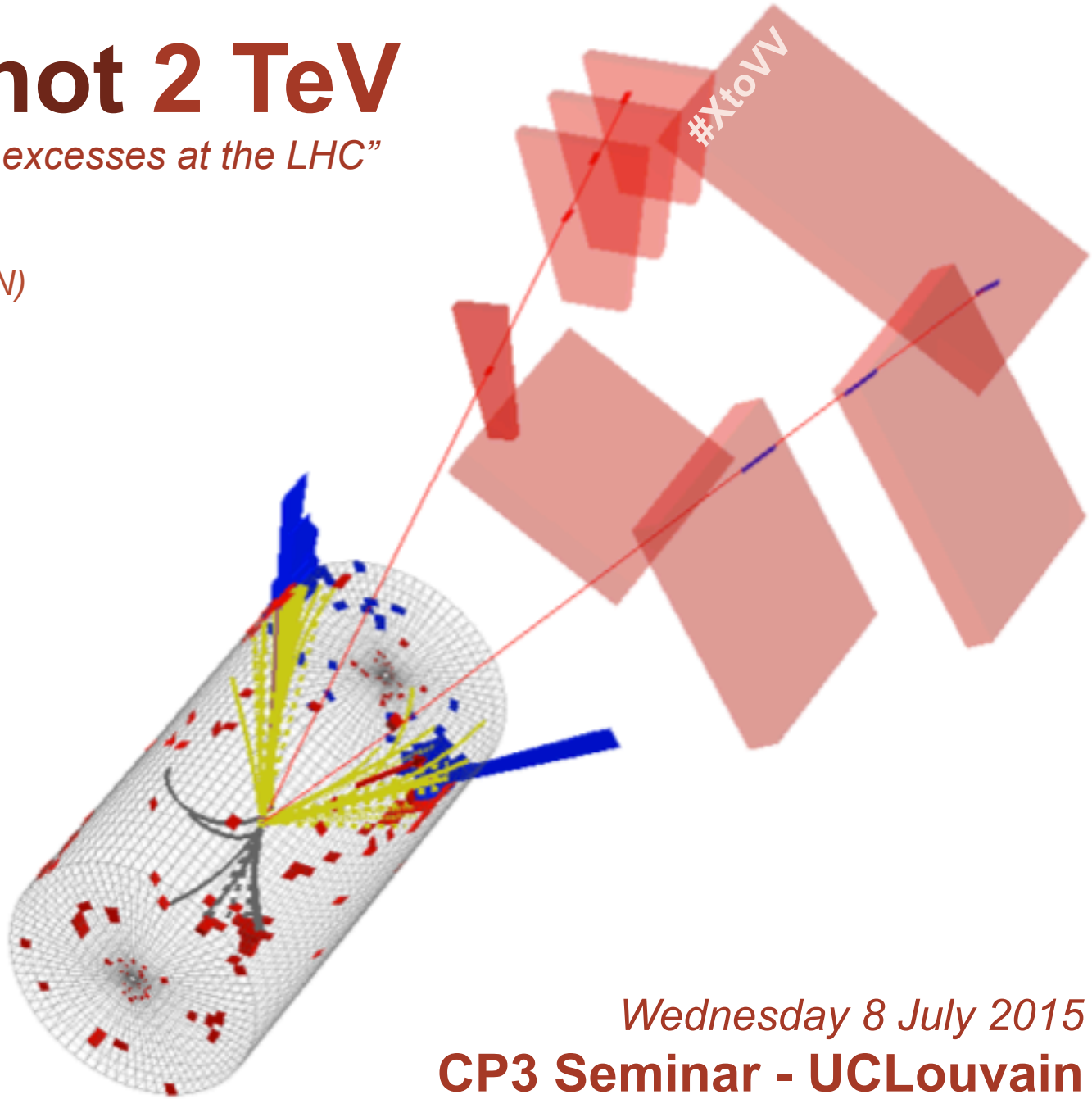
2 TeV or not 2 TeV

"Overview of the X→VV excesses at the LHC"

Tristan du Pree *(CERN)*



Outline:

Substructure

1.8 TeV excesses

- *VV: CMS & Atlas*
- *Other searches*
- *Comparisons*

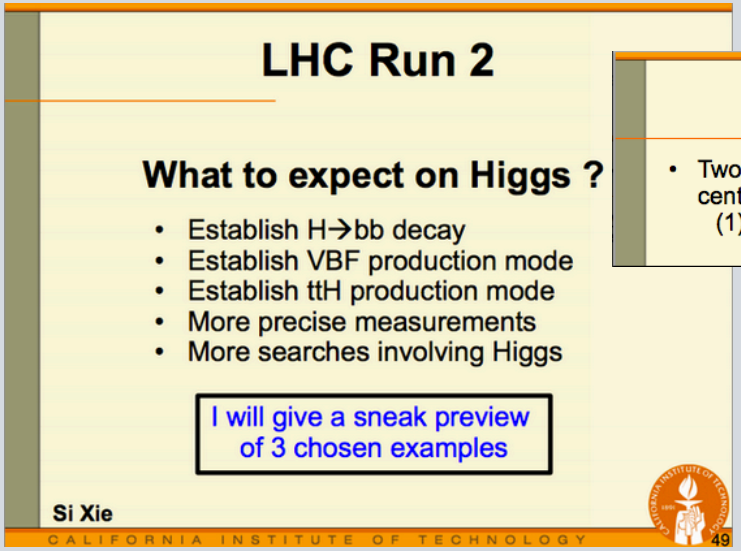
Run-2 outlook

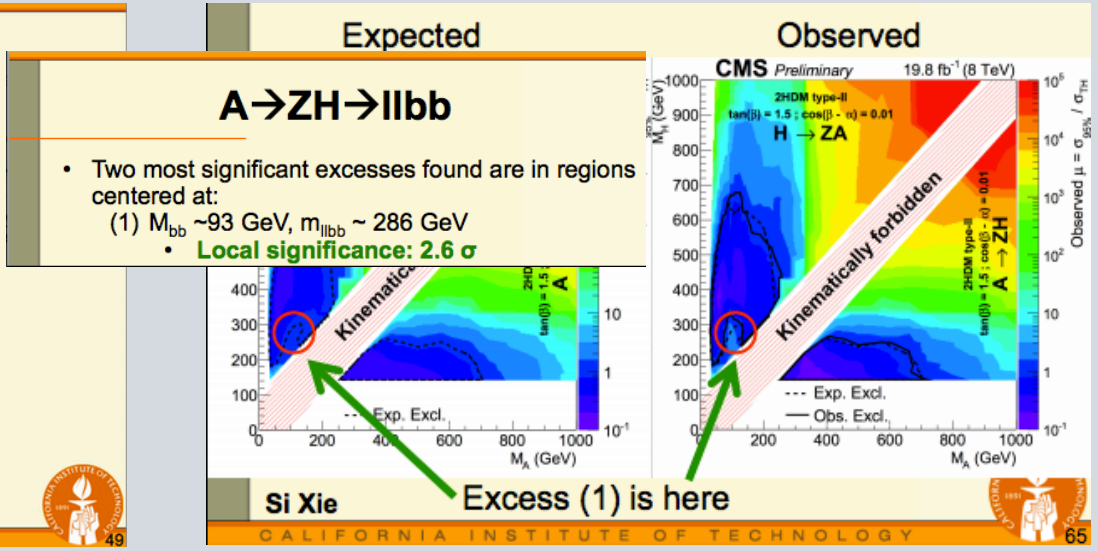
Wednesday 8 July 2015

CP3 Seminar - UCLouvain

Another excess

- **2HDM: H→ZA** [CMS HIG-15-001]
  - Slides Si Xie [Caltech] at Wine&Cheese seminar [Fermilab]





- **Not today's topic**
  - More info? Ask your CP3 colleagues!
    - Adrien, Alexandre, Christophe, Giacomo, Loic, Lucia, Roberto, …

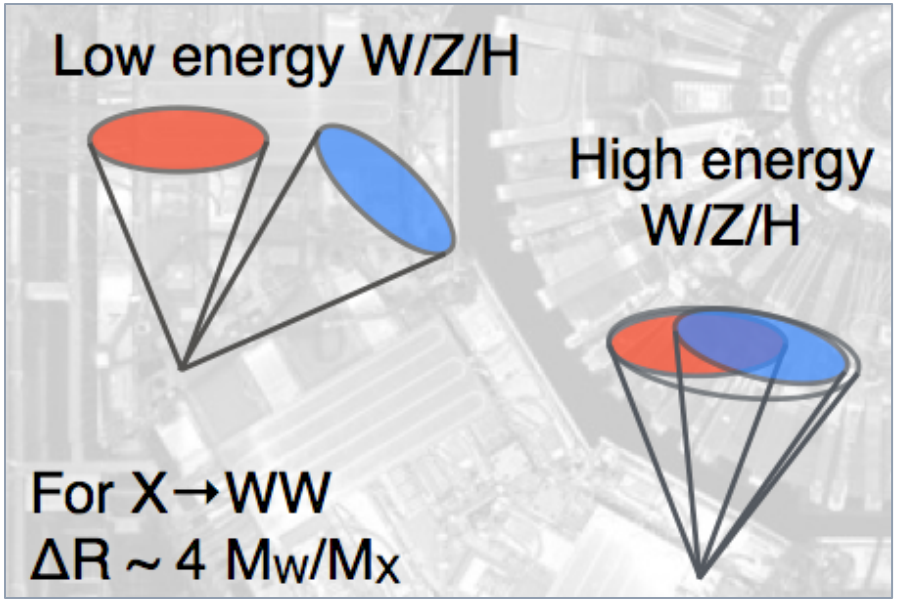
Introduction

- **'The 2 TeV excesses'**
  - Hot topic now
  - See several presentations:
    - **Maxime Gouzevitch** (LHC Crosstalk)
    - **Tiziano&Luca** (CMS Week), **Paris Sphicas** (CERN/FNAL HCP School)
    - **Roman Kogler** (CERN LPCC seminar): https://indico.cern.ch/event/388148/
- **Disclaimer**
  - I did not (yet) work on this subject myself
    - But interested for Run-2!
  - Much material taken from **Maurizio Pierini**
    - *https://indico.cern.ch/event/396272/contribution/1/material/slides/0.pdf*
- **Goal of coming 30 slides**
  - Give you an overview of the **existing results**
    - And some hope for Run-2
  - Have some discussion on **future plans**
    - Theory & Experiment
- **Warning: this will be a very optimistic presentation!**

CMS HIG-13-008

Boosted jets

- **W/Z/H bosons → qq final states**
  - Low p_T: 2 jets → **"resolved"**
  - Large p_T: decay products **merged in a single jet**
- **Merged jets: mass peaks at expected value**
  - Different from QCD backgrounds



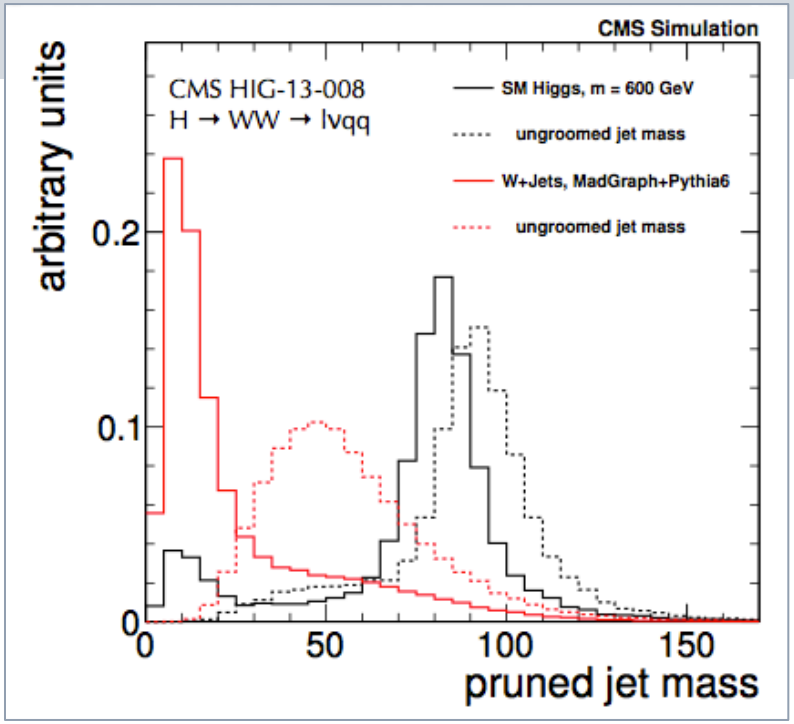
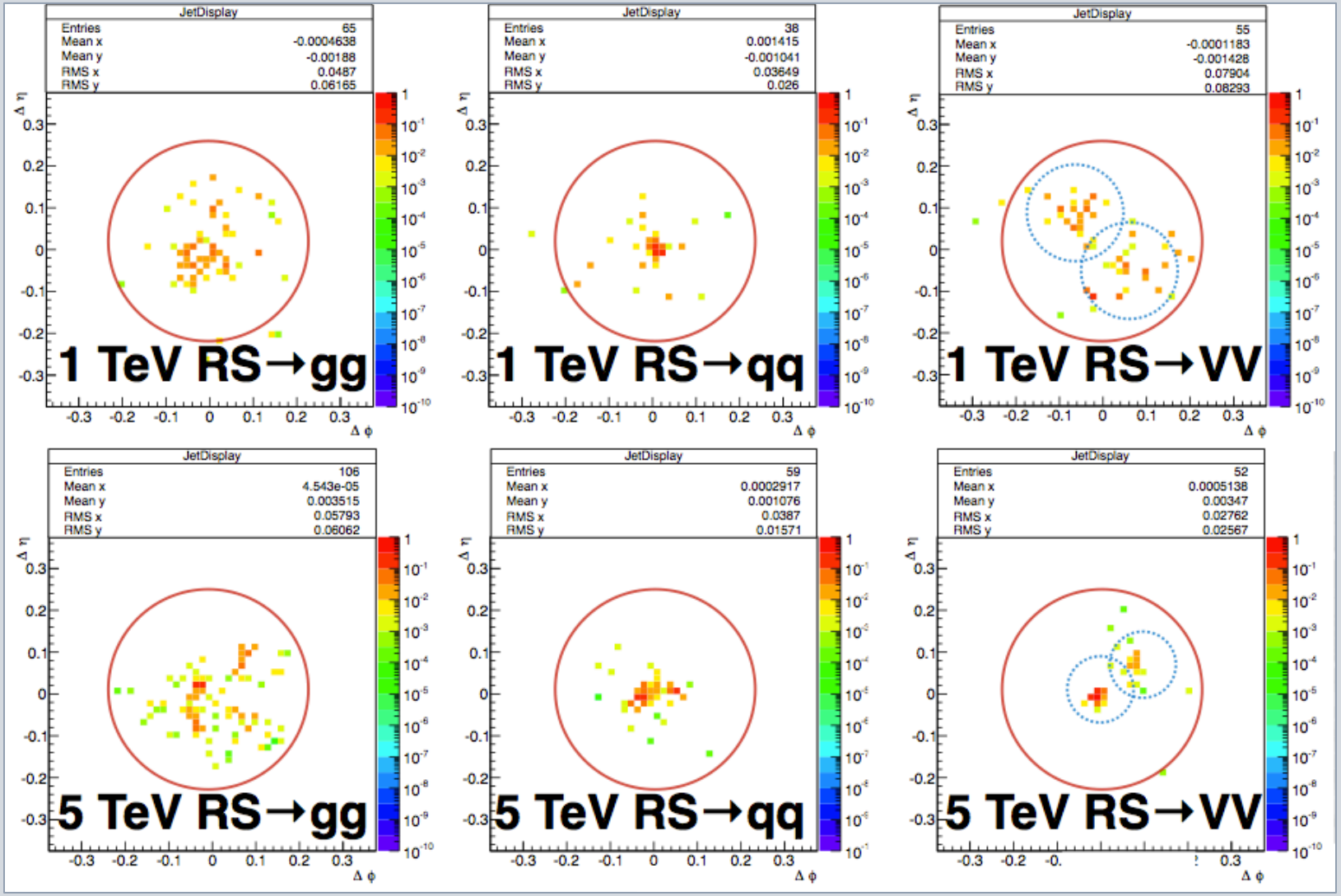


