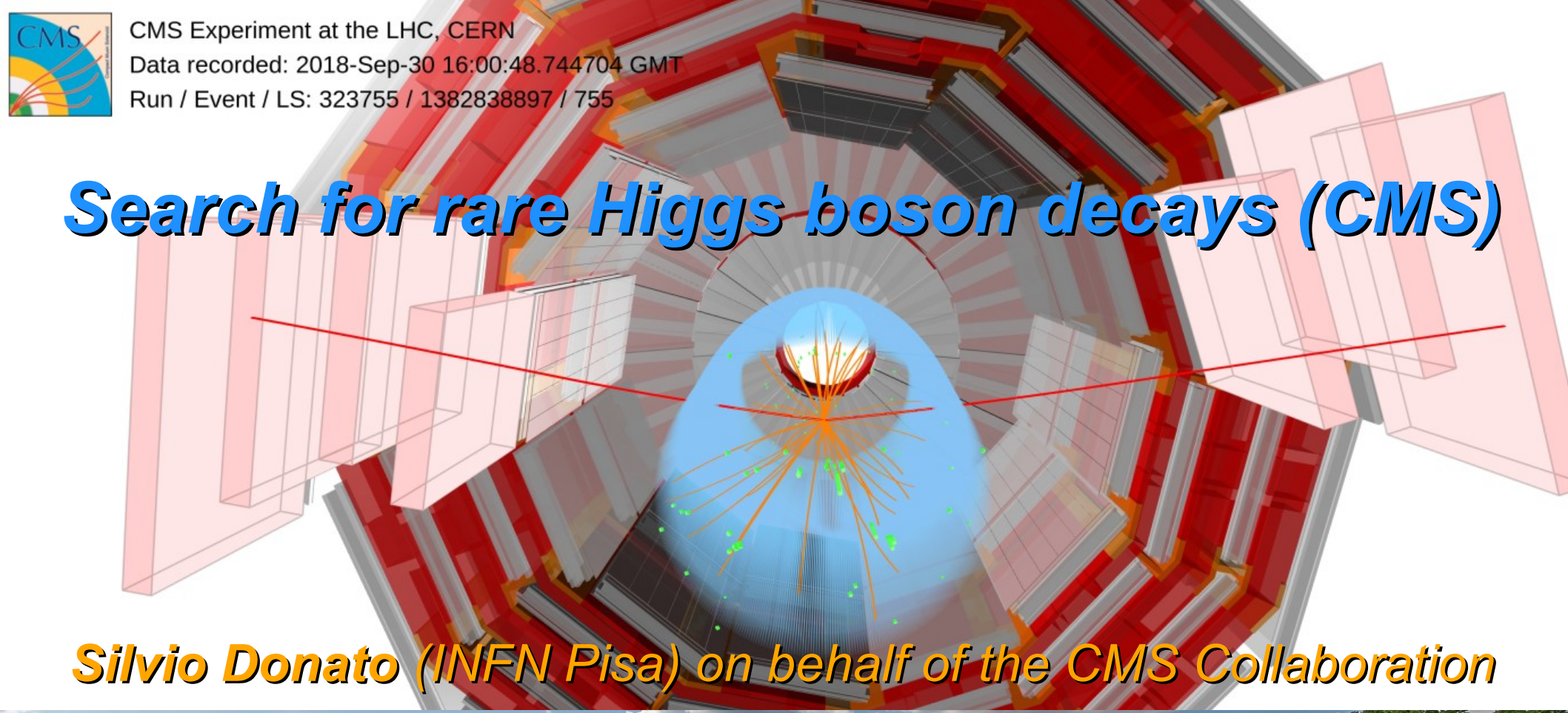


Search for rare Higgs boson decays (CMS)

Silvio Donato (INFN Pisa) on behalf of the CMS Collaboration

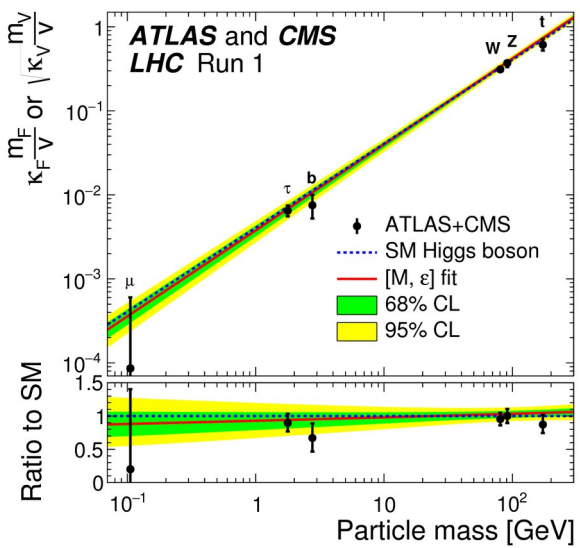
Contents

- Introduction
- Run-2 results:
  - Higgs to muons,
  - Higgs to Zρ or Zϕ.
- 2016-data results:
  - Higgs to $\ell\ell\,\gamma$,
  - Higgs to J/ψ γ,
- Conclusions

Introduction

- The Higgs boson has been observed decaying to
  - massive vector bosons (Z, W) and photons,
  - third-generation charged fermions (b, τ),
    - coupling to top quark has also been observed.
- The interaction to the 1st and 2nd gen fermions not observed yet.
- Small deviations from the SM expectation might reveal the presence of new physics,
  - rare decays could be modified by new physics interactions.

Run-1



Decay	BR
H → bb	**58 %**
H → WW	**21.6 %**
H → ττ	**6.3 %**
H → ZZ	**2.7%**
H → γγ	**0.23%**
H → Zγ	0.155 %
H → μμ	0.022 %

Higgs → μμ

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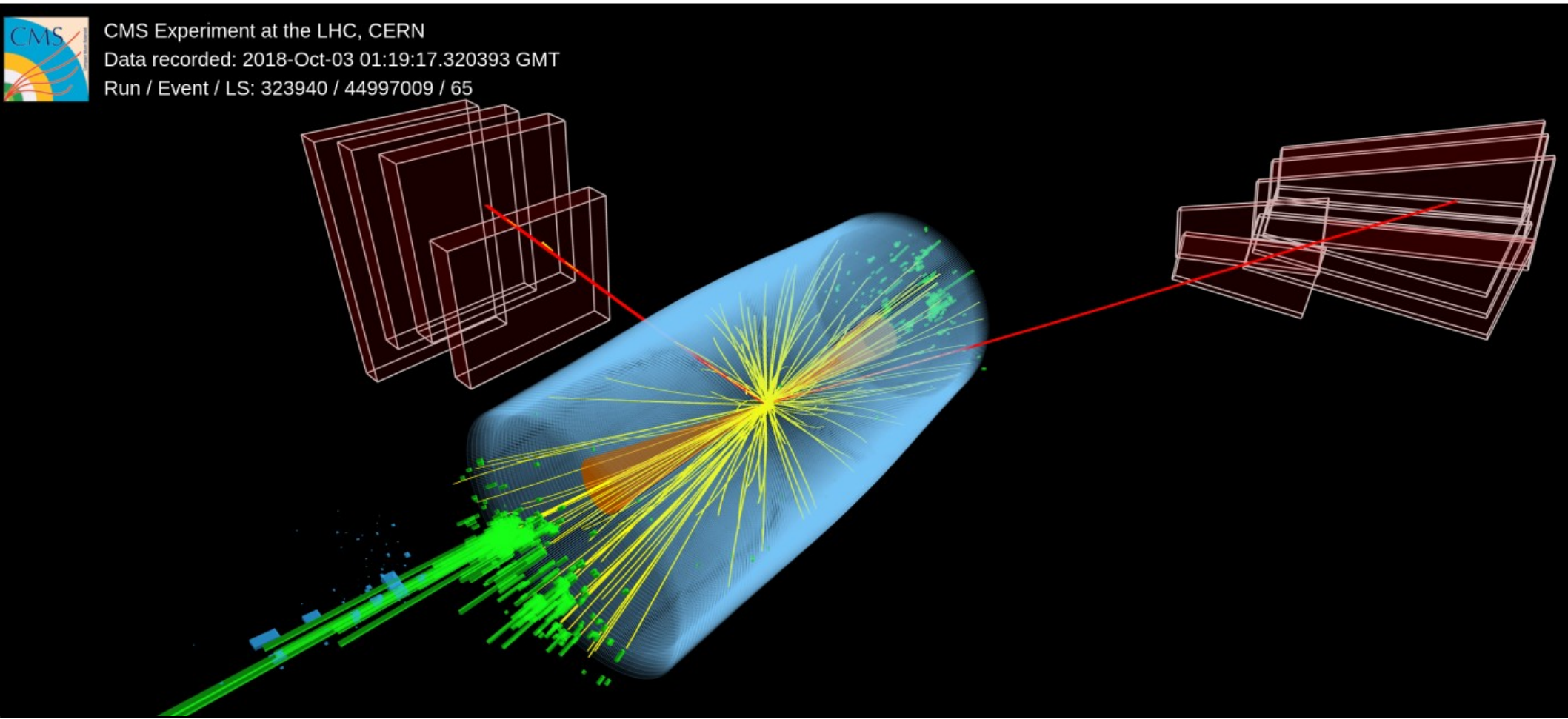

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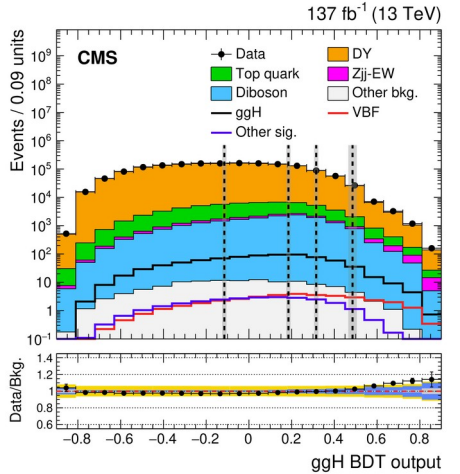
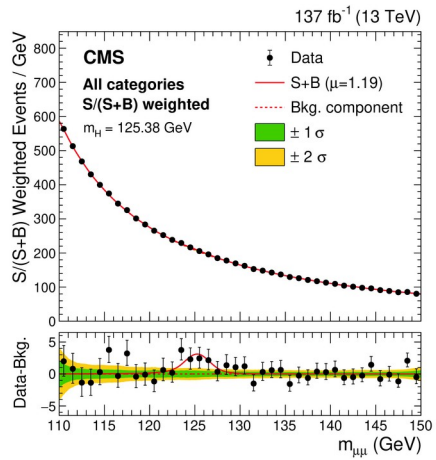
Higgs → μμ

