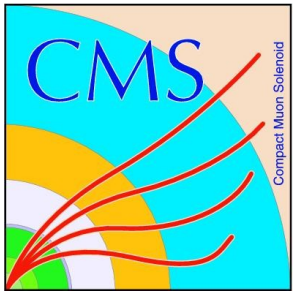
Massachusetts Institute of Technology



Beyond the SM Higgs Searches at CMS

Berkeley SUSY Workshop on Supersymmetry at the LHC 2011

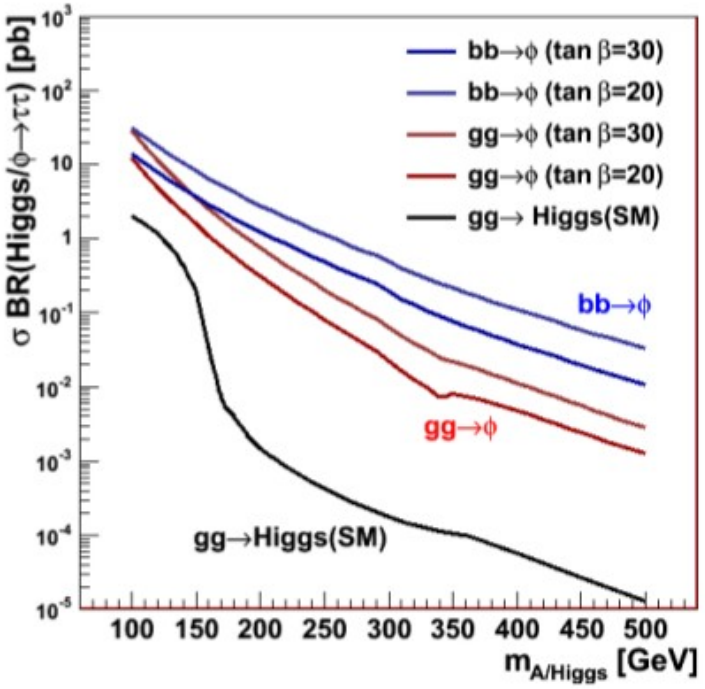
Roger Wolf
For the CMS Collaboration

Higgs Boson in SUSY and Beyond

- SUSY implies the presence of two Higgs doublets leading to the presence of five observable Higgs bosons:
- H, h (both CP-even), A (CP-odd), $H^{+/-}$. In the MSSM (for a large range of tanβ):

$m_A \leq 130$ GeV:	$m_A > 130$ GeV:
$m_h \approx m_A < m_H \approx 130$ GeV	$m_h \approx 130$ GeV $< m_H \approx m_A$

- Not finding a Higgs boson with $m_A \approx 130$ GeV will exclude the MSSM
- Main production mechanisms: gluon-gluon fusion ($gg \rightarrow \phi$), in association with b quarks ($gg \rightarrow \phi bb$)
- For tanβ≥20 BR into τ leptons is enhanced. $H/h \rightarrow \tau\tau$ perfect channel to search for SUSY Higgs bosons



Searches at CMS being Presented Today

- SUSY implies the presence of two Higgs doublets leading to the presence of five measurable Higgs bosons:
- H, h (CP-even), A (CP-odd), $H^{+/-}$. In the MSSM (for a large range of tanβ):

Search for Neutral Higgs boson decays (ϕ) into τ leptons (CMS-HIG-11-020 LP, 1.6fb^{-1})

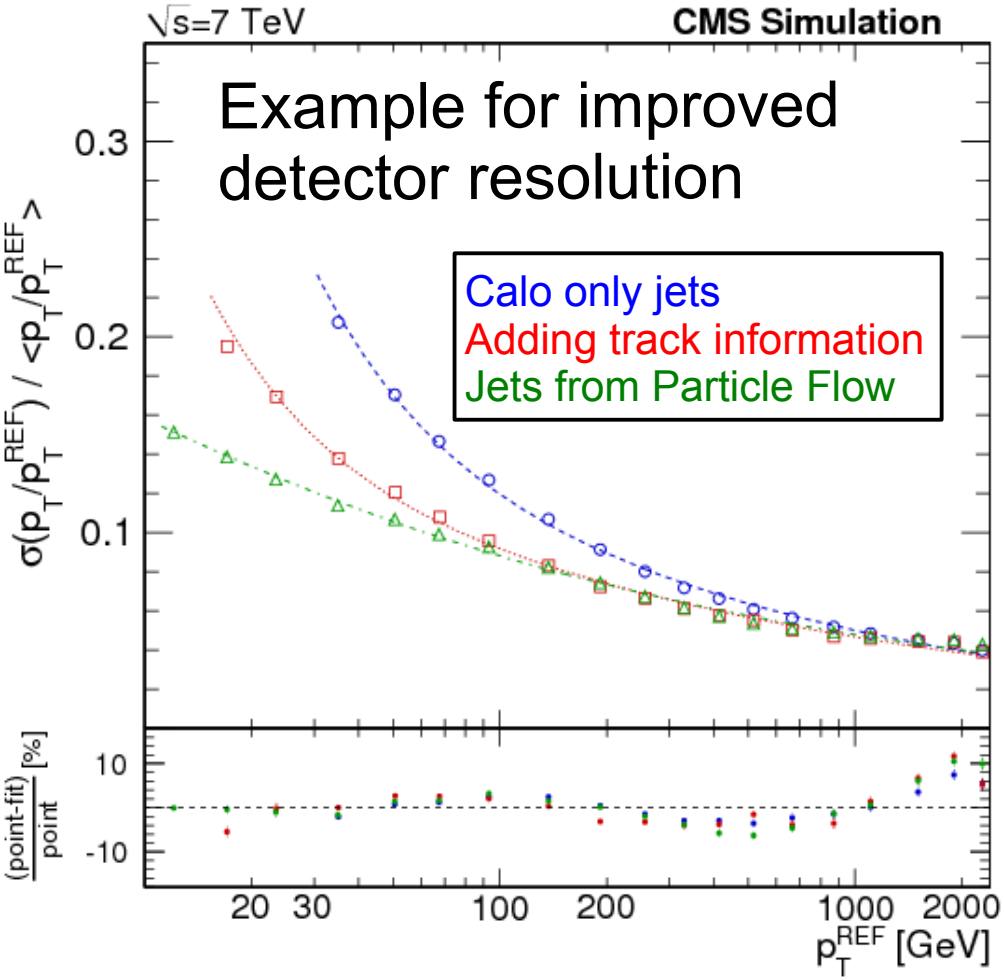
Search for Singly Charged Higgs boson decays ($H^{+/-}$) into τ leptons (CMS-HIG-11-008 EPS, 1fb^{-1})

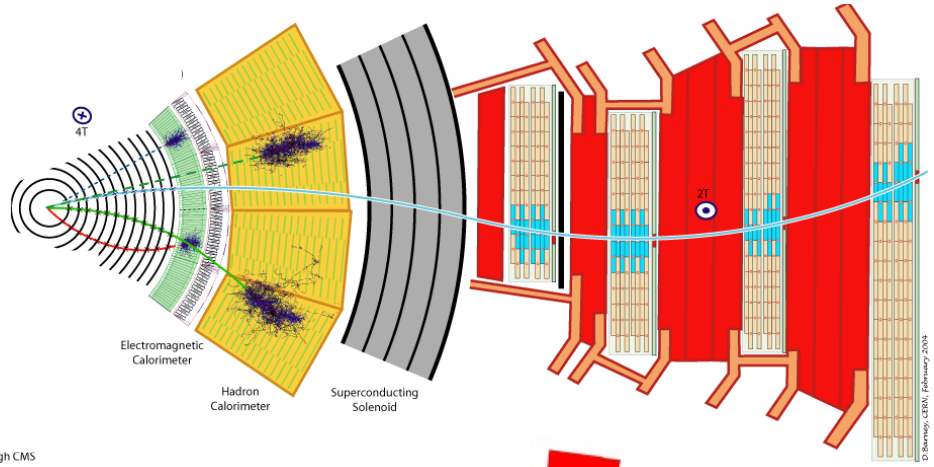
- In addition we present a search for doubly charged Higgs boson ($H^{++/--}$) decays into like-sign leptons (including hadronic τ decays) (CMS-HIG-11-008, 1fb^{-1})

Object Reconstruction

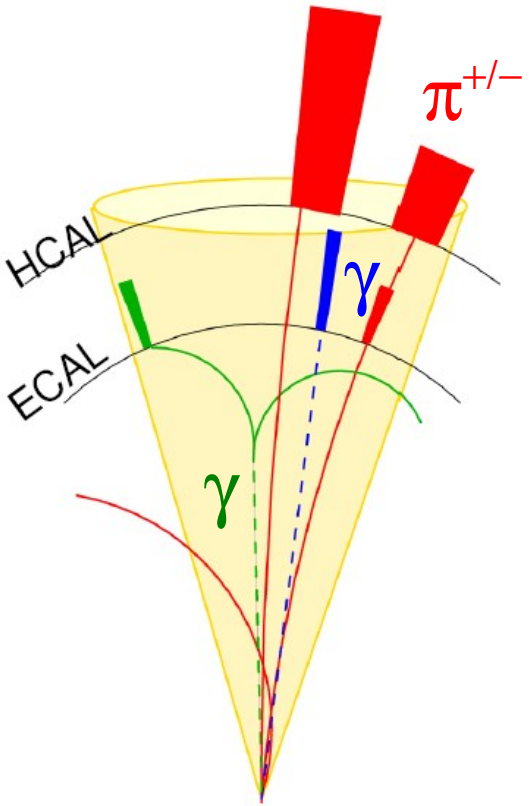
- Use the Particle Flow algorithm

  Make use of all available detector information for including particle interpretation to improve performance



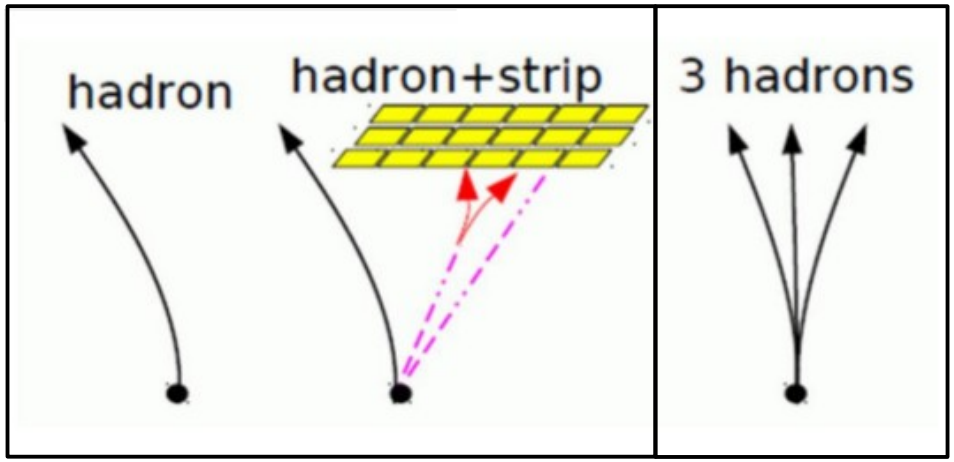


through CMS

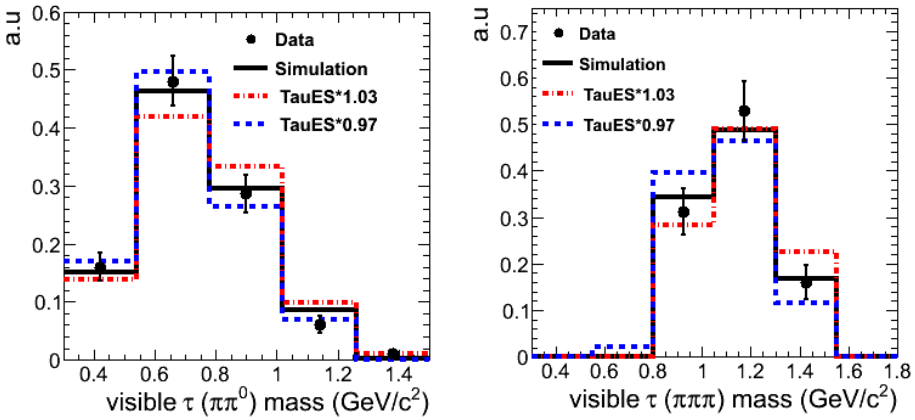


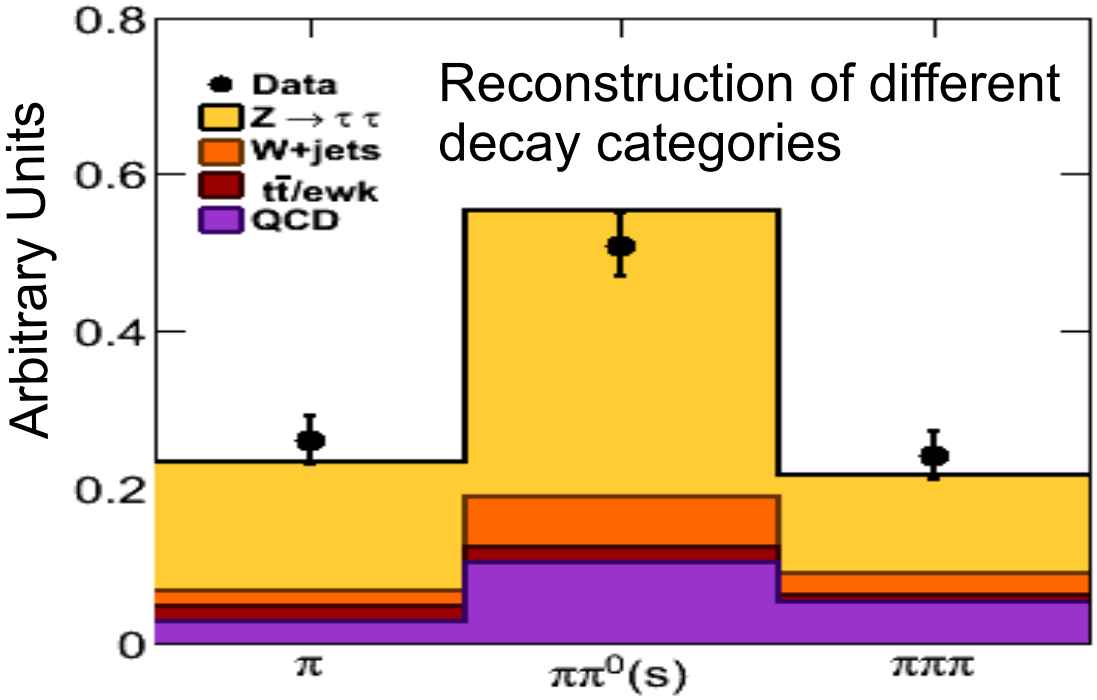
Reconstruction of τ Leptons

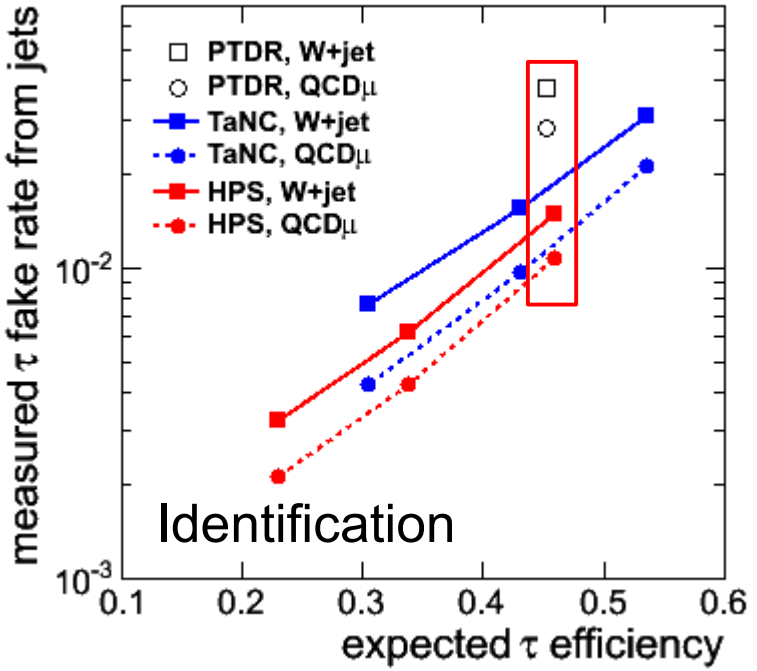
- Consider several decay classes:



Energy resolution







Search for Neutral Higgs boson decays ($\phi \to \tau\tau$)

- Search in three decay channels: $e\mu$, $\mu\tau_h$, $e\tau_h$
- Require 2 well reconstructed, isolated leptons of opposite sign:

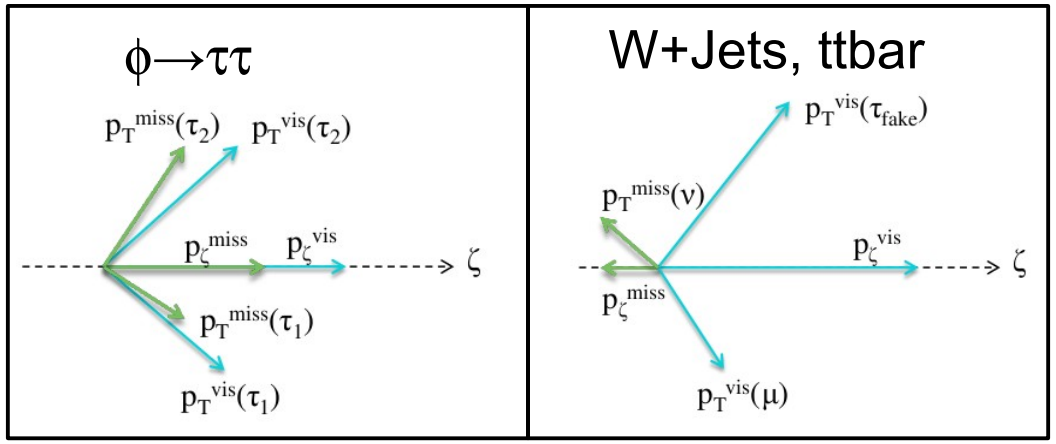
$e\mu$

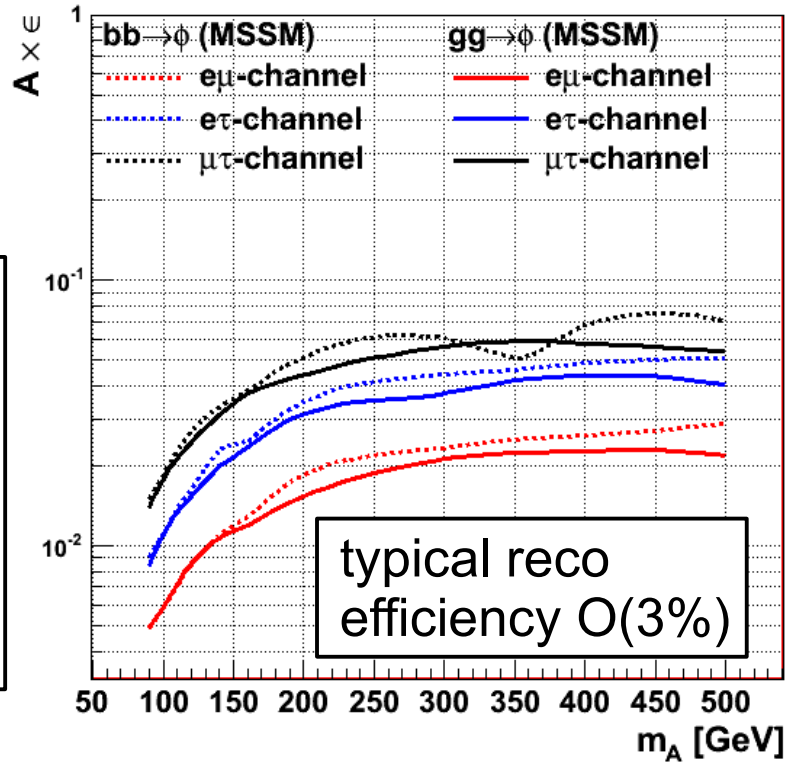
- e p_T>10(20) GeV, $|\eta|$<2.5
- μ p_T>20(10) GeV, $|\eta|$<2.1

$e\tau_h$ / $\mu\tau_h$

- e p_T>20 GeV, $|\eta|$<2.5
- μ p_T>15 GeV, $|\eta|$<2.1
- τ_h p_T>20 GeV, $|\eta|$<2.3

- Topological event selection:
  - $p_\zeta^{cut} = (p_\zeta - 1.85 \cdot p_\zeta^{vis}) > -25$ GeV ($e\mu$)
  - $p_\zeta^{cut} = (p_\zeta - 1.50 \cdot p_\zeta^{vis}) > -20$ GeV ($e\tau_h$ / $\mu\tau_h$)



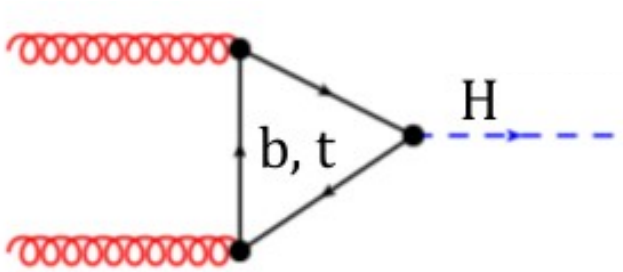


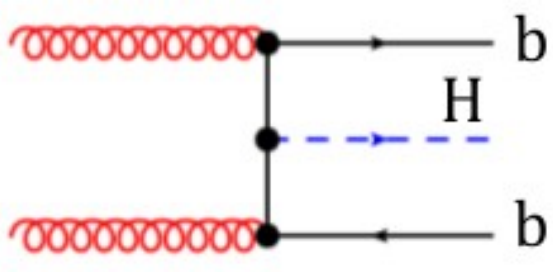
Definition of Event Categories

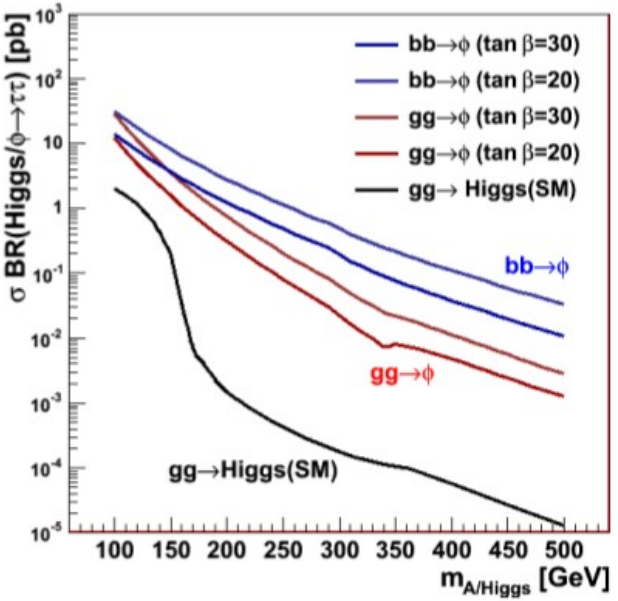
- Exploit dominant production channels:

Non B-Tag:
- $N_{jet}(30\ GeV) \leq 1$
- $N_{B\text{-}Tag}(20\ GeV) = 0$

B-Tag:
- $N_{jet}(30\ GeV) \leq 1$
- $N_{B\text{-}Tag}(20\ GeV) \geq 1$







$\mu\tau_h$

Process	*No B-Tag*	*B-Tag*
Di-Boson	42.6 ± 15.0	0.9 ± 0.4
$t\bar{t}$	15.1 ± 2.7	24.9 ± 4.2
Z^{l+jet}	755 ± 157	7.2 ± 1.6
Z^{ll}	2375 ± 452	22.0 ± 4.5
$W + jets$	3136 ± 208	30.7 ± 2.7
QCD	7665 ± 392	104 ± 13
$Z \to \tau\tau$	5658 ± 405	54 ± 10
Total Background	19646 ± 640	244 ± 18
Data	20384	223

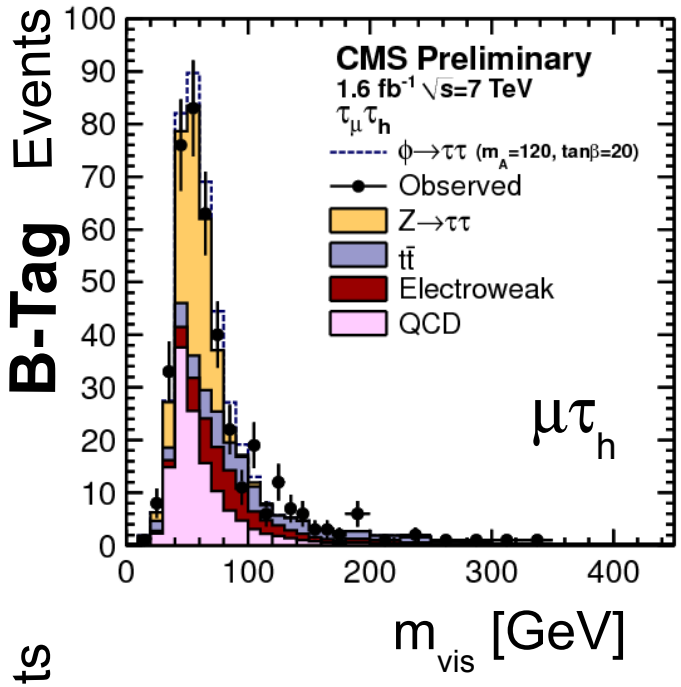
$e\tau_h$

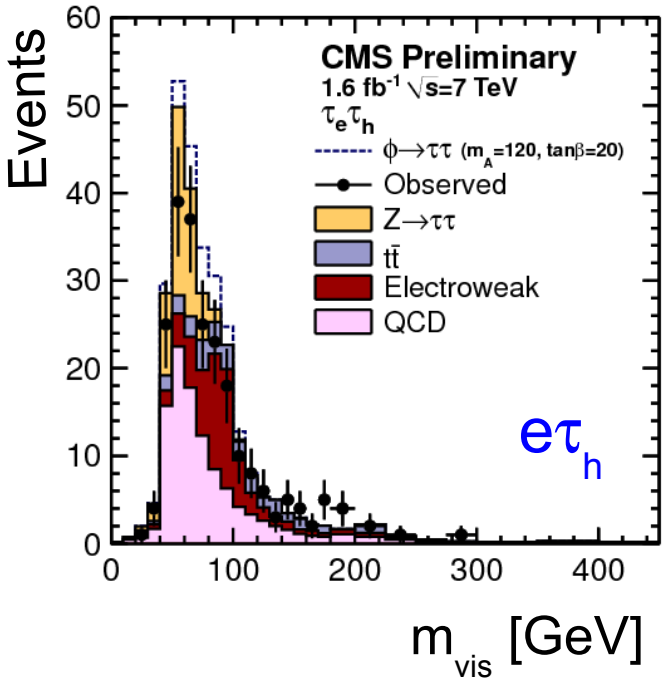
No B-Tag	*B-Tag*
102 ± 36	2.9 ± 1.0
31.4 ± 5.2	56.7 ± 9.1
458 ± 97	4.4 ± 1.0
210 ± 65	2.0 ± 0.6
5246 ± 331	49.7 ± 4.4
4420 ± 192	129 ± 14
14908 ± 1062	142 ± 27
25376 ± 1132	387 ± 31
25314	408

