Search for heavy Higgs bosons and Axion-Like Particles in the ttbar final state at CMS

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HELMHOLTZ

DESY.

Introduction

The Team, The Mission

- DESY CMS Exotica Group led by Christian Schwanenberger and Alexander Grohsjean
- Working on searches for (hints of) new physics
- With the CMS Collaboration

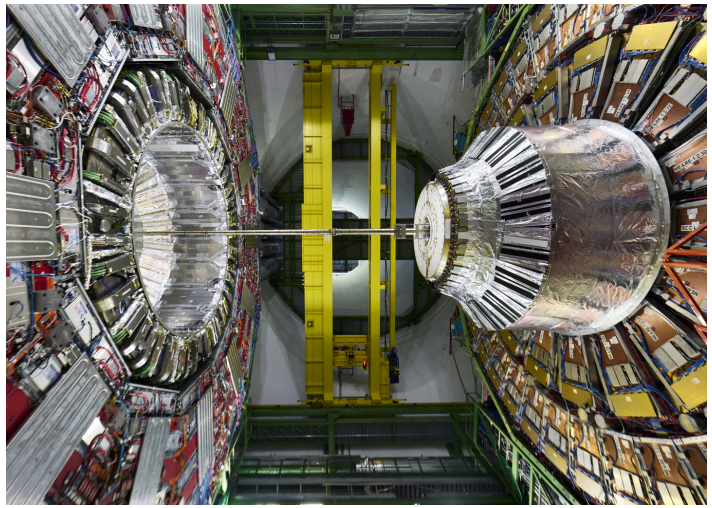
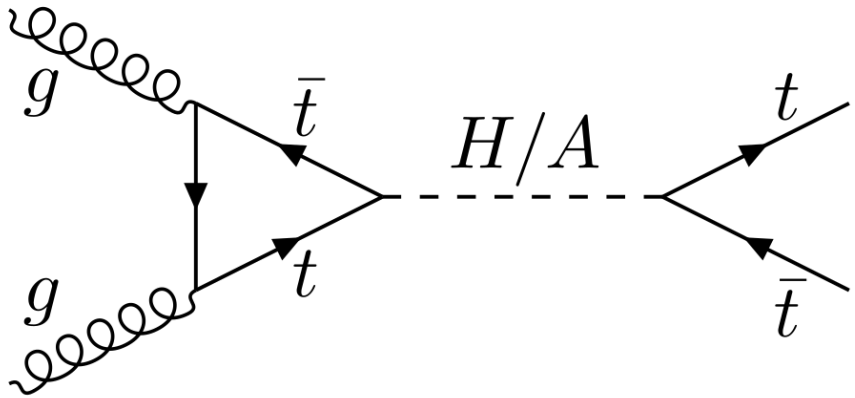


Image: https://home.cern/science/experiments/cms

Motivation

Searches for heavy Higgs bosons in top-antitop final states

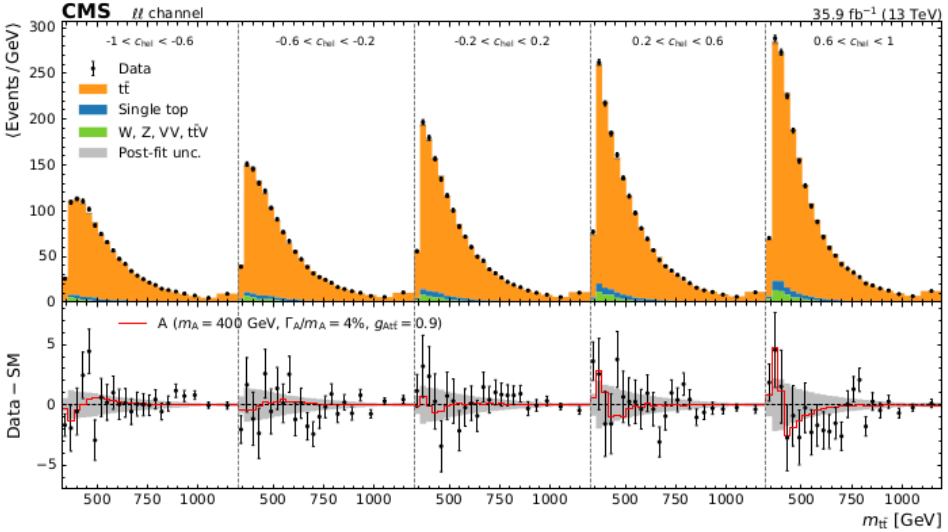
- We know the Standard Model (SM) has shortcomings – Dark Matter, CP violation, etc
- Common Beyond the SM (BSM) extensions:
    - 2 Higgs Doublet Models (2HDM)
    - Different Flavors of Supersymmetry
    - Axion-like particles
- Yukawa couplings scale with the mass – strongest coupling to the most massive SM particle: Top quark!
- Above the top-threshold: top-antitop decay of mediator is dominant

