The Search for a Heavy Higgs-like Boson in the WW(lvjj) Decay Channel with the ATLAS Detector

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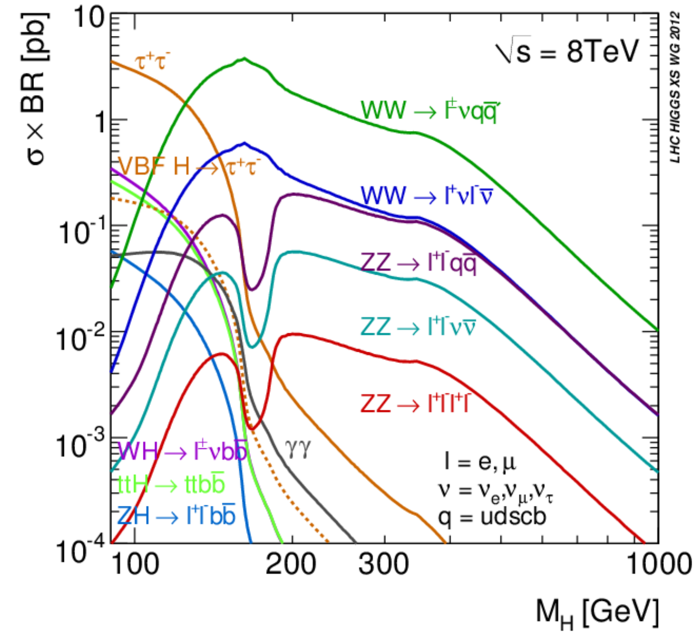
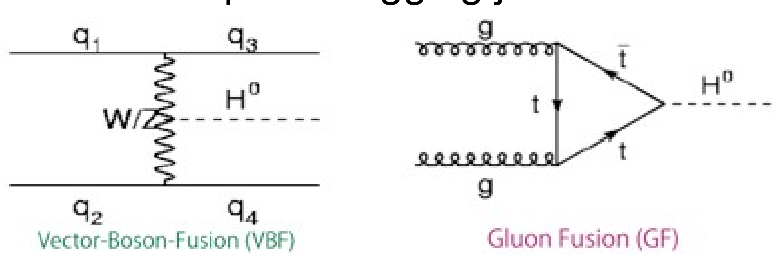
University of Toronto

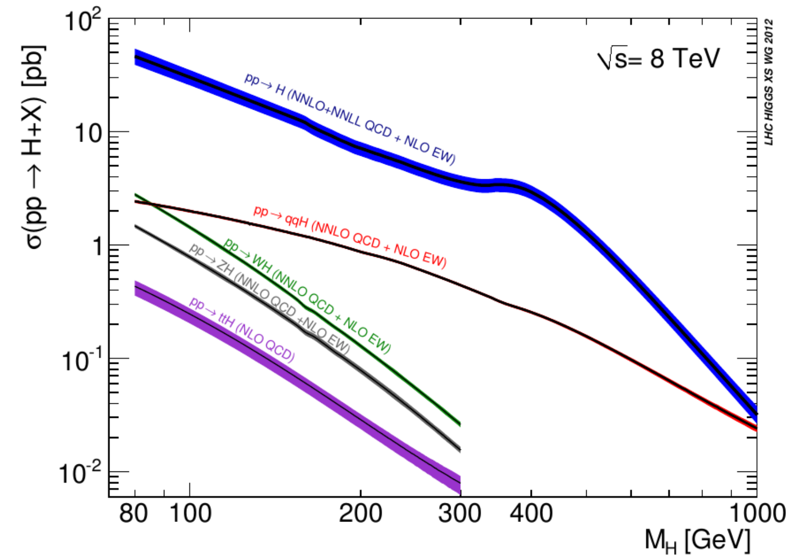
H → WW → lνjj

- Looking for Higgs-like signature in WW semi leptonic channel in the range 300 GeV → 1000 GeV
- Low sensitivity in low mass range (< 300 GeV)
- Benefit of being able to fully reconstruct Higgs mass (unlike WW → lνlν channel)
- Using full 2012 dataset: 20 fb^{-1} @ 8TeV
- Previous result using only 7 TeV data



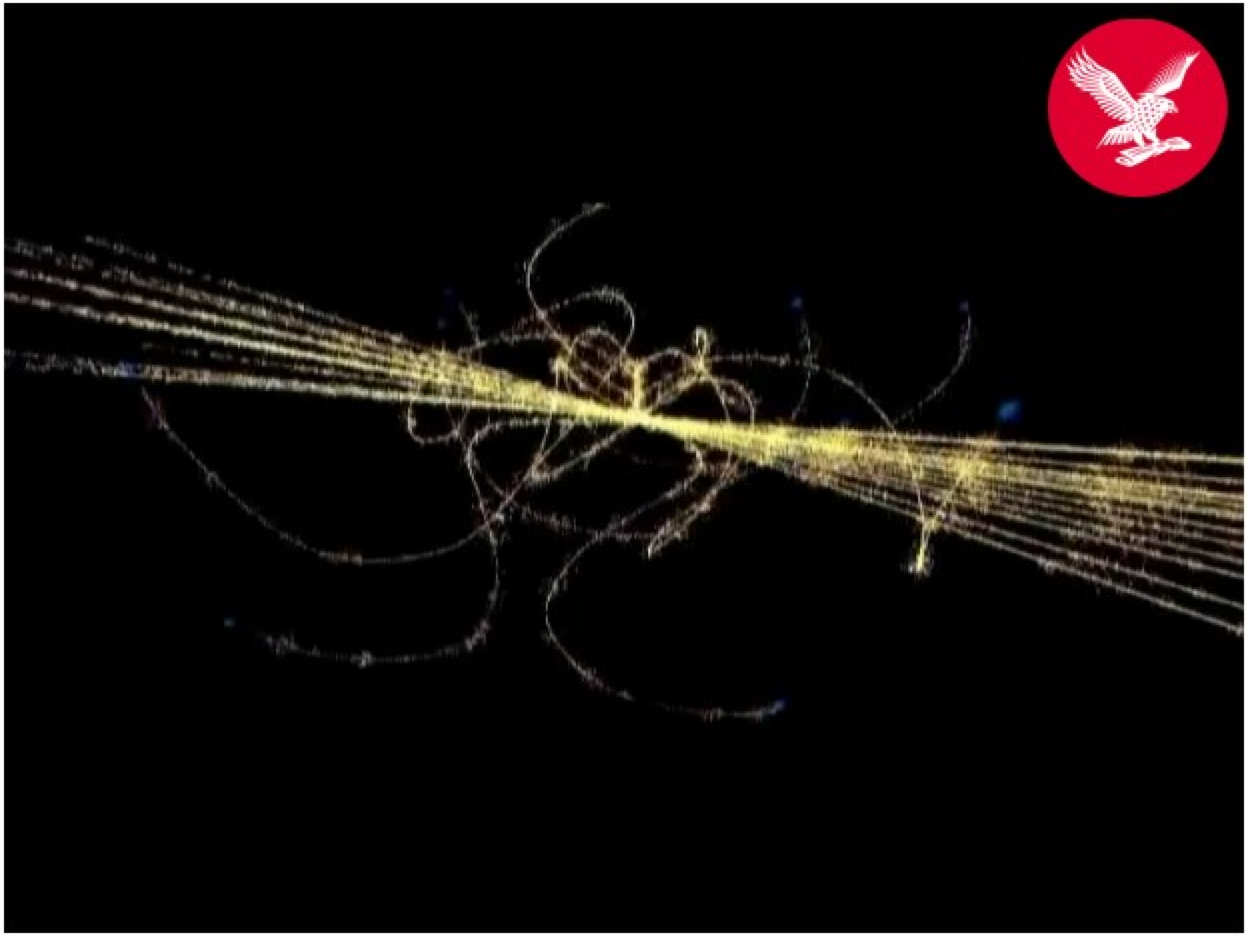
- Largest σ x BR in high mass region
- Main production mechanisms @ LHC are gluon-gluon fusion (ggF) and vector boson fusion (VBF)
- ggF dominates over full mass range but vector boson fusion (VBF) cross section grows at higher masses
  - VBF expected to dominate sensitivity at high mass
  - Separate VBF/ggF events based on presence of 2 hard, opposite hemisphere tagging jets





However....

Eureka! Cern announces discovery of Higgs boson 'God particle'



