Karlsruhe Institute of Technology

Search for H to bb in association with single top quarks as a test of Higgs boson couplings

Higgs Hunting 2015, Orsay

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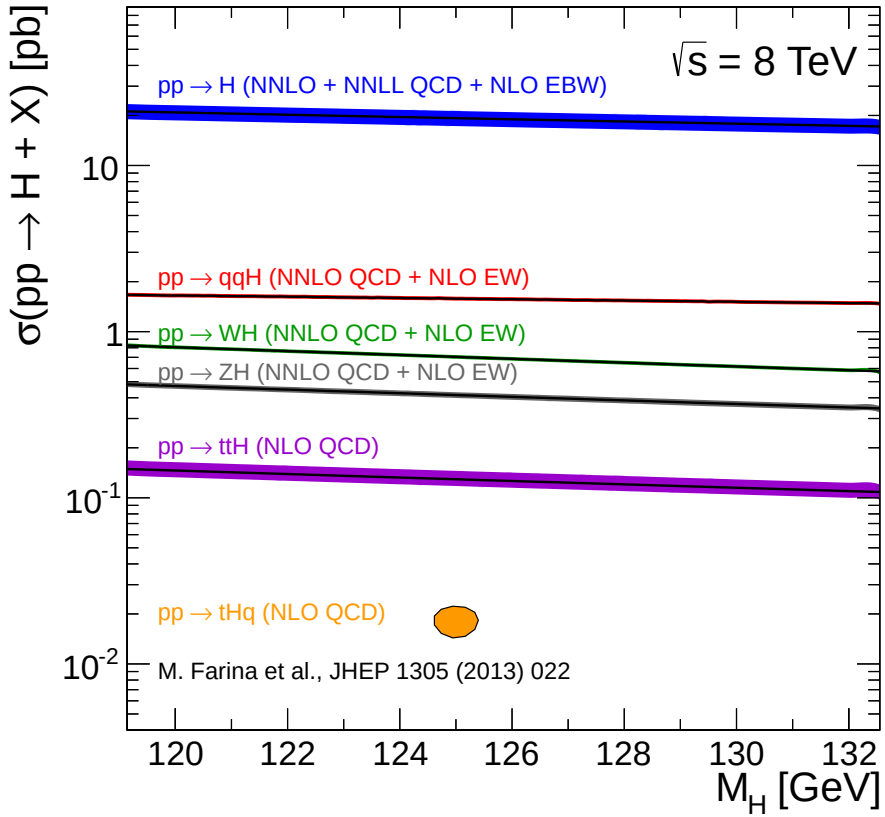
INSTITUT FÜR EXPERIMENTELLE KERNPHYSIK

Introduction

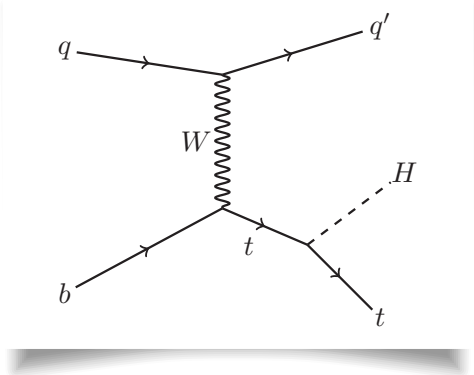
- search for associated production of Single Top Quarks with Higgs Bosons decaying to Bottom Quarks
- public result: **HIG-14-015**
- **very small production cross section**

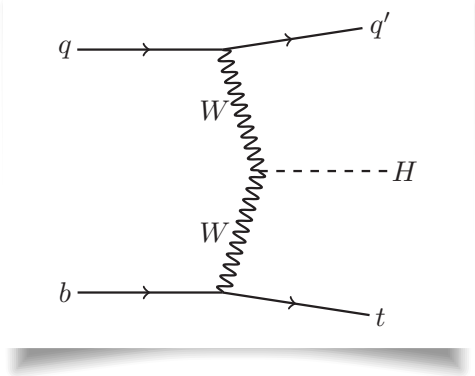


Why even bother searching?

