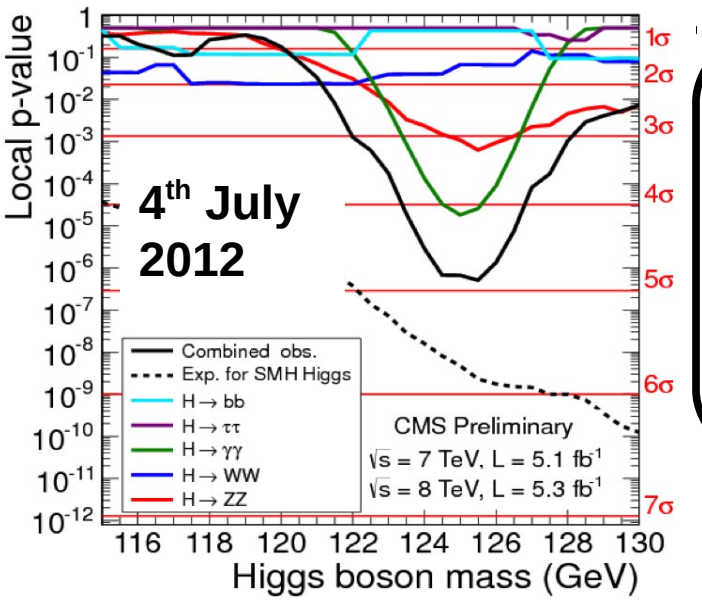
Karlsruhe Institute of Technology

BSM Higgs Searches (CMS)

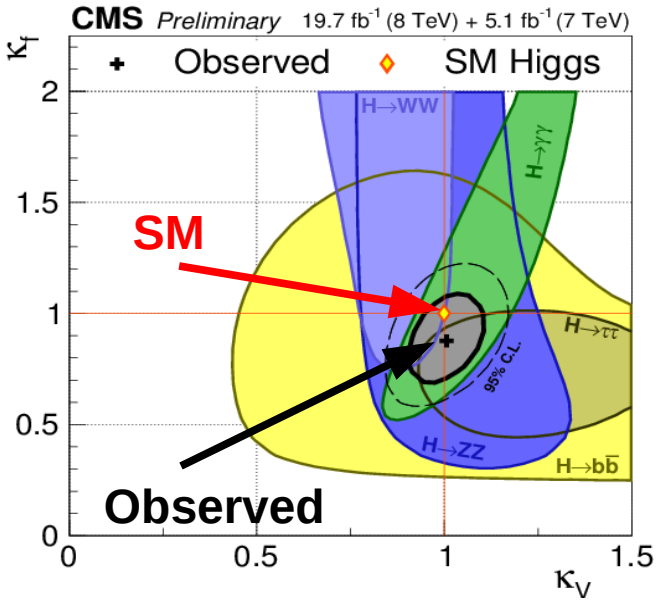
Felix Frensch for the CMS Collaboration
SUSY 2014; Manchester, England; 25th July 2014;

INSTITUTE OF EXPERIMENTAL PARTICLE PHYSICS (IEKP) – PHYSICS FACULTY

Discovery of a new particle at 125 GeV



- Higgs-like particle at 125 GeV
- In O(10%) agreement with Standard Model predictions



Is it *only* the SM Higgs boson?
Two ways to test:

Measure the properties of the new particle.
Search for deviations from the SM predictions.

Search for additional particles (e.g. Higgs bosons).
If a new particle will be discovered the SM is excluded, since it does not predict any more particles.

- Among many theories beyond the Standard Model **SUSY** is a favored one
  - Focus on results which can be interpreted in the MSSM

Outline

3) $X \rightarrow h_{SM} h_{SM} \rightarrow bb\gamma\gamma$

2) $H \rightarrow$ invisibe

4) $H^{+} \rightarrow c\bar{s}$

Many more... (backup)

1) $H \rightarrow \tau\tau$

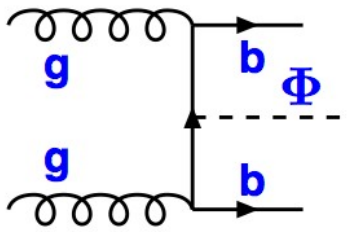
$H \rightarrow \tau\tau$

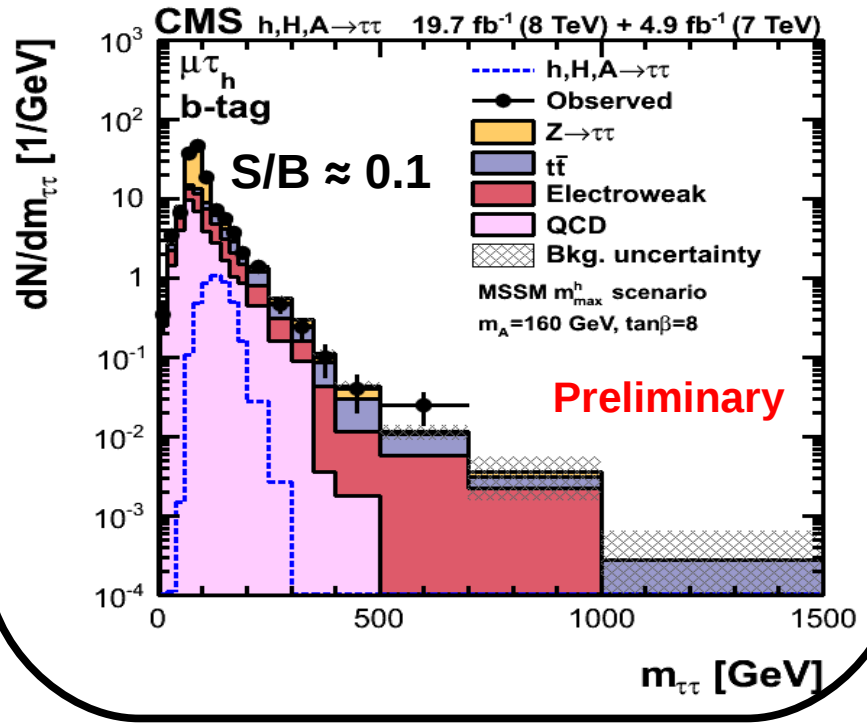
HIG-13-021

First time shown in conference

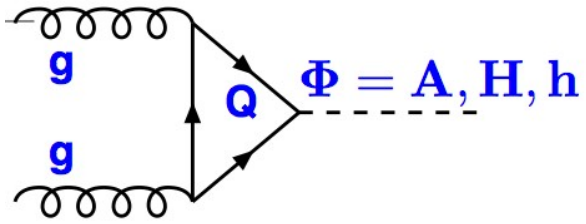
- $e\mu + e\tau_h + \mu\mu + \mu\tau_h + \tau_h\tau_h$ analyzed

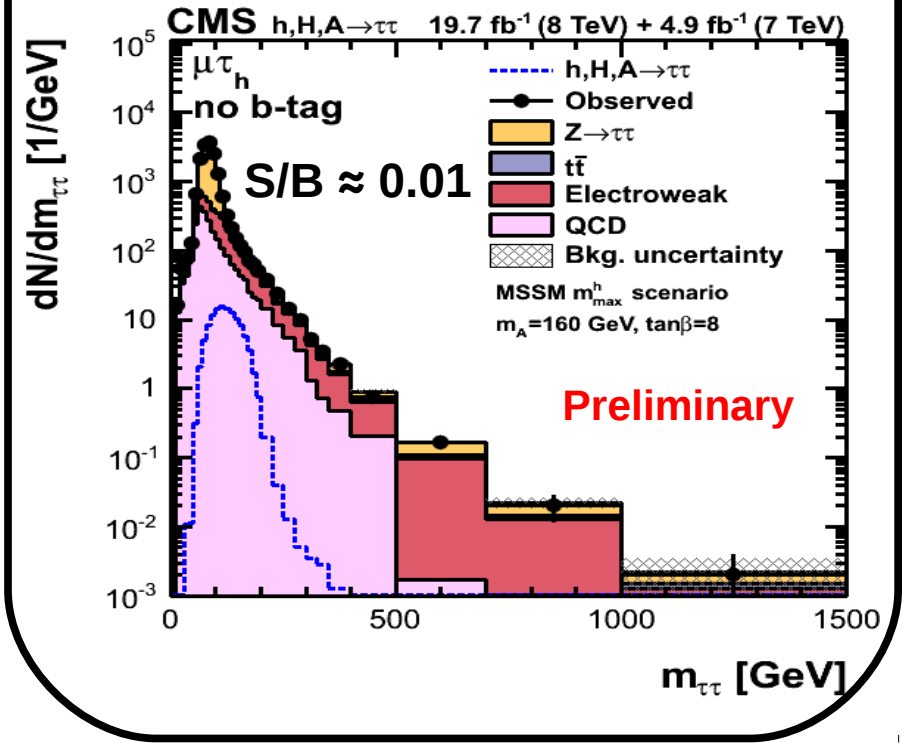
- b-tag category to exploit $bb\Phi$ production



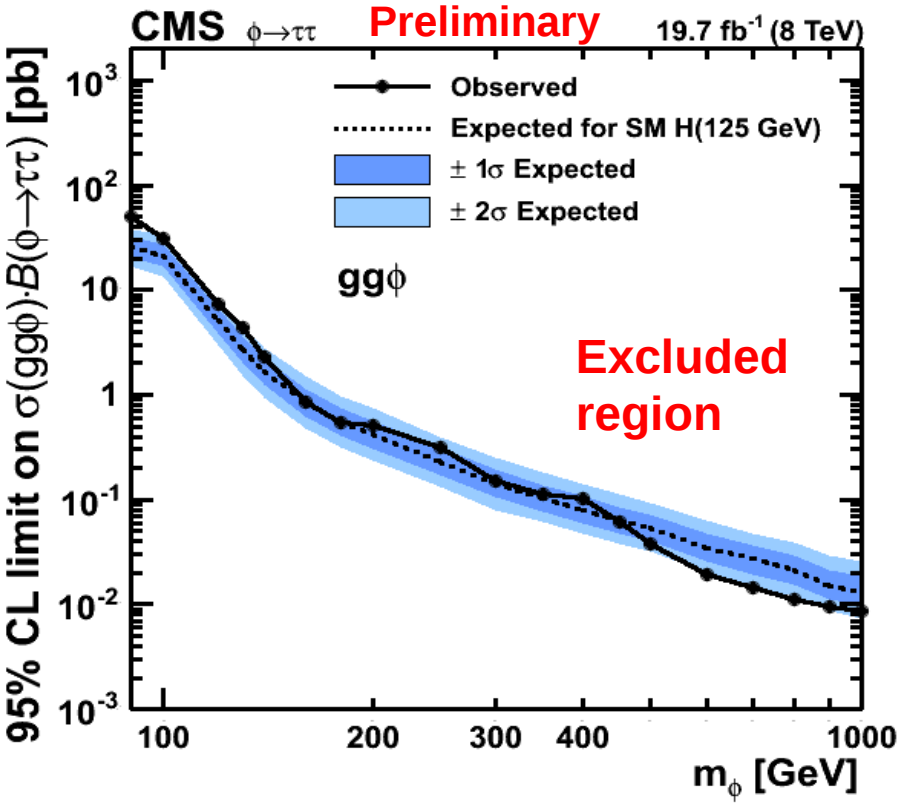


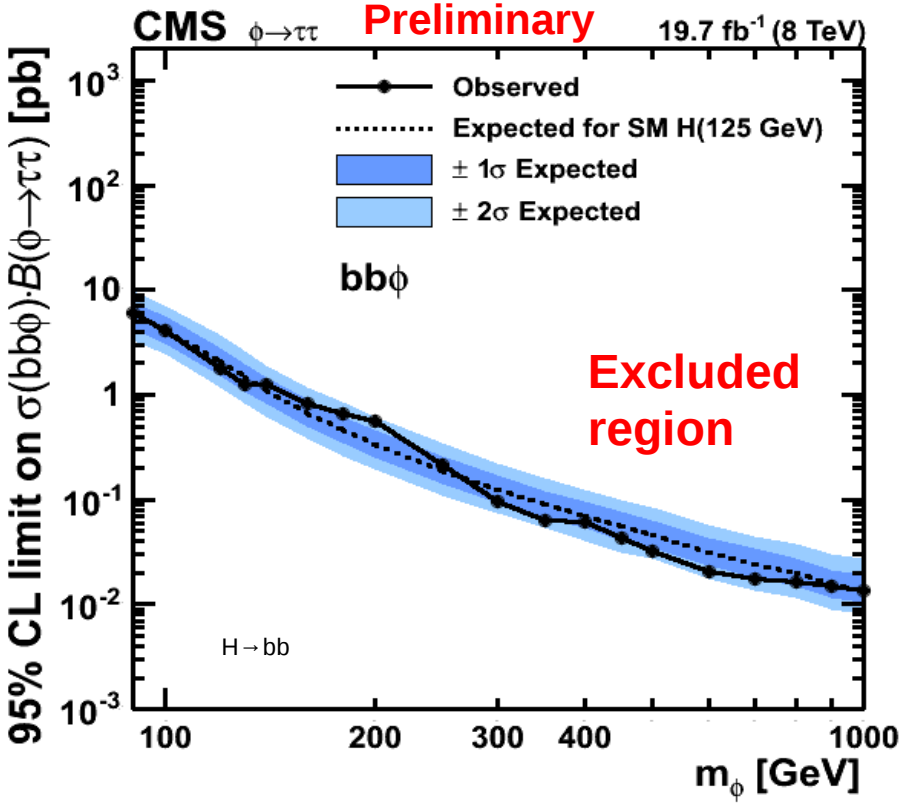
- no-b-tag category to catch $gg\Phi$ processes





