

ATLAS+CMS Higgs Combination

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Outline

- Procedure for combining ATLAS and CMS Higgs results
 - Correlated systematic uncertainties
 - Higgs mass points
 - Test statistics
 - Treatment of nuisance parameters
 - Naming conventions
 - Procedure for limit setting
 - Quantifying an excess – look elsewhere effect
 - Format of presenting results
 - ATLAS-CMS handshake

Procedure for ATLAS-CMS Higgs Combination

- The report has been approved in both ATLAS and CMS
 - ATLAS, ATL-PUB-PHYS-2011-11
<http://cdsweb.cern.ch/record/1363354>
 - CMS NOTE-2011/005

The ATLAS and CMS Collaborations

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ATLAS-CMS agreements

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- **Using RooStat. The common platform for exchanging information: the Workspace.**
 - It contains all information needed for statistical analyses and simplifies the logistics of data exchange between ATLAS and CMS

295 5.2.1 Naming convention

296 Nuisance parameters with the same name appearing in different analyses (within one or
297 both experiments) are taken to be 100% correlated. Different names imply no correla-
298 tions. Any two sources of uncertainties that are believed to be only partially correlated
299 are either broken further down to the independent sub-contributions or declared to be
300 correlated/uncorrelated, whichever is believed to be more appropriate or more conserva-
301 tive.

302 To avoid accidental correlations in the combination of two experiments, uncertainties
303 specific to each experiment will have a prefix ATLAS or CMS. Uncertainties without such
304 prefixes are assumed to be 100% correlated between the two experiments.

Higgs mass m_H grid

(motivation for the choice of steps driven by $\gamma\gamma$, ZZ mass resolutions)

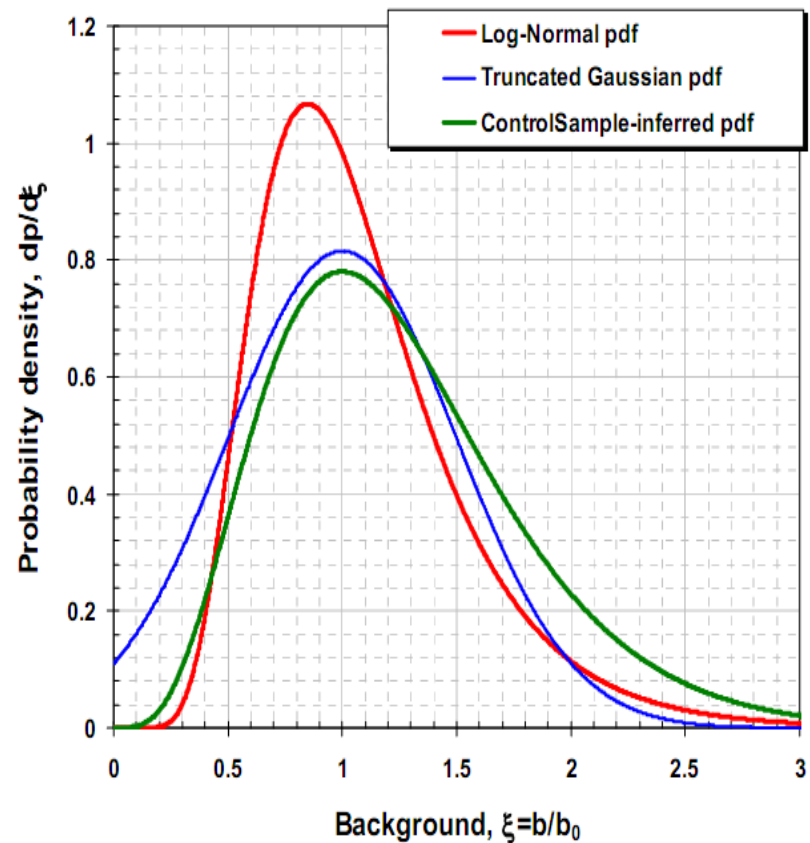
mass range	step	number of points
110-140	0.5	61
140-160	1	20
160-260	2	50
260-290	2	15
290-350	5	12
350-400	10	5
400-500	20	5
550, 600	20	5
Total number of points		173

Initially, we do not use < 1 GeV binning until we've tuned the $H \rightarrow \gamma\gamma$ resolution. Use interpolation for the mass points that are not simulated

Modeling Nuisance Parameter

An uncertainty on a nuisance parameter x (e.g. background, efficiency, cross section, luminosity, etc.) can be in general described in a form of some probability density function $pdf(x)$:

- Gaussian pdf's are discouraged. They are not well suited for positively defined observables (cross-section, efficiency, luminosity, etc). Unless one uses the "not particularly elegant" truncated Gaussian.
- Use log-normal pdf's for modeling systematic errors of non-statistical nature, correlated systematics.
- Gamma pdf for nuisance parameter of un-correlated systematics (MC statistics) or number of events in control region



Combination Procedure

5.1 Exclusion limits

The primary technique for deriving exclusion limits is based on the so-called CL_s prescription, which we use with the profile likelihood test statistic \tilde{q}_μ [94]:

$$\tilde{q}_\mu = -2 \ln \frac{\mathcal{L}(\text{data} | \mu, \hat{\theta}_\mu)}{\mathcal{L}(\text{data} | \hat{\mu}, \hat{\theta})}, \quad \text{with a constraint } 0 \leq \hat{\mu} \leq \mu \quad (1)$$

The likelihood is given by the product of the individual likelihoods for each channel

$$\mathcal{L}(\text{data} | \mu, \theta) = \text{Poisson} (N_i | \mu \cdot s_i(\theta) + b_i(\theta)) \cdot p(\tilde{\theta} | \theta). \quad (2)$$

Following the fully frequentist methodology, Monte Carlo pseudo-experiments, that includes pseudo-data and $\tilde{\theta}$ values of the nuisance parameters, are generated to construct the pdfs.

- $f_\mu(\tilde{q}_\mu | \mu, \hat{\theta}_\mu^{obs})$ under an assumed signal strength μ and the corresponding best-fit nuisance parameters $\hat{\theta}_\mu^{obs}$, given the observed data;
- $f_b(\tilde{q}_\mu | 0, \hat{\theta}_0^{obs})$ for the background-only hypothesis ($\mu = 0$) and the corresponding best-fit nuisance parameters $\hat{\theta}_0^{obs}$, given the observed data.

