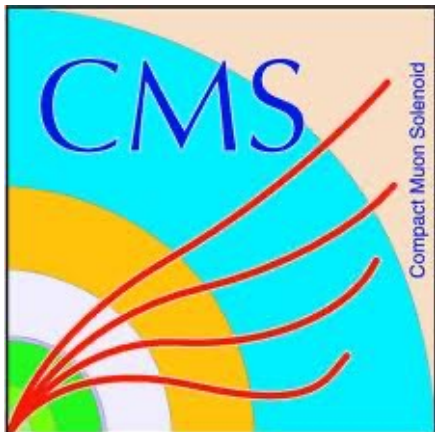
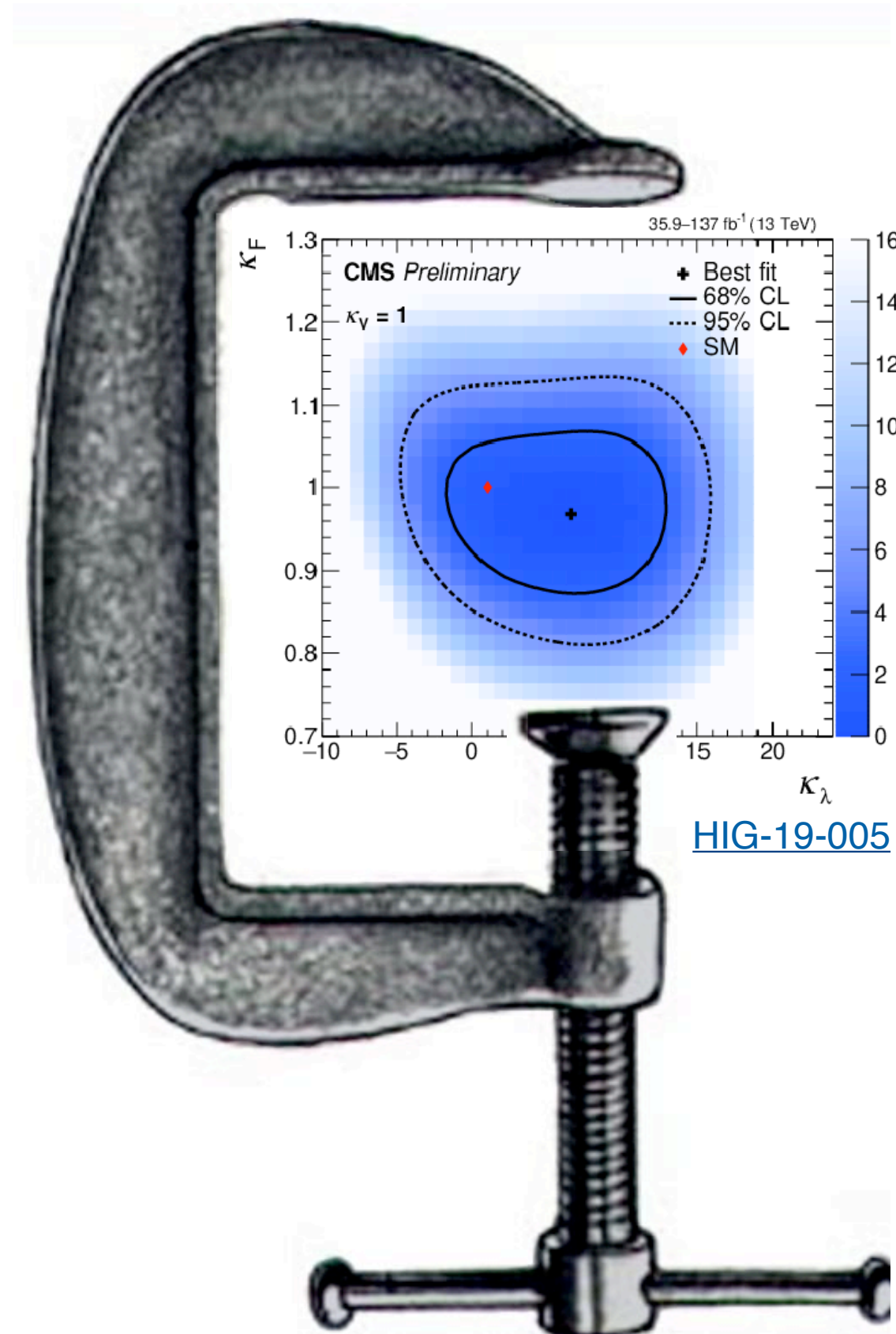


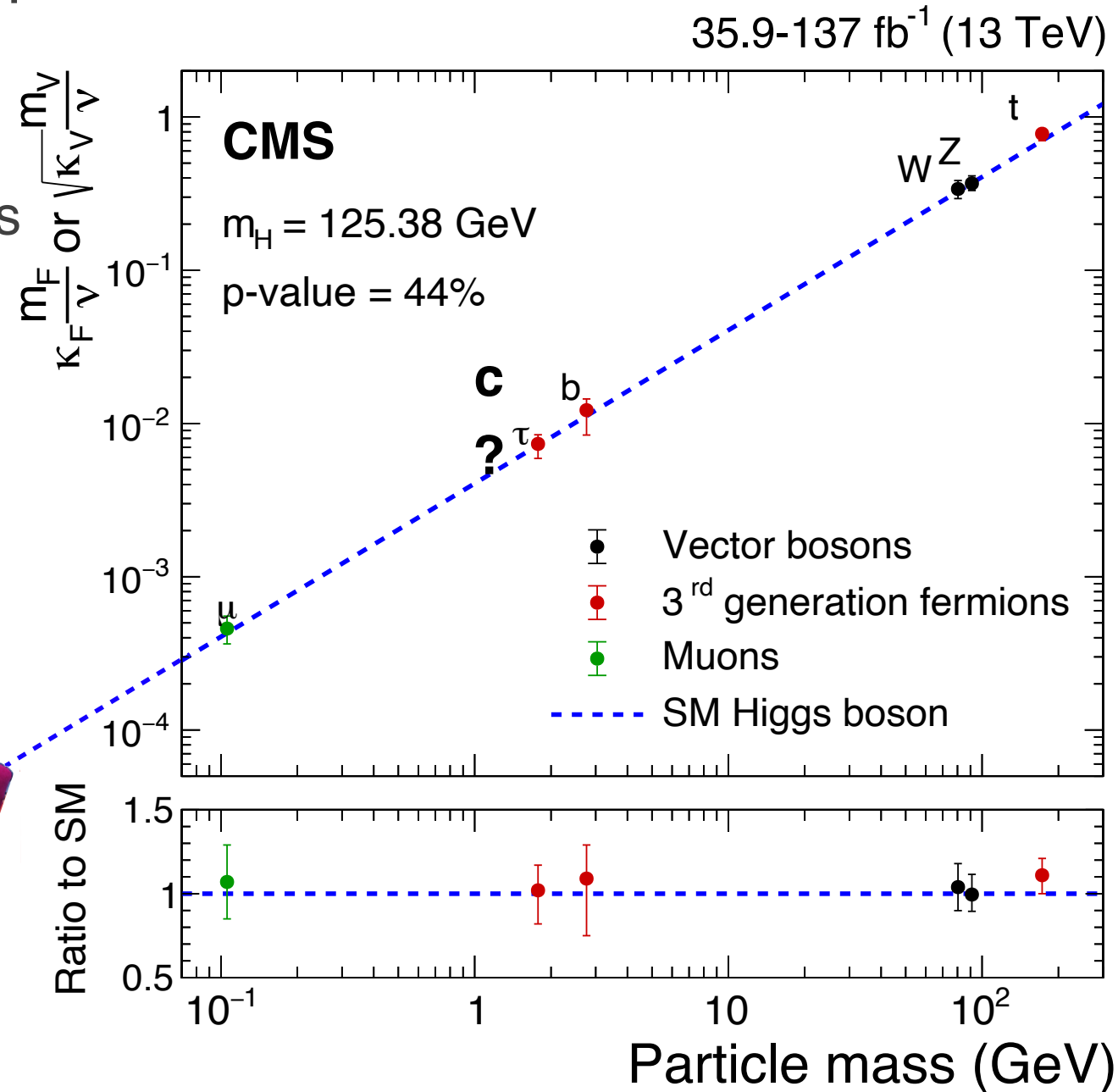
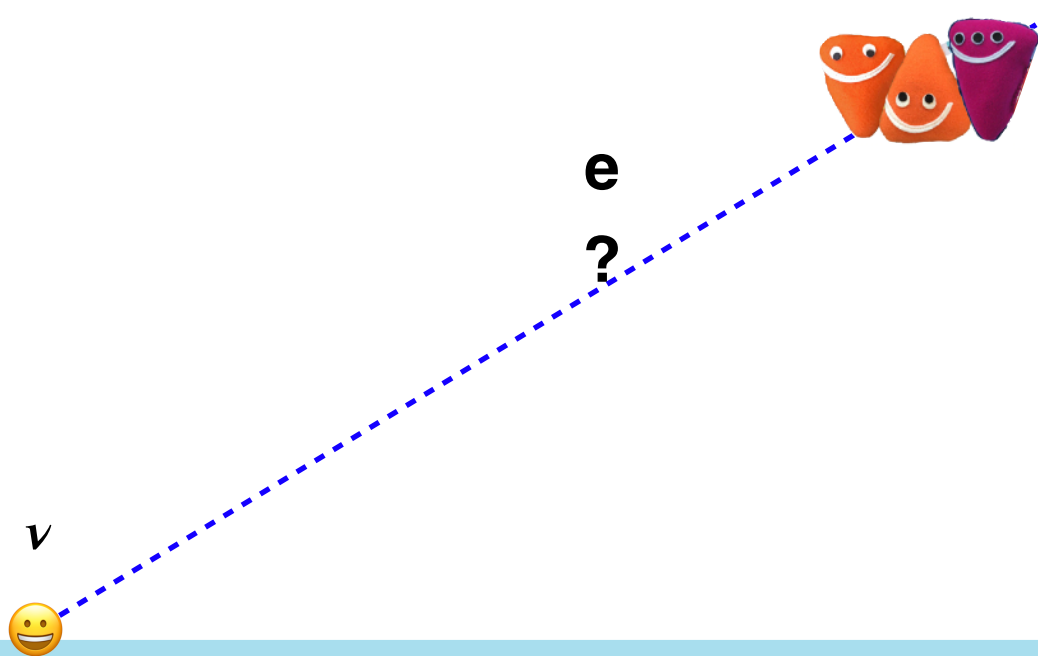
Measurements of Higgs-fermion interactions at CMS

Nick Smith
Pheno 2022
9 May 2022



Introduction

- The Yukawa term of the SM Lagrangian generates the Higgs-fermion coupling and fermion masses
 - A relation expected to hold over many orders of magnitude is formed
- CMS can experimentally probe Higgs couplings to most fermions via production and/or decay topologies
- Any deviation from the relation would be very interesting!



HIG-19-006

(arXiv:2009.04363)

