Search for heavy Higgs bosons

decaying to top quark pairs using the CMS experiment

Afiq Anuar, Samuel Baxter, Alexander Grohsjean,
Jonas Rübenach, Christian Schwanenberger, Dominic Stafford

Terascale14
November 23, 2021

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

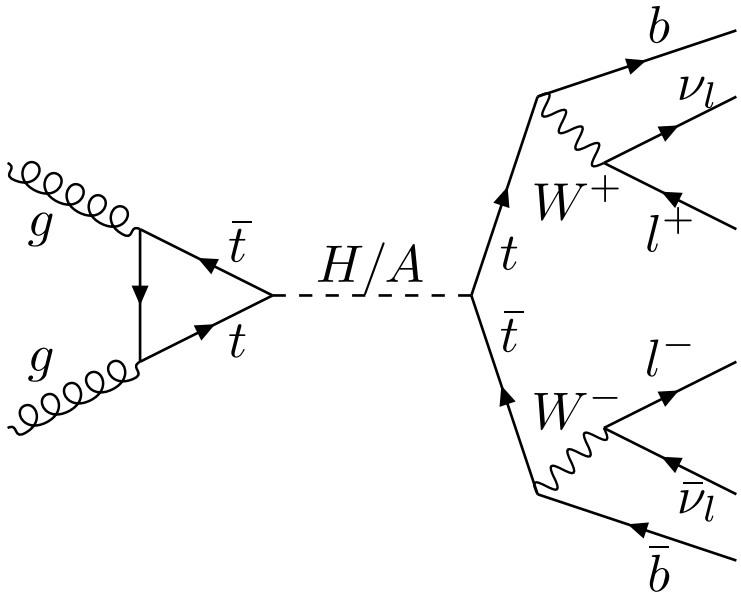
DESY.

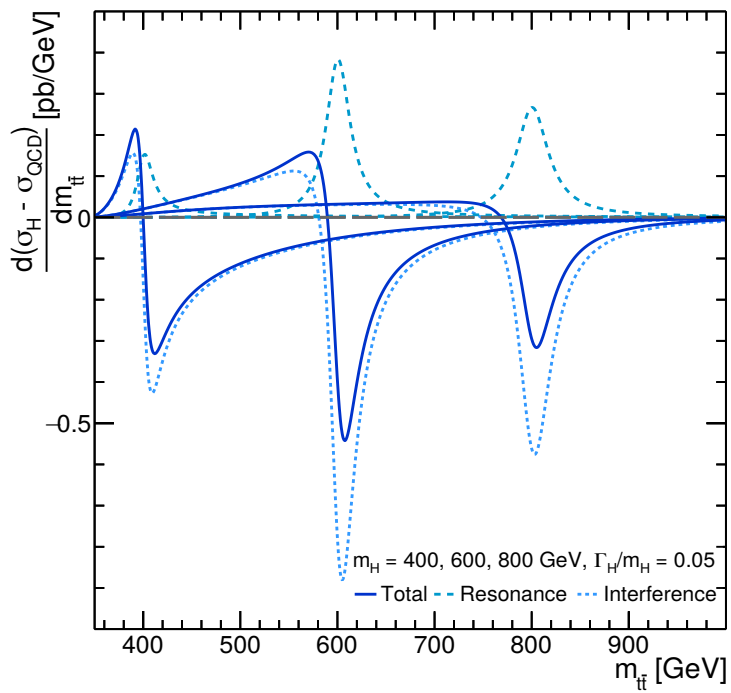
CMS

Overview

Search for heavy Higgs

- Many BSM theories predict additional Higgs bosons, e.g. neutral, heavy,
  - CP even (H) and
  - CP odd (A) Higgs bosons
- Possible DM mediator
- Assume CP conservation: No interference between A and H
- Channel: H/A $\rightarrow$ $t\bar{t} \rightarrow \ell\ell$
- Challenging because of interference with SM $t\bar{t}$, leading to a peak-dip-structure

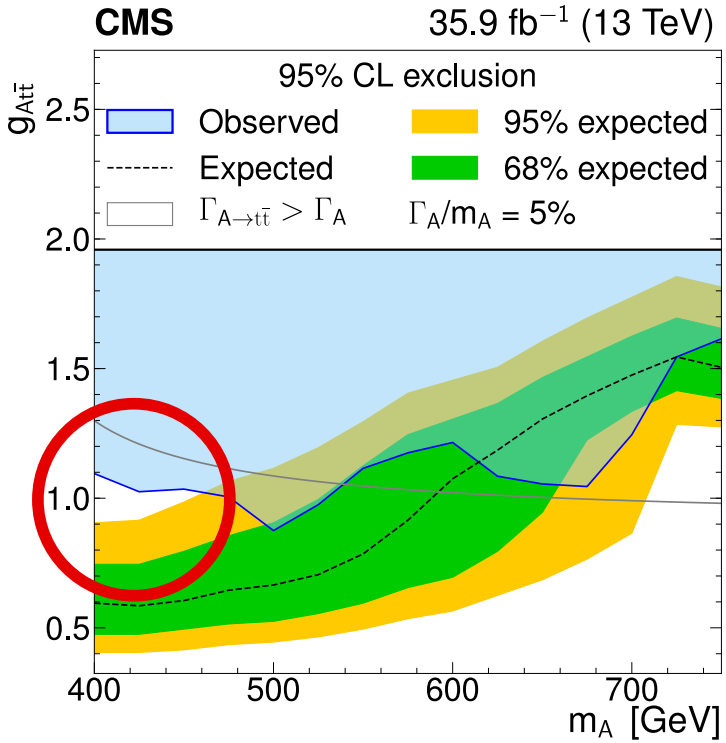




Motivation

From previous results

- Preceding analysis done for 2016 CMS data (JHEP04(2020)171)
- Combining di- and semi-leptonic channels
- Masses of 400 to 750 GeV, rel. width: 2.5 to 25% with inter- and extrapolation
- Limits on A coupling strength showed deviation at $m_A = 400$ GeV and 4 % width
- Locally 3.5σ, globally 1.9σ



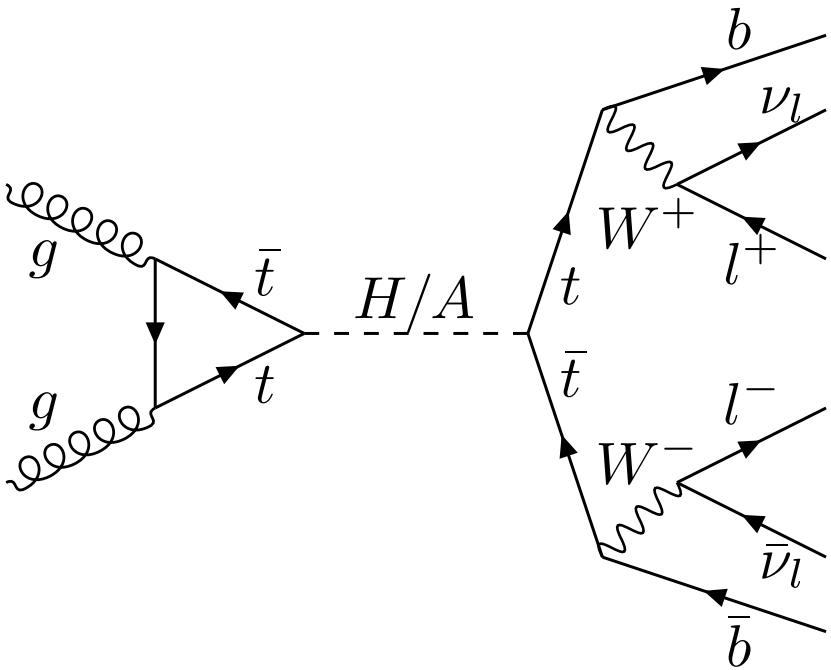
Several other recent analyses (arXiv:2002.12223, 1712.06518, 1903.00941) from ATLAS and CMS also show a small tension around this mass. ($A/H \to \tau\tau$, $A \to Zh$)

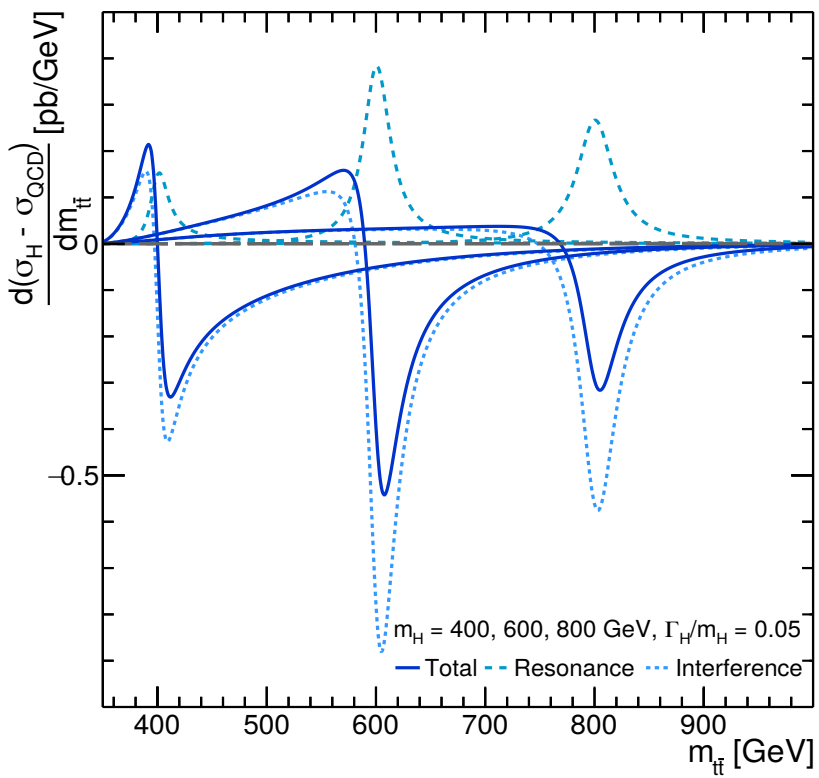
Strategy

Data and simulation

- $t\bar{t} \to jj\ell\ell\nu\nu$, $\ell \in \{e, \mu\}$, CMS data from 2016 to 2018
- Simulate heavy Higgs resonance and interference separately
  - Different dependence on coupling g of the cross section σ

$$\sigma = g^4 \sigma_{\text{res}} + g^2 \sigma_{\text{int}} + \sigma_{\text{SM}}$$

