Searches for h(125) properties beyond the Standard Model at the CMS experiment

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DESY

(on behalf of the CMS Collaboration)

29th Rencontres de Blois

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The state h(125) and its known properties

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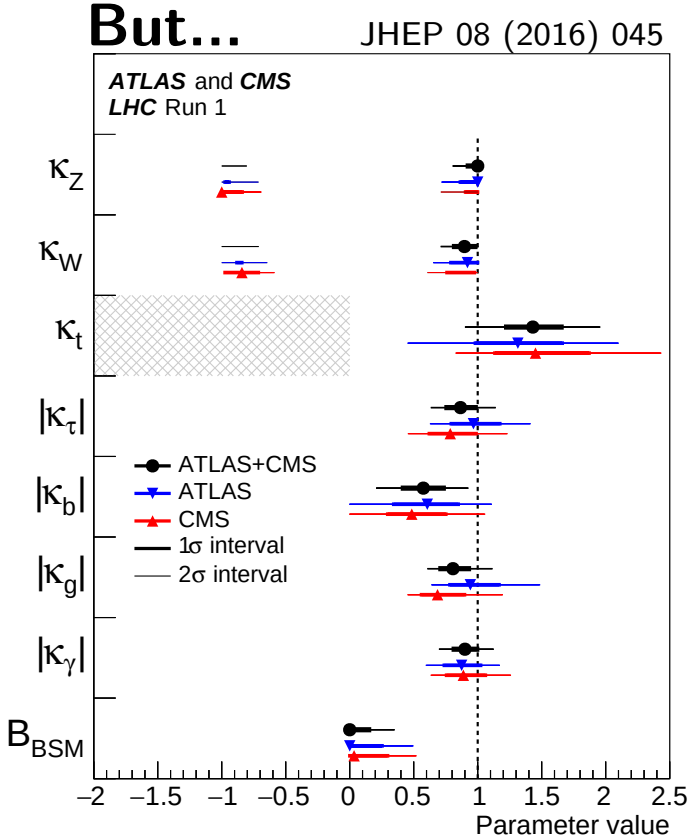

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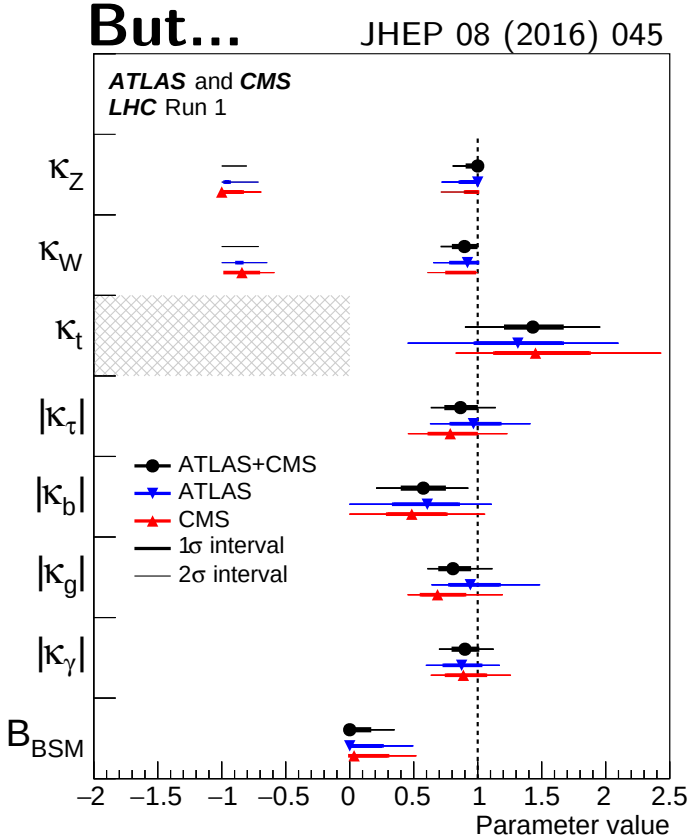

Still 34% branching ratio for non-SM decays possible (at 95% CL).

Beyond the Standard Model

How can new physics affect h(125) properties?

- Additional loop contributions from new particles alter couplings.
- New open decay channels to SM or non-SM particles.

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All 13 TeV results with full 2016 dataset!

Search for lepton flavour violating h(125) decays

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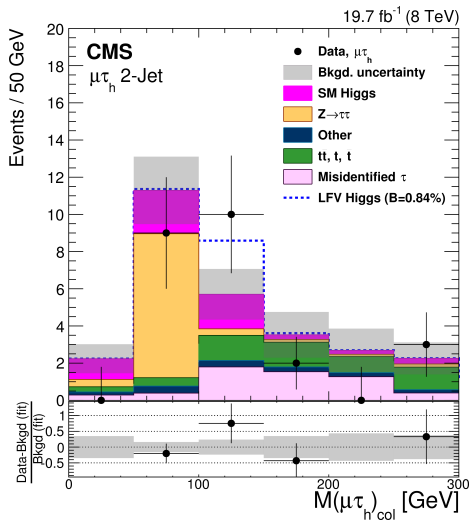
Lessons from 2012 and 2015 data:

- Excess (2.4σ) in $h(125) \rightarrow \mu\tau$ at 8 TeV at CMS.
  - Best fit branching ratio: $0.84 \pm 0.38\%$
- Also at ATLAS small excess (1σ) at 8 TeV.
  - Best fit branching ratio: $0.53 \pm 0.51\%$
- 2015 results did not allow firm conclusion.



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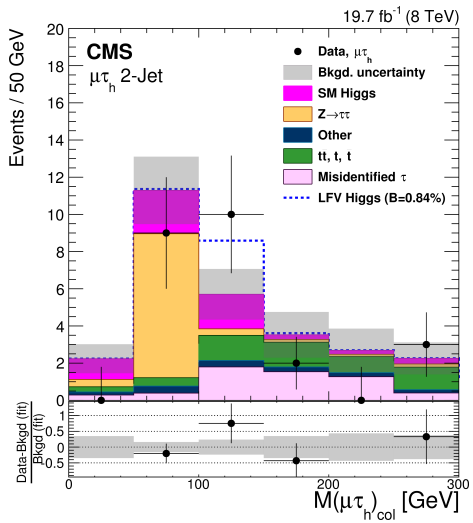


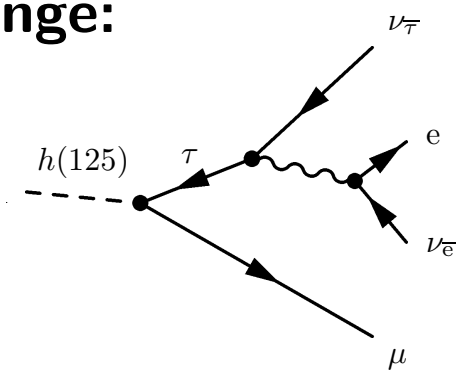
But new 2016 result will ...

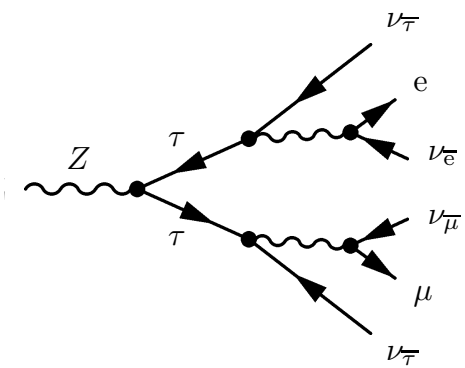
Search for lepton flavour violating h(125) decays 13 TeV

CMS-PAS-HIG-17-001

Final states: $h(125) \to \tau\mu$ and $h(125) \to \tau e$

Major challenge:

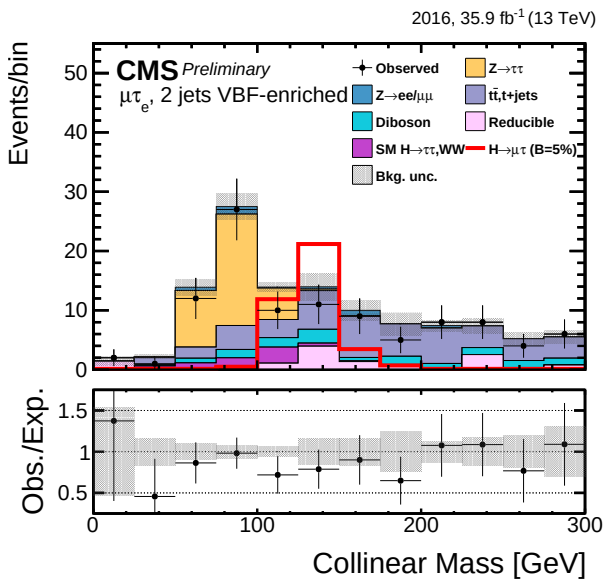




- Discrimination against $Z \to \tau\tau$ background

$\to$ Done with the help of kinematic quantities

  - Transverse momentum of e and μ
  - Missing transverse energy
  - Collinear mass
    - $M_{\text{col}} = M_{\text{vis}}(\tau, \mu/e)/\sqrt{x_\tau^{\text{vis}}}$

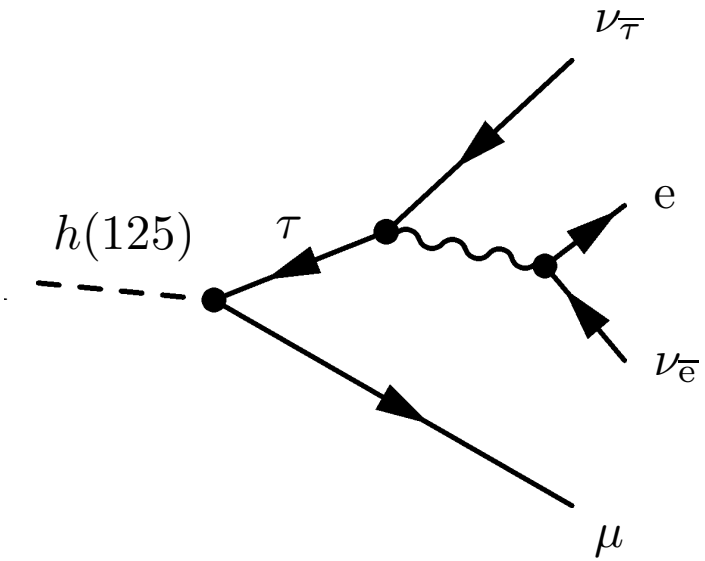


Search for lepton flavour violating h(125) decays 13 TeV

CMS-PAS-HIG-17-001

Selection steps:

- Require $\mu(e)$ and τ (τ_h, τ_e, τ_μ).
- Veto events with additional e, μ, τ.
- 4 different categories for different Higgs production mechanisms.



