Search for Heavy Resonances at the LHC

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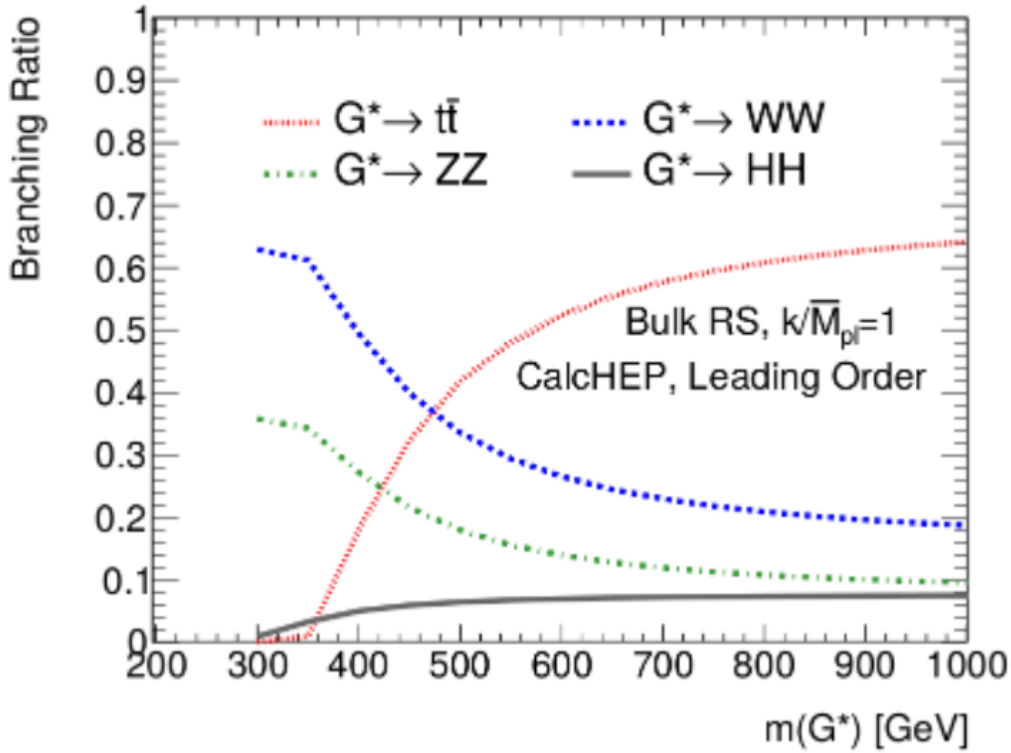
Search for Heavy Resonances at the LHC

- ATLAS and CMS systematically search for two-body decays:
  - → dijet, photon-jet, diphoton
  - → dilepton (ee, μμ, ττ, eμ, eτ, μτ, eυ, μυ)
  - → top-antitop
  - → lepton-photon (excited lepton)
  - → lepton-jet (e,μ,τ, leptoquark)
  - → WW/WZ/ZZ
  - → HH
  - → and much more...
- Caveat: this talk is
  - → mostly about diboson searches
  - → mostly showing ATLAS results
  - → (top-related searches will be covered in other talks)

Heavy gauge/Higgs boson searches: some LHC benchmark models

- Heavy gauge boson(s) Z' and W':
  - → Extended Gauge Model / Sequential Standard Model
    - SM couplings to fermions
    - Suppressed (or zero) coupling to WZ: (mW/mW')^2 to keep width narrow
    - Artificially small BR(W' → WZ) ~ 1%
- Kaluza-Klein excitations:
  - → KK graviton (RS1)
  - → Bulk RS graviton
    - enhanced ttbar, VV, HH BR
    - BR(WW) ~ 2*BR(ZZ) ~ 20%
  - → KK gluon: BR(ttbar) > 90%
- Heavy Higgs
  - → 2HDM
- Top-color Z', q*, quantum BH...
- In general, width is kept narrow

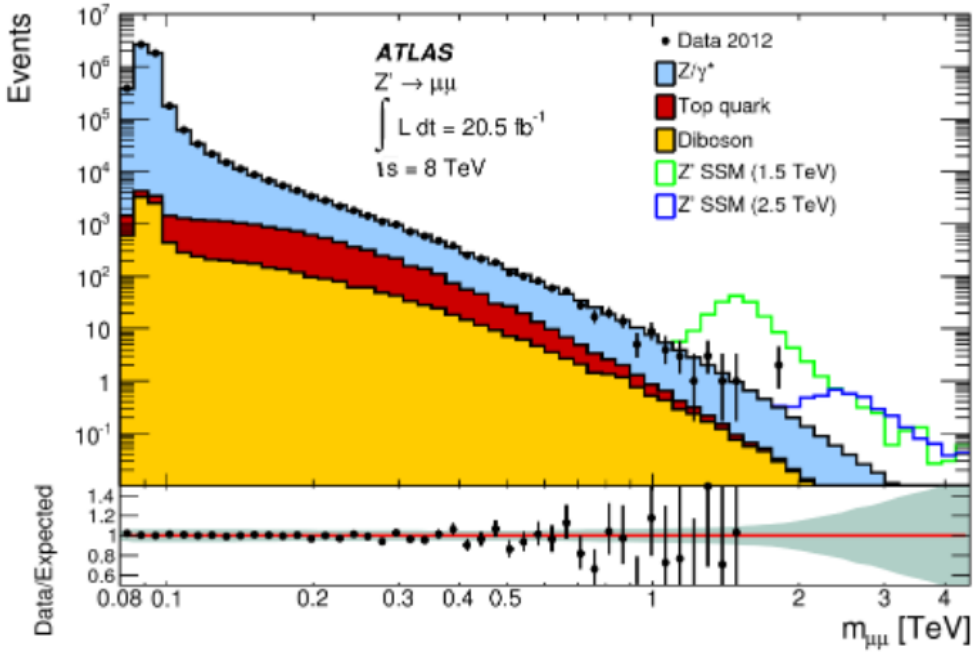


The usual suspects: dilepton and dijet resonances

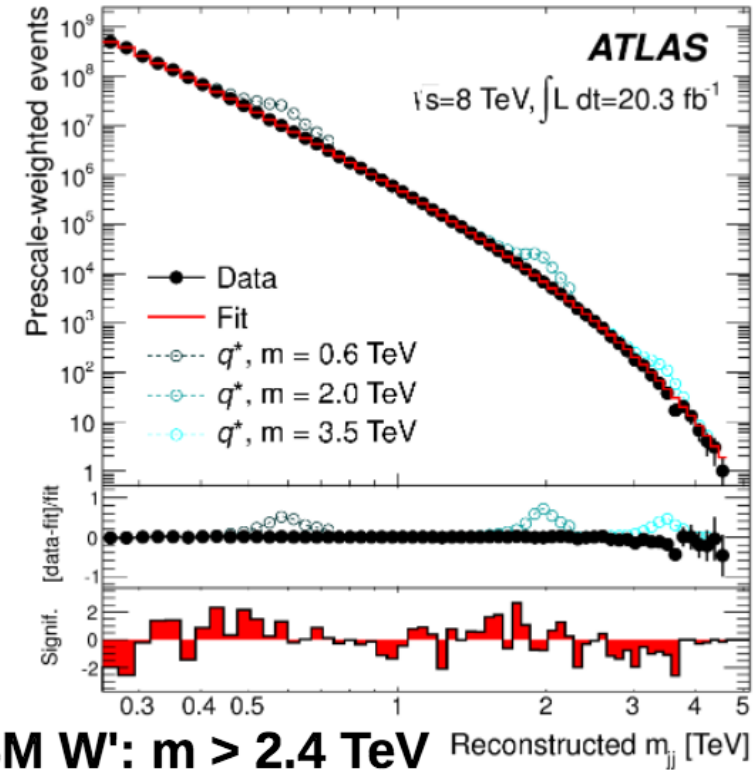
- Look for narrow peak over a smooth background
- Background estimation: Use data-driven technique when MC cannot be trusted

