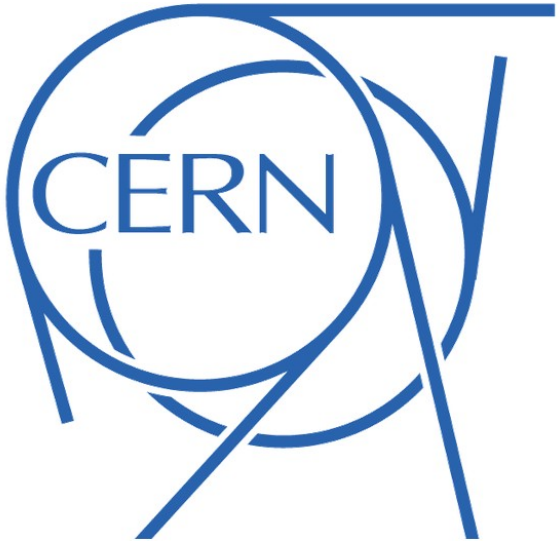
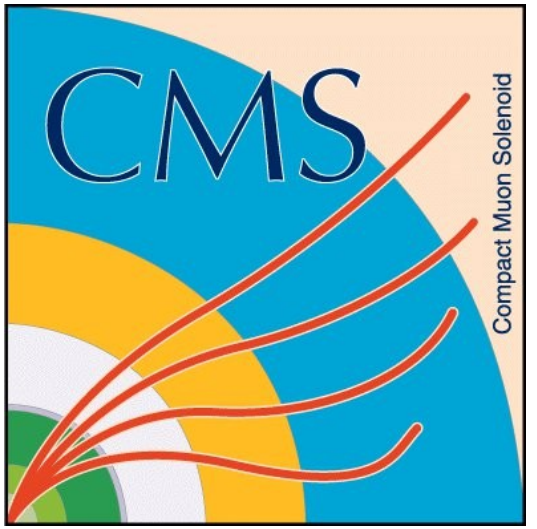




The CMS H $\rightarrow \tau\tau$ search
Latest results in SM & MSSM

M. Bachtis

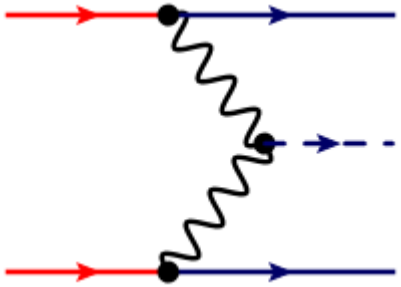
KITP Higgs Identification Workshop

Introduction

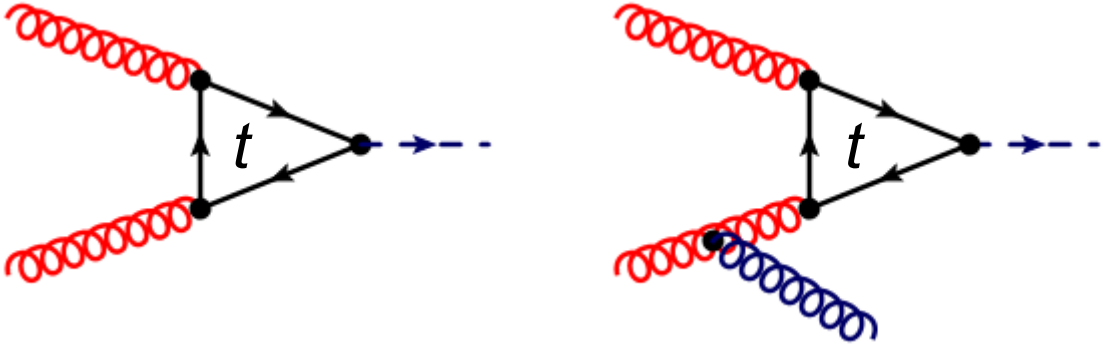
- $H \rightarrow \tau\tau$ is the only handle we have to study Higgs couplings to leptons at the LHC at the current luminosities
  - Significant branching ratio for the SM (~8%)
  - Enhanced branching ratio in the MSSM at high tanβ
    - Accompanied by enhanced production cross section makes MSSM $A/h/H \rightarrow \tau\tau$ search a must in the LHC
- Many experimental challenges
  - Huge $Z \rightarrow \tau\tau$ contamination
    - Requires exploiting additional objects in the final state to reduce it
    - Requires improved di-tau mass resolution despite the presence of 2-4 neutrinos in the final state
  - Hadronic decays of taus
    - Requires sophisticated tau identification and jet background rejection

Higgs production in the SM

Vector boson fusion(qqH)

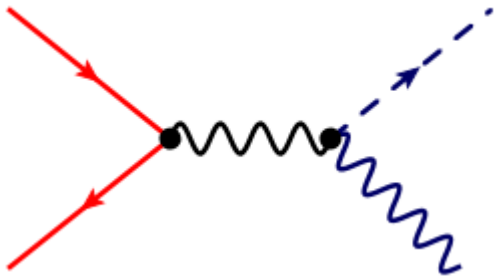


gluon fusion(ggH)



- Golden mode
  - Cross section ~ 1/10 ggH
  - Di-jet signature suppresses $Z \rightarrow \tau\tau$ ($\sim 10^4$)
- Largest cross section
  - Dominated by $Z \rightarrow \tau\tau$ background
  - H+1 jet experimentally more promising

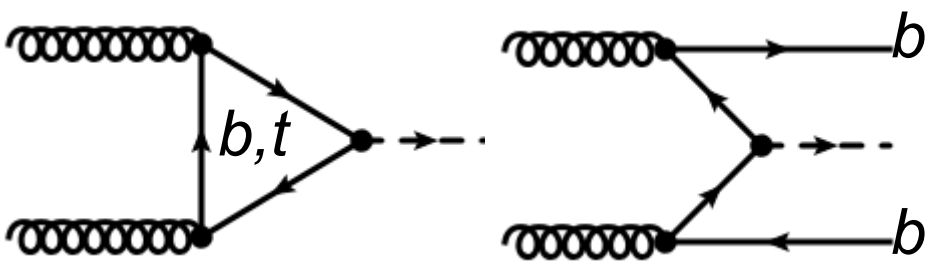
Associated production(VH)



- Additional boson suppresses $Z \rightarrow \tau\tau$
  - Dominant background: dibosons
  - Very small cross section

The Higgs sector in the MSSM

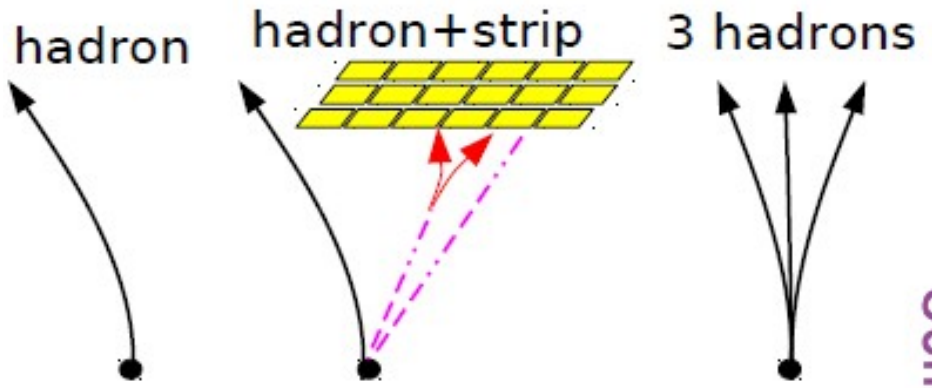
- Two Higgs doublets
  - 5 physical Higgs bosons
- At tree level
  - Higgs sector described by M_A, tanβ
  - $M_h < M_Z$
- Large loop corrections from SUSY particles
  - SUSY parameters fixed in benchmark scenarios
    - mh^{max} scenario used
  - $M_h < 133$ GeV

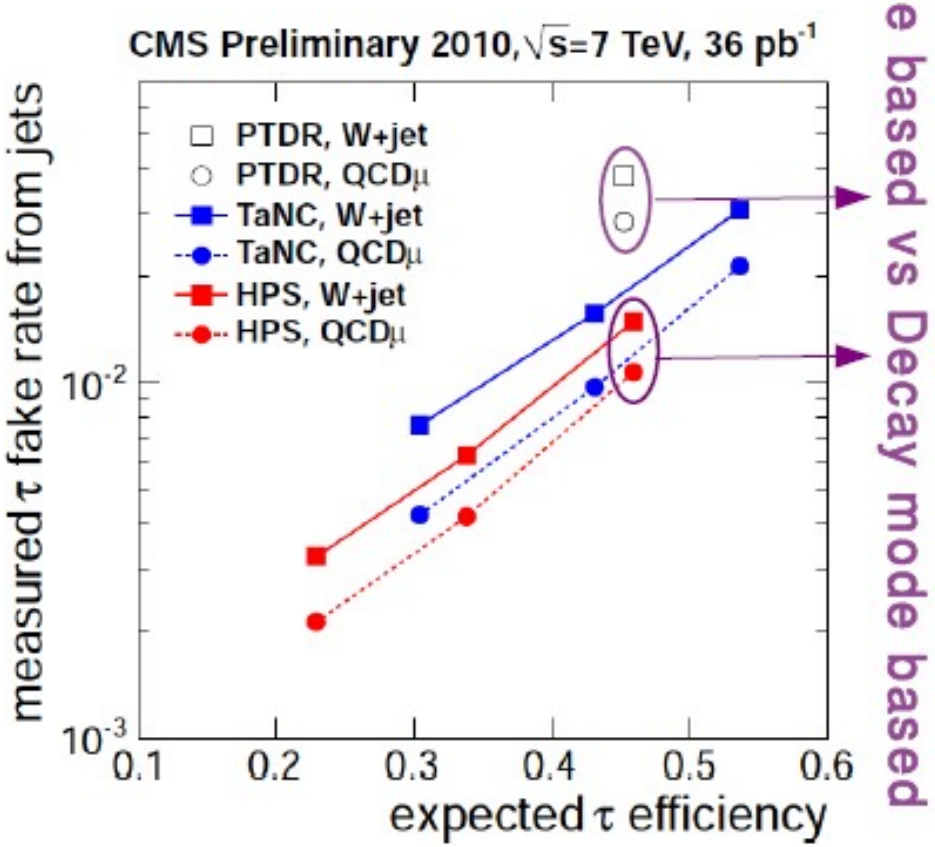


- At large tanβ
  - Cross section enhanced (~$\tan\beta^2$)
  - BR(ττ) ~10-15%
  - h+A or H+A degenerate
- $\Phi \rightarrow \tau\tau$: golden channel to study the MSSM

Tau Identification

- Combinatorial approach
  - Uses reconstructed particles from Particle Flow Algorithm
- Reconstructs individual decay modes
  - Using particles from Particle Flow event description)
- Energy of the tau measured using only associated decay mode PF constituents
  - Dominated by Tracker+ECAL
  - Pileup effect in energy scale minimal



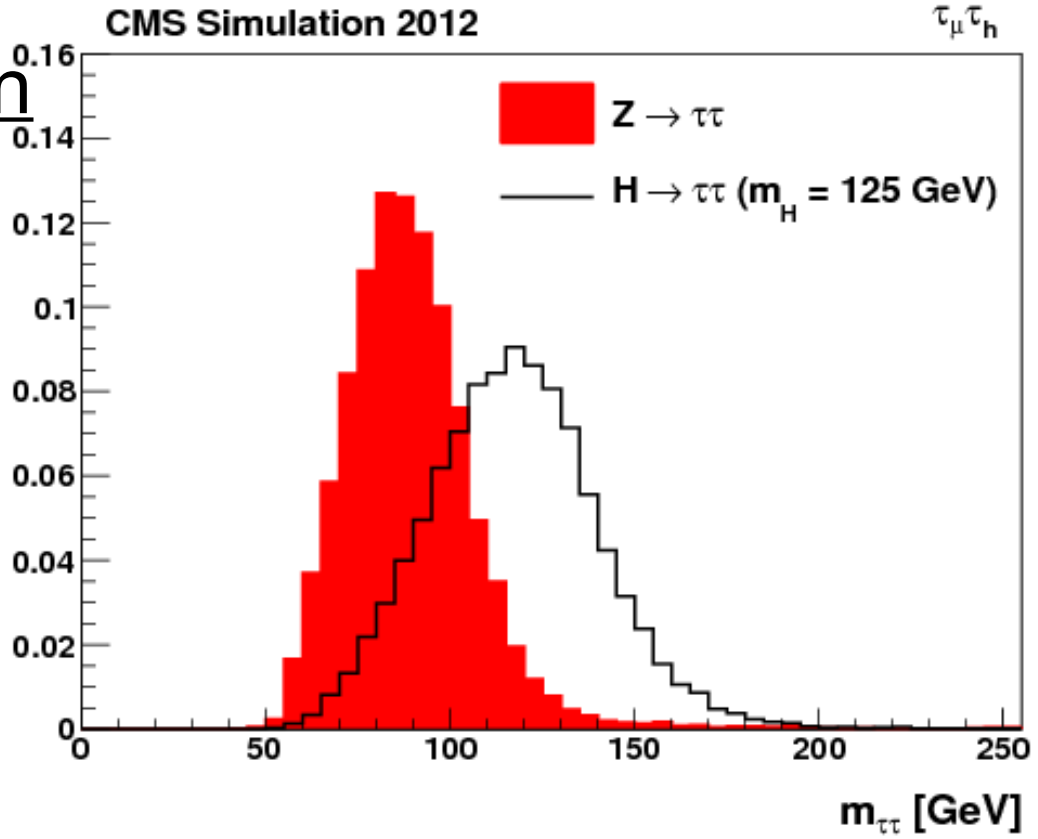


Reconstructing the di-tau mass

- Crucial to separate $Z \rightarrow \tau\tau$ from Higgs $\rightarrow \tau\tau$
- A semi-leptonic $\tau\tau$ final state has three neutrinos
  - Corresponding to 7 unknown variables
  - Missing ET and tau mass constraint reduces them to 3

<u>For the remaining unknown parameters:</u>

- Perform calculation by minimizing an event likelihood
  - Using visible decay kinematics and MET
  - Provides valid optimal solution for each event

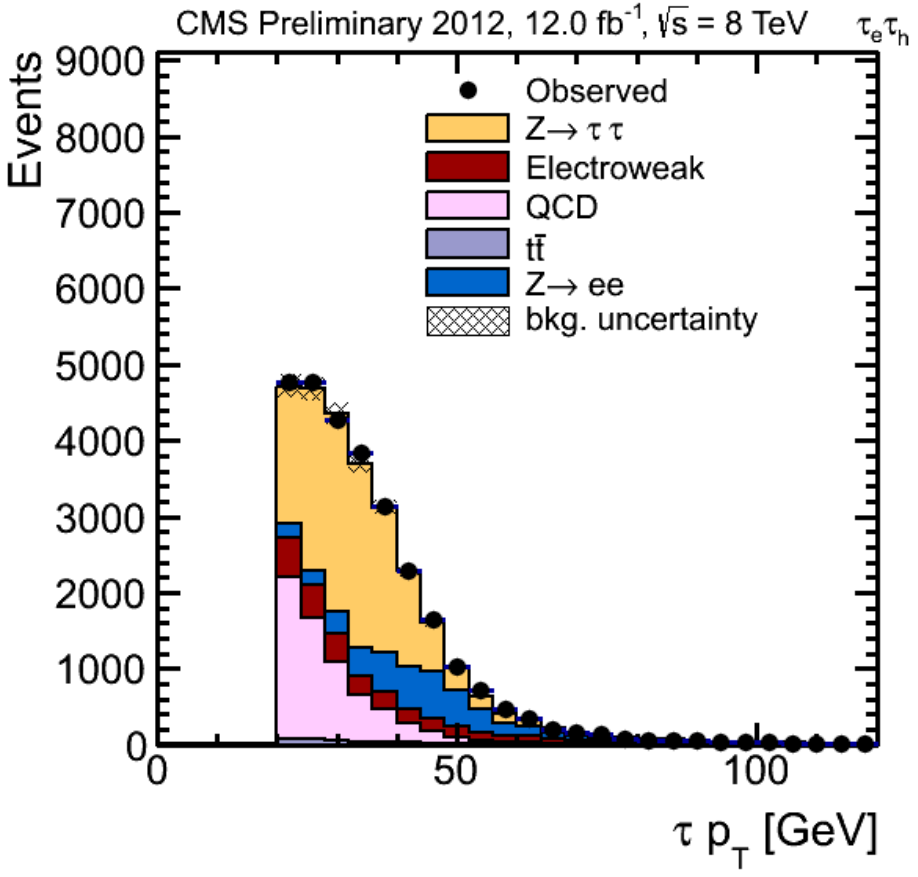


Baseline event selection

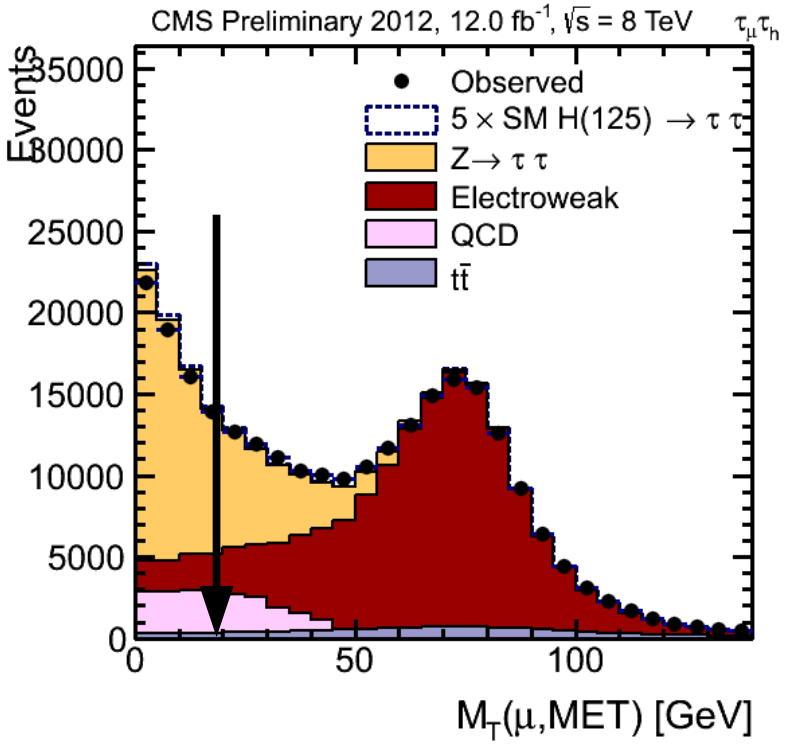
- Analyze events in the following di-tau final states
  - Muon + Hadronic tau (μ + τ_h)
    - Triggered by μ+τ trigger
    - Muon Pt > 17 (20) GeV ,|η|<2.1
    - Tau Pt > 20 GeV |η|<2.3
  - Electron + Hadronic tau (e + τ_h)
    - Triggered by e+τ trigger
    - Electron Pt>20 (24) GeV , |η|<2.1
    - Tau Pt > 20 GeV, |η|<2.3
  - Electron + Muon (e + μ)
    - Triggered by e+μ Triggers
    - Muon Pt >20/10 GeV ,|η|<2.4
    - Electron Pt >10/20 GeV ,|η|<2.3
  - Double Hadronic ($\tau_h + \tau_h$)-SM only
    - Triggered by di-tau(30 GeV) +jet trigger
    - Tau Pt threshold of 45 GeV, |η|<2.3