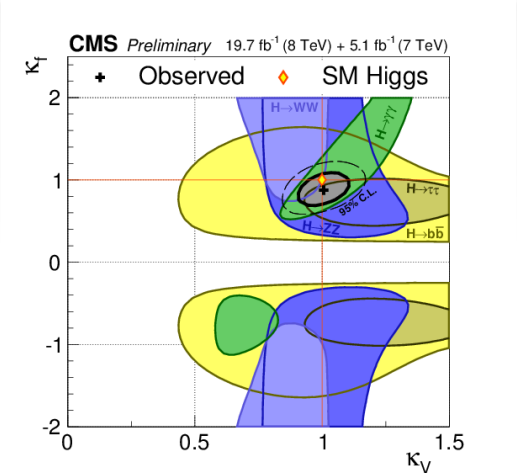
Introduction

- two feynman diagram for the tHq production

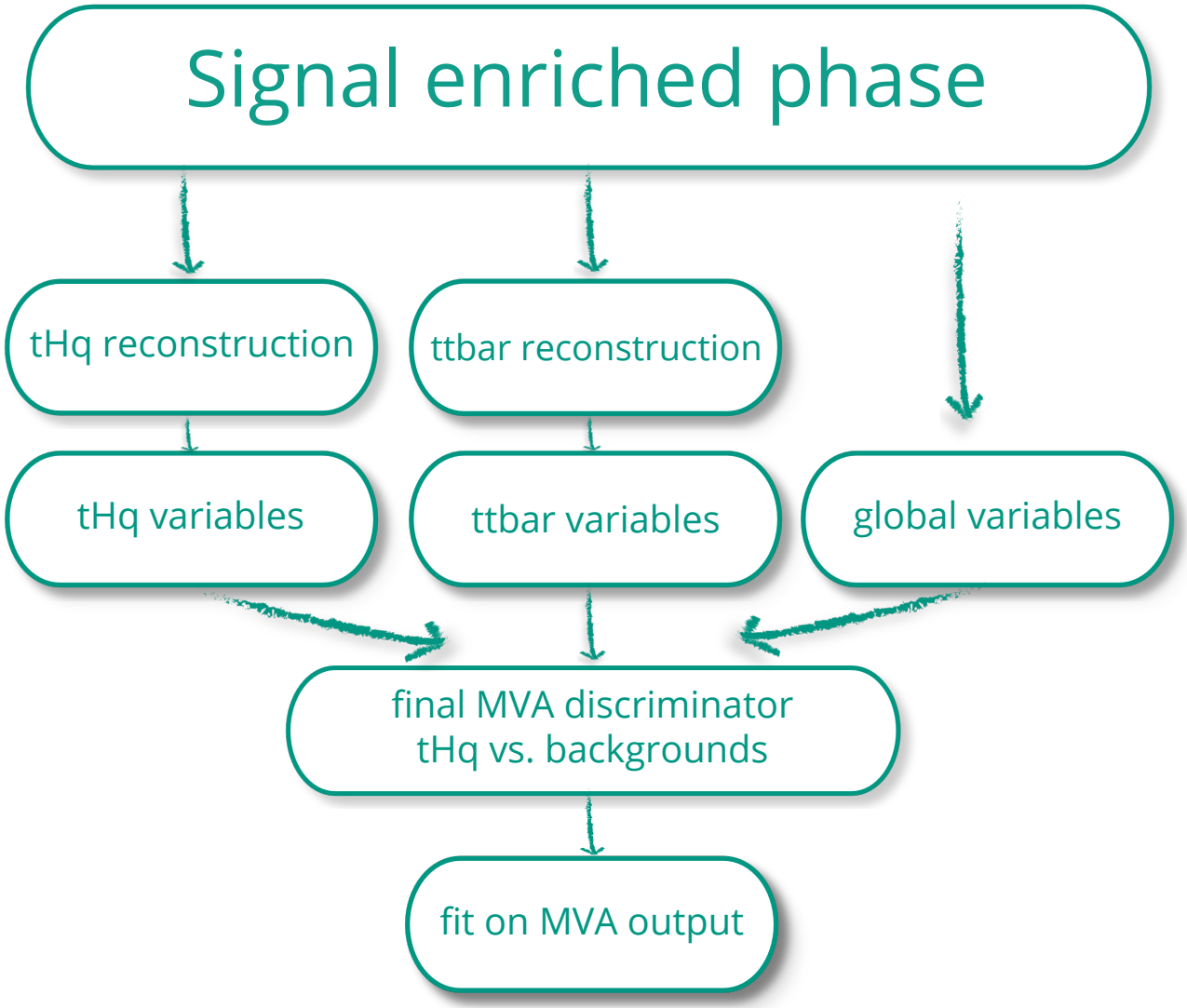




- destructive interference in SM
- $\mathcal{A} \propto (\kappa_V - \kappa_t)$
- with anomalous coupling ($\kappa_t = -1$) cross section increases to 234 fb

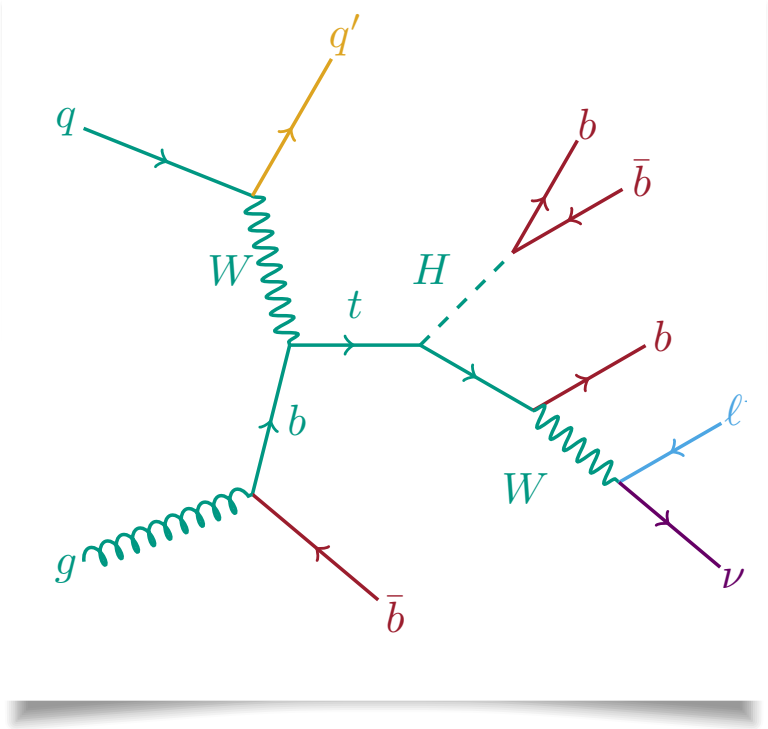


interference can increase production cross section by ~ 13


Signal enriched phase
tHq reconstruction
ttbar reconstruction
tHq variables
ttbar variables
global variables
final MVA discriminator
tHq vs. backgrounds
fit on MVA output

Event Selection

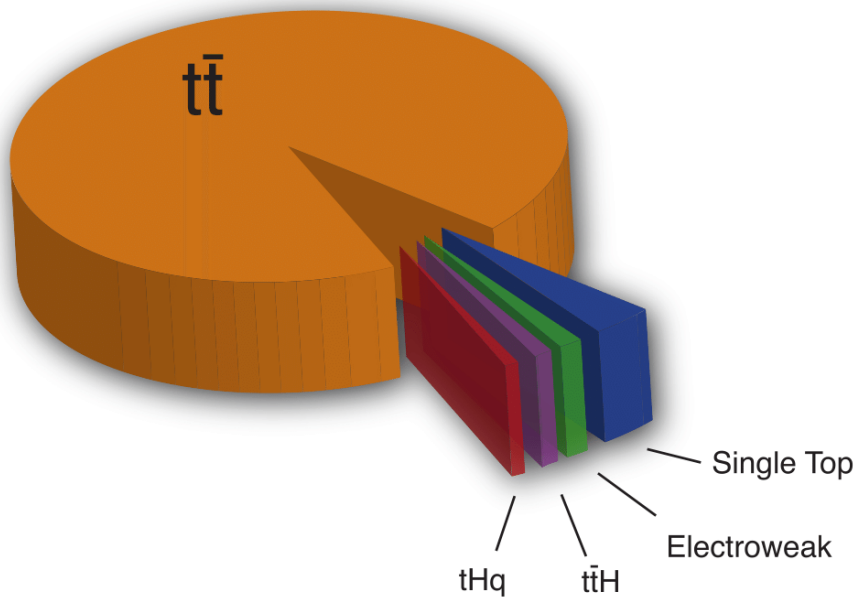
- event topology:
  - 4 b quarks
  - 1 isolated lepton
  - 1 light forward jet



