Constraints on Higgs to Heavy Flavour couplings in CMS

EPS-HEP 2025

Daina Leyva Pernia (DESY)
On behalf of the CMS collaboration

07.07.2025

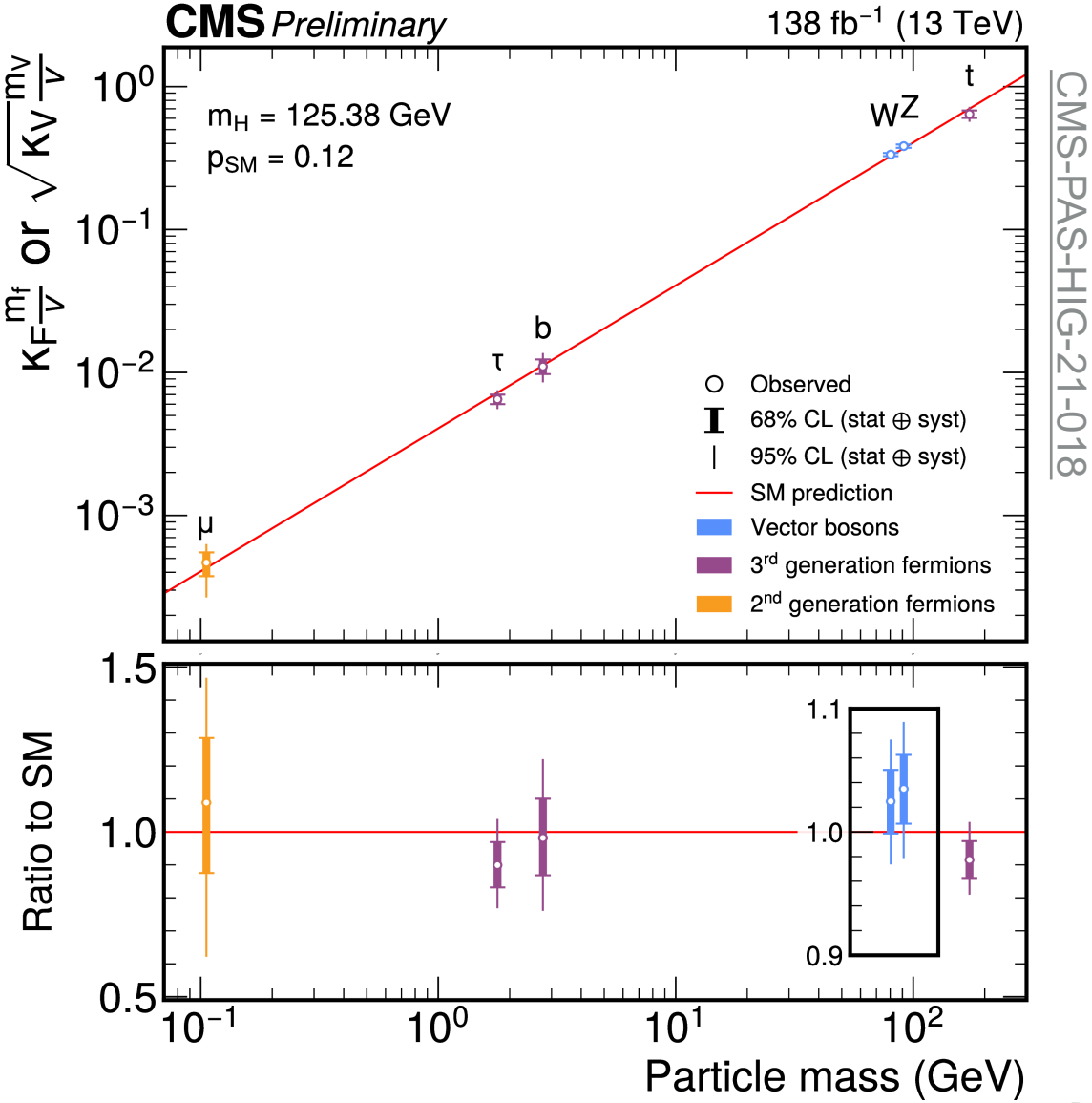
EPS-HEP CONFERENCE
07-11 JULY, 2025
PALAIS DU PHARO
MARSEILLE, FRANCE

The Higgs boson and its couplings

13 years after the discovery

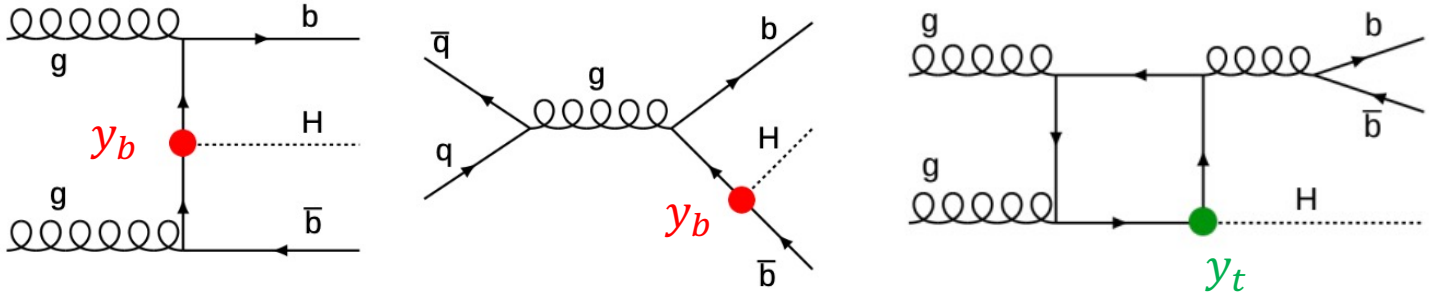
- The discovery of a particle compatible with the Standard Model (SM) Higgs boson completed the SM framework
  - Successfully established couplings to vector bosons and third generation fermions
- Probing couplings across fermions' flavours provides a window into the SM structure
  - **Direct probes:** Coupling measurements e.g. via H → bb/cc, or via rare decays e.g. H → meson+boson
  - **Indirect probes:** Via Higgs kinematics and inclusive measurements

Presenting latest constraints of Higgs to HF couplings set by the CMS collaboration



bbH($\tau\tau$/WW)

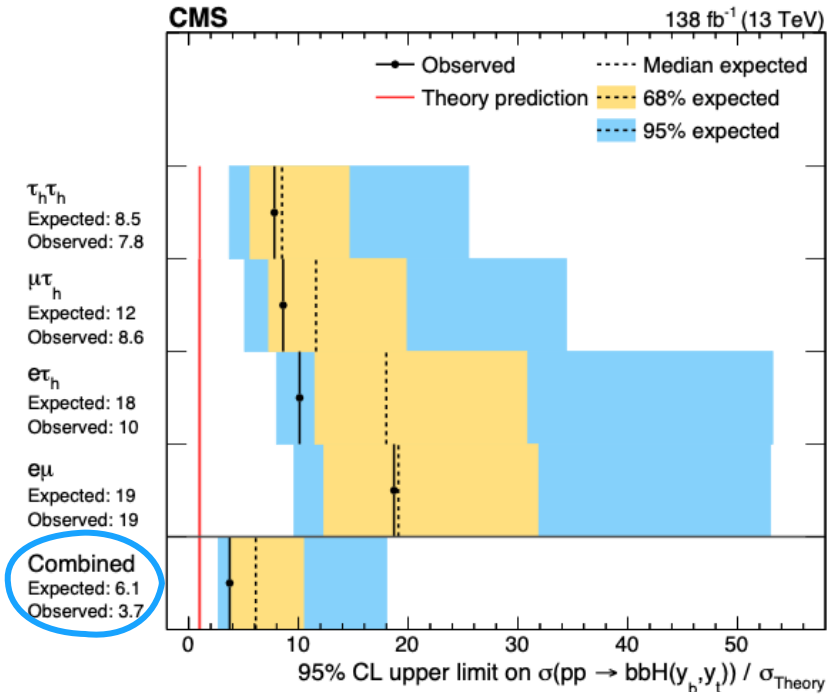
First search for b-associated SM Higgs boson production

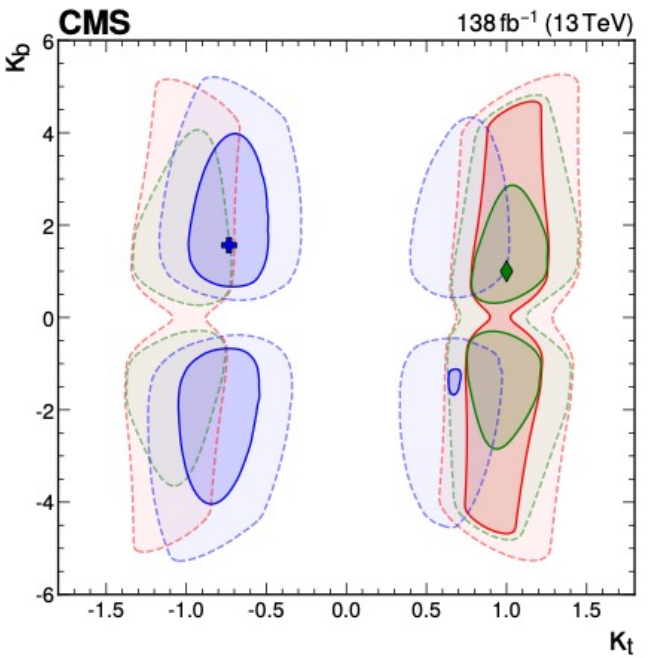


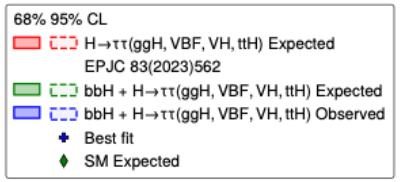
σ(bbH) [pb]: $y_b^2 \rightarrow 0.482$, $y_t^2 \rightarrow 1.04$, $y_t y_b \rightarrow -0.033$

- Studied H $\rightarrow \tau\tau$ in $\tau_h\tau_h, e\tau_h, \mu\tau_h, e\mu$ final states, and H $\rightarrow WW \rightarrow (l\nu)(l\nu)$ in the $e\mu$ final state
- Background estimation both data-driven (fake factor method or sideband region extrapolation), and MC based
- Signal-to-background discrimination optimized using multiclass BDT
- Signal extracted from simultaneous fit to the BDT score distributions in all event categories

Phys. Lett. B 860 (2024) 139173





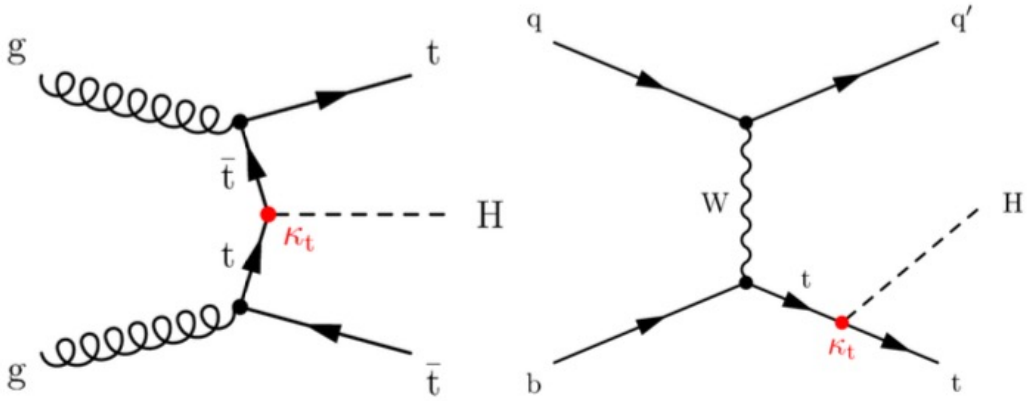


ttH and tH production, with H(bb)

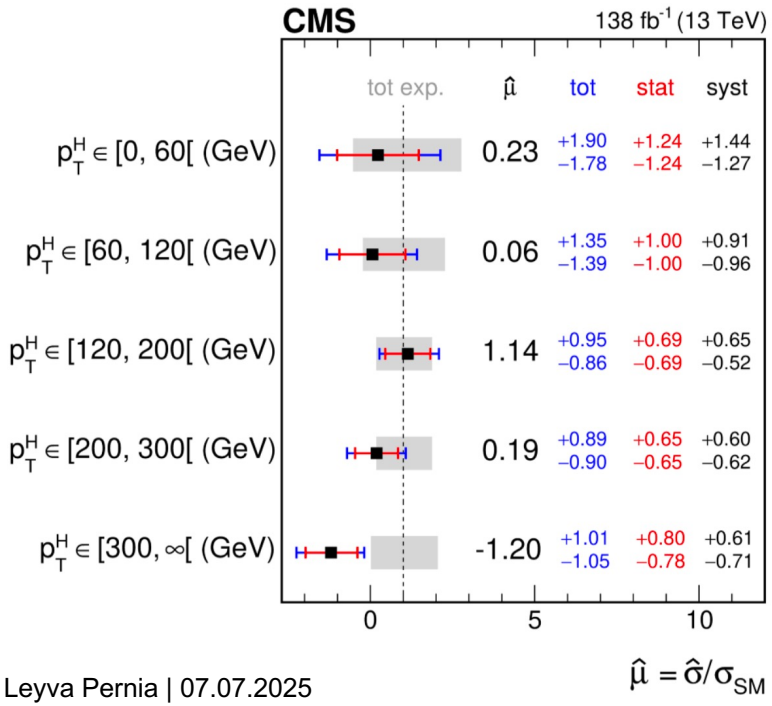
JHEP02(2025)097

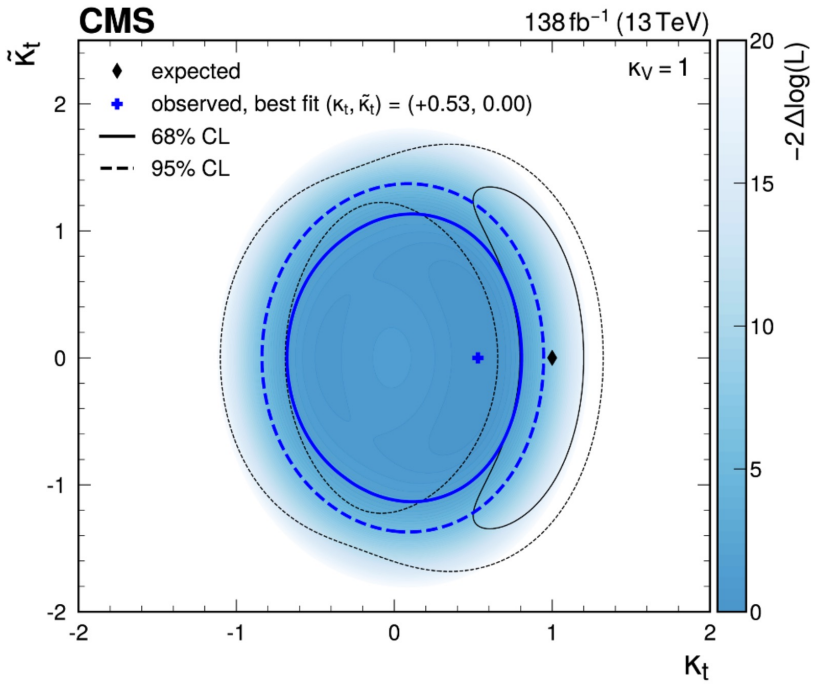
- Analysis targeting three final states (FS):
  - Fully Hadronic (FH) – 0 leptons
  - Single Lepton (SL) – 1 lepton
  - Dilepton (DL) – 2 leptons

  Event selection optimized for each FS, including multiple b-jets
- Major challenges: Large combinatorics in event reconstruction and huge irreducible background (particularly ttbb)
- Artificial neural networks (ANN) used for signal-to-background discrimination



Signal extracted from profile likelihood fit of the ANN score



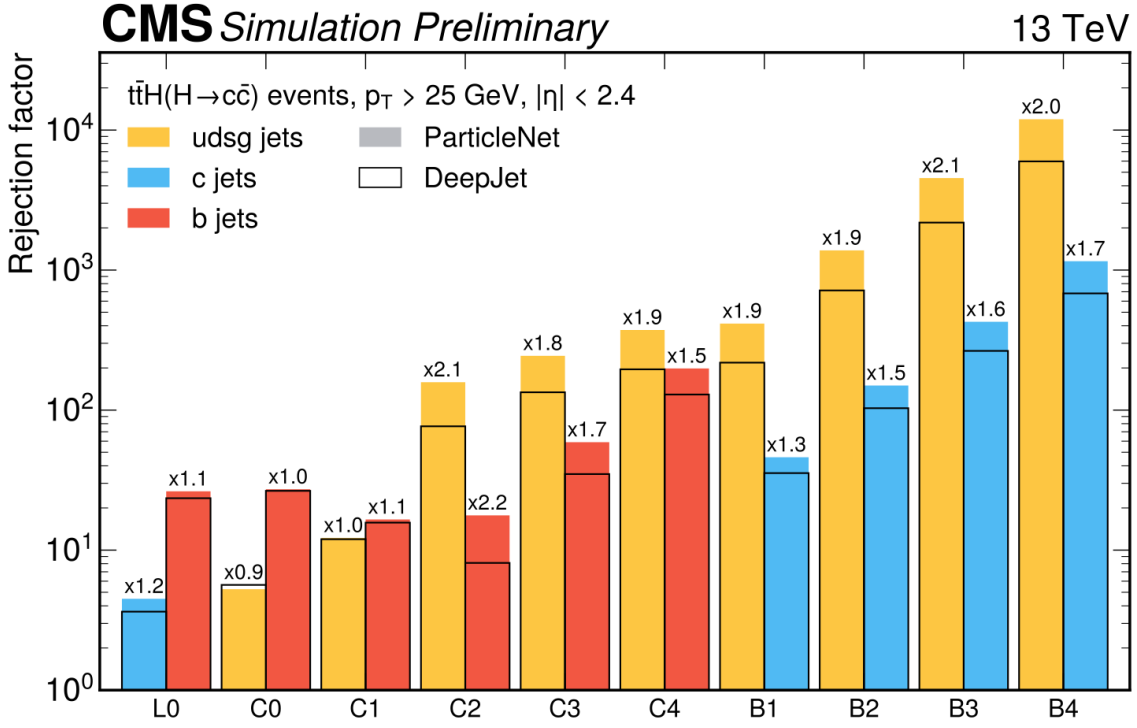


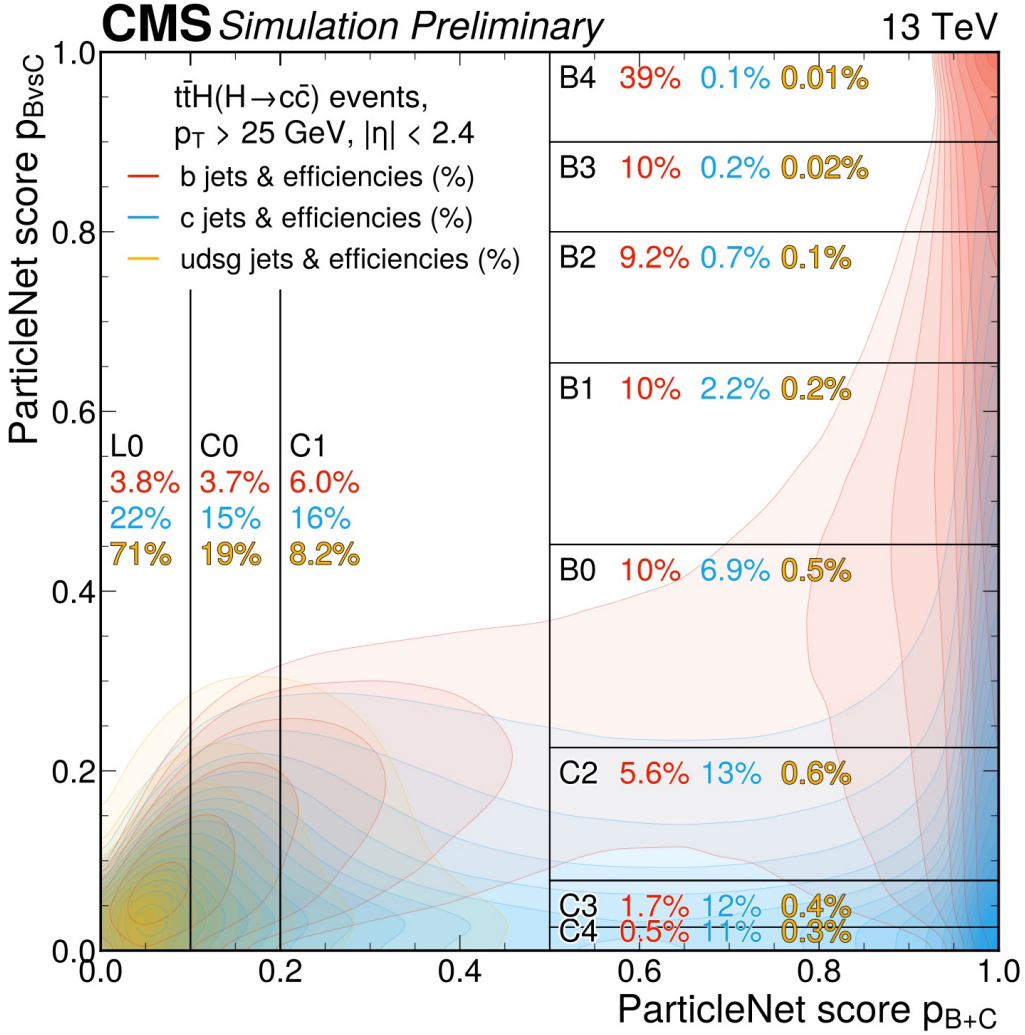
ttH(cc/bb) [1/3]

CMS-PAS-HIG-24-018

Towards next big milestone: the Higgs-charm coupling

- Also targeting FH, SL, and DL final states
- Major challenges: Achieve optimal jet flavour tagging
  - Crucial efficient b vs. c jet separation!
  - State-of-the-art ParticleNetAK4 tagger used





Rejection factor up to 2x improved with ParticleNetAK4

ttH(cc/bb) [2/3]

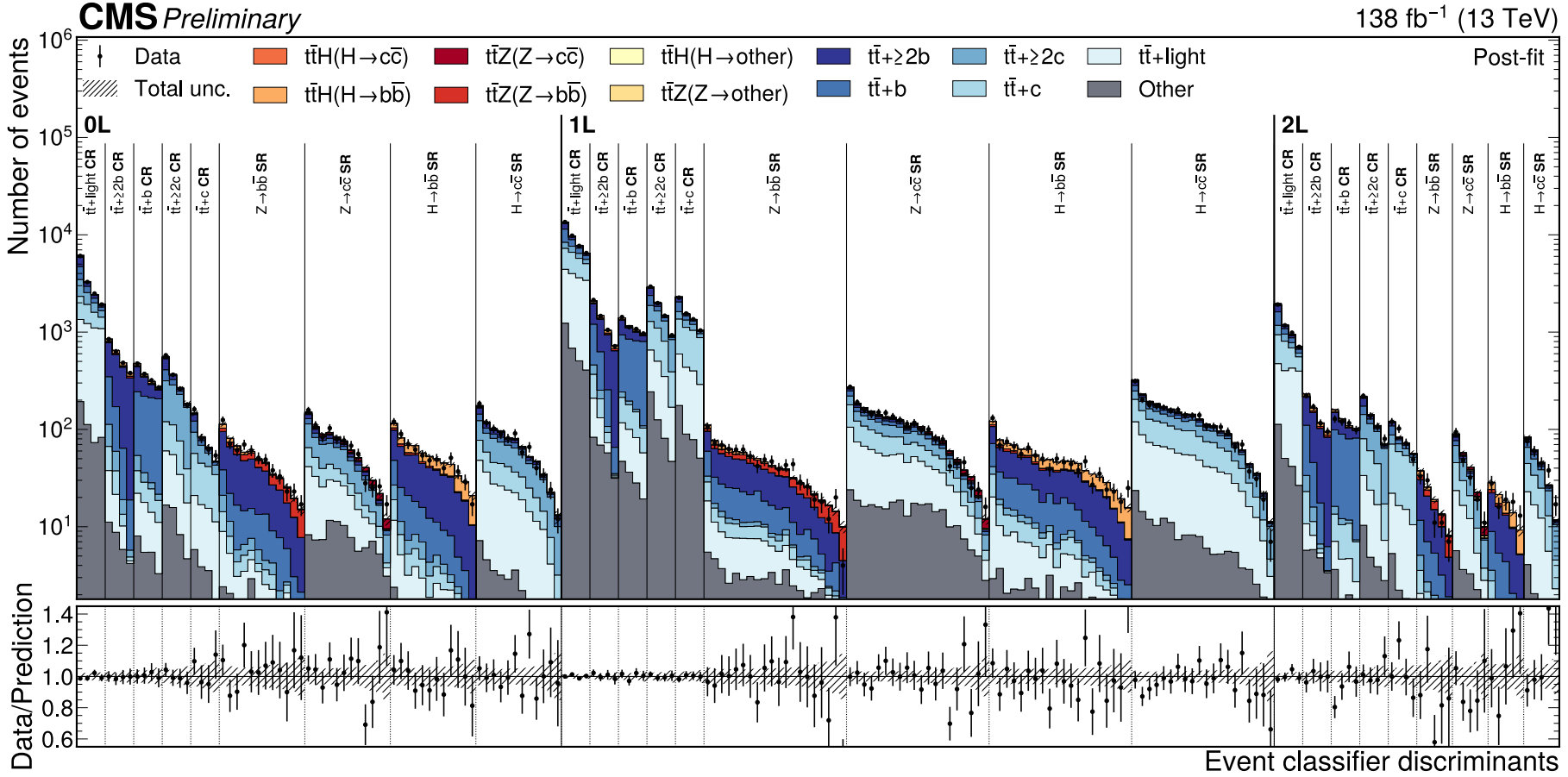
CMS-PAS-HIG-24-018

Towards next big milestone: the Higgs-charm coupling

- Also targeting FH, SL, and DL final states
- Major challenges: Event reconstruction with high jet multiplicity

Particle Transformer Classifier

- **Four signal classes**: ttH(cc), ttH(bb), ttZ(cc), ttZ(bb)
- **Five background classes**: tt+c, tt + ≥ 2c, tt+b, tt + ≥ 2b, tt+light (and QCD in FH channel)