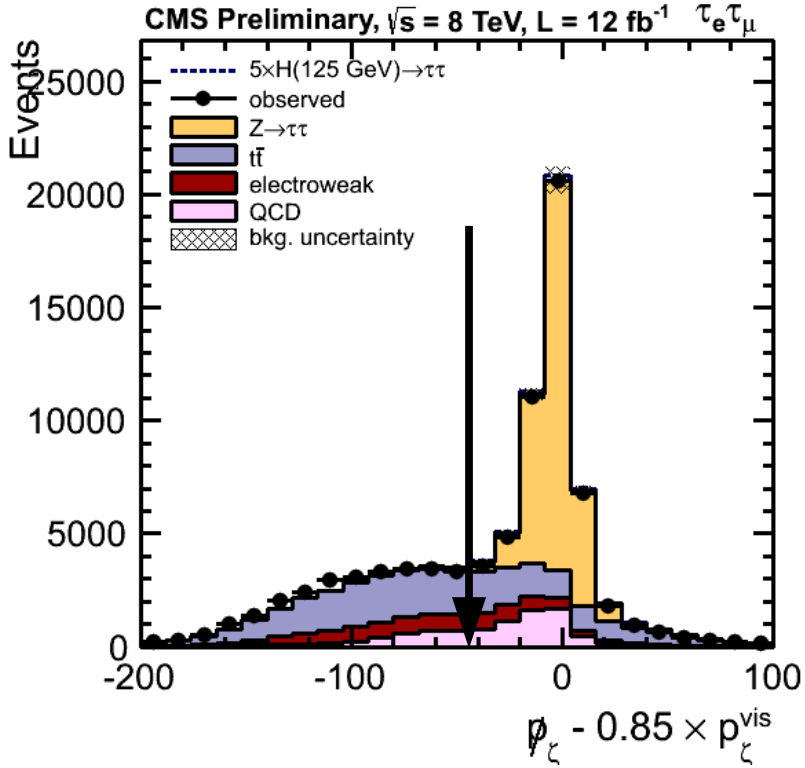
Di-Muon (μ + μ)

- Triggered by Double μ Triggers
- Muon Pt >20/10 GeV ,|η|<2.4



Rejecting W+jets and ttbar



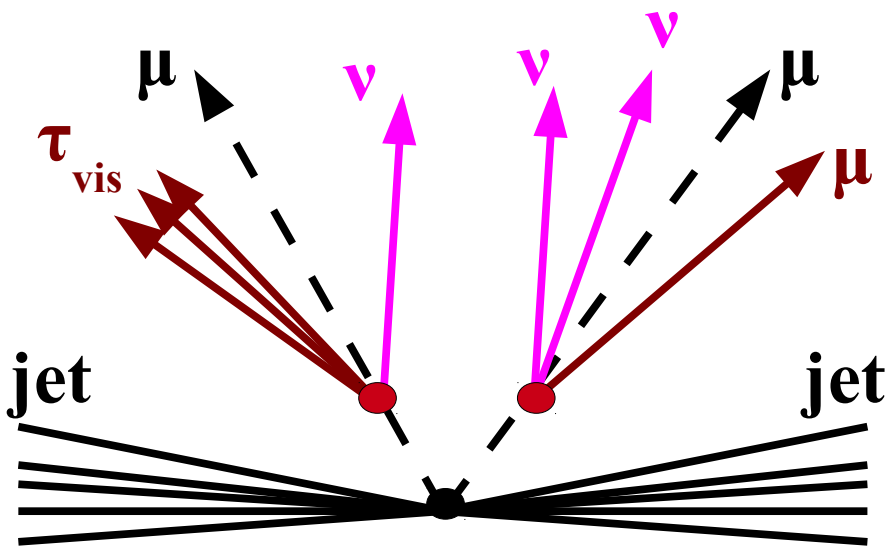


- Semileptonic final states
  - W+ jets/tt is rejected by exploiting M_T (ℓ,MET)
  - Require M_T< 20 GeV
- Di-Lepton final states
  - Tt/W+ jets is rejected by exploiting Pζ variable
  - Projection of MET and visible products in bisector axis
  - Require Pζ – $P\zeta_{vis}$>-20 GeV

Background estimation techniques

- Well established methods

Z from embedding technique

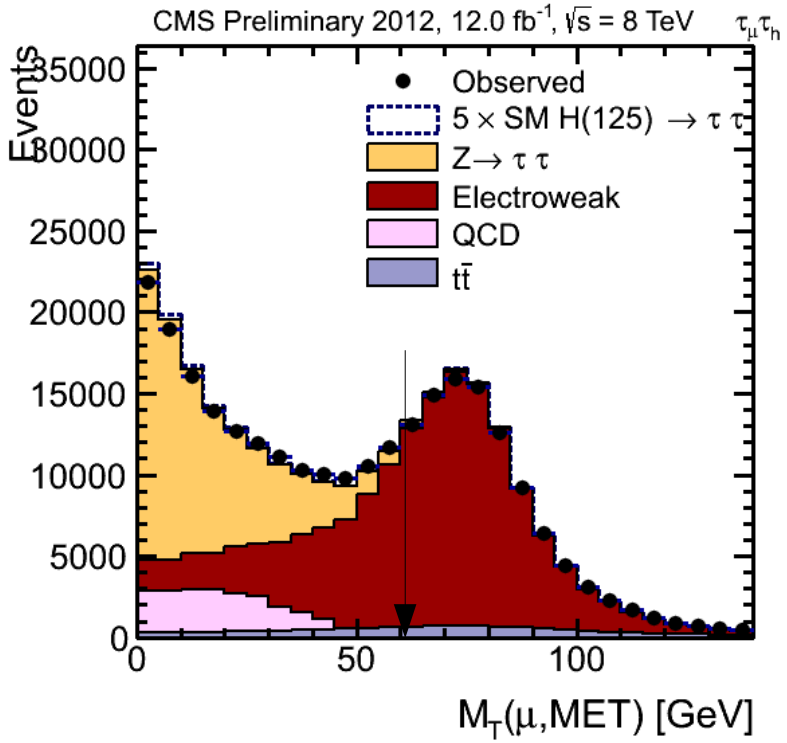


- Reconstruct Z → μμ events in data
- Replace μ with τ and decay the event
- Mix the simulated tau pair event with the initial events without the muon
- PU/UE and jets from data

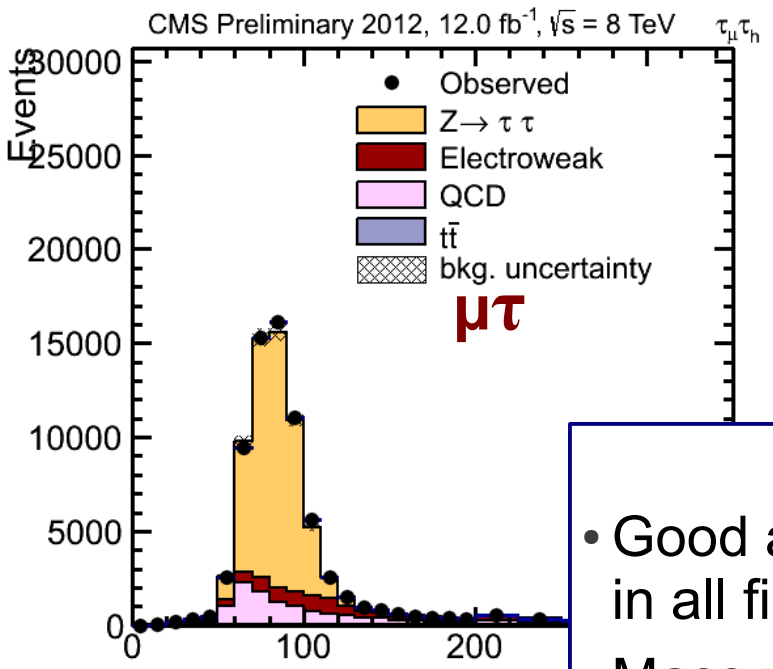
QCD from Same Sign Events

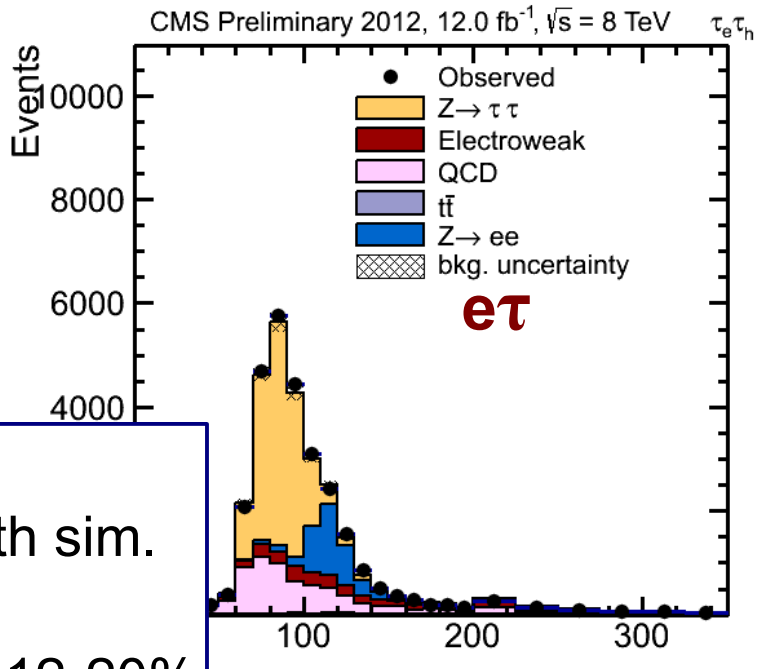
- Count events in SS region
- Subtract the other backgrounds from data/MC predictions
- Extrapolate in OS region

W/tt from sidebands

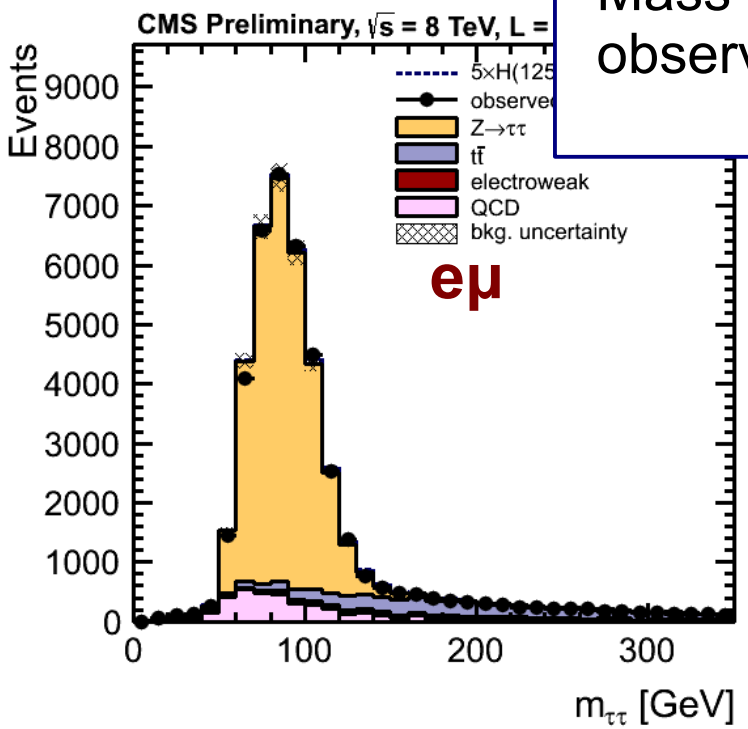


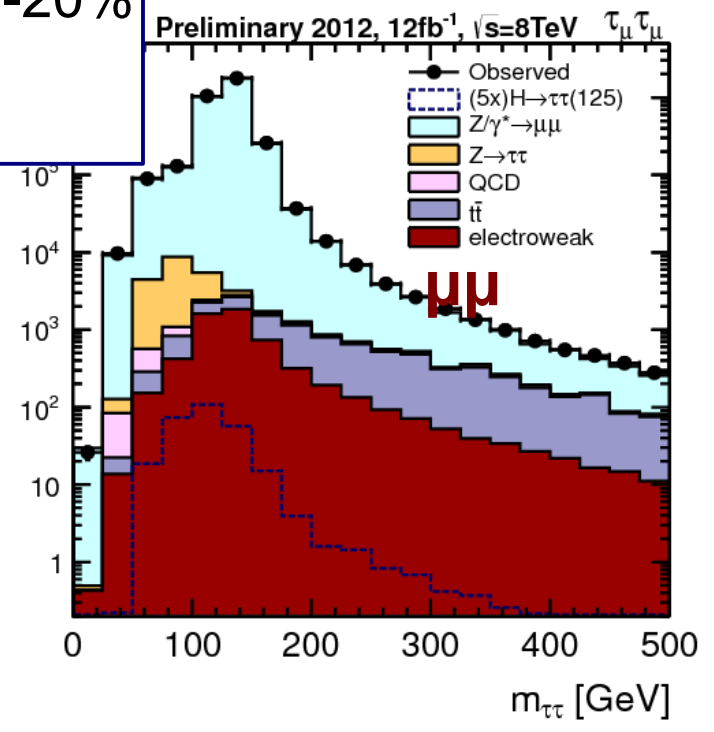
Inclusive ττ results





- Good agreement with sim. in all final states
- Mass resolution of 12-20% observed on Z → ττ

