VV/VH/HH Bumps @ ATLAS

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750(γγ) & Related : Ben Pearson

What are we doing?

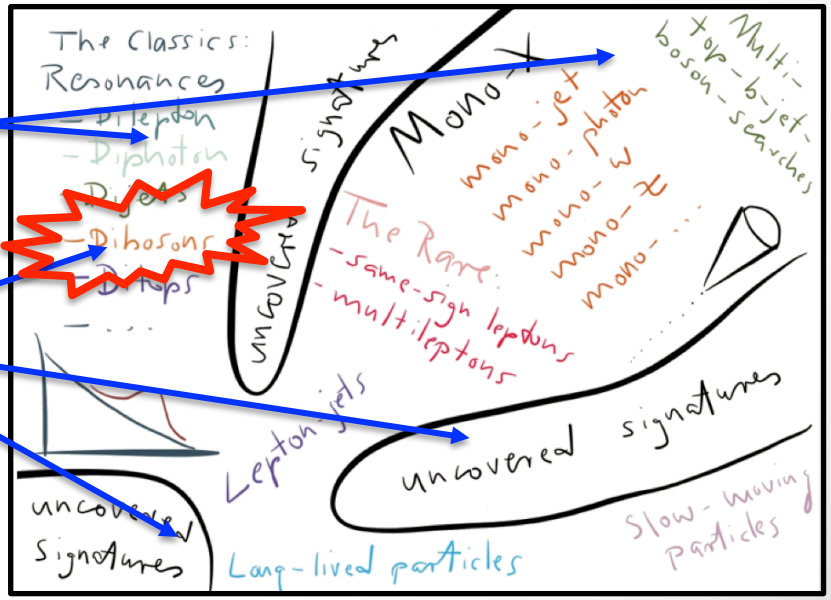
- Signature based searches
  - Basic Philosophy : cover (as much of) the theory space as we can with a set of searches based on more general experimental signatures

Our signature : X → VV/VH/HH ⊕ BR(V→qq) ~ 70%, BR(H→bb) ~ 60%

New Physics

(Hitoshi Murayama)

Experimental Signatures

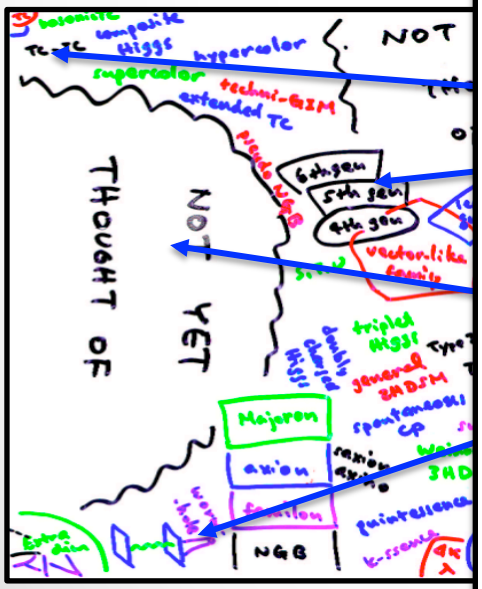


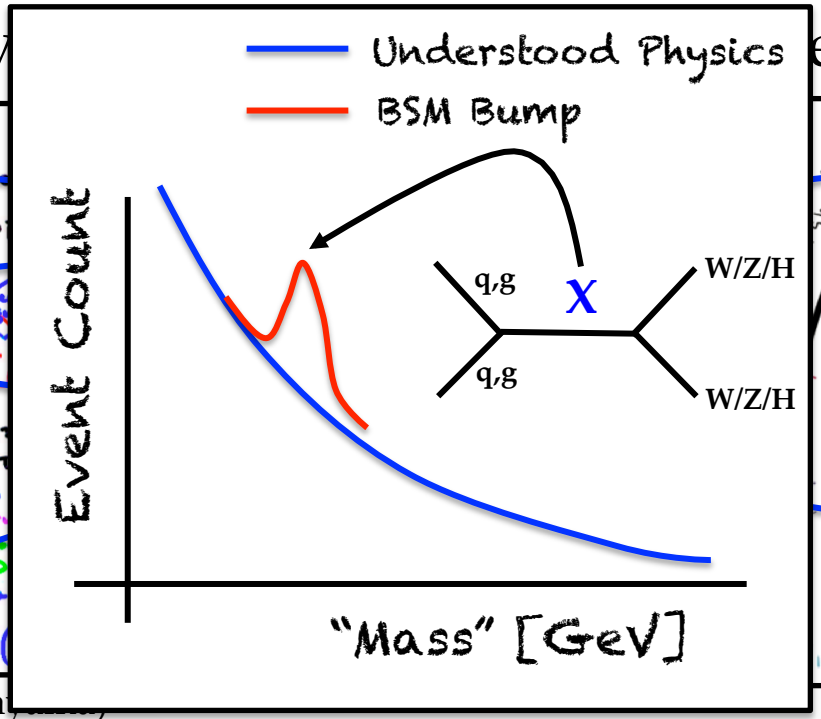
"No hole left behind!"

What are we doing?

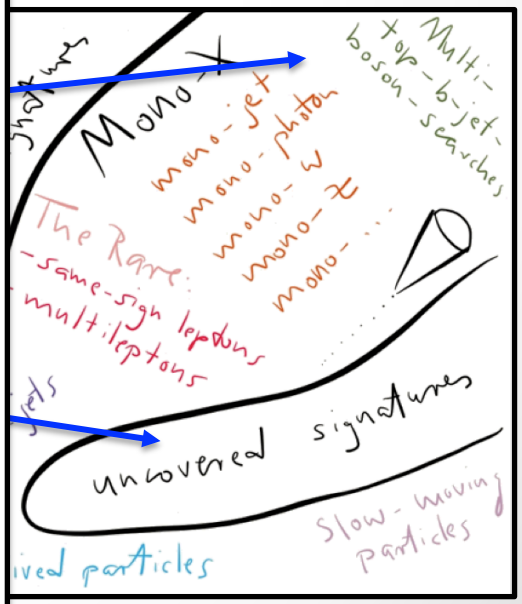
- Signature based searches
  - Basic Philosophy : cover (as much of) the theory space as we can with a set of searches based on more general experimental signatures
- Bumps and tails
  - Inspect some mass spectrum (or proxy mass spectrum) and look for excess not explained by well understood phenomena

New Phy





ental Signatures



(Hitoshi Mura

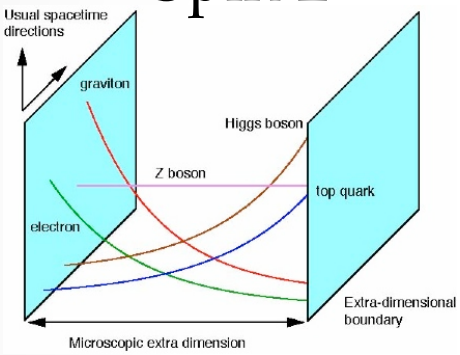
"No hole left behind!"

What are we "looking" for?

- Two(x) primary benchmark models used to guide searches

KK-Graviton (G*)

Spin 2



Parameters of Interest

Warping factor, k/M_{plank}

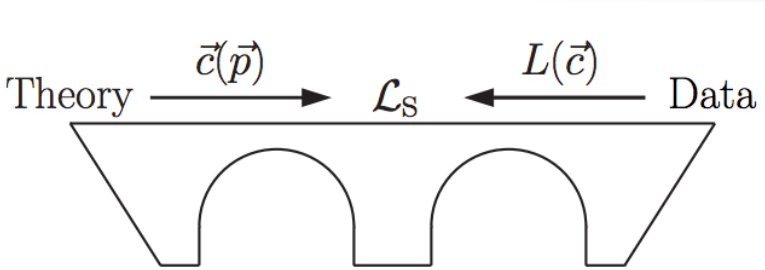
$$ds^2 = e^{-2kr_c\phi}\eta_{\mu\nu}dx^\mu dx^\nu + r_c^2 d\phi^2$$

Channels

G* → WW/ZZ/HH

Heavy Vector Triplet

Spin 1



Parameters of Interest

Couplings in "EFT-like" lagrangian

$$\mathcal{L} \subset i g_V c_H V_\mu^a H^\dagger \tau^a D^\mu H + \frac{g^2}{g_V} c_F V_\mu^a J_F^{\mu a}$$

Channels

$V'^{\pm}$ → WZ/WH , V'^{0} → WW/ZH

The Ingredients

Large-R Jets

"Standard"

(1) Electrons

(2) Muons

(3) R=0.4 Calo Jets

(4) Missing E_T

$\oplus$

The Special Ingredients

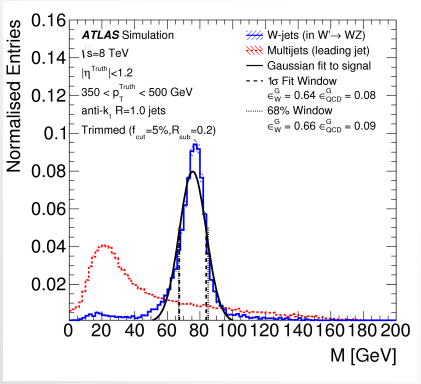
Large-R Jets

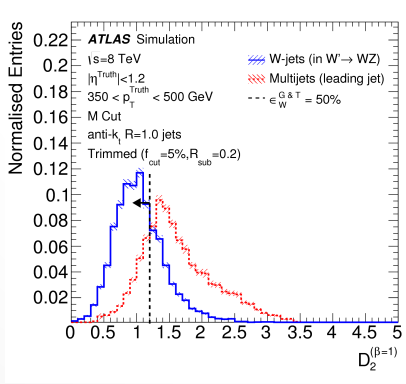
- Baseline Jet : Topoclusters → anti-kT R=1.0 → Trimmed(R_{sub}=0.2,f_{cut}=5%)
  - Kinematics : pT down to 200 (250) GeV & $|\eta| < 2.47$
- W/Z jet : [Mass] + [D_2] → tuned selections vs. p_T
- Higgs jet : [Mass] + [track jet b-tags]

