CMS Higgs searches

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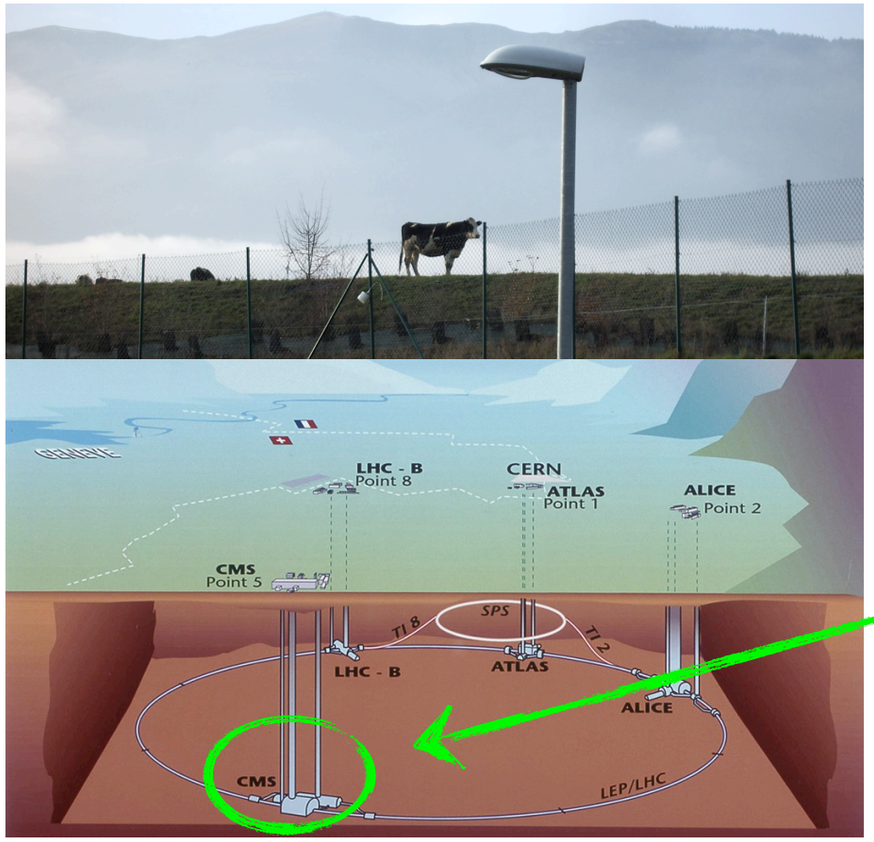
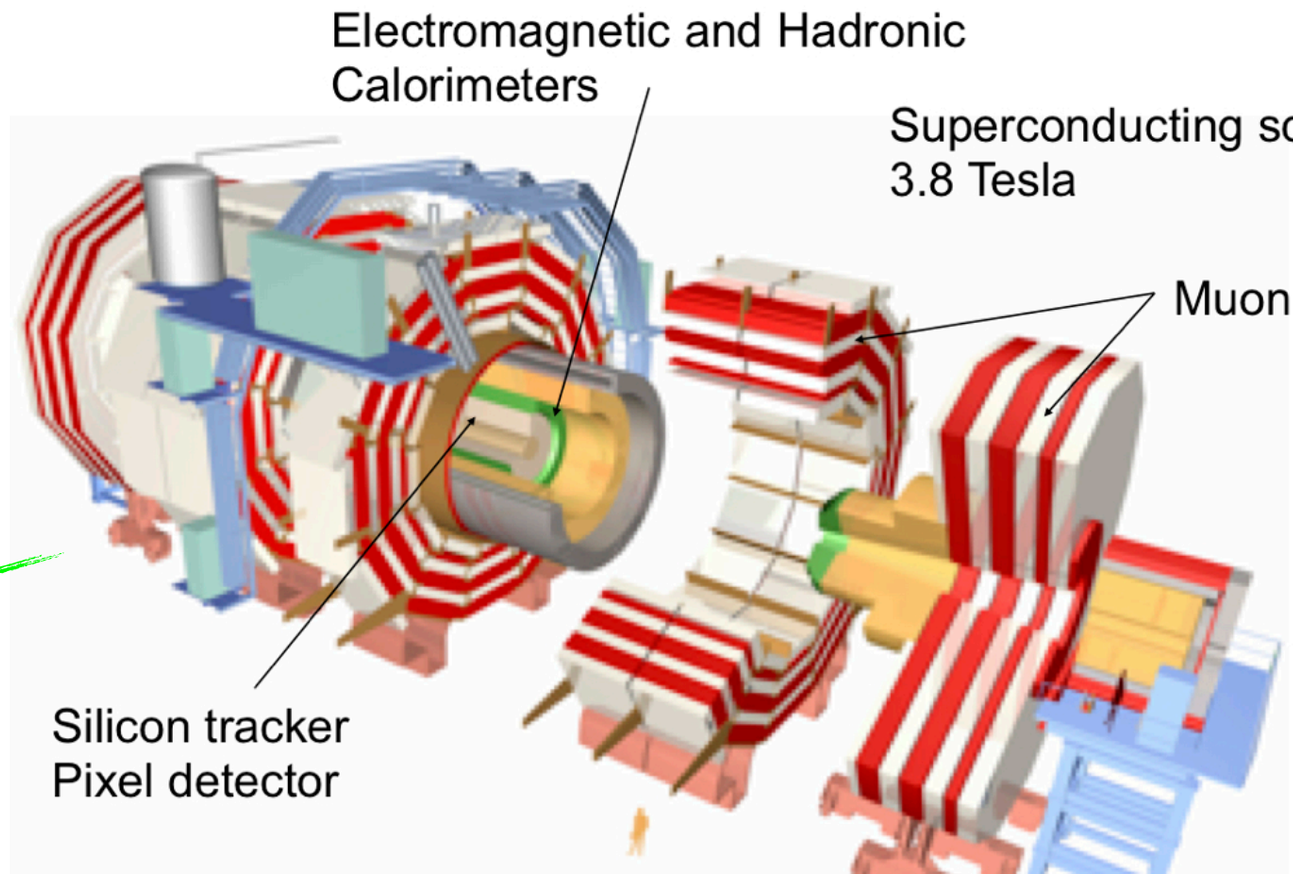
DESY

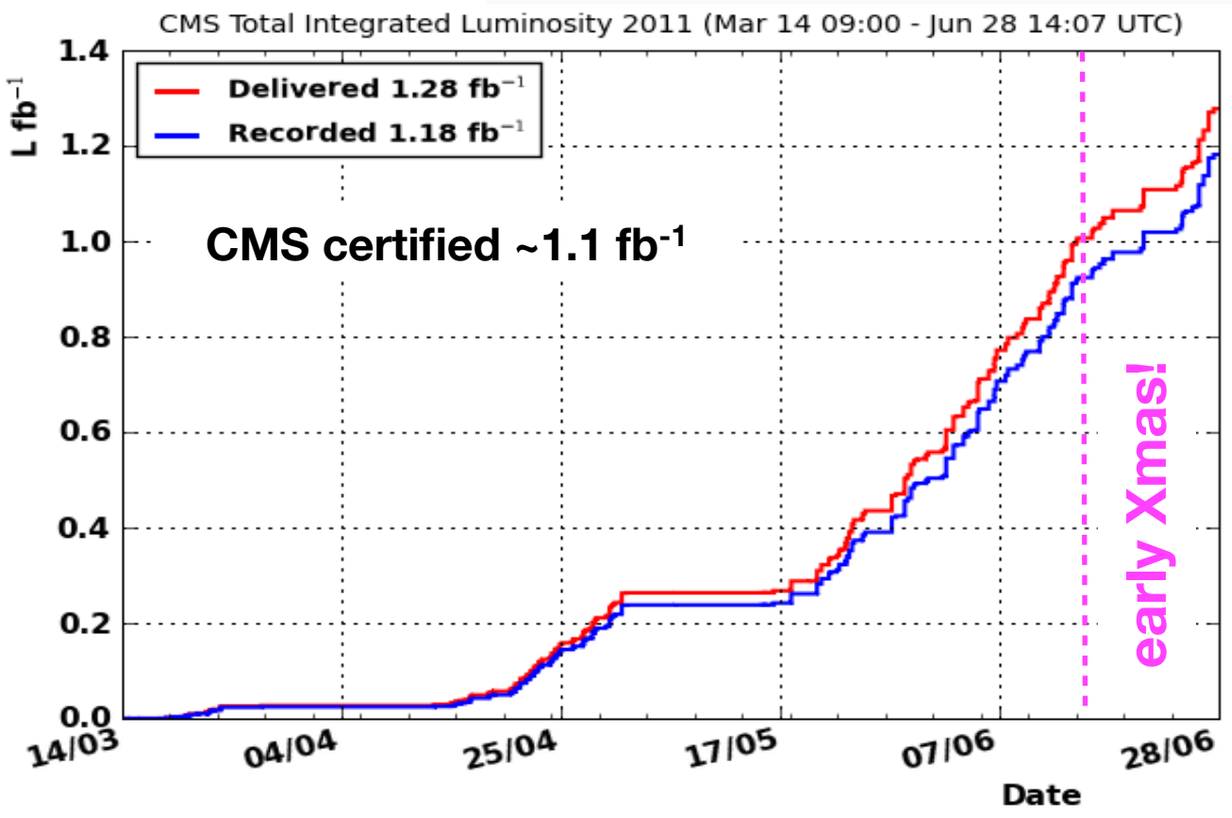
LHC Physics Discussions (LHC results for EPS)
25.07.2011 DESY

- Introduction
- Neutral Higgs searches in CMS
  - H → ττ (MSSM, SM)
  - H → WW (SM)
  - H → ZZ (SM)
  - H → γγ (SM)
- Combined results (SM)
- Summary

The CMS detector

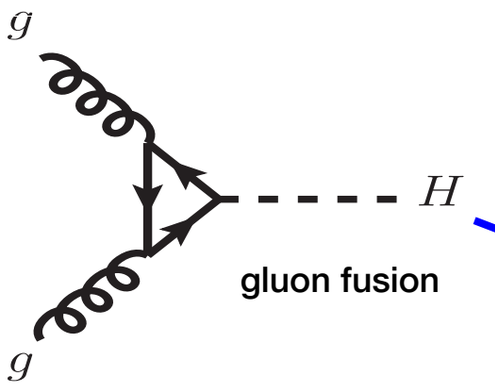




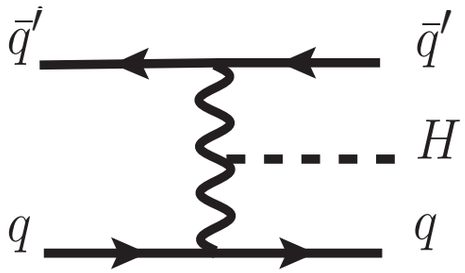


Higgs production at LHC

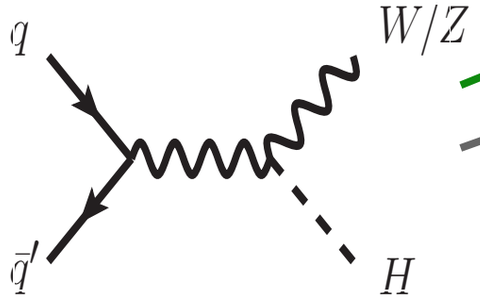
Standard Model



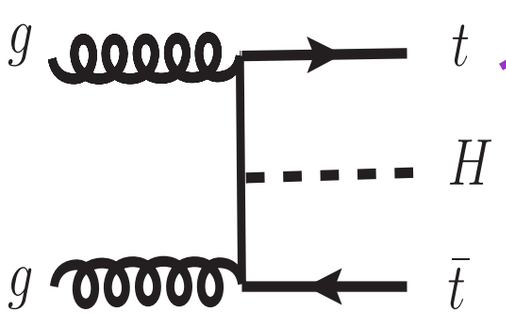
gluon fusion



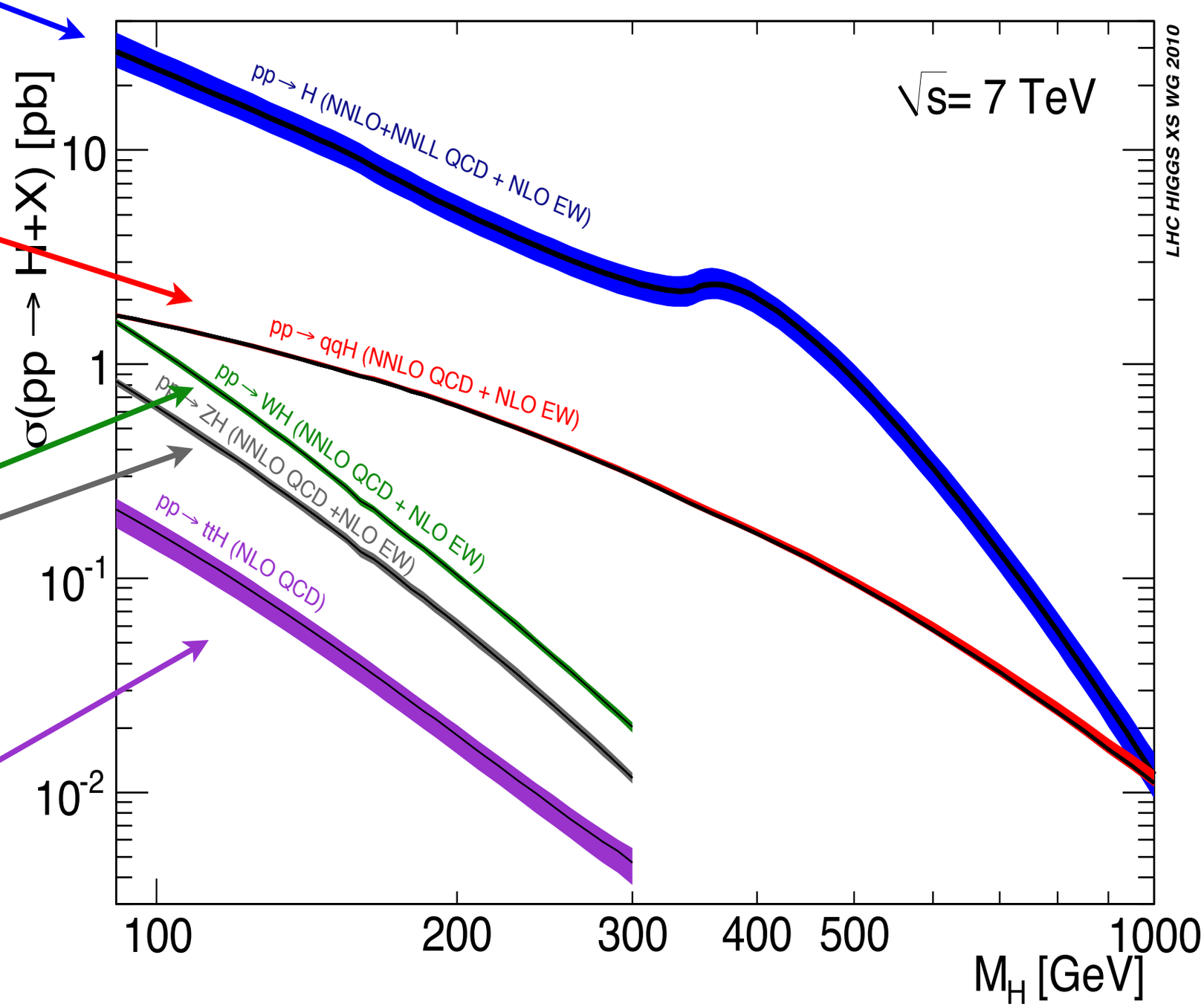
vector boson fusion



associated with vector boson

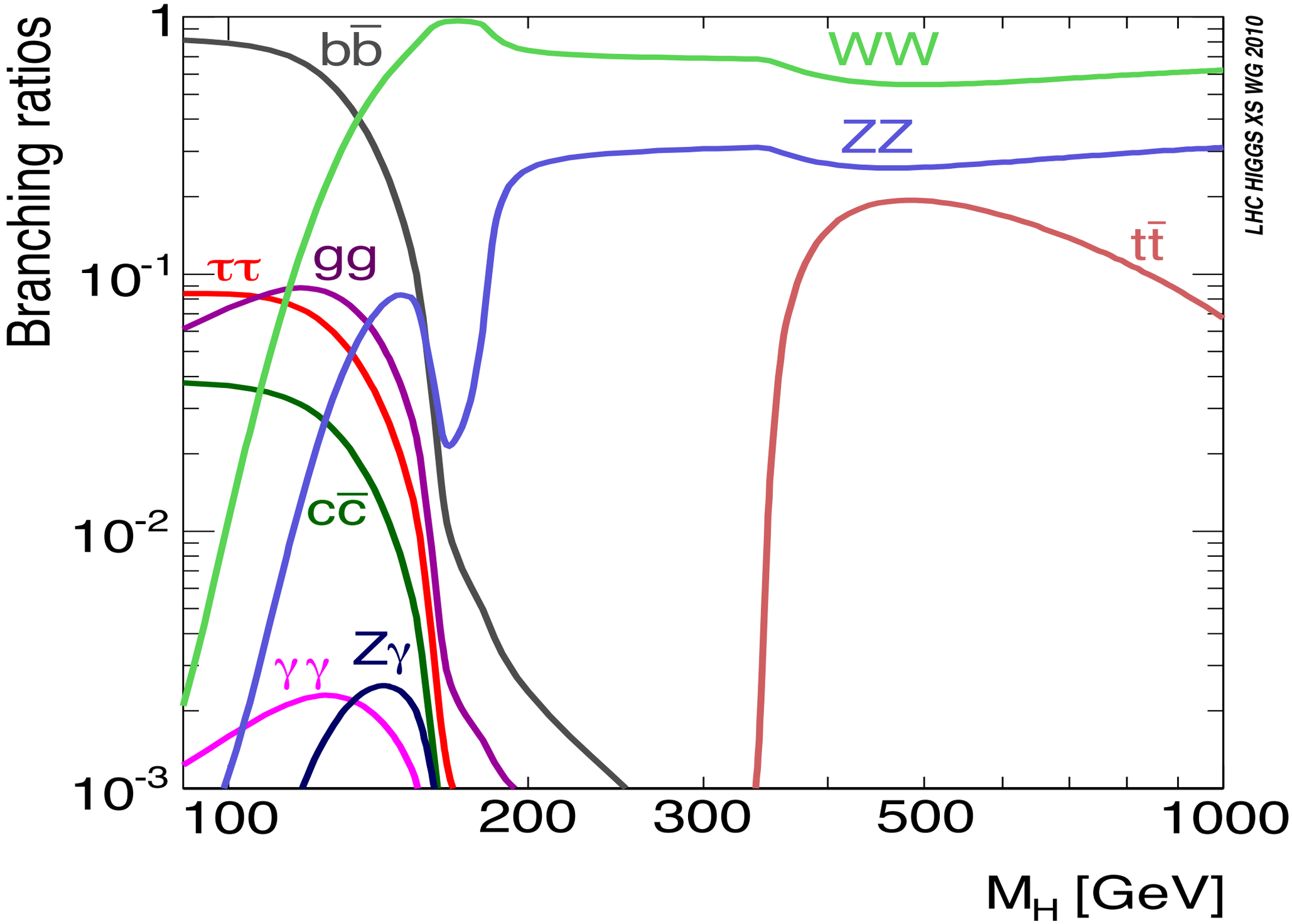


associated with top



Higgs decay modes

Standard Model



Higgs production at LHC

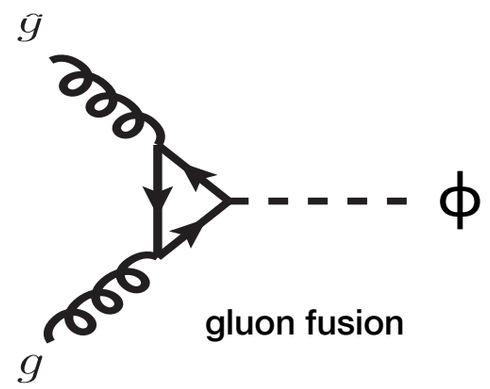
Minimal Supersymmetric Model

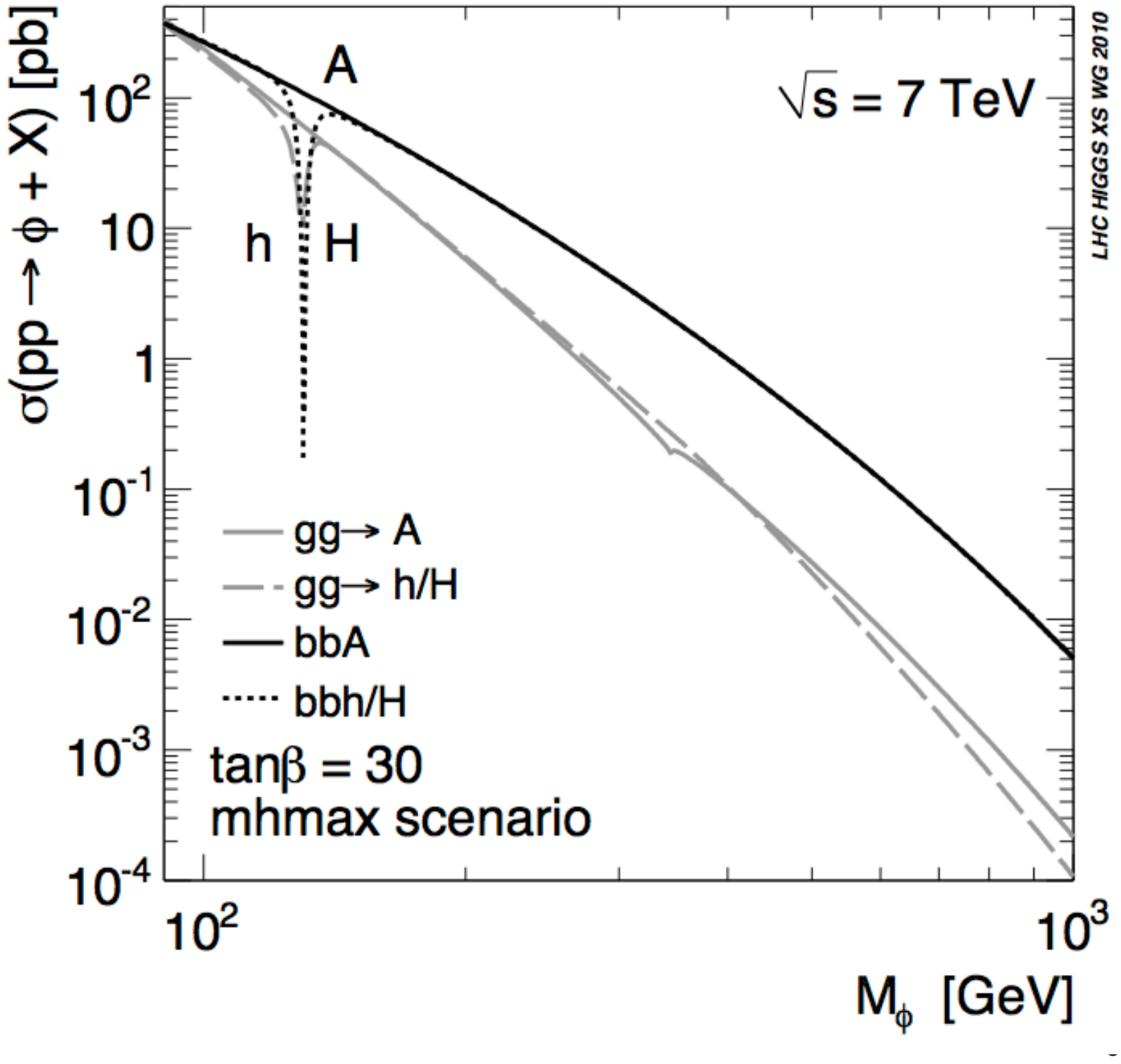
Three neutral Higgs: ϕ=h, H, A

Two charged Higgs: $H^{\pm}$
(not discussed here)

Parameters: tanβ and M_A

BR($\phi \to bb$) ≃ 85%–90%
BR($\phi \to \tau\tau$) ≃ 10%–15%





$H \rightarrow \tau\tau$

categorisation

- Standard Model categories
- Vector boson fusion (VBF)
  - #jets (pT>30GeV) = 2
  - Mjj > 350 GeV
  - $|\Delta\eta jj| > 3.5$
  - $\eta 1.\eta 2 < 0$
- Non-VBF
  - #jets (pT>30GeV) ≤ 1 .OR.
  - 2 jets that fail at least one of the VBF requirements

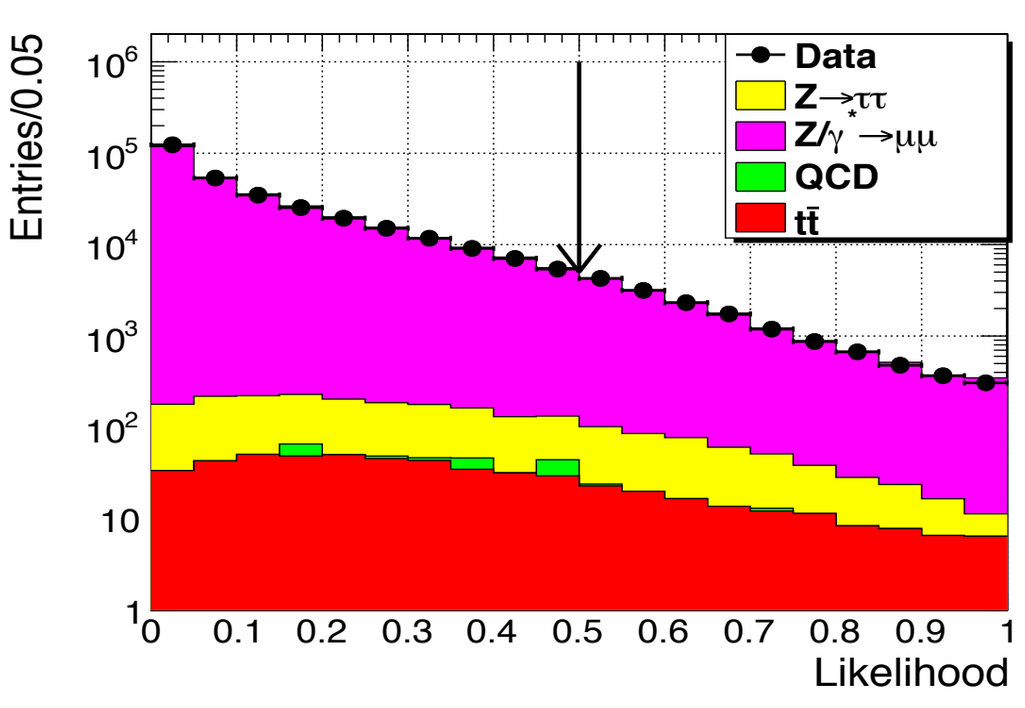
- MSSM categories
- b-tag
  - #jets (pT>30GeV) ≤ 1
  - #b-jets (pT>20GeV) > 0
- No b-tag
  - #jets (pT>30GeV) ≤ 1
  - #b-jets (pT>20GeV) = 0

