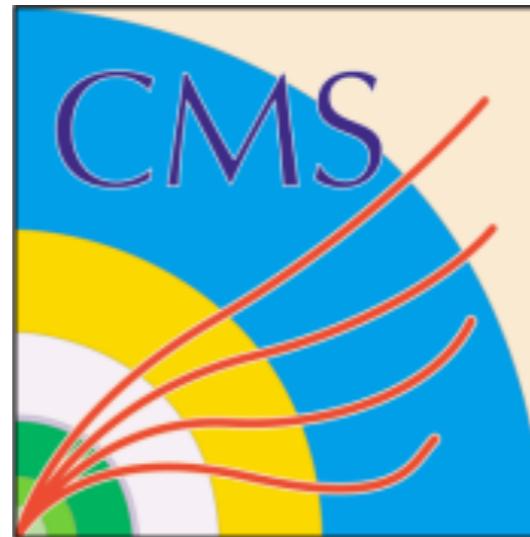


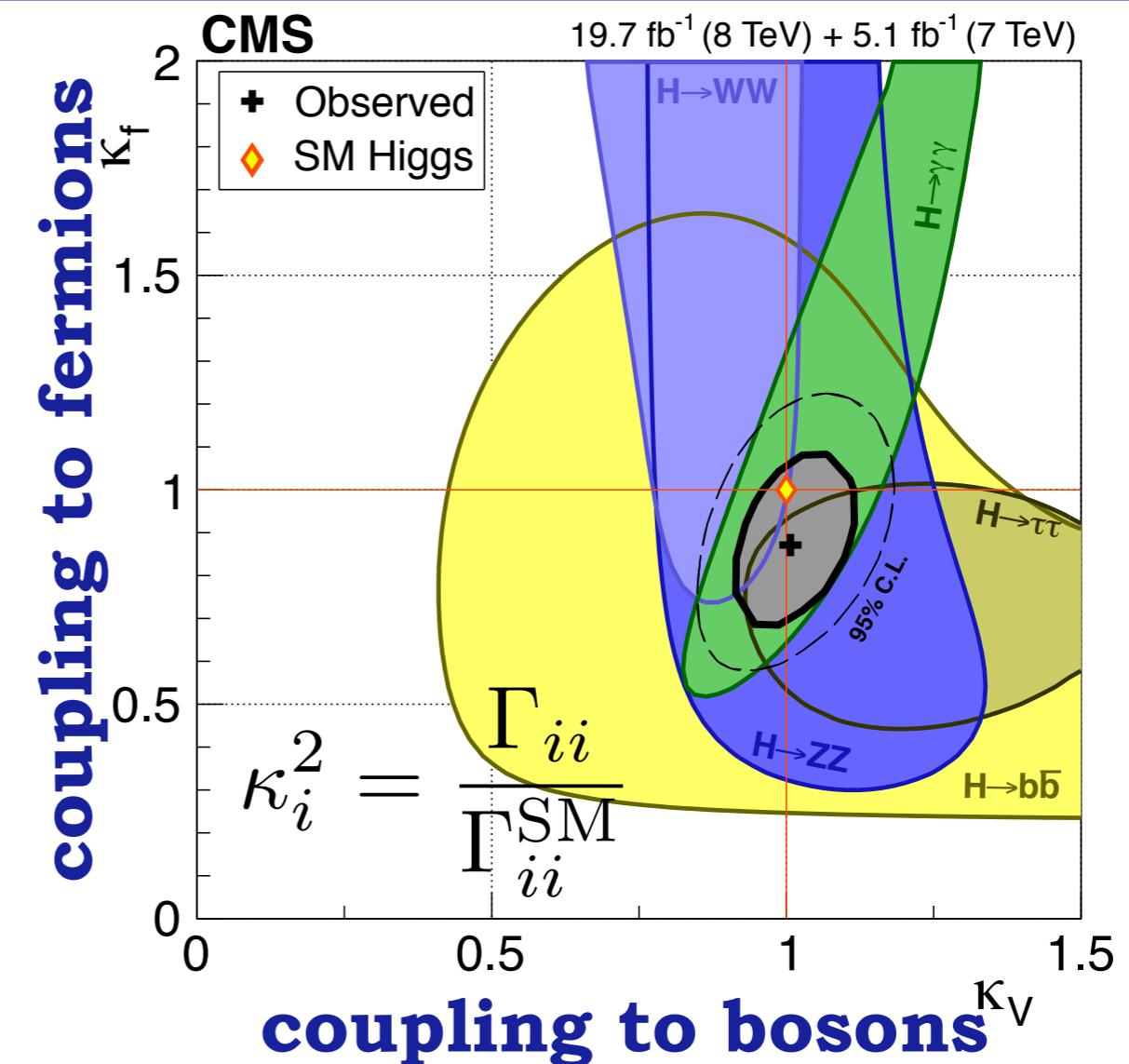
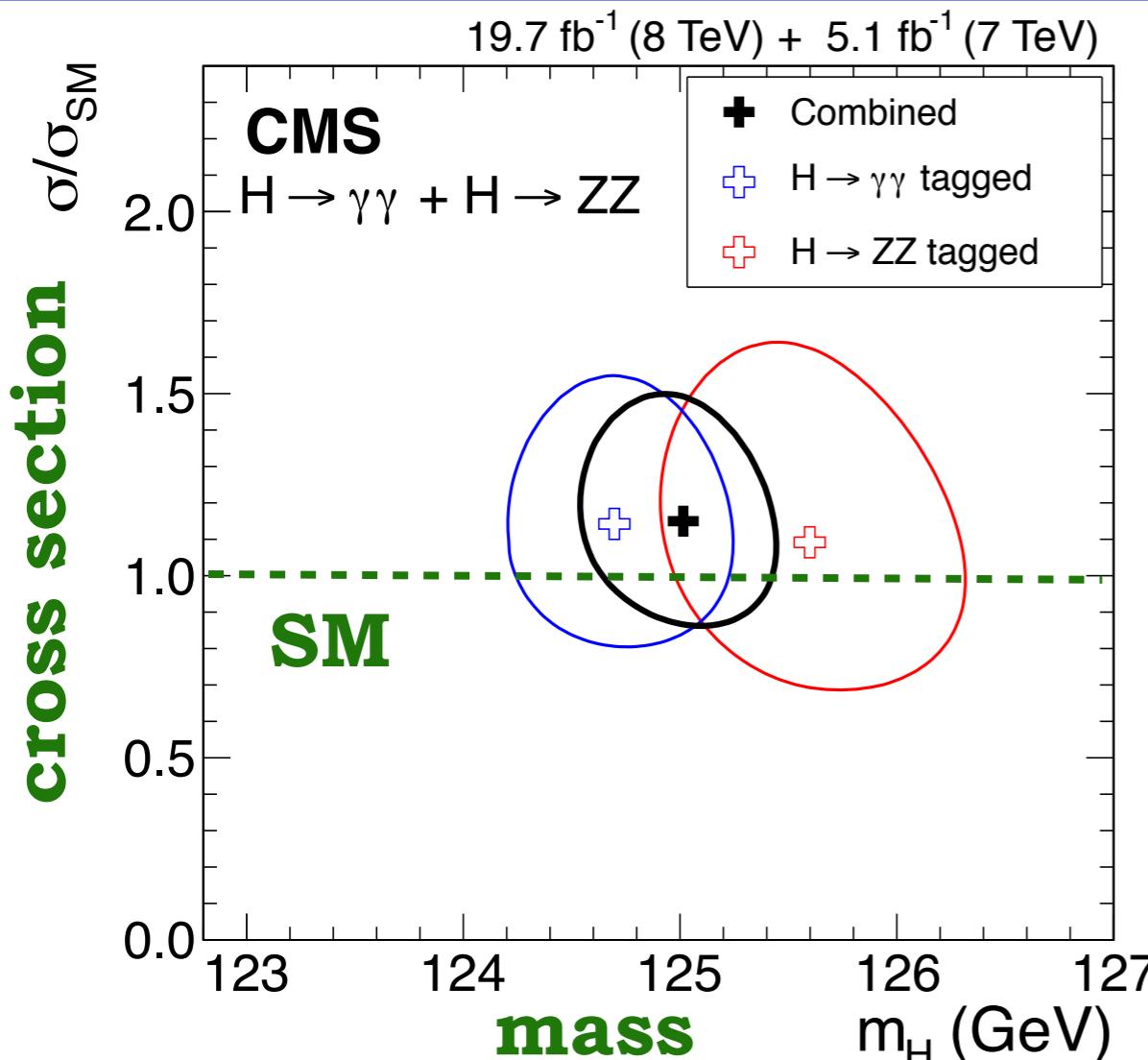
Search for the SM Higgs boson decaying to a bb pair with the CMS detector

Konstantinos Kousouris
CERN



*HEP 2015 - Conference on Recent
Developments in High Energy
Physics and Cosmology
Athens, Greece
15-18 April 2015*

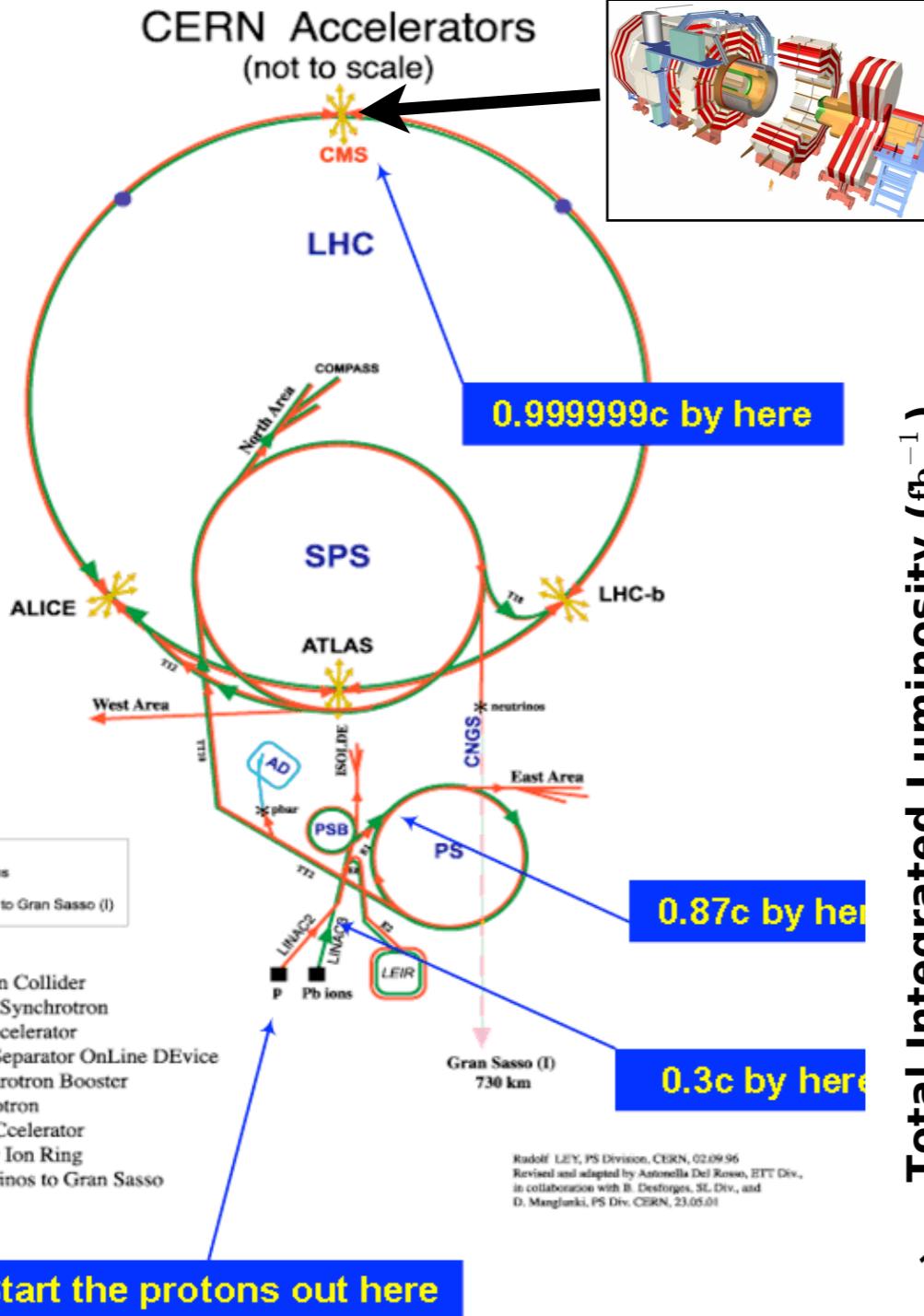
Motivation



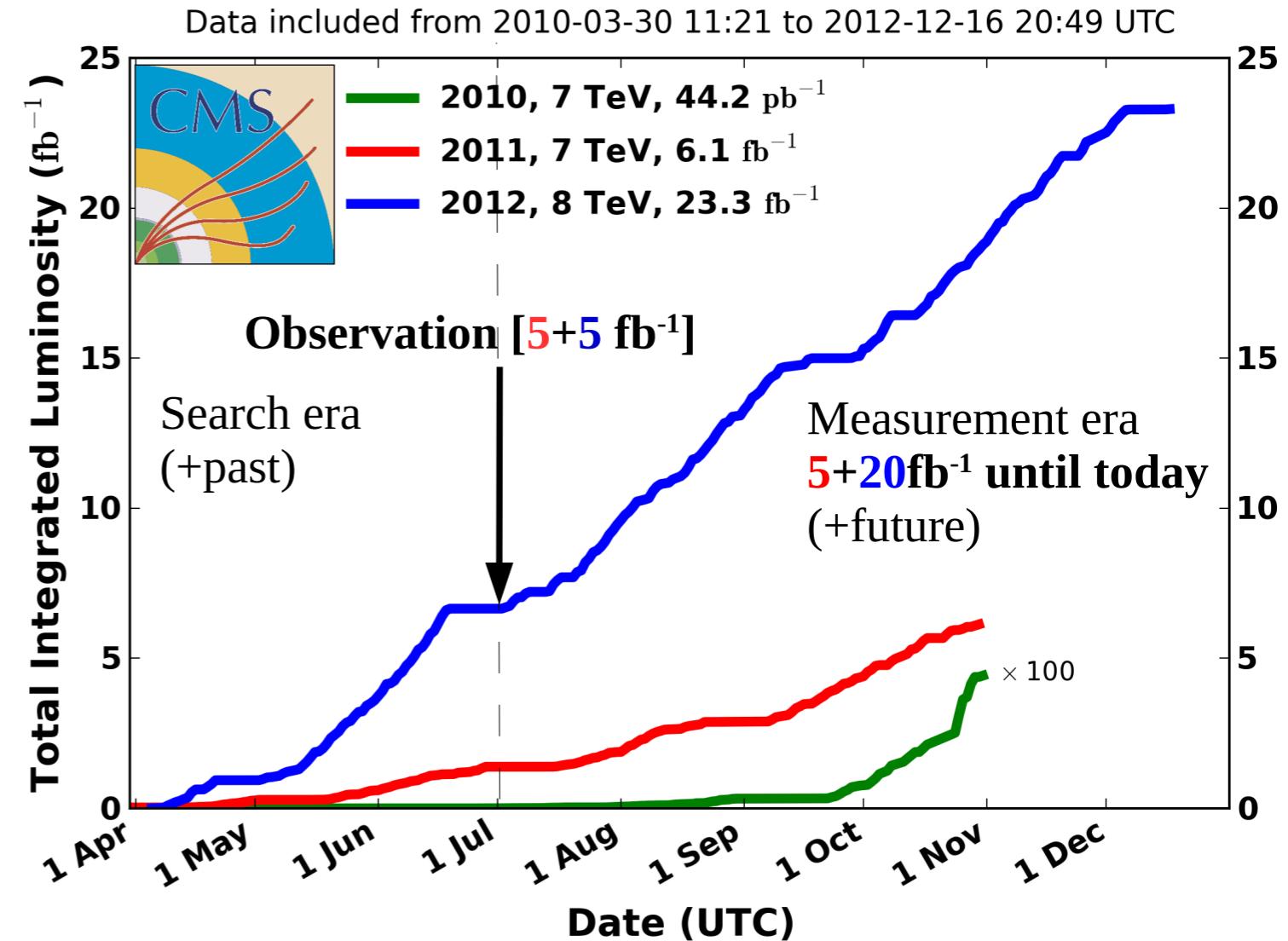
- ▶ **discovery of a SM-like Higgs boson**
 - observation in boson decay modes
- ▶ **but does it couple to fermions?**
 - not really needed for the fermions' mass
 - bosonic modes provide some indirect information
 - bb decay mode: measure directly the coupling to down-type quarks

