# Physics searches with tau leptons at CMS

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On behalf of CMS
Collaboration
(Faculty of Physics
University of Warsaw)

WORKSHOP tau lepton decays: hadronic currents from Belle BaBar data and LHC signatures
Kraków,  May 17 2012

**INNOVATIVE ECONOMY**
NATIONAL COHESION STRATEGY

**FNP**
*Foundation
for Polish Science*

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**EUROPEAN UNION**
EUROPEAN REGIONAL
DEVELOPMENT FUND

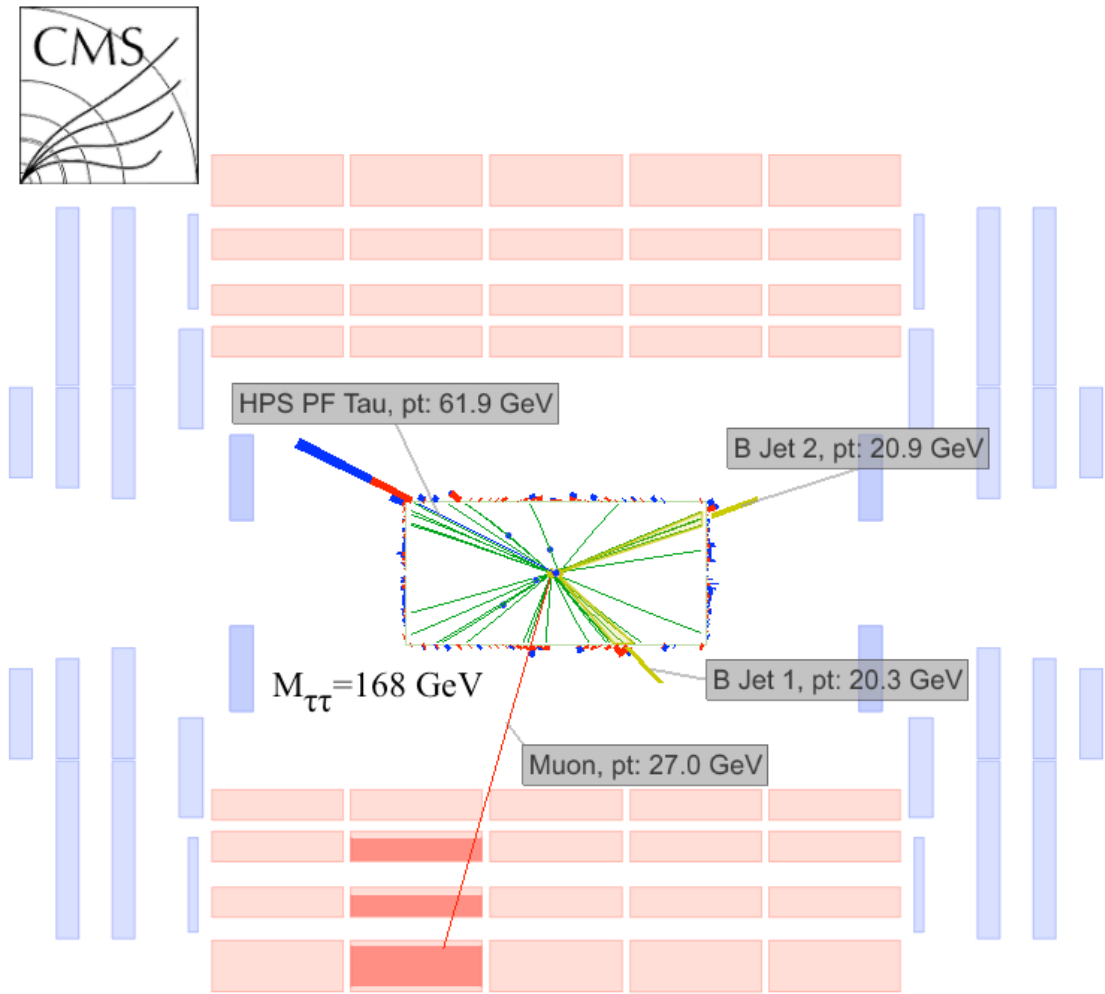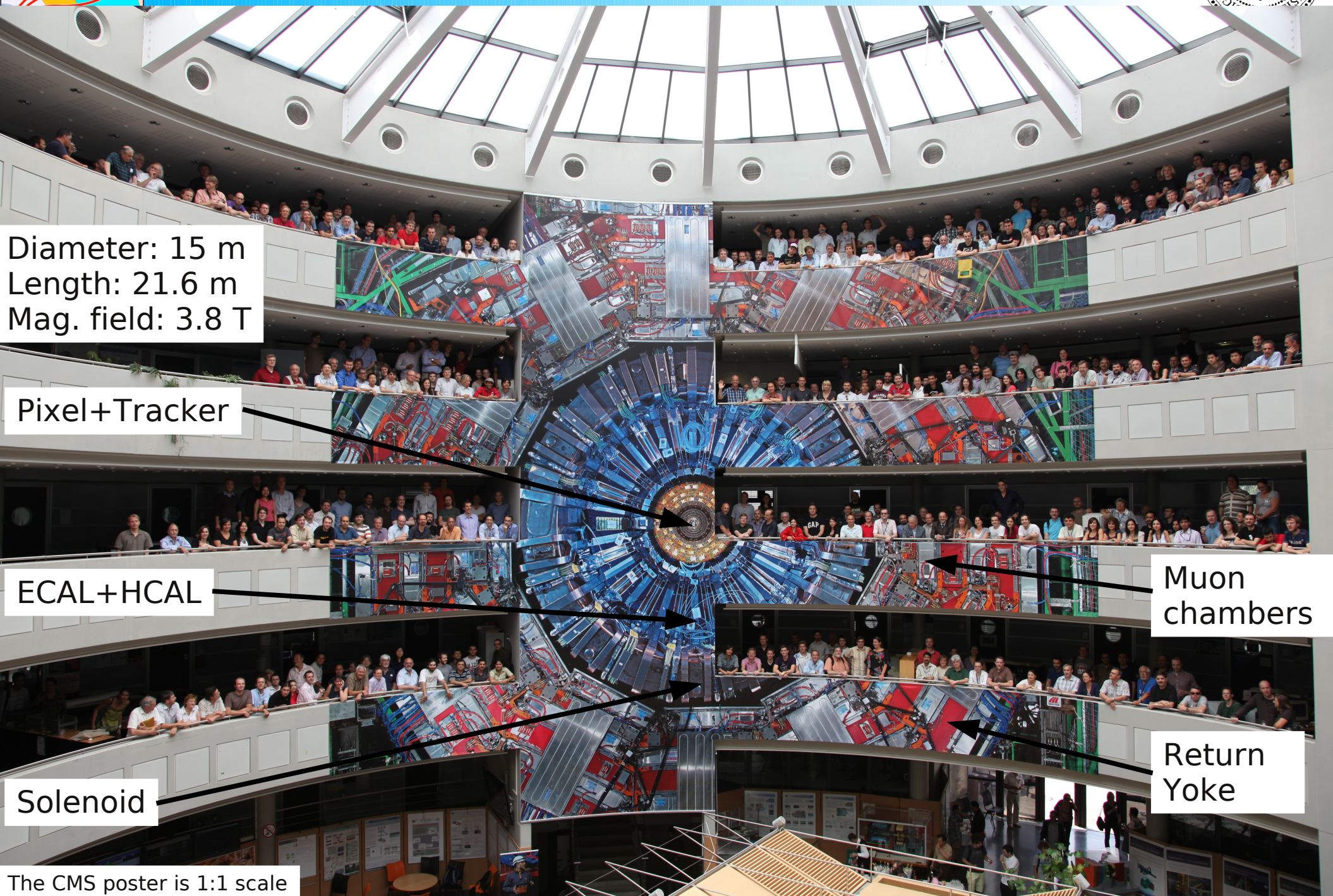# Outline

- SM analyses with tau leptons: W, Z and top
- SM and MSSM Higgs searches
- BSM searches with tau leptons: SUSY
- Conclusions



Candidate bbττ event

# The CMS

Diameter: 15 m
Length: 21.6 m
Mag. field: 3.8 T

Pixel+Tracker

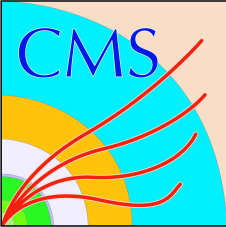ECAL+HCAL

Solenoid

Muon chambers

Return Yoke
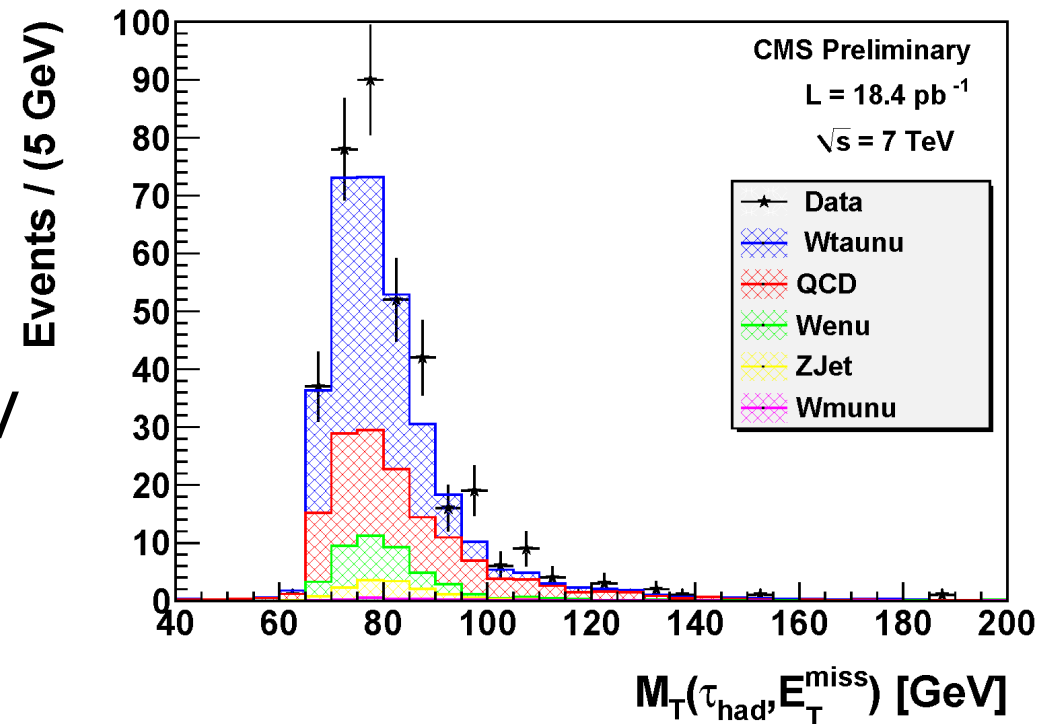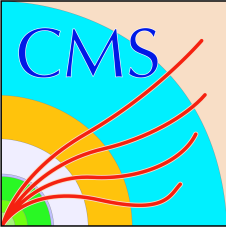
The CMS poster is 1:1 scale

# Early W→τν observation

- **Tau leptons used in CMS since early 2010 data, already with first 18 pb$^{-1}$**