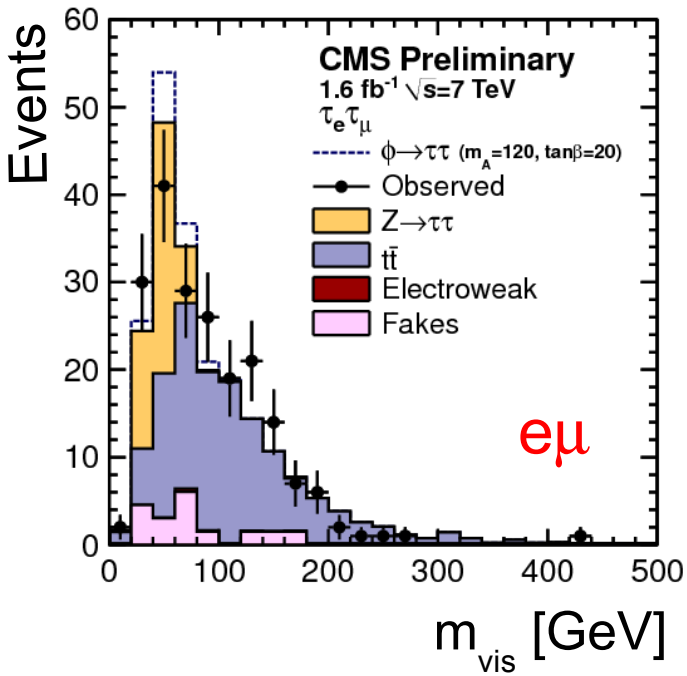
$e\mu$

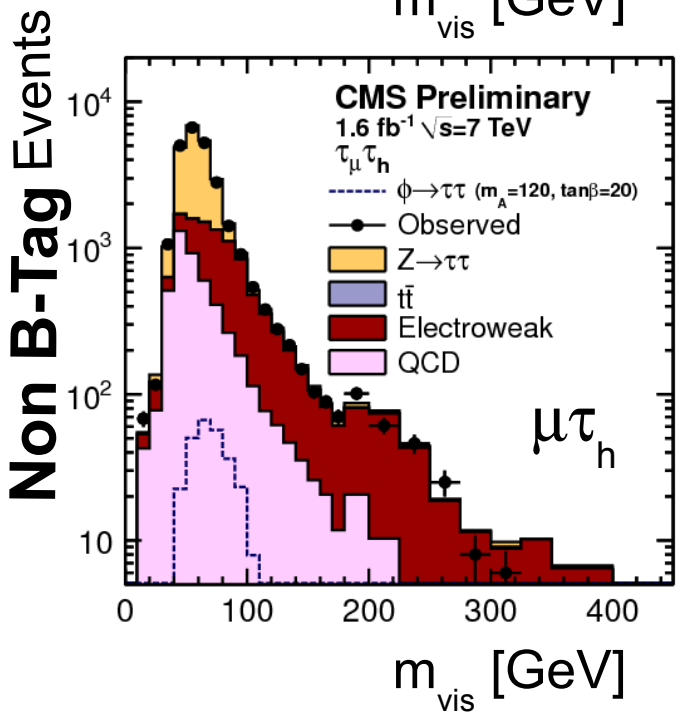
Process	*Non B-Tag*	*B-Tag*
Di-Boson	189 ± 57	1.6 ± 0.5
$t\bar{t}$	67 ± 7	115 ± 11
Fakes	422 ± 127	17 ± 9
$Z \to \tau\tau$	4818 ± 145	47 ± 2.3
Total Background	5496 ± 201	181 ± 14
Data	5528	201

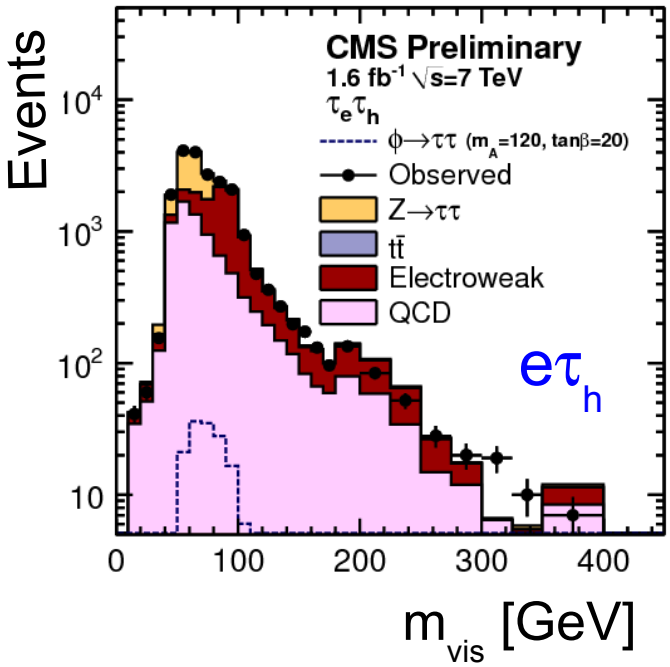
Visible Mass Distributions

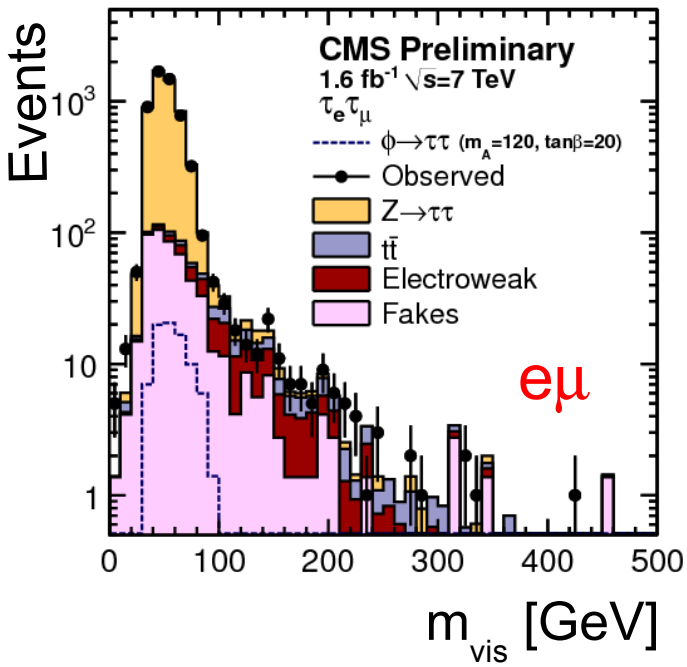






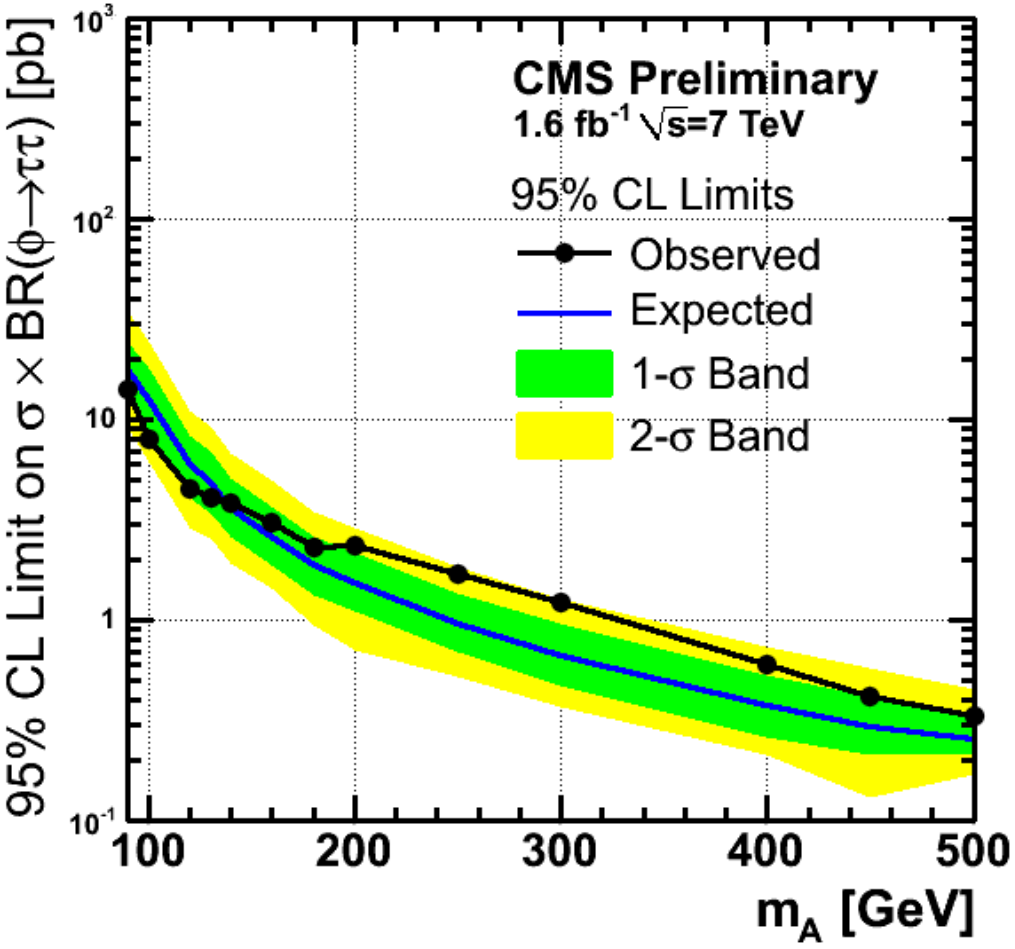




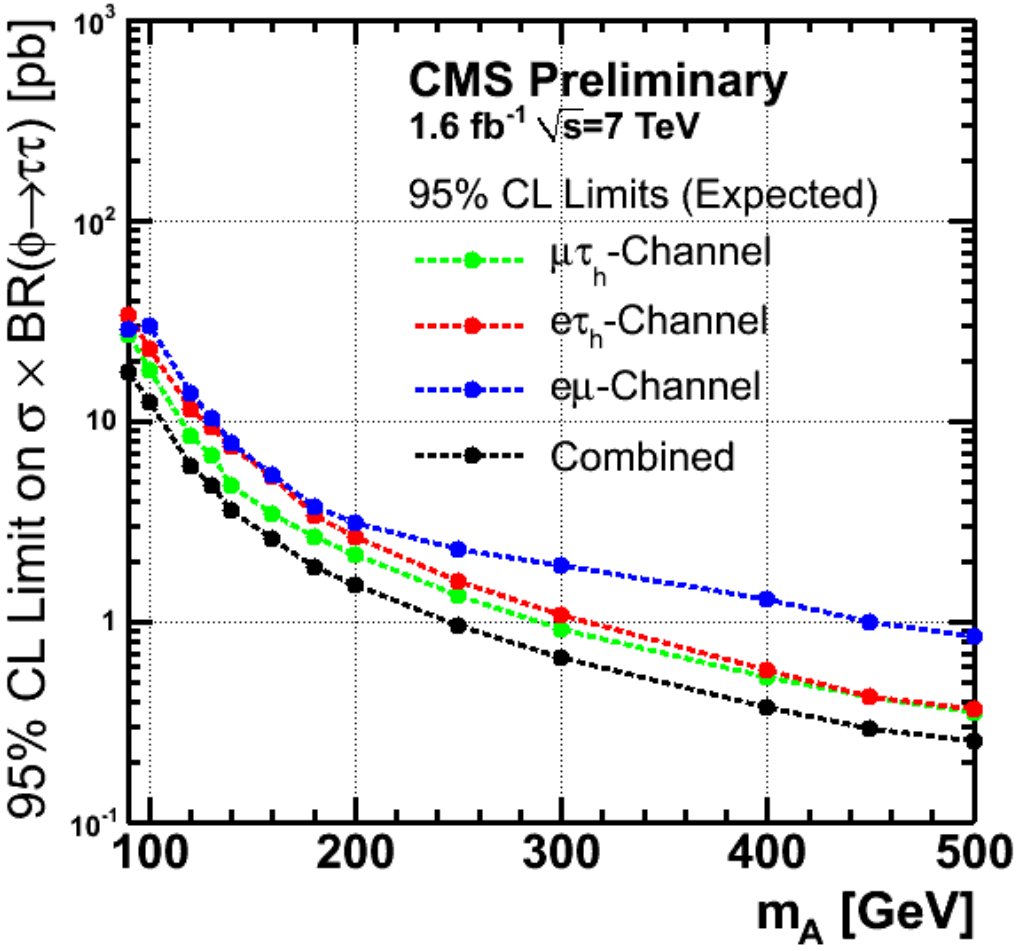


Limits on the Production Cross Section

All channels combined
(expected and observed)

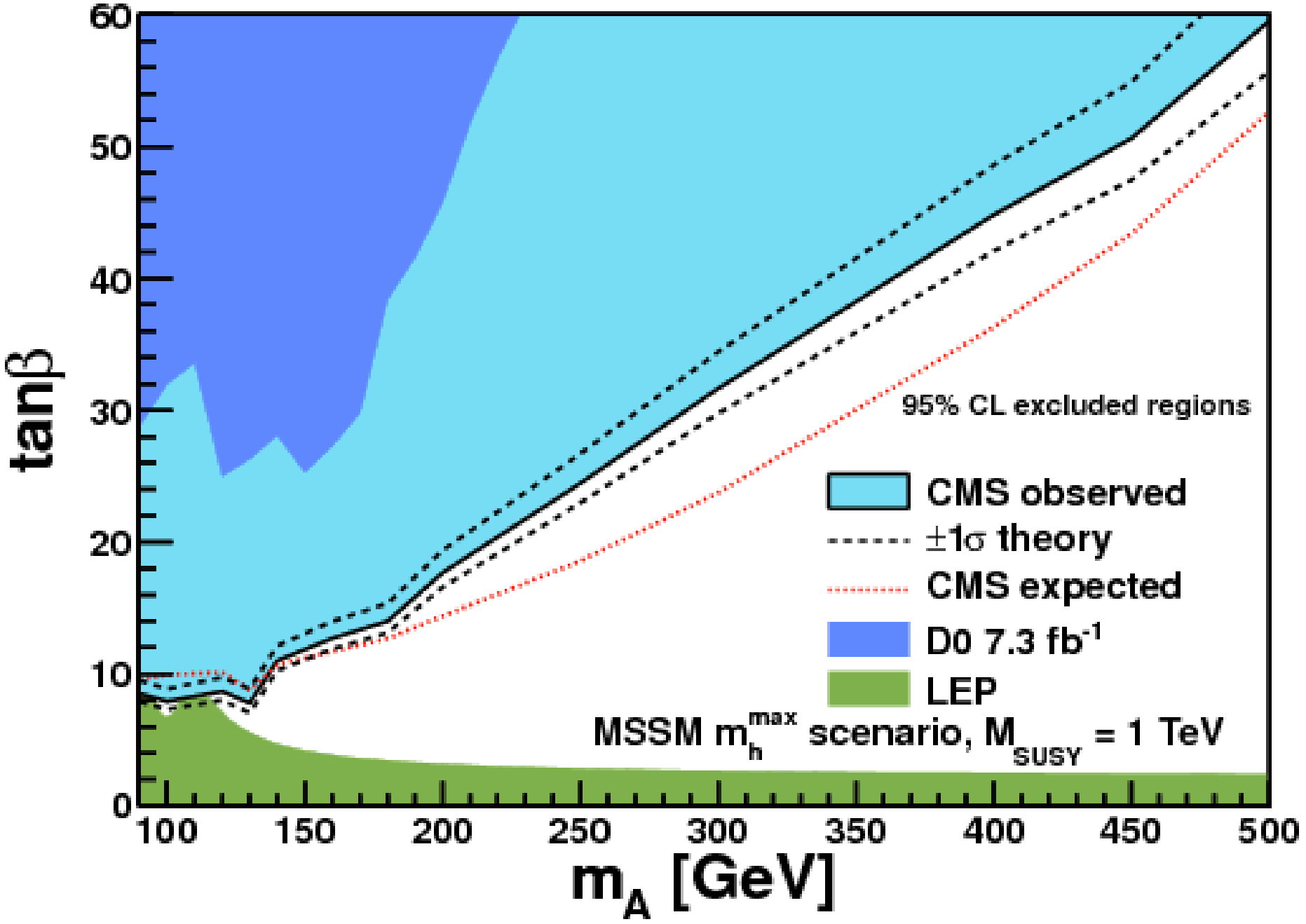


Individual contributions
(expected limit)



