Off-shell working group: theory update

Fabrizio Caola
CERN

Nikolas Kauer
Royal Holloway, University of London

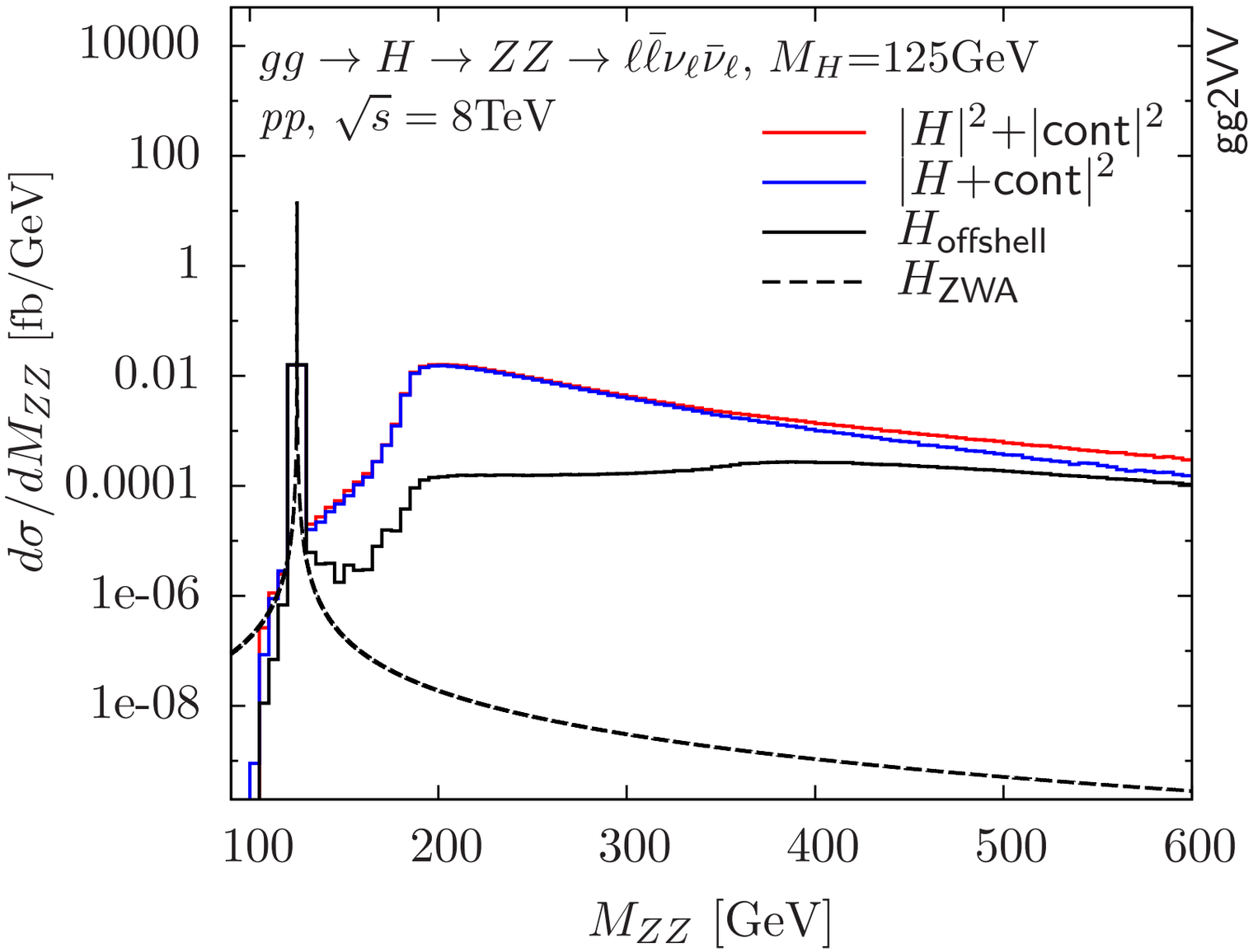
LHC Higgs Cross Section Working Group, 10th General Assembly

CERN, July 16th 2015

H-> VV and the off-shell cross-section

H->VV and the off-shell cross-section

[NK, Passarino (2012)]