Large Hadron Collider

CMS



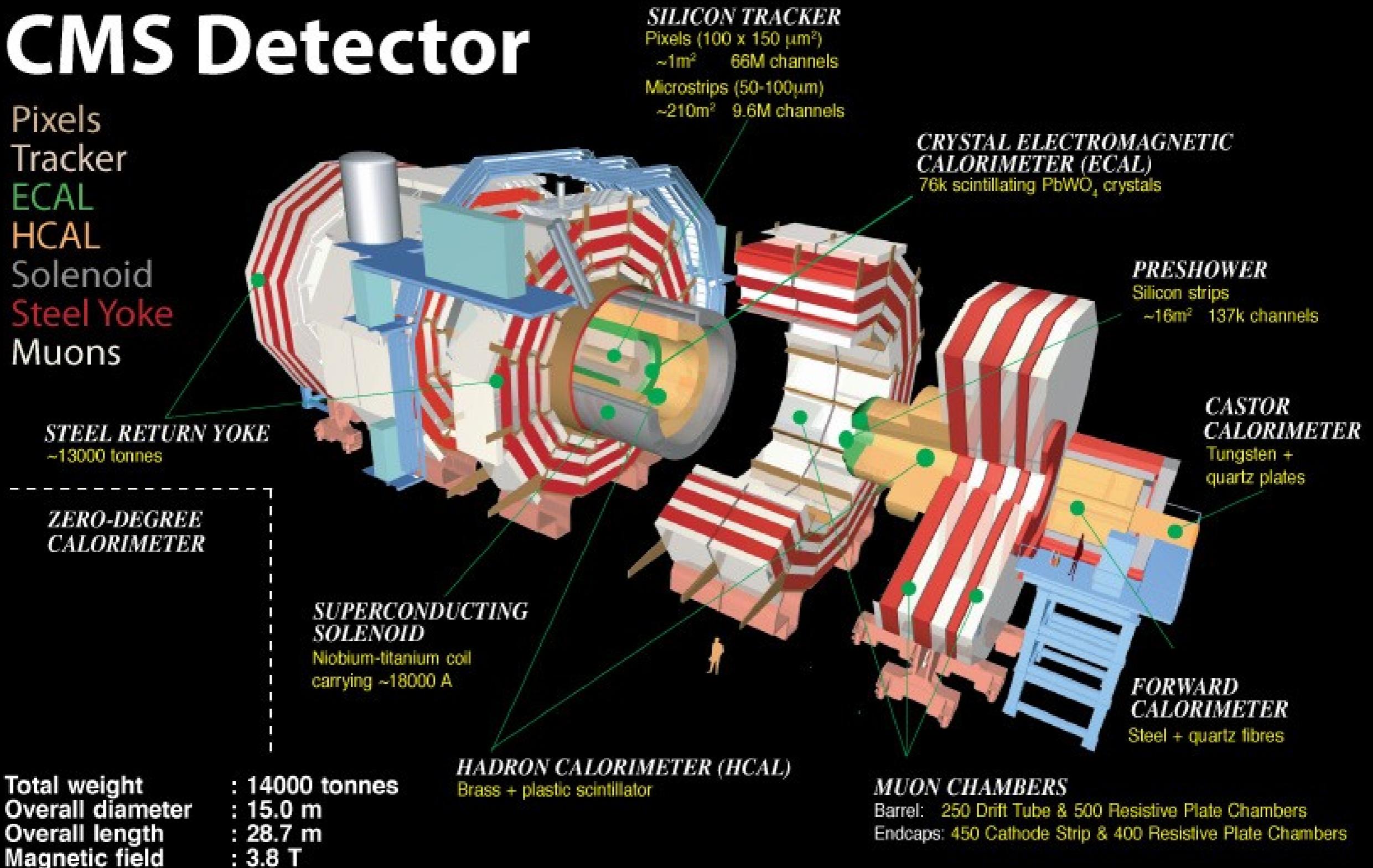
CMS Integrated Luminosity, pp



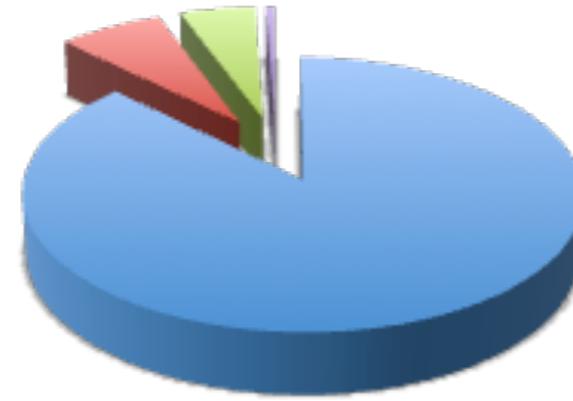
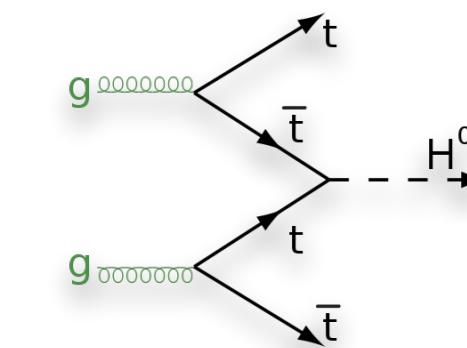
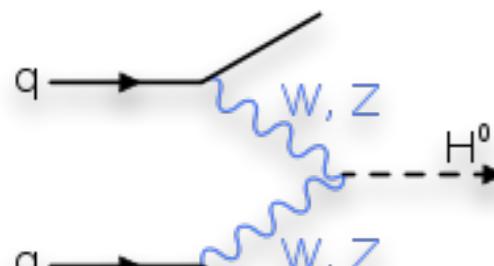
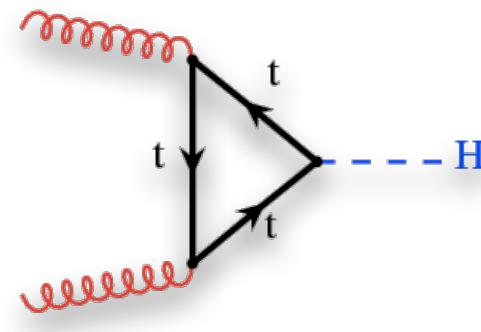
Compact Muon Solenoid

CMS Detector

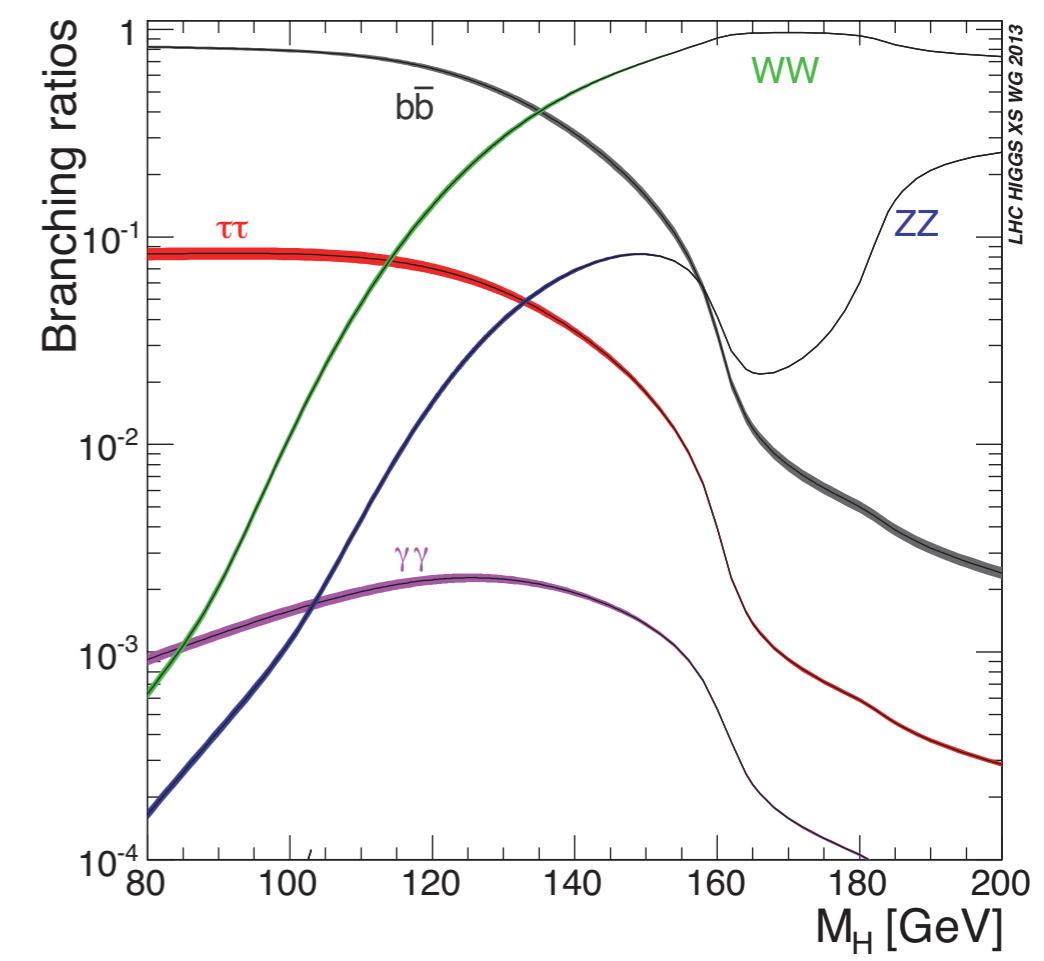
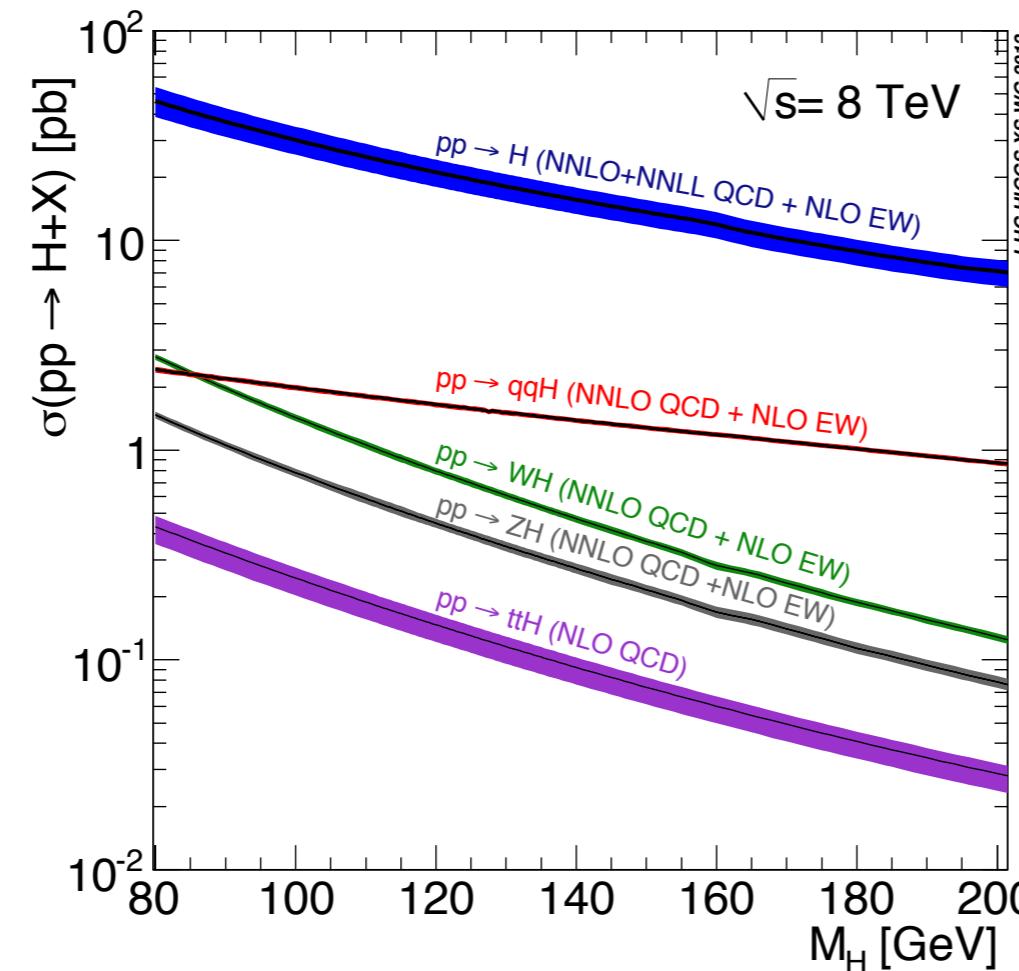
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



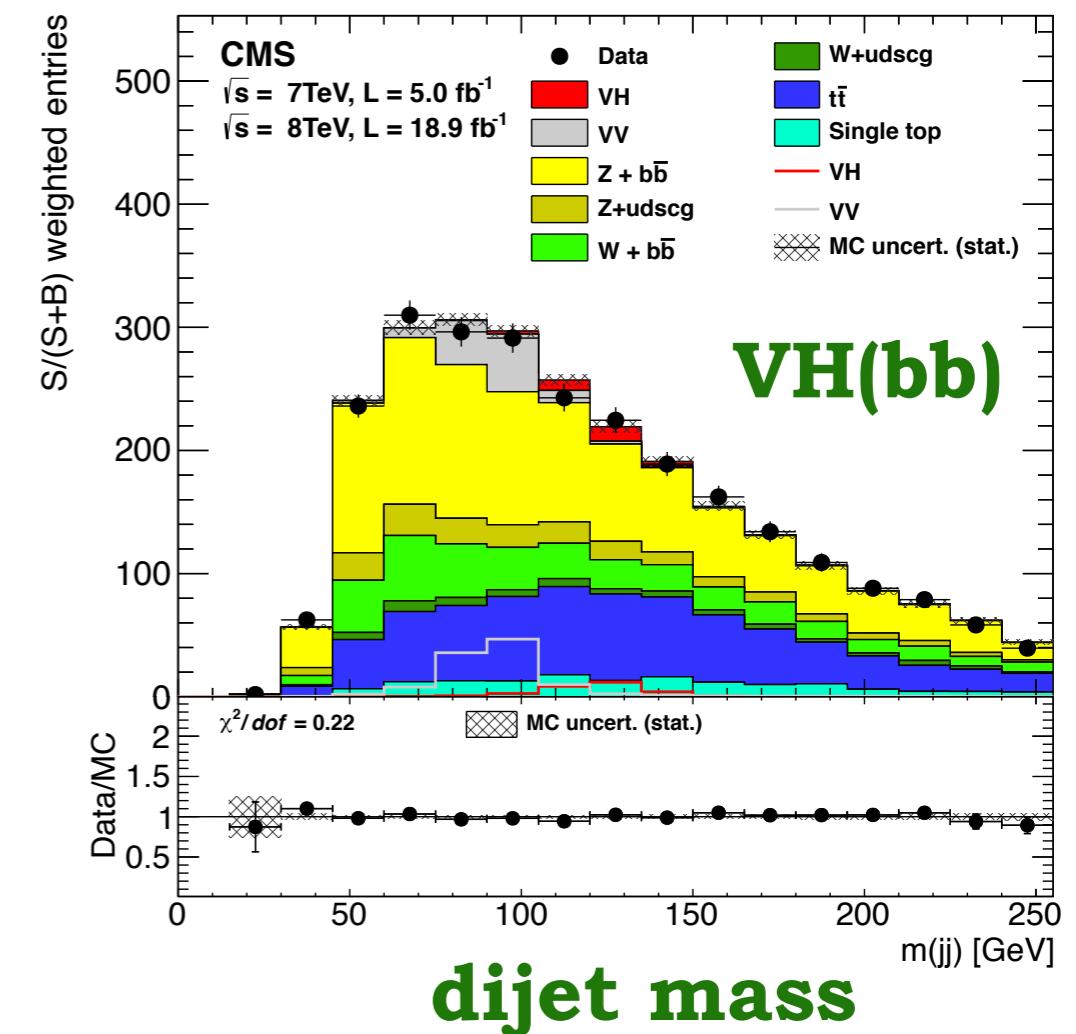
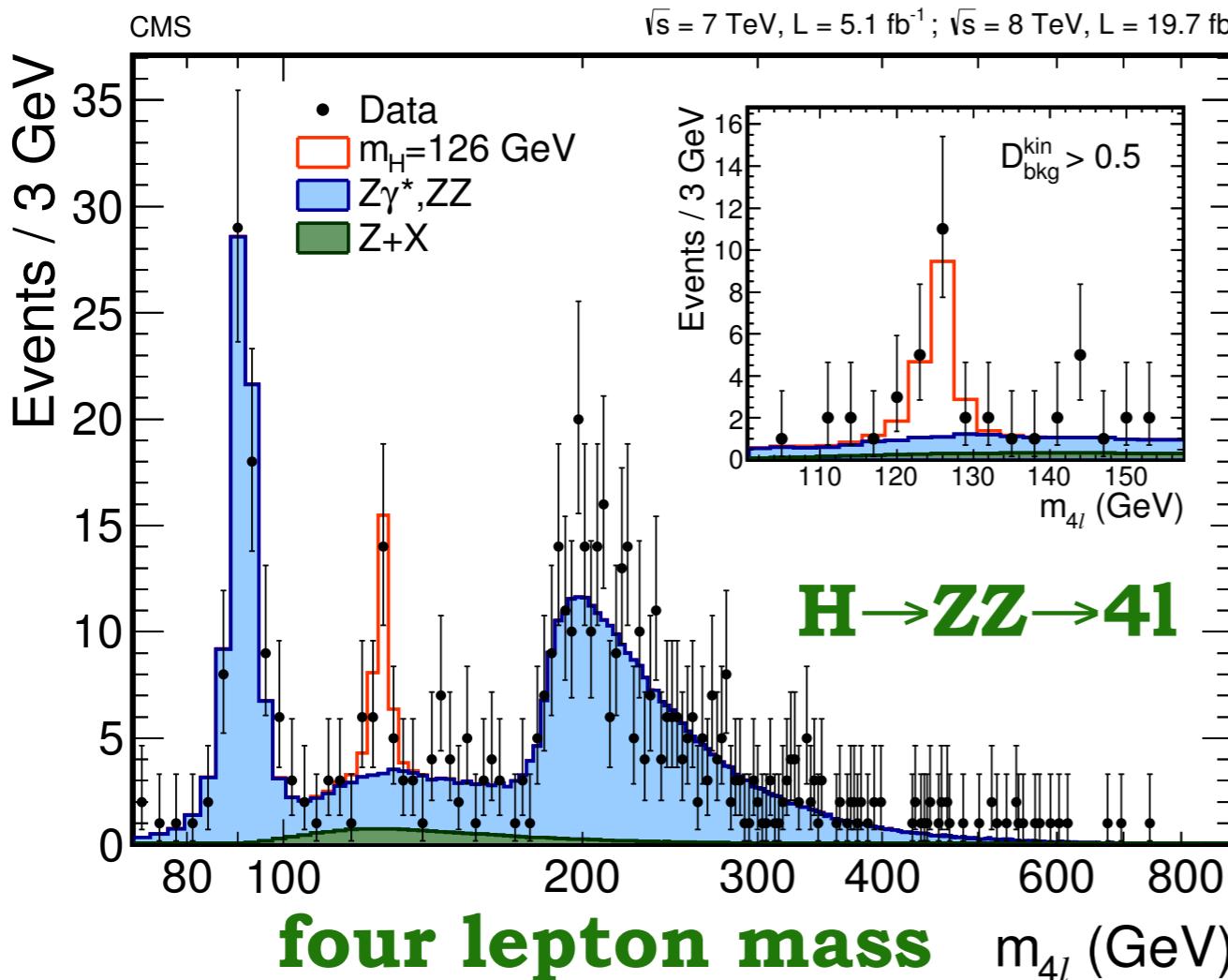
Production mechanisms and BR



- GF gluon fusion (87%) -- **impossible due to QCD !!**
- VBF vector boson fusion (7%)
- VH associated production with a vector boson (5%)
- ttH associated production with tops (0.6%)



Challenges



► **H(bb) abundant: why so difficult to observe?**

- much larger backgrounds
- much worse m_{bb} resolution
- more difficult to trigger on

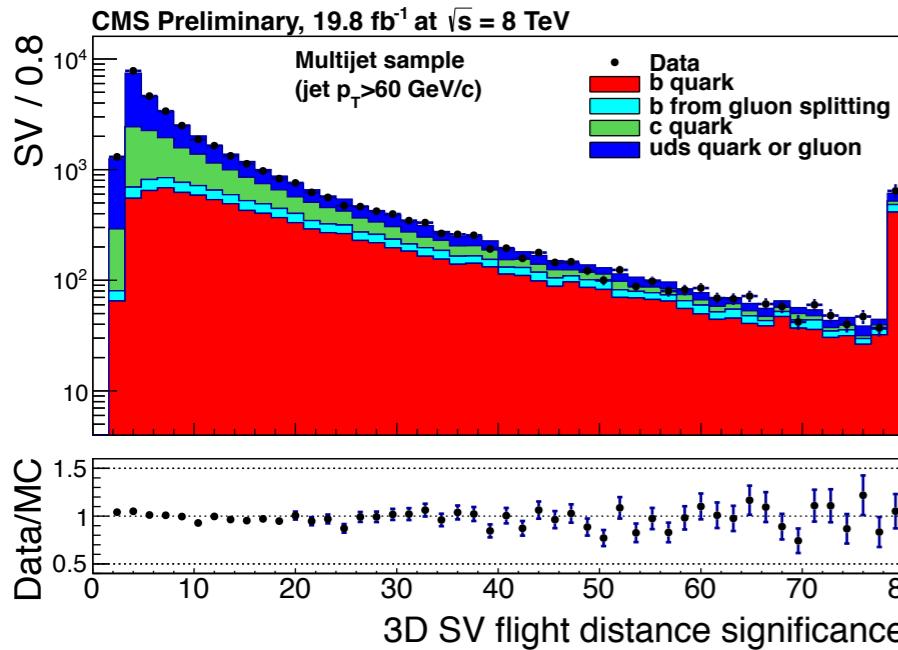
► **what can be done?**

- exploit every piece of information

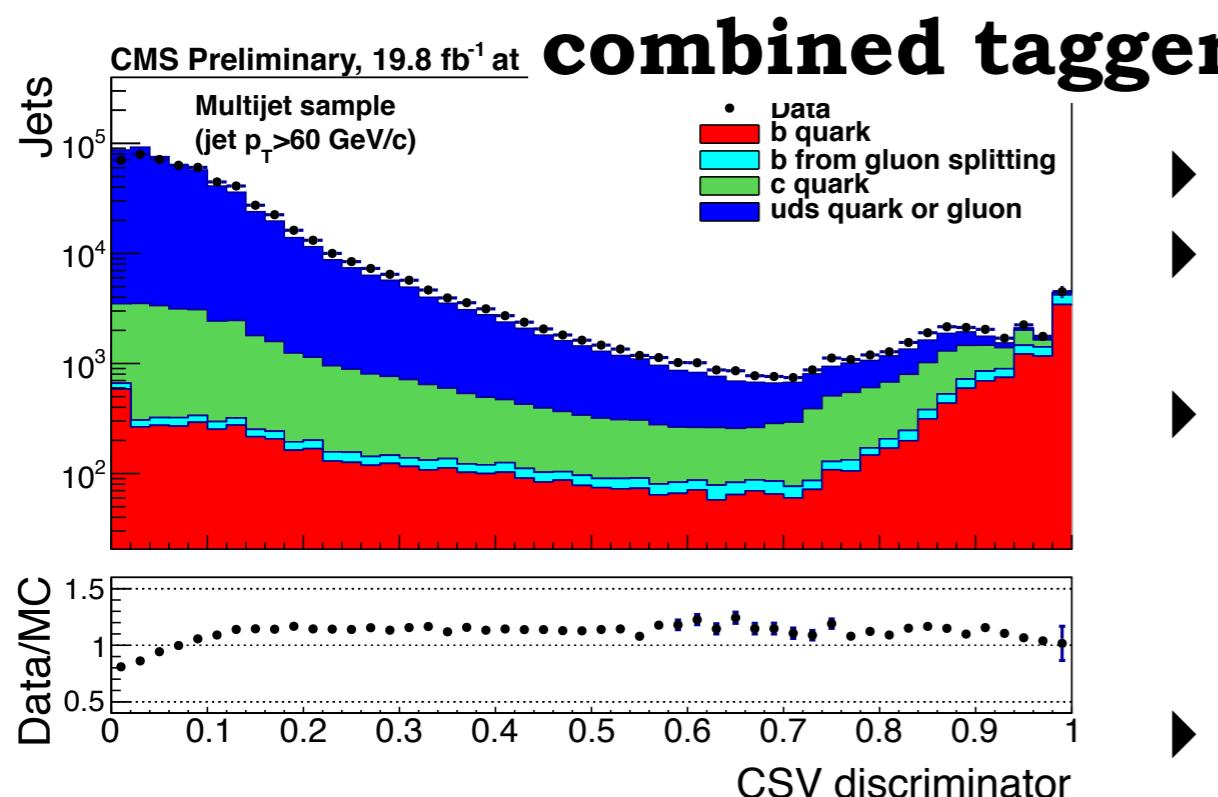
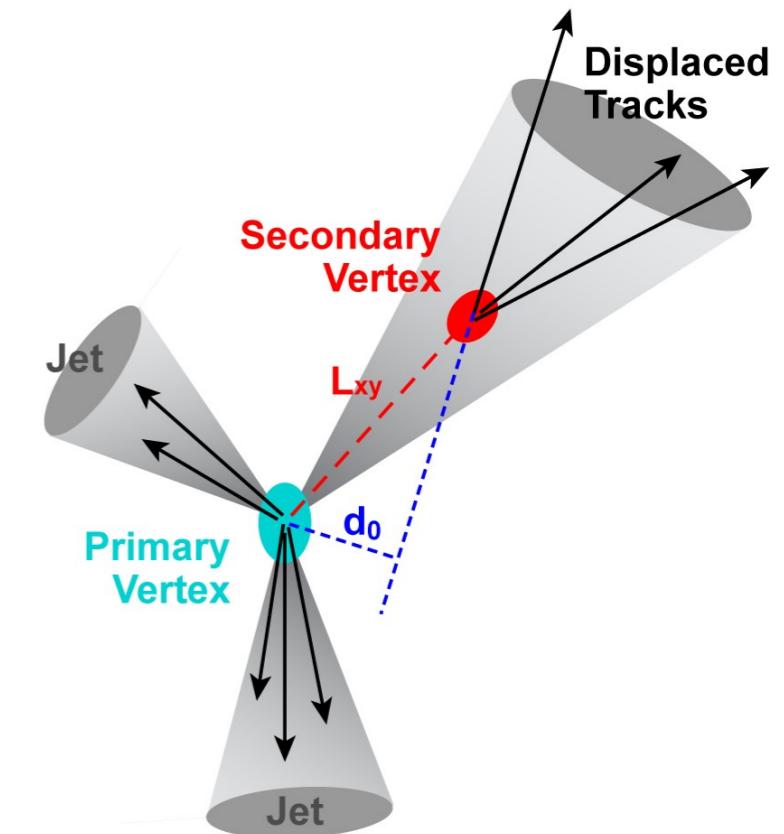
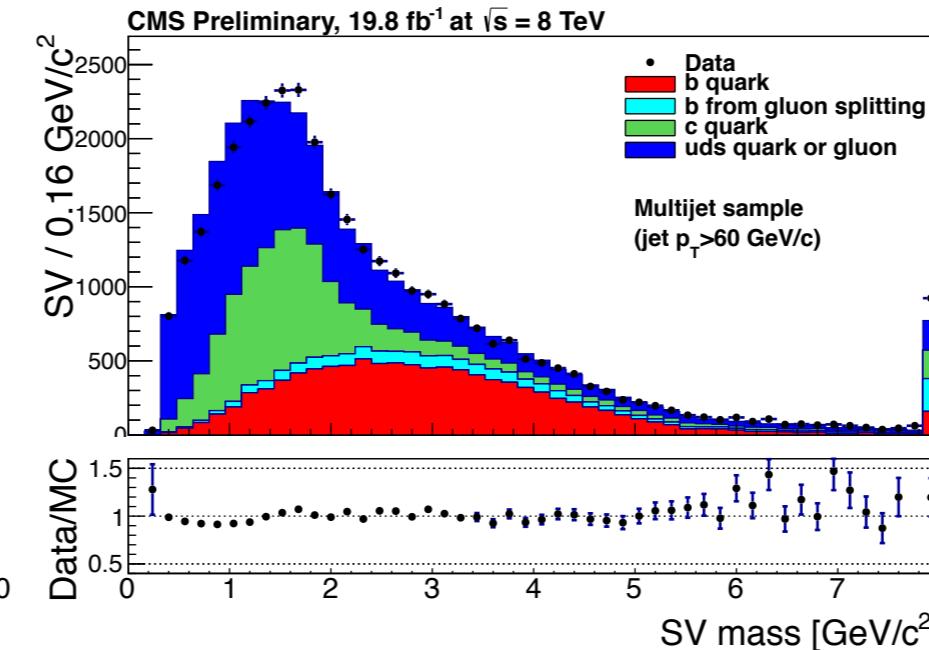
	H → 4 ℓ	H → b \bar{b}
BR	0.013%	58%
mass resolution	1%	10%
signal efficiency	30%	1.3%
S/B	2	0.05

Identification of b -jets (I)

SV flight distance / unc.



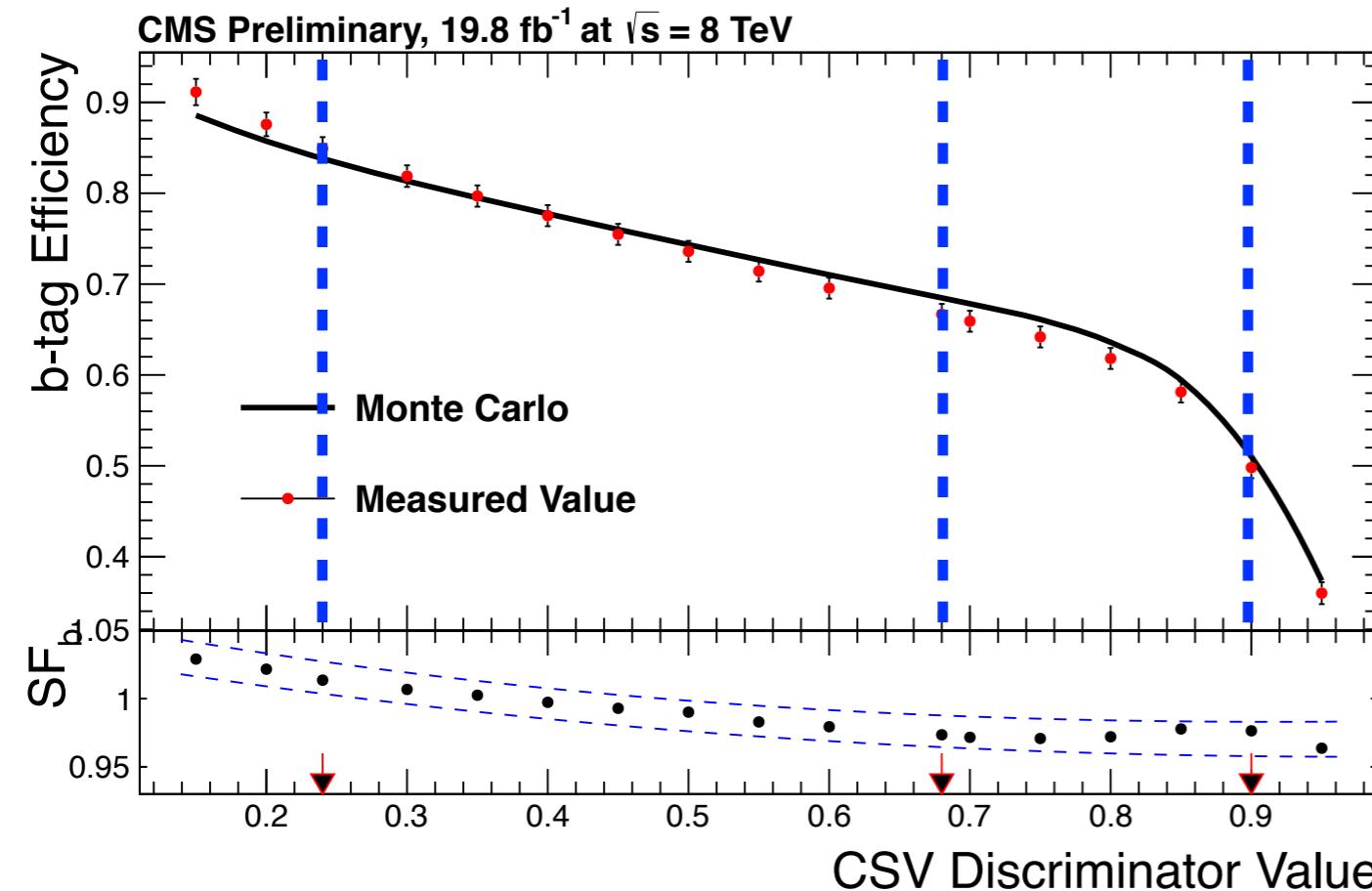
SV mass



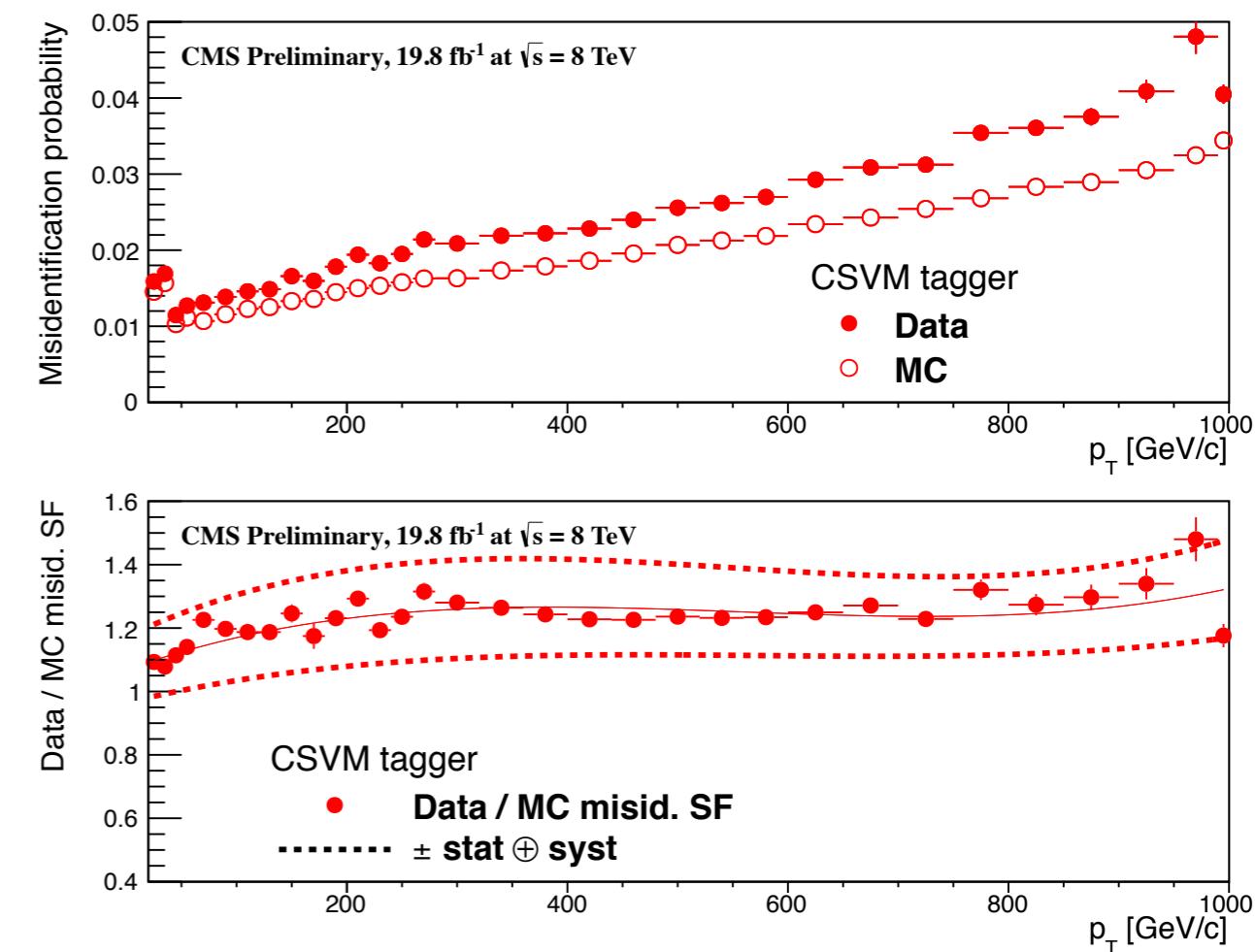
- ▶ exploit lifetime and mass of B-hadrons
- ▶ track information
 - impact parameter significance
- ▶ secondary vertex information
 - mass
 - transverse momentum
 - flight distance
- ▶ combined multivariate discriminator

Identification of b -jets (II)

b-tag efficiency



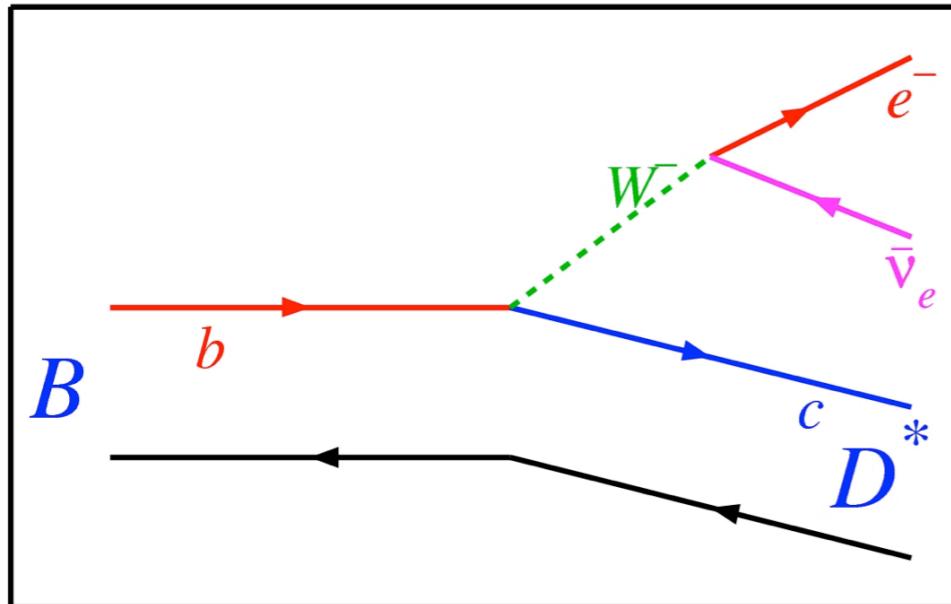
mis-id probability vs p_T



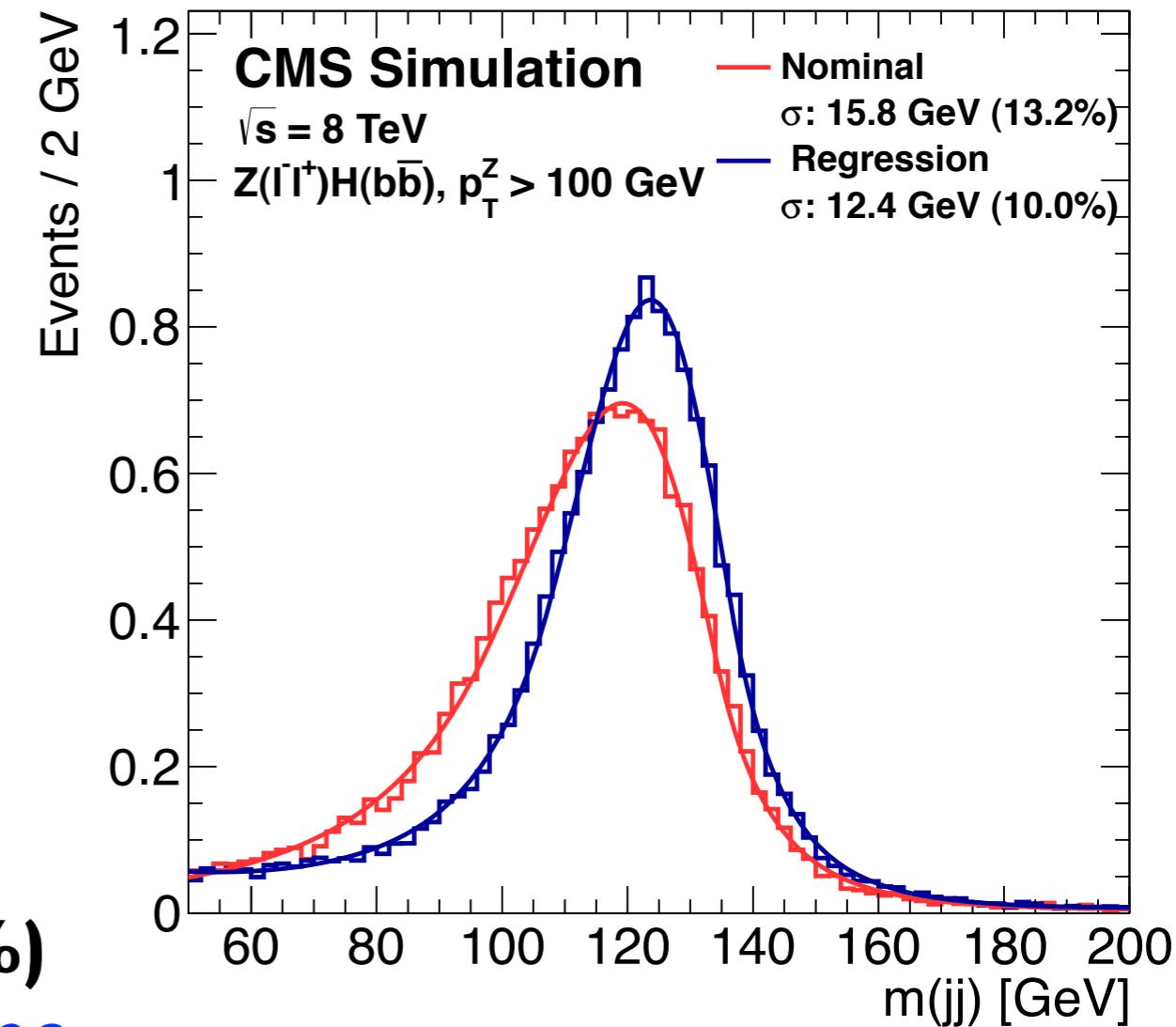
Working points

	<u>b</u>	<u>c</u>	light	[%]
Loose	85	32	10	
Medium	70	15	1	
Tight	50	6	0.1	

b-jet energy regression



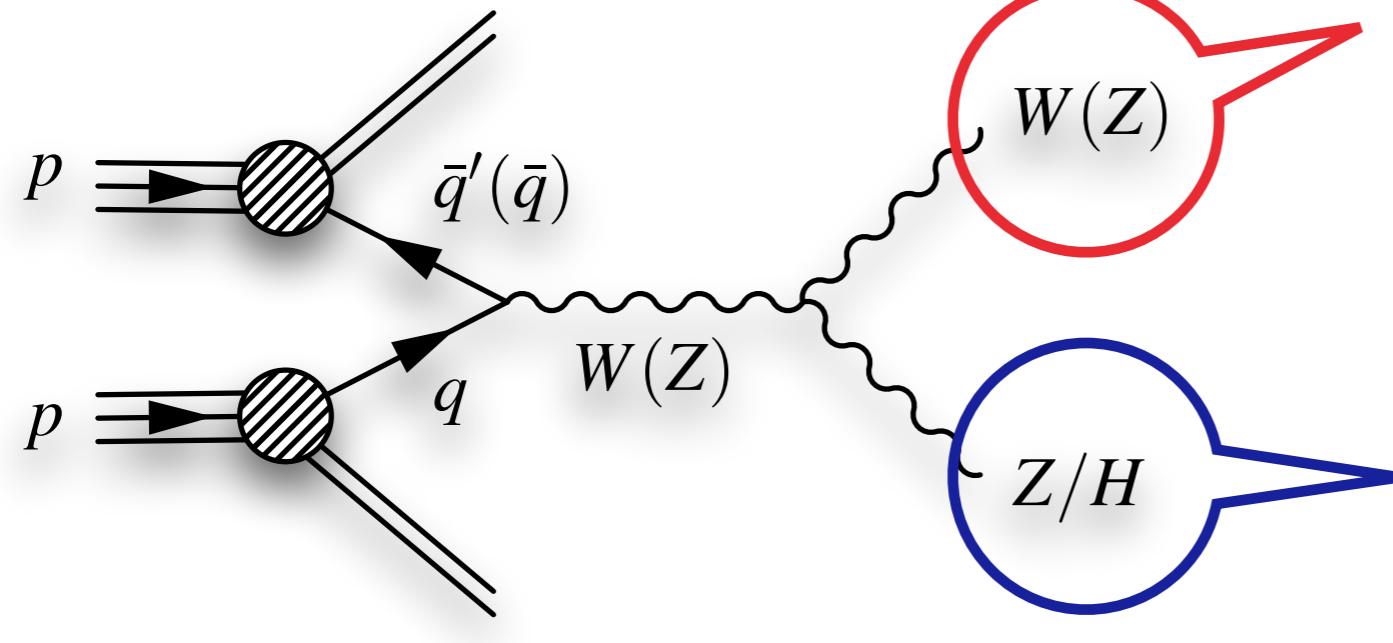
- ▶ **re-calibration of b-jets**
 - applied on top of default JEC
 - multivariate regression
- ▶ **target semileptonic decays (35%)**
 - jets badly mismeasured due to the neutrino
- ▶ **use jet and event information**
 - MET, soft lepton p_T , jet structure



15-25% m_{bb} resolution improvement

associated production with a vector boson

VH final state



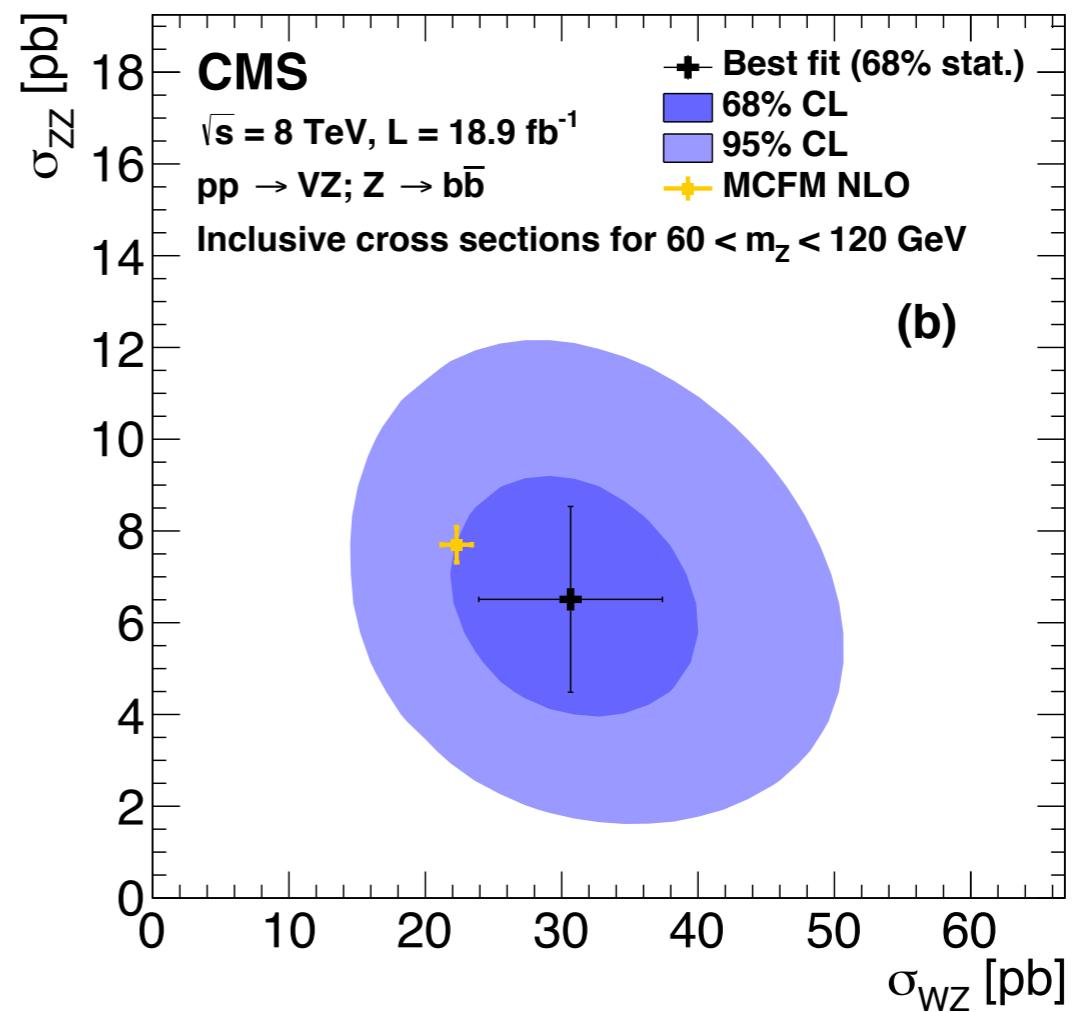
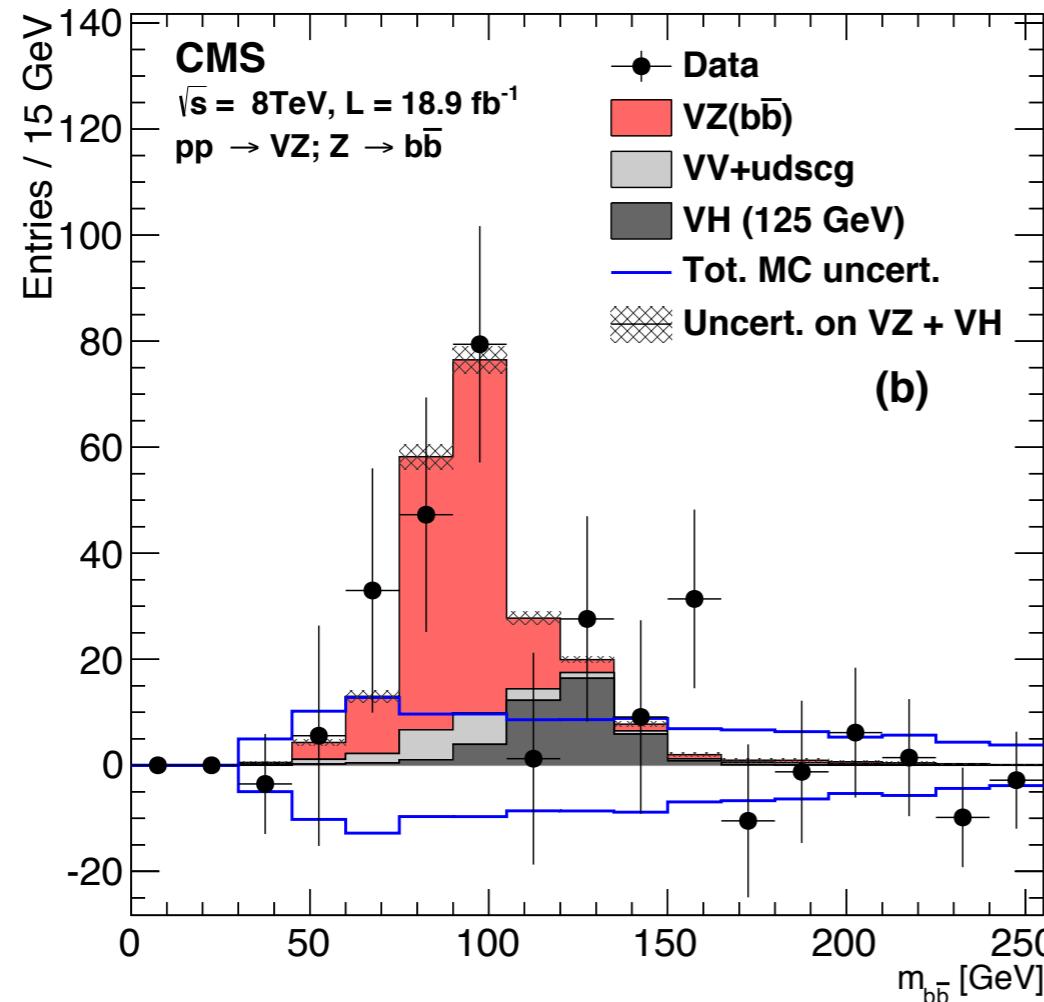
- trigger on leptonic decays
- suppress enormous QCD background
- search for the Higgs boson
- validate the strategy by observing $VZ(bb)$

	$\sigma \cdot \text{BR}$ at $\sqrt{s} = 8 \text{ TeV}$ [pb]		
bb	$W(\ell\nu)$	$Z(\ell\ell)$	$Z(\nu\nu)$
Z	1.13	0.08	0.24
H	0.13	0.01	0.04

irreducible backgrounds

- $W/Z + bb$
- $t-t\bar{b}$
- single top
- diboson

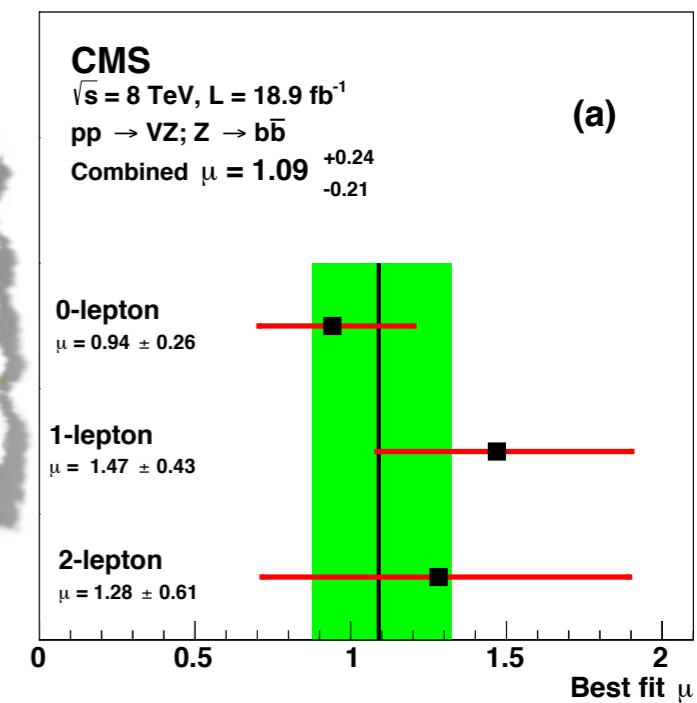
Validation with data: VZ(bb)



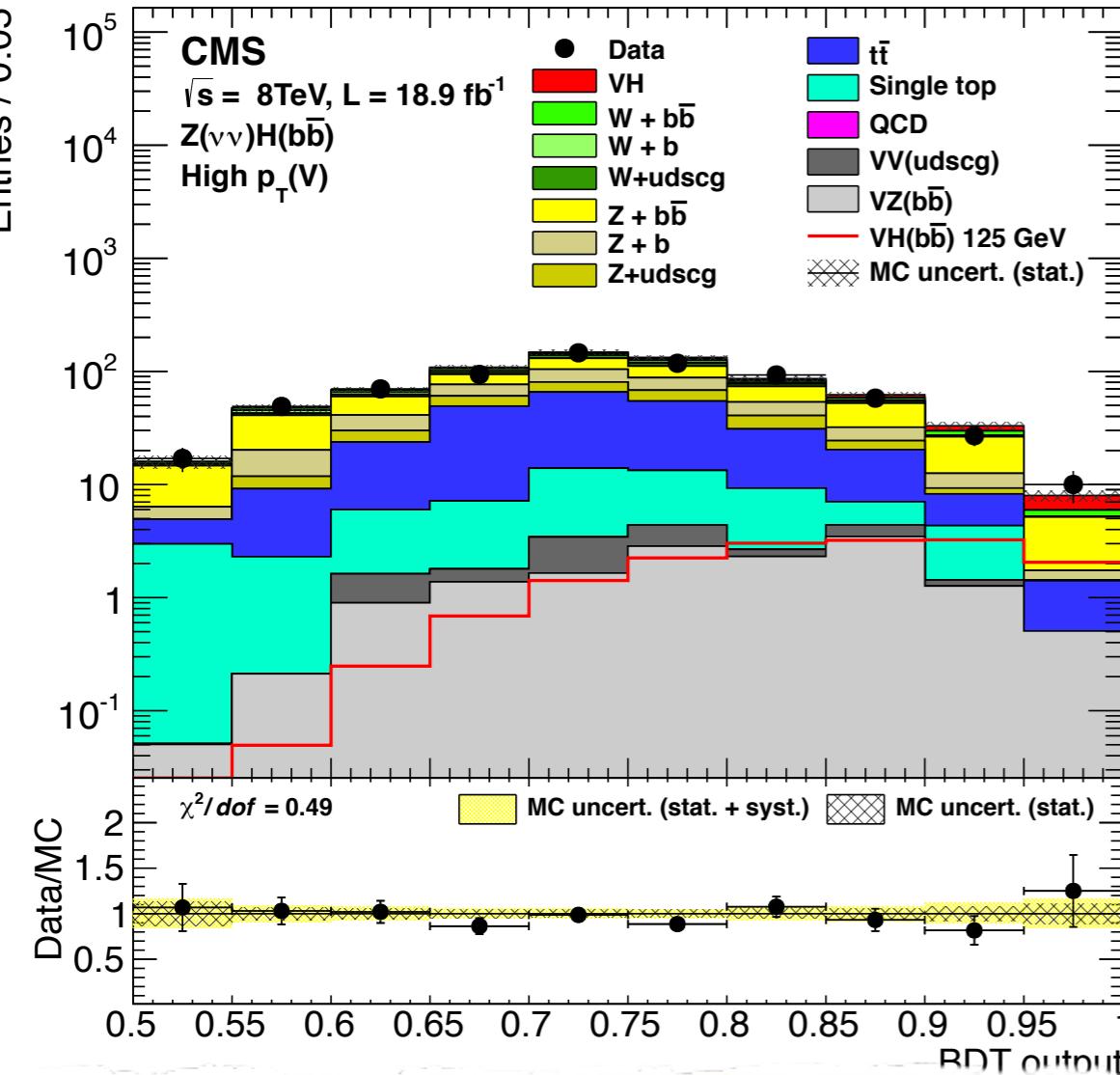
first observation (6.3σ) at a hadron collider

$$\sigma(\text{pp} \rightarrow \text{WZ}) = 4.8 \pm 1.4 \text{ (stat.)} \pm 1.1 \text{ (syst.) pb}$$

$$\sigma(\text{pp} \rightarrow \text{ZZ}) = 0.90 \pm 0.23 \text{ (stat.)} \pm 0.16 \text{ (syst.) pb}$$



VH search overview



Z($\nu\nu$)H($b\bar{b}$), $p_T(V) > 170$ GeV

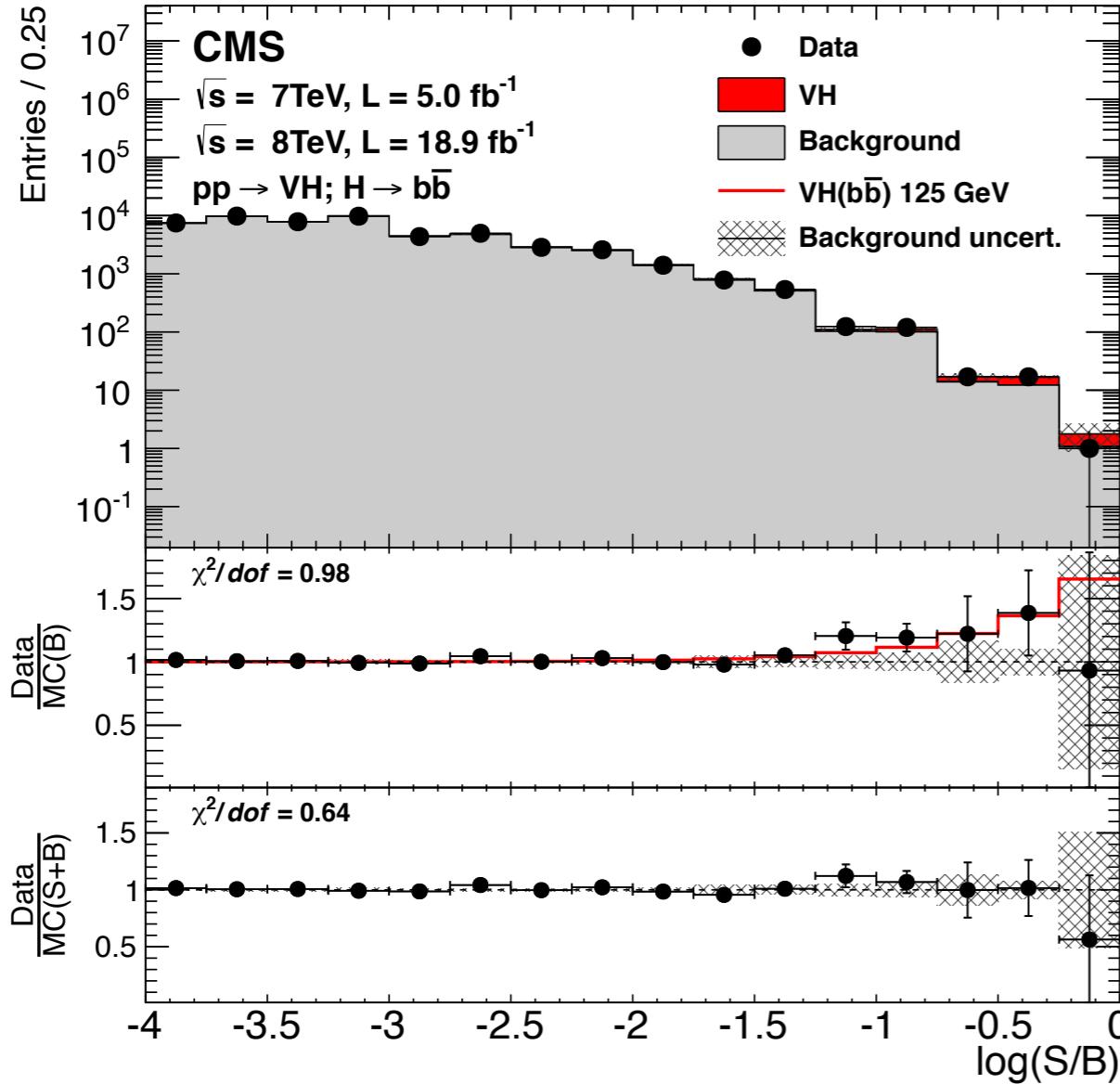
► complicated analysis

- 14 event categories based on the signature (0,1,2 leptons) and on the boson p_T
- multivariate discriminant (BDT)
- simultaneous fit for the signal in all categories