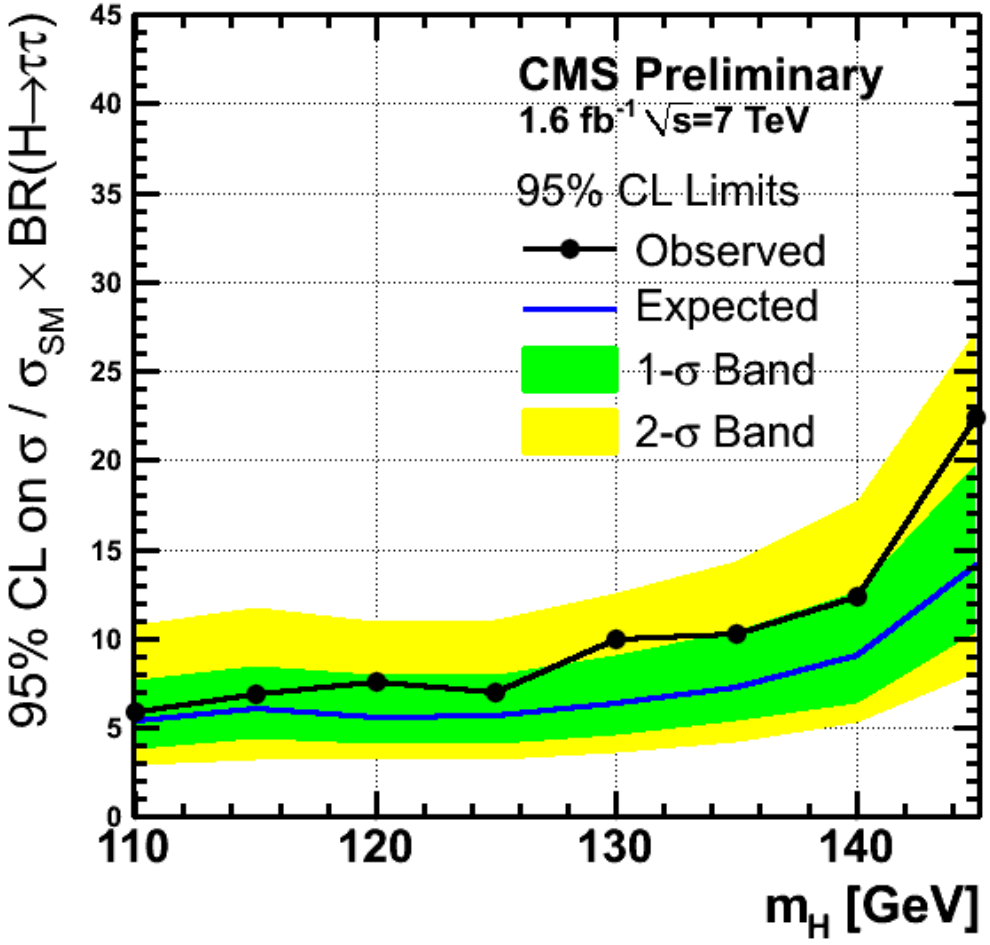
- Main systematics:
  τ identification (6%), τ energy scale (3%), jet energy scale (5%), b-jet (miss-)identification (10%), Z production cross section (3%)

Limits in mA-tanβ Plane

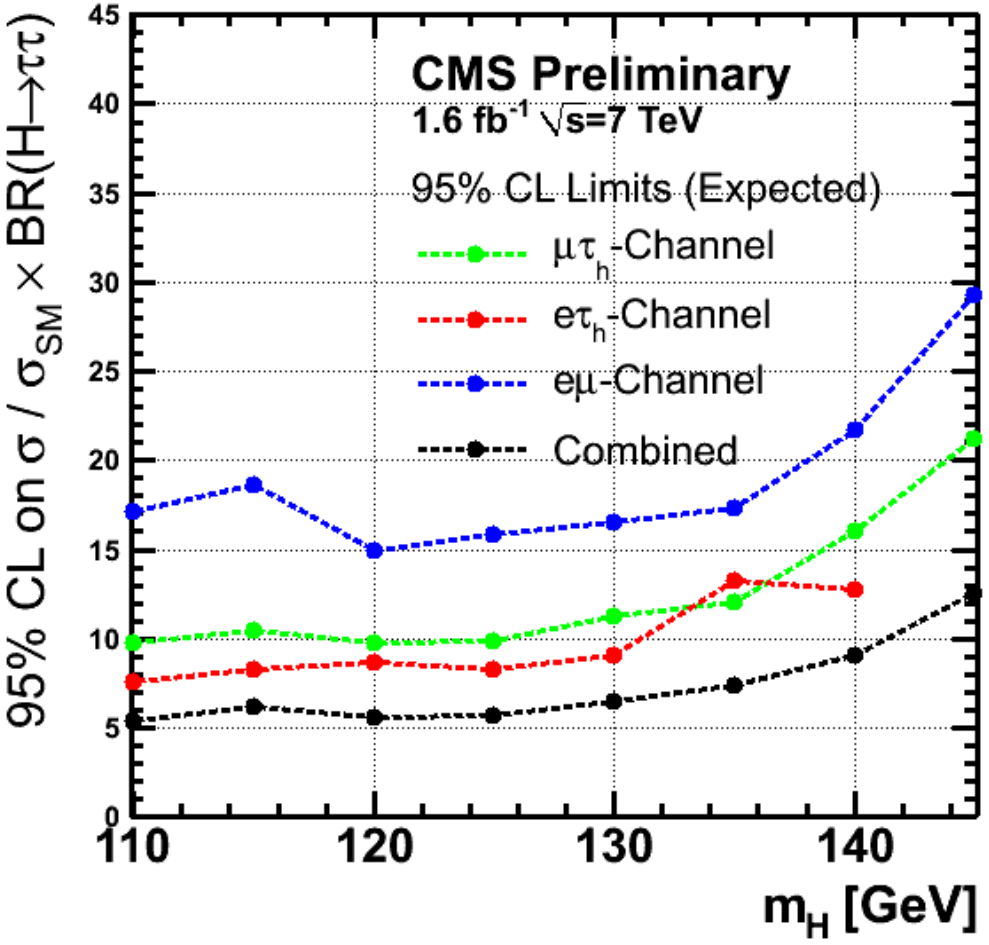


Note Bene: Latest Result of the **SM search**

All channels combined
(expected and observed)



Individual contributions
(expected limit)

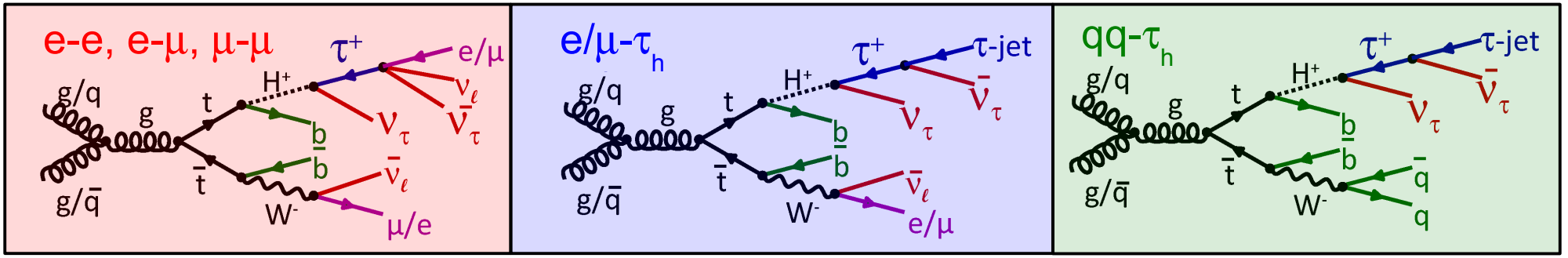


- Main systematics:
  τ identification (6%), τ energy scale (3%), jet energy scale (5%), b-jet (miss-)identification (10%), Z production cross section (3%)

Search for Singly Charged Higgs Boson Decay ($H^{+/-}$)

- If $m_{H+/-} < m_{top}$, $H^{+/-}$ can be produced via top quarks ($t \to H^{+/-} b$)
- Under the assumption $BR(H^+ \to \tau^+ \nu)=1$ limits can be derived on $BR(t \to H^+ b)$
- Current upper limits by CDF/D0 lie around $BR(t \to H^+ b) \approx 0.2$

- Search in three decay channels:

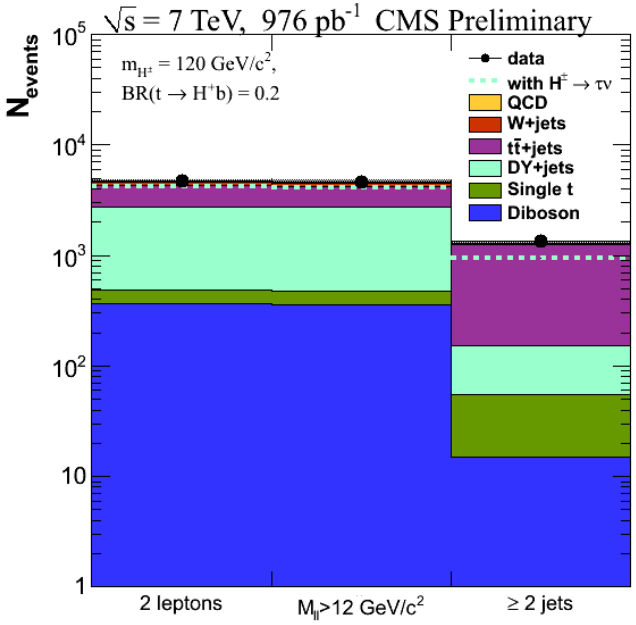


- Consider single ($tt \to W^{+/-} H^{-/+} bb$) and double ($tt \to H^{+/-} H^{-/+} bb$) $H^{+/-}$ production

- Use typical selection for top quark pairs
- Isolated e/μ, jets, b-jets, MET
- Expect $H^{+/-}$ signal as deviation from SM expectation for tt

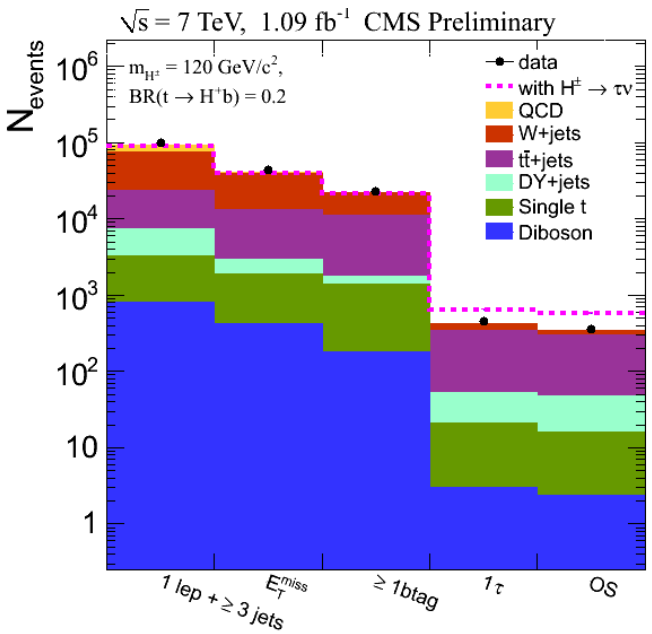
Event Selection

- e-e, eμ, μμ:
- e p_T>20 GeV, |η|<2.5
- μ p_T>20 GeV, |η|<2.4
- N_{Jet}(30 GeV)≥2



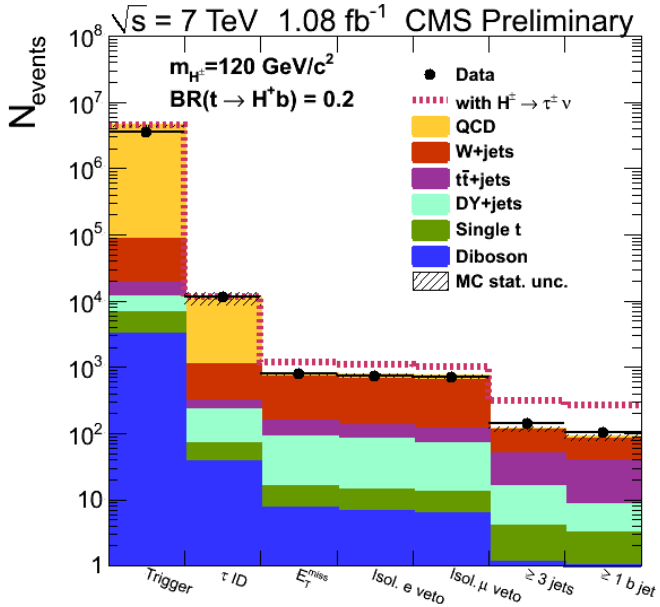
	stat.	syst.
Exp:	1264 ± 7	± 219
Obs:	1340	

- e/μ-τ_h:
- τ_h p_T>20 GeV, |η|<2.4
- μ p_T>20 GeV, |η|<2.1
- N_{Jet}(30 GeV)≥2
- $N_{B\text{-}Tag}$≥1, MET>40 GeV



	stat.	syst.
Exp:	377 ± 11	± 40
Obs:	361	

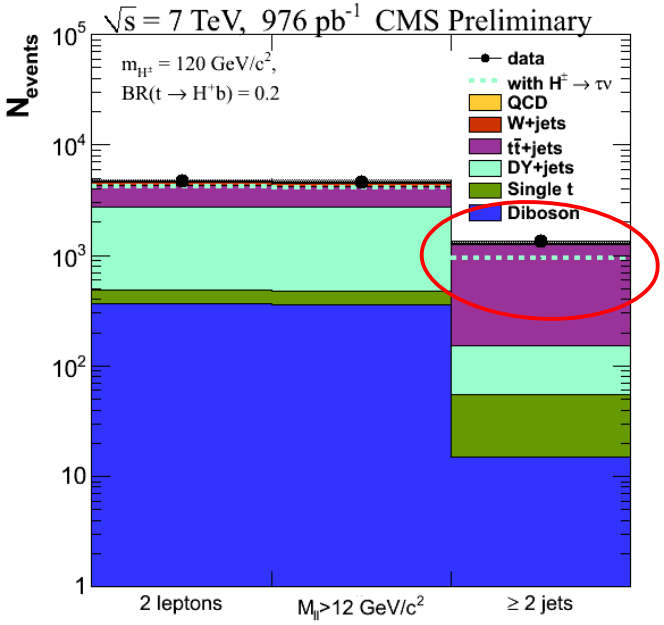
- qq-τ_h:
- τ_h p_T>40 GeV, |η|<2.1
- N_{Jet}(30 GeV)≥3
- $N_{B\text{-}Tag}$≥1, MET>70 GeV
- Veto againt iso. e/μ



	stat.	syst.
Exp:	82 ± 5	± 16
Obs:	104	

Event Selection

- e-e, eμ, μμ:
- e p_T>20 GeV, |η|<2.5
- μ p_T>20 GeV, |η|<2.4
- N_{Jet}(30 GeV)≥2



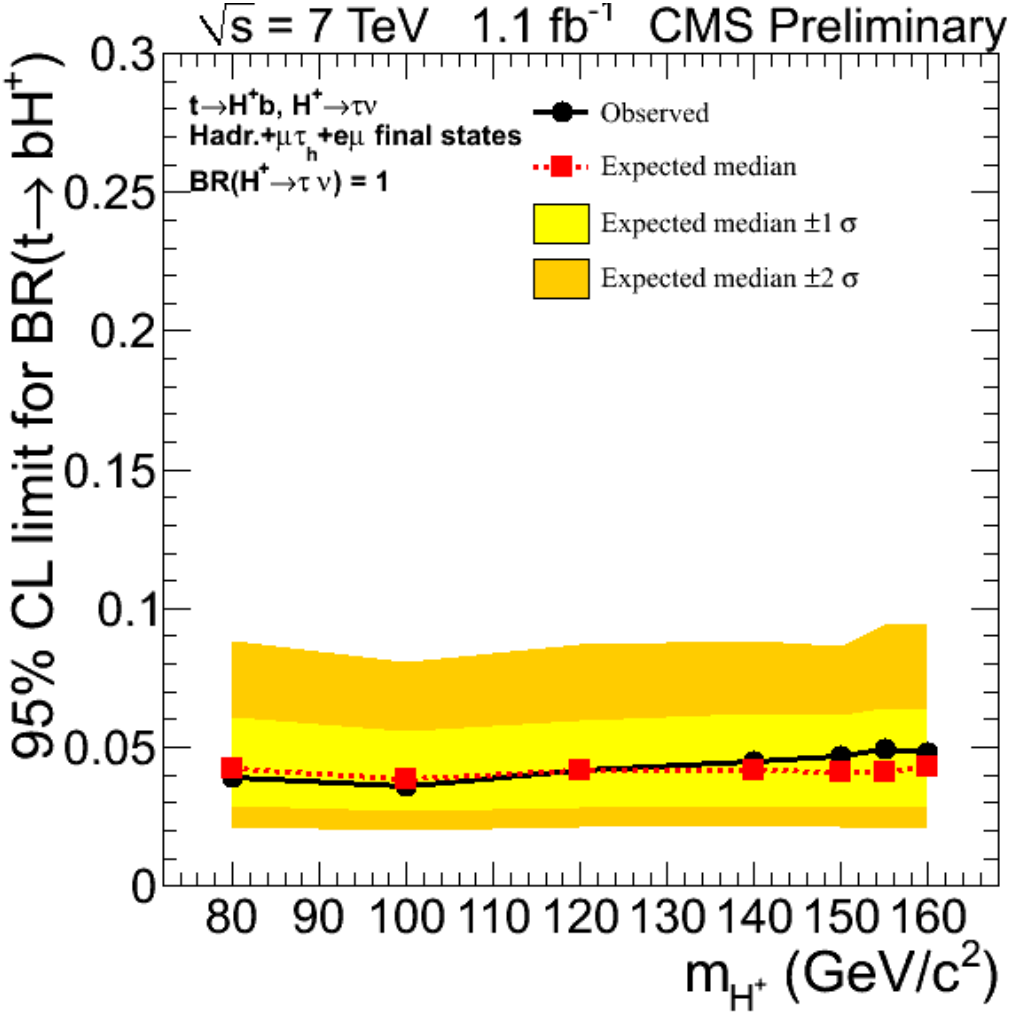
	stat.	syst.
Exp:	1264 ± 7	± 219
Obs:	1340	

- The major contribution to the event yield comes from tt→eμX
- The signal has a softer p_T(e/μ) spectrum wrt. prompt e/μ from tt decays due to the τ→lνν decay
- Therefore a larger contribution of signal would lead to a lower yield of reconstructed events

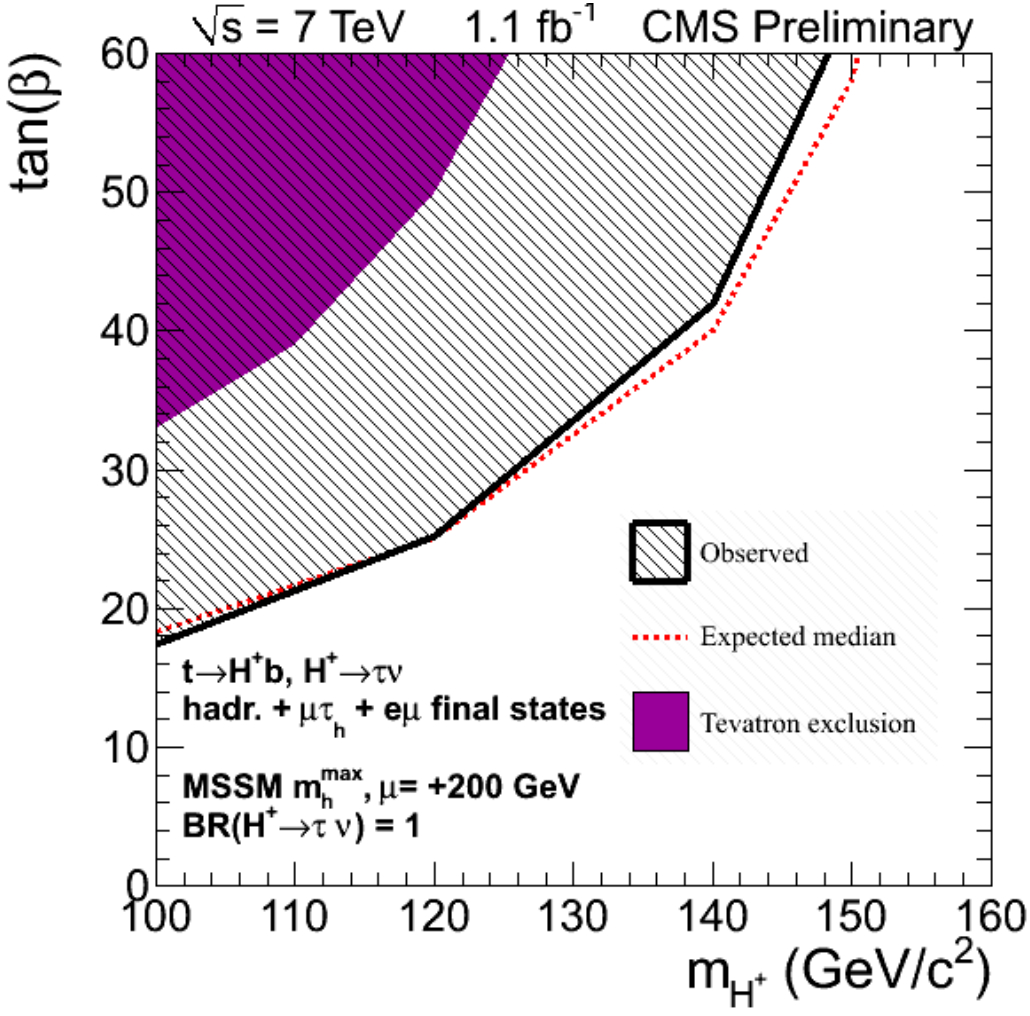
Source	N_{events} ± stat. ± syst.
HH+HW, m_{H^+}=120 GeV/c^2, BR=0.2	219 ± 7 ± 43
$t\bar{t}$	1094 ± 6 ± 219
$Z/\gamma^* \to ll$	98 ± 3 ± 12
W+jets	18 ± 3 ± 2
Single top	40 ± 1 ± 4
VV	14.7 ± 0.4 ± 1
Total expected from SM	1264 ± 7 ± 219
Data	1340

Limits on BR(t→H⁺b) and tanβ-m(H⁺) Plane

Limit on BR(t→H⁺b) (all channels combined)



Limit in m_{H+}-tanβ plane

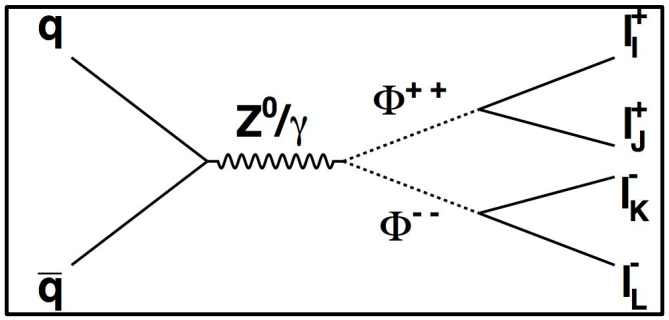


- Main systematics:
  τ (miss-)identification (7-15%), jet energy scale (5%), b-jet (miss-)tagging (10%)

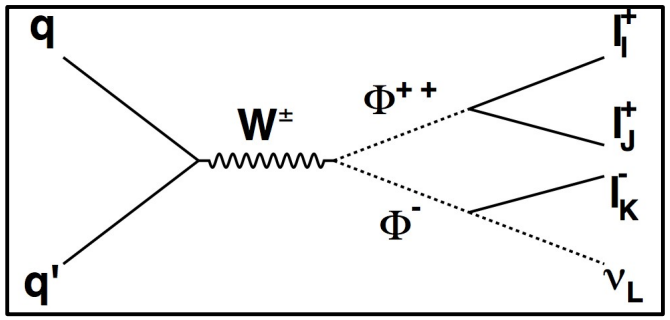
Doubly Charges Higgs Boson ($H^{++/--}$)

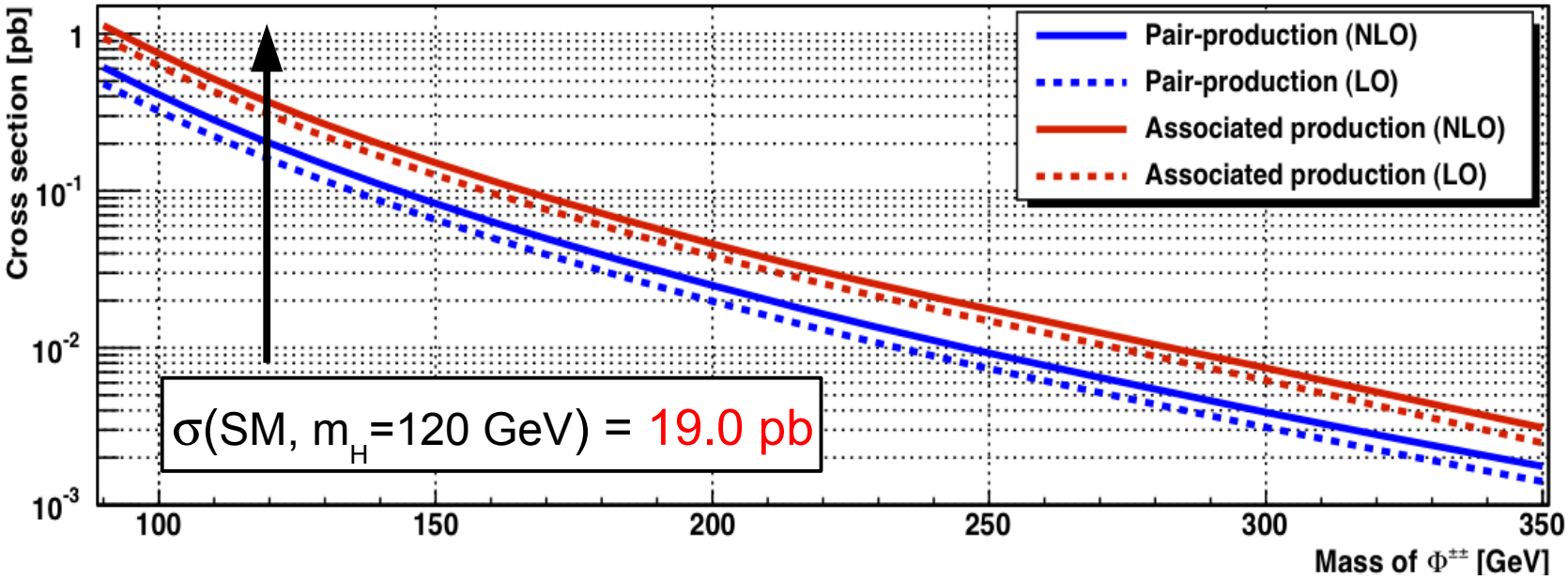
- Minimal seasaw models of type II, introduced to explain non-zero ν masses are realized with a triplet scalar field which introduces a doubly charged $H^{++/--}$ state:

Pair Production:



Associated Production:





Event Selection

- Search for 3 or 4 isolated leptons in mass dependent like-sign(!) resonance mass windows (search in 2-channels)
- Allow for lepton flavour violation (i.e. combine all kinds of flavours, include τ leptons)
- Exotic signature - basically free of SM backgrounds

Three Leptons:

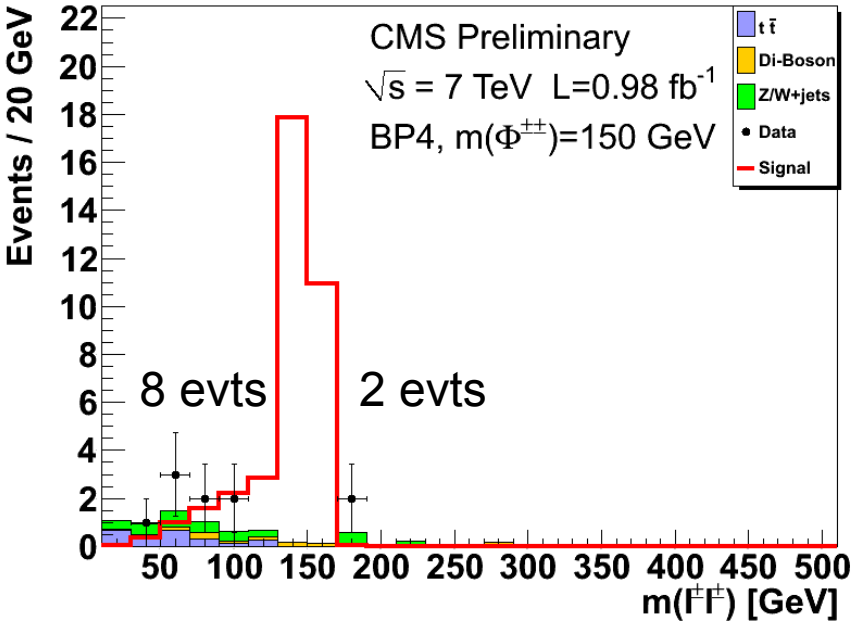
$\Sigma p_T(3l's) > m(\phi)+80GeV$

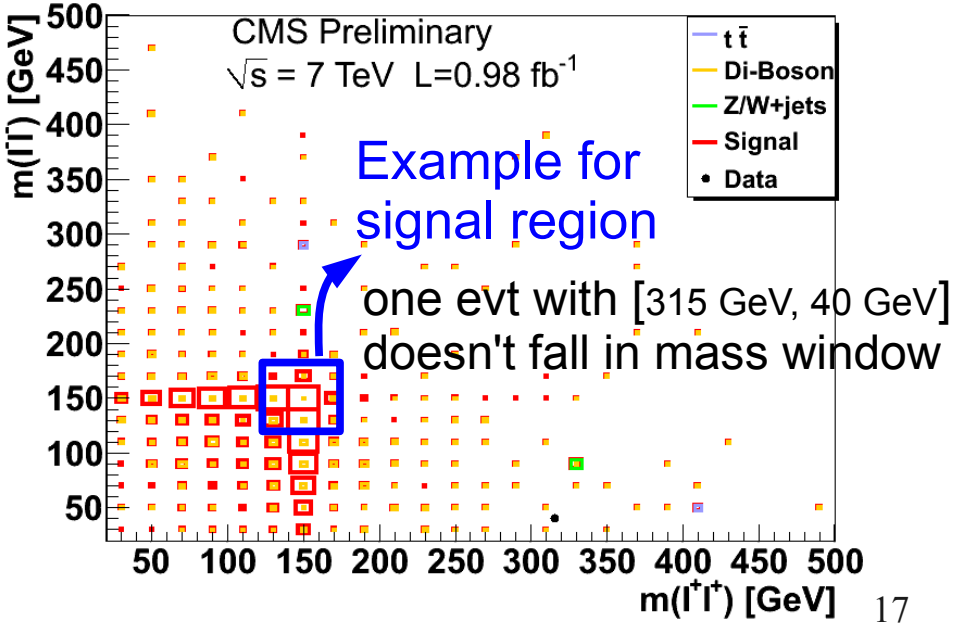
$m(ll)$ [$m_{lower}(flav)$, $m(\phi)+10GeV$]

Four Leptons:

$\Sigma p_T(4l's) > m(\phi)+80GeV$

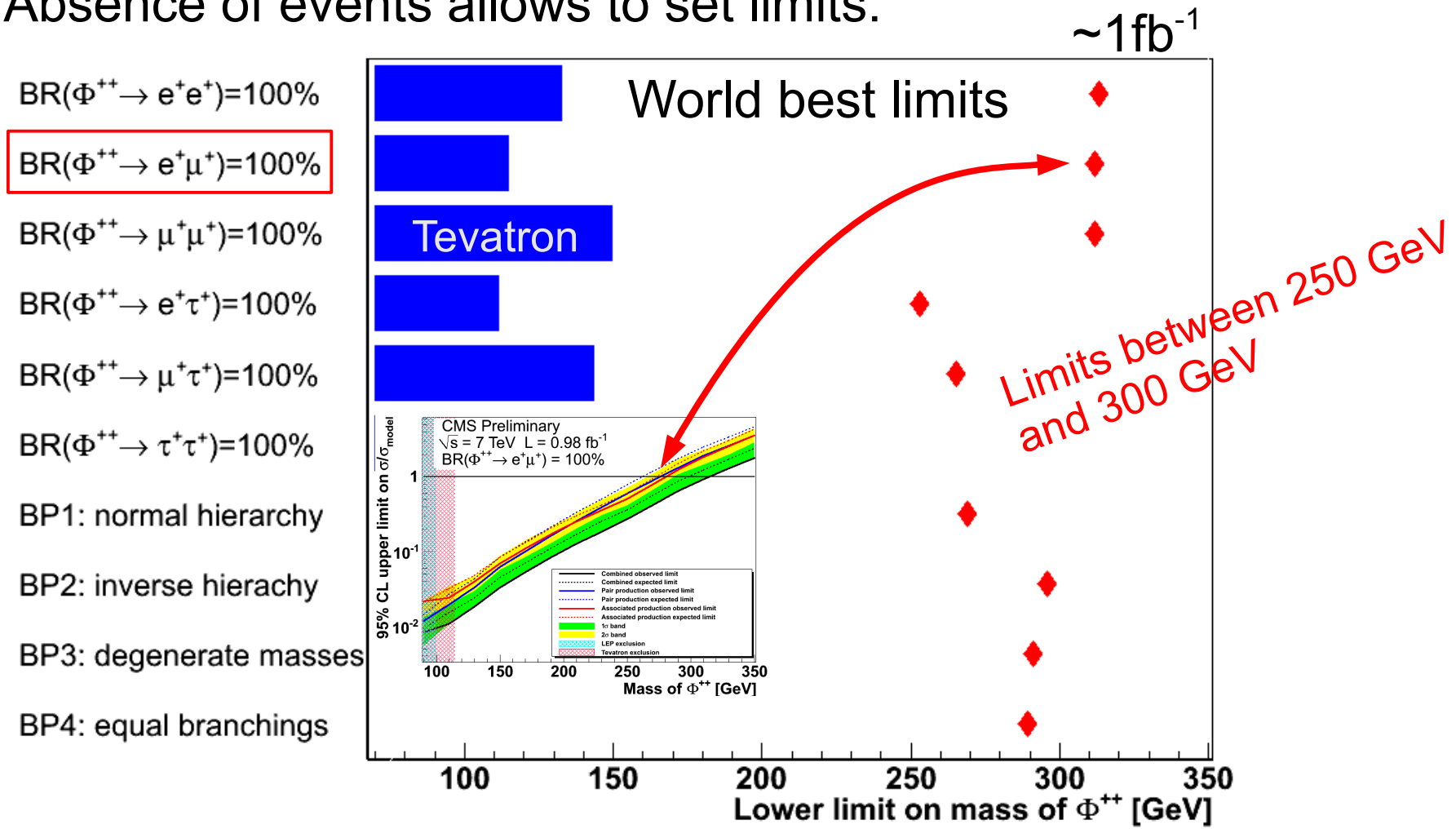
$m(ll)$ [$m_{lower}(flav)$, $m(\phi)+10GeV$]





Exclusion

- Absence of events allows to set limits:

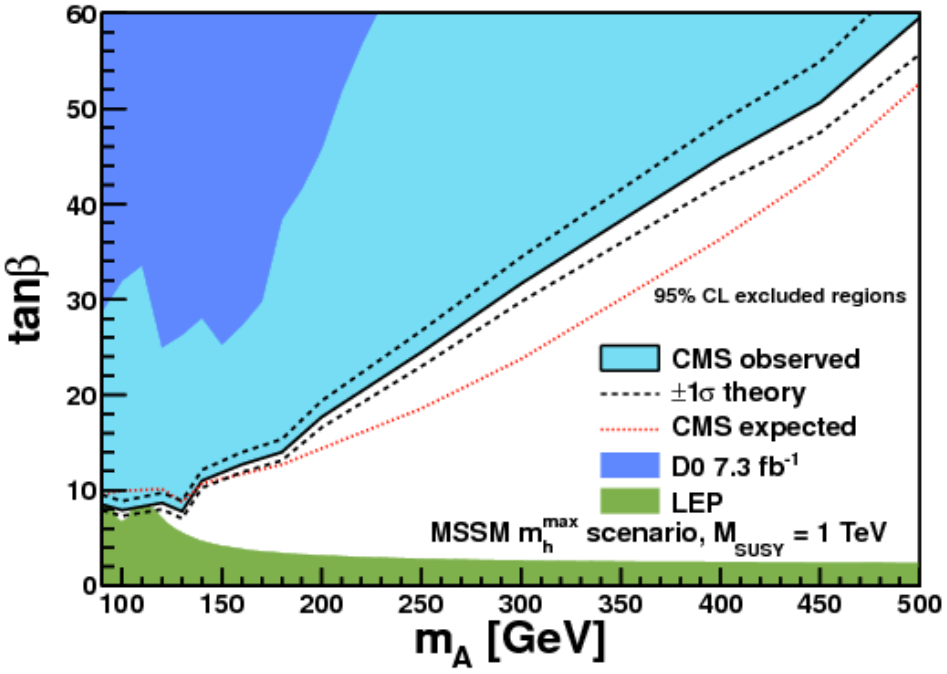


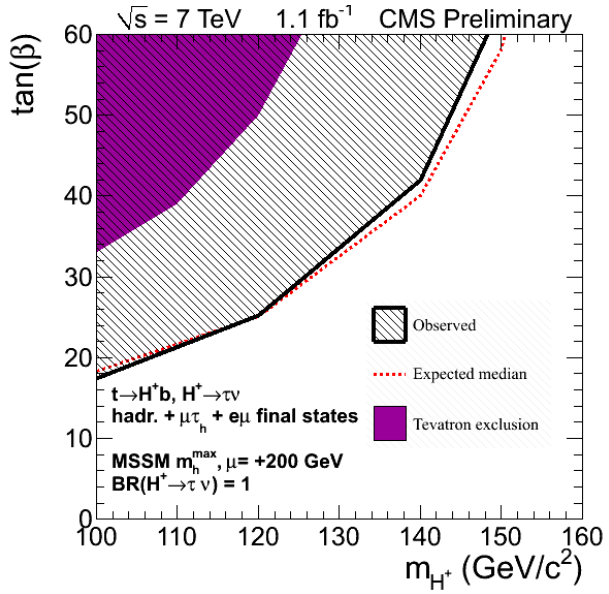
Main uncertainties:

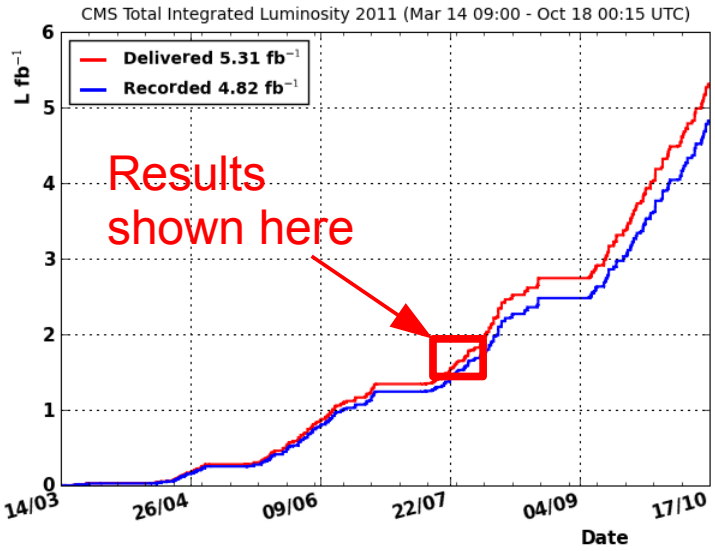
τ identification (8%), signal cross section (10%), stat. limitations in sidebands for background determination (10-100%)

Summary and Outlook

- New world records shown in sensitivity and limits on BSM Higgs models.



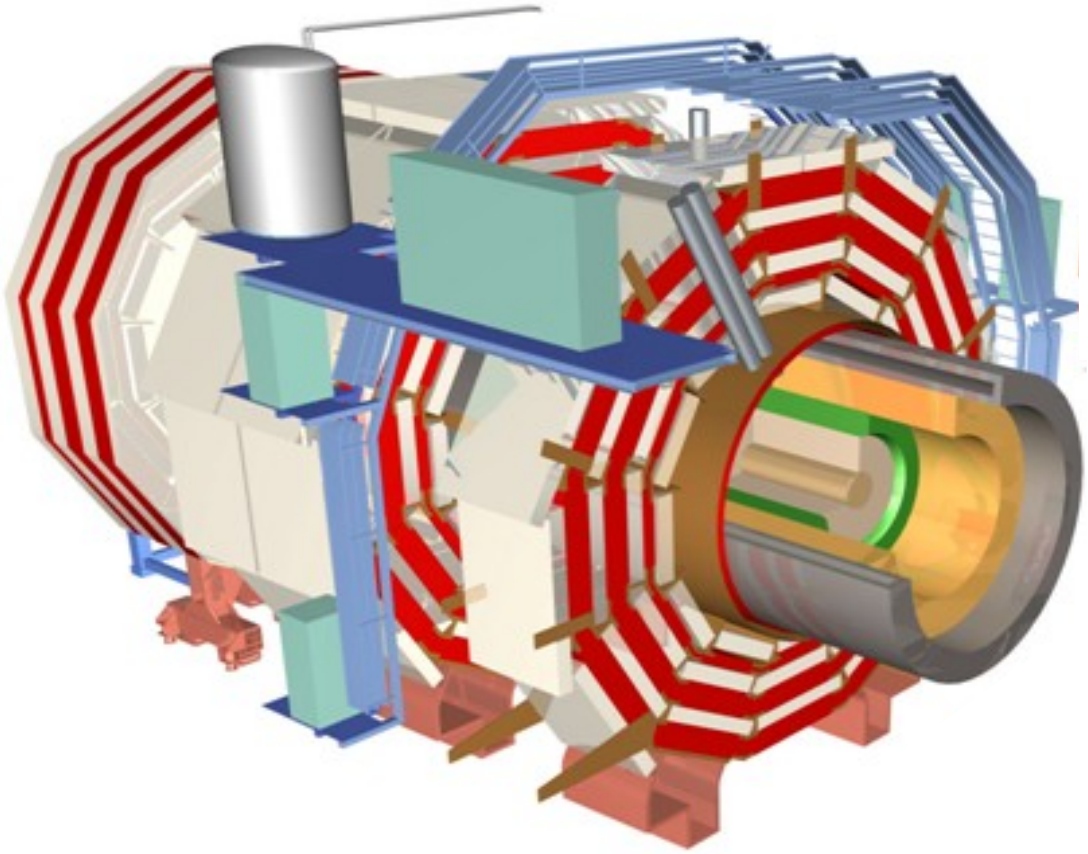




- In additional improvements to the analysis
- Expect MSSM H/h to be excluded up to ~150 GeV with full 2011 dataset
- To be published by the end of the year

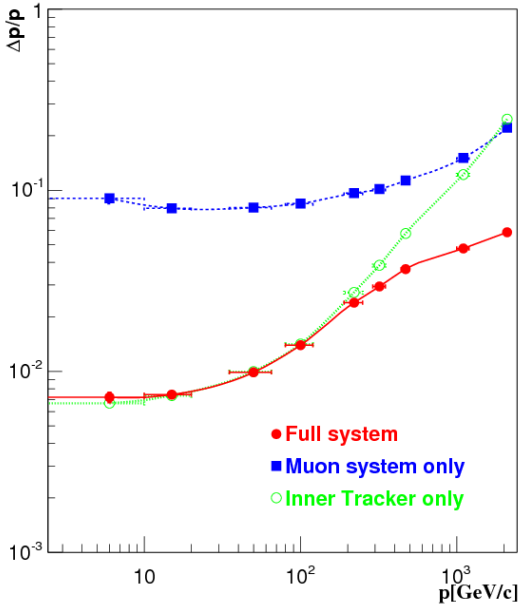
Backup

The Compact Muon Solenoid Detector (CMS)



- **Muon System:**

  →10% up to a 1 TeV Muon (in μ system only)



- **HCAL (Brass,Scintillator, 10λ_i):**

$$\frac{\sigma E}{E} = \frac{100\,\%}{\sqrt{E[\,\mathrm{GeV}]}} \oplus 4.5\,\%.$$

→10% for a single 100 GeV $\pi^{+/-}$

- **Track Detector (Pixel/Strips):**

$$\frac{\sigma p_T}{p_T} \simeq (15 \cdot p_T[\,\mathrm{TeV}] \oplus 0.5)\%$$

→ 0.5% for a 10 GeV Track of a charged particle

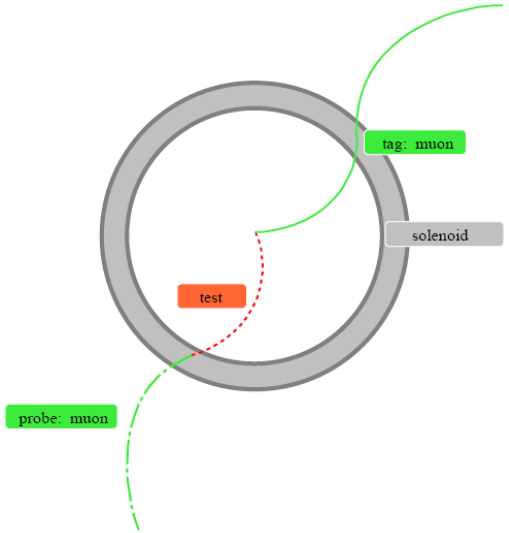
- **ECAL ($PbWO_4$, $28X_0$):**

$$\frac{\sigma E}{E} = \frac{(2.8 \pm 0.3)\,\%}{\sqrt{E[\,\mathrm{GeV}]}} \oplus \frac{0.124\,\mathrm{GeV}}{E} \oplus 0.3\,\%.$$

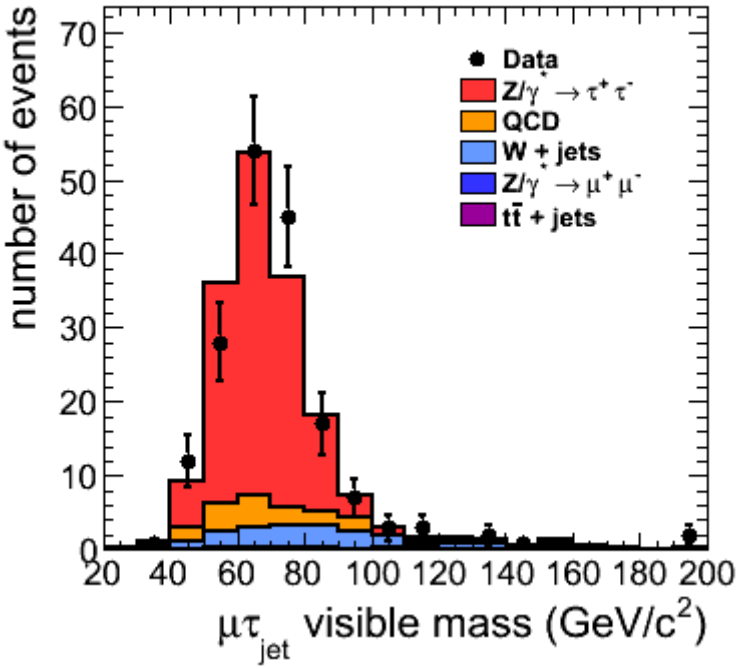
→1% for a 30 GeV e/γ

Estimate of τ-ID Efficiency from Tag & Probe

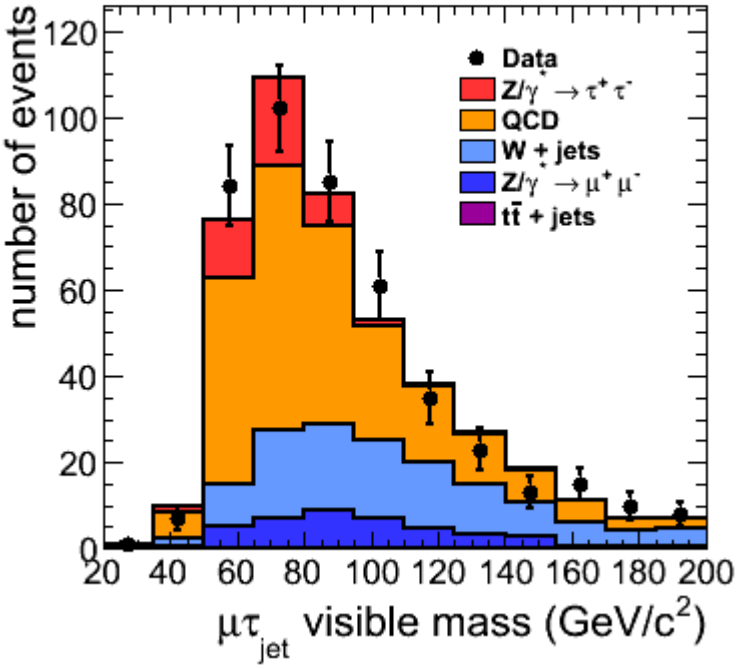
- Use Tag & Probe Method with Z→μτ events
- Detemine true number of τ leptons from template fit to visible mass