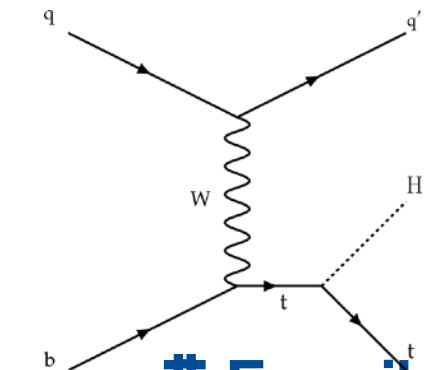
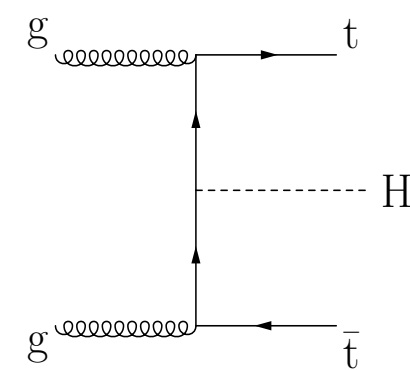
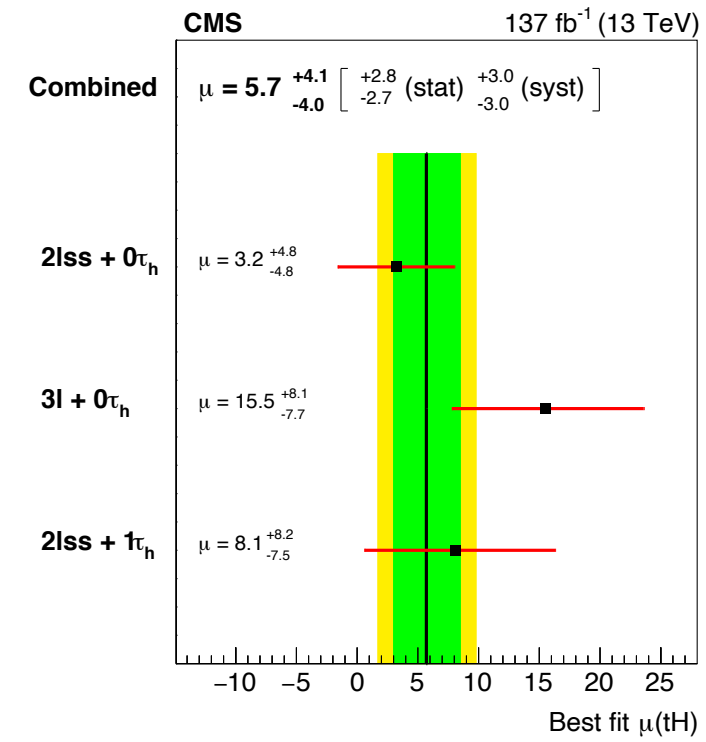
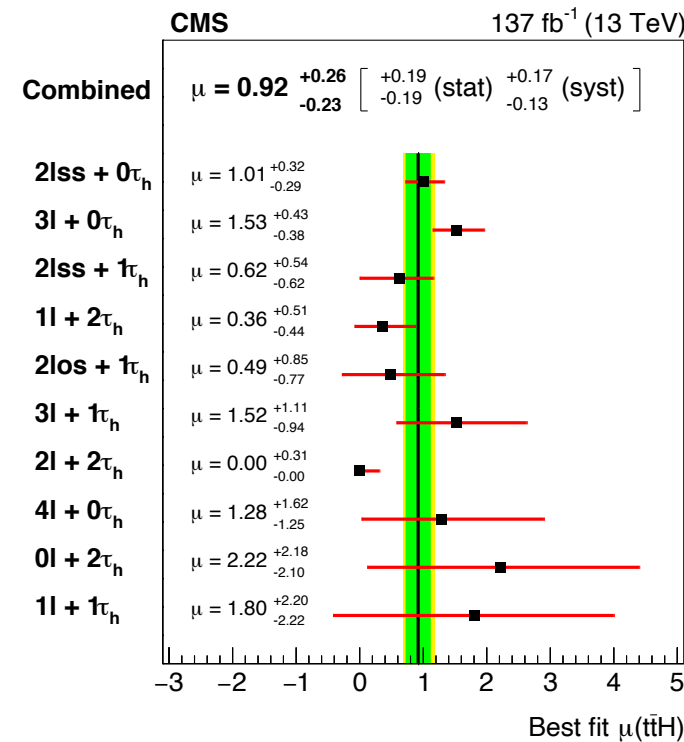
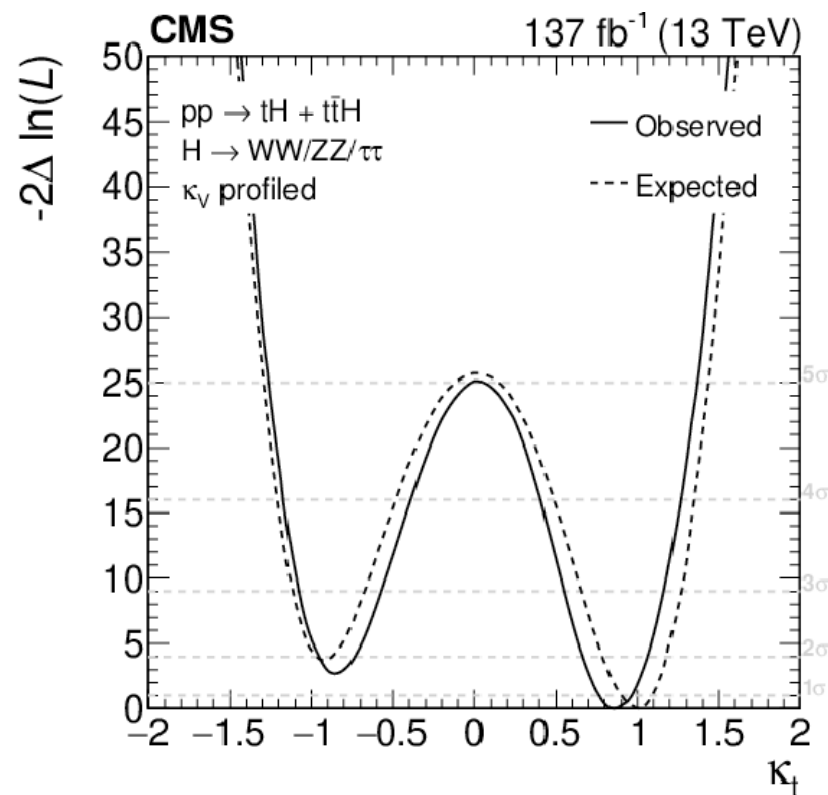
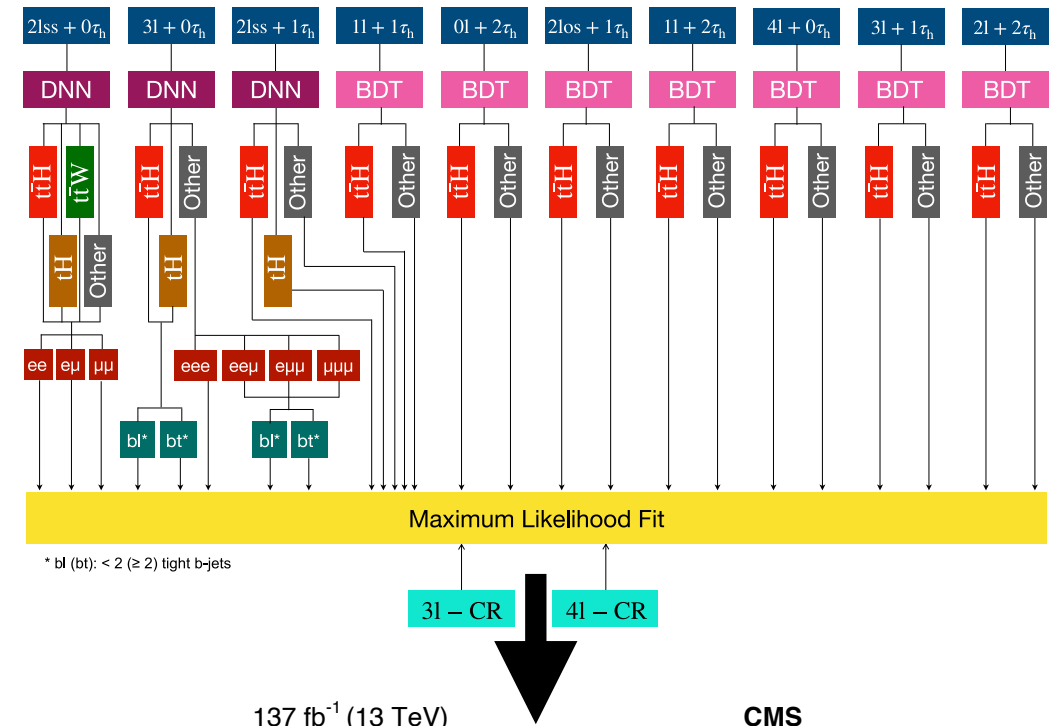


Starting from the top

HIG-19-008

(arXiv:2011.03652)

- ttH multilepton
 - Targeting $H \rightarrow WW, \tau\tau,$ and ZZ decays
 - Both hadronic and leptonic top decays
- Rich set of final states
 - 10 lepton multiplicity categories
 - Necessitates multivariate technique
- ttH at 4.7 (5.2) σ significance
 - tH at 1.4 (0.3) σ

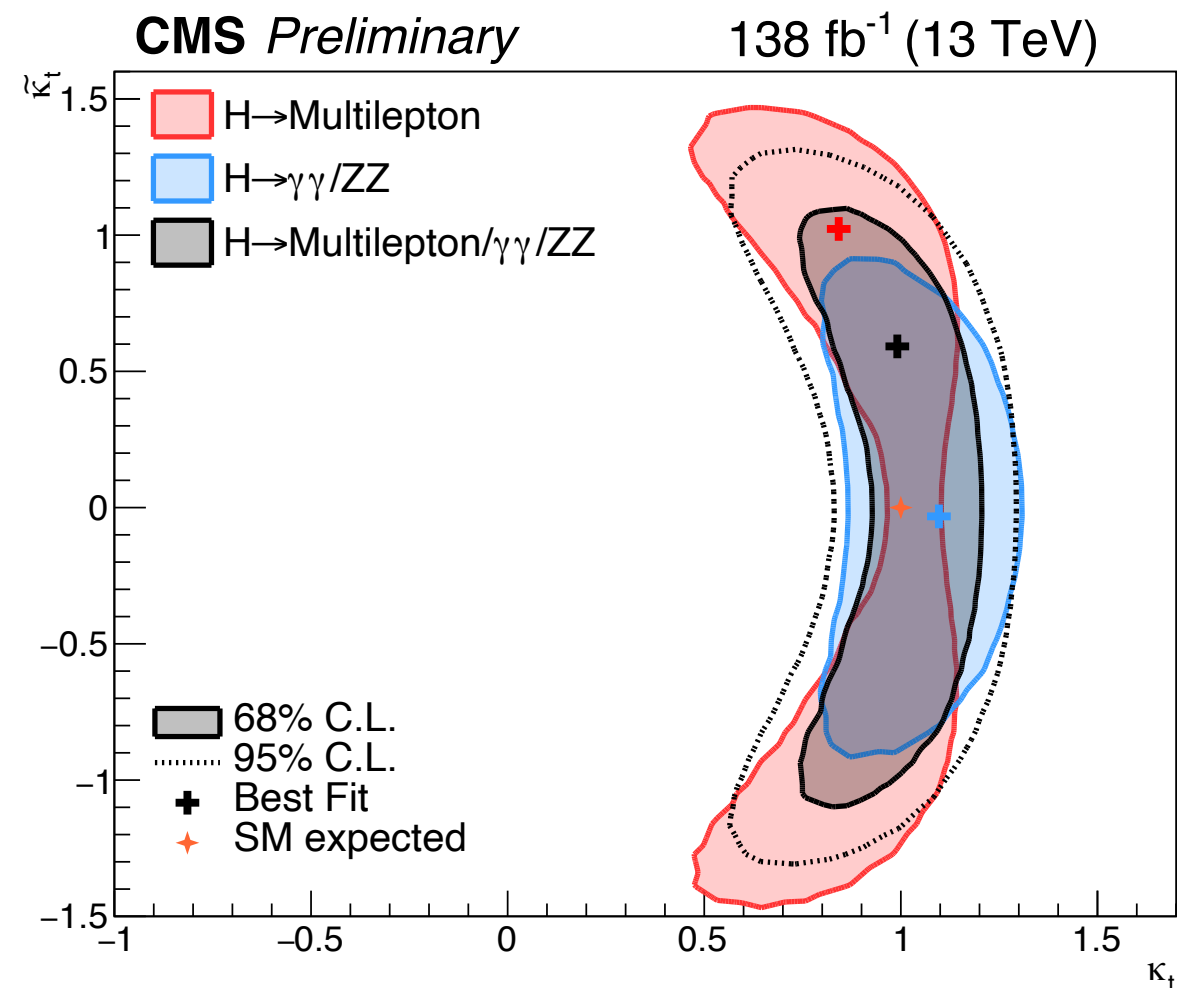
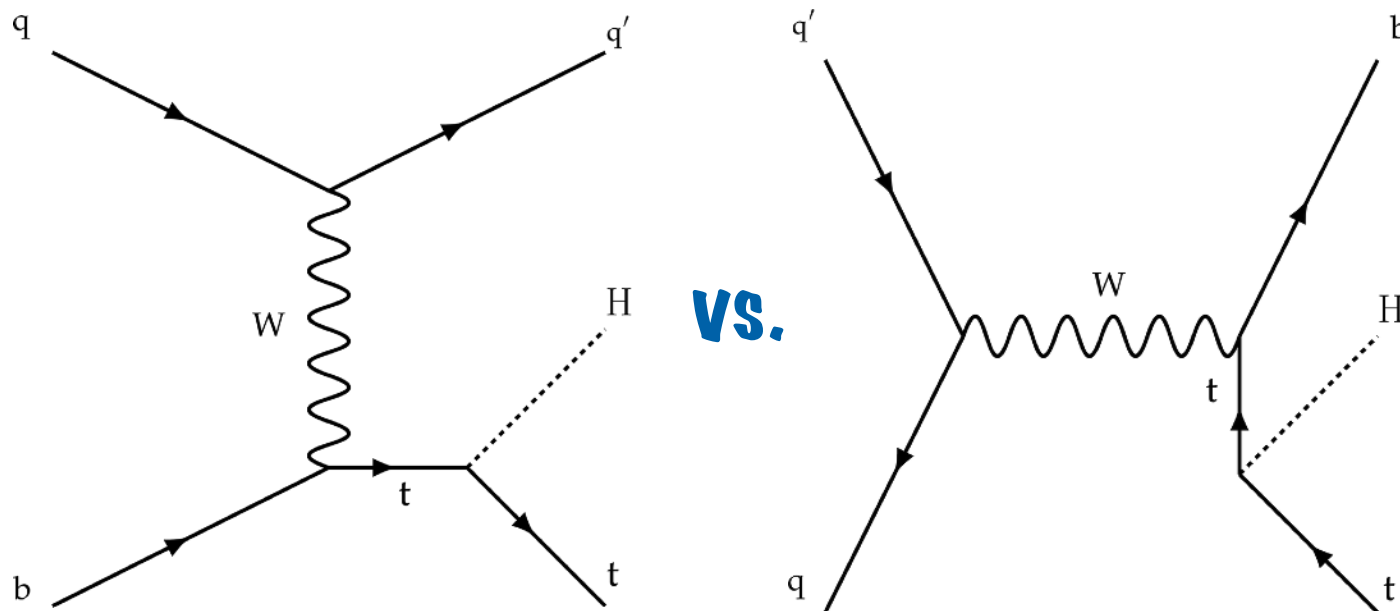


ttH CP structure

- New for Moriond '22: CP structure
 - Uses 3 most sensitive categories from previous result
- tH crucial in resolving sign of κ_t
 - Large variation in XS due to destructive interference
- Combined with earlier ttH($\gamma\gamma$ /ZZ) result
 - 1D interval: $0.96 < \kappa_t < 1.16$
 - Similar constraint from ggH production $\sim \kappa_t^2$

[HIG-21-006](#)

$$\mathcal{L}_{t\bar{t}H} = \frac{-y_t}{2} \bar{\psi}_t (\kappa_t + i\gamma_5 \tilde{\kappa}_t) \psi_t H.$$

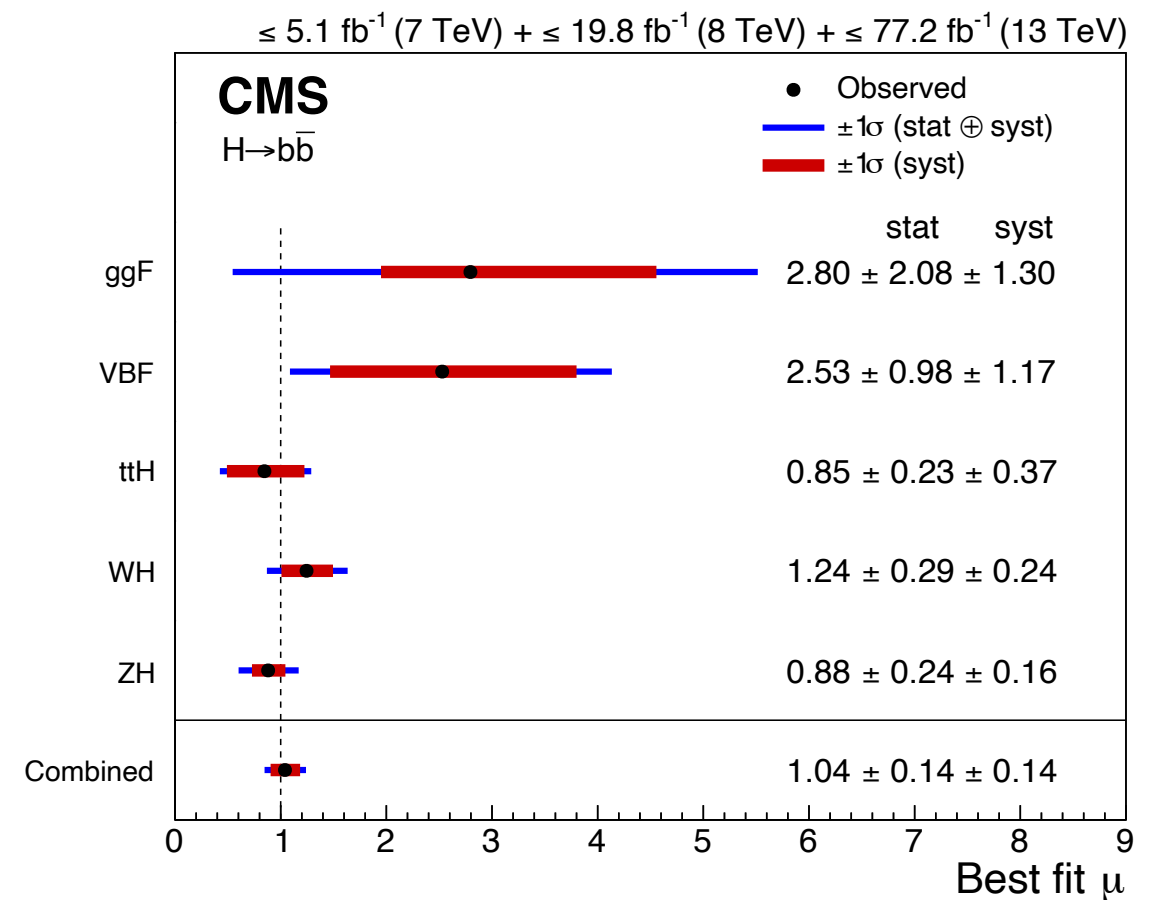
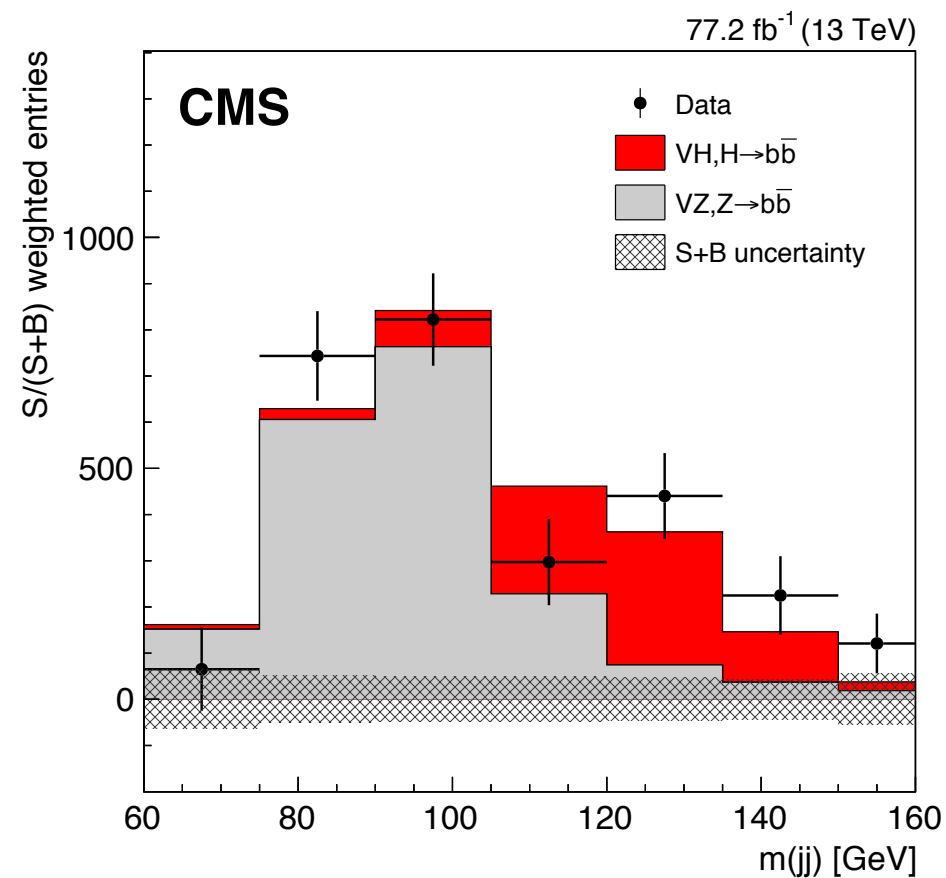


Higgs coupling to b quarks

- Observation of $VH(bb)$ in 2018 using Run I+2016+2017 data
 - Tag V boson based on lepton multiplicity categories
 - Use DNN to tag b jets and correct kinematics
 - Multi-region fit to constrain V+heavy flavor background
- Validating using $VZ(bb)$

[HIG-18-016](#)

[\(arXiv:1808.08242\)](#)

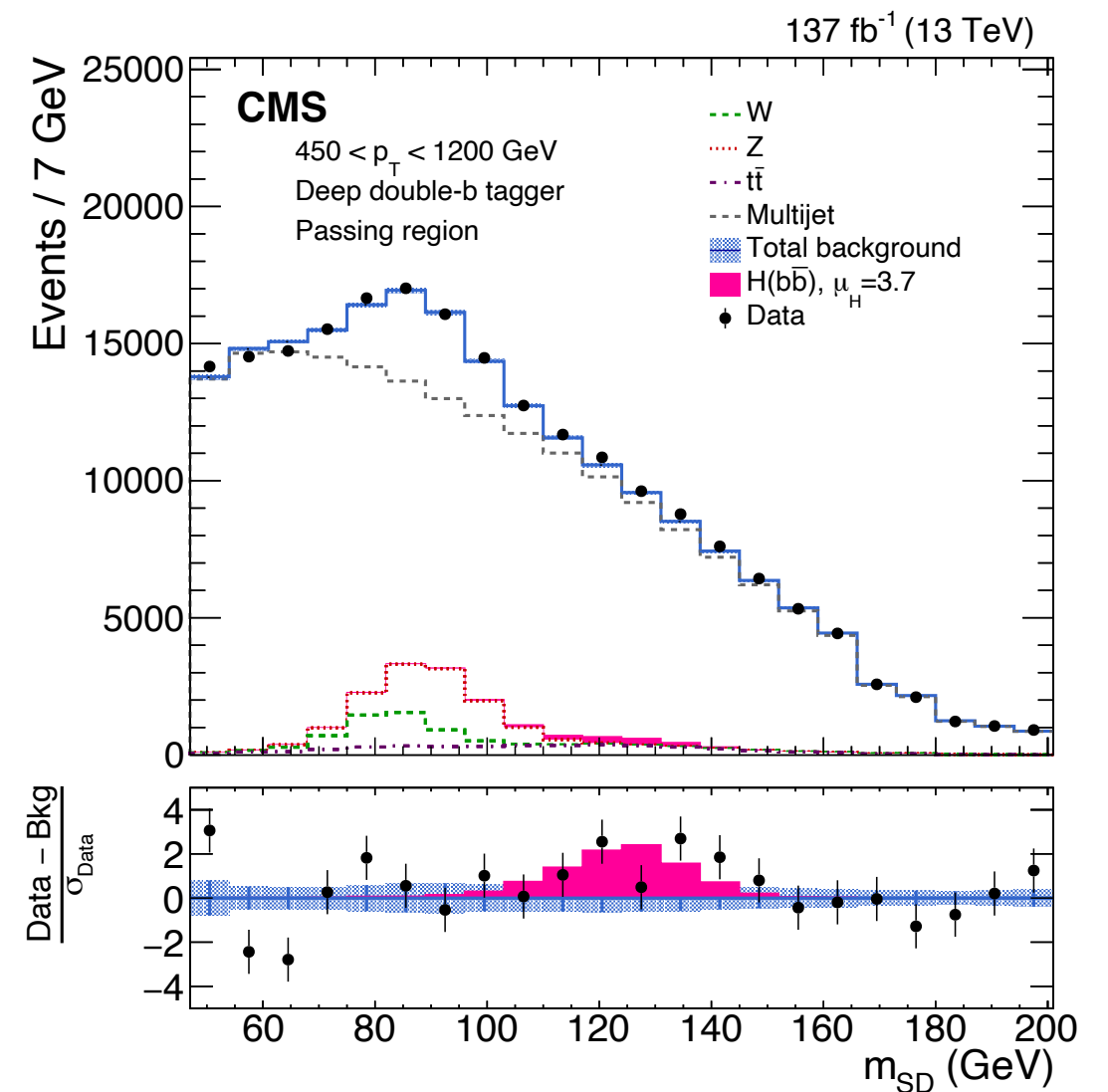
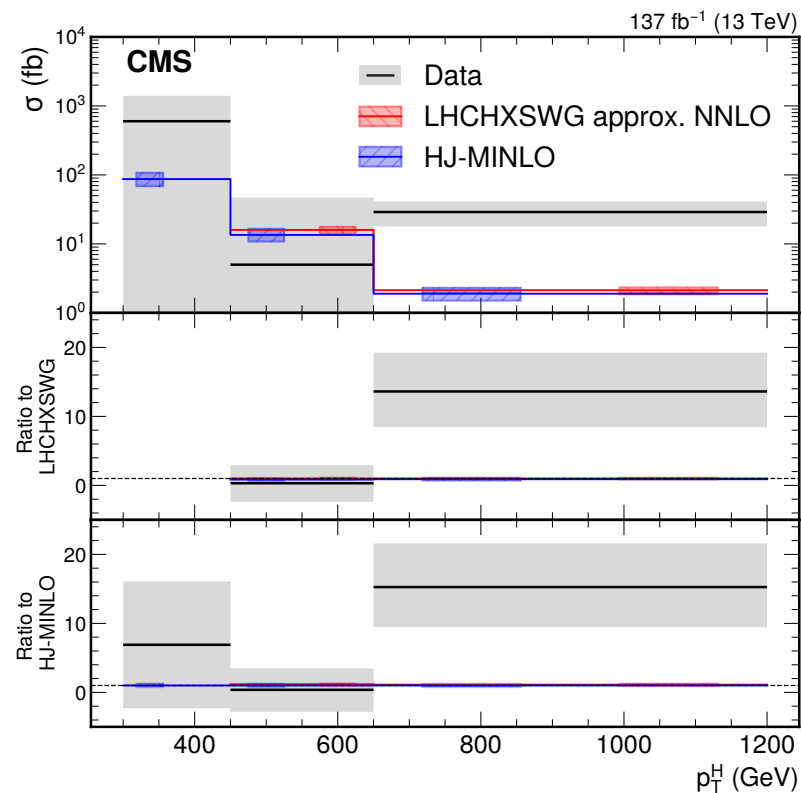


Higgs coupling to b quarks

- Inclusive search for boosted $H(bb)$ using Run II data
 - Select boosted AK8 jet with two-prong substructure
 - Use DNN tagger to select bb -enriched events
 - Search for peak in jet mass
- 2.5σ excess over background
- Validated using $Z(bb)$

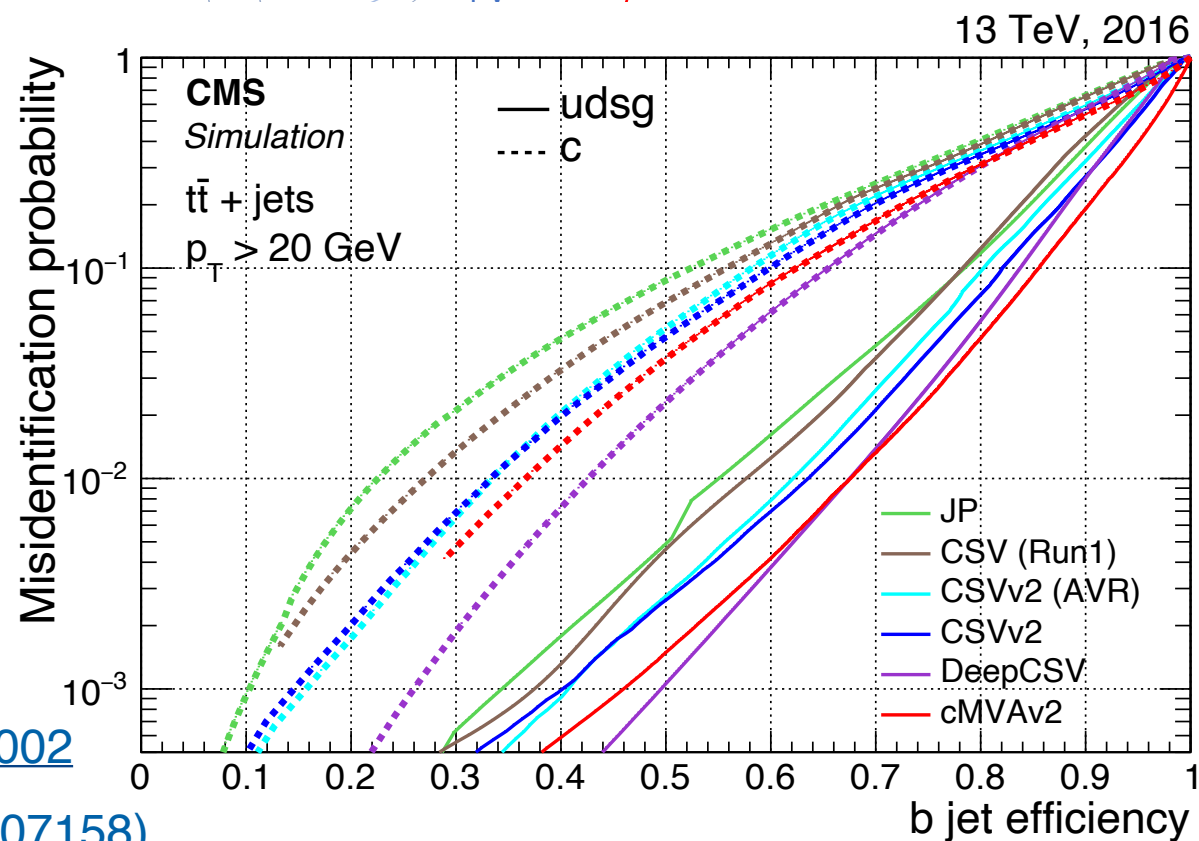
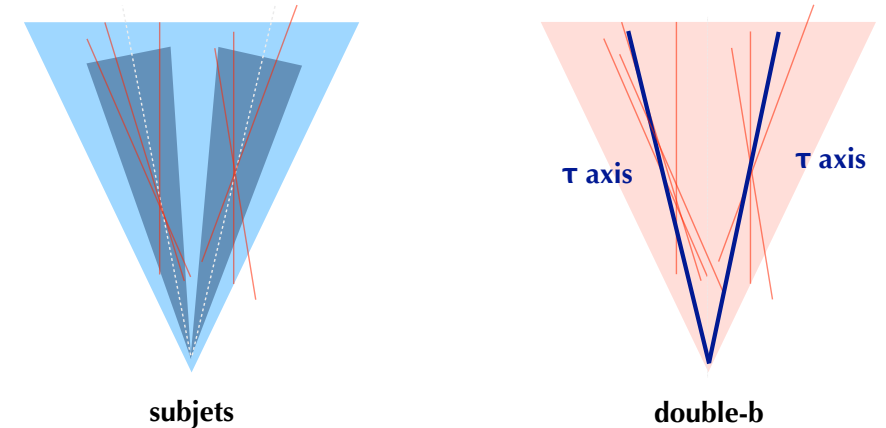
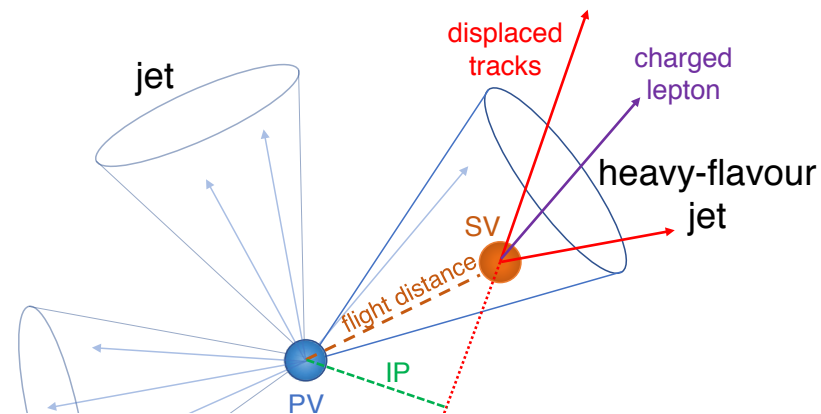
[HIG-19-003](#)

[\(arXiv:2006.13251\)](#)



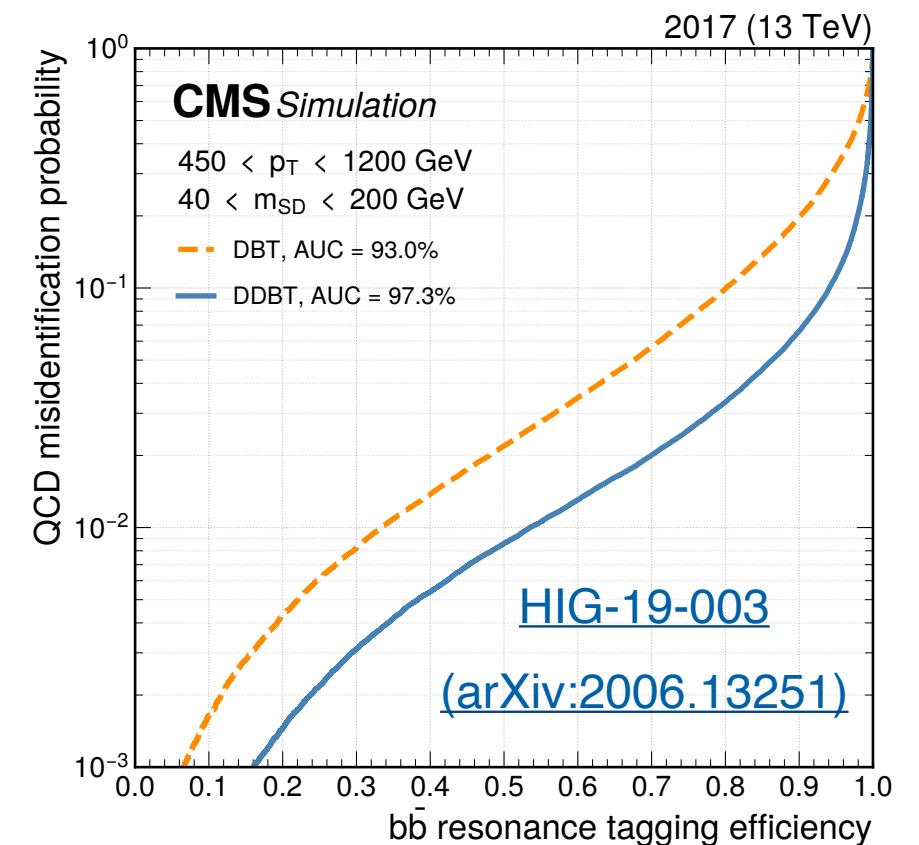
Flavor tagging developments

- Both VH(bb) and boosted H(bb) possible due to advances in DNN b-tagging
- Continuous progress in AK4 and AK8 jet b-tagging
 - All of these are already outdated



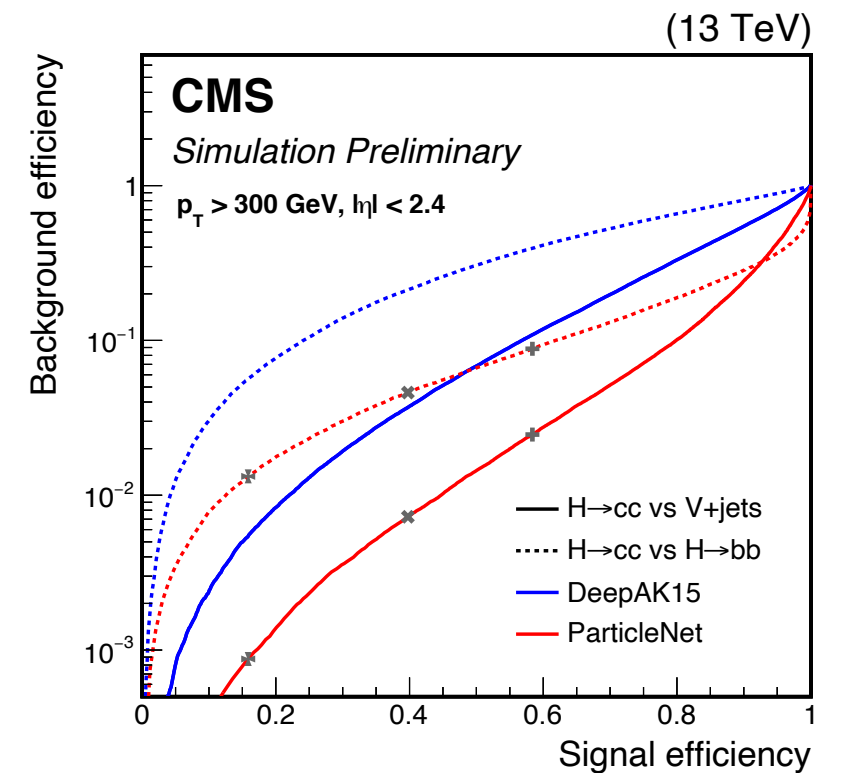
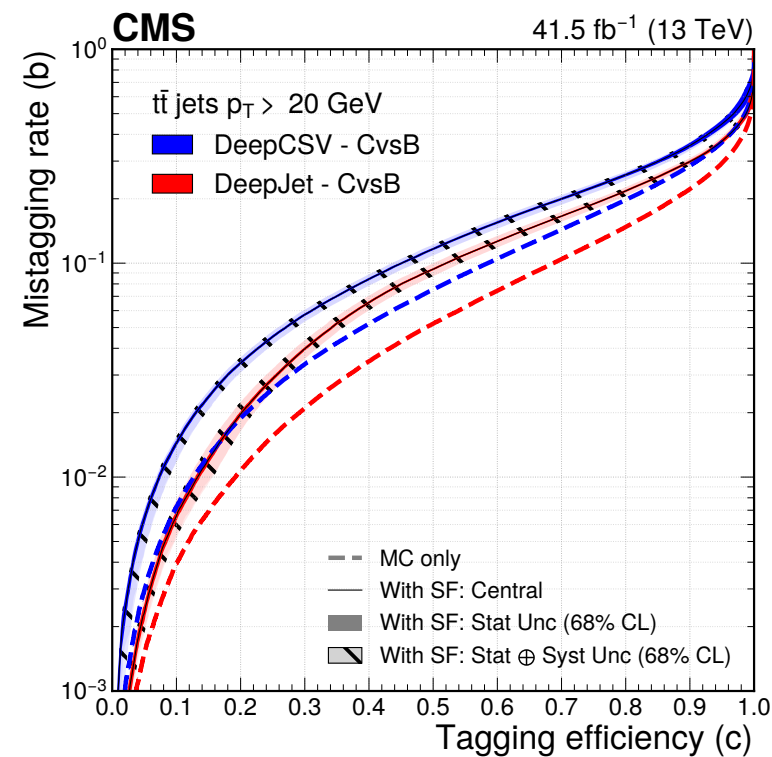
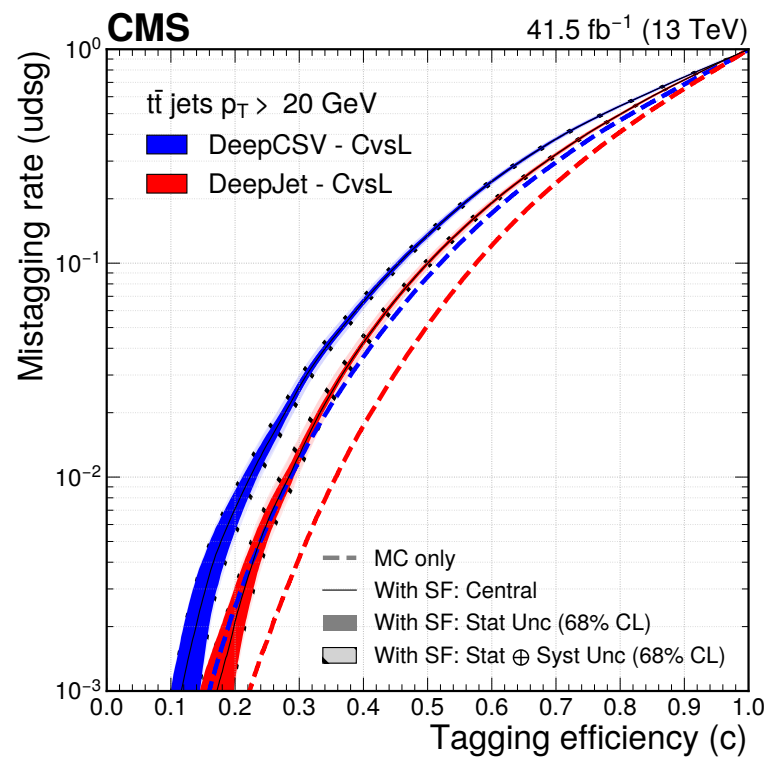
[BTV-16-002](#)

[\(arXiv:1712.07158\)](#)



Flavor tagging developments

- In parallel, similar progress in AK4 and AK8 jet c-tagging



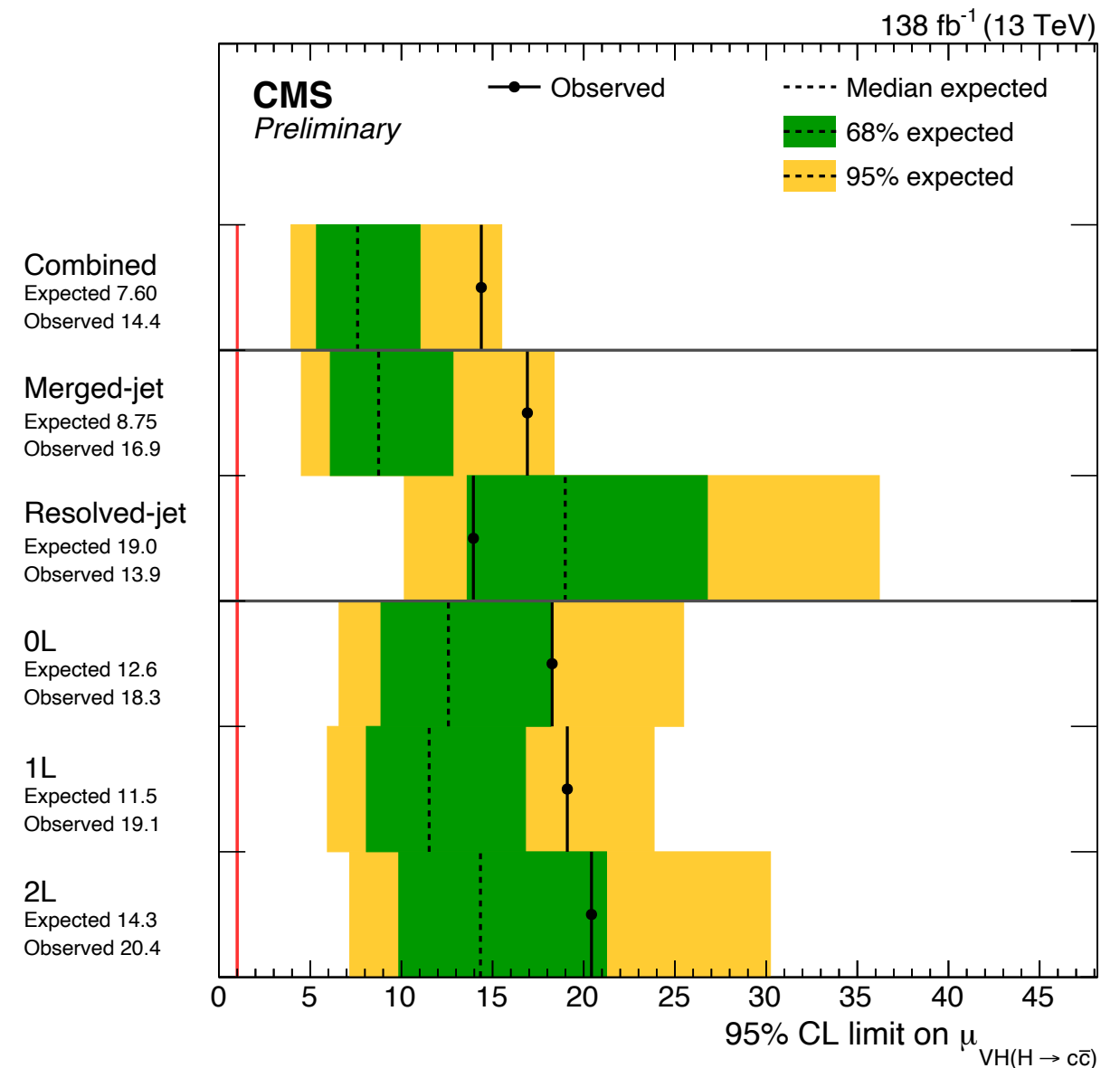
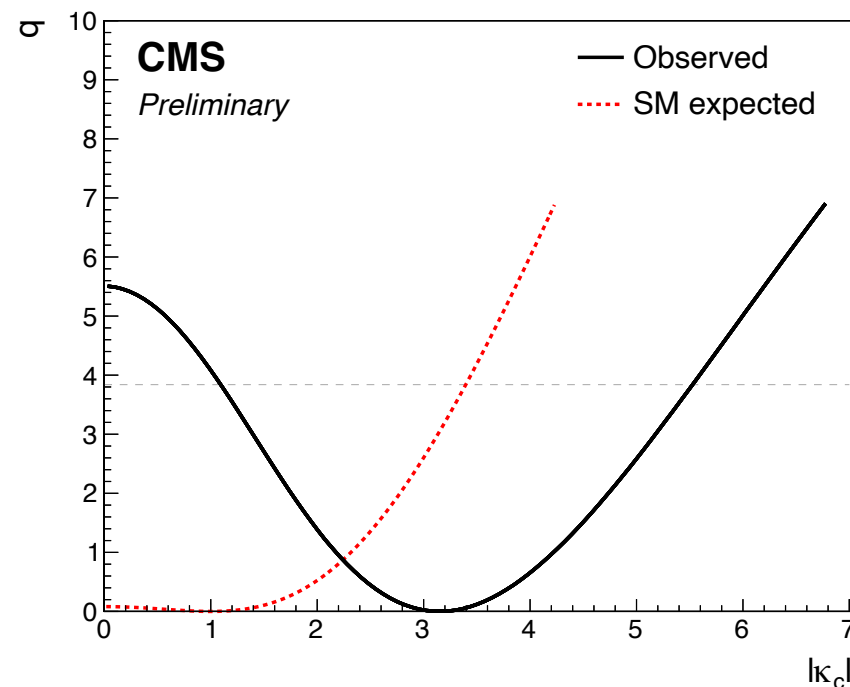
[BTV-20-001](#)

[HIG-21-008](#)

[\(arXiv:2111.03027\)](#)

Higgs decays to charm

- New for Moriond '22: full Run II VH(cc)
 - Combines resolved and merged-jet channels
 - Two AK4 DeepJet c-tagged jets
 - One AK8 ParticleNet cc-tagged jet
- Validated using VZ(cc)
 - Excess at 5.7 (5.9) σ , first observation of Z(cc) at a hadron collider
- VH(cc) upper limit: 14x SM
 - Best fit κ_c interpretation:



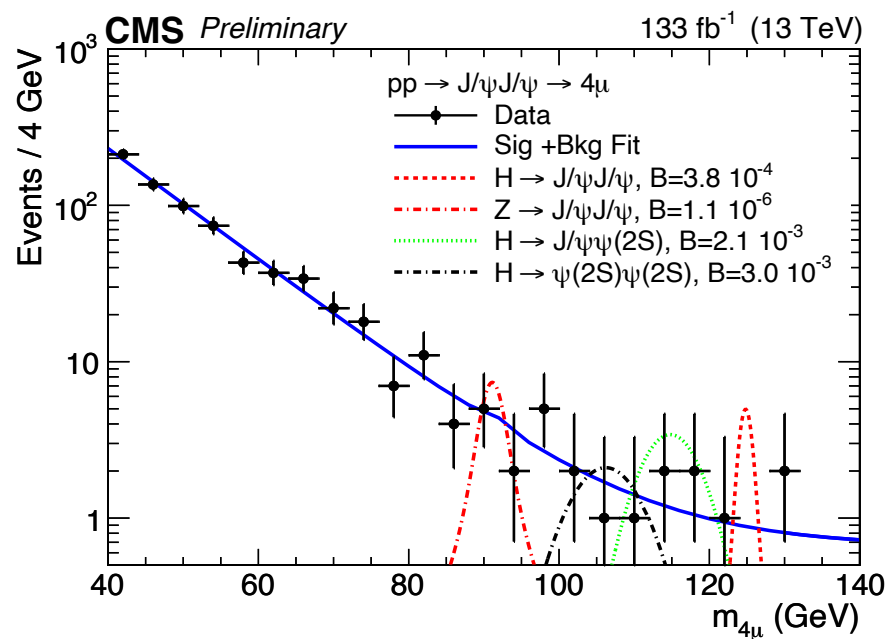
$$\mu_{VH(H \rightarrow c\bar{c})} = \frac{\kappa_c^2}{1 + \mathcal{B}_{SM}(H \rightarrow c\bar{c}) \times (\kappa_c^2 - 1)}$$

HIG-21-008

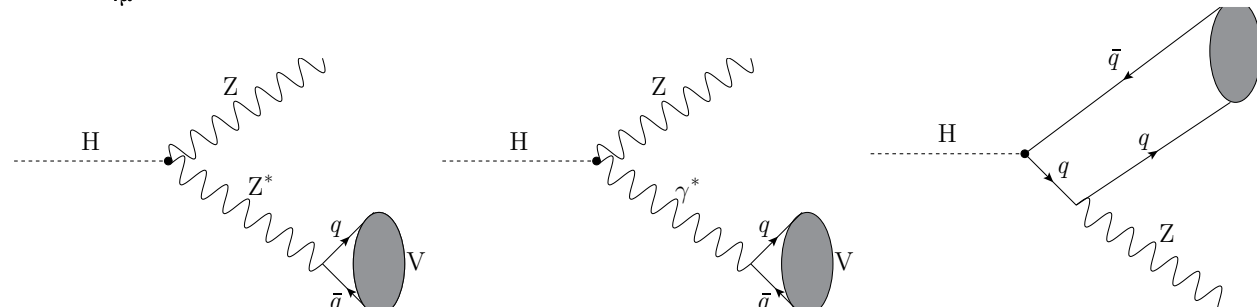
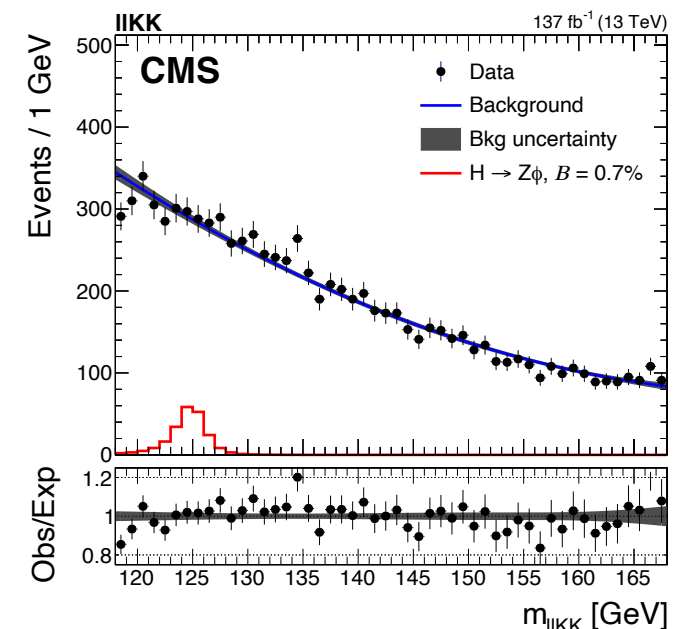
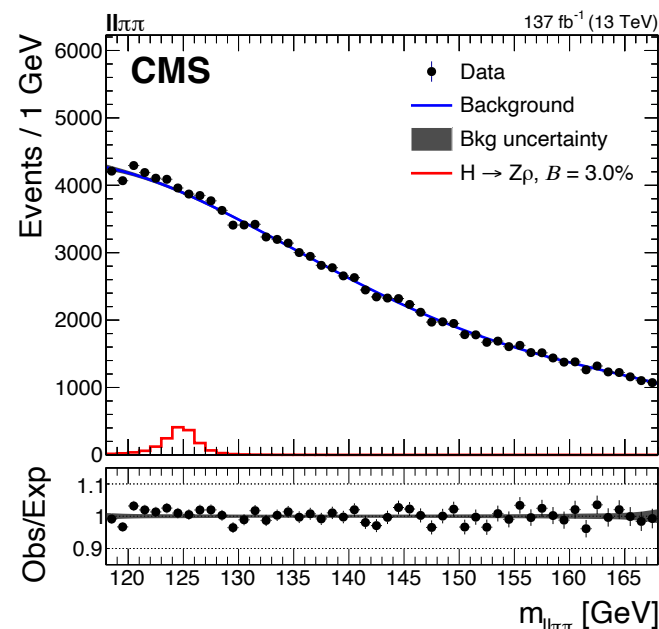
The other quarks