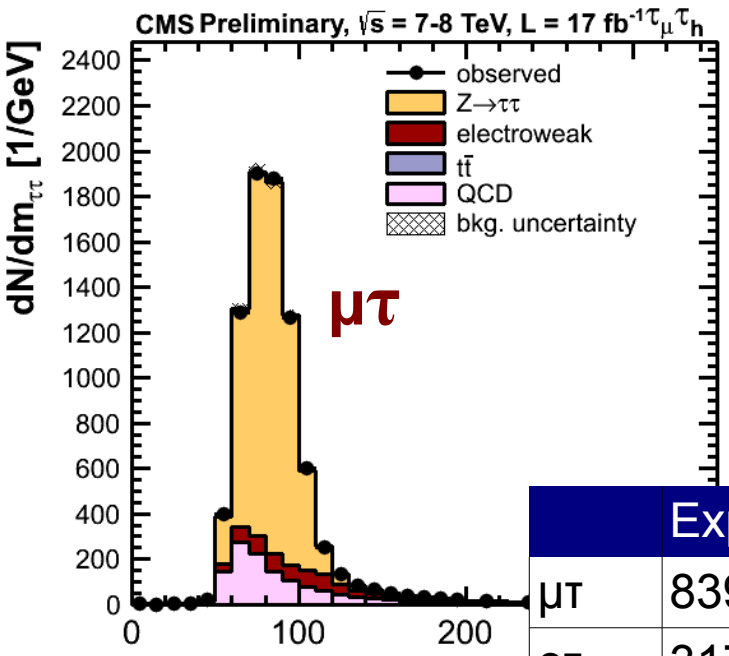


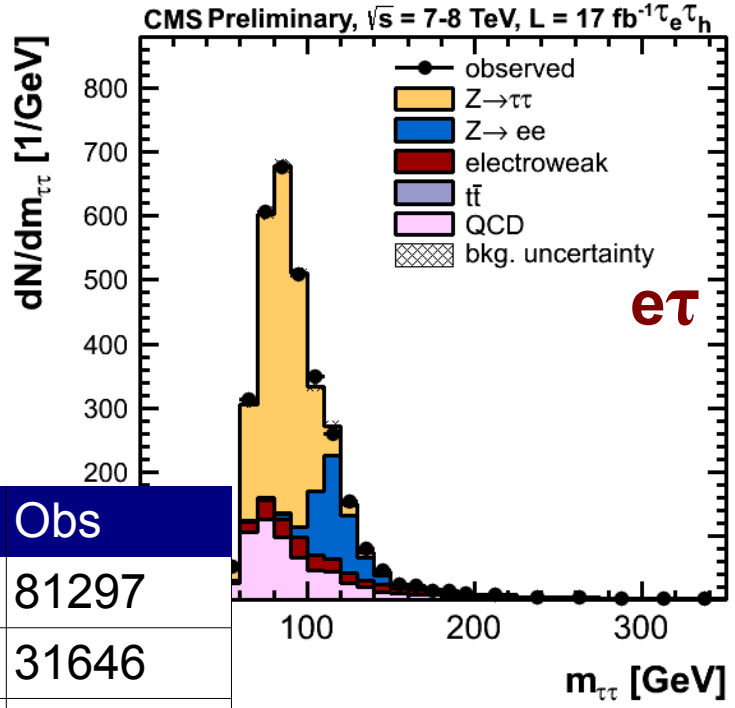


SM search strategy

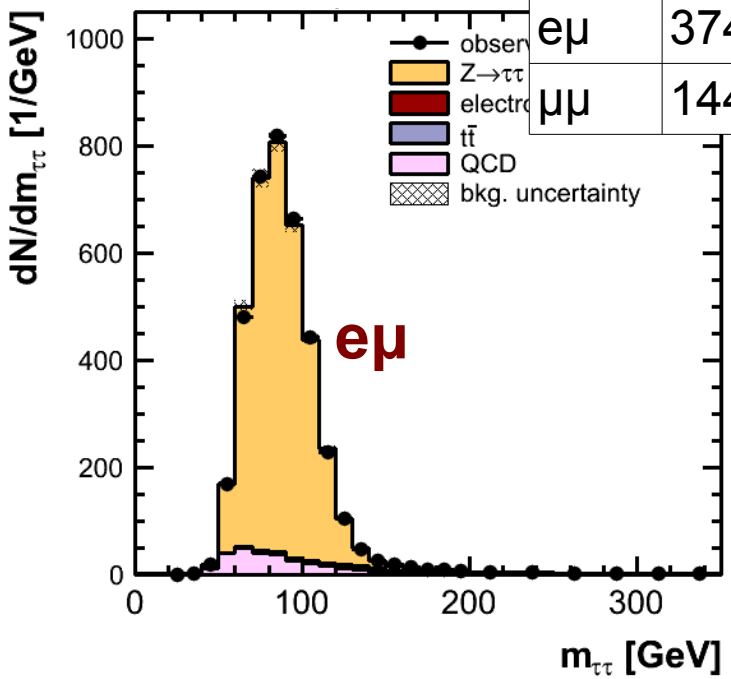
- Categorization (μτ,eτ,eμ,μμ)
  - **VBF:** Require 2 jets above 30 GeV , |η|<4.7. The jets must have Δη>3.5 and Mjj>500 GeV. Jet veto in the gap between the jets and the tau products
  - **1 jet:** Requires at least one jet> 30 GeV. Veto events accepted by VBF category.
  - **0 jet:** All other events. Signal negligible. Used for calibration
  - 0 and 1 jet categories split based on the tau pt (high pt, low pt)
- Categorization (ττ hadronic)
  - **VBF**: Require 2 jets as above but with Δη>2.5, Mjj>250 GeV. Require also Pt (di-tau) >110 GeV
  - **1 Jet**: Require one jet with Pt>140 GeV
- Categorization (VH)
  - **ZH**: require two leptons from Z plus 2 taus (μτ,eτ,eμ,ττ)
  - **WH**: require 2 SS leptons + a hadronic tau

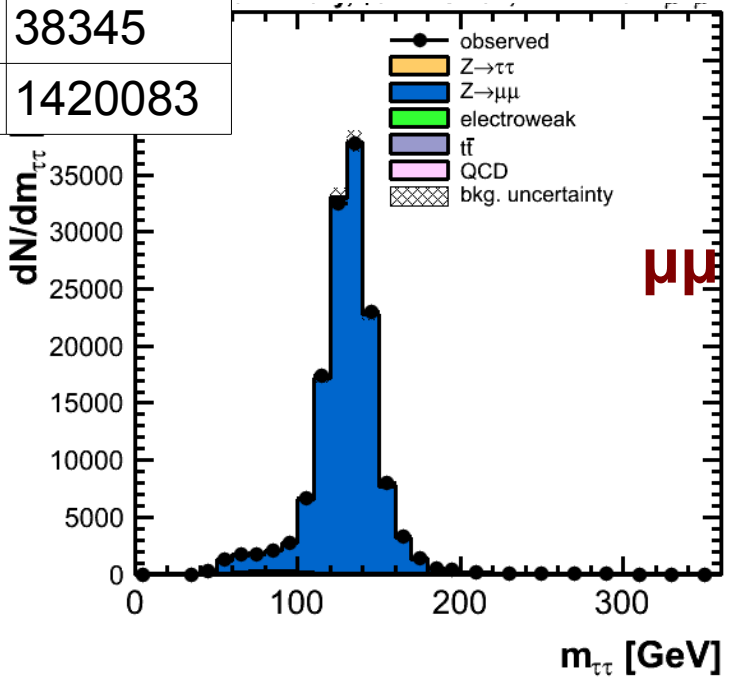
H+0 jet category



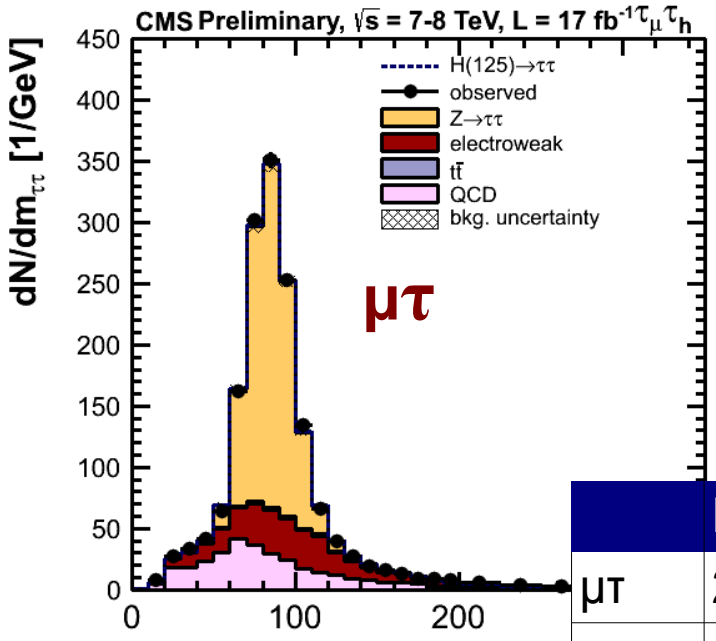


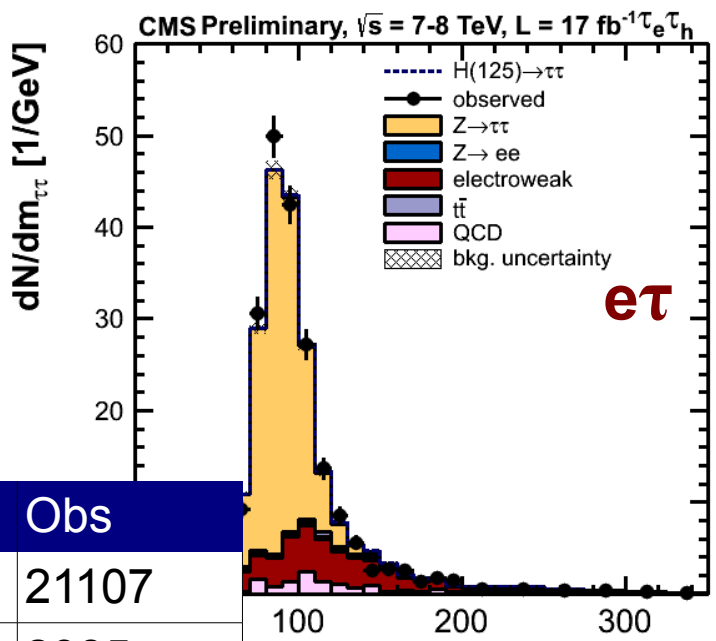
	Expected	Obs
μτ	83926 ± 3736	81297
eτ	31750 ± 1232	31646
eμ	37487 ± 1270	38345
μμ	1448705 ± 87710	1420083



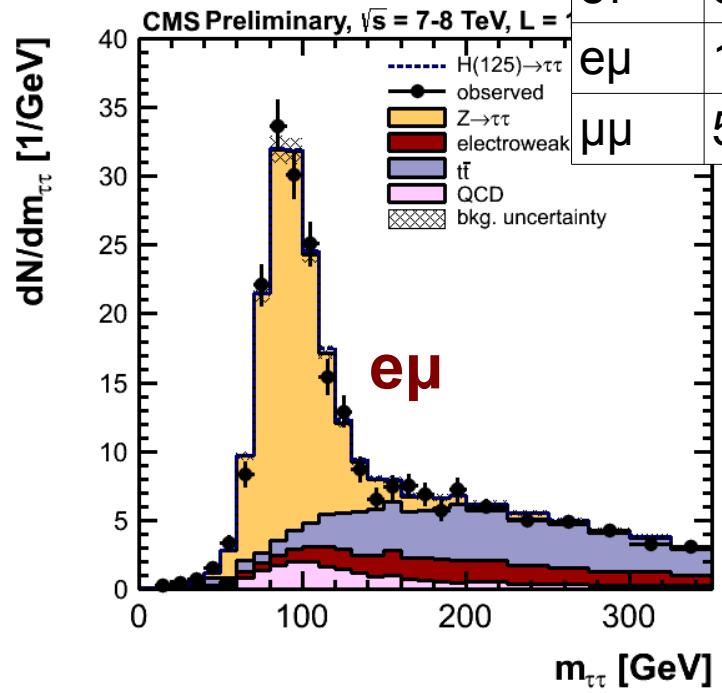


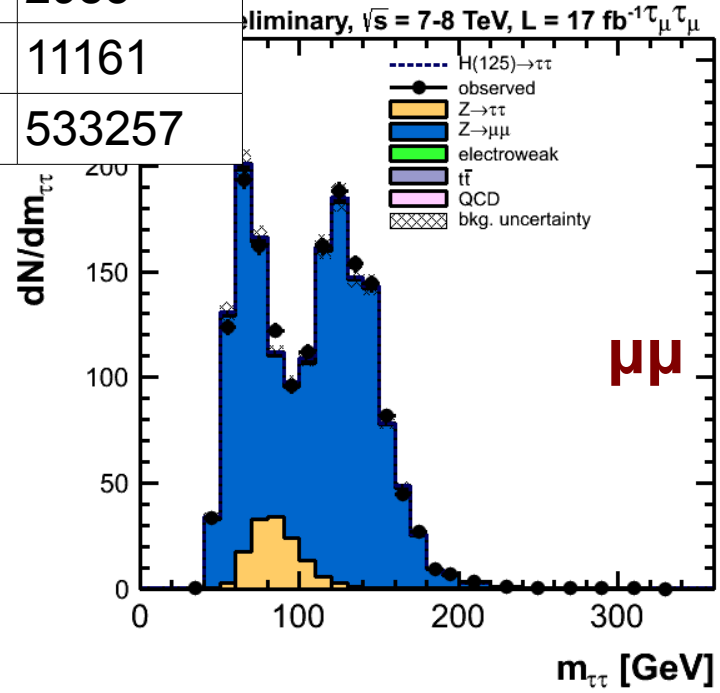
H+1 jet category (low pt)



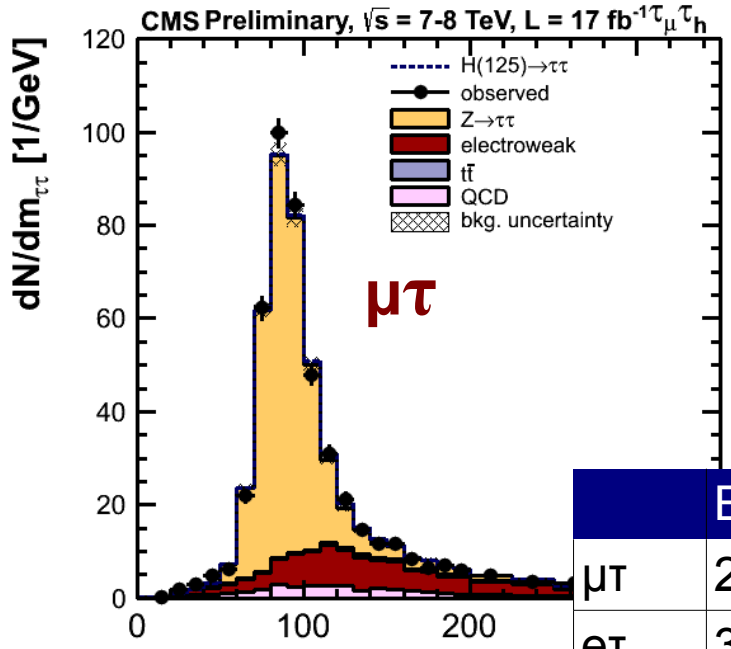


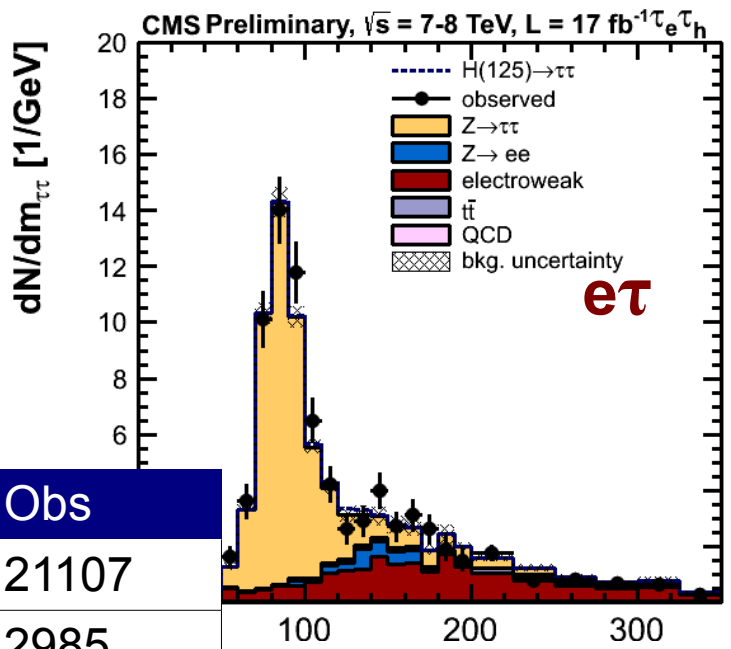
	Expected	Obs
μτ	21076 ± 815	21107
eτ	3097 ± 121	2985
eμ	11295 ± 404	11161
μμ	541484 ± 39368	533257





H+1 jet category (high pt)