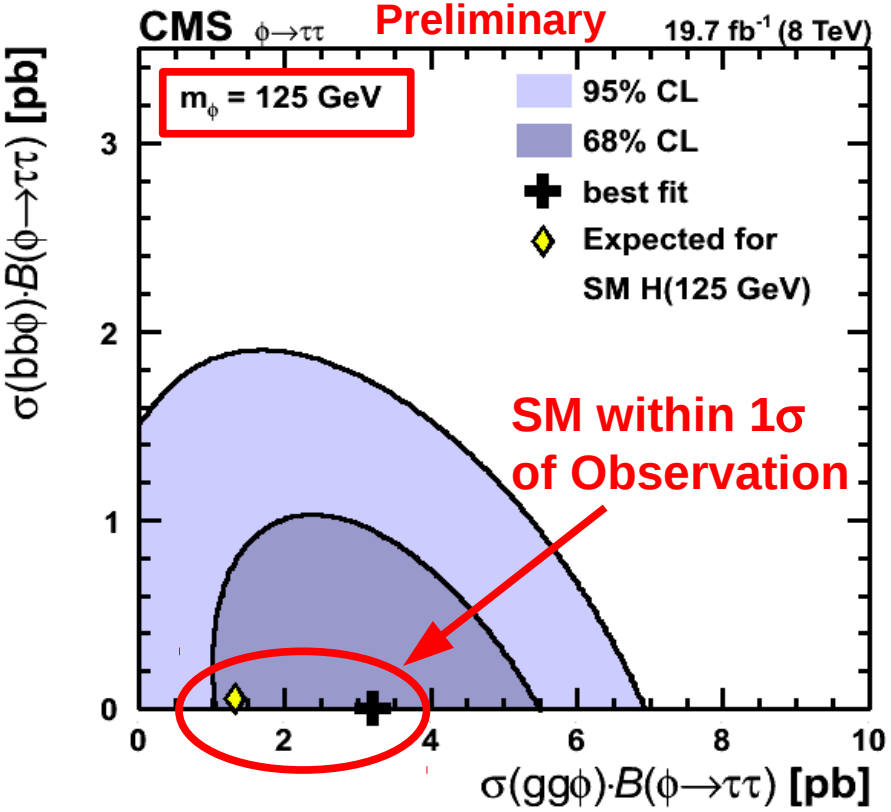
H → ττ : Cross section limits

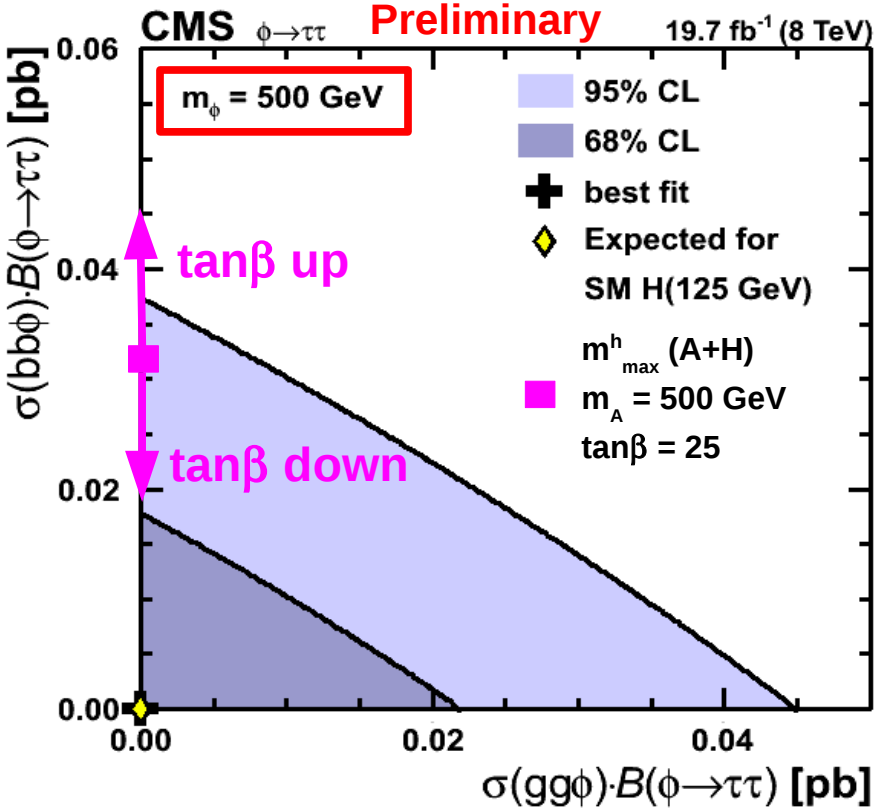




- Calculate σ*BR limit on one process while the other is left floating freely
- Expected limit is computed with a pseudo dataset including the SM Higgs boson at 125 GeV next to the nominal SM backgrounds

H → ττ : comparison with models

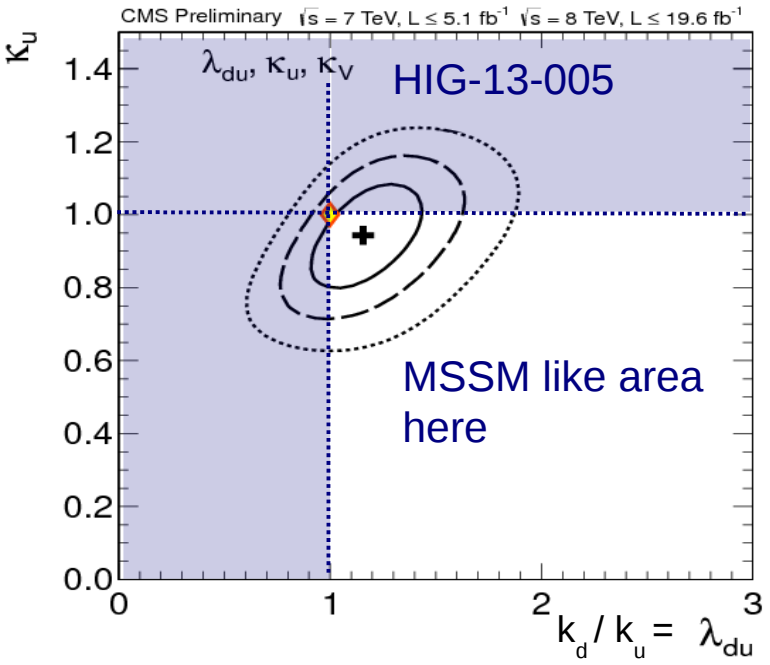




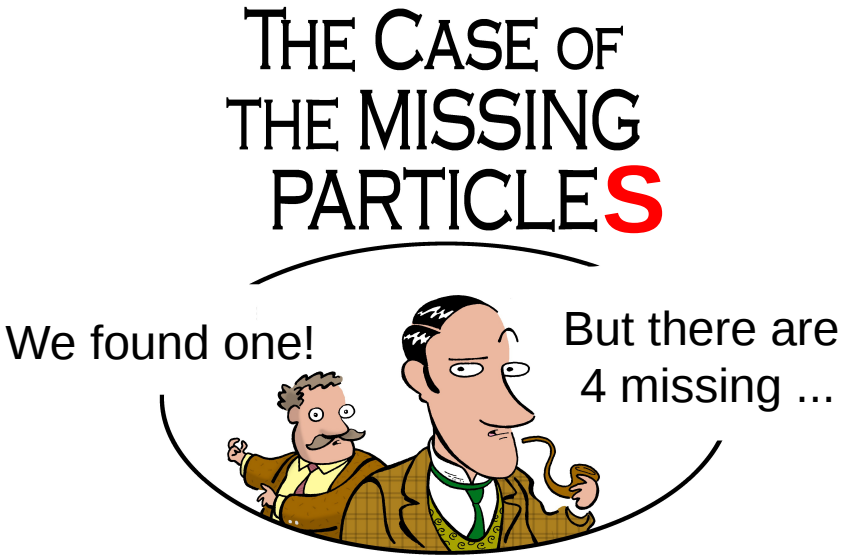
- Search for single narrow resonance
- Likelihood scan of ggΦ – bbΦ – m_Φ space projected to ggΦ – bbΦ plane
  - m_Φ from 90-1000 GeV scanned
- Possibility to compare observation to model predictions

Higgs Bosons in the MSSM

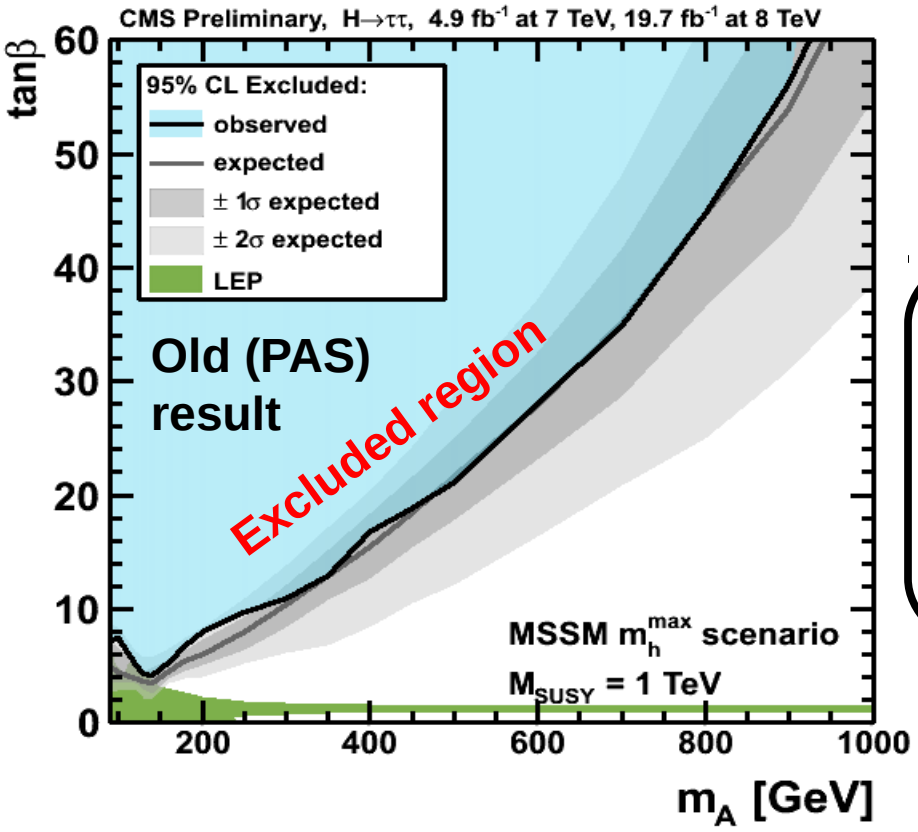
- 2 Higgs doublets in MSSM
- 8 degrees of freedom
  - → 3 Gauge-Bosons W^+, W^-, Z
  - → 5 Higgs-Bosons
    - h, A, H, H^+, H^-



- On tree level Higgs masses defined by m_A and tanβ
  - m_A – mass of pseudoscalar A
  - tanβ – ratio of the vacuum expectation values of the Higgs doublets
- Couplings to down-type quarks usually enhanced



Model dependent interpretations: Old vs New statistical approaches



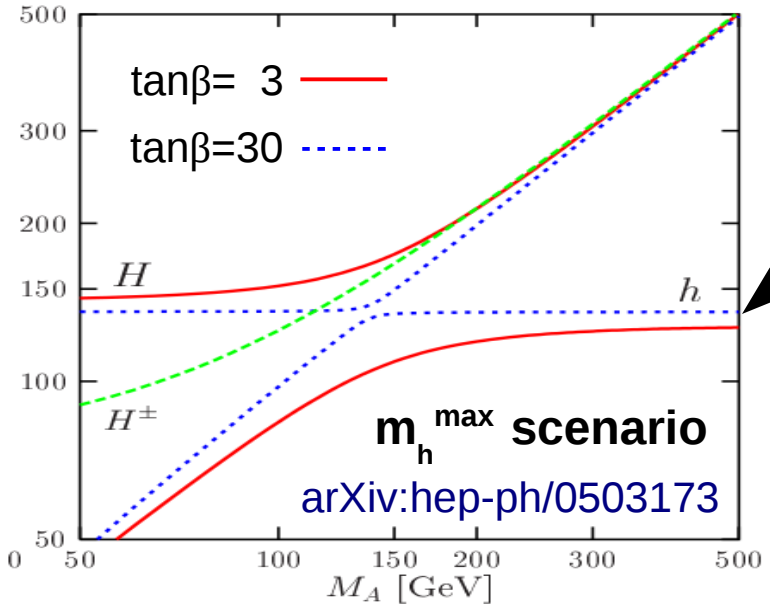
Old approach:

- Testing MSSM vs background only
  - (h+H+A + BG) vs (BG)
- New discovered particle was not taken into account

New Appoach:

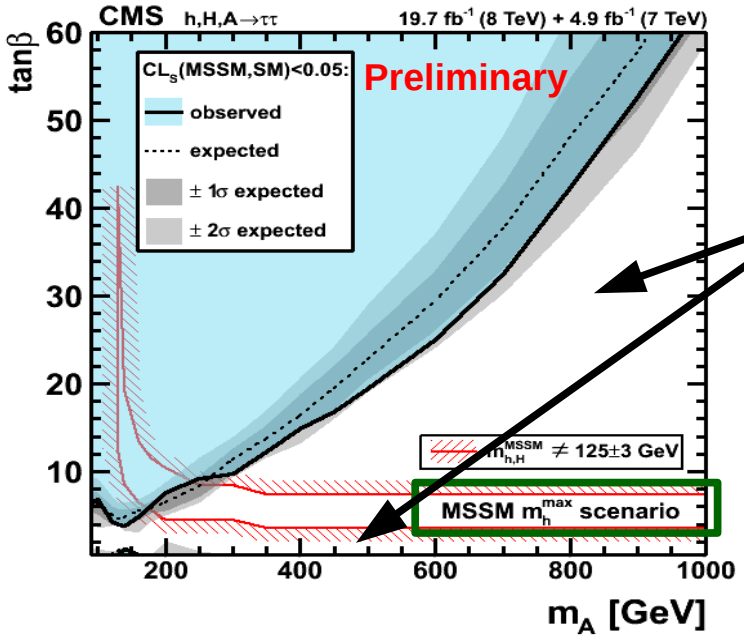
- Take into account the discovered Higgs boson at 125 GeV
- Hypothesis test of MSSM vs SM → (h+H+A + BG) vs (h_{SM} + BG)

Limits on MSSM benchmarks

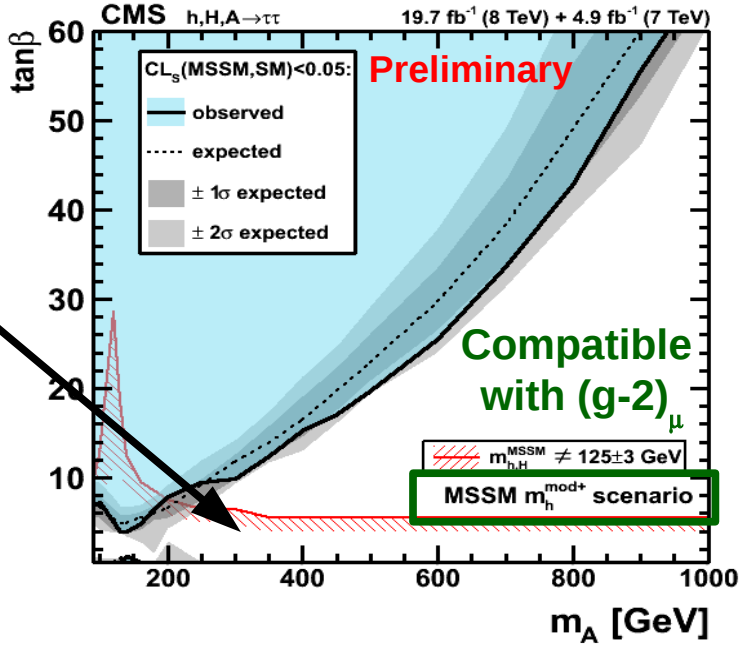


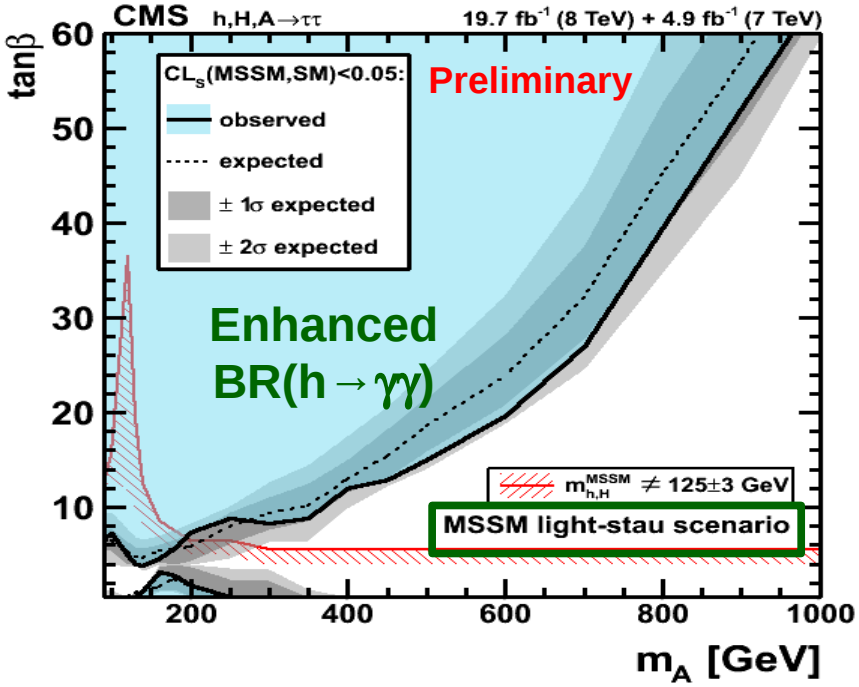
In m_h^{max}: $m_h \approx 130$ GeV.
→ Move to new scenarios with $m_h \approx 125$ GeV.

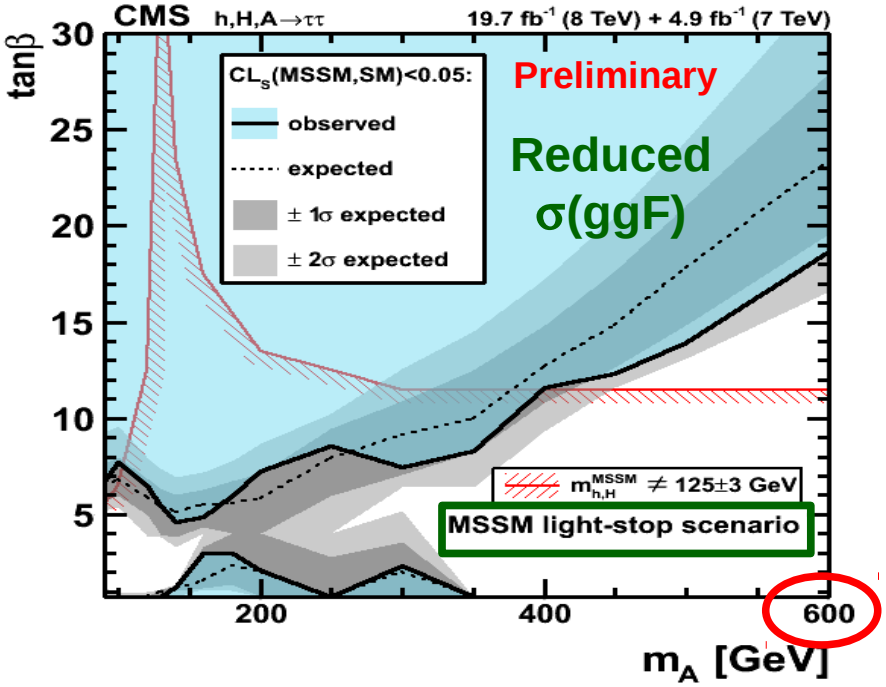
- 6 new MSSM benchmark scenarios:
  Proposed by Carena et al., Eur.Phys.J.C73, 2552 (2013)
- Each addressing a certain **phenomenology**

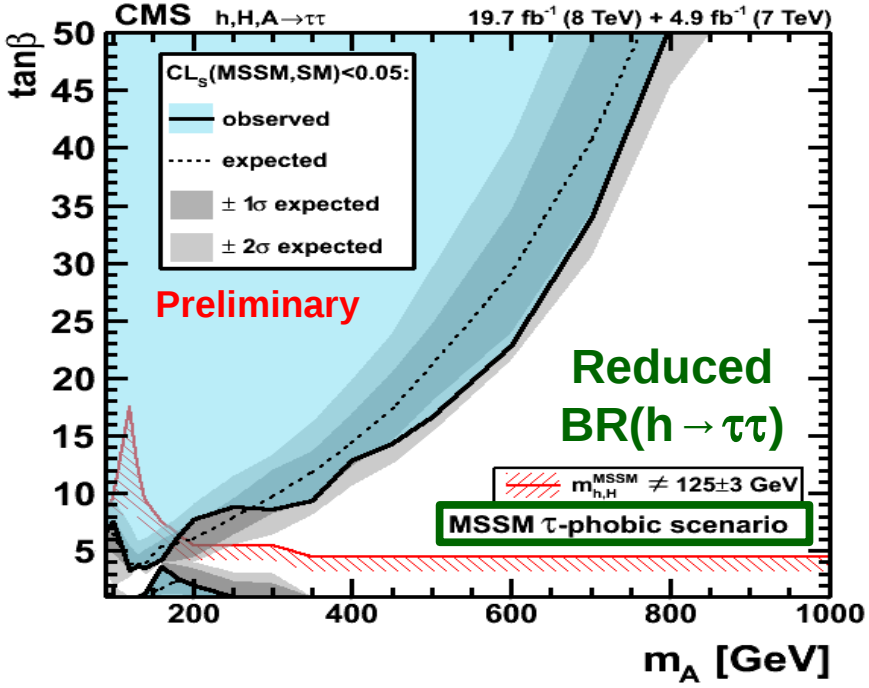


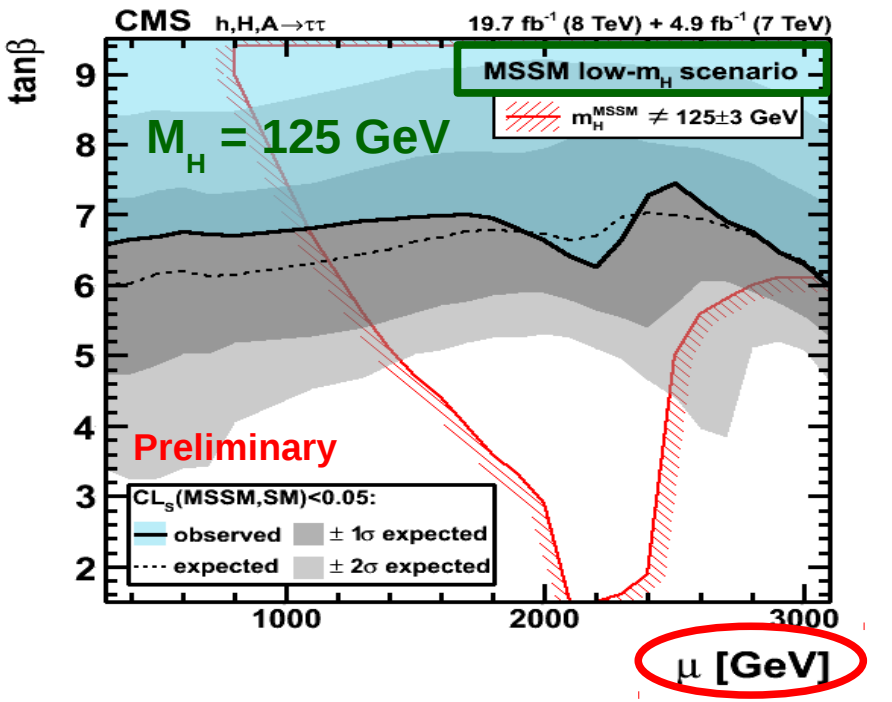
Incompatible with 125±3 GeV mass constraint




CMS h,H,A→ττ
19.7 fb-1 (8 TeV) + 4.9 fb-1 (7 TeV)
tanβ
CLs(MSSM,SM)<0.05:
observed
expected
± 1σ expected
± 2σ expected
Preliminary
Enhanced
BR(h→γγ)
mMSSMh,H ≠ 125±3 GeV
MSSM light-stau scenario
mA [GeV]


CMS h,H,A→ττ
19.7 fb-1 (8 TeV) + 4.9 fb-1 (7 TeV)
tanβ
CLs(MSSM,SM)<0.05:
observed
expected
± 1σ expected
± 2σ expected
Preliminary
Reduced
σ(ggF)
mMSSMh,H ≠ 125±3 GeV
MSSM light-stop scenario
mA [GeV]

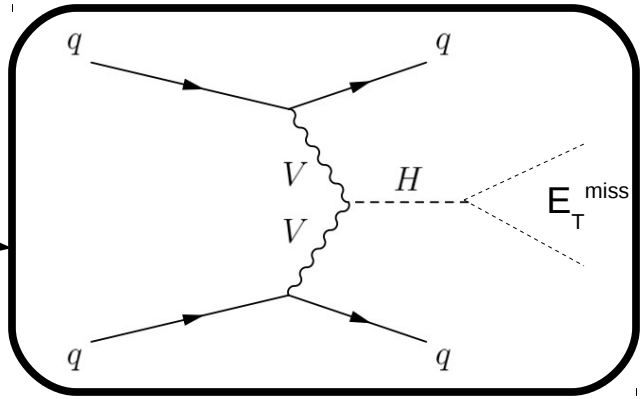

CMS h,H,A→ττ
19.7 fb-1 (8 TeV) + 4.9 fb-1 (7 TeV)
tanβ
CLs(MSSM,SM)<0.05:
observed
expected
± 1σ expected
± 2σ expected
Preliminary
Reduced
BR(h→ττ)
mMSSMh,H ≠ 125±3 GeV
MSSM τ-phobic scenario
mA [GeV]

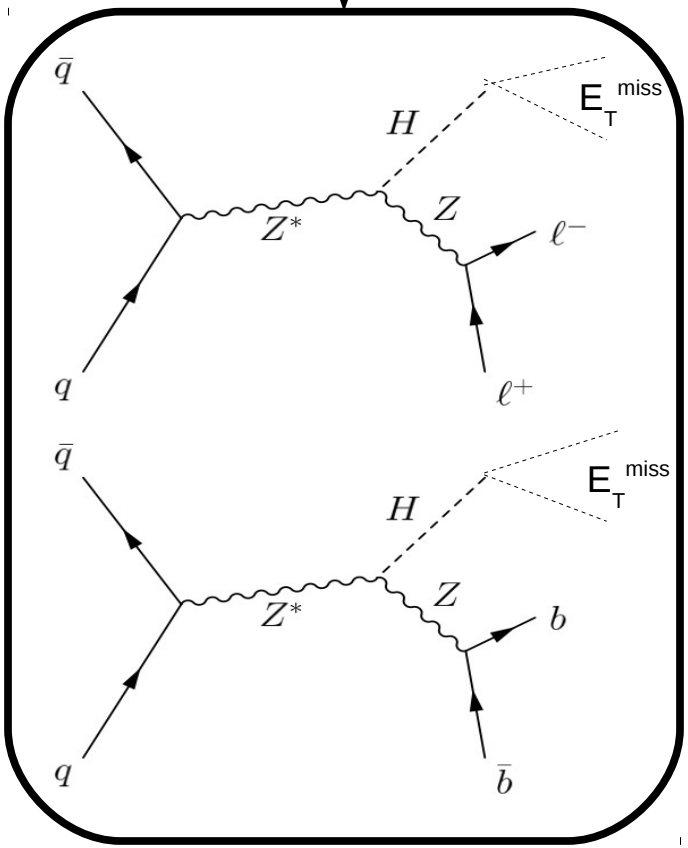

CMS h,H,A→ττ
19.7 fb-1 (8 TeV) + 4.9 fb-1 (7 TeV)
tanβ
MSSM low-mH scenario
mMSSMH ≠ 125±3 GeV
MH = 125 GeV
Preliminary
CLs(MSSM,SM)<0.05:
observed
expected
± 1σ expected
± 2σ expected
μ [GeV]

