Higgs boson acceptance and acceptance uncertainties

Les Houches 2013

Motivation

- Both ATLAS and CMS are about to reach fair sensitivities for unraveling **event yields** in different selection categories into **cross sections** **$\sigma_i \times$BR(X)** for individual Higgs production modes i, where i **= gF, VBF, VH, ttH**

- To convert **measured cross sections in separate fiducial volumes** (often so many per decay mode X that each of them is fairly meaningless, at least for now) into **gF, VBF, VH, ttH cross sections**, we need to know:
  - **acceptance efficiencies** for each experimental exclusive final state: **ε**
  - **uncertainties** on these acceptance efficiencies: **$\delta\varepsilon$,**
  - expressed via **independent nuisance parameters**

Prototypical examples

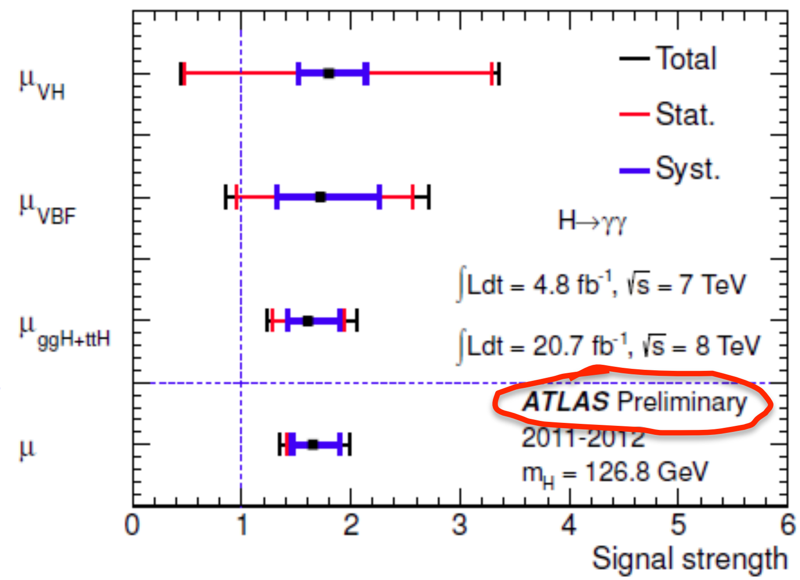
- **The goal of exercising the prototypical examples** specified below is two-fold:
  - **Define the prescription** for evaluation of acceptance uncertainties, so that the experiments can repeat calculations for the actual cuts used at any given time.
  - **Set benchmark numbers** (following the defined prescription), so that the experiments could have a set of reference points indicating what these uncertainties might be.
  - Since the prototypical selections are not too far from the real cuts, such benchmarking is very useful for weeding out potential bugs when the experiments repeat the prescribed workflow for evaluating the acceptance uncertainties **with the actual cuts** used in their analyses.

Prototypical examples #1: H→γγ

Why H→γγ?

- Overall, the H→γγ channel already has a very **good signal significance** opening the door for **cross section measurements**

- H→γγ measurements/search are now performed with tags targeting all four **main production mechanisms**



CMS: ttH, $H \to \gamma\gamma$ $\mu = -0.2^{+2.4}_{-1.9}$

ggF	VBF	VH	ttH
$\mu = 1.6^{+0.4}_{-0.4}$	$\mu = 1.7^{+0.9}_{-0.9}$	$\mu = 1.8^{+1.5}_{-1.3}$	$\mu = -0.2^{+2.4}_{-1.9}$

Prototypical H→γγ

	untagged		di-jet tag		MET tag	Lepton tag	ttH tag	
	BB+BE	BB	low m_{JJ}	high m_{JJ}			bbqqqq	bbqqlv
	8	7	6	5	4	3	2	1
gF	$\varepsilon_0(1\pm\delta)$	…	…	…	…	…	…	…
VBF	…	…	…	…	…	…	…	…
VH	…	…	…	…	…	…	…	…
ttH	…	…	…	…	…	…	…	…

Tag flow goes from right to left

* BB: barrel-barrel photons
BE+EE: barrel-endcap + endcap-endcap photons

All tags are mutually exclusive,
i.e. if an event passes the selection criteria for a particular tag N (moving from right to left), it is not allowed to be included in any other higher-N tag to the left

For simplicity, assume that

- selection of objects is 100% efficient
- mis-ID rate is 0%
- experimental measurements are 100% accurate

Prototypical $H \rightarrow \gamma\gamma$

	untagged		di-jet tag		MET tag	Lepton tag	ttH tag	
	BB+BE	BB	low m_{JJ}	high m_{JJ}			bbqqqq	bbqqlv
	8	7	6	5	4	3	2	1
gF	$\varepsilon_0(1\pm\delta)$	…	…	…	…	…	…	…
VBF	…	…	…	…	…	…	…	…
VH	…	…	…	…	…	…	…	…
ttH	…	…	…	…	…	…	…	…

* BB: barrel-barrel photons
BE+EE: barrel-endcap + endcap-endcap photons

What is needed:

- **8x4=32 theoretical efficiencies ε_0**
- **relative uncertainties** on theoretical efficiencies δ, **organized by independent sources**

Prototypical examples #1: $H \rightarrow \gamma\gamma$

SMALL-PRINT DISCLAIMER:

- **What follows a <u>PROTOTYPICAL EXAMPLE</u>**
- The cuts listed below do not represent accurately the actual selection used by either ATLAS or CMS

Prototypical selection #1: ttH semi-leptonic

- **Photons:**
  - at least **two photons** with **$|\eta|<1.5$, $p_T(1)>m_H/3$, $p_T(2)>m_H/4$**

- **Tag:**
  - at least **one lepton** (e/μ) with $p_T>20$, $|\eta|<2.4$
  - at least **two jets** with $E_T>25$, $|\eta|<2.4$
  - from all jets, at least **one is b-tagged**

- **Current default efficiency ε_0: PYTHIA**

<u>Prototypical</u> selection #2: ttH all-hadronic

- **Photons:**
  - at least **two photons** with **$|\eta|<1.5$, $p_T(1)>m_H/3$, $p_T(2)>m_H/4$**

- **Tag:**
  - **no leptons** (e/μ) with $p_T>20$, $|\eta|<2.4$
  - at least **four jets** with $E_T>25$, $|\eta|<2.4$
  - from all jets, at least **one is b-tagged**

- **Current default efficiency ε_0: <u>PYTHIA</u>**

Prototypical selection #3: VH leptonic

- **Photons:**
  - at least **two photons** with **$|\eta|<2.5$, $p_T(1)>m_H/3$, $p_T(2)>m_H/4$**
- **Tag:**
  - at least **one lepton** (e/μ) with $p_T>20$, $|\eta|<2.4$
- **Current default efficiency ε_0: PYTHIA**

Prototypical selection #4: VH MET

- **Photons:**
  - at least **two photons** with **$|\eta|<2.5$, $p_T(1)>m_H/3$, $p_T(2)>m_H/4$**
- **Tag:**
  - **no leptons** (e/μ) with with $p_T>20$, $|\eta|<2.4$
  - **MET** > 70
- **Current default efficiency ε_0: PYTHIA**

Prototypical selection #5: VBF high m_{jj}

- **Photons:**
  - at least **two photons** with **$|\eta|<2.5$, $p_T(1)>m_H/3$, $p_T(2)>m_H/4$**

- **Tag:**
  - at least **two jets** with $p_T>30$, $|\eta|<4.7$
  - **two highest E_T jets:**
    - $\Delta\eta = |\eta_{j1} - \eta_{j2}| > 3$ (note: no requirement on the rapidity gap)
    - $m_{jj}>500$
    - Zeppenfeld variable: $Z = | \eta_{\gamma\gamma} - (\eta_{j1}+\eta_{j2})/2 | < 2.5$
    - $\Delta\phi(jj,\gamma\gamma) > 2.6$

- **Current default efficiency ε_0: POWHEG**

Prototypical selection #6: VBF low m_{jj}

- **Photons:**
  - at least **two photons** with **$|\eta|<2.5$, $p_T(1)>m_H/3$, $p_T(2)>m_H/4$**

- **Tag:**
  - at least **two jets** with $p_T>20$, $|\eta|<4.7$
  - **two highest E_T jets:**
    - $\Delta\eta = |\eta_{j1} - \eta_{j2}| > 3$ (note: no requirement on the rapidity gap)
    - $m_{jj}>250$
    - Zeppenfeld variable: $Z = | \eta_{\gamma\gamma} - (\eta_{j1}+\eta_{j2})/2 | < 2.5$
    - $\Delta\phi(jj,\gamma\gamma) > 2.6$

- **Current default efficiency ε_0: POWHEG**

<u>Prototypical</u> selection #7: untagged BB

- **Photons:**
  - at least **two photons** with **$|\eta|<2.5$, $p_T(1)>m_H/3$, $p_T(2)>m_H/4$**
  - **both highest p_T photons** are in the barrel: **$|\eta|<1.5$**

- **Current default efficiency ε_0:**

  <u>**POWHEG** with Higgs p_T reweighted to match **HqT**</u>

Prototypical selection #8: untagged BE+EE

- **Photons:**
  - at least **two photons** with **$|\eta|<2.5$, $p_T(1)>m_H/3$, $p_T(2)>m_H/4$**
  - at least **one of the highest p_T photons** is in endcap: **$|\eta|>1.5$**

- **Current default efficiency ε_0:**

  POWHEG with Higgs p_T reweighted to match **HqT**

Question No. 1

Are the current ways to evaluate
the default efficiencies ε_0
in each event category **OK?**

ggF	Powheg, p_T(H) reweighted to match HqT
VBF	Powheg
VH	Pythia
ttH	Pythia

Question No. 2 (a, b)

(a) Can we continue to use **MCFM** for estimating **PDF uncertainties on ε_0** ?

(b) Can we associate **PDF uncertainties on ε_0** with **two independent nuisance parameters**?

- **gg-dominated processes**: ggF and ttH
- **qq-dominated processes**: VBF and VH

Below is the correlation table by Joey Huston from 2011

(Appendix B in the joint ATLAS-CMS Note: **ATLAS PHYS-PUB-2011-11, CMS NOTE-2011/005**)

m_H=120

	ggH	VBF	WH	ZH	ttH	Z	W+/W-	ZZ	WW	WZ	Wγ	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	0.95	0.47	0.28	-0.35	-0.12	-0.24	0.52
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	0.65/058	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

Question No. 3 (a, b)

(a) How many independent nuisance parameters do we need to account for independent theoretical uncertainties

- for each of the four Higgs production mechanisms
- in all fiducial volume acceptances (8 in this toy example)

(b) And what are the **prescriptions for estimating numerical value of each uncertainty**?

What's next?

- Further discussion…
- Who can do what?