- **Event selection:**

  - HPS $E_t^\tau$ >30 GeV

  - leading τ track $p_T$ >15 GeV

  - $E_T^{miss}$ >35 GeV

  - Anti μ/e vetos

- QCD background estimated from DATA with control regions

- Results consistent with MC expectations



CMS Preliminary
L = 18.4 pb$^{-1}$
$\sqrt{s}$ = 7 TeV

Data
Wtaunu
QCD
Wenu
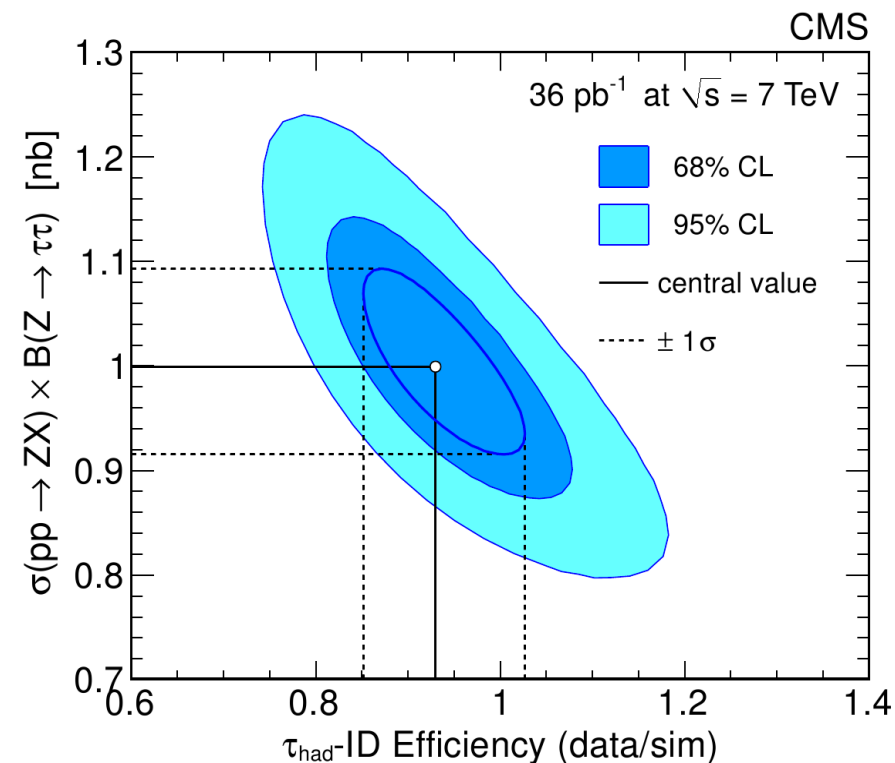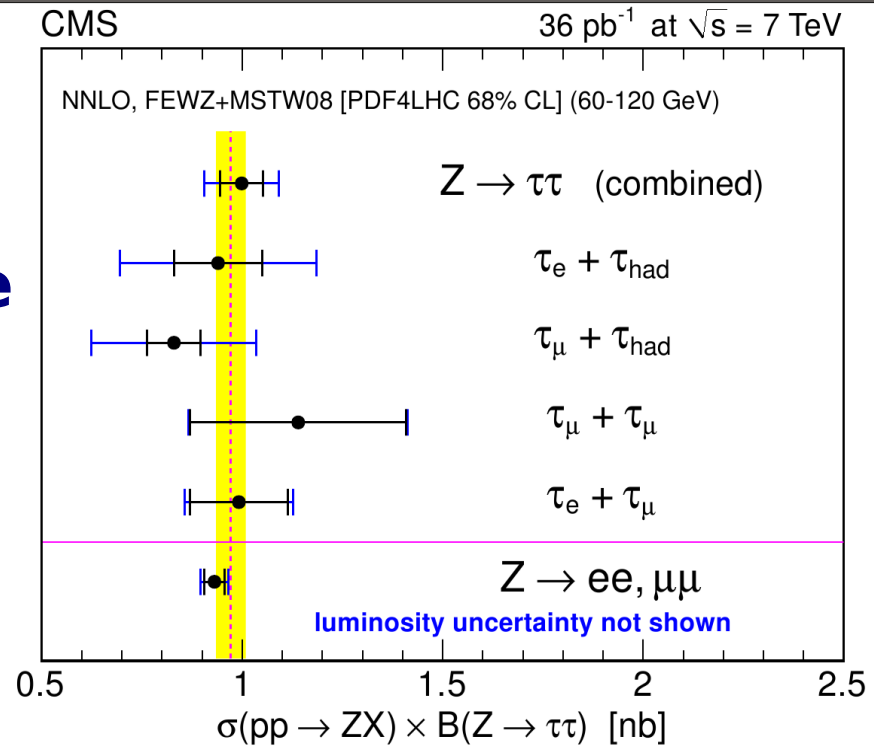ZJet
Wmunu

Events / (5 GeV)

$M_T(\tau_{had}, E_T^{miss})$ [GeV]

# Z→ττ observation

- **Z→ττ analysis crucial milestone towards H→ττ searches and important tool for data driven $\tau_h$ reconstruction efficiency**

- **Z→ττ→e-$\tau_{had}$, μ-$\tau_{had}$, e-μ, μμ** channels analysed

- Good agreement with Z→ee/μμ cross section measurement

- Simultaneous likelihood fit of cross section and DATA/MC $\tau_h$ ID efficiency ratio shown very good agreement between DATA and MC on $\tau_h$ ID
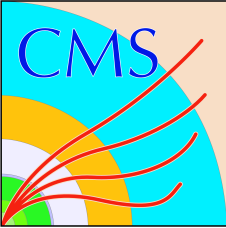


CMS                    36 pb$^{-1}$ at $\sqrt{s}$ = 7 TeV

NNLO, FEWZ+MSTW08 [PDF4LHC 68% CL] (60-120 GeV)

$Z \to \tau\tau$ (combined)

$\tau_e + \tau_{had}$

$\tau_\mu + \tau_{had}$

$\tau_\mu + \tau_\mu$

$\tau_e + \tau_\mu$

$Z \to ee, \mu\mu$

**luminosity uncertainty not shown**

$\sigma(pp \to ZX) \times B(Z \to \tau\tau)$ [nb]



CMS

36 pb$^{-1}$ at $\sqrt{s}$ = 7 TeV

68% CL
95% CL
central value
$\pm 1\sigma$

$\sigma(pp \to ZX) \times B(Z \to \tau\tau)$ [nb]

$\tau_{had}$-ID Efficiency (data/sim)

**Physics searches with tau leptons at CMS**

# tt→τ_h+(e/μ)

- **light, charged Higgs decays could give observable contribution in this channel**

- **Event selection:**

  – Isolated e(μ) with $p_T$>35(30) GeV

  – $E_T^{miss}$>45(40) GeV

  – HPS $E_t^\tau$>20 GeV

  – e(μ) – τ opposite sign

  – $E_T^{miss}$>35 GeV

  – At least two jets with $E_T$>30(35) GeV, at least one b-tagged

- **Measured $\sigma_{tt}$ in agreement with SM**

  $\sigma_{tt}$ = 143±14(stat)±22(sys)±3(lumi) pb

**Physics searches with tau leptons at CMS**
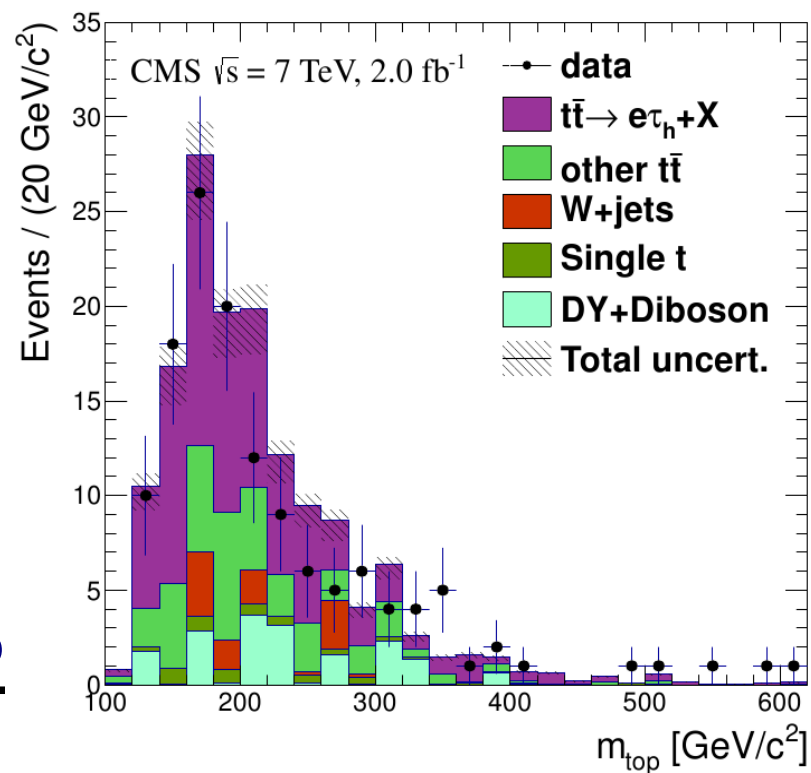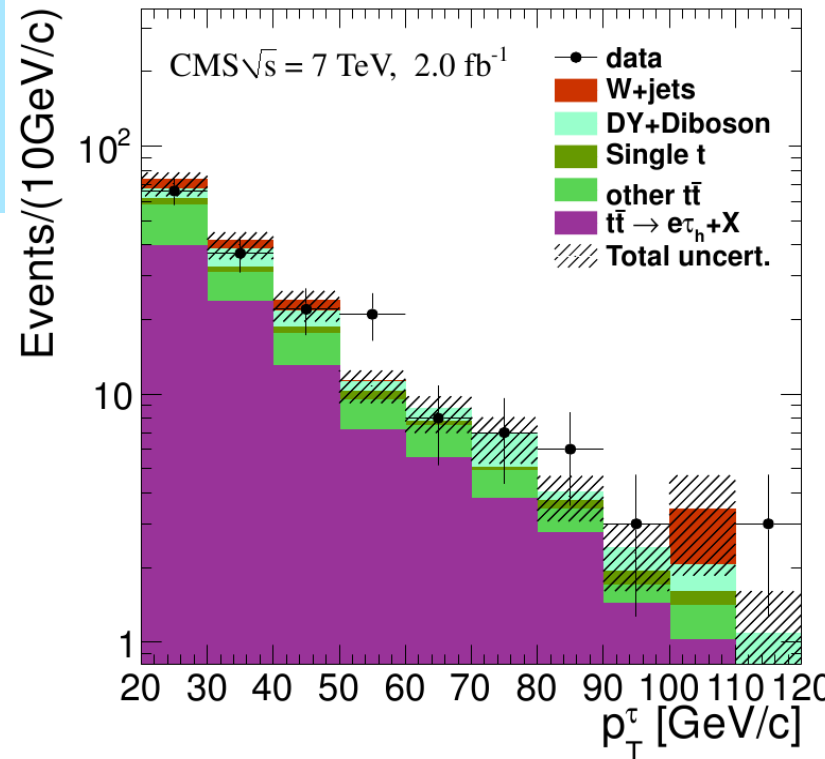
# tt→τ$_h$+jet