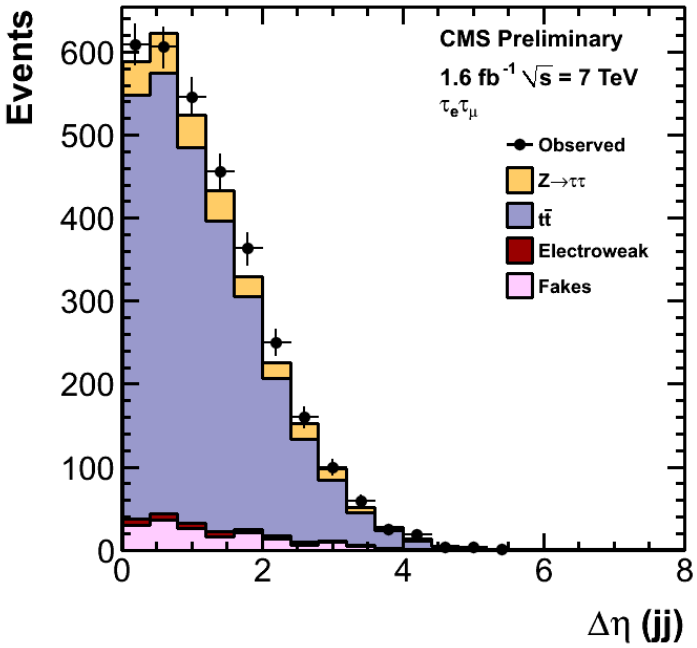
Passed

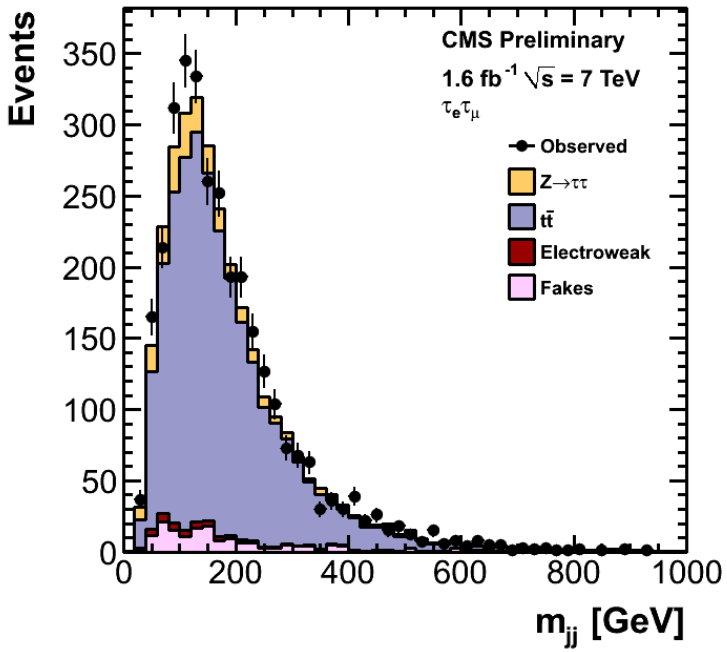


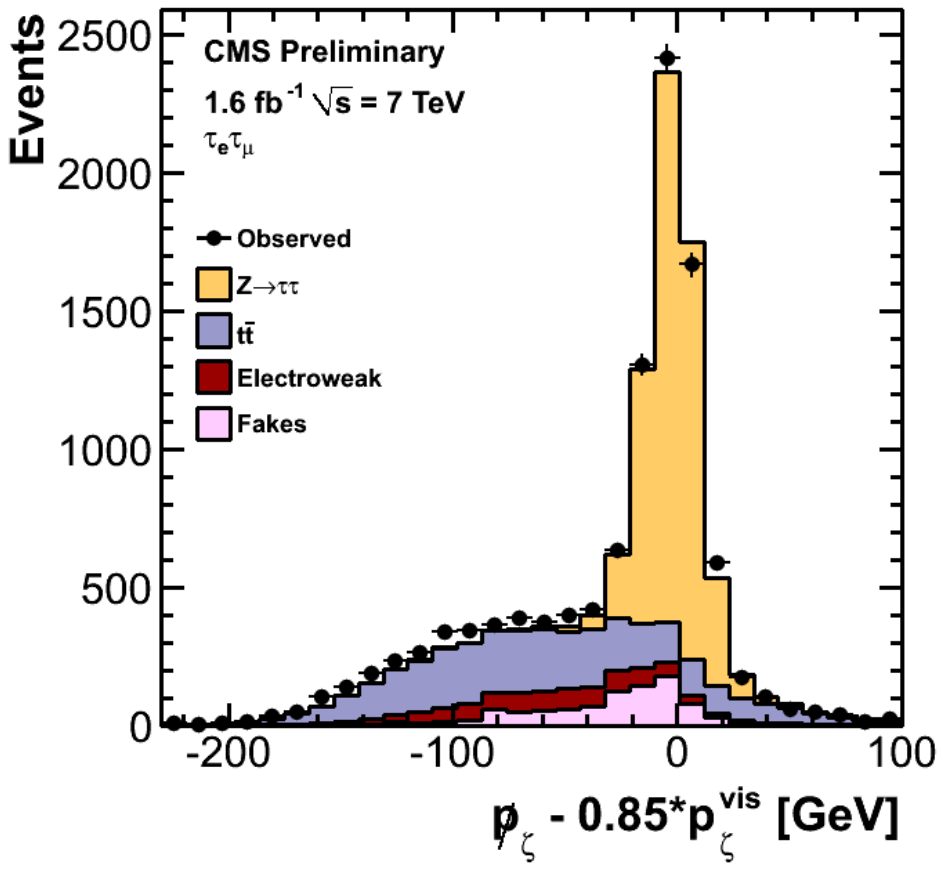
Fail



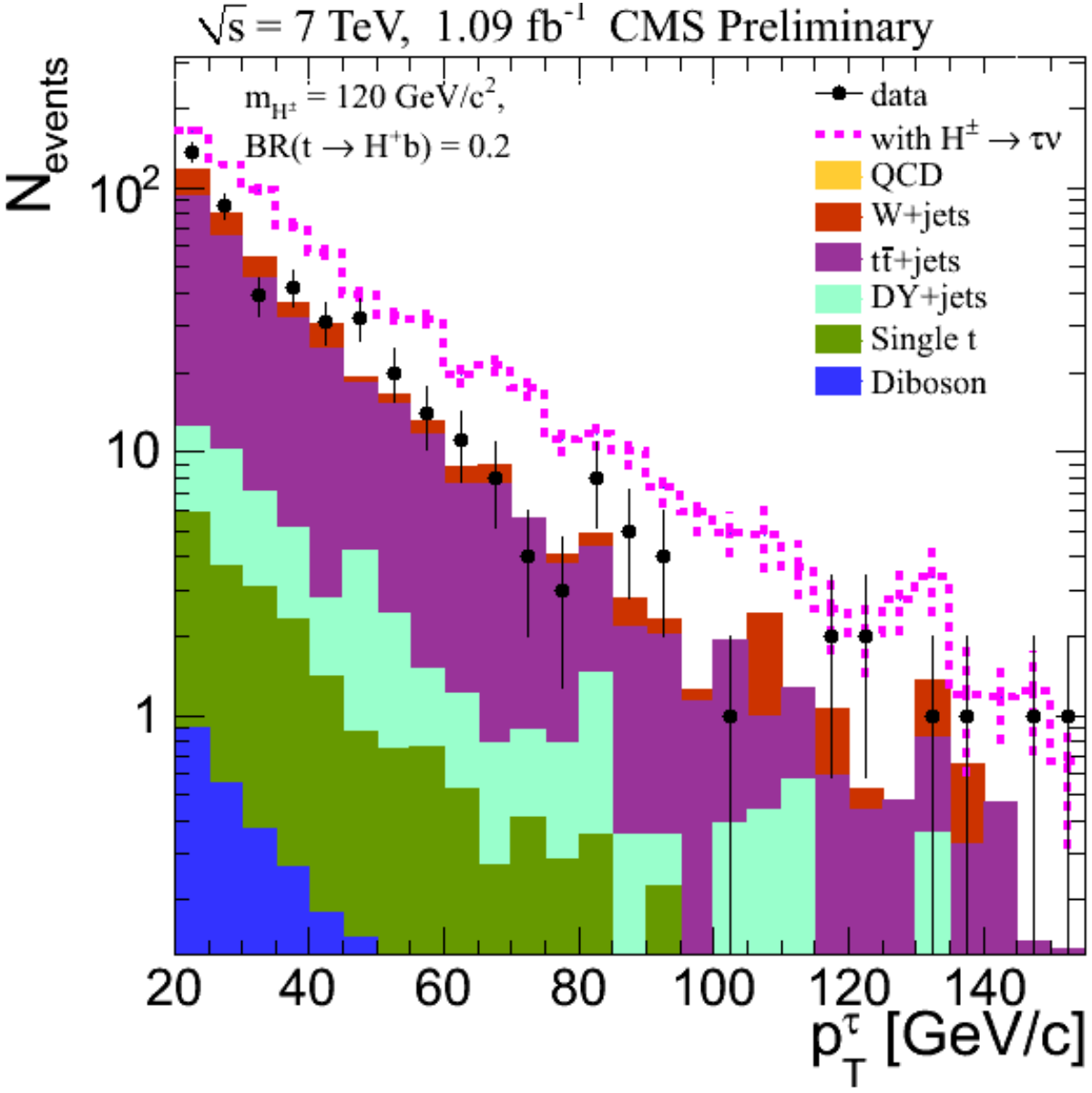
Control Distributions for $\phi \rightarrow \tau\tau$



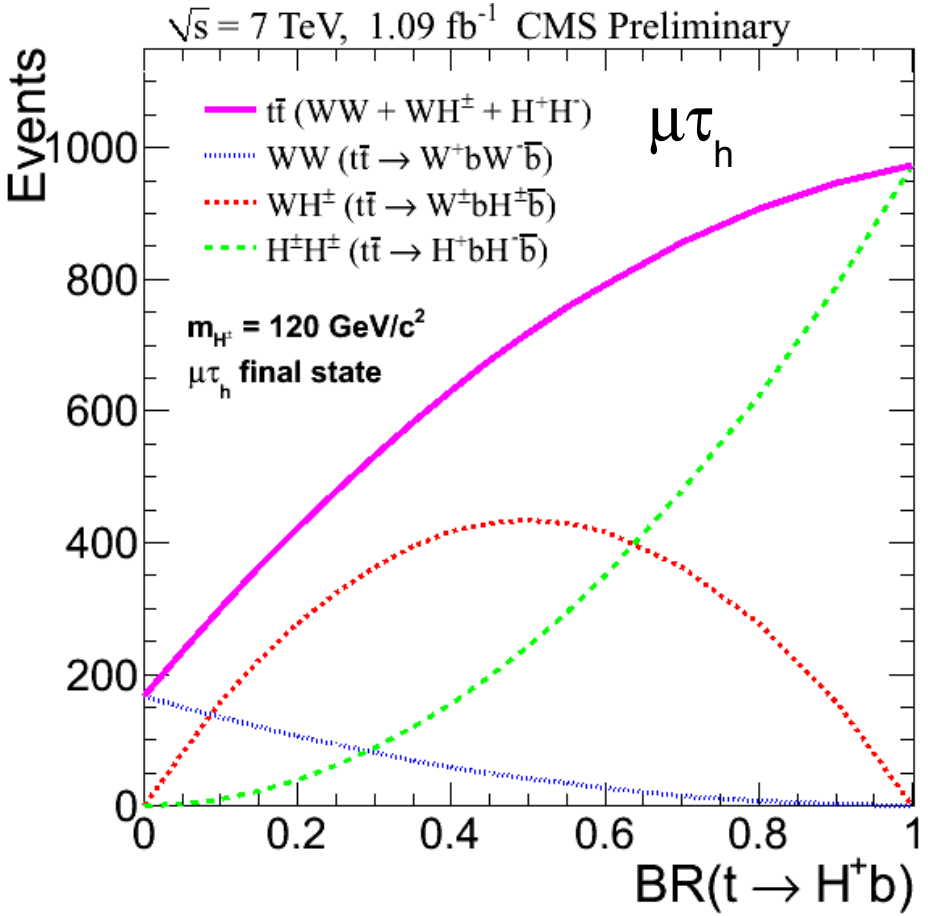


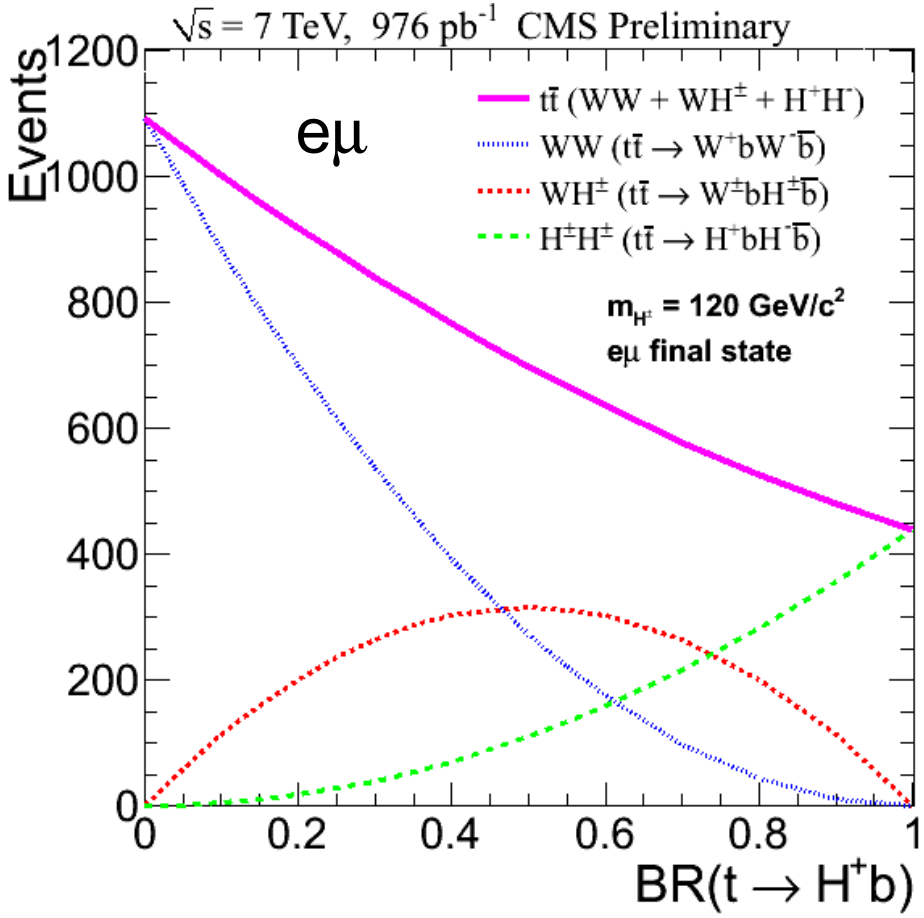


Control Distribution for $t \rightarrow H^+b$

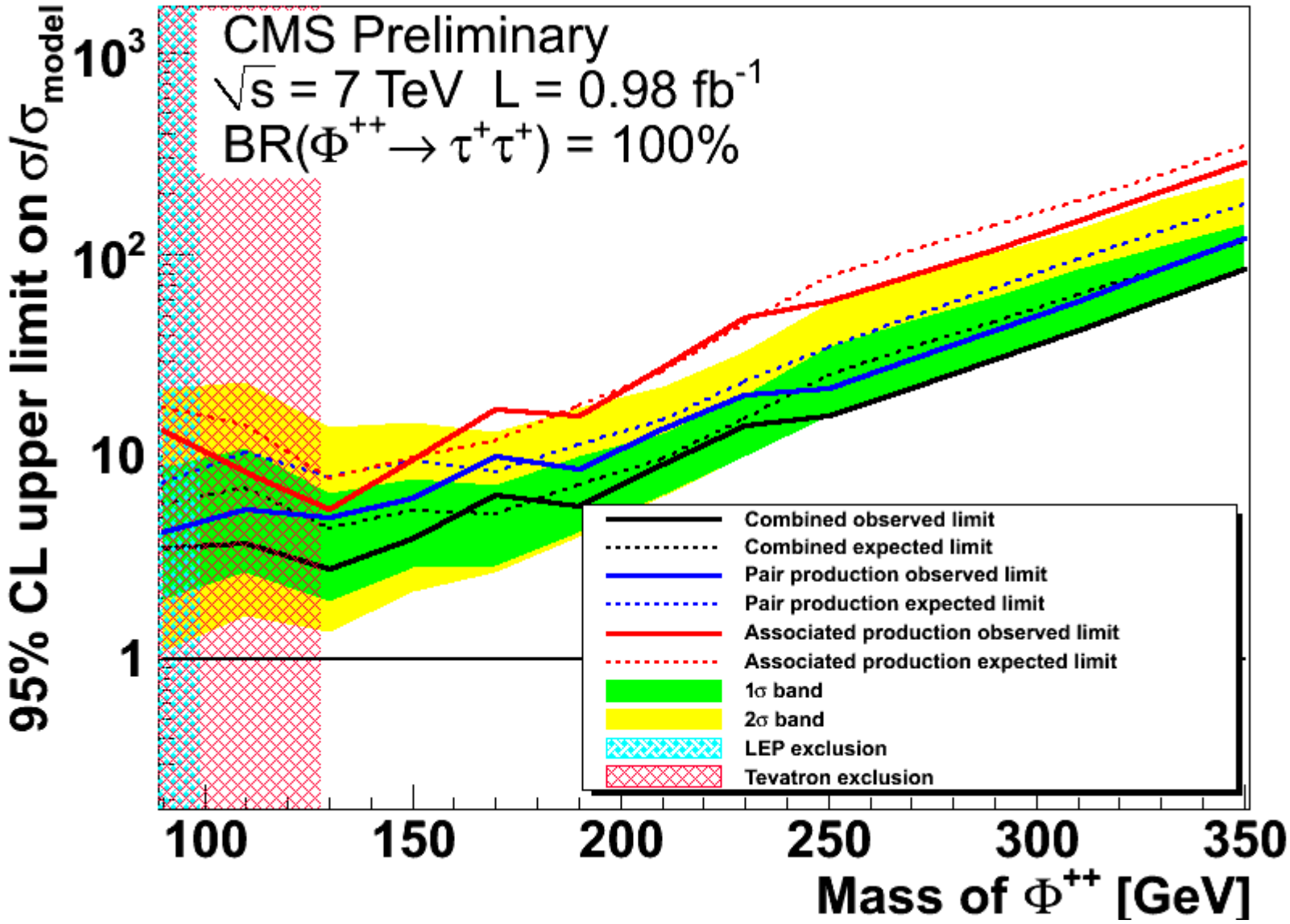


Event Composition as a function of BR(t→H⁺b)





Limits on H^{++} in the $\tau\tau$ Final State



$Z \rightarrow \tau\tau \rightarrow \mu\tau$ at CMS