Searches for BSM Higgs bosons in CMS

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On behalf of the CMS Collaboration

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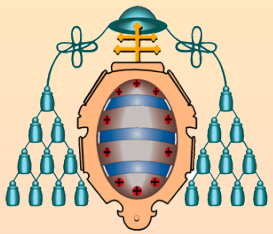


UNIVERSIDAD DE OVIEDO

Rencontres de Blois 2017

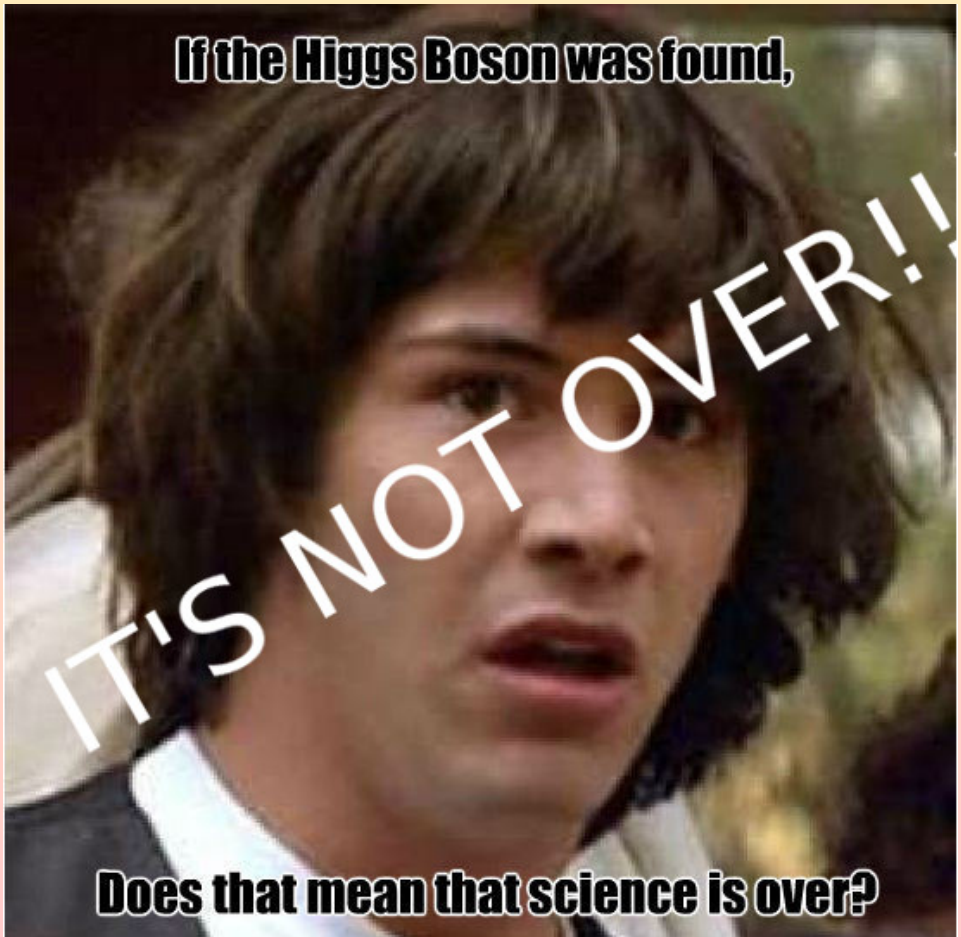
Why BSM bosons?

- Discovery of the $h(125)$ boson compatible with the SM is a major step towards understanding EW symmetry breaking

Image courtesy https://www.memecenter.com/fun/498786/higgs-boson

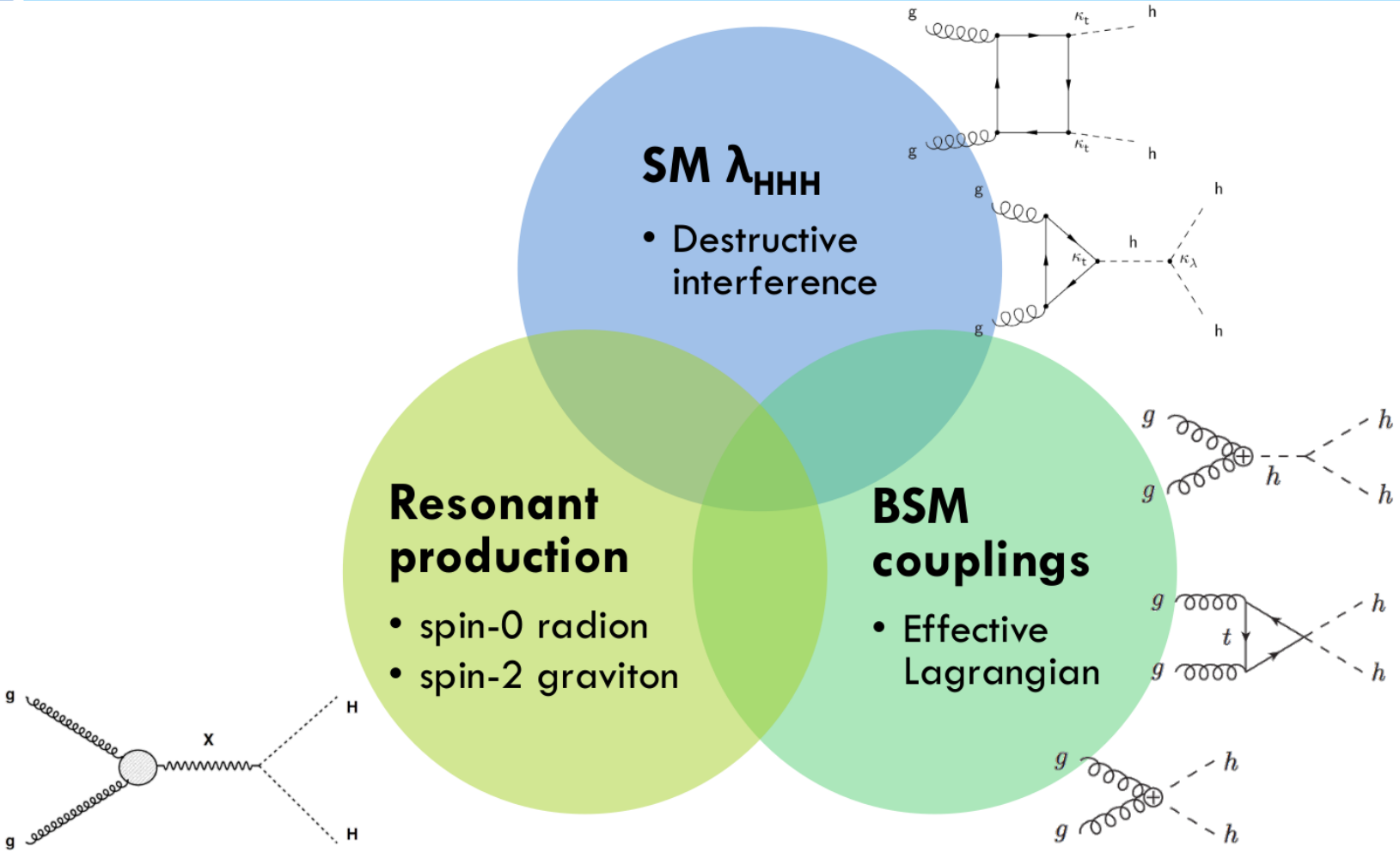
Why BSM bosons?

- Discovery of the $h(125)$ boson compatible with the SM is a major step towards understanding EW symmetry breaking
- Measuring Higgs boson couplings provides an independent test of the SM
  - Probing the Higgs field potential shape
- BSM physics effects can appear as anomalous couplings of the Higgs boson
- Minimal extensions of the SM predict additional Higgs bosons (at least four, for a total of five)
- Any such effect would be a smoking gun for new physics!
  - Searches for BSM Higgs bosons are a bleeding edge tool for new physics searches
  - Targeted and more exciting searches than the usual generalist SUSY searches
  - Absence of assumptions on SUSY particles is definitely an advantage



Why BSM bosons?

- Interlaced sectors of the theory lead to a rich experimental landscape



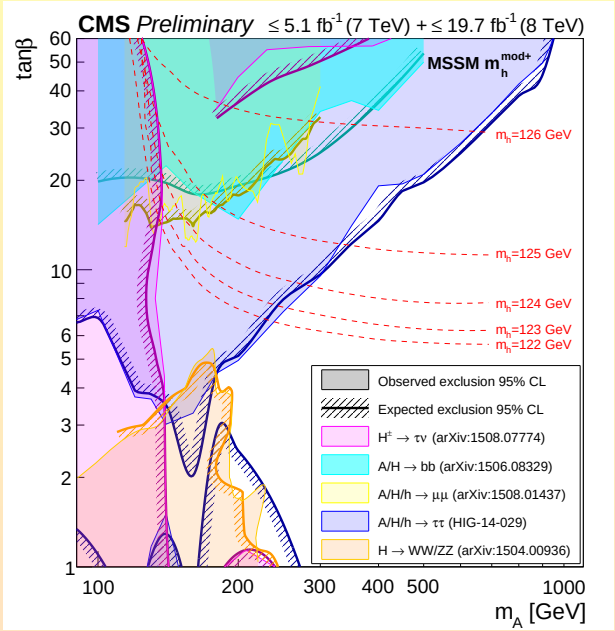
enjoying.higgs@cern.ch Benasque LHC Flavour, May 2017

