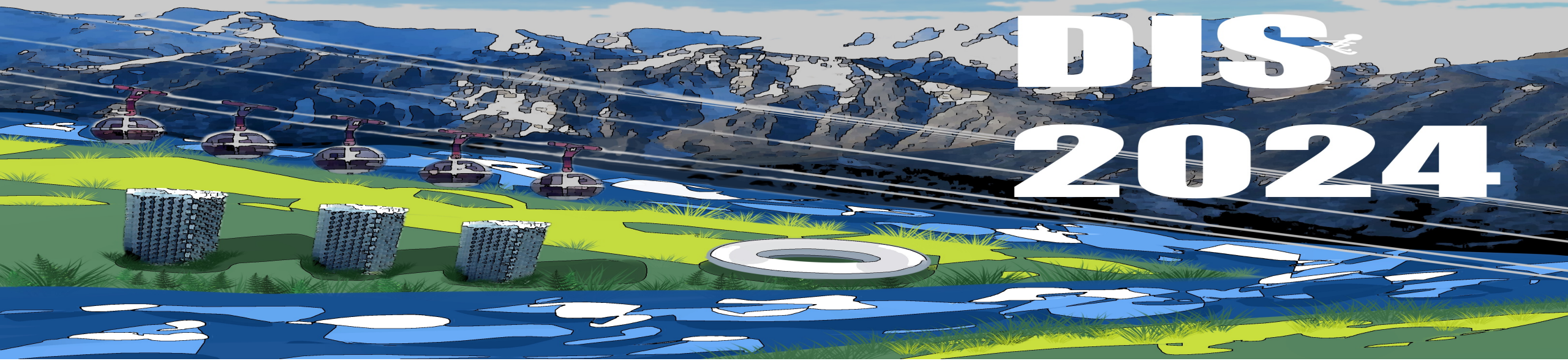


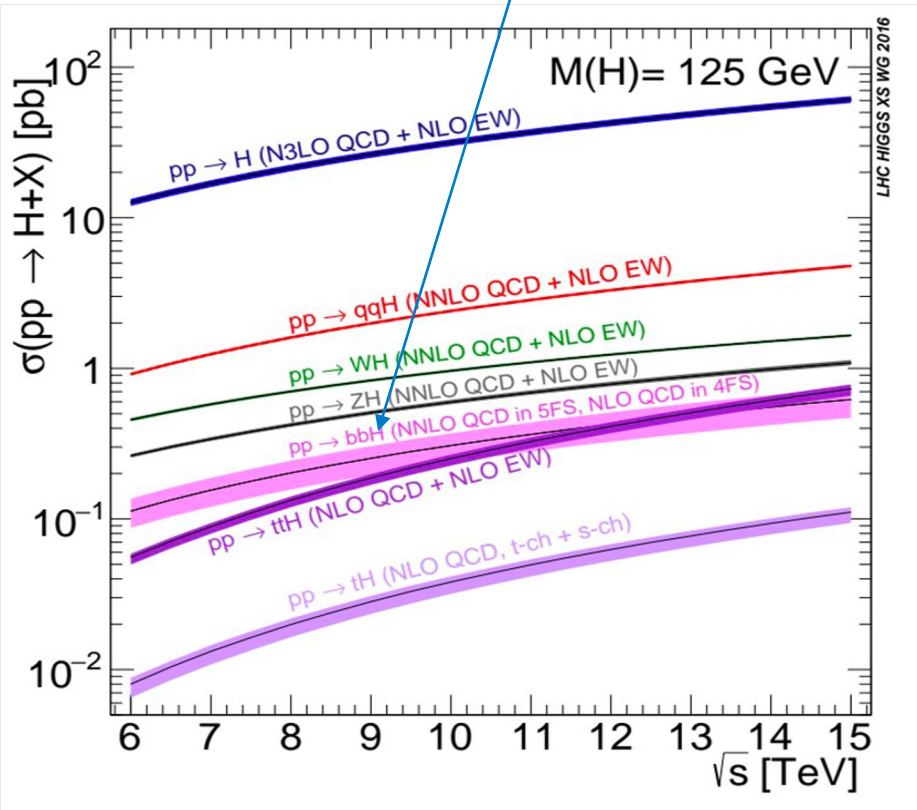
Search for b-associated production of Higgs boson in final state with leptons at CMS

Maryam Bayat Makou on behalf of the CMS Collaboration

Higgs boson

Production modes

- So far, most of the SM Higgs boson production modes have been studied at the LHC
- The search of **b-associated Higgs boson production (bbH)** is attempted for the first time for the SM Higgs boson