Illustration taken from Maurizio Pierini: https://indico.cern.ch/event/396272/contribution/1/material/slides/0.pdf

Jet substructure

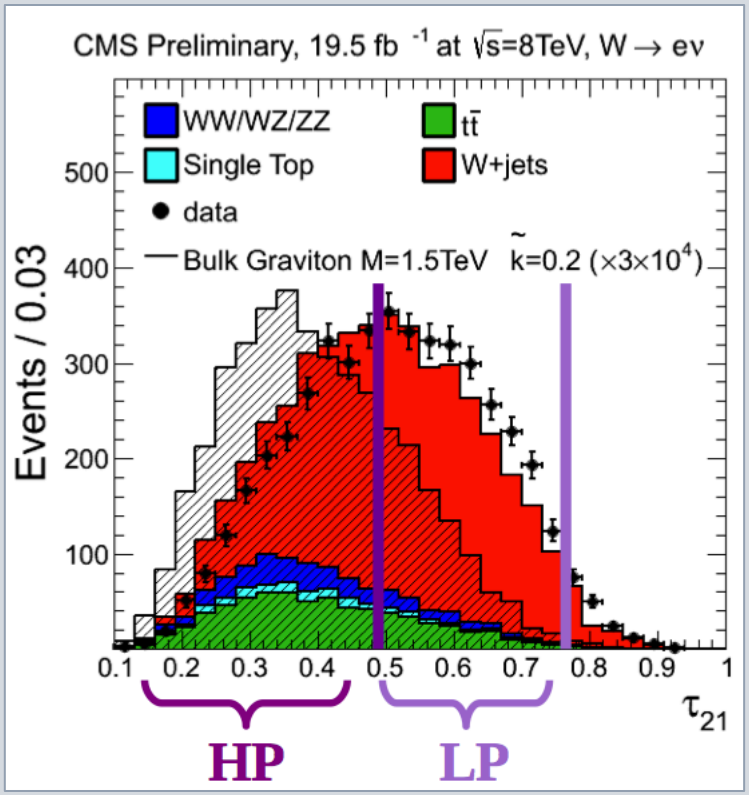


Substructure: CMS

- **N-subjettiness**
  - Quantifies arrangement of jet in **N subjets**
  - **arxiv/1011.2268**

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \, min\left\{\Delta R_{1,k}, \Delta R_{2,k}, \ldots, \Delta R_{N,k}\right\}$$

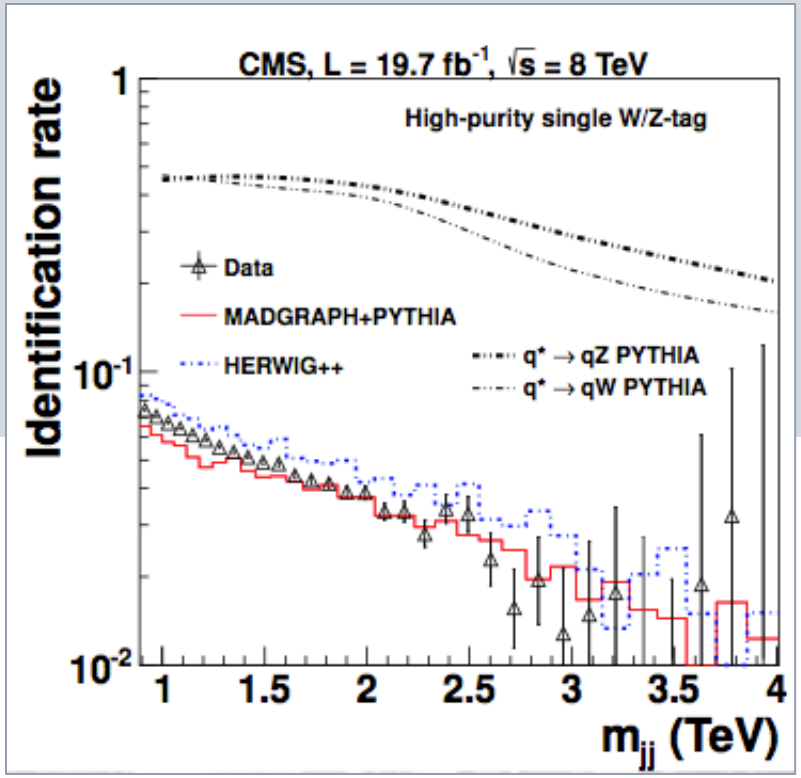
- **Can be computed for any N**
  - E.g. test **1-prong** vs **2-prong**
- **Consider ratio $\tau_{21}=\tau_2/\tau_1$**
  - Best S/B discrimination

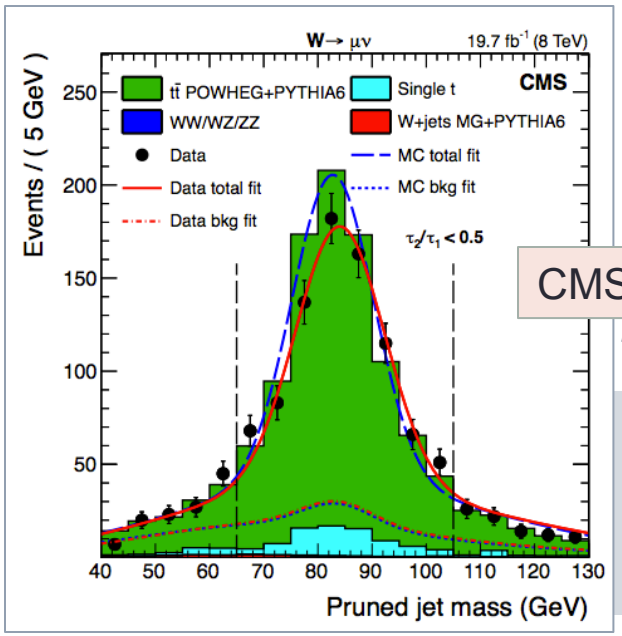


CMS EXO-12-024

Boosted tagging

- **Tagging efficiency: 20-40%**
  - Depends on resonance **mass**
  - Depends on value of τ_{21}
- **Mistag efficiency: <10%**
  - For HP-tagged events
  - Dropping at larger masses





CMS JME-13-007

"pruned mass"

- **Second variable: Jet mass**

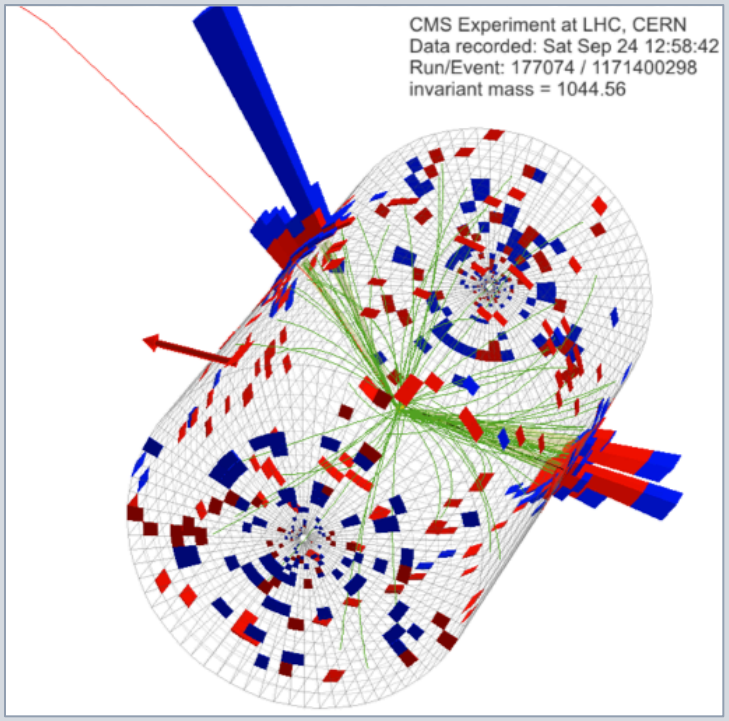
Further improve purity

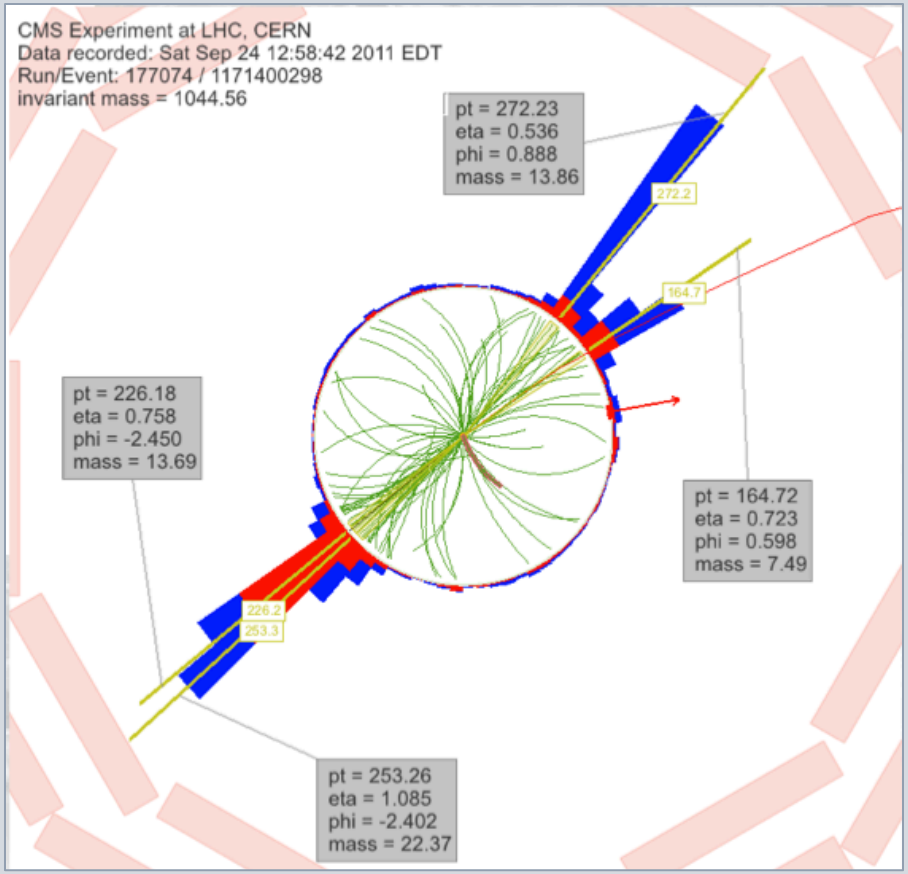
- Substructure references in backup

JJ event

CMS EXO-11-095

After tagging





RESULTS

X→V(J)V(J)

