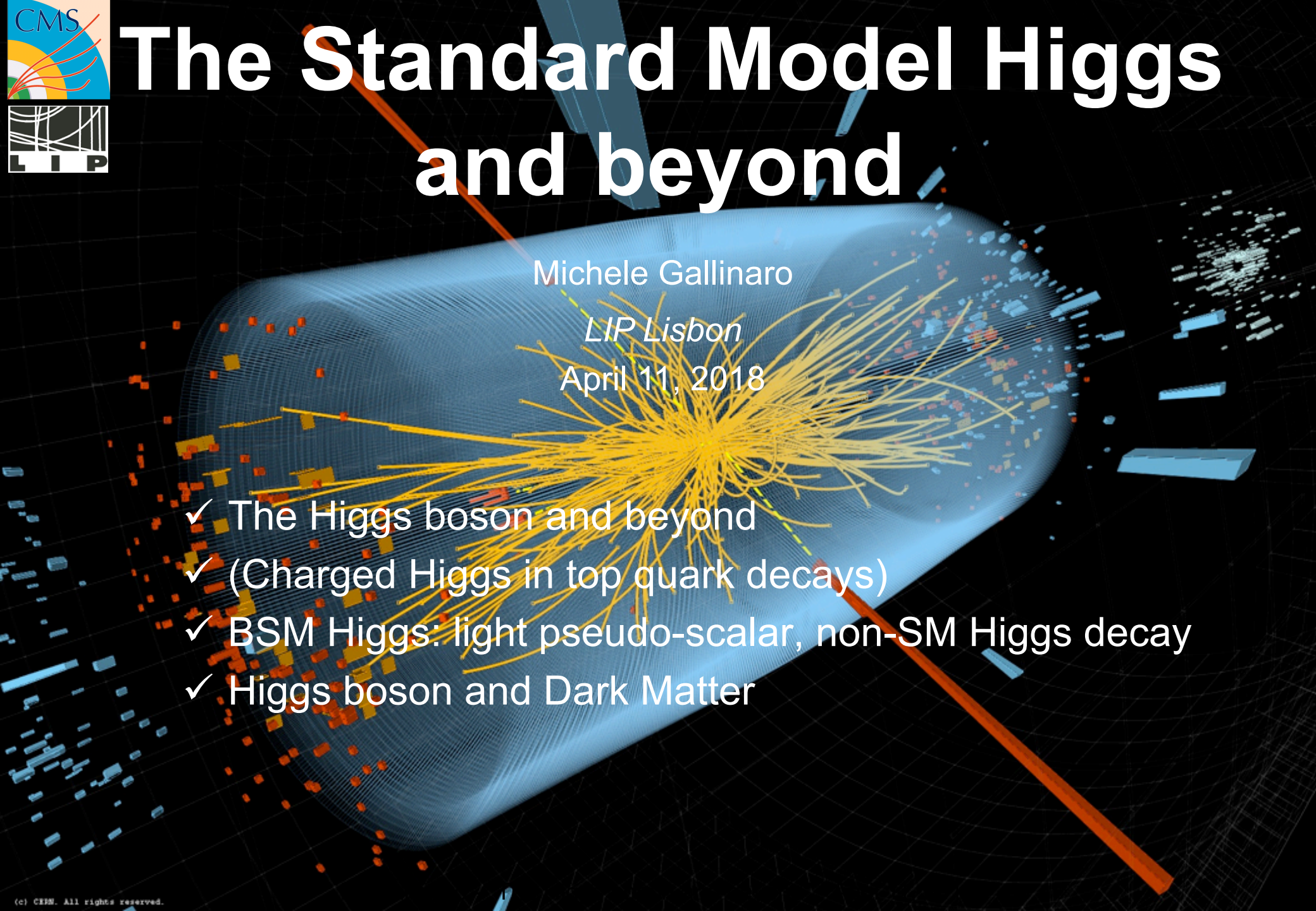


The Standard Model Higgs and beyond

Michele Gallinaro

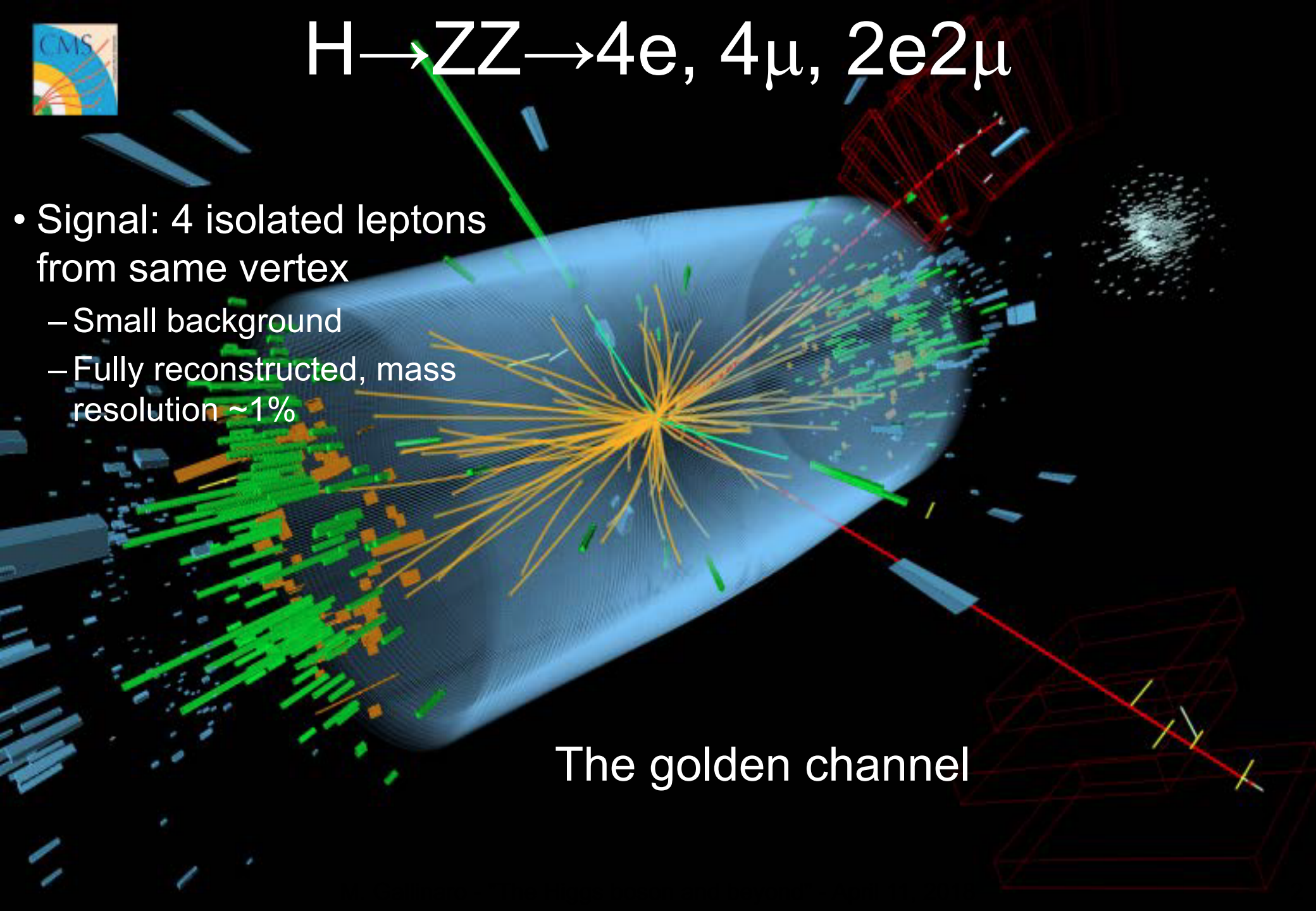
LIP Lisbon

April 11, 2018

- ✓ The Higgs boson and beyond
- ✓ (Charged Higgs in top quark decays)
- ✓ BSM Higgs: light pseudo-scalar, non-SM Higgs decay
- ✓ Higgs boson and Dark Matter

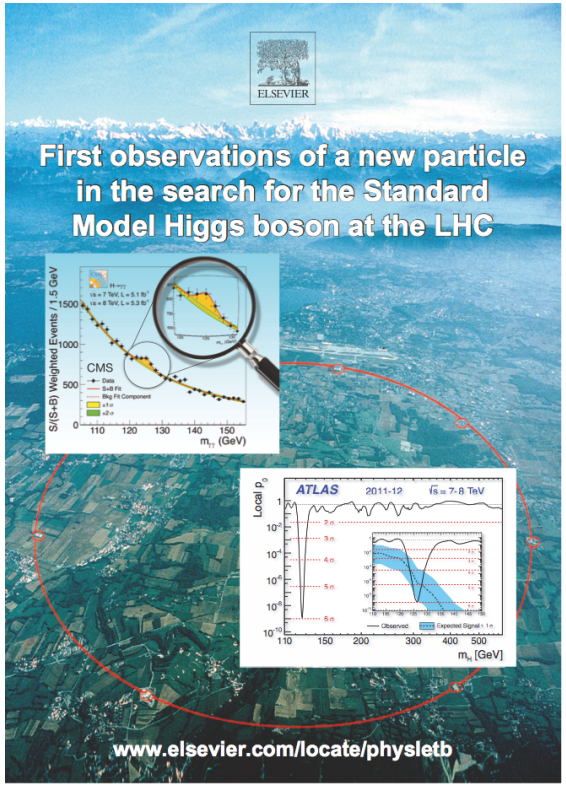
H→ZZ→4e, 4μ, 2e2μ

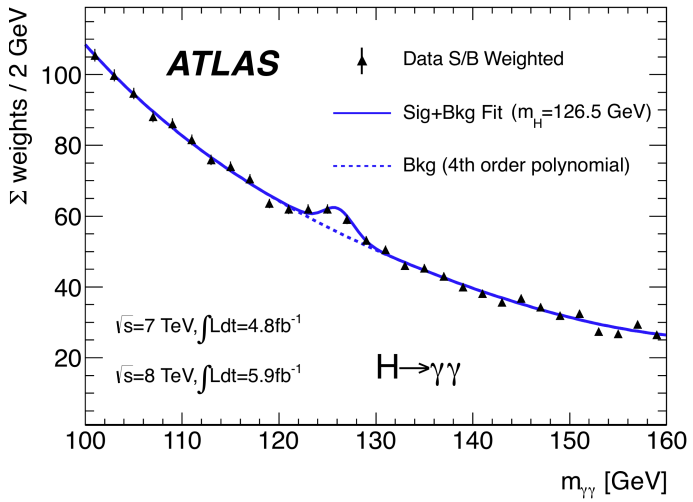
- Signal: 4 isolated leptons from same vertex
  - Small background
  - Fully reconstructed, mass resolution ~1%

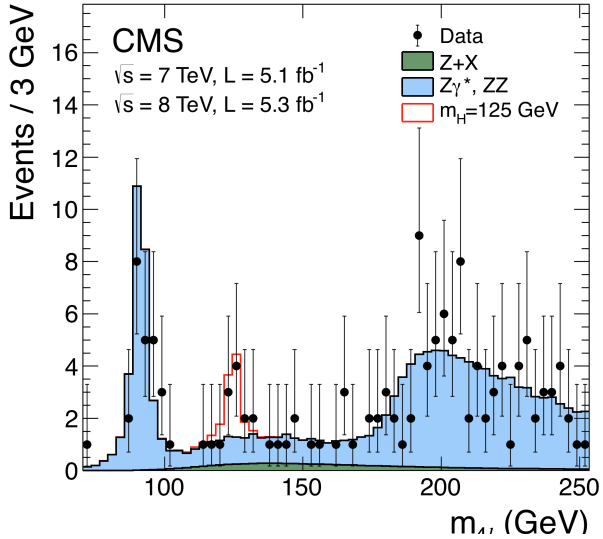


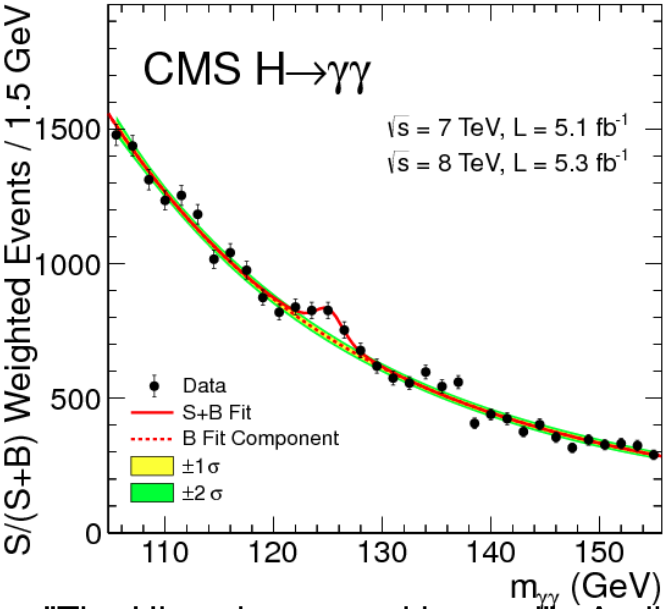
The golden channel

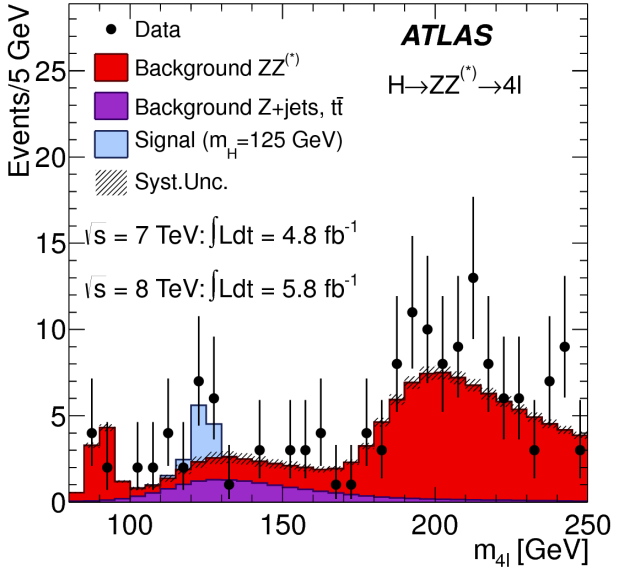
July 4th, 2012: A Higgs boson







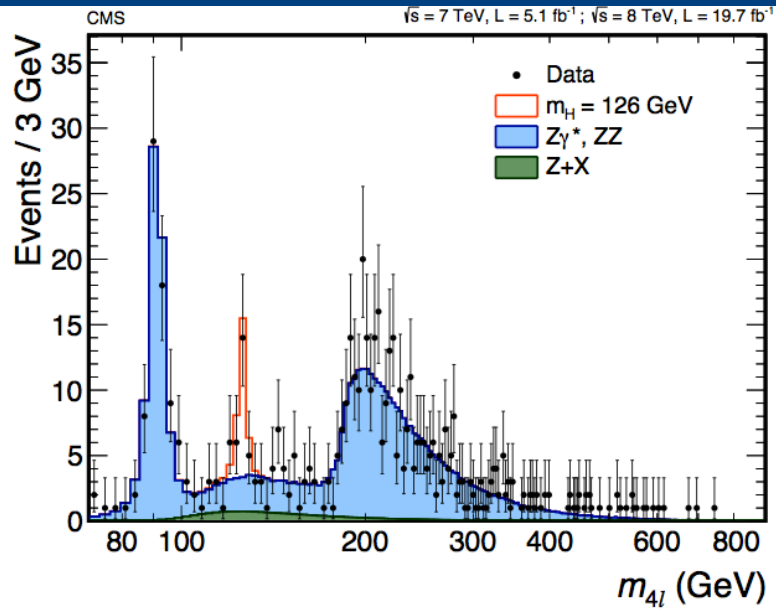


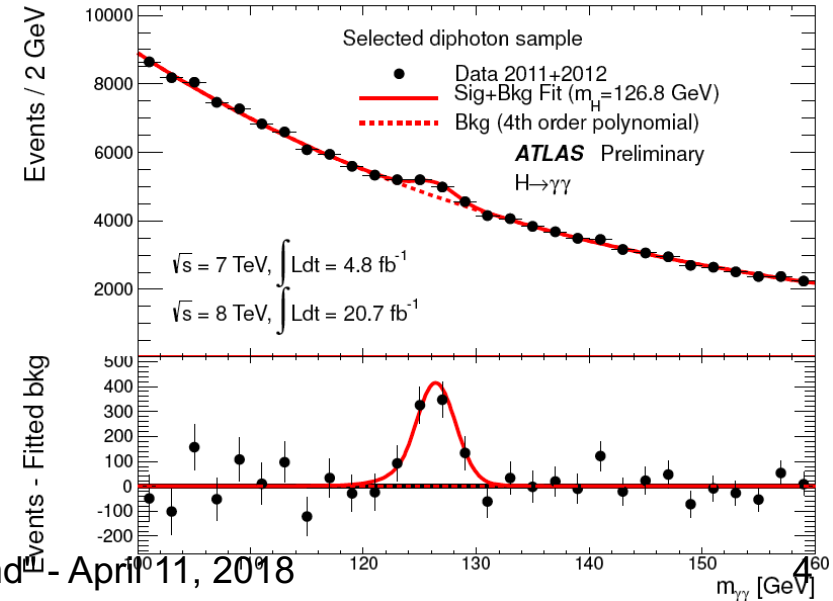


Higgs boson

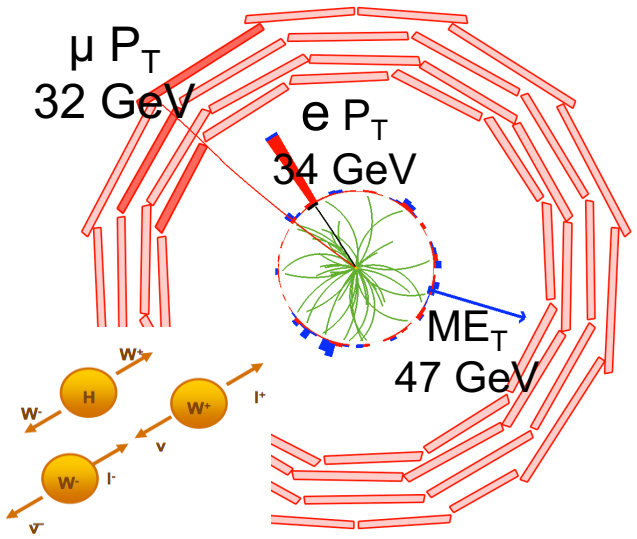
PRD 89 (2014) 092007, PLB726(2013)088

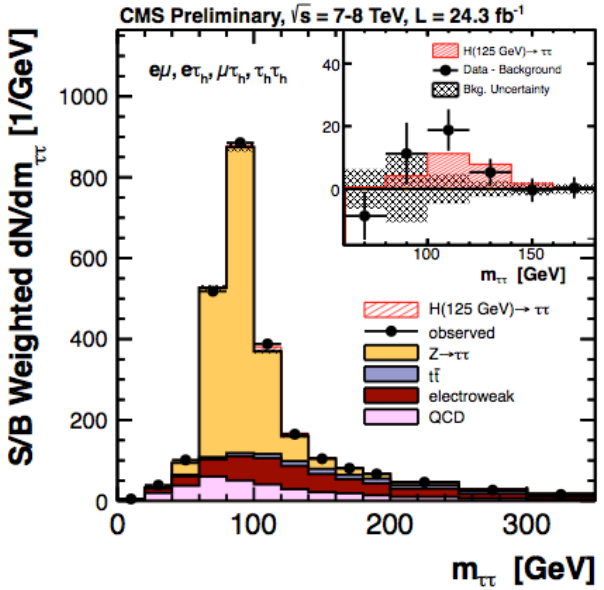
- Progress since Higgs discovery (July 2012)
  - Observation in boson channels
  - Evidence for fermion couplings
  - Precision mass measurement (~125 GeV)
  - Spin determined
- It looks more like SM Higgs boson