- **Event selection:**

  - Dedicated trigger: three jets+tau, $E_T$>40 or 45 GeV

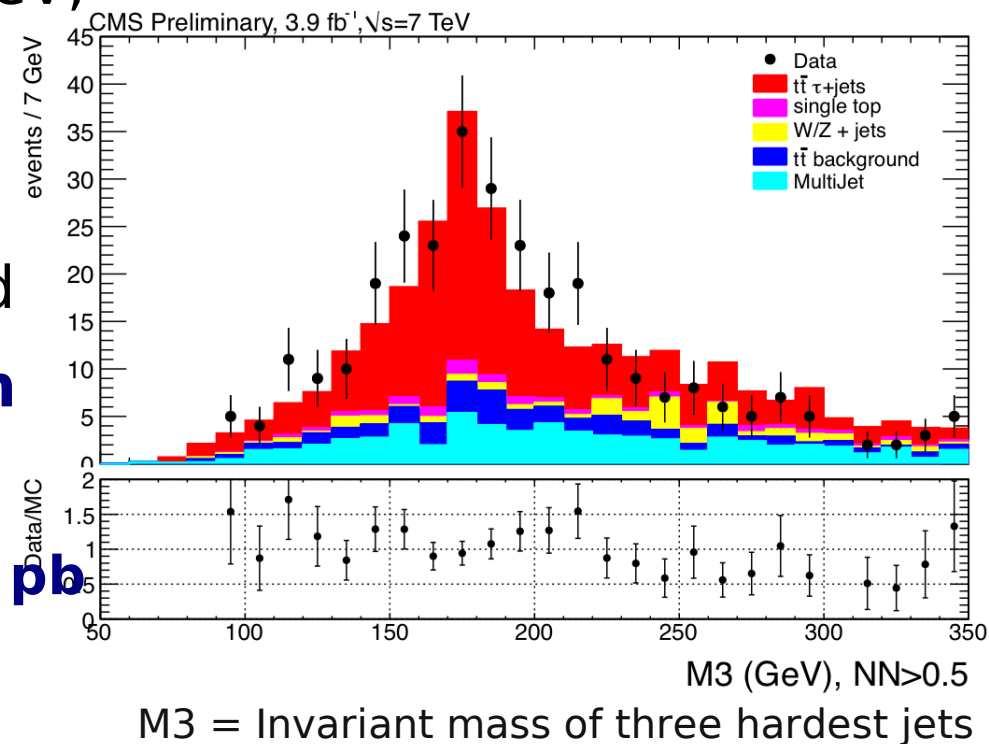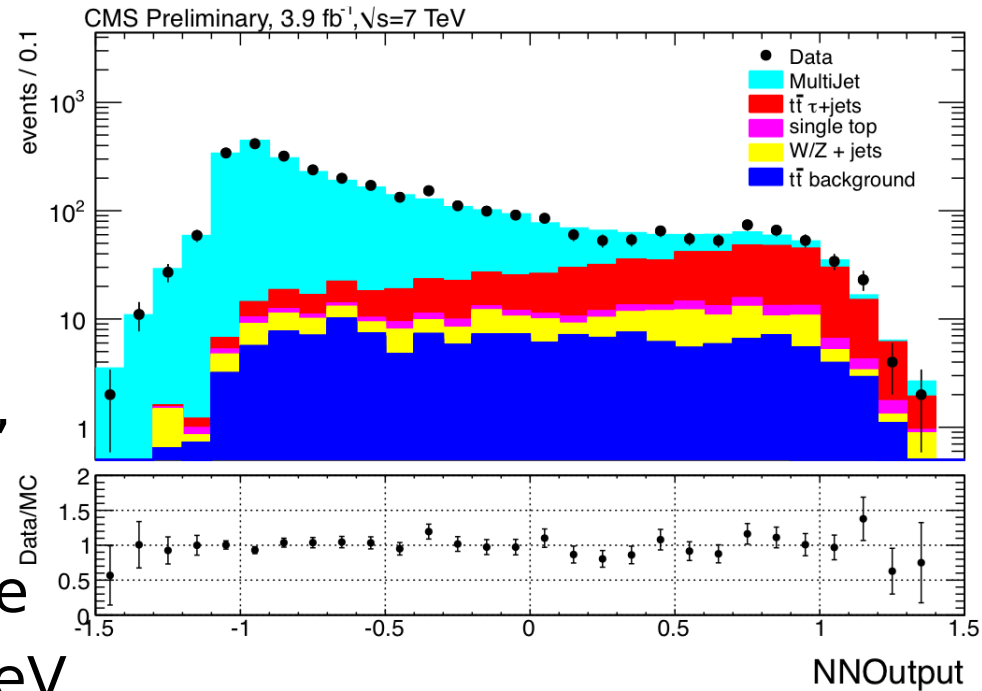  - Offline: HPS tau, $E_T$>45 GeV, three jets $E_T$>45 GeV, fourth $E_T$>20 GeV, one b-tag

  - Veto on leptons, $E_T^{miss}$>20 GeV

  - Neural Network (TMVA MLP) used

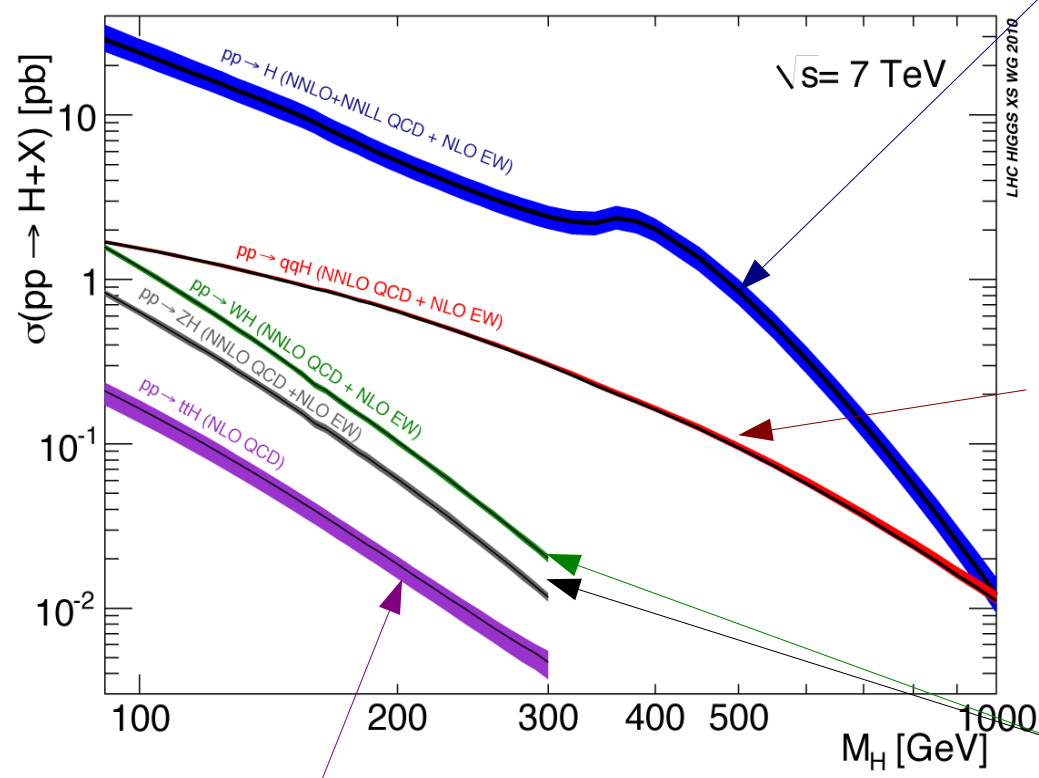- **Measured σ$_{tt}$ in agreement with SM and other CMS results**
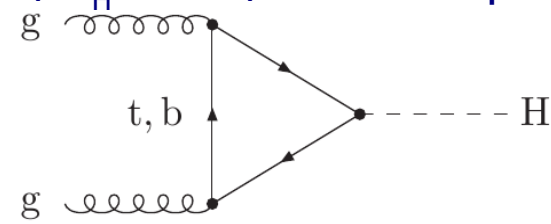
  **σ$_{tt}$ = 156±12(stat)±33(sys)±3(lumi) pb**



M3 = Invariant mass of three hardest jets
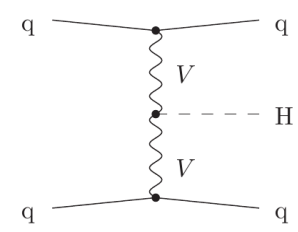
# SM Higgs production modes at the LHC
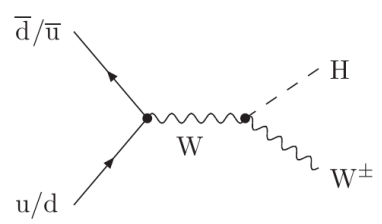


•Dominating production mode in pp collisions @7 TeV is gluon-gluon fusion gg→H: $\sigma(m_H=120) = 16.63$ pb

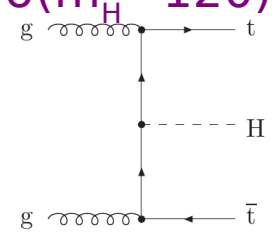•Next is Vector Boson Fusion (VBF) qq→qqH: $\sigma(m_H=120) = 1.27$ pb

•then is VH associated production: qq'→WH $\sigma(m_H=120) = 0.66$ pb and qq→ZH $\sigma(m_H=120) = 0.36$ pb

•Finally ttH associated production: qq→ttH $\sigma(m_H=120) = 0.098$ pb

# H→ττ searches at CMS

- **Signal signatures studied in CMS:**

  - $e$-$\tau_{had}$, $\mu$-$\tau_{had}$, $e$-$\mu$,

  - $\mu\mu$ (not covered here)

- **Irreducible background: Z→ττ**

- **Main reducible backgrounds:**

  - **QCD, tt, W+jets, Z→ll, WW, WZ, ZZ**

- **Event selection:**
  - Trigger: **ele/mu + isolated tau for $e$-$\tau_{had}$, $\mu$-$\tau_{had}$, Ele + mu for $e$-$\mu$**

  - Lepton selection ($e$-$\tau_{had}$, $\mu$-$\tau_{had}$):

    - **Mu: $p_T > 17$ GeV/c, $|\eta| < 2.1$, relative isol. , Ele: $p_T > 20$ GeV/c, $|\eta| < 2.1$, rel. isol.**

    - **Hadronic Tau: HPS Tau, $E_T > 20$ GeV/c, $|\eta| < 2.3$, tau id, veto against e/μ**
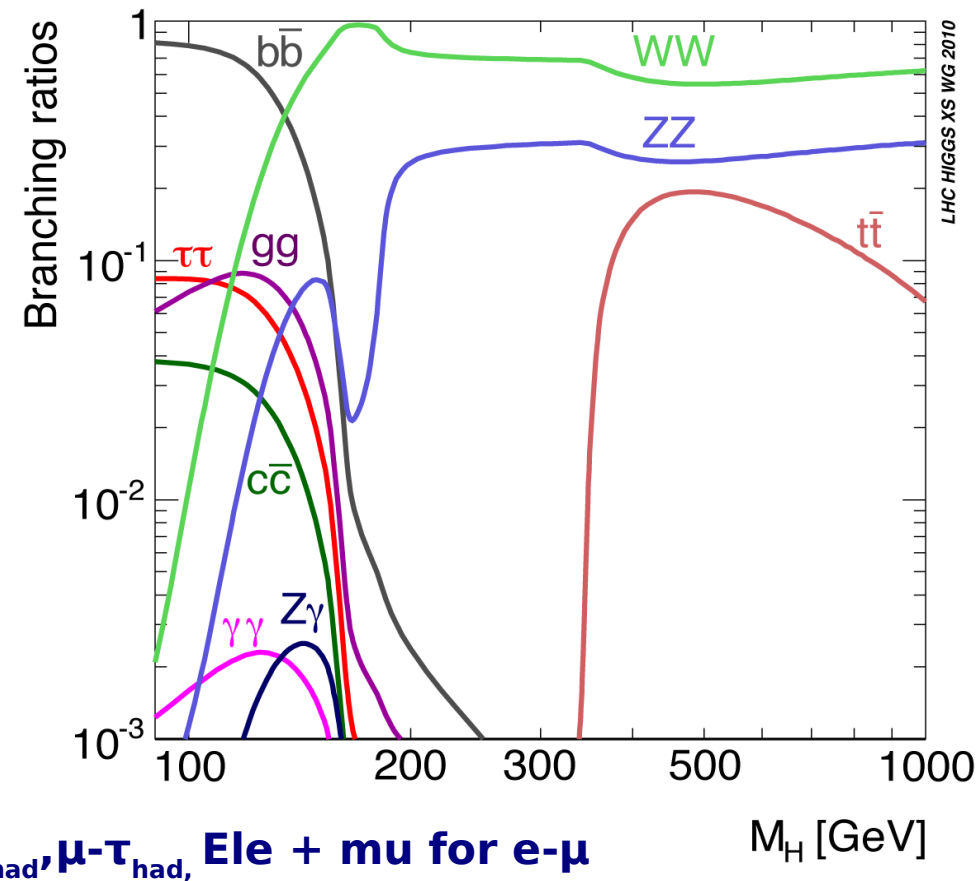
# Event selection

- **Opposite charge of the lepton pair**

- **Veto additional isolated leptons**

- **$m_T$ selection in $e\text{-}\tau_{had}, \mu\text{-}\tau_{had}$** (very effective against events with real W)

- **$P_\zeta$ selection $e\text{-}\mu$ and MSSM analysis**

- Selections related to production mode:
  **events divided exclusively into three categories:**