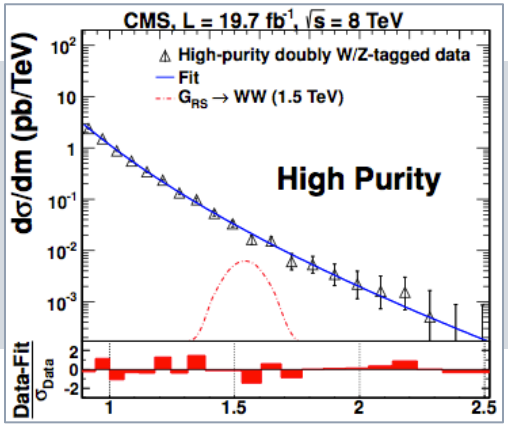
CMS + Atlas

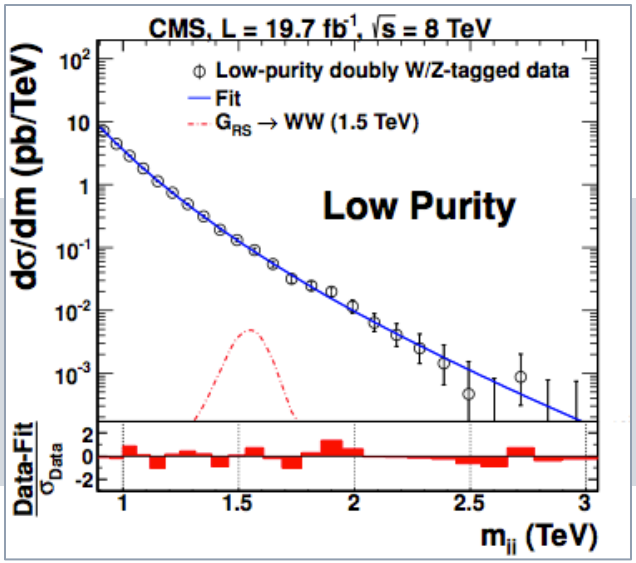
X→VV

CMS at 8 TeV

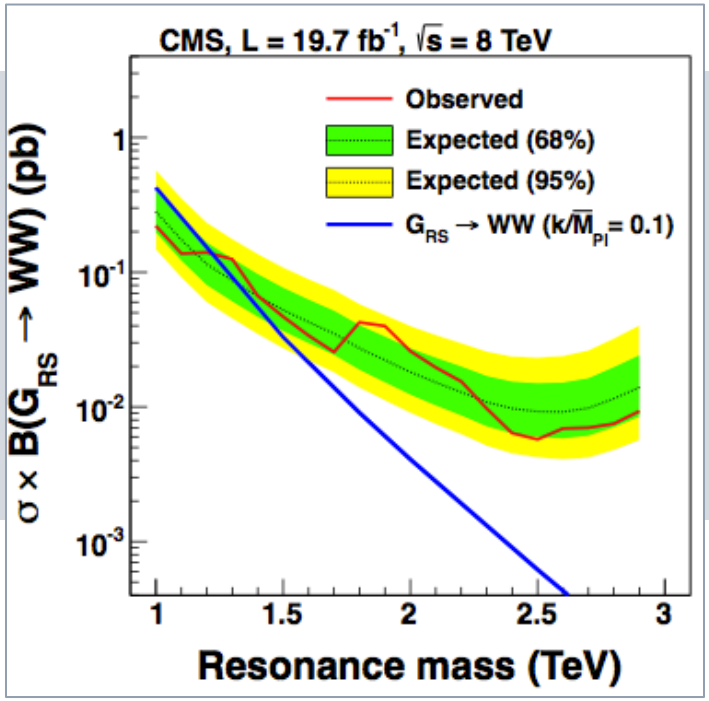
CMS EXO-12-024

- **Two bump hunts**
  - HP&LP
  - A la classic dijet search





- **Combination of results**
  - Using expected **yields for HP/LP**
  - According to hypothesis of **RS Graviton**
- **At M_J~2TeV: 1.8σ excess**
  - HP: No excess
  - LP: Larger excess



Atlas

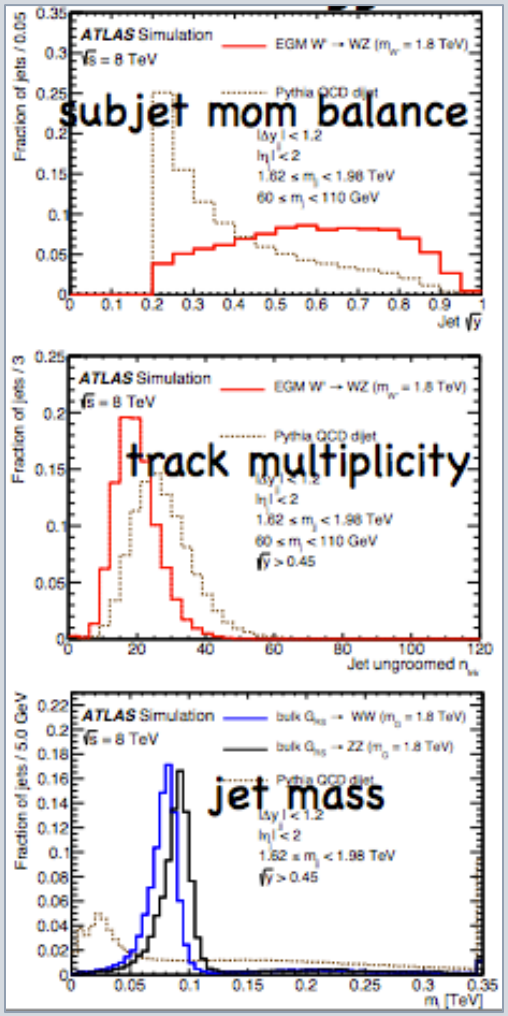
Boosted topologies

Atlas "filtering"

- **Different reconstruction**
  - CA with **R=1.2** (not 0.8)
  - **Grooming** algorithm differs: invert clustering for 2 subjets
  - **Substructure** quantified by subjet momentum balance

$$\sqrt{y} \equiv \min(p_{\mathrm{T}\,j_1}, p_{\mathrm{T}\,j_2}) \frac{\Delta R_{(j_1,j_2)}}{m_0} \geq \sqrt{y_{\mathrm{f}}}$$

  - **Track multiplicity** adds discrimination
- **Two (overlapping) jet mass windows**
  - **W**: 82.4 ± 13 GeV
  - **Z**: 92.8 ± 13 GeV
- **ATLAS arXiv:1506.00962**

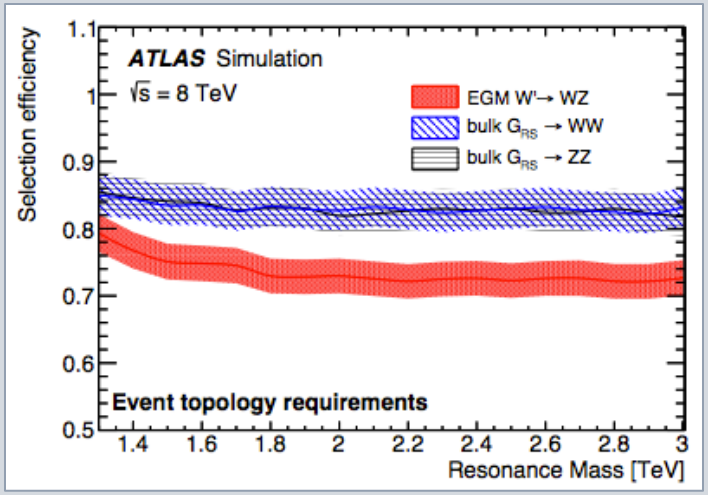


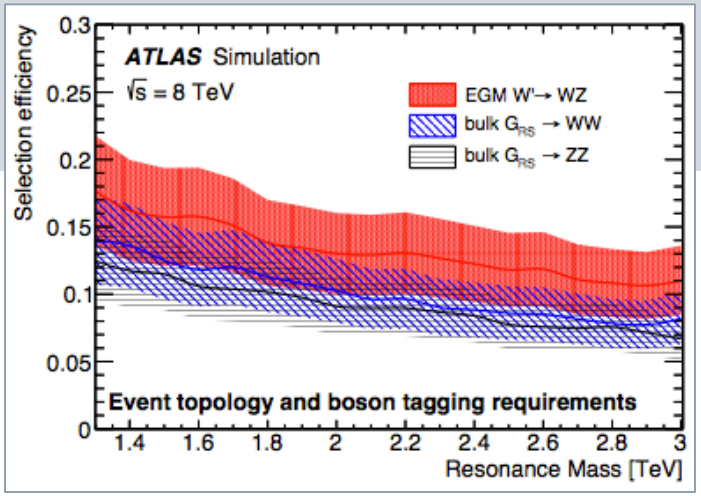
Atlas

Selection efficiency

arXiv/1506.00962

- **Selection**
  - Two jets
  - p_T>20 GeV, eta<2.0
- **Suppress QCD**
  - Require $|y_1-y_2| < 1.2$
- **Reject mismeasured jets**
  - $|p_{T,1}-p_{T,2}| / |p_{T,1}+p_{T,2}| < 0.15$
- **This selection: 75-80%**



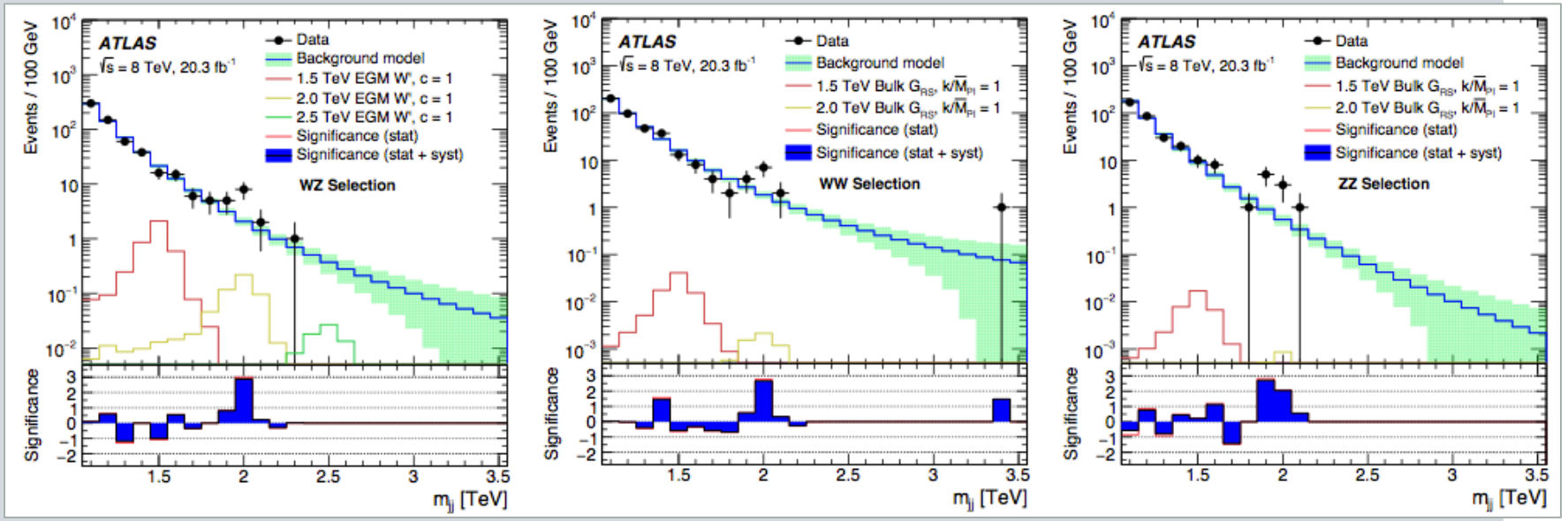


- **Plus boson tagging**
- **Final efficiency: 10-20%**

Atlas
X→V(J)V(J)

arXiv/1506.00962

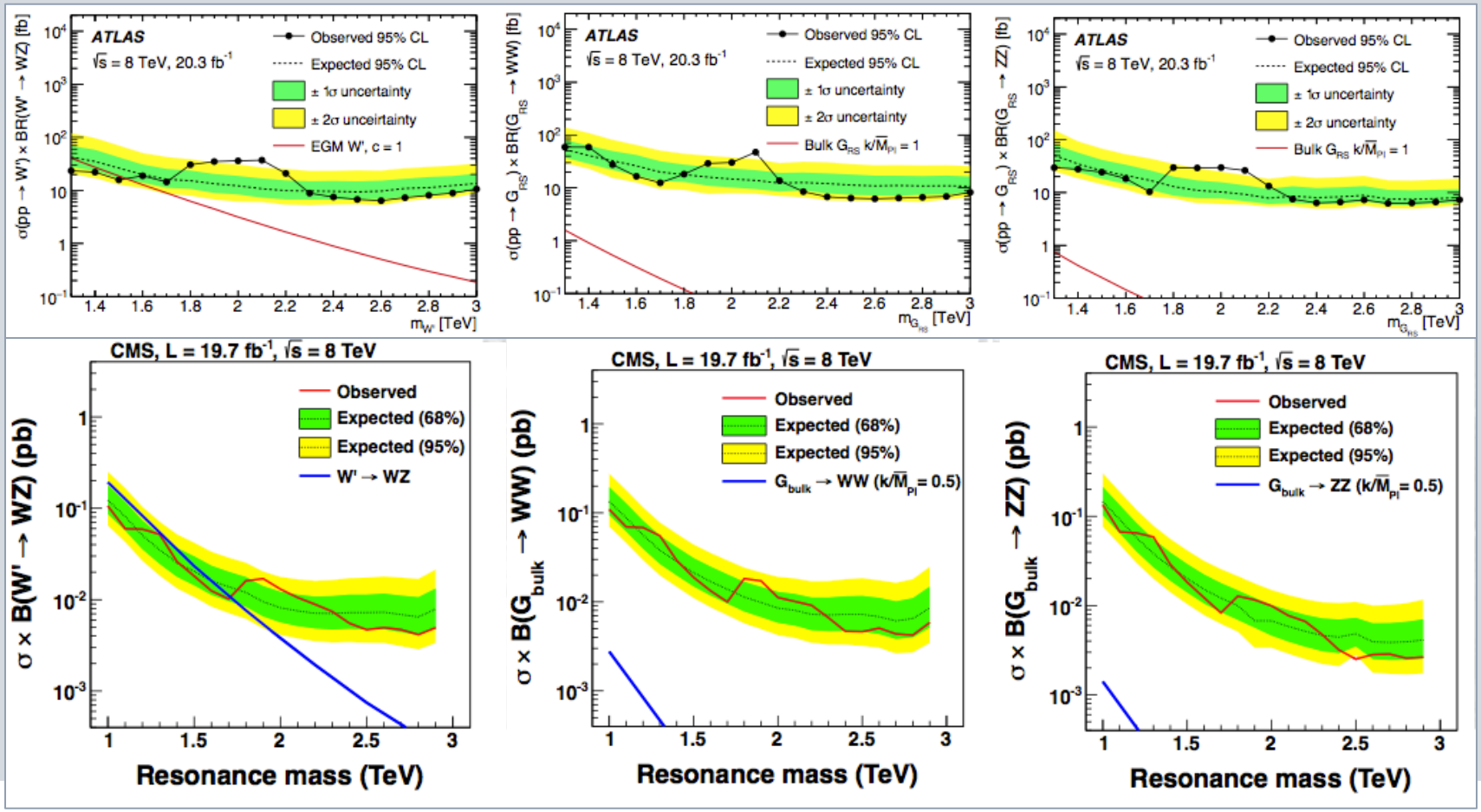
- **WW/WZ/ZZ results**



- **Yields & results not independent**
  - Jet mass windows overlap
- **Excess at ~2 TeV**
  - Local significances: **3.4σ** (WZ), **2.6σ** (WW), **2.9σ** (ZZ)
  - Global significance: **2.5σ** (WZ)