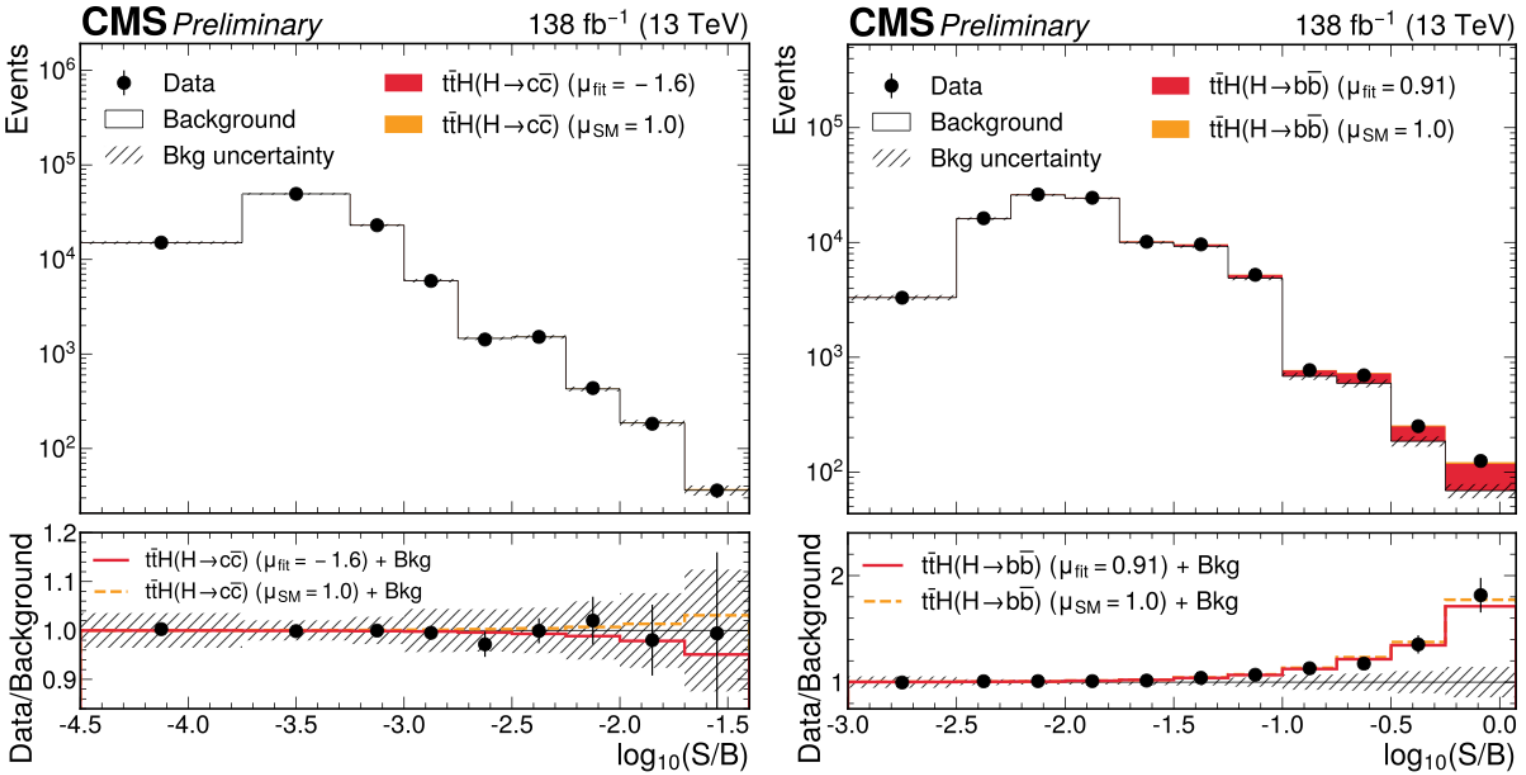
ttH(cc/bb) [3/3]

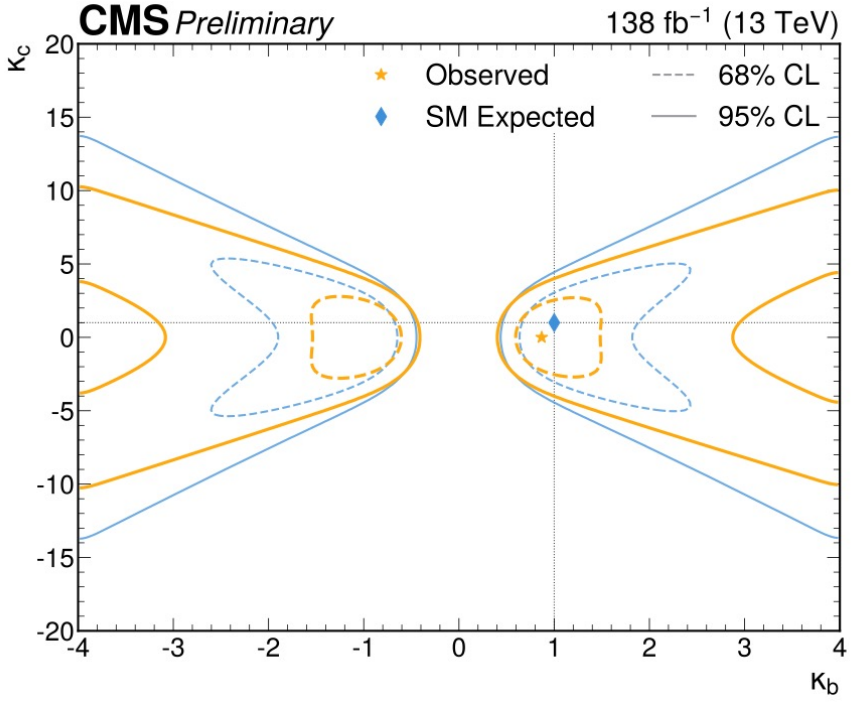
CMS-PAS-HIG-24-018

Towards next big milestone: the Higgs-charm coupling

- Also targeting FH, SL, and DL final states
- Major challenges: Background estimation and fit strategy

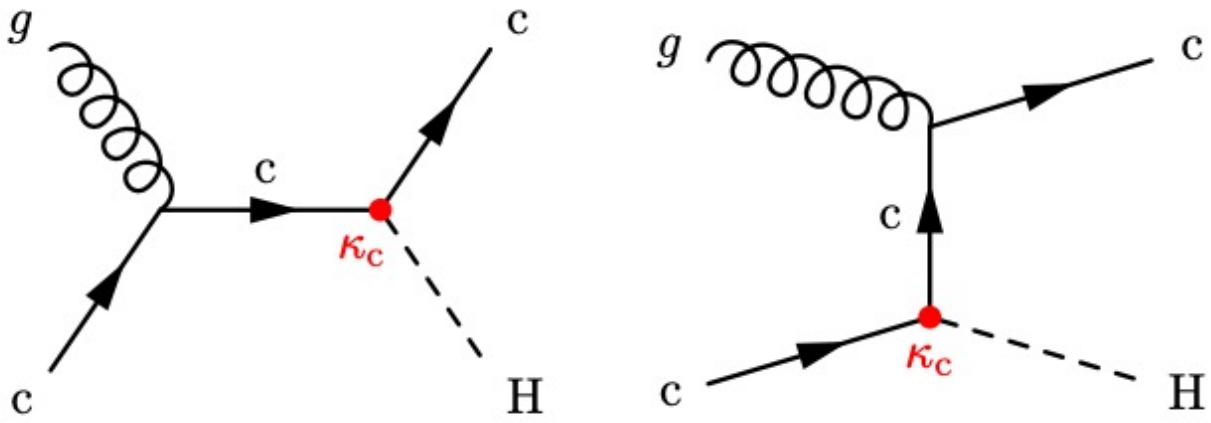
- Dominant background: tt+HF (DL/SL) + QCD (FH)
- Simultaneous ttH(cc) and ttH(bb)
  - ➢ constrain ttH(bb) background
- Signal extracted from binned profile likelihood fit to data in the discriminant





cH, H(WW) and H($\gamma\gamma$) [1/3]

Tackling charm coupling with H+c production



Sensitive to κ_c, with only one charm to be tagged

Cleaner final state

Complementary to H→cc searches

Challenges:

- Small SM cross-section
  - e.g. 0.2 fb for cH($\gamma\gamma$) compared to 6.6 fb VH(cc)
- Non-trivial MC simulation
- Soft (forward) c-tagging