  - **0/1 jets with $E_T > 30$ GeV and $E_T < 120$ GeV**

  - **"boosted": one jet with $E_T > 120$ GeV**

  - **"VBF": two jets, $E_T > 30$ GeV, $\Delta\eta > 4.0$, $\eta_1 \cdot \eta_2 < 0$, $m_{jj} > 400$ GeV, veto additional jets with $E_T > 20$ GeV**
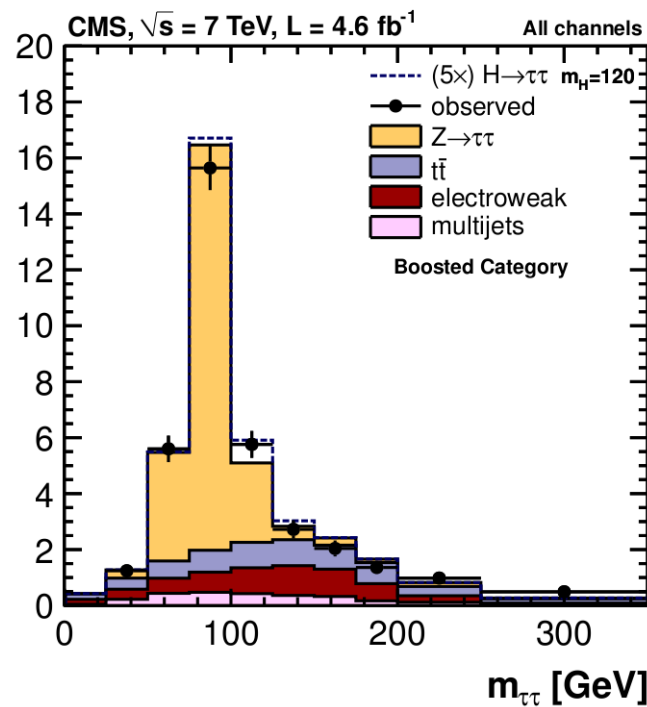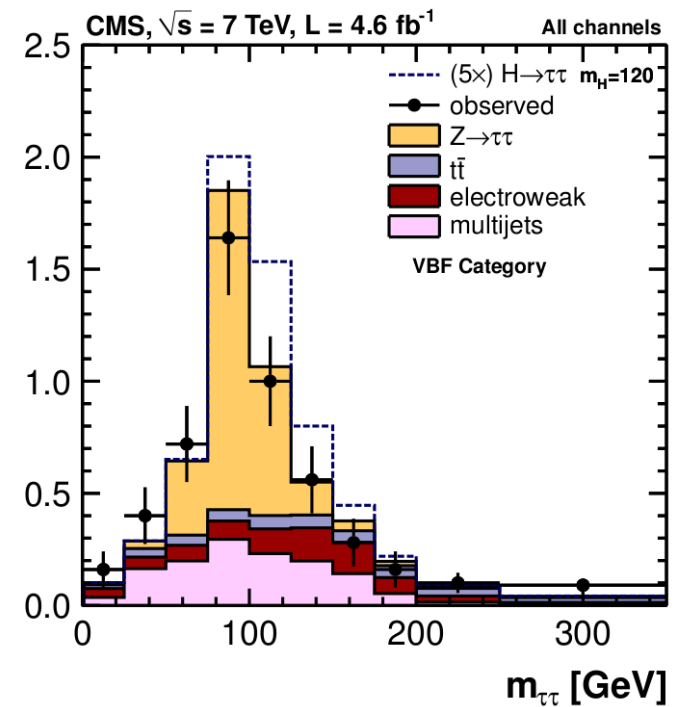
**Physics searches with tau leptons at CMS**
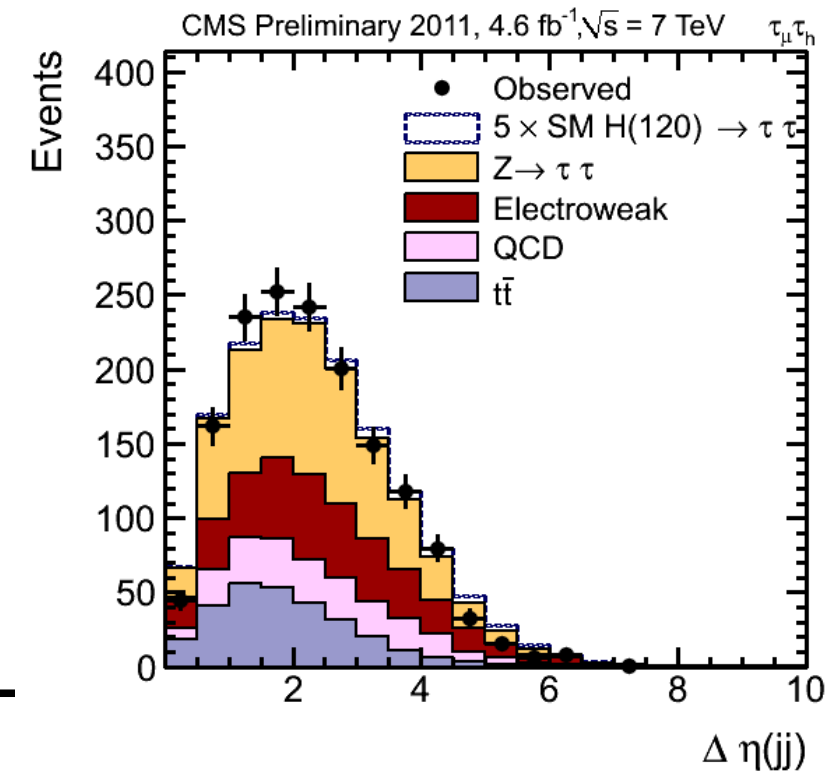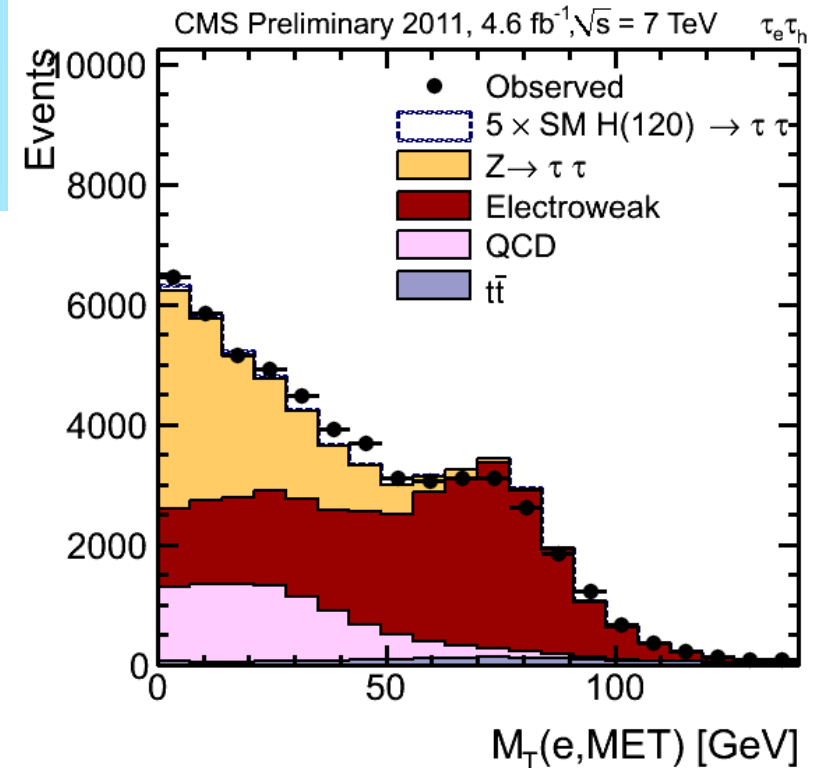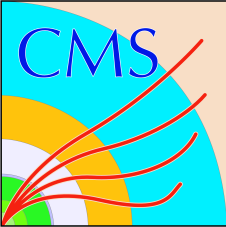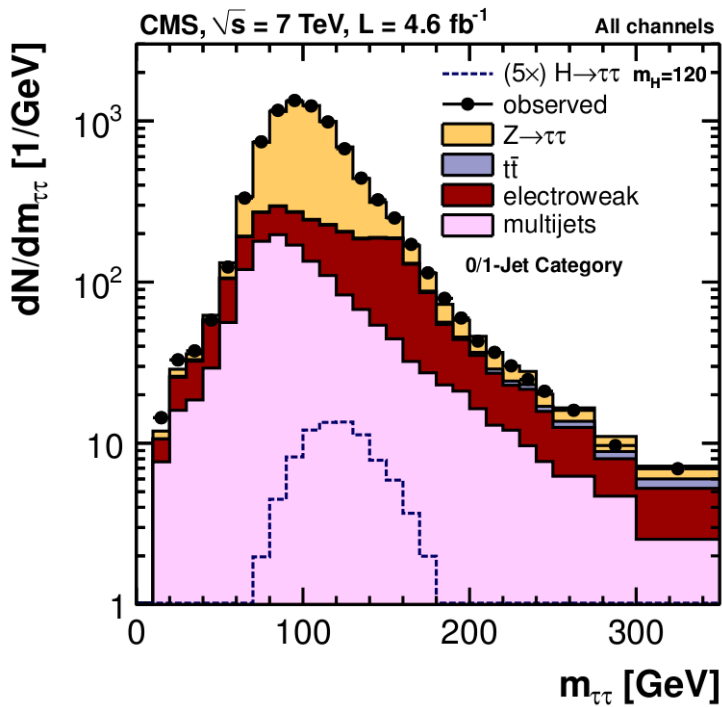
# ττ invariant mass



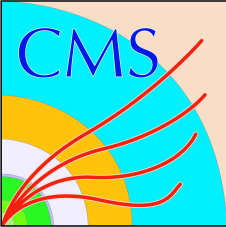0/1 jet          boosted          VBF
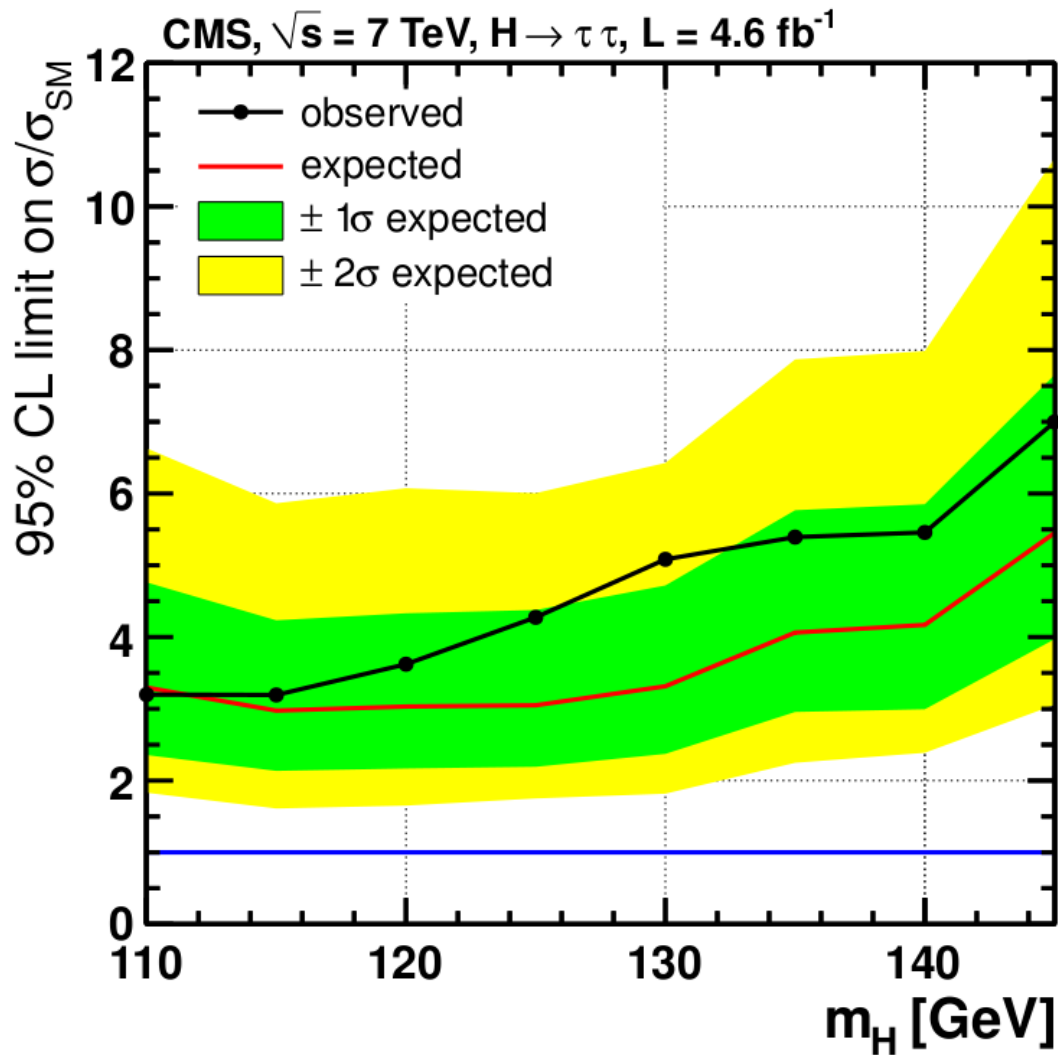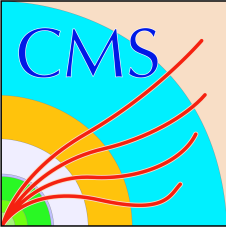
- Full ττ invariant mass reconstructed using likelihood technique
- **Significant sensitivity improvement with hard jet (boosted category) or VBF requirements**

