Karlsruher Institut für Technologie

Measuring the top-Higgs coupling

GRK Workshop 2015, Freudenstadt

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INSTITUT FÜR EXPERIMENTELLE KERNPHYSIK (IEKP)

Outline

1. The top-Higgs coupling and indirect constraints

2. Search for $t\bar{t}H$ production at CMS

The top-Higgs coupling

Top-Higgs Yukawa coupling in SM

$$\mathcal{L}_{ttH} = -\frac{m_t}{v}\bar{t}tH$$

- Strong compared to other Yukawa couplings – special?

The top-Higgs coupling

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Top-Higgs Yukawa coupling in SM

$$\mathcal{L}_{ttH} = -\frac{m_t}{v}\bar{t}tH$$

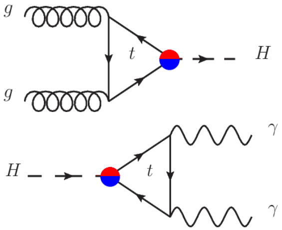
- Strong compared to other Yukawa couplings – special?
- Allow arbitrary strength κ_t, mixture of scalar and pseudo scalar coupling ζ_t

Scalar and pseudo scalar coupling

$$\mathcal{L}_{ttH} = -\frac{m_t}{v}\kappa_t(\cos(\zeta_t)\bar{t}t + \mathrm{i}\sin(\zeta_t)\bar{t}\gamma_5 t)H$$

- Motivation for mixture
  - So far not excluded from Higgs measurements
  - Mixture possible in some models, e.g., 2HDM
  - CP-violation

Dependence of Higgs cross sections and branching ratios on $t\bar{t}$H-coupling



- Top-Higgs coupling contributes to different Higgs production and decay modes
  - Dominant contribution to $gg \rightarrow H$
  - $H \rightarrow \gamma\gamma$: interference with W-loop
  - Also responsible for $t\bar{t}$H-production

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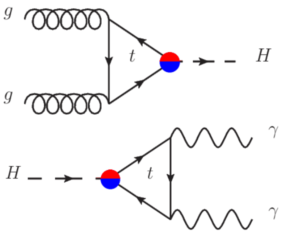

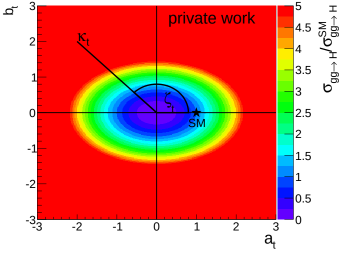

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- $\sigma_{gg\to H}$ [1]: larger for pseudo scalar coupling

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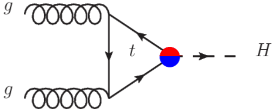

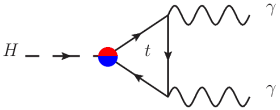

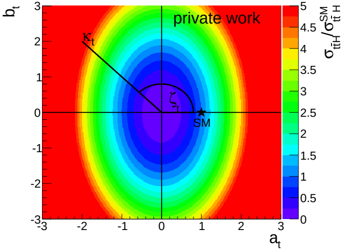

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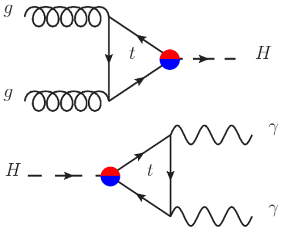

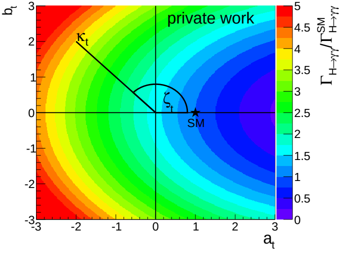

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- $\Gamma_{H\rightarrow\gamma\gamma}$ [1]: interference effects visible

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Indirect constraints of coupling

- From measurements μ^{Exp} and theory expectation $\mu^{\text{theo}}(\kappa_t, \zeta_t)$ for signal strengths constraints on ζ_t and κ_t can be calculated

