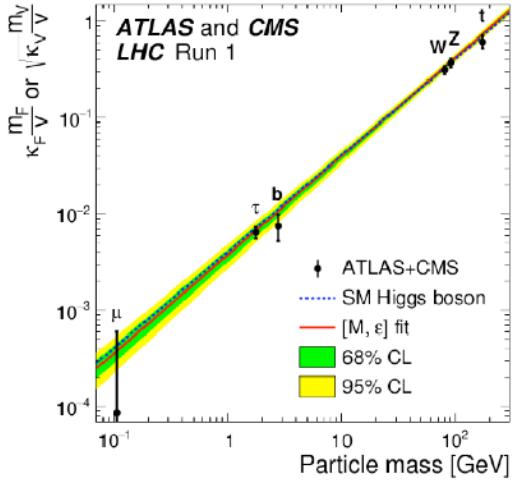
CMS rare and BSM Higgs decays

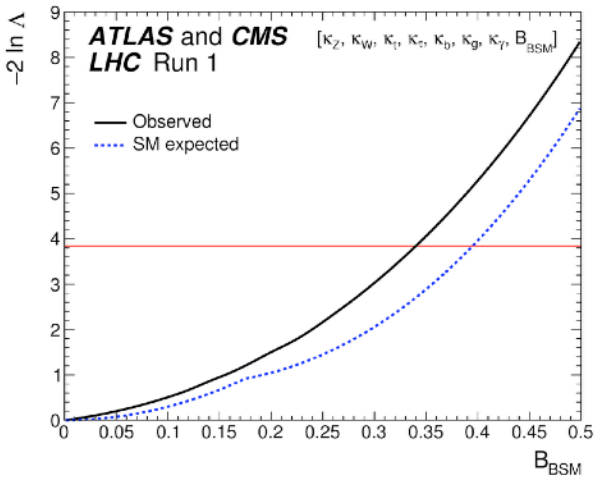
Silvia Taroni
for the CMS Collaboration

Motivation



- Higgs discovery was a great achievement for LHC
- Measurements of Higgs couplings and properties in the main decay channels show good compatibility with the SM predictions

- Room for new Physics: B(H → BSM) < 34% from Run-I as in JHEP08(2016)045

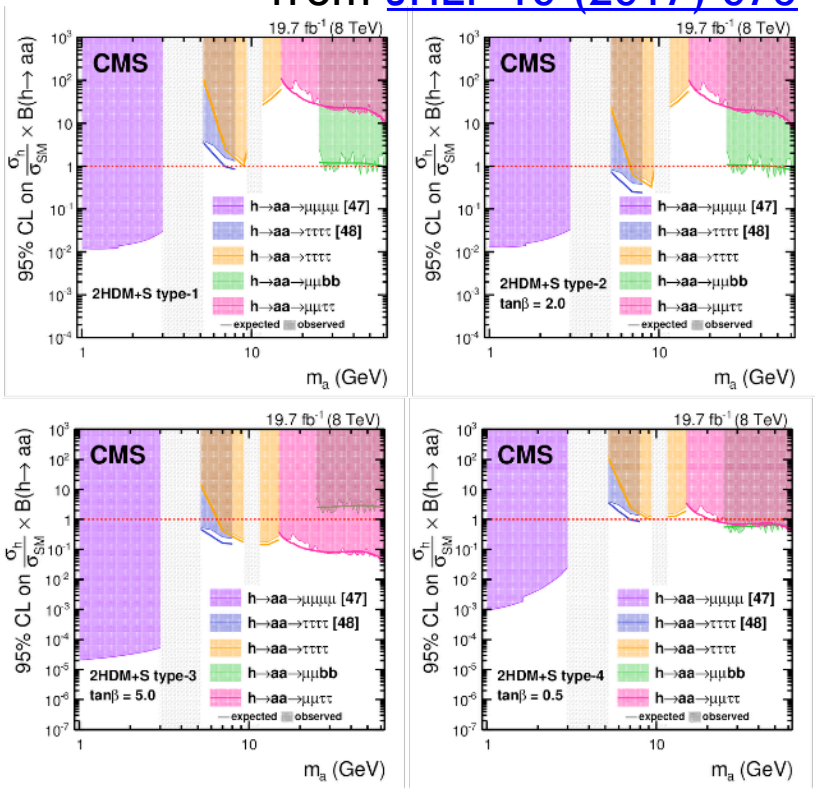


- CMS Higgs BSM investigations:
  - Direct searches of BSM processes:
    - H→aa
    - LFV decays
  - Deviation from SM prediction for rare decays:
    - H→μμ
    - H→invisible
    - H→llγ, H→J/ψγ

h→aa

- Motivation:
  - Not allowed either in SM or MSSM
  - allowed in other BSM theories
    - 2HDM+S foresees a scalar (compatible with the observed SM Higgs) and a pseudoscalar light enough for h→aa
  - B(H→aa) can be of several percent
- CMS performed many searches of the Higgs (M_h=125 GeV) decaying to new light resonances
  - Shown last year:
    - h→aa→2μ2b (8 TeV)
    - h→aa→4μ (7, 8, 13 TeV)
    - h→aa→2μ2τ (8 TeV)
    - h→aa→4τ (8 TeV)
- New results since HH2017
  - h→aa→2μ2τ arxiv:1805.04865
  - h→aa→2b2τ arxiv:1805.10191
  - h→4μ HIG-18-003

status at HH2017
from JHEP 10 (2017) 076

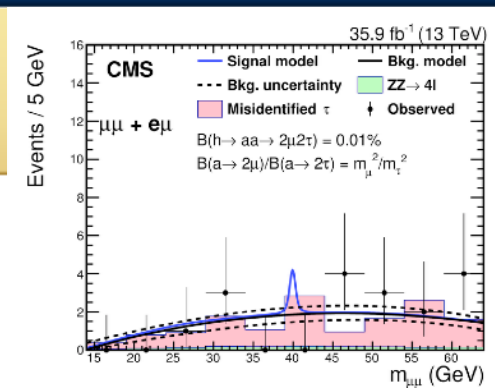


47: PLB 752 (2016) 146

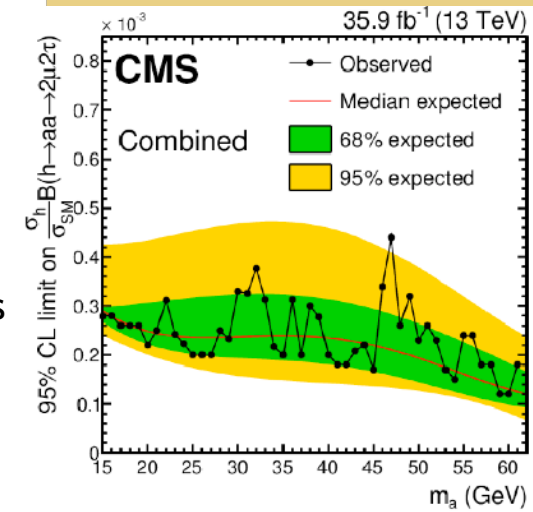
48: JHEP 01 (2016) 079

h→aa→2μ2τ

- 4 different final states: μμ+eμ, μμ+eτ$_h$, μμ+μτ$_h$, μμ+τ$_h$τ$_h$
  - events from H→aa→4τ are considered in the signal
- probed masses 15.0<m$_a$<62.5 GeV
  - cannot go below 15 GeV: a decay products are too boosted and result non-isolated
- Unbinned maximum likelihood to M(μμ)
- combined obs limit for M$_a$=60GeV: σ$_h$xB(H→aa→2μ2τ)<1.2x10^{-4} xσ$_{SM}$

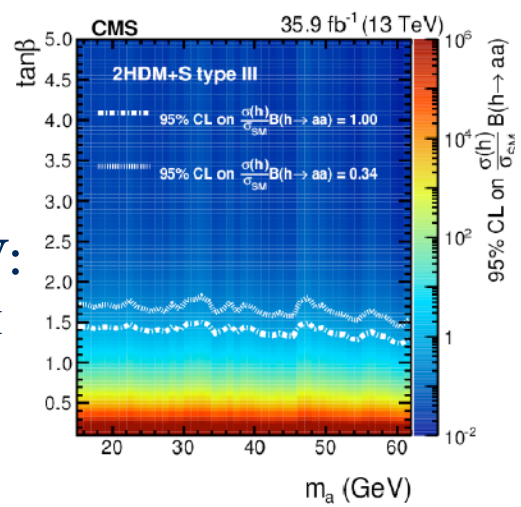


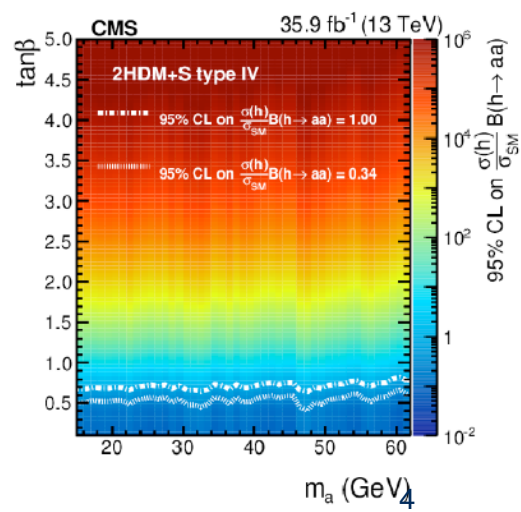
signal: Voigt function
bkg: Bernstein polynomials



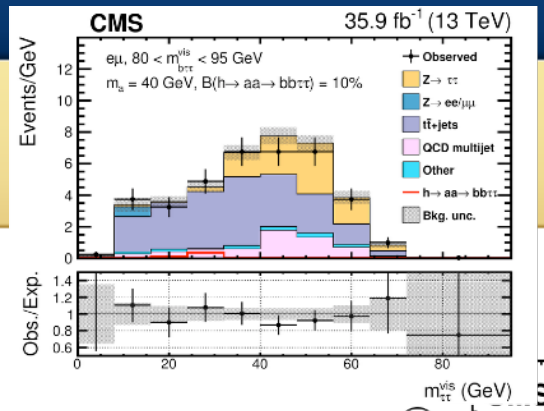
arxiv:1805.04865

CMS result improved (w.r.t 8 TeV) by at least a factor of 2 in all four types of 2HDM+S



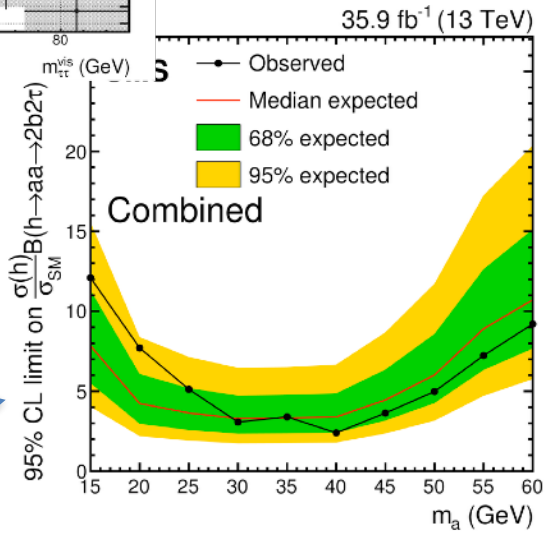


h→aa→2b2τ

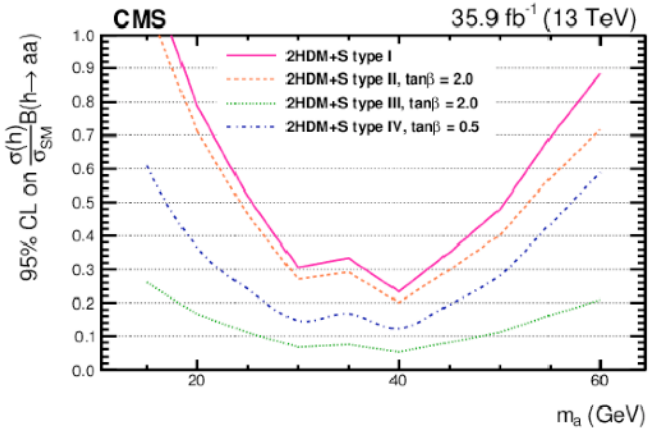


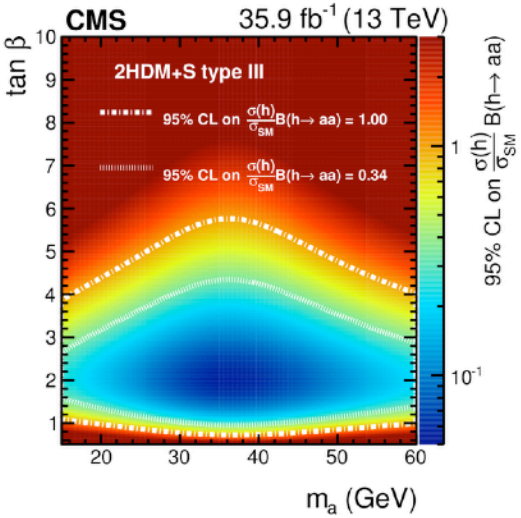
- signature: 1 b-jet + 1 lepton and 1 τ or 2 leptons
  - 3 different ττ final states: eμ, eτ$_h$, μτ$_h$
- 4 $m^{vis}_{b\tau\tau}$ categories
- probed masses 15<m_a<60 GeV
- binned maximum likelihood to $M^{vis}(\tau\tau)$

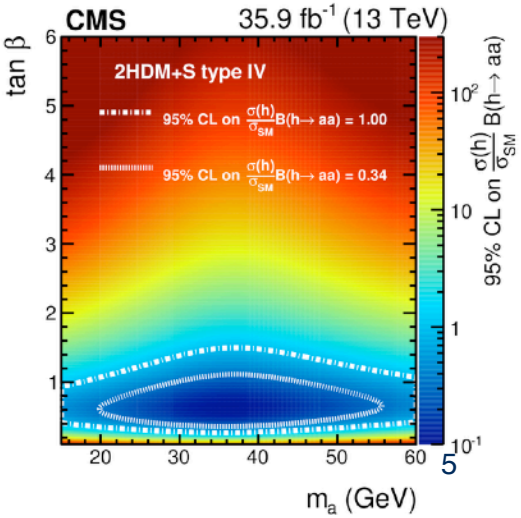
arxiv:1805.10191



- No excess observed
- combined obs limit varies from 3% to 12%
- highest sensitivity in intermediate mass region

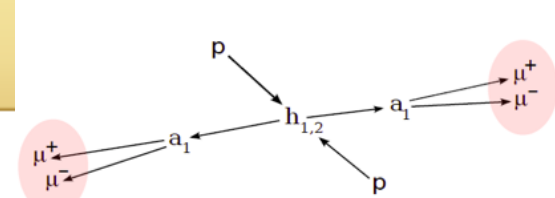


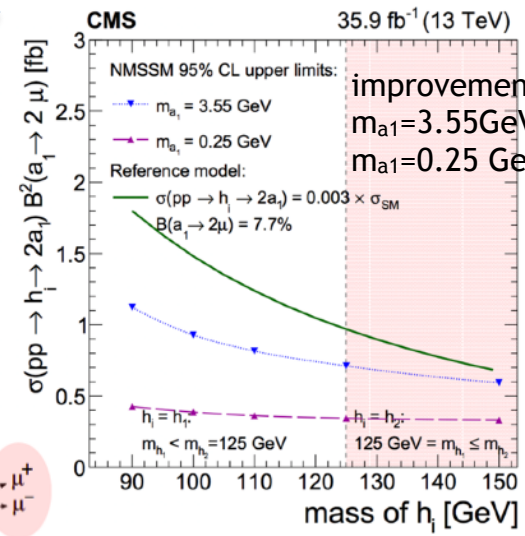




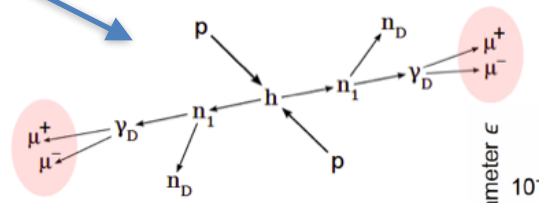
h→4μ

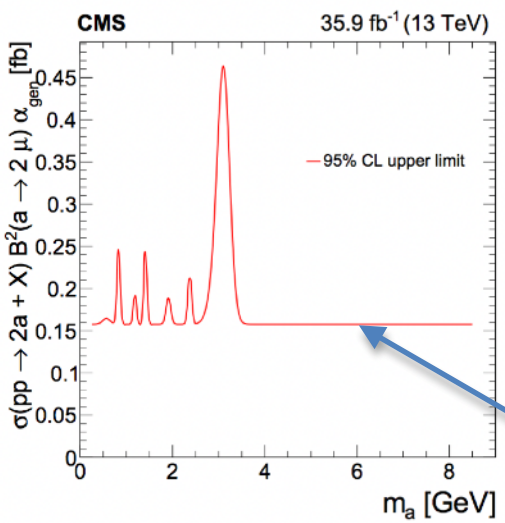
- clear signature: 4 muons
- Can be interpreted in many models:
  - NMSSM: $90 < m(h_{1,2}) < 150$ GeV, $0.25 < m(a_1) < 3.55$ GeV
  - Dark SUSY: $0.25 < m(\gamma_D) < 8.5$ GeV, $m(n_1) = 10$ GeV, $0 < c\tau(\gamma_D) < 100$mm, $m(n_D) = 1$ GeV





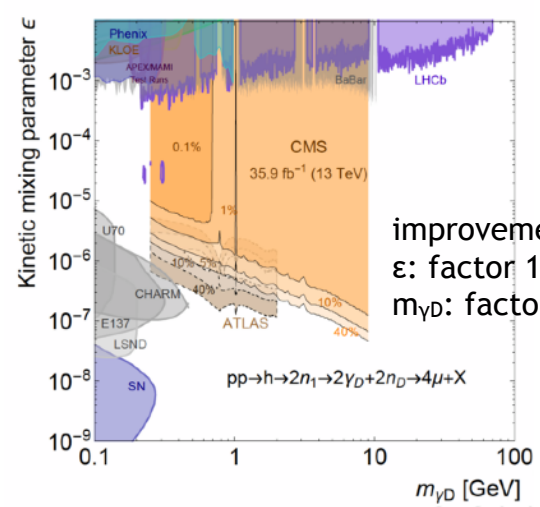
improvement
m_{a1}=3.55GeV: ~20%
m_{a1}=0.25 GeV: ~50%





13 events are observed.
SM background expectation:
9.90 ± 1.24 (stat.) ± 1.84 (syst.)

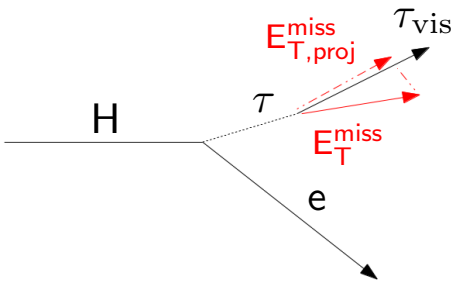
No event above 3 GeV



improvement:
ε: factor 10,
$m_{\gamma D}$: factor 5

LFV: H→e/μ + τ

- Forbidden in SM but allowed in several beyond the Standard Model theories
- CMS recently updated the search for LFV decays of the Higgs (m_H=125)
  - 2 Higgs decay channels
    - 2 τ decay channels: τ_{had} or $\tau_{\mu/e}$
    - 4 categories: 0 jet, 1 jet, 2 jets (ggH), 2 jets (qqH)
    - BDT classifier (collinear mass fit as cross check)
  - H→eμ not investigated: indirect limit B(H→eμ) < O(10^{-8}). CMS RunI observed limit is B(H→eμ) < 0.035%

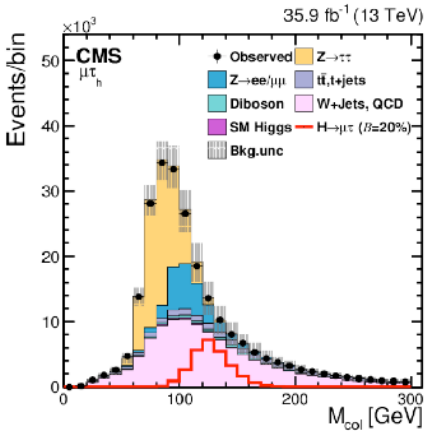


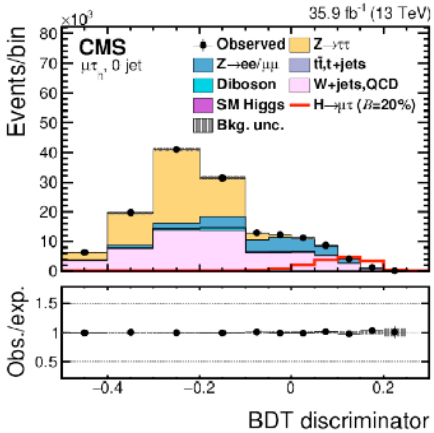
$$\vec{p}_T^{\,\nu} = \vec{E}_T^{miss} \cdot \hat{p}_T^{\tau_{vis}}$$

$$x_{vis} = \frac{|\vec{p}_T^{\,\tau_{vis}}|}{|\vec{p}_T^{\,\tau_{vis}}| + |\vec{p}_T^{\,\nu}|}$$

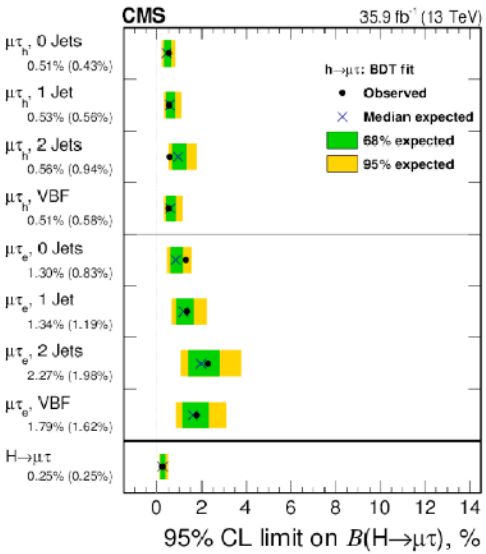
$$M_H \simeq M_{col} = \frac{M_{vis}}{\sqrt{x_{vis}}}$$

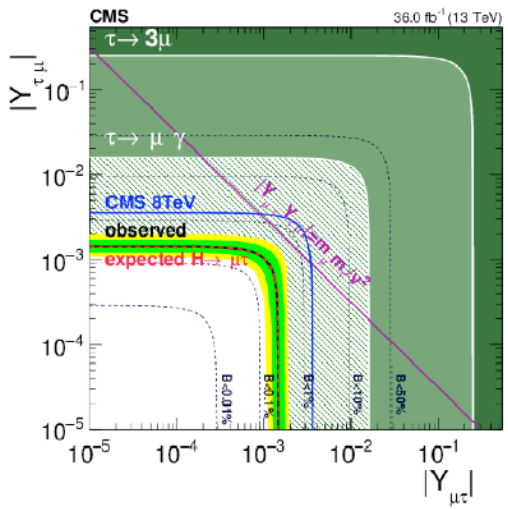
JHEP 06 (2018) 001





LFV: H→e/μ + τ





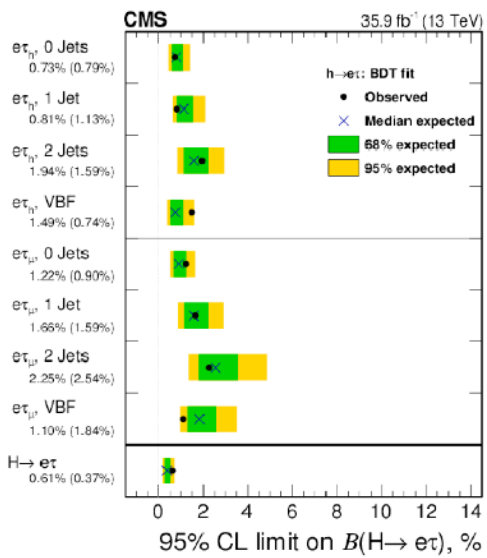
B(H→μτ)< 0.25% (0.25%)

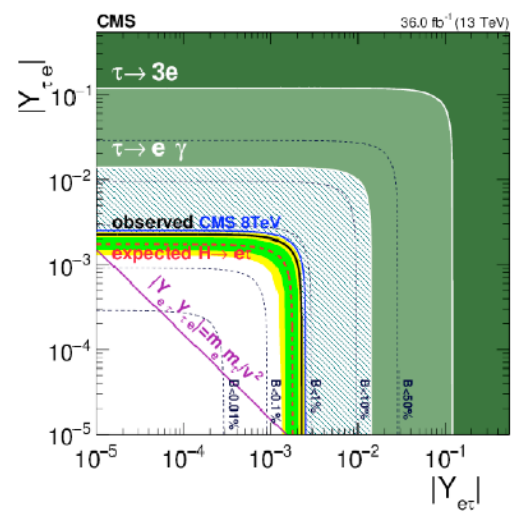
$$\sqrt{|Y_{\mu\tau}|^2 + |Y_{\tau\mu}|^2} = 2.26 \times 10^{-3}$$

B(H→eτ)< 0.61% (0.37%)

$$\sqrt{|Y_{e\tau}|^2 + |Y_{\tau e}|^2} = 2.26 \times 10^{-3}$$

Most stringent limits up to date





8 TeV CMS results

- obs (exp) B(H→μτ) < 1.51 (0.75) %
- obs (exp) B(H→eτ) < 0.69 (0.75) %

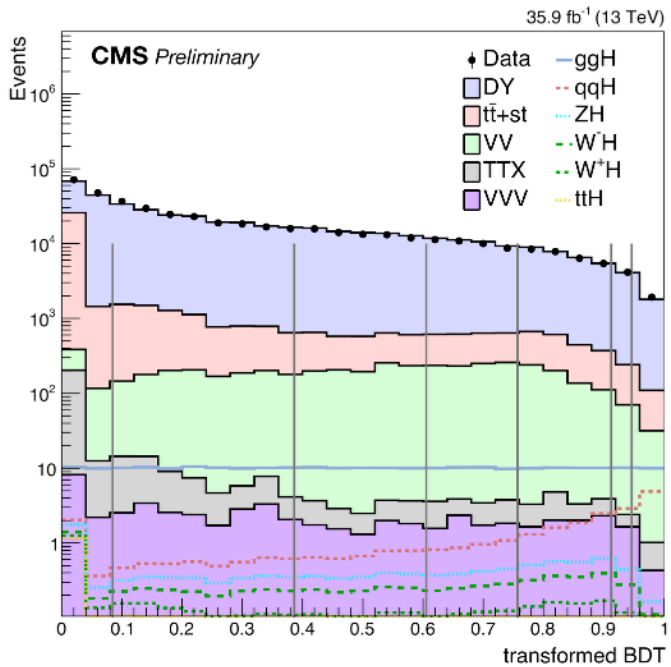
H→μμ

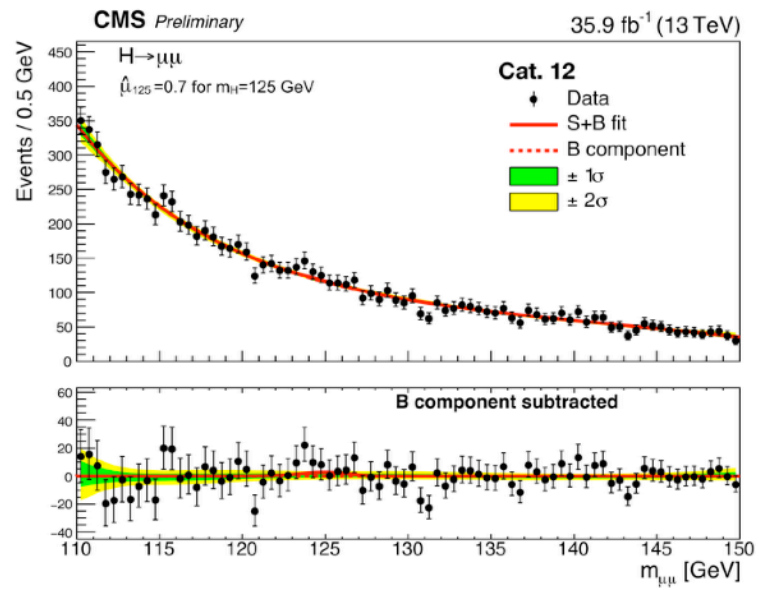
- Very rare decay, B=2.18E-4
- Clean and narrow peak on top of smoothly falling DY→μμ background
- Only SM H decay to 2nd generation expected to be seen at LHC
  - Could be enhanced by new physics

More details in yesterday talk by Artur Kalinowski

- 15 event categories (based on BDT and mass resolution) used to enhance sensitivity
- Maximum likelihood signal+background fit to M(μμ)

arxiv:1807.06325





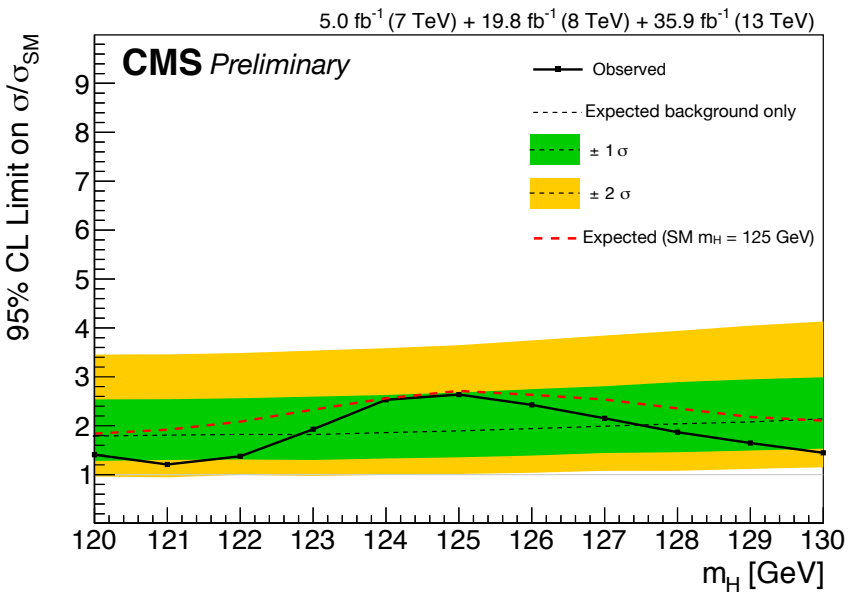
H→μμ

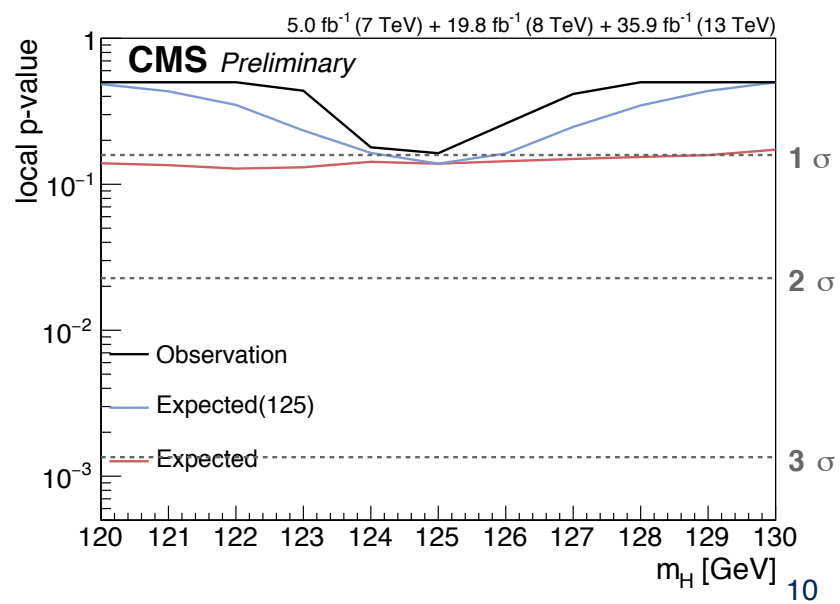
- Combining Run1 and 2016 data, limit less than a factor of 3 away from SM rate for M_H=125.09 GeV
  - best fit signal strength:

$$obs\ \hat{\mu}_{125}^{comb} = 1.0 \pm 1.0(stat)^{+0.1}_{-0.1}(syst),\ exp\ \hat{\mu}_{125}^{comb} = 1.0^{+1.1}_{-1.0}$$

  - obs (exp) significance: 0.9 (1.0) σ
  - B(H→μμ) < 6.4E-4 (obs)

More details in yesterday talk by Artur Kalinowski



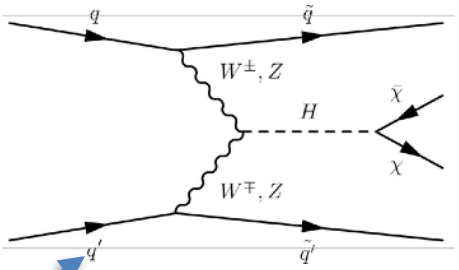


H→ invisible

- Events with high MET
- SM B(H→ZZ→4ν) ~0.12%

- Many possible extensions of the SM would allow enhance the rate: decays to dark matter, hidden valleys / portals, …

- CMS use combination of
  - VBF-tagged
  - associated W/Z (including boosted W/Z → quarks!)
  - ISR/mono-jet

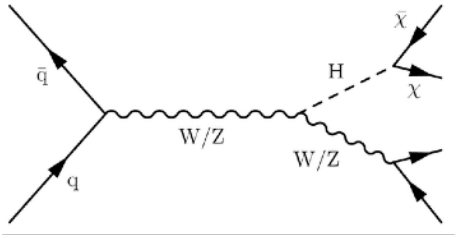


CMS HIG-17-023

Clear VBF signature: dijet system with large rapidity gap $\Delta\eta(j_1,j_2)$ and large dijet mass $M(j_1,j_2)$

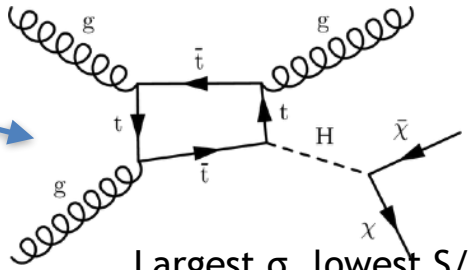
10.1140/epjc/s10052-018-5740-1

10.1103/PhysRevD.97.092005



Z-> OS/SF leptons close to M_Z
Smallest BR , Higher S/B

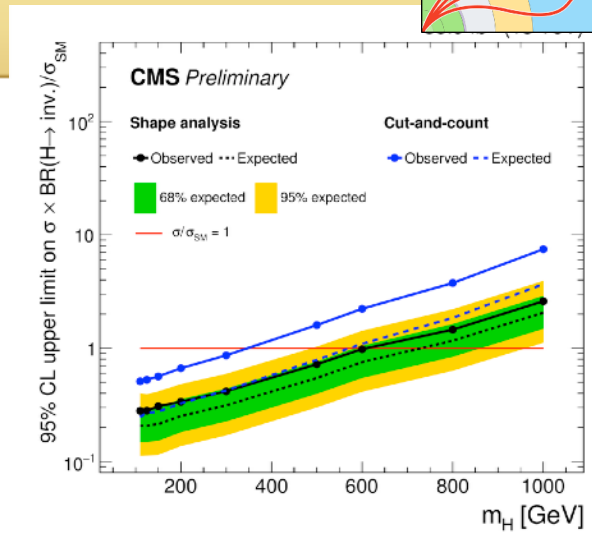
W-> qq: resolved or boosted

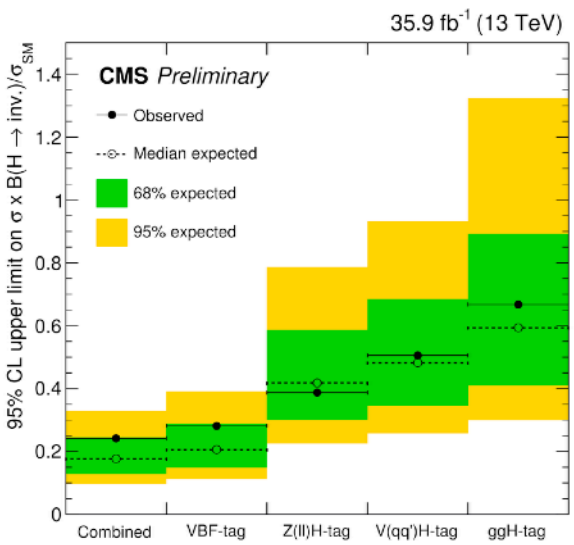


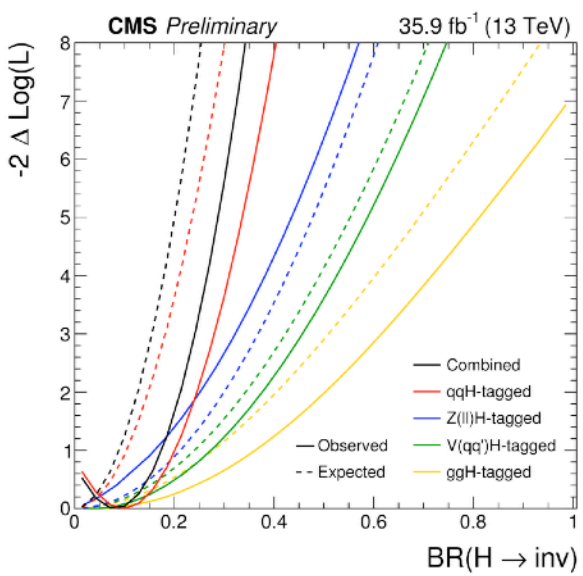
Largest σ, lowest S/B

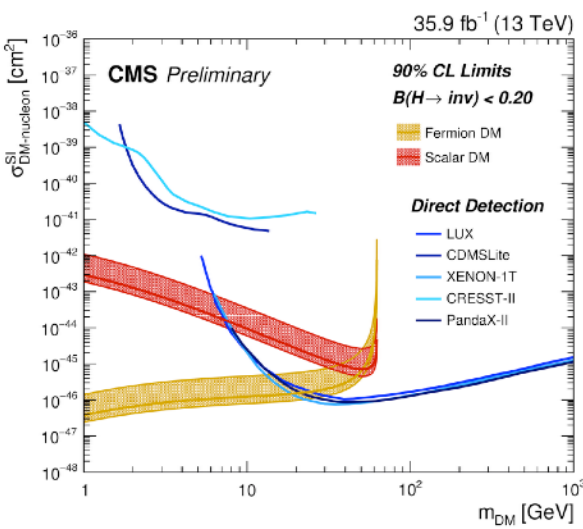
H→ invisible

- Different approaches uses:
  - VBF-tagged: cut-and-count + shapes analysis
  - Z(ll)-tagged: BDT Classifier
  - background estimated from simulation and CR
- Relative contributions between the different production mechanisms consistent with SM predictions
- BR(H→invisible)<24 (18) % (at 95% CL)









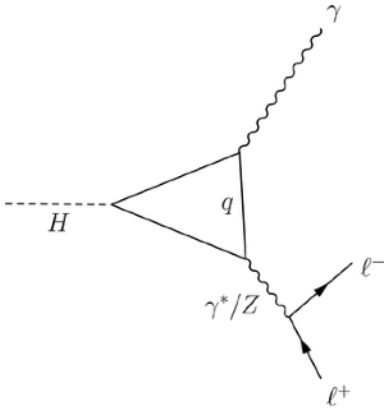
H→llγ

arxiv:1806.05996

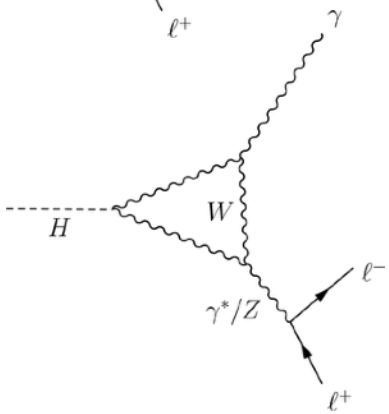
- Present in the SM, but very small rate:

$$\frac{\mathcal{B}(\mathrm{H} \to \gamma^*\gamma \to \mu\mu\gamma)}{\mathcal{B}(\mathrm{H} \to \gamma\gamma)} = (1.69 \pm 0.10)\%, \quad \frac{\mathcal{B}(\mathrm{H} \to \mathrm{Z}\gamma \to \mathrm{e}^+\mathrm{e}^-\gamma/\mu\mu\gamma)}{\mathcal{B}(\mathrm{H} \to \gamma\gamma)} = (2.27 \pm 0.14)\%$$

- loop-induced decay → sensitive to new physics

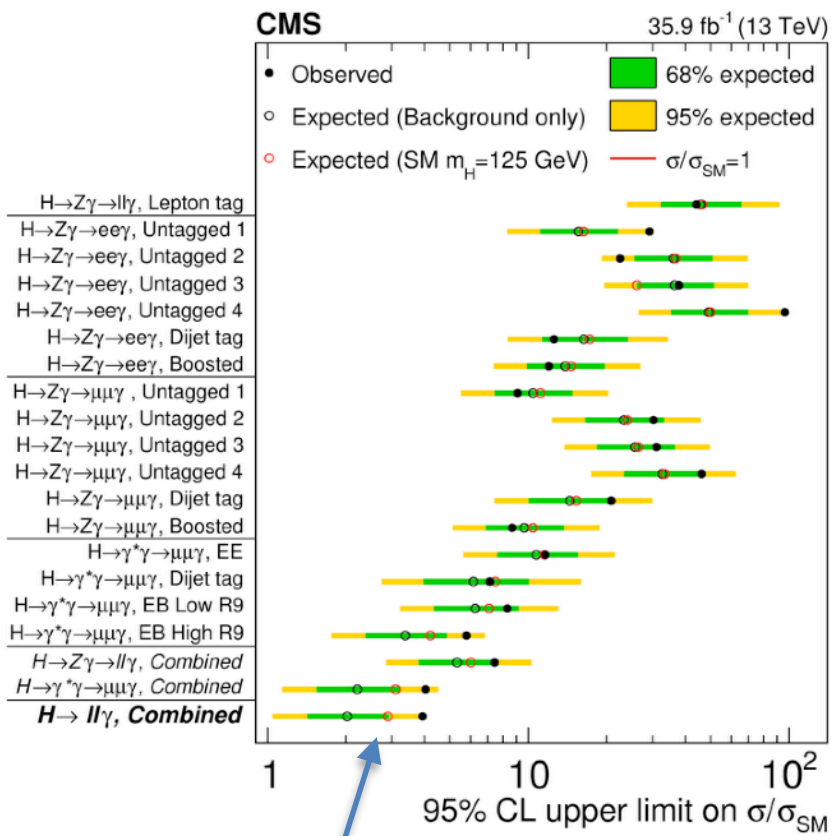


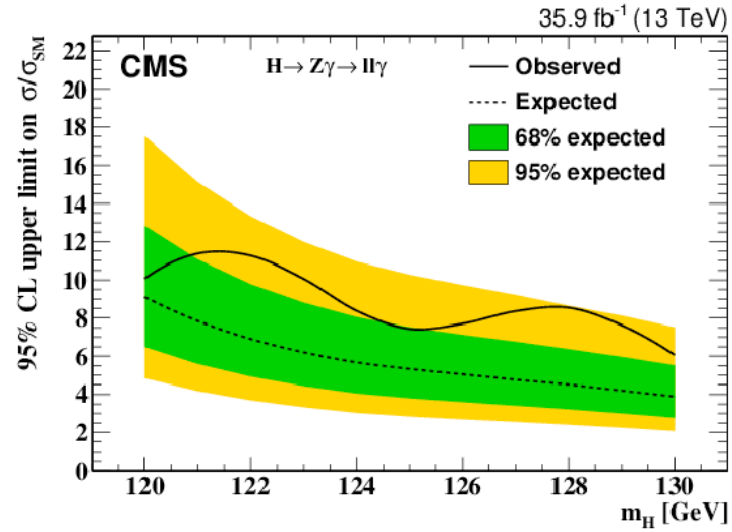
- Multiple lepton flavours:
  - M_{ll} > 50 GeV: H→Z(→ee/μμ)γ
  - M_{ll} < 50 GeV: H→γ*(→μμ)γ
- Multiple (7) event categories used to enhance signal sensitivity by 11-18%
  - presence of additional lepton or jets
    - lepton tag, di-jet tag
  - boosting
    - boosted tag: $p_T^{ll\gamma}$>60 GeV,
  - 4 untagged categories to enhance llγ mass resolution and S/B
    - photon and leptons η, shower-shape

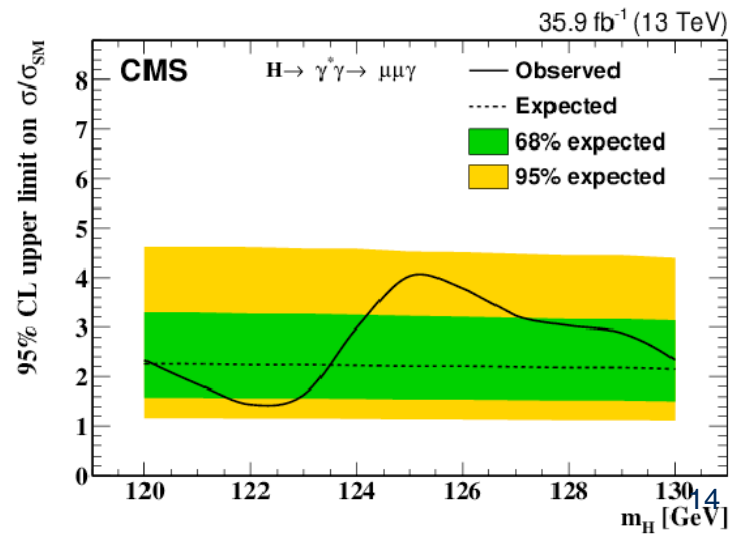


H→llγ

arxiv:1806.05996







combined exp (obs) σ < 3.9 (2.0) σ_{SM}
for M_H=125 GeV

H→J/ψγ

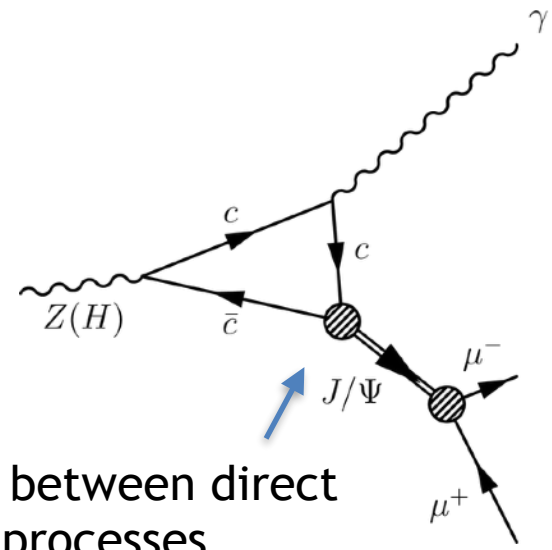
CMS-PAS-SMP-17-012

- Motivation: search for H → J/ψγ decays used to couplings to the second generation of quarks

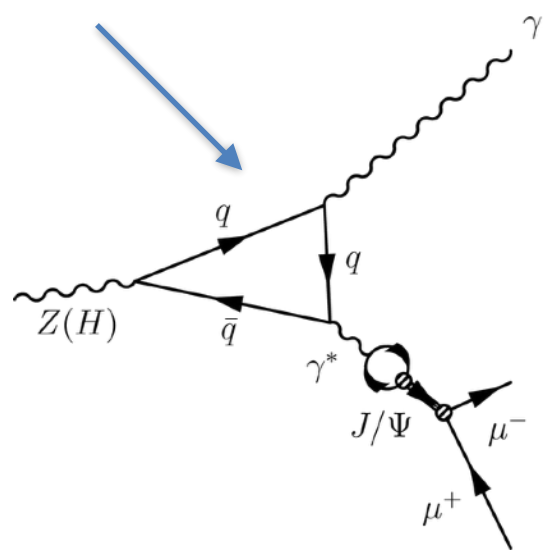
$$\mathcal{B}_{SM}(\mathrm{H} \to \mathrm{J}/\psi\,\gamma) = (3.0^{+0.2}_{-0.2}) \times 10^{-6}$$

- very small decay rate → few signal events expected priori to selections with Run-II statistics

- J/ψ → μμ: clean signature w.r.t. direct searches for H(cc) decays and H→γ*γ → μμγ



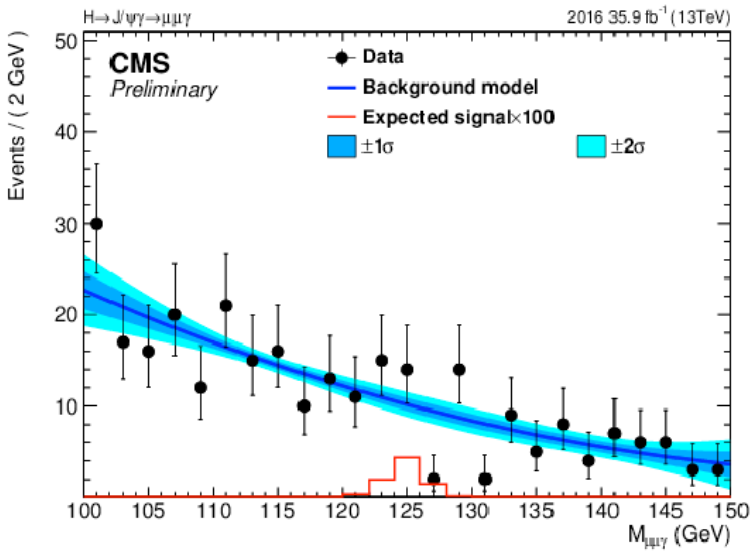
interference between direct and indirect processes



H→J/ψγ

CMS-PAS-SMP-17-012

- Analysis strategy: very similar to those of the H→γ*γ → μμγ search + m(μμ) requirement
- No categories based on production modes or mass resolution
- Fit to $M_{ll\gamma}$ mass
  - Bernstein polynomial used to fit the background



13 TeV obs. (exp.) limit: B(H→J/ψγ) < 7.6 (5.2) x 10^{-4}, 260 (170) times the SM expectation

13 + 8 TeV combination obs. (exp.) limit on B(H→J/ψγ) is 220 (160) x B_{SM} (H→J/ψγ)

Summary

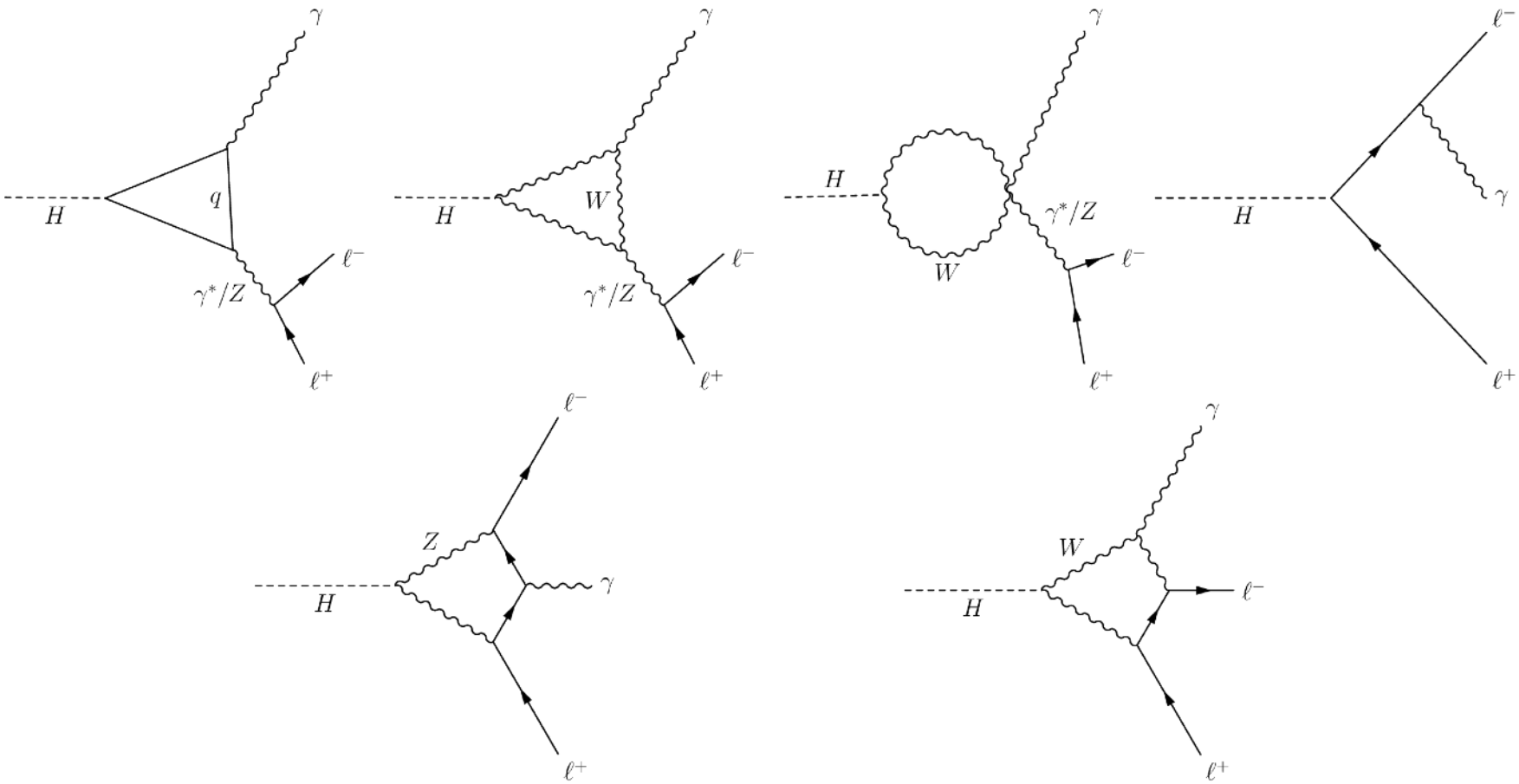
- Extensive, on-going program at CMS searching for Higgs rare and BSM decays:
  - Searching for decays to new light pseudoscalars foreseen in BSM theories
  - Probing off-diagonal Yukawa couplings
  - Probing coupling of the Higgs boson to second generation of leptons and quarks

- Enhancements from the SM prediction would directly point to BSM physics
  - So far, no significant deviations from SM predictions are observed

- Limits on decays to new light pseudoscalars
  - improved by (at least) a factor of 2 in the four types 2HDM+S in $2\mu2\tau$ channel
  - First limits in $2b2\tau$ channel
- Best direct limit of $H\to e\tau$ and $H\to\mu\tau$ branching ratios.
- Run-II sensitivity for Higgs invisible decays stronger than Run-I despite higher p_T^{miss} thresholds
  - VBF $H\to inv$ the most sensitive channel
  - VBF $H\to inv$ sensitivity improved by means of a m_{jj} shape fit
- $H \to \mu\mu$ search sensitivity around 2 x SM → goal would be reach SM sensitivity with full Run-II data
- $H \to ll\gamma$ final states give access to $BR(H\to Z\gamma)$ and $BR(H\to J/\psi\gamma)$
  - Sensitivity still far from the SM prediction → it will not be reached by the end of Run-II

ADDITIONAL MATERIAL

Dominant diagrams contributing to H→llγ



H→J/ψγ