CMS Physics News : Run1 Searches for BSM Φ → ττ

Alexei Raspereza

HTauTau Workshop, November 16th 2015

Recent public results

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

- MSSM $\Phi \rightarrow \tau\tau$ 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 $H \rightarrow hh \rightarrow (bb)(\tau\tau)$ and $A \rightarrow hZ \rightarrow (\tau\tau)(\ell\ell)$: HIG-14-034, arXiv:1510.01181, submitted to PLB

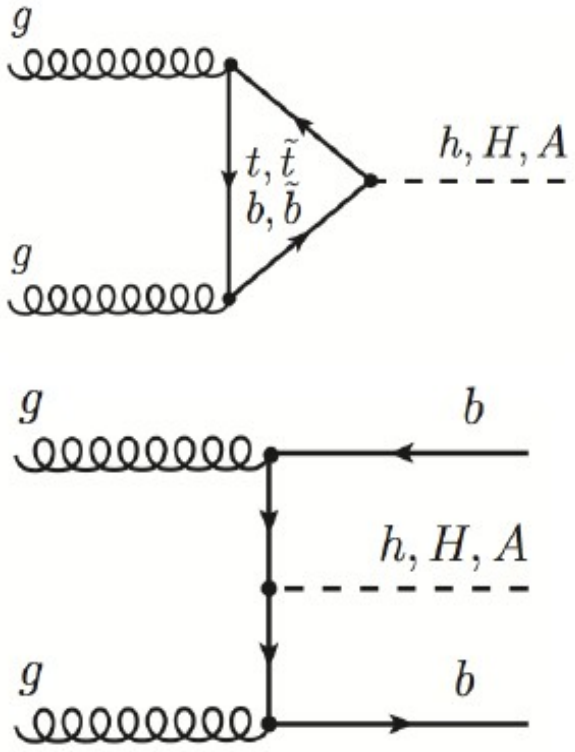
- search for low mass pseudoscalar produced in association with b quarks and decaying into tau pairs
  HIG-14-033, arXiv:1511.03610, submitted to PLB

- search for very light NMSSM Higgs bosons in $H(125) \rightarrow 2\varphi_1 \rightarrow 4\tau$:

  HIG-14-019, arXiv:1510.06534, submitted to JHEP

Updated MSSM Φ → ττ search

- 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) (see talk by C. Veelken)

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

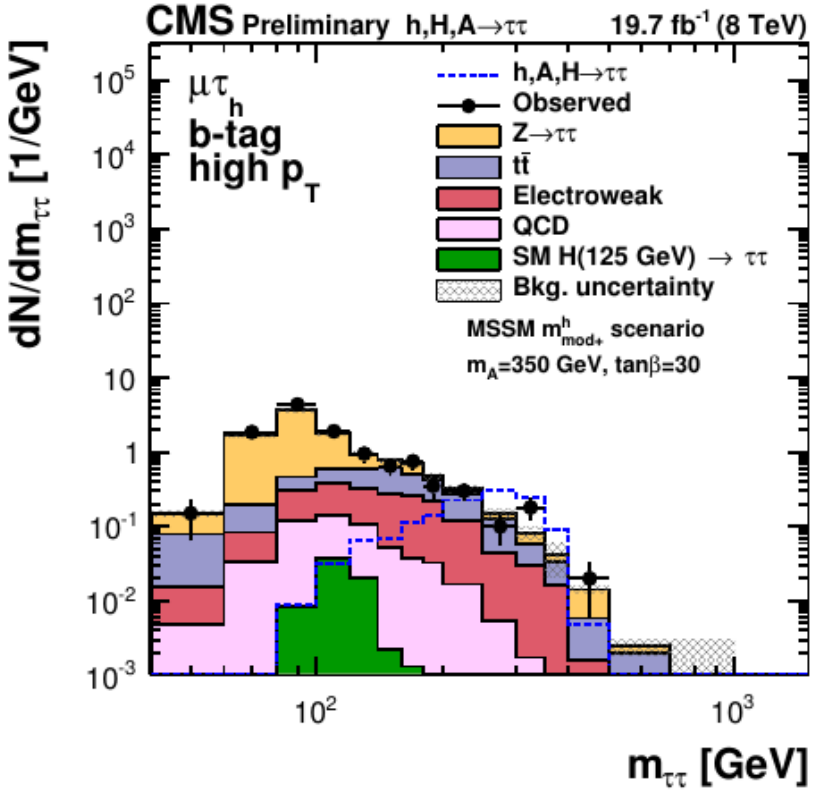
- Event categorization
  - no b-jets (p_T > 20 GeV, |η| < 2.4)
  - ≥ 1 b-jet (p_T > 20 GeV, |η| < 2.4)

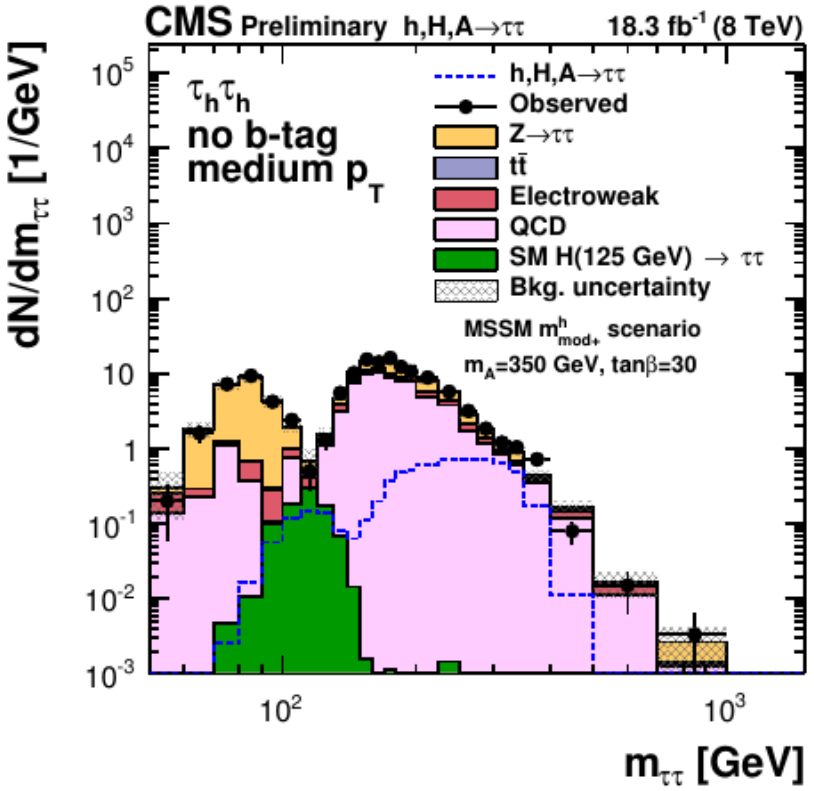
    < 2 jets (p_T > 30 GeV, |η| < 4.5)

- 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)

Updated MSSM Φ → ττ search

- Major backgrounds : Z → ττ, TTBar, W+Jets, QCD...
- Signal extracted using fully reconstructed di-tau mass distributions (dedicated talk by C. Veelken)
  - in the $\mu\mu$ channel signal is extracted from the 2D distributions [$m_{\tau\tau}$,$m_{\mu\mu}$]



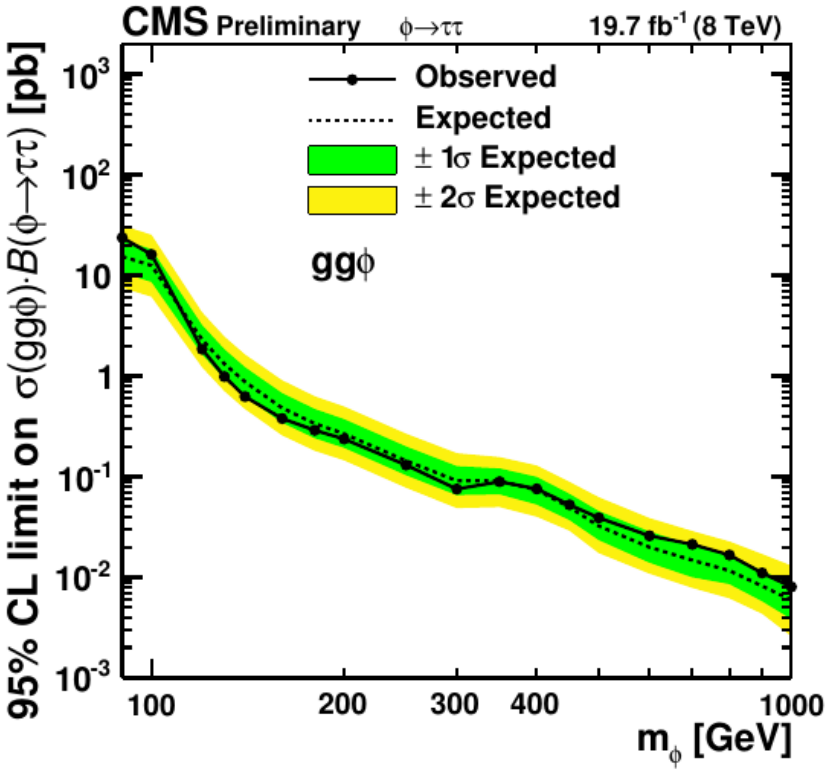


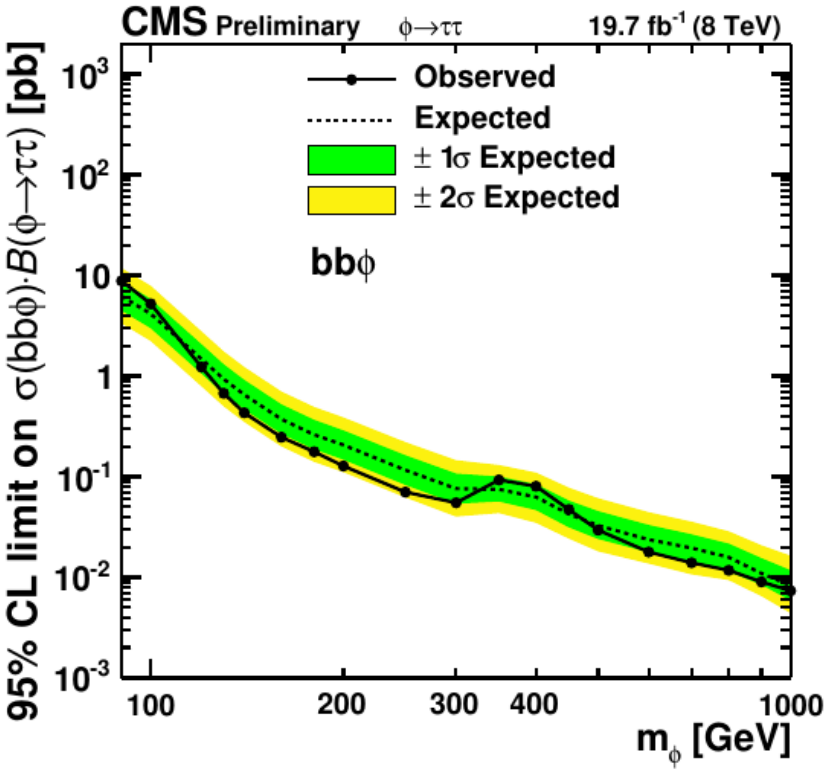
Updated MSSM Φ → ττ search

- 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)

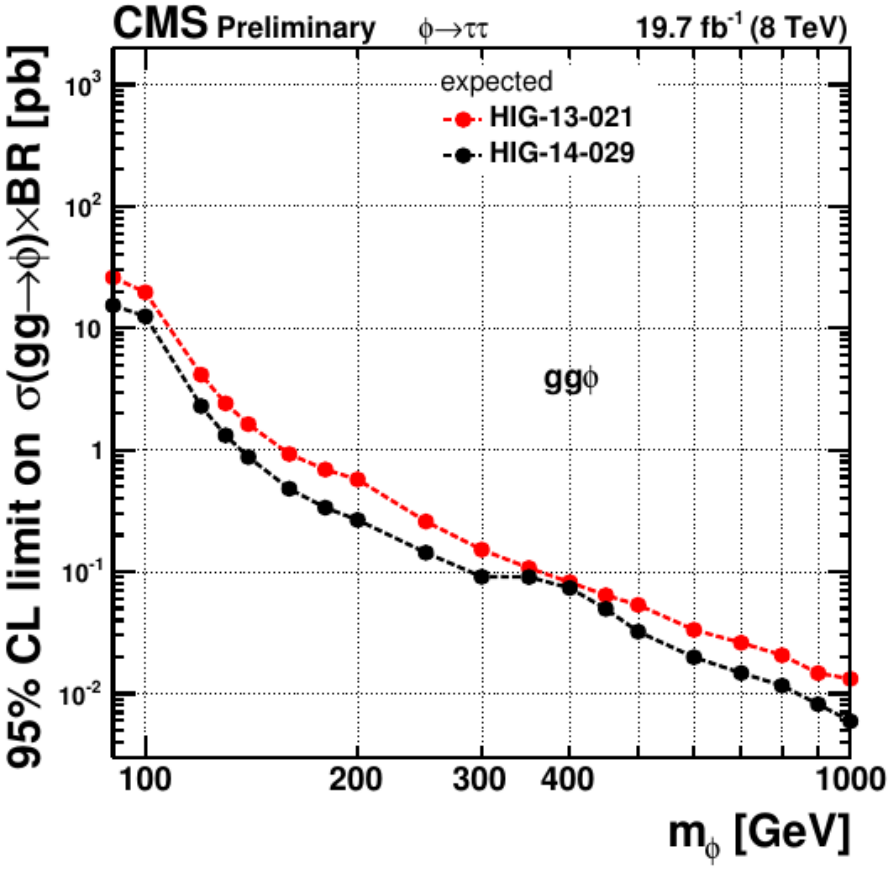
$$q_\mu = -2\ln\frac{\mathcal{L}\left(data|\mu\cdot s(\hat{\theta}_\mu)+h_{SM}(\hat{\theta}_\mu)+b(\hat{\theta}_\mu)\right)}{\mathcal{L}\left(data|\hat{\mu}\cdot s(\hat{\theta})+h_{SM}(\hat{\theta})+b(\hat{\theta})\right)}$$

