CMS Physics News :
# Run1 Searches for BSM Φ → ττ

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SFB B9 Meeting, Dec 14th 2015

Recent public results

- **Wrapping up analyses of Run 1 data : searches for BSM Higgs bosons decaying to tau leptons**

- MSSM Φ → ττ search using new tau identification algorithm and event categorization based on hadronic tau p_T
  CMS PAS HIG-14-029

- search for heavy Higgs bosons in channels H → hh → (bb)(ττ) and A → hZ → (ττ)($\ell\ell$) : HIG-14-034, arXiv:1510.01181, submitted to PLB

- search for low mass pseudoscalar produced in association with b quarks and decaying into tau pairs
  HIG-14-033, arXiv:1511.03610, submitted to PLB

- search for very light NMSSM Higgs bosons in H(125)→2φ$_1$→4τ :
  HIG-14-019, arXiv:1510.06534, submitted to JHEP

- Exploited production mechanisms
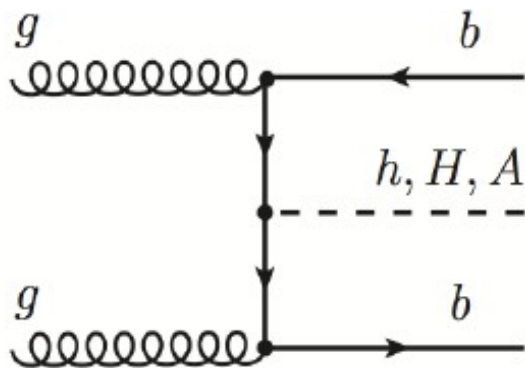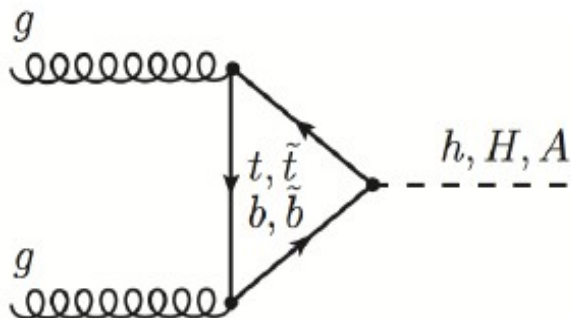
- Exploited di-tau decay modes

$$\mu\tau_{\mathrm{h}}, e\tau_{\mathrm{h}}, \tau_{\mathrm{h}}\tau_{\mathrm{h}}, e\mu, \mu\mu$$

- new MVA based τ_{h} identification using lifetime information (track impact parameters, secondary vertex information) (TAU-15-001 PAS)

$$\gamma\beta c\tau \approx 1 - 10\,\mathrm{mm}$$

- Event categorization
  - no b-jets ($p_{\mathrm{T}} > 20$ GeV, $|\eta| < 2.4$)
  - ≥ 1 b-jet ($p_{\mathrm{T}} > 20$ GeV, $|\eta| < 2.4$)
    < 2 jets ($p_{\mathrm{T}} > 30$ GeV, $|\eta| < 4.5$)

- Further event categorization in the $\mu\tau_{\mathrm{h}}, e\tau_{\mathrm{h}}$ channels based on tau p_{T} (trailing tau p_{T} in $\tau_{\mathrm{h}}\tau_{\mathrm{h}}$ channel)
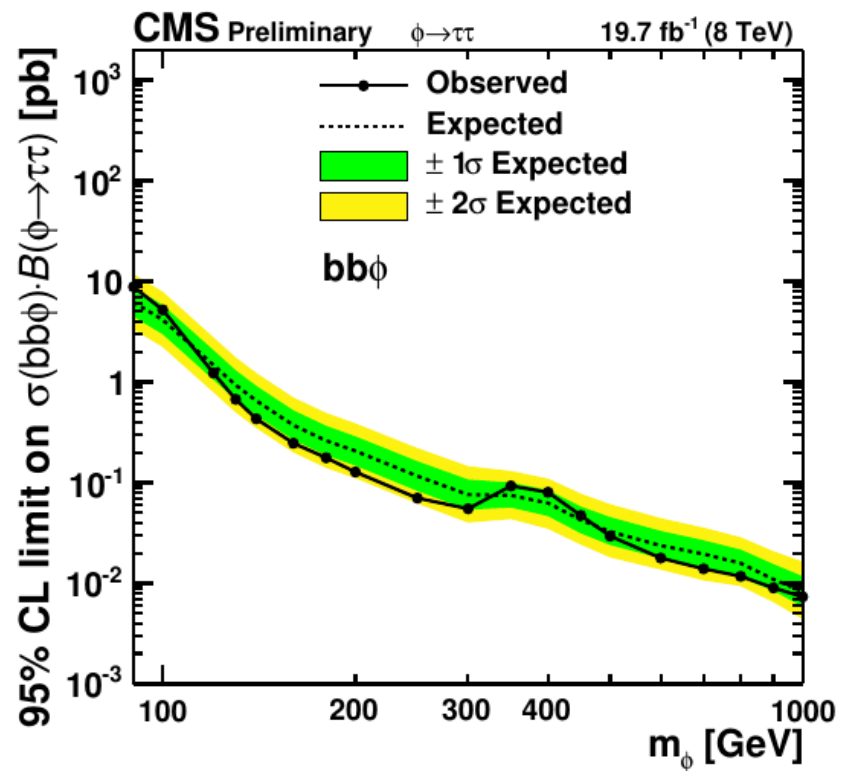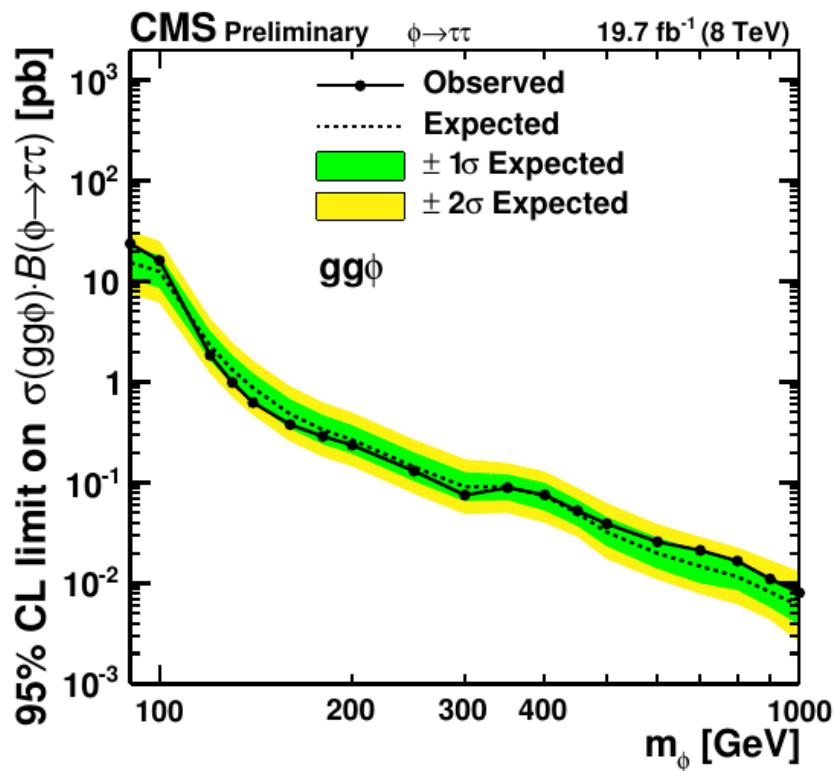
- Major backgrounds : Z → ττ, TTBar, W+Jets, QCD...
- Signal extracted using fully reconstructed di-tau mass distributions
  - in the $\mu\mu$ channel signal is extracted from the 2D distributions [$m_{\tau\tau}$, $m_{\mu\mu}$]
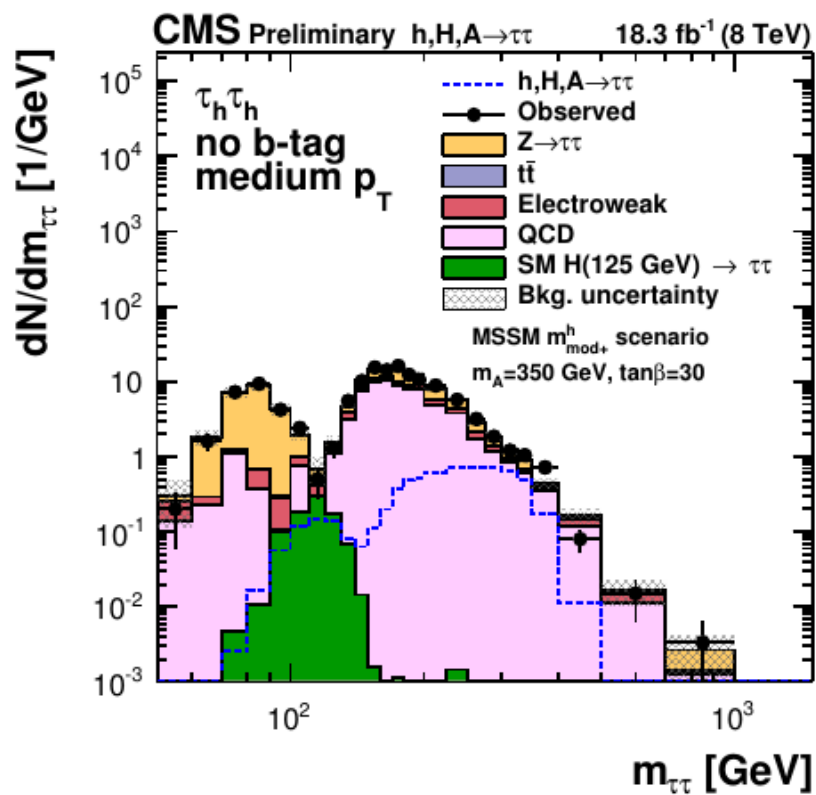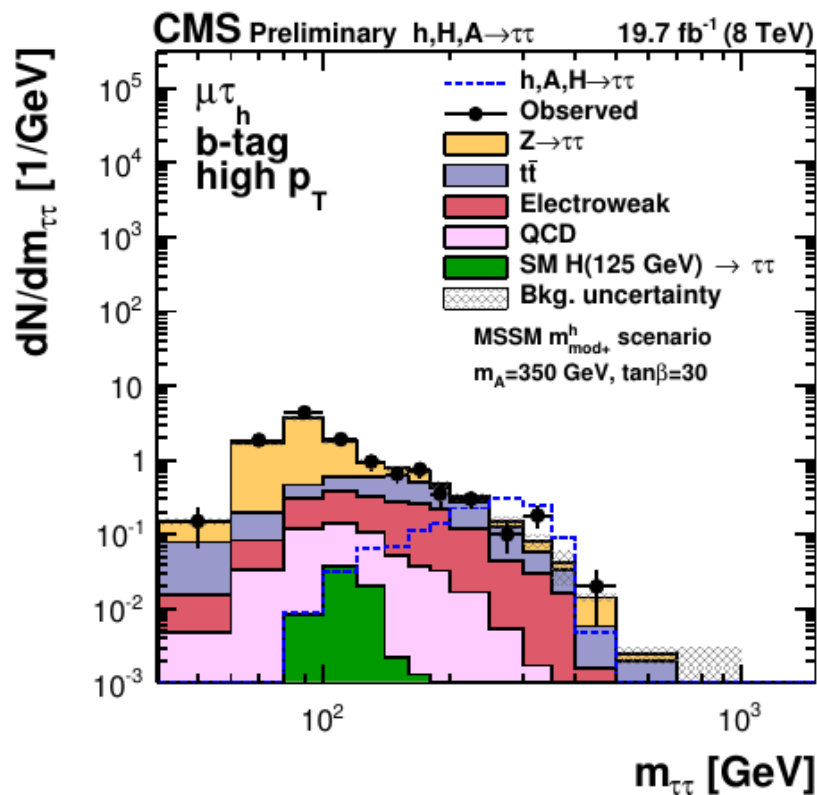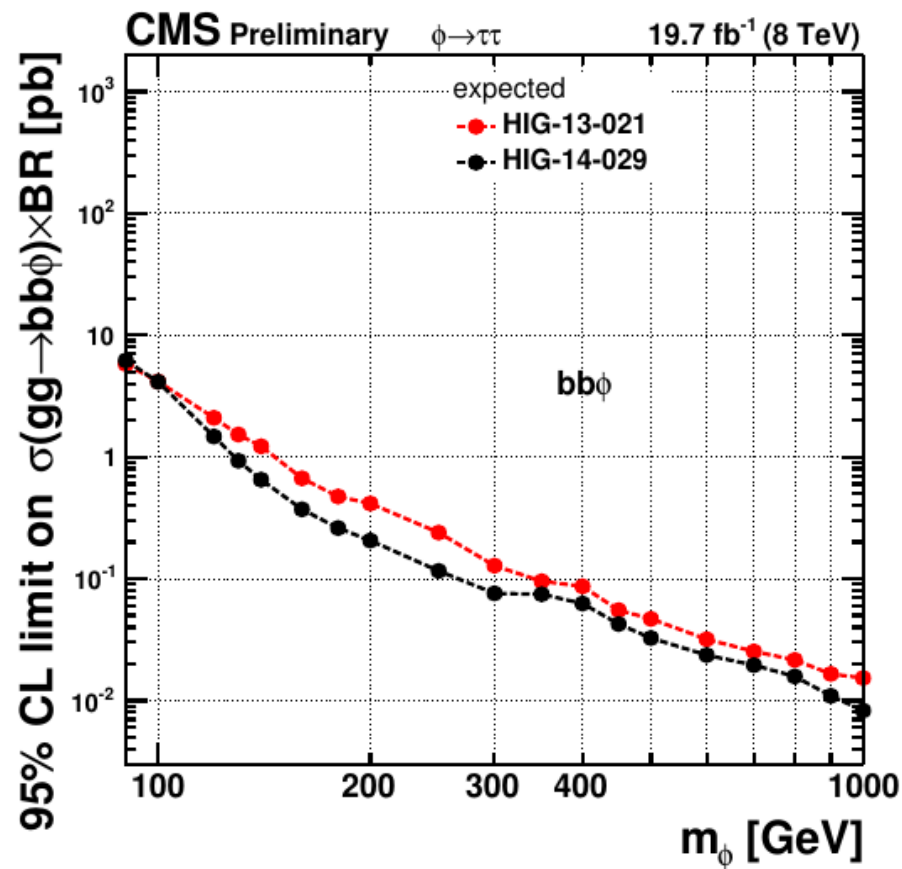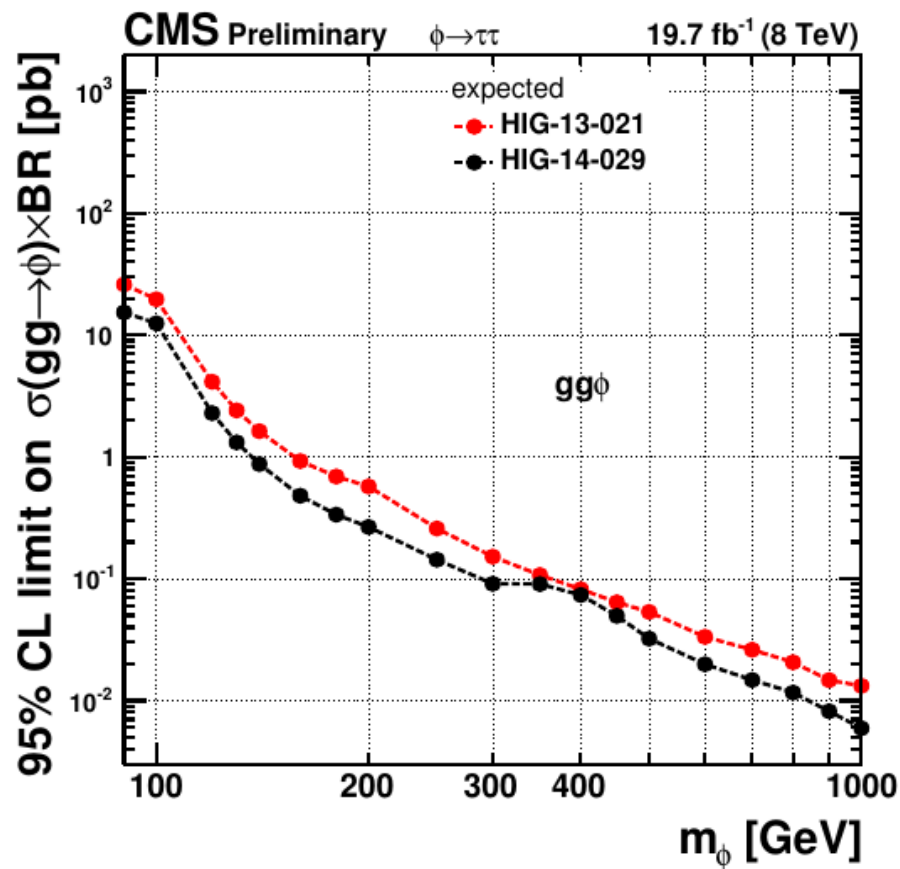
Updated MSSM Φ → ττ search

- No evidence of signal found
- Model independent result : constraints on signal production cross section times BR (search for narrow Φ → ττ resonance)

  set limits on each process
  (other process is profiled)

$$q_\mu = -2 \ln \frac{\mathcal{L}\left(data | \mu \cdot s(\hat{\theta}_\mu) + h_{SM}(\hat{\theta}_\mu) + b(\hat{\theta}_\mu)\right)}{\mathcal{L}\left(data | \hat{\mu} \cdot s(\hat{\theta}) + h_{SM}(\hat{\theta}) + b(\hat{\theta})\right)}$$

- **Improvement with respect to previous results**

- **Limits in 2D plane**

$$\sigma(\mathrm{gg} \to \phi)\mathcal{B}(\phi \to \tau\tau) \quad \text{vs.} \quad \sigma(\mathrm{bb}\phi)\mathcal{B}(\phi \to \tau\tau)$$
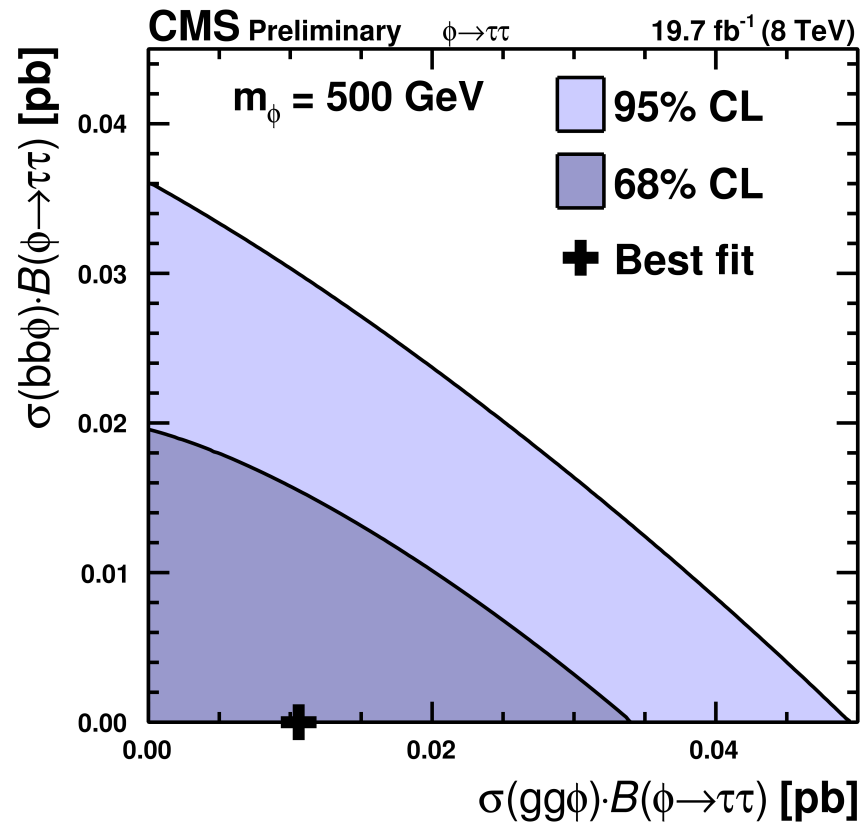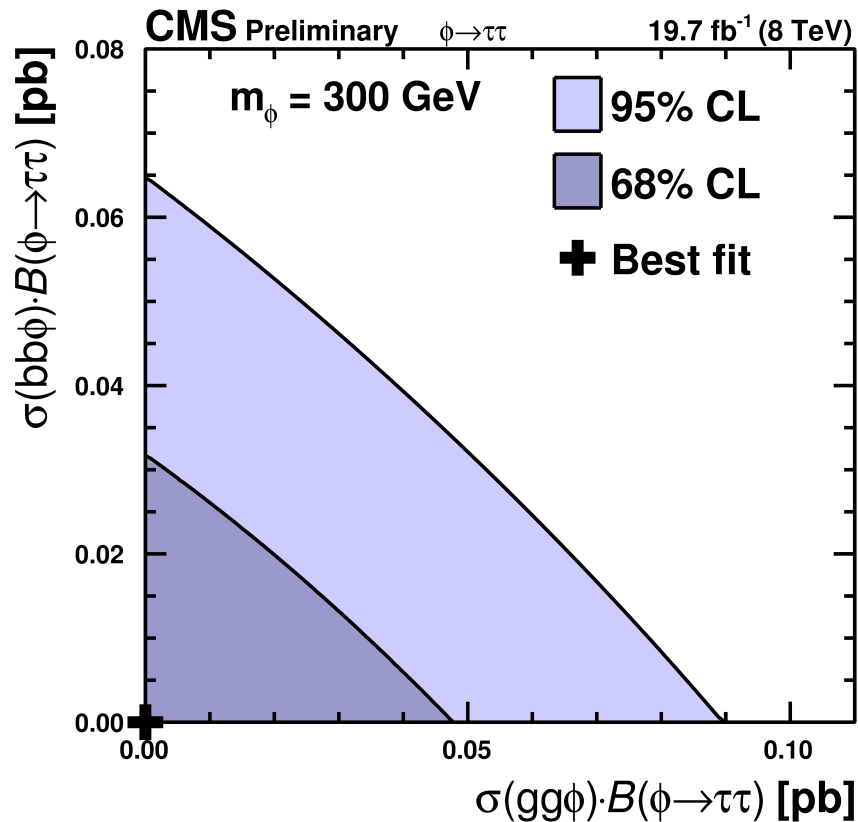
Updated MSSM Φ → ττ search

- **limits in (m_A, tanβ) plane**
- **m_h-mod+ : post-discovery scenario accommodates h(125) state**

old results
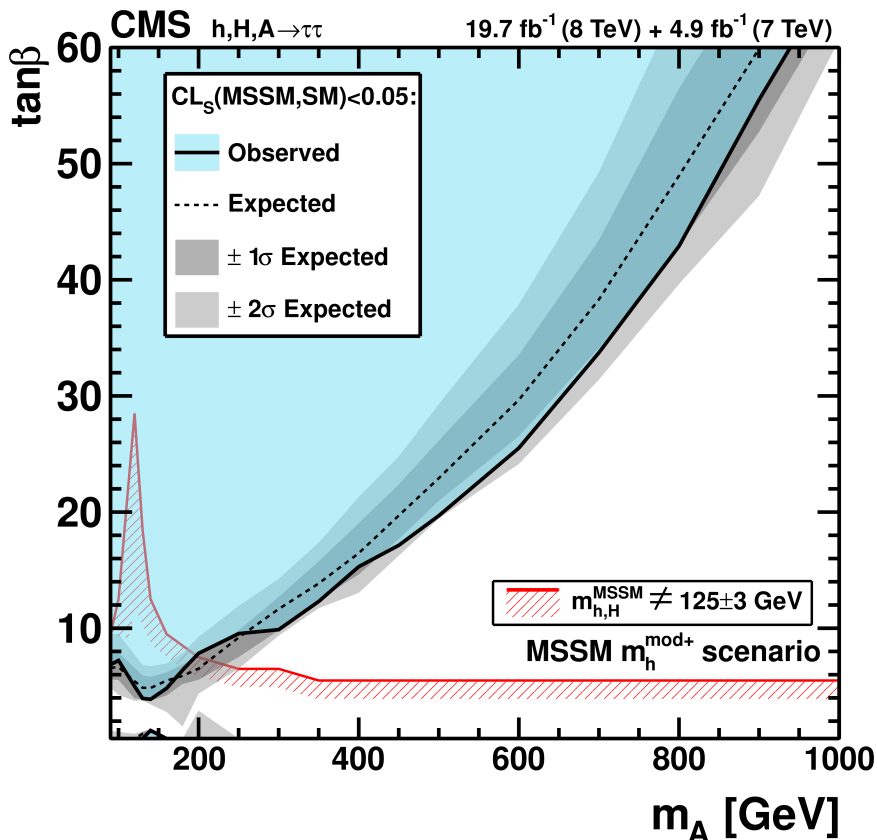
updated results
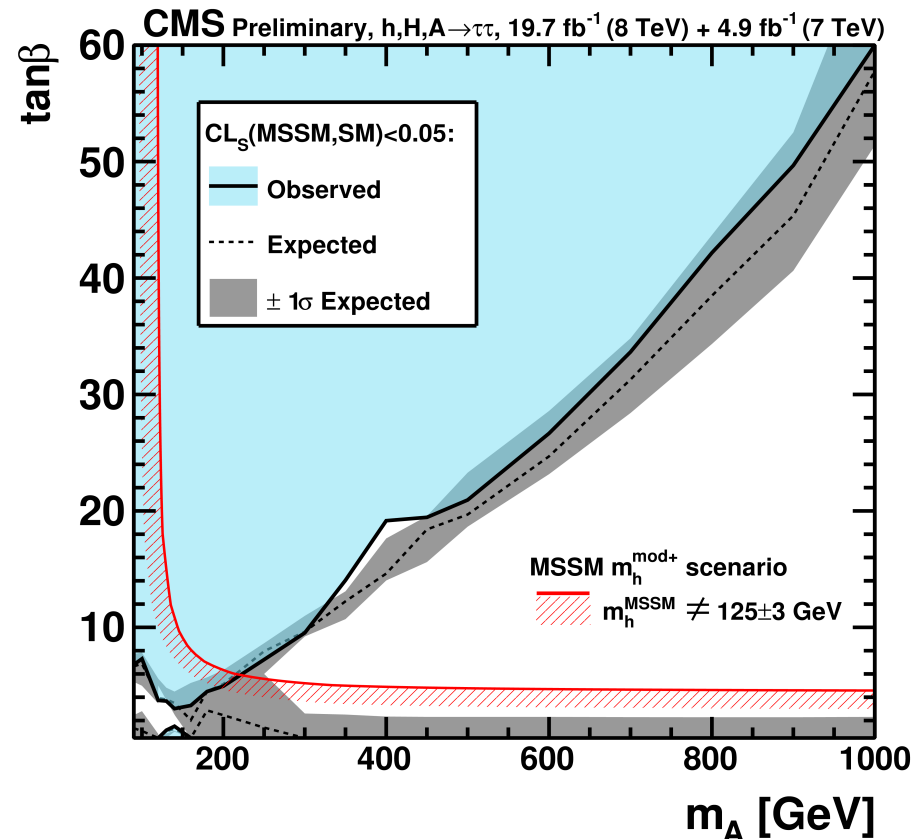
Search for H → h(125)h(125) → (bb)(ττ)

tanβ = 2

- 260 < m_H < 350 GeV , m_h = 125 GeV
  (m_H > 350 GeV ⇒ H → tt dominates)
- probes low tanβ domain of MSSM
- uses inclusive selection devised for the MSSM Φ → ττ analysis
  - $\mu\tau_h, e\tau_h, \tau_h\tau_h$

H→hh→bbττ   19.7 fb⁻¹ (8 TeV)

CMS
$\mu\tau_h$ inclusive

- Observed
- Bkg. uncertainty
- Z→ττ
- Z→μμ
- Electroweak
- QCD
- tt

Signal region

Transverse mass cut to suppress W+Jets and tt for eτ_h & $\mu\tau_h$

Events/ 4 GeV

m_T (GeV)

BR(H)

M_H [GeV]

- H → tt̄
- H → hh
- H → bb̄
- H → WW
- H → τ⁺τ⁻
- H → ZZ
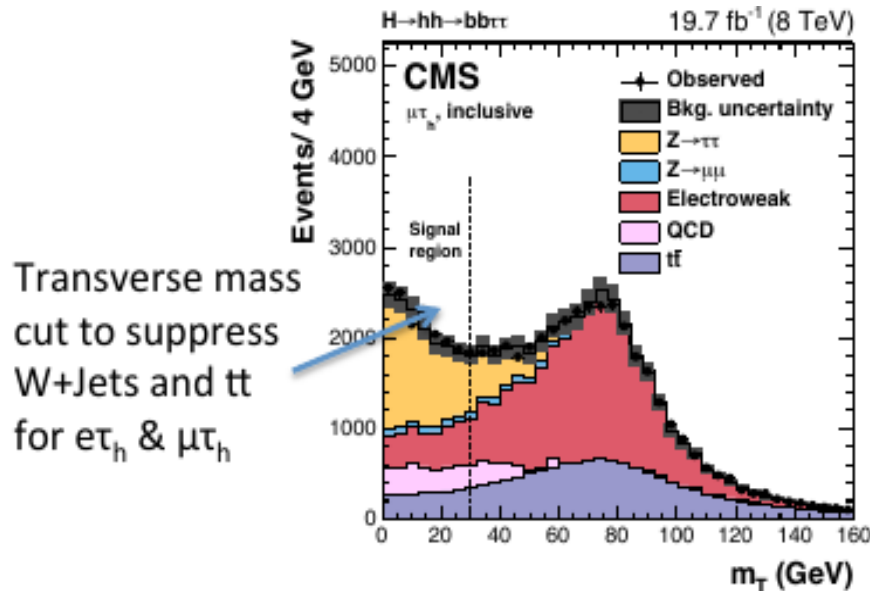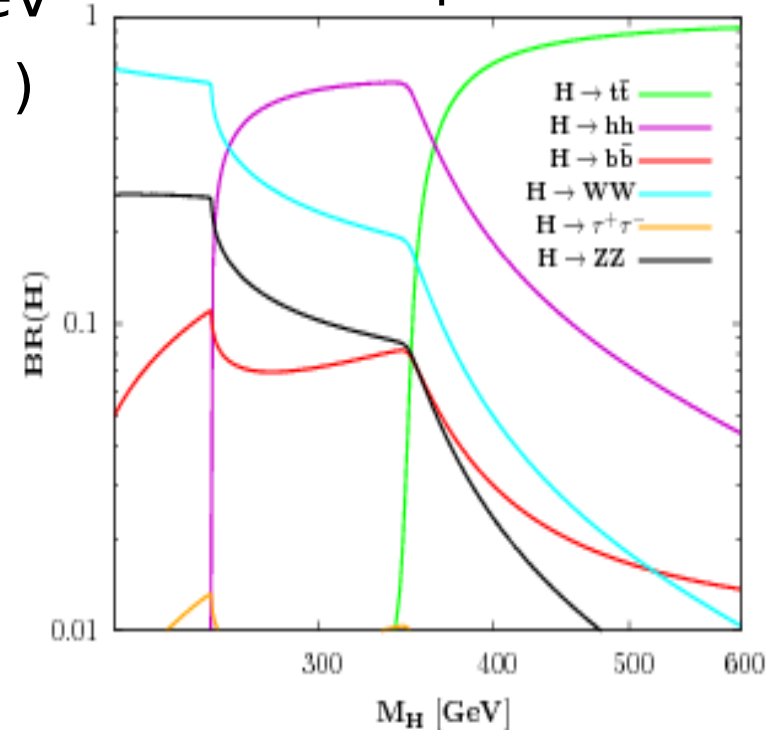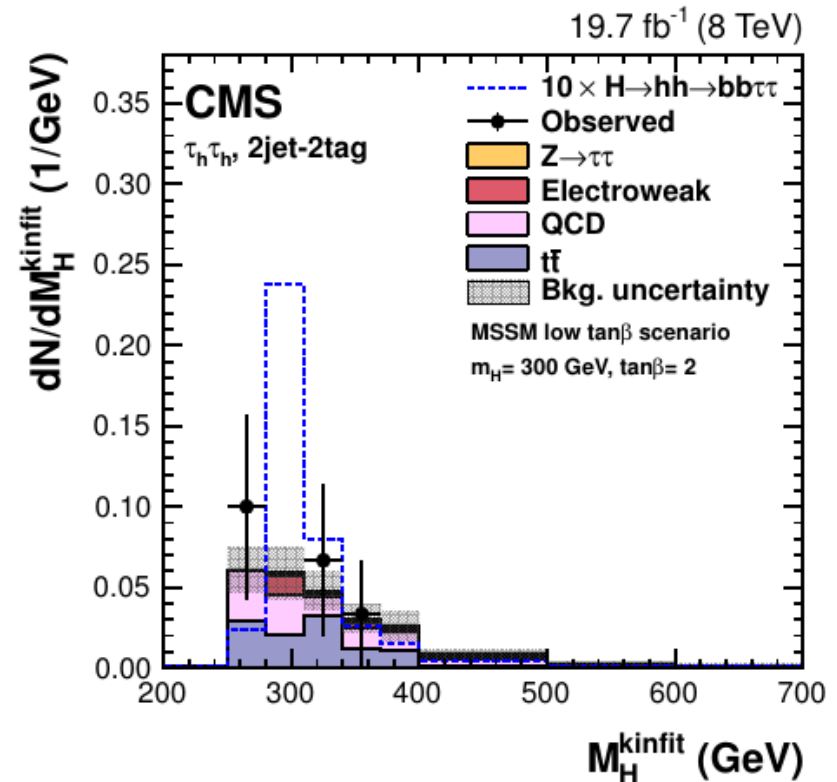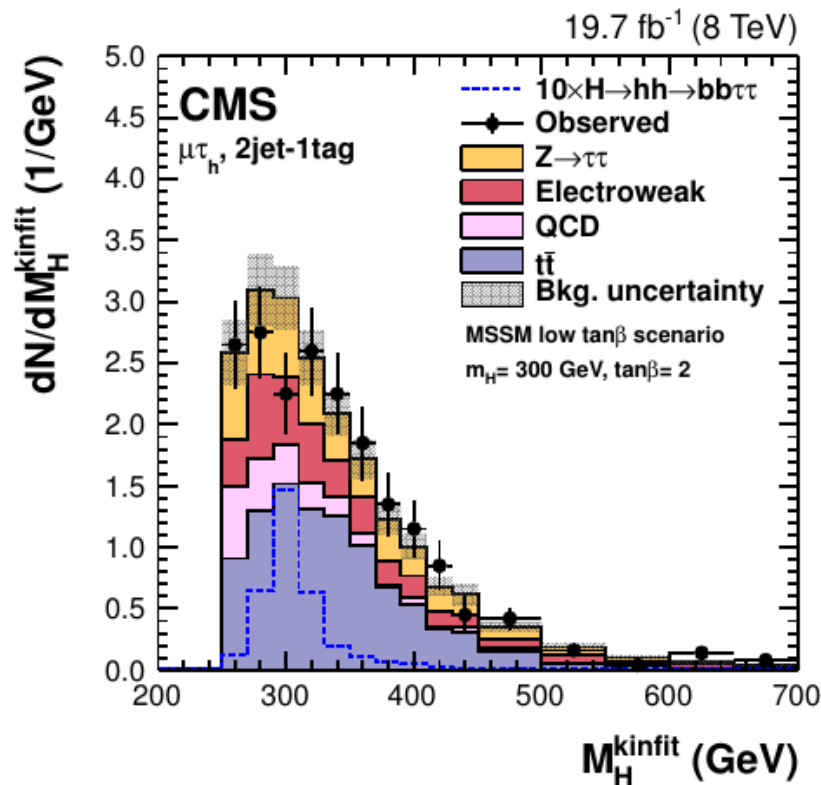
- Require 2 jets in the event
- Event categorization based on number of b-tagged jets
  - **0-tag :** background dominated
  - **1&2-tag :** share signal with **2-tag** most sensitive

- **Apply mass cut in a window around 125 GeV in m_{bb} and $m_{\tau\tau}$**

- **Extract signal from the fit to the 4-body mass**

  - **reconstructed using kinematic fit (developed by CMS UHH group)**

- **No signal is observed**

- **Interpretation with focus on MSSM/2HDM**

- **Both model independent and model dependent results provided**

  - **Constraints on** $\sigma \times \mathcal{B}$

  - **Model dependent results in combination with A → Zh(125) → (ℓℓ)(ττ) search (see next slides)**
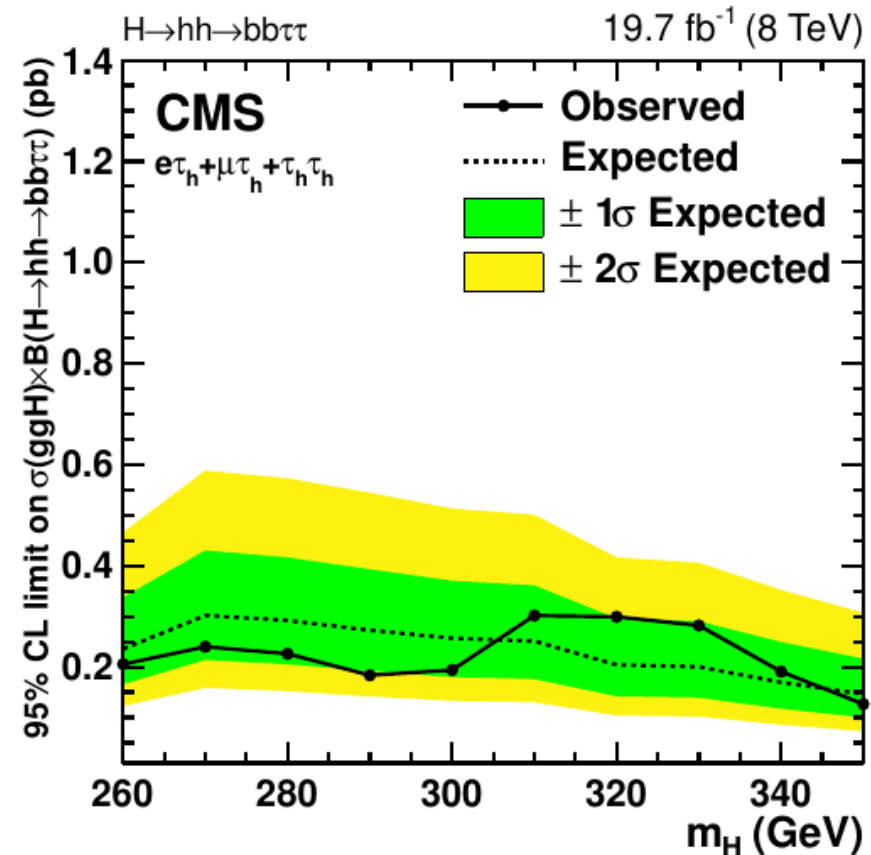
Search for A → Zh(125) → (ℓℓ)(ττ)

- **select Z → ee/μμ events**

- **select tau-pair :** $e\mu, \mu\tau_{\mathrm{h}}, e\tau_{\mathrm{h}}, \tau_{\mathrm{h}}\tau_{\mathrm{h}}$

- **apply cut**

$$L_{\mathrm{T}}^{\mathrm{h}} = p_{\mathrm{T}}^{\tau_1,\mathrm{vis}} + p_{\mathrm{T}}^{\tau_2,\mathrm{vis}} > 70\,\mathrm{GeV}$$

- **reconstruct 4-body mass (m$_A$)**

  - **tau momenta from CA**
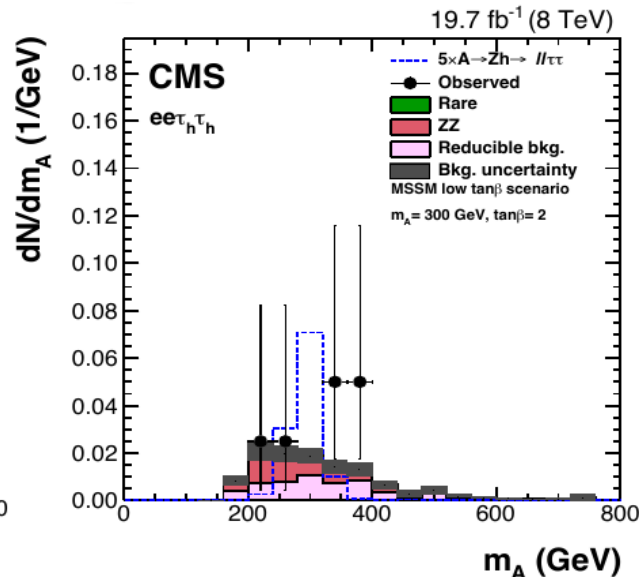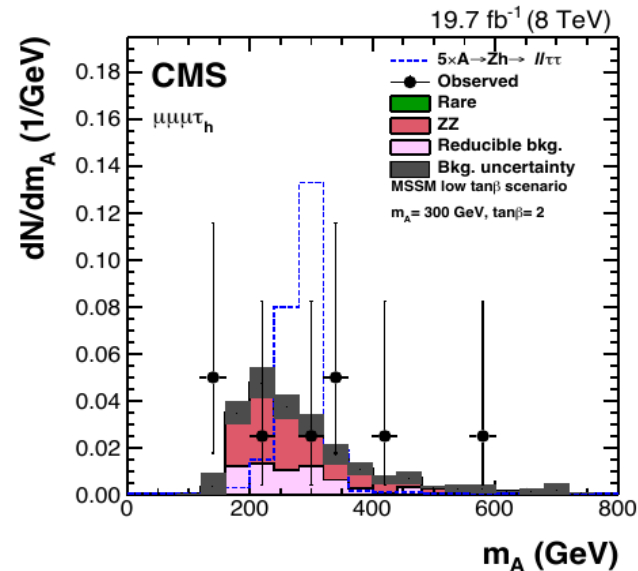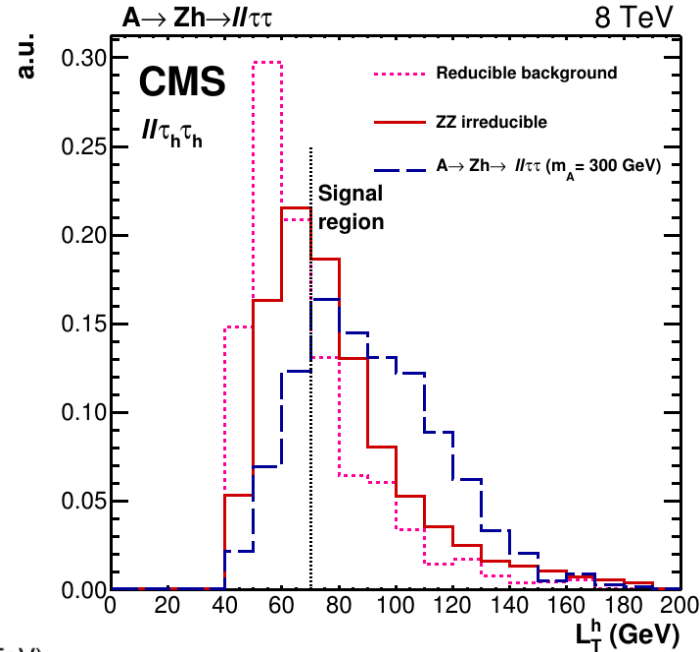
→ Combine 8 different channels and fit m$_A$ for signal extraction

Search for A → Zh(125) → (ℓℓ)(ττ)

- **No significant excess in data**

- **both model independent and model dependent results provided**

- **Constraints on $\sigma \times \mathcal{B}$ for the process $\mathrm{gg} \to \mathrm{A} \to \mathrm{Zh} \to \ell\ell\tau\tau$**

- **Model dependent results in low tanβ scenario and type II 2HDM scenario in combination with the H → h(125)h(125) → (bb)(ττ) analysis (next slide)**
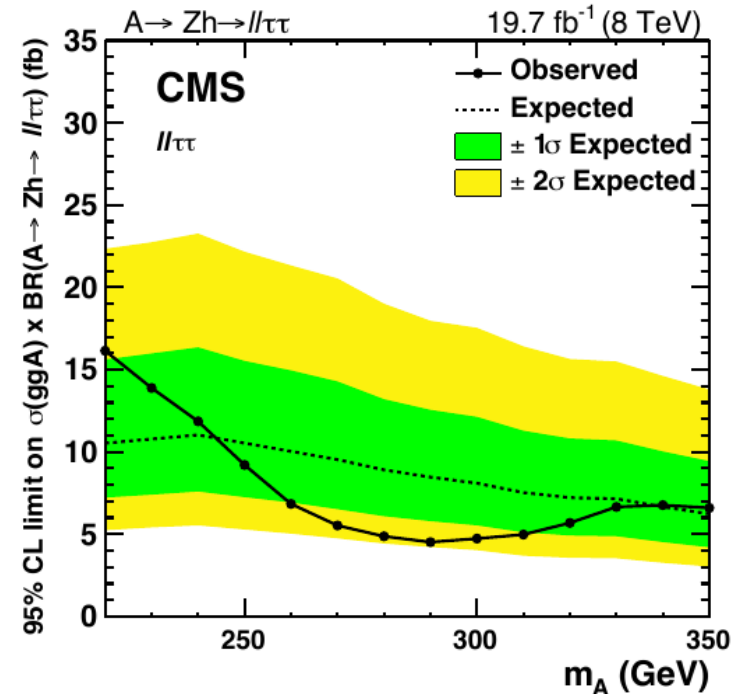
Excludes to a cross-section times branching ratio of ~10fb.

Combination of the two searches performed in two models
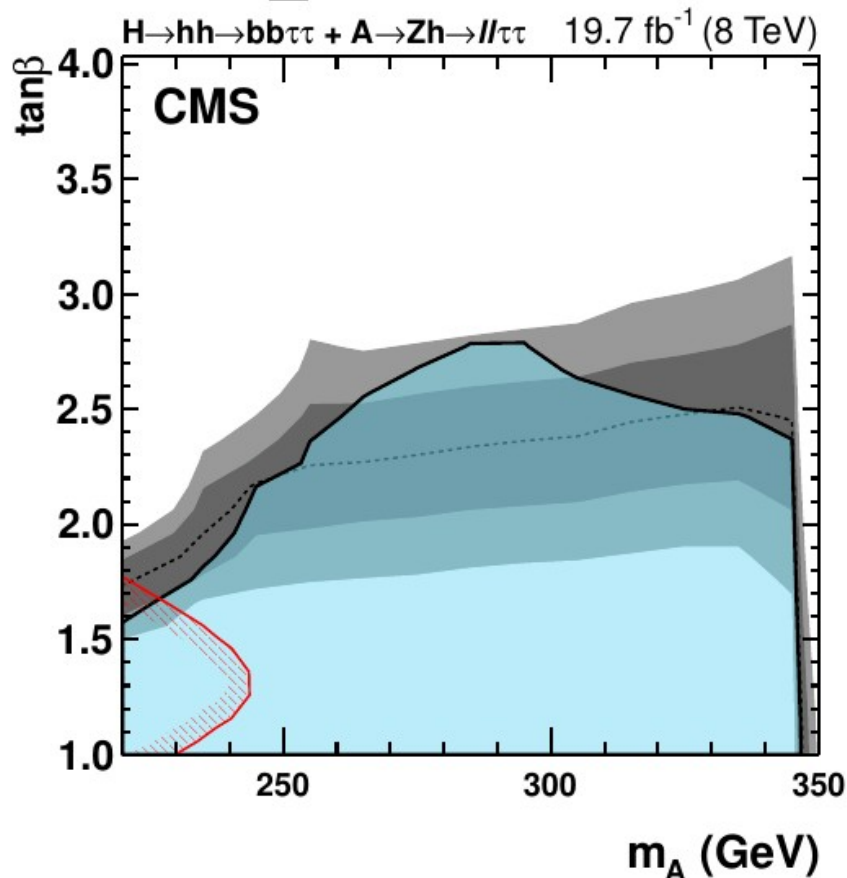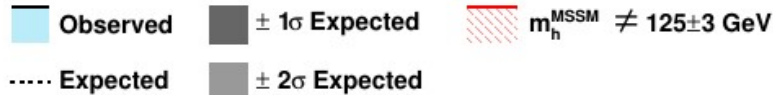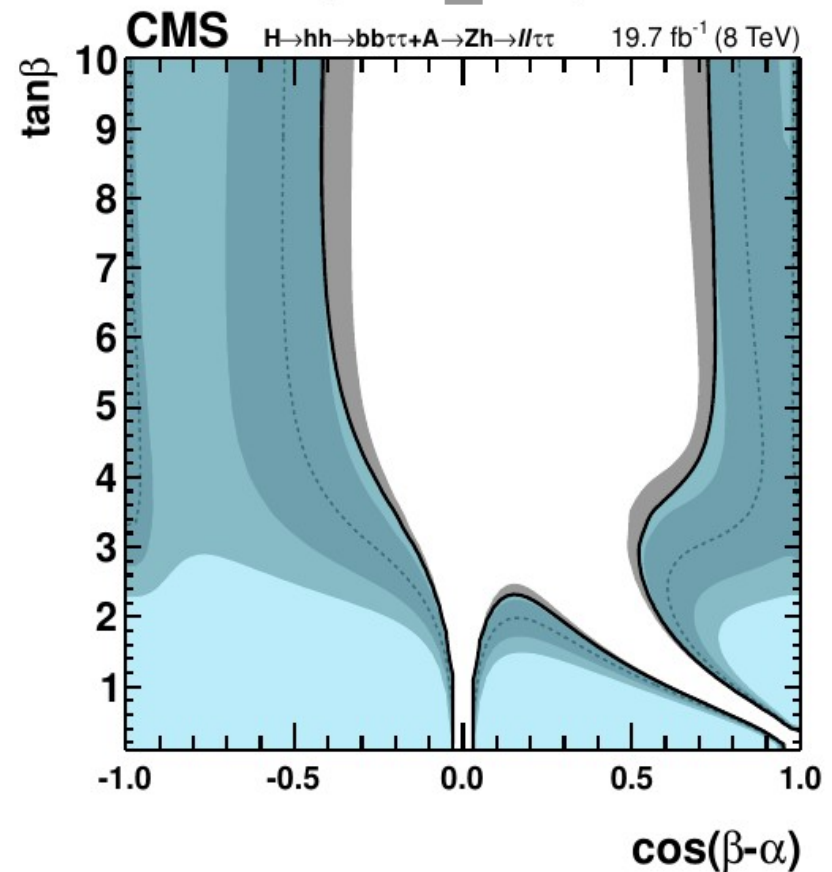
Low mass pseudoscalar decaying to ττ
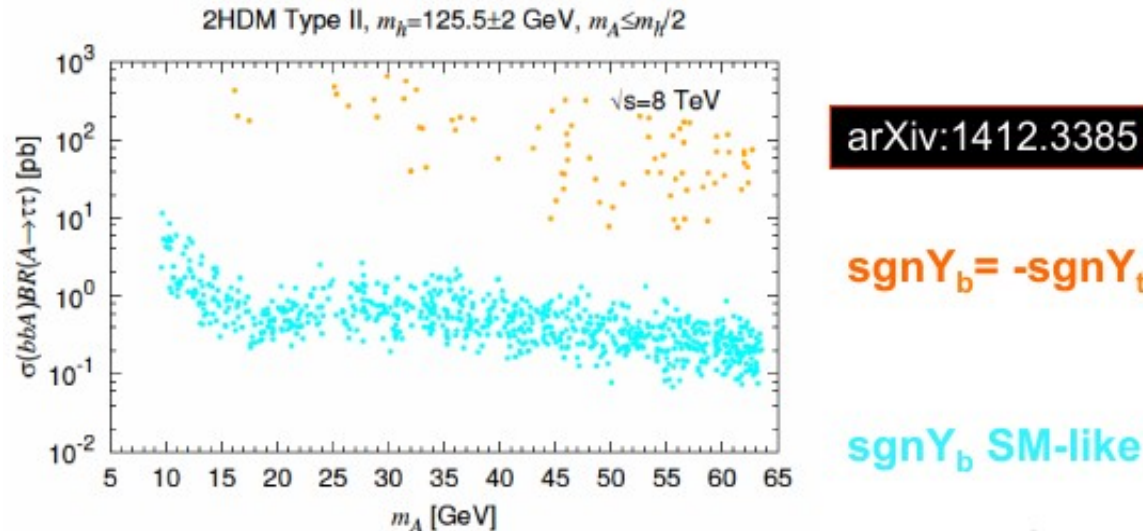
- **parameter scan within 2HDM of type II**
  - **experimental constraints from LEP , Tevatron and LHC are incorporated; light CP even state h is identified with H(125)**
- **models exist with light A state and large σ(bbA)xBR(A→ττ) (up to 100 pb)**
- **cyan points : sign(Y_b)= sign(Y_t)**
  - **sin(β–α)≈1 , cos(β–α) > 0**
- **orange points : sign(Y_b) = -sign(Y_t)**
  - **sin(β±α)≈1, cos(β–α) < 0**

- **mass range covered : m_A = 25 – 80 GeV**

- **di-tau decay channels exploited :** $e\mu,\ \mu\tau_{\mathrm{h}},\ e\tau_{\mathrm{h}}$

- **search targets b-associated production**
    - **require at least one b-tagged jet (p_T > 20 GeV, $|\eta|$<2.4)**

- **soft leptons → low p_T cuts (just a little above trigger thresholds)**
    - $\tau_{\mathrm{h}}\tau_{\mathrm{h}}$ **mode is excluded because of high trigger thresholds on tau p_T (very low acceptance)**

Signal extracted from $m_{\tau\tau}$ distributions
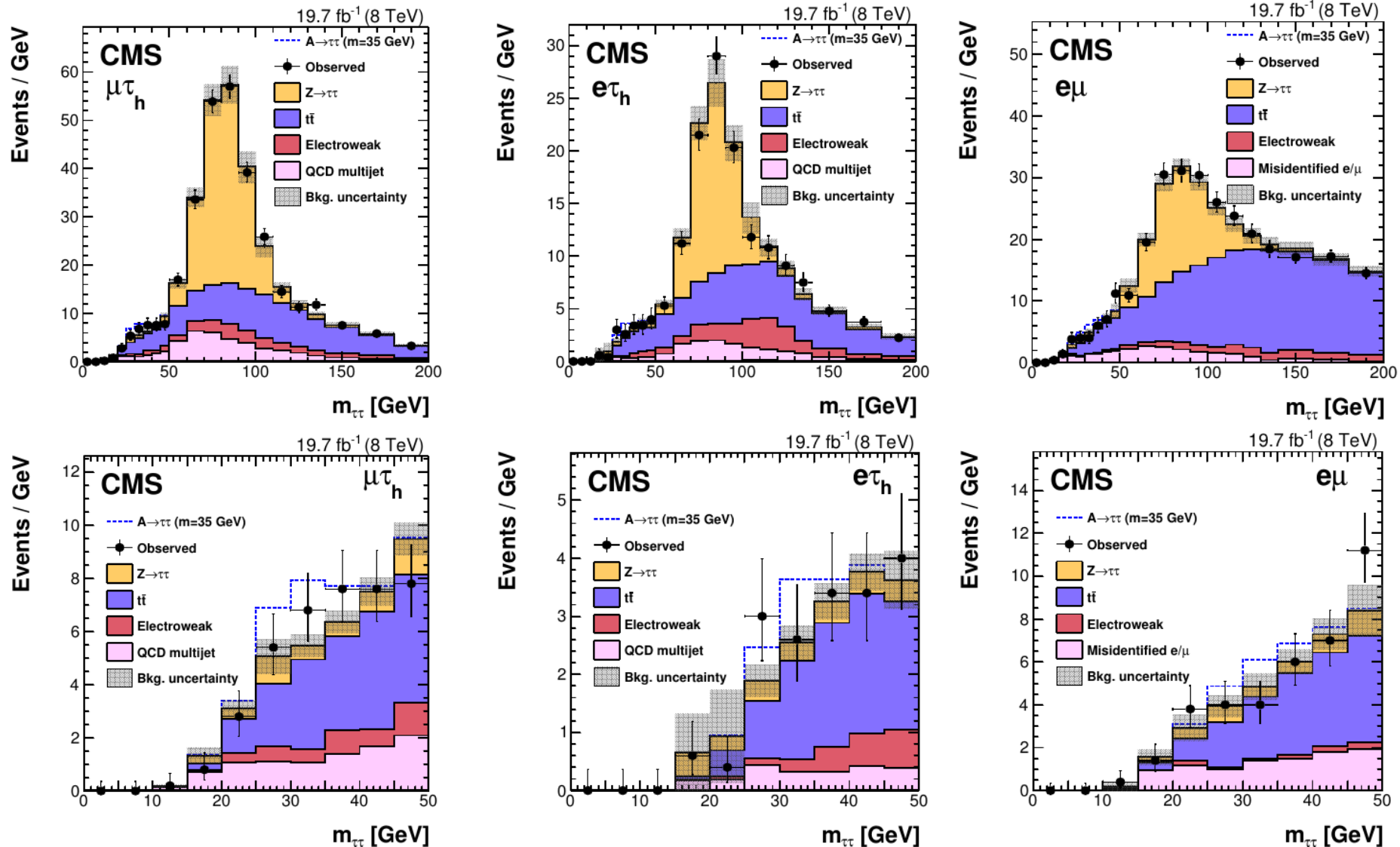
Search for low mass A boson decaying to ττ

- **No signal found**
- **Upper limits on** $\sigma(b\bar{b}A) \times \mathcal{B}(A \to \tau\tau)$
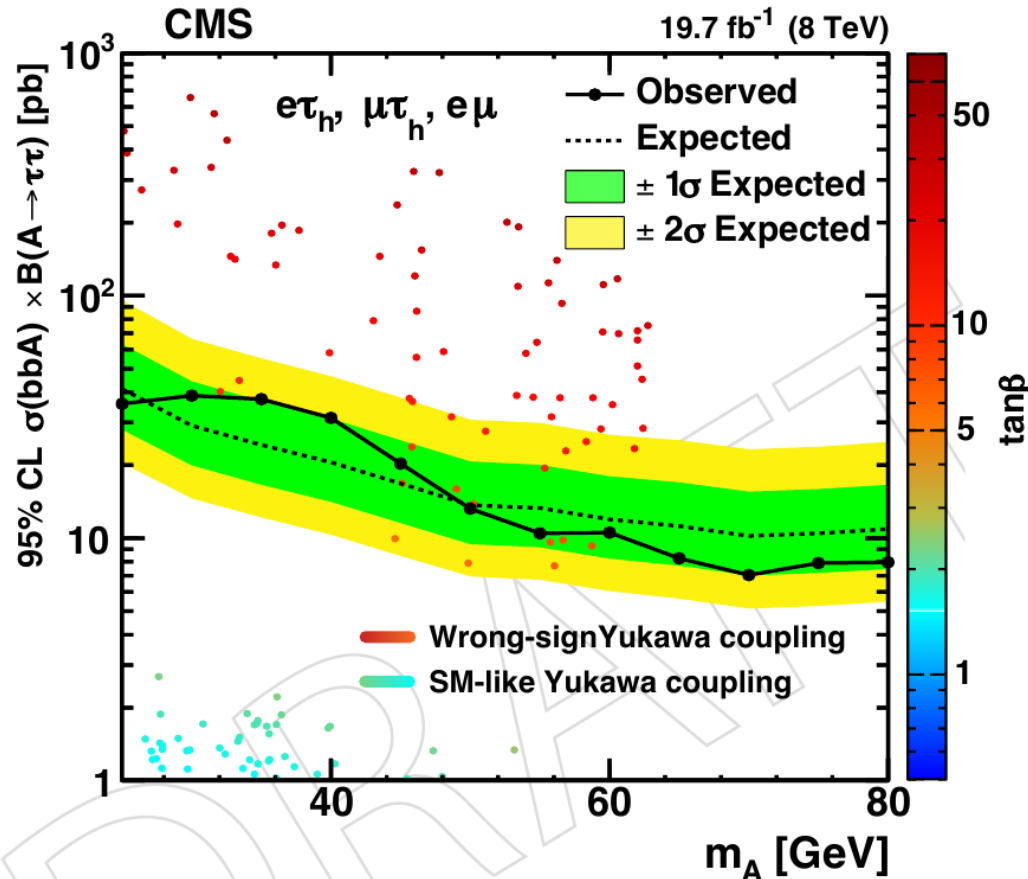
- **Search excludes nearly all scenarios with wrong sign Y_b of the SM-like h(125) state**

- **MSSM scenarios with $m_{h,A} < m_Z$ are excluded by experimental data from LEP , Tevatron and LHC**

- **SUSY scenarios are possible, relaxing this constraint**

- **NMSSM : additional singlet superfield $\hat{S}$**

  - **no gauge interactions**

  - **interacts with itself and Higgs doublets**

- **3 new states : one scalar + one pseudoscalar + one neutralino**

- **solves μ-problem of MSSM**

$$\lambda \hat{S}\hat{H}_u\hat{H}_d \rightarrow \mu_{eff} = \lambda \langle S \rangle$$
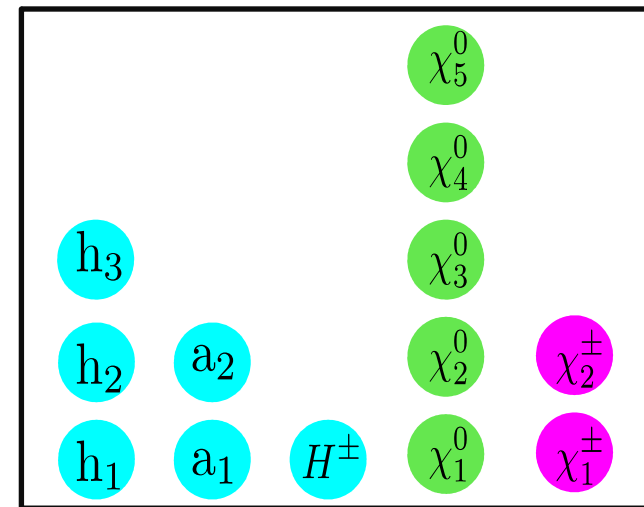
- light a_1 (h_1) state with large singlet component

→ reduced couplings to gauge and fermion fields

  – inaccessible through conventional production modes
  – can be searched via H(125) → $a_1 a_1$ ($h_1 h_1$)

$$h_2(h_1) \rightarrow 2\phi_1 \rightarrow 4\tau$$

Possible models

- H(125)=h$_2$, H(125) →h$_1$h$_1$
- H(125)=h$_2$, H(125) →a$_1$a$_1$
- H(125)=h$_1$, H(125) →a$_1$a$_1$

$$\phi_1 = a_1, h_1$$
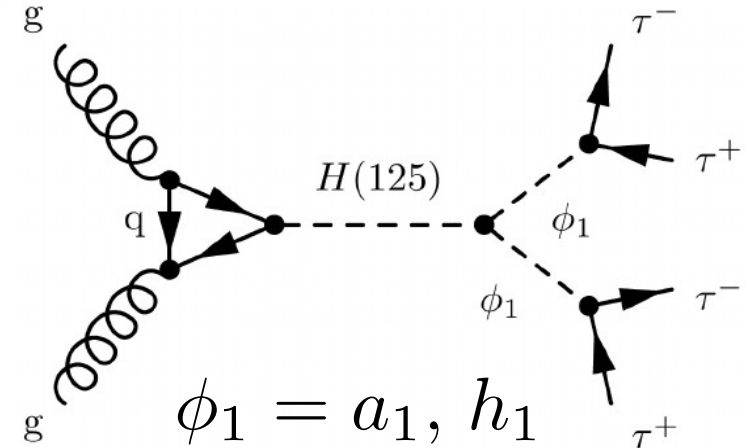
NMSSM scan (D. Barducci,
A. Belyaev, S. Moretti)

$$2m_\tau < m_{a_1} < 2m_b$$
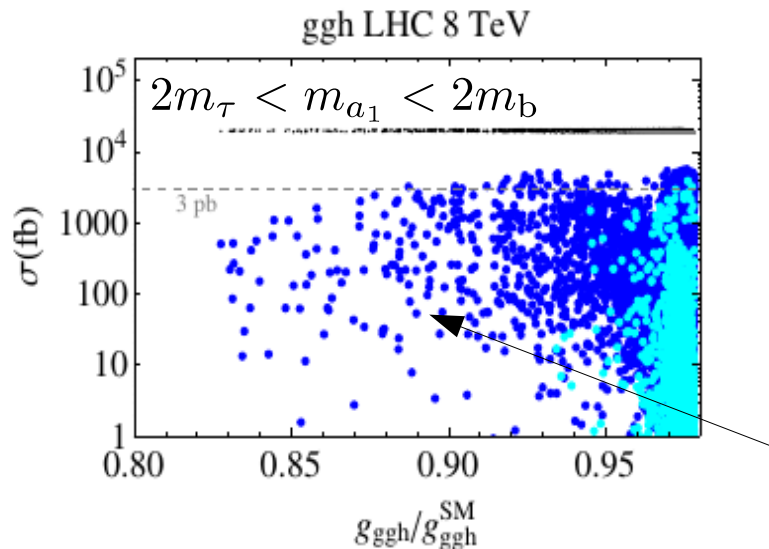
Probed mass range : [2m$_\tau$, 2m$_b$]

- Blue/Cyan:
  h_1/h_2 SM Higgs boson

- Black/Gray:
  $\sigma(pp \rightarrow h_{1/2}^{SM} X)$

$$\sigma(gg \rightarrow h_{1,2}) \times BR(h_{1,2} \rightarrow a_1 \rightarrow 4\tau)$$

- **H(125) → 2φ_1 → 4τ (2m_τ < $m_{\varphi 1}$ < 2m_b)**

- considered production mechanism
  gg → H(125)

- considered decays of light φ_1 state
  φ_1 → τ_μ + $\tau_{1\text{-prong}}$

- require two SS muons ($\mu^\pm\mu^\pm$) well separated in (η,φ) → suppression of QCD, EWK and top pair backgrounds

well separated same-sign muons

$\phi_1^{(2)}$

$\mu^\pm$

$\mu^\mp/e^\mp/h^\mp$

H(125)

$\mu^\pm$

$\mu^\mp/e^\mp/h^\mp$

$\phi_1^{(1)}$

Lorentz-boosted ϕ_1 states

→ $m_{H(125)}$ ≫ $m_{\varphi 1}$ → boosted φ_1
  – collimated products in φ_1 → ττ decays
  – small opening angle between muon and track from 1-prong tau (both muon and track coming from the same φ_1)
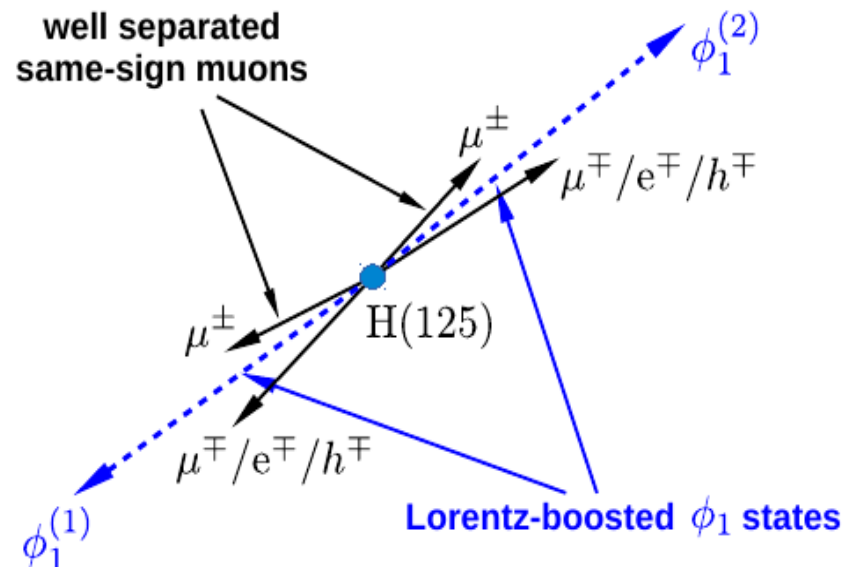
- **Final selected sample is dominated by QCD events**

- **Signal is extracted from 2D distribution of m_1 vs. m_2 (invariant masses of muon-track pairs coming from decays of two φ_1 bosons)**

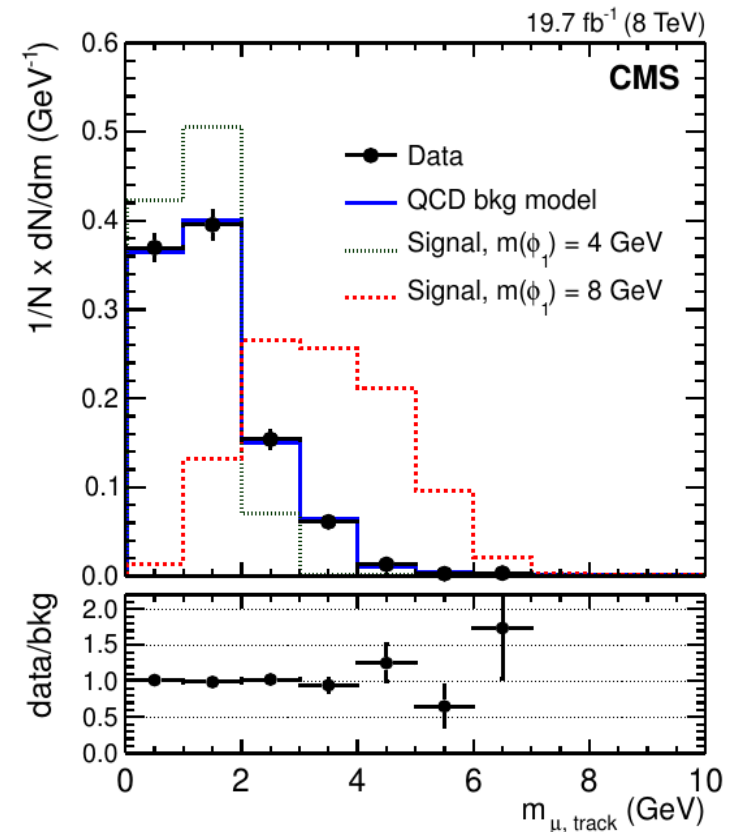| Sample	Number of events
Data	873
Expected background events	
QCD multijet	820 ± 320
$t\bar{t}$	1.2 ± 0.2
Electroweak	5.0 ± 4.7
Signal acceptance $\mathcal{A}(gg \to H(125) \to \phi_1\phi_1 \to 4\tau)$	
$m_{\phi_1} = 4\,\text{GeV}$	$(5.38 \pm 0.23) \times 10^{-4}$
$m_{\phi_1} = 5\,\text{GeV}$	$(4.36 \pm 0.21) \times 10^{-4}$
$m_{\phi_1} = 6\,\text{GeV}$	$(4.00 \pm 0.23) \times 10^{-4}$
$m_{\phi_1} = 7\,\text{GeV}$	$(4.04 \pm 0.20) \times 10^{-4}$
$m_{\phi_1} = 8\,\text{GeV}$	$(3.13 \pm 0.18) \times 10^{-4}$
Expected signal events for $(\sigma\mathcal{B})_{\text{sig}} = 5\,\text{pb}$	
$m_{\phi_1} = 4\,\text{GeV}$	53.0 ± 2.3
$m_{\phi_1} = 5\,\text{GeV}$	43.0 ± 2.0
$m_{\phi_1} = 6\,\text{GeV}$	39.5 ± 2.0
$m_{\phi_1} = 7\,\text{GeV}$	39.9 ± 2.0
$m_{\phi_1} = 8\,\text{GeV}$	30.8 ± 1.8

19.7 fb^{-1} (8 TeV)

CMS

- Data
- QCD bkg model
- Signal, $m(\phi_1) = 4$ GeV
- Signal, $m(\phi_1) = 8$ GeV

$1/N \times dN/dm$ (GeV^{-1})

data/bkg

$m_{\mu,\,\text{track}}$ (GeV)

- **QCD background shape is estimated in sideband, where one of the muon-track pairs is non-isolated**

Constructing 2D distribution

- **The μ-trk pair with higher mass labelled "2"**

- **binning of 2D distribution used in the analysis**

- **only non-hatched bins are filled**

QCD background normalization unconstrained prior to ML fit

QCD shape is modeled as

$$f_{2D}(i,j) = C(i,j)\big(f_{1D}(i)f_{1D}(j)\big)^{\text{sym}}$$

$f_{2D}(i,j)$ - content of bin (i,j) of normalized 2D distribution

$f_{1D}(i)$ - content of bin i of normalized 1D distribution (see previous slide)

$C(i,j)$ - mass correlation coefficients, determined in the background control region where muon-track pairs are non-isolated (consistent with unity)

$$\big(f_{1D}(i)f_{1D}(j)\big)^{\text{sym}} = f_{1D}(i)f_{1D}(j) + f_{1D}(j)f_{1D}(i), \text{ if } i \neq j$$
$$= f_{1D}(i)f_{1D}(j), \text{ if } i = j$$
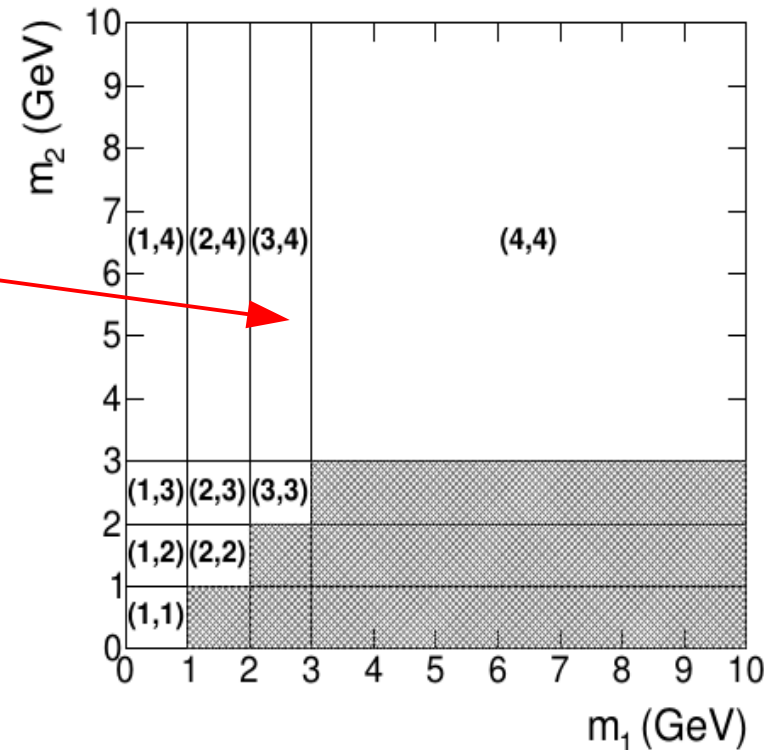
- Signal extracted with maximum likelihood fit of the 2D $[m_1, m_2]$ distribution
  - QCD background and signal normalizations are varied freely in fits

- Data are well described by background-only model → set limits on $\sigma \times \mathcal{B}$
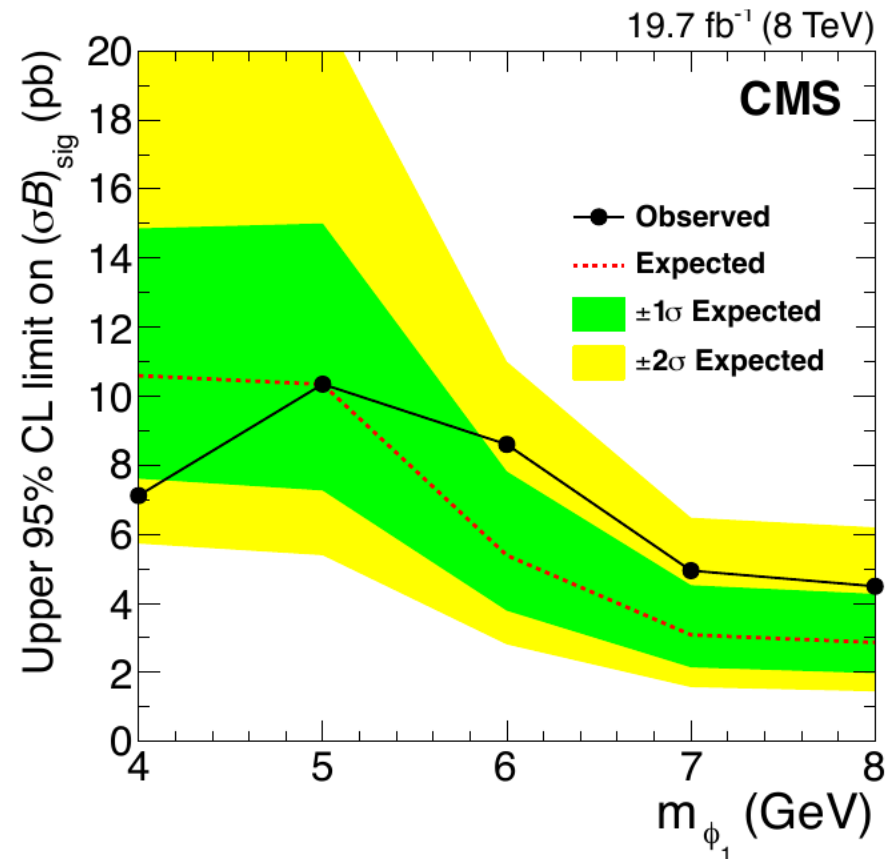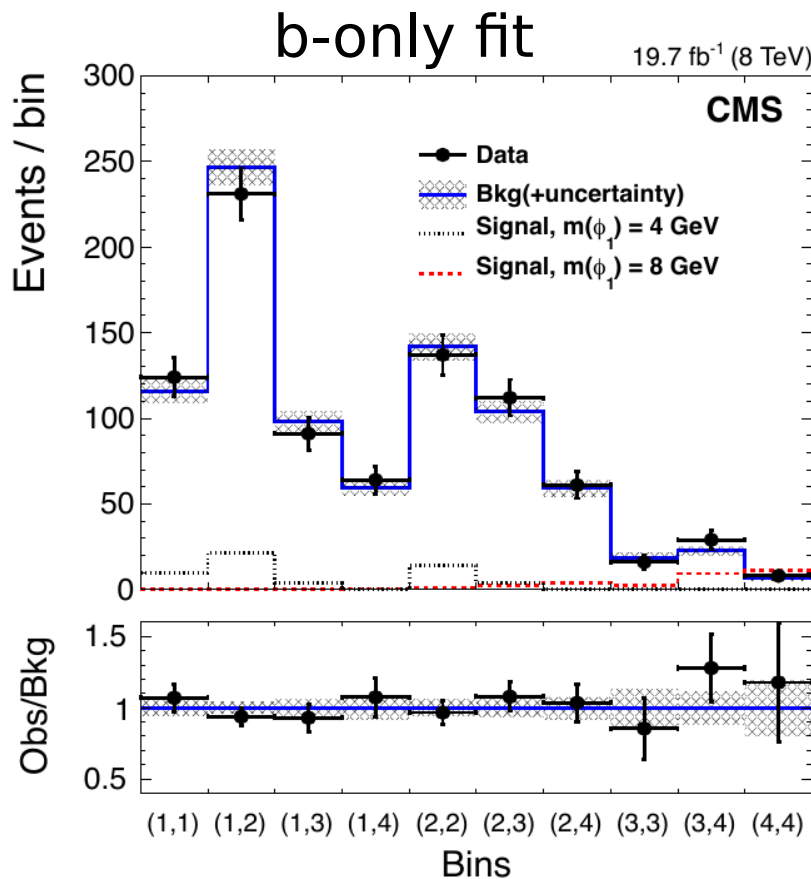
Summary

- **CMS is finalizing Run1 Higgs analyses**

- **Many new results on BSM Higgs searches in decays to tau leptons have been made public recently**

- **Unfortunately no additional Higgs states have been found so far**

  - **constraints on model parameters reinforced**

- **Focus is shifted to the analysis of Run2 data**

  - **further investigation of the H(125) state properties**

  - **continued hunt for additional Higgs states predicted in theories beyond the SM**