Boson Jets

Efficiency ~ 50% / Rejection ~ 50

W/Z mass ⊕ Two-lobes



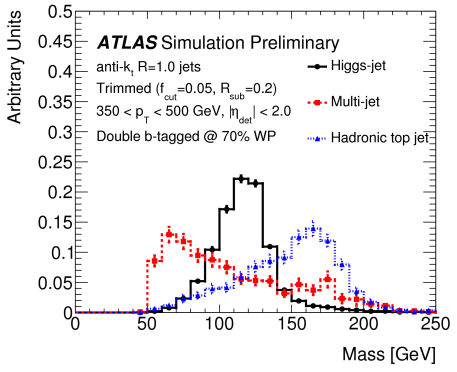


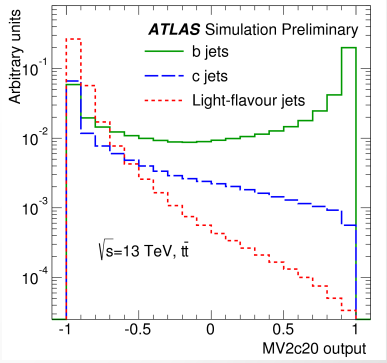
PERF-2015-03 , ATL-PHYS-PUB-2015-033

Higgs Jets

Efficiency ~ 50% / Rejection ~ $10 \rightarrow 10^6$

Higgs mass ⊕ Two flavored lobes





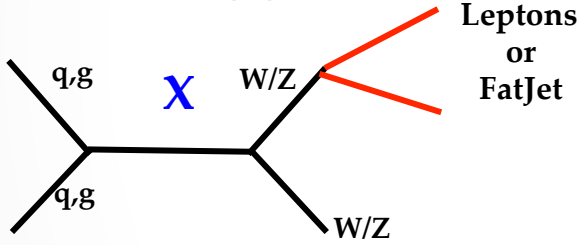
ATL-PHYS-PUB-2015-035 , ATL-PHYS-PUB-2015-022

VV
(vvqq/lvqq/llqq/qqqq)

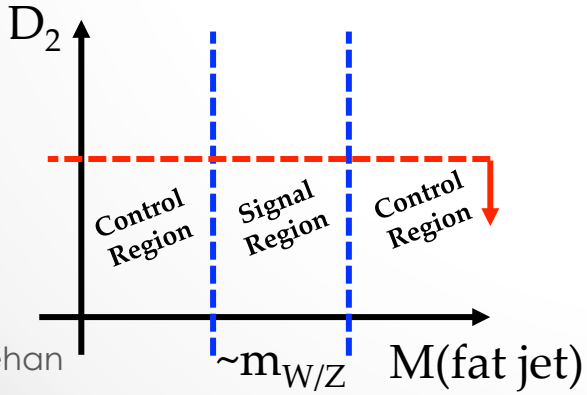
Search Strategy

- Search strategy
  - Semileptonic : Trigger on leptons → boson-tag hadronic jet
  - Fully Hadronic : Trigger on high pT jet → double boson-tag
- Background estimation by background composition
  - Semileptonic (V+jet/ttbar): MC-based with dedicated control regions
  - Fully Hadronic (Multijet) : Fit of smoothly falling background (ala dijet searches)

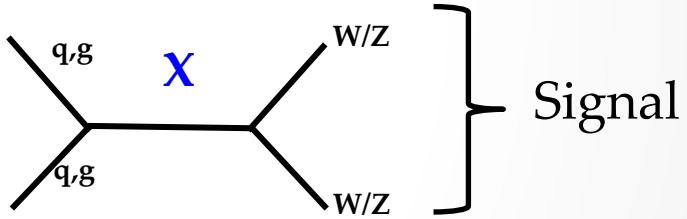
(1) Trigger

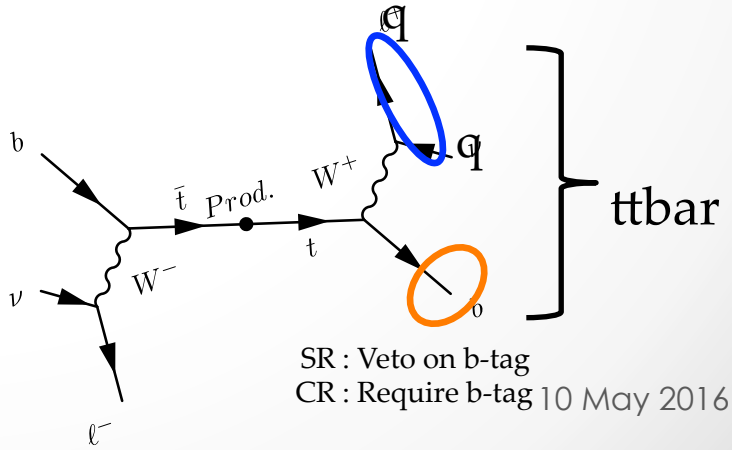


(2) Hadronic Boson Tag



(3) Controlling ttbar





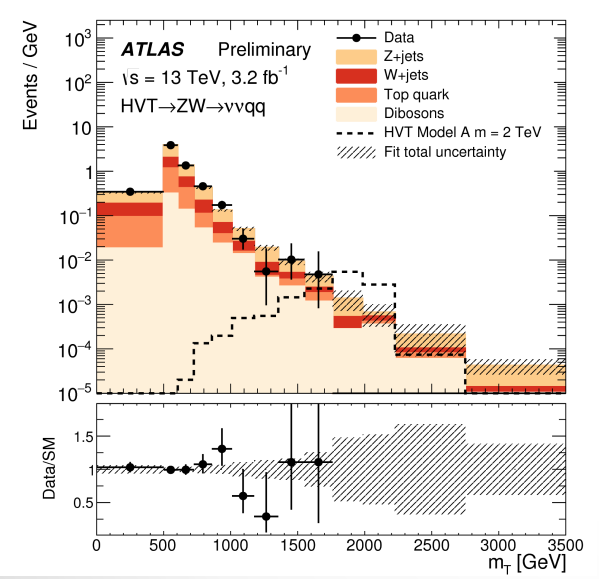
SR : Veto on b-tag
CR : Require b-tag

Search Results

- Search performed via combined fit to all SR and CR
  - Rely on MC backgrounds and constraints between SR's and CR's

0 Lepton (ZZ/ZW)

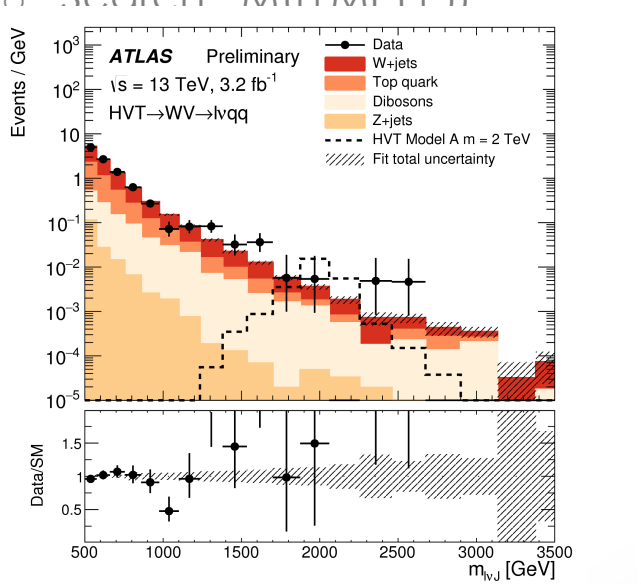
- MET trigger + high MET
- anti-QCD topology Cut
- Separated b-jet veto
- Search : MT(Met+J)



ATLAS-CONF-2015-068

1 Lepton (WW/WZ)

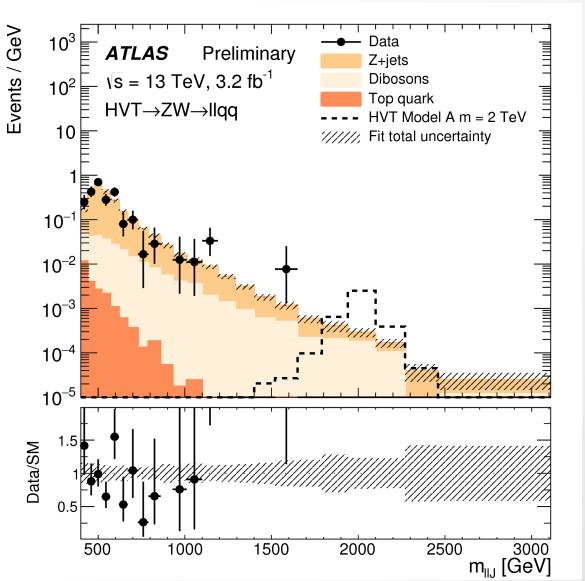
- Single e/μ trigger
- $p_Z(\nu)$ from M_W constraint
- Kinematic selections for sensitivity ($p_T^V/M_{l\nu}$)
- Search : M(l+MET+ J)



ATLAS-CONF-2015-075

2 Lepton (ZZ/ZW)

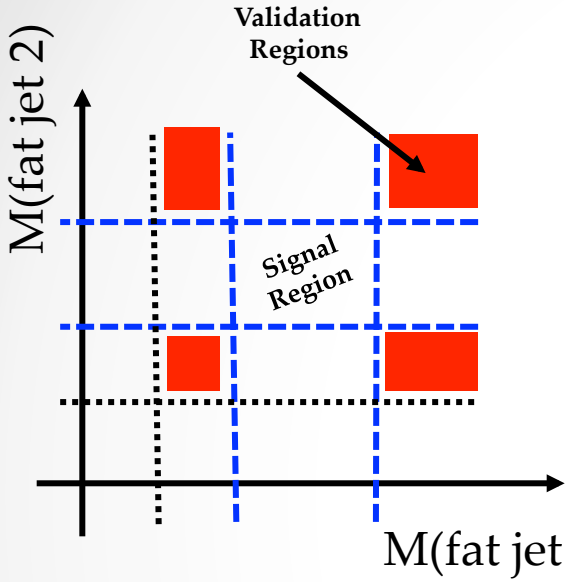
- Single e/μ trigger
- Dilepton mass m_{ll}~m_Z
- pT(ll) constraint by m_{ll}=m_Z
- Search : M(l+l+J)