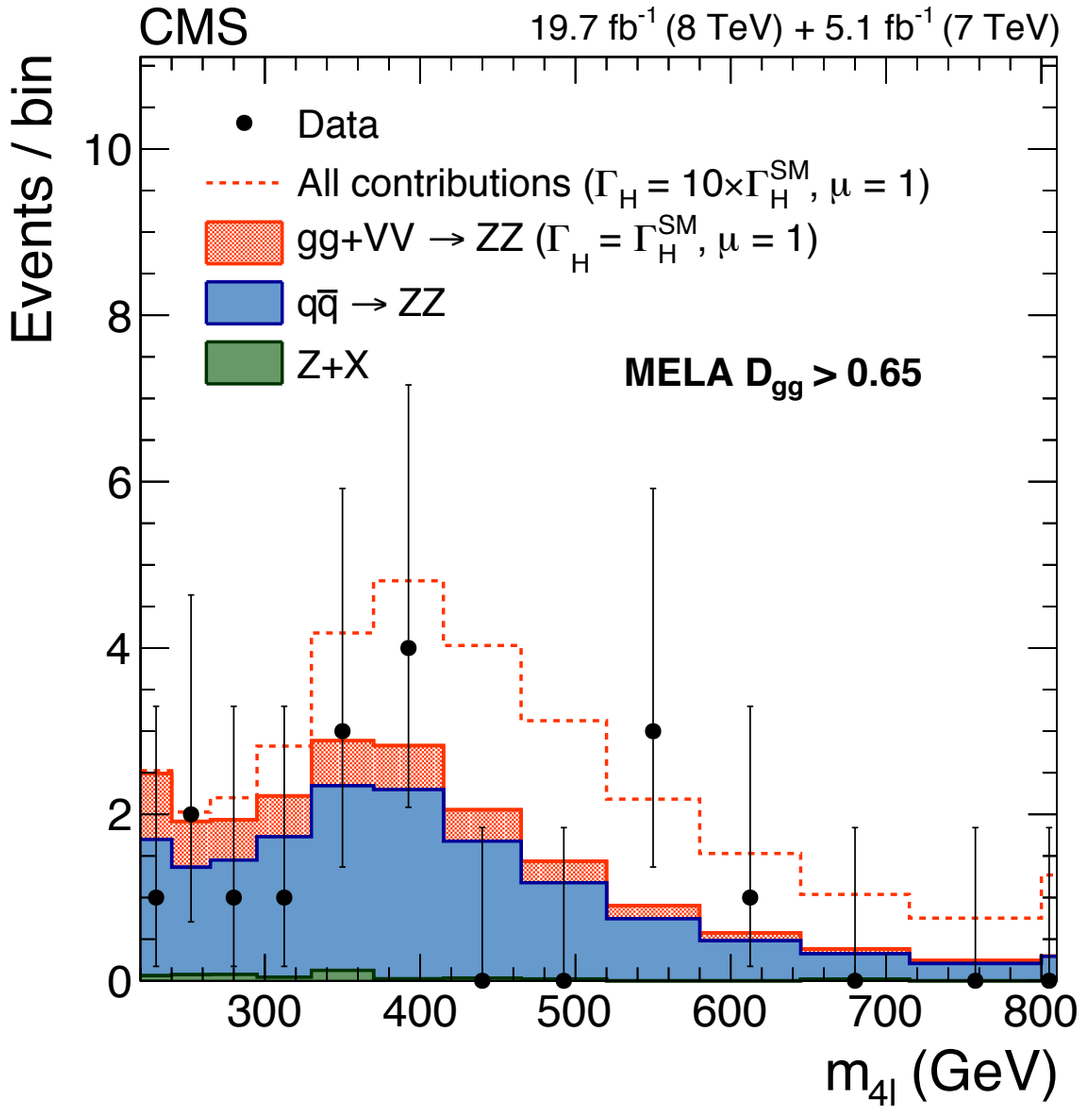


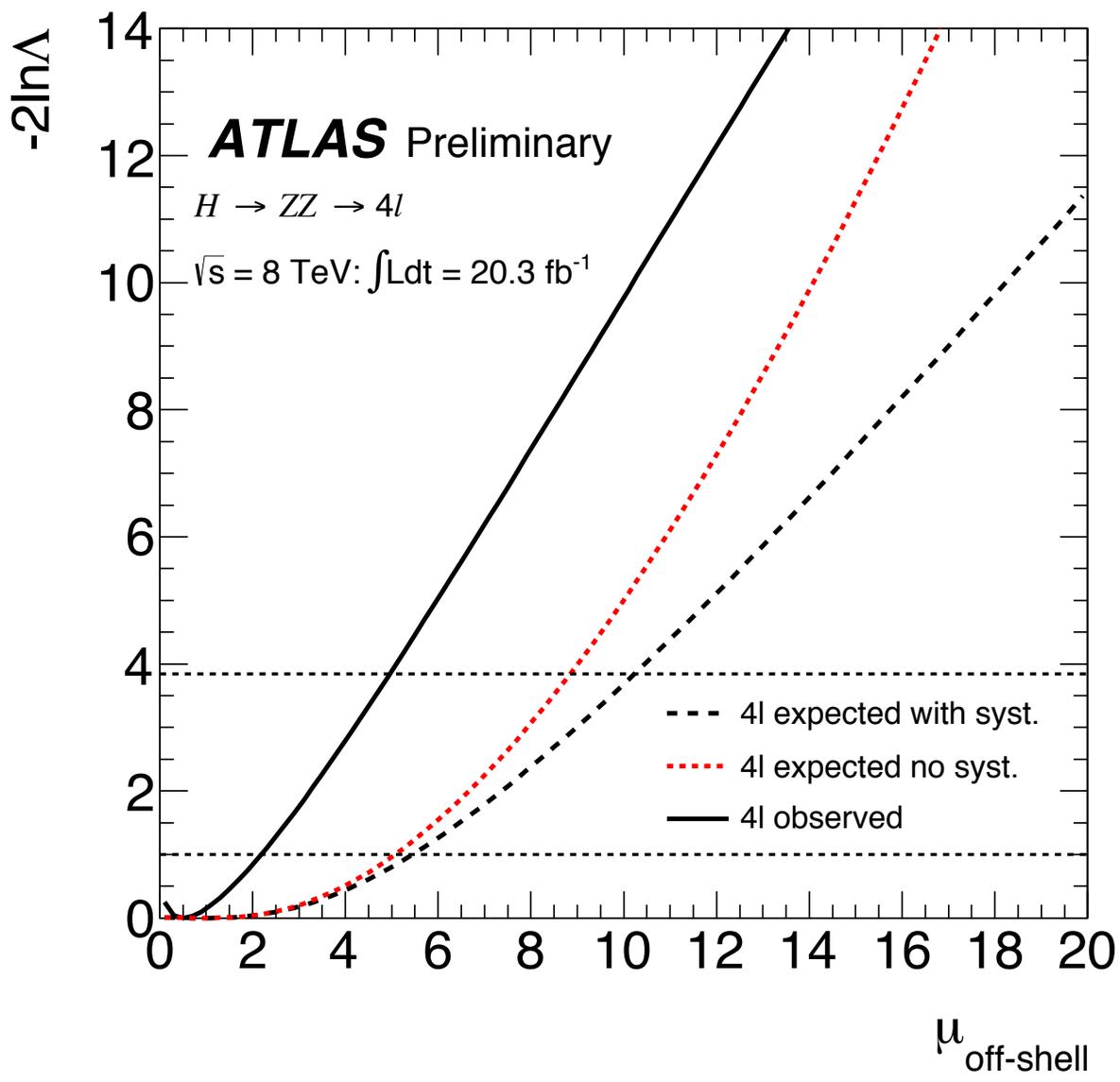
- Past the VV threshold: enhanced decays in $V_L V_L$ which compensate the rapid fall of the Higgs propagator (BW fails)
- Small but persistent effect, up to ~ 1 TeV (then washed away by PDF)
- Sensitive to (top) thresholds
- Width-independent effect
- Delicate signal / background interferences (unitarity)

- Tiny for standard analysis because of selection cuts
- But, can provide complementary information about the Higgs sector

Example: bounding the Higgs width

[FC, Melnikov; Ellis, Campbell, Williams (2013)]





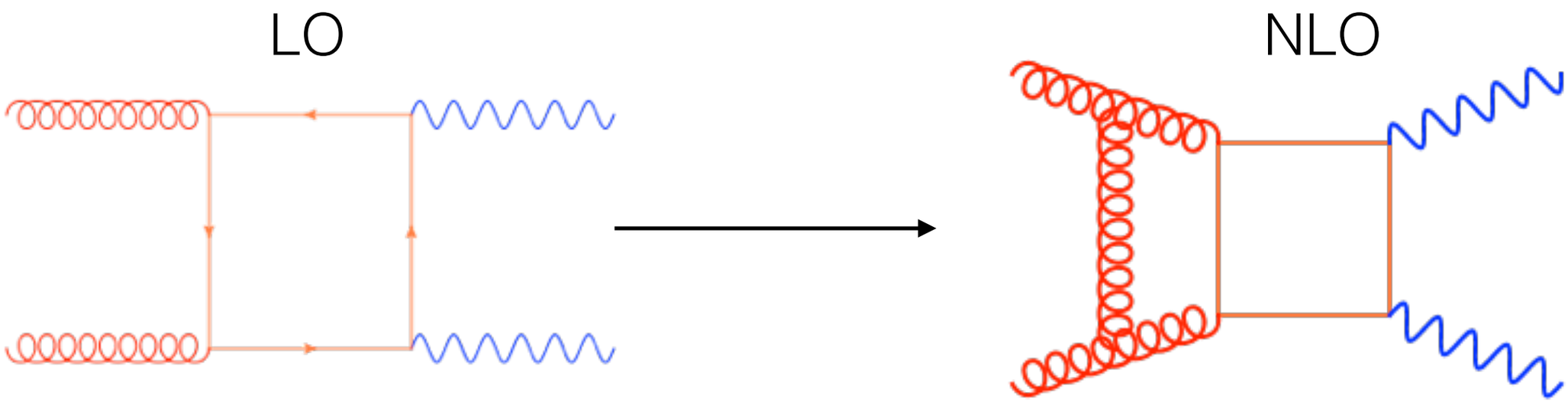
$\Gamma_H < 5.4\ \Gamma_{H,SM} = 22$ MeV @ 95CL

$\Gamma_H < 4.8\text{-}7.7\ \Gamma_{H,SM} = 20\text{-}32$ MeV @ 95CL

[with well defined assumptions]

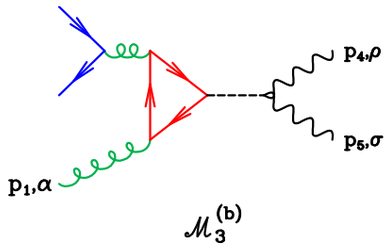
Modeling the SM background

- A major issue for these studies is a proper modeling of the pp-> 4l background, especially for the gg -> 4l channel

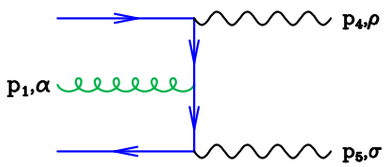


- So far, several tools to model gg->4l @ LO
  - gg2VV, MCFM —> dedicated tools, very efficient
  - OpenLoops + Sherpa —> merged gg->4l (+J) samples
  - MadGraph5_aMC@NLO —> gg -> 4l (+J) samples, BSM models
  - JHUGen+MCFM —> amplitudes for MEM, arbitrary anomalous couplings
  - Ongoing studies in GoSam

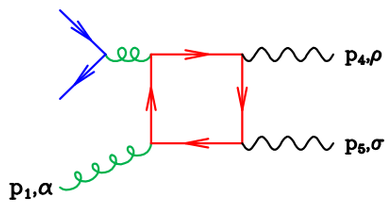
Results for pp->(H) -> ZZ+j



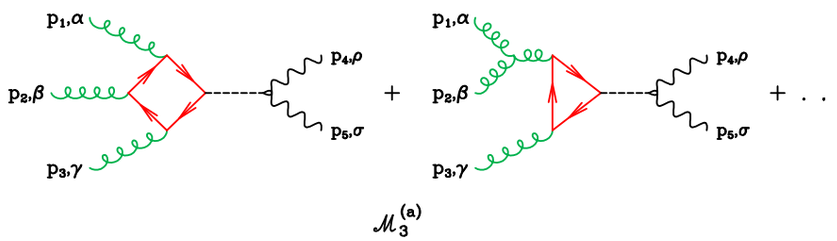
$\mathcal{M}_3^{(b)}$



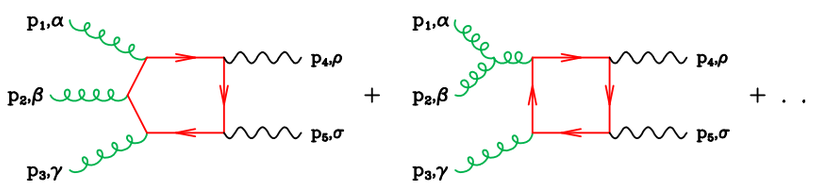
$\mathcal{B}_1^{(b)}$, $\mathcal{B}_1^{(c)}$



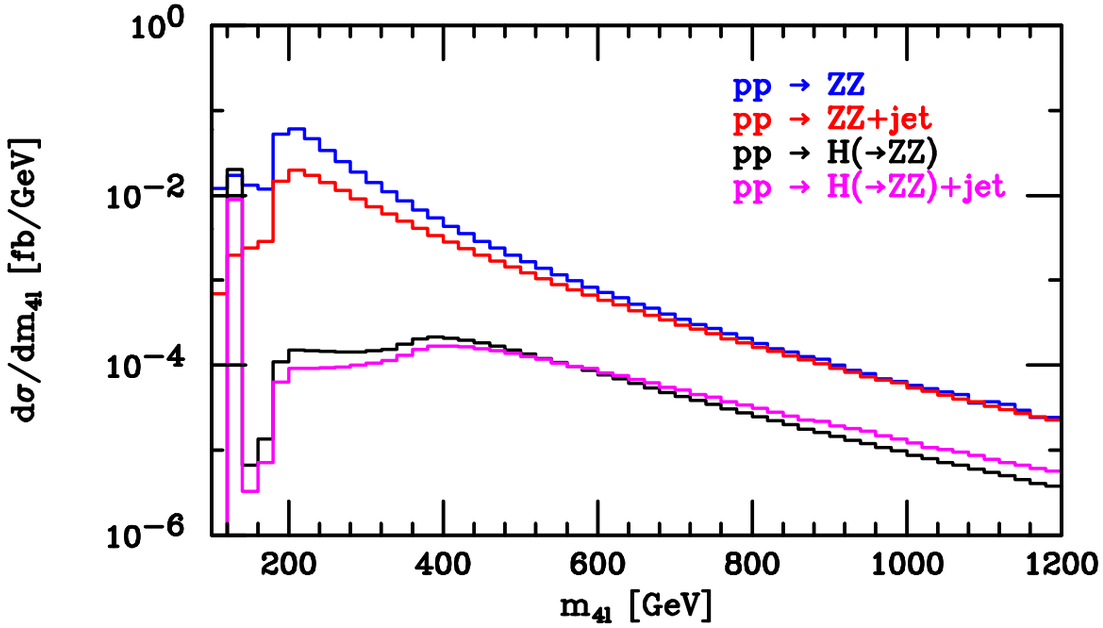
$\mathcal{B}_3^{(b)}$

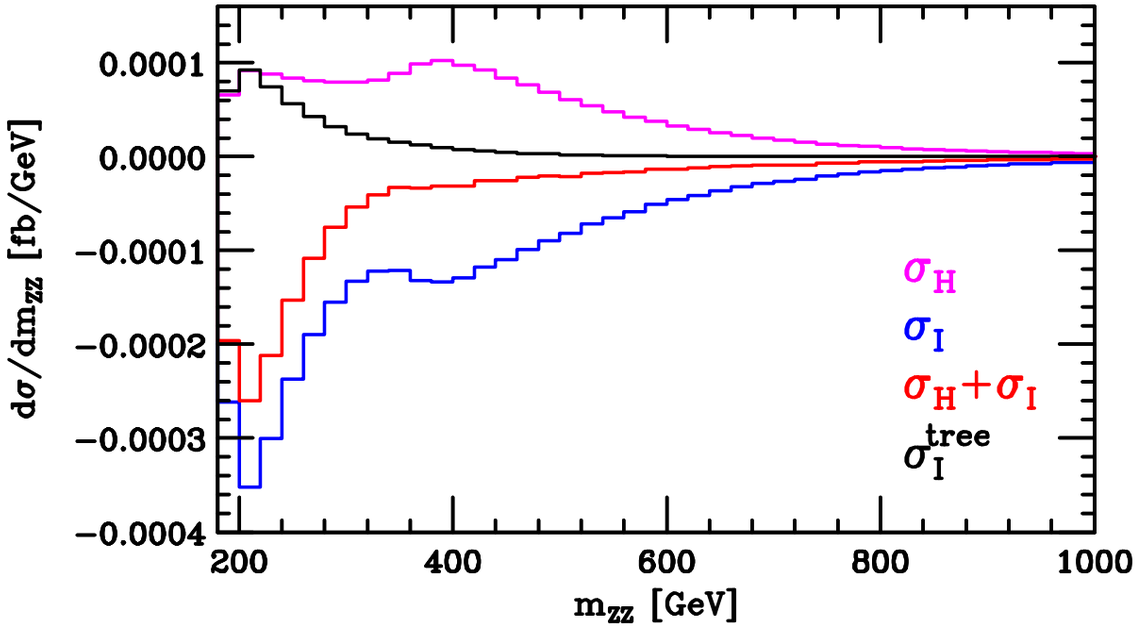


$\mathcal{M}_3^{(a)}$



$\mathcal{B}_3^{(a)}$

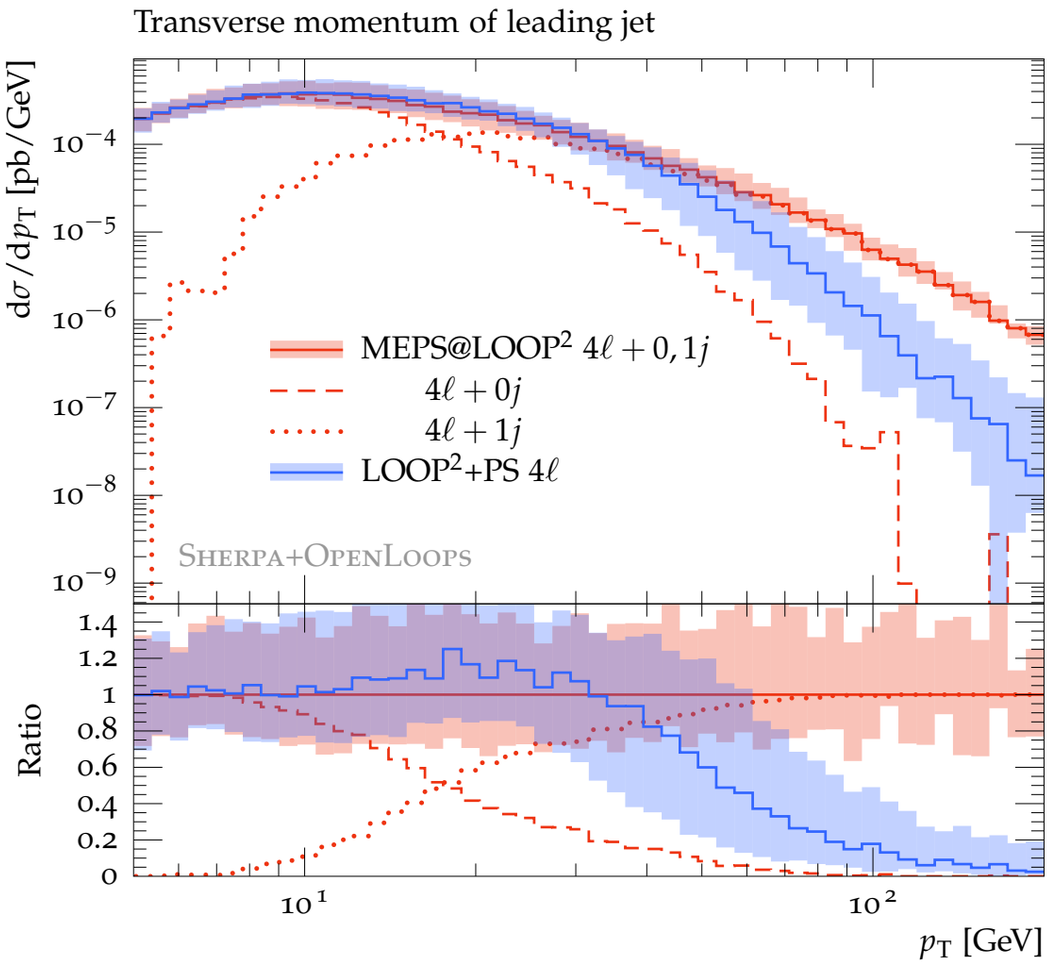


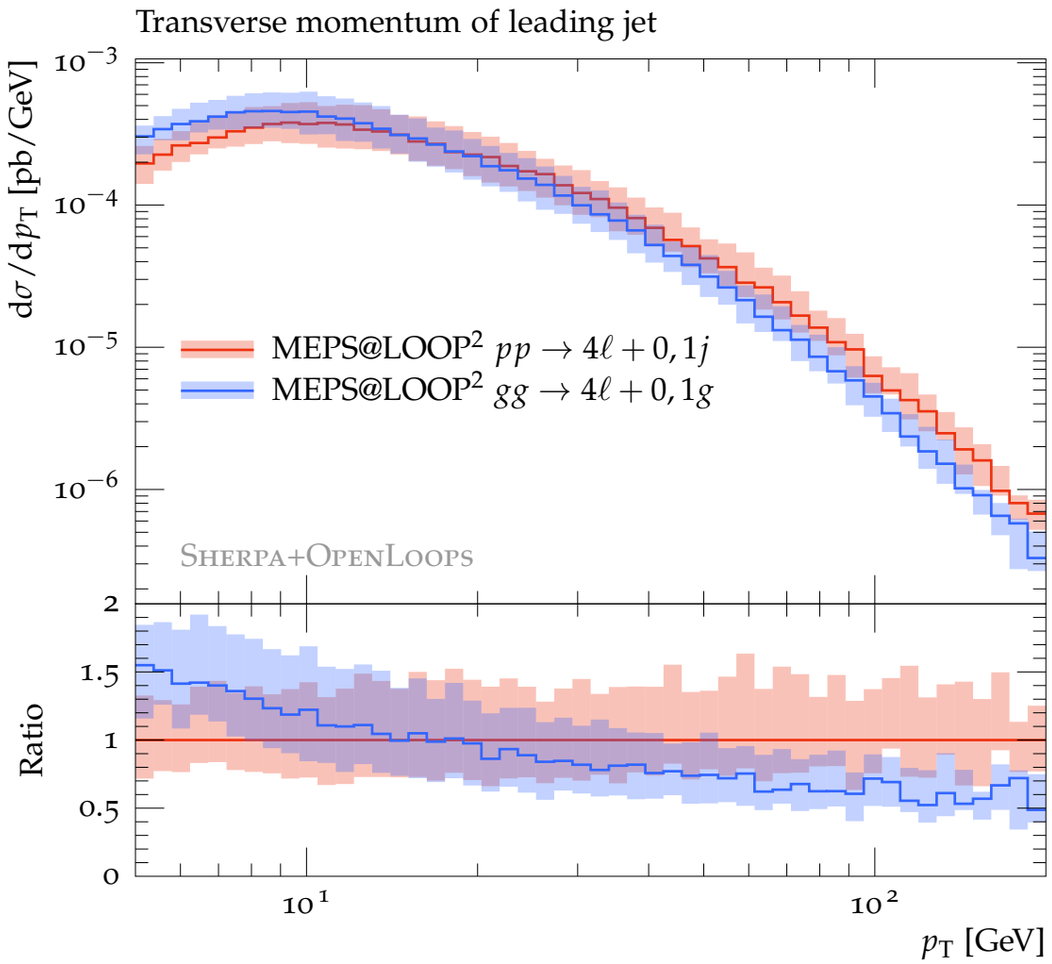


[Campbell, Ellis, Furlan, Rontsch (2014)]

- Signal / background interference pattern similar to 0j case
- Sizable yield —> jet binned analysis possible

pp->4l 1-loop squared merged samples



