# Signs of Hope

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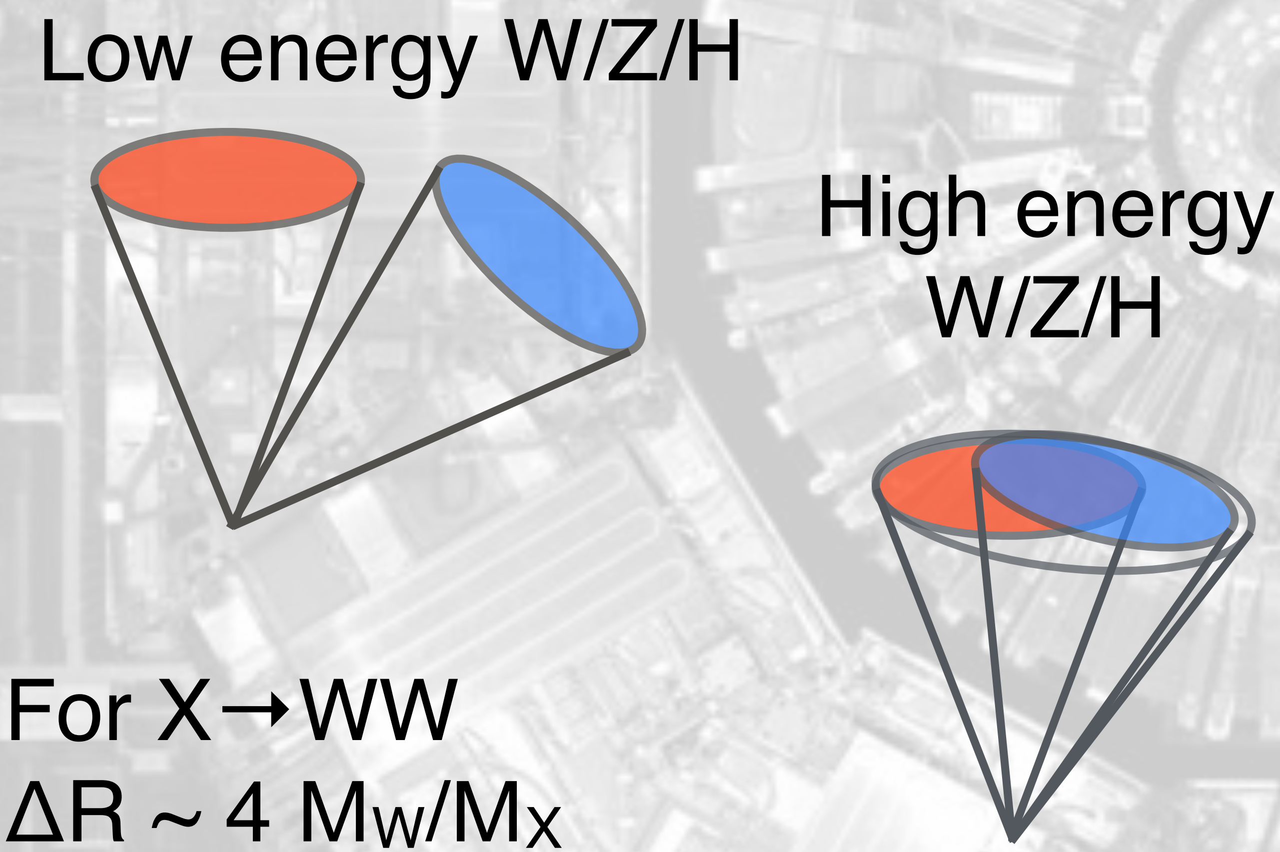
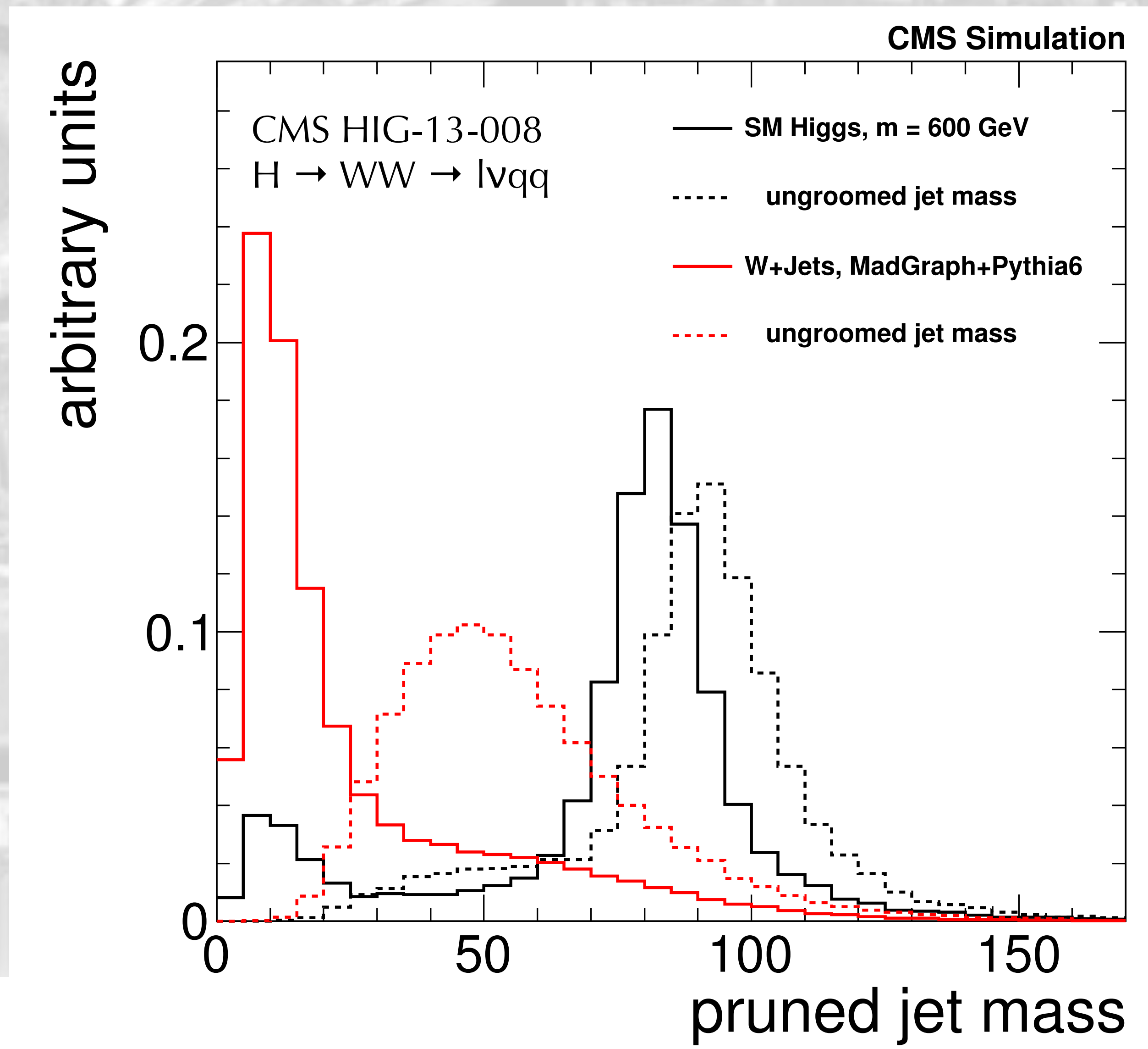
**CERN**

# A new front: boosted jets

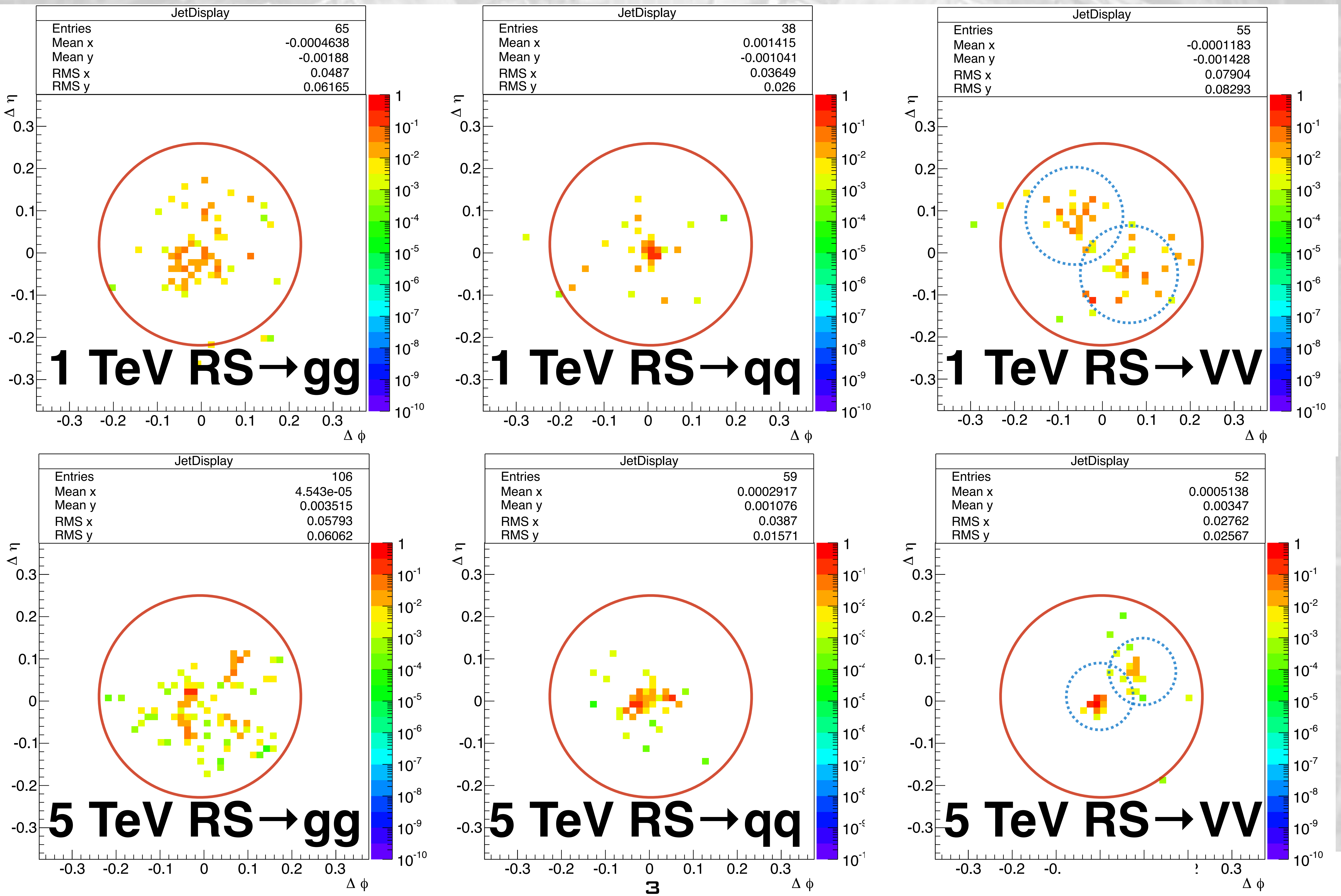
- W, Z, and H bosons can decay to 2q final states, giving normally 2 jets
- For large enough $p_T$, the decay products might merge into a single jet
- These jets are special: the mass of the jet peaks at the "right" value (unlike QCD jets, for which large mass values are generated by QCD)




For $X \to WW$
$\Delta R \sim 4\, M_W/M_X$
(to be compared with jet size R)



# Jet Substructure



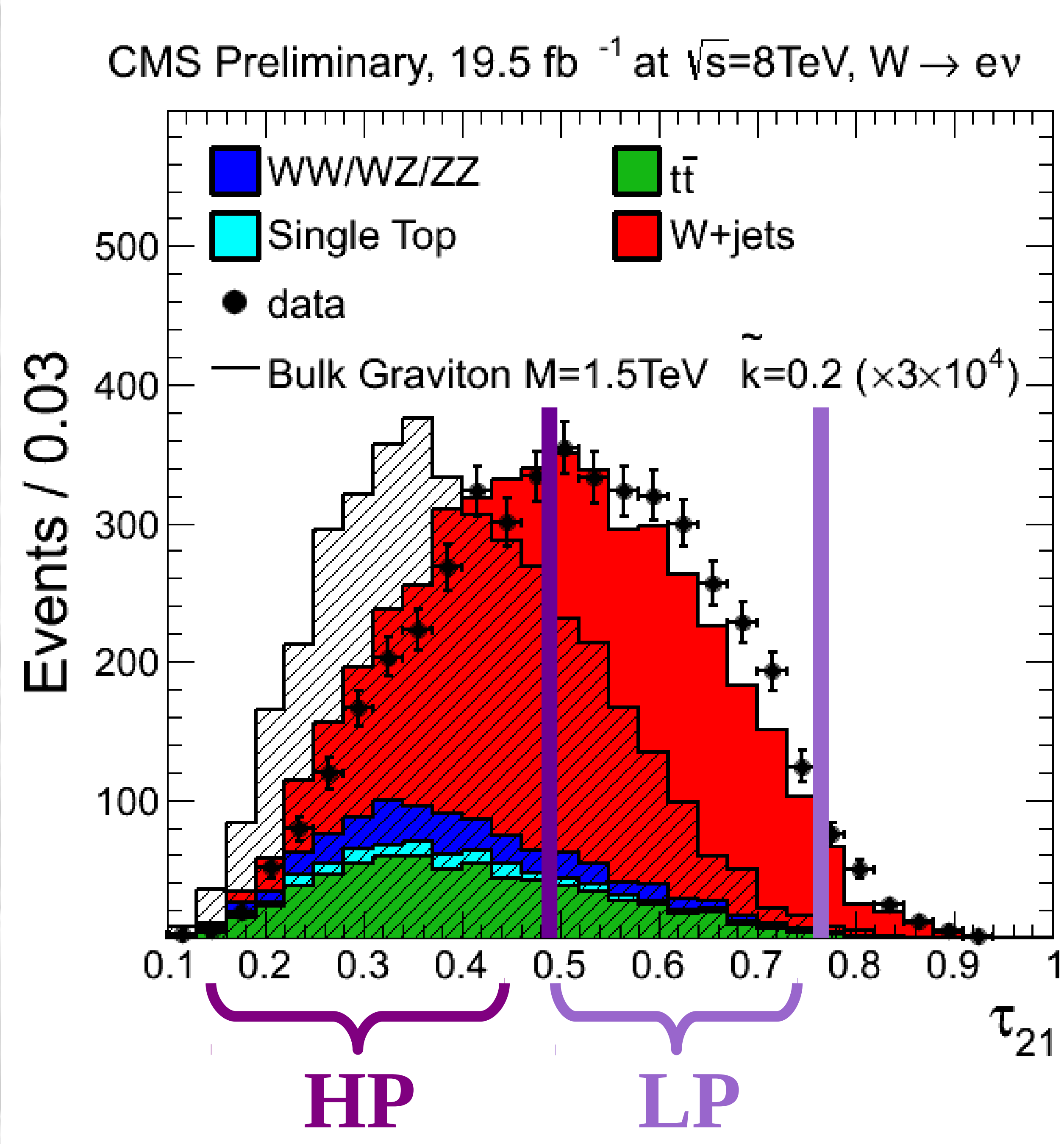
# Jet Substructure in CMS

- N-subjettiness proposed to quantify how well the constituents of a jet can be arranged in N subjets

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

- Possible to compute it for several N (e.g. test 1-prong vs 2-prongs hypotheses)

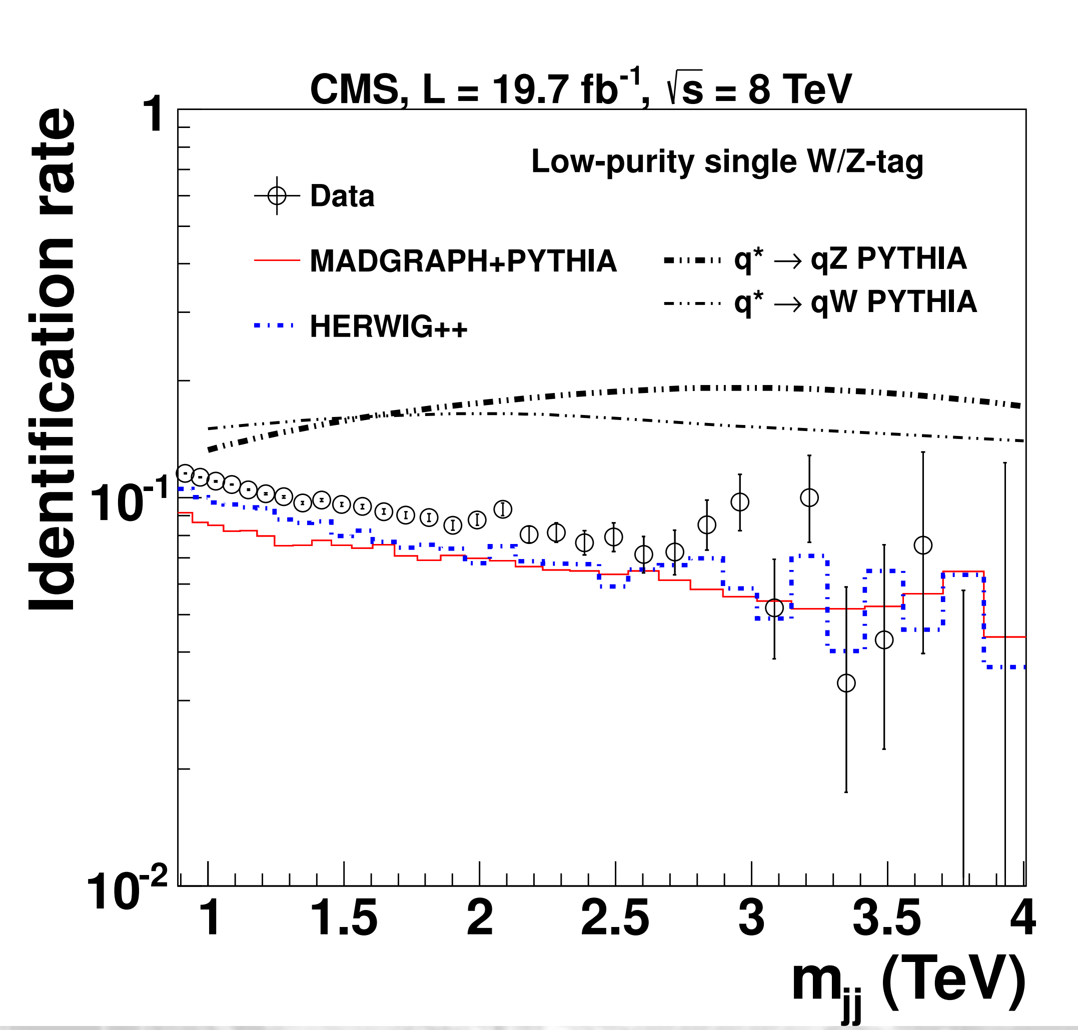
- Optimal S vs B discrimination when ratio $\tau_{21} = \tau_2/\tau_1$ is considered

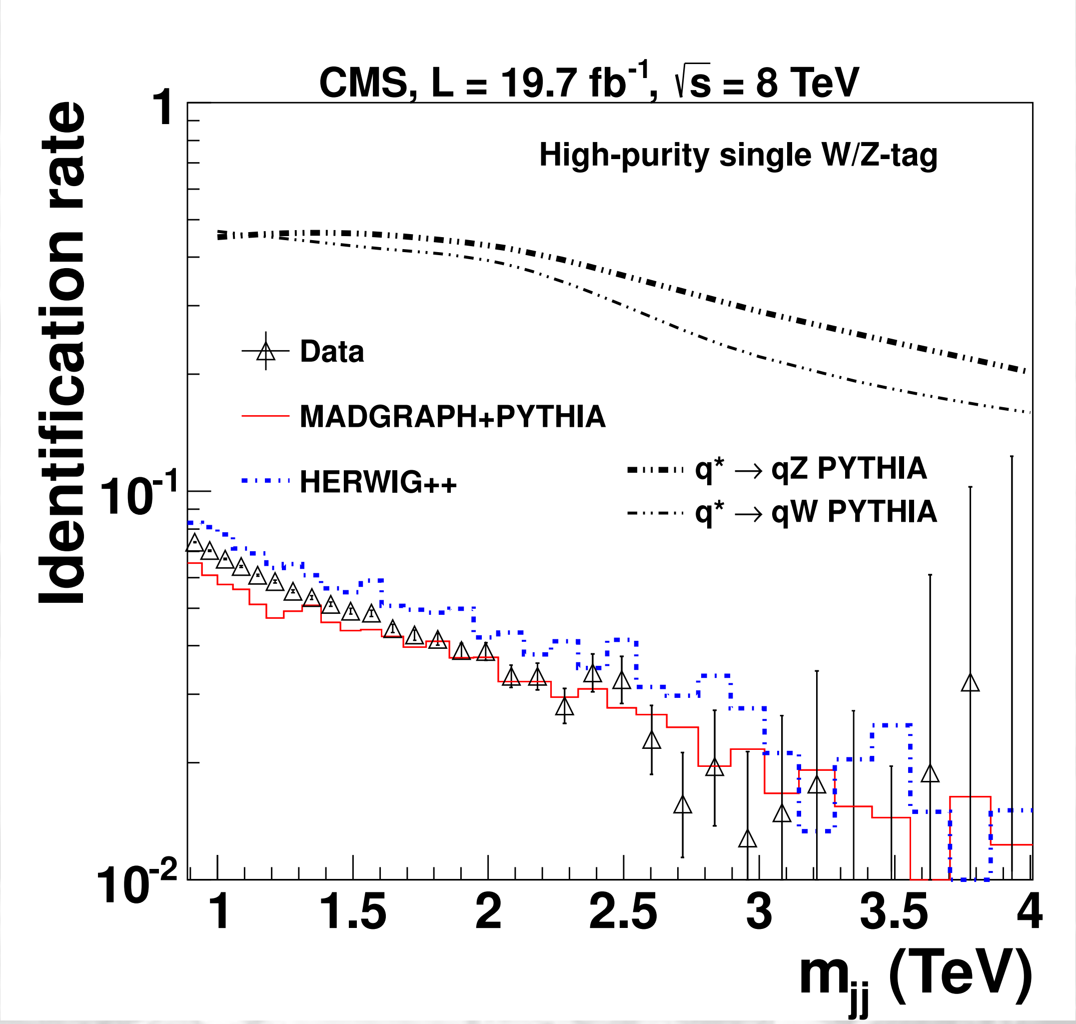



J. Thaler and K. Van Tilburg
http://arxiv.org/abs/1011.2268

# Tagging efficiency vs mistag

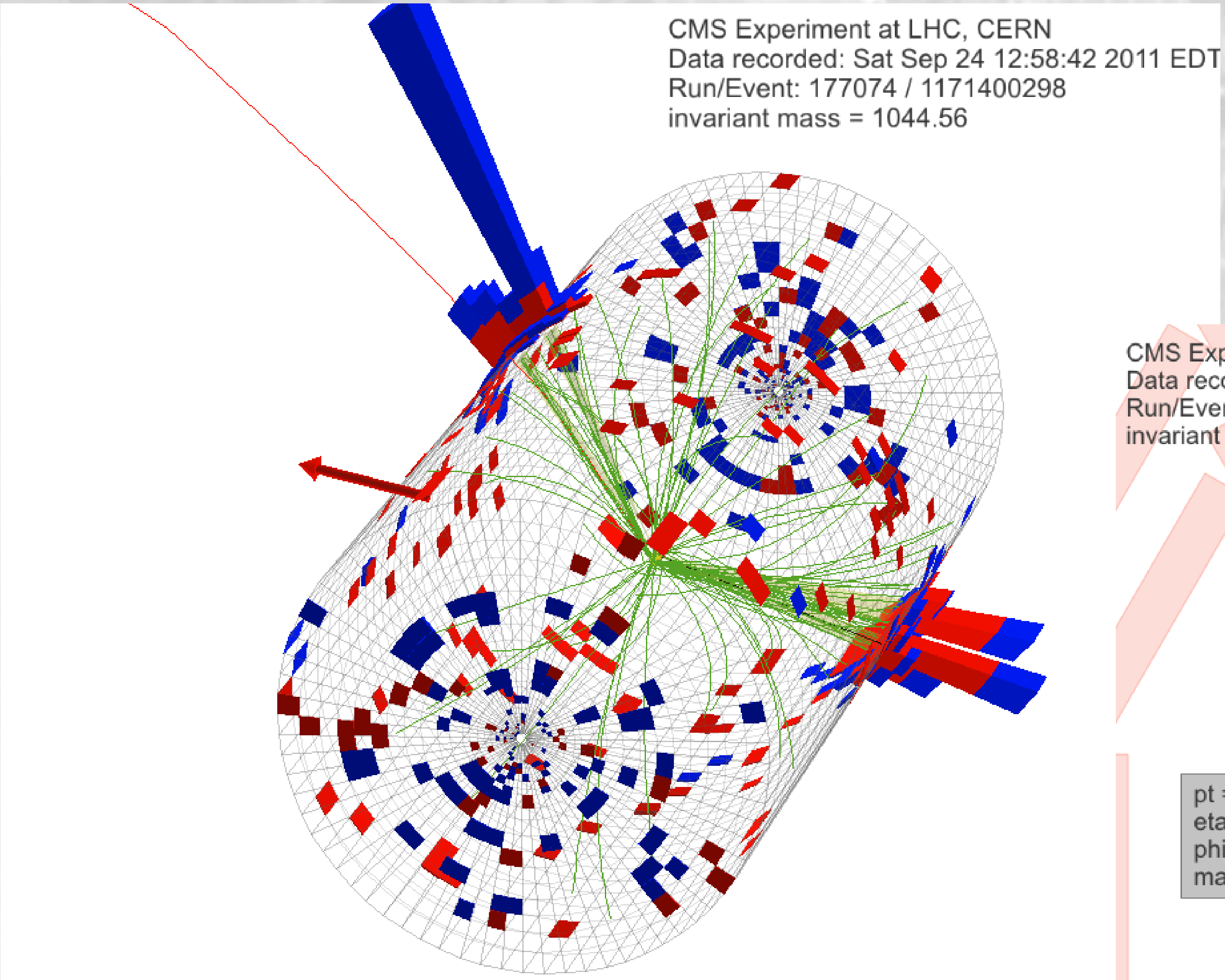
- Tagging efficiency between 20%-40%, depending on the resonance mass and the value of $\tau_{21}$
- Mistag probability below 10%, dropping quickly at large masses for HP tagged events

