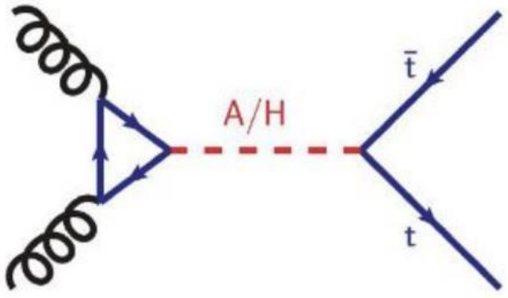
Search for A/H→ttbar with Interference
in 1-lepton Final State (Blinded)



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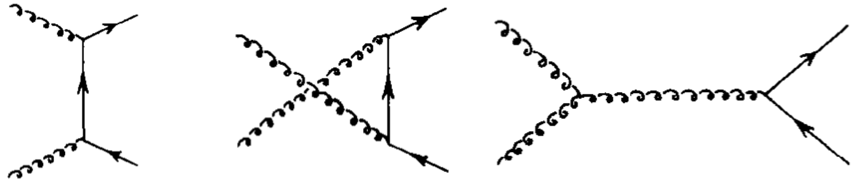
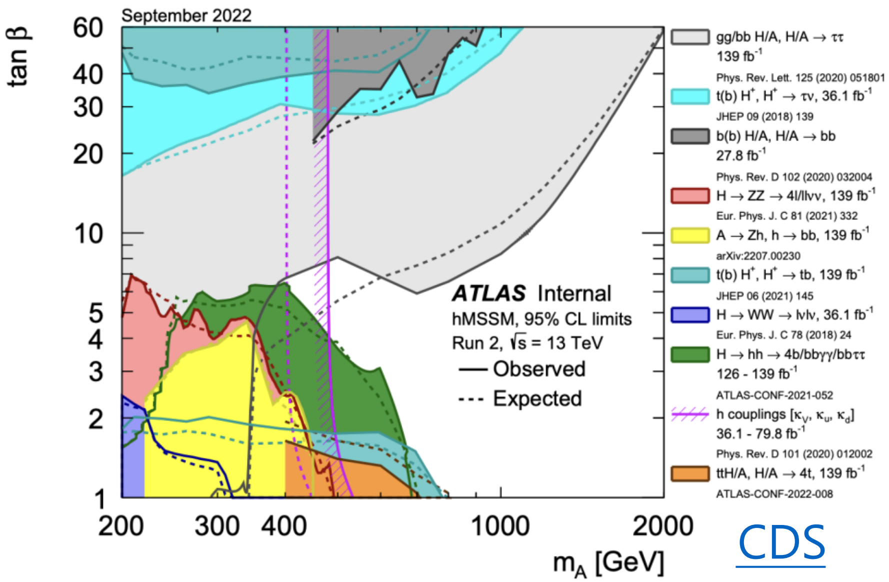
Motivation

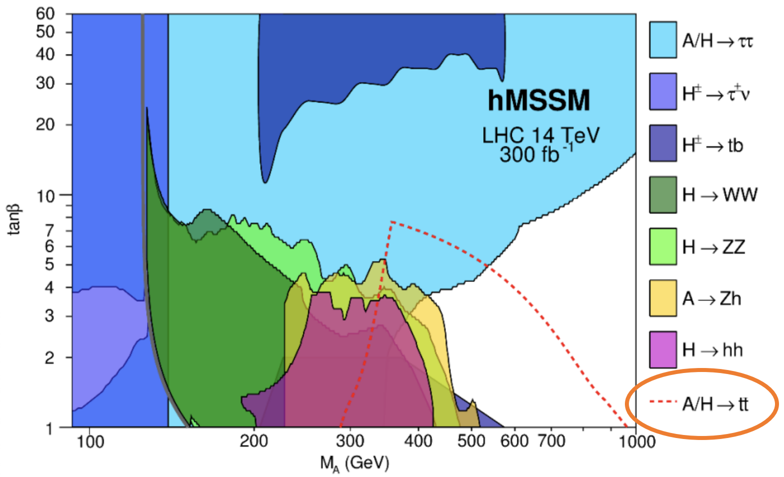
- **Blank at bottom-right of hMSSM exclusion limit**
  - Low $\tan\beta$ and high m_A
  - $gg \to A/H \to t\bar{t}$ is expected to be sensitive there
    - Large $g_{\Phi t\bar{t}}$
    - Dominant decay channel
    - Production cross sections are substantial
- **Strong interference between signal and background**
  - Rich $gg \to t\bar{t}$ progress in SM