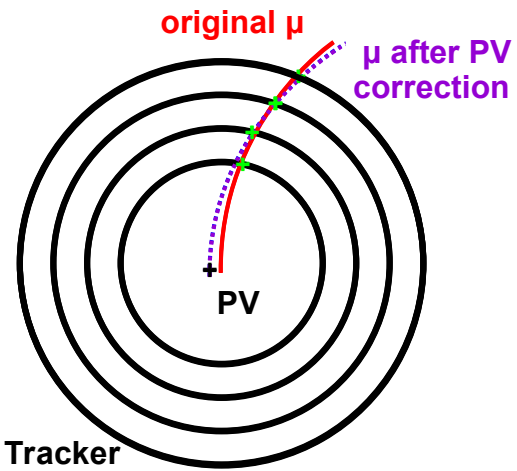
- The search is divided by the **production modes**:
  - VBF (no b jets, no additional leptons, VBF selection),
  - ggH (no b jets, no additional leptons, VBF veto),
  - WH (no b jets, 1 additional leptons),
  - ZH (no b jets, 2 additional leptons),
  - Leptonic ttH (≥1 b jets, 1 add. leptons),
  - Hadronic ttH (≥1 b jets, 2 add. leptons).
- A **multivariate** discriminator is trained in each region (except VBF).
  - categories with different signal **purity**,
  - **fit** the Higgs boson peak **dimuon mass**.

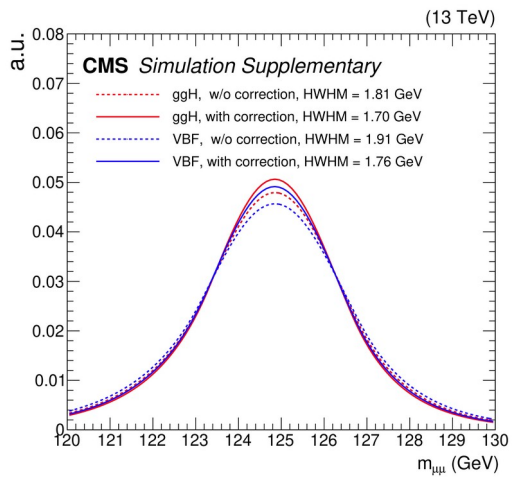




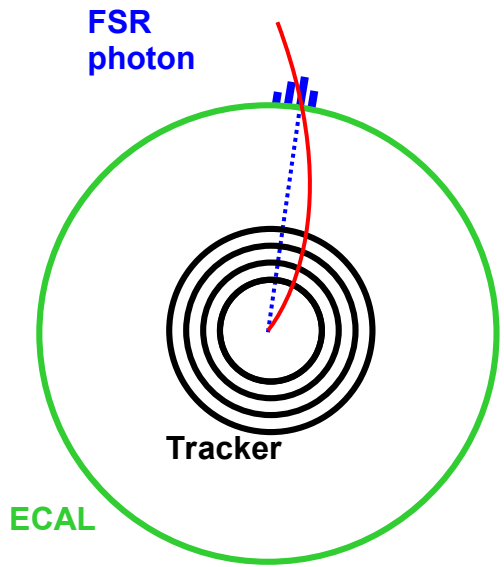
Higgs → μμ

- Muon track fitted using **primary vertex**,
  - p_T **resolution** improvement **(3 – 10 %)**.



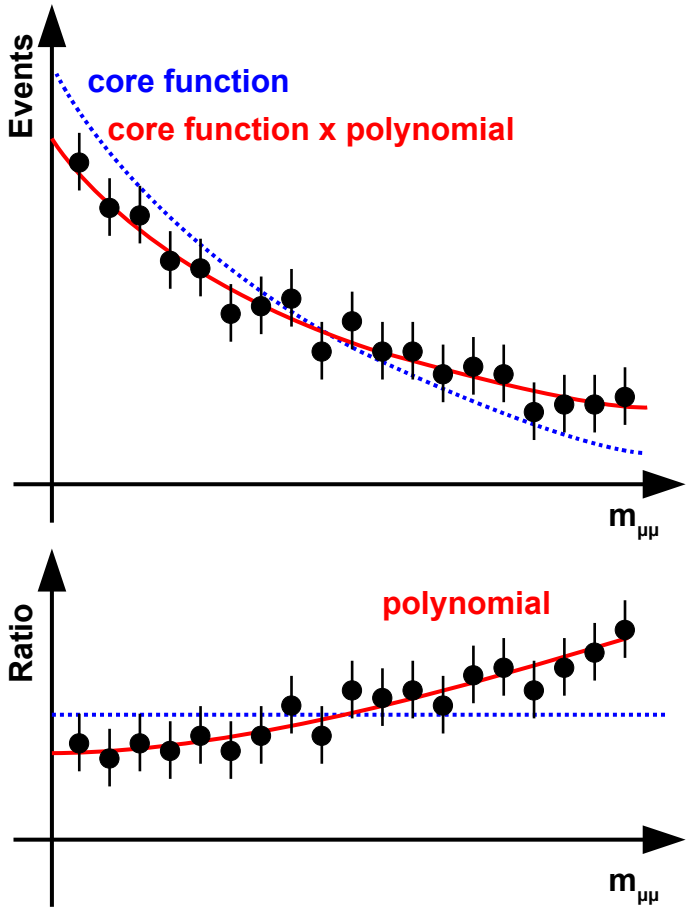


- **Final state radiation** (FSR) energy recovery:
  - p_T **resolution** improvement **(3%)**,
  - signal **efficiency** increase **(2%)**.