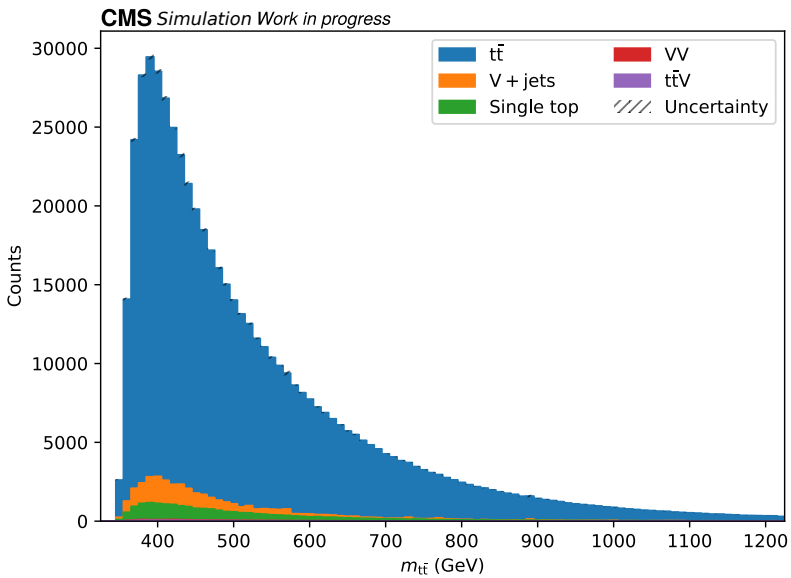


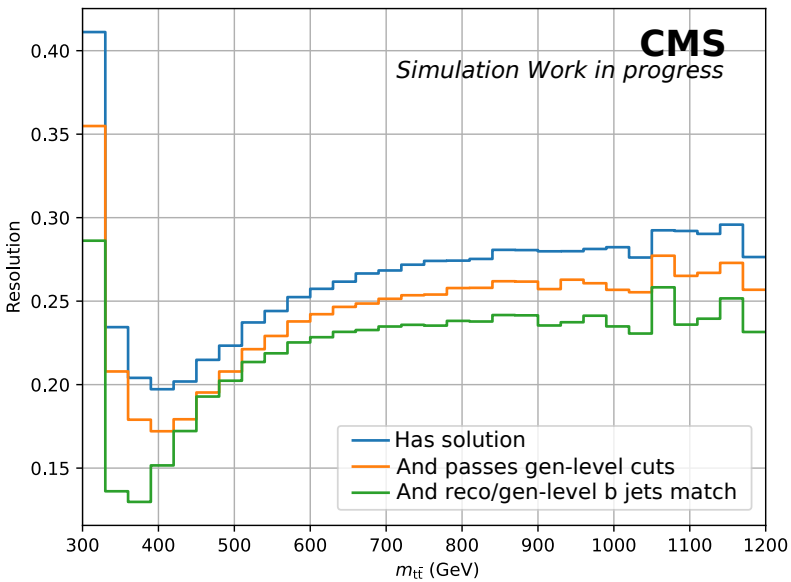


Strategy

Top quark system

- Kinematic reconstruction of top quarks from decay products
  - Assumptions: $m_t = 172.5$ GeV, $m_W = 80.4$, all $p_{T,miss}$ from $\nu\nu$
  - 25 % resolution on $m_{t\bar{t}}$



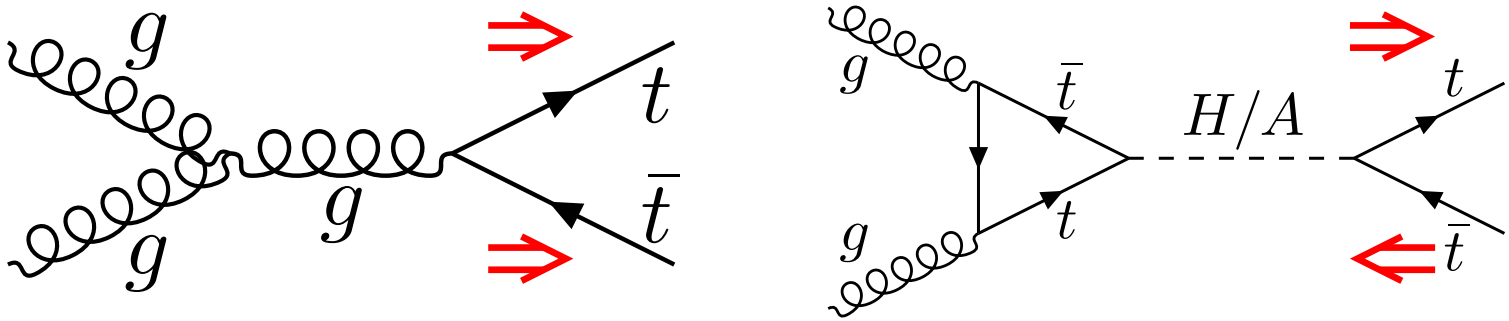


- Fit: Use invariant mass $m_{t\bar{t}}$ and c_{hel} (containing spin information)

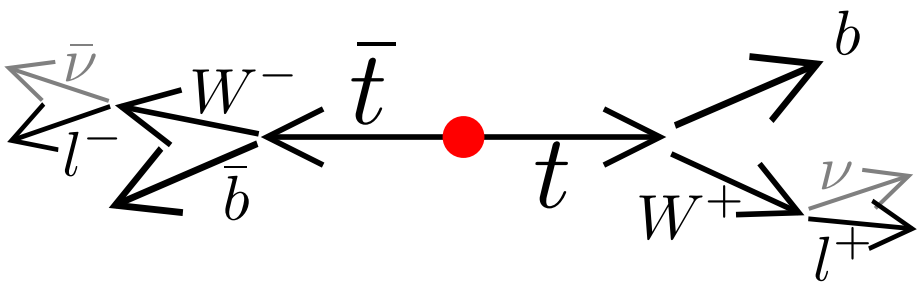
Spin information: C_{hel}

$C_{hel} = \cos\varphi$

Angle between leptons

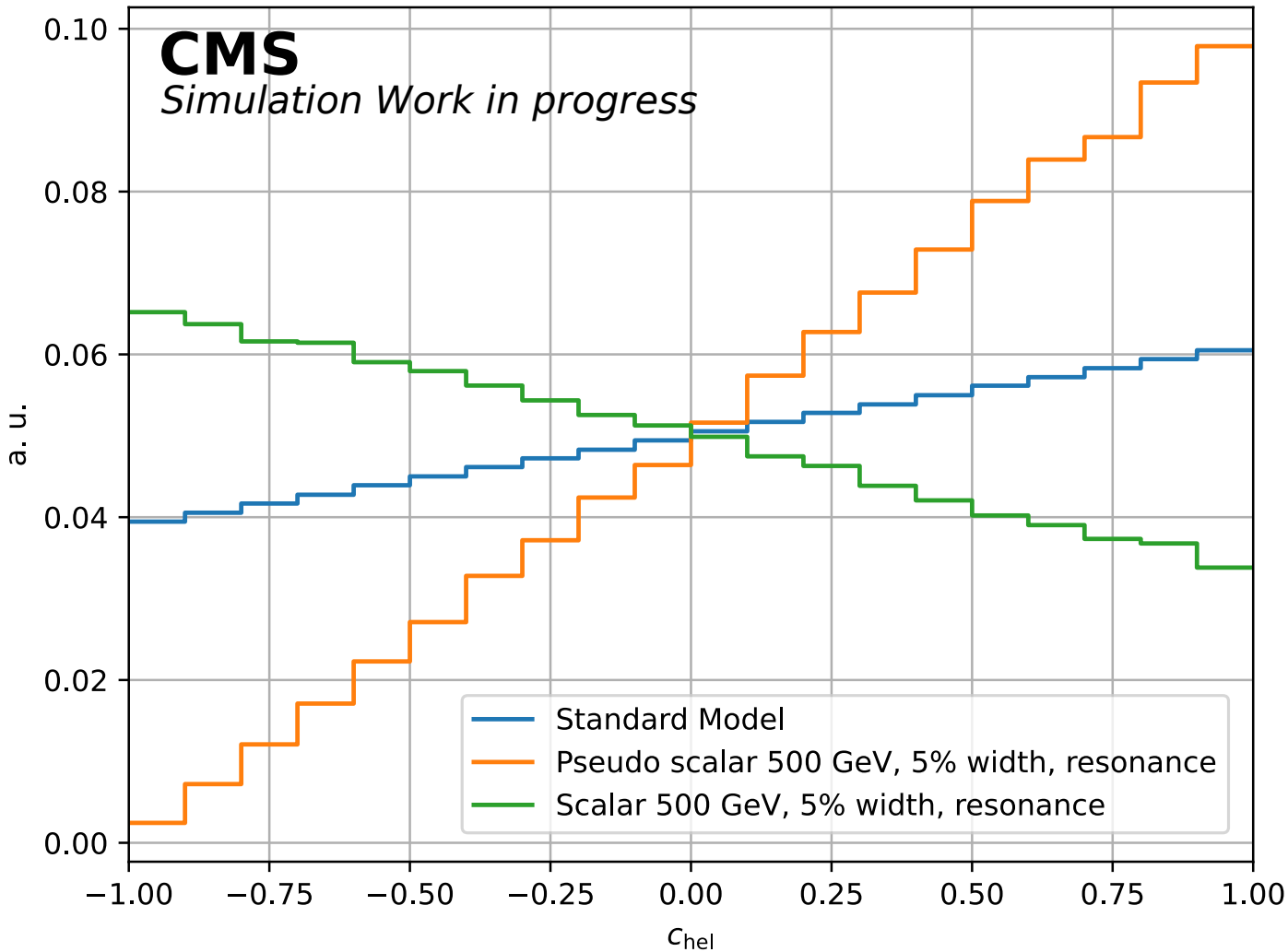


- Top's lifetime shorter than the spin decorrelation time
- The leptons have high spin analyzing power
- Use angle distribution of the leptons in their helicity frames



Spin information: c_{hel}

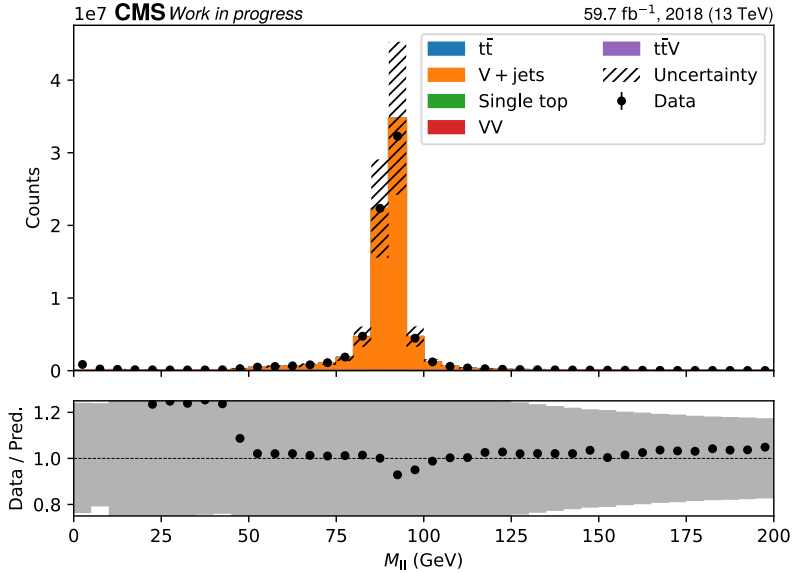
Making the difference between SM and heavy Higgs scenarios visible

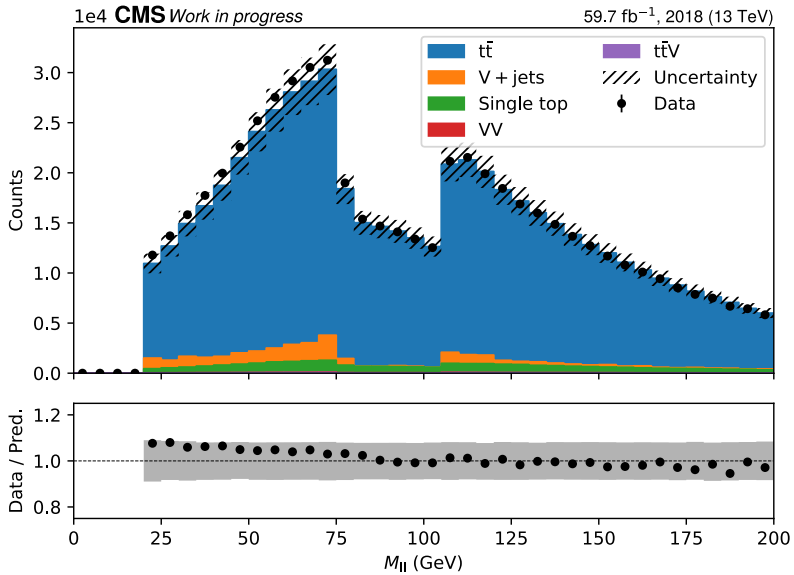


Particle definitions and cuts

Selection

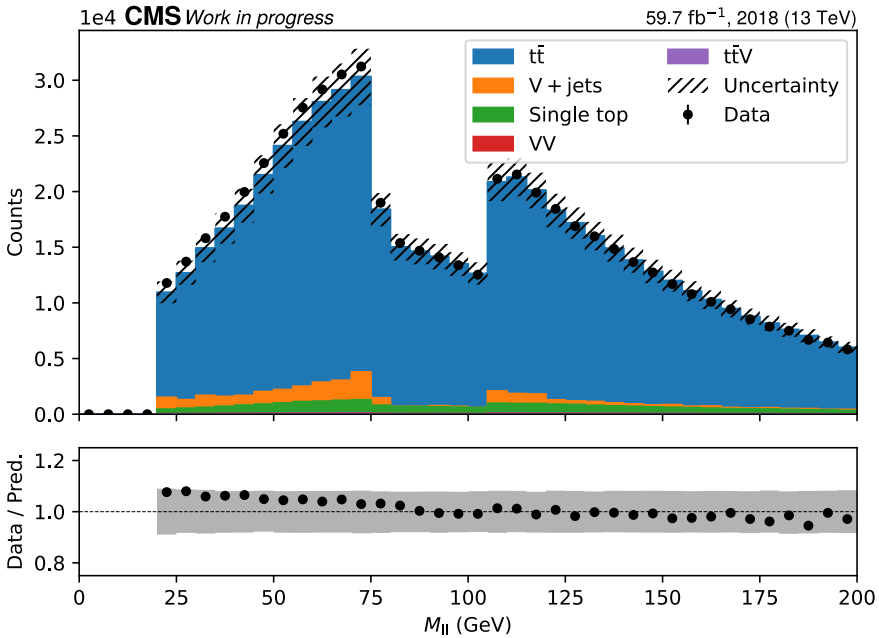
- 2 leptons (ignoring taus)
  - opposite sign
  - Invariant mass of > 20 GeV
  - At least one with $p_T > 25$ GeV
  - $|\eta| < 2.4$
- 2 jets
  - $p_T > 30$ (20) GeV
  - One tagged a bottom
- Z-boson window cut
  - $m_{\ell\ell} \notin [76; 106]$ GeV if same flavor
- $p_{T,miss} > 40$ GeV if same flavor

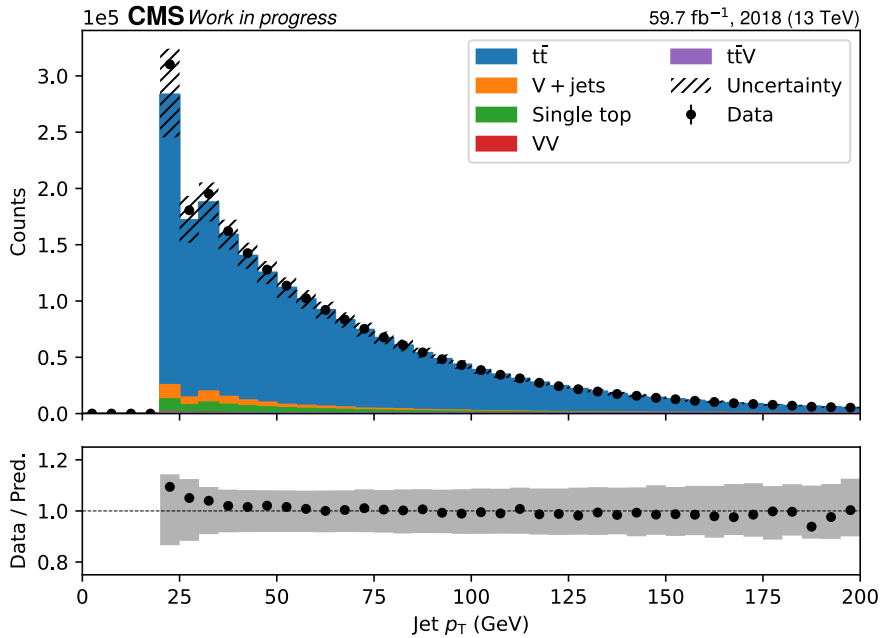




Data vs. Monte-Carlo agreement

2018 data and Standard Model

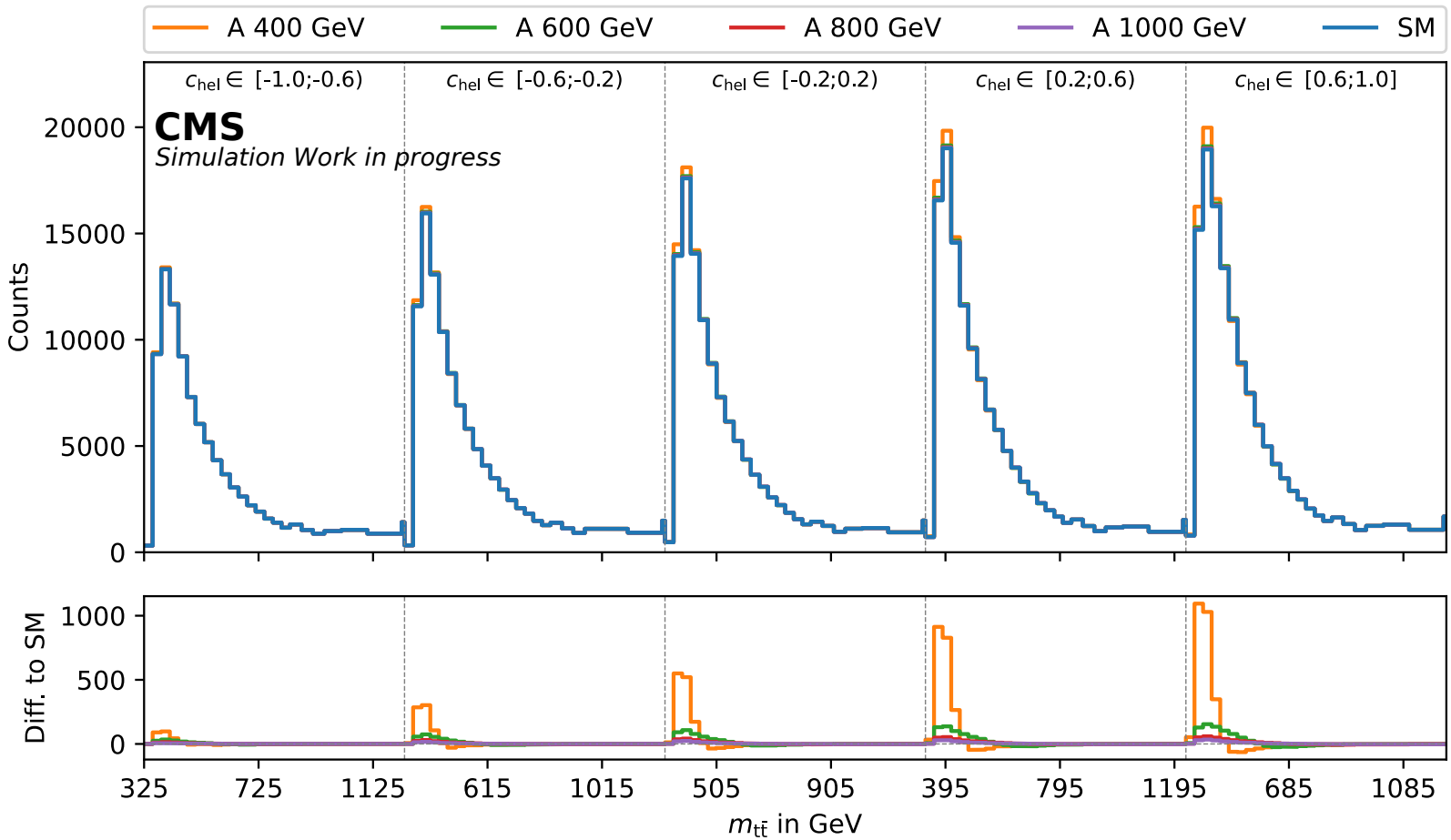




- Observed overall good agreement
- Slight slope in m_{ll}, also slightly visible in Jet p_T
  - Known observation, possibly due to higher order effects

Input to the fit to derive limits

- Two dimensional histogram of $m_{t\bar{t}}$ and c_{hel} unrolled
- Shown here: SM and natural width heavy Higgs
  - $\Gamma_{A/H} = \Gamma_{A/H \to t\bar{t}} \Leftrightarrow g_{A/H} = 1$



Yukawa coupling uncertainty

- Dependence of higher order EW corrections of $t\bar{t}$ to Yukawa coupling Y_t similar in shape to heavy Higgs at low masses

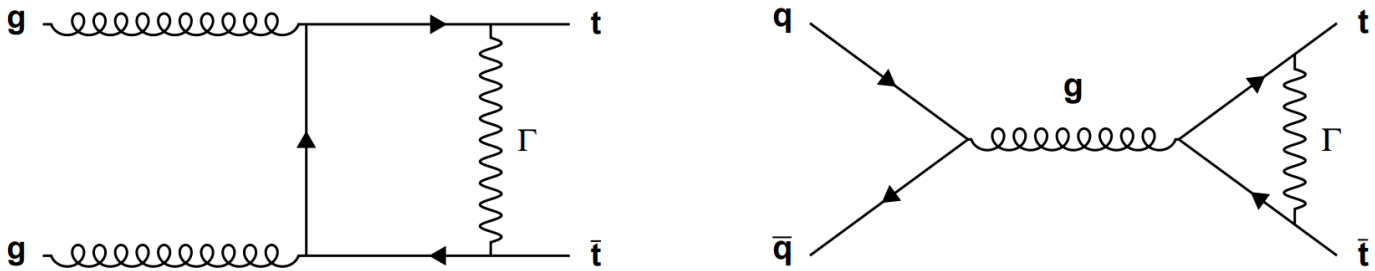
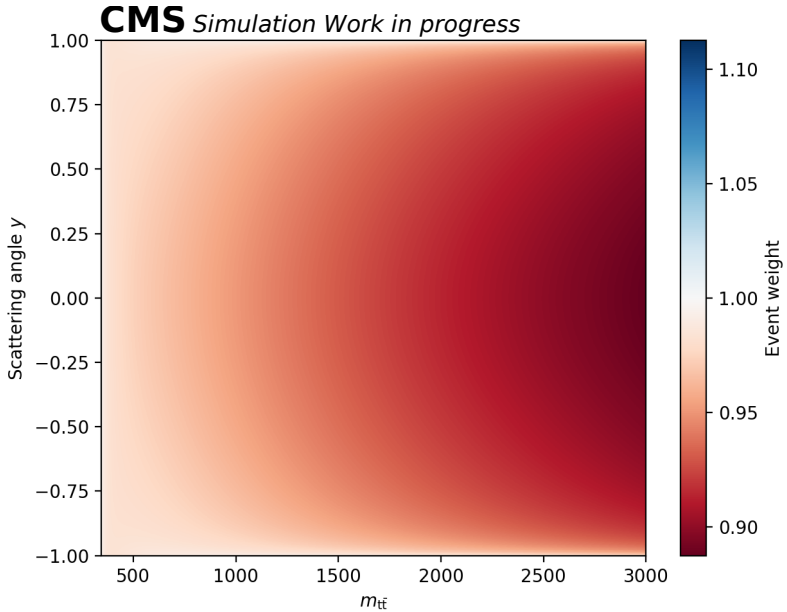


Figure taken from TOP-17-004,Γ: Neutral gauge boson, Higgs boson or pseudo-Goldstone boson

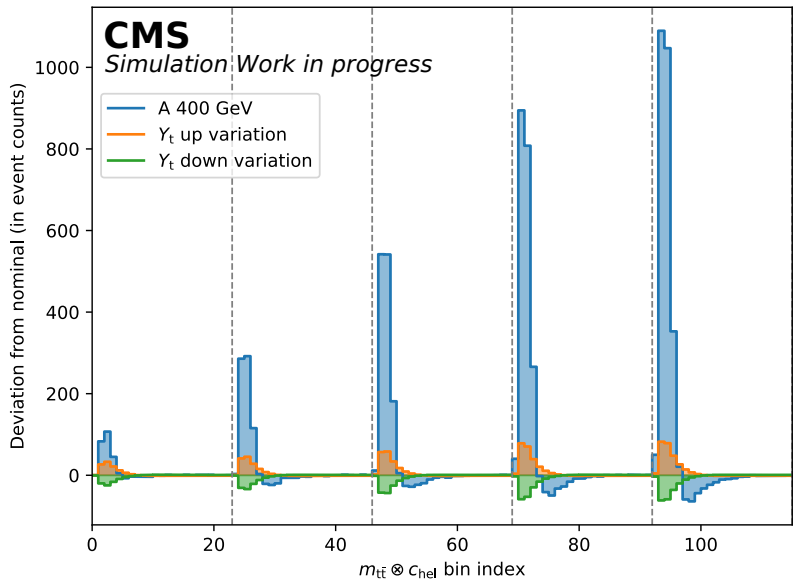
- Simulated EW corrections with Y_t varied ourselves
  - EW corrected histogram with $Y_t = 1$ (SM) as nominal
  - EW corrected with $Y_t = 1 \pm \sigma$ as Up/Down shape uncertainties
    - Using σ from arXiv:1804.02610 $(^{+0.1381}_{-0.1158})$
- Apply to SM $t\bar{t}$

EW correction and Y_t variation

EW correction weights for $Y_t = 1$



Y_t variation vs heavy Higgs



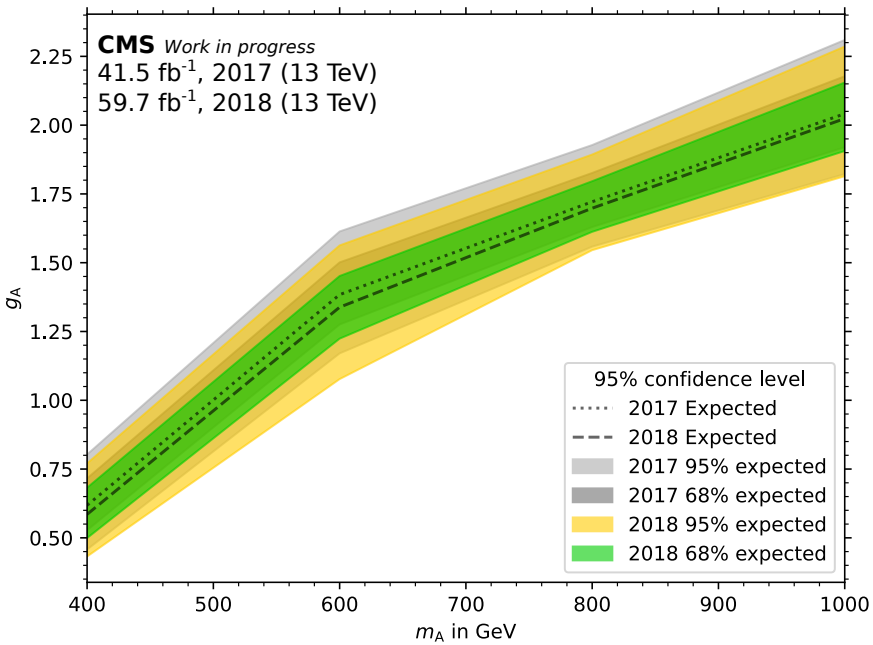
- EW correction weights binned in $m_{t\bar{t}}$, scattering angle and flavor of initial particles
- Y_t variation shape at the same region as the 400 GeV heavy Higgs peak, making it a valuable uncertainty