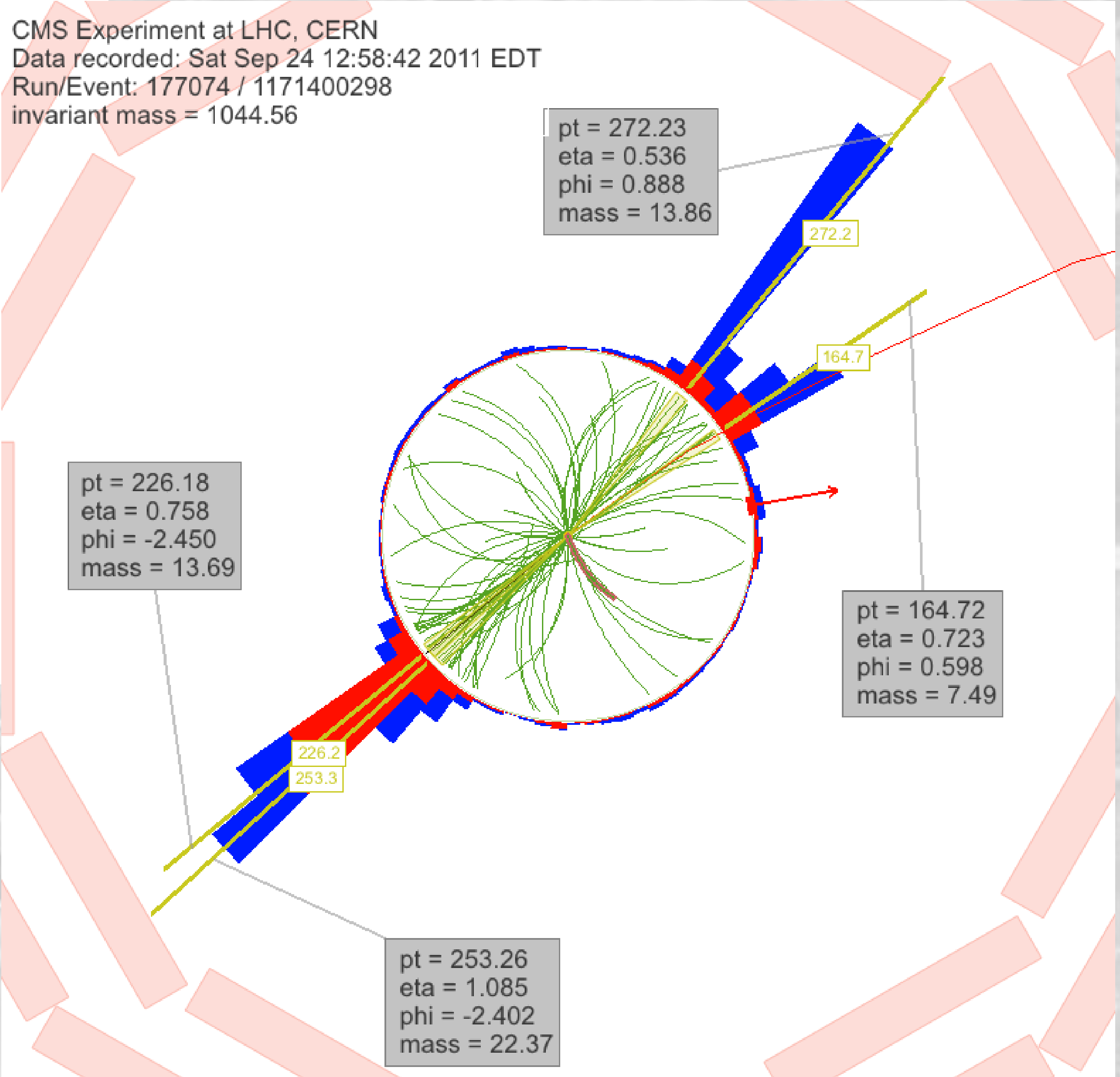



CMS-EXO-12-024

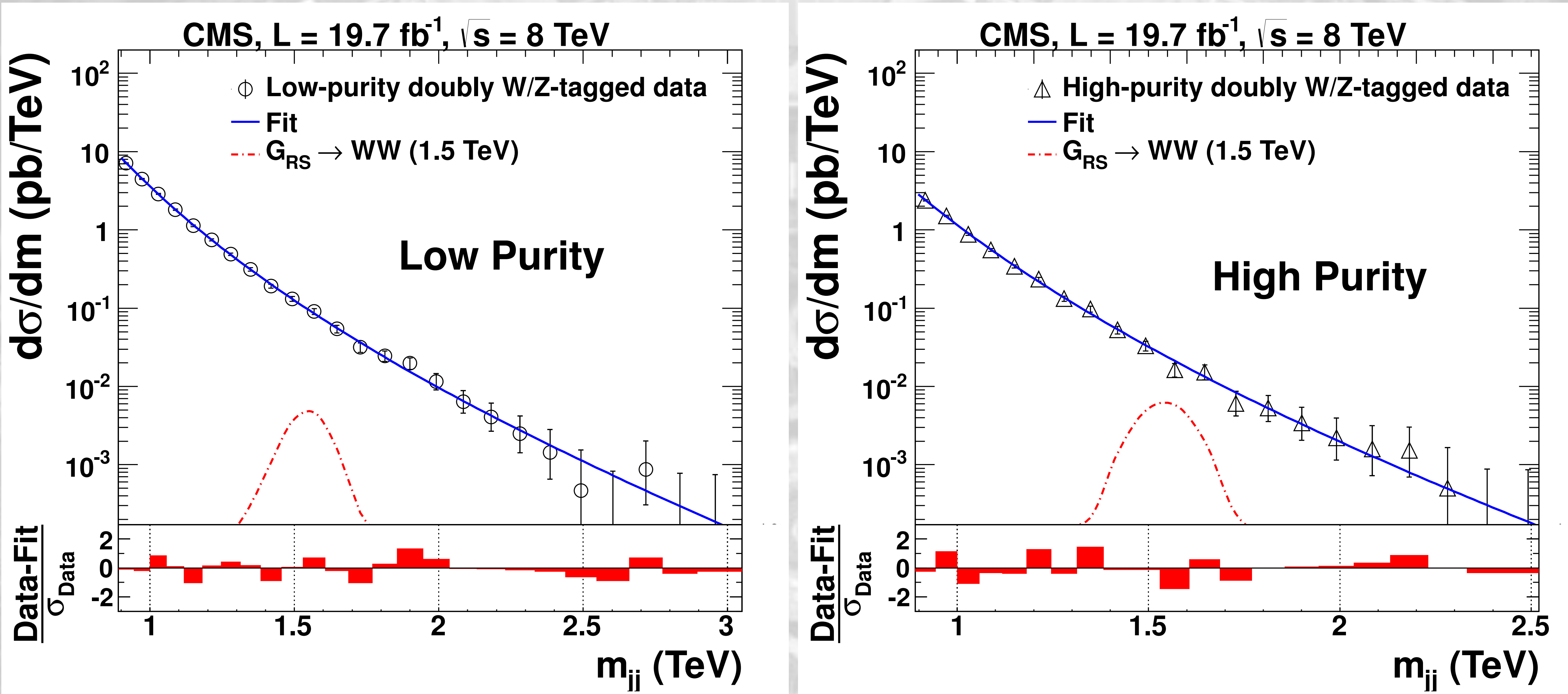
# A double-tag dijet event




CMS-EXO-11-095

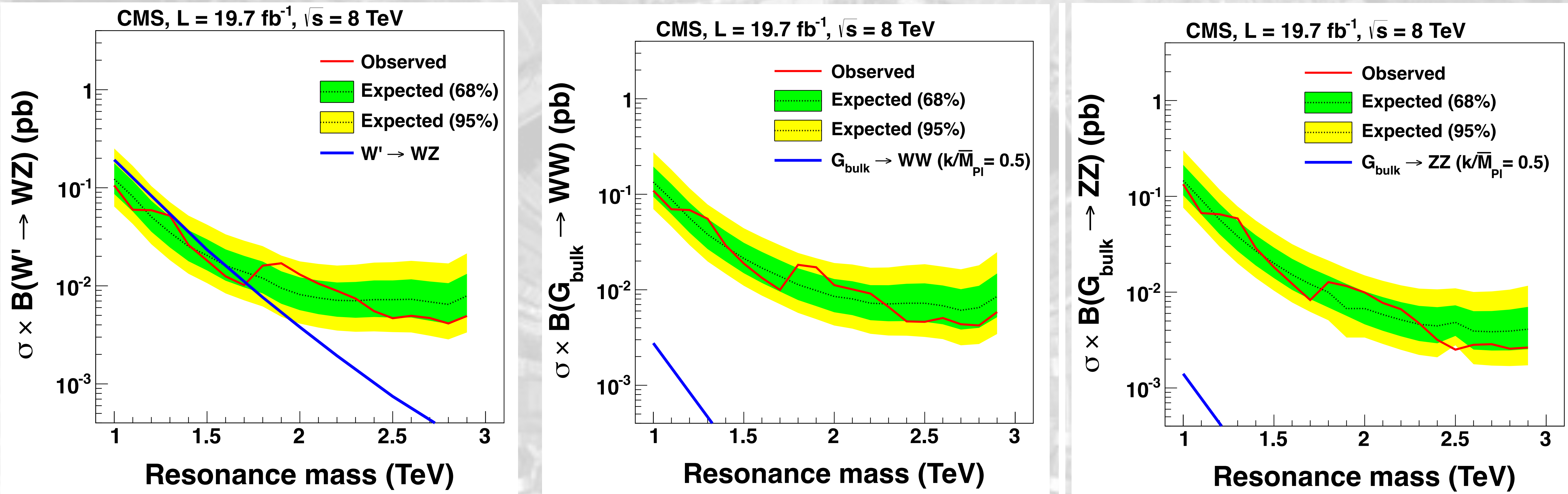
# CMS results with 8TeV data




- Two bump hunts in HP and LP samples, like "classic" dijet search
- Combined assuming the HP/LP breakdown expected for Randall-Sundrum gravitons
- Some excess seen in LP, not confirmed in HP

CMS-EXO-12-024

# CMS results with 8TeV data

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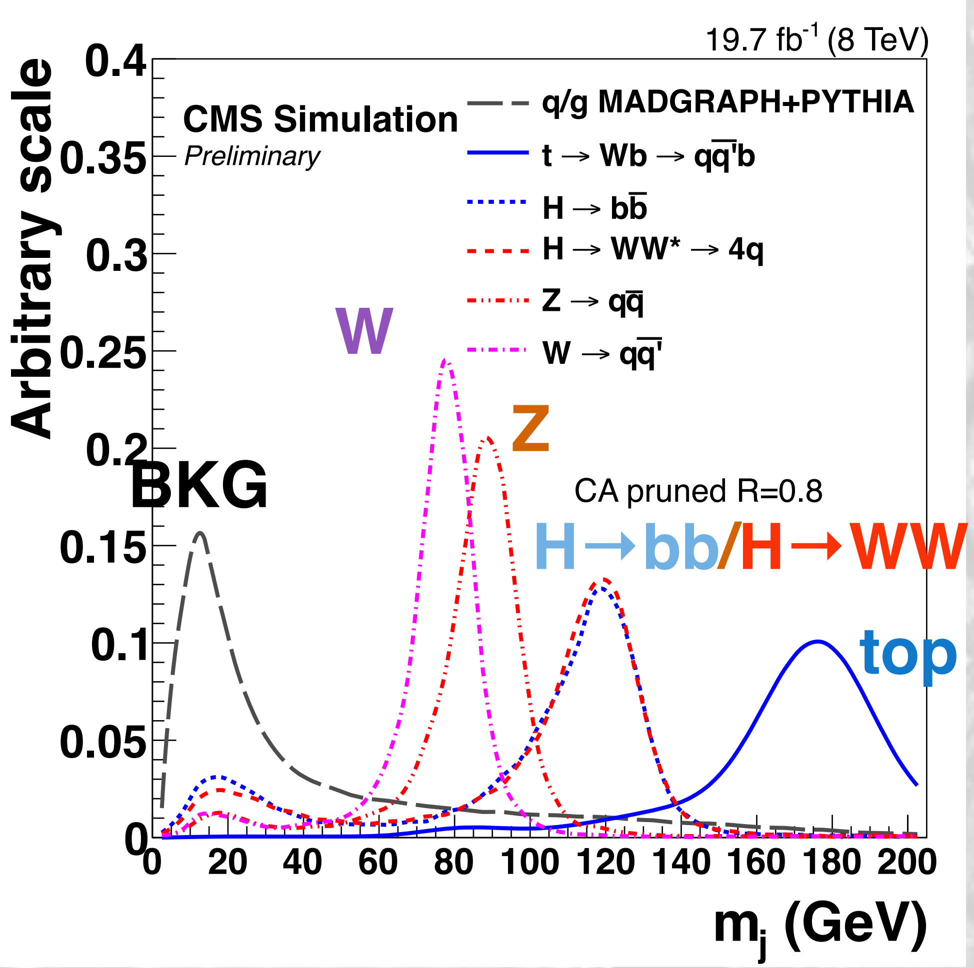
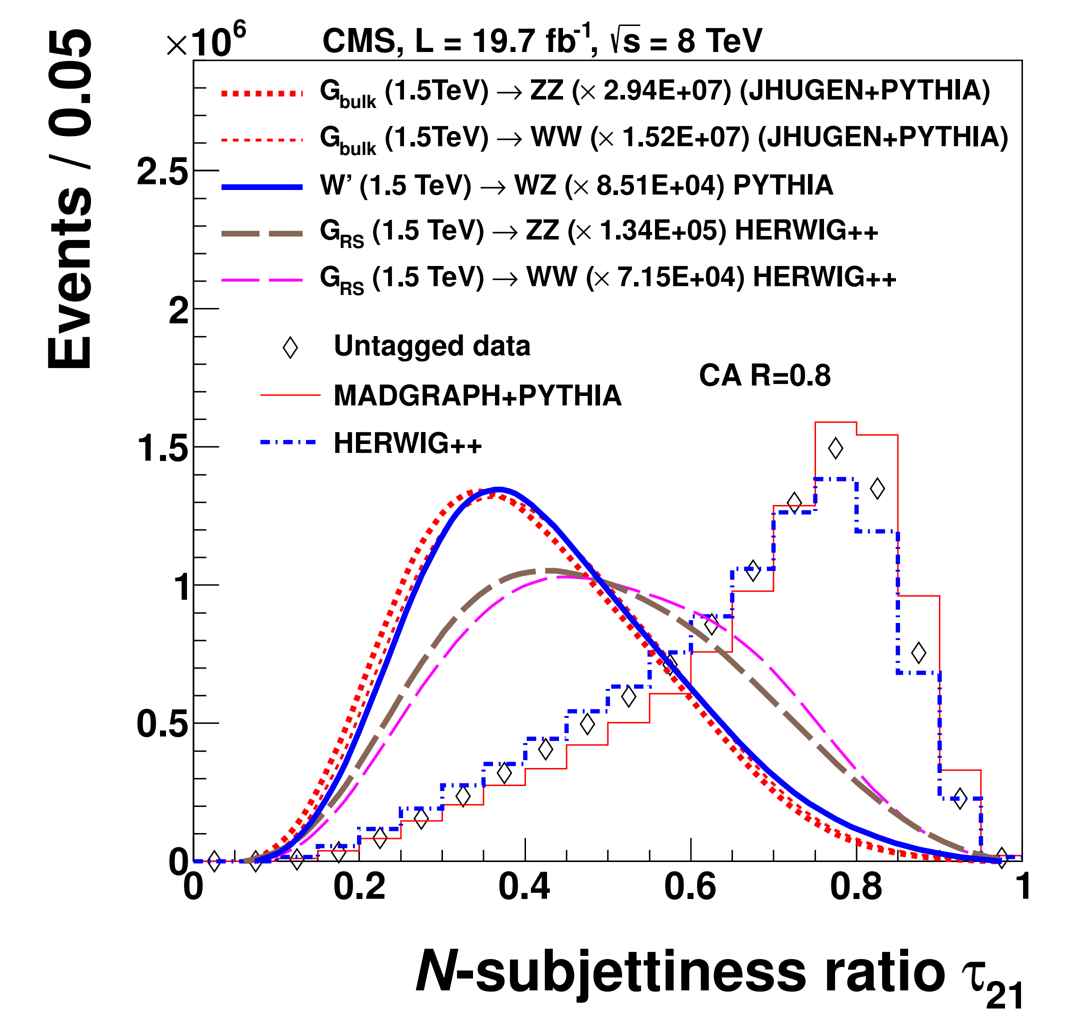
CMS-EXO-12-024

# Going beyond all-hadronic searches

# A W or a Z?

- Not possible to clearly separate Ws and Zs
  - The mass resolution is about 10 GeV ≈ W/Z mass split
  - Similar jet-substructure behavior



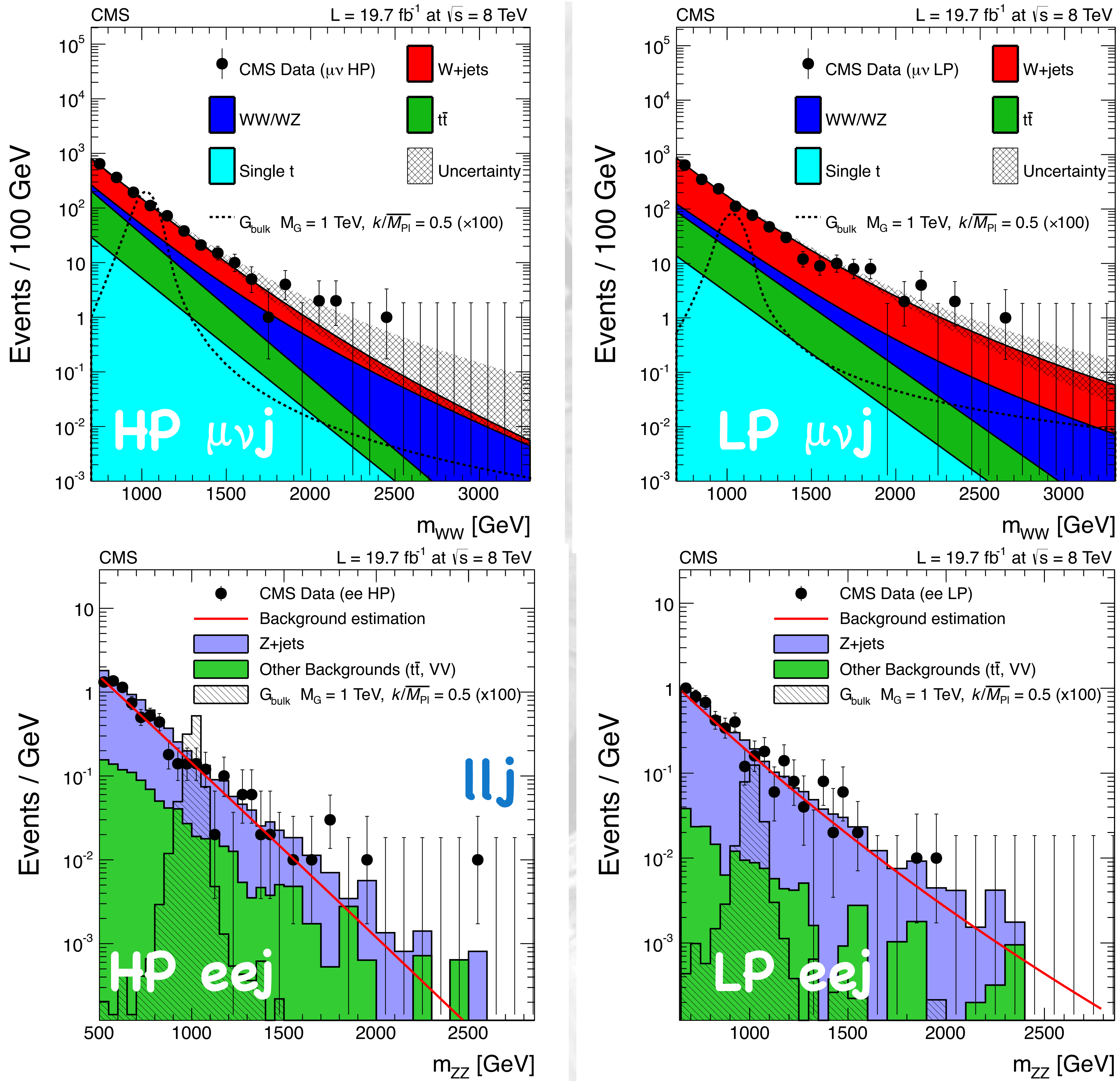




- Cannot distinguish ZZ/ZW/WW final states
- Analysis performed as bump hunt (like dijet search)
- Result interpreted under different signal hypotheses

**CMS-EXO-14-009** **CMS-EXO-12-024**

# Semileptonic Searches in CMS

- No striking excess seen
- Events found around 1800 GeV
- Yield small compared to bkg uncertainty
- Stronger in llj analysis
- Very weak in lνj analysis, which is the most sensitive to a VV signal




CMS-EXO-13-009

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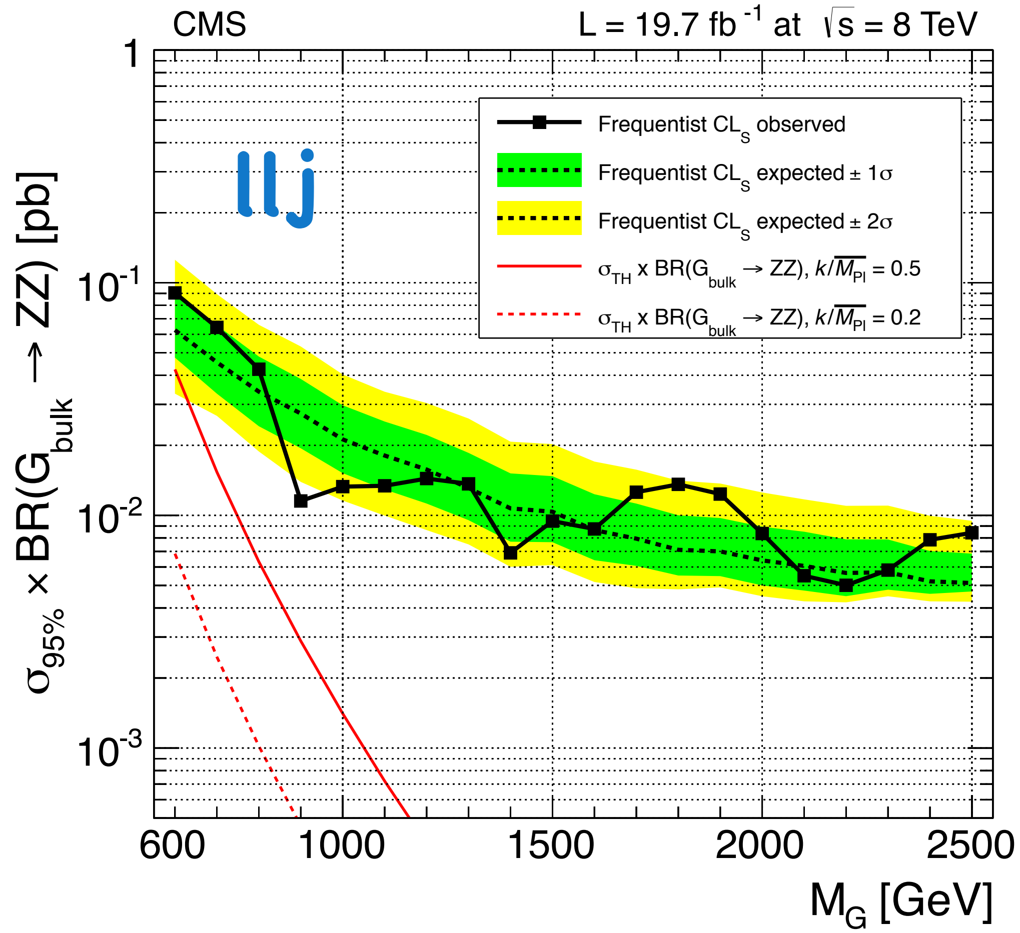
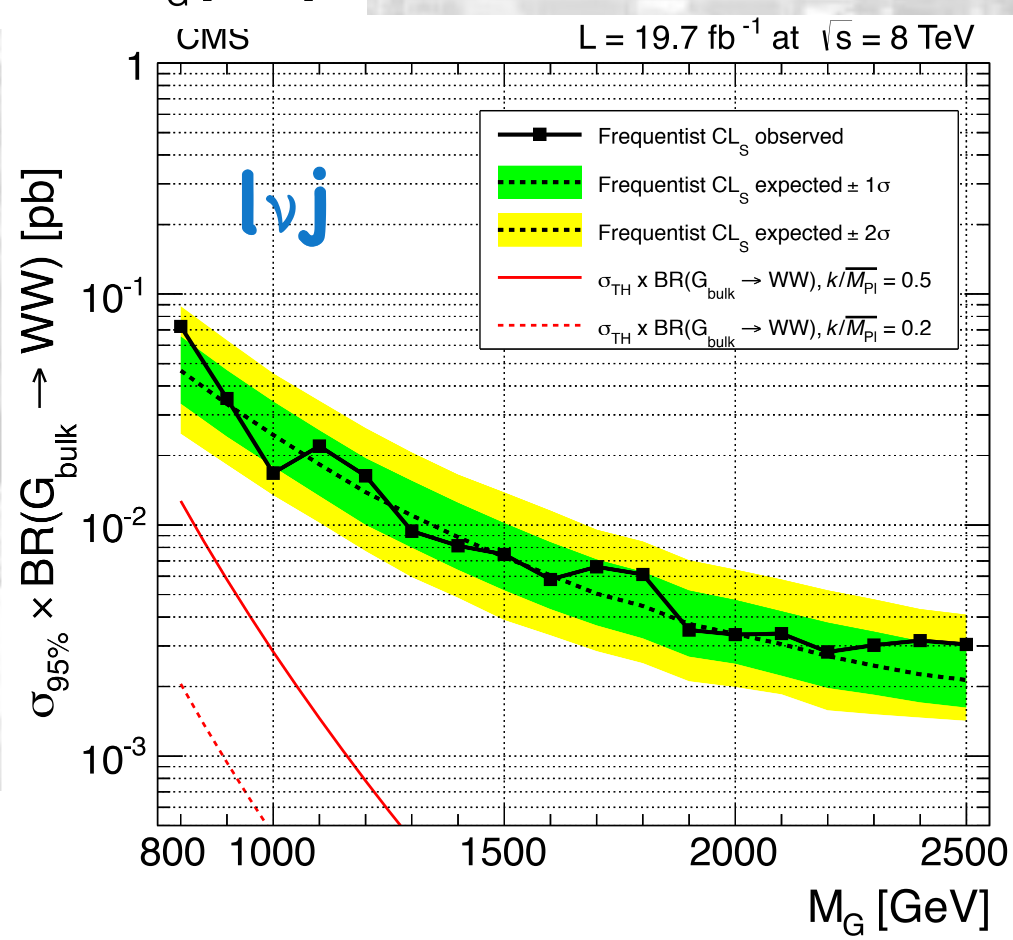
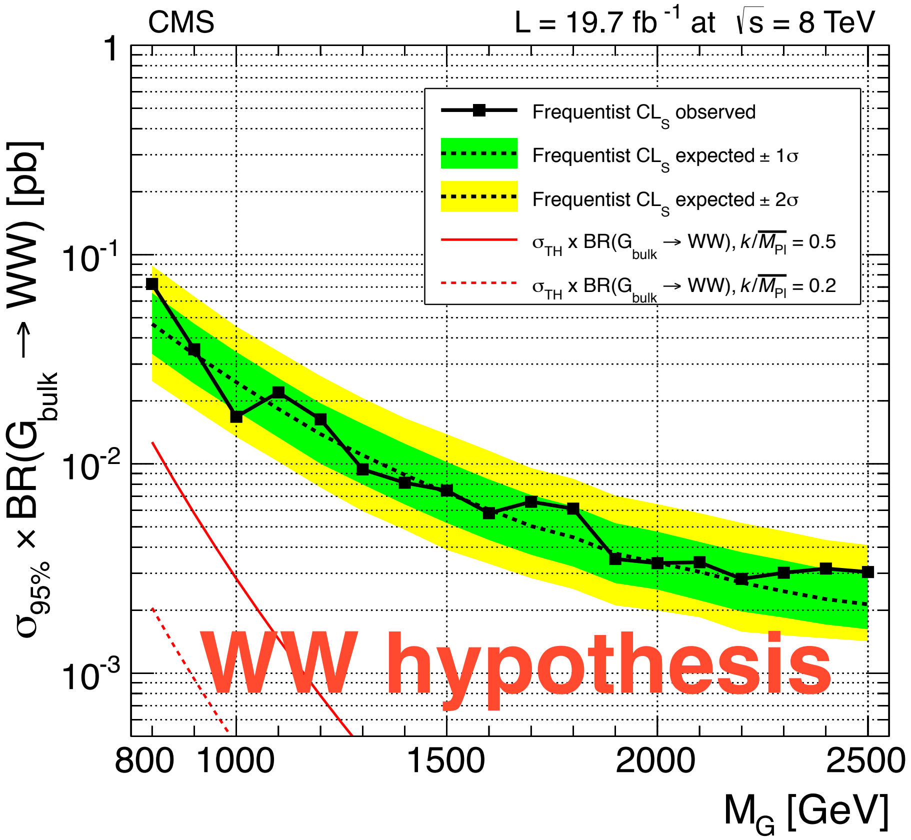
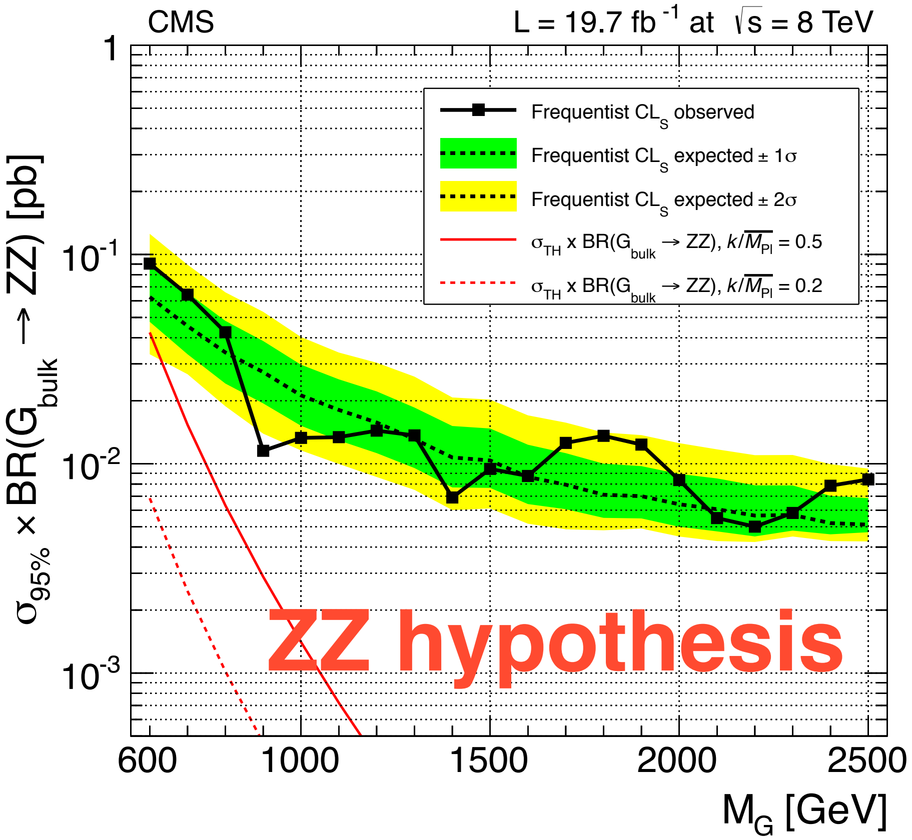