$$f(z) = p_1(1-z)^{p_2} z^{p_3 + p_4 \log z}$$

Dilepton: D-Y MC with NNLO corrections



Dijet: fit bgd with "smooth" function



SSM Z': m > 2.9 TeV

RS G* (k/M_{pl} = 0.1): m > 2.5 TeV

SSM W': m > 2.4 TeV

Excited quark: m(q*) > 4 TeV

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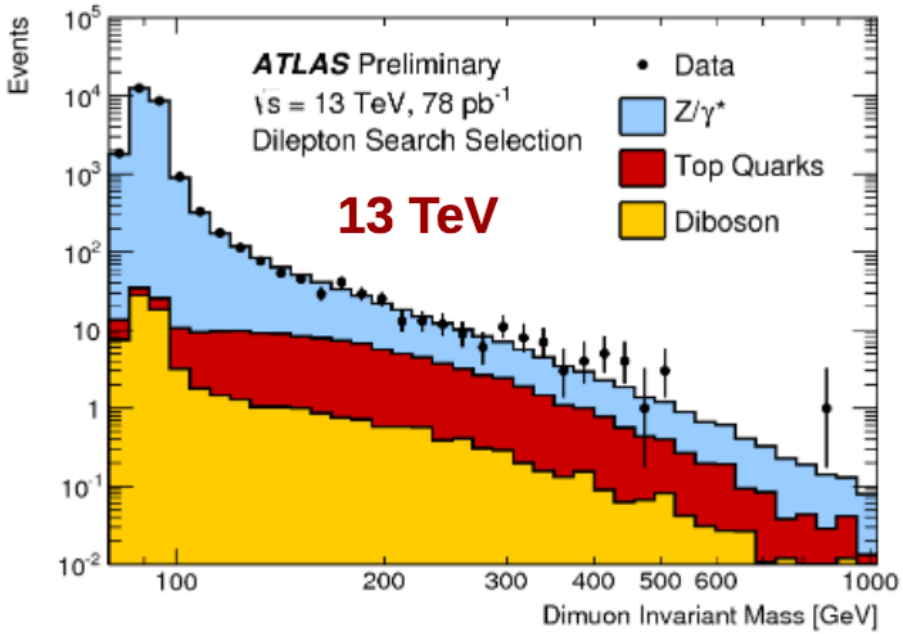
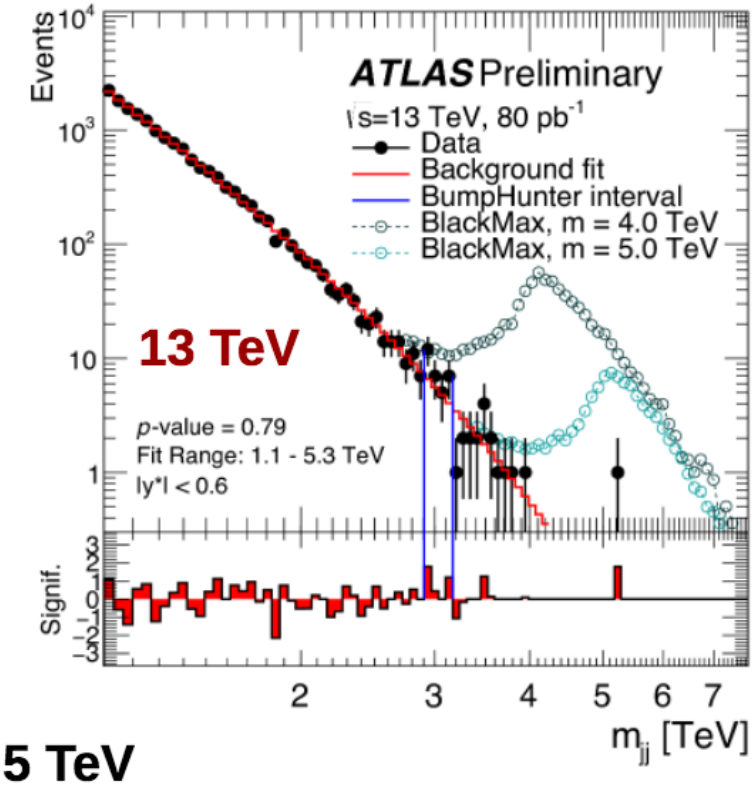


Dijet: fit bgd with "smooth" function



First look at 13 TeV with 80 /pb

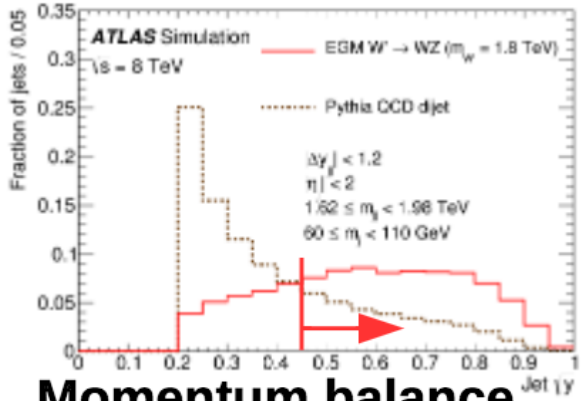
Reach Run 1 sensitivity only at very high mass ~ 5 TeV

Search for WW/WZ/ZZ resonances

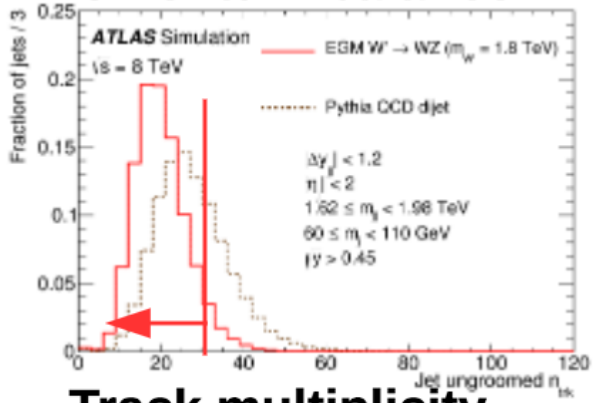
- Many channels:
  - → WW → lvlv or lvqq or (qq)(qq)
  - → WZ → lvll or lvqq or llqq or (qq)(qq)
  - → ZZ → (ll)(ll) or (ll)(vv) or llqq or (qq)(qq)
  - → … and more
  - → focus on the most sensitive
- Interpretation in terms of W' and bulk RS graviton
- Got some attention due to the all-hadronic (qq)(qq) ATLAS result → see next slides