Expected limits on coupling

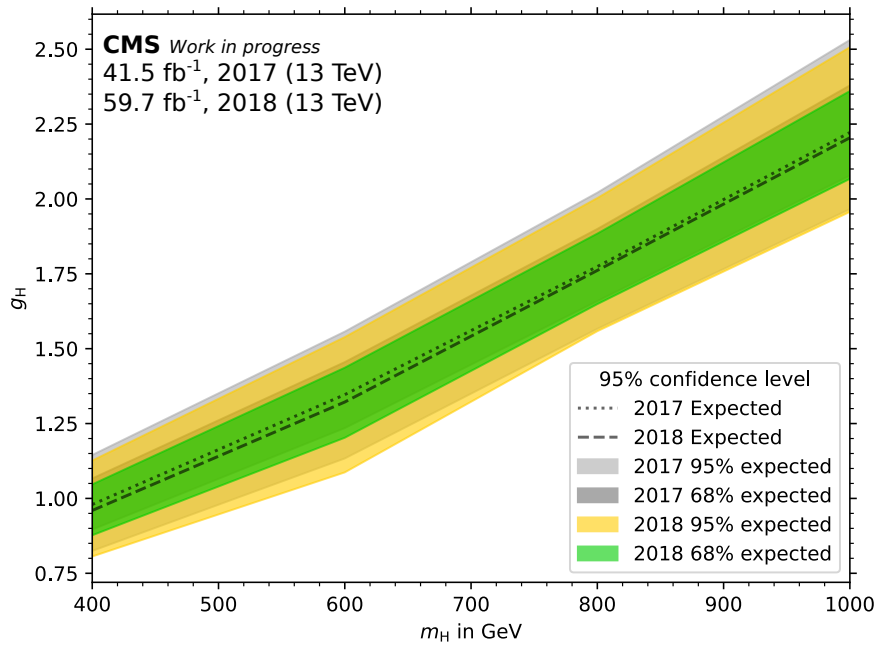
Limits for individual years

- Natural width, mass points at 400 GeV, 600 GeV, 800 GeV, 1000 GeV

Pseudoscalar heavy Higgs



Scalar heavy Higgs



- We are also considering additional signal points with different masses and widths

Summary and outlook

- Searching for A/H via $t\bar{t} \to \ell\ell$ using 2d distribution $m_{t\bar{t}}$ and c_{hel}
- $m_{t\bar{t}}$ and c_{hel} derived by reconstructing the t and $\bar{t}$ using their decay products
- Probing for A/H up to masses of 1000 GeV
- Many upgrades on top of 2016 analysis strategy including Yukawa coupling uncertainty

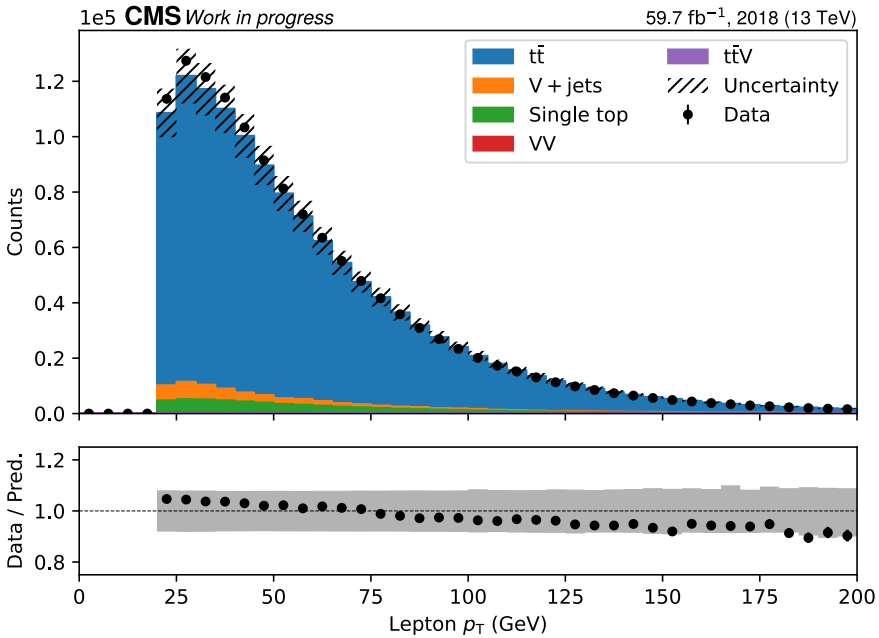
Work ongoing to combine with $t\bar{t} \to \ell j$ channel analysis.

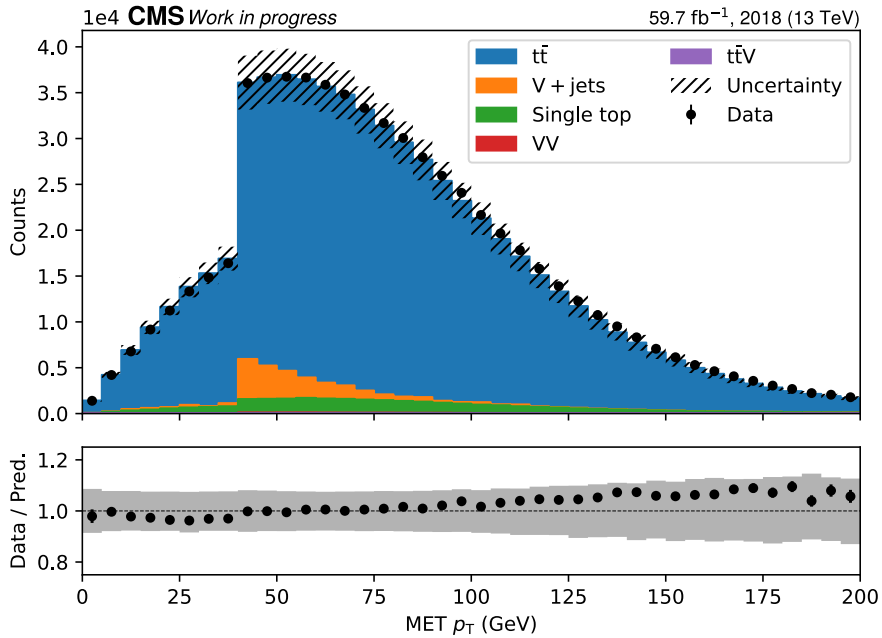
Thank you

Backup

Data vs. Monte-Carlo agreement

2018 data and Standard Model





Data vs. Monte-Carlo agreement

2018 data and Standard Model