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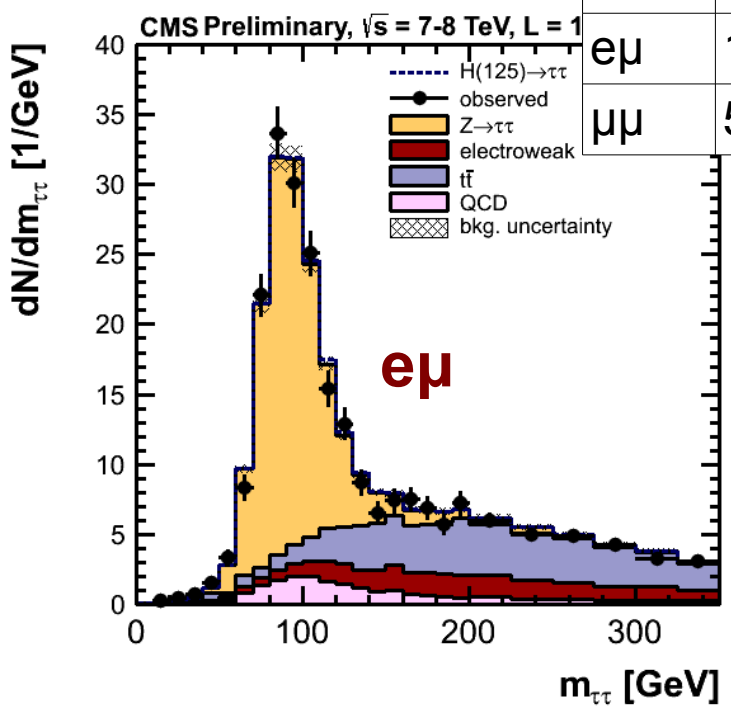
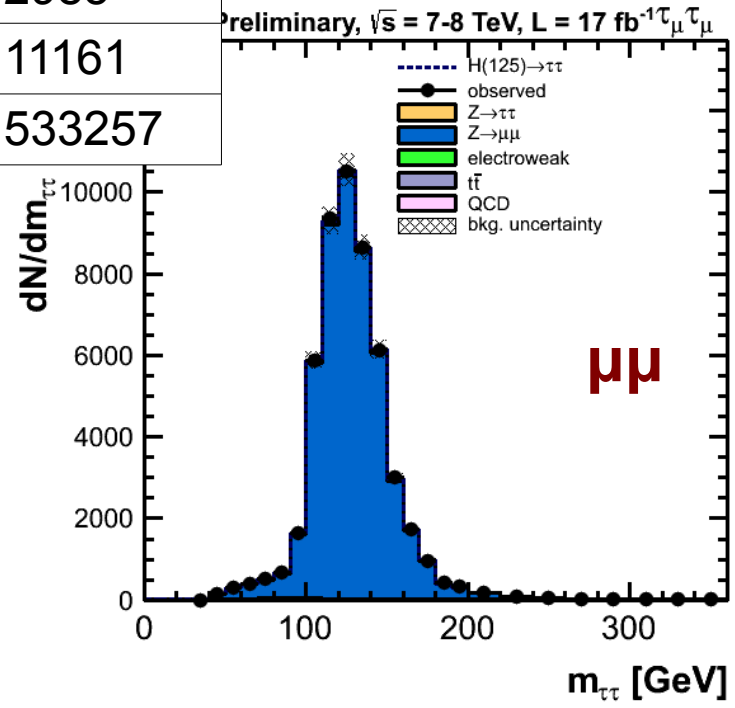
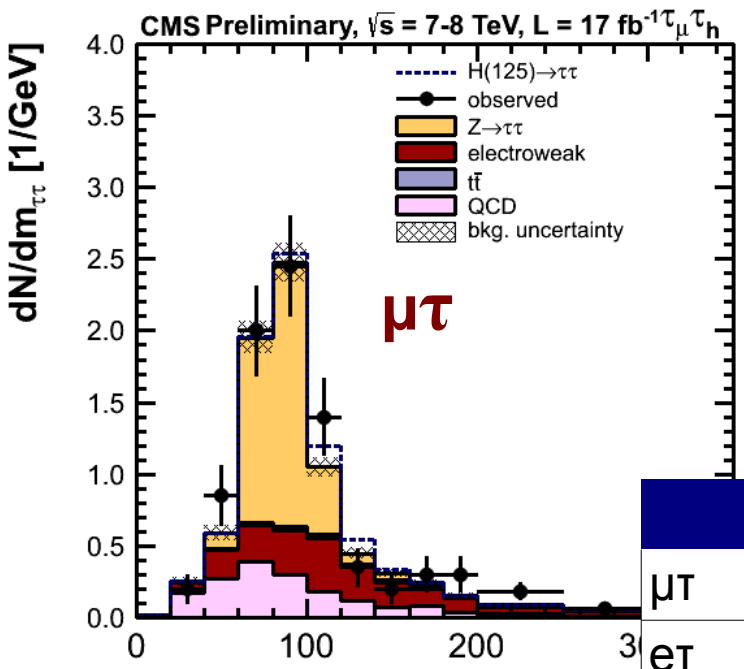
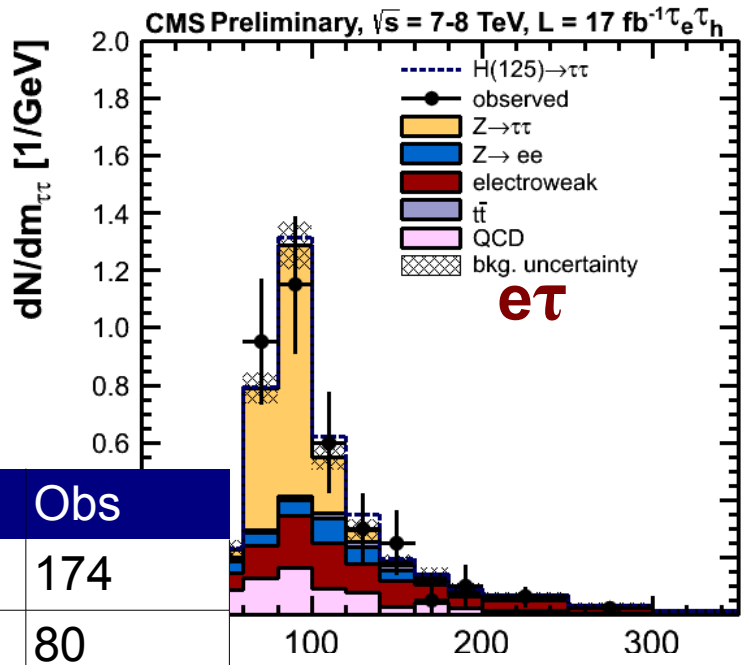


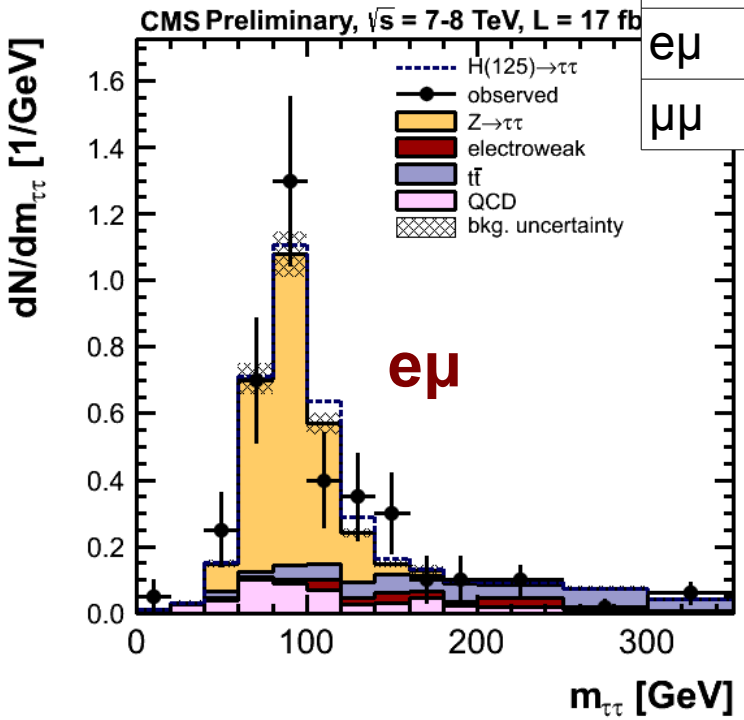


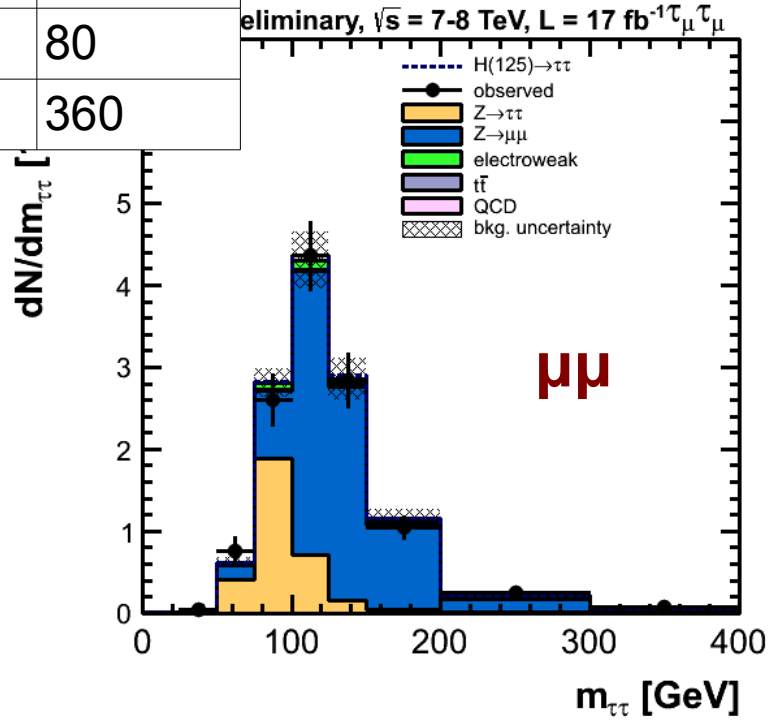
VBF category



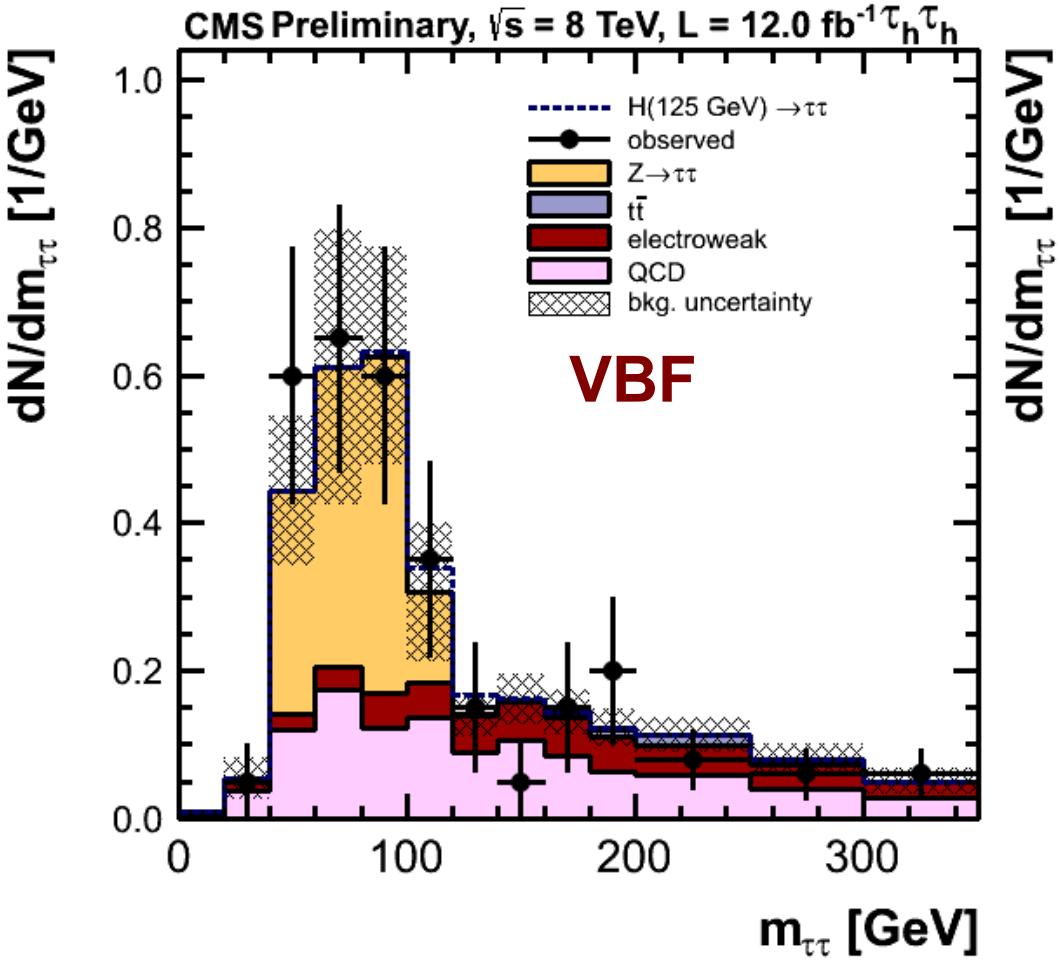


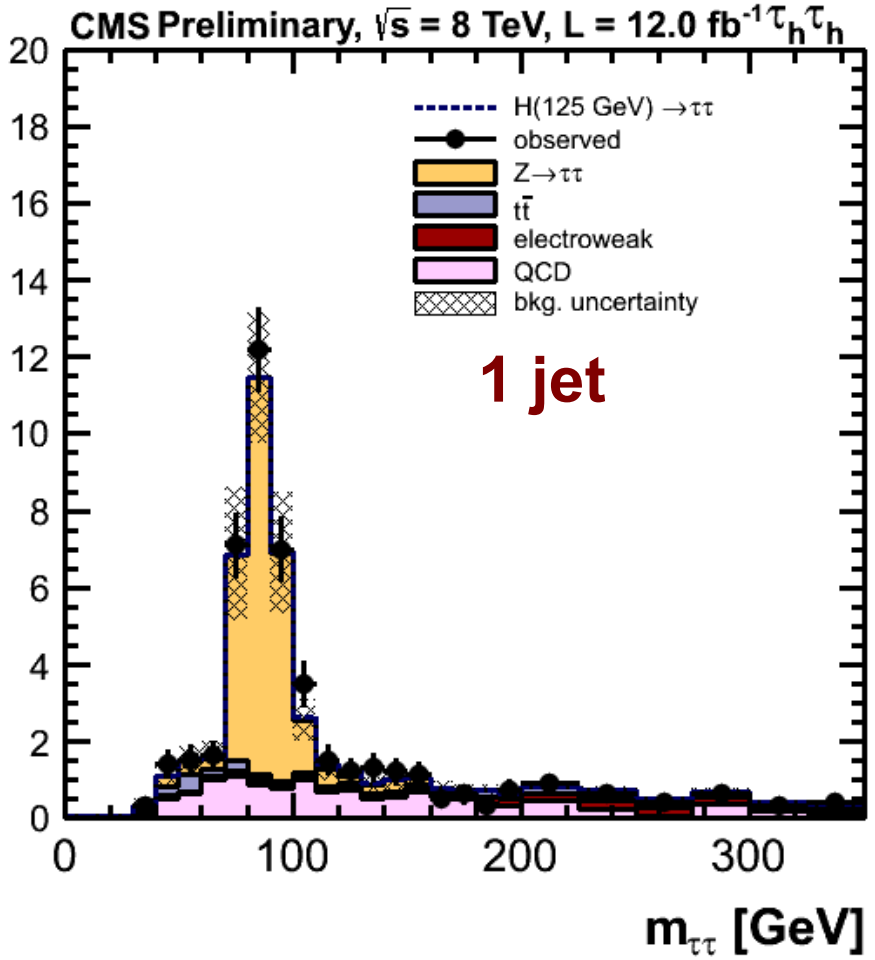
	Expected	Obs
μτ	154 ± 10	174
eτ	82 ±6	80
eμ	73 ± 5	80
μμ	377 ± 56	360





Double Hadronic final state

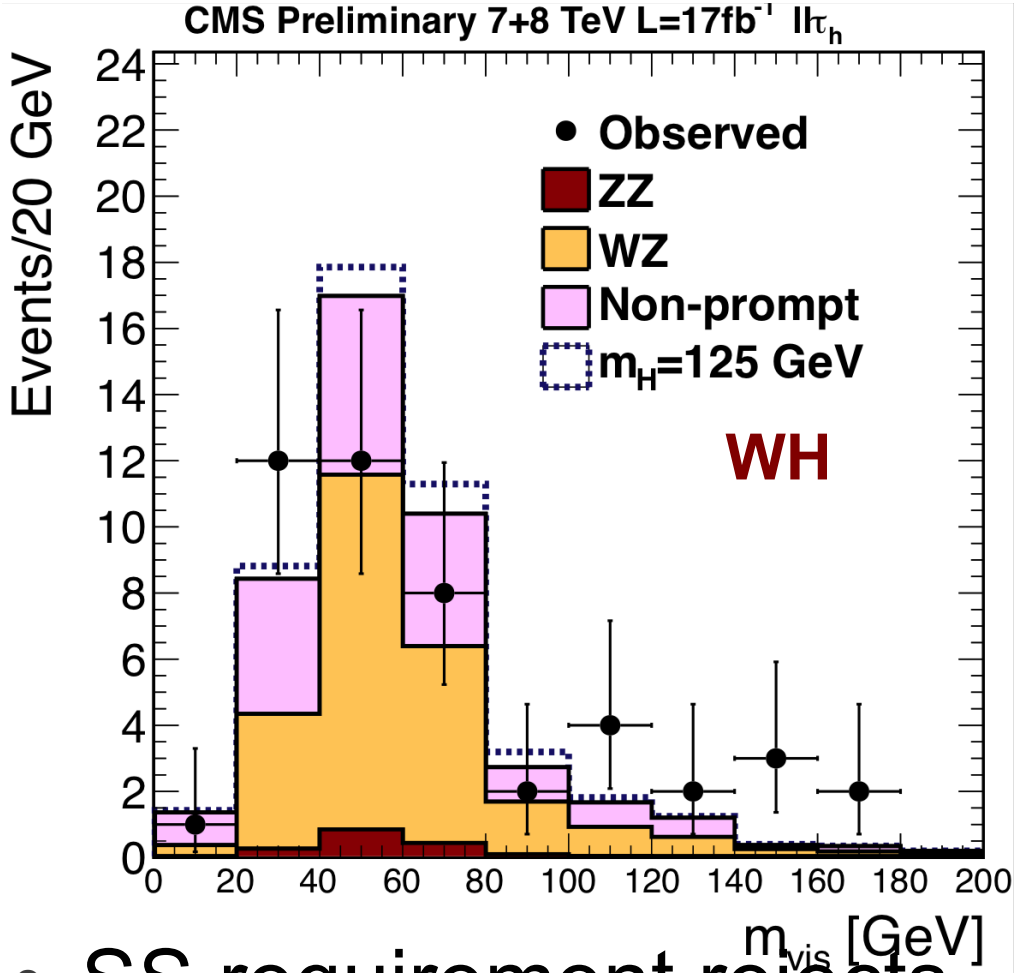


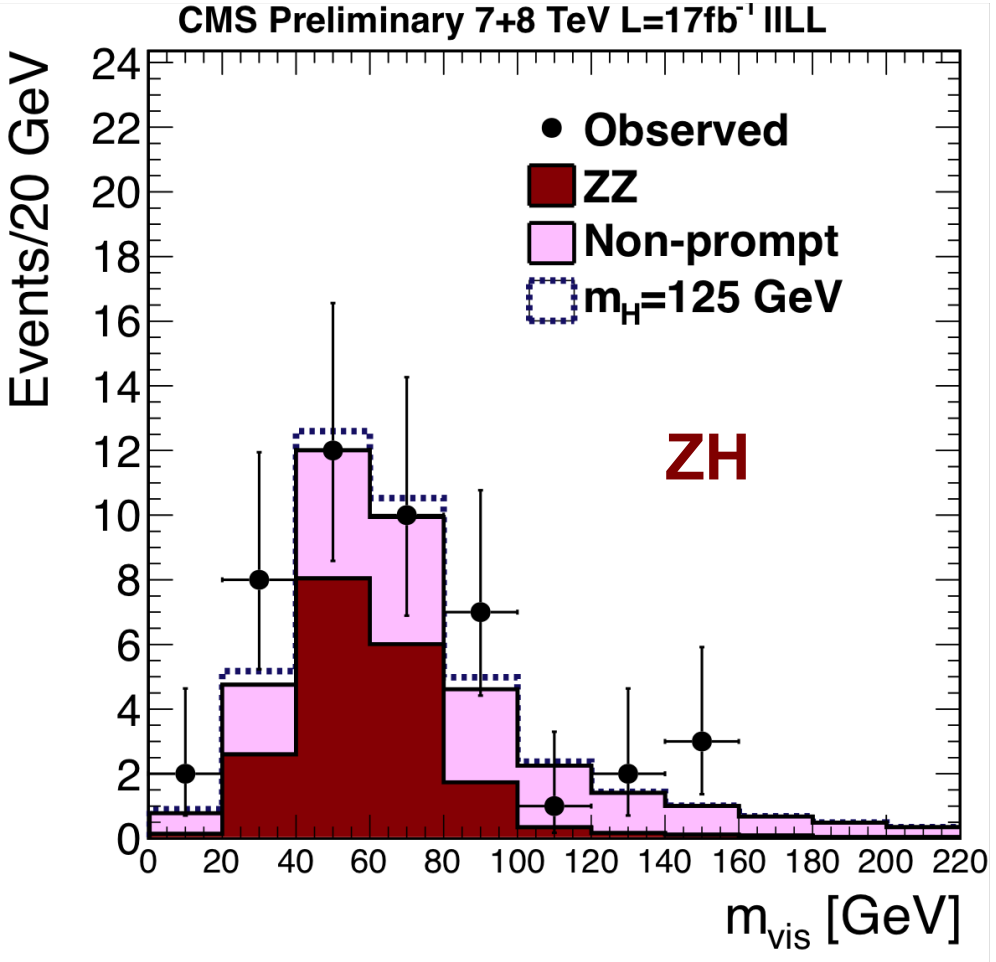


- VBF
  - Require Δη >2.5 , Mjj > 250 GeV
  - Di-tau Pt>110 GeV
- 1 Jet
  - Di-tau Pt>140 GeV

	Expected	Obs
VBF	61 ± 10	66
1-jet	503 ± 67	511

VH → Vττ





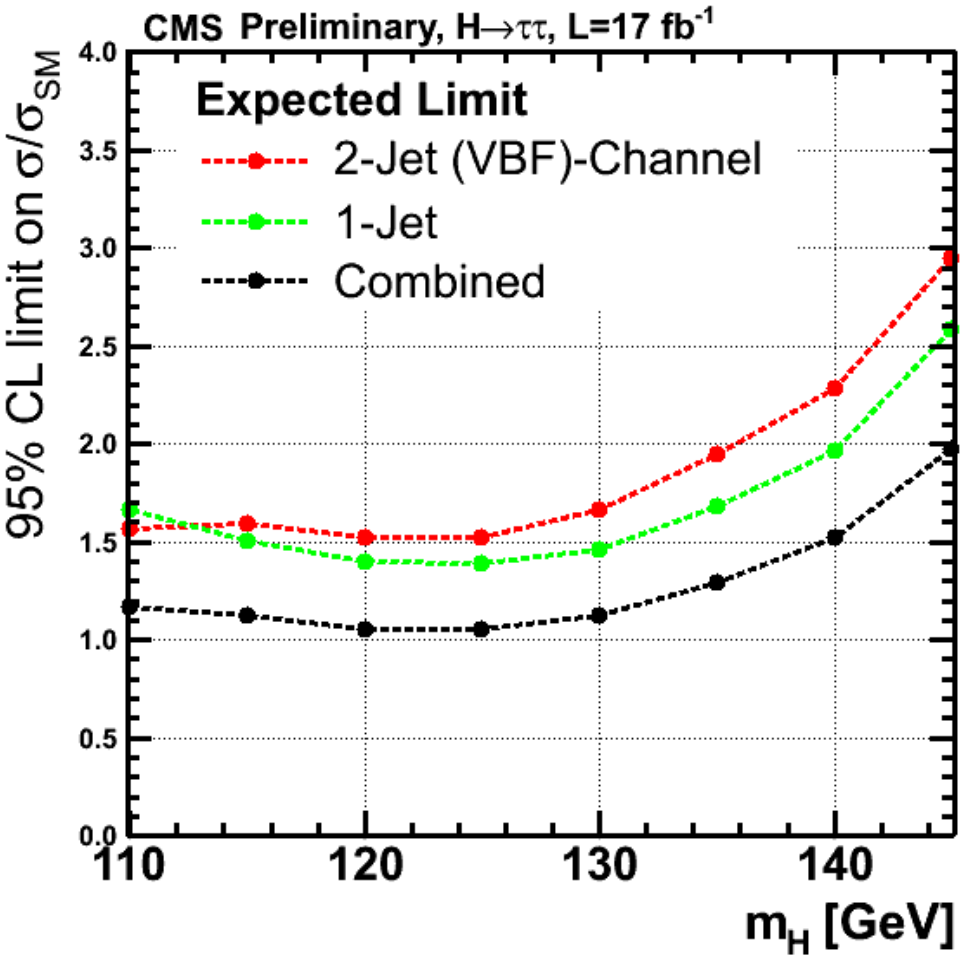
- SS requirement rejects Z+ jets in WH
- Visible mass used in both categories

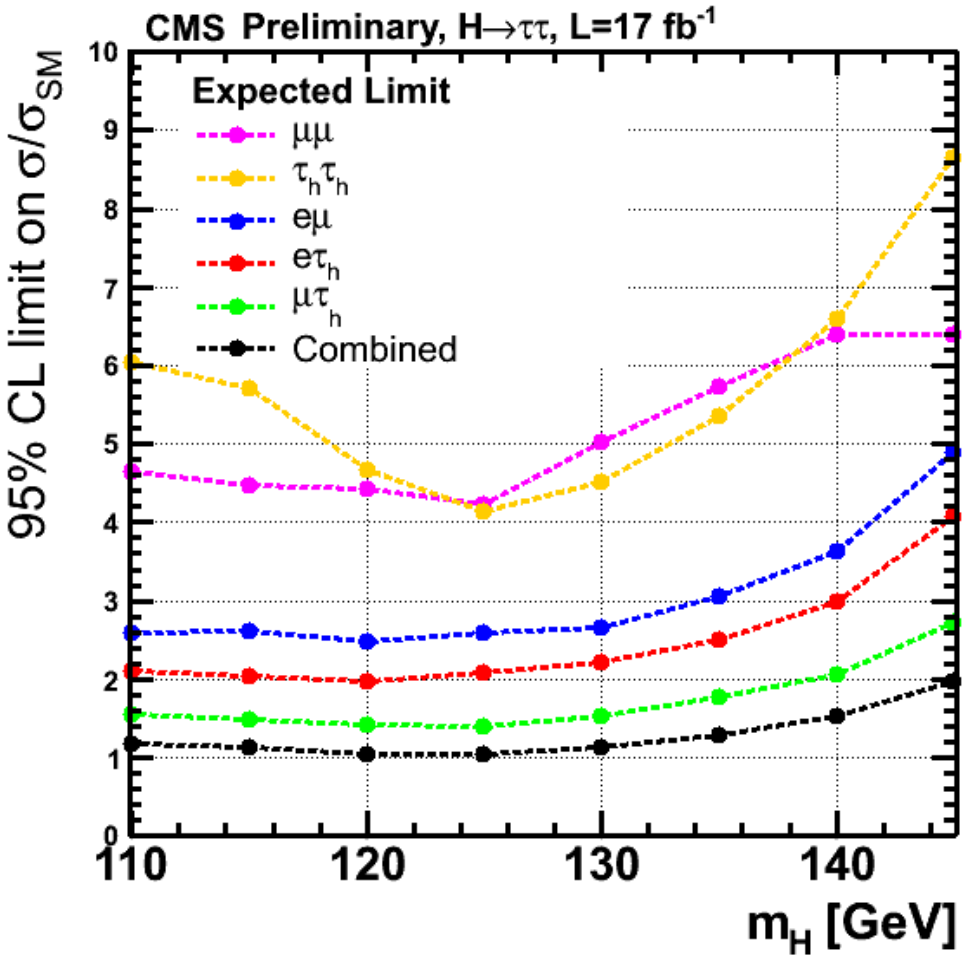
	Expected	Obs
WH	44 ± 4	46
ZH	36 ± 7	45

Relevant theoretical systematics

- Theoretical systematics only affect the signal
- Larger one: gluon fusion uncertainty in VBF selection
  - ggH events with 2 jets at high Δη and Mjj
  - + jet veto applied
  - Uncertainty = 30%
- Second largest one: gluon fusion uncertainty in the 1 jet category
  - At least one jet> 30 GeV
  - Uncertainty = 10%
- Both of them have relatively small effect in the analysis
  - Experimental systematics dominate

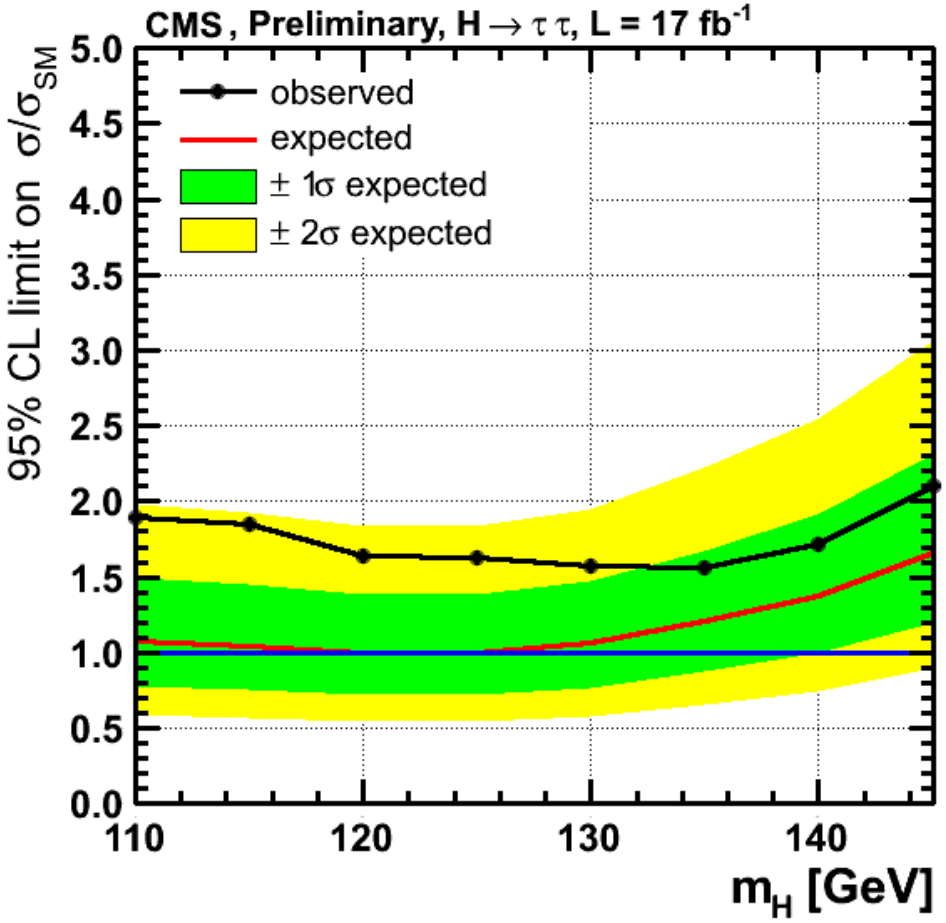
Expected Sensitivity

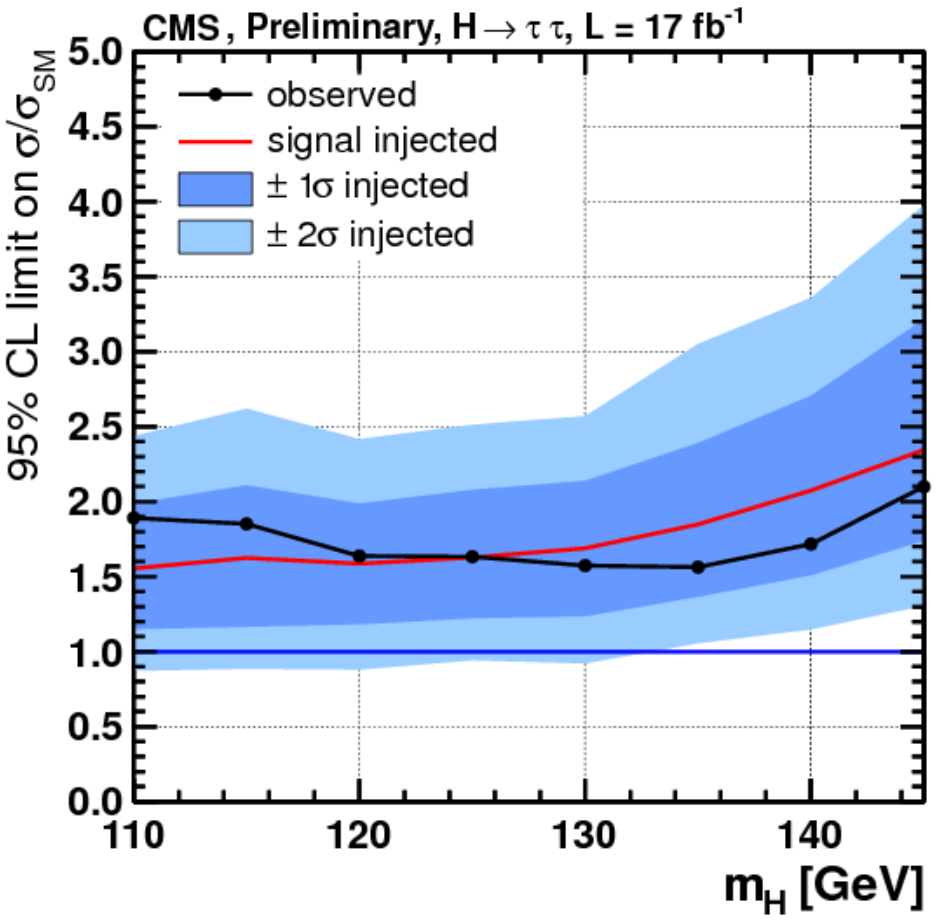




- Sensitivity comparable between VBF and 1 jet category
- Most sensitive final state is μτ