Diboson all-hadronic channel

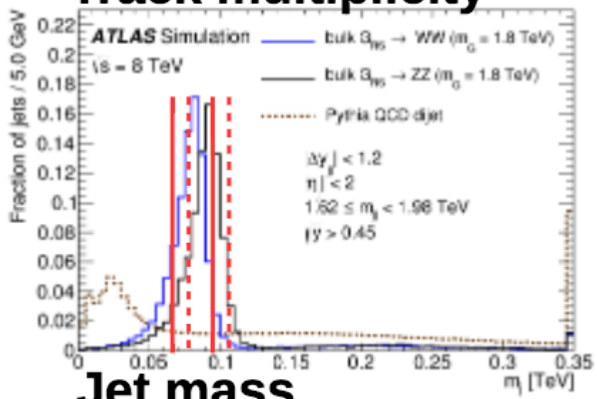
- Look for pair of vector bosons, each decaying to pair of quarks:
  - → WW or WZ or ZZ → (qq) (qq)
- High-momentum → boosted topology:
  - → Pair of large-radius jets (C/A, R = 1.2)
  - → $| y_1 - y_2 | < 1.2$
  - → Sub-structure reconstruction techniques
    - Filtering
    - $\sqrt{y} \equiv \min(p_{T\,j_1}, p_{T\,j_2}) \frac{\Delta R_{(j_1,j_2)}}{m_0} \geq 0.45$
    - N(tracks) < 30
    - Jet mass compatible with W or Z mass (26 GeV mass windows)



Momentum balance



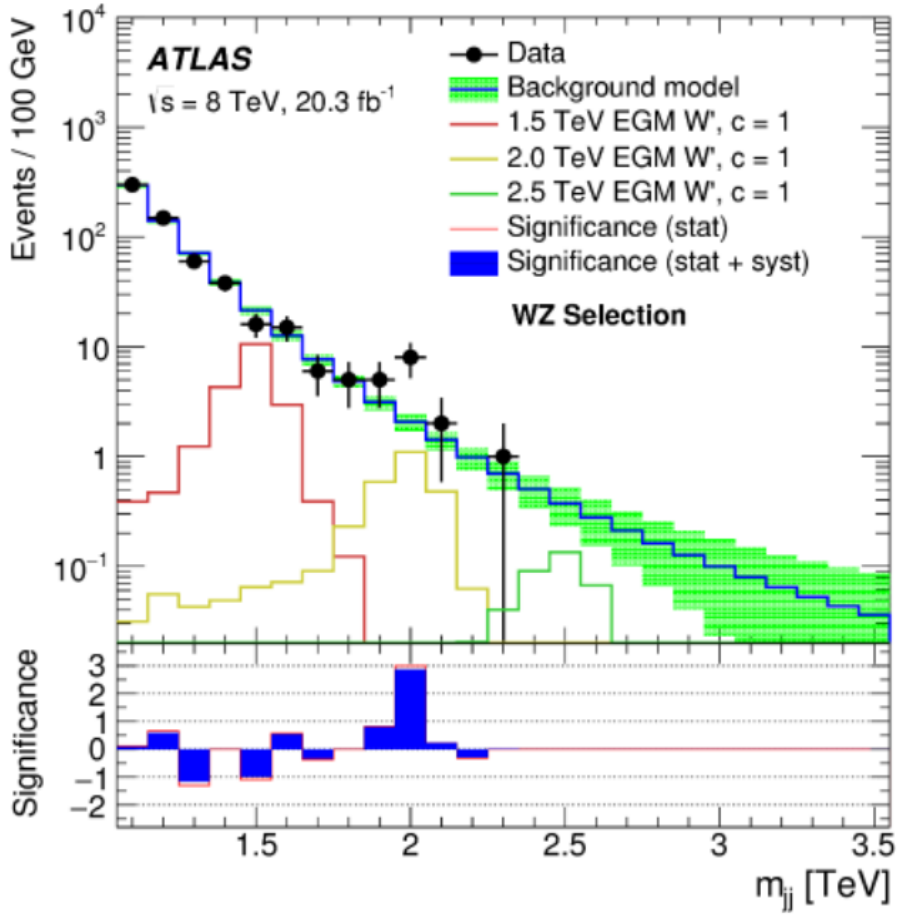
Track multiplicity



Jet mass

Diboson all-hadronic channel

- Background: fit data with same function as dijet analysis
- Look for deviation above background
- Largest excess at 2 TeV in WZ channel
  - → Local p-value = 3.4 σ
  - → Global p-value = 2.5 σ
    (taking into account trial factor, a.k.a. look-elsewhere effect)
  - → Roughly speaking:
    in one bin, observe 8 events where 2 are expected
- What can other channels tell us about this?



Diboson combination of 4 channels

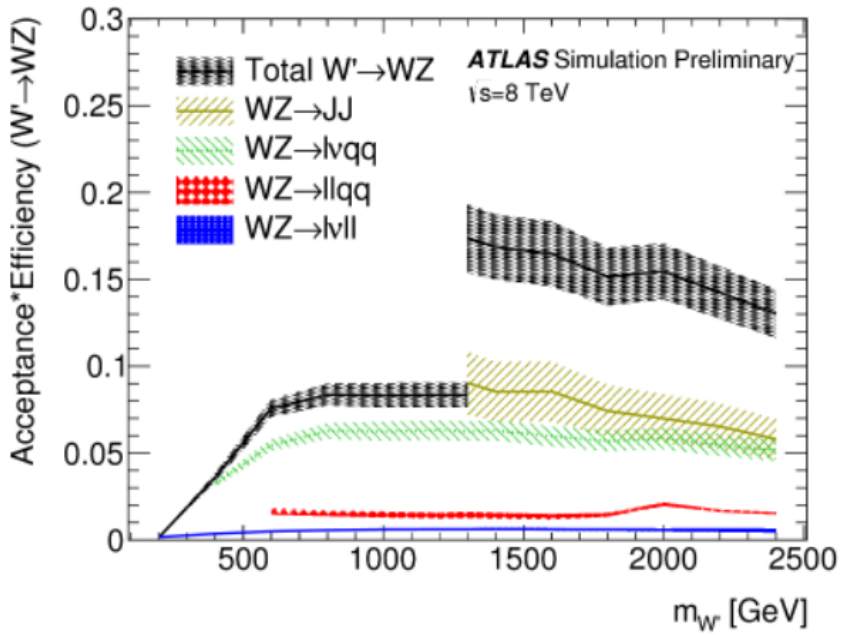
- Combine channels with lepton-multiplicity from 0 to 3:

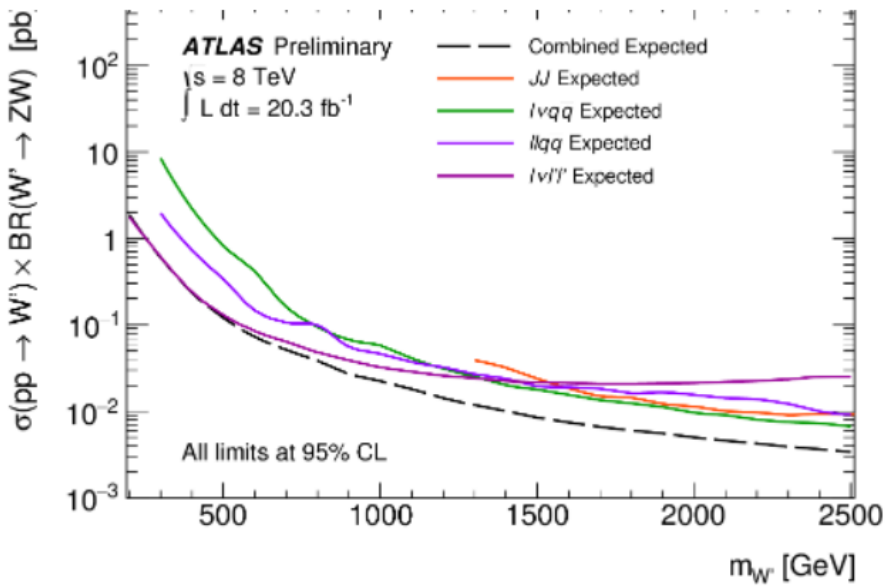
  (qq)(qq) (lν)(qq)