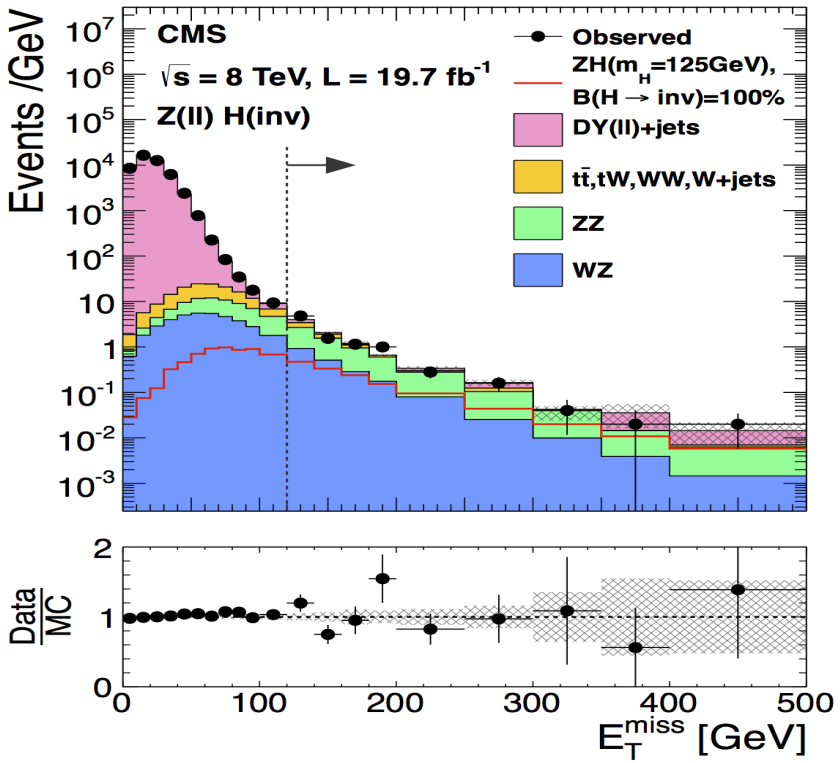
Invisible Higgs decays

HIG-13-030

- Direct search for invisible decaying Higgs boson
- σ of SM Higgs boson assumed
- Combination of **ZH** and **VBF**

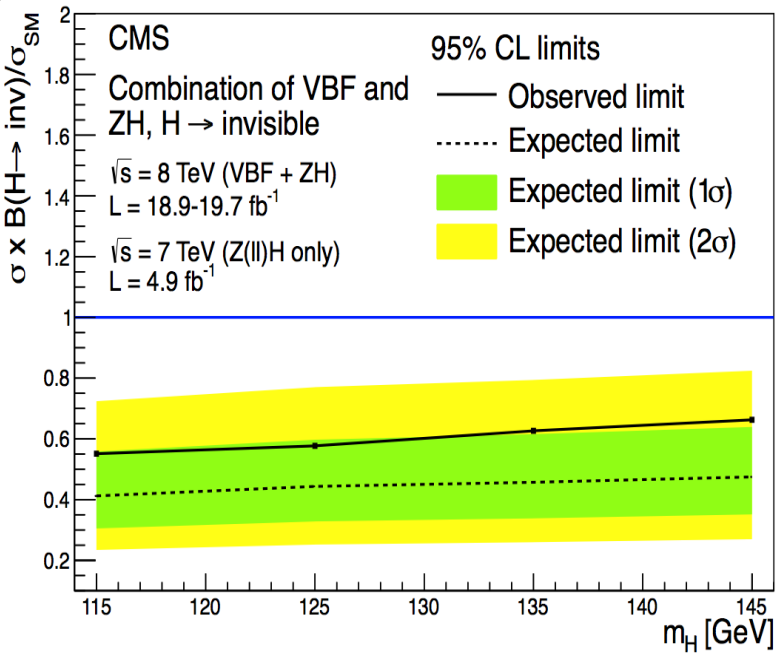






Invisible Higgs

- σ of SM Higgs boson assumed



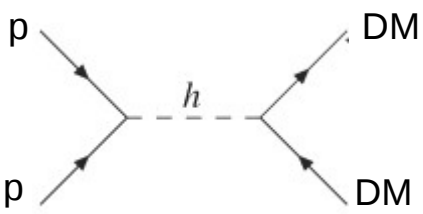
Excluded on 95% CL:

BR(H→inv.) < 0.58 at 125 GeV

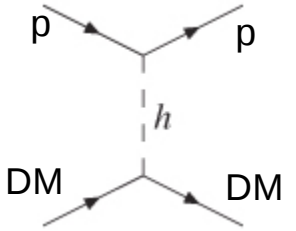
(expected < 0.44)

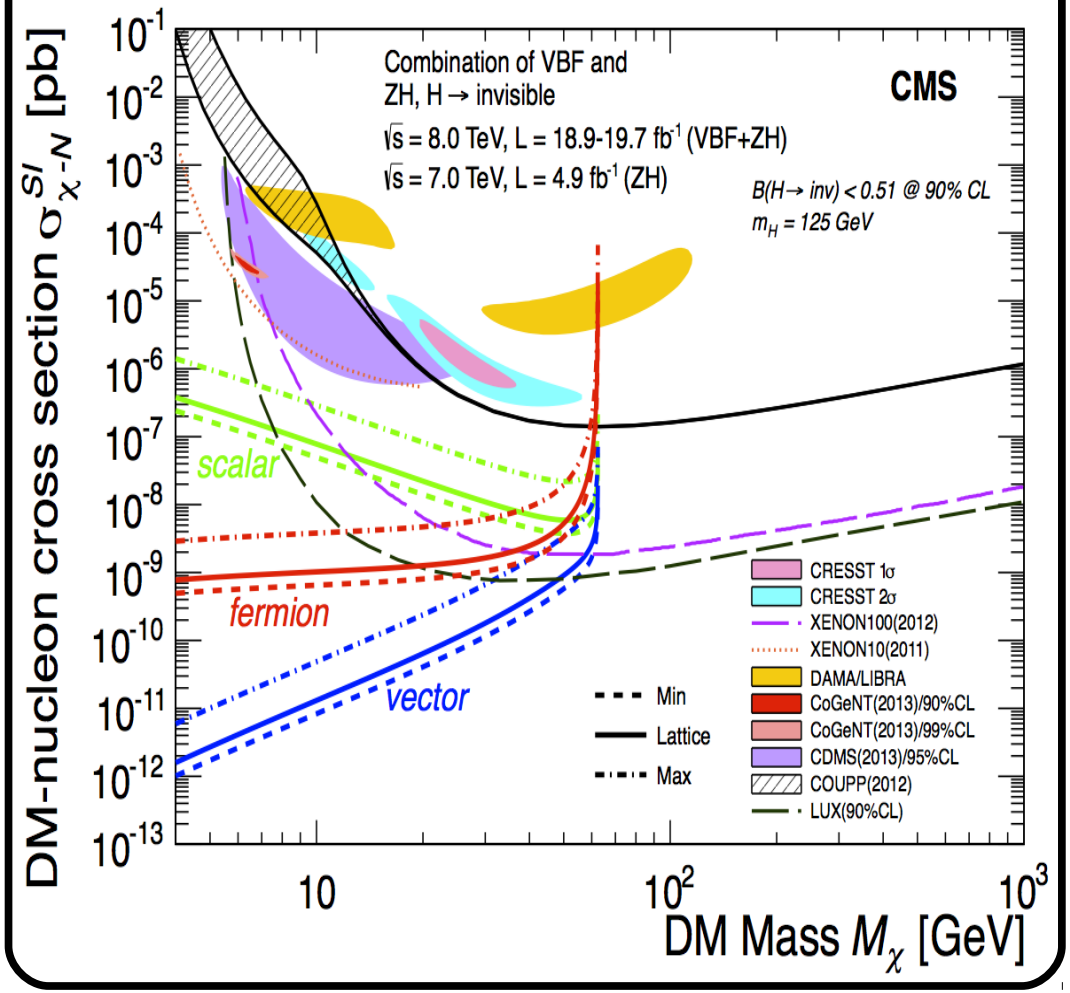
Dark Matter interpretation

Measured:



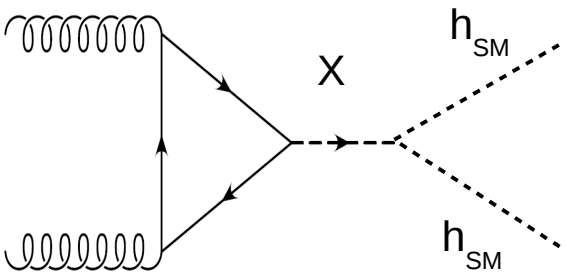
Translate into:



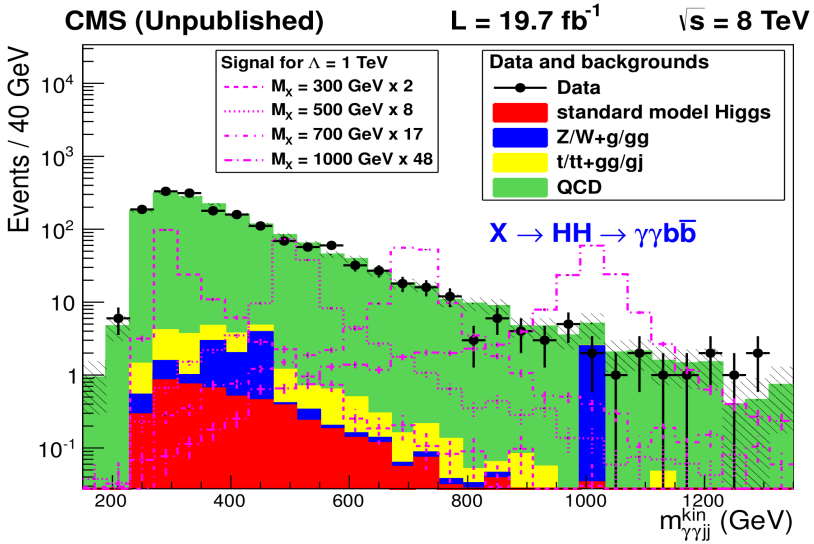


Multi Higgs events $X \rightarrow h_{SM}h_{SM} \rightarrow bb\gamma\gamma$

HIG-13-032

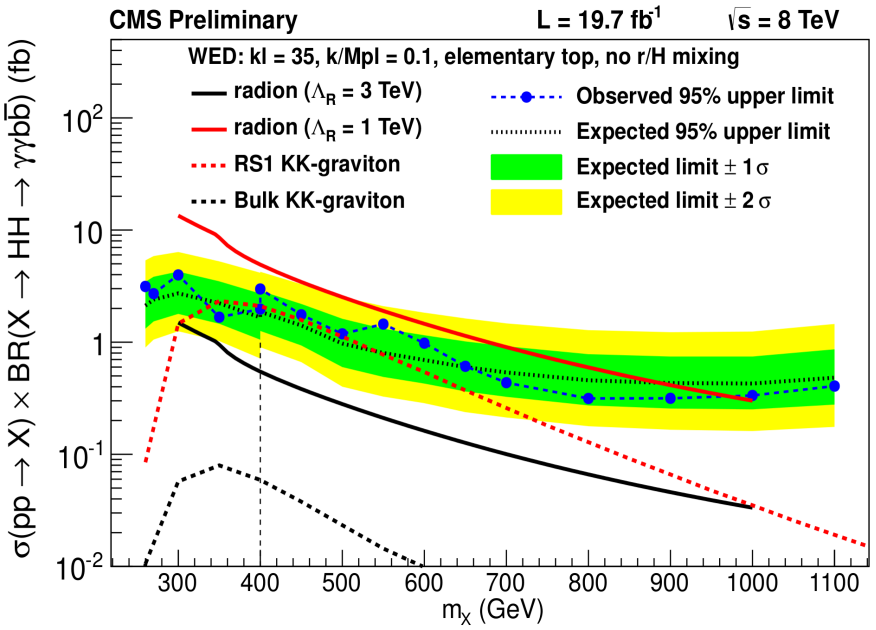


- Higgs decaying into lighter Higgs bosons enhanced for low tanβ
  - In 2HDM (e.g. MSSM) or higher order Higgs models



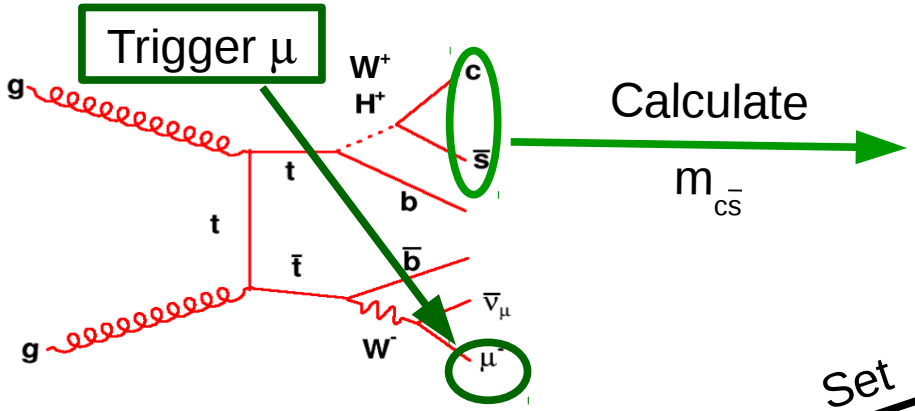
Kinematic fit to $m_{jj\gamma\gamma}$ (m_X > 400 GeV, shown) or $m_{\gamma\gamma}$ (m_X < 400 GeV) used for signal extraction

- Model independent limits set, tested against Warped Extra Dimension predictions

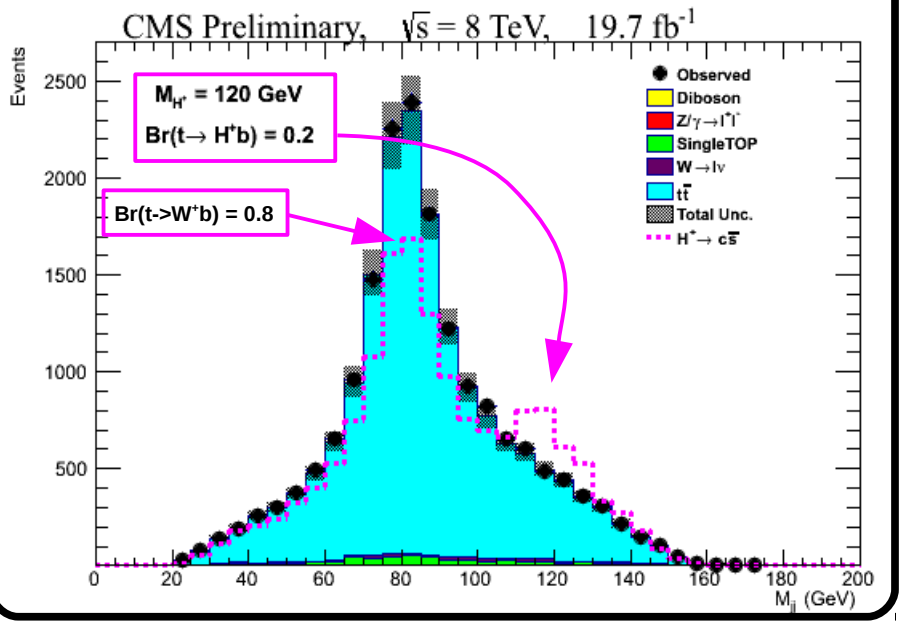


HIG-13-035

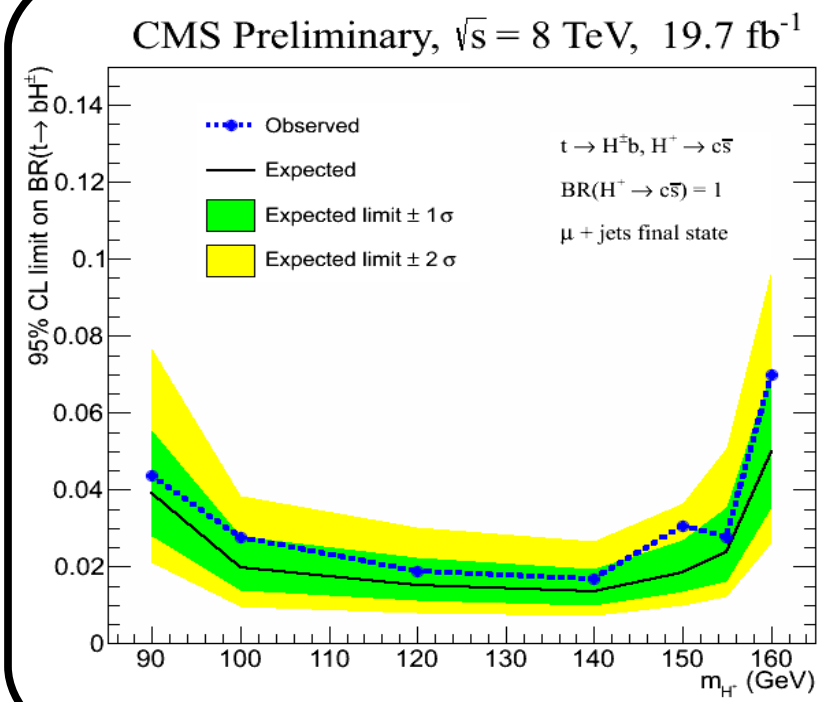
Charged Higgs search $H^+ \to c\bar{s}$



- A kinematic fit to fully reconstruct $t\bar{t}$ events from the final states
- Resulting in an improved mass resolution of the hadronically decaying boson.



Set Limits



- Light charged Higgs search $m_{H+} < m_t$
- Assume $BR(H^+ \to c\bar{s}) = 1$
- 95% CL: BR < 1.7 - 7.0% observed (1.5 – 5.0% expected)

Summary

- After the discovery of a new Higgs-like particle:
  A lot of activity BSM Higgs boson searches in CMS.

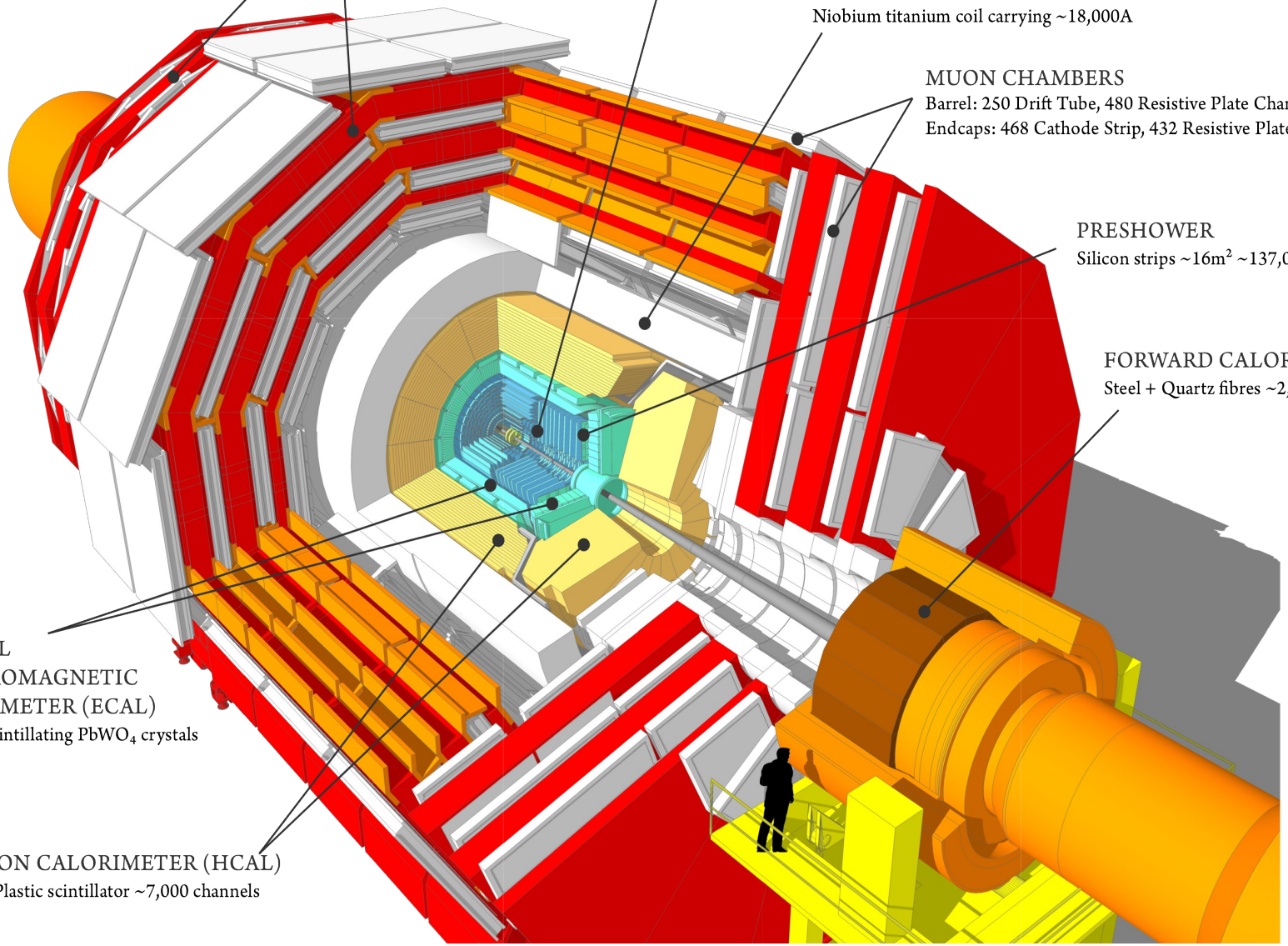
- Broad range of possible production and decay processes covered.

- If something new hides out there and is within range of sensitivity
  → **we will find it**.

BACKUP

CMS DETECTOR

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T



STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

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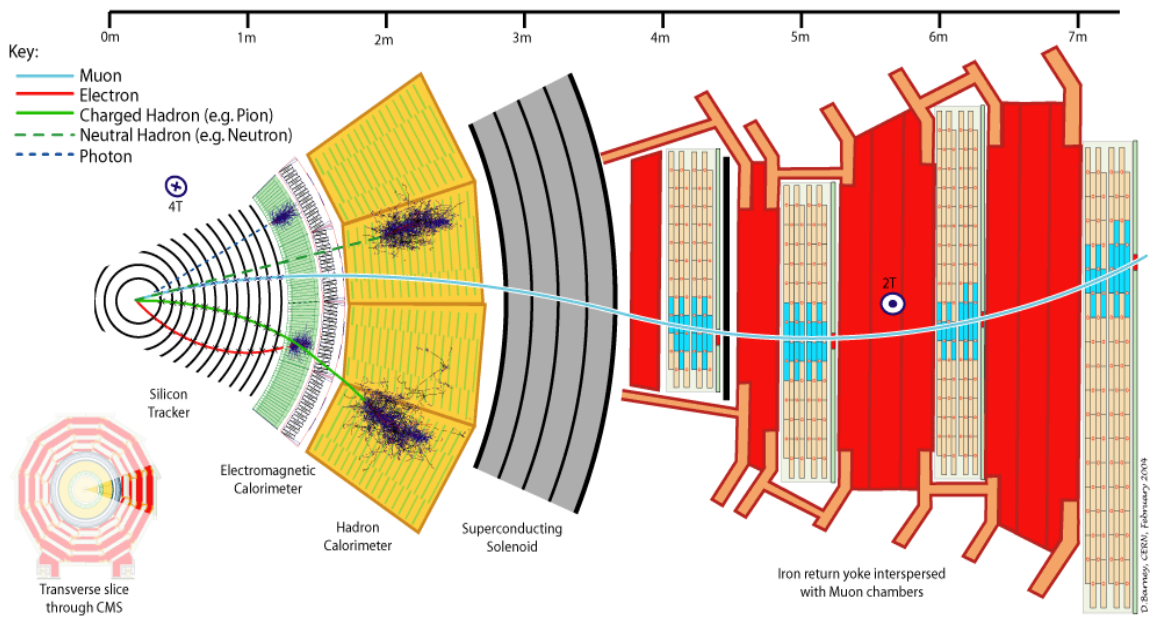
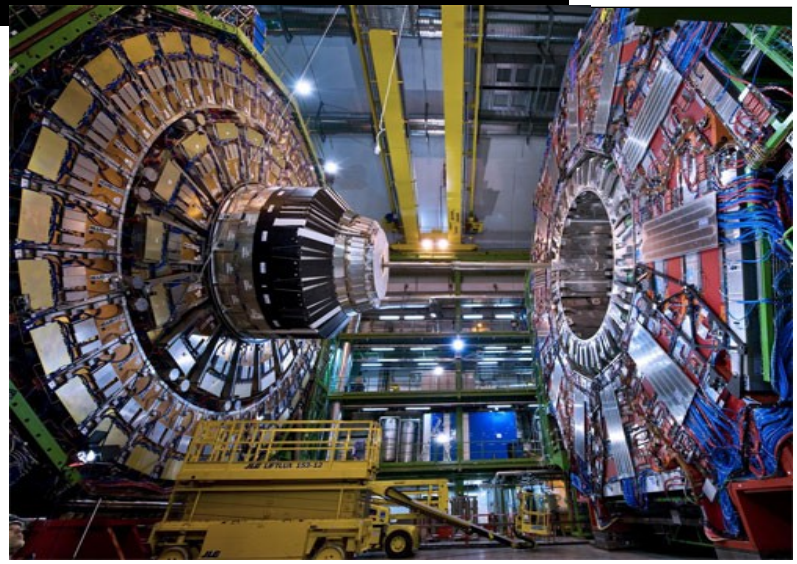
Compact Muon Solenoid

- Weight: 14000 tonnes

- Diameter: 15.0 m
- Length: 28.7 m

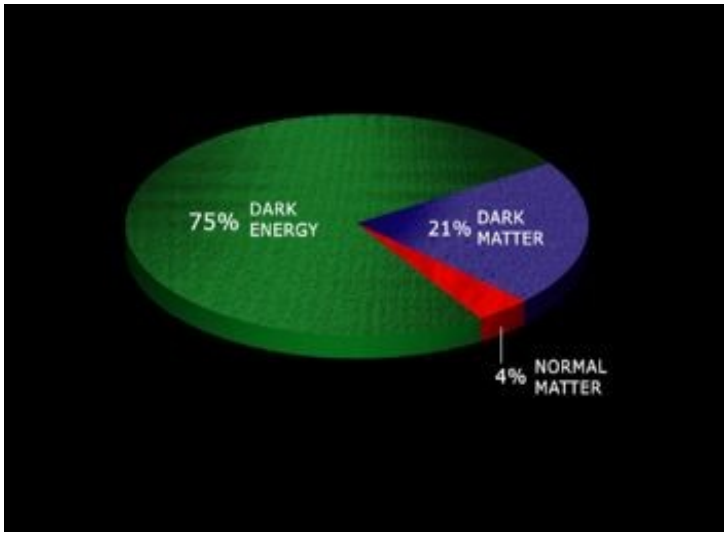


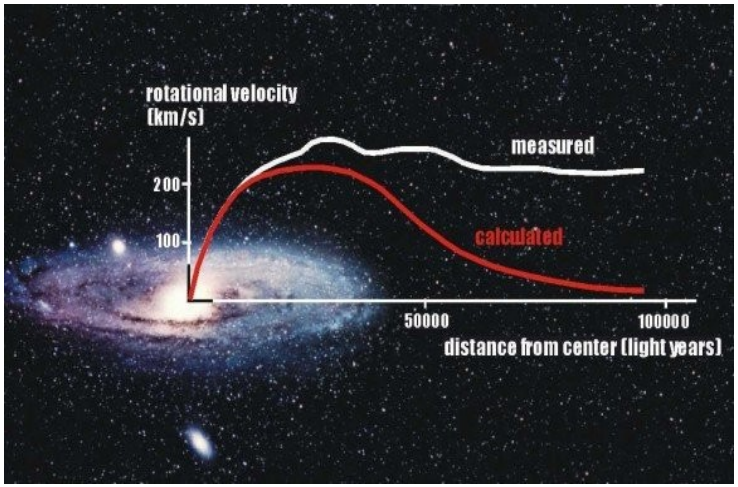


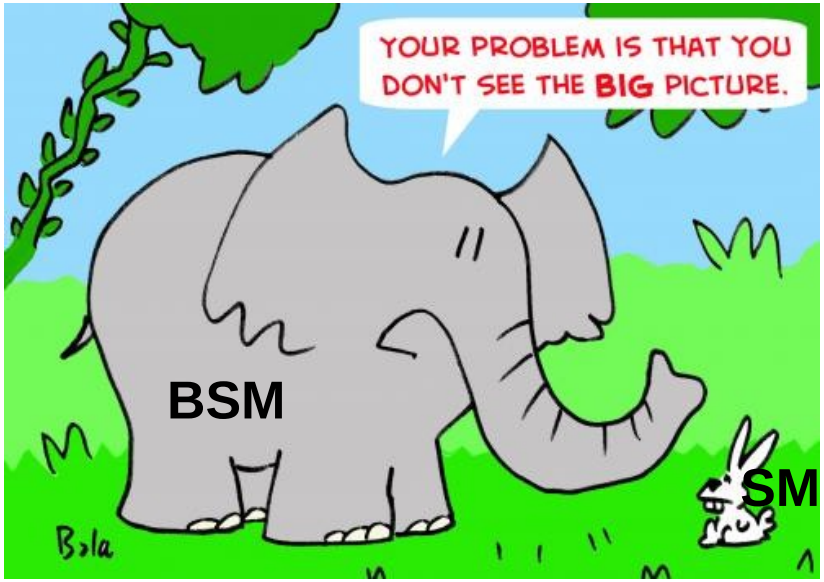
- Magnet field: 3.8 T (outside calorimeter)
- Tracker: Si ($\delta p / p = 0.5\%$ for a 10 GeV track)
- ECAL: $PbWO_4$ ($\delta E/E = 1\%$ for a 30 GeV e/γ, $X_0 = 28$)
- HCAL: Sampling (brass scintillator, $\delta E/E = 10\%$ for a 100 GeV $\pi^{\pm}$, $\lambda_i = 10$)

