# Higgs boson mass measurement at CMS

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for the CMS Collaboration

2016 Run 2 dataset (35.9 fb⁻¹ at 13 TeV), combined with Run 1 (24.8 fb⁻¹ at 7 and 8 TeV)

Workhorse channels for the measurement are $H \to ZZ \to 4\ell$ and $H \to \gamma\gamma$,
both giving resonant mass peaks of similar resolution, $\mathcal{O}(1\%)$,
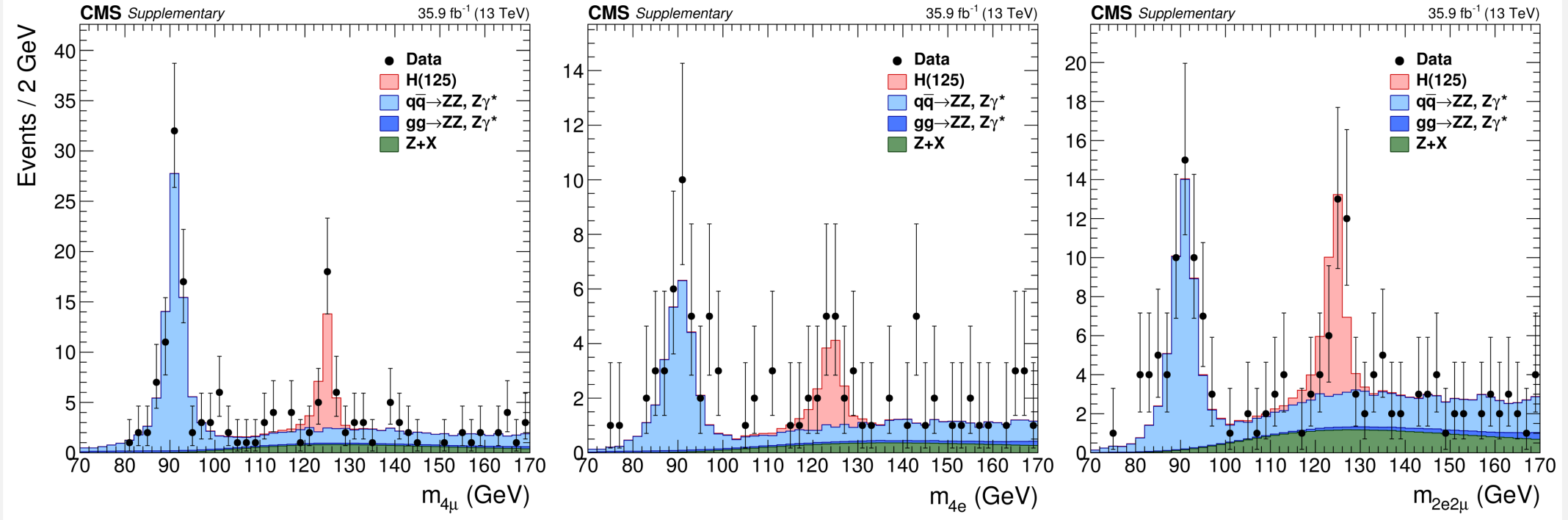but with very different signal event yields and signal-to-background event rate ratios

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$H \to ZZ \to 4\ell$

$\mathcal{L} \times \sigma \times \mathcal{B} \approx 250$ events
Expected reconstructed ≈ 66 events
S/B $\approx$ 4:1 at the peak
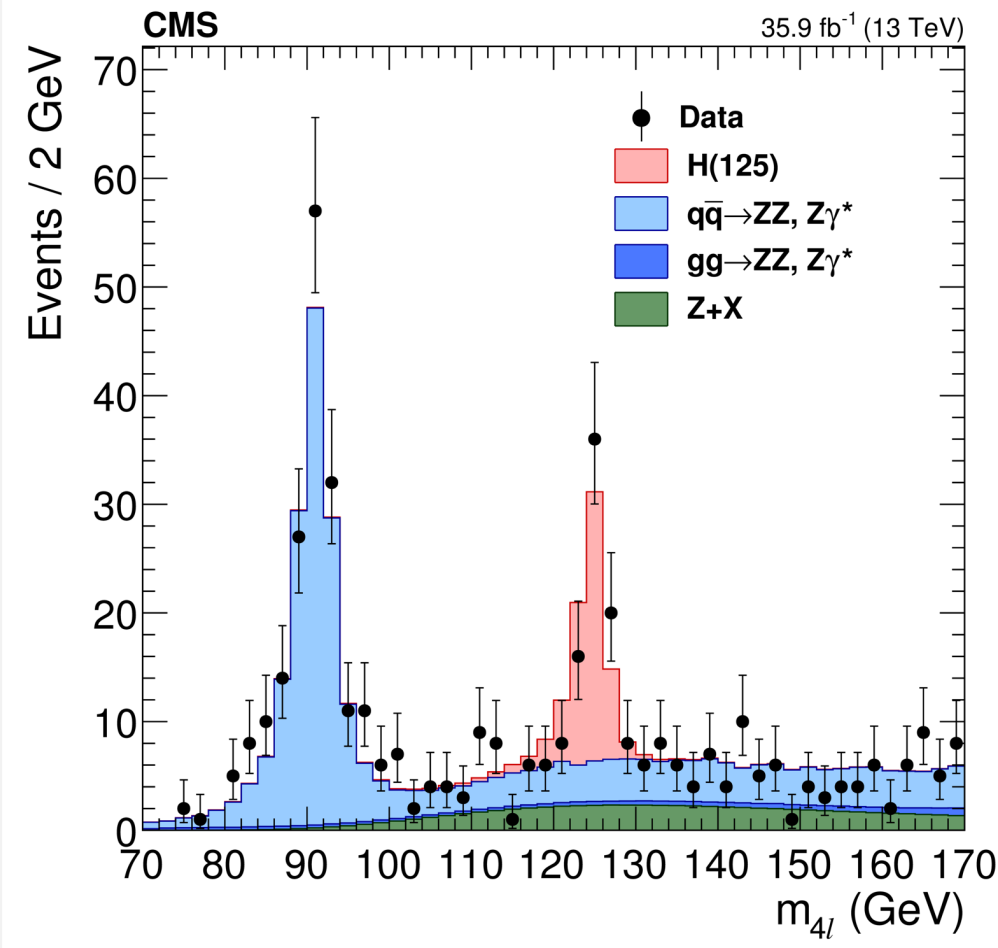
Event categorization:

4μ, 4e, 2e2μ (different resolutions, different S/B)

Z_1-mass constraint:

- $H \to Z_1 Z_2 \to 4\ell$: Z_1 is mostly on-shell with $m_{Z1} \sim m_Z$
- Use pdf(m_{2l}) for the Z_1 lepton pair to refit the leptons' momenta
- Works the best for di-electrons that have a worse momentum resolution: see the plot on the right
- Improves m_H measurement precision by 8%
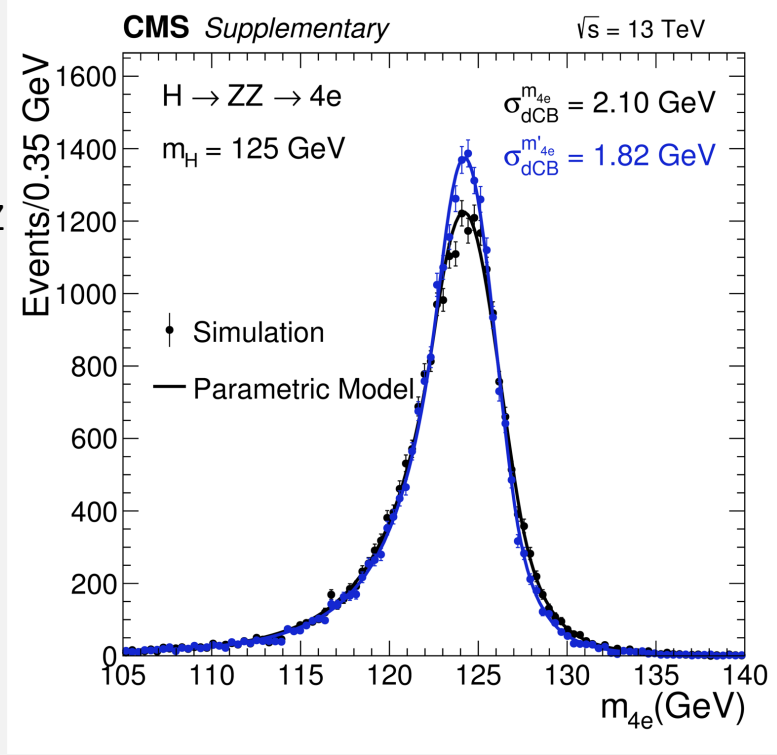
Per-event mass resolution:

- Within each event category, four-lepton mass resolution σ_m varies from one event to another
- Predicted per-event mass resolution uncertainties are calibrated using Z events: see plot on the right
- Introduce in the fit a 2nd observable: σ_m
- Improve m_H measurement precision by 10%
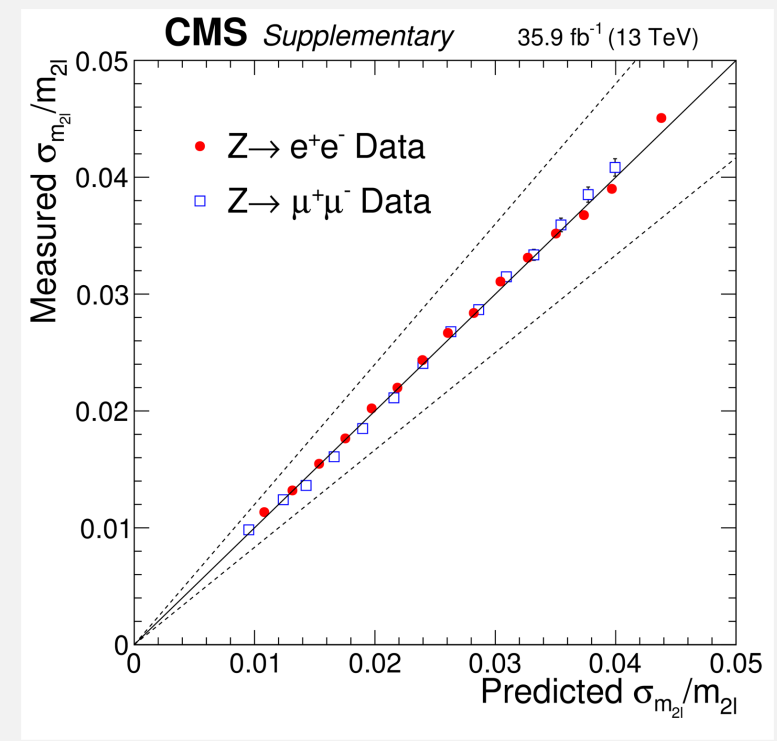
ME-based discriminant:

- Signal and background have different kinematic properties (mostly, due to the differences in the m_{Z2} distributions)
- Introduce in the fit a 3rd observable, D, based on the ratio of Matrix Elements computed on per-event basis: see the plot on the right
- Events that look more like background get smaller weight in the fit
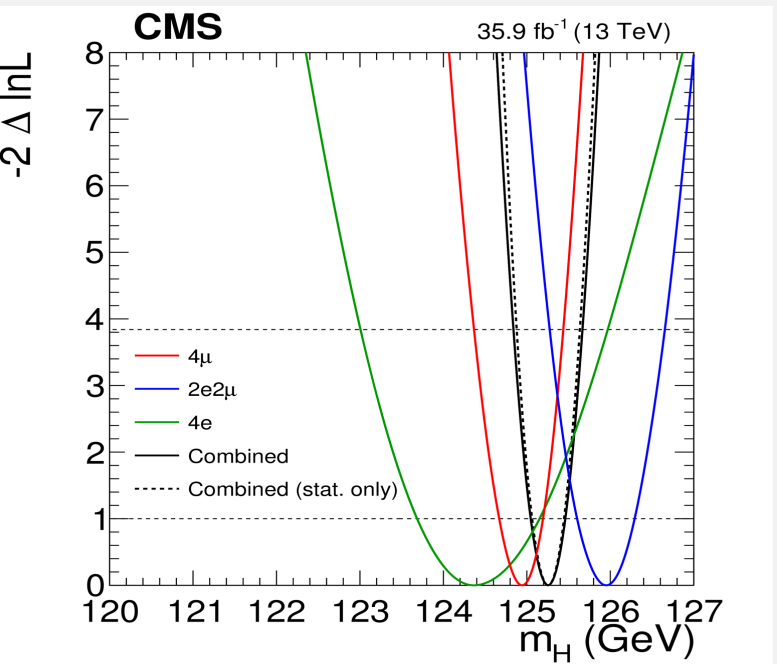- Improve m_H measurement precision by 3%
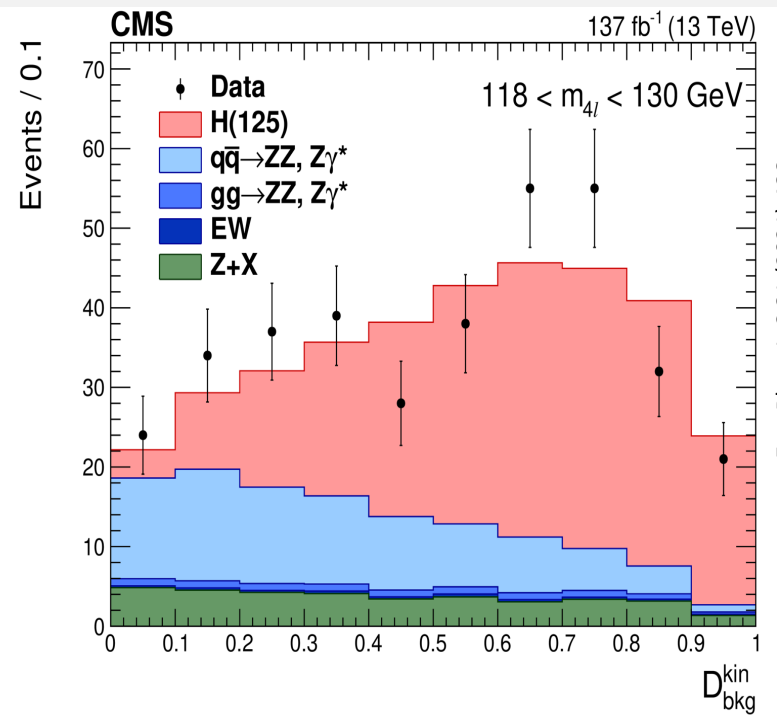
Final mass fit:

$N \cdot pdf(m_{4\ell}|m_H, \sigma_m) \cdot pdf(\sigma_m|m_{4\ell}) \cdot pdf(D|m_{4\ell}) + \text{BKG}$
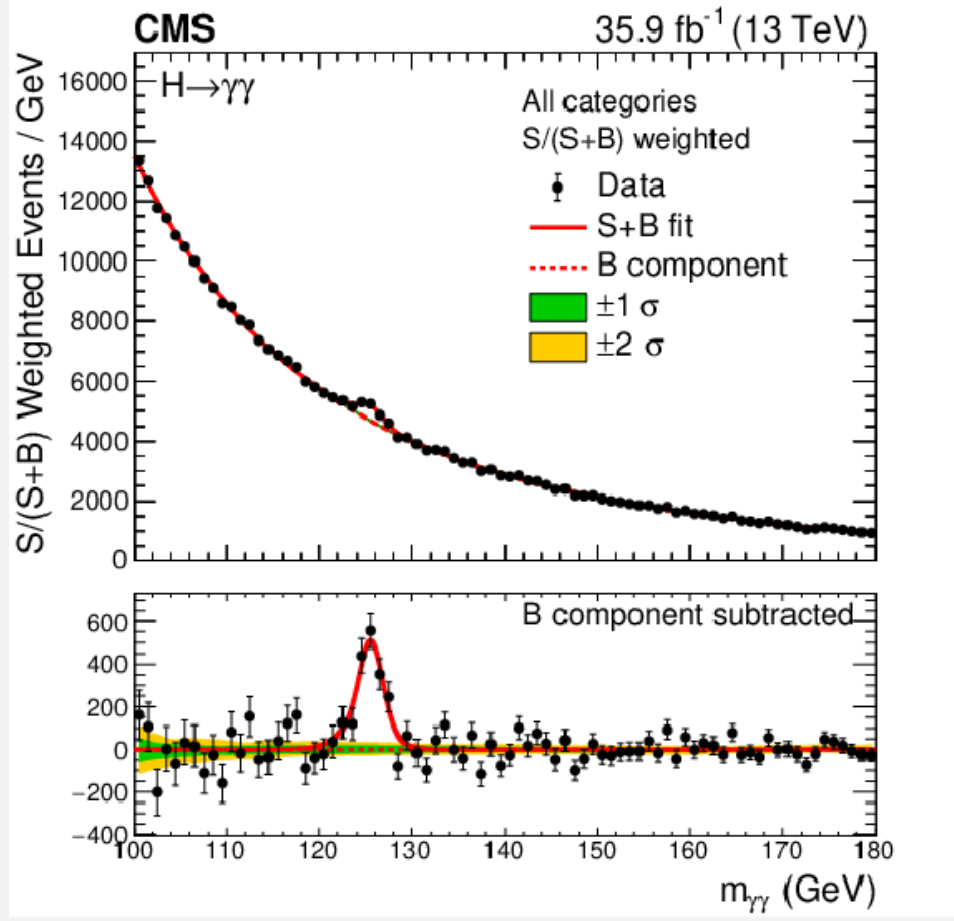in three event categories

Validation of the measurement:

- Higgs boson mass measurements in the three final states are self-consistent: see the plot on the right
- The Z boson mass measured in the $Z \to 4\ell$ decay is 90.84 ± 0.24 GeV is compatible the PDG value

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$H \to \gamma\gamma$

$\mathcal{L} \times \sigma \times \mathcal{B} \approx 4500$ events
Expected reconstructed ≈ 1900 events
S/B $\approx$ 1:10 at the peak (weighted events)

Event categorization:

- Di-photon MVA discriminant $D_{\gamma\gamma}$ (higher score for better mass resolution and higher photon purity)
- VBF MVA discriminant D_{VBF} (trained vs gg $\to$ H and background)
- Enhanced VBF MVA discriminant $D_{eVBF}(D_{VBF}, D_{\gamma\gamma}, p_T^{\gamma\gamma}/m_{\gamma\gamma})$

Untagged: remaining events, grouped in four categories according to $D_{\gamma\gamma}$
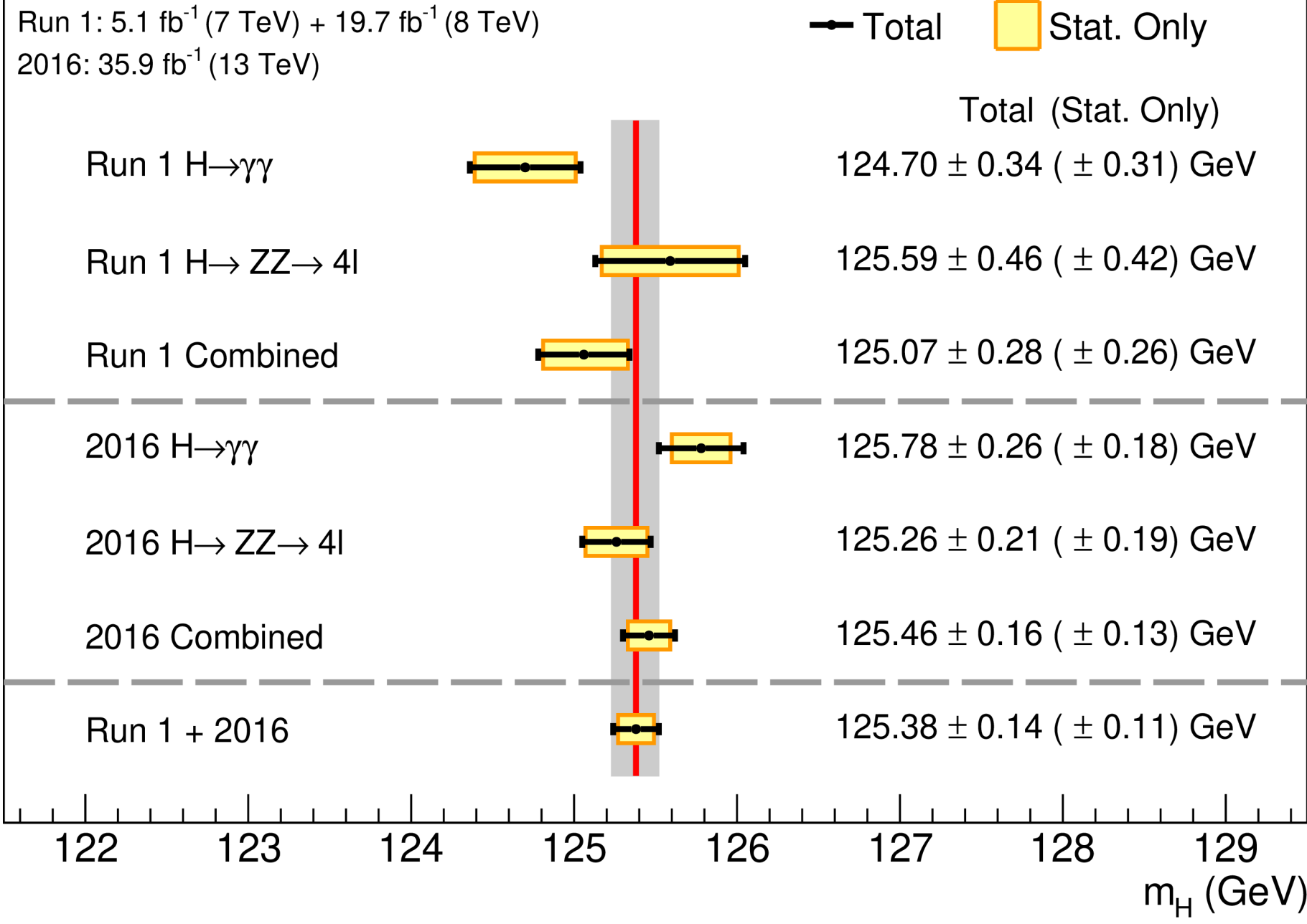
VBF-tagged: three categories with the highest scores of discriminant D_{eVBF}
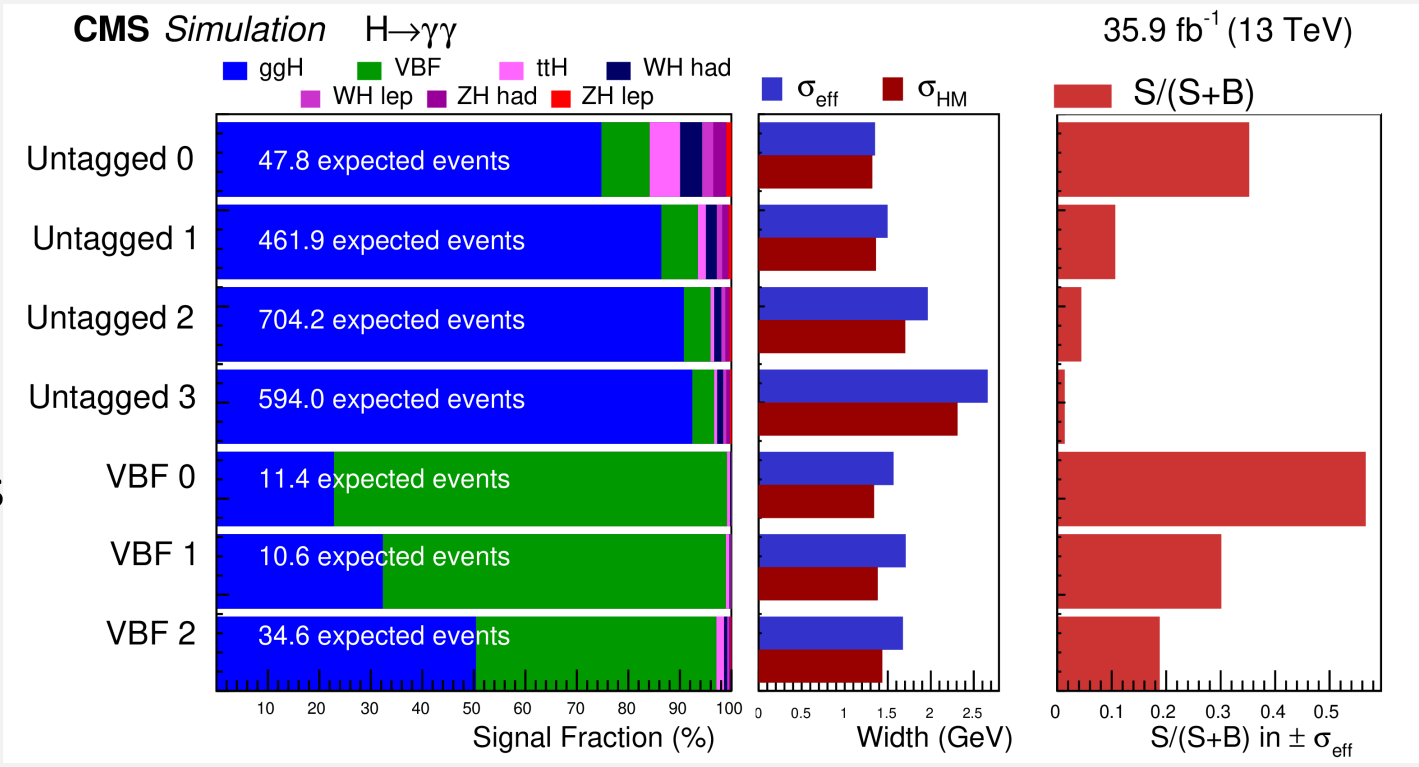
Final mass fit: $N \cdot pdf(m_{\gamma\gamma}|m_H) + \text{BKG}$ in seven event categories

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RESULTS

Run 1 + 2016: $m_H = 125.38 \pm 0.14$ GeV

NOTA BENE:
(1) The best measurement of the Higgs boson mass as of today
(2) Stat uncertainties in the two decay channels are similar
(3) Emerging experimental challenge in the $H \to \gamma\gamma$ channel: stat errors are becoming smaller than syst uncertainties

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Cross-reference:
ATLAS combination (Run 1 + 2016): $m_H = 124.97 \pm 0.24$ GeV [PLB 784 (2018) 345]
ATLAS $H \to 4\ell$ only (Run 1+ Run 2): $m_H = 124.94 \pm 0.18$ GeV [PLB 843 (2023) 137880]