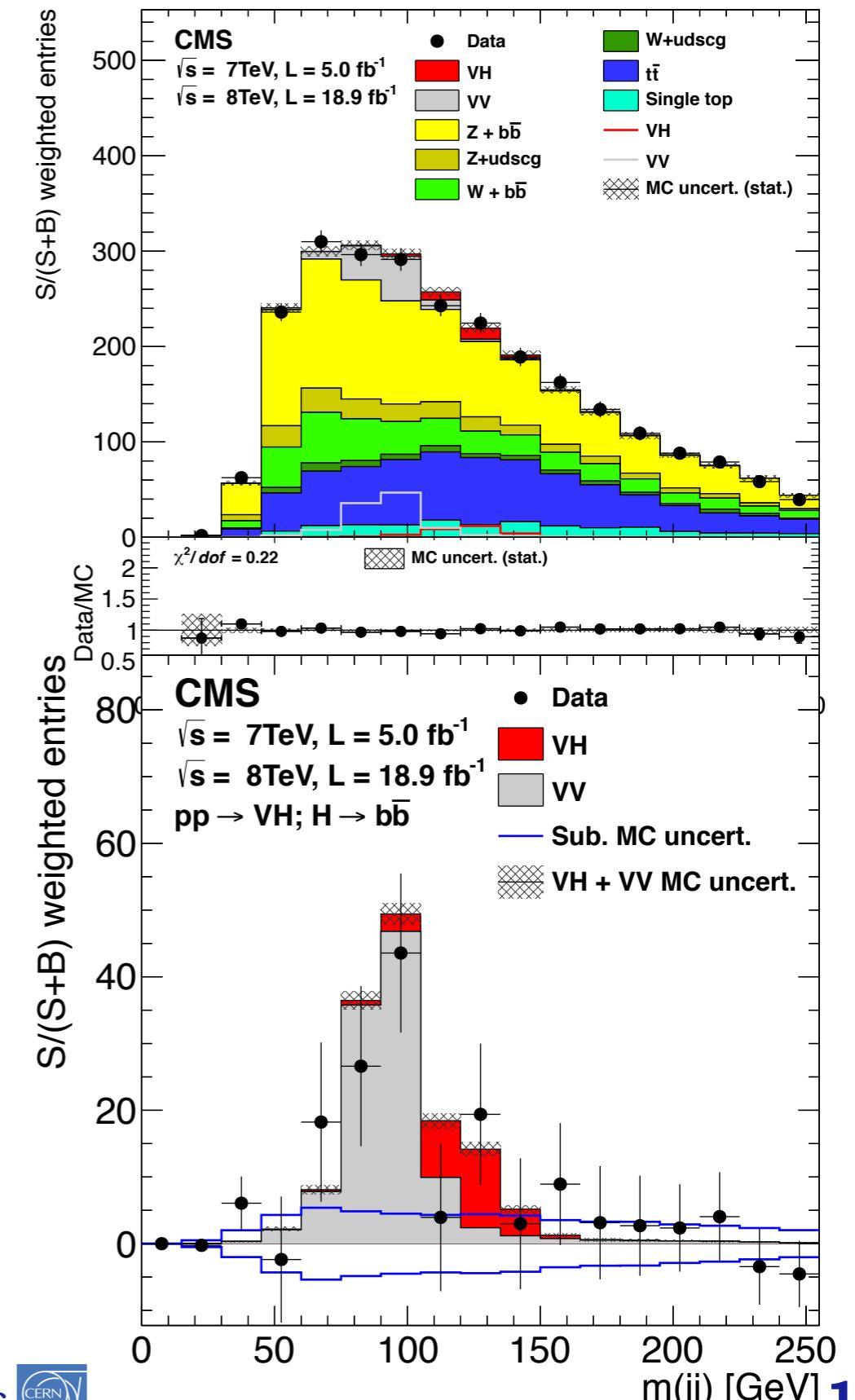
► background prediction

- BDT shape taken from the simulation
 - data vs MC scale factors applied (trigger, btag, $p_T(V)$, etc)
- normalization taken from data
 - control regions

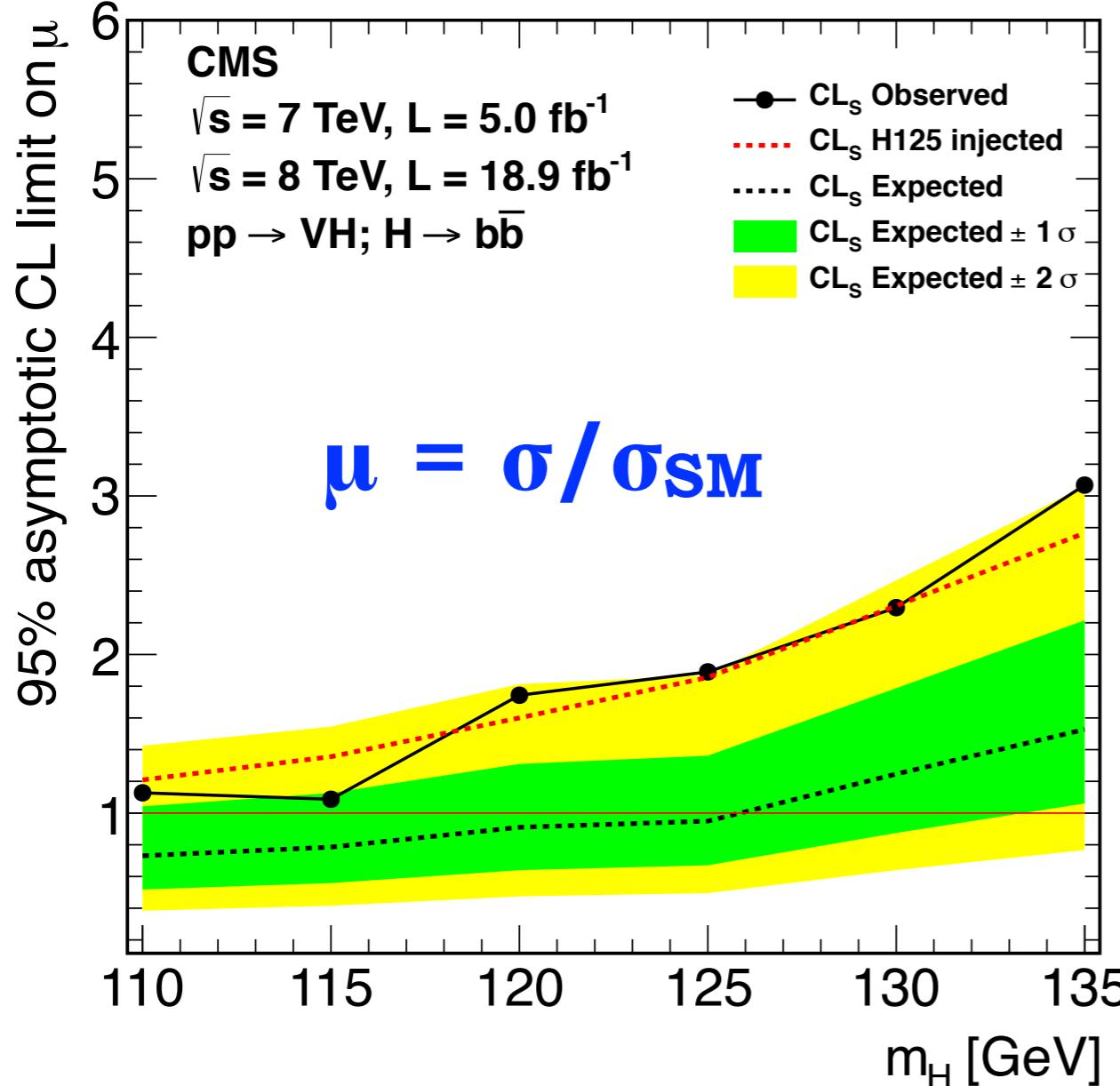
VH results (I)



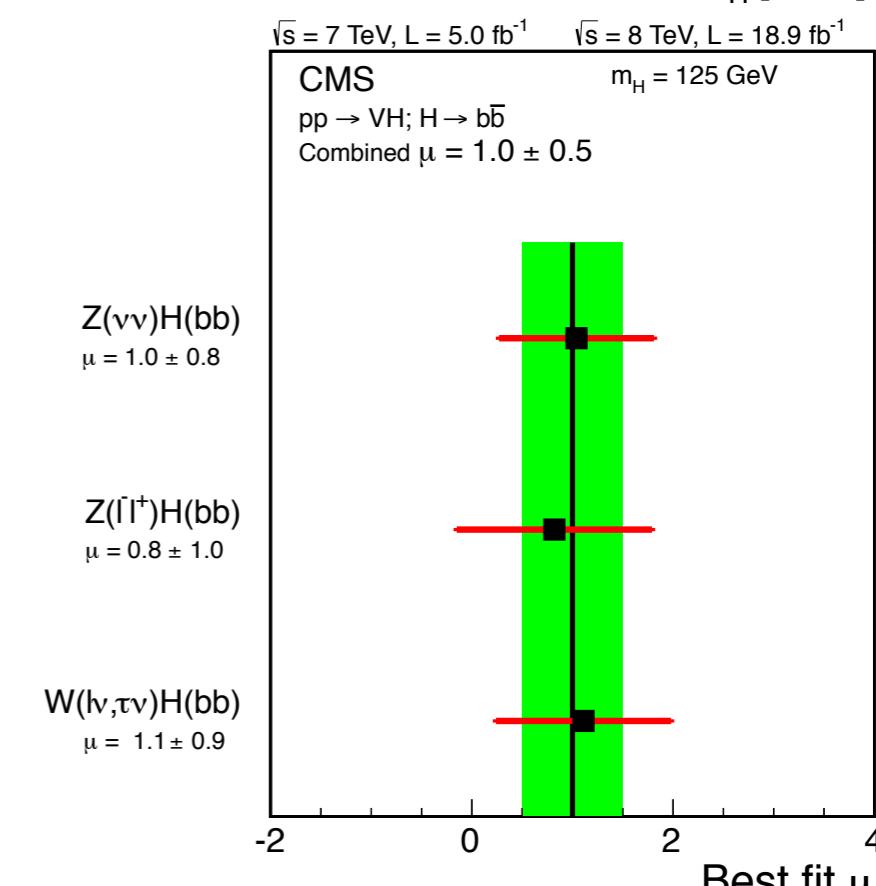
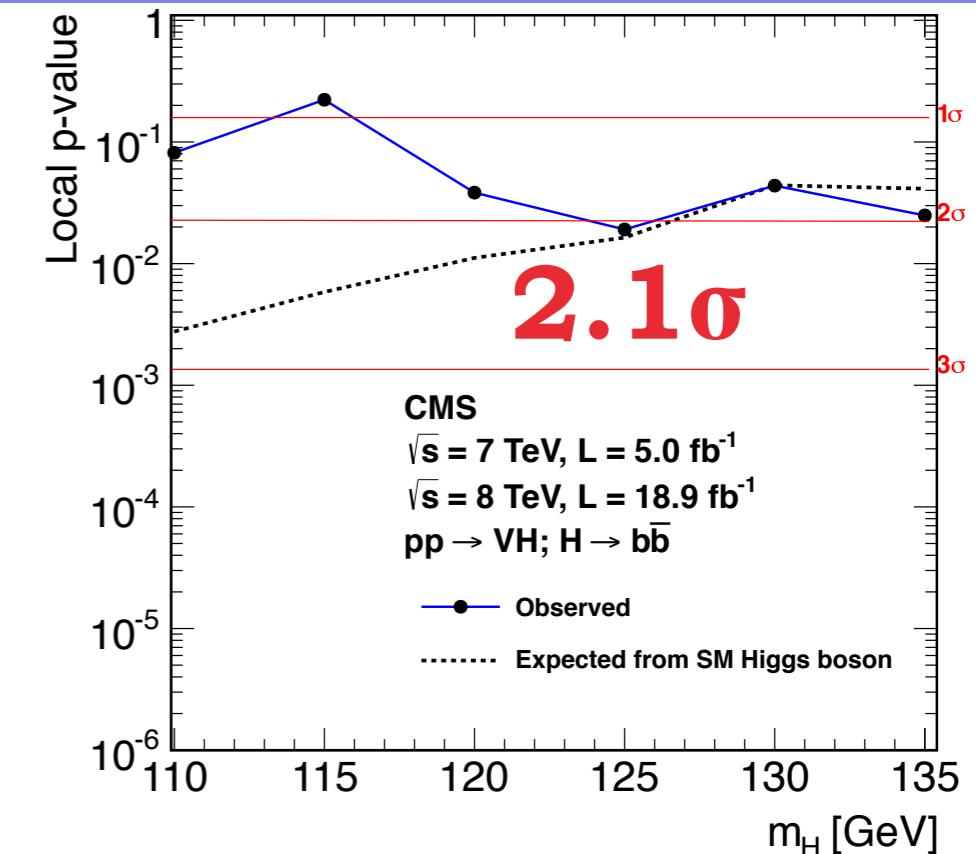
Events sorted by S/B



VH results (II)

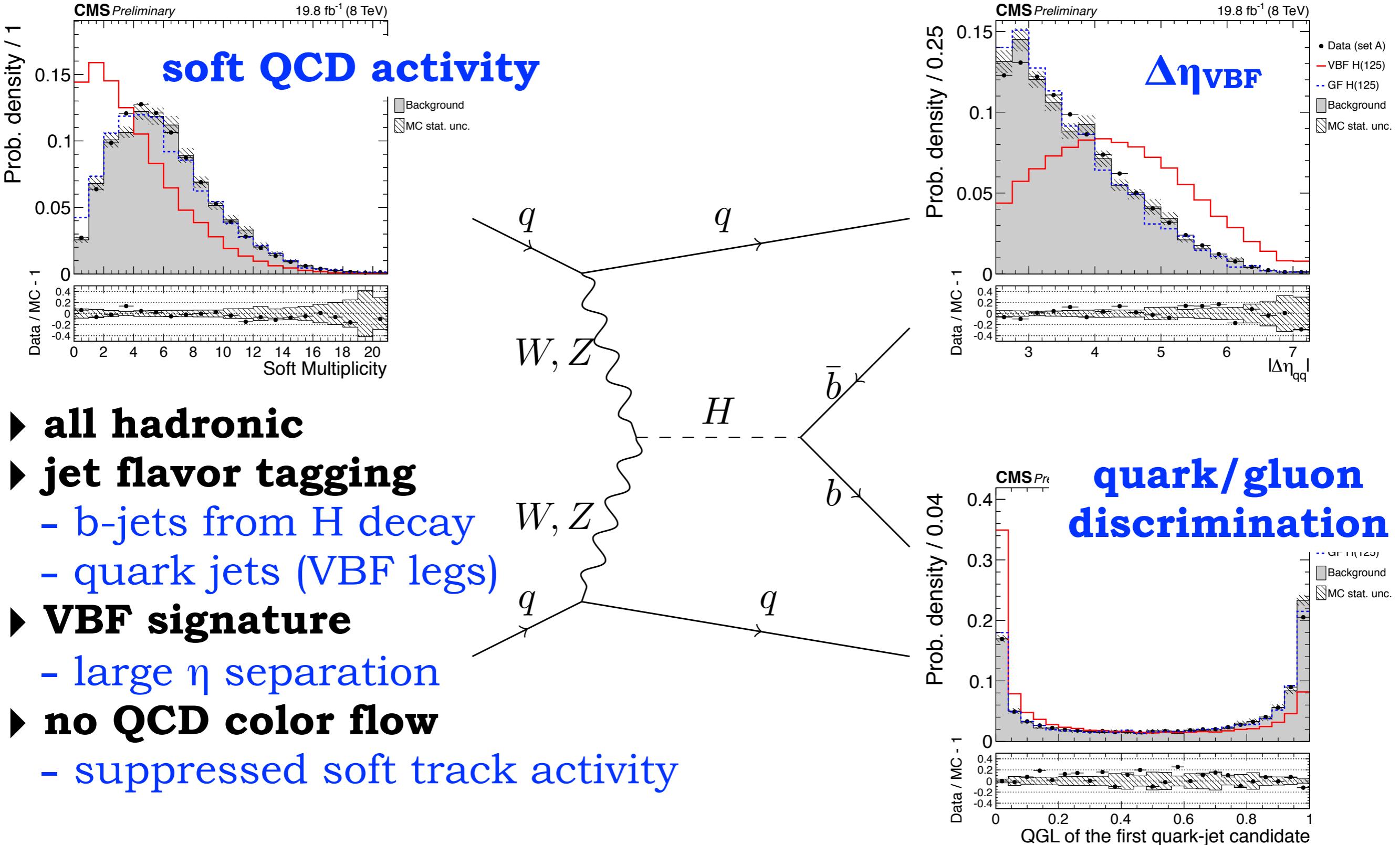


$\mu = 1.0 \pm 0.5$
 $\mu = 0.89 \pm 0.42$ (latest updates published in legacy Higgs paper)