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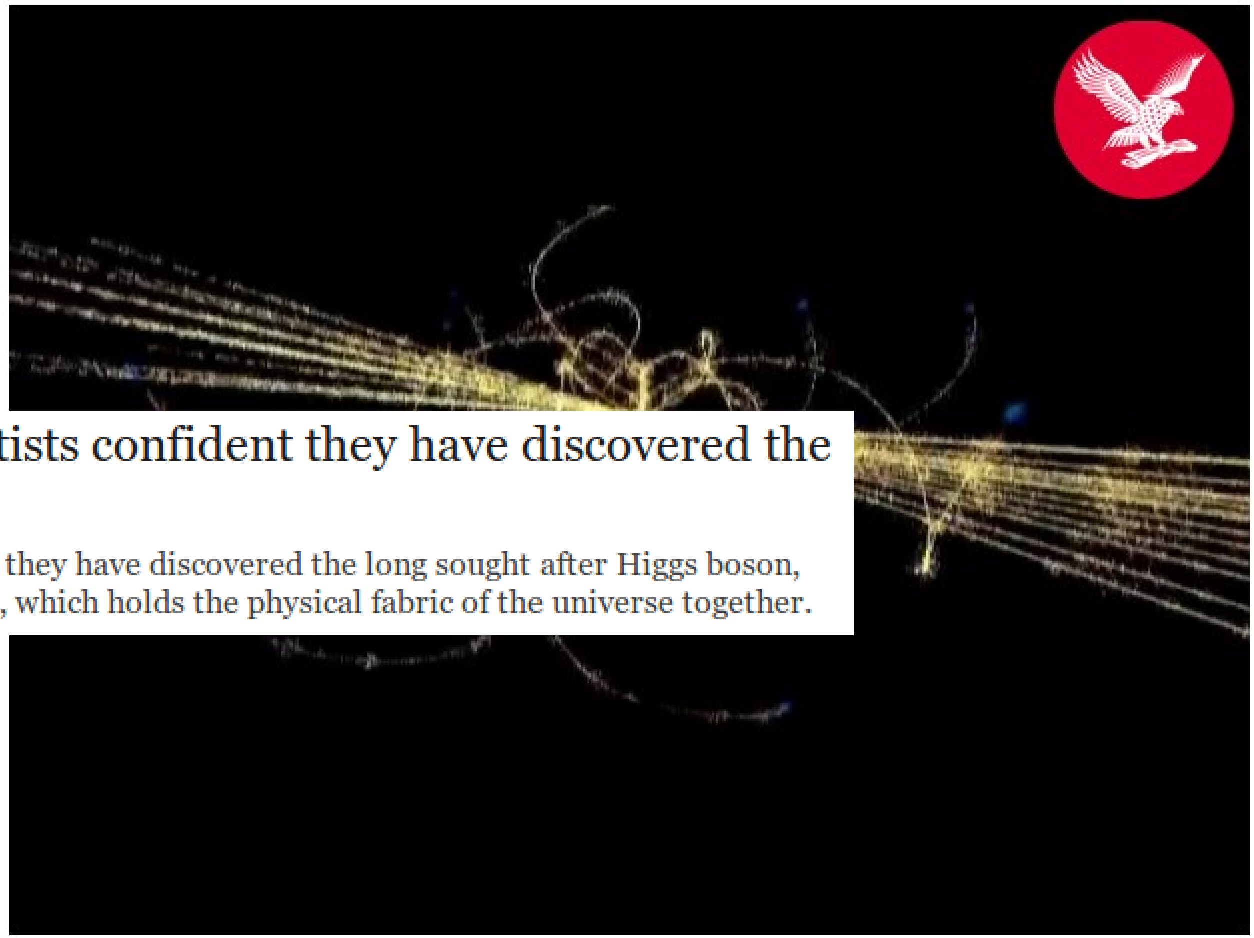

Higgs boson: scientists confident they have discovered the 'God particle'

Scientists are confident that they have discovered the long sought after Higgs boson, known as the “God particle”, which holds the physical fabric of the universe together.

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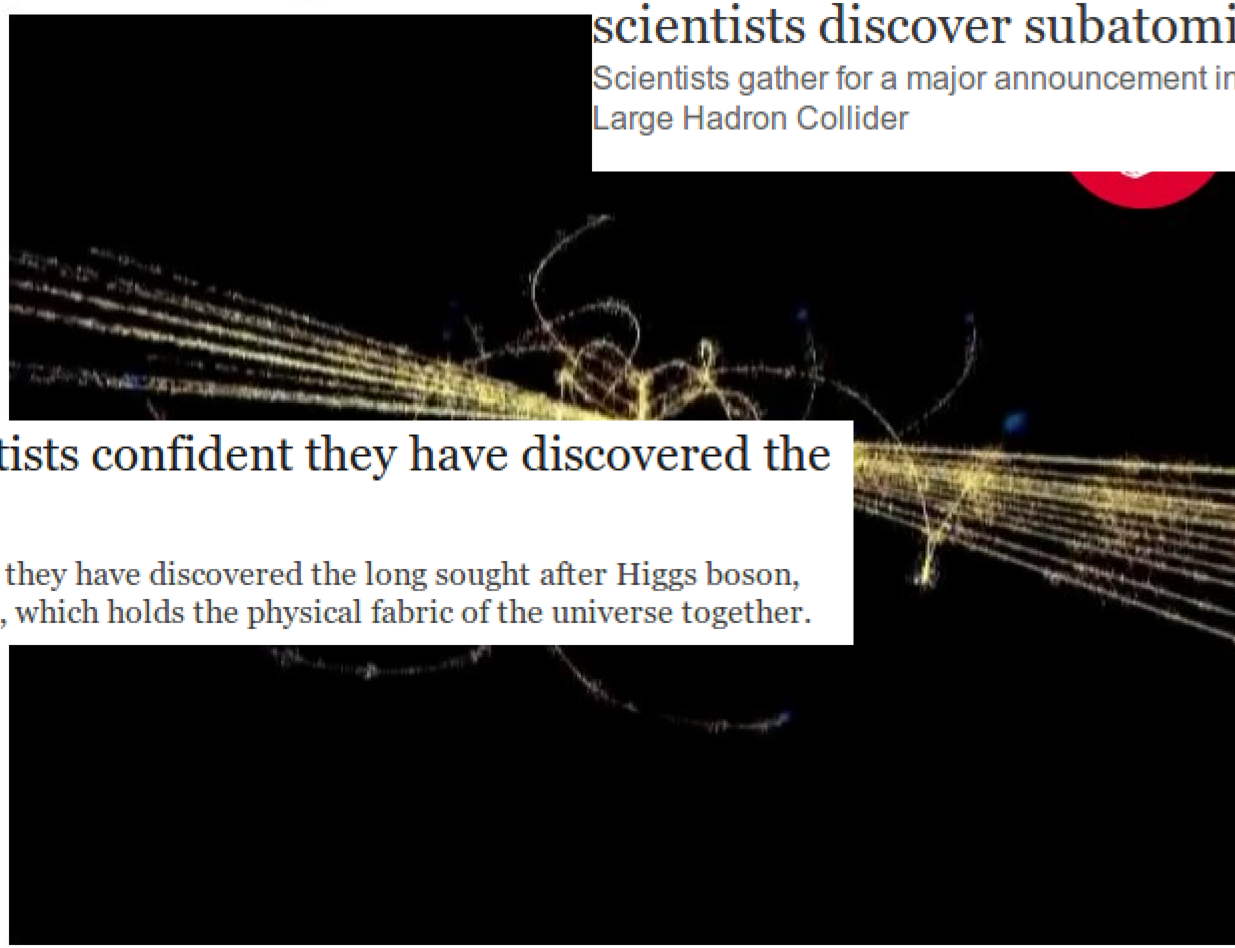
Higgs boson announcement: Cern scientists discover subatomic particle

Scientists gather for a major announcement in Cern, home of the Large Hadron Collider



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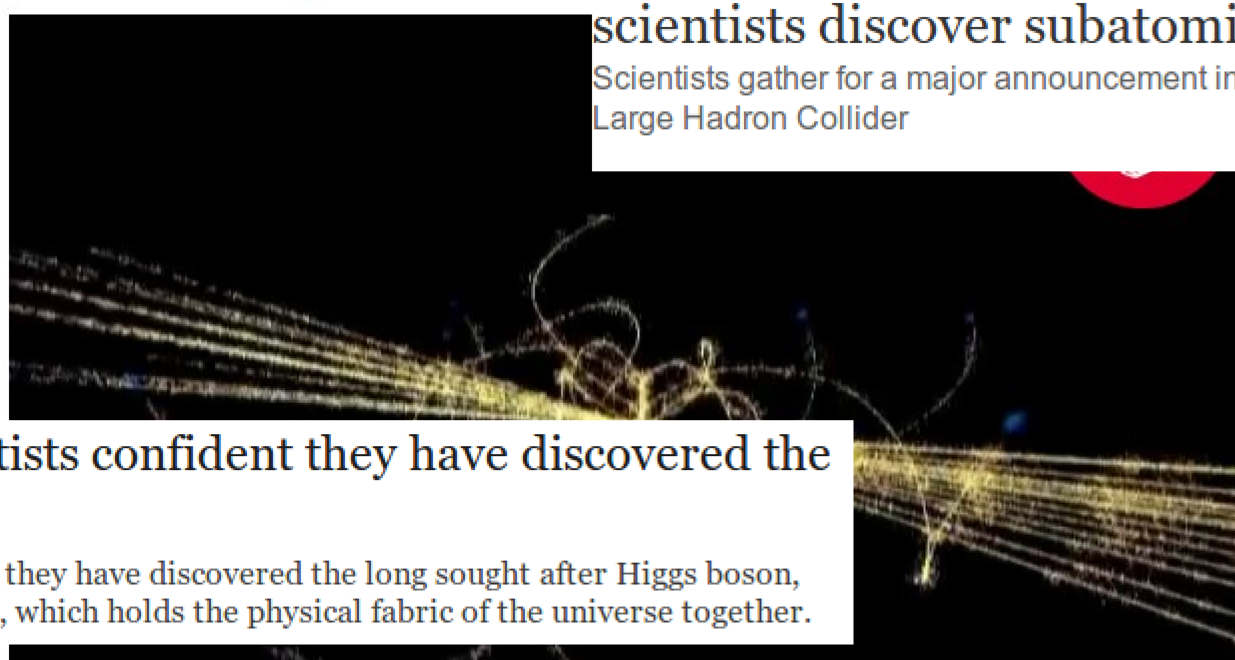

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CERN experiments observe particle consistent with long-sought Higgs boson

Physicists Find Elusive Particle Seen as Key to Universe

Pool photo by Denis Balibouse

Scientists in Geneva on Wednesday applauded the discovery of a subatomic particle that looks like the Higgs boson.