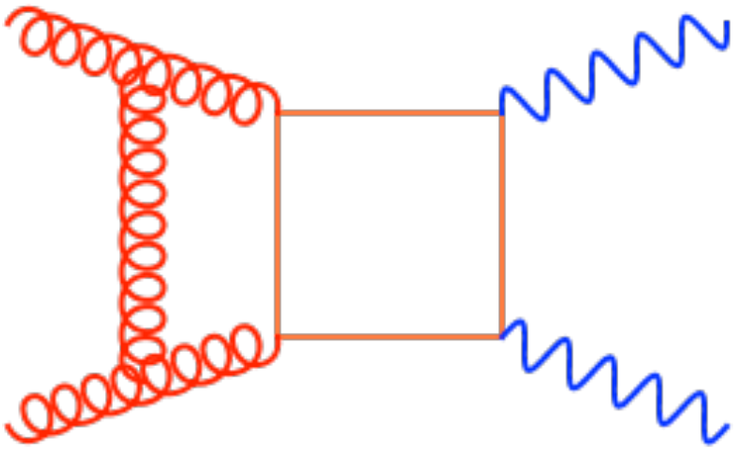


[Cascioli et al, OpenLoops+Sherpa (2013)]

- Pattern as expected
  - ✦ merged sample has harder spectrum
  - ✦ quark-induced (1loop^2) effects more relevant at high p_T
  - ✦ shifted Sudakov peak when quarks are present
  - ✦ reduced uncertainty in the high p_T region

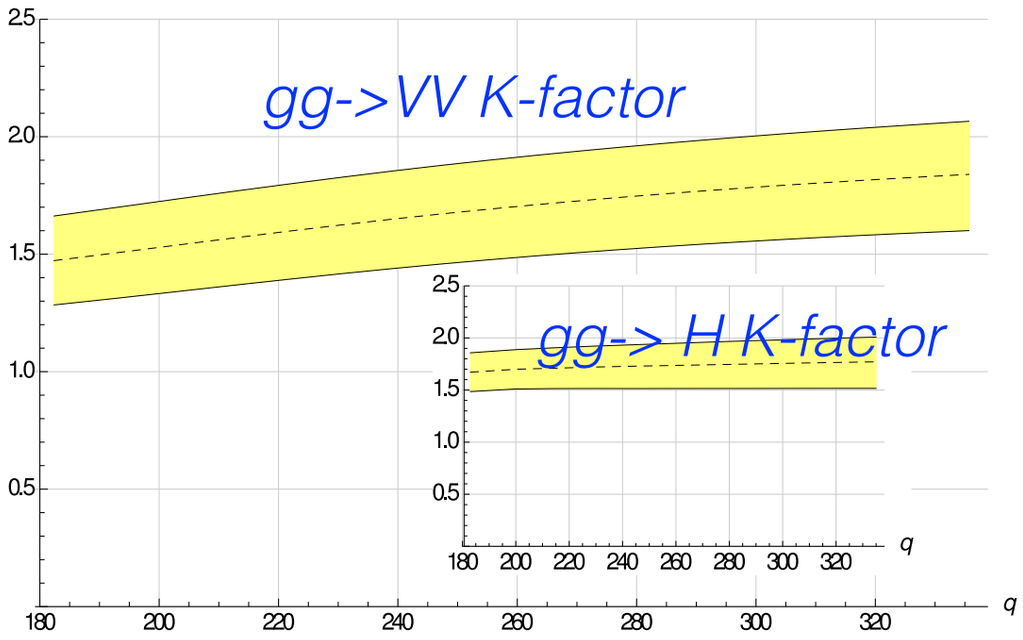
Progress towards (N)NLO predictions

- Full NNLO known for pp->VV channel [Gehrmann et al; Cascioli et al (2014)]