$H \rightarrow \tau\tau$

event selection

- Standard lepton, jet, E_{Tmiss} reconstruction and selection
- Events selected with at least one muon and/or an electron
  - **$\mu+\tau_{had}$**
    - **$p_{T,\mu} > 15$ GeV, $|\eta_\mu| < 2.1$**
    - **$p_{T,\tau had} > 20$ GeV, $|\eta_{\tau had}| < 2.3$**
  - **$e+\tau_{had}$**
    - **$p_{T,e} > 15$ GeV, $|\eta_e| < 2.1$**
    - **$p_{T,\tau had} > 20$ GeV, $|\eta_{\tau had}| < 2.3$**
  - **$\mu+e$**
    - **$p_{T,\mu} > 20$ (10) GeV, $|\eta_\mu| < 2.1$**
    - **$p_{T,e} > 10$ (20) GeV, $|\eta_e| < 2.5$**
  - **$\mu+\mu$**
    - **$p_{T,\mu 1} > 20$ GeV, $|\eta_{\mu 1}| < 2.1$**
    - **$p_{T,\mu 2} > 10$ GeV, $|\eta_{\mu 2}| < 2.4$**

- Suppression of backgrounds with topological selections
  - e.g. μ+μ analysis uses a likelihood discriminant based on
    - pT(2μ)/ ∑ pT(μ)
    - DCASig(2μ)
    - η(2μ)
    - $\Delta\Phi(\mu+, p_{Tmiss})$
    - valid tau pair kinematic reconstruction

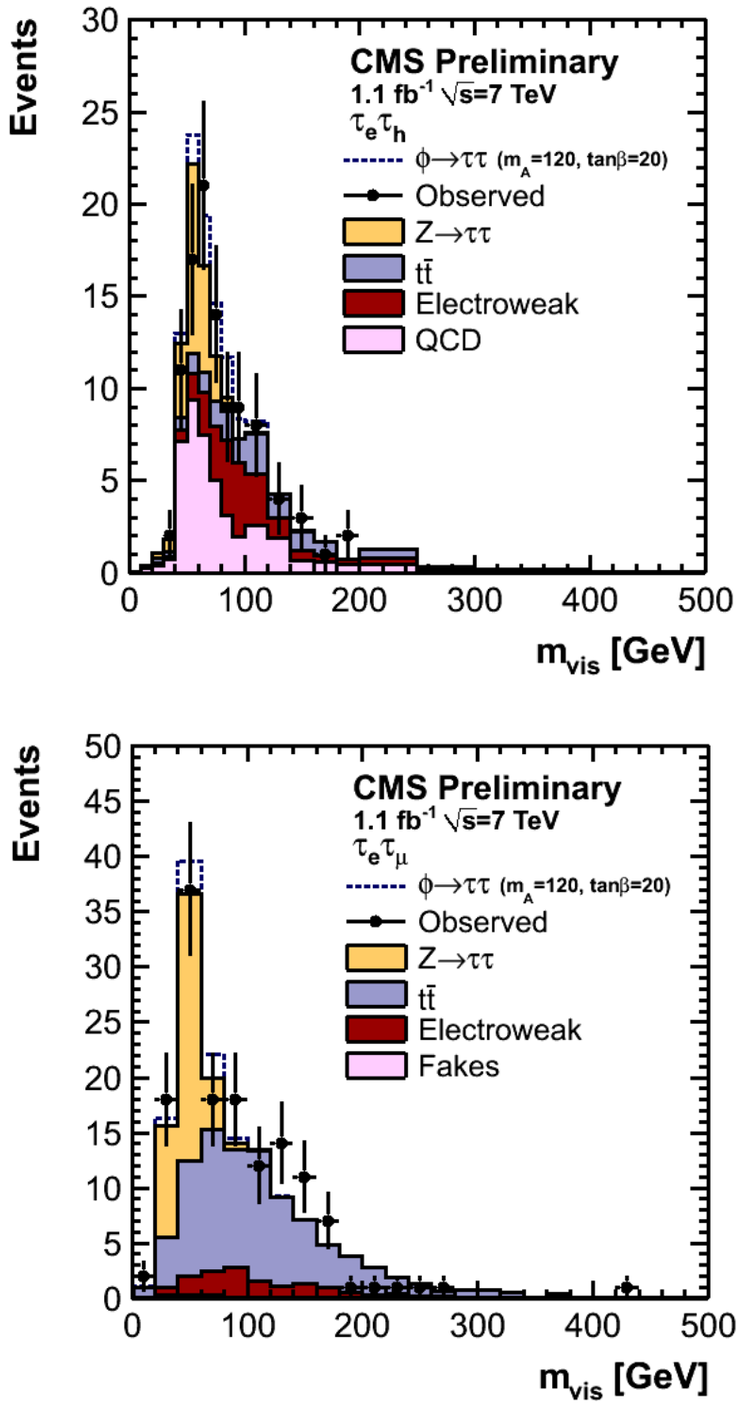


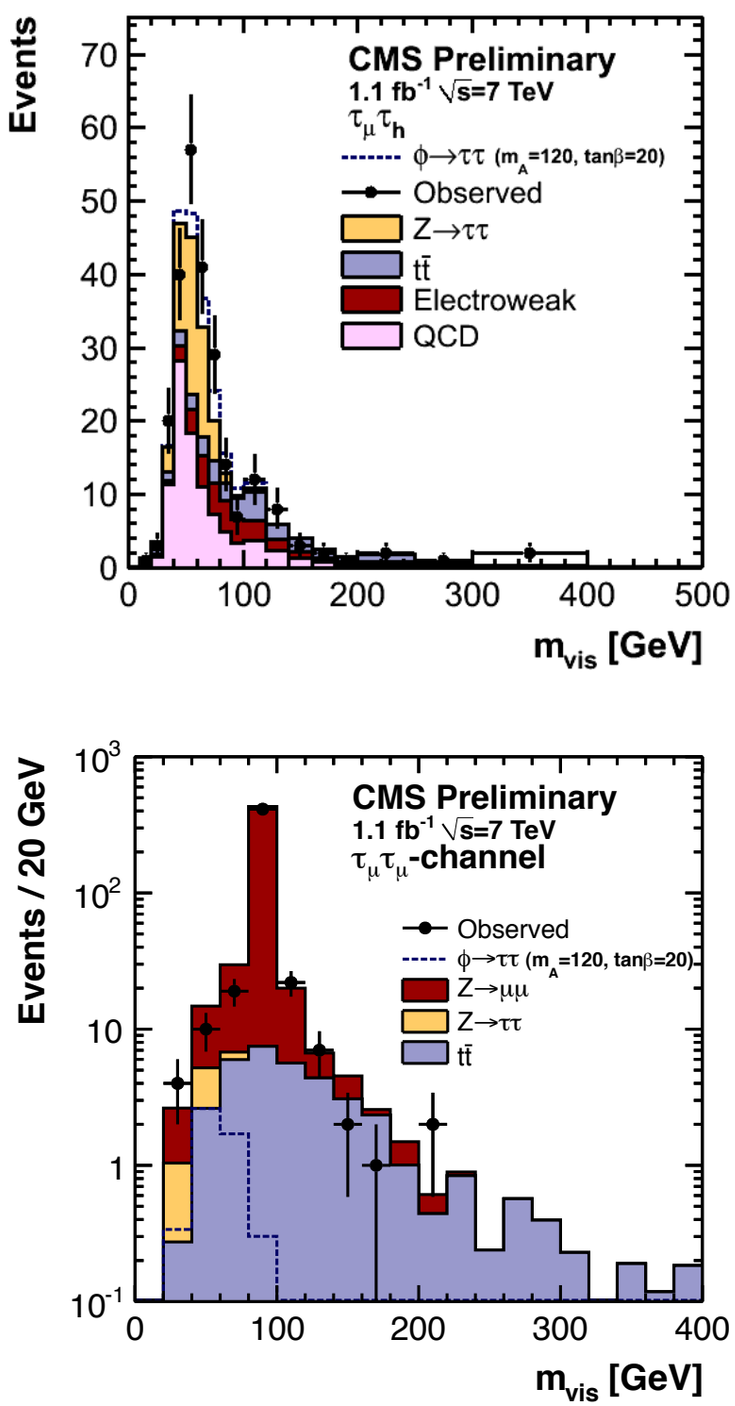
MSSM $\phi \rightarrow \tau\tau$

visible mass distributions

- Maximum likelihood fit of the tau pair visible mass spectrum
- In the μ+μ mode the fit is done in the 2D of the visible mass and the fitted tau invariant mass.
- No evidence for the presence of a Higgs boson signal…

b-tag

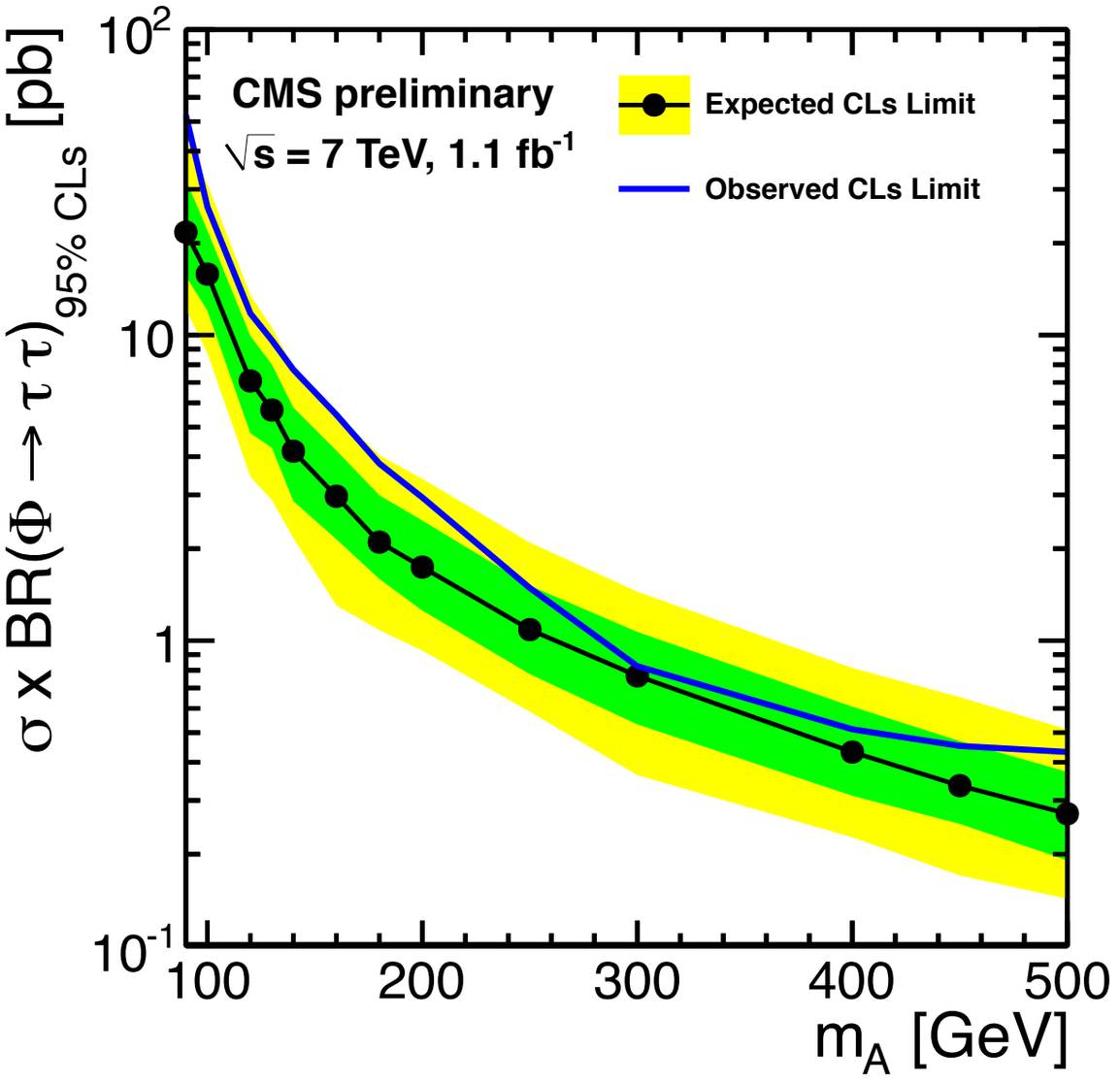


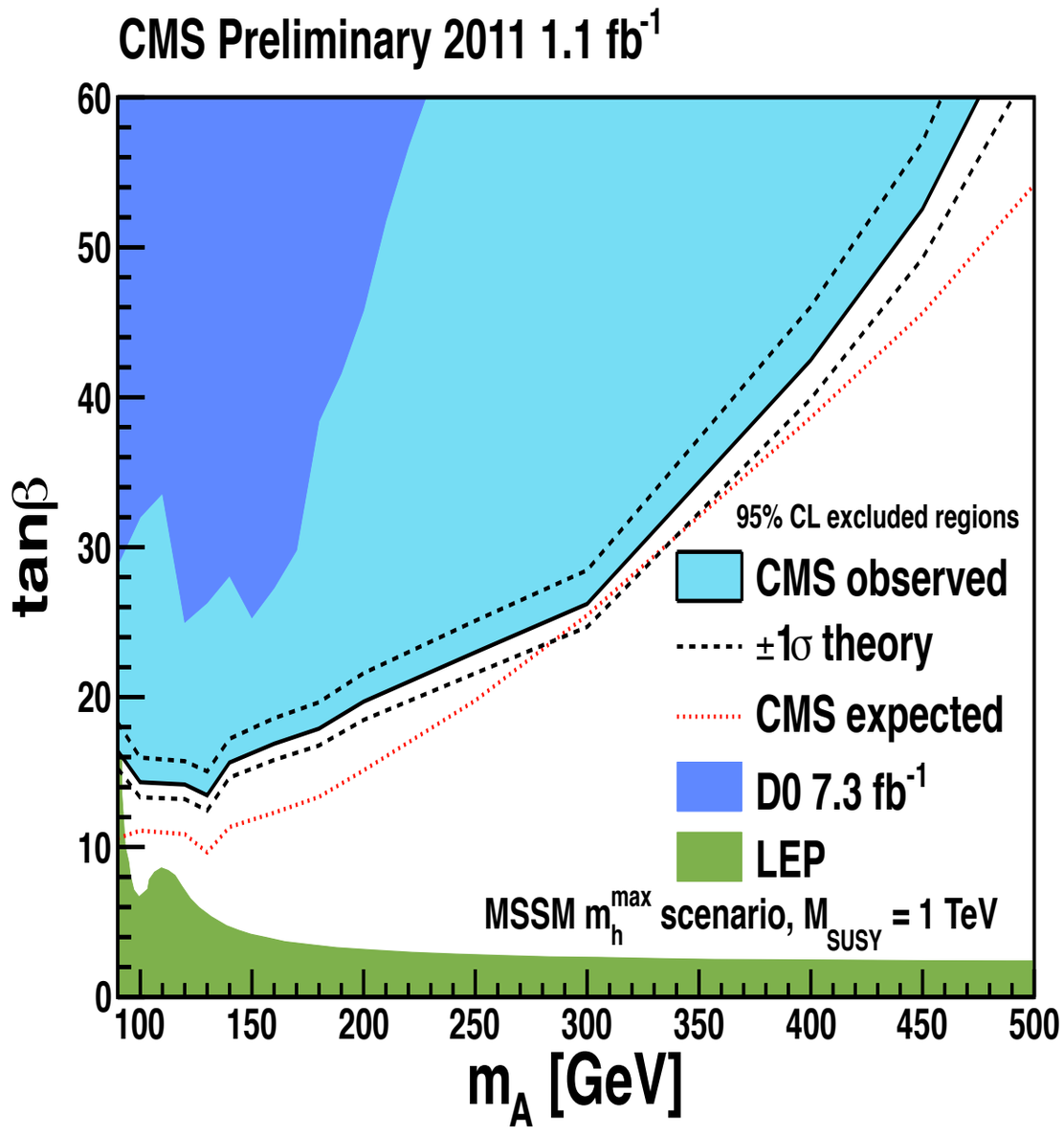


MSSM $\phi \rightarrow \tau\tau$

95% CL limits

- … 95% CL upper bounds are set on the Higgs cross section times the tau branching ratio.





SM H → ττ

visible mass distributions

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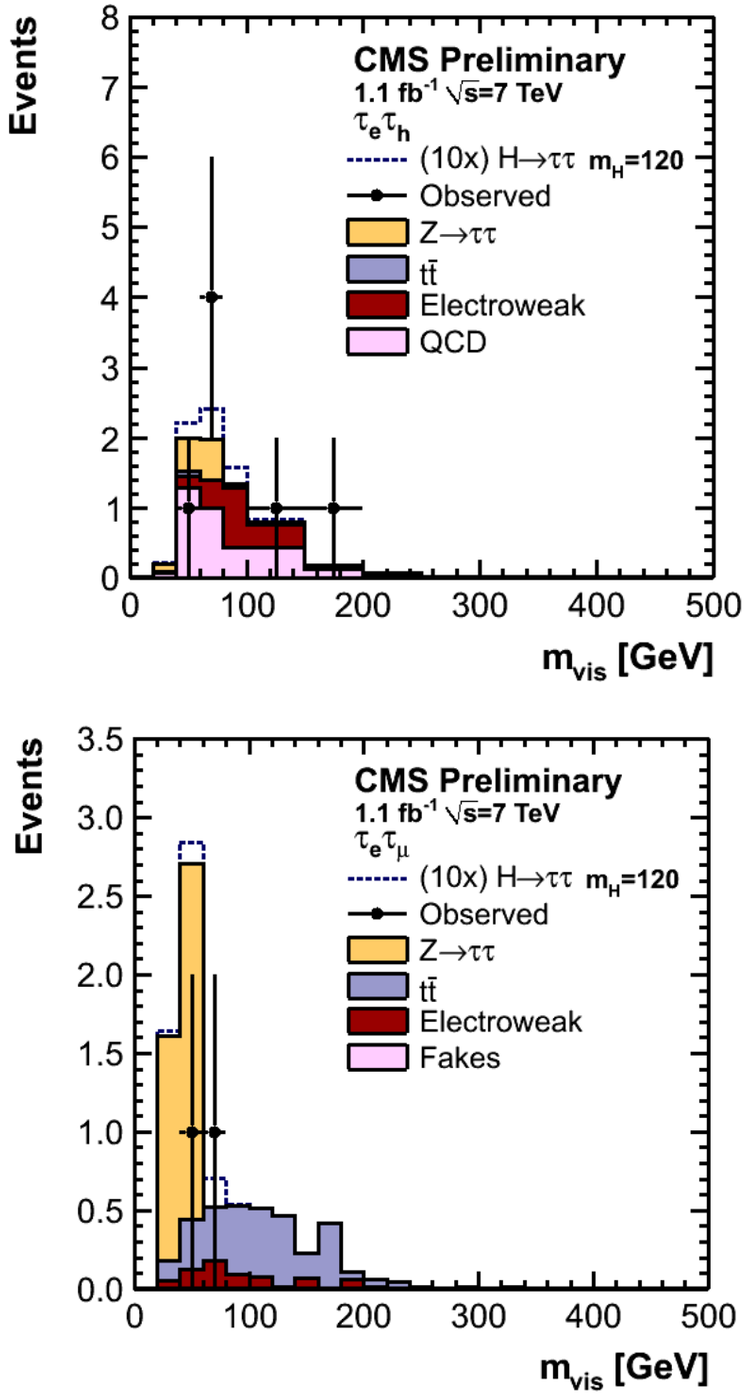
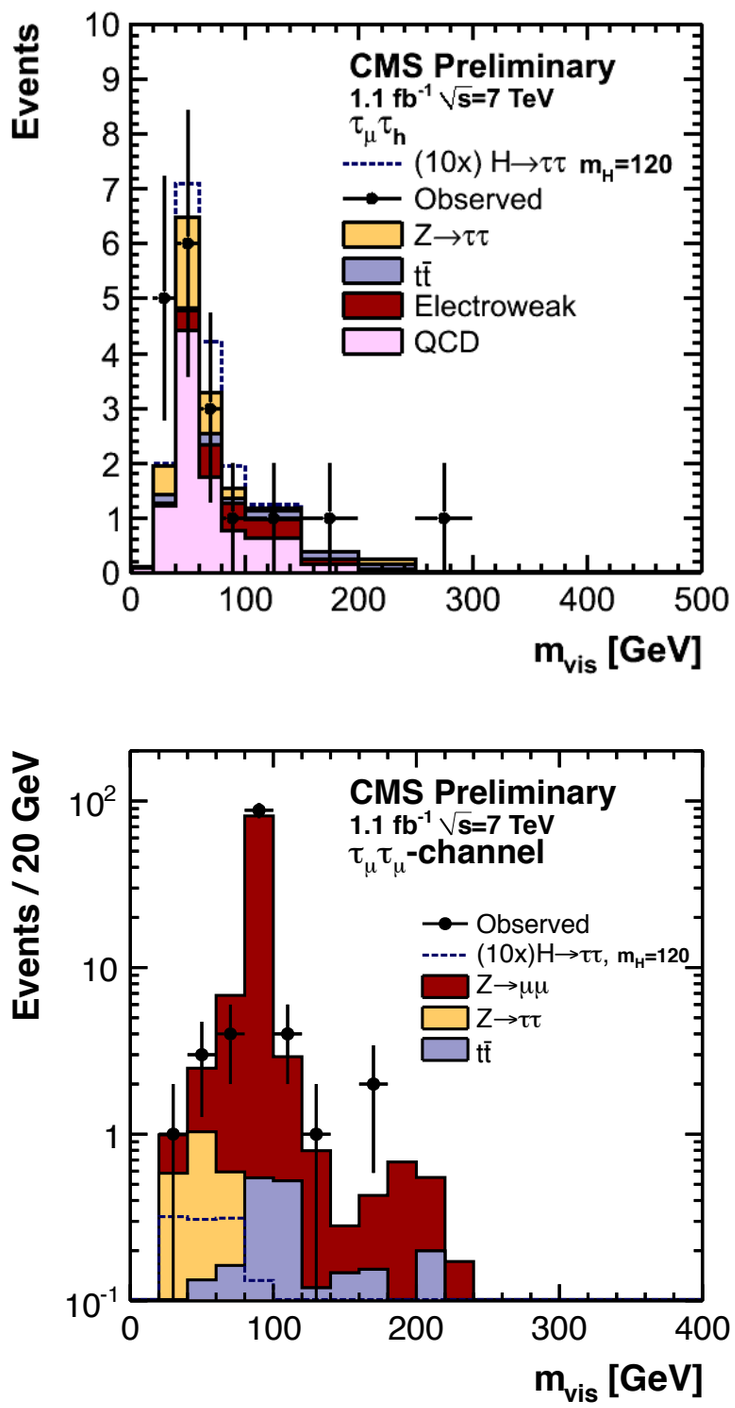
VBF





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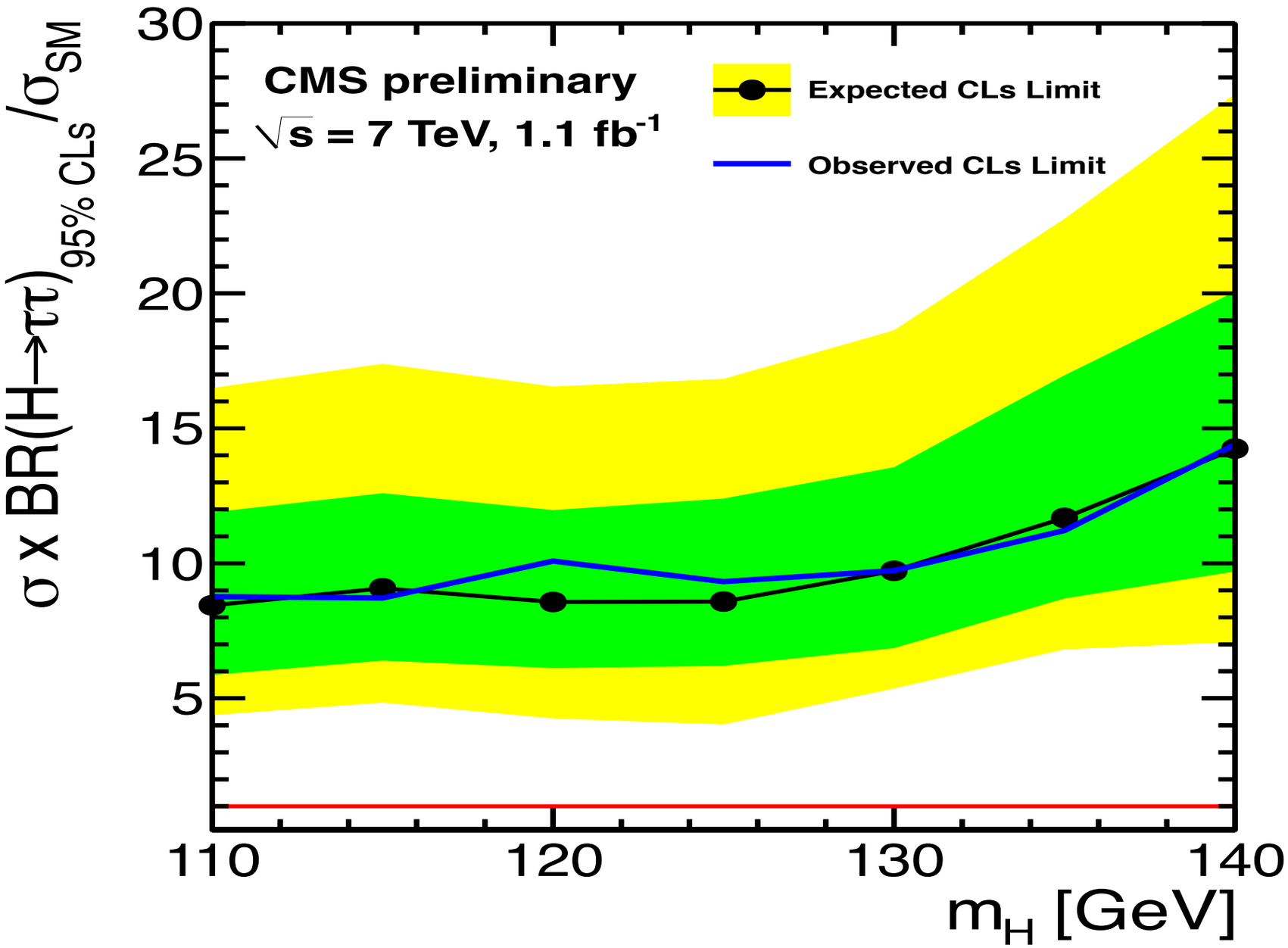
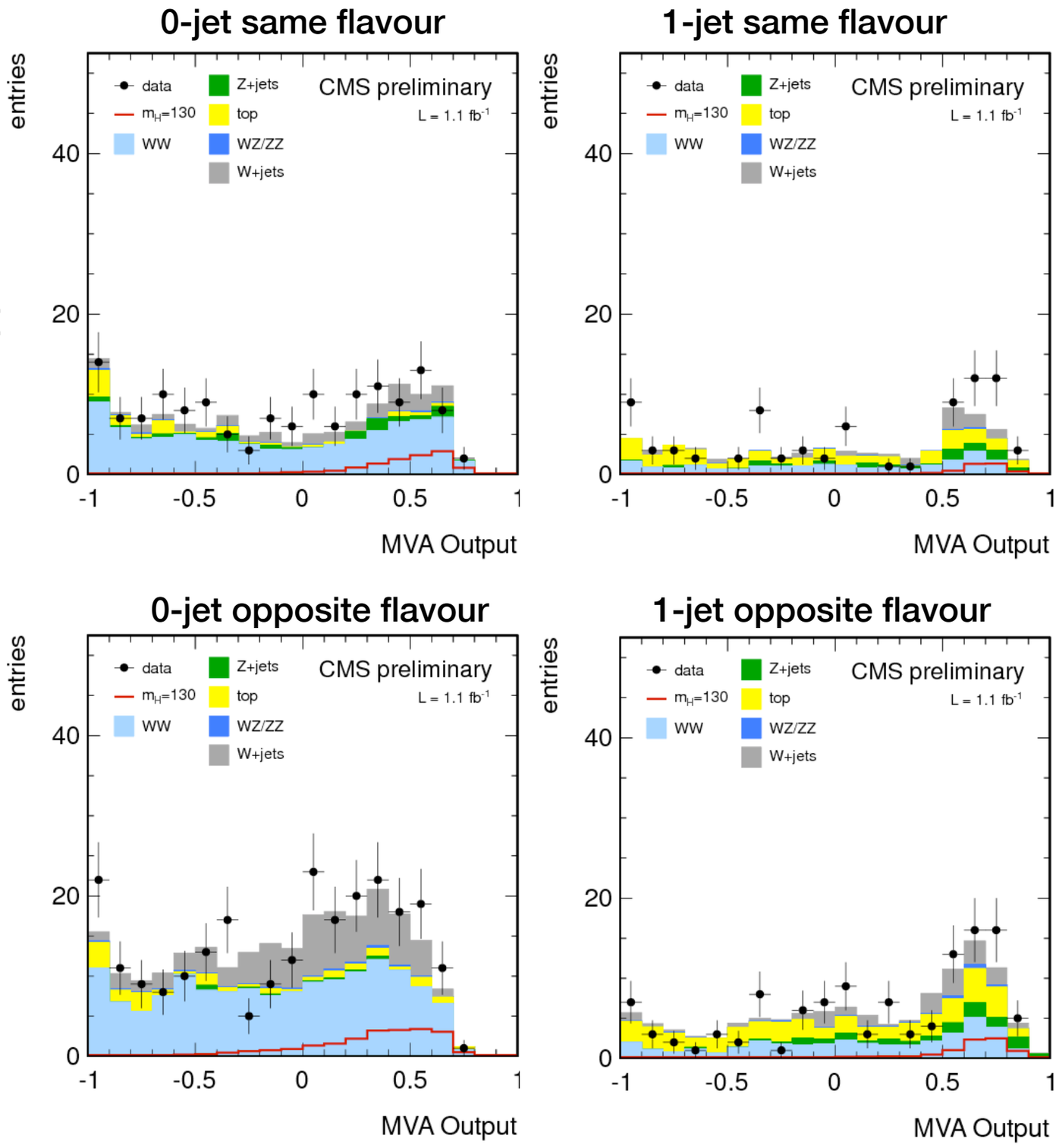


H → WW → 2 ℓ 2ν

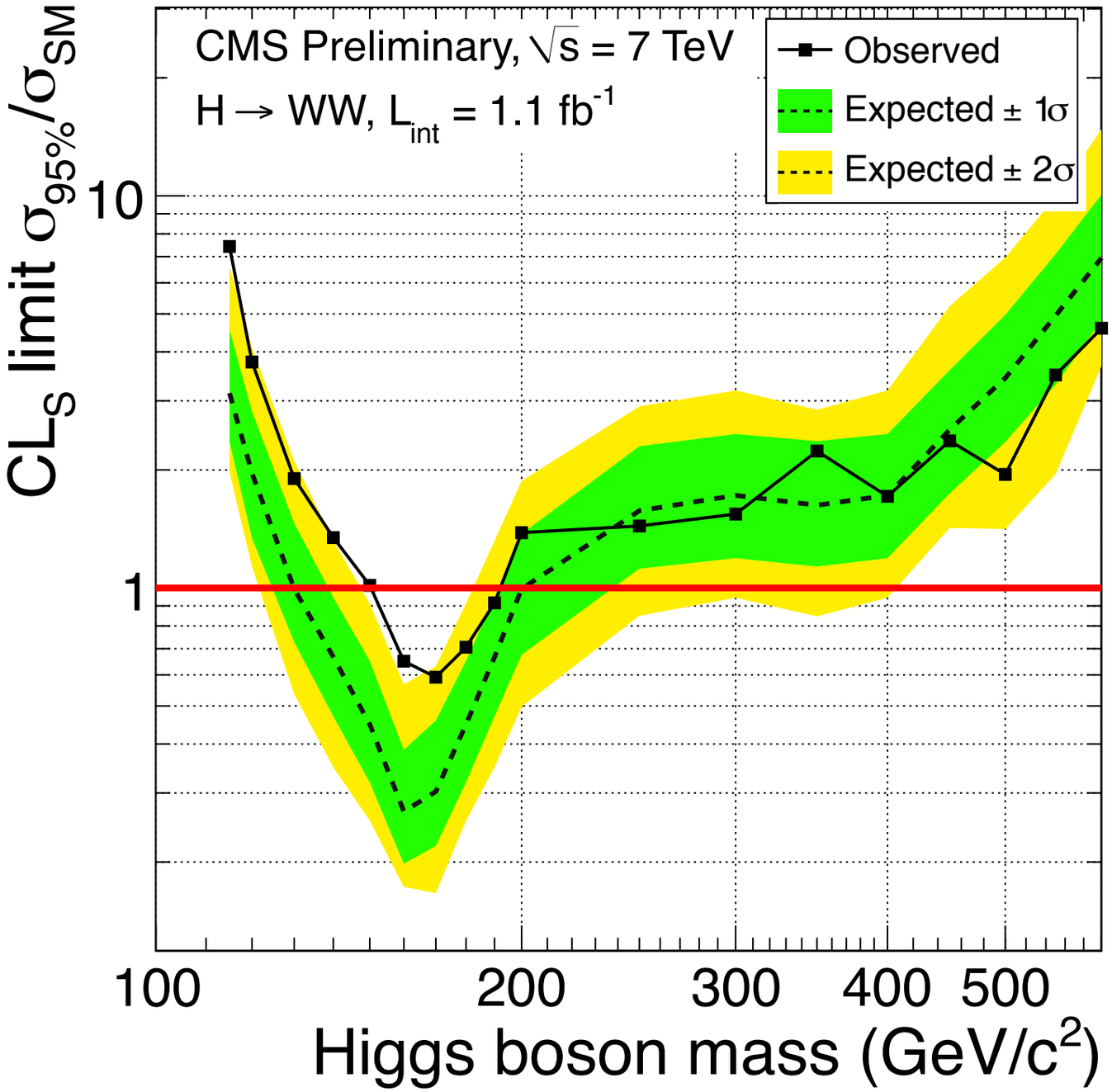
multivariate analysis

- 2 ℓ = ee, μμ, eμ
- Three categories
  - 0-jet, 1-jet, 2-jet
- Boosted Decision Tree for 0-jet and 1-jet categories based on discriminating variables:
  - p_{Tmax}, p_{Tmin} of leptons, m_{ll}, $m_T^{llEmiss}$, $\Delta\varphi_{ll}$, $\Delta\eta$, projected MET, ΔR_{ll}, flavour of leptons
  - One training per mass hypothesis
- Shape analysis using the binned MVA output comparing expected and observed event yields.



