BSM Higgs boson search results at CMS*

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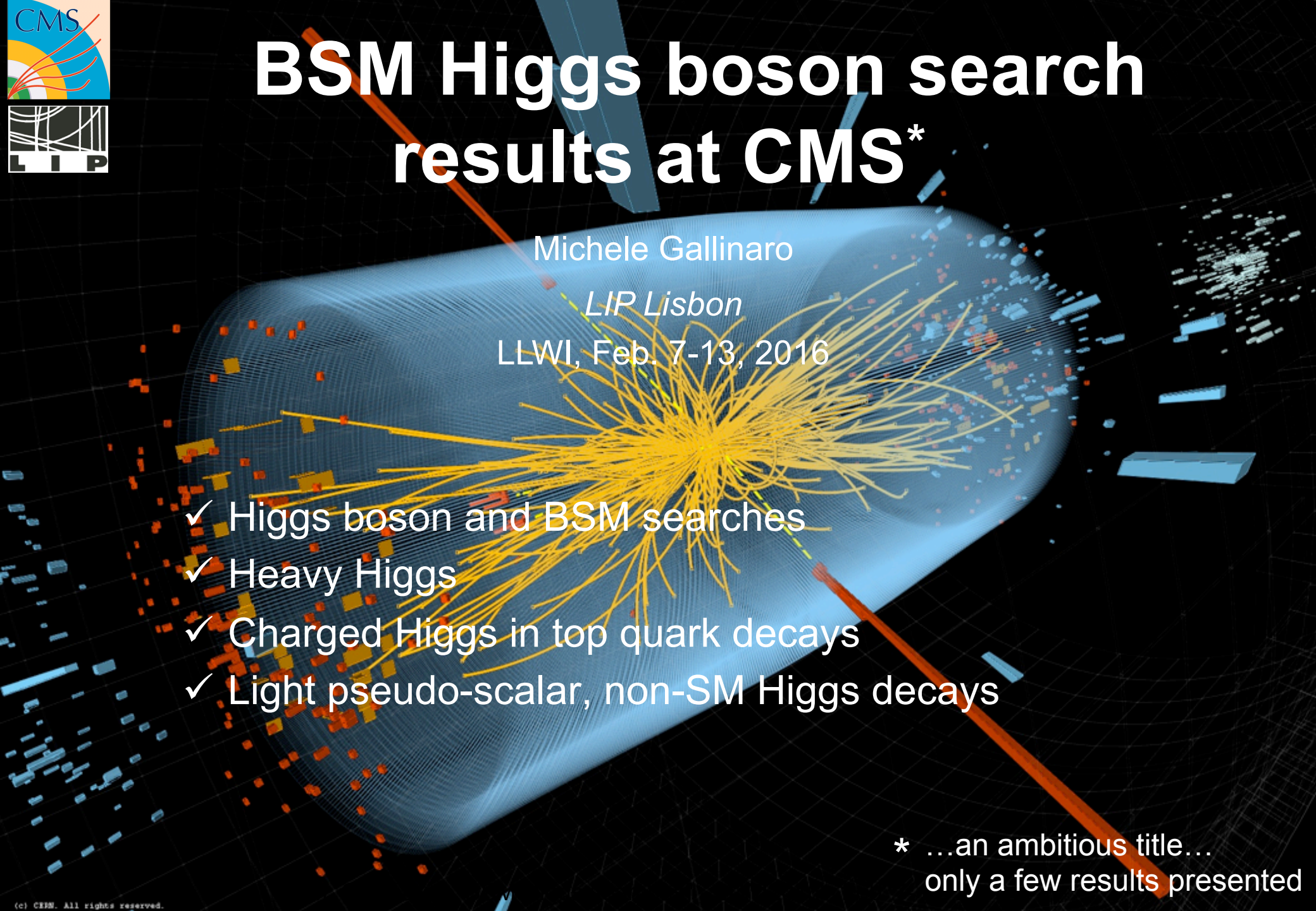
LIP Lisbon

LLWI, Feb. 7-13, 2016



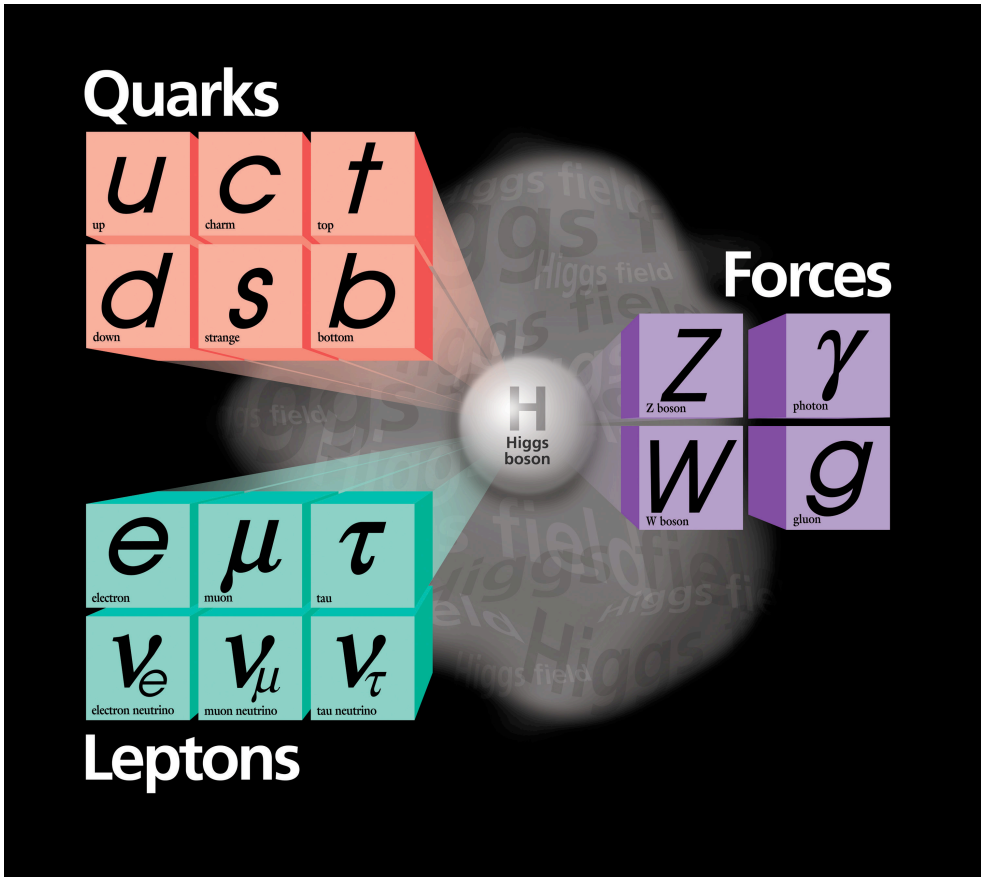
- ✓ Higgs boson and BSM searches
- ✓ Heavy Higgs
- ✓ Charged Higgs in top quark decays
- ✓ Light pseudo-scalar, non-SM Higgs decays

* …an ambitious title…
only a few results presented

Standard Model theory of everything?

- Discovery of the Higgs boson marks the triumph of the SM
- However, even with the inclusion of the Higgs boson, SM is an incomplete theory

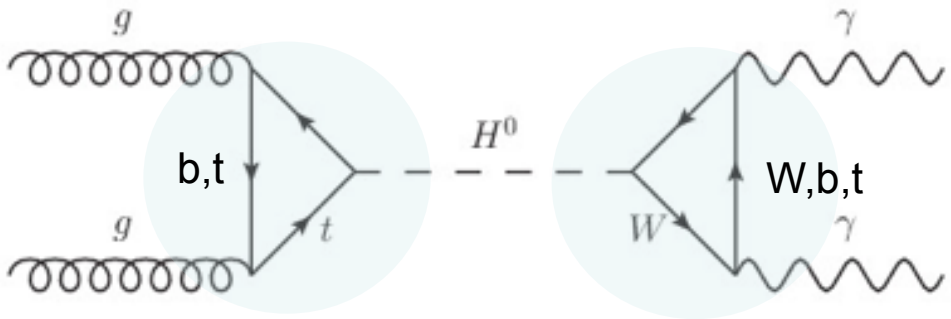
- Dark matter
- Asymmetry between matter and anti-matter
- Gravity and unification of forces
- Masses and neutrino hierarchy



Higgs and BSM

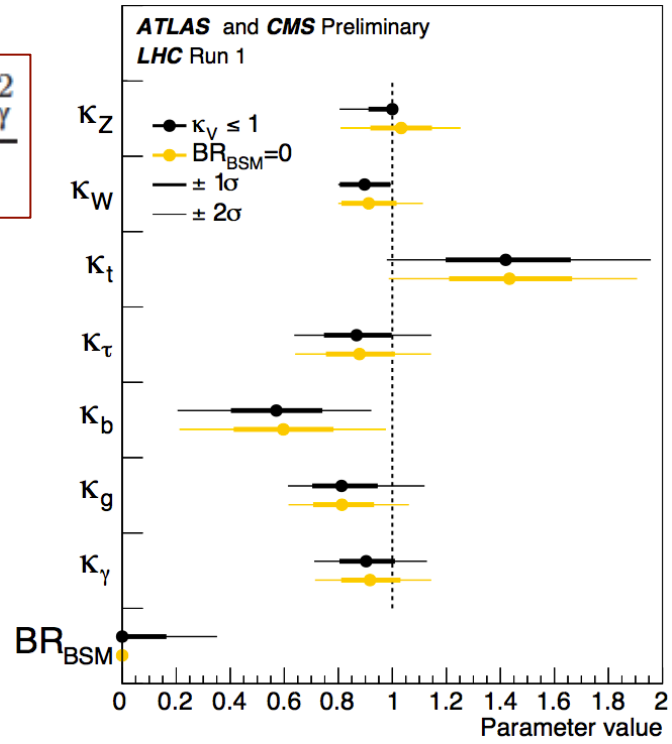
ATLAS-CONF-2015-044, CMS-HIG-15-002

- Is there BSM physics hidden in the "Higgs sector"?



$$(\sigma \cdot \mathrm{BR})\,(gg \to H \to \gamma\gamma) \;=\; \sigma_{SM}(gg \to H) \cdot \mathrm{BR}_{SM}(H \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

Strategy: parametrize deviations wrt SM in production and decay
⇒ loops are sensitive to BSM physics