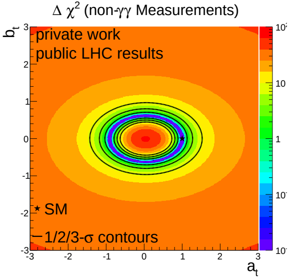
Calculation of $t\bar{t}H$ coupling constraints

- Using results from ATLAS and CMS stored in HiggsSignals[1] data base
- Constructing covariance matrix $C(\kappa_t, \zeta_t)$ with uncertainties of measurements and correlated theory uncertainties
- Comparing measurements and expectation $\Delta\mu_i = \mu_i^{\text{exp}} - \mu_i^{\text{theo}}(\kappa_t, \zeta_t)$
- Minimizing $\chi^2(\kappa_t, \zeta_t) = \Delta\mu^{\top} C^{-1} \Delta\mu$

[1] P. Bechtle, S. Heinemeyer, O. Stal, T. Stefaniak and G. Weiglein, Eur. Phys. J. C **74** (2014) 2, 2711

Indirect constraints

- Results from interpreting different ATLAS and CMS measurements
  - Measurements with $gg \to H$ enough to constrain κ_t



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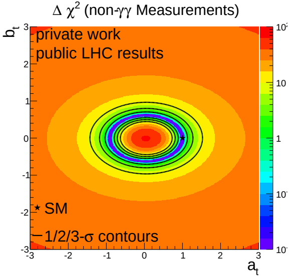
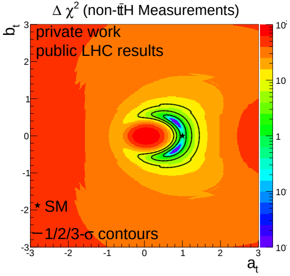
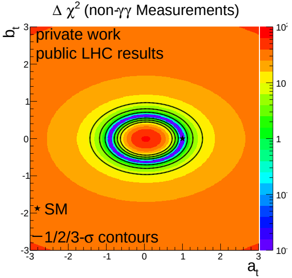
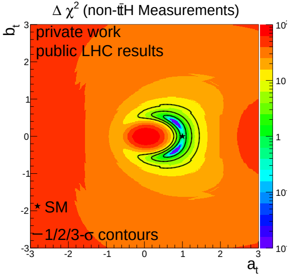


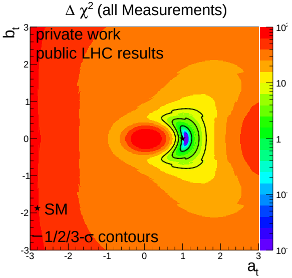


Indirect constraints

- Results from interpreting different ATLAS and CMS measurements
  - Measurements with $gg \rightarrow H$ enough to constrain κ_t
  - $H \rightarrow \gamma\gamma$ important for sign of a_t
  - $t\bar{t}H$ helps to constrain allowed region further



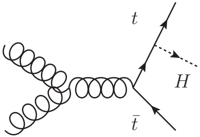




Limitations

- Showed tight constraints on $t\bar{t}H$ coupling
- However, model not too realistic – κ_t and ζ_t only free parameters
- New particles could contribute in loops
- Need way to measure coupling directly

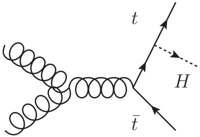
$t\bar{t}$H production

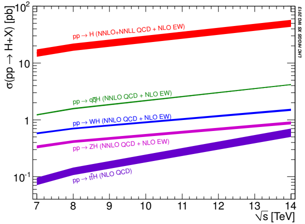


$t\bar{t}$H-Production

- Allows for more model-independent measurement of top-Higgs coupling
- Three heavy particles in final state

$t\bar{t}$H production





- Small cross section (130 fb @ 8 TeV, 510 fb @ 13 TeV)

