Answers to (some) ATLAS Questions for Higgs → $\gamma\gamma$ Interference and Width

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Questions

Q: What uncertainty sources were considered for $\sigma_{Continuum}$ & σ_{ggH}?

A: This is not really the right question. We are not trying to predict either $\sigma_{Continuum}$ *or* $\sigma_{ggH.}$

We are trying to predict the lineshape (and/or the apparent mass shift) as a function of the kinematical variables for Higgs production. Some things that affect a prediction of $\sigma_{Continuum}$ or σ_{ggH} can be expected to cancel out to some extent, such as the contributions of soft radiated gluons to the mass shift in an inclusive sample. That's because the (inclusive) mass shift is effectively a ratio of background to signal for a similar initial state. Other things arise that are not present in the computation of $\sigma_{Continuum}$ *or* $\sigma_{ggH.}$ (see next question).

Q: Higher order corrections are large in gg→H, do you think these changes are covered by the usual scale variations?

A: Probably not, unfortunately. In the inclusive sample, if you varied scales independently in the pure signal and in the interference term, you would surely overestimate the uncertainty by a lot. In 1305.3854 we varied them in common. For the mass shift in the inclusive sample, the error estimate we obtained is about +-7% (fig. 3 of the paper, for large pT(veto)). To be conservative, you might want to double that.

The bigger concern is the mass shift with a lower pT cut, fig. 4 at around 30-40 GeV. This comes from a cancellation between 2 different channels, gg and qg, and a LO computation for both channels. We wouldn't be surprised by shifts of 20 MeV or more in the SM from higher orders (HO) in QCD spoiling the cancellation.

PDFs: The inclusive mass shift is gg dominated, and is a ratio, so it has little sensitivity to pdfs. The plot in fig. 4 does have pdf sensitivity because of qg vs. gg cancellation; we haven't quantified that yet. We could and should do that; but it's still probably smaller than HO uncertainty

Q: The quark initial diagrams are formally at leading order; what effort would be needed to bring this up to NLO?

A: This is a do-able calculation now. All the one-loop matrix elements have been known for a long time; they would have to be assembled, phases cross-checked, and combined with a dipole subtraction for real radiation. The main question is whether it is worth doing in the absence of the (much harder) computation of the contribution of the gg channel at finite Higgs pT. The order counting is skewed by the large gluon distribution. At finite pT, the current calculation of the gg channel is one power of α_s higher, but it is the same size as the qg channel. So it would be best to do one more order in the gg channel at finite pT at the same time. But this (2-loop 2→3 amplitude for gg→$\gamma\gamma$g) is a bit beyond the current state-of-the art. On the next slide is a table of what we have in the code now.

TABLE I: Helicity amplitudes included in the calculation

		tree	1-loop	2-loop
Signal	$gg \to H \to \gamma\gamma$	Yes	Yes	No
	$q\bar{q} \to H \to \gamma\gamma$	0	0	0
	$gg \to Hg \to \gamma\gamma g$	Yes	No	No
	$qg \to Hq \to \gamma\gamma q$	Yes	No	No
Background	$gg \to \gamma\gamma$	0	Yes	Yes
	$q\bar{q} \to \gamma\gamma$	Yes	Yes	No
	$gg \to \gamma\gamma g$	0	Yes	No
	$qg \to \gamma\gamma q$	Yes	Partial[a]	No

[a] only the gauge-invariant subset of which diagrams contain a closed quark loop included

Q: **How does the summed line-shape change if these uncertainty sources are varied?**

A: Best guesses are given above, summarized here. PDF uncertainty should be very small for inclusive shift, larger for shift at finite pT cut. HO uncertainty for shift at finite pT cut is biggest worry, not captured by scale variation due to LO cancellation, could shift pT > 30 GeV result by 20 MeV or more in SM.

Q: **How should we deal with μ?**

A: For consistency with your measurement of the yield in $\gamma\gamma$, it is best to incorporate μ into theory model. The magnitude of the mass shift scales like $1/\sqrt{\mu}$. (The interference term goes like $\sqrt{\mu}$, but it is "tugging" on a signal that scales like μ.)

Q: What would be the effect on the interference if the gg→ $\gamma\gamma$ "part" of the measured continuum cross section would be very different from the value used in the interference?