X→V(J)V(J)

- **Atlas+CMS**



BEYOND V(J)V(J)

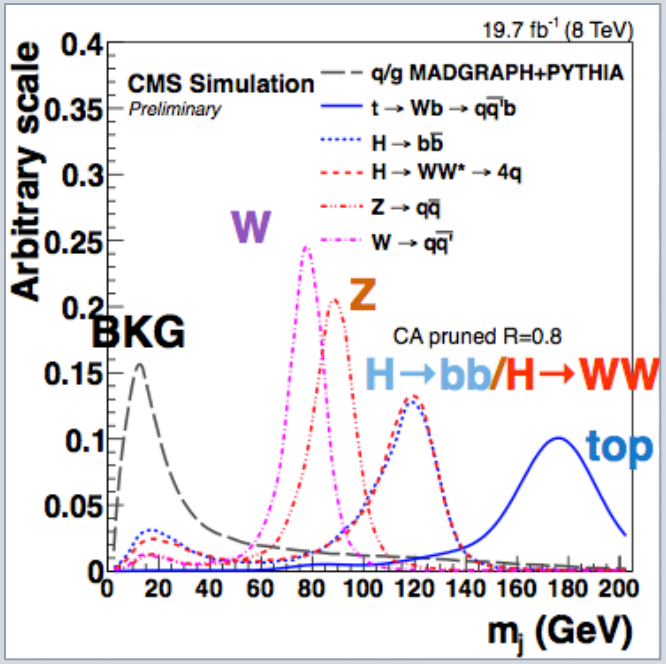
Now how about semileptonic decays?

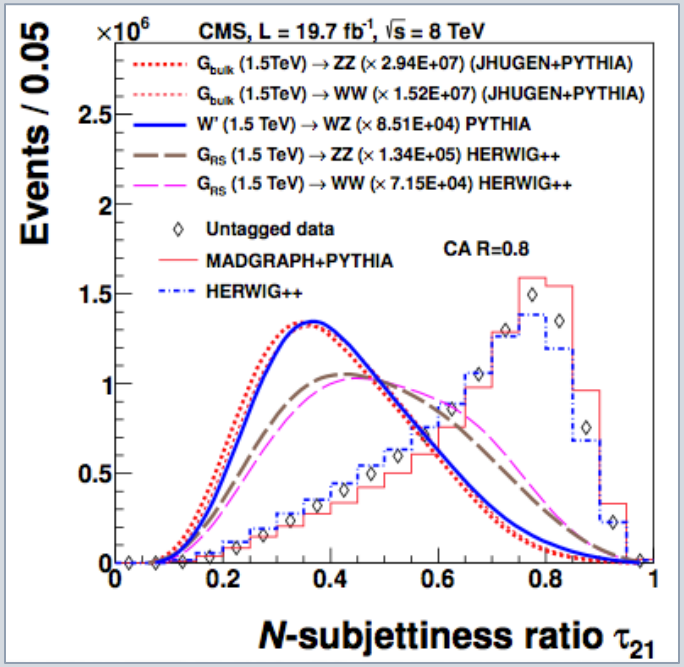
W or Z?

CMS EXO-14-009

CMS EXO-12-024

- **Hadronically difficult to distinguish W & Z**
  - **Resolution** ~10% (~ΔM) & similar **jet-substructure**



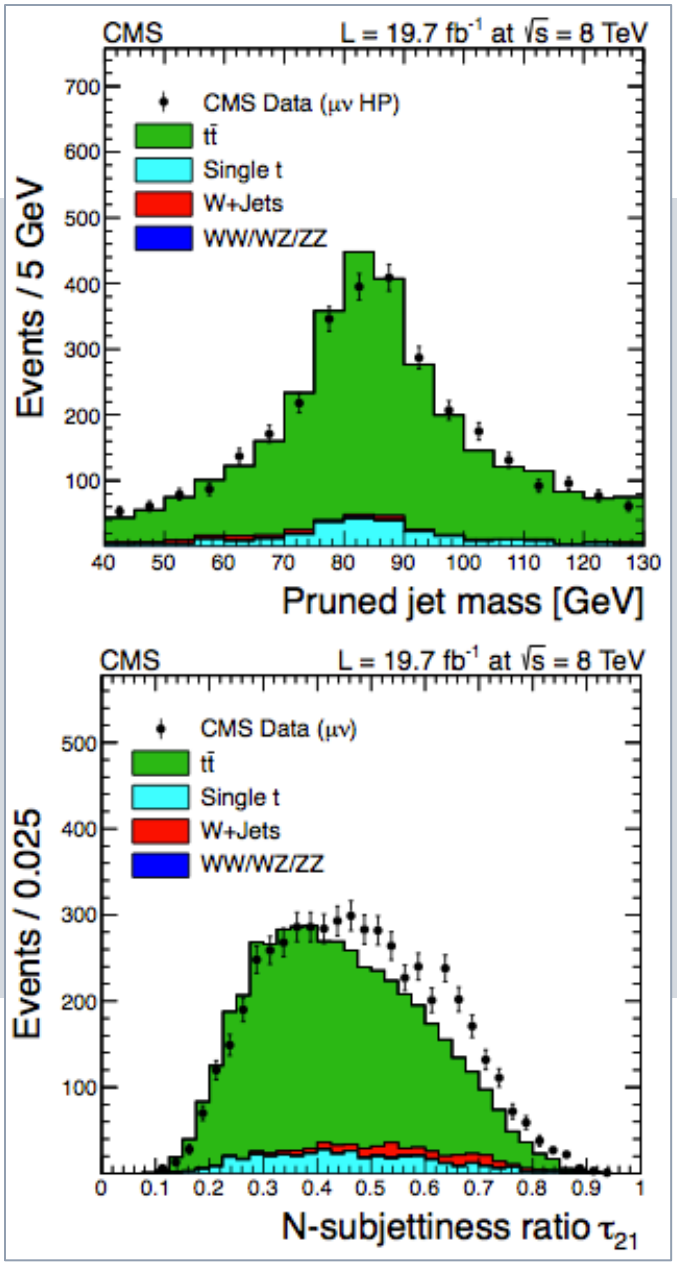


- **Difficult to distinguish WW/ZZ/WZ hadronically**
  - Small difference in bumphunt signal interpretations

W or Z?

CMS EXO-13-009

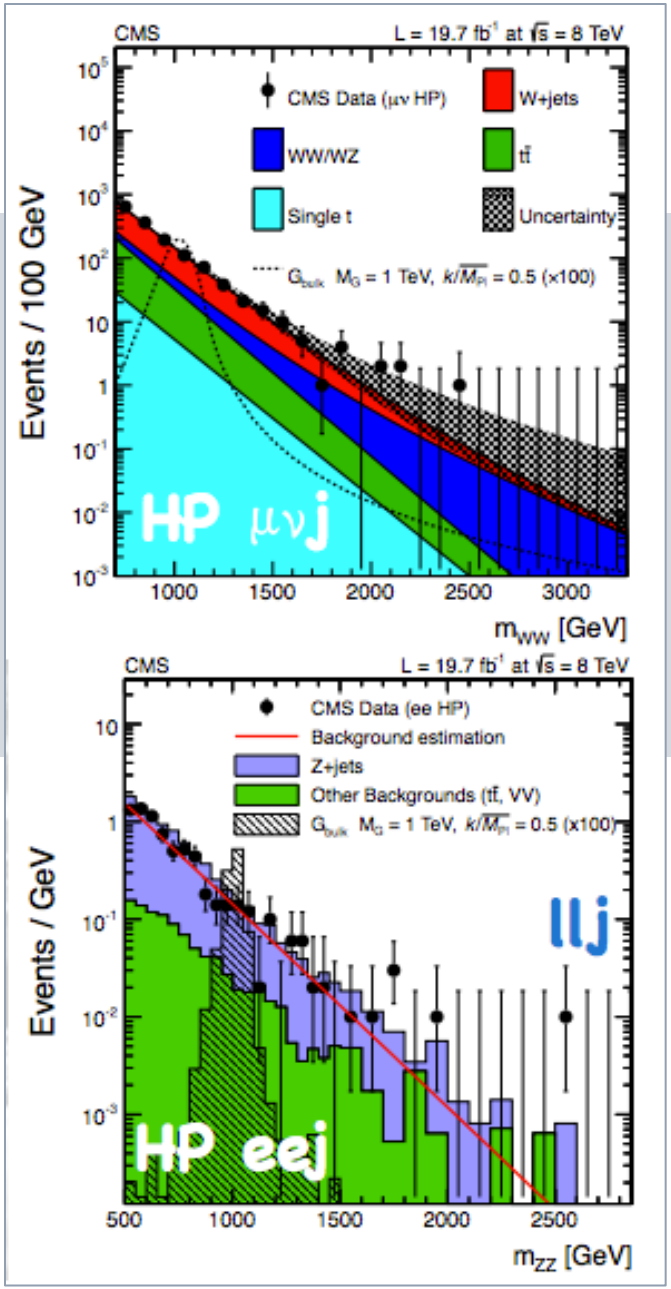
- **Improve discrimination: add leptonic decays**
  - WZ & ZZ: **llJ**
  - WZ & WW: **lvJ**
- **Analysis a la H→Z(ll)Z(qq)**
  - Mass sideband for M_{VV} shape
  - MC for interpolation
- **Validation: boosted W**
  - High-p_T tops
  - Data/sim: hadronization
    - ~5% systematics