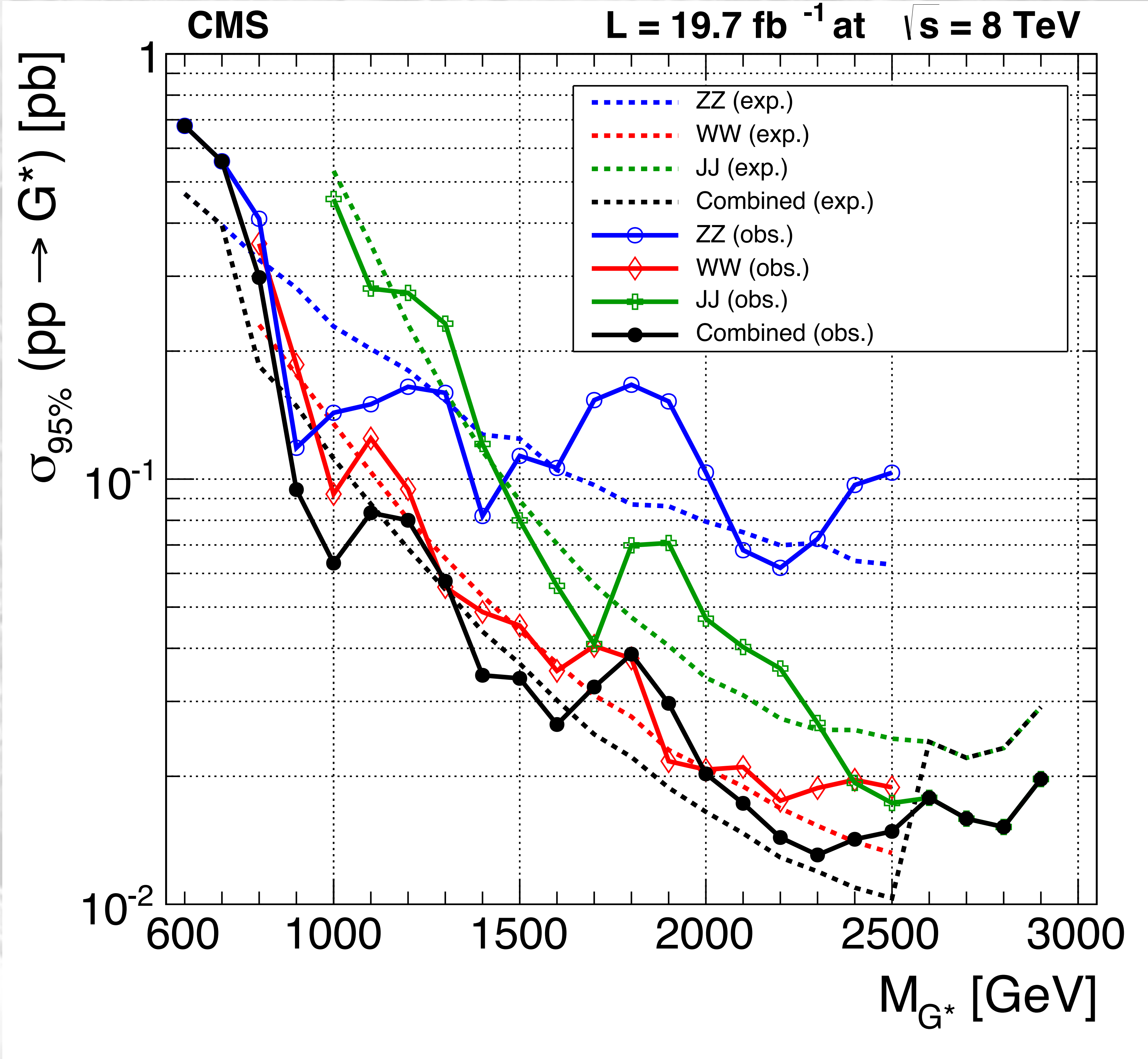




CMS-EXO-13-009

# Combination



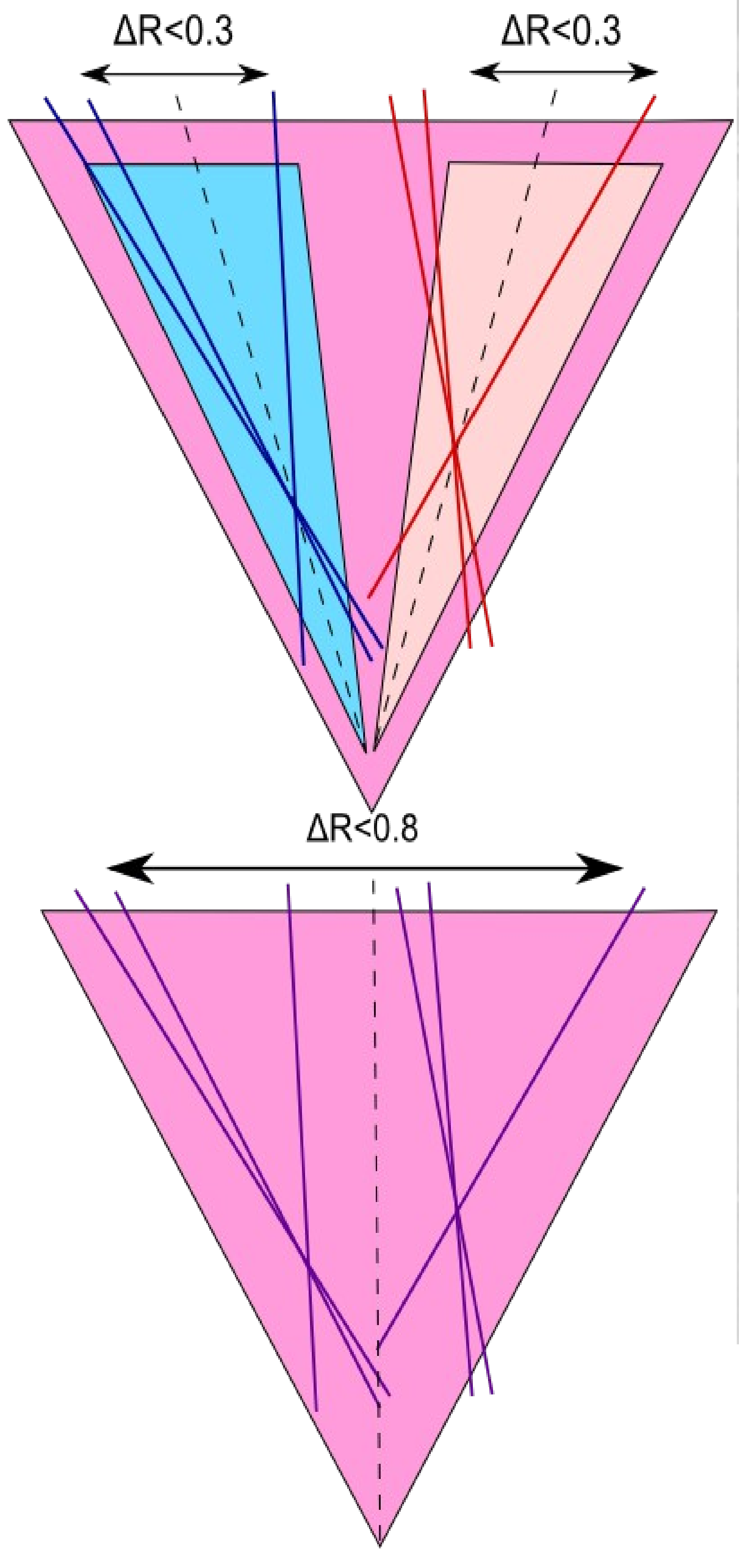



CMS-EXO-13-009

# Going beyond VV searches: HZ & HW

# CMS boosted H→bb Tagging

- **Subjet CSV**
  - resolve two subjets of R=0.2 inside the H jet
  - apply the standard b-tagging algorithm to the subjets
  - similar performances (and data/MC comparison) than the standard b-tagging algorithm
  - Strong bkg killer: 2 b-tags inside the jet
- **Fat-jet CSV**
  - apply the standard b-tagging algorithm to the subjets
  - no need to resolve subjets (less demanding for detector granularity)



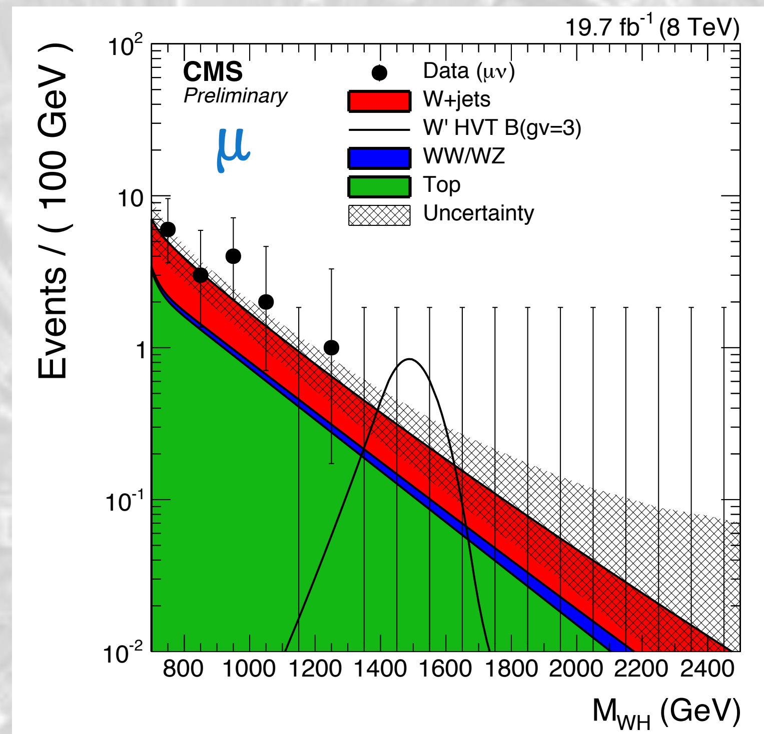

CMS-BTV-13-001

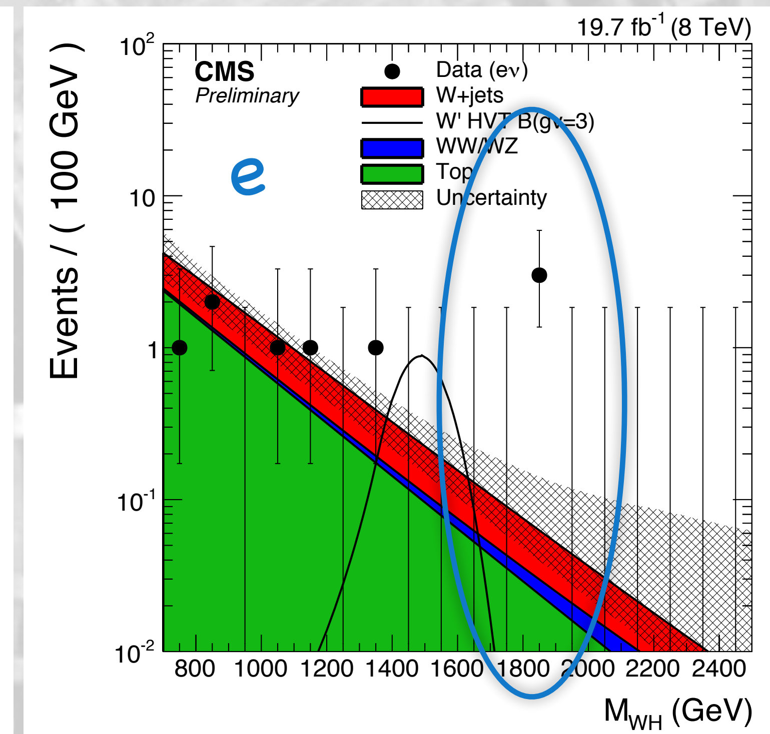
# X→H(bb)W(lν) CMS search

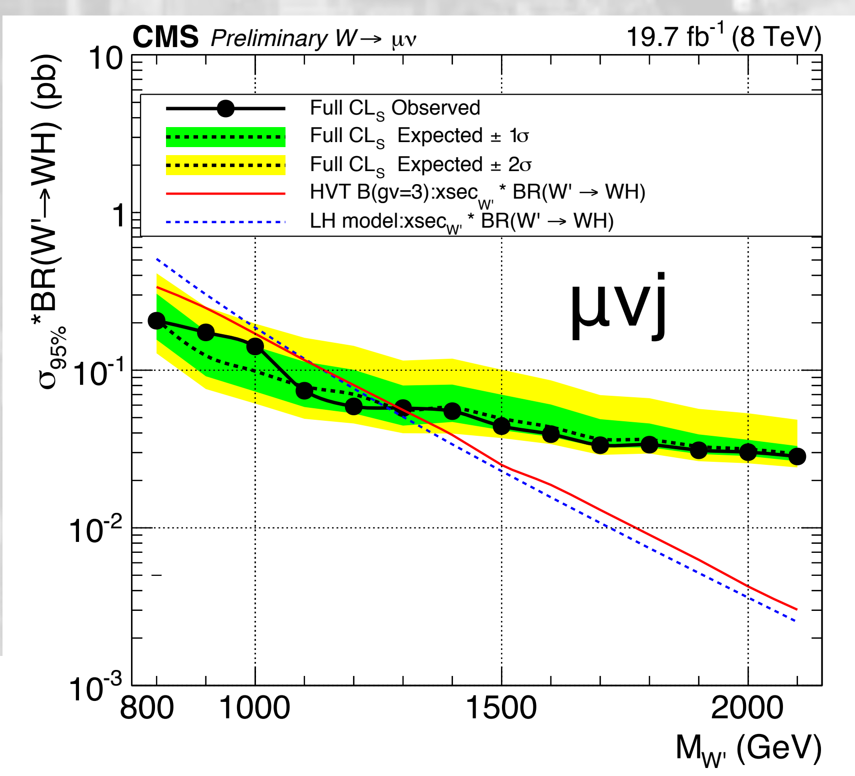
- Same analysis strategy as V(qq)W(ln). Better S/B
  - Added b-tagging for Higgs: large suppression factor to bkg
  - Tuned the jet mass window around 125 GeV: more bkg suppression

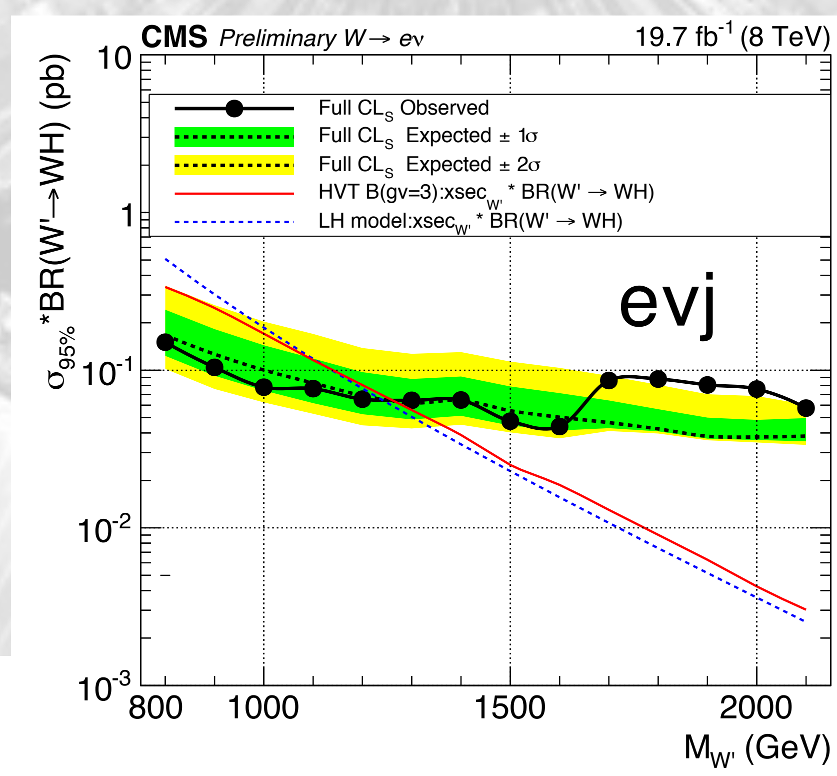
**CMS-EXO-14-010**

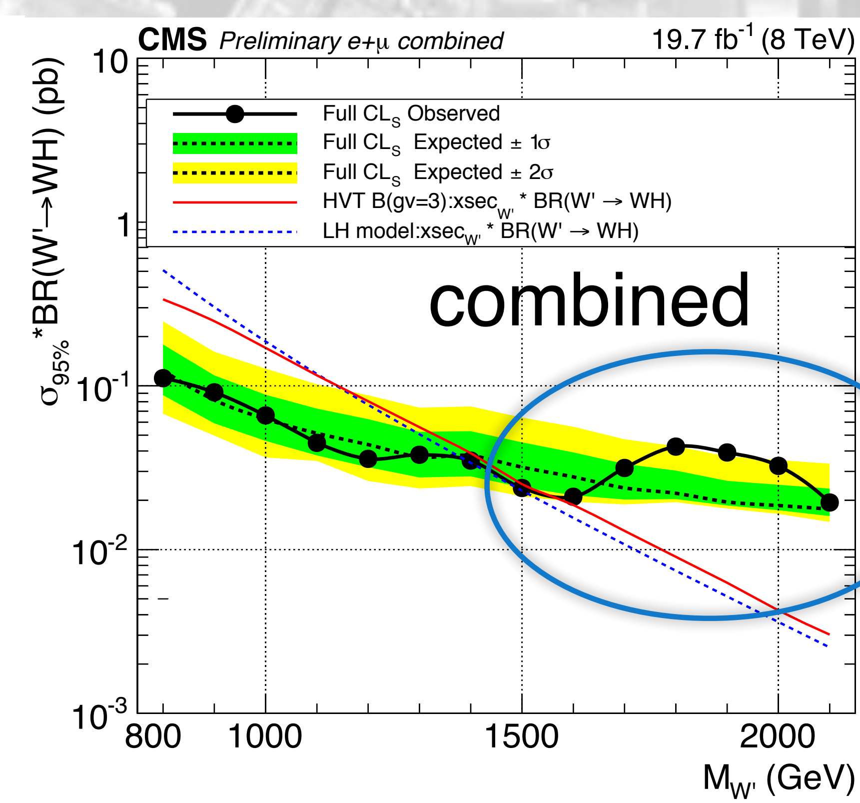
- Observed 4 events at $M_{WH} \approx 1800$ GeV in electron channel ($3\sigma$ local significance)
- Nothing in the muon
- Excess about $2\sigma$ of combined local significance



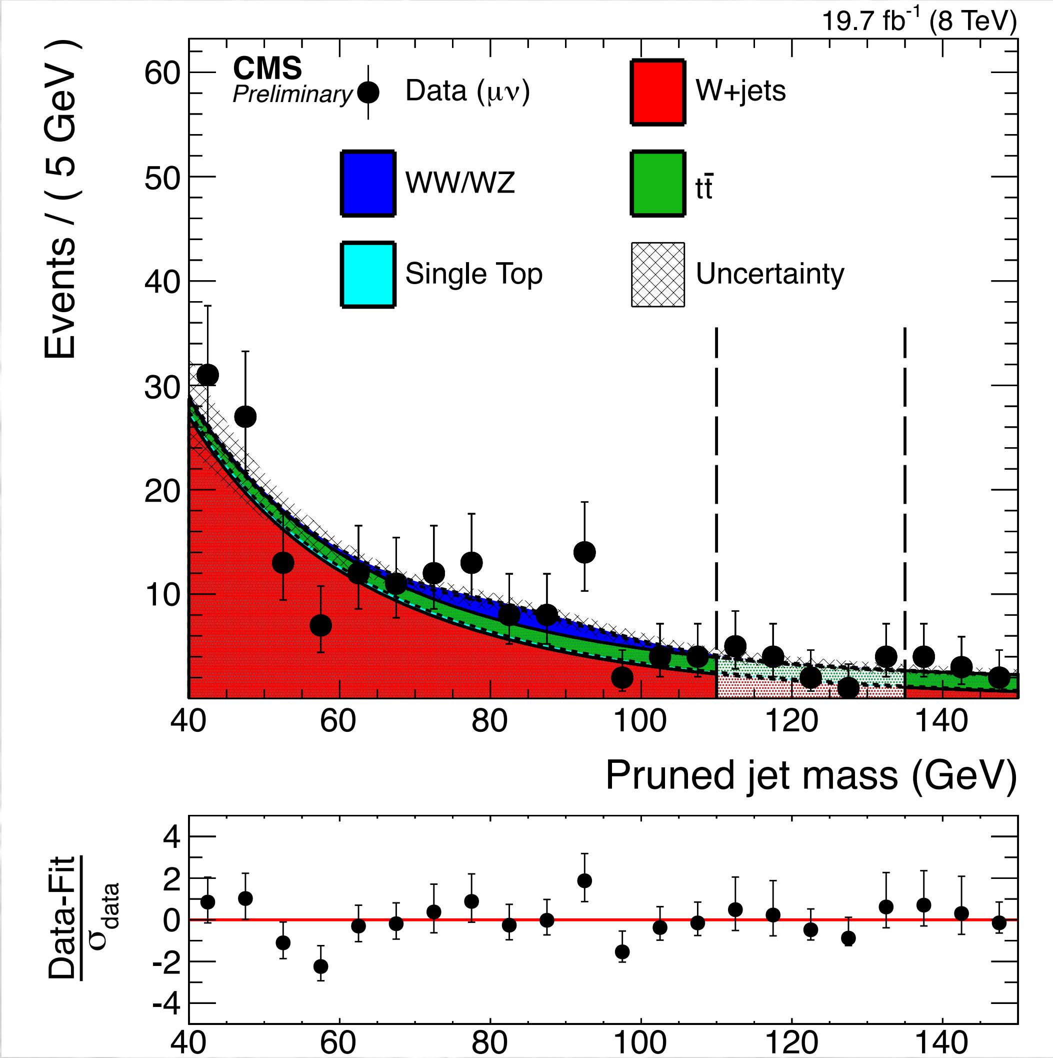



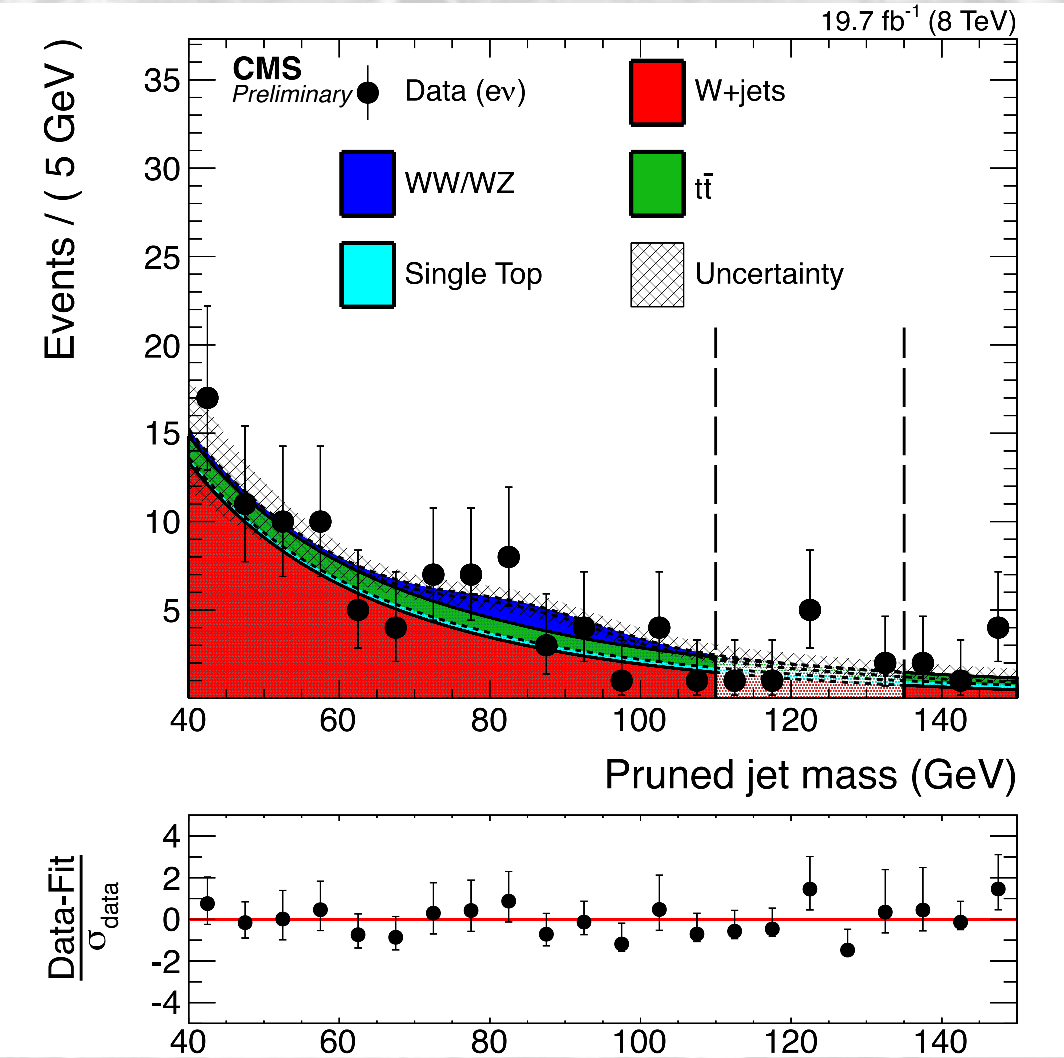



# X→H(bb)W(lν) CMS search

- Jet mass compatible with bkg-only distribution for muon sample
    - expected, since the bkg is from fake Hbb candidates
- Interestingly, the excess events translate into a signal-like bump also in the Higgs mass