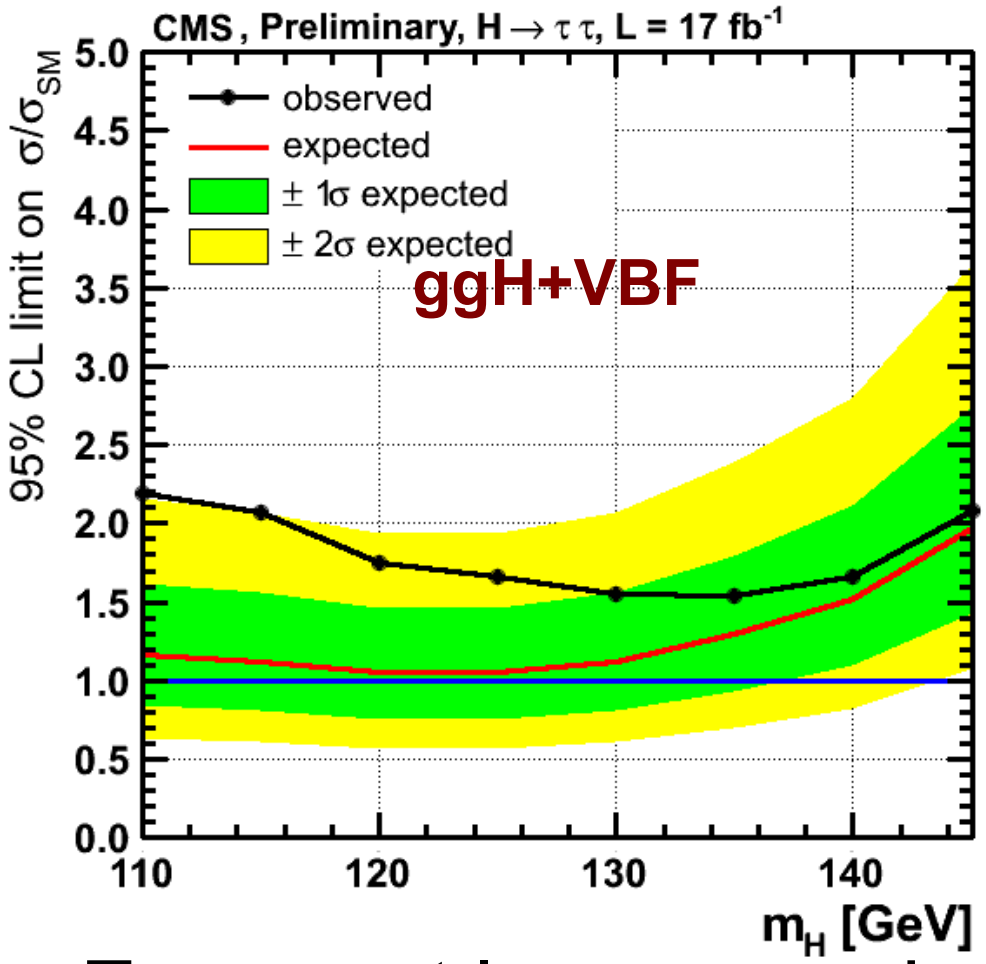
SM search results

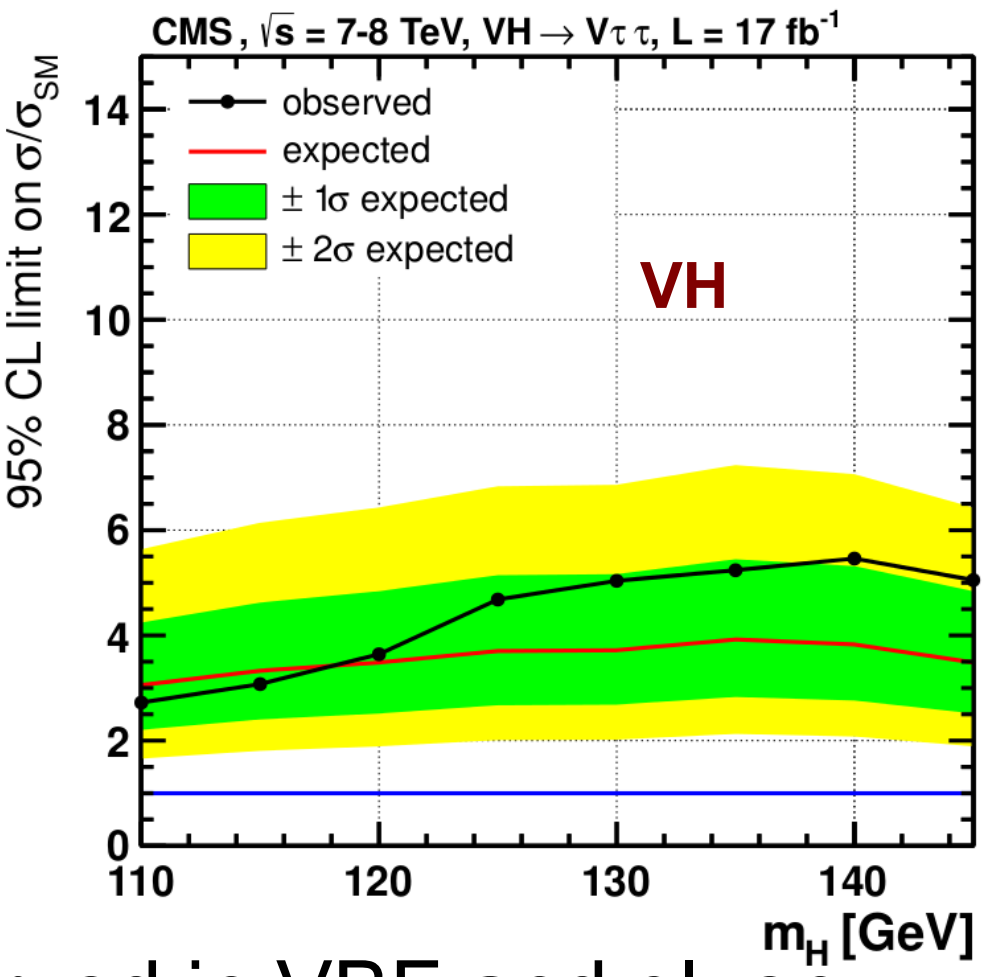




- Expecting to exclude a Higgs like particle with a cross section of 1x SM @ 126 GeV
  - Excluding 1.6 x SM
- Data still compatible with both background or signal+background hypotheses

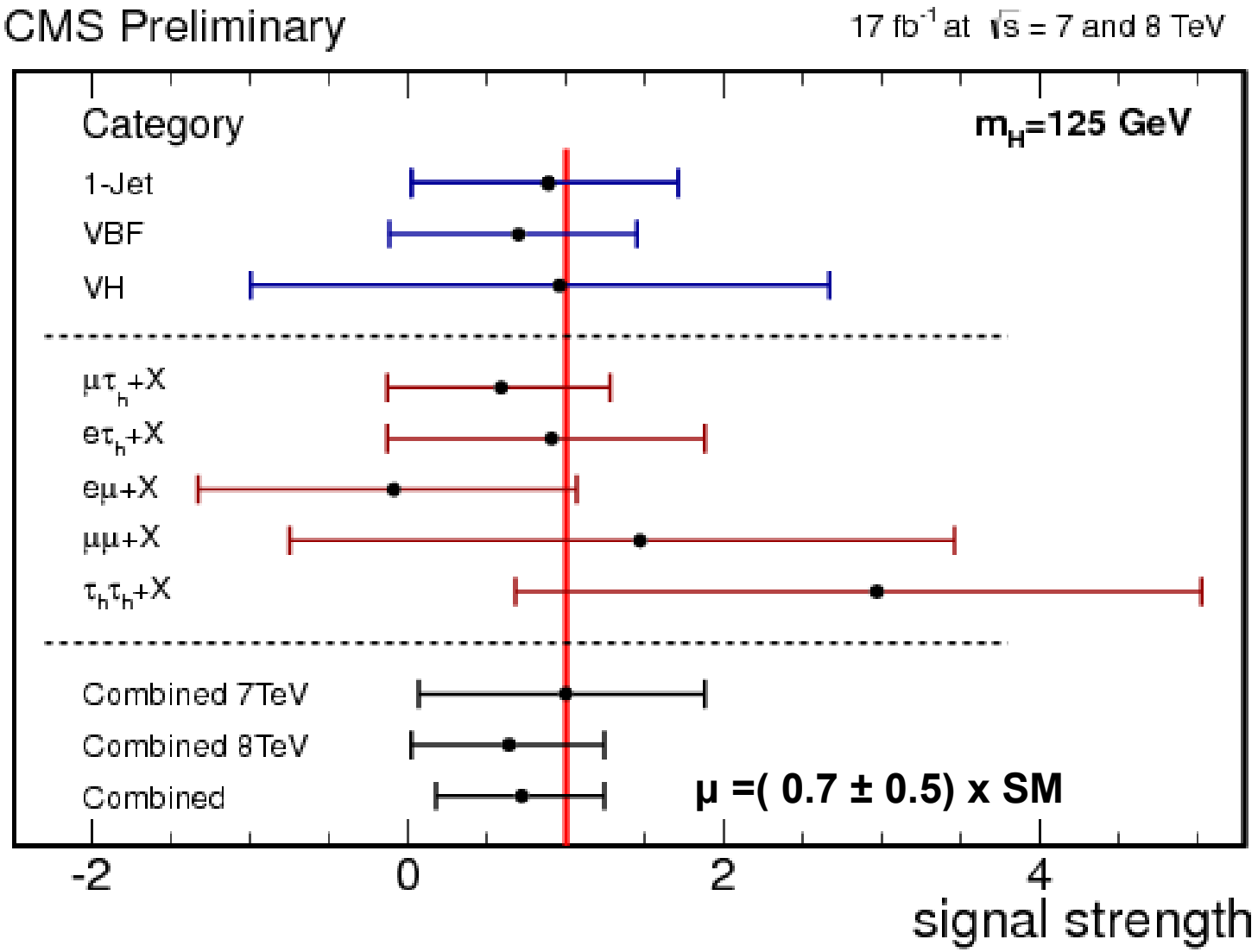
ggH+ VBF vs VH search





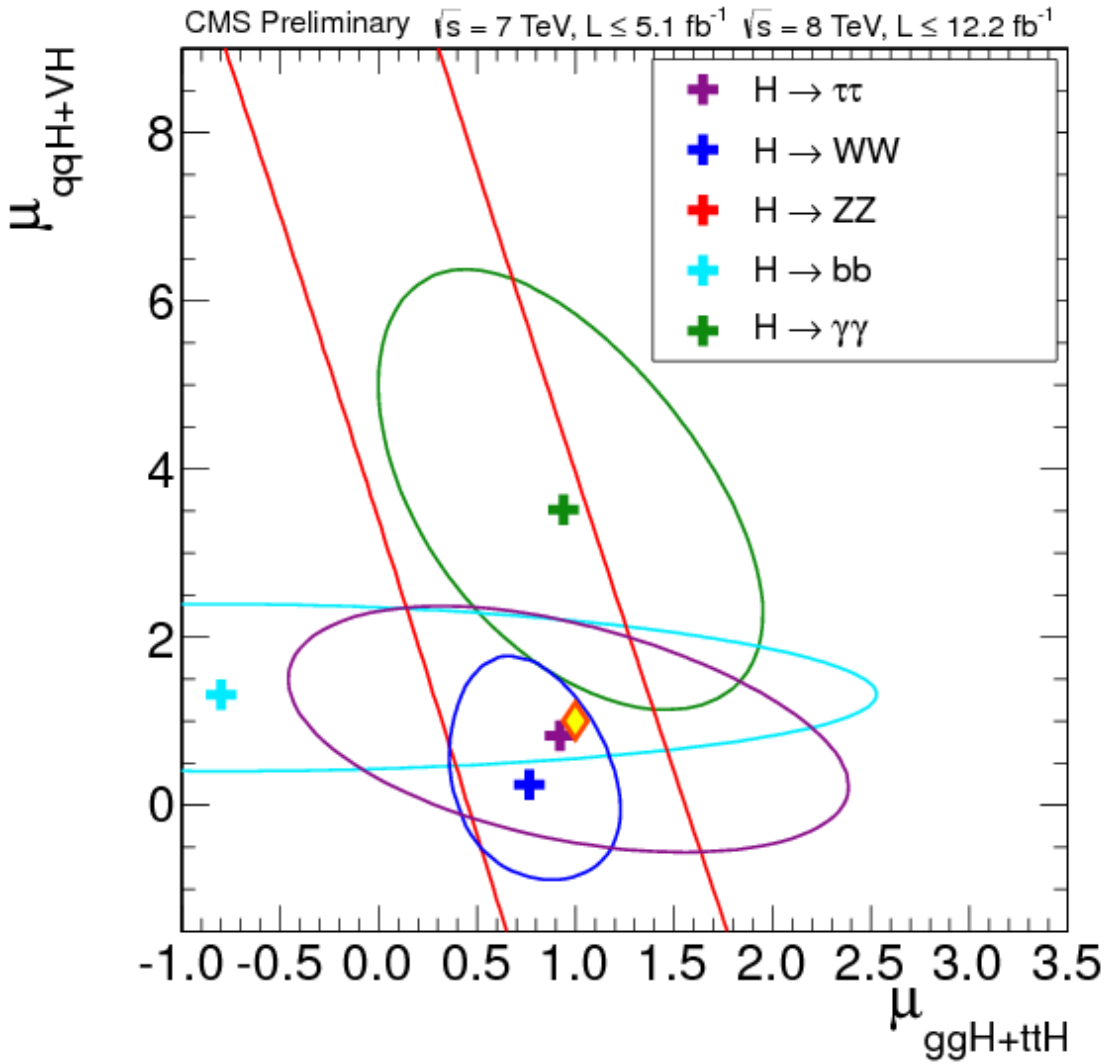
- Excess at low mass observed in VBF and gluon fusion search
- 1 σ Excess in the VH analysis above 120 GeV

Compatibility with SM



- Observation consistent with both SM Higgs signal+background only or background only
- Errors are huge to make concrete conclusions

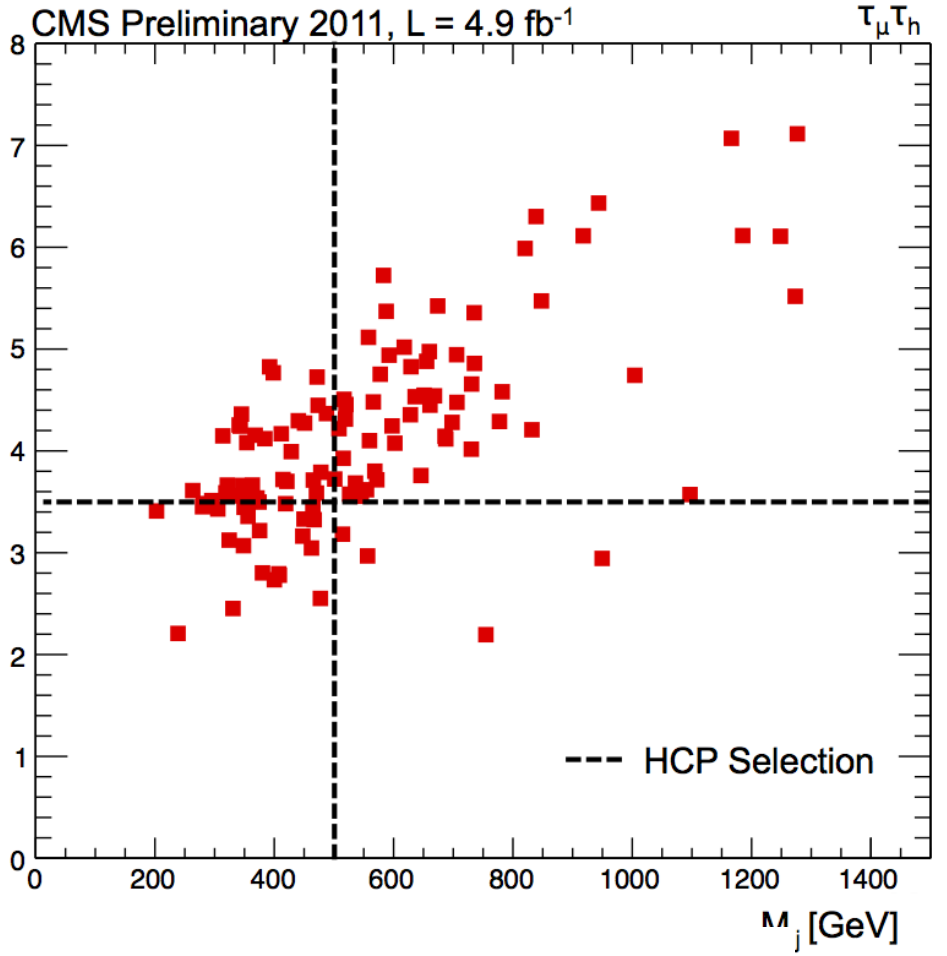
Disentangling production mechanisms

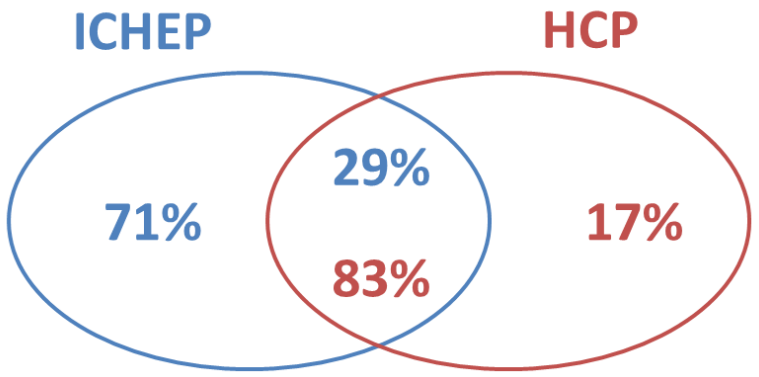


- Significant contribution to VBF cross section measurement
  - Even with very low statistics
- Better picture expected with the full dataset

Changes since ICHEP

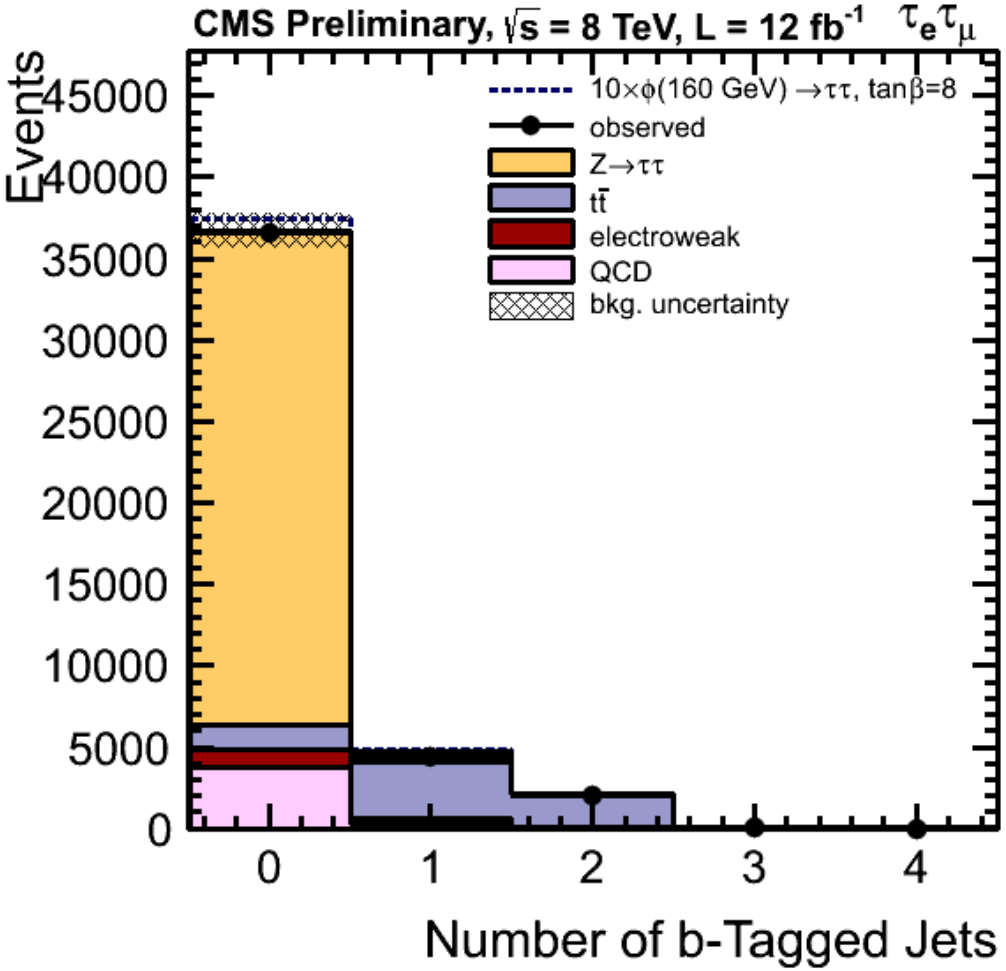
- Improved MET reconstruction
  - Gives better mass resolution
- Higher background rejection
  - M_T <20 GeV (was 40 GeV)
- Retuned VBF
  - Towards a common cut -based VBF approach for HCP
    - Before an MVA was used
    - New approach gives effectively the same sensitivity with higher purity
  - New jet energy calibration in the forward region



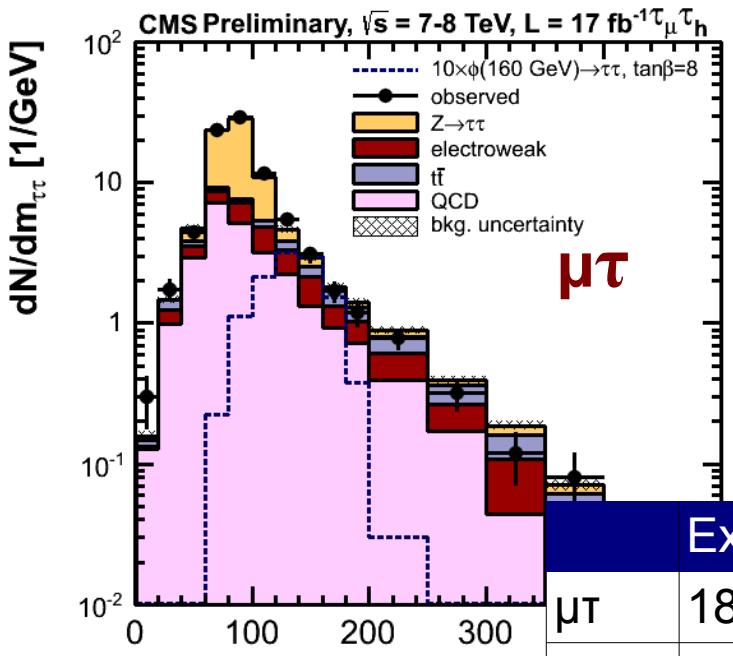


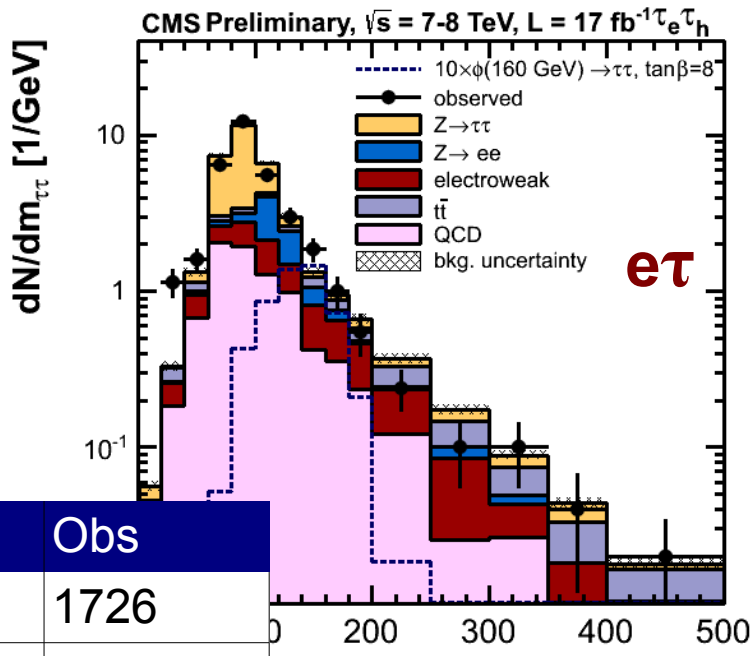
MSSM H → ττ search strategy

- Split the events into two categories
  - Events with a btagged jet>20 GeV and less than 2 jets > 30 GeV
    - Associated production with b quarks search
    - One jet requirement suppresses ttbar background and enhances bbΦ contribution
  - Events with no btagged jets > 20 GeV
    - Gluon fusion production search

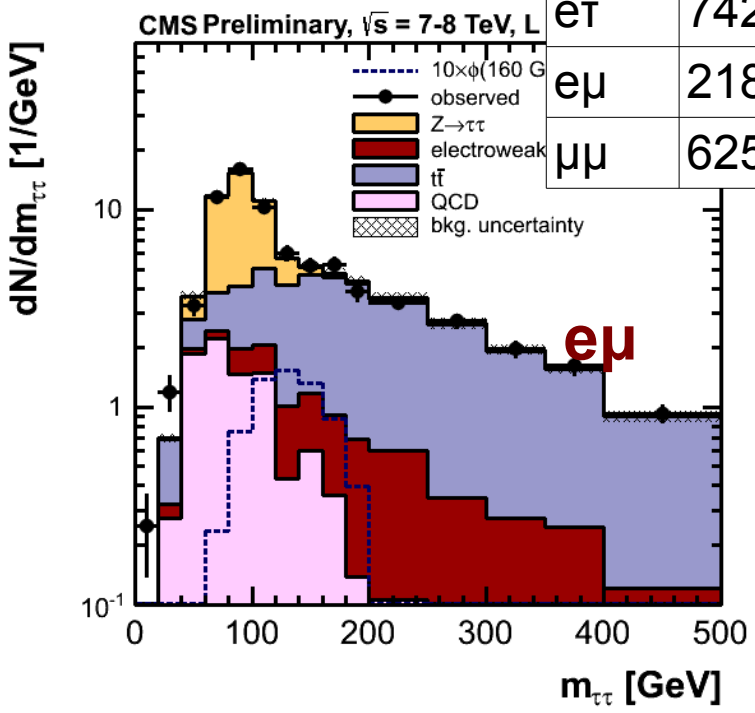


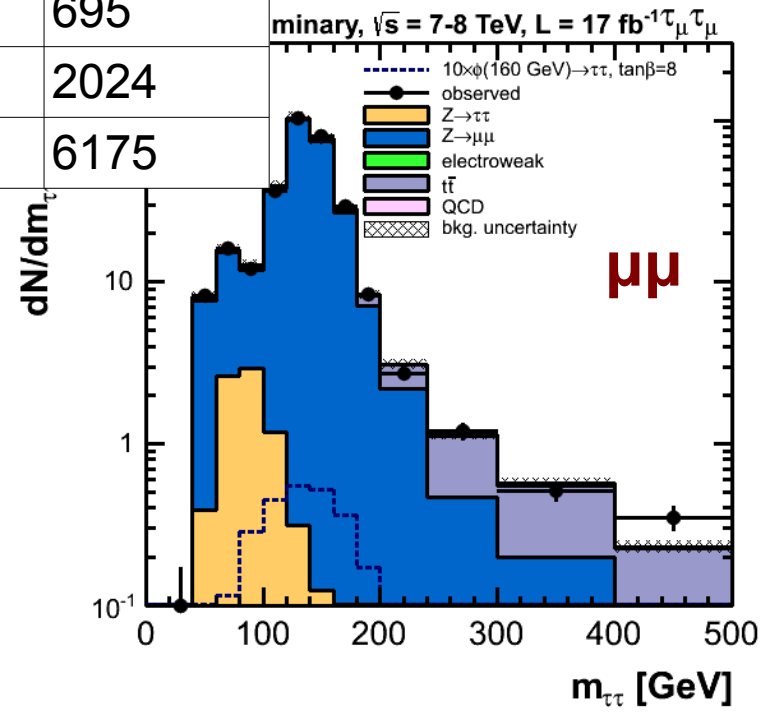
b-tagged category



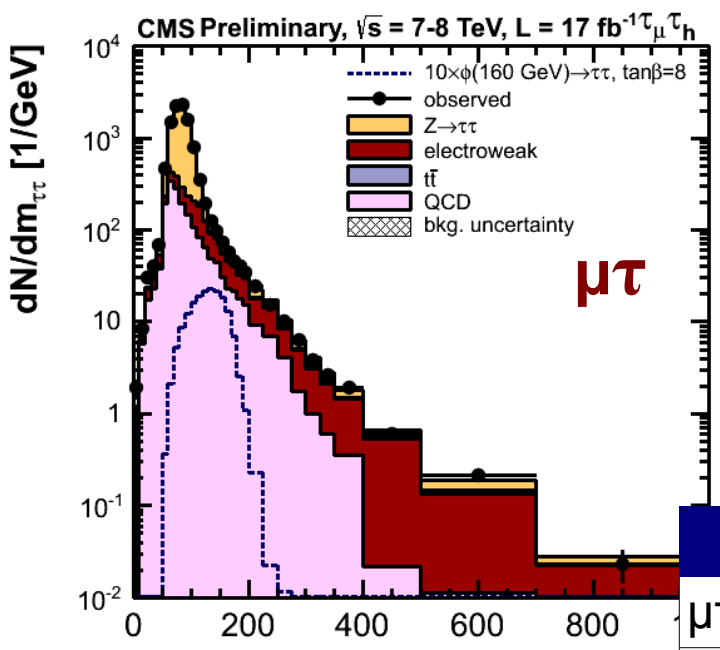


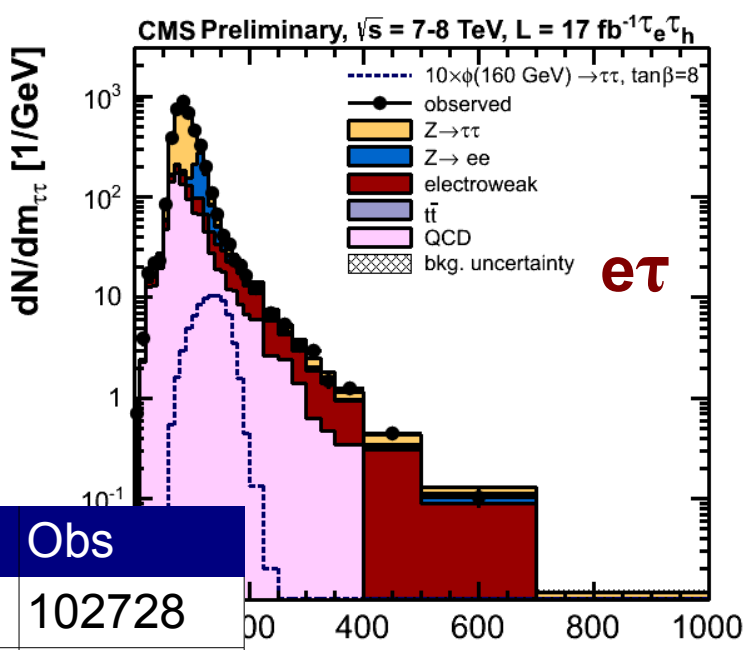
	Expected	Obs
μτ	1816 ± 117	1726
eτ	742 ± 45	695
eμ	2182 ± 152	2024
μμ	6258 ± 936	6175



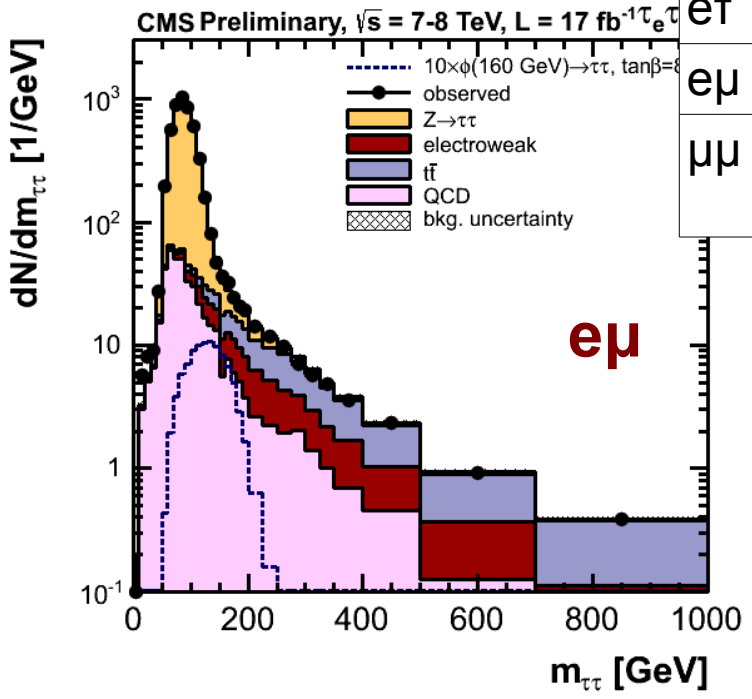


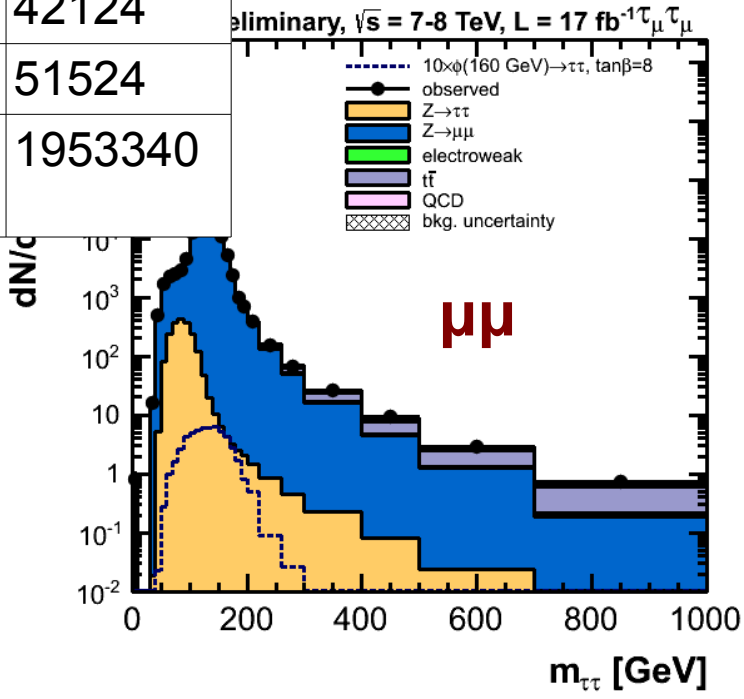
Non b-tagged category





	Expected	Obs
μτ	105267 ± 5216	102728
eτ	42387 ± 1876	42124
eμ	50761 ± 1598	51524
μμ	1990206 ± 132006	1953340