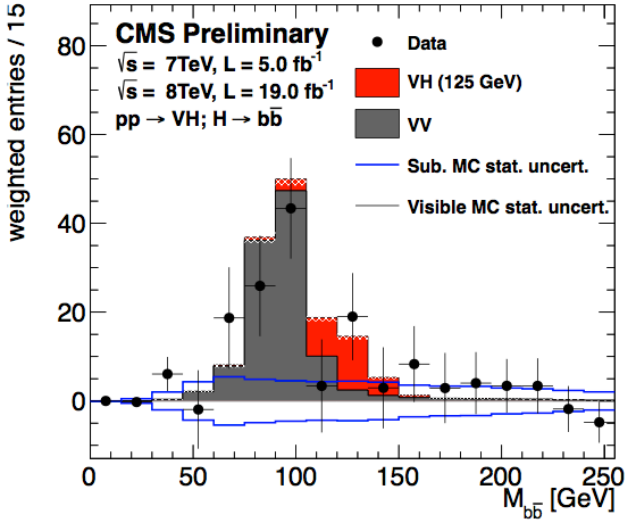


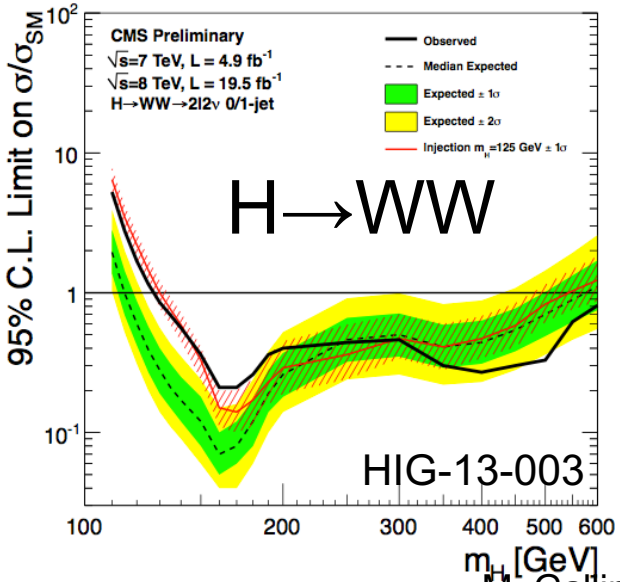


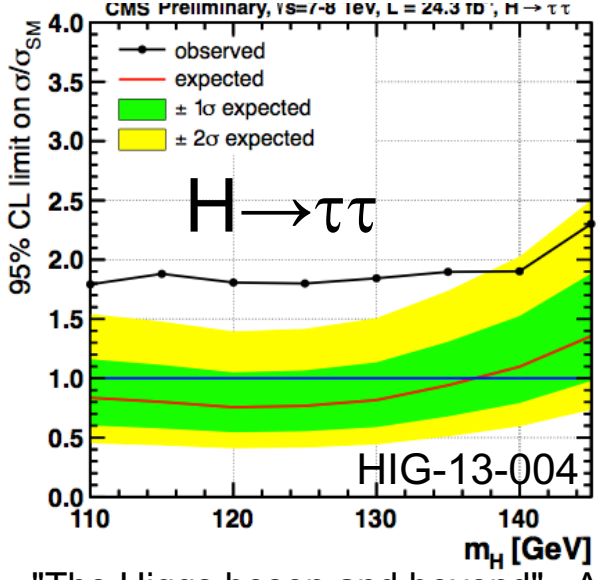
Low mass-resolution channels

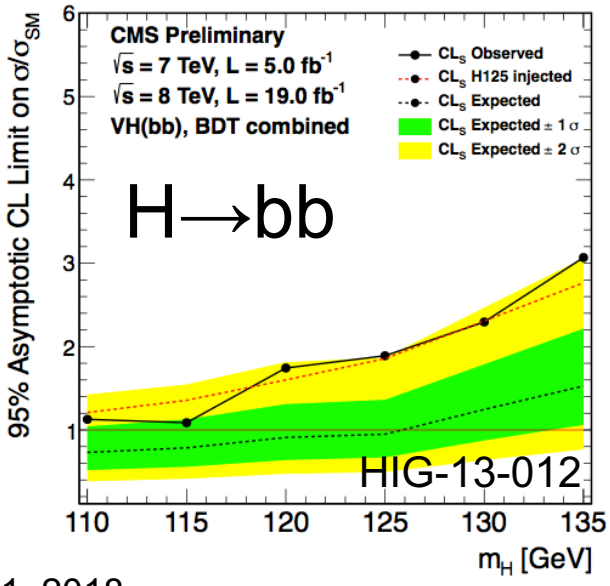








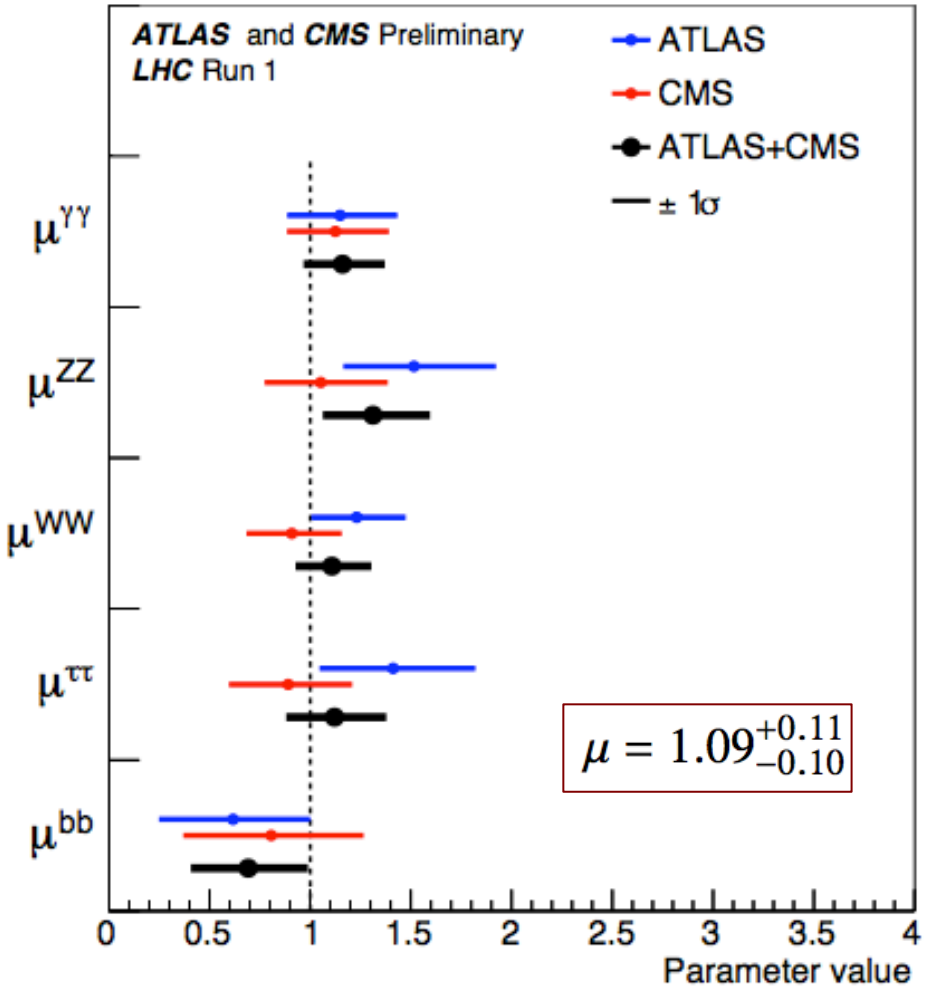




Couplings: individual channels

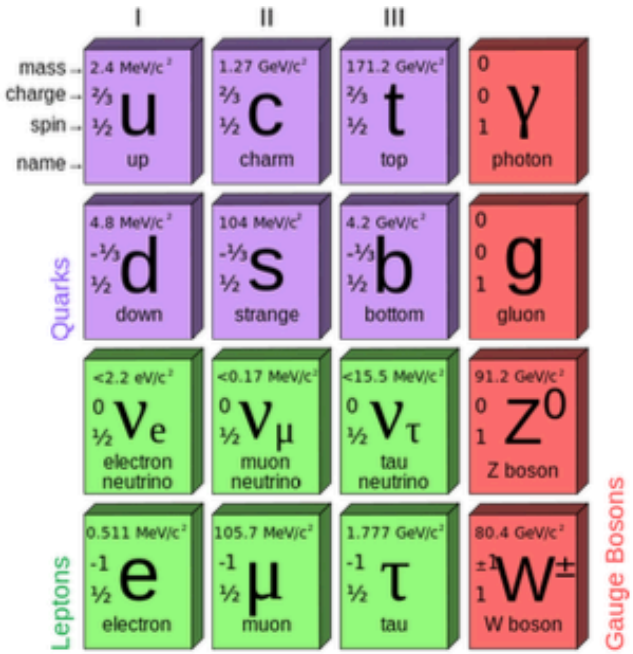
EPJC 75(2015)212, arXiv:1507.04548

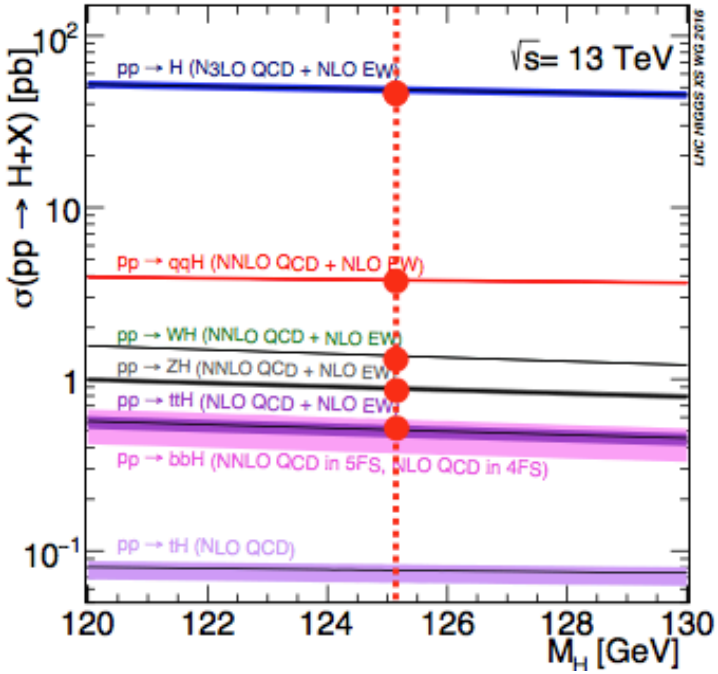
Results based on the full Run 1 data samples

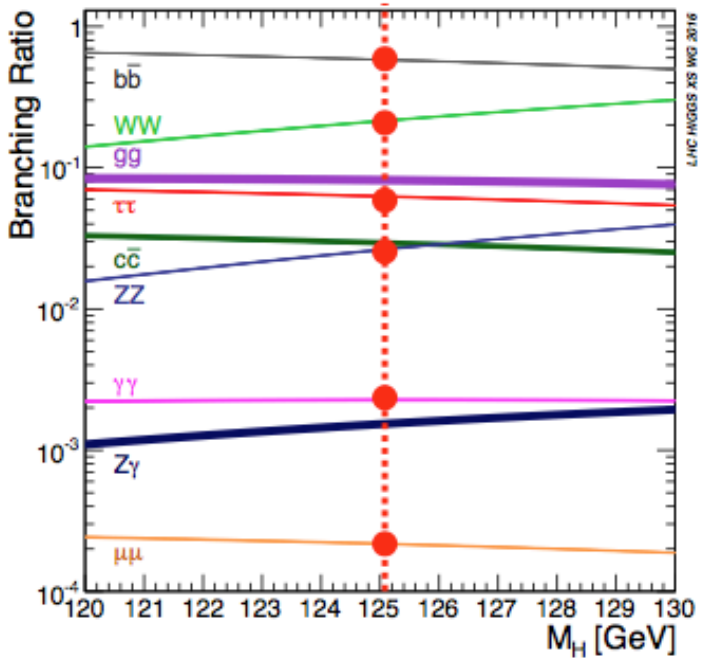


Combined Higgs measurements

- A wide range of production and decay modes accessible
- Important to establish unambiguous observation (>5σ significance) of these processes on the way to precision tests of the couplings
- Uncertainties on theoretical predictions also important (in some cases, already comparable to experimental uncertainties)





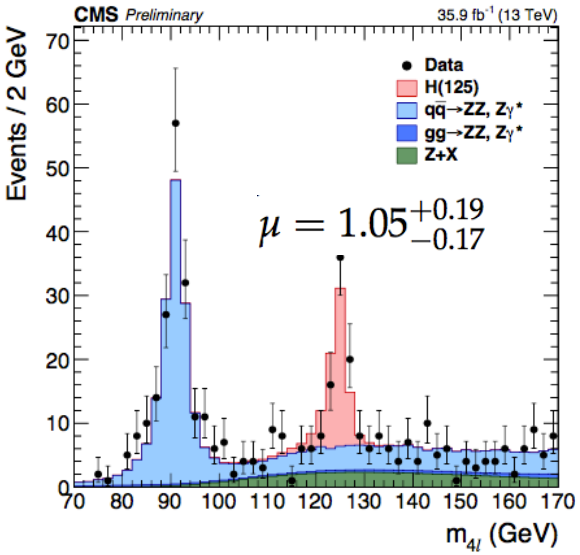


Vector bosons decay channels

CMS-HIG-16-041, arXiv:1804.02716

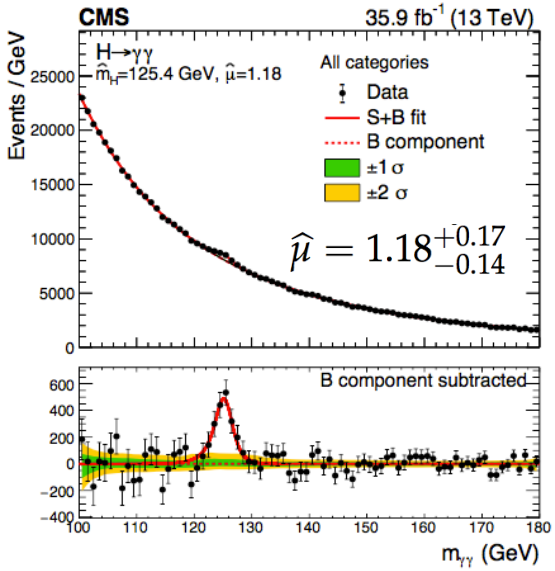
H→ZZ→4 leptons

- Main systematics:
  - Lepton ID efficiency
  - Theoretical uncertainties on ggH predictions



H →γγ

- Main systematics:
  - Photon identification and energy scale
  - Theoretical uncertainties on ggH prediction



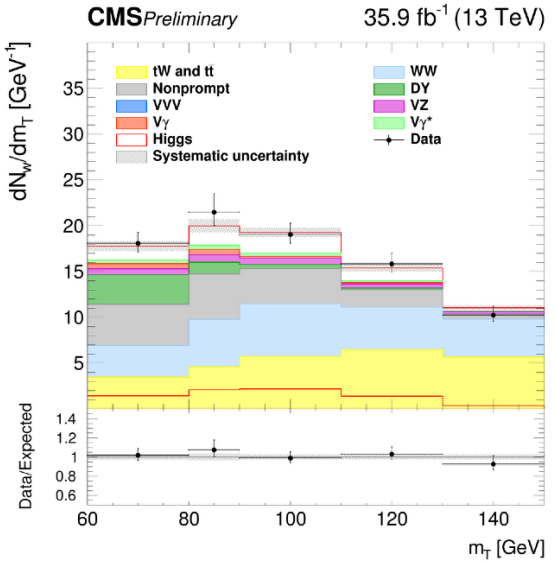
Differential measurements also performed in both channels

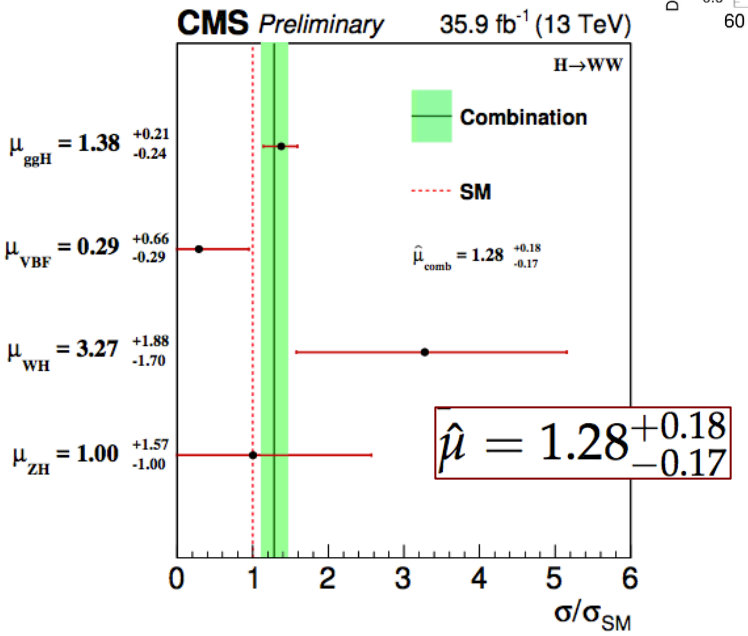
Vector bosons decay channels (cont.)

CMS-HIG-16-042

H→WW

- Dedicated event categories targeting ggH (0/1 jet), VBF and VH production, control regions to determine WW, top, DY bkgs
  - Categories for same-flavour (ee/μμ) lepton final state, and different-flavour (eμ)
- Main systematics:
  - Background determination
  - Luminosity
  - Theoretical uncertainties on signal normalization and acceptance



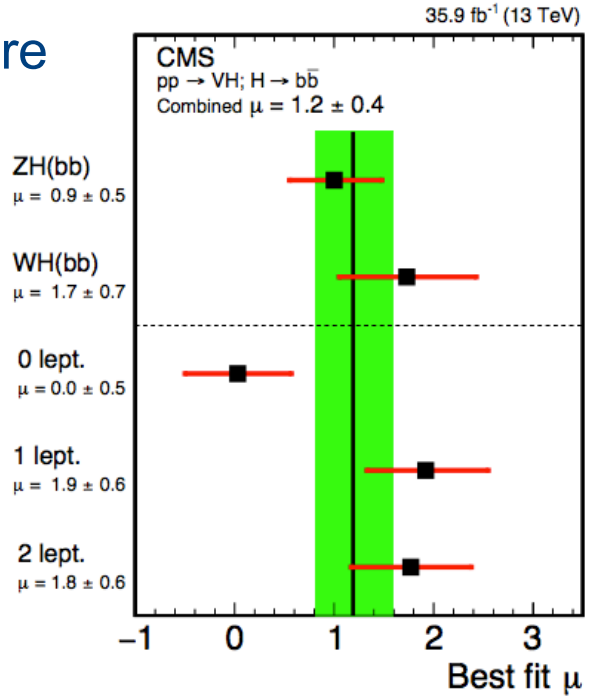


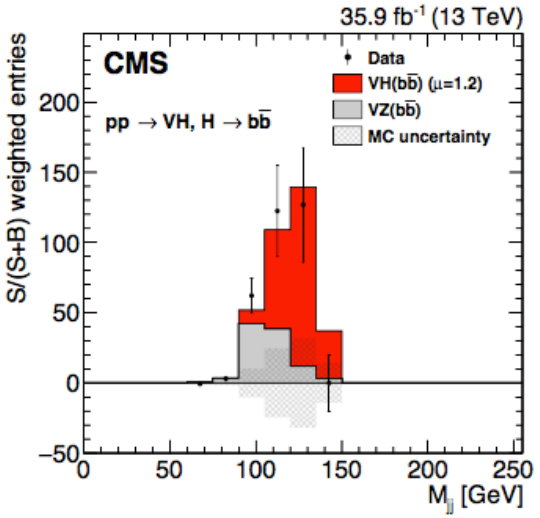
Fermion decay channels

arXiv:1709.07497

ggH→bb

- Dominant QCD background
- Reconstruct H(bb) decay within a single boosted jet, using substructure techniques





VH→bb

- BDT-based discriminant in 0/1/2 lepton categories
- Main backgrounds from V+HF/LF jets, and ttbar

- Main systematics:
  - Background normalization/modeling
  - MC statistics
  - B-tagging efficiency

Data used	Significance expected	Significance observed	Signal strength observed
Run 1	2.5	2.1	$0.89^{+0.44}_{-0.42}$
Run 2	2.8	3.3	$1.19^{+0.40}_{-0.38}$
Combined	3.8	3.8	$1.06^{+0.31}_{-0.29}$

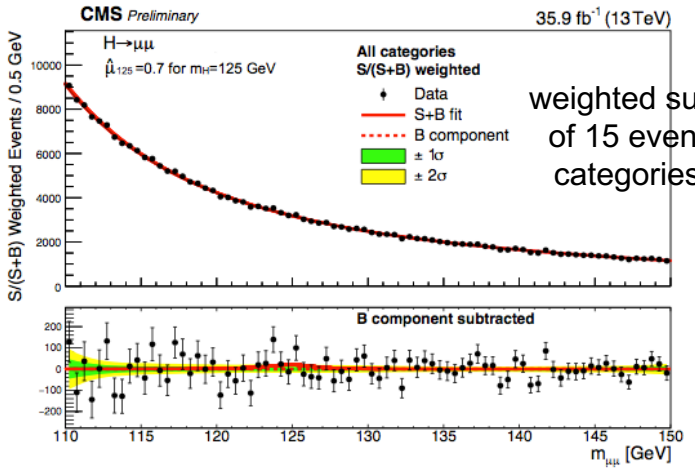
Fermion decay channels (cont.)

