Experimental Summary

tH/ttH Subgroup

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ttH Spectroscopy

$t\bar{t}H \rightarrow W^+b\,W^-\bar{b}\;\; H \rightarrow bb + (jjjj/l\nu jj/l\nu l\nu) + (bb/WW^*/ZZ^*/\tau\tau/\gamma\gamma)$

- **Lepton+b$\bar{b}$** *($t\bar{t}$ → (0) 1–2 leptons, **H → bb**)*
  - Large $t\bar{t}$+HF backgrounds but high signal yield
  - Challenging combinatorics

- **Multileptons** *($t\bar{t}$ → 1–2 leptons, **H → WW*/ZZ*/ττ** → 1–4 lep's)*
  - Mixture of ttW/ttZ and nonprompt lepton ($t\bar{t}$) backgrounds
  - Challenging ttW ↔ ttH separation
  - Very clean H→ZZ→4L selection, but very low BR

- **Diphoton** *($t\bar{t}$ → 0–1 leptons, **H → γγ**)*
  - High purity but low signal yield
  - Mostly other Higgs backgrounds

Selected Recent Results

- [*Spring 2018*] **ttH observation** papers by both experiments

  CMS *HIG-17-035* *PRL 120 (2018) 231801*

  ATLAS *HIGG-2018-13* *PLB 784 (2018) 173*

  - Both using **full 2015+2016 13 TeV data** and **all major channels**
  - 2017 data in Hγγ and HZZ4L for ATLAS

- [*Nov 2018*] CMS **ttH multilepton** updated with **2017 data**

  HIG-18-019

- [*Nov 2018*] CMS **ttH γγ** updated with **2017 data**

  HIG-18-018

- [*Nov 2018*] CMS **tH combination** with **2015+2016 data**

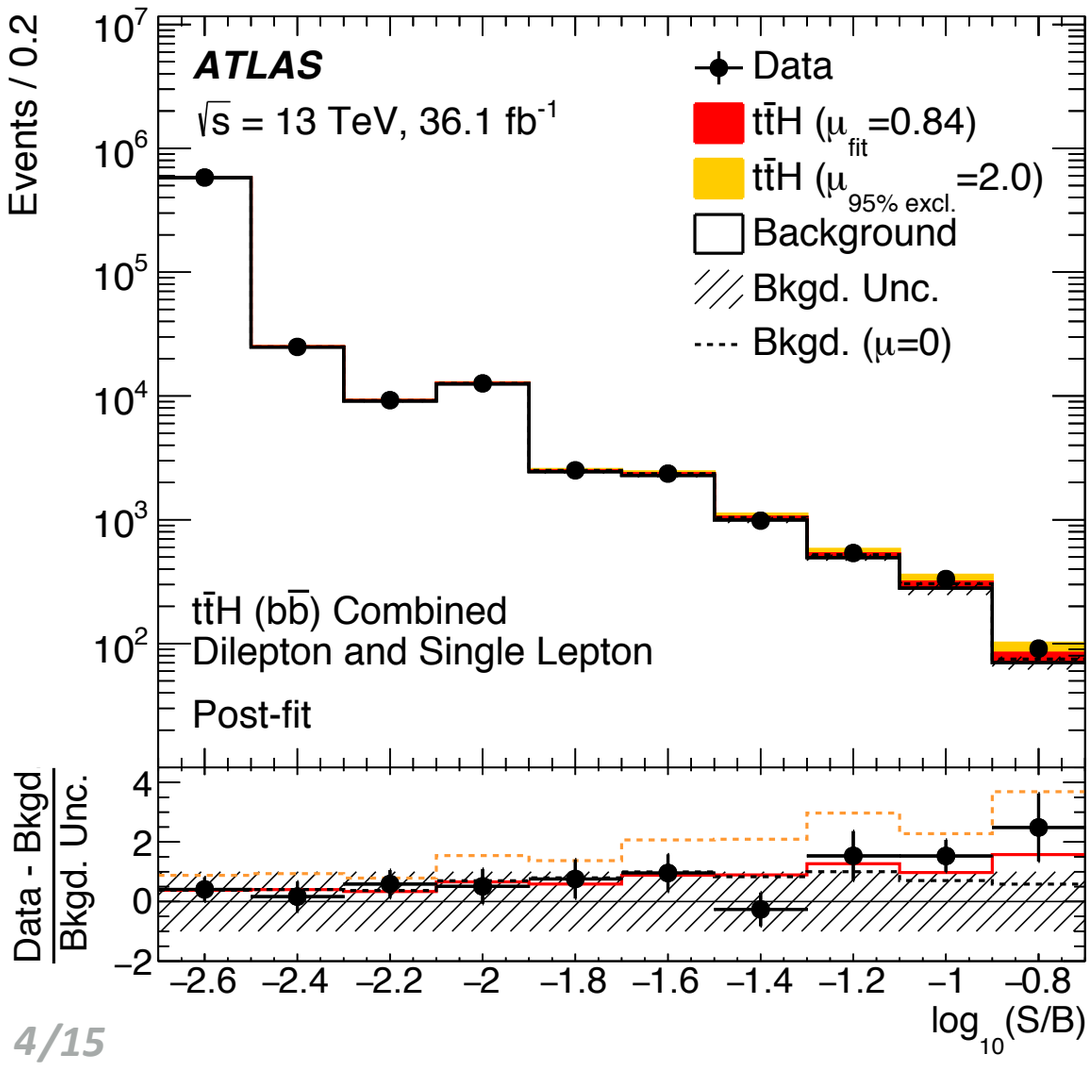
  HIG-18-009 *submitted to PRD*

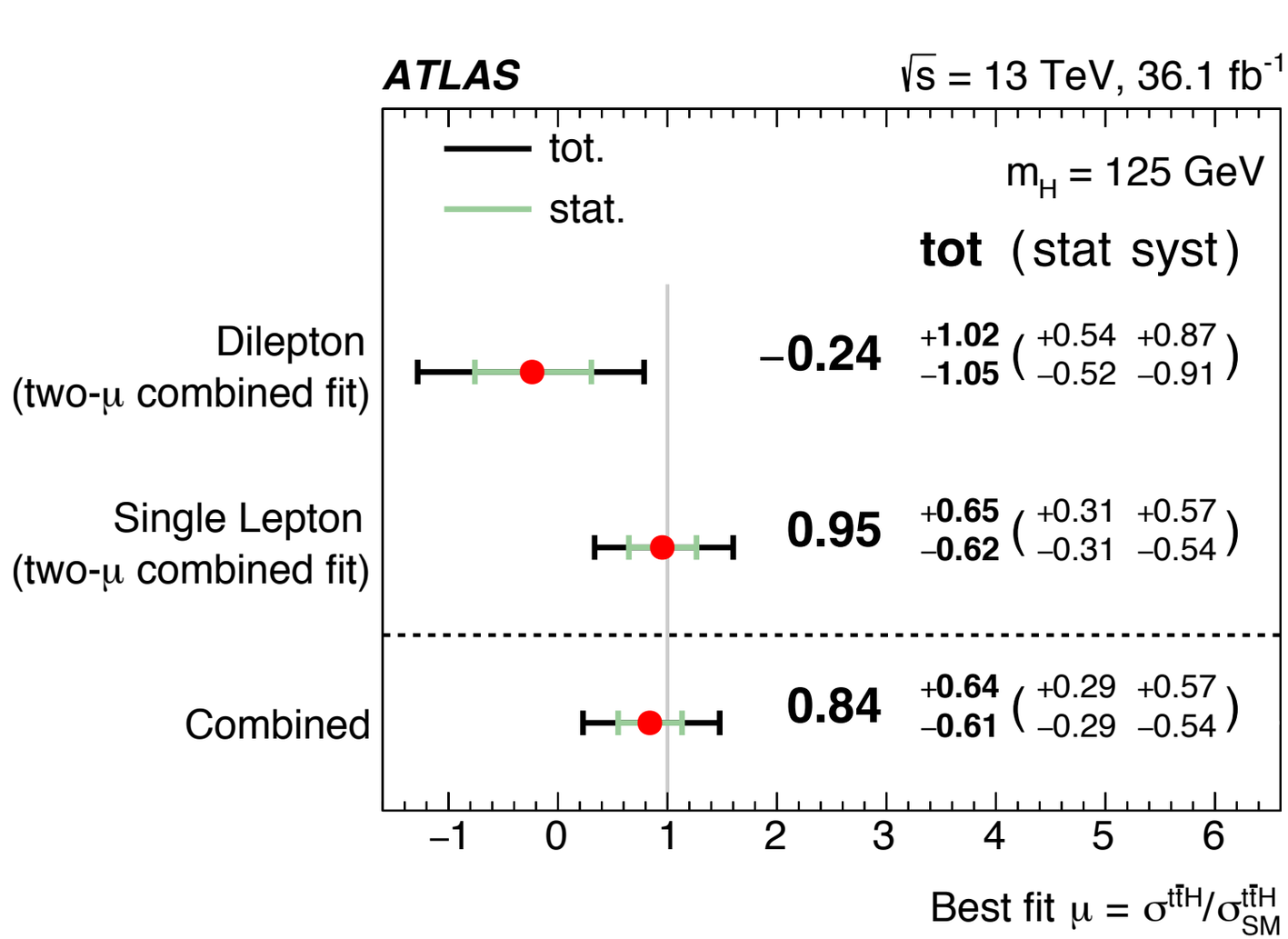
ATLAS ttH bb (2015+2016 data)

HIGG-2017-03

- Event **categorization** by numbers of jets and different b-tags
  - Separately for *dilepton*, *single lepton*, and *boosted single lepton*
- **Multi-stage** signal classification using BDTs *boosted decision tree*
- Dominant tt+HF background split into sub-categories
- Crucial issue is **modeling of tt+bb backgrounds**

…see also Stefano's talk

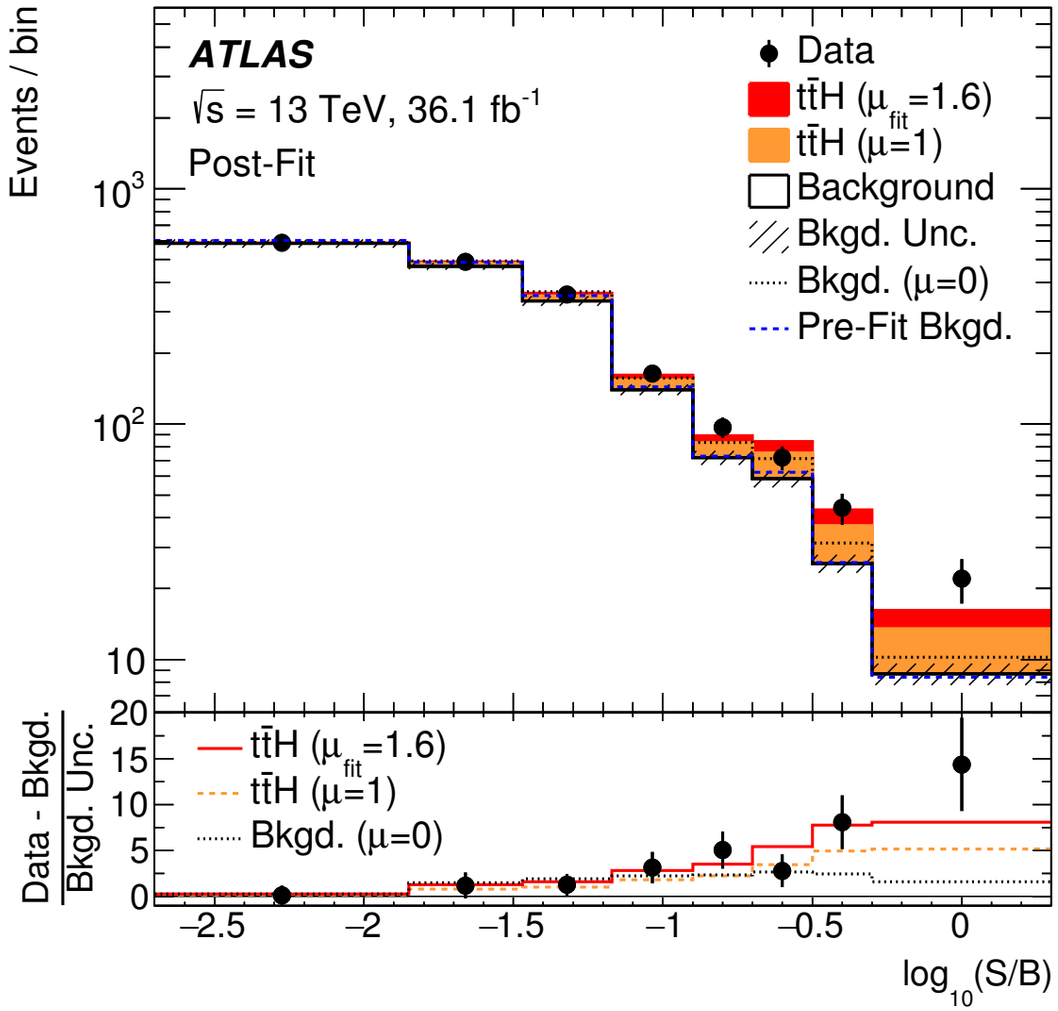


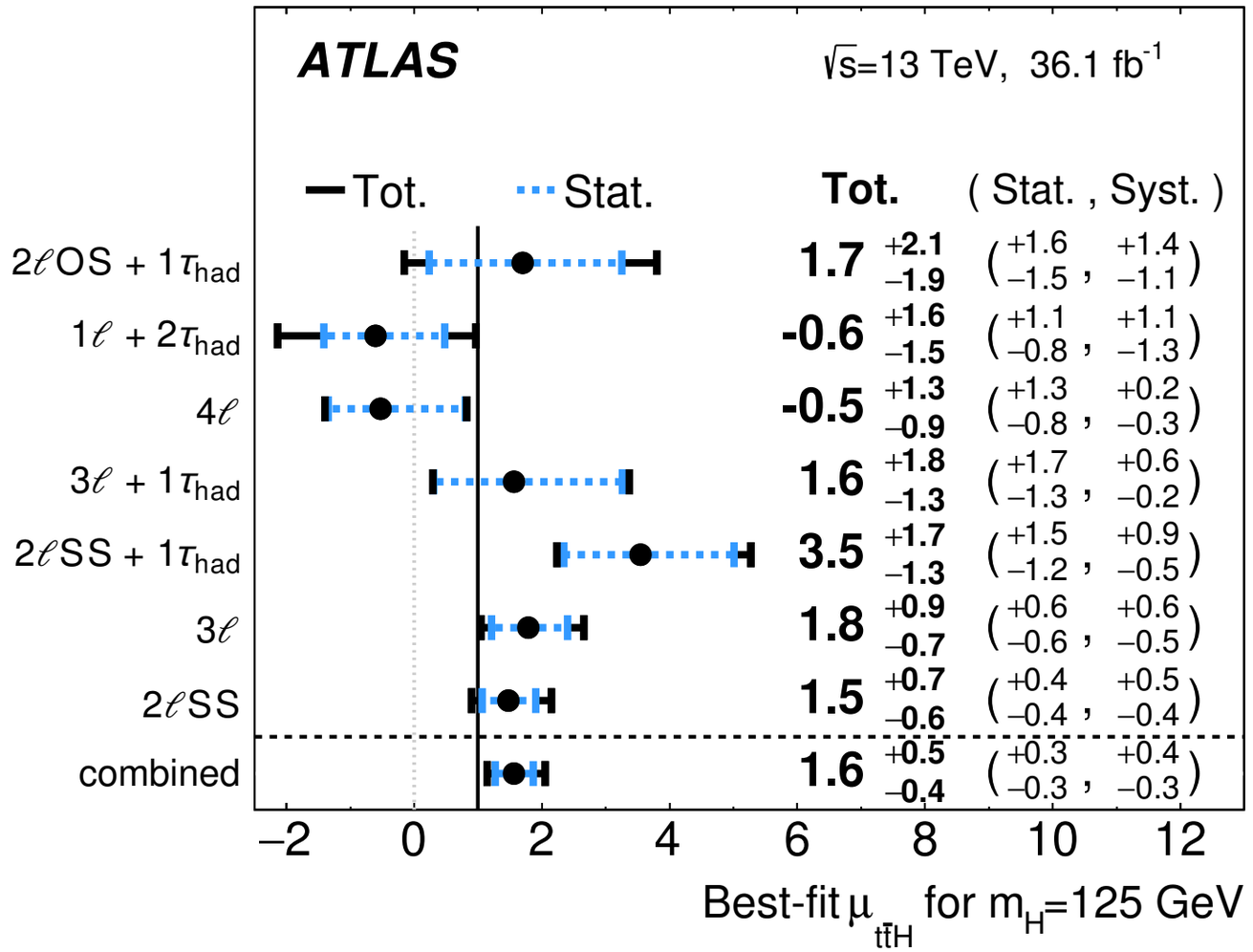


ATLAS ttH Multilepton (2015+2016 data)

HIGG-2017-02

- Leptons selected using dedicated BDTs to suppress nonprompts and charge misidentifications
- 7 signal regions with 2–4 light leptons and hadronic τ's and at least 2 jets and 1 b-tagged jet
- Signal discrimination using dedicated BDTs for each channel



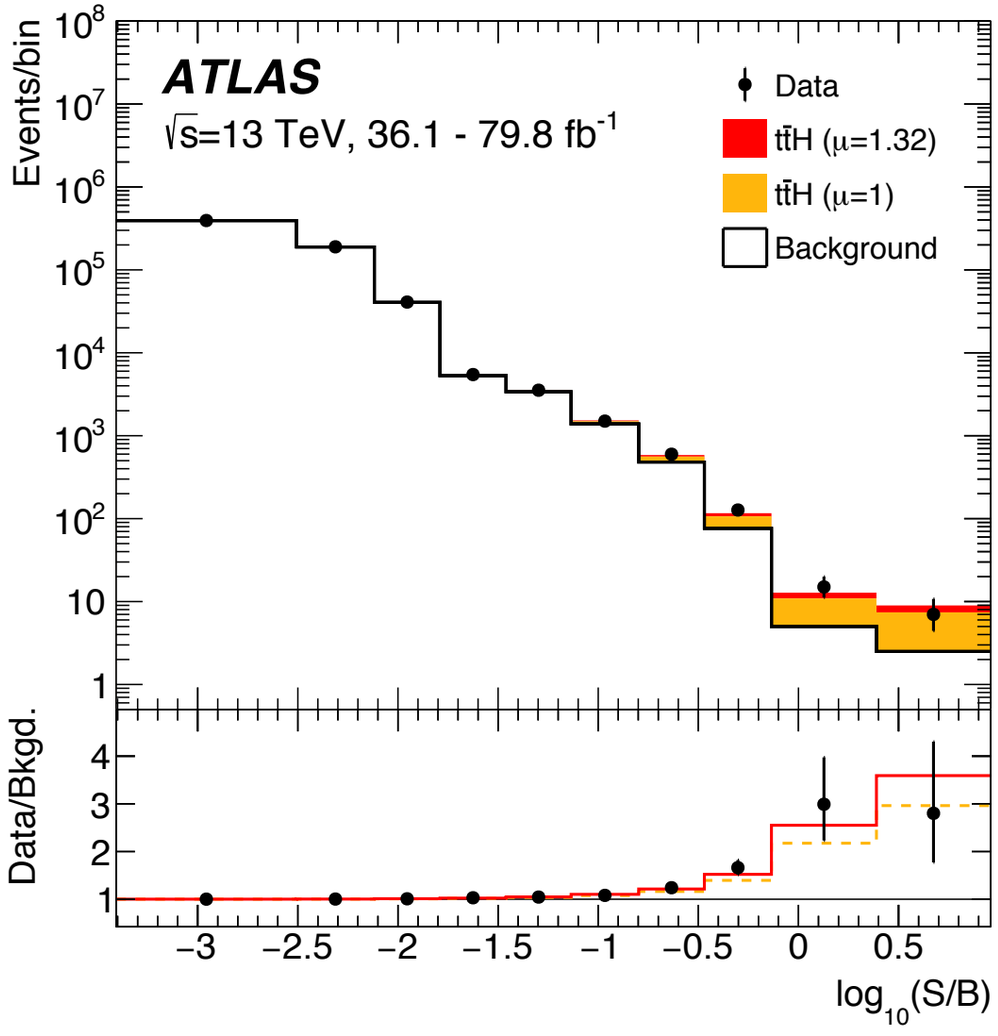


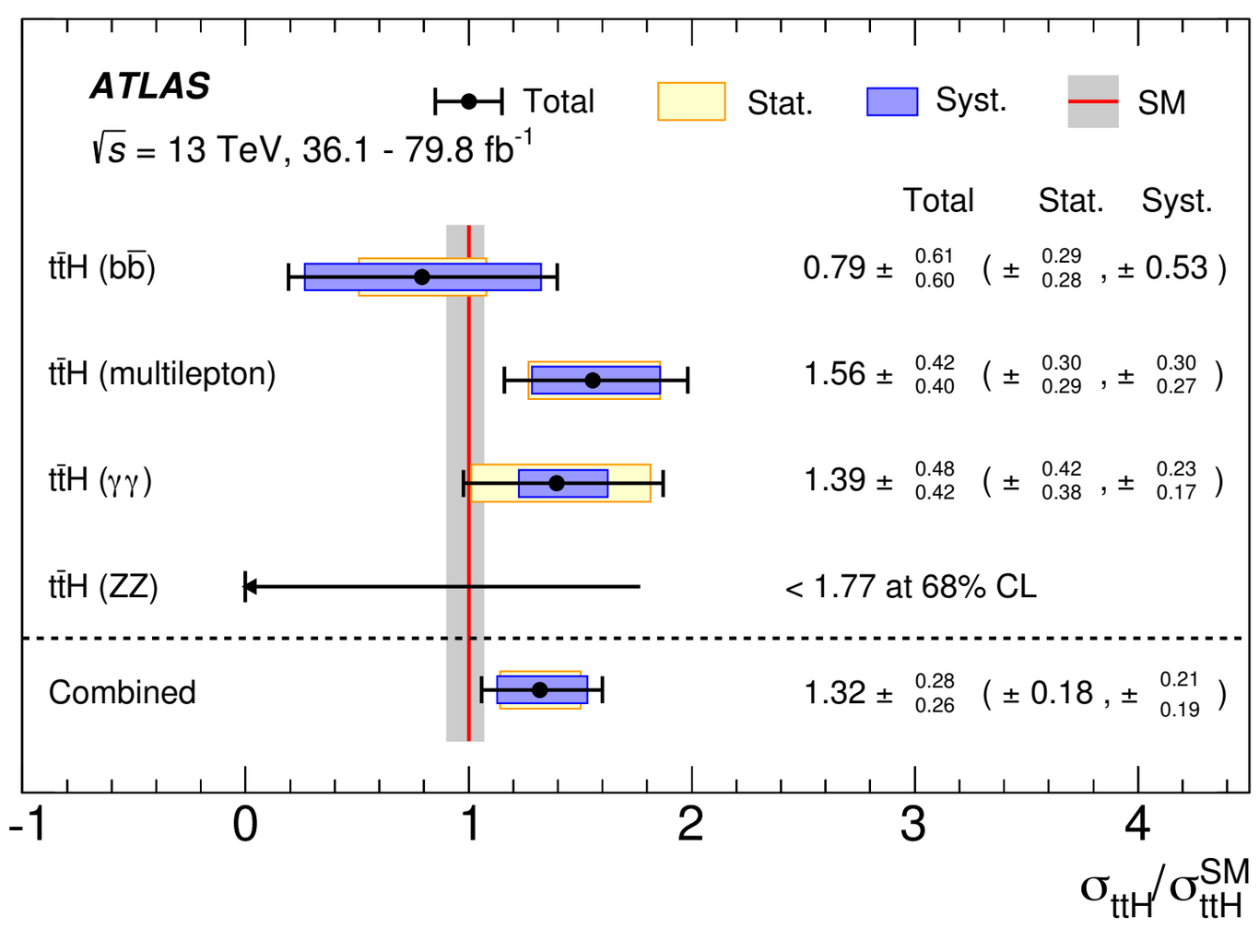
ATLAS ttH combination (2015+'16+'17 data) *HIGG-2018-13*

- Combine existing multilepton and bb results with γγ and ZZ4L
  - γγ + b-jet events categorized in leptonic/hadronic and in BDT bins
  - 4L + b-jet not yet sensitive 0 events observed (~1 expected)

- Overall **precision on σ_{ttH} of about 20%**

  6.3 σ significance (5.1 expected)

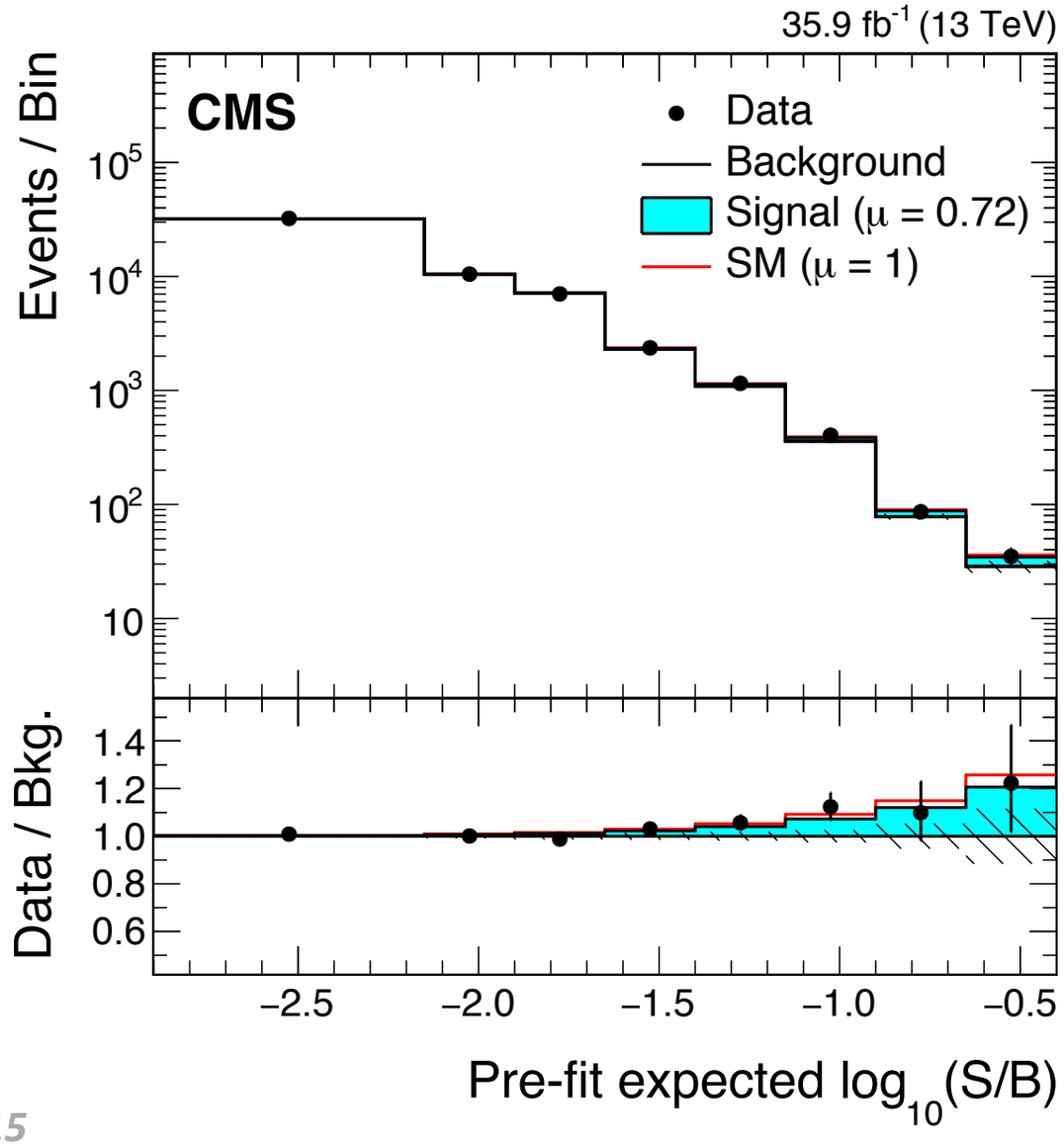


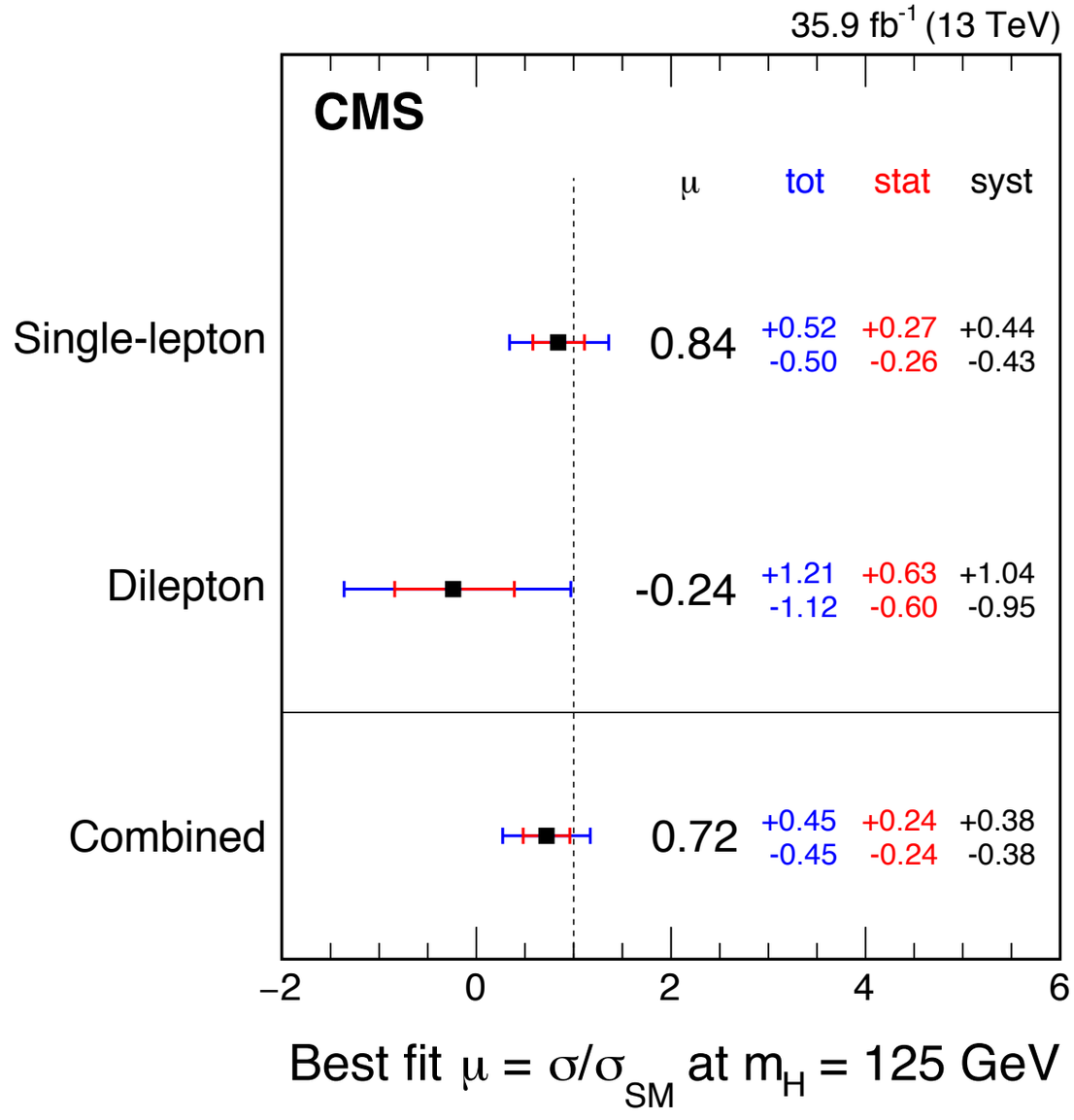


CMS ttH bb (2015+2016 data)

HIG-17-026

- Similar categorizations by N_{jets} and $N_{b\text{-}tags}$ to ATLAS analysis
- Same splitting of tt+HF background components as ATLAS
- **Multiclass DNN** to separate ttH from different tt+HF components
- Uncertainty on σ_{ttH} of about 60%



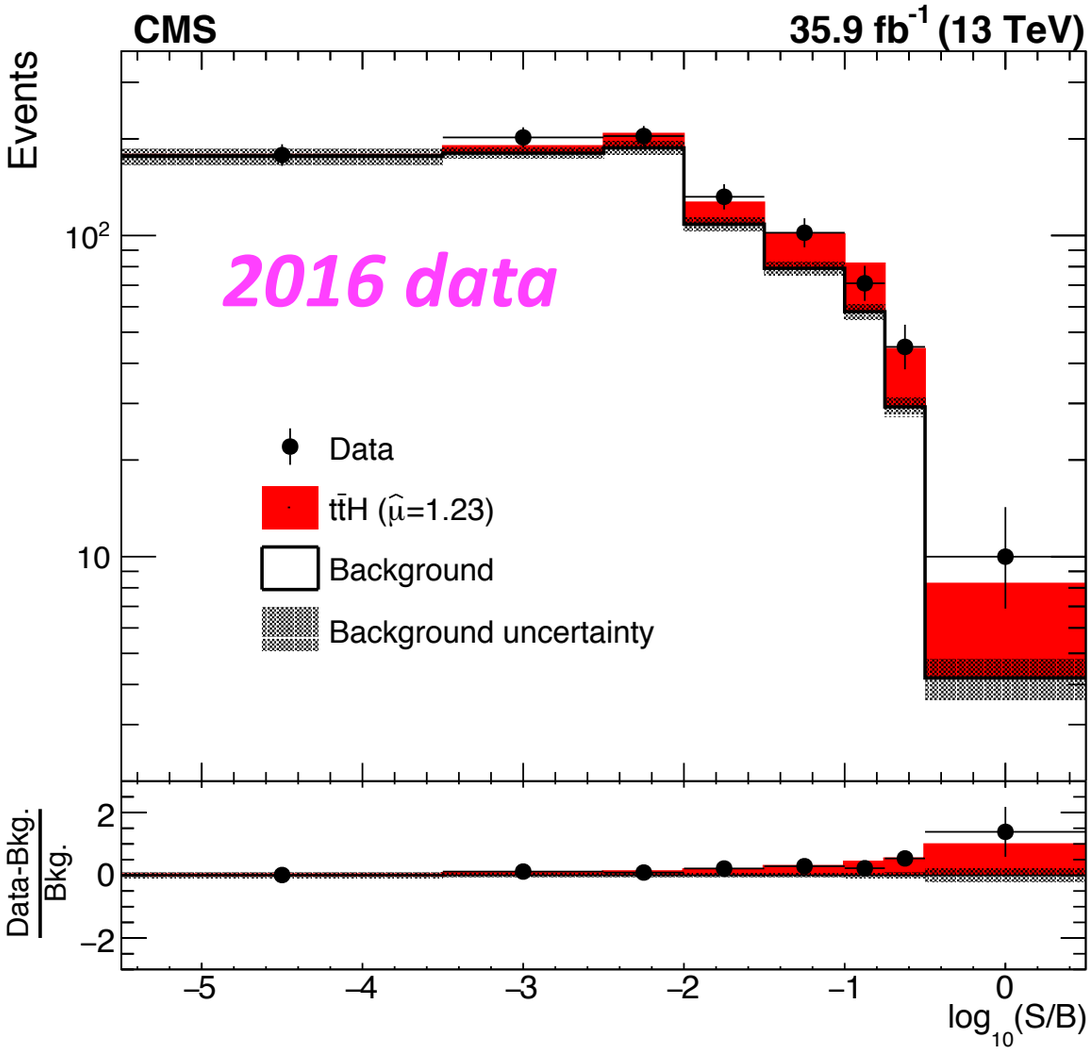


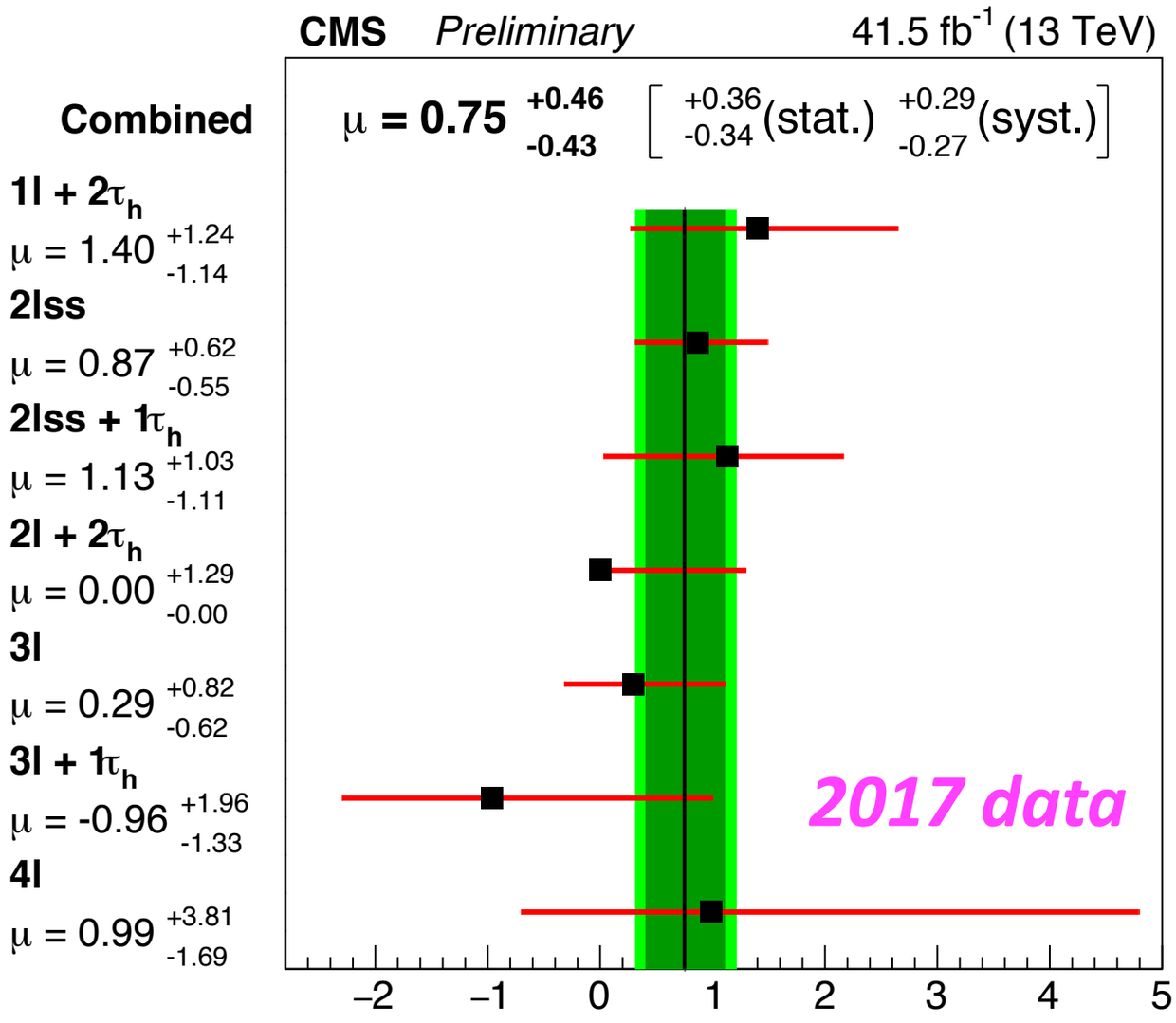
CMS ttH multilepton **(2017 data update)**

HIG-18-019

- BDTs used in lepton selection and signal classification
- Update of 2016 analysis with new 2L+2τ_h category
- Combined **uncertainty on σ_{ttH} of about 35%**

$$\hat{\mu} = 0.96\ ^{+0.34}_{-0.31}$$ 3.2 σ significance (4.0 σ expected)





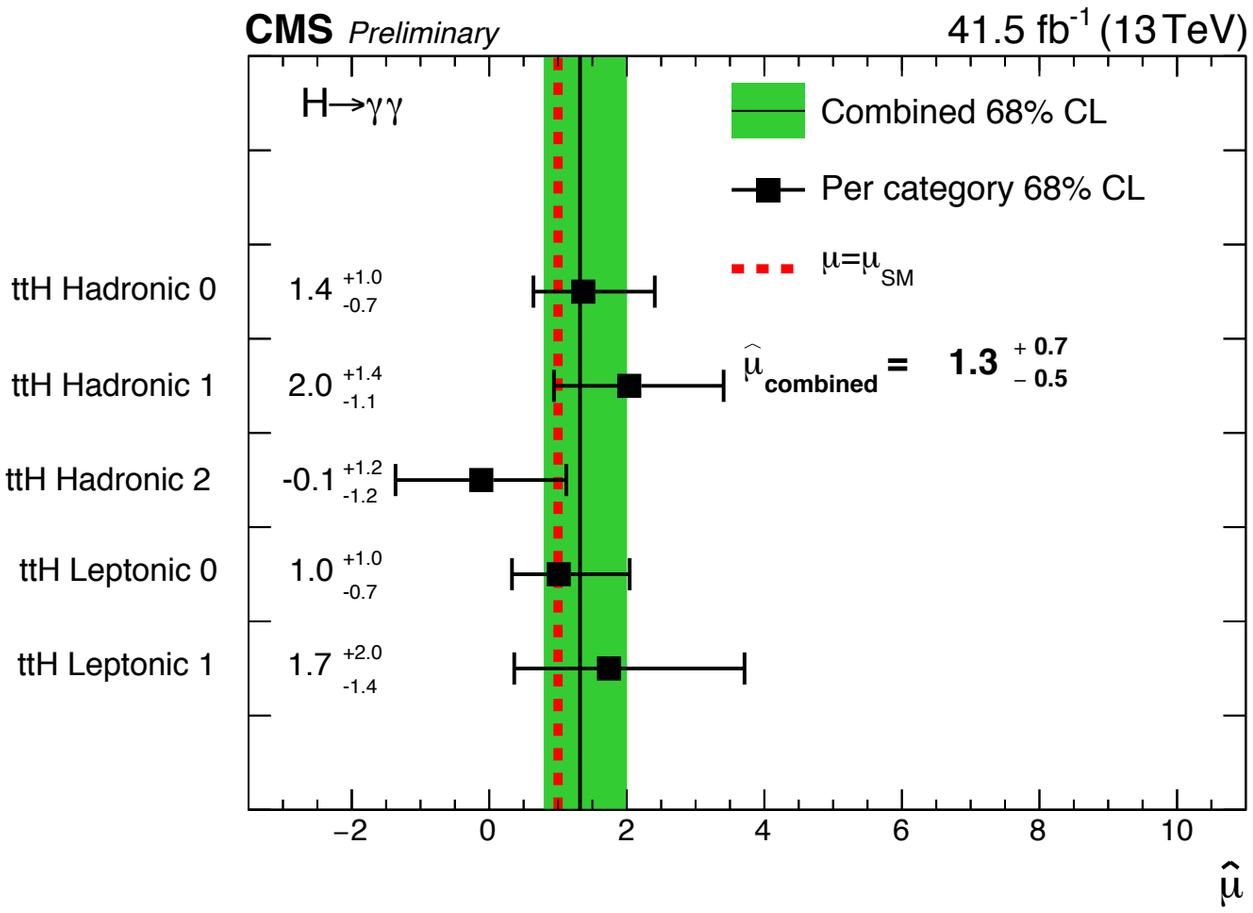
CMS ttH γγ update with 2017 data

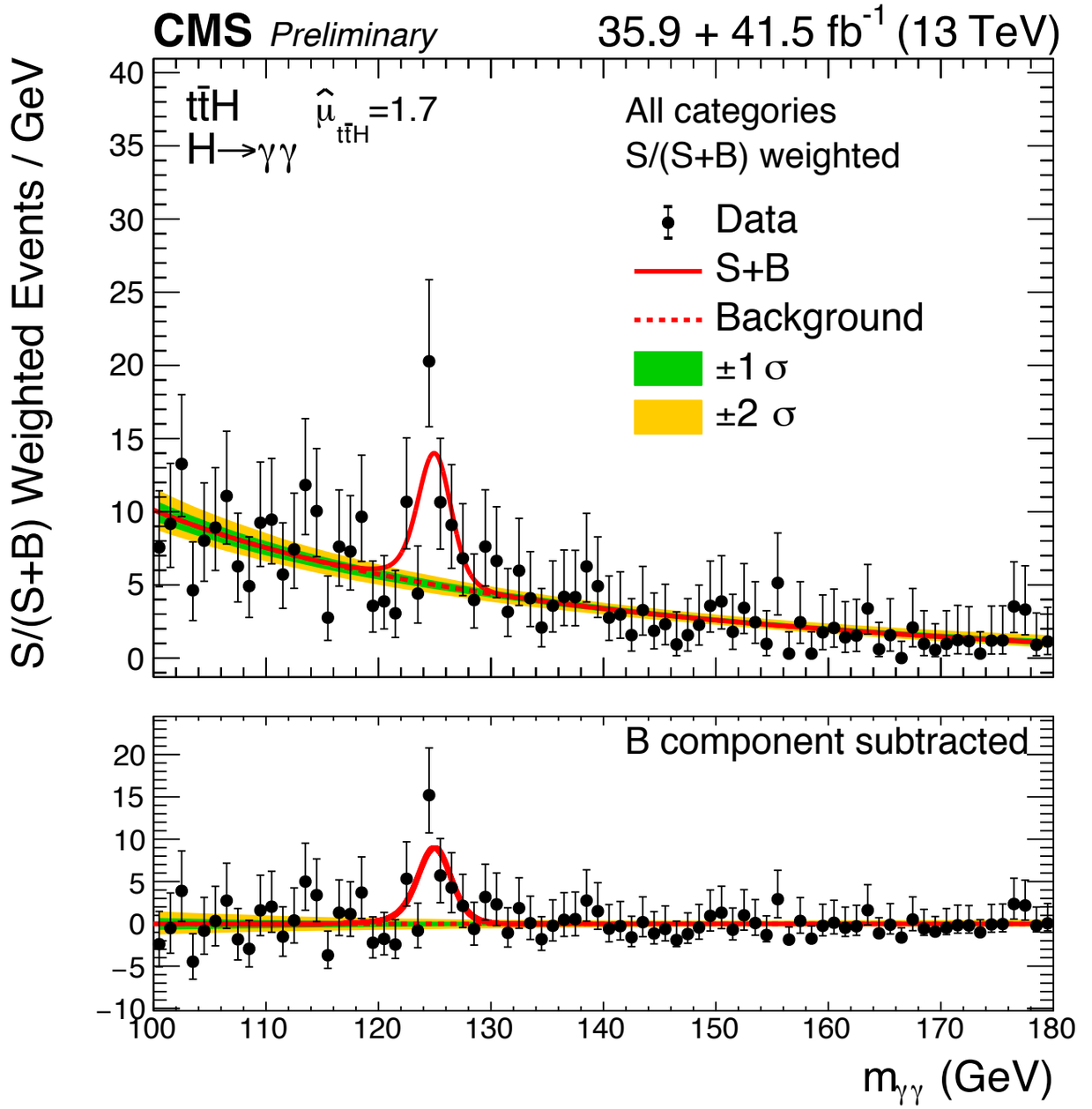
HIG-18-018

- γγ + b-jet events categorized by lepton and dedicated BDTs
- About **35% uncertainty on σ_{ttH}**
- Still **limited by statistical uncertainty**

$\hat{\mu} = 1.7\ ^{+0.6}_{-0.5}$ 4.1 σ significance

(2015+2016+2017 data)



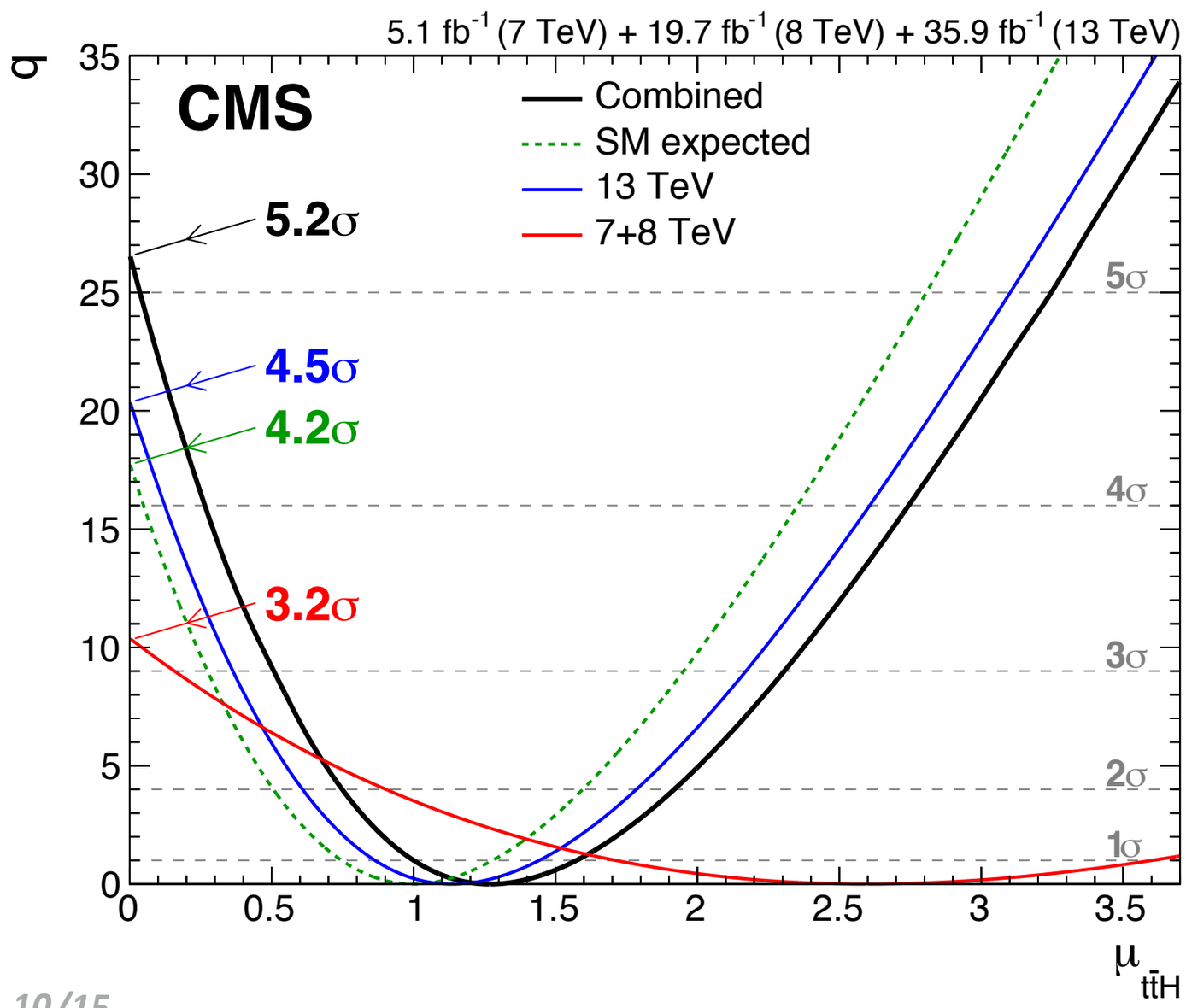


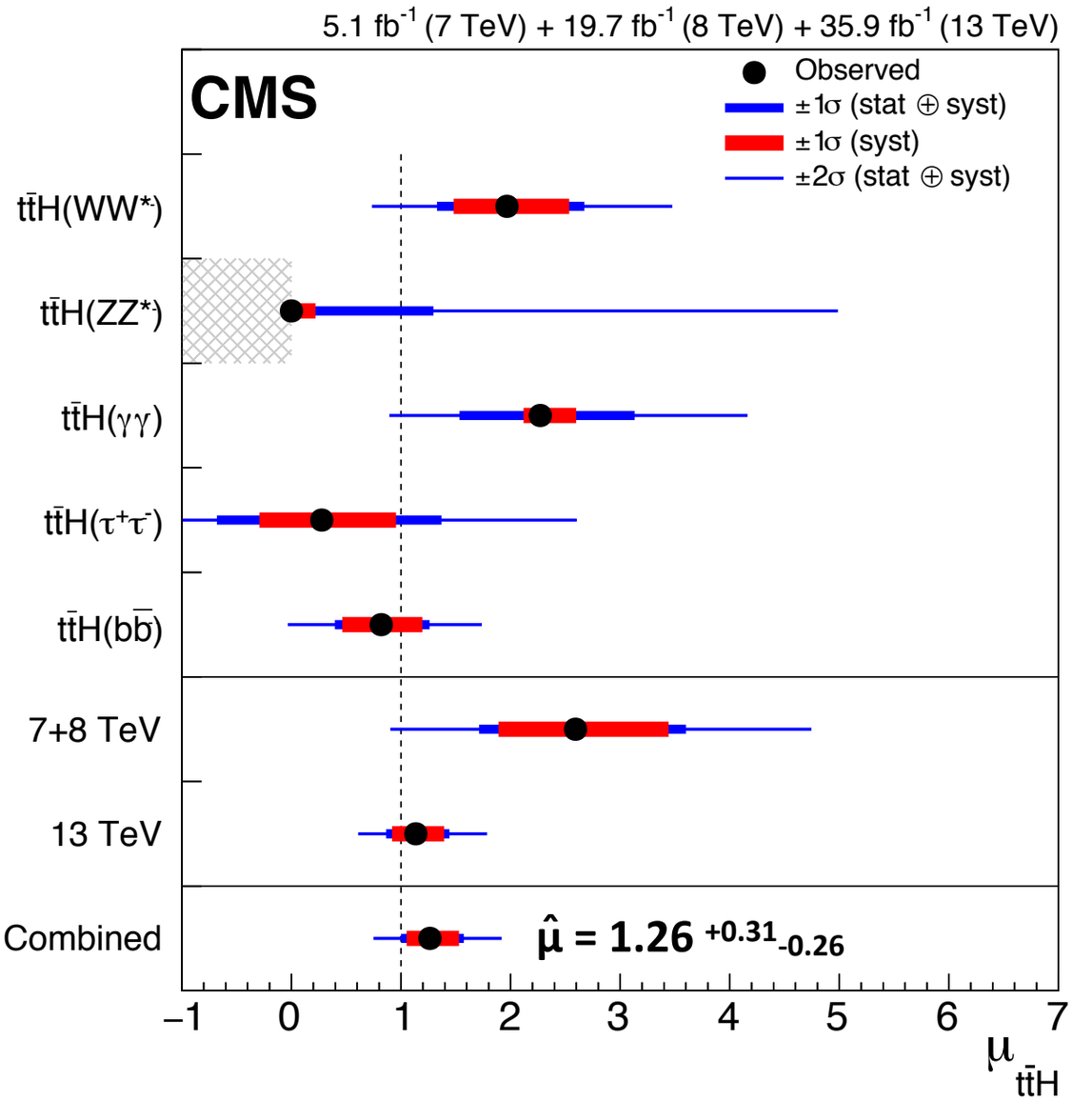
CMS ttH combination (2015+2016 data only)

HIG-17-035

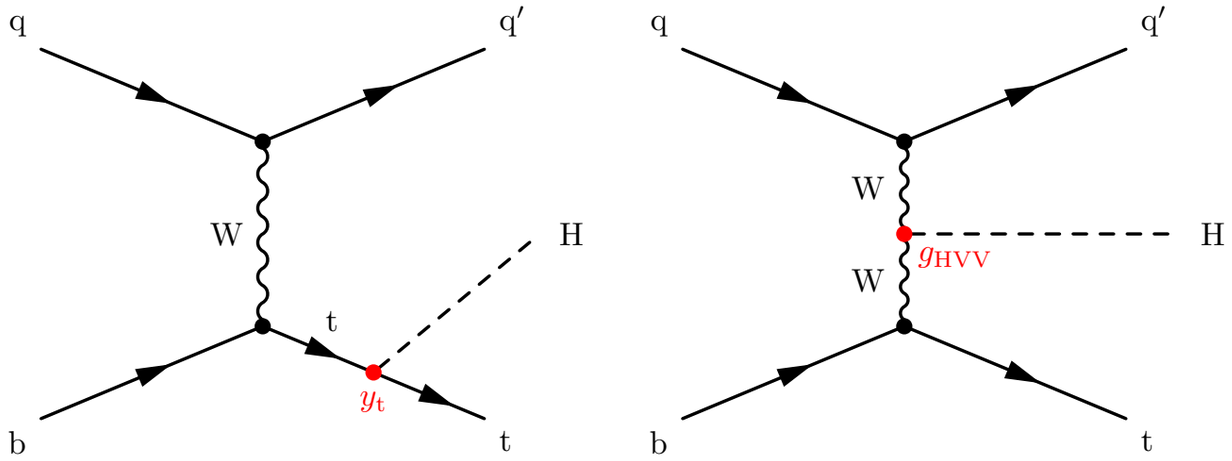
- bb, multilepton, and γγ analyses on **2016 13 TeV dataset**
  - Combined with 7 and 8 TeV datasets
- Overall **uncertainty of about 22% on σ_{ttH}**:

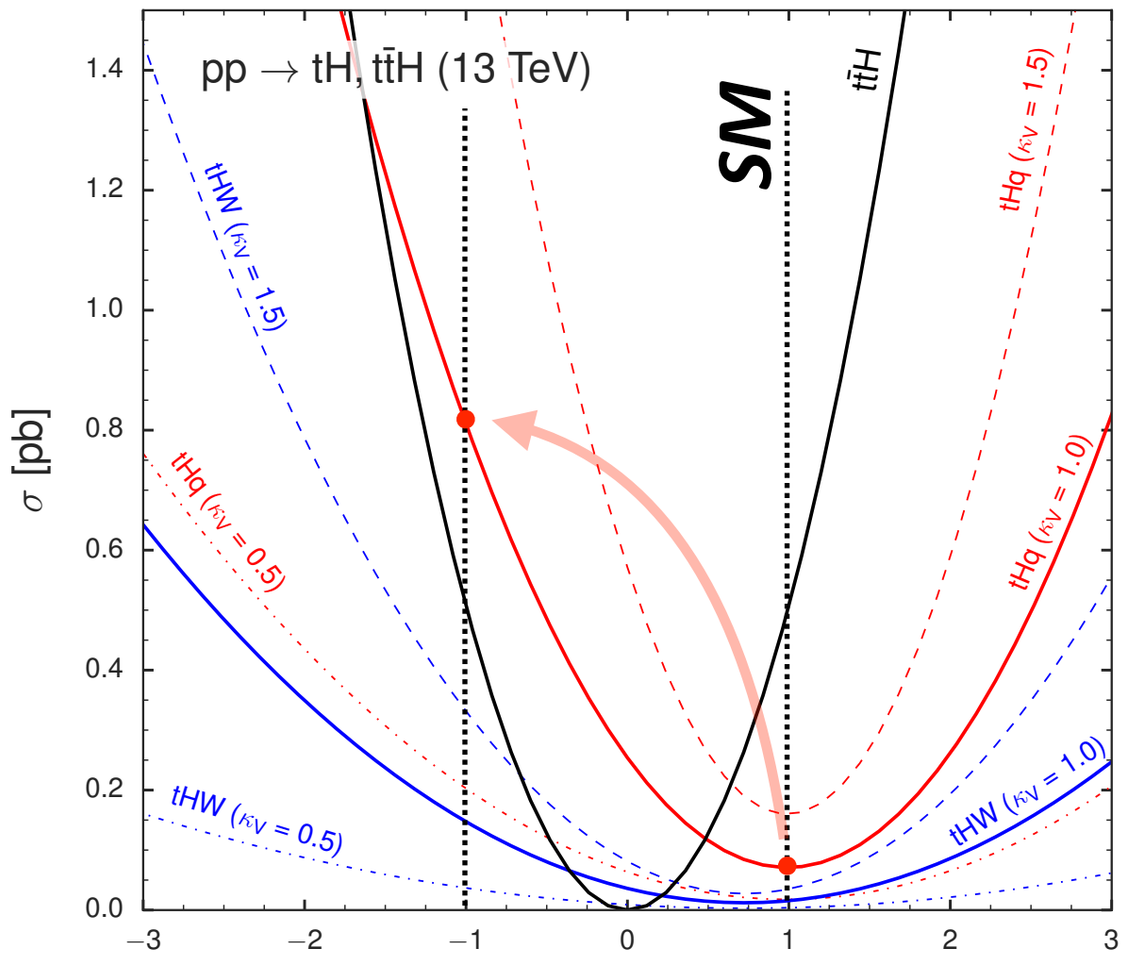
$$\hat{\mu} = 1.26\ ^{+0.31}_{-0.26}$$ 5.2 σ significance (4.2 σ expected)





Single top + Higgs cross section is sensitive to (amplitude,) **relative sign**, and **phase** of y_t and g_{HVV}.





$\kappa_t = y_t/y_t^{SM}$
$\kappa_V = g_{HVV}/g_{HVV}^{SM}$

- **Interference** between leading order diagrams (destructive in SM)
  - Non-SM couplings enhance tH
- **Similar signatures and channels** to ttH, but with lower multiplicities and forward activity
- Signal / background separation is more distinct
- Much lower signal cross section

Likelihood scan of y_t/y_t^{SM} with tH and ttH

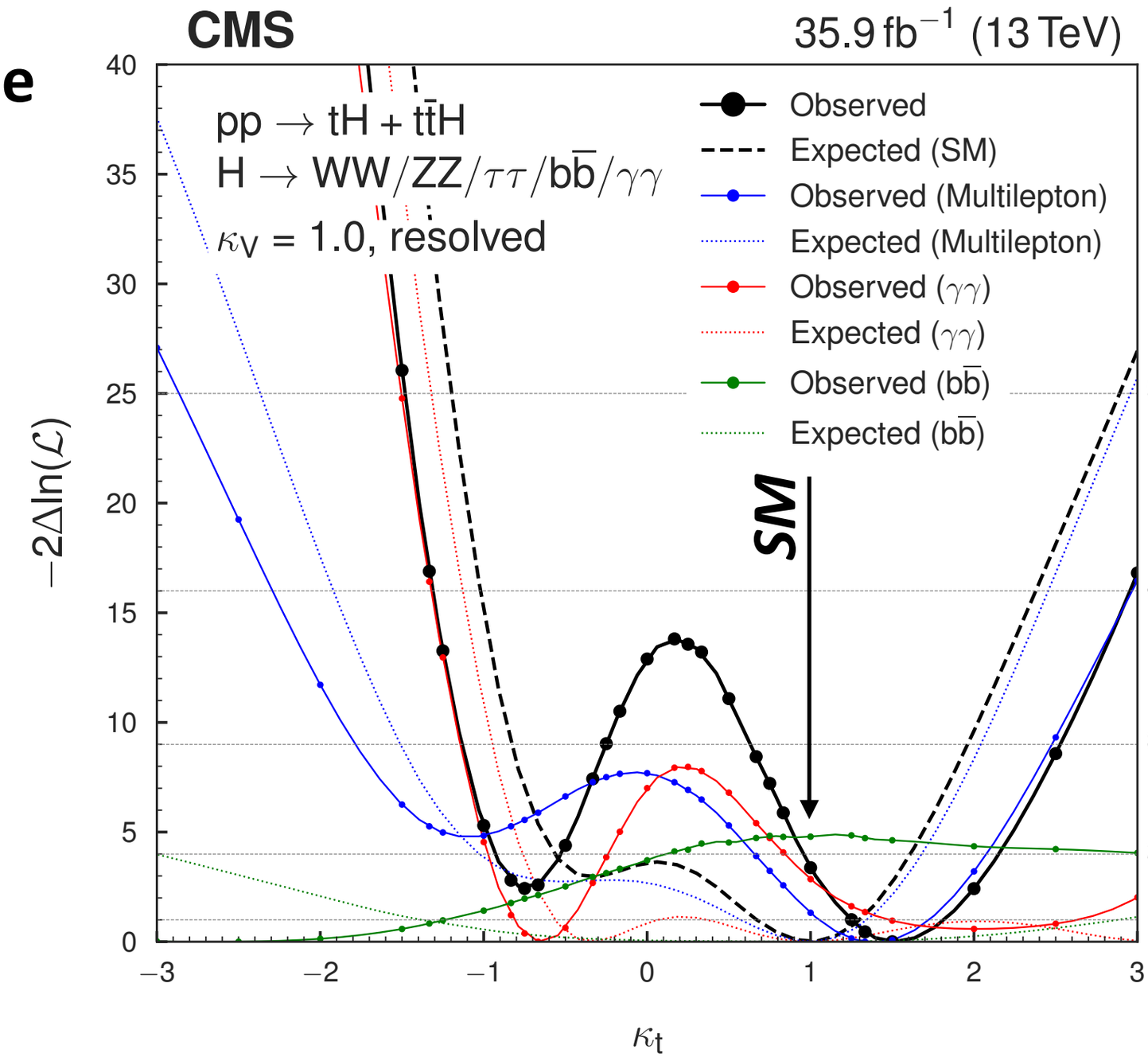
[HIG-18-009]

- CMS analysis of 2016 data in **multilepton** and **bb** channels
  - Reinterpretation of ttH **γγ** categories

- Sensitivity on y_t **magnitude** driven by ttH yield
- tH adds sensitivity to sign

- Data **prefer positive sign** by ~1.5 σ (4 σ expected)

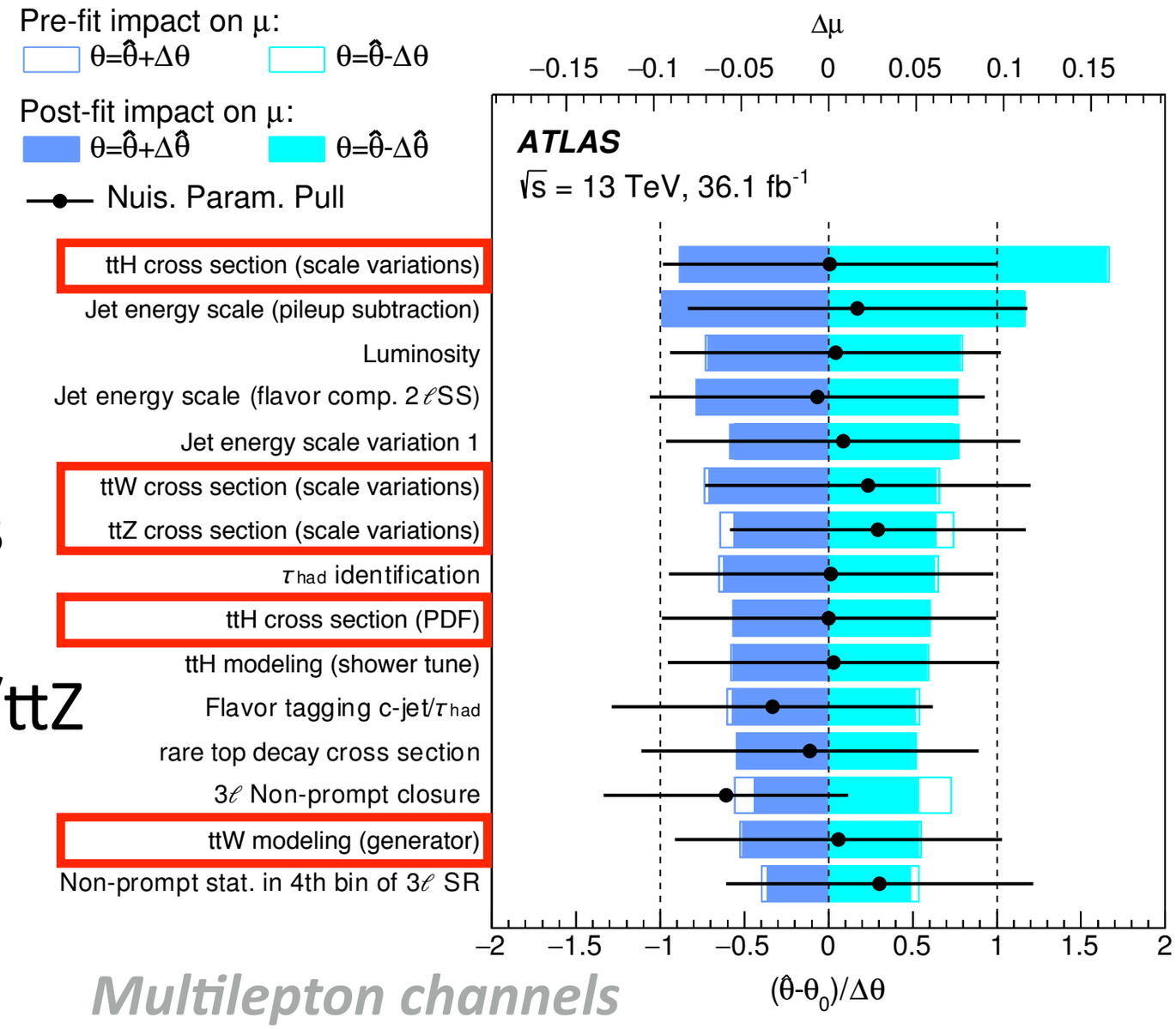
- Limit on SM-like tH at $\sigma < 25\ (12) \times \sigma_{tH}^{SM}$ 95 % C.L.



