Probing BSM physics using $H \to \gamma\gamma$ at CMS

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The Higgs boson

- Neutral scalar particle of mass $\sim$125 GeV
- Why was it proposed?
  - To keep Lagrangian locally gauge invariant, needed photon and weak bosons to be massless
  - But experiments suggested weak interaction was point-like
- Solution: introduce a complex scalar "Higgs" field:
  - Non zero VEV
  - Ground state break symmetry of Lagrangian
  - Predicts neutral scalar particle

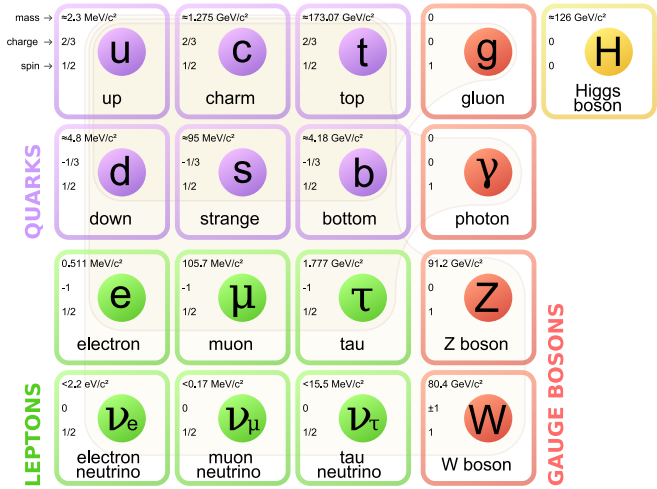


Figure 1: The Standard Model particles[1]

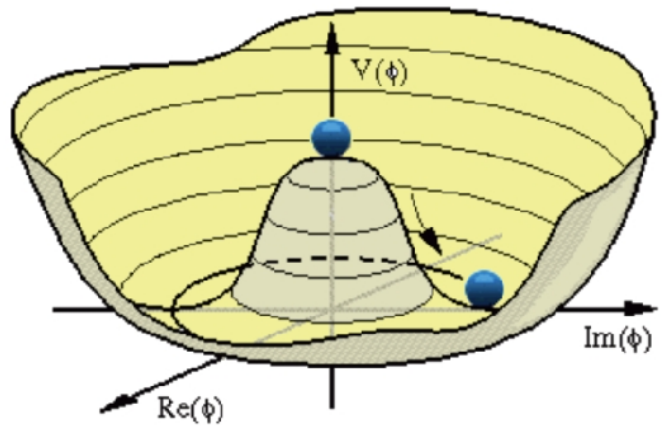
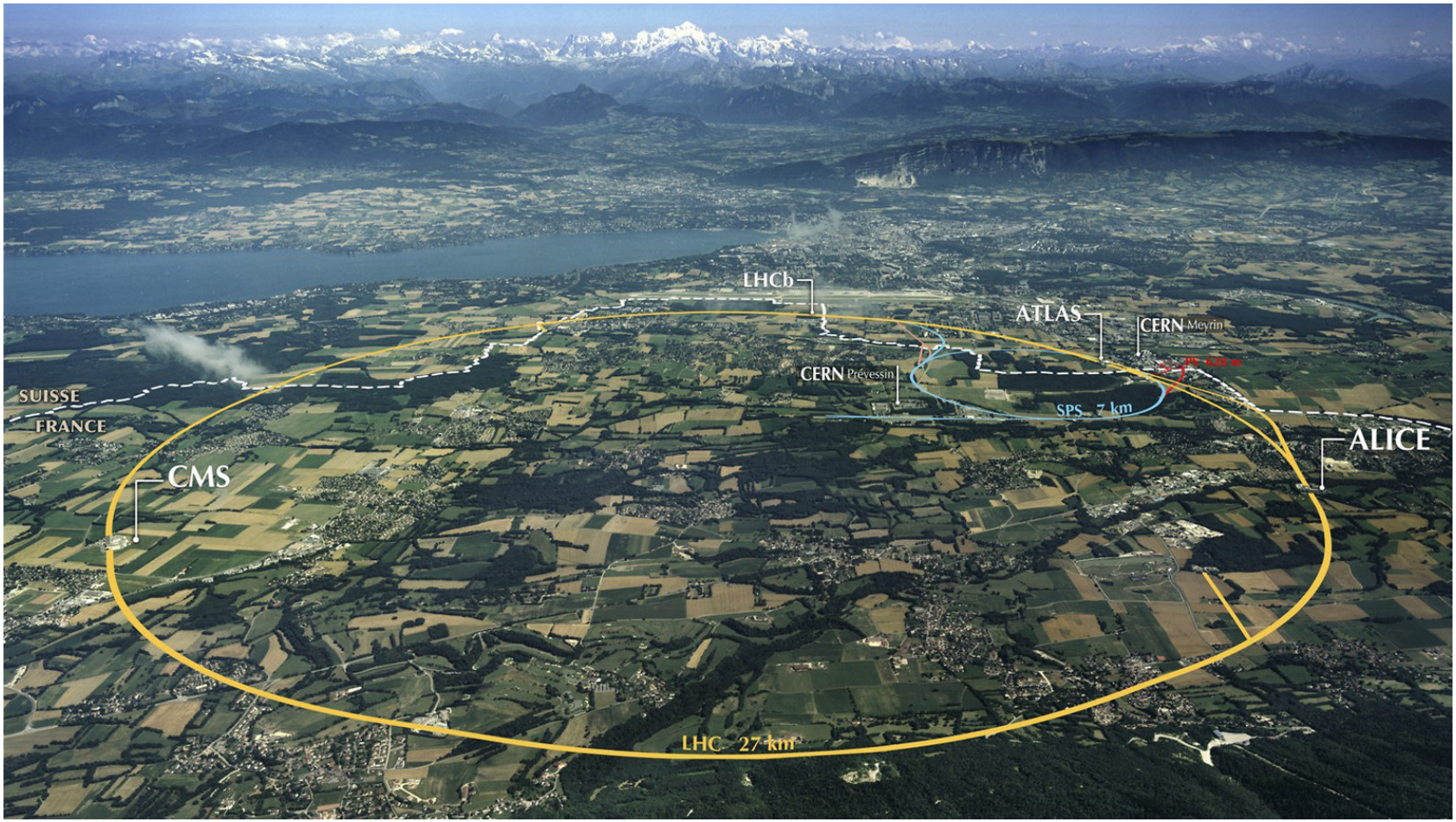


Figure 2: The Higgs potential[2]

The CMS detector

- One of the two general-purpose LHC detectors



The CMS detector

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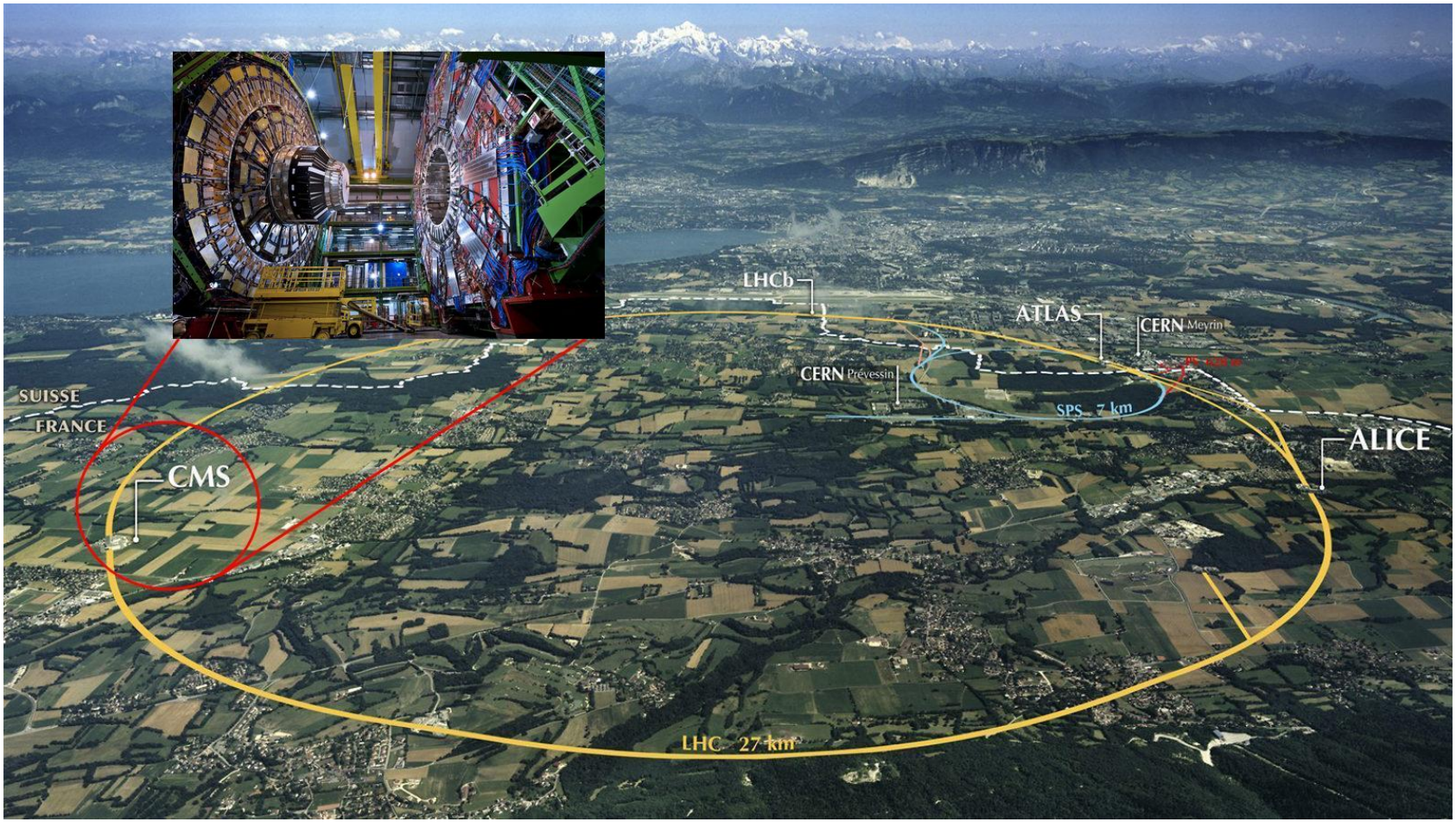

The CMS detector

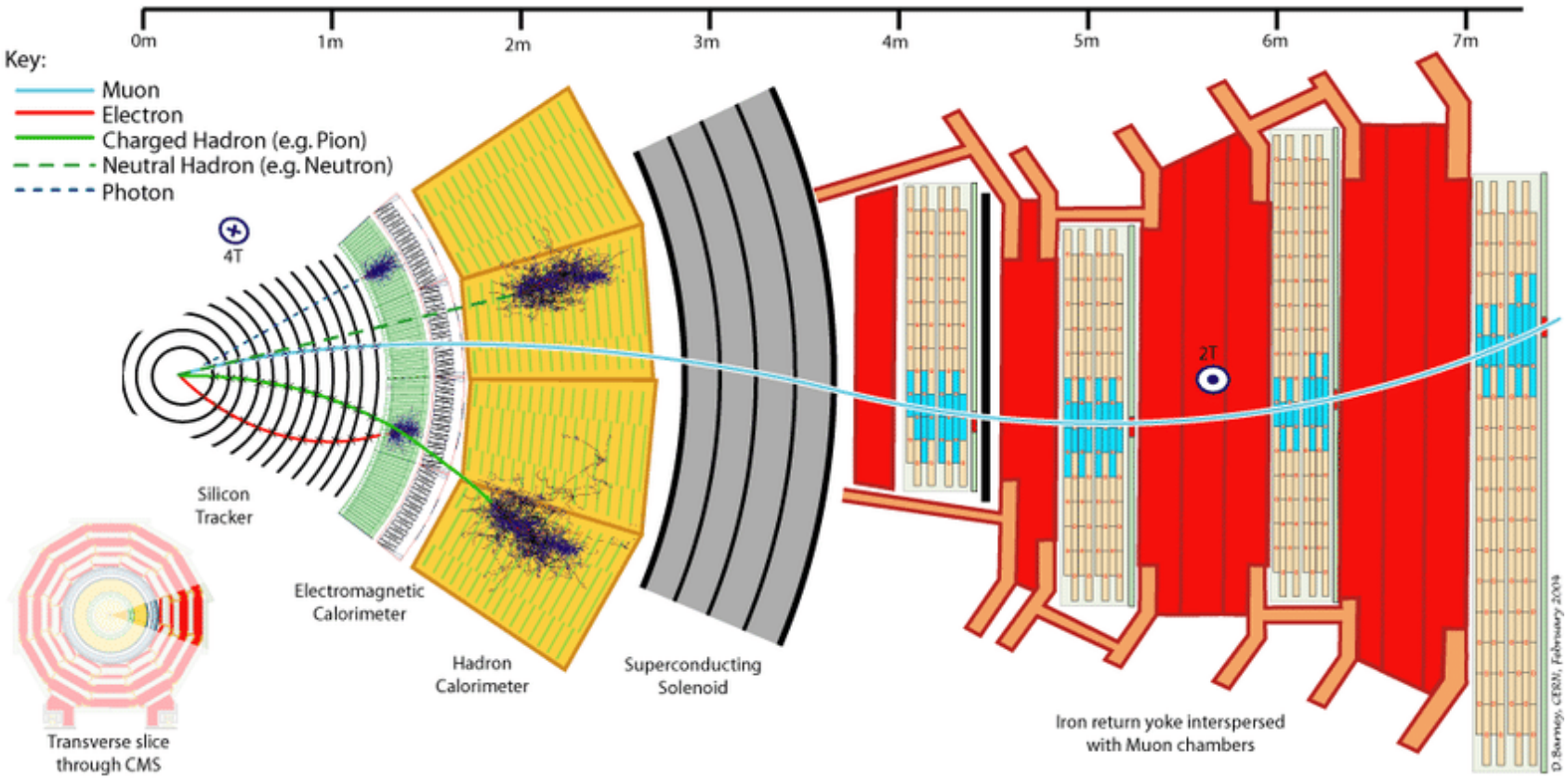

Figure 3: Cross-sectional view of the CMS detector[3].

- Particle flow algorithm used in global event reconstruction [4].

Higgs decay

Which channel to use?

- Might think that $b\bar{b}$ would have best sensitivity
- Hard to distinguish against backgrounds – only recently discovered [5]
- Diphoton channel has a low BR ($< 1\%$) but clean signature in ECAL
- Key channel in discovery[6, 7]

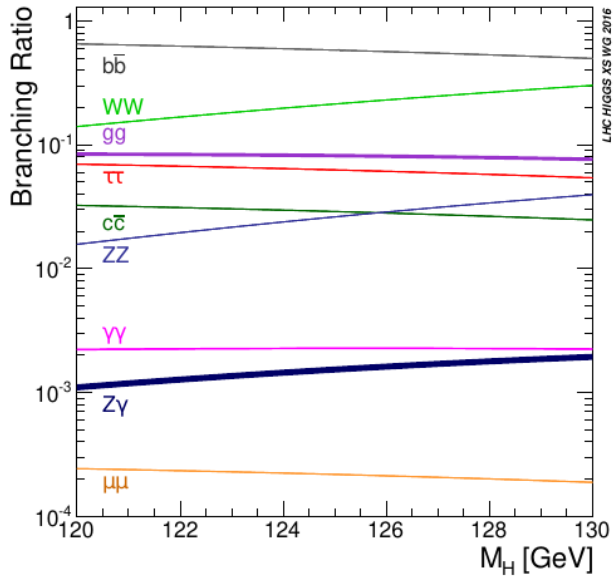

Figure 4: Higgs branching ratios as a function of Higgs mass [8].

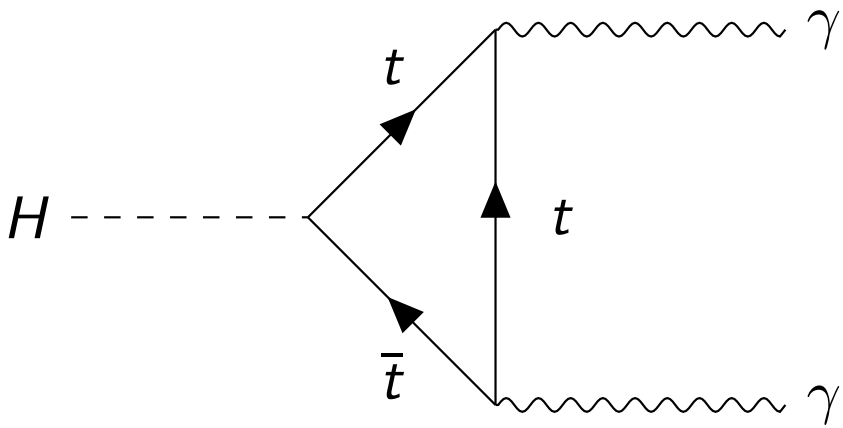

Figure 5: Higgs decaying to two photons.

Higgs decay

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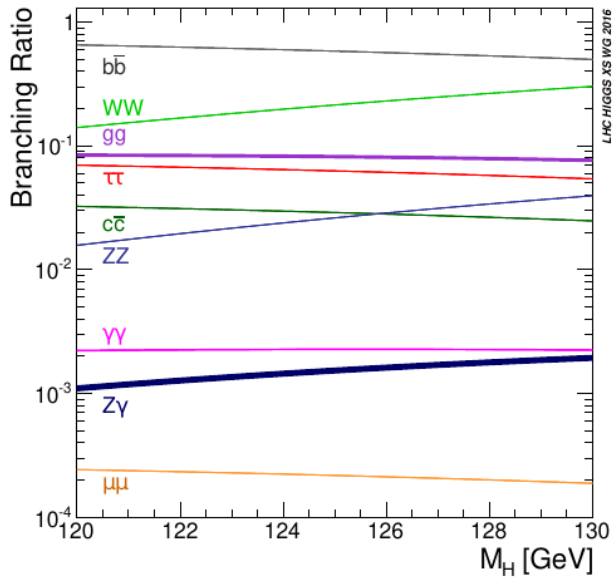

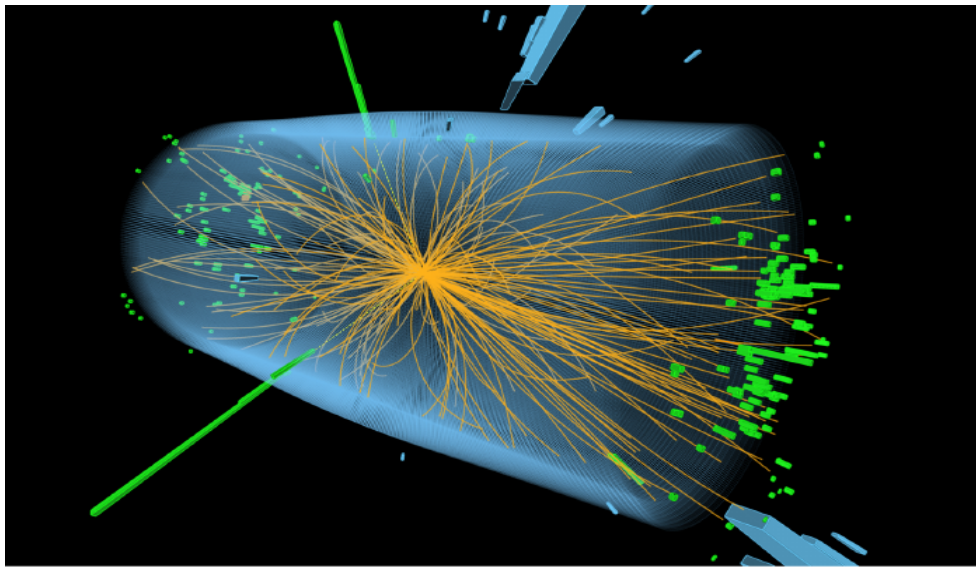

Figure 4: Higgs branching ratios as a function of Higgs mass [8].

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Analysis aim and strategy

Aim

To probe to what extent the Higgs boson behaves as the SM predicts

- How do we do this?
  - Measure the signal strength modifier, μ, defined as:

$$\mu = \frac{\text{Observed rate of } \mathrm{H} \to \gamma\gamma}{\text{SM rate of } \mathrm{H} \to \gamma\gamma}$$

  - Any deviations from $\mu = 1$ may indicate BSM physics
- Or measure cross sections for different categories of Higgs production and decay (STXS)
  - How do we obtain them?

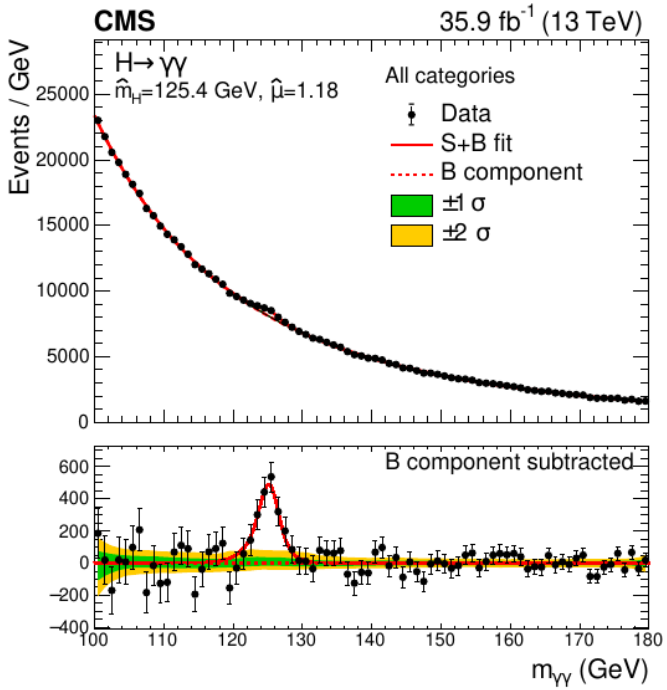
Reconstruction of Higgs mass signal

From conservation of 4-momentum:

$$m_{\gamma\gamma} = \sqrt{2\,E_1 E_2\,(1 - \cos\,\theta\,)} \tag{1}$$

- Photon energy measurements:
  - Dependent on resolution of ECAL
- Opening angle:
  - Dependent on vertex identification (BDT)

- Identify candidate photons from background pairs using a multivariate classifier:
  - Takes inputs such as shower shape, isolation, and pseudorapidity.
- Accepted signal candidates binned in histogram for each category



Simplified template cross sections (I)

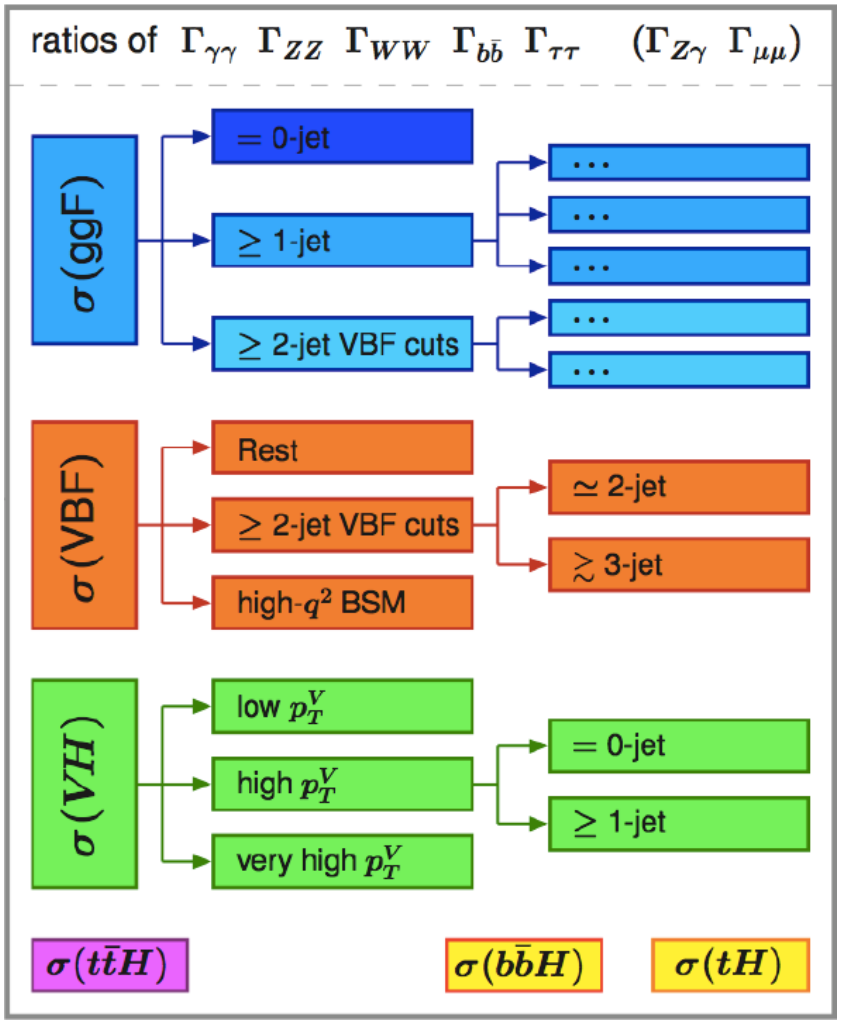


Figure 7: Event flow chart for STXS[10].

Event categorisation in STXS

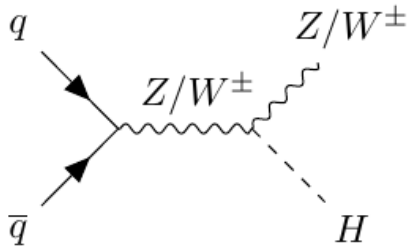
- **Stage 0**: construct categories for different Higgs production mechanisms
- **Stage 1**: further split by kinematic features and event topology of final state e.g. p_{T}, number of jets, etc.

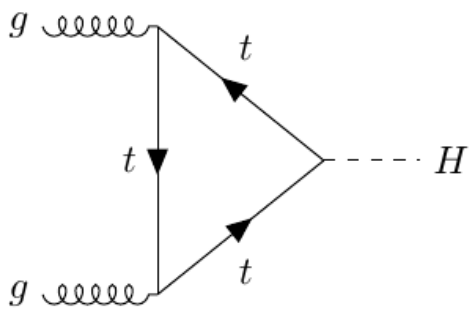
→ Extract μ or cross sections by simultaneous likelihood fit

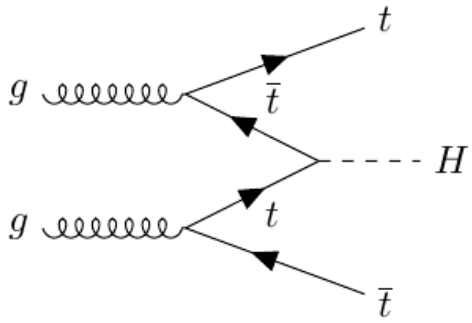
- Why do this?
  - Reduced theory uncertainty
  - Higher sensitivity than inclusive measurements

Simplified template cross sections (II)

- Some distributions for example categories[9]:







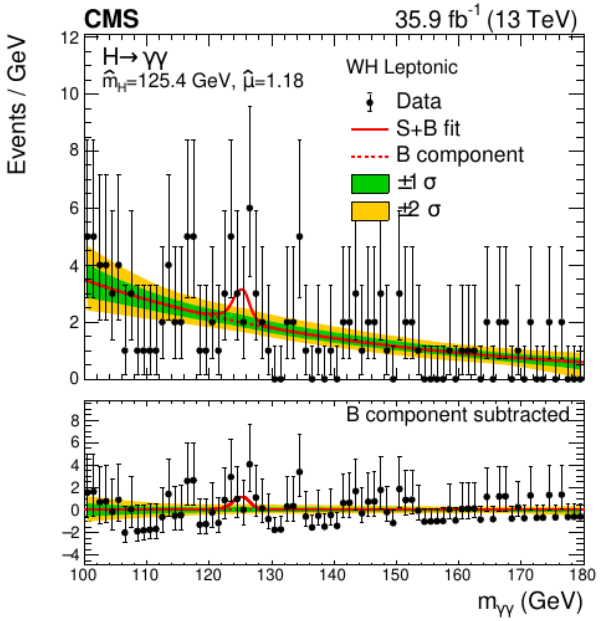


Figure 8: VH subcategory

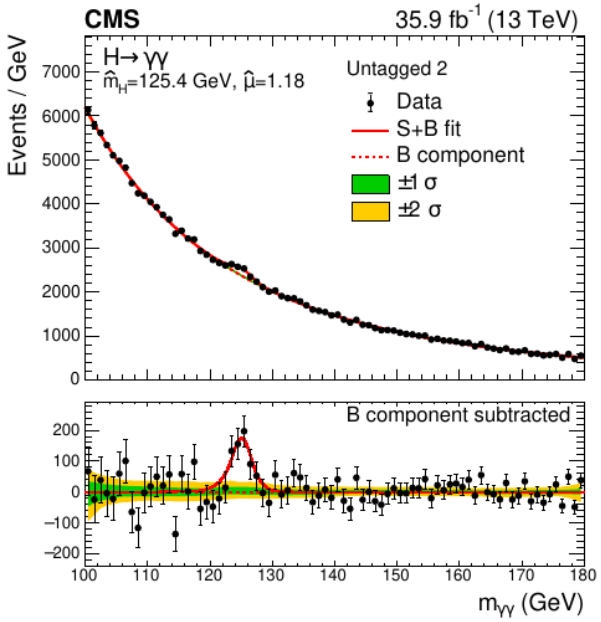


Figure 10: ggH subcategory

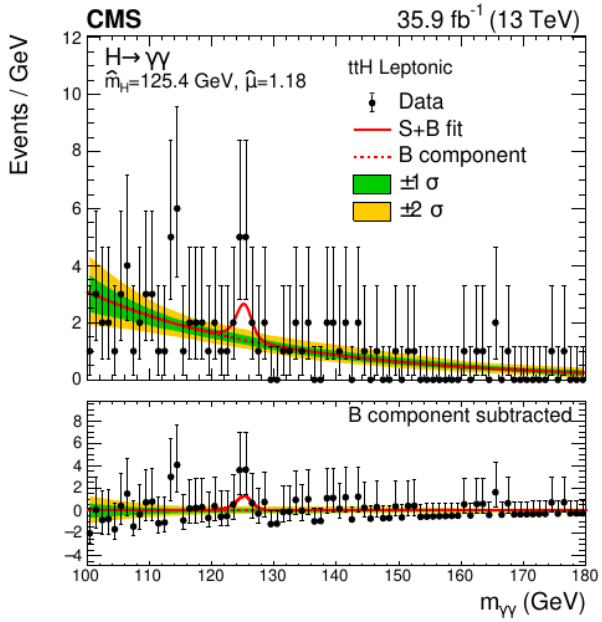
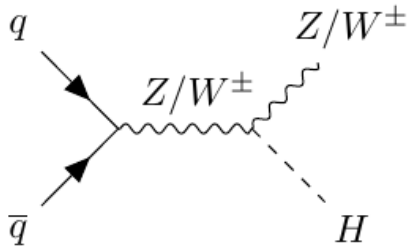
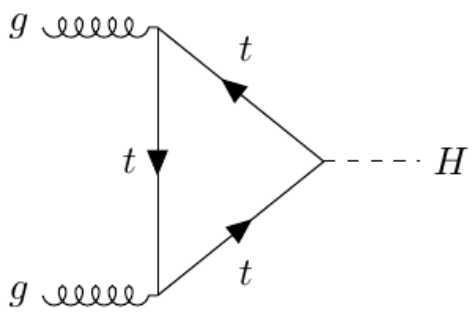


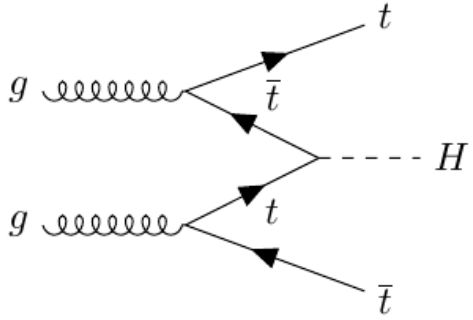
Figure 11: $t\bar{t}H$ subcategory

Simplified template cross sections (II)

- Some distributions for example categories[9]:







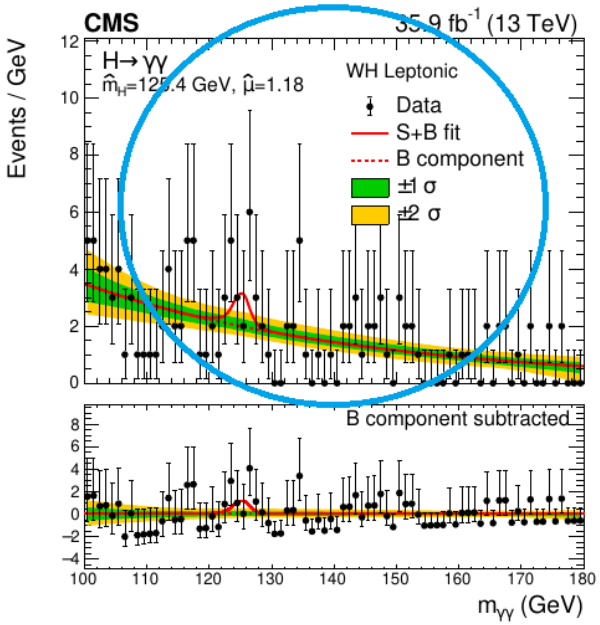


Figure 9: VH subcategory

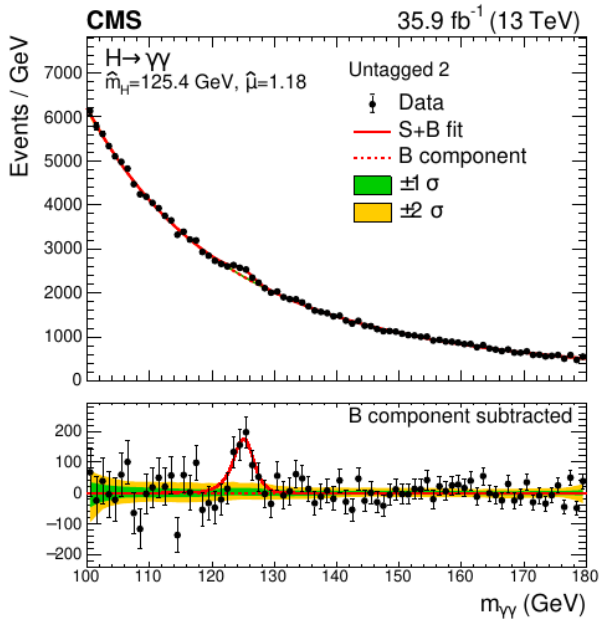


Figure 10: ggH subcategory

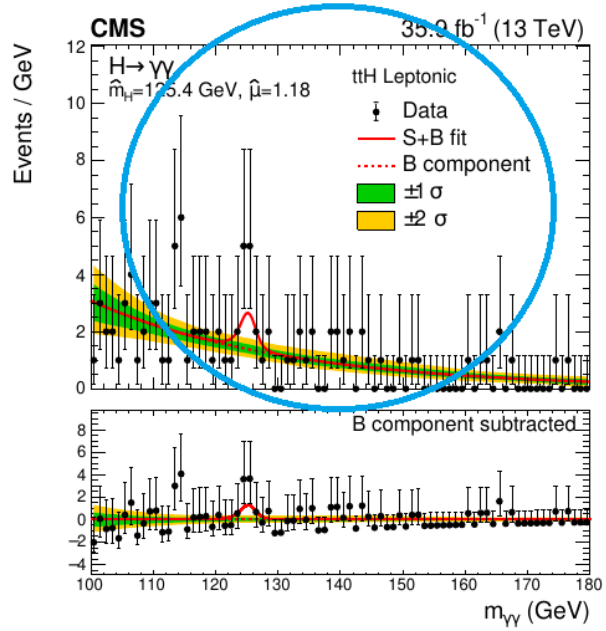


Figure 12: $t\bar{t}H$ subcategory

BSM Higgs and future studies

- From the fit, we can extract observed cross sections compare to some model (STXC stage 0)

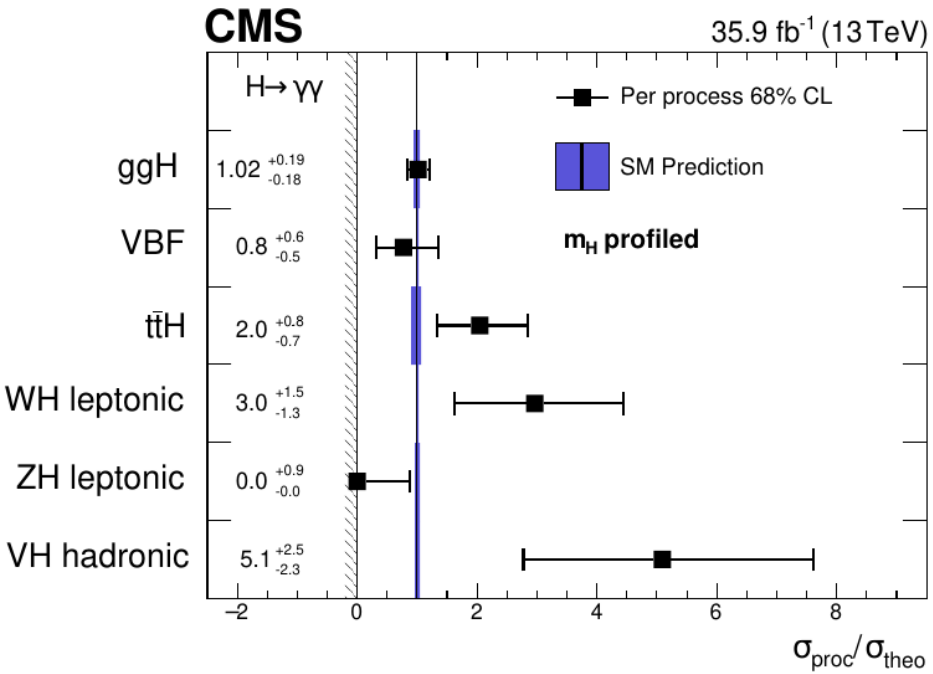


Figure 13: Stage 0 of the STXS framework[9]

- Theory uncertainty is factorised into model prediction
- For example, we could compare to the SM...
- Or re-interpret in different BSM contexts e.g. using EFT → quantify agreement with p-value

- Low statistics channels will benefit from full run 1 and run 2 data sets ($\sim$150fb^{-1})

Summary

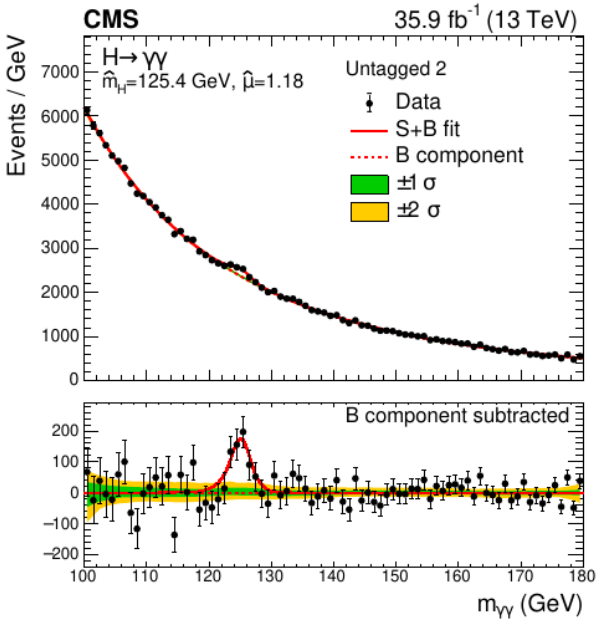
To conclude:

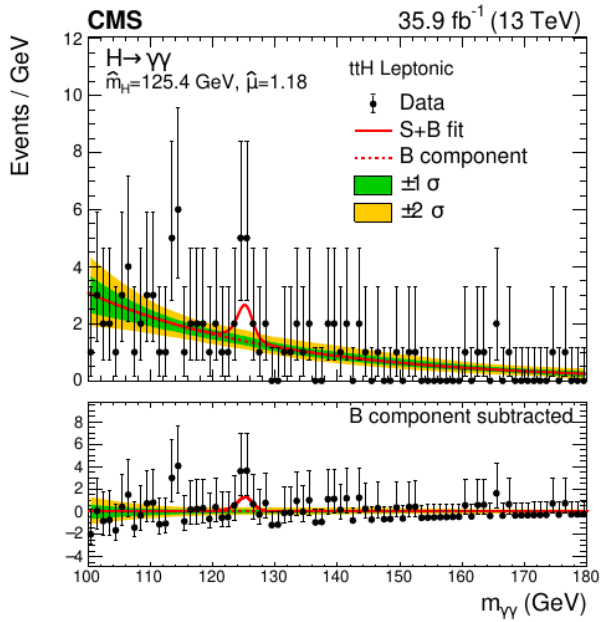
- We are now in the era of precision Higgs measurements
- Current results are compatible with the Higgs being SM-like
- Some categories still limited by statistics $\rightarrow$ Aim to improve these with the full run 1 and 2 data sets

