$t\bar{t}H$ Studies in CMS

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A Bit of Legacy

Over the years I did

- $Z \to 4\ell$ (discovery) @UF
- $H \to 4\ell$ (discovery) @UF
- $H \to 4\ell$ CP and properties @UF
- $t\bar{t}H$ (discovery) @Cornell U.
- $t\bar{t}H$ differential, CP, and properties ... @Cornell U./Vilnius

- Hardware: muon chambers, pixel tracker

Melange on the horizon: neutrinos, diHiggs.

$t\bar{t}H$ Overview

$t\bar{t}H$ Importance

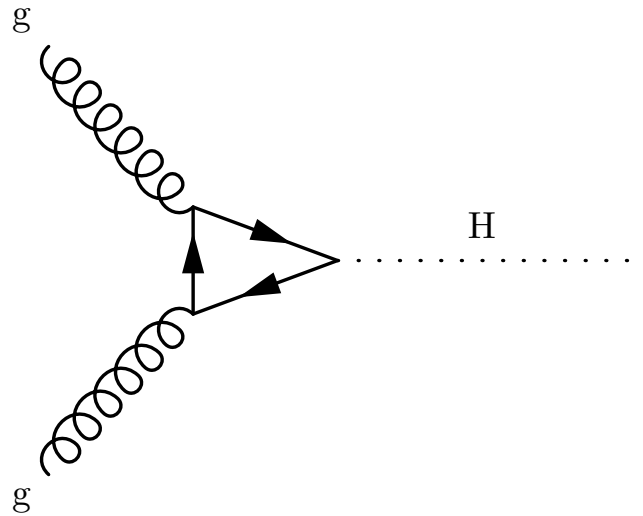
- Only way to directly probe $t\bar{t}H$ vertex:
  - ggH vertex depends on other fields.
  - Way to probe $f\bar{f}H$ Lorentz structure.
  - Critical piece of Higgs properties.
- Bridge to $t\bar{t}X$ searches.

Mode	gg	VBF	VH	$t\bar{t}H$	$b\bar{b}H$
σ, pb	43.9	3.7	2.2	0.5	0.5

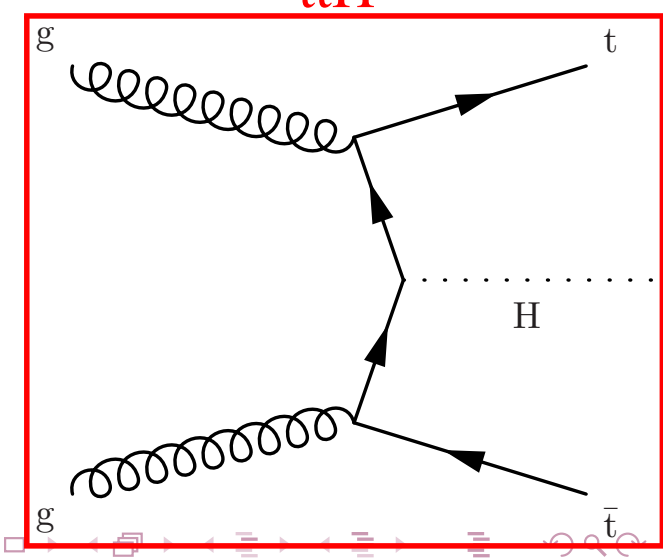
$\sqrt{s}$, TeV	7	8	13
σ, fb	89	133	507

Almost 4$\times$ better with 13 TeV!