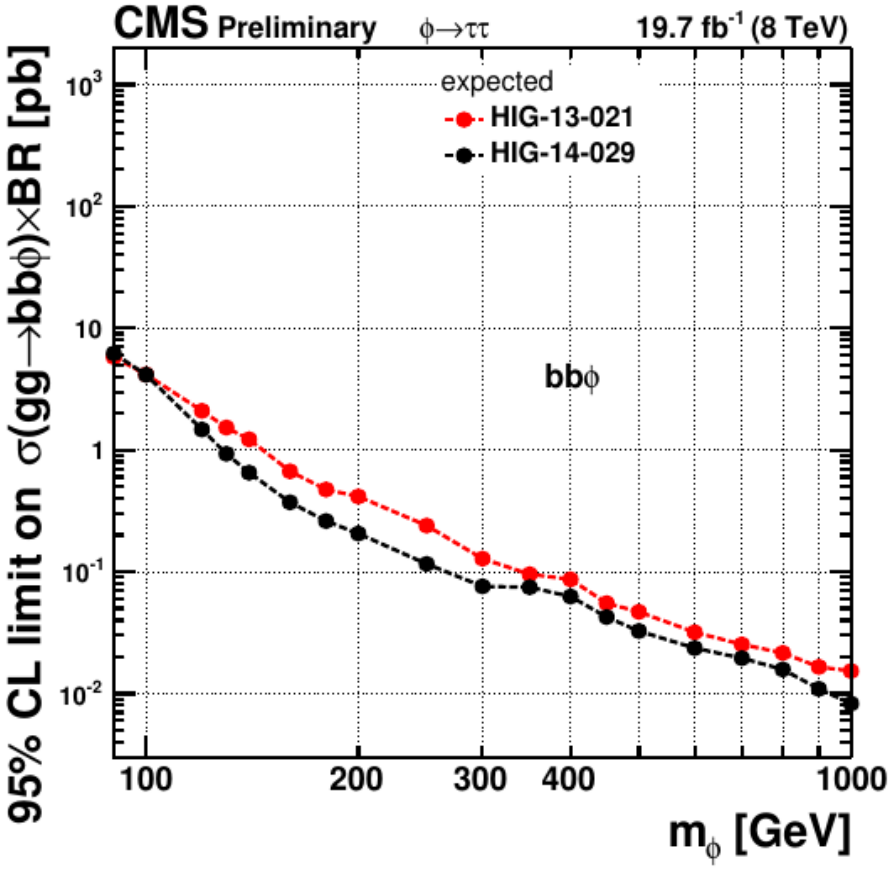




Updated MSSM Φ → ττ search

- **Improvement with respect to previous results**



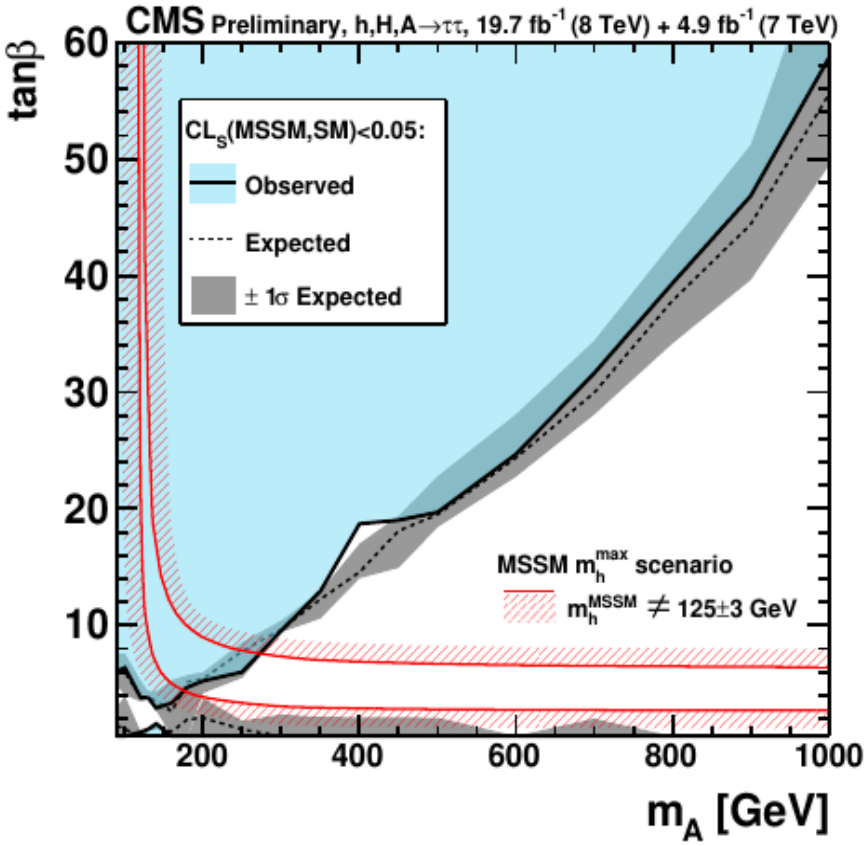


Updated MSSM Φ → ττ search

- **limits in (m_A,tanβ) plane (benchmark scenarios)**

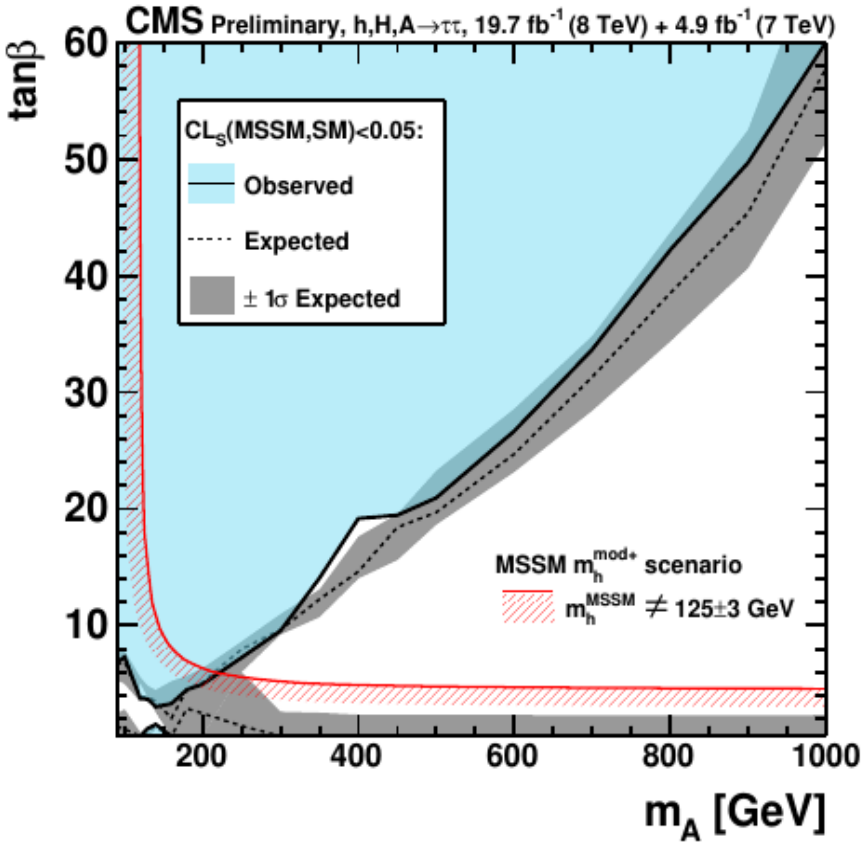
m_h-max : pre-discovery scenario

large area in [tanβ, m_A] plane is excluded by measured mass of H(125) state



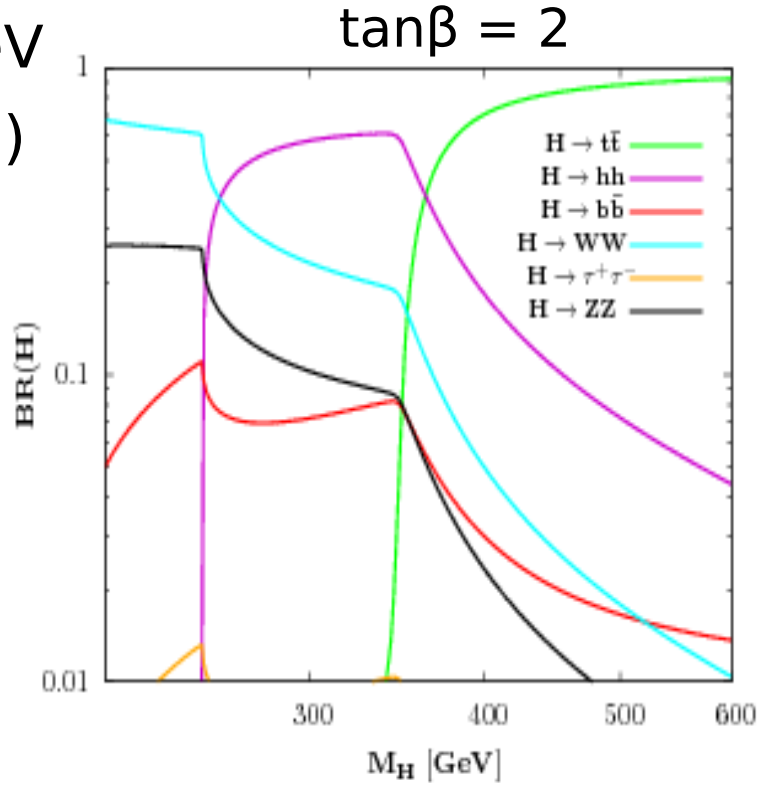
m_h-mod+ : post-discovery scenario

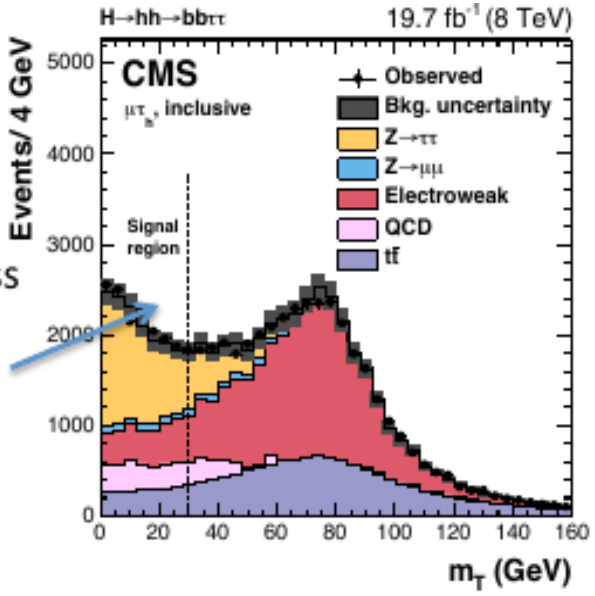
accommodates h(125) state



Search for H → h(125)h(125) → (bb)(ττ)

- $260 < m_H < 350$ 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
  - $\mu\tau_h, e\tau_h, \tau_h\tau_h$