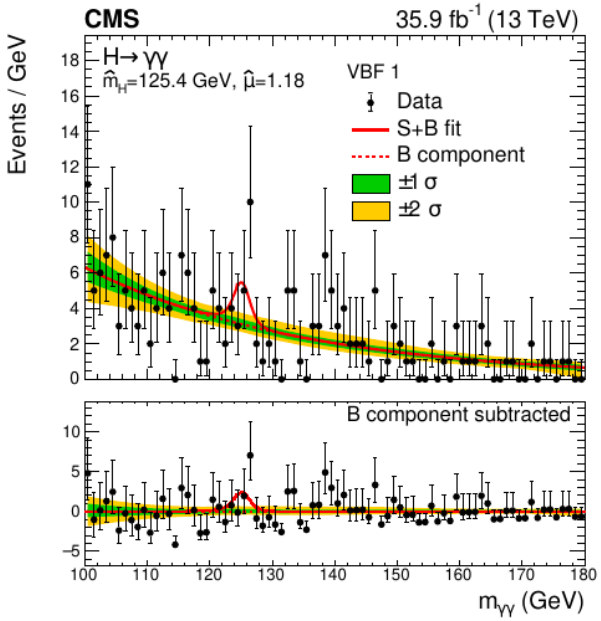
Thank you

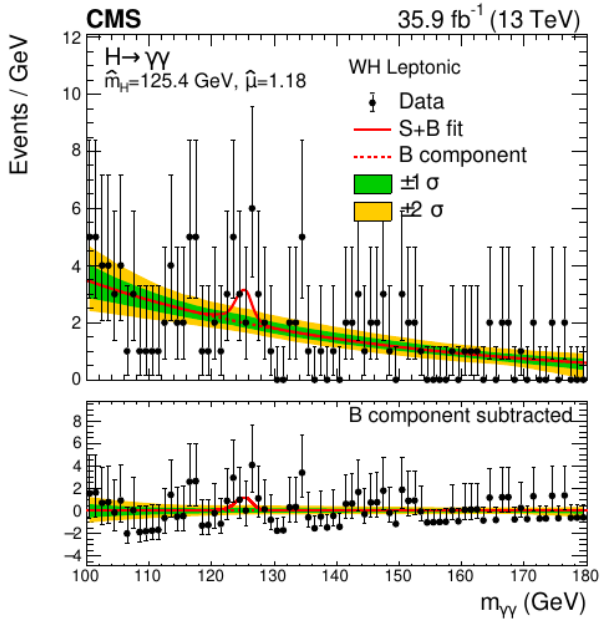
Back up slides

Invariant mass distributions

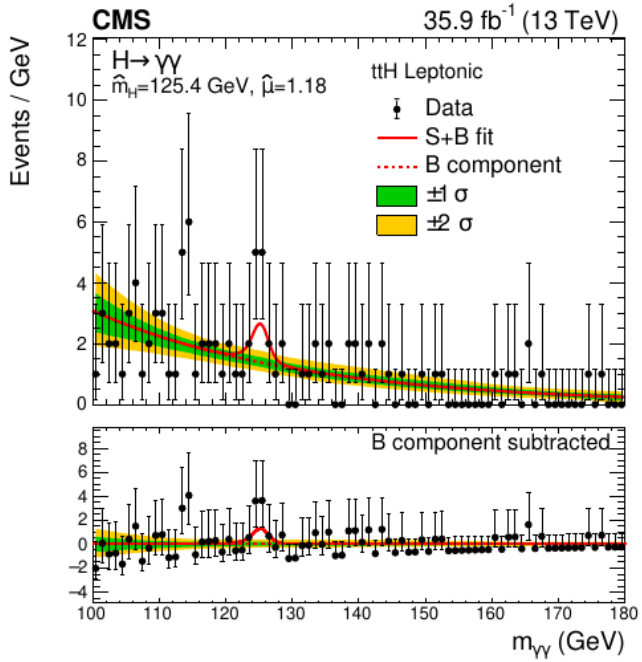


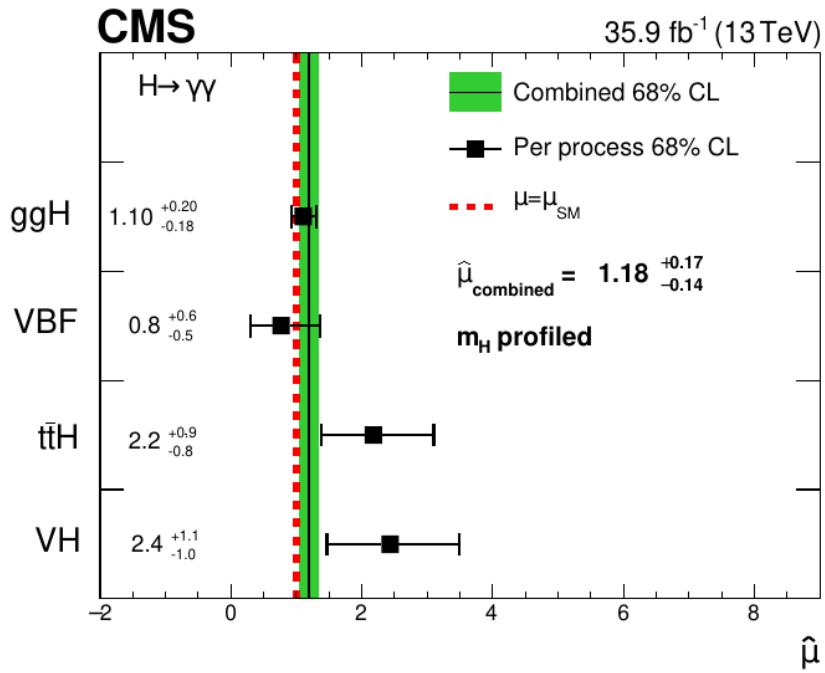






Traditional signal strength





- Can obtain a "traditional" signal strength: ratio of rates for each mode.
- Current best CMS result[9]:

$$\mu = 1.18^{+0.17}_{-0.14} = 1.18^{+0.12}_{-0.11}(\text{stat})^{+0.09}_{-0.07}(\text{syst})^{+0.07}_{-0.06}(\text{theo})$$

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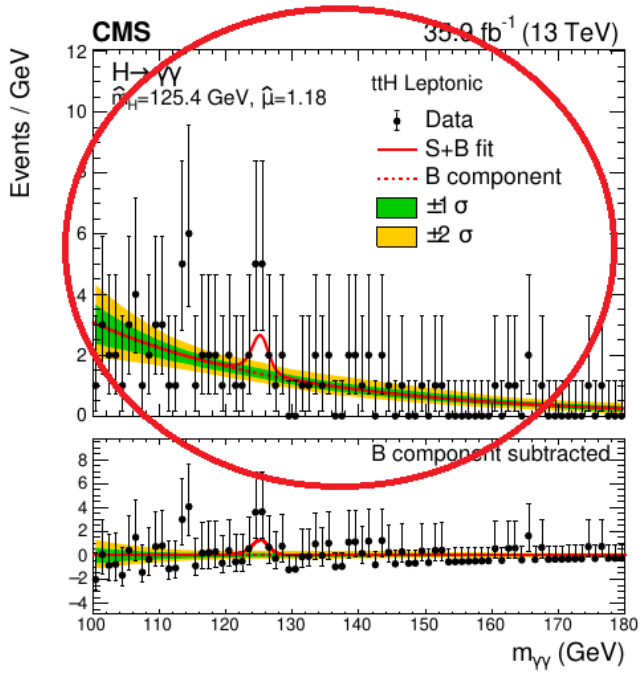