Experimental approach

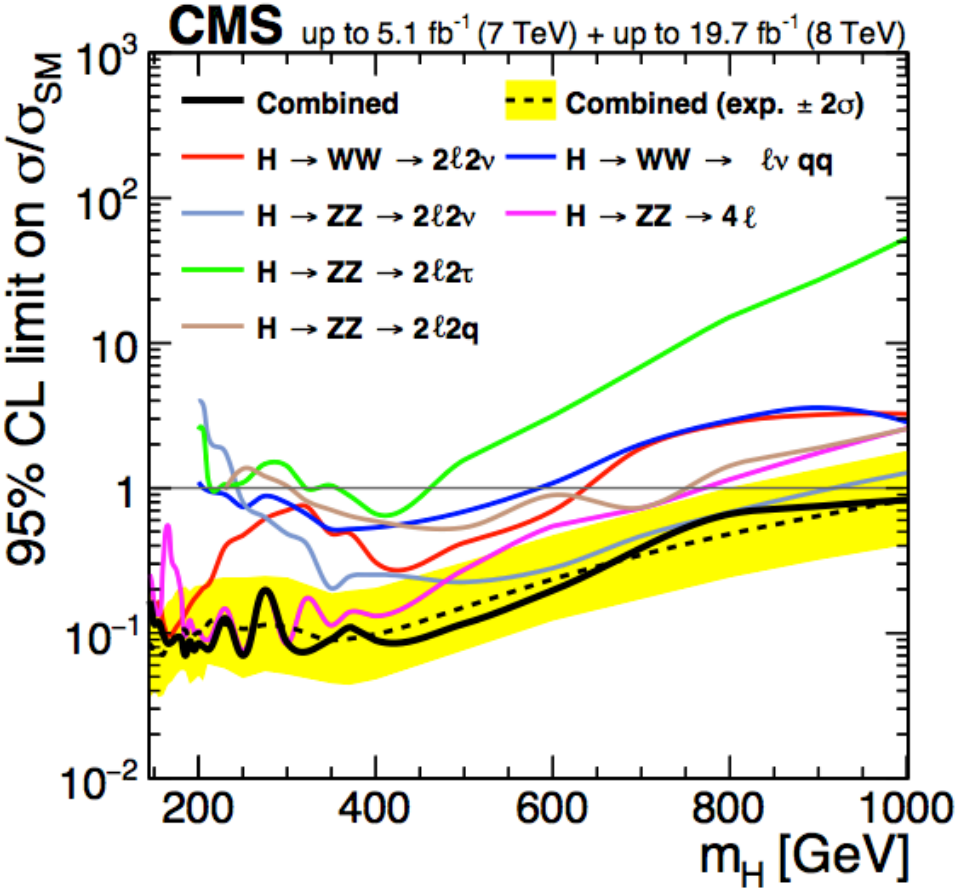
- Measure H(125) properties
- Search for additional Higgs bosons
- Search for BSM in signatures with Higgs bosons
- Search for BSM Higgs decays

See M. Machet's talk "Higgs properties at CMS"

High mass: H→WW/ZZ

JHEP 10(2015)144

- Search for a heavy Higgs boson
  - H→ZZ→4ℓ, 2ℓ2ν, 2ℓqq
  - H→WW→2ℓ2ν, 2ℓqq
- optimized separately for VBF and gluon fusion production processes
- SM-like Higgs boson excluded in 4ℓ and 2ℓ2ν/ℓνqq channels at 95%CL in mass ranges up to 1000 GeV
- Search interpreted in BSM scenario (heavy Higgs, heavy EWK singlet state)
  - evolution of signal strength of the singlet state with modified couplings/width wrt SM.
  - assume new scalar does not decay to any new particle



Extending searches

- Minimal Supersymmetric SM (MSSM)
  - Neutral Higgs: $\phi \to \tau\tau/bb/\mu\mu$
  - Charged Higgs (low/high mass, low/high tanβ, doubly)
- Next-to-MSSM
  - Light pseudoscalar: $h \to aa$
  - Non-SM decays: $h \to 2a \to 4\tau/4\mu$
  - Heavy Higgs: $H \to h_{125}h_{125}$ or $A \to Zh_{125}$
- FCNC: $t \to cH$
- LFV, exotic decays

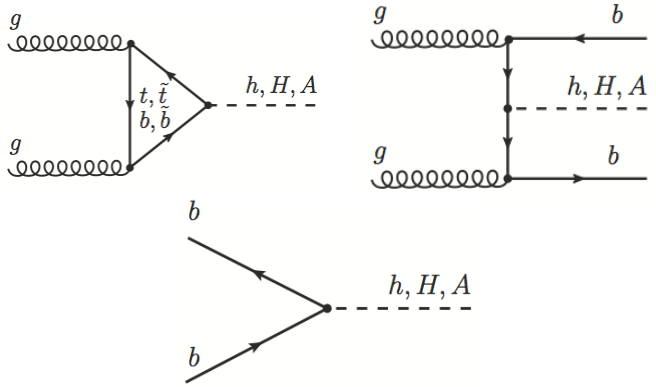
Neutral MSSM Higgs

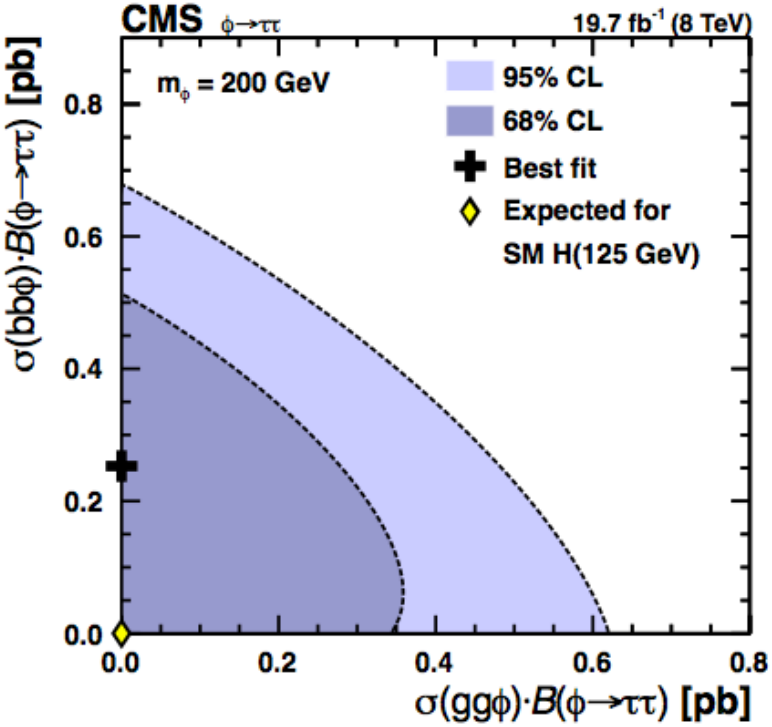
JHEP 10(2014)160

- Enhanced couplings of MSSM Higgs to down-type fermions (large tanβ)

⇒increased BR to τ leptons and b-quarks

- Search for neutral MSSM Higgs boson
- 5 final states used: $\mu\tau_h$, $e\tau_h$, $\tau_h\tau_h$, $e\mu$, $\mu\mu$
  - Reconstruct tau-pair invariant mass
  - Split in b-tag/no b-tag categories to enhance sensitivity
- Main backgrounds: $Z\rightarrow\tau\tau$, QCD/W+jets, DY,ttbar, dibosons
- No significant excess over bkg expectations
- Model-independent limits by separating production modes

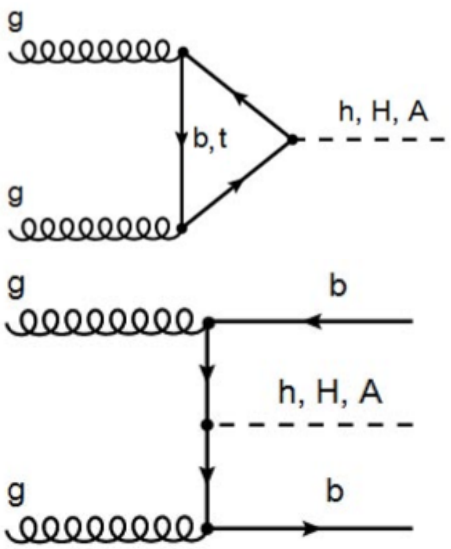


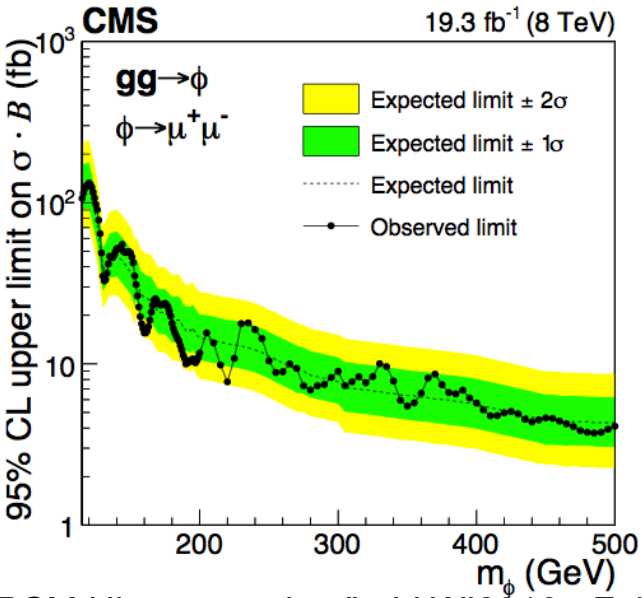


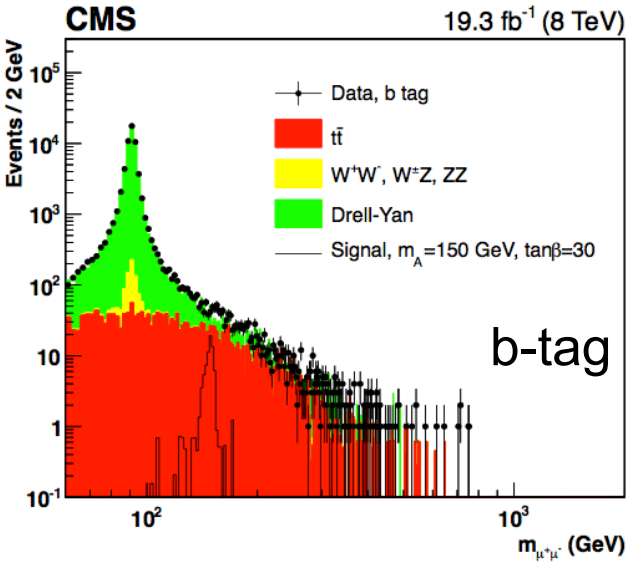
Neutral MSSM Higgs: $\phi \rightarrow \mu\mu$

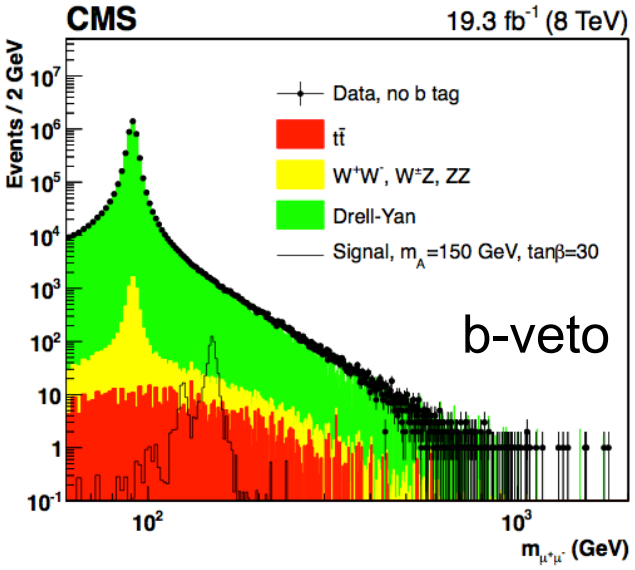
arXiv:1508.01437

- Search for a $\mu\mu$ mass resonance
  - Model-independent
  - associated production, gluon fusion
- Good mass resolution
  - full and clean reconstructed final state
- Split in b-tagged and non b-tagged categories to be sensitive to $gg \rightarrow \phi$ and $bb\phi$ production modes
- Main backgrounds: DY, VV, ttbar