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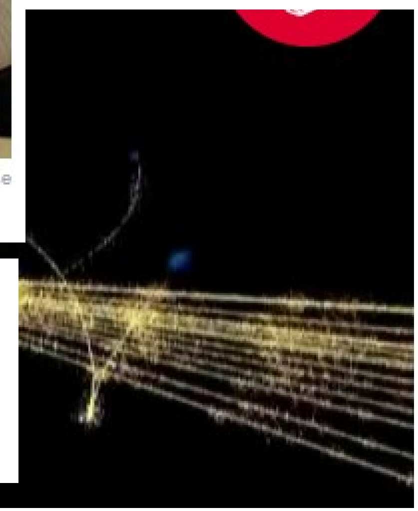

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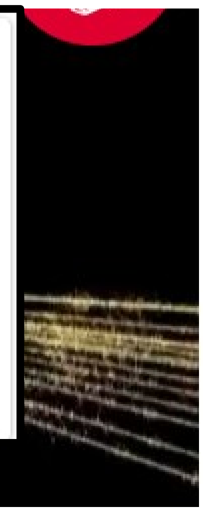

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@newscientist
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CERN PR just circulating room, pipping Gianotti to the post: #ATLAS sees #Higgs at around 126 Gev with 5 sigma certainty. Wow.

4:03 AM - 4 Jul 2012

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New Scientist @newscientist — Follow

CERN PR just circulating room, pipping Gianotti to the post: #ATLAS sees #Higgs at around ~~126 Gev~~ 125.5 GeV with 5 sigma certainty. Wow.

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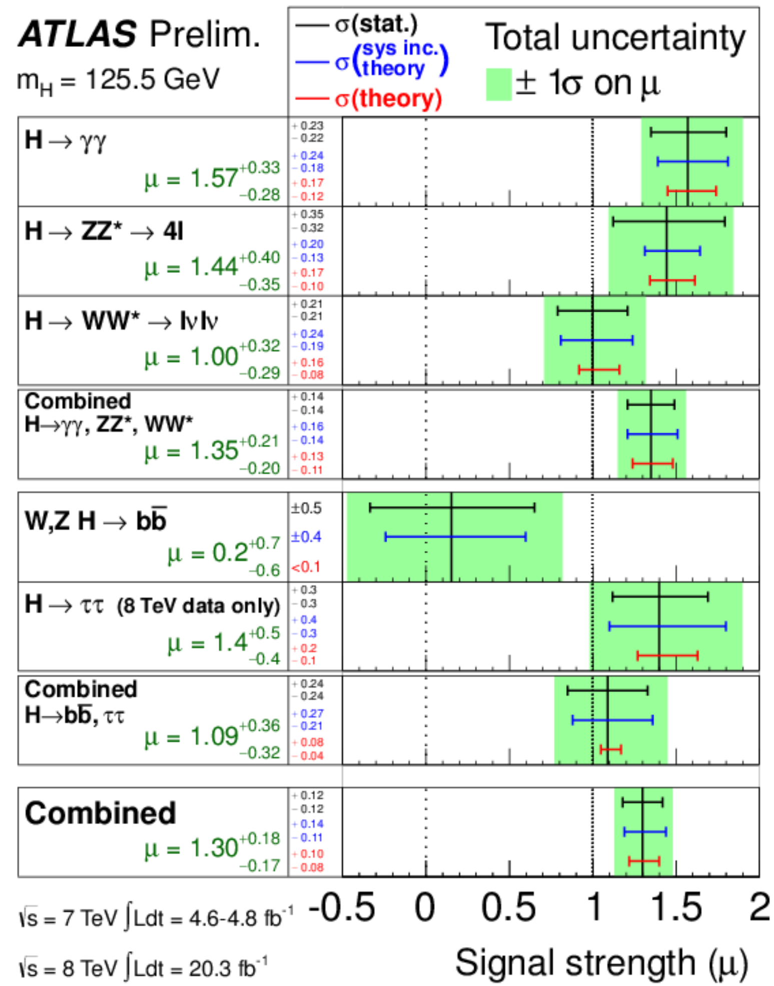
Standard Model → Beyond

- The particle discovered by CMS/ATLAS closely resembles the SM Higgs boson
  - Evidence strongly supports spin/parity of 0+, with signal strength consistent with Standard Model (SM) expectation
- Still the question; Is this "the" Higgs boson, or merely "a" Higgs boson?
- Strong evidence of SM particle, but still room for something else!



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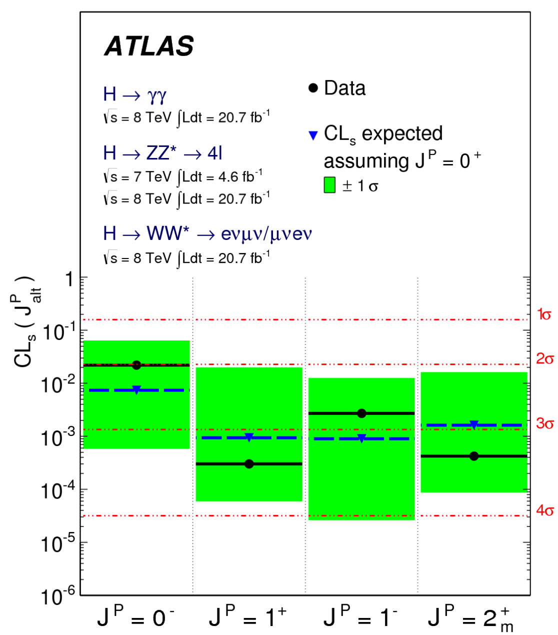


Phys. Lett. B 726 (2013)

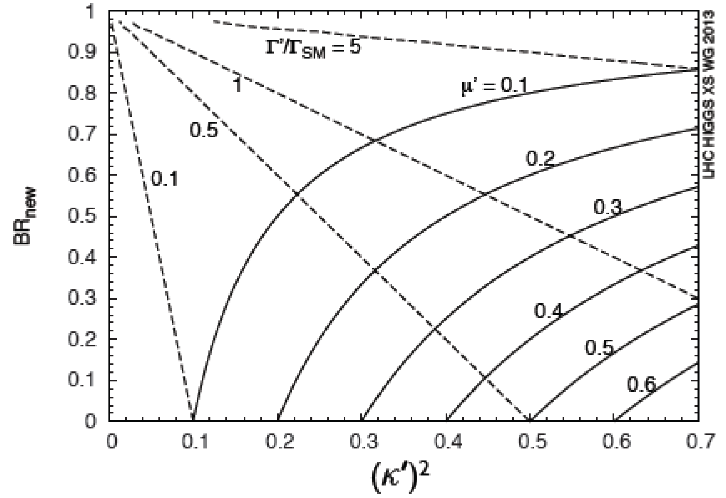
Standard Model → Beyond /2

- Still a chapter to close
  - With the amount of data we have + sensitivity of analysis, aim to exclude a heavy SM-like Higgs in the full “heavy” mass range from 300 GeV → 1000 GeV

BSM?

- Can look for specific model dependent extensions to the Standard Model (SUSY, Compositeness, Two Higgs Doublet models, etc) → not the subject of this talk
- Model Independent Searches
  - Electroweak Singlet (EWS): Most simple SM extension to Higgs sector is an extra heavy singlet (H) that mixes with light singlet (h @ 125.5 GeV)
    - Coupling scales in relation to SM couplings

$$\kappa^2(h) + \kappa'^2(H) = 1$$



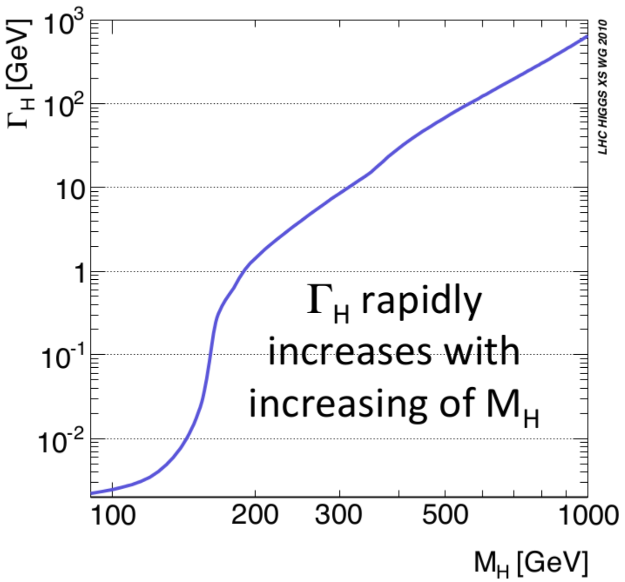
    - H can have non-SM decays (BR_{new})
    - Width of resonance, H, varies as function of couplings and BR_{new}

$$\Gamma' = \frac{\kappa'^2}{(1 - BR_{new})}\Gamma_{SM}$$

    - Given current measurements of signal strength, μ, if BR_{new} = 0, H would be very narrow (modeled by narrow width approximation)

SM + BSM @ High Mass

- For SM interpretation
  - At high mass, Higgs width increases to a degree that we can no longer approximate the lineshape as a Breit-Wigner
    - Assumption valid for $\Gamma < 10$ GeV
  - Higgs propagator → Complex function
    - Use complex pole scheme (CPS) propagator for $m_H > 400$ GeV
- For EWS Search
  - Extra H singlet can look SM-like, but with varying width (and some unknown lineshape)
  - Conduct search by scanning over widths between Γ_{NWA} and Γ_{SM} setting limits on σ x BR
- For Both:
  - pp → H → WW process will interfere with SM Higgs-less pp → WW production (SM continuum background)
  - Must reweight signal samples to take into account this interference effect
    - VBF: Using VBF@NLO with REPOLO (**Re**weighting **Po**wheg at **L**eading **O**rder) to assign weights to our signal-only CPS samples (VBF case)