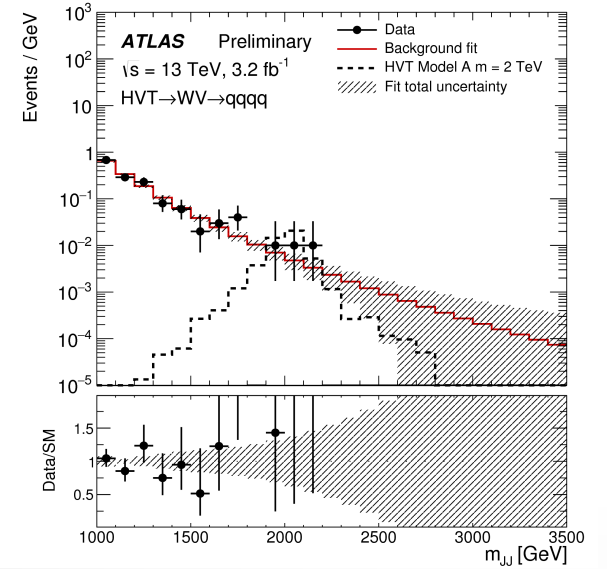
ATLAS-CONF-2015-071

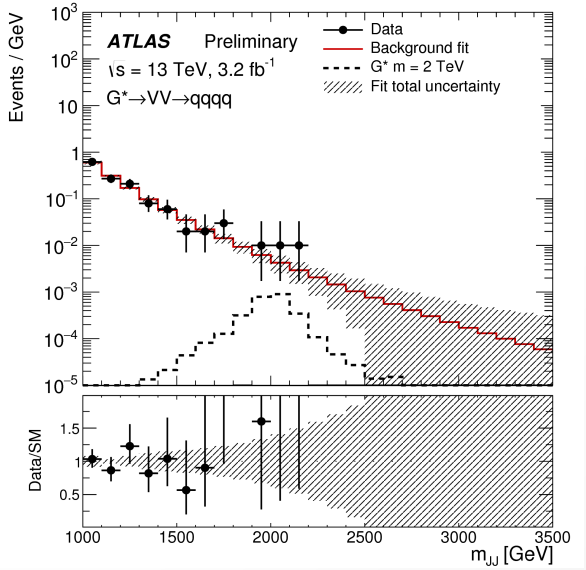
EXOT-2016-01

ZZ/ZW/WW→qqqq



- Signal Region
  - Large-R single jet trigger
  - Two leading boson-jet tags
  - selection on N_{track}(fatjet parent)
  - Topology selection : Dijet p_T balance + $\Delta y(JJ)$
- Backgrounds : data-driven
  - Parameterized background : $\frac{dn}{dx} = p_1(1-x)^{p_2+\xi p_3} x^{p_3}$
- Search : M(JJ)

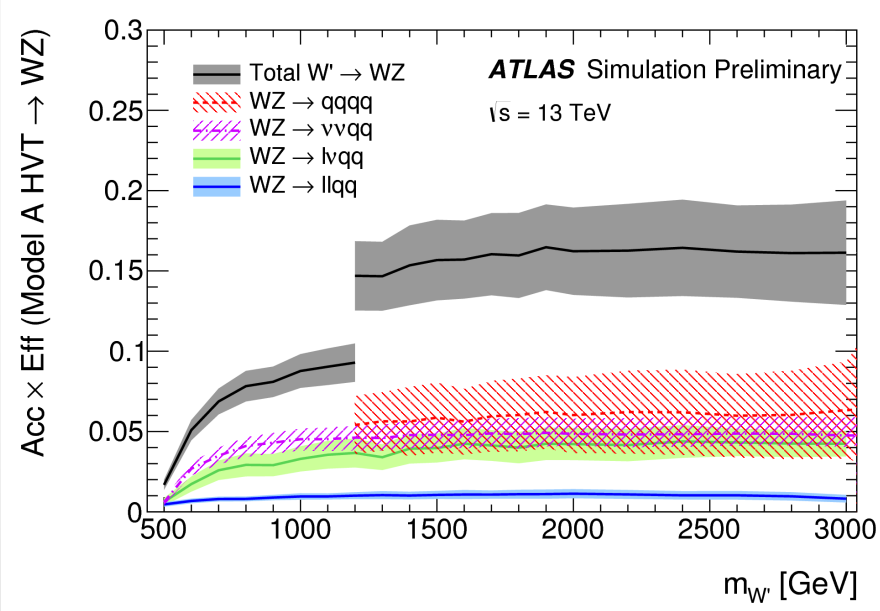


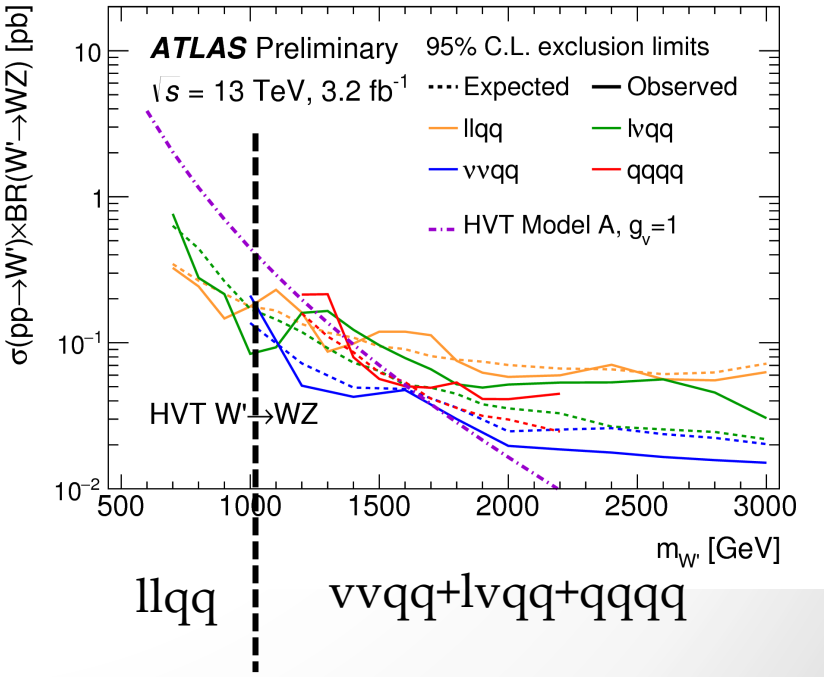


EXOT-2016-01

VV Combination

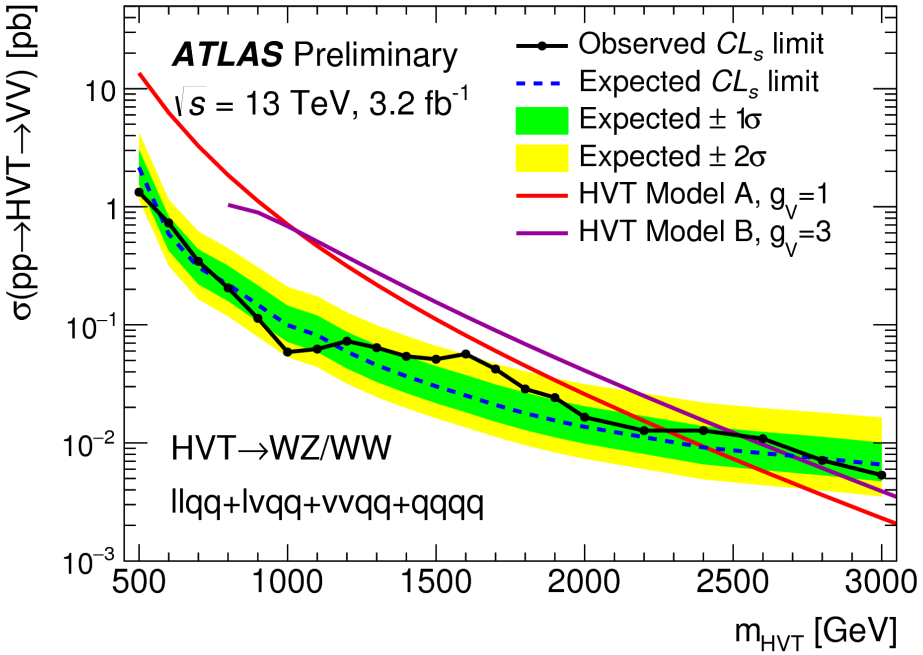
- No "dominant channel" above 1 TeV
  - Full combination of all channels really worth it → sizeable sensitivity gain
- Obvious question : Can qqqq go lower?
  - Trigger level analysis? JSS in the trigger? (https://cds.cern.ch/record/2104248)

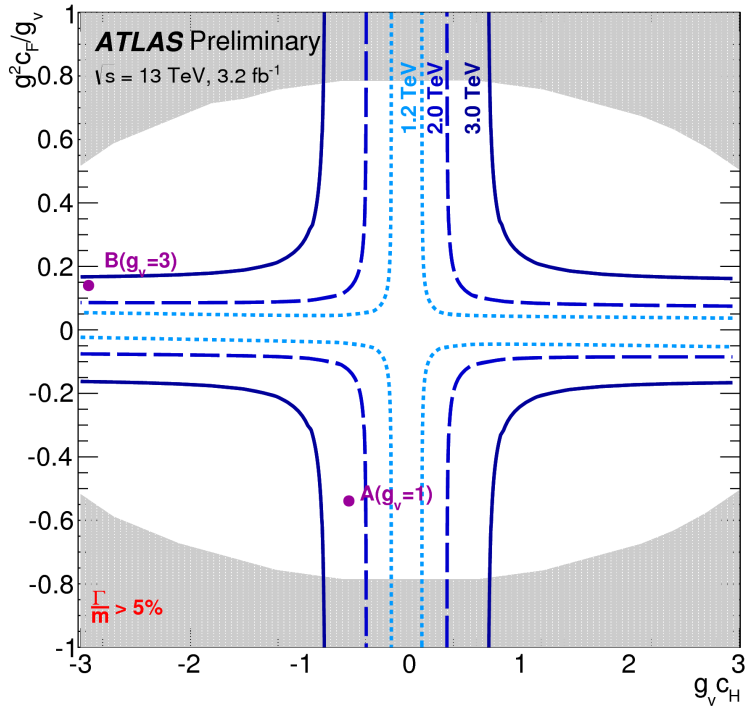




VV Combination

- What can we do with these results?
- Begin to constrain the HVT coupling strengths
  - Along with acceptances/efficiencies → more general constraints