Two Higgs decays modes covered

- cH($\gamma\gamma$) CMS-PAS-HIG-23-010
- cH(WW) CMS-PAS-HIG-24-009

Both explored for the first time

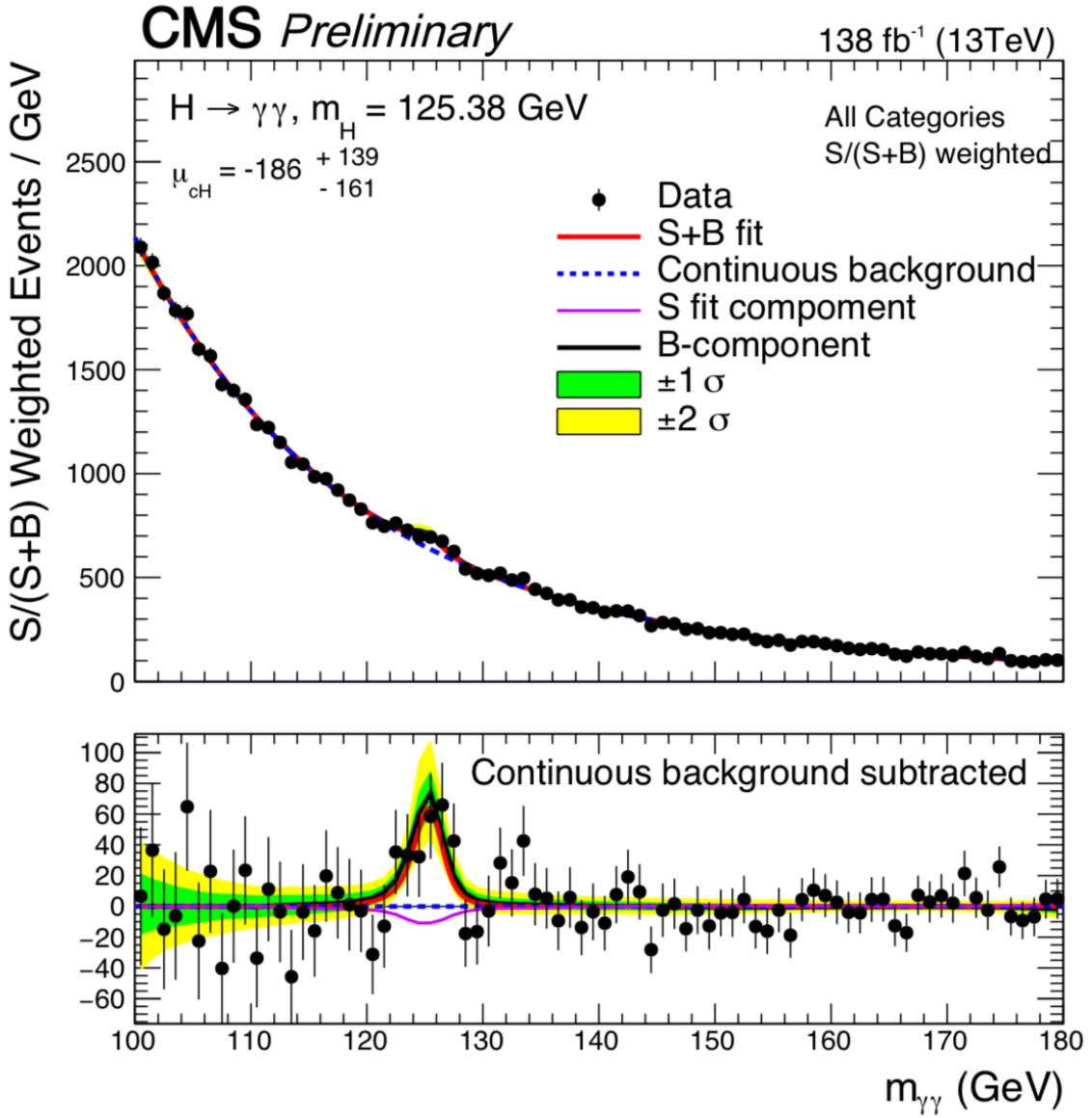
cH, H(WW) and H($\gamma\gamma$) [2/3]

cH($\gamma\gamma$) CMS-PAS-HIG-23-010

- **Main backgrounds**: ggH and continuous di-photon background ($\gamma\gamma$ and $\gamma\gamma$+jets)
- BDT categorization for signal-background separation exploiting jets and photons kinematics
- Signal extracted from analytic fit to the invariant mass of the di-photon system
- Discrete profiling for background description

Observed (expected) constraints:

$|\kappa_c| < 38.1$ ($|\kappa_c| < 72.5$) at 95% CL



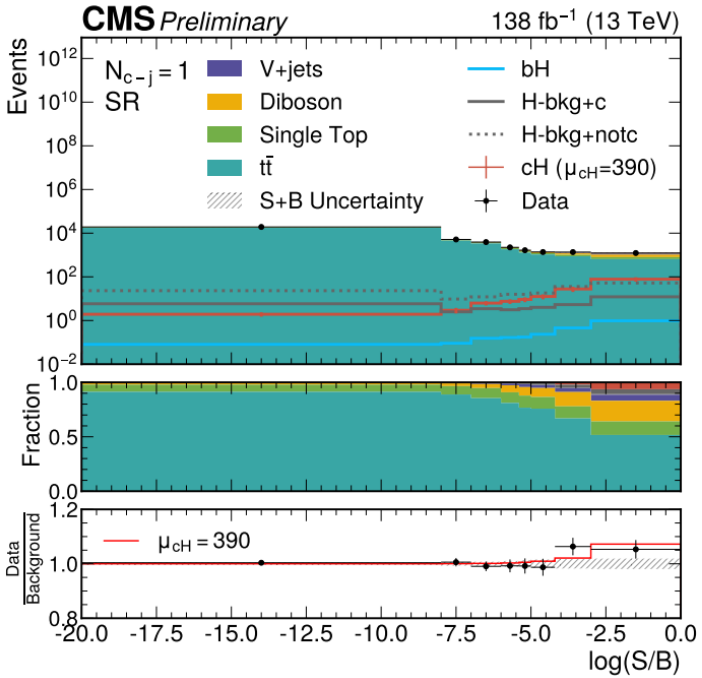
cH, H(WW) and H($\gamma\gamma$) [3/3]

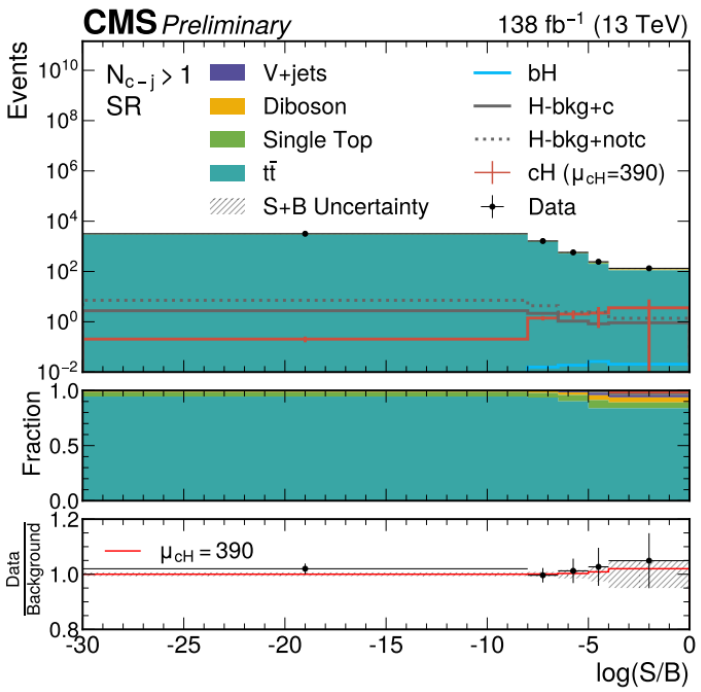
cH(WW) CMS-PAS-HIG-24-009

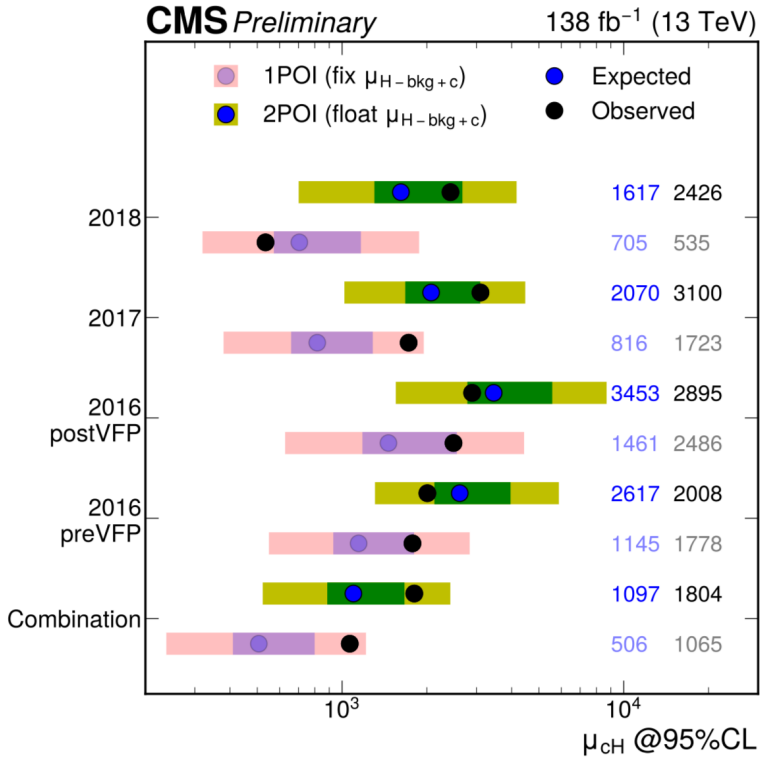
- **Main backgrounds**: non-Higgs, e.g. DL ttbar, and processes with Higgs, e.g. ggH or bH
- Two BDTs trained for categorization, optimizing signal-background separation for (non) Higgs backgrounds
- Signal extracted with binned maximum likelihood fit to data in all SRs and CRs

Observed (expected) constraints:

$|\kappa_c| < 211$
($|\kappa_c| < 95$)
at 95% CL



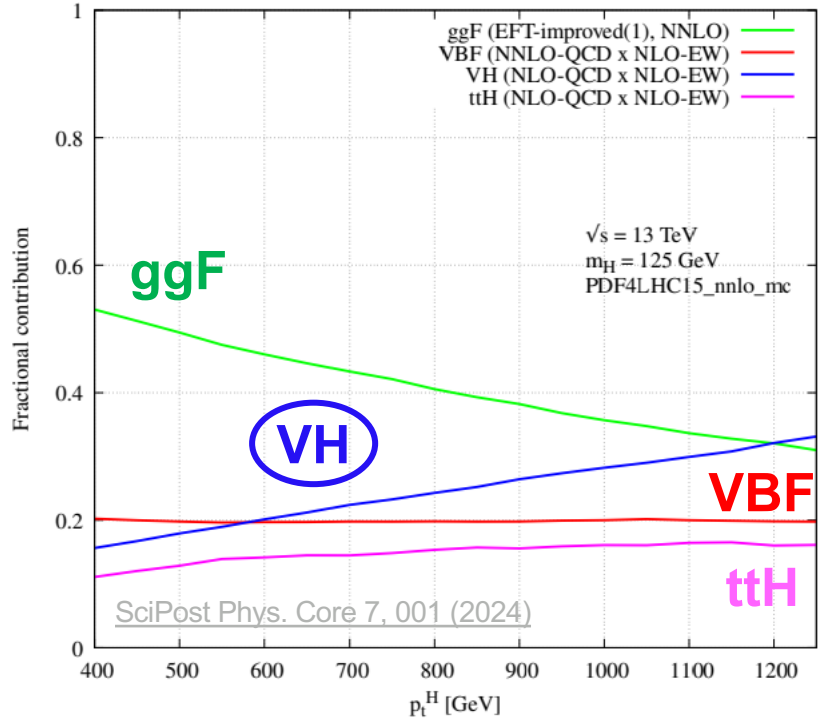


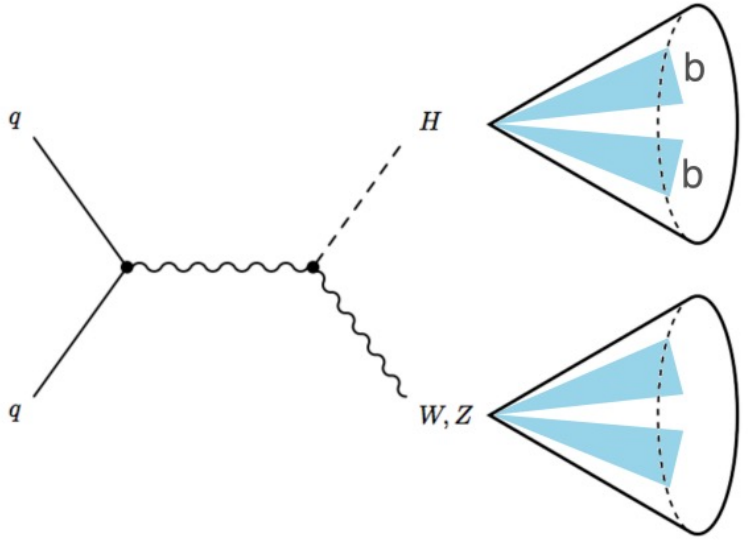


Boosted V(qq) H(bb) [1/2]

CMS-PAS-HIG-24-017

- Dominant LHC Higgs boson production mode: **ggF**
- At high Higgs p_T, the associated production with vector bosons (**VH**) increases, while **ggF** decreases
- Precise measurements of the boosted **VH** production could uncover BSM phenomena

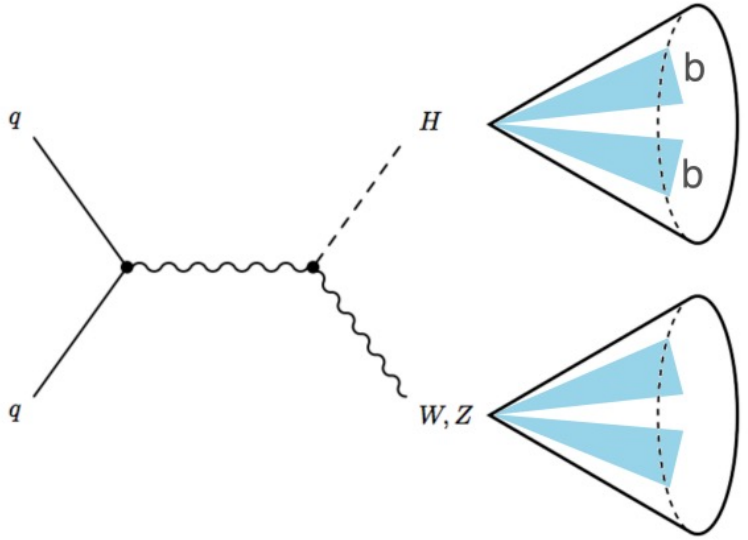


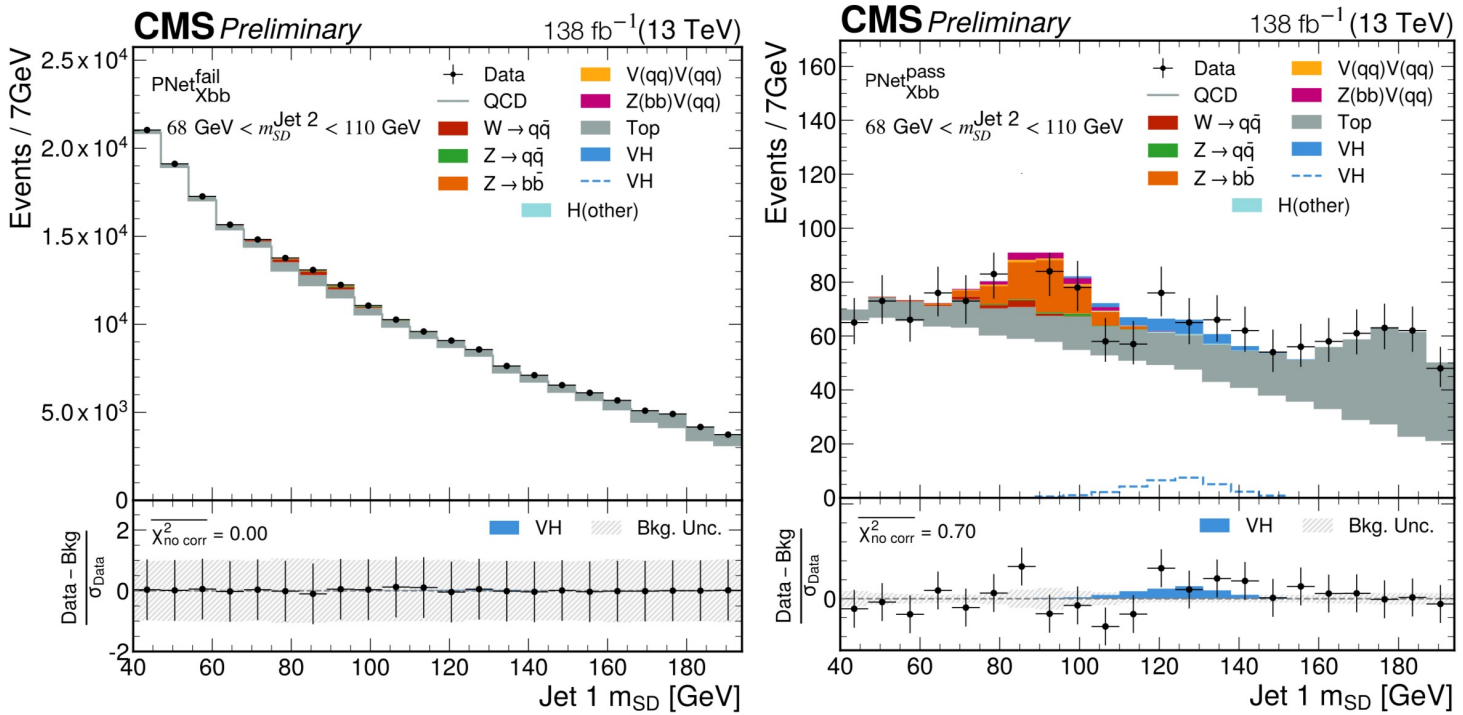


- Background estimation:
  - From simulations: W(qq), Z(qq), Z(bb), H(bb) + jets
  - Data-driven: QCD, ttbar and single-top
- Events categorized into three ranges of V candidate mass
- Split further by whether Higgs boson candidate passes or fails a ParticleNet-MD discriminant, defining a SR and CR
- Signal extracted from binned fit to the invariant mass of the Higgs boson candidate

Boosted V(qq) H(bb) [2/2]

- Dominant LHC Higgs boson production mode: **ggF**
- At high Higgs p_T, the associated production with vector bosons (**VH**) increases, while **ggF** decreases
- Precise measurements of the boosted **VH** production could uncover BSM phenomena





Observed (expected) significance of 1.00 (1.64) σ for V(qq)H(bb)

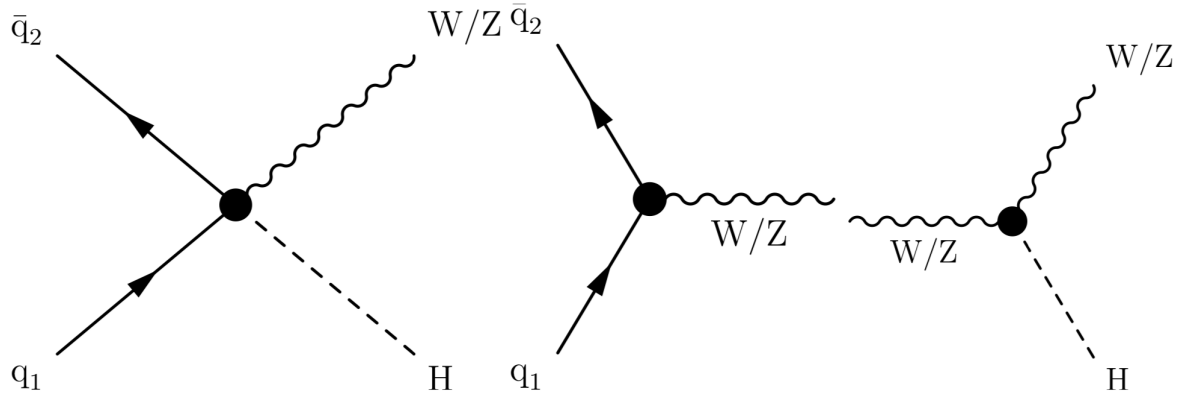
Signal strength relative to the standard model expectation:

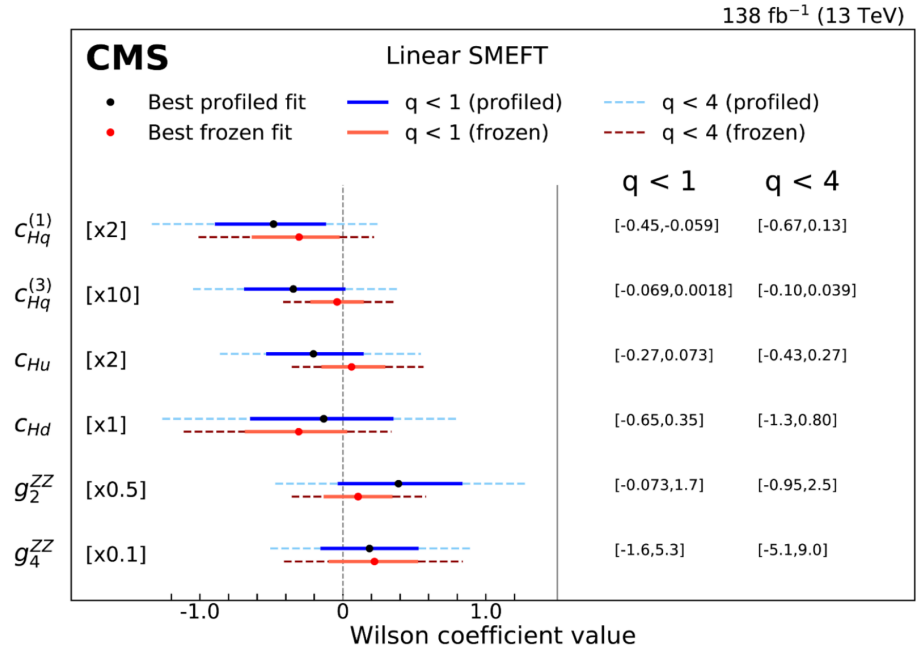
$$\mu_{VH} = 0.72^{+0.75}_{-0.71}$$

VH(bb) - EFT interpretations

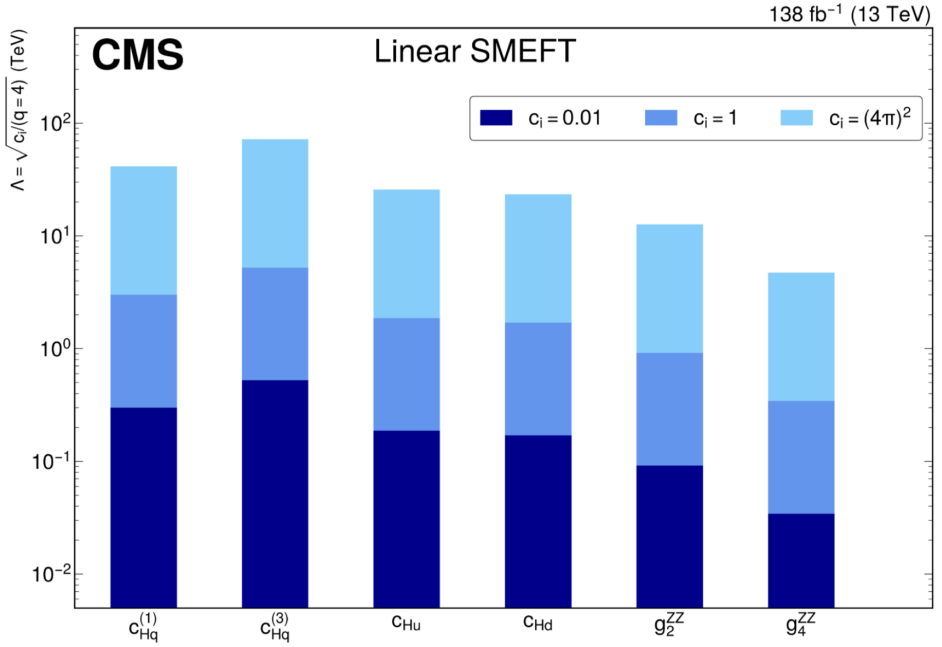
JHEP03(2025)114

- SMEFT as a tool to search for even subtle BSM hints



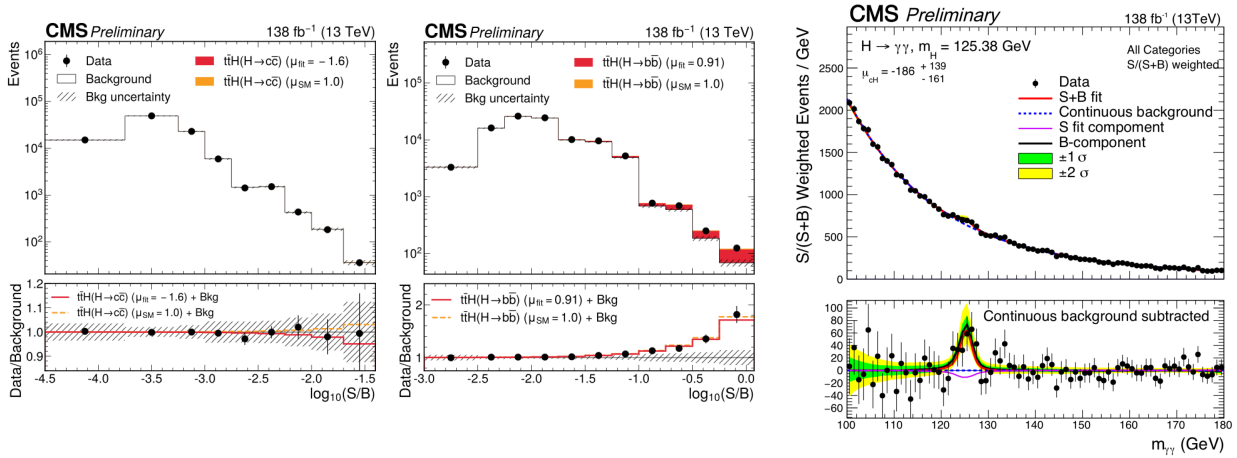


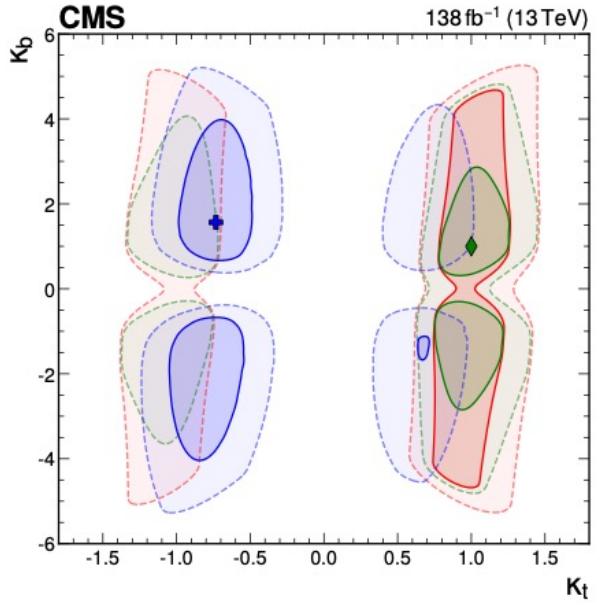
- Sensitive to anomalous fermion couplings
- Investigation of BSM physics after the STXS SM VH(bb) measurement Phys. Rev. D 109 (2024) 092011
- Bounds on six Wilson coefficients from unbinned fit to discriminant of boosted information tree (I,II)
- Observed data **consistent with the SM** with 84% p-value