VV
semi leptonic

V(lv)V(J)
- **Single-lepton:**
  No excess seen

V(ll)V(J)
- **Dilepton:**
  Some excess ~ 2 TeV



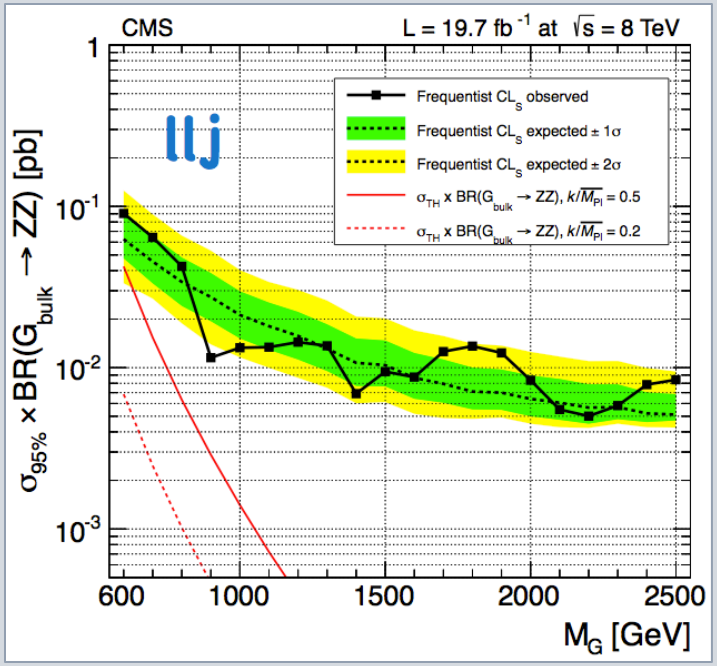
CMS EXO-13-009

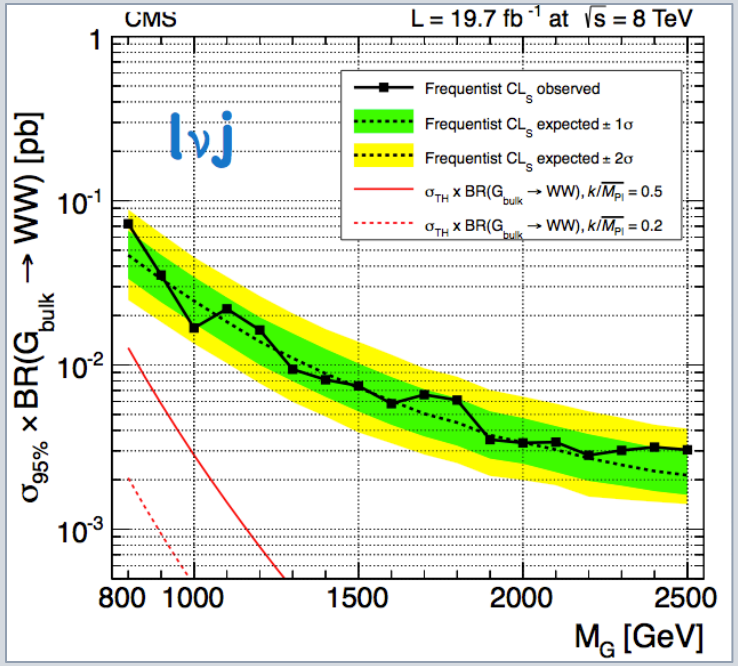
CMS EXO-12-022

VV semi-leptonic

CMS EXO-13-009

- **Some events around 1.8 TeV**



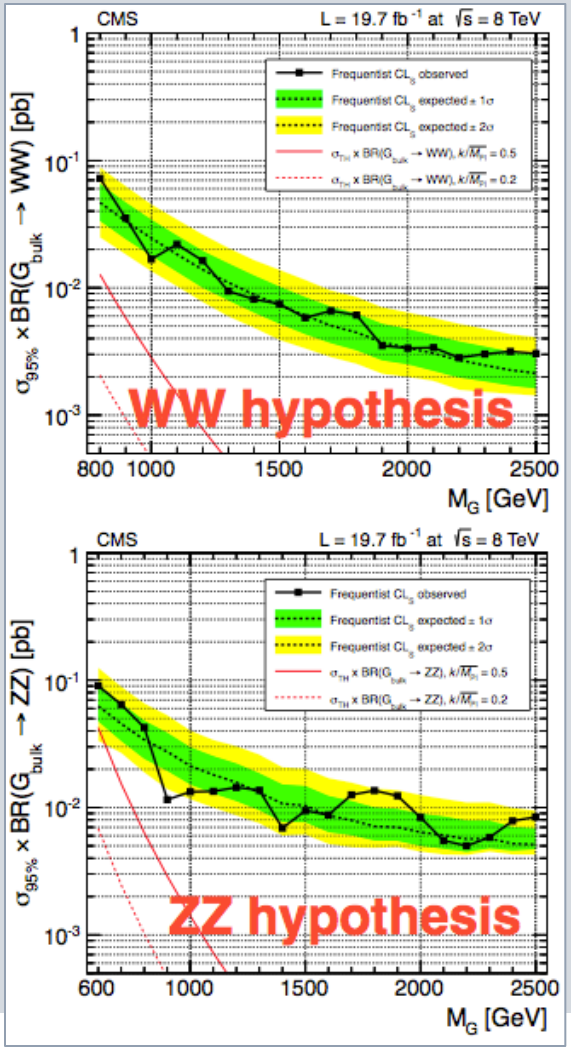


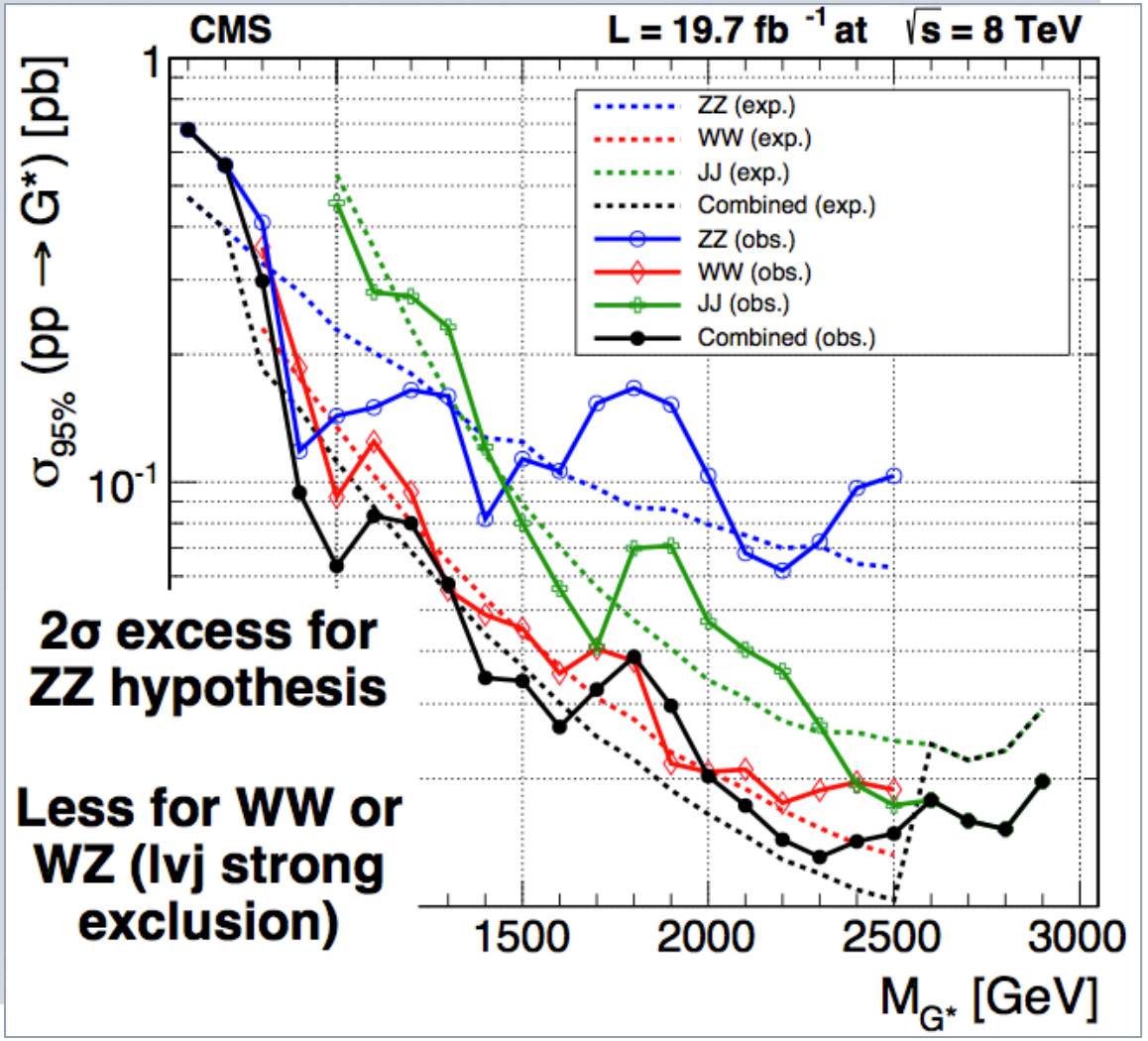
- **llJ: largest excess**
- **lνJ: would be more sensitive to VV**
  - Nothing particular in semileptonic diboson seen by Atlas [see backup]

VV: combination

Hadronic plus semi-leptonic

CMS EXO-13-009





BEYOND VV

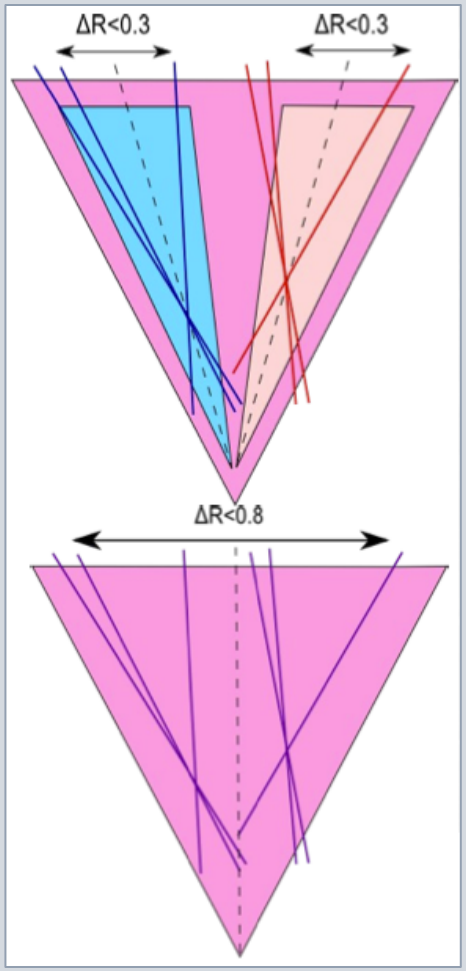
VH → ZH & WH

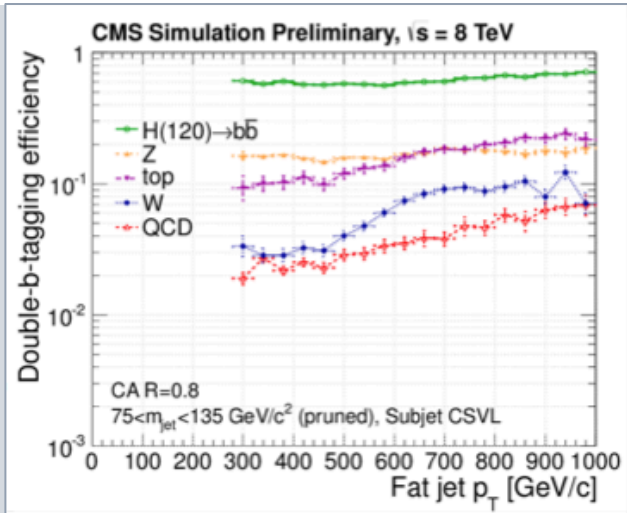
Boosted H→bb tagging

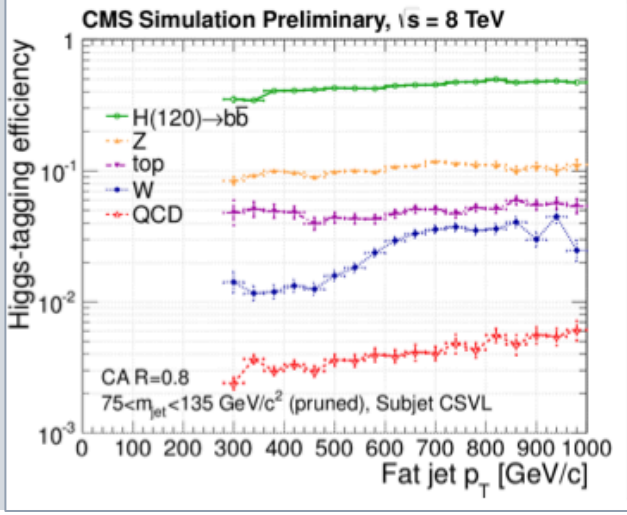
CMS BTV-13-001

1. **Subjet CSV**
   - **Two subjets** of R=0.2
   - **Standard b-tag** algorithm
   - Use Scale Factors from standard performance
   - Reject background: **2 b's in jet**
2. **Fatjet CSV**
   - Standard b-tag algorithm applied on fat jet
   - No need to resolve subjets

- **Improvements in Run-2**
  - A.o. Louvain!



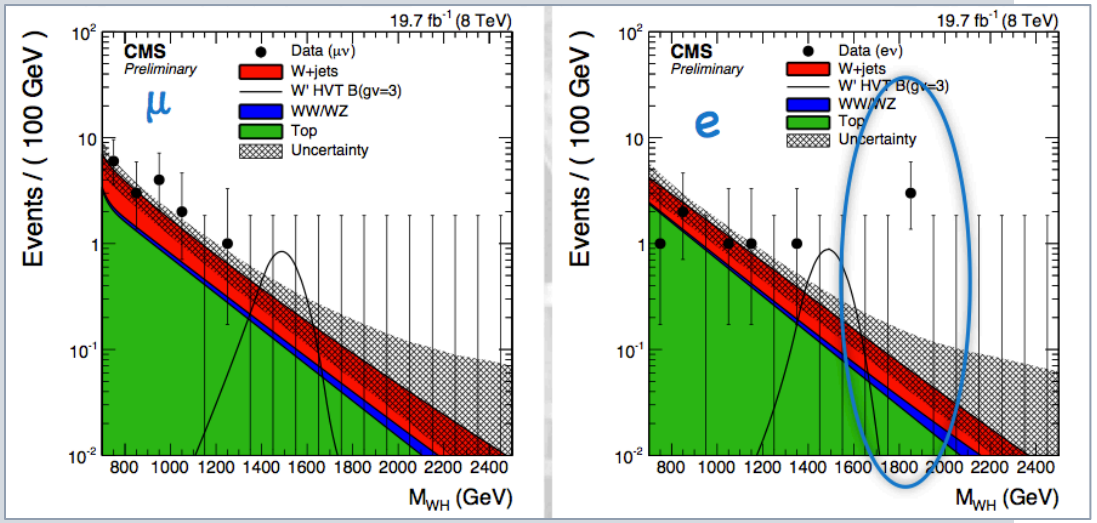


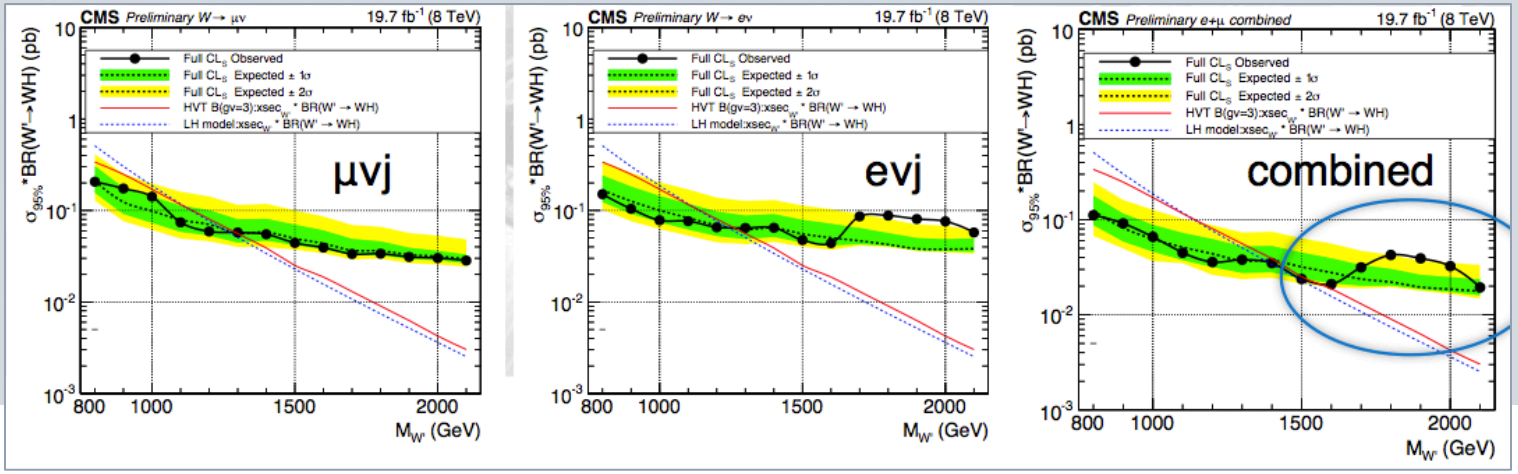


X→H(bb)W(lv)