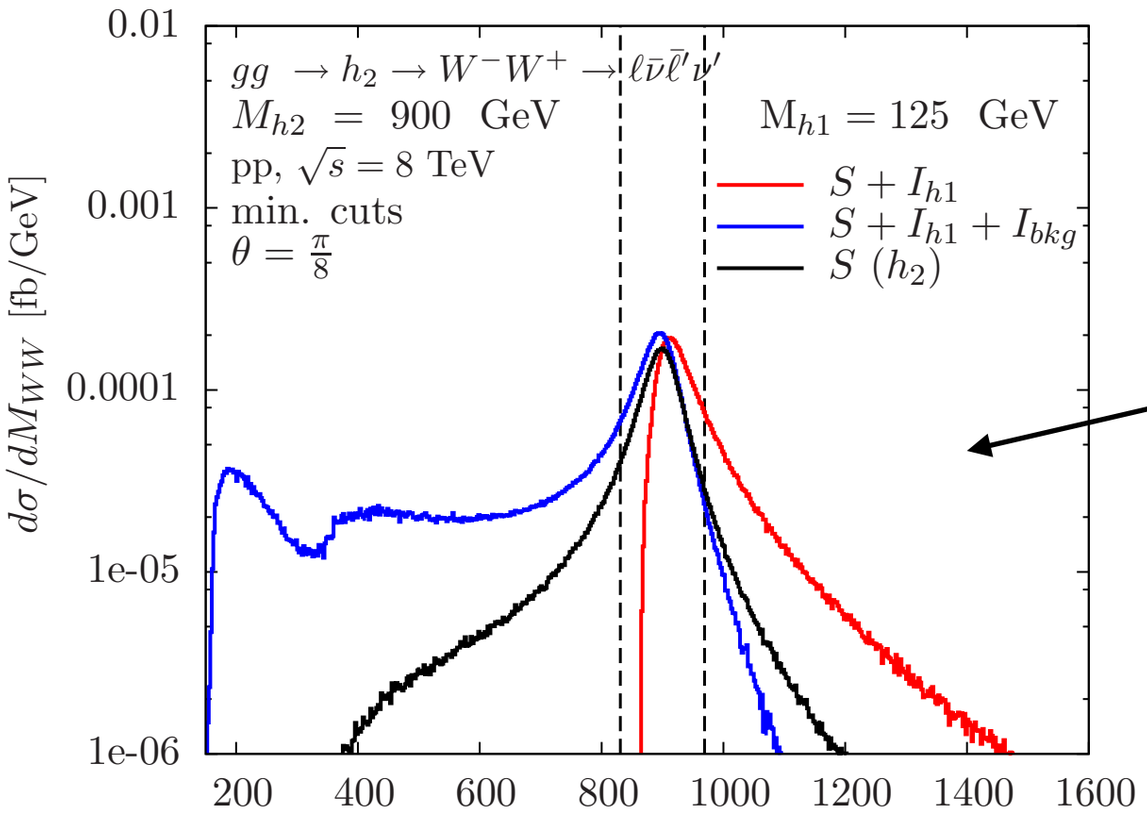
- 2-loop amplitudes for massless gg->VV known [FC et al; Manteuffel, Tancredi (2014)]
- Are existing tools efficient enough to manage real-emission corrections?

- 2-loop amplitudes for massive gg->VV beyond our reach
- Approximation: NLO in the $1/m_t$ expansion [Dowling, Melnikov (2015)]



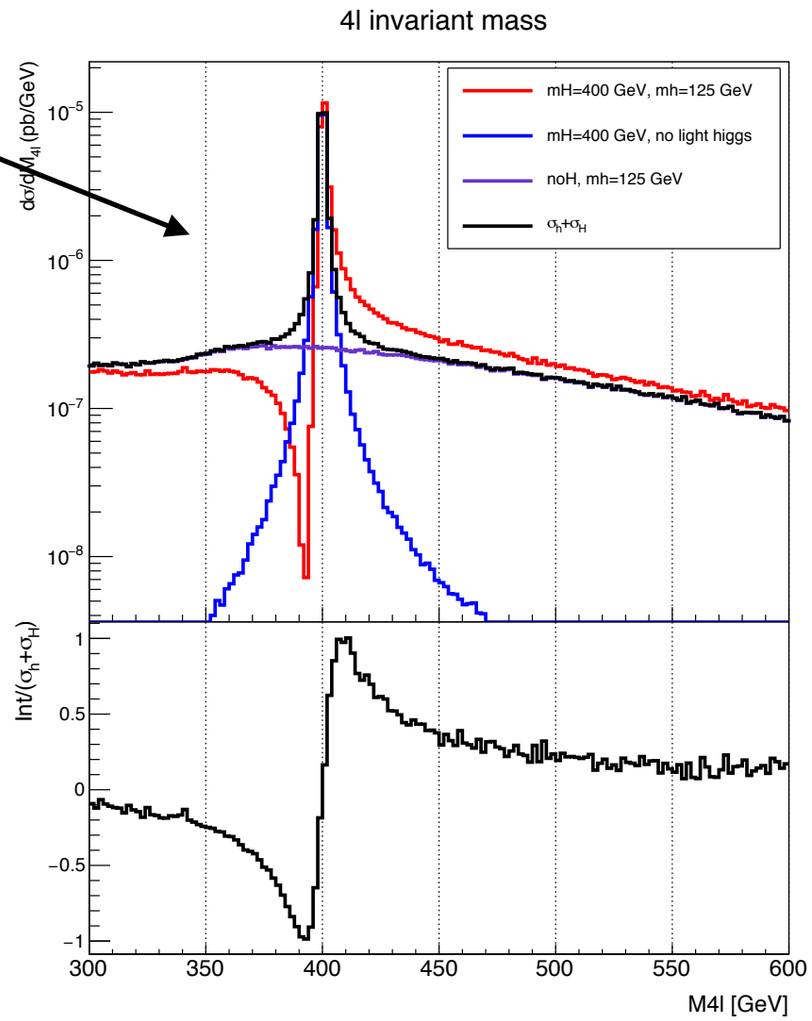
- Signal and background K-factors very similar
- Confirm naive expectations based on soft-gluon arguments

Beyond the SM: heavy/light Higgs interference

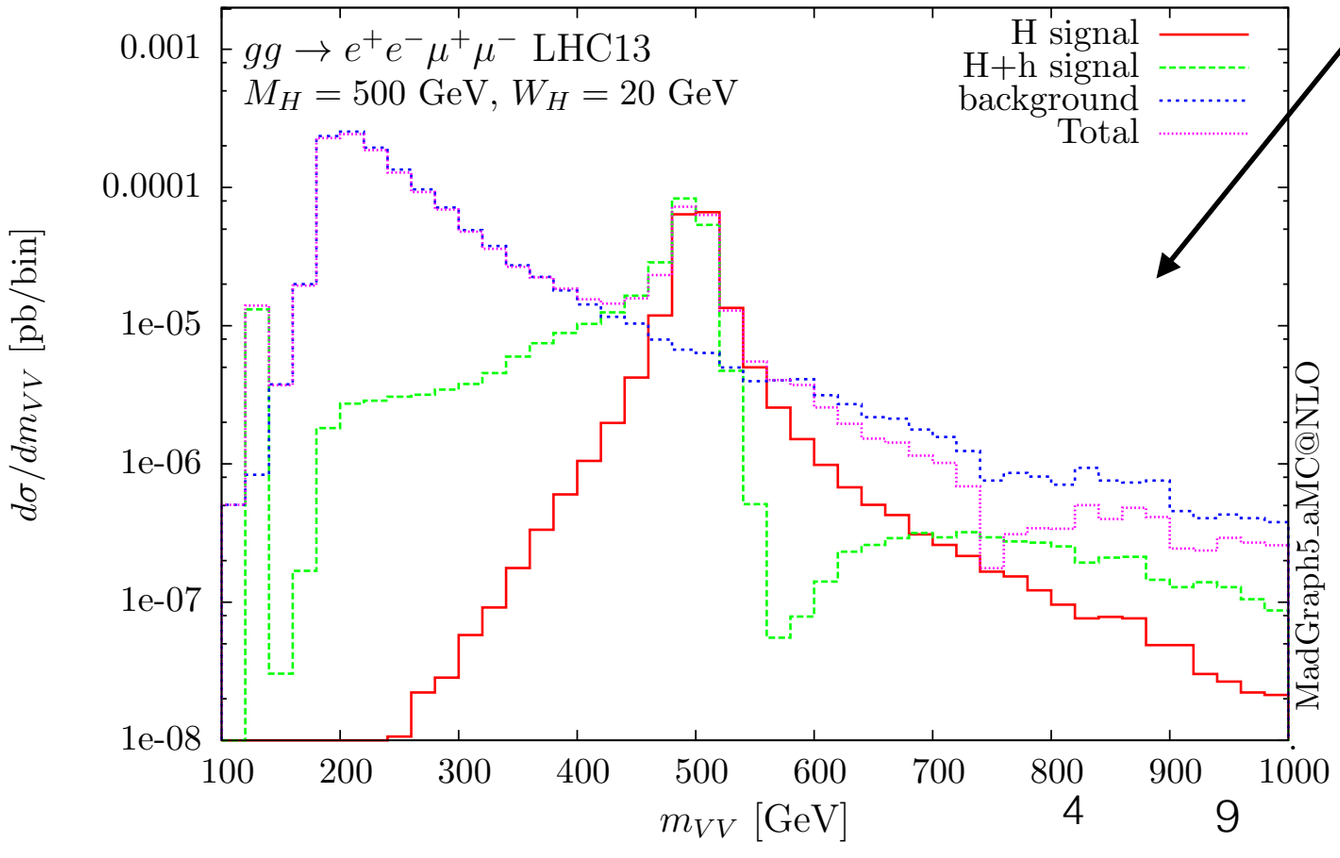


[Maina (2015)]

[NK, O'Brien (2015)]