A: Most likely there would be a problem in interpreting the continuum measurement in this way. So we would not encourage this exercise. As stated above, there are large soft-gluon effects for both ggH and gg→ $\gamma\gamma$ continuum, which largely cancel in the ratio relevant for the mass shift. There are also details of photon isolation in the best inclusive $\gamma\gamma$ continuum theoretical prediction (NNLO, by de Florian et al.). How well is the fragmentation contribution to gg→ $\gamma\gamma$ continuum known, etc.?

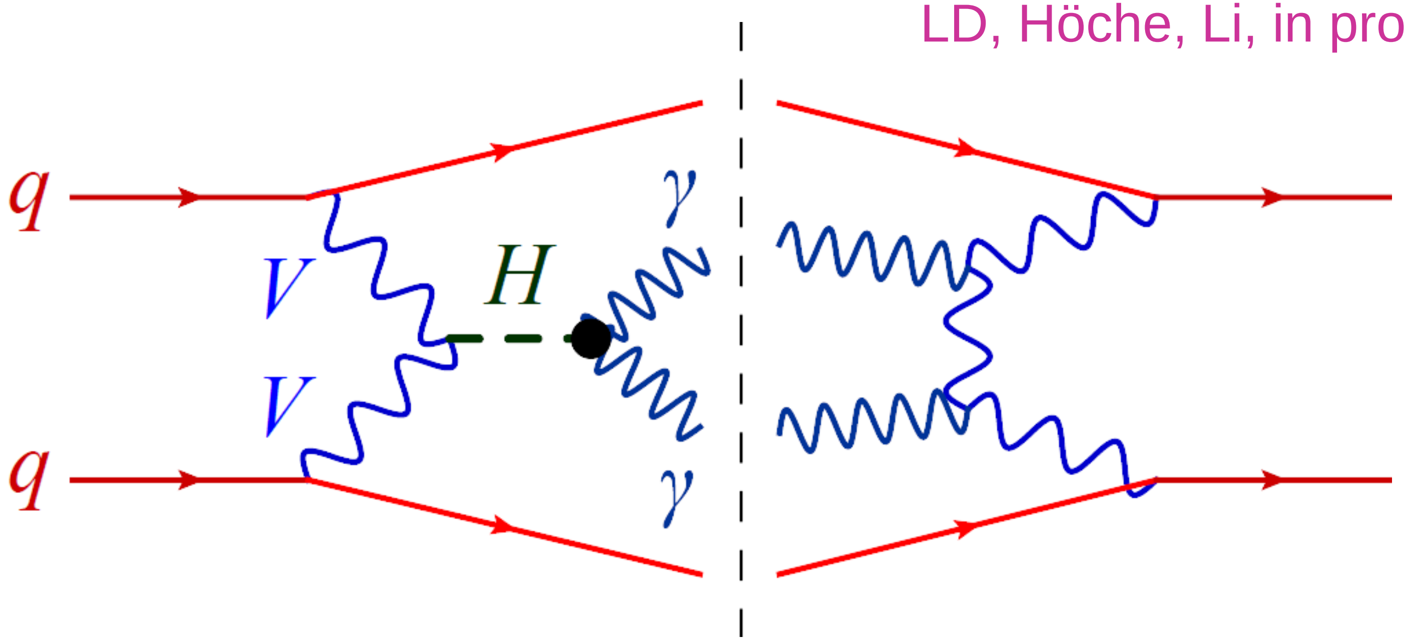
Another possible control mass

Mass in $\gamma\gamma$ in vector-boson-fusion (VBF) enhanced sample.

- Statistics are small, but background is lower, so mass determination may not be worse statistically than using high pT(Higgs) sample.
- Photon pTs may be more similar to inclusive Higgs sample, possibly reducing photon energy scale systematics
- Theoretical prediction of VBF mass shift will be more robust than that of high pT(Higgs) sample.