CMS EXO-14-010

- **Strategy as V(qq)W(lv)**
  - b-tagging → **better S/B**
  - **Jet mass** ~125 GeV
    - Further suppress bkg
- **4 events at M_{WH}~1.8 TeV**
  - Nothing in muon
  - Electron: **3σ** local sign.
- **Combined: 2σ** [local]



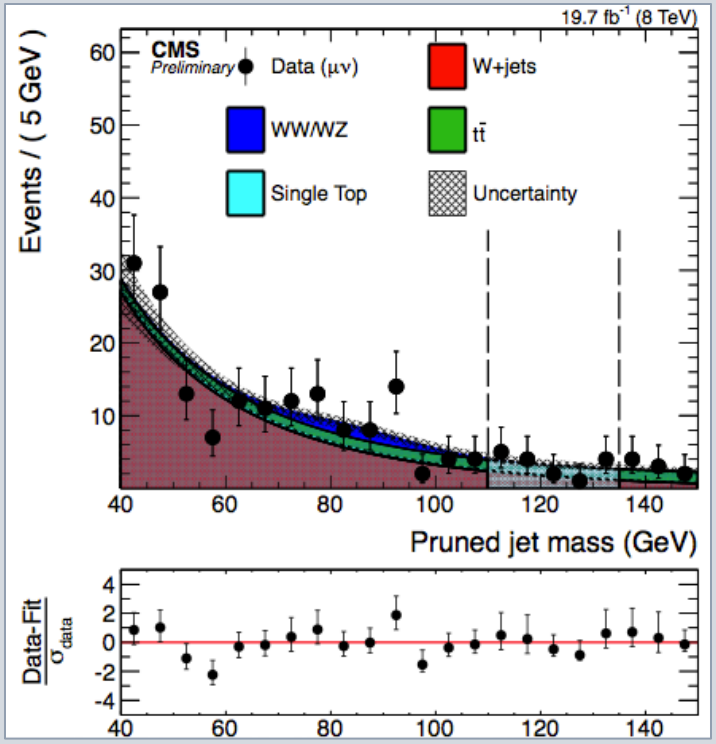


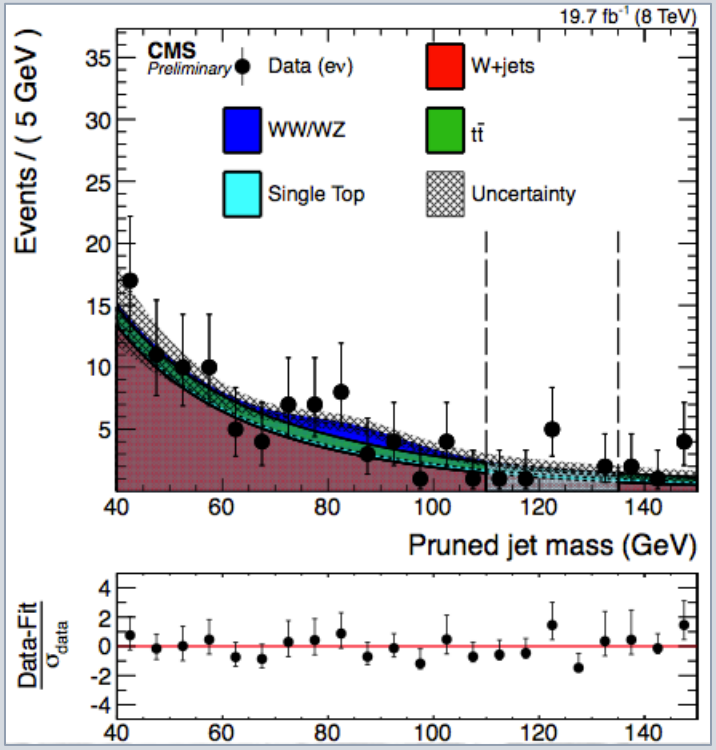
X→H(bb)W(lν)

CMS EXO-14-010

Jet mass as expected

- **Mu sample**: bkg-only
- **El sample**: events at 125 GeV

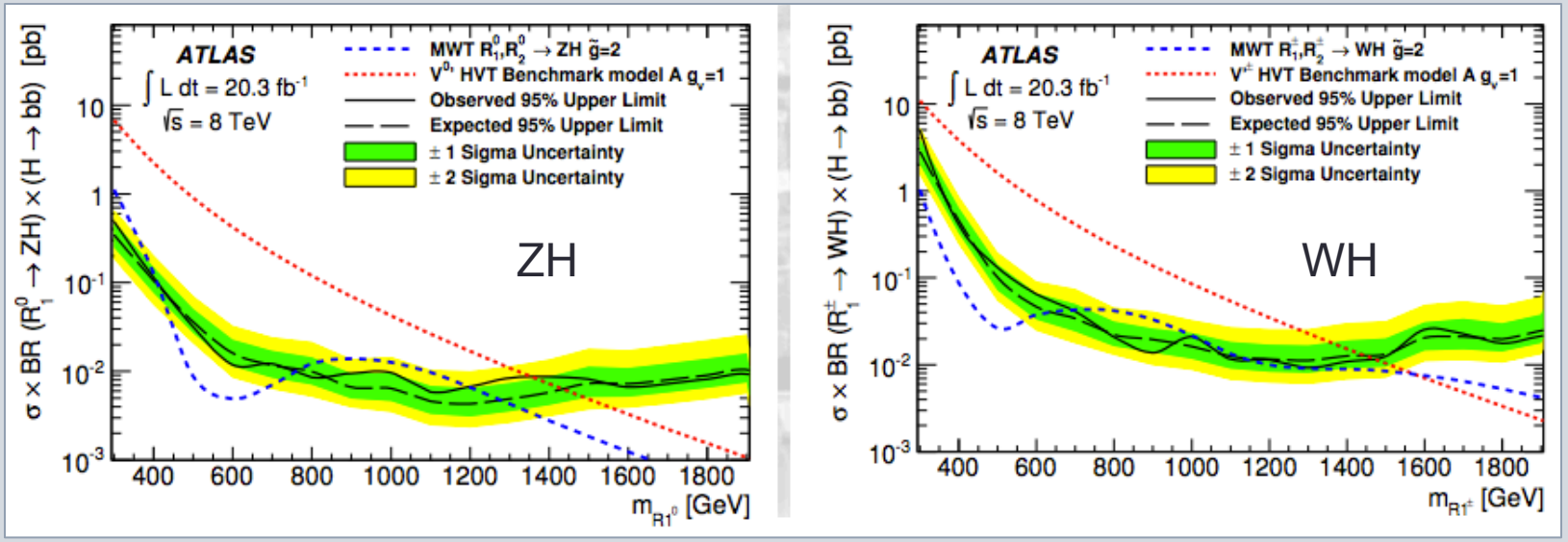




Atlas X→VH

arXiv/1503.08089

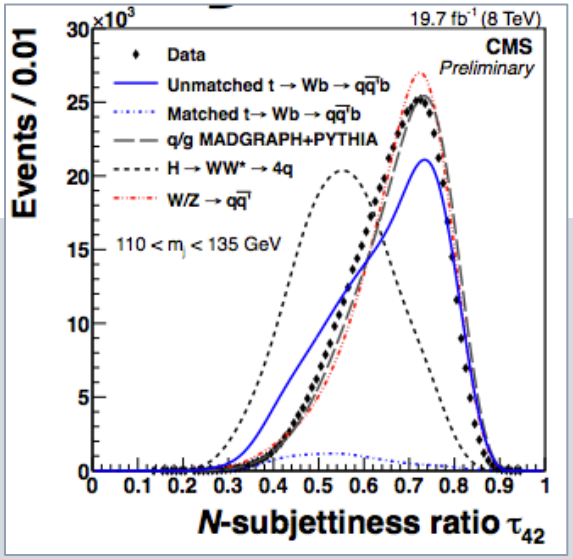
- **Atlas searches for VH with resolved H→bb**
  - Several final states: W(lv), Z(ll), Z(vv)
  - No boosted topology → dijet system
    - Anti-k_T jets, R=0.4
- **No excess at 1.8TeV**
  - Sensitivity limited at high masses

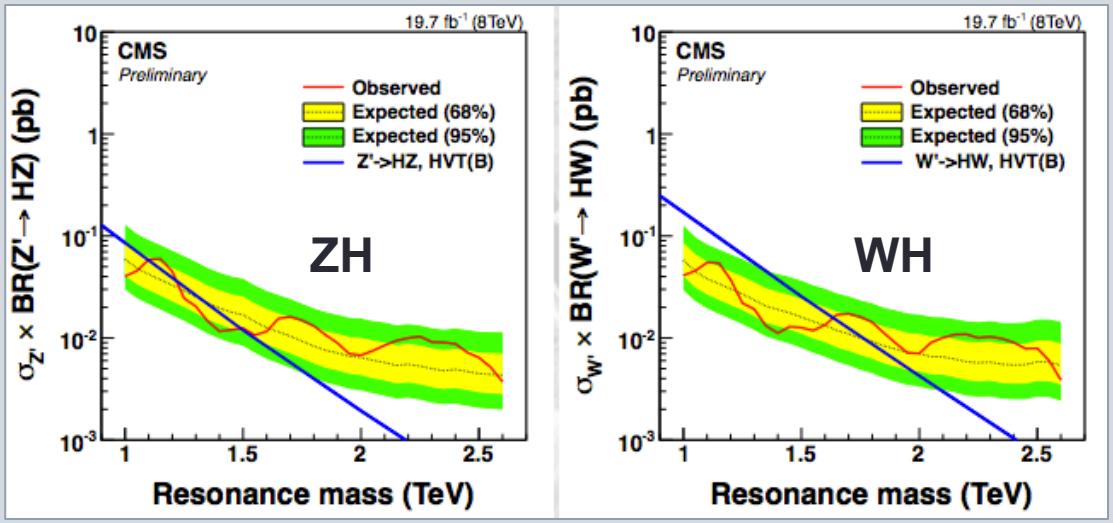


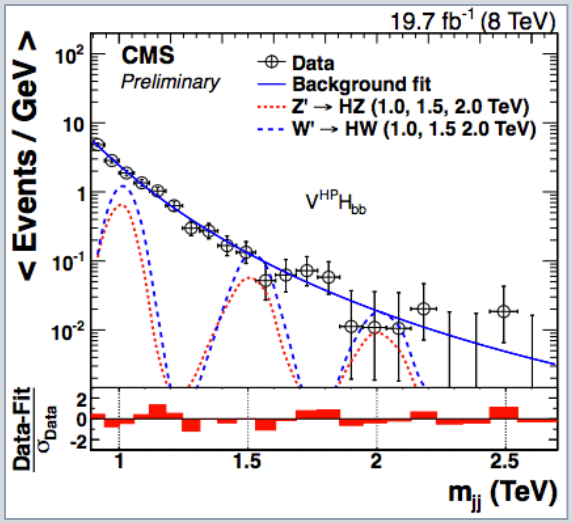
V(qq)H
CMS hadronic

- **V: Z & W**
- **H: H→bb & H→WW***
  - WW*: 4 jets in a single jet → τ_{42}
- **WH&ZH: strategy as hadronic VV**
  - Combine, assuming SM H BR's

CMS EXO-14-009







- **Also done: H→ττ. Boosted taus** [CMS EXO-13-007]
  - No excess, but smaller sensitivity due to BR