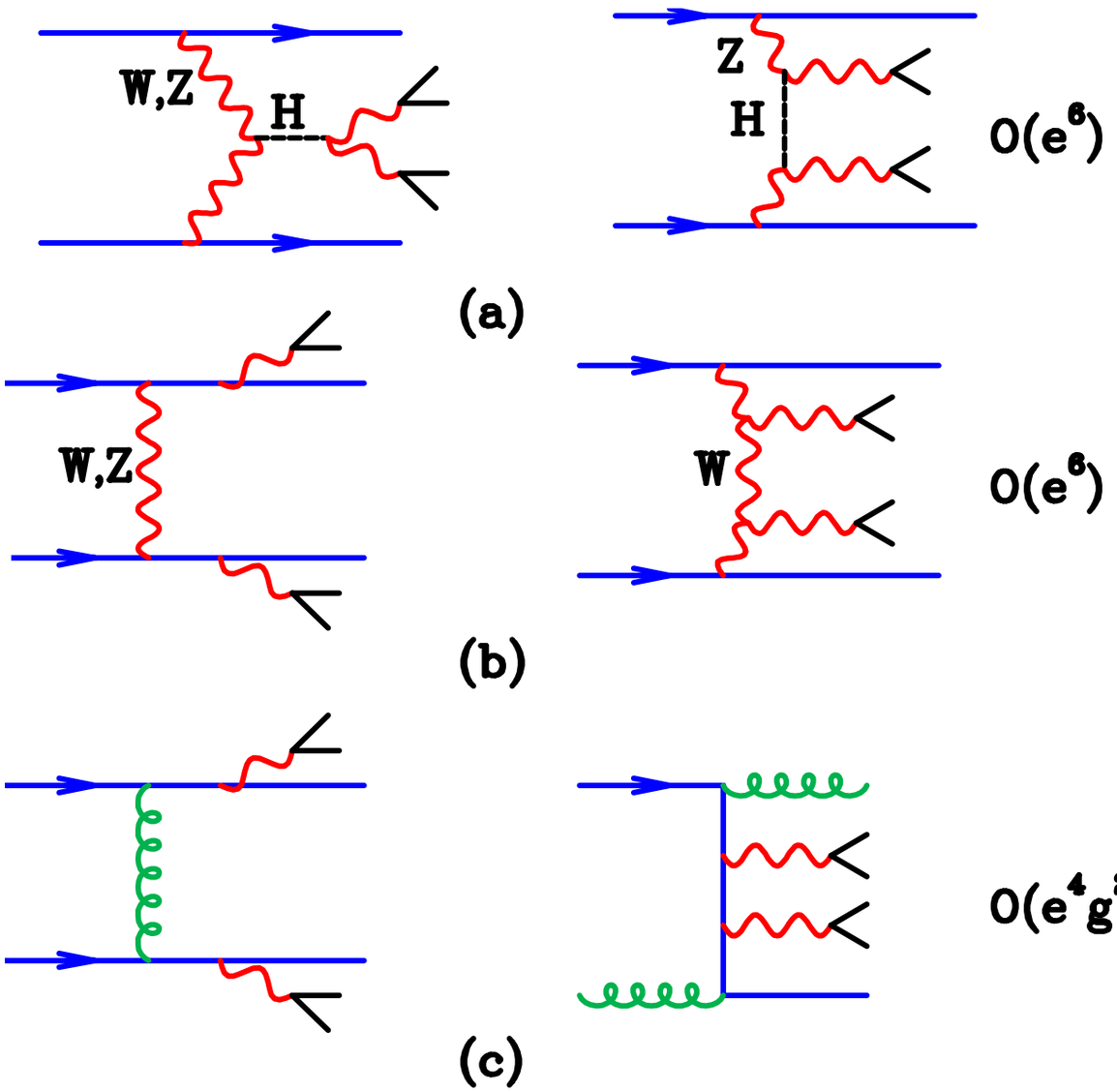
[Vryonidou, MadGraph5_aMC@NLO]



- Singlet extensions of the SM / 2HDM models
- Large shape distortion from interferences

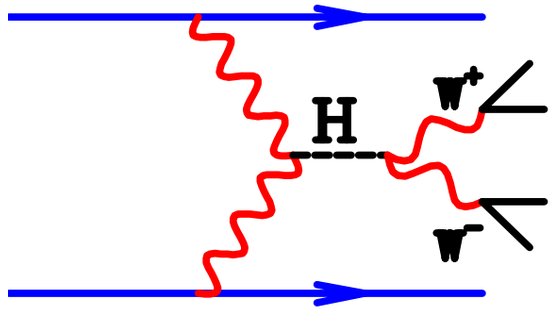
Off-shell studies in VBF

- Very different ‘theory systematic’ w.r.t. gluon fusion (no ggH vertex)
- Starts at tree-level -> radiative corrections under control (but beware of QCD features [Cacciari et al (2015)])

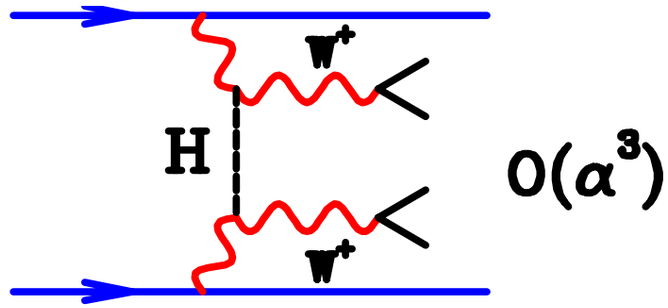


- Available tools:
  - ✦ MCFM
  - ✦ VBFNLO
  - ✦ PHANTOM
  - ✦ JHUGen+MCFM
  - ✦ MadGraph5_aMC@NLO
- Statistically limited, but doable

Off-shell studies in VBF



W^+W^- On-shell



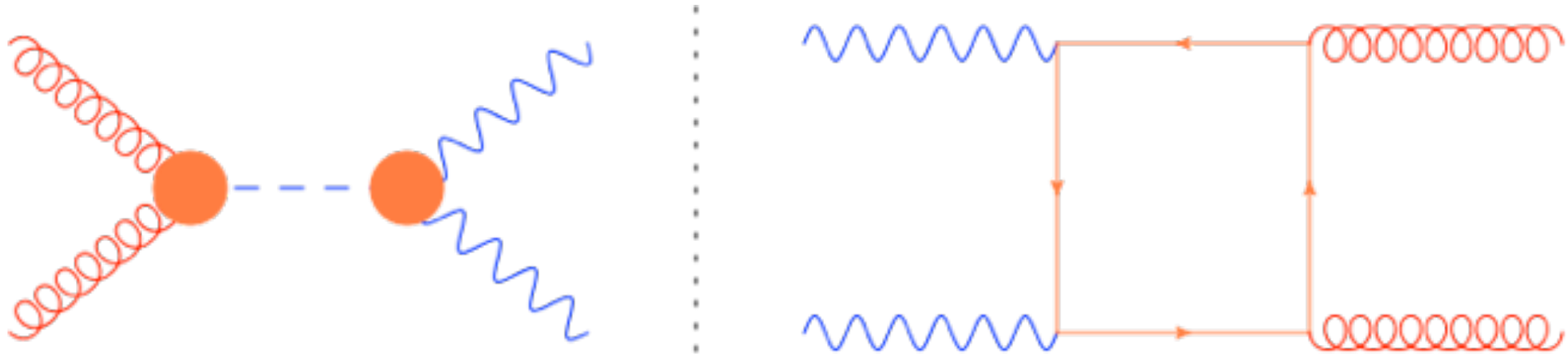
W^+W^+ Off-shell

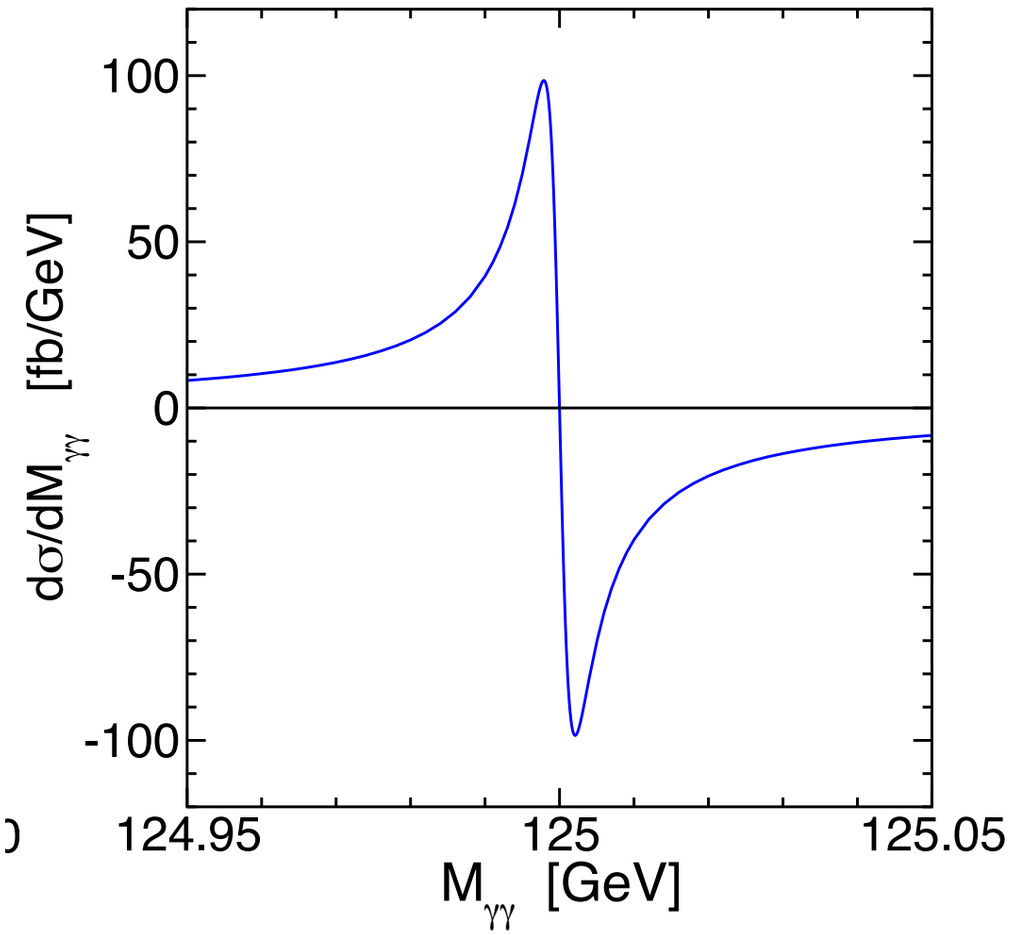
- Most promising channels: W^+W^- vs W^+W^+
- ATLAS W^+W^+: $\sigma^{measured} = 1.3 \pm 0.4(stat) \pm 0.2(syst)\,\mathrm{fb}$.
- Can be translated into $k_V < 7.8$
- In the width formulation, $\Gamma_H < 60.8\ \Gamma_{H,SM}$
- Less constraining than gg->VV, but theoretical more clean

[Campbell, Ellis (2015)]

Interference effects in H->γγ and the Higgs mass-shift

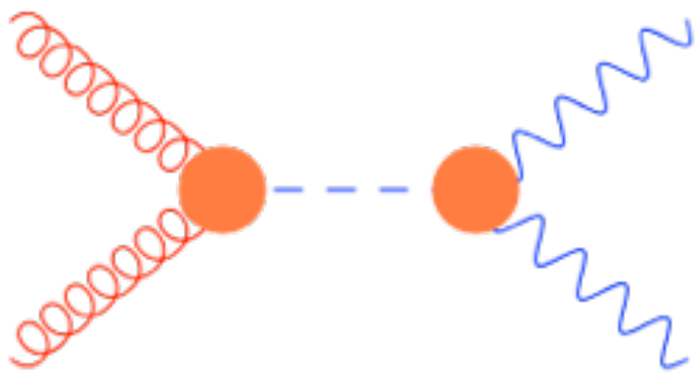
Interference and the mass-shift

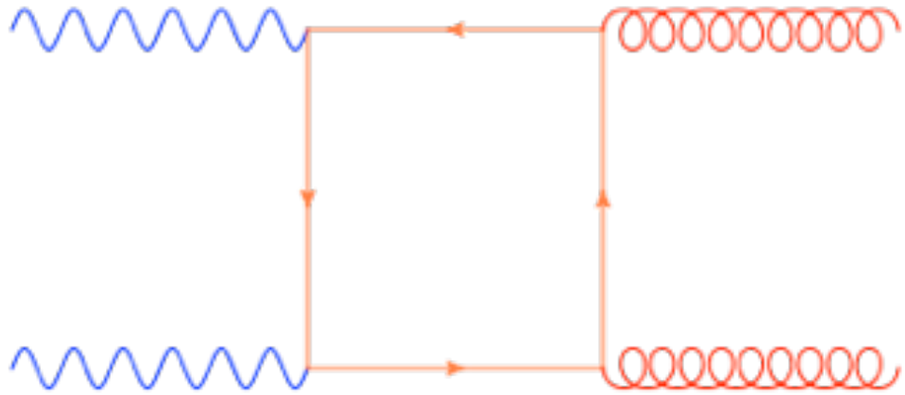


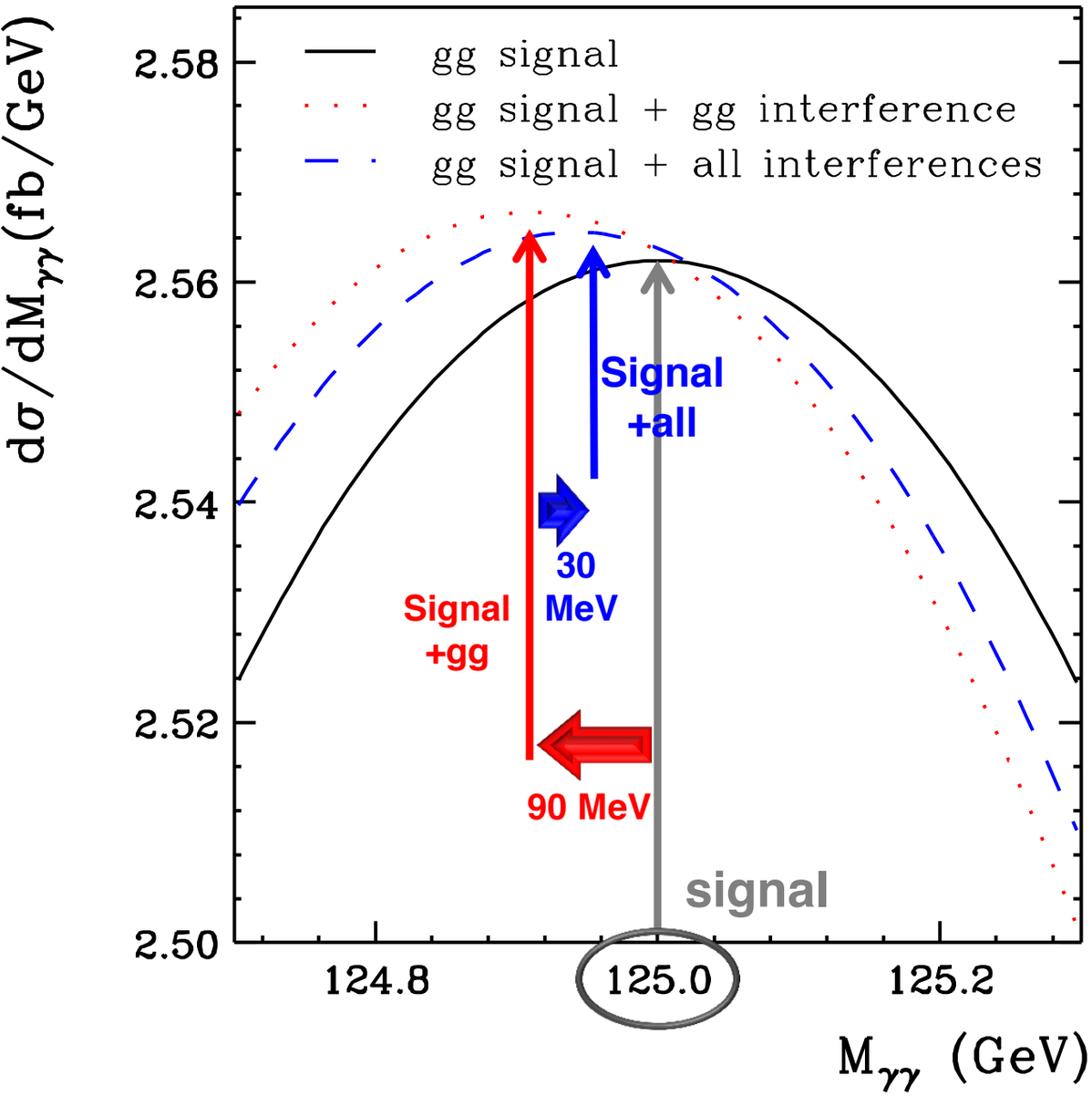


- Signal-background interference creates distortion of the $M_{\gamma\gamma}$ spectrum
- Because of environmental conditions (detector resolution) this translates in a shift of the $M_{\gamma\gamma}$ peak -> mass shift in the di-photon channel [Martin (2012)]
- Interference is proportional to $\sqrt{\Gamma_H}$ -> can be used to infer the Higgs total width [Dixon, Li (2012)]