Higgs → μμ

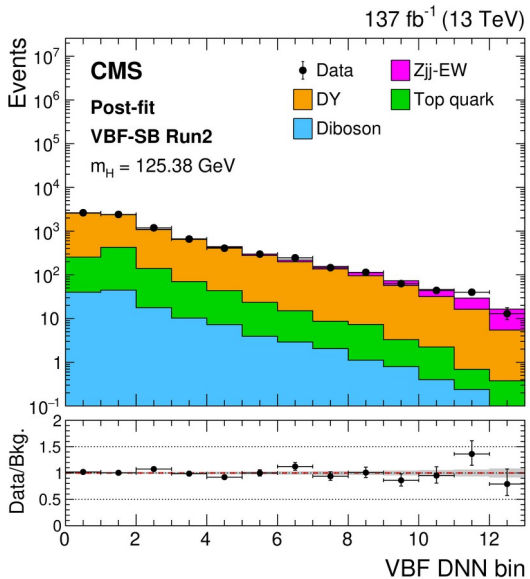
- Background model:
  “core” function x “empirical” function.
- **Core function:**
  - shared among all the categories;
  - based on theory to model the $Z/\gamma^* \rightarrow \mu\mu$ line-shape.
- **Empirical function:**
  - Chebyshev polynomial specific to each category.
- Thorough **bias studies**:
  - pseudo-experiments generated with alternative background functions.
- Reduced number of free parameters
  → improved sensitivity **~10%**



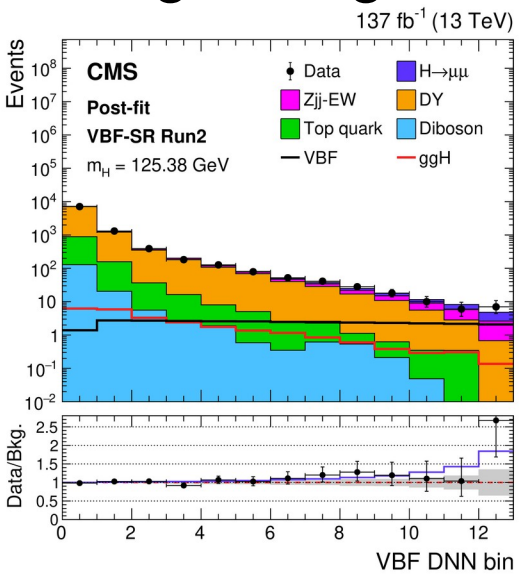
VBF Higgs → μμ

- **Simulation-based** analysis in **VBF** category:
  - signal extracted by fitting a **DNN** discriminator in
    - **signal region**: $m_{\mu\mu}$=115-135 GeV,
    - **side band**: $m_{\mu\mu}$=110-115 & 135-150 GeV.
  - The **$m_{\mu\mu}$** is an **input** of the DNN;
    - in the **side band** we manually set $m_{\mu\mu}$ = 125 GeV;
  - background estimated using simulation templates;
  - expected sensitivity: **+20%.**

Side band

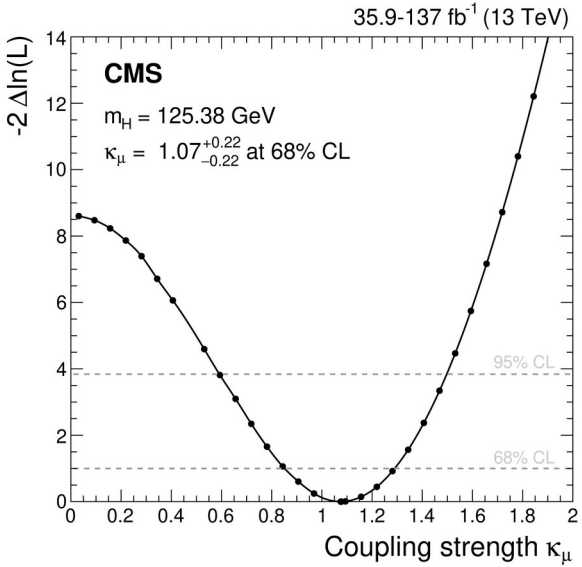


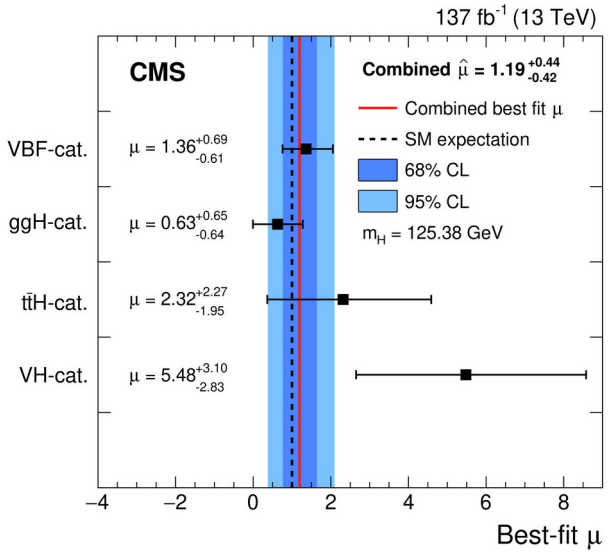
Signal region

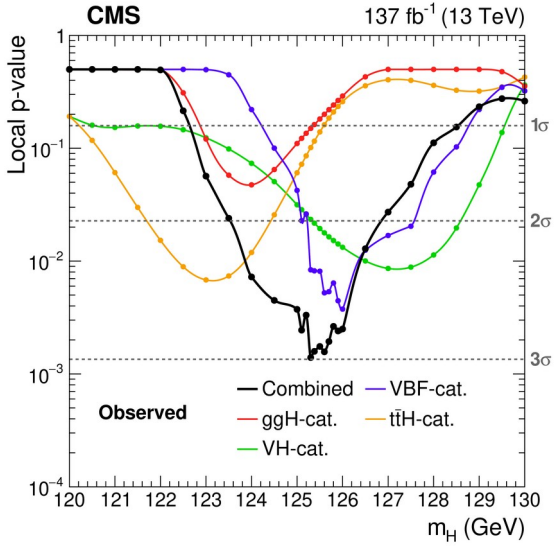


Higgs → μμ

- Results:
  - **p-value: 3.0σ (2.5σ exp.),**
  - μ = 1.19 ± 0.40 (stat) ± 0.15 (syst) → statistically limited.







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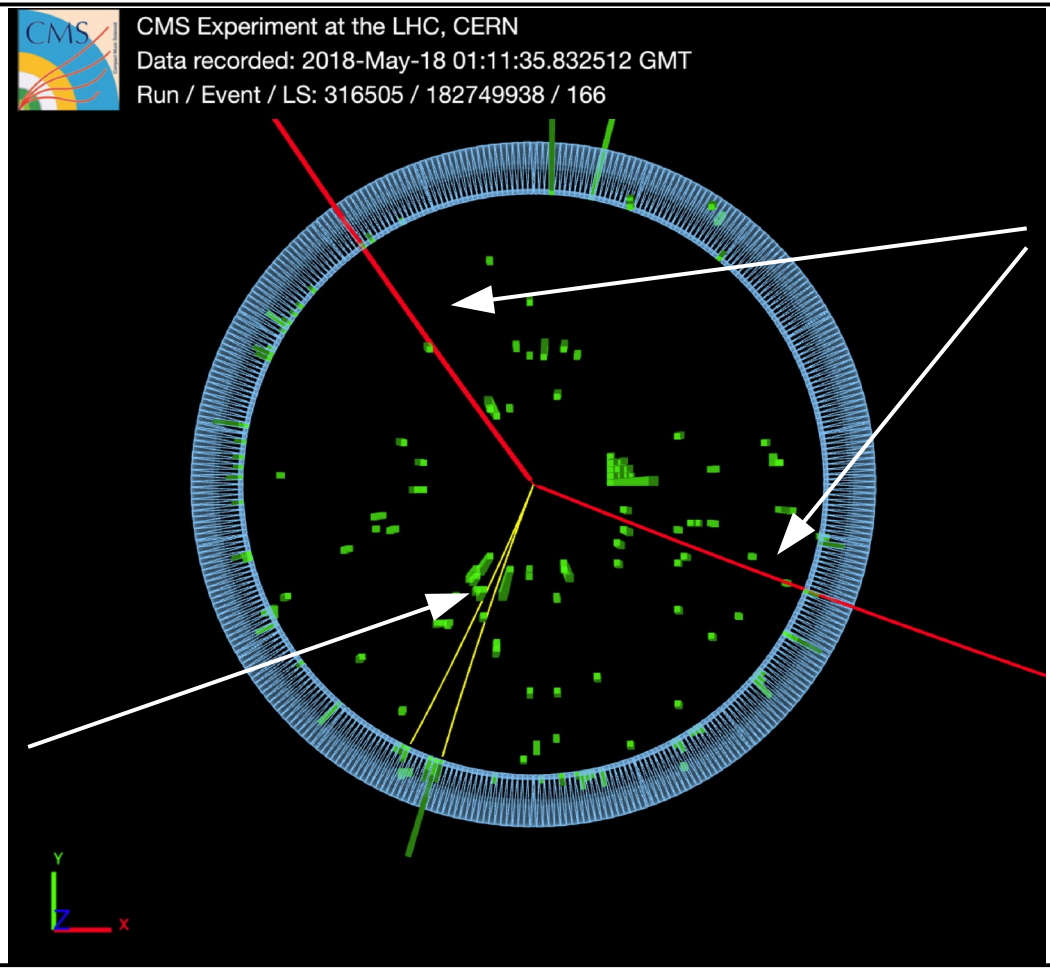
Higgs → Z ρ/ϕ

