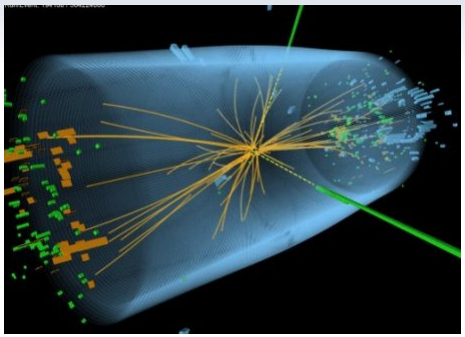
Theory Uncertainties in Higgs+2 jets

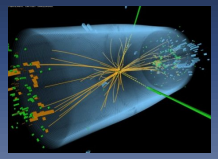


Shireen Gangal

October 12, 2012

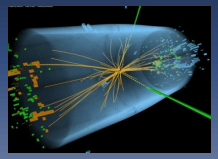
Deutsches Elektronen-Synchrotron (DESY)
Work done in collaboration with Frank Tackmann

Higgs Cross section working group meeting



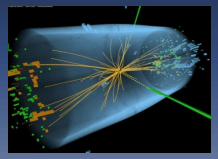
Plan of talk

1. Introduction
2. Jet Bin Uncertainties
3. Higgs+2jets
4. Theory Uncertainties in ggF-VBF separation
5. Conclusions



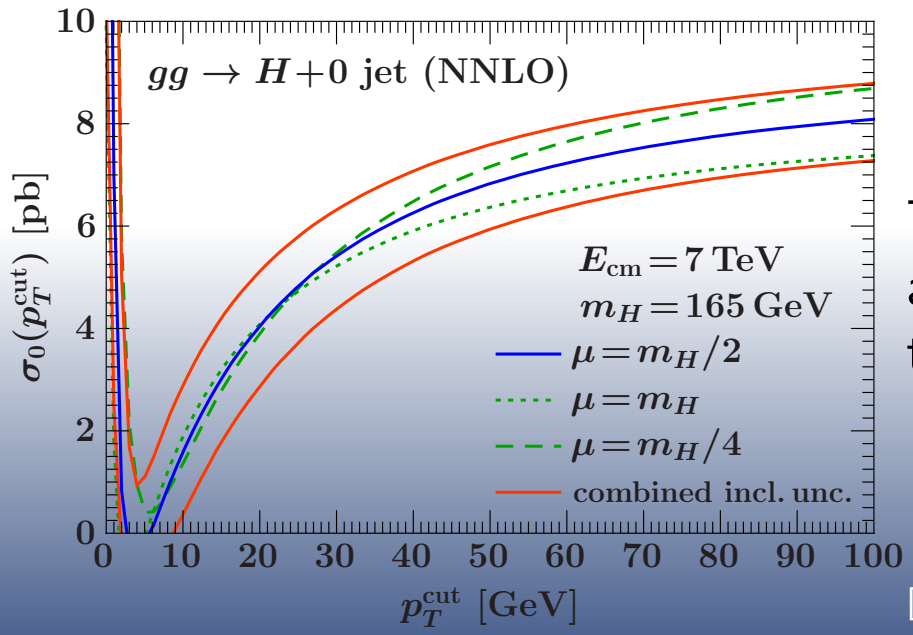
Introduction

- The main next step in measuring Higgs properties is to separately measure gluon gluon fusion (ggF) and vector boson fusion (VBF) processes.
- ATLAS and CMS use various dijet selection cuts to enhance VBF over gluon gluon fusion.
- VBF is still contaminated by significant fraction ($\sim 30\%$) of gluon gluon fusion which has large uncertainties.
- We study the theoretical uncertainties in gluon gluon fusion for H+2jets using ATLAS and CMS dijet selection cuts.



Jet Bin Uncertainties

- Scale Variation for the exclusive jet bins tends to underestimate the uncertainties as there are cancellations between large K factors and large logarithmic terms from the dependence on jetveto.
- To estimate realistic uncertainties: Use scale variation to determine the uncertainties in the inclusive N jet cross sections $\sigma_{\geq N}$.



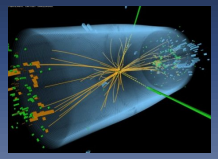
The exclusive N jet cross section is written as:

$$\sigma_N = \sigma_{\geq N} - \sigma_{\geq N+1}$$

The perturbative uncertainties in $\sigma_{\geq N}$ are taken as uncorrelated to estimate the size of jet-veto logs:

$$\Delta_N^2 = \Delta_{\geq N}^2 + \Delta_{\geq N+1}^2$$

[F. Tackmann & I. Stewart, arXiv:1107.2117]



Dijet selection cuts

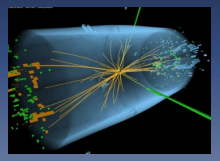
- The exclusive 2 jet cross section for H+2jets can be written as:

  $\sigma_2[2jetcuts](p_{Tj3} < p_T^{cut}) = \sigma_{\geq 2}[2jetcuts] - \sigma_{\geq 3}[2jetcuts](p_{Tj3} > p_T^{cut})$

  [2jet cuts] refers to inclusive 2jet cuts used in VBF selection.

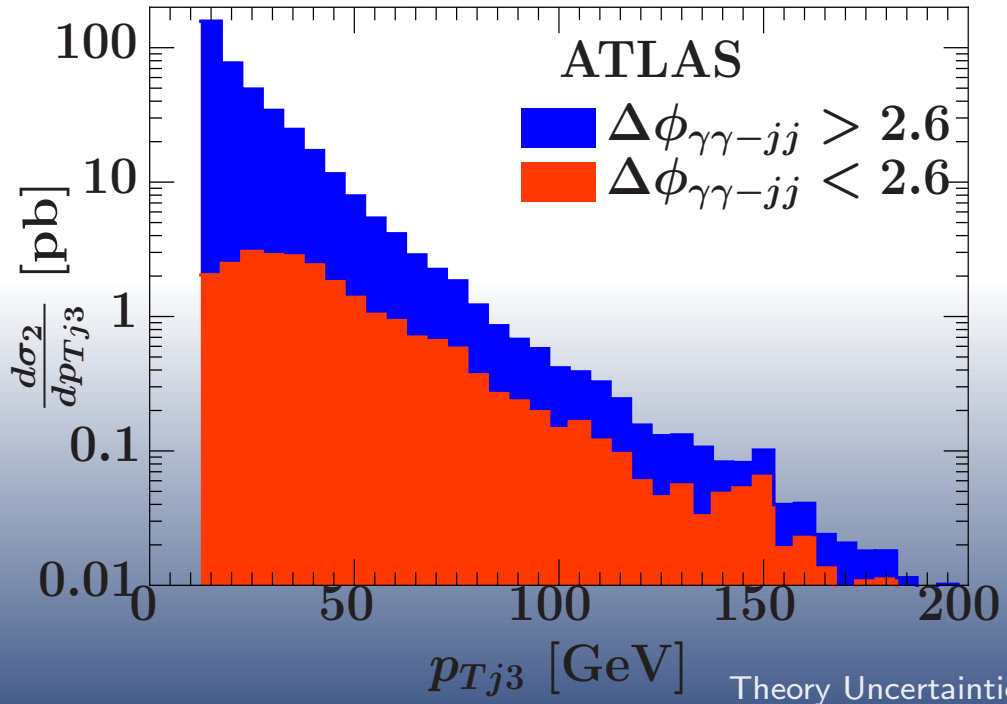
Variable	2012 $H \to \gamma\gamma$		
	ATLAS	CMS	
		Loose	Tight
p_{Tj1}	> 25, $\eta_{j1} < 2.5$	> 30, $\eta_{j1} < 4.7$	> 30, $\eta_{j1} < 4.7$
	> 30, $2.5 < \eta_{j1} < 4.5$		
p_{Tj2}	> 25, $\eta_{j2} < 2.5$	> 30, $\eta_{j2} < 4.7$	> 30, $\eta_{j2} < 4.7$
	> 30, $2.5 < \eta_{j2} < 4.5$		
$\Delta\eta_{j1j2}$	> 2.8	> 3.0	> 3.0
$\lvert\eta_{\gamma\gamma} - \frac{1}{2}(\eta_{j1} + \eta_{j2})\rvert$	-	< 2.5	< 2.5
m_{jj}	> 400	> 250	> 500
$\Delta\phi_{\gamma\gamma-jj}$*	> 2.6	> 2.6	> 2.6

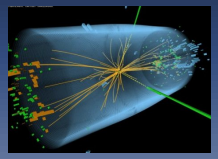
*Exclusive 2 jet selection cut



Physical Significance of $\Delta\phi_{\gamma\gamma-jj}$

- ATLAS and CMS use $\Delta\phi_{\gamma\gamma-jj} > \Delta\phi^{cut} = 2.6$.
- From momentum conservation in transverse plane, events with only 2 high p_T jets have $\Delta\phi_{\gamma\gamma-jj} \approx \pi$.
- Thus $\Delta\phi > 2.6$ is sensitive to the exclusive 2 jet region and behaves similar to the $p_T < p_T^{cut}$ exclusive jetveto.





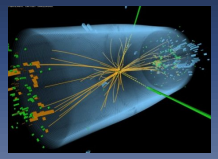
Generalizing to other cuts

- Generalize the procedure of combined inclusive scale variation to estimate uncertainties in any kinematic cuts that restrict to the exclusive 2 jet region and induce logarithmic terms in perturbative series eg: $\Delta\phi_{\gamma\gamma-jj}$
- Just as p_T^{cut} used to divide cross section into jetbins we can use $\Delta\phi_{\gamma\gamma-jj}$ to divide the cross section as:

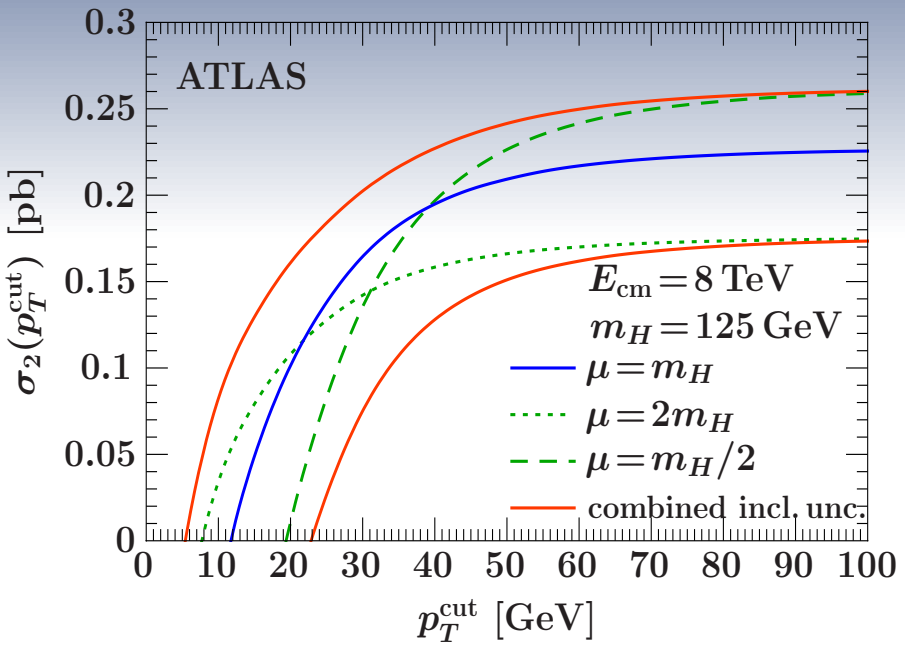
$$\sigma = \int_{\Delta\phi^{cut}}^{\pi} \frac{d\sigma}{d\phi} d\phi + \int_{0}^{\Delta\phi^{cut}} \frac{d\sigma}{d\phi} d\phi$$

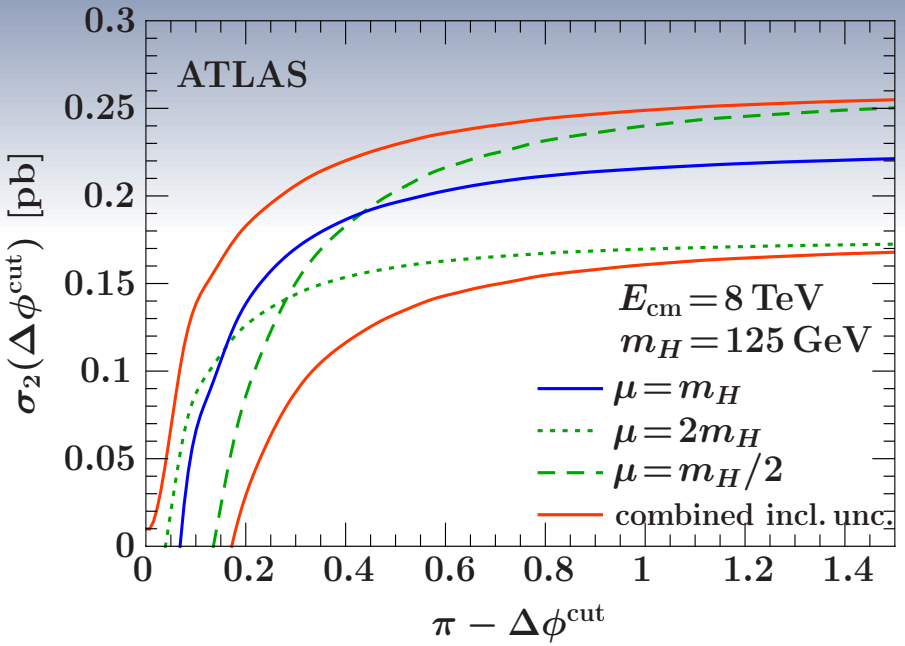
- The exclusive 2 jet cross section as a function of $\Delta\phi^{cut}$ can be written as:

$$\sigma_2(\Delta\phi_{\gamma\gamma-jj} > \Delta\phi^{cut}) = \sigma_{\geq 2} - \sigma_{\geq 3}(\Delta\phi_{\gamma\gamma-jj} < \Delta\phi^{cut})$$



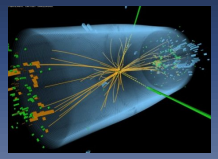
$gg \rightarrow$ Higgs + 2jets



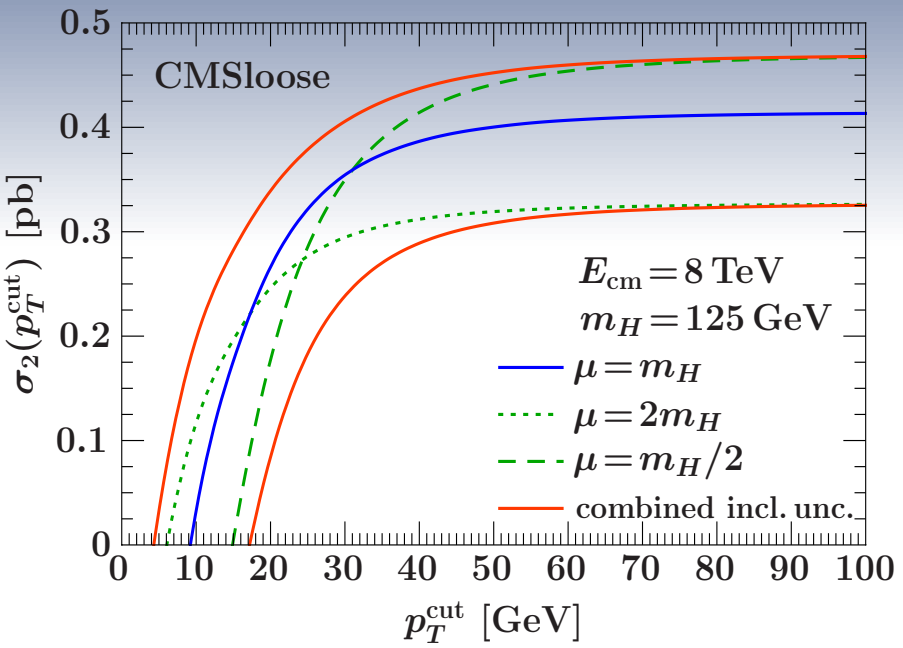


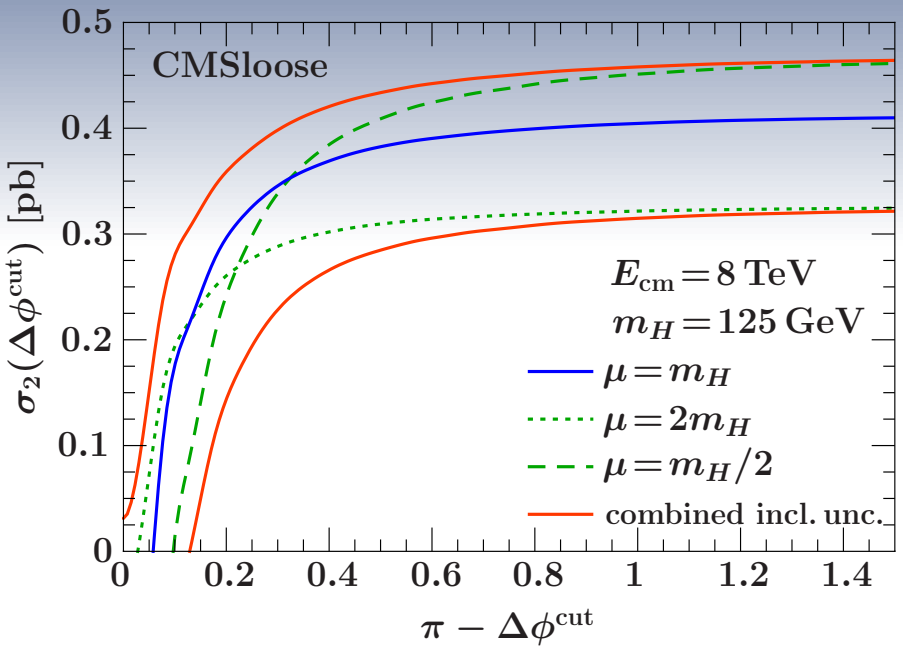
Variable	Direct Scale Variation Unc.	Combined Inclusive Unc.
$\sigma_{\geq 2}[ATLAS]$	$0.23^{+15\%}_{-23\%}(\pm 20\%)$	
$p_{Tj3}^{cut} = 30 GeV$	$0.17^{+0\%}_{-14\%}(\pm 10\%)$	$0.17^{+23\%}_{-52\%}(\pm 45\%)$
$\pi - \Delta\phi^{cut} = 0.5$	$0.20^{+3\%}_{-19\%}(\pm 11\%)$	$0.20^{+16\%}_{-31\%}(\pm 26\%)$

Above $\mu_R = \mu_F = \mu$



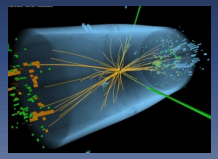
$gg \to$ Higgs + 2jets





Variable	Direct Scale Variation Unc.	Combined Inclusive Unc.
$\sigma_{\geq 2}[CMSloose]$	$0.41^{+19\%}_{-21\%}(\pm 20\%)$	
$p_{Tj3}^{cut} = 30 GeV$	$0.35^{+7\%}_{-17\%}(\pm 13\%)$	$0.35^{+21\%}_{-33\%}(\pm 29\%)$
$\pi - \Delta\phi^{cut} = 0.5$	$0.38^{+14\%}_{-19\%}(\pm 17\%)$	$0.38^{+20\%}_{-25\%}(\pm 23\%)$

Above $\mu_R = \mu_F = \mu$



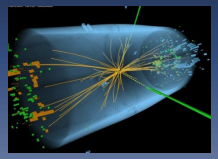
Combining exclusive cuts

- We can use our method to estimate uncertainties in case of more complicated cuts which force the kinematics into exclusive 2 jet region.
- As an example we study the uncertainties in the 2 jet exclusive cross section as a function of p_T^{cut} with an additional constraint that $\Delta\phi_{\gamma\gamma-jj} > 2.6$.

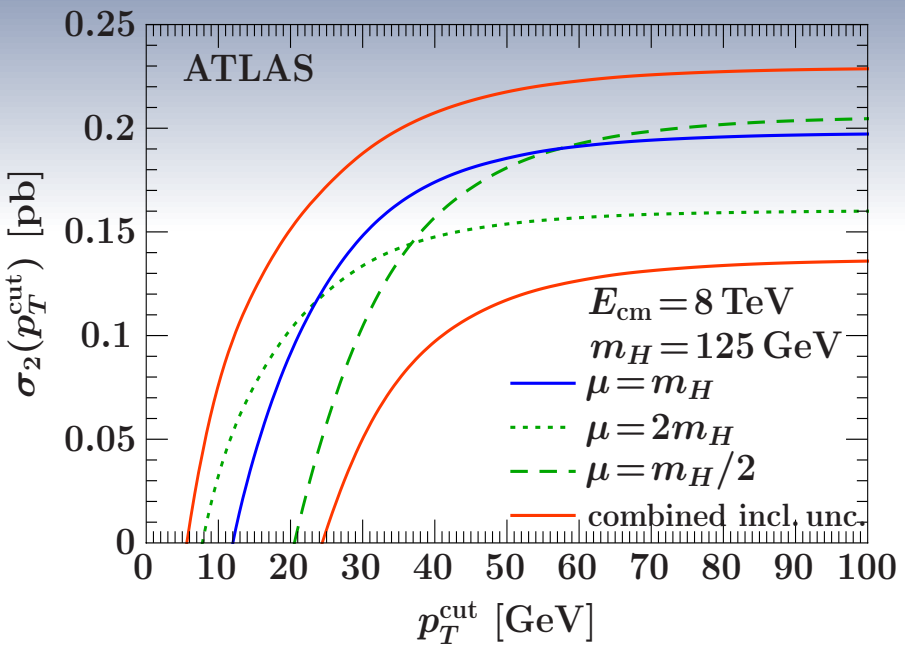
$$\sigma_2(\Delta\phi_{\gamma\gamma-jj} > 2.6, p_{Tj3} < p_T^{cut}) = \sigma_{\geq 2} - \\ -\sigma_{\geq 3}(\Delta\phi_{\gamma\gamma-jj} < 2.6 || p_{Tj3} > p_T^{cut})$$

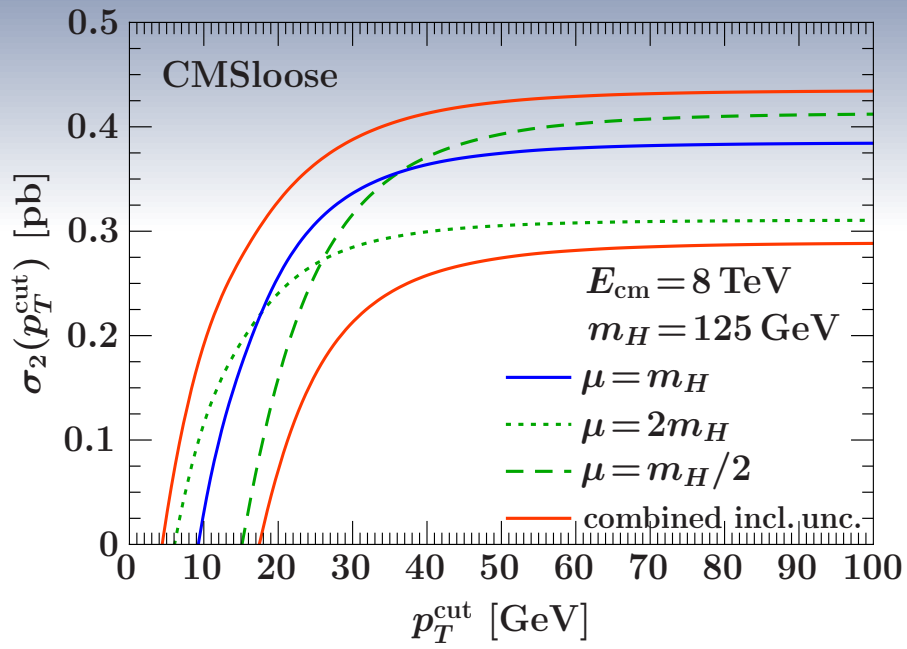
- The uncertainty in the exclusive 2 jet cross section is written as:

$$\Delta_2^2(\Delta\phi_{\gamma\gamma-jj} > 2.6, p_{Tj3} > p_T^{cut}) = \Delta_{\geq 2}^2 + \\ \Delta_{\geq 3}^2(\Delta\phi_{\gamma\gamma-jj} > 2.6 || p_{Tj3} > p_T^{cut})$$



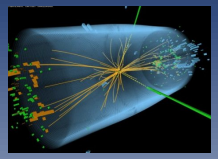
Combining exclusive cuts





Variable	Direct Scale Variation Unc.	Combined Inclusive Unc.
Atlas $p_{Tj3}^{cut} = 30 GeV$	$0.15^{+0}_{-20\%}(\pm 10\%)$	$0.15^{+25\%}_{-63\%}(\pm 55\%)$
CMS $p_{Tj3}^{cut} = 30 GeV$	$0.33^{+2\%}_{-15\%}(\pm 9\%)$	$0.33^{+21\%}_{-35\%}(\pm 30\%)$

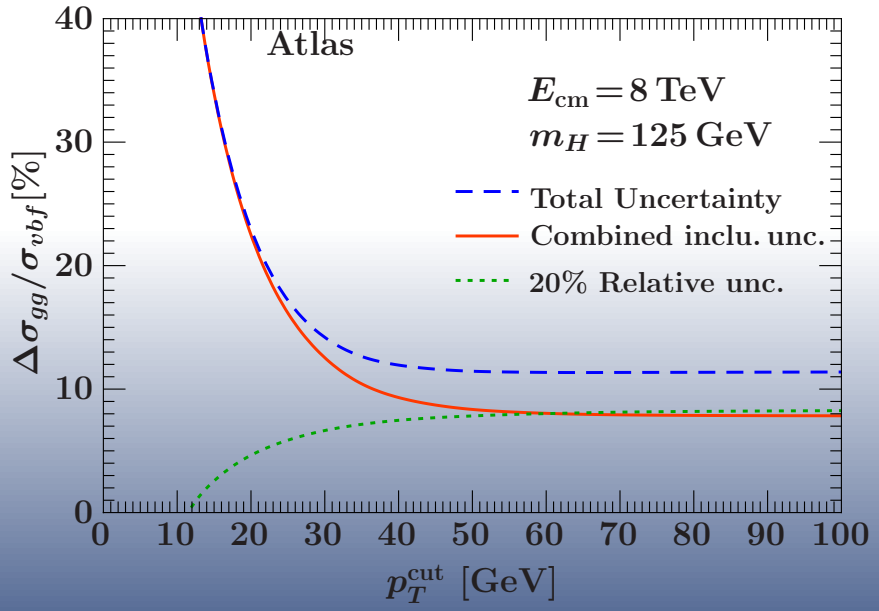
For large p_T^{cut}, correctly reproduce $\Delta\sigma_2(\Delta\phi_{\gamma\gamma-jj} > 2.6)$

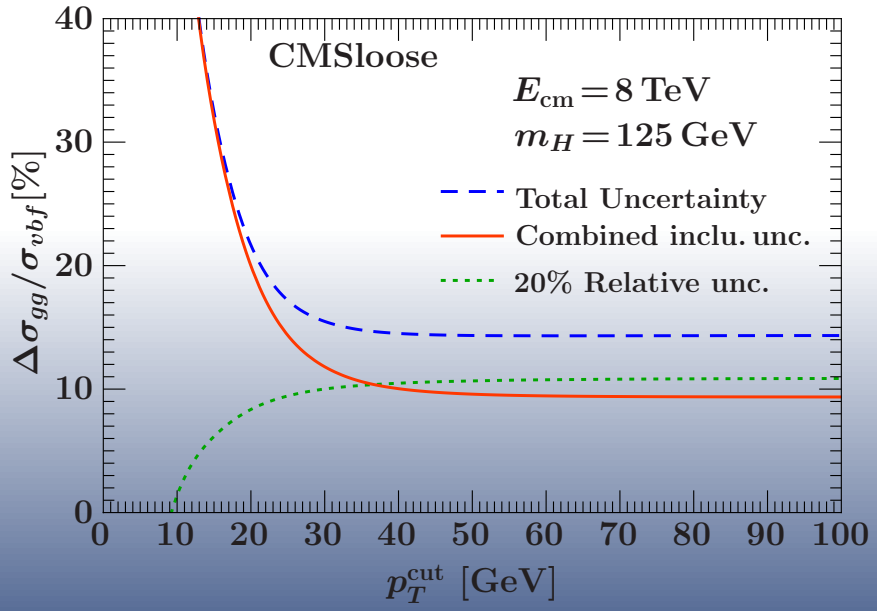


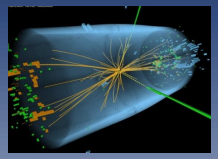
Theory Uncertainties in ggF-VBF separation

$$\sigma_2^{measured}(p_T^{cut}) = \sigma_{2,VBF}(p_T^{cut}) + \sigma_{2,gg}(p_T^{cut})$$

The main uncertainty in the ggF-VBF separation comes from the uncertainty in the gluon gluon fusion. So the relevant figure of merit is the relative uncertainty $\frac{\Delta\sigma_{gg}}{\sigma_{VBF}}$.

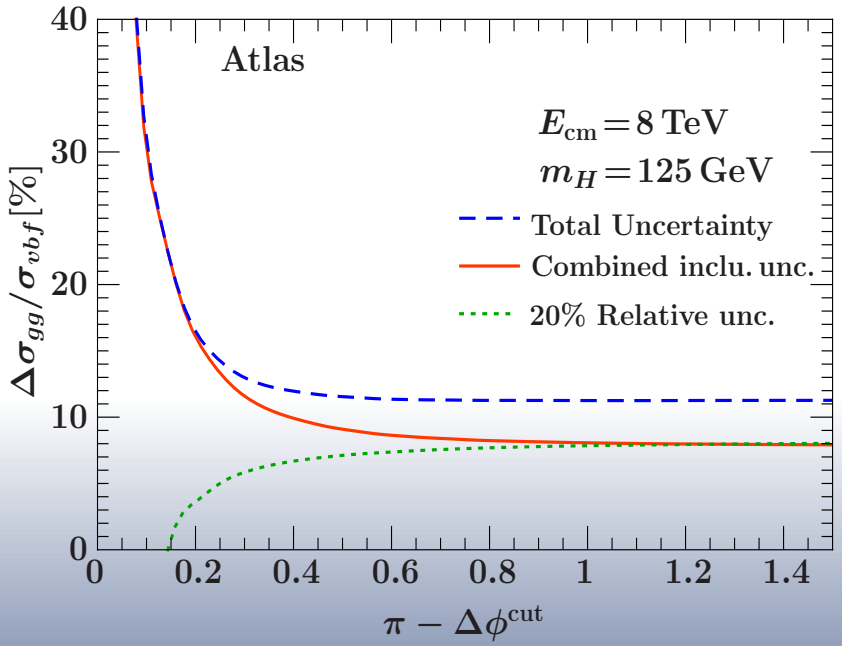


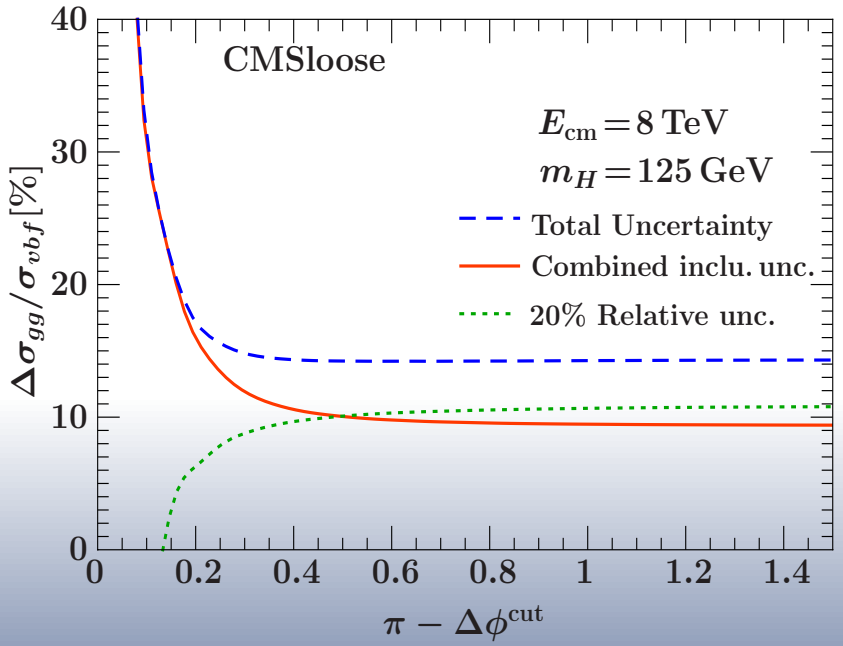


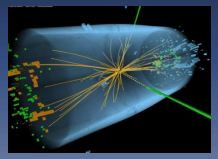


Theory Uncertainties in ggF-VBF separation

$$\sigma_2^{measured}(\Delta\phi^{cut}) = \sigma_{2,VBF}(\Delta\phi^{cut}) + \sigma_{2,gg}(\Delta\phi^{cut})$$

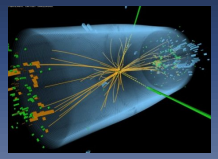






Conclusions

- Combined Inclusive scale variation allows to obtain realistic fixed order uncertainties for the 2 jet exclusive cross section.
- This method can be generalised to estimate uncertainties in any kinematic observable which restricts to the exclusive 2 jet region and induces logarithmic dependance in the perturbative series.
  $\Rightarrow \Delta\phi_{\gamma\gamma-jj}$ used in $H \to \gamma\gamma$ is a good example.
- Exclusive 3-jet veto in VBF does not necessarily help separating ggF and VBF due to increasing theory uncertainty.
  $\Rightarrow$One should combine theory and experimental uncertainties when optimizing cuts or in MVA.
  $\Rightarrow$ We are currently studying how to apply method at a differential level to allow propagation of uncertainties directly via MC.



Outlook

Work in progress with Florian Bernlochner.