- 3 tag signal region
  - 3 b-tags CSVT
  - # jets ≥ 4
  - exactly one muon/electron
- 4 tag signal region
  - 4 b-tags CSVT
  - # jets ≥ 5
  - exactly one muon/electron
- $t\bar{t}$ control region
  - 2 b-tags CSVT
  - # jets $= 4$

Event Selection

- event topology:
  - 4 *b* quarks
  - 1 isolated lepton
  - 1 light forward jet



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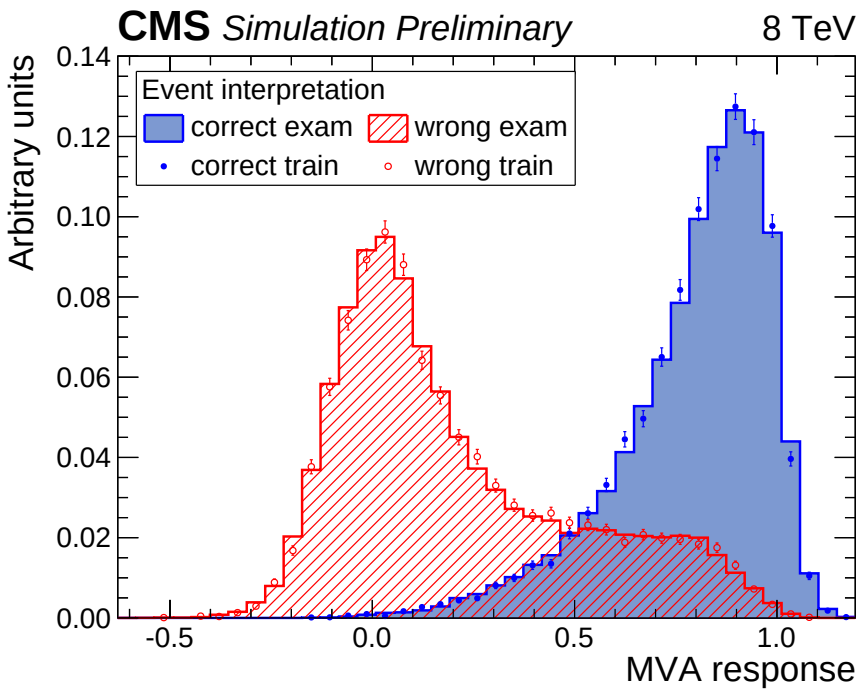
	S/B	
3 tag region	$\sim$ **0.7%**	(13/1900 events)
4 tag region	$\sim$ **2.1%**	(1.4/66 events)

Reconstruction using MVAs

- jet assignment ambiguous ⇒ MVA criteria to reconstruct events!

training on signal MC

- **correct interpretation:** all four quarks matched to a jet
- **wrong interpretations:** all other possible jet assignments
- train MVA to discriminate between correct and wrong interpretations
  - kinematic variables
  - b-tagging information
  - angular correlations



application to unknown events

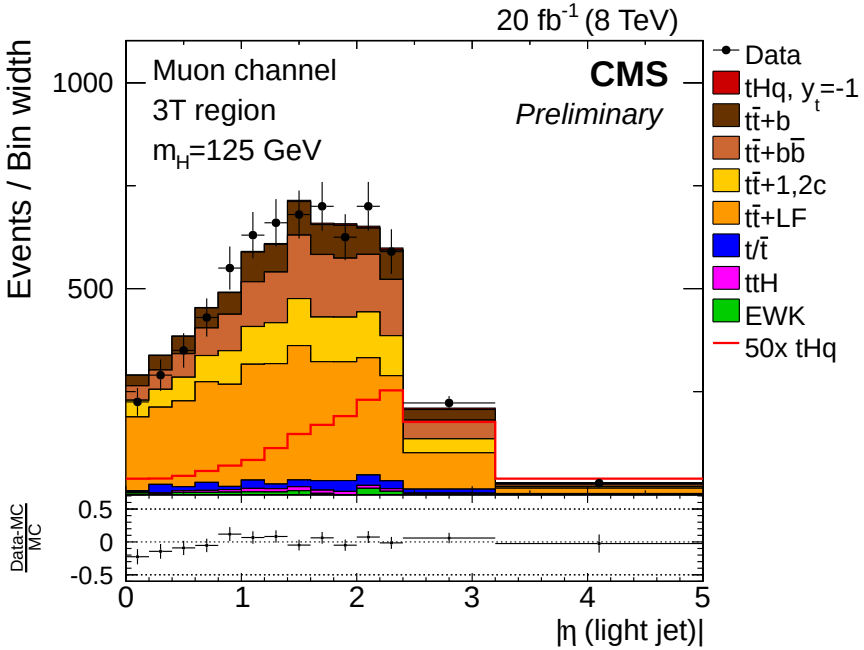
- reconstruct all interpretations
- take the one with largest MVA response

Event Interpretation

provide each event with **two interpretations**

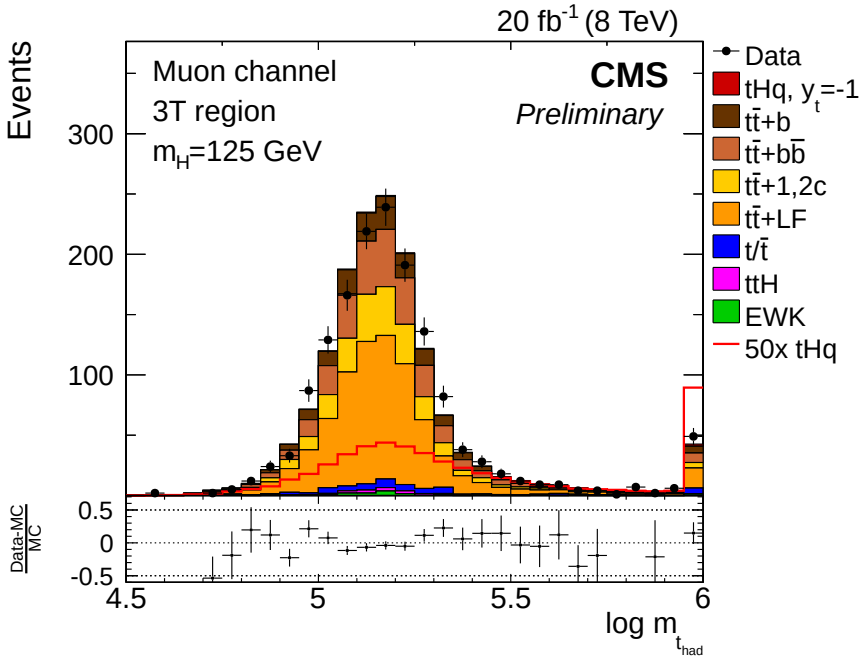
under tHq hypothesis

- e.g. $|\eta(\text{light jet})|$



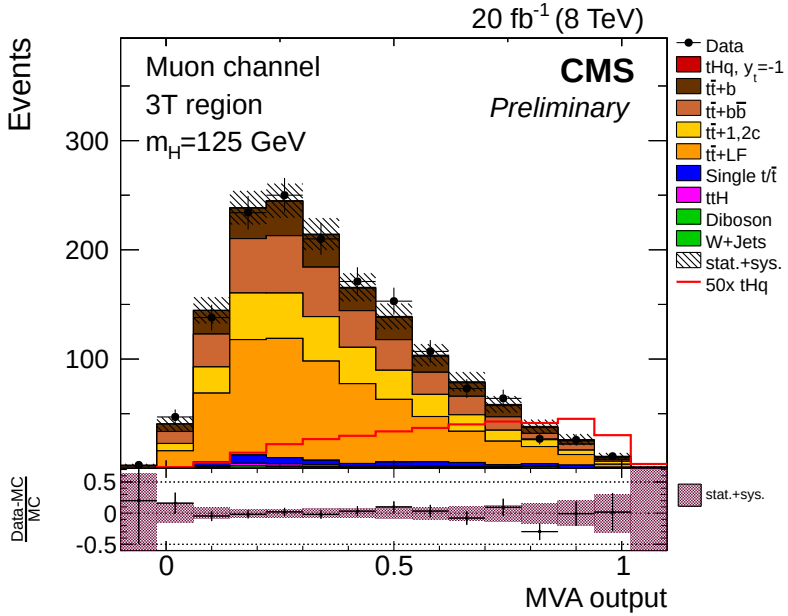
under $t\bar{t}$ hypothesis

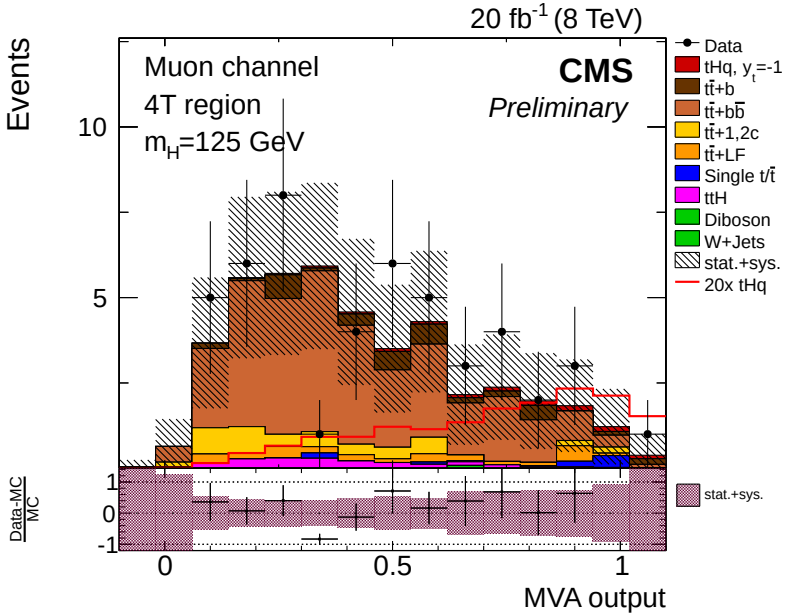
- e.g. $m(t_{had})$



Classification MVA

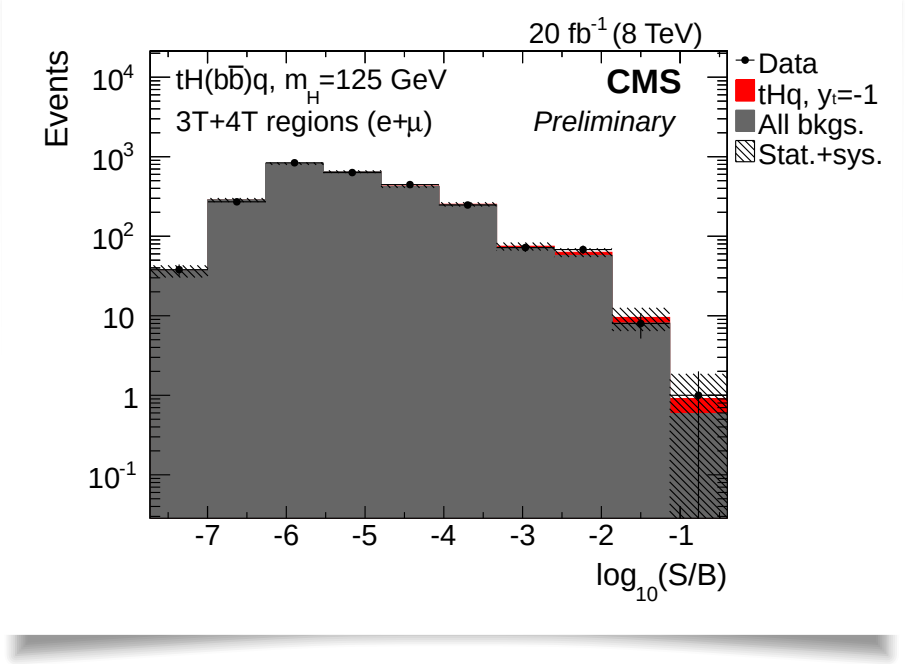
- use eight different variables in MVA obtained under different hypotheses
  4 tHq variables 3 $t\bar{t}$ variables 1 global variable
- simultaneous **fit in all four signal channels**
- consider all relevant systematics
  - $t\bar{t}$ + heavy flavor templates are determined in situ assuming large uncertainties
  - largest impact from Q^2 scale and jet energy scale





Limits

- set limits on tHq with $H \to b\bar{b}$ and $\kappa_t = -1$
- **exclude** production cross section **larger than 1.77 pb at 95% C.L.**
- observation agrees well with **b-only** and **s+b** hypotheses