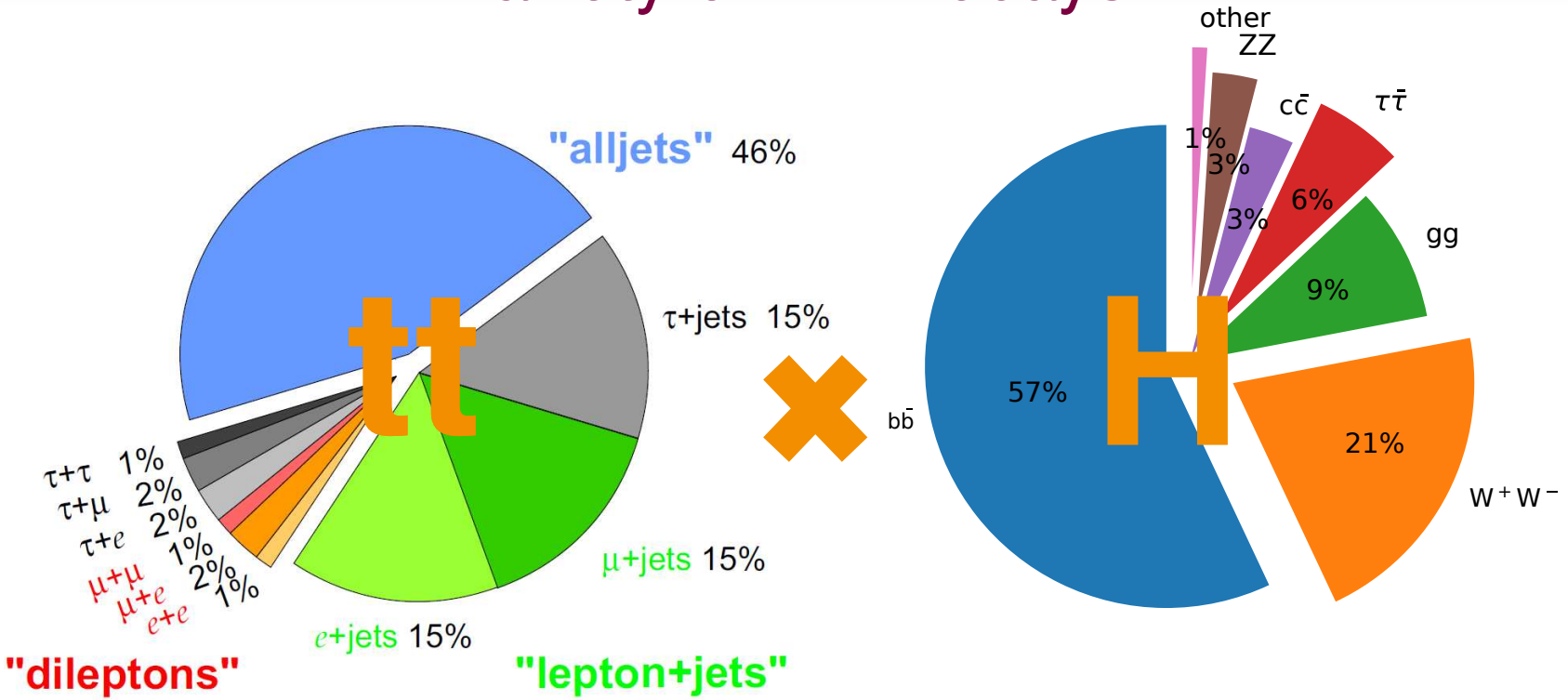
Dominant gg



$t\bar{t}H$



Variety of $t\bar{t}H$ Decays



- $t\bar{t}H, H \to b\bar{b}$: dileptonic, ℓ+jets, hadronic
- $t\bar{t}H, H \to \tau\bar{\tau}$: universal ("inclusive") categories
- $t\bar{t}H, H \to \ell_i$ (multileptonic): dileptonic, ℓ+jets
- $t\bar{t}H, H \to \gamma\gamma$: leptonic (dileptonic, ℓ+jets), hadronic
- $t\bar{t}H, H \xrightarrow{ZZ^*} 4\ell$: one special category

More events ↑

Fewer backgrounds ↓

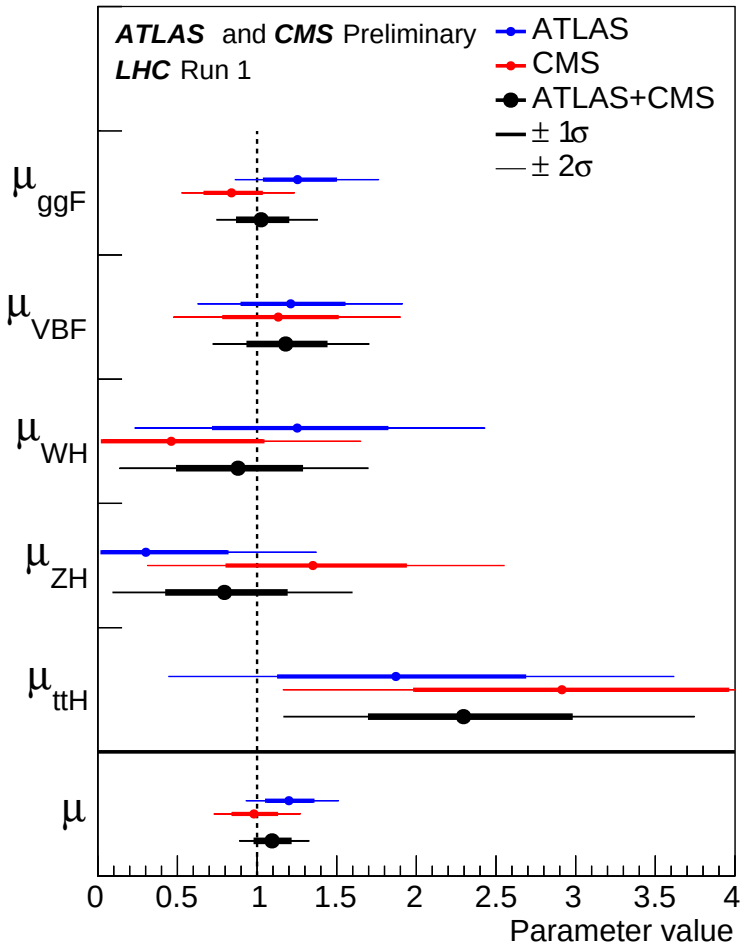
Summary of LHC Run 1 for ttH

All Higgs decay modes (7+8 TeV)

Production process	Measured significance (σ)	Expected significance (σ)
VBF	5.4	4.7
WH	2.4	2.7
ZH	2.3	2.9
VH	3.5	4.2
ttH	4.4	2.0
Decay channel		
$H \to \tau\tau$	5.5	5.0
$H \to bb$	2.6	3.7

In short:

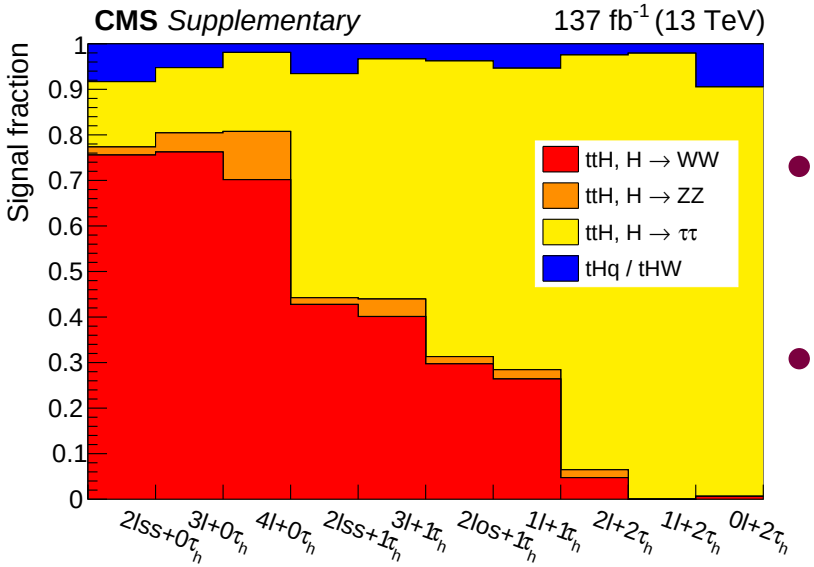
	μ_{ttH}
ATLAS	$1.9^{+0.8}_{-0.7}$
CMS	$2.9^{+1.0}_{-0.9}$
Both	$2.3^{+0.7}_{-0.6}$



Full Run 2: μ/diff/CP/EFT

$$t\bar{t}H \text{ in CMS} = \begin{cases} H \to b\bar{b} & \cdots/\cdots/\cdots/\cdots \\ \text{multilepton} & \checkmark/\cdots/\cdots/\cdots \\ H \to \gamma\gamma & \checkmark/\cdots/\checkmark/\cdots \end{cases}$$

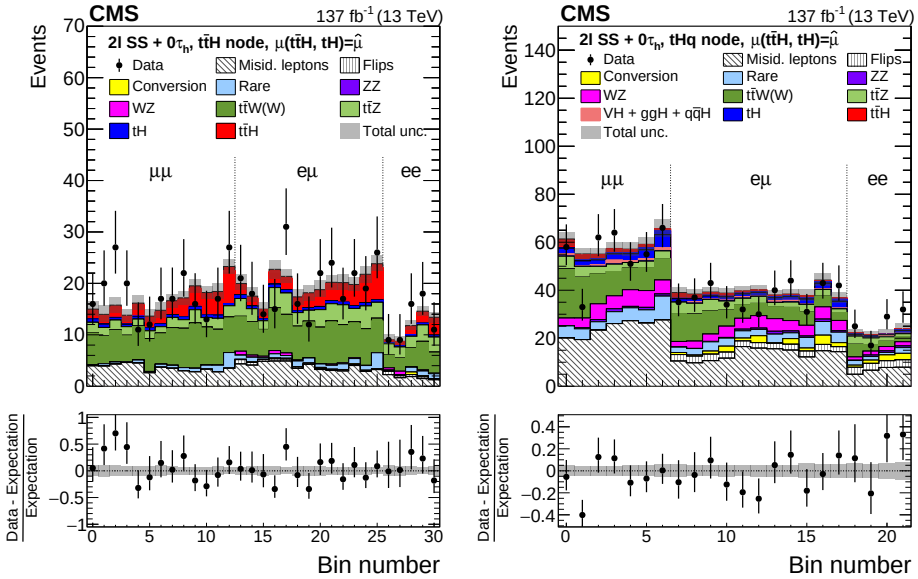
Multilepton $t\bar{t}H$ Strategy

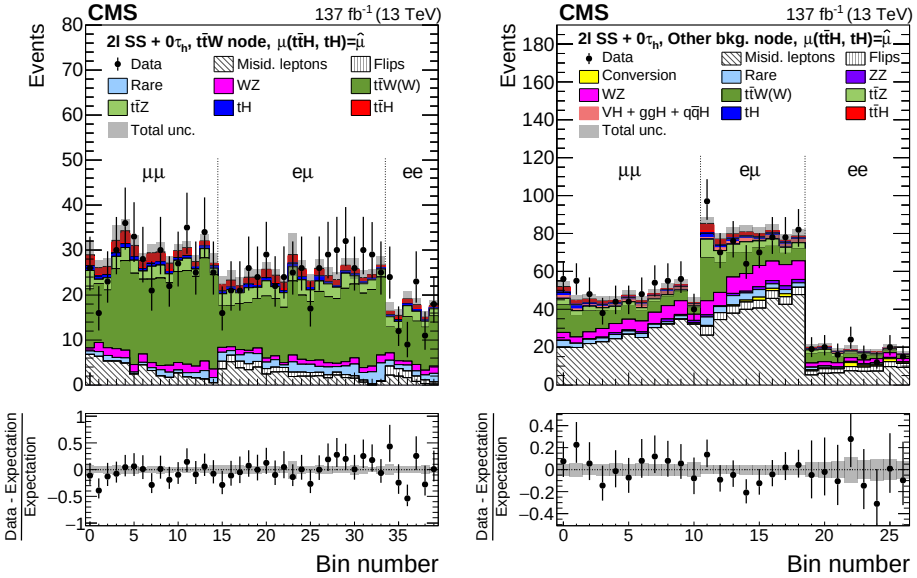


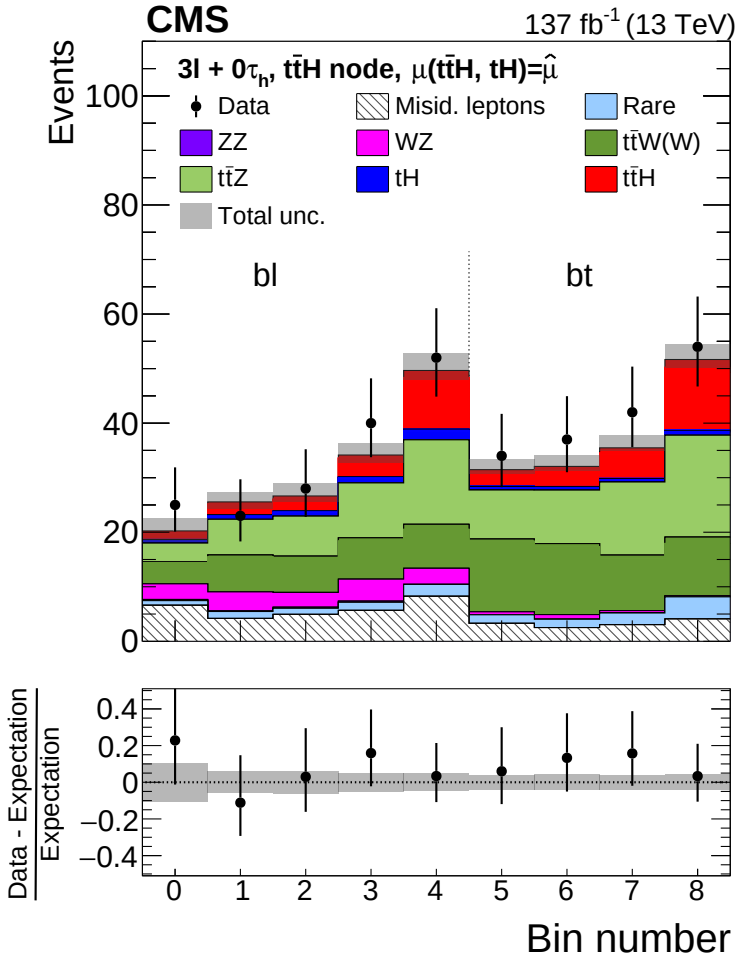
- Define signal regions on ℓ&τ_h multiplicity
  - Additional event selection for each cat.
- Sensitive to different Higgs decay modes
  - has different background composition

- Multivariate techniques to discriminate $t\bar{t}H$ and tH from bckgs.
  - Extra subcategorization in lepton flavor and b jet multiplicity
- Likelihood fit to all subcategories

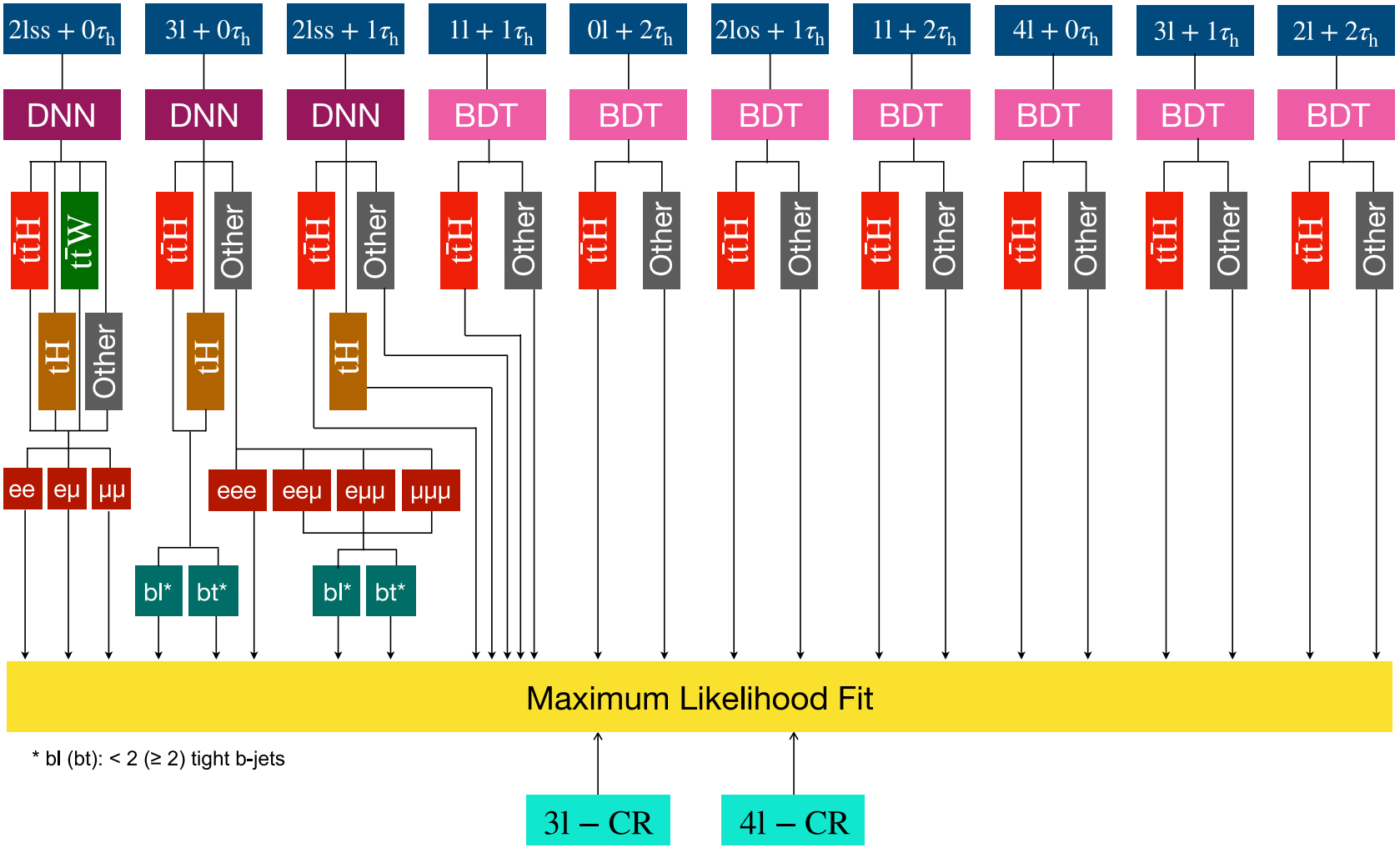
Some “Money Plots”



