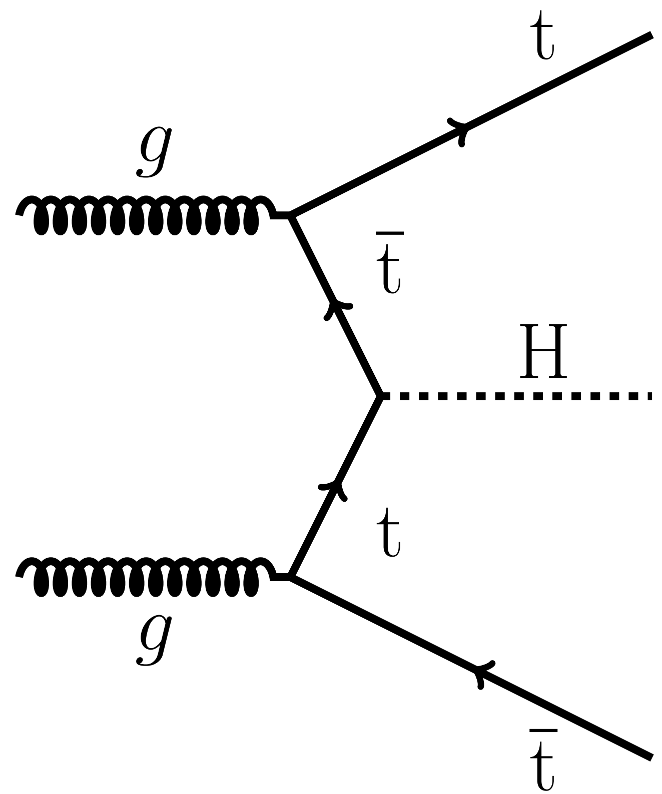
Latest CMS results on Higgs boson production in association with top quarks



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On behalf of the CMS collaboration

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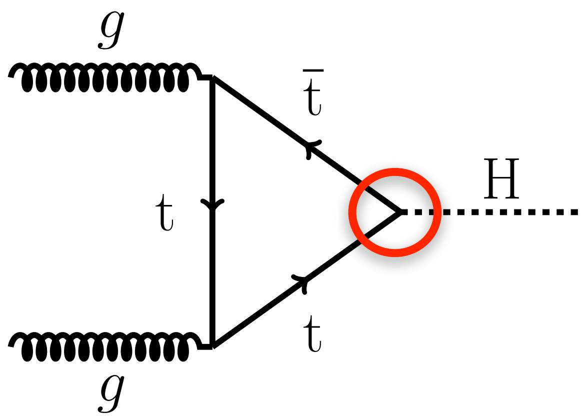
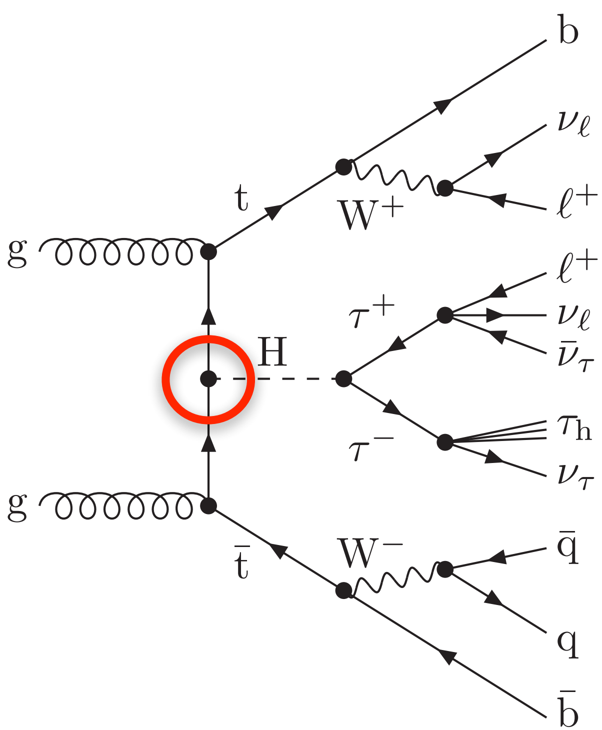
Introduction

- In SM, top-Higgs coupling (Y_t) **very large wrt other fermions:** good opportunity to study Higgs Yukawa couplings to fermions

- Access to Y_t with **ggF + H→$\gamma\gamma$ decay**

- **Only model-dependent constraints on Y_t,** assuming no BSM particles in the loop





- **ttH => direct probe to study Y_t**

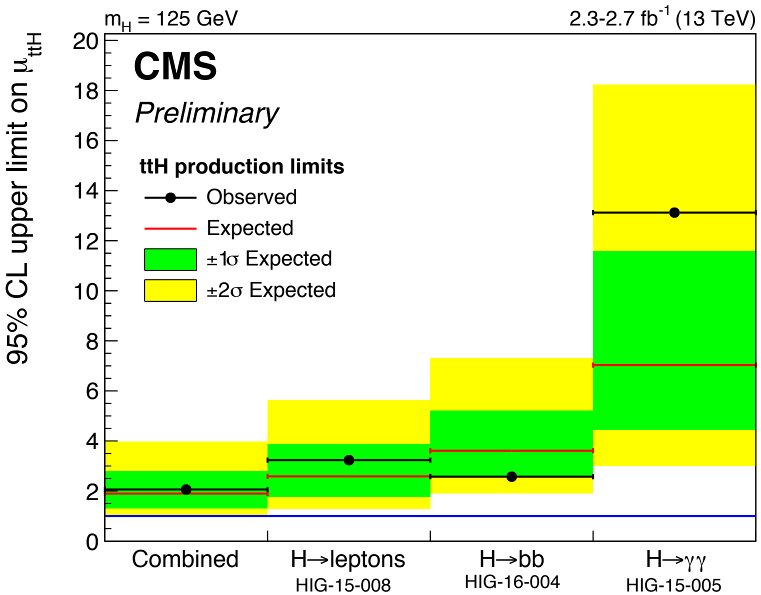
- Large cross-section boost from 8 to 13 TeV (x4) **=> expected to be observed by the end of LHC Run 2**

- Challenging because **complex final state** **=> use of MultiVariate Analysis (MVA) discriminants** for signal extraction

Previous CMS results

- ttH searches in CMS covers **all main Higgs boson decay modes:**
  - $H \to \gamma\gamma$
  - $H \to bb$
  - $H \to WW/ZZ/\tau\tau$ (multilepton)

- Sensitivity to processes with top quarks enhanced with **jet multiplicity + b-tagging**



[CMS ttH 2015 combination (link)]

- **Run 1 CMS ttH combination** yielded in a **mild 2σ excess** with respect to the SM expectation

- **2015 CMS ttH combination:**
  - **95% CL upper limit on μ(ttH): 2.1 obs. (1.9 exp.)**
  - Best fit

$$\hat{\mu}_{obs}(ttH) = 0.15^{+0.95}_{-0.81}$$

- Results presented here correspond to updates of all those analyses with **12.9/fb of 13 TeV collision data collected in 2016**

ttH H→$\gamma\gamma$ CMS PAS HIG-16-020

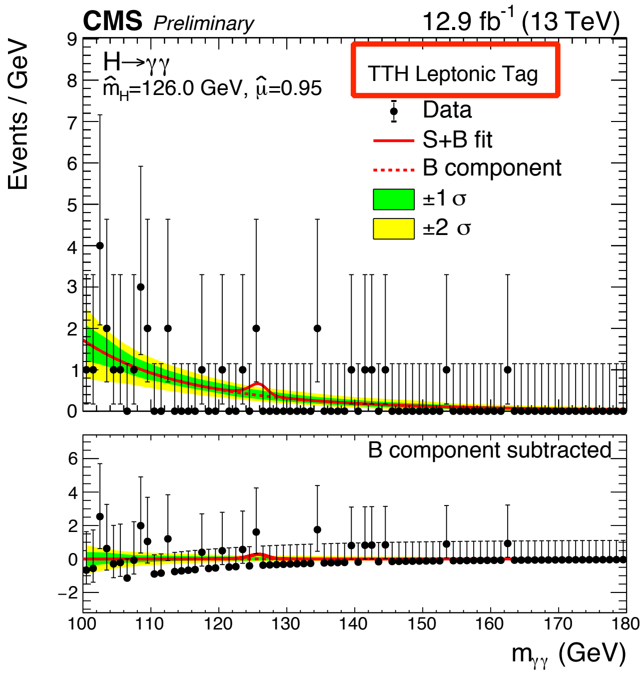
- Targets H→$\gamma\gamma$ decay mode: **limited statistics** but **distinctive signature + very pure channel**

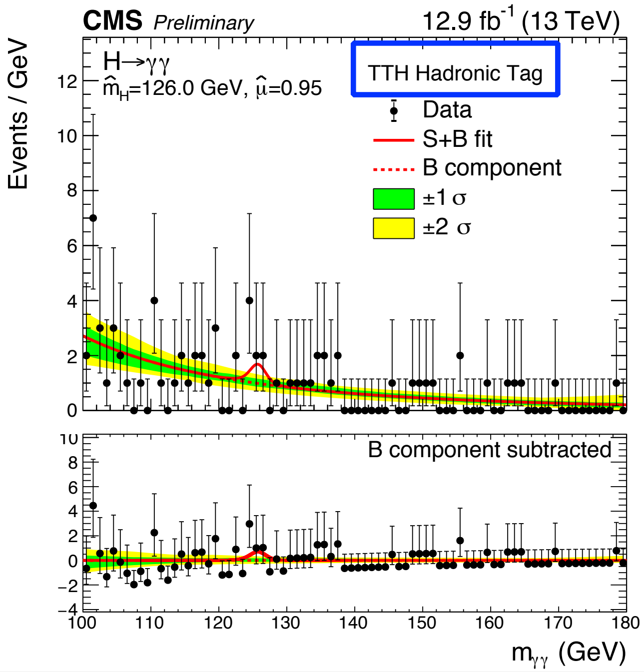
- Two ttH sensitive channels, part of main H→$\gamma\gamma$ analysis
  - **ttH leptonic**: 2γ + ≥1 lepton + ≥ 2 jets (≥ 1 b-tag)
  - **ttH hadronic**: 2γ + ≥ 5 jets (≥ 1 b-tag)

- **Main background tt+genuine/fakes γ:** estimated from fit of m($\gamma\gamma$) distribution

- **Diphoton mass m($\gamma\gamma$) used for signal extraction**

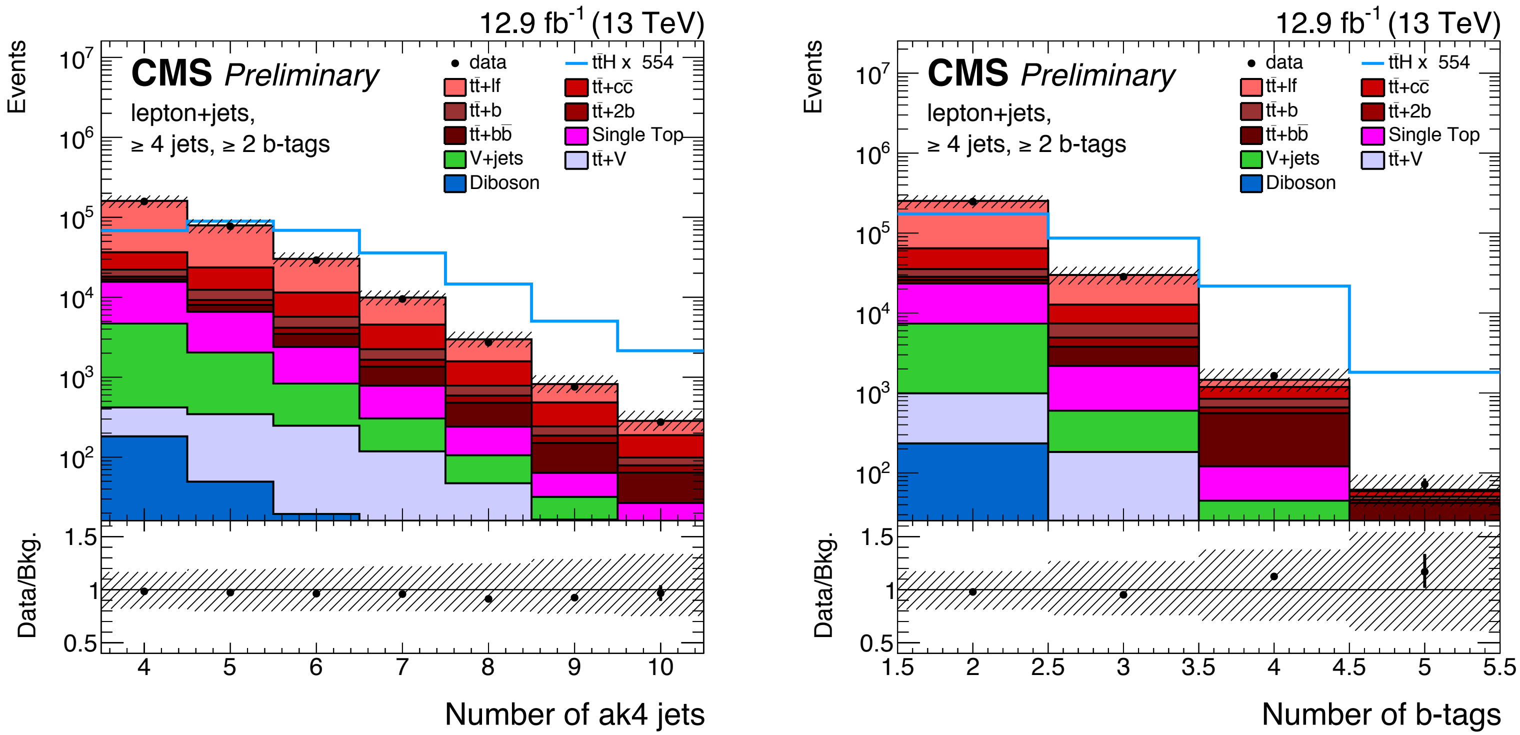
- **Best fit value** $\hat{\mu}_{obs}(ttH) = 1.91^{+1.5}_{-1.2}$





