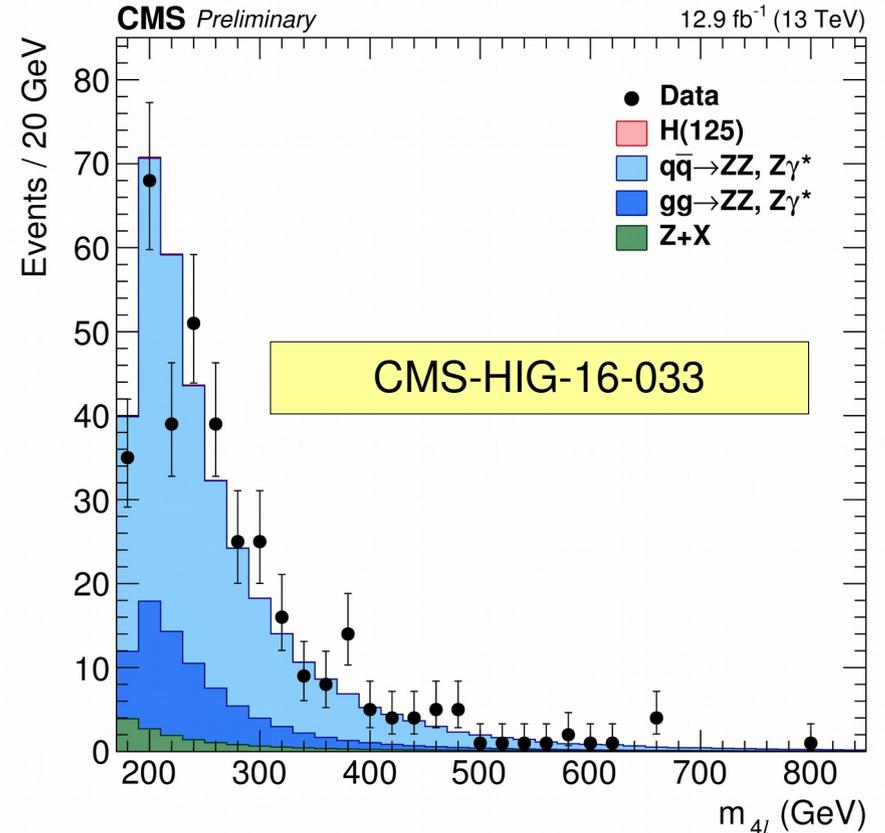
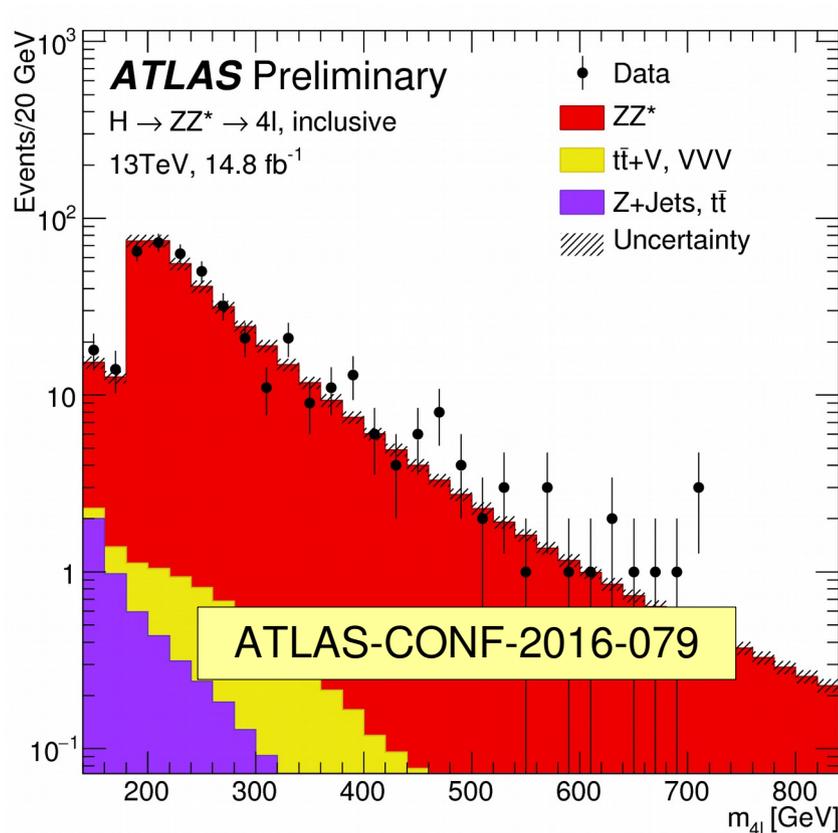


What about extra Higgs bosons?

- Two Higgs doublet models are popular for a number of reasons
 - e.g. SUSY requires two Higgs doublets
- Get 5 physical Higgs bosons with two Higgs doublets: h, H, A, H^{\pm}, H
- The recent diphoton excess if real would have killed the Two Higgs Doublet Model
 - the game is now back on!

Heavy Higgs searches

- ATLAS and CMS searched for heavy bosons
 - extension of the $h \rightarrow Z Z^*$ measurement (look in m_{4l} distribution, can also look in $ll\nu\nu$)



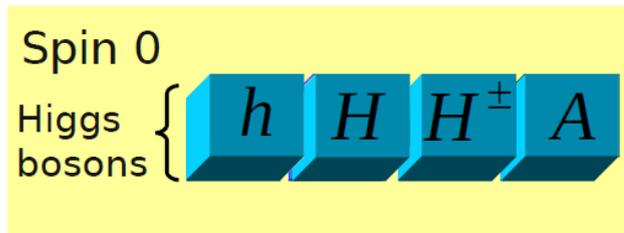
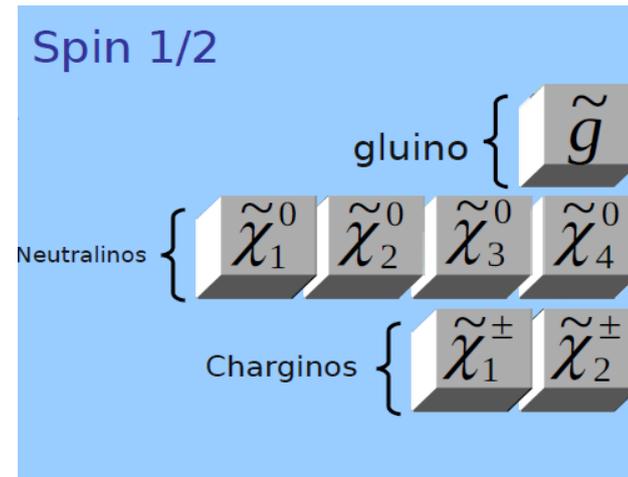
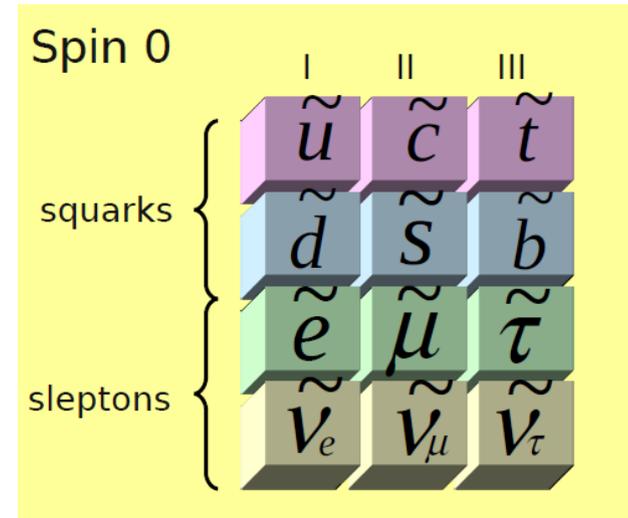
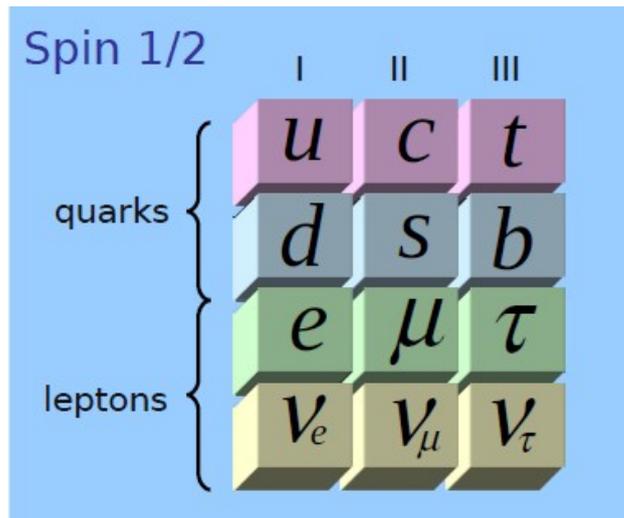
See other recent updates:

ATLAS-CONF-2016-085+CMS-HIG-16-006 ($\tau\tau$), ATLAS-CONF-2016-074+CMS-HIG-16-023 (WW),
 ATLAS-CONF-2016-073 (top pair)

See also charged Higgs searches:

ATLAS-CONF-2016-088, ATLAS-CONF-2016-089, CMS-HIG-16-027, CMS-HIG-16-030

SUSY: What we're looking for



This table could be more complicated in non-minimal SUSY scenarios

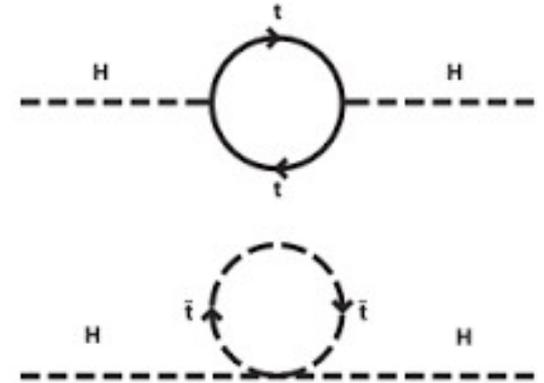
SUSY: What we know from Run I

- No evidence for sparticle production
- The single most interesting result for the MSSM is probably the Higgs mass measurement

→ need the quantum corrections to m_h to be *rather large* in the MSSM

→ need to have stop masses large, or large stop splitting

→ the stops are usually the lightest squarks

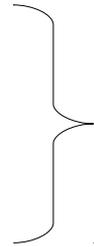


- Suggests that we should not be surprised that we didn't see evidence for SUSY in Run I...

SUSY: Run II results

- Huge list of preliminary results from ATLAS and CMS covering:

- squark and gluino production
- third generation squark production
- electroweak gaugino production
- compressed spectra



R-parity conserving (will focus on these today)

- R-parity violating sparticle decays
- Gauge-mediated SUSY scenarios

All current searches are excellent examples of null results

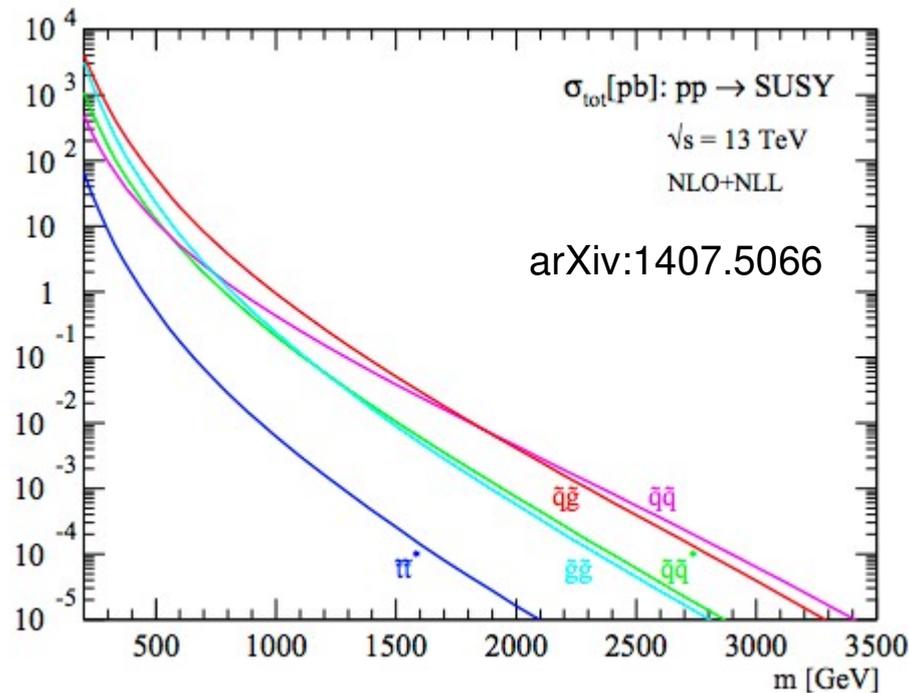
For full details see:

<http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SUS/index.html>

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults>

TODAY: Focus on recent results that are most constraining on “common garden” SUSY scenarios

SUSY: Run II prospects



Cross-sections are shown for degenerate squark and gluino masses

- If we have lots of light(ish) coloured sparticles:

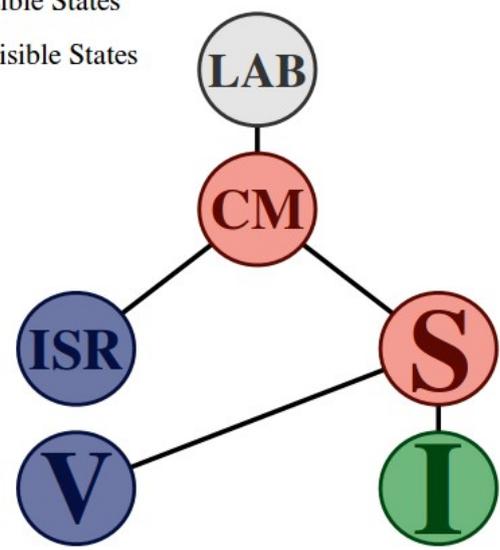
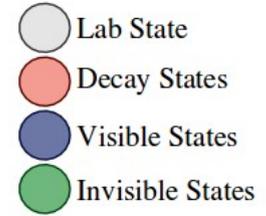
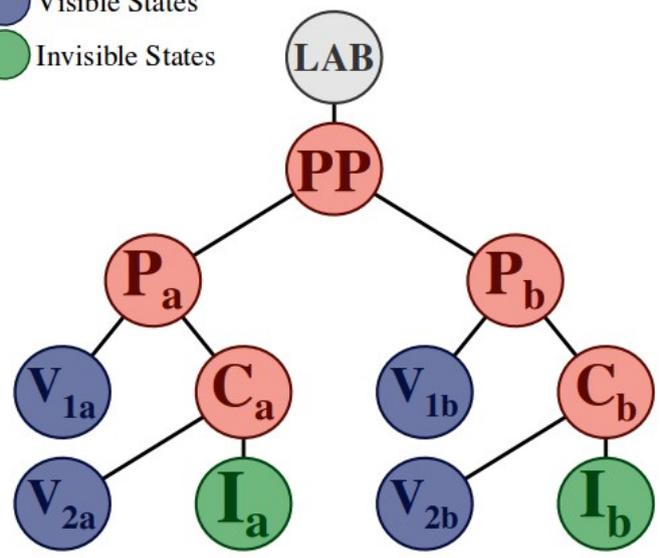
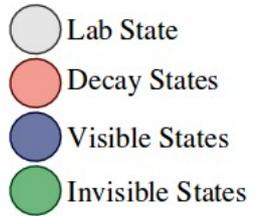
ALL: search for squarks and gluinos in final states with jets plus missing energy

- If the only light coloured sparticle is the stop:

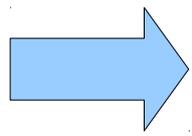
THIRD: look at third generation searches

- If no coloured sparticles are light:

EW: look for electroweak gauginos (typically in multilepton final states)



- Assume a decay topology and decompose events
- Define hemispheres using thrust axis of event
- Minimise hemisphere masses and assign missing d.o.f



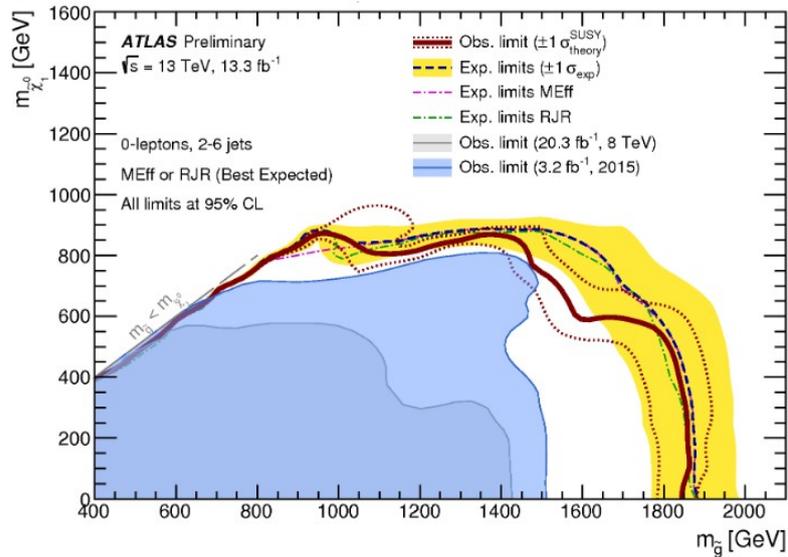
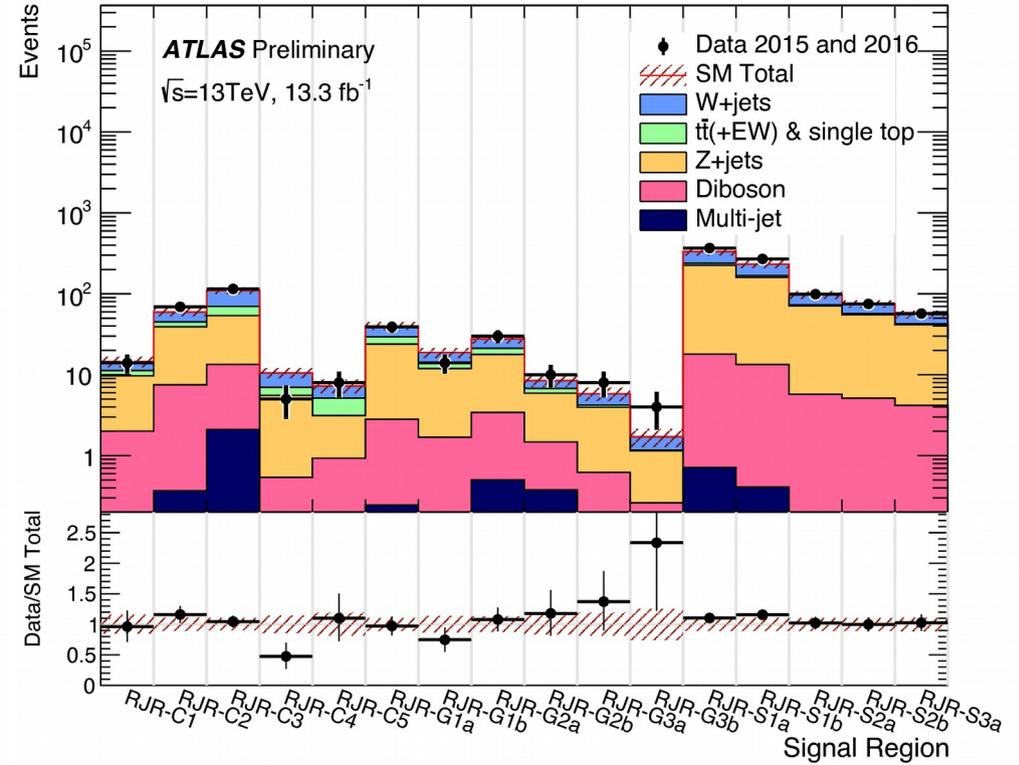
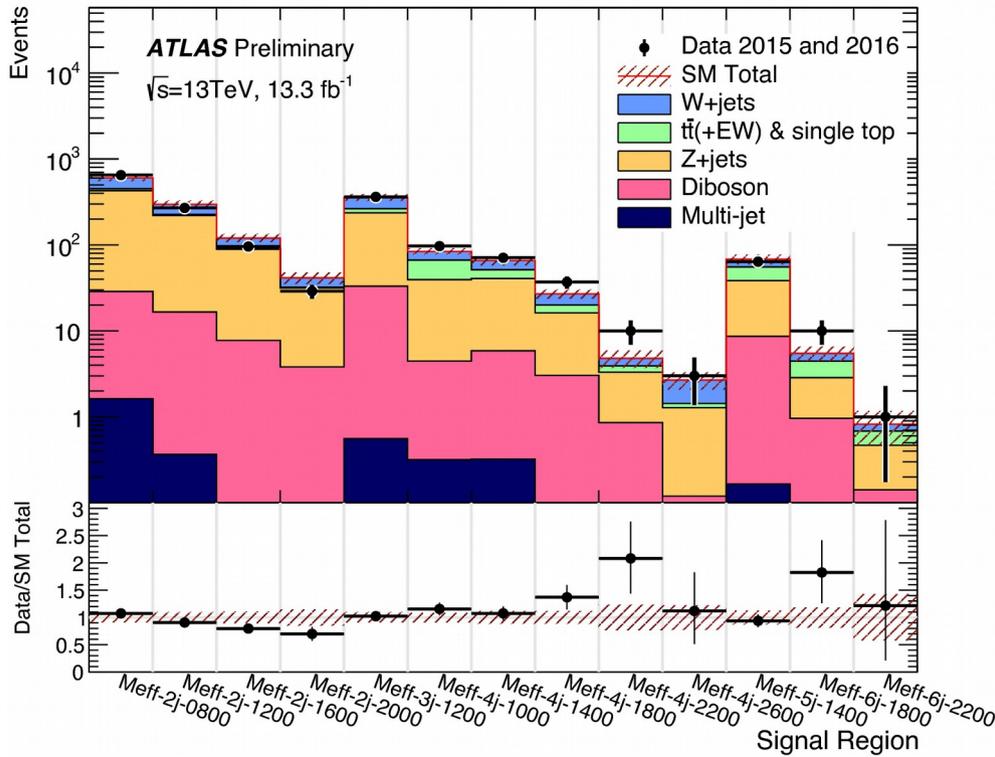
- Get variables in each rest frame
- Some have mass dimension
- Some do not

ATLAS analysis:

→ defines different RJ signal regions for squark, gluino and compressed cases

See also: alternate strategy based on $E_T^{\text{miss}}/m_{\text{eff}}$, $E_T^{\text{miss}}/\sqrt{H_T}$

ALL: ATLAS results (ATLAS-CONF-2016-078)



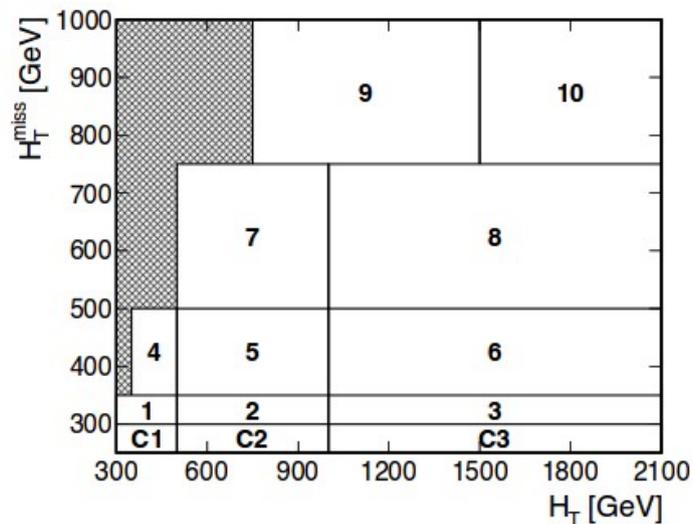
**Significant extension of previous gluino mass limits
 (in idealised case)**

ALL: CMS hadronic searches

CMS has several recent all-hadronic search updates with 12.9 fb^{-1} of 13 TeV data

SUS-16-014: H_T and H_T^{miss} search

- Binned in jet and b-jet multiplicity
- In each bin, bin further in H_T and H_T^{miss}



SUS-16-015: M_{T2} search

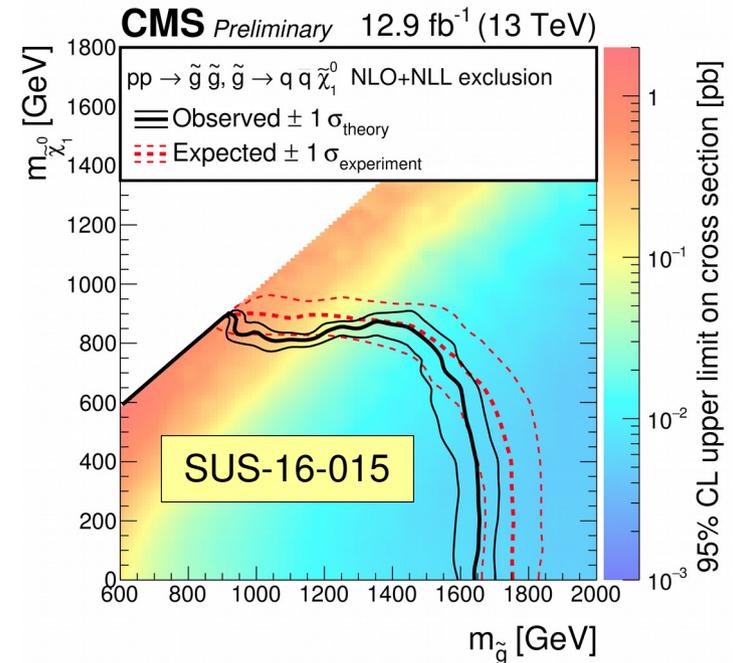
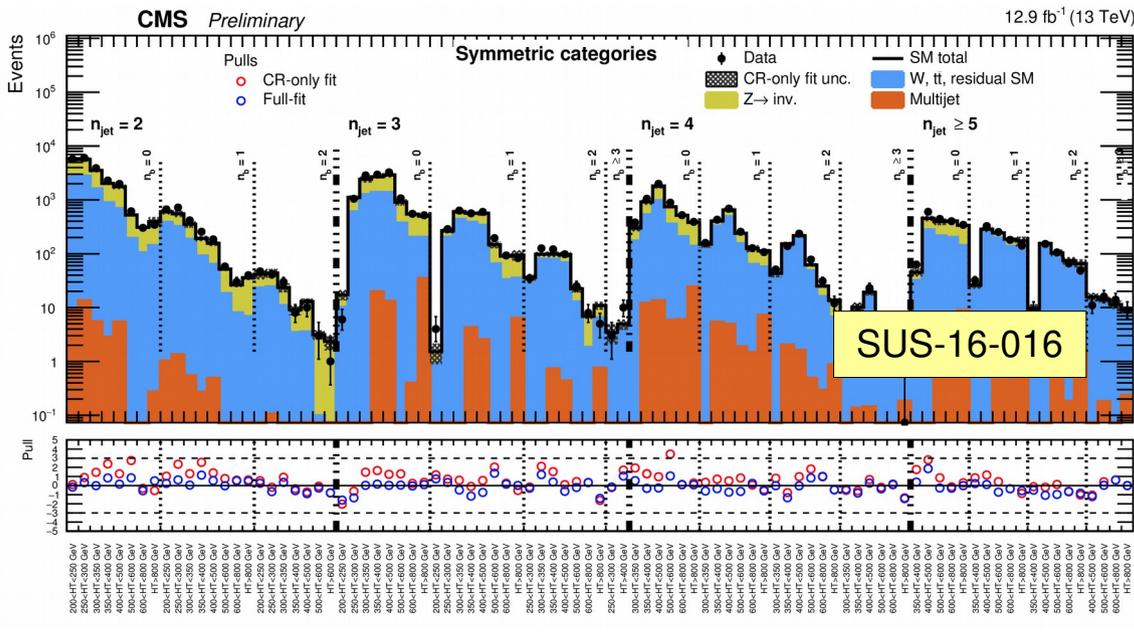
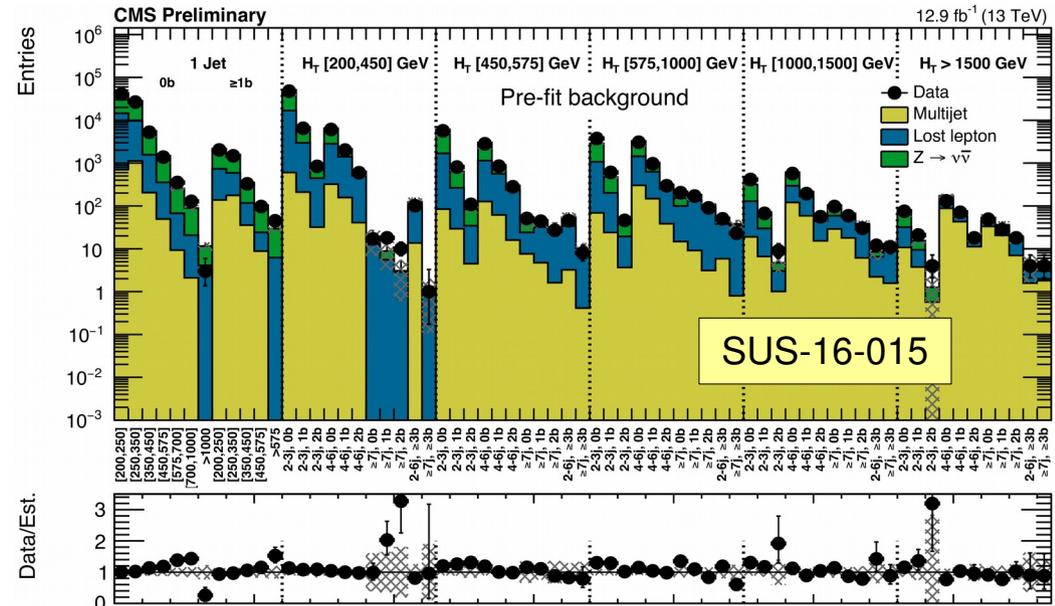
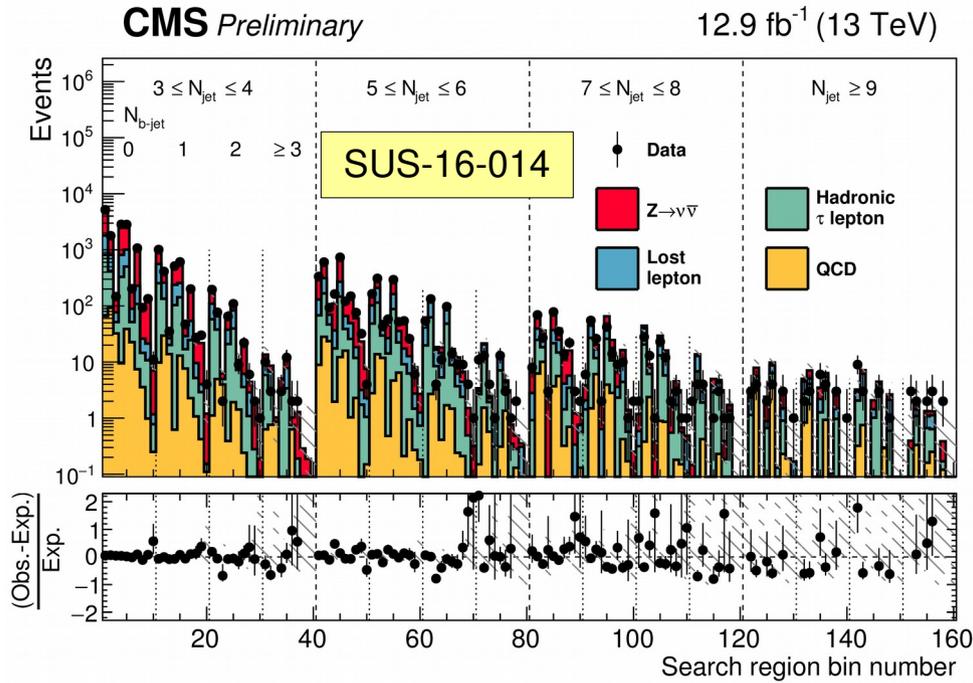
- Binned in H_T , jet and b-jet multiplicity
- In each bin, look at tails of M_{T2}

SUS-16-016: α_T search

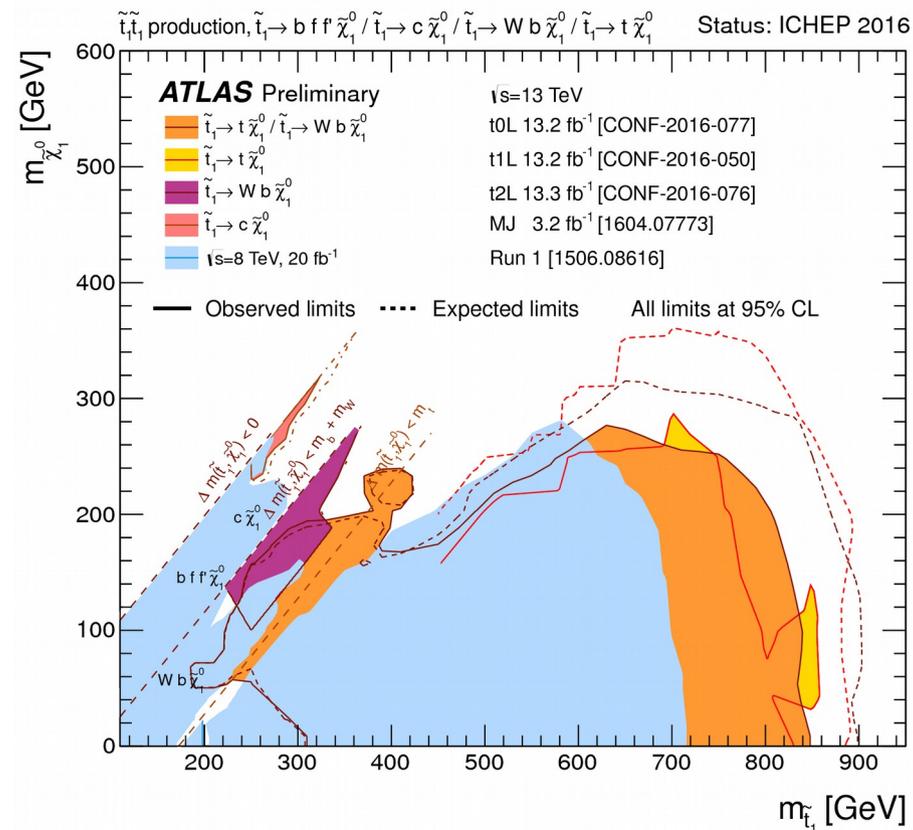
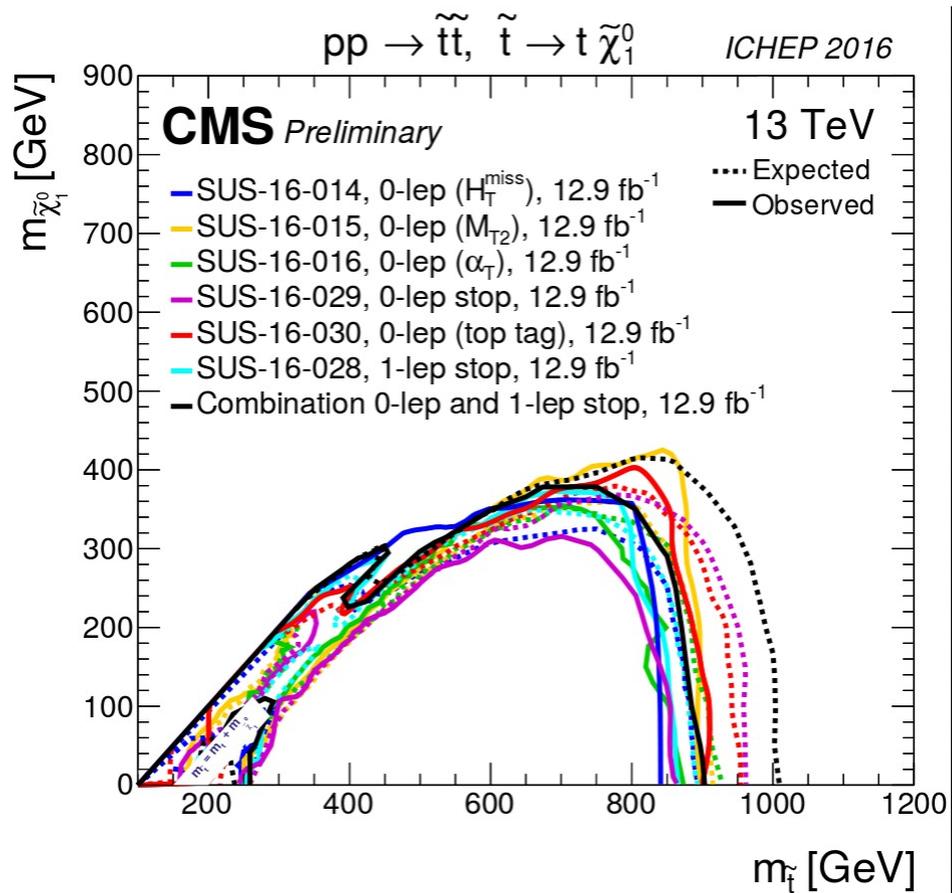
- Preselection based on α_T
- Bin in H_T , jet and b-jet multiplicity
- In each bin, look at tails of H_T^{miss}

In each case, background model is developed using control regions

ALL: CMS results



THIRD: Results



EW: General remarks

- If coloured sparticles much heavier than EW partners

- direct chargino/neutralino/slepton production

- Leptonic decay modes provide clean signature:

- many leptons (up to 4) + MET

- possibly taus

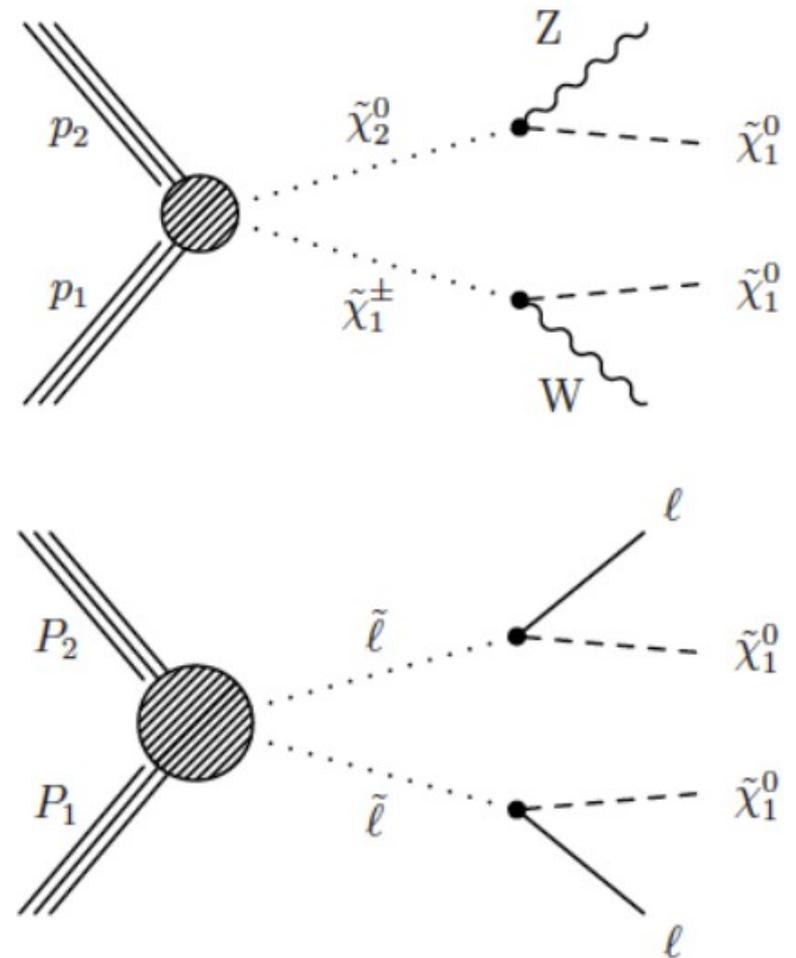
- possibly OSSF lepton pairs with $m_{ll} = m_Z$

- low jet activity

- in case of WZ + MET final state use:

$$M_T = \sqrt{2E_T^{\text{miss}} p_T^l (1 - \cos \Delta\phi_{l, E_T^{\text{miss}}})}$$

Example processes:



ATLAS:

ATLAS-CONF-2016-075: 4 lepton search (R-parity violation)

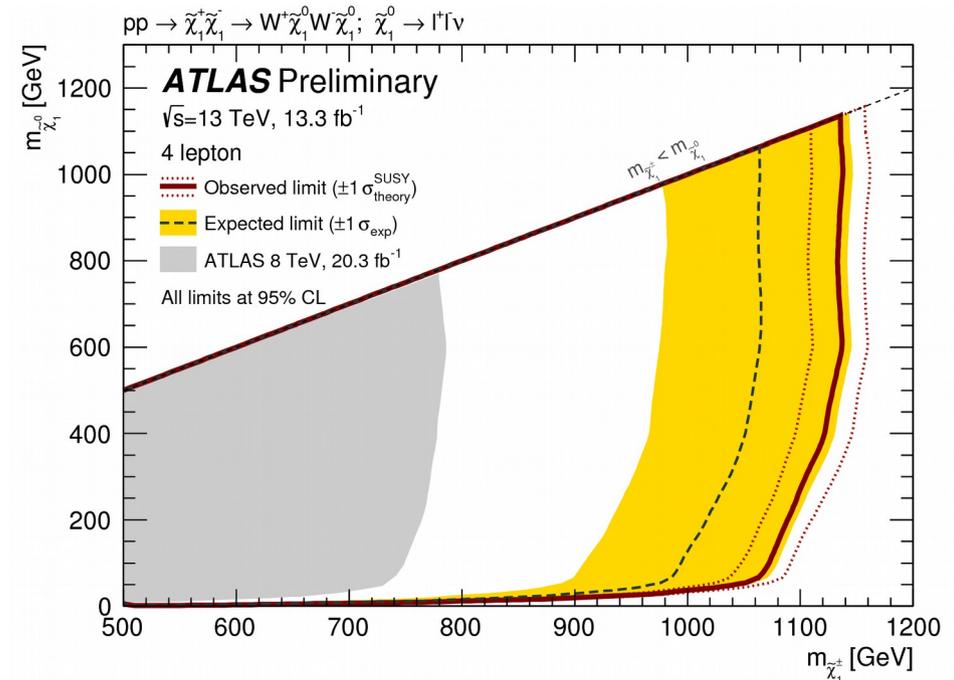
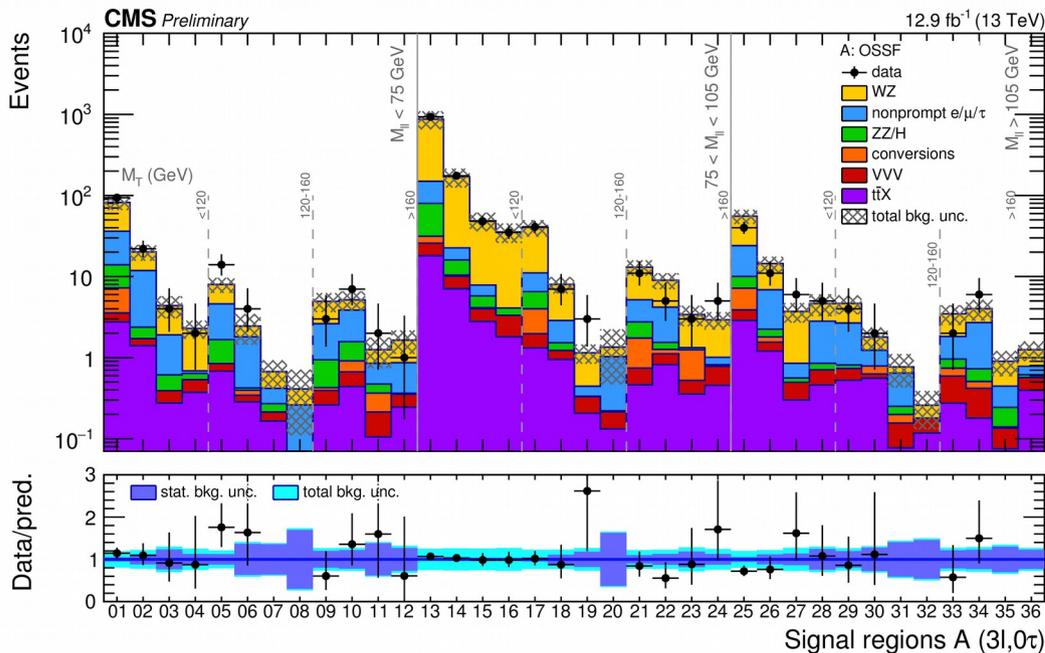
ATLAS-CONF-2016-093: 2 taus

ATLAS-CONF-2016-096: 2 and 3 lepton search

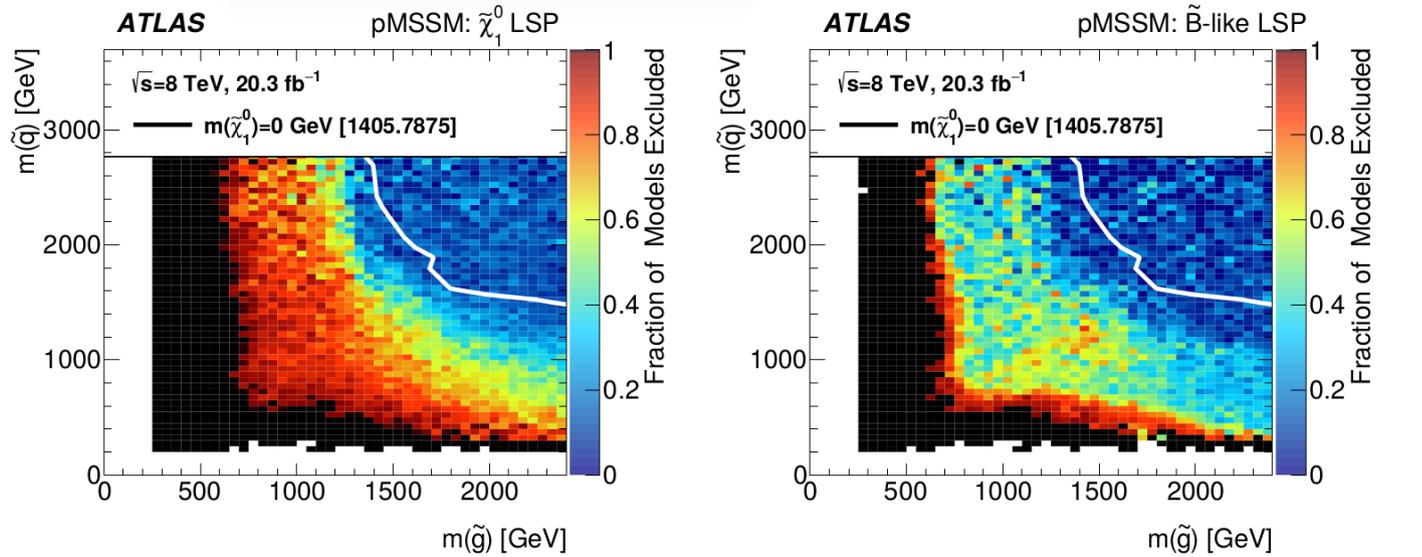
CMS

CMS-SUS-16-024: 3 (or 4) leptons (includes taus)

CMS-SUS-16-024: search in WH final state (leptonic W, $H \rightarrow b \bar{b}$)

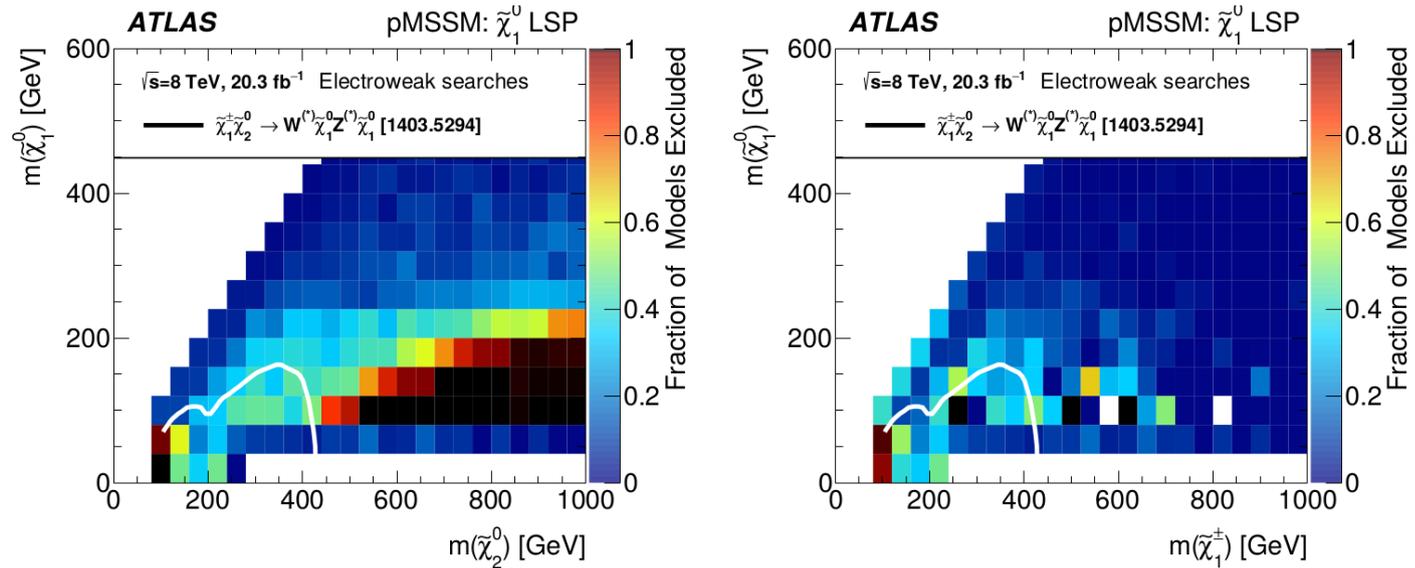


SUSY: Dead or Alive? (arXiv:1508.06608)



(a) All LSP types

(b) Bino-like LSPs



(a) Neutralinos

(b) Chargino-neutralino

CMS version available at: CMS-PAS-SUS-15-010

Exotics searches

- Exotics searches cover BSM physics that is (naively) not-SUSY
 - in practise often have some overlap
 - searches will also be sensitive to sparticle production in general

Lots of options!

New gauge bosons
(e.g. W' , Z')

Quantum black holes

Contact interactions

Excited leptons

Dark matter plus X

Generic new resonances

- ATLAS and CMS searches are split by final state (as in the case of SUSY)
 - wide coverage of potential options
 - exploration of extreme kinematic regime

An example: dijet searches

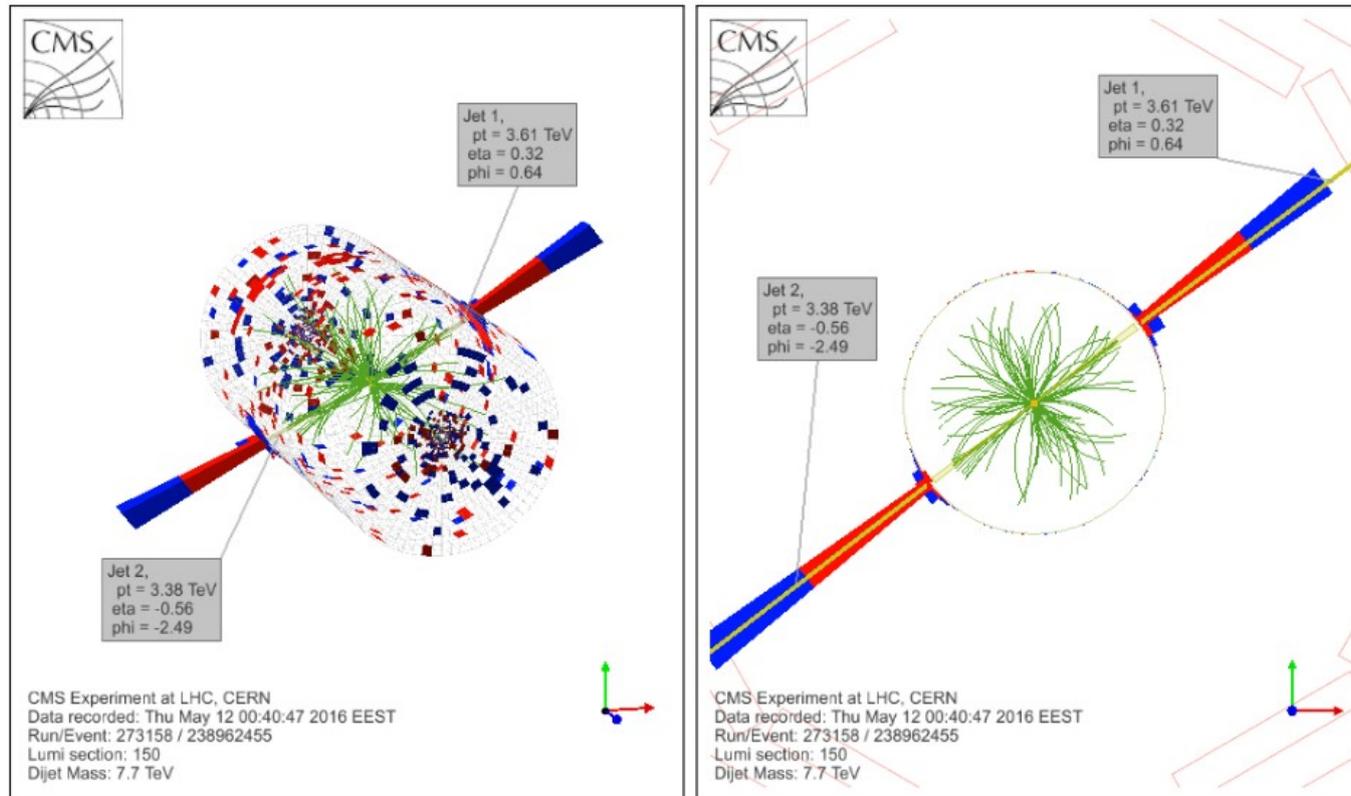
- Different options would disturb the dijet invariant mass distribution differently

Quantum black hole: Peak

Excited quarks: Peak

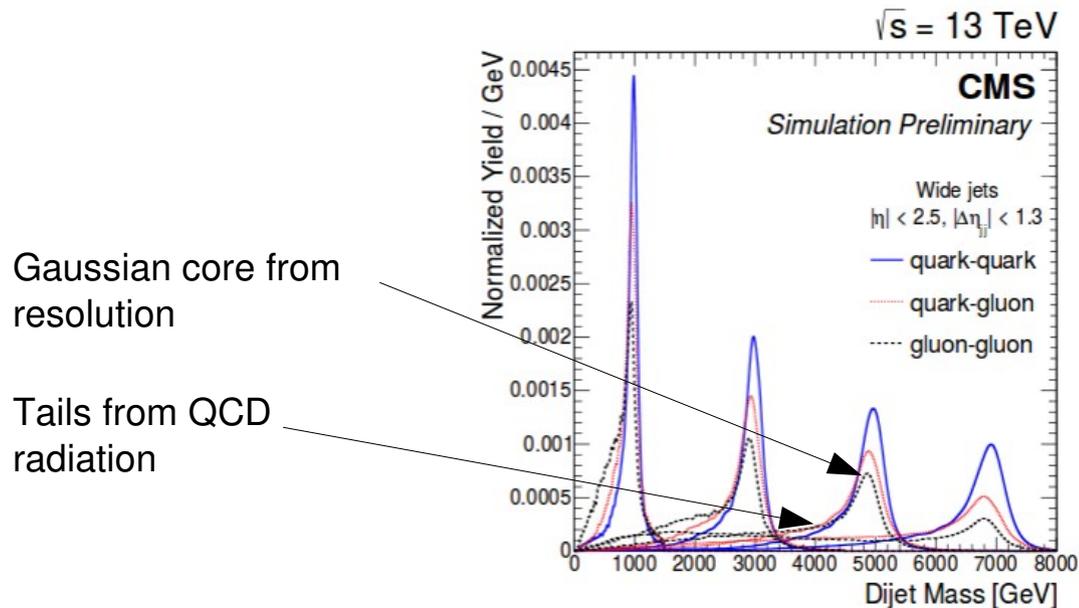
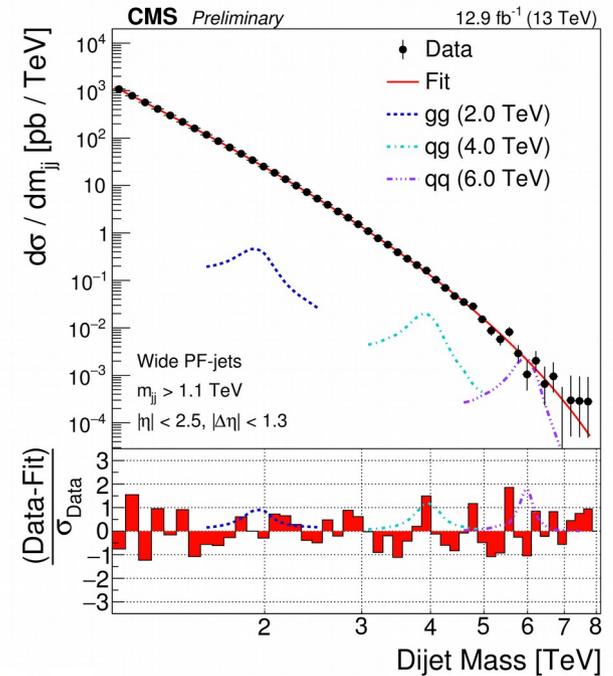
W' and Z': Peak

Contact interactions: Smooth changes in high mass m_{jj} tail (or probe angular distribution)

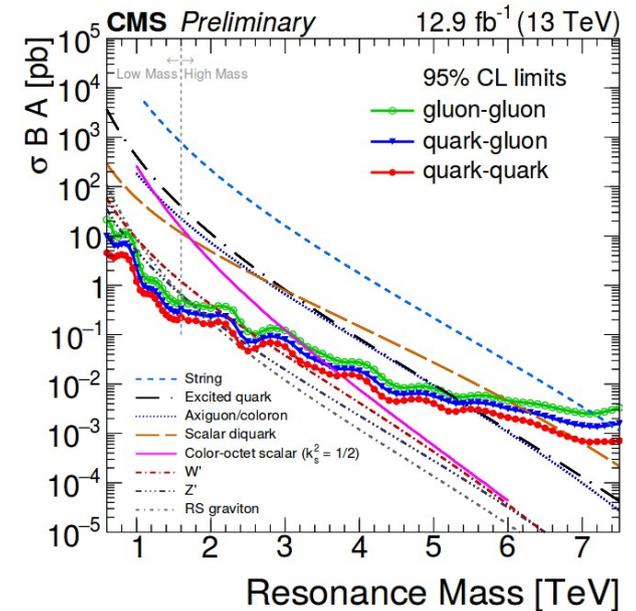


Dijet resonances: CMS-PAS-EXO-16-032 (High mass)

- Look for two jets with $p_{T,j} > 30$ GeV and $|\eta| < 2.5$
- Impose $|\eta_{ij}| < 1.3$ (suppresses t -channel dijet background)
- Use two leading jets as seeds, then:
 - add four vectors of extra jets within $\Delta R < 1.1$ of each jet
- Use dijet mass to search for narrow resonances

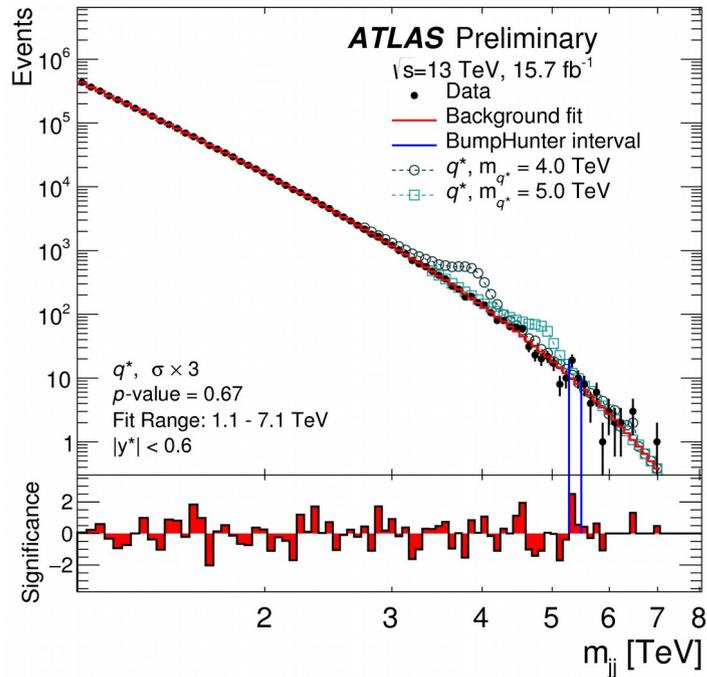


- Also do a low mass search using calo-jets from high level trigger (0.6 TeV – 1.6 TeV resonances)



See also: ATLAS-CONF-2016-030 (trigger-level analysis for low mass resonances)
CMS-PAS-EXO-16-030 (even lower mass search for vector resonances)

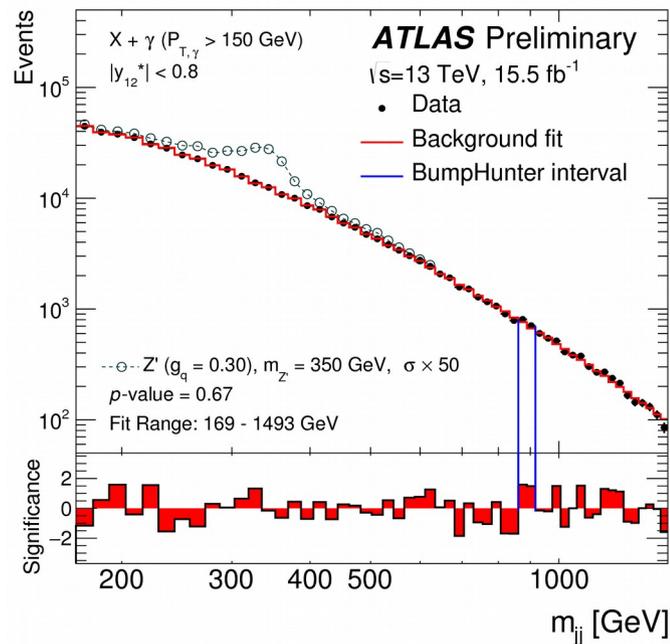
Dijet resonances: ATLAS-CONF-2016-069 (High mass)