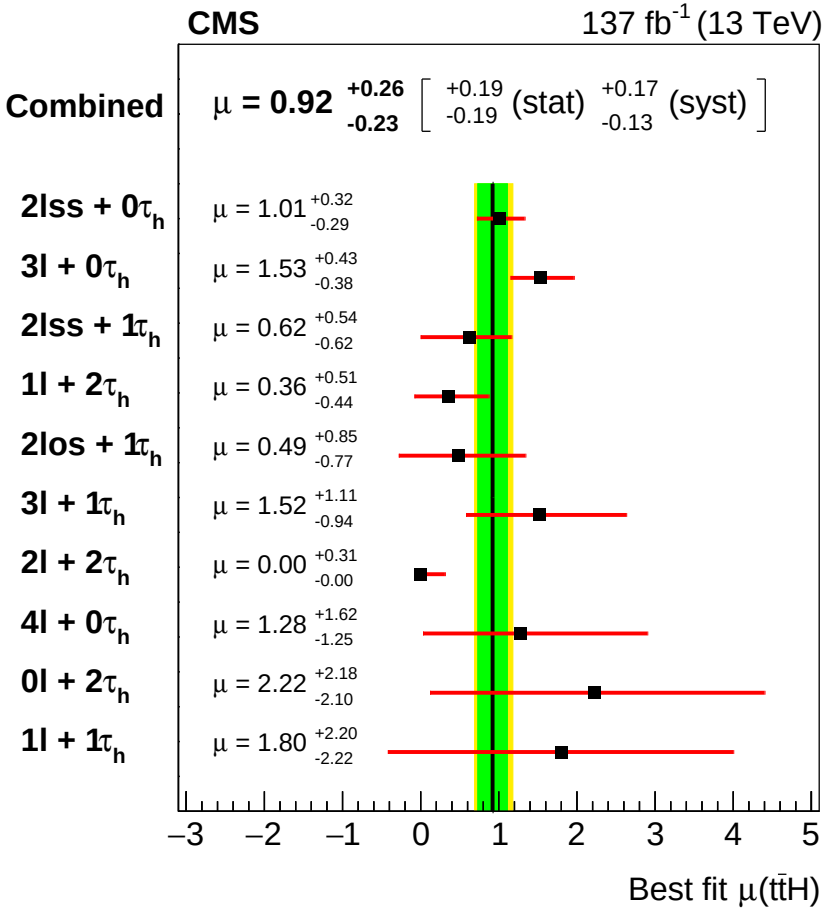


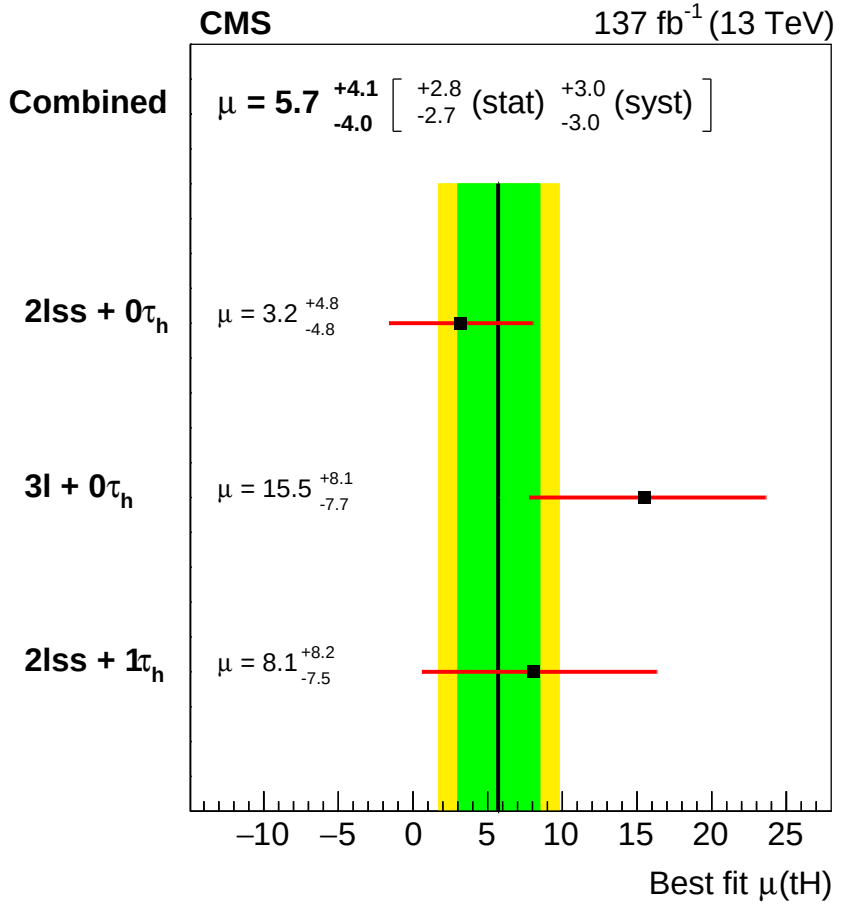


A Full Picture



Run 2 Results from Multilepton $t\bar{t}H$





For details see CMS HIG-19-008, arxiv, accepted in EPJC.