- H→bb decay mode: **highest BR** but:
  - **large b-jet multiplicity**
  - **irreducible ttbb background**

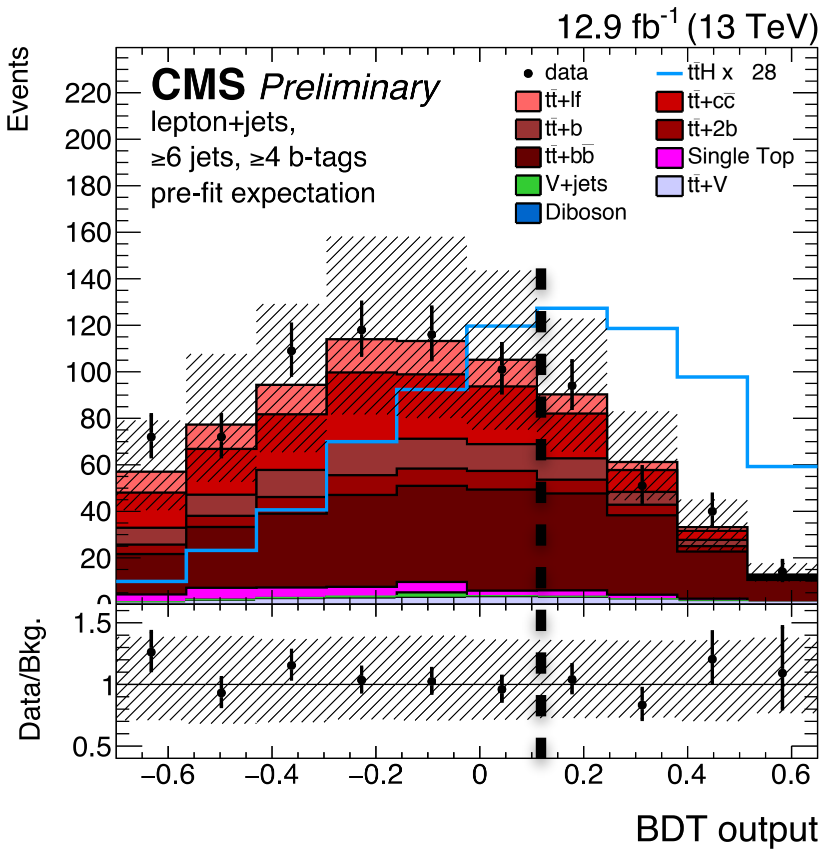
- Update wrt 2015 analysis:
  MC signal + ttbar background evaluated with **new CMS tune CUETP8M2T4 for Powheg Box v2 + Pythia 8** (α_{ISR}=0.118 and h_{damp}=272.2)
  => better data/MC agreement for jet multiplicity



ttH H→bb [CMS PAS HIG-16-038]

- **Two channels considered:**
  - lepton+jets: 1 lepton + ≥ 4 jets
  - dilepton: 2 OS leptons + ≥ 2 jets

- Categories based on **jet multiplicity + b-tagging**



Example:
BDT input in lepton+jets ≥ 6 jets, ≥ 4 b-tags

- best Higgs mass
- M_2(tag,tag) closest to 125 GeV
- M(jets,lepton,MET)
- 4th and 5th highest b-tag discriminator score
- Σp_T(jets,lepton,MET)

- Further categorization based on **Boosted Decision Trees (BDTs)**: **ttH(bb) signal** vs **inclusive ttbar background**

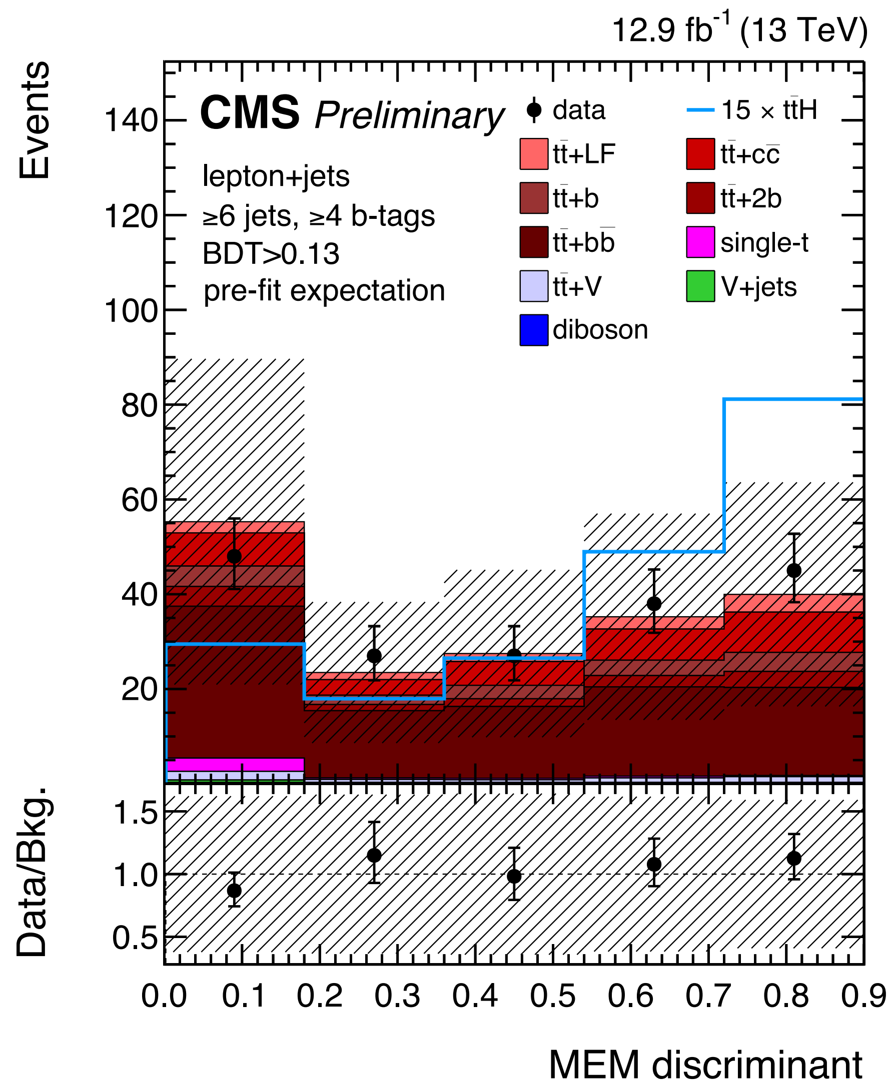
- **Subcategories for low/high BDT score**

- **Matrix Element Method (MEM)** used to compute per-event signal/background probability: **hard scattering ME + detector transfer functions**

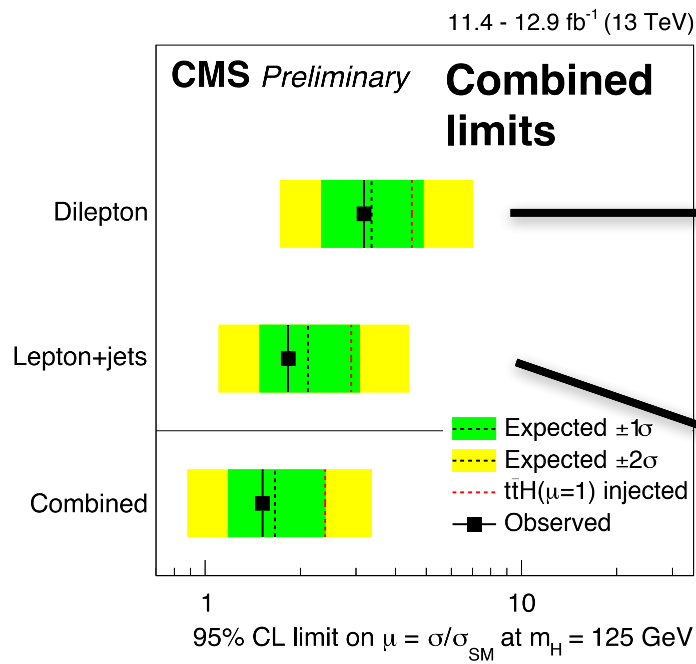
- Used to define MEM discriminant **optimized to separate ttH(bb) signal from irreducible ttbb background**

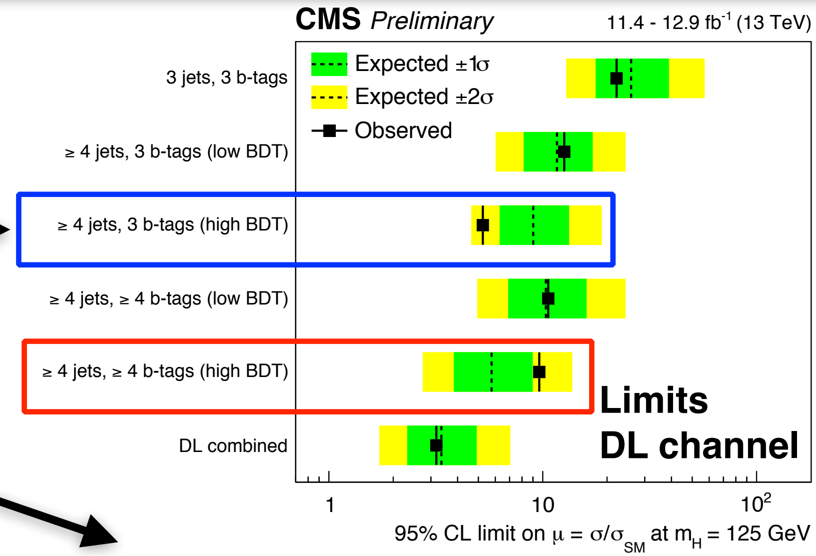
$$P_{s/b} = \frac{w(\vec{y}|t\bar{t}H)}{w(\vec{y}|t\bar{t}H) + k_{s/b}\, w(\vec{y}|t\bar{t}+b\bar{b})}$$

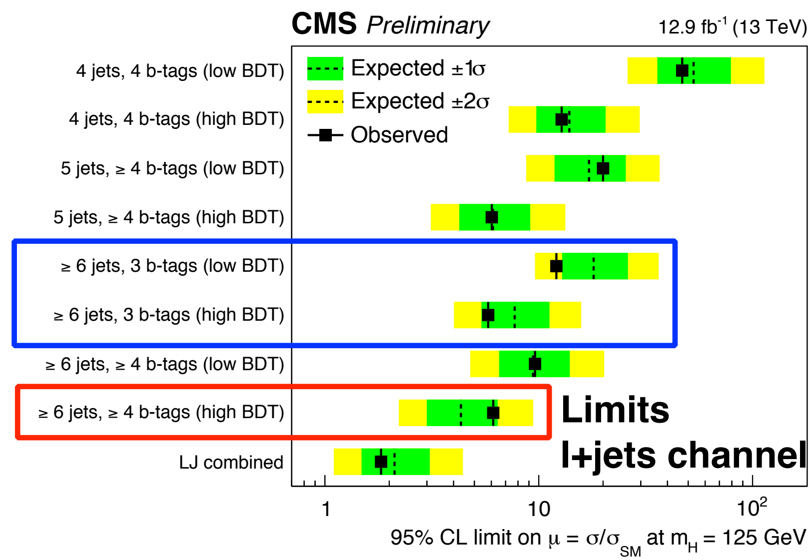
- **Fit MEM discriminant for signal extraction** in each BDT subcategories



ttH H→bb [CMS PAS HIG-16-038]







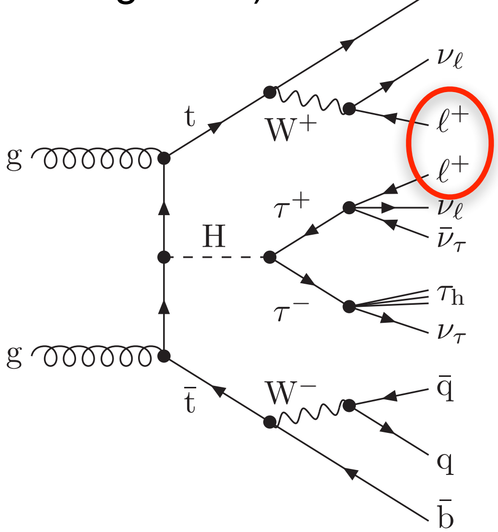
- **Upward fluctuations in most sensitive subcategories**
- **Downwards fluctuations in higher stat subcategories**
- **Best fit value** $\hat{\mu}_{obs}(ttH) = -0.19^{+0.80}_{-0.81}$
- **Combined observed (expected) limit of μ<1.5 (1.7) at 95% CL**

ttH multilepton CMS PAS HIG-16-022

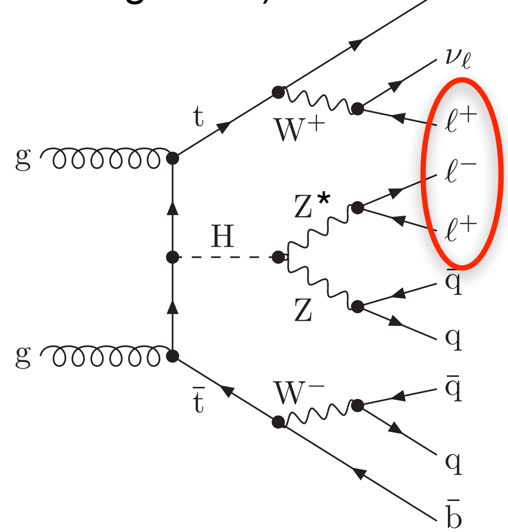
- **Multilepton final states from H→WW/ZZ/$\tau\tau$ decays**

- **Two main channels:**

  - **2 same-sign leptons**
    + ≥ 4 jets (≥ 1 b-tag medium or ≥ 2 b-tag loose)



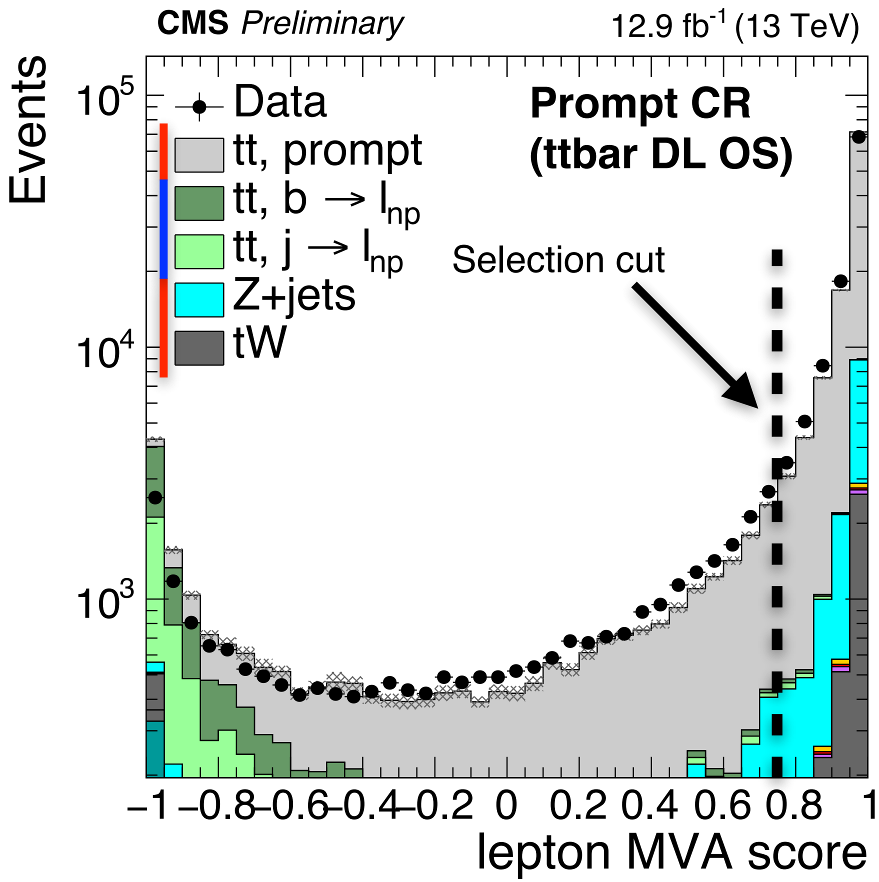
  - **3 leptons or more** (with Z-veto)
    + ≥ 2 jets (≥ 1 b-tag medium or ≥ 2 b-tag loose)



- Further categorization based on **lepton flavor, lepton charge, b-tagging, presence of hadronically-decaying τ**

- **Main sources of background:**
  - **irreducible:** ttV (from MC), di-boson (normalization from data)
  - **reducible:** non-prompt leptons and charge mis-ID (data-driven)

ttH multilepton CMS PAS HIG-16-022



- **Leptons** selected with **MVA** trained to discriminate **prompt leptons** (from W, Z or τ decays) from **non-prompt leptons** (from b-jets and mis-identified hadrons)
- **Inputs**:
  - isolation
  - vertex
  - lepton ID
  - jet variables
- Performance validated in data control regions (CR)

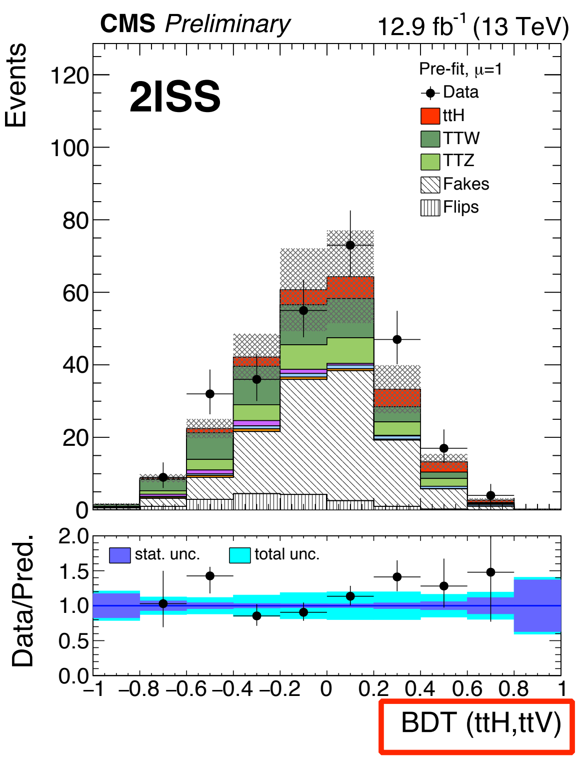
- Residual background with non-prompt evaluated using **tight-to-loose fake rate method**
- **Main systematics:**
  - lepton selection efficiency
  - fake rate measurement used for background estimation

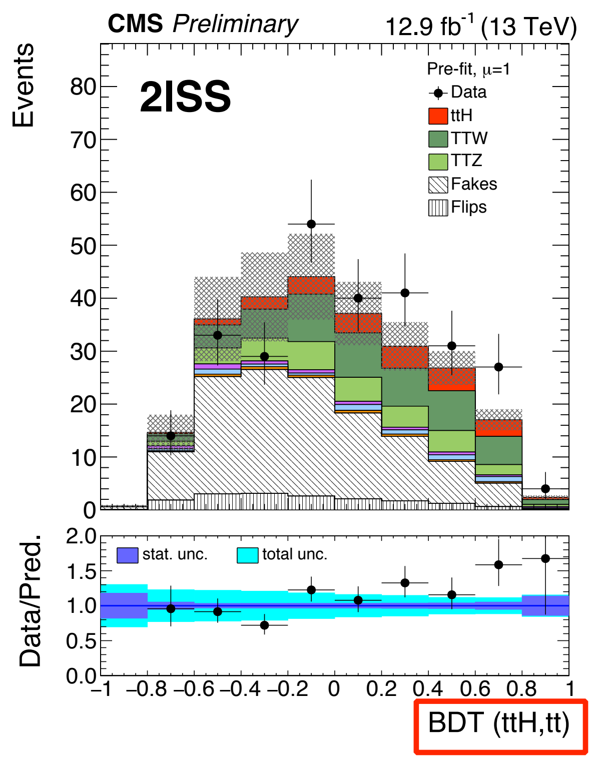
ttH multilepton CMS PAS HIG-16-022

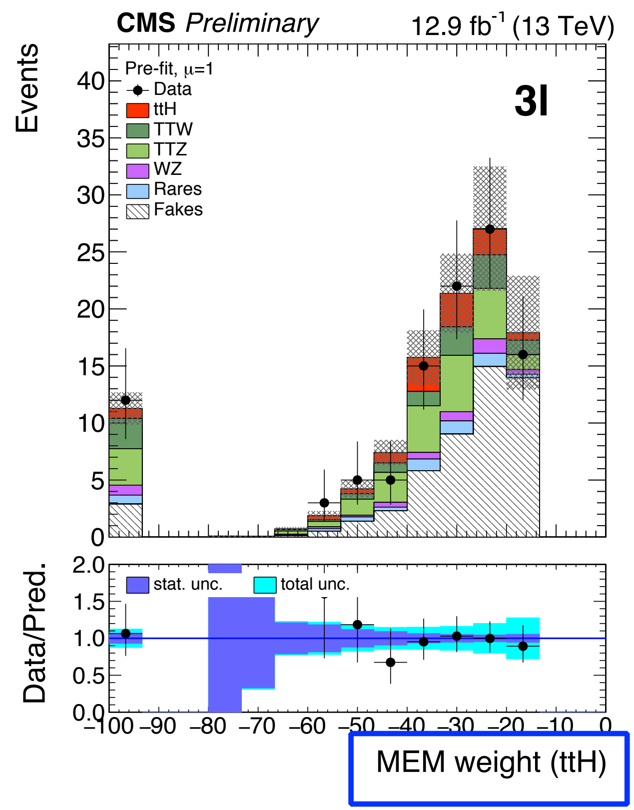
- **Signal extraction based on 2 BDTs** trained to discriminate **ttH / ttV** and **ttH / tt**
  Inputs: jet multiplicity, lepton/jet angular separation, MET, lepton p_T

- **New for 2016 analysis**: in 3l category, **MEM weights for ttH and ttV hypotheses** used as additional inputs

- **2D fit used for signal extraction**



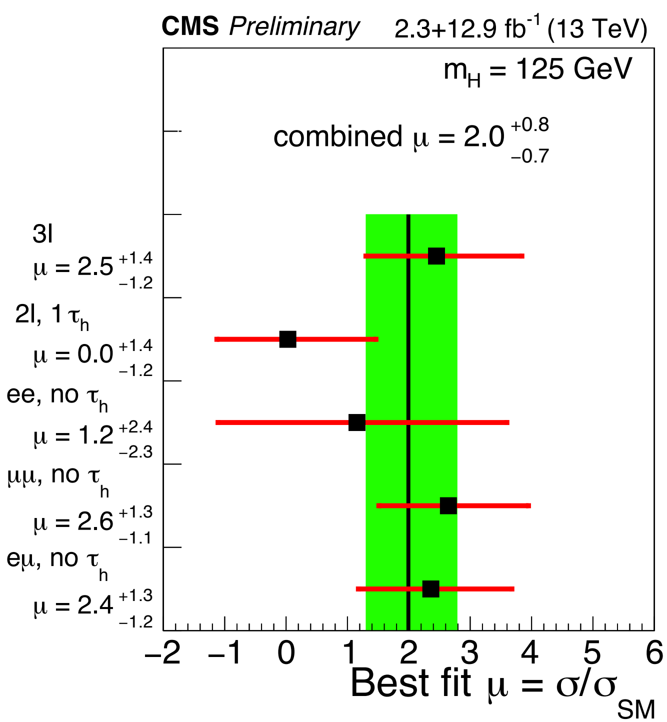


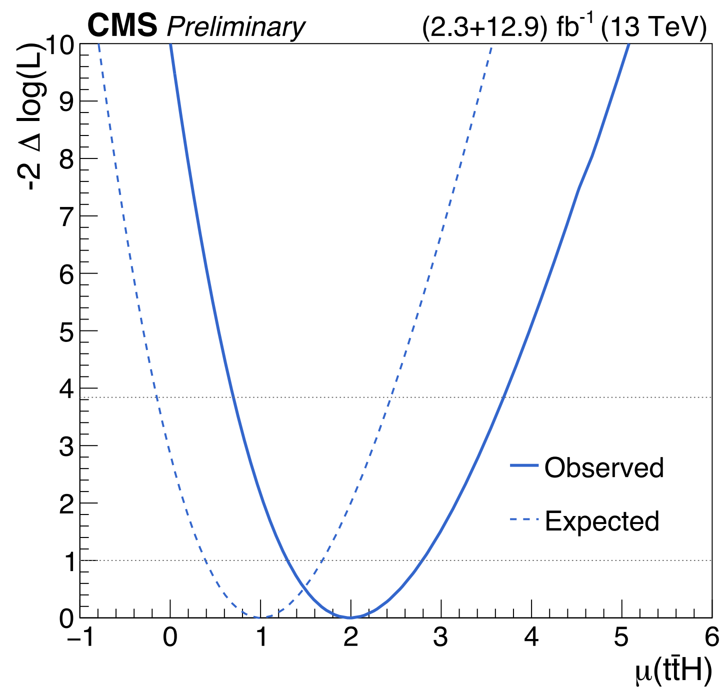


ttH multilepton CMS PAS HIG-16-022

- **Results from early 2016 dataset (12.9/fb) and from the combination with the ttH multilepton 2015 result**

Category	Obs. limit	Exp. limit $\pm 1\sigma$	Best fit $\mu \pm 1\sigma$
Same-sign dileptons	4.6	$1.7^{+0.9}_{-0.5}$	$2.7^{+1.1}_{-1.0}$
Trileptons	3.7	$2.3^{+1.2}_{-0.7}$	$1.3^{+1.2}_{-1.0}$
Combined categories	3.9	$1.4^{+0.7}_{-0.4}$	$2.3^{+0.9}_{-0.8}$
Combined with 2015 data	3.4	$1.3^{+0.6}_{-0.4}$	$2.0^{+0.8}_{-0.7}$



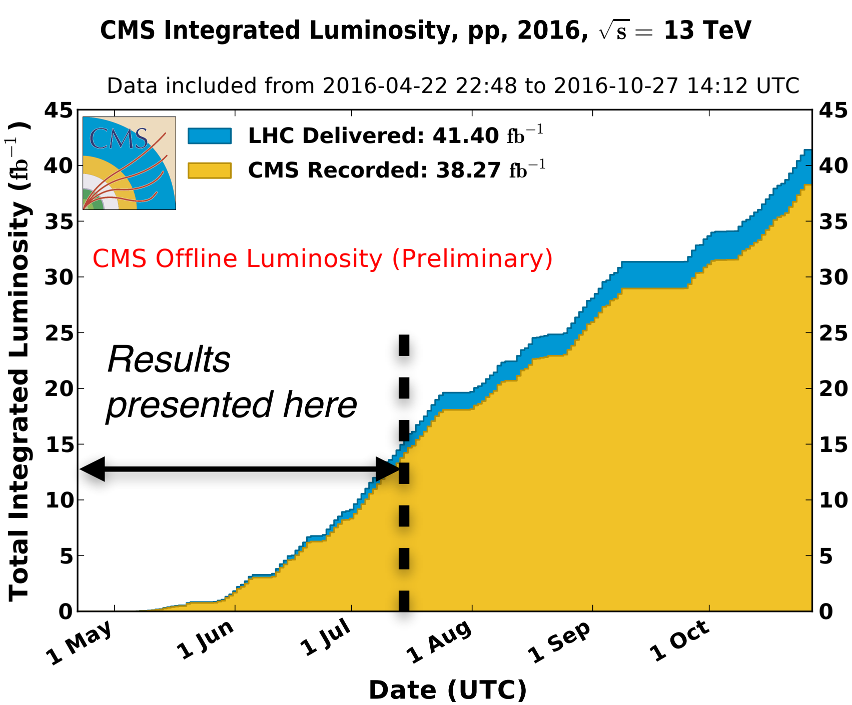


Conclusion

- Latest CMS results on the associated production of the Higgs boson with top quarks have been presented

- Allows to probe **top-Higgs coupling at tree level**

- Challenging final states with large multiplicity of jets and leptons but benefits from **advanced methods used to improve the sensitivity (BDT, MEM)**



- ttH, H→γγ $\hat{\mu}_{obs}(ttH) = 1.91^{+1.5}_{-1.2}$
- ttH, H→bb $\hat{\mu}_{obs}(ttH) = -0.19^{+0.80}_{-0.81}$
- ttH multilepton (2015+2016 combination) $\hat{\mu}_{obs}(ttH) = 2.0^{+0.8}_{-0.7}$

- Results compatible **both with SM or possible ttH excess**

- **Full 2016 dataset currently being analysed:** stay tuned for upcoming ttH results

Back-up

- **ttH leptonic tag selections**

  - leading photon $p_T > m_{\gamma\gamma}/2$;
  - sub-leading photon $p_T > m_{\gamma\gamma}/4$;
  - at least one lepton with $p_T > 20$ GeV: electrons must be within the ECAL fiducial region and pass the recommended criteria for loose requirements on the same observables as described in [27]. In addition the electron should satisfy $|m(e,\gamma) - m_Z| > 10$ GeV, where m_Z refers to the Z boson mass. Muons are required to have $|\eta| < 2.4$ and to pass a tight selection based on the quality of the track, the number of hits in the tracker and muon system, and the longitudinal and transverse impact parameters of the track with respect to the muon vertex; additionally, it has to satisfy a requirement on the relative isolation with pileup correction, based on the transverse momentum of the charged hadrons, transverse energy of the neutral hadrons and photons in a cone of $R = 0.4$ around the muon;
  - all selected leptons (ℓ) are required to have $\Delta R(\ell,\gamma) > 0.4$;
  - at least two jets in the event with $p_T > 25$ GeV, $|\eta| < 2.4$, and $\Delta R(\text{jet},\gamma) > 0.4$ and $\Delta R(\text{jet},\ell) > 0.4$;
  - at least one of the jets in the event has to be identified as b jet according to the CSV tagger medium requirement [28].
  - $\text{BDT}_{\gamma\gamma}$ output > -0.4. Too few events are available to optimise this selection for signifiance, so this choice is made simply to remove most of the events with low $\text{BDT}_{\gamma\gamma}$ score.

- **ttH hadronic tag selections**

  - leading photon $p_T > m_{\gamma\gamma}/2$;
  - sub-leading photon $p_T > m_{\gamma\gamma}/4$;
  - no leptons defined according to the leptonic tag;
  - at least five jets in the event with $p_T > 25$ GeV and $|\eta| < 2.4$;
  - at least one of the jets in the event has to be identified as a b-jet according to the CSV tagger medium requirement [28];
  - a minimum value of $\mathrm{BDT}_{\gamma\gamma}$ output. The value is a compromise between significance optimisation and the need of a minimum number of events to fit the background.

Matrix Element Method

[CMS PAS HIG-16-038](#) [CMS PAS HIG-16-022](#)

- Used in ttH H→bb and multilepton analyses
- Event weight computed for hypothesis Ω (Ω=ttH, ttbb, ttV…), using observables y as inputs (lepton + jet 4-momenta, MET) and integrating over unmeasured or poorly measured quantities x (neutrino 4-momenta, quark energies…)

$$w_\Omega(\mathbf{y}) \propto \sum_p \int d\mathbf{x} dx_a dx_b \frac{f(x_a,Q)f(x_b,Q)}{x_a x_b s} \delta^2(x_a P_a + x_b P_b - \sum p_k) |\mathcal{M}_\Omega(\mathbf{x})|^2 W(\mathbf{y}||\mathbf{x})$$

Numerical integration → $\int d\mathbf{x} dx_a dx_b$

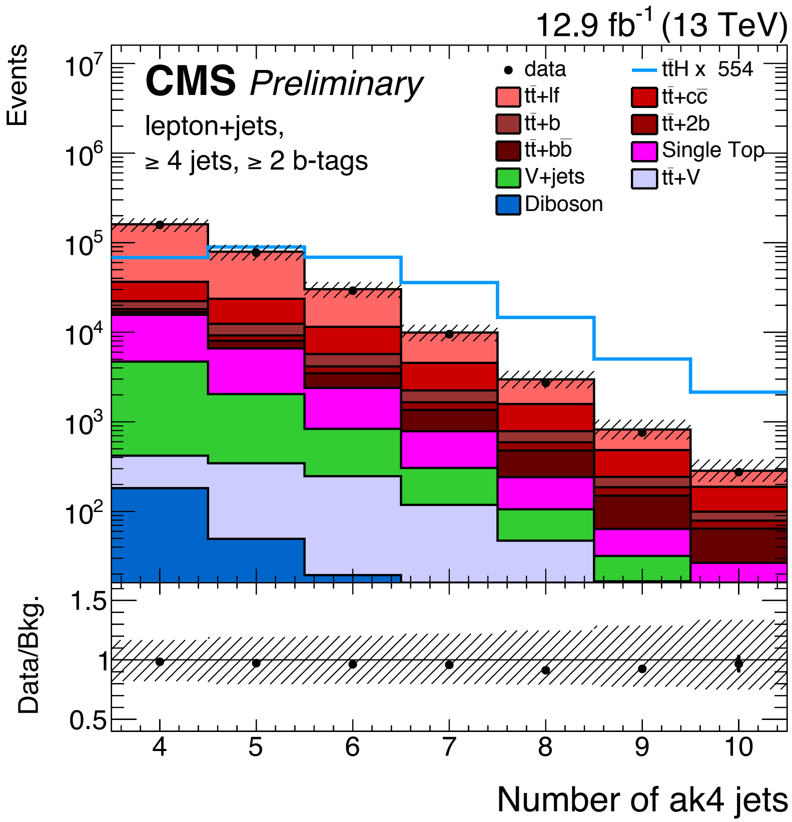
Parton density functions → $\frac{f(x_a,Q)f(x_b,Q)}{x_a x_b s}$

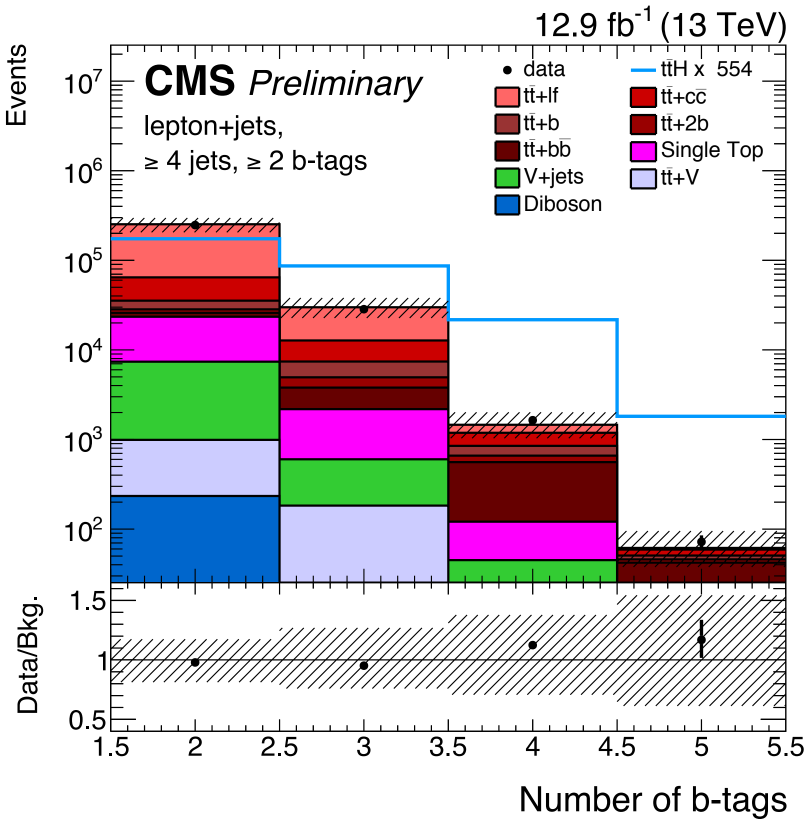
Momentum conservation → $\delta^2(x_a P_a + x_b P_b - \sum p_k)$

Hard-scattering matrix element → $|\mathcal{M}_\Omega(\mathbf{x})|^2$

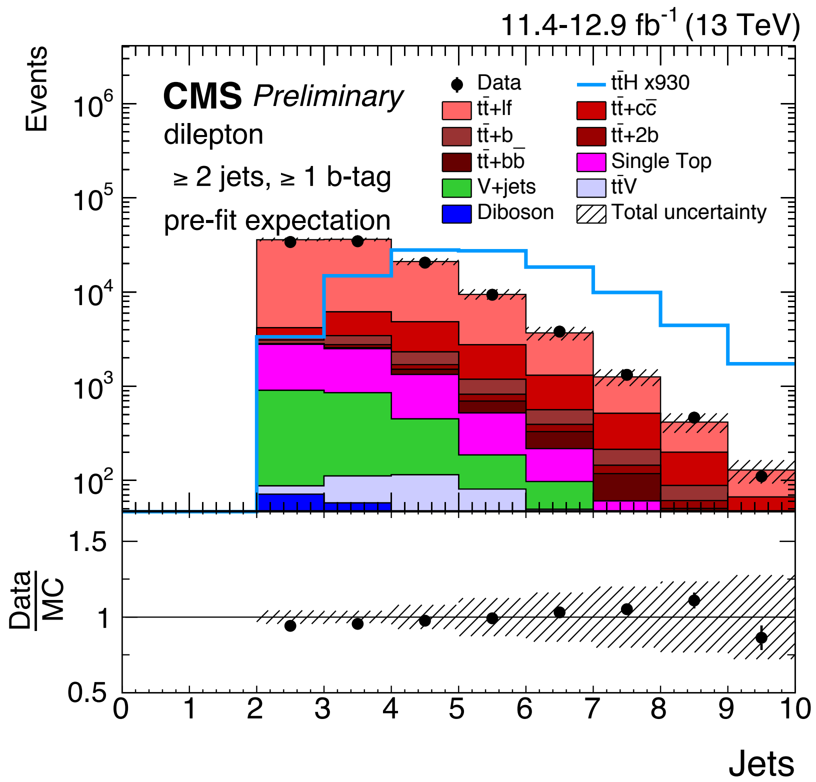
Detector transfer functions → $W(\mathbf{y}||\mathbf{x})$

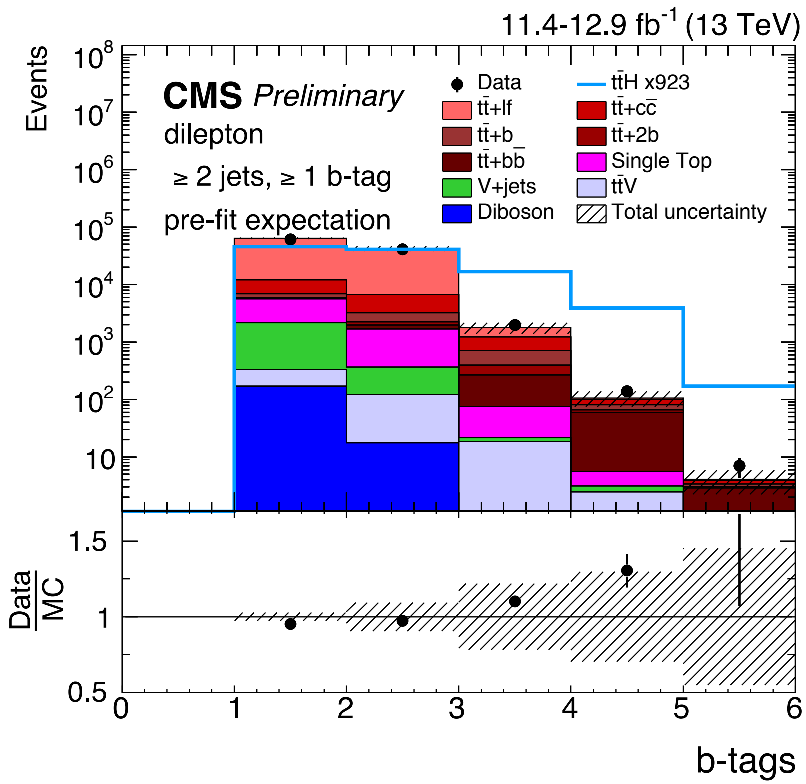
- **Jet multiplicity + b-tagged jets multiplicity**





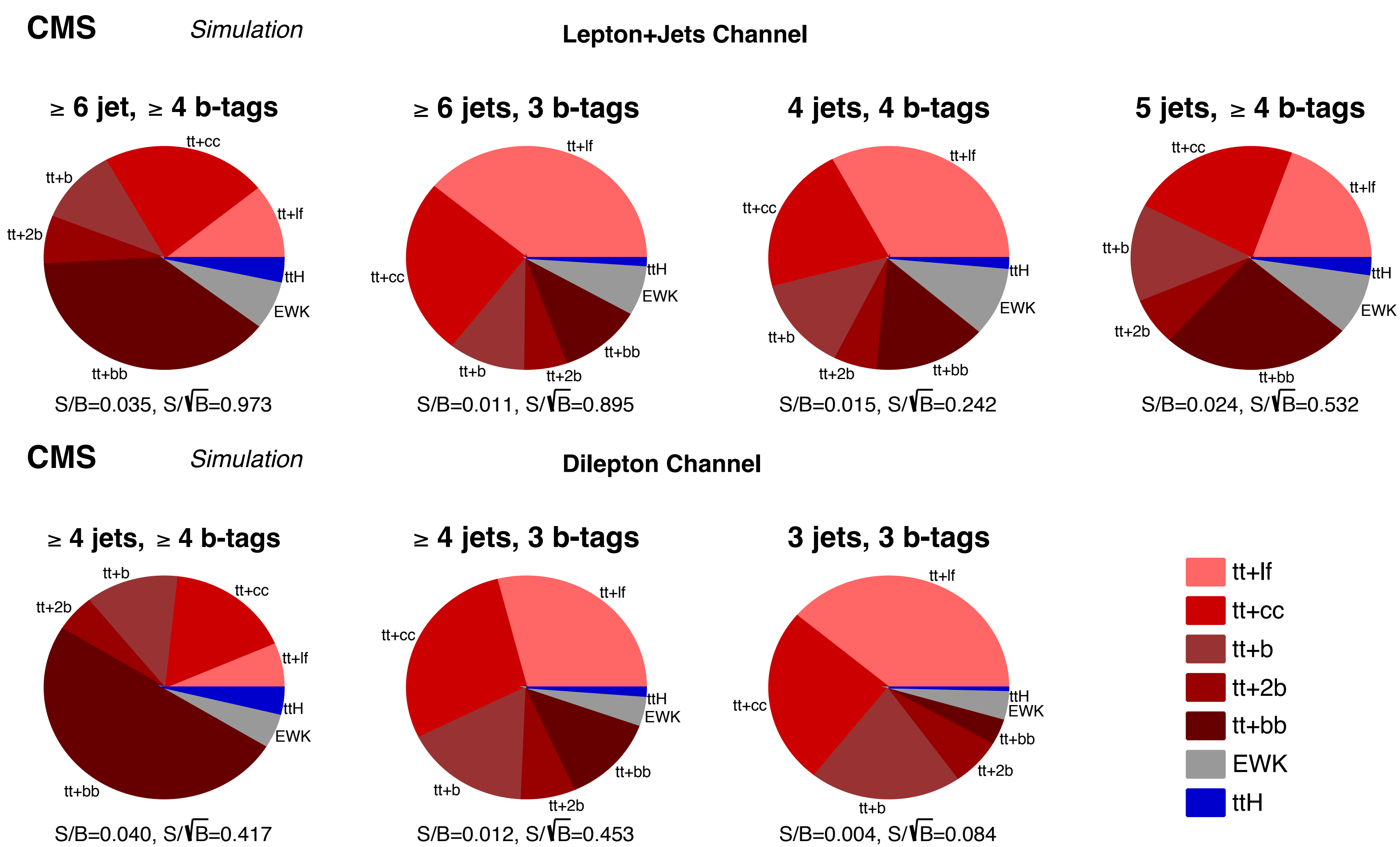
- **Jet multiplicity + b-tagged jets multiplicity**





ttH H→bb [CMS PAS HIG-16-038]

- **Categories based on jet multiplicity + b-tagging**



- **BDT input variables**

Event variable	Description
Object and event kinematics	
$\langle \Delta R_{\text{tag,tag}} \rangle$	Average ΔR between b-tagged jets
$\sum p_{T\text{jets,leptons}}$	Sum of the p_T of all jets and leptons
$\tau_{\text{jet,jet}}^{\text{max mass}}$	Twist angle between jet pair
min $\Delta R_{\text{tag,tag}}$	ΔR between the two closest b-tagged jets
max $\Delta \eta_{\text{tag,tag}}$	$\Delta \eta$ between the two furthest b-tagged jets
$M_{\text{jet,jet}}^{\min \Delta R}$	Invariant mass of jet pair with minimum ΔR
$M_{\text{higgs-like}}^{\text{jj}}$	Invariant mass of a jet pair ordered in closeness to the Higgs mass
$M_{\text{tag,tag}}^{\min \Delta R}$	Mass of b-tagged jet pair with minimum ΔR
$p_{T\ \text{tag,tag}}^{\min \Delta R}$	Sum of the p_T of b-tagged jet pair with minimum ΔR
Centrality (tags)	Ratio of the sum of the transverse momentum of all b-tagged jets and the sum of the energy of all b-tagged jets
Centrality (jets, leptons)	Ratio of the sum of the transverse momentum of all jets and leptons, and the sum of the energy of all jets and leptons

- **BDT input variables**

H_T	Scalar sum of transverse momentum for all jets
min $\Delta R_{\text{jet,jet}}$	ΔR between the two closest jets
median $M_{\text{jet,jet}}$	Median invariant mass of all combinations of jet pairs
$M^{\text{max mass}}_{\text{tag,tag}}$	Mass for b-tagged jet pair with maximum invariant mass combination
$\langle \Delta R_{jet,tag} \rangle$	Average ΔR between jets (with at least one b-tagged jet)
$p^{\min \Delta R}_{T\ jet,tag}$	Sum of the p_T of jet pair with minimum ΔR (with at least one b-tagged jet)
$\tau^{\text{max mass}}_{\text{jet,tag}}$	Twist angle between jet pair (with at least one b-tagged jet)
$\mathrm{m}^{\text{max p}_\text{T}}_{\text{jet,jet,jet}}$	Invariant mass of the 3-jet system with the largest transverse momentum.
$M^{\text{bj}}_{\text{higgs-like}}$	Invariant mass of a jet pair (with at least one b-tagged jet) ordered in closeness to the Higgs mass
CSVv2 b-tag	
$\langle d \rangle_{\text{tagged/untagged}}$	Average CSVv2 b-tag discriminant value for b-tagged/un-b-tagged jets
Event shape	
H_0, H_1, H_2, H_3, H_4	Fox-Wolfram moments **[?]**
C(jets)	$3\,(\lambda_1\lambda_2 + \lambda_1\lambda_3 + \lambda_2\lambda_3)$ **[?]**

- **BDT input variables**

4 jets, 4 tags	5 jets, $\geq$ 4 tags
$\sum p_T$(jets, lepton, MET) avg. CSVv2 of b-tagged jets aplanarity H_3 $(\Sigma p_T(\text{jet}))/(\Sigma E(\text{jet}))$ M_2 of min ΔR(tag, tag)	avg. $\Delta\eta$(jet, jet) HT avg. CSVv2 of b-tagged jets M_2(tag, tag) closest to 125 M_3 $\sum p_T$(jets, lepton, MET) M_2 of min ΔR(tag, tag) aplanarity avg. ΔR(tag, tag)
$\geq$ 6 jets, 3 tags	**$\geq$ 6 jets, $\geq$ 4 tags**
aplanarity $\sqrt{\Delta\eta(\text{t}^{\text{lep}}, \text{bb}) \times \Delta\eta(\text{t}^{\text{had}}, \text{bb})}$ $(\Sigma p_T(\text{jet}))/(\Sigma E(\text{jet}))$ min ΔR(tag, tag) 2nd moment of b-tagged jets' CSVv2 $\sum p_T$(jets, lepton, MET) b-tagging likelihood ratio	best Higgs mass M_2(tag, tag) closest to 125 M(jets, lepton, MET) 4th highest CSVv2 $\sum p_T$(jets, lepton, MET) 5th highest CSVv2

- **Lepton+jets channel**

- **Dilepton channel**

3 jets, 3 tags	$\geq$4 jets, 3 tags	$\geq$4 jets, $\geq$4 tags
$\langle d \rangle_{\text{tagged}}$	Centrality(jets & leptons)	Centrality(jets & leptons)
H_1(jets)	C(jets)	Centrality(tags)
$M^{\text{bj}}_{\text{higgs-like}}$	H_2(tags)	H_T^{tags}
$M^{\text{max mass}}_{\text{tag,tag}}$	$M^{\text{jj}}_{\text{higgs-like}}$	$M^{\text{jj}}_{\text{higgs-like}}$
min $\Delta R_{\text{tag,tag}}$	$M^{\text{max}\,p_T}_{\text{jet,jet,jet}}$	min $\Delta R_{\text{jet,jet}}$
max $\Delta\eta_{\text{jet,jet}}$	$M^{\text{min}\Delta R}_{\text{tag,tag}}$	$M^{\text{min}\Delta R}_{jet,tag}$
min $\Delta R_{\text{jet,jet}}$	min $\Delta R_{\text{tag,tag}}$	$M^{\text{max mass}}_{\text{tag,tag}}$
$\sum p_{T\,\text{jets,leptons}}$	max $\Delta\eta_{\text{tag,tag}}$	$M^{\text{min}\Delta R}_{\text{tag,tag}}$
H_4/H_0(tags)	$\tau^{\text{max mass}}_{\text{tag,tag}}$	max $\Delta\eta_{\text{jet,jet}}$
		max $\Delta\eta_{\text{tag,tag}}$
		median $M_{\text{jet,jet}}$

- **Particle Swarm**
  See: Particle swarm optimization, J. Kennedy, R. Eberhart
  Proceedings of the IEEE International Conference on Neural Networks, 1995.

- Optimization algorithm

- Different BDT setting (i.e. tree structure and variables) form the search-space

- A specific setting corresponds to one point in this search space

- **Algorithm**:
  - Create swarm of candidate BDTs
  - Each BDT is initialized with a random set of input variables and position in parameter-space
  - Do N iterations
    - Repeatedly train/test at current position
    - Vary input variables to maximize ROC curve
    - Then the BDTs move to new positions, based on their own and swarms best previous positions

ttH H→bb CMS PAS HIG-16-038

- **Systematics uncertainties**

Source	Type	Remarks
Luminosity	rate	Signal and all backgrounds
Lepton ID/Iso	shape	Signal and all backgrounds
Trigger efficiency	shape	Signal and all backgrounds
Pileup	shape	Signal and all backgrounds
Jet energy scale	shape	Signal and all backgrounds
Jet energy resolution	shape	Signal and all backgrounds
b-tag HF fraction	shape	Signal and all backgrounds
b-tag HF stats (linear)	shape	Signal and all backgrounds
b-tag HF stats (quadratic)	shape	Signal and all backgrounds
b-tag LF fraction	shape	Signal and all backgrounds
b-tag LF stats (linear)	shape	Signal and all backgrounds
b-tag LF stats (quadratic)	shape	Signal and all backgrounds
b-tag charm (linear)	shape	Signal and all backgrounds
b-tag charm (quadratic)	shape	Signal and all backgrounds

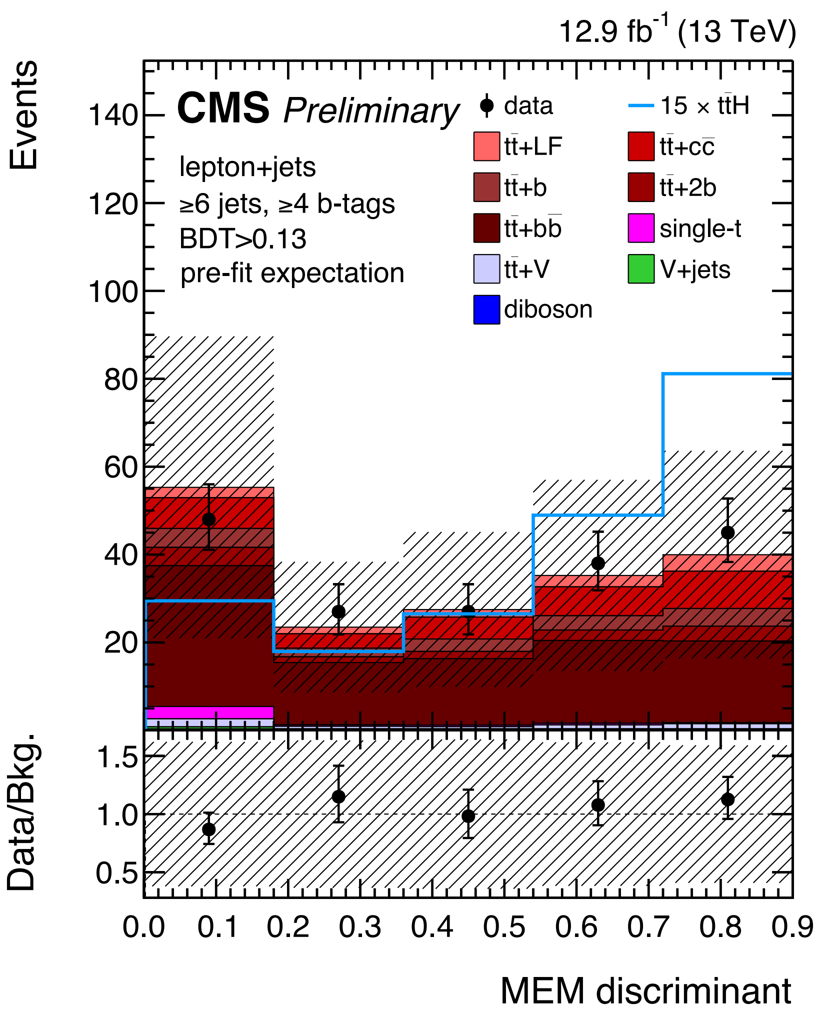
- **Systematics uncertainties**

QCD scale ($t\bar{t}$H)	rate	Scale uncertainty of NLO $t\bar{t}$H prediction
QCD scale ($t\bar{t}$)	rate	Scale uncertainty of NLO $t\bar{t}$ prediction
QCD scale ($t\bar{t}$+HF)	rate	Additional 50% rate uncertainty of $t\bar{t}$+HF predictions
QCD scale (t)	rate	Scale uncertainty of NLO single t prediction
QCD scale (V)	rate	Scale uncertainty of NNLO W and Z prediction
QCD scale (VV)	rate	Scale uncertainty of NLO diboson prediction
pdf (gg)	rate	PDF uncertainty for gg initiated processes except $t\bar{t}$H
pdf (gg $t\bar{t}$H)	rate	PDF uncertainty for $t\bar{t}$H
pdf ($q\bar{q}$)	rate	PDF uncertainty of $q\bar{q}$ initiated processes ($t\bar{t}$ W, W, Z)
pdf (qg)	rate	PDF uncertainty of qg initiated processes (single t)
Q^2 scale ($t\bar{t}$)	shape	Renormalization and factorization scale uncertainties of the $t\bar{t}$ ME generator, independent for additional jet flavors
PS Scale ($t\bar{t}$)	rate	Renormalization and factorization scale uncertainties of the parton shower (for $t\bar{t}$ events), independent for additional jet flavors
Bin-by-bin statistics	shape	statistical uncertainty of the signal and background prediction due to the limited sample size

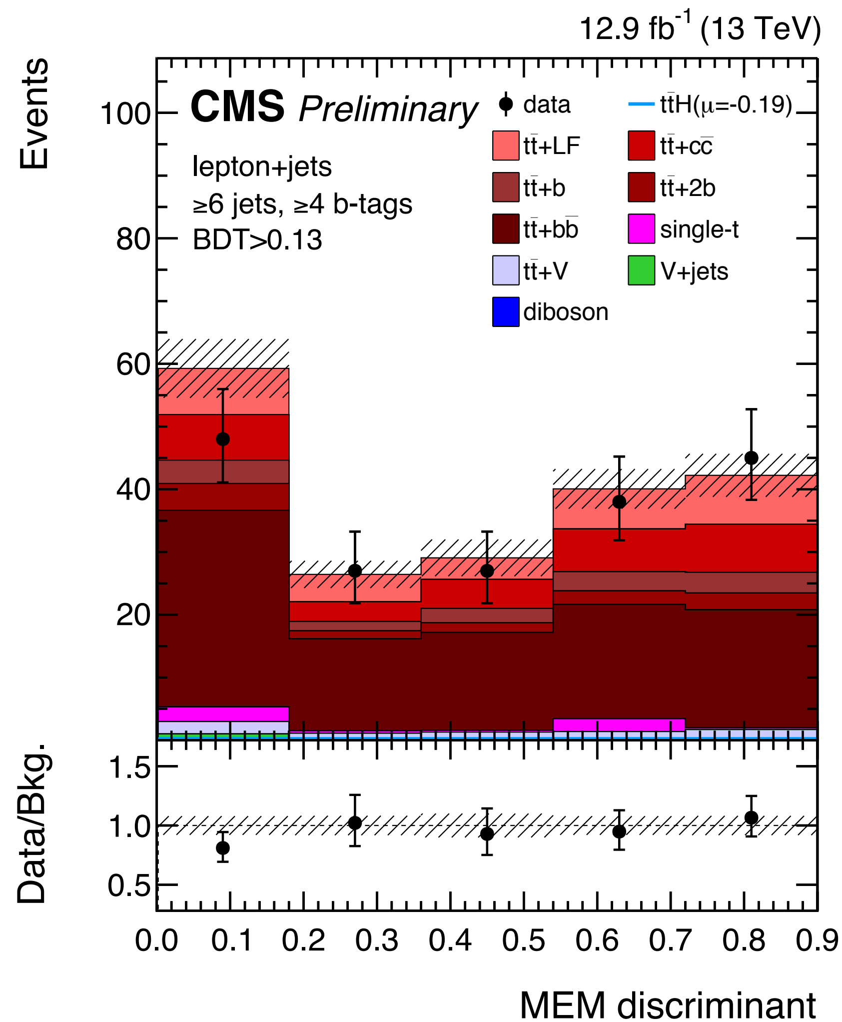
- **Specific effect of systematics uncertainties in ≥ 6 jets, 3 b-tag category**

Process	$t\bar{t}$ rate up/down [%]	$t\bar{t}H$ rate up/down [%]
Jet energy scale	+12.6/ − 11.8	+8.4/ − 8.0
Jet energy resolution	+0.2/ − 0.3	−0.0/ − 0.1
Pile-up	+0.1/ − 0.1	−0.2/ + 0.1
Electron efficiency	+0.5/ − 0.5	+0.5/ − 0.5
Muon efficiency	+0.4/ − 0.4	+0.4/ − 0.4
Electron trigger efficiency	+1.2/ − 1.2	+1.3/ − 1.3
Muon trigger efficiency	+0.8/ − 0.8	+0.9/ − 0.9
b-Tag HF contamination	−9.4/ + 9.8	−2.6/ + 2.8
b-Tag HF stats (linear)	−3.1/ + 3.3	−2.5/ + 2.7
b-Tag HF stats (quadratic)	+2.6/ − 2.4	+2.4/ − 2.2
b-Tag LF contamination	+7.1/ − 5.2	+5.8/ − 4.5
b-Tag LF stats (linear)	−2.0/ + 4.4	+0.5/ + 1.5
b-Tag LF stats (quadratic)	+2.1/ + 0.2	+1.5/ + 0.5
b-Tag charm Uncertainty (linear)	−11.1/ + 14.9	−3.1/ + 4.1
b-Tag charm Uncertainty (quadratic)	+0.5/ − 0.5	−0.0/ + 0.0
Q^2 scale ($t\bar{t}$+LF)	−6.2/ + 7.5	−
Q^2 scale ($t\bar{t}$+b)	−1.7/ + 2.0	−
Q^2 scale ($t\bar{t}$+2b)	−1.1/ + 1.4	−
Q^2 scale ($t\bar{t}$+$b\bar{b}$)	−2.0/ + 2.5	−
Q^2 scale ($t\bar{t}$+$c\bar{c}$)	−4.3/ + 5.4	−
PS scale ($t\bar{t}$+LF)	+4.8/ − 9.0	−
PS scale ($t\bar{t}$+b)	−0.9/ + 0.7	−
PS scale ($t\bar{t}$+2b)	−0.8/ + 0.9	−
PS scale ($t\bar{t}$+$b\bar{b}$)	−1.5/ + 2.7	−
PS scale ($t\bar{t}$+$c\bar{c}$)	−3.9/ + 3.0	−

- **Final discriminant in lepton+jets channel, ≥ 6 jets, ≥ 4 b-tag high-BDT category**



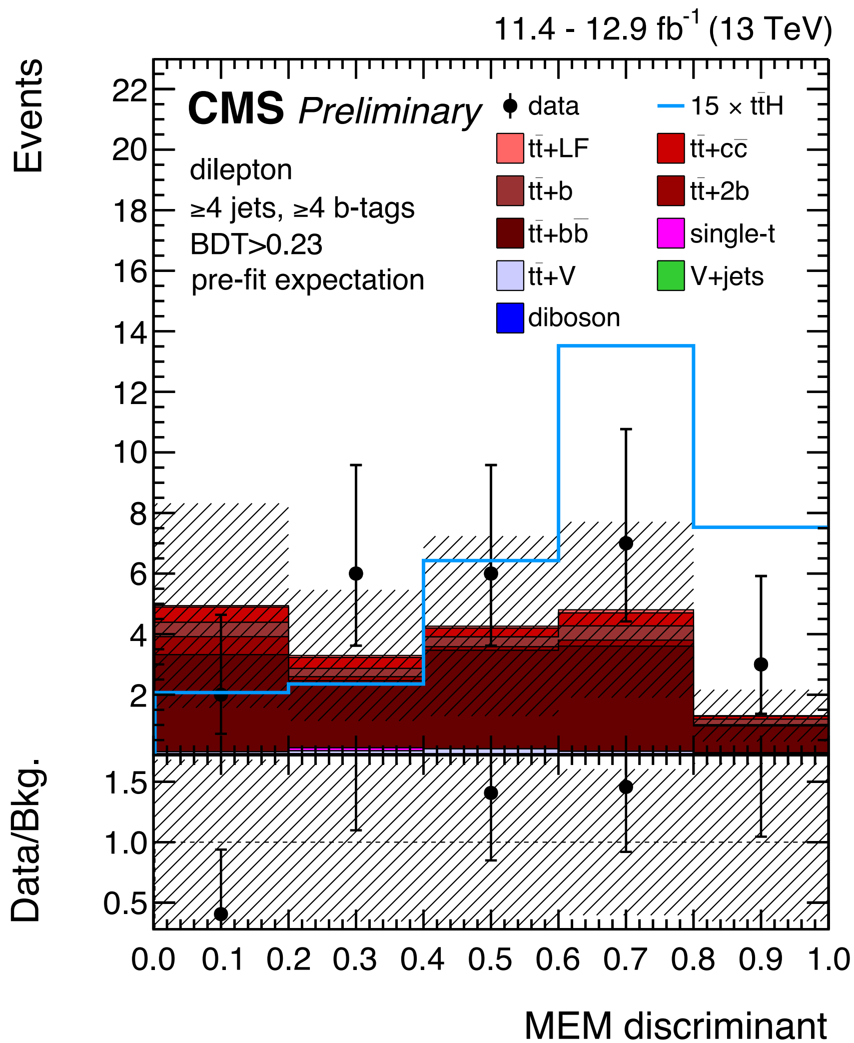
Pre-fit



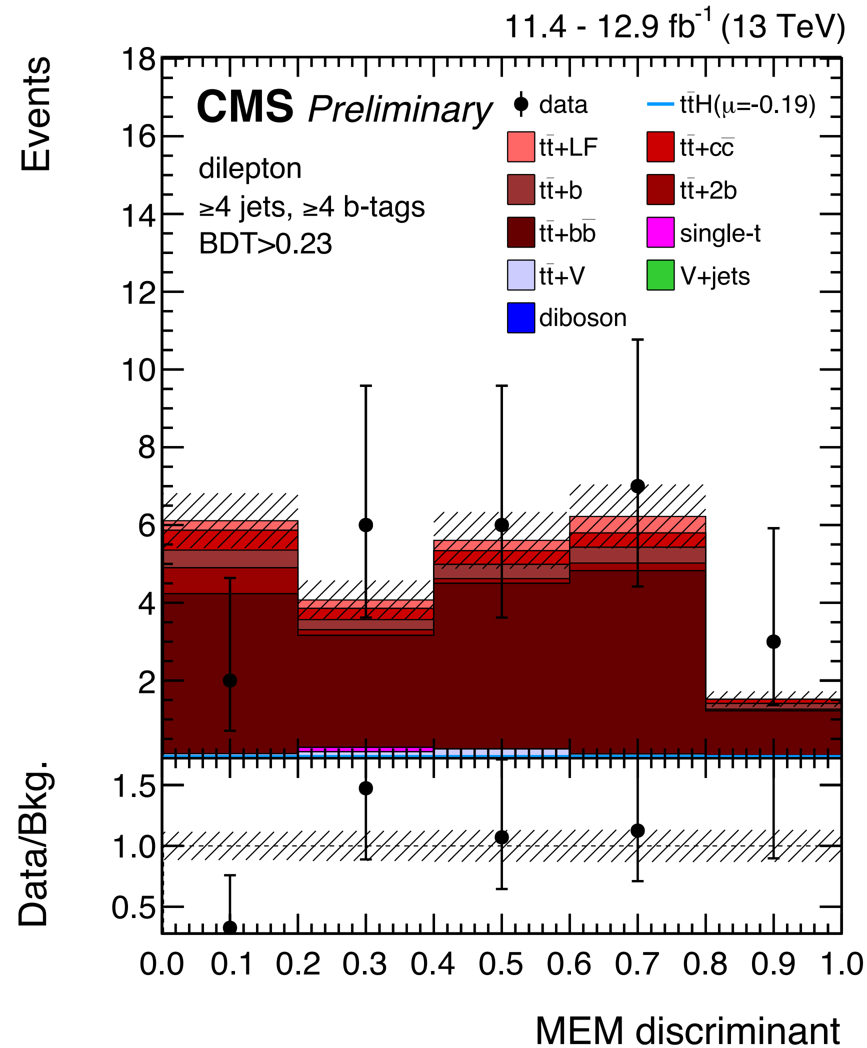
Post-fit

 CMS PAS HIG-16-038

- Final discriminant in dilepton channel, ≥ 4 jets, ≥ 4 b-tag high-BDT category



Pre-fit

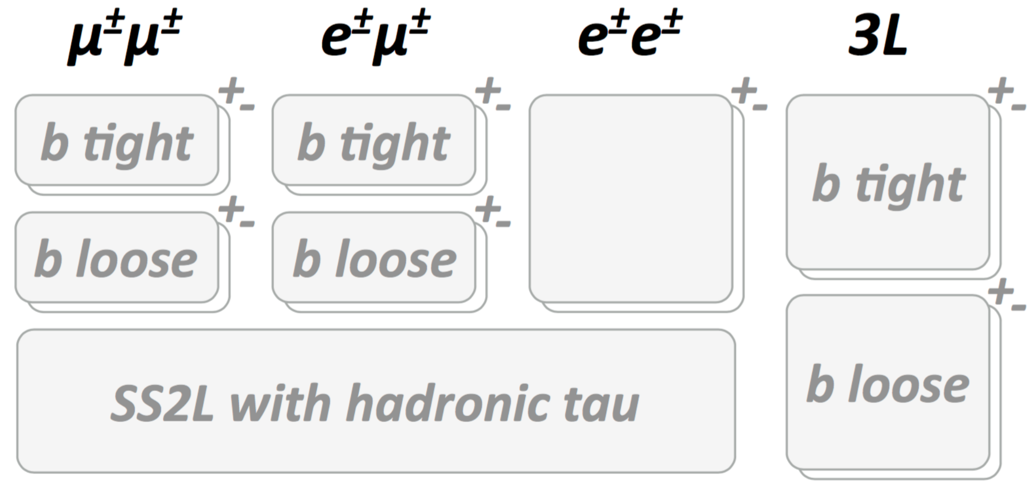


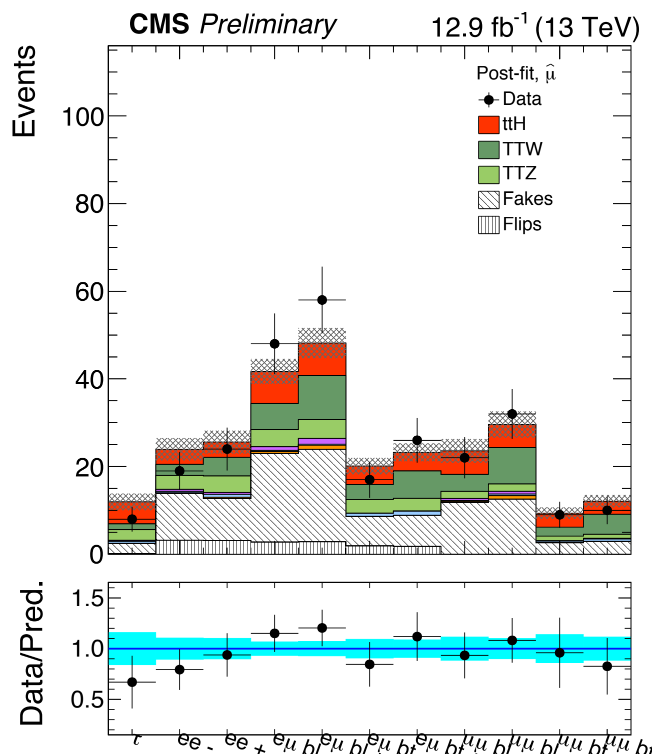
Post-fit

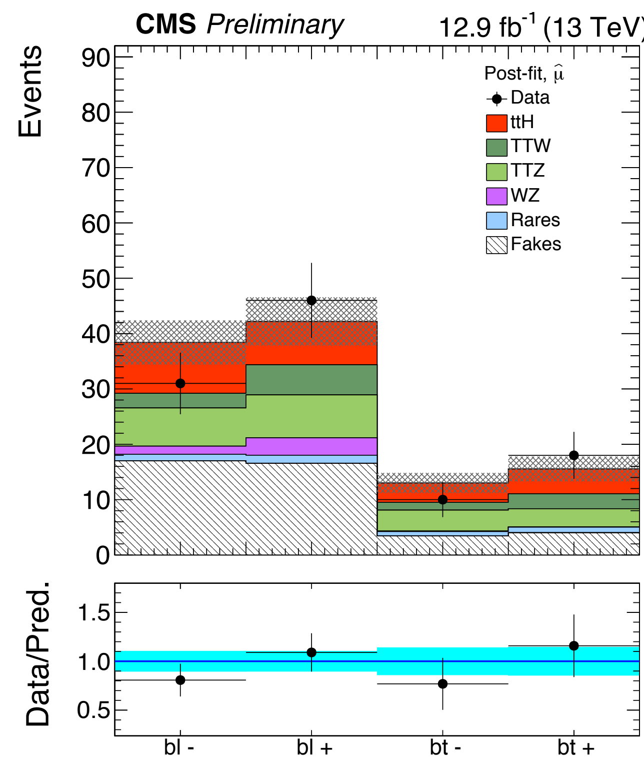
ttH multilepton

[CMS PAS HIG-16-022]

- Categorization based on lepton flavor, lepton charge, b-tagging, presence of hadronically-decaying τ