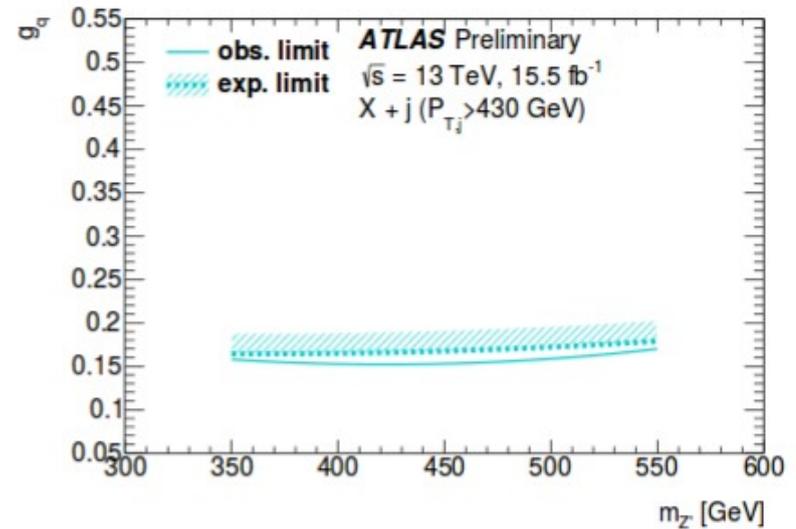
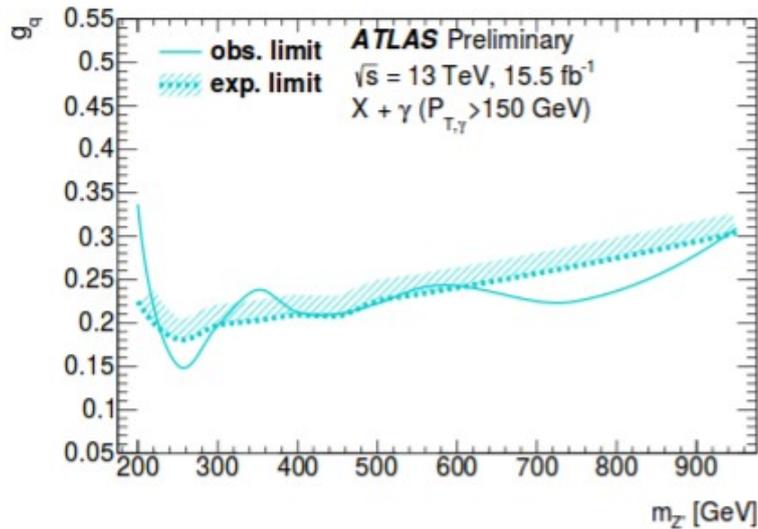
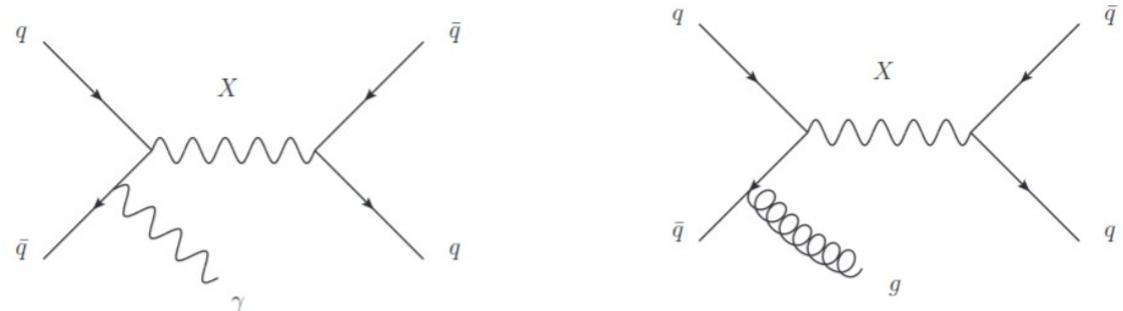
- look for ≥ 2 jets with $p_T > 440, 60$ GeV
- analyse m_{jj} distribution for $|y^*| < 0.6$ and $|y^*| < 1.2$
- Also analyse angular distribution (see backup slides)

| Model | 95% CL exclusion limit | |
|--|------------------------|----------|
| | Observed | Expected |
| Quantum black holes, ADD (BLACKMAX generator) | 8.7 TeV | 8.7 TeV |
| Excited quark | 5.6 TeV | 5.5 TeV |
| W' | 2.9 TeV | 3.3 TeV |
| W^* | 3.3 TeV | 3.3 TeV |
| Contact interactions ($\eta_{LL} = +1$) | 12.6 TeV | 13.7 TeV |
| Contact interactions ($\eta_{LL} = -1$) | 19.9 TeV | 23.7 TeV |

Dijet resonances: ATLAS-CONF-2016-070 (low mass)



- Use dijet events with an extra photon or jet from ISR



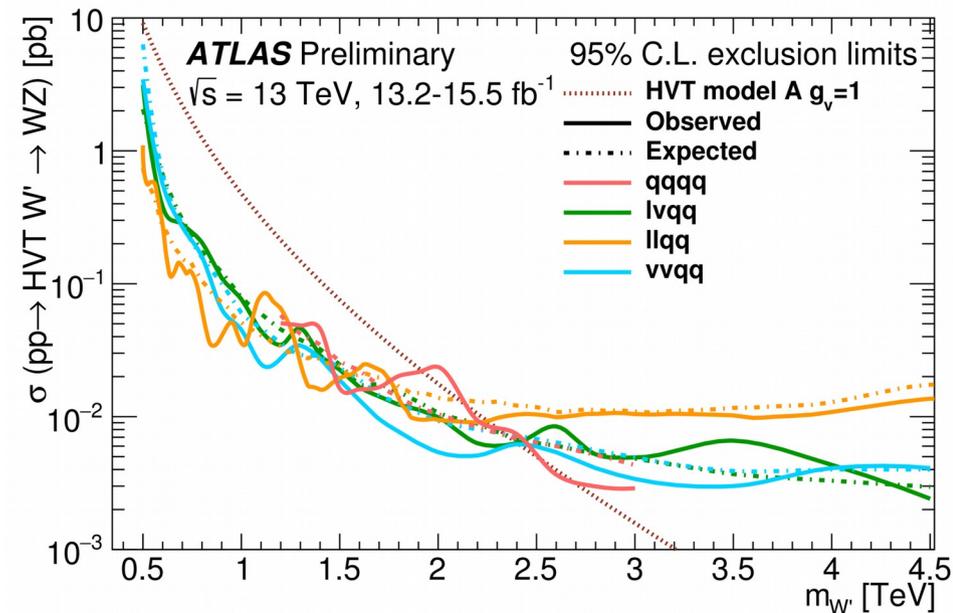
Other resonance searches

- Lots of production modes and final states:

- Z(II)V: ATL-CONF-2016-082, CMS-B2G-16-010
- Z($\nu\nu$) V: ATL-CONF-2016-082
- W(l ν) V: ATL-CONF-2016-062, CMS-B2G-16-020
- VV (JJ): ATL-CONF-2016-055 (boson-tagged jets)
- V(J) h: ATL-CONF-2016-083
- hh: ATL-CONF-2016-049, ATLAS-CONF-2016-071, ATLAS-CONF-2016-004, CMS-B2G-16-008
- Z γ : ATL-CONF-2016-044, CMS-EXO-16-034
- $\gamma\gamma$: ATL-CONF-2016-059, CMS-EXO-16-027
- ll: ATLAS-CONF-2016-045, CMS-EXO-16-031

| Model | Width [%] | θ_{E_6} [Rad] | Lower limits on $m_{Z'}$ [TeV] | | | | | |
|-------------------|-----------|----------------------|--------------------------------|------|----------|------|------------|------|
| | | | ee | | $\mu\mu$ | | $\ell\ell$ | |
| | | | Obs | Exp | Obs | Exp | Obs | Exp |
| Z'_{SSM} | 3.0 | - | 3.85 | 3.86 | 3.49 | 3.53 | 4.05 | 4.06 |
| Z'_χ | 1.2 | 0.50 | 3.48 | 3.49 | 3.18 | 3.19 | 3.66 | 3.67 |
| Z'_S | 1.2 | 0.63π | 3.43 | 3.44 | 3.14 | 3.14 | 3.62 | 3.61 |
| Z'_I | 1.1 | 0.71π | 3.37 | 3.37 | 3.08 | 3.08 | 3.55 | 3.55 |
| Z'_{η} | 0.6 | 0.21π | 3.25 | 3.25 | 2.96 | 2.94 | 3.43 | 3.42 |
| Z'_N | 0.6 | -0.08π | 3.23 | 3.23 | 2.95 | 2.94 | 3.41 | 3.41 |
| Z'_ψ | 0.5 | 0π | 3.18 | 3.18 | 2.90 | 2.88 | 3.36 | 3.35 |

$$Z'(\theta_{E_6}) = Z'_\psi \cos \theta_{E_6} + Z'_\chi \sin \theta_{E_6}$$



Summary

- There is a long list of recent results from ATLAS and CMS
 - building of course on the excellent base of 8 TeV analyses
 - most use $> 12 \text{ fb}^{-1}$ of data
- No evidence for BSM physics so far
 - but we are clearly sensitive to relatively high mass scales
 - limits are becoming progressively more interesting
- Much more to come
 - absolutely tremendous performance by the LHC so far this year
 - can expect at least 30 fb^{-1} by the end of the year

WATCH THIS SPACE!

Backup

SUSY: What we know from Run I

- No evidence for sparticle production
- The single most interesting result for the MSSM is probably the Higgs mass measurement
 - need the radiative corrections to m_h to be *rather large* in the MSSM

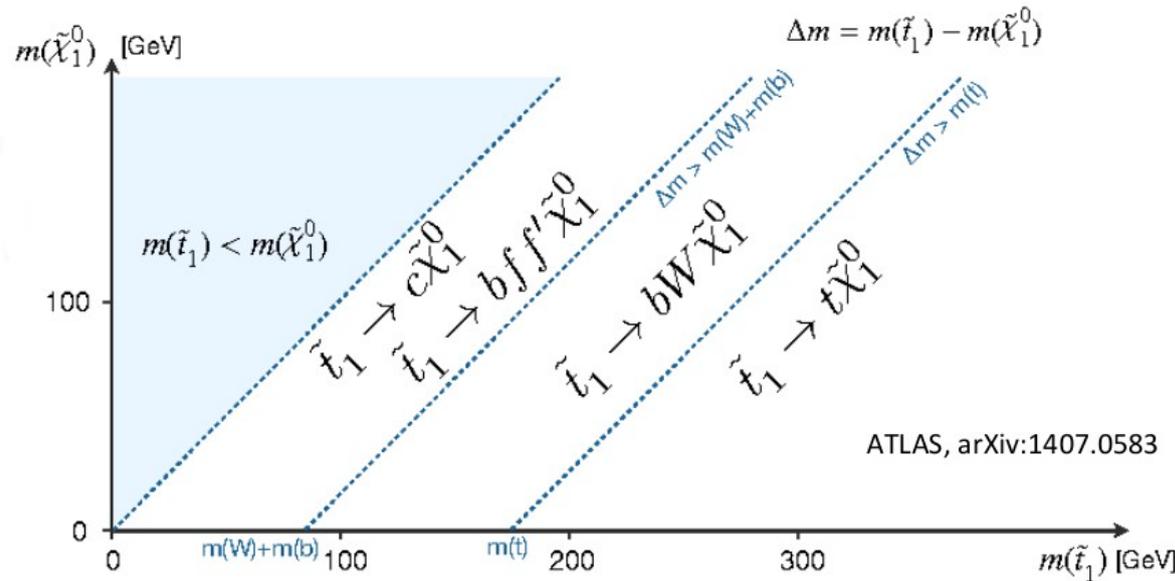
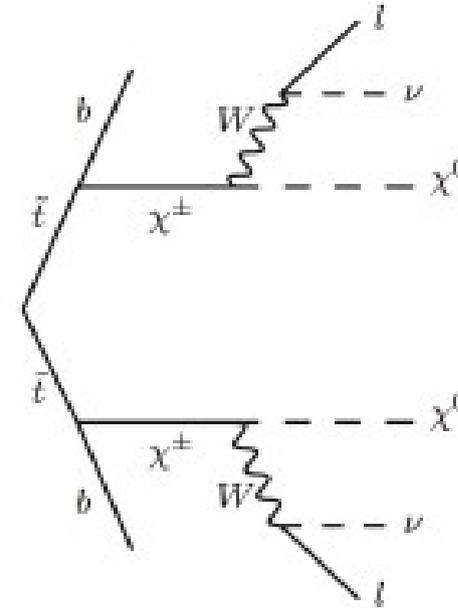
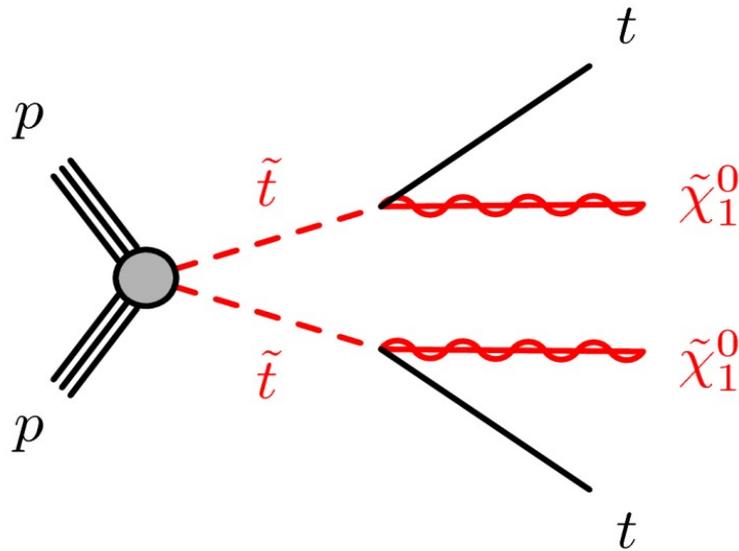
$$M_h^2 \approx M_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \left[\log \frac{\Delta_S^2}{m_t^2} + \frac{X_t^2}{\Delta_S^2} \left(1 - \frac{X_t^2}{12\Delta_S^2} \right) \right] \quad \text{with} \quad \Delta_S^2 = m_{\tilde{t}_1} m_{\tilde{t}_2}$$

- Either stops are heavy ($\gg 1$ TeV) \rightarrow Tension to “naturalness” (\rightarrow fine tuning)
- or large stop mass splitting (“Maximal mixing”)

$$\mathcal{M}_{\tilde{t}} = \begin{pmatrix} \tilde{m}_{t_L}^2 & \overbrace{m_t(A_t - \mu \cot \beta)}^{X_t} \\ m_t(A_t - \mu \cot \beta) & \tilde{m}_{t_R}^2 \end{pmatrix}$$

- Suggests that we should not be surprised that we didn't see evidence for SUSY in Run I...

THIRD: General remarks



- Signature depends on sparticle mass spectrum
- Generally optimise on specific decay modes
- Some attention is paid to mixed final states

THIRD: Hadronic searches

CMS-SUS-2016-029

- 60 signal regions targetting high stop-neutralino mass differences
 - binned by number of top and W tags, number of b jets, E_T^{miss} and m_T
- 40 signal regions targetting low stop-neutralino mass differences
 - binned by number of b tags, jet pT (various), number of jets and E_T^{miss}

ATLAS-CONF-2016-077

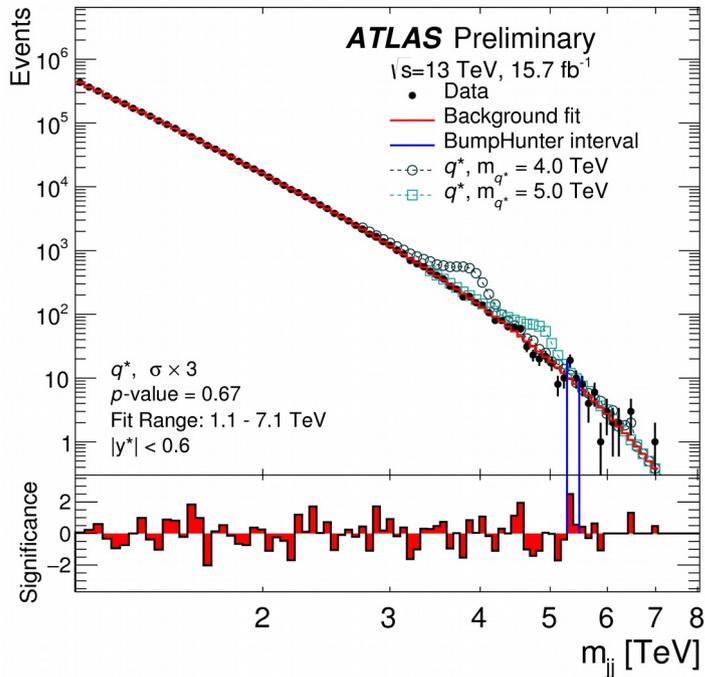
- Signal regions for high mass stops with large or small stop-neutralino mass difference
 - reconstruct top candidates, use E_T^{miss} and m_T
- One set of signal regions targets b-chargino decays
 - veto top candidates, optimise on jet p_T , use $E_t^{\text{miss}}/\sqrt{H_T}$
- One set of signal regions optimised for stop-neutralino mass difference close to m_t
 - use *Recursive Jigsaw Technique*
- One set of signal regions for boosted tops (use fat jets and jet mass variable, plus others)

THIRD: Other searches

- ATLAS-CONF-2016-050: single lepton search
 - selections on jets, b-jets and E_T^{miss}
 - optimisations for different mass differences
- ATLAS-CONF-2016-076: dilepton search
 - one analysis based on M_{T2} , one on the super-razor variables
- CMS-SUS-16-028: single lepton search
 - uses jet multiplicity, M_{T2}^W and E_T^{miss}
- CMS-SUS-16-028: all-hadronic, uses top tagging

And several more...

Dijet resonances: ATLAS-CONF-2016-069 (High mass)



$$y^* = (y_3 - y_4)/2$$

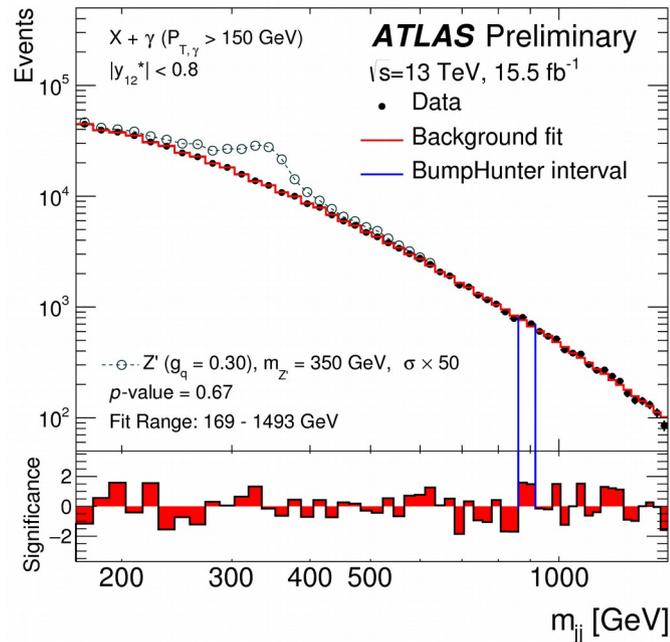
$$\chi = e^{2|y^*|} \sim \frac{1 + \cos \theta^*}{1 - \cos \theta^*}$$

$$y_B = \frac{1}{2} \ln(x_1/x_2) = (y_3 + y_4)/2$$

- look for ≥ 2 jets with $p_T > 440, 60$ GeV
- analyse m_{jj} distribution for $|y^*| < 0.6$ and $|y^*| < 1.2$
- analyse $dN/d\chi$ distribution for $|y^*| < 1.7$ and $|y_B| < 1.1$

| Model | 95% CL exclusion limit | |
|--|------------------------|----------|
| | Observed | Expected |
| Quantum black holes, ADD (BLACKMAX generator) | 8.7 TeV | 8.7 TeV |
| Excited quark | 5.6 TeV | 5.5 TeV |
| W' | 2.9 TeV | 3.3 TeV |
| W^* | 3.3 TeV | 3.3 TeV |
| Contact interactions ($\eta_{LL} = +1$) | 12.6 TeV | 13.7 TeV |
| Contact interactions ($\eta_{LL} = -1$) | 19.9 TeV | 23.7 TeV |

Dijet resonances: ATLAS-CONF-2016-070 (low mass)



- Use dijet events with an extra photon or jet from ISR

$X + \gamma$: • ≥ 1 photon with $p_T > 150 \text{ GeV}$

• $|0.5 (y_{j1} - y_{j2})| < 0.8$

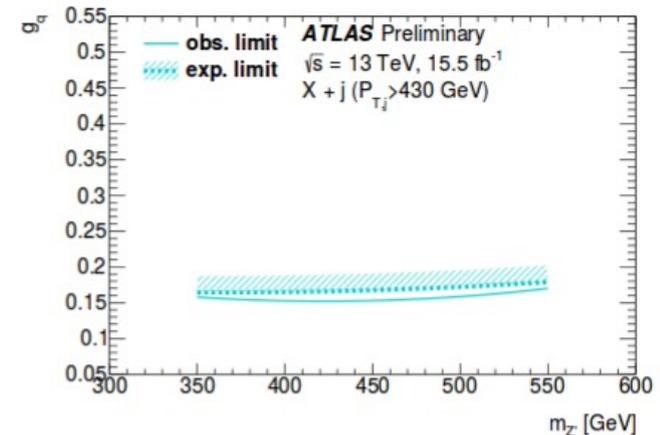
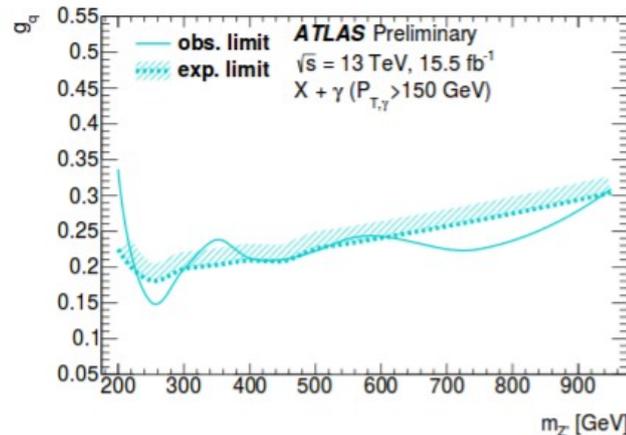
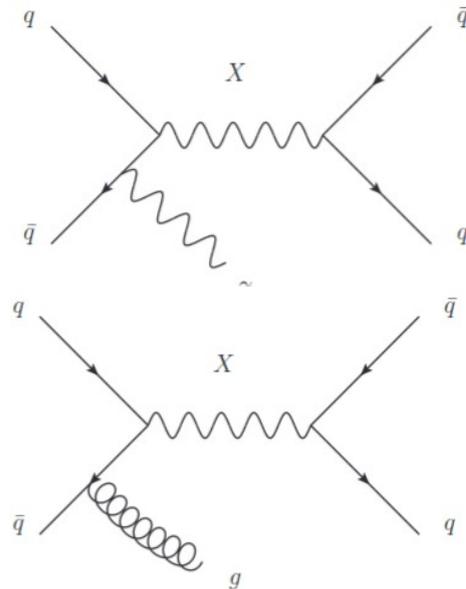
• Photon must have $\Delta R > 0.85$ to closest jet

$X + j$: • ≥ 1 jet with $p_T > 480 \text{ GeV}$

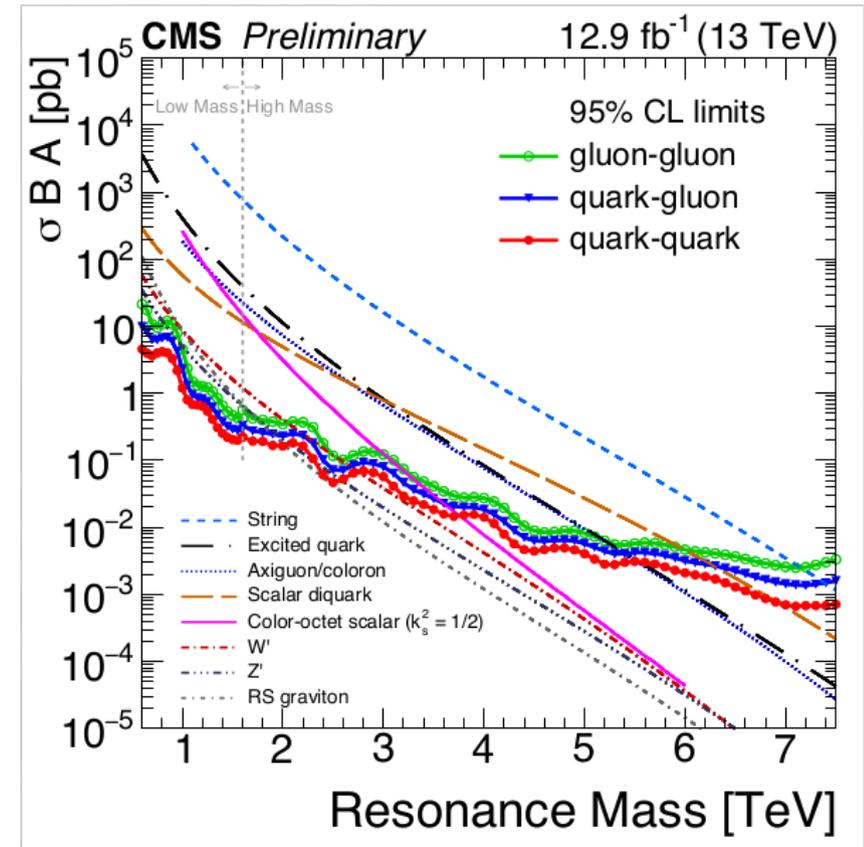
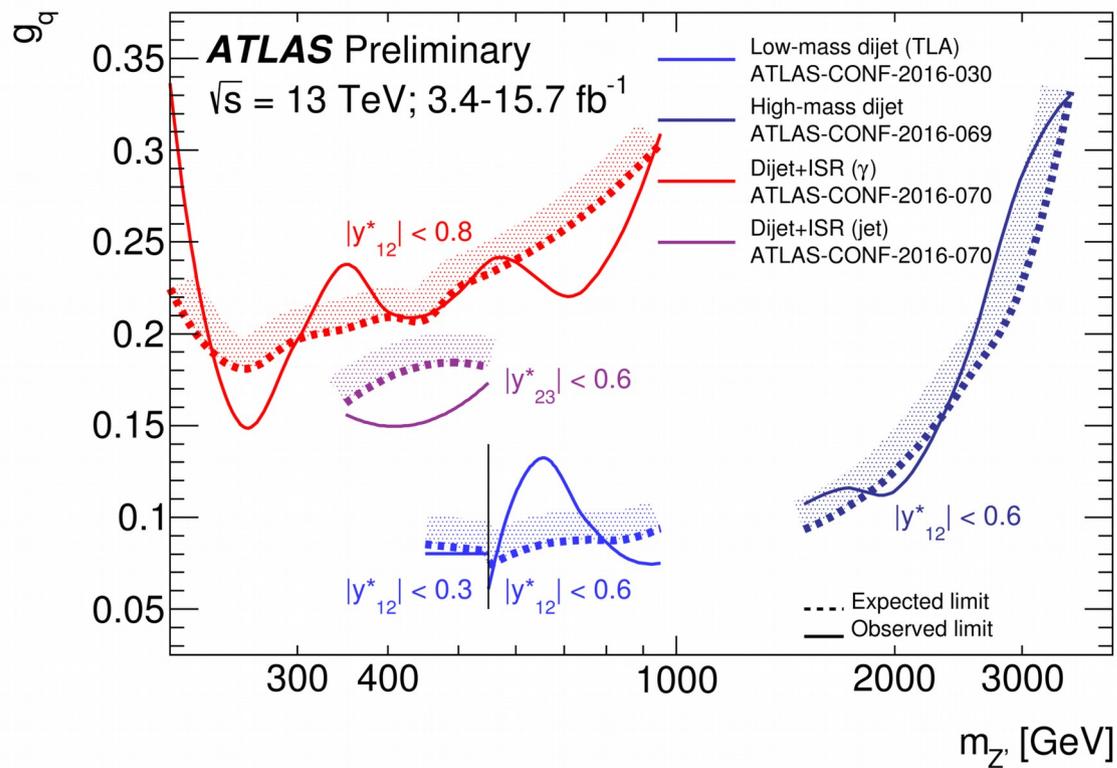
• ≥ 2 extra jets with $p_T > 25 \text{ GeV}$

• All jets have $|\eta| < 2.8$

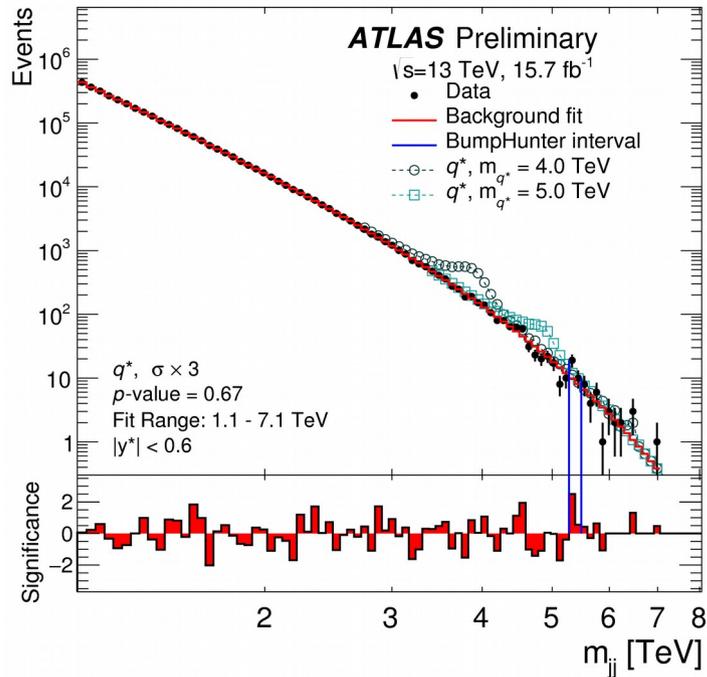
• 2nd and 3rd leading jets have $|0.5 (y_{j2} - y_{j3})| < 0.6$



Dijet searches: interpretation



Dijet resonances: ATLAS-CONF-2016-069 (High mass)



$$y^* = (y_3 - y_4)/2$$

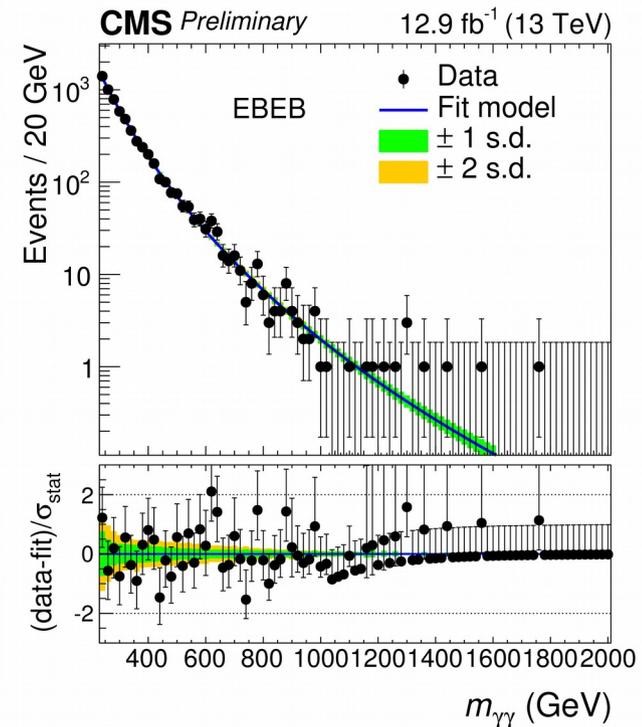
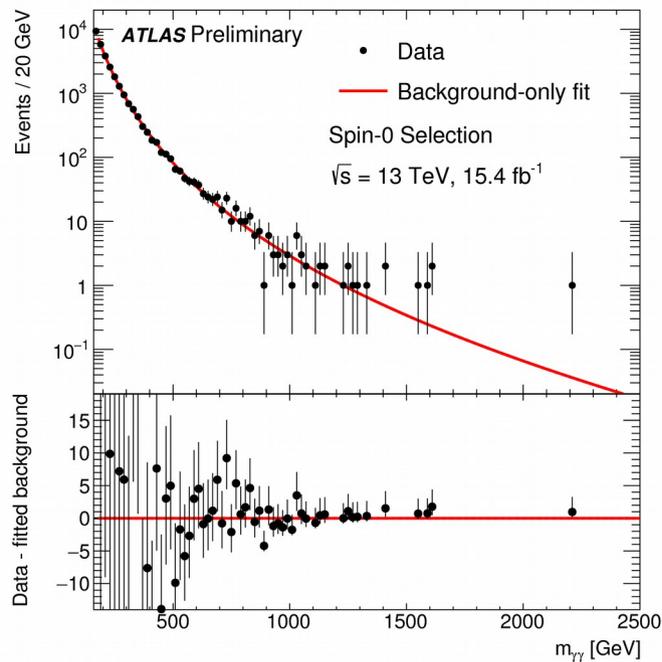
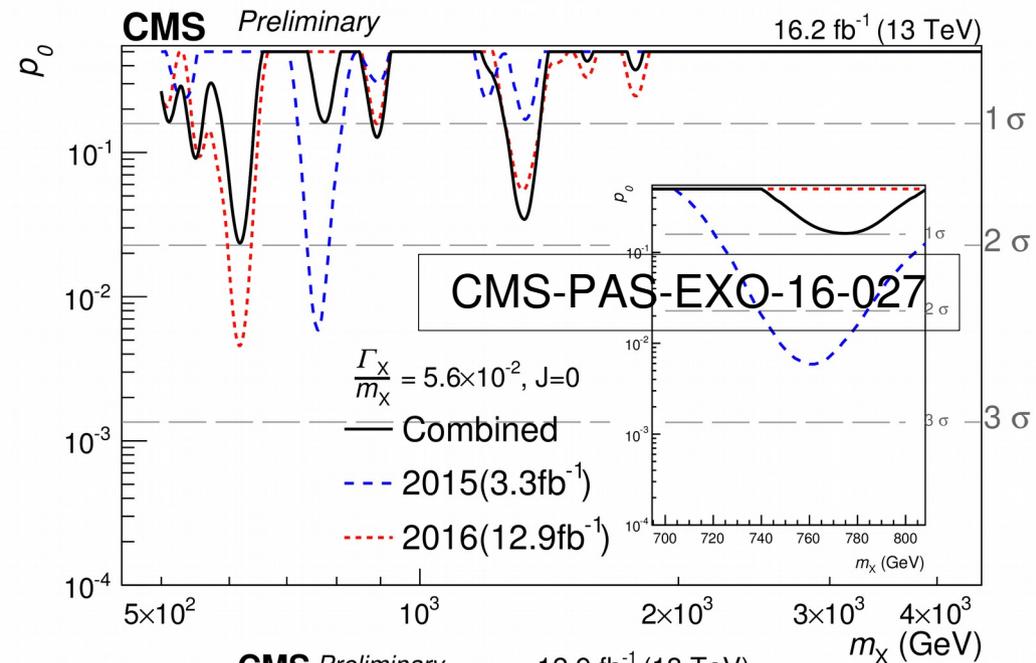
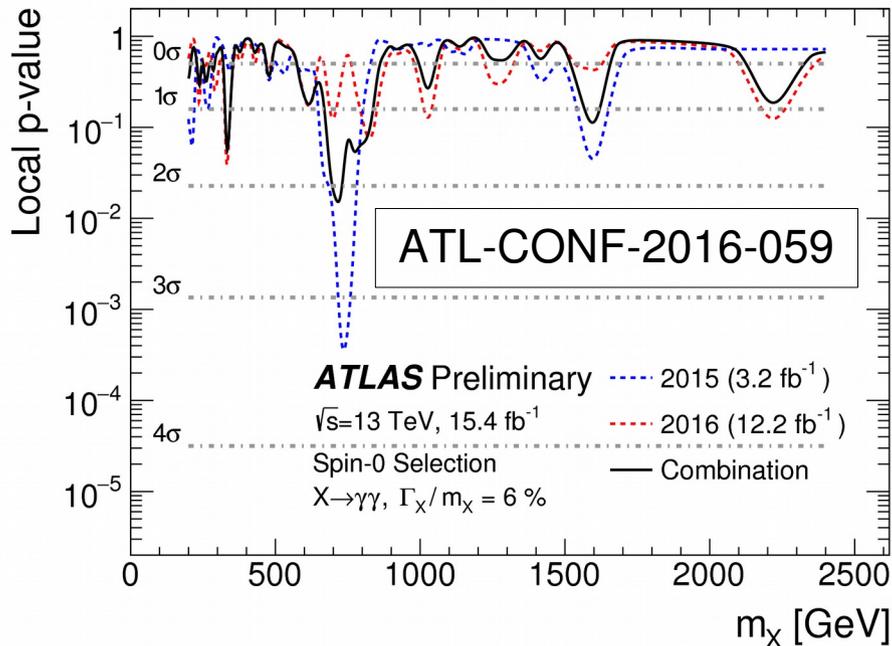
$$\chi = e^{2|y^*|} \sim \frac{1 + \cos \theta^*}{1 - \cos \theta^*}$$

$$y_B = \frac{1}{2} \ln(x_1/x_2) = (y_3 + y_4)/2$$

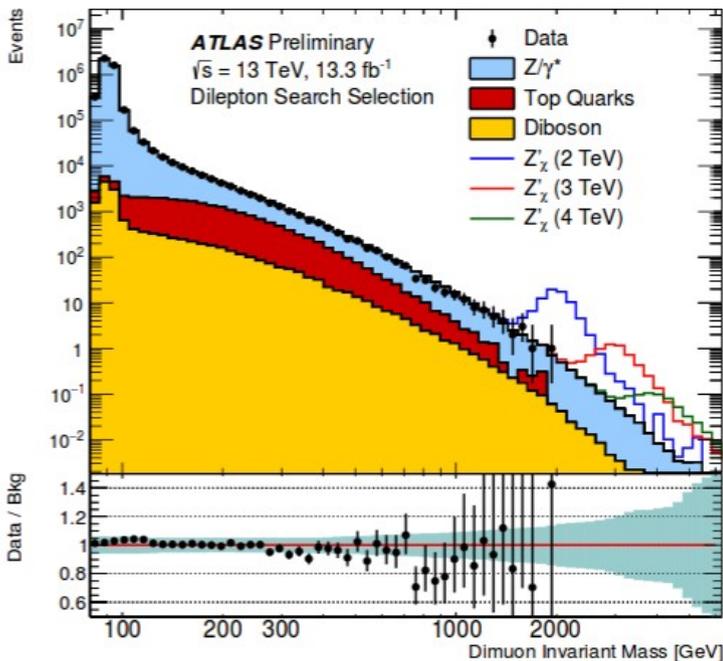
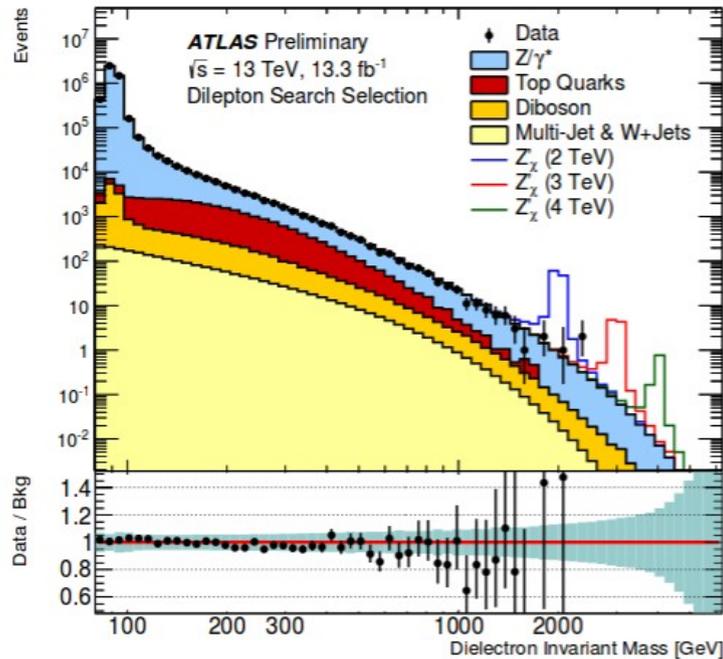
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| Model | 95% CL exclusion limit | |
|--|------------------------|----------|
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| W' | 2.9 TeV | 3.3 TeV |
| W^* | 3.3 TeV | 3.3 TeV |
| Contact interactions ($\eta_{LL} = +1$) | 12.6 TeV | 13.7 TeV |
| Contact interactions ($\eta_{LL} = -1$) | 19.9 TeV | 23.7 TeV |

Resonance searches: Diphotons



Dilepton resonance: ATLAS-CONF-2016-045



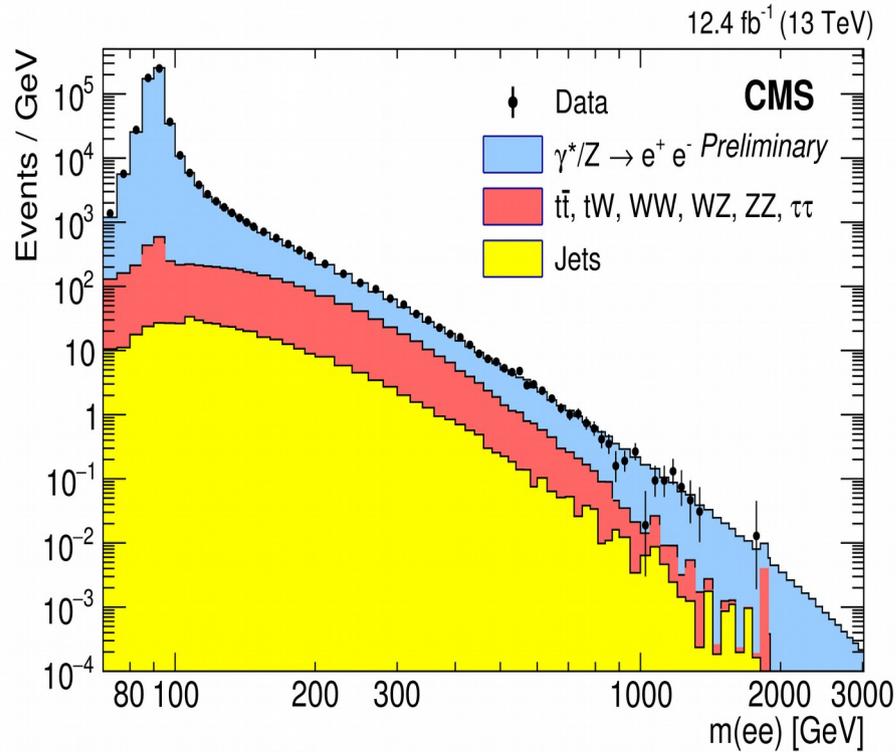
- ee or $\mu\mu$ final state
- e (μ) has E_T (p_T) > 30 GeV
- Backgrounds mostly estimated from MC
- matrix method for fake estimate

| Model | Width [%] | θ_{E_6} [Rad] | Lower limits on $m_{Z'}$ [TeV] | | | | | |
|------------|-----------|----------------------|--------------------------------|------|----------|------|------------|------|
| | | | ee | | $\mu\mu$ | | $\ell\ell$ | |
| | | | Obs | Exp | Obs | Exp | Obs | Exp |
| Z'_{SSM} | 3.0 | - | 3.85 | 3.86 | 3.49 | 3.53 | 4.05 | 4.06 |
| Z'_χ | 1.2 | 0.50 | 3.48 | 3.49 | 3.18 | 3.19 | 3.66 | 3.67 |
| Z'_S | 1.2 | 0.63π | 3.43 | 3.44 | 3.14 | 3.14 | 3.62 | 3.61 |
| Z'_I | 1.1 | 0.71π | 3.37 | 3.37 | 3.08 | 3.08 | 3.55 | 3.55 |
| Z'_η | 0.6 | 0.21π | 3.25 | 3.25 | 2.96 | 2.94 | 3.43 | 3.42 |
| Z'_N | 0.6 | -0.08π | 3.23 | 3.23 | 2.95 | 2.94 | 3.41 | 3.41 |
| Z'_ψ | 0.5 | 0π | 3.18 | 3.18 | 2.90 | 2.88 | 3.36 | 3.35 |

$$Z'(\theta_{E_6}) = Z'_\psi \cos \theta_{E_6} + Z'_\chi \sin \theta_{E_6}$$

See also: Same sign same flavour lepton search (ATLAS-CONF-2016-051)

Dilepton resonance: CMS-PAS-EXO-16-031



- Look in ee or $\mu\mu$ final state
- Backgrounds mostly estimated from MC
 - checked in $e\mu$ final state
- Data driven estimate for the fake component
- Two categories defined for electrons:

- 1) ECAL-barrel – ECAL-barrel
- 2) ECAL-barrel – ECAL-endcap

- Three categories for muons:

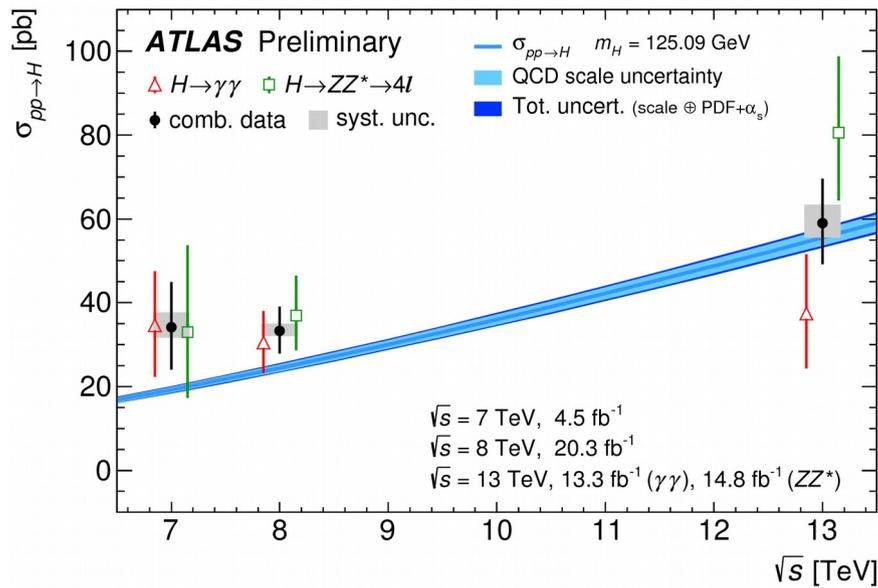
- 1) two muons in barrel region
- 2) at least one muon in negative endcap
- 3) one muon in barrel, one in positive endcap

SM-like couplings

E6 GUT model

| Channel | Z'_{SSM} | | Z'_ψ | |
|-------------------|------------|------------|------------|------------|
| | Obs. (TeV) | Exp. (TeV) | Obs. (TeV) | Exp. (TeV) |
| ee | 3.65 | 3.65 | 3.10 | 3.10 |
| $\mu^+\mu^-$ | 3.75 | 3.75 | 3.20 | 3.20 |
| $ee + \mu^+\mu^-$ | 4.0 | 4.0 | 3.50 | 3.50 |

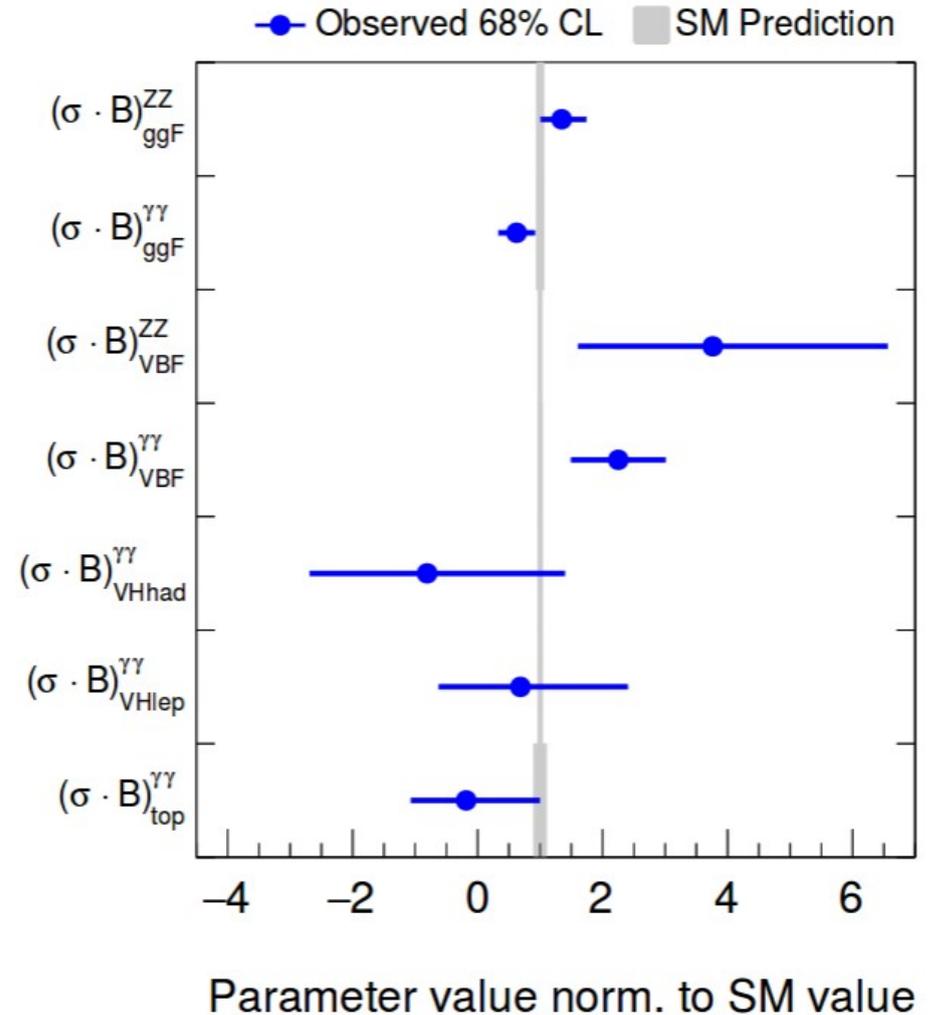
Higgs: ZZ^* and $\gamma\gamma$ combination



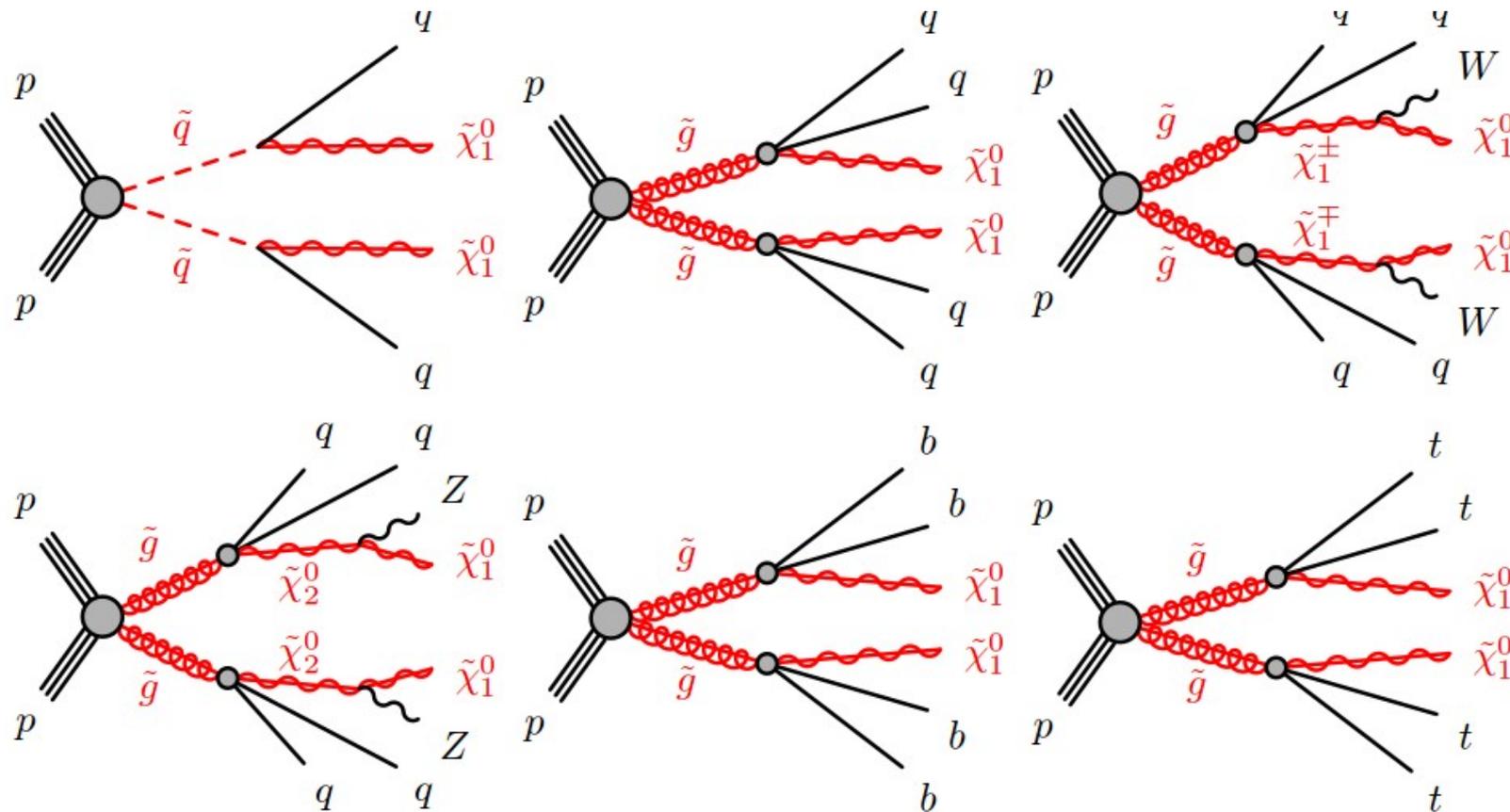
ATLAS-CONF-2016-081

- Signal strength: $\mu = 1.13 +0.18 -0.17$
- no deviation from SM behaviour observed

ATLAS Preliminary $m_H = 125.09$ GeV
 $\sqrt{s} = 13$ TeV, 13.3 fb^{-1} ($\gamma\gamma$), 14.8 fb^{-1} (ZZ)



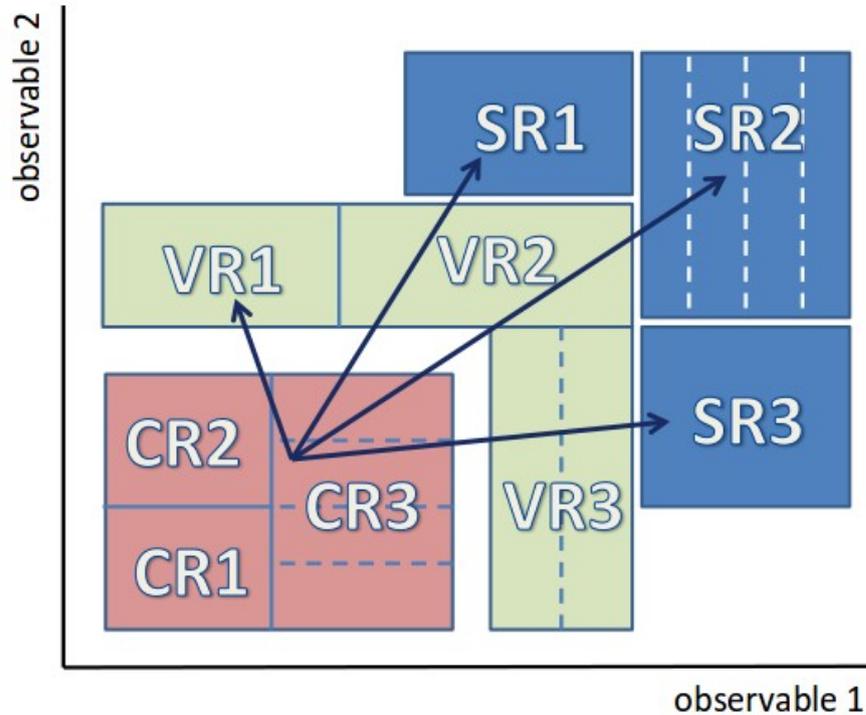
ALL: Hadronic final states



• Here are various gluino and squark decay modes

- significant variation in possible final states
- inclusive hadronic branching ratio is nevertheless high
- dramatic early SUSY signatures would be expected in final states with jets + MET

ALL: Basic ATLAS strategy

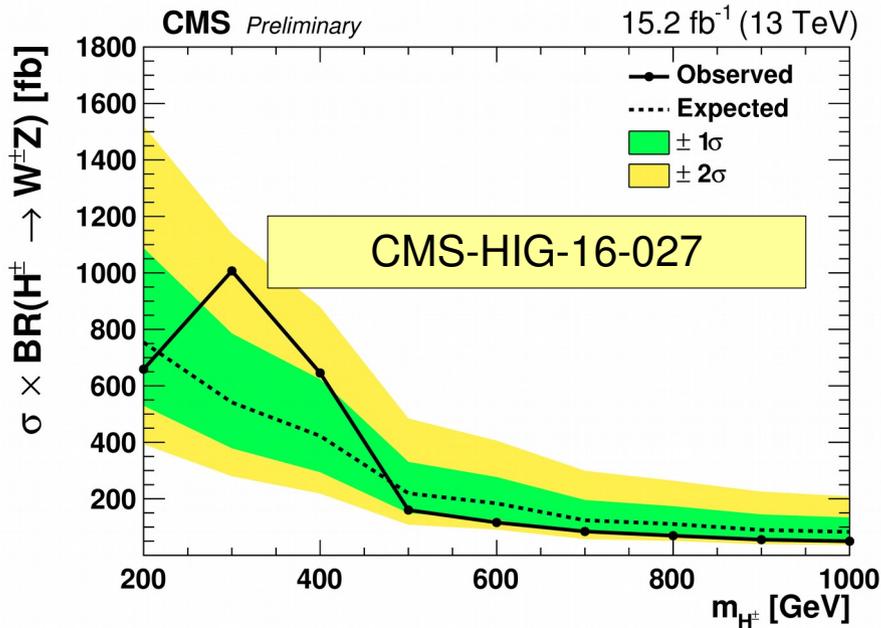
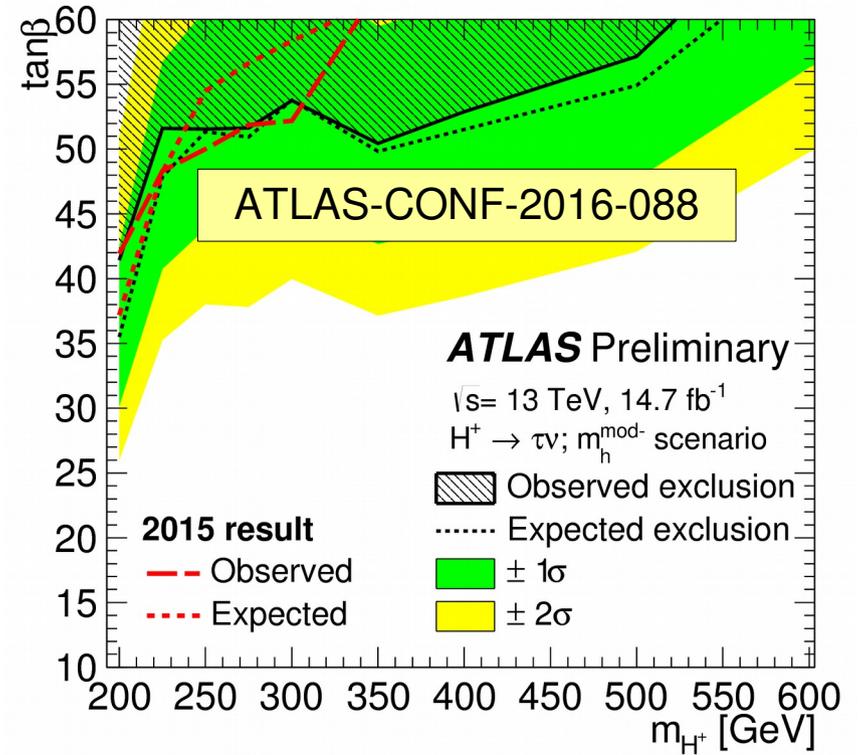
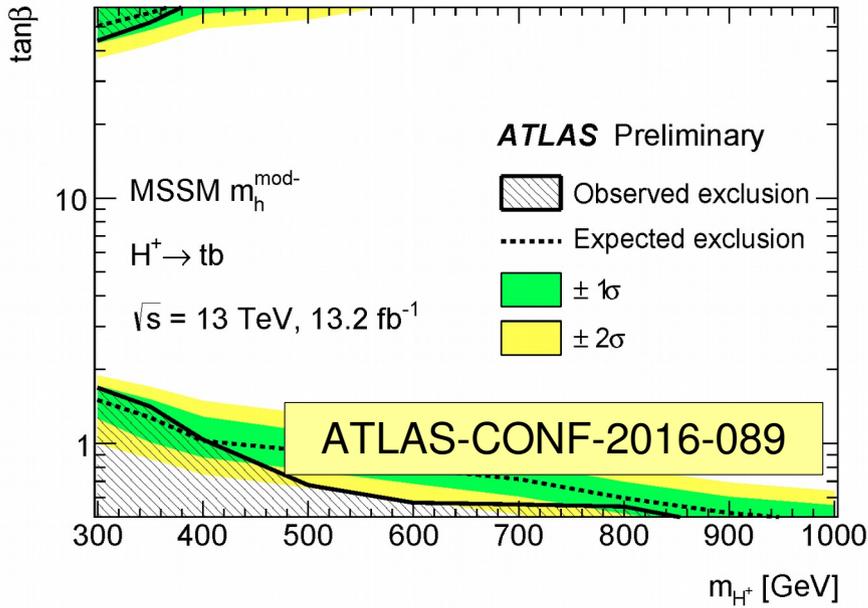


- Define signal regions using a list of effective kinematic discriminants
- Define control regions to calibrate SM background expectation
- Use orthogonal validation regions to check background model
- Extrapolate to signal region to obtain background measurement and look for an excess

ATLAS-CONF-2016-078

- Two searches for squarks and gluinos in hadronic final states
- One is similar to the 8 TeV approach (use $m_{\text{eff}} E_T^{\text{miss}} / m_{\text{eff}}$ and $E_T^{\text{miss}} / \sqrt{H_T}$)
- The second uses the new *Recursive Jigsaw* approach (arXiv:1607.08307)

Charged Higgs searches



- No evidence for charged Higgs production
- Limits set in a variety of scenarios

See also: CMS-HIG-16-030