  (ll)(qq) (lν)(ll)

- Leptonic channels are competitive with all-hadronic at high-mass
- lνqq best channel at 2 TeV for W'

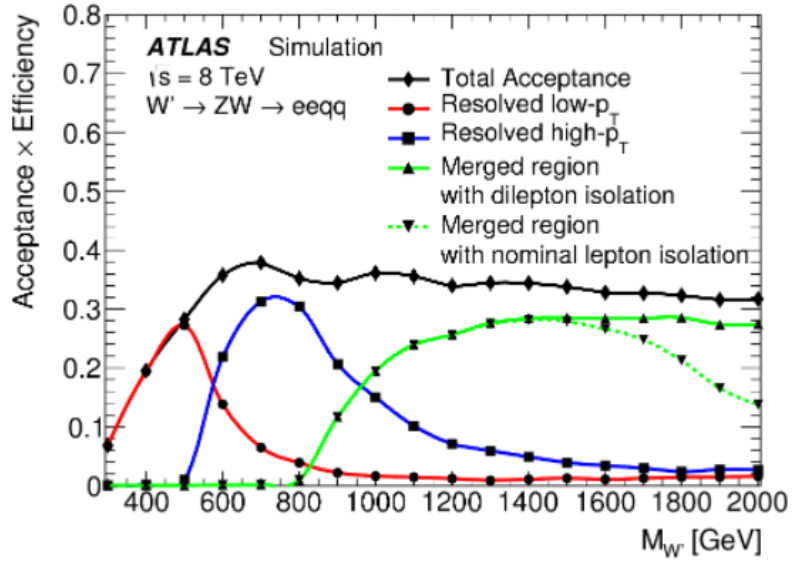
	lνll	lνqq	llqq	qqqq (JJ)
WZ	X	X	X	X
WW		X		X
ZZ			X	X

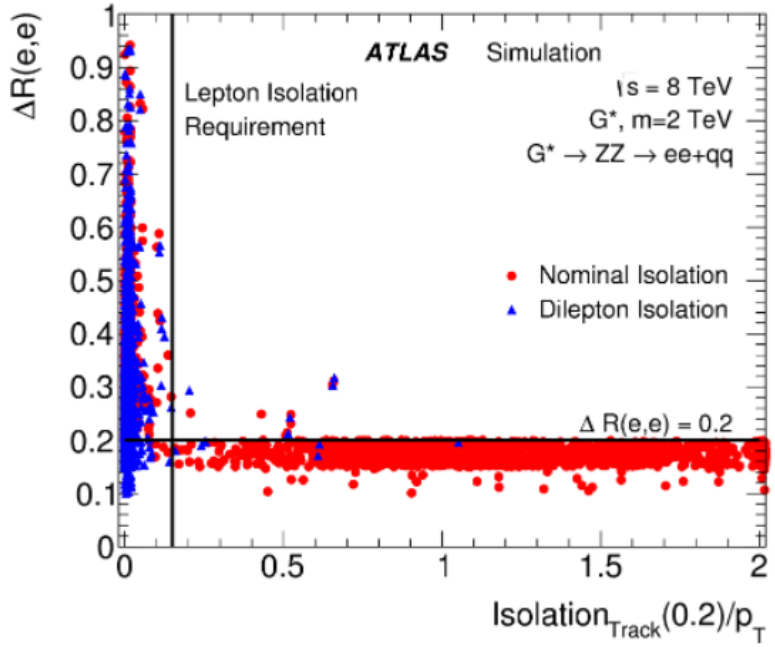




Diboson (ll)(qq) channels

- Three complementary kinematic selections:
  - → "resolved" (jets R = 0.4) low-pT
  - → "resolved" high-pT
  - → "merged" i.e. boosted (jets R = 1.2), same reconstruction as JJ
  - → (lv)(qq) channel follows same strategy
- Important to revisit isolation variable for high-momentum Z
  - → "dilepton" isolation replaces standard variable
  - → Double acceptance at 2 TeV

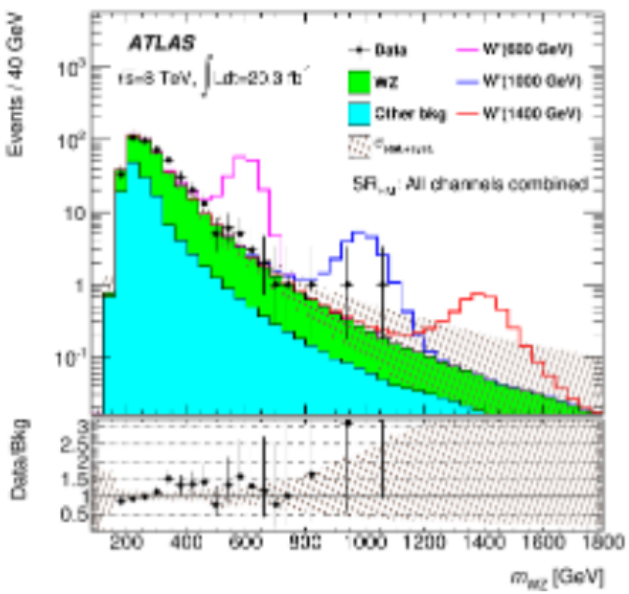




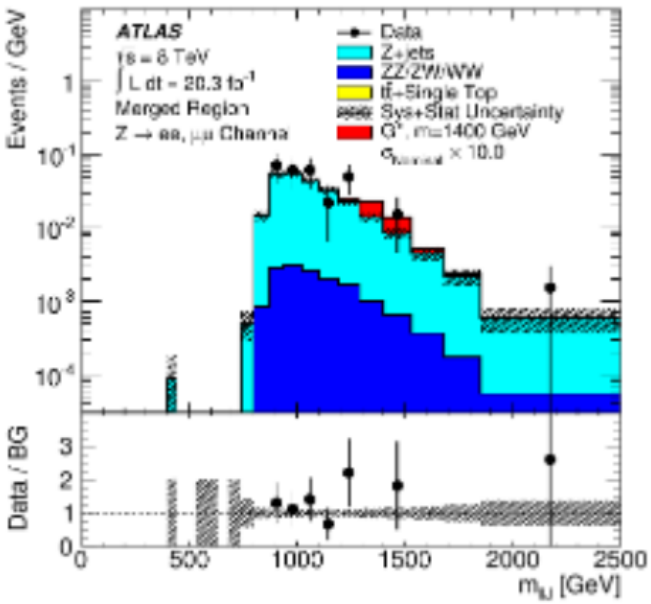
Diboson (semi)leptonic channels

- No excess seen in any of the (semi)leptonic channels
- (Showing only merged regions –most sensitive at high mass– for lvqq and llqq)