First steps towards improving theory input in the multilepton channels, starting with ttW background

(Stefano's talk)

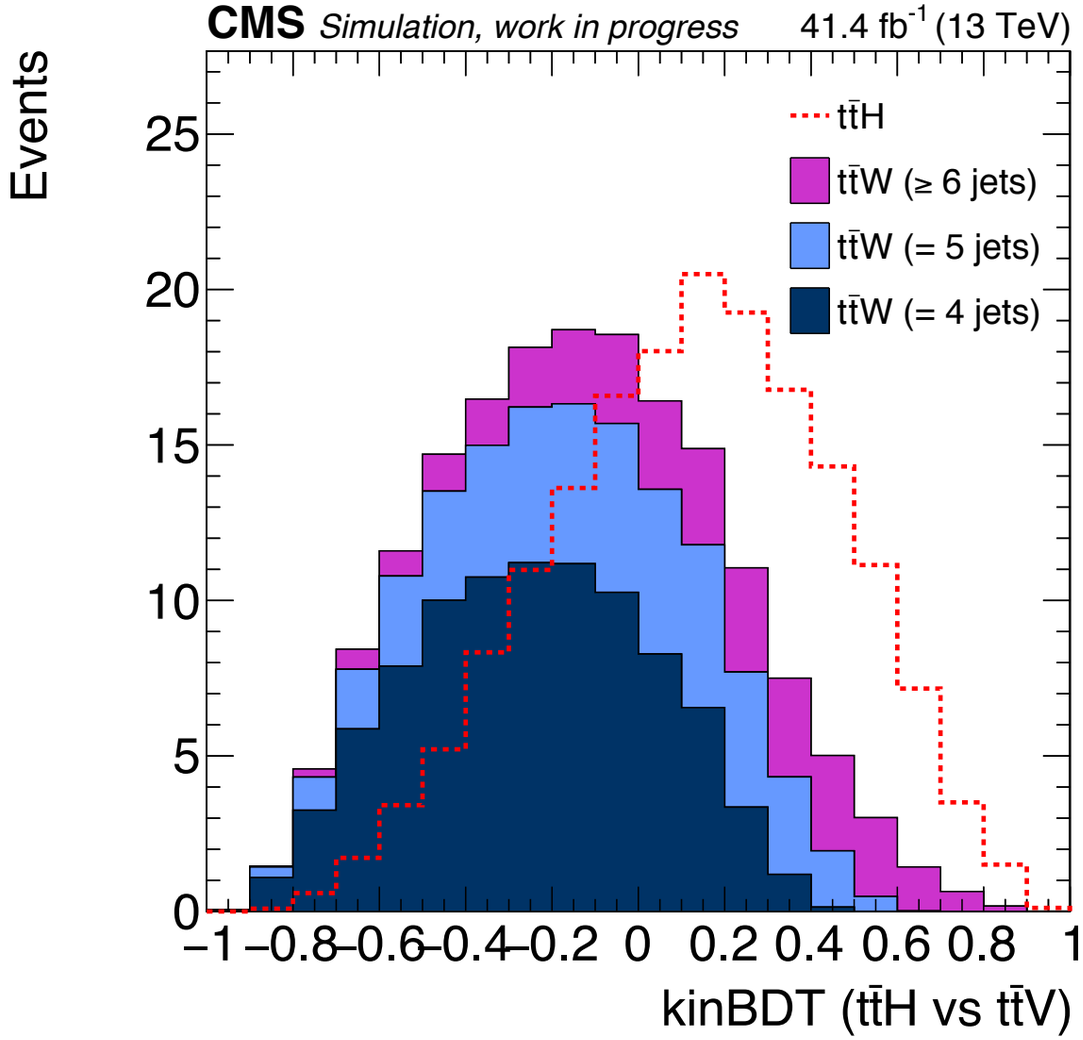
- LHC HXSWG focus on theory inputs to **ttbb** (and ttH(bb)) so far
- **Systematic uncertainties** now almost equal to statistics in multilepton channels
- **Theory systematics** more and more important
- Consider **modeling of main discriminating distributions**
- **Main backgrounds** are ttW/ttZ
  (Nonprompt leptons are estimated from the data)

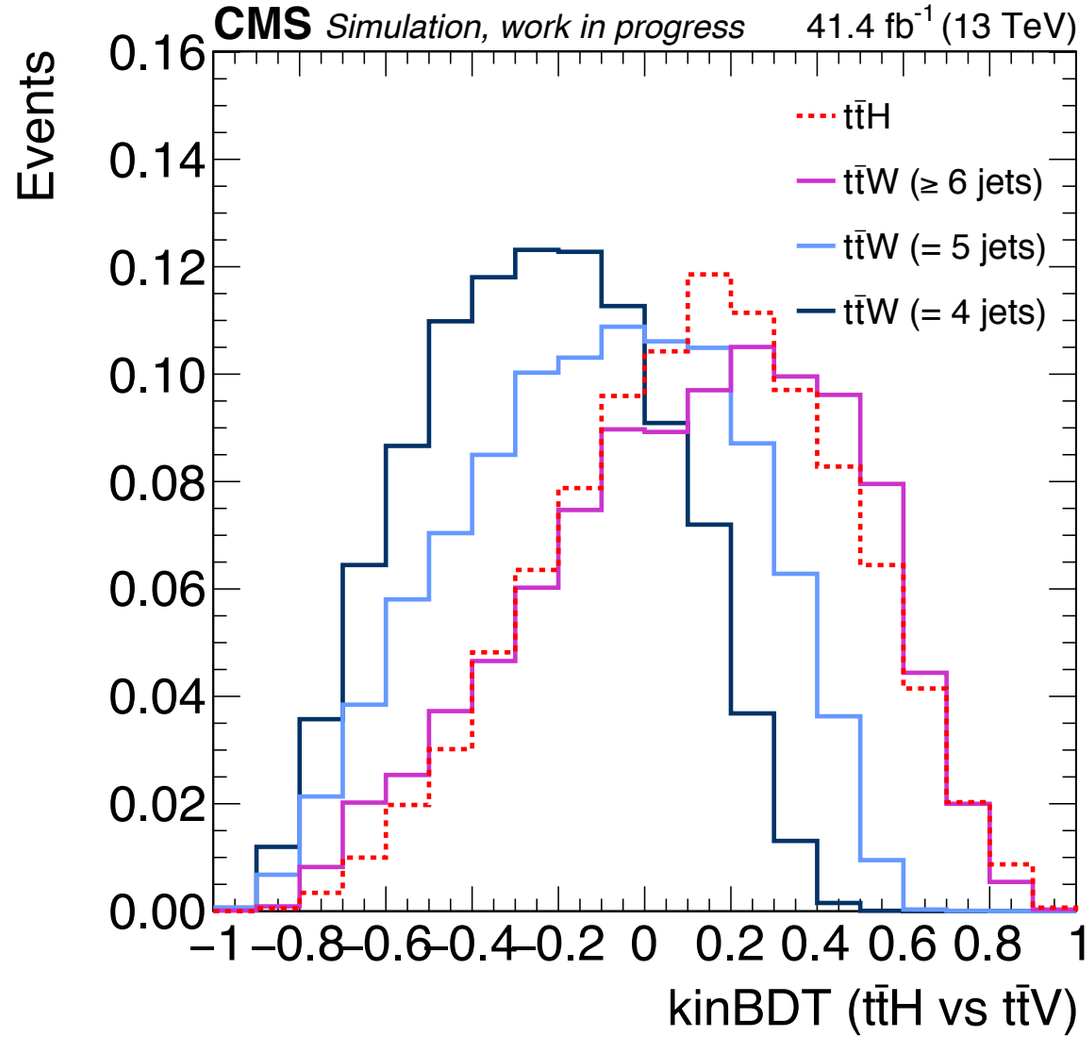


Multilepton channels

ttW + 2 jet events populate high-BDT, signal-like phase space. How well do we model these?

- Consider ttW events in **2LSS channels** (similar for 3L)
- Main discrimiating feature is **number of jets**
- Split **ttH vs ttV BDT output** for ttW events in bins of jets:





Summary/Conclusion

- **Observed ttH production** with 2016 (and 2017) data

- Steadily moving from **search/limits** to **measurements** and from **statistic dominated** to **systematic dominated** regime
  - Next step: **legacy Run II analyses** (full 13 TeV dataset)

- Dedicated tH analyses add sensitivity to **sign/phase of y_t**

- Starting efforts to improve **theory inputs** to **multilepton analyses**