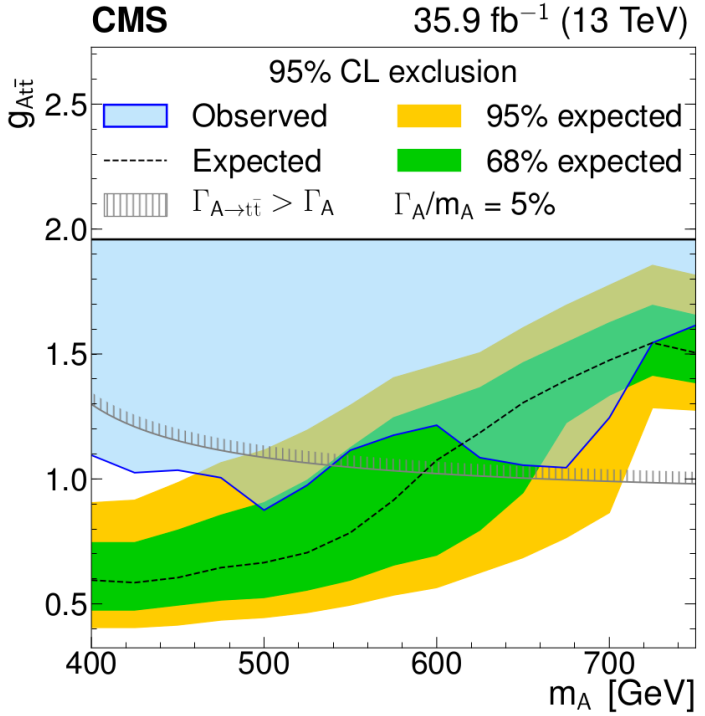


Motivation

Previous Searches for heavy Higgs bosons in top-antitop final states

- [CMS JHEP 04, 171 (2020)] saw a 3.5 standard deviations local (1.9 std global) excess for a pseudoscalar A, m=400 GeV
- Analysis done on 2016 data only, one and two lepton final state
- Now: Full Run 2 UL dataset available (2016, 2017, 2018)



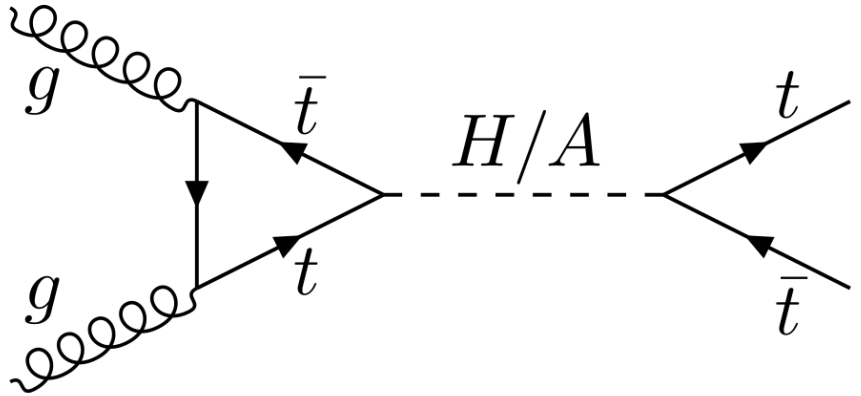


Signal

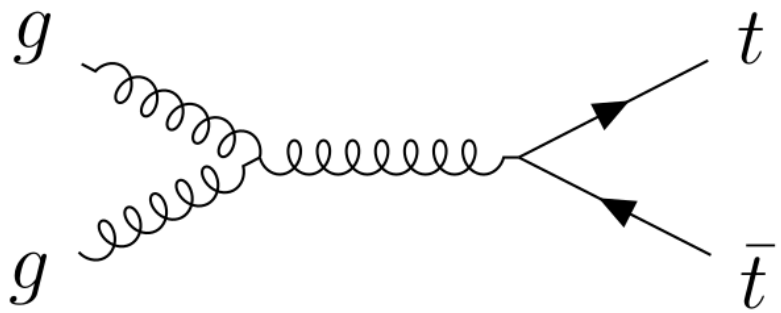
Interferences and more

- Heavy Higgs produced via gluon fusion inducing a top-loop
- We use a simplified model for a scalar (H) and pseudoscalar (A) particle with Yukawa couplings
- On top: SM top-antitop production has the same initial and final state → interference terms

$$|S_{\mathrm{A/H}} + B|^2 = |S_{\mathrm{A/H}}|^2 + 2Re(S_{\mathrm{A/H}}B) + |B|^2$$