$H \rightarrow WW \rightarrow 2\ell 2\nu$

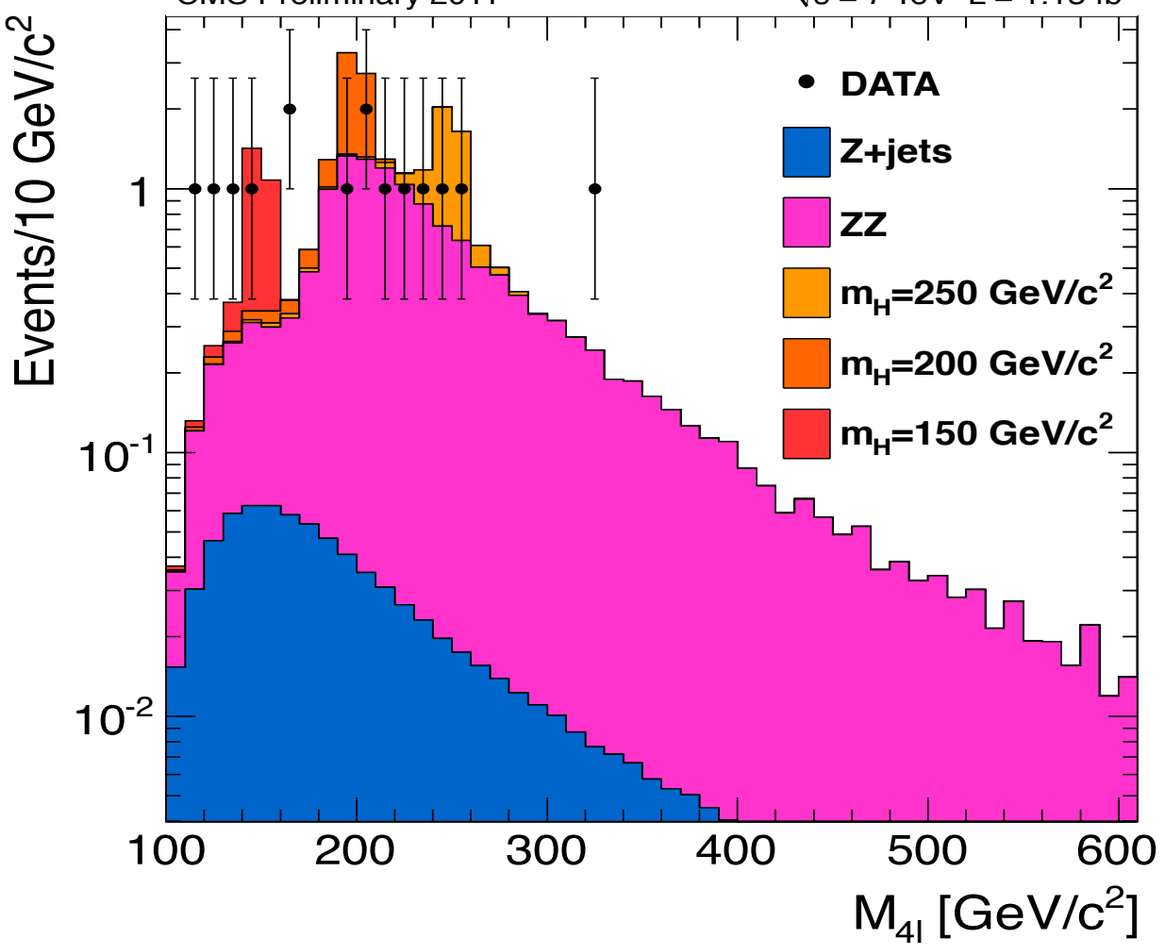
95% CL limits

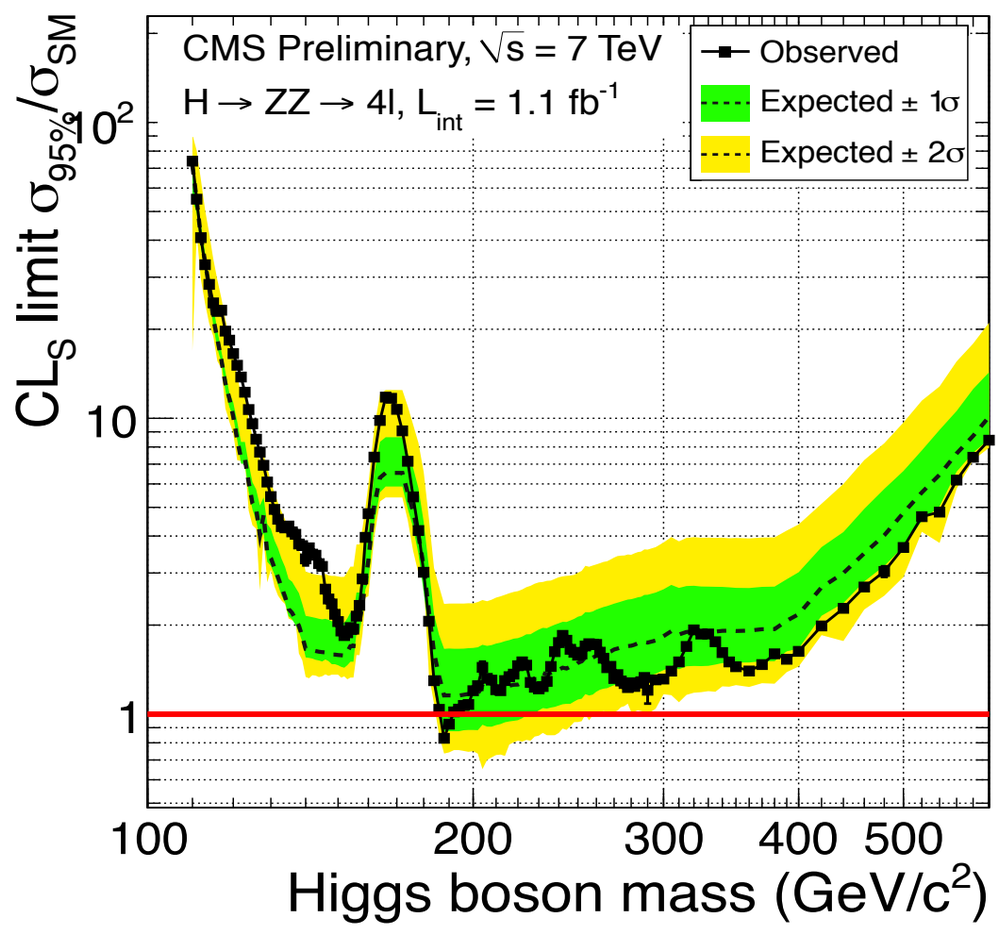


- No significant excess observed.
- Limits on the cross section times the branching ratio.
- Higgs with mass in range [150-193] GeV/c2 is excluded at 95% CL.

$H \rightarrow ZZ \rightarrow 4\ell$

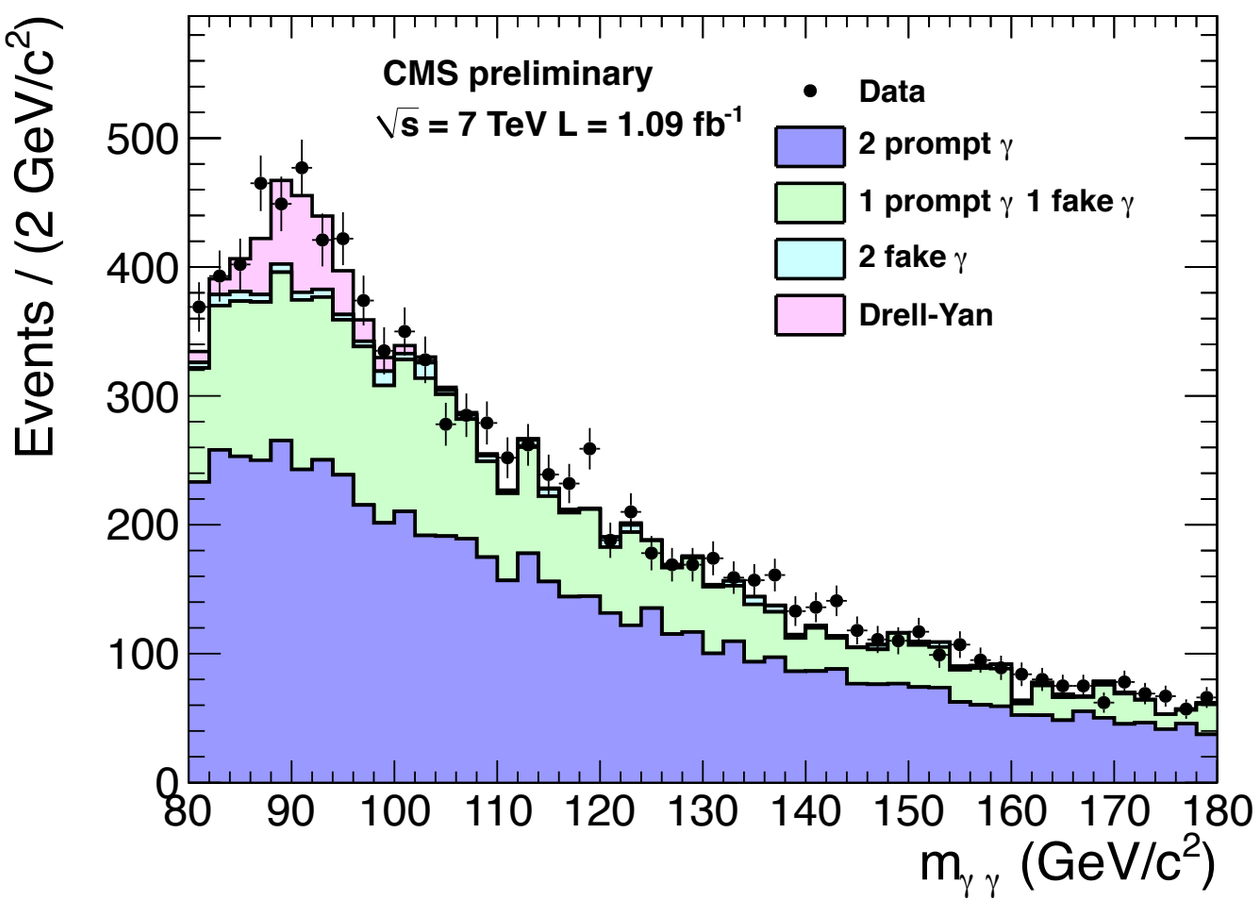
- 4ℓ = 4e, 4μ, 2e2μ
- $p_T(e) > 7$ GeV/c and $p_T(\mu) > 5$ GeV/c
- $p_{T1(2)} > 20$ (10) GeV; $m_{12} > 60$ GeV/c^2; $m_{34} > 12$ GeV/c^2
- $m_{4l} > 100$ GeV/c^2

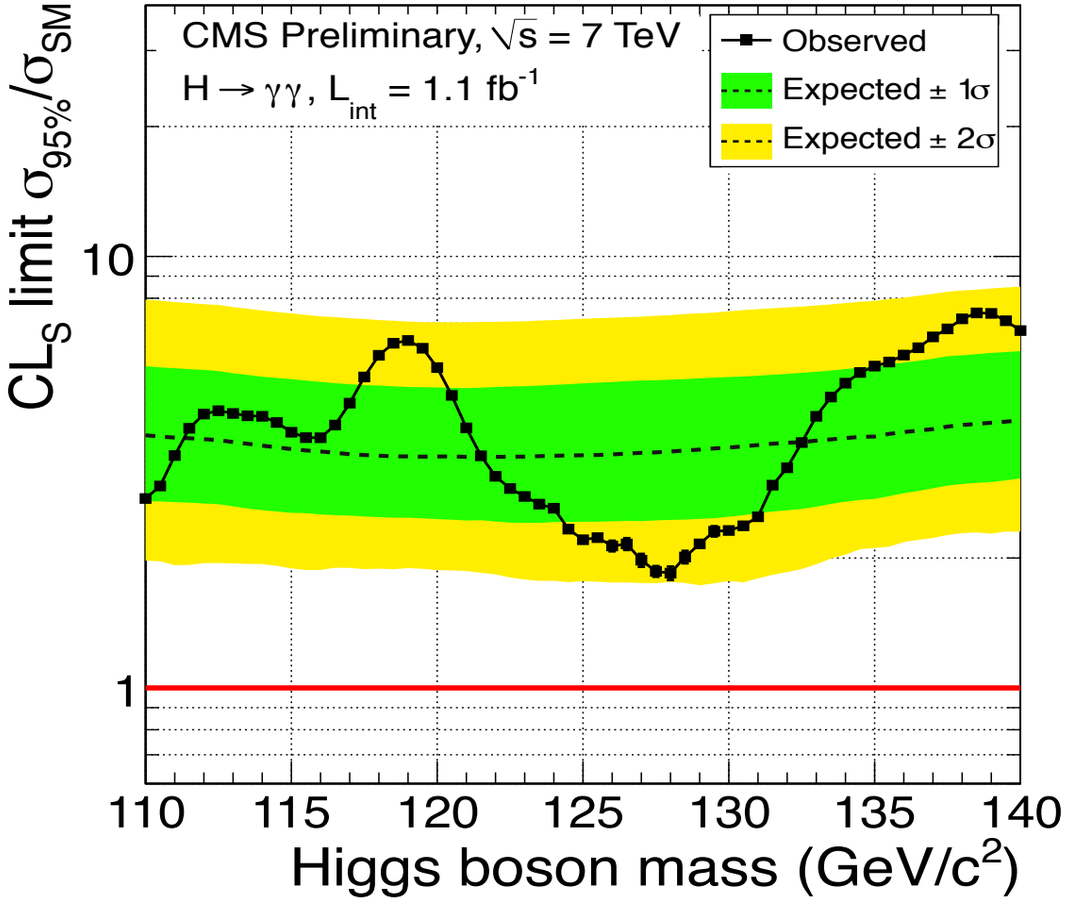




$H \rightarrow \gamma\gamma$

- Small branching ratio but one of the most significant discovery channel for low mass Higgs.
- Two isolated photons with $p_{T,\gamma 1} > 40$GeV and $p_{T,\gamma 2} > 30$ GeV;
  $|\eta| < 2.5$ excluding $1.4442 < |\eta| < 1.566$
- Analysis of eight categories to gain sensitivity.
- Good performance of the electromagnetic calorimeter.





