Higgs searches in TauTau final states @ LHC

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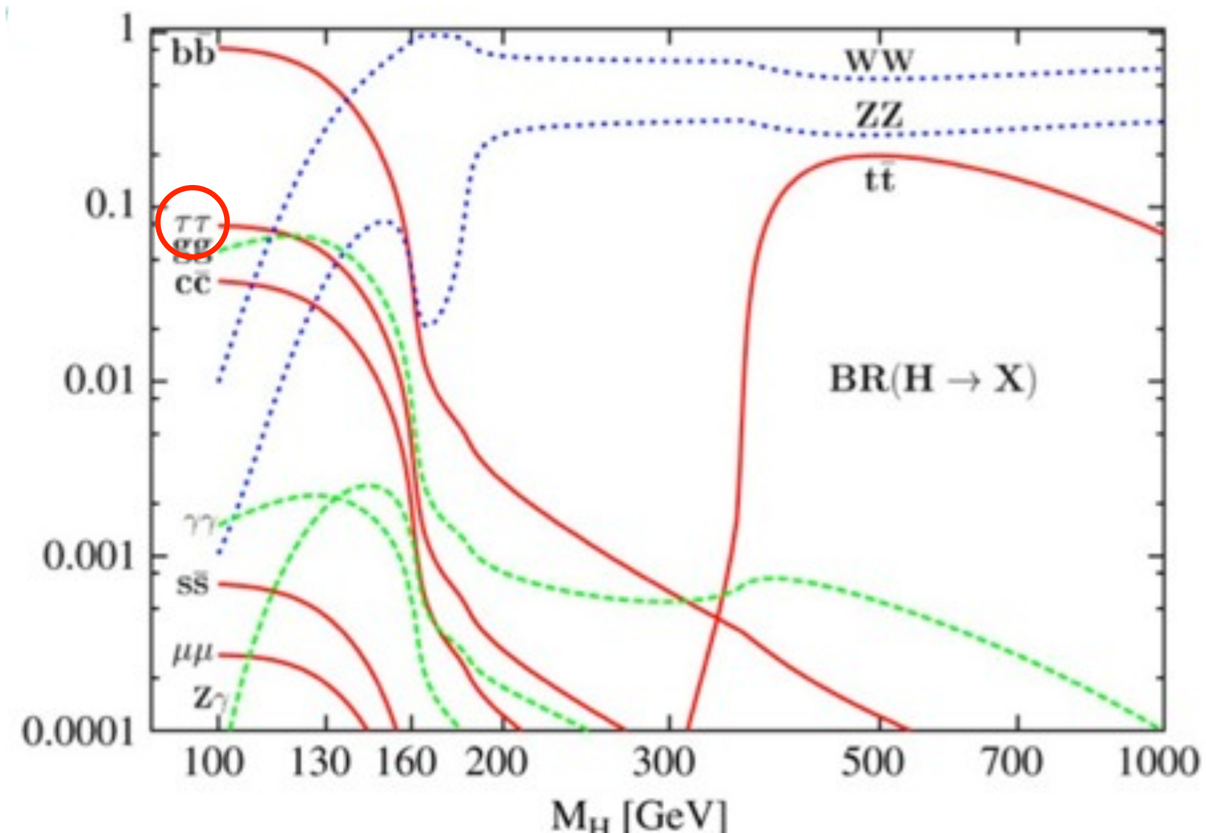
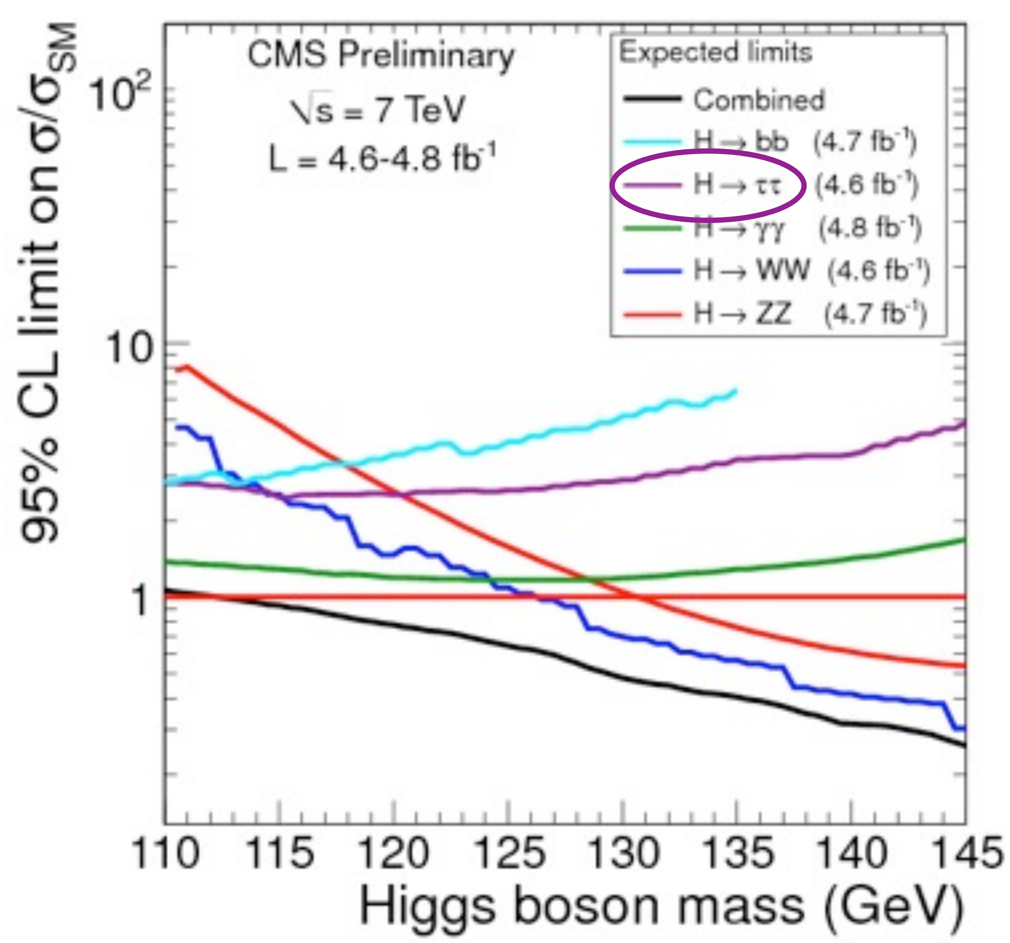
Mini-workshop Higgs Search at LHC
Frascati, March 28th, 2012

Motivations

- Why looking at H->TauTau?
  - second highest BR (after bb)
  - not-so-bad S/B ratio
    - improved S/B splitting analysis in various categories
  - one of the most powerful channel in the low mass region
  - sensitive to BSM physics





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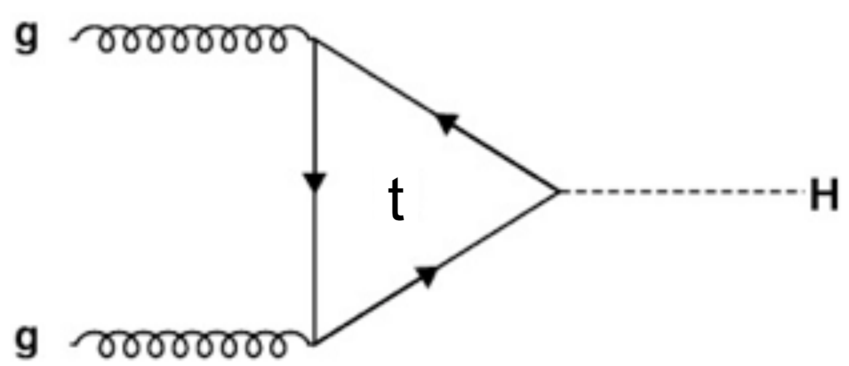
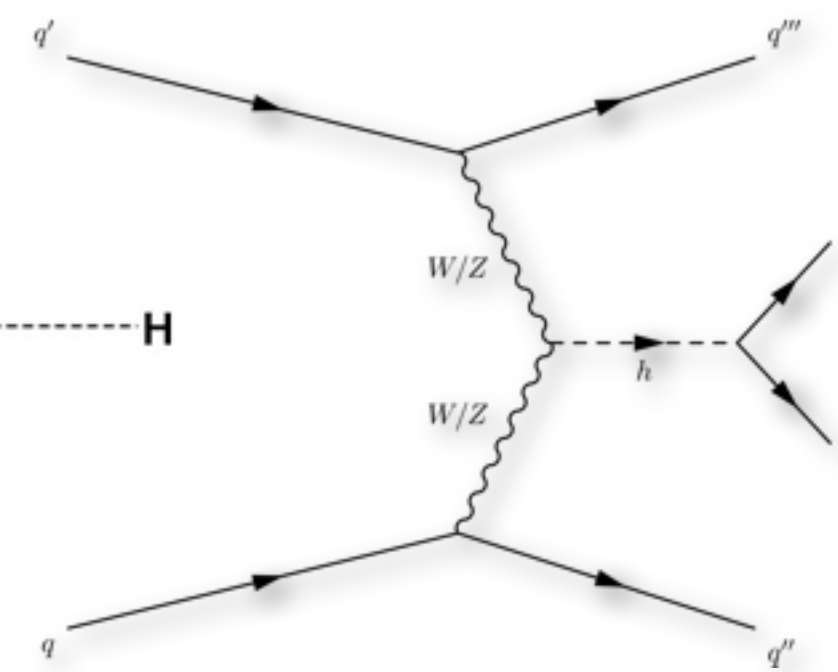
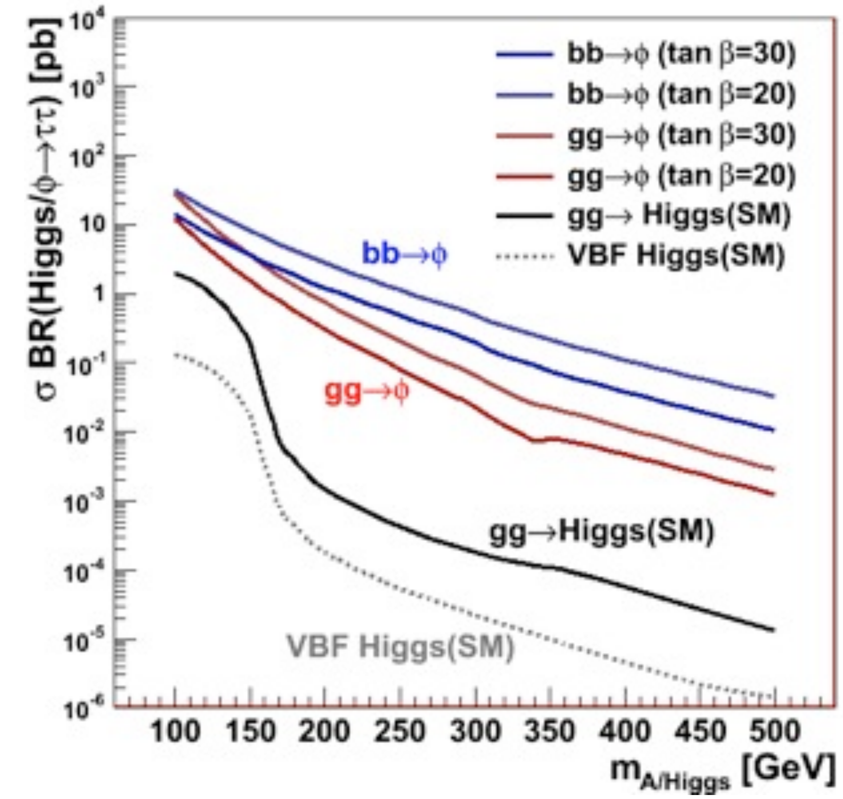
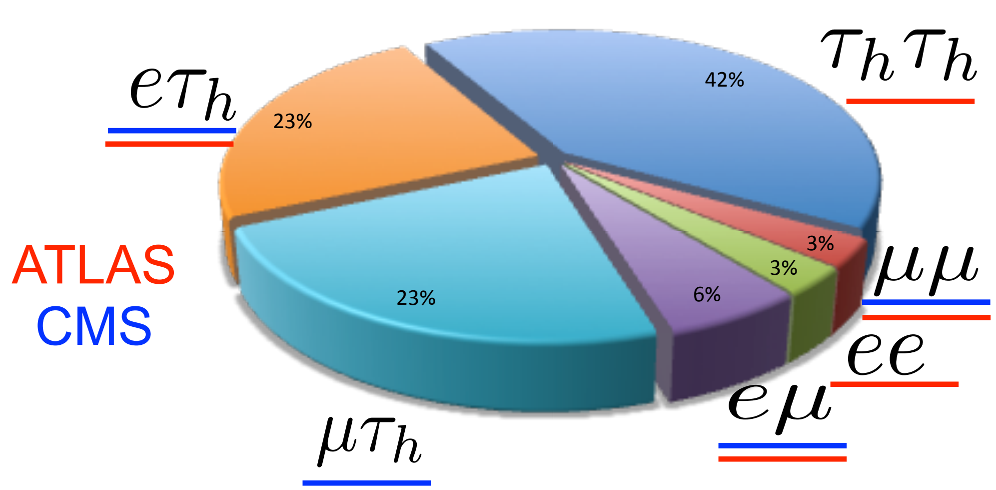
Higgs Production







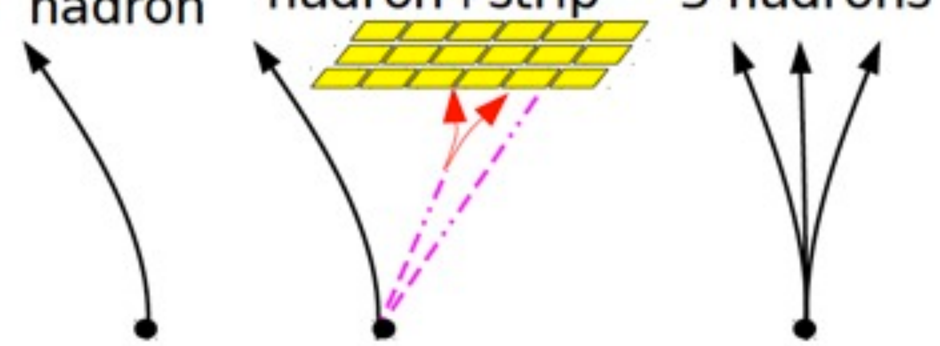
TauTau final states

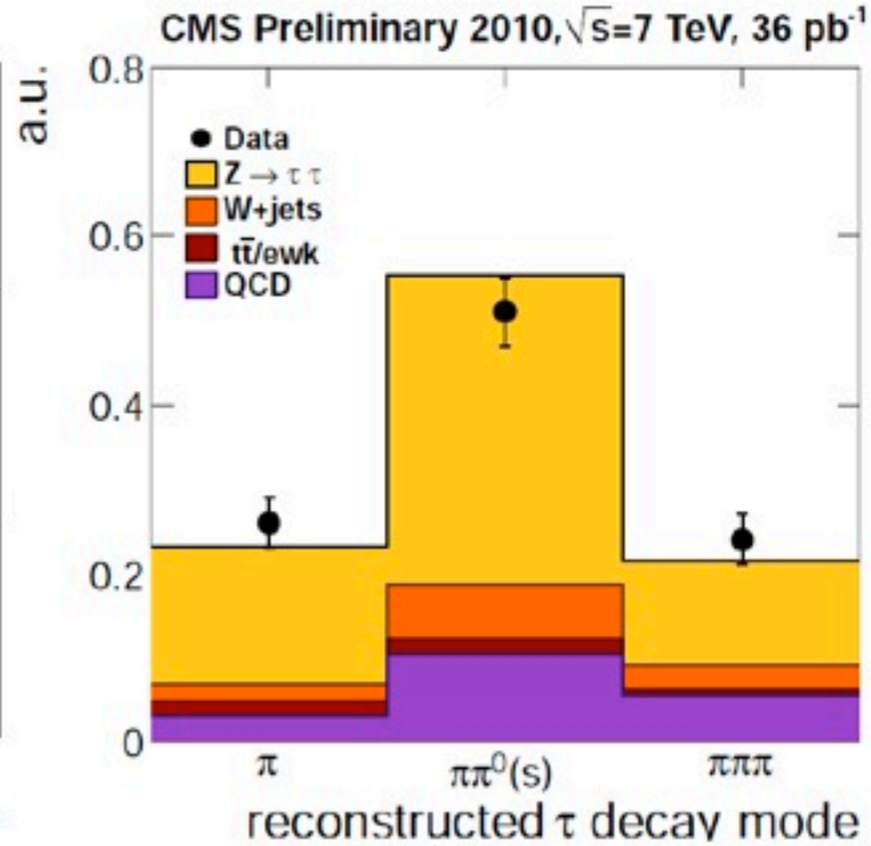


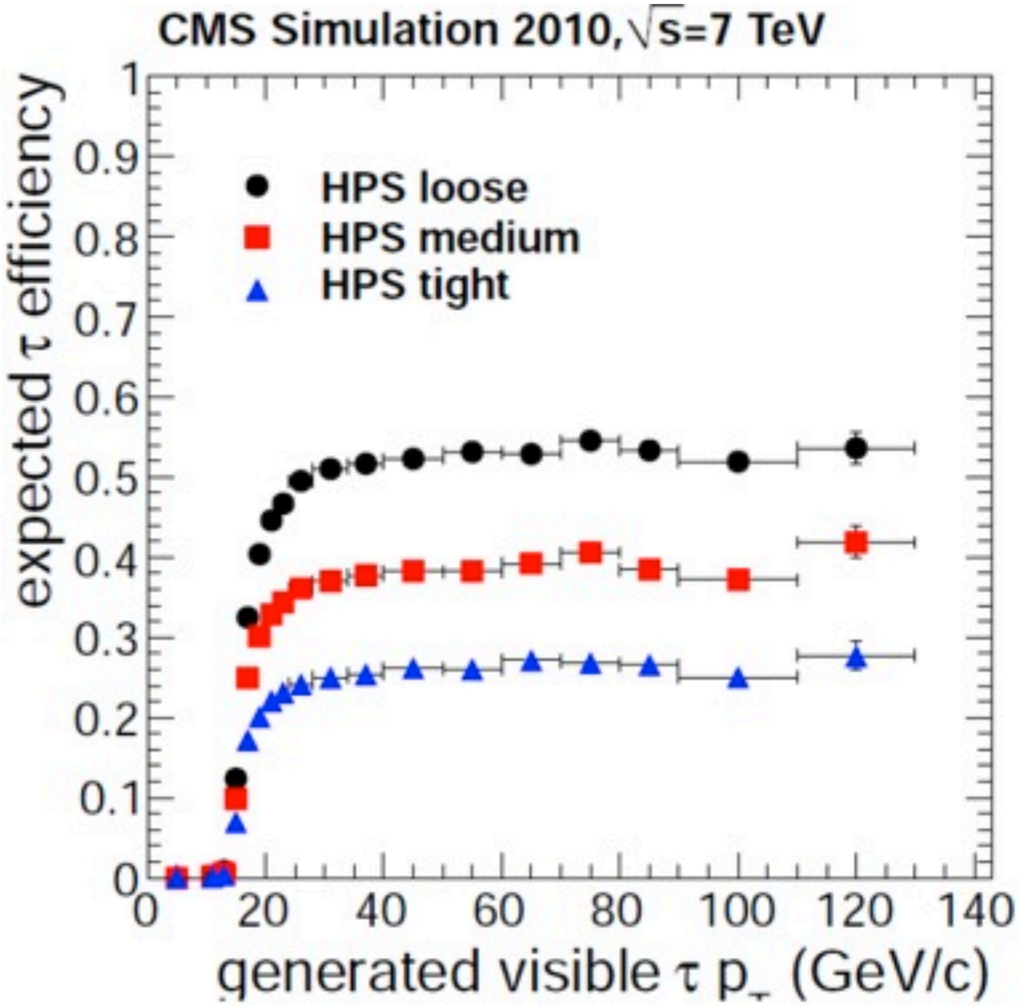
ATLAS presented only SM search
CMS also produced a MSSM limit

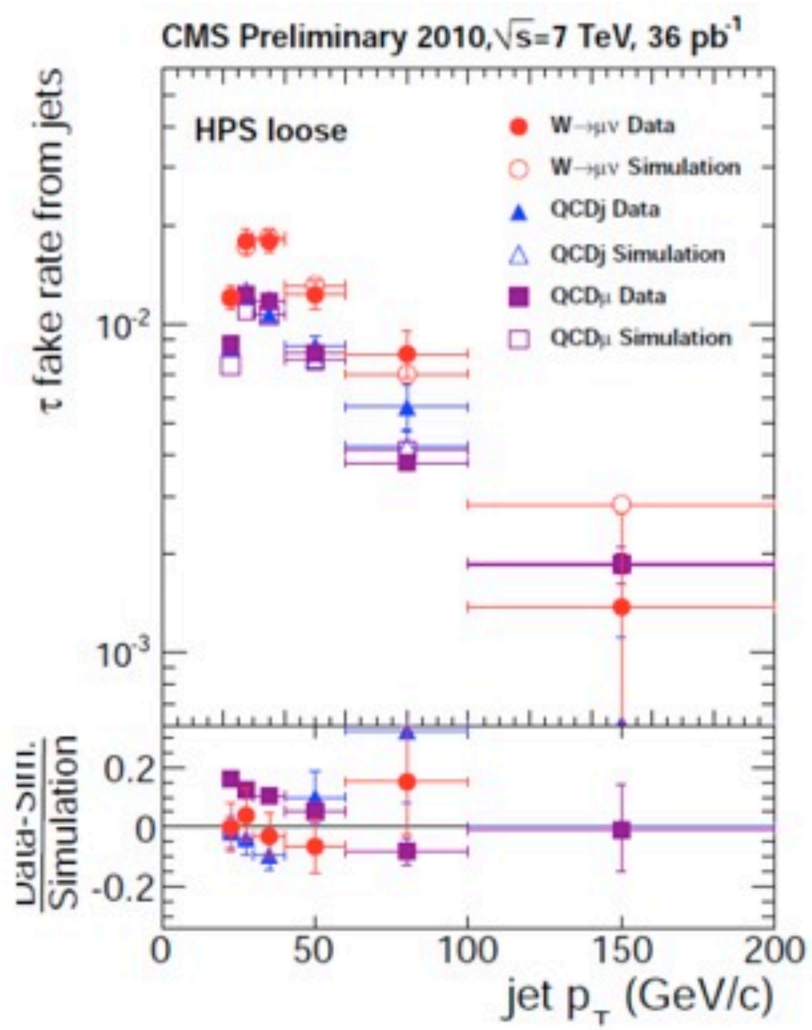
CMS Tau ID

- Reconstruction of the decay modes :
  - 1 prong, 1 prong + pi0's, 3 prongs
- Various working points for isolation
- additional selections to reject electrons and muons



