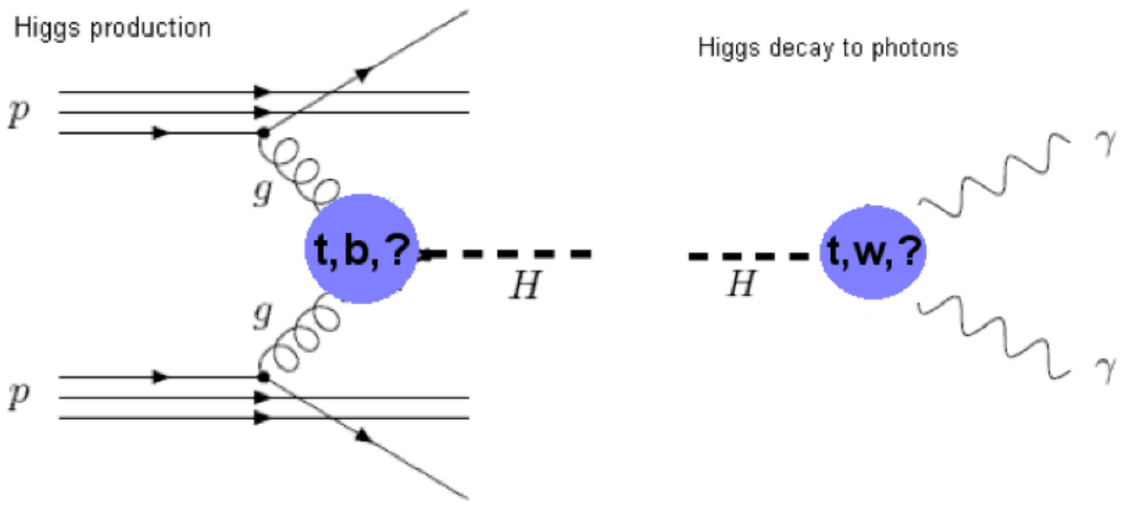
$t\bar{t}H$ at CMS

GDR terascale, May 2016, Nantes

Anne-Catherine Le Bihan
for the CMS collaboration

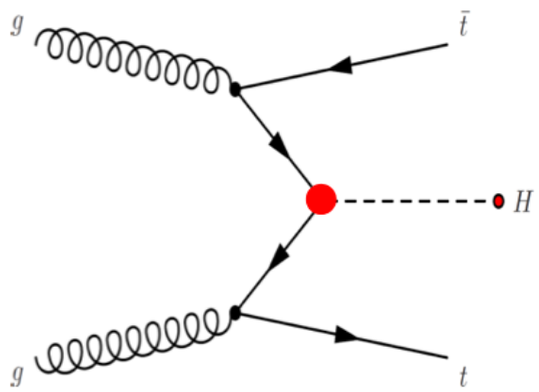
Motivations to study $t\bar{t}H$

- Higgs production at LHC already implies top-Higgs coupling



- $t\bar{t}H$ production allows to probe directly the top-Higgs coupling : $Y(top) \propto \sqrt{\sigma(ttH)}$

- Large deviations from SM could be a hint to some beyond SM models, not modifying Higgs decays



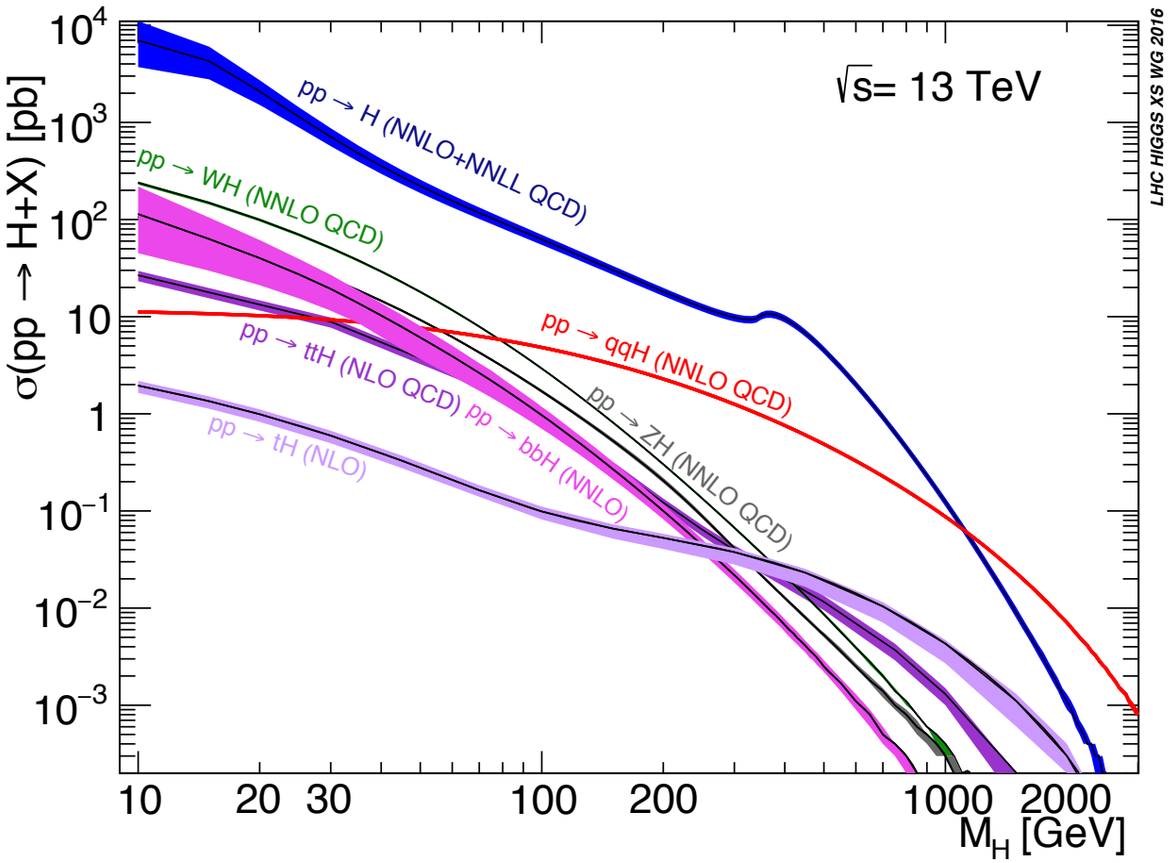
Y(top) ≈ 1 ?

Vector-like, heavy top quark partner, compositeness, RS, little Higgs… ?

A challenging measurement !

Challenges :

- Low signal cross section
- ~100 times smaller than inclusive one



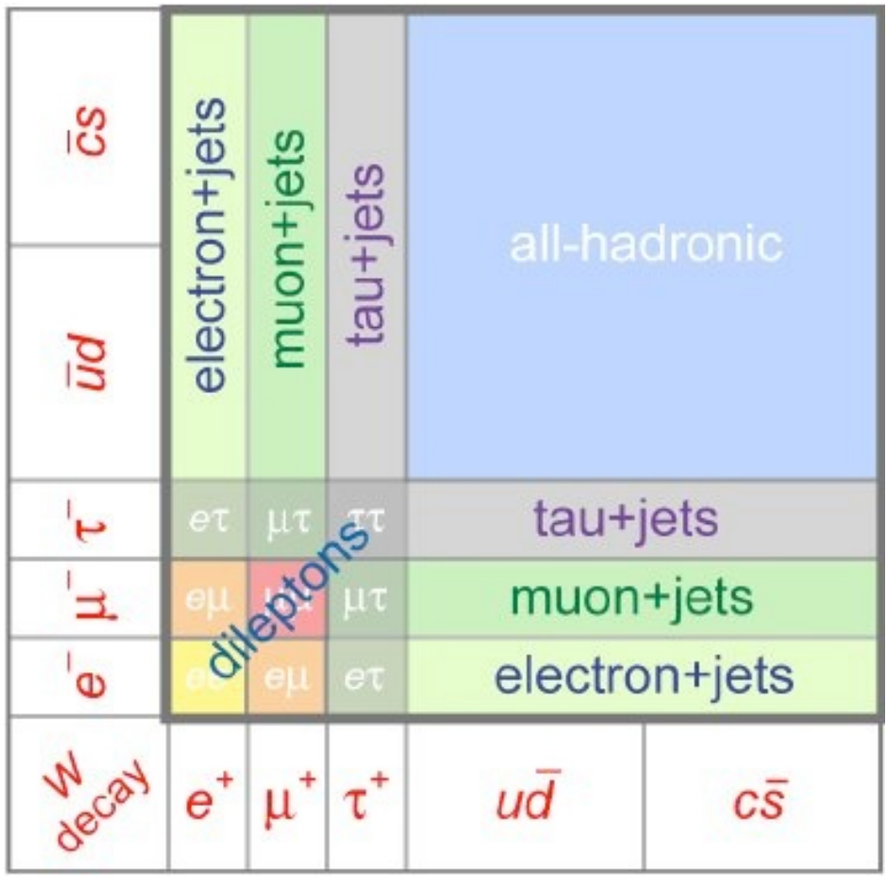
$\sqrt{s}$ (TeV)	7	8	13
$t\bar{t}H(m_H = 125GeV)$ (fb)	86	130	507
$t\bar{t}$ (pb)	177	253	832

$t\bar{t}H$ cross section increased by 3.9
$t\bar{t}$ cross section by 3.3

Larger fraction of events with pT(top), pT(Higgs) > 200 GeV
→ boosted topologies

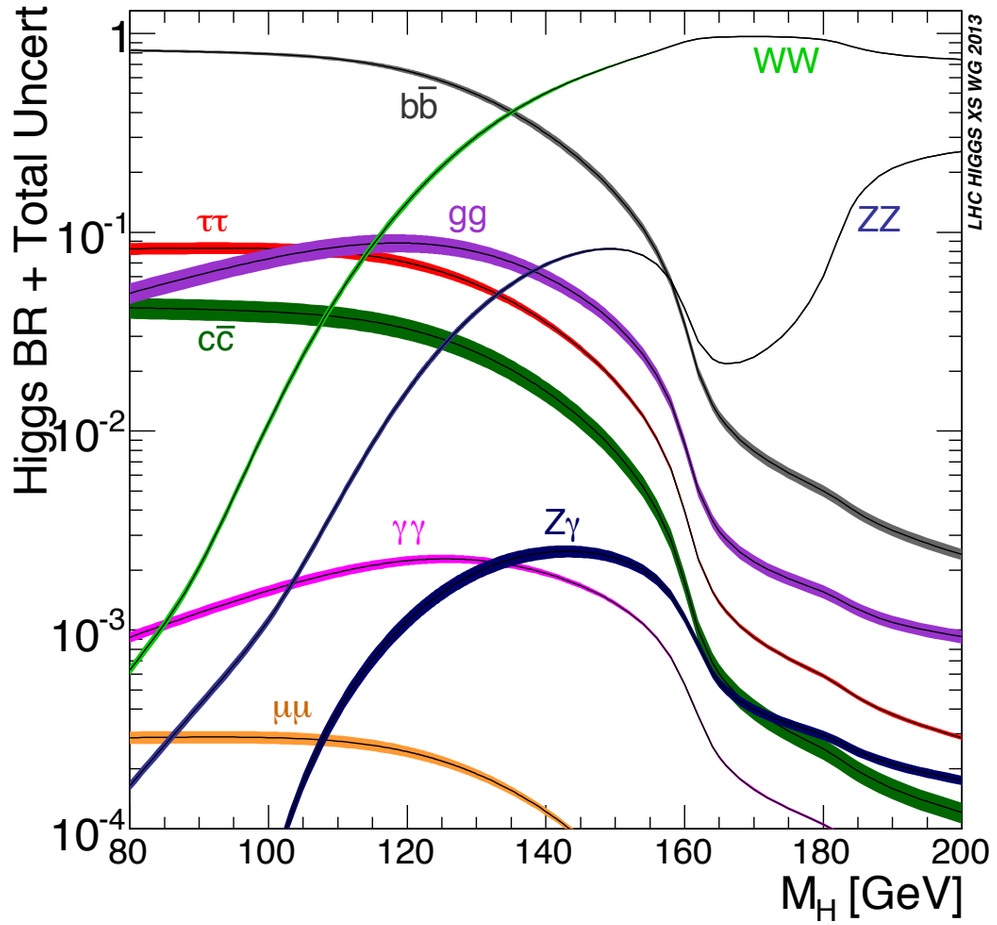
A challenging measurement !

Top decays



⊗

Higgs decays



Challenges :

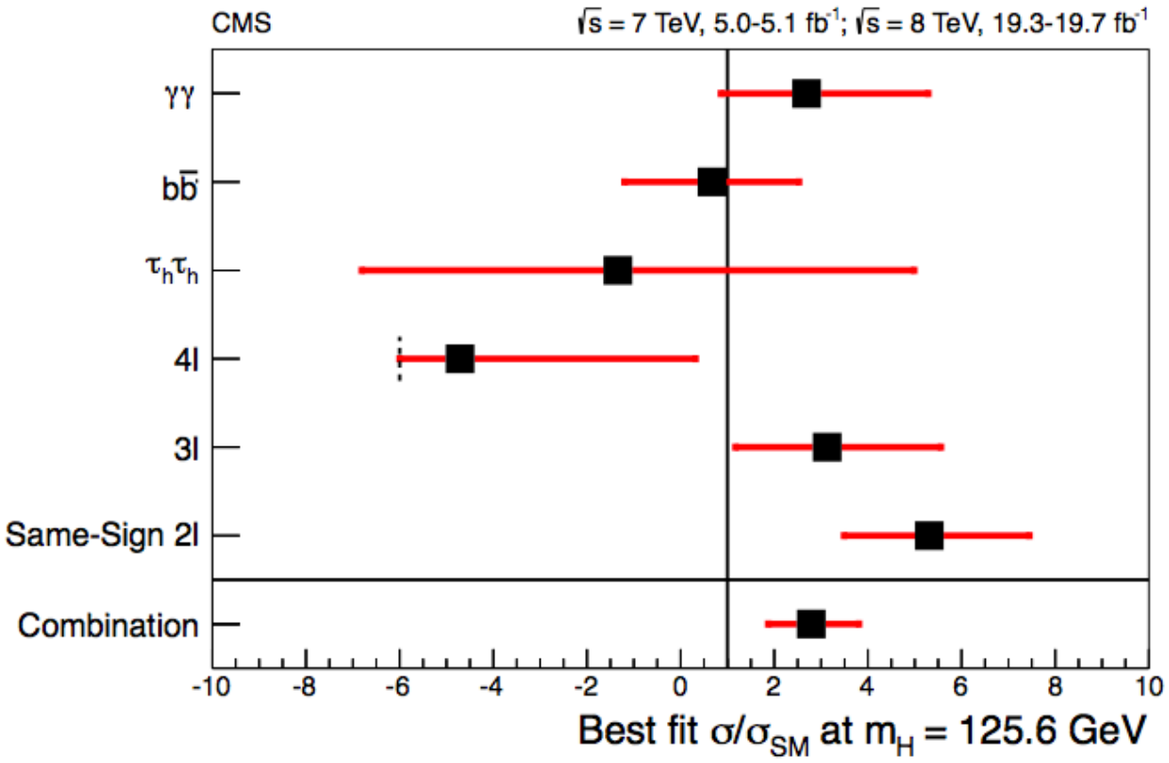
- Final states characterised through top and Higgs decay modes :
  - crowded final state with high jet / b-tag multiplicities
  - various signatures

Run I results

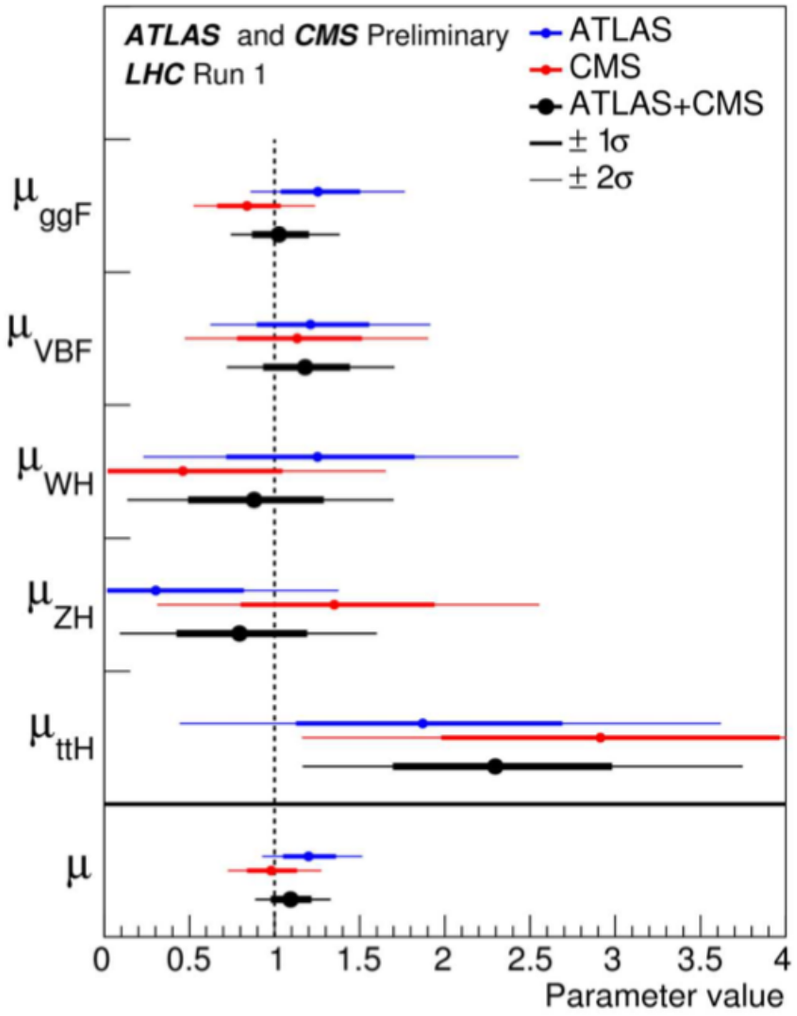
CMS :

Several signatures considered

Excess in $\mu^{\pm}\mu^{\pm}$



ATLAS + CMS combination :



Best fit μ(tt̄H) :

CMS : 2.9 + 1.0 - 0.9

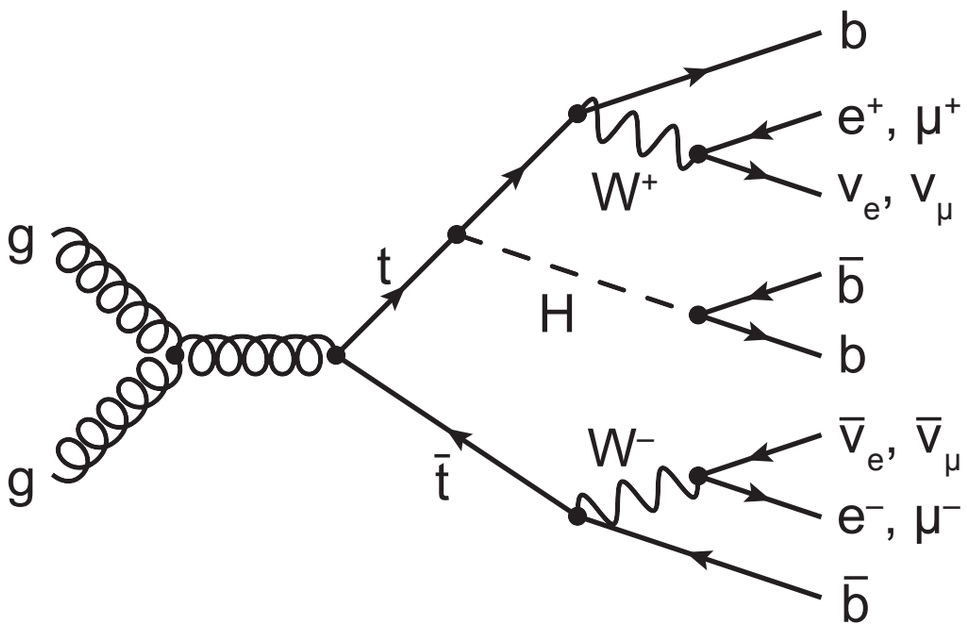
ATLAS : 1.9 + 0.8 - 0.7

ATLAS + CMS : 2.3 + 0.7 - 0.6, observed (expected) significance : 4.4 σ (2.0 σ)

Event selection

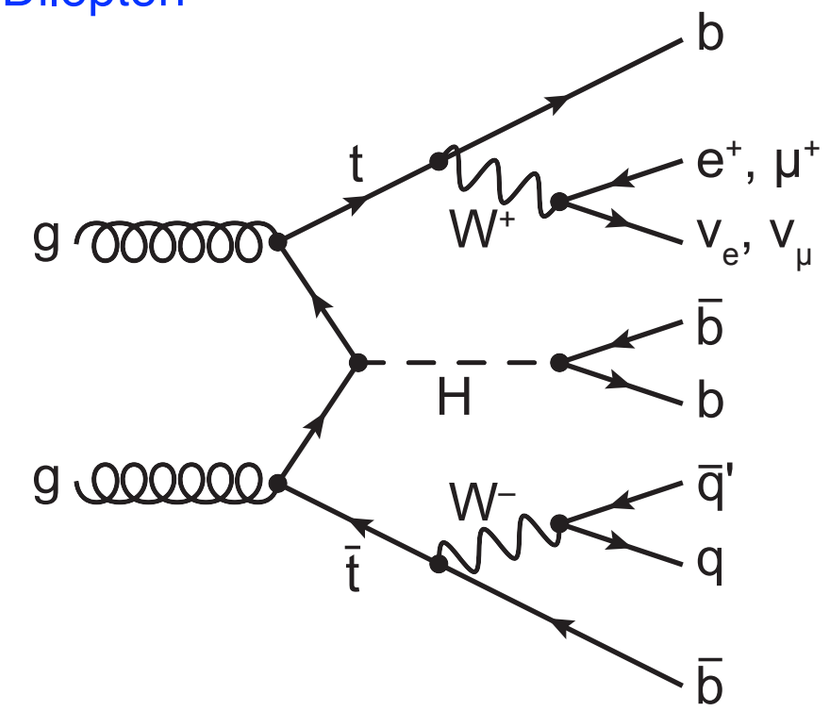
Two main categories according to the decays of top pairs

Lepton+jets



- 1 ℓ: pT>25,(30) GeV for μ (e), |η|<2.1
- ≥ 4 jets : pT>30 GeV, |η|<2.4

Dilepton

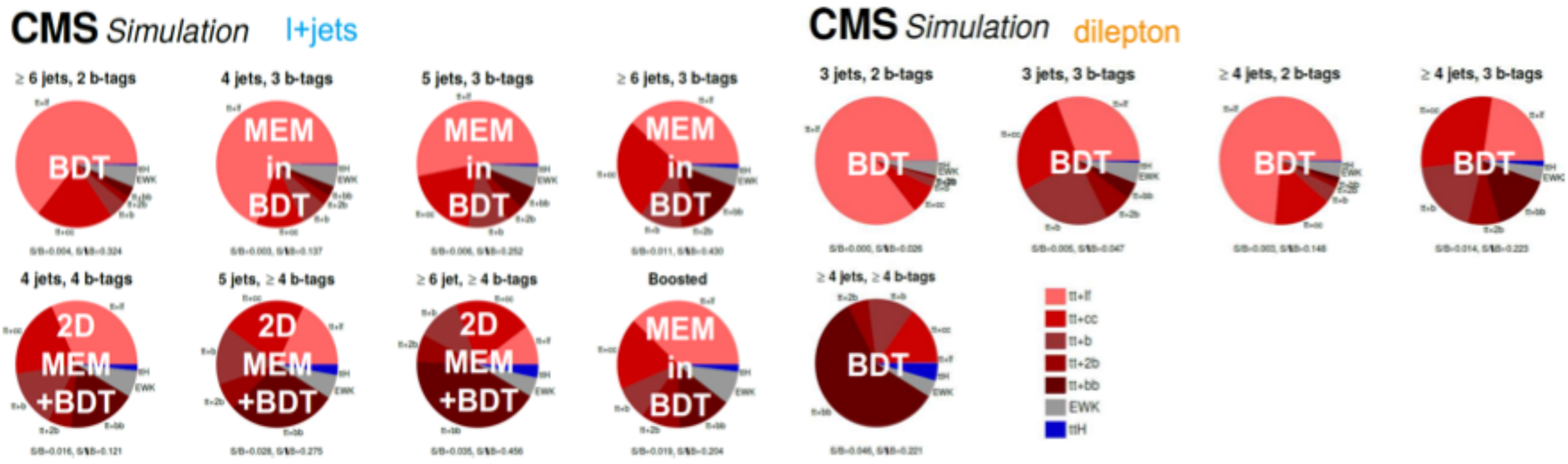


- 2 ℓ : pT>20,15 GeV, |η|<2.4
- ≥ 3 jets : pT>30, 30, 20 GeV, |η|<2.4

Main background :

- tt̄+jets (POWHEG), classification according to truth tt̄+bb tt̄+b, tt̄+2b, tt̄+c(c), tt̄+light
- tt̄+bb : irreducible, theoretically challenging (20-40% uncertainty at NLO)