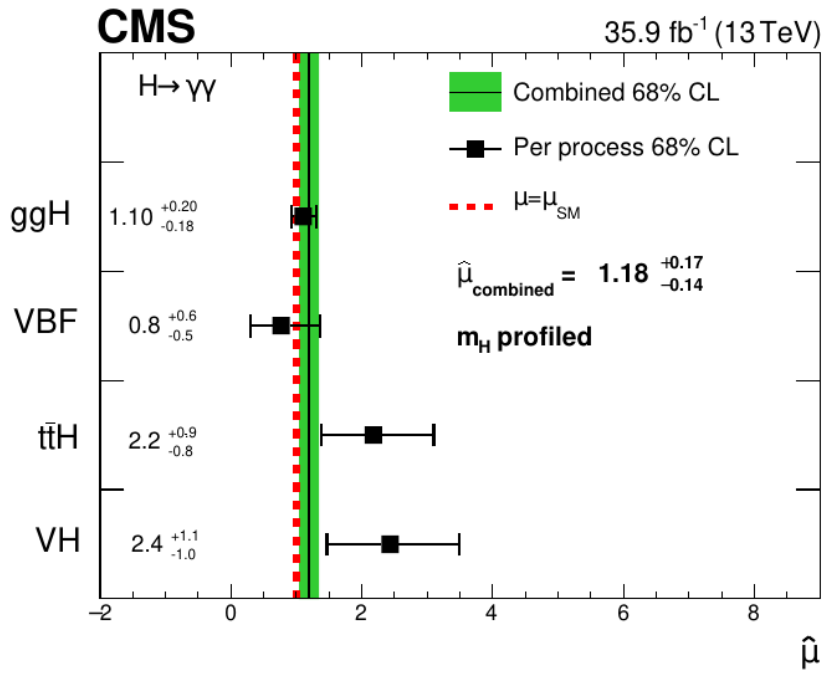

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Higgs production at the LHC

Four main LHC production modes

- Vector boson fusion (VBF)
- Production in association with:
  - a weak boson (VH)
  - a top-antitop pair ($t\bar{t}H$)
- Gluon-gluon fusion (ggH)

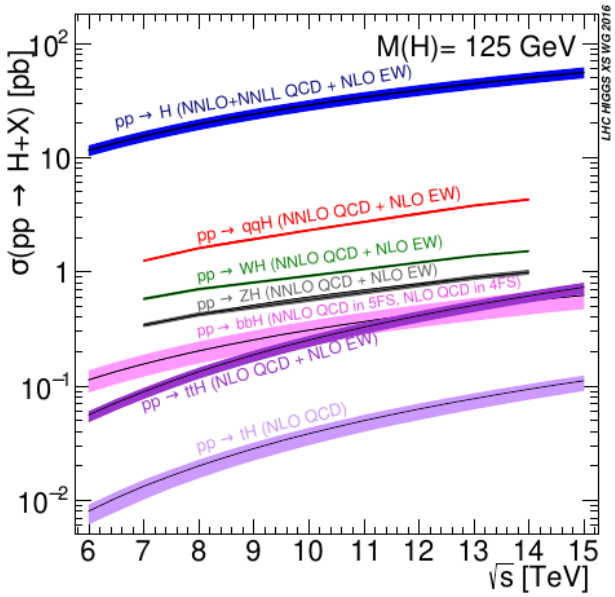
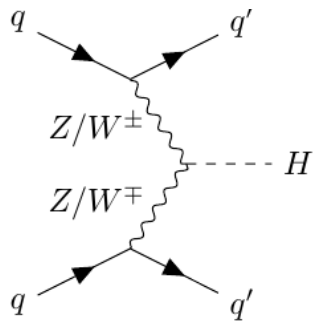
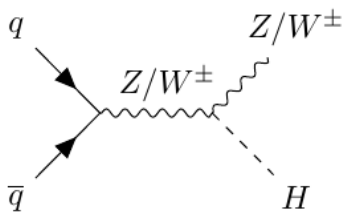


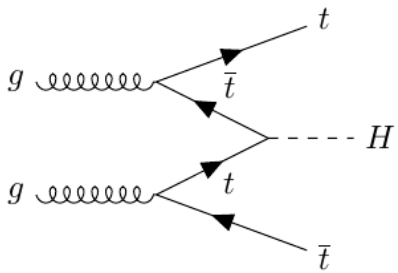
Figure 15: Higgs production cross sections as a function of Higgs mass, at $\sqrt{s} = 13$ TeV[8]



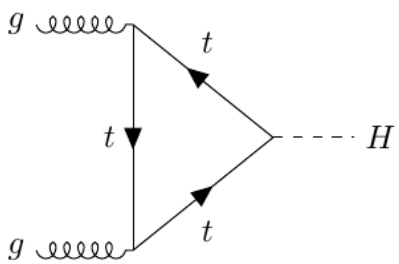
(a) Vector boson fusion.



(b) Higgs-strahlung.



(c) Associated top production.



(d) Gluon-gluon fusion.

BDTs

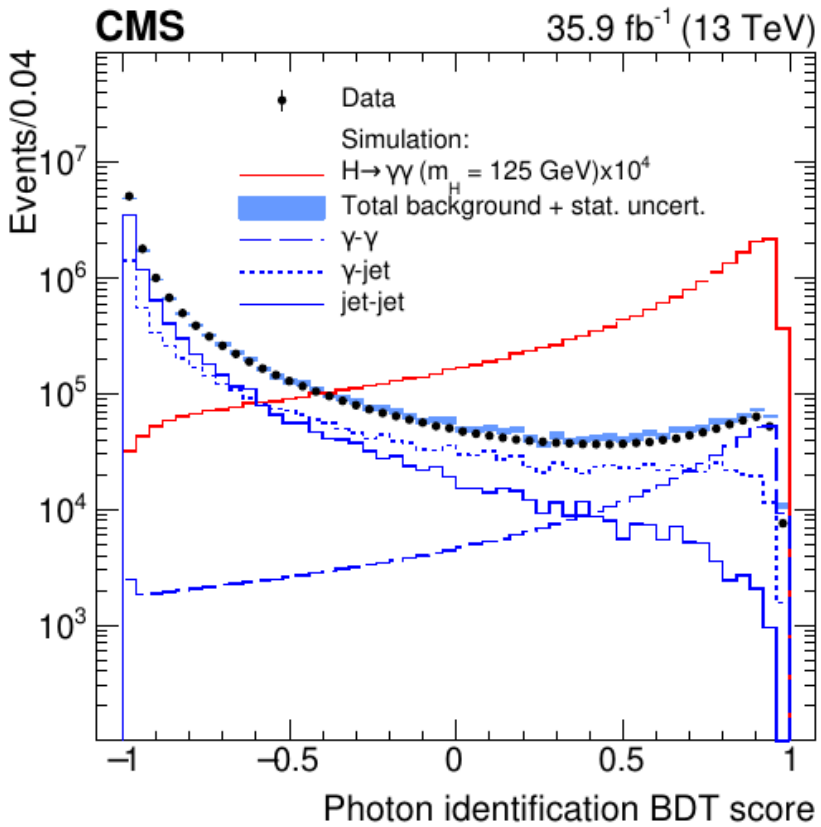


Figure 16: Photon BDT that separates background from signal[9].

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