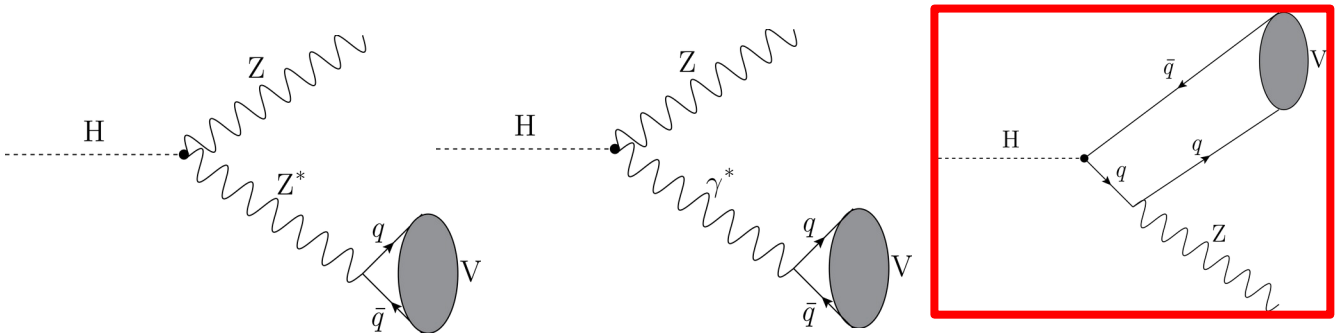


$Z \rightarrow \mu^+\mu^-$
or
$Z \rightarrow e^+e^-$

$\rho \rightarrow \pi^+\pi^-$
or
$\phi \rightarrow K^+K^-$

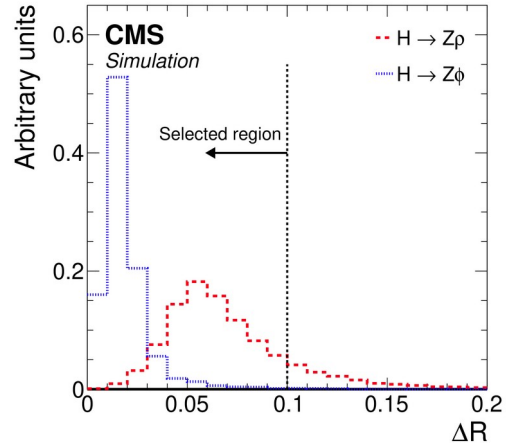
Higgs → Z ρ/ϕ

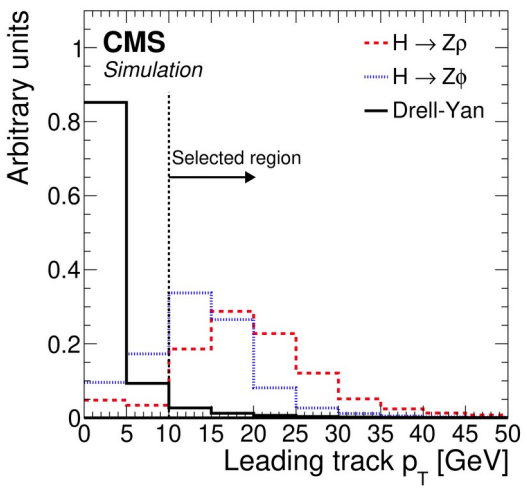
- Higgs boson decay to Z ρ/ϕ is mediated by three LO diagrams
- **Direct coupling** to quarks is suppressed by a factor m_q^2/m_H^2.
  - 2HDM with SFV predicts **enhancement** of the Yukawa coupling up to 30, 500, and 2000 for s, d, and u quarks.
- SM prediction:
  - $B(H \to Z\rho) = (1.4 \pm 0.1) \times \mathbf{10^{-5}}$
  - $B(H \to Z\varphi) = (4.2 \pm 0.3) \times \mathbf{10^{-6}}$



H → Z ρ/ϕ

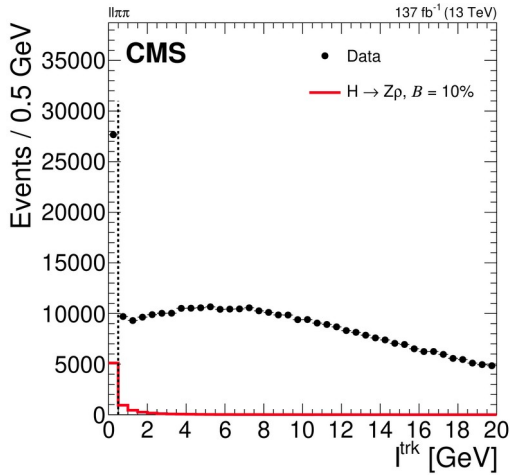
- Z boson decay:
  - single lepton (e/μ) **trigger**,
  - exactly two opposite sign same flavour **leptons** with p_T > 20 GeV,
  - no additional lepton.
- Two isolated tracks (p_T > 1 GeV) from ρ/ϕ decay,
  - close between them (**ΔR<0.1**),
  - leading track with p_T > 10 GeV.
- Select track pair with the largest p_T.
  - **selection efficiency**: 98–99%.

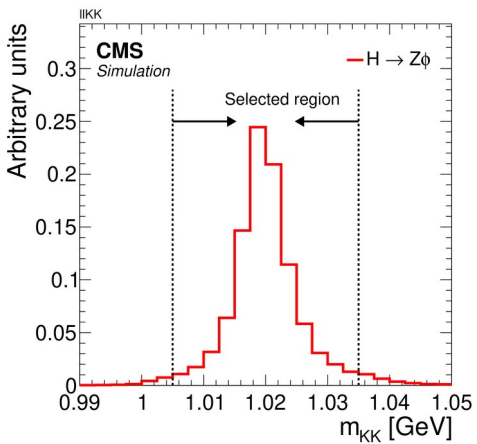


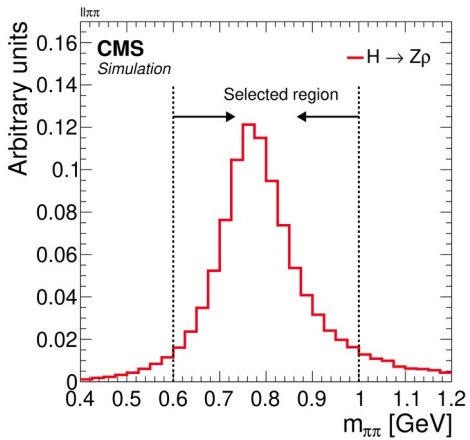


H → Z ρ/ϕ

- **No additional track** in a cone of ΔR<0.3 around ρ/ϕ candidate.
- Ditrack mass windows:
  - ρ: 0.6 < $m_{\pi\pi}$ < 1 GeV (m_π = 139.6 MeV)
  - ϕ: 1.005 < m_{KK} < 1.035 GeV (m_K=493.7 MeV)



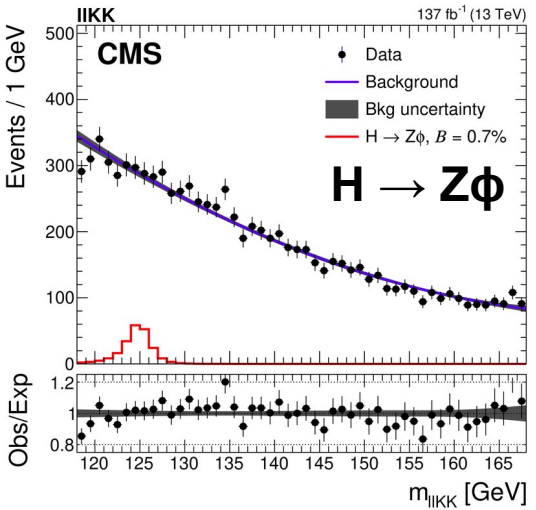


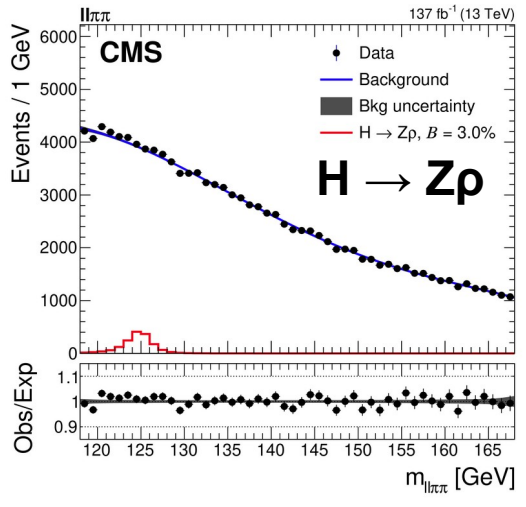


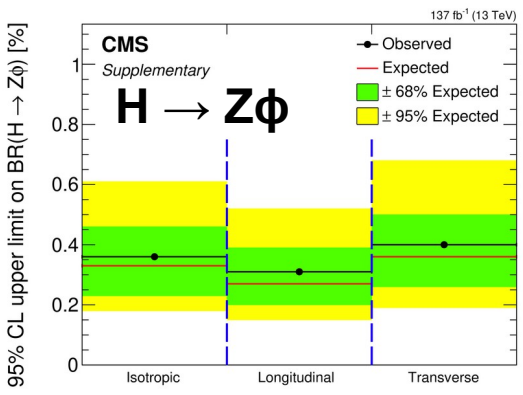
- Measurement of the isolation cut efficiency:
  - tag&probe in Z → μμ data.

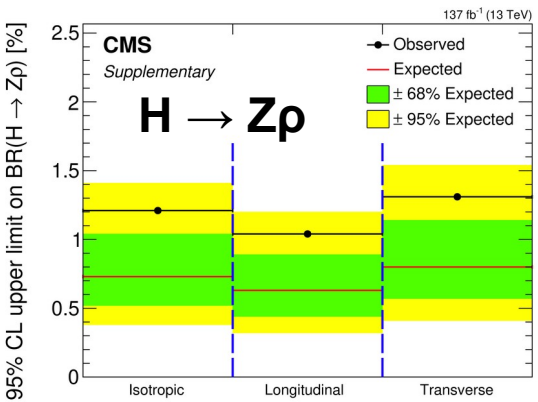
H → Z ρ/ϕ

- Signal template from simulation
- Analytic background function
  - Polynomial (2nd-5th deg.).
- Limits obtained for the isotropic, longitudinal, transverse polarization.
- No signal excess.
- Limits on BR:
  - B(H → Zρ): 740-940 x B_{SM};
  - B(H → Zϕ): 730-950 x B_{SM}.









Other rare SM Higgs decay

Higgs → J/ψ γ

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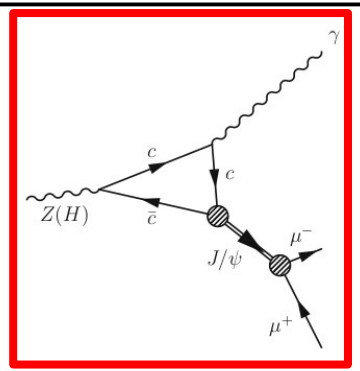
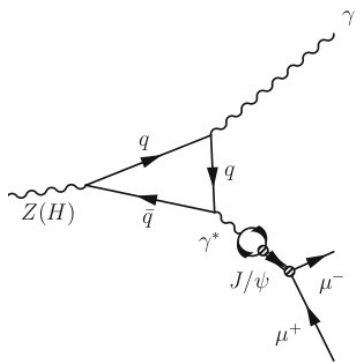
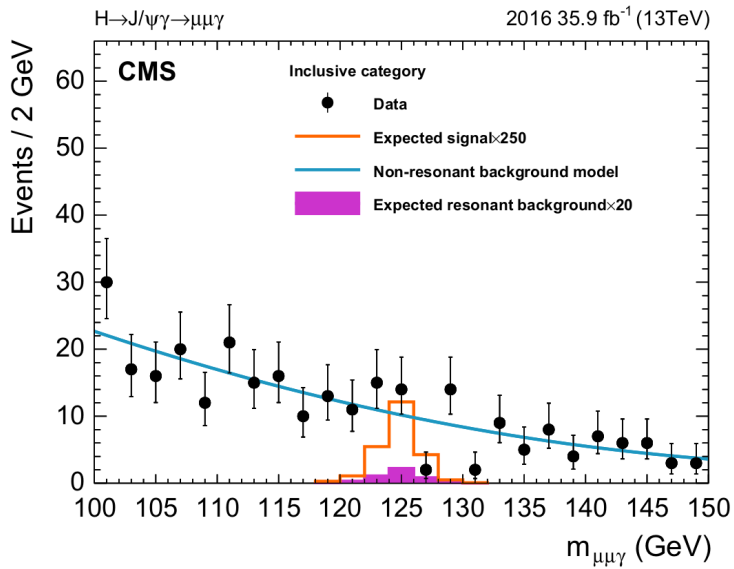
- The decay **H → J/ψ γ** can be mediated by the Higgs boson coupling to **charm** quark,
  - other diagrams contributes to the decay.
- The **SM prediction** of the decays is
  - B_{SM} (H → J/ψ γ) = 3.0 ± 0.2 10^{-6}.
- Analysis performed on 2016 data
  - Exploring the J/ψ → μμ channel.
- The 95% CL upper limit obtained is
  - BR < 7.6 10^{-4} (260 x B_{SM})
- (see Aliya's talk on H → cc)