- CMS probes lightest quark Yukawas via Z+meson searches
 - J/ψ or Υ are complementary probes of c and b coupling
 - ρ and ϕ mesons probe u, d, and s coupling
- In all cases, direct Higgs-fermion coupling very small in SM
 - Dominated by ZZ^* where Z^* decays to a meson
 - Upper limits correspond to $\sim 800x$ SM expectation



[HIG-20-008](#)



[HIG-19-012](#)

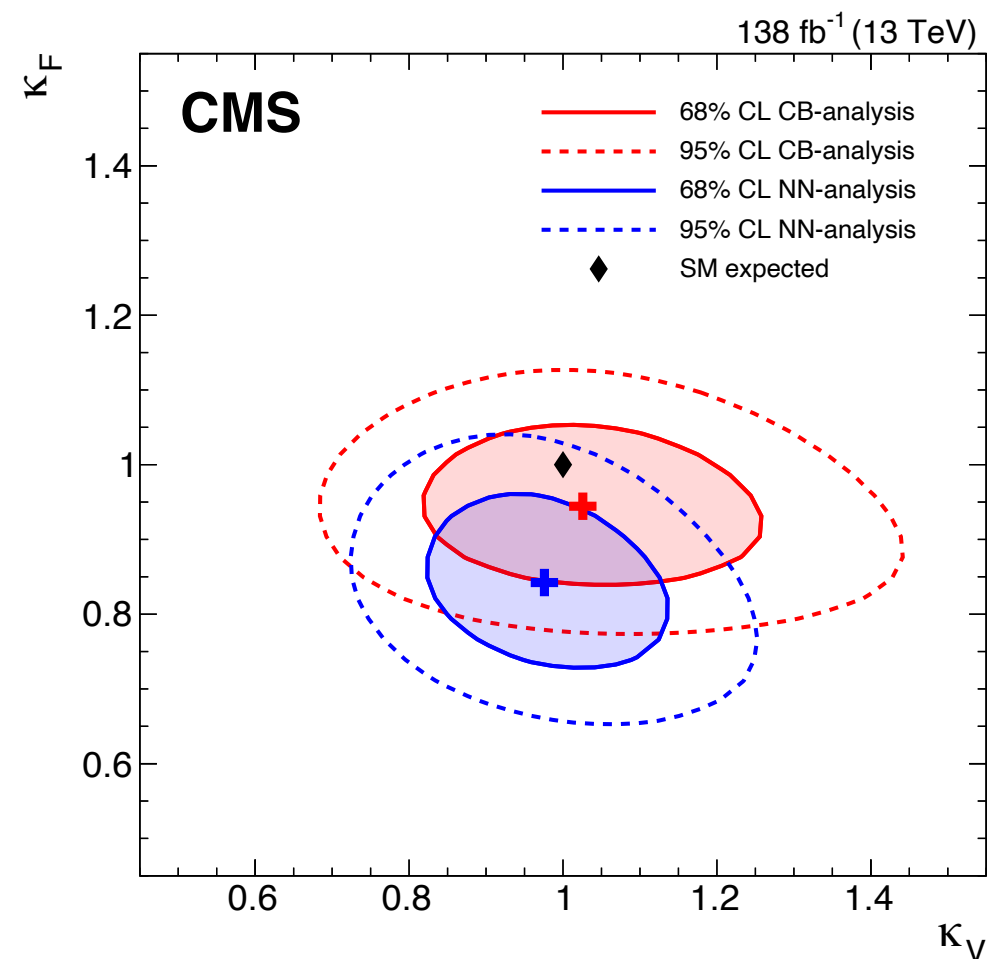
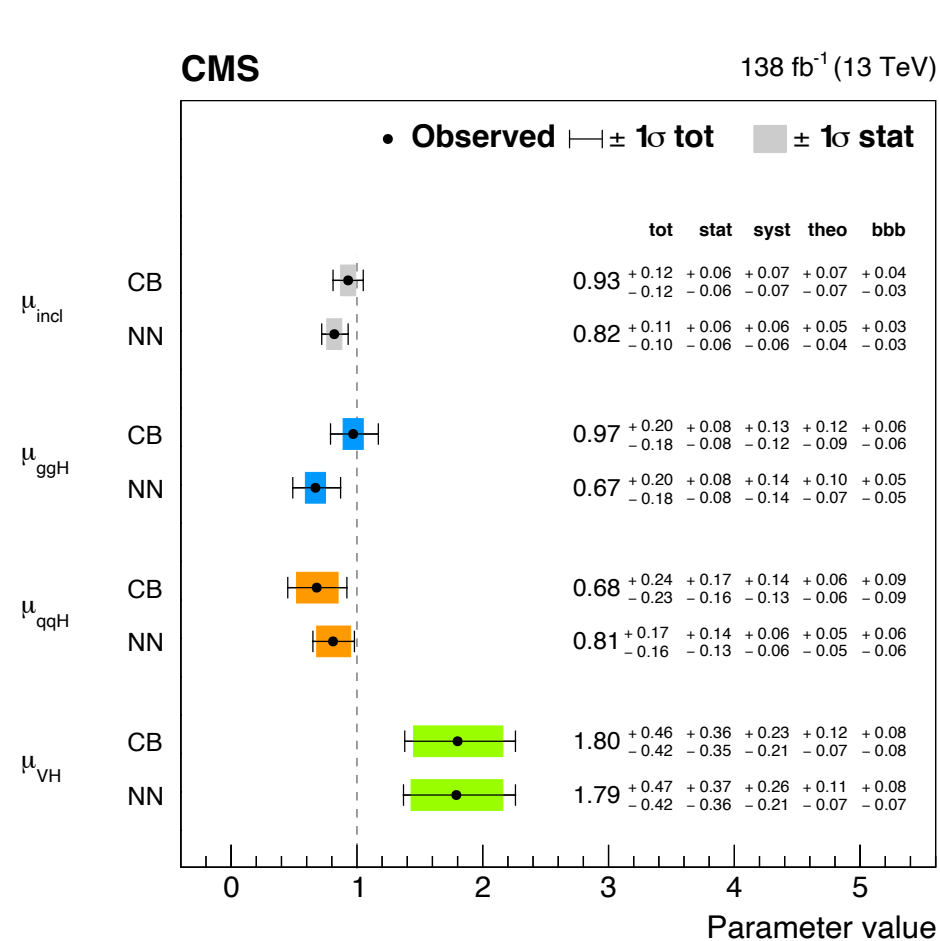
[\(arXiv:2007.05122\)](#)

Higgs to taus

HIG-19-010

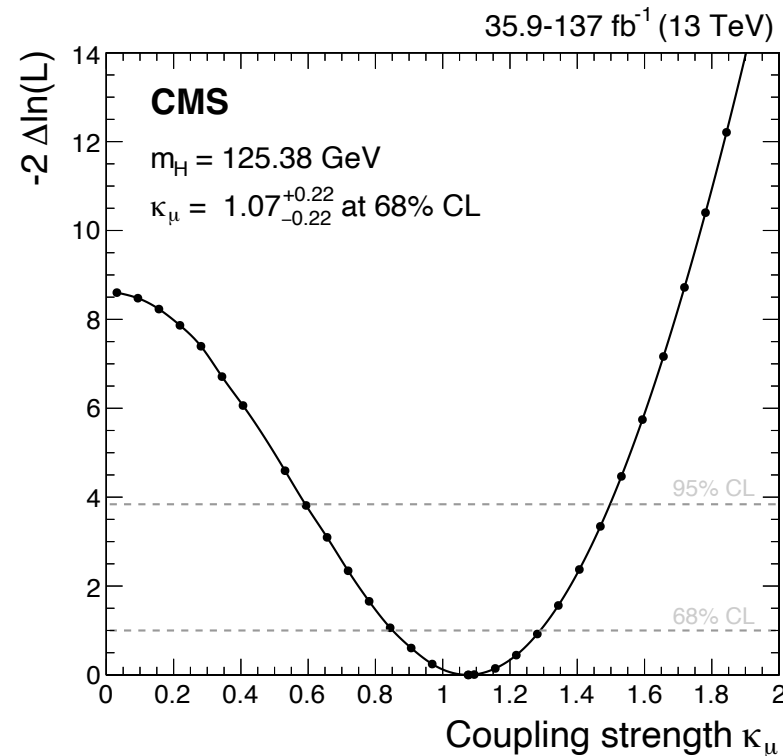
(arXiv:2204.12957)

- τ coupling observed since 2016
- Now in the era of precision measurement
 - ggH signal strength already systematic-limited
- Complementary cut-based and DNN approach
 - NN result slightly more sensitive in STXS binning
 - Slight deficit in κ_F ($=\kappa_t=\kappa_b=\kappa_\tau$), while κ_V ($=\kappa_W=\kappa_Z$) close to SM

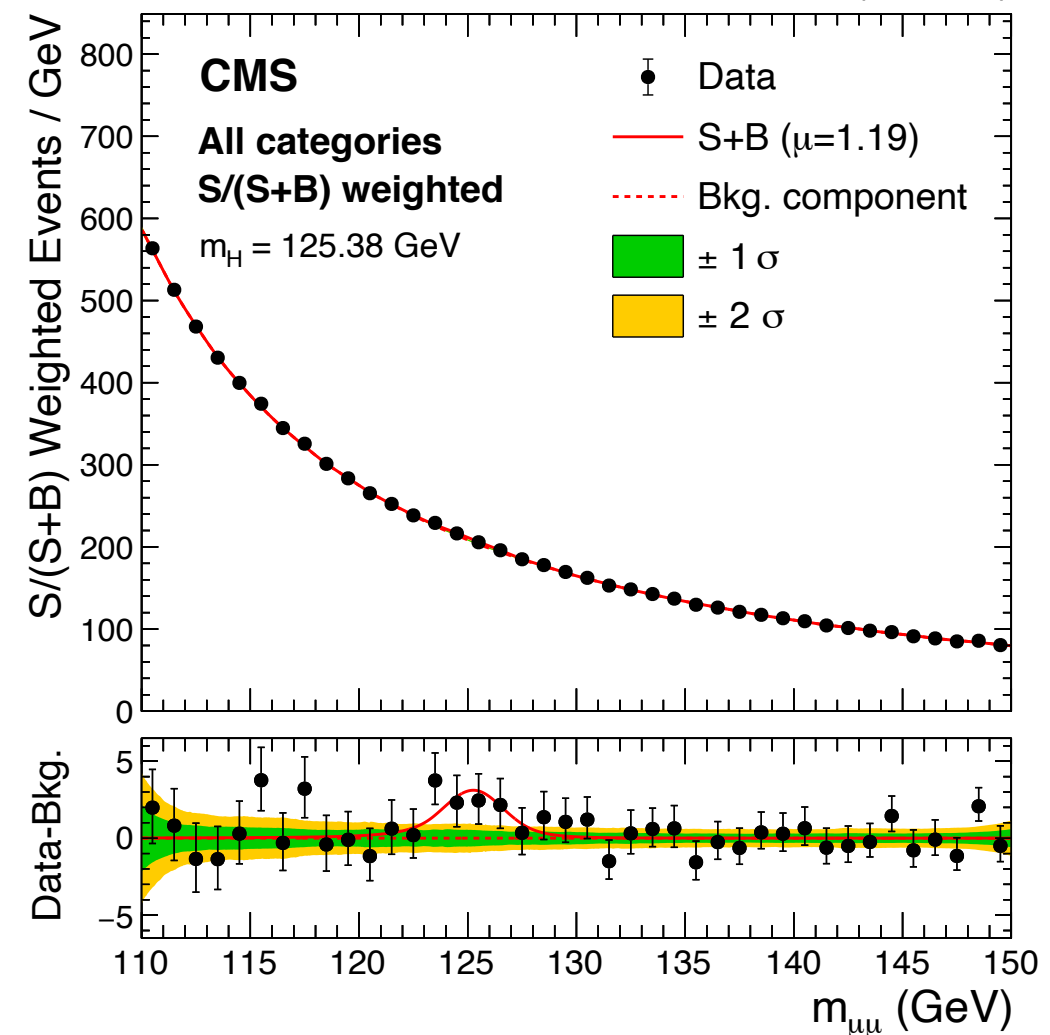
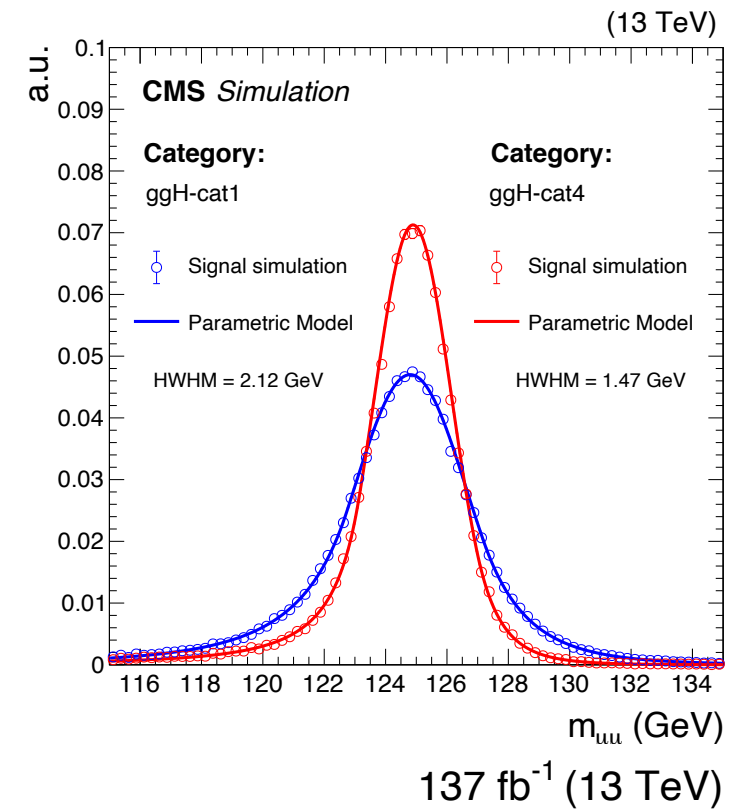


