Fiducial Volume Definition and Model Dependence

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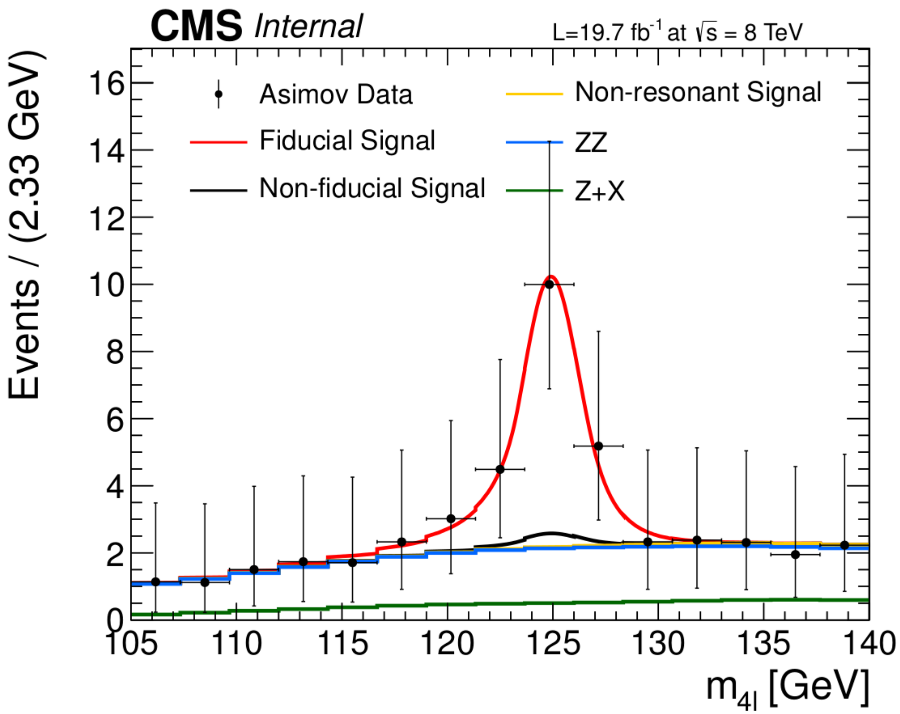
Discussion Topics

- Definition of the "signal" fiducial cross section that is measured by the experiments
- How to treat the m(H) hypothesis
- Definition of the fiducial volume and fiducial level objects
- How to define and report model dependence

What to Measure

- For the measurement of H → 4ℓ cross section, the following sources of reconstructed events can be identified:
  - **Fiducial Signal *(shape given by P_{res})***
  - **"Non-Fiducial" Signal: Reconstructed but from outside the fiducial volume**
  - **"Non-Resonant" Signal *(shape given by P_{nonres})*: selected leptons not from H decay (e.g. WH, ZH, ttH), ~20% in (105,140) GeV for ZH**
  - ***qqZZ,ggZZ (irreducible background)***
  - ***Z+X (reducible background)***



- Current thinking is to report the fiducial cross section of the resonant signal (other components are considered as background)
  → Should we also include non-resonant signal and/or irreducible background?
- Extract the fiducial cross section by fitting m(4ℓ)
  → Choice whether to fix m(H) to one value, float the relative branching fractions

$$N^{f,i}_{obs}(m_{4\ell}) = N^{f,i}_{fid}(m_{4\ell}) + N^{f,i}_{nonres}(m_{4\ell}) + N^{f,i}_{nonfid}(m_{4\ell}) + N^{f,i}_{bkg}(m_{4\ell})$$

$$= \left(1 + f^{f,i}_{nonfid}\right) \cdot \sigma^{f,j}_{fid} \cdot \epsilon^{f}_{i,j} \cdot \mathcal{L} \cdot \mathcal{P}_{res}(m_{4\ell}) + N^{f,i}_{nonres} \cdot \mathcal{P}_{nonres}(m_{4\ell}) + N^{f,i}_{bkg} \cdot \mathcal{P}_{bkg}(m_{4\ell}),$$

f = final state
i = observable bin at reco level

Mass Hypothesis

Different options on how to treat the m(H) hypothesis

1. Do not fit m(4ℓ) to extract the cross section

→ Makes the m(H) hypothesis irrelevant to first order

→ But, not using m(4ℓ) sidebands to constrain irreducible background

→ Can only measure H+X→4ℓ and not H(→4ℓ)+X

→ Only an option for ZZ, not possible for γγ

2. Treat m(H) as a free parameter and fit for it

→ Implies reporting the fiducial/differential cross section for the fitted value of m(H), and can be different for each observable.

→ Theory comparison should be made at the fitted values which is a complication

3. Fix the m(H) to the best-fit value measured by experiment(s)

→ The cross section will be fitted at the point that is slightly off-peak, ~1% effect

→ Raises the question on the exact choice of the best-fit value

Fiducial Volume Definition

- Current thinking is to define the fiducial volume in a way that minimizes model dependence
  → Close to reconstruction level selection
  → To accomplish this it is essential to include isolation in the fiducial volume definition
- For the definition of leptons, can use born, bare or dressed
  → reconstruction algorithms recover QED radiation, Born level is simplest, dressed preferred by theorists?

Lepton kinematics and isolation	
leading lepton	> 20 GeV
next-to-leading lepton	> 10 GeV
additional electrons (muons)	$> 7(5)$ GeV
pseudorapidity of electrons (muons)	$\|\eta\| < 2.5(2.4)$
sum of all stable particles within $\Delta R < 0.4$ from lepton	less than $0.4 \cdot p_{\mathrm{T}}$

Event topology	
existence of at least two SFOS lepton pairs, where leptons satisfy criteria above	
inv. mass of the Z_1 candidate	$40\ \mathrm{GeV} < m(Z_1) < 120\ \mathrm{GeV}$
inv. mass of the Z_2 candidate	$12\ \mathrm{GeV} < m(Z_2) < 120\ \mathrm{GeV}$
distance between selected four leptons	$\Delta R(\ell_i \ell_j) > 0.02$ for any $i \neq j$
inv. mass of any opposite sign lepton pair	$m(\ell^+ \ell'^-) > 4$ GeV
inv. mass of the selected four leptons	$105\ \mathrm{GeV} < m_{4\ell} < 140\ \mathrm{GeV}$
the selected four leptons must originate from the decay	

Fiducial Volume Definition

- By using this definition of the fiducial volume, the "model dependence" i.e. variation in the factor $(1+f_{nonfid})\epsilon$, is stabilized to within less than 7% over a wide range of exotic models
  → Isolation effects are instead moved to the acceptance

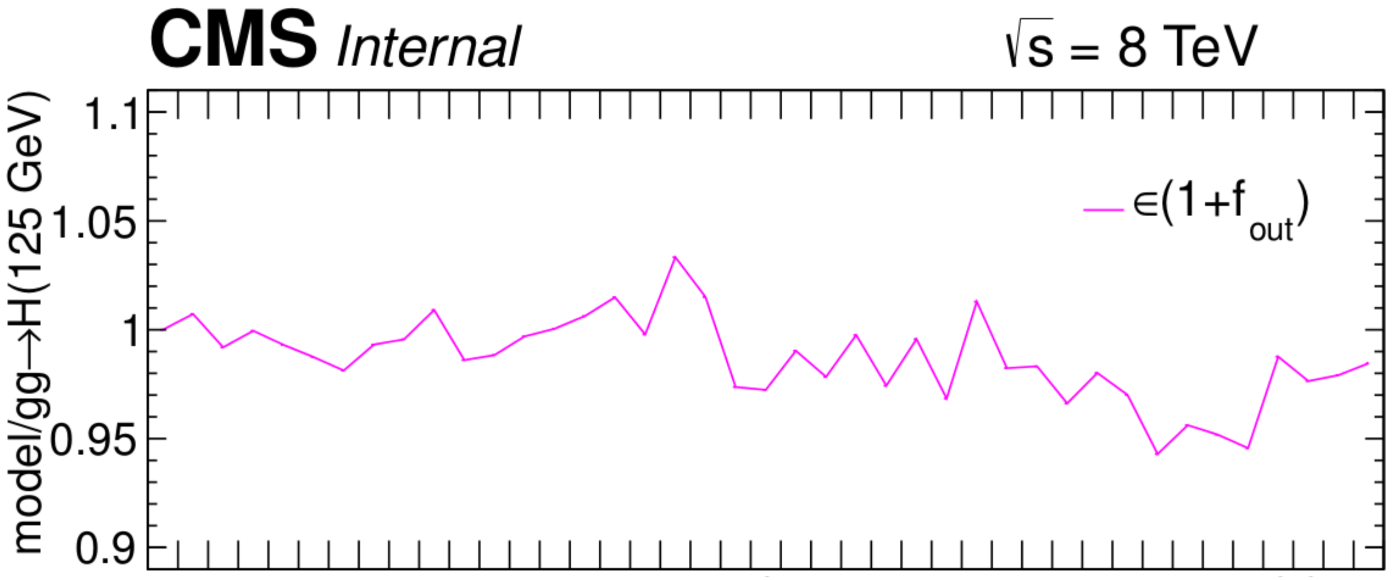
<u>Fiducial Acceptance:</u>
Significant variations between all models, due to kinematic acceptance (including isolation)

<u>"model dependence" factor:</u>
Significant variations only for very exotic models

Signal process	$\mathcal{A}_{\text{fid}}$	ϵ	f_{nonfid}	$(1+f_{\text{nonfid}})\epsilon$
Individual Higgs boson production modes				
gg→ H (POWHEG+JHUGEN)	0.422 ± 0.001	0.647 ± 0.002	0.053 ± 0.001	0.681 ± 0.002
VBF (POWHEG)	0.476 ± 0.003	0.652 ± 0.005	0.040 ± 0.002	0.678 ± 0.005
WH (PYTHIA)	0.342 ± 0.002	0.627 ± 0.003	0.072 ± 0.002	0.672 ± 0.003
ZH (PYTHIA)	0.348 ± 0.003	0.634 ± 0.004	0.072 ± 0.003	0.679 ± 0.005
ttH (PYTHIA)	0.250 ± 0.003	0.601 ± 0.008	0.139 ± 0.008	0.685 ± 0.010
Some characteristic models of Higgs-like boson with exotic decays and properties				
$q\bar{q} \to \text{H}(\text{J}^{\text{CP}}=1^-)$ (JHUGEN)	0.238 ± 0.001	0.609 ± 0.002	0.054 ± 0.001	0.642 ± 0.002
$q\bar{q} \to \text{H}(\text{J}^{\text{CP}}=1^+)$ (JHUGEN)	0.283 ± 0.001	0.619 ± 0.002	0.051 ± 0.001	0.651 ± 0.002
gg→ H → $\text{Z}\gamma^*$ (JHUGEN)	0.156 ± 0.001	0.622 ± 0.002	0.073 ± 0.001	0.667 ± 0.002
gg→ H → $\gamma^*\gamma^*$ (JHUGEN)	0.188 ± 0.001	0.629 ± 0.002	0.066 ± 0.001	0.671 ± 0.002

Model Dependence

- Higgs has only just been discovered, one choice is to use as many models as possible to determine the model dependence
- Alternatively, use experimental constraints
- Build response matrix and repeat the unfolding procedure once per model → quote the envelope as a systematic uncertainty
- Should agree how many models, and with what constraints, should be considered



Using all exotic models the model dependence is ~7%

Using combination of SM production modes with cross sections constrained to experimentally measured values, model dependence is less than 1%