Higgs → ℓℓγ

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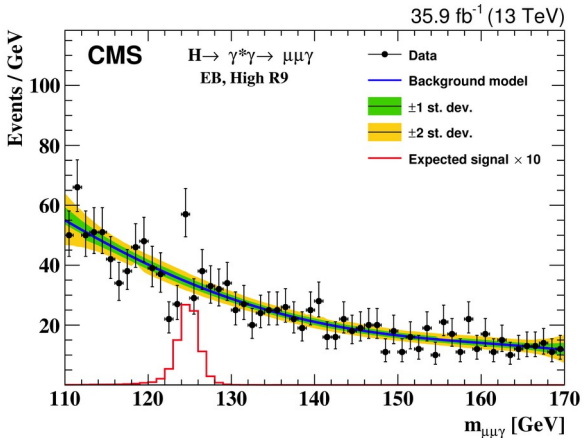
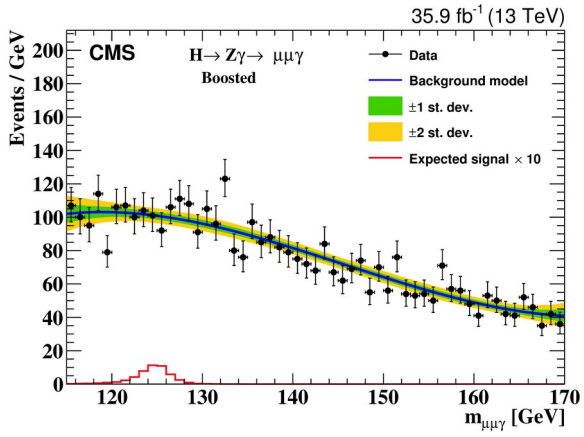
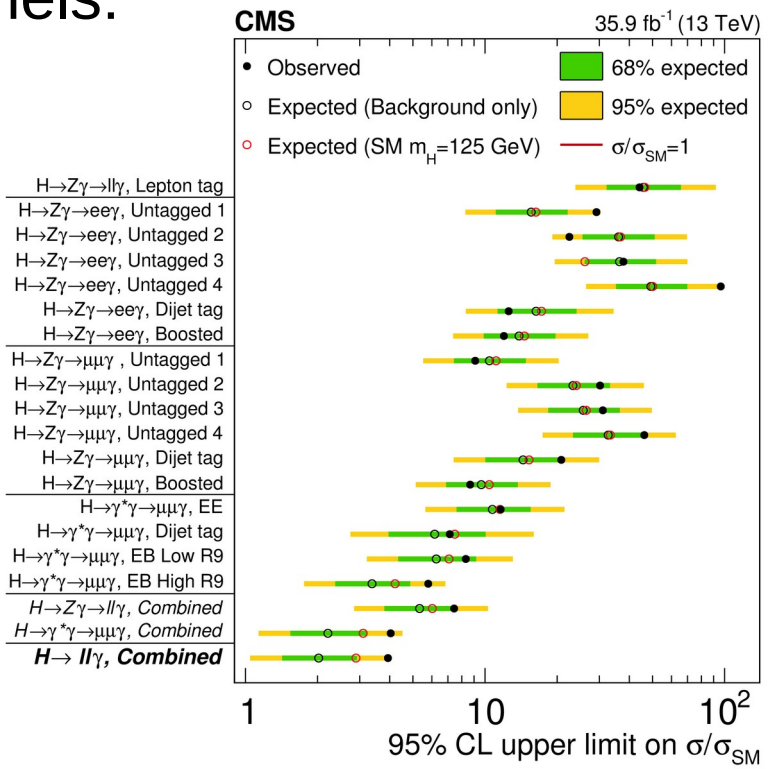
- Search for H → ℓℓγ performed in two channels:
  - H → γ*(μμ)γ ($m_{\mu\mu}$<50 GeV) [BR_{SM} = 3.8 10^{-5}],
  - H → Z(ℓℓ)γ ($m_{\mu\mu}$>50 GeV) [BR_{SM} = 5.1 10^{-5}].
- Categories with different purities.
- 95% CL upper limit: μ < 3.9 (μ < 2.0 exp.)







Conclusions

- Evidence at the 3σ level for H → μμ has been shown,
  - A large improvement has been obtained wrt the previous analysis.
- Limits have been set on the Higgs boson decays with a **meson** in the final state.
- Further improvements will be obtained with Run-3 data, and finally with HL-LHC data.
- We are probing the Higgs boson decay branchion ratios at the level of **10^{-4}** !
  - No significant deviation from the SM prediction has been found, so far...