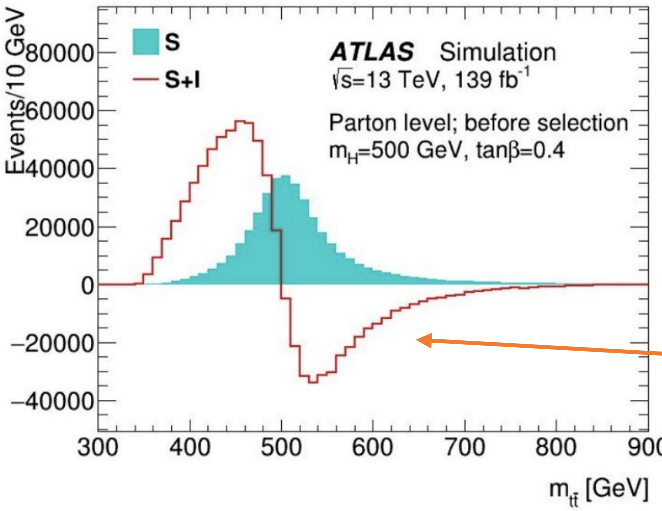
  - Destroy the common signal shape
  - Complicated peak-dip structure
  - Due to on-shell t in gluon-fusion
  - Highly model-dependent



CDS



[1502.05653] (arxiv.org)



What we are looking for

Signal Production

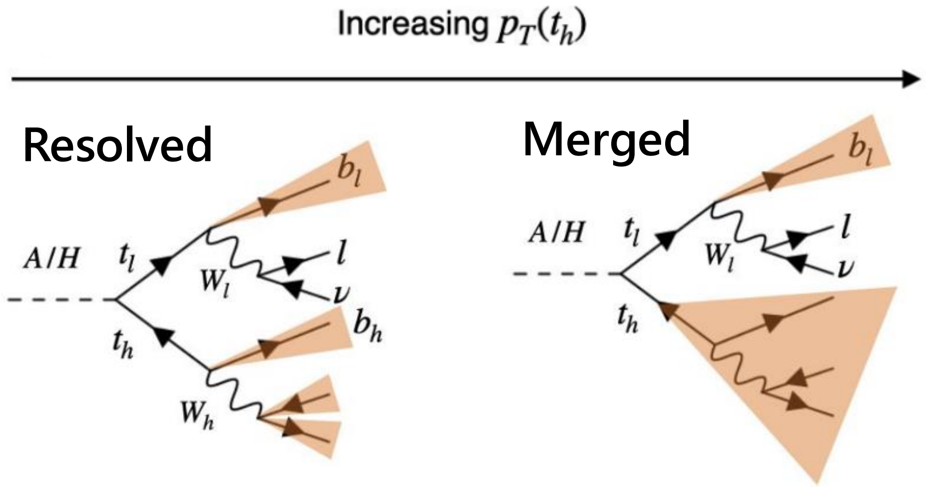
- **Signal process is implemented at LO via MadGraph**
  - Hack MadGraph to subtract background matrix element from the total process
    - Produce S+I for A: g g > t t~ / H QCD<=99 QED<=99
    - Consistent results with quadratic production as well as an alternative hack method by CMS
    - Agreed by MG author
- **Apply normalization factor to estimate the NLO case**
  - $S_{NLO} + I_{NLO} = k_S \times S_{LO} + \sqrt{k_S k_B} \times I_{LO}$
  - Not possible to produce NLO interference in a cpu-time-saving way so far
- **The relative widths could change a lot among different points**
  - The signal shapes closely relate to heavy Higgs widths
  - Need signal samples for many parameter points of many interpretations
  - Re-use the full simulated samples via parton-level reweighting

$$W_{\text{new}} = \frac{|M_{\text{new}}|^2}{|M_{\text{old}}|^2} \times W_{\text{old}}$$

Event Selection

Common selection:

- Standard run and event cleaning
- Single-lepton trigger
- Exactly 1 lepton with $p_{\mathrm{T}} > 28\mathrm{GeV}$
- $E_{\mathrm{T}}^{\mathrm{miss}} > 20\mathrm{GeV}$, $E_{\mathrm{T}}^{\mathrm{miss}} + m_{\mathrm{T}}^{W} > 60\mathrm{GeV}$
- $\geq$ 1 b-tagged jet (DL1r 77% WP)



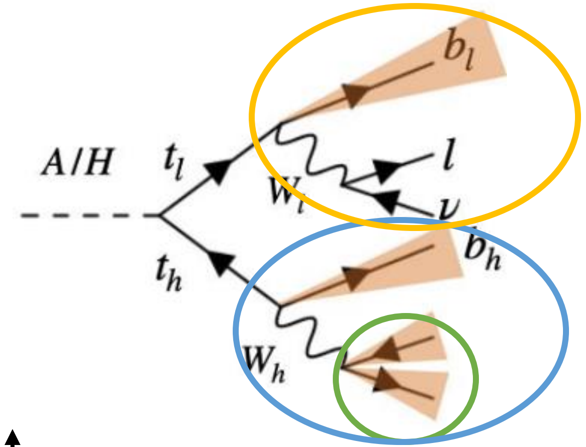
Resolved

- **Number of jets:**
  - $\geq$ 4 small-R jets
- **Well-reconstructed $t\bar{t}$:**
  - $\log_{10}(\chi^2) < 0.9$
- **Orthogonality:**
  - Veto events passing merged selection

Merged:

- **Top tagging:**
  - $\geq$ 1 large-R jet with $p_{\mathrm{T}} > 300\mathrm{GeV}$ and $m > 100\mathrm{GeV}$
  - $\longrightarrow t_h$
- **Close-to-lepton jet:**
  - $\geq$ 1 small-R jet with $\Delta R(l, \mathrm{jet}) < 2.0$
  - $\longrightarrow b_l$
- **Avoid overlap between objects:**
  - $\Delta R(l, t_h) > 1.5$
  - $\Delta R(b_l, t_h) > 1.5$

Analysis Strategy



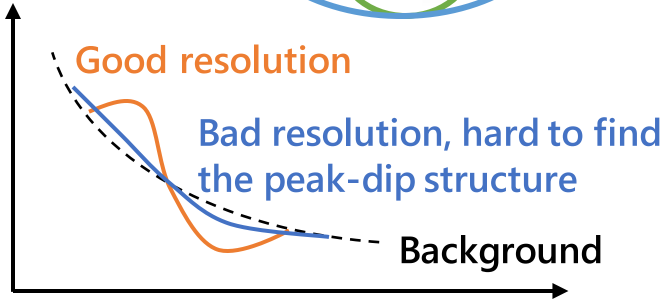
Merged:

- Variable of interest: $m_{t\bar{t}} = m(t_h + b_l + l + \nu)$

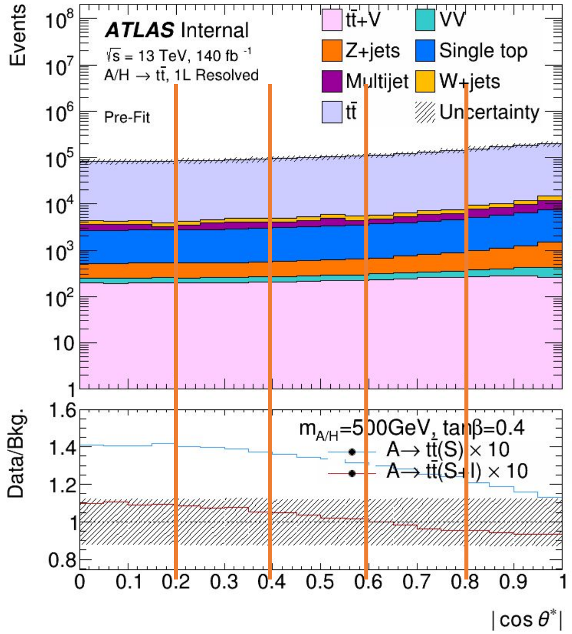
Resolved:

- Variable of interest: $m_{t\bar{t}} = m(j_1 + j_2 + j_3 + j_4 + l + \nu)$
- Minimize chi2 to select the four jets for the $t\bar{t}$ system

$$\chi^2 = \left[\frac{m_{jj} - m_W}{\sigma_W}\right]^2 + \left[\frac{m_{jjb} - m_{jj} - m_{t_h\text{-}W}}{\sigma_{t_h\text{-}W}}\right]^2 + \left[\frac{m_{jl\nu} - m_{t_l}}{\sigma_{t_l}}\right]^2 + \left[\frac{(p_{T,jjb} - p_{T,jl\nu}) - (p_{T,t_h} - p_{T,t_l})}{\sigma_{diff\ p_T}}\right]^2$$

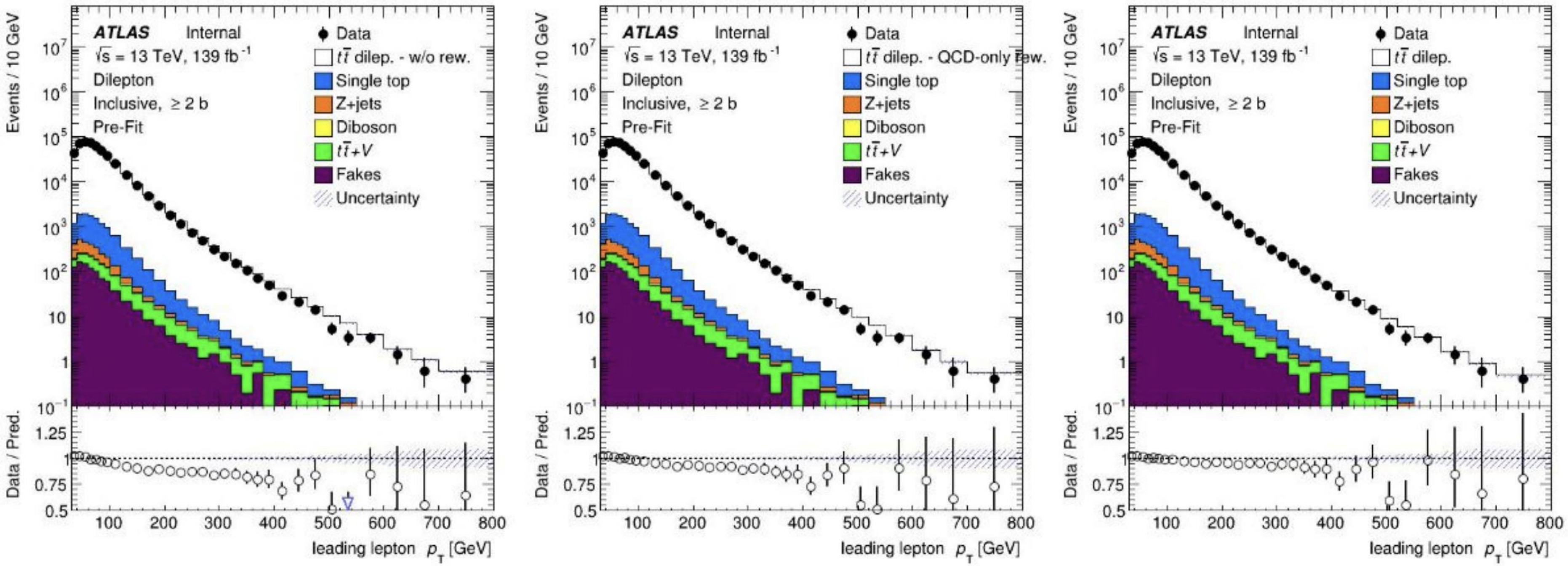


  - Scale energies of jets used for t_h for better $m_{t\bar{t}}$ resolution
- Categorized by b-tagging:
  - **2b region:** b-jet exists in both t_h and t_l
  - **1b region:** b-jet only appear in t_h or t_l
- Equally split to 5 SRs by angle variable $|\cos\theta^*|$
  - The angle between $t\bar{t}$ system and t_l momentum in $t\bar{t}$ rest frame
  - The signal Higgs decay into $t\bar{t}$ isotropically
  - SM $t\bar{t}$ background will show a peak at 1

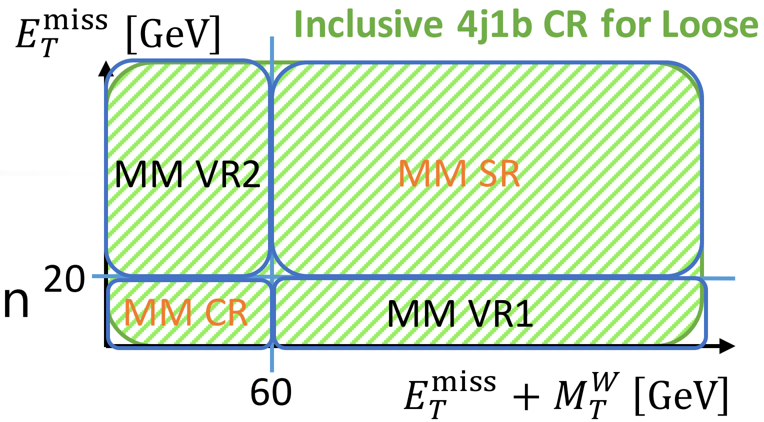


NNLO Reweighting for SM ttbar

- Generated SM ttbar MC (Powheg + Pythia) at NLO in QCD, no higher-order EW corrections
- Higher-precision differential predictions at NNLO-QCD+NLO-EW calculated by [Mitov et al]()
- Reweight generated MC samples to higher-order predictions
  - ➢ Iterative recursive reweighting in $p_T(\mathrm{top,avg})$ and $m_{t\bar{t}}$
  - ➢ Using parton-level momentum after FSR
- Excellent closure after 3 iterations, significantly improves Data/MC agreement
  - no reweighting   reweighting to NNLO-QCD   full reweighting

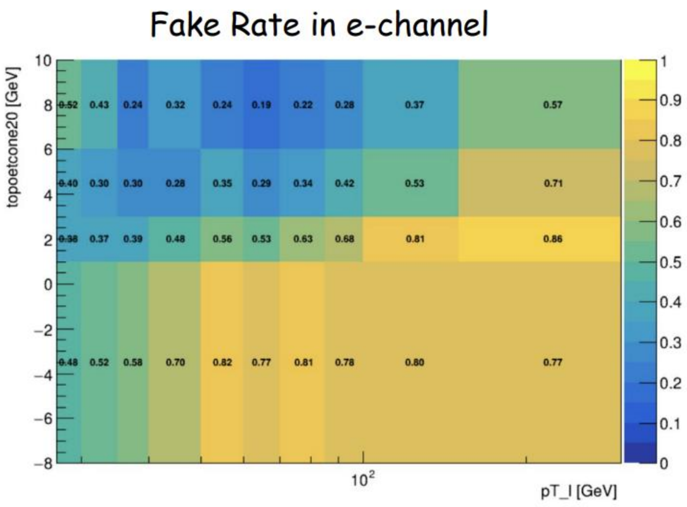


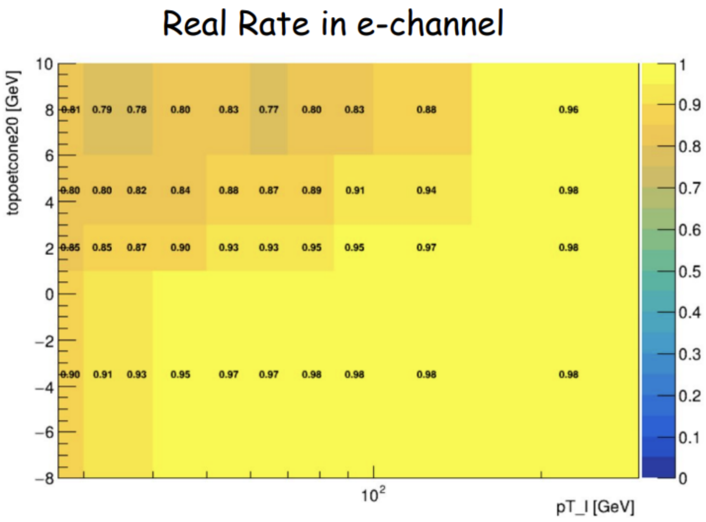
Multijet Estimation

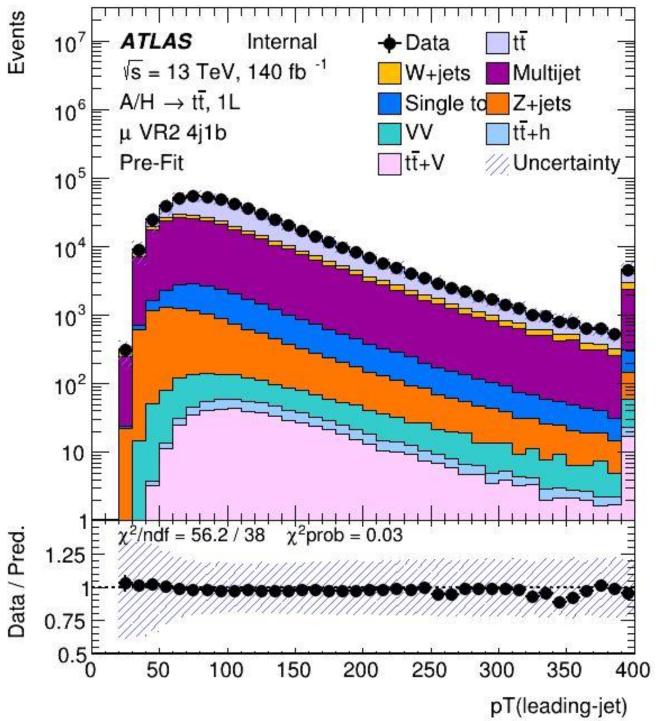


- **Matrix method**
  - Alternative inclusive regions based on a loose lepton definition
  - Compare yields in loose and tight definitions
    - $N^{\text{Loose}} = N^{\text{real}} + N^{\text{fake}}$
    - $N^{\text{Tight}} = \epsilon N^{\text{real}} + f N^{\text{fake}}$
  - Real rate ϵ from MC in MM SR, fake rate f from fake-enriched CR
  - Multijet in SR obtained by reweighting data under loose definition

$$w_{\text{multijet}}\left(N^{\text{Tight}}, N^{\text{Anti-Tight}}\right) = \frac{(\epsilon - 1)f}{\epsilon - f} N^{\text{Tight}} + \frac{\epsilon f}{\epsilon - f} N^{\text{Anti-Tight}}$$





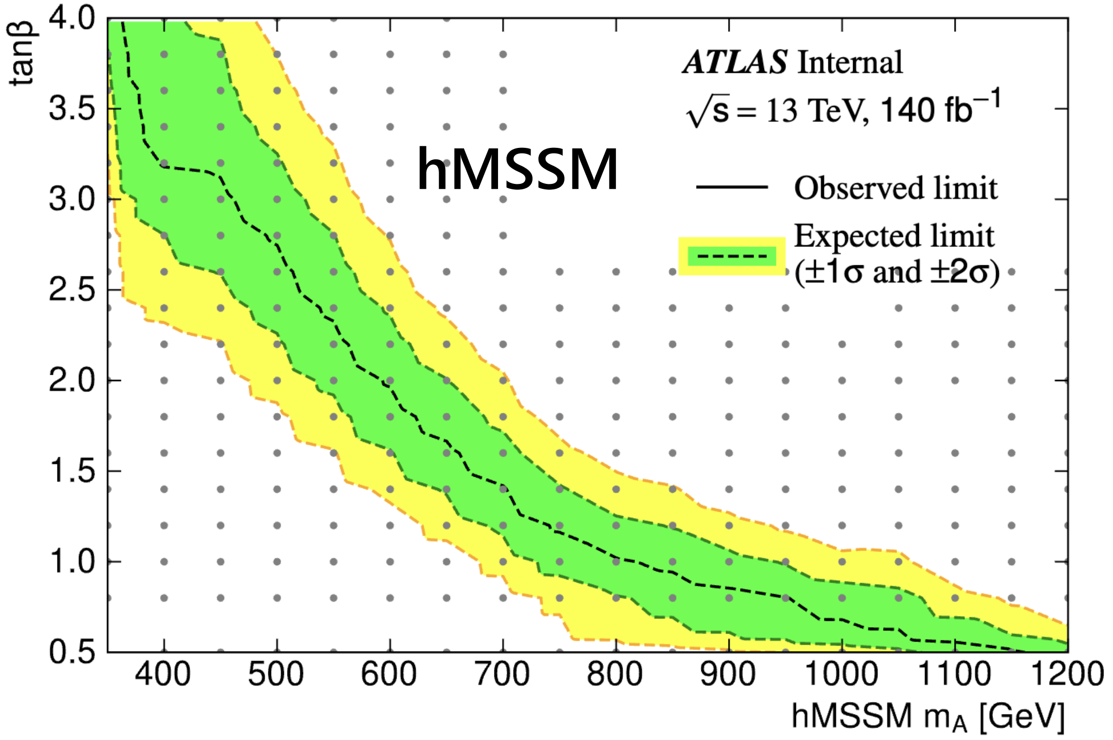


Expected Exclusion

$$g^4_{\Phi\bar{t}t} \times S + g^2_{\Phi\bar{t}t} \times I \rightarrow \mu \times S + \sqrt{\mu} \times I$$

- Extend likelihood to include interference term

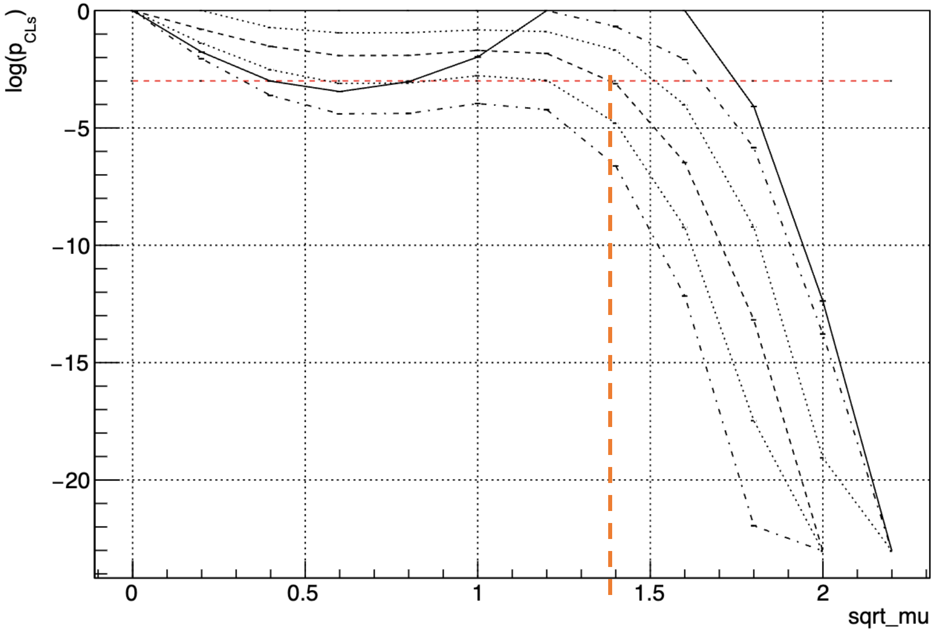
$$\mathcal{L} = \prod_{bin} \mathcal{P}\left(n|(\mu - \sqrt{\mu})S + \sqrt{\mu}(S+I) + B\right)$$



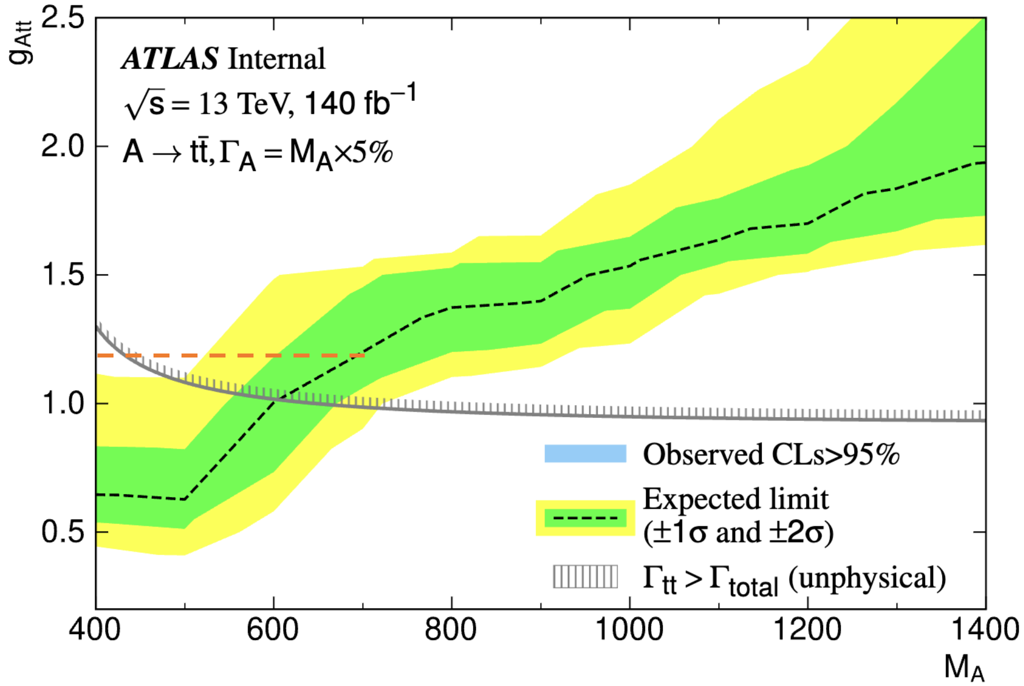
Asimov Study

Model-independent Interpretation

- Unable to provide a cross-section upper limit as a function of mass
- The widths and couplings depended on model parameters determine the signal shape.
- Try to make exclusions on coupling-mass plane for different relative heavy Higgs widths
  - Should help in re-interpretation of those models with additional (pseudo-)scalar Higgs
  - Lower sensitivity due to LO cross-section and no A/H combination



$\sqrt{\mu} \simeq 1.4 \rightarrow g_{\Phi t\bar{t}} \simeq 1.18$



Asimov Study

Summary

- **Search for A/H→ttbar interference with ATLAS detector**
  - Working in progress
  - Statistically combining 1L channel and 2L channel
    - The exclusion limits will be improved afterwards
- **Expected to complement the low $\tan\beta$ and high m_A region in hMSSM**
- **Other interpretations are also supported**
- **Nice to see that more and more analysis taking interference into account**

Backup

Object Definitions

- **Muons**
  - Leading $p_T > 28$ GeV
  - Sub-leading $p_T > 25$ GeV
  - $|\eta| < 2.5$
  - Medium ID
  - FCTightTrackOnly isolation
  - OR with jets: BoostedSlidingDRMu
- **Electrons**
  - Leading $p_T > 28$ GeV
  - Sub-leading $p_T > 25$ GeV
  - $|\eta| < 2.47$, excluding cracks
  - TightLH ID
  - TightTrackOnly isolation
  - OR with jets: electron-in-jet subtraction
    - Custom OR by Z' analysis
    - Details in Z' FAR presentation
- **Small-R jets**
  - Anti-kt 0.4, EM-PFlow
  - $p_T > 25$ GeV, $|\eta| < 2.5$
  - JVT
- **B-tagging**
  - Applied on EM-PFlow jets
  - DL1r tagger, 77% WP
- **Large-R jets**
  - Re-clustered from AntiKT0.4 jets
  - Variable-R algorithm optimized for tops
    - $R = \max\{R_{\text{min}}, \min\{R_{\text{max}}, \rho/p_T\}\}$
    - $R_{\text{max}} = 1.5, R_{\text{min}} = 0.4, \rho = 600$ GeV
  - $p_T > 200$ GeV, $|\eta| < 2.0$
  - $m > 100$ GeV

Uncertainties Estimation

- **Experimental**

  Updated to the latest recommendations
  - ➢ Luminosity 0.83% for 140 ifb
  - ➢ Pile-up reweighting
  - ➢ Full JES and JER systematics
  - ➢ JMS and JMR for 1L Large-R jets
  - ➢ Flavor tagging SF uncertainties
  - ➢ Lepton SF uncertainties (reco, id, trigger, iso)
    - Extra ±10% on electron ID SF for $\Delta R<0.4$ (yet to be included in 1L)

- **Modelling**
  - ➢ Signal (for both S and S+I):
    - Scale variations (μR, μF), PDF variations
    - PS generator tunes (ISR, FSR)
    - M(top) variation with alternative reweighing
  - ➢ SM ttbar:
    - On NNLO prediction
      - Scale variations, PDF variations
    - On NLO+PS prediction
      - All recommended weight uncertainty (ISR/FSR)
      - All alternative samples reweighted (ME, PS, hdamp, mtop)
    - Reweighting method uncertainties
      - Reweighting order, one-emission sample
    - Cross section uncertainty

Uncertainties Estimation

- **Modelling**
  - Single-top (Wt):
    - Scale variations, PDF variations, PS generator tunes (ISR, FSR), cross section uncertainty
    - PS (compare with PhPy8 samples), ME-PS (compare with aMC@NLO+Py8 samples)
    - Diagram removal vs subtraction scheme
      - Using up-to-date DR and DS sample with dynamic scales recommended by PMG (uncertainty much reduced)
  - W+jets (1L):
    - Scale variations, PDF variations
    - ±20% normalization uncertainty for x-section and flavour composition
  - Z+jets:
    - 2L: Uncertainty from data-driven correction
    - 1L: Cross section uncertainty
  - Individual backgrounds:
    - ±50% for multijet in 1L channel
    - ±30% for fakes in 2L channel
    - Cross section uncertainties for others

Background process	Up variation	Down variation
$t\bar{t}$	+5.6%	-6.1%
Single-top: Wt-channel (both)	+5.4%	-5.4%
Single-top: t-channel (both $t, \bar{t}$)	+4.3%	-3.7%
Single-top: s-channel (both $t, \bar{t}$)	+4.4%	-4.1%
$t\bar{t}+Z$	+10.4%	-12.0%
$t\bar{t}+W$ (both W^+, W^-)	+13.3%	-12.0%
$t\bar{t}+h$	+6.8%	-9.8%
Z+jets (1L)	+5.0%	-5.0%