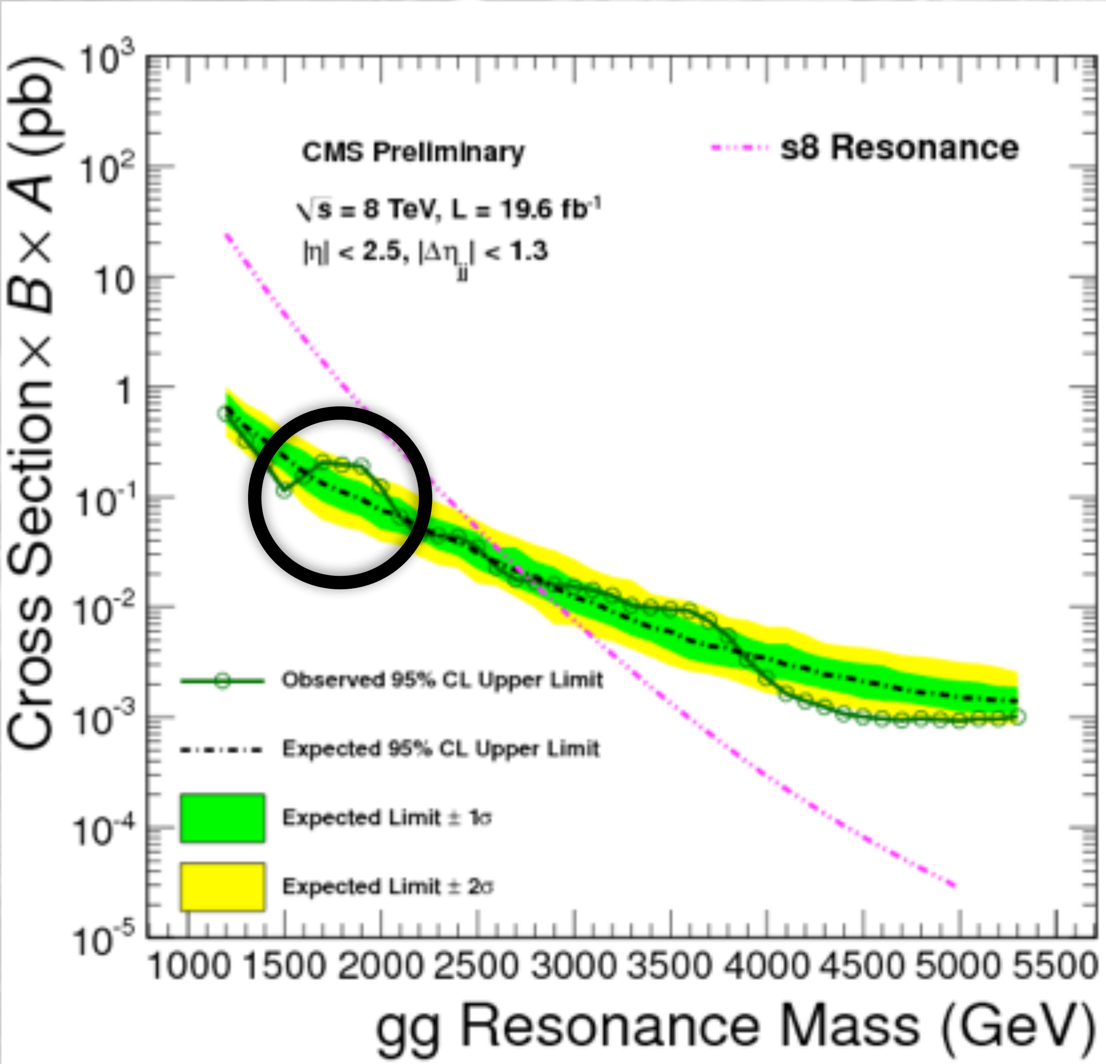


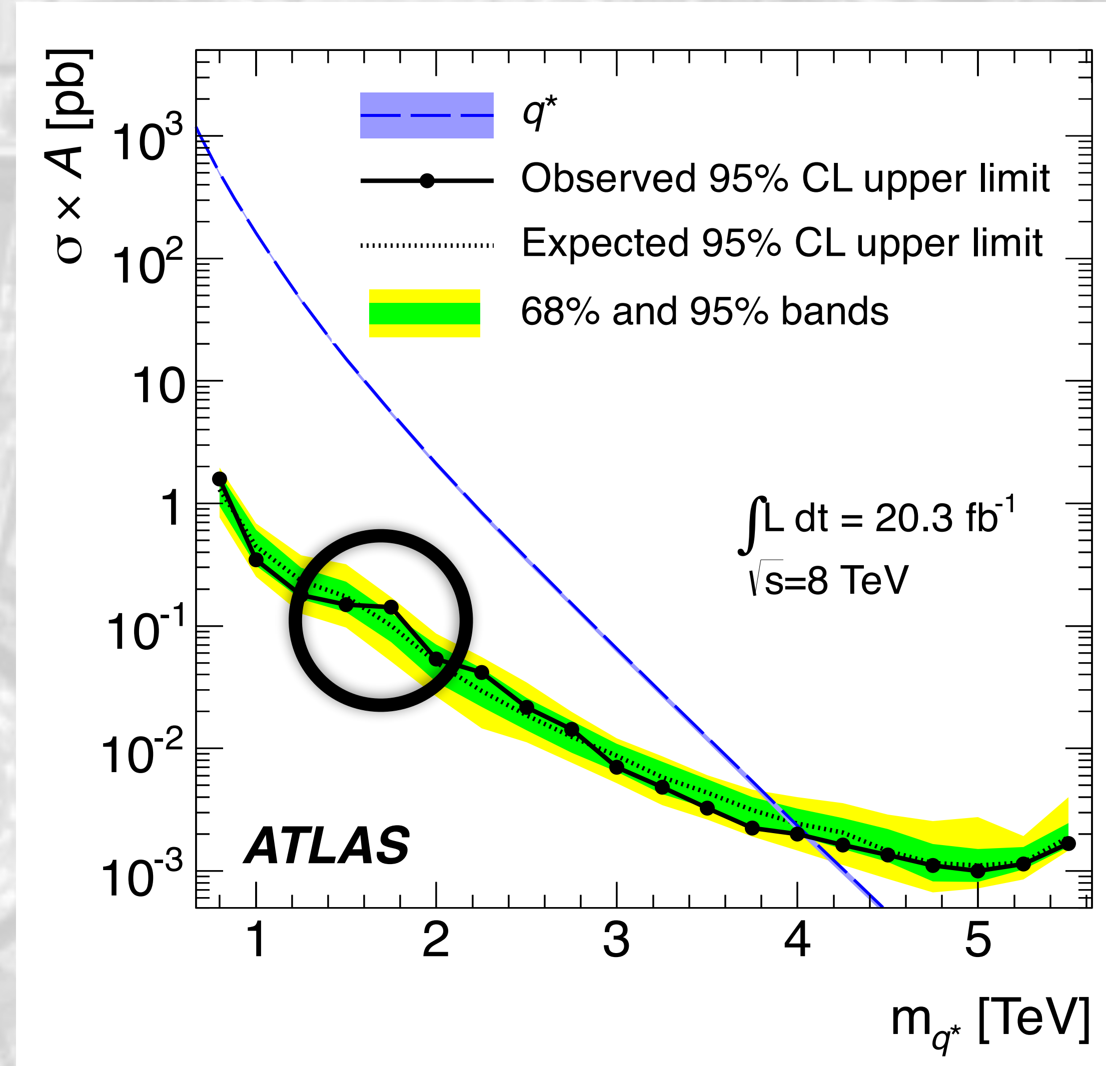




**CMS-EXO-14-010**

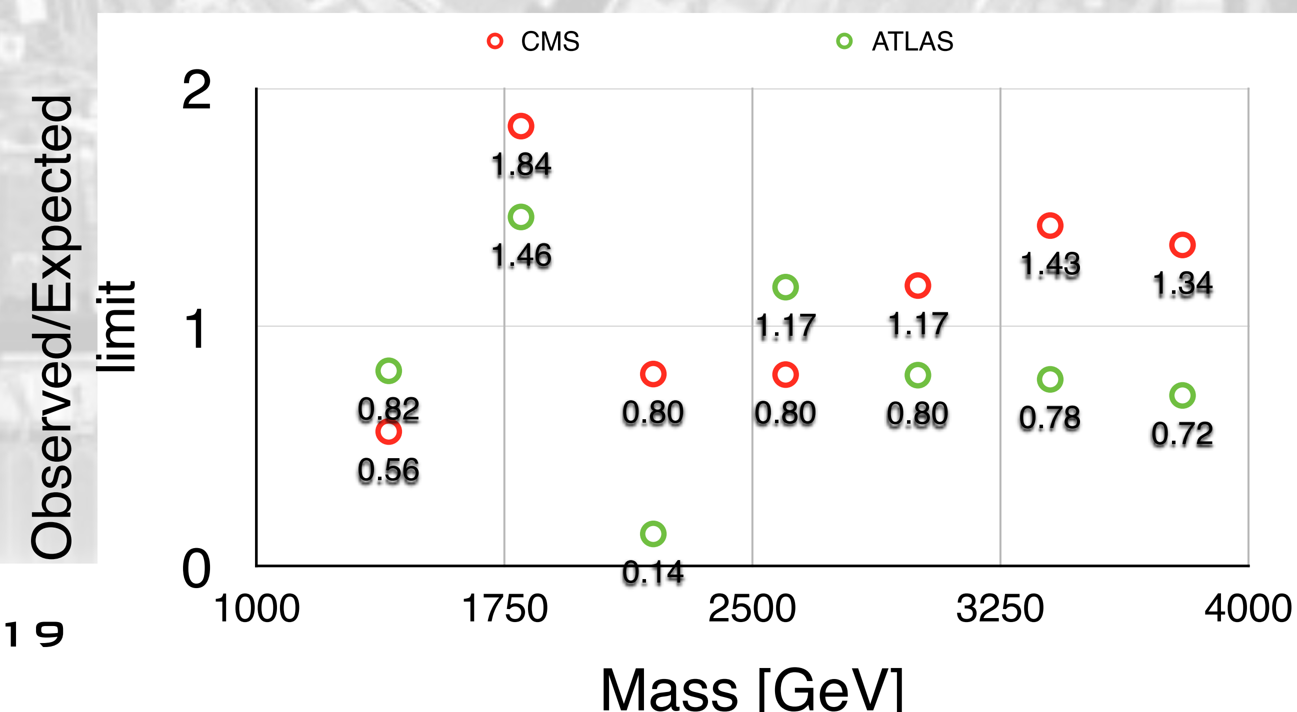
# Dijet/dilepton searches

# Dijet



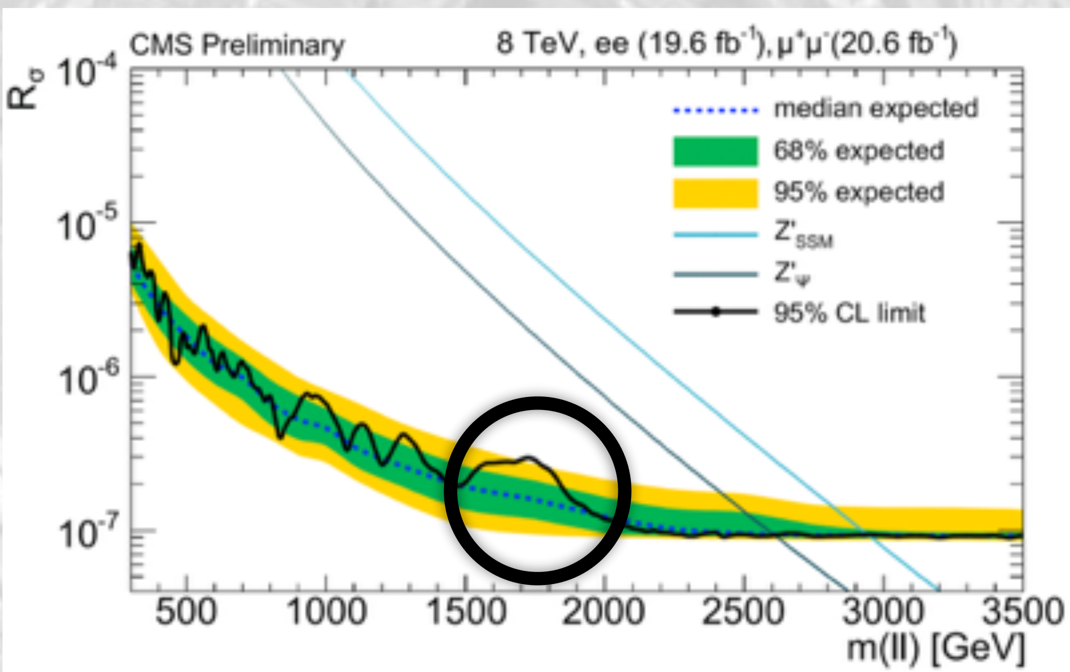



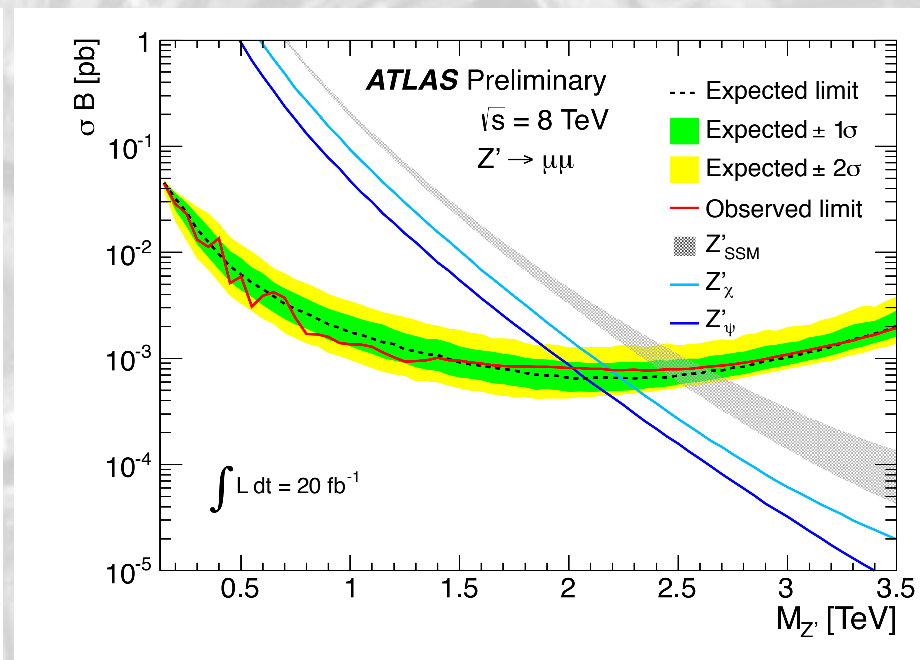

- Not much in ATLAS
- ≈2σ (local) in CMS
- Only place where both experiments have observed limit > expectation

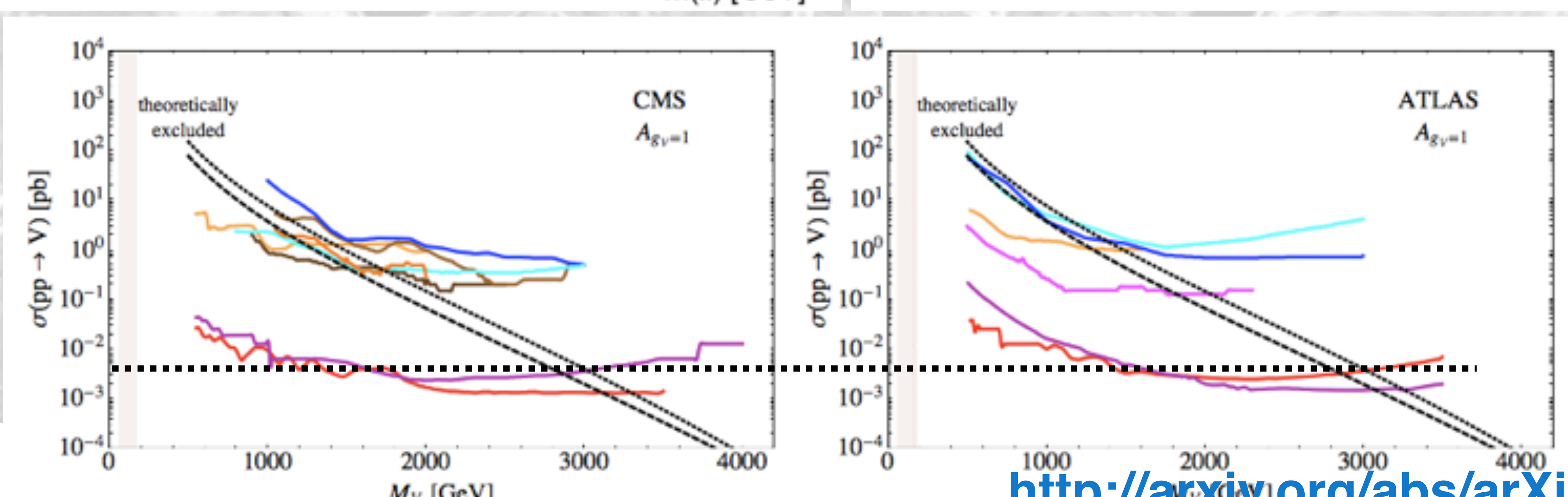


# Dilepton

- CMS sees excess (among many others). Not relevant per se (LEE), but interesting in the full picture
- ATLAS sees no excess
- Two statements are not in contradiction: same observed limits



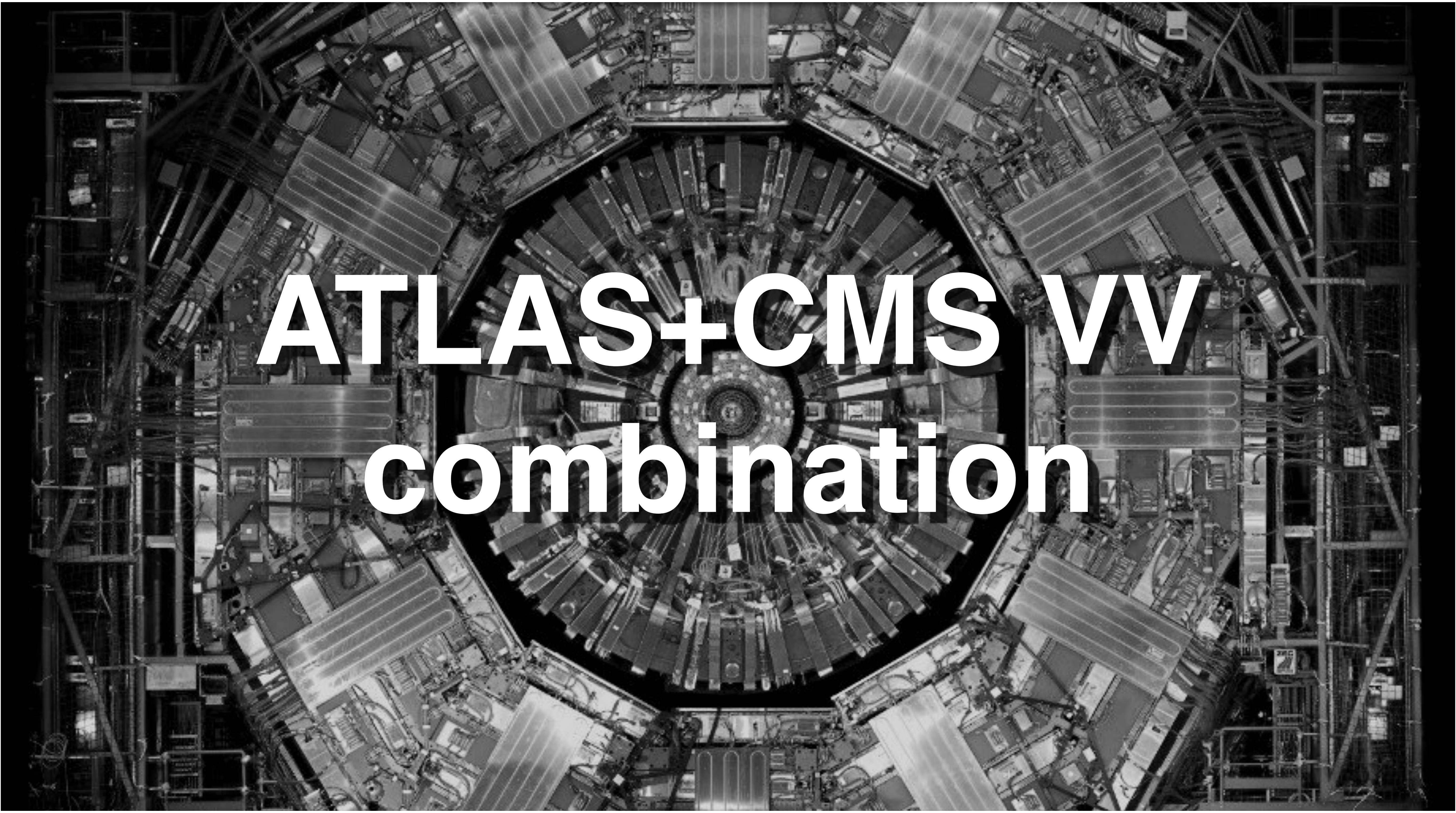




http://arxiv.org/abs/arXiv:1402.4431

# Conclusions (so far)

- No claim of discovery (of course)
- Still, there are a few interesting excesses around 2 TeV
    - overall, in VV (with some **confusing pattern**, atlas too)
    - in WH
    - in dijet (ATLAS too), and maybe in dilepton
- For sure something to hope for
    - ... and to watch carefully in Run II

# ATLAS+CMS VV combination



# Bkg estimate from bump-hunt fit

## Combination of Run-1 Exotic Searches in diboson final states at the LHC

F. Dias,[c] S. Gadatsch,[a] M. Gouzevich,[b] C. Leonidopoulos,[c] S.F. Novaes,[d] A. Oliveira,[e] M. Pierini,[a] T. Tomei[d]

[a] *CERN, Geneva*

[b] *Université Claude Bernard-Lyon I, Lyon*

[c] *University of Edinburgh, Edinburgh*

[d] *Universidade Estadual Paulista, Sao Paulo*

[e] *Universita e INFN, Padova*

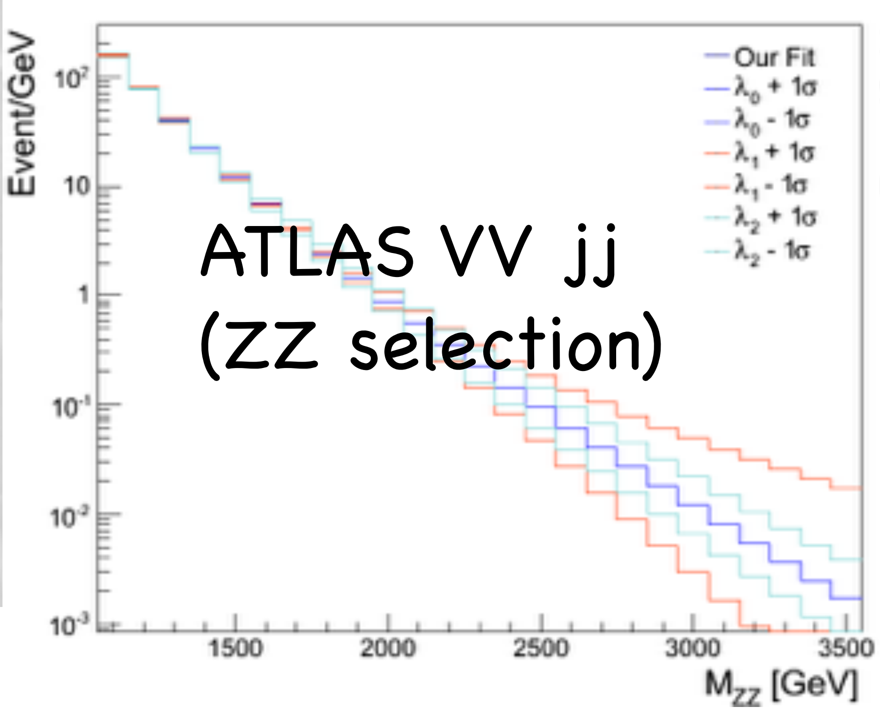
- Few ATLAS/CMS individuals working together to combine ATLAS+CMS results from publicly available information
- Work incomplete, still missing some signal (e.g. WZ in all channels), and jobs are still running
- Stay tuned for the paper to see the full picture