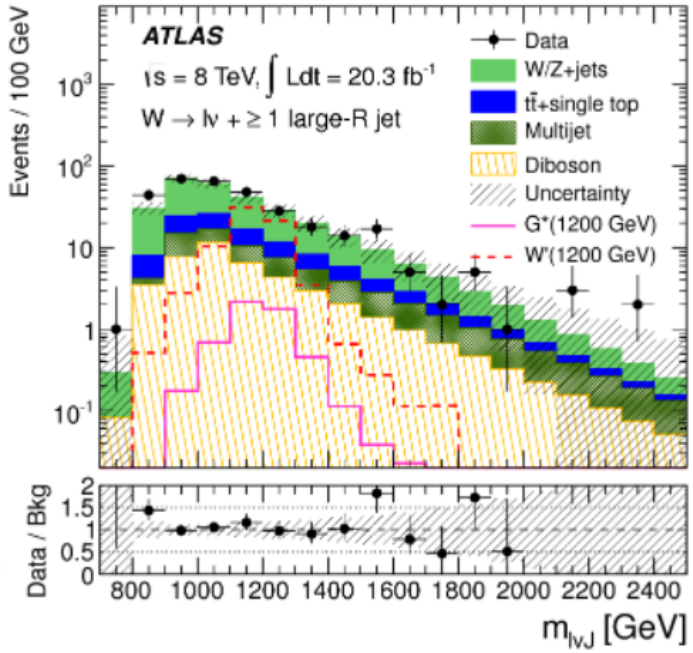
(lv)(ll)



(ll)(qq) (merged region)

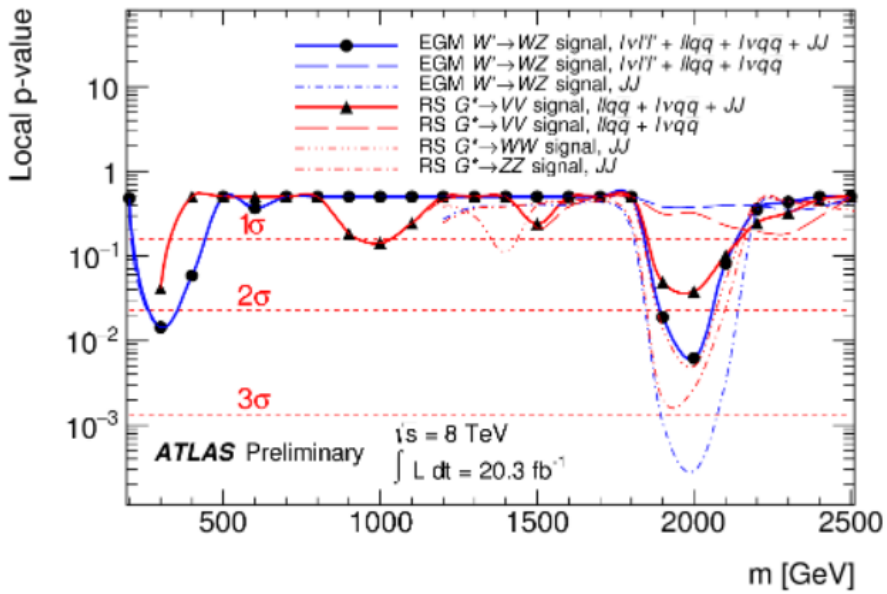


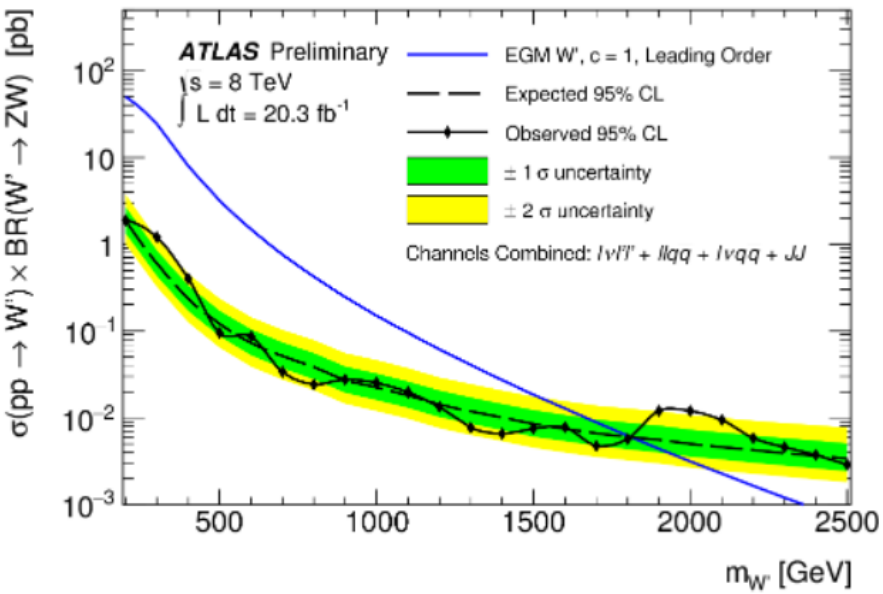
(lv)(qq) (merged region)

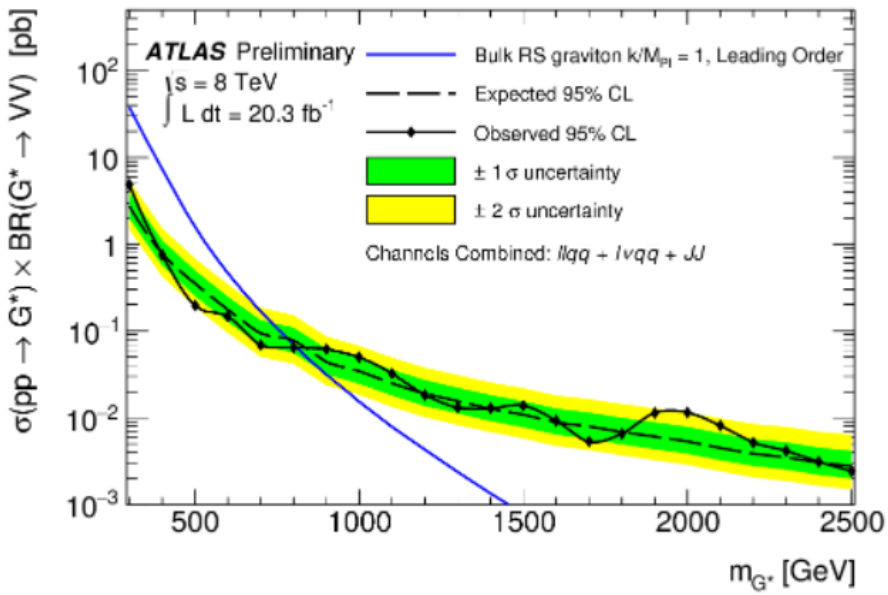


Diboson combination of 4 channels

- No excess in other three channels → <u>local</u> p-value drops from 3.4 σ to 2.5 σ, i.e. not significant