# Exclusion limits for H→ττ



CMS, $\sqrt{s}$ = 7 TeV, H→ττ, L = 4.6 fb$^{-1}$

- observed
- expected
- ± 1σ expected
- ± 2σ expected

95% CL limit on σ/σ$_{SM}$

m$_H$ [GeV]

- With 4.6 fb$^{-1}$ the expected exclusion limit in this channel is between 3.3·σ$_{SM}$ and 5.45·σ$_{SM}$
- No significant data excess above expected background is observed
- **The observed limit is between 3.2·σ$_{SM}$ and 7·σ$_{SM}$**

In the MSSM there are five Higgs bosons:
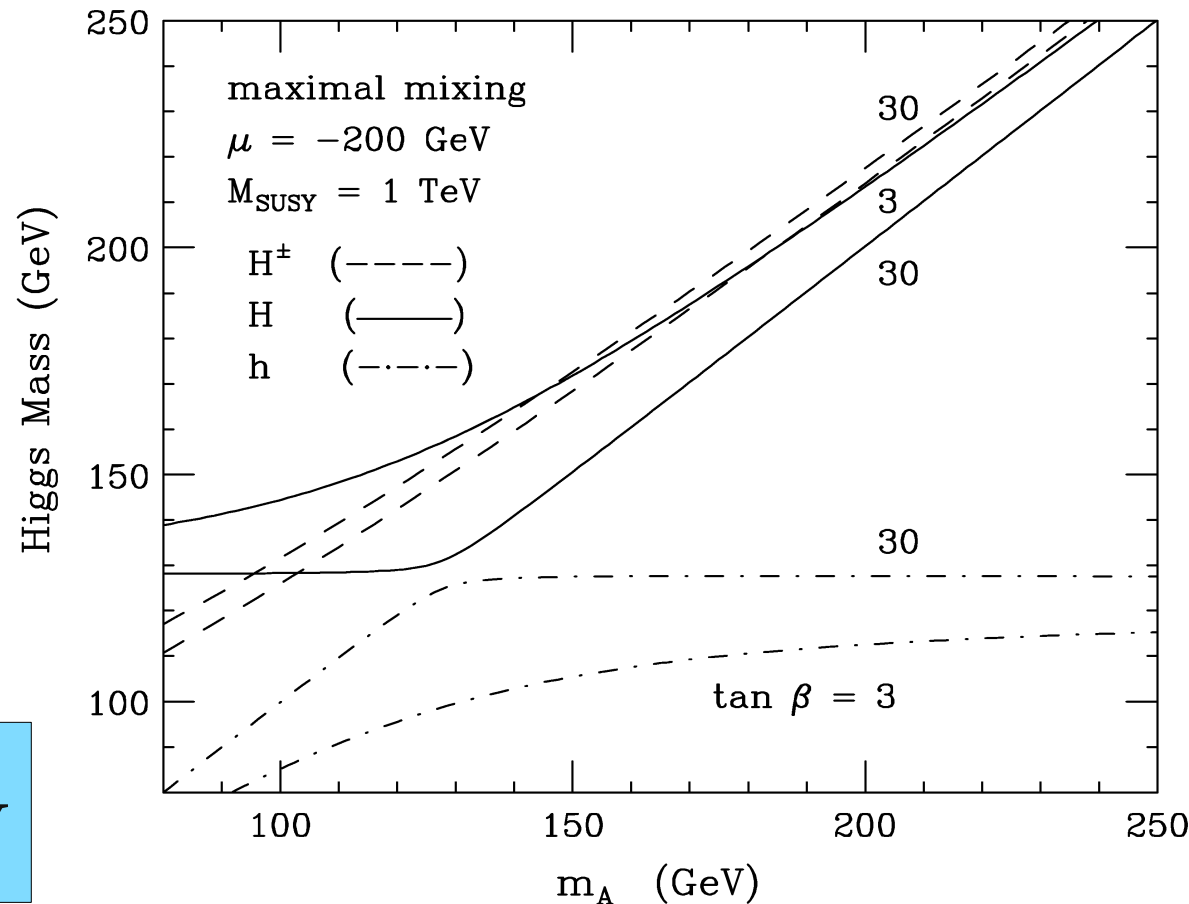**h, H, A, H±**

At the tree level the Higgs sector is described by two parameters:

$$\tan\beta = \frac{v_1}{v_2} \text{ and } m_A$$

$$m_{H,h}{}^2 = \tfrac{1}{2}[\ (m_A{}^2 + m_Z{}^2)\ \pm$$

$$((m_A{}^2 + m_Z{}^2)^2 -$$

$$4m_Z{}^2 m_A{}^2\ (\cos^2 2\beta))^{1/2}\ ]$$

$$m_{H+}{}^2 = m_A{}^2 + m_W{}^2$$

Large loop corrections:
$$m_h < m_Z \rightarrow m_h \sim 130\, GeV$$

maximal mixing
$\mu = -200$ GeV
$M_{SUSY} = 1$ TeV

H± (– – – –)
H (———)
h (– · – · –)

30

3

30

30

30

$\tan\beta = 3$
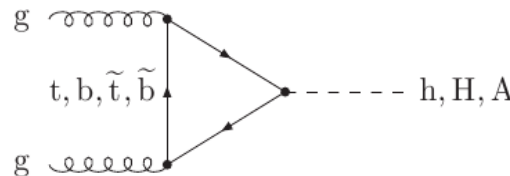
Higgs Mass (GeV)

$m_A$ (GeV)

250

200

150

100

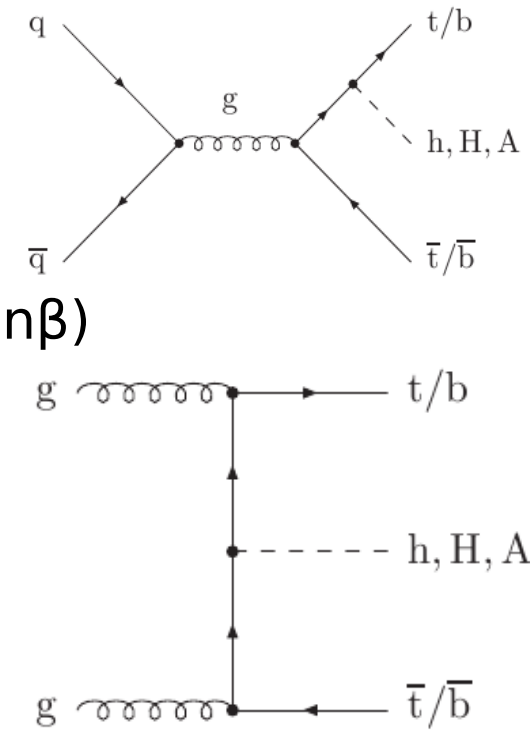100   150   200   250

# Production modes

- **The main production modes at LHC are:**

**gg→φ**

(dominant at low tanβ)

**gg→bbφ**

(dominant at high tanβ)
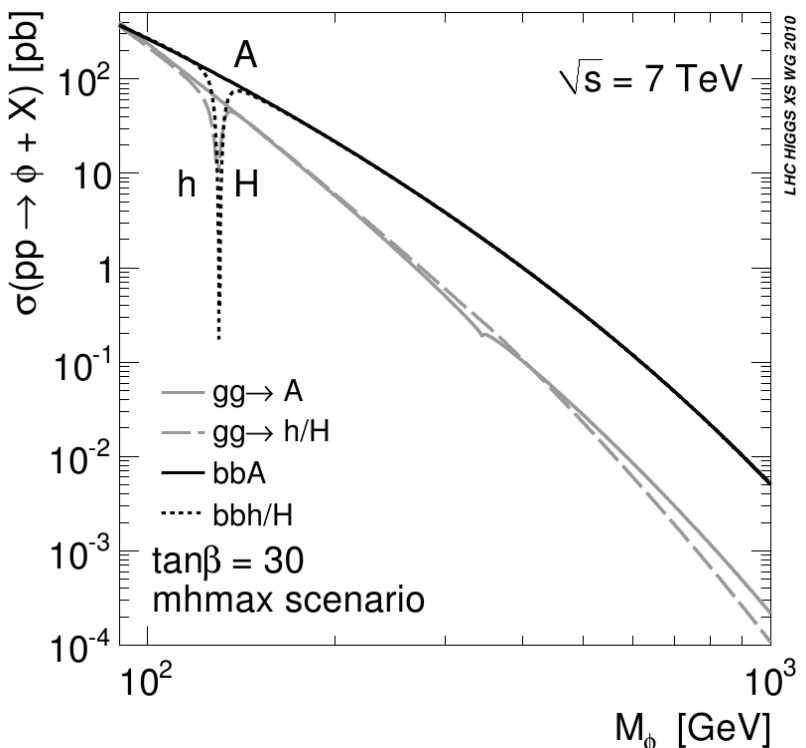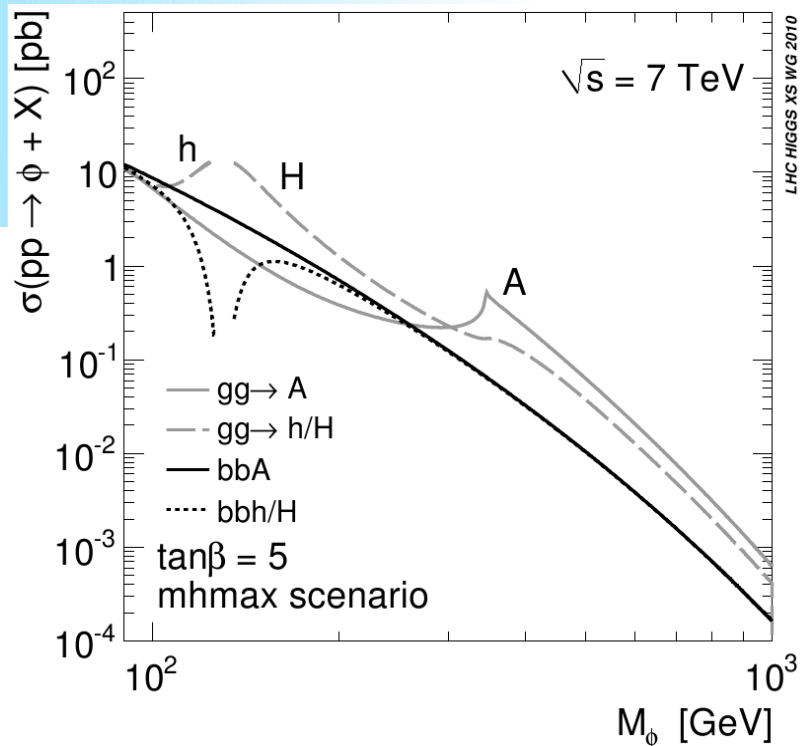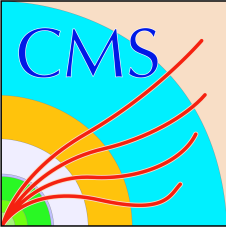
**Intense coupling regime:**
tanβ=30
$100 < m_A < 140$
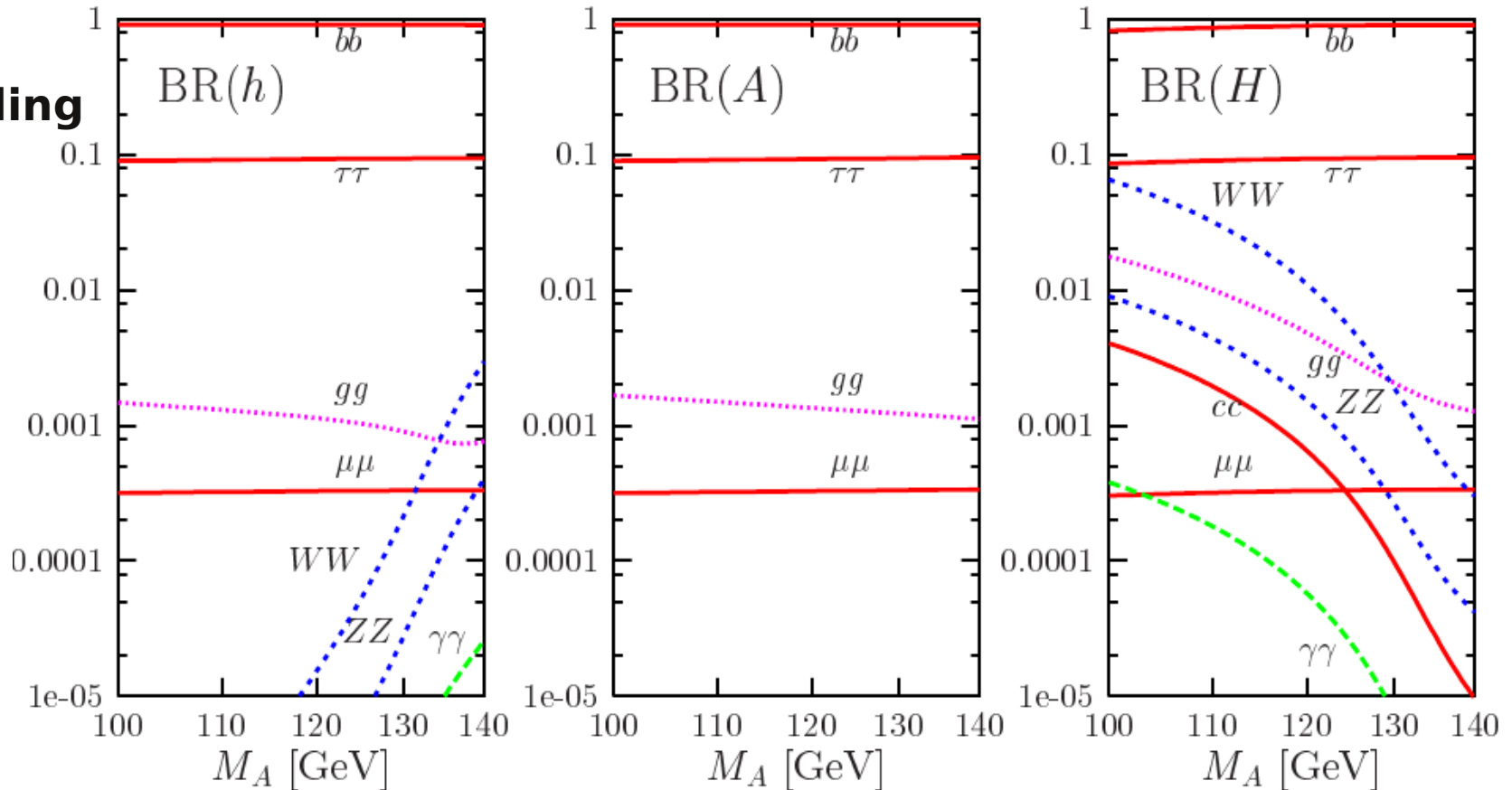


- depends on the point in the MSSM parameter space
- **at high tanβ BR(Φ→ττ)=10%** → **the main search mode**
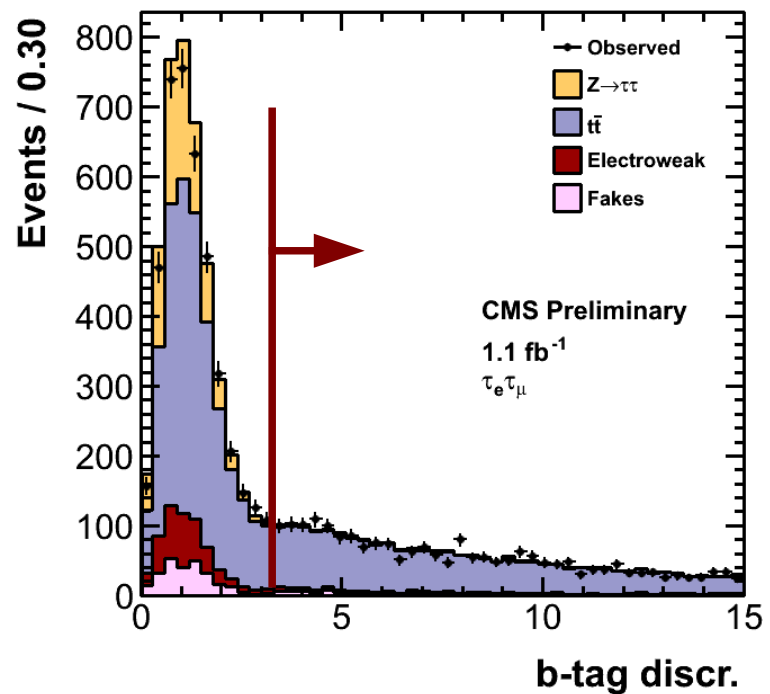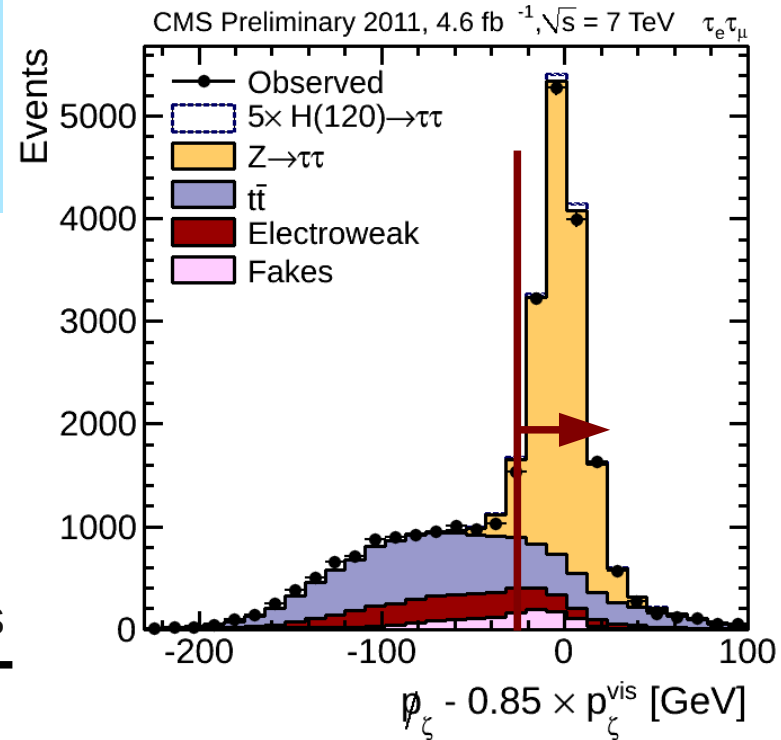- **at high tanβ BR(Φ→bb)=90%** → extremely **difficult experimentally**

# Neutral Higgs event selection

- **Most of the selections the same as in case of SM Higgs**

- **$P_\zeta$ selection for all search channels**
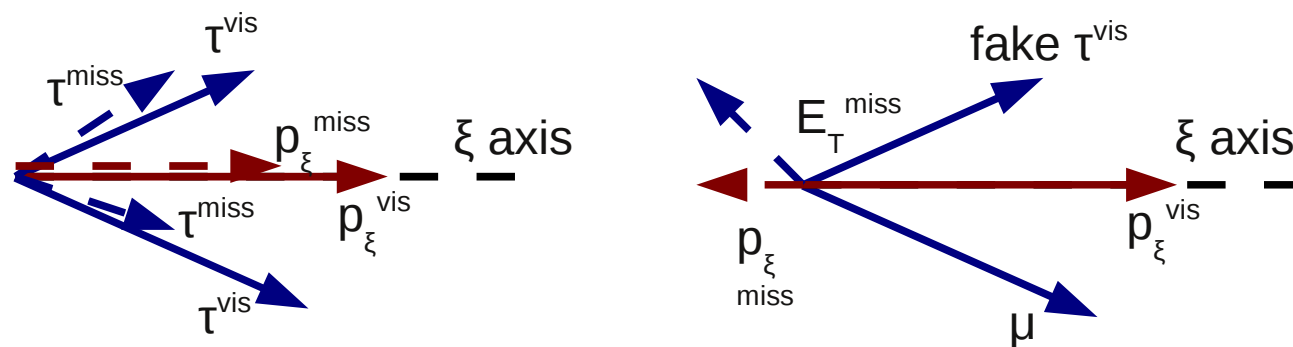




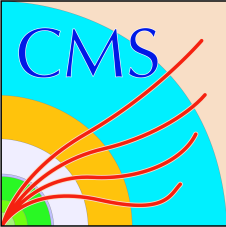Selections related to production mode:

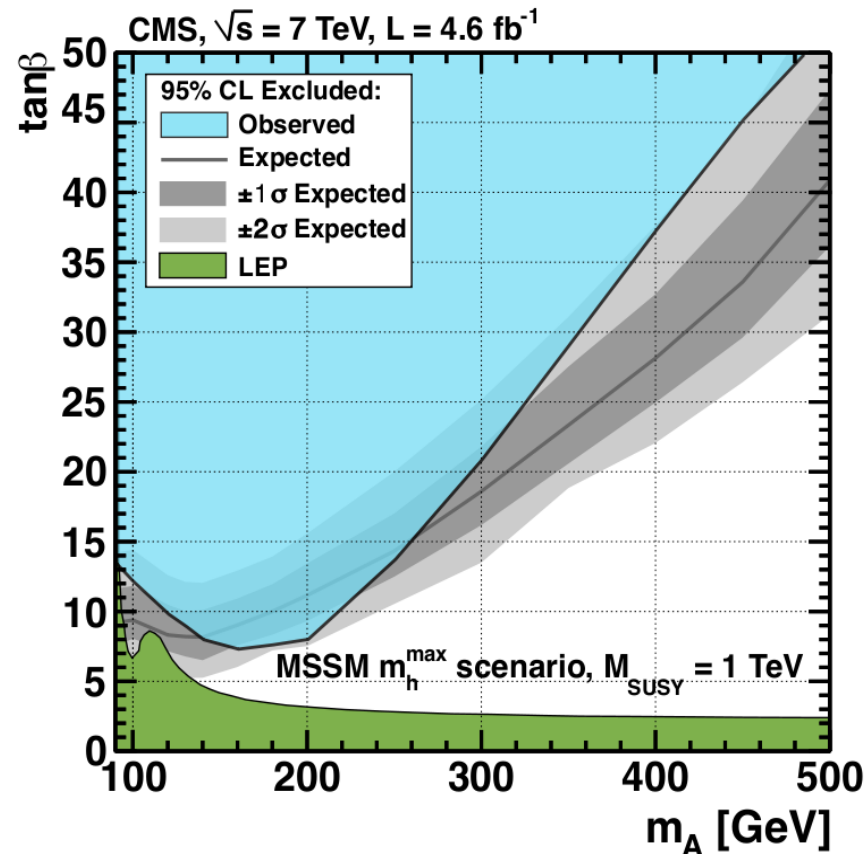- **at most 1 jest with $E_T > 30$ GeV**

- **Selected events divided exclusively into two categories:**
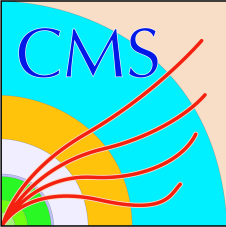
  **with/without b-tagged jet with $E_T > 20$ GeV**

# MSSM exclusion limits



- **No significant data excess above expected background is observed in neutra Higgs searches**

- **With 4.6 fb⁻¹ of data CMS has covered large fraction of (m$_A$,tanβ) parameter space**