- **bbH** production mode:
  - Direct probe of Higgs couplings to the bottom quark (y_b) in production
  - Complementary to the other measurements such as, H→bb decay mode
  - Possibility to constrain top and bottom Yukawa coupling
  - Investigate experimental sensitivity to open the testing of recent theoretical computation of the bbH production cross-section

- Challenges:
  - Large background contribution for example more than ttH
  - Interference between different production modes

bbH production modes

Feynman diagrams

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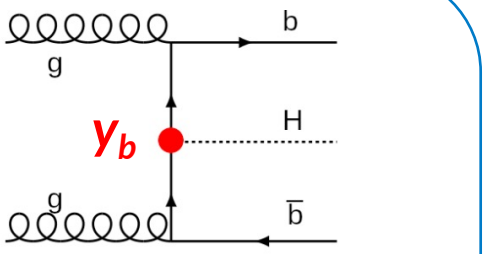
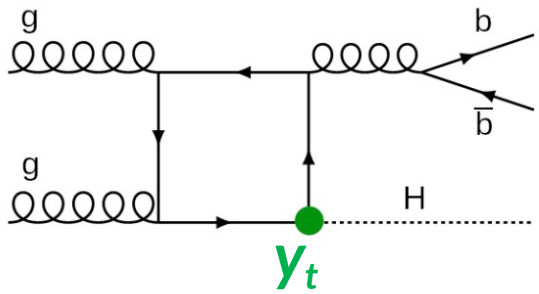
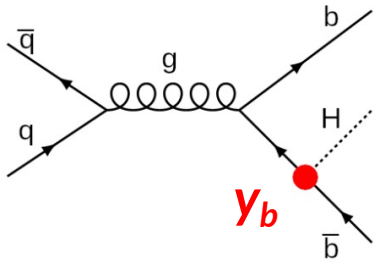
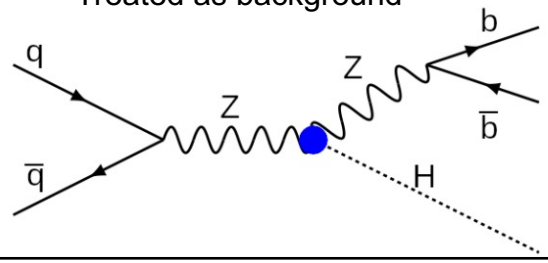






Treated as background



Analysis goal

1. Constrain inclusive cross-section of b-quark associated production $\sigma(y_b, y_t)$
2. Estimated value of $\sigma(y_b, y_t)$ (NLO) = 1.49 pb
3. Constrain Higgs Yukawa couplings to 3rd generation quarks: 2D likelihood scan of (κ_t, κ_b)

term	σ (pb)
y_t^2	1.040 (+0.468,-0.489)
y_b^2	0.482 (+0.048,-0.070)
$y_b y_t$	-0.033 (+0.007, -0.008)

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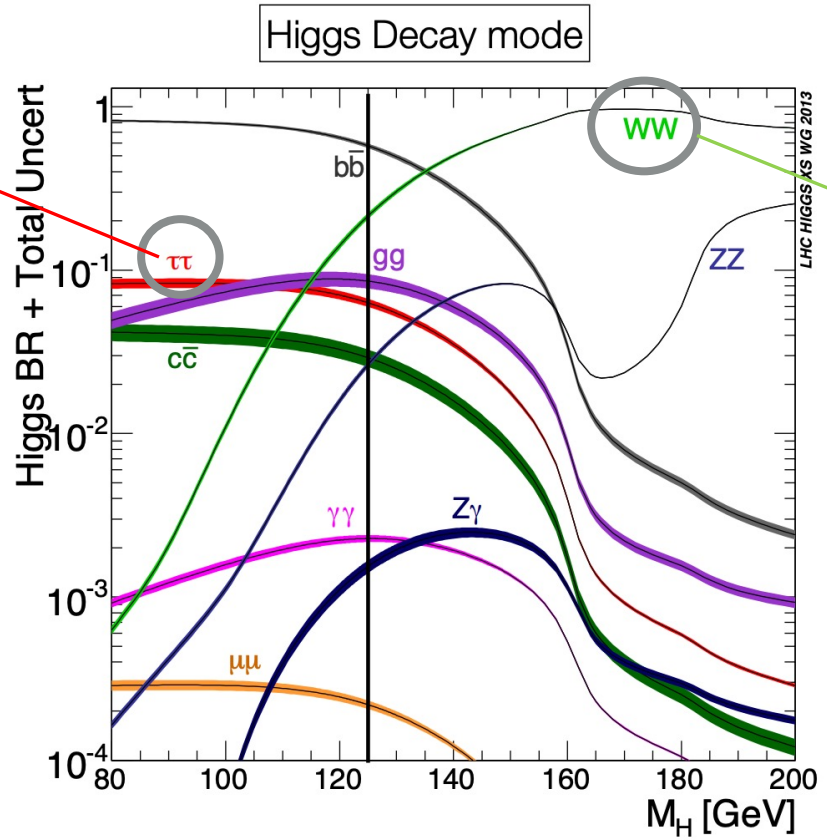
Targeted decay channels

Higgs decay to tau and Higgs decay to W bosons

H→ττ covering 4 final states: $\mu\tau$, $e\tau$, $\tau\tau$ & **$e\mu$**

Final state	BR
$\tau_h\tau_h$	42%
$\mu\tau_h$	22%
$e\tau_h$	23%
$e\mu$	6%



H→WW covering 1 final state: **$e\mu$**

Decay mode	BR
H→ττ	0.062
H→WW →$(\ell\nu)(\ell\nu)$	0.023

- Analysis is performed with the **full Run 2** data set of 138 fb^{-1} at 13 TeV

Event selections & Background

All channels and their respective modelling methodes

- General event selection:
  - Lepton pair, opposite sign: eμ, eτ_h, μτ_h, $\tau_h\tau_h$
  - At least one b-tagged jet
  - angular separation : ΔR(l/τ_h,l/τ_h)>0.5 (0.3 for eμ)

- Channel-dependent selection to suppress reducible backgrounds: e.g. transverse mass (m_T) cut to suppress reducible background in eτ_h, μτ_h channel

$$m_T(p_{T,\ell}, p_{\mathrm{T}}^{\mathrm{miss}}) = \sqrt{2 p_{T,\ell} p_{\mathrm{T}}^{\mathrm{miss}} (1 - cos(\Delta\phi(\vec{p}_{T,\ell}, \vec{p}_T^{miss}))}\,,$$

- Background processes contributing to the Analysis:

Estimation method: MC simulation

- $t\bar{t}$ contributes to all final states (eμ, eτ_h, μτ_h, $\tau_h\tau_h$)
- Drell-Yan + Jets
- Other SM Higgs production e.g. ttH

Data-driven

- Jets faking τ_h (eτ_h, μτ_h, $\tau_h\tau_h$)
- QCD multi jet events in eμ

Event Classification

All Channels

- Multiclass BDT (XGBoost, LightGBM) is trained in all channels to classify events into background and signal categories
- Individual training is performed per channel and year
- Only well-modelled variables
- Respective MC samples are used in the training

Channel	$e\mu$	$e\tau_h$	$\mu\tau_h$	$\tau_h\tau_h$
BDT classes	Drell-Yan , $t\bar{t}$, bbH →WW, bbH → $\tau\tau$	Drell-Yan , $t\bar{t}$, bbH → $\tau\tau$	Drell-Yan , $t\bar{t}$, bbH → $\tau\tau$	Drell-Yan & Higgs, $t\bar{t}$, Jet → τ_h fakes, bbH → $\tau\tau$,

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- Kinematics of the events are used as input variables
- Mix of high and low level variables

Variable	$e\mu$	$e\tau_h$	$\mu\tau_h$	$\tau_h\tau_h$
$m_{\tau\tau}$	×	✓	✓	✓
m_{vis}	✓	✓	✓	✓
Collinear mass	×	✓	✓	×
D_ζ	✓	✓	✓	×
$\Delta\eta$ between lepton and τ_h	×	✓	✓	×
Total transverse mass	✓	×	×	×
Di-τ p_T	✓	✓	✓	✓
Electron p_T	✓	×	×	×
Muon p_T	✓	×	×	×
p_T of leading τ_h	×	×	×	✓
p_T of trailing τ_h	×	×	×	✓
Transverse mass	×	✓	✓	×
Number of b-jets	✓	×	×	✓
p_T of leading b-jet	✓	✓	✓	✓
p_T of trailing b-jet	×	✓	✓	×
B-tag score for leading b-jet	×	✓	✓	✓
$\Delta\eta$ between di-τ p_T and leading b-jet	×	✓	✓	×
B-tag score for trailing b-jet	×	✓	✓	✓
Number of jets	✓	×	×	✓
p_T of leading jet	✓	×	×	✓
p_T of trailing jet	✓	×	×	✓
Di-jet invariant mass	×	×	×	✓
Di-jet $\Delta\eta$	✓	×	×	✓
p_T^{miss}	×	×	×	✓

Postfit distributions

Signal categories all channels

- Postfit plots for the signal classes in all channels : HWW in eμ and Hττ in $e\tau_h$, $\mu\tau_h$, and $\tau_h\tau_h$
- good sensitivity in high BDT score region

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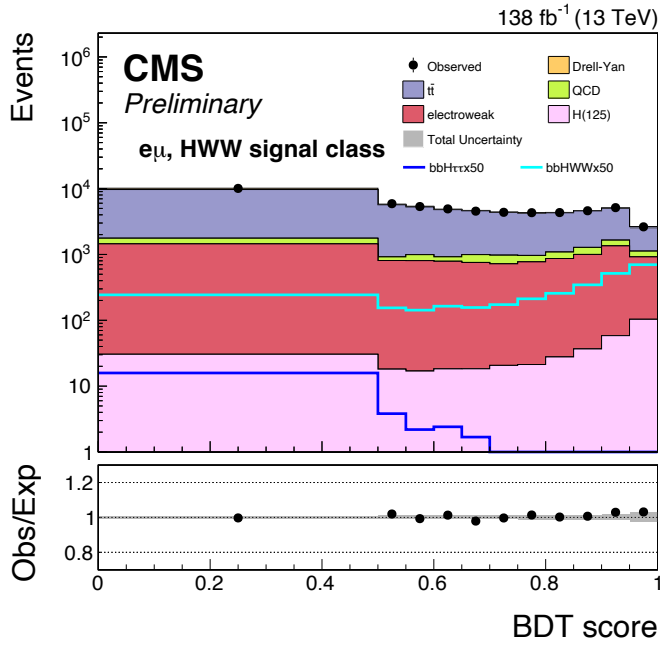

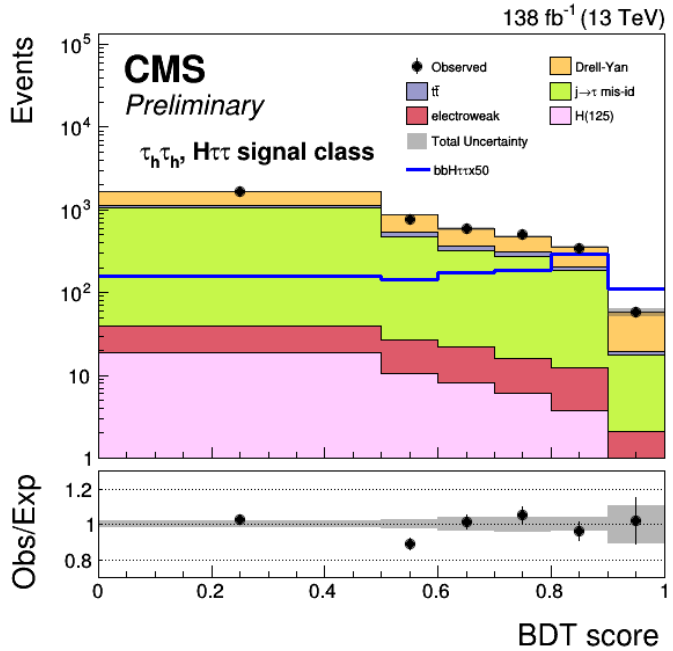

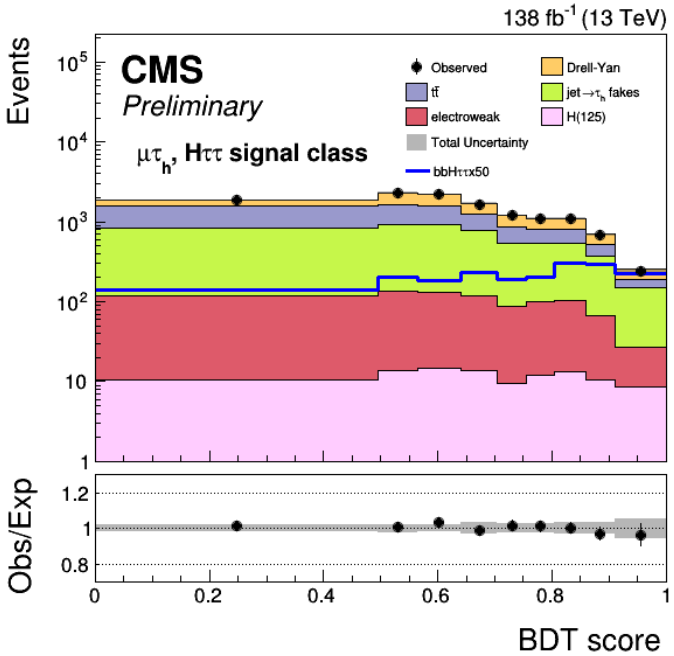

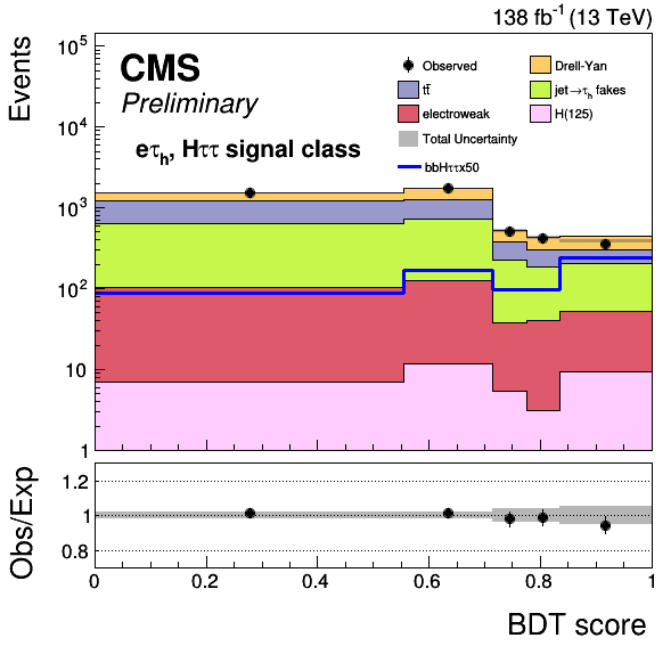

Uncertainties

- Analysis statistically limited
- Dominant uncertainties:
  - Statistical uncertainties
  - Theory uncertainties on the signal model
  - The shape correction for the b-tagging classifier introduces shape-altering effects on the BDT.
  - Uncertainties originate from correcting the top quark p_T spectra

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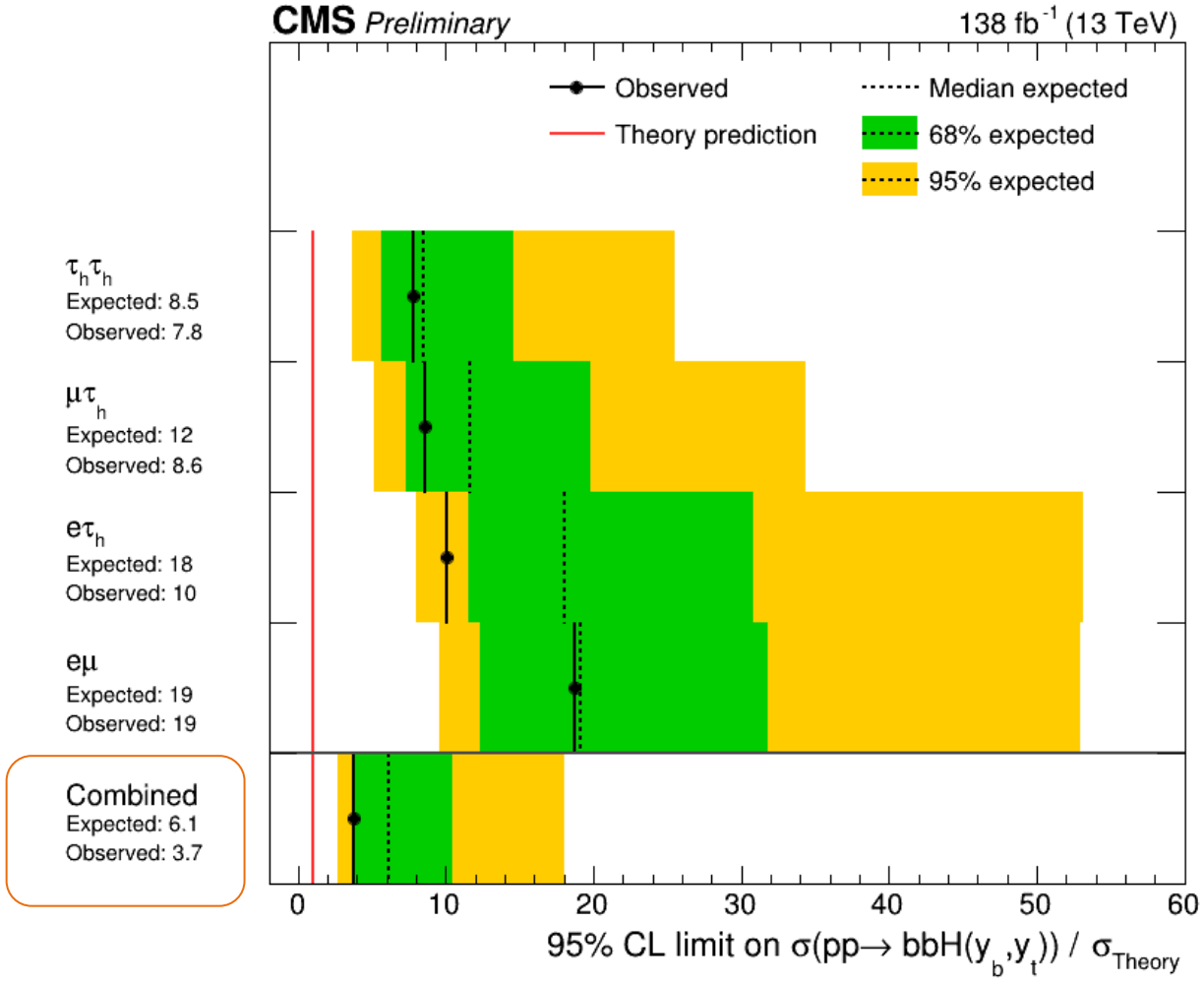
Description	Value	Templates affected	Type
Luminosity uncertainty	2016: 1.2%	MC	lnN
	2017: 2.3%		
	2018: 2.5%		
DY+jets production cross section	2%	DY	lnN
$t\bar{t}$ production cross section	6%	$t\bar{t}$	lnN
W+jets production cross section	4%	W+jets	lnN
Di-boson production cross section	5%	VV	lnN
Single top quark production cross section	5%	ST	lnN
$t\bar{t}$ +V+jets production cross ection	15%	$t\bar{t}$ +V+jets	lnN
Higgs boson production cross section	2-5%[19]	H (except bbH)	lnN
$H \to \tau\tau$ branching fraction	2.1%[19]	$H \to \tau\tau$	lnN
$H \to WW$ branching fraction	1.5%[19]	$H \to WW$	lnN
α_S variation	3.2%	bbH	lnN
μ(e) identification	1(2)%.	MC	lnN
μ trigger	2%	MC	lnN
τ_h trigger	p_T dep.	MC	shape
b tagging	1-9%	$t\bar{t}$, ST	shape
$\mu(e) \to \tau_h$ FR	η_{τ_h} dep.	MC with $\ell \to \tau_h$	shape
τ_h identification	p_T and DM dep. (2-3%)	MC	shape
τ_h ES	1%	MC	shape
μ ES	0.4–2.7%	MC	shape
$\mu \to \tau_h$ ES	1%	MC with $\mu \to \tau_h$	shape
$e \to \tau_h$ ES	η_{τ_h} and DM dep.	MC with $e \to \tau_h$	shape
Jet ES	event-dep.	MC	shape
Jet energy resolution	event-dep.	MC	shape
p_T^{miss} recoil corr.	event-dep.	MC	shape
p_T^{miss} unclustered ES	event-dep.	MC	shape
top quark p_T reweighing	10%	$t\bar{t}$, ST	shape
Z p_T reweighing	10%	DY	shape
QCD multijet uncertainty	event-dep.	$j \to \ell$ fakes (eμ channel)	lnN
FF uncertainties	event-dep.	$j \to \tau_h$ fakes	shape
Pre-firing	event-dep.	MC	lnN
Bin-by-bin stat. uncertainty	event-dep.	All	shape

Results

Expected & Observed limits

- Limits on b-associated Higgs production signal strength obtained by a simultaneous fit on all BDT categories
  - 3 output categories in eτ_h, $\mu\tau_h$
  - 4 output categories in eμ, $\tau_h\tau_h$
- Inclusive measurement: the different contributions to the signal are scaled by varying proportionally the y_b^2 , y_t^2 and $y_b y_t$
- Observed and expected **3.7 (6.1)** 95% CL upper limits on signal strength in individual channels and for their combination



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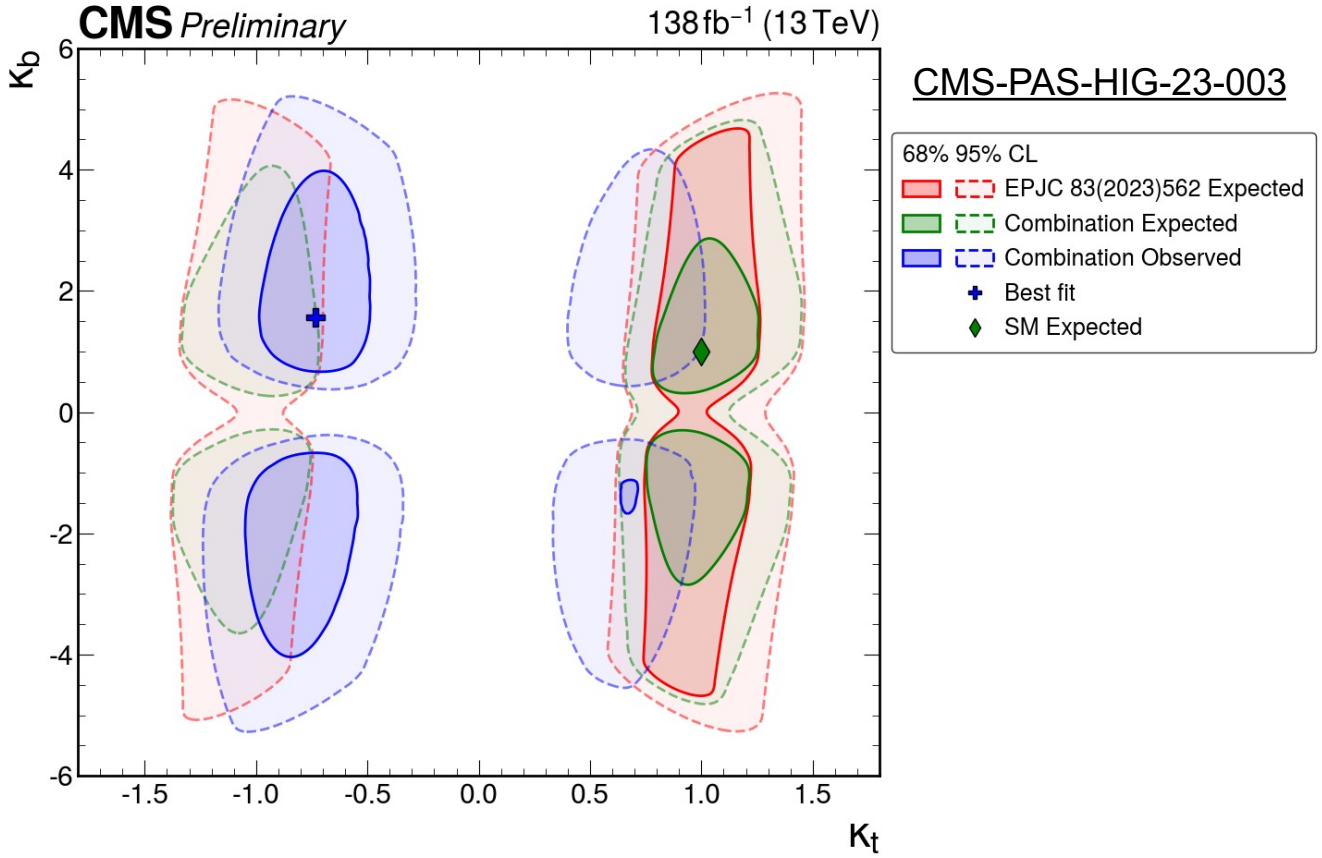
Results

2D likelihood scan (κ_t, κ_b)

- limits are derived on the Higgs boson coupling to b quarks ($\kappa_b = y_b/y_{b,SM}$) and top quarks ($\kappa_t = y_t/y_{t,SM}$)
  - ggH term ~ $1.04\kappa_t^2 + 0.002\kappa_b^2 - 0.04\kappa_t\kappa_b$
  - bbH term ~ κ_b^2
  - interference term ~ $\kappa_t\kappa_b$
- To constrain κ_t , analysis is combined with STXS H→ττ analysis (CMS-HIG-19-010)
  - CMS-HIG-19-010 analysis vetoed events with b-tagged jets → orthogonal to our selection
- Best fit values: (κ_t, κ_b) = (-0.73, 1.58)



