Observation of the Standard Model Higgs Boson Produced in Association with a Z or W Boson and Decaying to Bottom Quarks
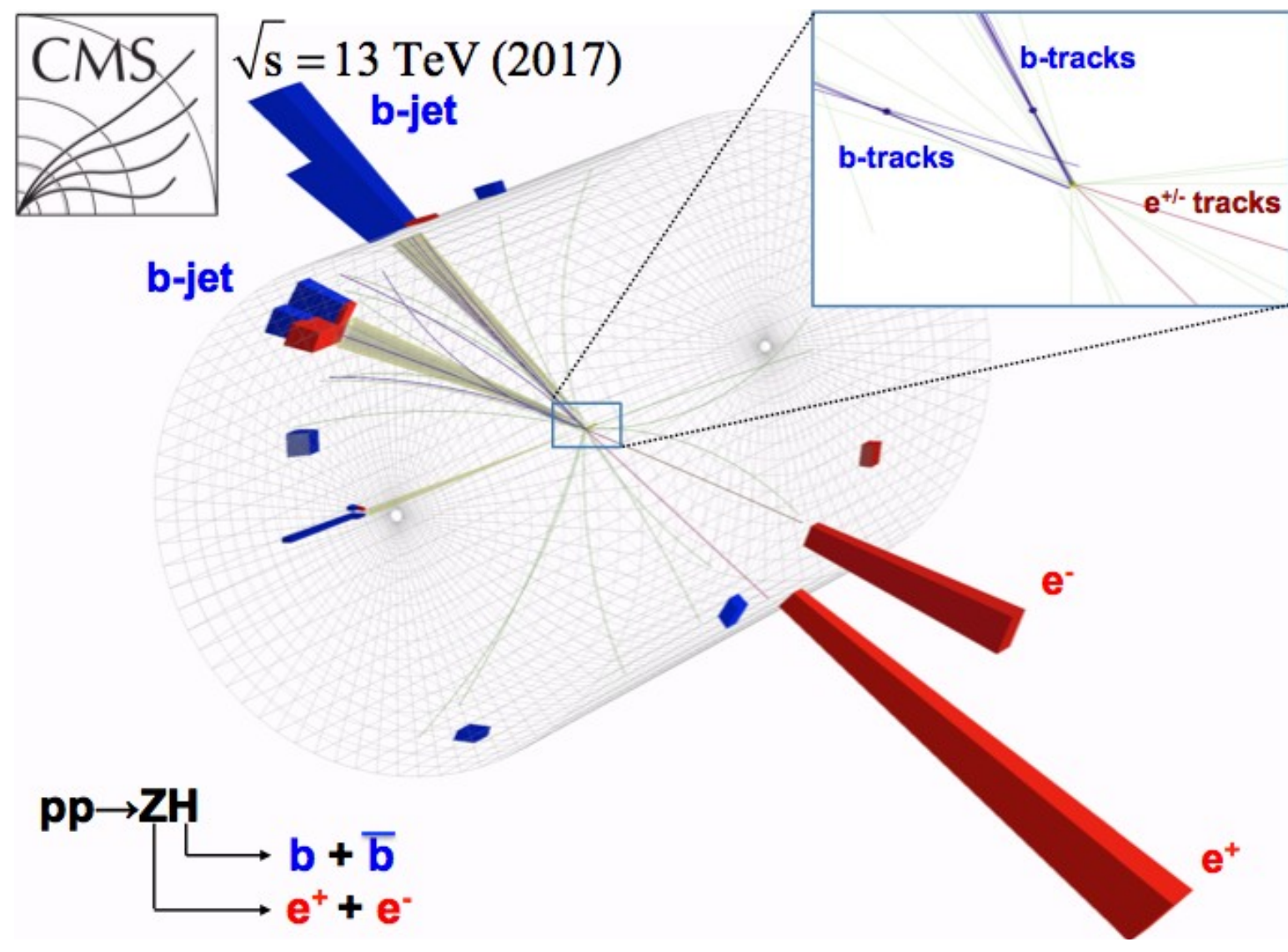
Krunal B. Gedia, on behalf of the CMS Collaboration
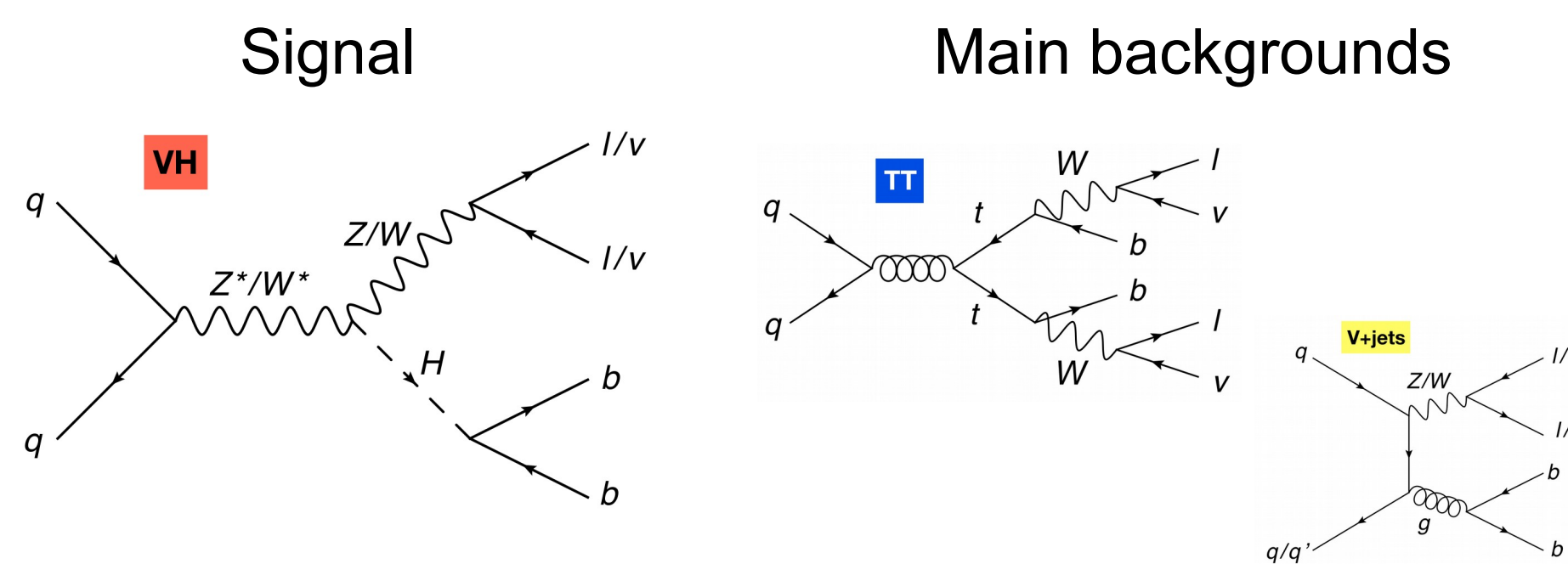
Motivation

- The **Higgs boson** discovered in H→γγ, H→ZZ*→4l channels in 2012.

- SM BR(H→ bb) = 58.24% (largest BR)

- H→ bb coupling not established in Run 1.

- **Most sensitive channel is VH.**

Event display

An event candidate for the production of a Z boson in conjunction with a Higgs boson in the CMS detector.

Analysis Strategy

Signal   Main backgrounds

Vector boson associated (VH) production

Decay modes
- **Z → ll (e+e- or μ+μ-)**
- **Z → νν**
- **W→ lν (eν or μν)**

- Suppress QCD, V+jets, top quark background.

Boosted
- Trigger path when W/Z decays to charged leptons.

- Z(νν)H channel accessible via large E_T^{miss}.

Dominant backgrounds: V+jets, diboson, top quark

Signal and Control regions

Signal Regions (SR)

- High signal efficiency. (S/B ~ 1/100 – 5/100)
- Used to extract signal strength/significance.

Control Regions (CR): V+HF, V+LF, TT

- Selection optimizing specific background purity
- Verifying data/MC shape agreement.
- Constrain normalization of MC in combined fit.

Measurement performed by **simultaneous fit of control and signal regions.**
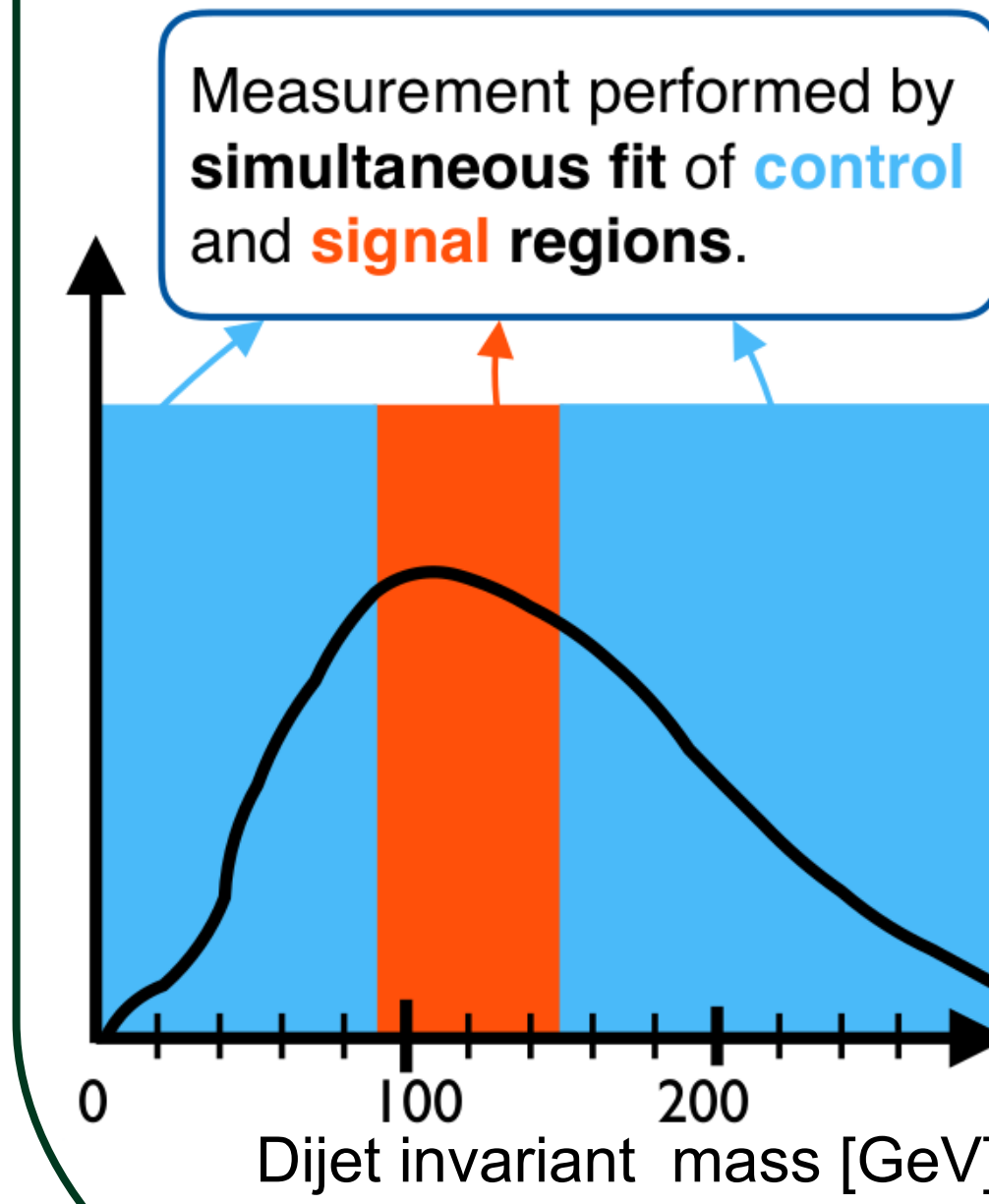
Signal characteristics
- m(bb) peaks at 125GeV
- m(ll/lν/νν) peaks at m(V)
- ΔΦ (V,H) ≈ π
- $p_T(b) ≈ M_H / 2$

DNN Classifier

- m(bb) not alone discriminating enough in SR.

- SR still dominated by background.

  - V+jets (in 2-lepton channel)
  - tt (in 0/1 lepton channel)
  - di-boson

- DNN classifier (14-16 inputs) trained for each channel.

- DNN outputs of SR of all channels used in the SR+CR fit to extract signal strength/significance.
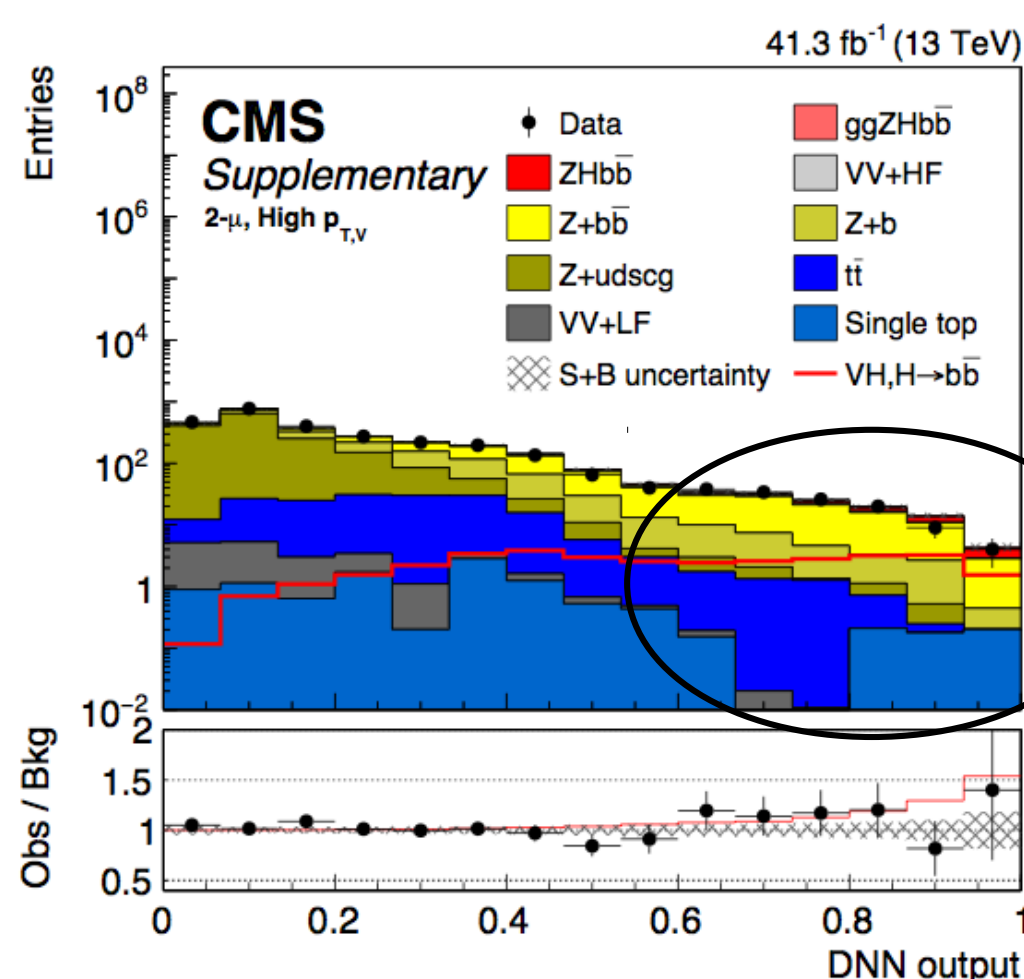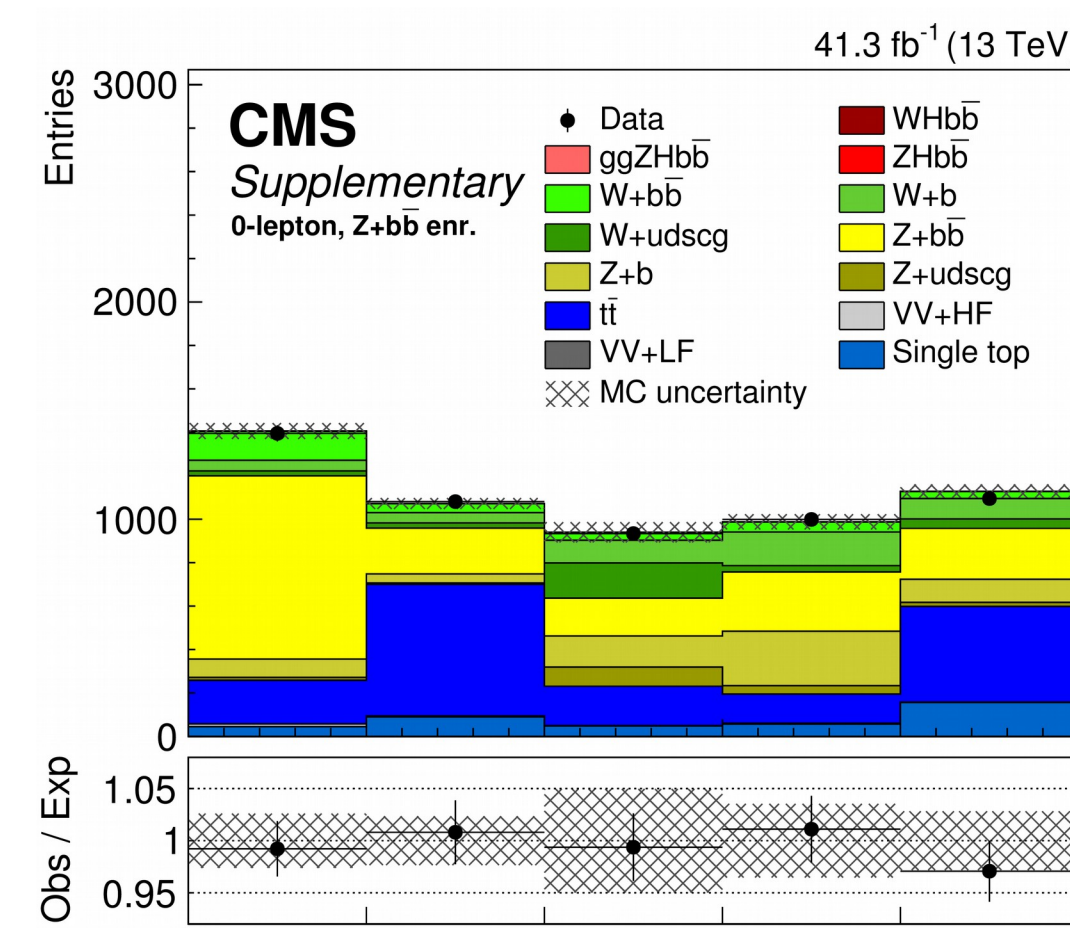

Background in significant bins

DNN output for Z→ μμ.

DNN Multiclassifier

- Systematic uncertainty due to background normalization (SF) among most important impacts.

- Multi-output DNN trained to classify background sources (t, tt, V+b, V+bb, V+light).

- Used in simultaneous fit for V+HF CR in 0 and 1 lepton channel.

DNN output of V+HF CR of Z→ νν channel

mjj cross-check analysis

- Alternative way to fit DNN output score.

- Fit mjj distribution in different bins of DNN score.

- Combine channels by weighing event with S/(S+B).
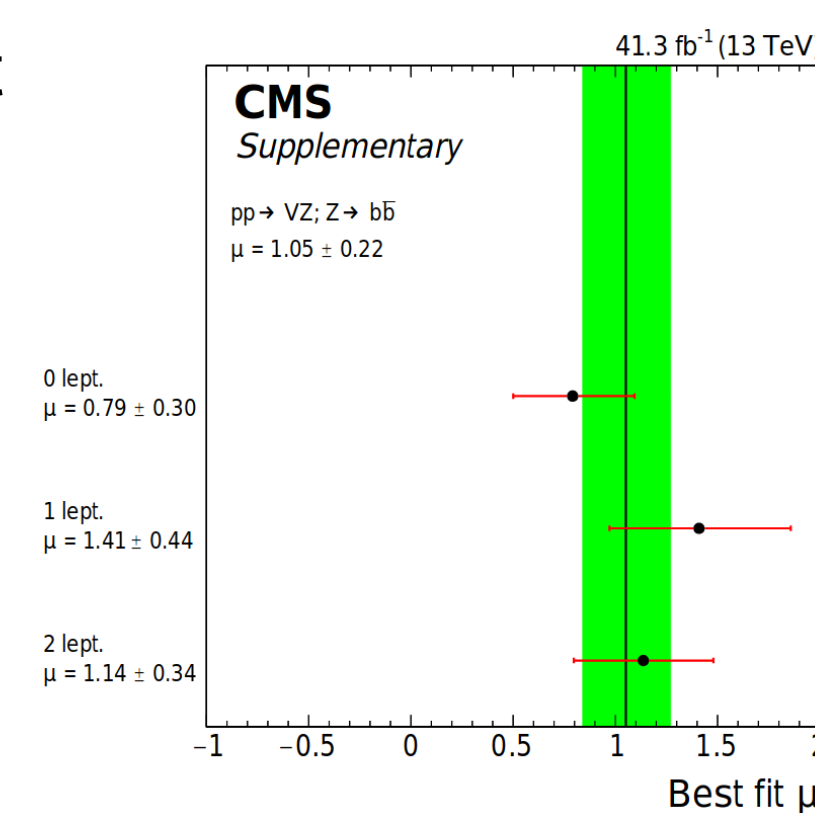
- Sensitivity little lower than for fit with DNN score
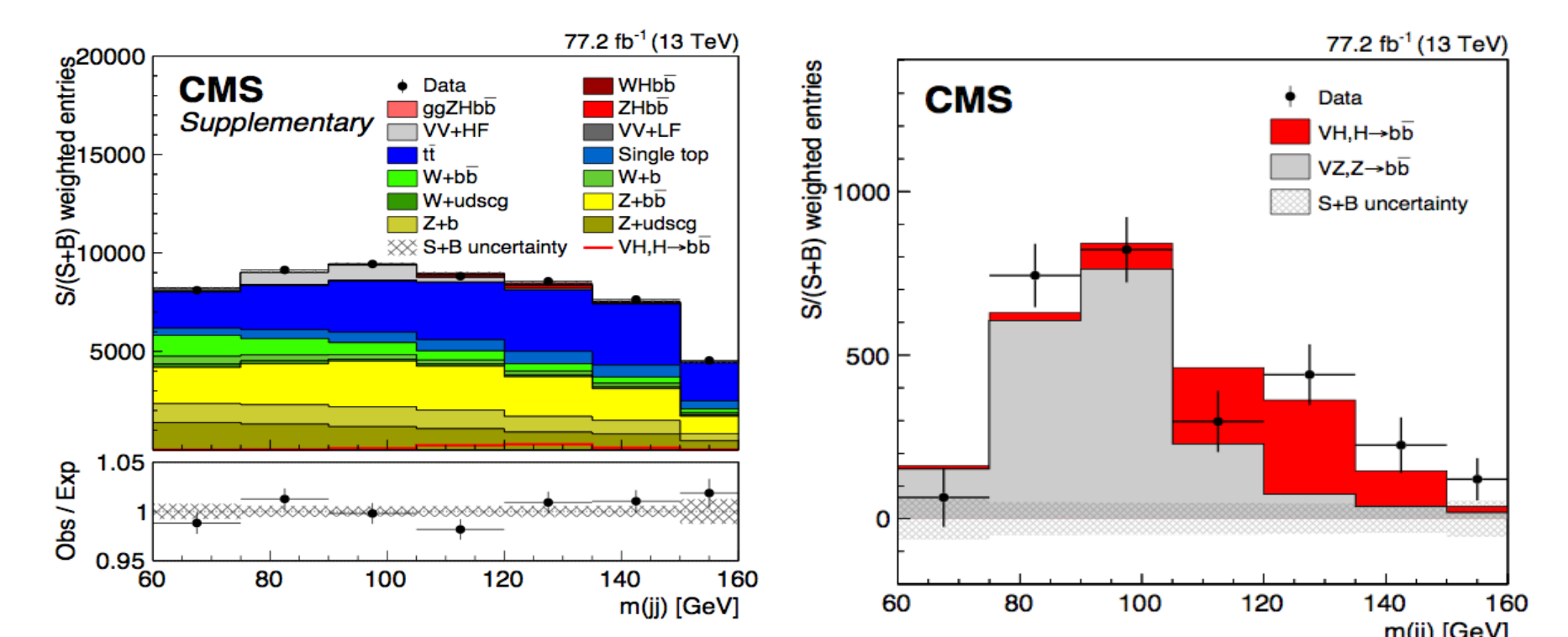
Background subtracted

Result: [2016 + 2017 dataset]
- **μ = 1.16 ± 0.29**
- **obs.** (exp.) **sig.** : **3.8 σ** (3.3 σ)

VZ(bb) cross-check analysis

- Same final state, similar kinemtaics but different dijet invariant mass.

  - DNNs retrained for VZ(bb) as signal.

Result:
- **μ = 1.05 $^{-0.22}_{-0.21}$**
- **obs.** (exp.) **sig.** : **5.2 σ** (5.0 σ)

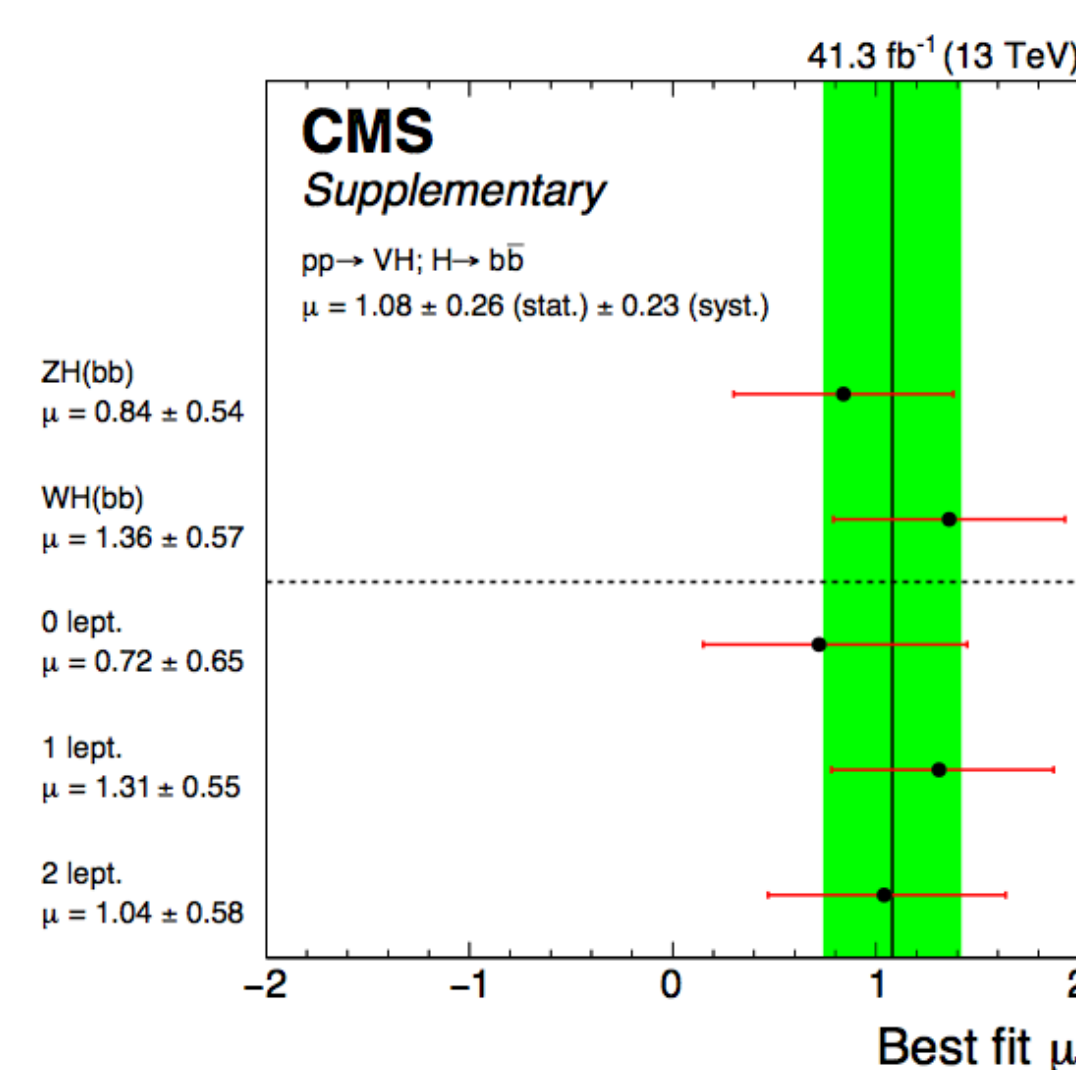## Extraction of process SF

Scale factors for background normalization derived from CR + SR fit

Process	Z(νν)H	W(lν)H	Z(ll)H low-p_T	Z(ll)H high-p_T
W + udscg	1.04 ± 0.07	1.04 ± 0.07	–	–
W + b	2.09 ± 0.16	2.09 ± 0.16	–	–
W + bb̄	1.74 ± 0.21	1.74 ± 0.21	–	–
Z + udscg	0.95 ± 0.09	–	0.89 ± 0.06	0.81 ± 0.05
Z + b	1.02 ± 0.17	–	0.94 ± 0.12	1.17 ± 0.10
Z + bb̄	1.20 ± 0.11	–	0.81 ± 0.07	0.88 ± 0.08
tt̄	0.99 ± 0.07	0.93 ± 0.07	0.89 ± 0.07	0.91 ± 0.07

Results

Channel compatibility is 97%

Combine results of all SR
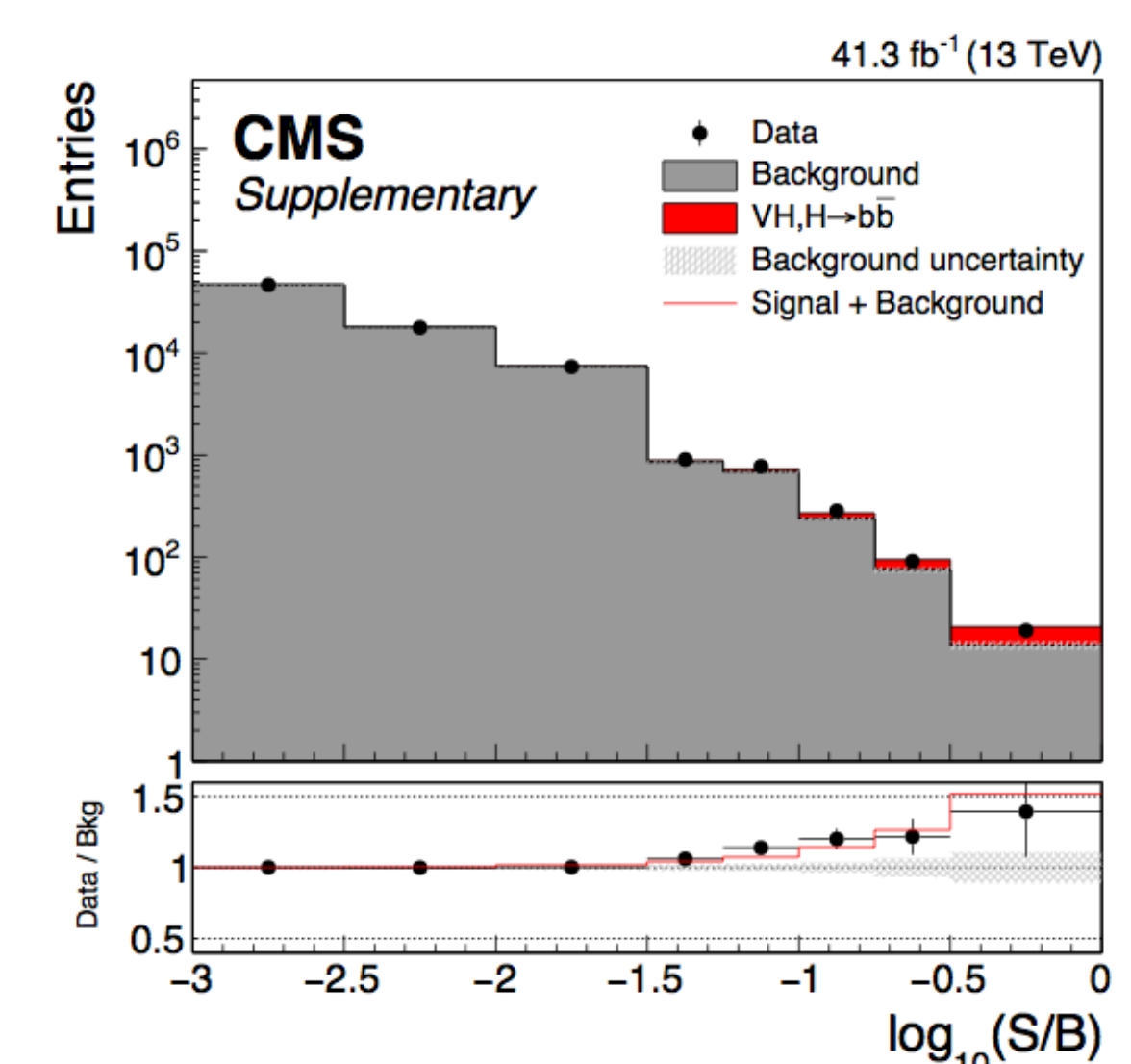
Expected with VHbb
Background only

Using 2017 dataset (41.3fb⁻¹ at 13 TeV)
- **μ = 1.08 ± 0.34**
- **obs.** (exp.) **sig.** : **3.3 σ** (3.1 σ)

Using the Run1 + Run2 dataset
- **μ = 1.01 ± 0.23**
- **obs.** (exp.) **sig.** : **4.8 σ** (4.9 σ)

Ref: Observation of Higgs Boson Decay to Bottom Quarks, CMS Collaboration, Phys. Rev. Lett. **121**, 121801

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