Mass-shift: estimates





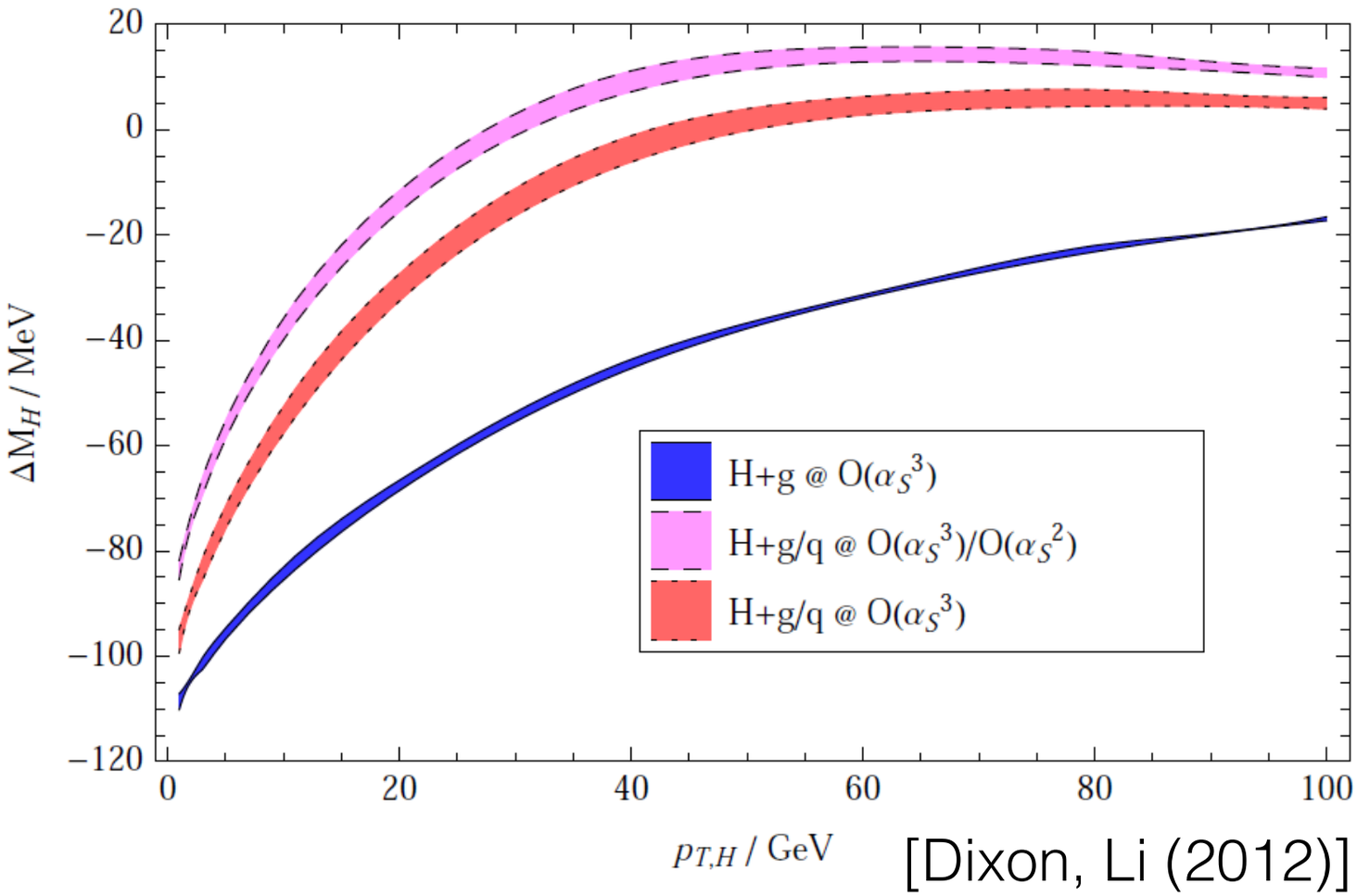


- LO shift: ~ 100 MeV
  [Martin; Dixon, Li (2013)]
- NLO shift: ~ 60 MeV
  [Dixon, Li; de Florian et al (2013)]
- Theoretical predictions obtained assuming gaussian smearing
- ATLAS full detector simulation seems to yield slightly smaller shifts

Control mass

- Interference in the ZZ channel negligible —> no shift
- m_{4l} could be used as control mass
- if only di-photon channel is used: reduction in systematics

- first option: discriminate according to $p_{T,H}$

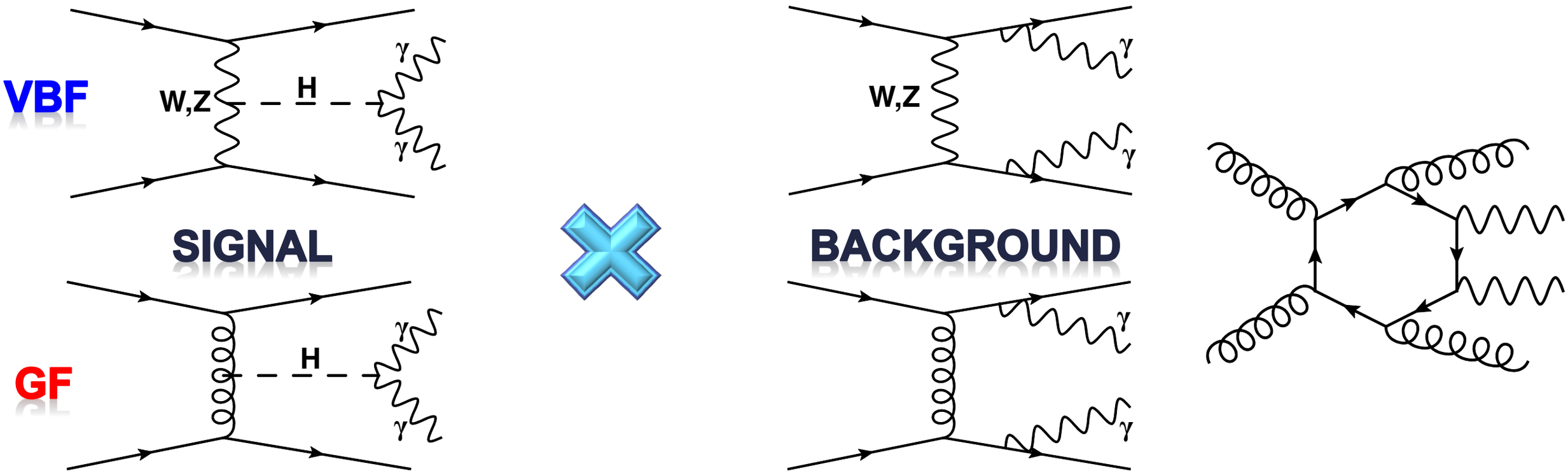


[Dixon, Li (2012)]

- interference larger at low p_T
- use p_T > 30 GeV as control region
- problem: theoretical modelling at high p_T

Control mass

- second option: control mass from γγ + 2 jets [Coradeschi et al (2015)]



- shift in VBF and GF in opposite directions —> very small net effect
- good theoretical control
- careful experimental feasibility studies are required

Discussion and topics for YR4

1. Introductory review section

2. interference and line-shape effects in gg-> VV + {0,1} jets as well as related VBF production modes using various dedicated as well as automated tools used by theorists and ATLAS & CMS (coordinated with LH)

3. theoretical & experimental status of H -> gamma gamma constraints on the Higgs width including a prediction of what can ultimately be achieved with LHC data and a discussion of available tools

4. possibly a section on gg -> VV @ NLO progress if the massless quark loop results are available in time for YR4

- Theory YR4 contacts for 2:
  - ✦ MadGraph5_aMC@NLO —> Eleni Vryonidou
  - ✦ OpenLoops + Sherpa —> Frank Siegert, Frank Krauss
  - ✦ GoSam —> Nicolas Greiner
  - ✦ MCFM —> Ciaran Williams
  - ✦ JHUGen —> Markus Schulze
  - ✦ VBFNLO —> Michael Rauch
  - ✦ PHANTOM —> Ezio Maina
  - ✦ gg2VV —> NK
- Theory YR4 contacts for 3:
  - ✦ Nerina Fidanza (Buenos Aires)
  - ✦ Ye Li (SLAC)