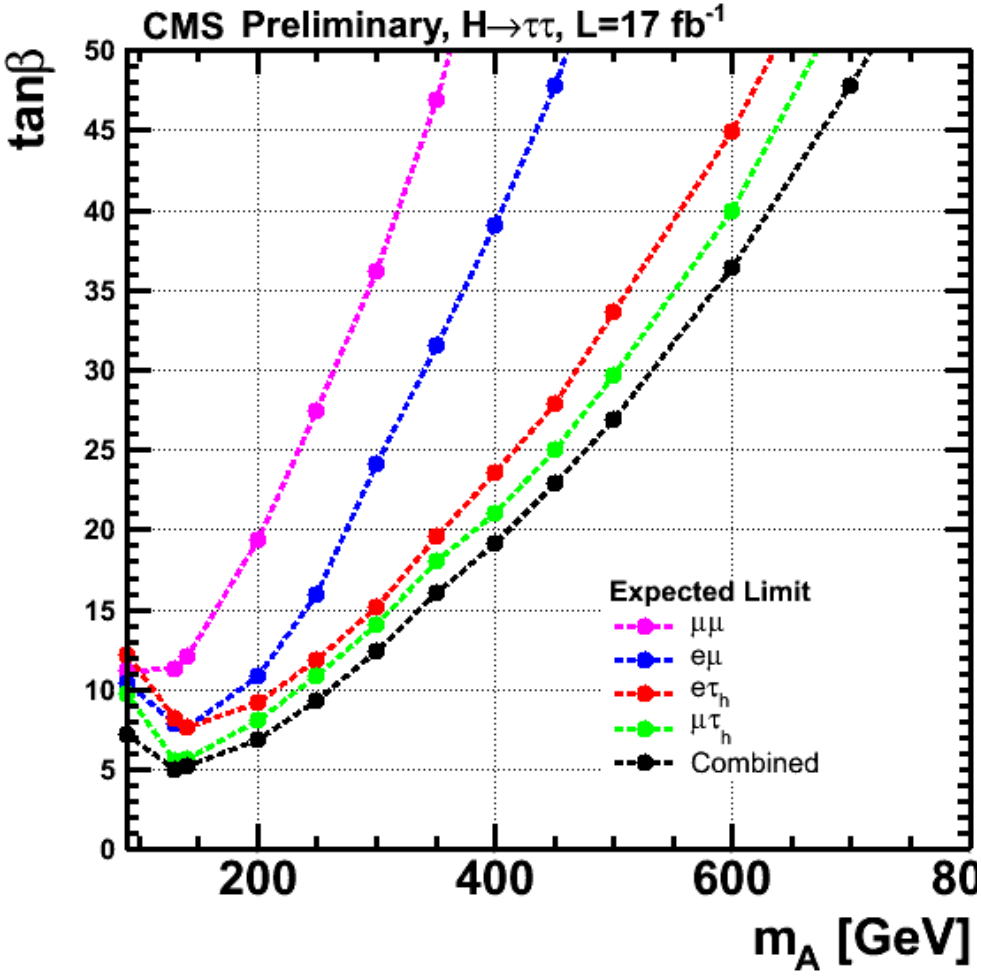


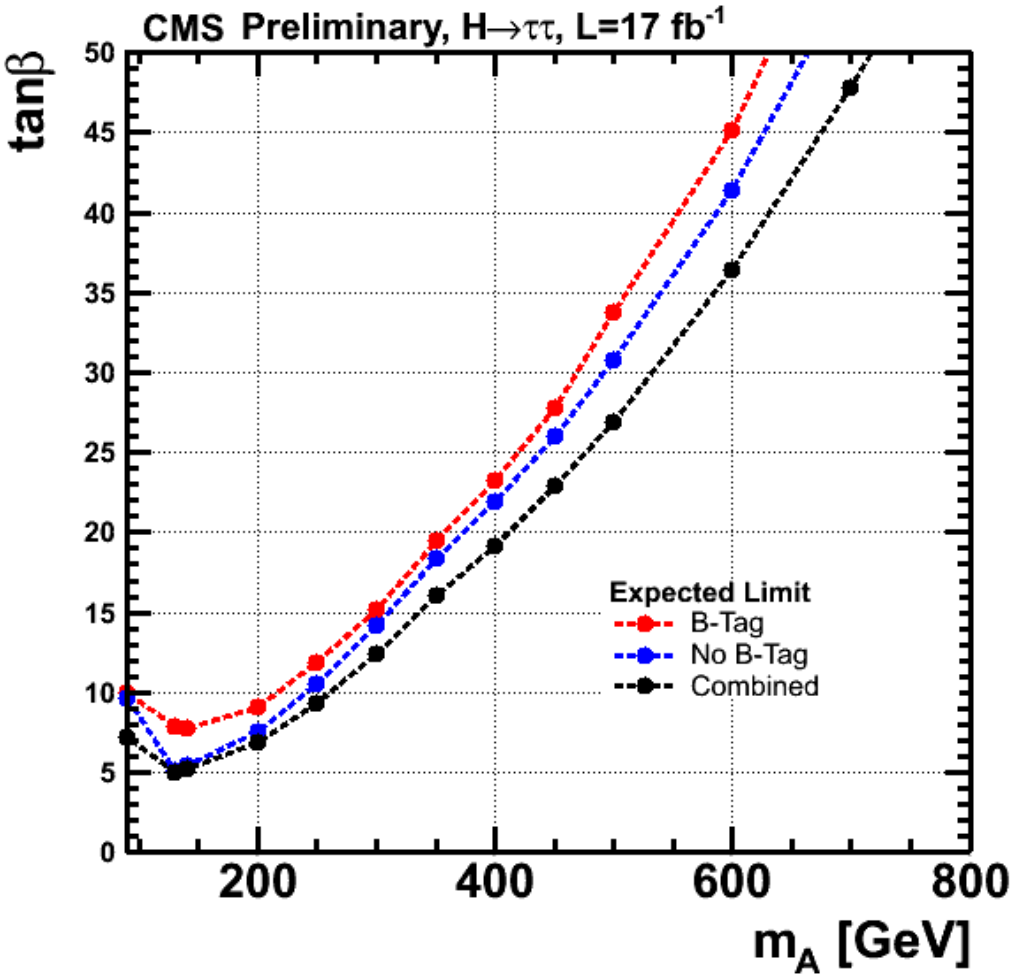


Combined MSSM fit

- At every point in the MA – tanβ plane using the mh^{max} scenario
  - The masses of h,A,H are calculated and different di-tau mass shapes are constructed for each physical boson
  - The cross section for each production mechanism is calculated.
  - Results are calculated in the full mA -tanβ grid by interpolating between the points
  - Width variation is not taken into account (small compared to the resolution)
- NOTE: due to the fact that each boson has different mass (especially at low MA) it is hard to provide scenario independent results
  - Need to find a language to propagate model independent results to the theory community to exclude other models etc

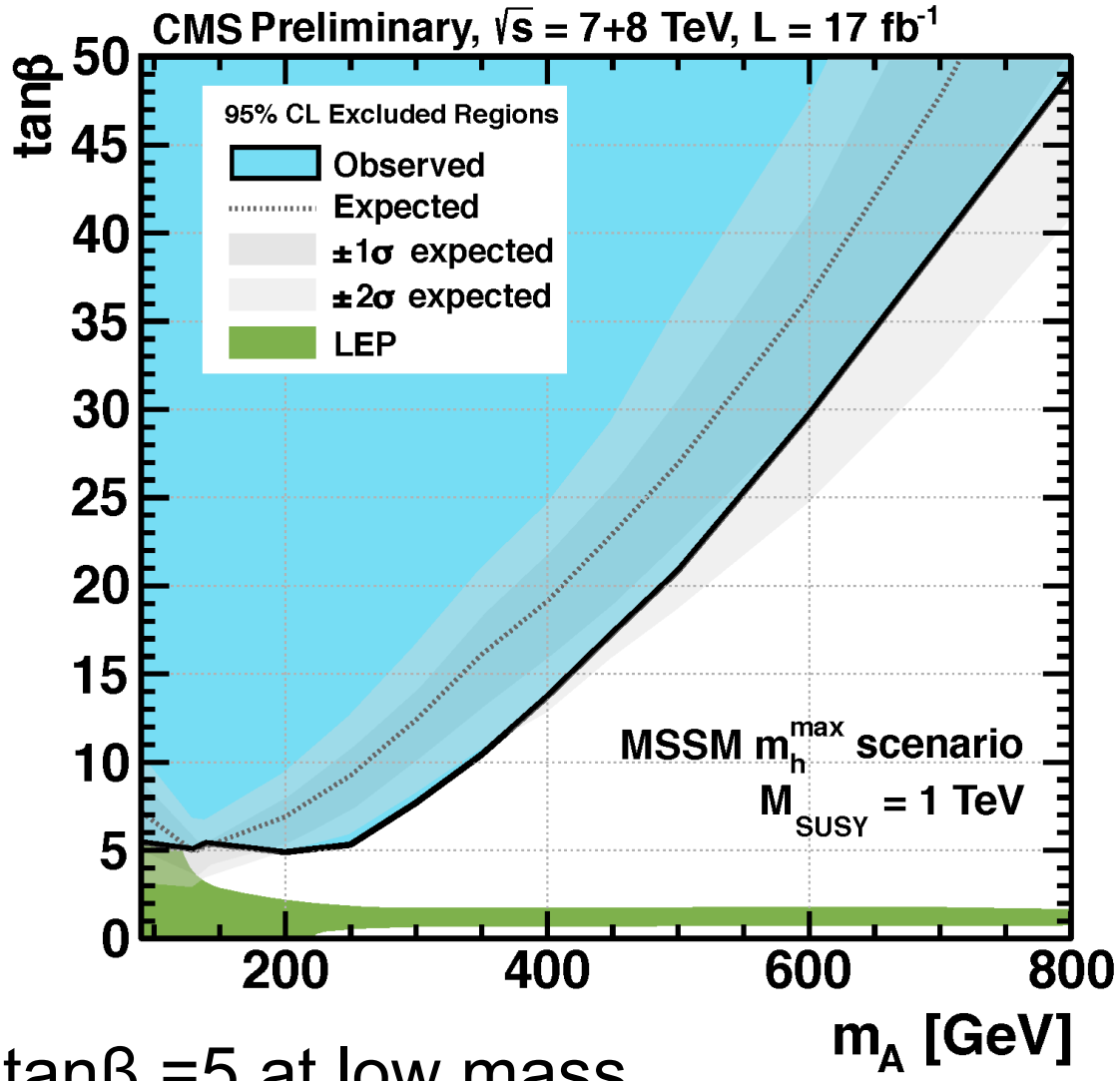
Expected Sensitivity





- Expected to exclude tanβ =5 @ 150 GeV
- Most sensitive channel μ+τ

MSSM results (m_h^{max})



- Excluding tanβ =5 at low mass
- Deficit (1-1.5σ) observed in data (mainly from btagged category)
- Best MSSM Higgs direct search results to date

Communicating results for 2HDM searches

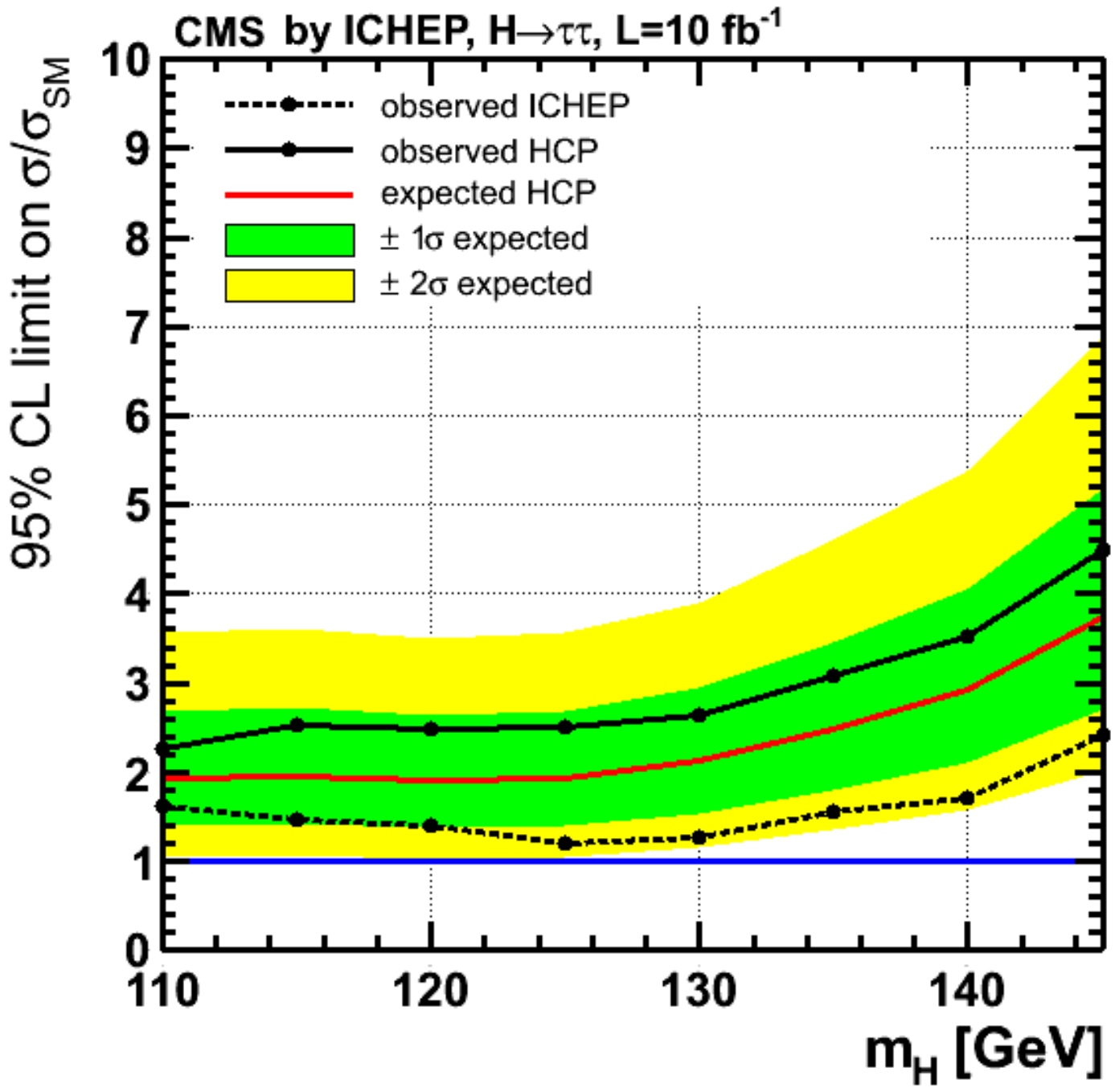
- It would be interesting to discuss
  - What is the best way to provide our results in a model independent way
  - What about fitting ggH , bbH cross sections separately at different mass hypotheses?
  - At low mA this is very hard due to the degeneracy
    - If we assume the h,H,A have the same mass we overestimate the sensitivity
  - Other ideas?

Conclusions

- SM & MSSM $H \rightarrow \tau\tau$ results have been updated with $17fb^{-1}$.
- Expected sensitivity of the SM search reached 1x SM
  - Data compatible with both S+B and B hypotheses
  - Signal strength of 0.7 ± 0.5 for a 125 GeV Higgs boson hypothesis
- MSSM Higgs search has been updated
  - Excluding $\tan\beta=5$ at low mass
  - Need to interact with the theory community about how to propagate results
  - Currently not taking into account the h126 GeV state in the MSSM search

Backup

SM Higgs limit compared to ICHEP



New MET performance