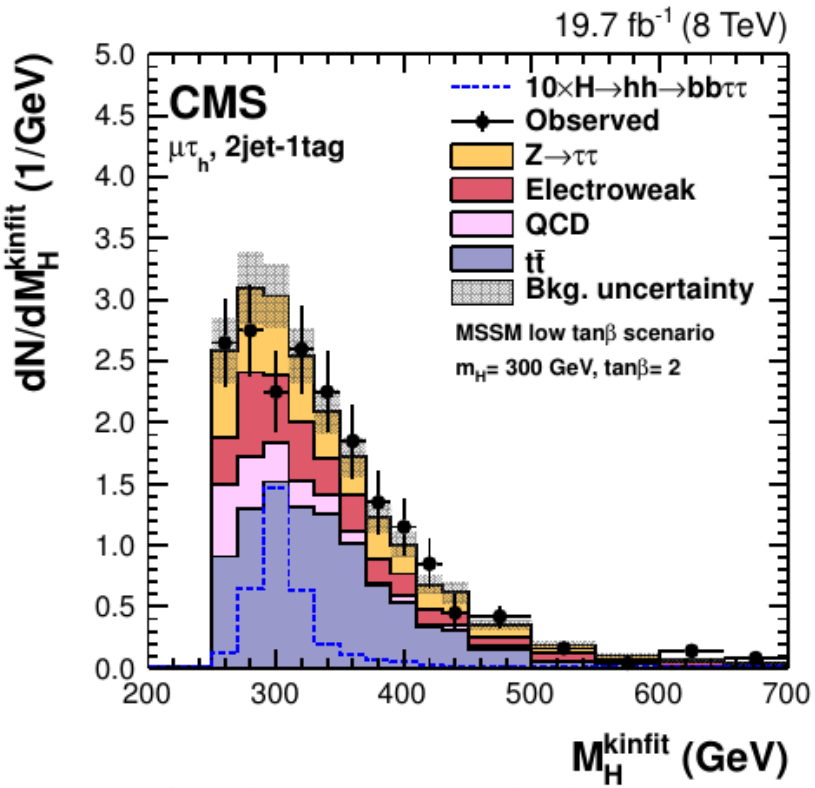


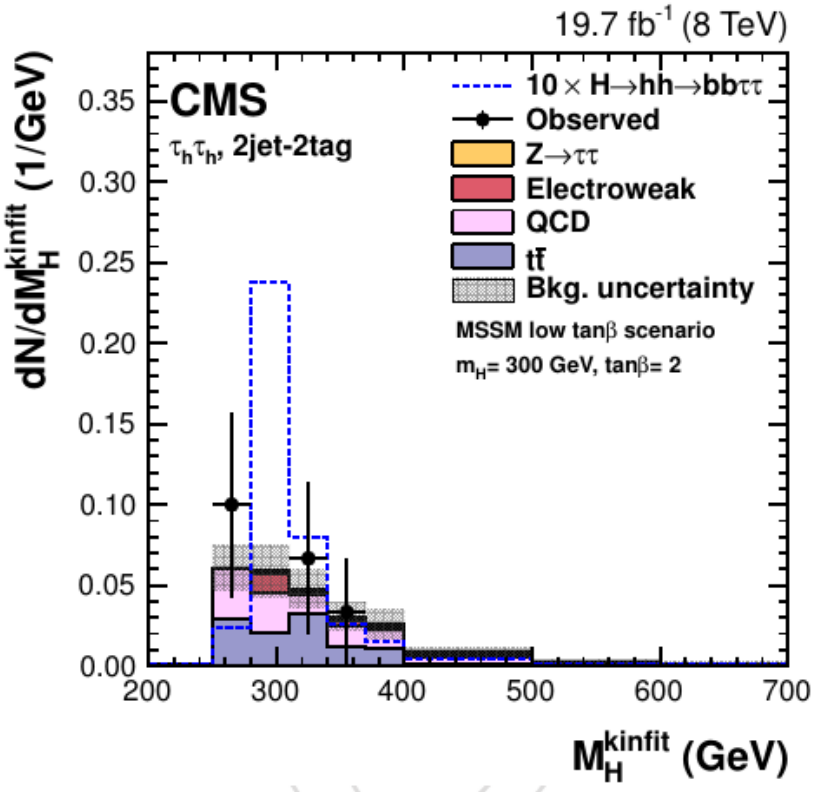
Transverse mass cut to suppress W+Jets and tt for $e\tau_h$ & $\mu\tau_h$

- 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

Search for H → h(125)h(125) → (bb)(ττ)

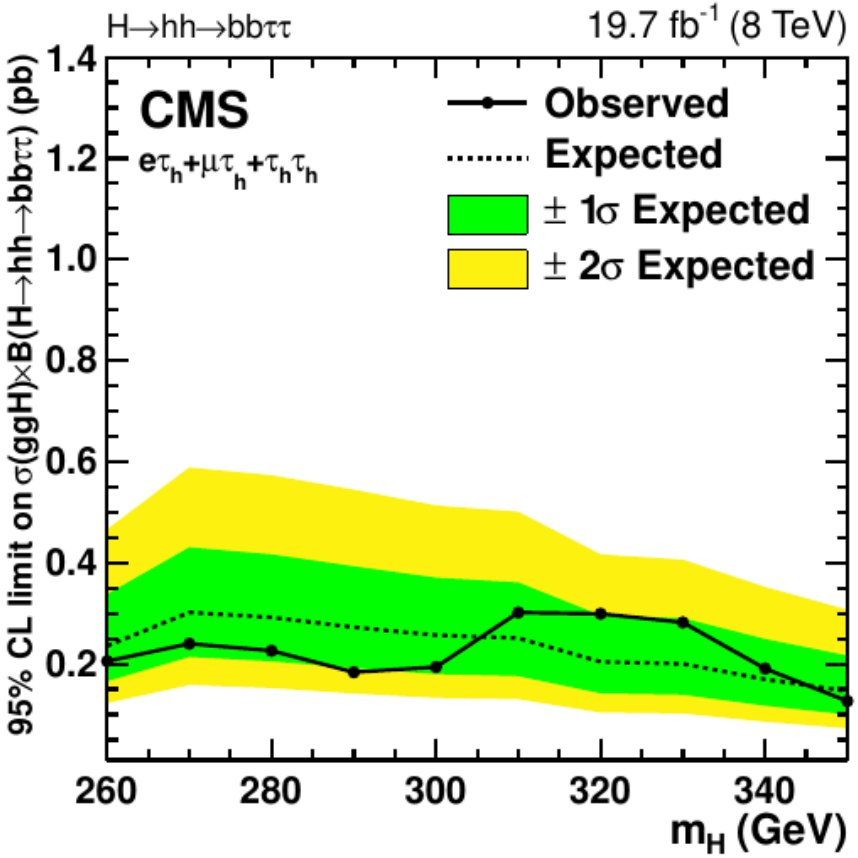
- **Apply mass cut in a window around 125 GeV in m_{bb} and $m_{\tau\tau}$**
- **Extract signal from the fit to the 4-body mass**
  - **reconstructed using kinematic fit (dedicated talk by Benedikt)**





Search for H → h(125)h(125) → (bb)(ττ)

- **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)**

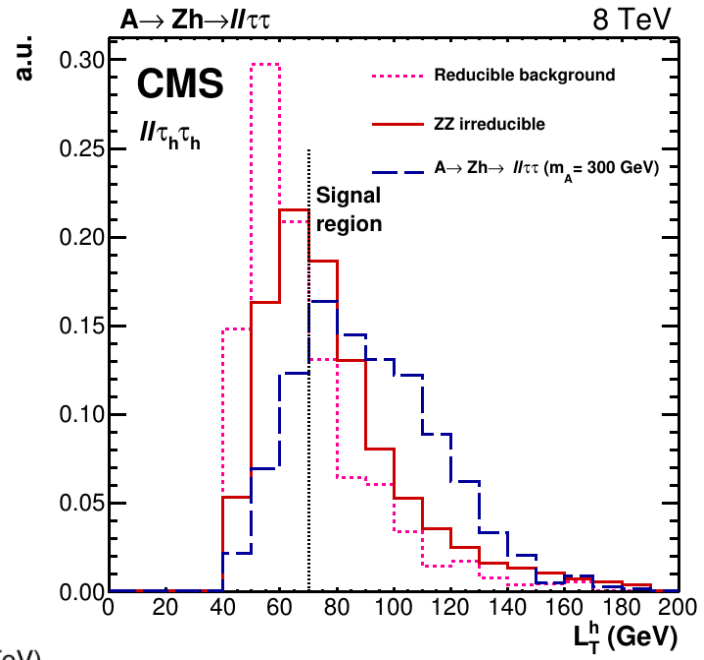


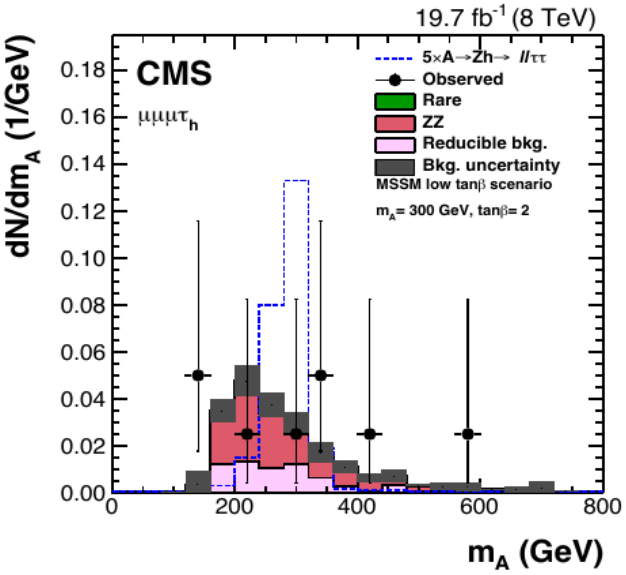
Search for A → Zh(125) → (ℓℓ)(ττ)

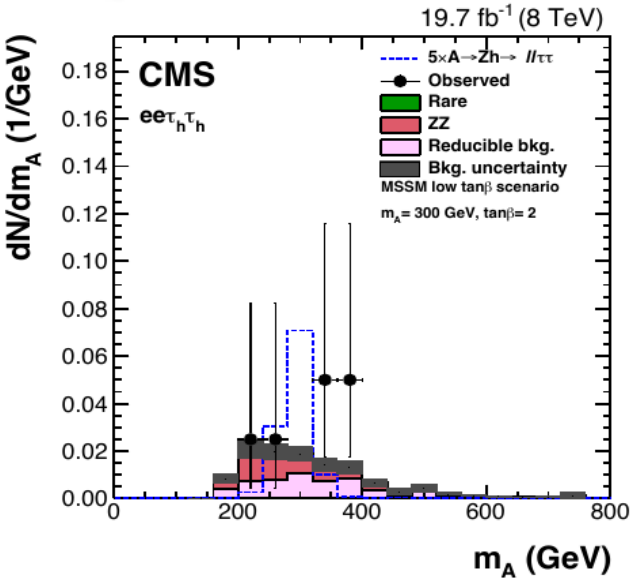
- **select Z → ee/μμ events**
- **select tau-pair :** $e\mu, \mu\tau_{\mathrm{h}}, e\tau_{\mathrm{h}}, \tau_{\mathrm{h}}\tau_{\mathrm{h}}$
- **apply cut**

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

- **reconstruct 4-body mass (m_A)**
  - **tau momenta from CA**



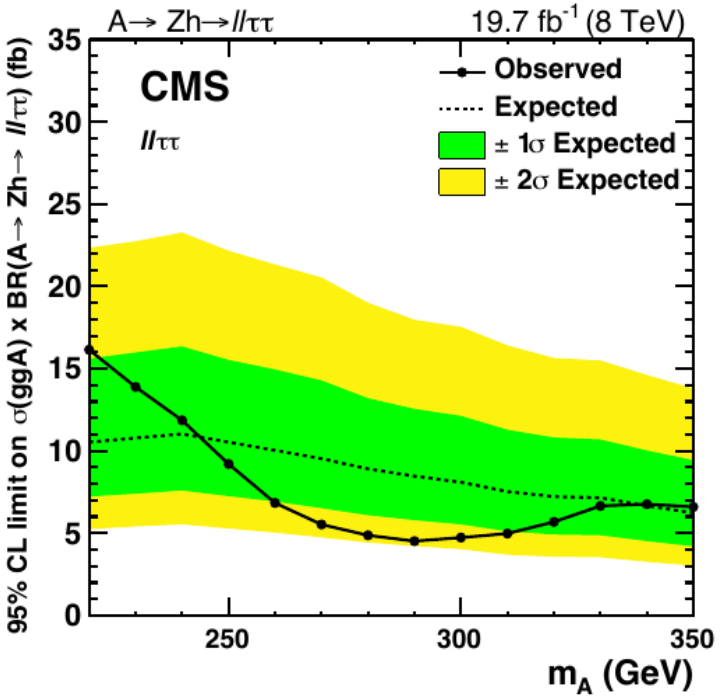




→ Combine 8 different channels and fit m_A for signal extraction

Search for A → Zh(125) → (ℓℓ)(ττ)

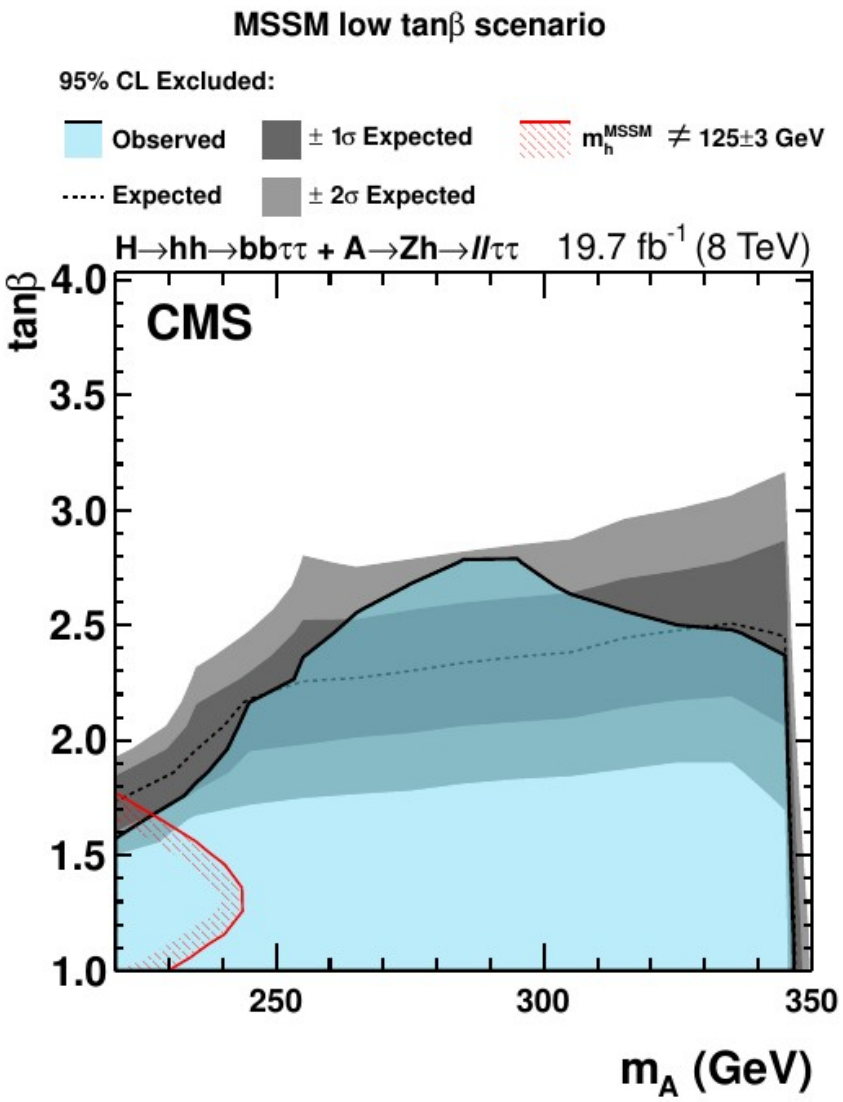
- **No significant excess in data**
- **both model independent and model dependent results provided**
- **Constraints on** $\sigma \times \mathcal{B}$ **for the process** $\mathrm{gg} \to \mathrm{A} \to \mathrm{Zh} \to \ell\ell\tau\tau$
- **Model dependent results in low tanβ scenario and type II 2HDM scenario in combination with the H → h(125)h(125) → (bb)(ττ) analysis (next slide)**

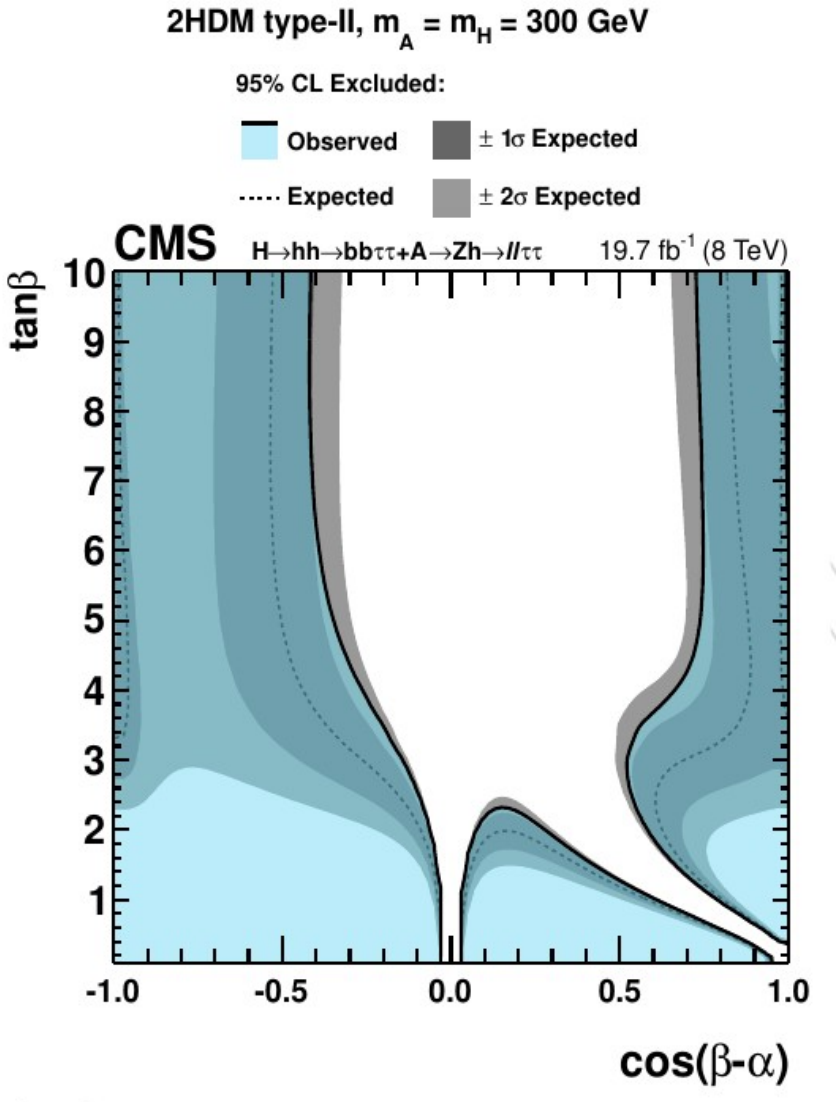


Excludes to a cross-section times branching ratio of ~10fb.

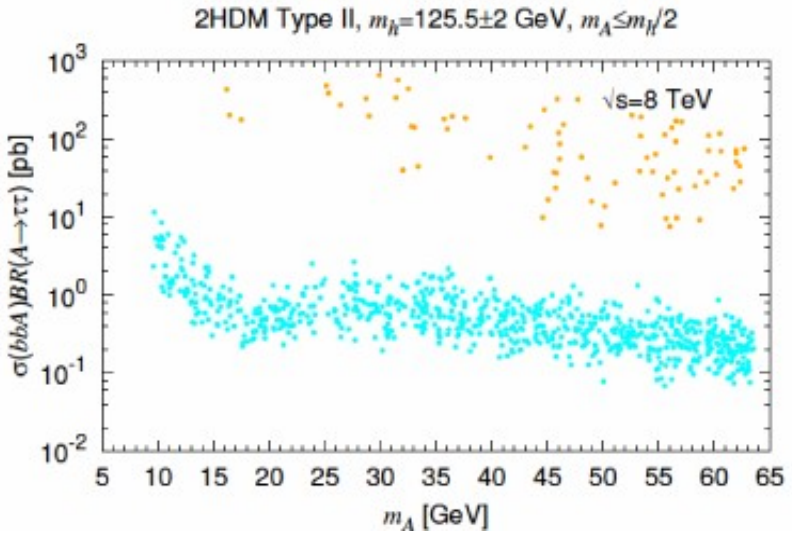
H → h(125)h(125) → bb(ττ) and A → Zh(125) → (ℓℓ)(ττ)