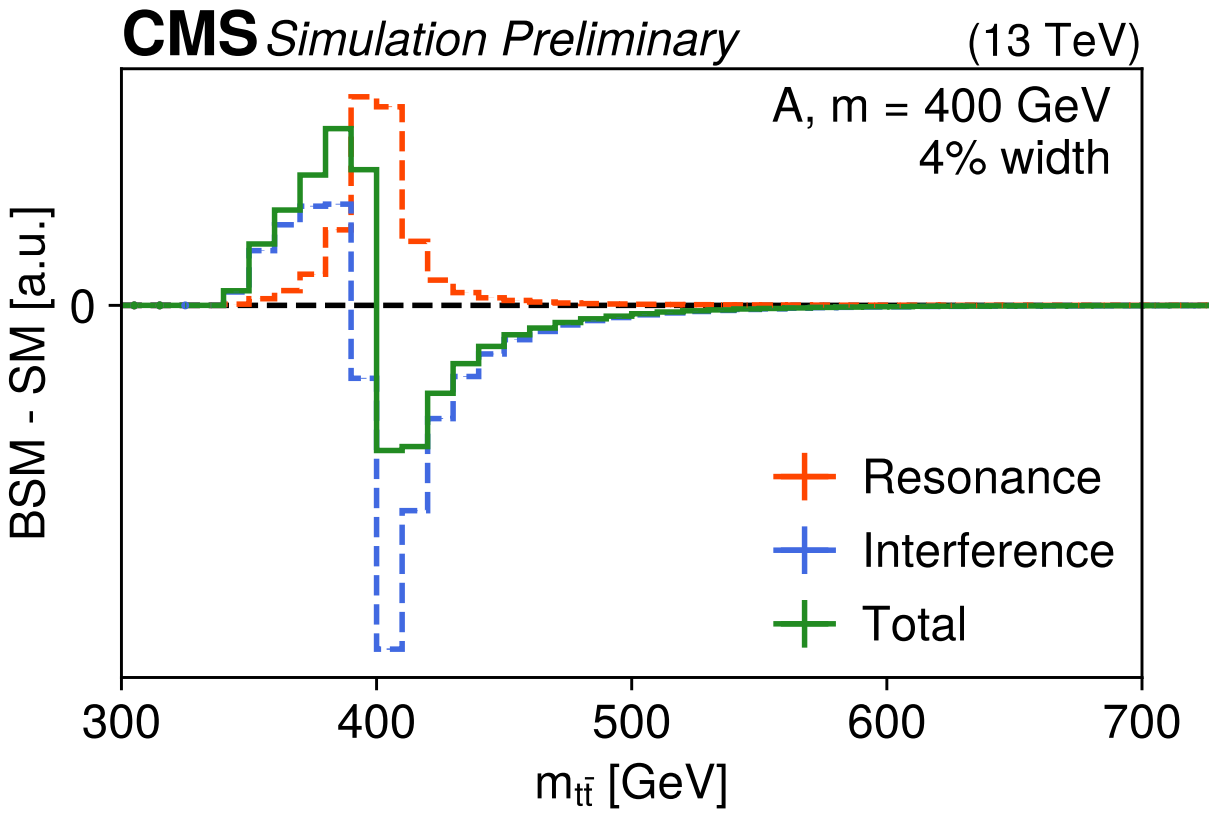


- We assume CP conservation → no A/H interference
- These terms don't have the same g dependence – interference scales with g^2, while the resonance scales with g^4

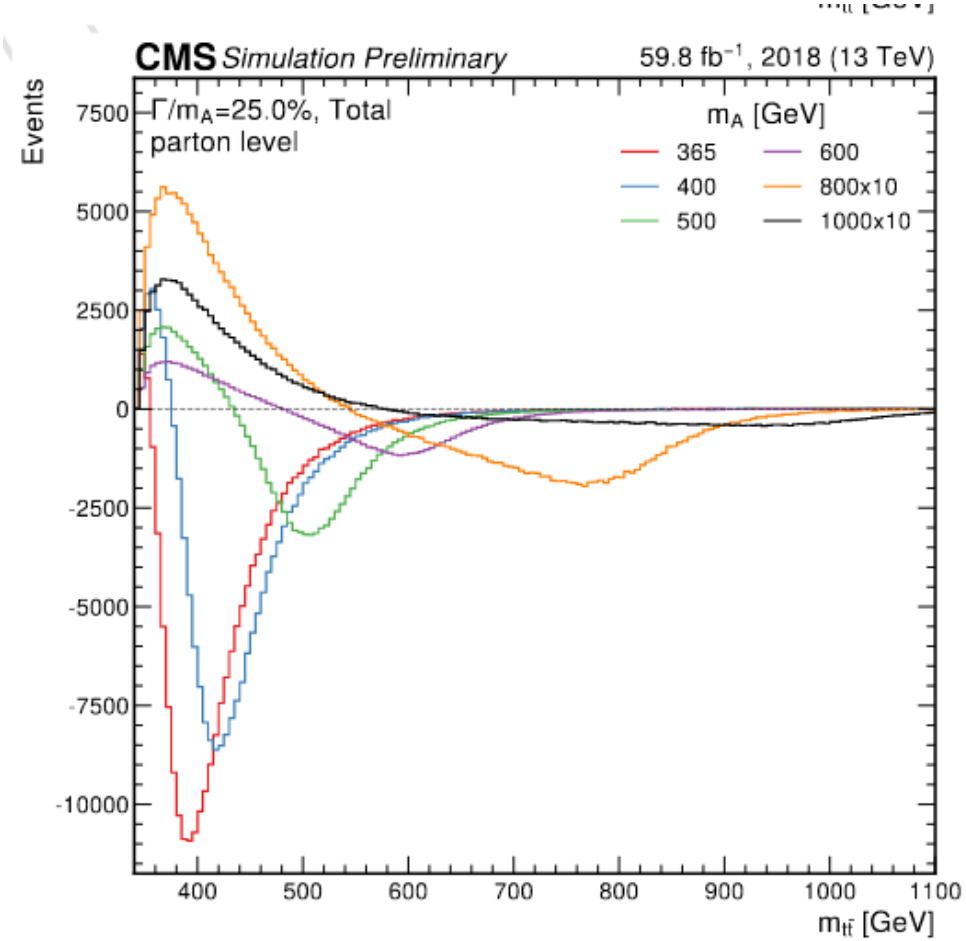


Signal

Peak-Dip Structure



BSM – SM for pseudoscalar 400 GeV, 4% width point

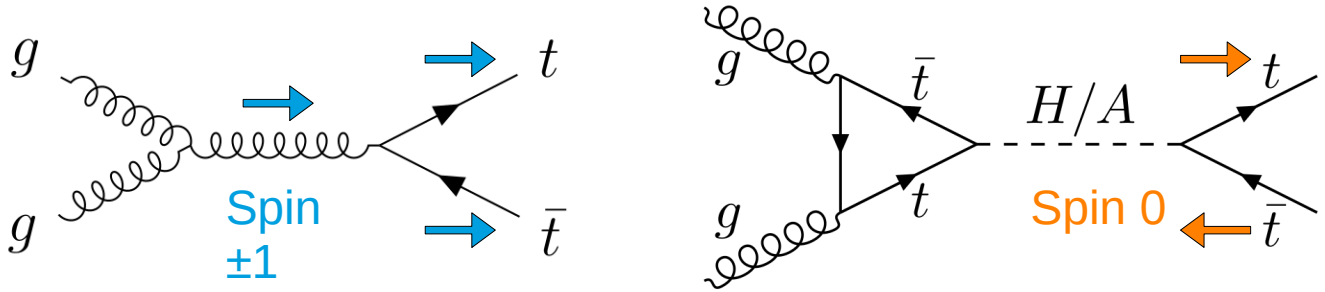


Event yield for the full signal for different signal hypothesis

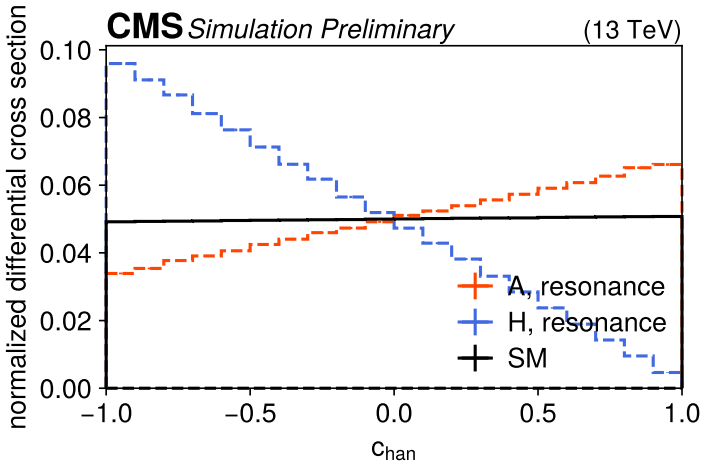
Analysis Outline

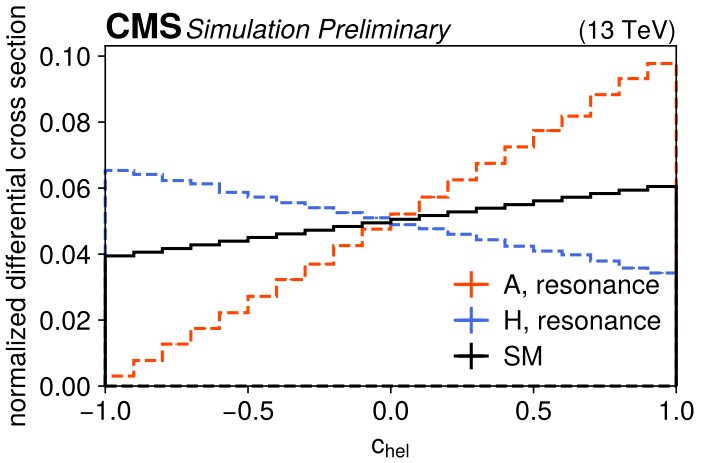
Spin Correlation Variables

- Top decays before spins decorrelate – spin information is conserved in the leptonic decay!
- Spin states differ for signal and background



- By boosting the kinematically reconstructed system into the tt-restframe, measure the lepton angles to the parent tops in their respective restframes → construct the spin-density matrix
- c_{hel} variable: cosine of angle between leptons
- c_{han} variable: linear combination of spin density matrix components

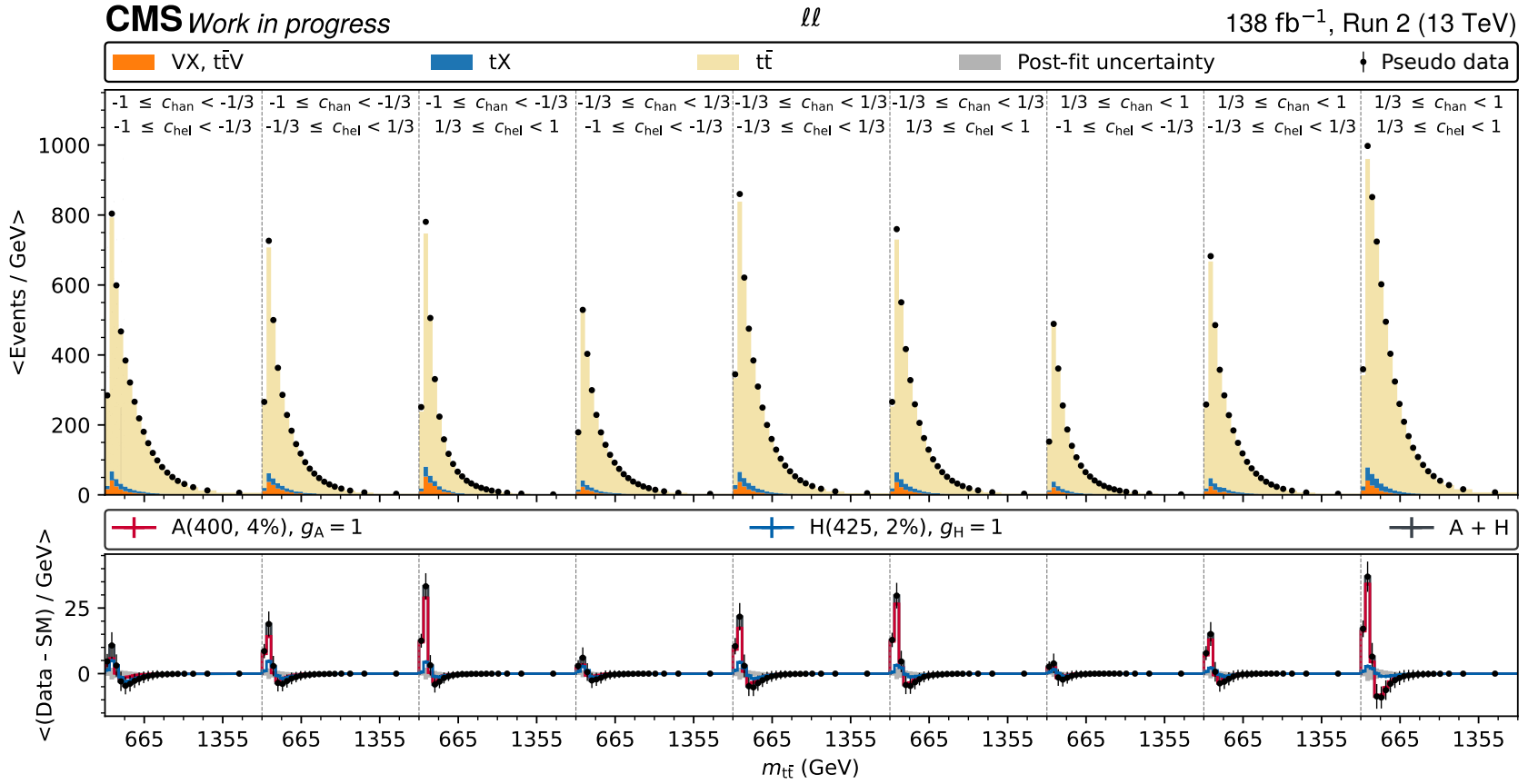




Analysis Outline

Invariant Mass x c_{han} x c_{hel}

- As a search variable we use the invariant $t\bar{t}$ system mass in conjunction with these spin variables



Results

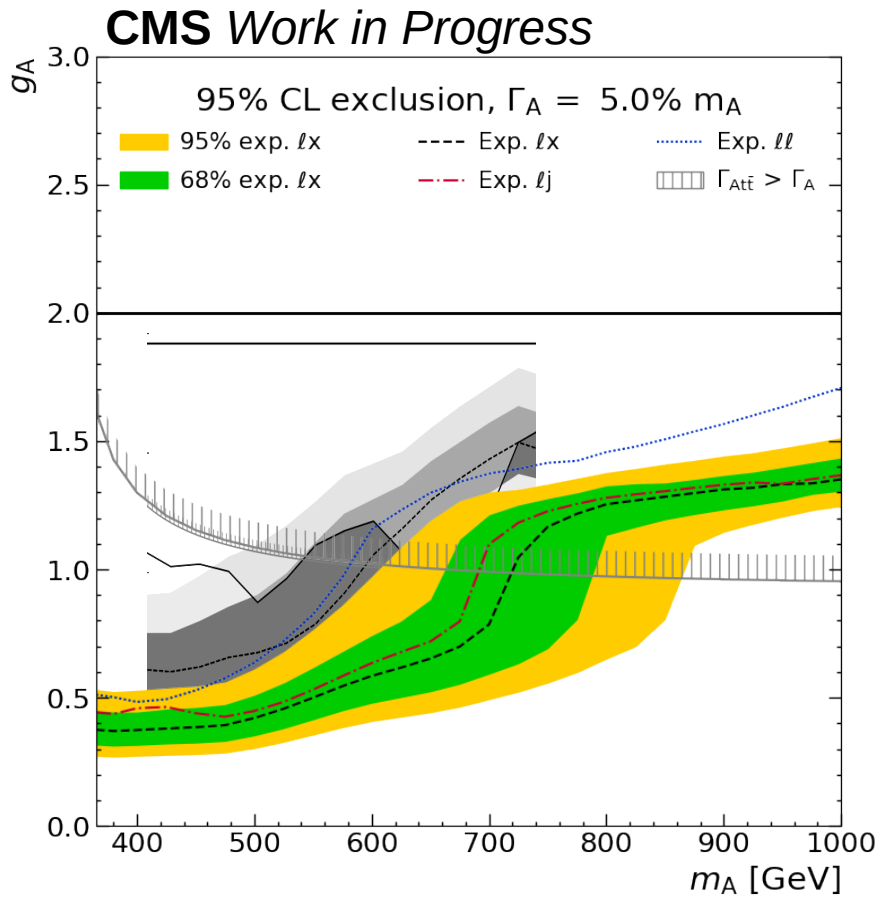
Uncertainties and Fitting

- Fit on the templates – incorporating the fact that the signal strength is different for resonant and interference signal contribution
- Full set of systematic uncertainties for A/H signal as well as the background, listing leading contributions:
    - Experimental: Jet energy scale, btagging eff. (both split into subsources)
    - Theory: ME-PS matching (h_{damp}), missing higher orders, EW corrections (including top-Yukawa)
    - Currently under investigation: $t\bar{t}$ threshold effect (non-pert. QCD)

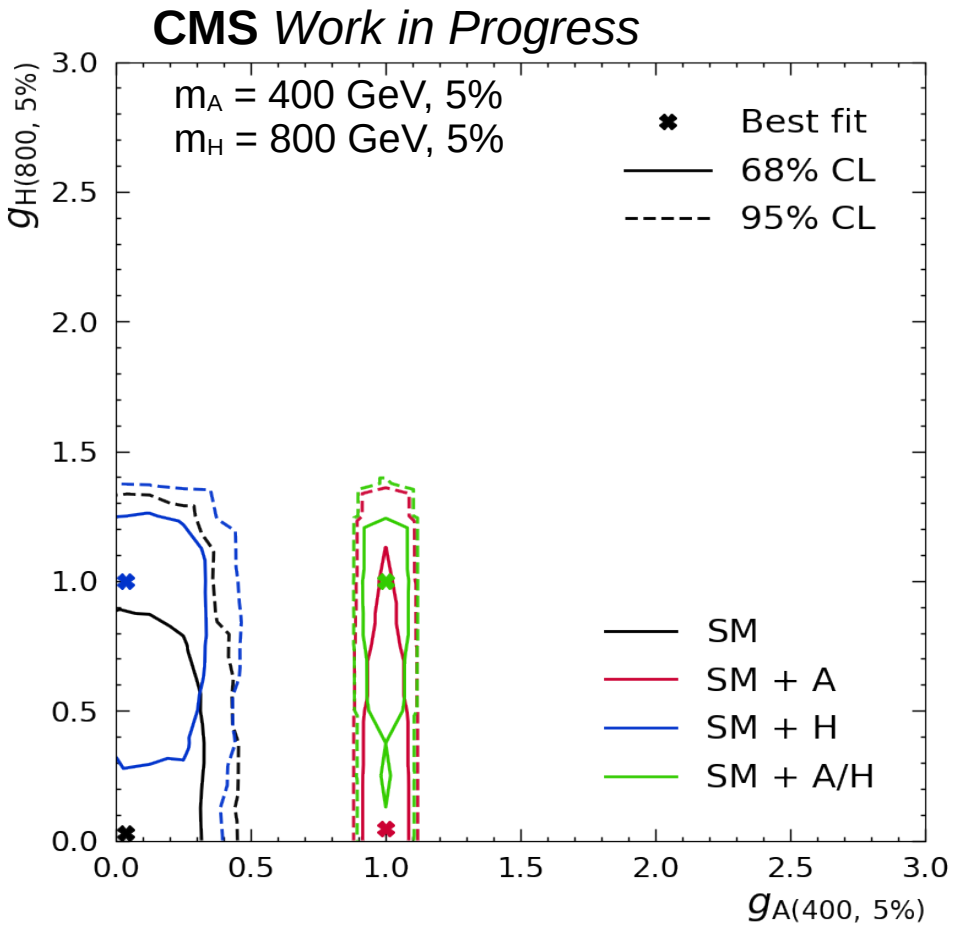
- Goal: 1D Limits and 2D Limits (simultaneous A and H fit)

Results

Uncertainties and Fitting



expected 1D Limits

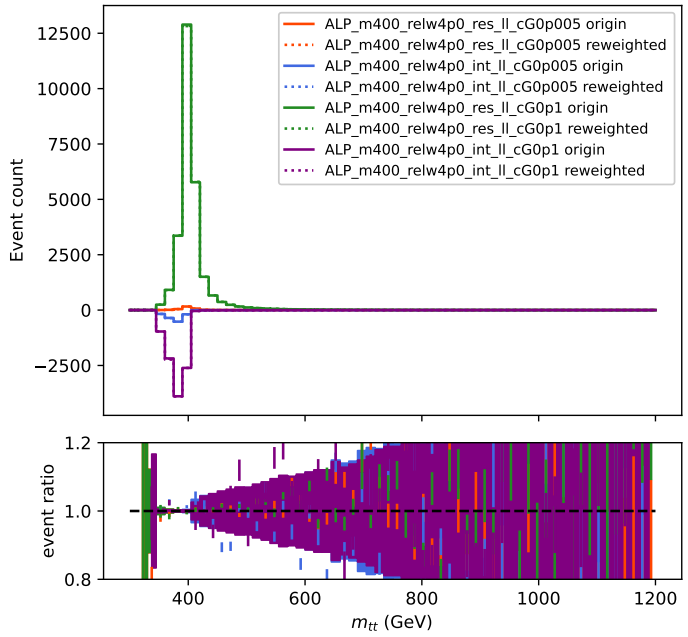


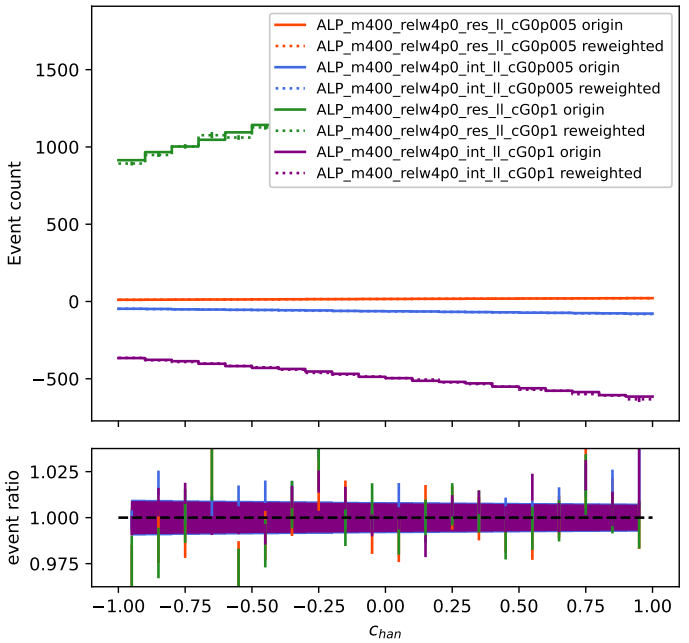
expected 2D Limits

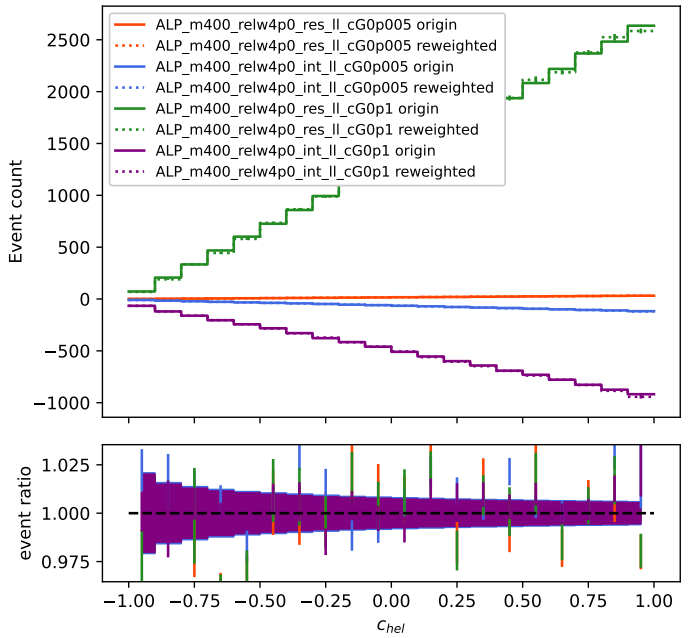
Results – Axion Like Particles

Reweighting and other Signal Models

- Inspired by Laurids Jeppes contribution “Distinguishing Axion-Like Particles from Extended Higgs Sector Models in $t\bar{t}$ production at the LHC”
- Same signal final state, well covered by our A/H samples
- Use post-mortem reweighting of the A/H to the ALPs cross-sections
- Also extract limits on pseudoscalar ALP particle between 365-1000 GeV







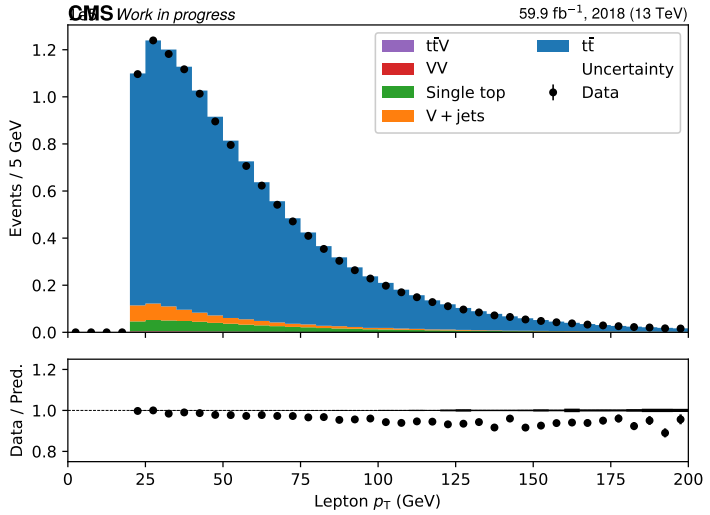
Conclusion

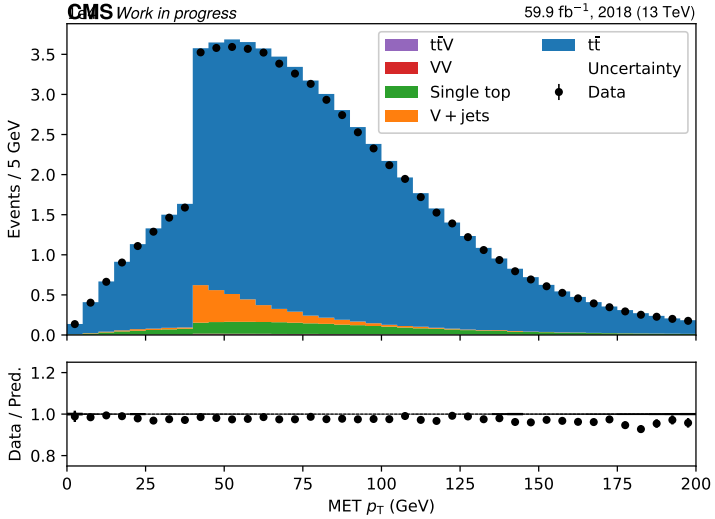
- Presented a search for a scalar/pseudoscalar heavy Higgs boson between 365 and 1000 GeV
- $t\bar{t}$ dileptonic final state combined with l + jets
- Usage of invariant mass + spin variables to gain sensitivity
- Currently in unblinding

- Outlook:
    - New limits (hopefully) soon
    - Interpretation in an ALPs scenario, possibility to distinguish from A/H scenario

Backup – Object Selection

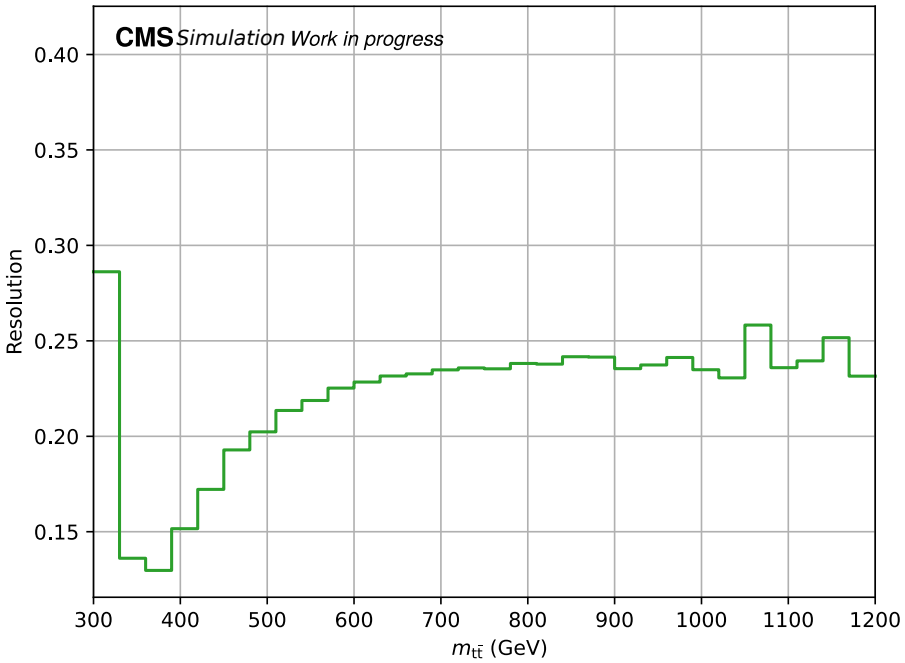
- Selection optimized for pure $t\bar{t}$ final state:
- Single-lepton or dilepton triggers (e or μ)
- 2 leptons, high p_T requirements (> 25 GeV)
- Split into eμ, ee and μμ channels
- In ee/μμ: Remove Z peak, MET > 40 GeV
- At least 2 jets with at least 1 b tag
- Result: ~93% $t\bar{t}$, remainder mostly tW and Z+jets
- SM $t\bar{t}$ background is irreducible → need accurate simulation!





Backup –Top Reconstruction

- Kinematic reconstruction from analytical solution of momentum conservation
  - Inputs: Lepton & b-jet p^{μ}, MET
  - Assumptions: m_t, m_W fixed, all MET from neutrinos
- Caveat: reconstruction often fails!
  - Reasons: detector resolution, wrong jet assignment etc.
  - Solution: Rerun 100 times with randomized smearing of inputs → ~90% efficiency for $t\bar{t}$



Backup – Monte-Carlo Sim

- Best available $t\bar{t}$ simulation: Powheg+Pythia NLO in QCD
  - Signal effects are %-level – NLO QCD is not enough!
- Generator-level reweighting for corrections at…
  - NNLO in QCD: with MATRIX [arXiv:1711.06631, https://matrix.hepforge.org]
  - NLO in EW: with HATHOR [arXiv:1007.1327, arXiv:1305.5773]

- Signal:
  - simulation at LO with MadGraph
  - cross section at NNLO from SusHi

Backup – Theory Uncertainties

- Missing higher orders (factorization and renormalization scales): Seperately for SM tt and signal; includes rate uncertainty for tt
- PDF: PCA for 100 Hessian eigenvectors, keep largest + alphaS
- ISR&FSR (parton shower scales): seperately for tt and signal
- ME/PS matching (hdamp): for SM tt
- Top quark mass: ±1 GeV rate+shape for SM tt; rate for signal
- EW reweighting: SM top Yukawa coupling, EW-QCD cross terms
- Minor backgrounds: 5% DY, 15% tW, 30% everything else

Backup – Experimental Uncertainties

- Jet energy scale: split into all subsources; forward sources dropped
- Jet energy resolution
- Unclustered MET
- Btag efficiencies: split into subsources (new for this analysis)
- Lepton + Trigger efficiencies
- Pileup
- Luminosity
- L1 prefiring for 2017

Backup – Impacts

- Impacts for ll only
- Asimov, g=1, A, 400 GeV, 5%
- Note: slightly outdated version of the fit