Open questions

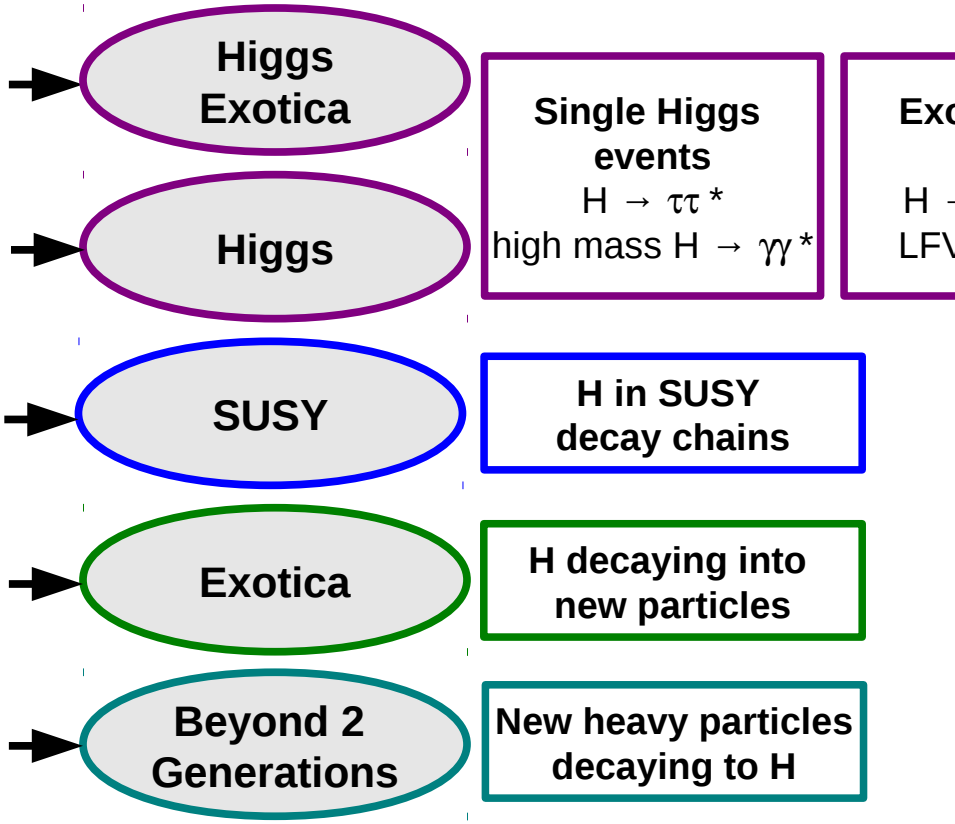
- Many unanswered questions:
  - The hierarchy problem
  - Gravity is not included
  - Neutrino masses are not included
  - Anomalous magnetic moment of the muon
  - Dark matter is not included
  - Dark energy is not included
  - ...
- The SM is not the ultimate theory.







BSM Higgs Searches in CMS



CMS tests broad range of possible BSM Higgs scenarios

***Results presented in this talk**

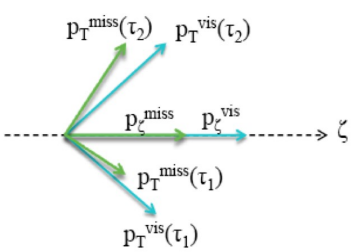
Event selection (H → ττ)

- Two well reconstructed, isolated leptons of opposite sign:

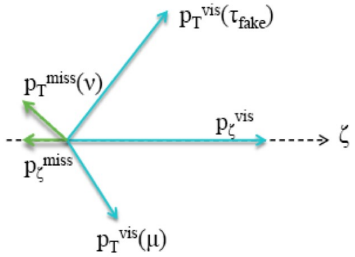
channel	p_T	$\|\eta\|$	p_T	$\|\eta\|$
eμ	> 20 GeV (e/μ)	< 2.3 (e/μ)	> 10 GeV (μ/e)	< 2.3 (μ/e)
eτ	> 24 GeV (e)	< 2.1 (e)	> 20 GeV (t)	< 2.1 (τ)
μμ	> 20 GeV (μ)	< 2.1 (μ)	> 10 GeV (μ)	< 2.1 (μ)
μτ	> 20 GeV (μ)	< 2.1 (μ)	> 20 GeV (τ)	< 2.3 (τ)
ττ	> 45 GeV (τ)	< 2.1 (τ)	> 45 GeV (τ)	< 2.1 (τ)

- eμ: $D_\zeta = P_\zeta - 1.85 \cdot P_\zeta^{vis} > -20$ GeV

Genuine ττ event



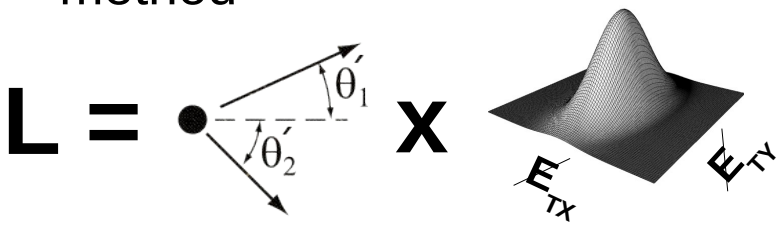
W+jets or $t\bar{t}$ event



- eτ, μτ: $M_T < 30$ GeV
- μμ: Special BDT trained for rejection of $Z/\gamma^* \rightarrow \mu\mu$ events

Reconstruction of Di-τ System

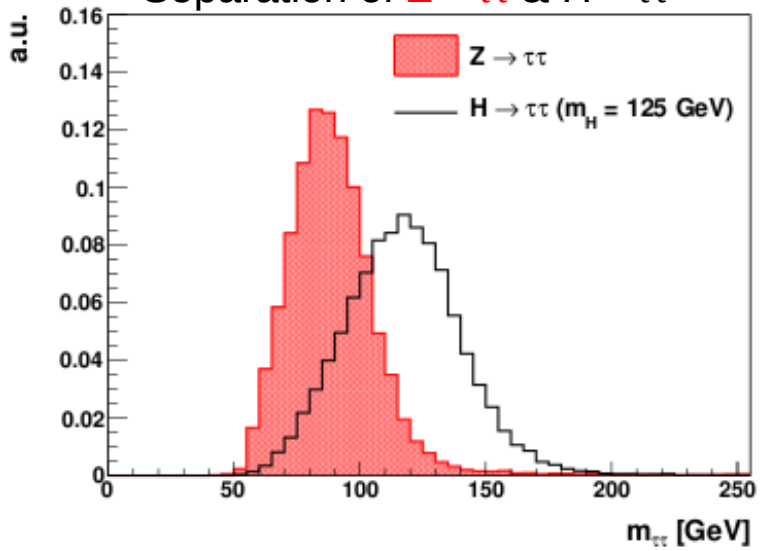
- Determine invariant mass of di-τ system with maximum likelihood method



Phasespace of τ-decays

Expected $\not{E}_T$ Resolution

Separation of $Z \rightarrow \tau\tau$ & $H \rightarrow \tau\tau$



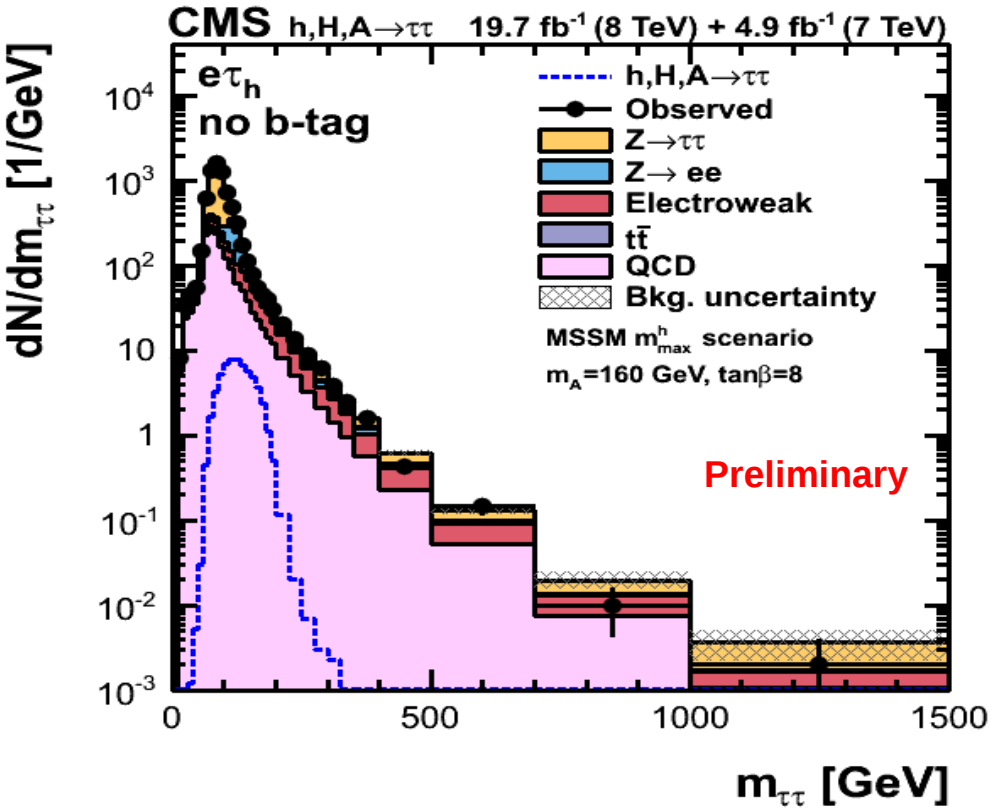
- Estimate of di-τ system, to be true for given value of $m_{\tau\tau}$
- Inputs: four-vector information of visible leptons, x- and y-component of $\not{E}_T$ on event basis.
- Free Parameters: φ, θ^*, $m_{\upsilon\upsilon}$ per τ (4-6 parameters)
- Full integration of kernel to determine maximum for given $m_{\tau\tau}$
  - Scan of $m_{\tau\tau}$ from m_τ up to 2TeV
- 10-20% resolution of the reconstructed $m_{\tau\tau}$ mass depending on decay mode

Discrimination of signal from backgrounds ($H \to \tau\tau$)

$Z/\gamma^* \to \tau\tau$:
- Embedding: in $Z \to \mu\mu$, replace μ by sim. τ decay
- Normalized to $Z \to \mu\mu$ events

ttbar:
- Shape from simulation
- Normalization from sideband

QCD:
- Normalization and shape from SS/OS or fake-rate



Di-boson/W+jets:
- Shape from simulation
- Normalization from sideband (W-jets) or from MC (Di-bosons)

$Z/\gamma^* \to$ ee ($\mu\mu$):
- From data ($\mu\mu$–channel) or simulation (all other channels)
- Corrected for jet $\to \tau$, $e/\mu \to \tau$ fake-rate

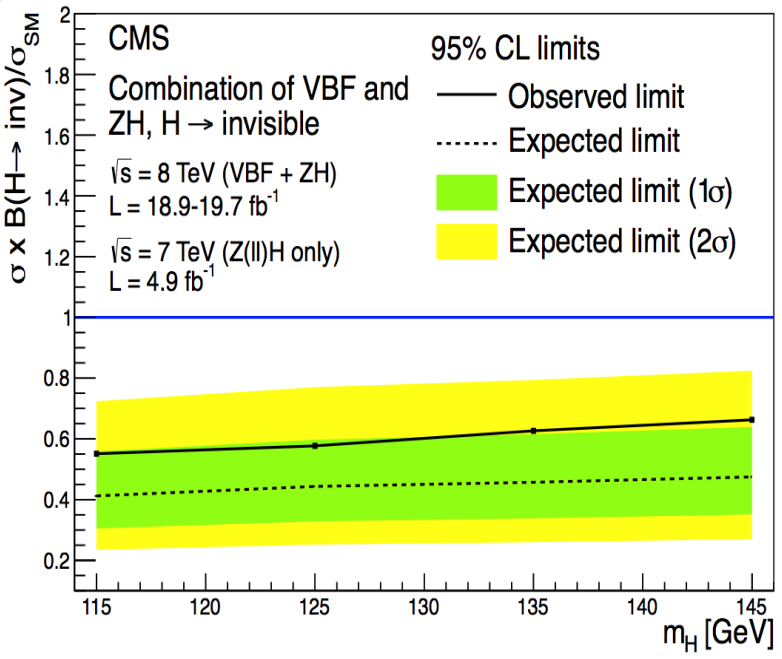
MSSM Benchmark Scenarios

Proposed by Carena et al., Eur.Phys.J.C73, 2552 (2013)

scenario	Mass (GeV)	Higgs sector phenomenology
m_h^{max}	$M_h \sim 135$	stop mixing parameter: $X_t = 2$ TeV
m_h^{mod+}	$M_h \sim 125$	mhmax except $X_t = 1.5$ TeV — compatible w. $(g-2)_\mu$
m_h^{mod-}	$M_h \sim 125$	mhmax except $X_t = -1.9$ TeV — compatible w. $B(b \to s\gamma)$
light-stop	$M_h \sim 125$	$M_{stop,1} \sim 340$ GeV & suppressed decay mode $\tilde{t} \to t+\chi 0$ reduced ggH rate
light-stau	$M_h \sim 125$	$M_{stau} \sim 245$ GeV → enhanced $H \to \gamma\gamma$ rate
tauphobic	$M_h \sim 125$	Light Higgs boson h has Reduced coupling to down-type fermions
low-m_H	$M_H \sim 125$	$M_A = 110$ GeV Variation in tanβ–μ (Higgsino mass parameter)

Invisible Higgs

- σ of SM Higgs boson assumed



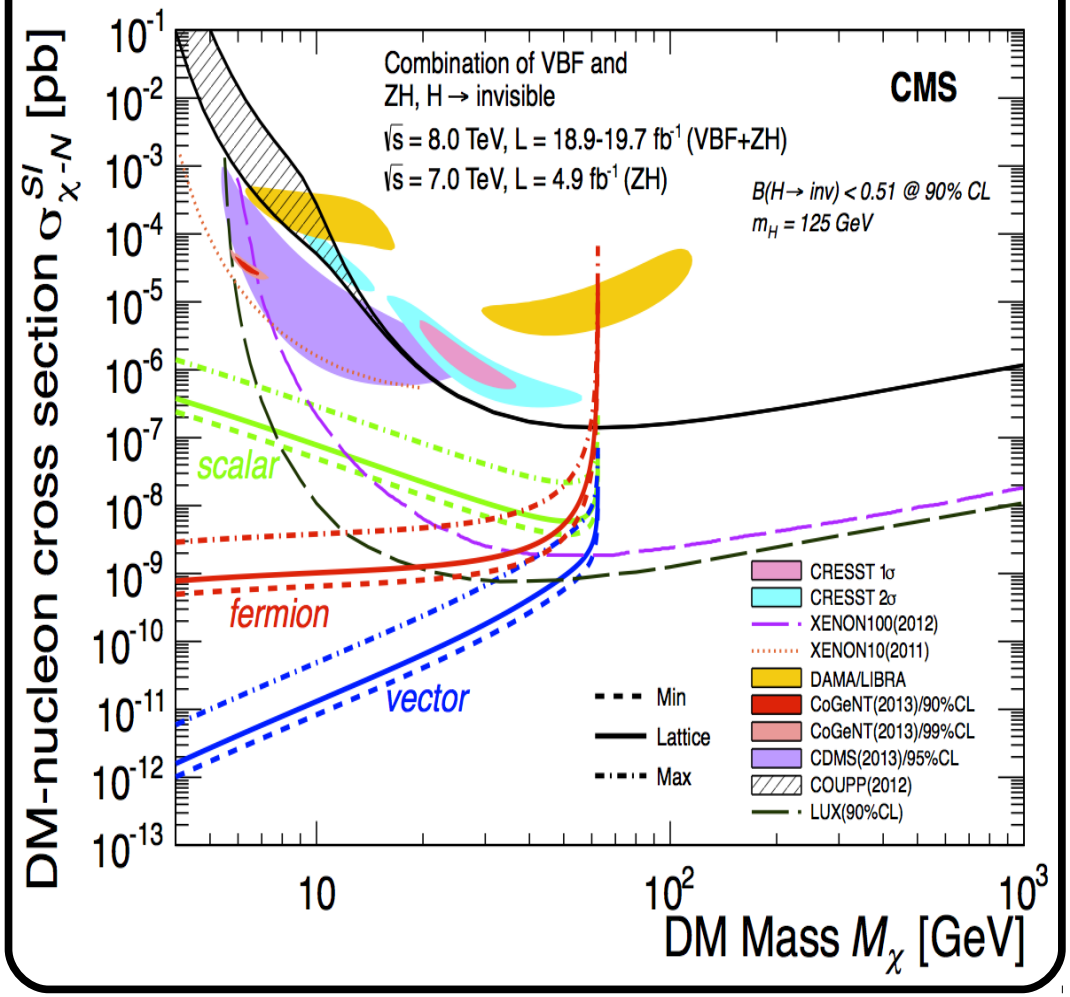
Excluded on 95% CL:

BR(H→inv.) < 0.58 at 125 GeV

(expected < 0.44)

Dark Matter interpretation

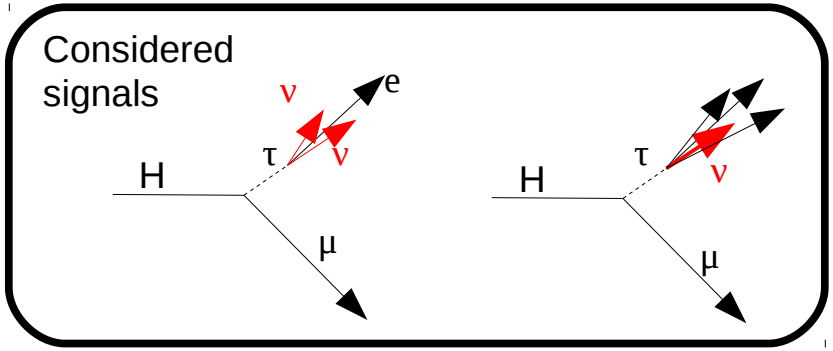
- Upper limits on the spin-independent DM-nucleon cross section in Higgs-portal models.
- Limits are shown separately for scalar, vector and fermion DM.



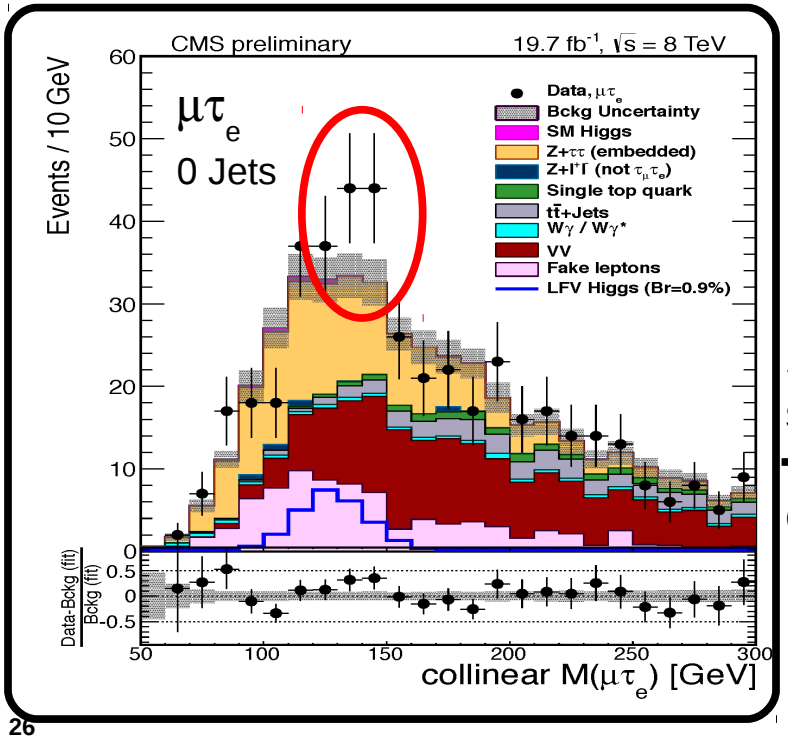
Lepton Flavour Violating H → μτ

HIG-14-005

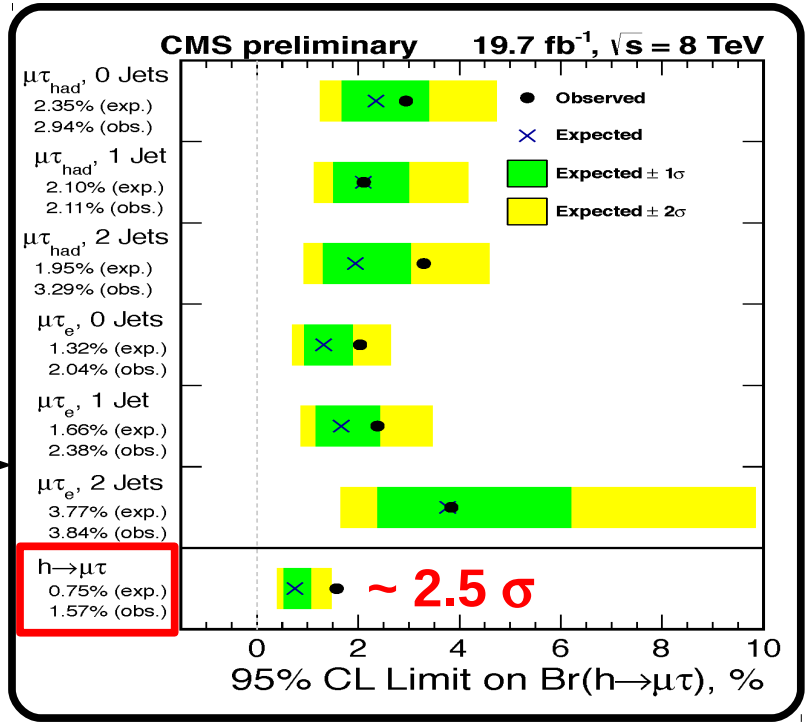
Karlsruhe Institute of Technology



- Assume SM σ for production processes and m_H = 125 GeV
- Set limits on flavor violating BR



Slight excess seen in some categories



Lepton Flavour Violating H → μτ

HIG-14-005

- Set limits on flavor violating Yukawa coupling

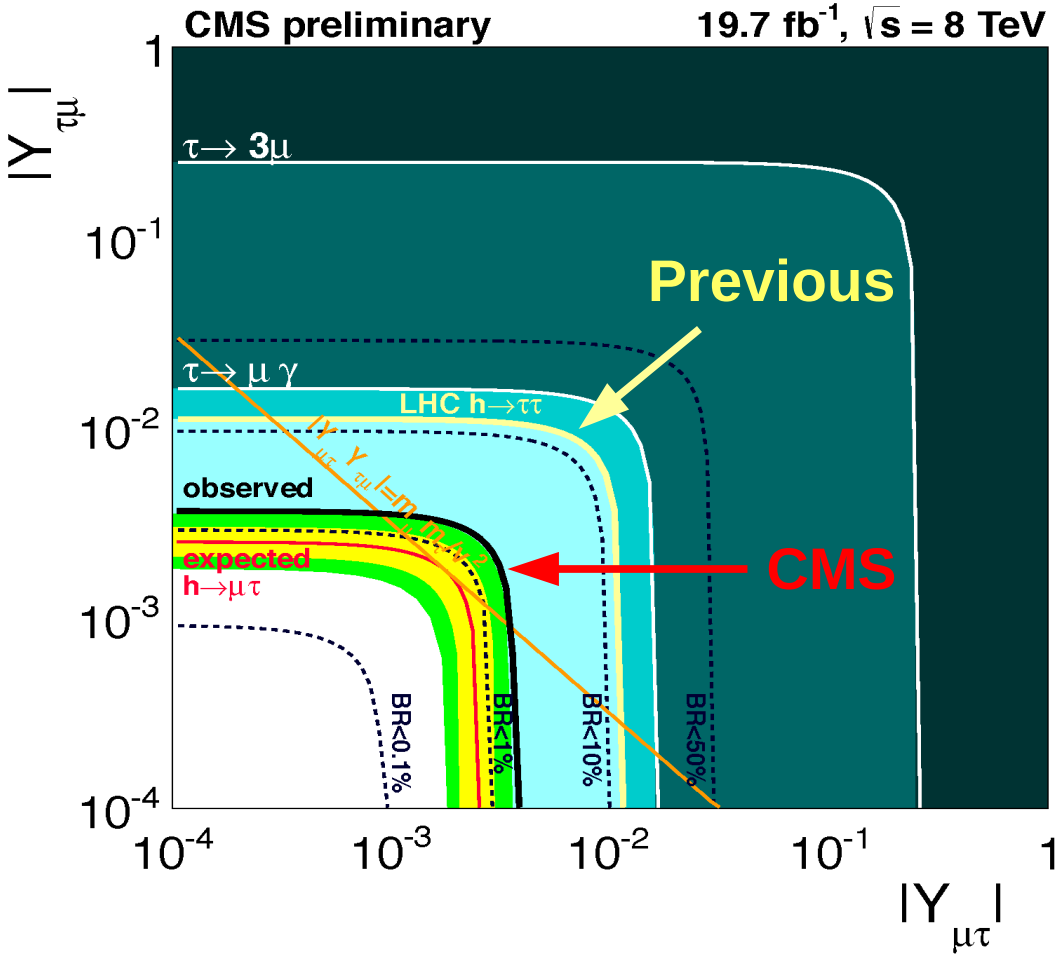
New Limits:

BR(h → μτ) < 1.57 %

Improvement of factor **~ 10**

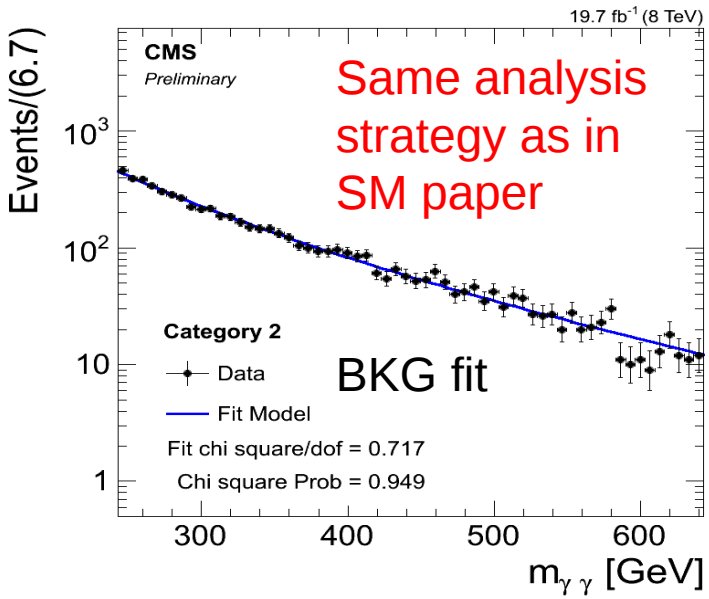
$$\sqrt{|\mathbf{Y}_{\mu\tau}|^2 + |\mathbf{Y}_{\tau\mu}|^2} < 3.6 \times 10^{-3}$$