Mass shift in VBF

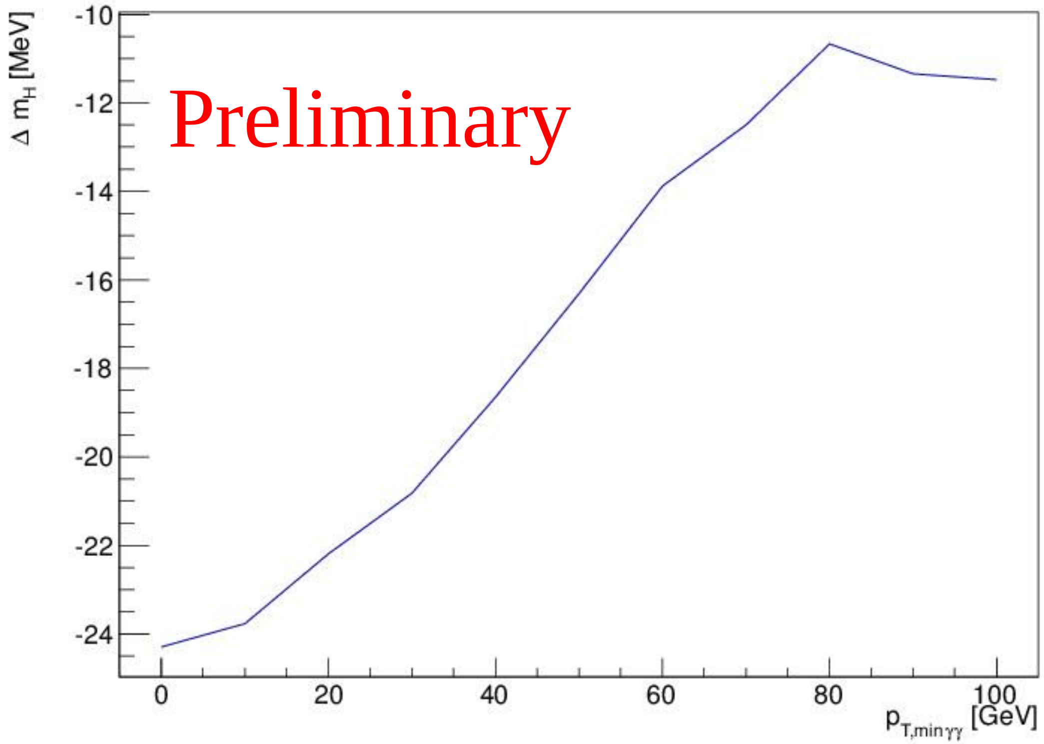
LD, Höche, Li, in progress



V = W or Z.

W channel should dominate mass shift because background photons can be more central when radiated off of charged *W* line in *t* channel

Mass shift in VBF (cont.)



$p_T(\gamma_{1,2}) > 20$ GeV
$|\eta(\gamma_{1,2})| < 2.5$

$p_T(j_{1,2}) > 20$ GeV
$M_{jj} > 800$ GeV
$|\Delta\eta(jj)| > 4$

- About 1/3 of effect in gluon fusion, and same sign
- Also declines as cut on minimum Higgs p_T is raised
- So you get about 2/3 of effect by using VBF as control.

Availability in SHERPA

- Sherpa version 2.0.0 includes the Higgs interference code of arXiv:1305.3854. The related parameters are documented in Sec. 10.3.1 of the online manual:

  https://sherpa.hepforge.org/doc/SHERPA-MC-2.0.0.html#LHC_005fHInt

- The simulation documented there is fixed order parton level only, i.e. no shower effects or hadronization are included. To produce events at the particle level, simply replace 'NLO_QCD_Mode 1‘ by 'NLO_QCD_Mode 3'.
- However, please note that the MC@NLO simulation in H+jets events has large uncertainties, which we have discussed extensively in arXiv:1111.1220.
- The prediction of the pT spectrum is LO accurate only and it deviates substantially from the fixed-order result (see Fig.1 in arXiv:1111.1220). Therefore you need to interpret your MC@NLO results very carefully. Please note also arXiv:1202.1251, especially Fig.4, on the same topic.

SHERPA (cont.)

- To obtain the real part of the interference, run the code with option 'HIGGS_INTERFERENCE_ONLY 1;' and test whether the invariant mass of the diphoton pair is below or above the nominal Higgs mass (i.e. 125GeV, or the number you specify using MASS[25]=<mass>). In case it is below, you accept the event as is for analysis. In case it is above, you invert the sign of the weight. This will project out the odd (real) part of the interference contribution. Similarly, if you run the code using 'HIGGS_INTERFERENCE_ONLY 1;' and leave the weight untouched, you will project out the even (imaginary) part of the interference contribution.
- You can simulate the entire effect at LO by removing the line 'NLO_QCD_Mode 1; NLO_QCD_Part BVIRS;' from the input file.
- This will automatically enable the parton shower.
- SHERPA run cards are available from Ye Li and Stefan on request.