BEYOND VV & VH

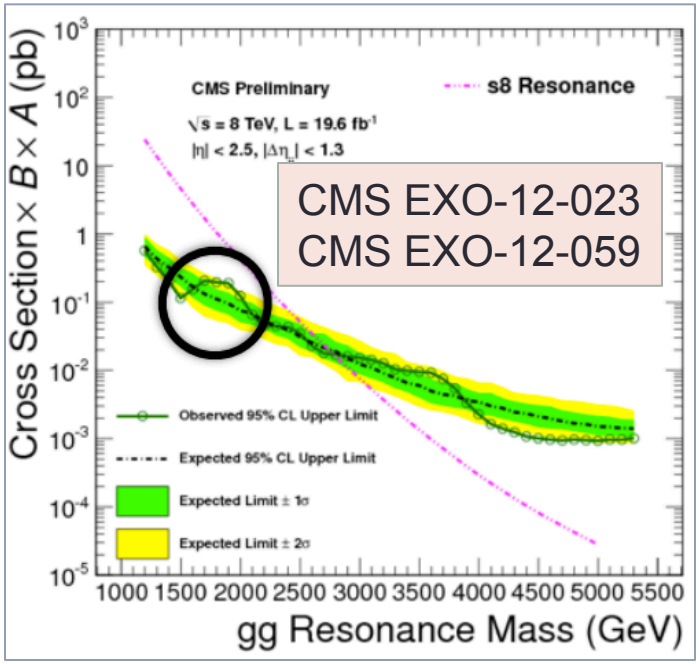
Dijet

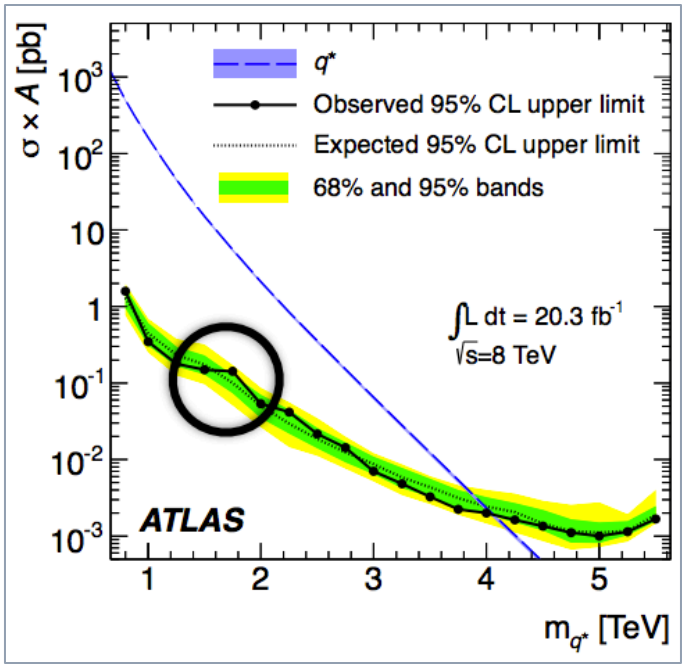
Dilepton

Ttbar

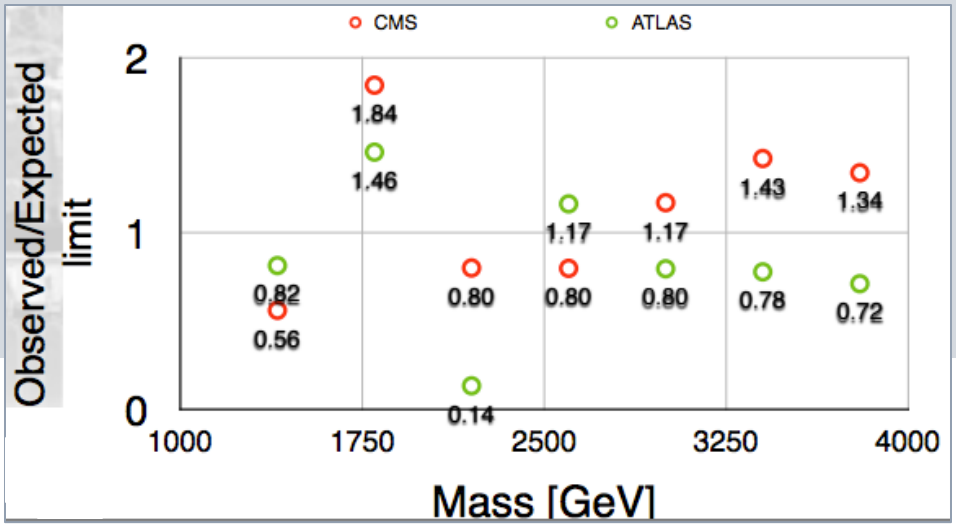
Even further: VR

Dijet

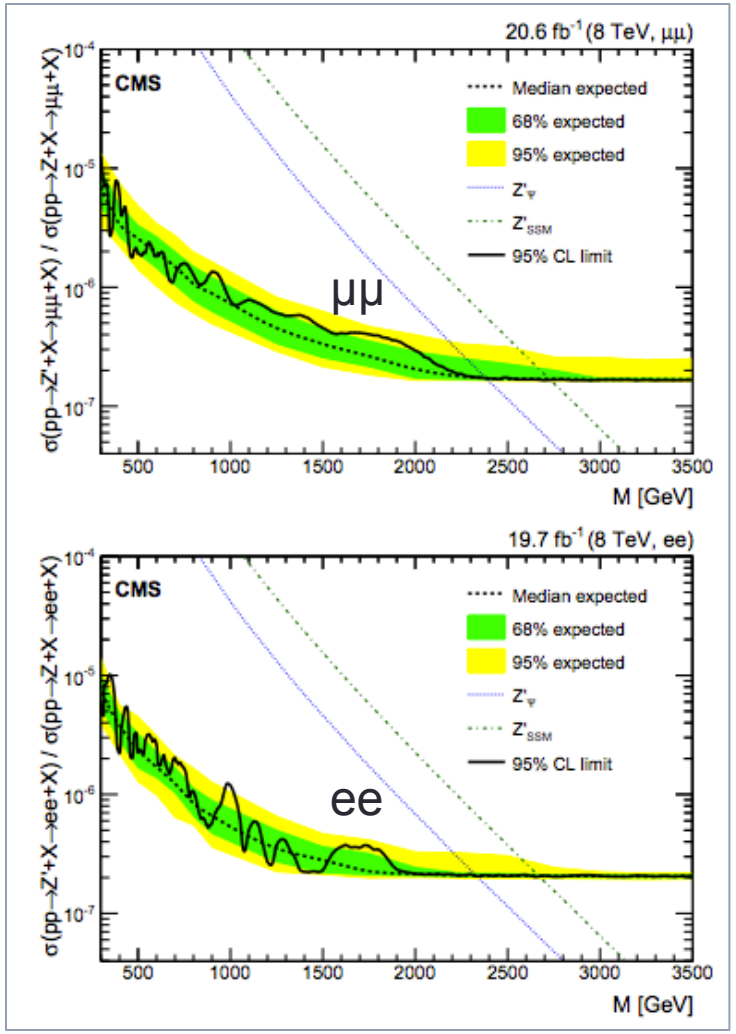




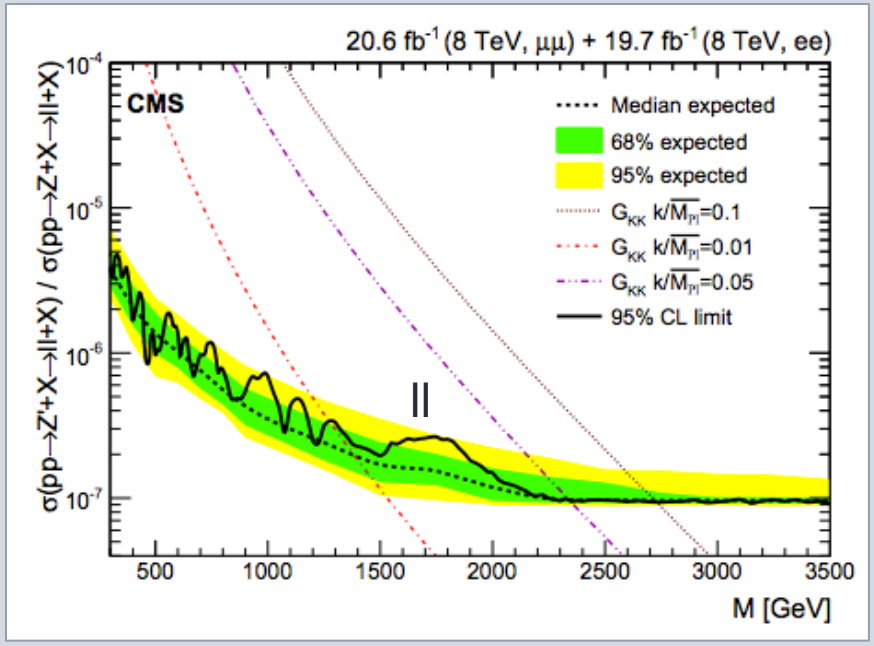
- **Atlas**: not much
- **CMS**: 2 sigma (local)
- **Only place** where both have excess



Dilepton

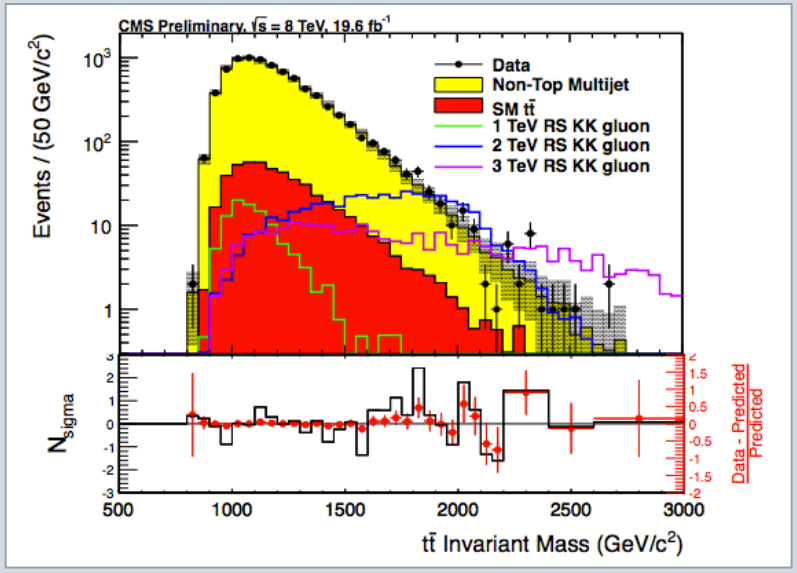


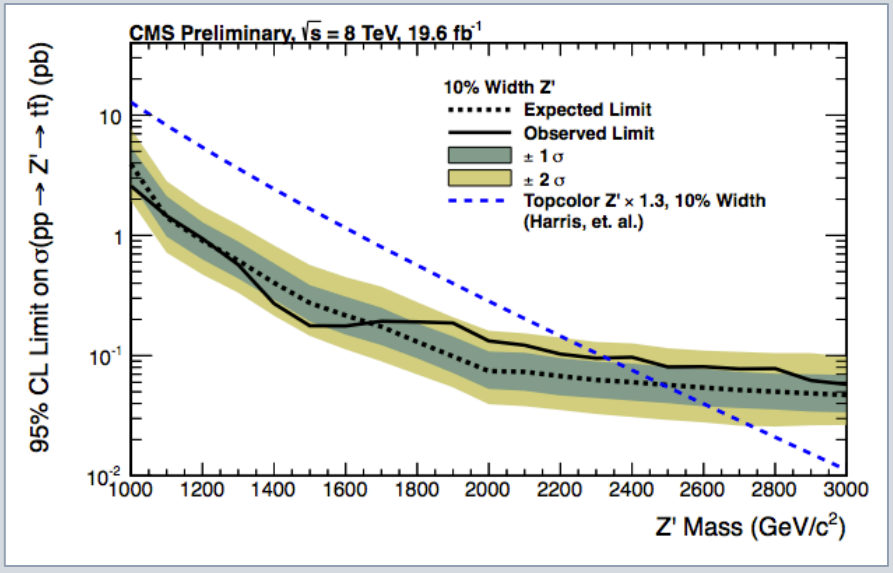
- **CMS sees excess at same mass in dilepton spectrum**
  - Not significant (also), but interesting in the full picture



ttbar

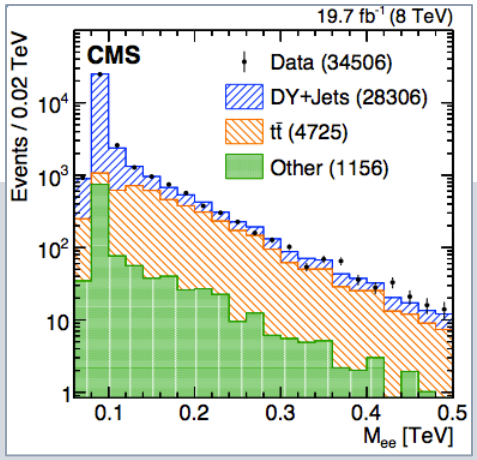
- **Z'→ttbar**
  - ttbar also relevant for high-mass Z' searches
  - Tagging of boosted tops important
  - No deficit

