Low mass scalar searches at CMS

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Higgs Couplings 2017 - Heidelberg

Low invariant mass searches!

Experimentally, among the most difficult analyses at LHC

→ Special tuning of selection tools
→ Theoretical guidance sometimes limited
→ Trigger, trigger, trigger

CMS low mass searches

$h \to aa$ signatures		
- $h \to aa \to 4\mu$	8 TeV	Phys. Lett. B 752 (2016) 146
	13 TeV	CMS PAS HIG-16-035
- $h \to aa \to 4\tau$	8 TeV	JHEP 01 (2016) 079 (low m_a)
		HIG-16-015 (high m_a)
- $h \to aa \to 2\mu 2\tau$	8 TeV	HIG-16-015
- $h \to aa \to 2\mu 2b$	8 TeV	HIG-16-015
$h \to \gamma\gamma$		
	8 TeV	CMS PAS HIG-14-037
	13 TeV	CMS PAS HIG-17-013
bbA, $A \to \mu\mu$	8 TeV	HIG-15-009, accepted by JHEP
bbA, $A \to \tau\tau$	8 TeV	Phys. Lett. B 758 (2016) 296

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- $h \to aa \to 2\mu 2b$	8 TeV	HIG-16-015

Will (mostly) cover these today

$h \to \gamma\gamma$

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NMSSM

2HDM + S

~~NMSSM~~

CMS HIG-16-015, accepted by JHEP

Run1 "combination"

All channels below the h→ aa kinematic limit

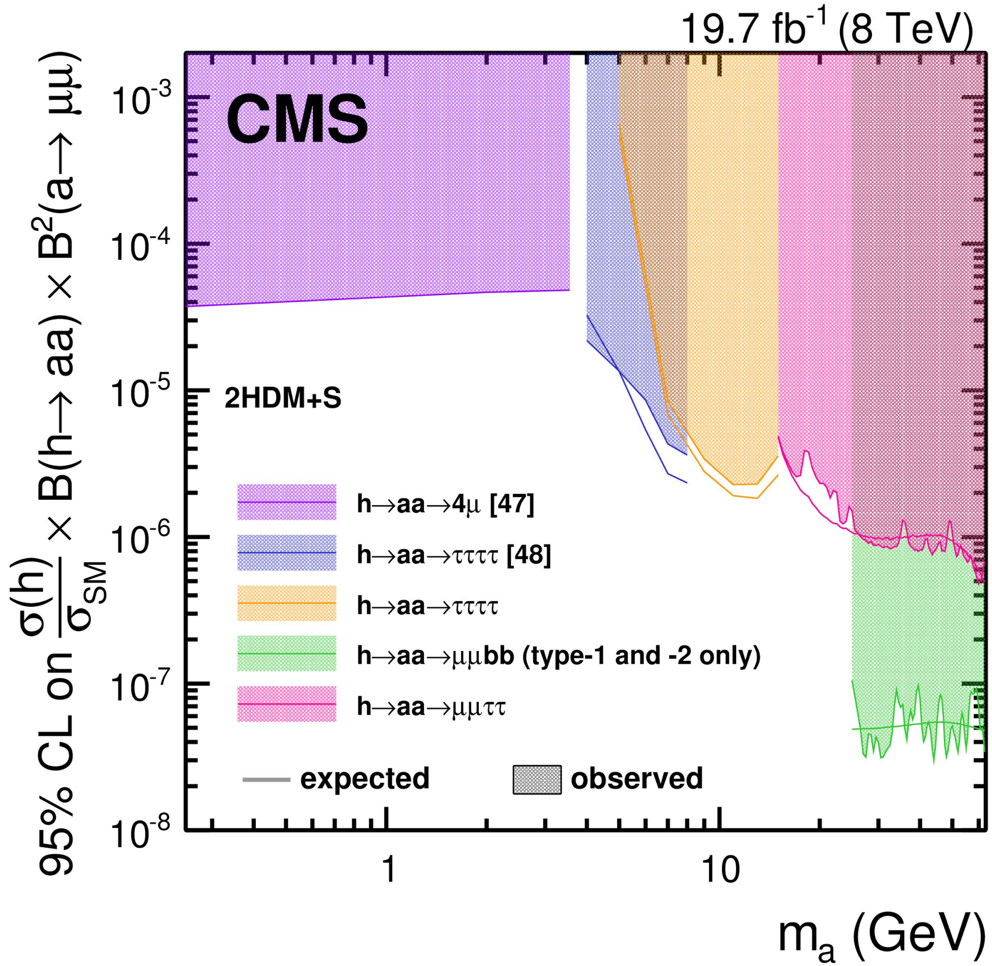
(all channels possible thanks to lepton triggers)

Reminders:

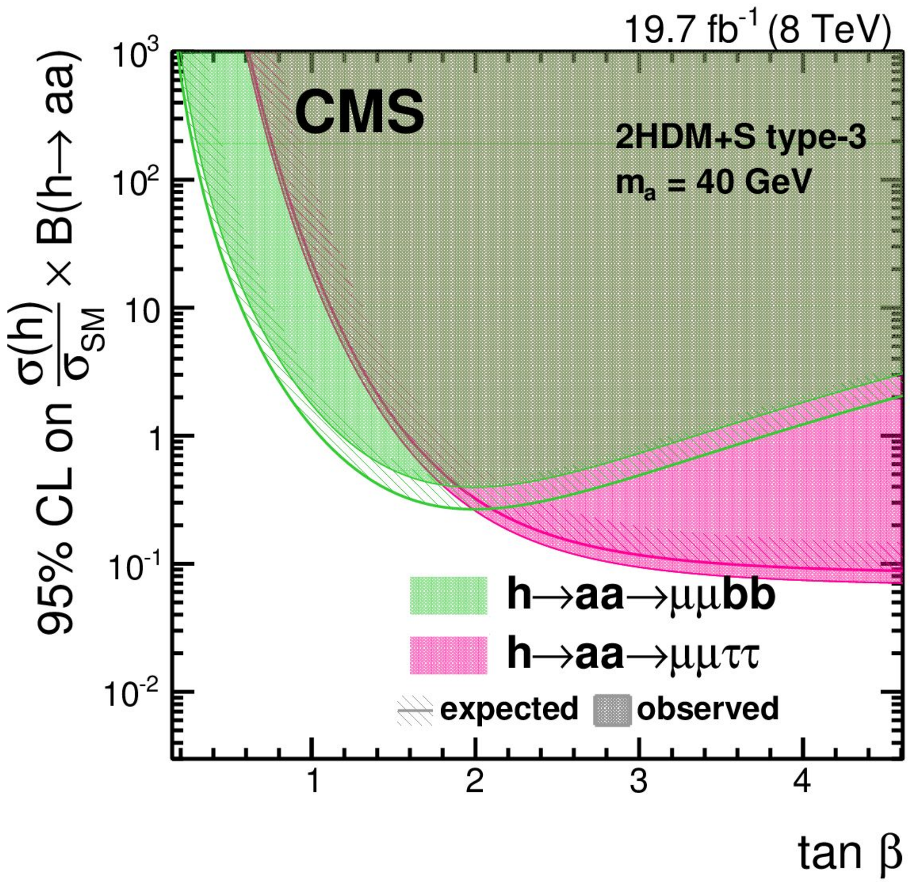
-BR(a→$\mu\mu$)/BR(a→$\tau\tau$) does not depend on tanβ in 2HDM+S

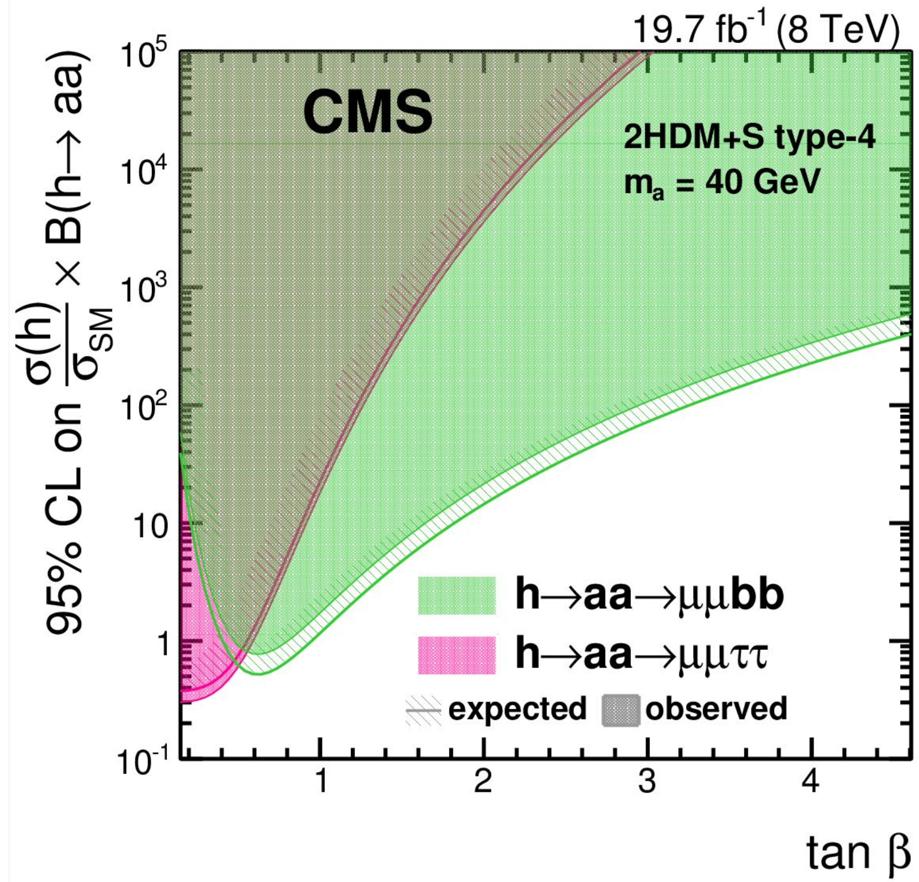
-This is true for

BR(a→$\mu\mu$)/BR(a → bb) for Types I-II



Caveat on sensitivity





Very model (and parameter!) dependent

Example: $\tau\tau$/bb sensitivity as function of tanβ

So conclusions on most sensitive channels are to be drawn carefully

$h \rightarrow \gamma\gamma$ at low mass

CMS PAS HIG-17-013

Main characteristics

Similar concept to the standard $H \to \gamma\gamma$ analysis, but in different region

8 TeV: $80 < m_{\gamma\gamma} < 110\ GeV/c^2$

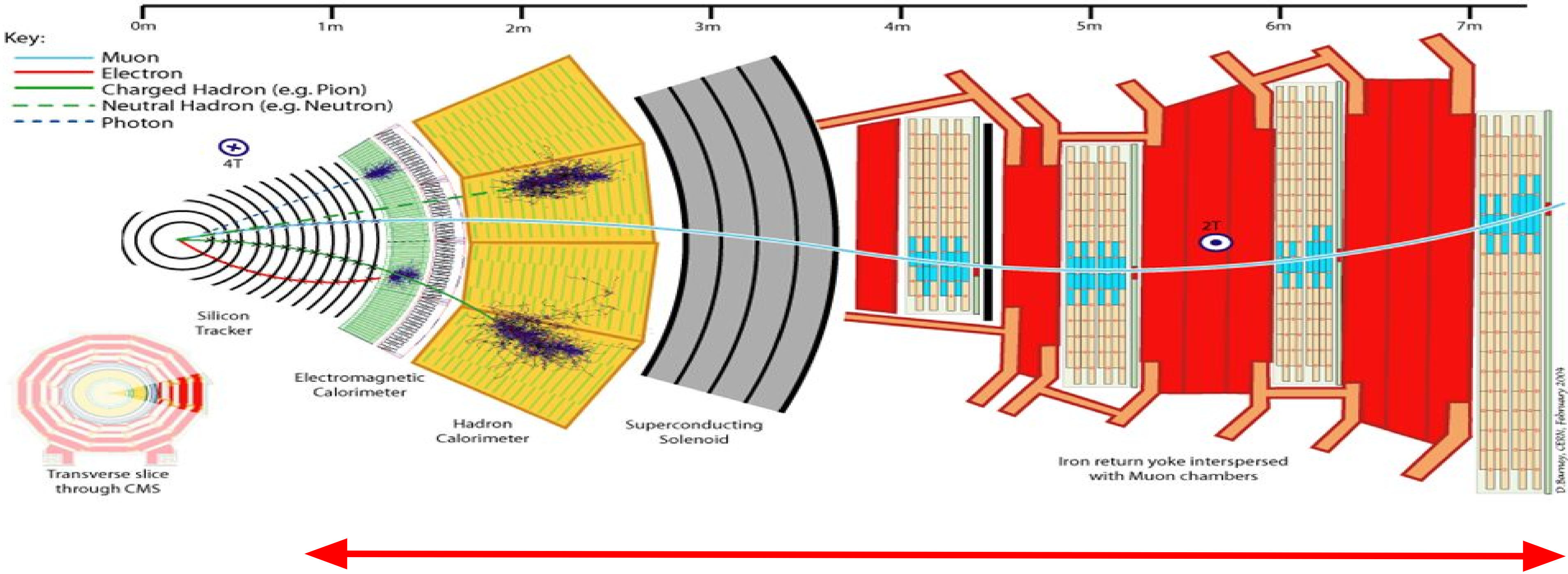
13 TeV: $70 < m_{\gamma\gamma} < 110\ GeV/c^2$

Main differences:

- Lower E_T, a bit more aggressive selection cuts
- Edge of the trigger acceptance
- Important $Z \to e^+e^-$ background

Note: 8 TeV analysis limited at 80 GeV because of trigger, this was improved at 13 TeV

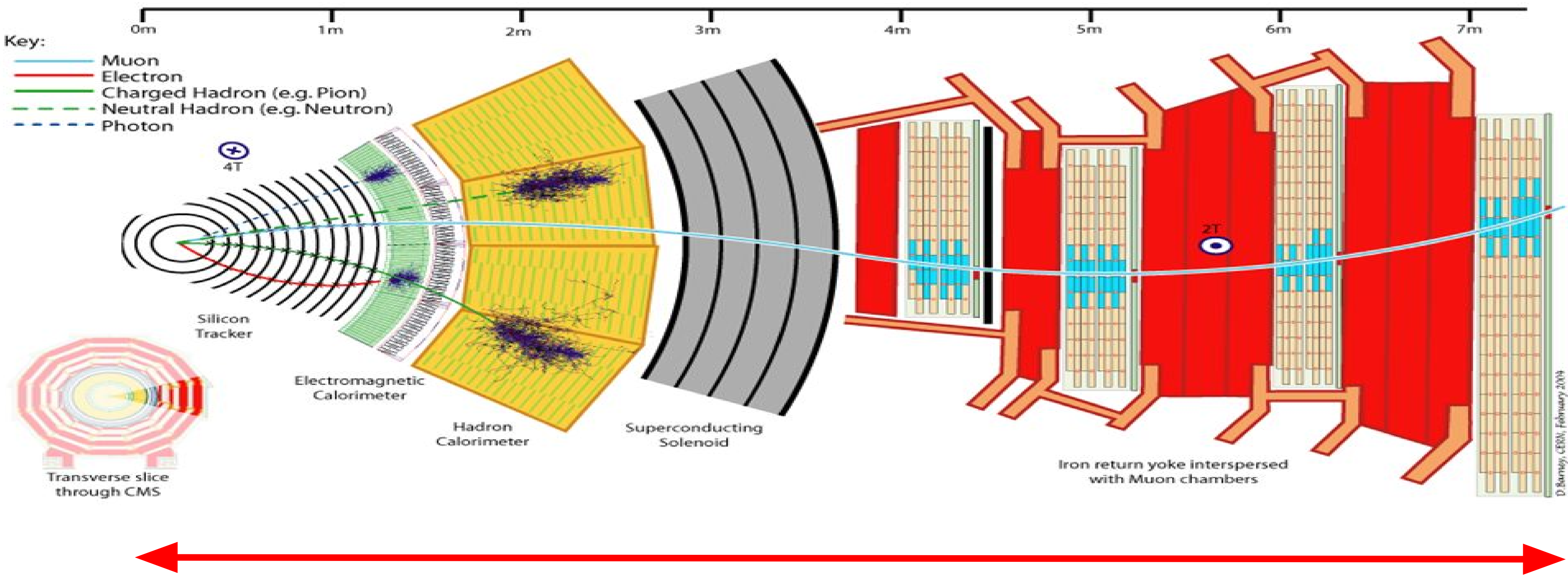
Why trigger matters



L1 Trigger: only calorimeters and muons

- Limited to maximum 100 kHz
- **Electrons and photons indistinguishable**
- In design system: no “complex” operations possible
- Typical e/ɣ thresholds in 2016:
  - Around 30 GeV for one object
  - Around 20/15 GeV for two objects

Why trigger matters



HLT: can use the tracker

- Limited to about 1 kHz
- **Discriminate electrons from photons**
- Dedicated algorithms for low mass γγ analysis in 2016!

Event election (13 TeV)

Trigger

- E_T > 30/18 GeV
- Pixel veto for electron rejection
- $m_{\gamma\gamma}$ > 55 GeV
- Distinguish photons in barrel and endcap:
  - In endcap
    - Additional shower shape selections
    - Cuts on hadronic/EM energy
    - Isolation

Selection

- $p_{T,\gamma 1}/m_{\gamma\gamma}$ > 30.6/65 $p_{T,\gamma 2}/m_{\gamma\gamma}$ > 18.2/65
- Standard single photon selection criteria
- MVA (BDT) to reject non-prompt photon pairs
- BDT to classify events (based on kinematics, photon ID, mass resolution) in four categories

Signal characterization

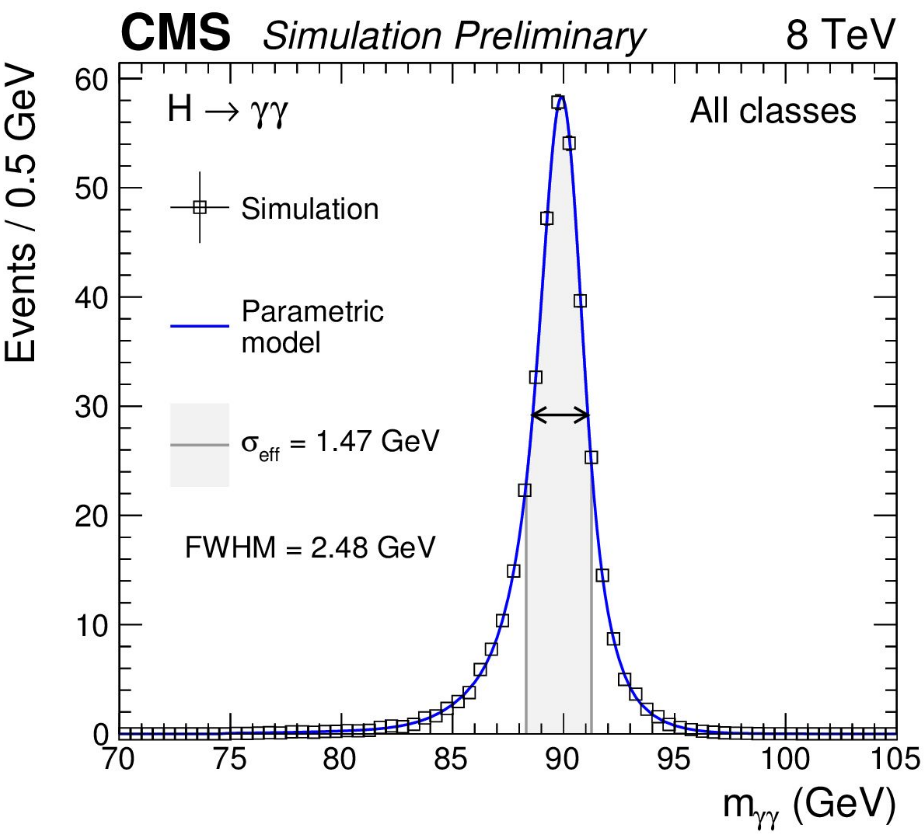
Use $Z \rightarrow e^+e^-$ events, only EM part reconstructed, retune MC

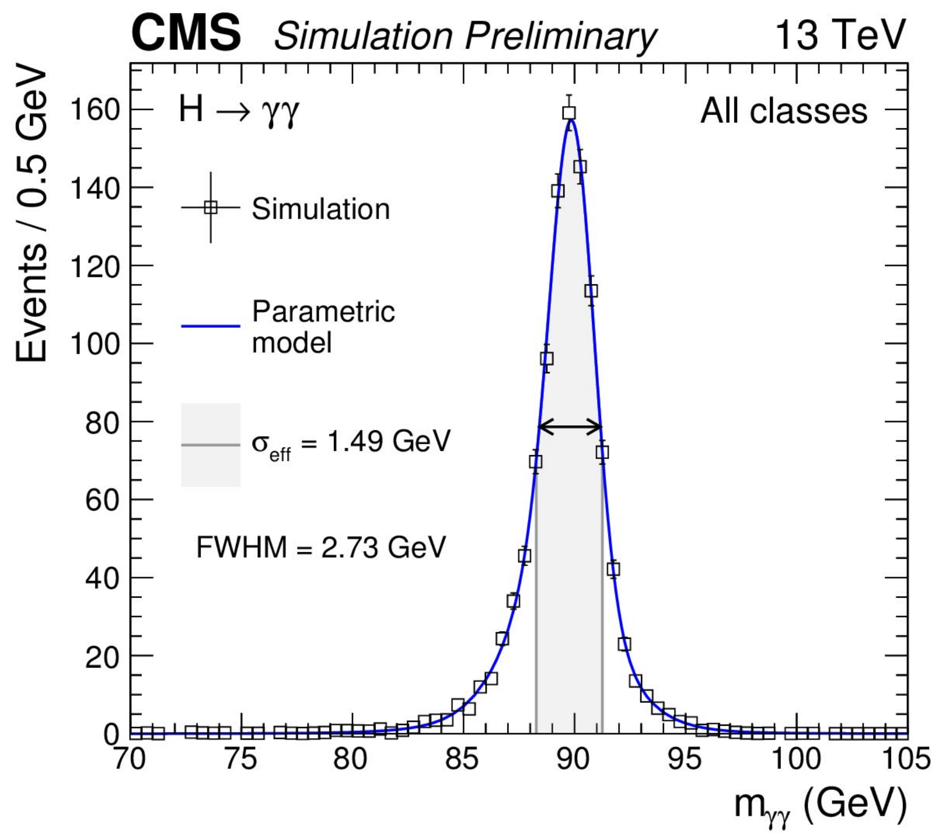
Reparametrized on full mass range with signal MC and extrapolated

$$m_{\gamma\gamma} = \sqrt{4 E_{\gamma_1} E_{\gamma_2} \sin^2\left(\frac{\theta}{2}\right)}$$

ECAL performance

Vertex determination





Background parametrization

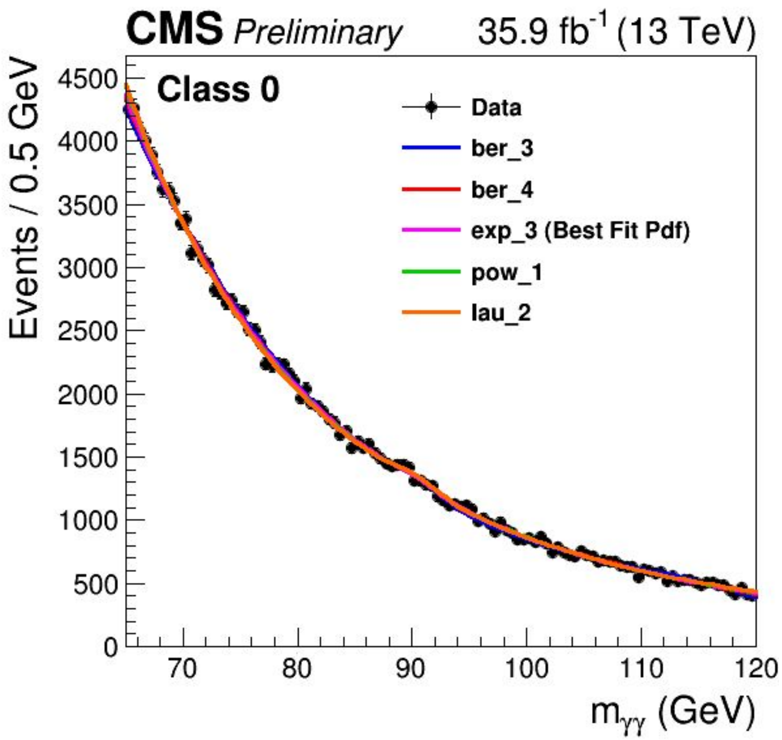
Two components: smoothly falling and Z → e^+e^- double mis-ID

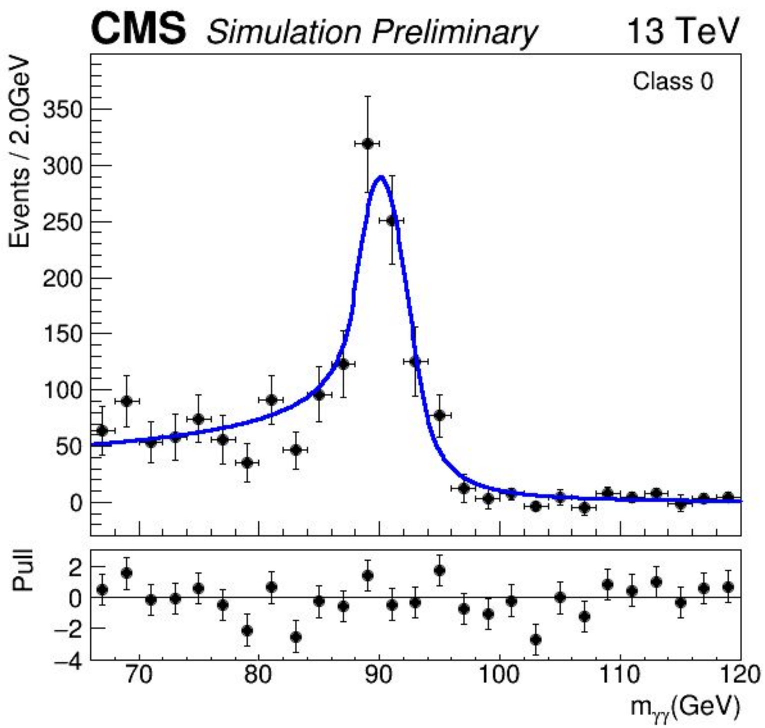
- For continuum, exp/N-order polynomials
- For Z → e^+e^-, Double Crystal Ball

13 TeV: Discrete profiling → choice of background function discrete parameter in likelihood

Order of polynomials decided with F-test

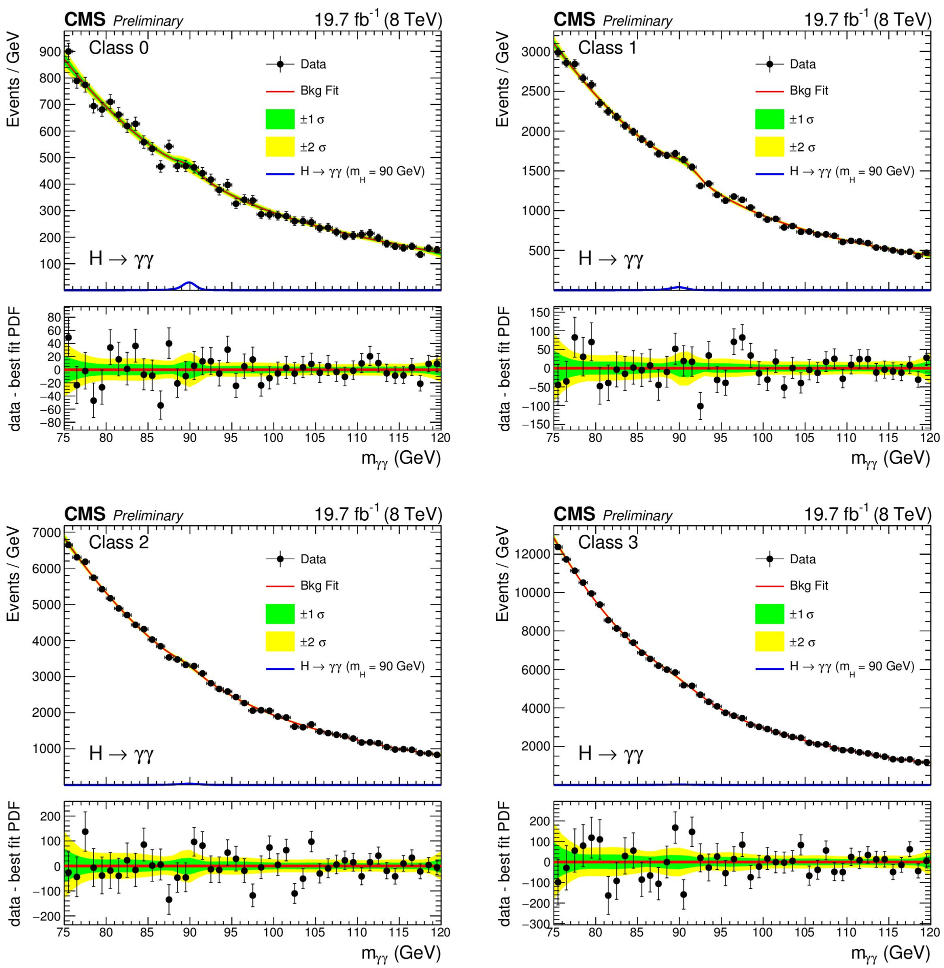
Extensive bias studies to validate background choice



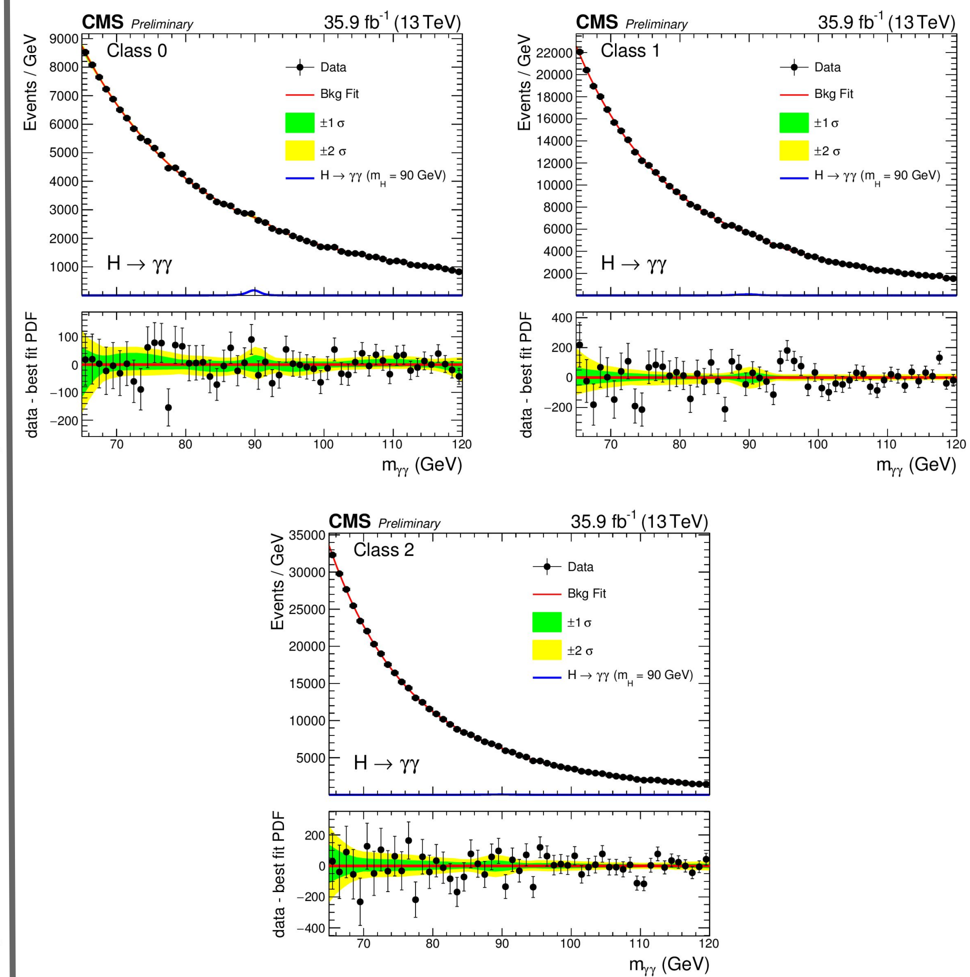


Invariant mass fits

8 TeV

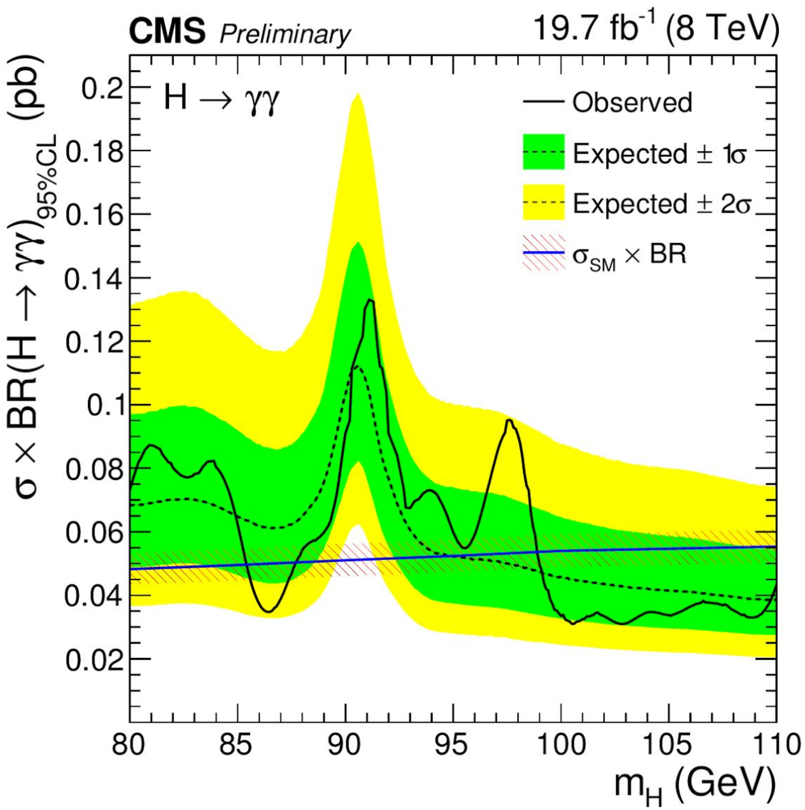


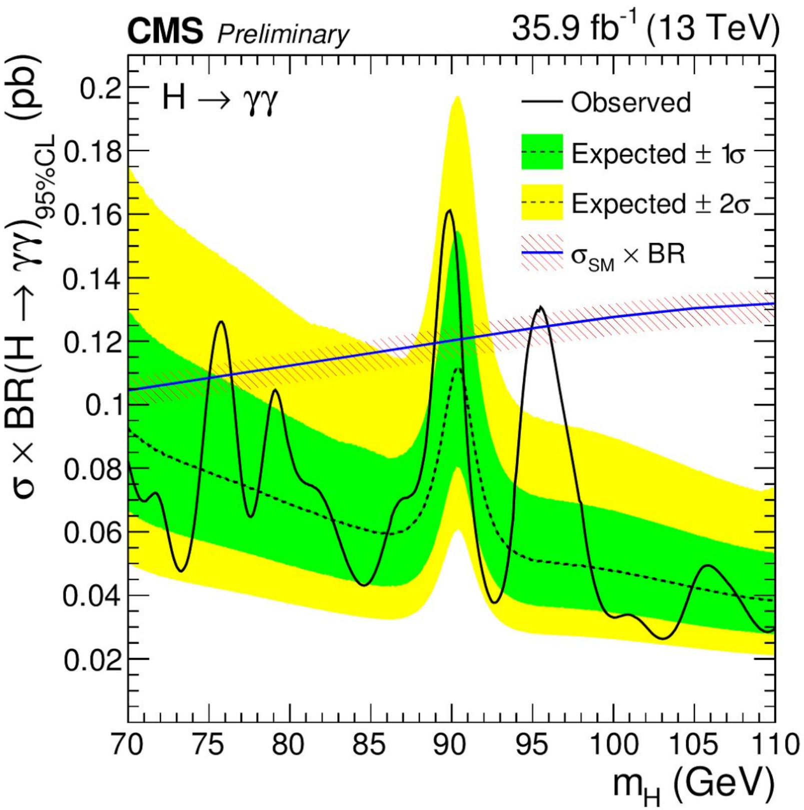
13 TeV



Low stat higher sensitivity categories merged in 13 TeV sample

Interpretation





Main systematic uncertainties

Photon ID, largest unc. 14.6% (VBF, 13 TeV)

Photon energy resolution 13.7% (gg, 8 TeV)

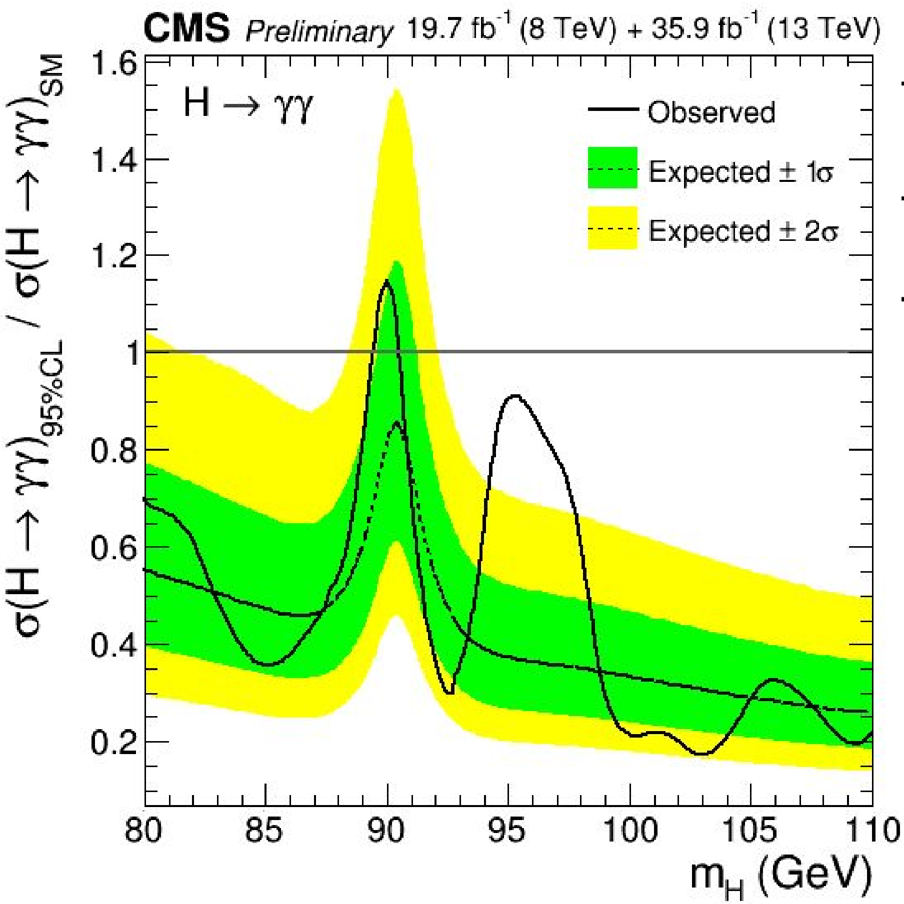
QCD scale 7.5% (gg, 8 TeV)

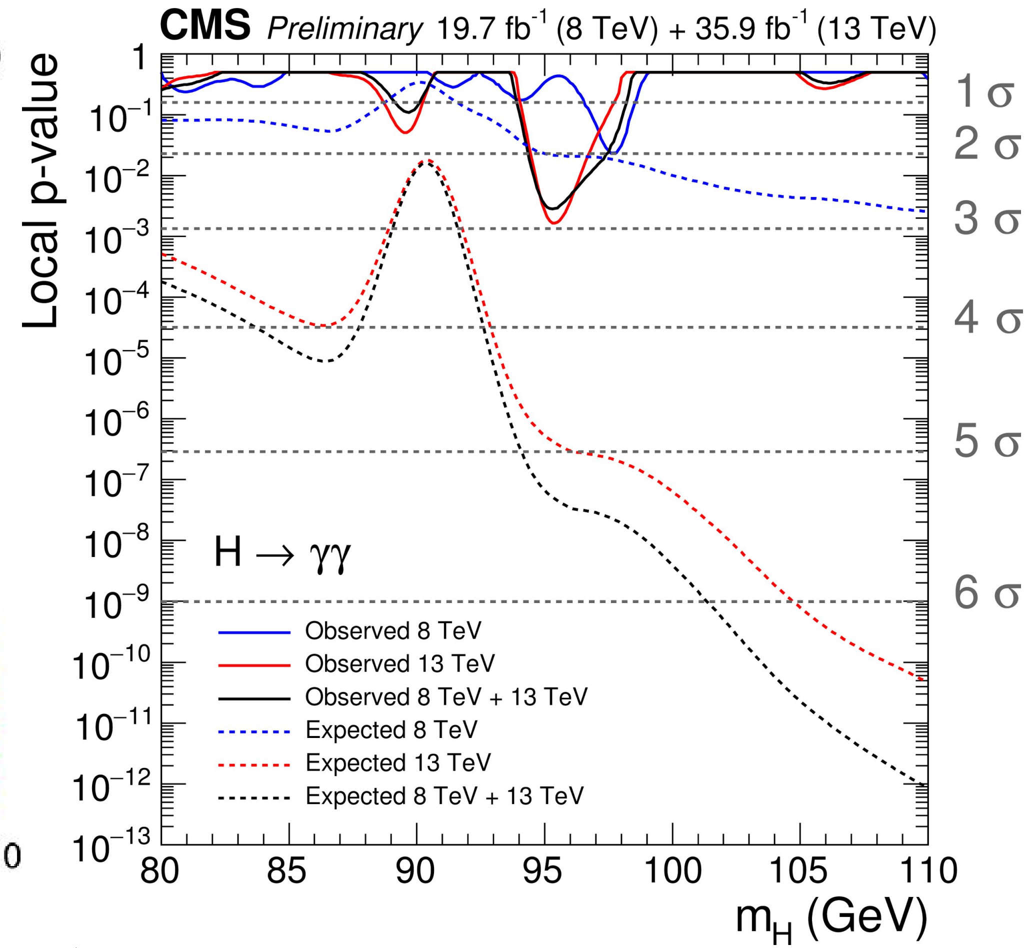
Trigger efficiency 5.5% (13 TeV)

8 TeV: Excess with ~2.0σ local significance at 97.6 GeV

13 TeV: Excess with ~2.9σ local (1.47 σ global) significance at 95.3 GeV

Combination





All systematics uncorrelated, but for signal acceptance (for scale) and on production cross section (100% correlated)

Production processes contribution assumed with SM ratio

8TeV+13 TeV: Excess with ~2.8σ local (1.3σ global) significance at 95.3 GeV

2HDM with low mass A

bbA $\rightarrow$ bb$\mu\mu$

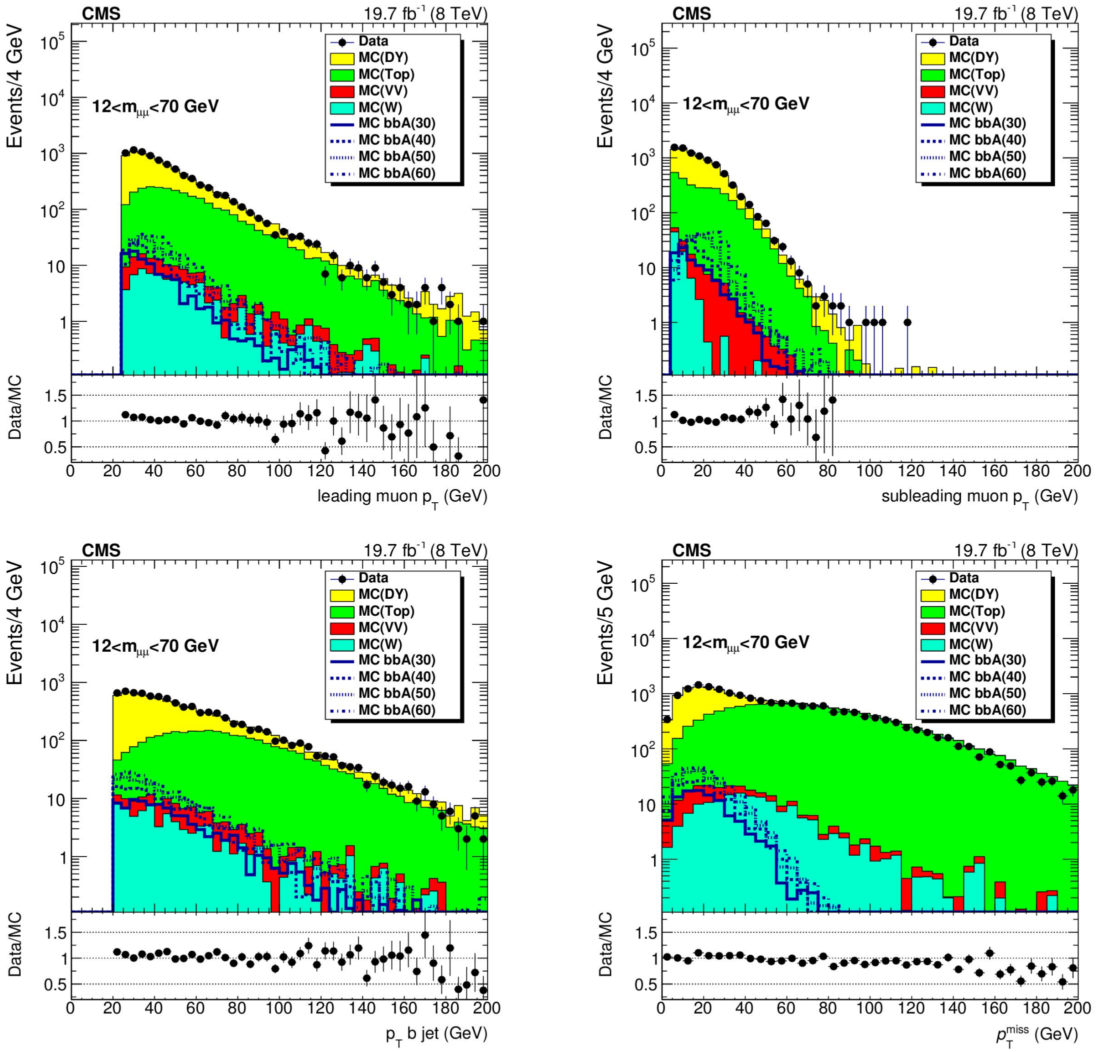
CMS HIG-15-009, Accepted by JHEP

Selection criteria

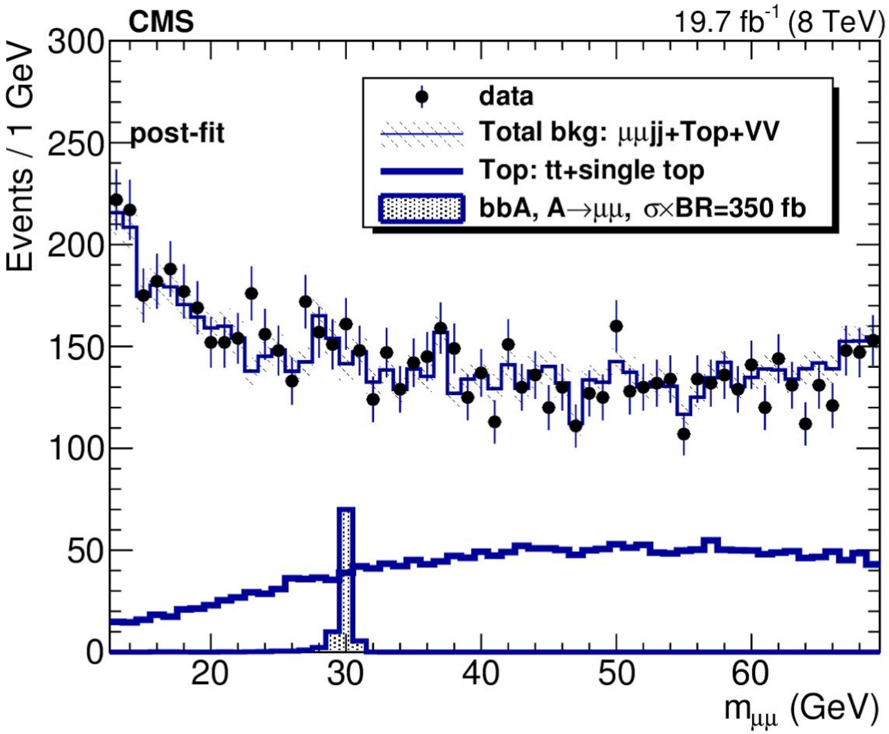
- Single (24 GeV) or double (17/8 GeV) isolated muon trigger
- Offline request of PV and combined isolation
- At least one b-jet with $p_T > 20$ GeV
    - ID Efficiency ~ 45% with 6% mis-ID, mainly charm)
- $p_{T,miss} < 40$ GeV
- $12 < m_{\mu\mu} < 70$ GeV

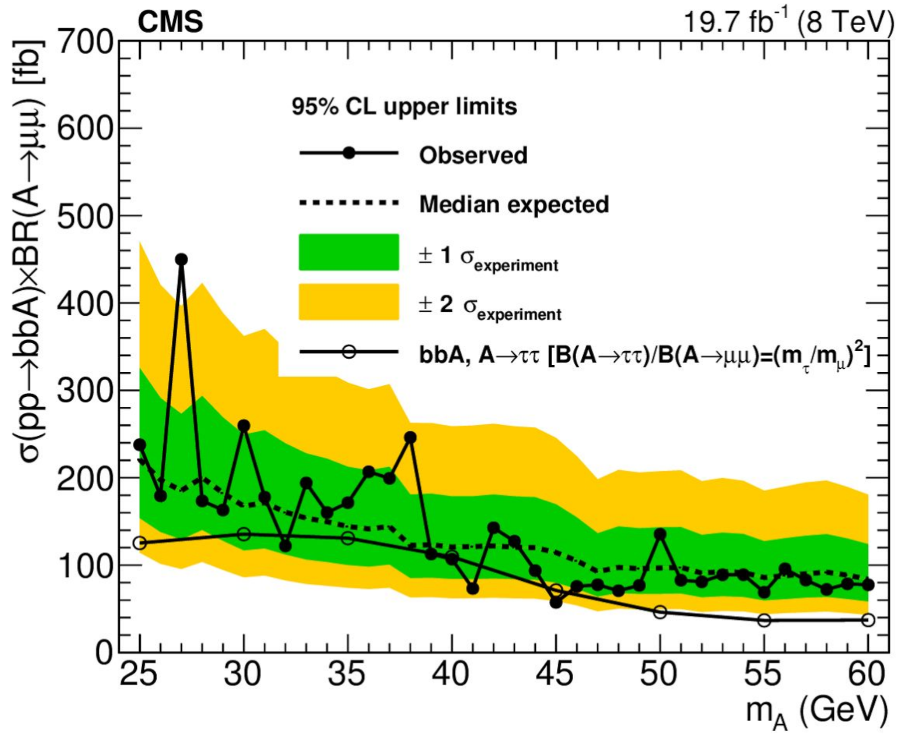
Analysis strategy: fit $m_{\mu\mu}$ with signal and background templates from MC

Use m_{ee} to validate background modelization



Results





Main sources of systematic uncertainty:

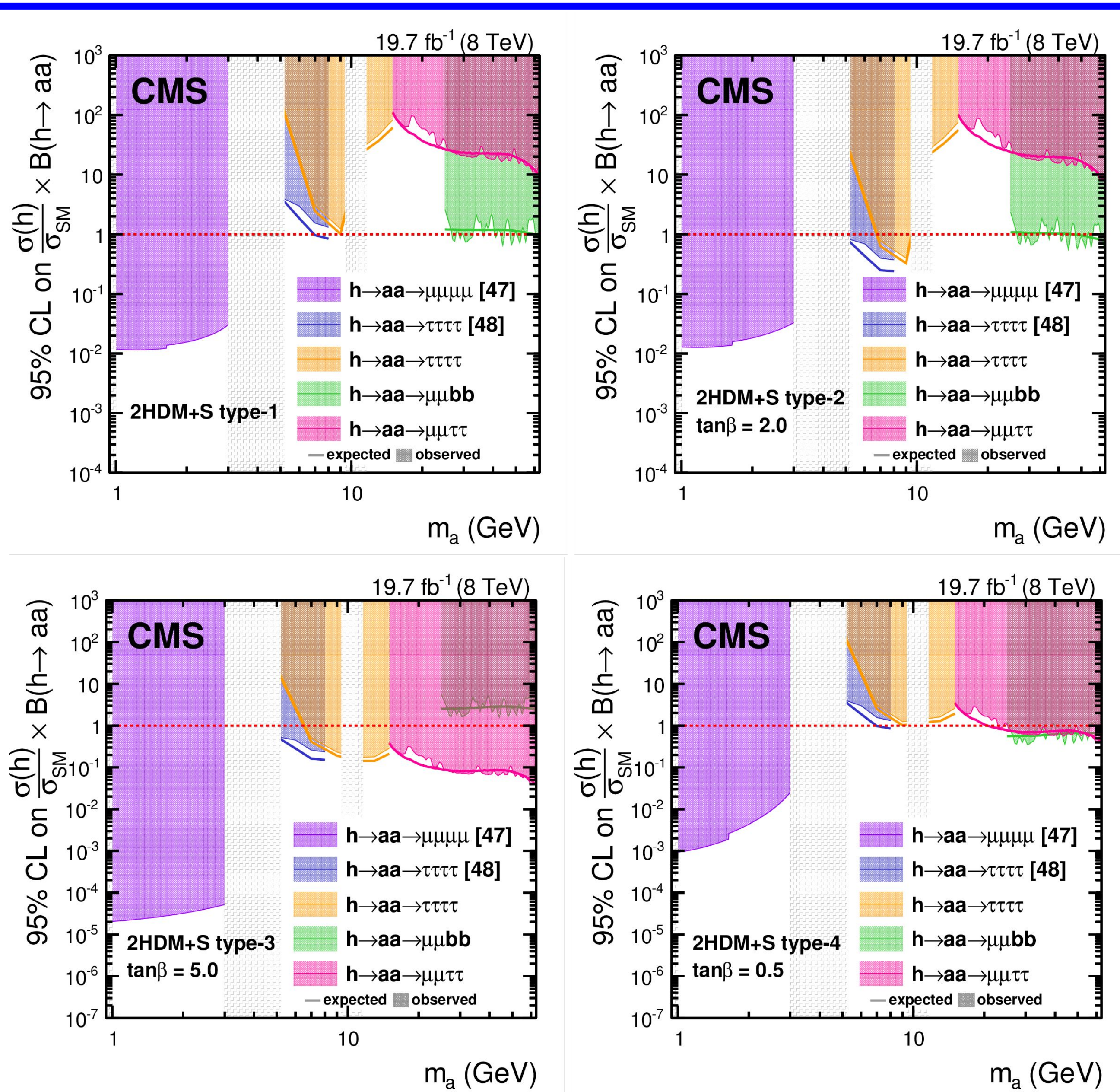
- Top quark normalization uncertainty: 7%
- Renormalization and factorization scales on DY: 20%
- Uncertainty on signal acceptance (shower scale, renormalization and factorization, PDFuncertainties): ~ 18%

Conclusions

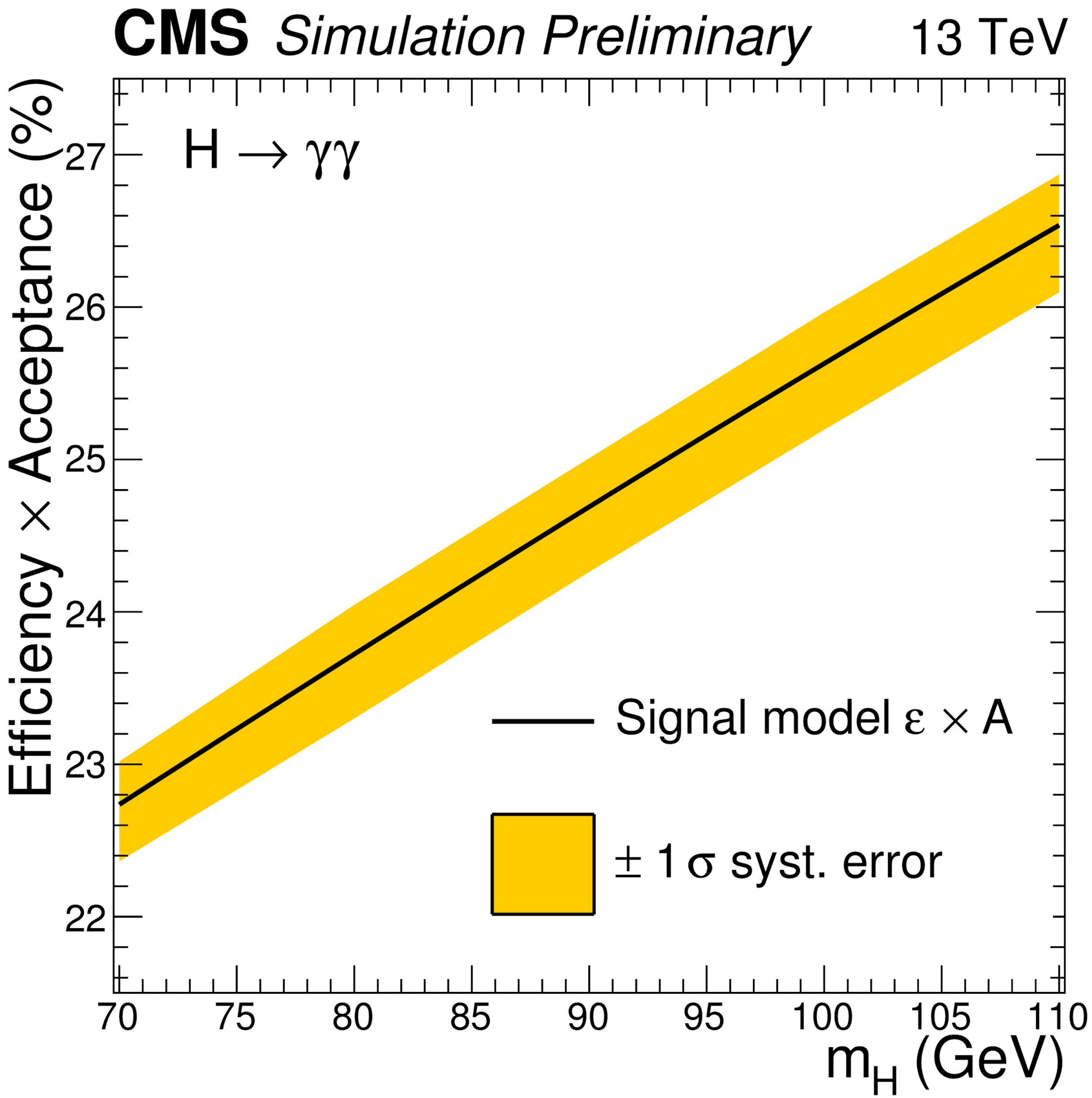
We have just started to extract the physics potential of the 13 TeV dataset!

- We have a comprehensive view of the potential of the main channels from the Run1 experience
- Yet, some lessons can be learned:
  - Necessary to plan our trigger needs in advance, either to maintain or improve our sensitivity
  - Dedicated tools and studies for low p_T searches
  - In other words, sensitivity depends also on interest in particular class of topologies
- Feedback with theory community fundamental to keep interest in exploring these signatures

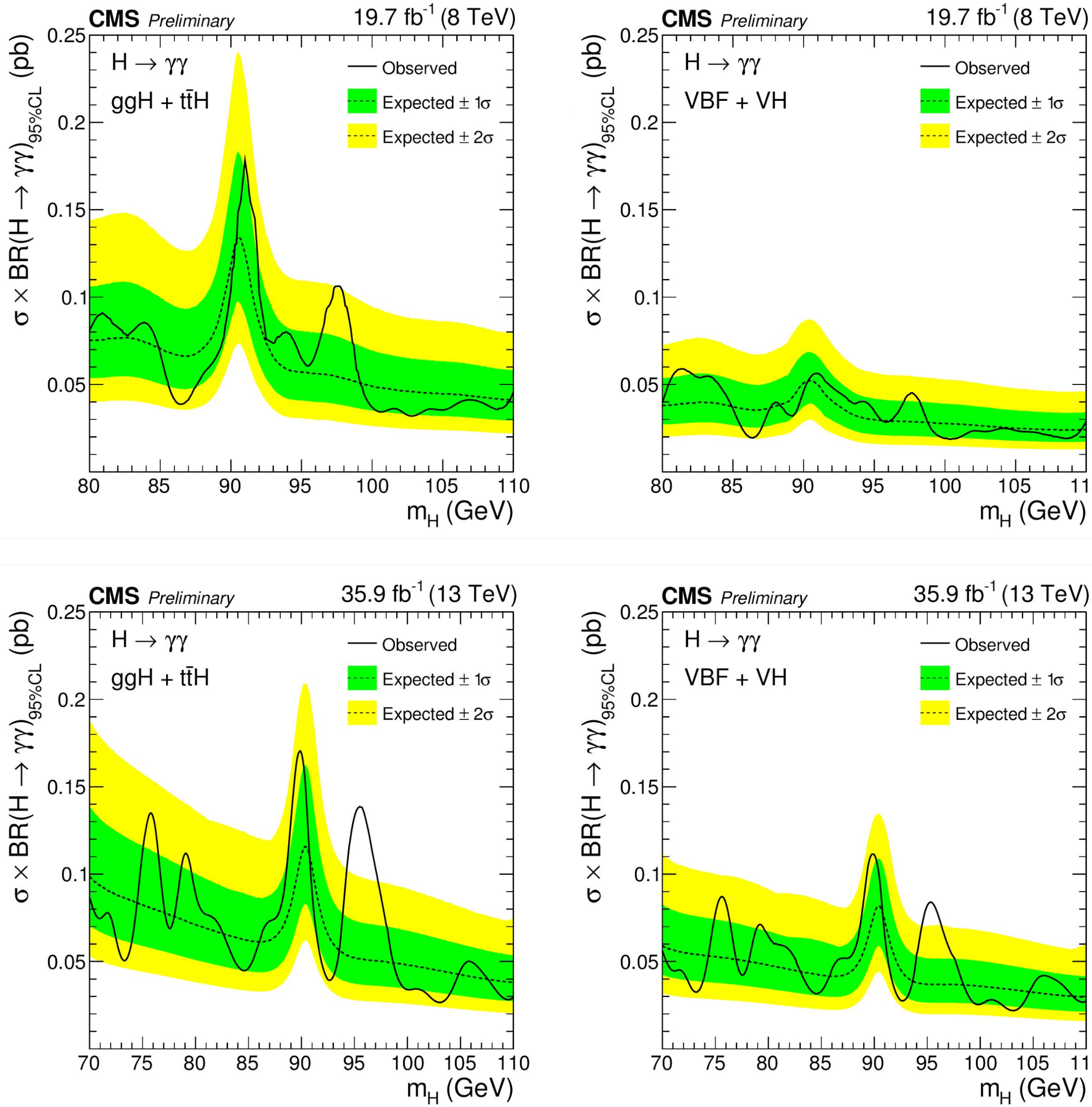
Backup



19.7 fb^{-1} (8 TeV)
CMS
2HDM+S type-1
h→aa→μμμμ [47]
h→aa→ττττ [48]
h→aa→ττττ
h→aa→μμbb
h→aa→μμττ
expected
observed
95% CL on $\frac{\sigma(h)}{\sigma_{SM}} \times B(h \to aa)$
m_a (GeV)
19.7 fb^{-1} (8 TeV)
CMS
2HDM+S type-2
tanβ = 2.0
19.7 fb^{-1} (8 TeV)
CMS
2HDM+S type-3
tanβ = 5.0
19.7 fb^{-1} (8 TeV)
CMS
2HDM+S type-4
tanβ = 0.5



CMS Simulation Preliminary
13 TeV
H → γγ
Efficiency × Acceptance (%)
27
26
25
24
23
22
70
75
80
85
90
95
100
105
110
m_H (GeV)
Signal model ε × A
± 1σ syst. error


CMS Preliminary
19.7 fb^-1 (8 TeV)
H → γγ
ggH + tt̄H
Observed
Expected ± 1σ
Expected ± 2σ
σ × BR(H → γγ)95%CL (pb)
mH (GeV)
CMS Preliminary
19.7 fb^-1 (8 TeV)
H → γγ
VBF + VH
Observed
Expected ± 1σ
Expected ± 2σ
σ × BR(H → γγ)95%CL (pb)
mH (GeV)
CMS Preliminary
35.9 fb^-1 (13 TeV)
H → γγ
ggH + tt̄H
Observed
Expected ± 1σ
Expected ± 2σ
σ × BR(H → γγ)95%CL (pb)
mH (GeV)
CMS Preliminary
35.9 fb^-1 (13 TeV)
H → γγ
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Observed
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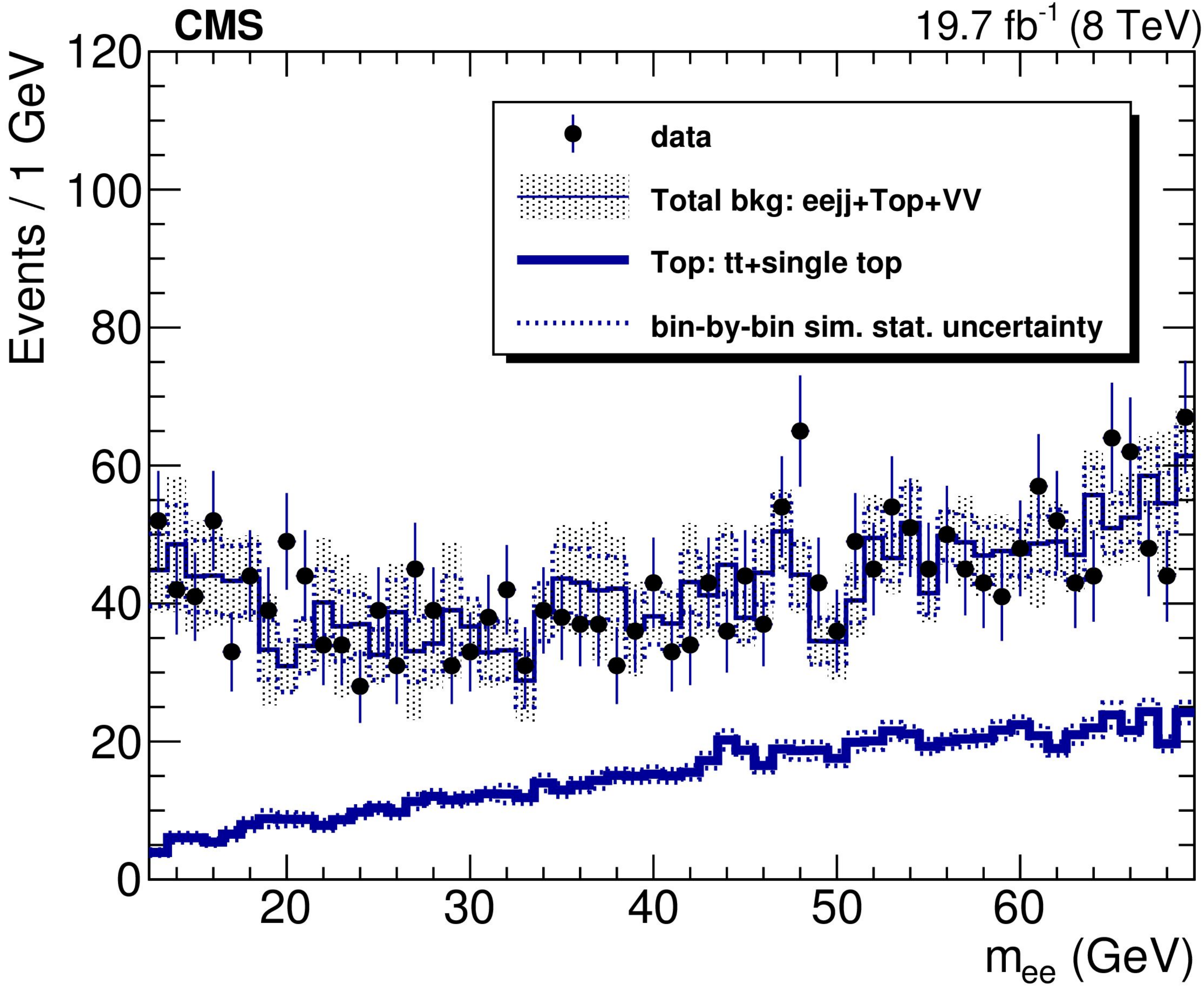
mH (GeV)


CMS
19.7 fb-1 (8 TeV)
Events / 1 GeV
data
Total bkg: eejj+Top+VV
Top: tt+single top
bin-by-bin sim. stat. uncertainty
m_ee (GeV)
0
20
40
60
80
100
120
20
30
40
50
60