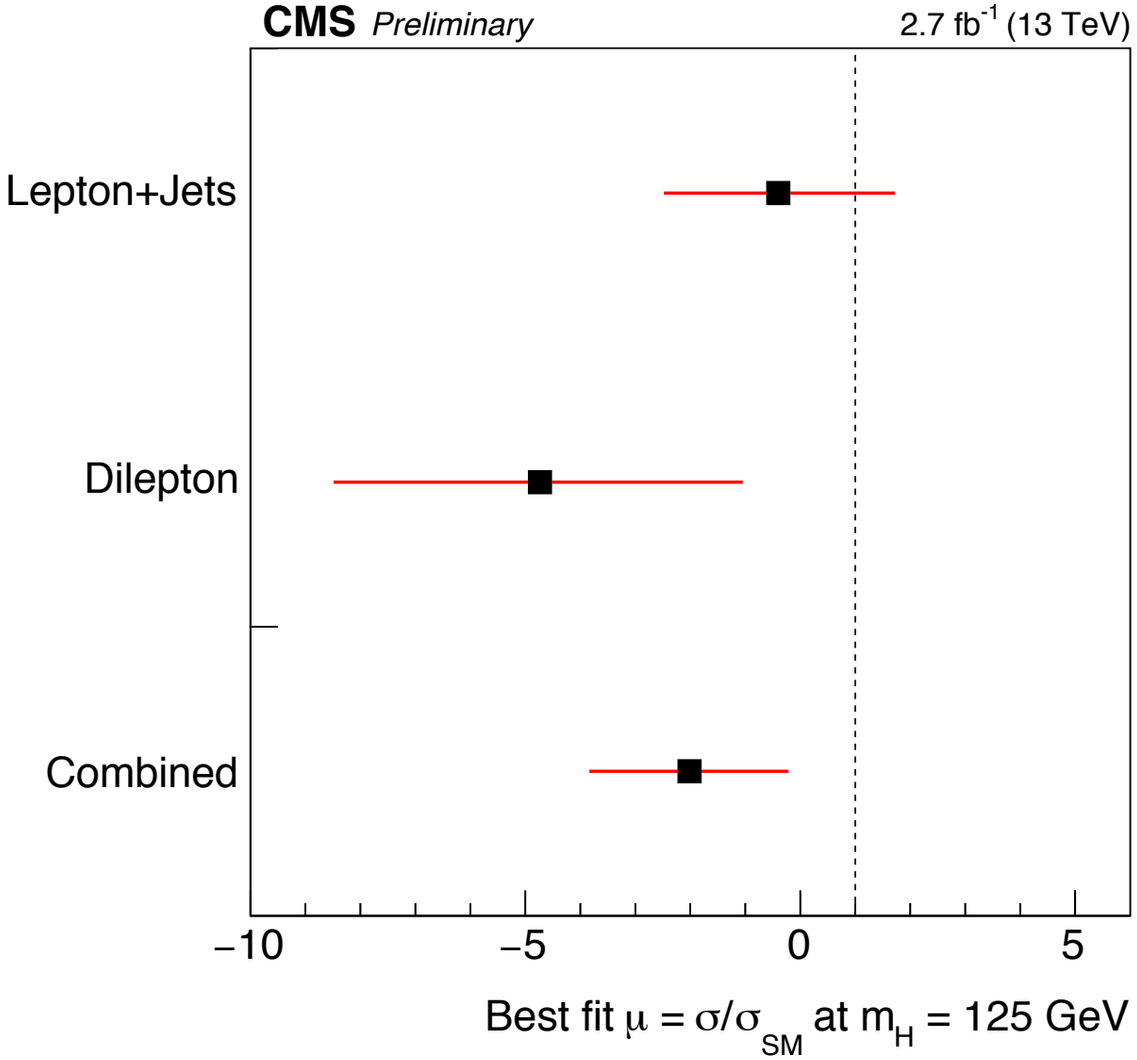
Background estimation & modeling

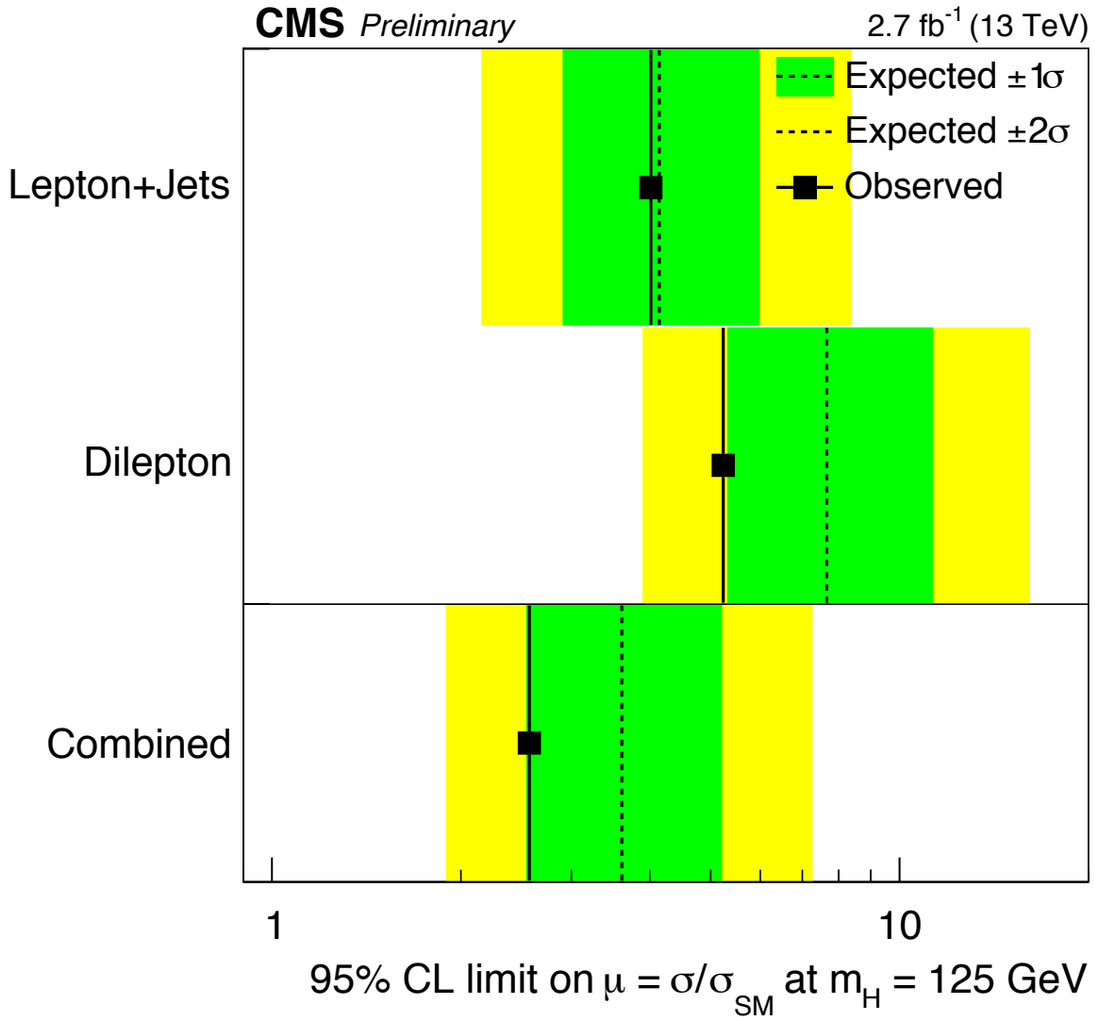


- Use dedicated BDT per category and/or MEM methods in l+jets ($t\bar{t}$+bb as background hypothesis)
- New boosted category for Run II : identification of Cambridge/Aachen 1.5 jets, subject filtering techniques to identify top and Higgs
- S/B increases with N(jets) and N(b-jets), categories w/ low S/B used to constrain backgrounds and systematics

Results

Simultaneous binned maximum likelihood fit to all categories.





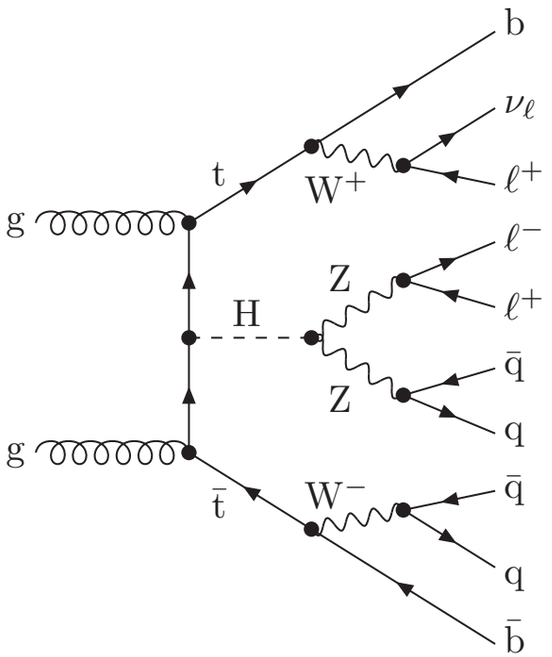
Best fit μ(ttH) : -2.0 ± 1.8
1.7 σ below SM expectation

Observed limit : 2.6
Expected limit : 3.6 + 1.6 -1.1

Event selection

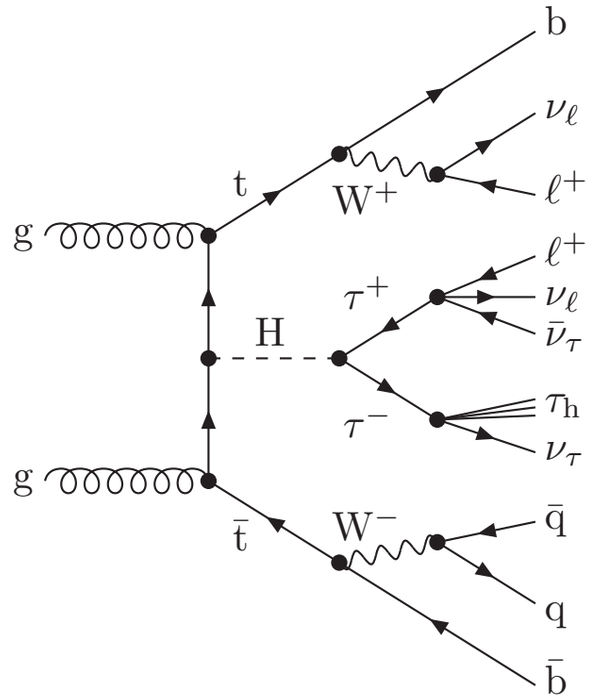
Two main categories according to the lepton multiplicity

Dileptons



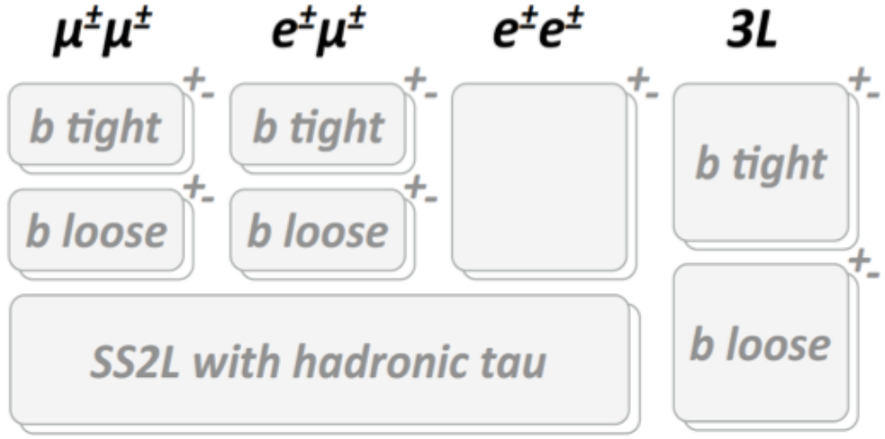
- 2 same-sign ℓ : pT>20, 10 (15) GeV for μ (e), |η|<2.4
- ≥ 4 jets : pT > 25 GeV, |η|<2.4
- 0.6 MET + 0.4 HT > 30 GeV

3 or 4 leptons



- 3 or 4 ℓ : pT>20, 10, 10 GeV, |η|<2.4
- ≥ 2 jets : pT > 25 GeV, |η|<2.4
- 0.6 MET + 0.4 HT > 30 GeV (45 GeV if OSSF)

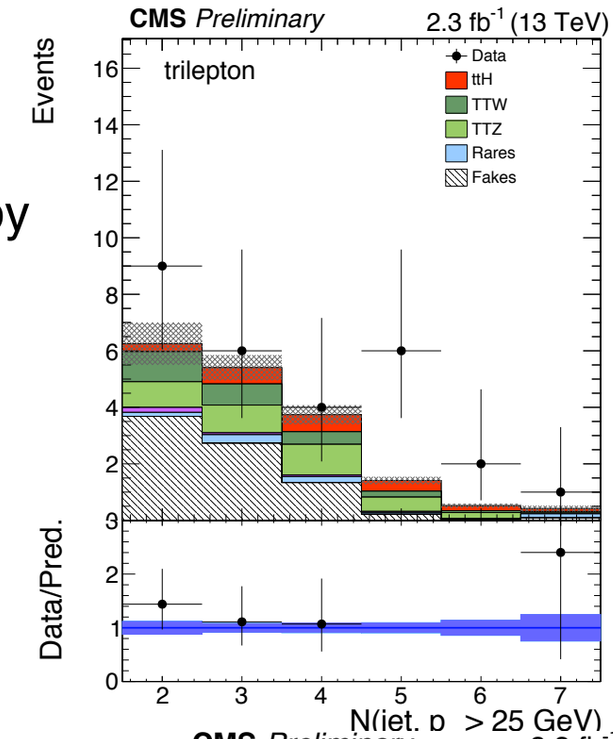
Additional sub-categorisation :
lepton flavour/charge
presence of τ
multiplicity of b-jets

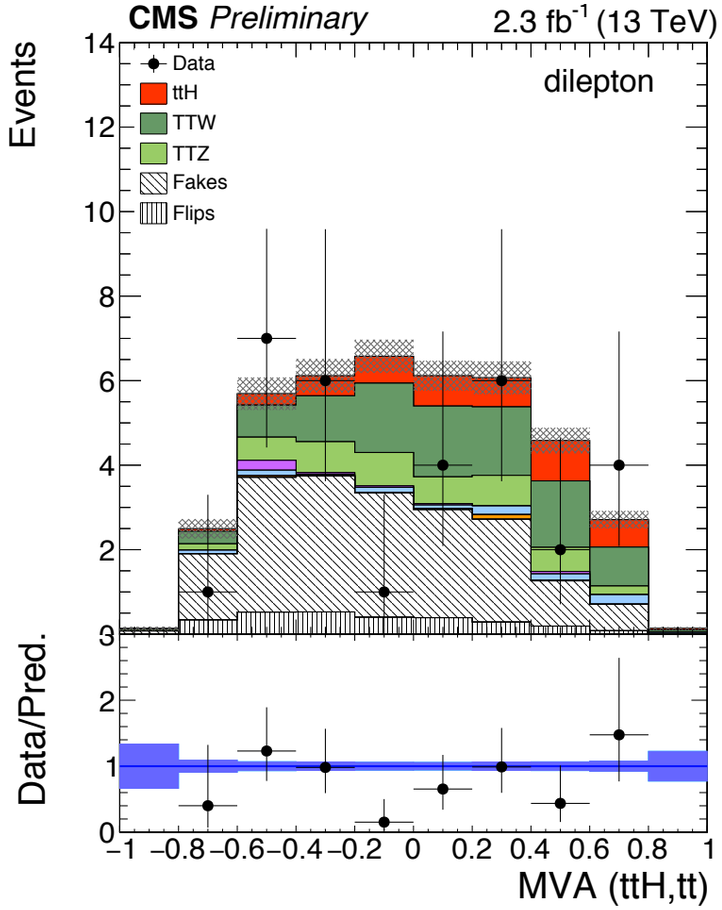


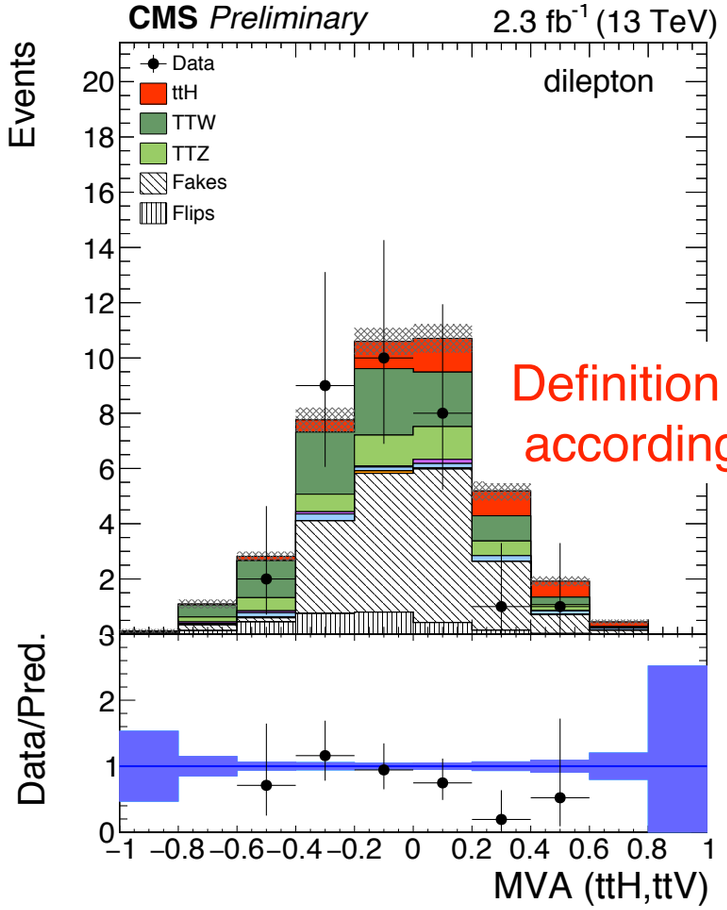
Background estimation

- Lepton identification through a BDT to mitigate non-prompt leptons
- Fake ratio method (30-50% uncertainty) : in multijet and Z+jets events by reversing lepton BDT

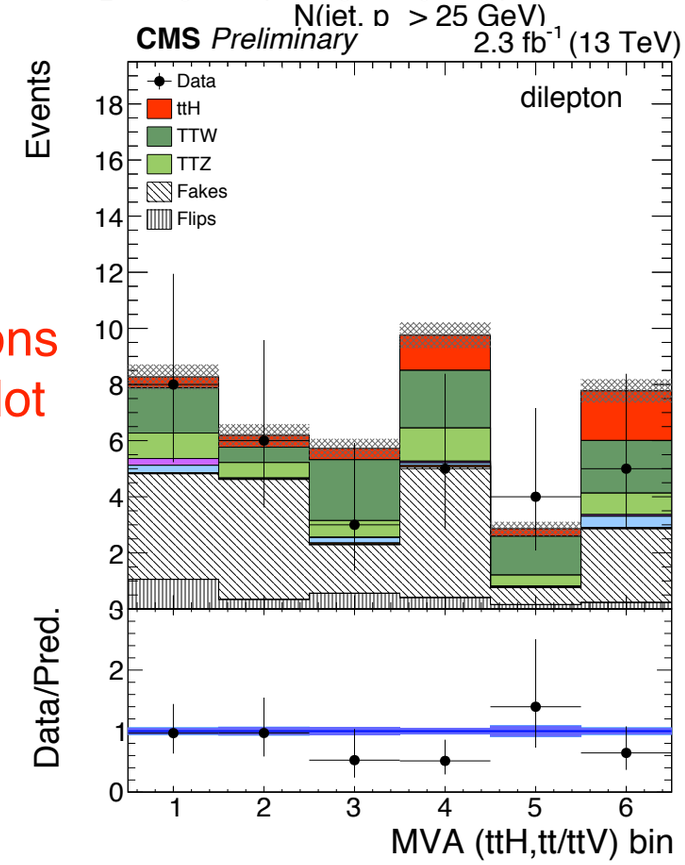
Two MVAs : one to mitigate ttH/tt̄ and one for ttH/ttV
ttV estimates from NLO (QCD+EWK) calculations





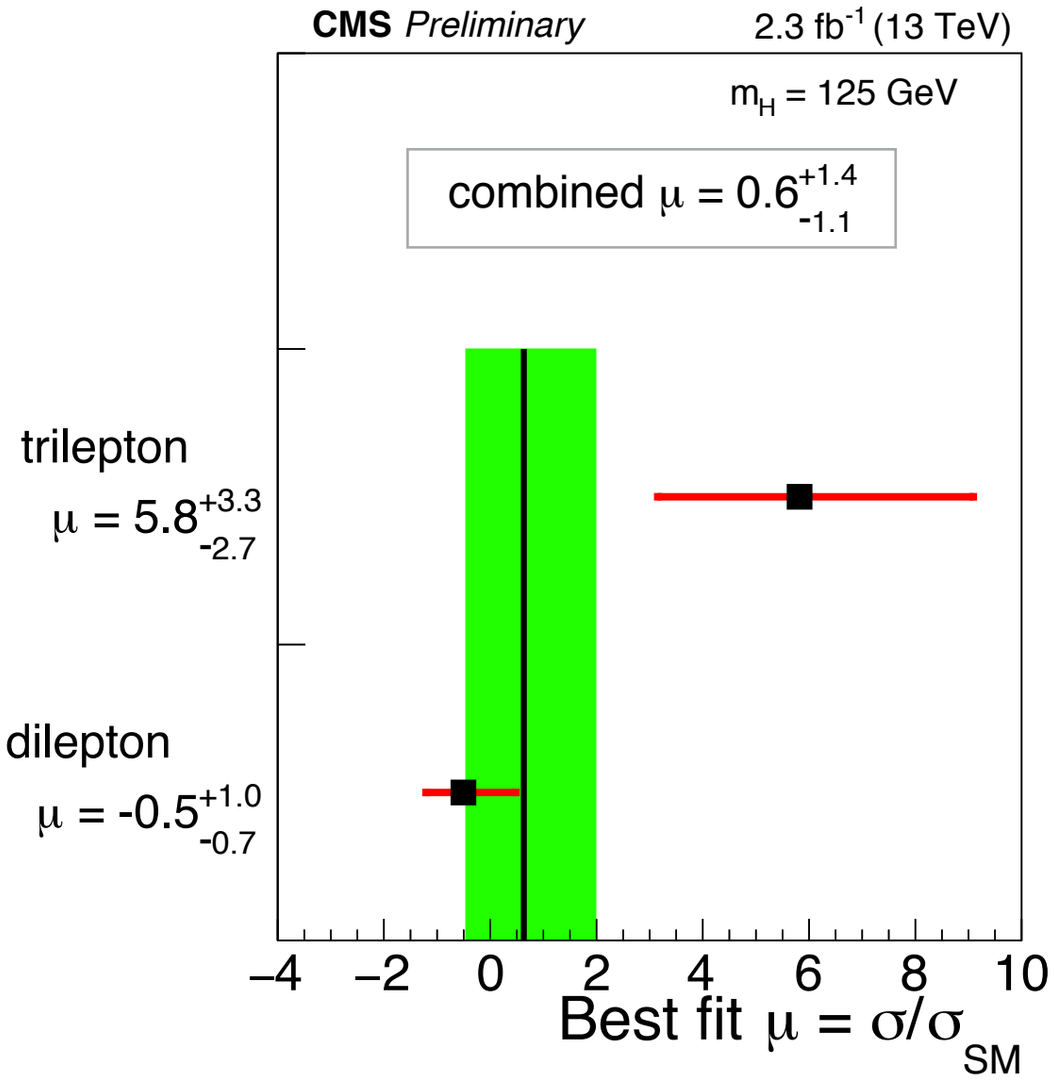


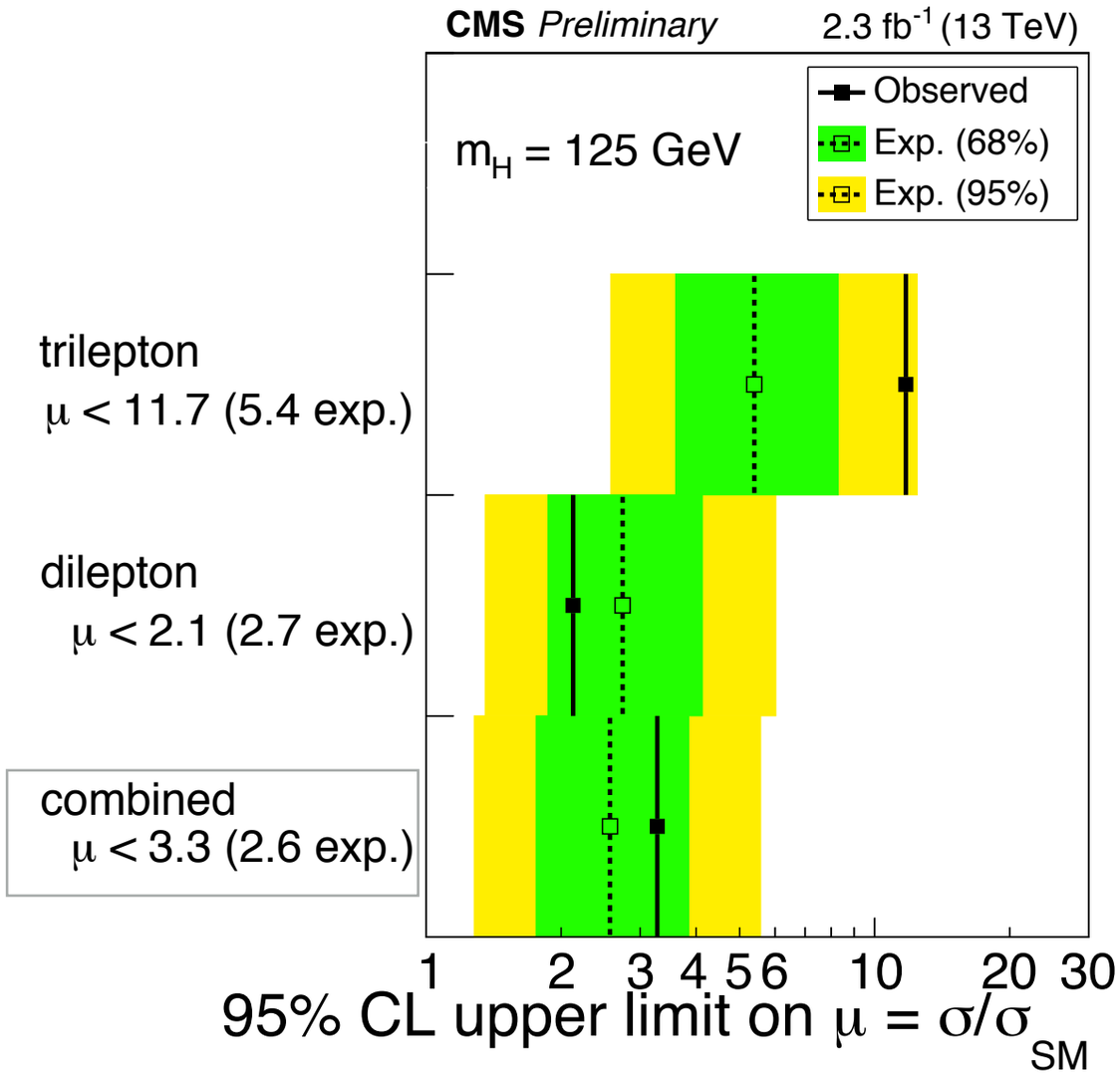
Definition of signal regions according to 2D MVA plot →



Results

Signal extraction by combined fit to all bins defined by the two discriminants (against $t\bar{t}$ and $t\bar{t}V$).



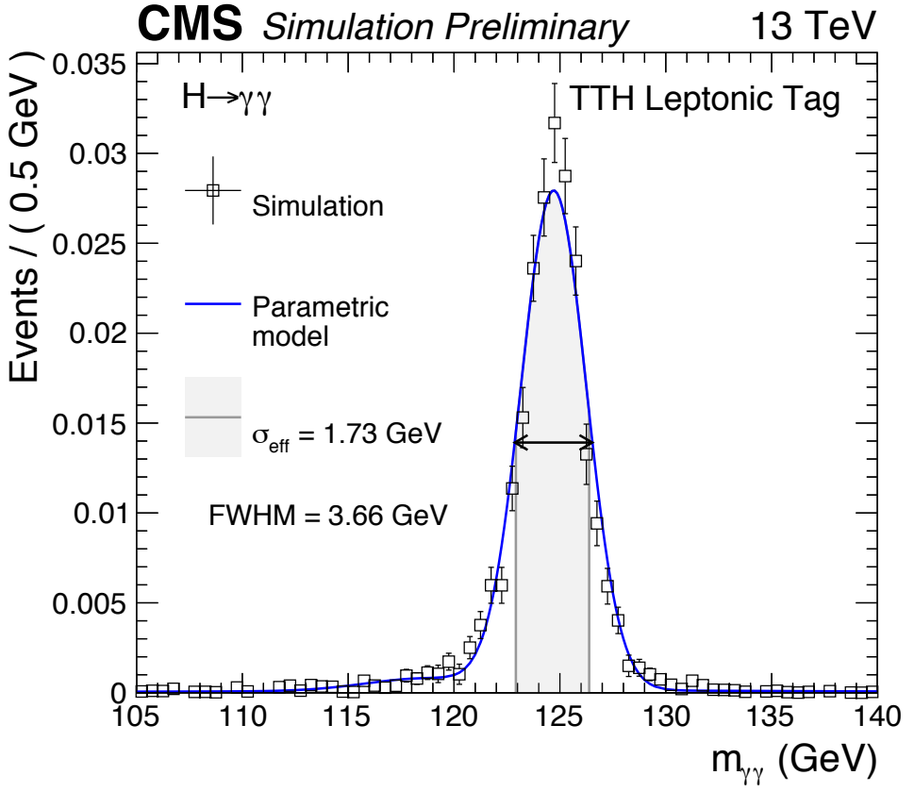


Event selection

Two main categories according to the decays of top pairs (loose top selection, diphoton triggers)

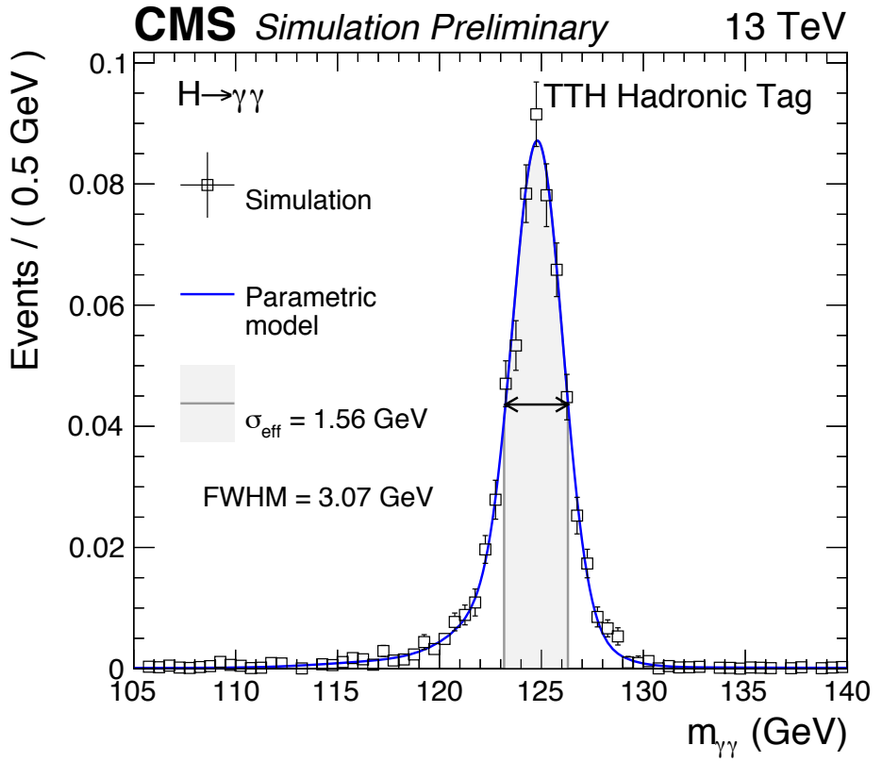
Leptonic tag

- 2 γ : pT> mγγ/2, mγγ/4
- Diphoton selection through dedicated BDT
- 1 ℓ : pT > 20 GeV
- ≥ 2 jets : pT> 25 GeV, |η|<2.4, 1 b-jet



Full hadronic

- 2 γ : pT>mγγ/2, mγγ/4
- Diphoton selection through dedicated BDT
- No leptons
- ≥ 5 jets : pT> 25 GeV, |η|<2.4, ≥ 1 b-jet

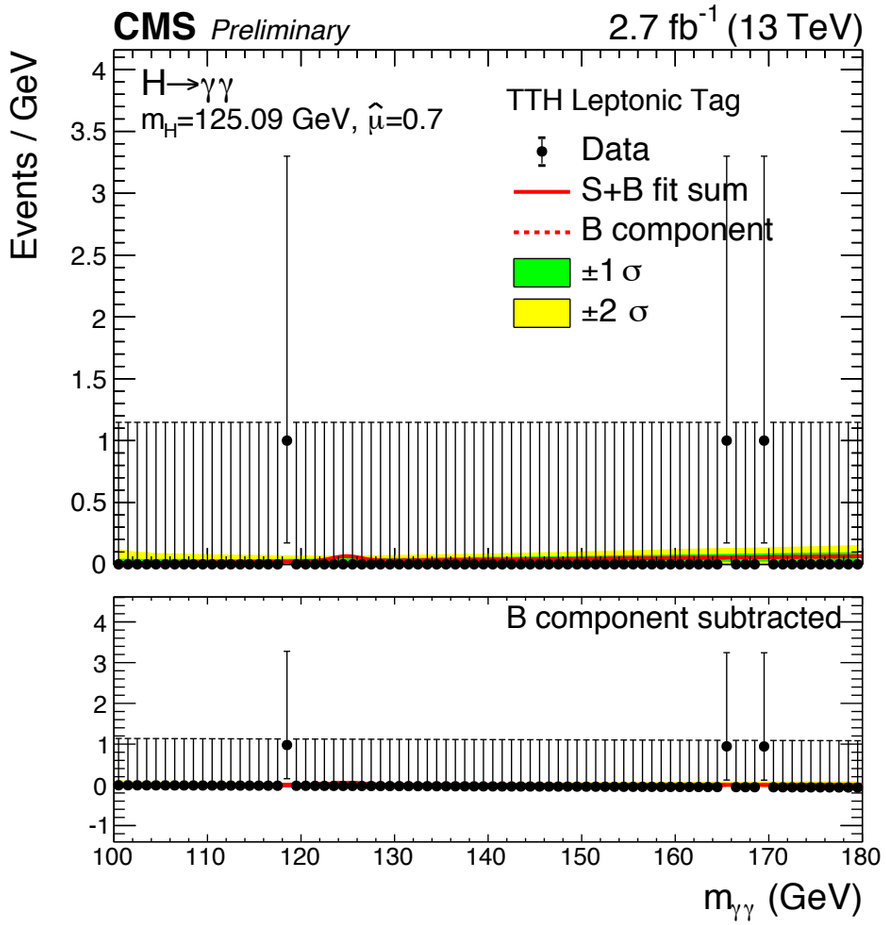


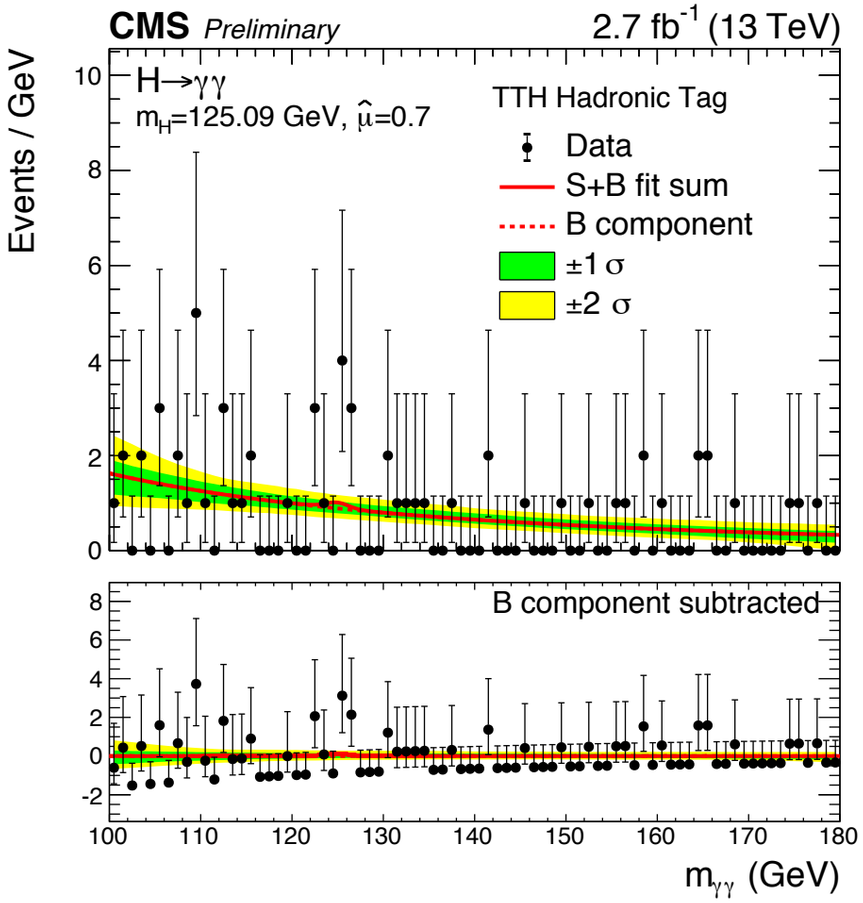
- Main background : tt̄ + γγ, tt̄ + fake photons

Results

- Contributions from other Higgs production modes are minor - 96 %, 87% purity for leptonic, hadronic tags

- Fit mγγ distribution as in inclusive analysis, several functional forms tested *(discrete profiling)*

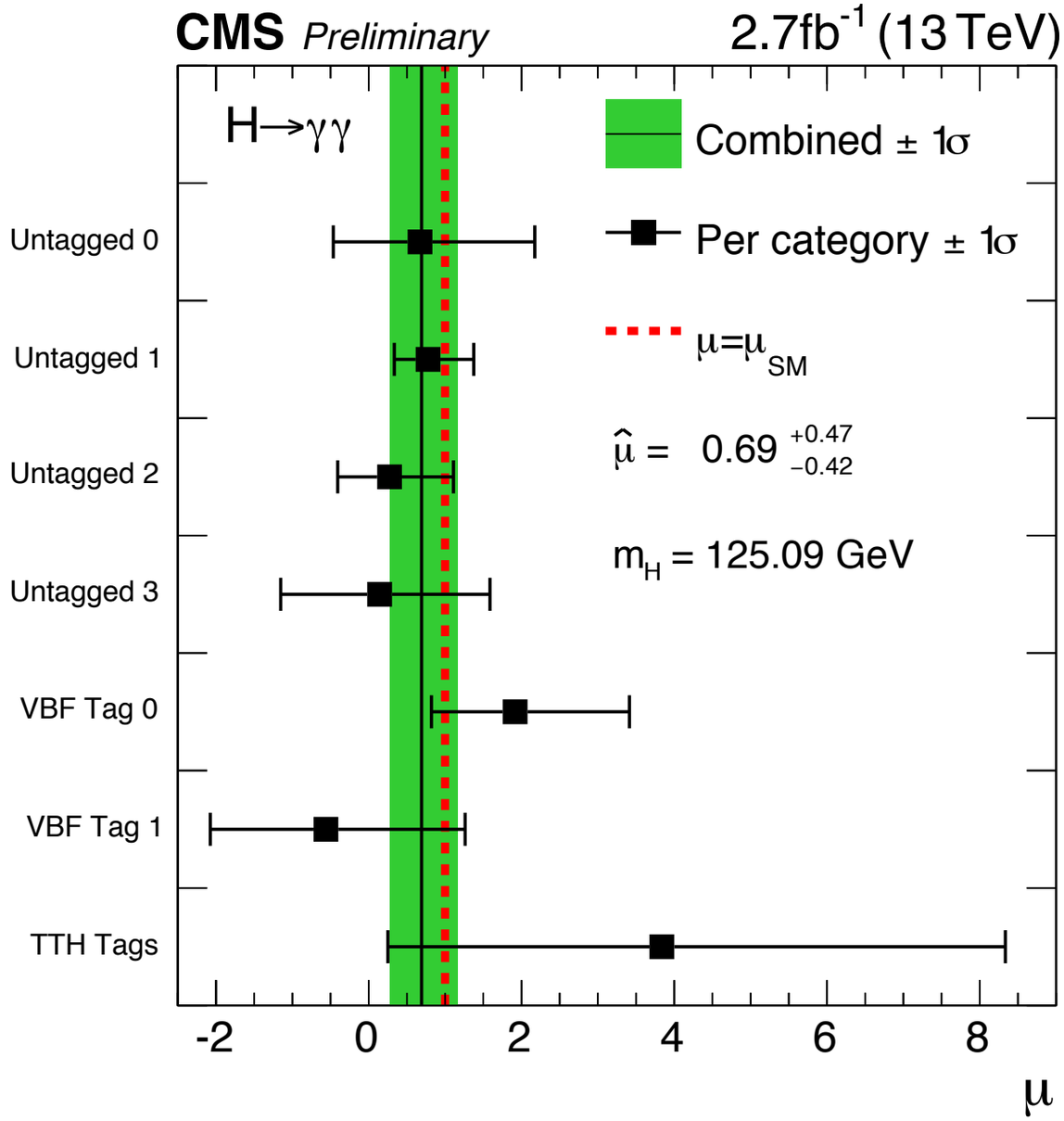




Statistically limited
Best fit μ(ttH) : 3.8 + 4.5 - 3.6

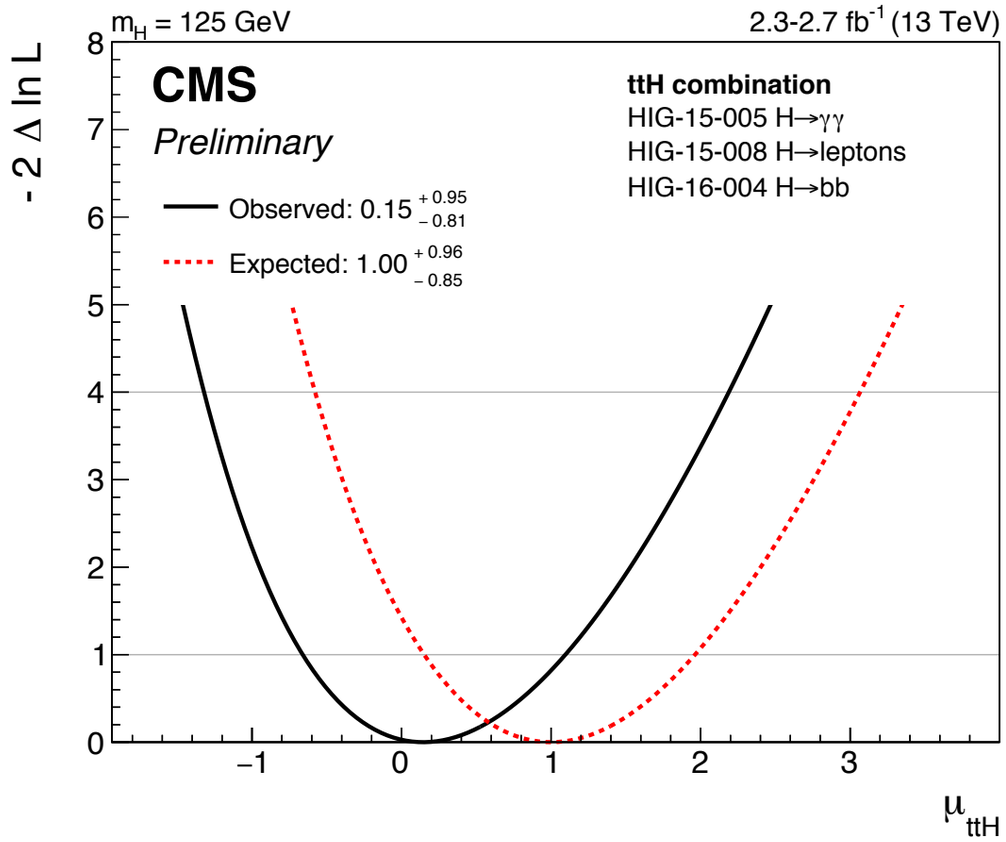
Results

- Full picture of H→γγ results

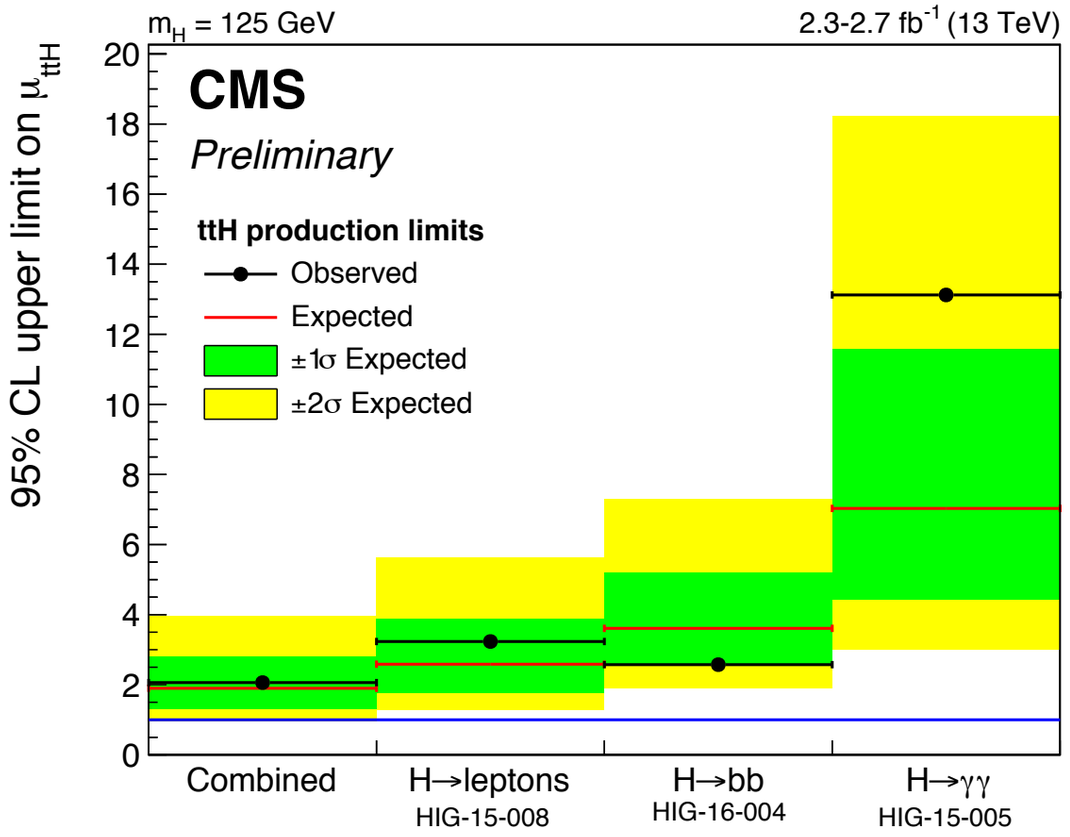


Combined results

Best fit value of μ(tt̄H) = 0.15 + 0.95 - 0.81
Expected = 1.00 + 0.96 - 0.85



Observed limit on μ(tt̄H) = 2.1
Expected limit = 1.9 (Run I : ATLAS 1.4, CMS 2.9)



Fully correlated between channels : QCD scale and pdf, luminosity and b-tag uncertainties
Other Higgs contributions can vary within the theoretical and experimental uncertainties

Conclusion

- CMS has performed following measurements with 13 TeV data of 2015 :
  $t\bar{t}H$, H→bb,
  $t\bar{t}H$, H→multileptons,
  $t\bar{t}H$, H→$\gamma\gamma$

- Several improvements : MEM for H→bb, boosted topologies, improved lepton identification and kinematic variables, 2l SS with τ, NLO generators…

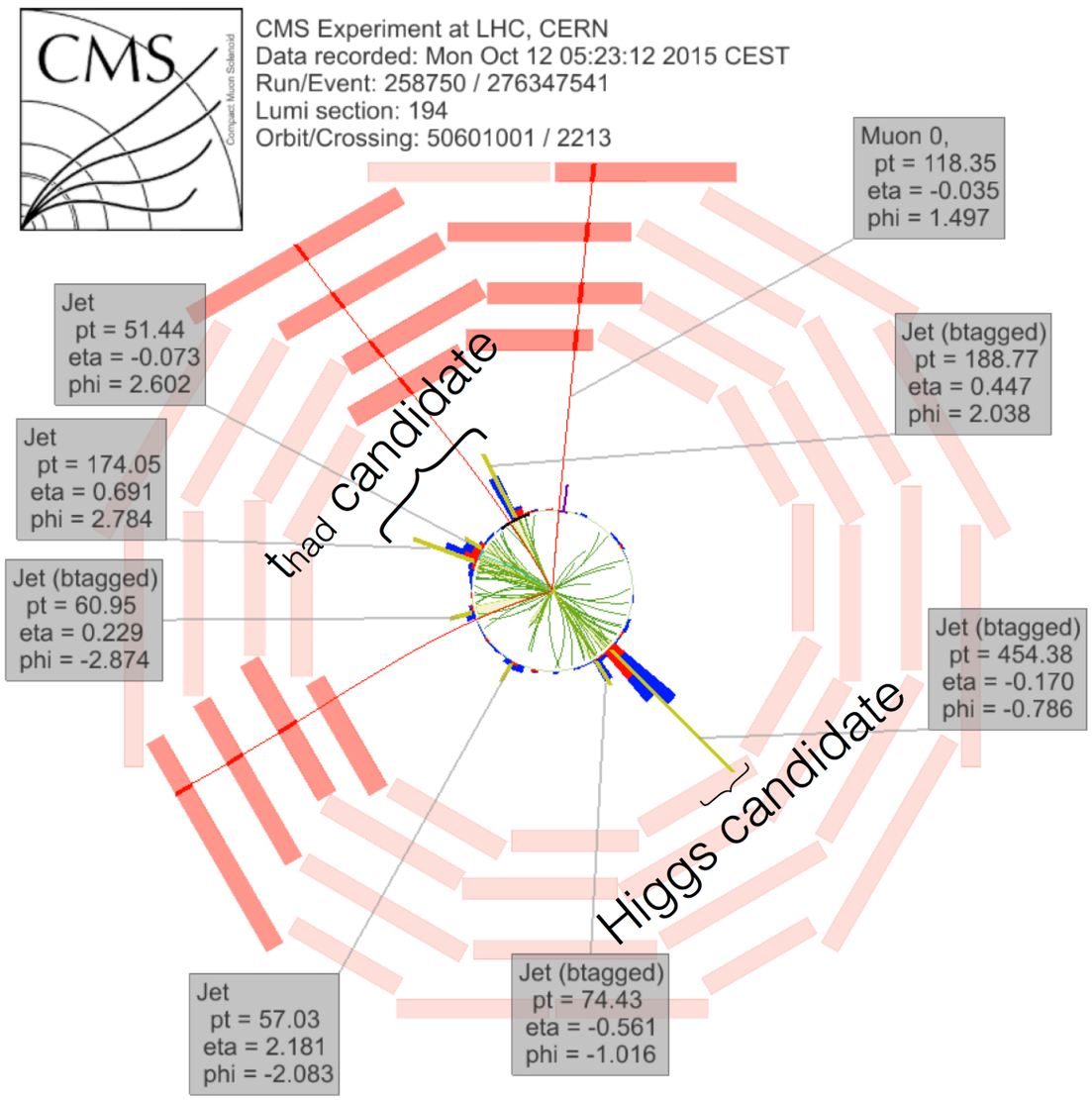
- Combined results :
  Best-fit value of $\mu(t\bar{t}H)$ = 0.15 + 0.95 - 0.81 (expected = 1.00 + 0.96 - 0.85)
  Observed limit on $\mu(t\bar{t}H)$ = 2.1 (expected = 1.9)

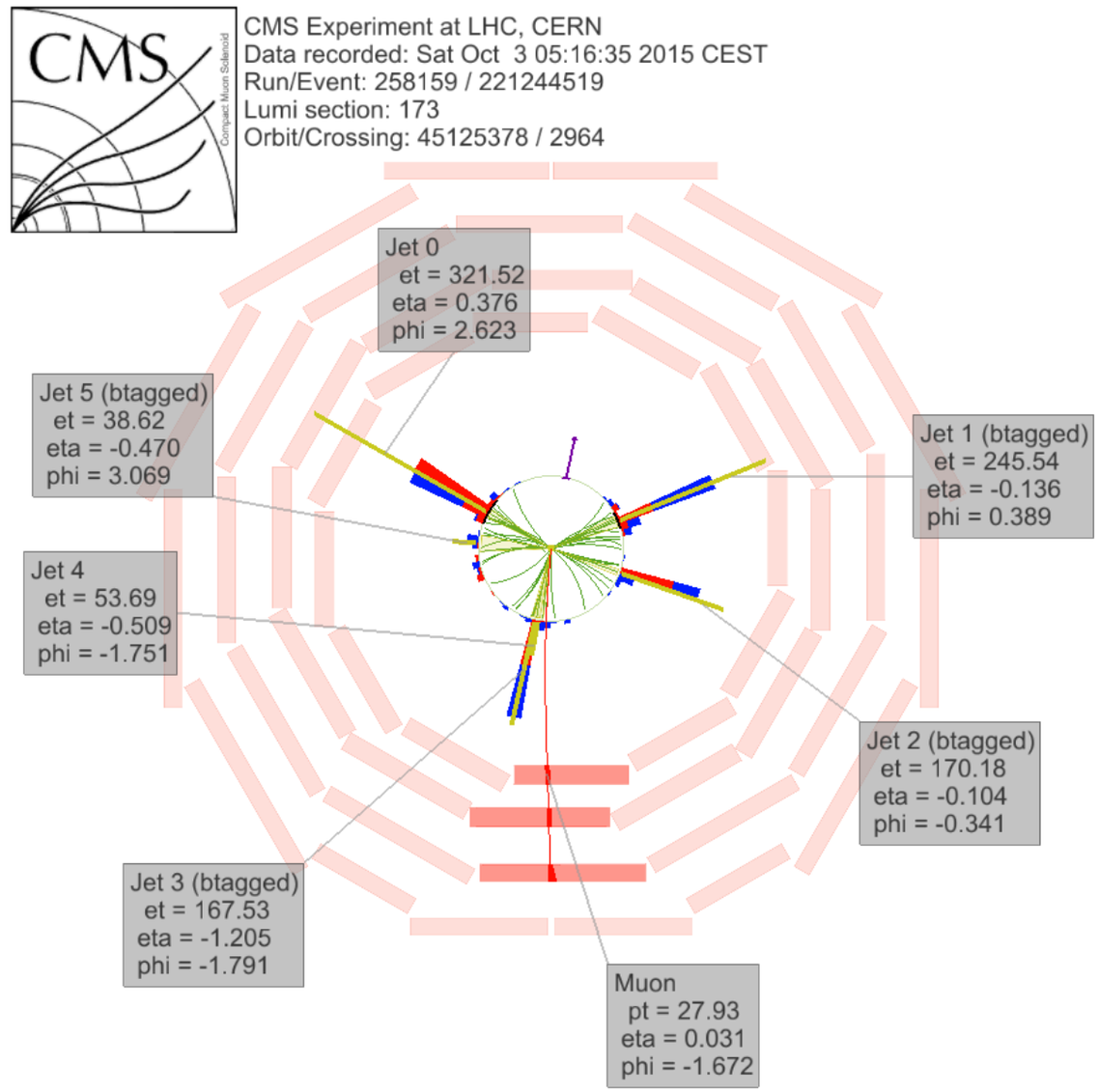
- $t\bar{t}H$ observation and Yukawa coupling measurement amongst priorities for Run 2 !

- About 30 fb^{-1} in 2016 !

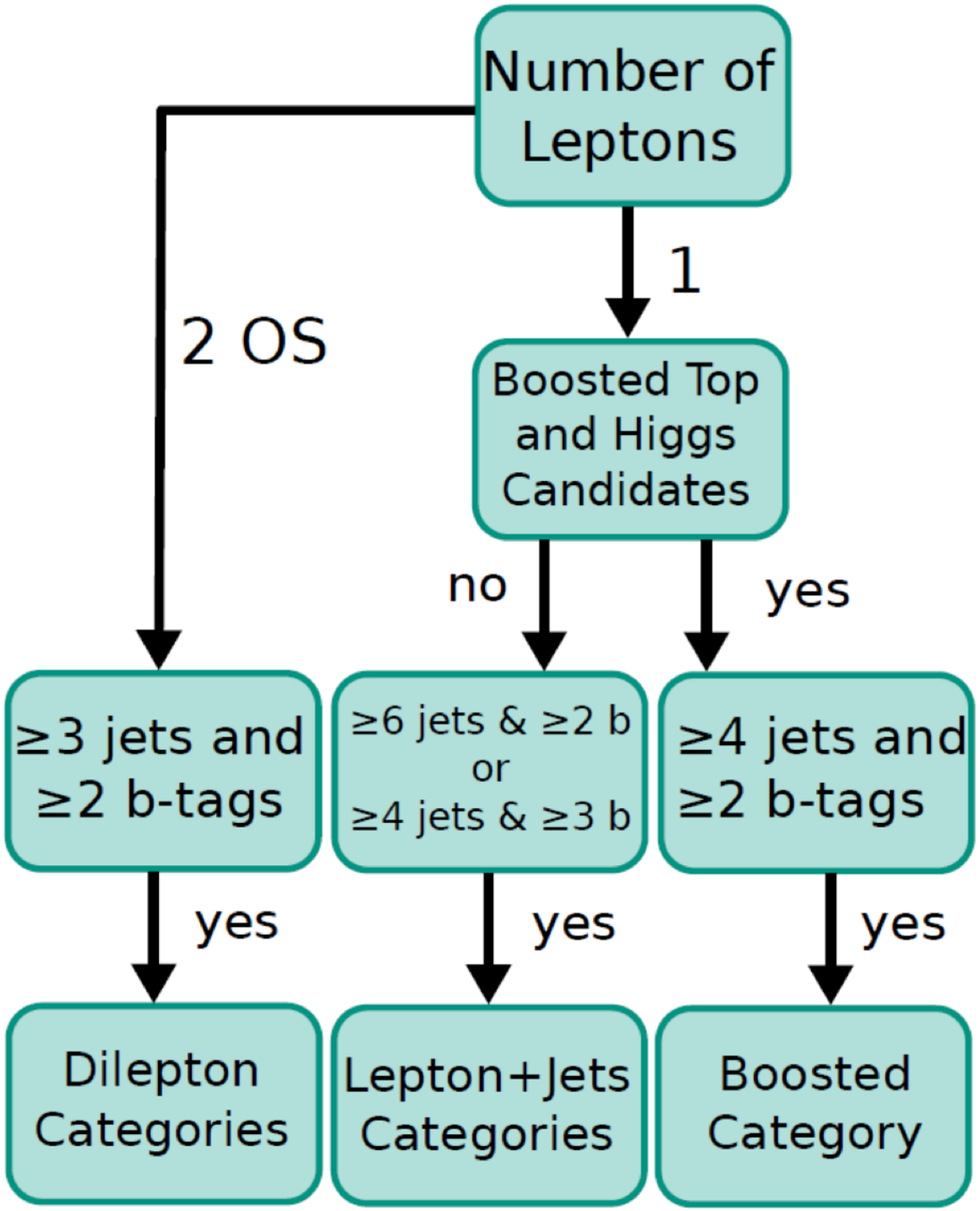
Backup...

ttH, H →bb, HIG-PAS-16-004

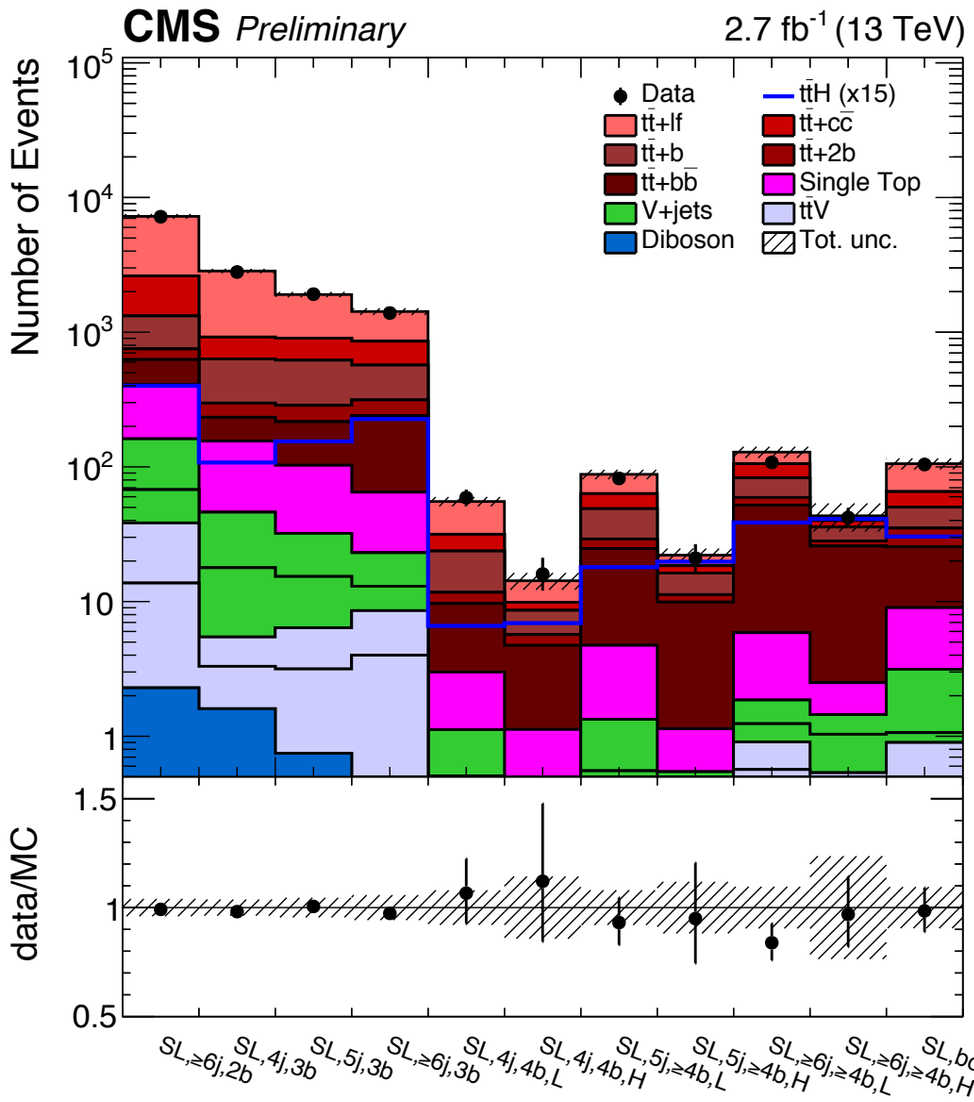


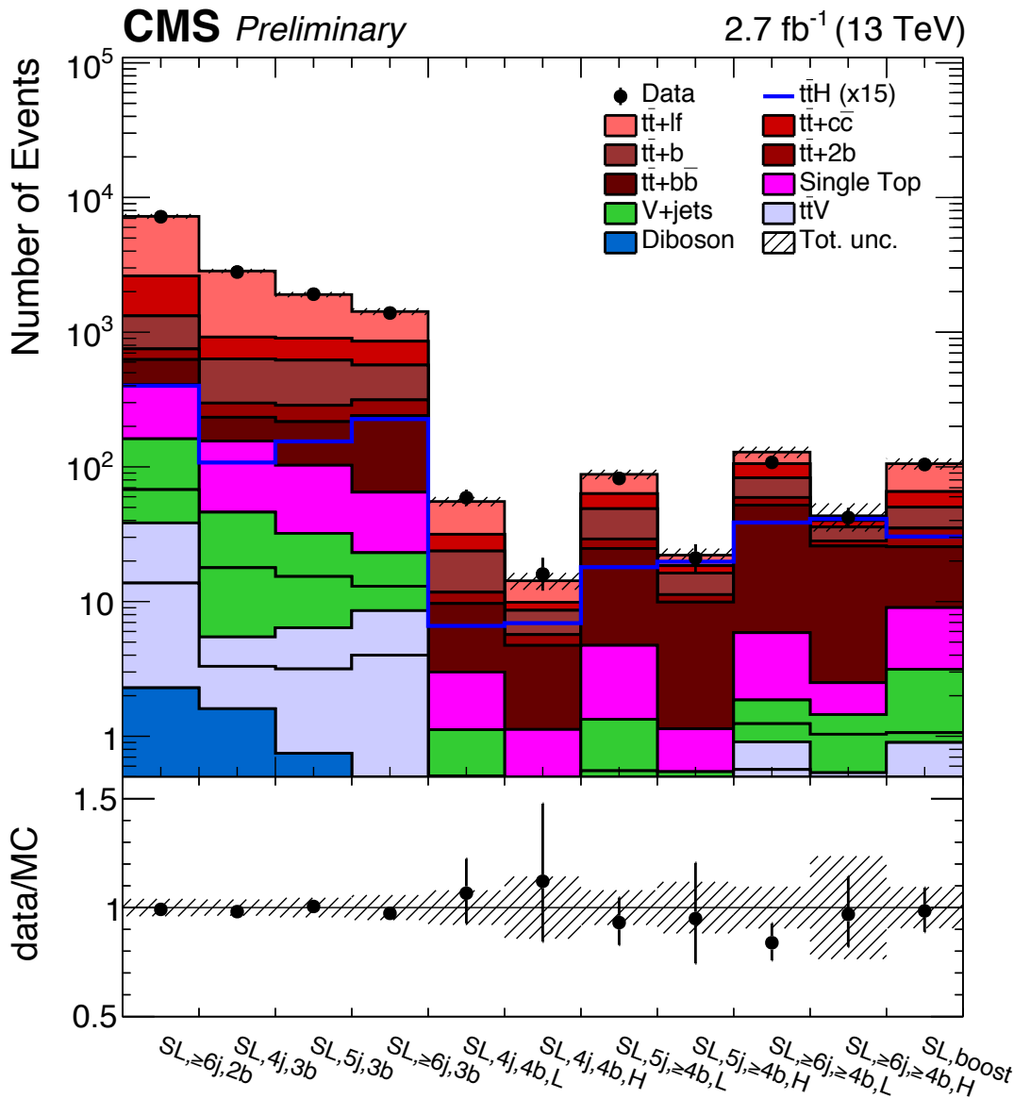


Categorisation



tt +jets modeling





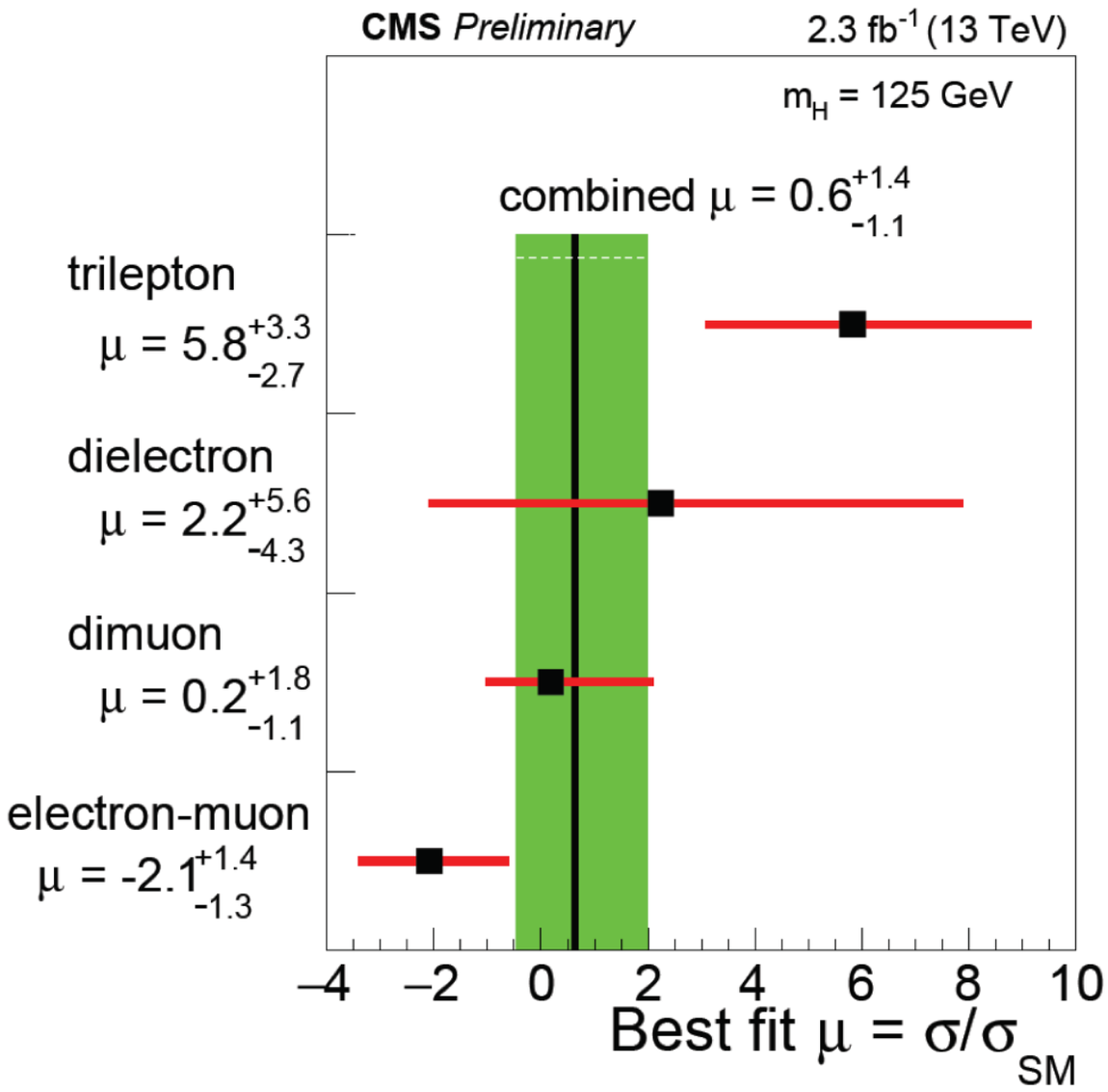
- tt+HF modeling : good agreement in HF enriched regions
- tt+jets modeling ongoing : differential tt cross section as function of multiplicity of additional jets ongoing (ATLAS-CONF-2015-065, CMS-TOP-16-011)

Cut flow

S/B : 1/10

	$\mu\mu$	ee	eμ	3ℓ
$t\bar{t}W$	3.22 ± 0.16	1.47 ± 0.11	4.95 ± 0.19	2.56 ± 0.14
$t\bar{t}Z/\gamma^*$	0.82 ± 0.03	1.14 ± 0.14	2.42 ± 0.17	3.75 ± 0.18
WZ	0.09 ± 0.05	0.06 ± 0.06	0.25 ± 0.11	0.33 ± 0.11
tttt	0.19 ± 0.03	0.11 ± 0.02	0.28 ± 0.03	0.22 ± 0.03
tZq	0.10 ± 0.06	0.00 ± 0.00	0.12 ± 0.13	0.44 ± 0.17
rare SM bkg.	0.06 ± 0.03	0.04 ± 0.04	0.13 ± 0.06	0.16 ± 0.59
non-prompt (data)	3.99 ± 0.38	3.58 ± 0.38	10.10 ± 0.65	8.08 ± 0.67
charge mis-ID (data)		1.11 ± 0.05	1.65 ± 0.05	
all backgrounds	8.47 ± 0.42	7.52 ± 0.44	19.90 ± 0.73	15.55 ± 0.95
$t\bar{t}H$ signal	1.53 ± 0.08	0.69 ± 0.05	2.27 ± 0.10	2.12 ± 0.09
data	9	11	11	28

μ by category



MVAs

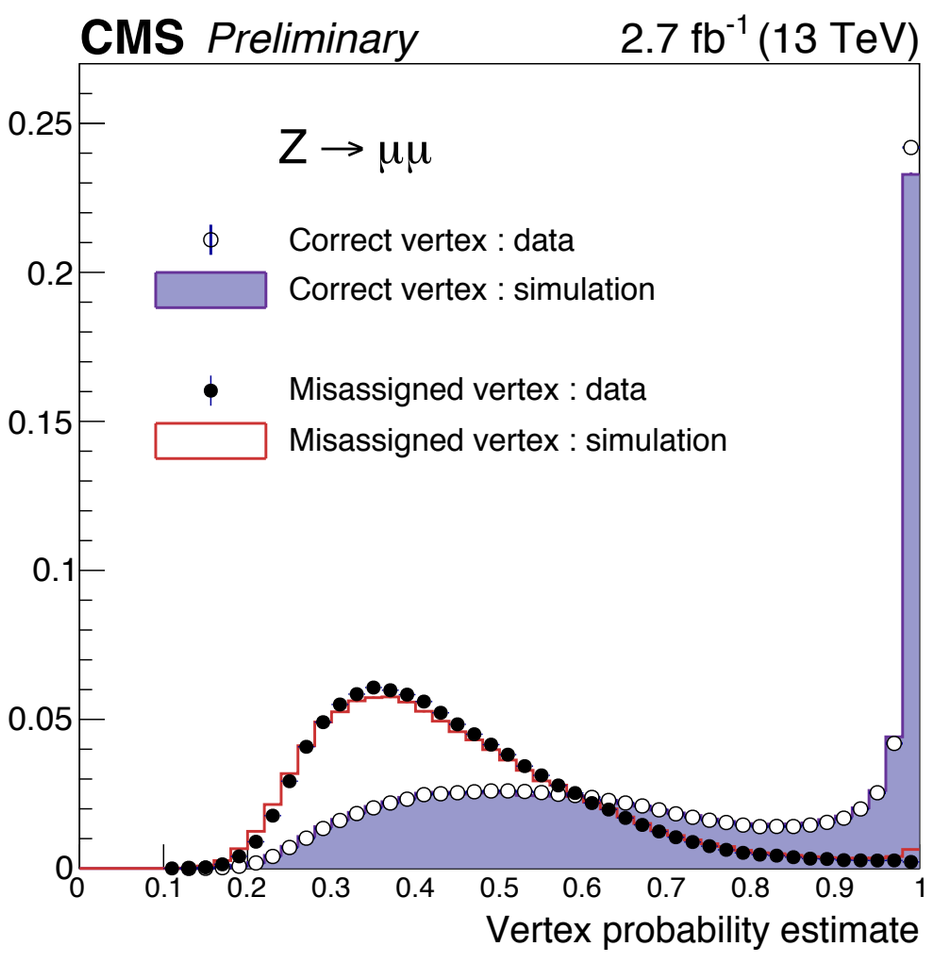
- Lepton BDT against leptons from b hadron decays :
  - IPs, PF isolation, closest jet to lepton (pT(l)/pT(jet), b-tagging, pTrel, n charged), lepton IDs…

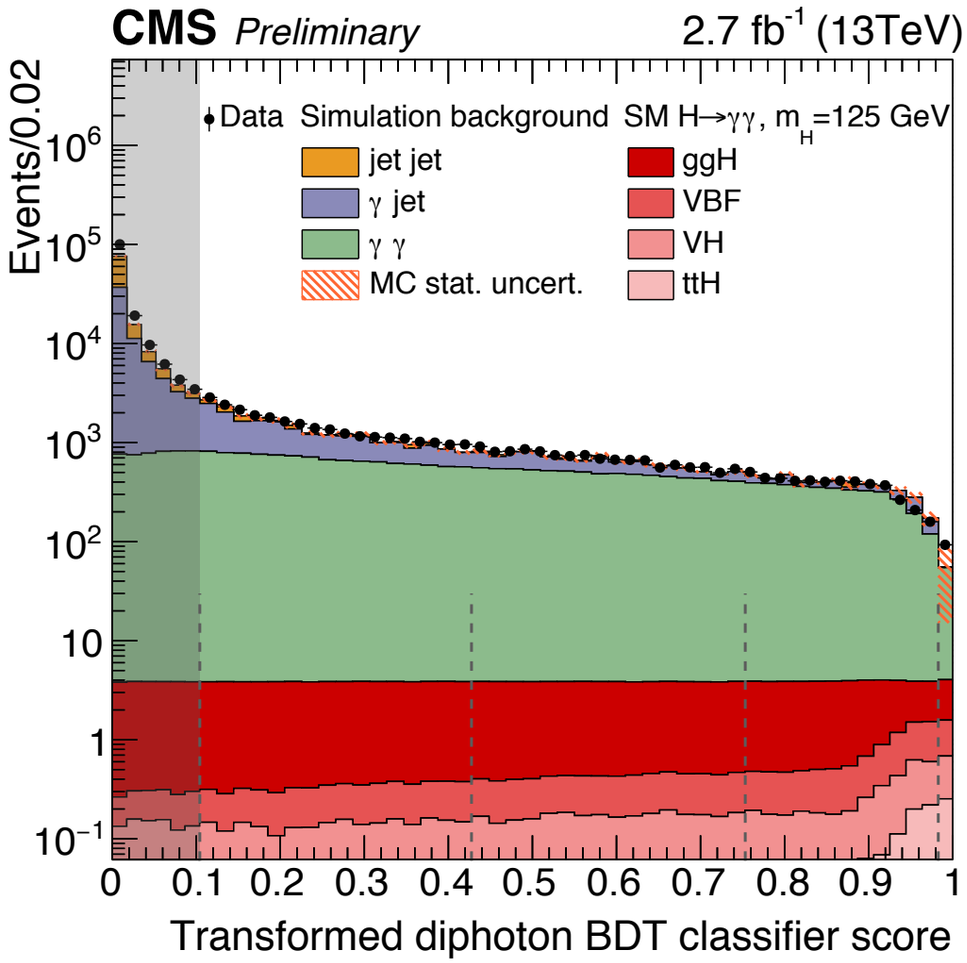
- ttH/tt BDT : maximum |η| of two leading leptons, jet multiplicity, minimum distance between lead. (trailing) lepton and closest jet, met or HT, MT(met, lead. lepton), average jet-jet separation…

- ttH/ttV BDT : pT of leading and trailing leptons instead of met and average jet-jet separation…

MVAs…

- Regression for γ energy calibration
- BDT for di-γ vertex assignment (tracks recoiling against γγ…)
- BDT to estimate the vertex probability to be less than 1 cm away from the IP - diphoton mass resolution dominated by ECAL energy only if IP known to better than 1cm
- BDT for γ ID (shower shapes, iso variables…)
- BDT for di-γ selection (γ kinematics, mass resolution, γ ID, PV proba…) - should be independent of di-γ mass





Cut flow

Event Categories	SM 125 GeV Higgs boson expected signal yield								Bkg (GeV^{-1})
	Total	ggH	VBF	WH	ZH	ttH	σ_{eff} (GeV)	σ_{HM} (GeV)	
Untagged 0	2.08	**76.19** %	10.06 %	7.45 %	3.98 %	2.32 %	1.25	1.17	0.93
Untagged 1	30.44	**86.24** %	7.13 %	3.73 %	2.12 %	0.79 %	1.41	1.22	61.19
Untagged 2	43.36	**91.16** %	4.80 %	2.39 %	1.29 %	0.36 %	1.86	1.50	165.52
Untagged 3	42.18	**92.18** %	4.21 %	2.05 %	1.16 %	0.40 %	2.63	2.20	350.94
VBF Tag 0	3.00	35.28 %	**63.48** %	0.68 %	0.19 %	0.36 %	1.61	1.24	1.57
VBF Tag 1	4.08	53.14 %	**43.62** %	1.69 %	0.85 %	0.69 %	1.77	1.35	6.85
TTH Hadronic Tag	0.64	8.76 %	0.41 %	1.66 %	2.10 %	**87.06** %	1.56	1.31	0.90
TTH Leptonic Tag	0.23	0.14 %	0.09 %	2.91 %	1.31 %	**95.55** %	1.73	1.56	0.03
Total	126.00	86.92 %	7.87 %	2.62 %	1.45 %	1.14 %	1.94	1.49	587.92