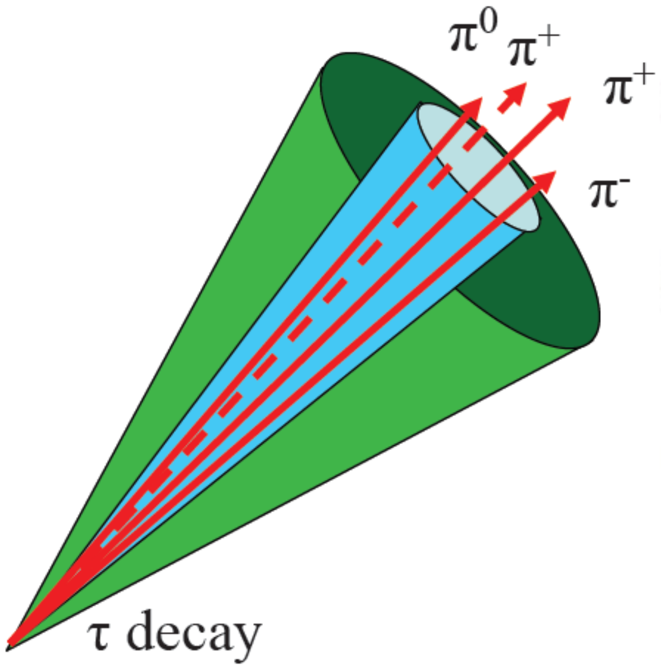


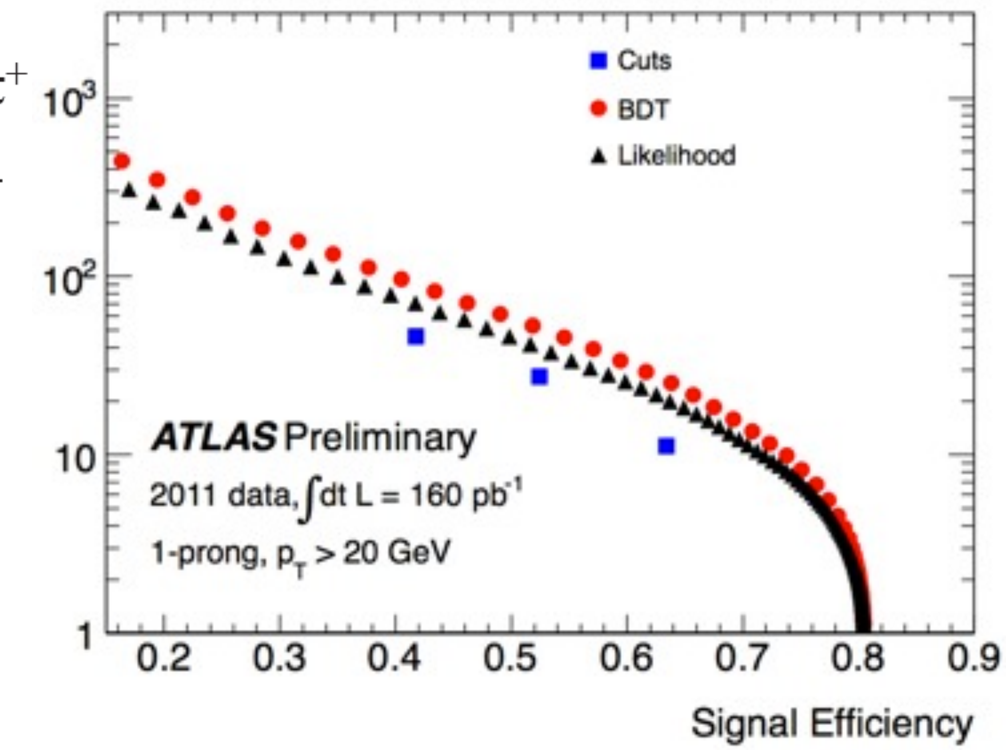


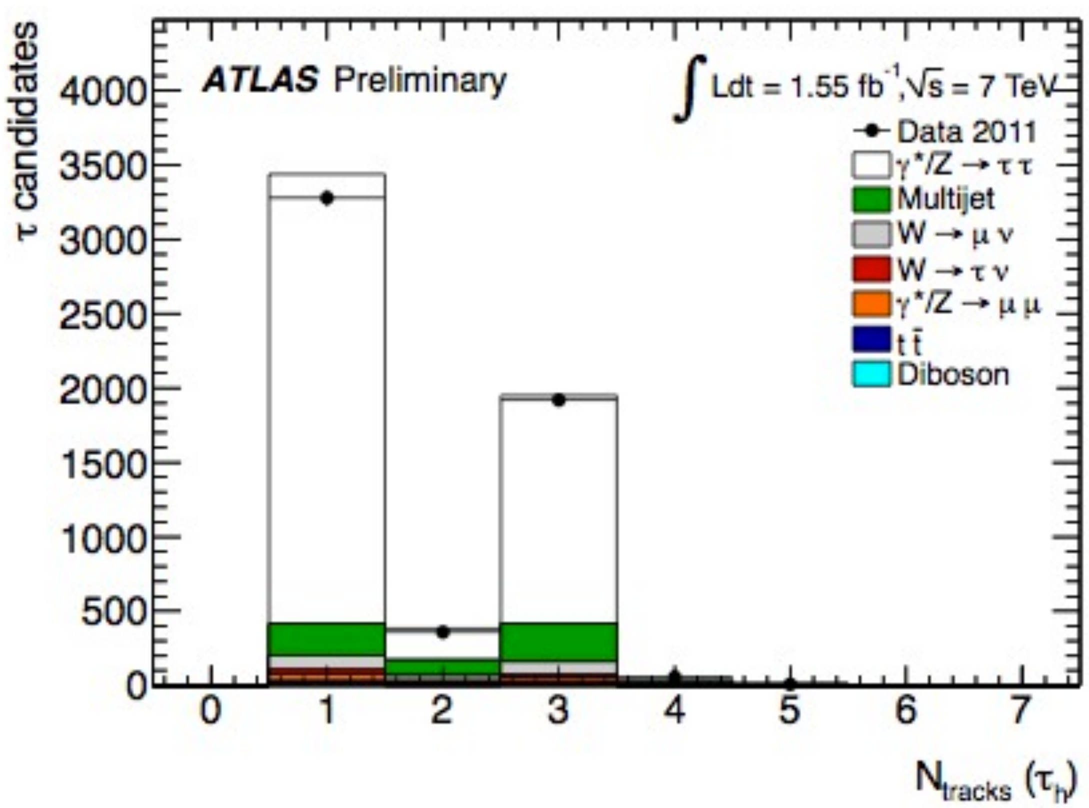


ATLAS Tau ID

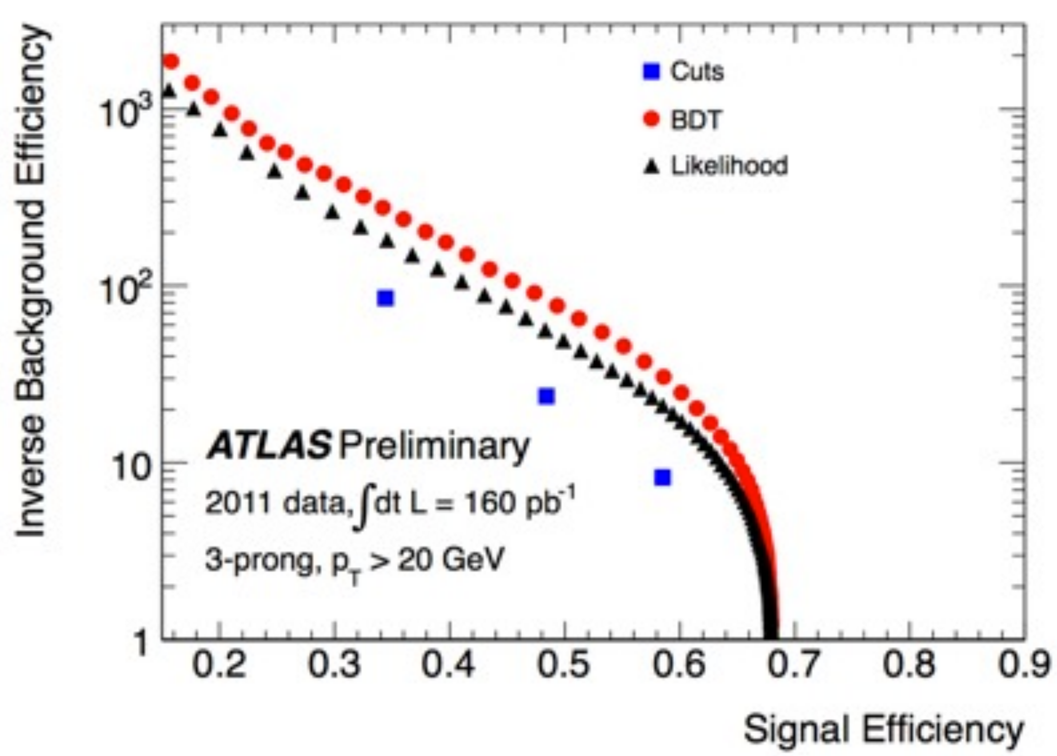
- BDT based tau identification
  - variables build from track and calorimeter deposits
    - three working points as for CMS



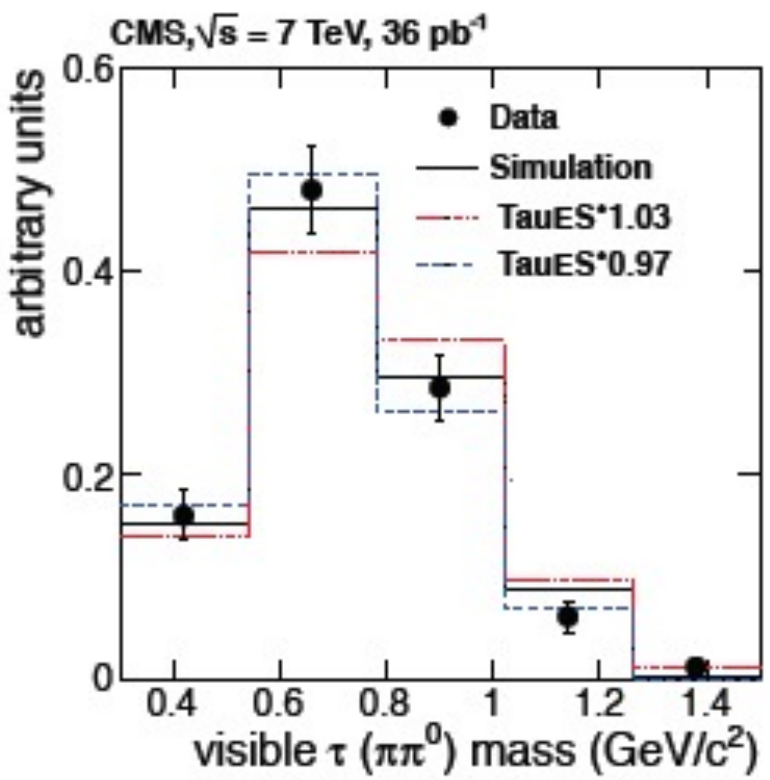


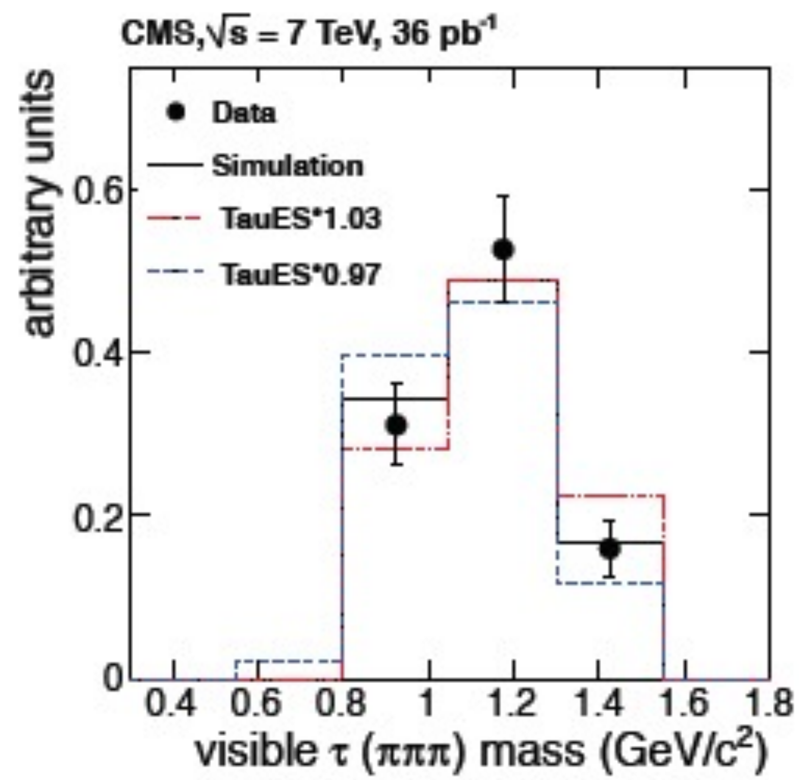


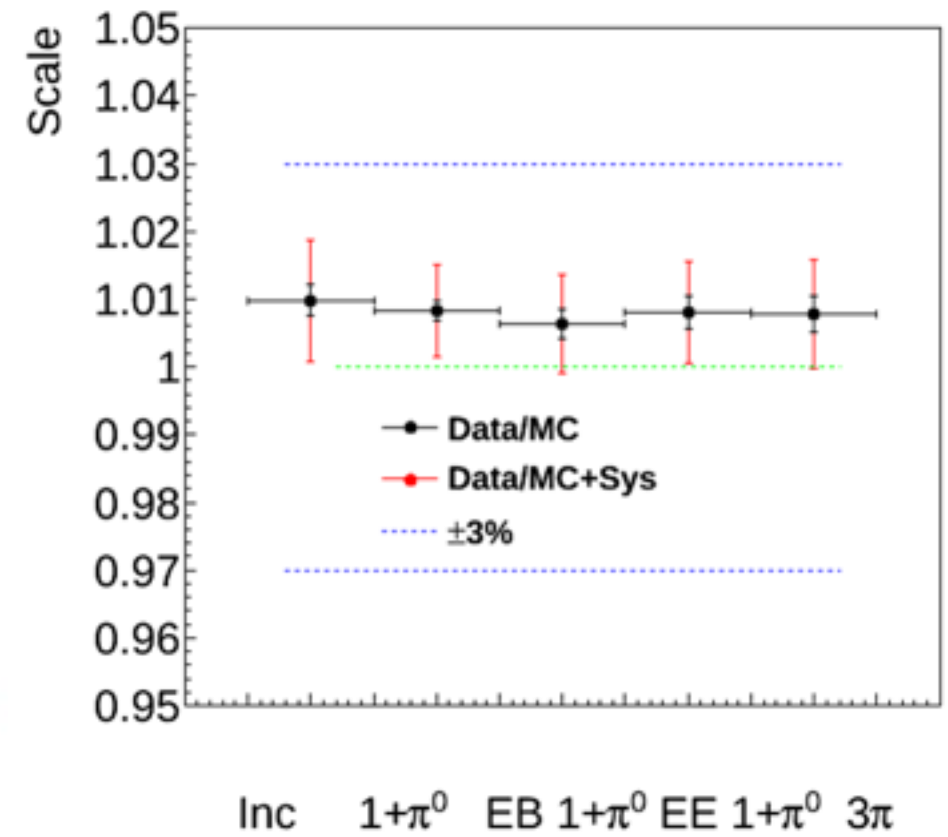
(a) $\tau_\mu \tau_h$ channel

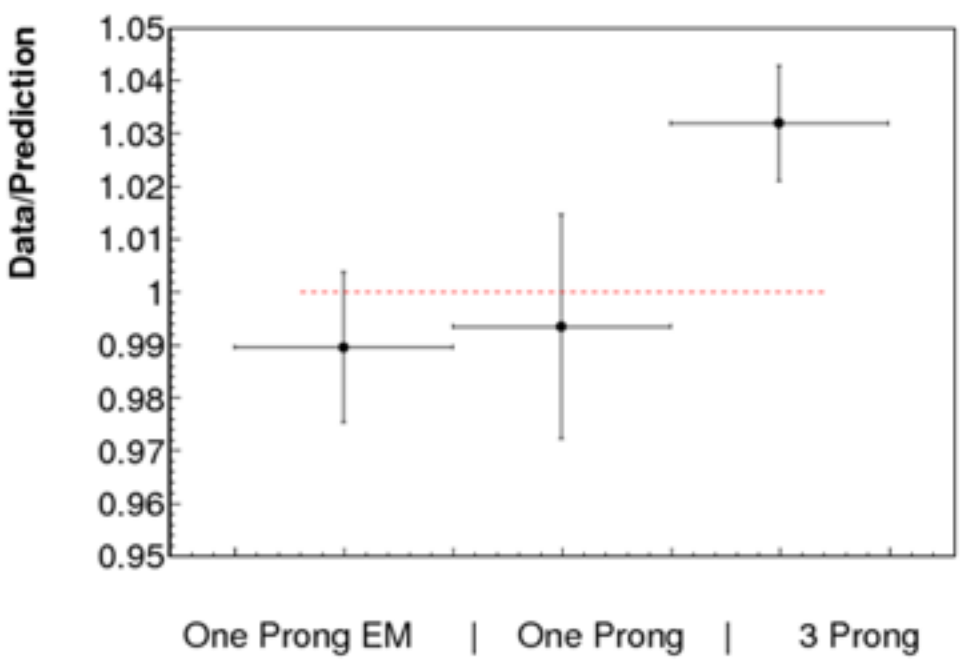


Tau energy scale









- the tau invariant mass has been used to quantify the tau energy scale uncertainty
  - comparing the data to the simulation
- The results validates the 3% uncertainty from the previous study

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Analysis: CMS Vs ATLAS

- CMS
  - better tau ID
    - better bkg rejection
  - MET used only in topological variable and mass reconstruction
  - 1 jet bin with very high pT threshold
  - Full mass reconstruction with the same algorithm for all final states
  - Limit also in the MSSM
- ATLAS
  - better calorimeter trigger
    - making tau_h tau_h possible
    - MET used to reduce QCD
      - and in category definition
    - 1 jet bin with low-ish pT threshold
    - Full mass reconstruction algorithm depends on the final state
    - full hadronic final state included

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Lepton Selections

CMS

l+tau

lepton pT > 20 GeV
(17 muon)
|eta| < 2.1
tau pT >20 GeV
|eta| < 2.3

mu+ele

lead pT > 20 GeV
sub-lead pT >10 GeV
|eta_e| < 2.3
|eta_mu| < 2.1

mu+mu

lead pT > 20 GeV
sub-lead pT >10 GeV
|eta_1st| < 2.1
|eta_2nd| < 2.4

ATLAS

l+tau

lepton pT > 25 GeV
(20 muon)
|eta| < 2.5
tau pT >20 GeV
|eta| < 2.5

l+l

ele pT > 15-24 GeV
muon pT > 15-20 GeV
|eta| < 2.5

tau+tau

lead pT > 35 GeV
sub-lead pT >25 GeV
|eta| < 2.5

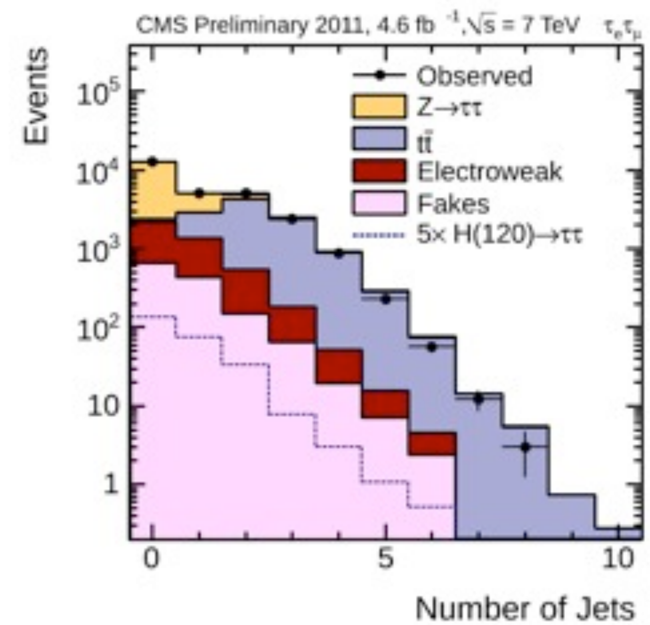
CMS Event Categorization

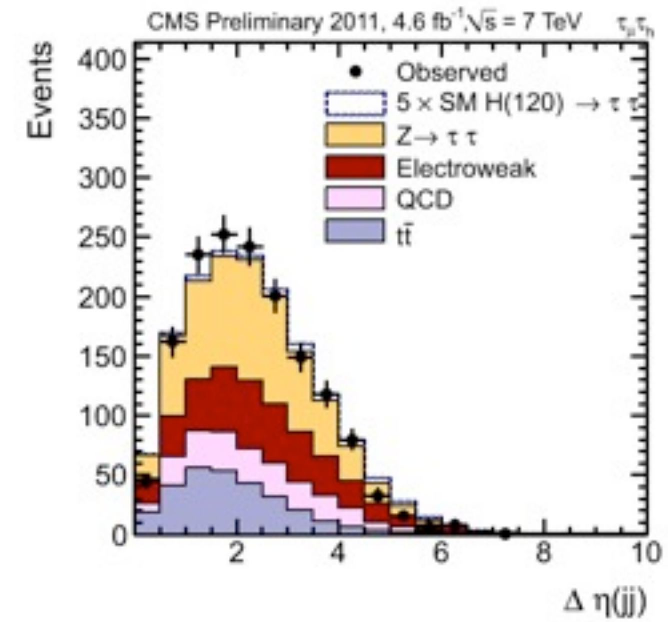
- three categories to have enriched signal-to-background ratio and maximize the sensitivity
  - Signal extraction based on fit to the full reconstructed mass

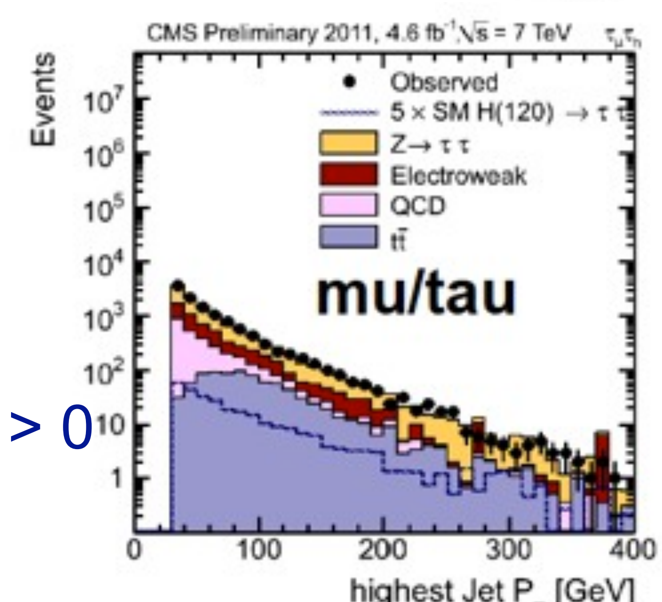
0/1 jet
Jets (pT > 30 GeV) < 2 &&
jet pT < 150 GeV

VBF
Jets (pT > 30 GeV) = 2 &&
central jet veto &&
VBF selections*

Boosted
Jets (pT > 150 GeV) > 0 &&
No VBF selections*







* VBF selectionsL:
pT jet > 30 GeV
Mjj>400 GeV
DeltaEtajj > 4, eta_j1 * eta_j2 > 0

ATLAS Event Categorization

- Categorization depends on the final state
  - Signal extraction based on fit to the full reconstructed (MMC or collinear approximation) or effective mass
  - Missing ET cut used in the event selections

l+l
VBF* ,VH(2jets), (0 jet only for e-mu), 1jet (pT >40 GeV)
Collinear approx is used to reconstruct the full mass
(Effective mass in the H+0 jets)

l+tau
VBF*, 0 jet, 1jet (pT >25 GeV)
0 jet category is split into MET <20 and MET > 20 GeV
MMC is used to reconstruct the full mass

tau+tau
1jet (pT >40 GeV)
Collinear approx is used to reconstruct the full mass

* Also the VBF selection depends on the final state.
pT > 30-25 GeV
Mjj>300-350 GeV
DeltaEtajj > 3, eta_j1 * eta_j2 > 0

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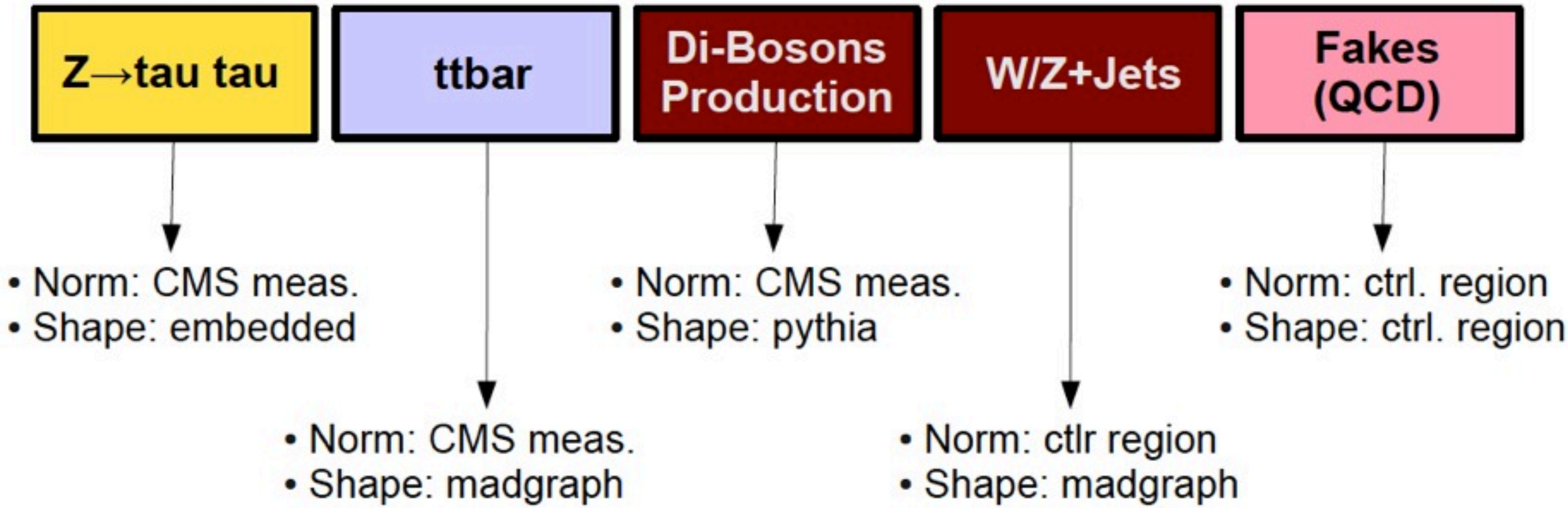
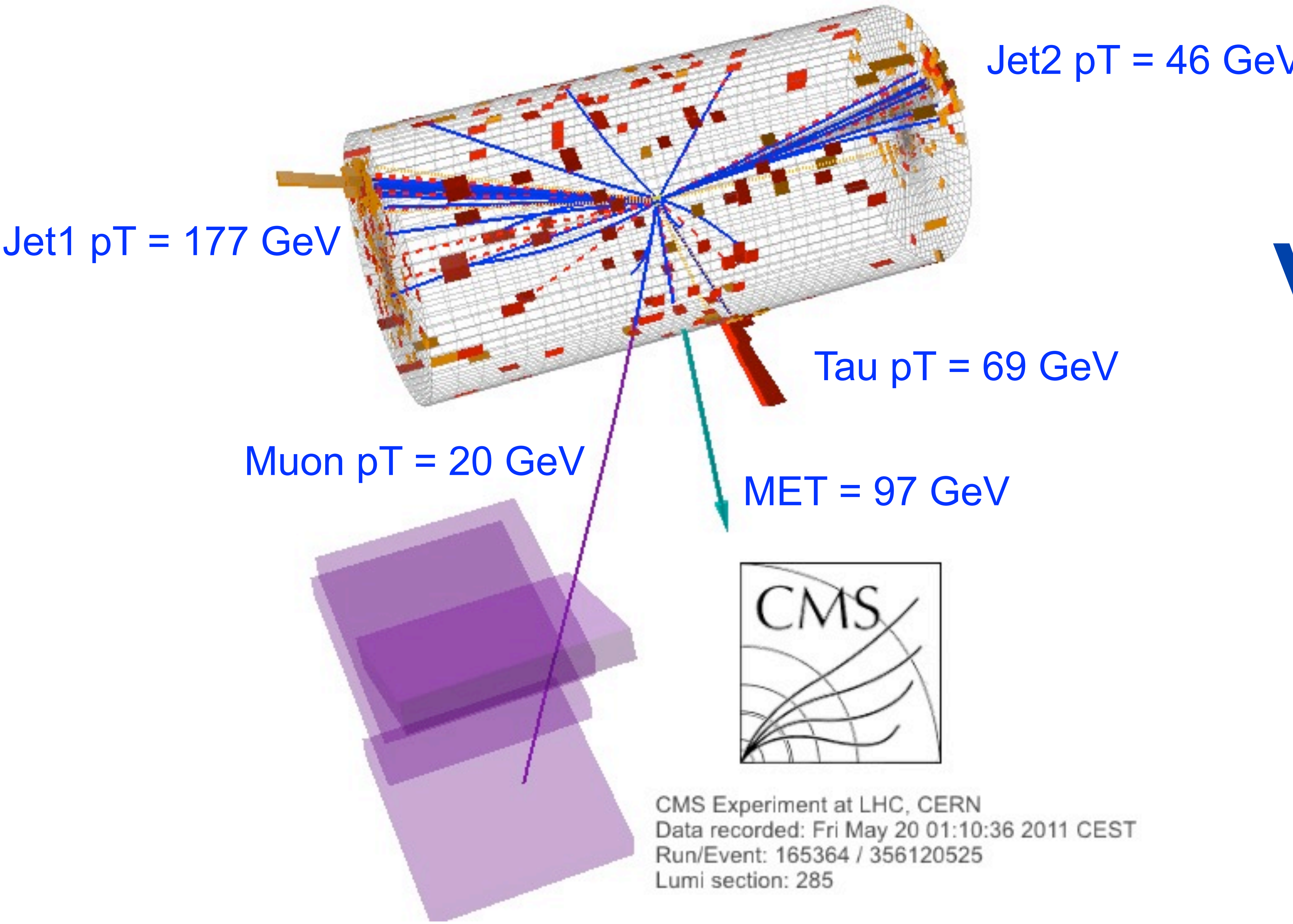
Background estimation

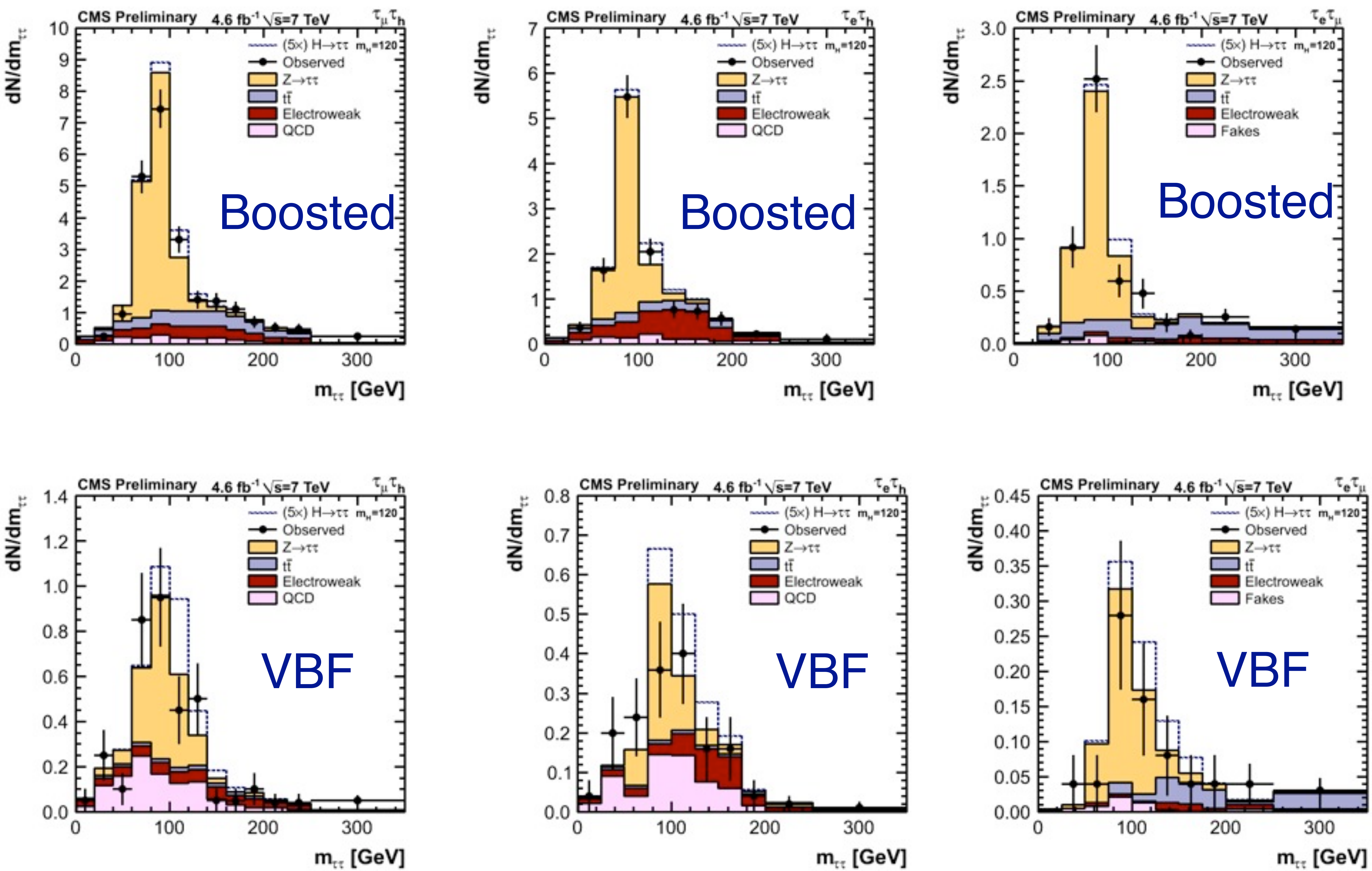


At least the normalization mostly also the shape of all backgrounds are estimated from data in one or the other way

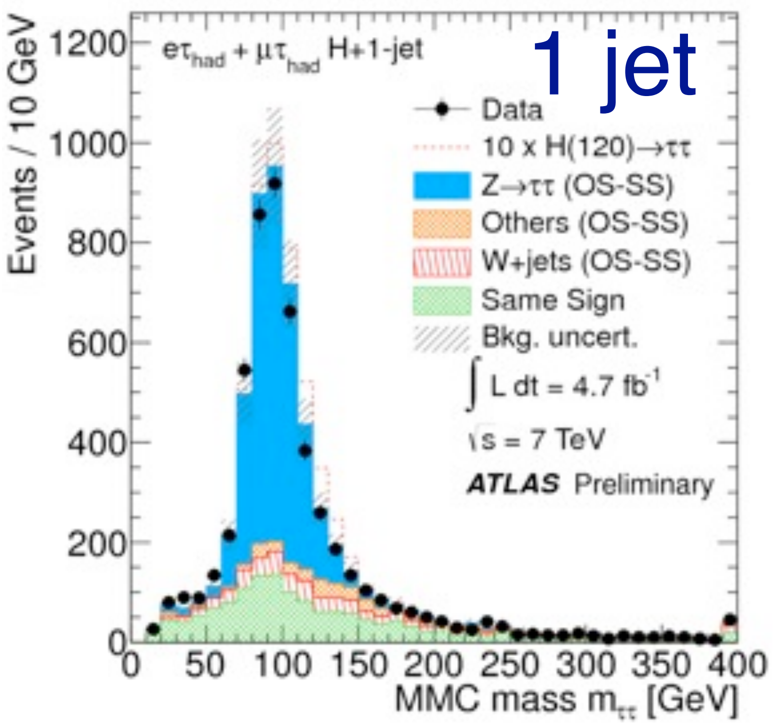
VBF

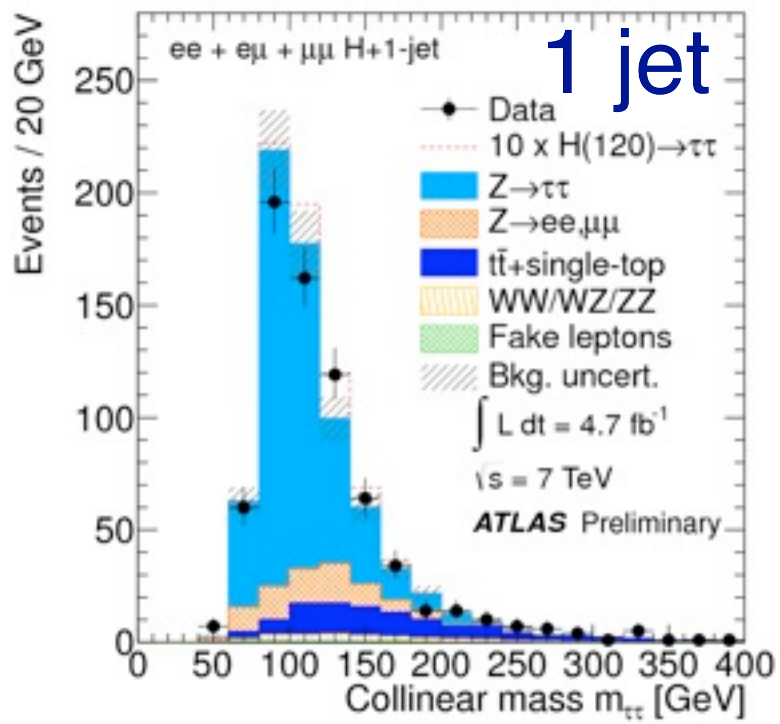

Jet2 pT = 46 GeV
Jet1 pT = 177 GeV
Tau pT = 69 GeV
Muon pT = 20 GeV
MET = 97 GeV
CMS
CMS Experiment at LHC, CERN
Data recorded: Fri May 20 01:10:36 2011 CEST
Run/Event: 165364 / 356120525
Lumi section: 285

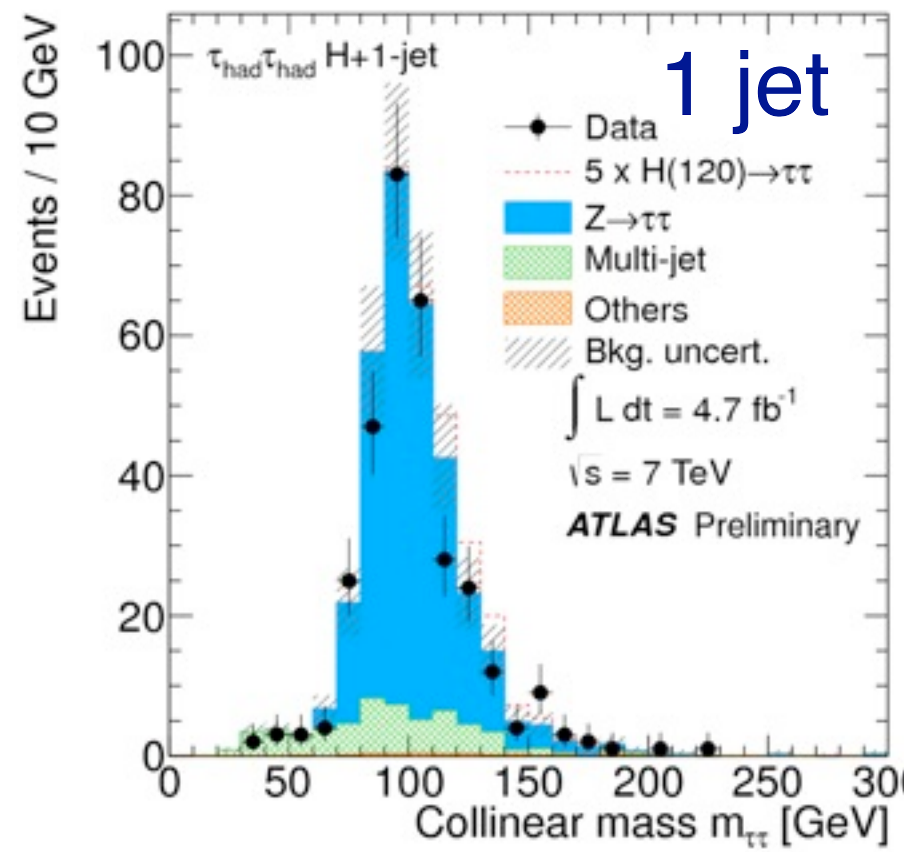
Mass distribution per channel

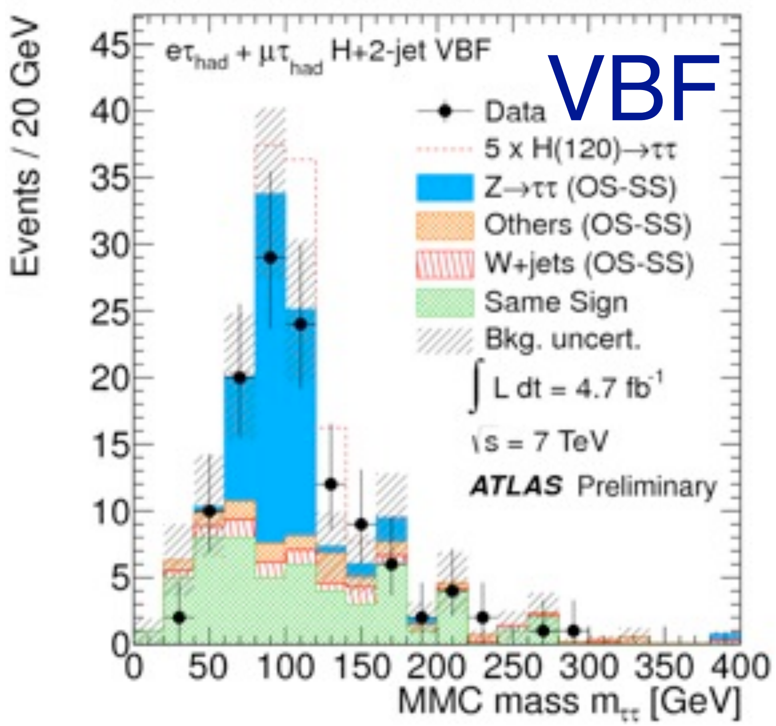


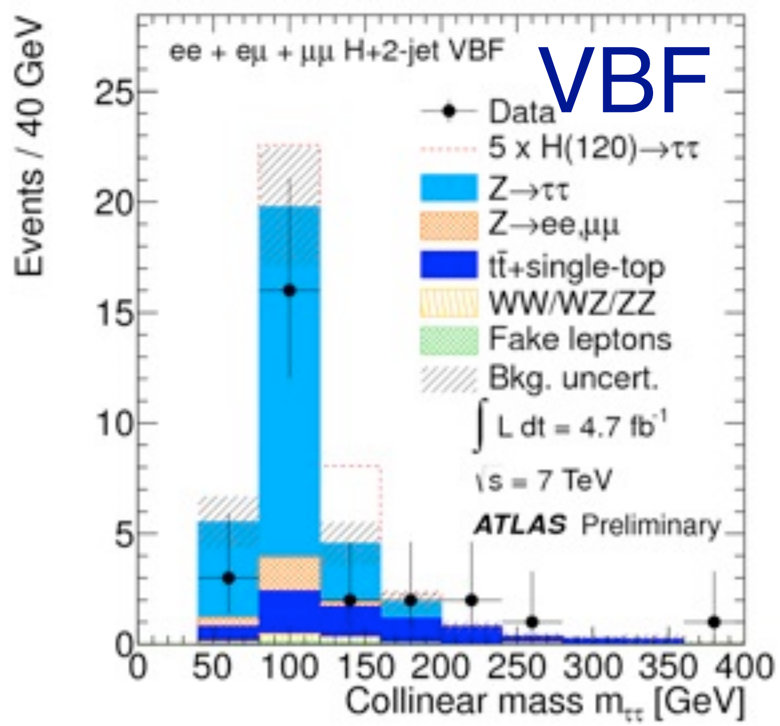
Few ATLAS Plots











Few numbers

m_H = 120 GeV

- CMS
  - mu-tau

	Standard Model		
Process	*0/1-Jet*	*Boost*	*VBF*
$Z \to \tau\tau$	28115 ± 1946	294 ± 21	35 ± 2
Fakes	7852 ± 141	36 ± 2	23 ± 2
W+jets	5834 ± 393	65 ± 4	9 ± 1
$Z \to ll$	755 ± 95	5 ± 1	1.0 ± 0.2
$t\bar{t}$	143 ± 15	91 ± 12	4 ± 1
Di-Boson	173 ± 54	9 ± 4	0.4 ± 0.4
Total Background	42872 ± 2644	500 ± 46	71 ± 7
$H \to \tau\tau$	93 ± 16	6.7 ± 1.6	3 ± 0.5
Data	43612	500	76