The CL_s value is calculated as the ratio of two probabilities:

$$\text{CL}_s(\mu) = \frac{P(\tilde{q}_\mu \geq \tilde{q}_\mu^{obs} | \mu, \hat{\theta}_\mu^{obs})}{P(\tilde{q}_\mu \geq \tilde{q}_\mu^{obs} | 0, \hat{\theta}_0^{obs})}. \quad (3)$$

Combination Procedure

$$p_\mu = P(\tilde{q}_\mu \geq \tilde{q}_\mu^{\text{obs}} | \text{signal+background}) = \int_{\tilde{q}_\mu^{\text{obs}}}^{\infty} f(\tilde{q}_\mu | \mu, \hat{\theta}_\mu^{\text{obs}}) d\tilde{q}_\mu,$$

$$1 - p_b = P(\tilde{q}_\mu \geq \tilde{q}_\mu^{\text{obs}} | \text{background-only}) = \int_{\tilde{q}_0^{\text{obs}}}^{\infty} f(\tilde{q}_\mu | 0, \hat{\theta}_0^{\text{obs}}) d\tilde{q}_\mu,$$

- If for $\mu=1$, $\text{CLs} < 0.05$, the SM Higgs with the nominal production rate is said to be excluded at 95% CL.
- We also quote limits on the signal strength modifier μ by requiring $\text{CLs}(\mu)=0.05$
- The main results based on toy MC are supplemented with results based on asymptotic approximation
- We also present results with the Bayesian approach based on the marginalization of the nuisance parameters, and assuming a flat prior on μ .

In generation pseudo datasets, nuisance parameters are fixed to their maximum Likelihood estimates by fitting to the observed data but are allowed to float in fits needed to evaluate the test statistics.

The test statistics

Table 11: Comparison of CL_s definitions as used at LEP, Tevatron, and adopted for the summer 2011 Higgs combination at LHC.

	Test statistic	Profiled?	Test statistic sampling
LEP	$q_\mu = -2 \ln \frac{\mathcal{L}(data \mu, \tilde{\theta})}{\mathcal{L}(data 0, \tilde{\theta})}$	no	Bayesian-frequentist hybrid
Tevatron	$q_\mu = -2 \ln \frac{\mathcal{L}(data \mu, \hat{\theta}_\mu)}{\mathcal{L}(data 0, \hat{\theta}_0)}$	yes	Bayesian-frequentist hybrid
LHC	$\tilde{q}_\mu = -2 \ln \frac{\mathcal{L}(data \mu, \hat{\theta}_\mu)}{\mathcal{L}(data \hat{\mu}, \hat{\theta})}$	yes ($0 \leq \hat{\mu} \leq \mu$)	frequentist

The LHC-type CLs has some advantages:

It uses a test statistics with the desired asymptotic properties

The sampling distribution of the test statistics can be built as purely frequentist

Signal cross section
Taken for the LHC
Higgs cross section group

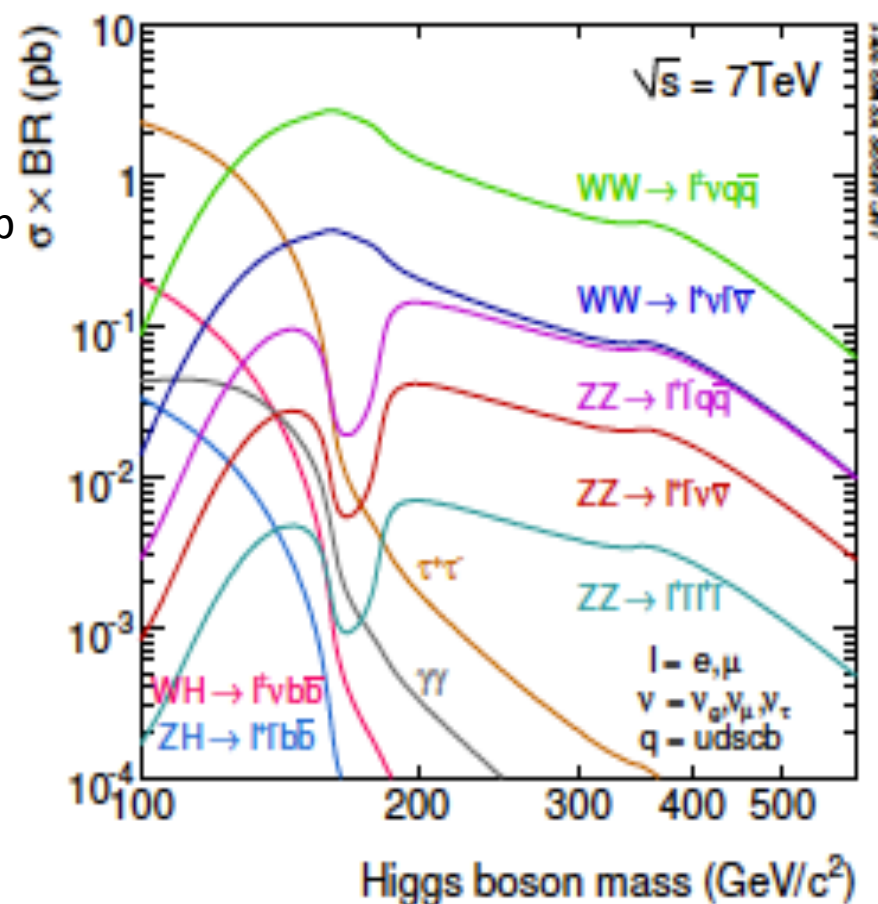


Figure 1: The SM Higgs boson production cross sections multiplied by decay branching ratios in pp collisions at $\sqrt{s} = 7\text{TeV}$ as a function of Higgs boson mass. All final states analysed in this note are shown, where all production modes in $\tau\tau$, $\gamma\gamma$, or $WW/ZZ \rightarrow 4$ leptons are summed except where explicitly mentioned. In the $H \rightarrow b\bar{b}$ channel, only the vector-boson associated production is considered.

Background Cross Sections

- Most backgrounds in signal regions are derived from control region measurements
 - Data driven background estimations
- A few relied on theoretical predictions, namely
 - $gg/qq \rightarrow WW/ZZ$ in $H \rightarrow WW/ZZ$ searches

116 The following programs are used to estimate the background cross sections: MCFM [53]
117 for vector-boson pair production cross section at NLO and many other processes, FEWZ [54,
118 55] for W and Z production NNLO cross sections, HATHOR [56] for the approximate
119 NNLO QCD calculation of top-pair production.

Correlated uncertainties

- Theoretical uncertainties on inclusive cross sections: PDF + α_s , higher orders. **[as for EPS]**
- Higher order uncertainties on acceptance when considered (H->WW).
- Underlying event, parton shower, hadronization (PYTHIA vs HERWIG; only in H->WW)
- Systematic uncertainty in fake rate method from the difference between QCD and W+jets

Theoretical Uncertainties

- **Theoretical errors can be viewed from 3 different points**
 - Uncertainties on the total cross-section σ_{tot} . This is the starting point. But not necessarily applicable to analyzes where experimental cuts restrict the final phase space
 - **Uncertainties on Acceptance (A). Needed to set limit on σ x BR from measurements performed in a restricted phase space**
 - Uncertainties on the cross-section within a limited Acceptance: σA . Needed when setting limit by combining analyzes of various sensitivities from different Higgs production mechanisms. A priori, level of correlation between σ and A not known

Systematic Errors Correlated between ATLAS and CMS

- **Un-correlated systematic errors**
 - e.g., MC statistics
 - Control sample measurements, ...
 - Detector systematics
- **Correlated systematics uncertainties**
 - Luminosity
 - PDF+ α_s
 - Theoretical renormalization/factorization scales
 - Underlying event and parton showering

Systematic Errors Associated With PDF+ α_s Uncertainties

- First, we group all processes in 3 categories based on the prevailing production source
- Second, we assume PDF+ α_s systematic errors between all processes in one group are 100% positively correlated and not correlated between processes from different groups
- The actual level of correlations are described in the Appendix A of this document: <http://cdsweb.cern.ch/record/1363354>
- Our assumption of 100% correlation is conservative

Group	Example of Process	Naming Convention
gg	ggF, ttH, Zbb, ttbar, gg \rightarrow VV	pdf_gg
qqbar	VH, V, VV, $\gamma\gamma$, VBF H	pdf_qqbar
qg	γ +jets	pdf_qg

Systematic Uncertainties associated with QCD scale

- Assume all physics processes have uncorrelated QCD scale uncertainties, except closely related ones (W, Z production; WW, WZ, ZZ production, etc) that we take to be 100% correlated

Process	Naming Convention
ggF	QCDscale_ggH
VF	QCDscale_VH
VBF H	QCDscale_qqH
ttH	QCDscale_ttH
V	QCDscale_V
V + heavy flavor QQ	QCDscale_VQQ
gg \rightarrow VV	QCDscale_ggVV
VV up to NLO	QCDscale_VV
Top (ttbar+Single top)	QCDscale_ttbar

Acceptance and extrapolation factor uncertainties

- **Acceptance: to set limit on $\sigma \times \text{BR}$ of a particular production and decay mode, one is interested in the uncertainty on the Acceptance (A)**
 - $A = (\sigma \text{ with cuts}) / \sigma_{\text{tot}}$
 - Depending on the cuts, some uncertainties may cancel out
- **Extrapolation factor: uncertainty of a similar type arises in data-driven techniques**
 - For evaluating the event rate n of some particular background in the signal region from an observation of N events in a control region: $n = \alpha N$
 - When the extrapolation factor α is obtained from theory/MC: $\alpha = (\sigma \text{ with cuts I}) / (\sigma \text{ with cuts II})$

Cross-Section x Acceptance Uncertainties

- **Uncertainties on acceptance of all cuts except jet counting are treated as independent from the total cross-section.**
 - Most of the time, the acceptance uncertainties of all cuts (except jet counting ones) are smaller than the total cross section uncertainties but this should not be neglected for all channels ...
- **However, for $gg \rightarrow H + 0/1/2\text{jets}$, the fractions of 0-, 1- and 2-jet bins are sensitive to the choice of the QCD scales. To properly account for these correlations, we introduce 3 additional nuisance parameters**
 - In fact exclusive 0/1/2j σ uncertainties are larger than the total σ uncertainties and have + and – correlations
 - LHC Higgs XS Group recommends that ggF with $> 0j$, ggF with $> 1j$ and ggF with $> 2j$, have independent theoretical uncertainties. Hence the 3 nuisance parameters in the table below.
 - The procedure to propagate the inclusive σ uncertainties into the exclusive 0/1/2j σ uncertainties is in the Appendix B of this document:
<http://cdsweb.cern.ch/record/1363354>

Process	Naming Convention
ggF with > 0 jet (inclusive)	QCDscale_ggH
ggF with > 1 jet (inclusive)	QCDscale_ggH1in
ggF with > 2 jets (inclusive)	QCDscale_ggH2in

Other Uncertainties

- Systematic errors associated to the underlying events. 100% correlated between ATLAS and CMS. Naming: **UE_PS**
- Luminosity uncertainties. 100% correlated between ATLAS and CMS. Naming: **lumi**
- Uncorrelated uncertainties
 - Their names should have the prefix ATLAS, CMS, e.g., **ATLAS_xxxx** or **CMS_xxxx**, etc, to avoid accidental correlations

Acceptance and extrapolation factor uncertainties

Given that the cuts are ever evolving, calculations of the acceptance and extrapolation factor uncertainties are to be performed within the ATLAS and CMS Higgs groups according to the prescriptions from the LHC Higgs cross-section group

We currently assume that the acceptance and extrapolation factor uncertainties are independent from the total cross-section uncertainties, except for the acceptance associated to jet counting in $H + 0/1/2\text{jets}$

Two data-driven techniques used by ATLAS and CMS to estimate WW and $t\bar{t}$ backgrounds in $H \rightarrow WW \rightarrow 2l2\nu + 0\text{jet}$. Error dominated by QCD scale. Associated nuisance parameters:

Description of the extrapolation	Naming Convention
$WW \text{ CR} \rightarrow \text{SR}$	QCDscale_WW_EXTRAP
$t\bar{t} \text{ CR} \rightarrow \text{SR}$	QCDscale_ttbar_EXTRAP

Table 12: List of nuisance parameters for systematic uncertainties assumed to be 100% correlated between ATLAS and CMS.

PDF+ α_s uncertainties

nuisance	groups of physics processes
pdf_gg	$gg \rightarrow H, t\bar{t}H, VQQ, t\bar{t}, tW, tb$ (s -channel), $gg \rightarrow VV$
pdf_qqbar	VBF $H, VH, V, VV, \gamma\gamma$
pdf_qg	tbq (t -channel), γ +jets

QCD scale uncertainties

nuisance	groups of physics processes
QCDscale_ggH	total inclusive $gg \rightarrow H$
QCDscale_ggH1in	inclusive $gg/qg \rightarrow H + \geq 1$ jets
QCDscale_ggH2in	inclusive $gg/qg \rightarrow H + \geq 2$ jets
QCDscale_qqH	VBF H
QCDscale_VH	associate VH
QCDscale_ttH	$t\bar{t}H$
QCDscale_V	W and Z
QCDscale_VV	WW, WZ, and ZZ up to NLO
QCDscale_ggVV	$gg \rightarrow WW$ and $gg \rightarrow ZZ$
QCDscale_ZQQ	Z with heavy flavor $q\bar{q}$ -pair
QCDscale_WQQ	W with heavy flavor $q\bar{q}$ -pair
QCDscale_ttbar	$t\bar{t}$, single top productions are lumped here for simplicity

Phenomenological uncertainties

nuisance	groups of physics processes
UE_PS	all processes sensitive to modeling of UE and PS

Acceptance uncertainties

nuisance	comments
QCDscale_WW_EXTRAP	extrap. factor α for deriving WW bkgd in HWW analysis
QCDscale_ttbar_EXTRAP	extrap. factor α for deriving $t\bar{t}$ bkgd in HWW analysis

Instrumental uncertainties

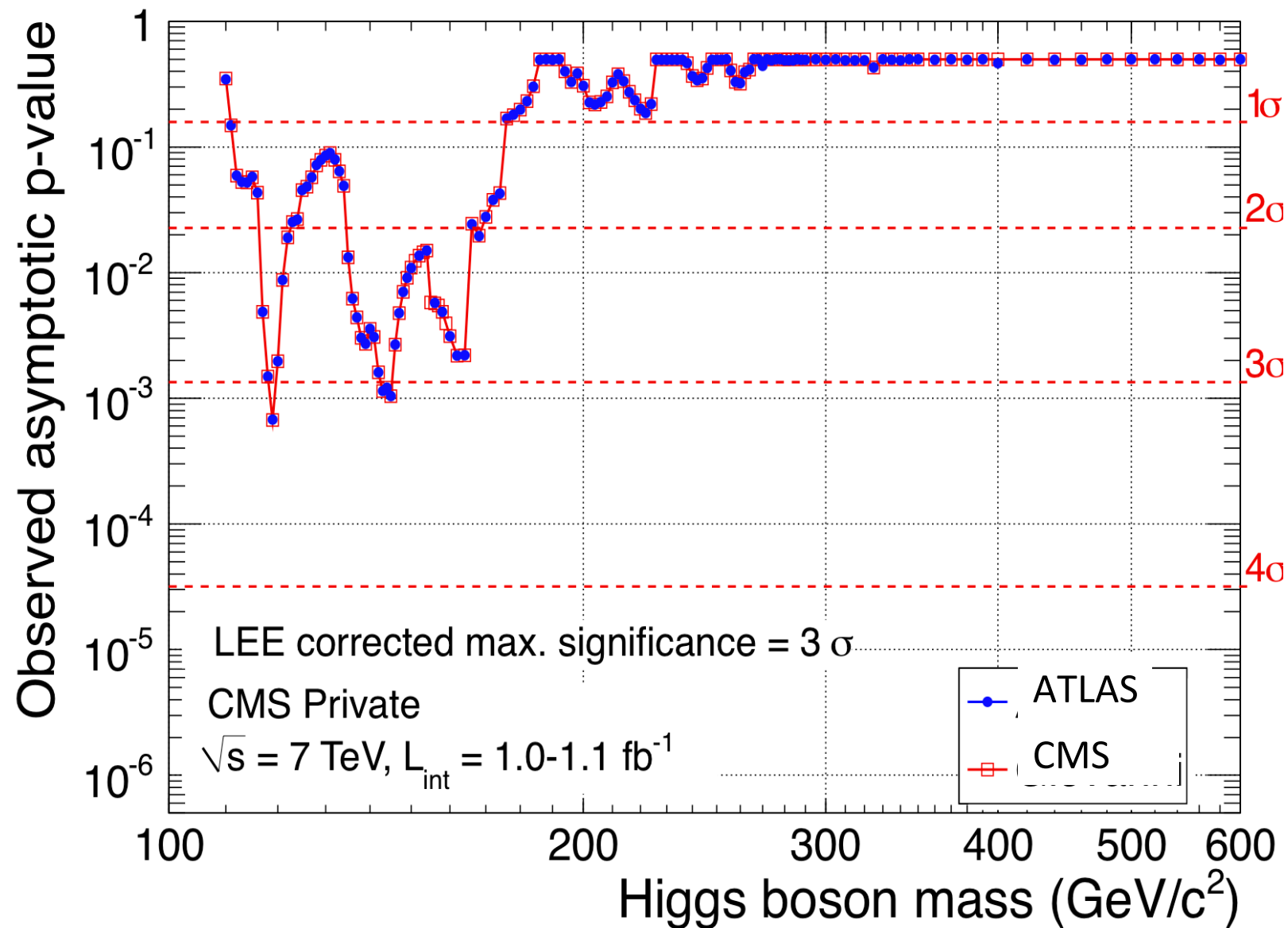
nuisance	comments
lumi	uncertainties in luminosities

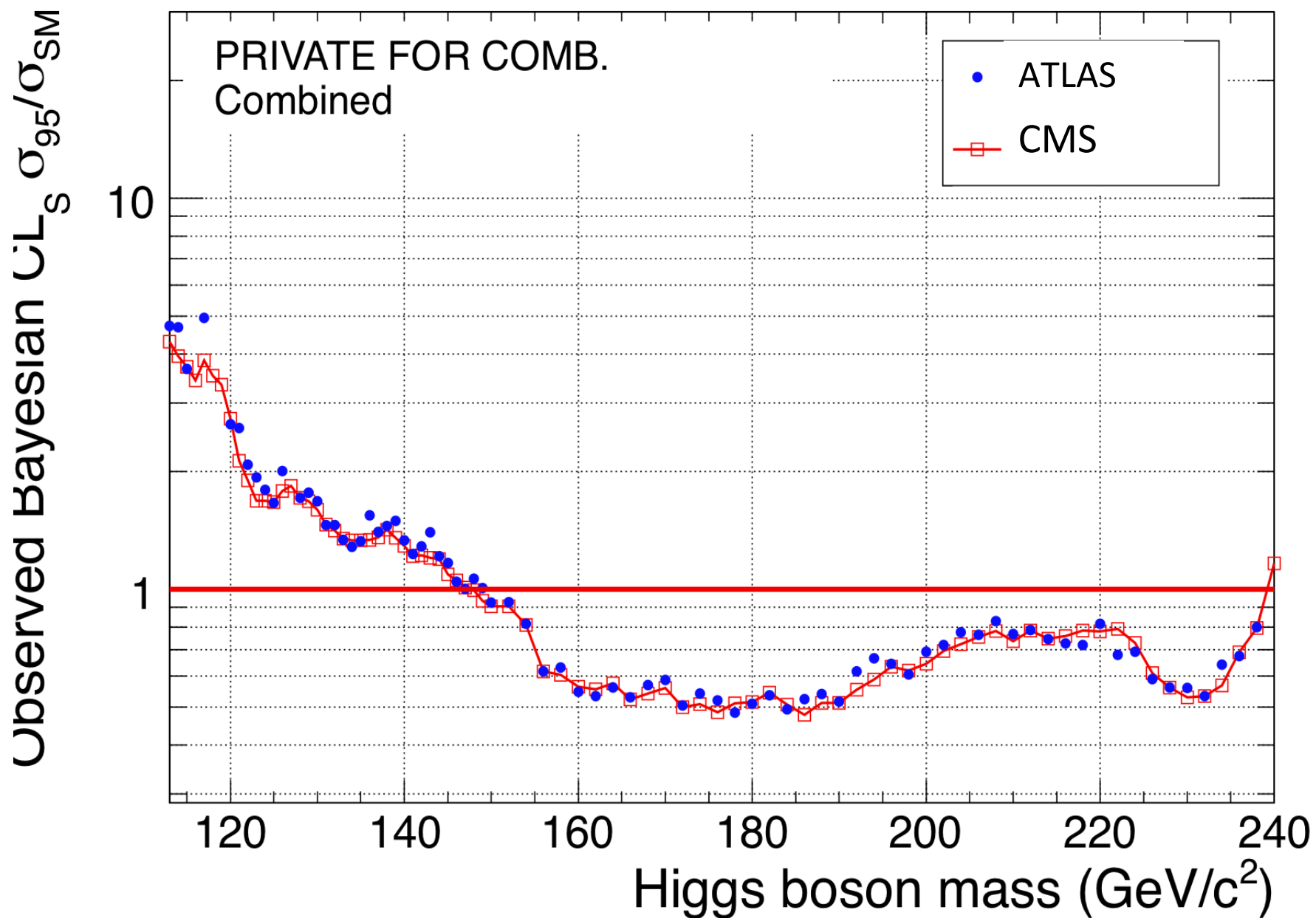
Systematics checks

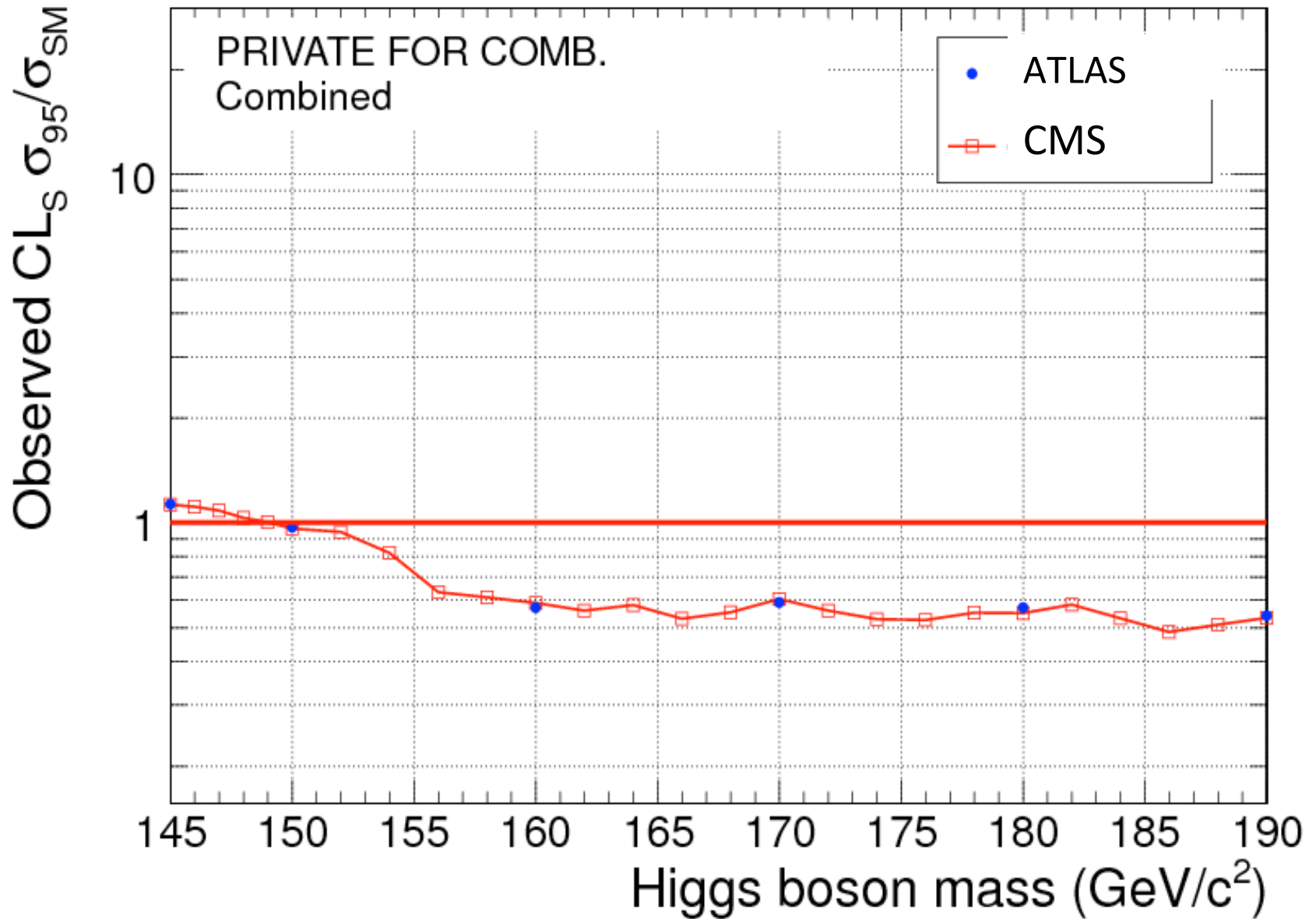
- Impact of correlating the systematics on **b-tagging efficiency** and **jet energy scale** (partially driven by MC modelling)
Negligible effect: 4% or smaller for Higgs masses up to 250 GeV, and below 1% for higher masses.
- Impact of **theoretical uncertainties** by computing expected limits also with without them.
Effect on σ/σ_{SM} limit 3-6% except for very high mass.
Expected exclusion changes by 1 GeV at low mass, 20 GeV at high mass

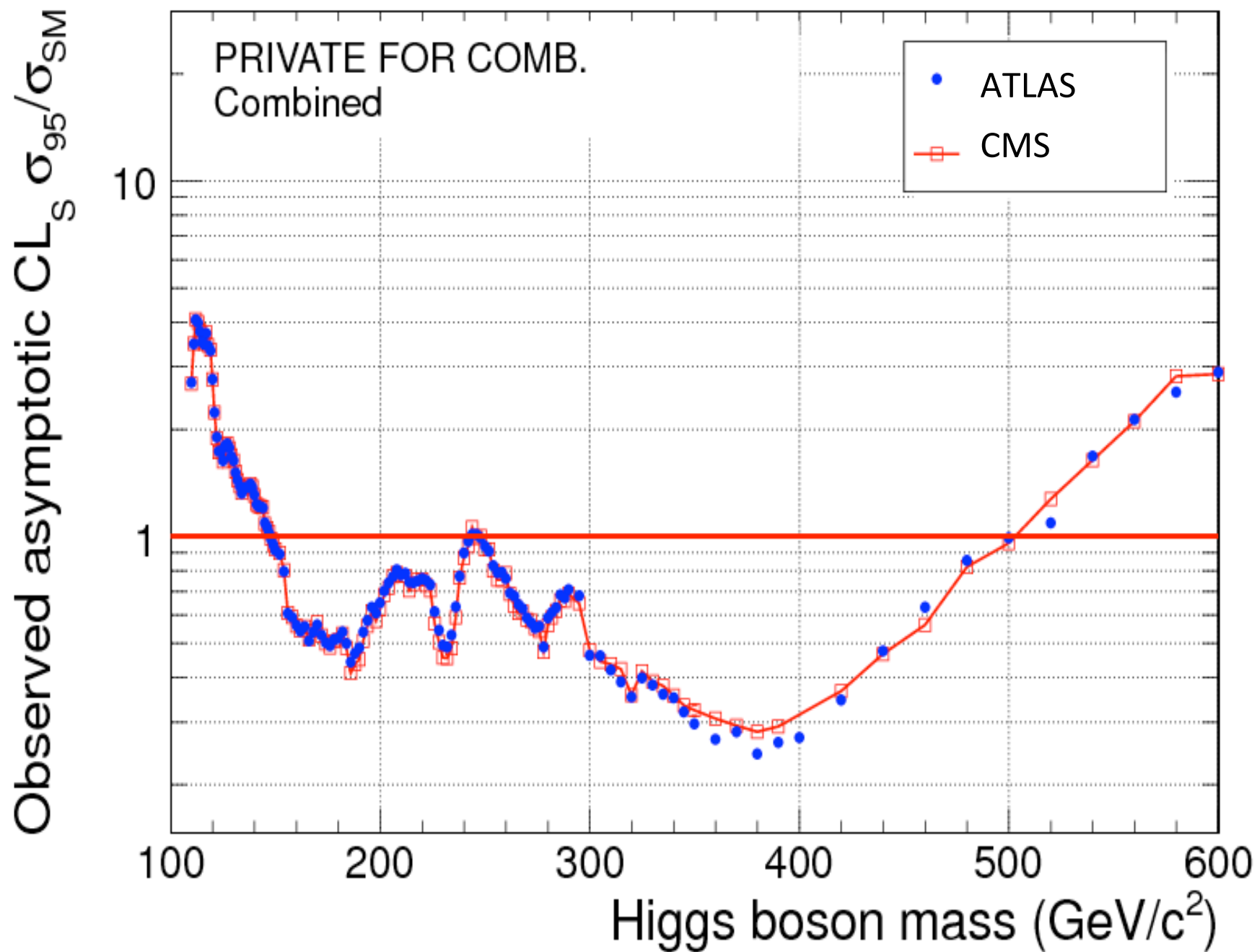
ATLAS-CMS Handshakes

- **A few tests were carried out to check the agreed upon procedure for combination**
 - Using toy data from each experiment
 - Combining toy data from ATLAS and CMS
- **Each collaboration prepares their own Workspaces**
 - For some analyses
 - For their combined analyses
 - Perform statistical analysis on their Workspaces and on the Workspaces of the other experiment
 - Prepare ATLAS+CMS their combined Workspace
- **The results obtained on the ATLAS-only, CMS-only and ATLAS+CMS are required to agreed within some precision of the calculations**
- **Various statistical methods were used in the handshake**
 - Profile Likelihood Approximation
 - LEP-style CLs
 - LHC style CLs









417 5.2 Quantifying an excess of events

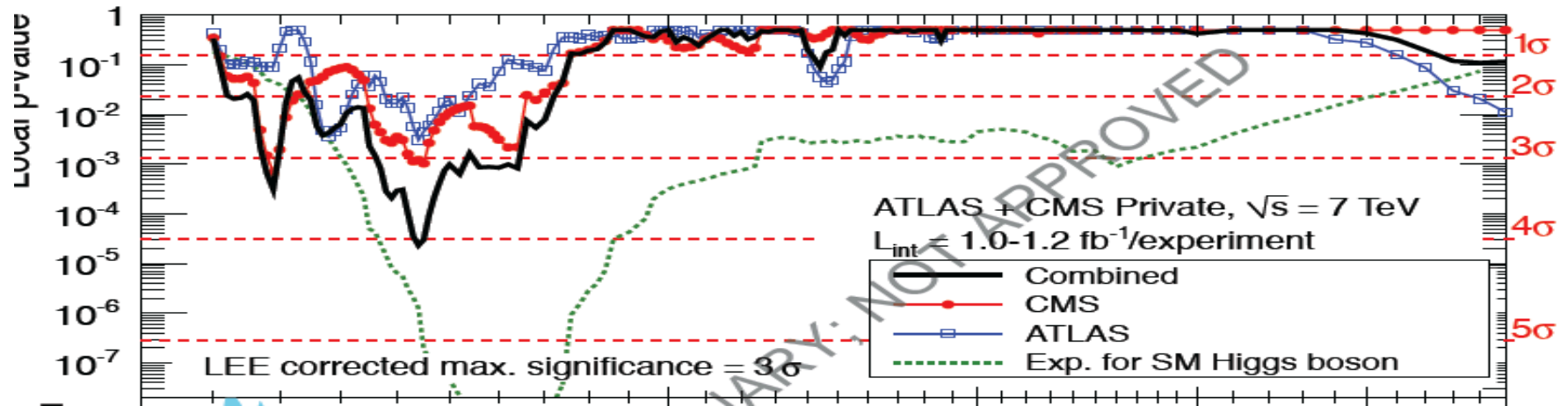
To quantify an excess of events, we use the test statistic q_0 , defined as follows:

$$q_0 = -2 \ln \frac{\mathcal{L}(\text{data}|0, \hat{\theta}_0)}{\mathcal{L}(\text{data}|\hat{\mu}, \hat{\theta})} \quad \text{and } \hat{\mu} \geq 0. \quad (4)$$

This test statistic is known to have the proper χ^2 distribution, which allows us to evaluate significances (Z) and p -values (p_0) from the following asymptotic formula:

$$Z = \sqrt{q_0^{obs}}, \quad (5)$$

$$p_0 = P(q_0 \geq q_0^{obs}) = \int_Z^\infty \frac{e^{-x^2/2}}{\sqrt{2\pi}} dx = \frac{1}{2} \left[1 - \text{erf} \left(Z/\sqrt{2} \right) \right]. \quad (6)$$

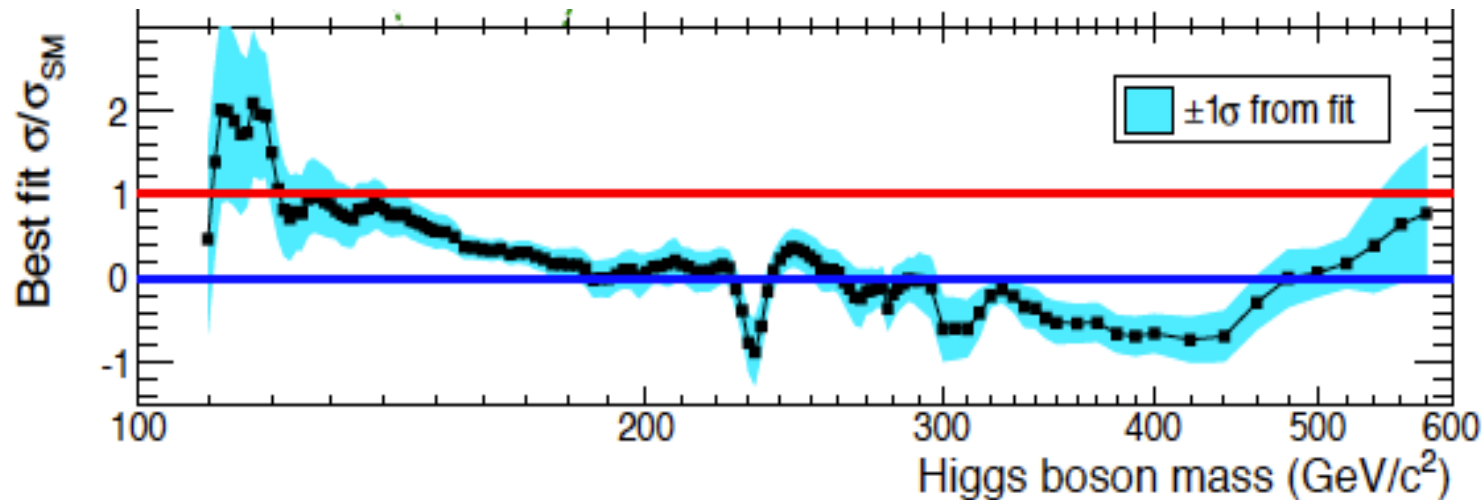


The local minimum p -value is $p_0^{\min} = 2.3 \cdot 10^{-5}$.

It corresponds to a local maximum significance of $Z_{\max} \sim 4\sigma$.

Estimate of the Look-Elsewhere Effect

The local p_0 , p_0^{\min} and the corresponding maximum significance Z_{\max} may be misleading. Estimate the global probability, p_0^{global} to observe p_0^{\min} by counting the number of up-crossings



The number of up-crossings at 0 is $N_0 = 3$

$$p_0^{\text{global}} \sim p_0^{\min} + N_0 e^{-\frac{1}{2} Z_{\max}^2}.$$

With $p_0^{\min} = 2.3 \cdot 10^{-5}$ and $Z_{\max} \sim 4\sigma$,
 $p_0^{\text{global}} = 10^{-3}$ corresponding to $Z_{\text{global}} = 3\sigma$

Conclusions

- The procedure for ATLAS+CMS Higgs combination has been agreed upon and tested, and released as public documents in both ATLAS and CMS.
- ATLAS+CMS Higgs combination for HCP (Nov 14, 2011) is currently being approved by both collaborations

BACKUP

Backgrounds

	Z	W	ZZ	WW	WZ	Wy	WQQ	ZQQ	ggWW	ggZZ	ttbar	tW	tb	tbq
Z	1	0.95	0.67	0.70	0.95	0.9	0.43/0.53	0.08	-0.67	-0.75	-0.74	-0.81	0.59	-0.29
W	0.95	1	0.52/0.69	0.60/0.71	0.88/1.0	0.90/0.80	0.39/0.50	0.08	-0.67	-0.74	-0.73	-0.8	0.57	-0.29
ZZ	0.67	0.52/0.69	1	0.97	0.54/0.73	0.62	0.78/0.87	-0.09	-0.36	-0.34	-0.17	-0.81	0.9	-0.23
WW	0.70	0.60/0.71	0.97	1	0.63/0.75	0.69	0.80/0.86	-0.02	-0.34	-0.33	-0.20	-0.33	0.94	-0.08
WZ	0.95	0.88/1.0	0.54/0.73	0.63/0.75	1	0.9	0.55	0.1	-0.64	-0.71	-0.71	-0.73	0.61	-0.34
Wy	0.9	0.90/0.80	0.62	0.69	0.9	1	0.63/0.53	0.32	-0.44	-0.54	-0.68	0.61	0.61	0
WQQ	0.43/0.53	0.39/0.50	0.78/0.87	0.80/0.86	0.55	0.63/0.53	1	0.08	-0.12	-0.12	-0.05	-0.15	0.64	-0.32
ZQQ	0.08	0.08	-0.09	-0.02	0.1	0.32	0.08	1	0.54	0.36	-0.26	-0.05	-0.03	0.59
ggWW	-0.67	-0.67	-0.36	-0.34	-0.64	-0.44	-0.12	0.54	1	0.98	0.65	0.81	-0.28	0.63
ggZZ	-0.75	-0.74	-0.34	-0.33	-0.71	-0.54	-0.12	0.36	0.98	1	0.79	0.91	-0.27	0.55
ttbar	-0.74	-0.73	-0.17	-0.20	-0.71	-0.68	-0.05	-0.26	0.65	0.79	1	0.97	-0.12	0.17
tW	-0.81	-0.8	-0.81	-0.33	-0.73	0.61	-0.15	-0.05	0.65	0.91	0.97	1	-0.25	0.31
tb	0.59	0.57	0.9	0.94	0.61	0.61	0.64	-0.03	-0.28	-0.27	-0.12	-0.25	1	0.04
tbq	-0.29	-0.29	-0.23	-0.08	-0.34	0	-0.32	0.59	0.63	0.55	0.17	0.31	0.04	1

Figure 10: Correlations of PDF-associated errors between different backgrounds.

$m_H=120$

	ggH	VBF	WH	ZH	ttH	Z	W+/W-	ZZ	WW	WZ	Wy	WQQ	ZQQ	ggWW	ggZZ	ttbar	tW	tb	tbq
ggH	1	-0.57	-0.23	-0.14	-0.6	0.01	0.03	0.02	-0.20	0.04	0.23	-0.14	0.93	0.47	0.28	-0.33	-0.12	-0.24	0.32
VBF	-0.57	1	0.63/0.73	0.76	0.09	0.43	0.26/0.41	0.79	0.72	0.28/0.43	0.28/0.37	0.52/0.71	-0.41	-0.47	-0.4	-0.10	-0.28	0.65	-0.25
WH	-0.23	0.63/0.73	1	0.93	0	0.62	0.52/0.64	0.92	0.93	0.65/0.58	0.65/0.56	0.79/0.95	-0.02	-0.29	-0.28	-0.15	-0.28	0.99/0.77	0.05/-0.30
ZH	-0.14	0.76	0.93	1	0.03	0.64	0.53/0.66	0.99	0.99	0.55/0.71	0.63	0.83	-0.07	-0.31	-0.3	-0.14	-0.28	0.93	-0.14
ttH	-0.6	0.09	0	0.03	1	-0.61	-0.6	0	-0.05	-0.58	-0.64	0.04	-0.5	0.03	0.56	0.94	0.84	0.02	-0.07

$m_H=160$

	ggH	VBF	WH	ZH	ttH	Z	W+/W-	ZZ	WW	WZ	Wy	WQQ	ZQQ	ggWW	ggZZ	ttbar	tW	tb	tbq
ggH	1	-0.61	-0.29	-0.35	-0.24	-0.32	-0.32	-0.35	-0.29	-0.29	-0.06	-0.12	0.9	0.82	0.68	0.1	0.33	-0.27	0.67
VBF	-0.61	1	0.62	0.74	0.2	0.35	0.19/0.34	0.75	0.66	0.20/0.36	0.19/0.28	0.46/0.70	-0.47	-0.46	-0.37	-0.03	-0.22	0.6	-0.29
WH	-0.29	0.62	1	0.93	0.1	0.55	0.52	0.9	0.93	0.56	0.56	0.93	-0.07	-0.26	-0.23	-0.07	-0.21	1	0.03
ZH	-0.35	0.74	0.93	1	0.16	0.54	0.43/0.58	0.98	0.97	0.45/0.63	0.52	0.93	-0.14	-0.29	-0.25	-0.04	-0.2	0.91	-0.16
ttH	-0.24	0.2	0.1	0.16	1	-0.59	-0.58	0.03	-0.03	-0.56	-0.62	-0.05	-0.54	0.33	0.51	0.92	0.8	0.04	-0.12

$m_H=200$

	ggH	VBF	WH	ZH	ttH	Z	W+/W-	ZZ	WW	WZ	Wy	WQQ	ZQQ	ggWW	ggZZ	ttbar	tW	tb	tbq
ggH	1	-0.5	-0.26	-0.3	0.13	-0.59	-0.59	-0.36	-0.32	-0.55	-0.33	-0.11	0.68	0.98	0.93	0.5	0.69	-0.27	0.67
VBF	-0.5	1	0.60/0.73	0.72	0.26	0.28	0.13/0.28	0.7	0.62	0.15/0.30	0.12/0.20	0.40/0.69	-0.52	-0.44	-0.34	0.02	-0.17	0.55	-0.32
WH	-0.26	0.60/0.73	1	0.92	0.2	0.44	0.44/0.38	0.89	0.86	0.48/0.41	0.47/0.36	0.78/0.74	-0.15	-0.24	-0.2	0	-0.15	0.98/0.69	0
ZH	-0.3	0.72	0.92	1	0.24	0.46	0.34/0.51	0.95	0.93	0.37/0.56	0.43	0.74/0.85	-0.19	-0.3	-0.22	0.02	-0.14	0.88	-0.2
ttH	0.13	0.26	0.2	0.24	1	-0.57	-0.57	0.03	-0.03	-0.55	-0.63	0.03	-0.56	0.29	0.48	0.9	0.78	0.03	-0.15

$m_H=300$

	ggH	VBF	WH	ZH	ttH	Z	W+/W-	ZZ	WW	WZ	Wy	WQQ	ZQQ	ggWW	ggZZ	ttbar	tW	tb	tbq
ggH	1	-0.16	-0.08	-0.09	0.66	-0.8	-0.79	-0.31	-0.31	-0.76	-0.64	-0.11	0.12	0.9	0.97	0.92	0.98	-0.23	0.43
VBF	-0.16	1	0.33/0.72	0.68	0.29	0.16	0.04/0.19	0.6	0.51	0.05/0.20	0.03	0.27/0.65	-0.57	-0.42	-0.31	0.09	-0.11	0.44	-0.39
WH	-0.08	0.33/0.72	1	0.92	0.23	0.32	0.20/0.36	0.82	0.80/0.71	0.34/0.37	0.30/0.20	0.68/0.64	-0.24	-0.22	-0.16	0.1	-0.06	0.89	-0.06
ZH	-0.09	0.68	0.92	1	0.27	0.32	0.20/0.38	0.87	0.82	0.21/0.44	0.26	0.61/0.81	-0.29	-0.25	-0.18	0.11	-0.07	0.79	-0.28
ttH	0.66	0.29	0.23	0.27	1	-0.6	-0.59	-0.05	-0.12	-0.58	-0.65	-0.04	-0.58	0.28	0.47	0.9	0.78	-0.04	-0.17

$m_H=500$

	ggH	VBF	WH	ZH	ttH	Z	W+/W-	ZZ	WW	WZ	Wy	WQQ	ZQQ	ggWW	ggZZ	ttbar	tW	tb	tbq
ggH	1	0.09	0.05	0.05	0.91	-0.78	-0.76	-0.25	-0.28	-0.75	-0.73	-0.13	-0.3	0.63	0.78	0.99	0.97	-0.2	0.15
VBF	0.09	1	0.38/0.70	0.6	0.24	0.073	0.0/0.12	0.47	0.37	0/0.12	-0.08	0.11/0.59	-0.58	-0.4	-0.29	0.1	-0.08	0.29	-0.48
WH	0.05	0.38/0.70	1	0.9	0.16	0.19	0.09/0.26	0.69	0.64	0.20/0.20	0.14/0.09	0.55/0.53	-0.3	-0.21	-0.14	0.14	-0.02	0.73	-0.12
ZH	0.05	0.6	0.9	1	0.16	0.22	0.09/0.29	0.77	0.68	0.10/0.34	0.12	0.44/0.74	-0.35	-0.27	-0.19	0.13	-0.05	0.65	-0.37
ttH	0.91	0.24	0.16	0.16	1	-0.63	-0.61	-0.18	-0.23	-0.61	-0.69	-0.14	-0.57	0.3	0.48	0.89	0.79	-0.15	-0.14

Figure 11: Correlations of PDF-associated errors between different SM Higgs production mechanisms as well as between Higgs production modes and different backgrounds.