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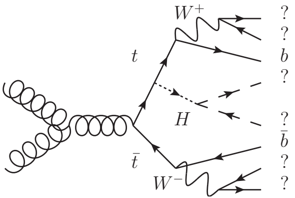
$t\bar{t}H$ production



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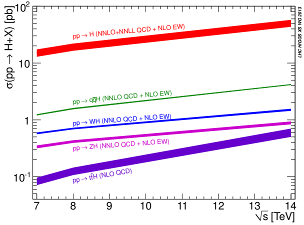
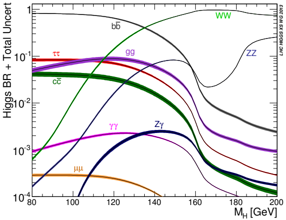
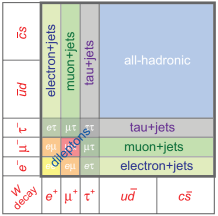
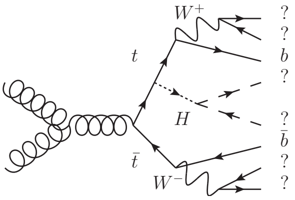






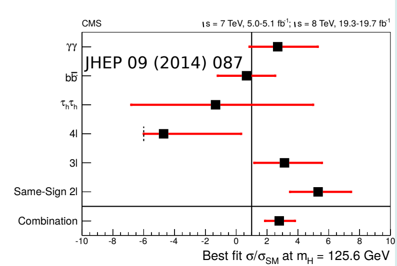
- Small cross section (130 fb @ 8 TeV, 510 fb @ 13 TeV)
- Many possible decays of 125 GeV Higgs boson
- W's can decay hadronically or leptonically

CMS results on $t\bar{t}H$



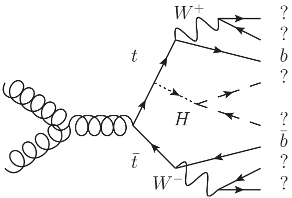
- Many of the possible final states are analyzed at CMS
- Most important ones
  - $H \rightarrow b\bar{b}$
  - $H \rightarrow \gamma\gamma$
  - Events with same sign leptons

CMS run I results



- $\mu_{t\bar{t}H(125)} = \sigma_{ttH} / \sigma_{ttH}^{SM} = 2.8^{+1.0}_{-0.9}$
- Excess of $\mu^{\pm}\mu^{\pm} + X$ events

KIT analysis



- Our KIT group is mostly working in the lepton + jets channel

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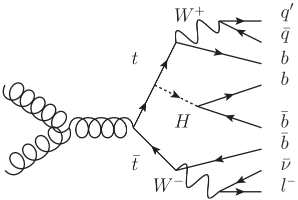

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Lepton + Jets Channel

- Higgs to b$\bar{\text{b}}$: high branching ratio
- Lepton needed for trigger and suppression of QCD-multijet events
- Four b-jets and two light jets expected

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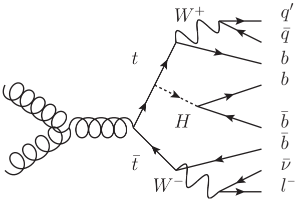

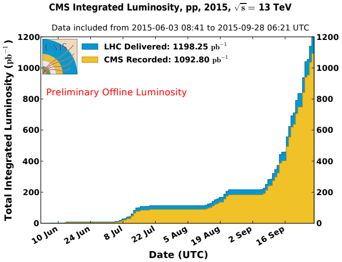

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Lepton + Jets Channel

- Higgs to $b\bar{b}$: high branching ratio
- Lepton needed for trigger and suppression of QCD-multijet events
- Four b-jets and two light jets expected

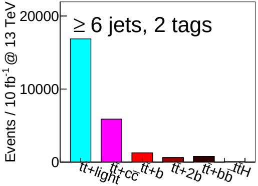
- Currently preparing analysis of 13 TeV data
- Expecting 3 fb^{-1} this year – unfortunately not enough to see more than in run I

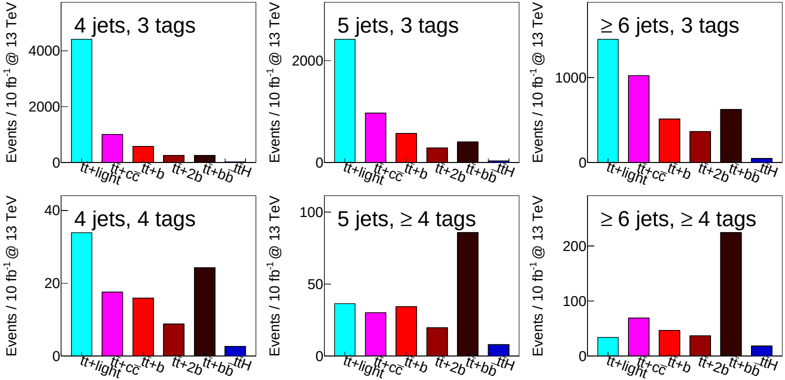
Analysis strategy

1. Selection
   - 1 isolated lepton
   - At least 4 jets and 2 b-tags
   - Mostly $t\bar{t}$+jets background left
2. Categorization
   - Split according to jet- and b-tag multiplicities
   - Different background composition in categories
   - Different topologies – different discriminating variables
3. Multivariate analysis
   - Train a BDT in all categories
   - Separates signal from background
4. Fit
   - Build signal and background model
   - Fit BDT-output with both: what fits better?

Categories

- $t\bar{t}$-background composition in categories
  - More jets/tags ⇒ larger signal and $t\bar{t}$ plus heavy flavor fraction
  - Different categories help constraining different backgrounds





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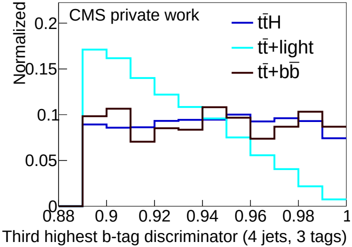

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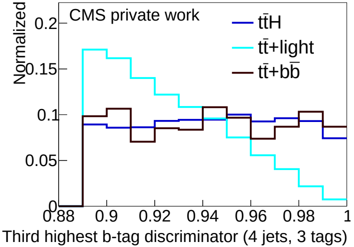
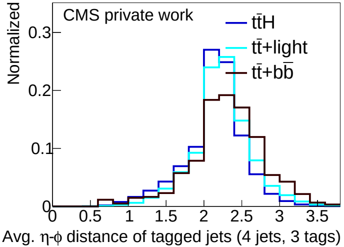
  - Event shape / kinematic





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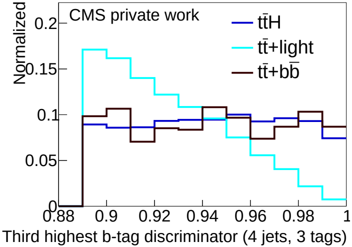
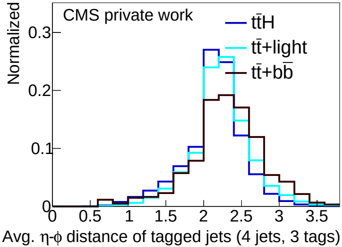
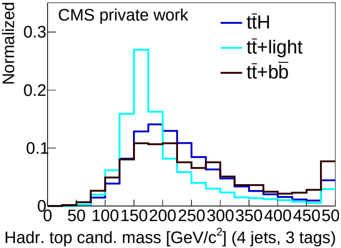
  - Invariant masses







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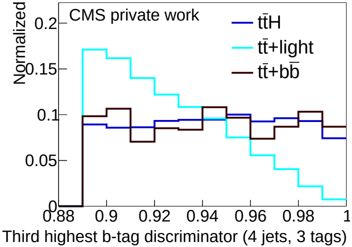
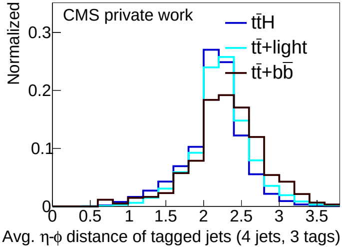
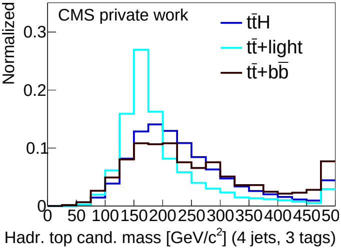
  - b-tagging variables
  - Event shape / kinematic
  - Invariant masses
  - More complicated variables

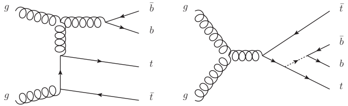


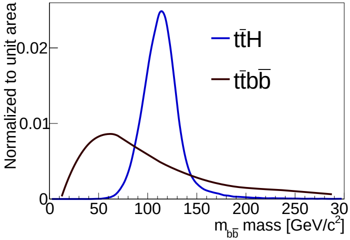




$t\bar{t}H/t\bar{t}b\bar{b}$ likelihood ratio

- $t\bar{t}b\bar{b}$ background differs in
  - Invariant mass of $b\bar{b}$-pair
  - Kinematics of tops and b's





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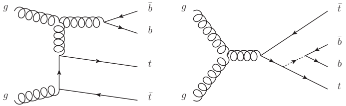
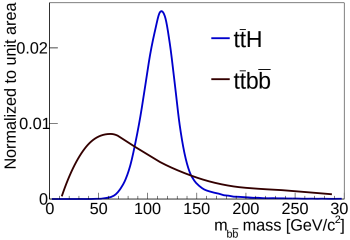
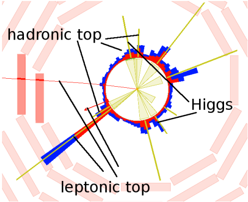




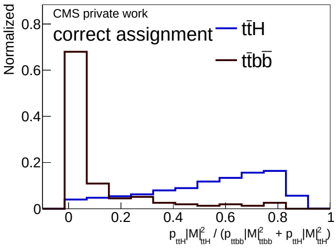


- Interpret jets as quarks, MET as neutrino
- Calculate $t\bar{t}H$ and $t\bar{t}b\bar{b}$ likelihoods, containing
  - p_{ttH} / p_{ttbb}, the probabilities of the invariant $b\bar{b}$ mass to come from $t\bar{t}b\bar{b}$ / $t\bar{t}H$
  - $|M_{ttH}|^2$ / $|M_{ttbb}|^2$, describing whether the $t\bar{t}b\bar{b}$-kinematics are signal- or background-like

Final discriminant is a likelihood ratio: $p_{ttH}|M_{tth}|^2/(p_{ttbb}|M_{ttbb}|^2 + p_{ttH}|M_{tth}|^2)$

$t\bar{t}H/t\bar{t}b\bar{b}$ likelihood ratio

- $p_{ttH}|M_{tth}|^2/(p_{ttbb}|M_{ttbb}|^2 + p_{ttH}|M_{tth}|^2)$ nice discriminator – for the correct jet assignment
- But: correct assignment unknown



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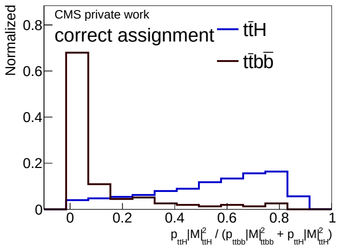
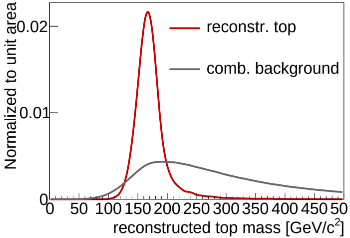
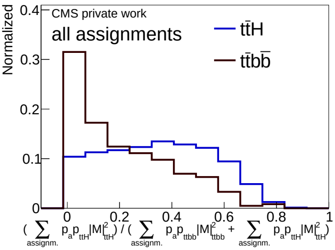
- $p_{ttH}|M_{tth}|^2/(p_{ttbb}|M_{ttbb}|^2 + p_{ttH}|M_{tth}|^2)$ nice discriminator – for the correct jet assignment
- But: correct assignment unknown
- Sum up all possible assignments
- Assignments are weighted by probability that they are correct p_a – correct assignments have W/top resonances







MVA analysis

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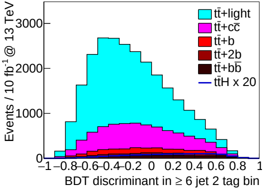
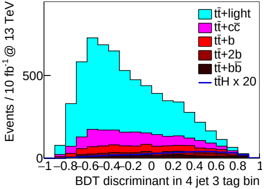
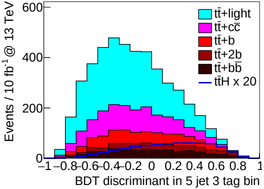
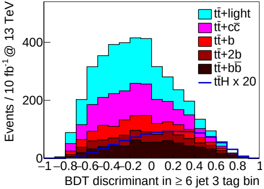
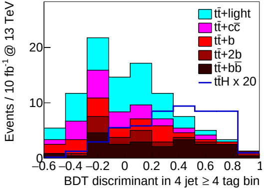
- Creating BDT discriminant in all categories
- Optimizing selection of BDT parameters and variables used in every category
- Signal (blue line) at higher BDT values, backgrounds at lower values

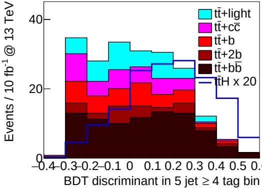


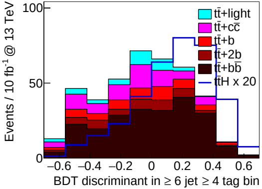




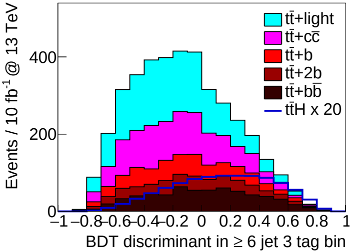








Signal extraction



- Wait for data
- Fit data with a background and a background + signal model
- Decide which is more likely
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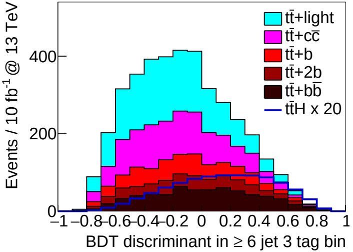

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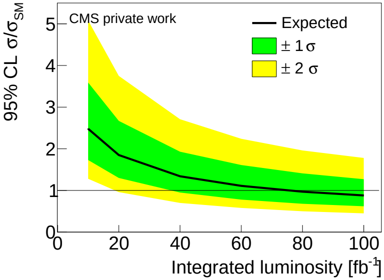
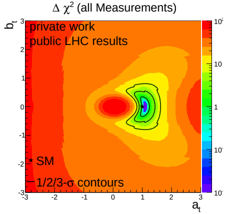
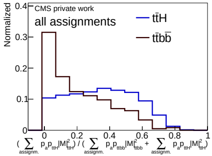
- Calculated expected limit at 13 TeV with very preliminary systematics
- Combination with other channels will increase sensitivity

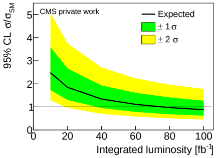


Conclusion and outlook

- $t\bar{t}H$-coupling interesting
- Keep an open mind for a coupling that differs in more than just strength κ_t from SM
- $t\bar{t}H$-coupling can be constrained indirectly
- Direct measurement in $t\bar{t}H$ important
- Complex search for $t\bar{t}H$ in preparation
- Interesting results to be expected at the end of run II







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- With enough data, not only strength but also structure of the Top-Higgs coupling could be measured in $t\bar{t}H$