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# Theory Status for Offshell Higgs Studies

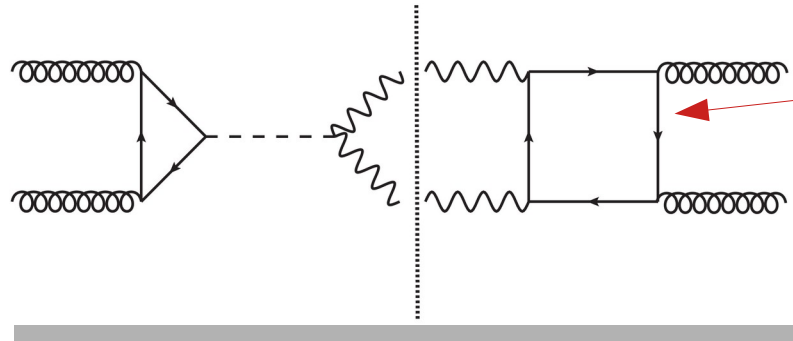
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WG1 Meeting  
3 February 2022

# Offshell Higgs production in gluon fusion

- Higgs can be produced offshell in any production mode
  - focus on those which have **significant number of events** in offshell regime, e.g.  $gg \rightarrow H \rightarrow ZZ$  [Kauer, Passarino ('12)]
- **Large destructive interference** – need to consider **background** (e.g.  $gg \rightarrow ZZ$ ) and **interference** effects.
- Most phenomenological studies: focused on gluon fusion production in  $H \rightarrow VV$  decay mode.
  - Constraints on Higgs widths [Caola, Melnikov ('13)]
  - Offshell studies in EW production, cf. [Campbell, Ellis ('15); Gritsan *et al.* ('20)]

- Focus on  $gg \rightarrow (H) \rightarrow VV$



- **Full dependence** on top quark mass.

# Theory status of offshell $gg \rightarrow (H) \rightarrow VV$

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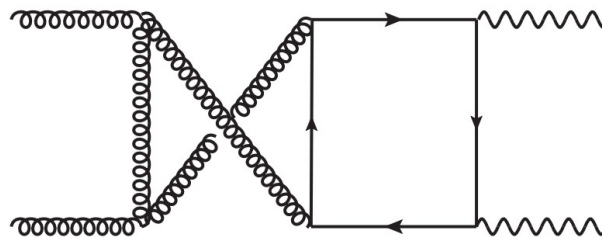
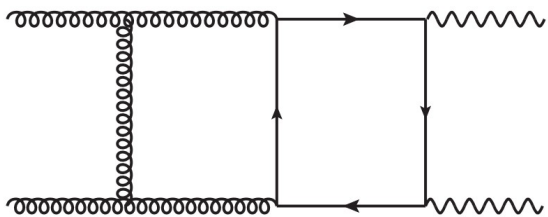
- Higher order corrections **very difficult to compute** even at NLO.
- Status ~ middle of 2020:
  - LO results (with full top mass dependence) in several public codes (`gg2VV`, `MCFM`, `MG5_aMC@NLO`, ...)
  - NLO results known using  **$1/m_t$  expansion** for background amplitudes [Campbell, Czakon, Ellis, Kirchner ('16); Caola, Dowling, Melnikov, R.R., Tancredi ('16)];
    - Valid below  $2m_t$  threshold – breaks down in **far offshell regime**.
  - Improvements in approximation:
    - **Padé approximation** [Campbell, Czakon, Ellis, Kirchner ('16)]; including **threshold effects** as input [Gröber, Maier, Rauh ('19)]
    - Two-loop amplitudes expanded in  $s, |t| > m_t^2$  [Davies, Mishima, Steinhauser, Wellmann ('20)] – **access far offshell regime**.
- Results beyond LO only available at **parton-level** and in **private codes**.

# Theory status of offshell $gg \rightarrow (H) \rightarrow VV$

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Progress in 2020-2021:

- **Two-loop QCD amplitudes** for  $gg \rightarrow ZZ$  and  $gg \rightarrow WW$  including massive quark effects computed [Agarwal, Jones, von Manteuffel ('20); Brønnum-Hansen, Chen ('20,'21)]

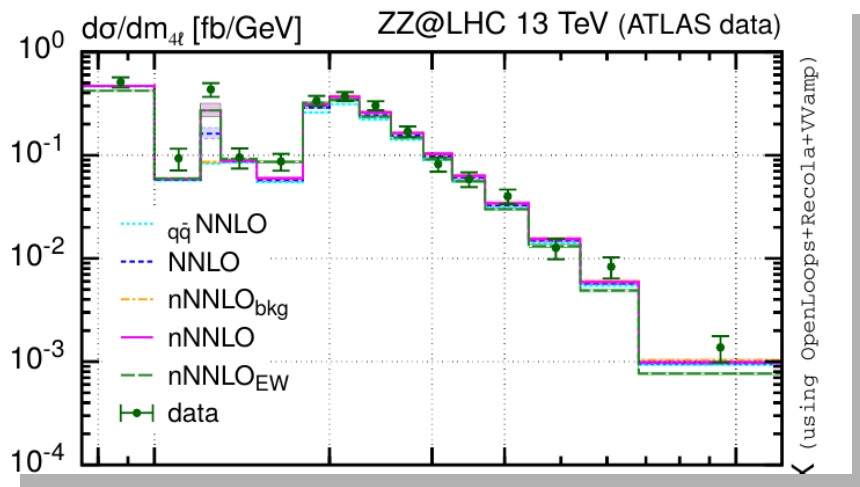


- NLO results with full top mass dependence **now in sight!**
- Substantial computing resources required: **still not used in cross section calculations...**
- Progress in developing interpolation methods for obtaining cross sections [cf. **Witteveen, CERN Student Report ('21)**]

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Progress in 2020-2021:

- NLO corrections in  $gg \rightarrow (H) \rightarrow ZZ$  combined with **NNLO QCD + NLO EW** corrections to  $pp \rightarrow ZZ$  in MATRIX [Grazzini, Kallweit, Wiesemann, Yook ('21)]
  - Mass effects in two-loop  $gg \rightarrow ZZ$  included via **reweighting**

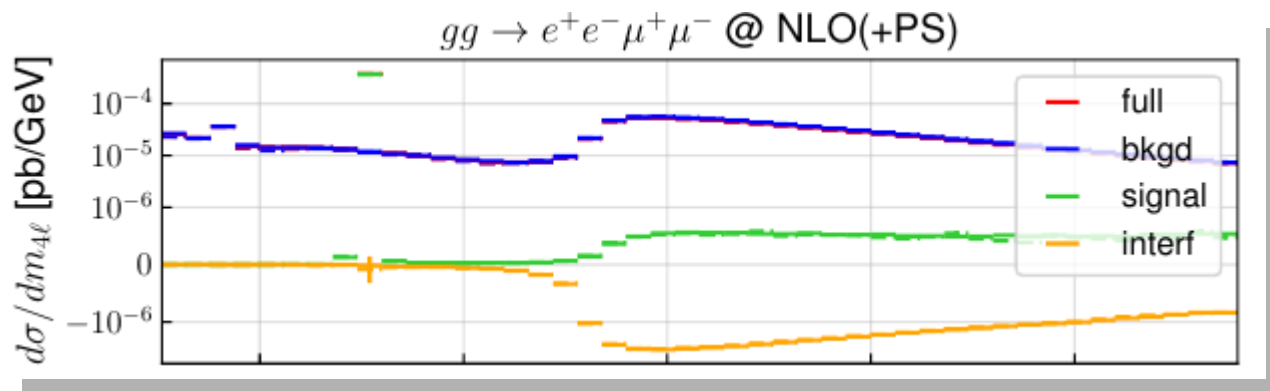


- Will be included in upcoming **public MATRIX** release (currently available on request).

# Theory status of offshell $gg \rightarrow (H) \rightarrow VV$

Progress in 2020-2021:

- NLO corrections in  $gg \rightarrow (H) \rightarrow ZZ$  **matched with parton shower** in POWHEG-BOX.  
[Alioli, Ferrario Ravasio, Lindert, R.R. ('21)]



- **Code publicly available:** `svn://powhegbox.mib.infn.it/trunk/User-Processes-RES/gg4l`

# Theory Status and Outlook

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- **Substantial progress** on higher-order calculations for offshell Higgs production through gluon fusion in last ~ 1 year.
- (Optimistic) outlook: within the next ~ 1 year, **full NLO corrections** will be included both in **parton level** and in **parton-shower** codes, **publicly available**.
- Progress on correction in other channels / EW corrections?

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THANK YOU FOR YOUR ATTENTION