Improvement of factor **~ √(10)**

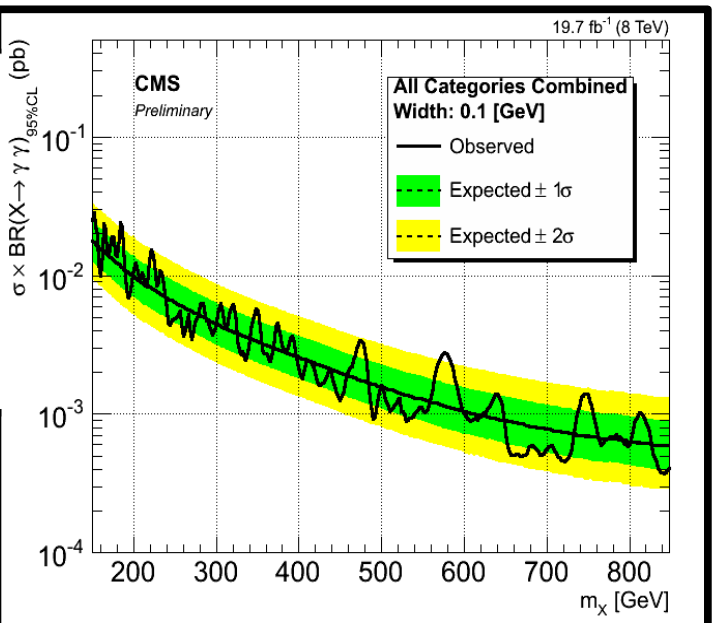


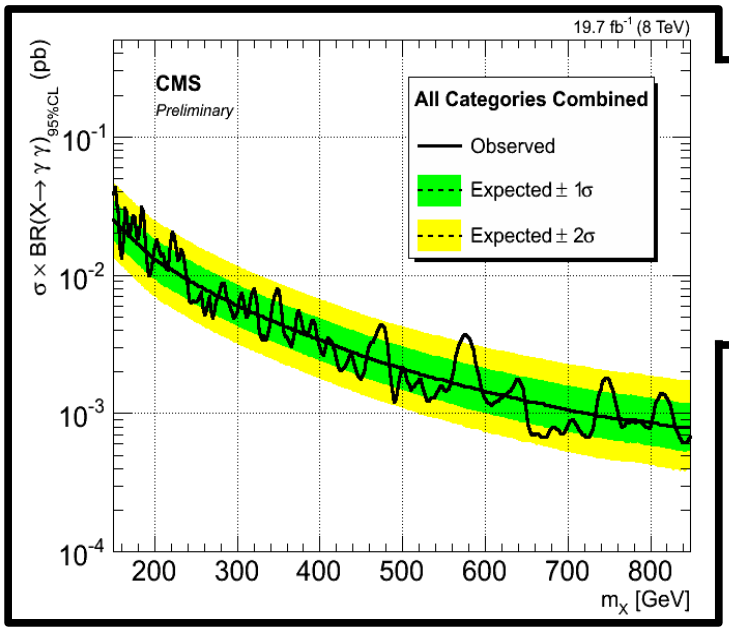
High mass search h → γγ

HIG-14-006

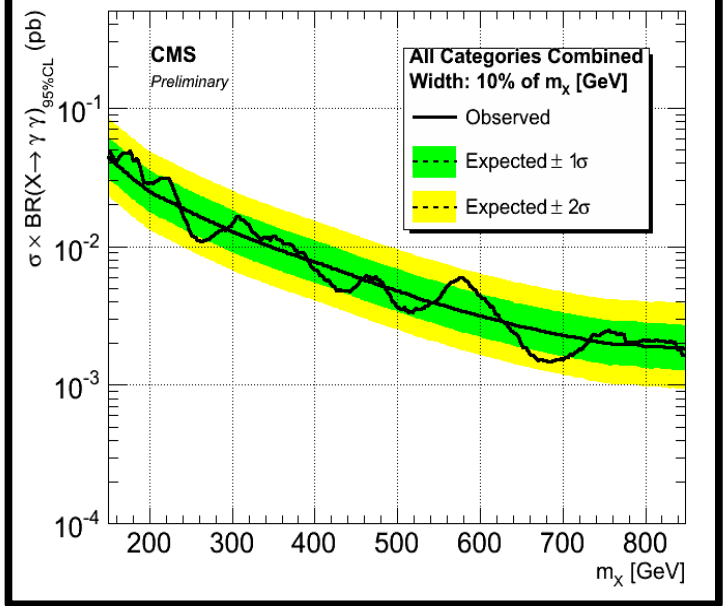


- Limit on σ*BR over width
- Two masses tested
- ggΦ σpin 0 resonance assumed

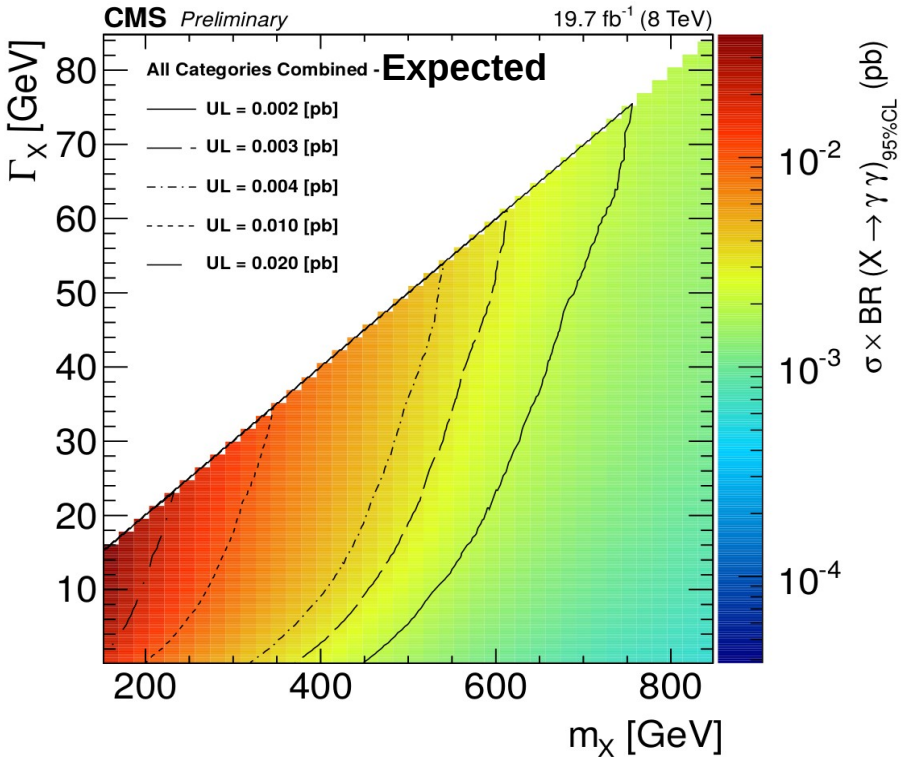


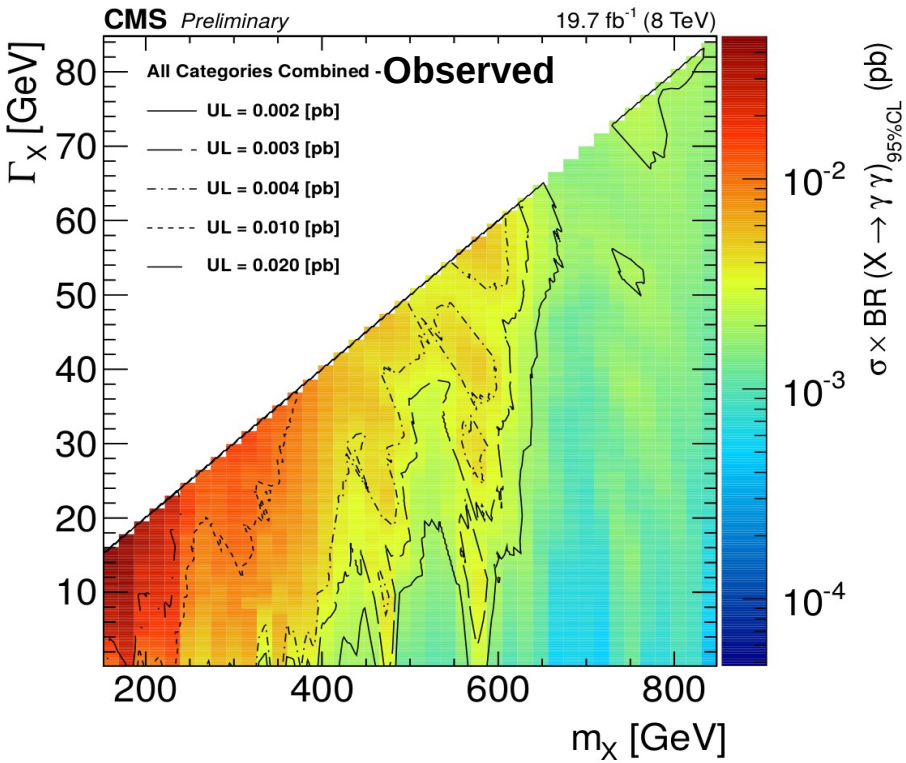


- Limit on σ*BR
- ggΦ spin 2 resonance assumed



H → γγ : 2D limits



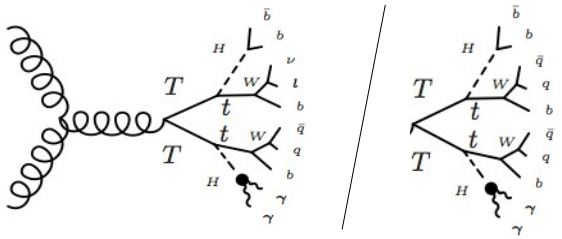


- H→γγ : considers ggΦ and spin 0 resonance
  - In 2D limits limit on σ*BR is plotted over width and mass
    - (UL = Upper Limit)

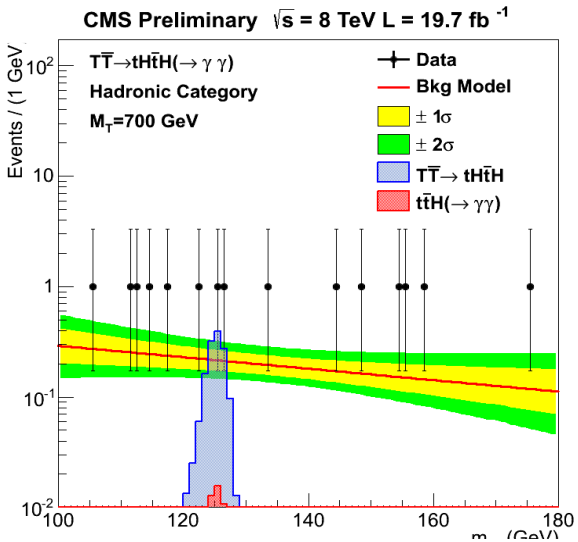
Higgs production in T → tH

B2G-14-002
B2G-14-003

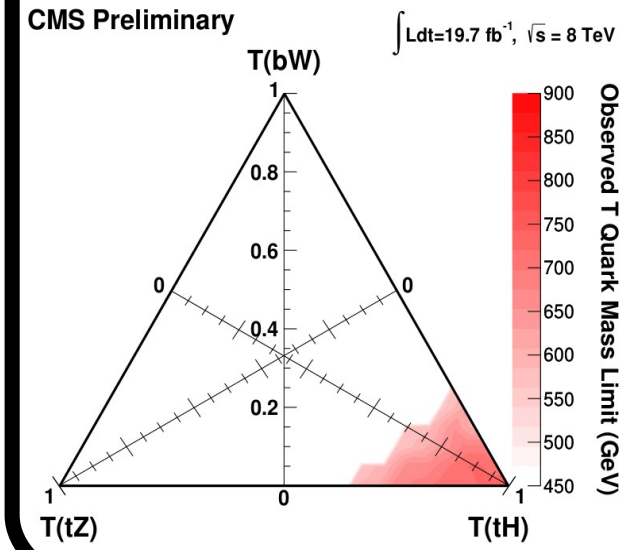
- Search for top partner T decaying to top quark and Higgs boson.
- Higgs is assumed to be SM like

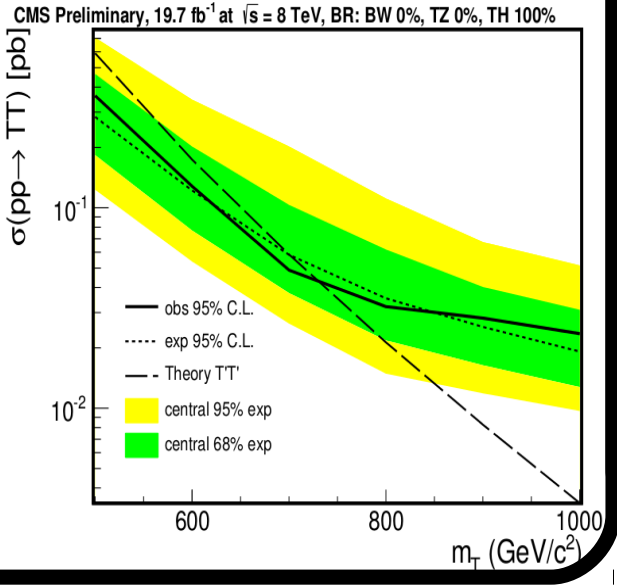


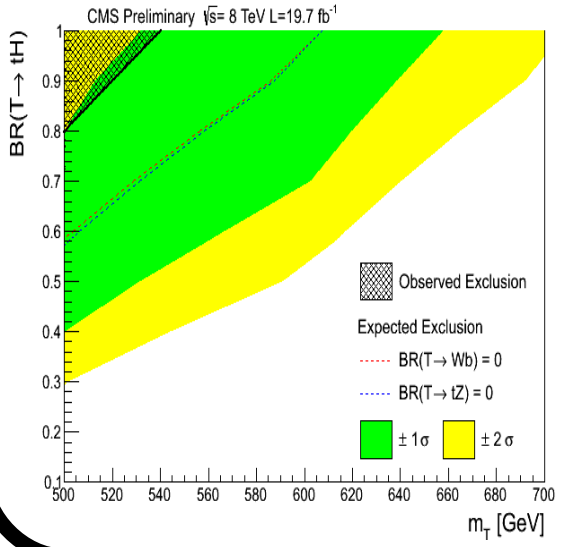
H → γγ in semileptonic and full hadronic final states



H → bb in full hadronic final states







Links

- $H \rightarrow \tau\tau$
  - http://cds.cern.ch/record/1623367?ln=en
- $H \rightarrow bb$
  - http://arxiv.org/pdf/1302.2892.pdf
- LFV $H \rightarrow \mu\tau$
  - http://cds.cern.ch/record/1740976?ln=en
- $X \rightarrow HH \rightarrow \gamma\gamma bb$
  - http://cds.cern.ch/record/1697512?ln=en
- $H^+ \rightarrow c\bar{s}$
  - http://cds.cern.ch/record/1728343?ln=en
- High mass $H \rightarrow \gamma\gamma$
  - http://cds.cern.ch/record/1714076?ln=en
- $H \rightarrow$ invisible
  - http://arxiv.org/pdf/1404.1344.pdf

Links

- T → tH
  - https://cds.cern.ch/record/1706121?ln=en
  - http://cds.cern.ch/record/1709129?ln=en