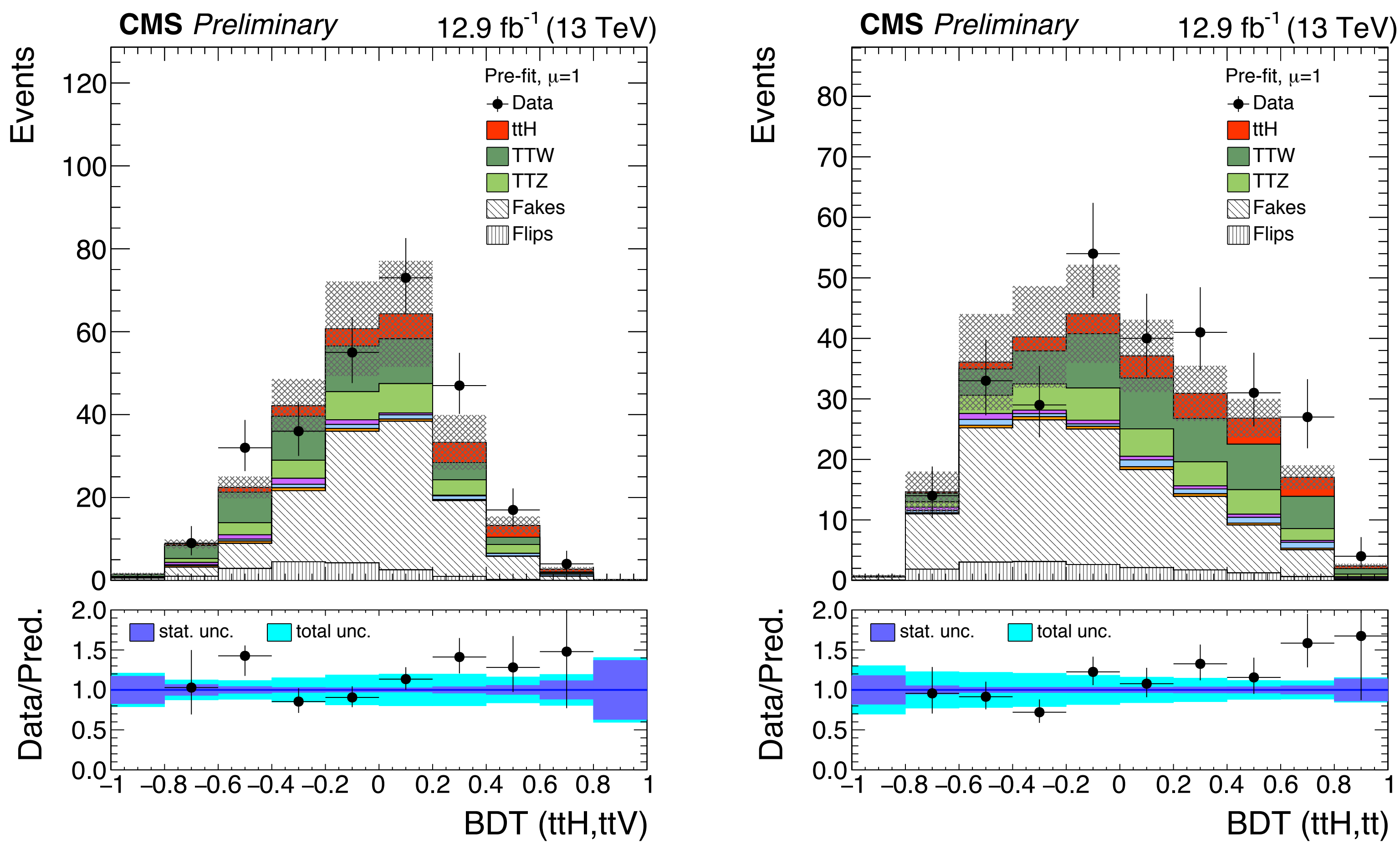






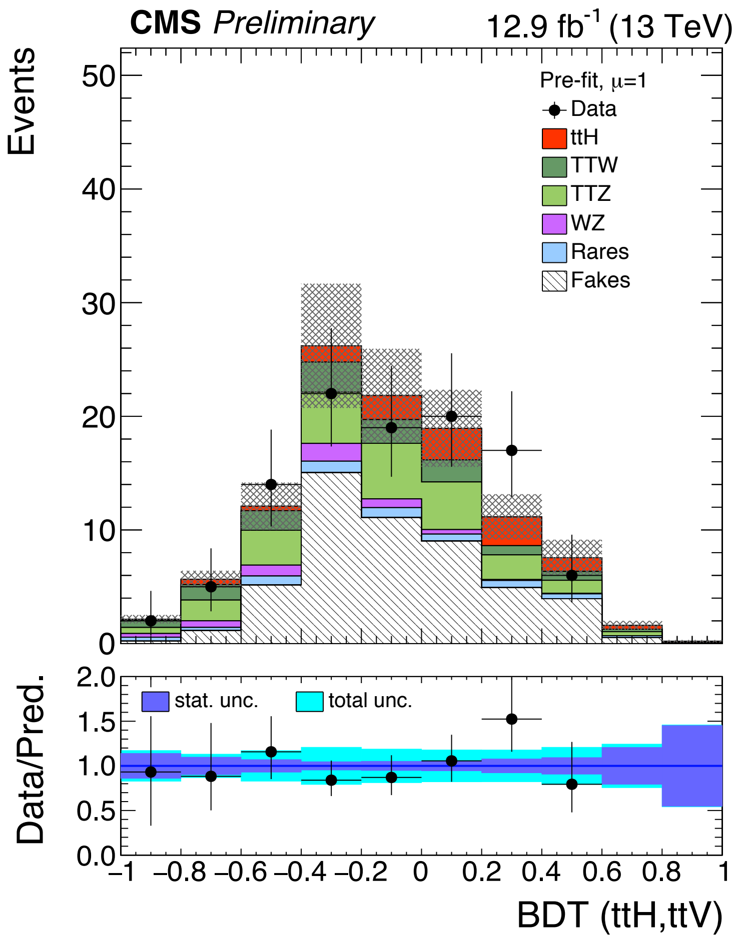
ttH multilepton CMS PAS HIG-16-022

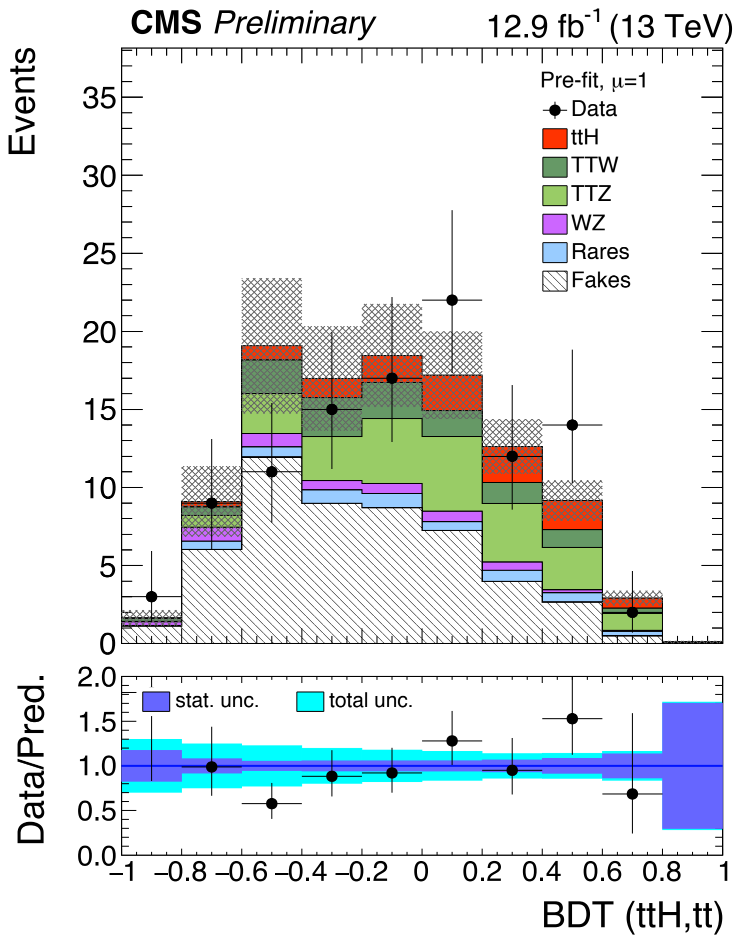
- **BDTs in 2lSS channel**



ttH multilepton CMS PAS HIG-16-022

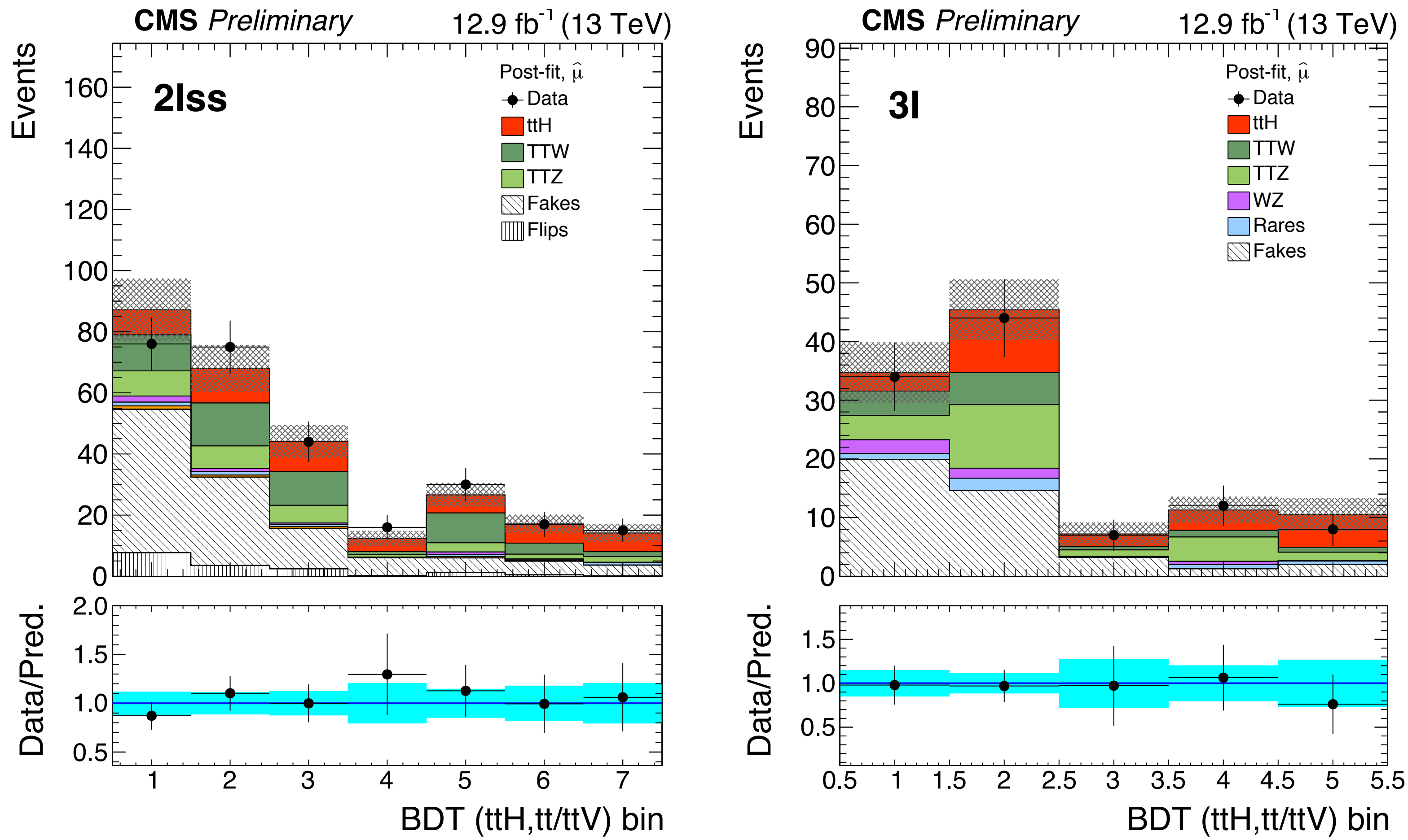
- **BDTs in 3l channel**





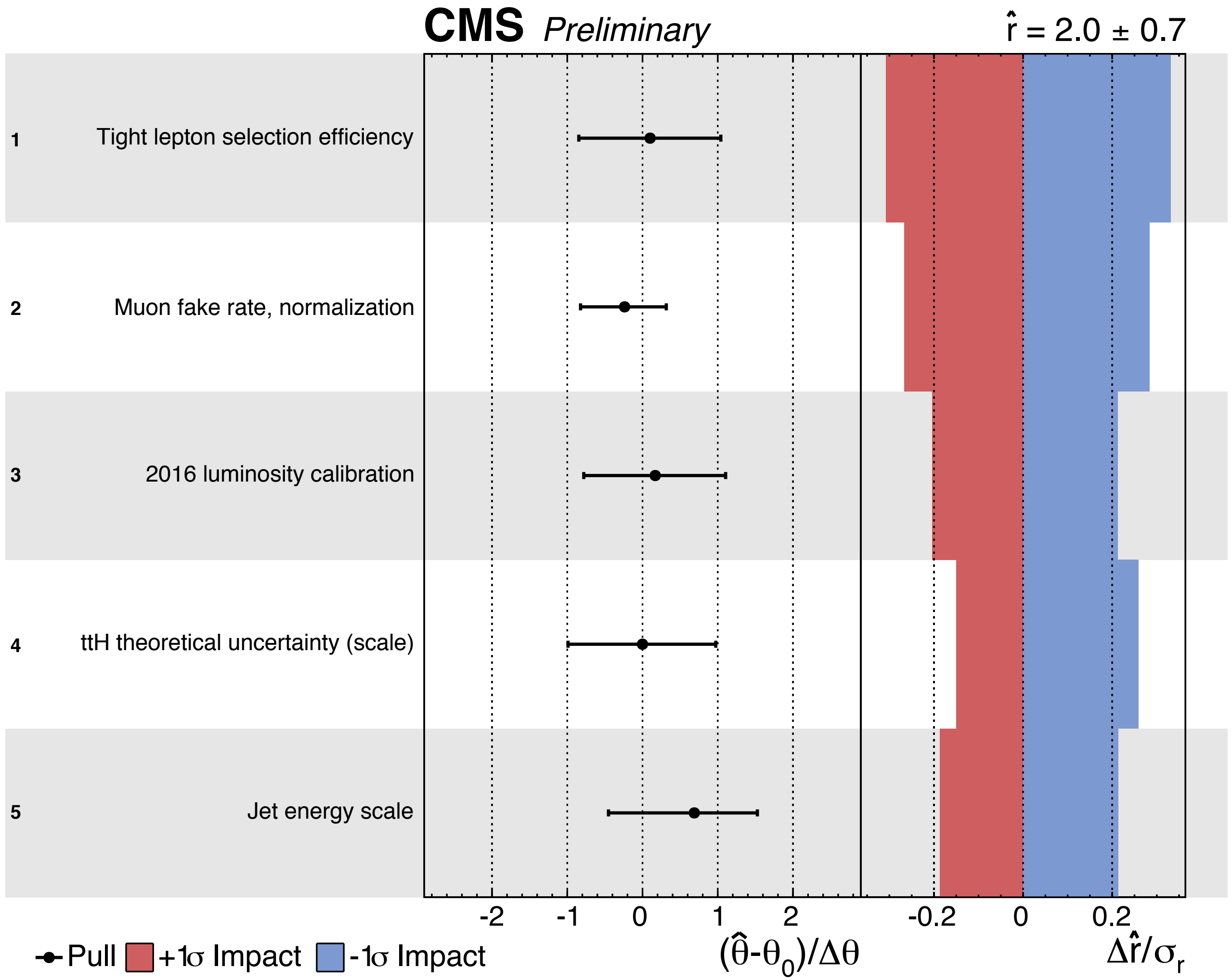
ttH multilepton CMS PAS HIG-16-022

- **Unfolded 2D BDTs distribution for used for signal extraction**



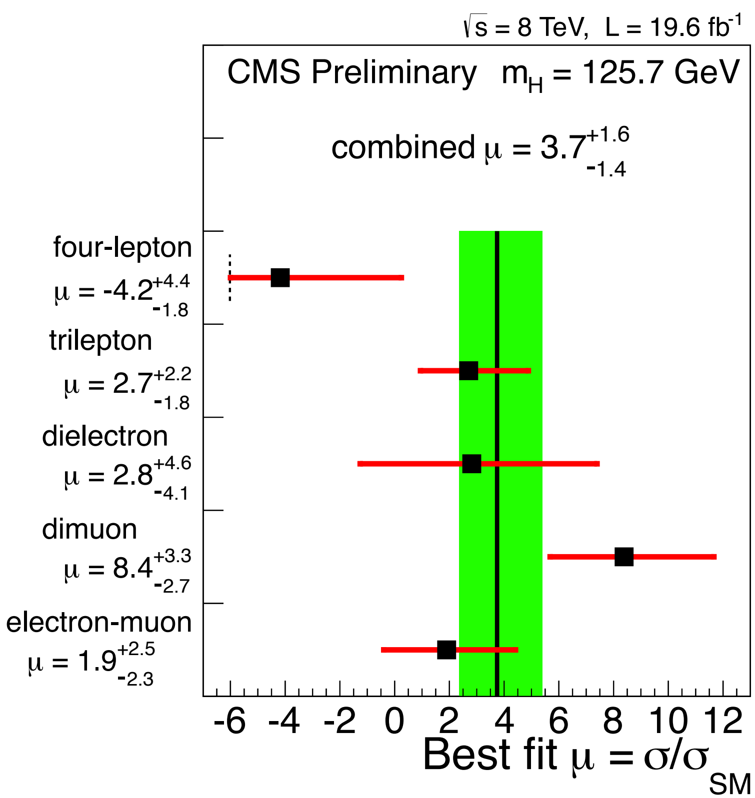
ttH multilepton [CMS PAS HIG-16-022]

- **Systematics with largest effect on the fitted signal strength**

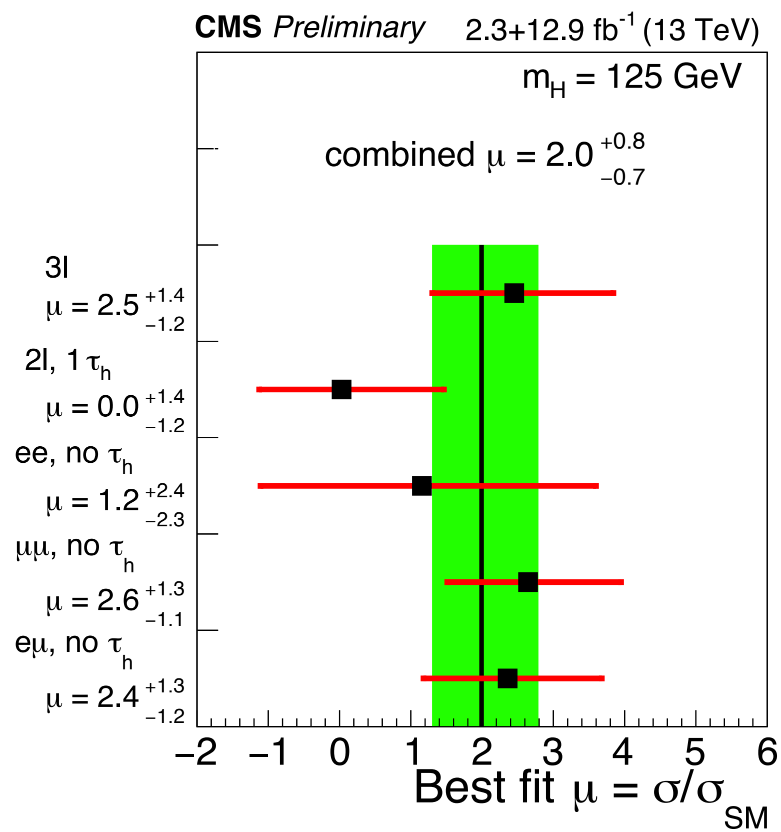


ttH multilepton CMS PAS HIG-16-022

- **Best fit signal strength**

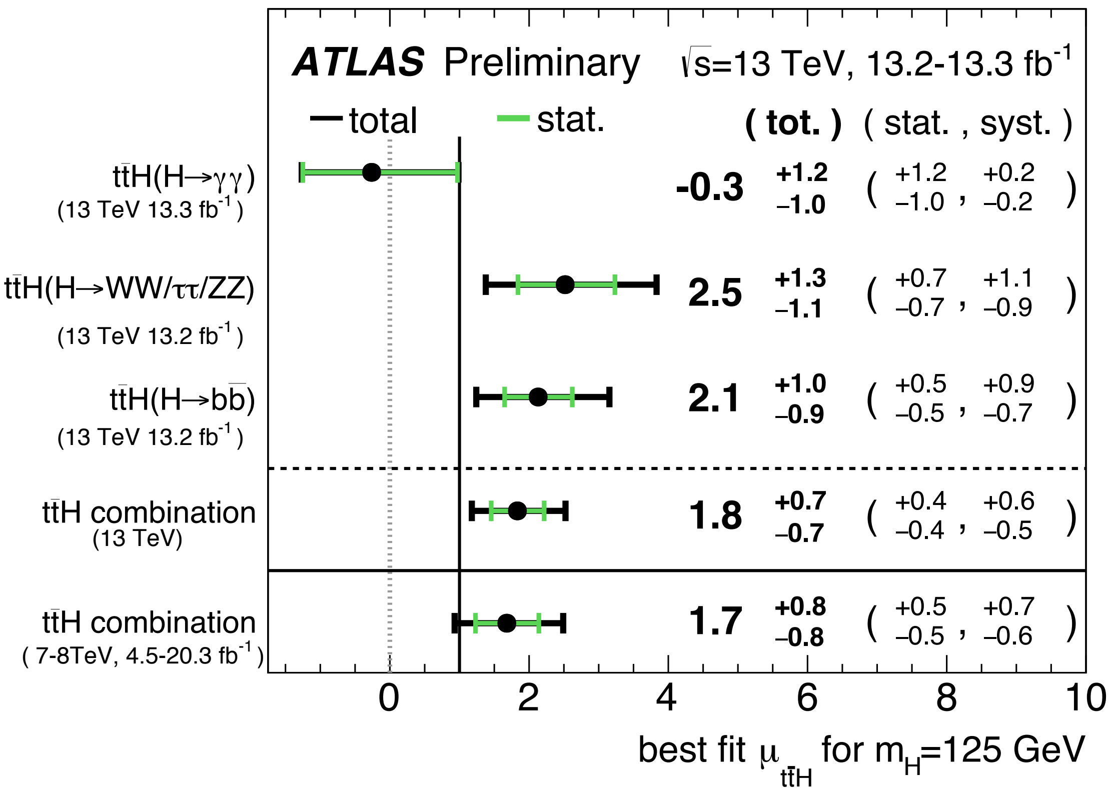


Run 1 analysis



Preliminary
Run 2 analysis

ATLAS results on ttH ATLAS-CONF-2016-068



- **CMS results:**
  - ttH, H→$\gamma\gamma$ $\hat{\mu}_{obs}(ttH) = 1.91^{+1.5}_{-1.2}$
  - ttH, H→bb $\hat{\mu}_{obs}(ttH) = -0.19^{+0.80}_{-0.81}$
  - ttH multilepton (2015+2016 combination) $\hat{\mu}_{obs}(ttH) = 2.0^{+0.8}_{-0.7}$