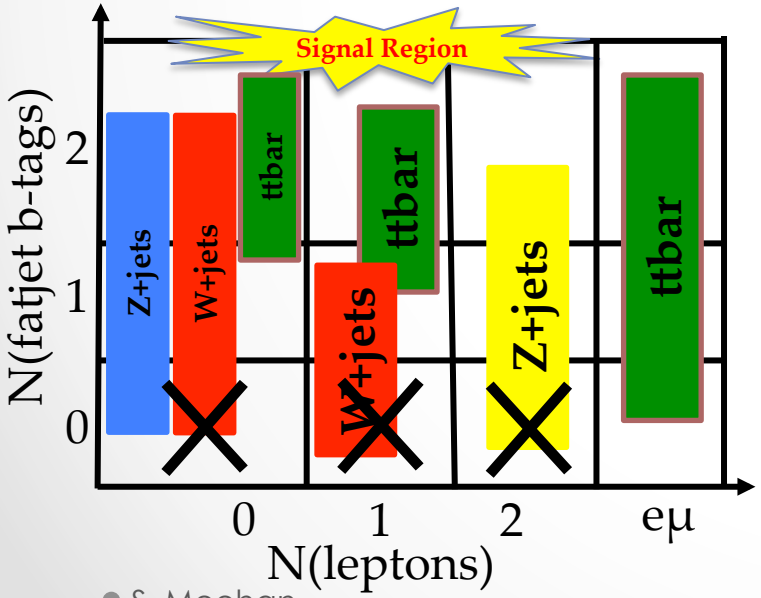


VH
(vvbb/lvbb/llbb)

ATLAS-CONF-2015-074

Search Strategy

- Analysis very similar to semi-leptonic VV
  - Rely on flavor for control region design
- Backgrounds : fully MC-based
  - WZ+jets → ttbar → SM diboson → single top
  - Combined likelihood fit constrains backgrounds
    - Much experience from Run 1 SM-VH(bb) search



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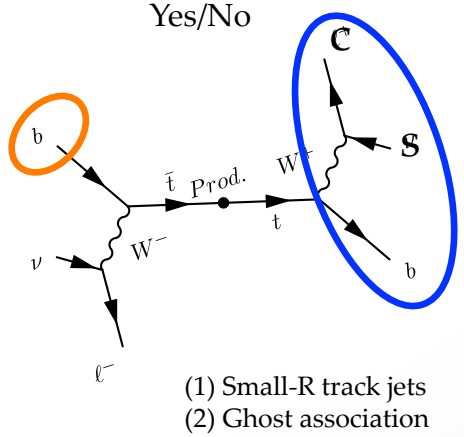

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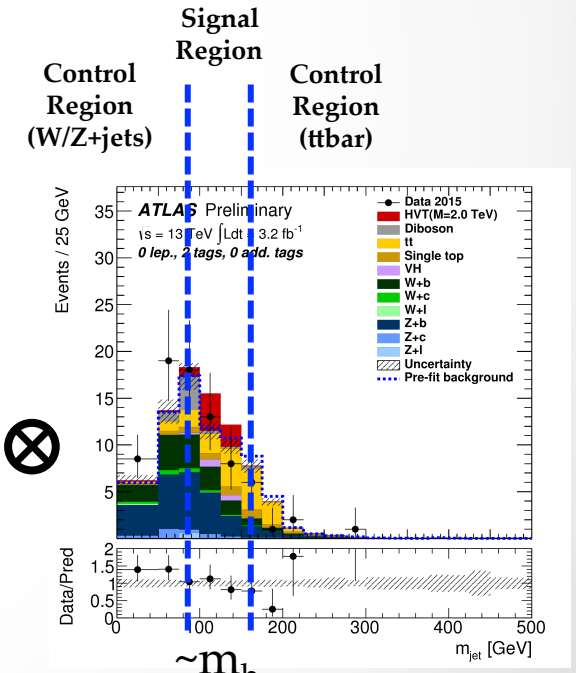
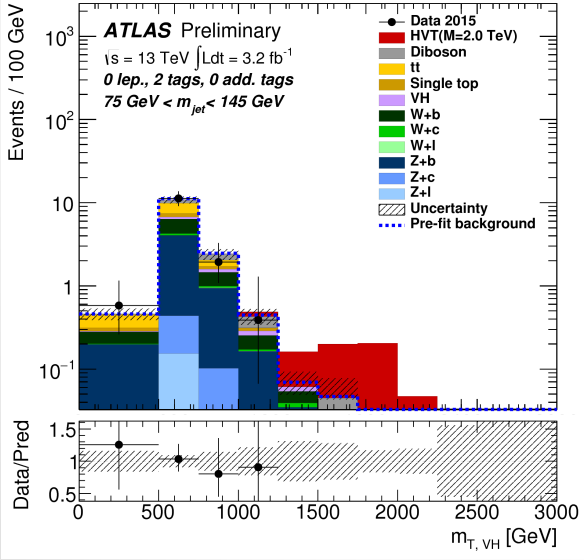


Search Results

- Analysis very similar to semi-leptonic VV … with flavor
  - Rely on flavor for control region design

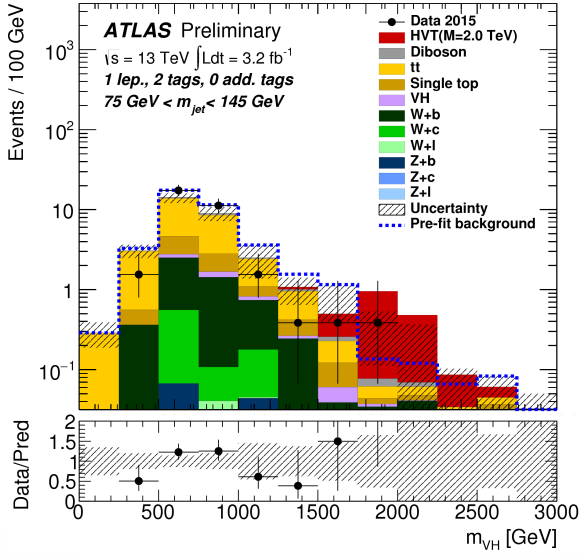
0 Lepton (ZH)

- MET trigger + high MET
- Separated b-jet veto
- Search : M_T(MET+J)



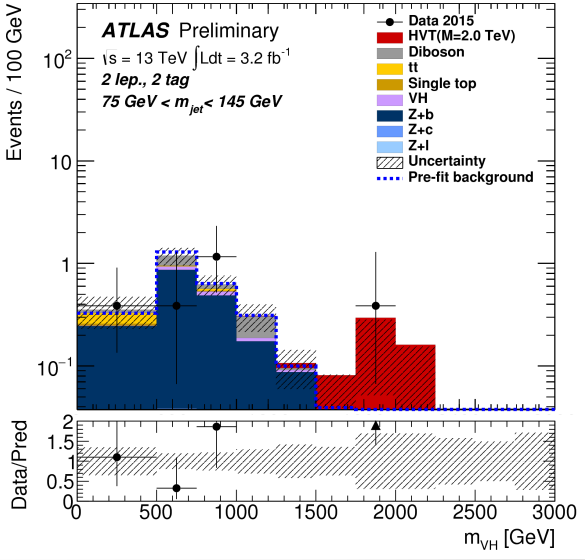
1 Lepton (WH)

- Single e/μ trigger
- High MET
- Search : M(l+MET+J)



2 Lepton (ZH)

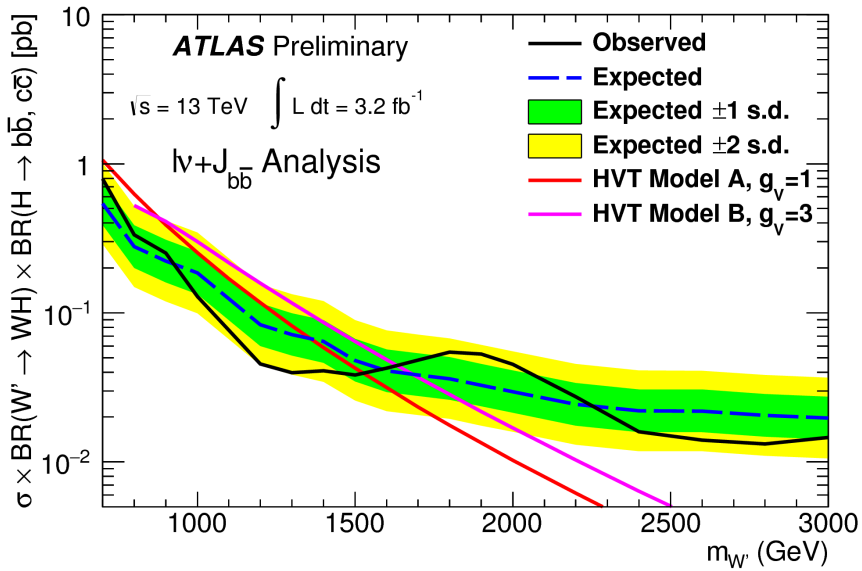
- Single e/μ trigger
- Dilepton mass $m_{ll} \sim m_Z$
- Search : M(l+l+J)



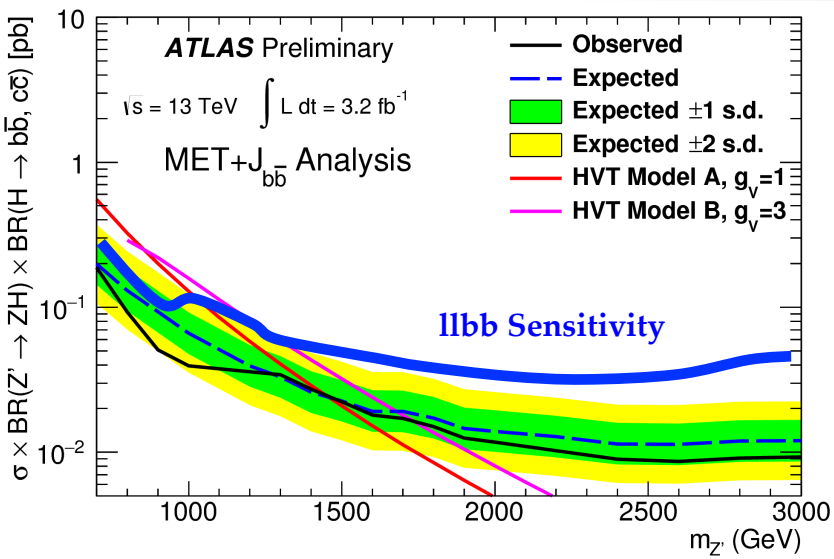
Constraints

- Heavy Vector Triplet is main benchmark
  - $V'^{\pm}$ constrained from 1 lepton channel
  - V'^{0} constrained from 0/2 lepton channels
- Combine with VV searches? → more global constraints

HVT Charged $V^{\pm}$



HVT Neutral V^{0}

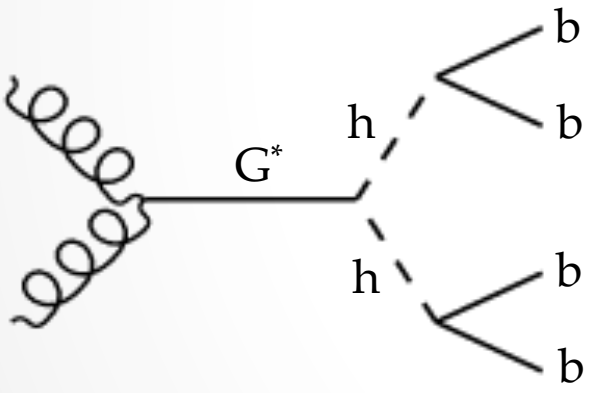


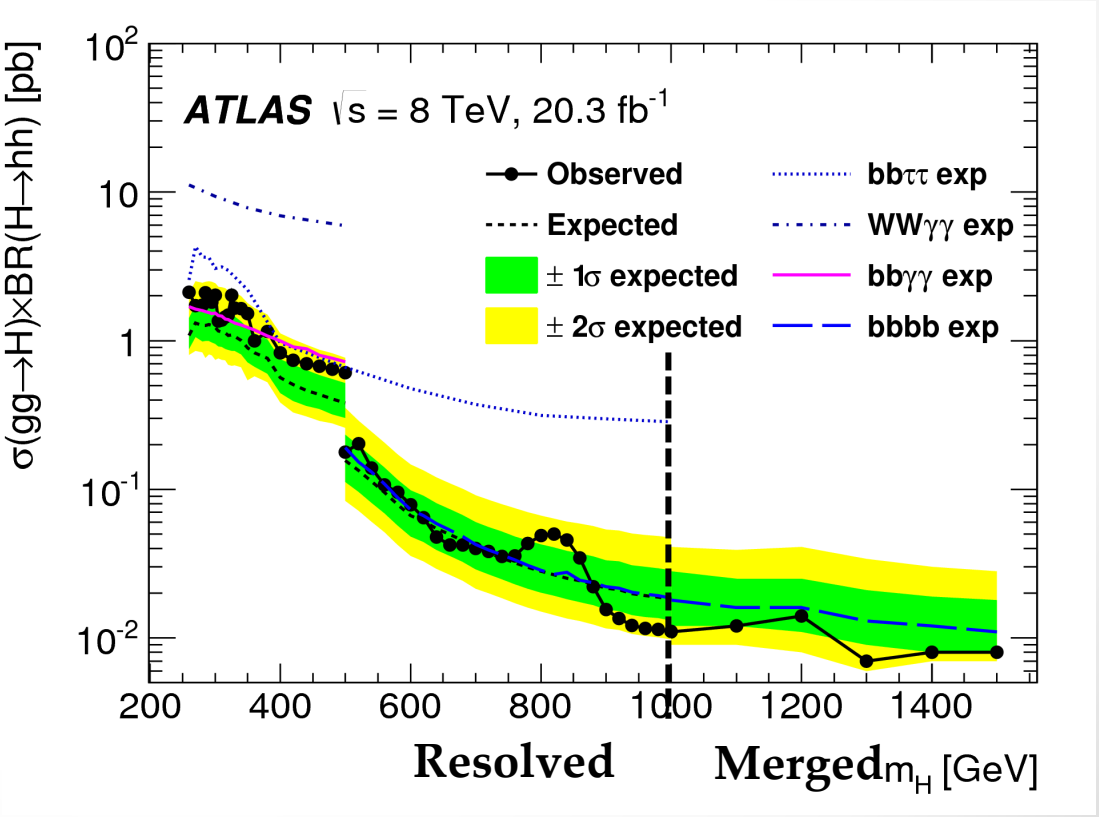
HH
(bbbb)

HIGG-2013-33

HH from Run 1

- Run 1 result : sensitivity dominated by 4b
- Run 2 priority : push sensitivity boundary with 4b





ATLAS-CONF-2016-017

Search Strategy

- Hard division based on M(X) @ 1100 GeV

Resolved

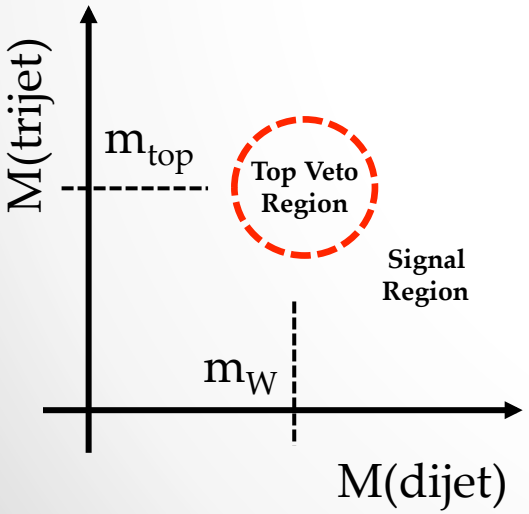
Small-R calo jets → M(j,j,j,j)

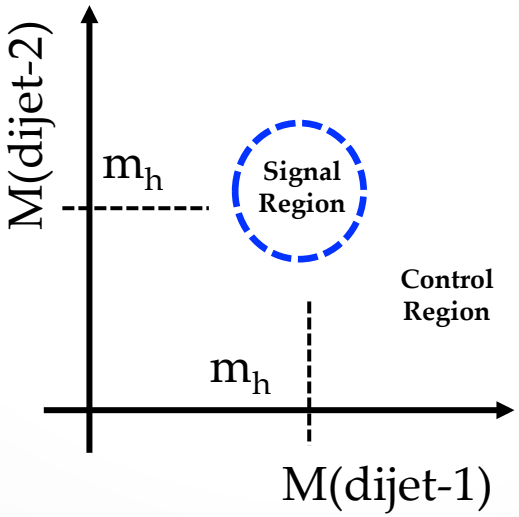
- 1 OR 2 b-jet trigger → pT(dijet) & $\Delta R(j,j)<1.5$ in dijet
- Topology selections on $\Delta\eta$ (dijet,dijet) and tt-veto
- 4 b-tags

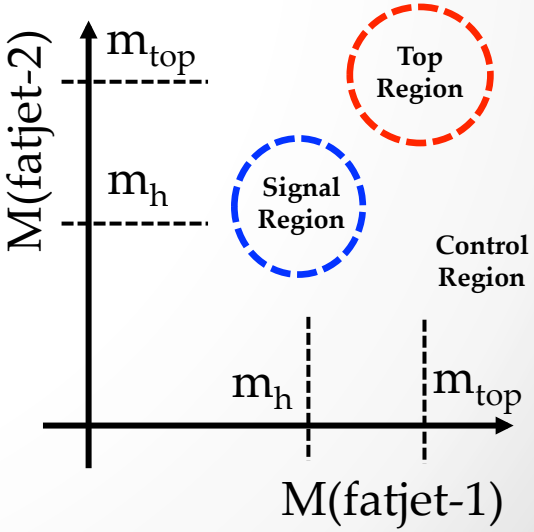
Merged

Trimmed+track jets→ M(J,J)

- Single large-R jet trigger
- $p_T(J_1)>350$ GeV for "tt-veto"
- Topology selection on $\Delta\eta$ (J,J)
- 3 OR 4 b-tags







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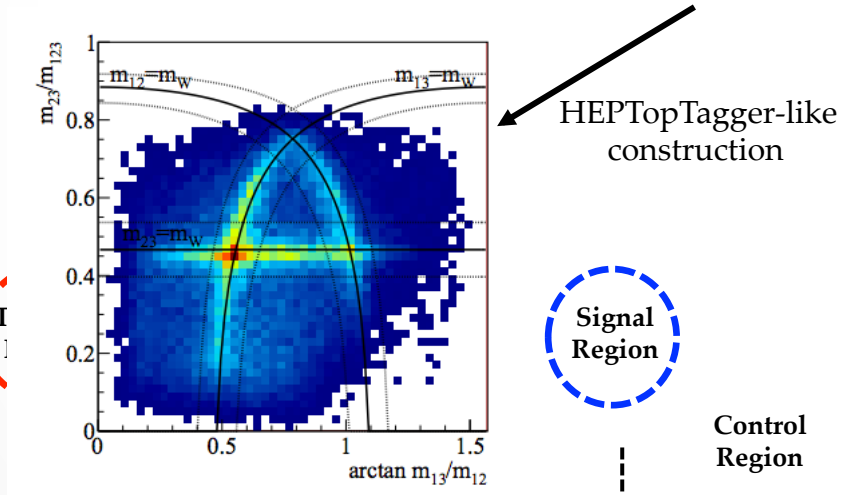
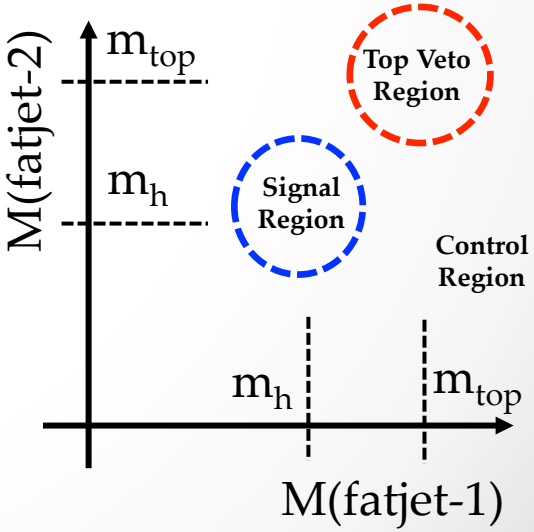
- 4 b-tags



Merged

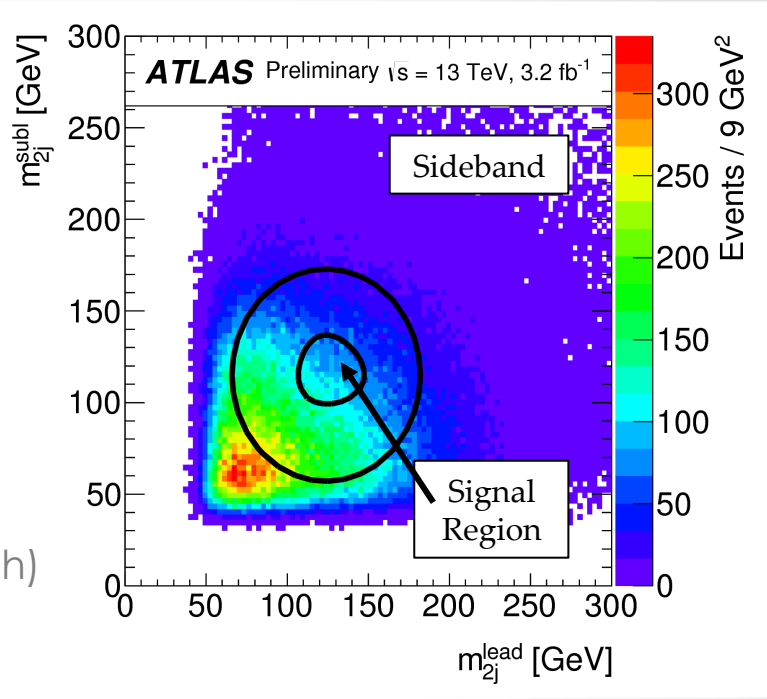
Trimmed+track jets→ M(J,J)

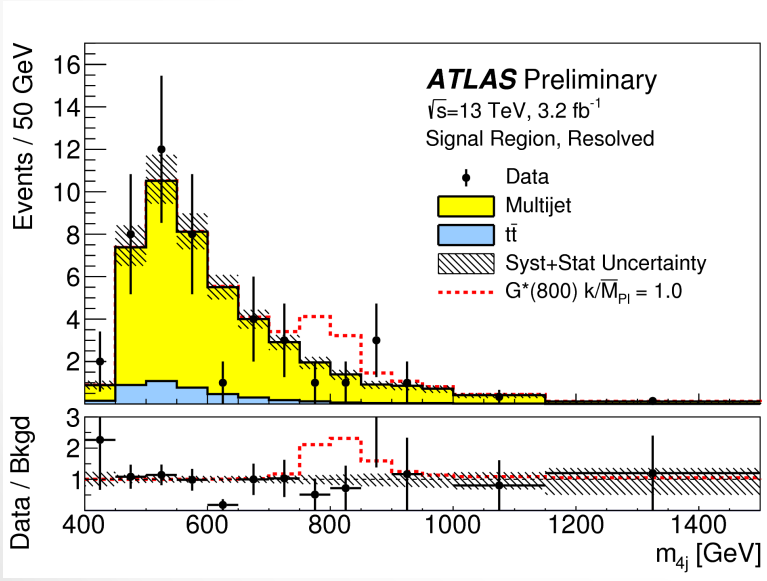
- Single large-R jet trigger
- $p_T(J_1)>350$ GeV for "tt-veto"
- Topology selection on $\Delta\eta$ (J,J)
- 3 OR 4 b-tags

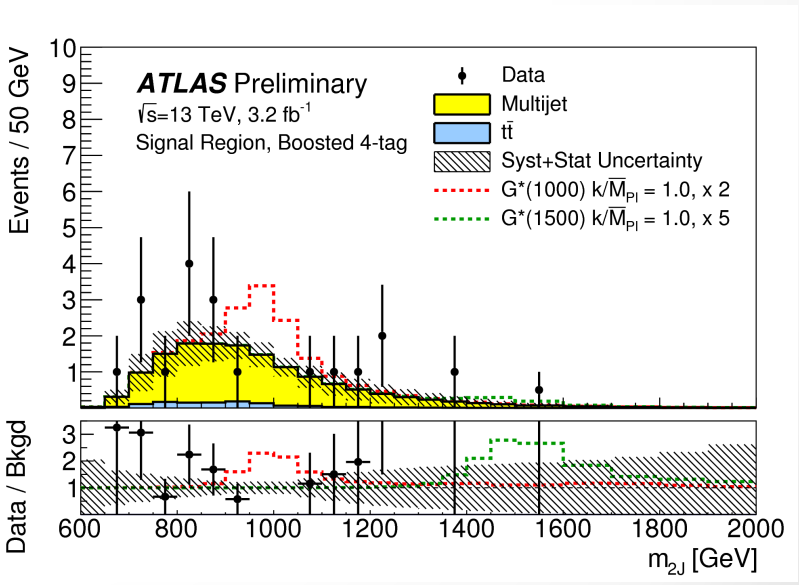


Results

- Backgrounds : multijet + ttbar
- Multijet : 2-tag SR × μ_{sideband}
  - Resolved : μ_{sideband} from simple ratio (4-tag/2-tag)
  - Merged : μ_{sideband} from fit jet mass (top peak!)
- ttbar
  - Resolved : invert tt-veto → scale by ε (top to fake h)
  - Merged : MC → normalized simultaneous to MJ



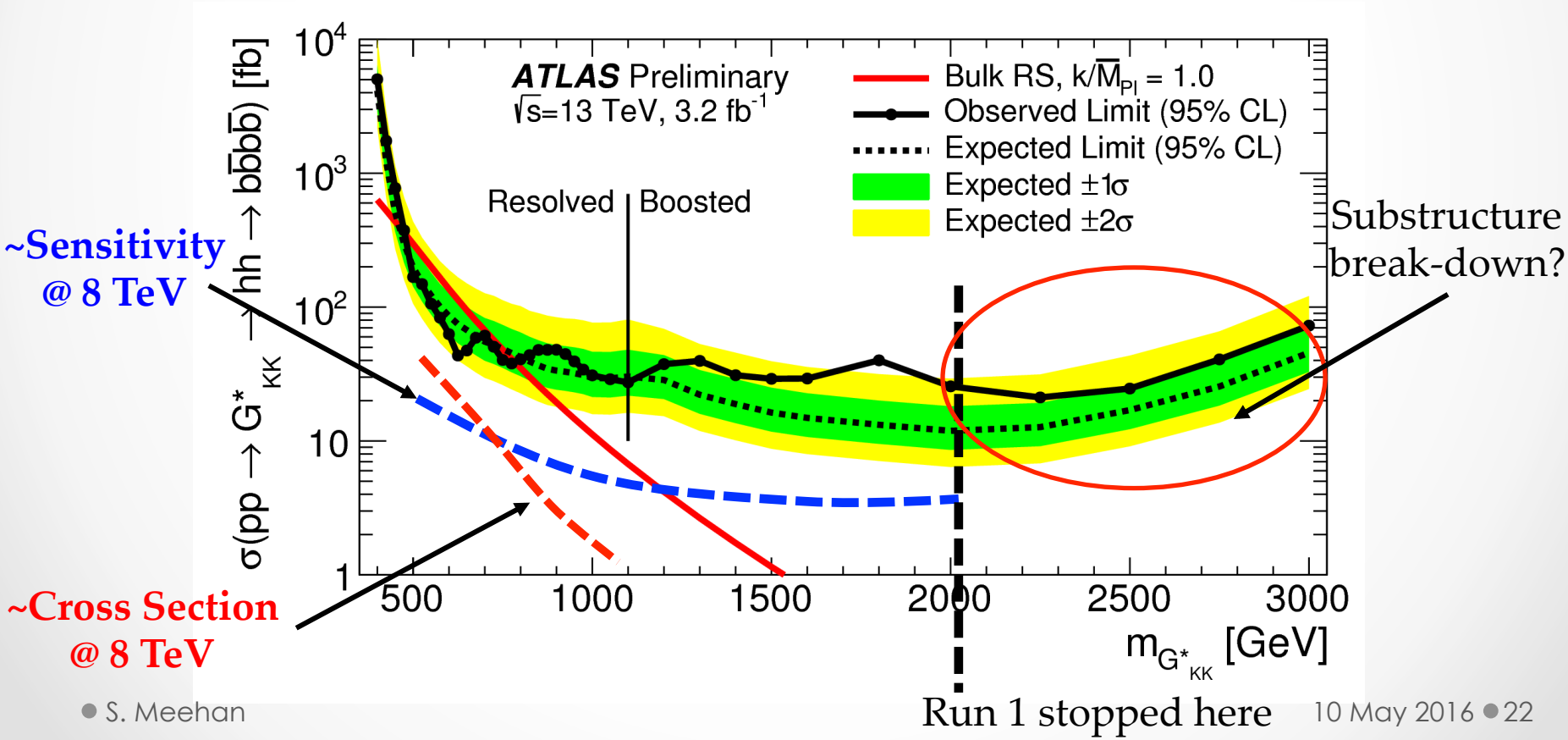




Constraints

- Sensitivity to BSM already at Run 1 level
  - Pushing phase space to "ultra"-boosted region
- Sensitivity still far away from SM prediction of σ (pp→hh)
  - Limit here : σ < 1.22 pb
  - SM prediction : σ_{SM} < 12.9 fb

… factor of 100 to go …



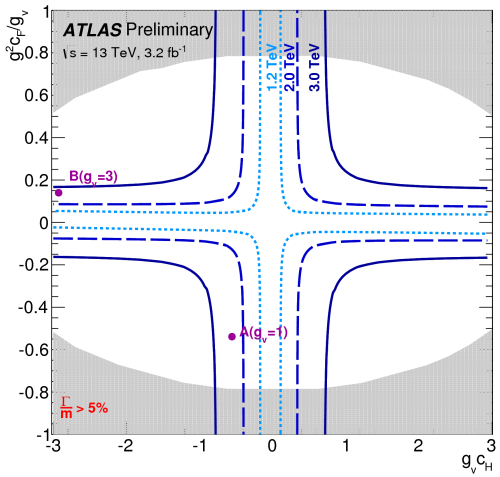
Conclusions / Thoughts

- Run 2 dataset (thus far) handled well due to experience/ knowledge obtained in Run 1
  - Many results we've had since December
- Still many opportunities for improvement!
  - Fatjet performance … trigger level analyses … more global combinations … VBF

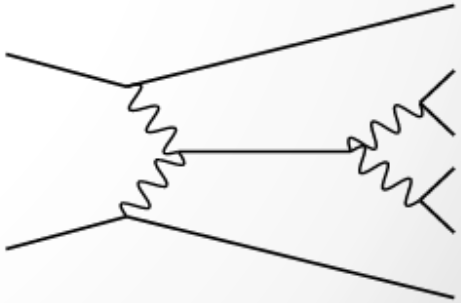
Performance
Experimental uncertainties

Type of uncertainty	Impact (%)
Total	81
Data statistical	78
Systematic	22
Experimental uncertainties	
R = 0.4 jets	4.4
E_T^{miss}	2.2
R = 1.0 jets	16
Theoretical uncertainties	
Signal	6.5
Z+jets	9.9
W+jets	9.1
Top	11

Interpretations
VV … +VH … +HH



New Channels
Tag the production



Let the data roll …

BACKUP

What are the ingredients?

Electrons

- e-cal cluster with track
- p_T down to 7 GeV
- $|\eta| < 2.47$
- Quality based on shower shape likelihood (loose, medium, tight)
- Track (and calo) isolation
- d_0, z_0 Impact parameter

Small-R Jets

- Topoclusters → anti-k_t R=0.4
- p_T down to 20 GeV
- $|\eta| < 2.5$ (4.5)
- JetVertexTagger for low pT jets
  - Pileup rejection
- B-tagging : BDT combination
  - BDT(Vertexing + $d_{0,tracks}$)
  - 70% (77%) signal efficiency

Muons

- ID track + MS track
- p_T down to 7 GeV
- $|\eta| < 2.5$
- Quality based on tracking reco
- Track (and calo) isolation
- d_0, z_0 Impact parameter

Missing E_T

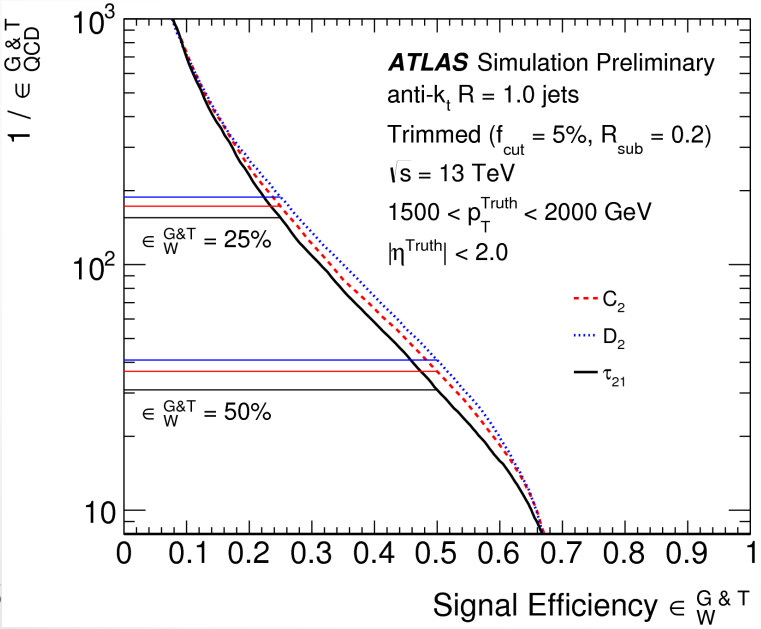
- Vector sum of two components
- Calibrated activity (hard objects):
  - Electrons, muons, small-R jets
- Unassigned activity (soft stuff):
  - Inner detector tracks

The Special Ingredients

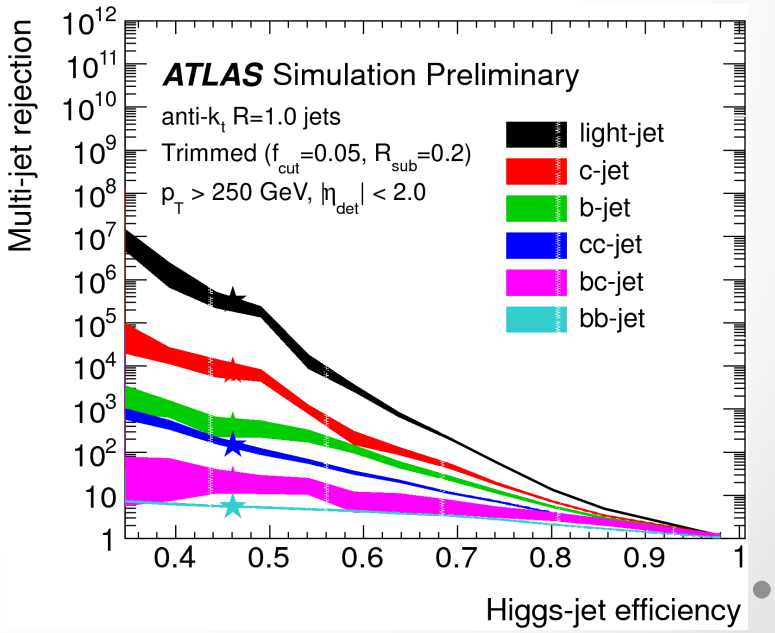
Large-R Jets

- Baseline Jet : Topoclusters → anti-kT R=1.0 → Trimmed(R_{sub}=0.2,f_{cut}=5%)
  - Kinematics : pT down to 200 (250) GeV & $|\eta| < 2.47$
- W/Z jet : [Mass] + [D_2] → tuned selections vs. p_T
- Higgs jet : [Mass] + [track jet b-tags]

Boson Jets

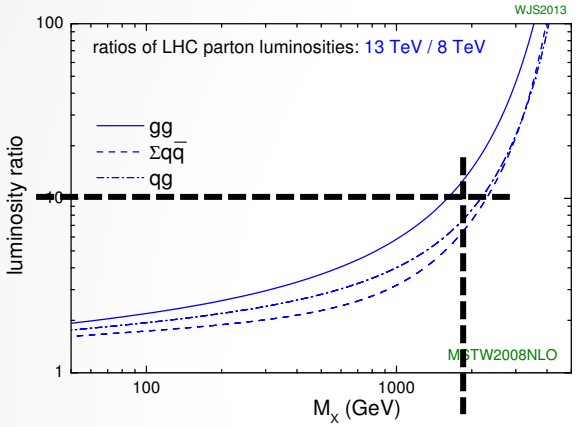


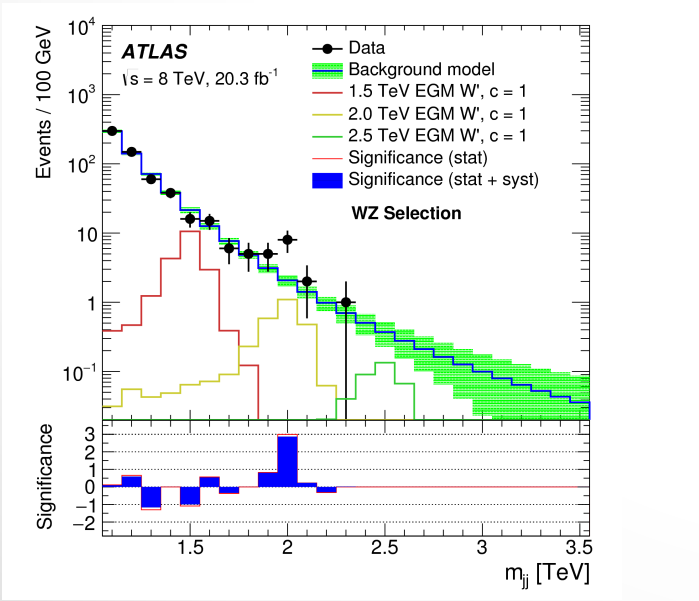
Higgs Jets



VV Combination

- Question 1 : What happened to Run 1 excess?

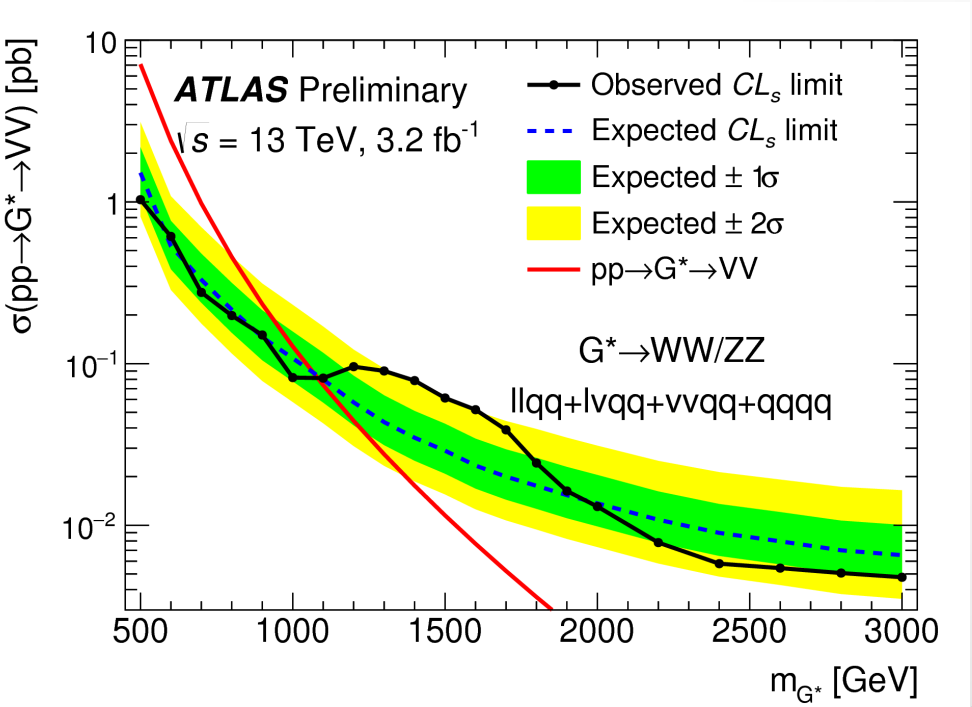




WARNING!

Not CLs-profile-likelihood-with-correlated-NP's

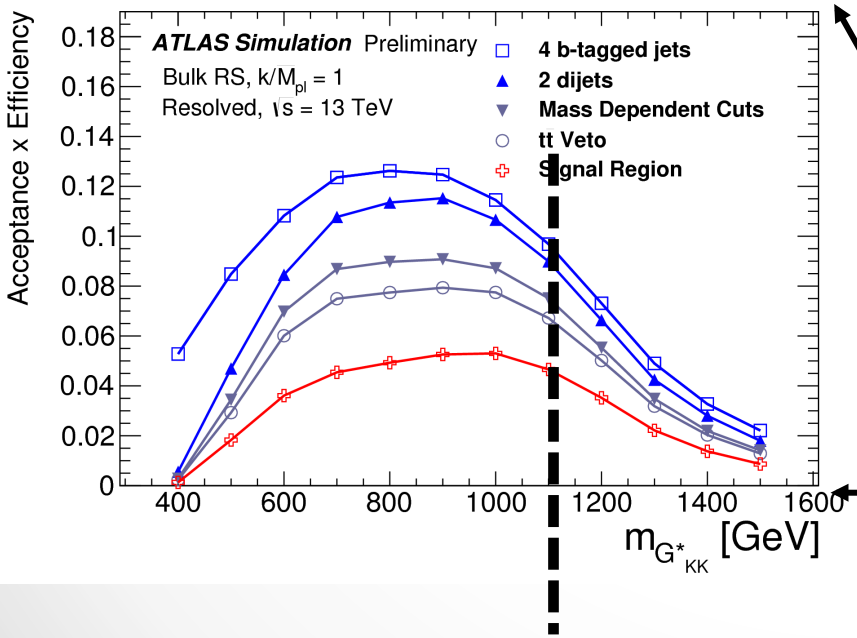
- X Production : σ (pp→X) increased by 5-10
- Sensitivity to X : Still less sensitive by factor ~3
- Should have shown up!
  - We have gamma-gamma now ☺



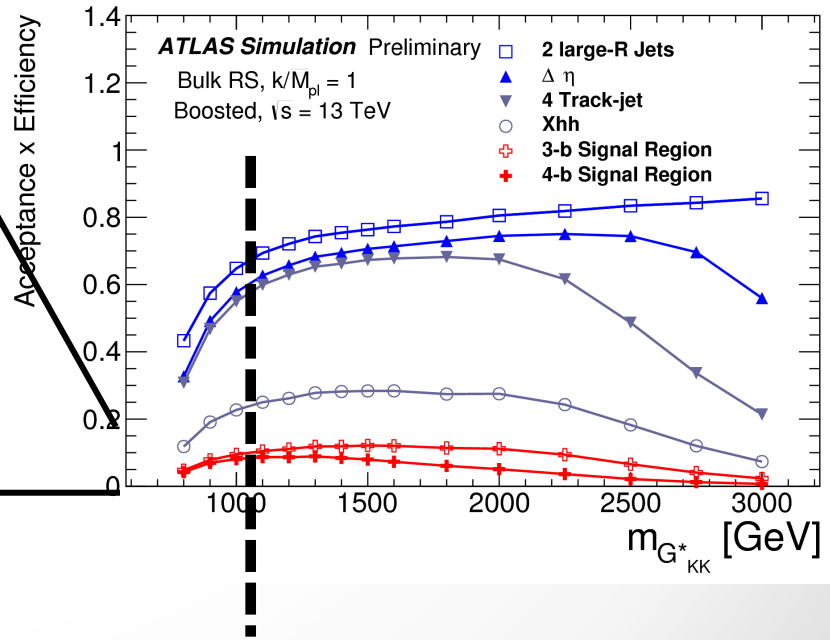
HH→4b

- Very low backgrounds → Hard division "makes sense" from signal efficiency point of view
- Higgs tagging relies on true separation/isolation of objects
  - What happens in the "ultra"-boosted regime?

Resolved

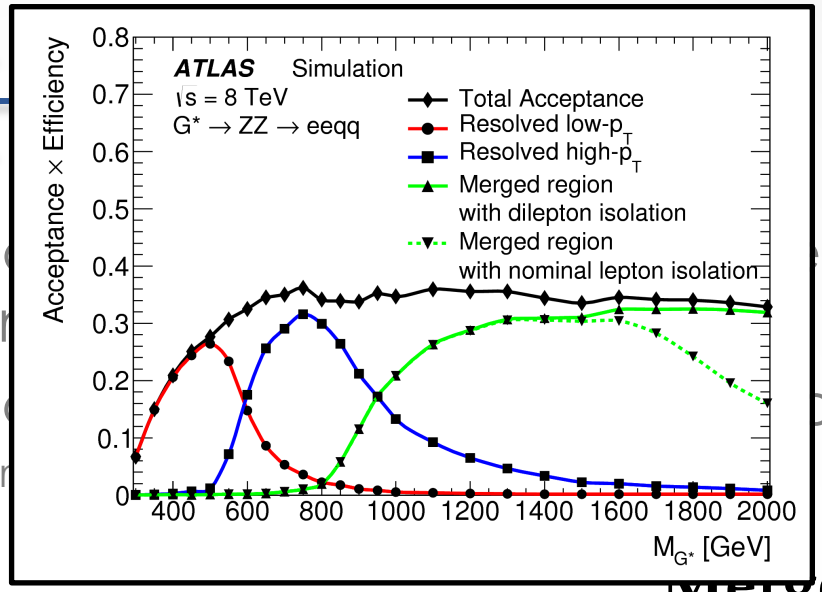


Merged



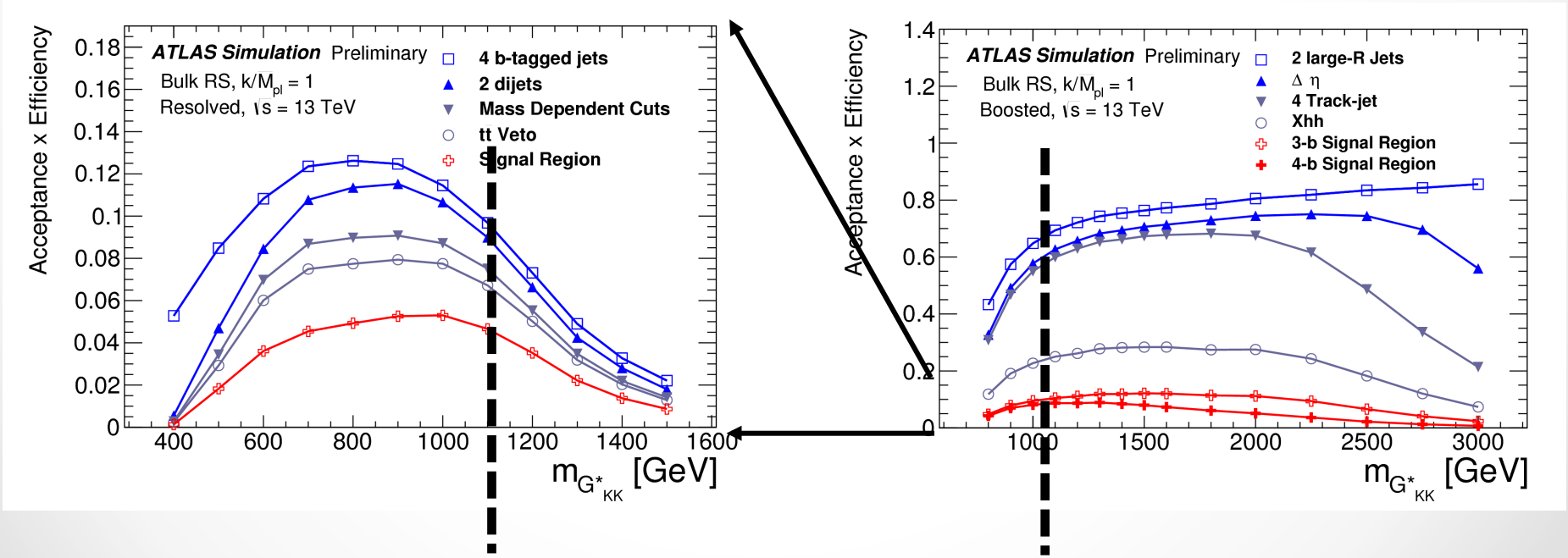
H

- Very low backgroun nse" from signal efficiency poi
- Higgs tagging relies of objects
  - What happens in the "ultr



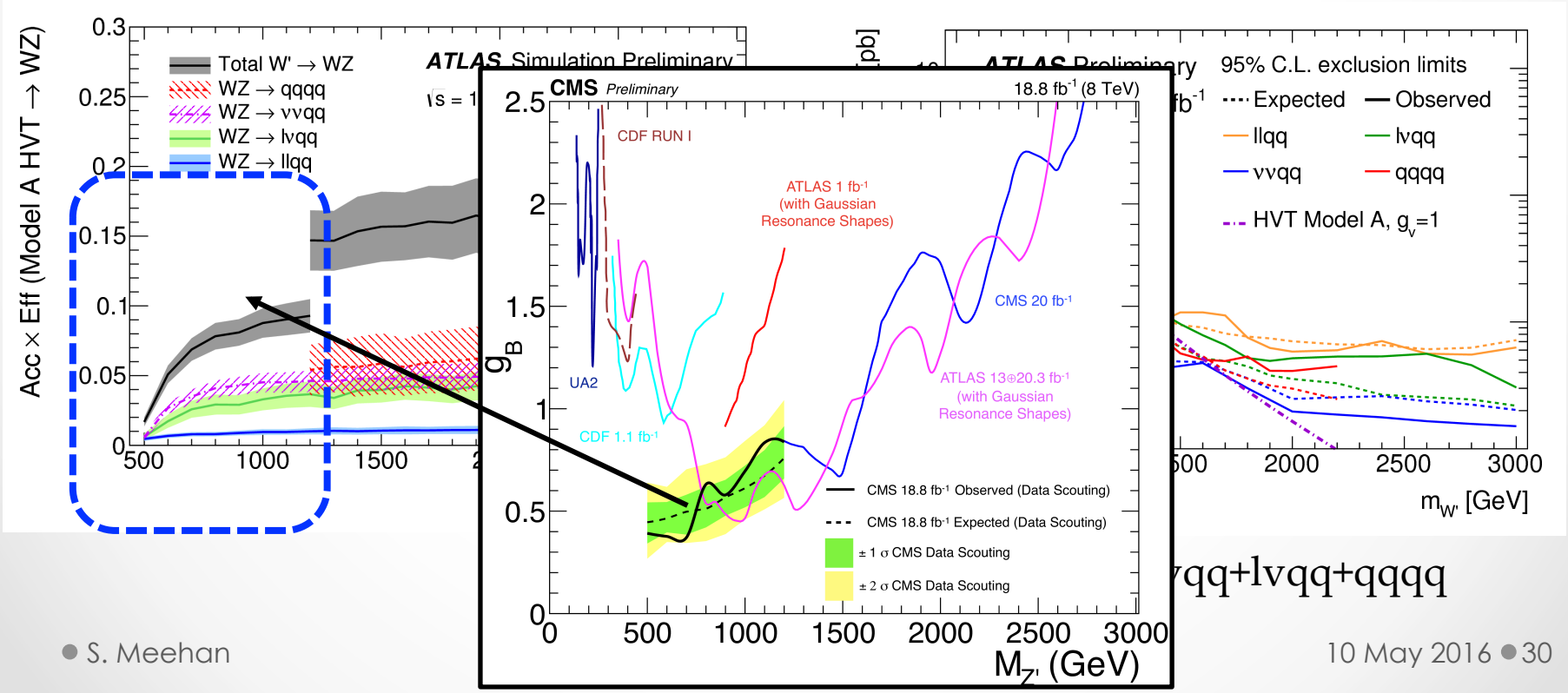
Resolved

Merged



VV Combination

- No "dominant channel" above 1 TeV
  - Full combination of all channels really worth it
  - Factor of 3 gain in sensitivity
- Obvious question : Can qqqq go lower?
  - Trigger level analysis? JSS in the trigger? (https://cds.cern.ch/record/2104248)



Ntracks(Ungroomed)

- N(tracks,ungroomed)<30 used in analysis
- Additional calibration of tagger performed