- ATLAS
  - mu-tau

Samples	0-Jet	1-Jet	VBF
$Z \to \tau\tau$	10710	1870	57
Total Background	14610	2790	122
$H \to \tau\tau$	28	14.1	< 3
Data	14481	2711	131

Treatment of systematics

- Overall normalization uncertainty
  - theoretical
  - sample normalization from control regions
  - luminosity uncertainty
  - Detector-related uncertainties
    - jet, MET and tau ES
    - data/MC scaling factors
- Shape systematics have been considered through a morphing technique

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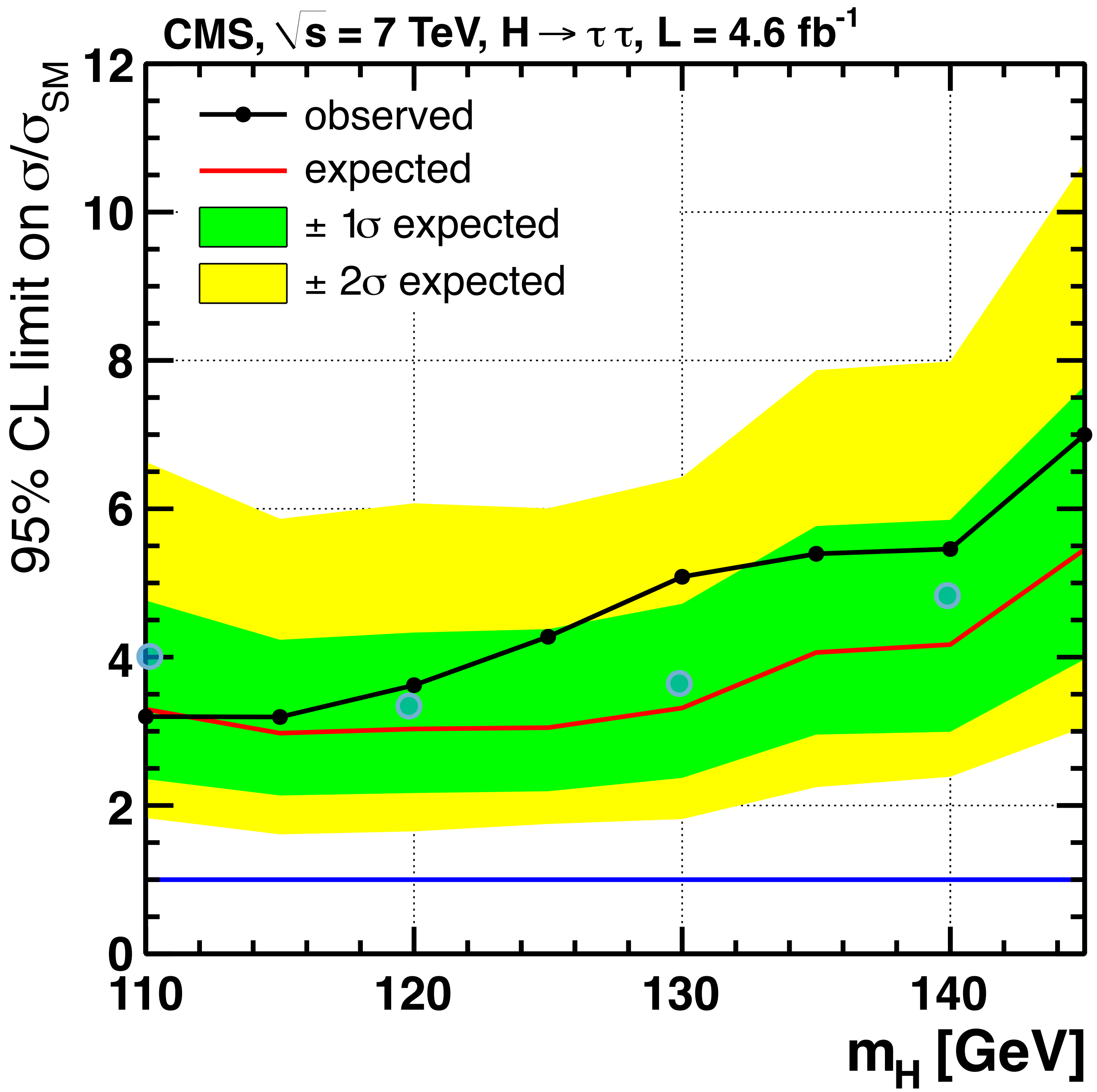
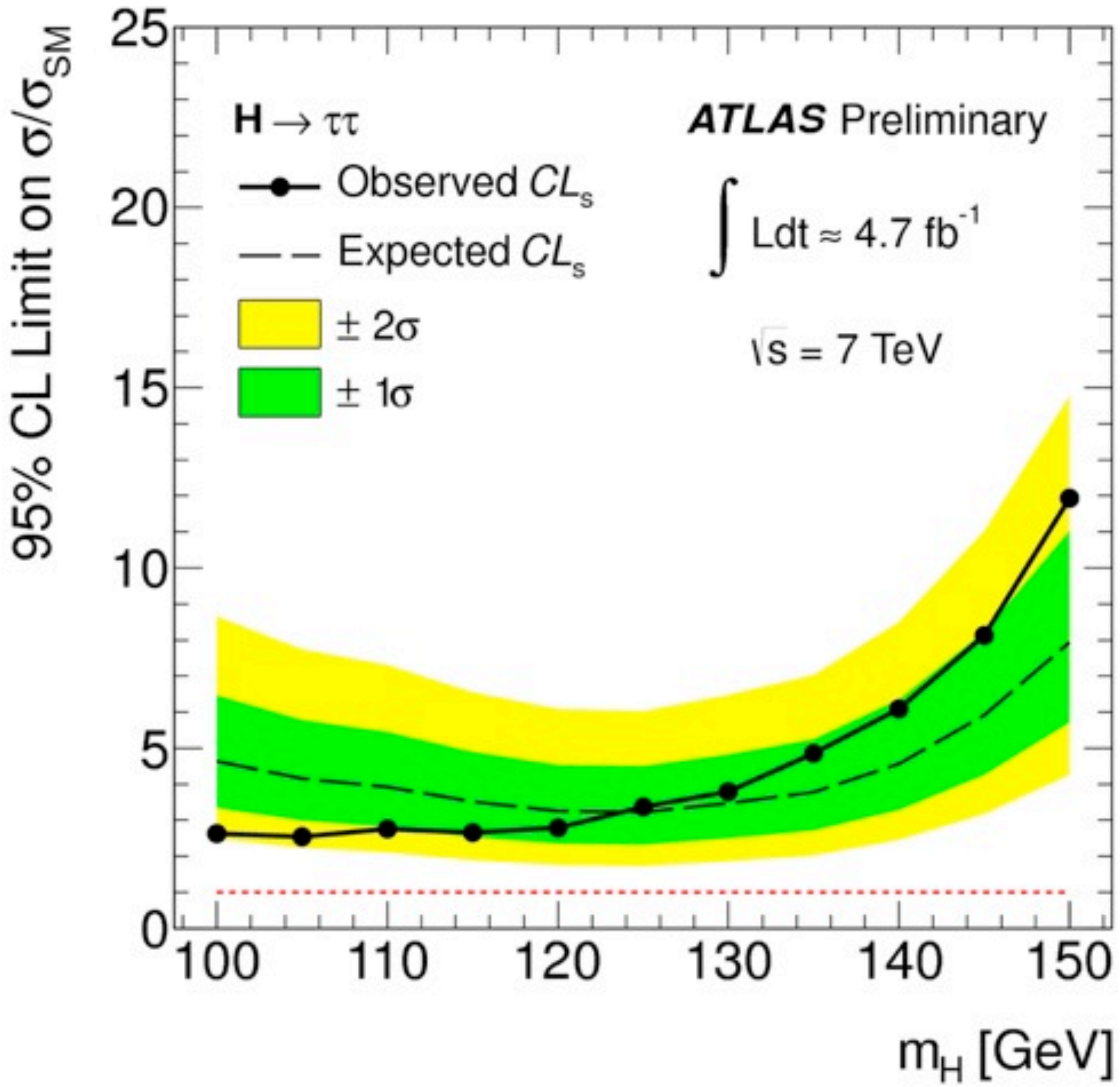
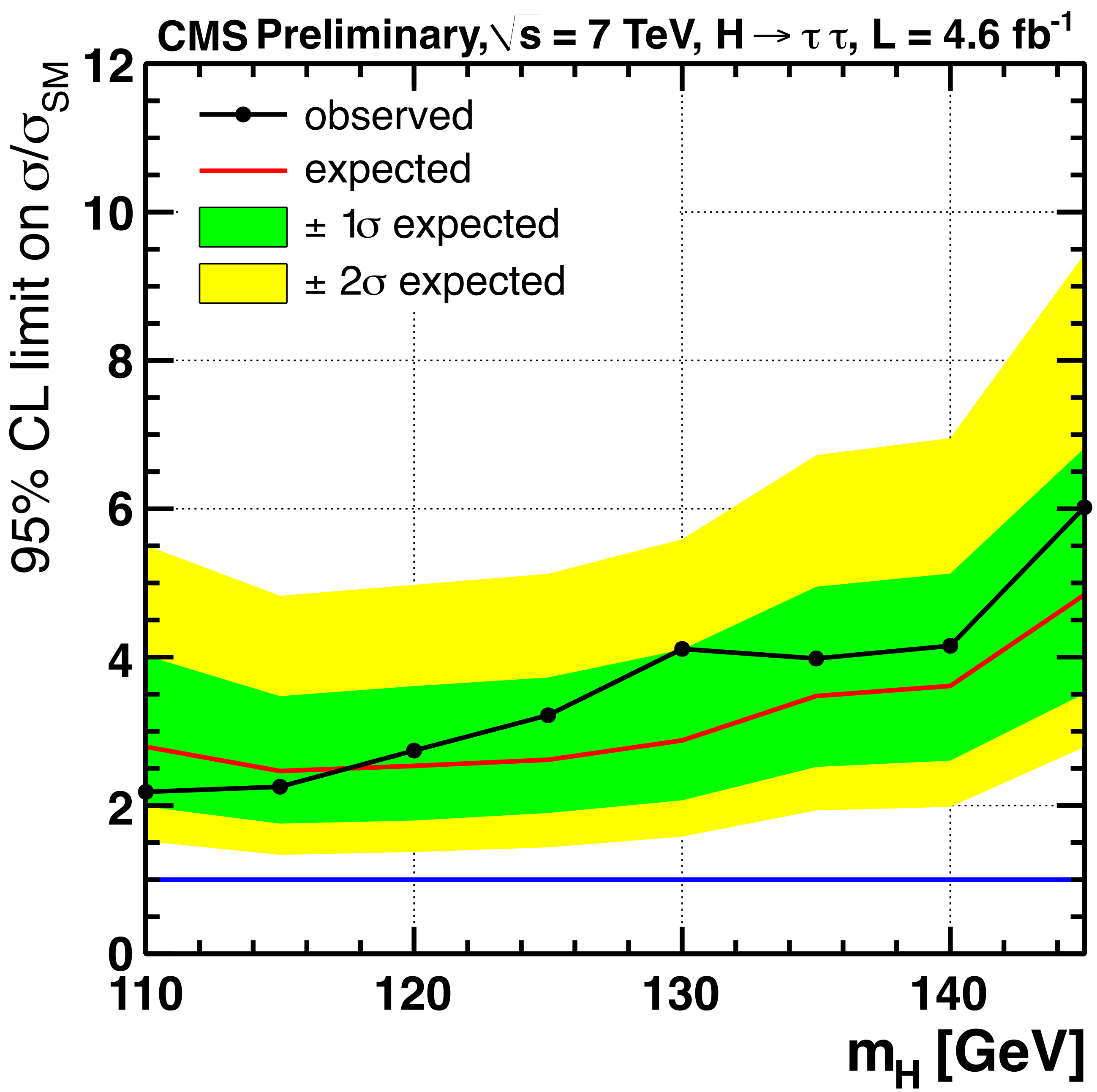
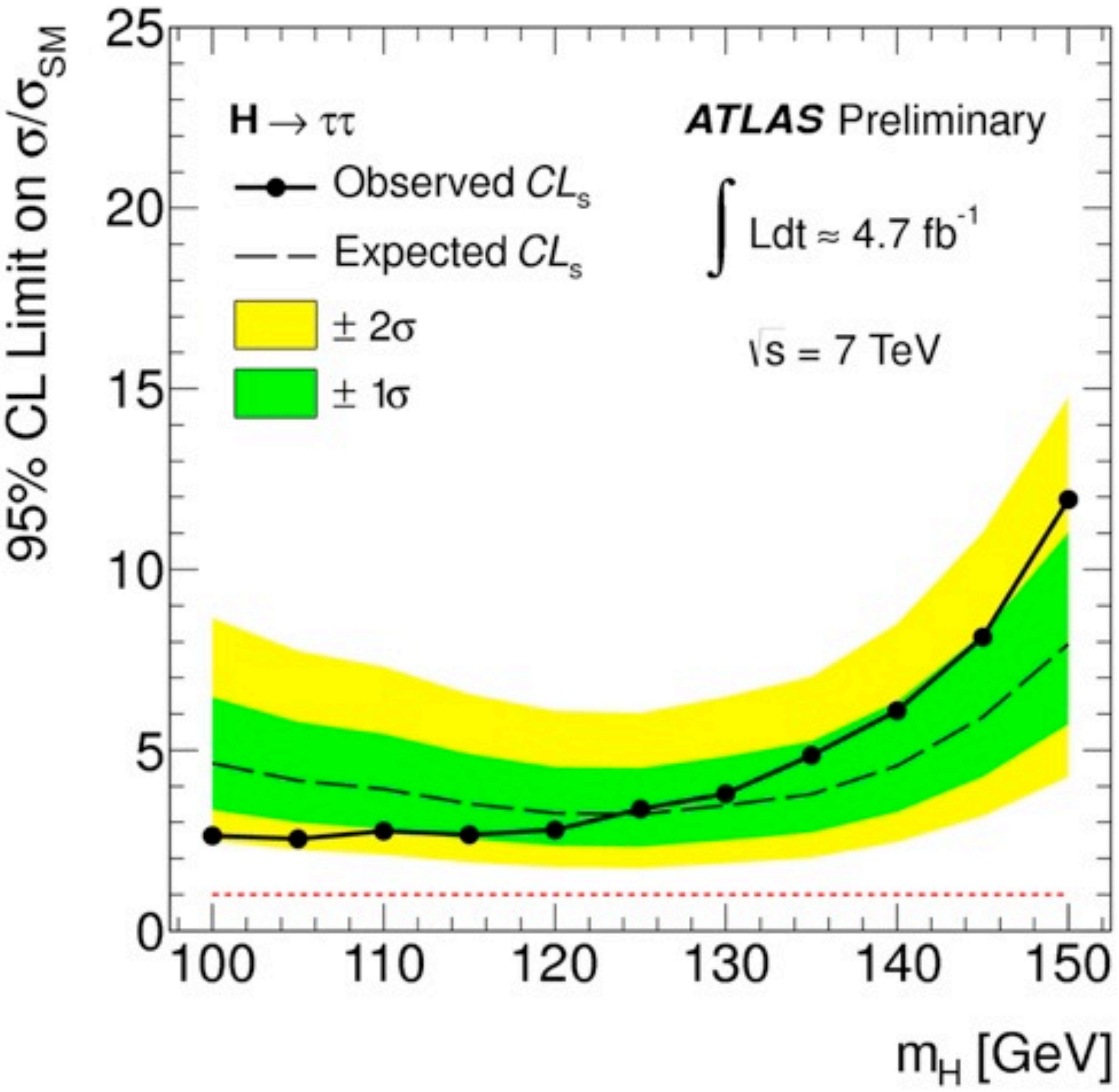
Limits


CMS, √s = 7 TeV, H → τ τ, L = 4.6 fb-1
observed
expected
± 1σ expected
± 2σ expected
95% CL limit on σ/σSM
mH [GeV]
0
2
4
6
8
10
12
110
120
130
140

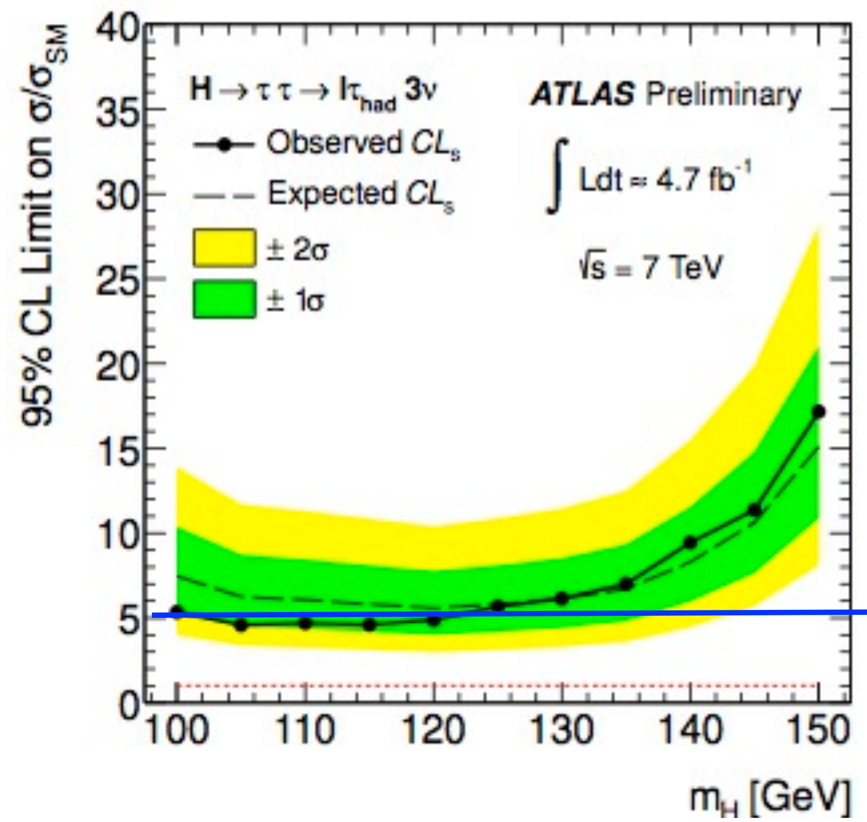

H → ττ
ATLAS Preliminary
Observed CLs
Expected CLs
∫ Ldt ≈ 4.7 fb-1
± 2σ
± 1σ
√s = 7 TeV
95% CL Limit on σ/σSM
mH [GeV]
0
5
10
15
20
25
100
110
120
130
140
150