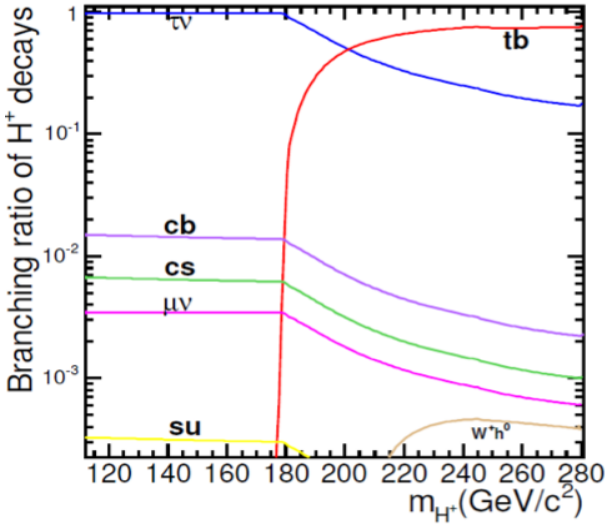




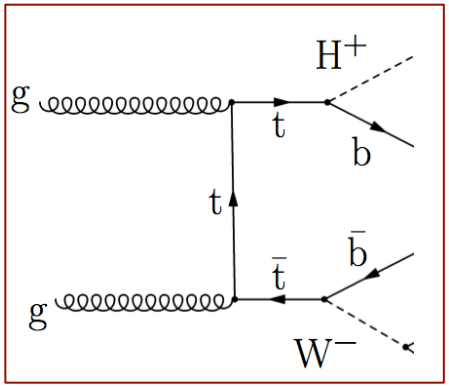


Charged Higgs

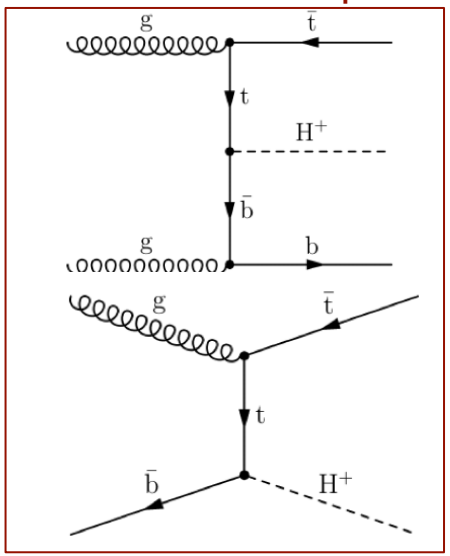
- If found, a clear indication of BSM
- Study non-SM Higgs in two mass regimes:
- $m_H < m_{top}$
  - Mostly produced in top quark decays
  - Large tanβ: $H^{\pm} \rightarrow \tau^{+}\nu$
  - Small tanβ (<1): $H^{+} \rightarrow c\bar{s}$
- $m_H > m_{top}$
  - Produced in gluon-gluon fusion
  - Main decays: $H^{+} \rightarrow tb$, $H^{+} \rightarrow \tau^{+}\nu$
- Main backgrounds: ttbar, W+jets



$m_H < m_{top}$



$m_H > m_{top}$

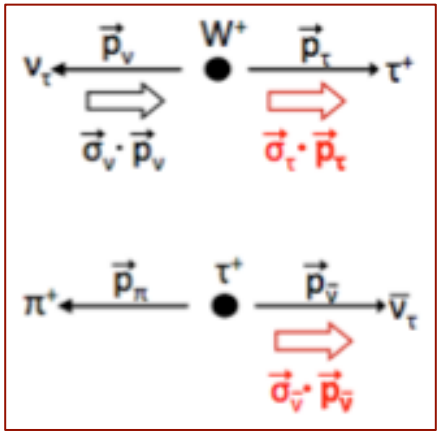


Looking at tau decays

CMS-HIG-12-052

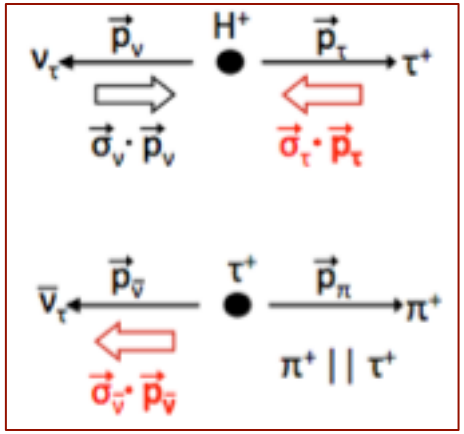
- Use R variable in the limit extraction: binned maximum-likelihood fit
- Tau fake component is data-driven, includes uncertainties

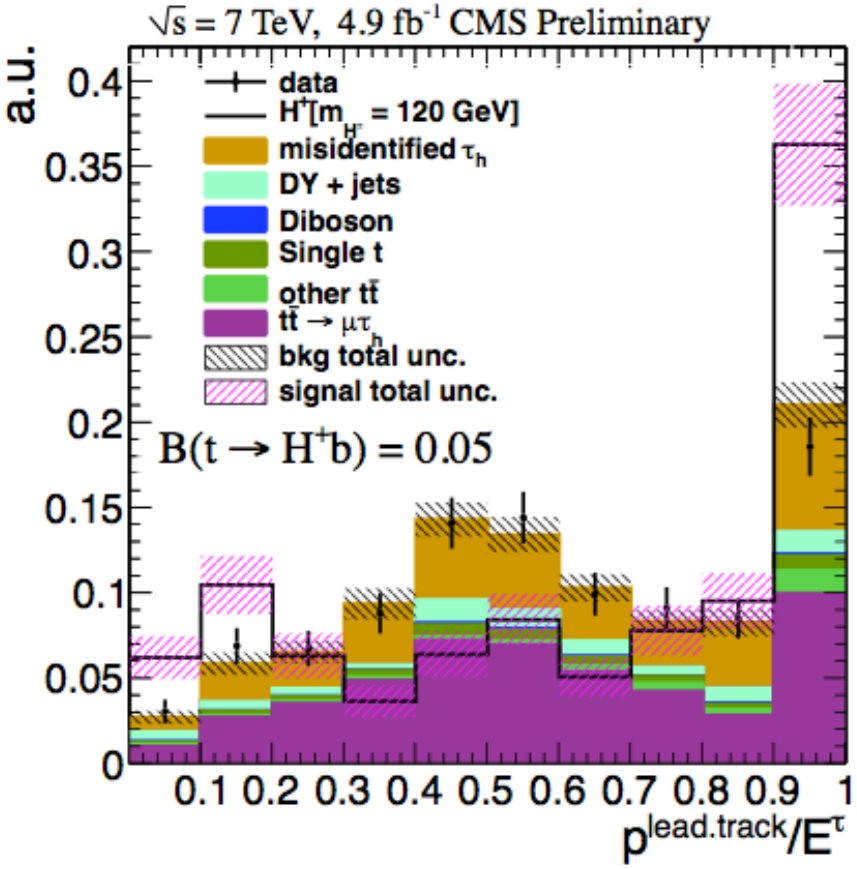
SM



vs

BSM





Is there a charged Higgs?

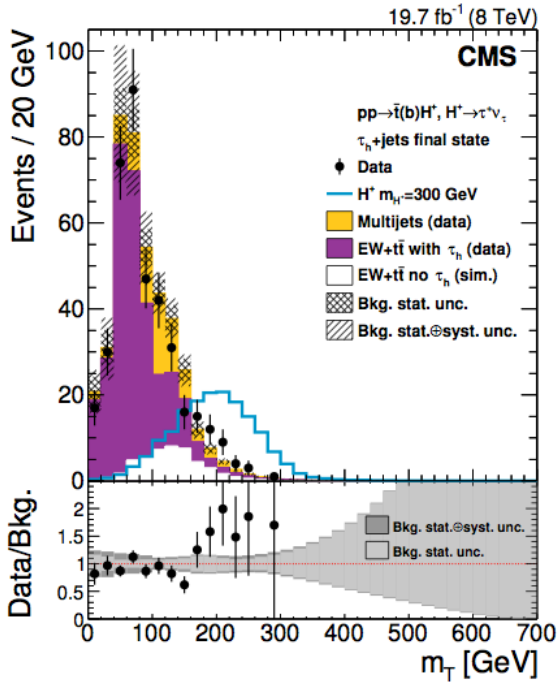
arXiv:1508.07774

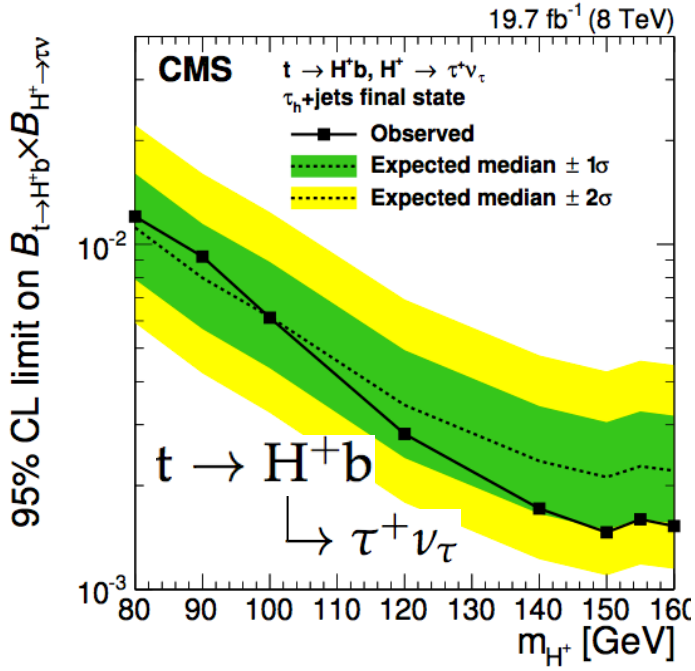
- If anomalous tau/lepton production in ttbar decays there may be contribution from H^+

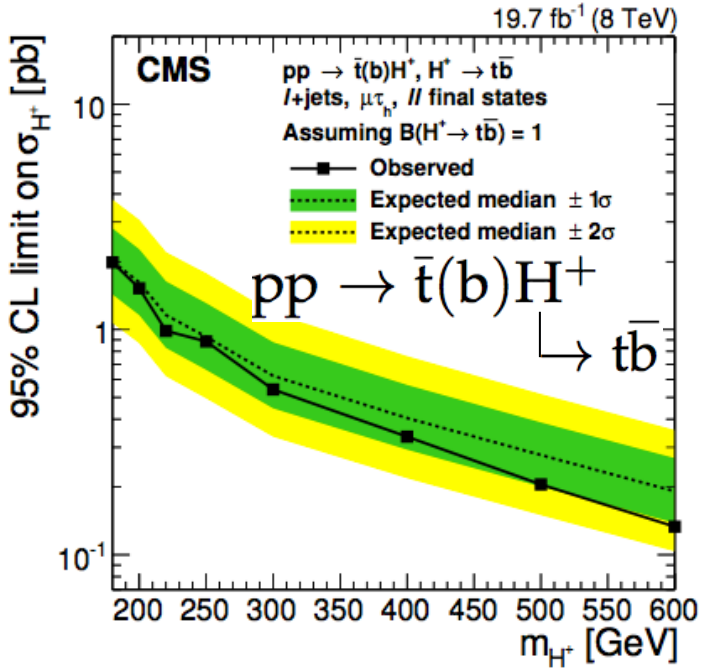
Yields in agreement with expectations ⇒ set limits

m_H: 80-160 GeV $\mathcal{B}(t \to bH^+) < 1.2\text{-}0.3\%$

200-600 GeV $\sigma(pp \to \bar{t}(b)H^+) < 2.0\text{-}0.2$ pb







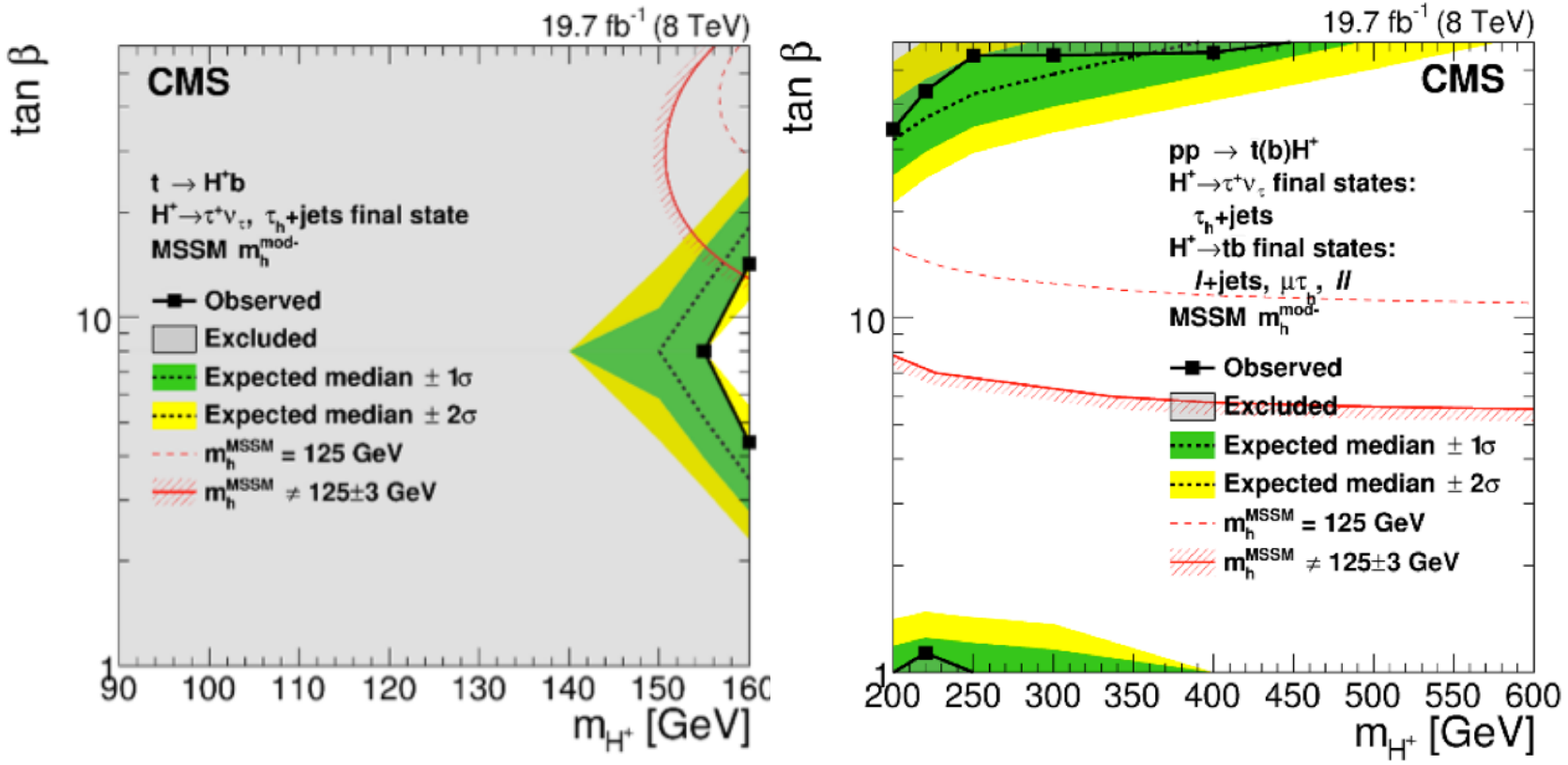
At 13TeV, expect improvement with 5-10/fb for m_{H+}>300GeV ⇒

- ttbar xsection increases x3.3
- signal increases x6(x7) for m_{H+}=500(600)GeV

Still hope for MSSM?

arXiv:1508.07774

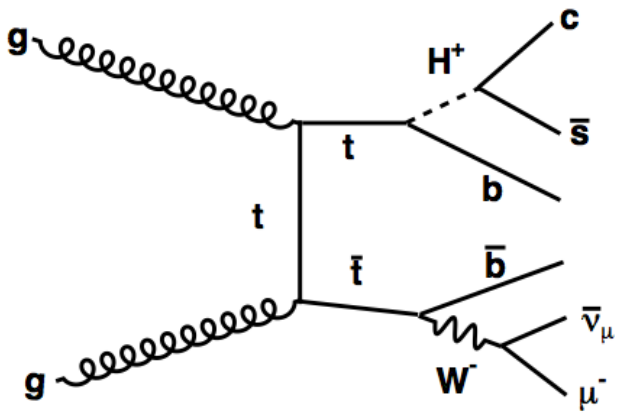
- A new modified MSSM scenario: m_h^{mod} (arXiv:1302.7033)
- Reduce amount of mixing in the stop sector (X_t/M_{SUSY})
- A/H decays to chargino/neutralinos allowed (arXiv:0709.1029)
- Allows for reduction of decays into $\tau\tau$ and bb

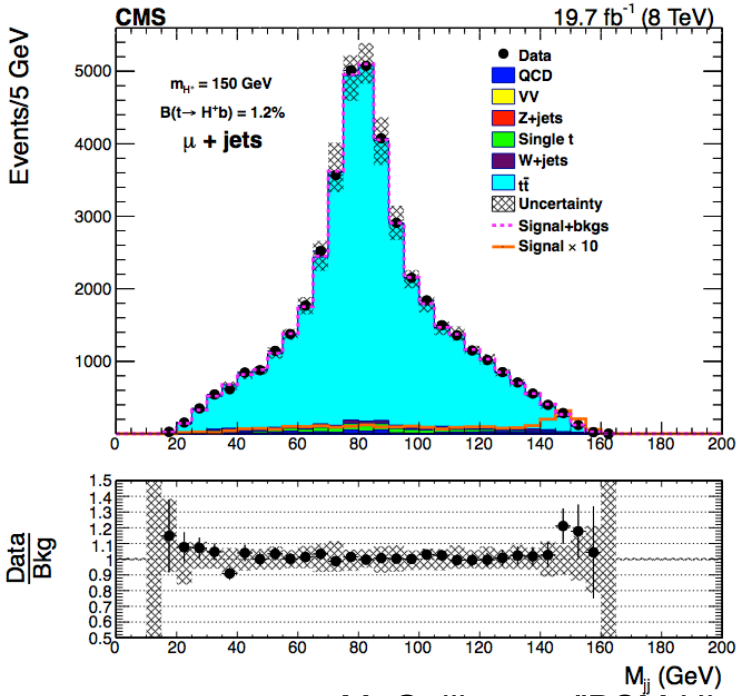


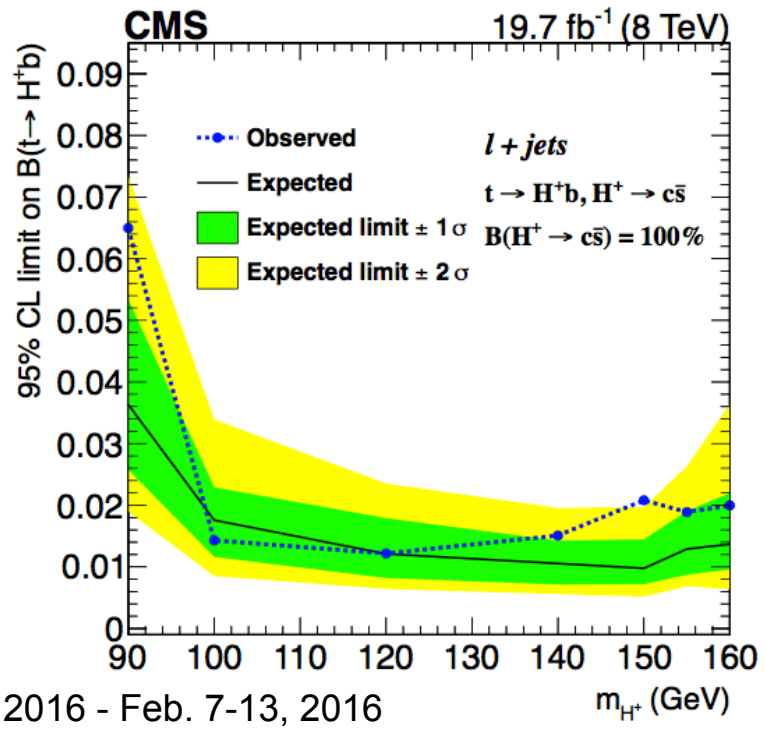
Light charged Higgs: csbar

JHEP 12(2015)1, arXiv:1510.04252

- H→csbar decay
  - dominant in low tanβ region
- Lepton+jet final states
- Dominant bkg from ttbar
- Kinematic fit to reconstruct W/H mass
- Set model-independent limits on BR(t→H⁺b)~2-7%

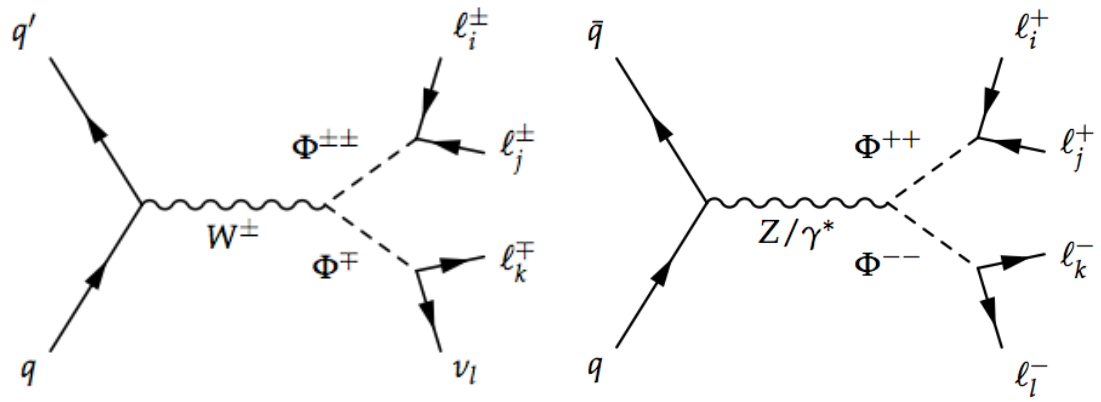




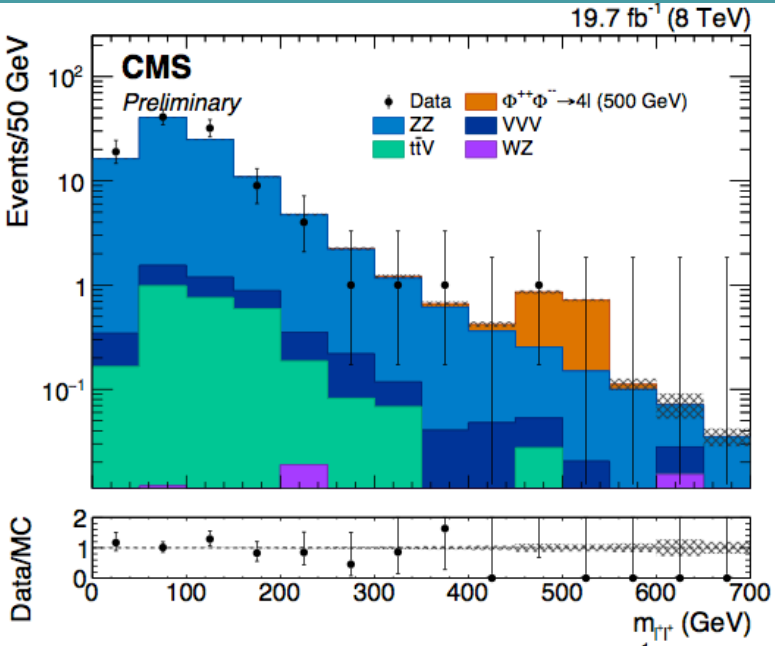


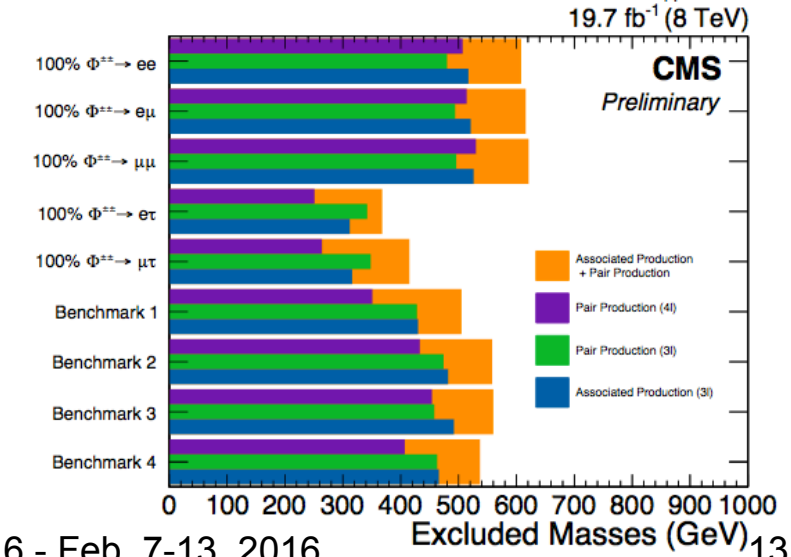
Doubly charged Higgs

EPJC 72 (2012) 2189, CMS-HIG-14-039



- Model
  - SM extended with scalar triplet (Φ^{++}, Φ^{+}, Φ^{o})
  - Triplet responsible for neutrino masses
  - Search for doubly- and singly-charged
  - DY pair production is most common
  - SS lepton pair of any flavor combination
- Search with ≥3 leptons of any flavor
  - Search for excess of events in one or more flavor combinations of SS lepton pairs
- Dilepton invariant mass as discriminant

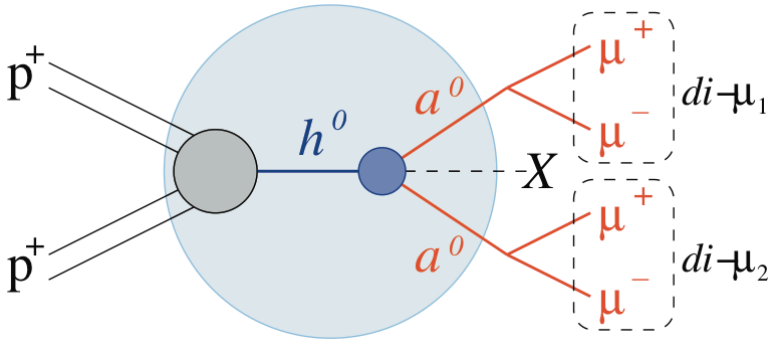


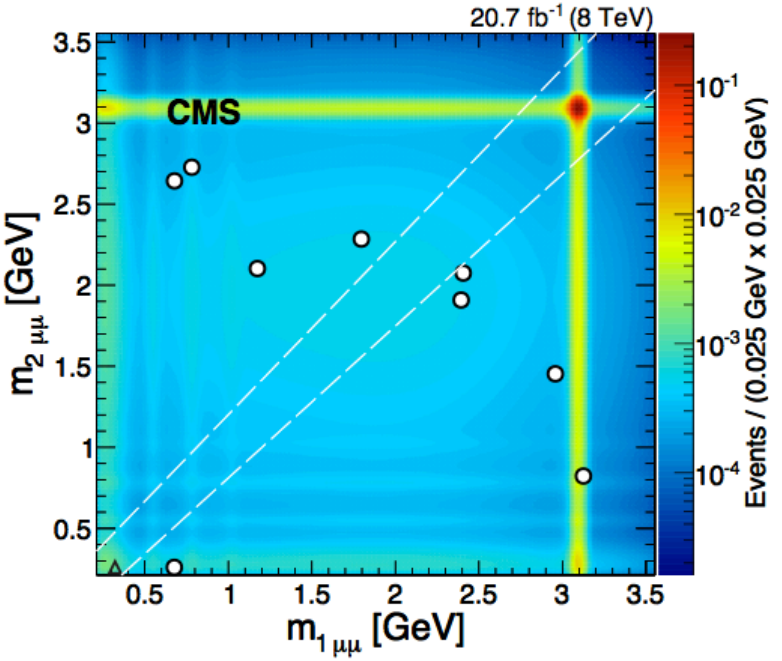


non-SM Higgs decay: $h_{125} \rightarrow 2a \rightarrow 4\mu$

PLB 726(2013)564, arXiv:1506.00424

- Explore non-SM decays of a Higgs boson (h)
  - h_{125} can be SM or not
  - include production of two new light boson (a^0)
  - large B($a \rightarrow \mu\mu$) if $2m_\mu < m_a < 2m_\tau$
- Search for generic Higgs decays: $h \rightarrow 2a+X \rightarrow 4\mu+X$
- Selection: minimize sensitivity to model details
  - Find low mass muon pairs ("dimuons")
  - Require each event to have two dimuons
  - Require two dimuon masses to be consistent
- Results
  - Observe 9 events in off-diagonal region, consistent with bkg expectations
  - Signal region: 1 event (2.2±0.7 bkg)
  - Limits on production rates, benchmark models





NMSSM and Dark SUSY Limits

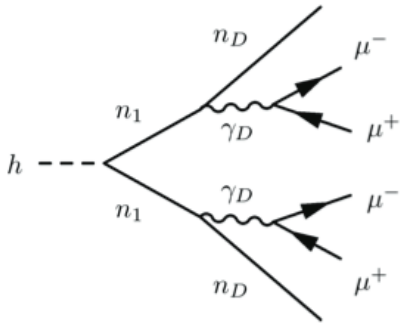
PLB 726(2013)564, arXiv:1506.00424

Results interpreted in NMSSM and dark SUSY

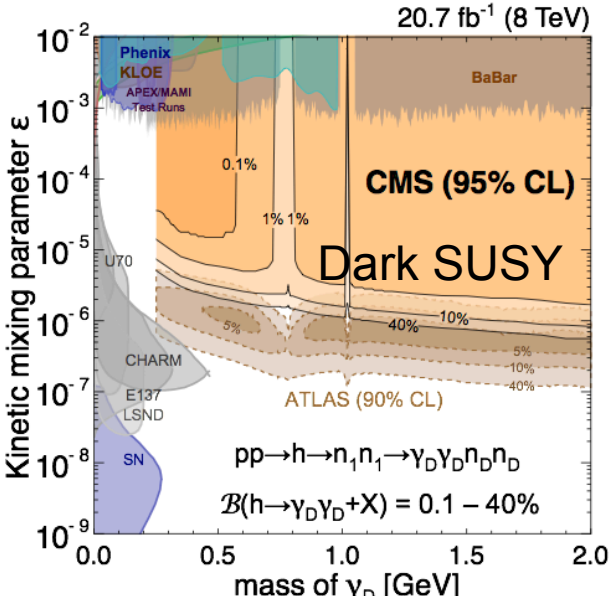
- Dark SUSY: h decay to pair of neutralinos (n_1): LSP

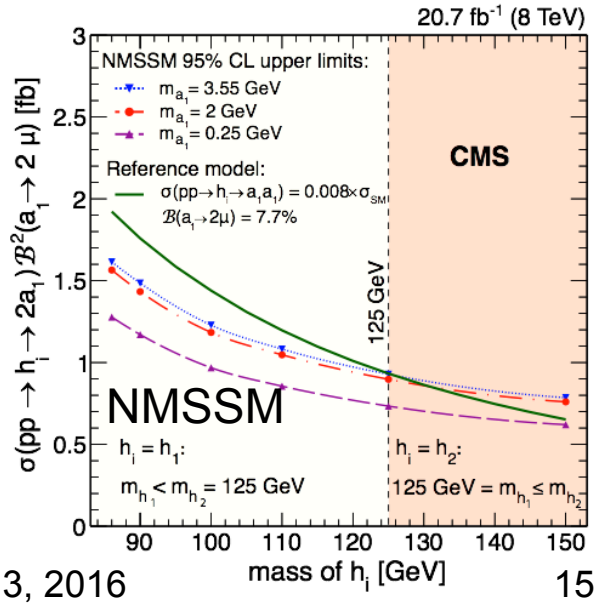
$n_1 \rightarrow n_D \gamma_D$ decays

- $\gamma_D \rightarrow \mu\mu$
- n_D → invisible



- NMSSM: Extend MSSM by adding a complex singlet field (1 CP-even+1 CP-odd boson)
- NMSSM: $h_{1,2} \rightarrow 2a_1$; $a_1 \rightarrow 2\mu$
- Compare to SM Higgs cross section