PLB780(2018)283, HIG-17-019

$H \to \mu\mu$

- Not yet sensitive to SM signal

$$\hat{\mu}_{125}^{\text{comb}} = 0.9^{+1.0}_{-0.9}$$

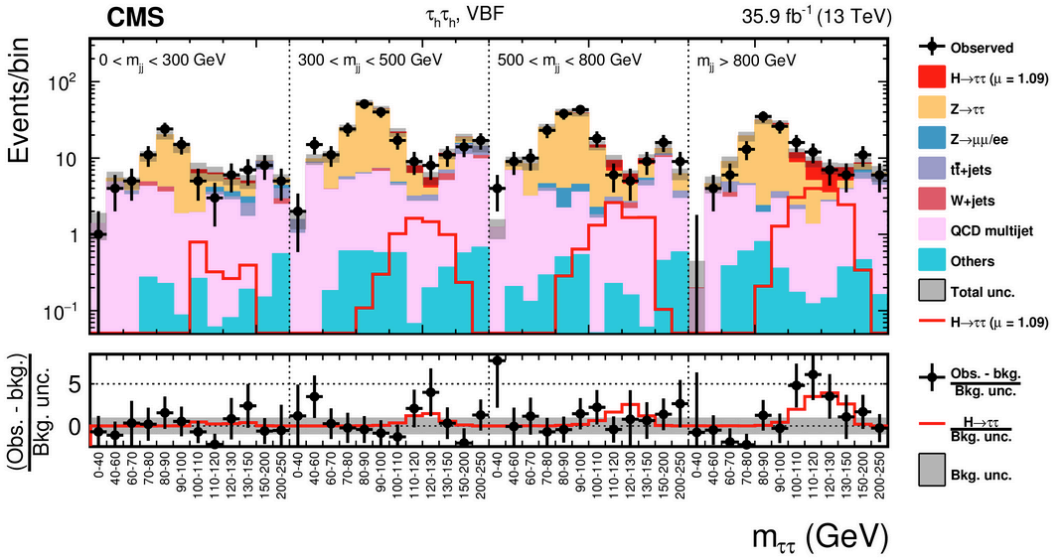


weighted sum of 15 event categories

$H \to \tau\tau$

- Main experimental uncertainties from tau(h) and MET scales, background normalization and MC statistics
- Main theory uncertainties on signal cross section and ggH production

$$\mu = 1.09^{+0.27}_{-0.26}$$

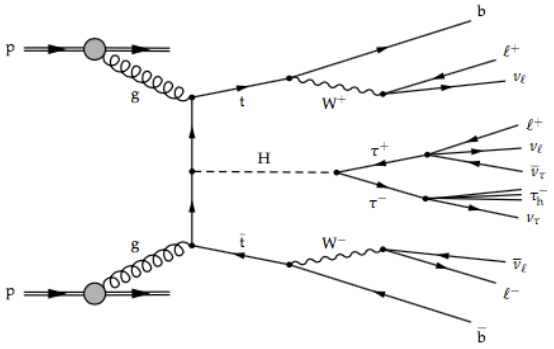


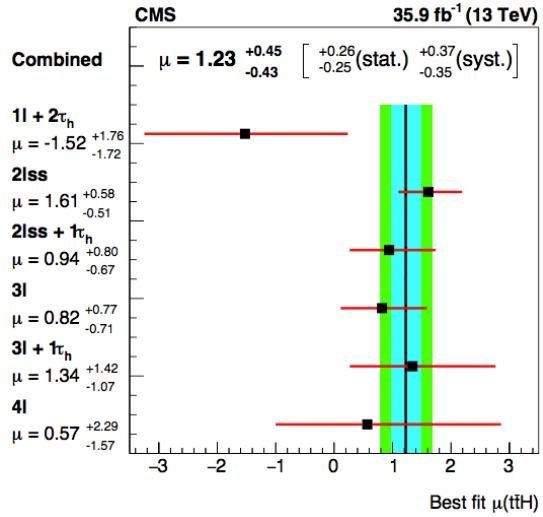
ttH production

arXiv:1803.05485, CMS-HIG-17-026

ttH→multileptons

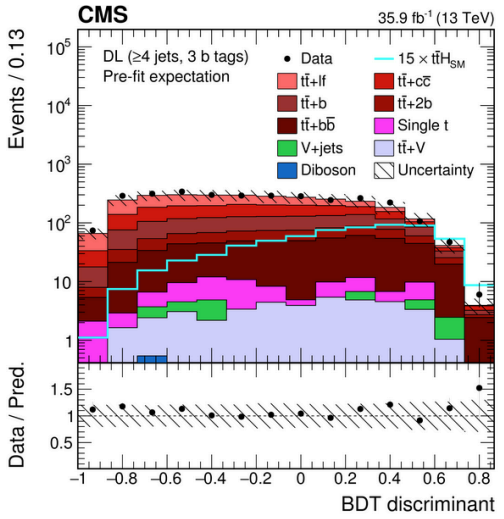
- Search categories based on # of leptons (e/μ) and hadronic taus
- Discrimination from main backgrounds (ttV, lepton fakes) with BDT and MEM techniques
- Main systematics:
  - lepton efficiencies, lepton misID, normalization of irreducible backgrounds

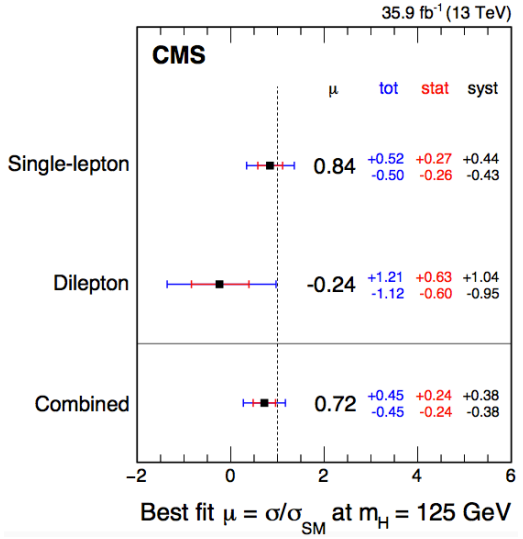




ttH→bb

- H(bb): Leptonic and hadronic
- Large QCD multijet background
- Use MVA methods to separate S/B
- Main systematics:
  - b-tagging efficiency, MC stat, tt+HF



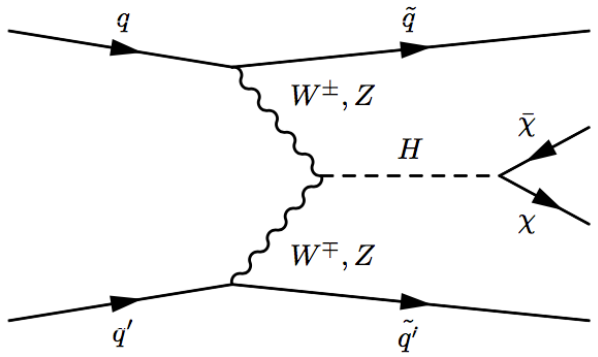


ttH production (cont.)

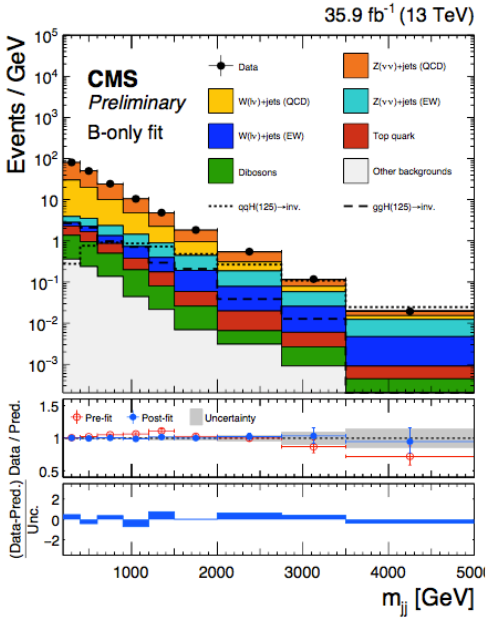
CMS-HIG-17-023

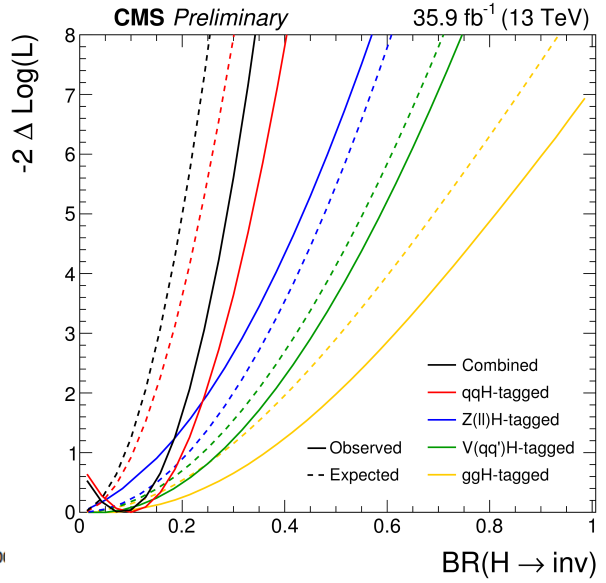
ttH→invisible

- Search for invisible decays in VBF
- Select large MET and 2-jet events with large $\Delta\eta(jj)$



- Fit to dijet invariant mass distributions
- Combination of ggH, V(jj)H, and Z(ll)H production modes
- Upper limits: 24%@95%CL (18% exp.)

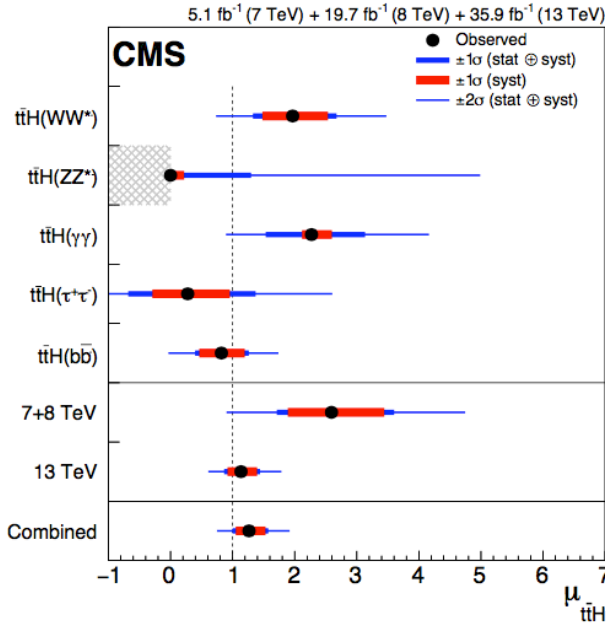


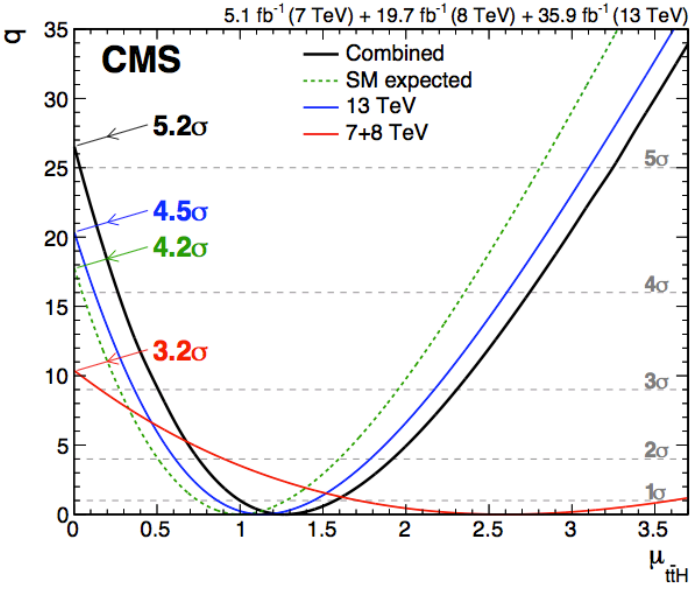


ttH production (cont.)

arXiv:1804.02610

- Combination of ttH results: 7+8+13 TeV results
- Uncertainties
- Experimental: lepton misID, b-tagging, MC stats
- Background theory: mainly from tt+HF predictions in ttH(bb)
- Signal theory: mainly from inclusive ttH predictions



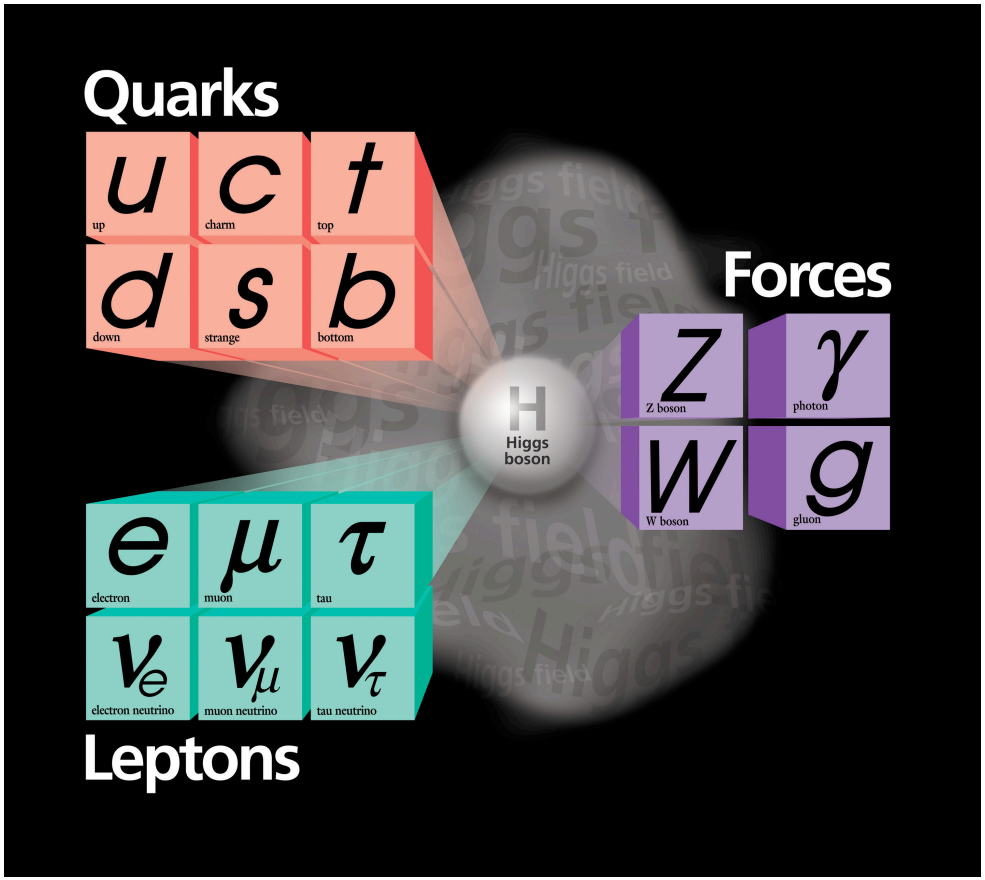


$$\mu_{\mathrm{t\bar{t}H}} = 1.26^{+0.31}_{-0.26}$$

$$\mu_{\mathrm{t\bar{t}H}} = 1.26^{+0.31}_{-0.26} = 1.26^{+0.16}_{-0.16}(\mathrm{stat})^{+0.17}_{-0.15}(\mathrm{expt})^{+0.14}_{-0.13}(\mathrm{bkg\ th})^{+0.15}_{-0.07}(\mathrm{sig\ th})$$

Standard Model theory of everything?

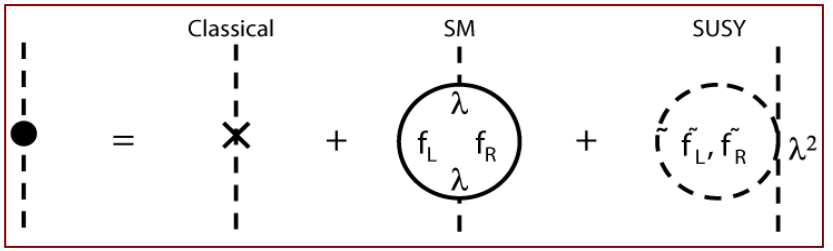
- Discovery of the Higgs boson marks the triumph of the SM
- However, even with the inclusion of the Higgs boson, SM is an incomplete theory



Higgs and the SM

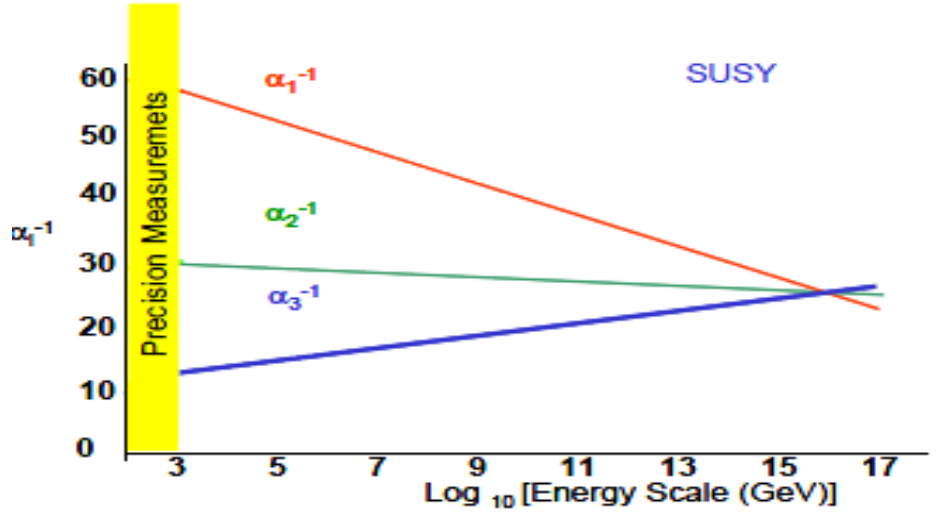
- SM is a successful theory
- Nothing prevents the SM to survive up to the Planck scale. However, it is unnatural.
- Virtual particles in quantum loops contribute to the Higgs mechanism
  - Contributions grow with Λ (upper scale validity of the SM)
  - Higgs mass depends quadratically on Λ: $m^2 = m_0^2 + g^2\Lambda^2$
- Miraculous cancellations are needed to keep m_H<1TeV
- Is there a symmetry that protects the Higgs mass from receiving large corrections?

cancelation?



Higgs and the SM (cont.)

- SUSY postulates a new symmetry between fermions and bosons
  - Loops of particles and their SUSY partners have the ability to cancel the quadratic divergences in the Higgs field self-couplings, solving the naturalness problem
  - SUSY foresees unification of couplings at large energy scales ~10^{15} GeV
  - Provides DM candidates (LSP)
- It suggests many options, but the LHC may not be able to find it
- # of experimental scenarios is large



Beyond the Standard Model

The SM answers many of the questions about the structure of matter. But SM is not complete; still many unanswered questions:

a) Why do we observe matter and almost no antimatter if we believe there is a symmetry between the two in the universe?

b) What is this "dark matter" that we can't see that has visible gravitational effects in the cosmos?

c) Are quarks and leptons actually fundamental, or made up of even more fundamental particles?

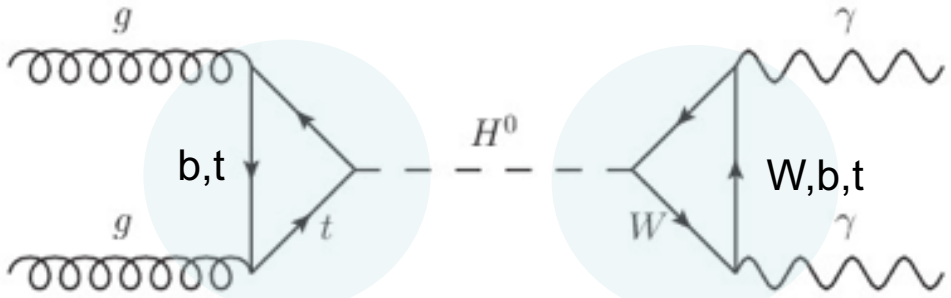
d) Why are there three generations of quarks and leptons? What is the explanation for the observed pattern for particle masses?

e) How does gravity fit into all of this?

Higgs and BSM

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

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

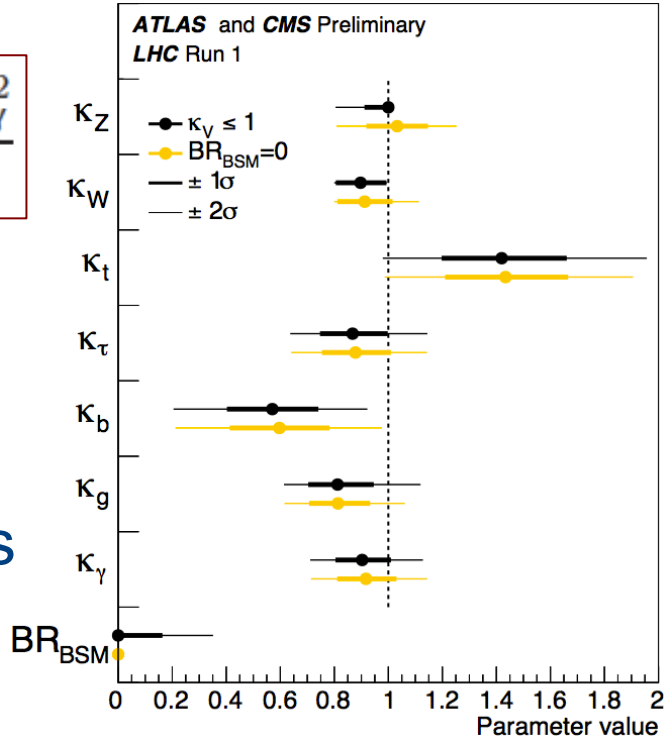


$$(\sigma \cdot \mathrm{BR})\,(gg \to H \to \gamma\gamma) \;=\; \sigma_{SM}(gg \to H) \cdot \mathrm{BR}_{SM}(H \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

Experimental approach

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

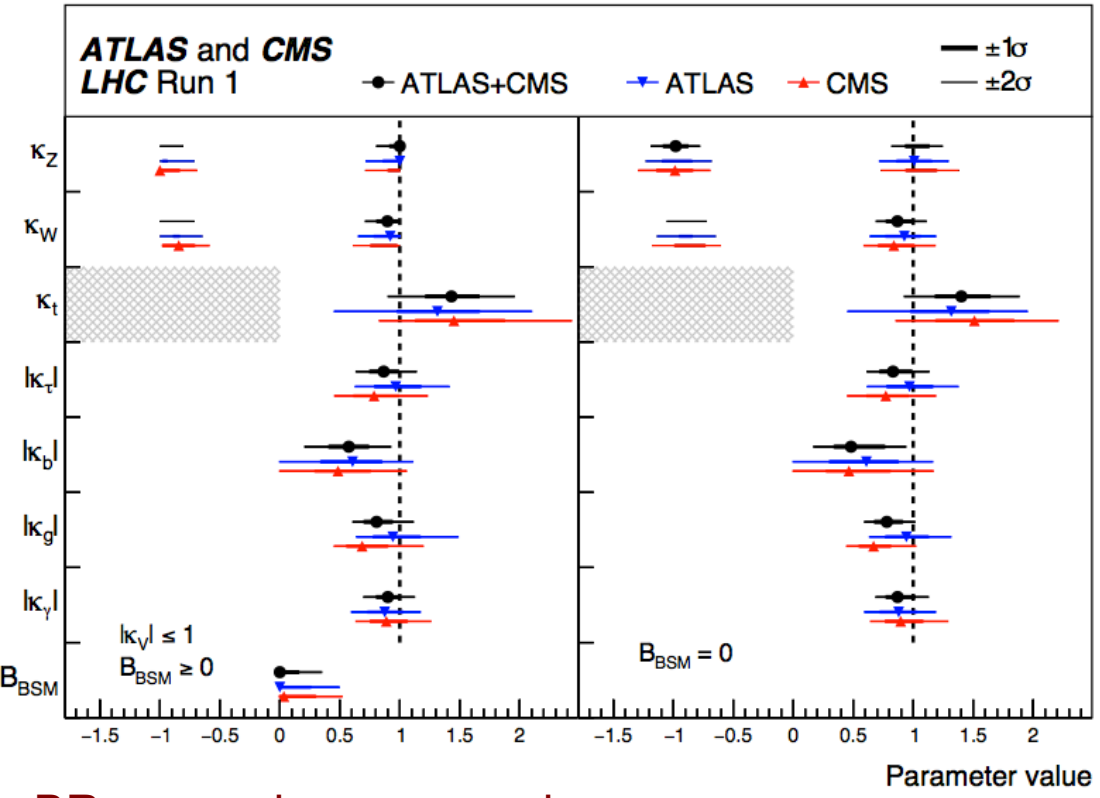
Strategy: parametrize deviations wrt SM in production and decay
⇒ loops are sensitive to BSM physics



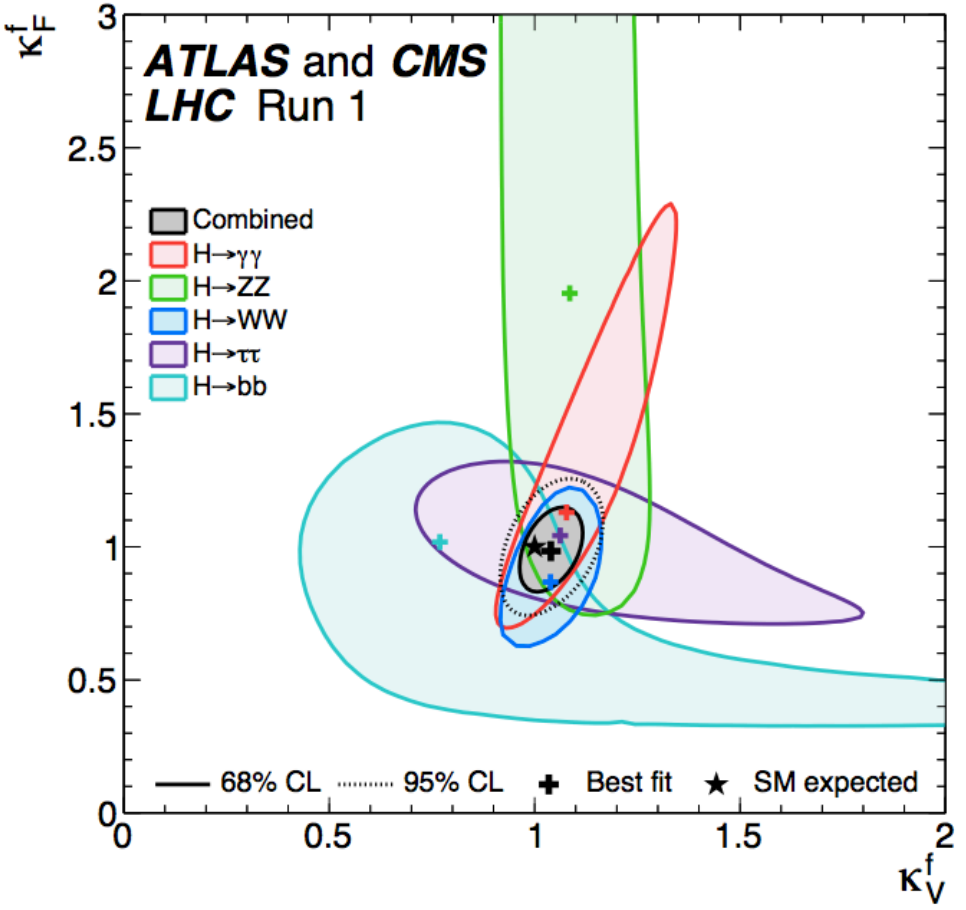
Couplings: decays

ATLAS-CONF-2015-044, CMS-HIG-15-002, JHEP08(2016)045

BSM physics in the loop



Vector and fermion couplings



BR_{BSM} can be measured

BR_{BSM} < 0.34 at 95% C.L. (assuming $\kappa_V \leq 1$)

BR_{BSM} includes non standard decays, visible or invisible

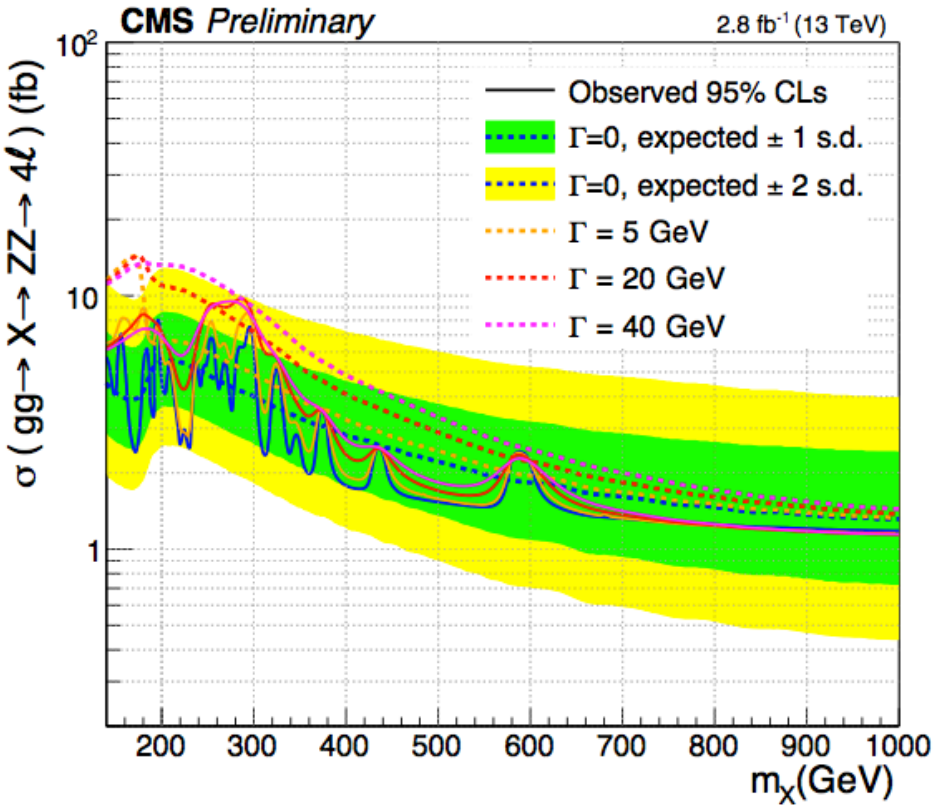
⇒Results in agreement with SM (k_V=k_F=1) within 1σ

High mass: H→WW/ZZ

JHEP 10(2015)144, HIG-15-004

- 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

No significant excess
⇒set limits: $\sigma \cdot B(X \to ZZ \to 4\ell)$
~ a few fb@m_X=400GeV
~1fb@m_X=1TeV



high-mass searches improve at 13TeV

Extending searches

- Minimal Supersymmetric SM (MSSM)
  - Neutral Higgs: $\phi \to \tau\tau/bb/\mu\mu$
  - Charged Higgs
- 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: $t \to cH$

Higgs sector in the MSSM

Higgs sector in SUSY contains two scalar doublets:

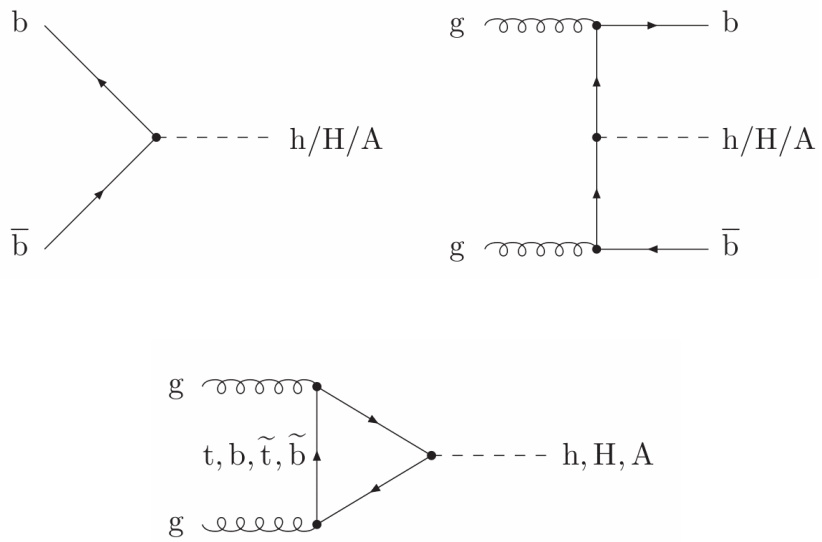
- 5 physical Higgs bosons
  - 3 neutral: CP-even ϕ=h,H CP-odd A
  - 2 charged $H^{\pm}$
- SM-like Higgs boson: h

Neutral Higgs ϕ decay modes:

- BR($\phi \to$ bbar)~90%
- BR($\phi \to \tau\tau$)~10%
- BR($\phi \to \mu\mu$)~0.1%

Two main production modes:

- $gg \to H$
- $b\bar{b}H$

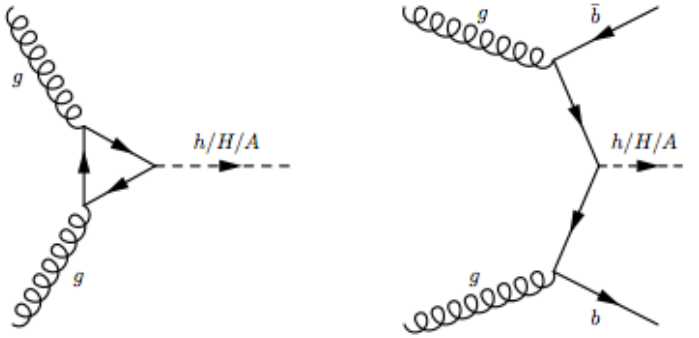


Neutral MSSM Higgs

JHEP 10(2014)212, arXiv:1803.06553

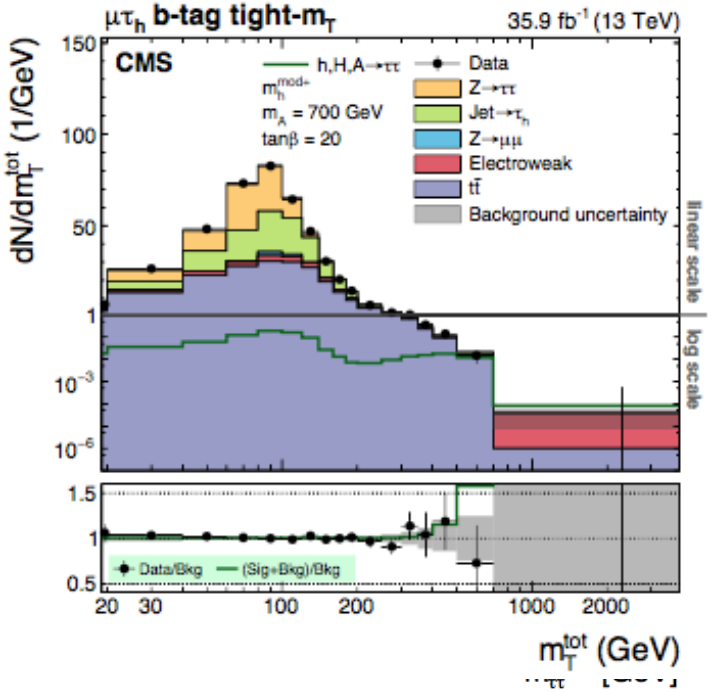
- Enhanced couplings of MSSM Higgs to down-type fermions (large tanβ)

⇒increased BR to τ leptons and b-quarks



$$m_{\mathrm{T}}^{\mathrm{tot}} = \sqrt{m_{\mathrm{T}}^2(p_{\mathrm{T}}^{\tau_1}, p_{\mathrm{T}}^{\tau_2}) + m_{\mathrm{T}}^2(p_{\mathrm{T}}^{\tau_1}, p_{\mathrm{T}}^{\mathrm{miss}}) + m_{\mathrm{T}}^2(p_{\mathrm{T}}^{\tau_2}, p_{\mathrm{T}}^{\mathrm{miss}})},$$

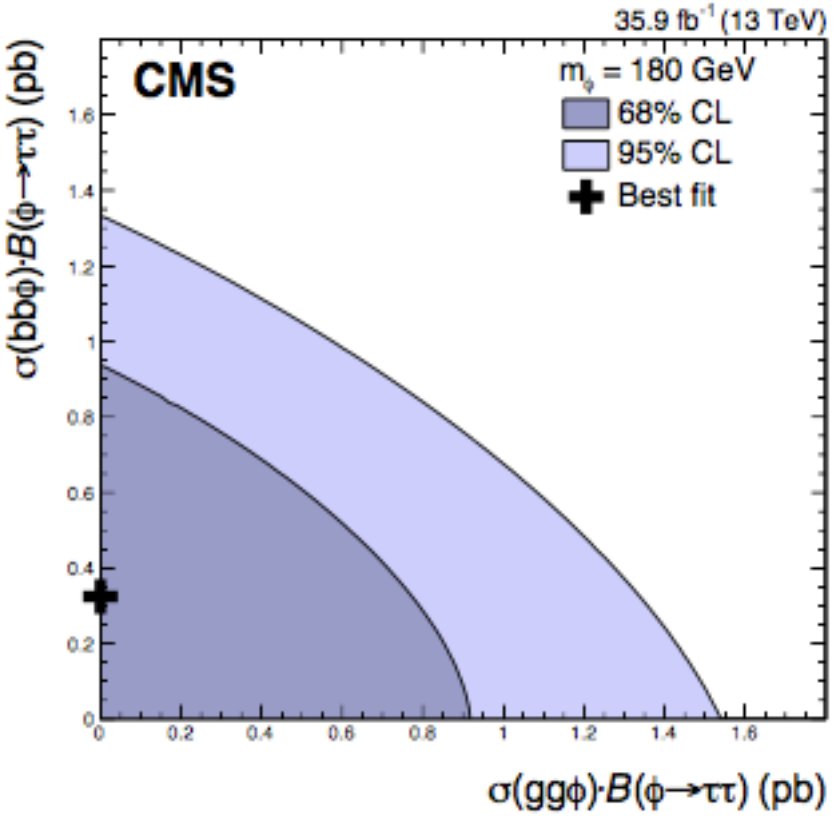
- Search for neutral MSSM Higgs boson
- 5 final states used: $\mu\tau_h$, $e\tau_h$, $\tau_h\tau_h$, $e\mu$, $\mu\mu$
  - Reconstruct tau-pair invariant mass
  - Split in b-tag/no b-tag categories to enhance sensitivity
- Main backgrounds: $Z\rightarrow\tau\tau$, QCD/W+jets, DY,ttbar, dibosons



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

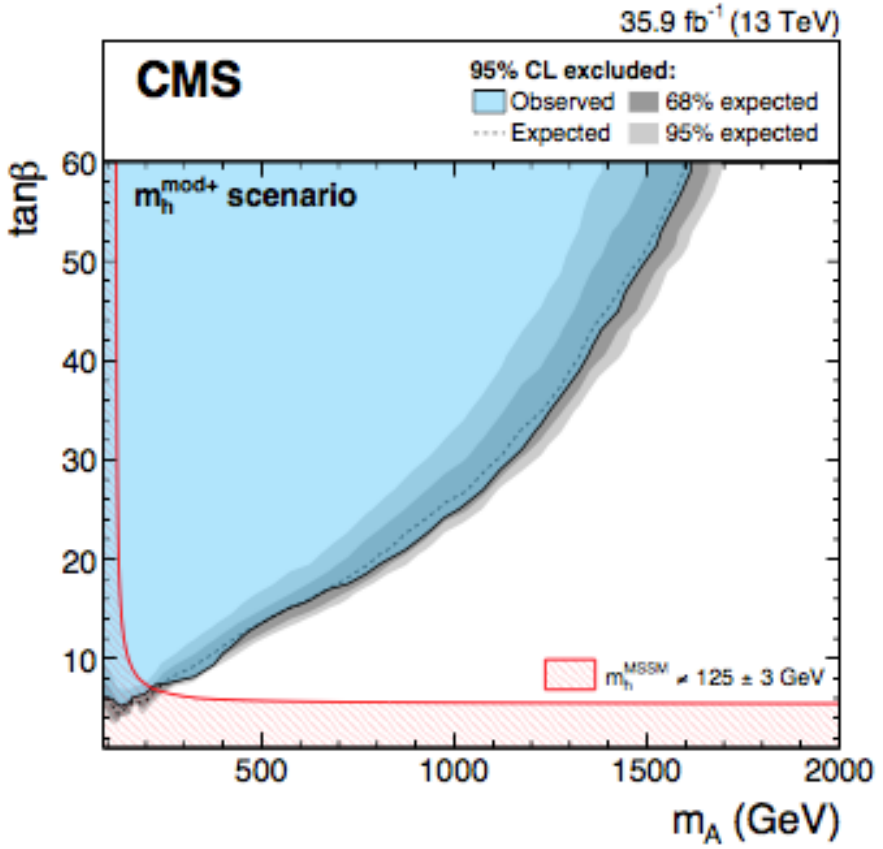
JHEP 10(2014)212, arXiv:1803.06553

- Direct search: inclusive and b-tagged
- τ in both leptonic and hadronic decays



Model-independent limits by separating production modes

$\tan\beta$ vs m_A window becoming smaller

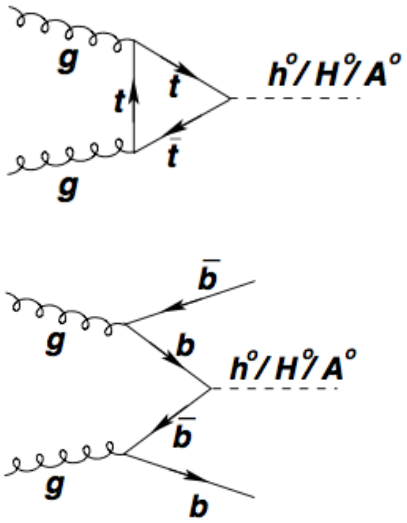


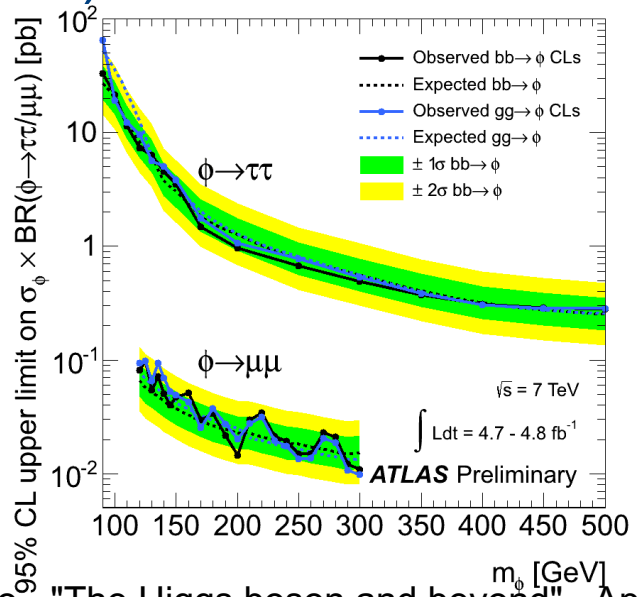
No significant excess over bkg expectations

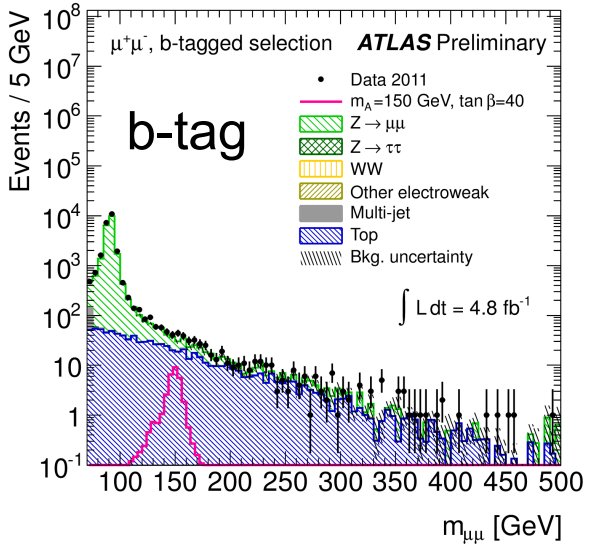
Neutral MSSM Higgs: $\phi \rightarrow \mu\mu$

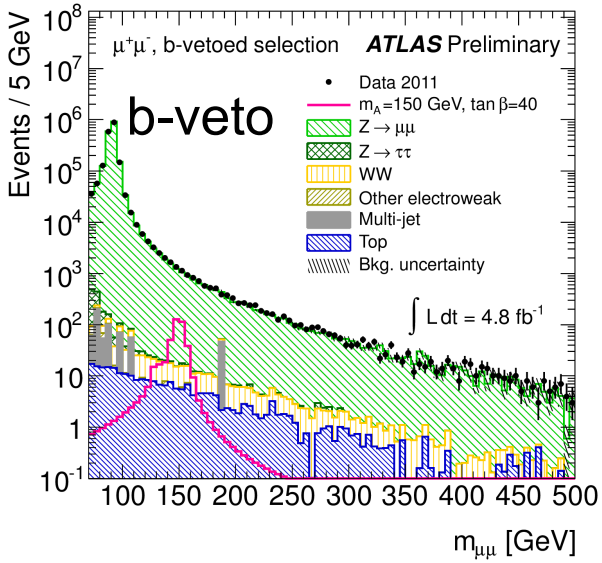
arXiv:1508.01437

- Search for a $\mu\mu$ mass resonance
- 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: Z(bbar), ttbar, WW





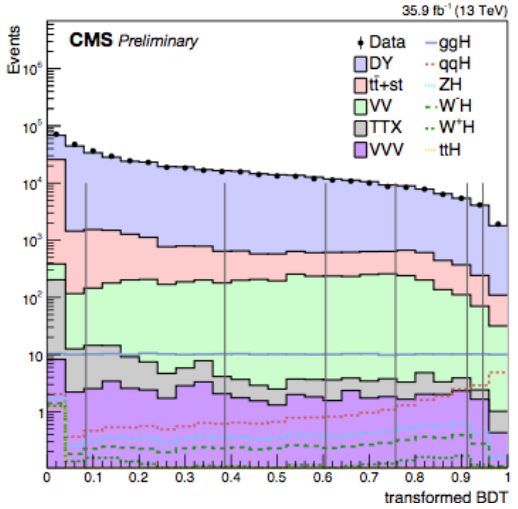


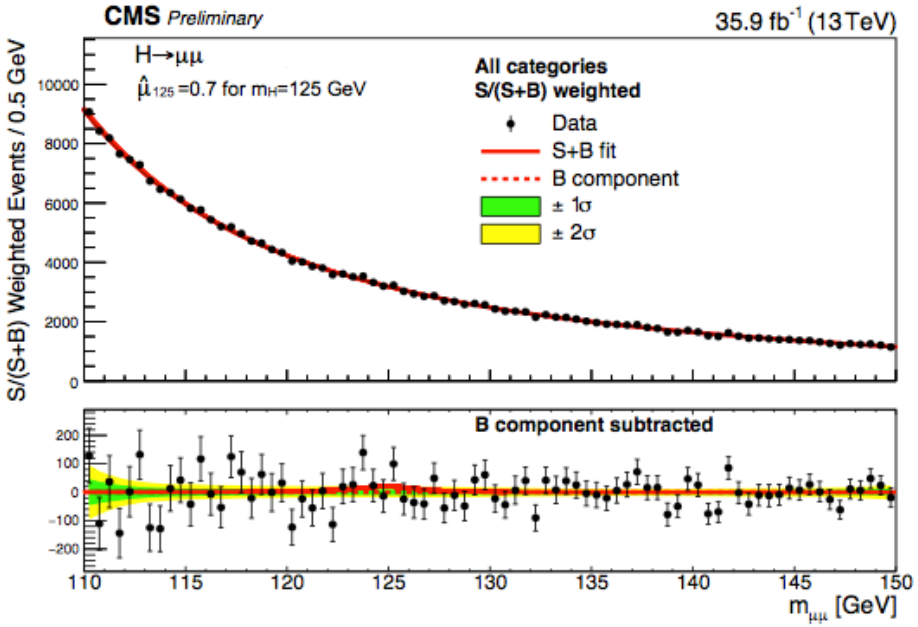


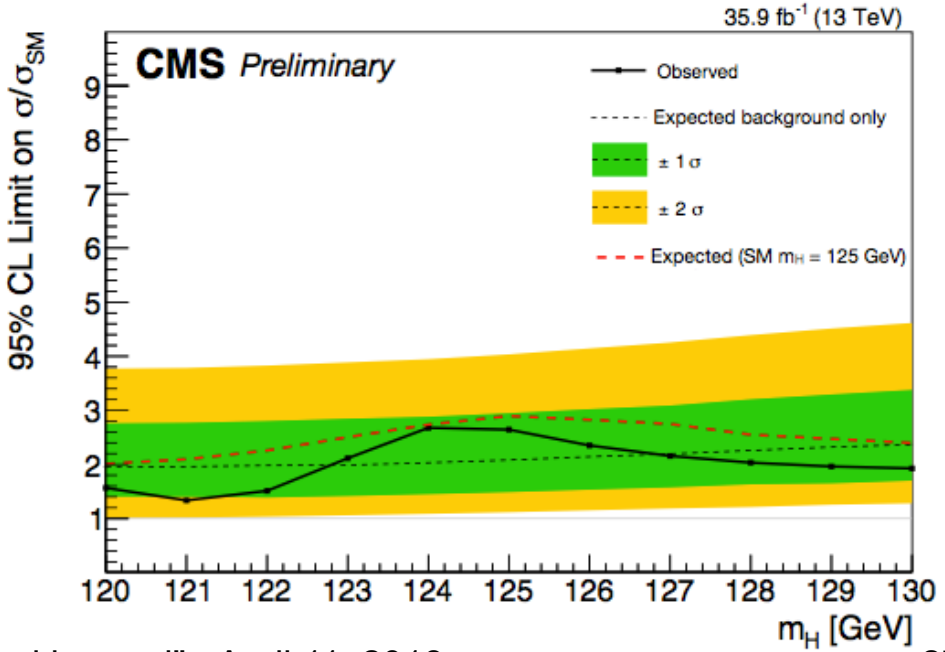
Search for SM H→μμ

HIG-17-019

- Search based on BDT discriminant
  - Event categories based on BDT score
- Weighted sum of individual fits to each category
- Signal starting to appear in the data
- Signal strength: μ<2.64 (2.08) obs. (exp.)

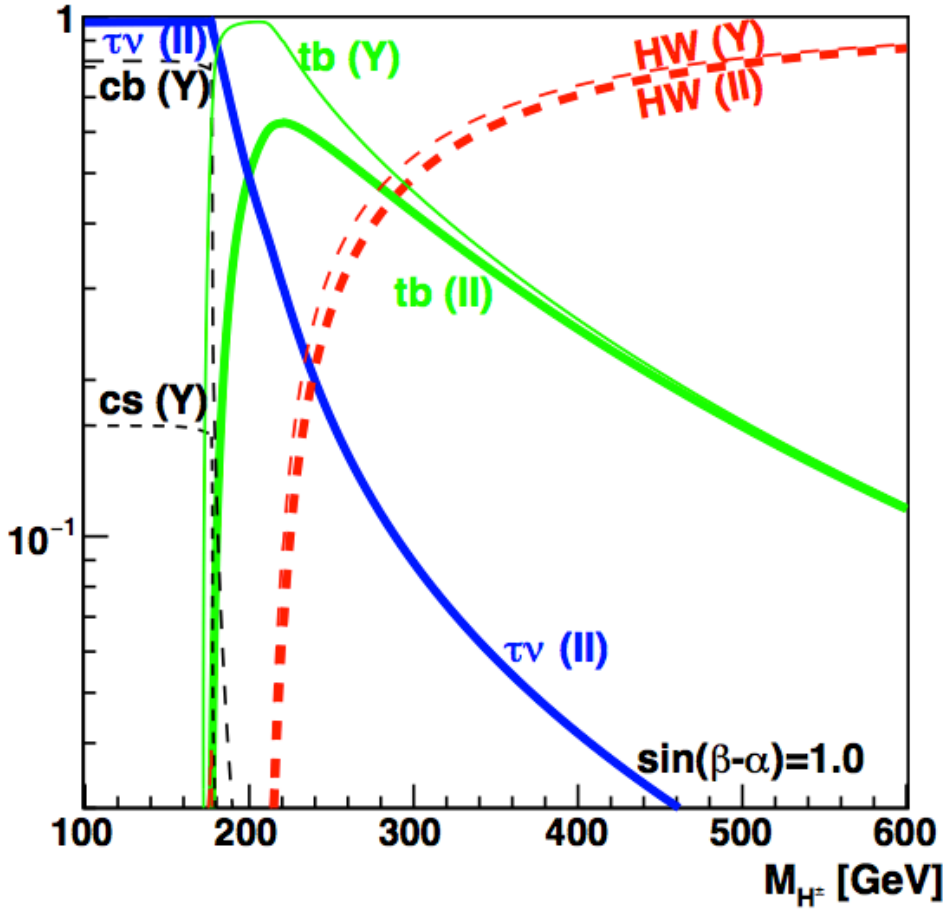






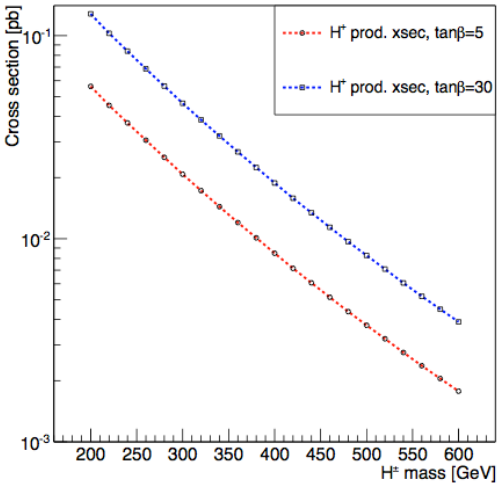
Charged Higgs

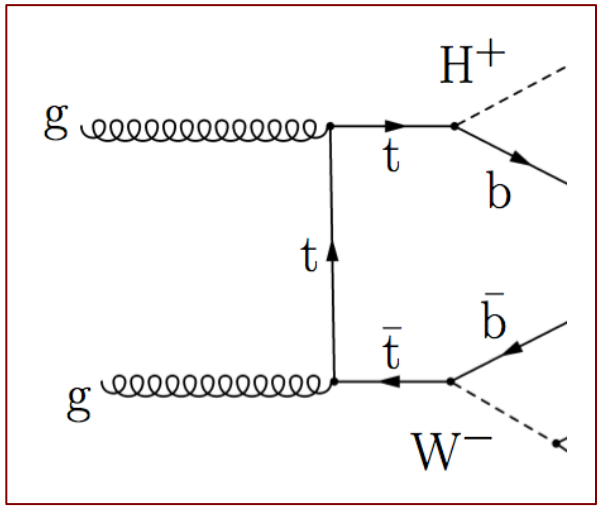
- If found, a clear indication of BSM
- Study non-SM Higgs in two mass regimes:
- $m_H < m_{top}$
  - Mostly produced in top quark decays
  - Large tanβ: $H^{\pm} \rightarrow \tau^{+}\nu$
  - Small tanβ (<1): $H^{+} \rightarrow c\bar{s}$
- $m_H > m_{top}$
  - Produced in gluon-gluon fusion
  - Main decays: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



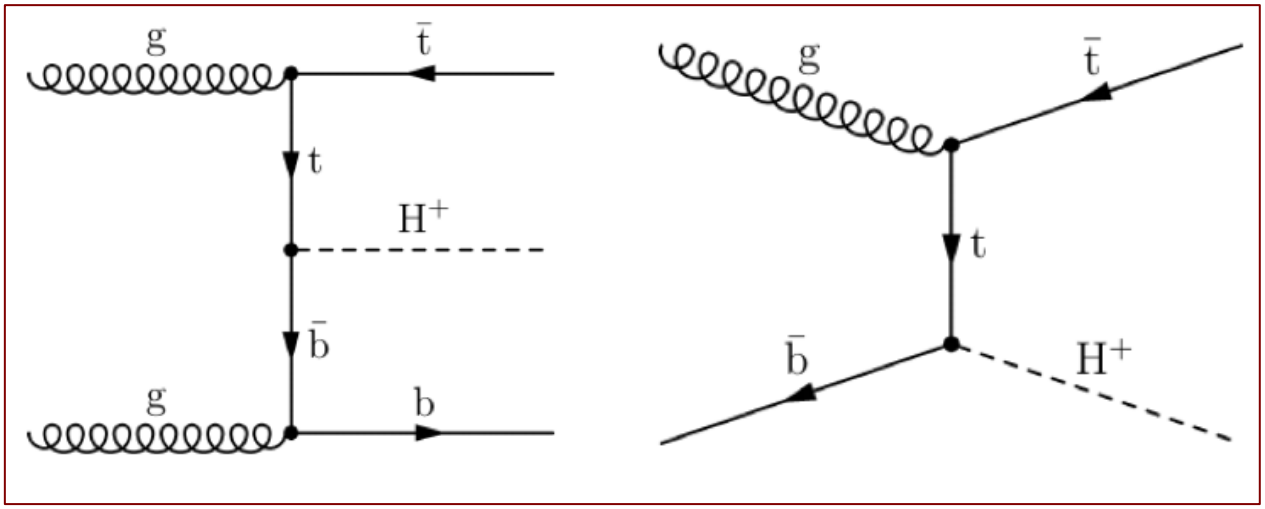
Charged Higgs (cont.)

- Different strategies for low- and high-mass searches
- tau+lepton, lep+jets, and eμ final states
- b-tagged jet categorization
- limited by statistics at high-mass





$m_H < m_{top}$

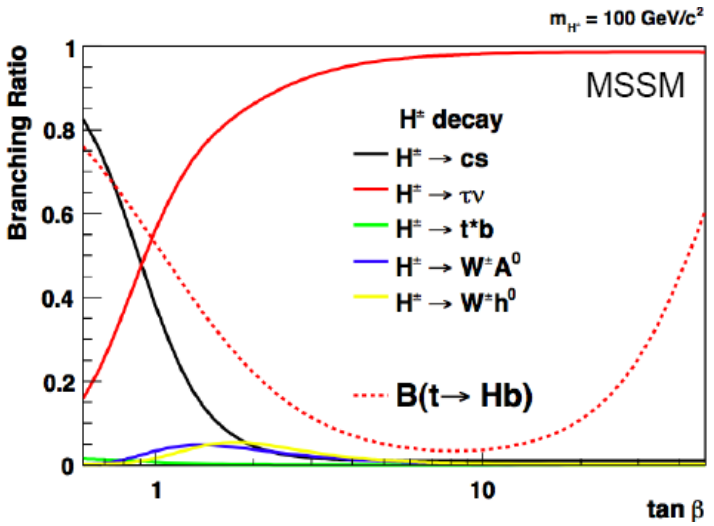


$m_H > m_{top}$

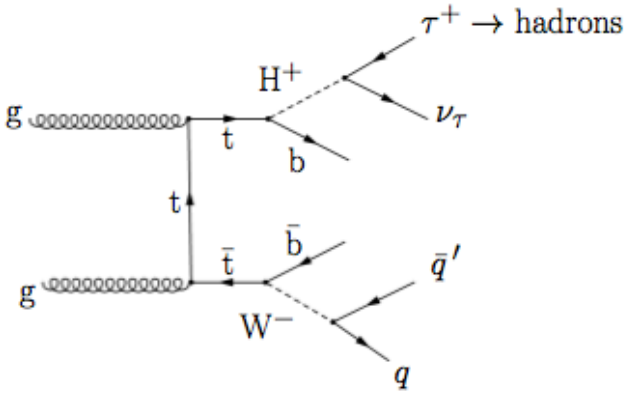
Charged Higgs and top quark decays

JHEP 07(2012)143, arXiv:1508.07774, HIG-16-031

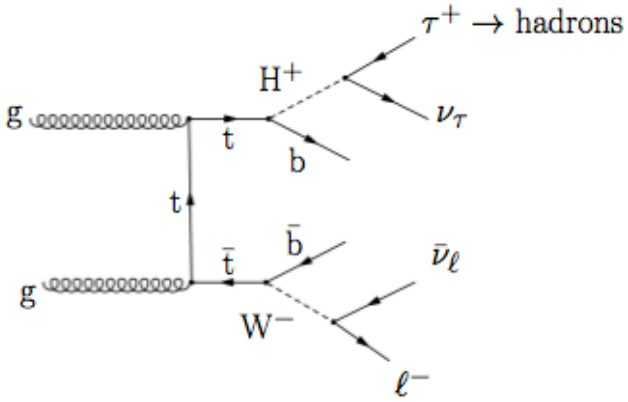
- Look for charged Higgs in four final states:
  - Tau+lepton (electron or muon)
  - Dilepton (tau decays leptonically)
  - lepton+jets
  - Fully hadronic: tau+jets



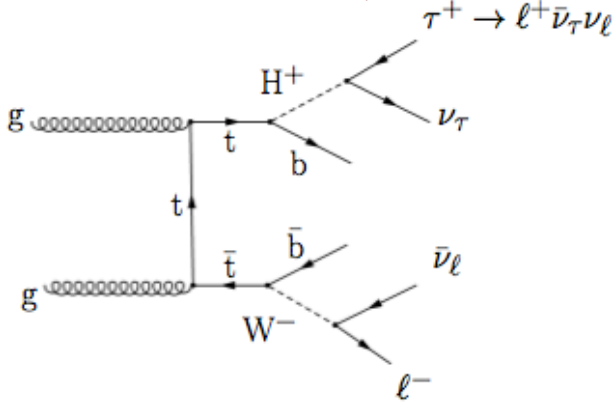
τ_h+jets



τ_h+lepton (e/μ)



di-lepton (eμ)



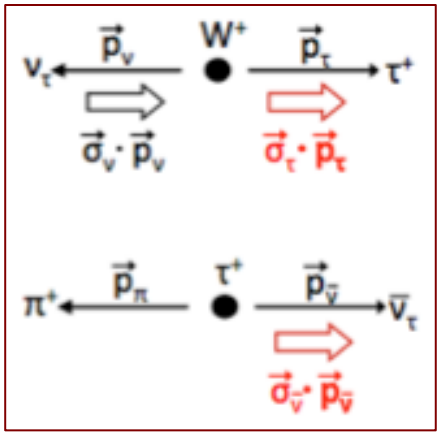
Looking at tau decays

CMS-HIG-12-052

Low H^+ mass:

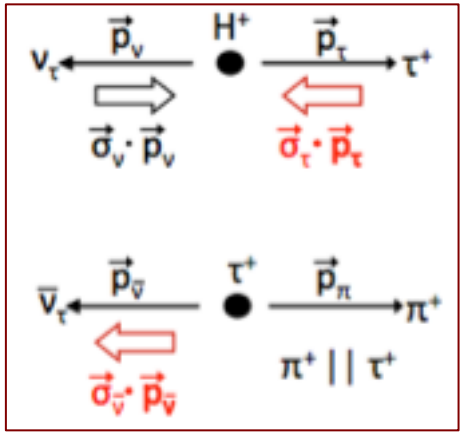
- Use R variable in the limit extraction: binned maximum-likelihood fit
- Tau fake component is data-driven, includes uncertainties

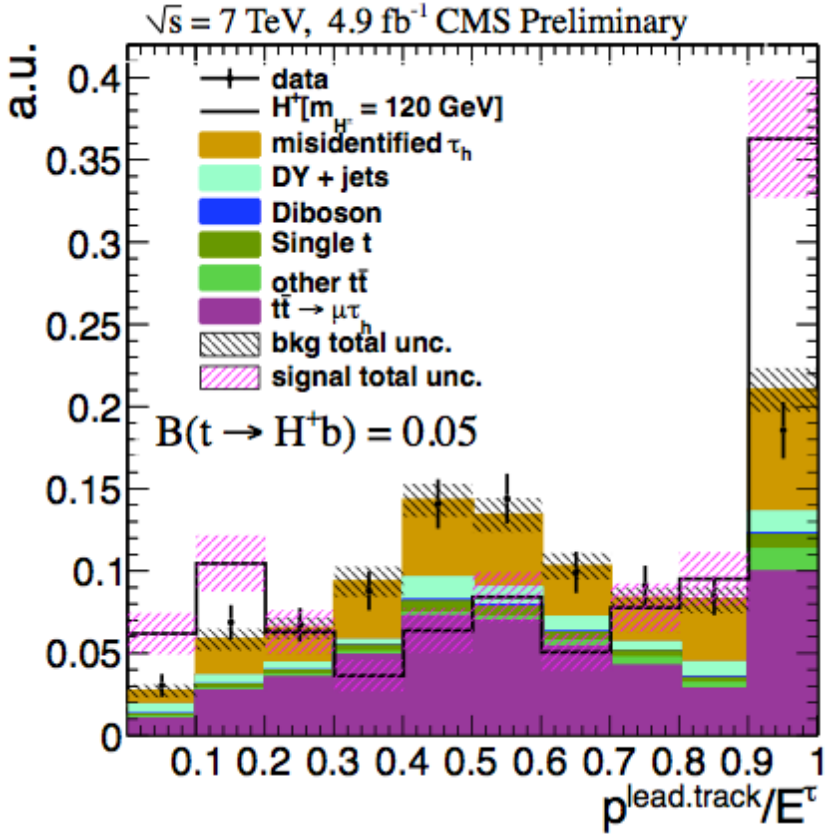
SM



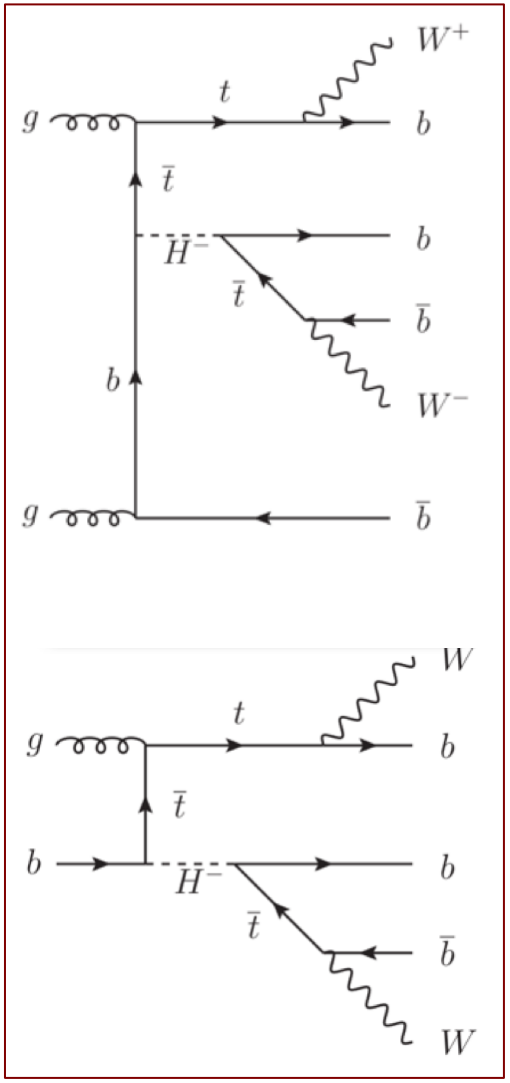
vs

BSM

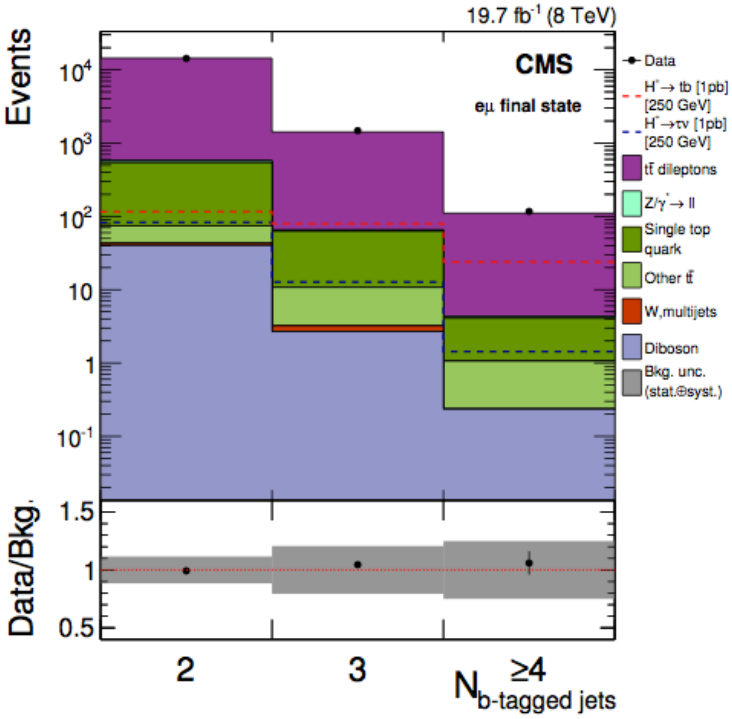


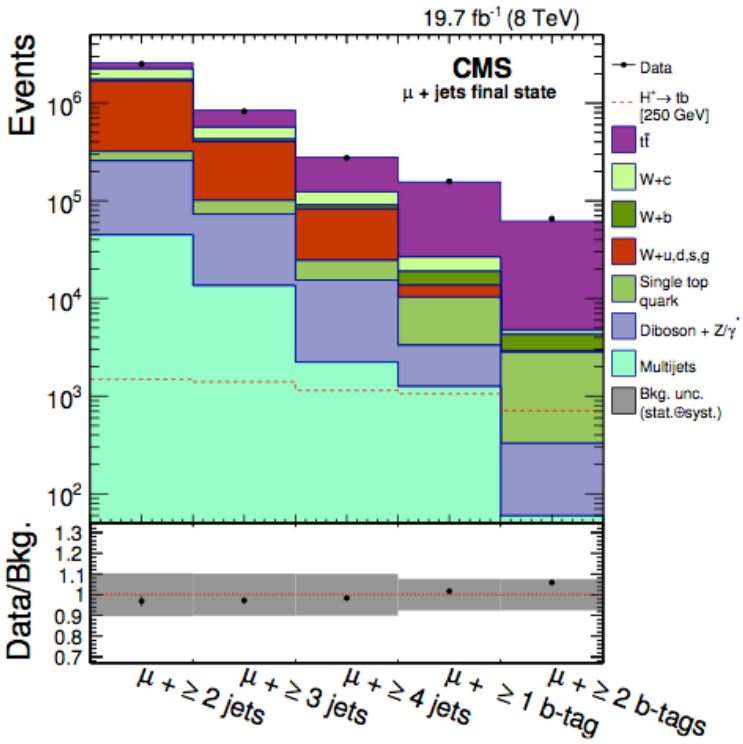


Number of b-tagged jets



High-mass H^+ search: look at b-tag multiplicity





Is there a charged Higgs?

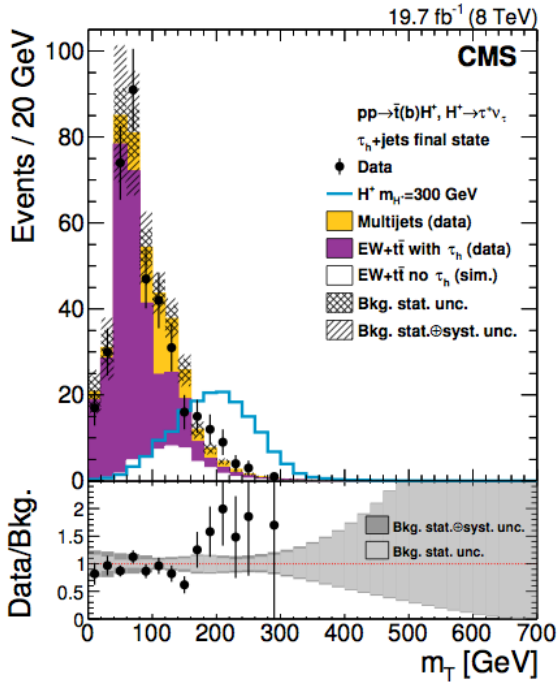
JHEP 07(2012)143, CMS-HIG-12-052, arXiv:1508.07774

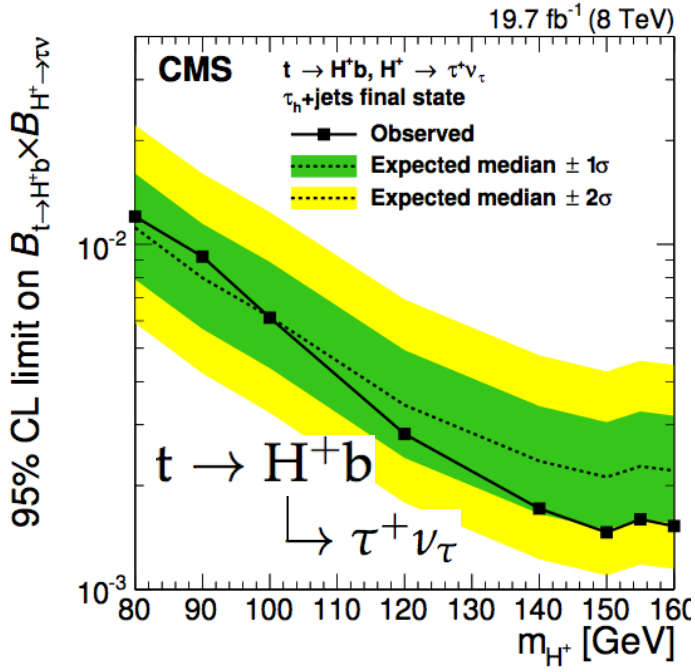
- If anomalous tau/lepton production in ttbar decays there may be contribution from H^+

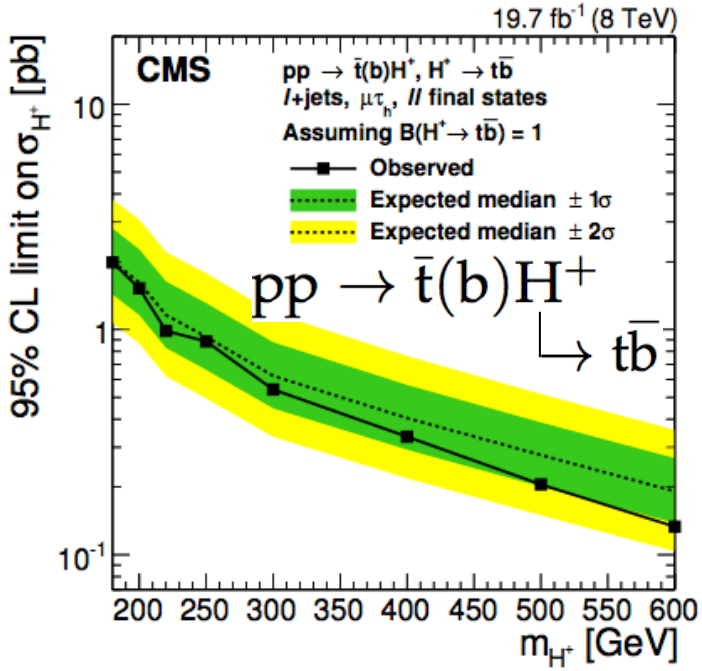
  Yields in agreement with expectations ⇒ set limits

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

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







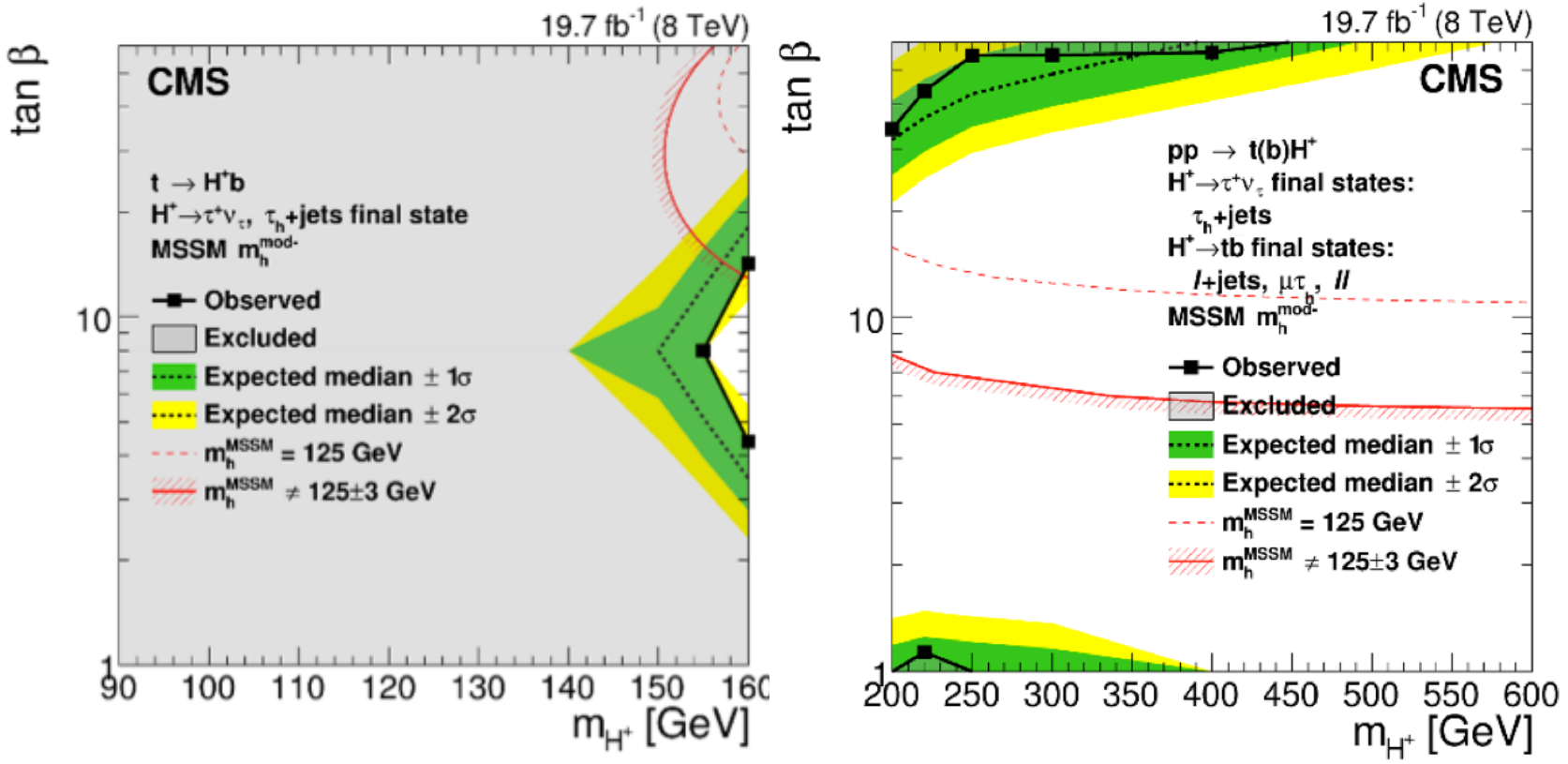
At 13TeV, expect improvement with 5-10/fb for m_{H+}>300GeV ⇒

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

Still hope for MSSM?

JHEP 07(2012)143, CMS-HIG-12-052, 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



Cross section ratios

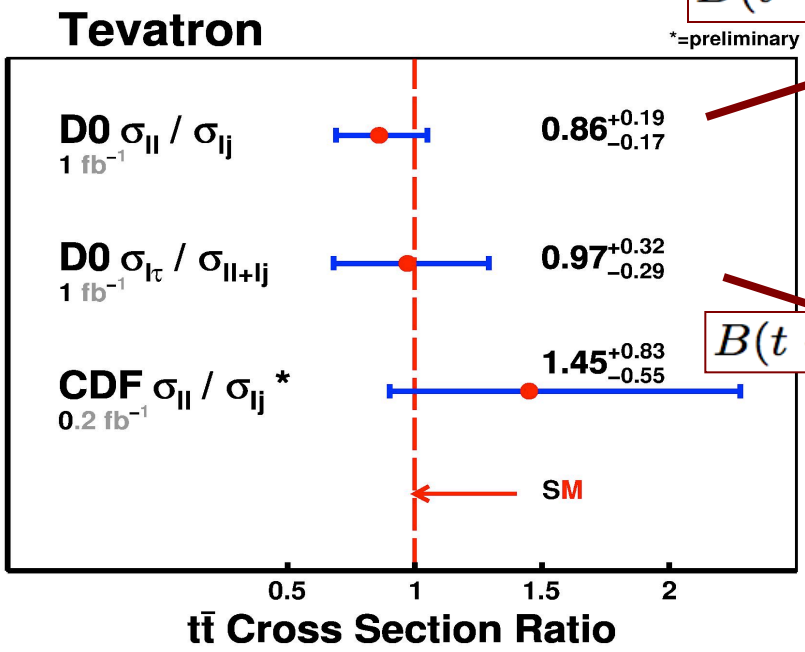
PRD 80(2009) 071102

Many systematic unc. cancel in the ratio

Study of cross section ratios

⇨sensitive to BSM

1. BR(ℓ+jets)/BR(ℓℓ)
2. BR(ℓ+tau)/BR(ℓℓ)

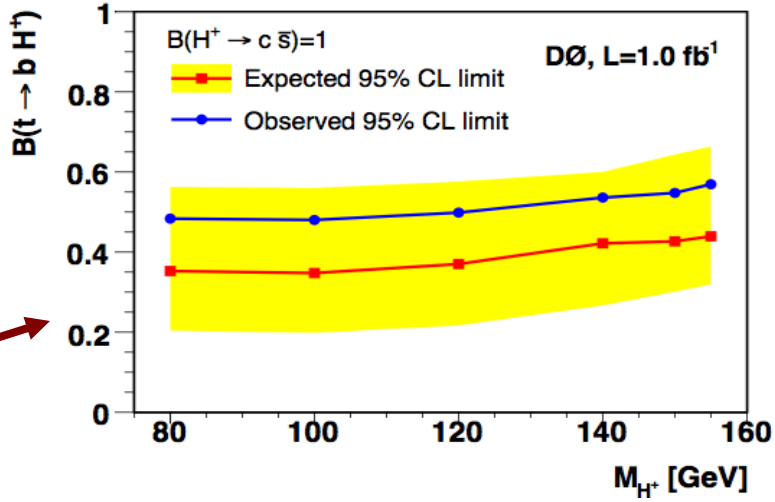


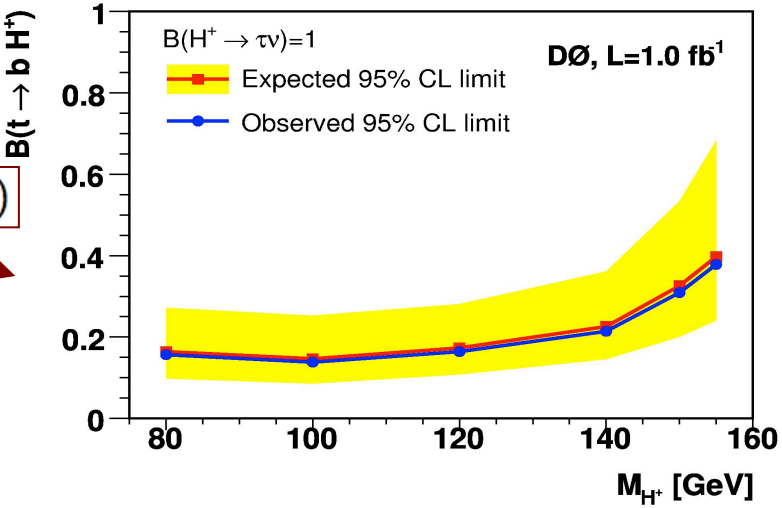
$B(t \to H^+ b \to c\bar{s}b)$

lept.+jets

$B(t \to H^+ b \to \tau^+ \nu b)$

tau leptons

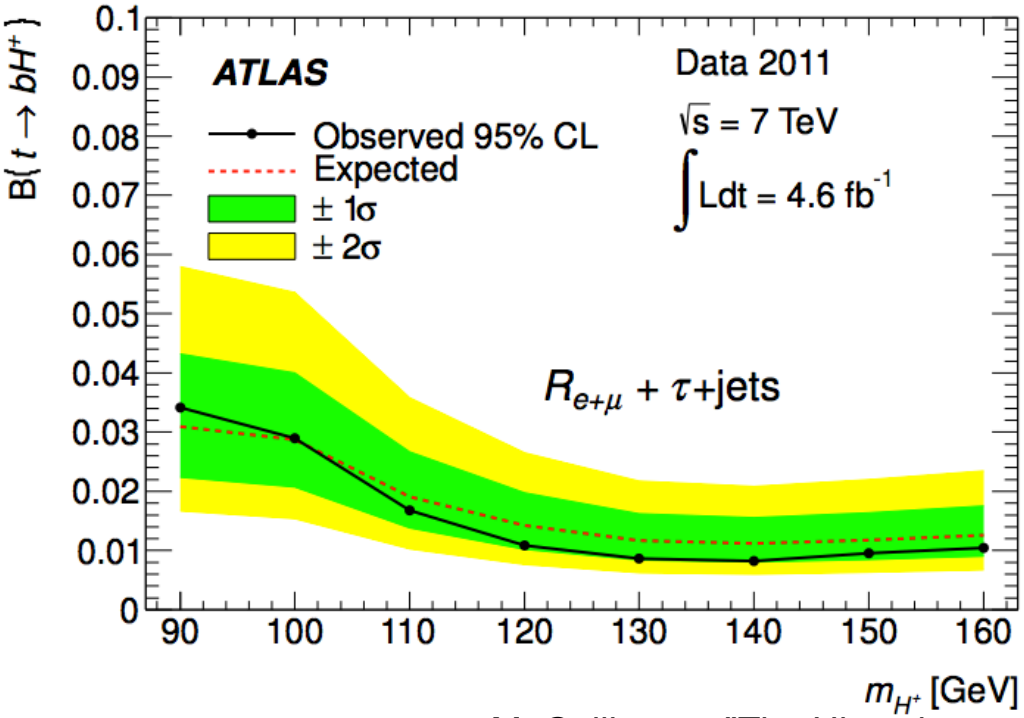


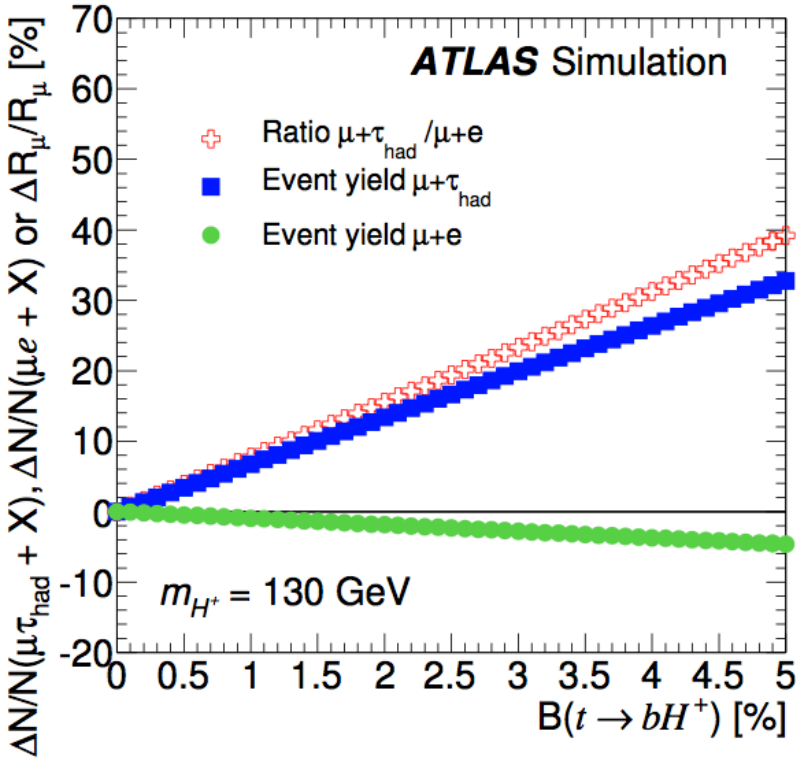


Combination of more channels

JHEP 03(2013)076

- Search for charged Higgs boson
- Use τ_{had}+lep and τ_{had}+jets final states
  - compare to eμ yields
- Search for anomalous decays





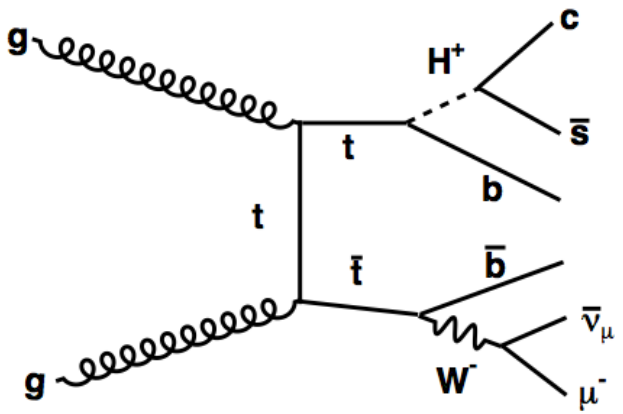
Set limits on:

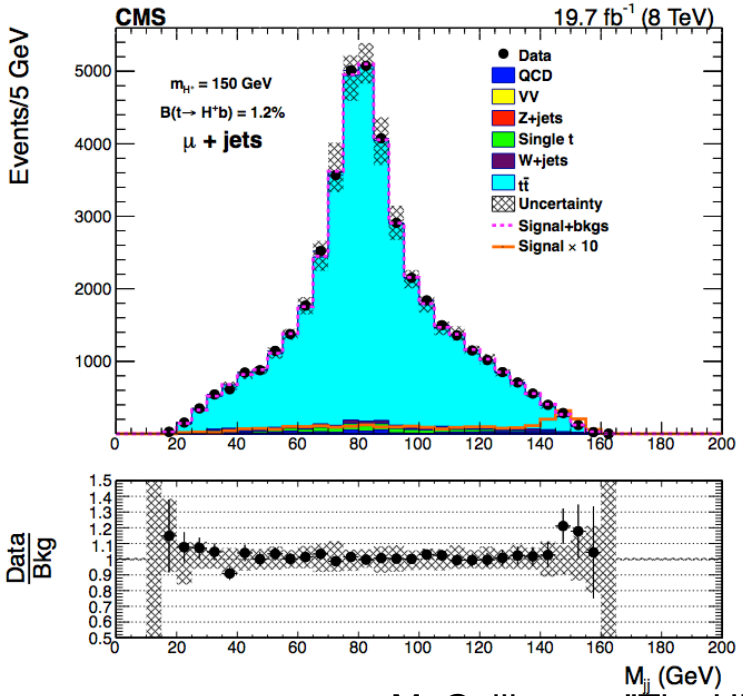
$$\mathcal{B}(t \to bH^+)$$

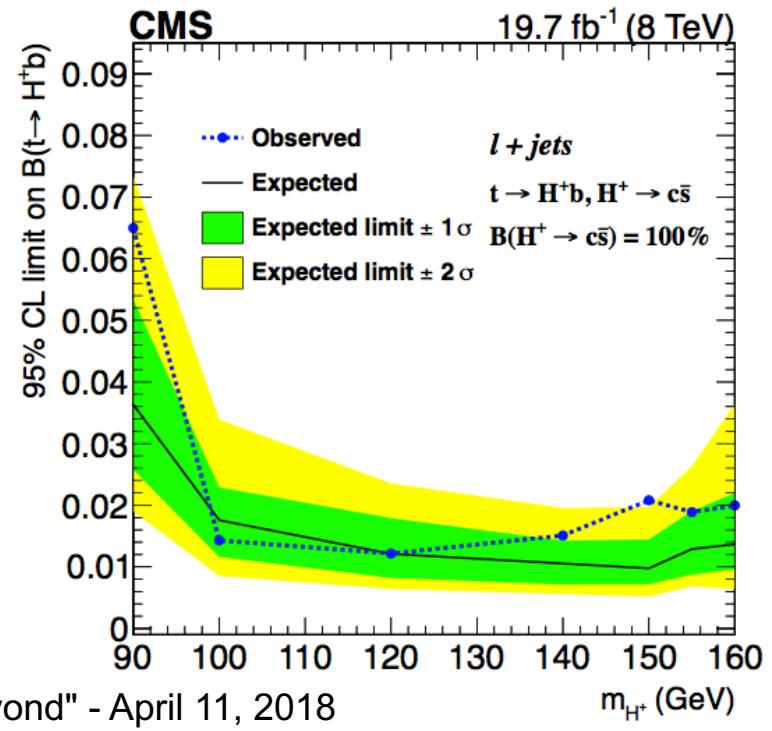
Light charged Higgs: csbar

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%



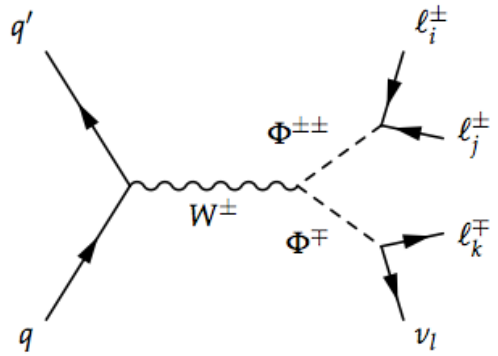


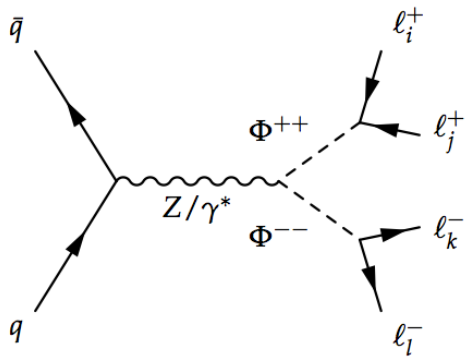


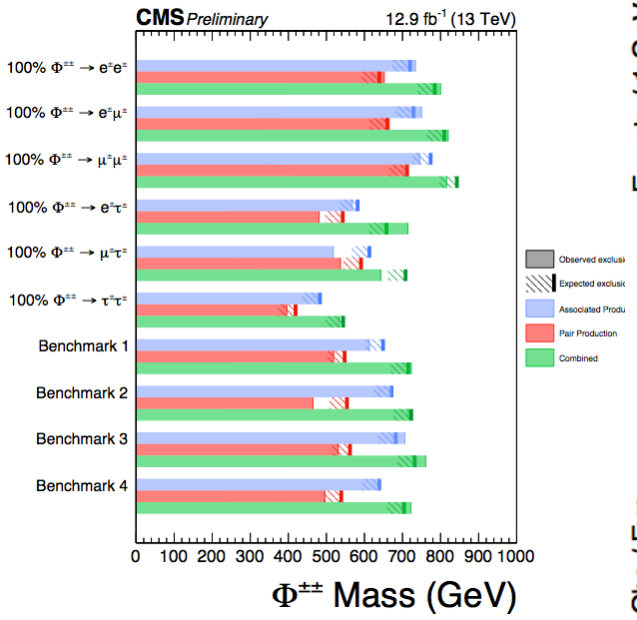
Doubly charged Higgs

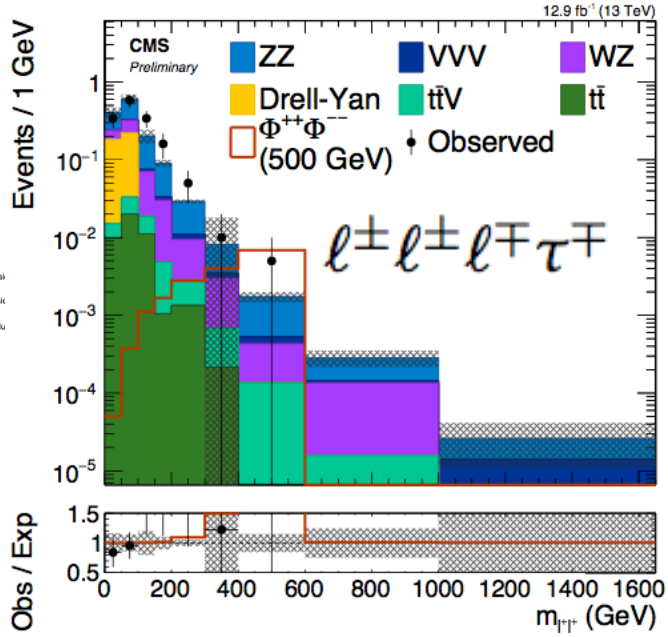
EPJC 72 (2012) 2189, CMS-HIG-14-039, HIG-16-036

- 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



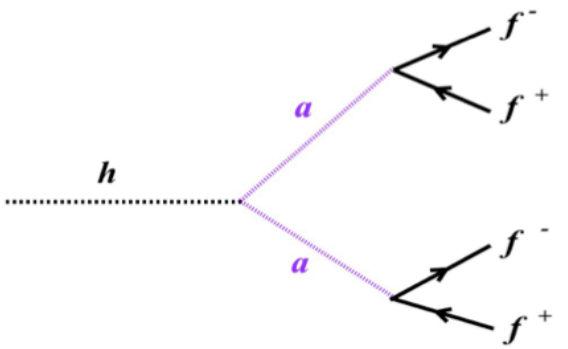


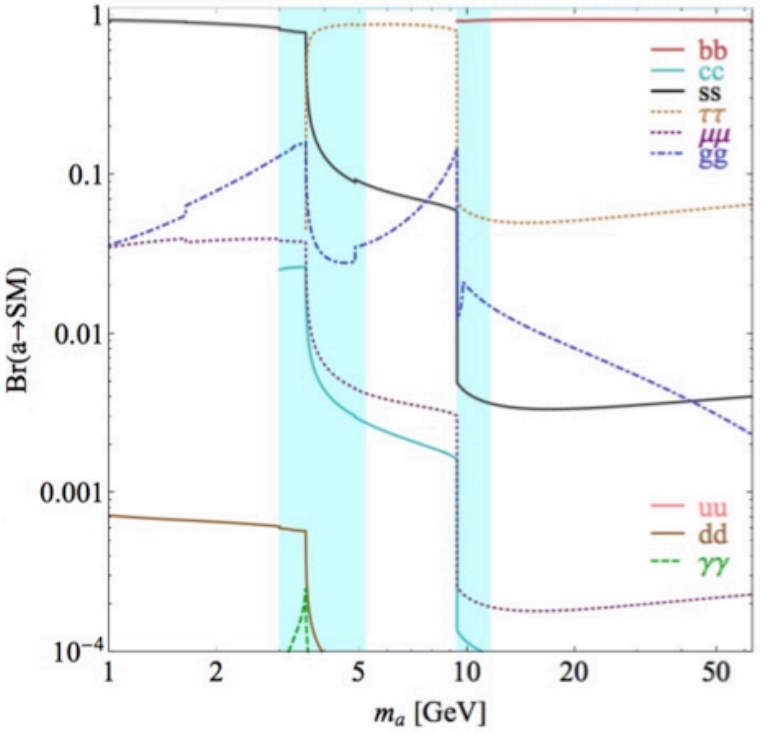




non-SM Higgs decay: h→aa→4X

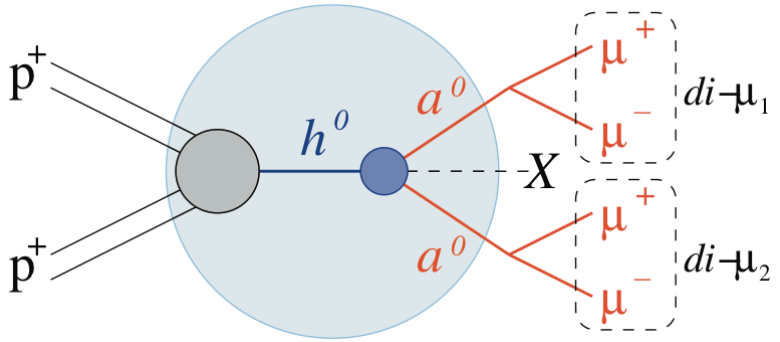
- Standard search for light (pseudo)- scalar Higgs with $m_a < m_h/2$
  - generic prediction of BSM theories (extended Higgs sector, NMSSM, etc)
  - Final states go to fermions (b, τ, μ, …)
  - BR depends on boson mass, model parameters



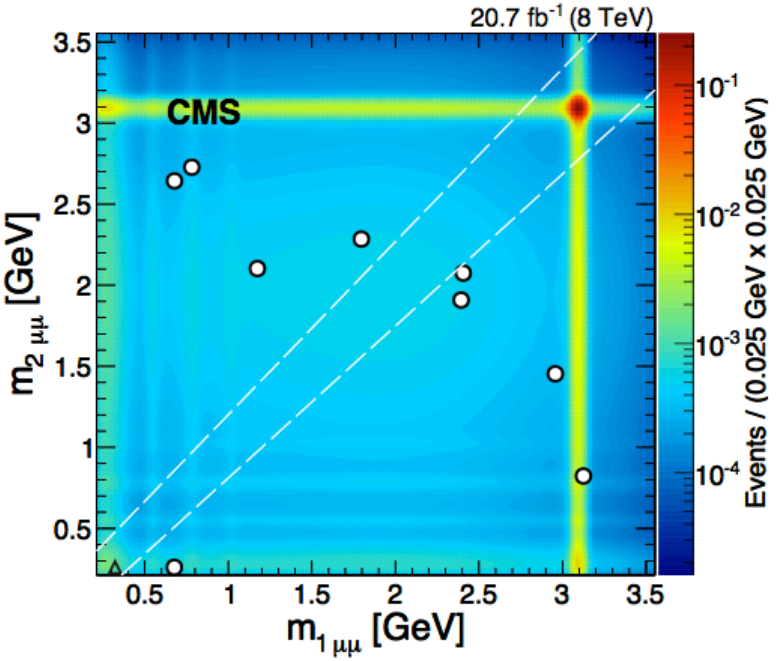


non-SM Higgs decay: h→aa→4μ

PLB 726(2013)564, arXiv:1506.00424, HIG-16-035



- Explore non-SM decays of a Higgs boson (h)
  - Higgs boson (h) can be SM or not
  - include production of two new light boson (a^0)
- Search for generic Higgs decays: h→2a+X→4μ+X
  - Require two dimuon pairs with consistent masses
  - Observe 9 events in off-diagonal region
  - 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

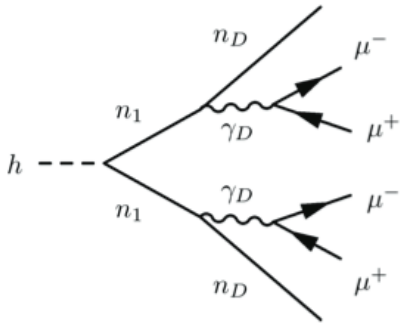
Results interpreted in NMSSM and dark SUSY

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

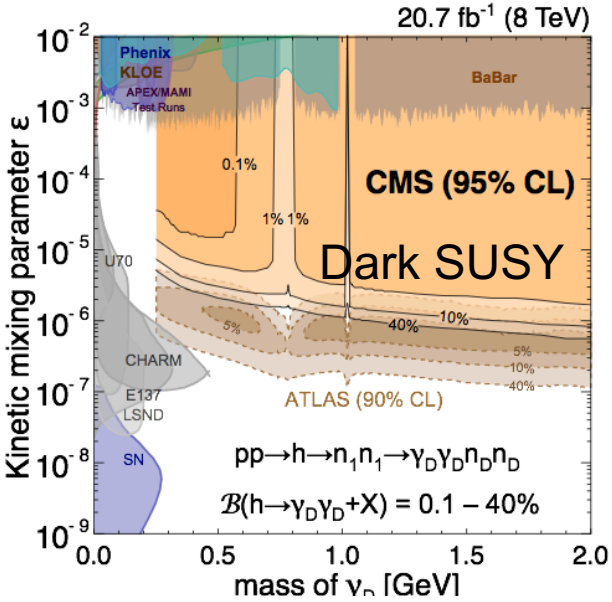
$n_1 \rightarrow n_D \gamma_D$ decays

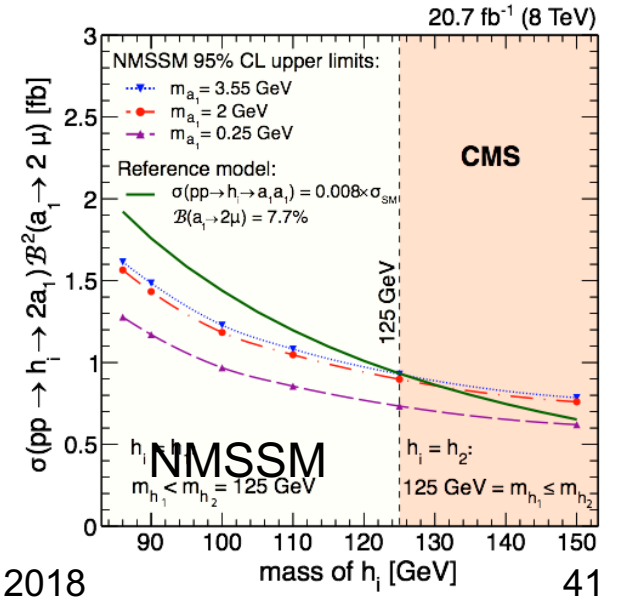
$\gamma_D \rightarrow \mu\mu$

$n_D \rightarrow$ 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

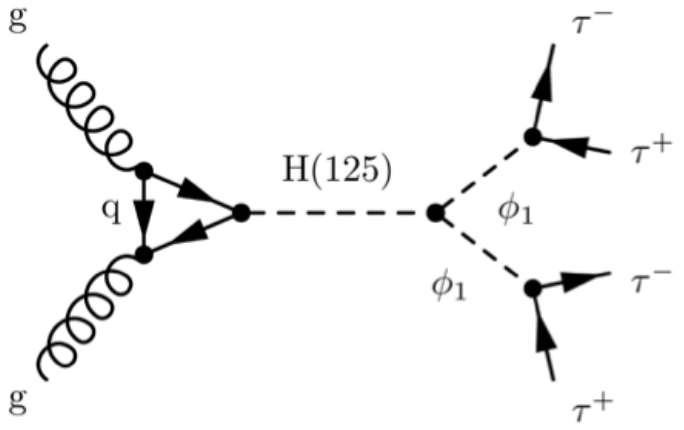


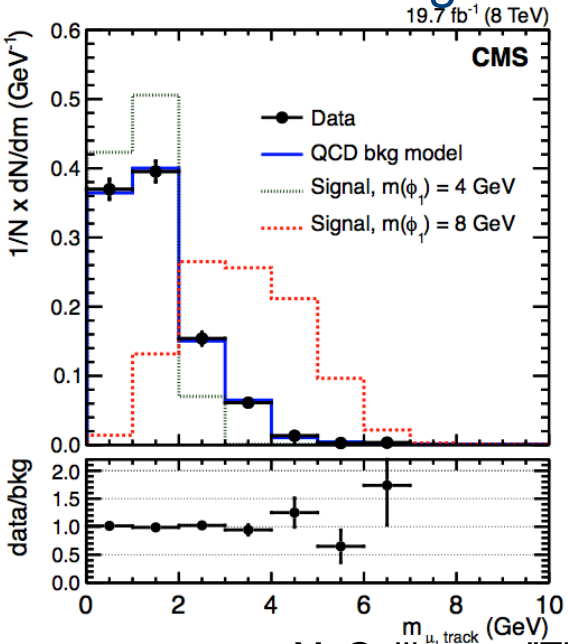


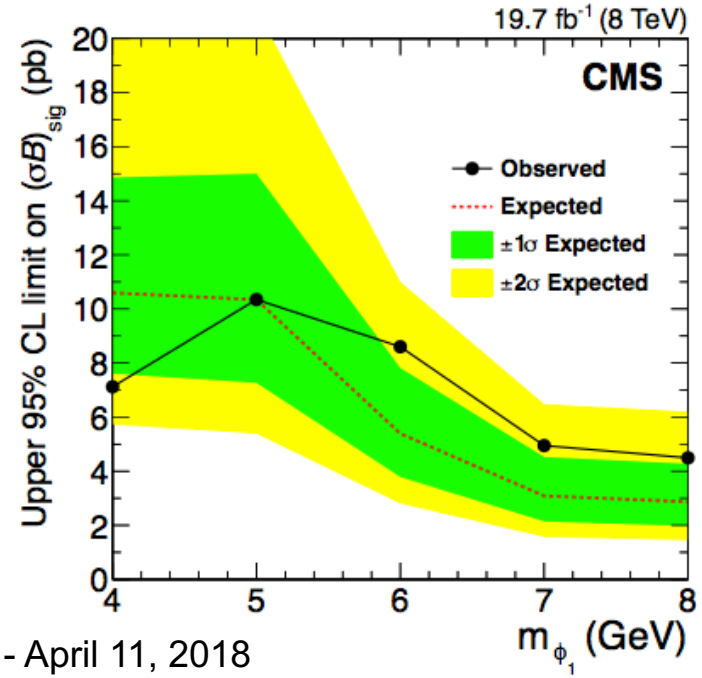
non-SM Higgs decay: $H_{125} \rightarrow 2h(a) \rightarrow 4\tau$

JHEP01(2016)079

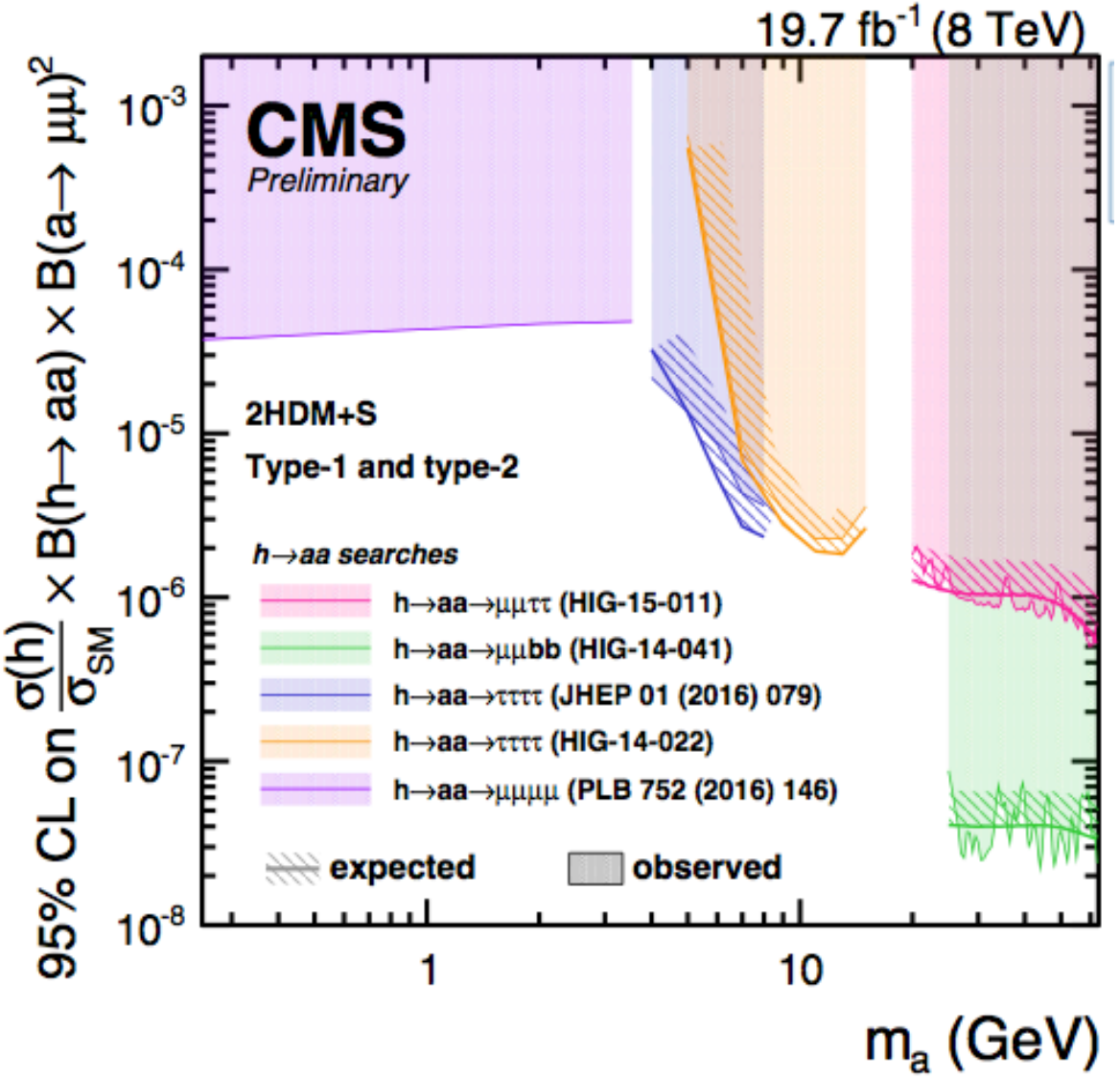
- Search for very light Higgs in NMSSM
  - $h_{1,2}$ (CP-even), $a_{1,2}$ (CP-odd) to a pair of τ leptons
  - $H(125) \rightarrow h_1 h_2 (a_1 a_2) \rightarrow 4\tau$
- Reconstruct μ-track invar. mass (m_1,m_2)
  - SS dimuon sample (removes DY)
  - bin in 2-dim distribution, fit signal and bkg
  - QCD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







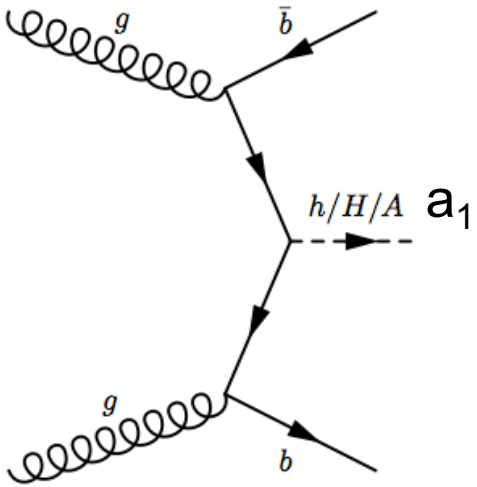
Summary for Higgs exotic decays

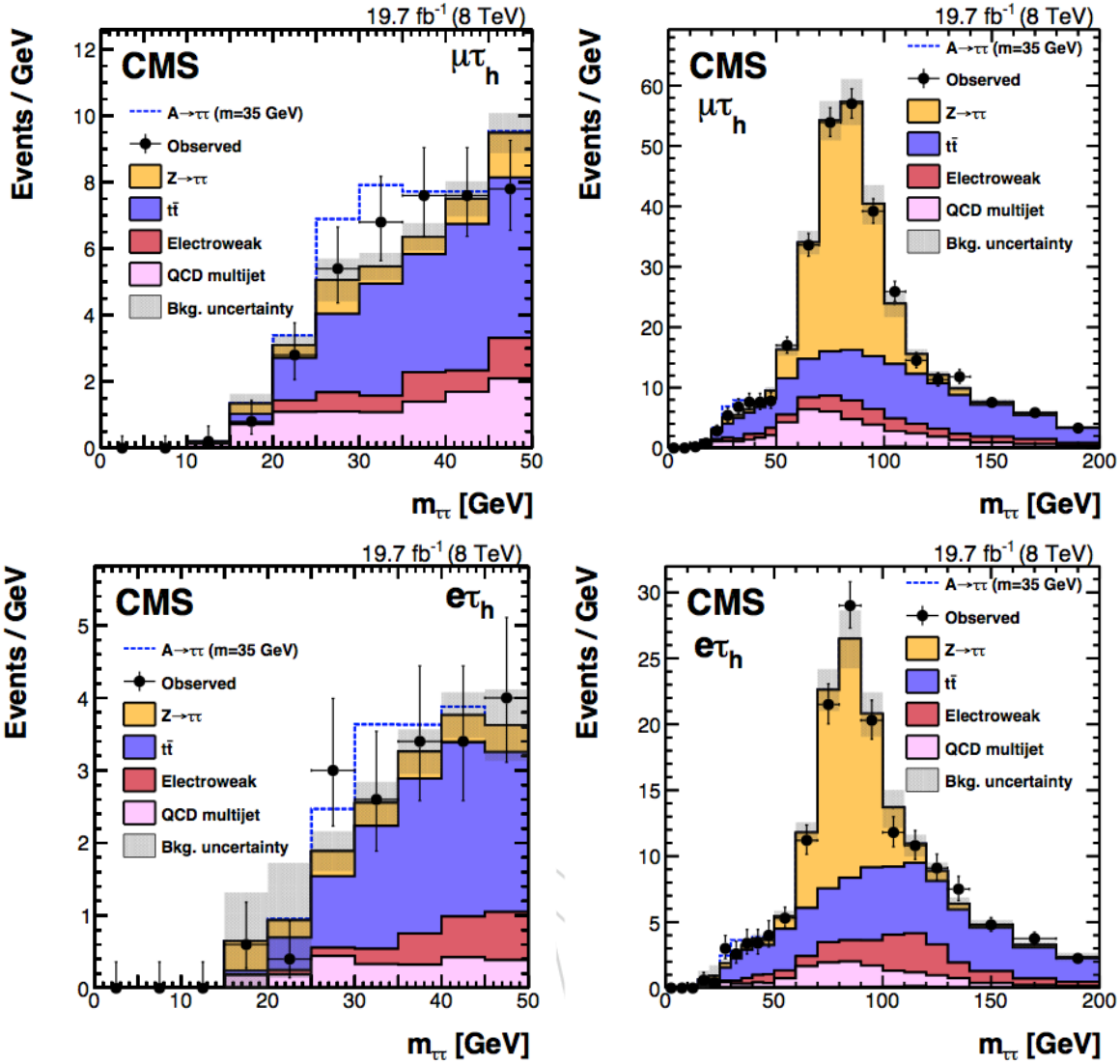


Low mass Higgs: a(→ττ)bb

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: $\sigma \times B$~9-39 pb



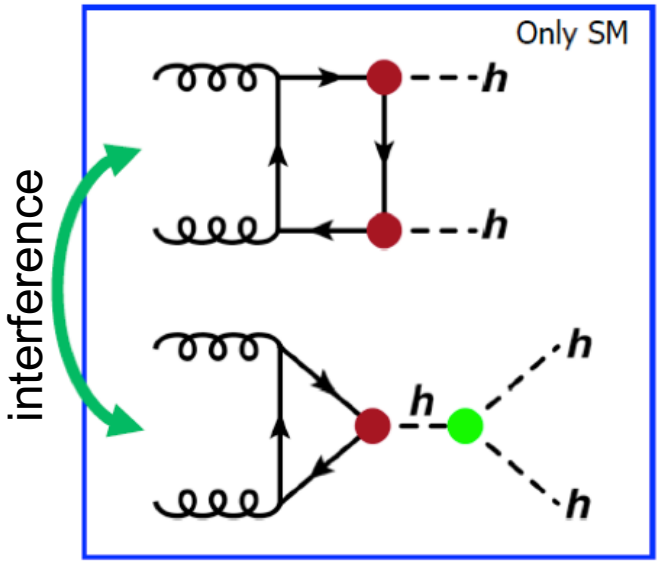


di-Higgs searches

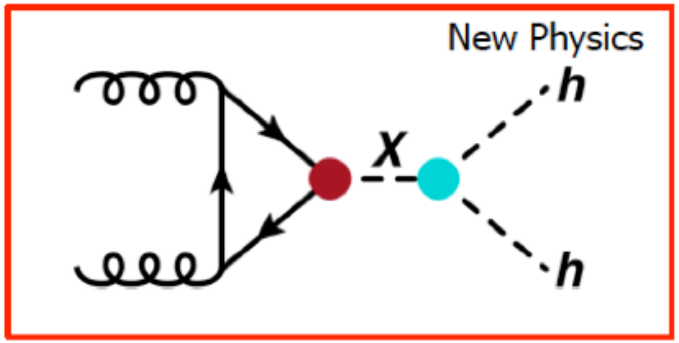
- Destructive interference in SM
- Could be altered in BSM
- If constructive, it could be large enhancement
- In SM, only σ=33fb at 13 TeV
- Study different final states

		BR	Mass scale
(X→)hh→	bbbb	34%	High
	bbττ	7.3%	
	bbWW	27%	
	bbγγ	0.26%	Low

non-resonant production

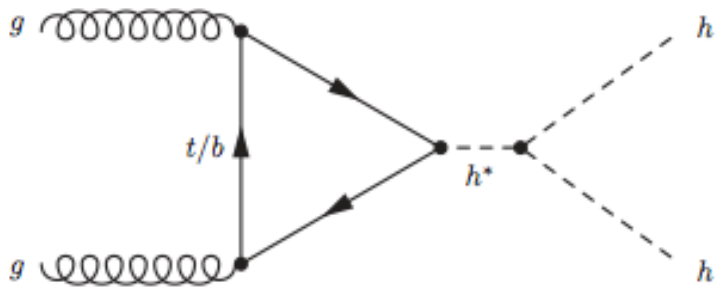


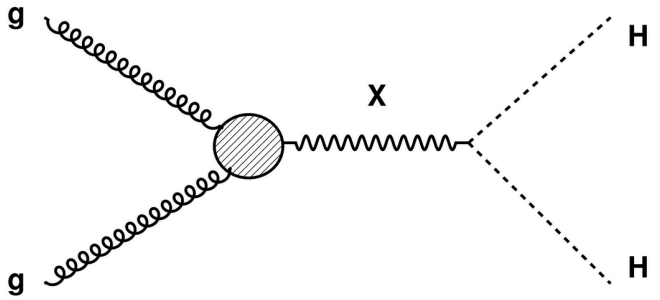
resonant production



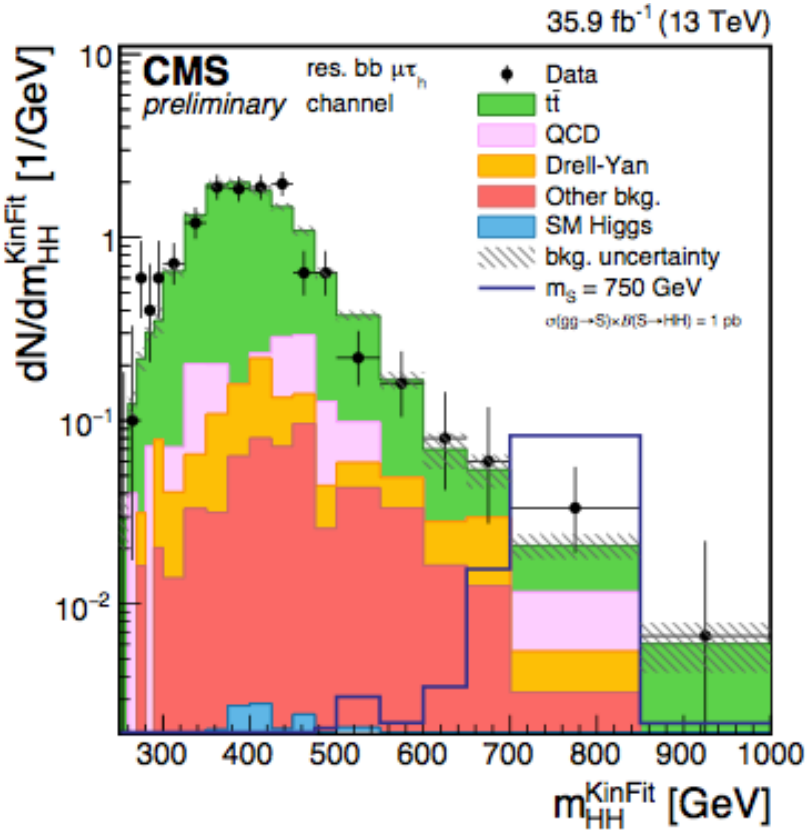
Heavy Higgs to $h_{125}h_{125} \rightarrow \tau\tau bb$

CMS-EXO-15-008, CMS-HIG-16-012, CMS-HIG-17-002





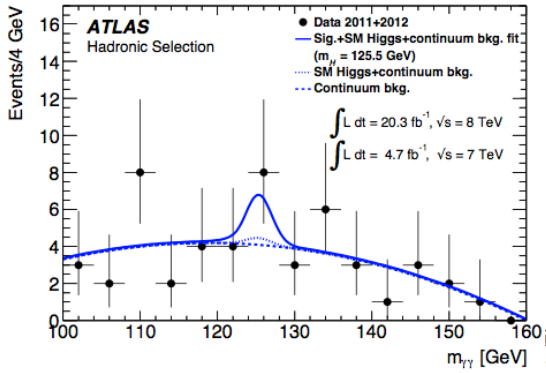
- Resonant and non-resonant production
  - Double Higgs production to determine λ_{hhh}
  - Check couplings: $\kappa_\lambda=\lambda_{hh}/\lambda_{hhh}^{SM}$; $\kappa_t=y_t/y_t^{SM}$
  - BSM could enhance non-resonant hh production
  - $H \rightarrow h_{125}h_{125} \rightarrow bb\tau\tau$
- h_{125} decay products nearly collinear
  - boosted "single" merged jet ($\rightarrow$bb)
- use $\tau_e\tau_h$, $\tau_\mu\tau_h$, and $\tau_h\tau_h$ final states
  - sidebands/inverted isolation to estimate bkg
- set limits as function of mass



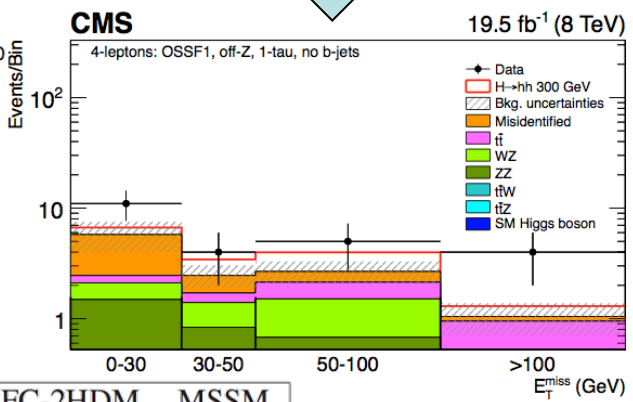
Heavy Higgs: $H \to h_{125}h_{125}$, $A \to Zh_{125}$

PRD90(2014)112013, PLB755(2016)217

- MSSM: Heavy Higgs searches
  - Search for $A \to Zh_{125}$ and $H \to hh$
- Exclusive search in multilepton and diphoton+lepton channels
- Search for FCNC decays



- $H \to WW^* \to \ell\nu\ell\nu$,
- $H \to \tau\tau$,
- $H \to ZZ^* \to jj\ell\ell, \nu\nu\ell\ell, \ell\ell\ell\ell$,
- $H \to \gamma\gamma$.



- Search for $tt \to (bW)(ch)$
  - Not forbidden but highly suppressed
  - enhanced w/some parameter models
- SM Higgs now a background
  - ATLAS: $H \to \gamma\gamma$
  - CMS: $H \to \gamma\gamma$ and multileptons
- b-tag provides bkg suppression

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}

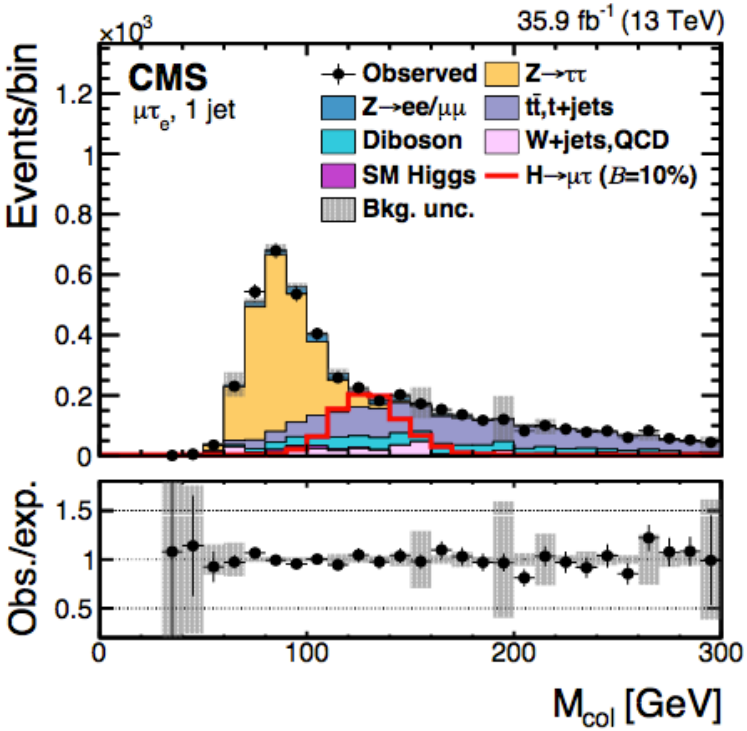
FCNC decays

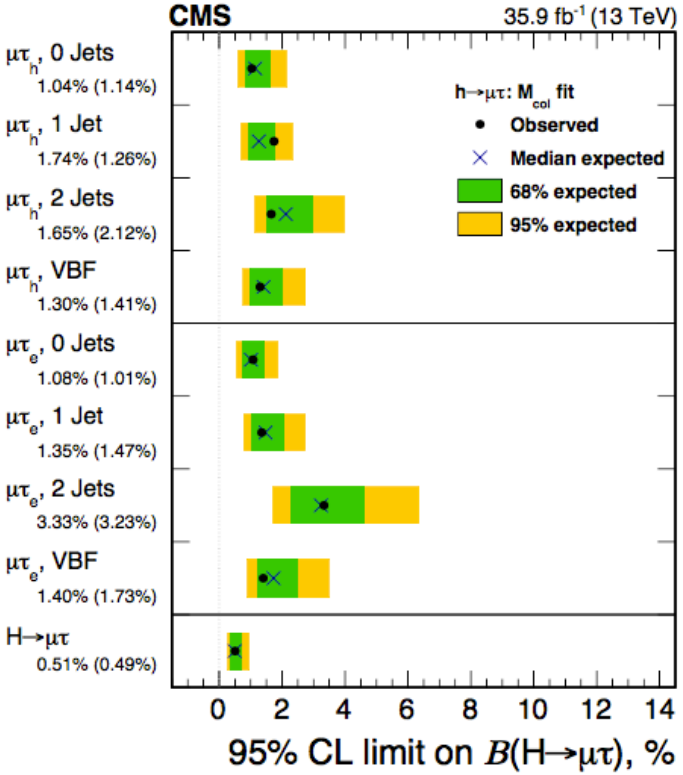
	ATLAS obs(exp)	CMS
BR(t→cH) (95%CL)	<0.79% (0.51%)	<0.56% (0.65%)

LFV in Higgs decays

PLB 763(2016)472, arXiv:1712.07173

- Some BSM models allow for LFV Higgs decays
- Search for H→eτ, eμ, μτ final states
- Categories: N_{jet}, lepton kinematics
  - N_{jet} to target ggH and VBF production
- Main background from DY, ttbar, WW



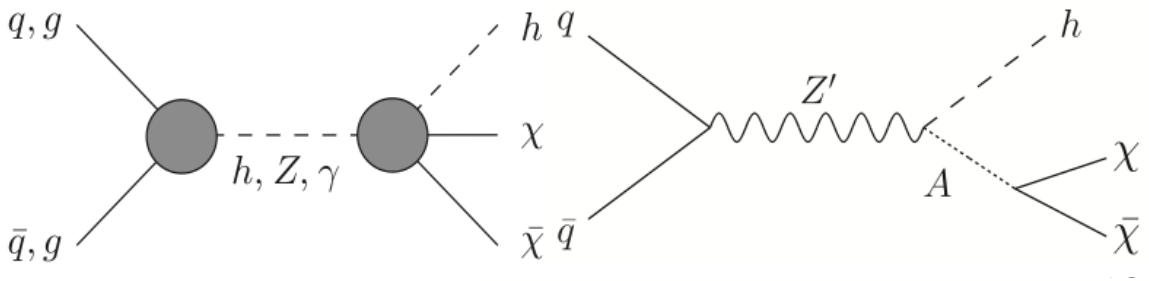


	Observed (expected) limits (%)		Best fit branching fraction (%)	
	BDT fit	M_{col} fit	BDT fit	M_{col} fit
$H \to \mu\tau$	<0.25 (0.25)%	<0.51 (0.49) %	0.00 ± 0.12 %	0.02 ± 0.20 %
$H \to e\tau$	<0.61 (0.37) %	<0.72 (0.56) %	0.30 ± 0.18 %	0.23 ± 0.24 %

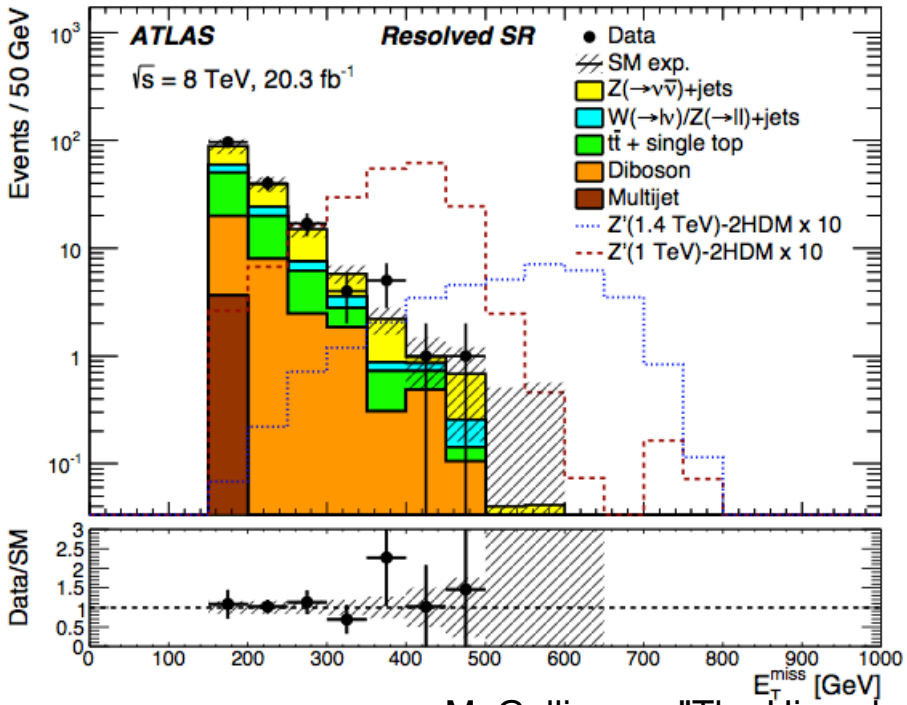
Dark Matter+Higgs

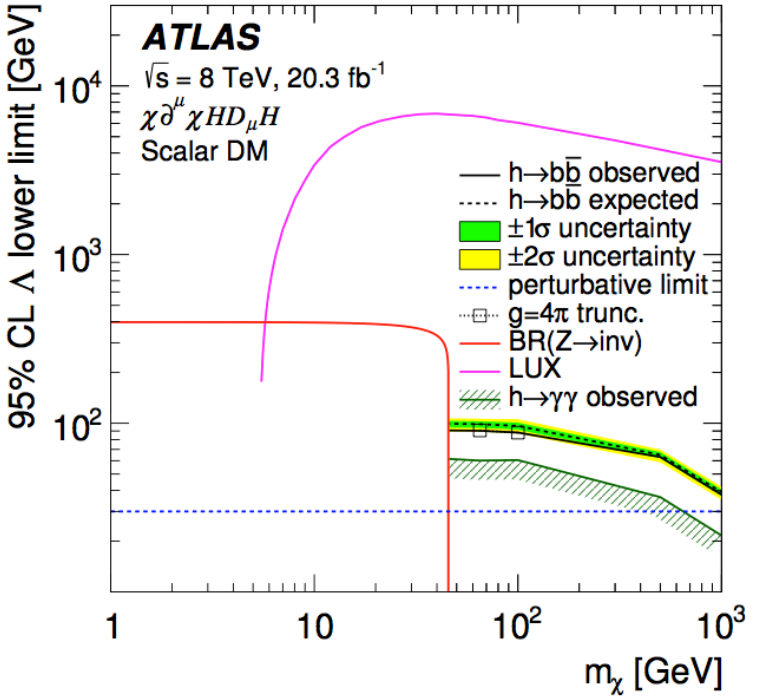
arXiv:1510.06218, arXiv:1506.01081

- Generic search: pp→X+MET
- Search for DM + h(→bb)
- Model-independent search
  - Signature: h(→ZZ/bb/γγ)+MET
  - Simplified model with Z' or pseudo-scalar Higgs A(→χχ)
- Signal events at large MET



DM particle (χ): can be scalar or fermion
Pseudo-scalar Higgs A





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
- Searches provide no hints for BSM yet