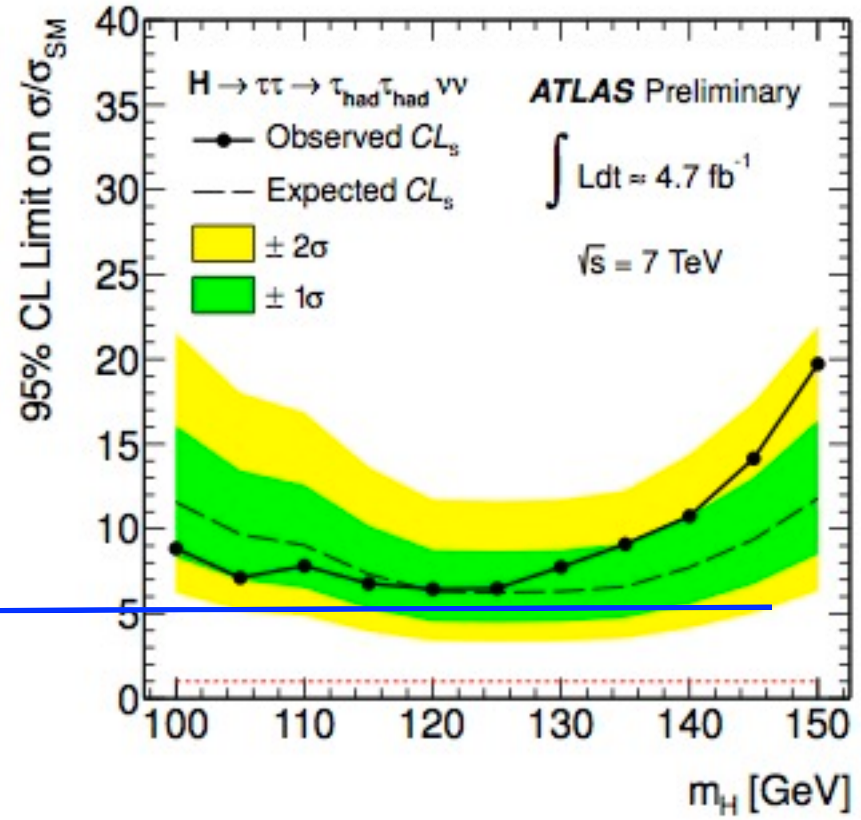
Limit adding H2Tau2Mu and WH



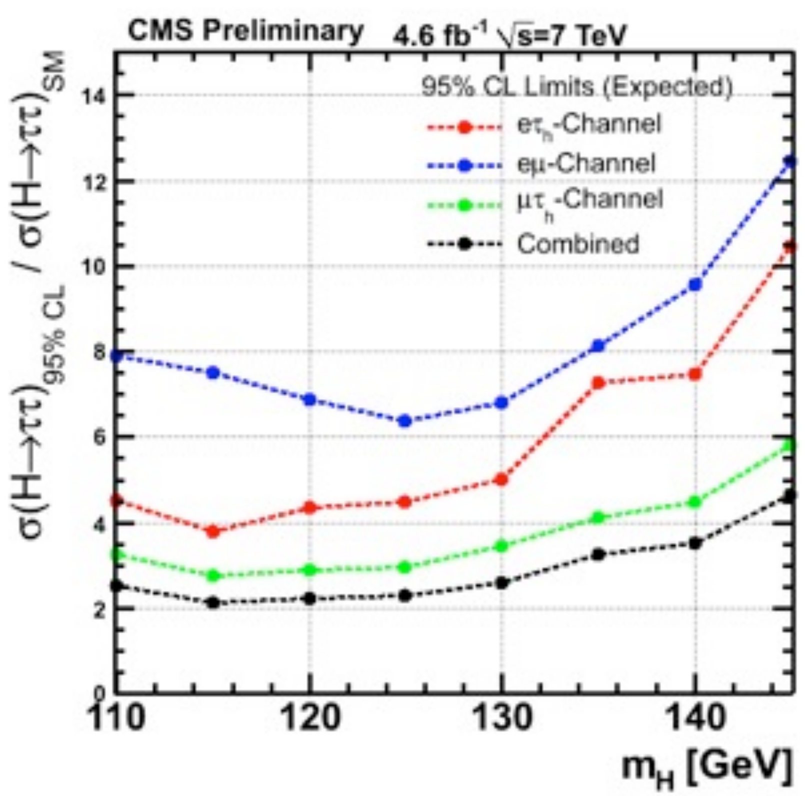


Again on limits





(c) $\tau_{had}\tau_{had}\ \nu\nu$



Differences in mu+Tau sensitivity are compensated by the extra channel

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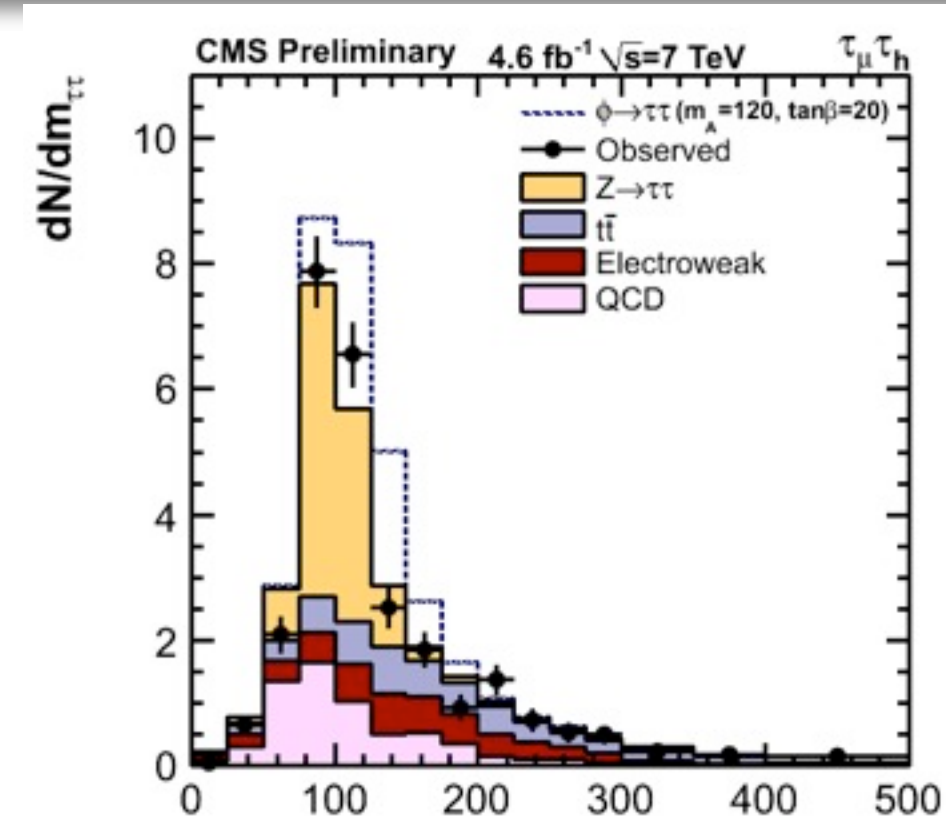
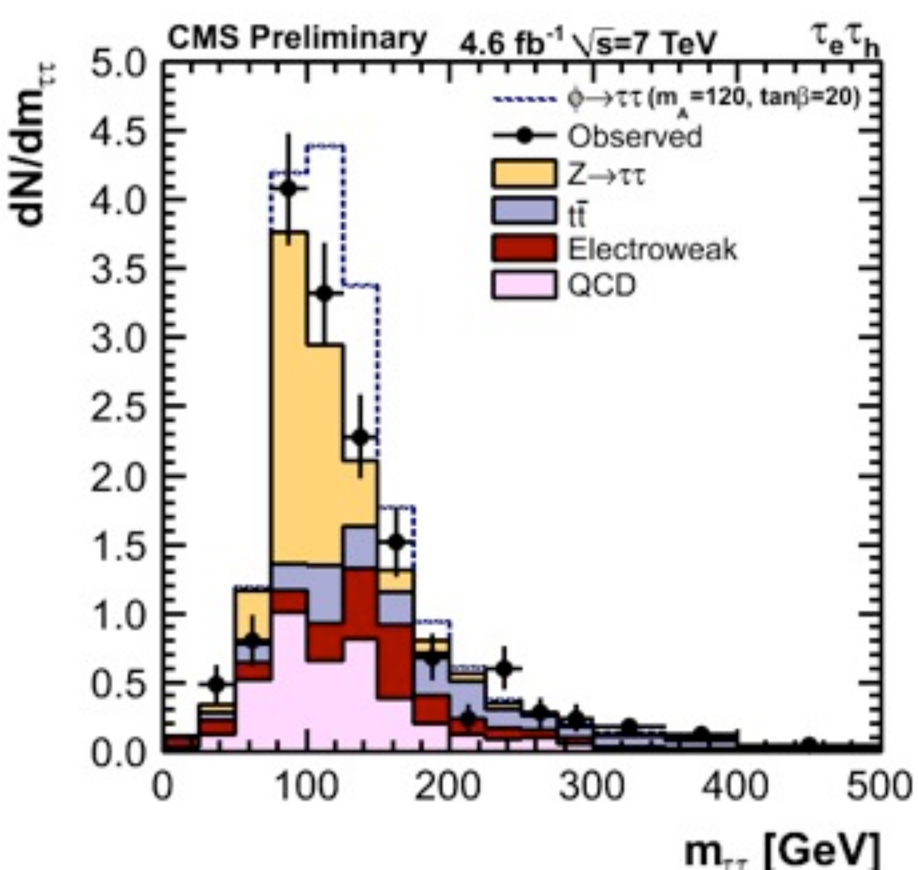
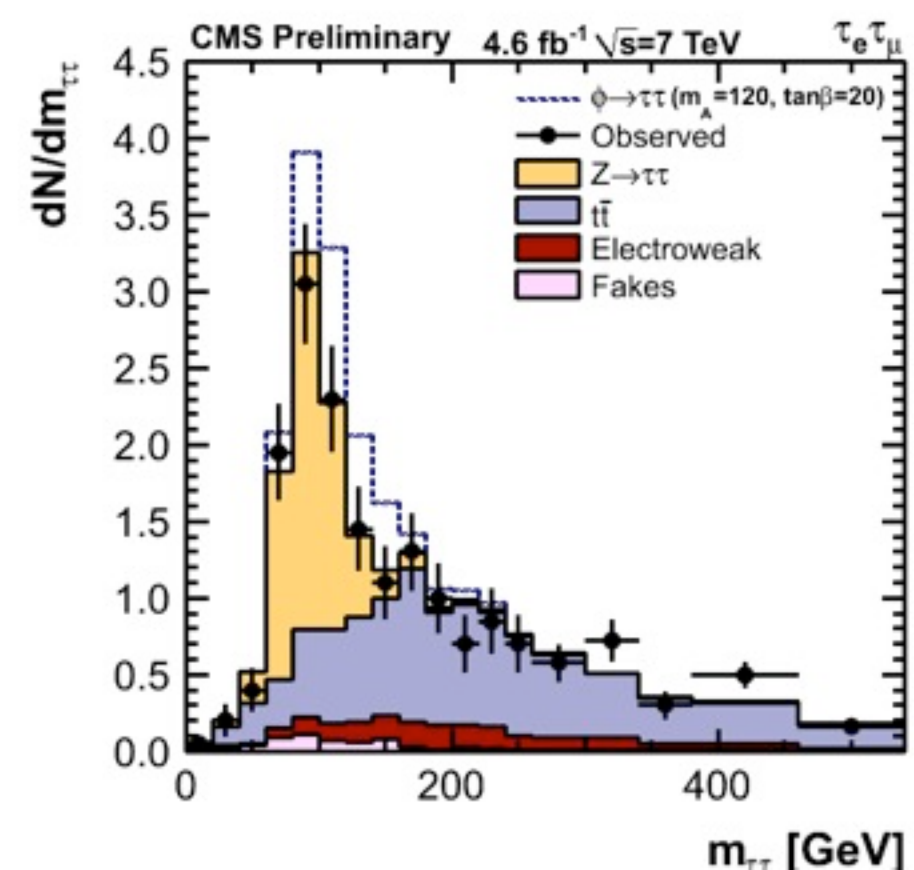
MSSM case

bTagging
Jets (pT > 30 GeV) < 2
AND
btagged jets (pT > 20 GeV) > 0

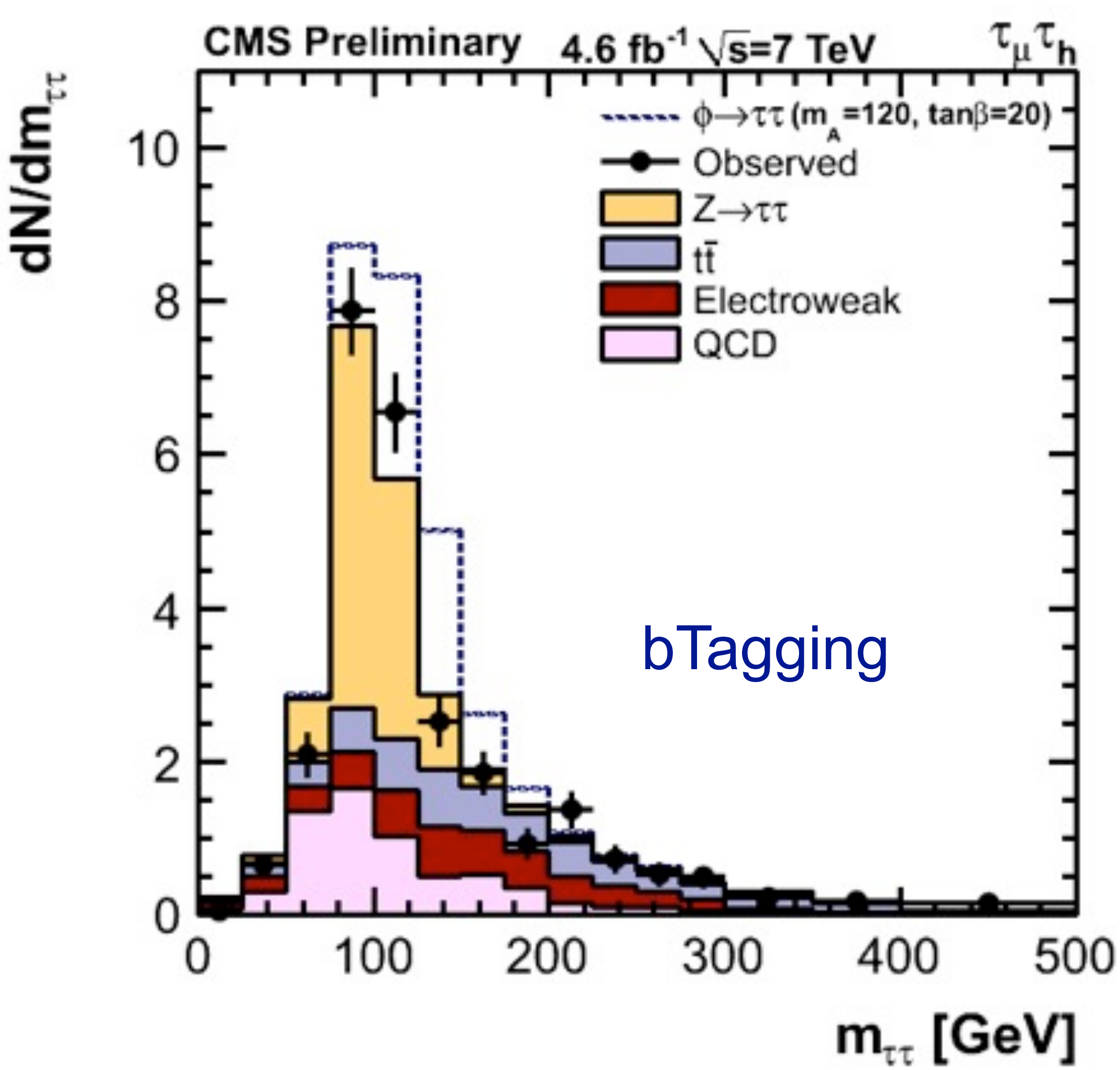
NOT bTagging
Jets (pT > 30 GeV) < 2
AND
btagged jets (pT > 20 GeV) = 0



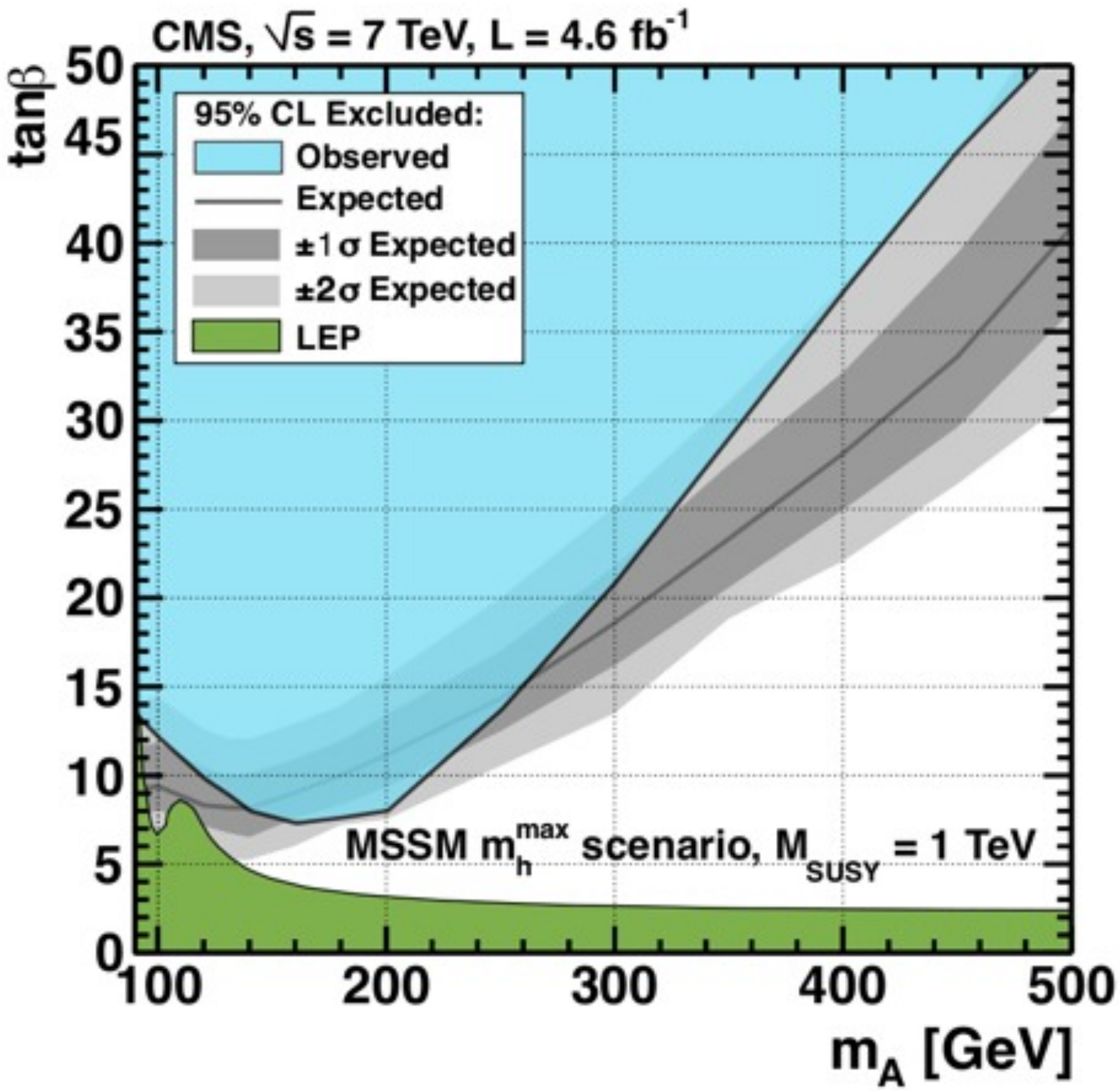




MSSM case

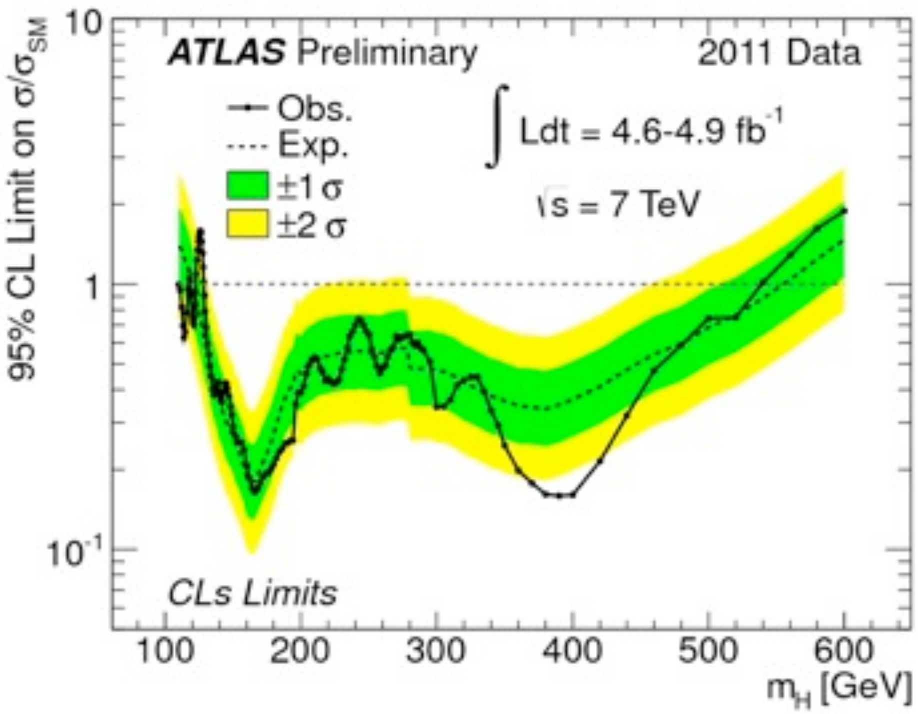


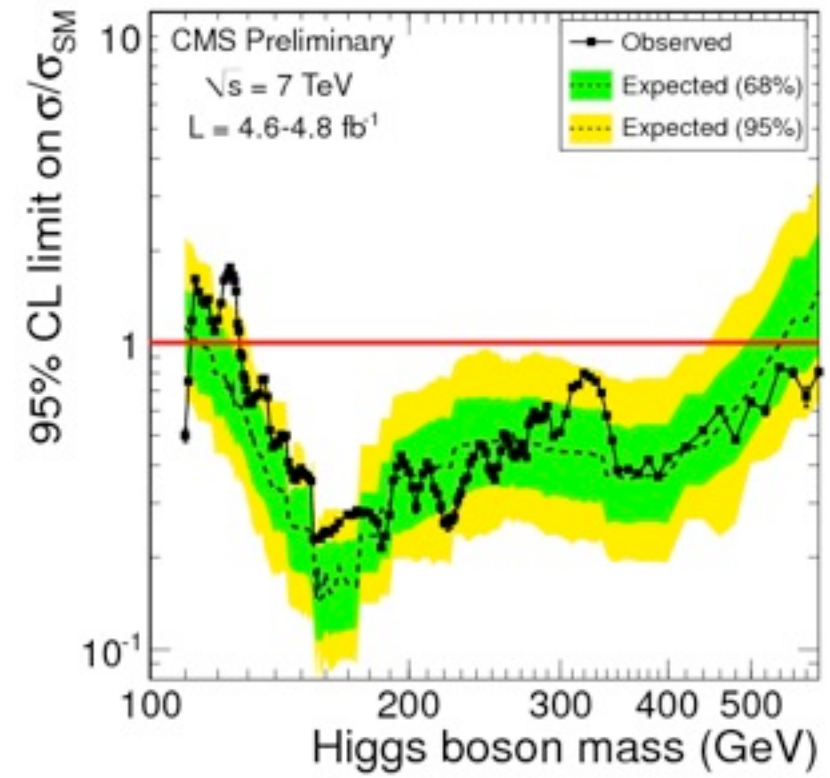
CMS Preliminary 4.6 fb-1 √s=7 TeV
τμτh
dN/dmττ
φ→ττ (mA=120, tanβ=20)
Observed
Z→ττ
tt̄
Electroweak
QCD
bTagging
mττ [GeV]

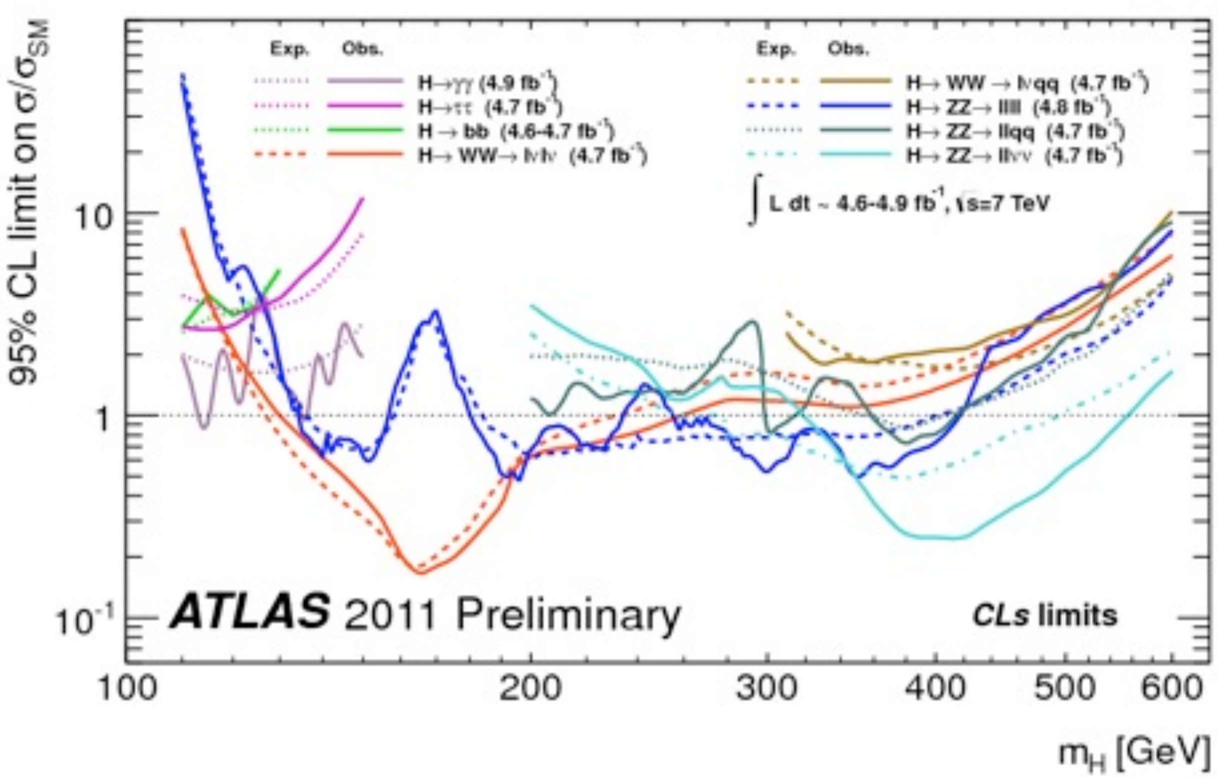


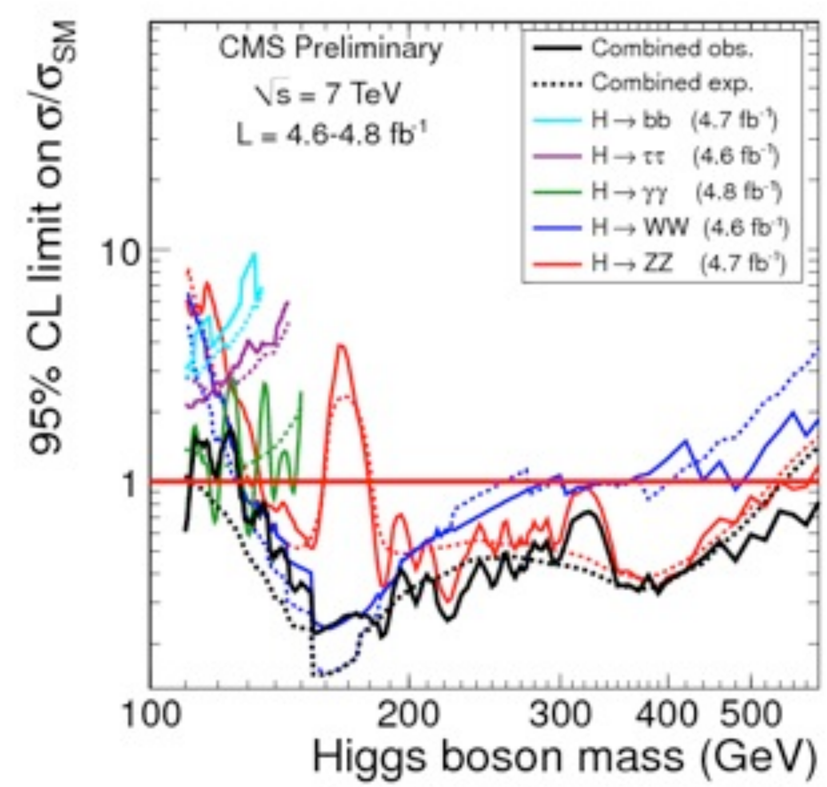
CMS, √s = 7 TeV, L = 4.6 fb-1
tanβ
95% CL Excluded:
Observed
Expected
±1σ Expected
±2σ Expected
LEP
MSSM mhmax scenario, MSUSY = 1 TeV
mA [GeV]

Combining all the channels

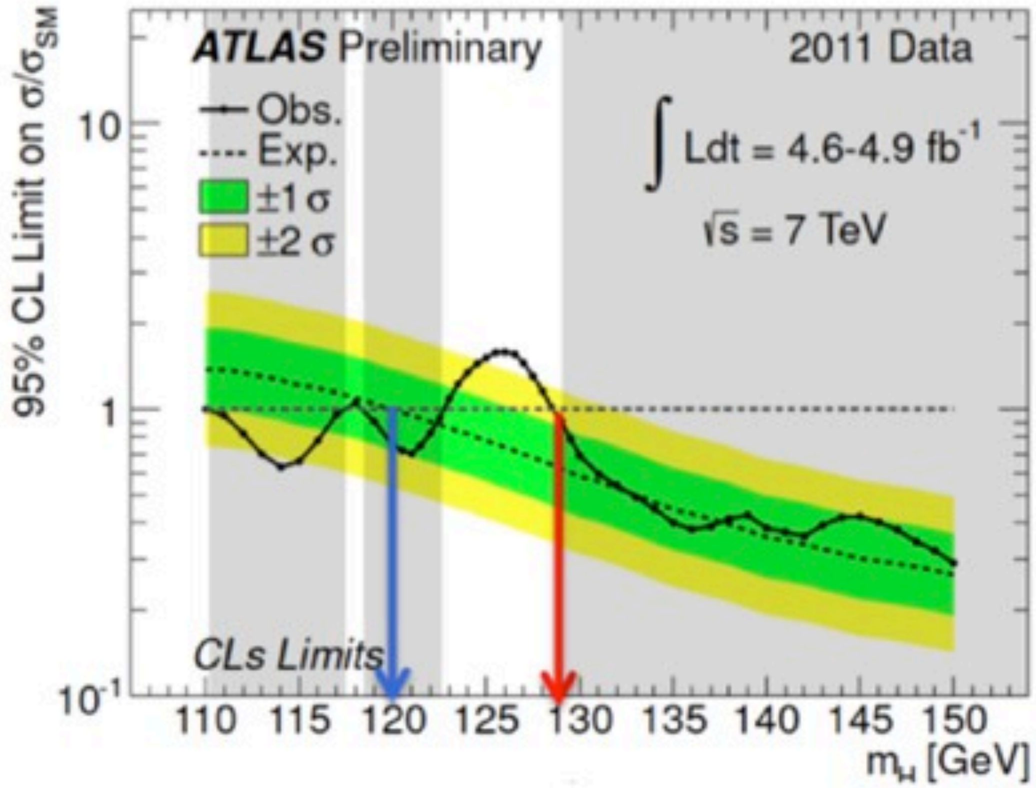






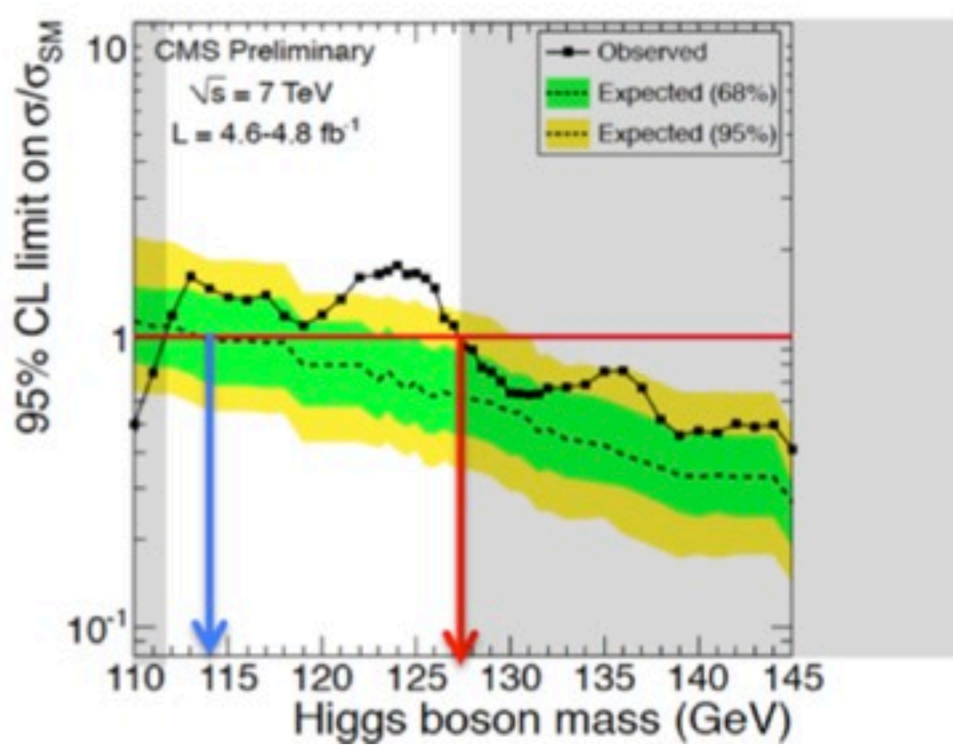


Low mass region



ATLAS:

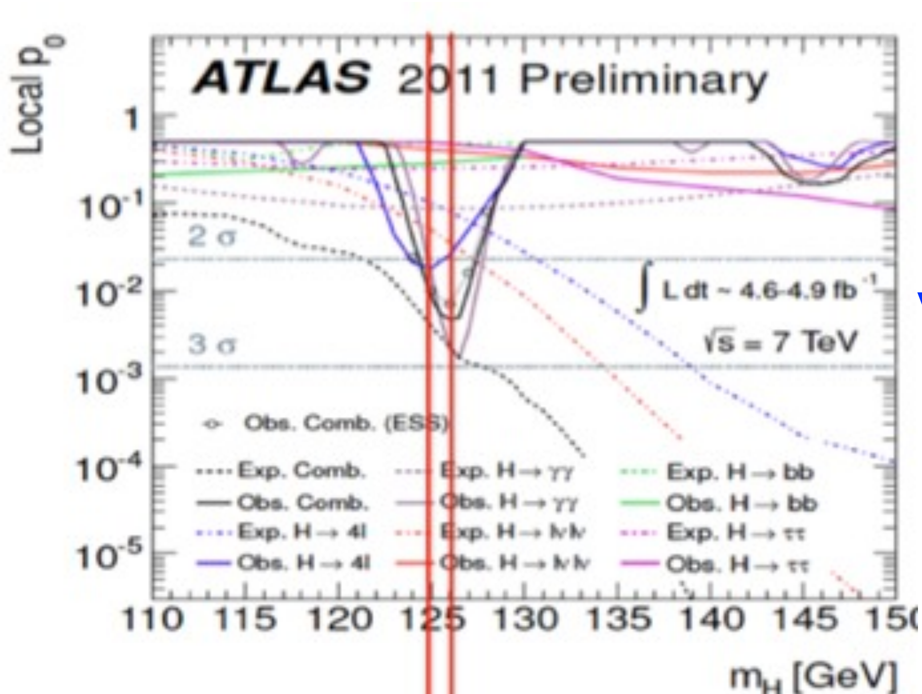
- expected: **120–...** GeV,
- observed: **129.0–...** GeV
  110.0–117.5 GeV
  118.5–122.5 GeV



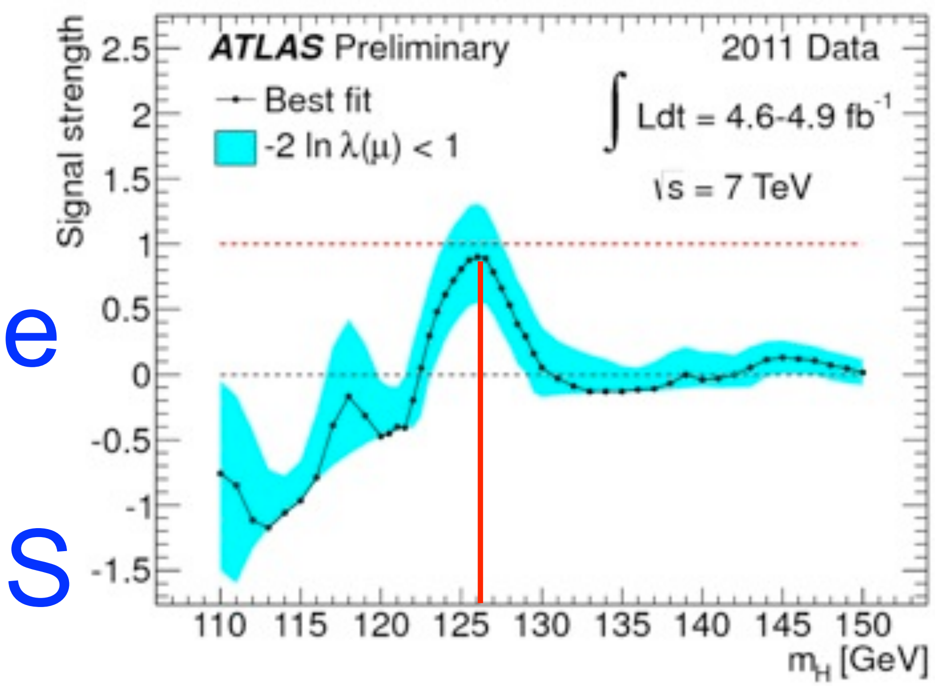
CMS:

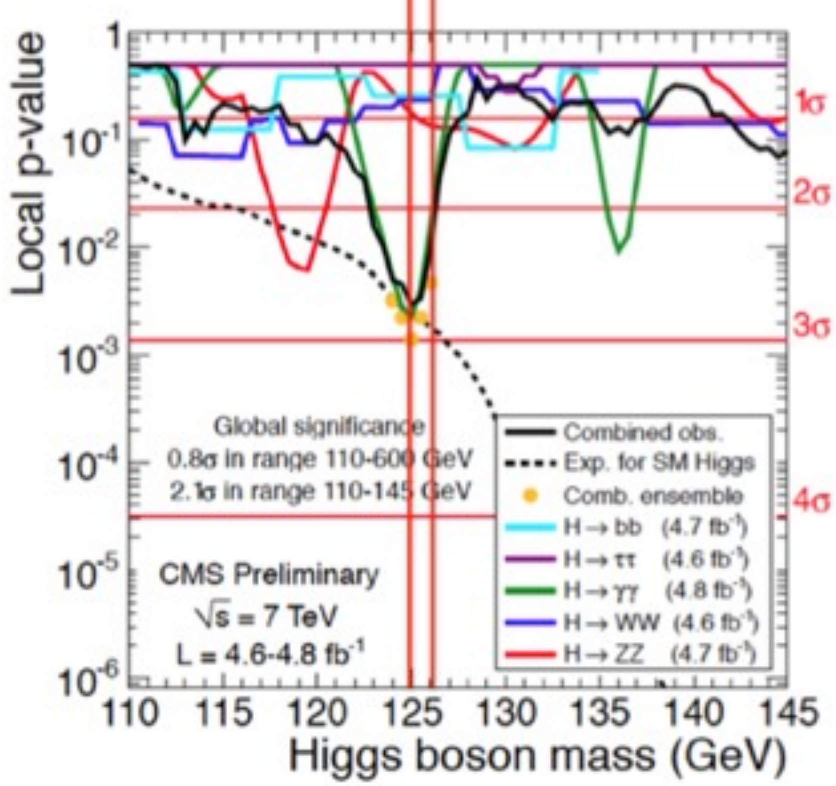
- expected: **114.5–...** GeV
- observed: **127.5–...** GeV

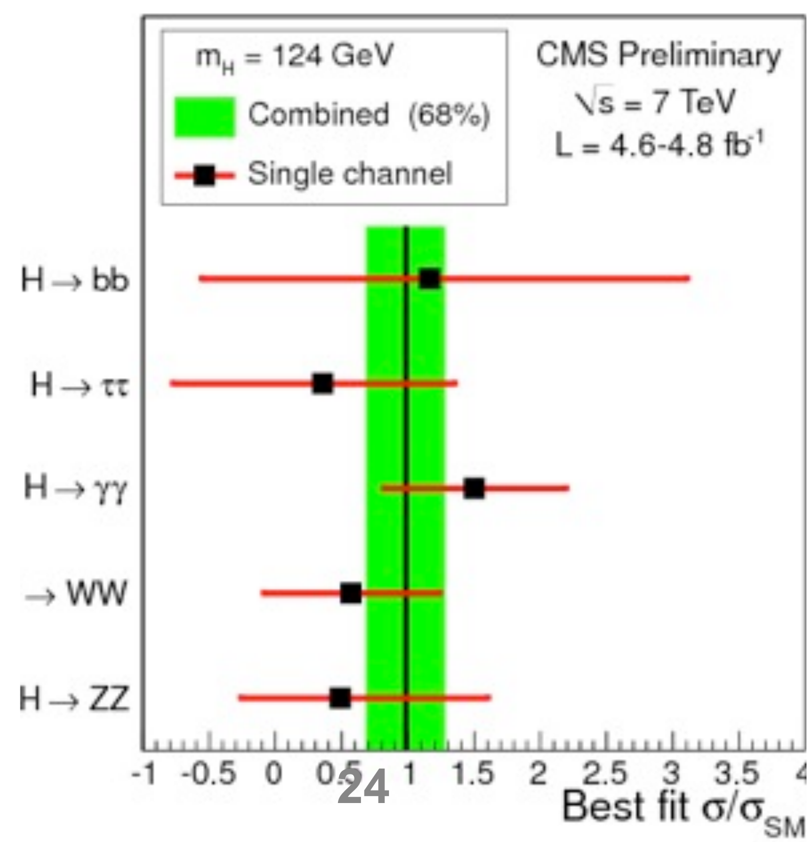
local p-values

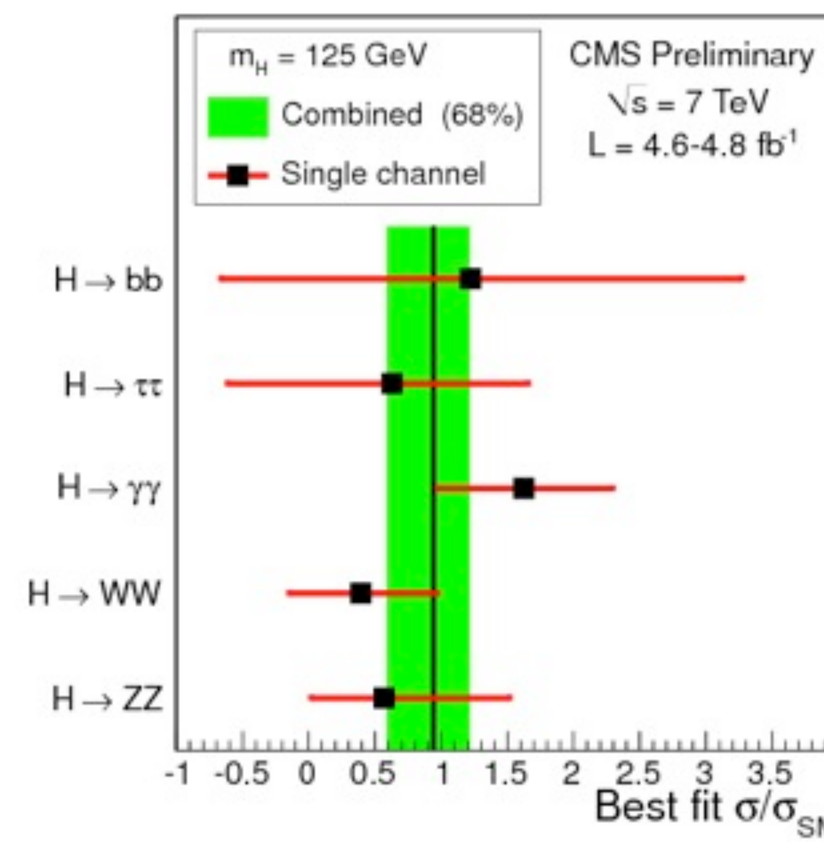


Best fit mass value compatible between ATLAS and CMS









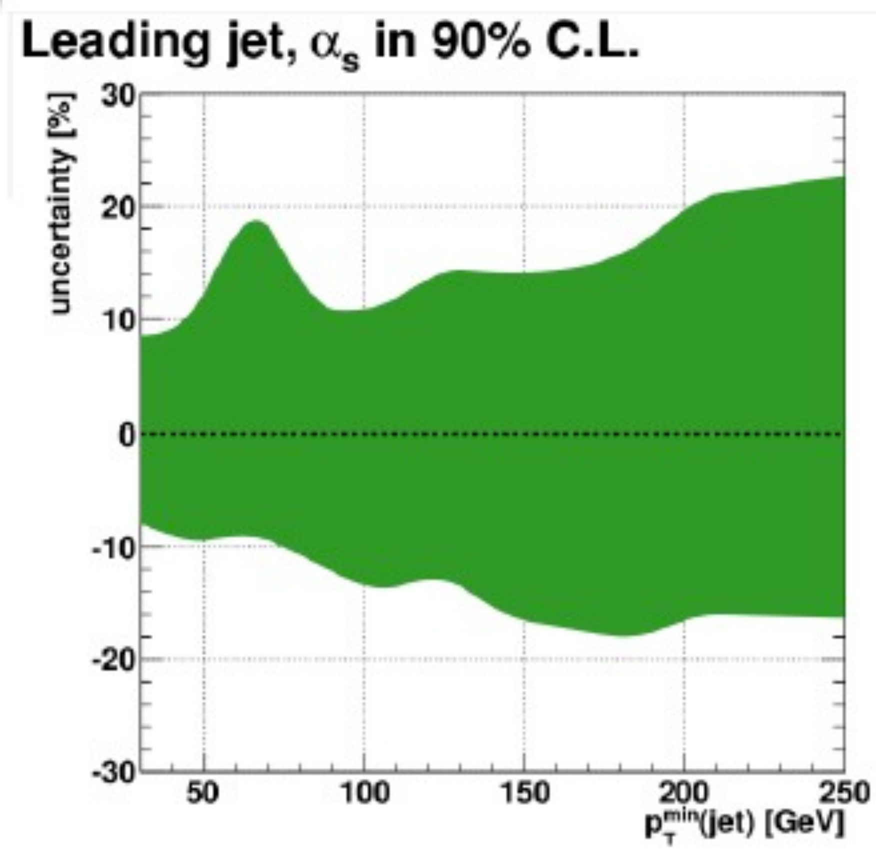
Conclusions

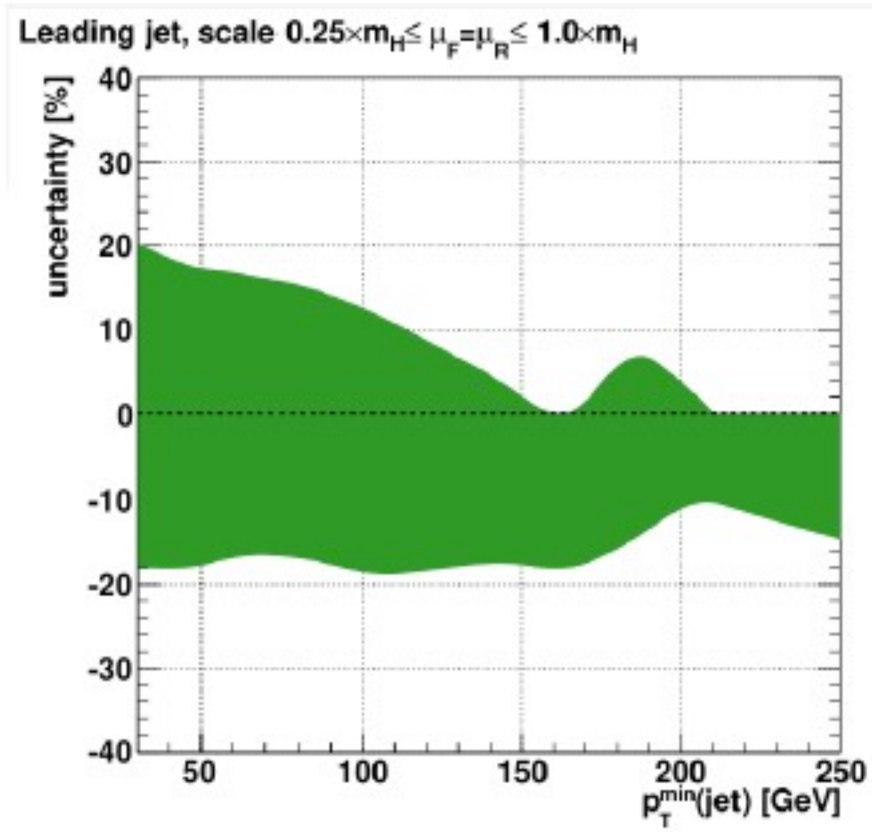
- H->TauTau analyses from ATLAS and CMS give comparable results
  - l+tau CMS analysis have better limit
  - ATLAS recovers with the full hadronic channel
    - challenging for CMS
  - CMS presented also the MSSM limit
- Present limit is around 2.5-3xSM
- On the combination side:
  - CMS excludes an Higgs with mass larger than 127 GeV
  - ATLAS excludes an Higgs with mass lower than ~ 122 GeV
    - if we do not consider the region between 117.5 and 118.5 GeV
- Expecting to have updates for ICHEP from both experiments