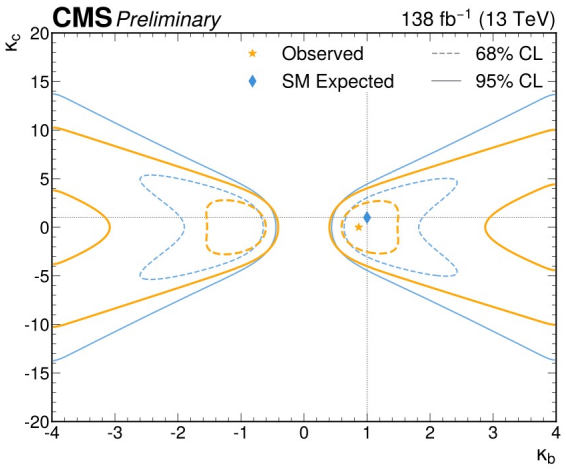


Summary

- Probing the Higgs boson to heavy flavour couplings remains an active and developing field
- Notable advancements have been made in recent years, driven by:
  - Enhanced analysis techniques
  - Advancements in detector performance and flavour tagging algorithms
- Efforts span **multiple complementary approaches**, including indirect and direct probes
- Anticipating further developments with Run 2 and Run 3 data



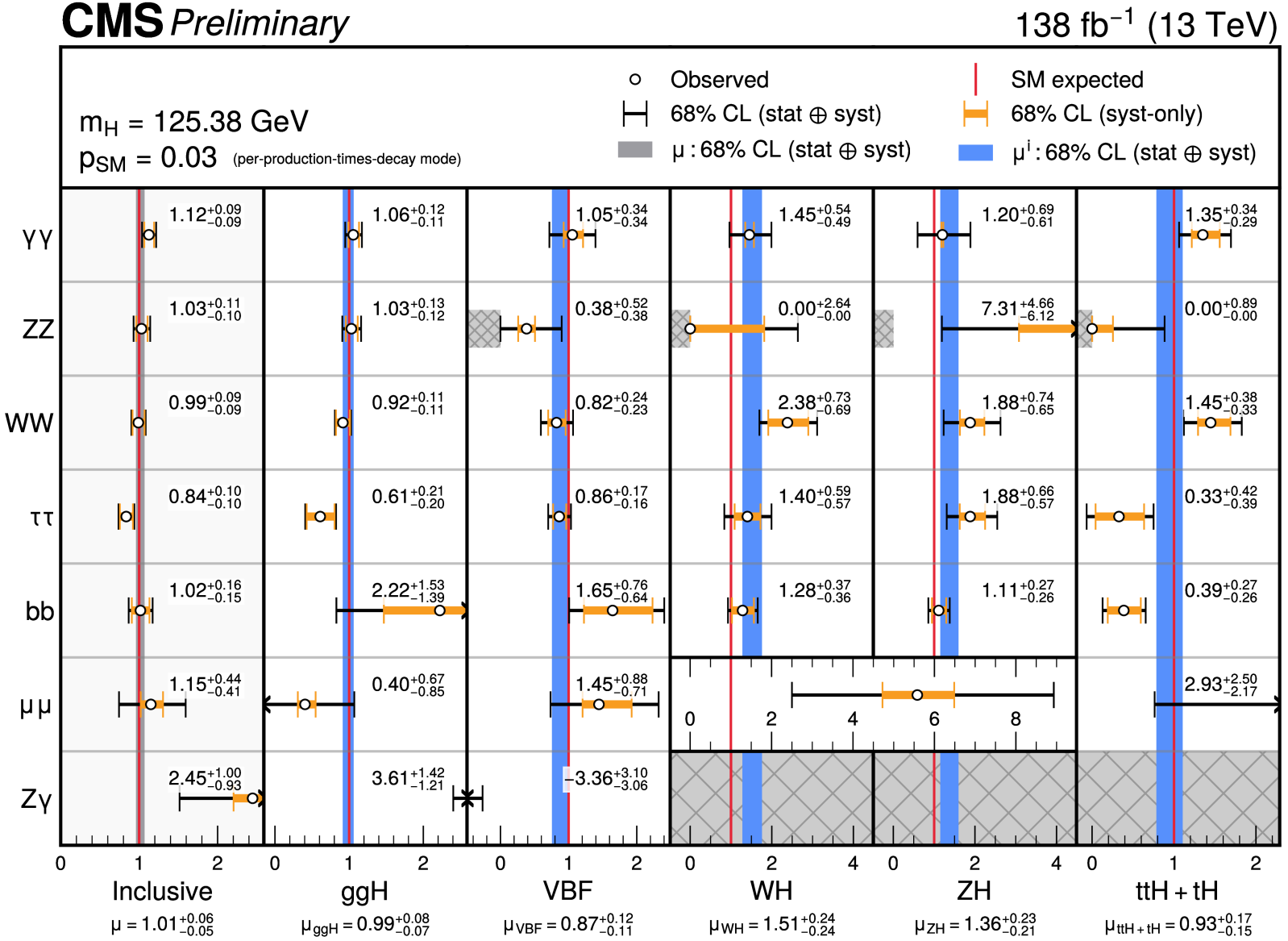




Thank you!

BACKUP

Summary of signal strength modifier measurements

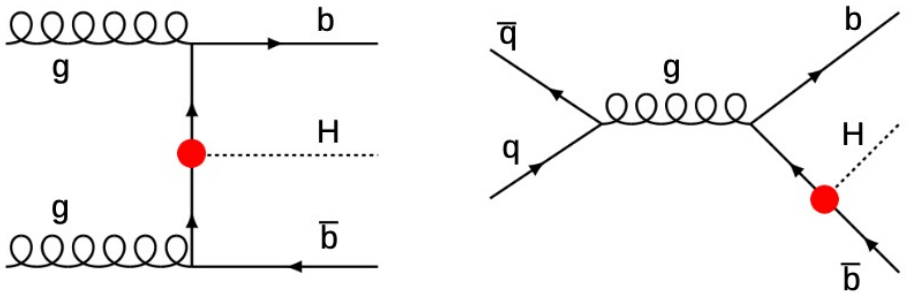


CMS-PAS-HIG-21-018

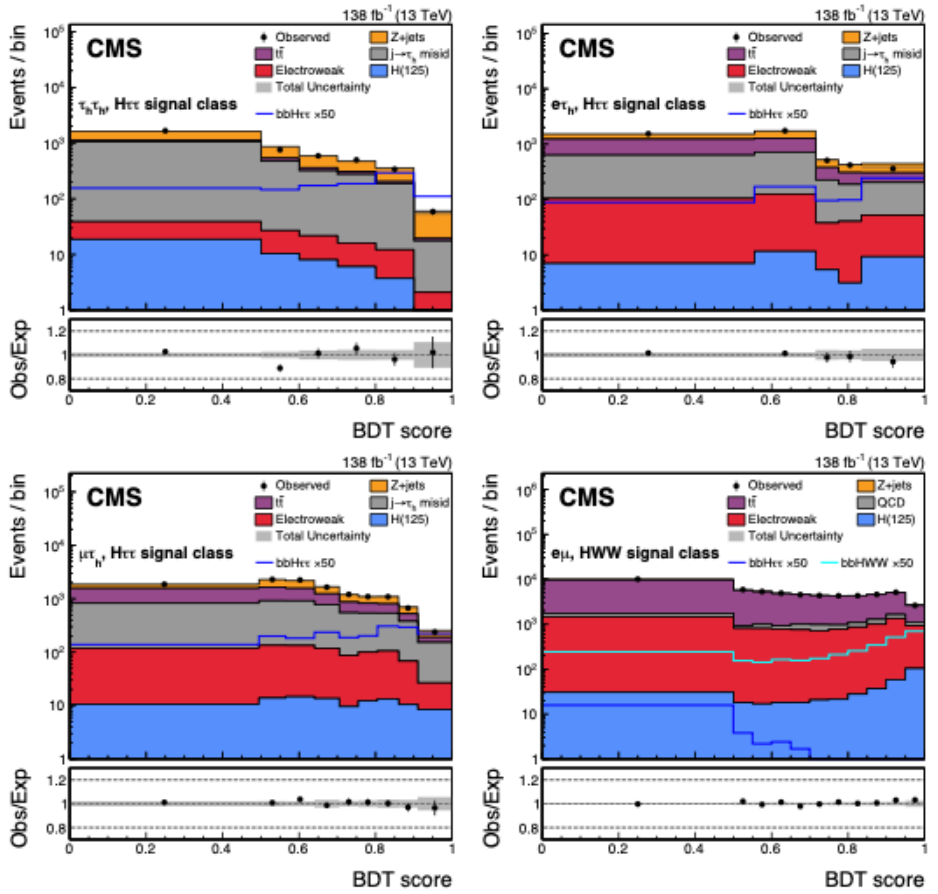
bbH($\tau\tau$/WW)

Phys. Lett. B 860 (2024) 139173

First search for b-associated SM Higgs boson production



- Studied H → $\tau\tau$ in $\boldsymbol{\tau_h\tau_h, e\tau_h, \mu\tau_h, e\mu}$ final states, and H → WW → $(l\nu)$ $(l\nu)$ in the $\boldsymbol{e\mu}$ final state
- Trigger on events with a single $e(\mu)$ or two τ_{h}, depending on final state
- Background estimation both data-driven (fake factor or extrapolation of sideband regions), and MC based
- Signal-to-background discrimination optimized using a multiclass BDTs (XGBoost, LightGBM)
- Signal extracted from the simultaneous fit to the BDT score distributions in all event categories



Contact

Deutsches Elektronen-
Synchrotron DESY

www.desy.de

Daina Leyva Pernia
CMS Higgs Group
daina.leyva.pernia@desy.de
daina.leyva.pernia@cern.de