

LHC Higgs Cross Section WG - BR Subgroup

POWHEG/Prophecy4f Interface

Michael Dührssen¹, Alexander Mück², Daniela Rebutuzzi³

¹CERN - ²RWTH, Aachen - ³Pavia University and INFN

With the contribution of Reisaburo Tanaka, Giampiero Passarino

GOAL: have the most accurate description of the Higgs decay, including interference

Prophecy4f includes complete NLO QCD+EW corrections in $H \rightarrow 4f$ with all interference

(ONE OF THE) MOTIVATION(S): Detailed study of the lepton pairing (i.e. tracing the parent of di-lepton pair in POWHEG MC sample) \rightarrow there is 10% mis-pairing effect in $H \rightarrow ZZ^* \rightarrow 4e/4\mu$ due to phase-space overlap

Mis-pairing matters for all property measurements of Higgs mass and tensor structure

IDEA: Take the Higgs produced by POWHEG and use Prophecy4f to decay it

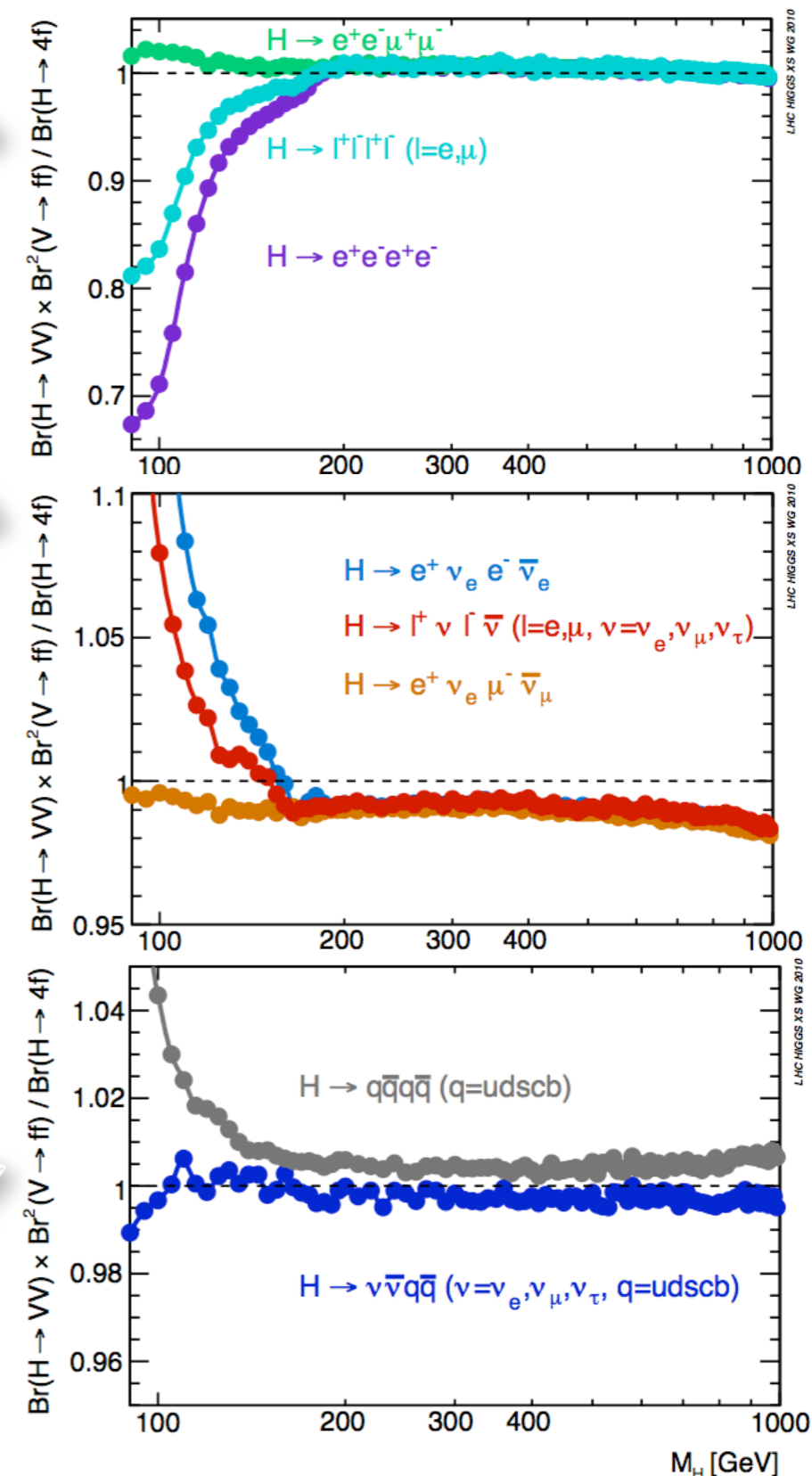
[<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/BRs>]

- $H \rightarrow ZZ \rightarrow \mu\mu\mu\mu$: for $H \rightarrow eeee$ or $\mu\mu\mu\mu$ large enhancement on BR due to interference for $M_H < 200$ GeV (i.e. below WW/ZZ thresholds)
- $H \rightarrow WW/ZZ \rightarrow l\nu l\nu$: for $H \rightarrow e\nu e\nu$ or $\mu\nu\mu\nu$, interference effect for $M_H < 200$ GeV - NWA overestimates the BR for $H \rightarrow e\nu e\nu$ and $\mu\nu\mu\nu$ by **+5.4%** at $M_H = 120$ GeV

Interference effect is corrected for $H \rightarrow ZZ^* \rightarrow 4e/4\mu$ via Prophecy4f BR, however, it has never been taken into account in $H \rightarrow WW^*/ZZ^* \rightarrow e\nu e\nu/m\nu m\nu$ as NO NLO MC exists for $H \rightarrow 4f$

We could not discuss Higgs properties below this precision!

- $H \rightarrow ZZ \rightarrow \nu\nu q\bar{q}$, $H \rightarrow WW/ZZ \rightarrow q\bar{q}q\bar{q}$: for $H \rightarrow q\bar{q}q\bar{q}$, interference effect for $M_H < 200$ GeV



[A. Bredenstein, A. Denner, S. Dittmaier, A. Mück, M.M. Weber]

PropHecy4f

**A Monte Carlo generator for a
Proper description of the Higgs decay into 4 fermions**

PROPHECY4F is a Monte Carlo integrator for $H \rightarrow WW/ZZ \rightarrow 4$ fermions which includes:

- NLO QCD and electroweak corrections
- All interferences (signal/signal) at LO and NLO
- Corrections beyond NLO from heavy-Higgs effects
- Optional inclusion of a 4th fermion generation (w/ or w/o leading two-loop improvements)

Version 2.0

- Unweighted events for leptonic final states and on-shell Higgs (fixed invariant mass) **NEW!**
- (for semi-leptonic and hadronic final states at present unweighted events only for Born and Improved Born Approximation for these channels)

C/ROOT code based on standard LHE event reader/writer

- Takes two LHE files as input: POWHEG (DS167892 or DS160155, for instance) and Prophecy4f (the Higgs decayed in its rest frame here)
 - Boosts POWHEG Higgs back in its rest frame
 - Scales Prophecy4f Higgs decay so that the Prophecy4f mass corresponds to the mass generated by POWHEG (for event close to the mass shell) *See comment later*
 - Boosts the Higgs decay products (leptons) back in the POWHEG Higgs reference system
 - Gives mass to the leptons (massless in Prophecy4f) using some Herwig routines used also in Alpgen
- **INPUT:** POWHEG LHE and Prophecy4f LHE files
 - **OUTPUT:** a new LHE file with the Higgs and the fermions coming from its decay
 - Pythia8 runs on this new LHE file with the option of not decaying Higgs and Z's

```
topAlg.Pythia8.Commands += [  
    '25:onMode = off', #decay of Higgs  
    '23:onMode = off' #decay of Z  
]
```

POWHEG 116703.ggH_SM_M125_8TeV Event

```

4 10000 1.00000E+00 1.71874E+01 -1.00000E+00 1.71945E-01
21 -1 0 0 502 511 0.000000000E+00 0.000000000E+00 6.780654601E+01 6.780654601E+01 0.000000000E+00 0.00000E+00 9.000E+00
21 -1 0 0 501 502 0.000000000E+00 0.000000000E+00 -2.543706497E+02 2.543706497E+02 0.000000000E+00 0.00000E+00 9.000E+00
25 1 1 2 0 0 1.142638683E+01 -1.283923136E+01 -2.372195570E+02 2.686852980E+02 1.249930517E+02 0.00000E+00 9.000E+00
21 1 1 2 501 511 -1.142638683E+01 1.283923136E+01 5.065545326E+01 5.349189774E+01 1.348699152E-06 0.00000E+00 9.000E+00
#pdf 21 21 0.38965517E-02 0.62648594E-01 0.12500000E+03 0.14825033E+02 0.15679245E+01

```

Prophecy4f H→2e2mu Event

```

4 1 0.100000000000000E+01 -1 0.754985640363811E-02 0.119000000000000E+00
11 1 0 0 0 0 -0.106863944873259E+02 -0.542061301634663E+01 0.772864417488012E+01 0.142588223003740E+02 0.00E+00 0 9
-11 1 0 0 0 0 -0.123217705225076E+02 0.118748915970855E+02 0.621375769875442E+01 0.182057645813270E+02 0.00E+00 0 9
13 1 0 0 0 0 -0.183047870191773E+02 0.282837501039185E+02 0.739829352259559E+01 0.344930499492989E+02 0.00E+00 0 9
-13 1 0 0 0 0 0.413129520290107E+02 -0.347380286846574E+02 -0.213406953962301E+02 0.580423631690001E+02 0.00E+00 0 9

```



POWHEG+Prophecy4f merged event

```

8 10000 1 17.1874 -1 0.171945
21 -1 0 0 502 511 0 0 67.80654601 67.80654601 0 0 9
21 -1 0 0 501 502 0 0 -254.3706497 254.3706497 0 0 9
25 2 1 2 0 0 11.42638683 -12.83923136 -237.219557 268.685298 124.9930517 0 9
21 1 1 2 501 511 -11.42638683 12.83923136 50.65545326 53.49189774 1.348699152e-06 0 9
11 1 3 3 0 0 -9.820286066 -6.392844805 -10.24045266 15.56192 0.00051 0 9
-11 1 3 3 0 0 -11.06723518 10.46534558 -19.81737443 24.99470908 0.00051 0 9
13 1 3 3 0 0 -15.69102833 25.3463834 -46.84266954 55.52381808 0.10566 0 9
-13 1 3 3 0 0 48.00493641 -42.25811553 -160.3190604 172.6048508 0.10566 0 9
#pdf 21 21 0.38965517E-02 0.62648594E-01 0.12500000E+03 0.14825033E+02 0.15679245E+01

```

Some Comments

- Prophecy4f produces unweighted NLO events only for 4 lepton final states and not for every possible final state
For $H \rightarrow ZZ^/WW^* \rightarrow 2e2\mu$ works fine*
- In principle the Higgs width and the propagator should be handled correctly, but 4 MeV natural width for the 125 GeV Higgs is small enough and one can approximate with NWA
For a 125 GeV Higgs works fine
- Prophecy4f deals with on-shell Higgs \rightarrow problems also for a light Higgs with POWHEG events generated with a far off-shell Higgs (above the WW/ZZ threshold)
effect 0(1%) for $H \rightarrow ZZ() \rightarrow 4L$, larger for $H \rightarrow WW(*) \rightarrow l\nu l\nu$*
 - These events should in principle be handled separately \rightarrow simply following the implemented procedure would lead to a completely wrong kinematics
 - **Ongoing discussion:** should the code leaves them as pure POWHEG events (no merging with Prophecy4f) or cut them away and we rely on other MC for the off-shell tails?
*For 4 charged leptons in a narrow mass window, this does not matter
For the WW channel without additional cuts \rightarrow percent-level effects from far off-shell Higgses, though*

- FSR: two possible options
 - LO Prophecy4f events *AND* Photos *This way we loose Prophecy4f NLO EW accuracy*
 - NLO Prophecy4f events *WITHOUT* Photos *Best option for Higgs mass measurements probably*
- If we are more concerned about hard photon radiation, Prophecy4f is the tool to use while if we want to control the soft radiation, Photos might have advantages
- ➔ For Higgs property measurement, Prophecy4f might be better if NLO EW corrections matters more than photon corrections

But we need comparison between Prophecy4f and PHOTOS on FSR photons!
- The DRM code could be included in ATHENA, to merge LHE files (POWHEG and Prophecy4f) before Pythia8 showering, but for the moment it works offline
- The code will be located under <https://svnweb.cern.ch/cern/wsvn/lhchiggsxs/repository>

IN THE IMMEDIATE (for Moriond?):

- Run the DRM code on the existing POWHEG ggF H(125) events, merging with NLO Prophecy4f LHE
- Produce new datasets which can be immediately made available for studies
- Perform a comparison between Prophecy4f and PHOTOS on FSR photons

Hopefully one of Rei's students working on this

Mis-Pairing studies (Rei's proposal)

- Using POWHEG/Prophecy4f samples, consider all possible combinations in $H \rightarrow ZZ^* \rightarrow 4e/4\mu$ with permutation, weighting each combination with its matrix element
- **Drawback:** this works only for SM 0+ case, one needs further development of arbitrary J^{PC} , to consider spin propagation for spin-1,2 cases

IN THE FUTURE:

- Interface the DRM code in ATHENA, making the LHE merging procedure automatic (controlled by a variable in the jobO)
- Include treatment for higher Higgs masses (???)