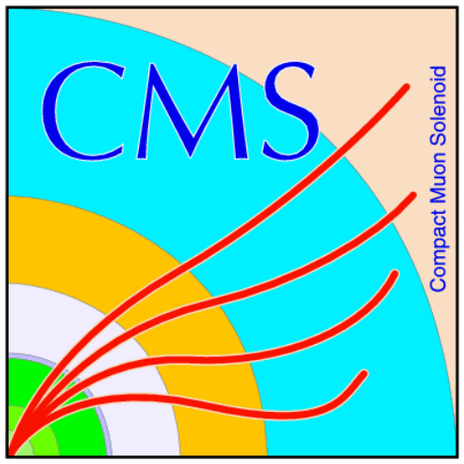
CMS Higgs(125) difermion results

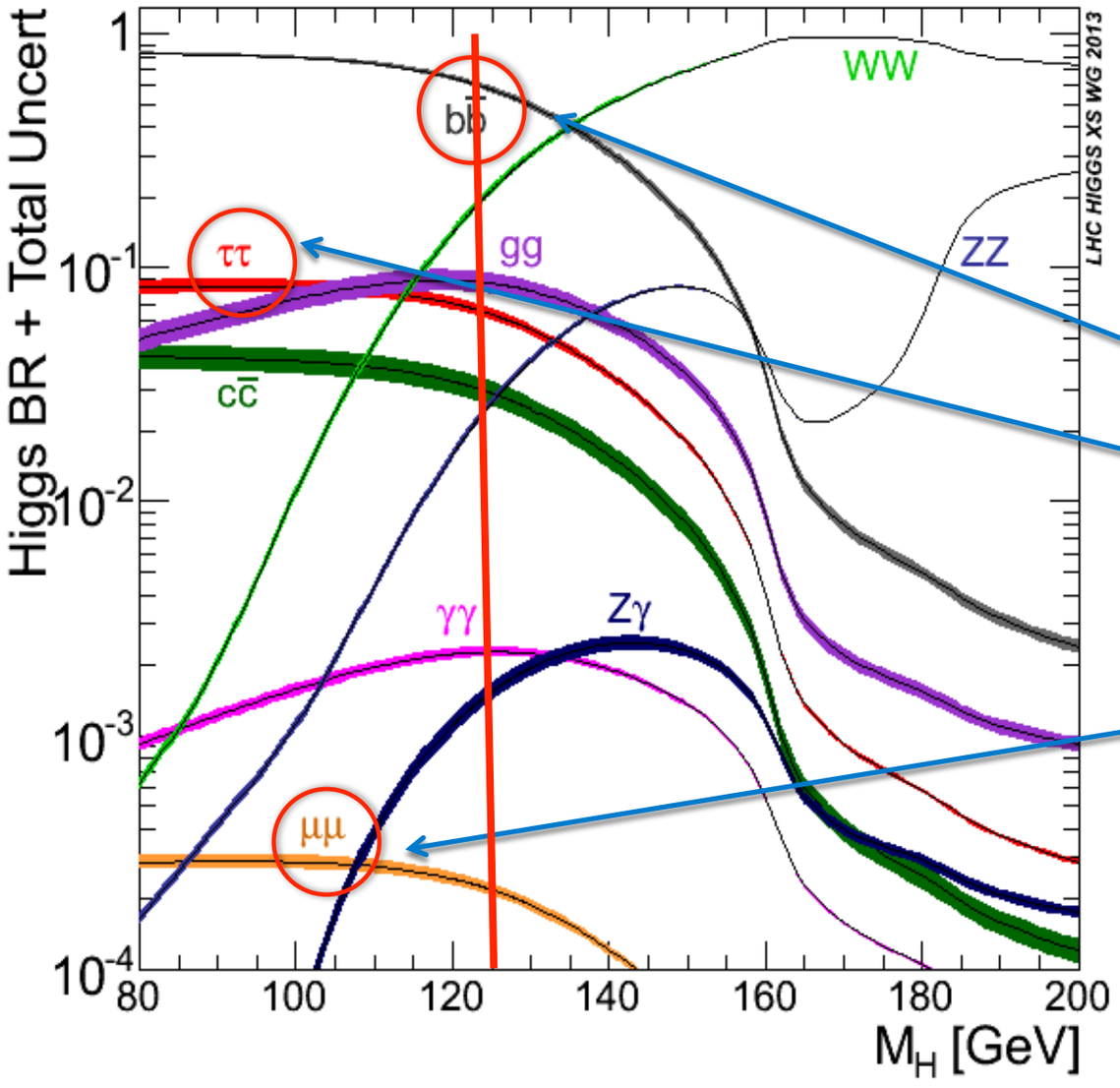


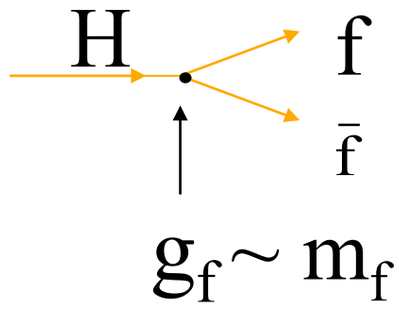
Arun Nayak
IoP, Bhubaneswar, India
(For CMS collaboration)

Higgs Hunting 2016
31 Aug – 02 Sep, LPNHE, Paris

Introduction

Probing Higgs to fermion coupling at LHC is important to establish the nature of Yukawa couplings





By Decay Modes:

H → bb(bar)

H → ττ

H → μμ

By Production Modes:

gg → tt(bar)H

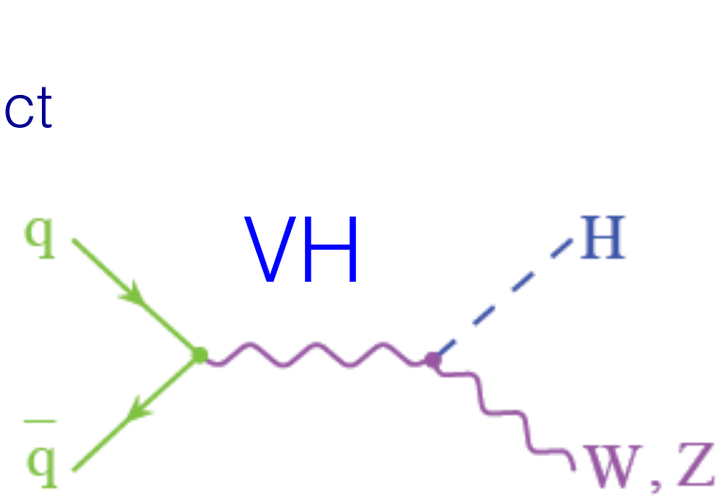
Emphasis on recent 13 TeV results

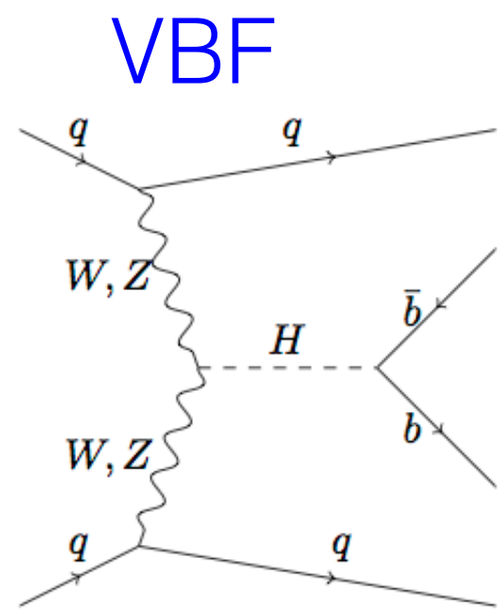
Higgs → bb

Summary of run-1 searches

- Large mutijet backgrounds
- Searches in the production mode where additional leptons/jets present with distinct signatures
  - VH and VBF productions
- Improved b-jet ES using MVA regression
- MVA analysis exploiting production and decay kinematics between signal & backgrounds

CMS-HIG-13-012 CMS-HIG-14-004





$H \to b\bar{b}$	Best fit (68% CL)	Upper limits (95% CL)		Signal significance	
Channel	Observed	Observed	Expected	Observed	Expected
VH	0.89 ± 0.43	1.68	0.85	2.08	2.52
$t\bar{t}H$	0.7 ± 1.8	4.1	3.5	0.37	0.58
VBF	$2.8^{+1.6}_{-1.4}$	5.5	2.5	2.20	0.83
Combined	$1.03^{+0.44}_{-0.42}$	1.77	0.78	2.56	2.70

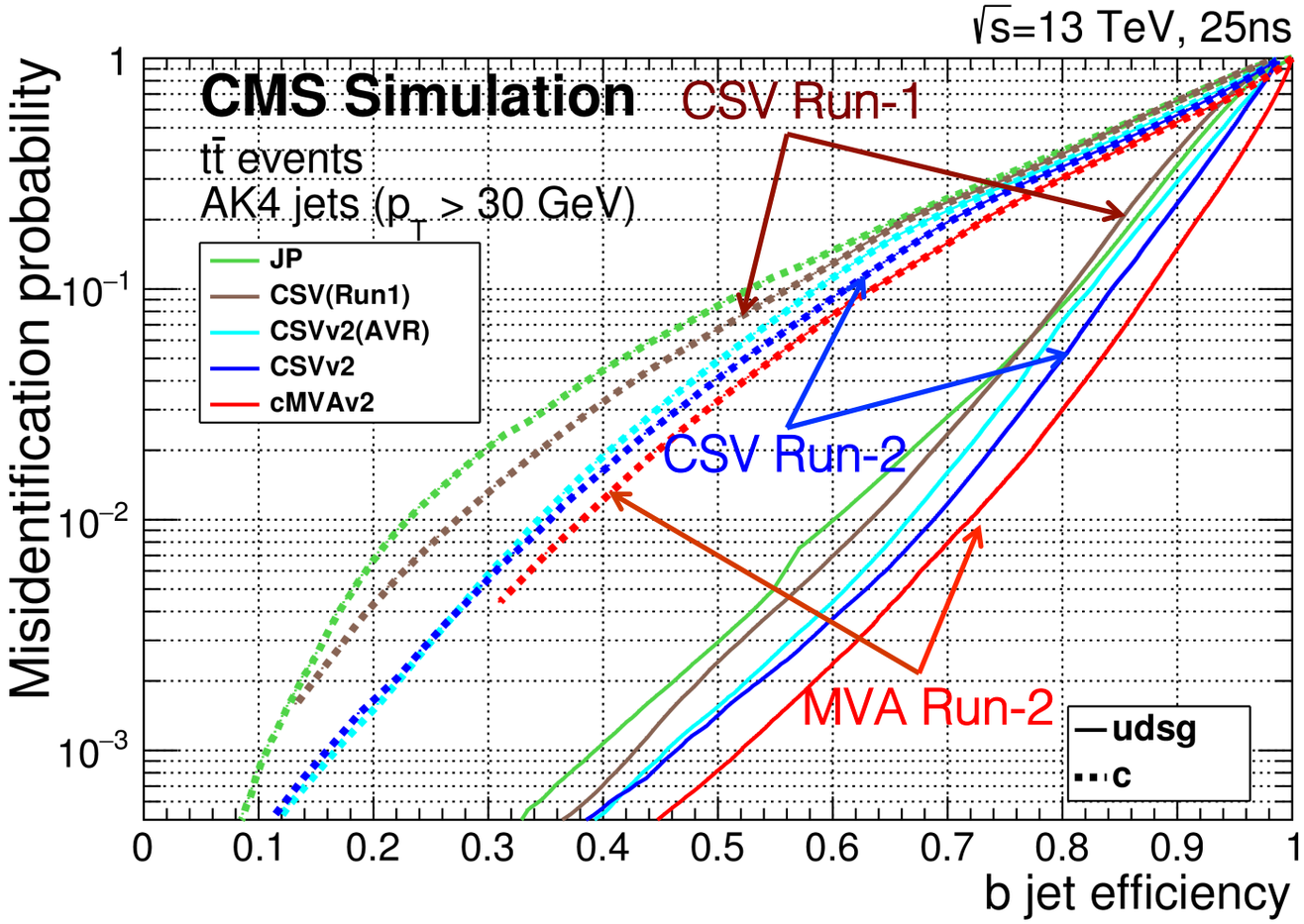
Preparation for 13 TeV data

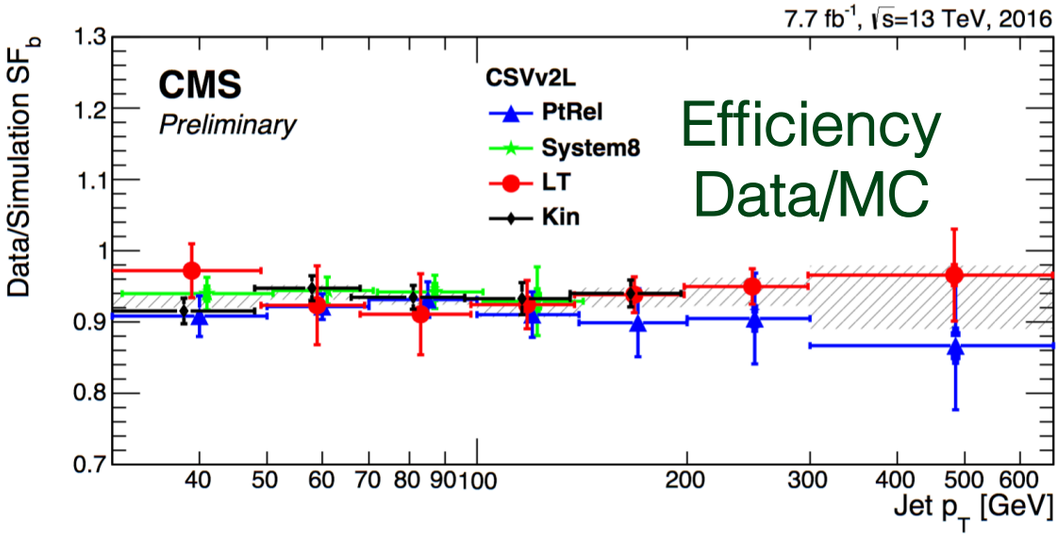
CMS PAS BTV-15-001, CMS DP-2016/042

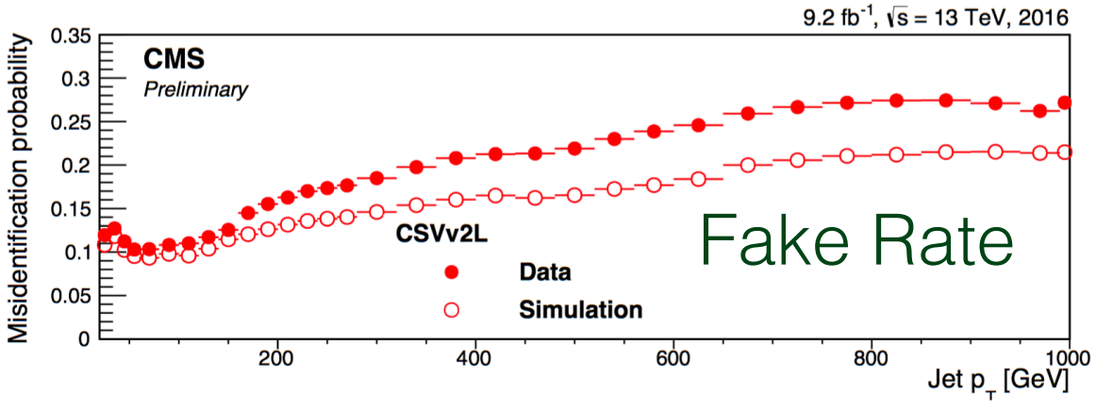
Large Improvement in b-Tagging

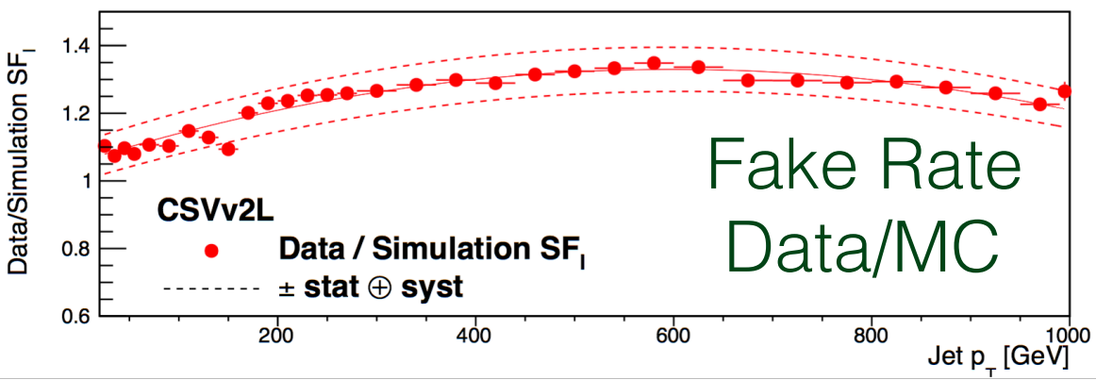
Commissioned using 13 TeV data collected in 2015/2016

Re-optimized Combined Secondary Vertex (CSV) algorithms, and a new MVA algorithm combining all other algorithms for Run-2







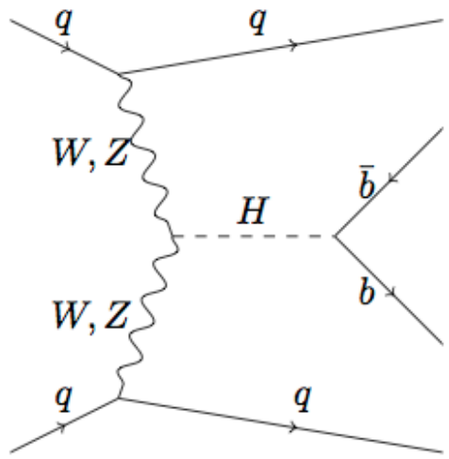


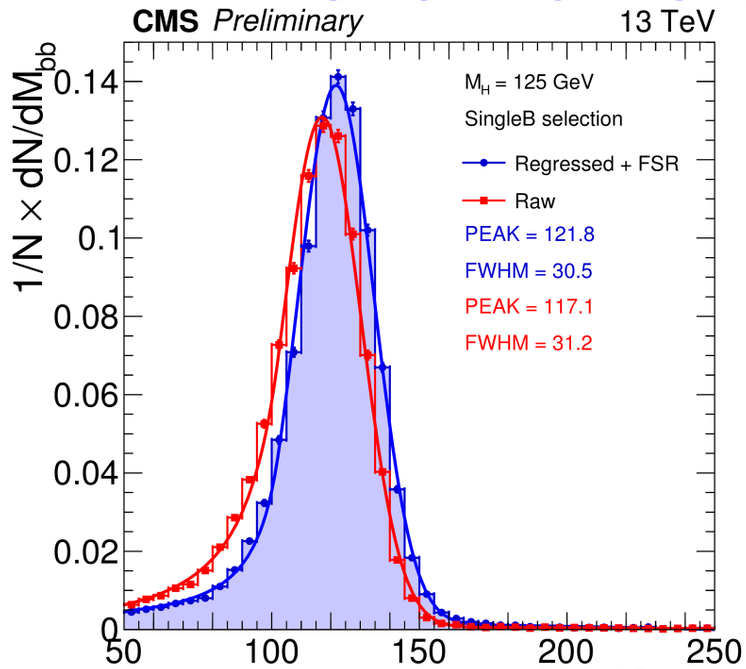
VBF H → bb (2015 data @13 TeV)

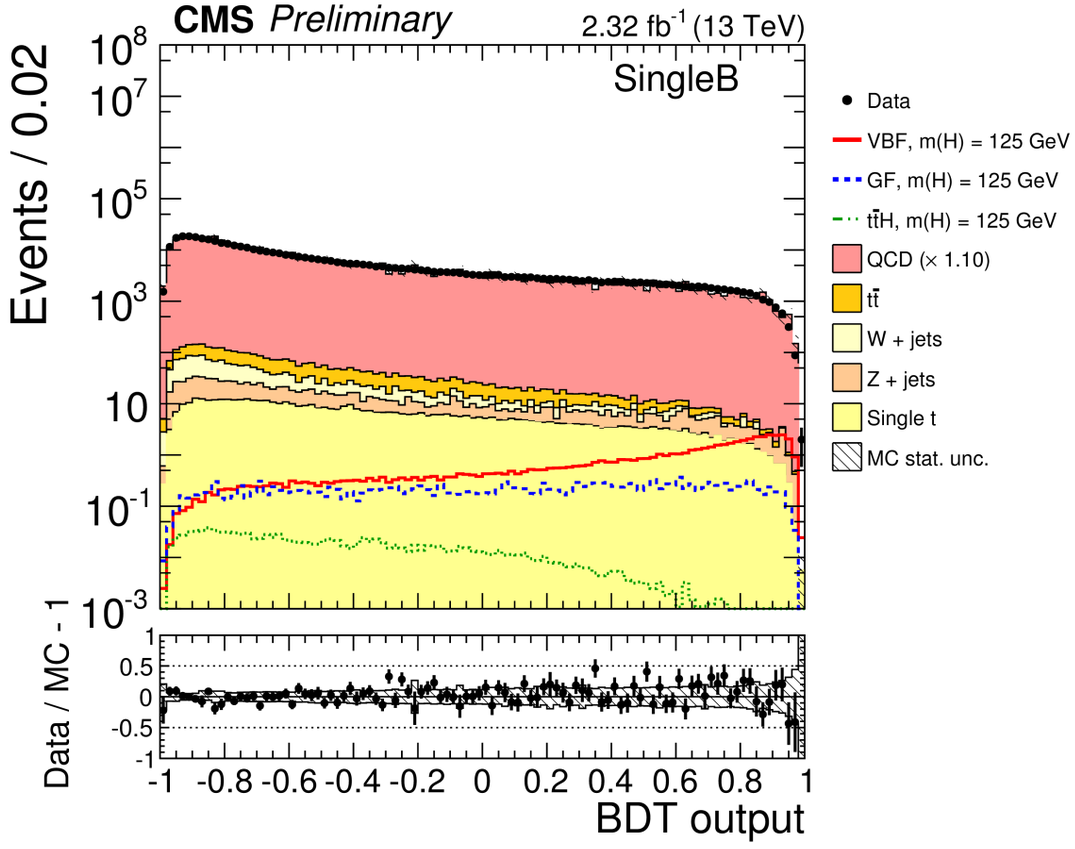
CMS-PAS-HIG-16-003

Exploit unique VBF signature:

- 4 hard jets
- 2 central b-jets (b-tagging)
- 2 forward quark jets (q/g discriminator)
- Large M(jj), $\Delta\eta$(jj)





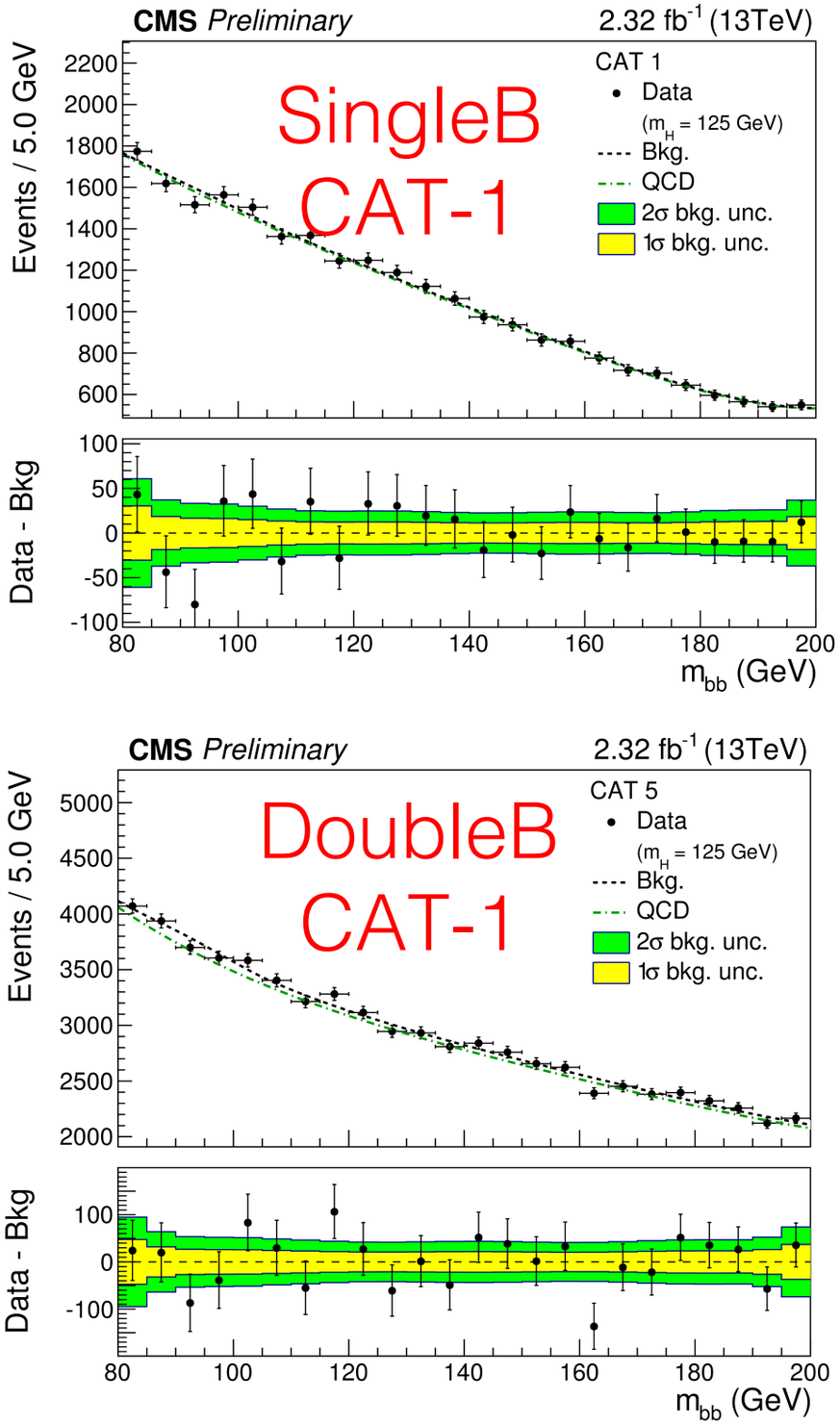


Analysis Strategy:

- Dedicated topological trigger based on VBF properties and b-tagging requirement: **SingleB & DoubleB trigger**
- **BDT discriminant** to exploit difference between signal from QCD background
- Events categorized based on BDT output - S/B bins
- **b-Jet energy regression improves m(bb) resolution**
- Fit m(bb) distribution to extract signal

VBF H → bb (13 TeV Results)

CMS-PAS-HIG-16-003

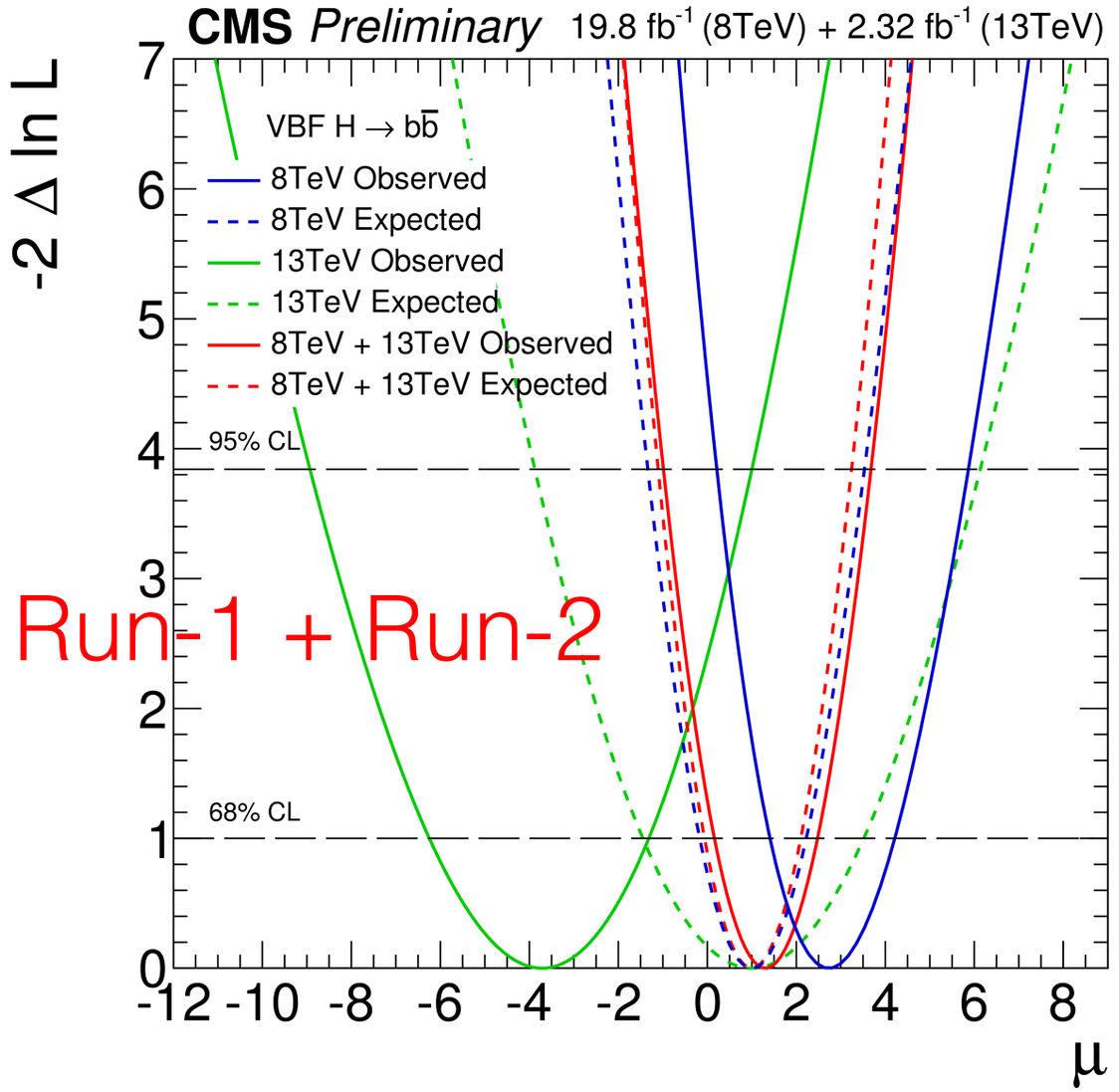


13 TeV results (2.32 fb^{-1} of 2015 data)

$\mu = \sigma/\sigma_{SM}$ = -3.7 (+2.4, -2.5)

Run-1 + Run-2 Combination:

$\mu = \sigma/\sigma_{SM}$ = 1.3 (+1.2, -1.1)



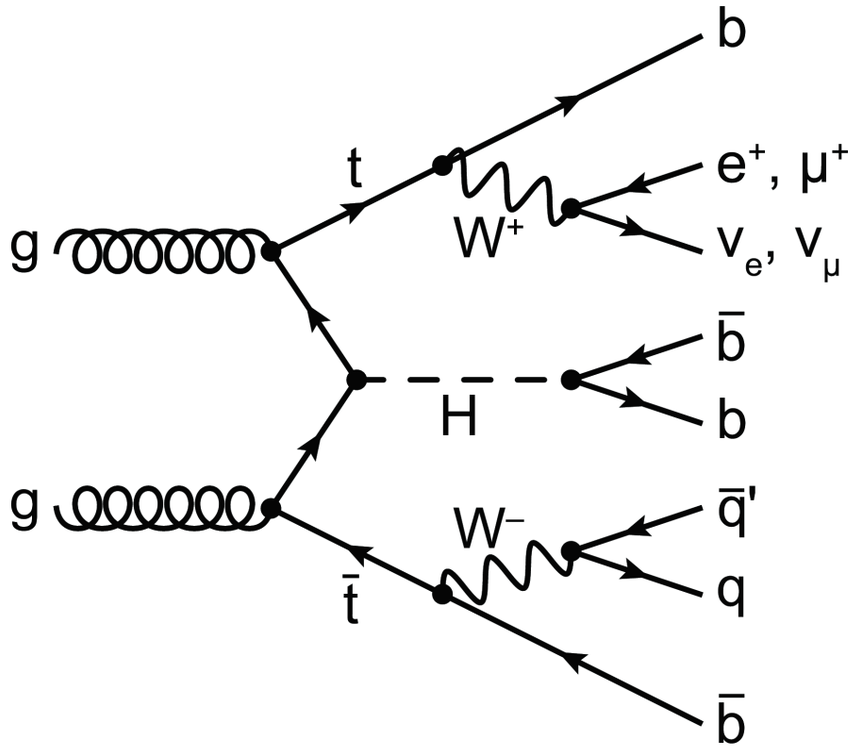
$$t\bar{t}H, H \rightarrow b\bar{b}$$

$$tH, H \rightarrow b\bar{b}$$

ttH, H → bb

Probing Higgs to Top coupling:

- Production via gluon fusion (assumes no BSM coupling)
- **Associated production with top-quark pair**

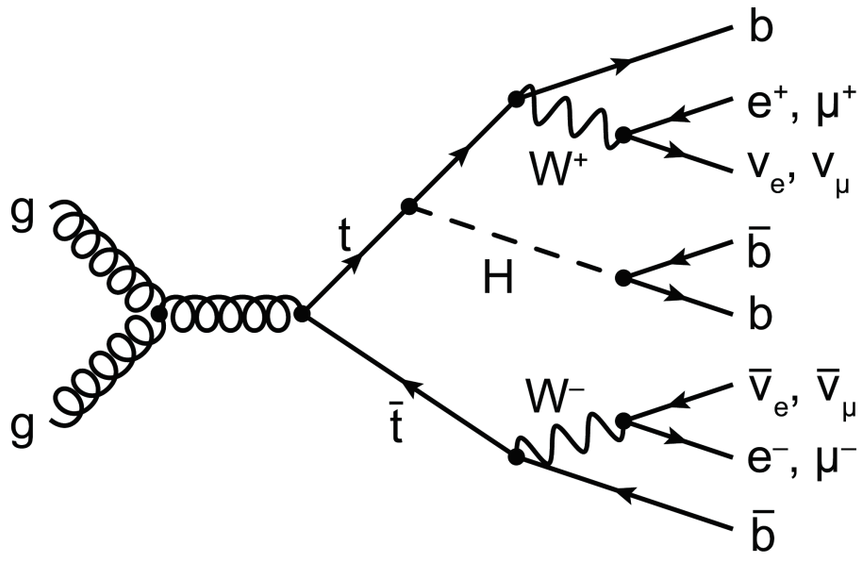


The Challenge:

- Large tt+jets (and tt+bb) backgrounds: 10^3 times higher than signal

  σ(ttH) ~ 510 fb, σ(ttbar) ~830 pb

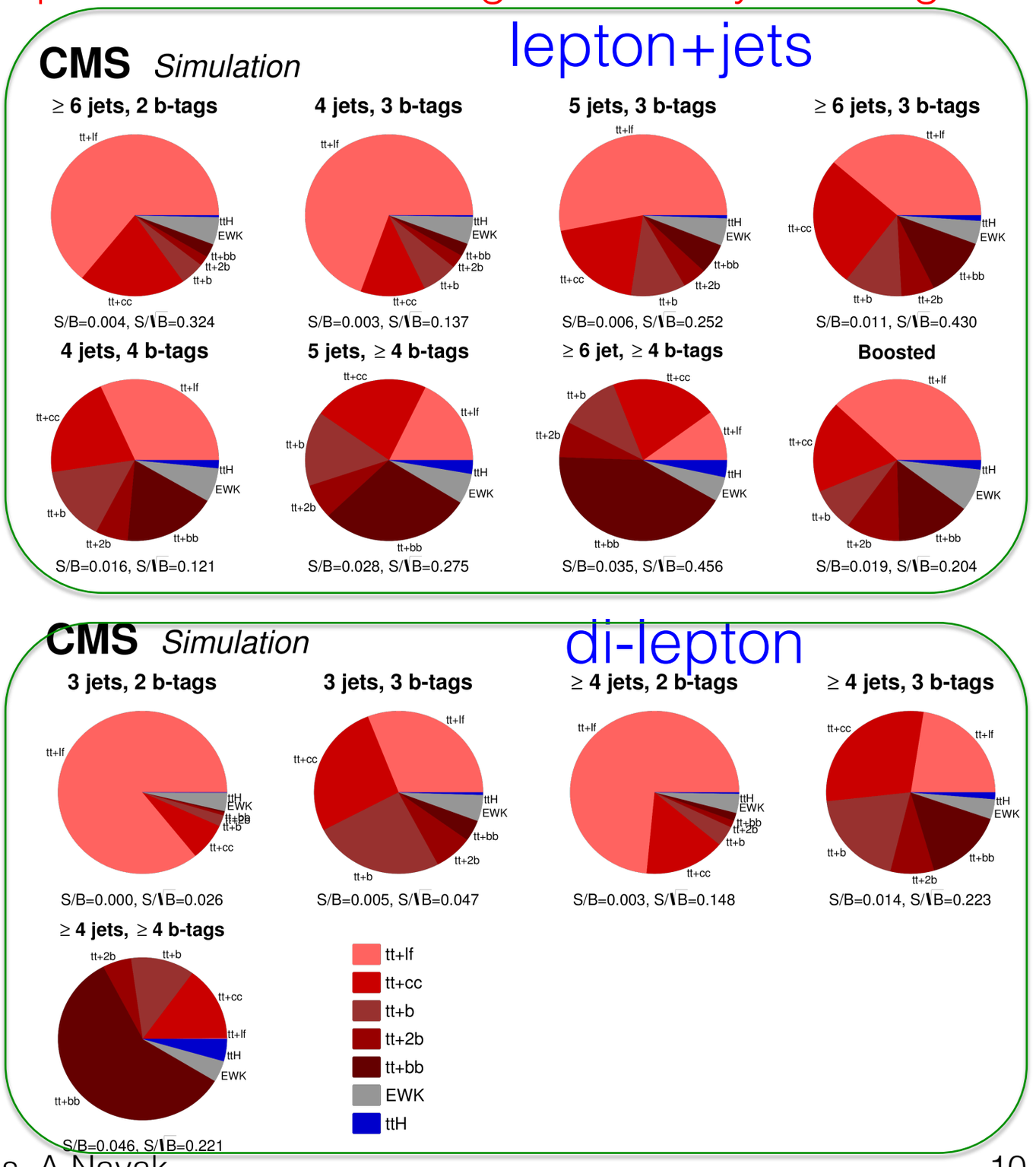
- Large combinatorics of leptons and jets from top decay



ttH, H → bb Analysis

Fraction of processes contributing in the analysis categories.

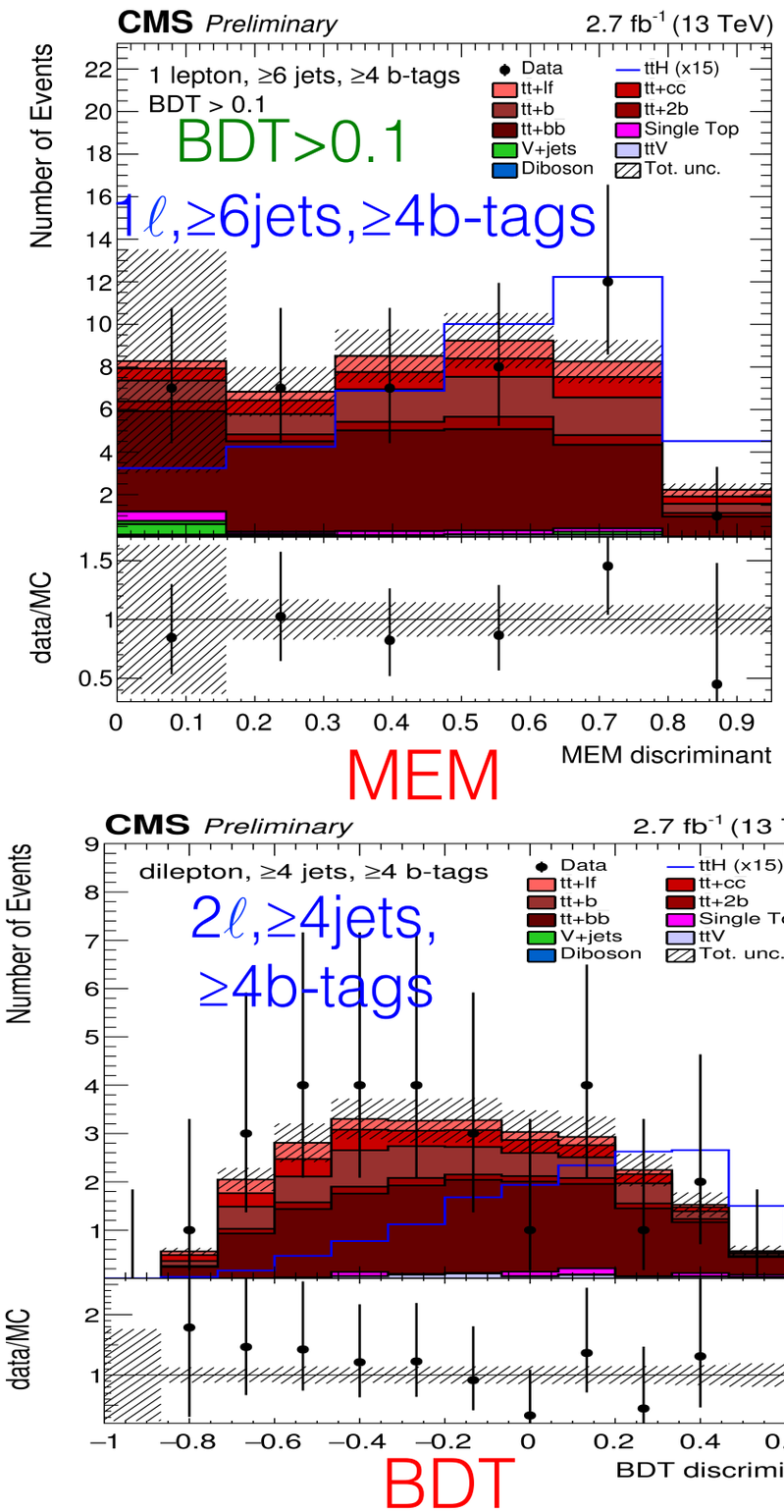
- Analysis channels:
  - l+jets: tt→ℓνqq'bb, H→bb
  - dilepton: tt→ℓνℓνbb, H→bb
- At least 3 to 6 jets, with at least two to four b-tagged (depending on channel)
- Divide further events into several categories (based on N_{jets} & $N_{b\text{-}jets}$)
- In ℓ+jets channel, an additional "**boosted**" category where t→bqq and H→bb decay products are collimated into a single large jet
  - Identified using a sub-jet algorithm

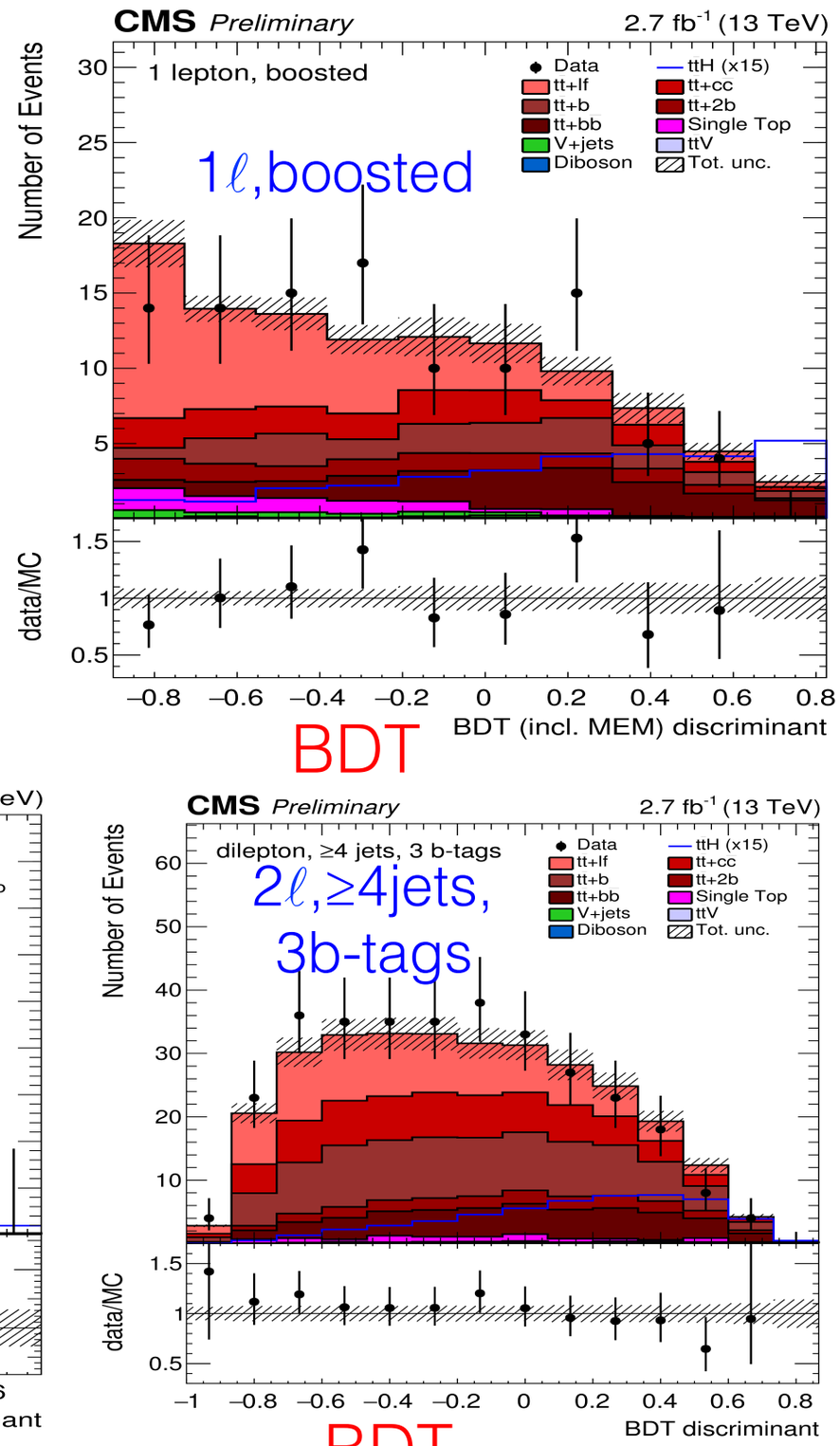


ttH, H → bb Analysis

CMS-PAS-HIG-16-004

- MVA (BDT) and Matrix-Element methods used to separate signal from background
- Separate BDT for each categories
  - Object kinematics, event shape, and b-tag discriminators as input to BDT
  - MEM used as input to BDT in some categories
  - In most sensitive ℓ+jet categories, a 2D (BDT vs MEM) fit is performed





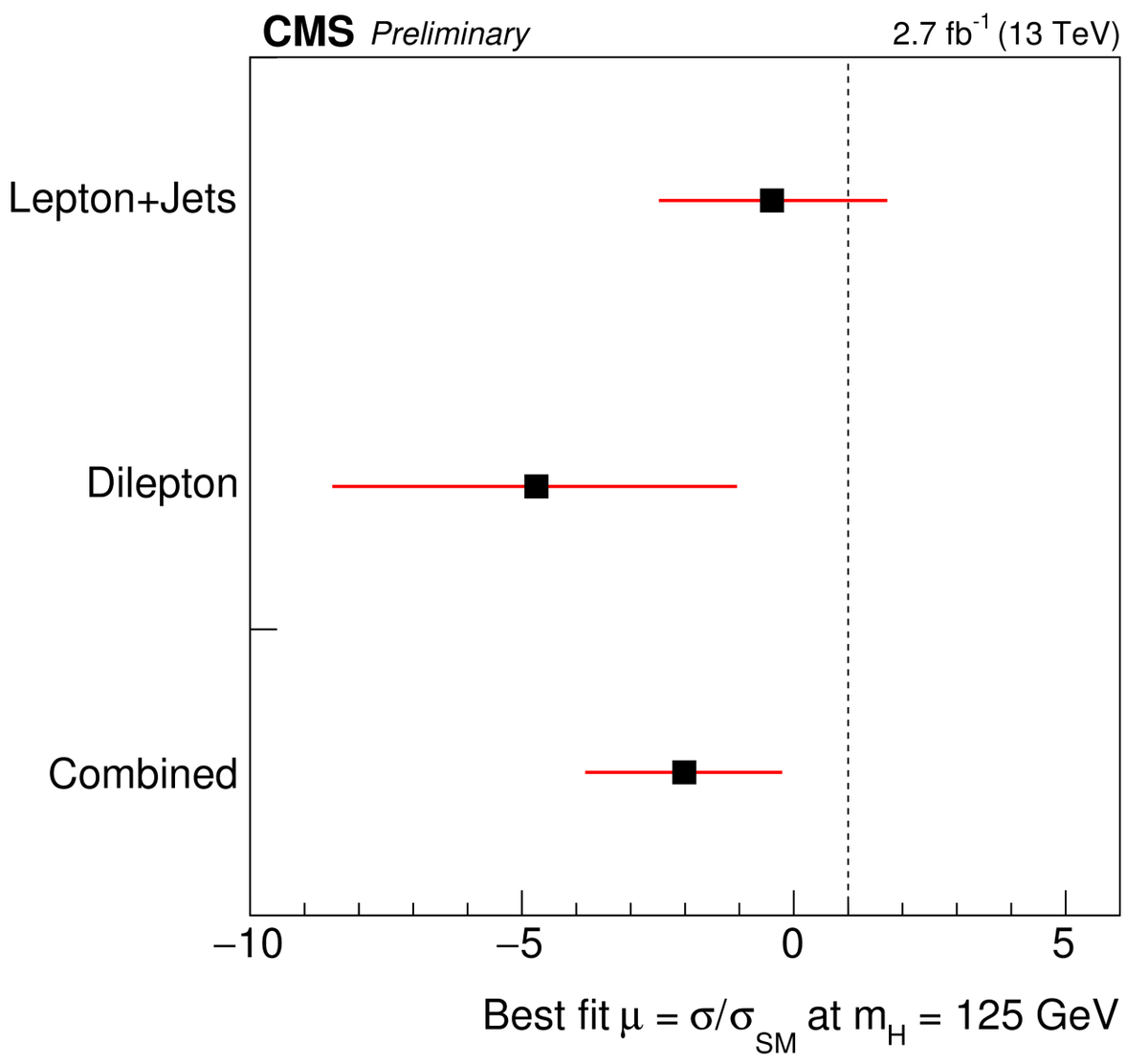
ttH, H → bb Results

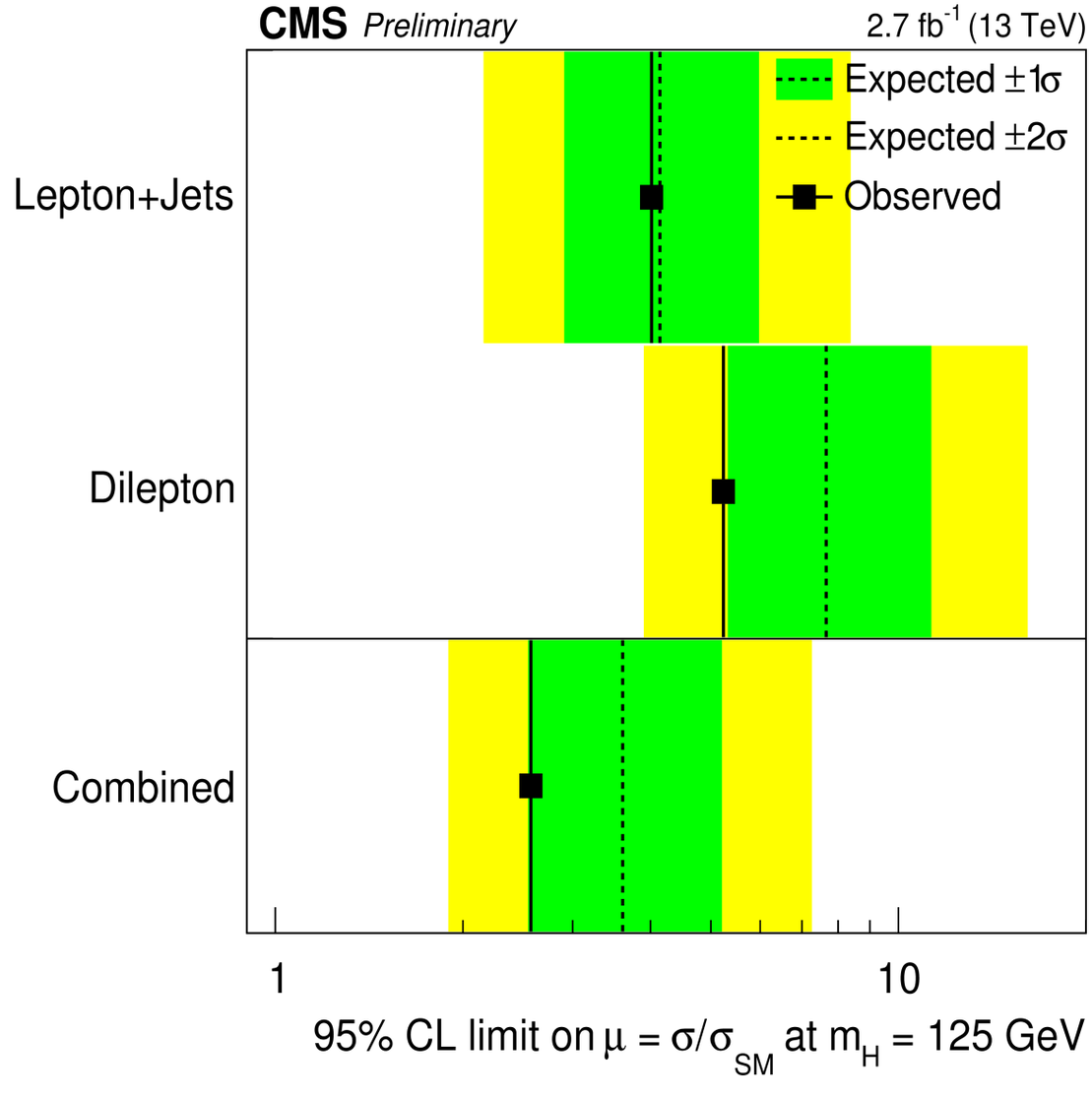
CMS-PAS-HIG-16-004

2.7 fb^{-1} of 2015 data @ 13 TeV

Best fit μ = -2.0 ±1.8

95% CL upper limit on μ
2.6 (3.6 exp.)



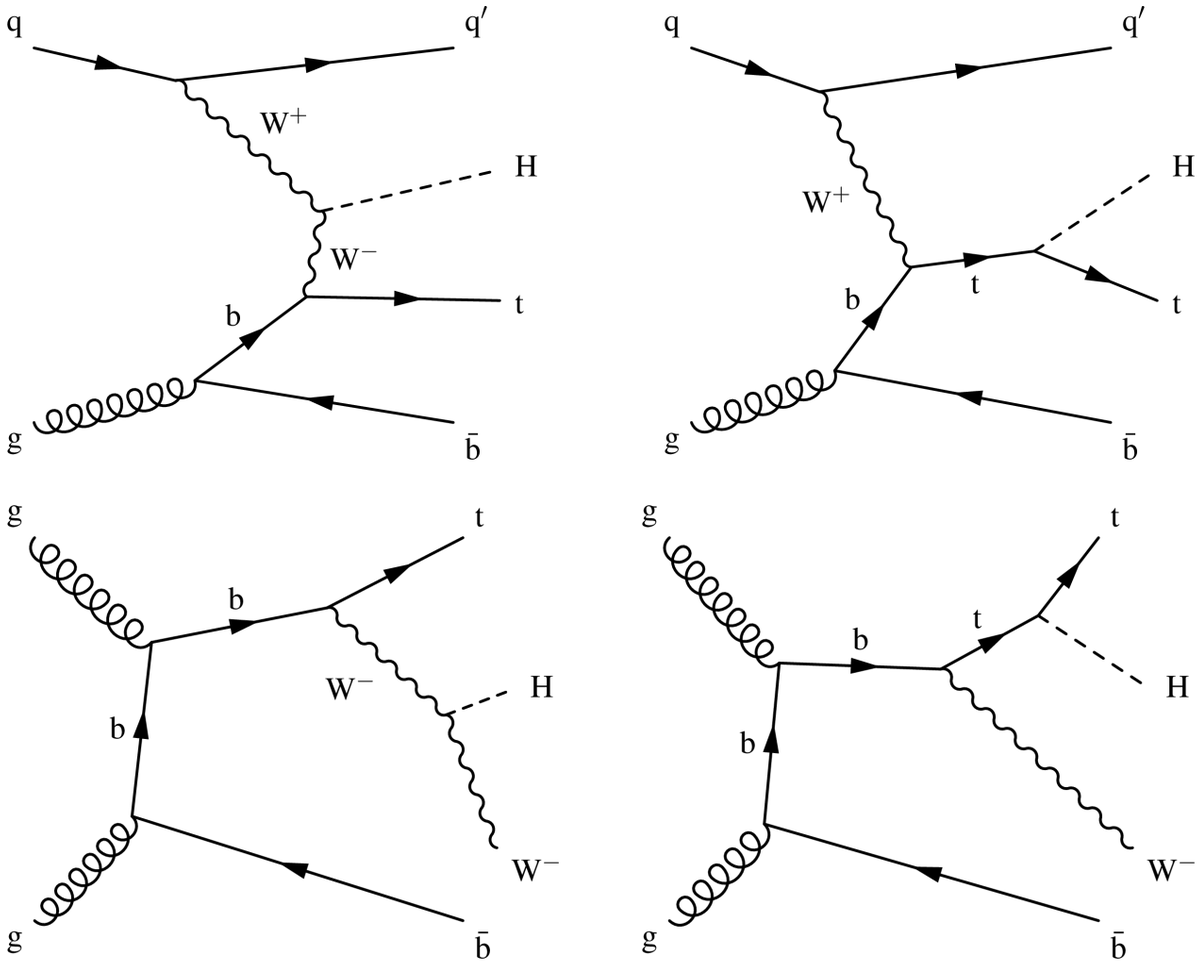


Analysis with 2016 data ongoing…

tH, H → bb

CMS-PAS-HIG-16-019

Includes tHW production in 13 TeV analysis



Destructive interference in SM and Constructive interference in inverted top coupling (ITC) scenarios

- The channel is sensitive to sign of y_t
- The SM x-section is 71 fb (tHq) and 16 fb (tHW) @ 13 TeV
- $y_t < 0$ is disfavored indirectly by H→$\gamma\gamma$ measurements

Analysis Strategy

- Only Semi-leptonic top decays are considered
- MVA (BDT) used to assign jets to both tHq and tt hypothesis and to seprate signal from background
- Main background (tt) is modeled using MC

tH, H → bb Results

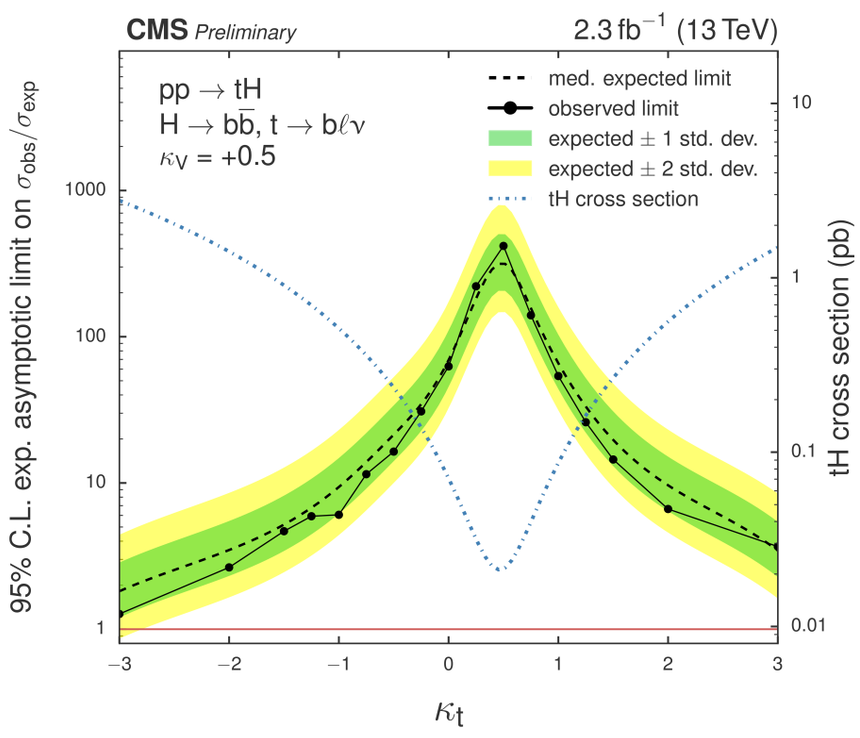
2015 data @13 TeV

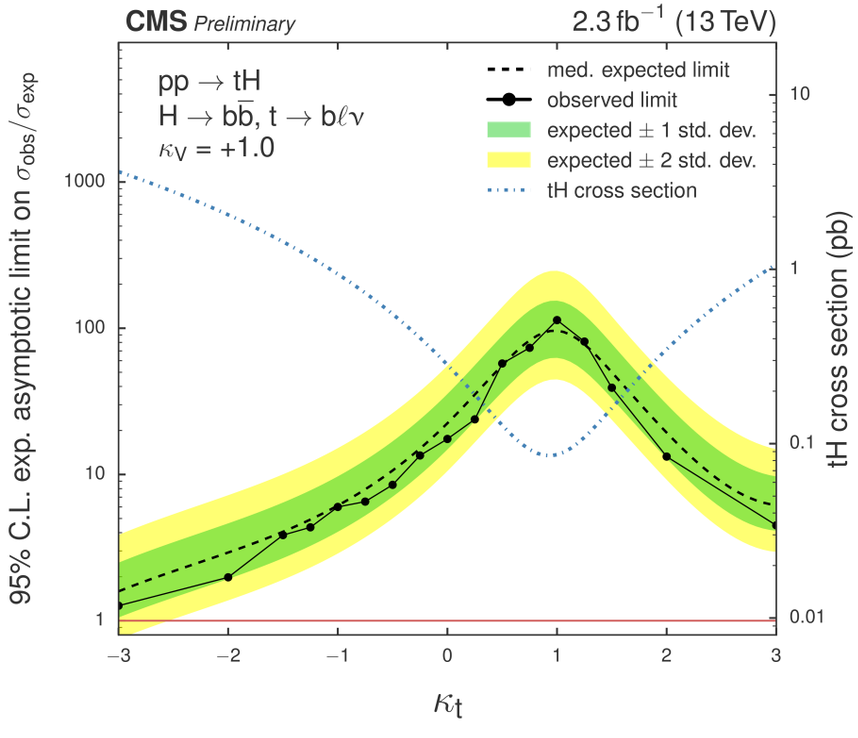
CMS-PAS-HIG-16-019

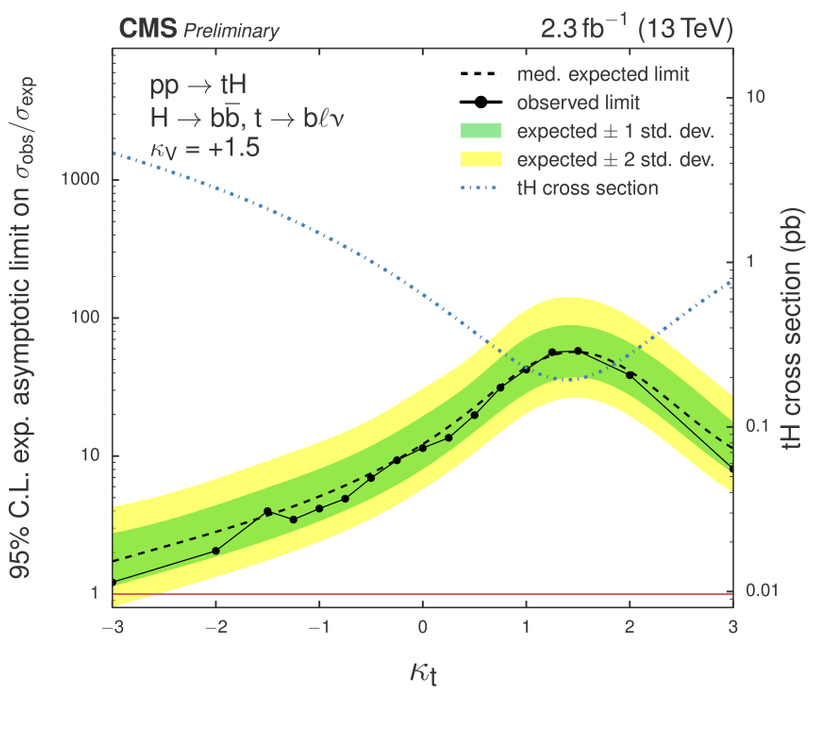
	Observed Limit	Expected Limit		
		Median	$\pm1\sigma$	$\pm2\sigma$
SM scenario	**113.7**	**98.6**	**[64.0 , 159.2]**	**[45.3 , 254.8]**
ITC scenario	**6.0**	**6.4**	**[4.2 , 10.1]**	**[3.0 ,15.7]**

Exclusion limits for all 51 studied couplings (3 values of k_V and 17 values of k_t)

Comparable to Run-1 result (5.4 σ_{ITC} (exp))







Higgs → ττ

H → $\tau\tau$ (Run-1 Summary)

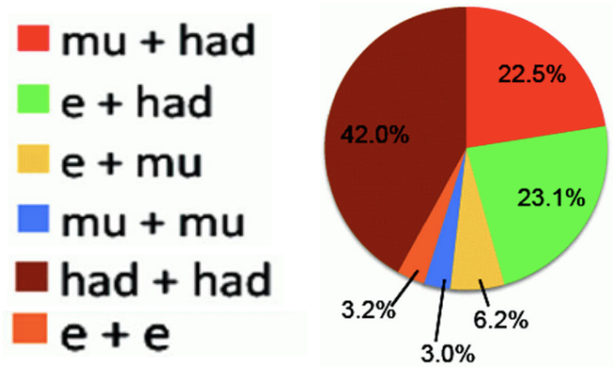
JHEP05(2014)104

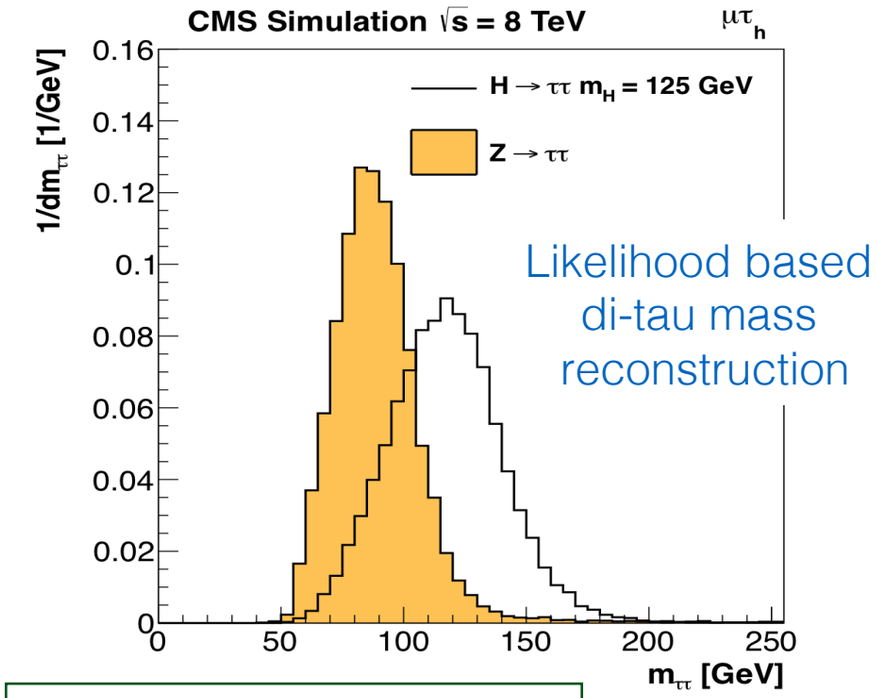
All production Process:

gg→H, VBF, VH

Channels:

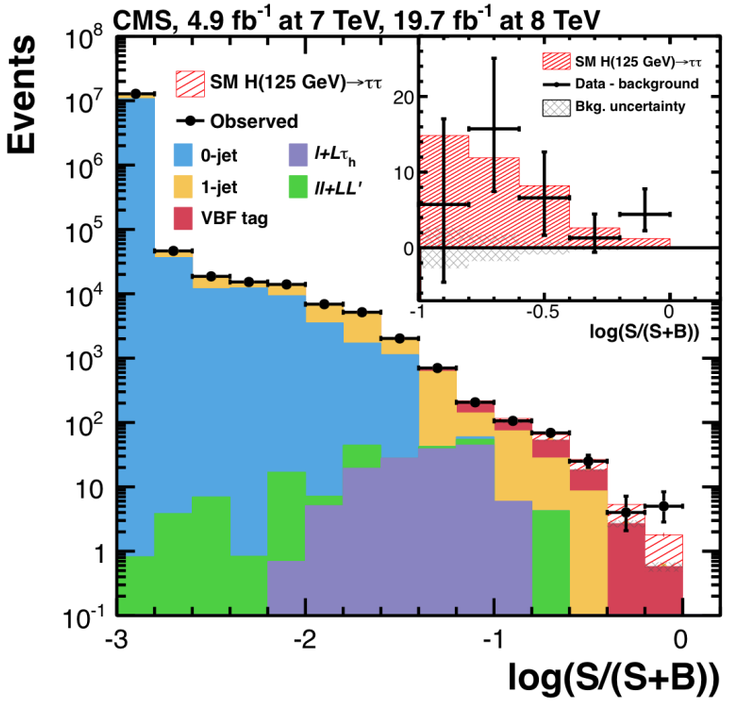
ee,μμ,eμ,eτ_h,μτ_h,$\tau_h\tau_h$





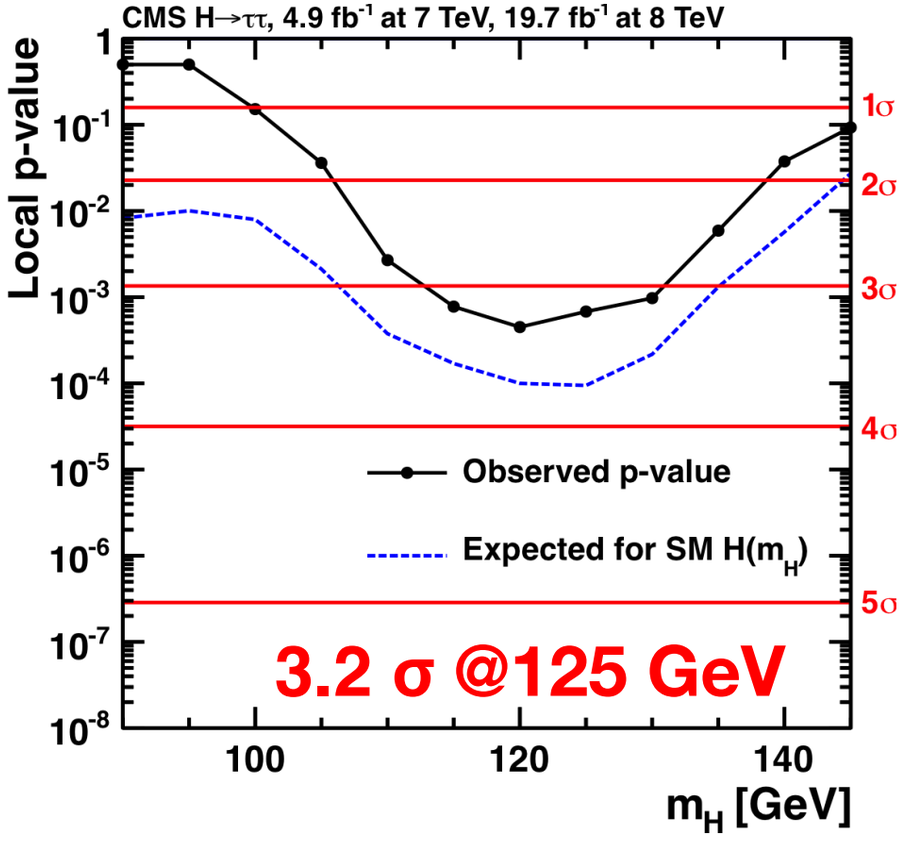
Likelihood based di-tau mass reconstruction

Simultaneous fit of mττ in all categories



Categorize events to exploit production mechanisms:

- VBF (Exploit VBF production signature)
  - Further divided to Loose & Tight categories
- 1 Jet or boosted (Suppression of Z+jet bkgs)
  - Further divided using τ p_T and Higgs p_T
- 0 Jet (Control region to constrain nuisances)

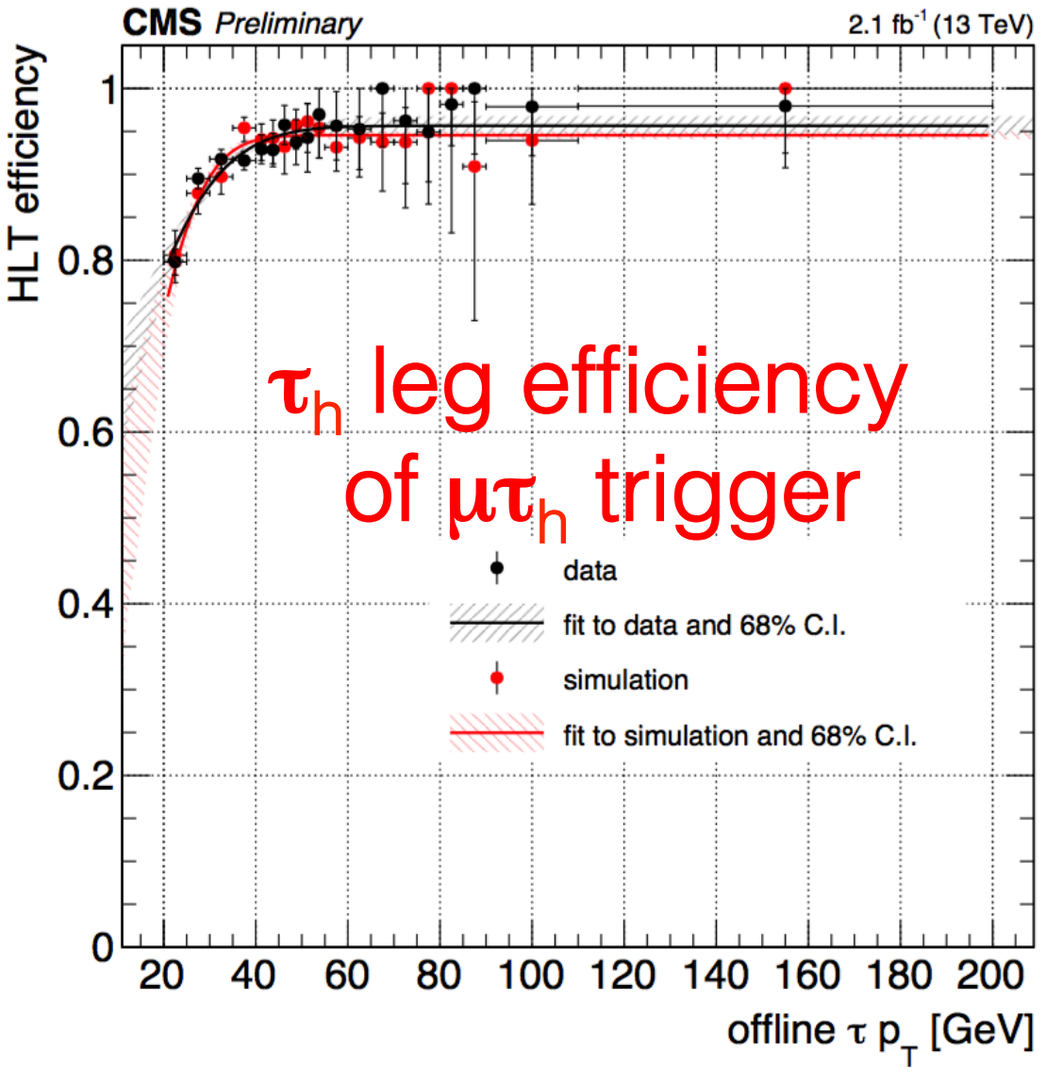


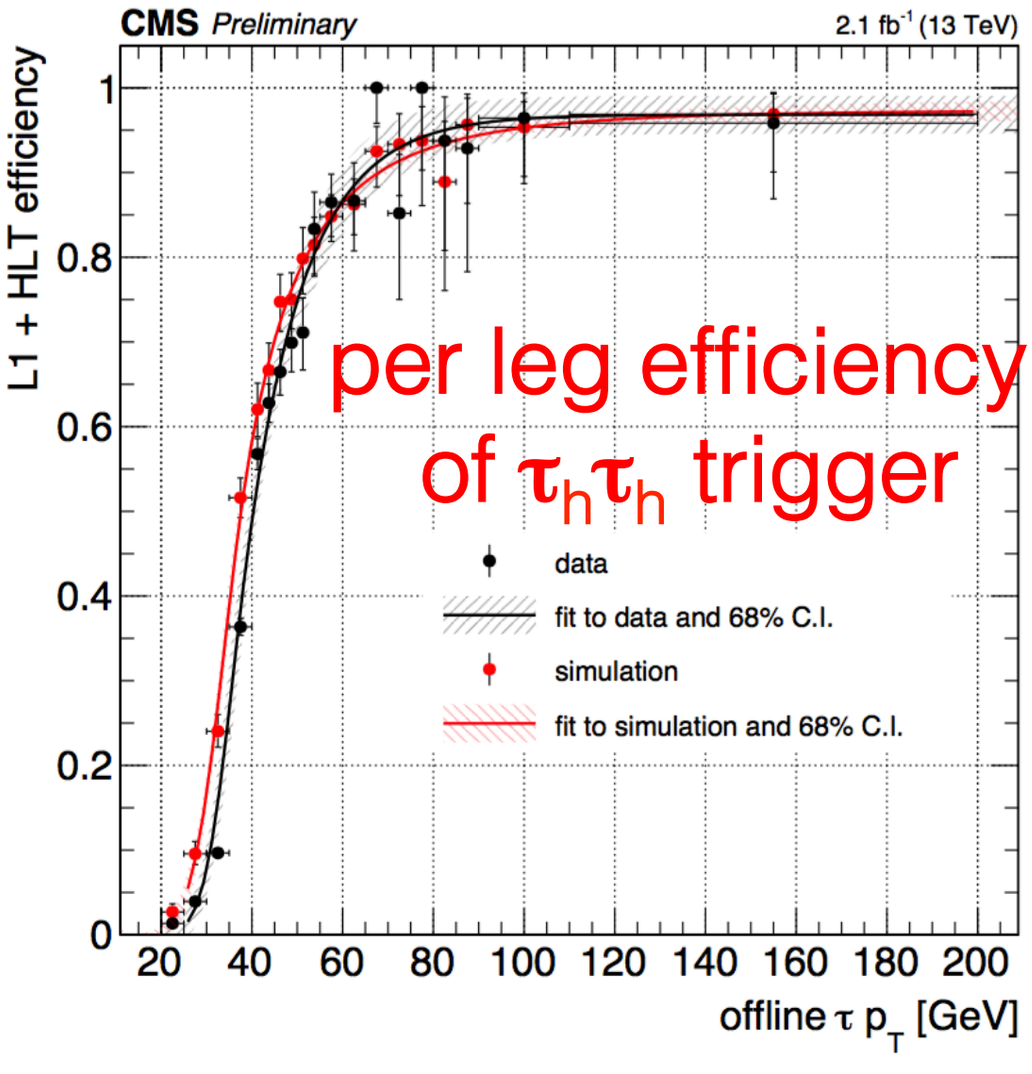
Preparation towards13 TeV

CMS-DP-2016/037

Level-1 Tau trigger was re-designed for Run-2
and, thanks to this, we are able to keep di-tau
trigger thresholds at ~30 to 35 GeV

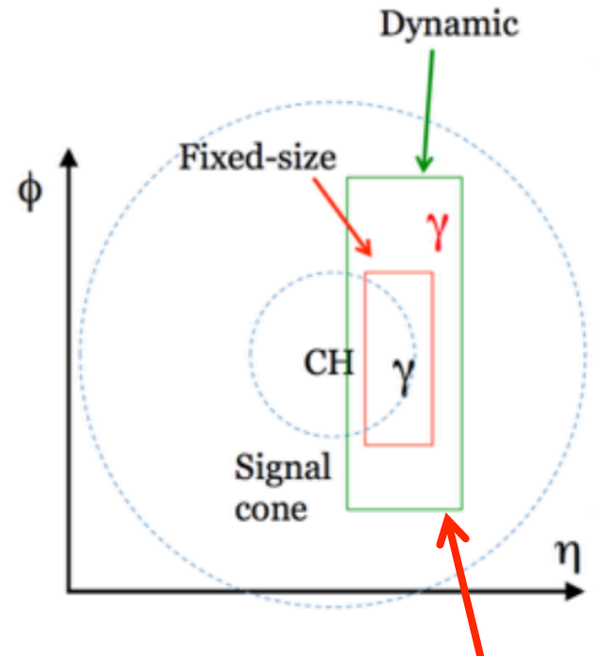
Higgs → ττ triggers performing quite well…





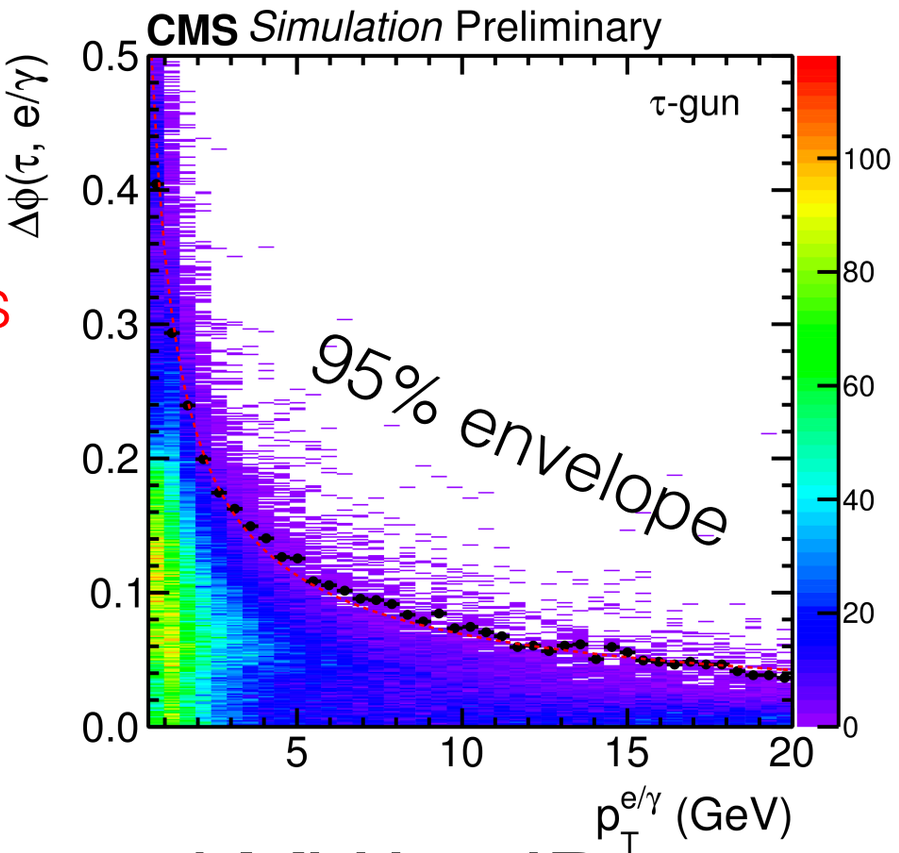
τ-Identification in 13 TeV

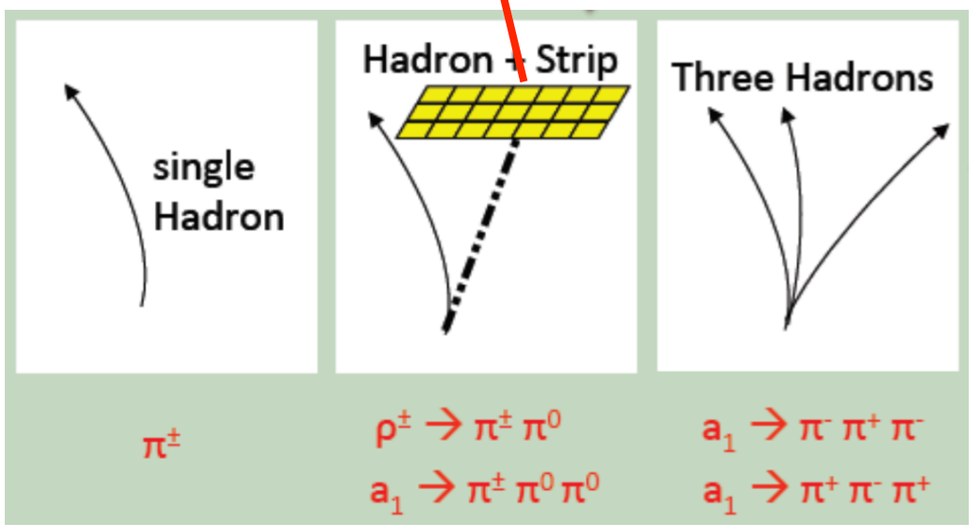
CMS-PAS-TAU-16-002



New for Run-II:

- Dynamic reconstruction of strips size to reconstruct π^0s from e/γ candidates
- size of the strip depends on the e/γ p_T
- Re-optimization of cuts and Δβ (pileup) correction



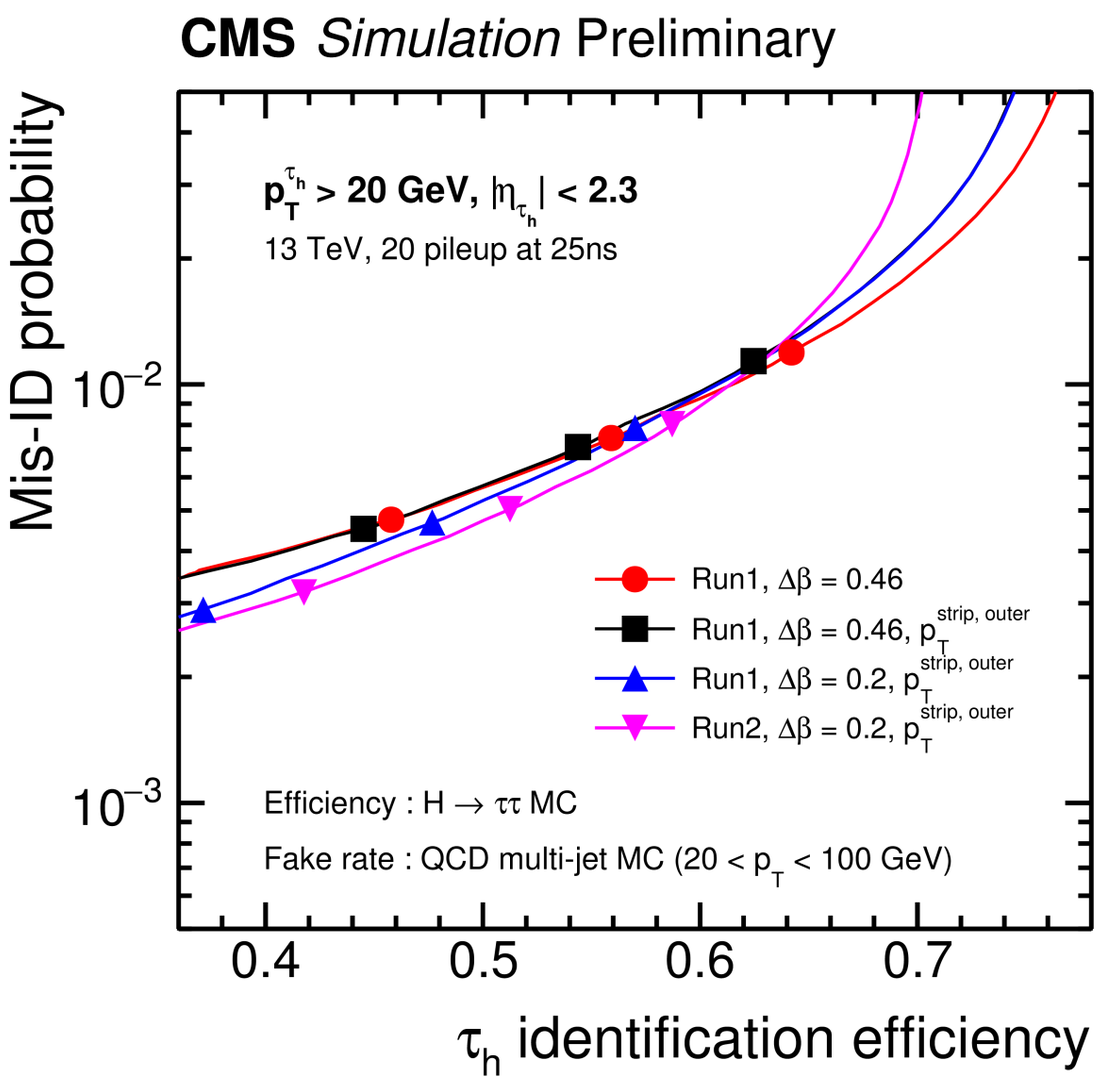


Improved MVA τ-ID:

- New lifetime variables in the MVA training: **signed 3D IP and it's significance**
- New PF photon variables within signal and isolation cones
- Re-training of BDT with 13 TeV MC sample

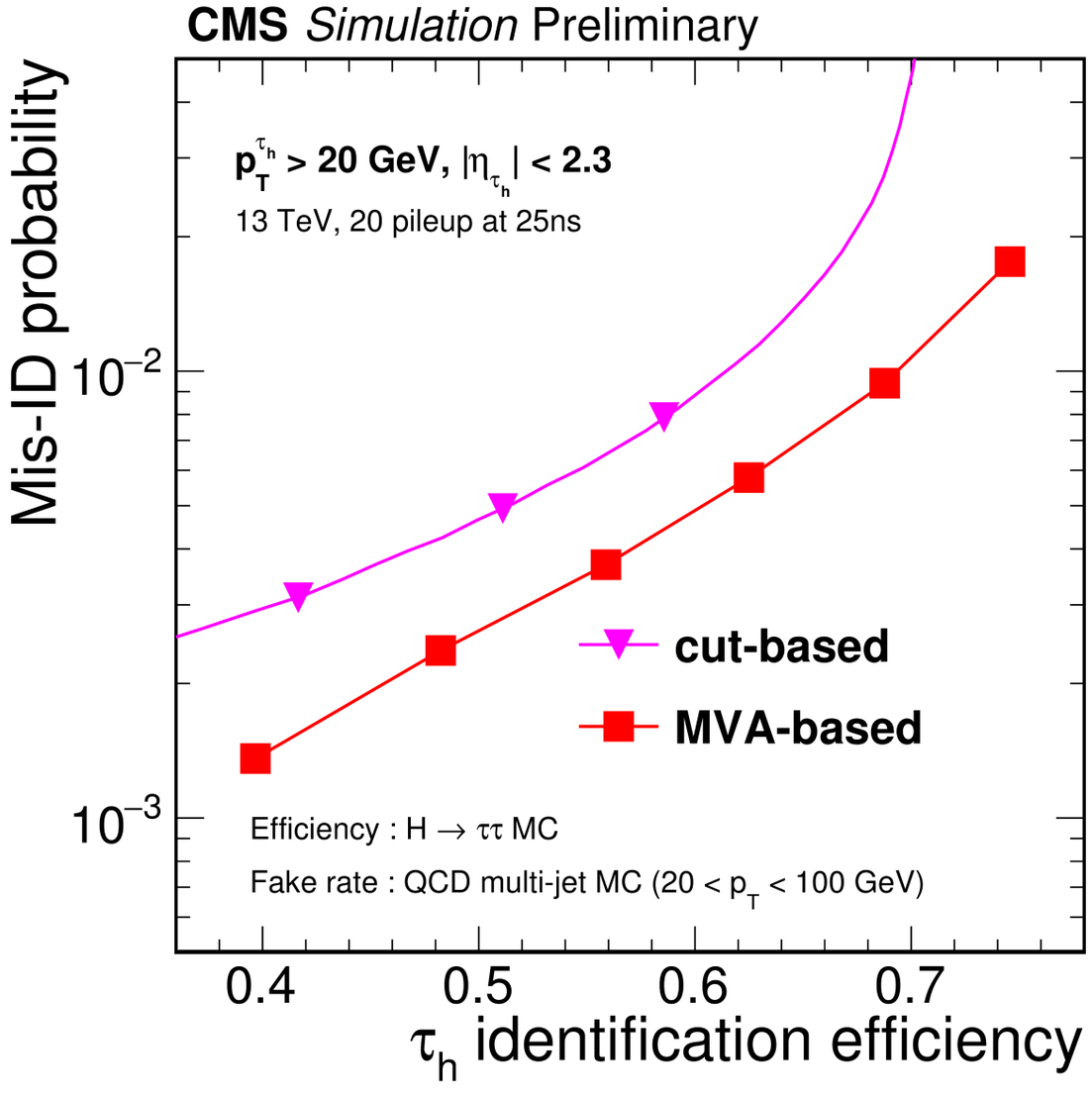
τ-ID Performance

CMS-PAS-TAU-16-002



Dynamic strip algorithm with cut-based isolation

Improved performance compared to run-1



Dynamic strip algorithm with MVA isolation

Factor of ~2 reduction in fakes compared to cut-based

τ-ID commissioning with 13 TeV data

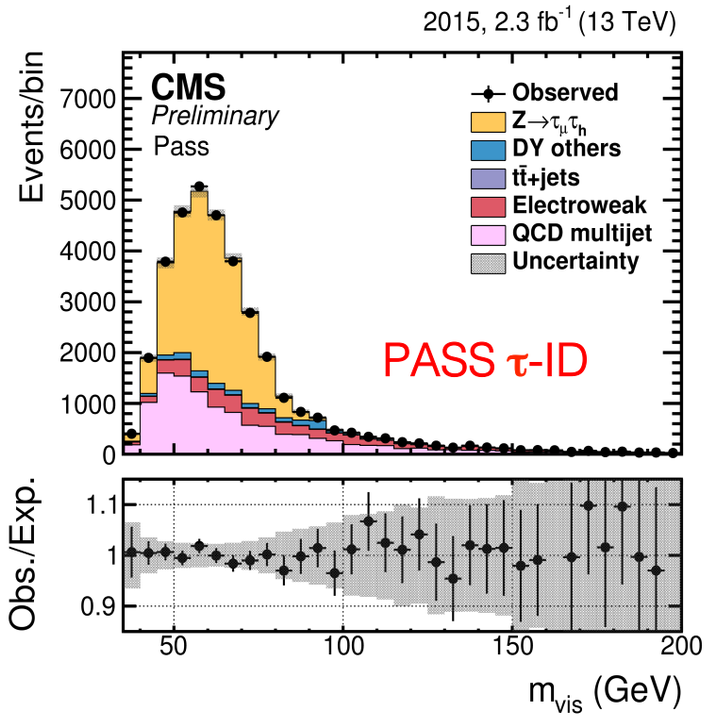
CMS-PAS-TAU-16-002, CMS DP-2016/040

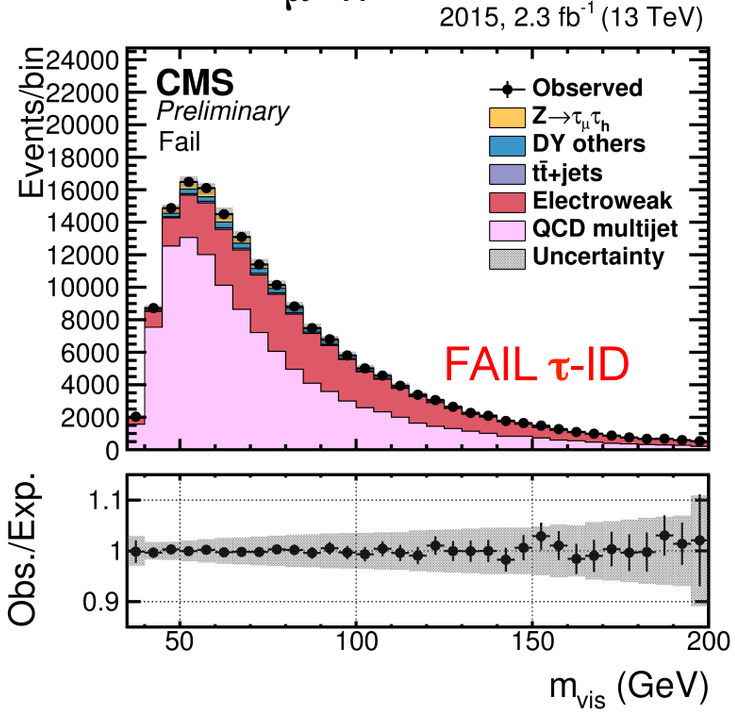
- Tau ID efficiency measured from $Z \rightarrow \tau\tau \rightarrow \tau_\mu\tau_h$ events using a **Tag** (μ) & **Probe** (τ_h) method.

  Data/MC SF consistent with 1

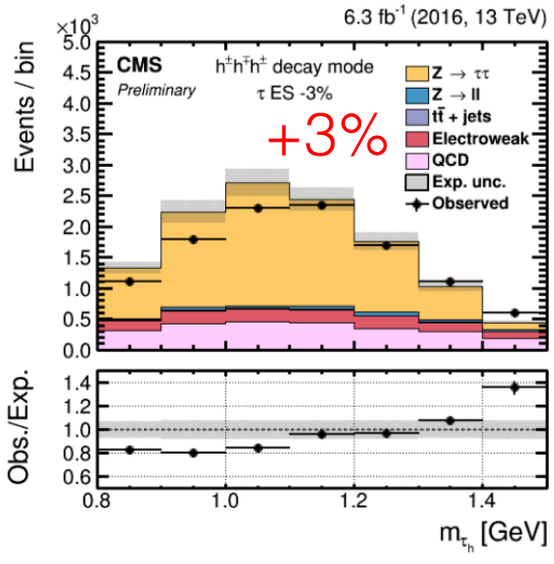
- $e \rightarrow \tau_h$ & $\mu \rightarrow \tau_h$ fake rate measured from $Z \rightarrow ee$ & $Z \rightarrow \mu\mu$ events, respectively
- Jet $\rightarrow \tau_h$ fakes measured from $W(\mu\nu)$+jets events

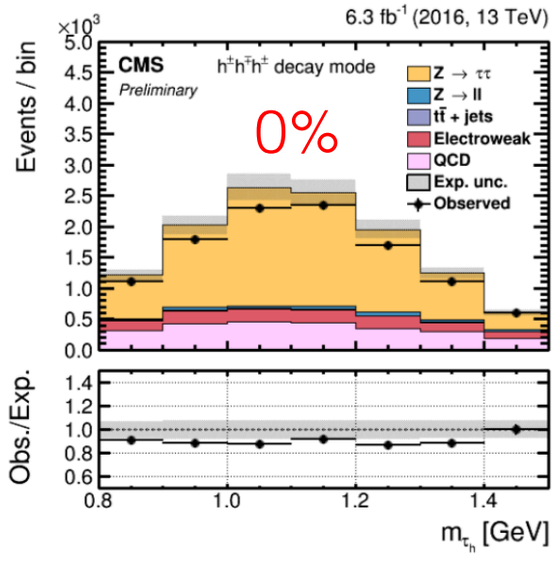
Visible mass of $\tau_\mu\tau_h$

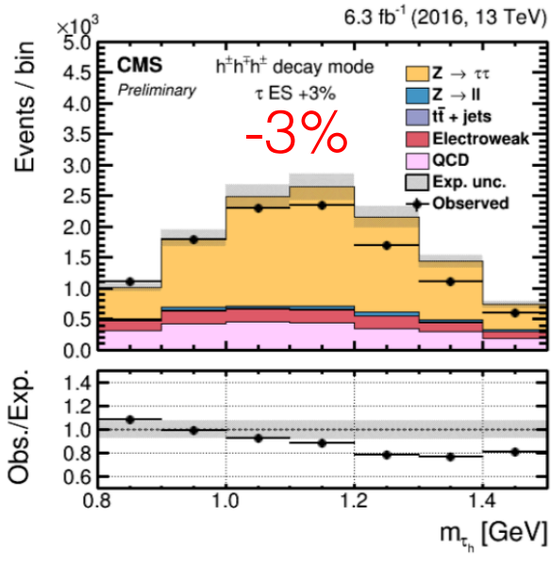




τ_h energy scale measured by fitting $m_{vis}(\mu\tau_h)$ and $m_{vis}(\tau_h)$ distributions







Decay mode	Tau energy scale [%]
1-prong	+0.0 ± 1.1
1-prongπ^0	+1.0 ± 0.4
3-prong	-0.1 ± 0.2

Summary

- LHC has delivered so far close to 30 fb^{-1} of data at 13 TeV (2015+2016)

- Study of Higgs coupling to fermions well on track:

  - Improved object identification techniques (b-tagging, τ_h-ID....), already commissioned using 2015/2016 data

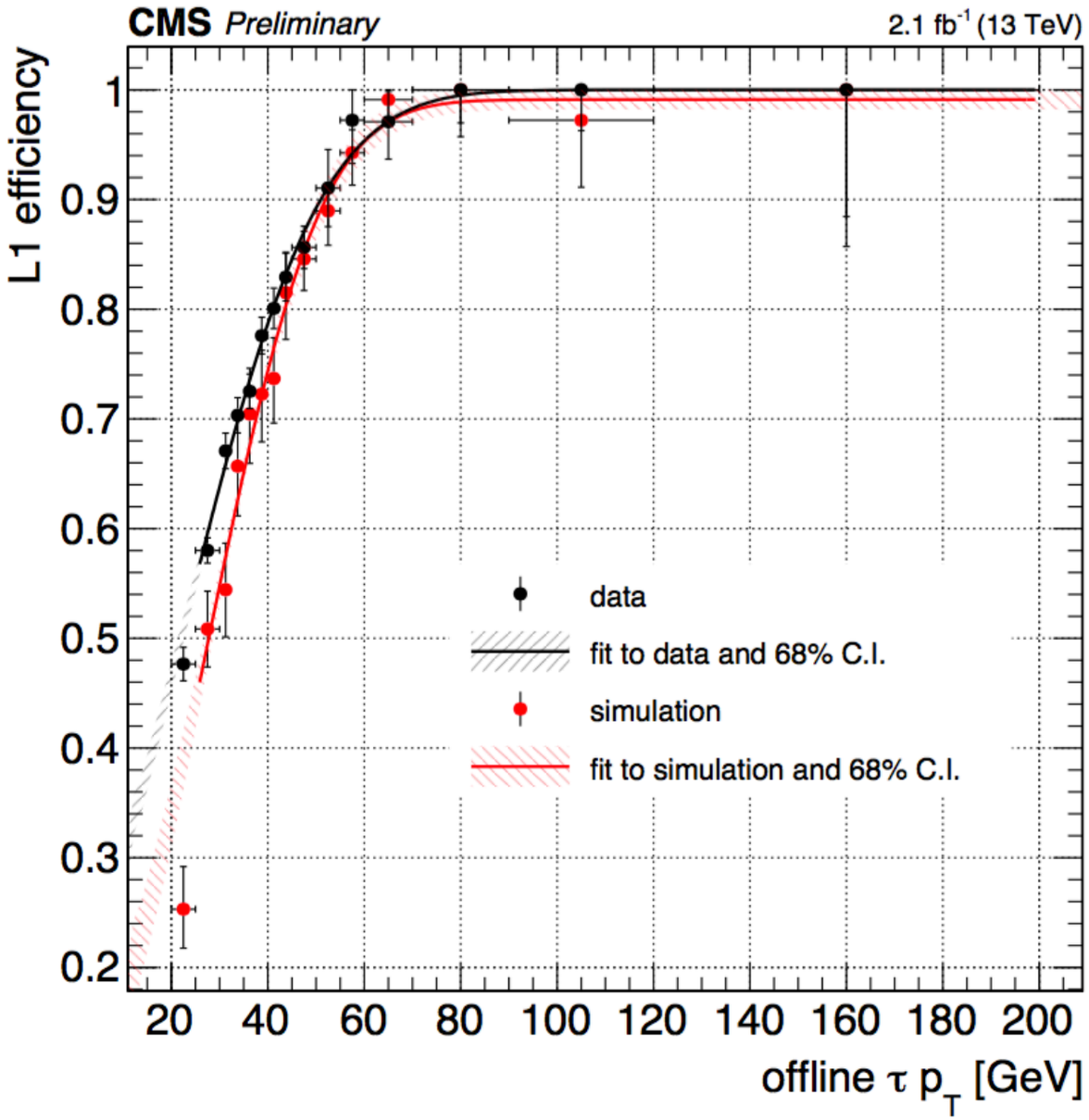
  - Searches for VBF H→bb, ttH, H→bb performed using 2015 data with new/improved analysis methods

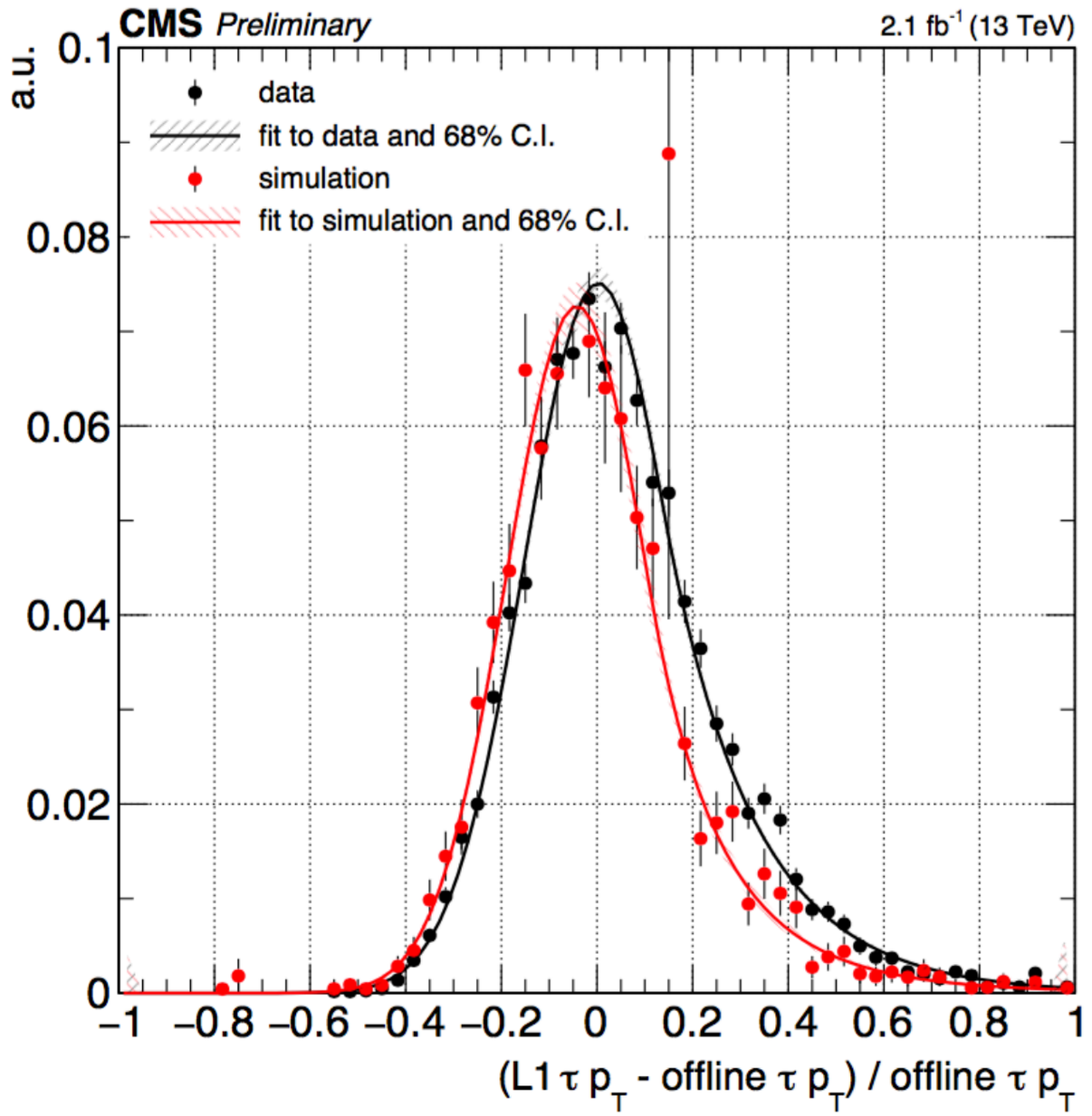
  - Sensitivity of tH, H→bb is already similar to run-1 results with only 2.3 fb^{-1} of 2015 data

  - Analysis ongoing for all fermionic channels with 2016 data: Expected to have much better precision than run-1 by end of the year

BACKUP

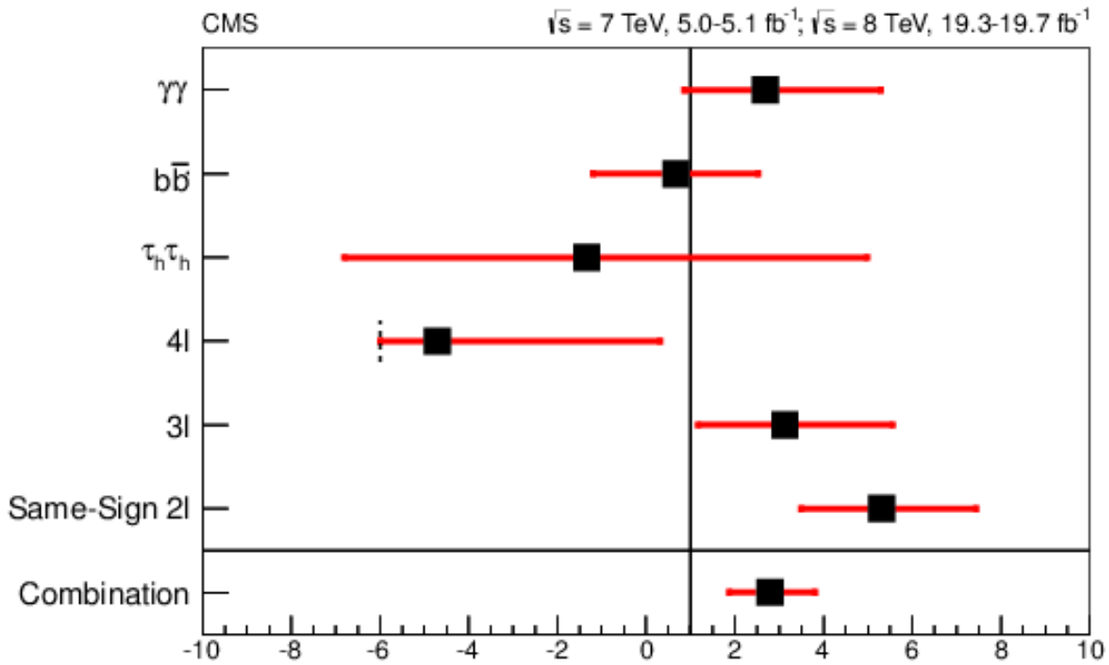
Level-1 τ_h trigger Performance



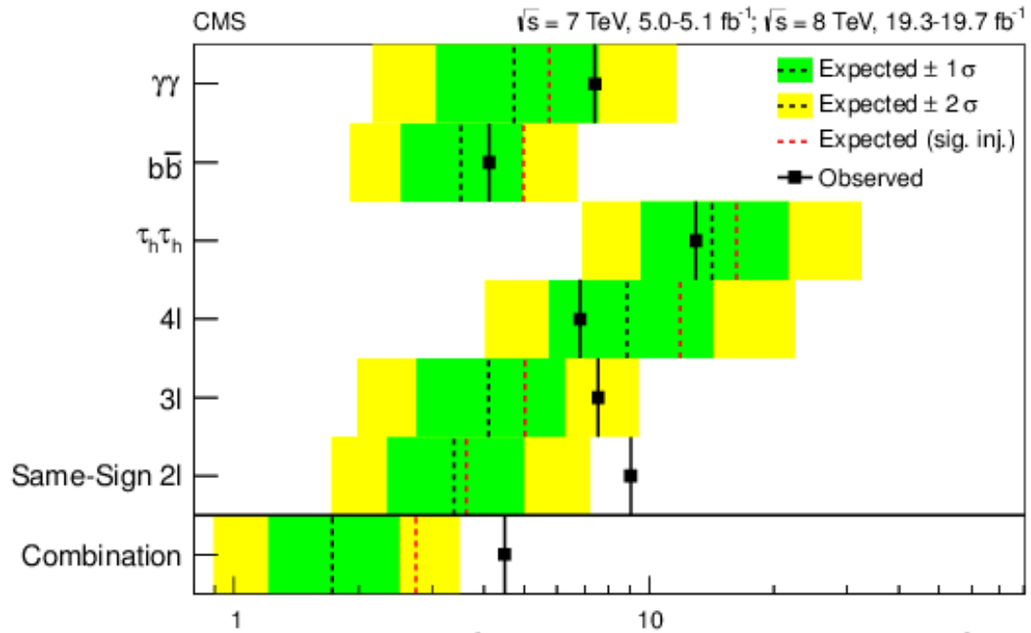


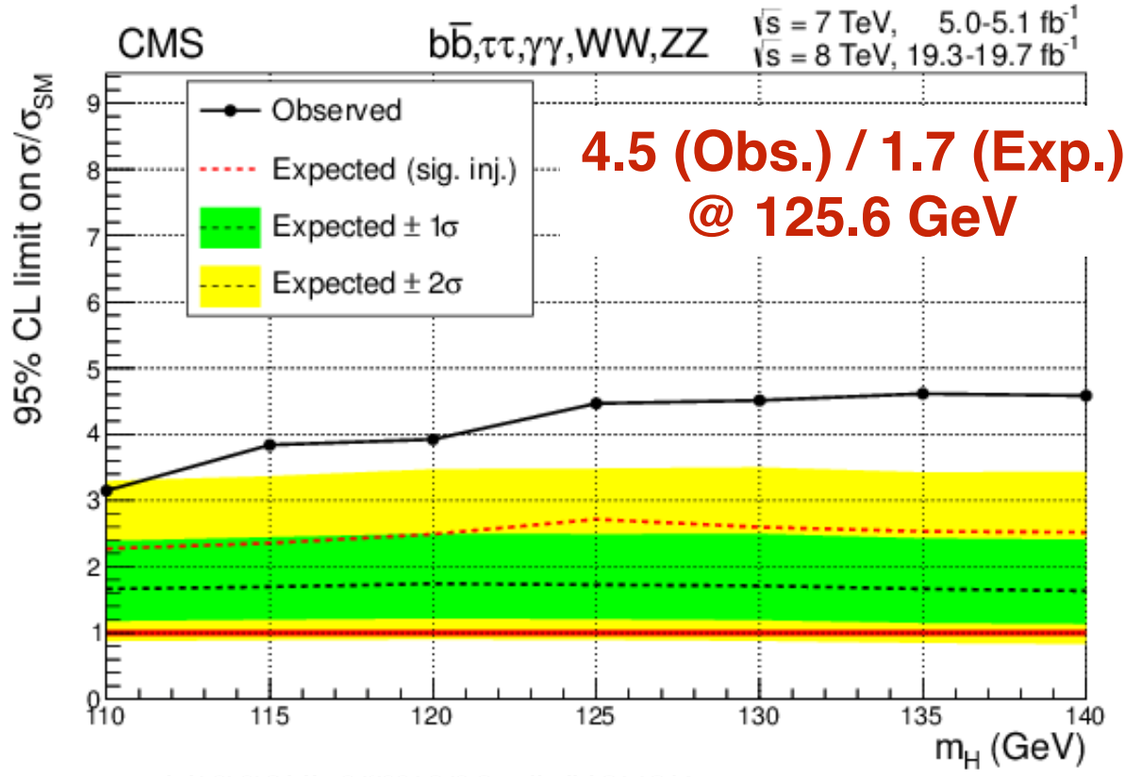
ttH (run-1)

CMS-HIG-13-029



95% CL upper limit on σ/σ_{sm}



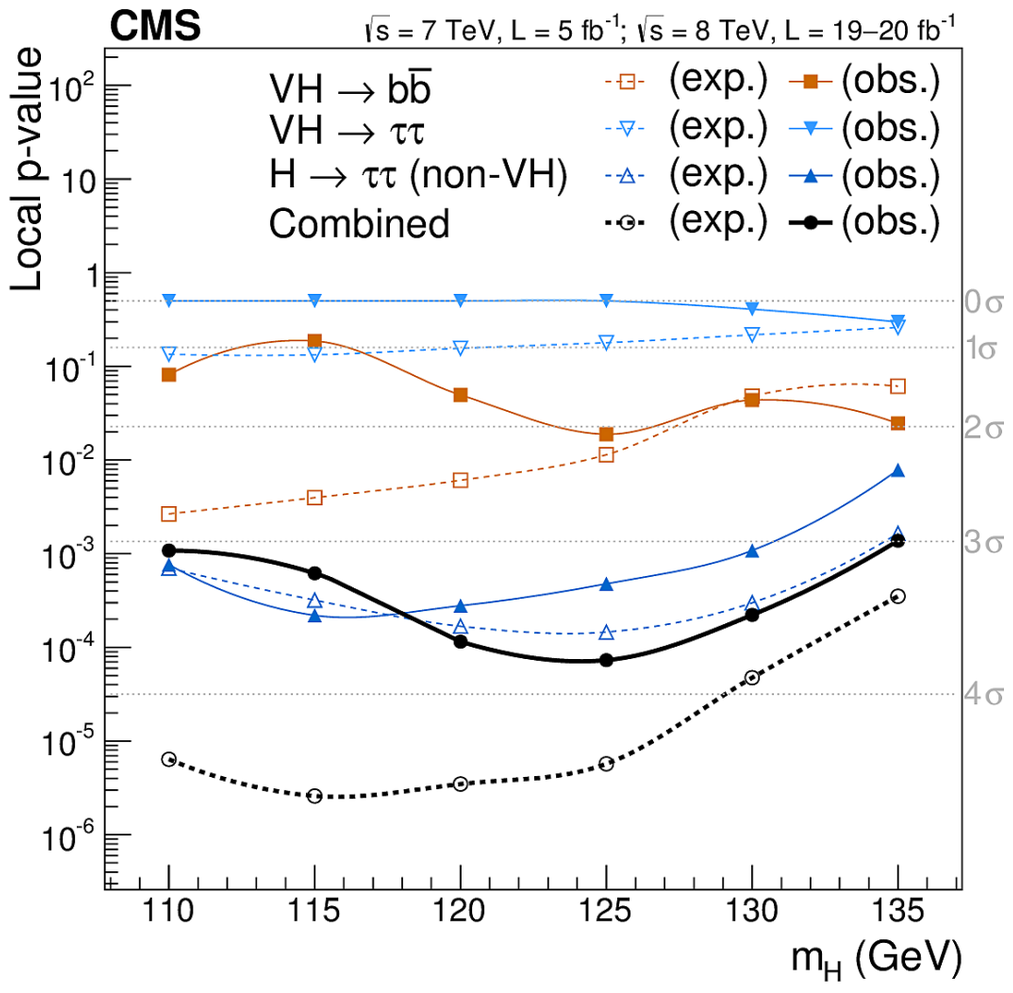


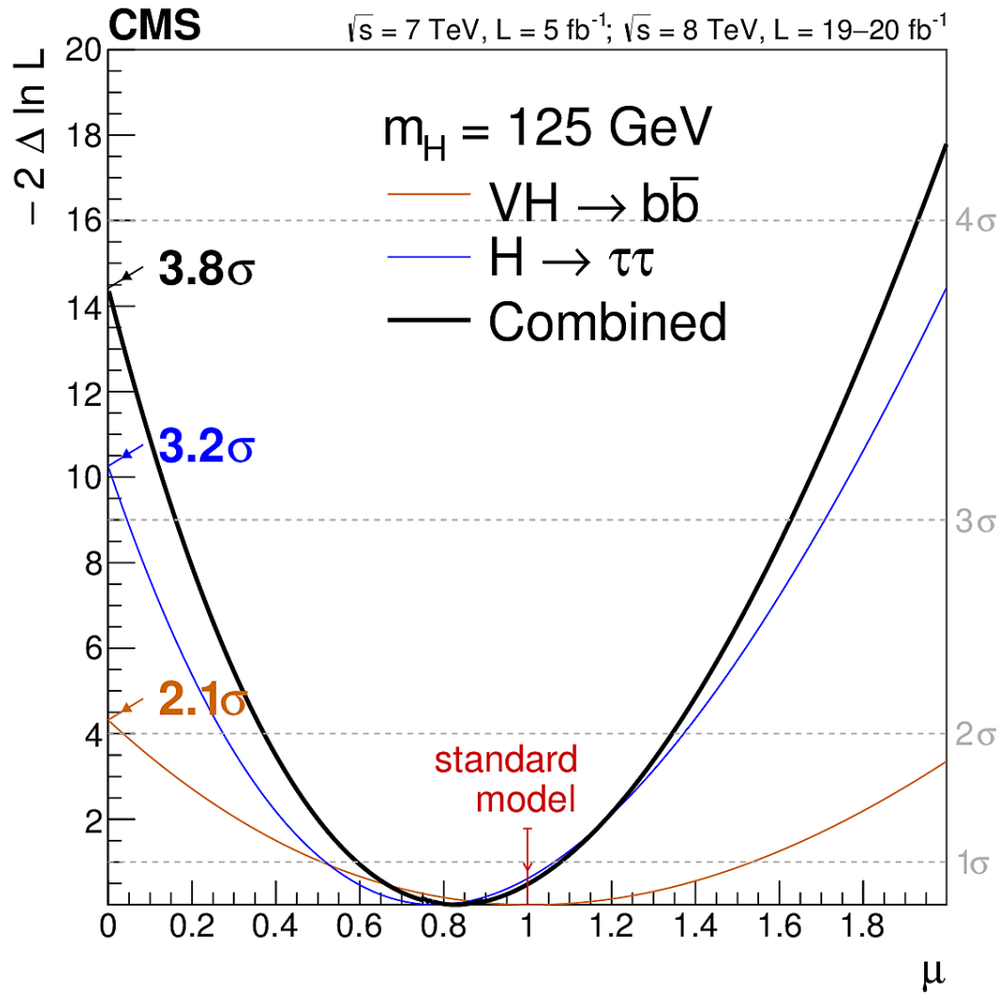
4.5 (Obs.) / 1.7 (Exp.) @ 125.6 GeV

H → fermions (run-1)

CMS: *Nature Phys.* 10 (2014) 557-560

Channel ($m_H = 125\,GeV$)	Significance (σ)		Best-fit
	Expected	Observed	μ
$VH \to b\bar{b}$	2.3	2.1	1.0 ± 0.5
$H \to \tau\tau$	3.7	3.2	0.78 ± 0.27
Combined	4.4	3.8	0.83 ± 0.24





H → μμ & ee (run-1)

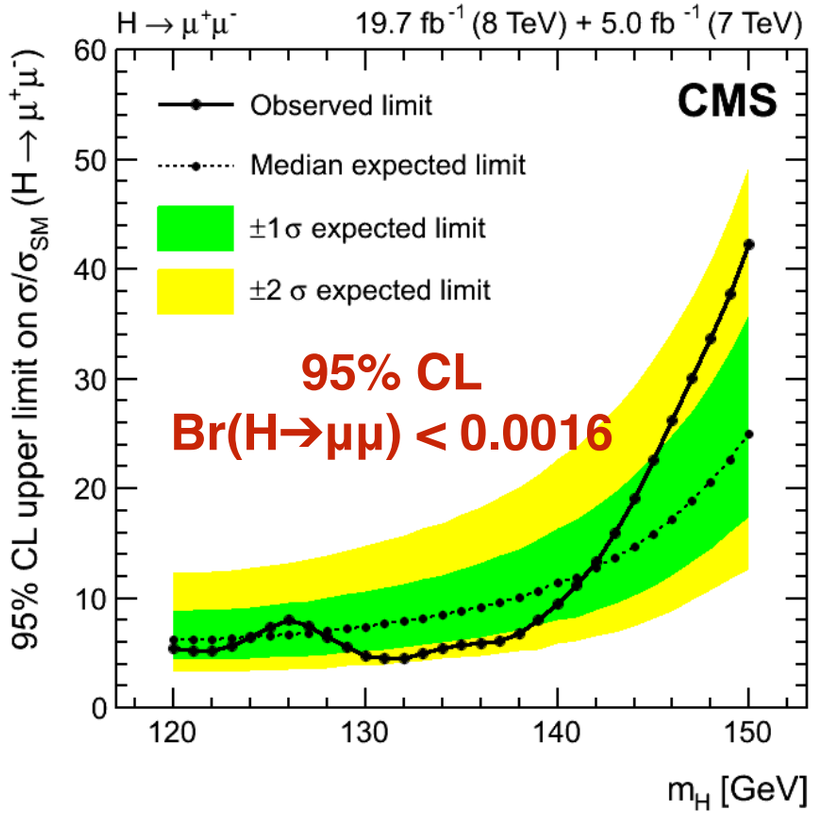
CMS:arXiv:1410.6679

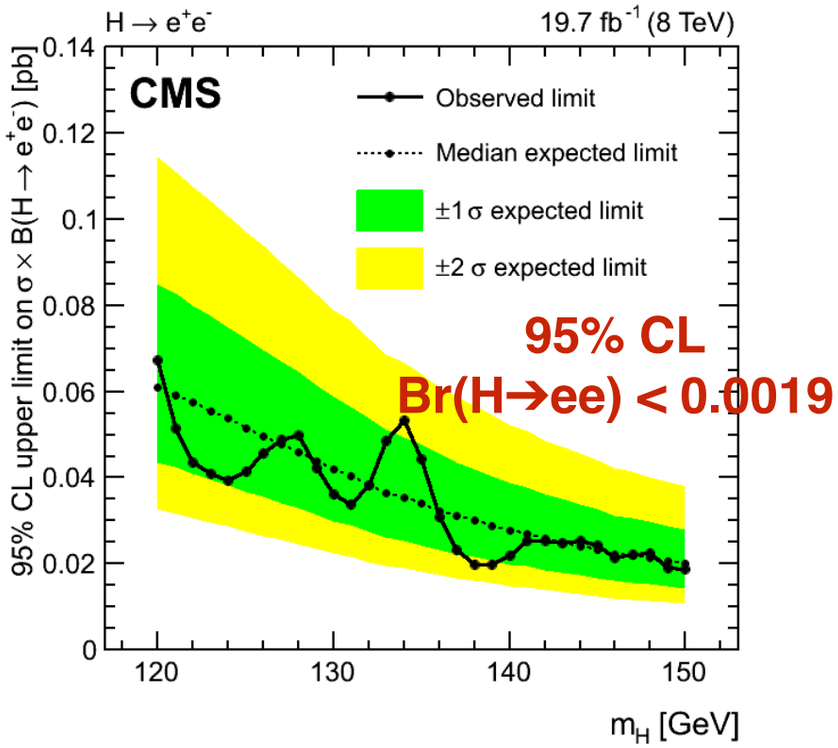
- Cleanest of the fermionic decays
- Br(H→μμ) in SM is among the smallest accessible at LHC (~10^{-4})
- Test of Yukawa coupling to second and third-generation fermions

Analysis Strategy

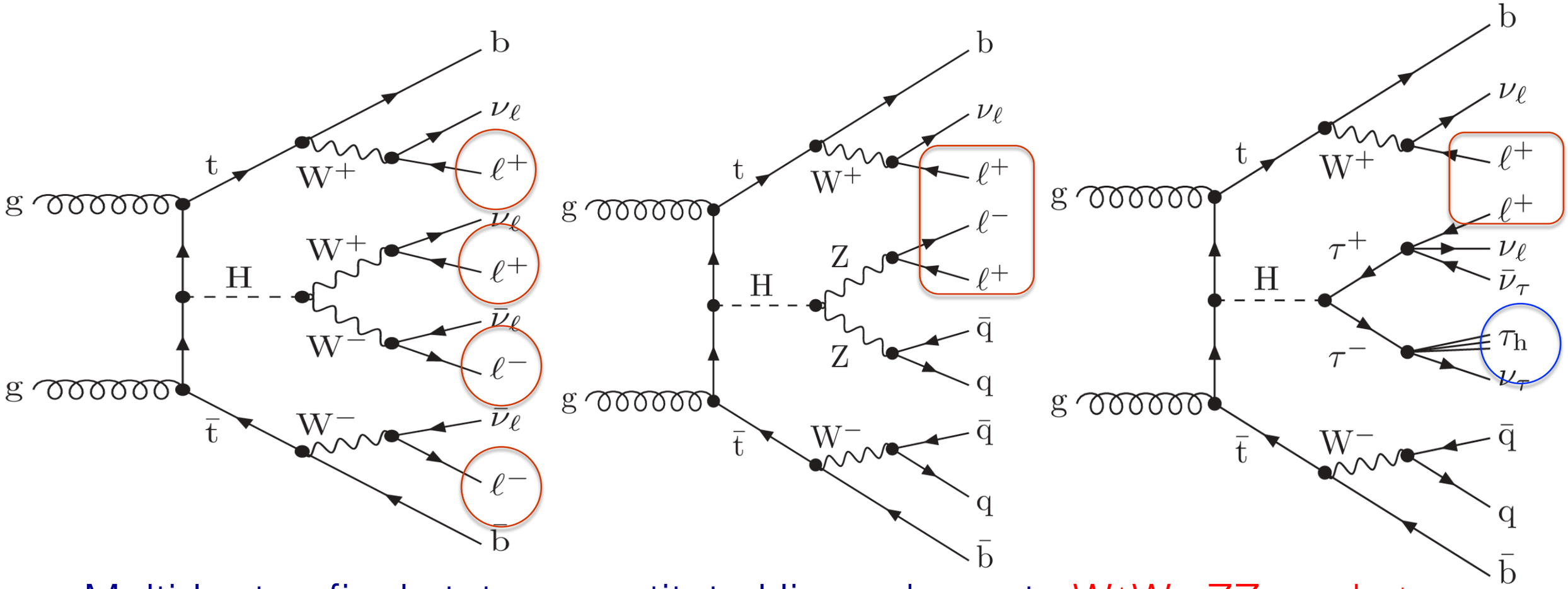
- Search for a peak in dilepton mass spectrum over smoothly falling backgrounds
  - Divide events into extensive categories
  - Extract signal by fitting M_{ll} distribution simultaneously in all categories

- No Excess, consistent with SM
  - Confirmation of "Higgs to lepton coupling is not flavor-universal"





ttH, H → multi-leptons



Multi-lepton final states constitute Higgs decay to W^+W^-, ZZ, and $\tau^+\tau^-$

Search performed in 2 channels:

- Two same-sign leptons (2Lss) + 4-jets
  - 4 sub-channels: ee, μμ, eμ, 2Lss+1τ_h
- ≥ 3 leptons (3L) + 2-jets

Additional kinematic selections: E_T^{miss} and Z-veto depending on channels

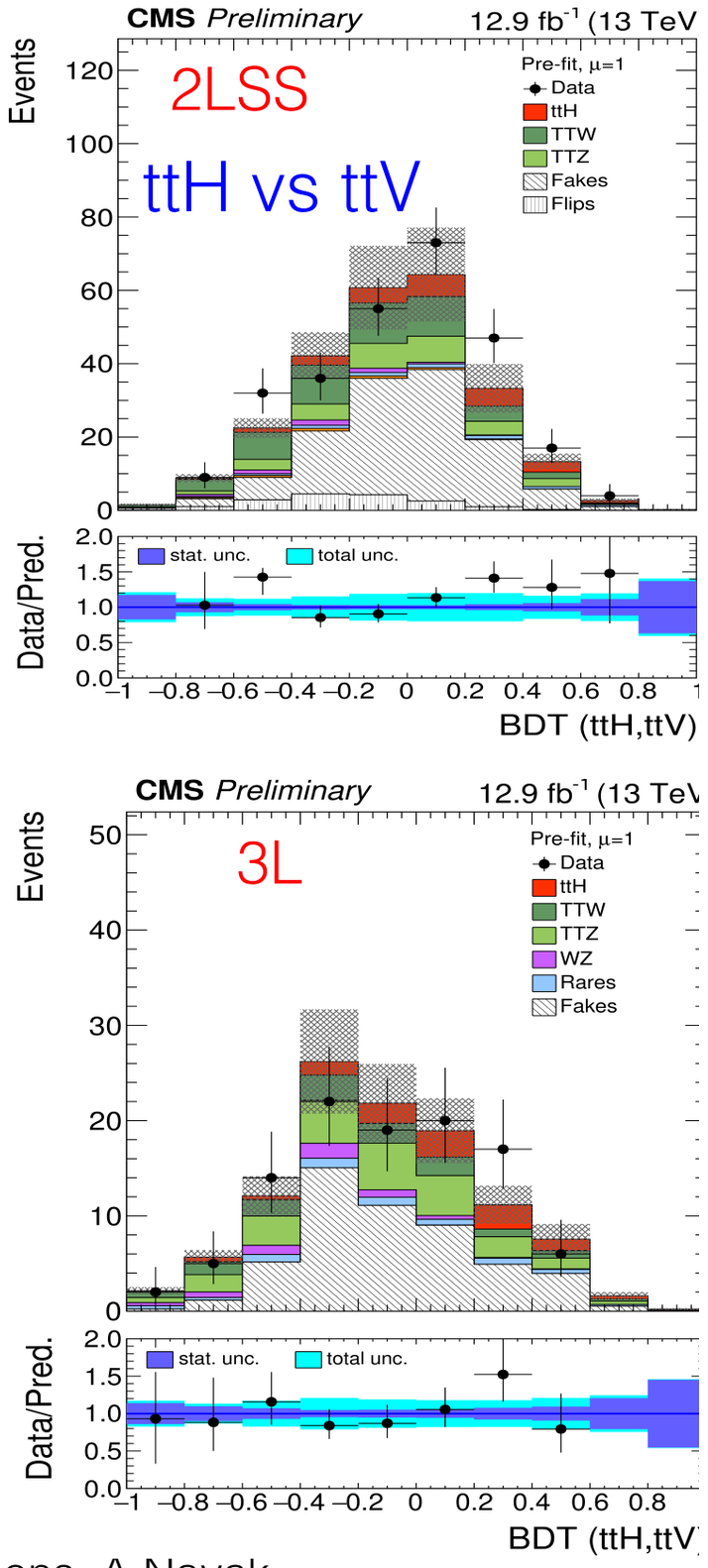
ttH, H → multi-leptons

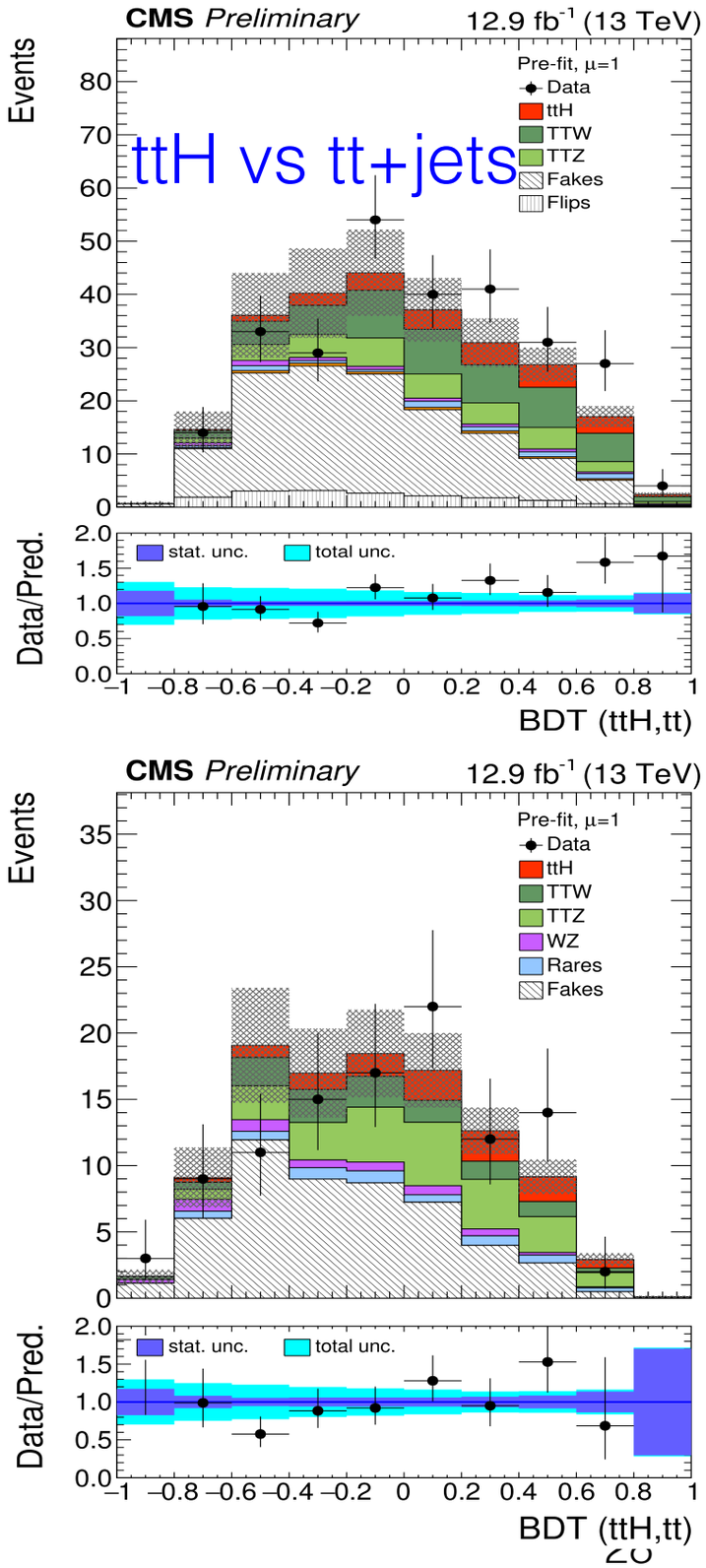
Major backgrounds:

ttV, di-boson (irreducible) and
tt+jets (non-prompt leptons)

Signal Extraction:

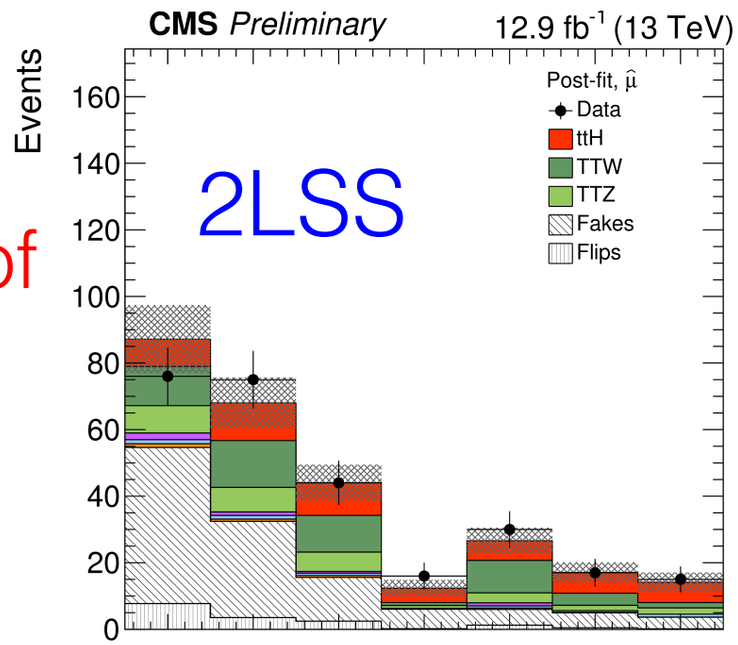
- MVA analysis: Separate BDTs for ttH vs ttV and ttH vs tt+jets
  - Matrix-Element weights as input to BDT in 3L category (new in 2016 analysis)
- Further division into sub-categories of 2Lss (w/o τ_h) and 3L events:
  - Based on b-Jets: 2 b-tagged medium ("b-tight") or 2 b-tagged loose ("b-loose")
  - Based on sum of lepton charges

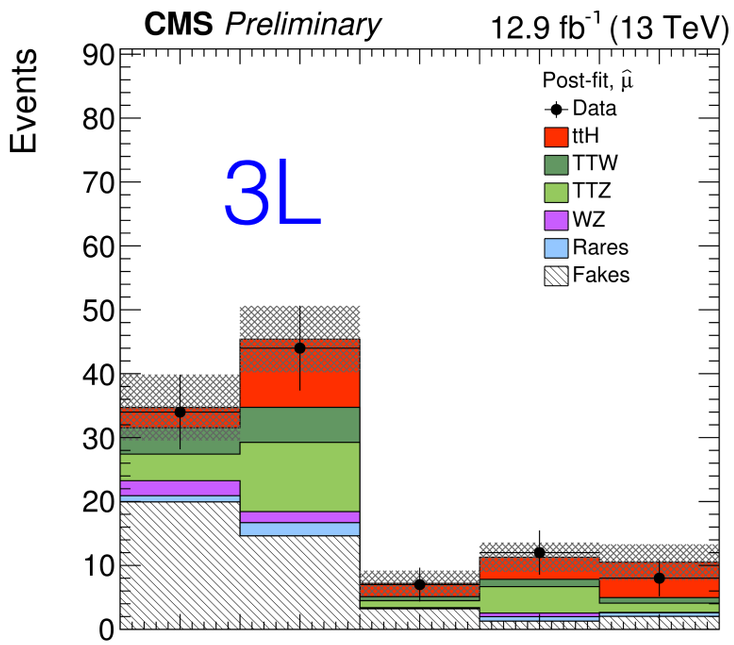




ttH, H → multi-leptons (Results)

Signal extracted by 2D fit of the BDT discriminants





Exclusion limits at 95% CL and signal strength with 2015+2016 data

Category	Obs. limit	Exp. limit $\pm 1\sigma$	Best fit μ $\pm 1\sigma$
Same-sign dileptons	4.6	$1.7^{+0.9}_{-0.5}$	$2.7^{+1.1}_{-1.0}$
Trileptons	3.7	$2.3^{+1.2}_{-0.7}$	$1.3^{+1.2}_{-1.0}$
Combined categories	3.9	$1.4^{+0.7}_{-0.4}$	$2.3^{+0.9}_{-0.8}$
Combined with 2015 data	3.4	$1.3^{+0.6}_{-0.4}$	$2.0^{+0.8}_{-0.7}$