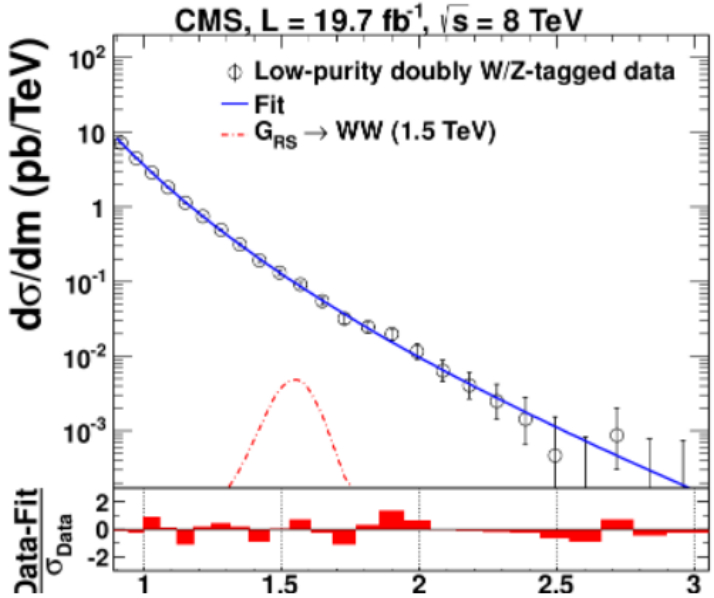


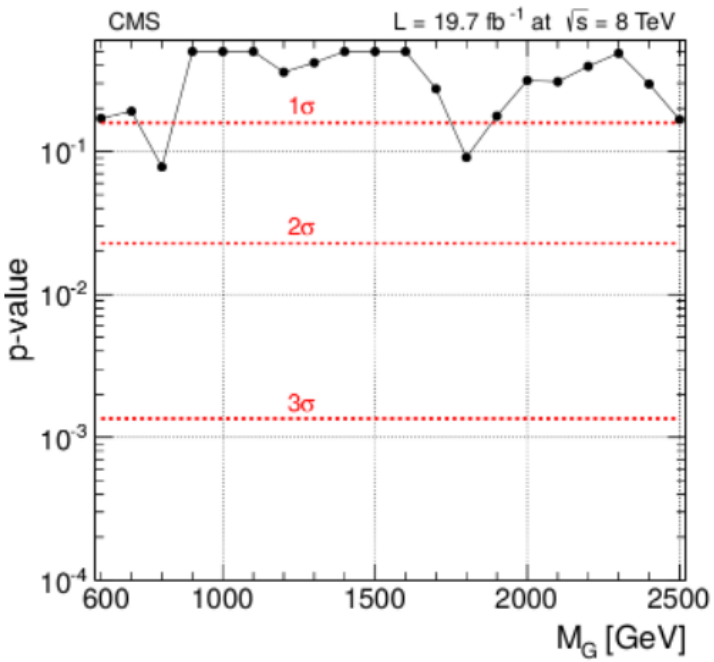


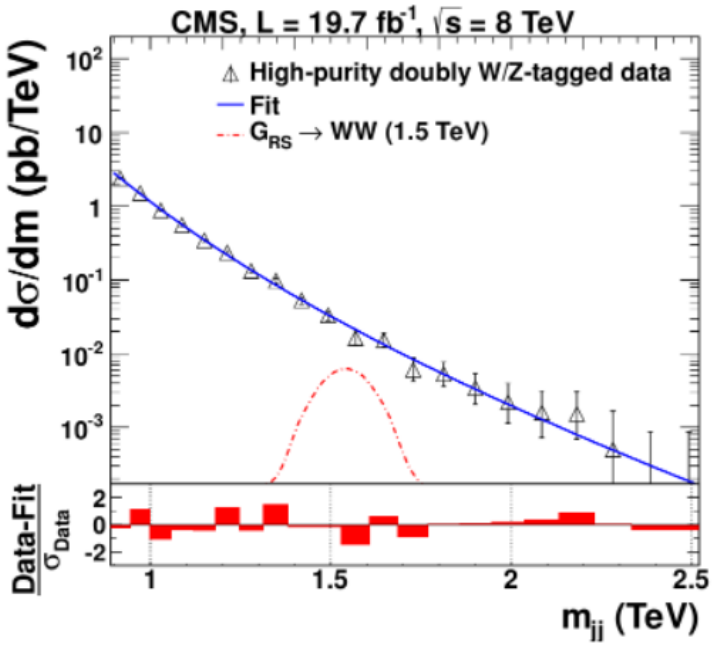
Diboson: what does CMS see?

- All-hadronic:
  - → "excess" at 1.9 TeV of 1.3 σ local p-value
  - → no excess in high-purity region
- Combination with (semi)leptonic channels: no excess at 2 TeV
- Conclusion:

  No excess!







W' : other channels

- EGM W' : leptonic channel (W' → lν) obviously better than diboson channel; W' → tb comparable

Analysis	Branching ratio (high m)	W' mass limit
Lepton + MET	BR(W' → eν or μν) = 16%	3.2 TeV
Dijet	BR(W' → qq) = 48%	2.4 TeV
Diboson	BR(W' → WZ) = 1.2%	1.8 TeV
Top-bottom	BR(W' → tb) = 24%	1.7 TeV

- EGM W' not really suited for WZ search. Suggestions?

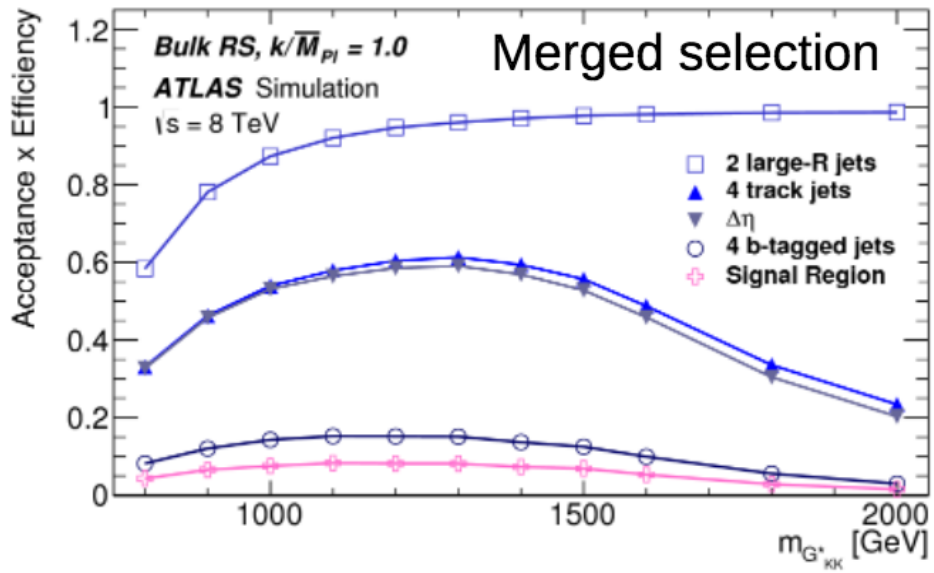
Bulk RS Graviton : other channels

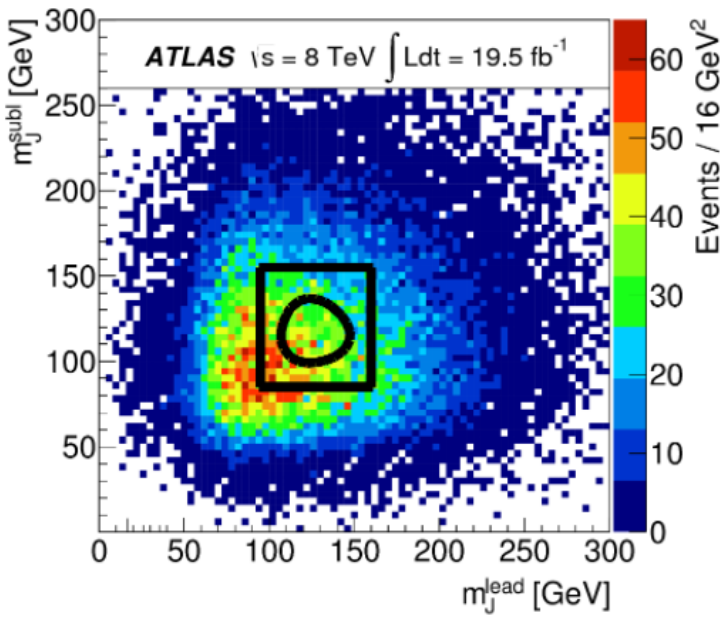
- Bulk RS Graviton was chosen as benchmark for its large diboson branching ratio (k/M_Pl = 1.0)