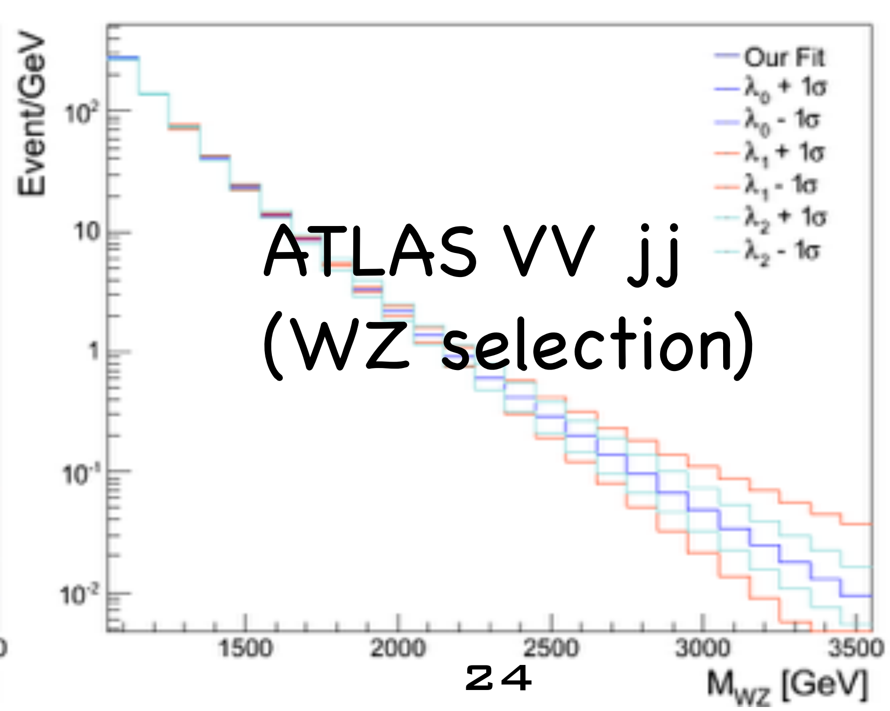
# Bkg estimate from bump-hunt fit

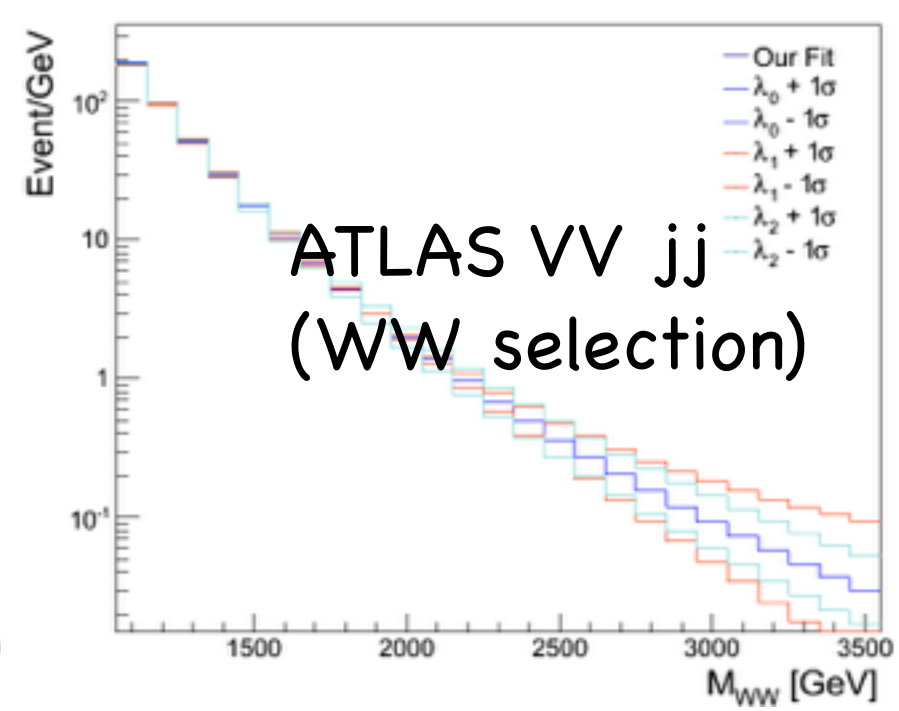
- Start from the published data (hep format or plots)
- Bkg estimate problematic
  - missing correlations, which often matter
  - (sometimes) bkg uncertainties not quoted
- When info missing, bkg estimate using a dijet-like bump hunt
  - fit in sideband vs full region give similar results
  - Simpler function (expo) used for low-stat channels (llJ)
  - For ATLAS VV fully hadronic, simplified function used according to ATLAS prescription
- Diagonalize covariance matrix + Bkg systematic for eigenvalues

$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\ln(x)}}$$

$$x = m_{jj}/\sqrt{s}$$

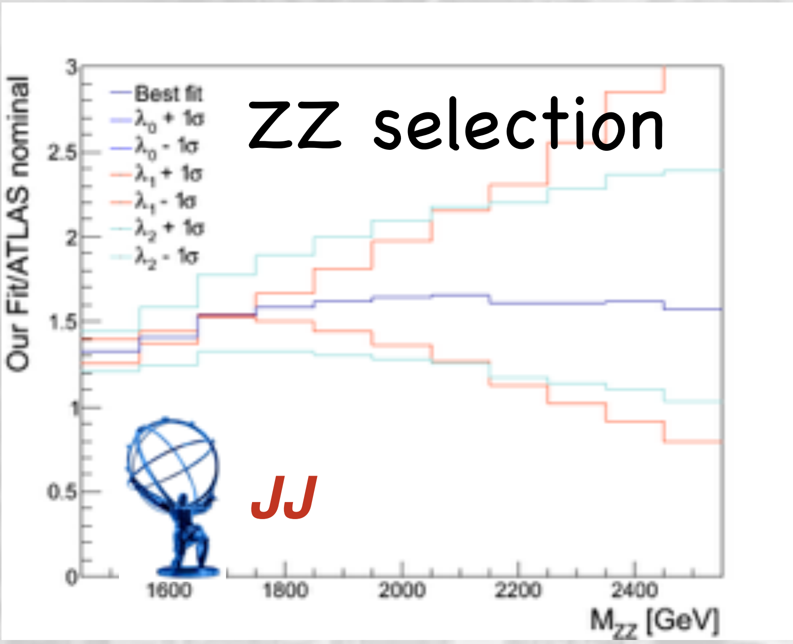


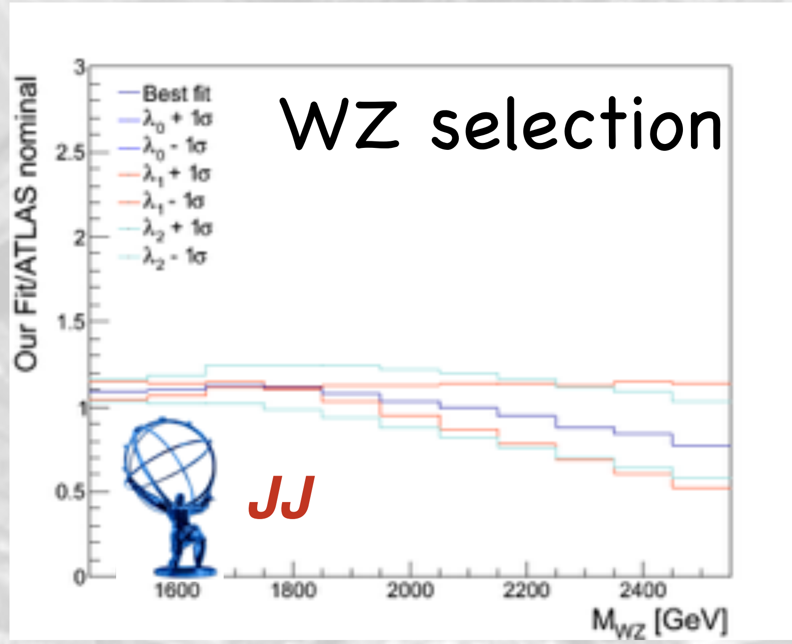



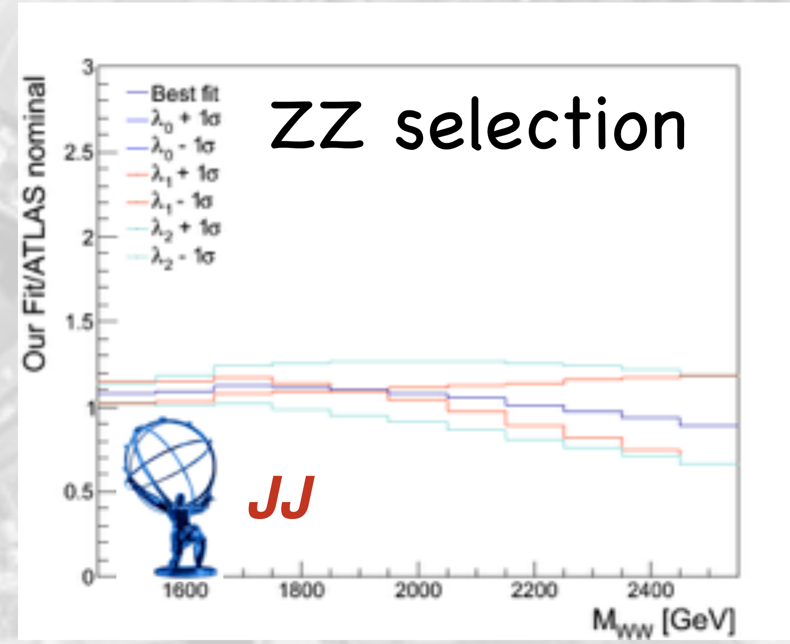



# Comparison with nominal result

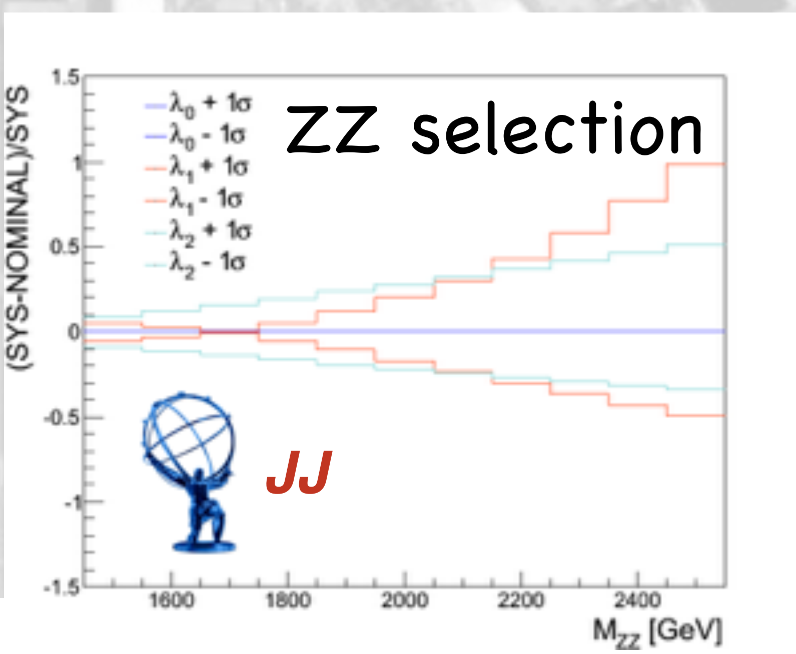
- In general, nominal bkg (from ATLAS or CMS) within our fit+systematic

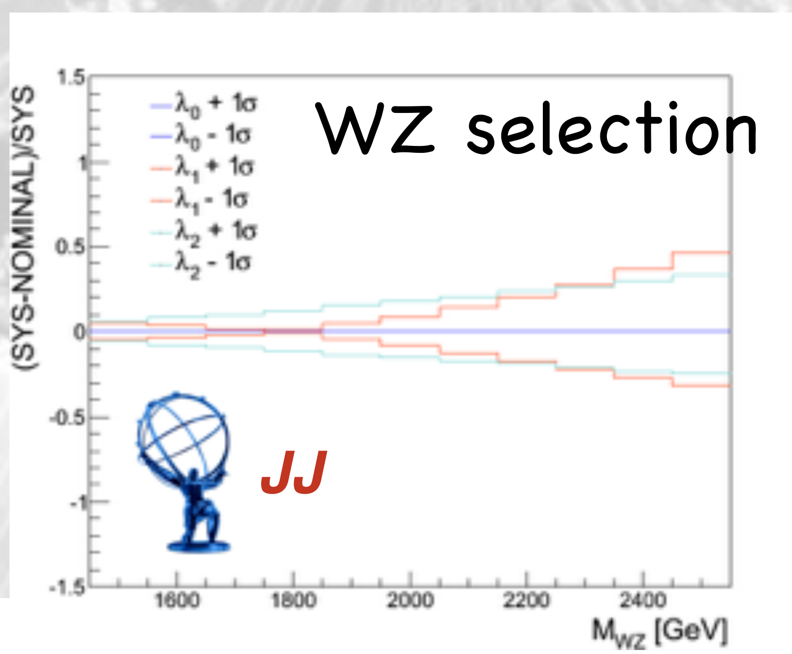


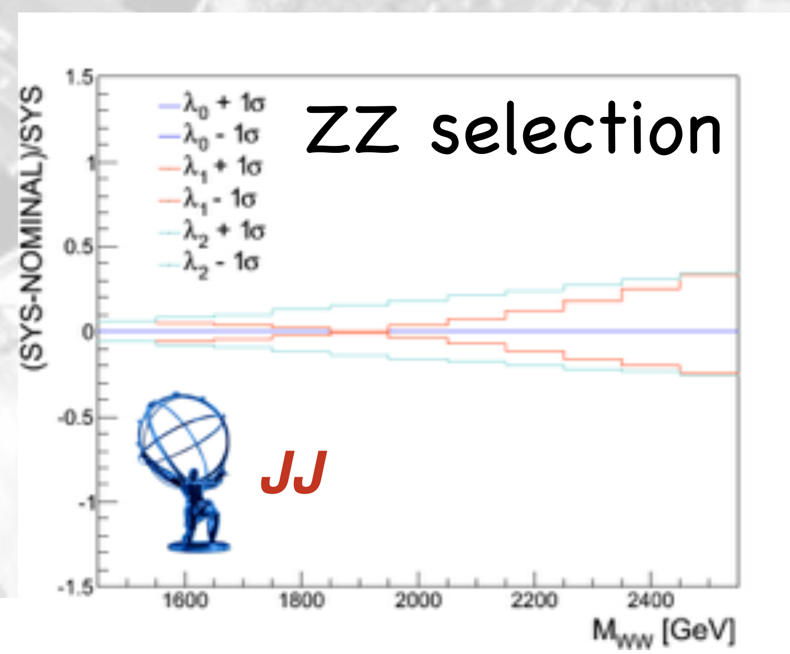




- Sometimes (e.g. ATLAS ZZ) larger deviations observed
  - We use the nominal result as a background estimate
  - We rescale the systematic variations by nominal/our fit ratio
- Rescaling not always needed (e.g. CMS lνJ & llJ)



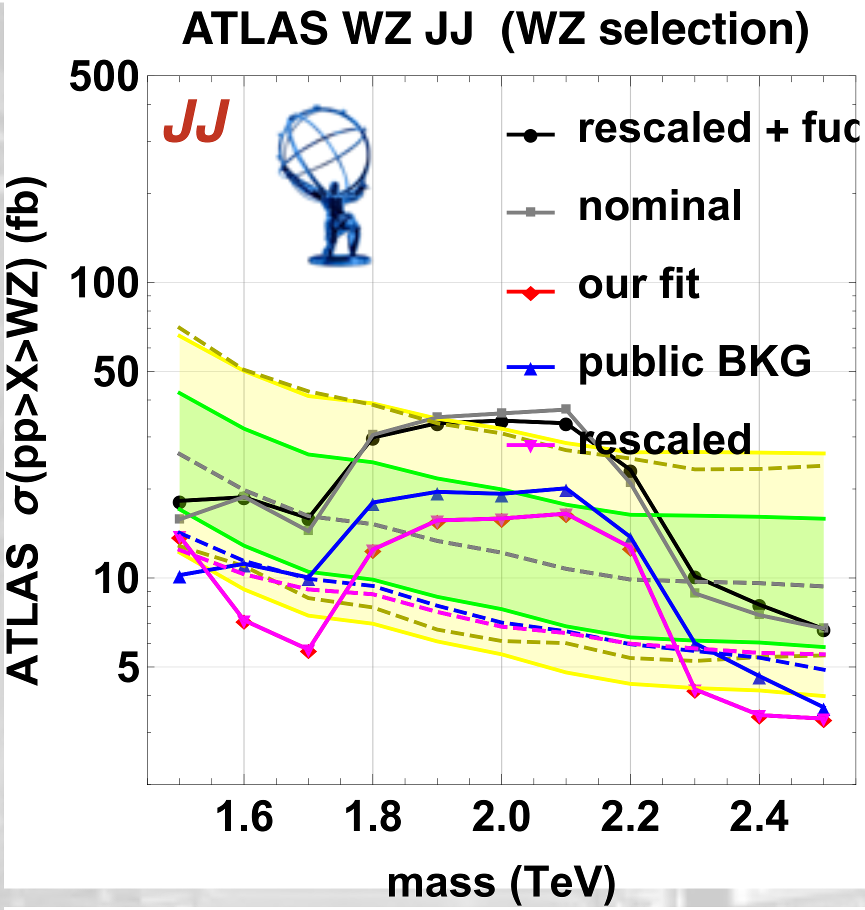



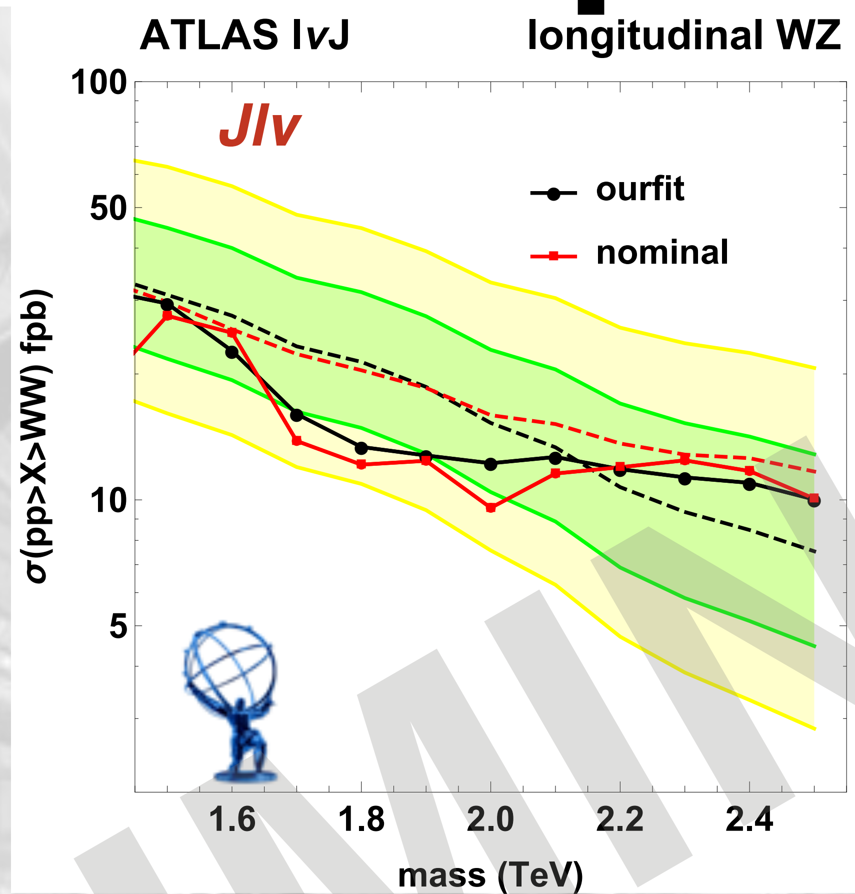



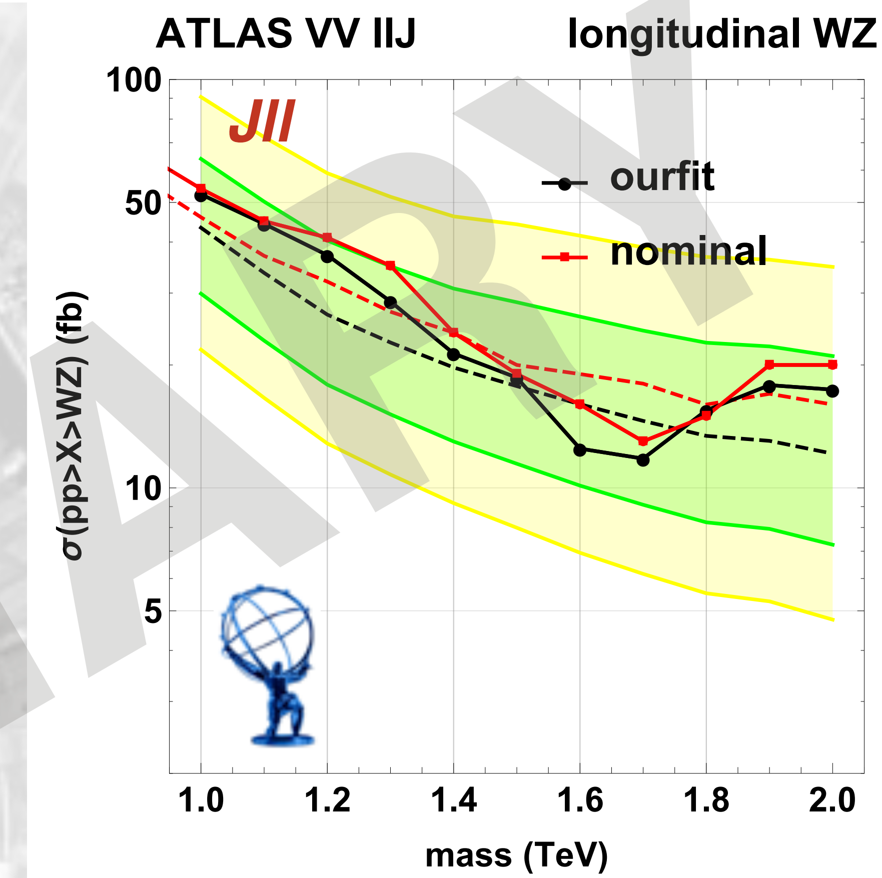
# Limit Comparison

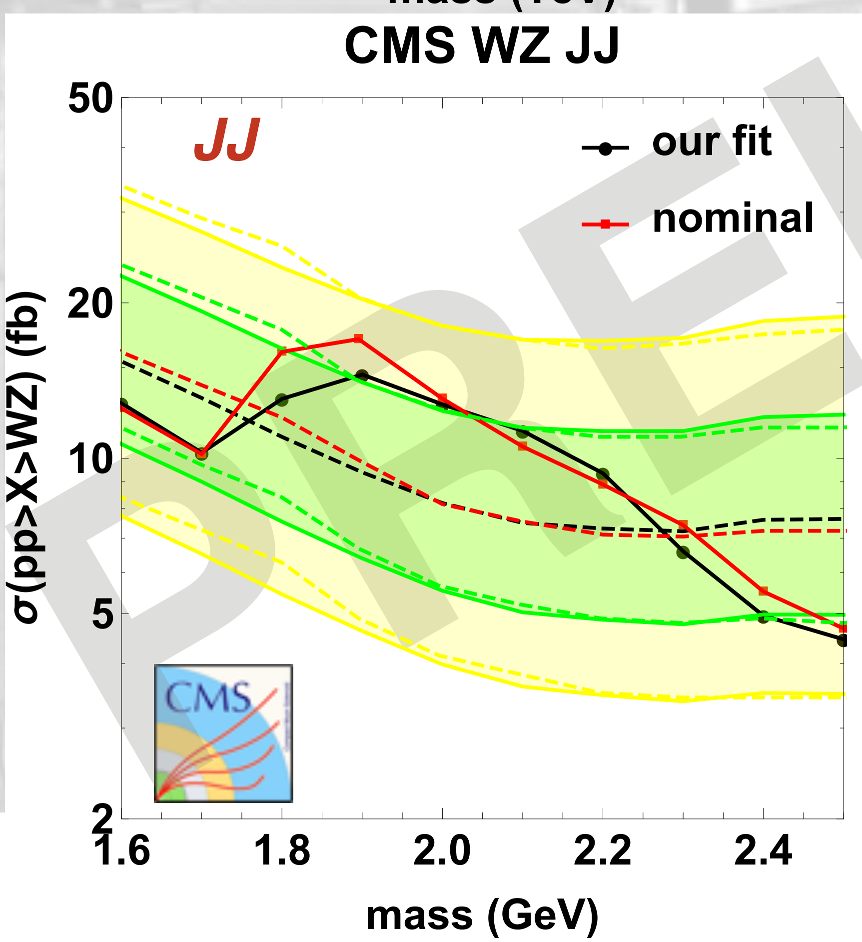
- Nominal+systematics estimate used in a template fit
- Signal parameterized from available information
  - signal efficiency
  - benchmark models for specific mass values
  - linear interpolation within benchmarks for generic mass values
- Limit extraction with asymptotic CLs reproduces trends in nominal result
- Discrepancies between nominal results & out fit (channel dependent)
  - approximately mass independent
- Rescale the expected limit by constant factor to match nominal
- Good agreement observed after rescaling (fudge factor)