Higgs to muons

- Evidence for $H(\mu\mu)$ decay with Run II data
 - 3.0 (2.5) σ excess over background
 - Data-driven estimate for ggH , VH , ttH channels
 - Limiting factor: mass resolution
 - VBF: low statistics in mass sideband
 - MC estimate binned in DNN score: 20% improvement
- First CMS two-sided interval on κ_μ



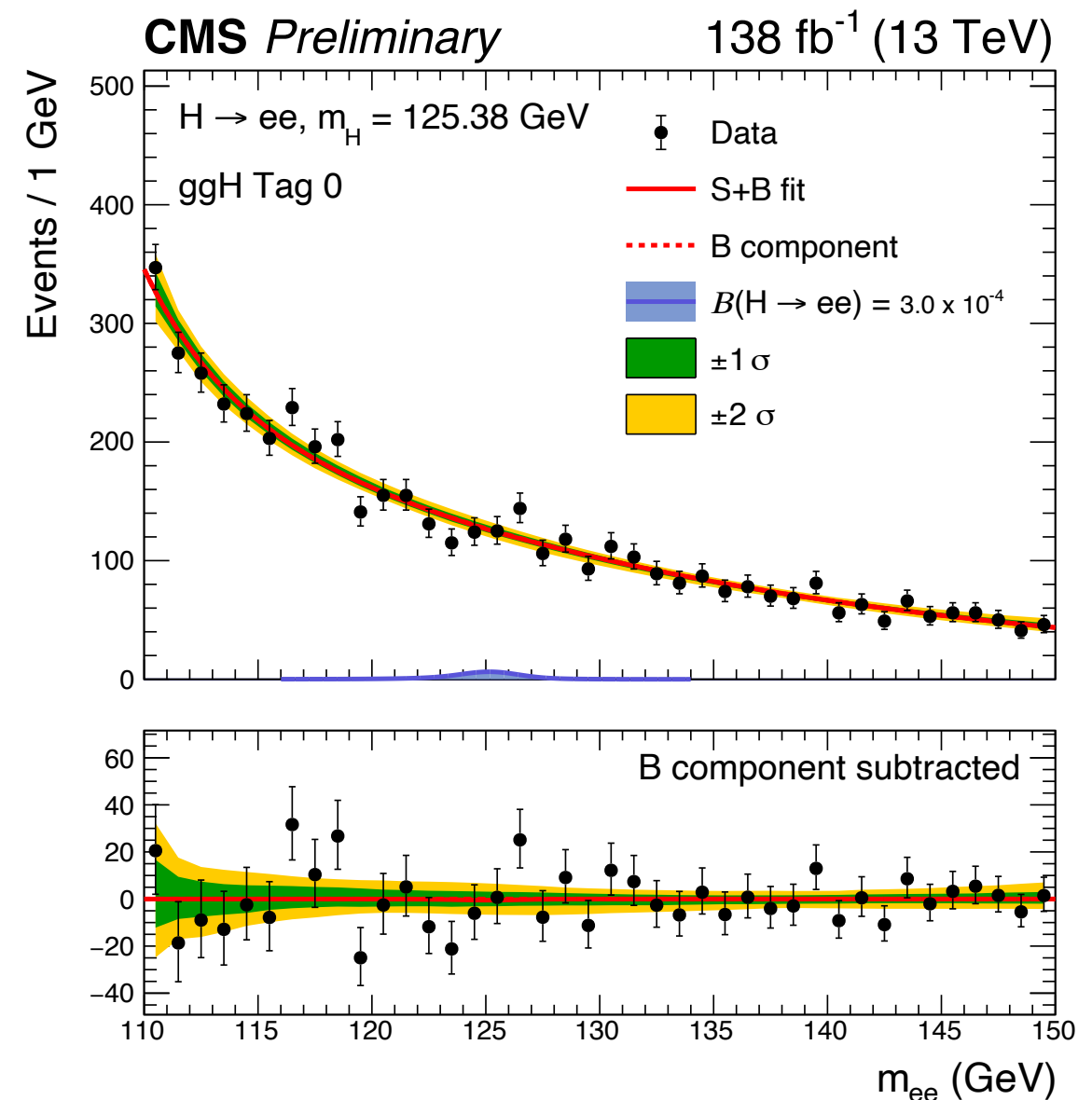
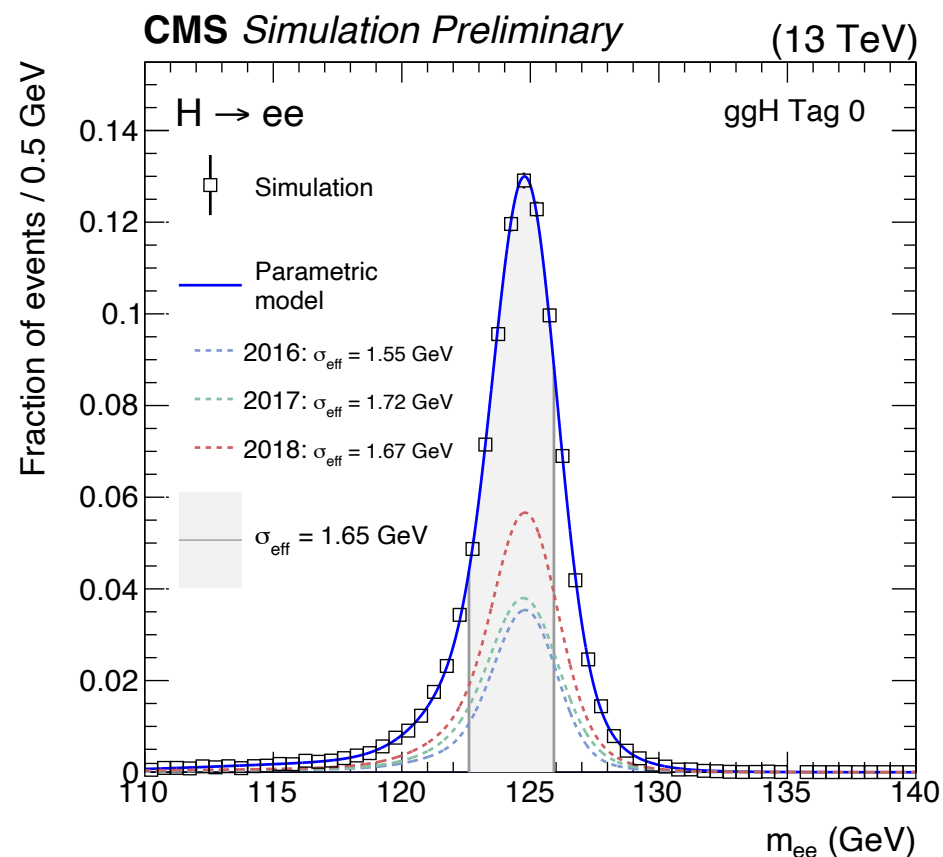
[HIG-19-006](#)
 (arXiv:2009.04363)



Higgs to electrons

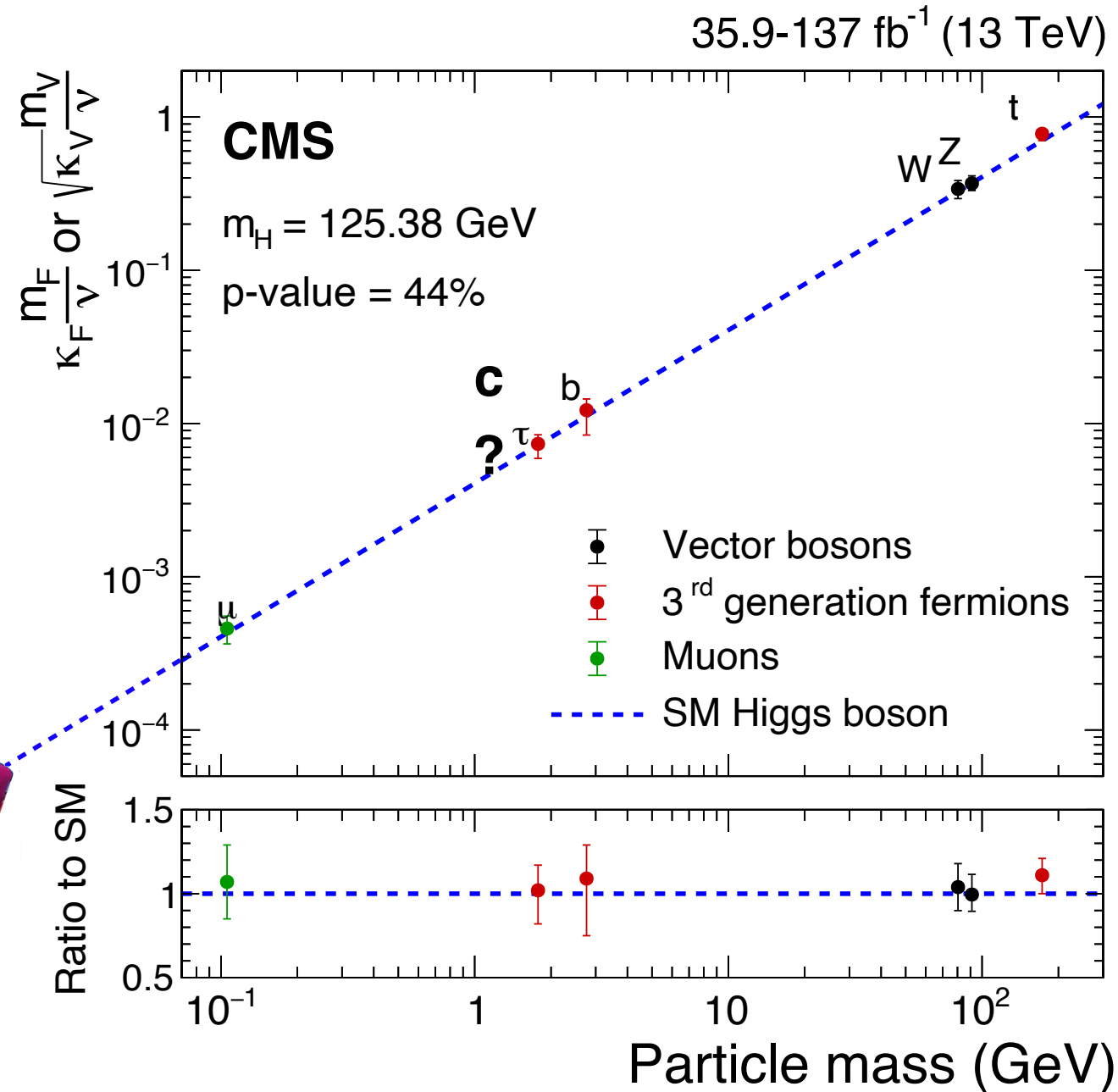
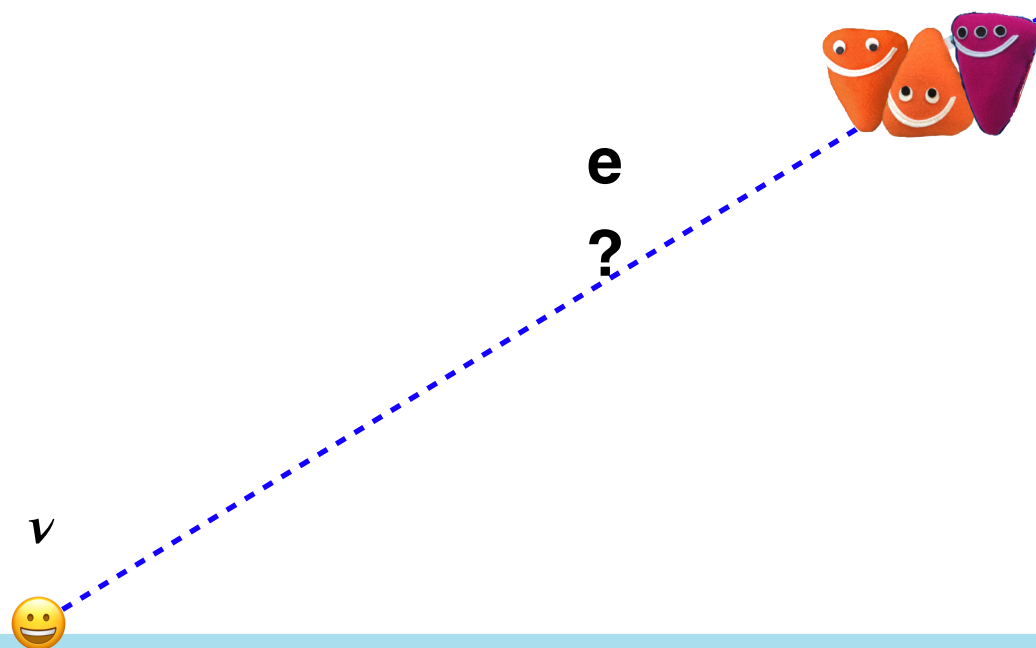
- New for Moriond '22: H(ee)
 - Search targeting ggH and VBF production modes
- Upper limit on $BR(H \rightarrow ee) < 3 \times 10^{-4}$ at 95% CL
 - SM: 5×10^{-9}
- Shown: highest S/B ggH channel
 - Mass resolution 30% lower than for H($\mu\mu$)