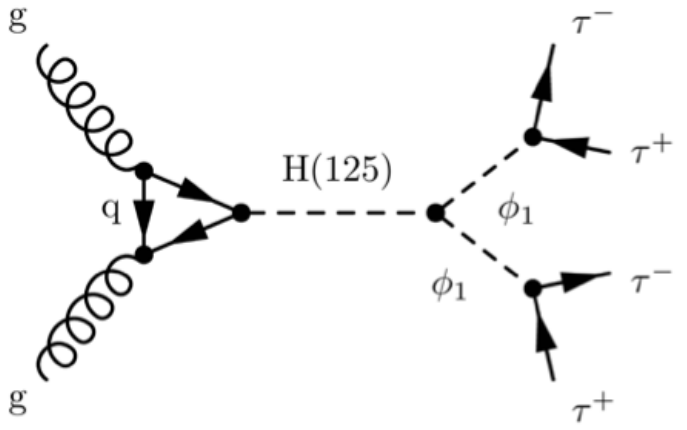


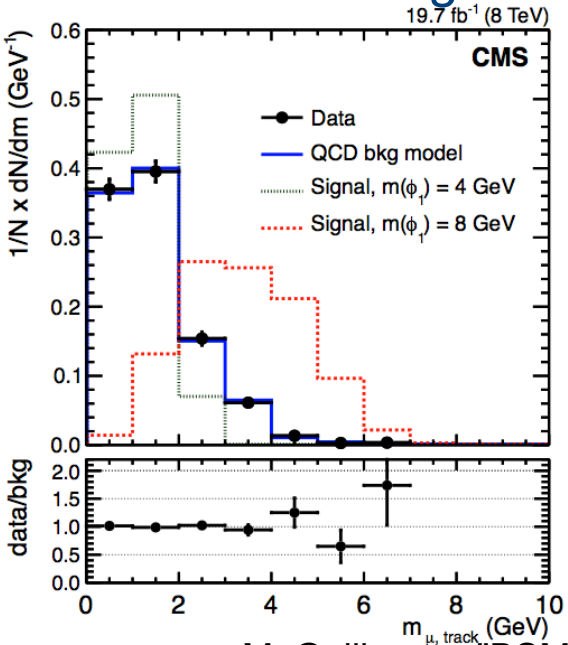


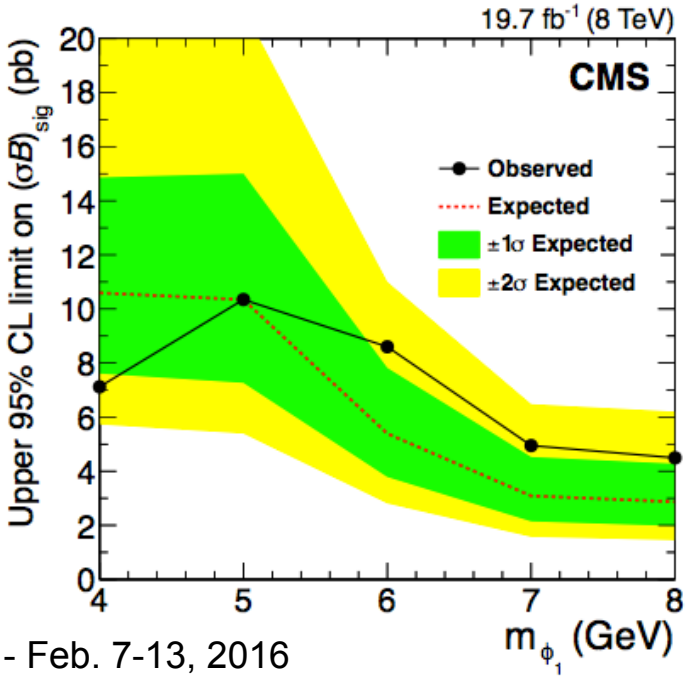
non-SM Higgs decay: $H_{125} \rightarrow 2h(a) \rightarrow 4\tau$

arXiv:1510.06534

- Search for very light Higgs in NMSSM
  - $h_{1,2}$ (CP-even), $a_{1,2}$ (CP-odd) to a pair of τ leptons
  - $H(125) \rightarrow h_1 h_2 (a_1 a_2) \rightarrow 4\tau$
- Reconstruct μ-track invar. mass (m_1,m_2)
  - SS dimuon sample (removes DY)
  - bin in 2-dim distribution, fit signal and bkg
  - QCD bkg from control region
- No excess over SM backgrounds



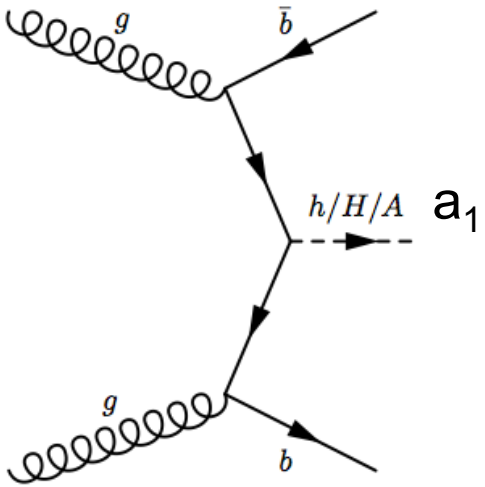


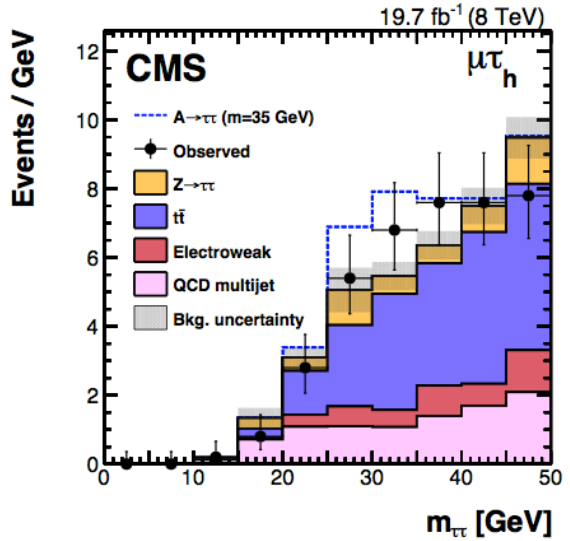


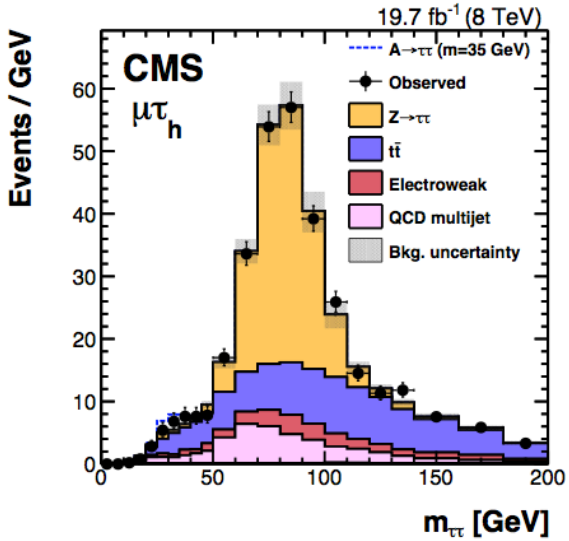
Low mass Higgs: a(→ττ)bb

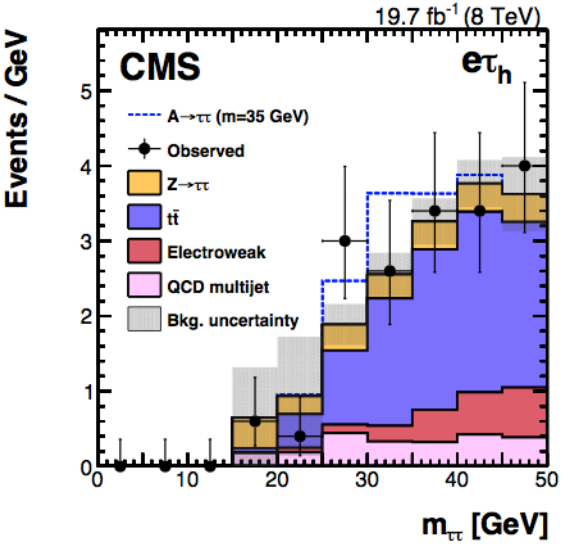
arXiv:1511.03610

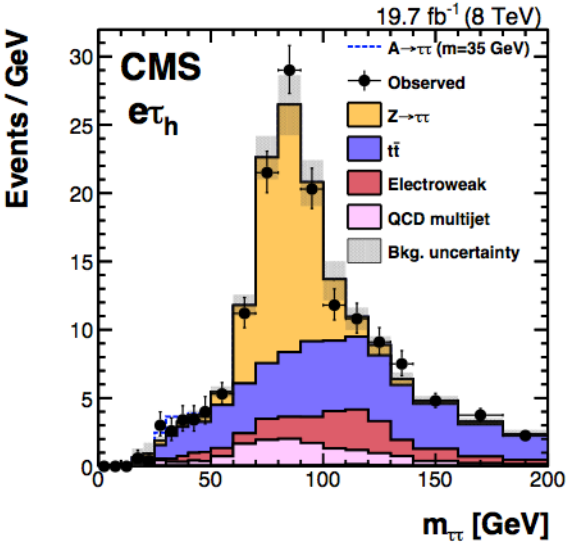
- Low mass Higgs in the NMSSM
- Low mass pseudo-scalar ($a_1 \to \tau\tau$) in association with bbar: $a_1 bb \to \tau\tau\, bb$
- Similar strategy to $H \to \tau\tau$
- Search for a_1 masses below Z mass
- No evidence for signal
- Set limits: σxB~9-39 pb