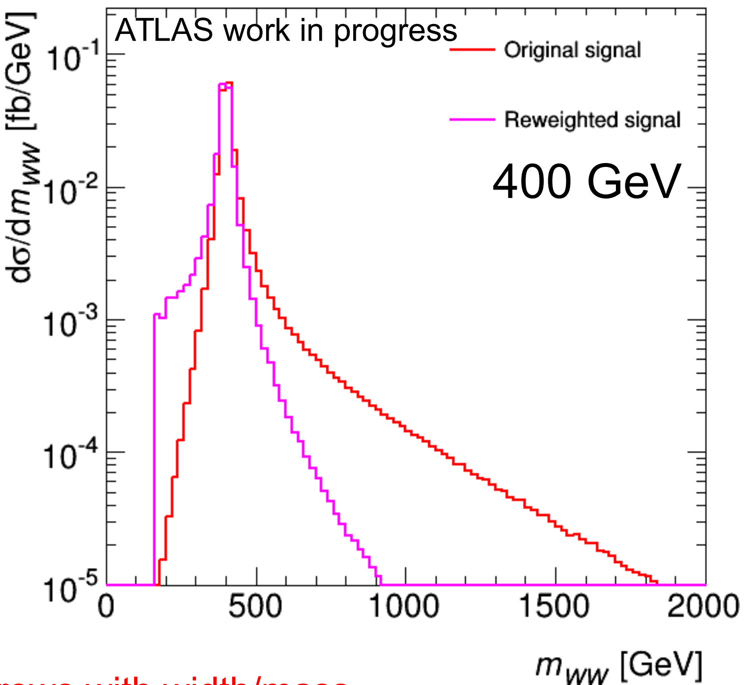


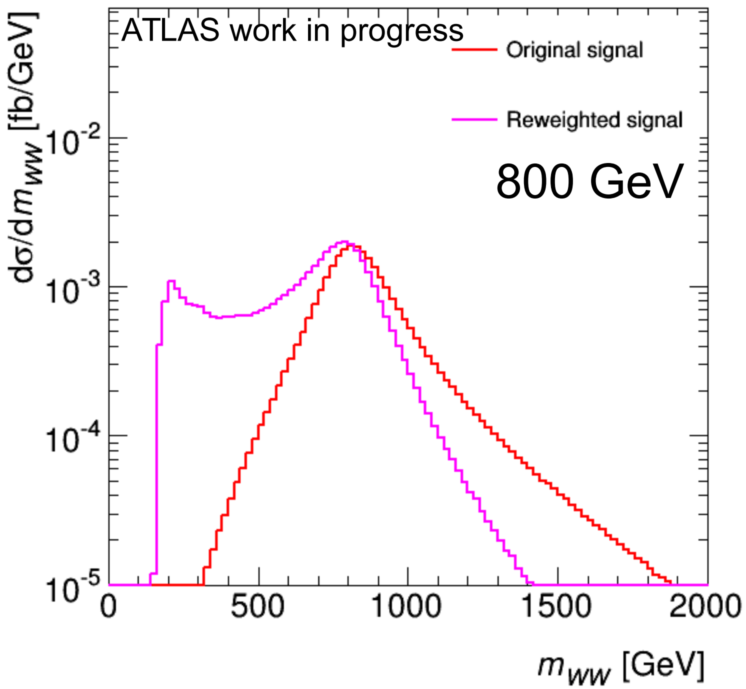
Interference Weights (VBF)

- REPOLO takes Signal only Les Houches event file as input and reweights the events by the ratio of matrix elements;

$$\frac{|\mathcal{M}_{\mathcal{BSM}}|^2}{|\mathcal{M}_{SM}|^2}$$

- Interference on samples results in much broader signal
- Constructive in low mass spectrum, destructive in high mass spectrum

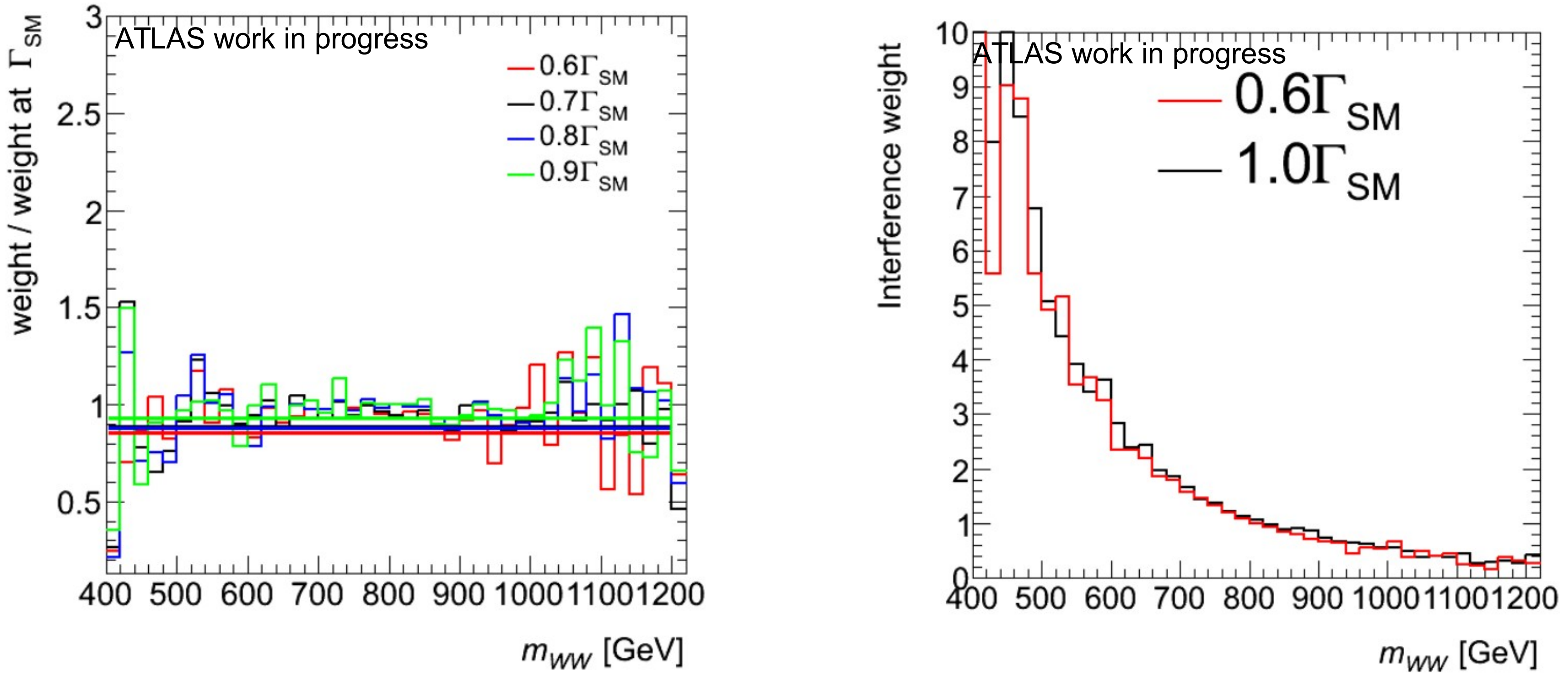




Effect grows with width/mass

Interference Weights in BSM (VBF)

- Interference must be evaluated for each width and each mass
  - Interference weights evaluated with different Higgs widths result in the same interference weights (not true for ggF weights)
- Using Breit-Wigner lineshape as opposed to Complex Pole Scheme
  - Confirmed with VBF@NLO + REPOLO and PHANTOM generators that BW and CPS interference weights are equivalent for a given mass

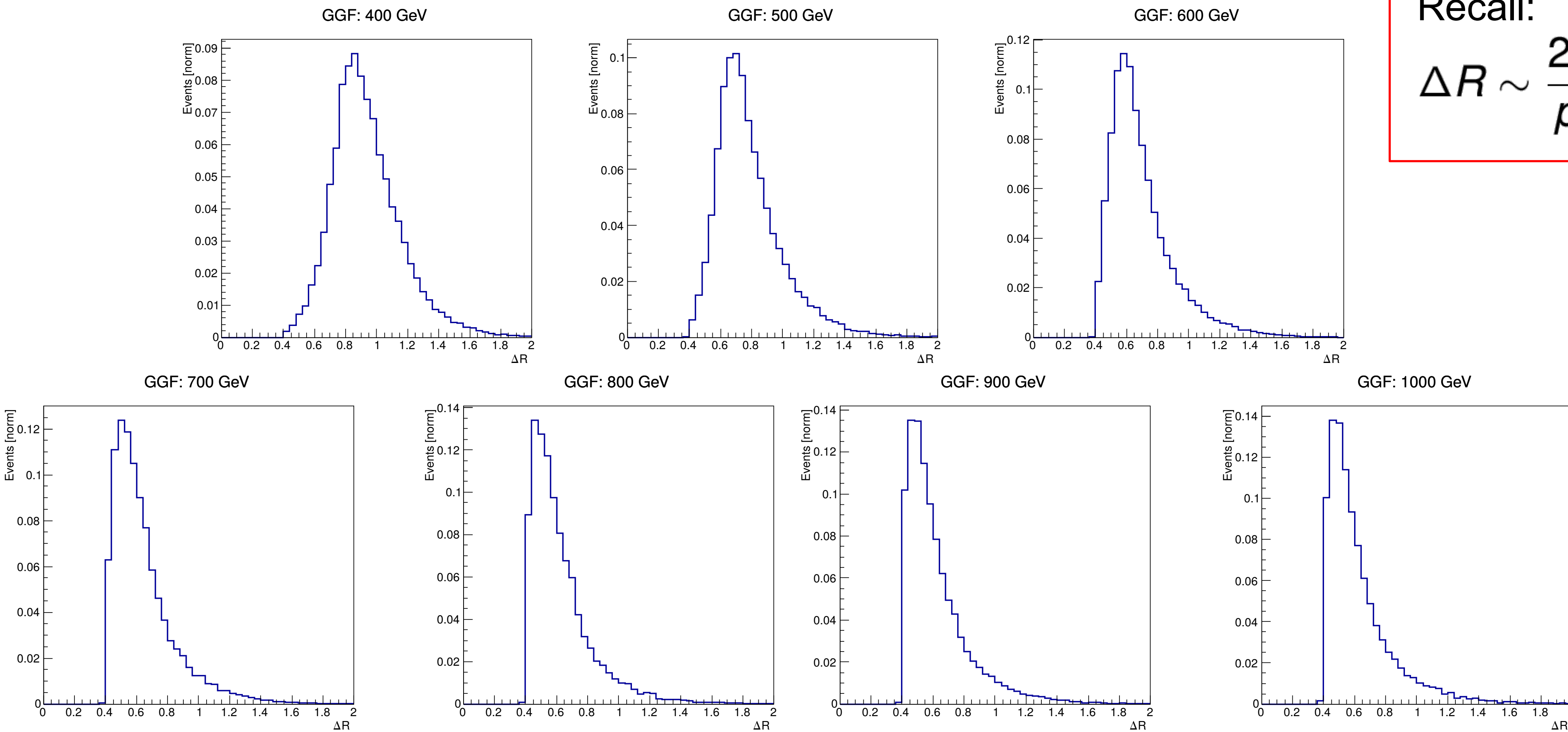


Boosted Decays

- Higher Higgs Mass → larger boost to W → ΔR of decay products gets smaller
- Back of the envelope calculation indicates that R=0.4 jets will begin to merge with Higgs masses >~ 700 GeV
- If only looking at di-jets to reconstruct W, we lose more and more events as mass increases

Recall:

$$\Delta R \sim \frac{2m}{p_T}$$



ATLAS work in progress

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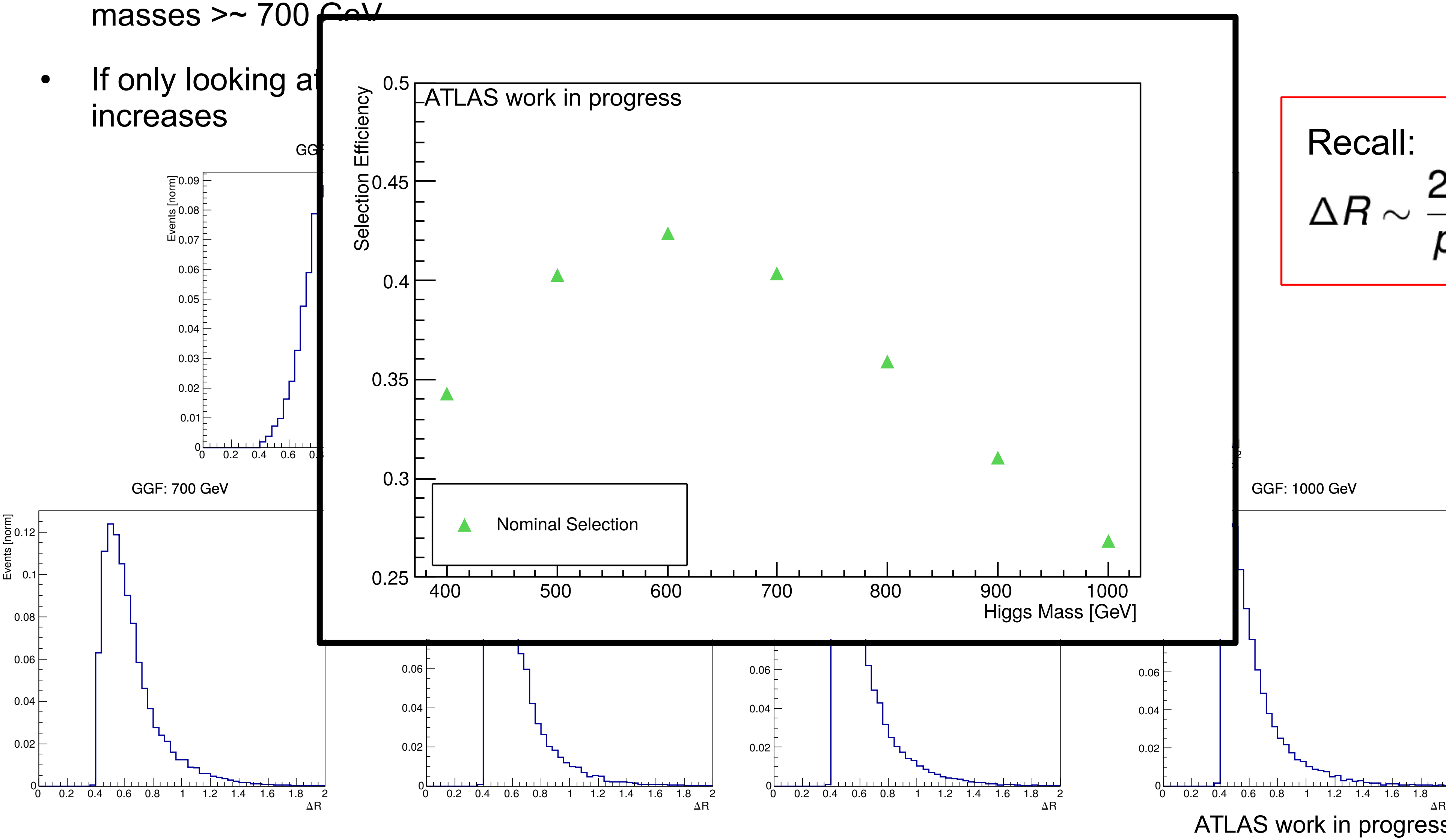

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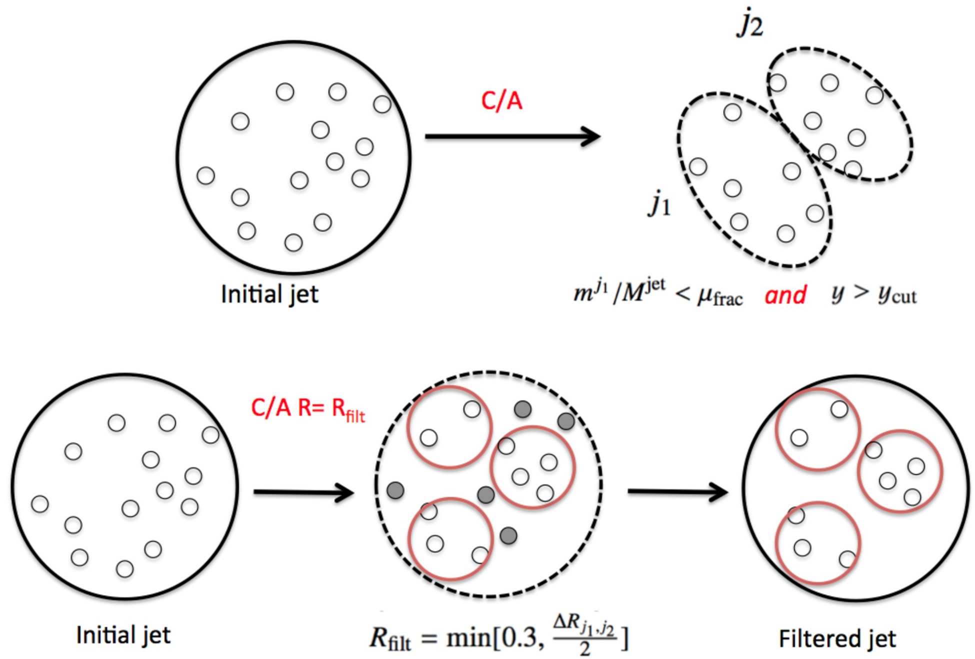
Large-R and Groomed Jets

- Can circumvent the resolving power of R=0.4 jets by instead looking at wider cone jets
  - Larger cone → more area for unrelated energy deposits/pile-up energy to be deposited
- Use **groomed** jets that rely on underlying large-R jet substructure to filter out the soft components
- Our analysis uses a mass-drop filter algorithm on Cambridge – Aachen jets (R = 1.2)
  - Step 1 (Mass drop)
    - Requires some amount of symmetry between the two sub-jets
  - Step 2 (Filtering)
    - Contents of jet are reclustered into smaller subjets. All but 3 hardest sub-jets are filtered out



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- Select events that have either two R=0.4 anti-kT jets, or one large-R groomed jet that matches to the W mass.
  - lvjj <OR> lvJ (+ n other jets)
  - Event is chosen as lvjj or lvJ event based on dijet/groomed jet agreement with W mass

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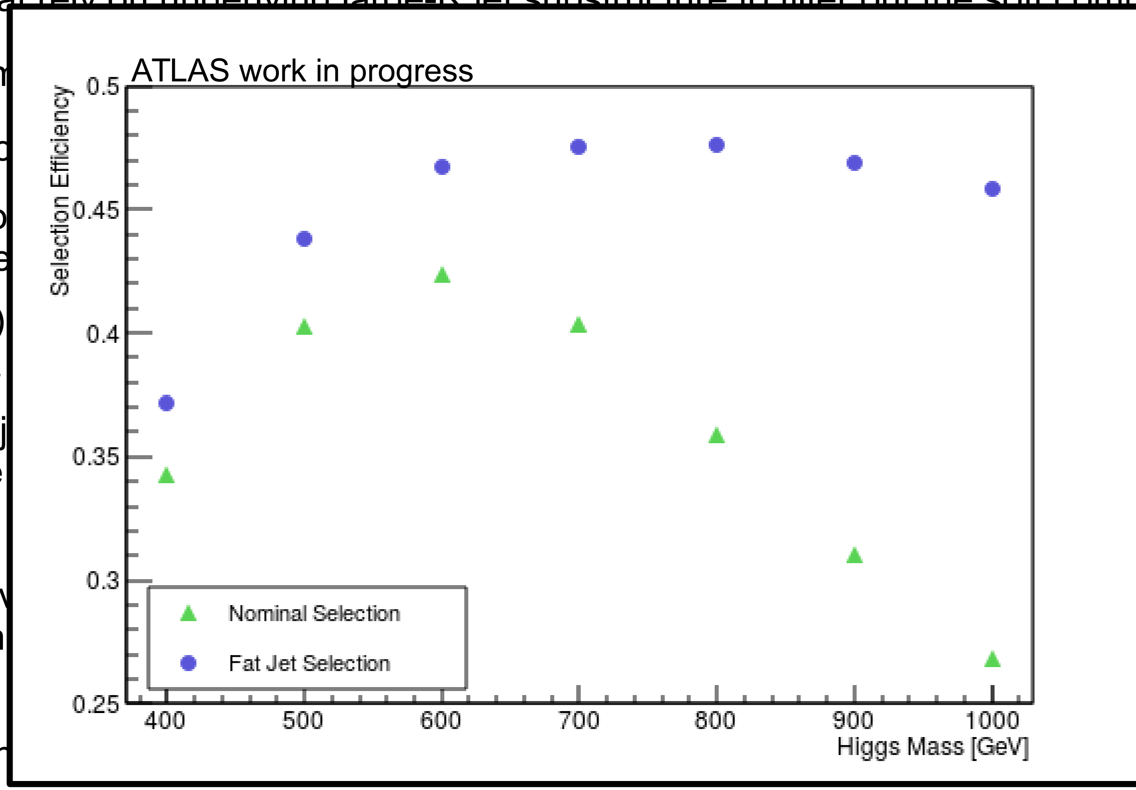

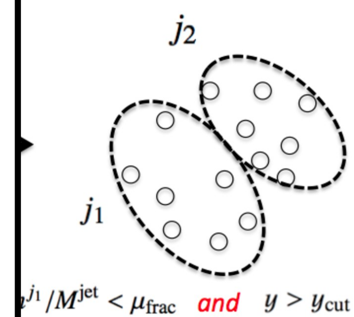

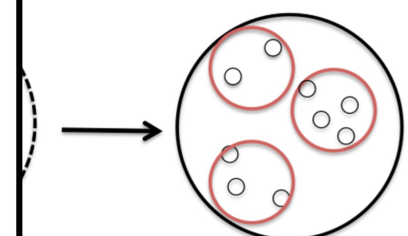

Filtered jet

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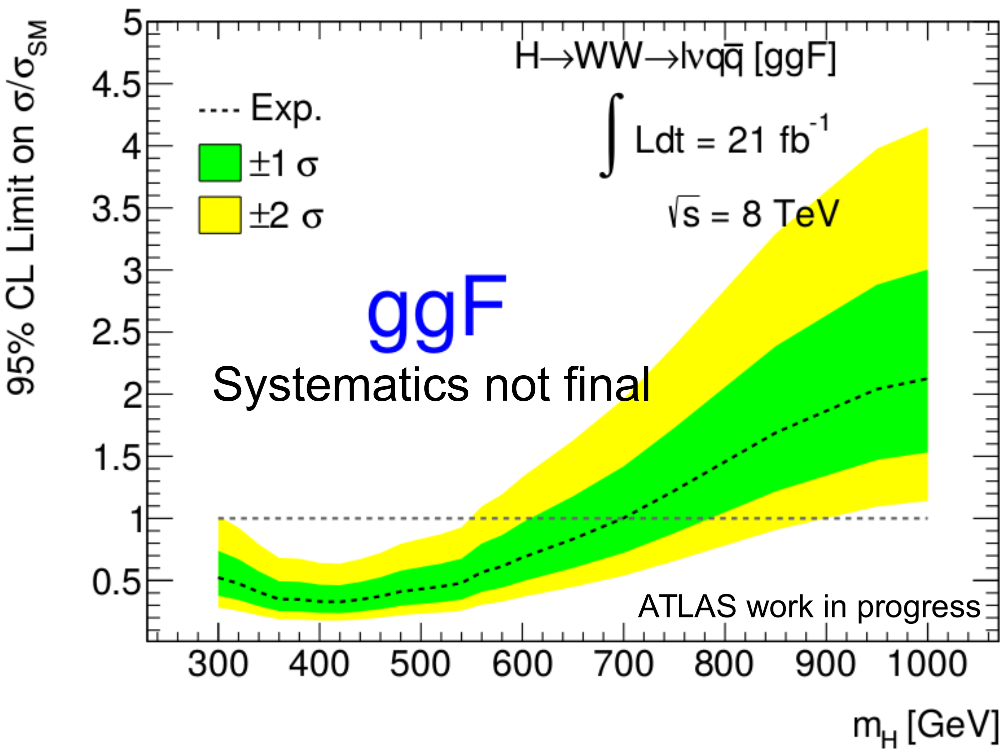
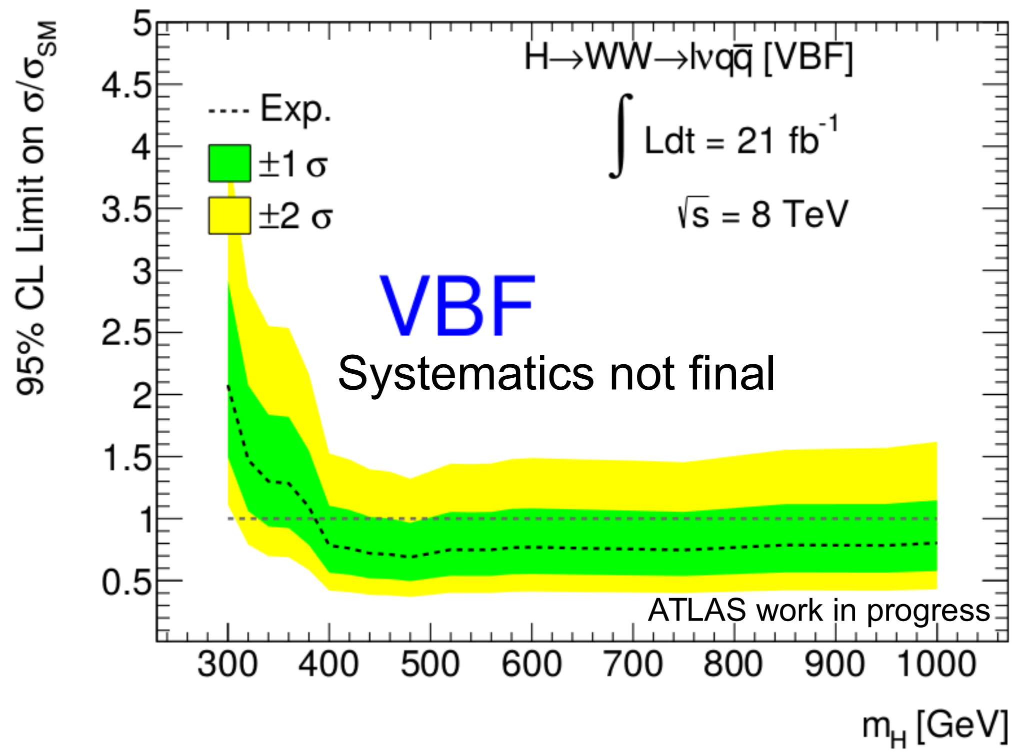
Limits (Norm. systematics only)

SM INTERPRETATION





Summary

- The Heavy Higgs sector presents interesting and challenging hurdles
  - Interference with continuum background → more diffuse signal
  - Boosted object → jet merging, substructure techniques

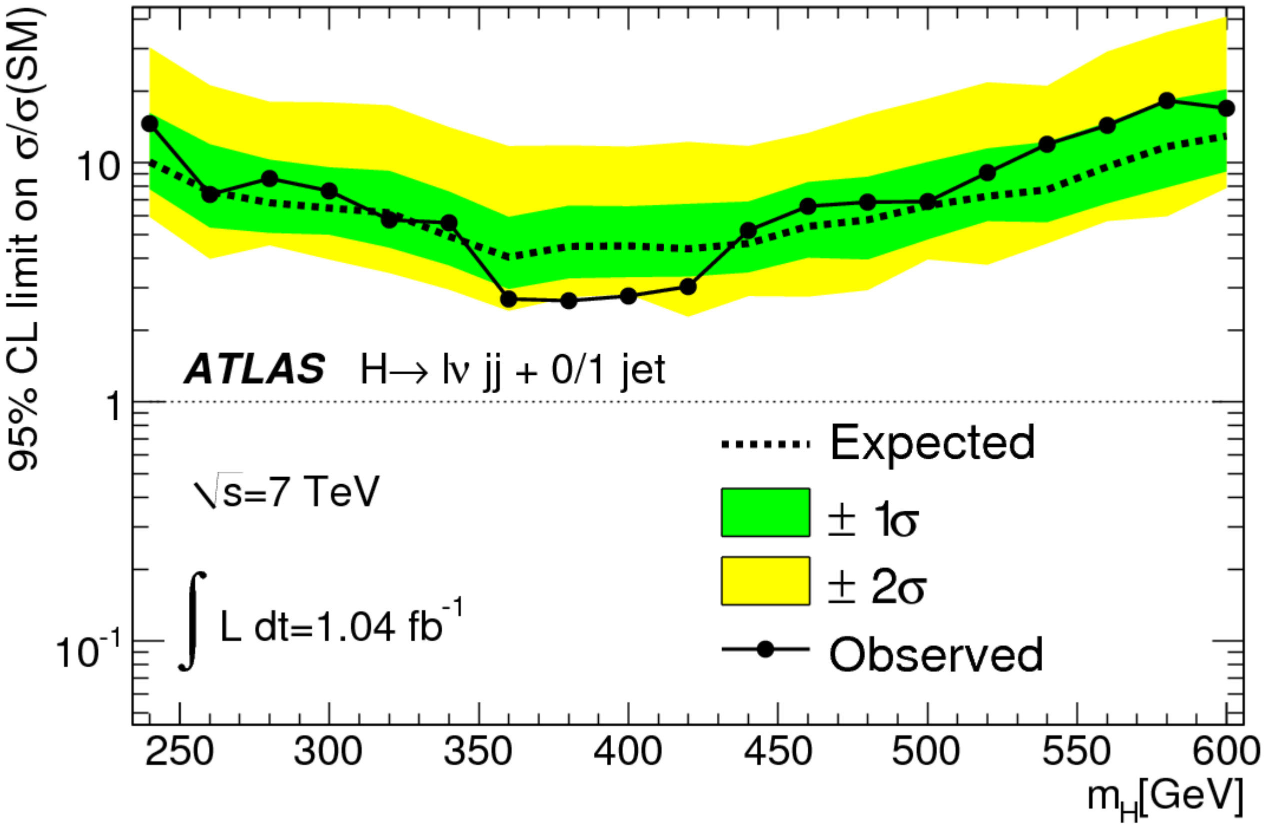
- Want to "finish the story" by setting limit (excluding?) the entire heavy SM Higgs mass range (300 – 1000 GeV)
- The presence of the 125.5 GeV Higgs-like object does not rule out the presence of another Higgs at High mass
  - Adapting the analysis to take into account a heavy Higgs-like object with variable width

- Stay tuned!

Thanks

lvjj @ 7 TeV

Last lvqq public result: Phys.Rev.Lett. 107 (2011) 231801



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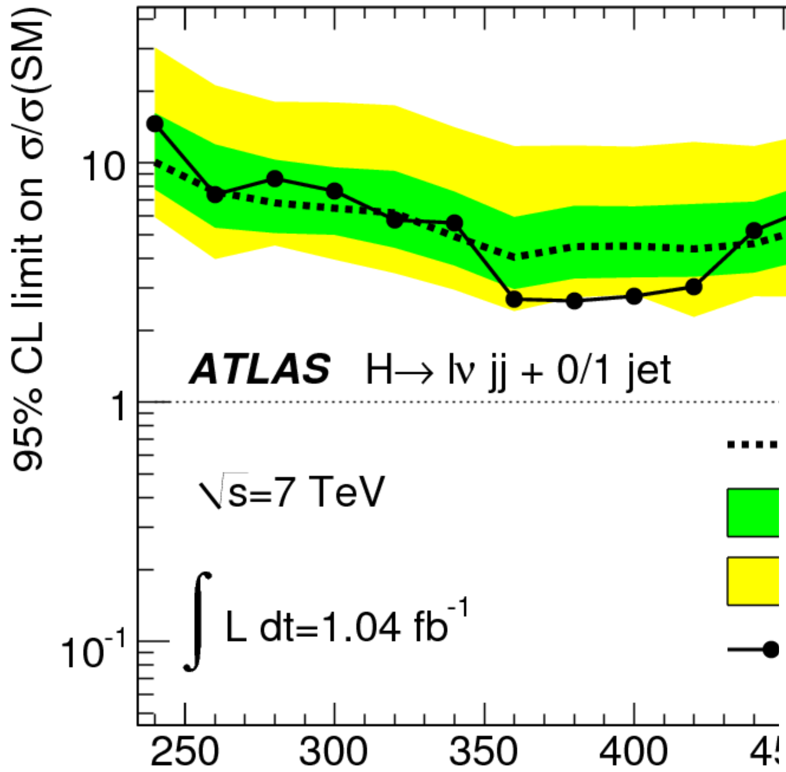
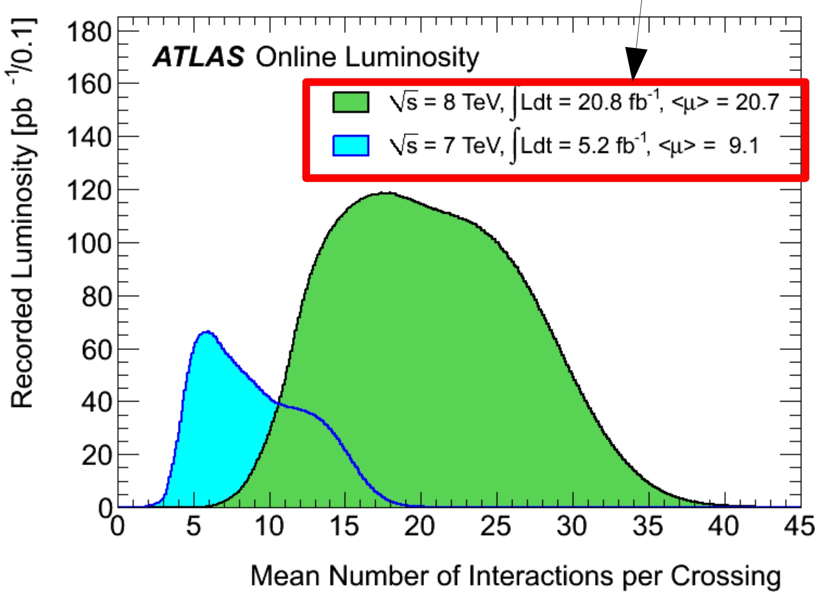


Much more data available, but with challenging conditions



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResults

Aim to extend search up to 1000 GeV, and use full 2012 dataset

Mass-drop filtering

- Isolates concentrations of energy from ~ symmetric subjets
- Uses C/A algorithm (angular ordered shower history, as opposed to p_T ordered in kT based algorithms)

- Mass Drop Step:
  - 'Undo' last C/A clustering to get 2 subjets – j1, j2 (ordered by mass)
  - Require mass drop from original jet and most massive subjet:

$$\frac{m_{j1}}{m_J} < \mu_{frac}, \; \mu_{frac} = 0.67$$

  - Both jets required to carry some significant portion of p_T

$$\frac{min\left[(p_T^{j1})^2, (p_T^{j2})^2\right]}{(m_J)^2} \times \Delta R^2_{j1,j2} > y_{cut}, \; y_{cut} = 0.09$$

- Filtering Step:
  - Jet reclustered with C/A and new radius parameter. All but three hardest subjets discarded

$$R_{filt} = min\left[0.3, \Delta R_{j1,j2}/2\right]$$

Searching for Wide range in mass

- Searching over a wide range in phase space (300 → 1000 GeV)
  - Adapting search cuts to include 300 GeV signal would make cuts on background at high mass (where we are quite sensitive) too loose.
- Adapting mass dependent cut values to kinematic variables helps increase sensitivity at high masses.

All Events:

- Δφ(lepton,neutrino)
- Δφ(j,j) (for di-jet events)

ggF Events

- Groomed Jet pT (groomed jet events)
- Leading jet pT (di-jet events)
- Subleading jet pT (di-jet events)
- MET
- Lepton pT