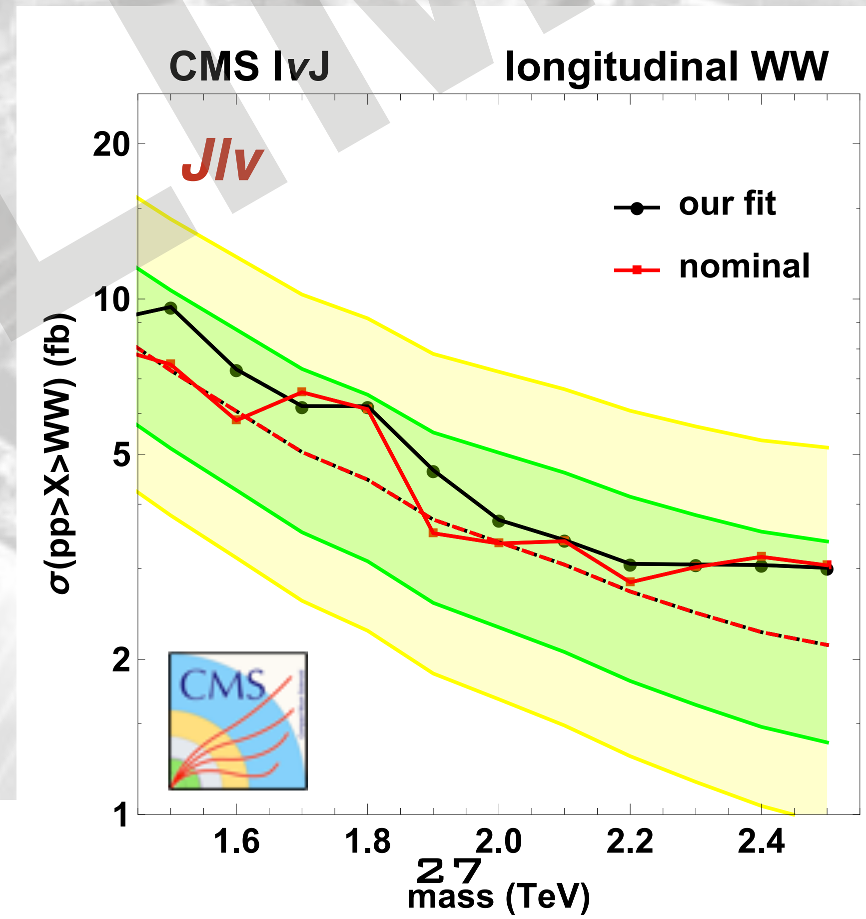
# Limit Comparison

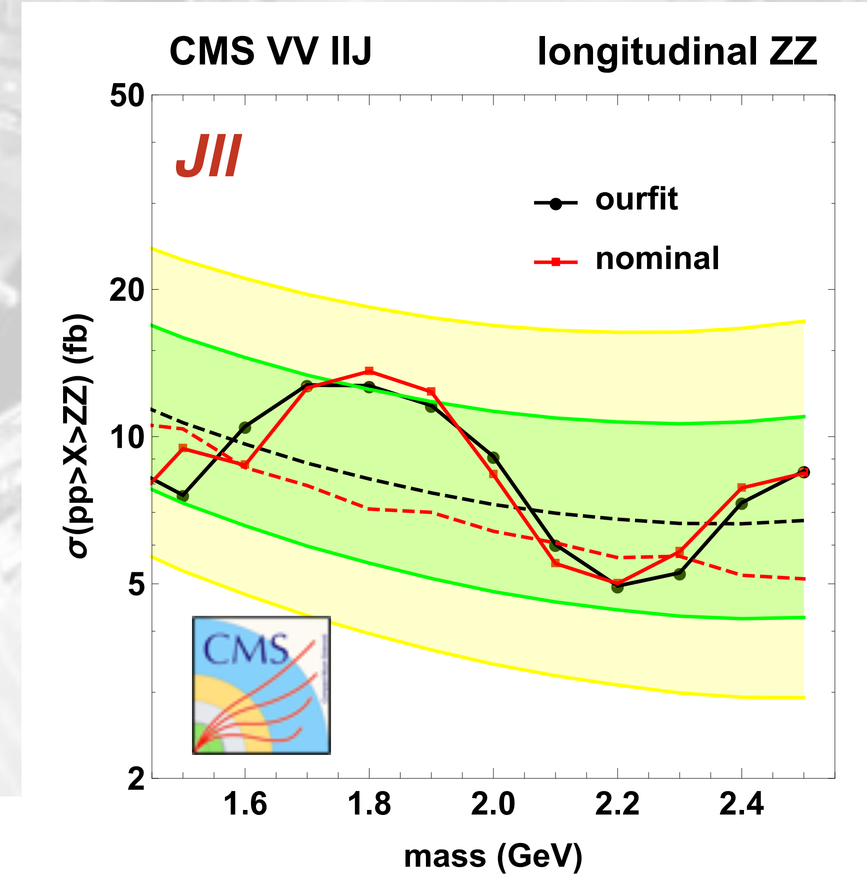


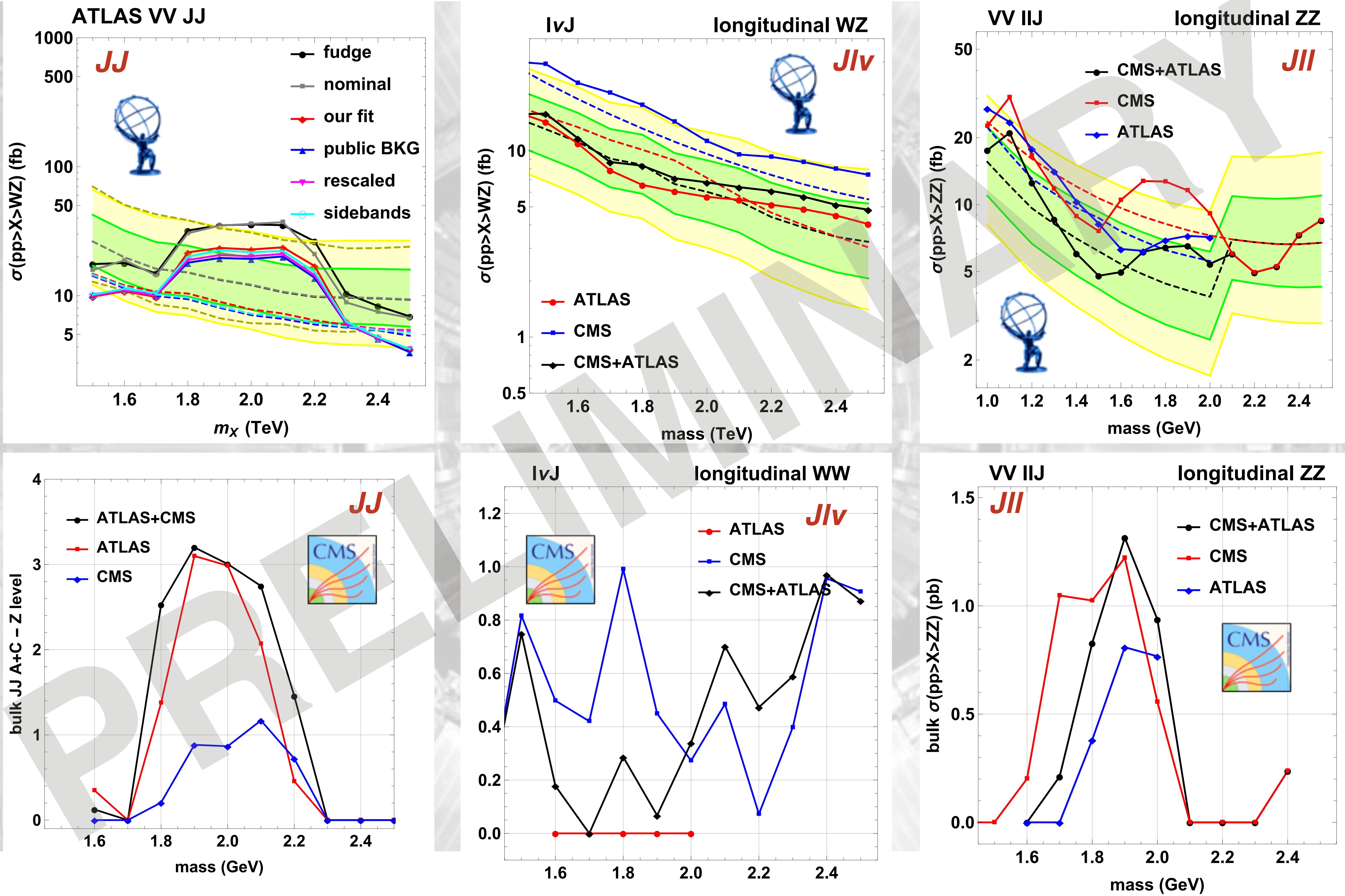



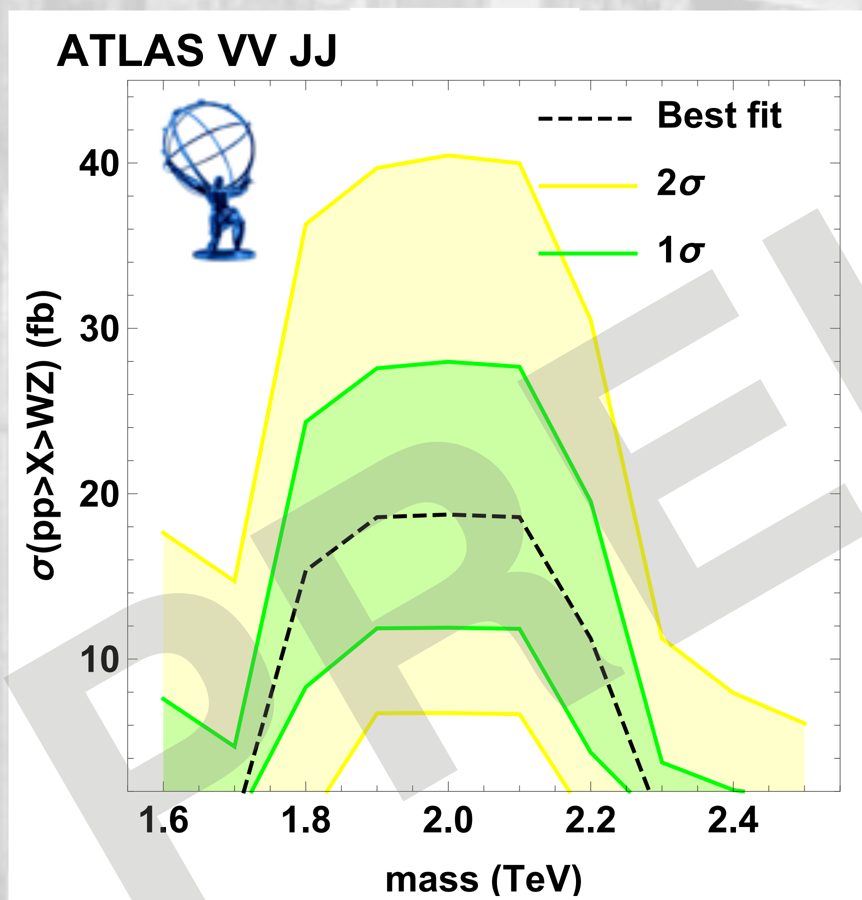



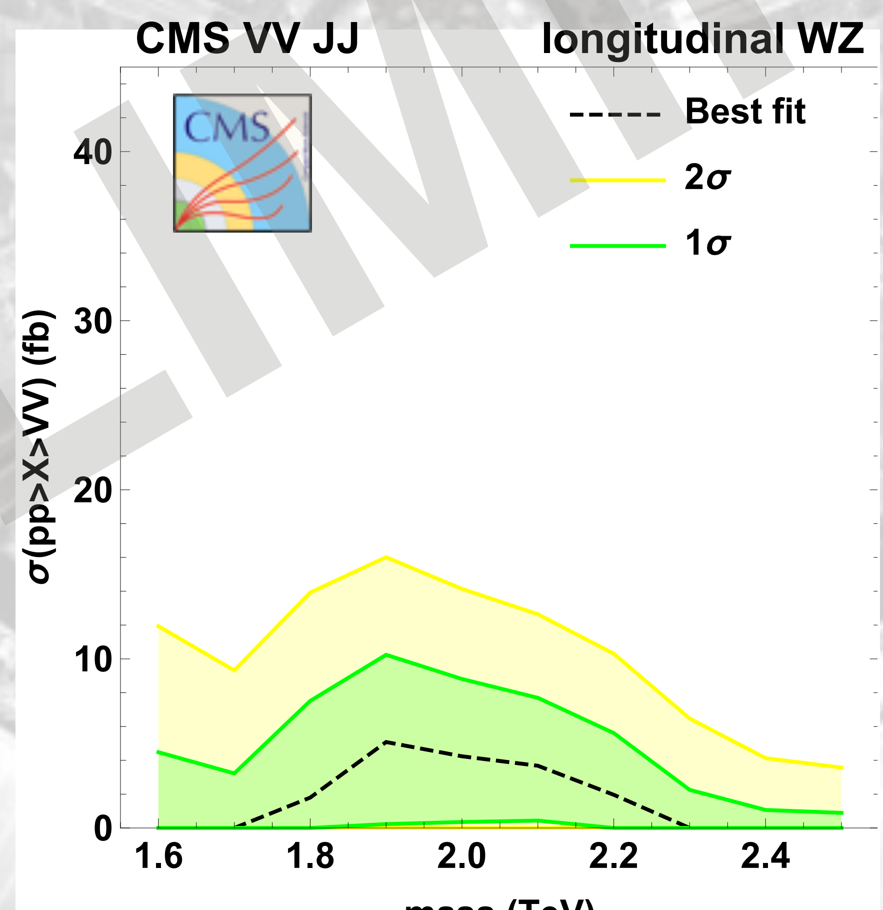
# ATLAS+CMS combo: one channel

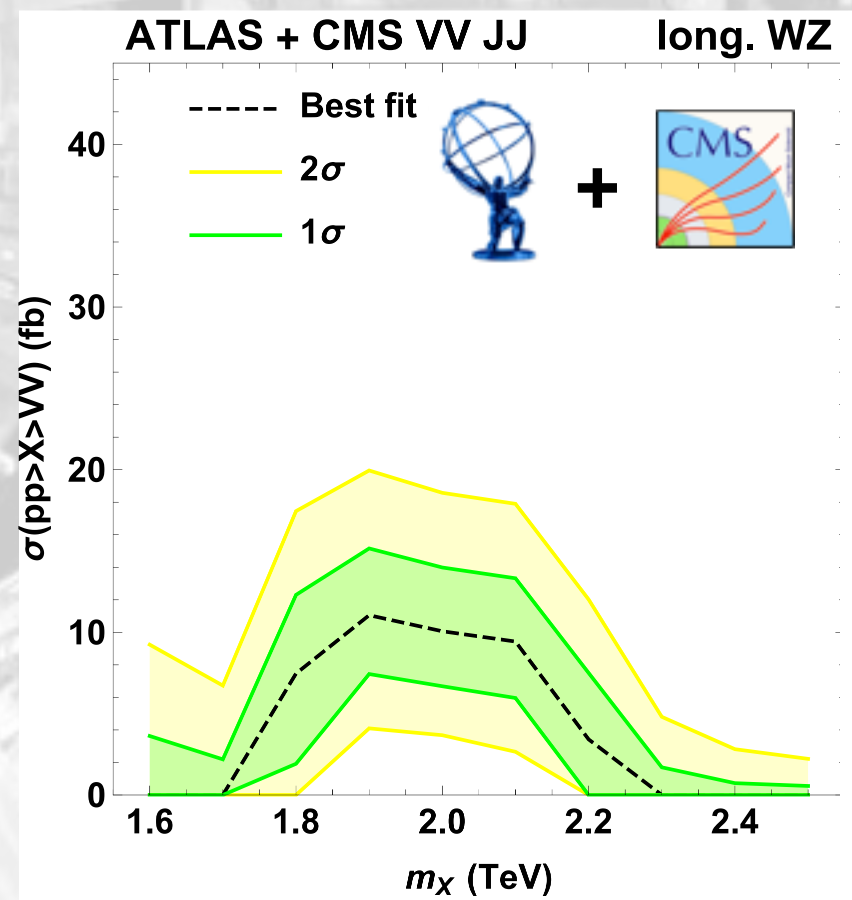


# Signal Strength: JJ only

- Combining ATLAS large excess + CMS small excess point to a cross section of about 10 fb-1
- With this smaller signal value, the discrepancies across channel is mitigated (e.g. wrt lνJ)
- Despite the reduction in signal strength, the significance is basically unaffected (see next slide)
  - Out of ATLAS+CMS combination a more consistent picture emerges



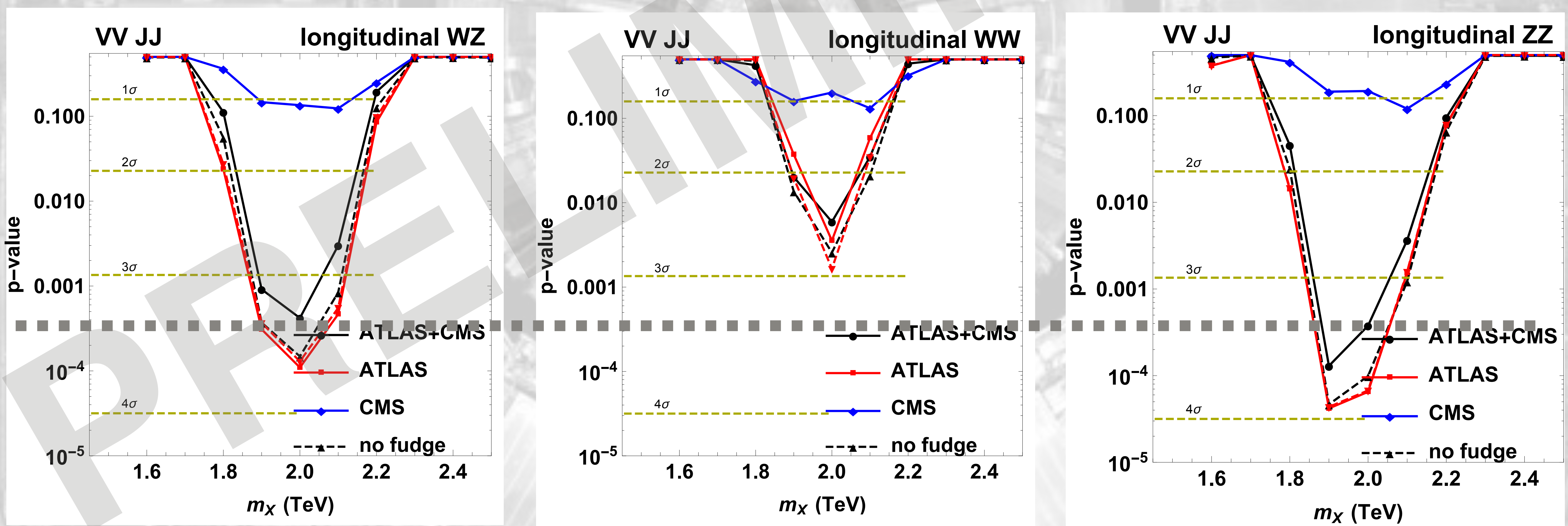



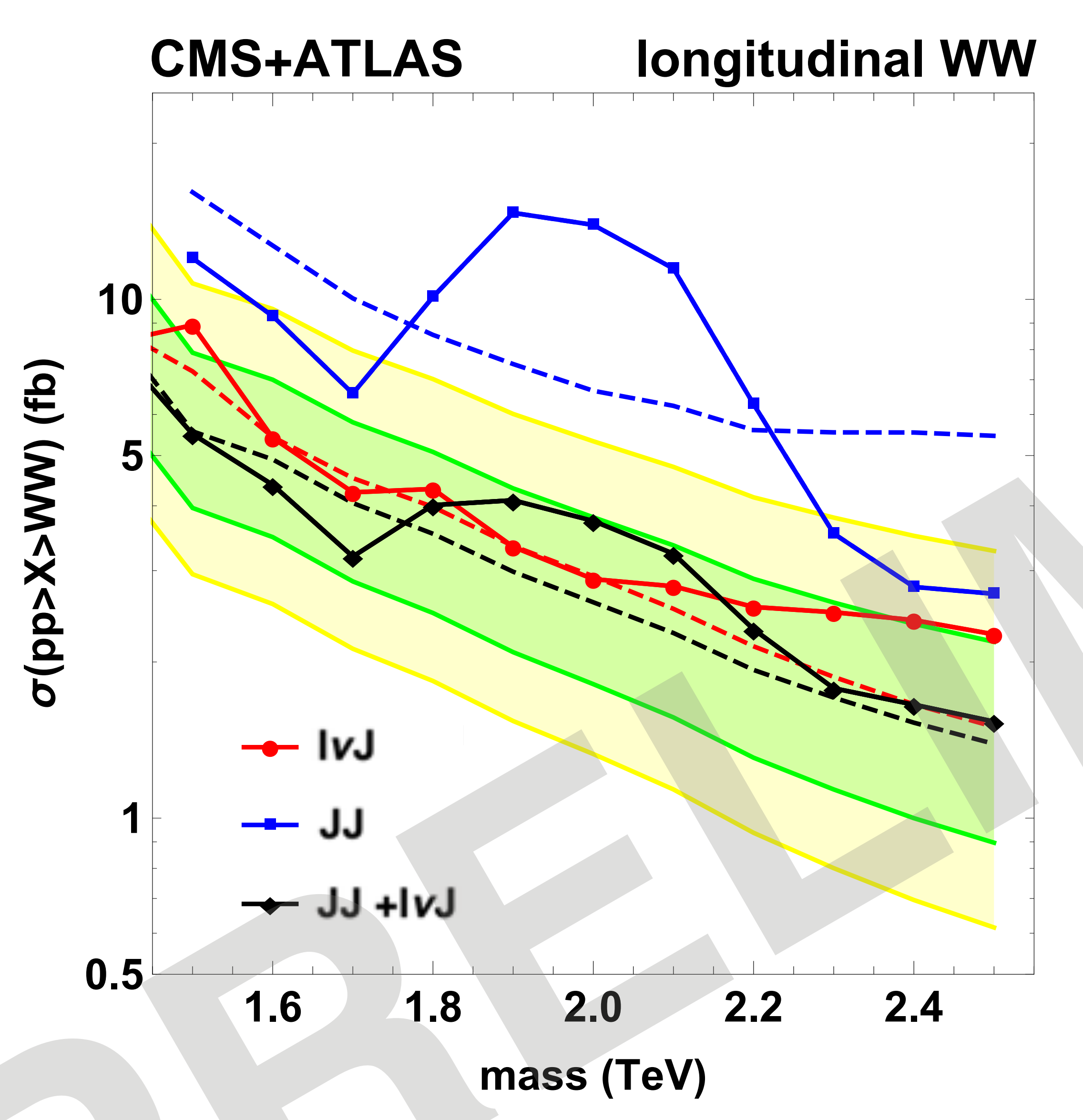
# Model Dependence: JJ only

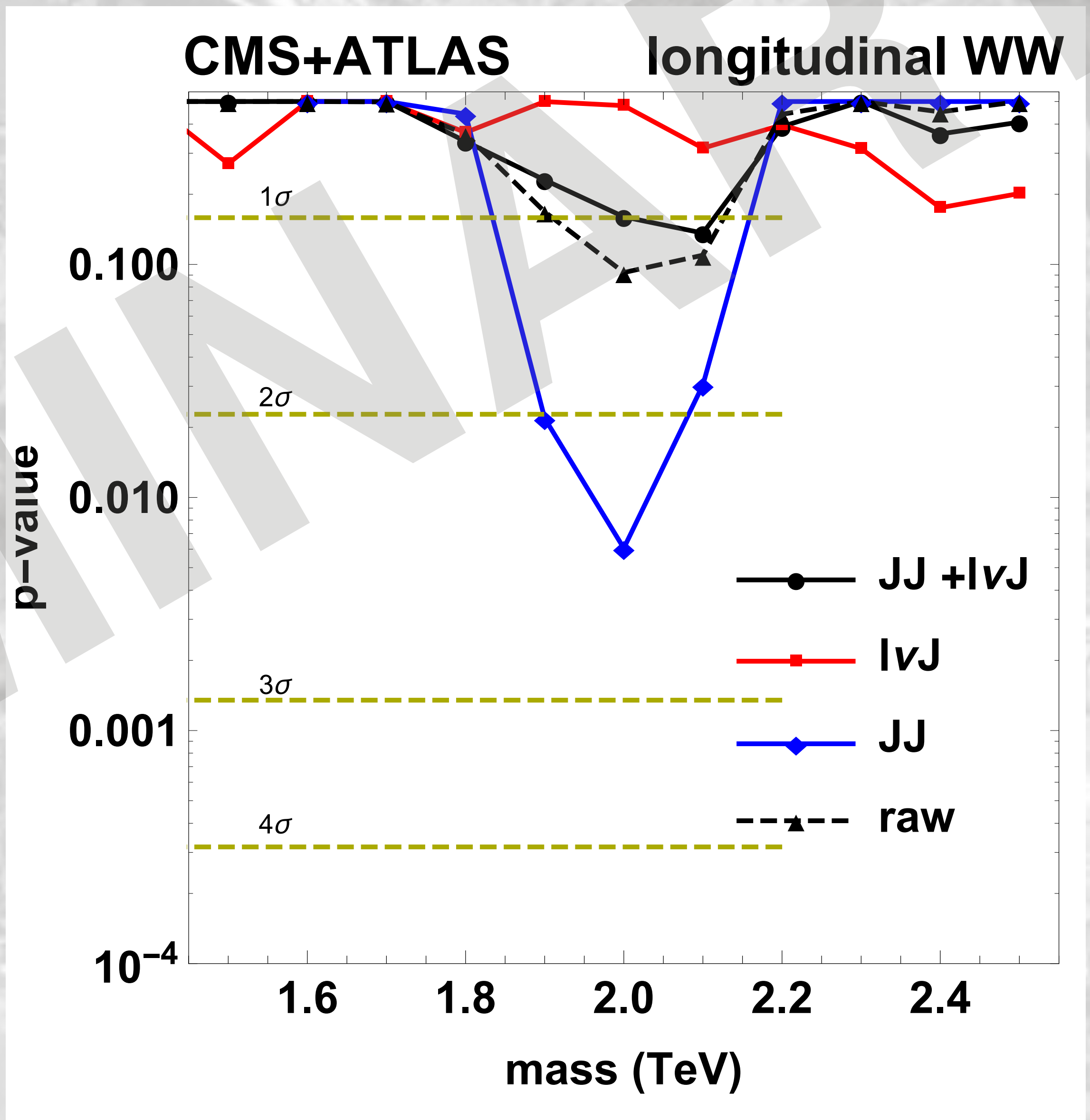
- Combination confirms the signal excess (with much reduced signal strength)
- The significance of the signal depends on the signal hypothesis
- Interestingly enough, significance maximised when WW decay suppressed (consistent with picture emerging from other signals)
  - direct consequence of bkg breakdown in ATLAS 3 categories

*WZ* — *Bulk Graviton to WW* — *Bulk Graviton to ZZ*

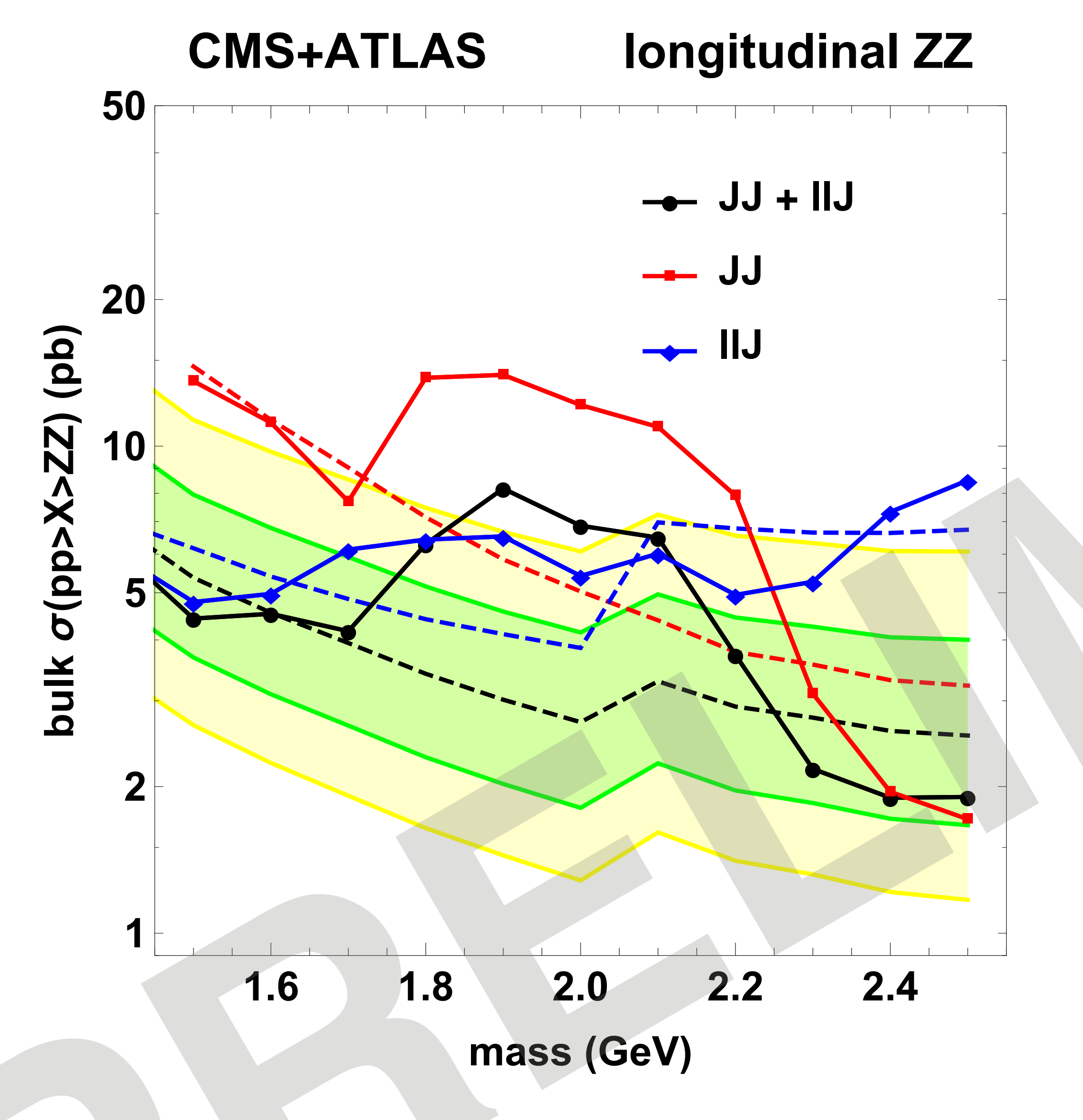


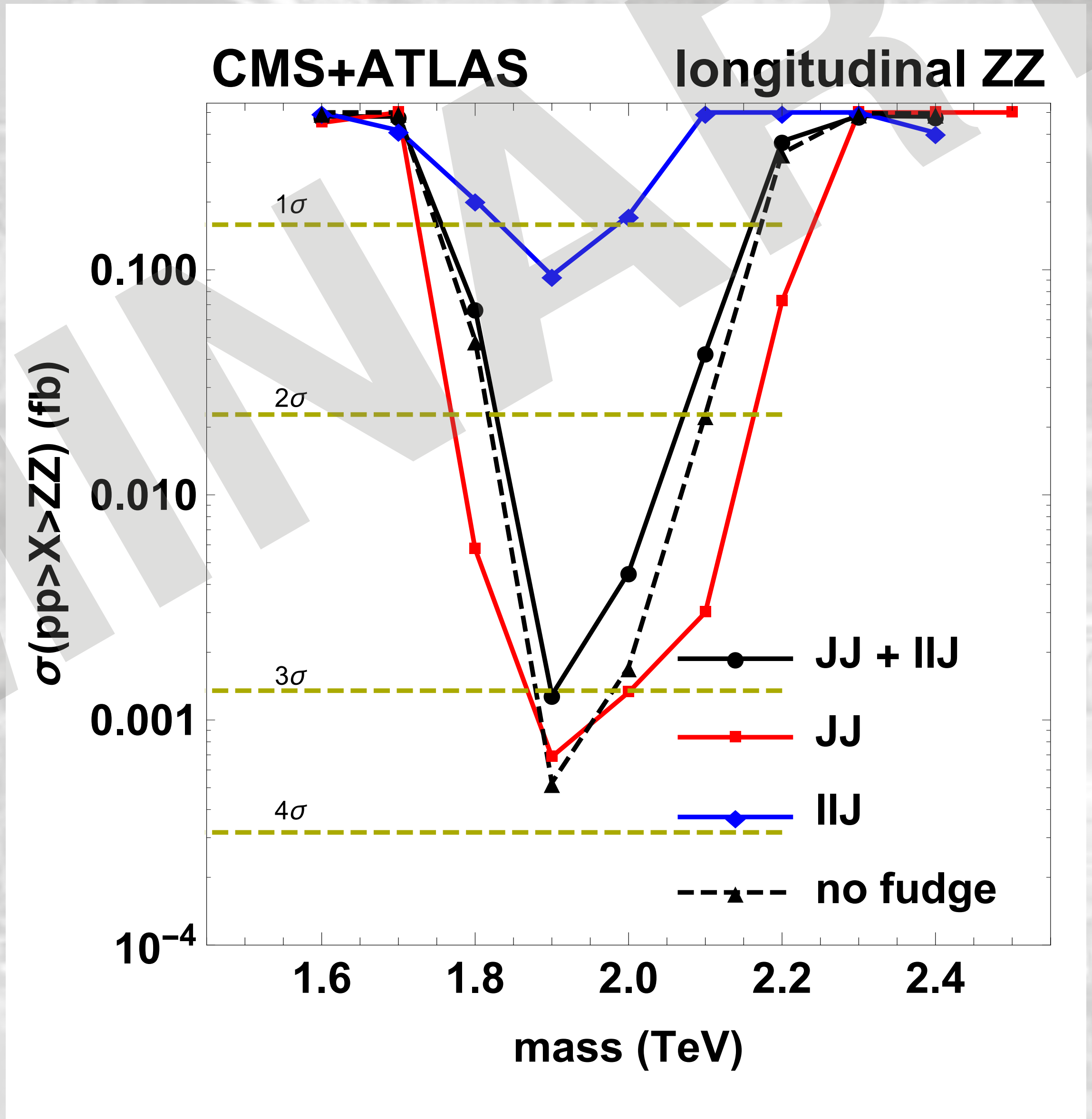
# ATLAS+CMS combo: WW hypothesis



# ATLAS+CMS combo: ZZ hypothesis



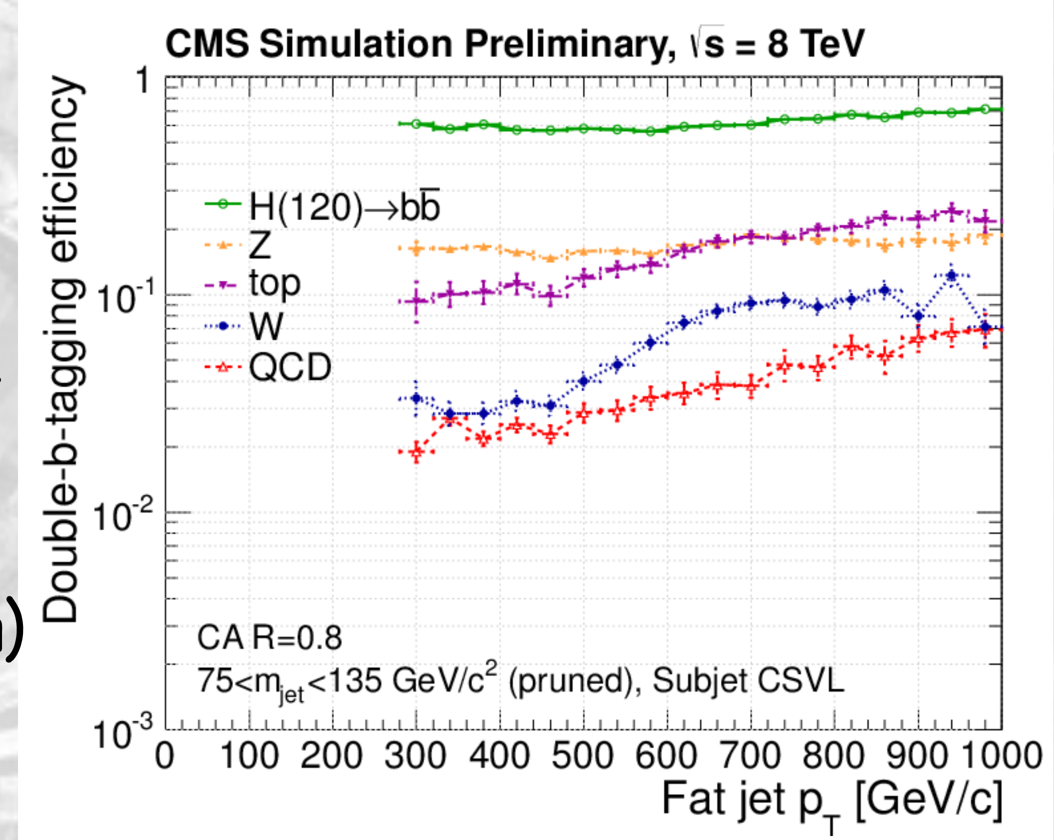



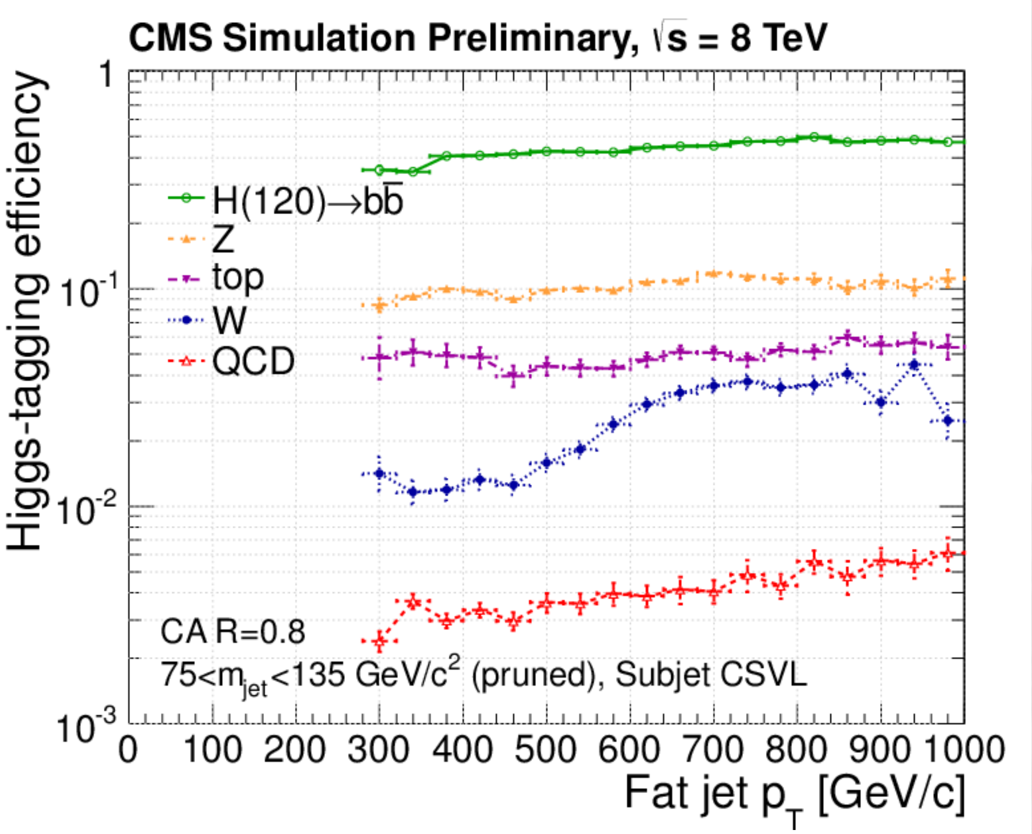
# ATLAS+CMS combo: WZ hypothesis

# Backup Slides

# From boosted V to boosted H→bb

- **Subjet CSV**
  - resolve two subjets of R=0.2 inside the H jet
  - apply the standard b-tagging algorithm to the subjets
  - similar performances (and data/MC comparison) than the standard b-tagging algorithm
  - Strong bkg killer: 2 b-tags inside the jet
- **Fat-jet CSV**
  - apply the standard b-tagging algorithm to the subjets
  - no need to resolve subjets (less demanding for detector granularity)



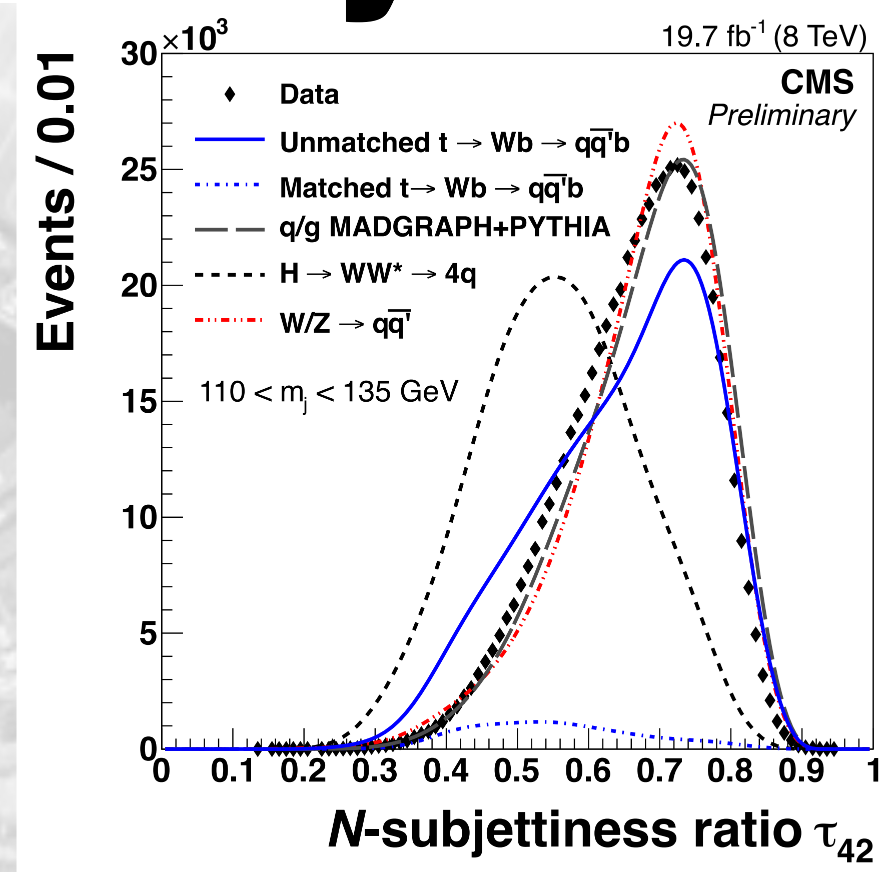

CMS-BTV-13-001

# More Higgs decays

## H→WW*

- Four jets collapsing into a single jet
- Same strategy as boosted V, using $\tau_{42}$ rather than $\tau_{21}$

**CMS-EXO-14-009**



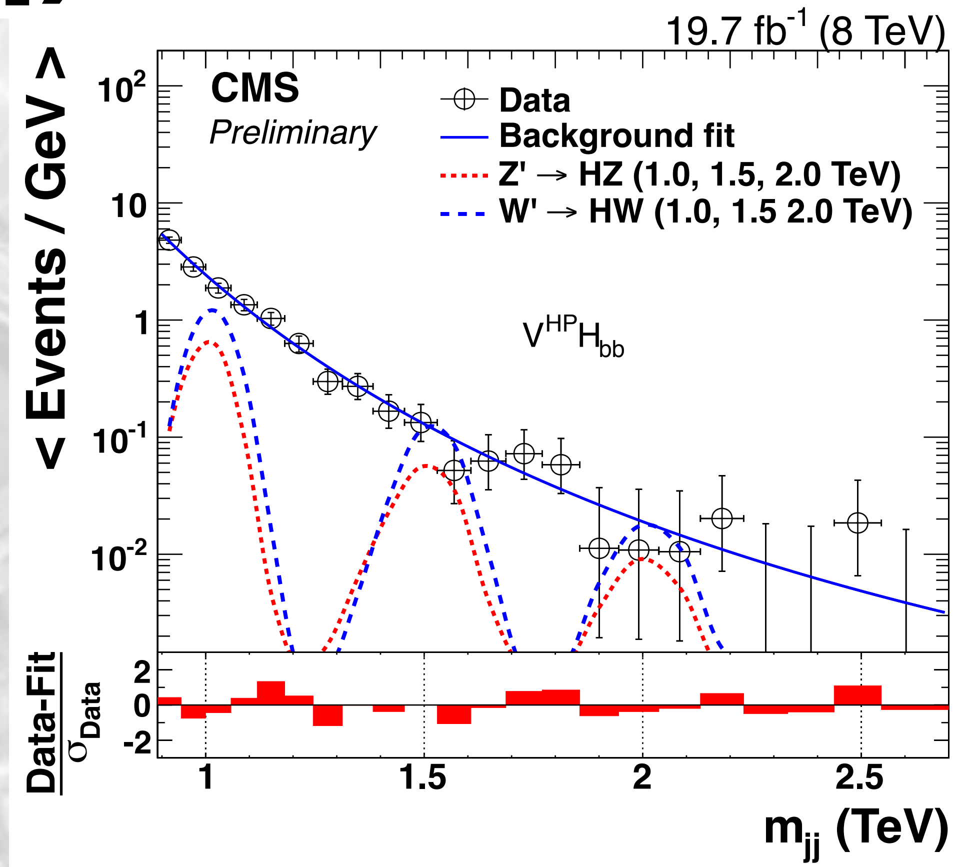

## H→ττ

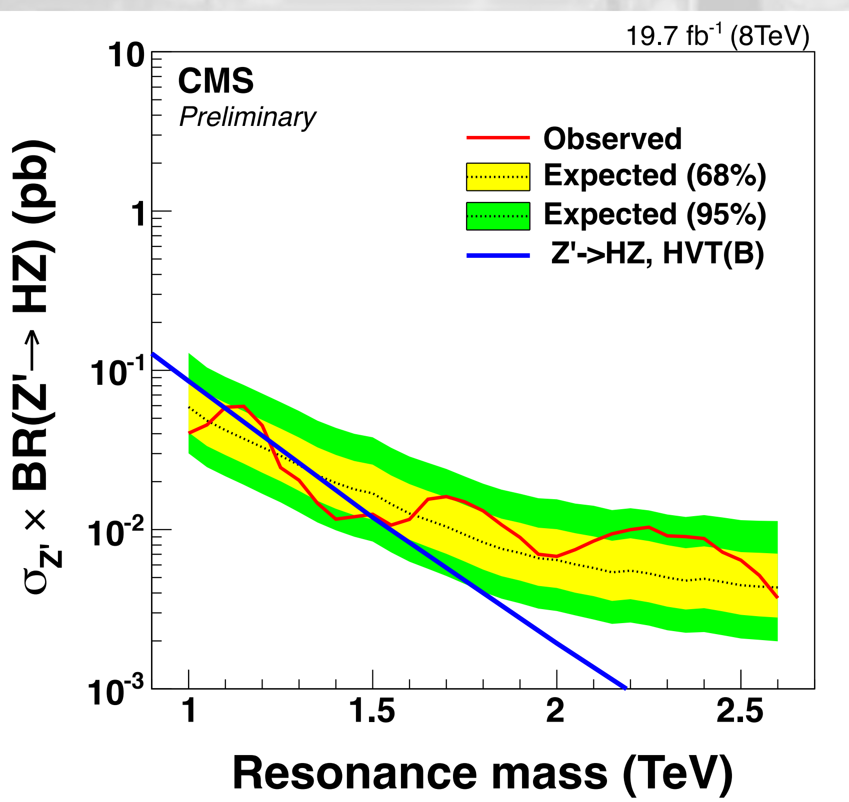
- Same strategy as standard tau reconstruction
- In this case, two overlapping taus
  - for eth and mth, search for a tau overlapping with an e/m, removing isolation requirements
  - for thth, modify the tau identification algorithm to consider the case of two overlapping taus (i.e., different multiplicity requirements

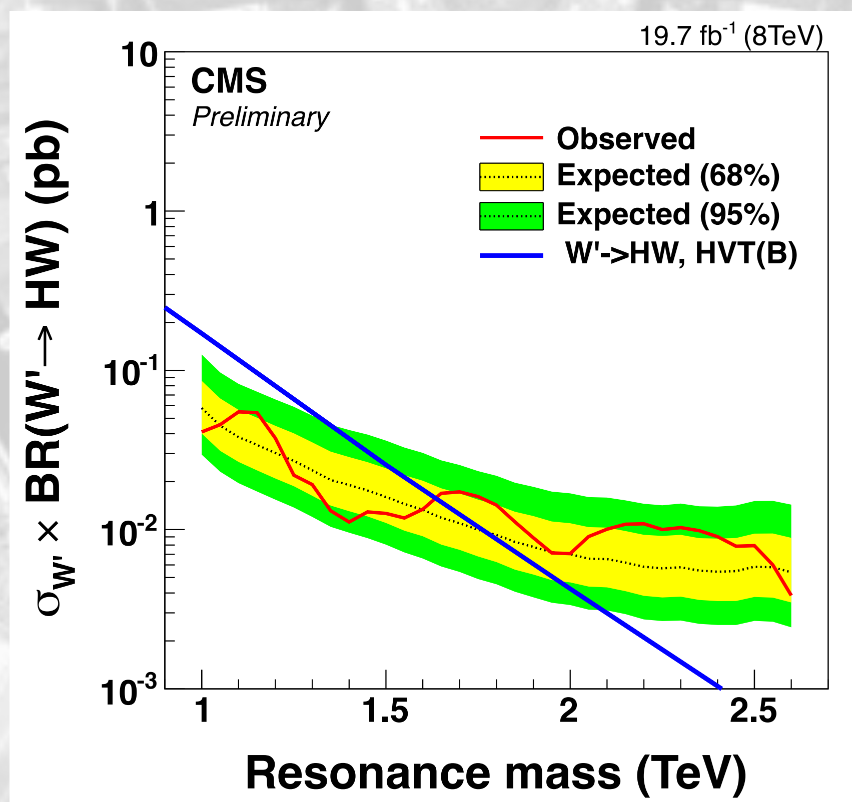
**CMS-EXO-13-007**

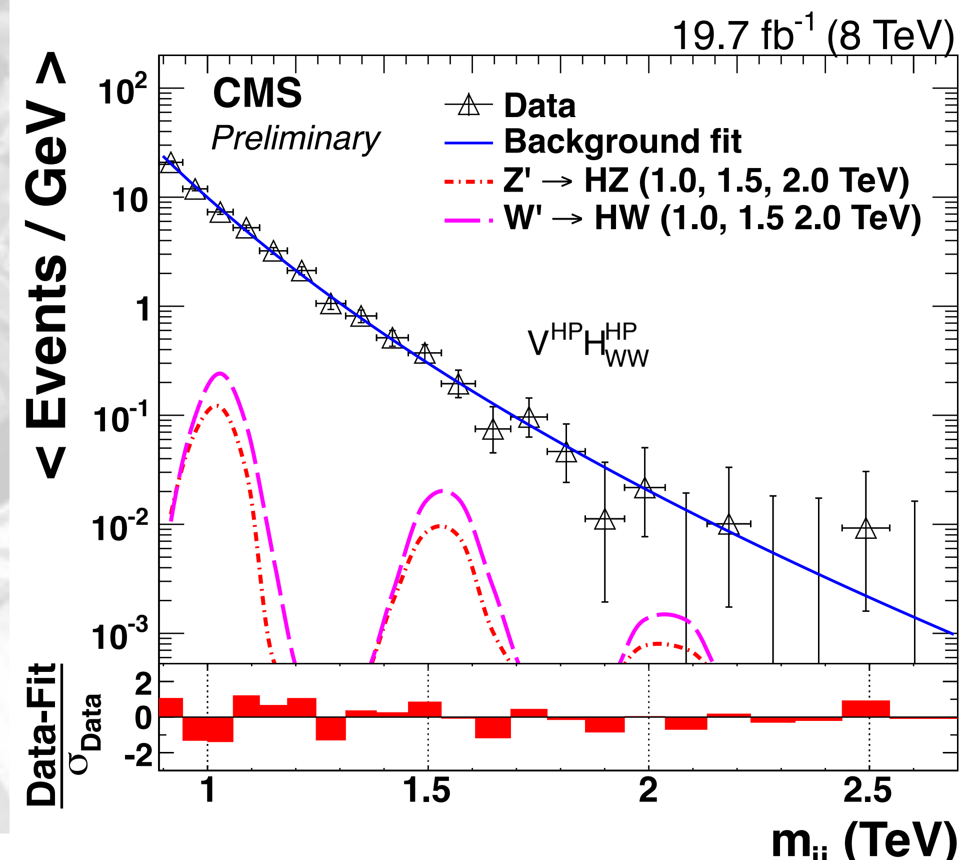
# X→H(bb/WW*)V(qq) search

- Same strategy as fully hadronic VV search
- Sensitive to both WH and ZH (no discrimination)
- No significant excess seen: some hint of a bump, but uncertainty on bkg shape "covers" it
- Results combined assuming Higgs SM BRs



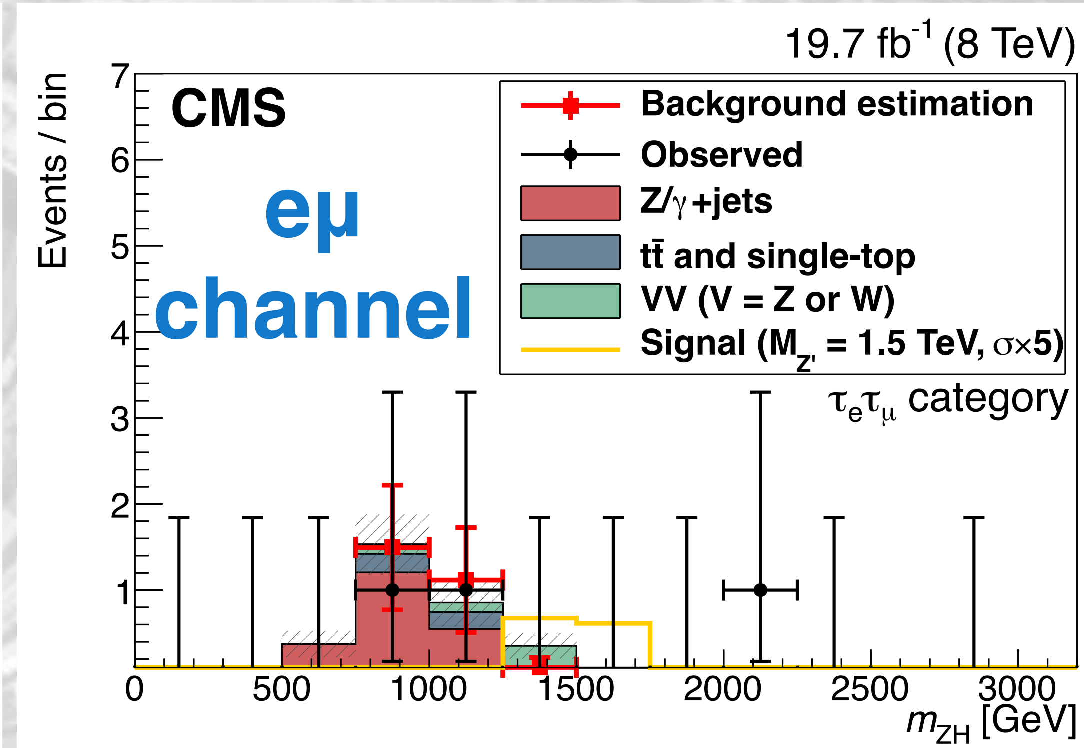



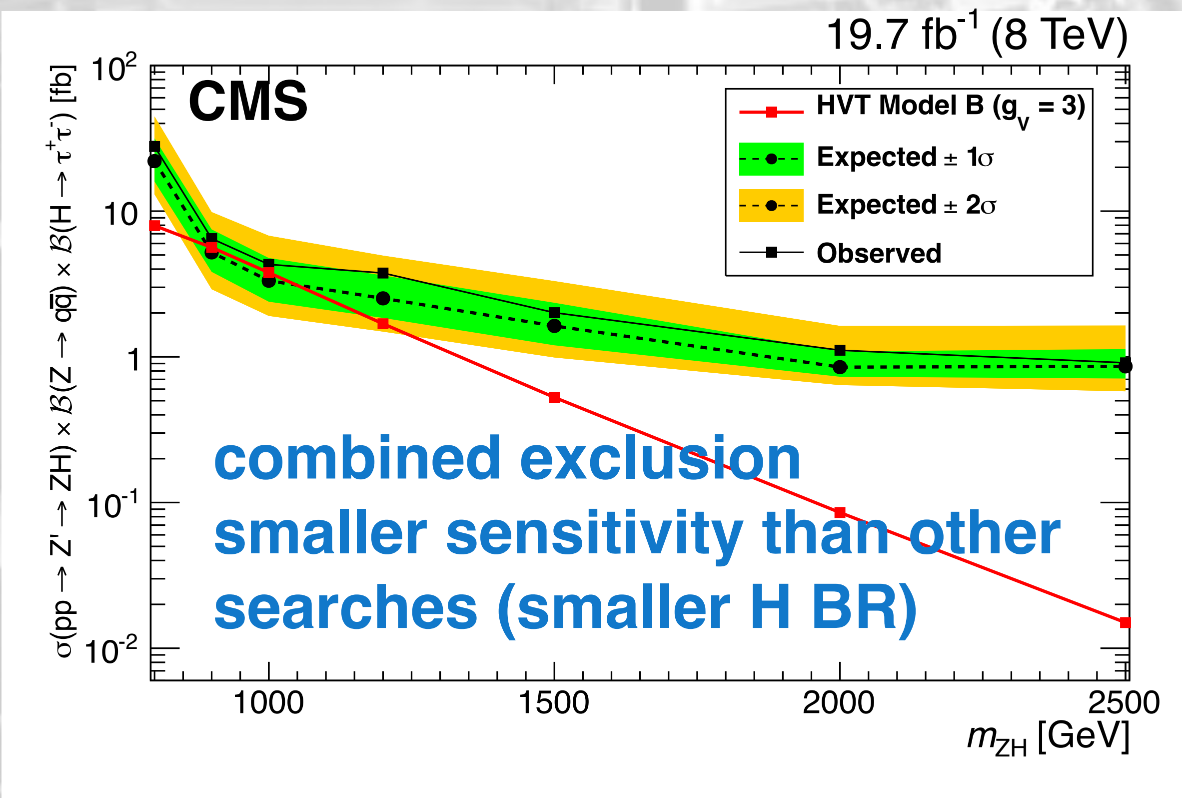



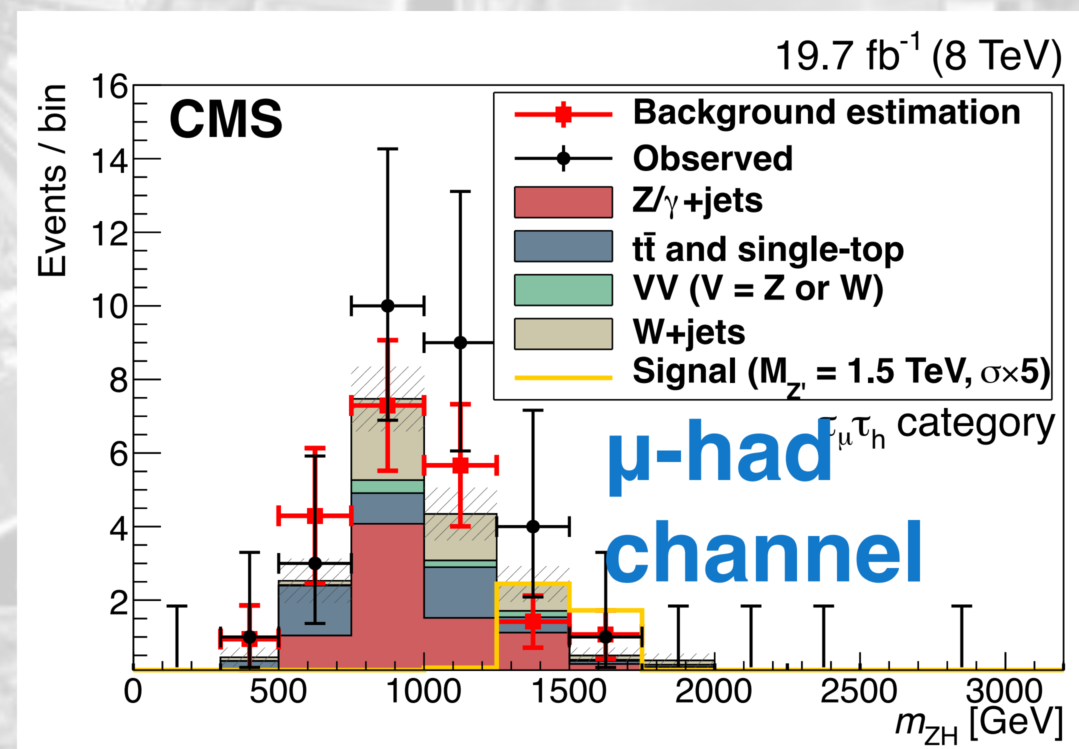

CMS-EXO-14-009

# X→H(ττ)V(qq) search

- Same V tagger as other analyses
- Special reconstruction of boosted taus
- Background predicted from data sidebands
  - low jet mass window
  - ditau mass window below the Z
- No excess observed



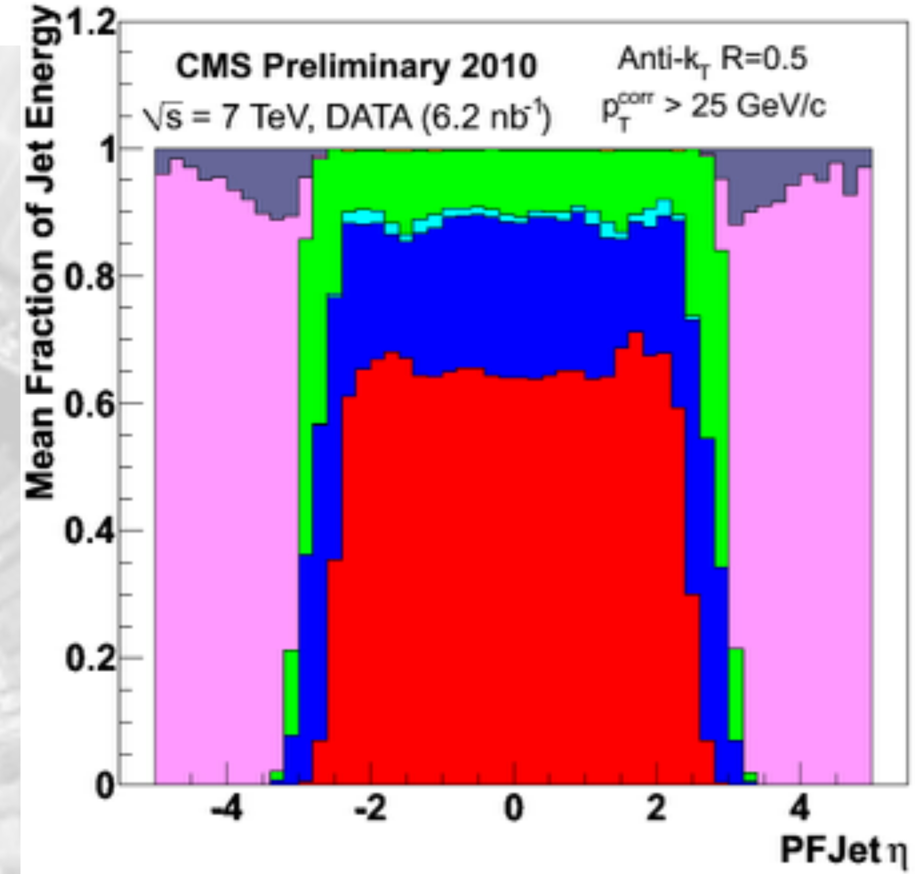



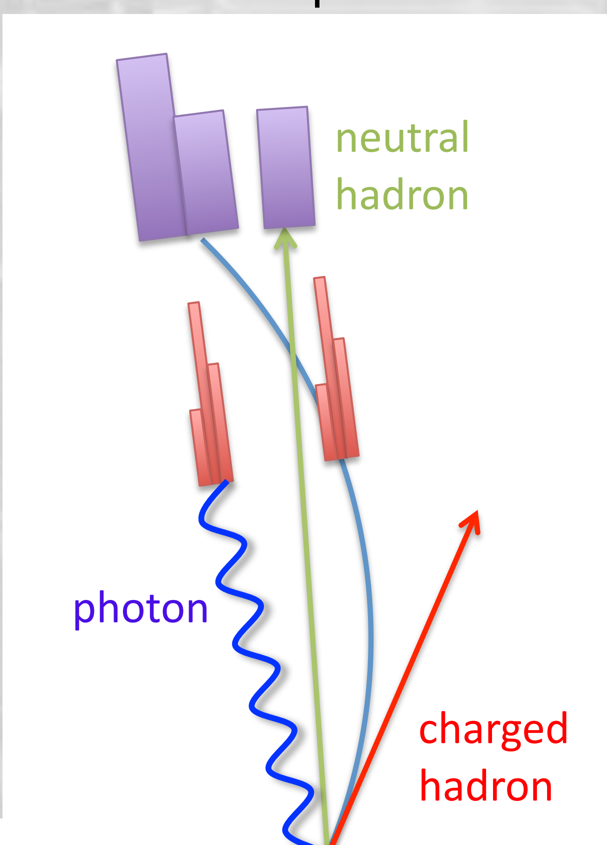

CMS-EXO-13-007

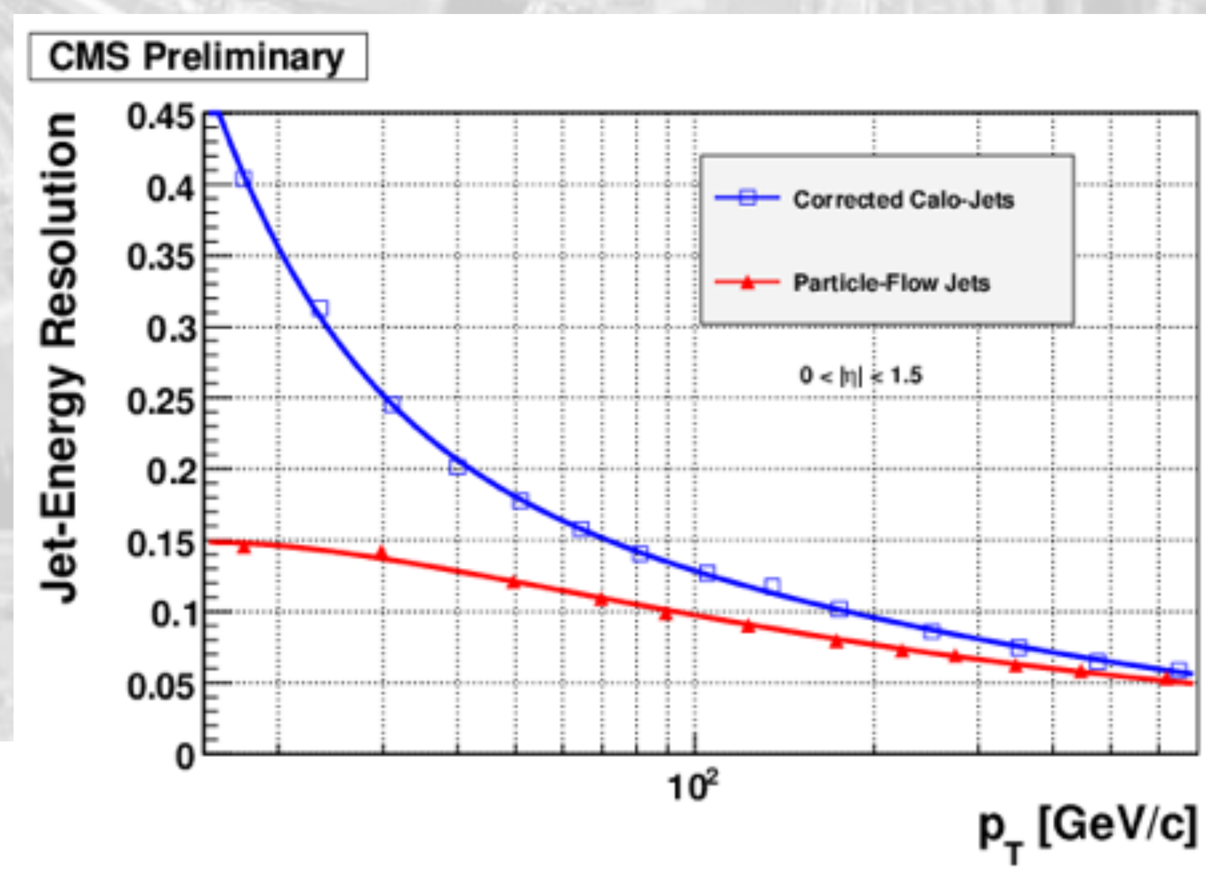
# Jets of What?

- **Traditionally**, jets of energy deposits in calorimeters
  - Call each deposit a massless “particle”
  - Add the 4-mom of particles to get jet 4-mom
  - Require good calorimeter resolution



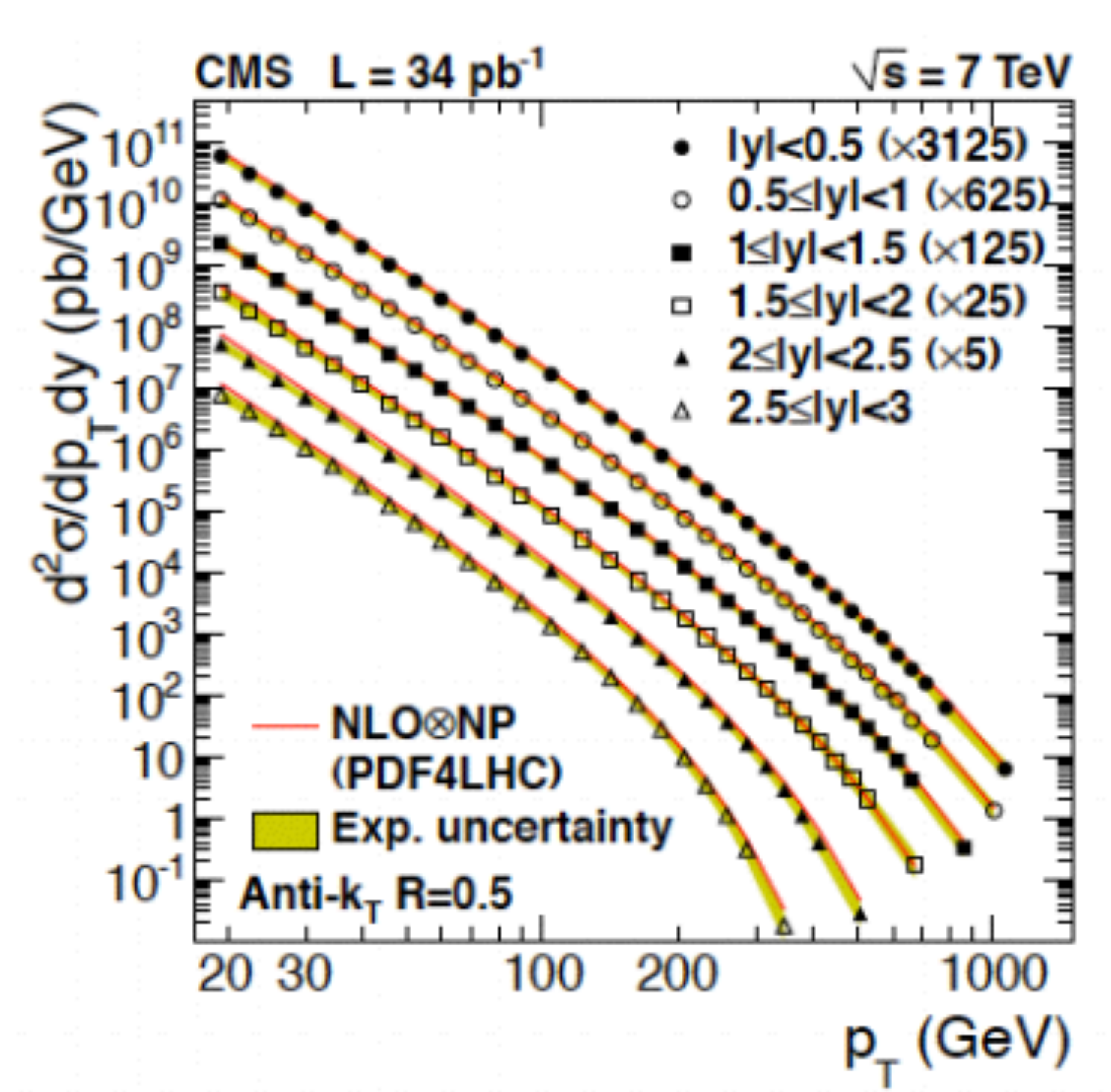

- **Particle Flow**: use information from all detector components
  - reconstruct particles first (**e**, **μ**, **γ**, **charged hadrons** and **neutral hadrons**)
  - cluster particles in jets
  - Better energy resolution and much more



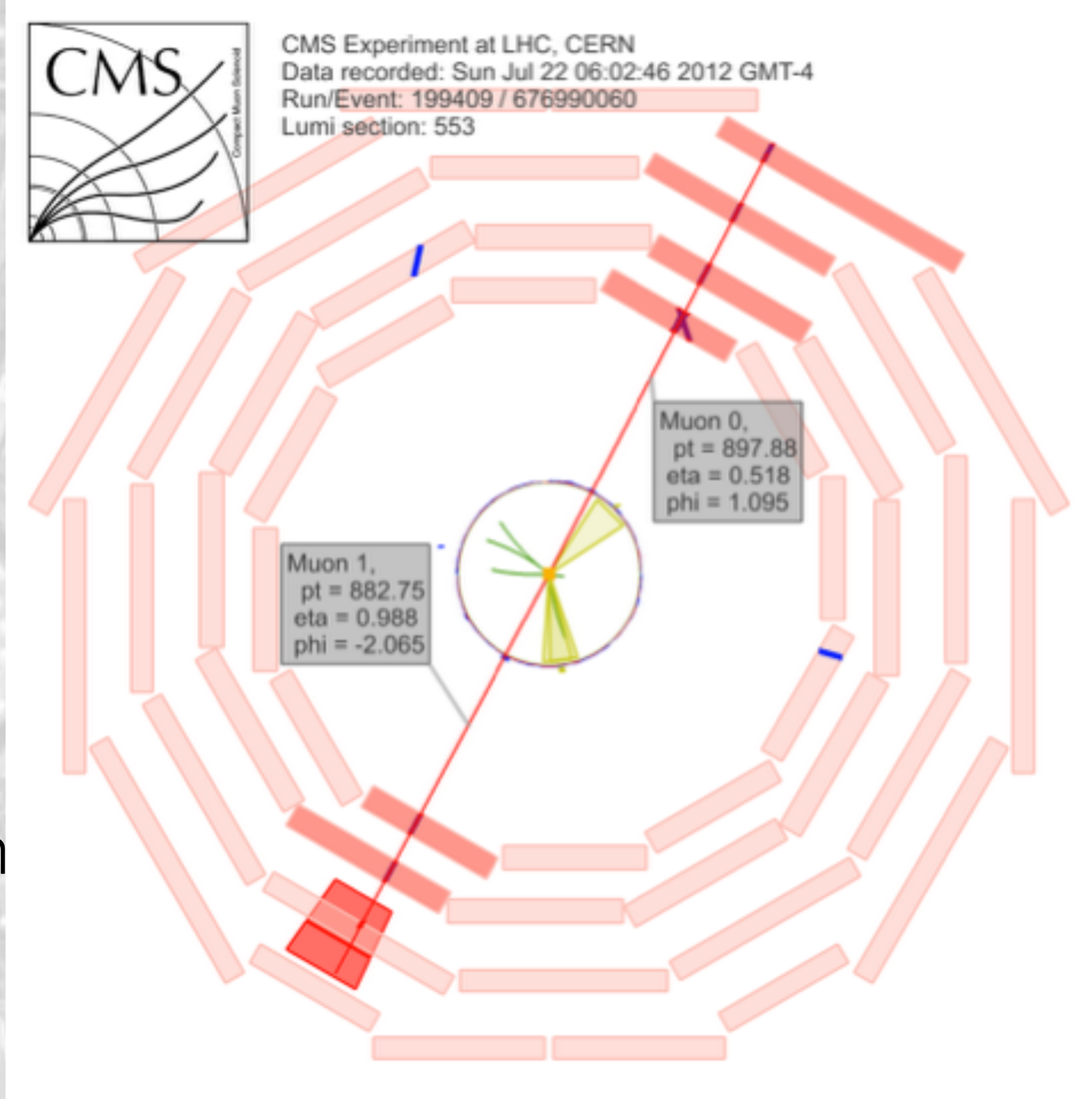
# Precision Physics with jets

- Jet physics @LHC is precision physics
  - Multijet NLO calculations in event generators
  - Accurate simulation of detector effects
  - Solid jet definition
- Intense program of SM measurements served as precise validation
- This set the stage for an extended search for New Physics with jets



# High-PT Muons

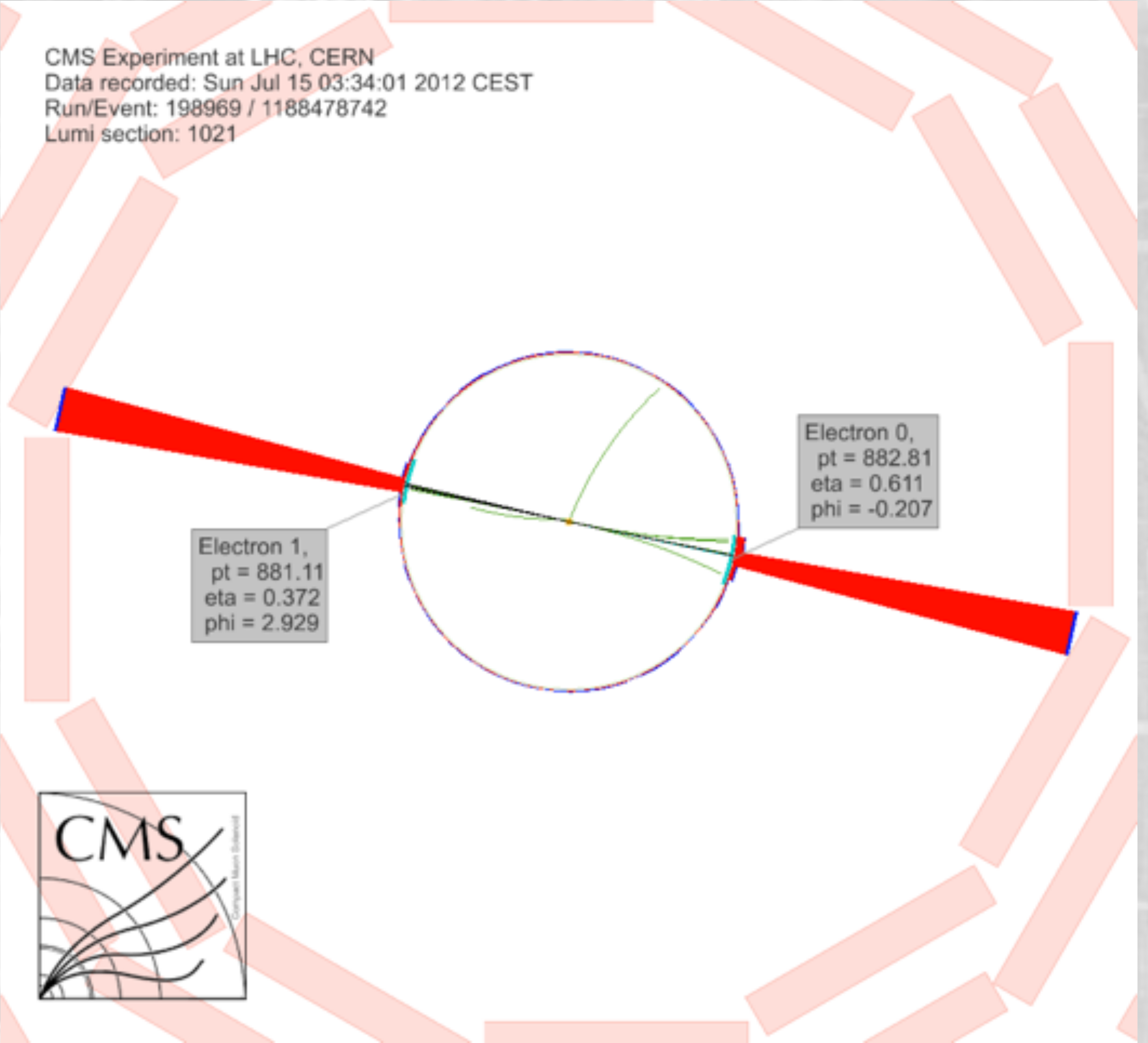
- Muon momenta are measured through the bending in the magnetic fields
- The bending is reduced at large muon momenta
- For high-pT muons, the precision deteriorates
- Unlike the case of measurements with W/Z/top/H, muon final states are not the golden channel for this physics
- Despite the resolution, high-pT muons are an excellent discovery tool




$$\sigma_{p_T}/p_T \sim p_T/(qBL)$$

# High-Pt Electrons

- Electron momenta are measured in the tracker and in the calorimeter
- The resolution of the calorimeter improves with energy, giving a better S vs B discrimination above 1 TeV
- Electrons (and photons) are excellent tools to search for davy resonances and measure their masses



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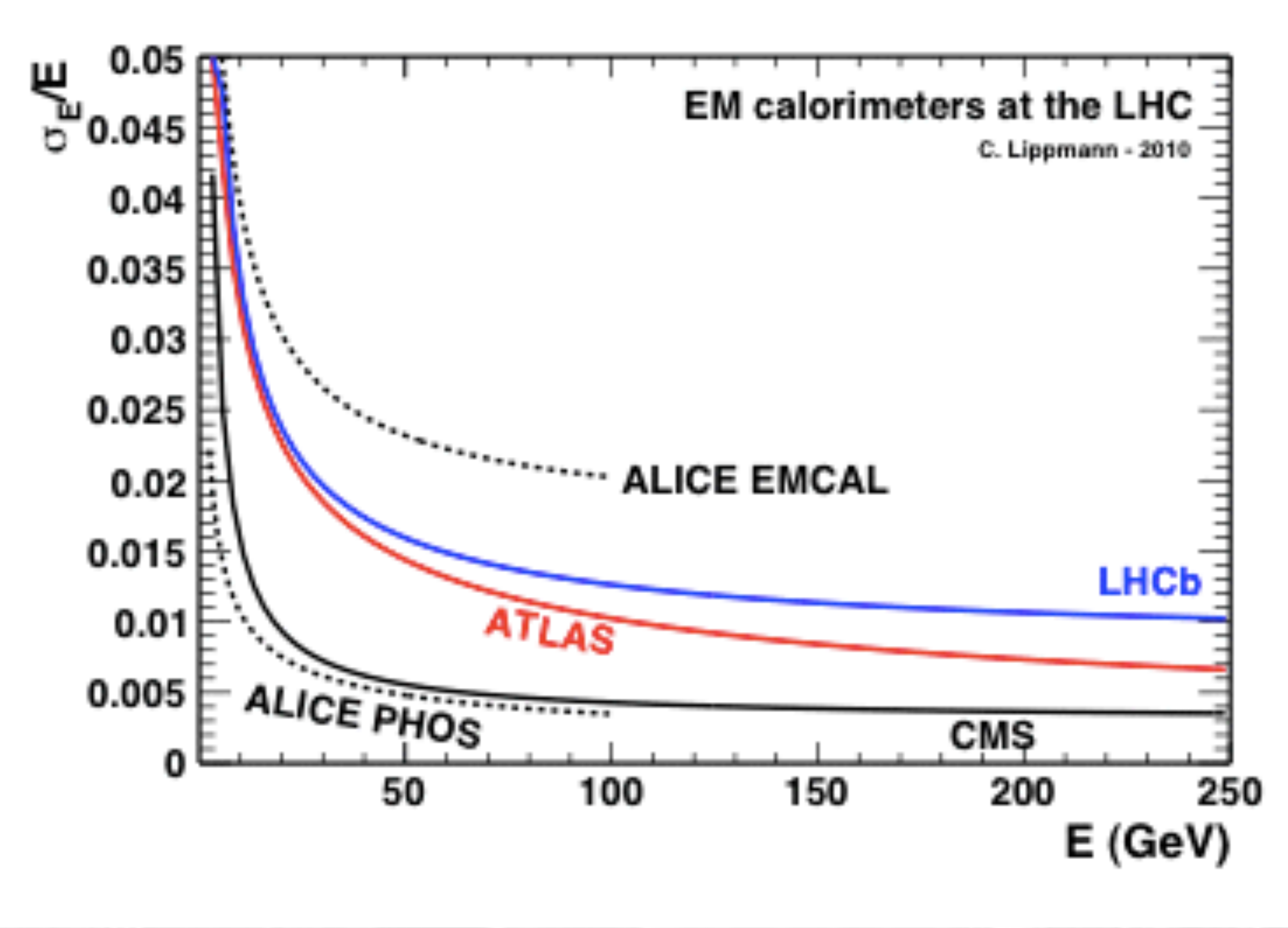


$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

a ~ 0.027 $GeV^{1/2}$
b < 200 MeV
c ~ 0.005

# Dilepton Search