Combined results

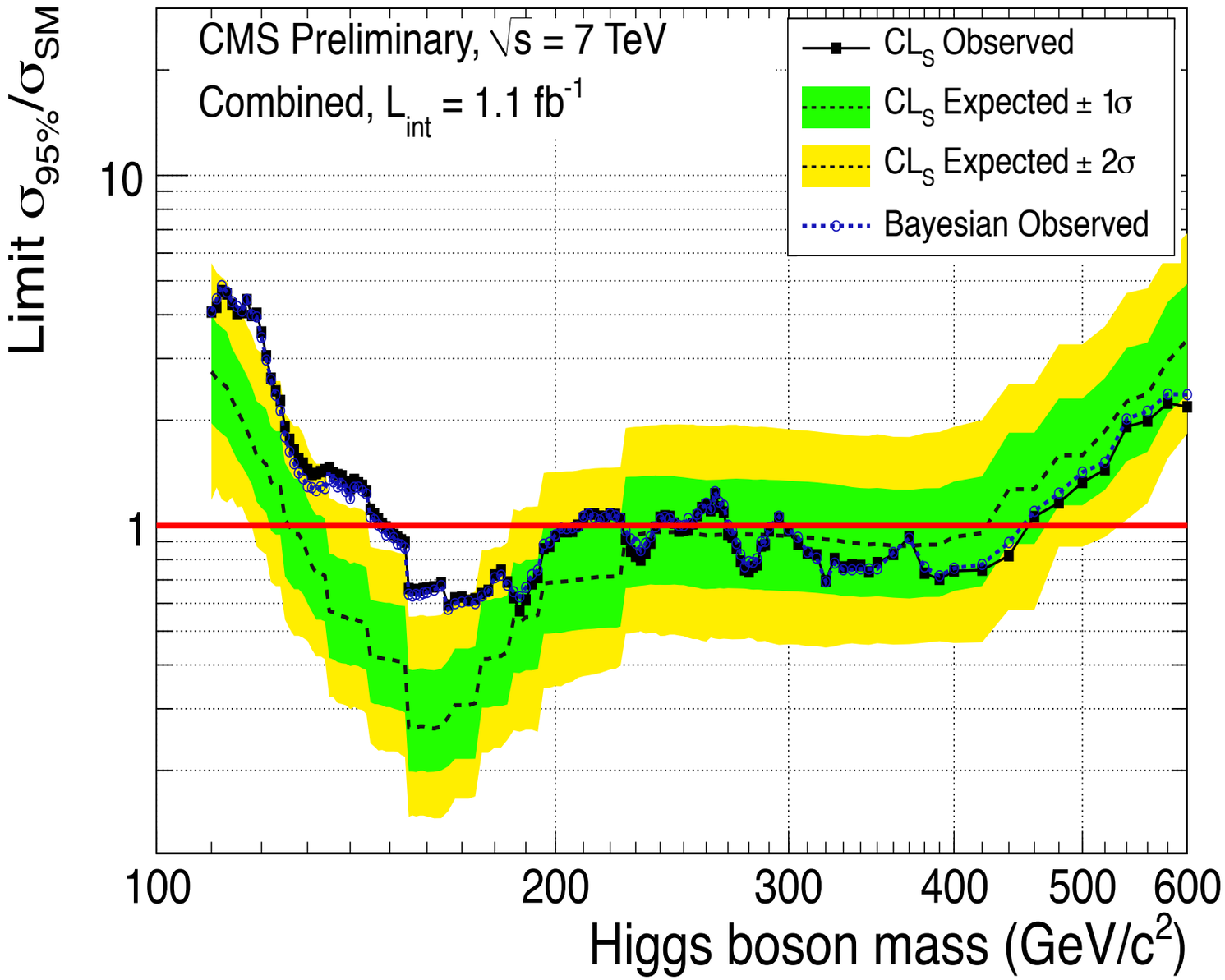
- Channels used in the combination

channel	mass range (GeV/c^2)	luminosity (fb^{-1})	number of sub-channels	type of analysis	number of nuisances
$H \to \gamma\gamma$	110-140	1.1	8	mass shape (unbinned)	3+40=43
$H \to \tau\tau$	110-140	1.1	6	mass shape (binned)	10+21=31
$H \to WW \to 2\ell 2\nu$	110-600	1.1	5	MVA (binned); cut&count	16+36=52
$H \to ZZ \to 4\ell$	110-600	1.1	3	mass shape (unbinned)	12+7=19
$H \to ZZ \to 2\ell 2\nu$	250-600	1.1	2	cut&count	14+4=18
$H \to ZZ \to 2\ell 2q$	226-600	1.0	6	mass shape (unbinned)	13+10=23
TOTAL (6)	**110-600**	**1.0-1.1**	**30**		**24+118=142**

- Method: modified frequentist limit (CL_S). Bayesian limits are also evaluated for comparison.

Combined results

95% CL limit on σ/σ_{SM}

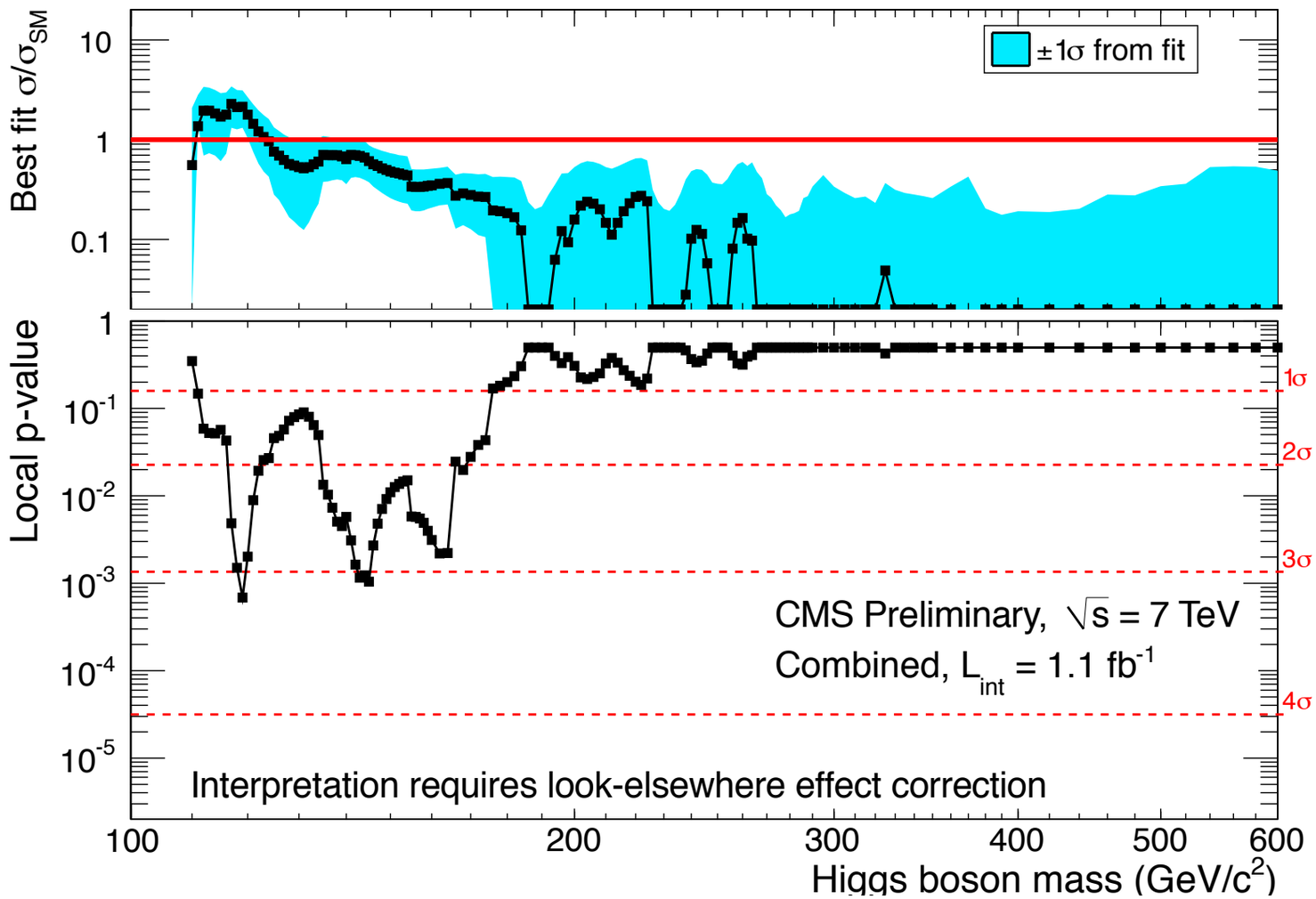


- Expected Higgs mass range excluded [127–420] GeV/c2
- Excluded range [149–206] GeV/c2 and [300–440] GeV/c2
- >2σ excesses at low mass compelled by H->WW, H->ZZ->4l and H->γγ

Combined results

Local p-value and best-fit σ/σ_{SM}

- Small p-value means excess, but no telling whether a signal or not.
- LEE trial factors range from 1–100 for the individual analysis.
- ~2σ excess at low masses
  - H->WW with LEE trial factor ~3 and poor mass resolution ~30GeV
  - H->ZZ->4l and H->γγ with large trial factors (up to 100!)



Summary

- A very brief overview of some of the latest results on Higgs search in CMS were presented.
- MSSM $\phi \rightarrow \tau\tau$ analysis much improved exclusion of $\tan\beta$ x M_A, with $\tan\beta$ limit as low as ~14 for low mass values.
- No evidence of Higgs boson found.
- $H \rightarrow WW$ analysis excludes Higgs in the mass range [150-193] GeV/c^2 with 95% CL.
- Combined results of six channels exclude Higgs in the mass ranges [149–206] GeV/c^2 and [300–440] GeV/c^2 with 95% CL.
- $>2\sigma$ excess observed at low mass values driven by channels with large look elsewhere effect and poor mass resolution.

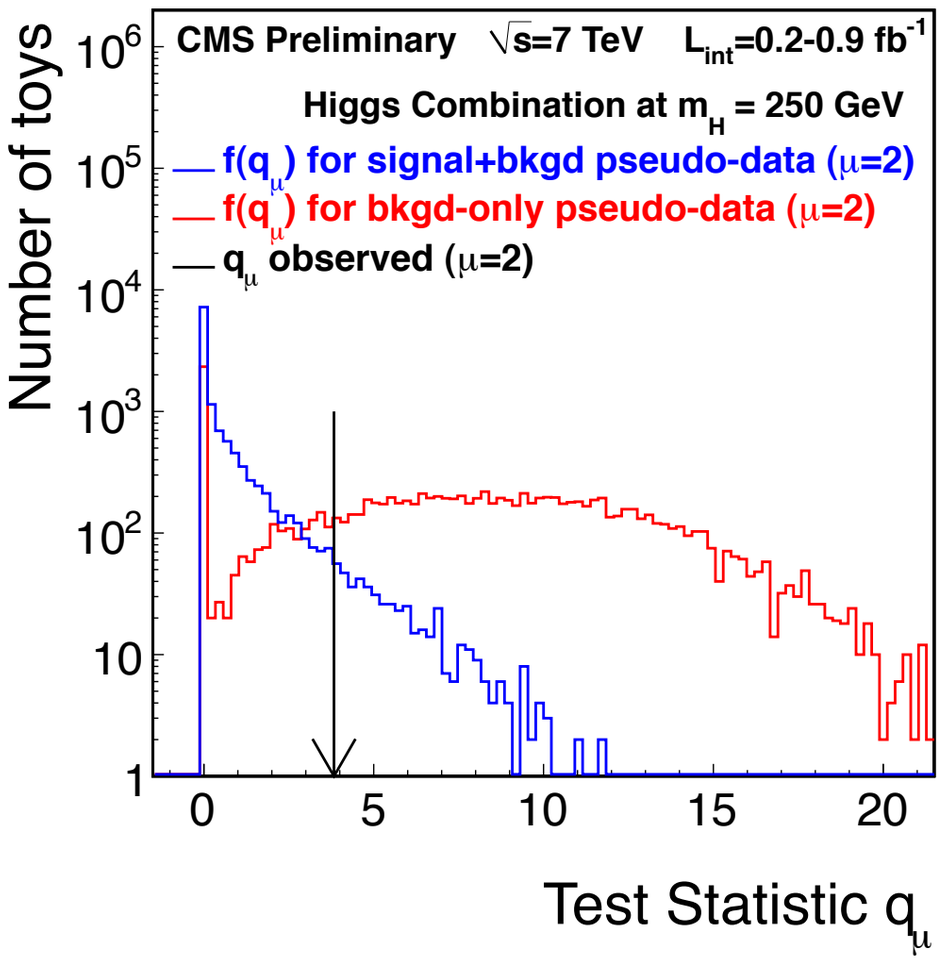
References

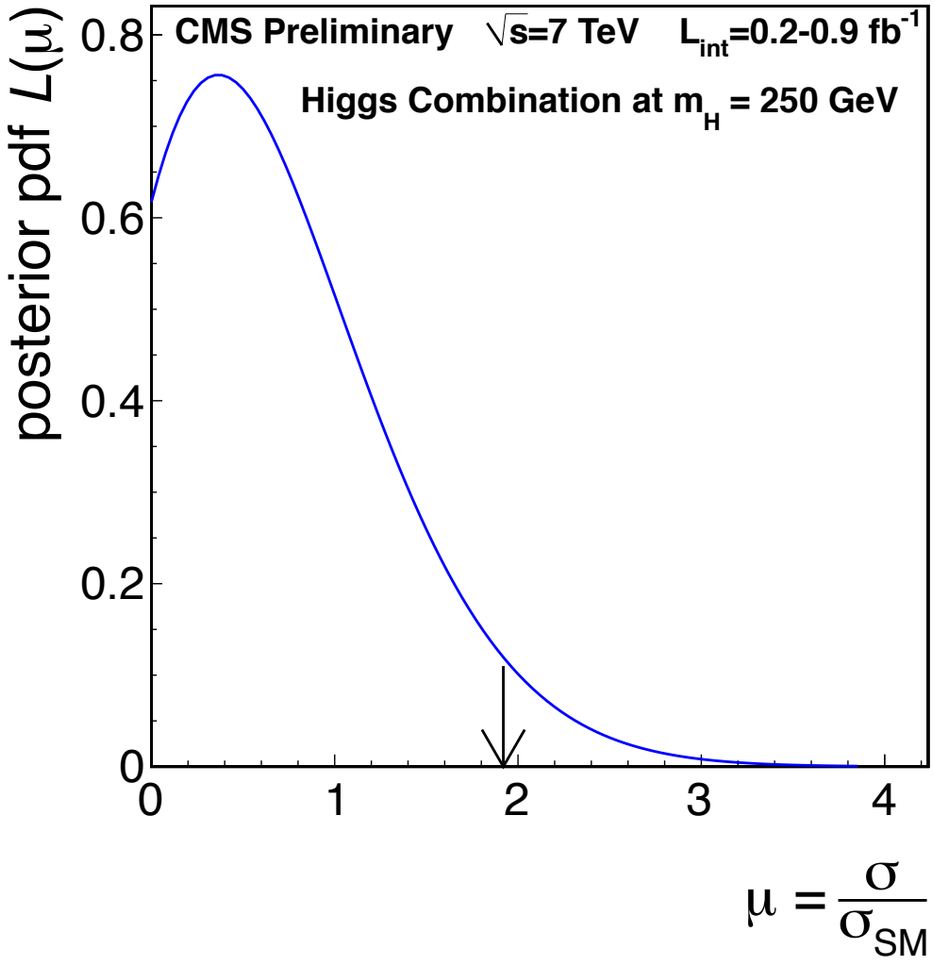
Analysis	Reference
H → ττ	CMS PAS HIG-11-009
H → WW → 2l2ν (0, 1, 2 jets)	CMS PAS HIG-11-003
H → ZZ → 4l	CMS PAS HIG-11-004
H → ZZ → 2l2ν	CMS PAS HIG-11-005
H → ZZ → 2l2q	CMS PAS HIG-11-006
H → γγ	CMS PAS HIG-11-010
H++ → l+l+	CMS PAS HIG-11-007
H+ → τ+ in top decays	CMS PAS HIG-11-008
Combined results	CMS PAS HIG-11-011

back up slides

Combined results

- Method: modified frequentist limit (CL_S).
- CLS = p0/pμ
- p0 (pμ) = probability to find an observation above the observed test statistic value for the background-only (background + signal) hypothesis.
- 95% confidence level: CLs = 0.05





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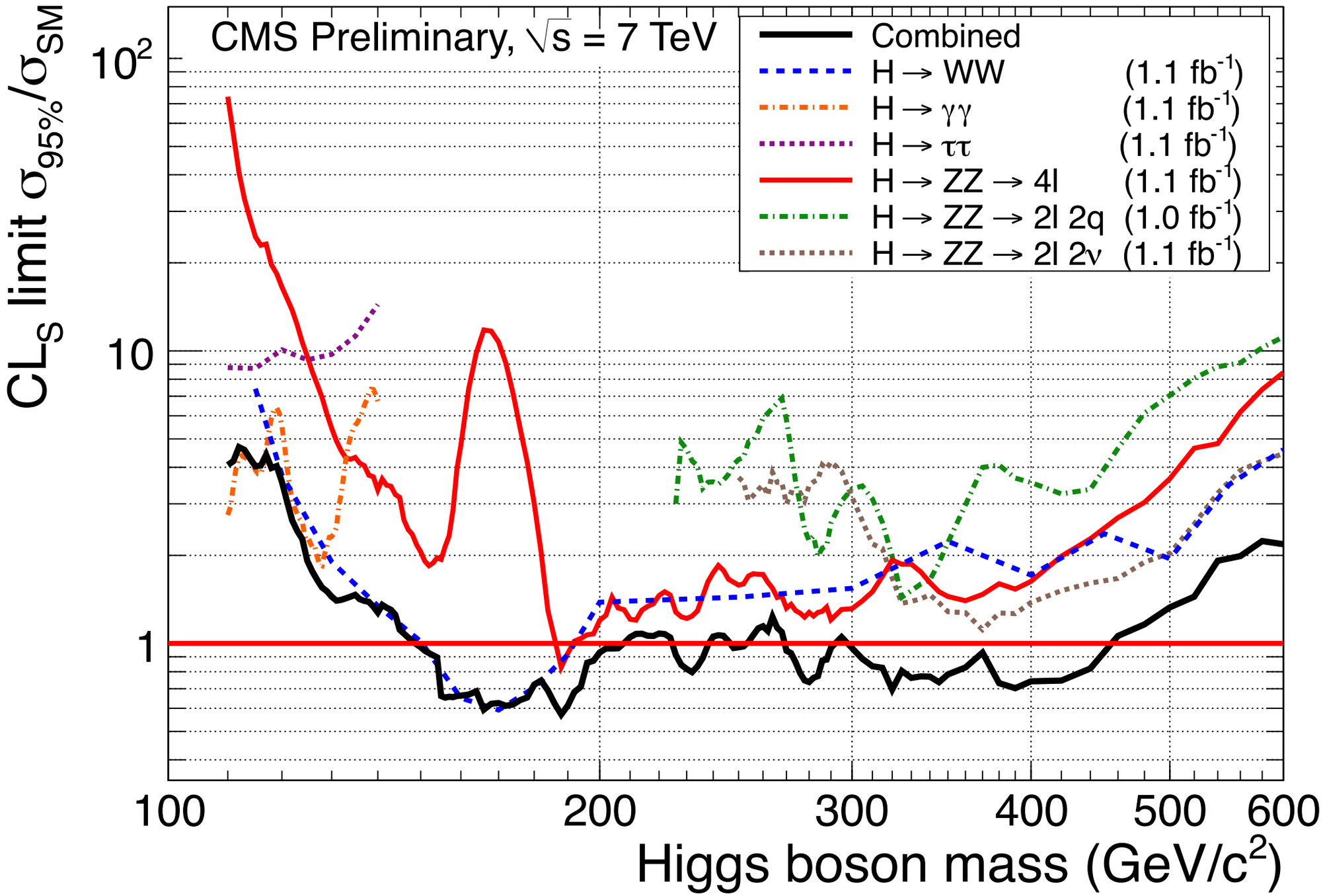

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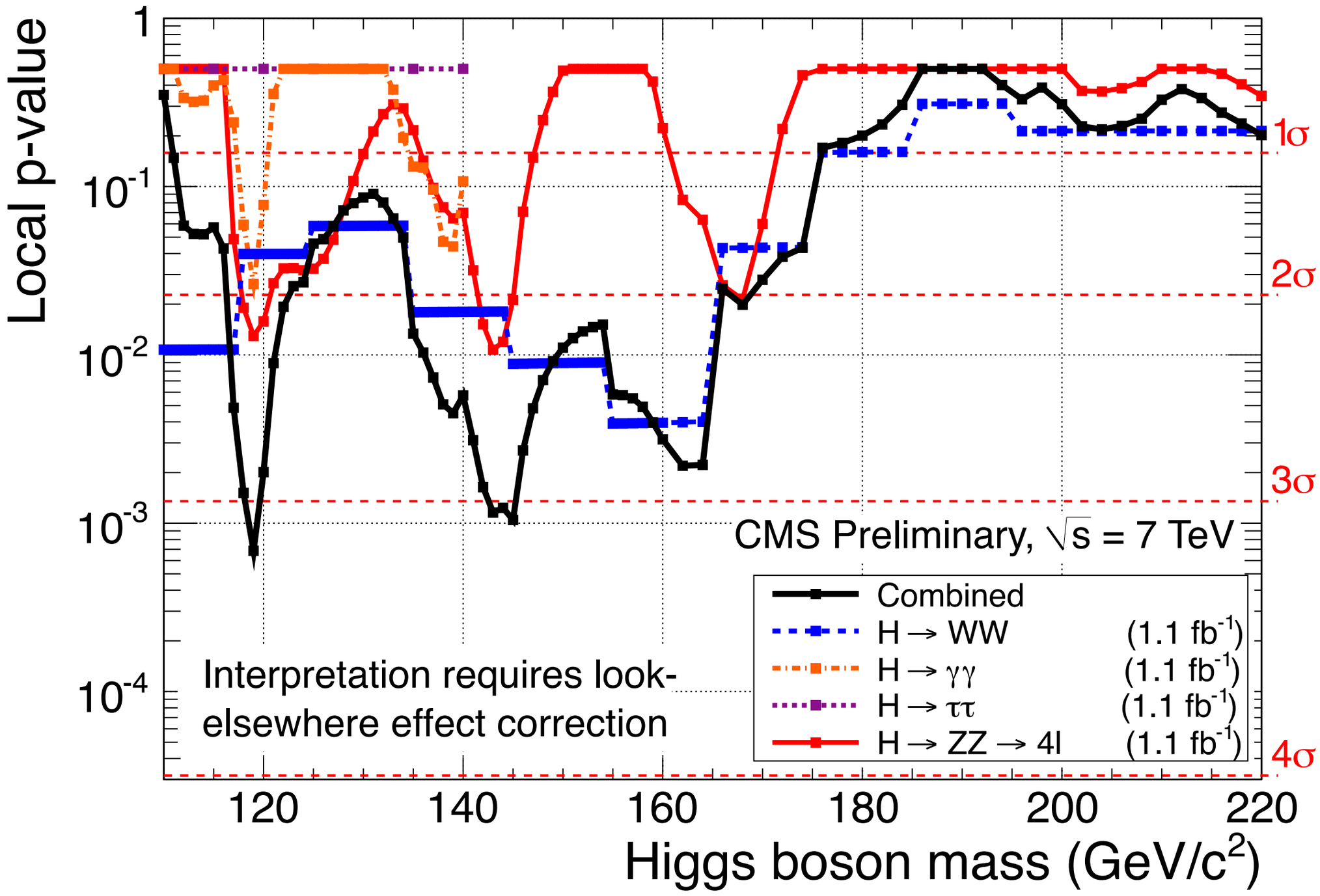

$H \rightarrow \tau\tau$

systematic uncertainties

- total integrated luminosity (6%)
- jet energy scale (5%)
- background normalisation
- Z production cross section (3%)
- lepton identification and isolation efficiency (1.0%)
- trigger (1.0%)
- tau identification efficiency uncertainty (6%)
- SM search theoretical uncertainty on the Higgs production (12% for ggH and 3.5% for qqH)
- uncertainty on the efficiency to identify a b-jet (10%) - MSSM search
- Uncertainties that contribute to mass spectrum shape variations include the tau (3%), muon (1%), and electron (2%) energy scales.

H → WW

systematic uncertainties

Table 3: Summary of all systematic uncertainties (relative). This is just an indicative table, since the precise values depend on the final state and jet-bin.

Source	$H \to$ W^+W^-	$qq \to$ W^+W^-	$gg \to$ W^+W^-	non-Z resonant WZ/ZZ	top	DY	W + jets	$V(W/Z)$ $+\gamma$
Luminosity	6	—	—	6	—	—	—	6
Trigger efficiencies	1.5	1.5	1.5	1.5	—	—	—	1.5
Muon efficiency	1.5	1.5	1.5	1.5	—	—	—	1.5
Electron id efficiency	2.5	2.5	2.5	2.5	—	—	—	2.5
Momentum scale	1.5	1.5	1.5	1.5	—	—	—	1.5
$E_{\mathrm{T}}^{\mathrm{miss}}$ resolution	2.0	2.0	2.0	2.0	2.0	3.0	—	1.0
Jet counting	7-20	—	5.5	5.5	—	—	—	5.5
Higgs cross section	5-15	—	—	—	—	—	—	—
WZ/ZZ cross section	—	—	—	3.0	—	—	—	—
$qq \to WW$ norm.	—	15	—	—	—	—	—	—
$gg \to WW$ norm.	—	—	50	—	—	—	—	—
W + jets norm.	—	—	—	—	—	—	36	—
top norm.	—	—	—	—	25	—	—	—
$Z/\gamma^* \to \ell^+\ell^-$ norm.	—	—	—	—	—	60	—	—
Monte Carlo statistics	1	1	1	4	6	20	20	10

$H \rightarrow ZZ \rightarrow 4l$

systematic uncertainties

Summary of the magnitude of systematic uncertainties in percent.

Luminosity	6
Trigger efficiency	1.5
Higgs cross section	17-20
Higgs B.R.	2
Lepton reco/ID eff.	2-3
Lepton isolation eff.	2
Electron energy scale	3

$H \to \gamma\gamma$

systematic uncertainties

Source	Uncertainty	
Photon identification efficiency		
barrel	1.0%	
endcap	2.5%	
R_9 >0.94 efficiency		
(results in class migration) barrel	4%	
endcap	6.5%	
	$R_9 > 0.94$	$R_9 < 0.94$
Energy resolution ($\Delta\sigma/E_{MC}$)		
barrel	0.2%	0.4%
endcap	0.5%	0.4%
Energy scale ($(E_{data} - E_{MC})/E_{MC}$)		
barrel	0.05%	0.34%
endcap	0.26%	0.26%

Source	Uncertainty
Standard Model	
gg cross section (scale)	12.5%
gg cross section (PDF)	7.9%
Fermiophobic model	
VBF cross section (scale)	0.5%
WH cross section (scale)	0.8%
ZH cross section (scale)	1.6%
VBF + VH cross section (PDF)	3.1%
Fermiophobic H $\to \gamma\gamma$ BR	5%

Source	Uncertainty
Integrated luminosity	6%
Trigger efficiency	
both photons in barrel	1.0%
one or more photon in endcap	1.0%
Vertex finding efficiency	0.5%
p_{T}^{H} >40 GeV/c in gluon fusion (class migration)	6%