Combination of the two searches performed in two models



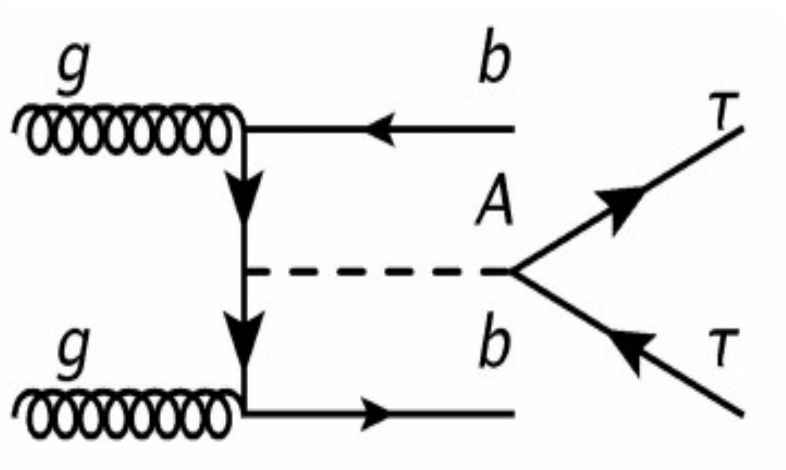


Low mass pseudoscalar decaying to ττ



- **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**

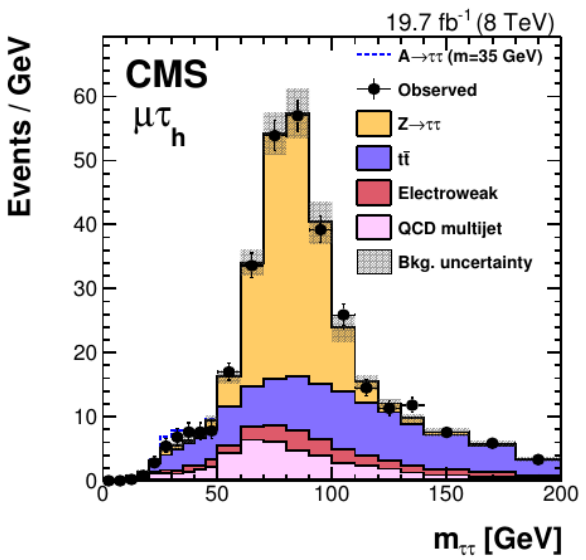
Search for low mass A boson decaying to ττ

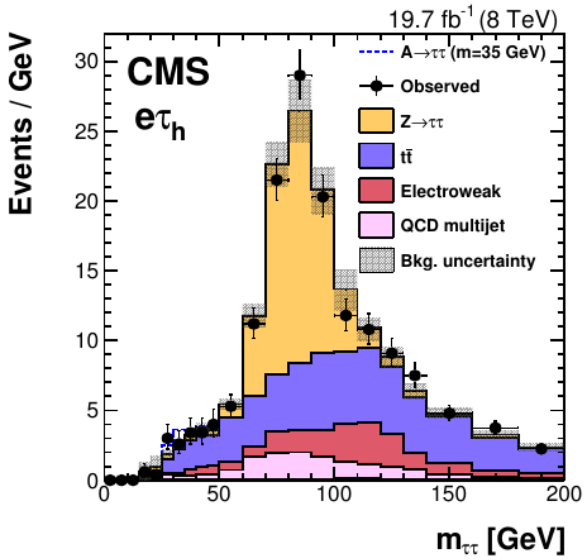


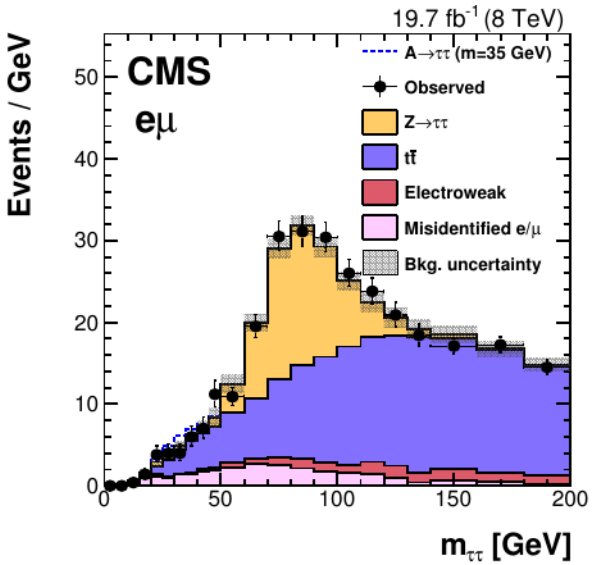
- **mass range covered : m_A = 25 – 80 GeV**
- **di-tau decay channels exploited :** $e\mu,\ \mu\tau_h,\ e\tau_h$
- **search targets b-associated production**
  - **require at least one b-tagged jet (p_T > 20 GeV, |η|<2.4)**
- **Soft leptons → low p_T cuts (just a little above trigger thresholds)**
  - $\tau_h\tau_h$ **mode is excluded because of high trigger thresholds on tau p_T (very low acceptance)**

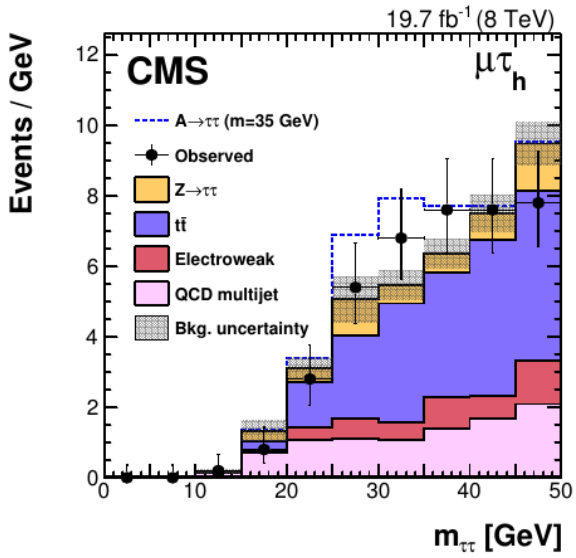
Search for low mass A boson decaying to ττ

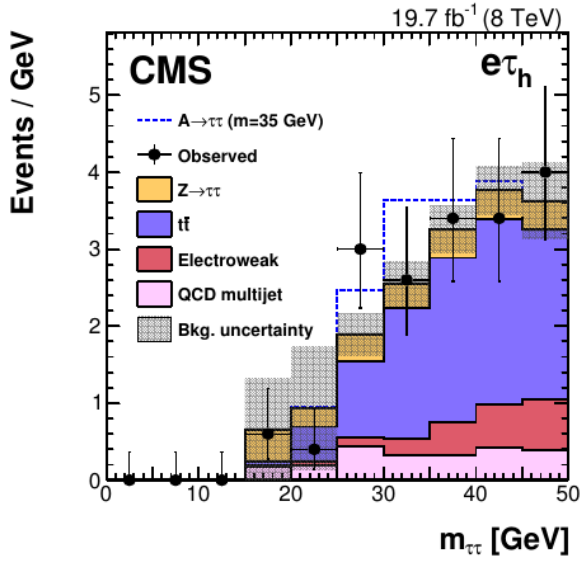
Signal extracted from $m_{\tau\tau}$ distributions