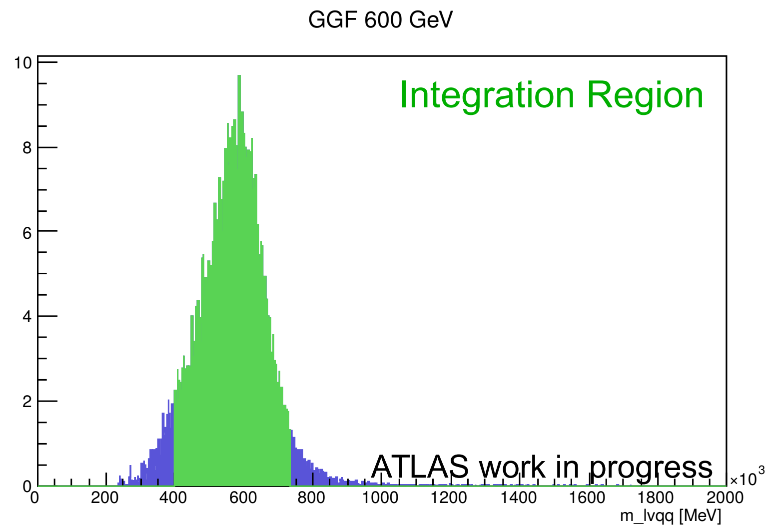
VBF Events

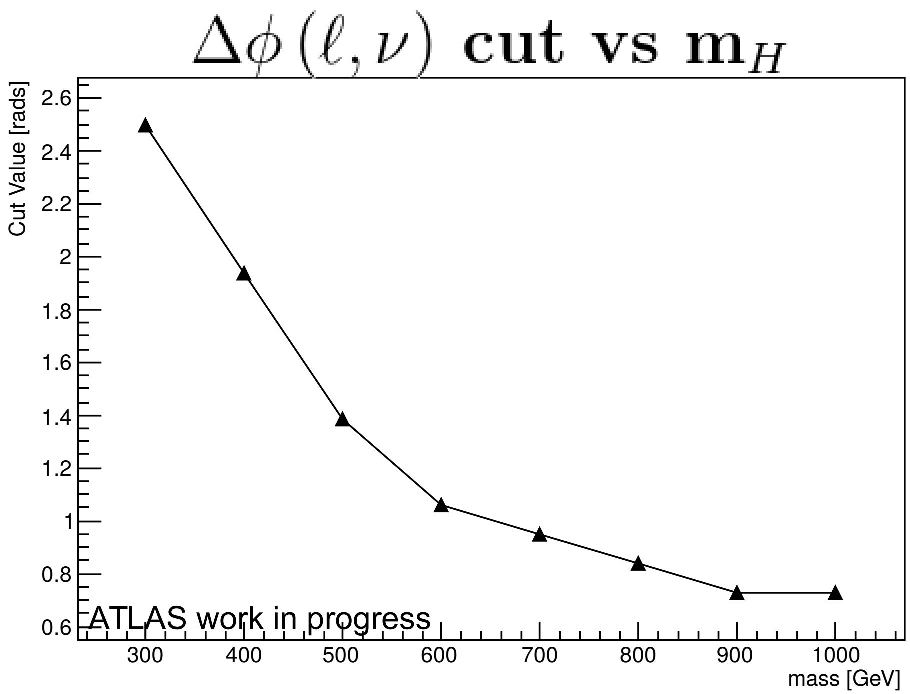
- pT balance

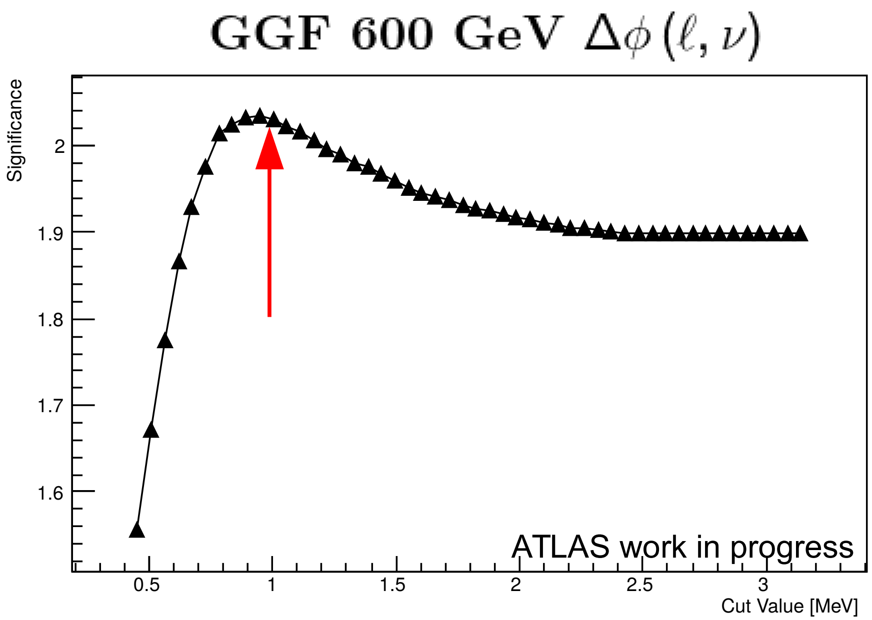
$$p_T^{Balance} = \frac{(\vec{p}_\ell + \vec{p}_\nu + \vec{p}_{j,W1} + \vec{p}_{j,W2})_T}{p_T^\ell + p_T^\nu + p_T^{j,W1} + p_T^{j,W2}}$$

Mass Dependent Cuts

- Cuts are chosen in order to maximize sensitivity (pre-selection already defined to maximize sensitivity @ 300 GeV Higgs mass)
- Integration window chosen in order to isolate Higgs signal (integrate signal and background to include mass range in which 90% of signal resides)

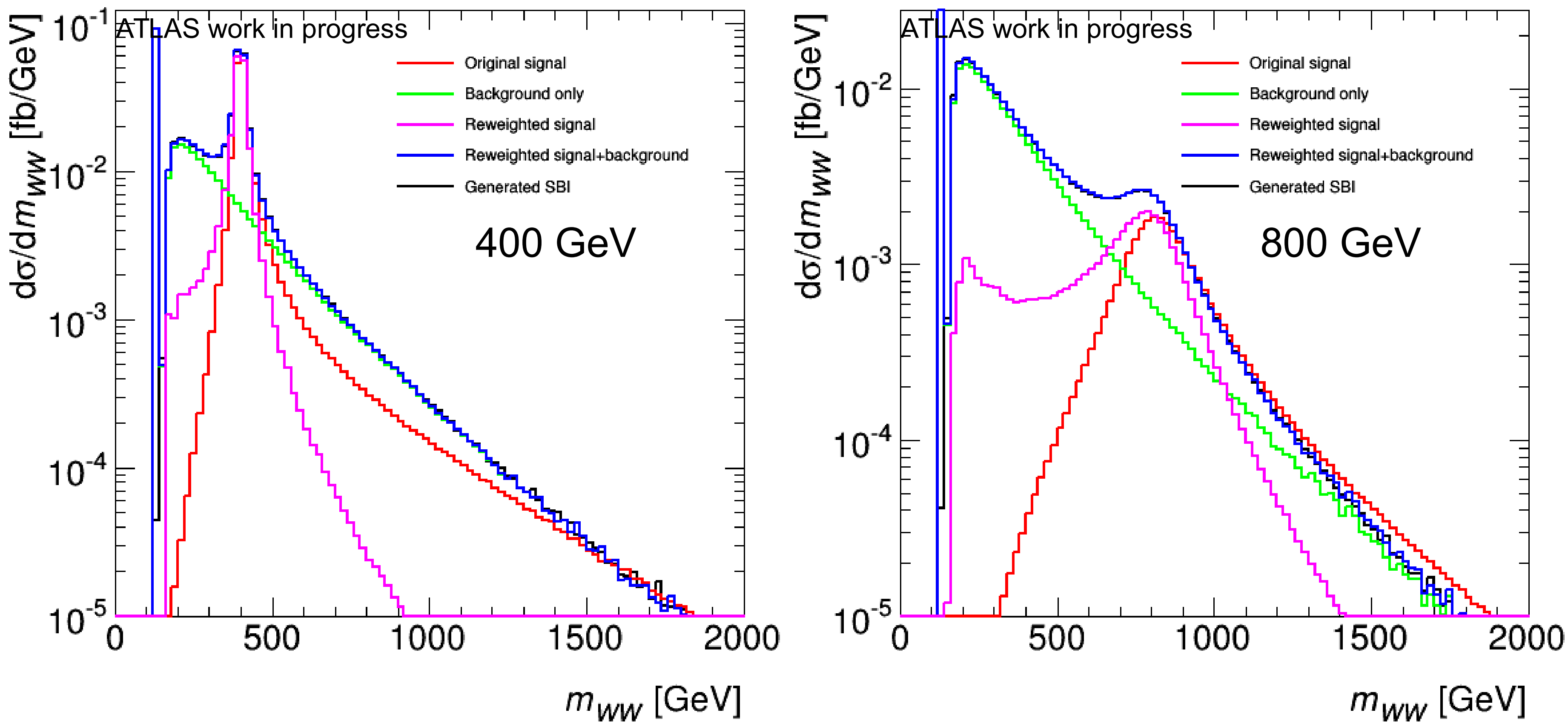






Systematics on VBF Interference

- To check REPOLO rescaling of samples, can separately generate Background (B) and Signal+Background+Interference (SBI) samples with VBF@NLO
    - Distribution of SBI – B should return same result as S samples rescaled with REPOLO
- Systematic taken as symmetrized envelope around difference between SBI-B and S+I from REPOLO



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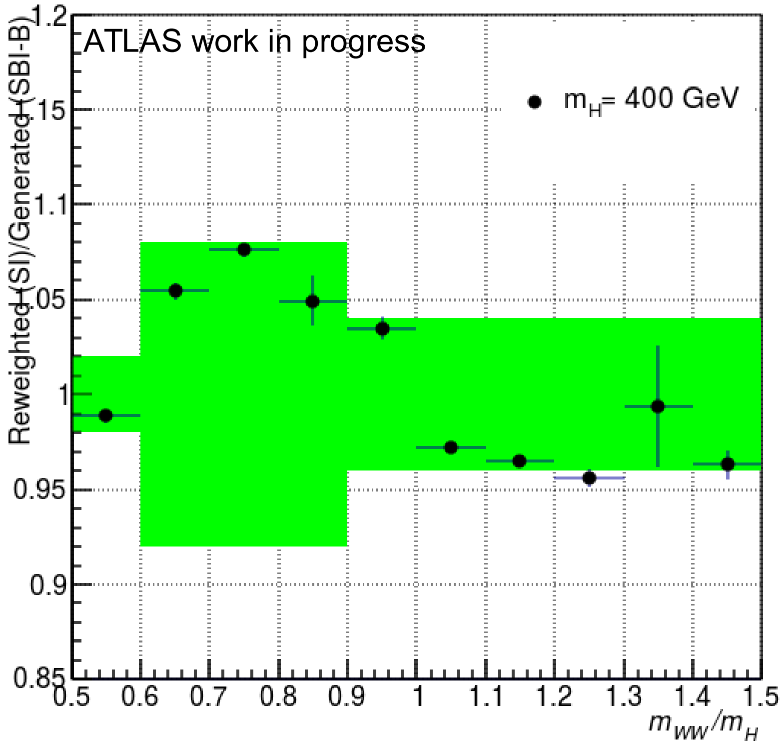

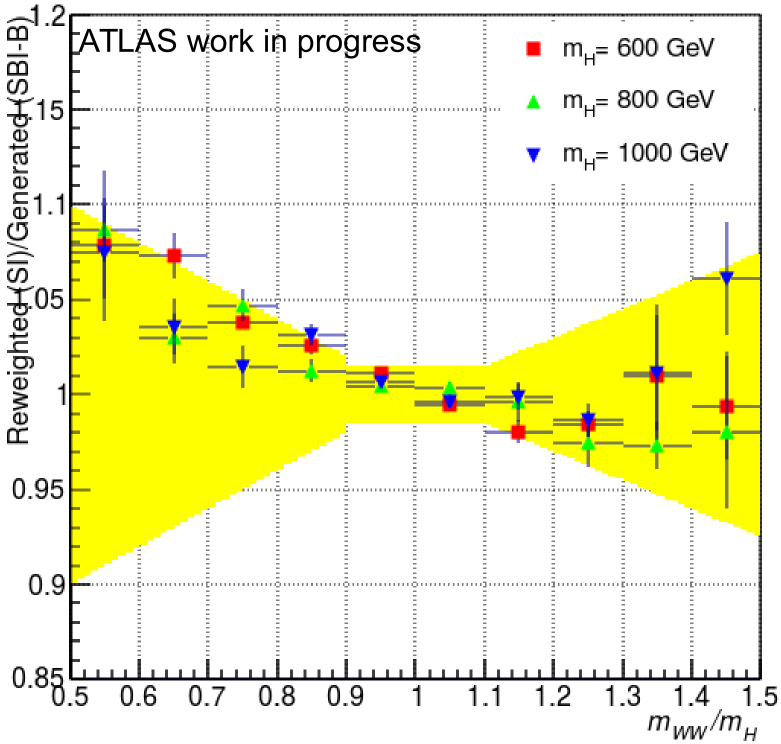

Coloured band: Assigned systematic