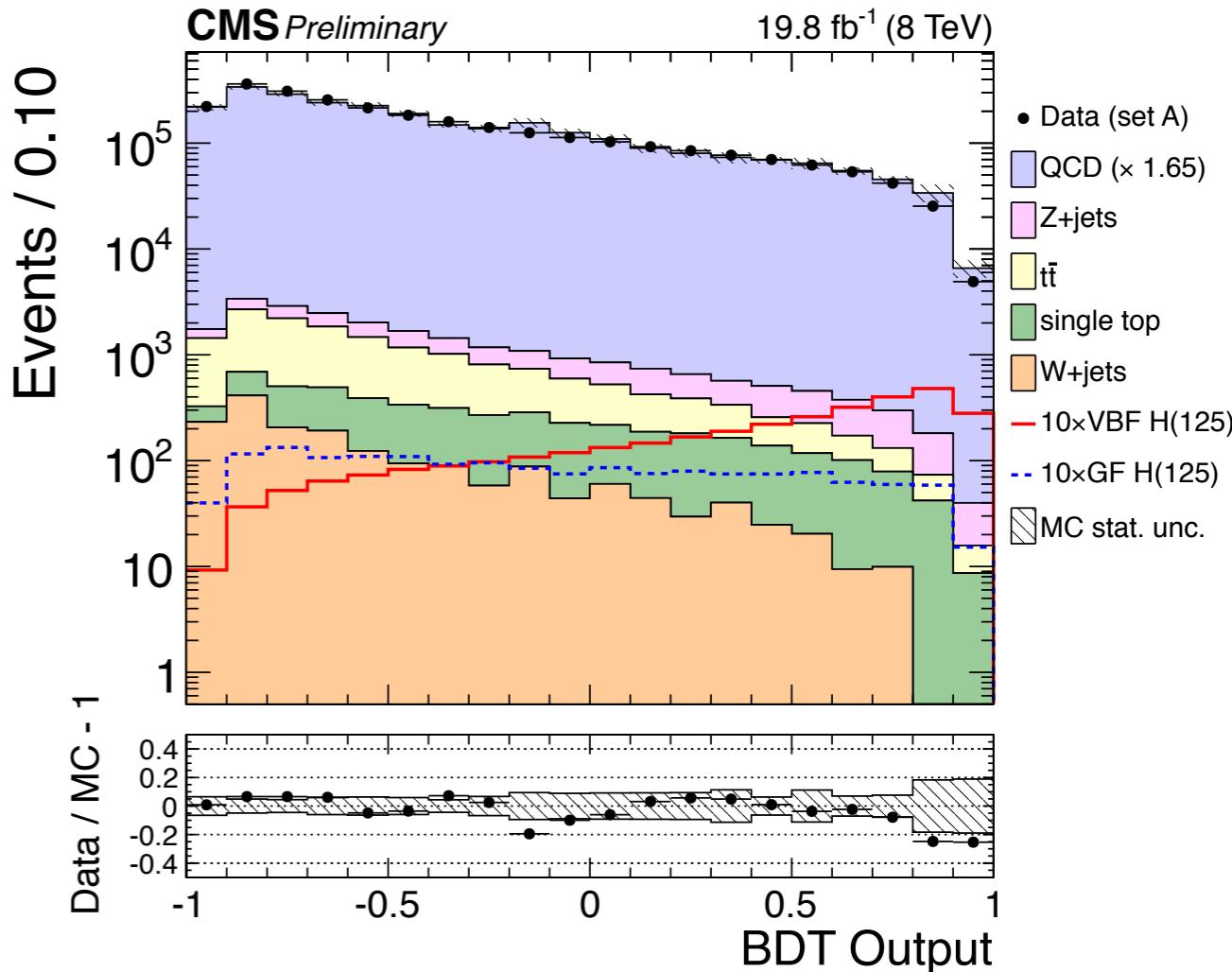
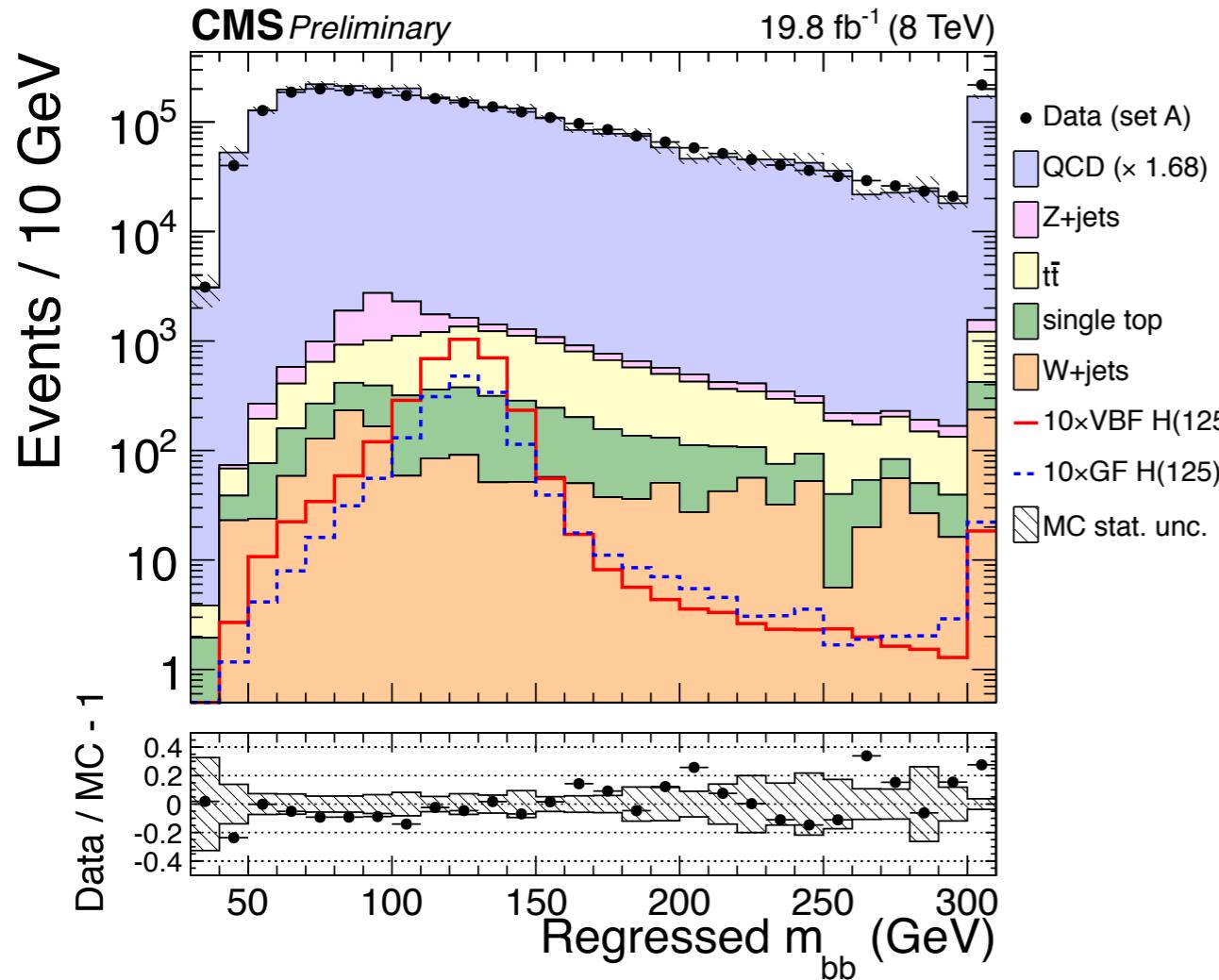


vector-boson fusion

VBF final state



VBF search overview



► multivariate discriminant (BDT)

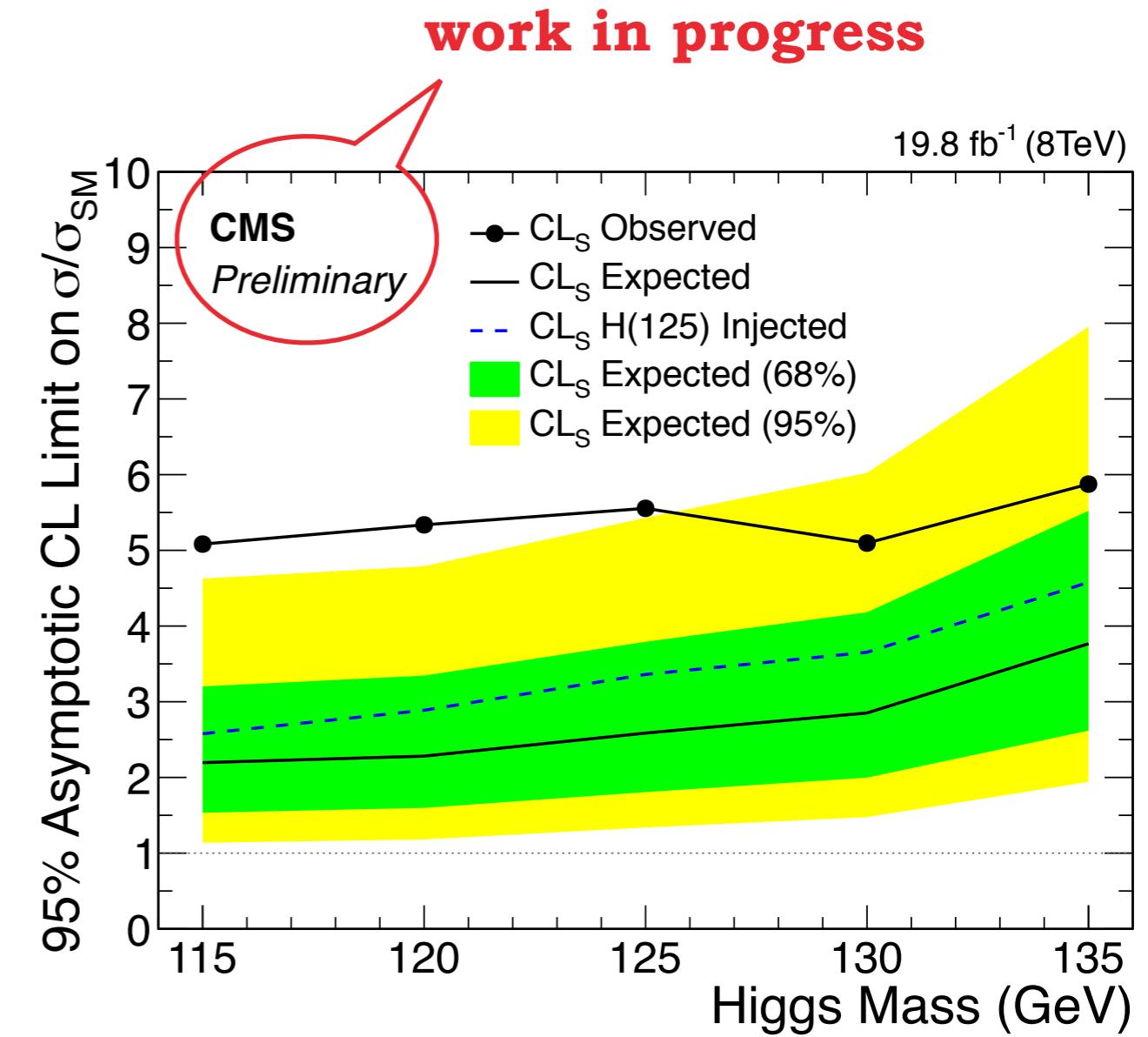
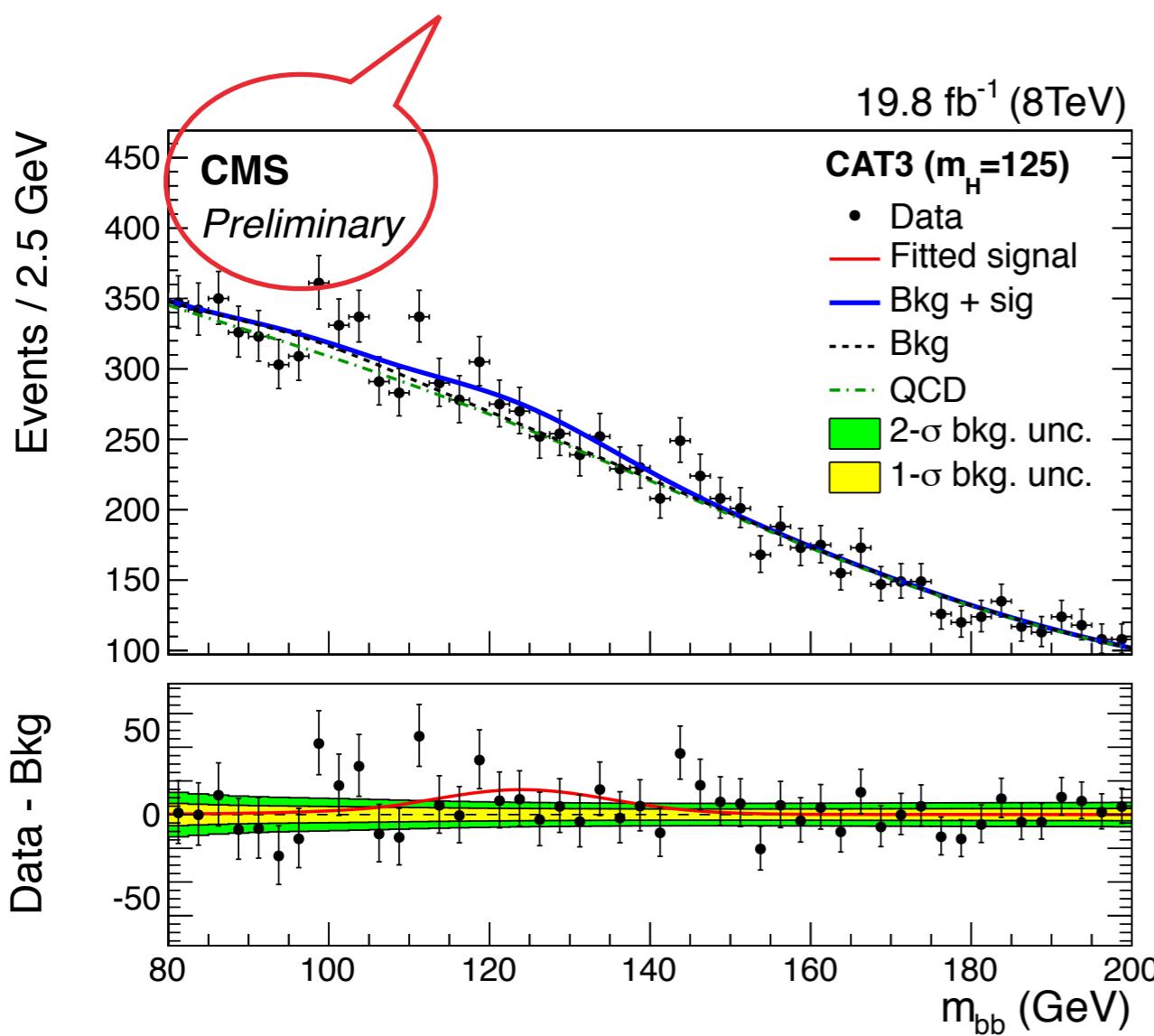
- aim to suppress the overwhelming QCD background
- minimum correlation to m_{bb}

► fit of the m_{bb} spectrum

- simultaneously in multiple event categories based on the BDT
- similar to the $H \rightarrow \gamma\gamma$

VBF results

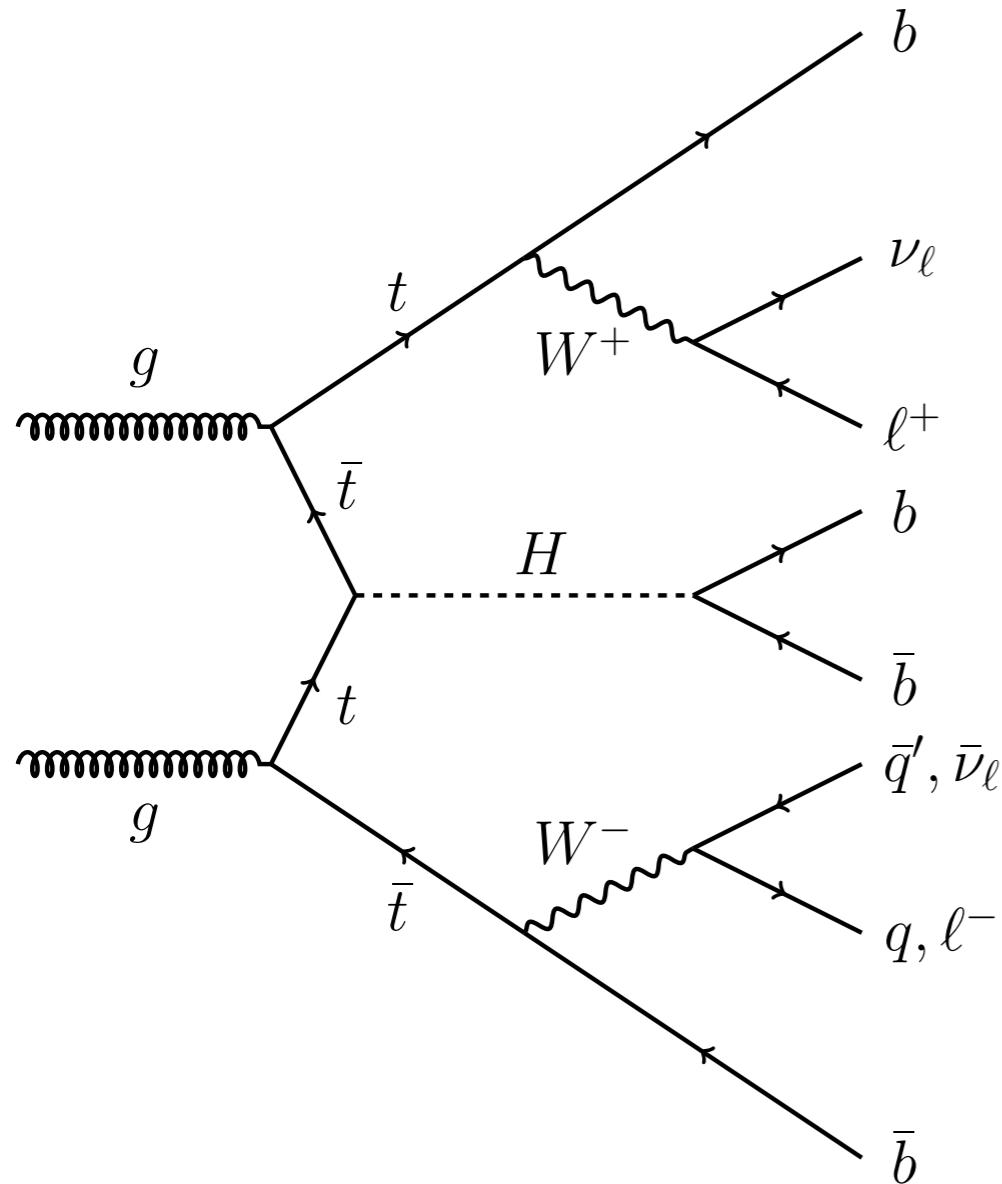
work in progress



$$\mu = 2.8 \pm 1.5 \text{ (2.2}\sigma\text{, 0.8}\sigma\text{ exp)}$$

associated production with a top-quark pair

ttH final state & analysis strategy



► “crowded” events

- additional b-jets, jets/leptons from top decays
- easier to trigger on

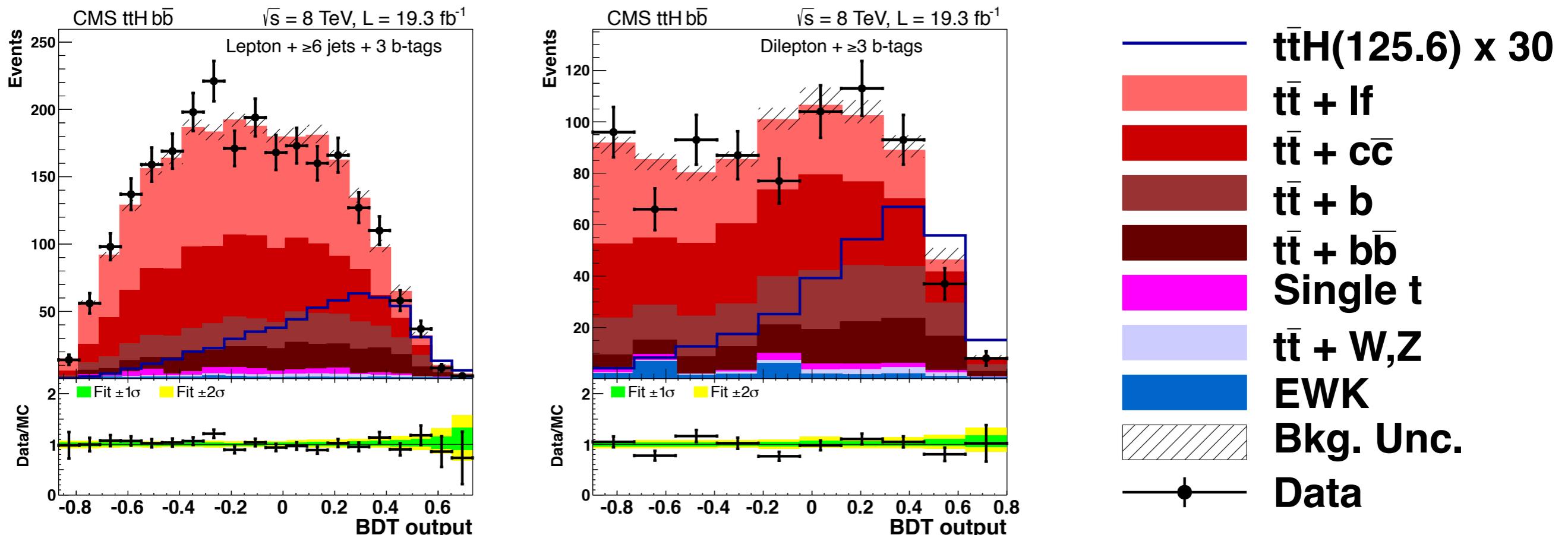
► channels

- semileptonic, dileptonic
- all hadronic not used in Run I

► strategy

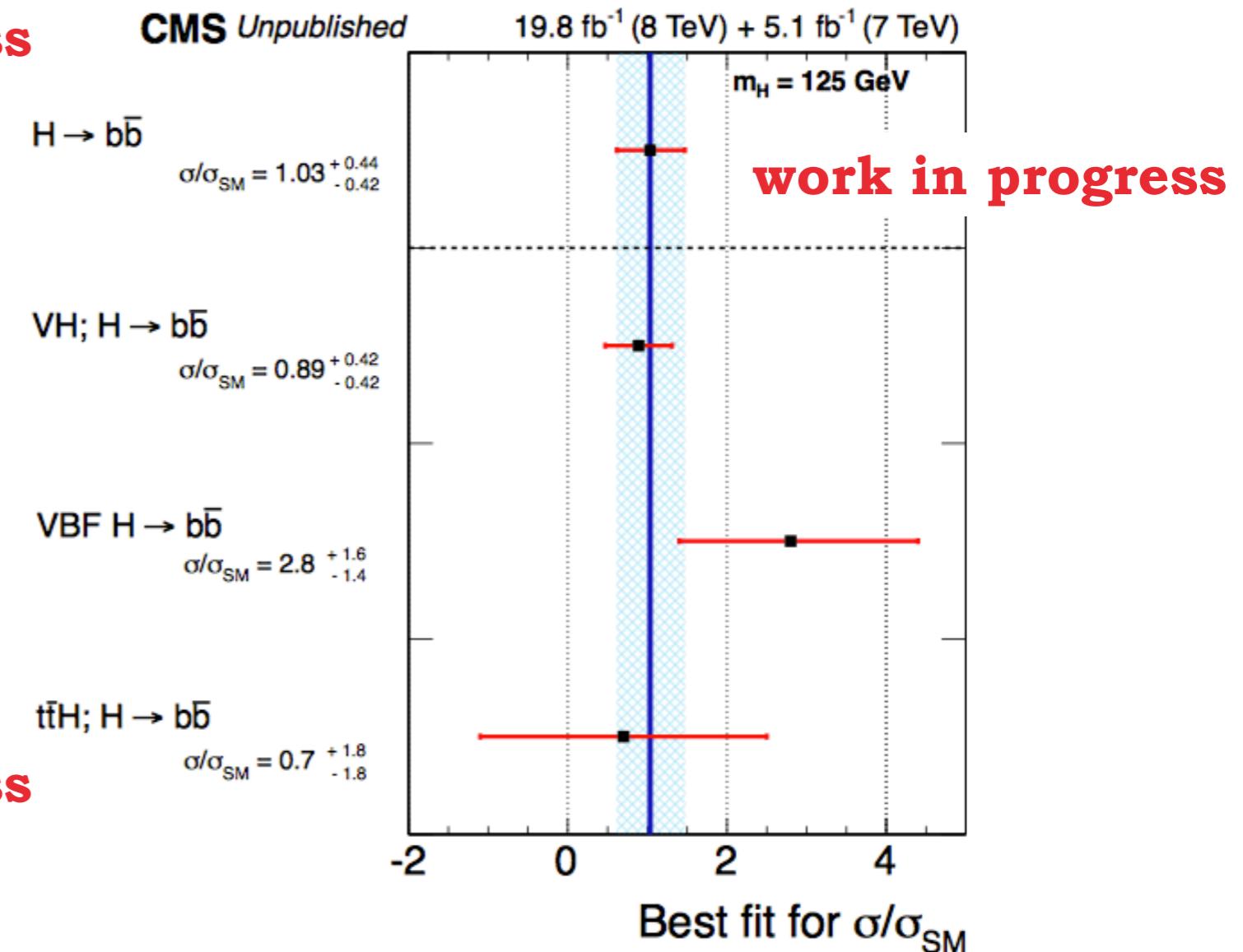
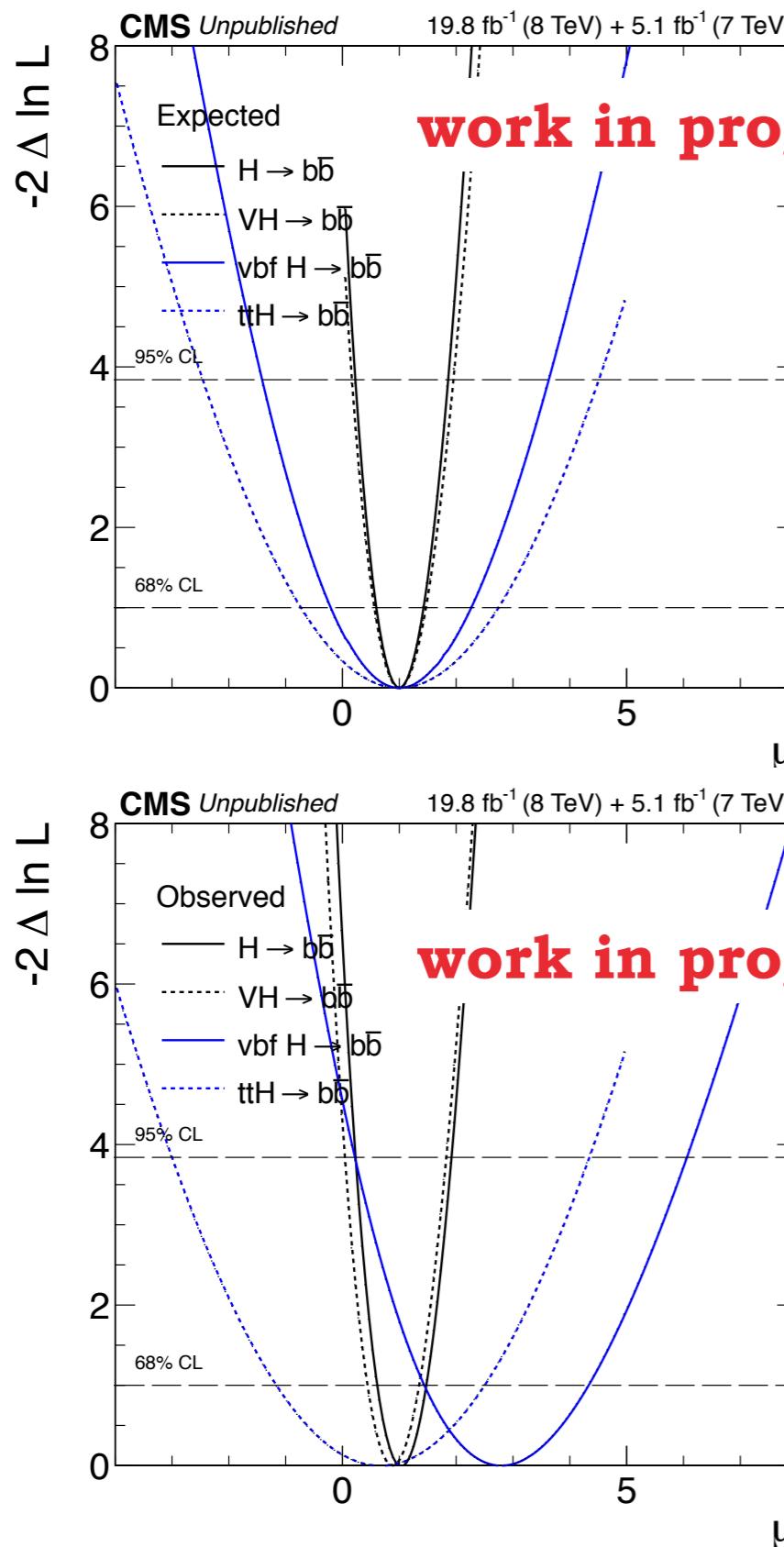
- further categories based on N_{jets} and N_{bjets}
- multivariate discriminant (BDT)
- simultaneous fit to all BDT outputs
 - background shapes taken from MC

ttH results



$$\mu = 0.7 \pm 1.8 \text{ (} 0.4\sigma, 0.6\sigma \text{ exp)}$$

Combined $VH + VBF + t\bar{t}H$



$\mu = 1.0 \pm 0.4 \text{ (2.6}\sigma, 2.7\sigma \text{ exp)}$

Summary

◆ CMS has performed $H \rightarrow bb$ searches in all feasible production modes (VH, VBF, ttH)

- important to make an independent observation
- important to measure the coupling to down-type quarks

◆ combined result

- consistent with SM: $\mu = 1.0 \pm 0.4$
- **2.6 σ observed significance**
- largely driven by the VH mode (most sensitive)

◆ Run II prospects

- Run I result statistics dominated: more data needed ($O(10 \text{ fb}^{-1})$ @ 13 TeV for similar sensitivity as in Run I) !!
- new ideas being considered to reduce systematics and enhance S/B
- additional channels explored (e.g. boosted VH and all-hadronic ttH)