[HIG-21-015](#)



Conclusions

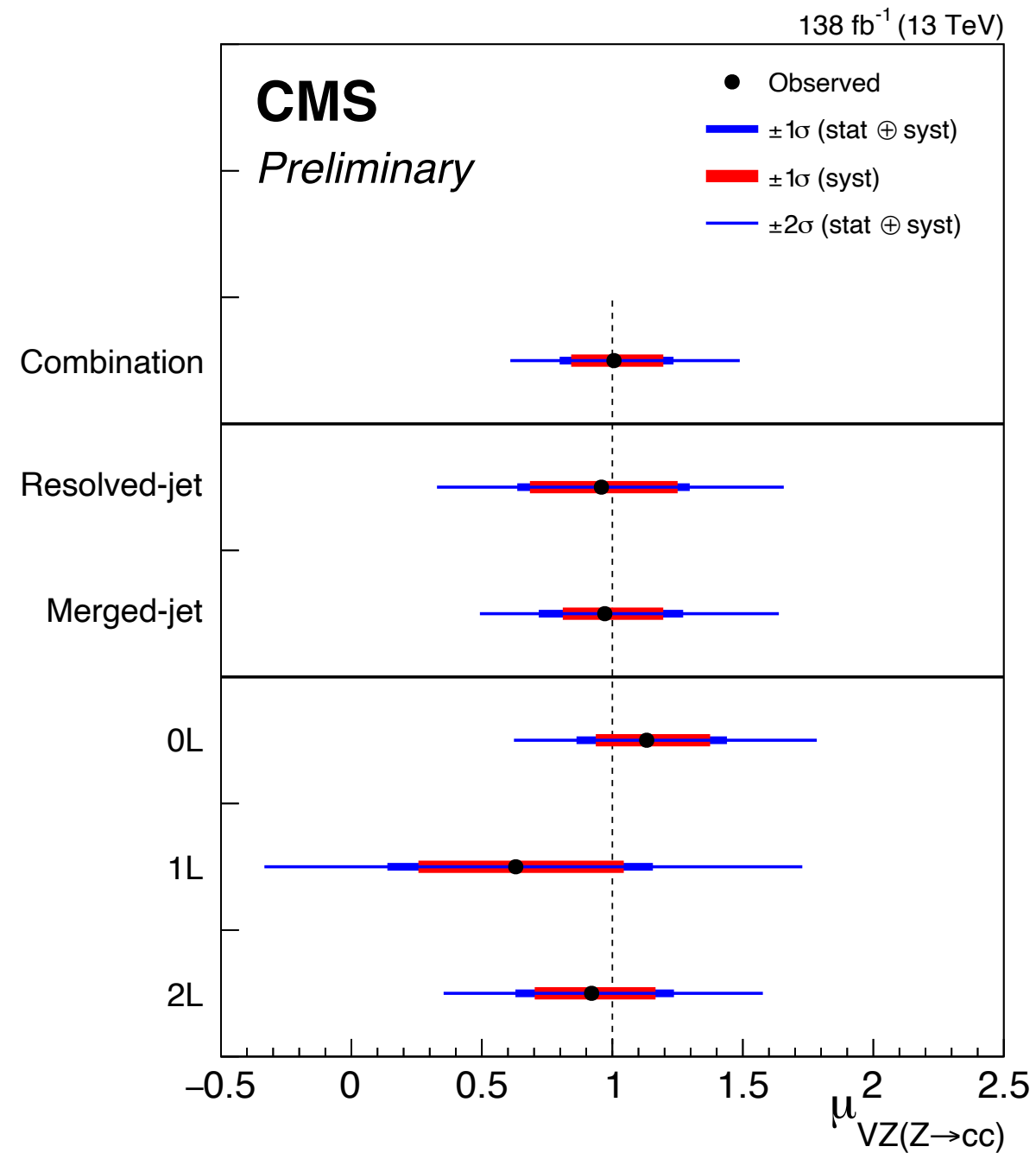
- CMS has measured or set limits on Higgs Yukawa couplings that vary over several orders of magnitude
 - Including at least one result per generation
 - In some cases, CP structure explored
- Results consistent with SM
- Full combination of latest results soon



Backup

VZ(cc)

- As in H(bb), use VZ(cc) as SM candle for validation

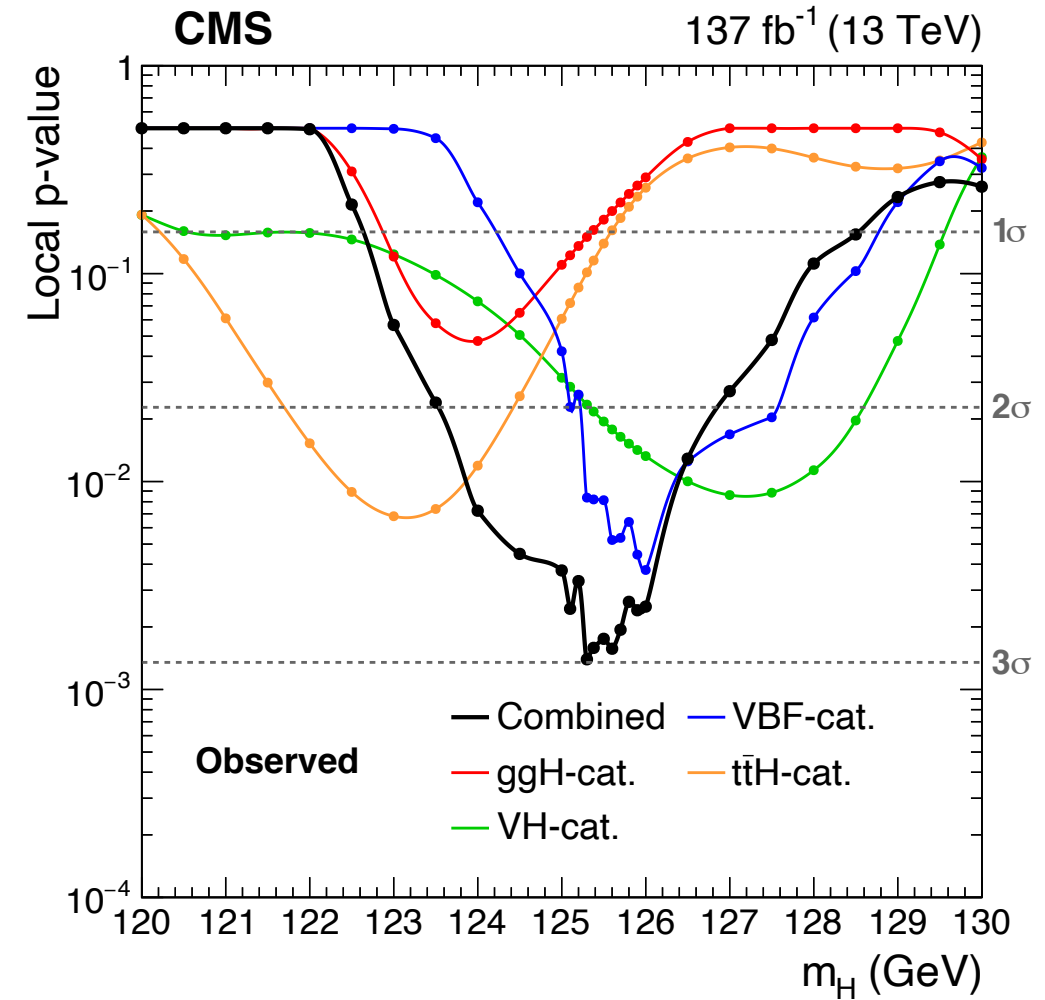
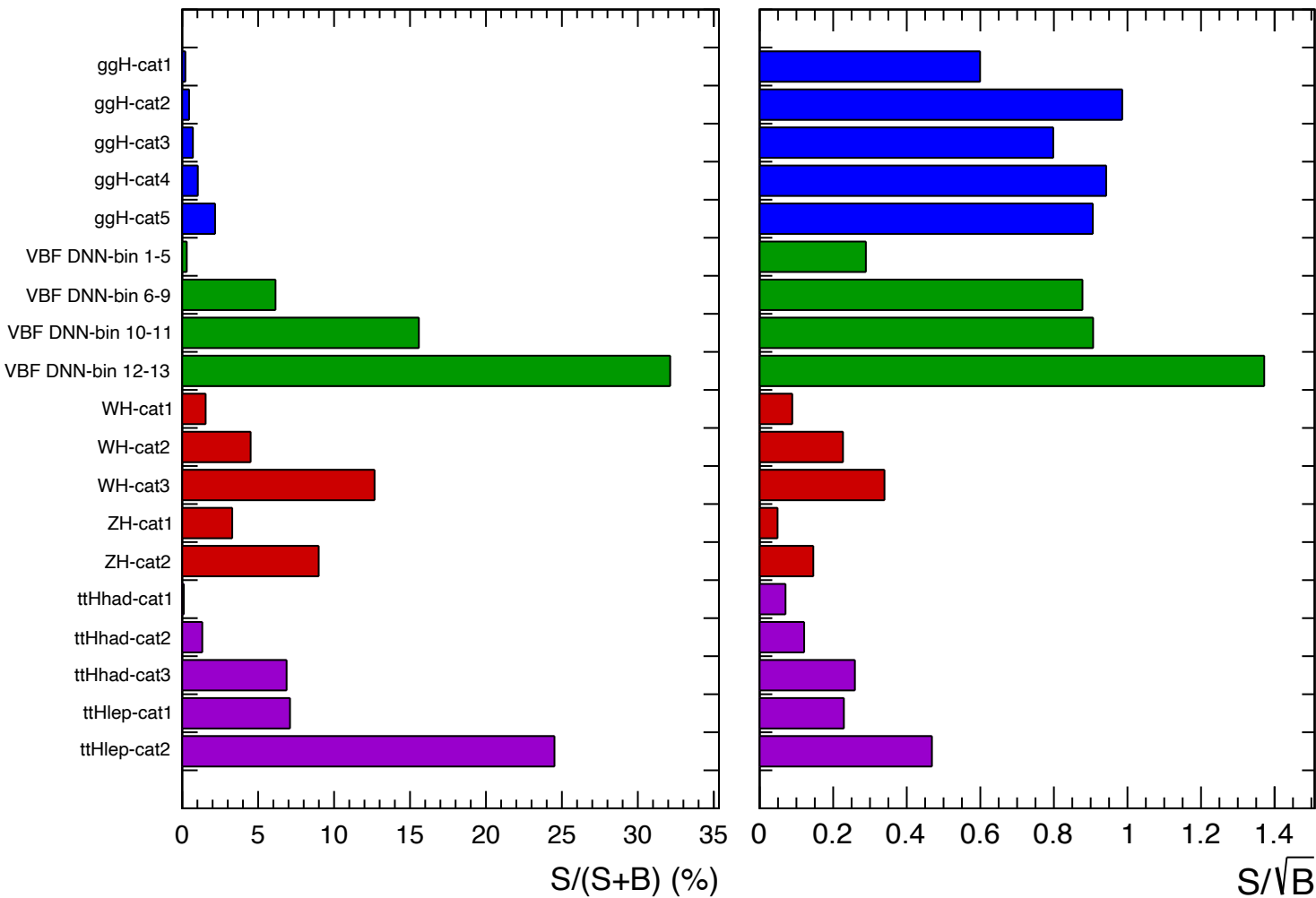


H($\mu\mu$)

- Category importance and significance vs. mass

CMS Supplementary

137 fb⁻¹ (13 TeV)



H($\mu\mu$)

- VBF mass sideband (110-115, 135-150 GeV) and signal region