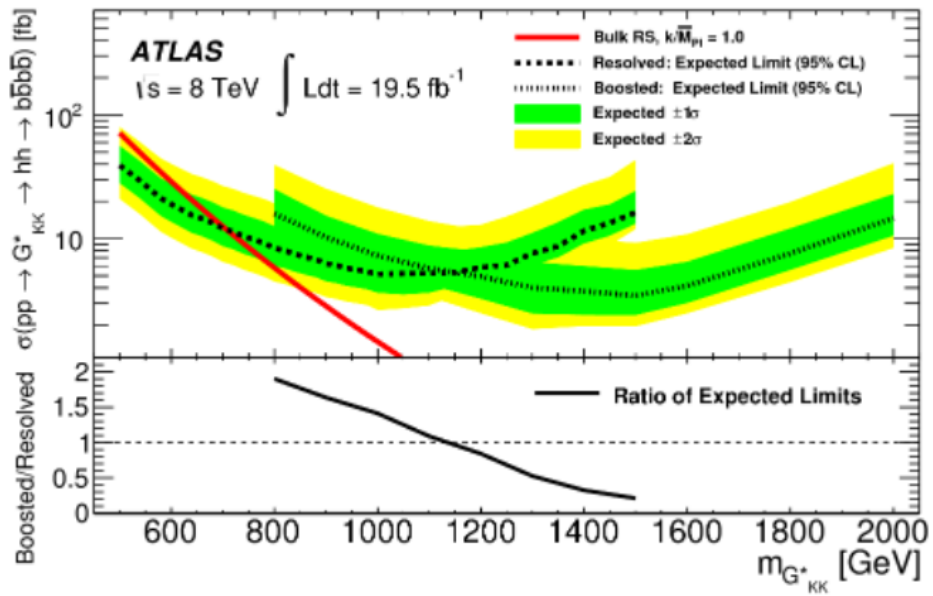
Analysis	Branching ratio (high m)	G* mass limit
Di-Higgs	BR(G* → HH) = 8%	720 GeV
Diboson	BR(G* → WW) = 2.BR(G* → ZZ) = 16%	810 GeV
Top-antitop	BR(G* → tt) = 65%	-

HH → 4b's resonance

- Look for 2 pairs of b-jets compatible with H → bb
- Resolved + Merged channels
- Require 4 b-tags in high-momentum, high-density environment!
  - → Use narrow track-jets

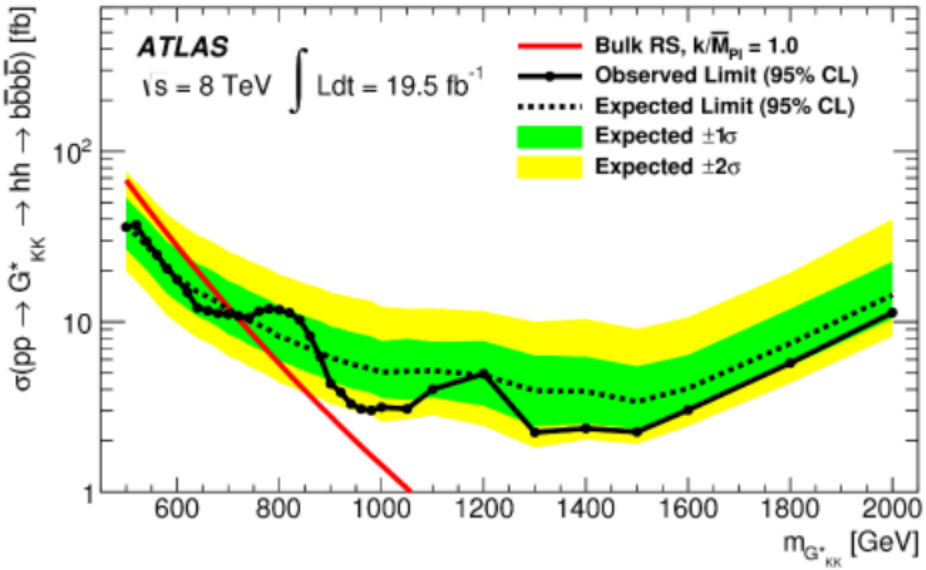


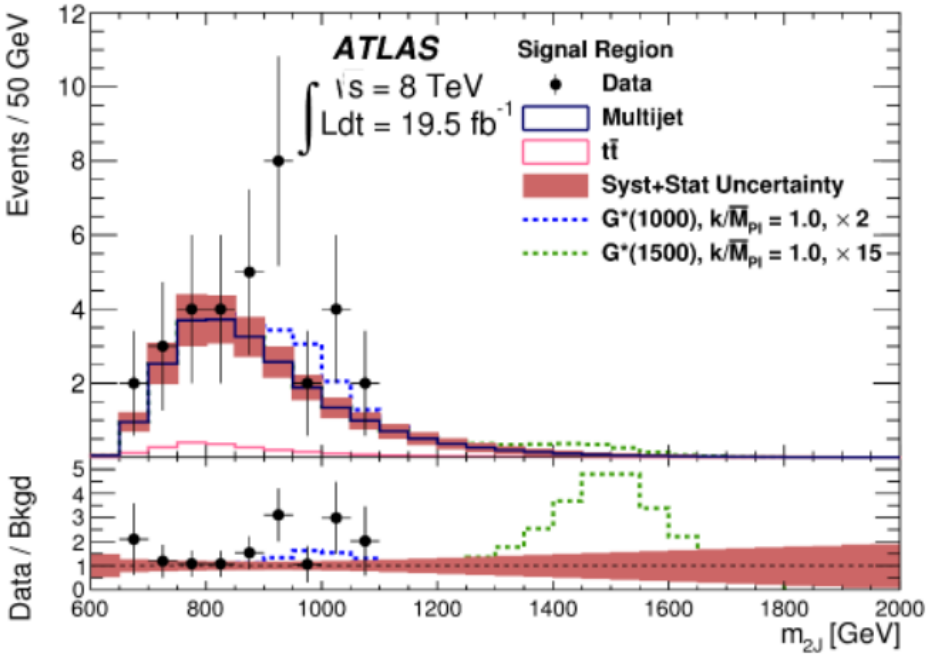


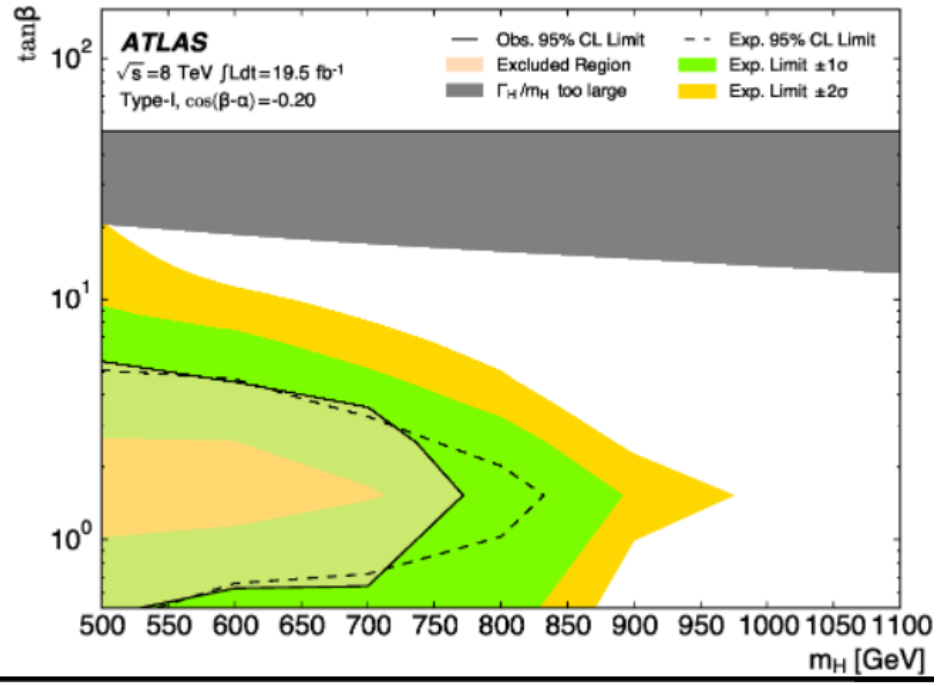


HH → 4b's resonance

- Interpretations in terms of:
  - → Bulk RS: m(G*)>710 GeV (k/M_Pl = 1.0)
  - → 2HDM models
- 2HDM includes width up to Γ/m~20%

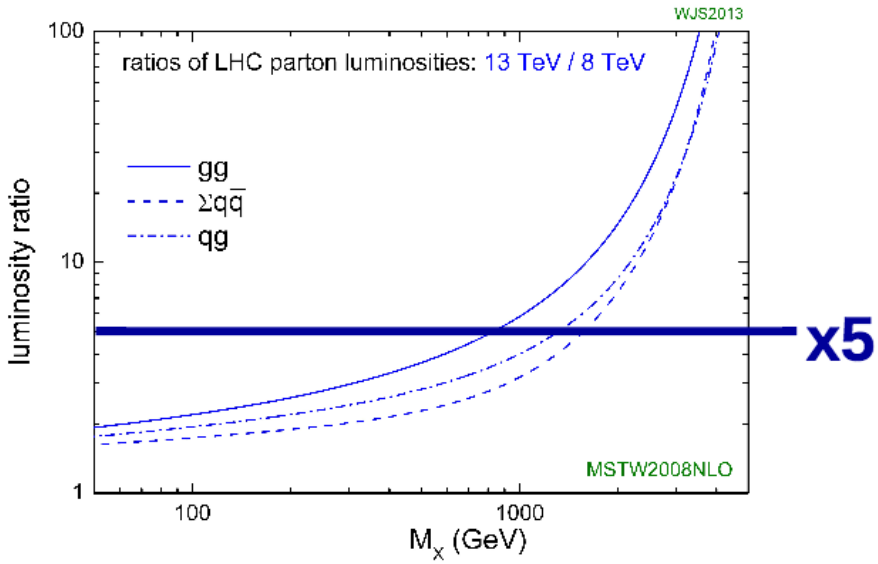




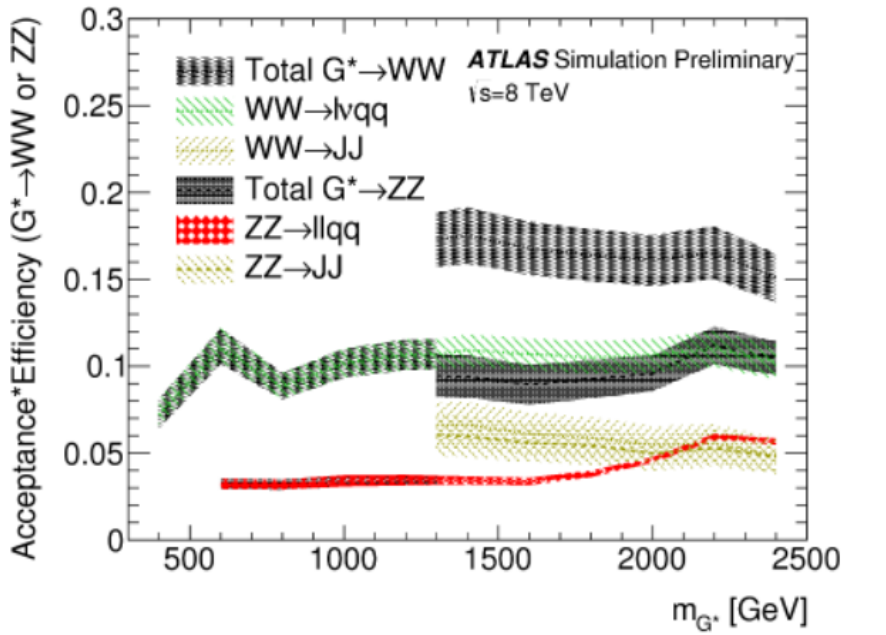
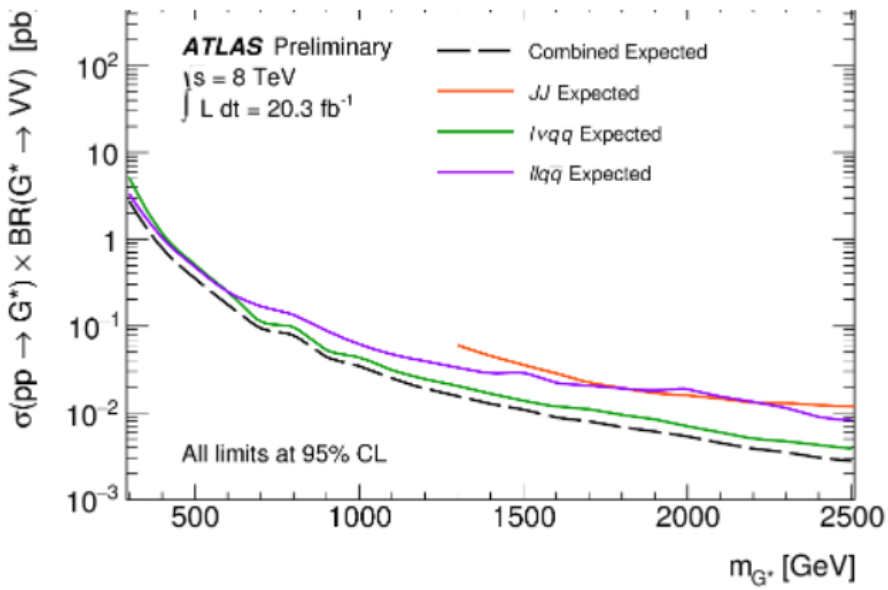


Conclusion

- Run 1 searches finally (almost) completed
- Boosted techniques now the norm
  - → including lepton isolation and combination with resolved channels
- Expect ~ 4 /fb at 13 TeV in a month (already 2 recorded!) → enough to exceed Run 1 sensitivity at masses above 1 TeV



Backup

Diboson combination of 4 channels

- G*: same picture as W', namely:
- Channels with 1-lepton and/or two leptons are competitive with all-hadronic at 2 TeV!