# Search for H$^\pm$



- **Two mass regimes:**
  1) $m_{H^\mp} < m_t$
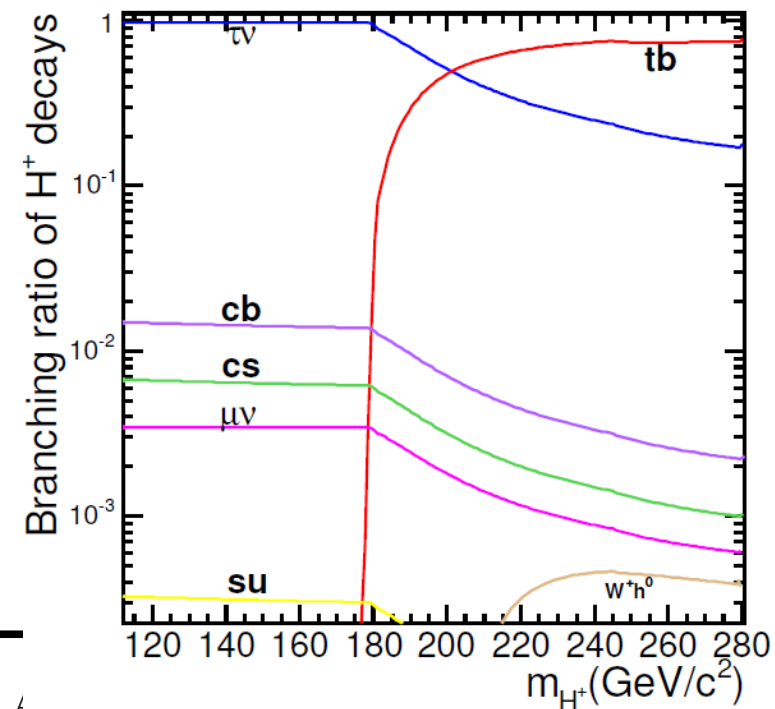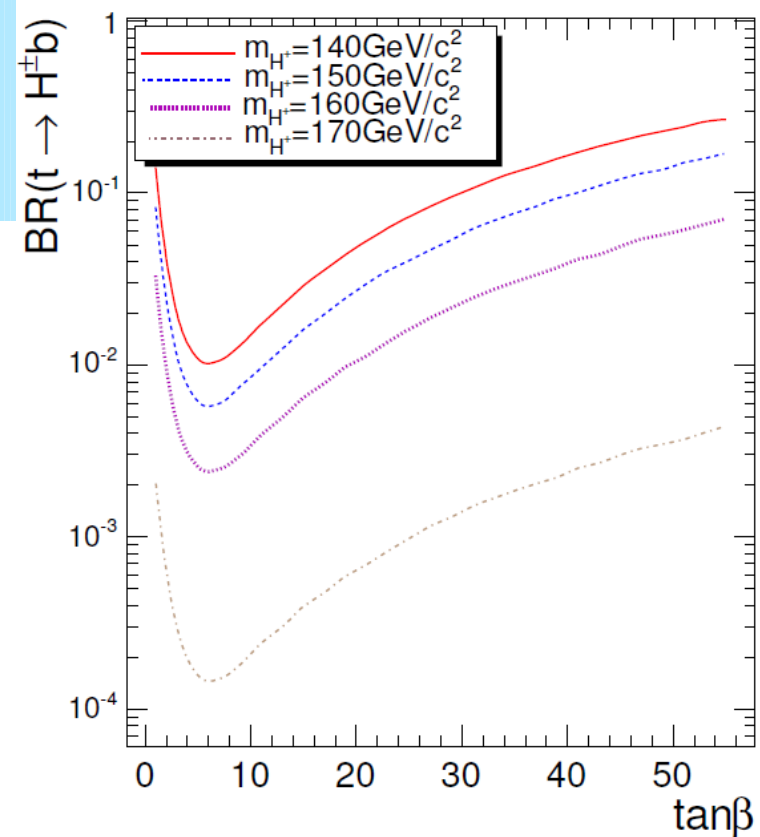     - mainly produced in top decays
     - main decay path:
       - Large tanβ: $H^\pm \to \tau^\pm \nu$
       - tanβ<1: $H^\pm \to cs$
     - search strategy: estimate the BR(t→Hb), assuming 100% BR(H→τν), or BR(H→cs)

  2) $m_{H^\mp} > m_t$
     - mainly produced in gluon-gluon fusion
     - main decay paths: $H^\pm \to tb, \tau^\pm \nu$

- **Main background: QCD, W/Z+jets, VV, tt, single t**

# Charged Higgs selections
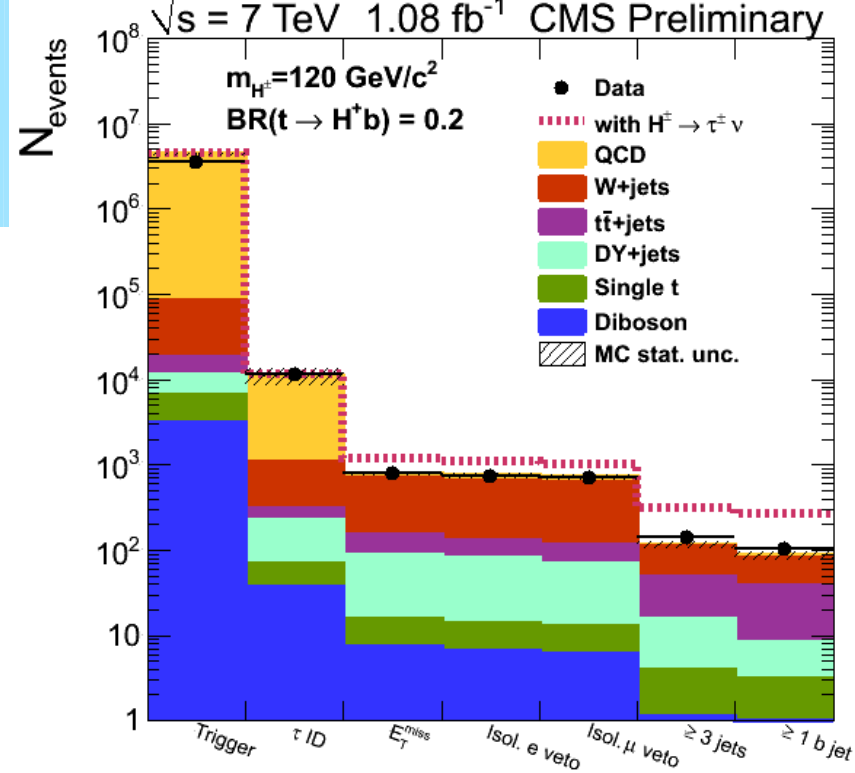
- **Fully hadronic event selection:**

  – HPS $E_T^\tau > 40$ GeV, only single prong, $p_T^{leading\ tk.} > 20$ GeV

  – At least three jets, $E_T > 40$ GeV, one b-tagged

  – No isolated μ/e with $p_T > 15$ GeV, $E_T^{miss} > 70$ GeV

- **μ+τ$_h$ event selection:**

  – HPS $E_t^\tau > 20$ GeV, $p_T^\mu > 20$ GeV,

  – At least two jets, $E_T > 30$ GeV, one b-tagged, $E_T^{miss} > 40$ GeV
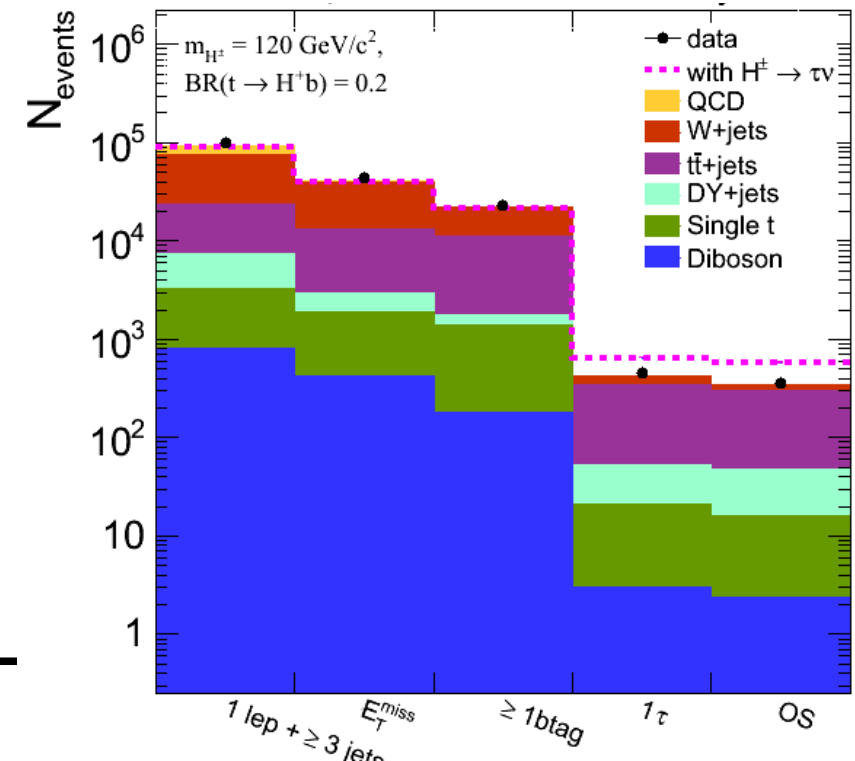
# Exclusion limits
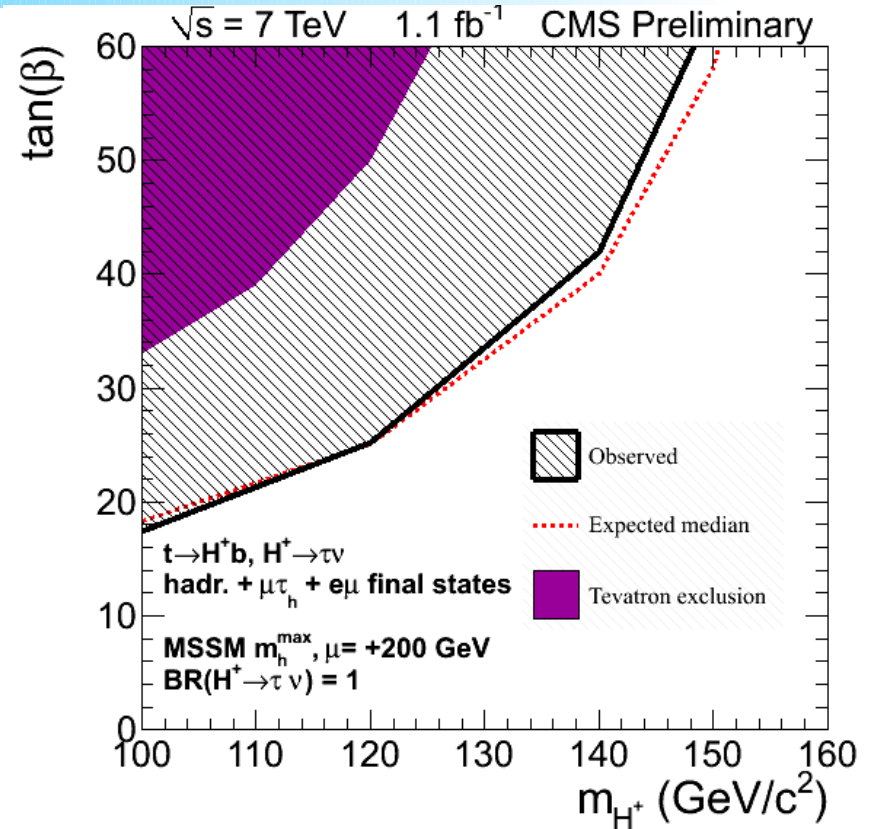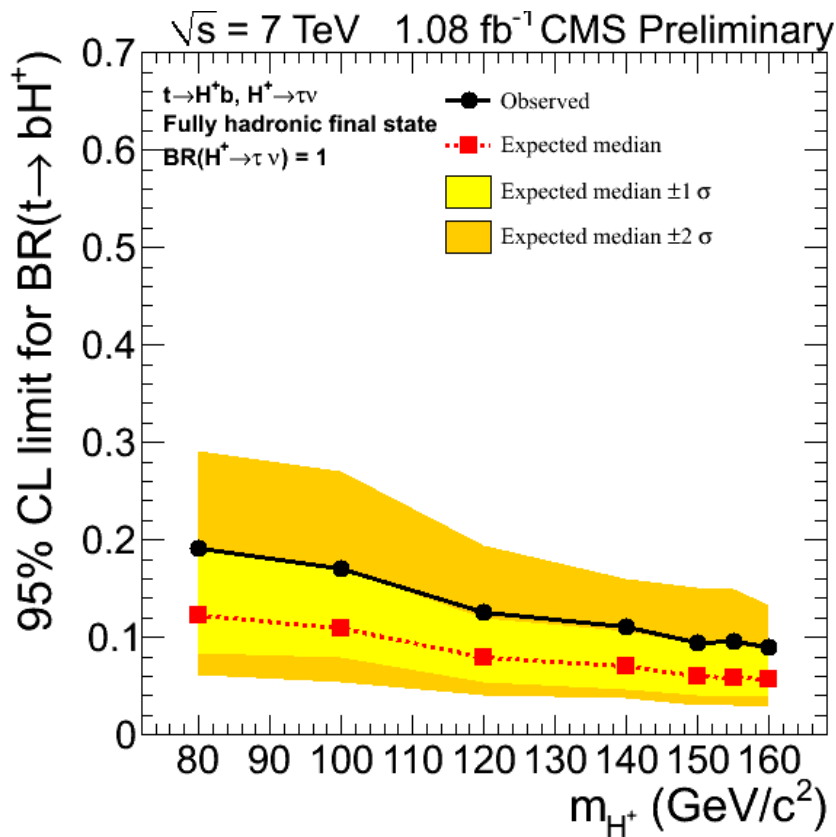


- **No significant data excess above expected background is observed in charged Higgs searches**

- **Exclusion limits from charged Higgs searches are much weaker than in neutral mode, but already with 1.1 fb⁻¹ much better then existing limits**

# SUSY searches with OS ττ

- **couplings to third generation leptons can be enhanced leading to final states that predominantly contain tau leptons**

- di-tau final states with $\tau_{had}$ are considered: **$e$-$\tau_{had}$, $\mu$-$\tau_{had}$, $\tau_{had}\tau_{had}$**

- Fully leptonic final states included in generic di-lepton SUSY searches

- **Event selection:**

  - $p_T^{\tau,e/\mu} > 20$ GeV ($e/\mu$-$\tau_{had}$), $p_T^{\tau} > 15$ GeV ($\tau_{had}\tau_{had}$)

  - two jets, $E_T > 30(100)$ GeV for $e/\mu$-$\tau_{had}$ ($\tau_{had}\tau_{had}$),

  - $E_T^{miss}$, $H_T^{(miss)}$ cuts
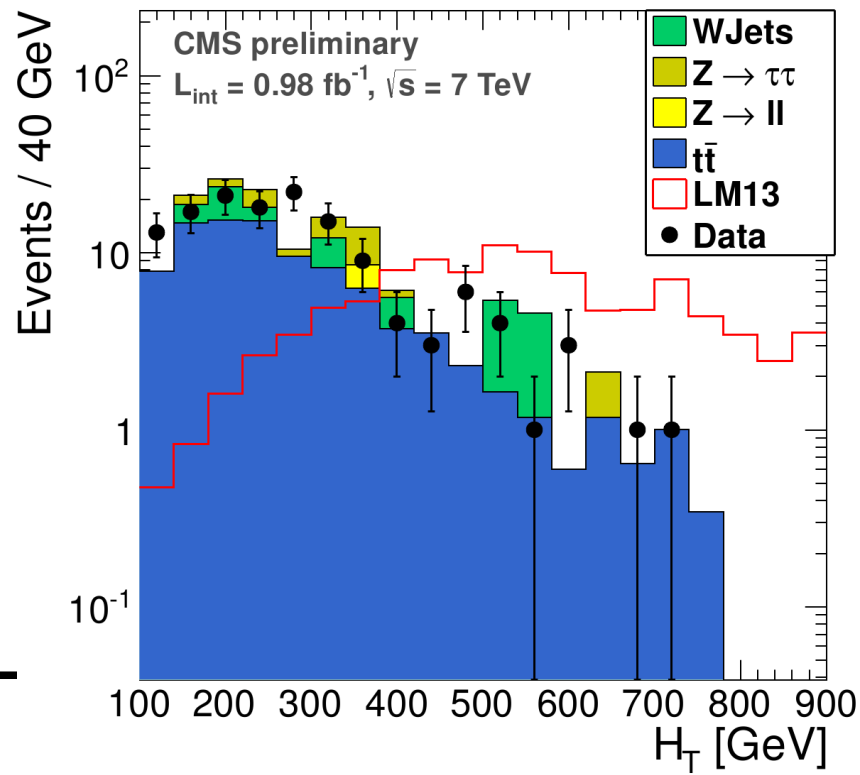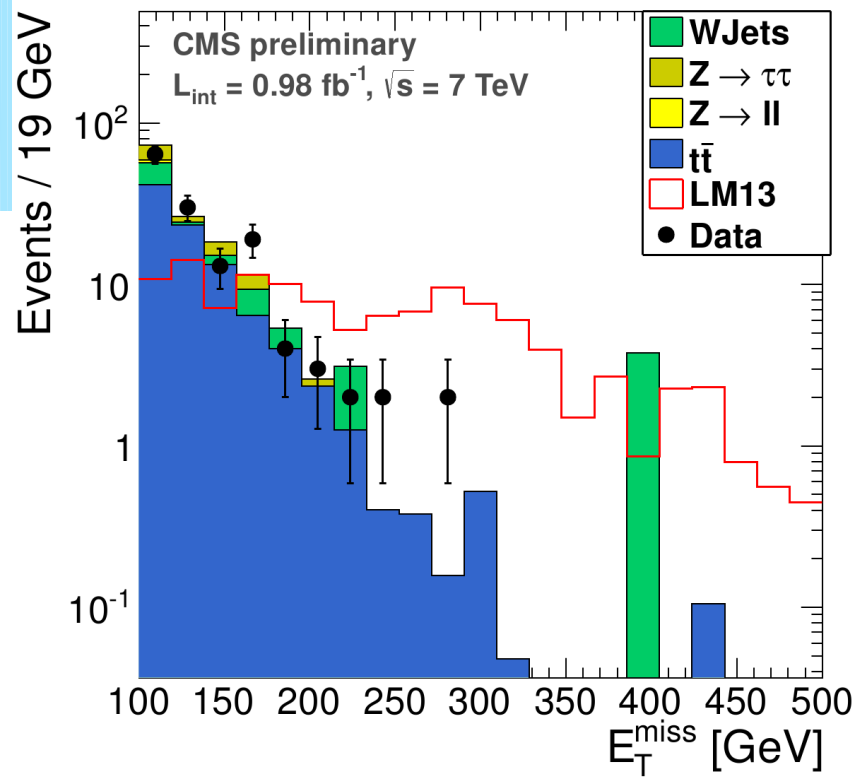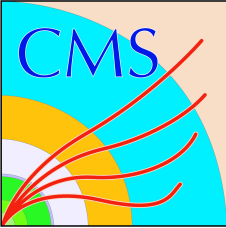
# SUSY results

- e/μ-$\tau_{had}$ channels: two signal regions defined: high $E_t^{miss}$, high $H_T$

- $\tau_{had}\tau_{had}$ channel: separation between $H_T^{miss}$ and next-to leading jet required to suppress QCD background

- **Model independent upper limits on non SM contribution to signal regions set by the analyses, as no excess over SM expectation observed**

- **$\tau_{(had)}$ leptons used in many more SUSY analyses: same/opposite sign dileptons, multi lepton**
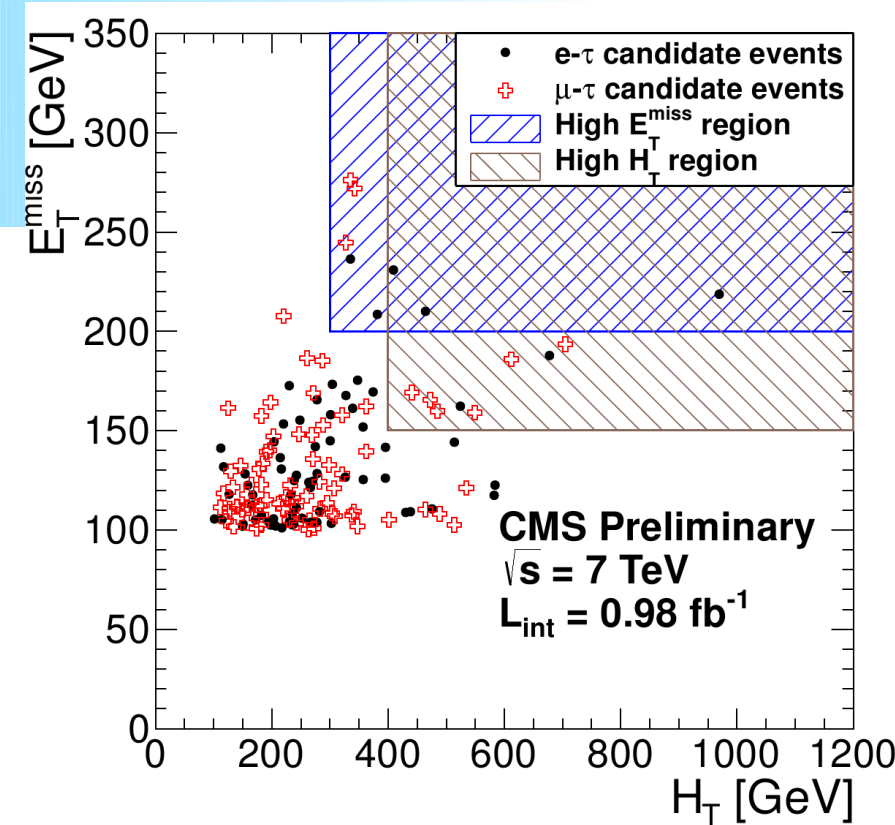


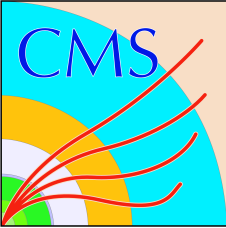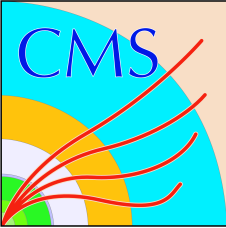| high $H_T$ signal region (e/μ $\tau_h$) | LM1 | LM2 | LM13 |
|---|---|---|---|
| UL $\sigma_{expected}^{CL_S^{95\%}}$ [pb] | $3.8 \pm 1.9$ | $2.6 \pm 1.2$ | $2.1 \pm 1.5$ |
| UL $\sigma_{measured}^{CL_S^{95\%}}$ [pb] | 4.2 | 2.9 | 2.5 |
| high $E_T^{miss}$ signal region (e/μ $\tau_h$) | LM1 | LM2 | LM13 |
| UL $\sigma_{expected}^{CL_S^{95\%}}$ [pb] | $3.3 \pm 1.9$ | $2.3 \pm 1.1$ | $2.3 \pm 1.5$ |
| UL $\sigma_{measured}^{CL_S^{95\%}}$ [pb] | 3.7 | 2.5 | 2.6 |
| $\tau_h \tau_h$ | LM1 | LM2 | LM13 |
| UL $\sigma_{expected}^{CL_S^{95\%}}$ [pb] | $3.9 \pm 1.9$ | $0.6 \pm 0.3$ | $1.8 \pm 1.2$ |
| UL $\sigma_{measured}^{CL_S^{95\%}}$ [pb] | 4.2 | 0.7 | 2.0 |
| high $H_T$ signal region (e/μ $\tau_h$) and $\tau_h \tau_h$ | LM1 | LM2 | LM13 |
| UL $\sigma_{expected}^{CL_S^{95\%}}$ [pb] | $2.5 \pm 1.5$ | $0.6 \pm 0.3$ | $1.2 \pm 1.0$ |
| UL $\sigma_{measured}^{CL_S^{95\%}}$ [pb] | 2.9 | 0.7 | 1.5 |
| high $E_T^{miss}$ signal region (e/μ $\tau_h$) and $\tau_h \tau_h$ | LM1 | LM2 | LM13 |
| UL $\sigma_{expected}^{CL_S^{95\%}}$ [pb] | $2.4 \pm 1.4$ | $0.6 \pm 0.3$ | $1.2 \pm 1.0$ |
| UL $\sigma_{measured}^{CL_S^{95\%}}$ [pb] | 2.8 | 0.6 | 1.5 |
| $\sigma_{model}^{NLO}$ [pb] | 6.6 | 0.8 | 9.8 |

# Conclusions

- **The CMS experiment is performing analyses with τ's in final state since very early data taking periods**

- **Well known Standard Model processes with τ are studied as benchmarks**

- **Channels with τ's are extensively used in the SM and SUSY Higgs boson searches**

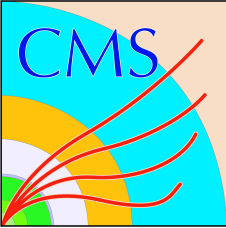- **SUSY analyses are using τ's in all decay modes and in complex multi jet, multi lepton environments**

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