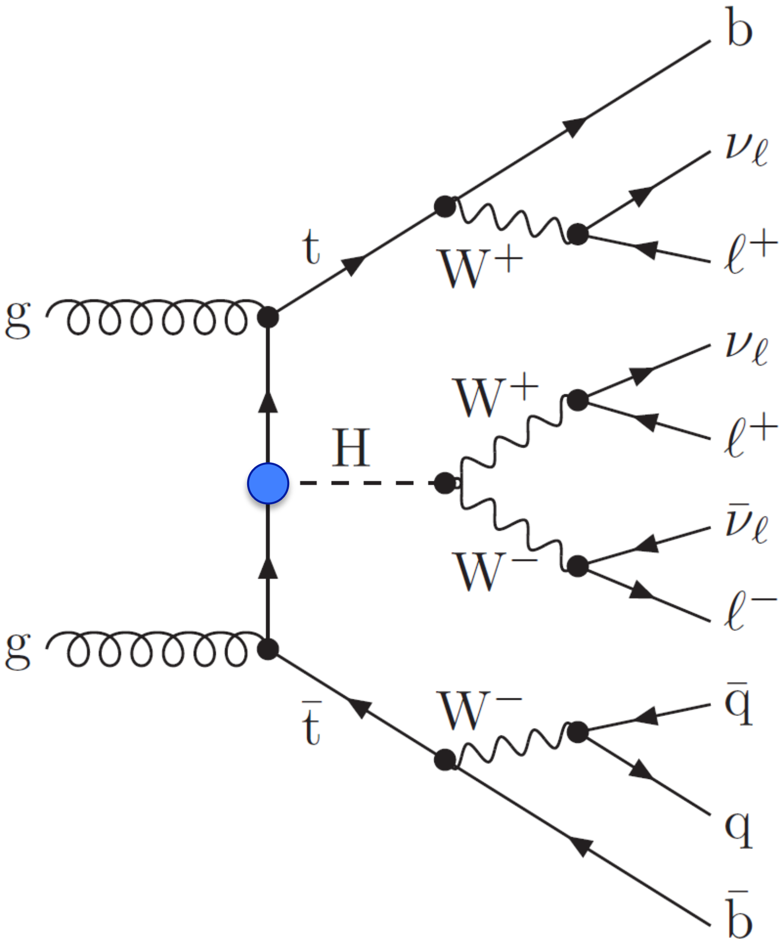
Progress on the ttH coupling at LHC, and projections for HL-LHC



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Introduction

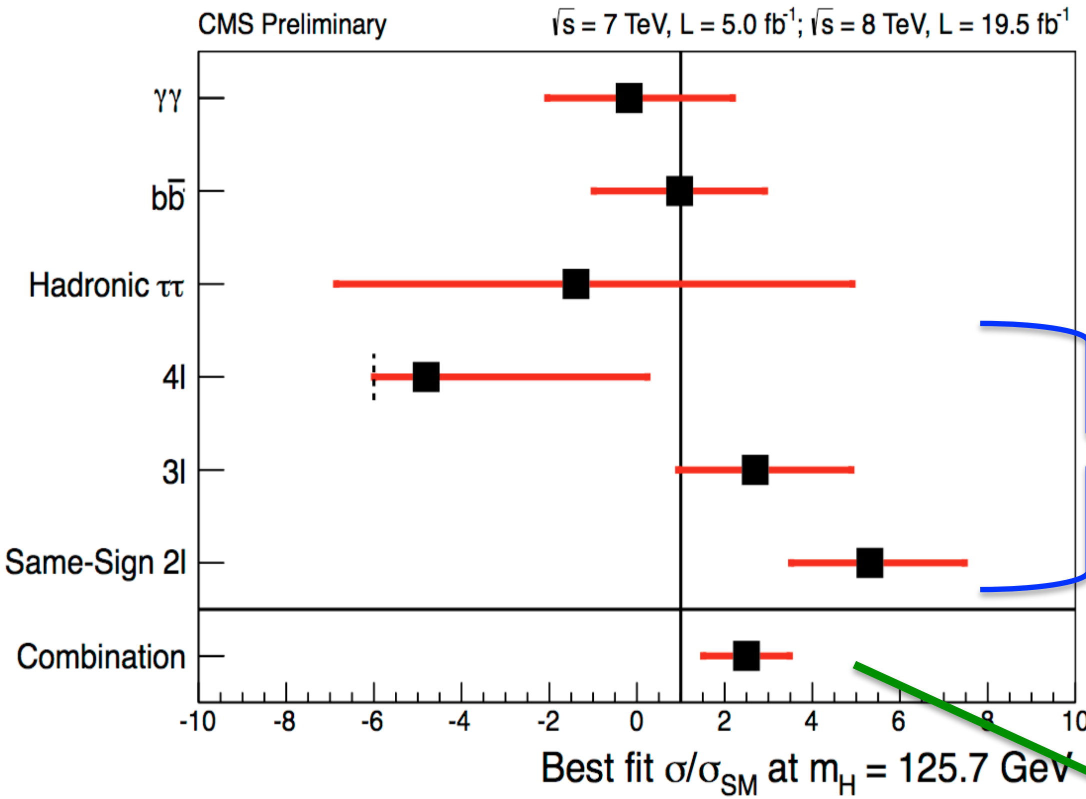
- Two main probes of ttH coupling at LHC:
  - gluon fusion production cross section ($\sigma \sim |y_t|^2$), assuming no BSM particles in the loop.
  - ttH associated production cross section, a tree level process proportional to $|y_t|^2$
- The first is pretty well known: already now the experimental accuracy on y_t is ~20%
- Significant progress from the experimental side on the second point in the last months.

ttH searches at LHC

Experimental signatures considered:

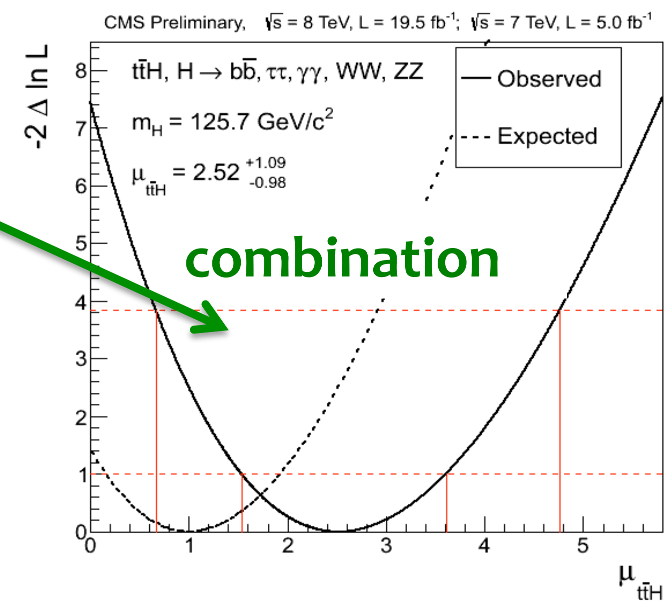
- **tt + b-jets**, to search for H⟶bb
  old staple, explored both at ATLAS & CMS
- **tt + γγ:** very small signal yield, considered mostly for the high-luminosity projections as systematics play a negligible role in it.
- **tt + 4ℓ:** statistics limited, O(50) events in 3 ab^{-1}
- **tt + ττ:** with hadronically decaying taus
- **tt + leptons + jets (inclusive):** latest CMS search for H⟶ WW, ZZ, ττ (τ ⟶ ℓ)

ttH searches at CMS, 8 TeV



multi-lepton channel

combination



ttH leptonic analysis

- Search for final states with multiple leptons (e or μ) from the top and Higgs decays:
  - Three viable signatures: ($\ell^{\pm}\ell^{\pm}$, 3ℓ, 4ℓ) + b-jets
- Main challenges:
  - **Reducible background:** tt with fake ℓ from b-jets Dedicated lepton ID developed to suppress it.
  - **Irreducible backgrounds** (ttW, ttZ/γ^*): rely on theoretical predictions, charge asymmetry, and kinematic (jet multiplicity, event centrality)
  - **Full event kinematic can't be reconstructed:** combine partial kinematic variables in an MVA

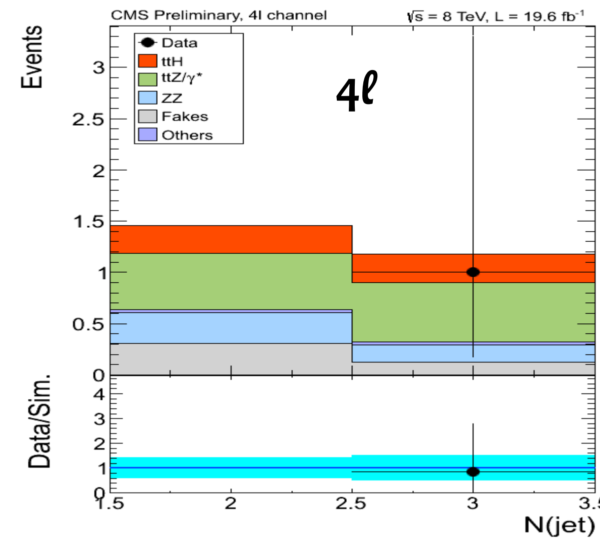
ttH leptonic analysis: 8 TeV

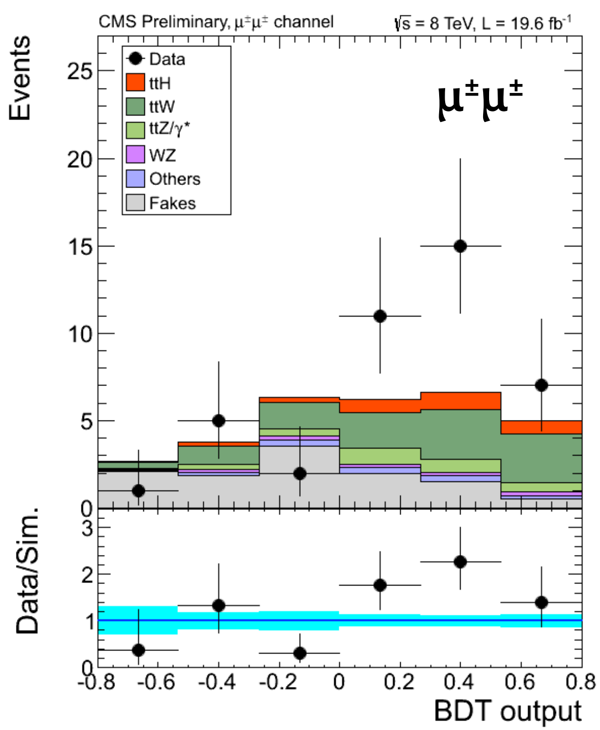
- Expect 0.5-4.4 events, inclusive S/B ~ 1/10

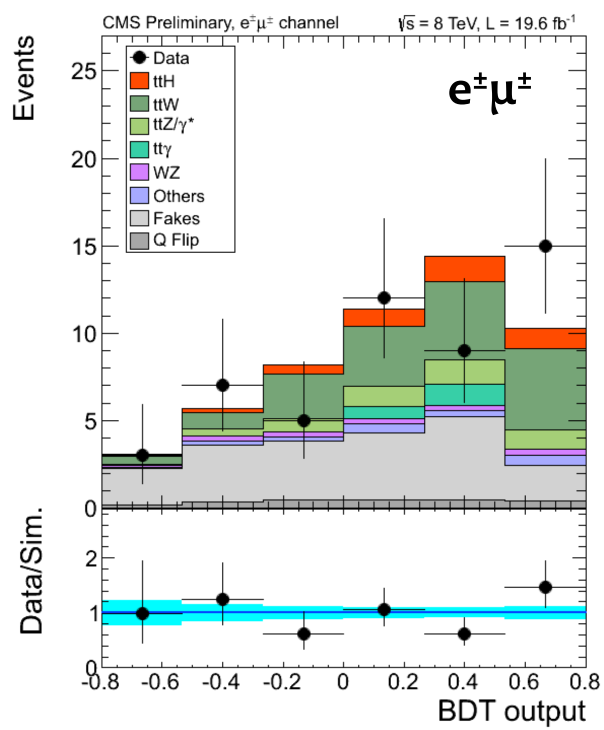
		$\mu\mu$	ee	$e\mu$	3ℓ	4ℓ
ttH	$t\bar{t}H$, $H \to WW$	2.0 ± 0.3	0.9 ± 0.1	2.7 ± 0.4	3.2 ± 0.6	0.28 ± 0.05
	$t\bar{t}H$, $H \to ZZ$	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.09 ± 0.02
	$t\bar{t}H$, $H \to \tau\tau$	0.6 ± 0.1	0.3 ± 0.0	0.9 ± 0.1	1.0 ± 0.2	0.15 ± 0.02
ttV	$t\bar{t}\,W$	8.2 ± 1.5	3.4 ± 0.6	13.0 ± 2.2	9.2 ± 1.9	-
	$t\bar{t}\,Z/\gamma^*$	2.5 ± 0.5	1.6 ± 0.3	4.2 ± 0.9	7.9 ± 1.7	1.25 ± 0.88
	$t\bar{t}\,WW$	0.2 ± 0.0	0.1 ± 0.0	0.3 ± 0.1	0.4 ± 0.1	0.04 ± 0.02
	$t\bar{t}\,\gamma$	-	1.3 ± 0.3	1.9 ± 0.5	2.9 ± 0.8	-
VV	WZ	0.8 ± 0.9	0.5 ± 0.5	1.2 ± 1.3	4.2 ± 0.9	-
	ZZ	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.4 ± 0.1	0.45 ± 0.09
	rare SM bkg.	1.1 ± 0.0	0.4 ± 0.0	1.5 ± 0.0	0.8 ± 0.0	0.01 ± 0.00
fakes	non-prompt	10.8 ± 4.8	8.9 ± 4.5	21.2 ± 8.1	33.2 ± 12.3	0.53 ± 0.32
	charge flip	-	1.9 ± 0.6	2.4 ± 0.8	-	-
	all signals	2.7 ± 0.4	1.2 ± 0.2	3.7 ± 0.6	4.4 ± 0.8	0.52 ± 0.09
	all backgrounds	23.7 ± 5.2	18.0 ± 4.7	45.9 ± 8.6	58.9 ± 12.7	2.28 ± 0.94
	data	41	19	51	68	1

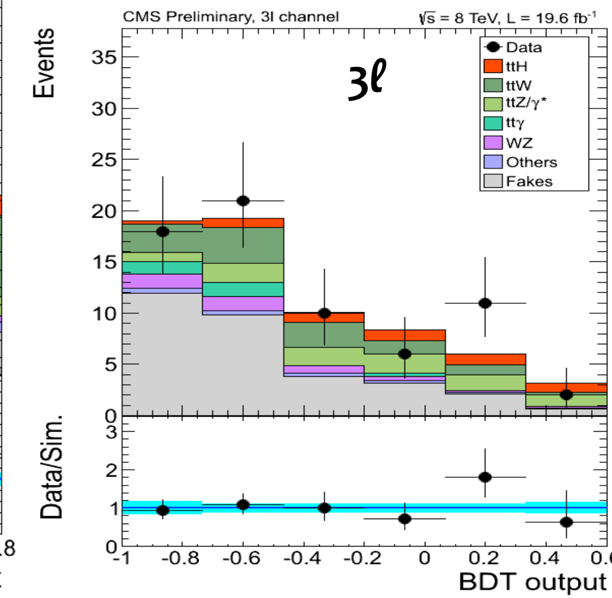
ttH leptonic analysis: 8 TeV

- Signal extraction from MVA output distribution ($\ell^{\pm}\ell^{\pm}$, 3ℓ), or jet multiplicity (4ℓ)









ttH leptonic analysis: beyond

- Current analysis designed for 20 fb^{-1} at 8 TeV:
  - Inclusive selection to preserve signal efficiency
  - Main focus was to contain the reducible bkg.
- The picture will change at 14 TeV and high luminosity. Higher event yields will allow isolating categories of higher S/B events, or whose kinematic can be reconstructed (important in case there will be non-Higgs BSM physics in the energy reach of LHC!)

Projections for LHC and HL-LHC

CMS Projections for 14 TeV, 300 & 3000 fb^{-1}

- Including bb, $\tau_h\tau_h$, $\gamma\gamma$ & multilept. (no $H\rightarrow 4\ell$) the multilepton is new wrt the ECFA studies.
- Two scenarios:
  1. Pessimistic: keep systematics as in 8 TeV analysis
  2. Optimistic: assume experimental systematics improve as √L, theoretical systematics halved

	300 fb^{-1}		3000 fb^{-1}	
	scenario 1	*scenario 2*	*scenario 1*	***scenario 2***
Δy_t from ggH	8%	6%	5%	**3%**
Δy_t from ttH	12%	9%	8%	**4%**

ttH @ HL-LHC: exp

Several reasons to be optimistic from the experimental side:

- ttH is easy to trigger: signatures leptons or photons, jets, b-jets, missing energy…
- unlike in VBF, jets in ttH are central: pile-up can be dealt with using the tracker.
- the analyses do not depend critically on the performance of any single physics object
- multiple channels with promising sensitivity provide a good redundancy

ttH @ HL-LHC: theory

- theory uncertainties are a big component of the projected uncertainty, but there is room for improvements:
  - σ(ttH): existing result only done at NLO QCD
  - PDF uncertainties: can gain from σ(tt)?
  - Other relevant uncertainties: modelling of tt +jets, and σ(ttV) also known only at NLO.
- Big cancellations on exp and th uncertainties on the σ(ttH)/σ(ttZ) ratio.
  (for multi-lepton and γγ final states)

Conclusions

- LHC Run I will yield a direct measurement of the top-Higgs Yukawa coupling within ~50% from ttH, and an indirect one within ~15% from the gluon fusion cross section.
- CMS Projections for HL-LHC give 4%–10% uncertainty on the direct y_t measurement (depending on assumptions on systematics), and 3%–5% on the indirect one from $\sigma(ggH)$

References

- CMS Higgs Physics Results
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG
- CMS HL-LHC Projections for ECFA
  [reference to be added]
- ATLAS HL-LHC Projections
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies