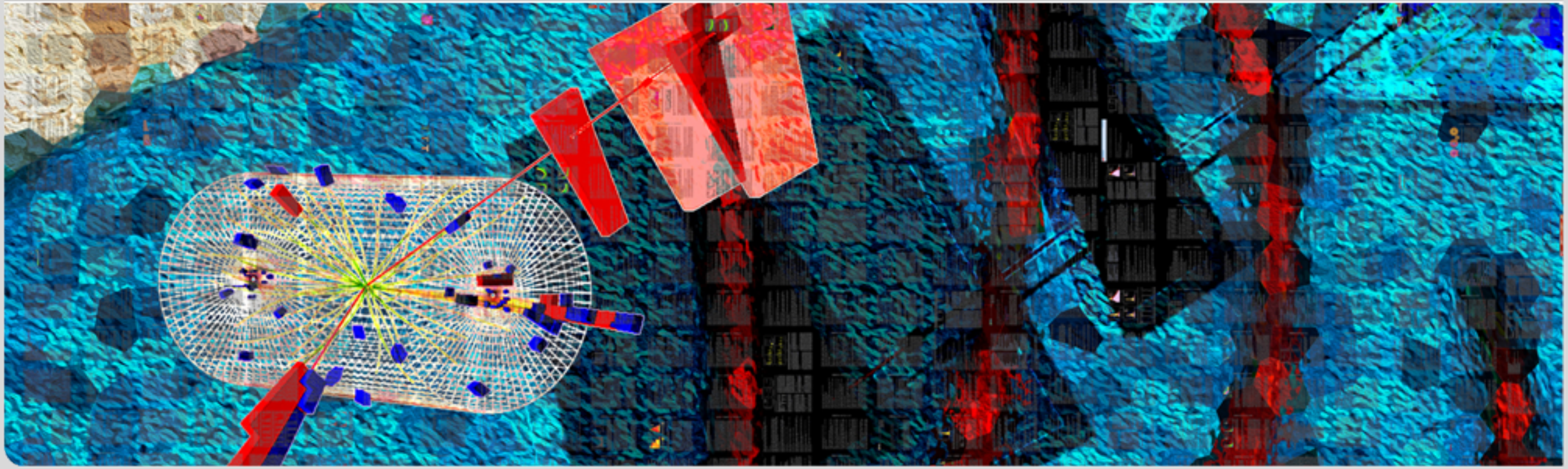
Karlsruhe Institute of Technology

CMS ττ Physics News

Andrew Gilbert

13th Workshop of the ττ Analysis Working Group | 3 December 2014

INSTITUTE OF EXPERIMENTAL PARTICLE PHYSICS (IEKP) – PHYSICS DEPARTMENT



CMS Results in 2014

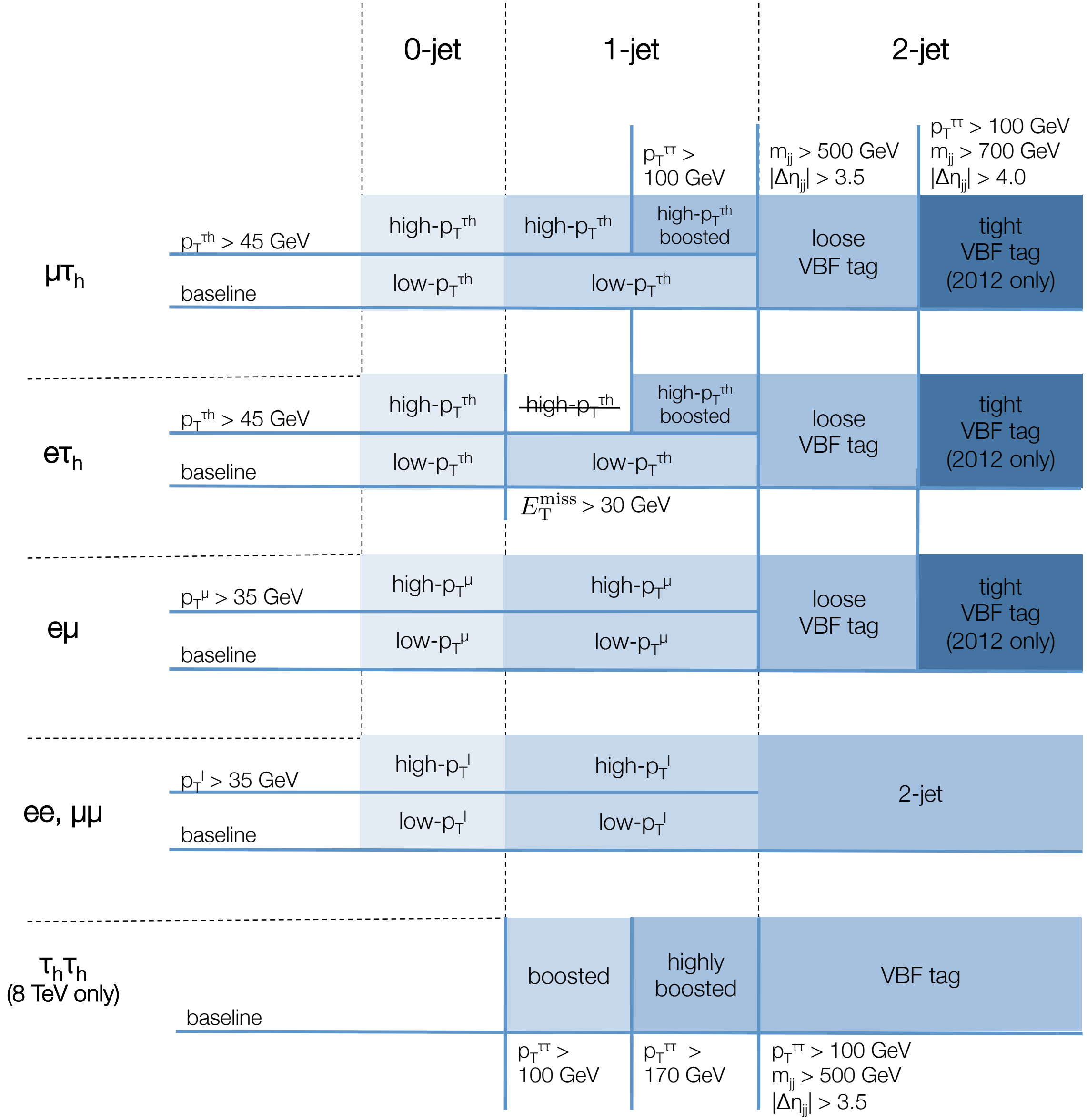
Result	Date	Dataset	Ref.
SM $H \rightarrow \tau\tau$	Jan 2014	4.9 fb^{-1} (7 TeV) + 19.7 fb^{-1} (8TeV)	JHEP 05 (2014) 104
$H \rightarrow \tau\mu$ LFV decays (*D. Tröndle*)	July 2014	19.7 fb^{-1} (8TeV)	HIG-14-005
MSSM $h/H/A \rightarrow \tau\tau$	Aug 2014	4.9 fb^{-1} (7 TeV) + 19.7 fb^{-1} (8TeV)	JHEP 10 (2014) 160
ttH($\tau\tau$) [ttH Combination]	Aug 2014	19.3 fb^{-1} (8TeV)	JHEP 09 (2014) 087
MSSM $H^{+} \rightarrow \tau\nu$	Sept 2014	19.7 fb^{-1} (8TeV)	HIG-14-020

- **Developments for Run II & Beyond**
  - Tau Embedding - *this talk*
  - Hadronic Tau Reconstruction (*C. Veelken*)
  - CP Studies in $H \rightarrow \tau\tau$ (*A. Nayak*)

SM $H \rightarrow \tau\tau$

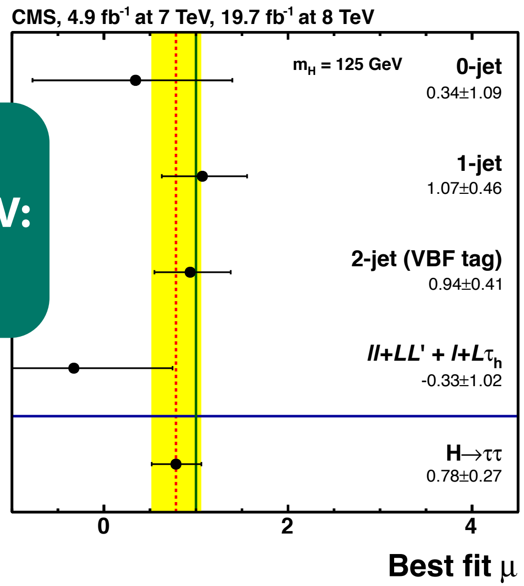
SM Categorisation

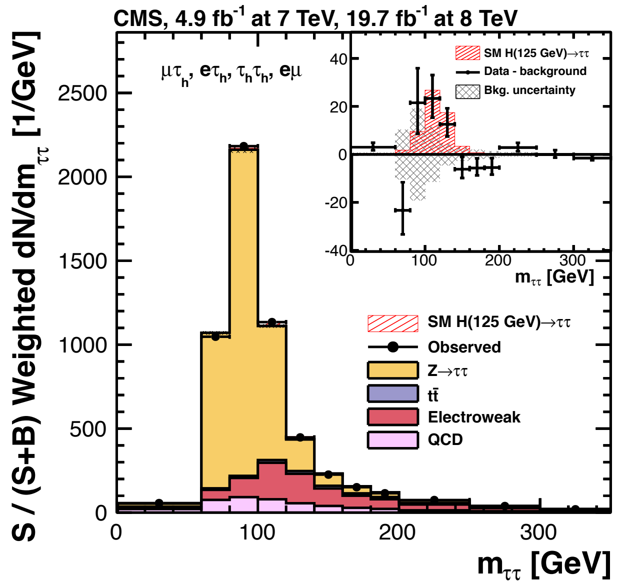
- Main categorisation on number of jets
- **0-jet**: Small s/b - calibrate backgrounds
- **1-jet**: boosted-Higgs categories improve s/b of gluon-fusion events
- **2-jet**: Loose and Tight VBF-tags



SM Results

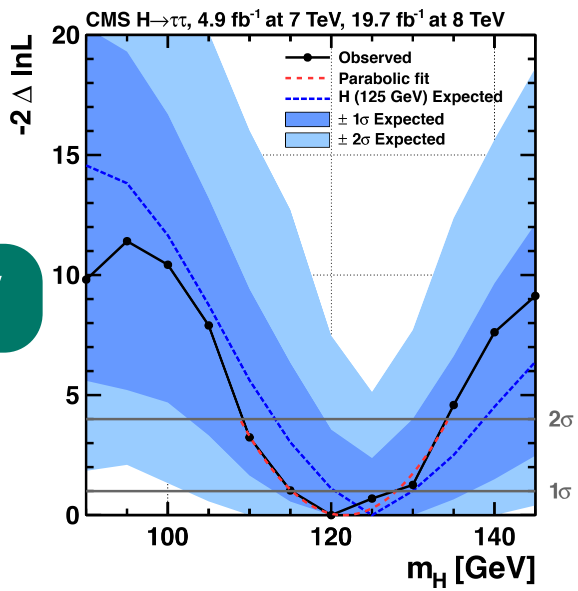
Best-fit signal strength @ 125 GeV: μ = 0.78 ± 0.27

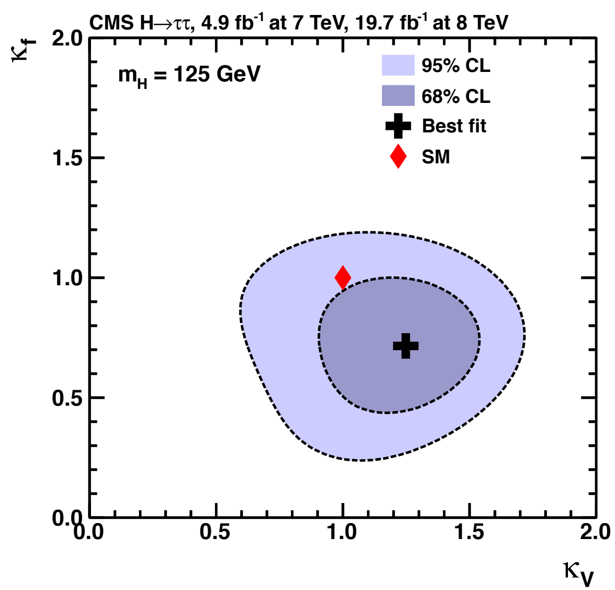




Significance @ 125 GeV: 3.2 (3.7) observed (expected)

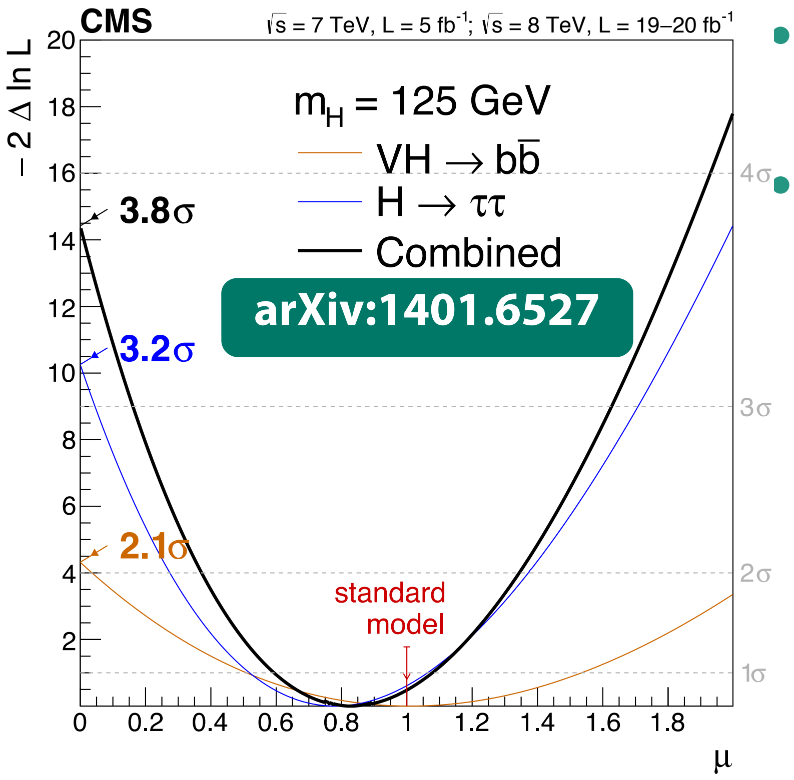
m_H = 122 ± 7 GeV



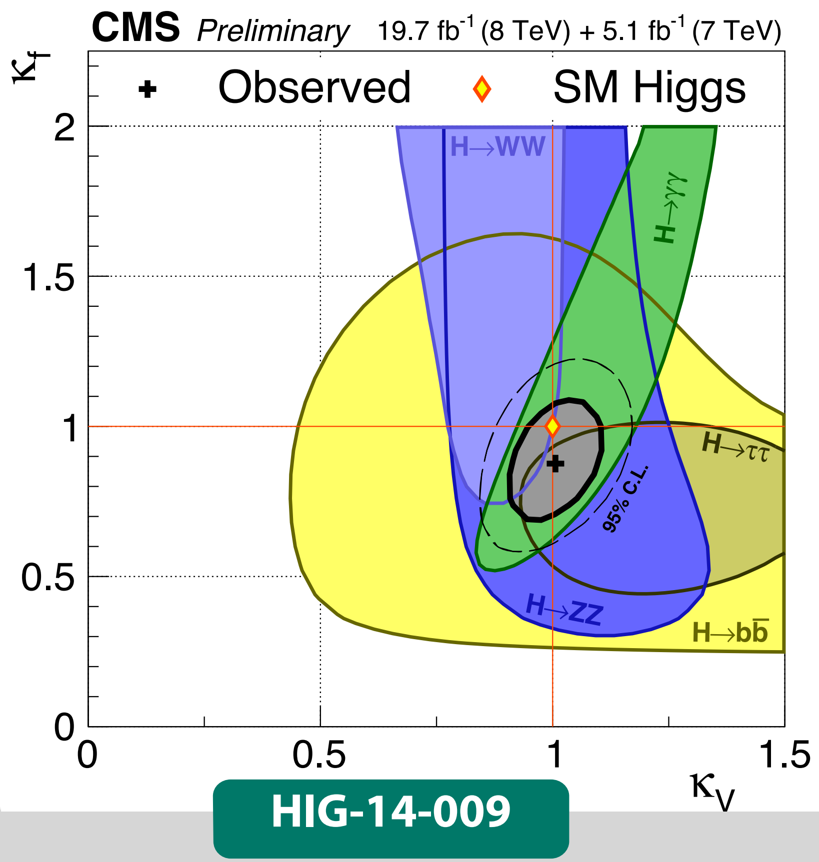


Includes H→WW as signal

$H \to \tau\tau$ in the CMS Combination



- Combination of $H \to \tau\tau$ and $H \to bb$ searches
- Evidence of coupling to fermions



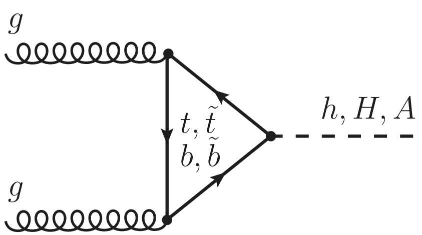
- Significant contribution to measurement of fermionic coupling parameter κ_f
- **⇒ Ensure Run II analysis continues to perform here**

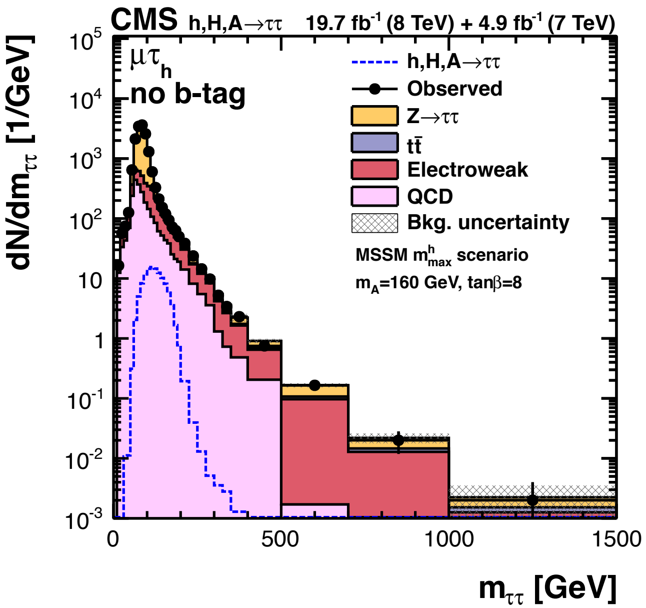
MSSM H→ττ

Event Categorisation

Gluon Fusion Production (ggΦ)

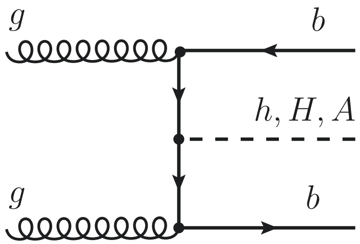
No B-Tag: = 0 b-tagged jets

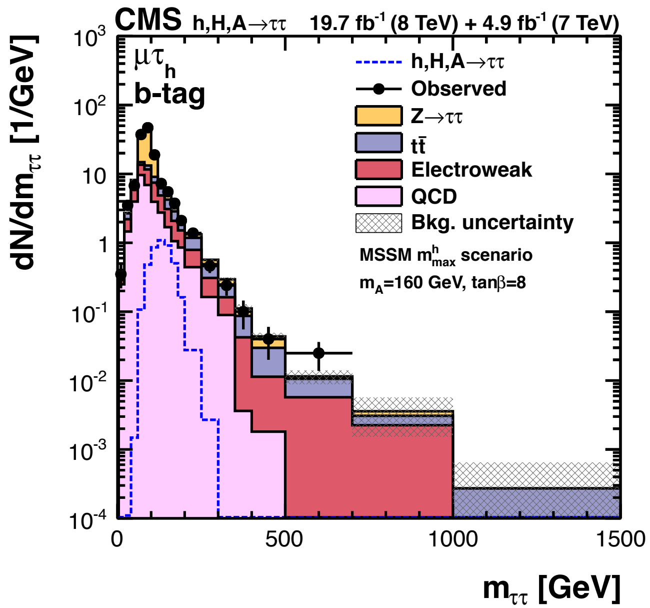




b-Associated Production (bbΦ)

B-Tag: ≥1 b-tagged jet, ≤ 1 jet

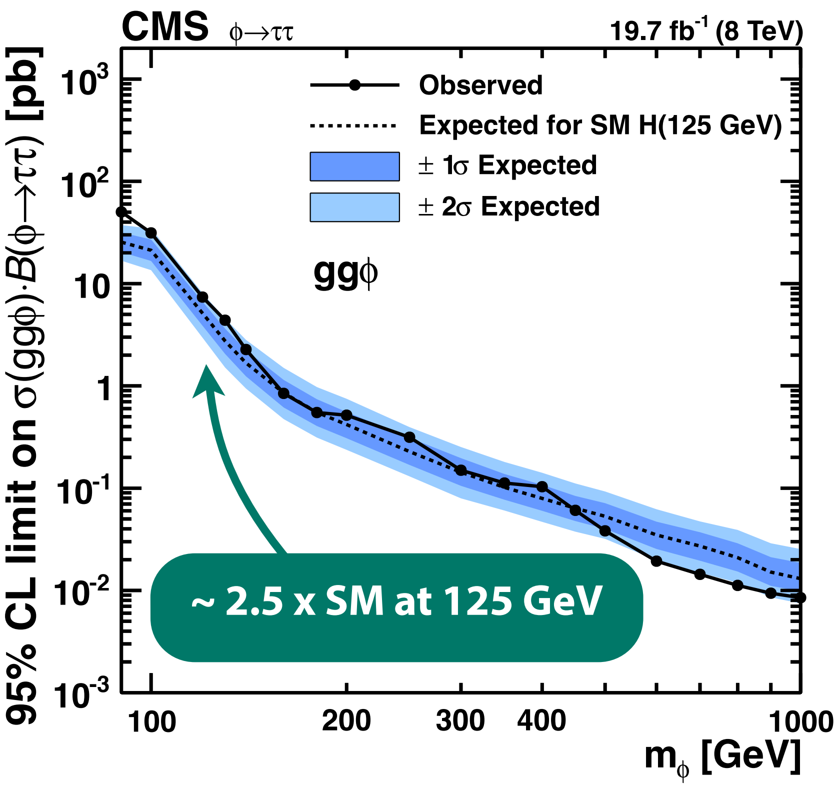


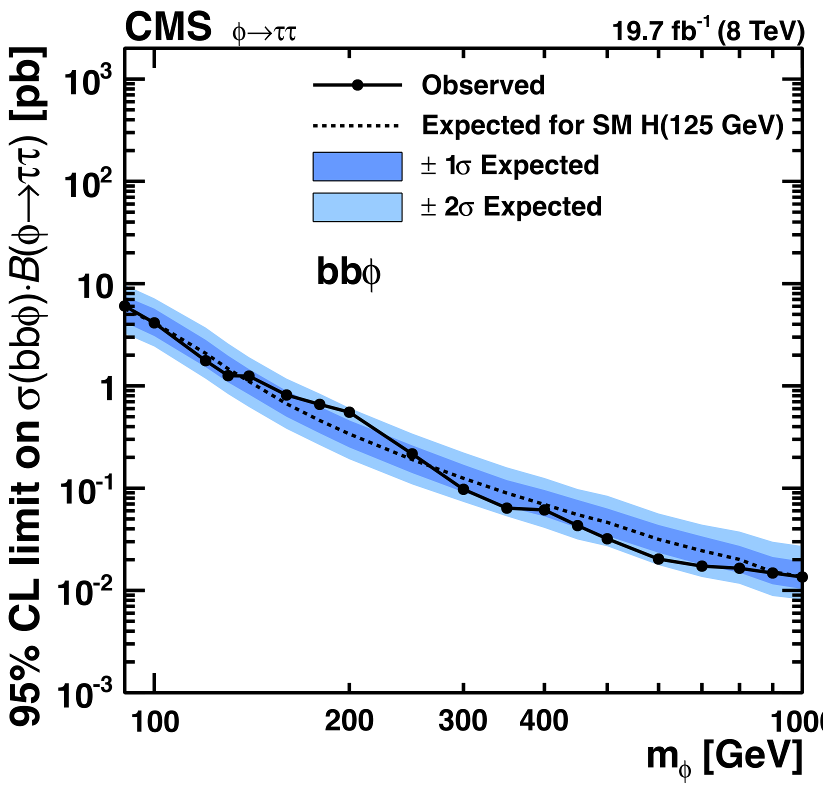


1D Limits

- Set limits on each process in turn - other process is profiled
- Expected limit for presence of h(125) in dataset
- Less sensitive to ggh(125) than SM analysis

$$q_\mu = -2\ln\frac{\mathcal{L}(\mathrm{data}\mid\mu\cdot s+b,\hat{\theta}_\mu)}{\mathcal{L}(\mathrm{data}\mid\hat{\mu}\cdot s+b,\hat{\theta})}$$

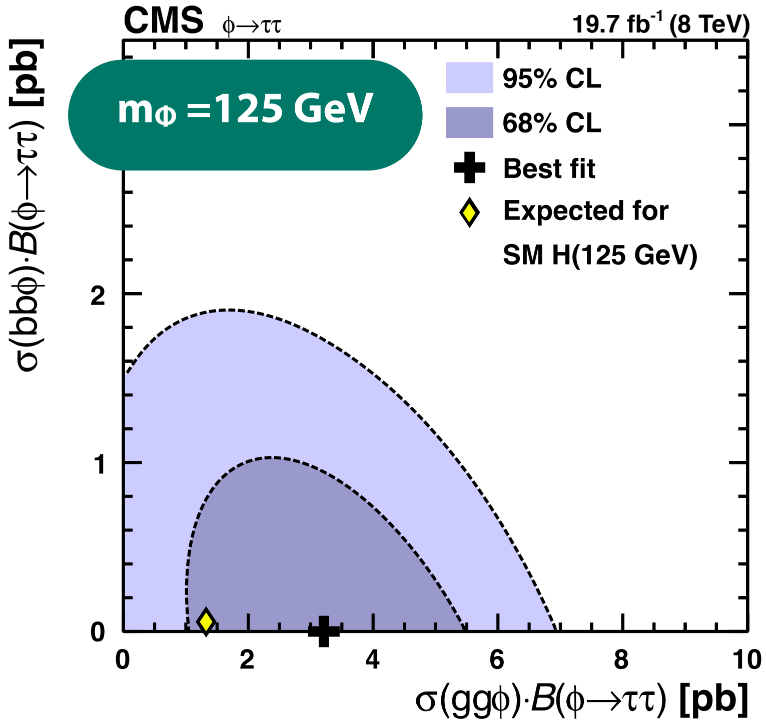


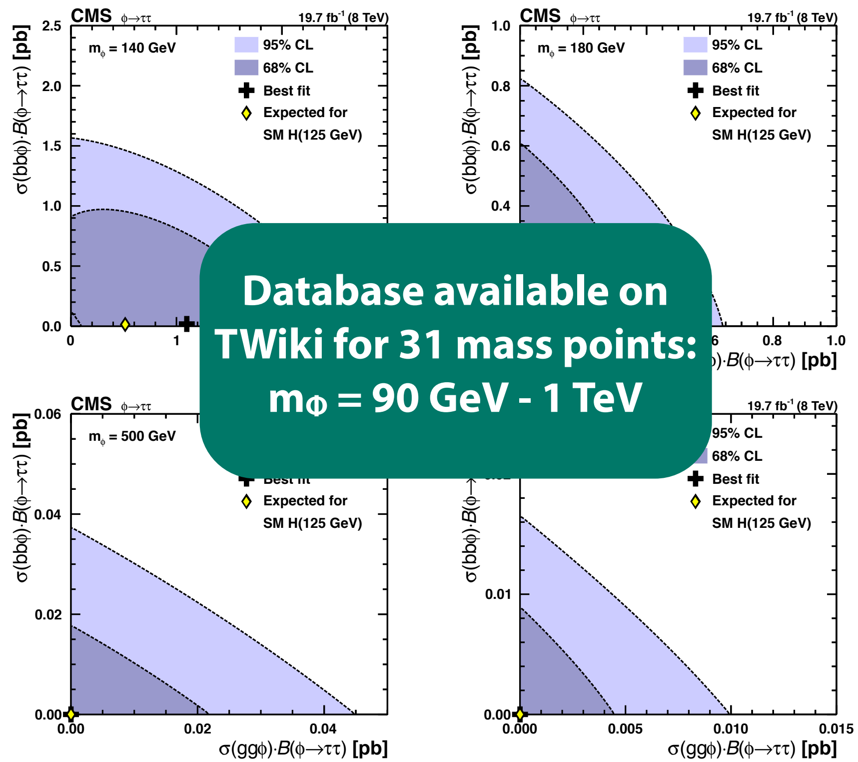


2D Model Independent Limits

- Search for a single narrow resonance Φ, produced in ggΦ and bbΦ modes
  - Assume independent cross section for each process
- Determine **best-fit σ·BR**, 68% and 95% CL regions
- Provide 3D database of likelihood values for interpretation in other models

m_Φ =125 GeV



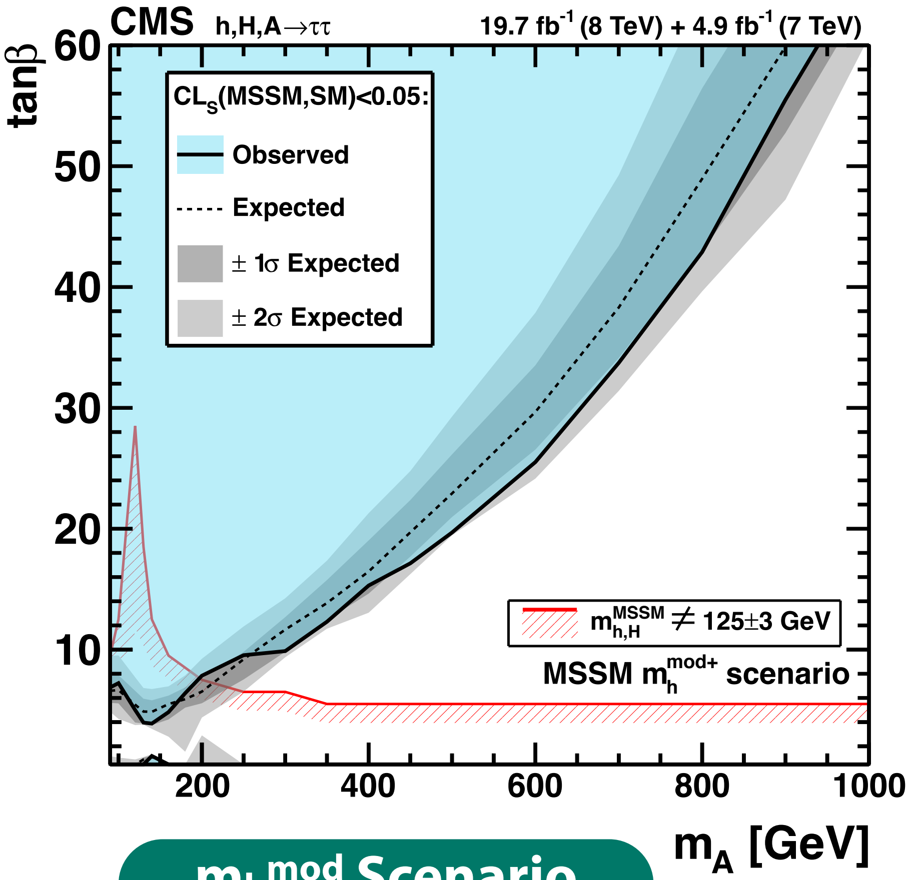


Database available on TWiki for 31 mass points: m_Φ = 90 GeV - 1 TeV

$$q_\mu = -2\ln\frac{\mathcal{L}(\text{data}\mid \boldsymbol{\mu}\cdot \boldsymbol{s}+b,\hat{\theta}_\mu)}{\mathcal{L}(\text{data}\mid \hat{\boldsymbol{\mu}}\cdot \boldsymbol{s}+b,\hat{\theta})}$$

Model Testing

- Signal modelled as sum of three resonances: h + H + A
- Two free parameters in MSSM benchmark models: **m_A, tanβ**
- These determine: **$m_{[h,H]}$, $\sigma_{gg[h,H,A]}$, $\sigma_{bb[h,H,A]}$, $BR_{[h,H,A]}$**



mhmod Scenario

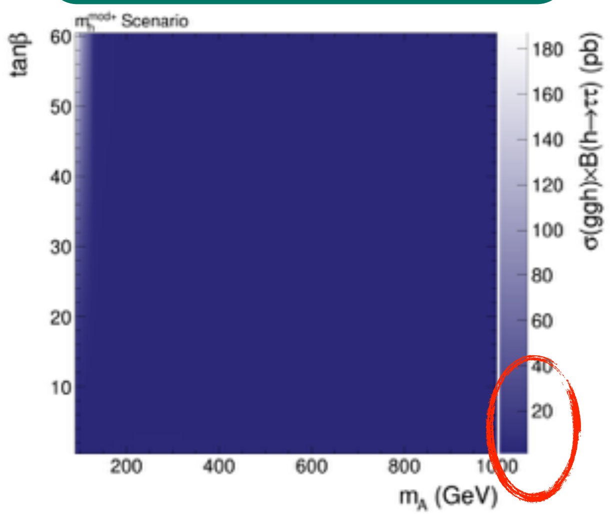
- **Red hatched region:** $m_h \neq 125 \pm 3$ GeV in model
- Evidence for h(125)→ττ decay (> 3σ)
- New test statistic needed: MSSM vs SM hypothesis test

$$q_{\text{MSSMvsSM}} = -2\ln\frac{\mathcal{L}(\text{data}\mid s_{\text{MSSM}}+b,\hat{\theta}_{\text{MSSM}})}{\mathcal{L}(\text{data}\mid s_{\text{SM}}+b,\hat{\theta}_{\text{SM}})}$$

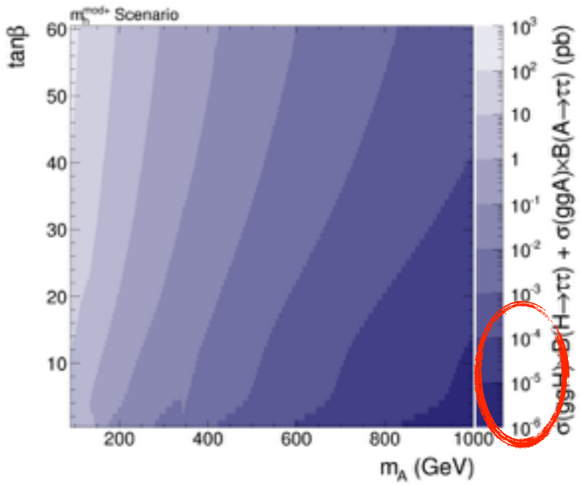
Why MSSM vs SM?

- In Run II: sensitivity reaches ~ 1x SM Higgs @ 125 GeV
  - ⇒ Not just a problem at low m_A
- At high m_A: $\sigma \times B$ for A+H production drops rapidly as tanβ
  - SM-like h stays ~ 1.2 pb
- In the presence of h(125) only a significant MSSM signal would appear
  - **$q_{MSSMvsSM}$ protects against this**

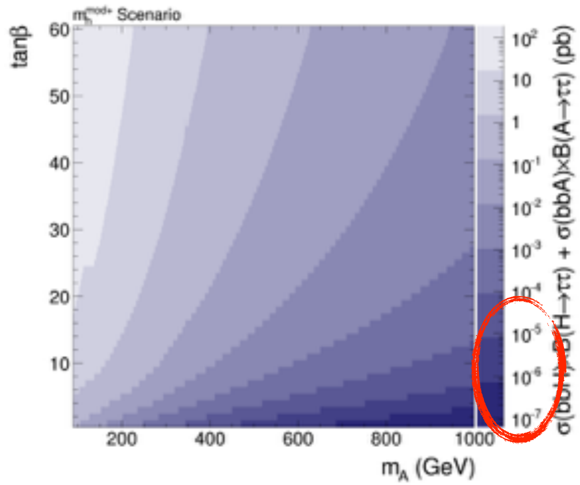
σxBR ggh [pb]



σxBR gg(H+A) [pb]



σxBR bb(H+A) [pb]

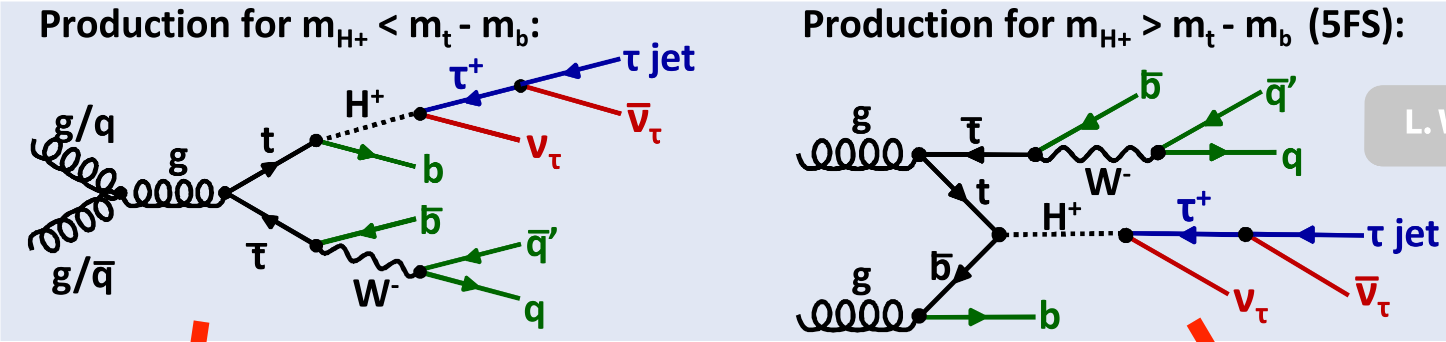


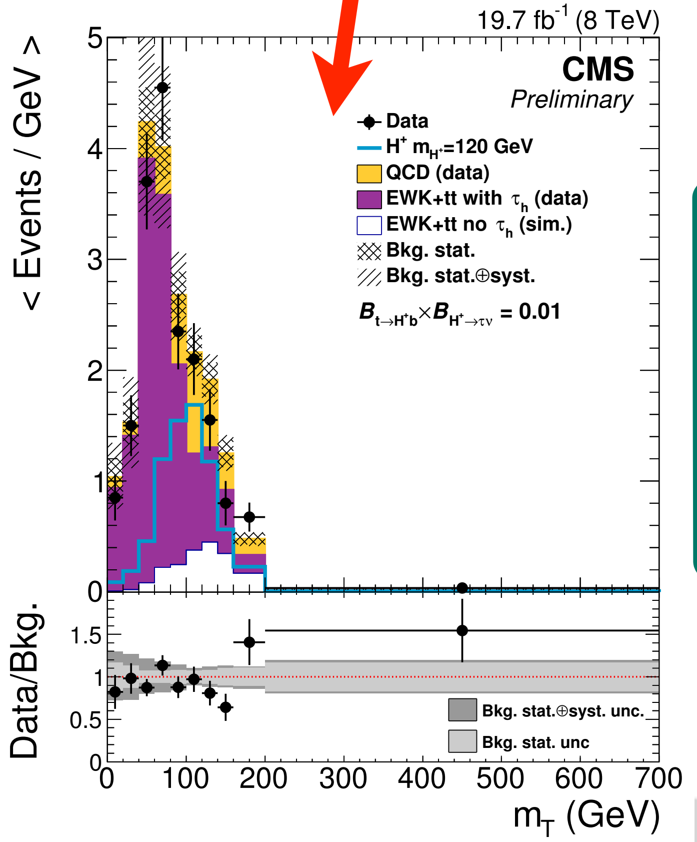
MSSM $H^+ \rightarrow \tau\nu$

Charged Higgs: $H^+ \to \tau_h \nu$

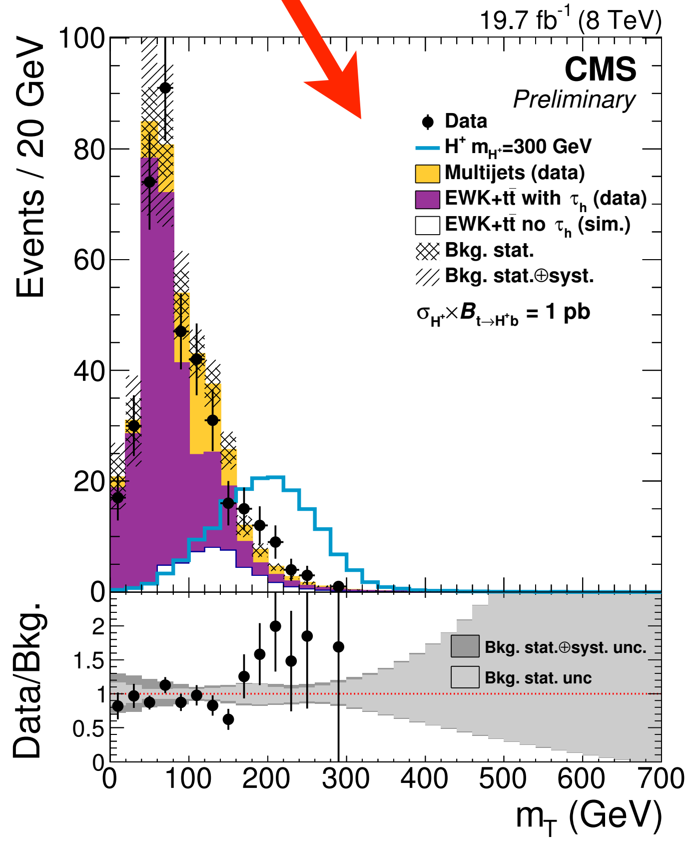
HIG-14-020

L. Wendland



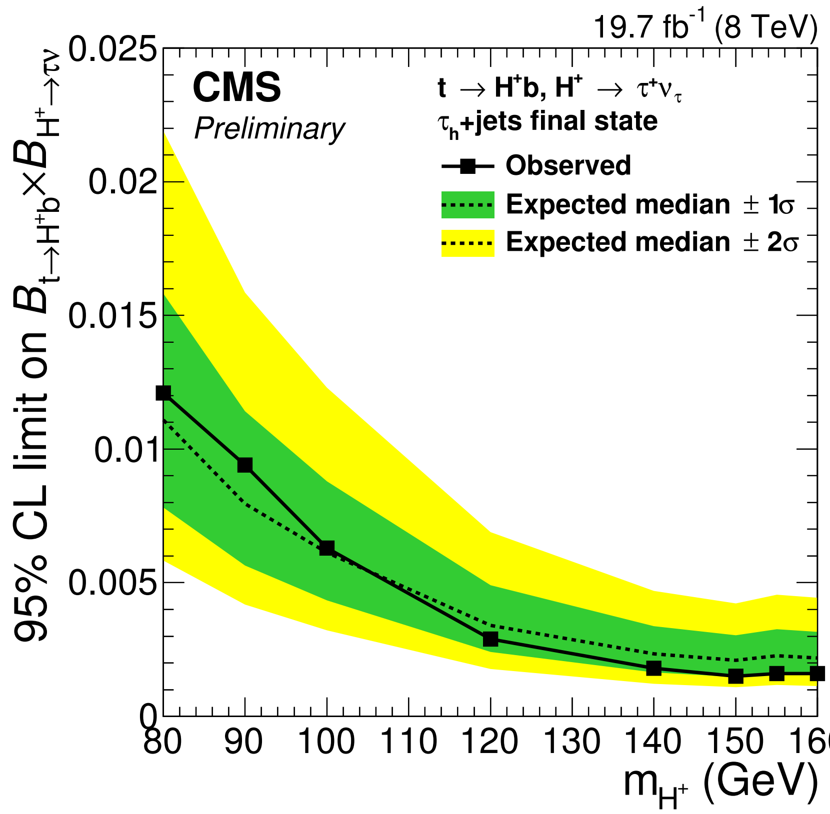


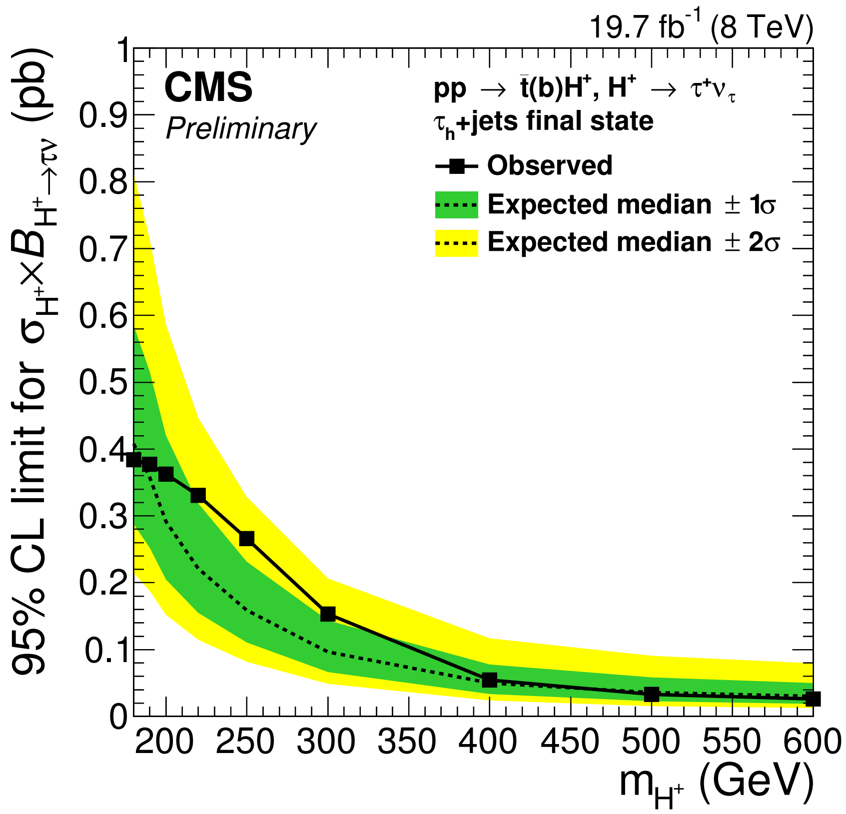
Fit $m_T(\tau_h, E_T^{miss})$ to discriminate against main EWK+tt bkg.



Model-independent Limits

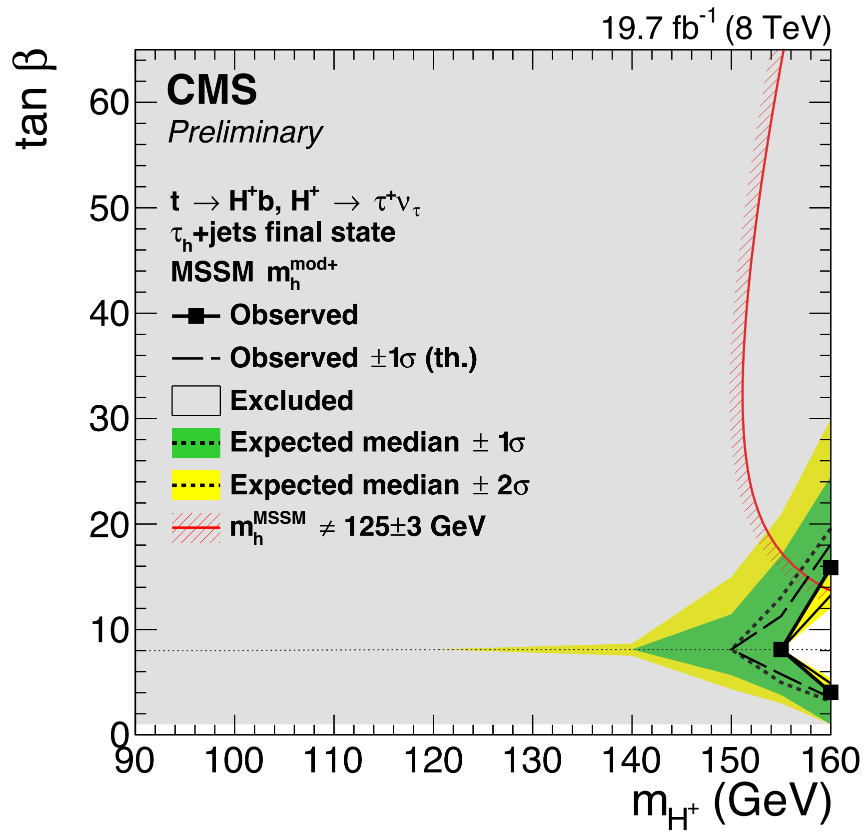
- 95 % CL upper limit on **$B(t \rightarrow bH^+) * B(H^+ \rightarrow \tau^+ \nu_\tau)$**:
  - **1.2–0.16 % for m_{H+} = 80-160 GeV**
- 95 % CL upper limit on **$\sigma(pp \rightarrow tbH^+) * B(H^+ \rightarrow \tau^+ \nu_\tau)$**:
  - **0.38–0.026 pb for m_{H+} = 180-600 GeV**

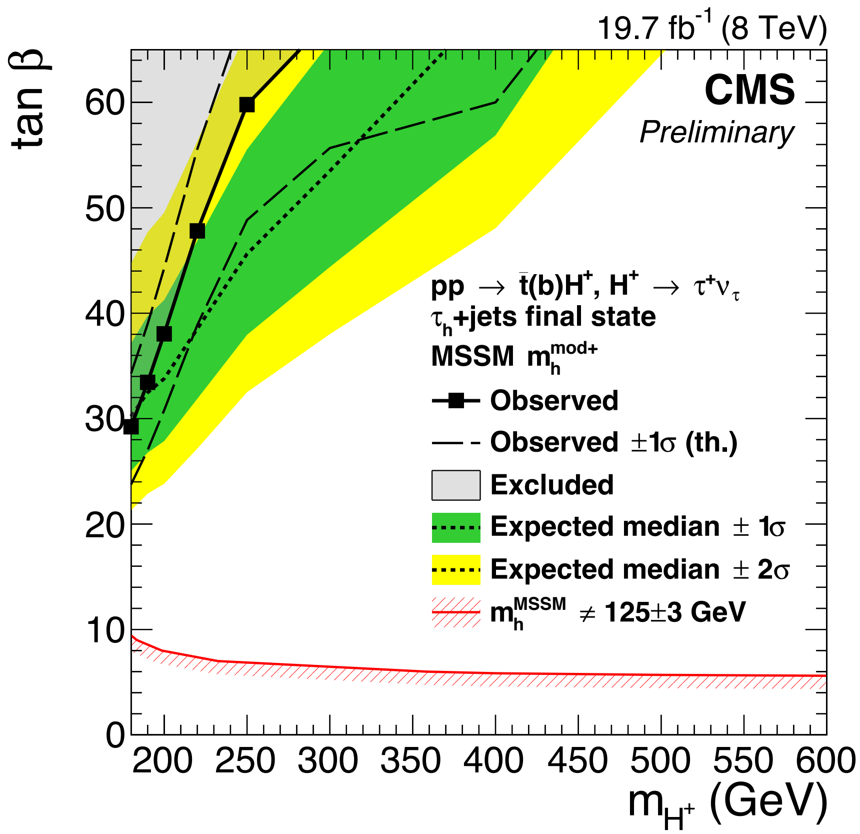




Benchmark Model Limits

- Re-interpret limits in **m_{H+},tanβ** plane
- **Red hatched region:** $m_h \neq 125 \pm 3$ GeV in model
- m_{H+} excluded for $m_{H+} < 155$ GeV

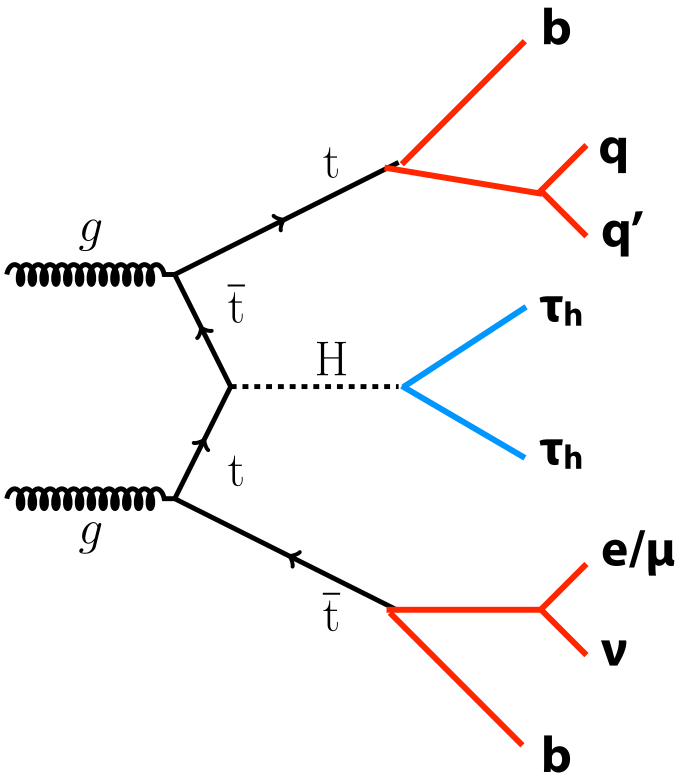




ttH(ττ)

ttH(ττ)

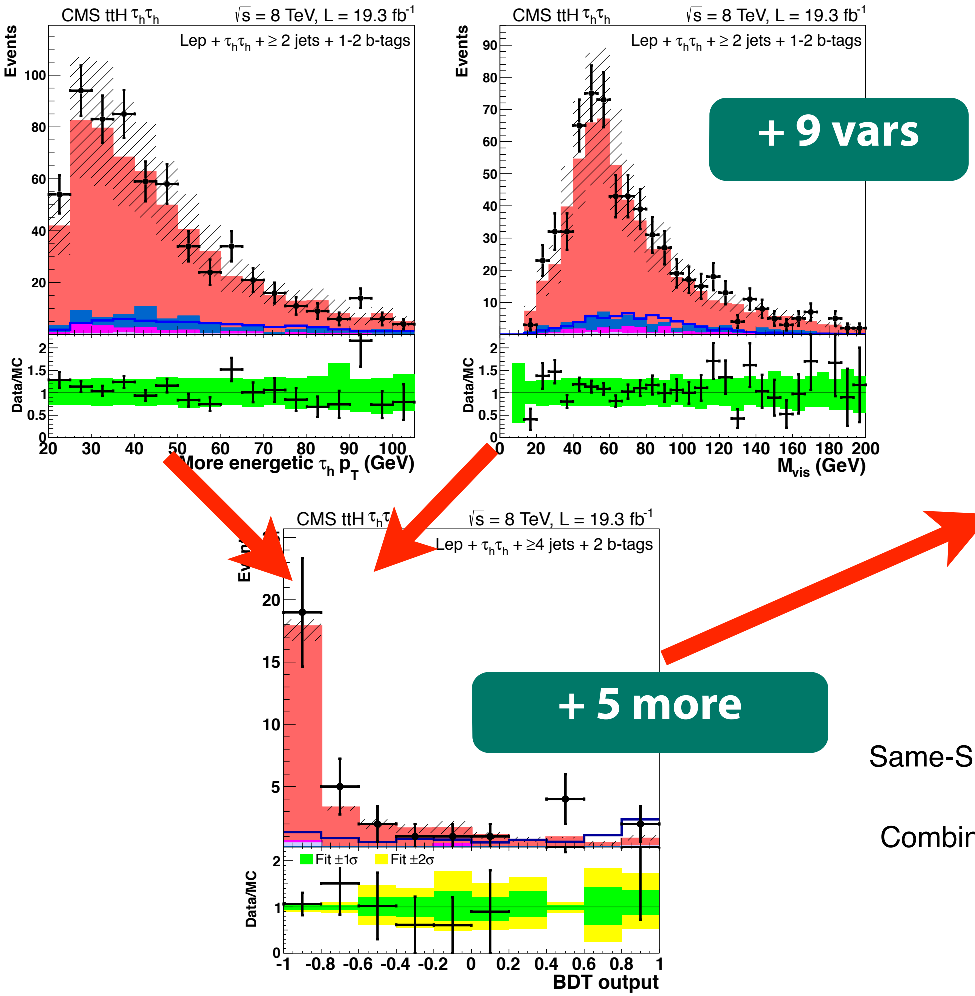
- Combination of many ttH channels separated by production & decay modes
- Exploit multi-jet, multi-b-jet and multi-lepton final states
- Look for fully-hadronic H→ττ decays in semi-leptonic production
  - Additional contribution of H→ττ→leptons in other channels



Category	Signature	Trigger	Signature
H → Hadrons H → $b\bar{b}$ H → $\tau_h\tau_h$ H → WW	Lepton + Jets ($t\bar{t}H \to \ell\nu jjbbbb$)	Single Lepton	1 e/μ, $p_T > 30$ GeV $\geq$4 jets + $\geq$2 b-tags, $p_T > 30$ GeV
	Dilepton ($t\bar{t}H \to \ell\nu\ell\nu bbbb$)	Dilepton	1 e/μ, $p_T > 20$ GeV 1 e/μ, $p_T > 10$ GeV $\geq$3 jets + $\geq$2 b-tags, $p_T > 30$ GeV
	Hadronic τ ($t\bar{t}H \to \ell\nu\tau_h[\nu]\tau_h[\nu]jjbb$)	Single Lepton	1 e/μ, $p_T > 30$ GeV 2 τ_h, $p_T > 20$ GeV $\geq$2 jets + 1-2 b-tags, $p_T > 30$ GeV
H → Photons H → $\gamma\gamma$	Leptonic ($t\bar{t}H \to \ell\nu jjbb\gamma\gamma$, $t\bar{t}H \to \ell\nu\ell\nu bb\gamma\gamma$)	Diphoton	2 γ, $p_T > m_{\gamma\gamma}/2\,(25)$ GeV for 1st (2nd) $\geq$1 e/μ, $p_T > 20$ GeV $\geq$2 jets + $\geq$1 b-tags, $p_T > 25$ GeV
	Hadronic ($t\bar{t}H \to jjjjbb\gamma\gamma$)	Diphoton	2 γ, $p_T > m_{\gamma\gamma}/2\,(25)$ GeV for 1st (2nd) 0 e/μ, $p_T > 20$ GeV $\geq$4 jets + $\geq$1 b-tags, $p_T > 25$ GeV
H → Leptons H → WW H → $\tau\tau$ H → ZZ	Same-Sign Dilepton ($t\bar{t}H \to \ell^{\pm}\nu\ell^{\pm}[\nu]jjj[j]bb$)	Dilepton	2 e/μ, $p_T > 20$ GeV $\geq$4 jets + $\geq$1 b-tags, $p_T > 25$ GeV
	3 Lepton ($t\bar{t}H \to \ell\nu\ell[\nu]\ell[\nu]j[j]bb$)	Dilepton, Trielectron	1 e/μ, $p_T > 20$ GeV 1 e/μ, $p_T > 10$ GeV 1 $e(\mu)$, $p_T > 7(5)$ GeV $\geq$2 jets + $\geq$1 b-tags, $p_T > 25$ GeV
	4 Lepton ($t\bar{t}H \to \ell\nu\ell\nu\ell[\nu]\ell[\nu]bb$)	Dilepton, Trielectron	1 e/μ, $p_T > 20$ GeV 1 e/μ, $p_T > 10$ GeV 2 $e(\mu)$, $p_T > 7(5)$ GeV $\geq$2 jets + $\geq$1 b-tags, $p_T > 25$ GeV

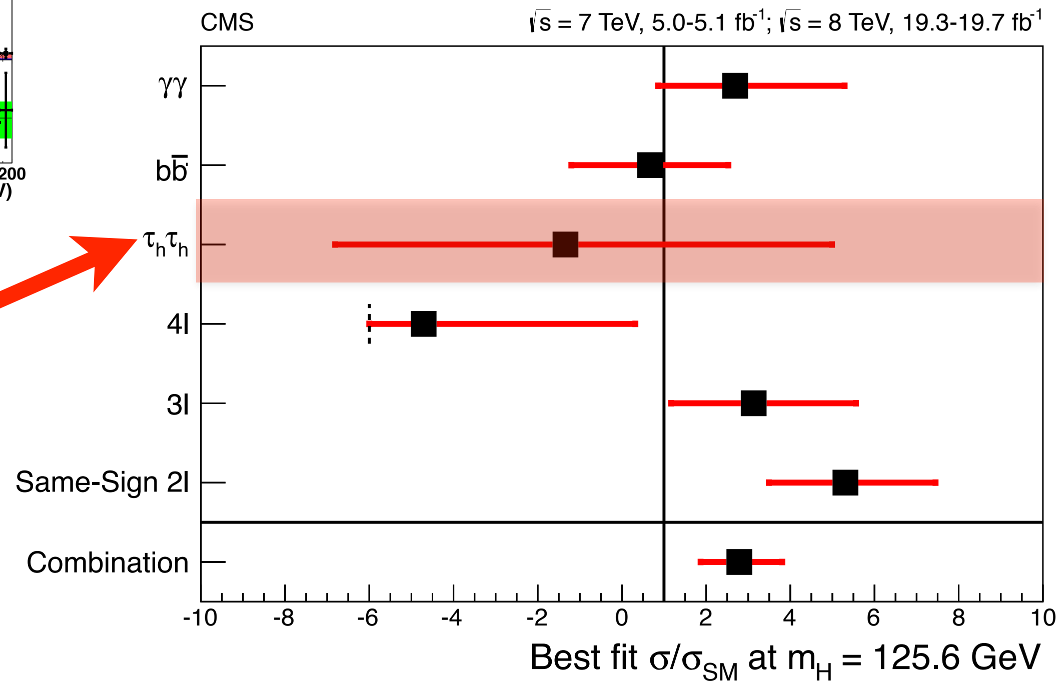
ttH(ττ)

- BDT trained to separate signal from tt+jets backgrounds
  - Input variables include object kinematics and b-tagging information



- 6 categories based on N(jets) x N(b-jets):
  - (2, 3, 4) * (1, 2)

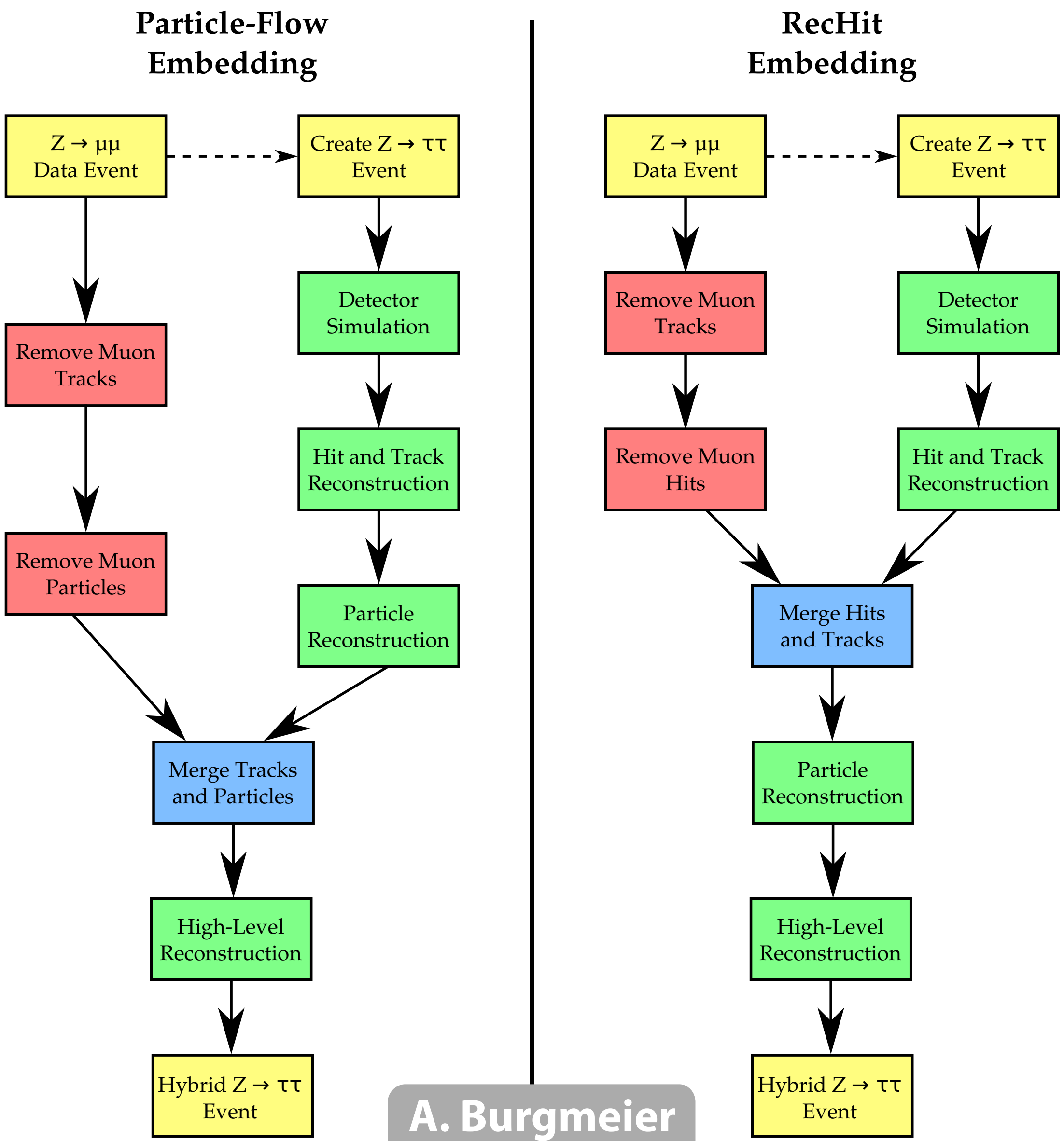
$\mu = -1.3^{+6.3}_{-5.5}$



Embedding

Embedding

- **Can perform embedding at different levels:**
- **Particle-flow:**
  - Merge at the level of final reconstructed particles
- **RecHit:**
  - Merge earlier - at the level of calorimeter and muon chamber hits
- In both cases merge tracks after reconstruction

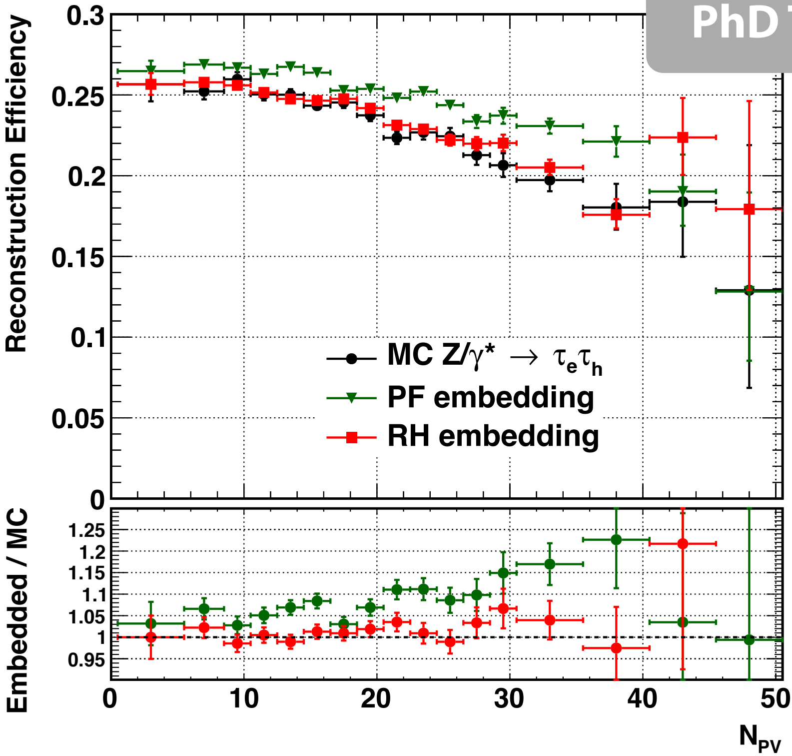


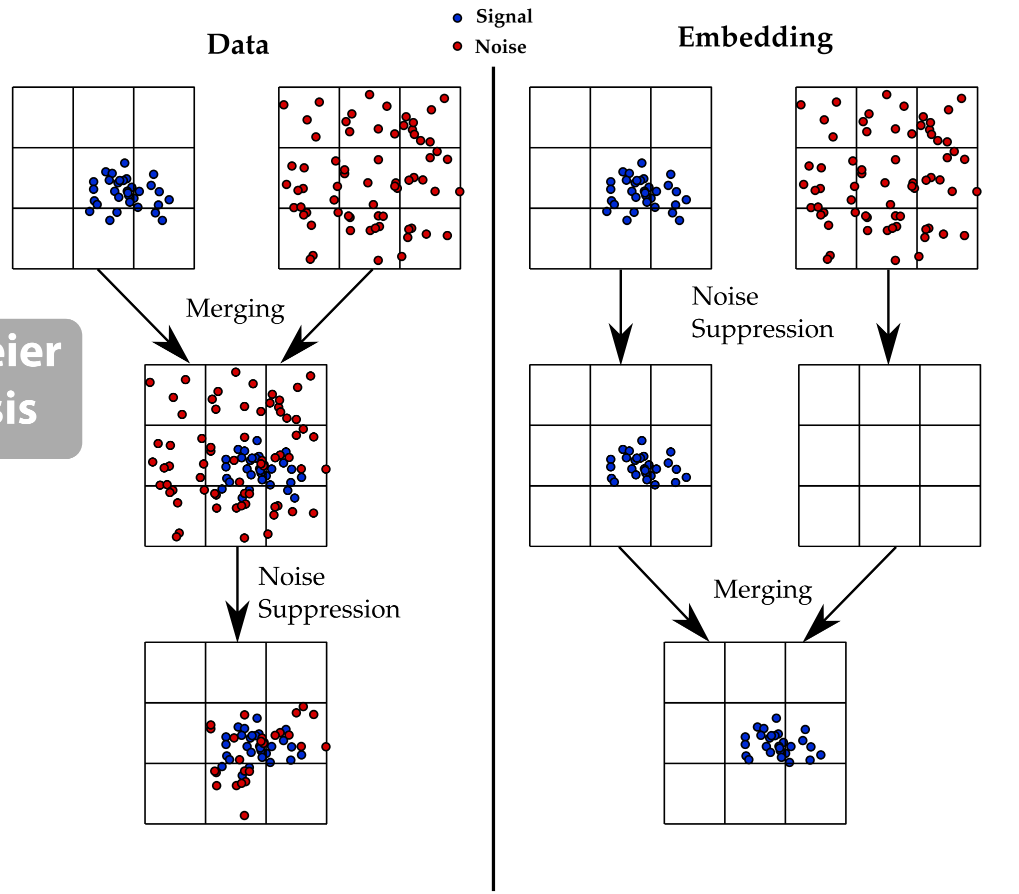
A. Burgmeier PhD Thesis

Embedding

- Indication that PF embedding leads to biases at high pileup
- RecHit embedding more robust

A. Burgmeier PhD Thesis





- Still areas for improvement, e.g. handling of detector noise

Summary

- Great success with Run I data
  - Evidence for $h(125)\rightarrow\tau\tau$ decays > 3σ
  - Searches for BSM signatures: MSSM $h/H/A\rightarrow\tau\tau$, $H^{+}\rightarrow\tau\nu$, $h(125)\rightarrow\tau\mu$, more still underway…

- In Run II: $H\rightarrow\tau\tau$ has a big part to play in h(125) measurements and BSM searches

Backup

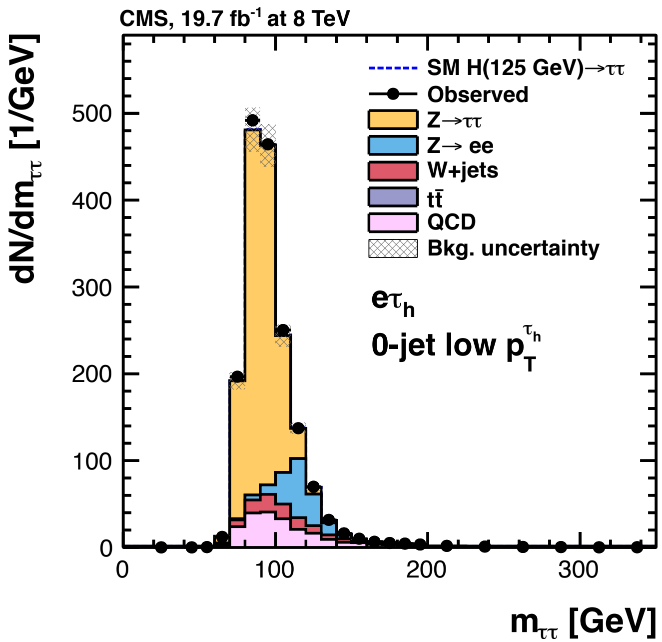
Background Evaluation

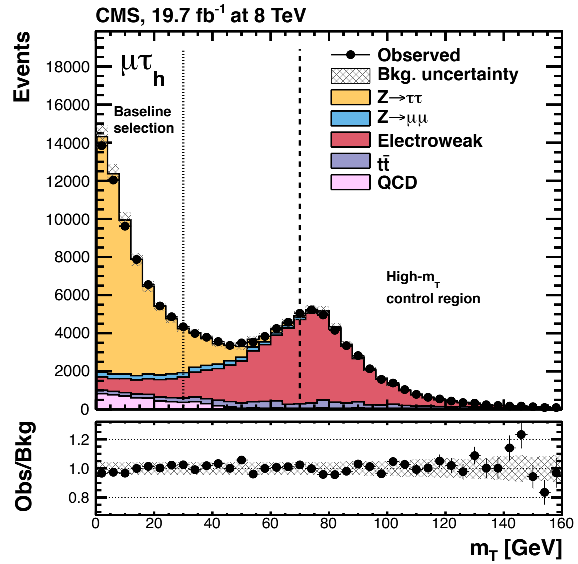
W+jets

- Shape from MC
- Normalisation from high mT sideband in data

Z→ττ

- Normalisation from Z→μμ data
- Embedding: Z→μμ events in data replacing μ with simulated τ
- Provides mass shape and category efficiency





Top

- Shape from MC
- Normalised from sideband (requiring b-jets)

QCD

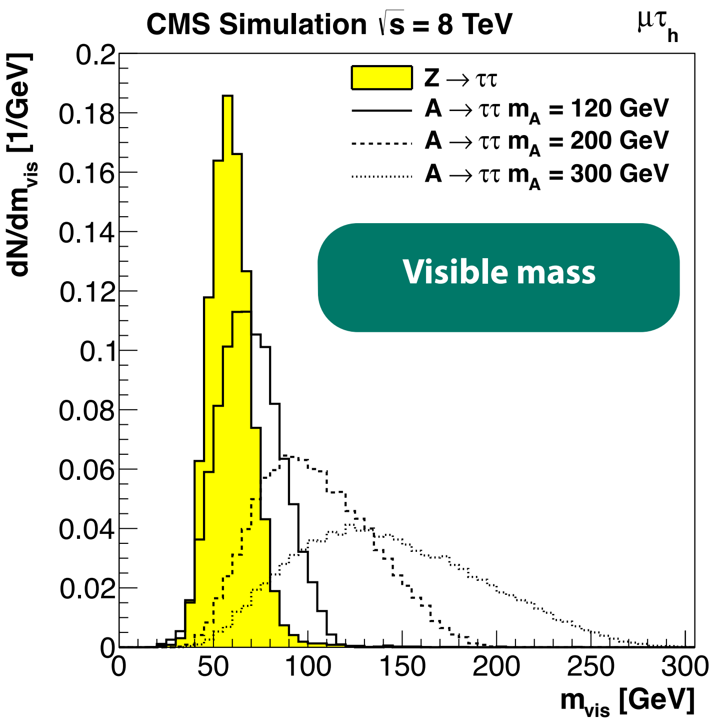
- Shape & normalisation from same-sign data (Subtracting small contribution from other backgrounds in this region)

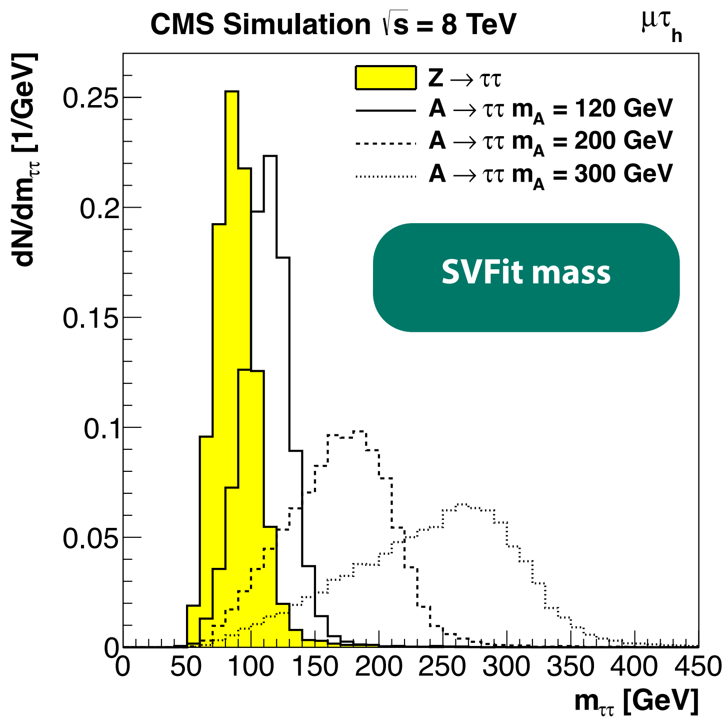
Z→ee/μμ

- Shape from MC, corrected for l→τ fake rate
- Large background in ee/μμ channels. Controlled with inter-lepton DCA

Di-tau Mass Reconstruction

- Always have at least one neutrino when tau decays
- SVFit: event-by-event likelihood-based estimate of full di-tau mass, $m_{\tau\tau}$
- Input is lepton four-momenta, E_T^{miss} and expected E_T^{miss} resolution
- Achieves mass resolution of 10-20%

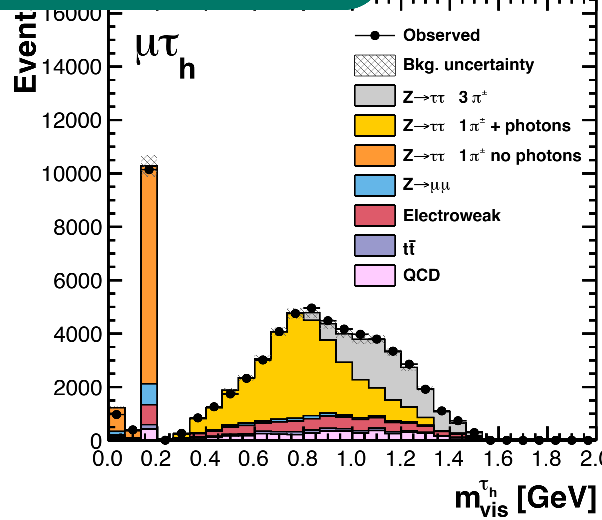


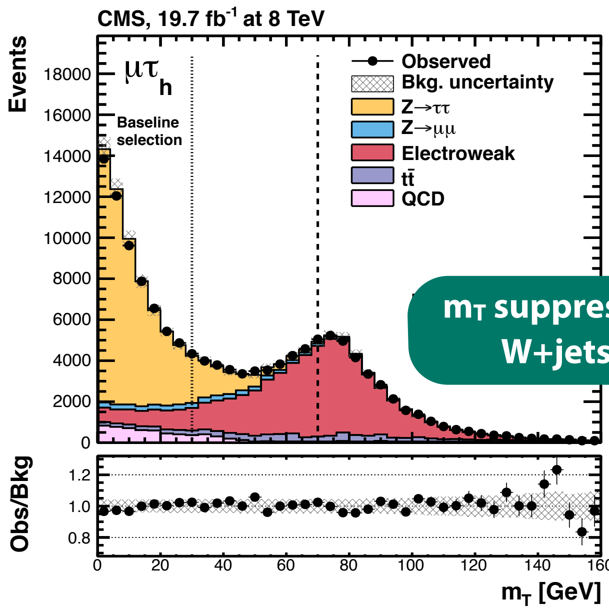


Analysis Strategy

- Require isolated and well-identified leptons to suppress background from fakes (e.g. QCD)
- Exploit PF reconstruction of τ_h
- Topological cuts to suppress backgrounds
- Reconstruct full di-tau mass
- Split events into categories to enhance sensitivity to specific signal processes
- Simultaneous binned likelihood-fit of $m_{\tau\tau}$ distributions in all channels & categories

Use τ_h Mass to Calibrate Energy Scale





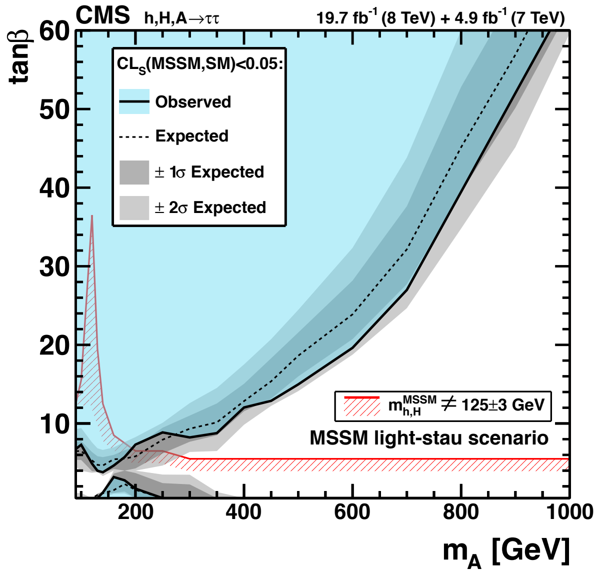
m_T suppresses W+jets

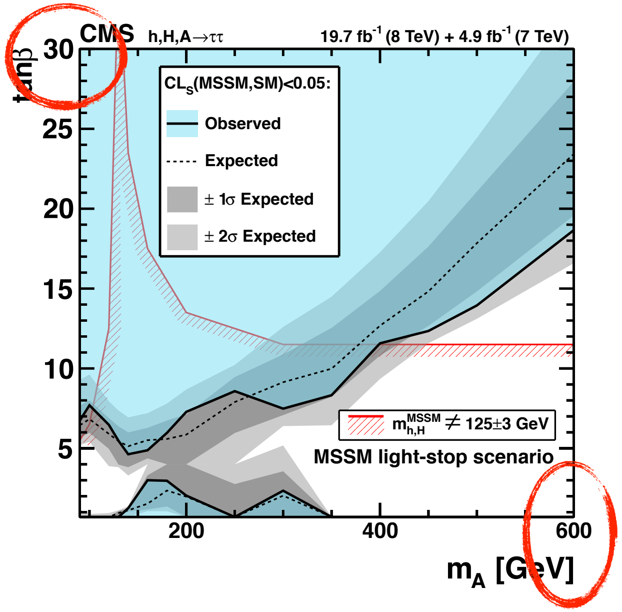
Other Scenarios

arXiv:1302.7033

Light-stau

Enhanced h(125)→ γγ at high tanβ



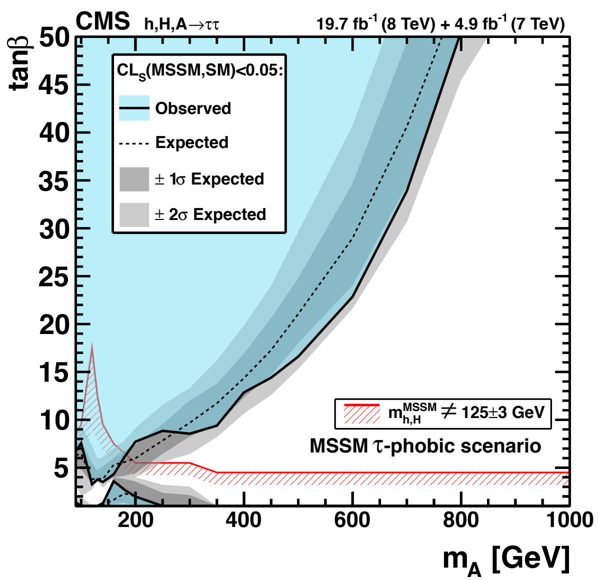


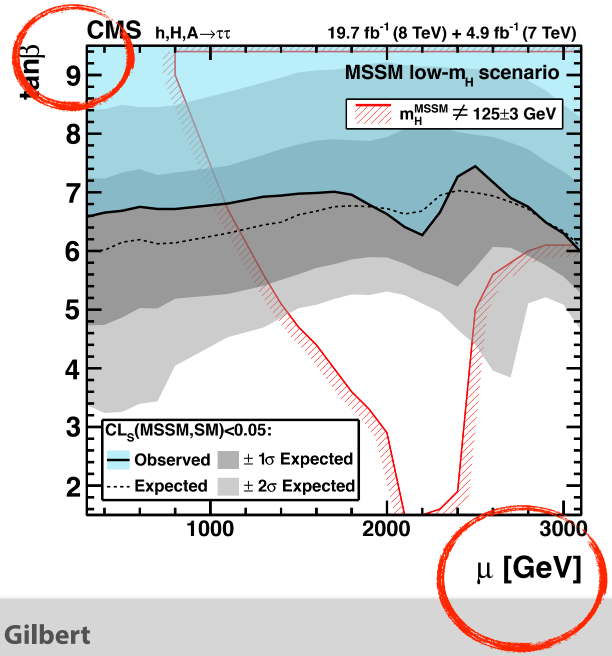
Light-stop

Reduced ggh(125) production

τ-phobic

Reduced BR(h→ττ)





Low-m_H

Interpret H as 125 GeV state