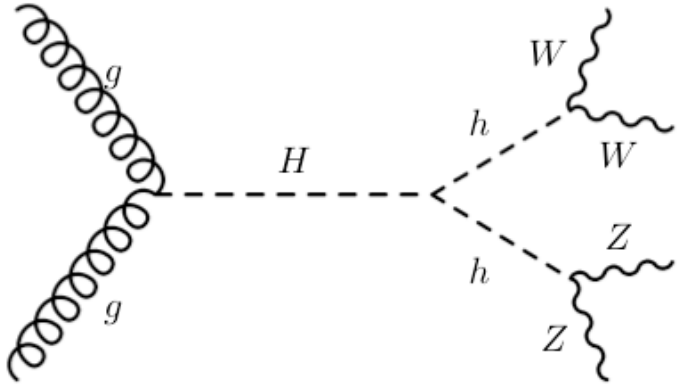


Heavy Higgs: $H \to h_{125}h_{125}$, $A \to Zh_{125}$

arXiv:1410.2751, arXiv:1510.01181

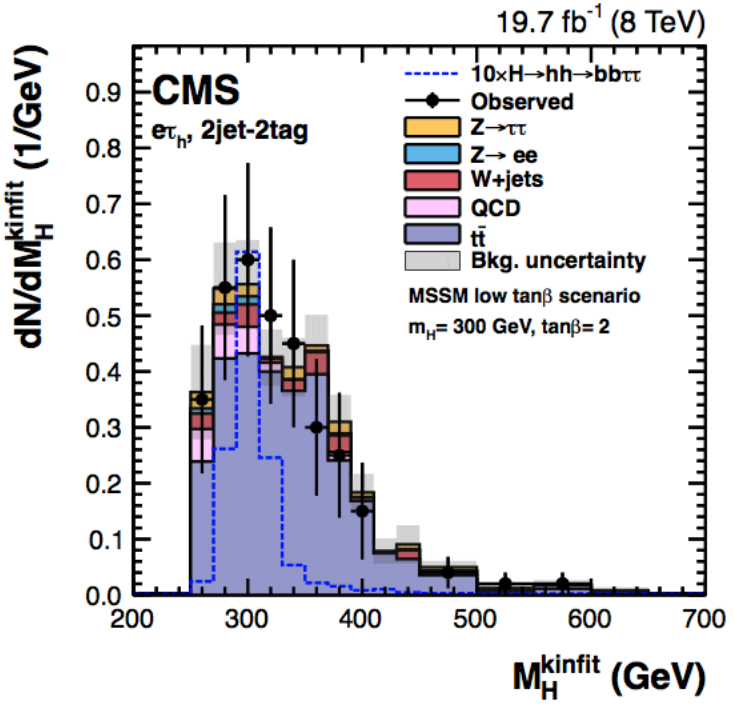
- MSSM: Heavy Higgs searches
  - Search for $A \to Zh_{125}$ and $H \to hh$
- Exclusive search in multilepton and diphoton +lepton channels
  - Also bbττ (hh), or llττ (Zh)
  - exclusive channels (leptons, taus, photons, N_{btags}, etc)

⇒No excess in data, set limits



FCNC decays

Process	SM	QS	2HDM-III	FC-2HDM	MSSM
$t \to u\gamma$	$3.7 \cdot 10^{-16}$	$7.5 \cdot 10^{-9}$	—	—	$2 \cdot 10^{-6}$
$t \to uZ$	$8 \cdot 10^{-17}$	$1.1 \cdot 10^{-4}$	—	—	$2 \cdot 10^{-6}$
$t \to uH$	$2 \cdot 10^{-17}$	$4.1 \cdot 10^{-5}$	$5.5 \cdot 10^{-6}$	—	10^{-5}
$t \to c\gamma$	$4.6 \cdot 10^{-14}$	$7.5 \cdot 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$2 \cdot 10^{-6}$
$t \to cZ$	$1 \cdot 10^{-14}$	$1.1 \cdot 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$2 \cdot 10^{-6}$
$t \to cH$	$3 \cdot 10^{-15}$	$4.1 \cdot 10^{-5}$	$1.5 \cdot 10^{-3}$	$\sim 10^{-5}$	10^{-5}



- Also search for $tt \to (bW)(ch)$
  - Not forbidden but highly suppressed
  - enhanced w/some parameter models
- BR(t→cH)<0.56% (0.65%) @95%CL

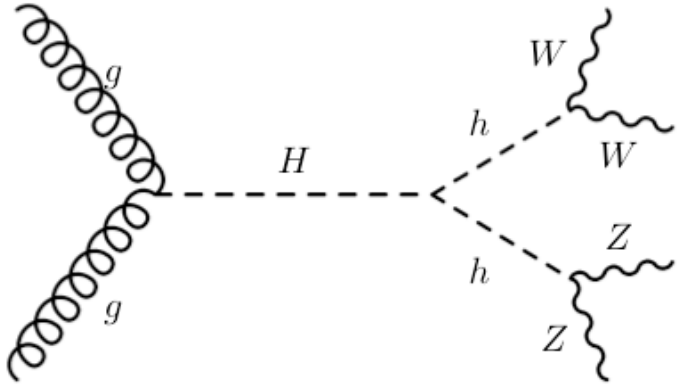
See Y. Chao's talk "Search for FCNC decays at CMS"

Heavy Higgs: $H \to h_{125}h_{125}$, $A \to Zh_{125}$

arXiv:1410.2751, arXiv:1510.01181

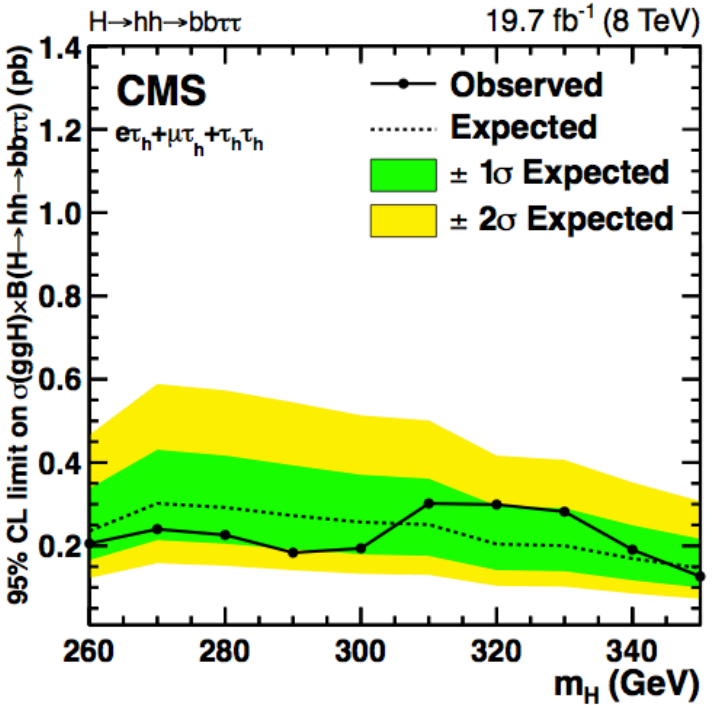
- MSSM: Heavy Higgs searches
  - Search for $A \to Zh_{125}$ and $H \to hh$
- Exclusive search in multilepton and diphoton +lepton channels
  - Also bbττ (hh), or llττ (Zh)
  - exclusive channels (leptons, taus, photons, N_{btags}, etc)

⇒No excess in data, set limits



FCNC decays

Process	SM	QS	2HDM-III	FC-2HDM	MSSM
$t \to u\gamma$	$3.7 \cdot 10^{-16}$	$7.5 \cdot 10^{-9}$	—	—	$2 \cdot 10^{-6}$
$t \to uZ$	$8 \cdot 10^{-17}$	$1.1 \cdot 10^{-4}$	—	—	$2 \cdot 10^{-6}$
$t \to uH$	$2 \cdot 10^{-17}$	$4.1 \cdot 10^{-5}$	$5.5 \cdot 10^{-6}$	—	10^{-5}
$t \to c\gamma$	$4.6 \cdot 10^{-14}$	$7.5 \cdot 10^{-9}$	$\sim 10^{-6}$	$\sim 10^{-9}$	$2 \cdot 10^{-6}$
$t \to cZ$	$1 \cdot 10^{-14}$	$1.1 \cdot 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-10}$	$2 \cdot 10^{-6}$
$t \to cH$	$3 \cdot 10^{-15}$	$4.1 \cdot 10^{-5}$	$1.5 \cdot 10^{-3}$	$\sim 10^{-5}$	10^{-5}

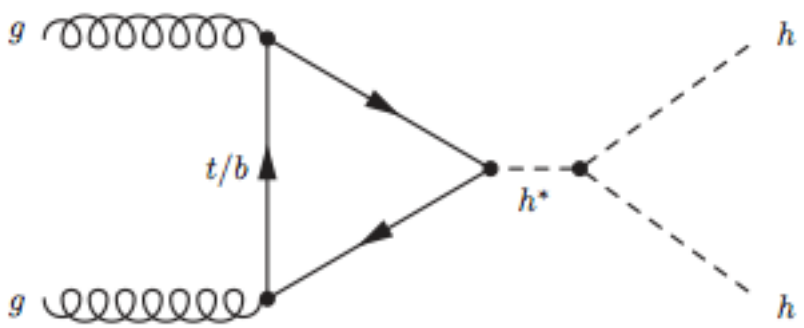


- Also search for tt→(bW)(ch)
  - Not forbidden but highly suppressed
  - enhanced w/some parameter models
- BR(t→cH)<0.56% (0.65%) @95%CL

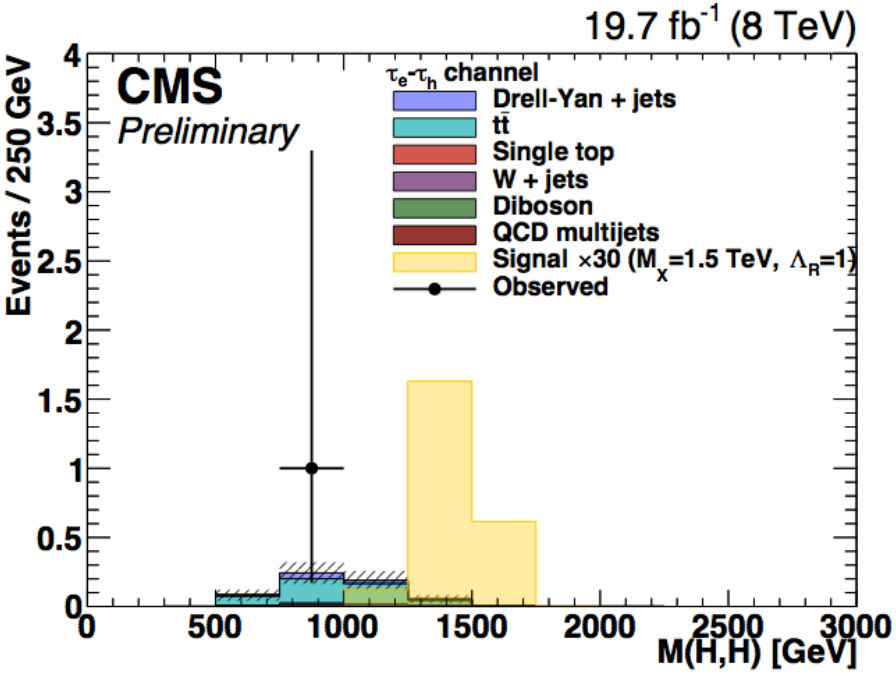
See Y. Chao's talk "Search for FCNC decays at CMS"

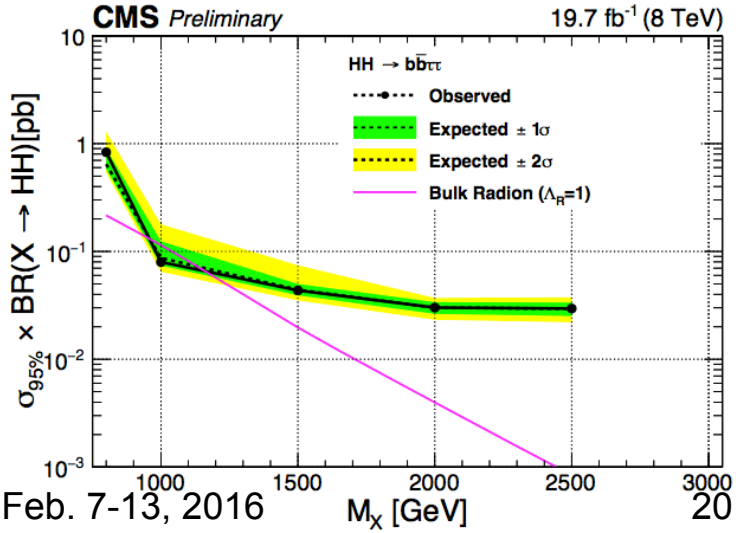
Heavy Higgs to $h_{125}h_{125} \rightarrow \tau\tau bb$

CMS-EXO-15-008



- High-mass (≥1 TeV) resonant production
  - $H \rightarrow h_{125}h_{125} \rightarrow bb\tau\tau$
- h_{125} decay products nearly collinear
- boosted "single" merged jet ($\rightarrow bb$)
- use $\tau_e\tau_h$ and $\tau_\mu\tau_h$ final states
- sidebands/inverted isolation to determine bkg
- set limits on spin-0 resonance at 850-30fb for M_X=0.8-2.5 TeV

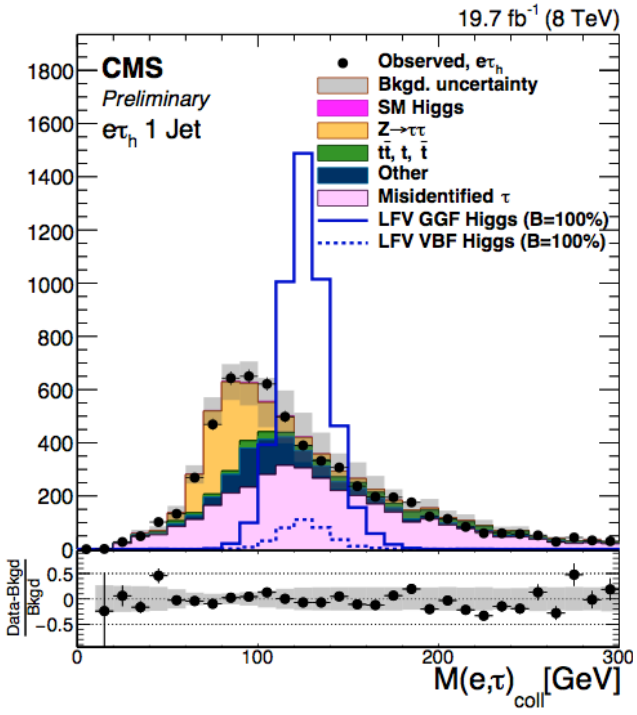


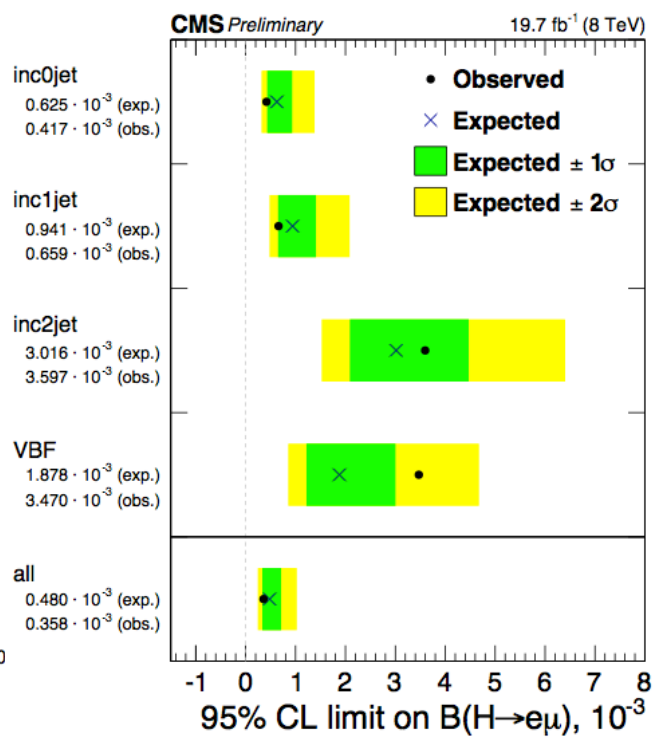


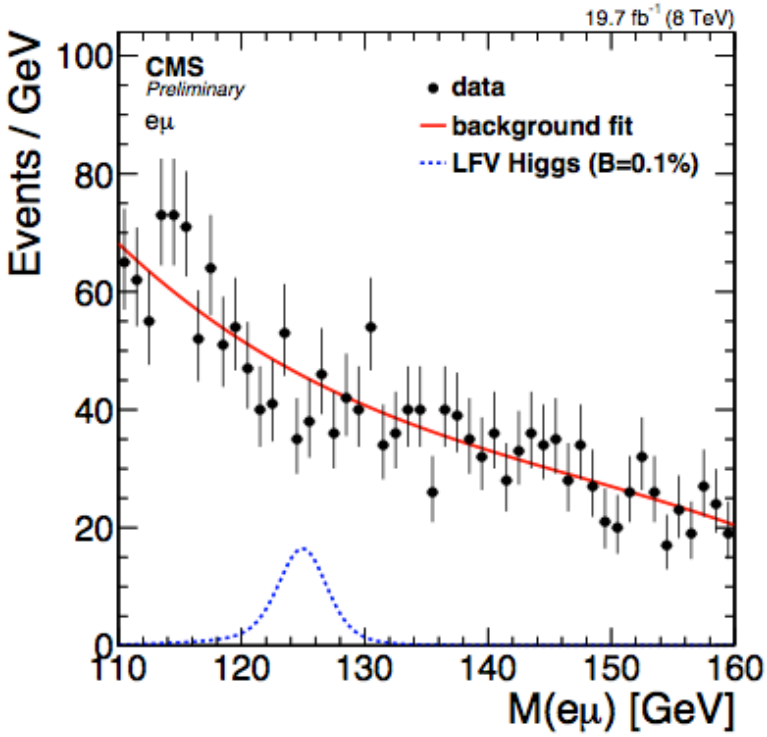
LFV Higgs decays

CMS-HIG-14-040

- Study eτ, eμ final states
- Categories: N_{jet}, lepton kinematics
- VBF with jets
- Main background from DY, ttbar, WW
- Upper limits on B(H→eτ)<0.7% and B(H→eμ)<0.036% @95%CL



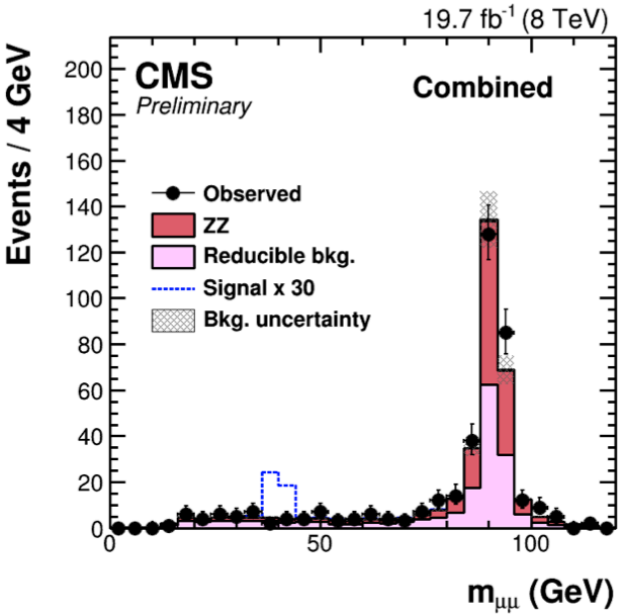


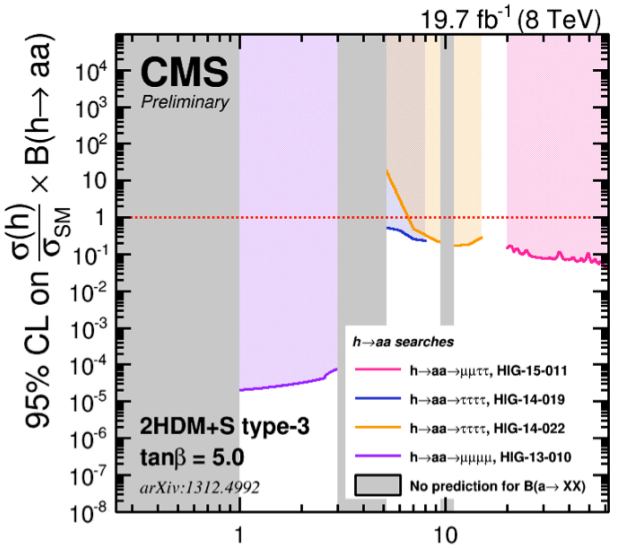


Exotic Higgs decays: h→aa→μμττ

CMS-HIG-15-011

- h_{125}: small width compared to its mass
- Exotic decays with large BR possible
- Study h→aa→μμττ final state
  - enhancement decays to down/up-type fermions for low/high tanβ
  - larger BR to taus than to muons
- excellent μμ mass resolution
- Unbinned shape of $m_{\mu\mu}$ distr.
- (non-) irreducible background: ZZ→4l, Z/W+jets, etc.





	Signal		Backgrounds			Obs.
	m_a = 20 GeV	m_a = 60 GeV	ZZ	Reducible	Total	
$\mu\mu\tau_e\tau_e$	0.20±0.02	0.58±0.06	4.64±0.39	2.49±1.03	7.13±1.10	8
$\mu\mu\tau_e\tau_\mu$	0.58±0.08	1.42±0.16	0.10±0.01	1.70±0.74	1.80±0.74	2
$\mu\mu\tau_e\tau_h$	0.74±0.08	2.02±0.20	0.16±0.02	5.65±1.77	5.81±1.77	5
$\mu\mu\tau_\mu\tau_h$	0.96±0.10	2.30±0.22	0.13±0.02	0.99±0.31	1.12±0.31	1
$\mu\mu\tau_h\tau_h$	0.60±0.06	1.90±0.18	0.06±0.01	4.64±0.98	4.70±0.98	3
Combined	3.08±0.31	8.22±0.82	5.09±0.39	15.47±2.41	20.56±2.44	19

Summary

- Excellent consistency of SM but SM is incomplete
- Extensions foresee existence of additional bosons
- Searches for BSM bosons natural companion to precision SM Higgs boson measurements
- Charged Higgs searches with top quark decays
- Other BSM searches show no indication of deviations
  - Only a few results presented. More available or in the making.

- Searches provide no hints for BSM yet

acknowledgments

- To the LHC team

OE, FCT-Portugal, CERN/FIS-NUC/0029/2015
FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR