Search for Higgs boson production in association with single top quark in $h \to b\bar{b}$ decay channel

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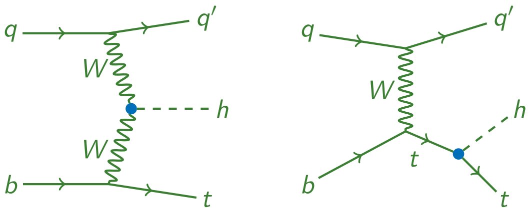
Scalar Search and Study in Belgium
24 Jan 2014

Associated *th* production

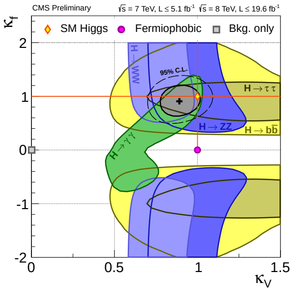
- There are two dominant diagrams for *thq* production in SM:

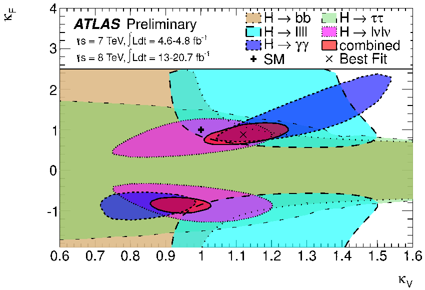


  - Destructive interference in SM ⇒ cross section 18.3 fb
  - With an inversed sign of Yukawa coupling $\kappa_t = -1$ the interference is constructive, $\sigma = 234$ fb ($\times 13$ enhancement)
- Phenomenological studies:
  - M. Farina, C. Grojean, F. Maltoni, E. Salvioni, A. Thamm, JHEP 1305 (2013) 022, arXiv:1211.3736
  - S. Biswas, E. Gabrielli, B. Mele, JHEP 1301 (2013) 088, arXiv:1211.0499

Constraints on Higgs coupings from LHC

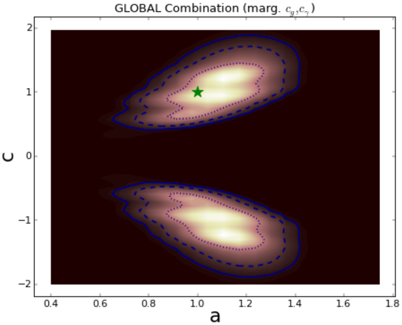
- Interest to *thq* process was originally motivated by presence of two allowed regions in the plane of higgs couplings to bosons and fermions
  - $h \to \gamma\gamma$ is the only channel sensitive to the sign of κ_f
  - However, in the Moriond'13 update (below) CMS nearly ruled out possibility of $\kappa_f = -1$; ATLAS still allowed it





Higgs couplings with BSM contribution allowed

- But if BSM contributions to $h\gamma\gamma$ or hgg (loop-induced) couplings are allowed, $\kappa_f = -1$ is still tolerated
  - J. Ellis, T. You, JHEP 06 (2013) 103, arXiv:1303.3879
  - Analysis is based on combination of CMS, ATLAS, and Tevatron measurements
  - The Fig. shows constraints while marginalising over possible BSM contributions to $h\gamma\gamma$ or hgg (meaning of factors a, c is similar to κ_V, κ_f resp.)

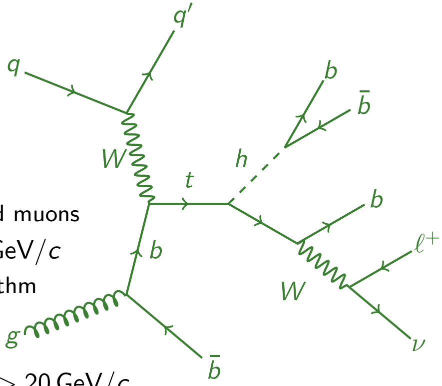


Analysis strategy

- The ultimate goal is to derive constraints on higgs couplings in the (κ_t, κ_W) plane
- For the first result we concentrate on the $\kappa_t = -1$ case
- Focus on decay $h \to b\bar{b}$ for its large branching
  - There is a complementary analysis of th, $h \to \gamma\gamma$, but it will not be addressed in the talk
- Exploit full 8 TeV data
  - In future will profit from Run II: larger cross section, a bit better S/B ratio, larger int. luminosity

Baseline event selection

- Decay channel:
  - $t \to b\ell\nu$, $\ell = e, \mu$ ($\mathcal{B} \approx 0.22$)
  - $h \to b\bar{b}$ ($\mathcal{B} \approx 0.58$)
- Single-lepton triggers
- A tight muon (electron) with $p_T > 26\ (30)\,\mathrm{GeV}/c$
  - Veto additional loose electrons and muons
- $3 \div 4$ b-tagged jets with $p_T > 20\,\mathrm{GeV}/c$
  - Tight working point of CSV algorithm
  - $3t$ and $4t$ regions considered independently
- At least one untagged jet with $p_T > 20\,\mathrm{GeV}/c$
- Additionally, $p_T(j_4) > 30\,\mathrm{GeV}/c$
  - To further suppress QCD and $W+\mathrm{jets}$



Expected event yield

Expected number of events at 19 fb^{-1} in $e+\mu$ channel:

Process	**3t region**		**4t region**	
	Expected	**MC stat.**	**Expected**	**MC stat.**
thq, $\kappa_f = -1$	17	15.8 k	1.5	1.5 k
$t\bar{t}h$	21	10.1 k	2.2	1.1 k
$t\bar{t}$	1940	32.7 k	25.1	460
Single top, t-ch.	23	280	0.3	5
Single top, tW-ch.	45	121	—	0
W + jets	15	46	—	0
Total background	2040	—	27.6	—
S/B	0.8%	—	5.4%	—

Modelling of $t\bar{t}$ background

- (Semileptonic) $t\bar{t}$ is by far the dominant background
  - Reliable and precise modelling of it is essential
- A data-driven approach is adopted as an alternative to MC
  - The data template is taken from $t\bar{t}$ control region with two b-tagged jets
  - Each event is assigned a weight to reflect the probability that an event with the same jet momenta and flavours ends up in a signal region
  - The probability that an event containing n jets with momenta p_i and flavours f_i obtains m b-tags is

$$\mathcal{P}_m = \sum_{\text{comb}} \prod_{i=1}^{m} \epsilon(p_i, f_i) \cdot \prod_{j=m+1}^{n} (1 - \epsilon(p_j, f_j)),$$

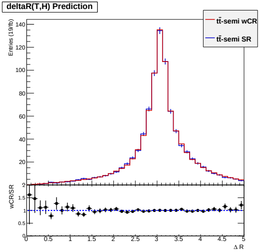
    where ϵ is b-tagging efficiency and the sum is taken over all $\binom{n}{m}$ ways to choose m tagged jets
- The weight is calculated as

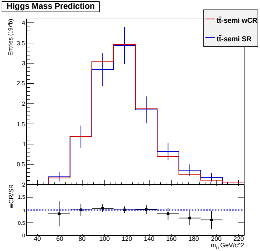
$$w = \mathcal{P}_3/\mathcal{P}_2 \quad \text{or} \quad \mathcal{P}_4/\mathcal{P}_2$$

  in $3t$ or $4t$ region resp.

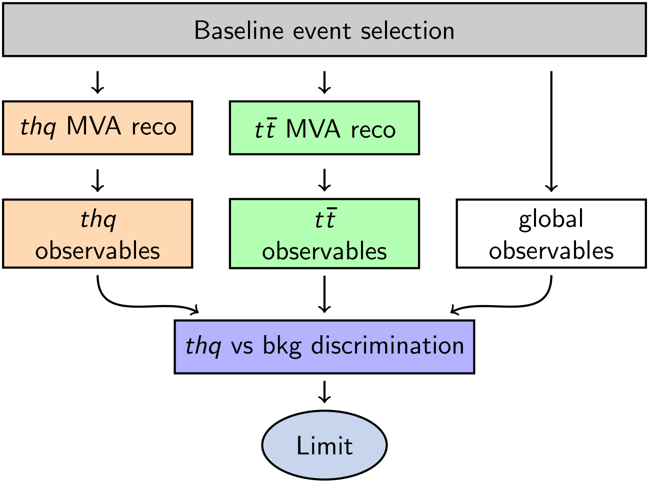
Modelling of $t\bar{t}$ background

- The method is designed to reproduce both shape and normalisation
- Verified with a closure test in simulation
  - Normalisation reproduced within statistical uncertainties in both 3t and 4t regions
  - Good modelling of shape (Fig.)
- A drawback is that the method does not allow to use values of b-tags in subsequent analysis
  - These variables discriminate thq from $t\bar{t}$ relatively well $\Rightarrow$ would like to exploit them
  - The method still allows to use boolean information: whether a jet is b-tagged or not
- We exploit MC simulation in parallel with the data-driven approach
  - Can make use of values of b-tags
  - Cross-check the data-driven method

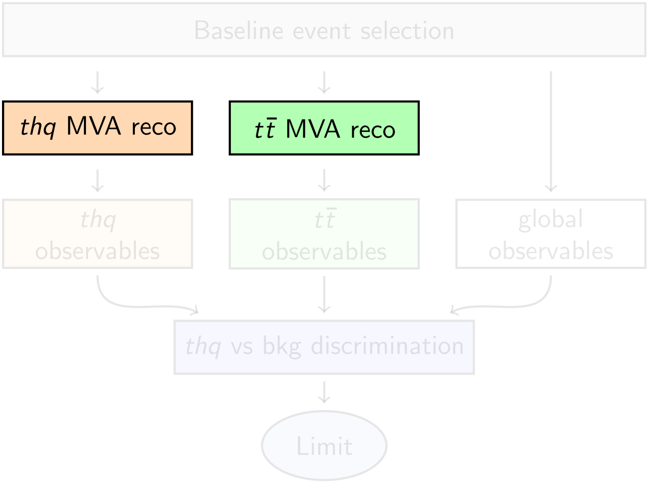




Analysis scheme

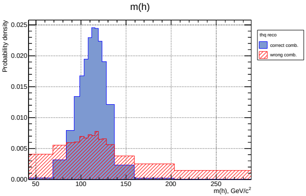


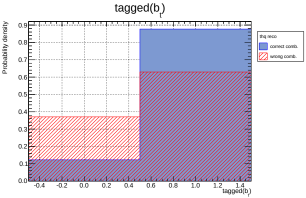
Jet assignment



Jet assignment under signal hypothesis

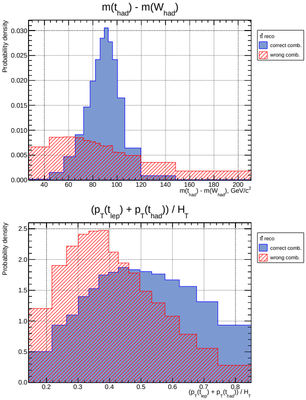
- Consider all the ways to match four reco jets to quarks in $thq \to \ell\nu 3bq$
- Train an MVA to find the correct match
  - MVA is used in classification mode
  - Only events in which the correct match is present, are considered
    - It might happen that a quark does not give birth to reco jet
  - If at least one jet is mismatched, the match is a background
  - In this talk BFGS NNs from TMVA are used
- Jet assignment with trained MVA
  - In each event consider all possible matches
  - Choose the one with largest MVA response



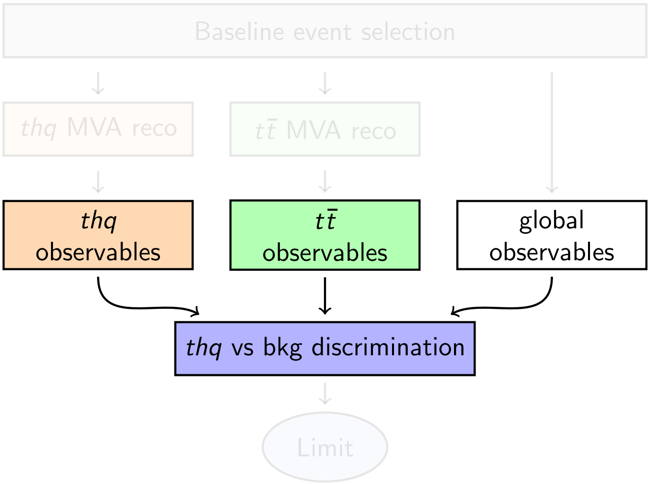


Jet assignment under $t\bar{t}$ hypothesis

- Because of huge amount of $t\bar{t}$, it is important to exploit observables intrinsic to $t\bar{t}$ events
  - Hence the dedicated reconstruction
- The jet assignment is performed in the same way as for signal:
  - Train an MVA to choose the correct match
  - Identify the jets according to the match with largest MVA response
  - Only semileptonic $t\bar{t}$ is considered

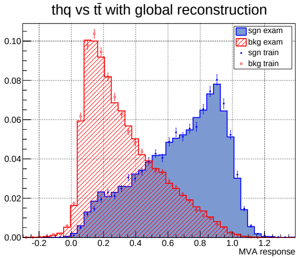


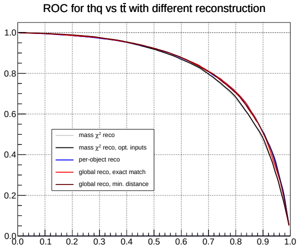
Signal extraction



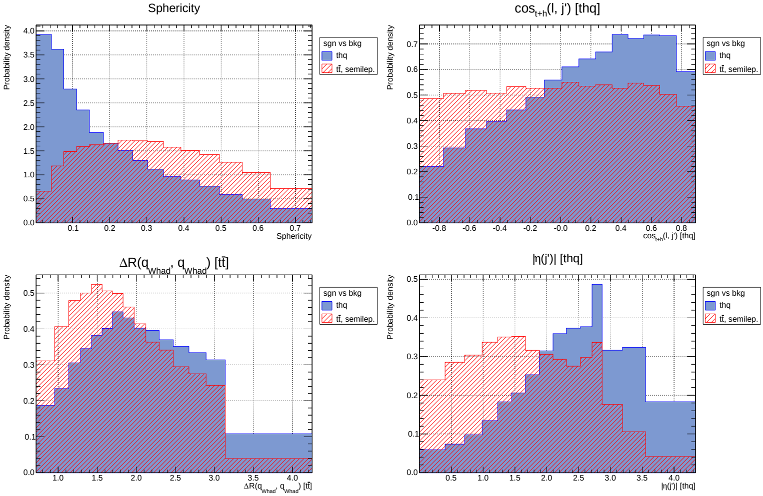
Signal extraction

- Signal is discriminated from backgrounds with a dedicated MVA
- Three sets of input variables are used (examples in next slide)
  - Defined under *thq* hypothesis
  - Defined under $t\bar{t}$ hypothesis
  - Variables that do not rely on jet assignment



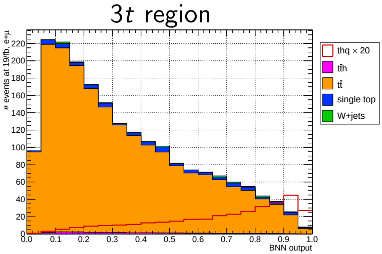


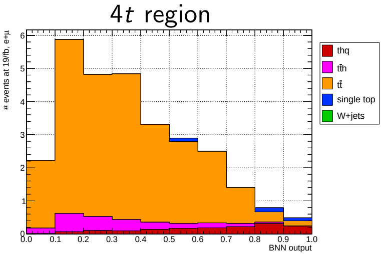
Signal extraction



Signal extraction

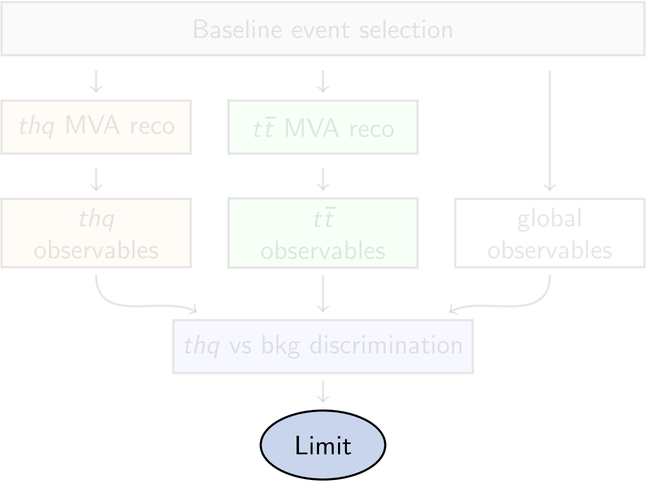
- Expected distributions over MVA output with the whole 8 TeV data in $e + \mu$ channels:





- Normalisation of signal process is deduced from distributions over MVA output

Limit calculation



Limit calculation

- At the moment the signal region is kept blinded
- We evaluate expected CL_s limits $(\kappa_t = -1)$
  - Use the `theta` package for prototyping, will obtain final results with `combine`
  - Nuisance parameters are fitted to data
- Included systematical variations:
  - uncertainties of cross sections,
  - b-tagging (tag and mistag rate),
  - JEC and JER,
  - unclustered $\not{E}_{\mathrm{T}}$,
  - pile-up

Region	$\sigma_{95\%}/\sigma_{\mathrm{exp}}$
$3t$	$3.9^{+1.9}_{-1.1}$
$4t$	$5.5^{+2.3}_{-1.5}$
$3t+4t$	$3.0^{+1.5}_{-0.7}$

- Variations currently missing:
  - factorisation/renormalisation scale (expected to be significant),
  - ME/PS matching scale for $t\bar{t}$,
  - dedicated uncertainties of the data-driven method,
  - scale factors for triggers and lepton IDs, luminosity, ...

Summary and status

- Associated *th* production provides a handle to access additional information on higgs couplings
- Analysis scheme is proven to work, all key components validated
  - Baseline event selection
  - Data-driven modelling of the dominant $t\bar{t}$ background
  - MVA approach to jet assignment
  - Signal extraction with an MVA
- Analysis is being reloaded after the Grid step has been redone
  - Re-reco of data, new datasets (full sim. of *thq*, systematics for $t\bar{t}$), additional information (jet charge, pull angle), bug fixes
- Pending issues:
  - Careful check of data modelling in control region(s)
  - Incorporation of missing systematics
  - Documentation
- We aim at Moriond'14

BACKUP

Cross sections

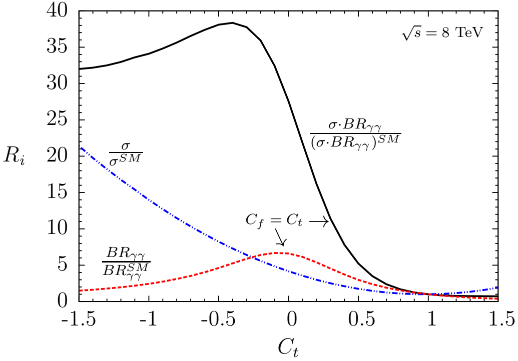
- Cross section is challengely small
  - The main background is $t\bar{t}$; its cross section is provided for comparison

Cross-section	8 TeV	14 TeV
thq, $\kappa_t = +1$ (SM)	18.3 ± 0.4 fb	$88.2^{+1.7}_{-0.0}$ fb
thq, $\kappa_t = -1$	$233.8^{+4.6}_{-0.0}$ fb	980^{+30}_{-0} fb
$t\bar{t}$	245^{+9}_{-10} pb	950^{+40}_{-30} pb

thq cross sections are cited according to M. Farina et al., JHEP 1305 (2013) 022 [arXiv:1211.3736]. Cross-sections for $t\bar{t}$ are calculated in M. Czakon, P. Fiedler, Phys. Rev. Lett. 110 (2013) 252004 [arXiv:1303.6254]. Uncertainties are combined following R. Barlow, arXiv:physics/0306138

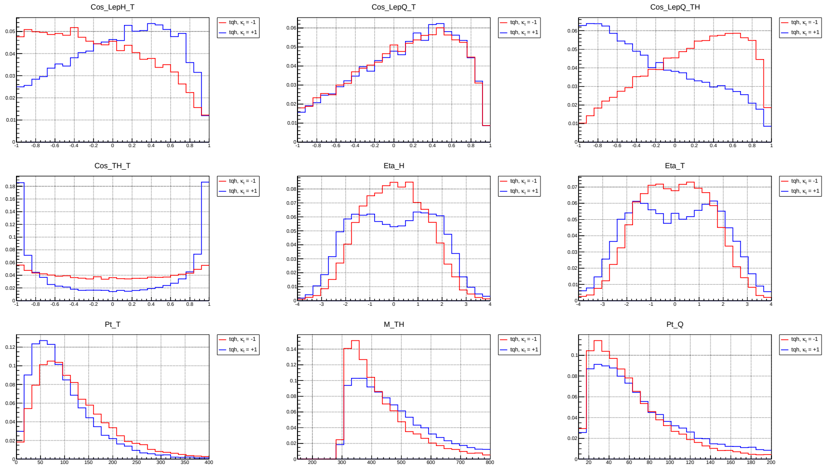
Sensitivity of $\mathcal{B}(h \to \gamma\gamma)$ to κ_t

- Dependence of $\mathcal{B}(h \to \gamma\gamma)$ on κ_t is moderate
  - Note that the fermiophobic case $\kappa_t \sim 0$, in which the branching ratio is maximal, is well excluded by LHC data

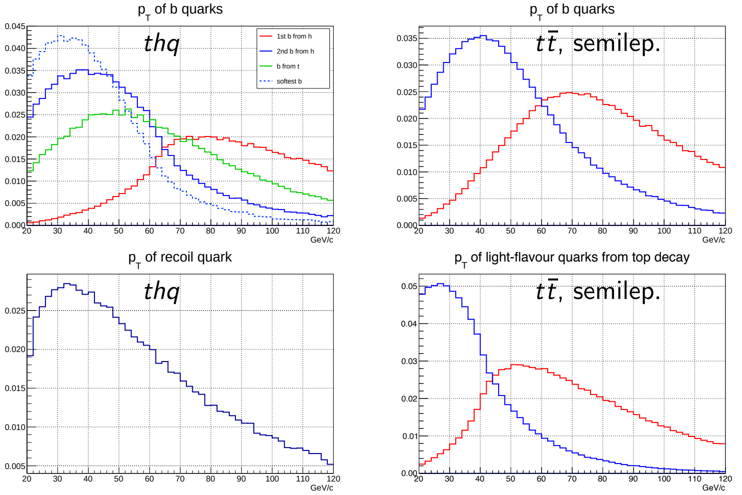


S. Biswas et al., JHEP 1301 (2013) 088, arXiv:1211.0499

Generator-level comparison of $\kappa_t = \pm 1$ cases

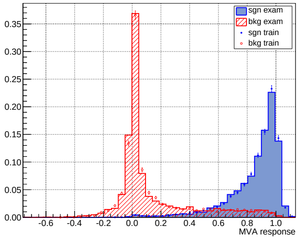


Transverse momenta of jets matched to partons

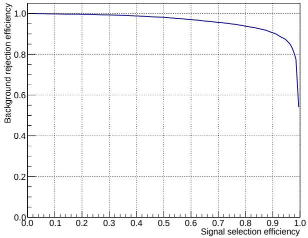


Individual MVAs in global reconstruction

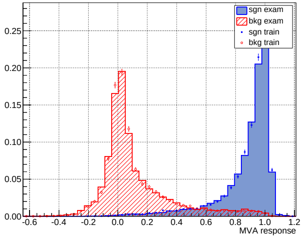
Global reconstruction of thq events



Global reconstruction of thq events



Global reconstruction of semilep. $t\bar{t}$ events



Global reconstruction of semilep. $t\bar{t}$ events