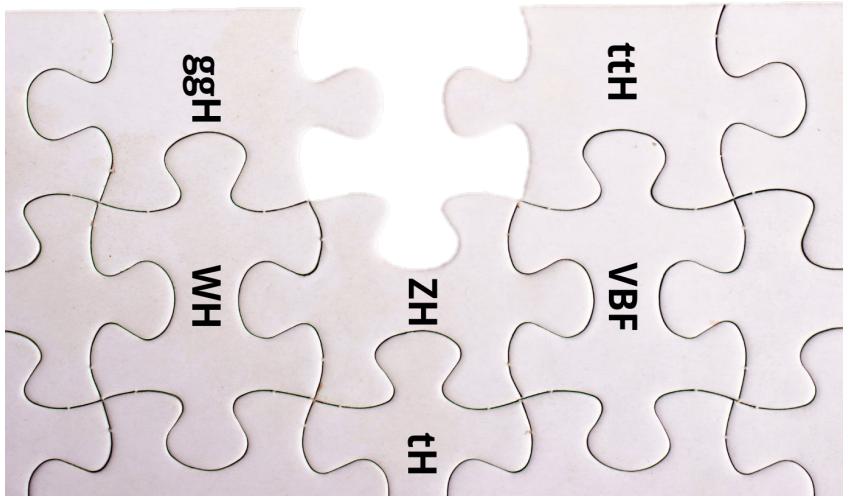
Summary

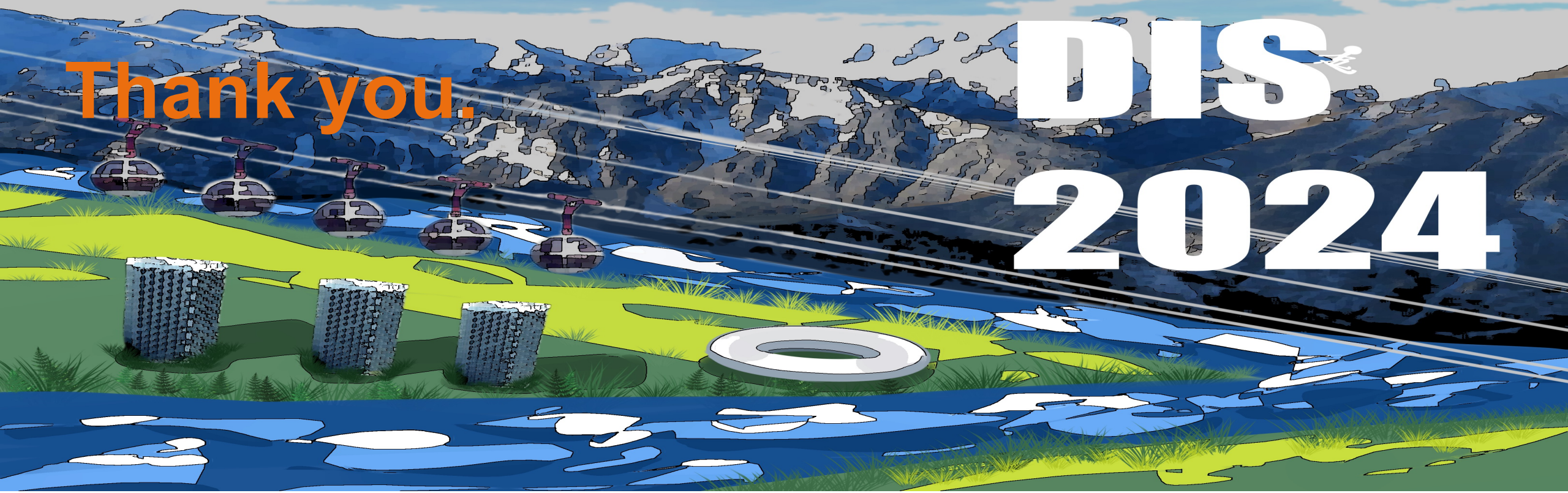
- First results constraining the bbH cross section for the SM Higgs boson are presented in 4 final states, eμ, eτ_h, μτ_h, $\tau_h\tau_h$:

  - Observed (Expected) **3.7 (6.1)** upper limits on bbH signal strength
  - Constraints on Higgs boson coupling to top and bottom:

  $(\kappa_t, \kappa_b) = (-0.73, 1.58)$

- Statistically limited analysis in addition to the large theory uncertainties
- Good prospects for combining the results with Run 3 data and searches in different final states
- Link to CMS-PAS-HIG-23-003





Contact

Deutsches Elektronen-
Synchrotron DESY

www.desy.de

Maryam Bayat Makou
CMS - DESY
maryam.bayat.makou@desy.de