From André David's talk in Benasque LHC Flavour

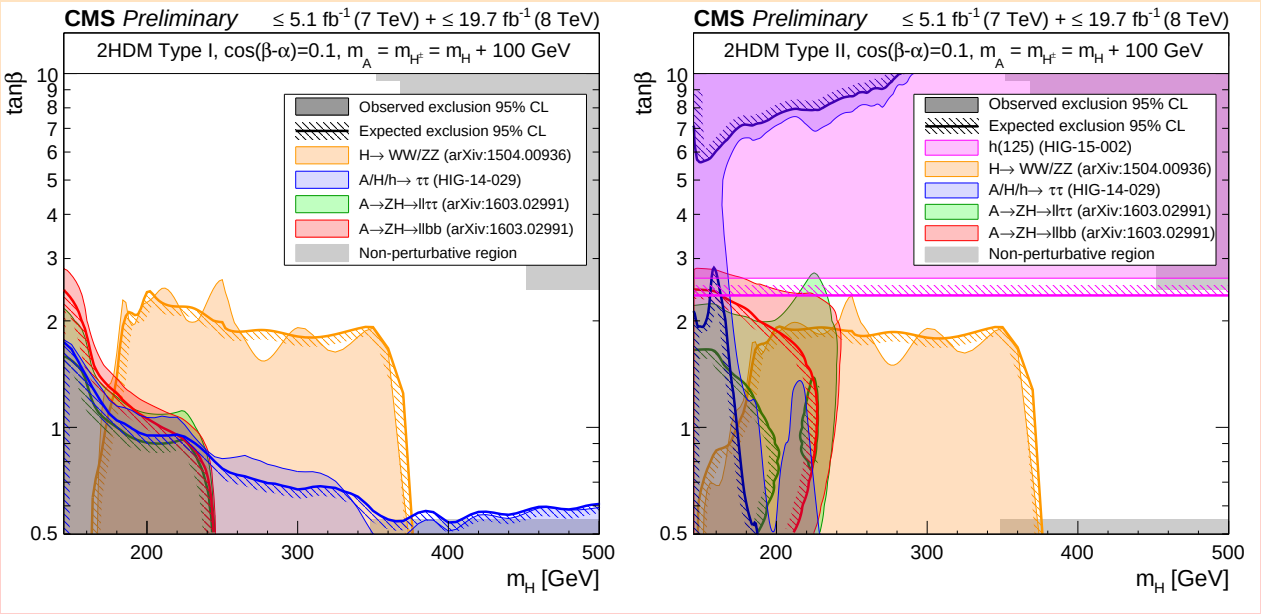
Summary of Run-I CMS searches (HIG-16-007)

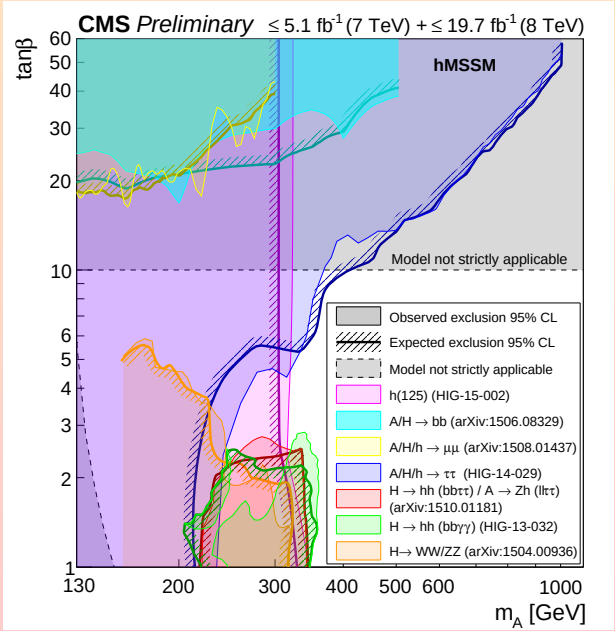
- Additional bosons searched extensively in Run-I
- Grand summaries of all CMS heavy Higgs boson searches
  - 2HDM and MSSM scenarios chosen to maximize contribution of all analyses
- Type-II 2HDM more constrained than Type-I because of enhanced coupling of A H to down-type fermions for increasing *tanβ*
- hMSSM more constrained than MSSM because A/H/h $\rightarrow\tau\tau$ sensitivity to shift of M_H to higher values w.r.t. M_A for low *tanβ*

MSSM and hMSSM



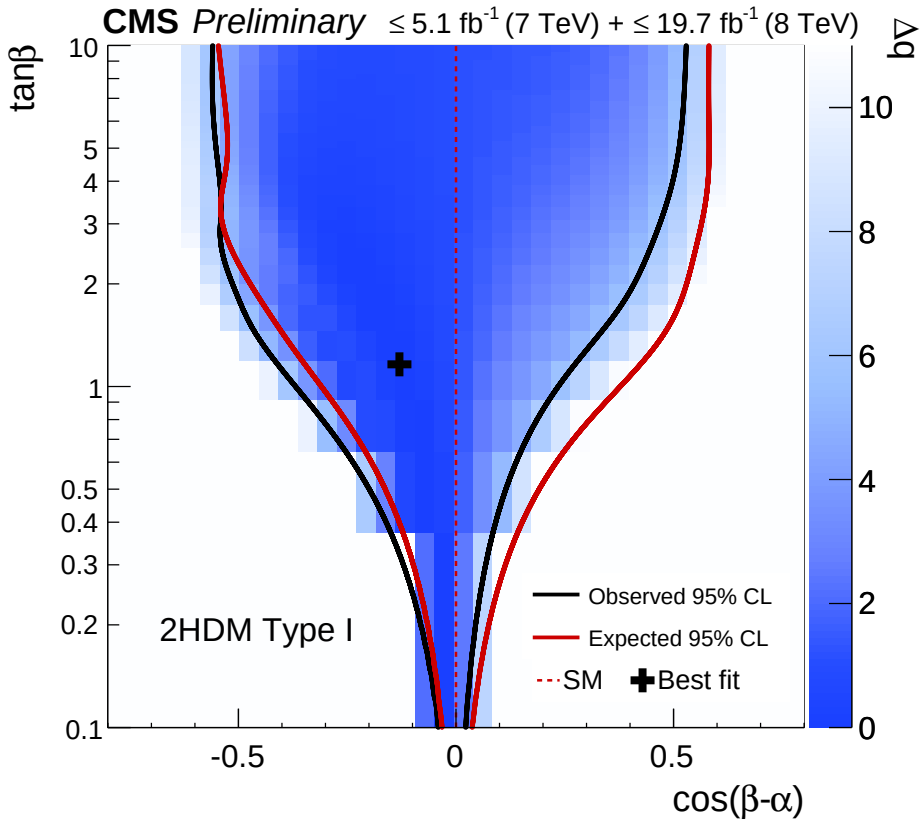
2HDM Type-I and Type-II

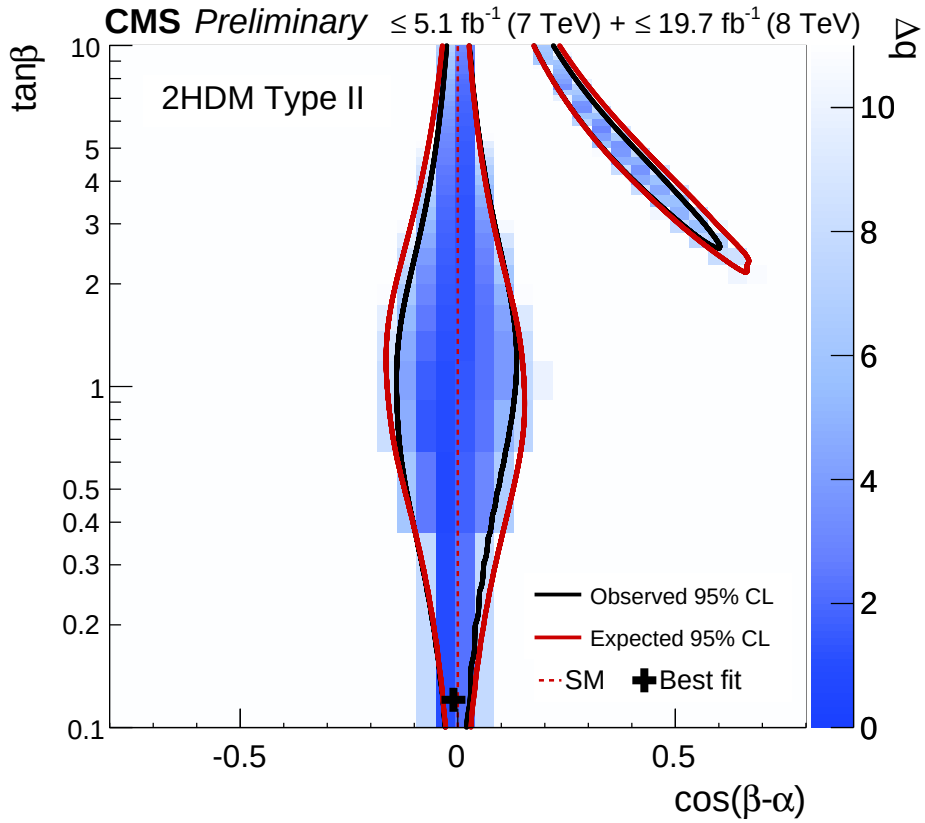




Summary of Run-I CMS searches (HIG-16-007)

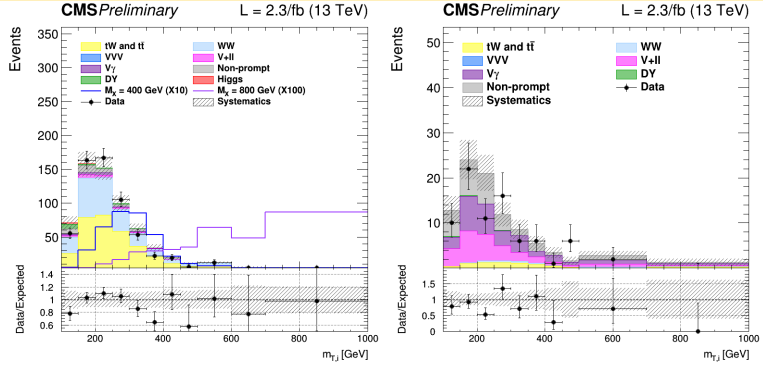
- Interpreted h(125) as the lighter neutral 2HDM boson h
  - The observed production and decay rate constrains model phase space
- Simultaneous fit of ratios of the t3 LO coupling modifiers (k_u, k_d, k_V), and derive exclusion contours
  - Combining experimental information from all probed $h(125)$ decays

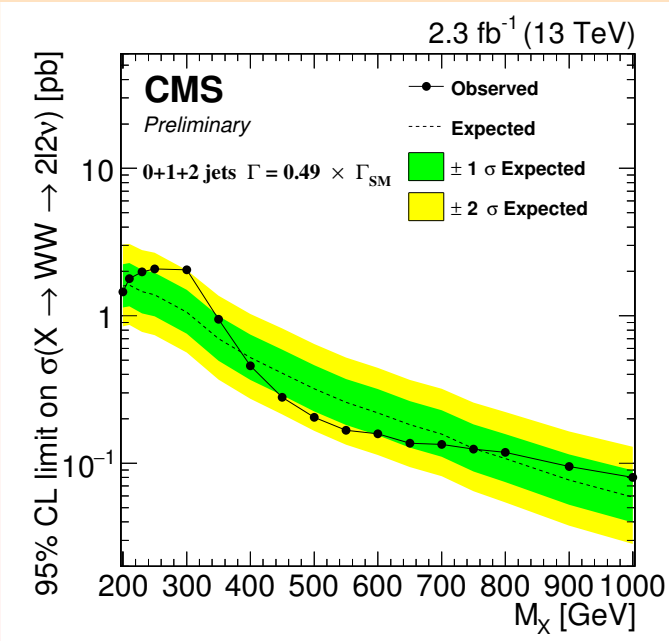




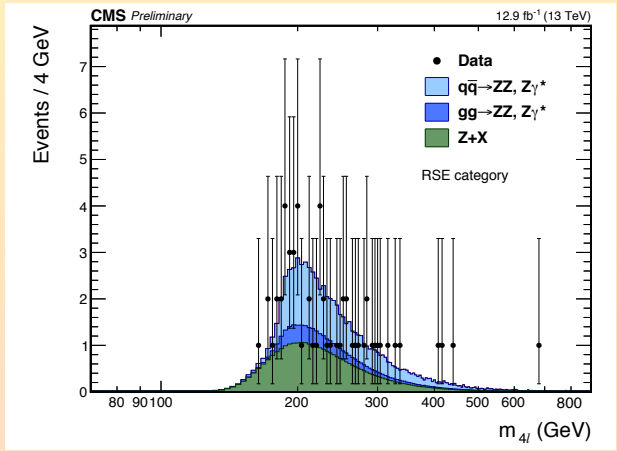
Heavy BSM bosons to WW and ZZ

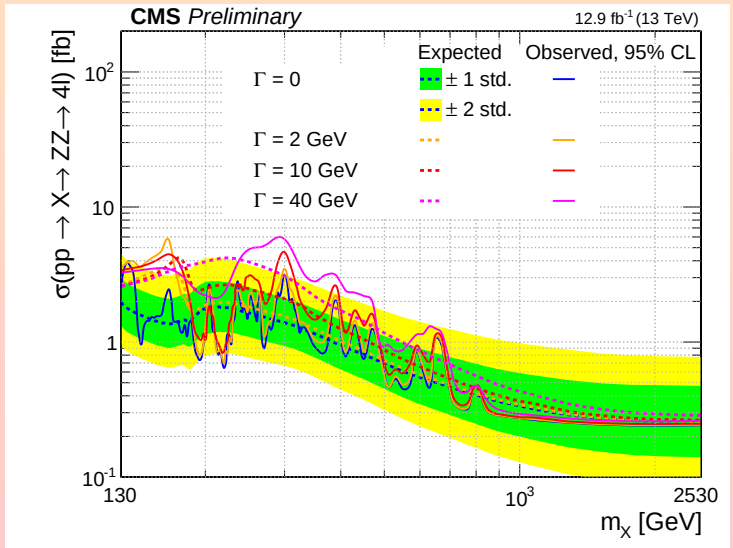
- $\mathrm{H} \to \mathrm{WW} \to \mathrm{e}\mu\nu_{\mathrm{e}}\nu_{\mu}$ **(HIG-16-023)**
- Only $\mathrm{e}\mu$ final state to avoid DY contamination in SF final states
  - Veto additional leptons
  - Reject DY$\to\tau\tau$w/ cut on $p_{\mathrm{T}}^{\ell\ell}$
- W+jets contribution estimated from data





- $\mathrm{H} \to \mathrm{ZZ} \to \ell\ell\ell'\ell'$ **(HIG-16-033)**
- Find Z candidates ($12 < M_{\ell^+\ell^-} < 120$ GeV)
  - Additional requirements to low mass resonances
- Multiple matrix-element discriminators

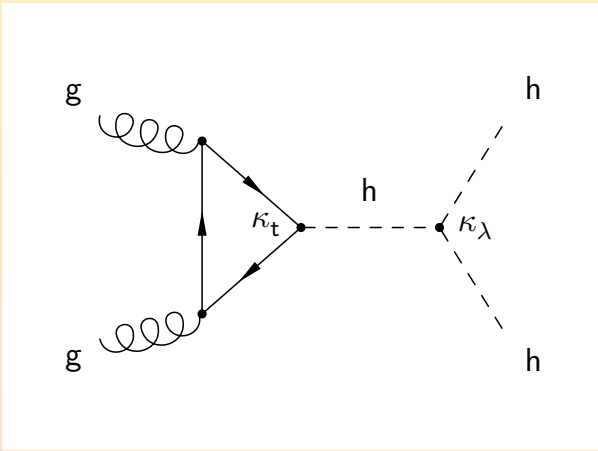


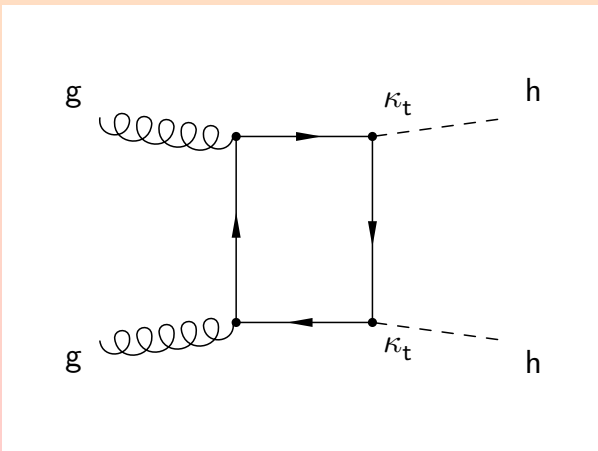


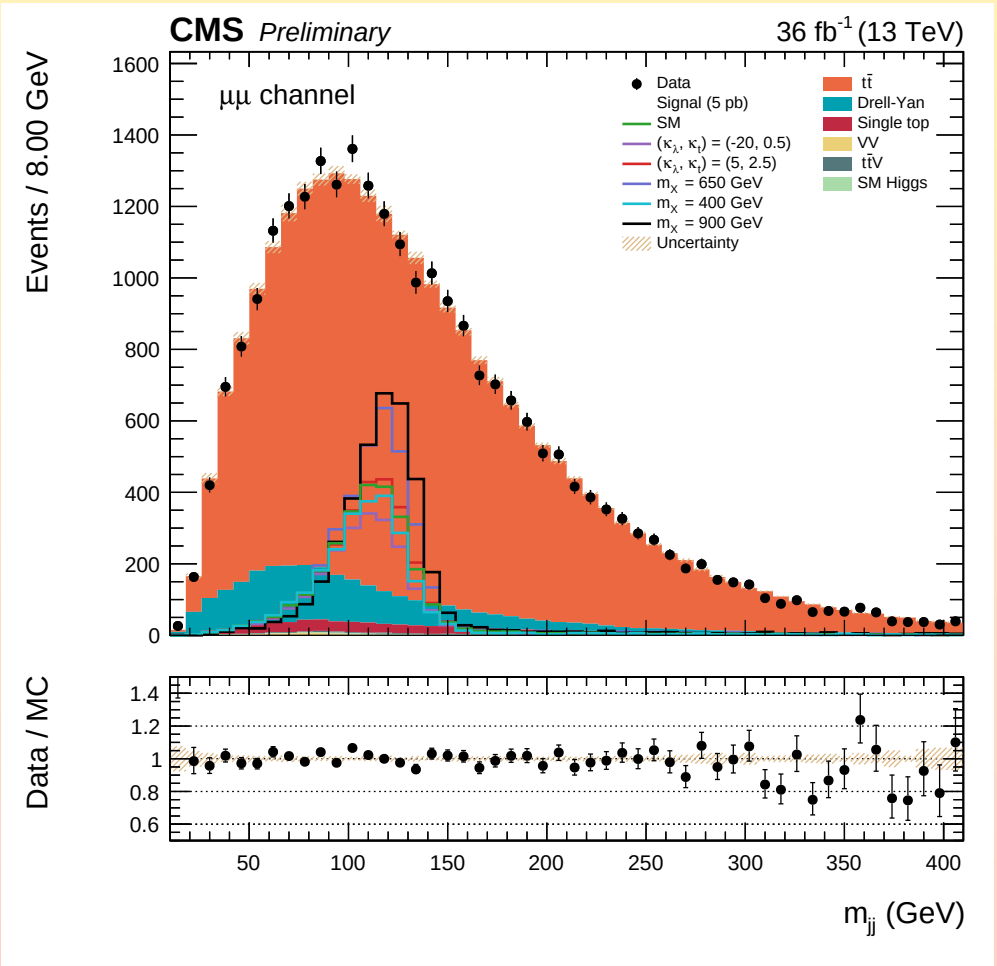
h h $\to$ bb**VV**$\to$ bb$\ell\ell\nu\nu$ (**HIG-17-006**)

- 2 OS leptons, 2b, $M_{\ell\ell} < m_Z - 15$ (reduces resonant Z peak and high DY and $t\bar{t}$ tails)
- DY contribution in OSSF+2bestimated in data via a dedicated BDT classifier
  - Re-weight data according to BDT classifier and k(=light,c,b)-flavour efficiencies
  - Residual non-DY contribution subtracted from the re-weighted data

- $\ell := e, \mu, \tau$ (leptonic tau decays accounted for!)
- Other backgrounds estimated from simulation



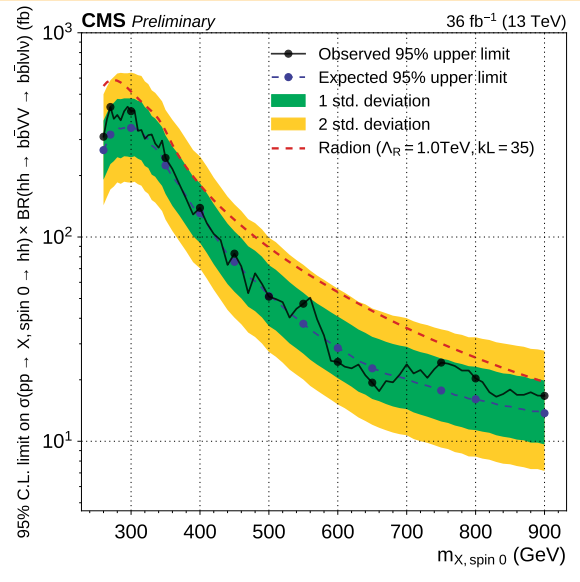


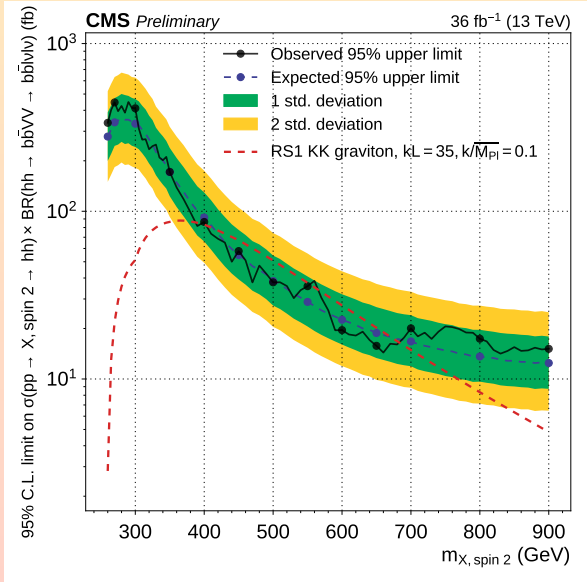


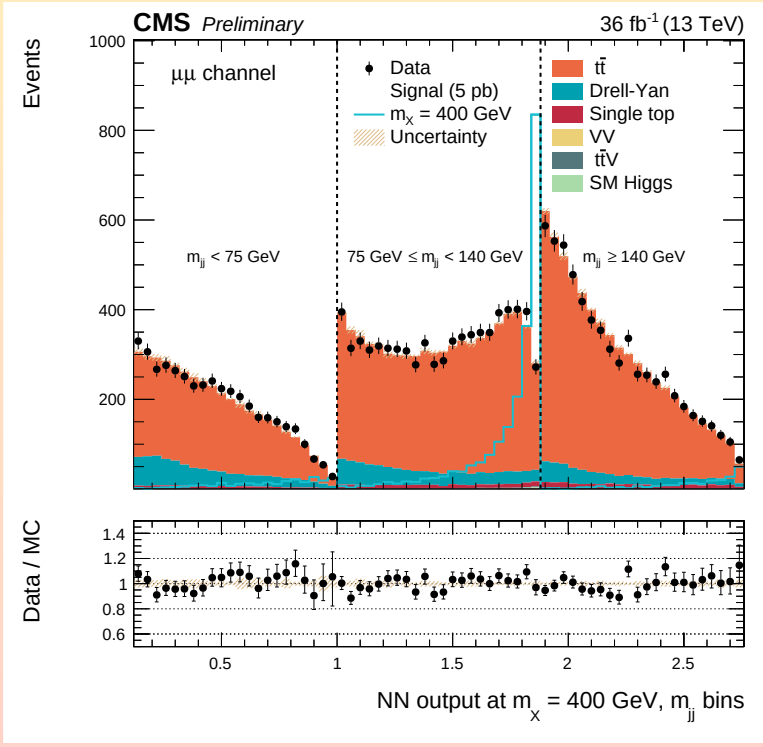
h h →bb**VV**→ bb$\ell\ell\nu\nu$ (**HIG-17-006**)

- DNN classifier improves signal separation from $t\bar{t}$ main background
- Parameterized machine learning technique to ensure optimal sensitivity to all mass hypotheses
  - Performance as good as individual networks trained for specific mass hypotheses
  - Provides a smooth interpolation to cases not fed during the training phase
  - Parameterized with resonance mass, dilepton flavour (SF/OF)

- No significant excess (neither resonant nor non-resonant)
- Set exclusion regions on heavy resonances

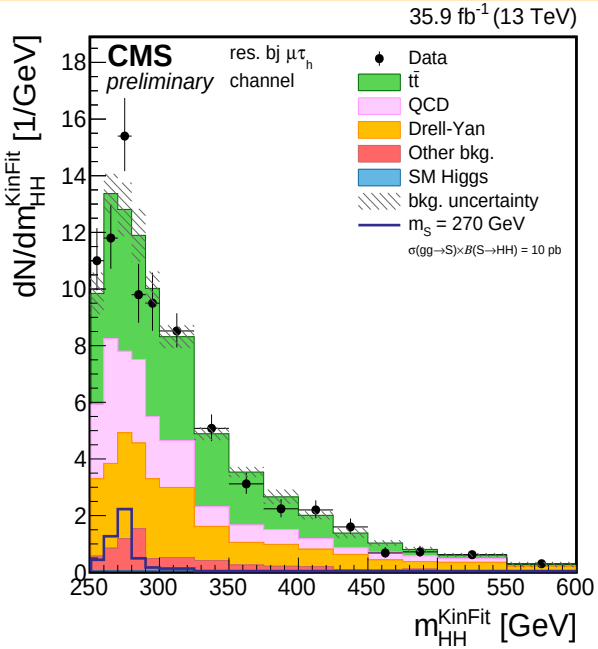


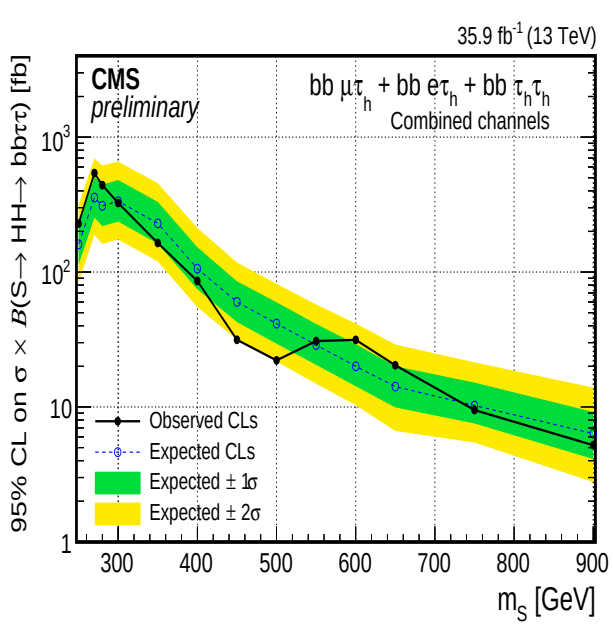


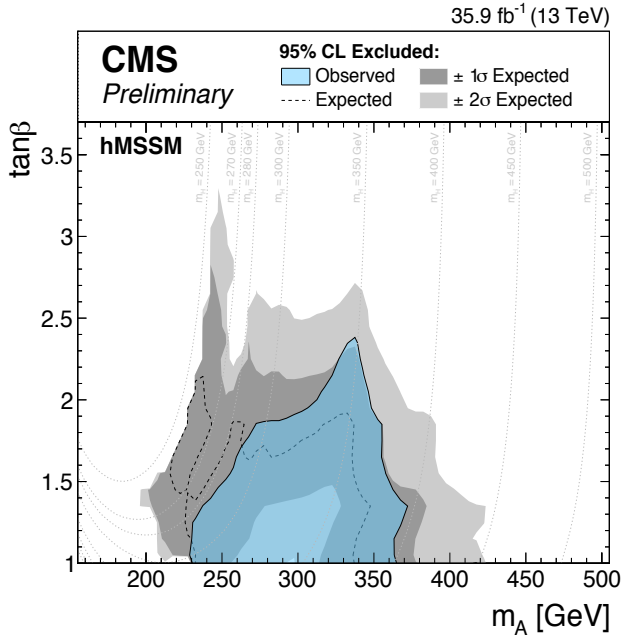


Resonant h h $\to\tau\tau$bb (HIG-17-002)

- Trilinear self couplings λ_{HHH} probed in Higgs boson pair production
  - Resonant prodution is a feature of Singlet models, 2HDM, MSSM, Warped Extra Dimensions models
- Account for 80% of the decays of the $\tau\tau$ system ($\ell\tau\nu_\tau$, or $\tau_h\,\tau_h$)
- Select events with 2 opposite charge leptons, and two large ($\Delta R = 0.8$) anti-K$_T$ jets
  - Resolve boosted topologies using jet substructure taggers
- Suppress $\mathrm{t\bar{t}}$ by requiring a 90% rejection in cutting on a dedicated BDT classifier
- Kinematic fit to reconstruct $M_{\mathrm{HH}} := M(\tau\tau\mathrm{bb})$



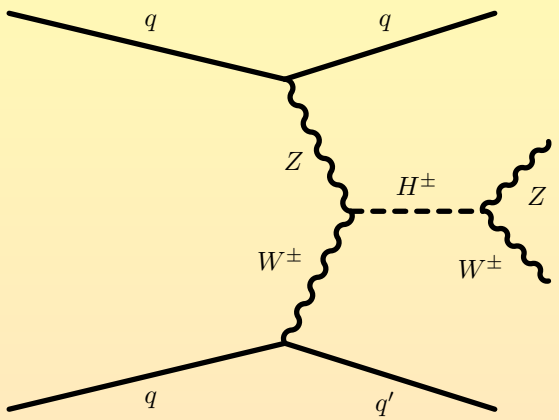


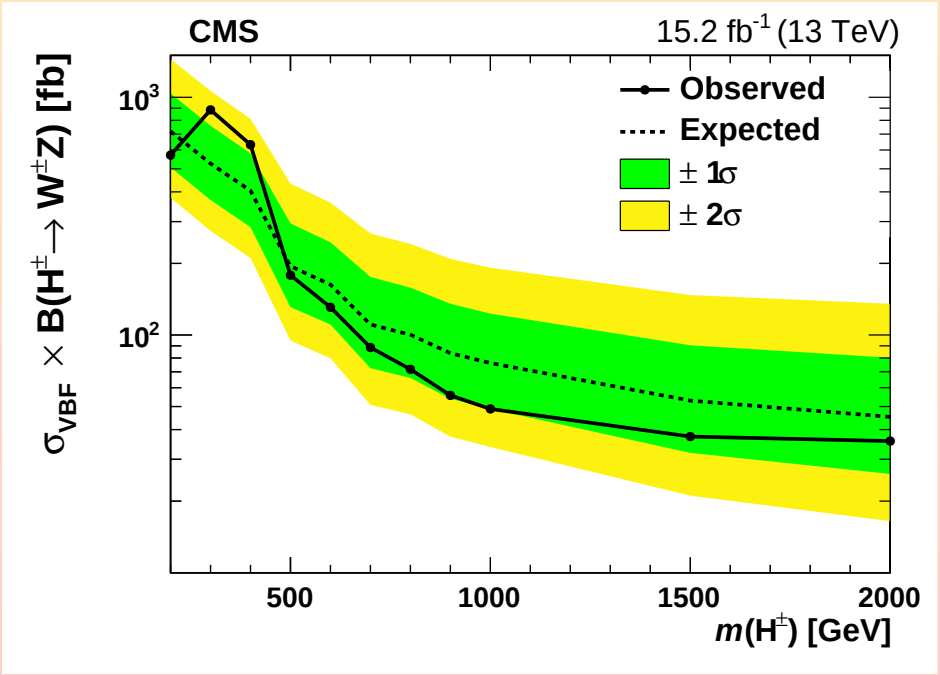


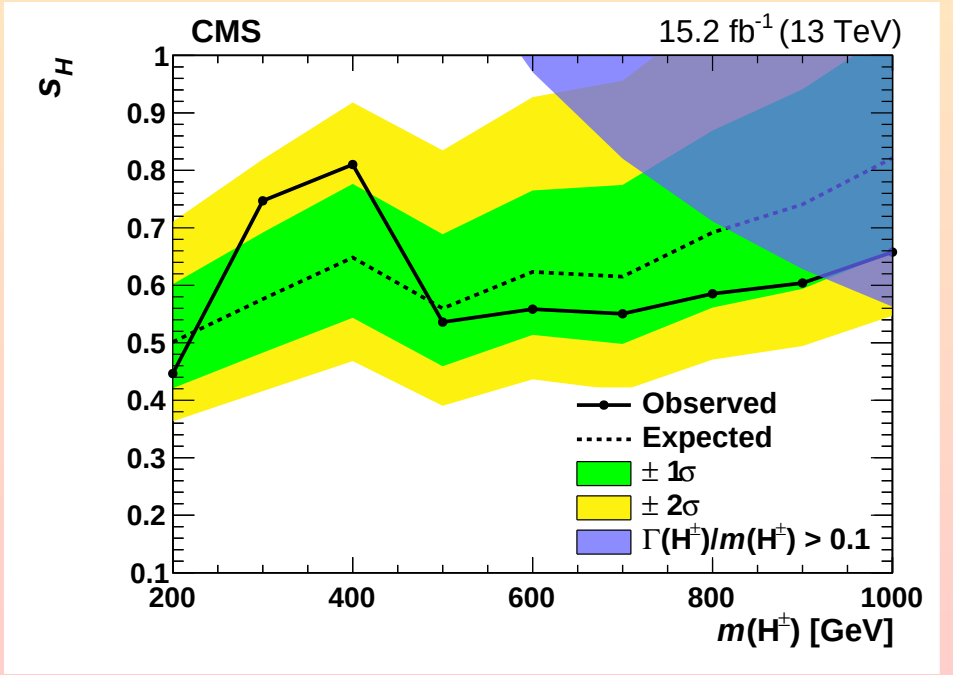
Non-resonant production covered by Teresa Lenz in her talk!

Charged Higgs to WZ (HIG-16-027)

- Tree-level couplings rise when extending Higgs sector with SU(2) triplets
- VBF topology: two $M_{jj} > 500$ GeV jets
- Three leptons (veto additional ones)
  - Reconstruct Zas pair with $M_{\ell\ell}$ closest to M_Z
- Estimate QCD from low-M_{jj} sidebands
- Used 2015 (2.3 fb^{-1}) and 2016 (12.9 fb^{-1}) data
- Most stringent limit on Georgi-Machacek triplet model

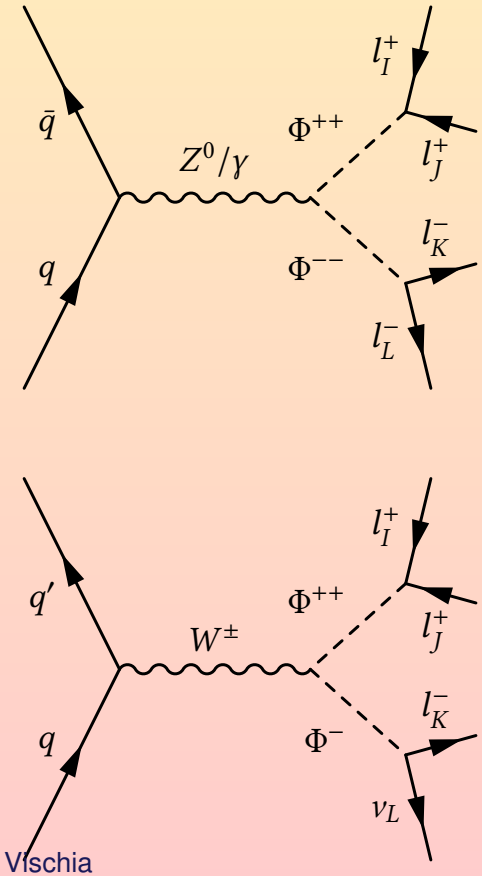


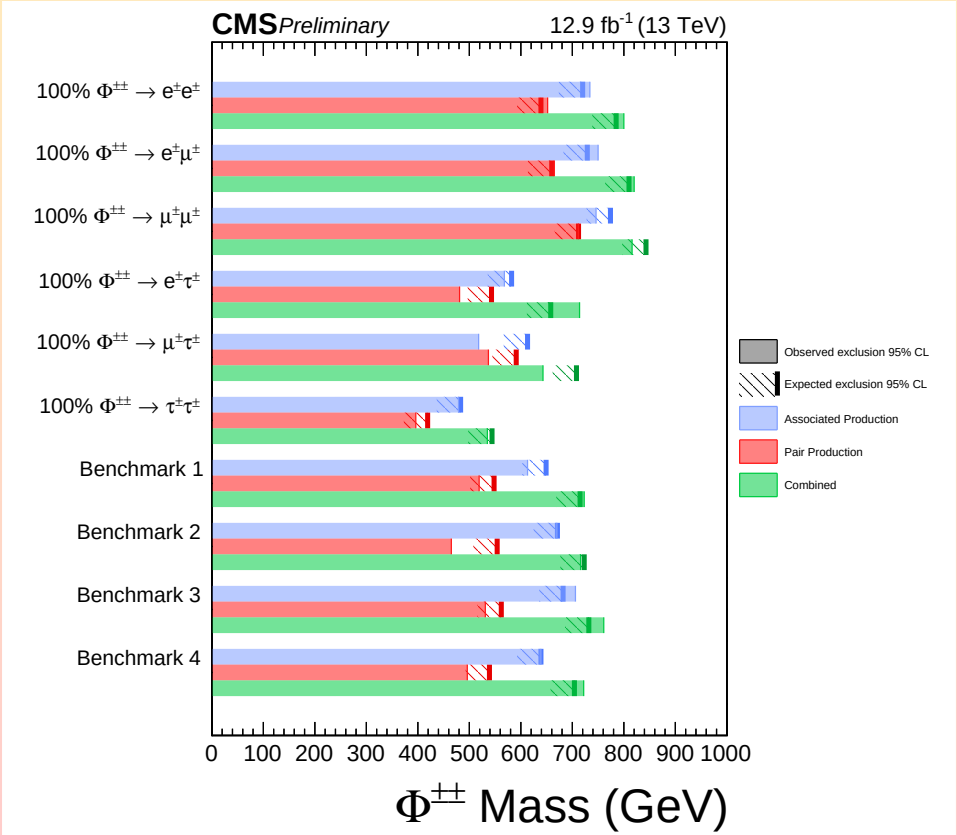




Doubly charged Higgs (HIG-16-036)

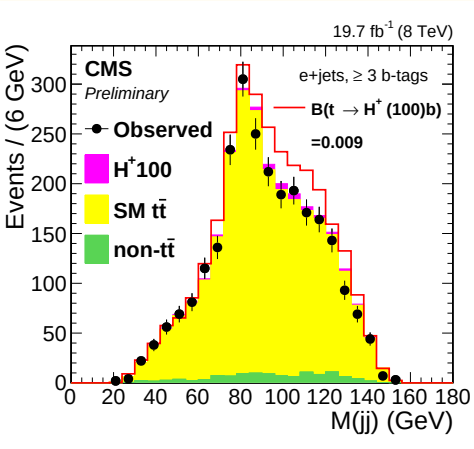
- Scalar triplet coming from minimal Type-II seesaw mechanism
  - Small v.e.v. (otherwise unnaturally small Yukawa couplings)
  - Decays to lepton pairs: WW decays are suppressed because proportional to v.e.v.
- Three leptons ($\Phi^{\pm\pm}\Phi^{\pm}$) and four leptons final states ($\Phi^{++}\Phi^{--}$)
- Backgrounds estimated in sidebands (outside of mass window)
  - Non-prompt leptons component estimated with tight-to-loose ratio
  - Contaminations from W+jets, Z, and low resonances removed via mass/transverse mass cuts
- Limits on $\sigma_{\Phi}^{\pm\pm}$ set assuming 100% BR for each flavour combination
- Mass exclusions around 500–700 GeV for each flavour combination and Type-II see-saw models benchmarks

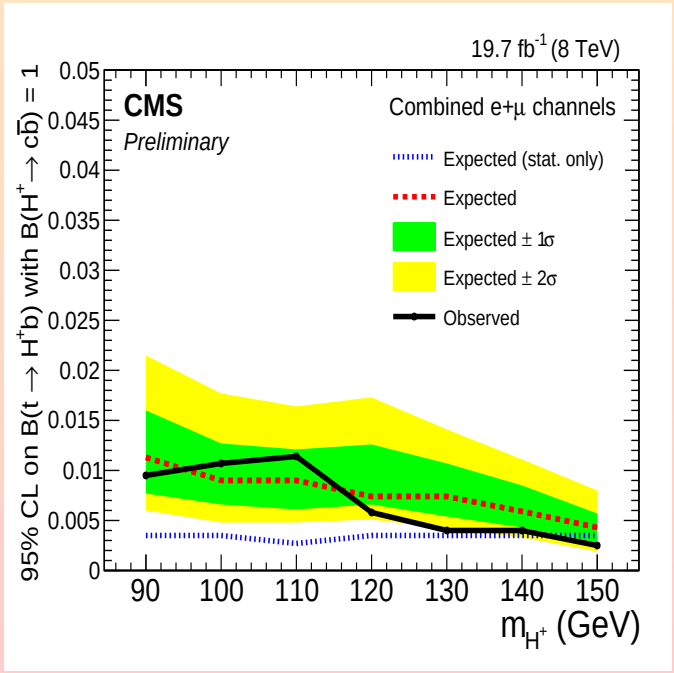




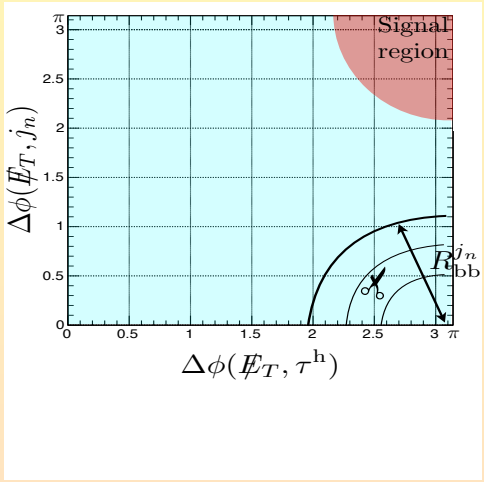
Other 13 TeV charged Higgs results

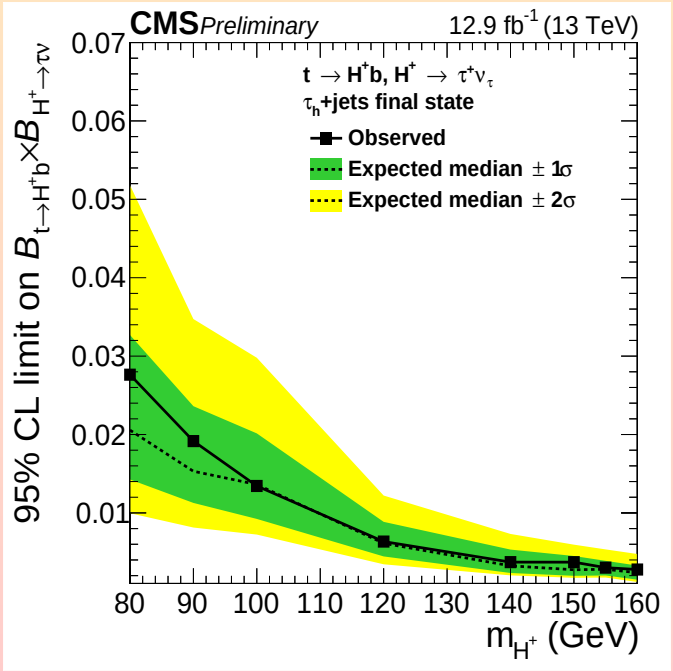
- $H^+ \to c\bar{b}$ **(HIG-16-030)**
- Dijet mass reconstruction in ℓ+jets
- Set limits on $\mathcal{B}(t \to H^+ b)$



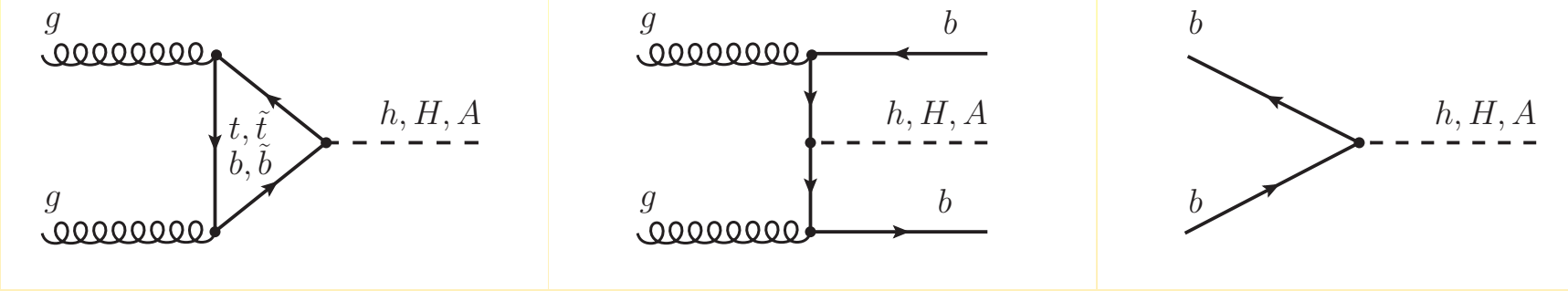


- $H^\pm \to \tau^\pm \nu_\tau$ **(HIG-16-031)**
- Background rejection via τ-related angular variable
- Stringent limits set (light and heavy case)
- $H^\pm \to t\bar{b}$ coming soon





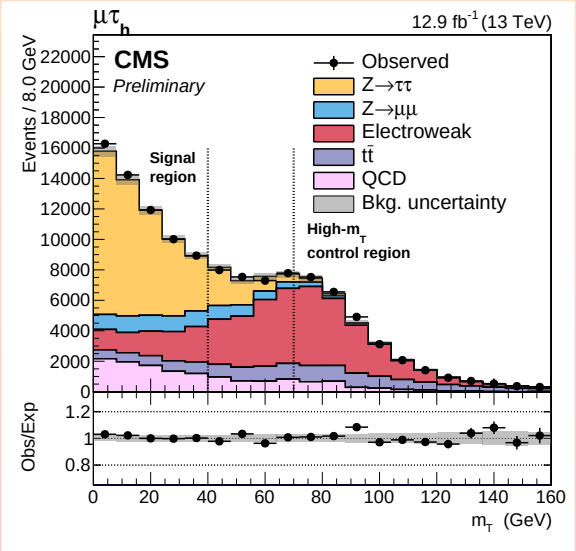
Neutral MSSM $H \to \tau\tau$ (HIG-16-037)



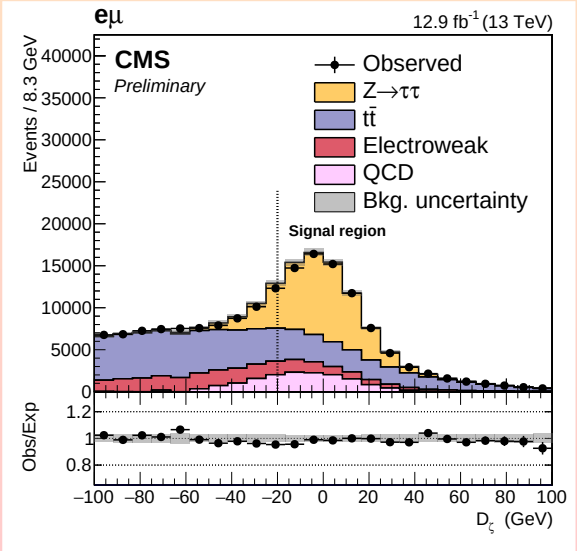
(a) (b) (c)

- Final states (eμ, eτ_h, $\mu\tau_h$, $\tau_h\,\tau_h$) studied w/ targeted triggers and offline selection
- Contribution from events with fake hadronic taus is estimated in data
  - Mainly W+jets and QCD multijets events
- Signal regions identified via dedicated cuts in different final states
  - $\ell\tau$: transverse mass between the light lepton and the $E_{\mathrm{T}}^{\mathrm{miss}}$
  - eμ: topological discriminator D_ζ based on projecting momenta and $E_{\mathrm{T}}^{\mathrm{miss}}$ on the axis ζ bisecting $p_{\mathrm{T}}^{\mathrm{e}}$,$p_{\mathrm{T}}^{\mu}$

$\mu\tau$ final state

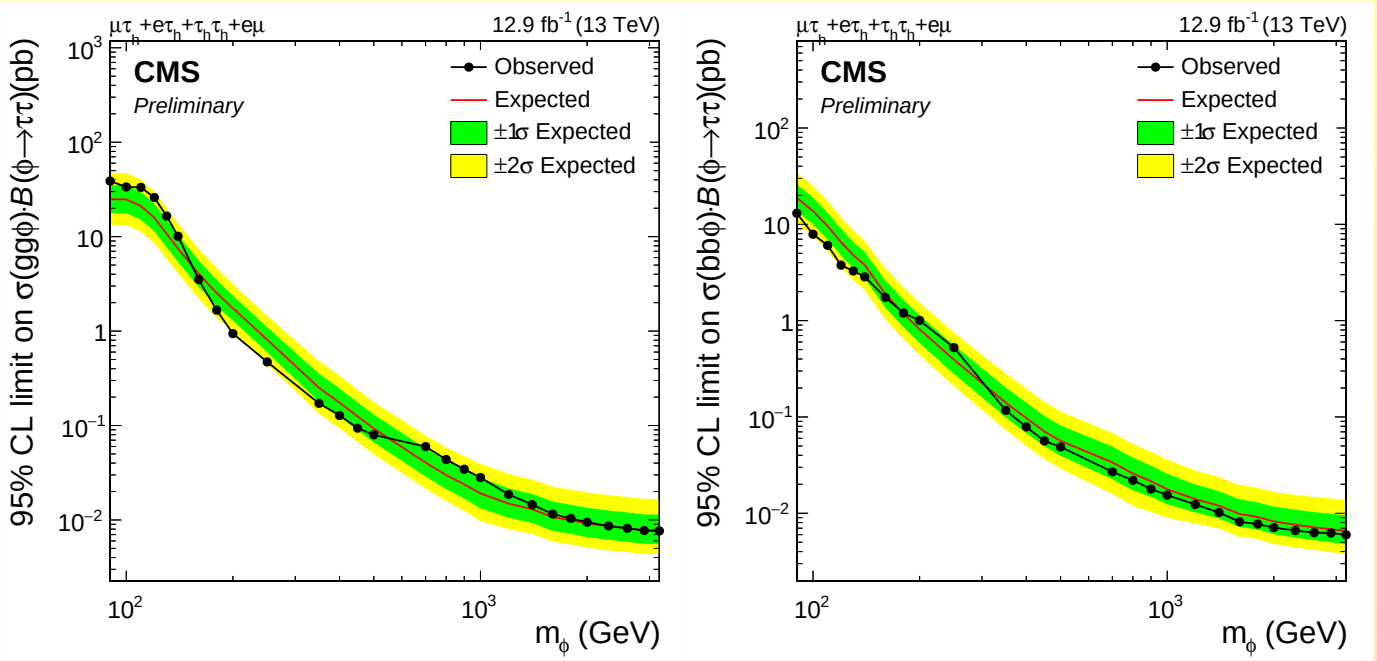


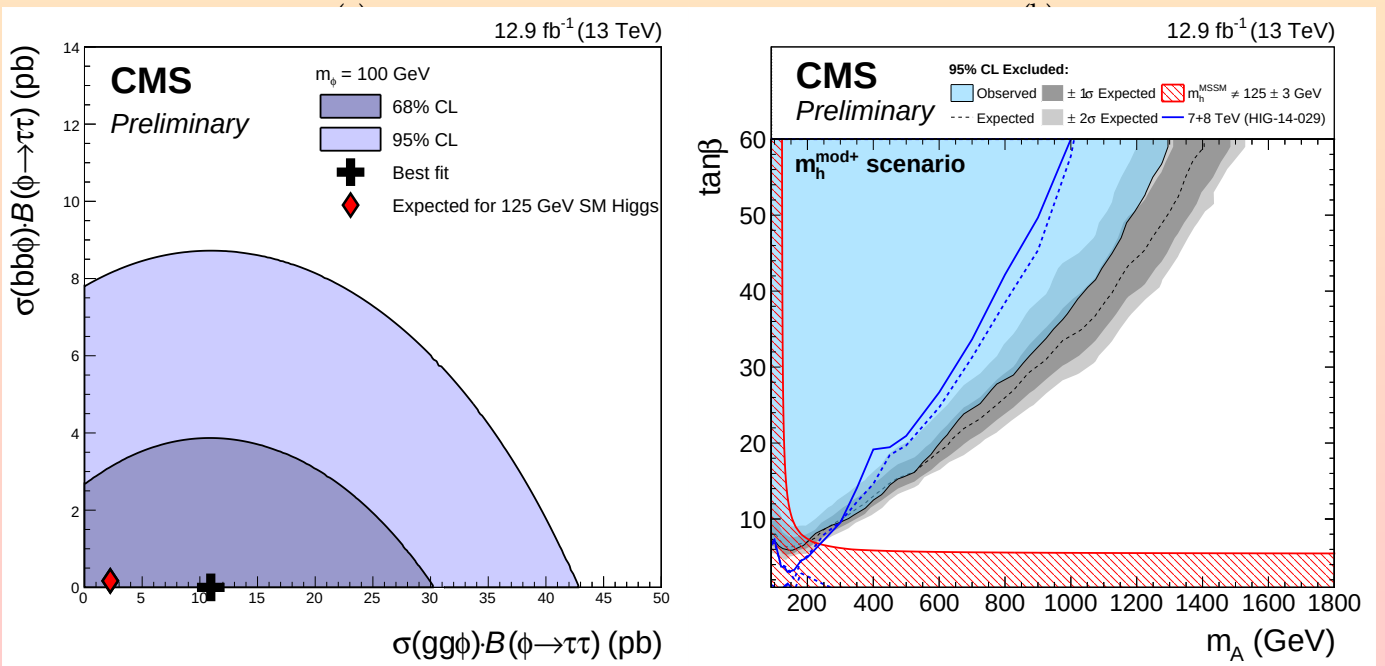
eμ final state



Neutral MSSM $H \to \tau\tau$ (HIG-16-037)

- Obtain limits on each production mode independently
- Scan the two production modes
- Set limits on MSSM scenarios (m_{ϕ}^{mod+})

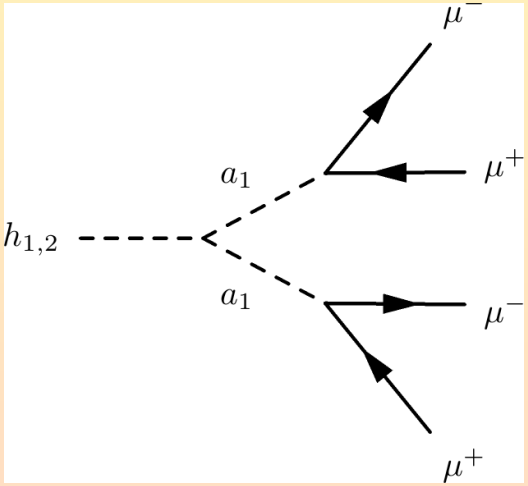


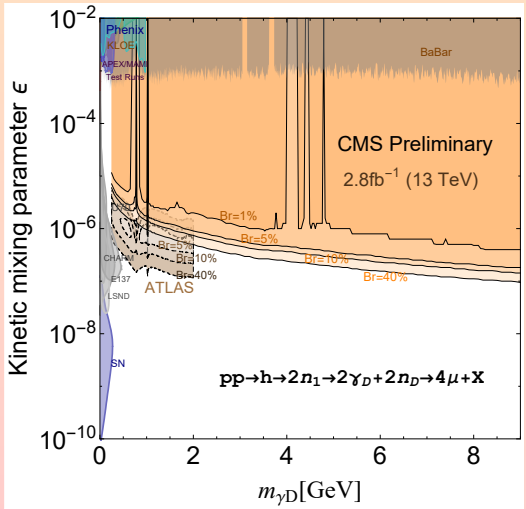


Other searches for resonances

BSM $H \to aa \to 4\mu$ (HIG-16-035)

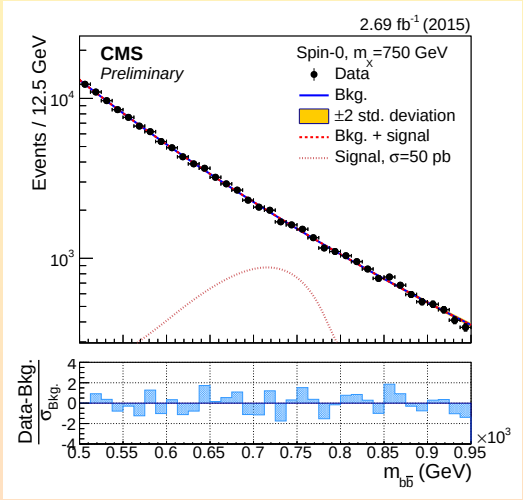
- 2 OS muon pairs
- Iso requirements to suppress dimuons from jets
- Model independent 95% CL upper limit: 1.7 pb

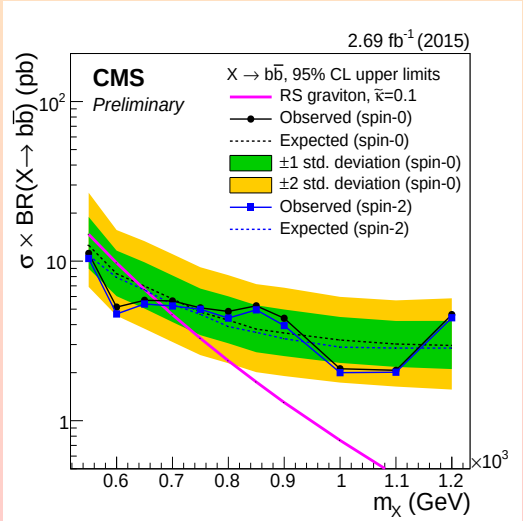




Heavy BSM $H \to b\bar{b}$ (HIG-16-025)

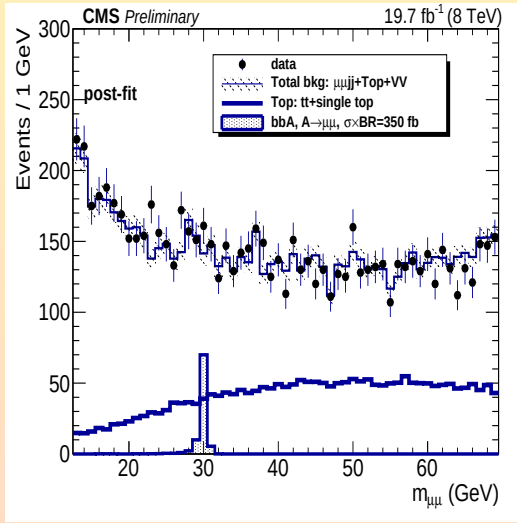
- 2b-jet, 0ℓ final state
- Fit dijet invariant mass spectrum

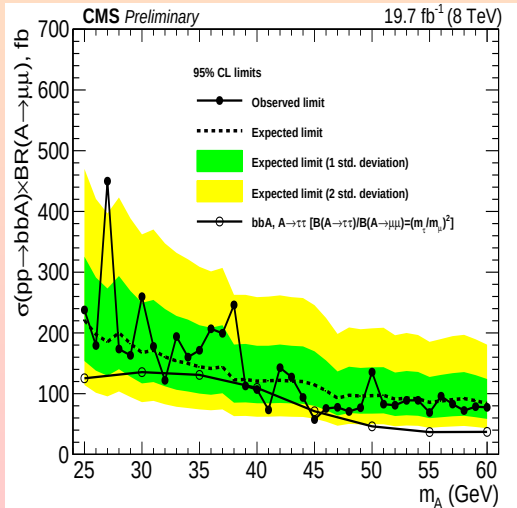




Light BSM $b\bar{b}H \to b\bar{b}\mu\mu$ (HIG-15-009)

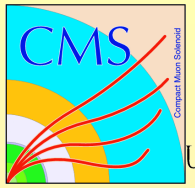
- Optimized cuts to enhance signal
- Complementary to $A \to \tau\tau$ search
- Fit dimuon mass spectrum





Summary

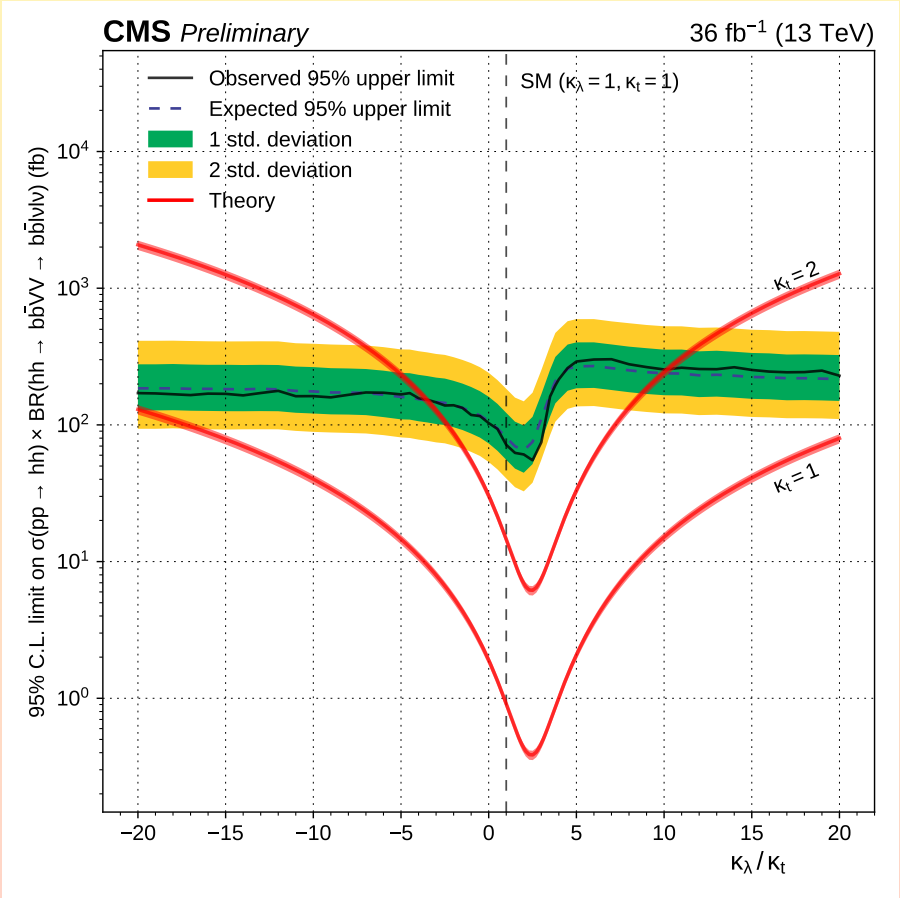
- BSM Higgs boson searches at the LHC are a bleeding edge tool for testing the SM
- Any measured effect would be a smoking gun for new physics
- Rich CMS program in various final states
  - Full combination of Run-I results improved comprehension of theory landscape
  - Run-II results complement and expand the set of experimental results
- Self couplings and additional neutral bosons searched for with advanced tools
  - Advanced multivariate classifiers (DNN)
  - Jet substructure in boosted topologies
  - Sophisiticated kinematical cuts
- Multilepton topologies favoured (low SM backgrounds)
- Topologies with heavy objects (b quarks, τ leptons) favoured
- Many new results to come or be updated soon!!!
- Stay tuned! https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

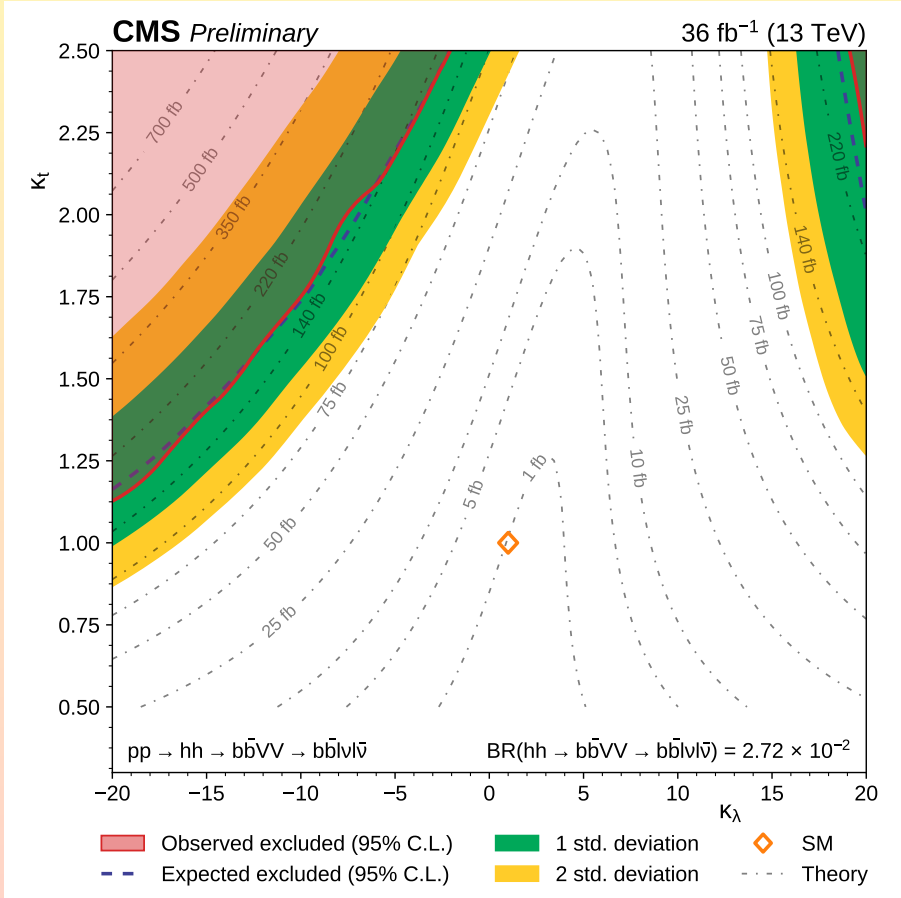


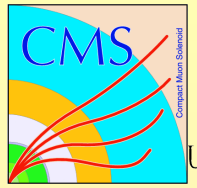
THANKS FOR THE ATTENTION!

Backup

- Non-resonant case: upper limits are set as a function of $\frac{k_\lambda}{k_t}$






CMS
Compact Muon Solenoid

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