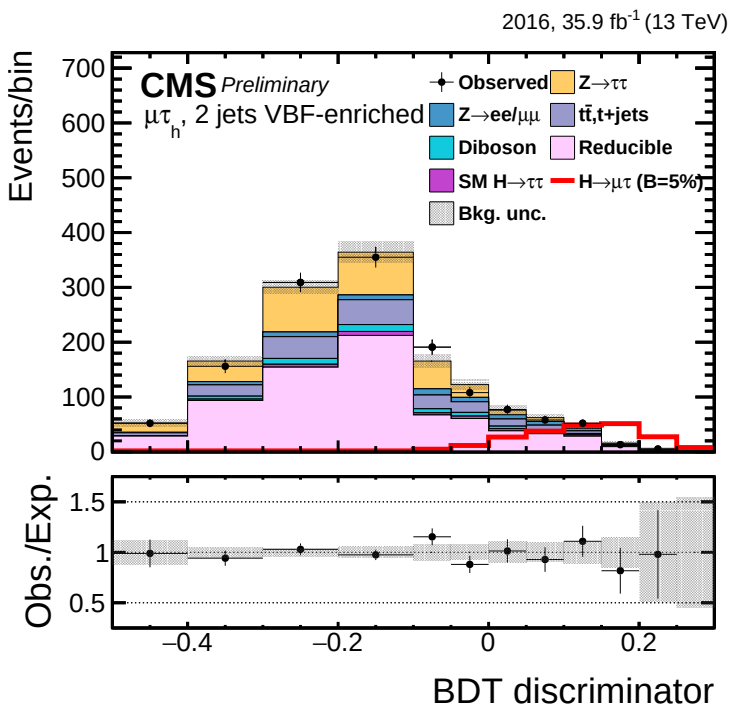
Multivariate analysis technique

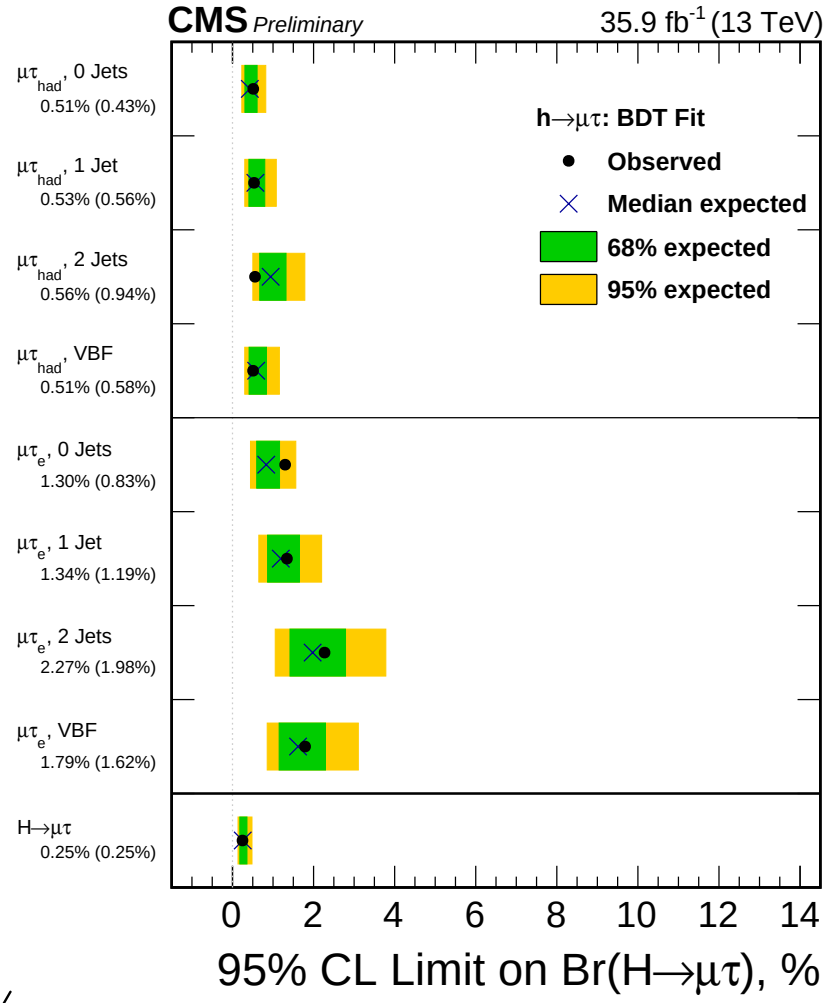
- **B**oosted **D**ecision **T**ree classifies signal vs. background events.
- Input variables:
  - p_T^e, p_T^μ, $p_T^{\tau_h}$
  - M_{col}, $M_T(e,\not{E}_T)$, $M_T(\mu,\not{E}_T)$, $M_T(\tau_h,\not{E}_T)$
  - $\Delta\phi(e,\not{E}_T)$, $\Delta\phi(\mu,\not{E}_T)$, $\Delta\phi(\tau_h,\not{E}_T)$
- Second non-BDT approach: using M_{col} as final discriminator

Search for lepton flavour violating h(125) decays 13 TeV

CMS-PAS-HIG-17-001

Results:





→ Result is compatible with Standard Model expectation.

→ Best fit: $\mathcal{B}(h \to \mu\tau) = 0.00 \pm 0.12\%$.

→ Upper 95% CL limit: $\mathcal{B}(h \to \mu\tau) < 0.25\%$.

Search for h(125) decays to light Higgs bosons 8 TeV

1701.02032

Even lighter Higgs bosons possible in many models beyond the SM.

- E.g. Next-to-Minimal Supersymmetric Standard Model
  H H S $\rightarrow$ after SSB $\rightarrow$ h_1 h_2 h_3 a_1 a_2 $h^{\pm}$
- A light pseudoscalar Higgs (a_1) possible.

- Search for $h(125) \rightarrow a_1 a_1$ in various final states performed:
  - $h \rightarrow a_1 a_1 \rightarrow 4\mu$
  - $h \rightarrow a_1 a_1 \rightarrow 4\tau$
  - $h \rightarrow a_1 a_1 \rightarrow 2\mu 2\tau$
  - $h \rightarrow a_1 a_1 \rightarrow 2\mu 2b$
- Target different mass ranges of a_1.

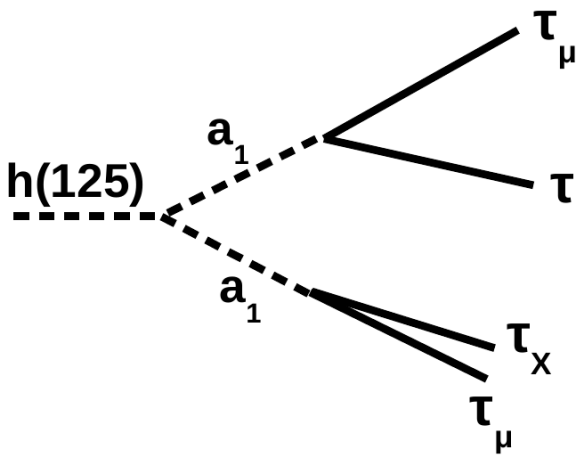
Various searches $\rightarrow$ various challenges

Search for h(125) decays to light Higgs bosons 8 TeV

$h \to a_1 a_1 \to 4\tau$

1701.02032

- Targets mass range between $5 - 15\,\text{GeV}$.
  - $\to$ Large Lorentz boost of a_1 $\to$ decay products can overlap.
  - $\to$ Special tau reconstruction techniques.



Approach:

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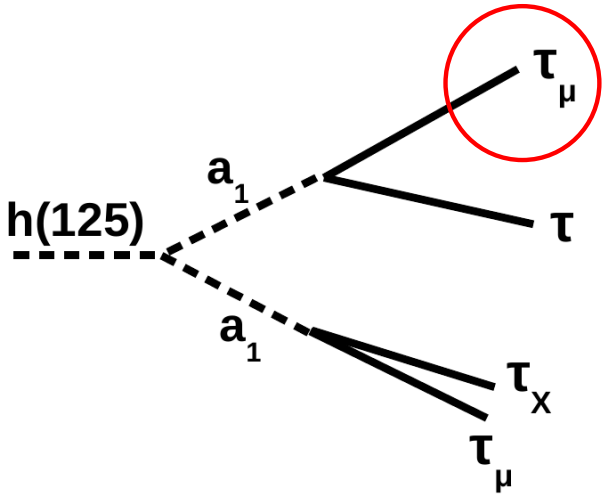

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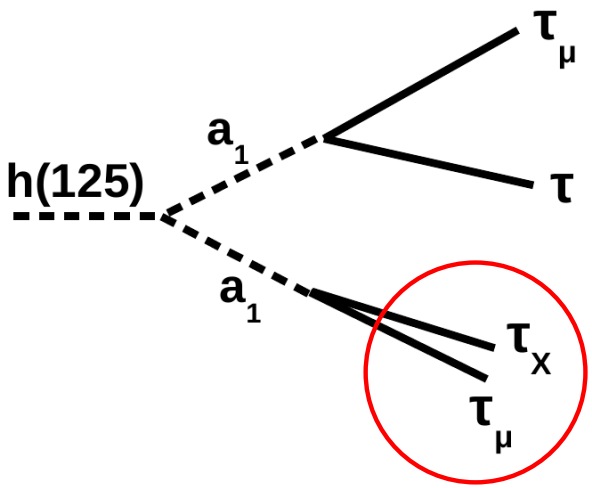

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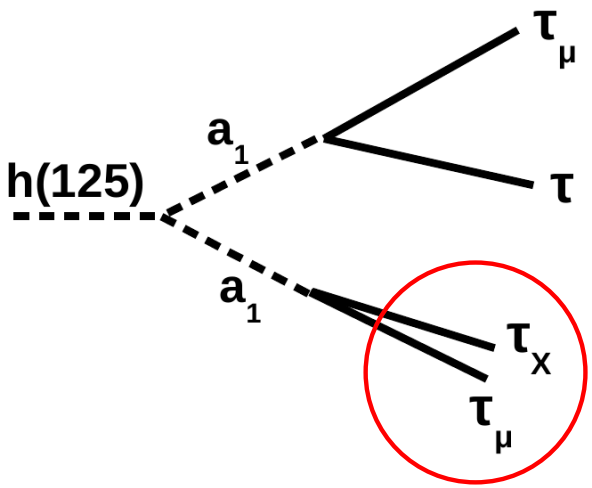

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  - Successful reconstruction of a tau $\to$ Successful τ_μ - τ_X reconstruction.

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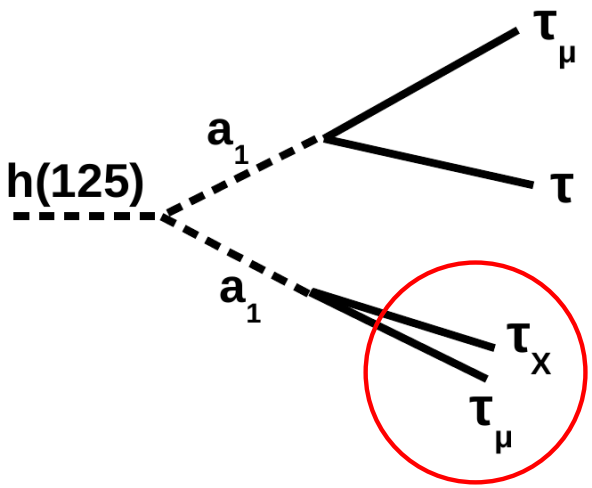

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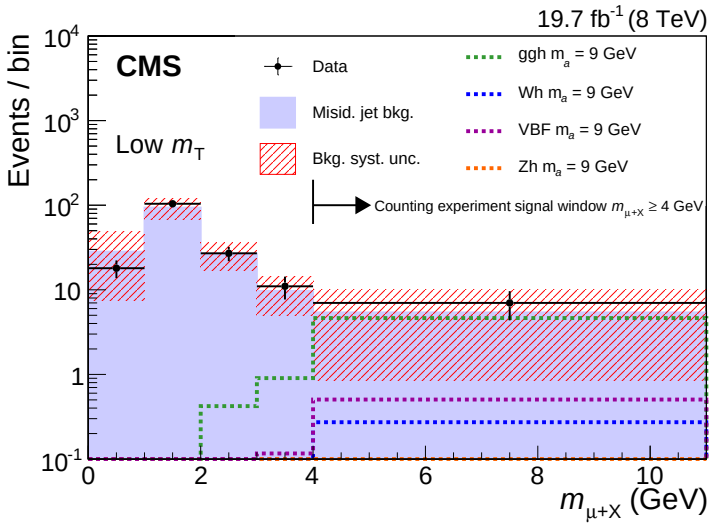

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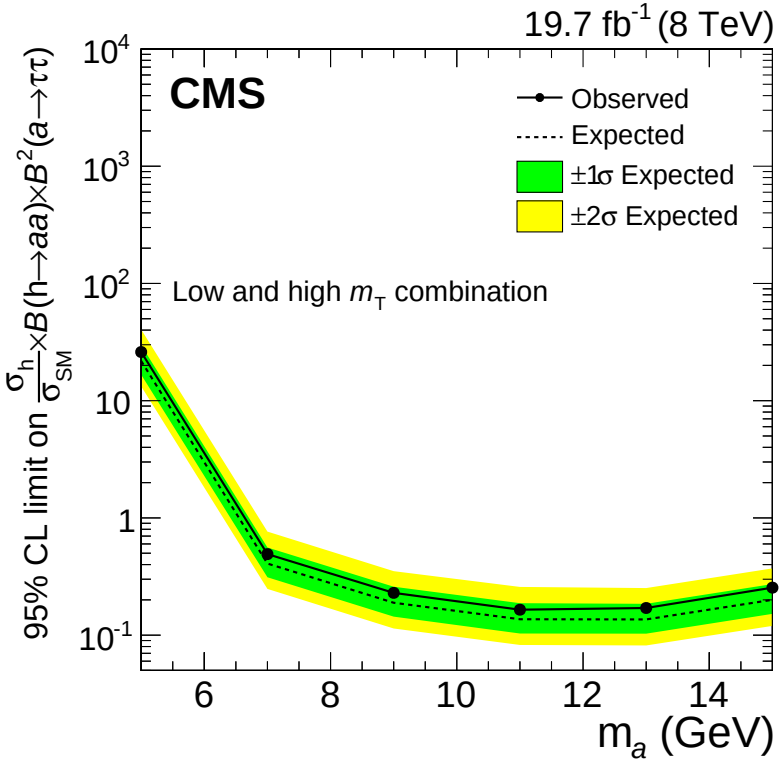
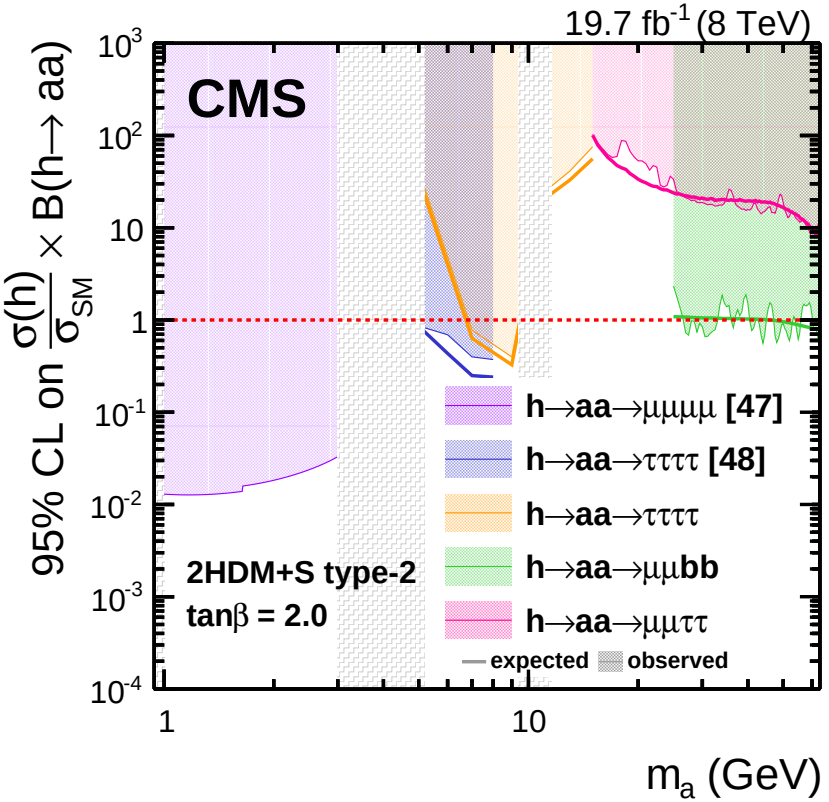


All searches

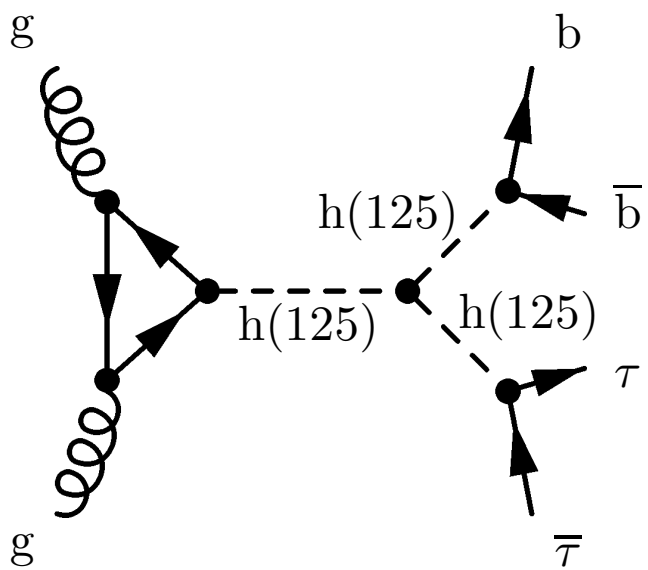


- All measurements are compatible with SM expectations.
- Upper 95% CL limits on $\mathcal{B}(h \to a_1 a_1)$ go down to 17, 16, 4% for different decay modes.

Search for anomalous self-coupling of h(125) 13 TeV

CMS-PAS-HIG-17-002

- Pair production of h(125): many possible final states
- Today: $h \to hh \to \tau\overline{\tau}b\overline{b}$



- Non-resonant pair production of SM Higgs bosons possible in the Standard Model (but very small).
- SM: Destructive interference of tree-level (λ_{hhh}) and fermionic loop contributions.
- SM prediction: $\sigma \approx 33$fb.

Measurement sensitive to anomalous contributions to y_t and λ_{hhh}

Please see talk by Pietro Vischia for resonant $X \to hh$ production.

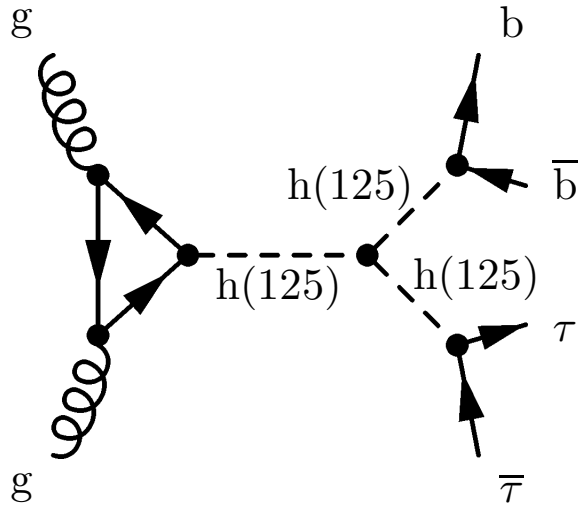
Search for anomalous self-coupling of h(125) 13 TeV

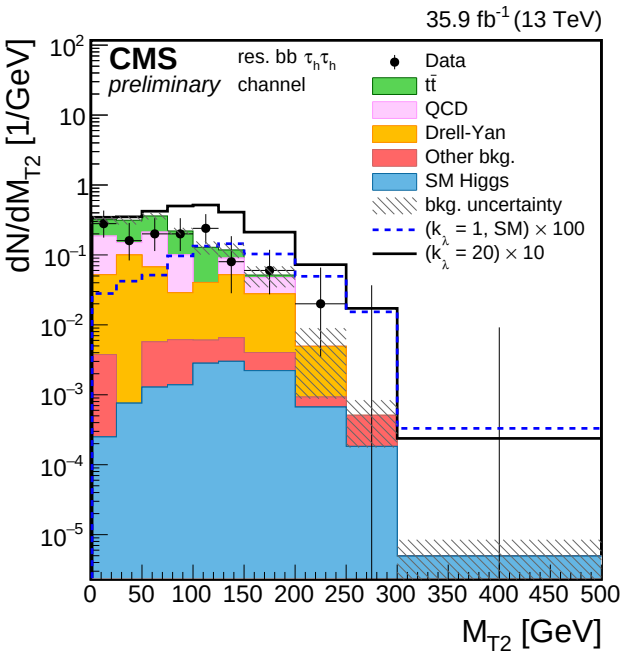
CMS-PAS-HIG-17-002

Pecularities:

- Mass reconstruction of $m_{b\bar{b}}$ and $m_{\tau\bar{\tau}}$.
- Separation from $t\bar{t}$ background.

→ The "stransverse mass" M_{T2} is used as final discriminator.





- For $t\bar{t} \to b\bar{b}WW \to b\bar{b}\tau\nu_\tau\tau\nu_\tau$: upper bound at m_t.
- Signal can have larger values.

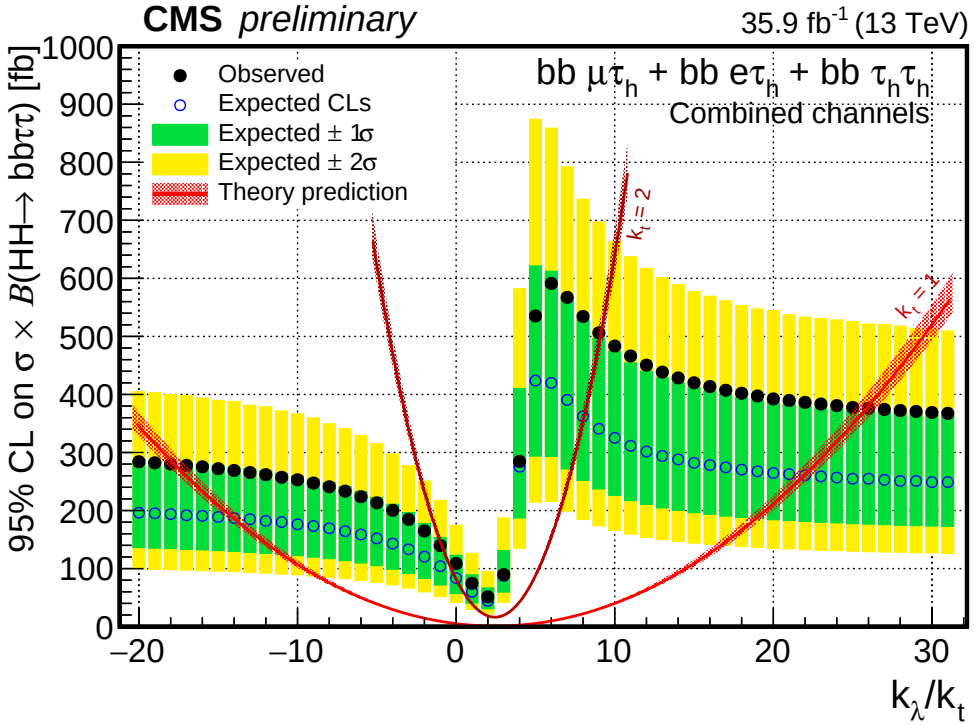
Search for anomalous self-coupling of h(125) 13 TeV

CMS-PAS-HIG-17-002

Results:

- Deviations from SM parametrized with: $k_\lambda = \lambda_{hhh}/\lambda_{hhh}^{SM}$

  $k_t = y_t/y_t^{SM}$



→ Observed upper limit on $\sigma \cdot \mathcal{B}(hh \to b\bar{b}\tau\bar{\tau})$ is 28 times larger than in the SM.

→ No sign for new physics.

Search for anomalous h(125) couplings to VV 13 TeV

CMS-PAS-HIG-17-011

- $J = 0$ nature of h(125) established in Run1.
- Still: Non-SM like couplings of the Higgs to vector bosons possible.

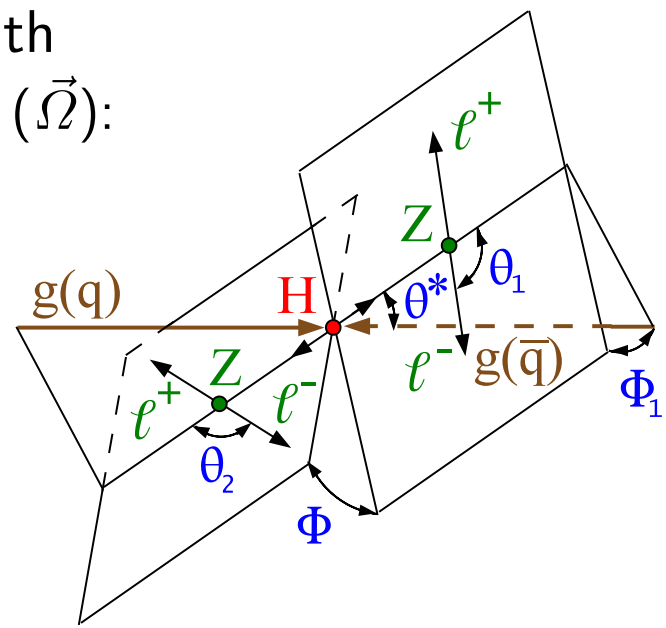
$\rightarrow$ 4 different anomalous couplings tested.

- New to 8 TeV: Anomalous couplings also tested via production.

Approach:

- Full kinematic information is extracted with
  - Up to 13 observables as input per event ($\vec{\Omega}$):
    - Decay products: $M_{\text{inv}}^{\text{leptons}}$, angles
    - Angles between decay frame and production axis, ...
  - Matrix element likelihood approach.

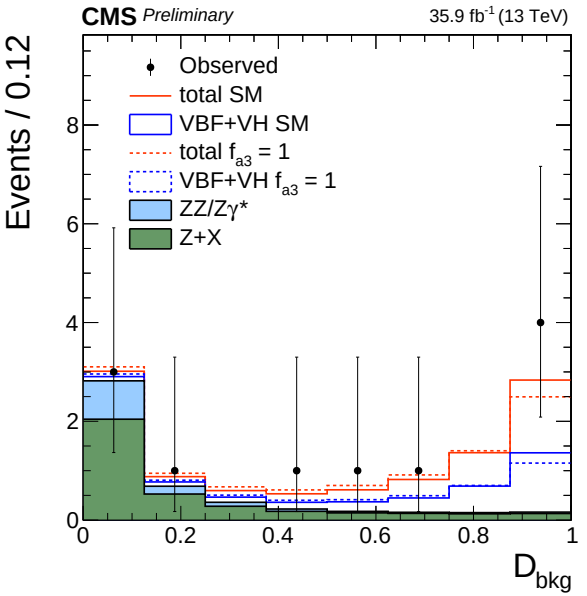
$\rightarrow$ Reduced set of informative observables (discriminants)

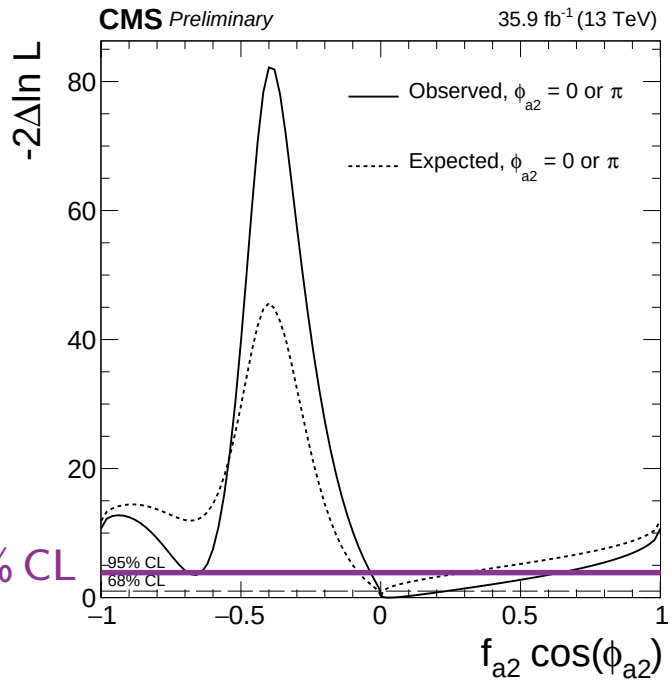


Search for anomalous h(125) couplings to VV 13 TeV

CMS-PAS-HIG-17-011

- Discriminants: e.g $\mathcal{D}_{\text{bkg}} = \frac{\mathcal{P}_{\text{SM}}(\vec{\Omega})}{\mathcal{P}_{\text{SM}}(\vec{\Omega})+\mathcal{P}_{\text{bkg}}(\vec{\Omega})}$.
- Event observables $\vec{\Omega}$ compared to theoretical hypothesis α: $\mathcal{P}\left(\vec{\Omega}|\alpha\right)$.
- Ratios reduce systematic uncertainties.





95% CL

- $f_{a2} = 0$: CP-even Higgs boson
- $f_{a2} = 1$: CP-odd Higgs boson

$\rightarrow$ All observations are consistent with Standard Model expectations.

Conclusion

- BSM properties of h(125) can be tested in many different ways.
  - → Non-SM decays (lepton flavour violating decays, $h \to a_1 a_1$).
  - → Anomalous couplings to itself and other particles.

- Excess in LFV Higgs decays disappeared in full 2016 dataset.
- Upper limit of $\mathcal{B}(h \to \mu\tau) < 0.25\%$ is set.

- No hint for $h \to a_1 a_1$ decays.
- Updates with 13 TeV data are expected soon.

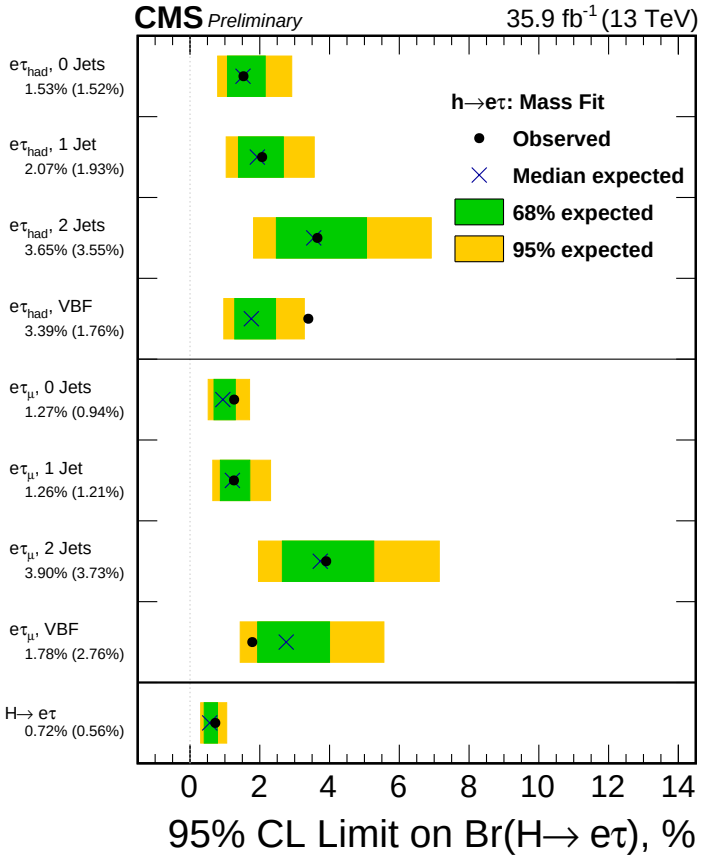
- No hint for anomalous couplings of h(125) to itself or vector bosons.

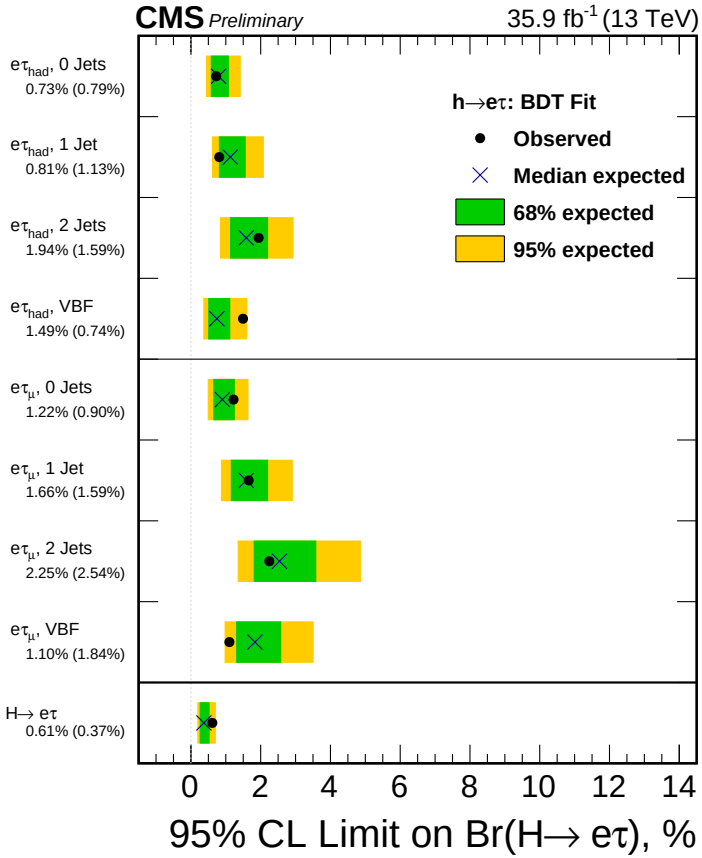
No non-SM properties of h(125) found, so far.

Thank you

Backup

Search for LFV h(125) decays: $h \to e\tau$ results





- Best fit: $0.30 \pm 0.18\%$
- Upper 95% CL limit: $\mathcal{B}(h \to e\tau) < 0.61\%$

Search for anomalous h(125) self-coupling: M_{T2}

Definition of M_{T2}:

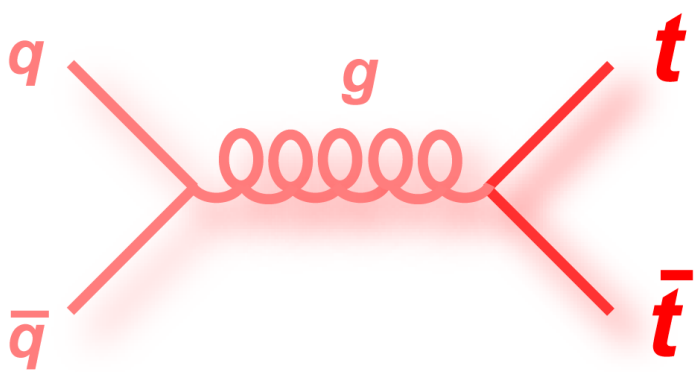
$$M_{T2} = \min_{p_T^{\tau 1} + p_T^{\tau 2} = p_T^{\Sigma}} \{\max(m_T^1, m_T^2)\}$$

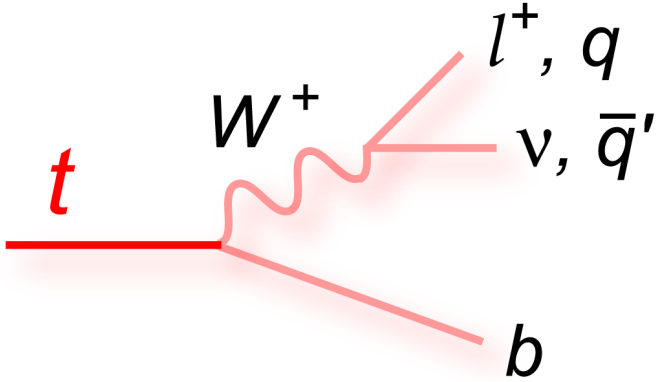
with:

$$m_T = \sqrt{m_b^2 + m_{\text{vis}\,\tau}^2 + 2(E_b E_\tau - p_T^b p_T^\tau)}$$

$$p_T^{\Sigma} = p_T^{\text{vis}\,\tau 1} + p_T^{\text{vis}\,\tau 2} + p_T^{\text{miss}}$$

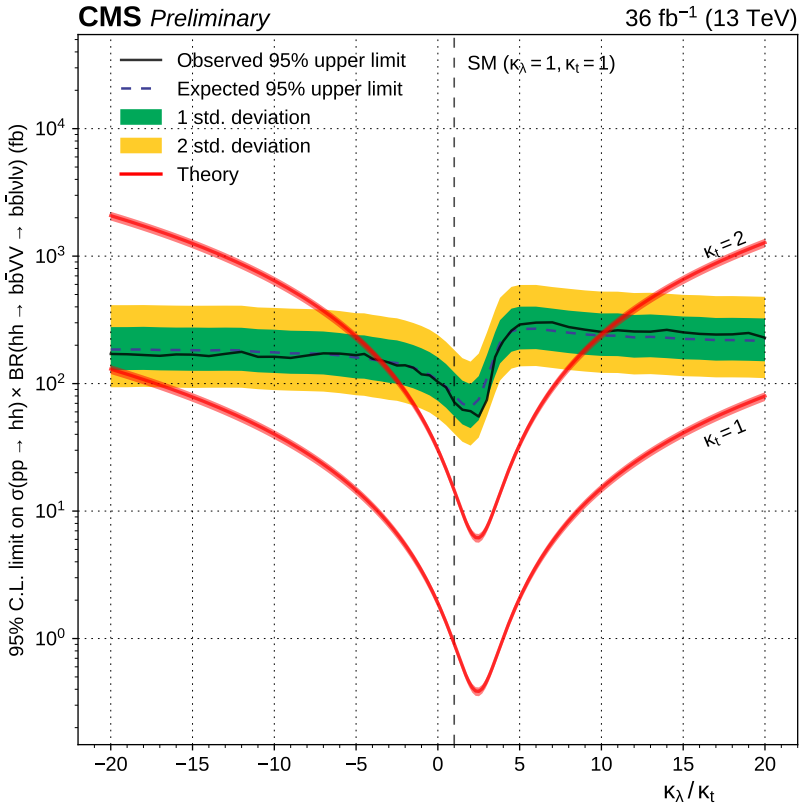
$\rightarrow$ Minimization over various $p_T^{\tau 1}$ and $p_T^{\tau 2}$ hypotheses.





Search for anomalous h(125) self-coupling: $hh \to b\bar{b}\ell\nu\ell\nu$

CMS-PAS-HIG-17-006



- Observed upper limit on $\sigma \cdot \mathcal{B}(hh \to b\bar{b}\ell\nu\ell\nu)$ is 79 times larger than in the SM.

Search for anomalous h(125) couplings to VV: Results

Parameter	Observed	Expected
$f_{a3}\cos(\phi_{a3})$	$0.30^{+0.19}_{-0.21}$ $[-0.45, 0.66]$	$0.000^{+0.017}_{-0.017}$ $[-0.32, 0.32]$
$f_{a2}\cos(\phi_{a2})$	$0.04^{+0.19}_{-0.04}$ $[-0.69, -0.64] \cup [-0.04, 0.64]$	$0.000^{+0.015}_{-0.014}$ $[-0.08, 0.29]$
$f_{\Lambda 1}\cos(\phi_{\Lambda 1})$	$0.00^{+0.06}_{-0.33}$ $[-0.92, 0.15]$	$0.000^{+0.014}_{-0.014}$ $[-0.79, 0.15]$
$f_{\Lambda 1}^{Z\gamma}\cos(\phi_{\Lambda 1}^{Z\gamma})$	$0.16^{+0.36}_{-0.25}$ $[-0.43, 0.80]$	$0.000^{+0.020}_{-0.024}$ $[-0.49, 0.80]$

- All observed values in agreement with the Standard Model.