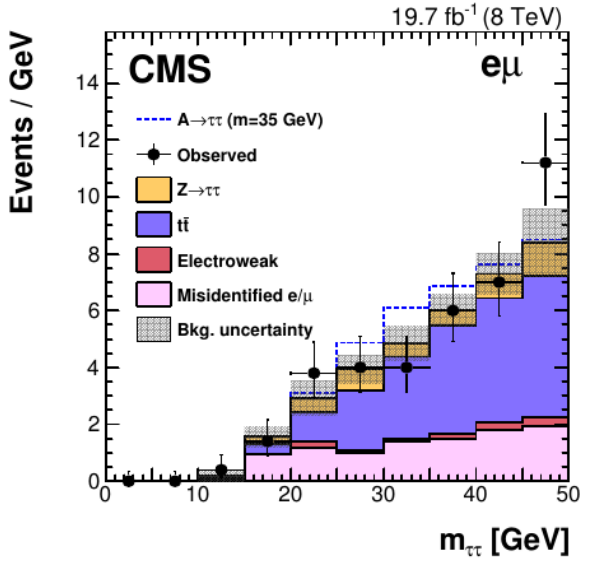






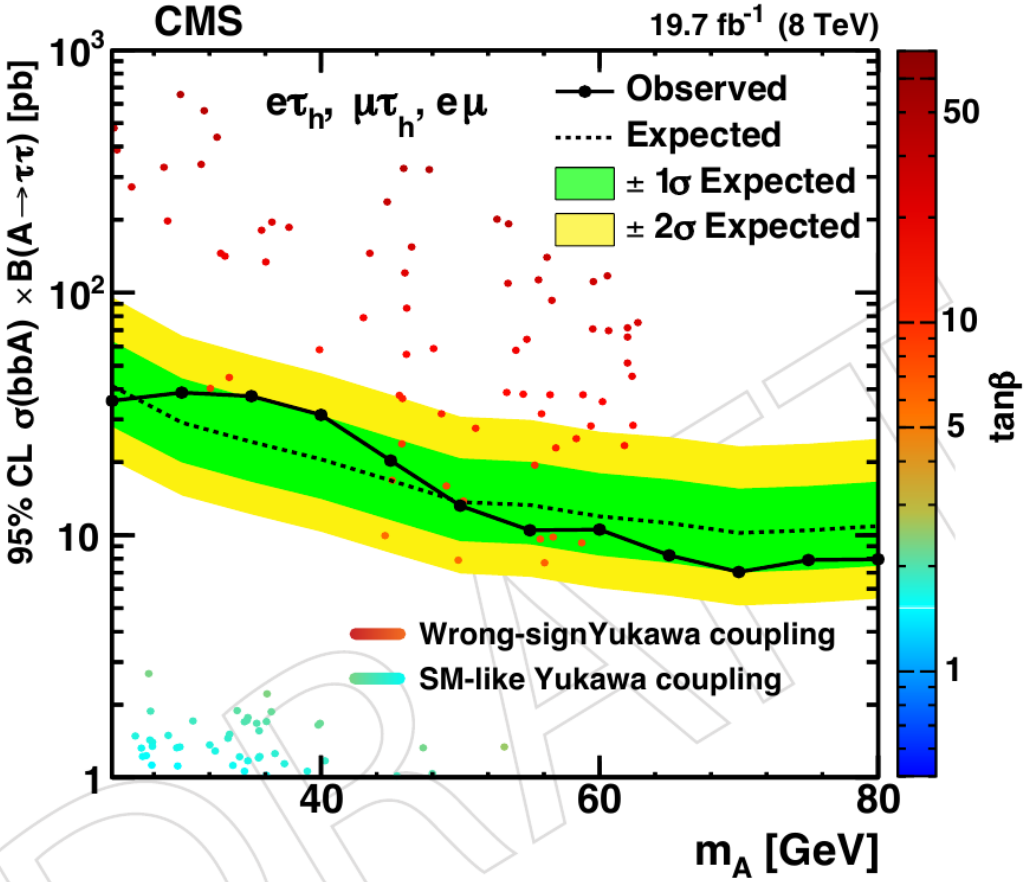






Search for low mass A boson decaying to ττ

- **No signal found**
- **Upper limits on** $\sigma(\mathrm{b\bar{b}A}) \times \mathcal{B}(\mathrm{A} \to \tau\tau)$

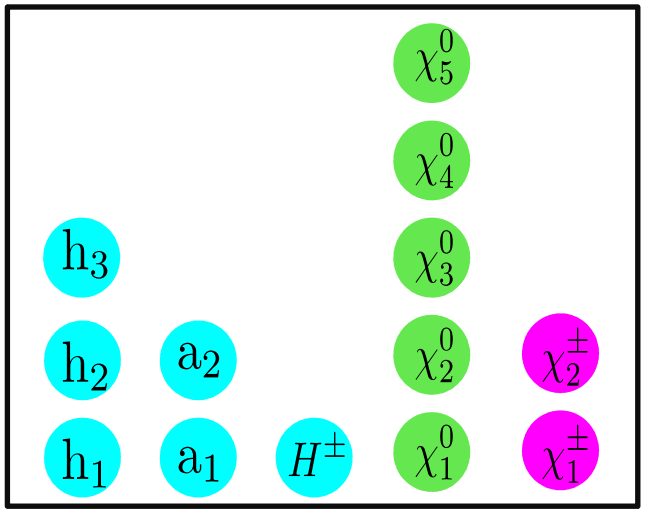


- **Search excludes nearly all scenarios with wrong sign Y_b of the SM-like h(125) state**

NMSSM

- **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

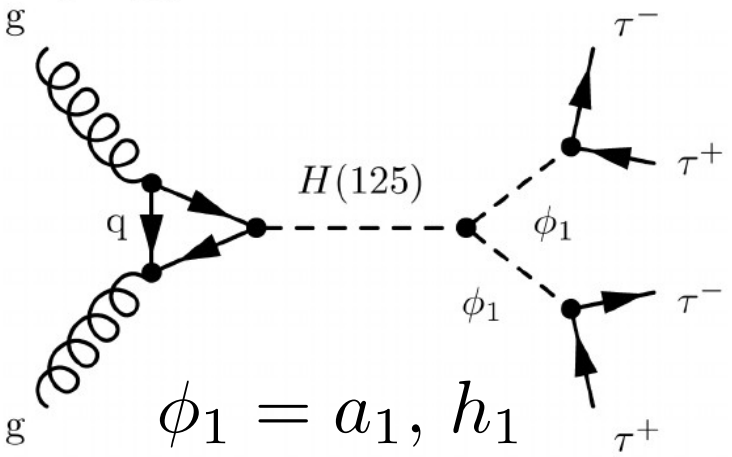
– can be searched via H(125) → a_1a_1 (h_1h_1)

Search for very light NMSSM Higgs bosons

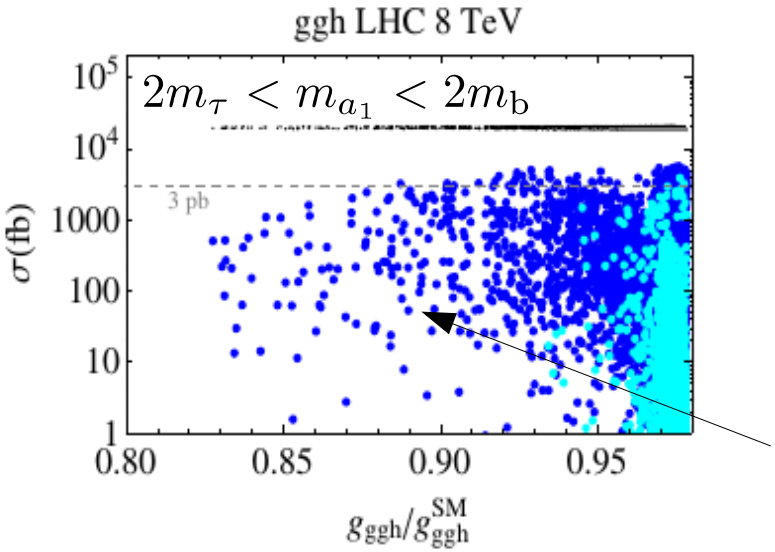
$$h_2(h_1) \to 2\phi_1 \to 4\tau$$

Possible models

- H(125)=h_2, H(125) →h_1h_1
- H(125)=h_2, H(125) →a_1a_1
- H(125)=h_1, H(125) →a_1a_1



NMSSM scan (D. Barducci, A. Belyaev, S. Moretti)



Probed mass range : [$2m_\tau$, $2m_b$]

- Blue/Cyan: h_1/h_2 SM Higgs boson
- Black/Gray: $\sigma(pp \to h_{1/2}^{SM} X)$

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

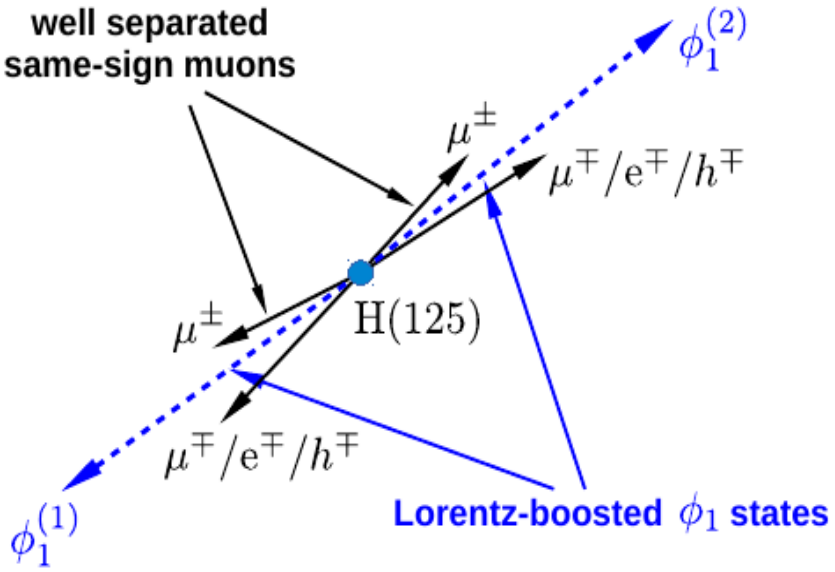
Signal Topology

- **$H(125) \rightarrow 2\varphi_1 \rightarrow 4\tau$ ($2m_\tau < m_{\varphi 1} < 2m_b$)**

- considered production mechanism
  $gg \rightarrow H(125)$

- considered decays of light φ_1 state
  $\varphi_1 \rightarrow \tau_\mu + \tau_{1\text{-prong}}$

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



→ $m_{H(125)} \gg m_{\varphi 1}$ → boosted φ_1

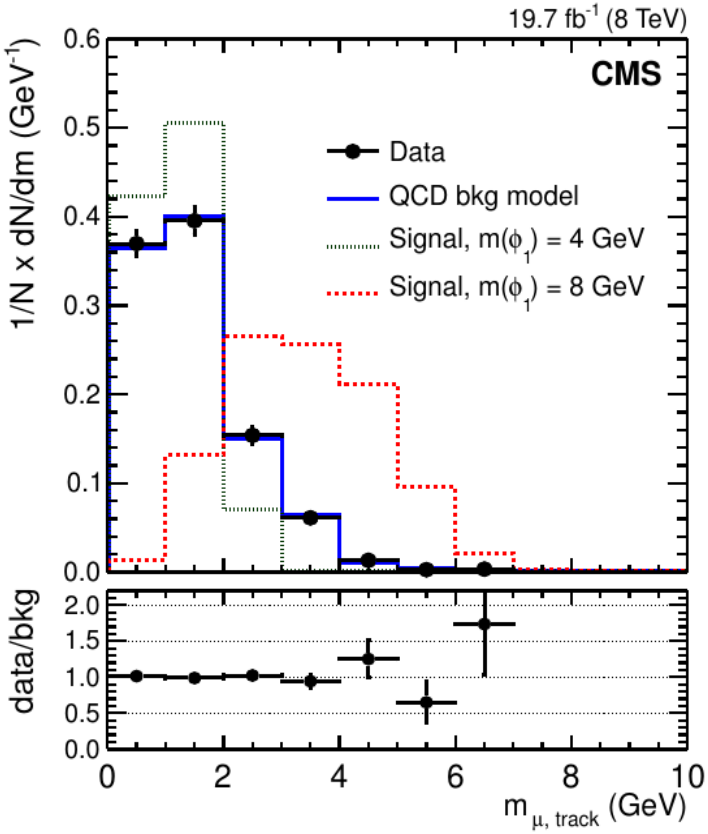
– collimated products in $\varphi_1 \rightarrow \tau\tau$ decays

– small opening angle between muon and track from 1-prong tau (both muon and track coming from the same φ_1)

Selected sample and Signal Extraction

- **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 $(\sigma\mathcal{B})_{sig} = 5\,\text{pb}$	
$m_{\phi_1} = 4\,\text{GeV}$	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

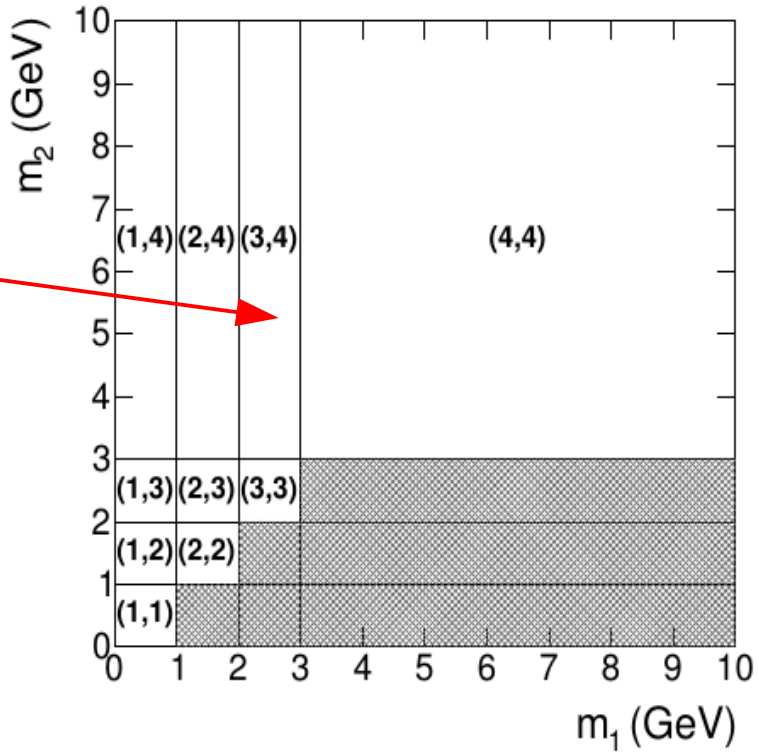


- **QCD background shape is estimated in sideband, where one of the muon-track pairs is non-isolated**

QCD Background Model

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

$$f_{2D}(i,j) = C(i,j)\left(f_{1D}(i)f_{1D}(j)\right)^{\mathrm{sym}}$$

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

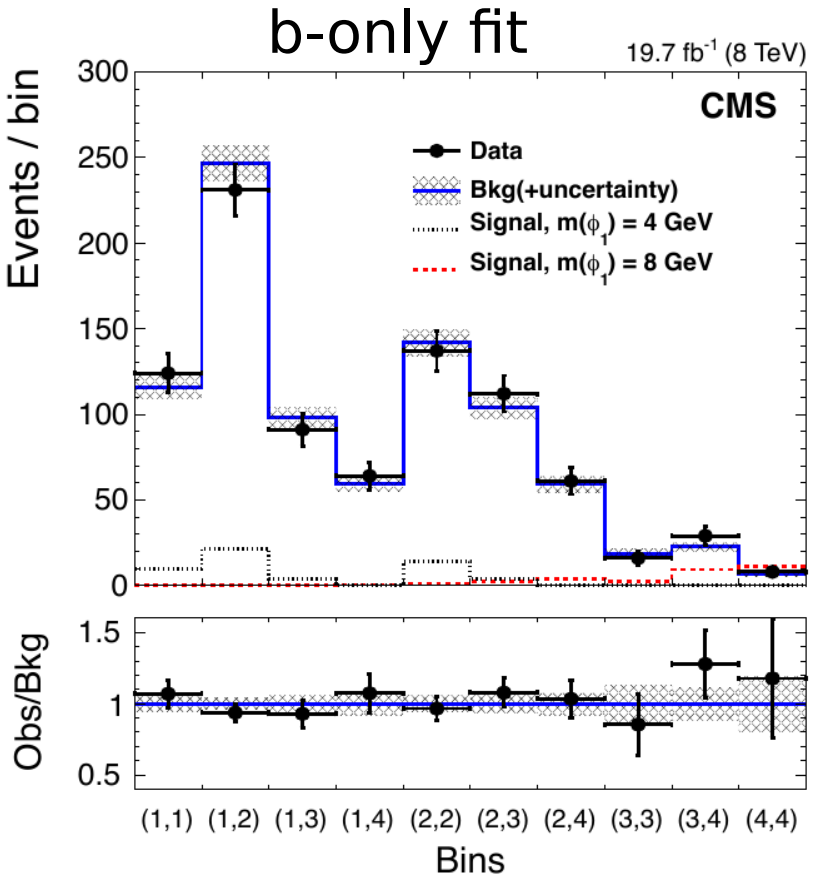
$f_{1D}(i)$ - content of bin i of normalized 1D distribution (see previous slide)

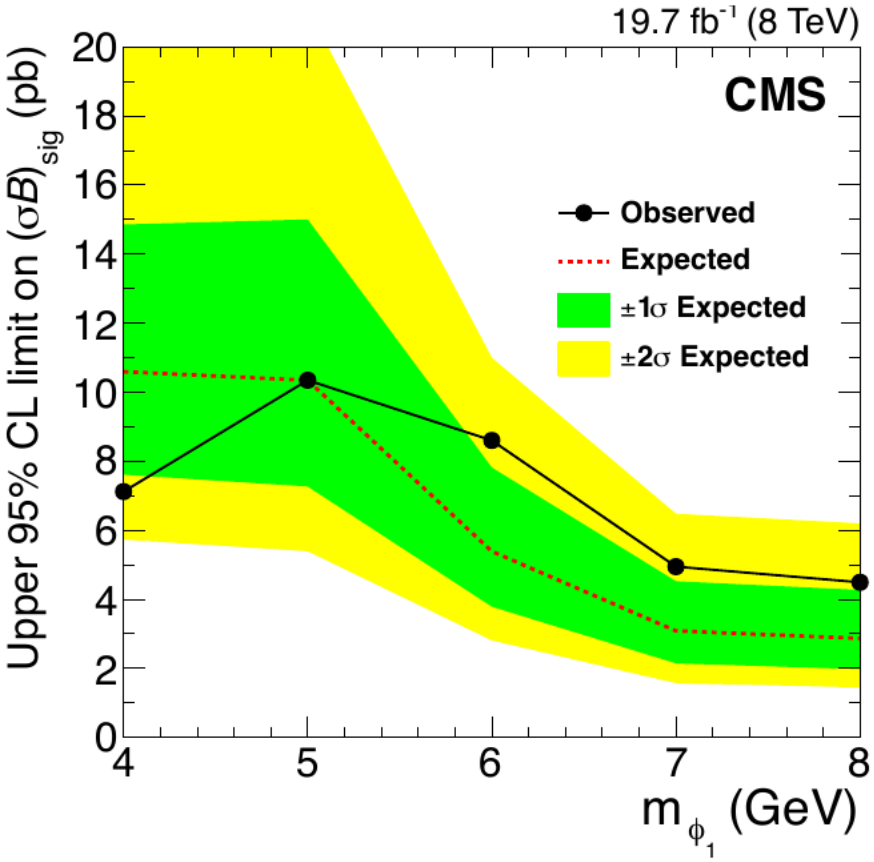
$C(i,j)$ - mass correlation coefficients, determined in the background control region where muon-track pairs are non-isolated (consistent with unity)

$$\left(f_{1D}(i)f_{1D}(j)\right)^{\mathrm{sym}} = f_{1D}(i)f_{1D}(j) + f_{1D}(j)f_{1D}(i), \text{ if } i \neq j$$
$$= f_{1D}(i)f_{1D}(j), \text{ if } i = j$$

Search for H(125) → 2φ$_1$ → 4τ : Results

- 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 strengthened**
- **Focus is shifted to the analysis of Run2 data**
  - **further investigation of properties of H(125) state**
  - **continue hunt for additional Higgs states predicted in theories extending SM**