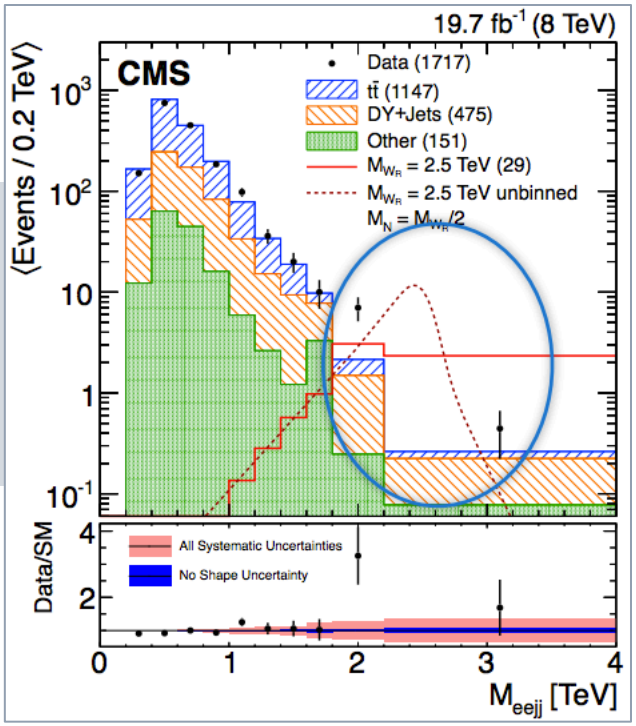


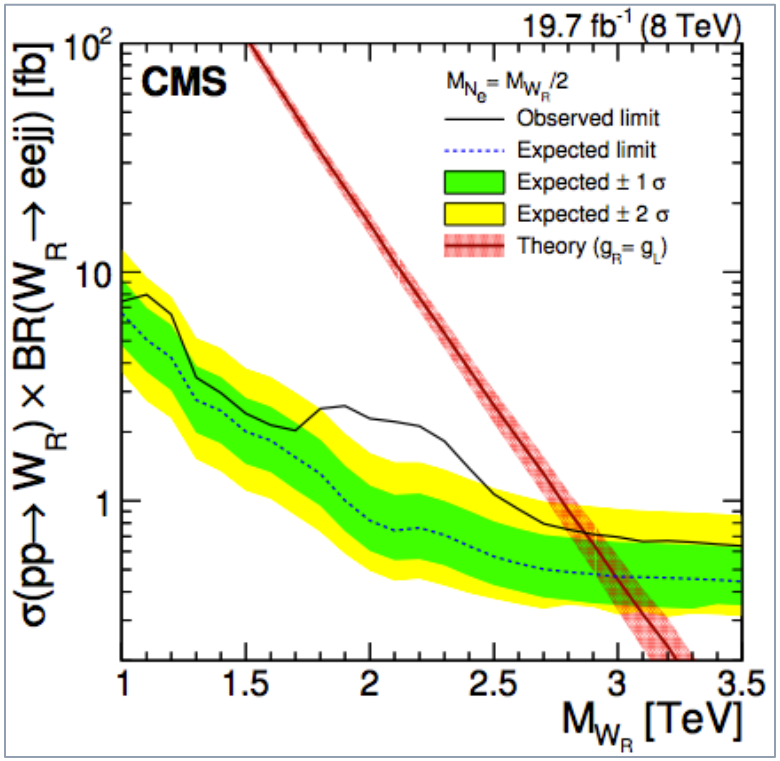


V_R

- **Search for $W_R \rightarrow l\nu_R$**
  - $\nu_R \rightarrow llq$
  - OS&SF leptons
  - Mll non-resonant



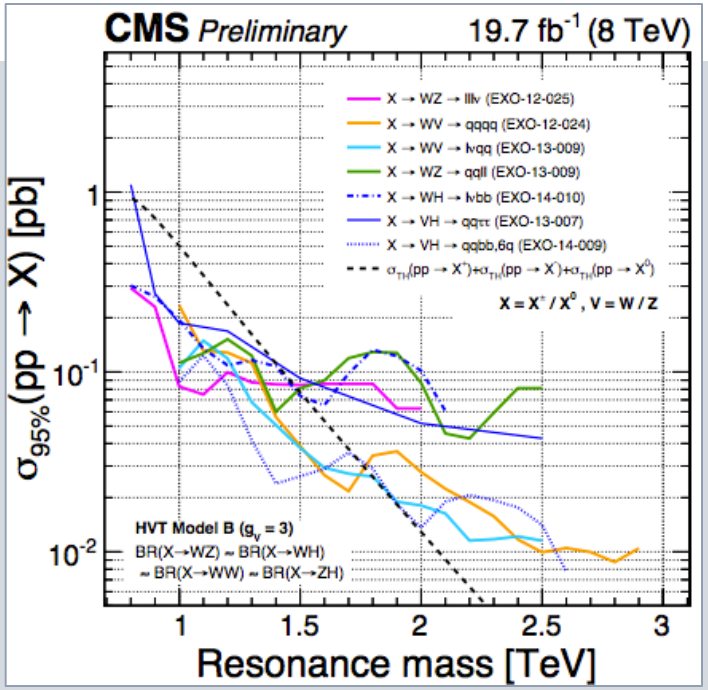




- **Excess 2.8 sigma** [local]
  - Electron channel only
  - Limit derived with M_v=1/2M_{WR}
  - Similar region as VV excesses

Conclusions

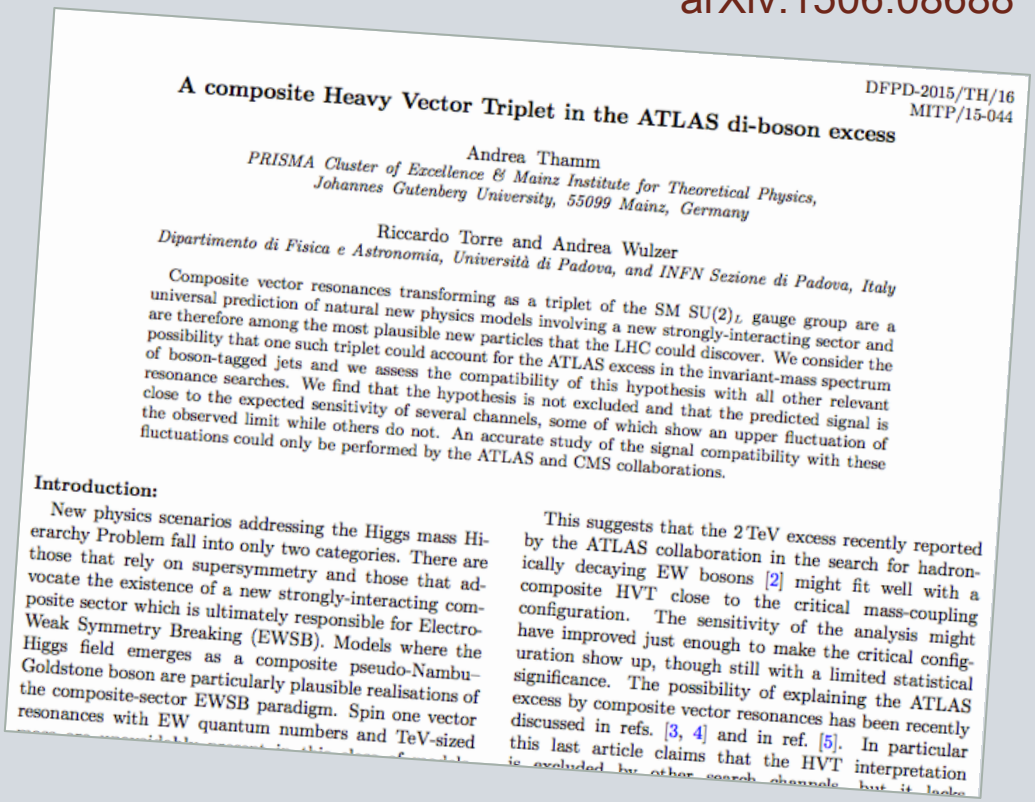
EXO-14-010



- **Hints in various channels around 1.8 TeV**
  - VV
  - VH
  - Others
  - Atlas + CMS
  - Hadronic + leptonic
- **Each excess not significant** [LEE]
- **But combination seems interesting**
- **Room for theorists & outlook for Run-2!** [see last 2 pages]

HVT

arXiv:1506.08688



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MITP/15-044

A composite Heavy Vector Triplet in the ATLAS di-boson excess

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Composite vector resonances transforming as a triplet of the SM $SU(2)_L$ gauge group are a universal prediction of natural new physics models involving a new strongly-interacting sector and are therefore among the most plausible new particles that the LHC could discover. We consider the possibility that one such triplet could account for the ATLAS excess in the invariant-mass spectrum of boson-tagged jets and we assess the compatibility of this hypothesis with all other relevant resonance searches. We find that the hypothesis is not excluded and that the predicted signal is close to the expected sensitivity of several channels, some of which show an upper fluctuation of the observed limit while others do not. An accurate study of the signal compatibility with these fluctuations could only be performed by the ATLAS and CMS collaborations.

Introduction:

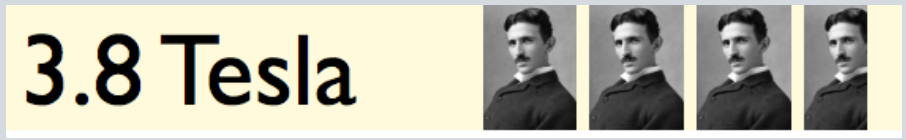
New physics scenarios addressing the Higgs mass Hierarchy Problem fall into only two categories. There are those that rely on supersymmetry and those that advocate the existence of a new strongly-interacting composite sector which is ultimately responsible for Electro-Weak Symmetry Breaking (EWSB). Models where the Higgs field emerges as a composite pseudo-Nambu–Goldstone boson are particularly plausible realisations of the composite-sector EWSB paradigm. Spin one vector resonances with EW quantum numbers and TeV-sized

This suggests that the 2 TeV excess recently reported by the ATLAS collaboration in the search for hadronically decaying EW bosons [2] might fit well with a composite HVT close to the critical mass-coupling configuration. The sensitivity of the analysis might have improved just enough to make the critical configuration show up, though still with a limited statistical significance. The possibility of explaining the ATLAS excess by composite vector resonances has been recently discussed in refs. [3, 4] and in ref. [5]. In particular this last article claims that the HVT interpretation

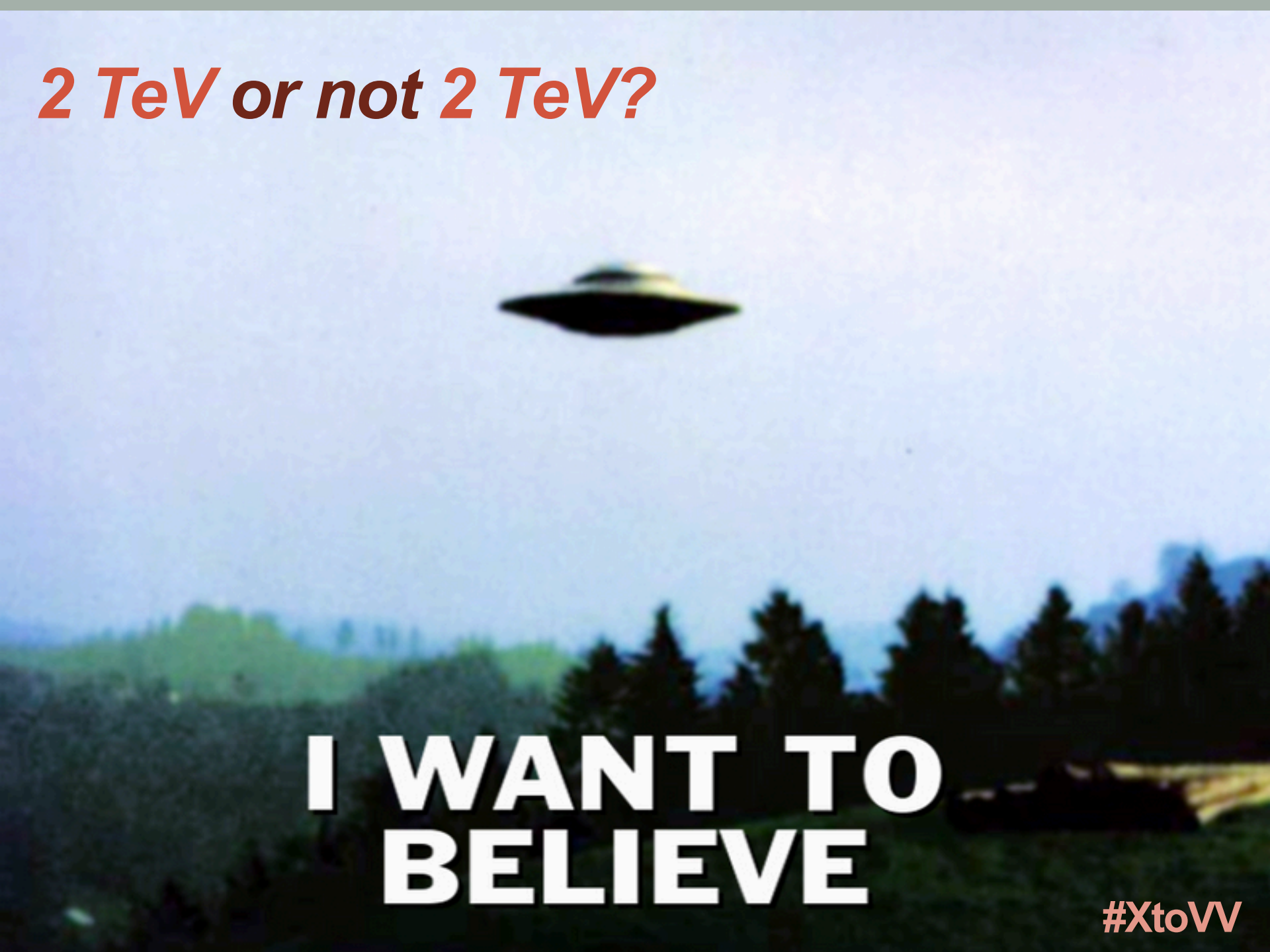
- **Not to mention all B-physics observables**
  - Kμμ/Kee, K*μμ, ϕμμ, final states with τ's. etc…

Run-2 outlook

- **Substructure methods**
  - CMS: many developments
  - Atlas: PF?
  - **Boosted H→bb** [Louvain]
- **Signal hypotheses**
  - E.g. W polarization
  - Relevant for analysis strategy
- **Include more VV & VH**
  - Uncovered final states
  - Add e.g. **X→Z(ll)H(bb)** and **X→Z(vv)H(bb)**
- **13 TeV: expect sensitivity already with ~3fb^{-1}**
- **Something in your final state?**
  - **Dark Matter**: possibilities for 2 TeV mediator? See tomorrow!



2 TeV or not 2 TeV?



#XtoVV