back-up

Few worlds on the boosted category

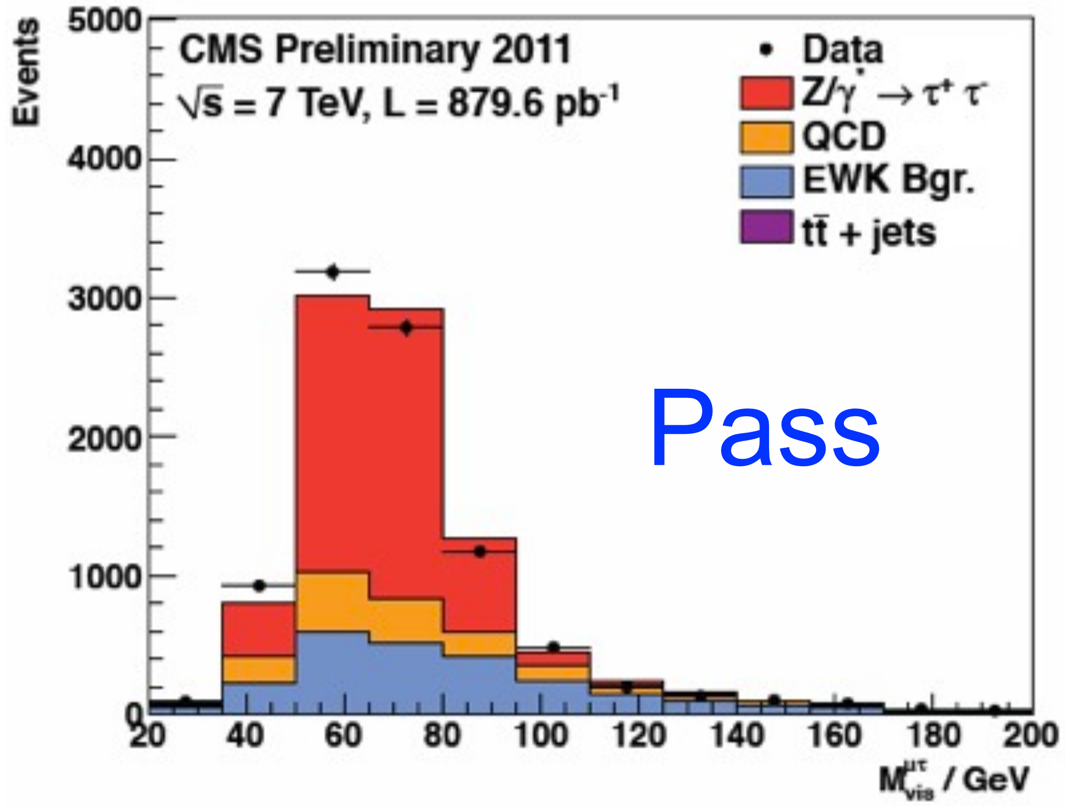
- Large theoretical uncertainty
  - the jet pT cut is near the Higgs mass
    - uncertainty computed using NNLO codes
      - FeHiPro and HQT
    - Higgs pT rescaling factors
    - total uncertainty ~ 25%
- Much better mass resolution
  - boosted taus, hence better MET reconstruction
  - improving Z-H separation in the low mass region
- Still room for improvement

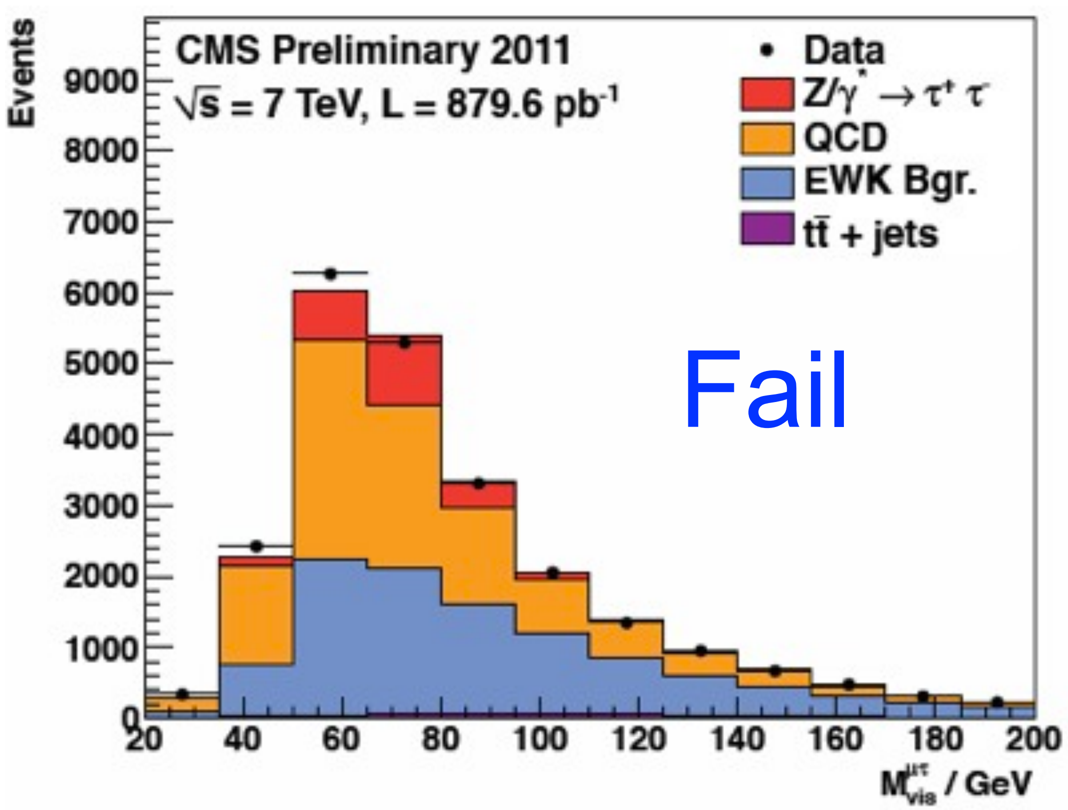




Tau ID efficiency

- Improved tau ID using Tag & Probe
  - BKG constrained from sidebands





Uncertainty's source	
Muon Momentum Scale	<< 1%
τ-Jet Energy Scale	< 1%
Track Reconstruction	3.9%
Track Momentum Scale	< 1%
Lead. Track P_T Cut	1%
Loose Isolation	2.5%
Jet → τ_{had} Fakes	1.2%
Lead. Track Corr. Factor	1.7%
Loose Iso. Corr. Factor	2.1%
Fit (Statistical Uncertainty)	2.6%
Total uncertainty	6%

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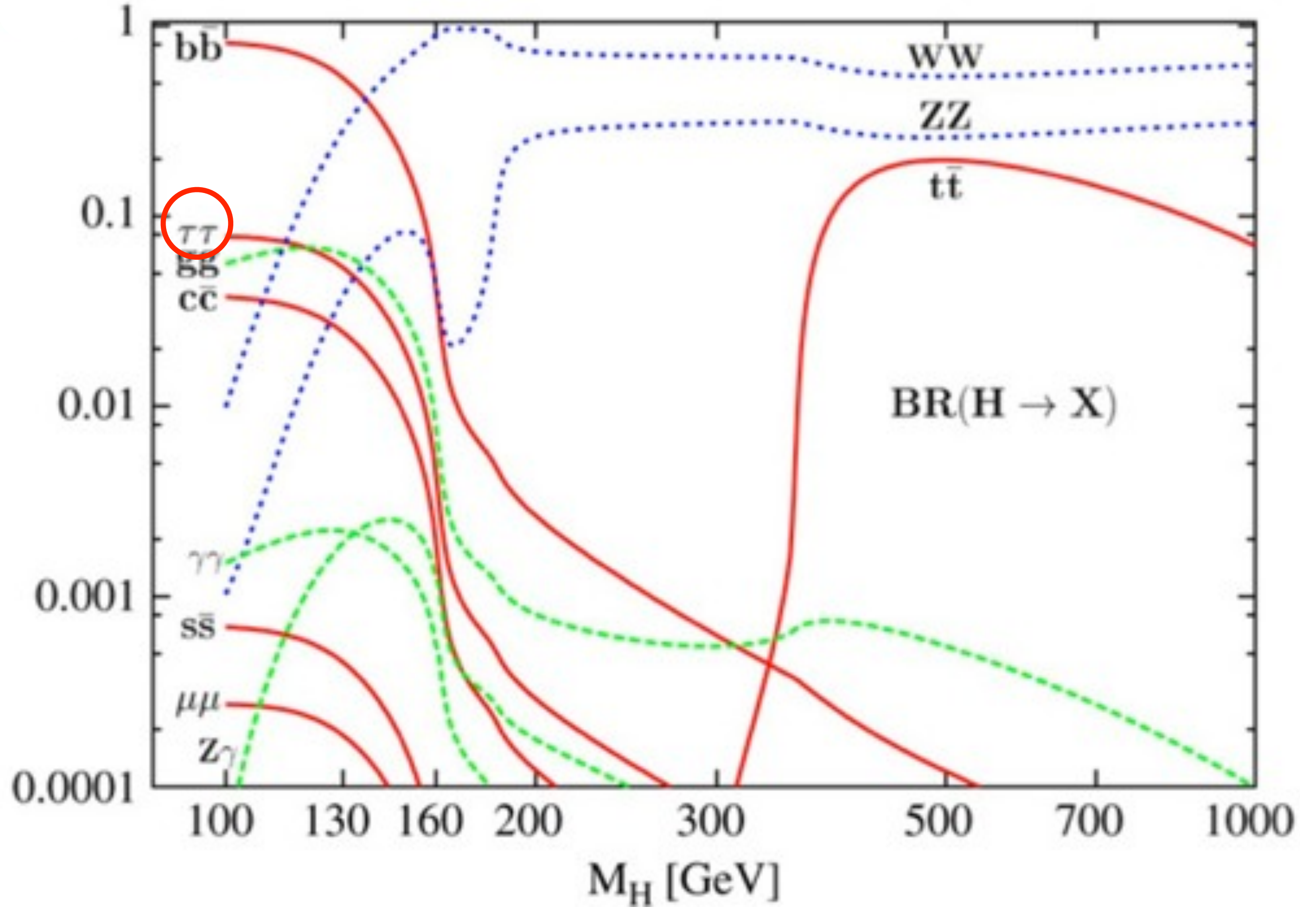
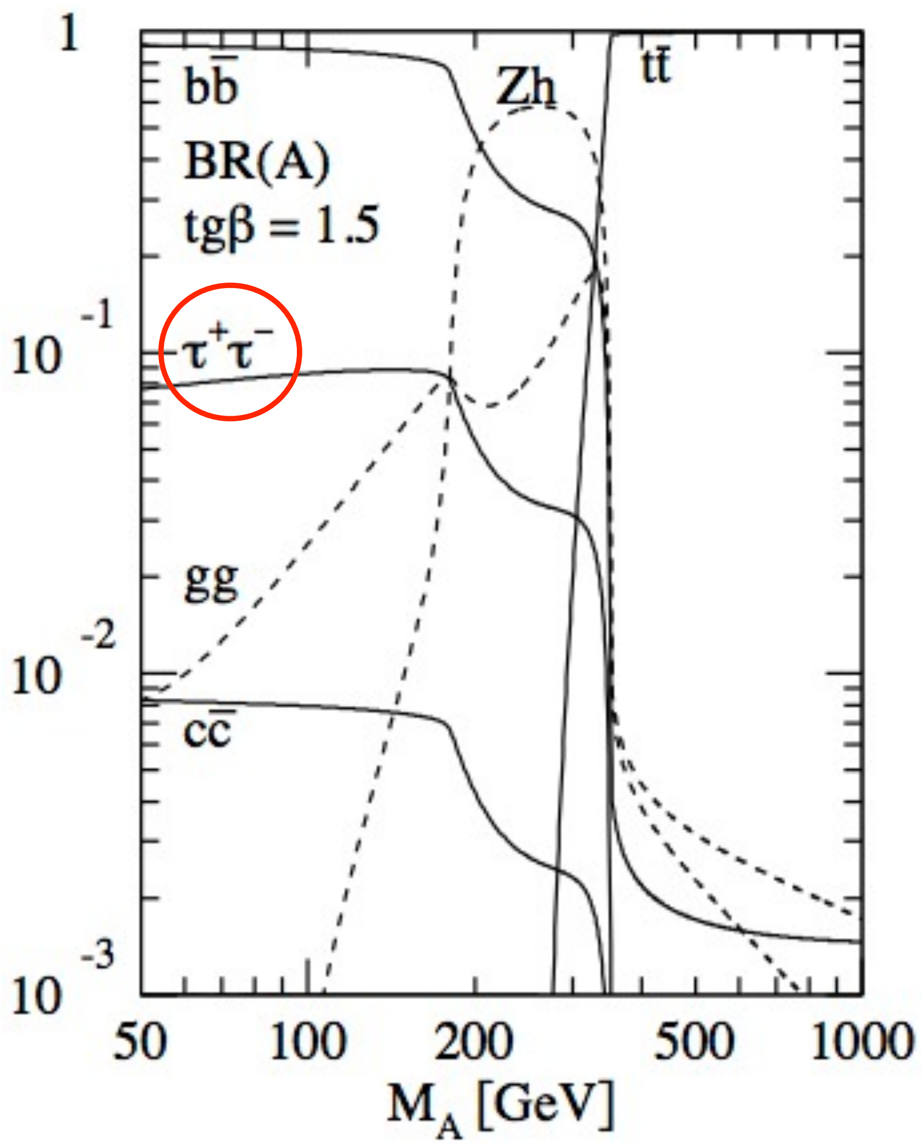
Decay modes

SM

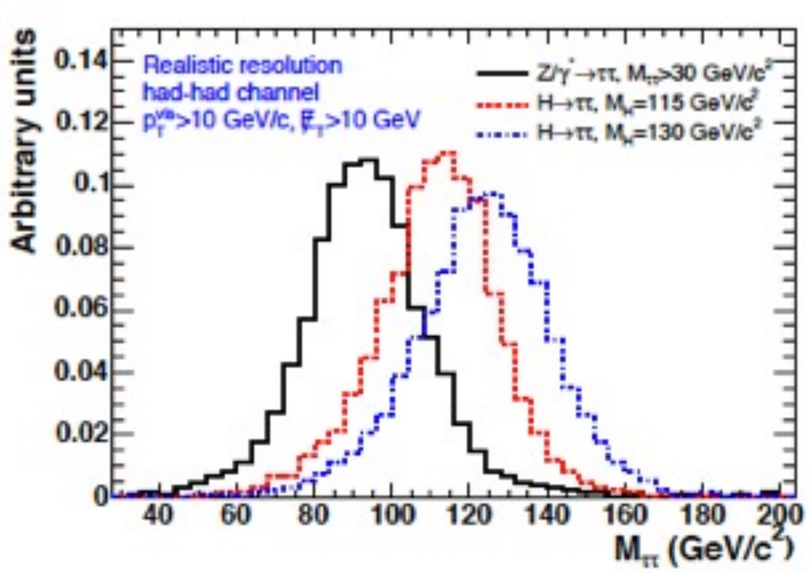


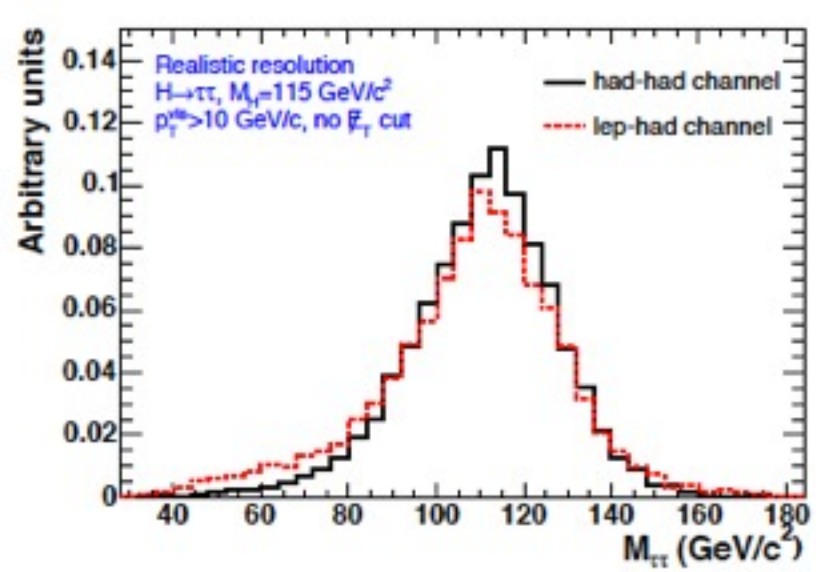
MSSM

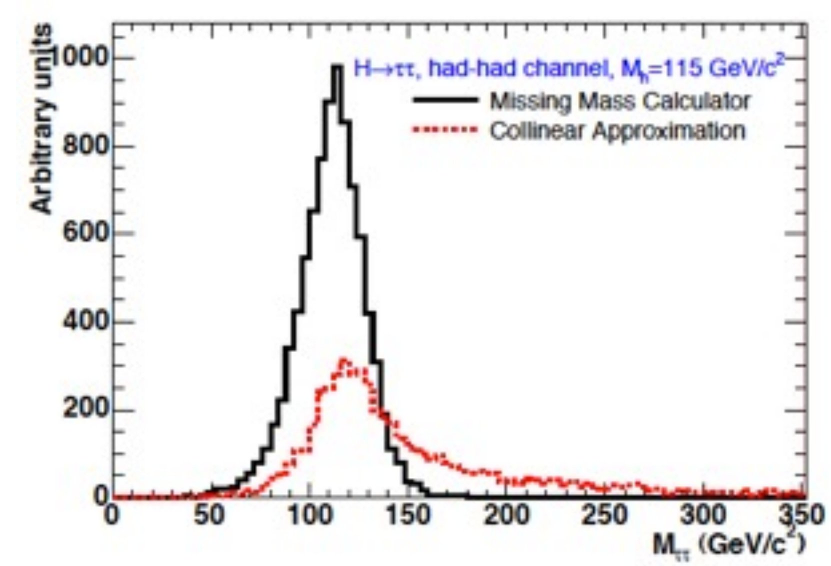


Full mass reconstruction

- Various methods are now available on the market
  - all of them uses constraints from the measurement of the MET
- New techniques makes use of likelihood functions to optimize the reconstruction
  - Most advanced techniques
    - Missing Mass Calculator (MMC) by Elagin et al.
      - http://www.sciencedirect.com/science/article/pii/S0168900211014112
    - Secondary Vertex Fit (SVFIT) by Conway et al.

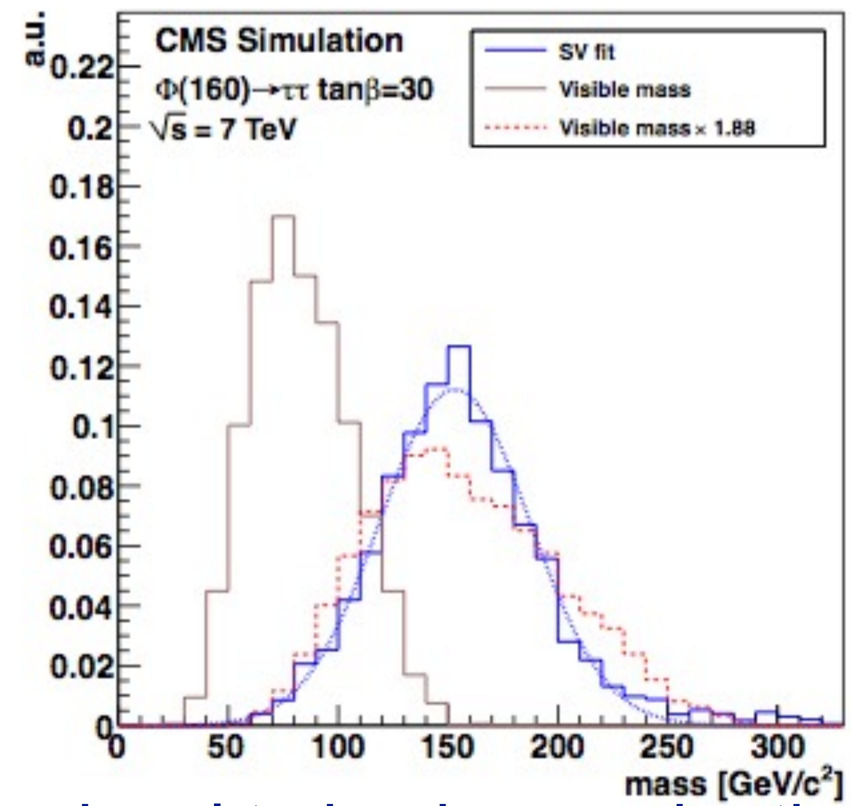




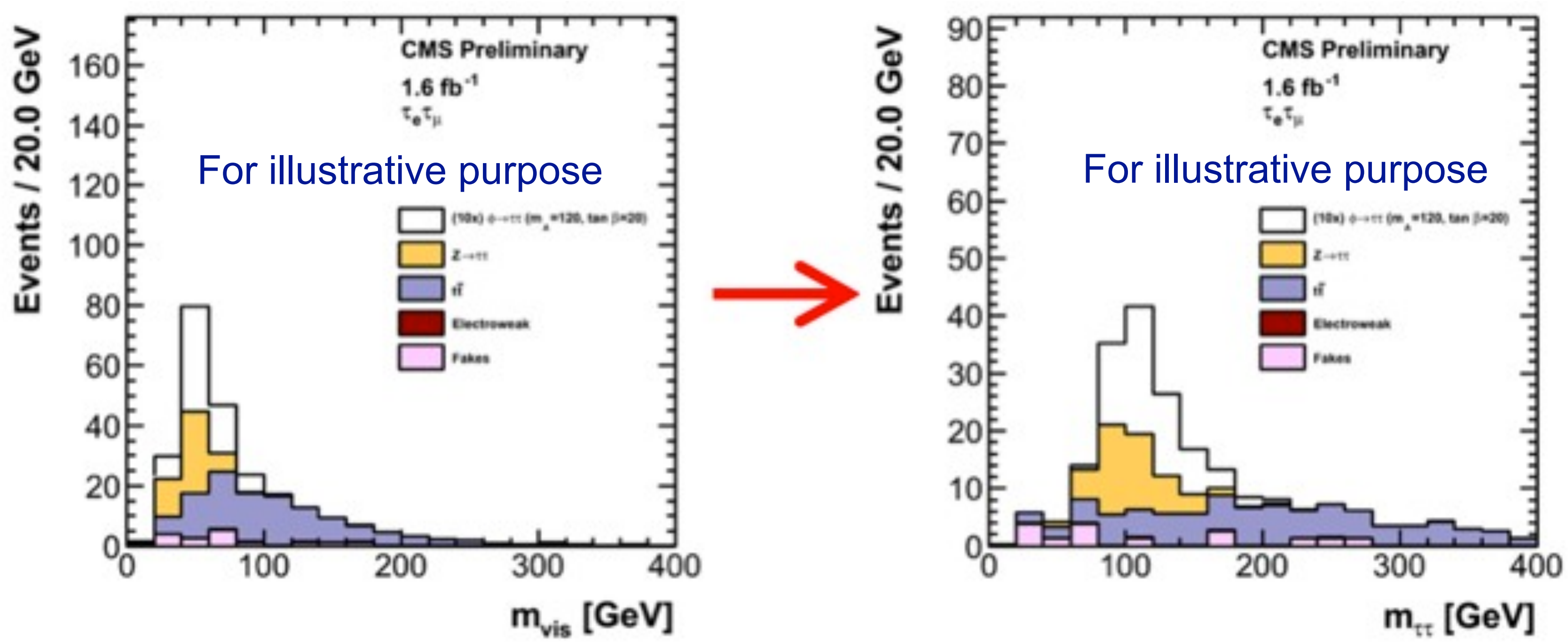


SVFIT

- CMS is using SVFIT algorithm
  - optimized to work with large PU environment
  - similar to the MMC method
  - tails are reduced due to the use of a Log(Minv) term in the likelihood function
- Invariant mass resolution improves
- the peak value is nearer to the generated one
  - hence better discrimination between Higgs and Z->TauTau



- Not resonant bkg are flattened improving further the signal to background ratio



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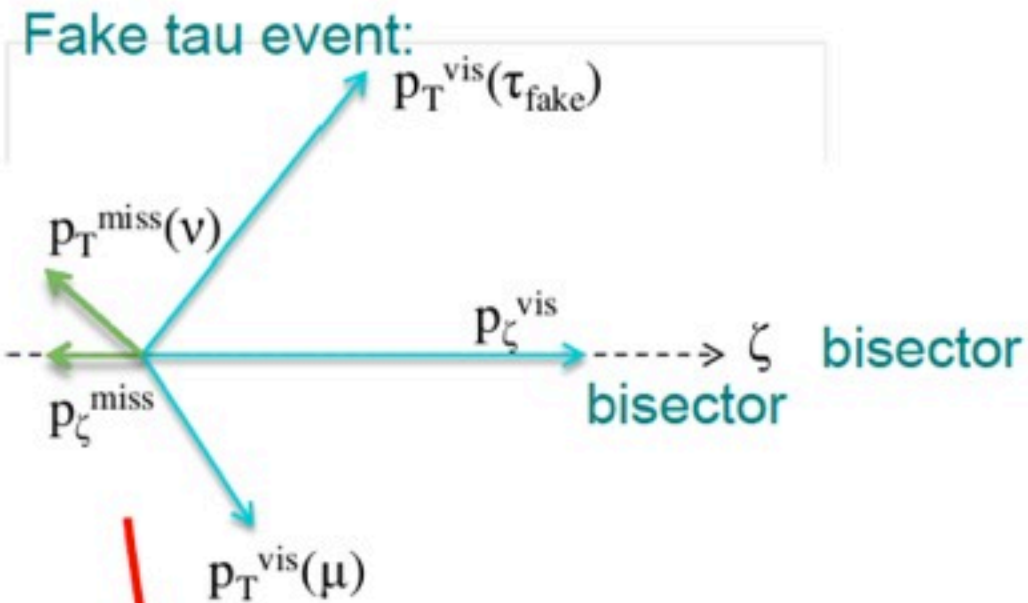
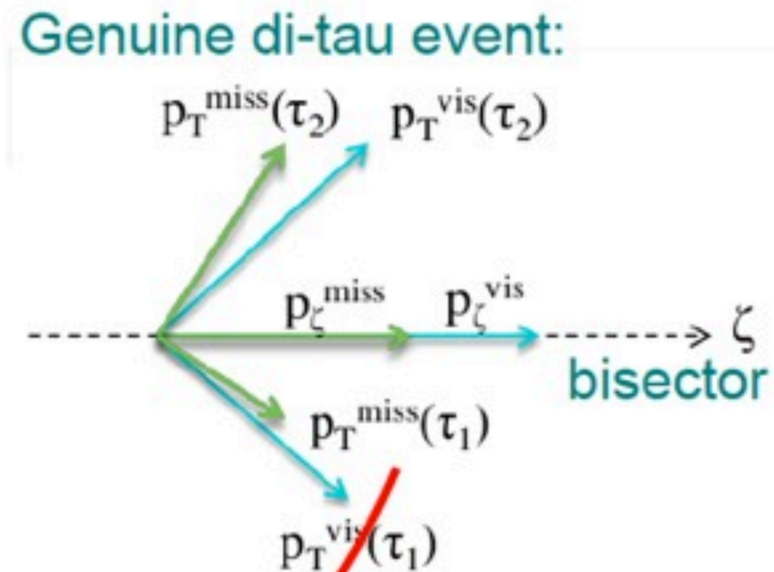
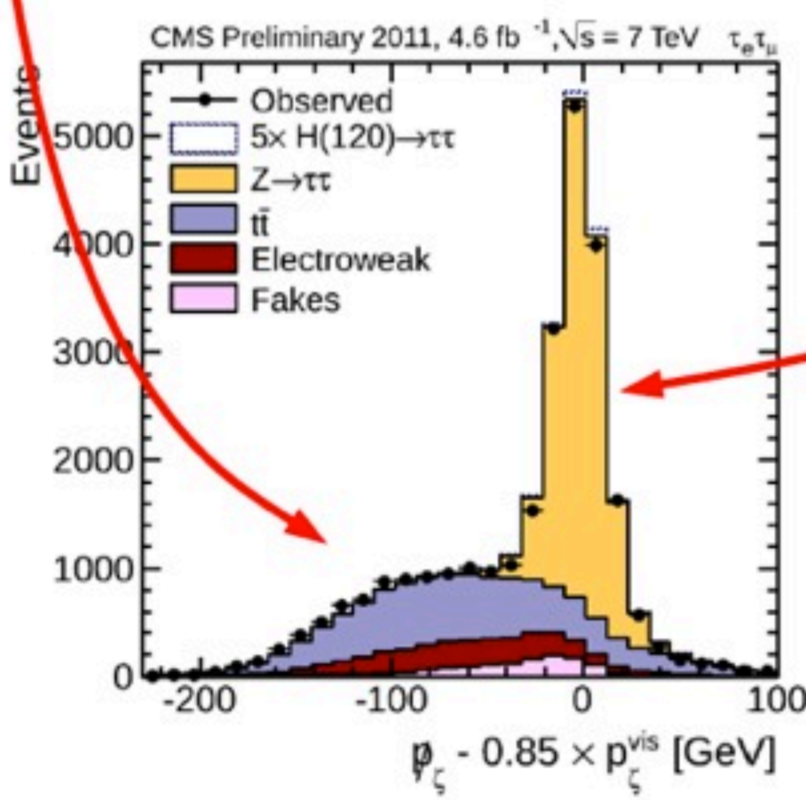
Topological cuts

- Used to distinguish between W's and signal events





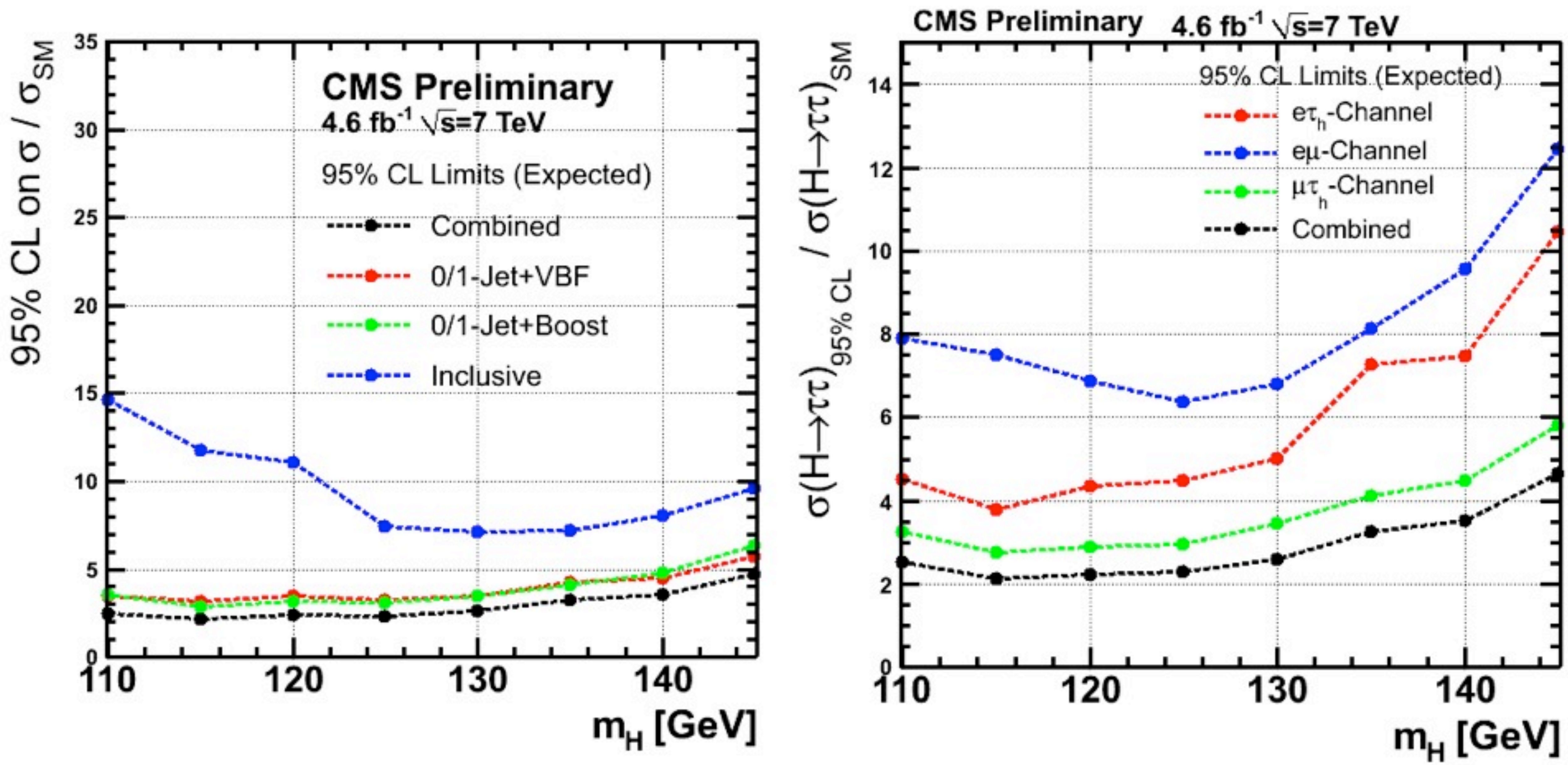


$$p_\zeta^{cut}(\alpha) = p_\zeta^{miss} - \alpha \cdot p_\zeta^{vis}$$

$\mu\tau_h$-channel	$p_\zeta^{cut}(\alpha = 0.50) > -20$ GeV
$e\tau_h$-channel	$p_\zeta^{cut}(\alpha = 0.50) > -20$ GeV
$e\mu$-channel	$p_\zeta^{cut}(\alpha = 0.85) > -25$ GeV

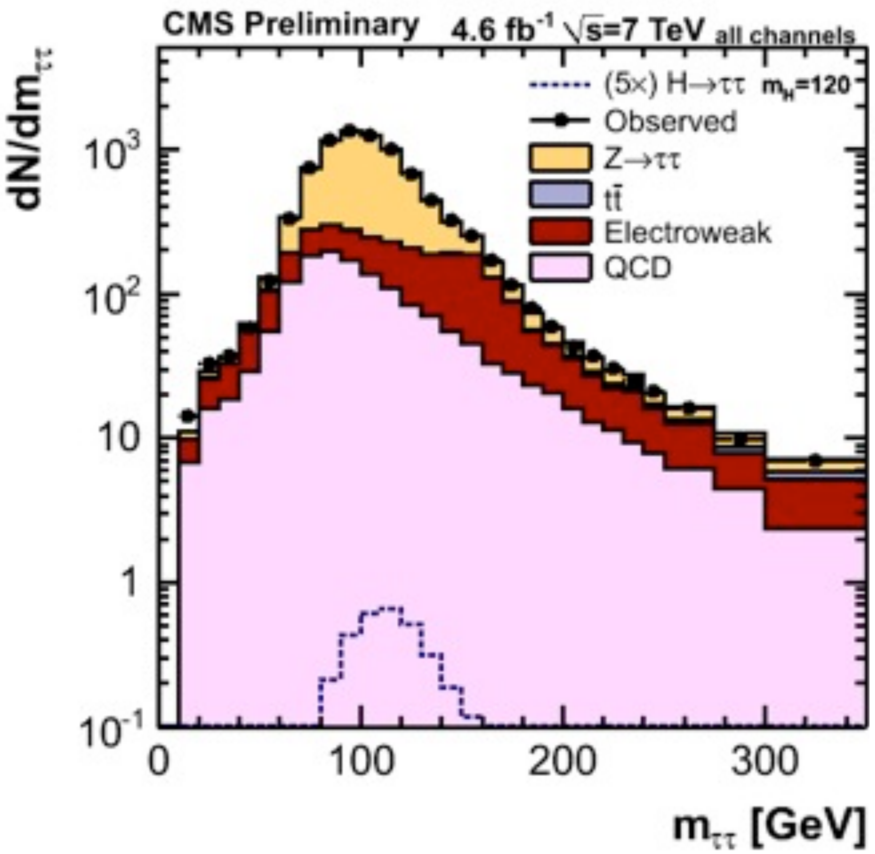
- Used for MSSM analysis (also for SM in e-mu)
- For SM analysis m_T is used in the mu-tau and e-tau channel

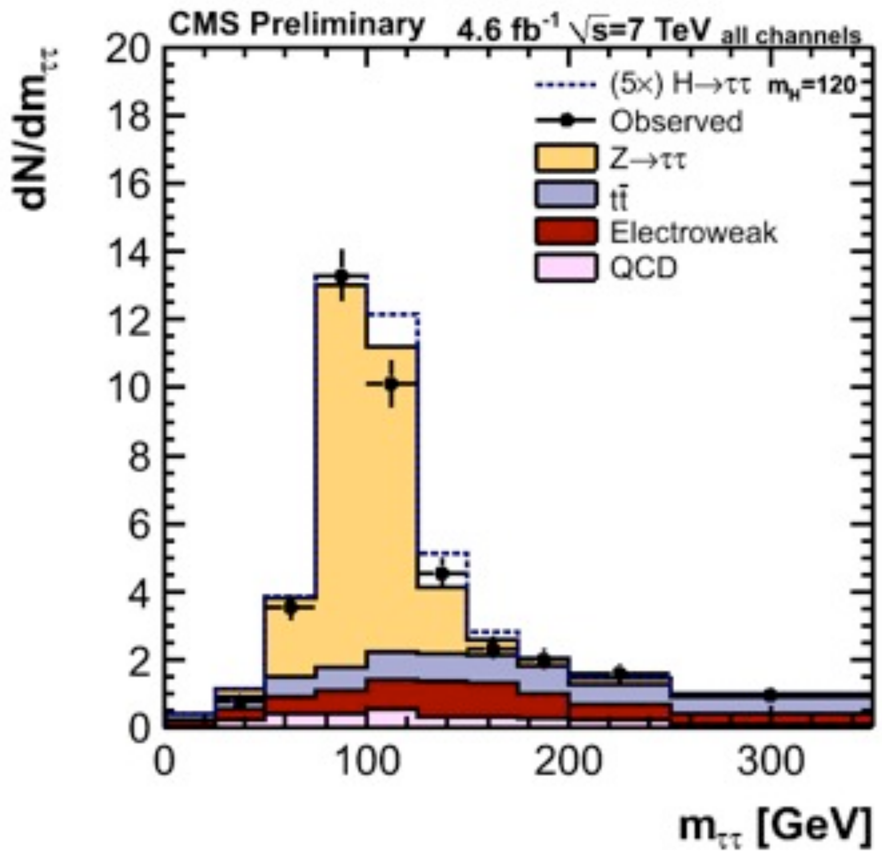
SM limits/category

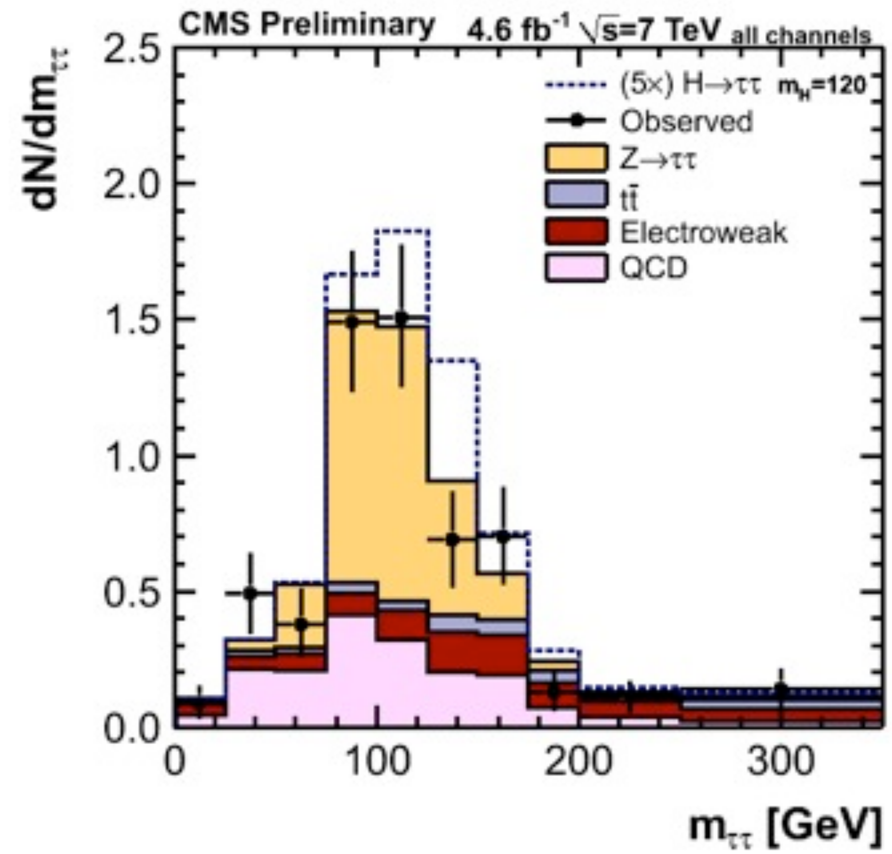


- Categorization improves the limit by more than a factor 3
- mu-tau channel is the most sensitive one

Mass distributions







No Jet category

Boosted category

VBF category

Provides the best mass reconstruction
hence better separation between Z and H

Uncertainties table

Experimental Uncertainties		Propagated to Limit Calculation				
Uncertainty	Estimate	*0/1-Jet*	*Boost*	*VBF*	*Non B-Tag*	*B-Tag*
Electron ID & Trigger	±2%	±2%	±2%	±2%	±2%	±2%
Muon ID & Trigger	±2%	±2%	±2%	±2%	±2%	±2%
JES (Norm.)	±2.5 – 5%	∓1%	±2%	±12.5%	∓1%	±4%
b-Tag Efficiency	±10%	-	-	-	∓1%	±5%
Mis-Tagging	±30%	-	-	-	±4%	∓1%
Norm. $Z \rightarrow \tau\tau$	±3.3%	±3.3%	±10%	±15%	±3.3%	±15%
Norm. $t\bar{t}$	±7.5%	±7.5%	±7.5%	±7.5%	±7.5%	±7.5%
Norm *EWK*	±15%	±15%	±15%	±15%	±15%	±15%
Norm Fakes	±30%	±30%	±30%	±30%	±30%	±30%
Lumi (Signal & EWK)	±4.5%	±4.5%	±4.5%	±4.5%	±4.5%	±4.5%
Norm. $W + jets$	±6.5 – 7%	±7%	±7%	±7%	±6.5%	±6.5%
Norm. Z: l fakes τ_h	±8.6 – 60%	±10.1%	±8.8%	±31.4%	±24.5%	±62.7%
Norm. Z: jet fakes τ_h	±24.6%	±10.2%	-	-	±10.6%	-

Theory Uncertainties (SM)		Propagated to Limit Calculation				
Uncertainty	Estimate	*0/1-Jet*	*Boost*	*VBF*	*Non B-Tag*	*B-Tag*
PDF	-	±3%	±3%	±3%	-	-
$\mu_r/\mu_f(gg \rightarrow H)$	-	±12%	±25%	±12%	-	-
$\mu_r/\mu_f(qq \rightarrow H)$	-	±3.5%	±4%	±4%	-	-
Underlying event & PS	-	∓4%	±4%	±4%	-	-

Main differences in the l+tau channel

- Larger acceptance for CMS
  - lower lepton thresholds thanks to combined triggers
    - steep exponential falling distribution
  - no MET cut applied

- Better tau ES uncertainty for CMS
  - less systematics
    - ATLAS MET cut is very sensitive to the tau ES uncertainty