	Expected	Observed
Limit	$\mathbf{5.14^{+2.14}_{-1.44}}$	**7.57**

Conclusions

- presented search for tHq with $H \to b\bar{b}$ and $\kappa_t = -1$
- excluded production cross section larger than 1.77 pb at 95% C.L.
- results public under **HIG-14-015**

Outlook

- combination paper with other tHq channels in the pipeline
- looking forward to 13 TeV analysis


BACKUP

Cross sections

- cross section is challengingly small
  - the main background is $t\bar{t}$; its cross section is provided for comparison

Cross-section	8 TeV	14 TeV
tHq, $y_t = +1$ (SM)	18.3 ± 0.4 fb	$88.2^{+1.7}_{-0.0}$ fb
tHq, $y_t = -1$	$233.8^{+4.6}_{-0.0}$ 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

Impact of uncertainty sources

Source	Type	impact as exclusive source on final limit [%]	improvement of final limit after removal [%]
JES	shape	17	3
JER	shape	< 1	< 1
BTag light flavor	shape	13	< 1
BTag heavy flavor	shape	17	< 1
Pile up	normalization	< 1	< 1
Unclustered energy	shape	3	1
Lepton efficiency	normalization	5	< 1
Luminosity	normalization	10	< 1
Cross section (PDF)	normalization	8	< 1
Cross section (Scale)	normalization	9	< 1
MC Bin-by-Bin unc.	shape	< 1	< 1
Q^2 scale ($tHq + t\bar{t}$)	shape	20	4
Matching	shape	2	2
Top p_T reweighting	shape	19	2
$t\bar{t}$ HF rates (b)	normalization	13	< 1
$t\bar{t}$ HF rates ($b\bar{b}$)	normalization	15	< 1
$t\bar{t}$ HF rates (c / $c\bar{c}$)	normalization	13	1

tHq input variables

Electric charge of b-quark jet from decay of top quark, multiplied by lepton's charge. The jet charge is defined as in Eq. (1) in Ref. [37], with $\kappa = 1$
ΔR between the two jets from decay of Higgs boson
ΔR between b-quark jet and W boson from decay $\mathrm{t} \to \mathrm{bW}$
ΔR between reconstructed top quark and Higgs boson
Pseudorapidity of recoil jet
Invariant mass of b-quark jet from decay of top quark and charged lepton
Mass of reconstructed Higgs boson
Pseudorapidity of the most forward jet from decay of H
Tranverse momentum of the softest jet from decay of H
Number of b-tagged jets among the two jets from decay of H
Boolean variable that equals 1 if the b-quark jet from decay of t is b-tagged, 0 otherwise
Relative H_T, $(p_\mathrm{T}(\mathrm{t}) + p_\mathrm{T}(\mathrm{H}))/H_\mathrm{T}$

$t\bar{t}$ input variables

Difference of electric charges of b-quark jets from decays of t_{had} and t_{lep}, multiplied by lepton's charge
ΔR between the two light-flavor jets from decay of t_{had}
ΔR between b-quark jet and W boson from decay $t_{had} \to bW$
ΔR between b-quark jet and W boson from decay $t_{lep} \to bW$
Difference between masses of t_{had} and W from decay of t_{had}
Pseudorapidity of t_{had}
Invariant mass of b-quark jet from decay of t_{lep} and charged lepton
Mass of W from decay of t_{had}
Number of b-tagged jets among the two light-flavor jets from decay of t_{had}
Boolean variable that equals 1 if the b-quark jet from decay of t_{had} is b-tagged, 0 otherwise
Boolean variable that equals 1 if the b-quark jet from decay of t_{lep} is b-tagged, 0 otherwise
Transverse momentum of t_{had}
Transverse momentum of t_{lep}
Relative H_T, $(p_T(t_{had}) + p_T(t_{lep}))/H_T$
Sum of electric charges of the two light-flavor jets from decay of t_{had}, multiplied by lepton's charge

MVA input variables

Electric charge of the lepton
Pseudorapidity of the recoil jet
Number of b-tagged jets among the two jets from the Higgs boson decay
Transverse momentum of the Higgs boson
Transverse momentum of the recoil jet
ΔR between the two light-flavor jets from the decay of t_{had}
Mass of t_{had}
Number of b-tagged jets among the two light-flavor jets from the decay of t_{had}

post-fit electron channel