News from Madgraph5_aMC@NLO

Marco Zaro, LPTHE - UPMC Paris VI

LHCPhenonet Meeting@CERN

December 3, 2013

NLO computations and matching with parton showers

- Why NLO + PS?
  - Reliable predictions of rates and shapes
  - Reliable estimate of uncertainties (scale & PDF)
  - Better theoretical accuracy, less need of fine tuning
  - Realistic description of the final state
  - Better understanding of data
  - Steep increase in complexity (in particular for higher multiplicities)

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Ask a computer to do the hard job
Automation!

NLO: how to?

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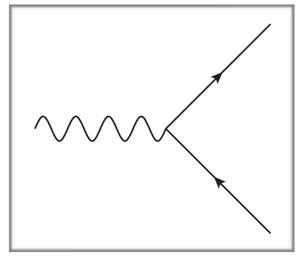
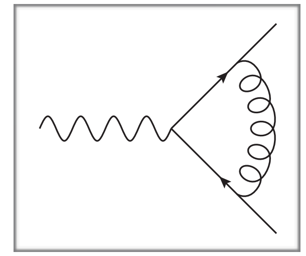
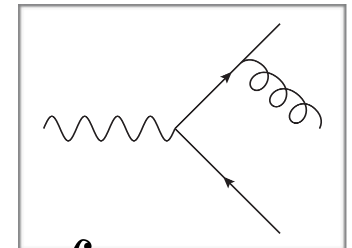
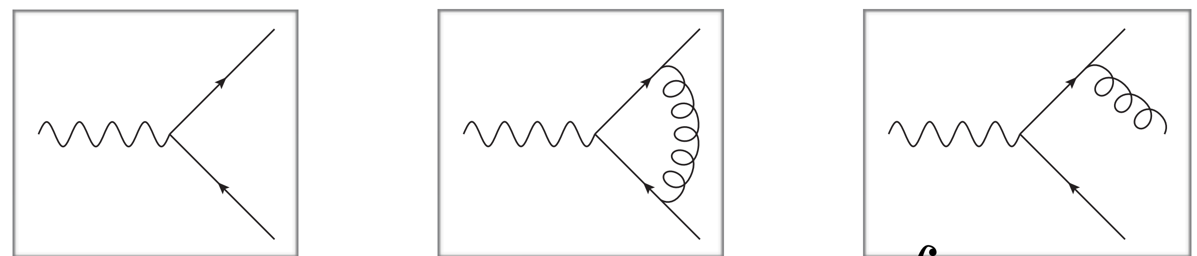






$$d\sigma^n_{NLO} = d\sigma^n_{LO} + d\sigma^n_V + \int d\Phi_1 \, d\sigma^{n+1}_R$$

NLO: how to?



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  - Divergences cancel with those from virtuals (in D=4-2eps)
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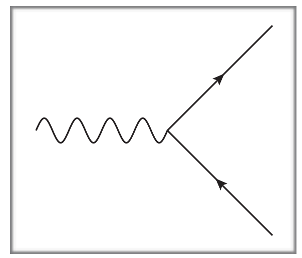
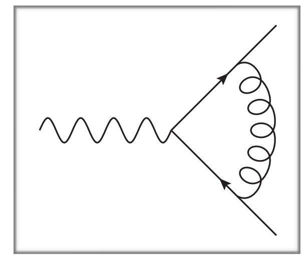
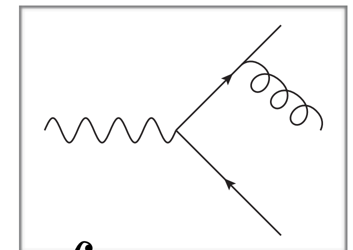

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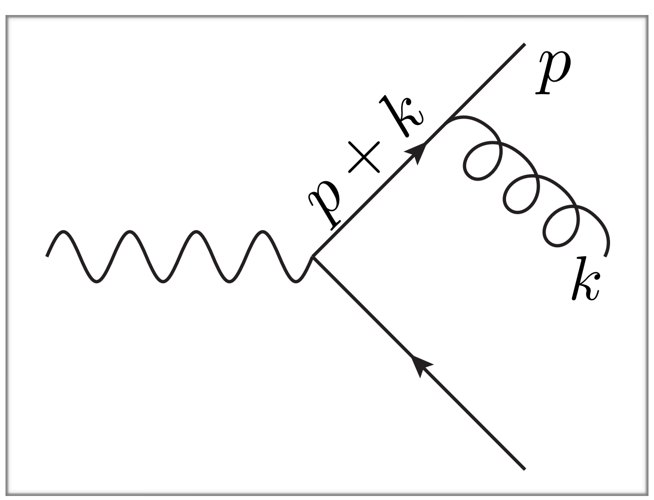
- Warning! Real emission ME is divergent!
  - Divergences cancel with those from virtuals (in D=4-2eps)
  - Need to cancel them before numerical integration (in D=4)
- Structure of divergences is universal:

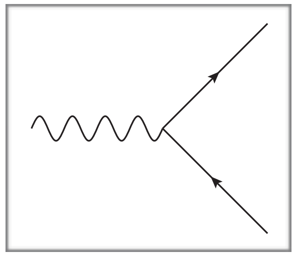
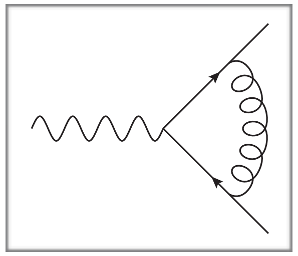
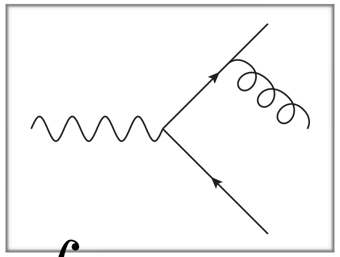


$$(p+k)^2 = 2E_pE_k(1-\cos\theta_{pk})$$

$$\lim_{p//k} |M_{n+1}|^2 \simeq |M_n|^2 \, P^{AP}(z)$$

$$\lim_{k\to 0} |M_{n+1}|^2 \simeq \sum_{ij} |M_n^{ij}|^2 \frac{p_i p_j}{p_i k \; p_j k}$$

NLO: how to?

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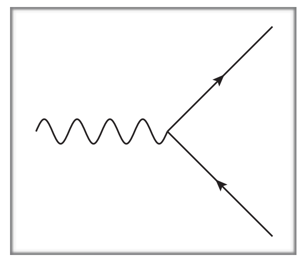
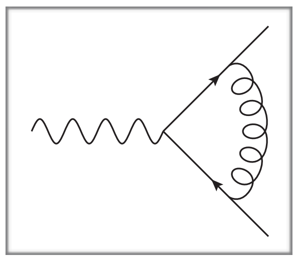
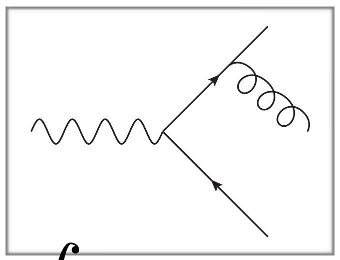

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$$d\sigma^n_{NLO} = d\sigma^n_{LO} + d\sigma^n_V - \int d\Phi_1 \, C + \int d\Phi_1 \, \left(C + d\sigma^{n+1}_R\right)$$

- Add local counterterms in the singular regions and subtract its integrated finite part (poles will cancels against the virtuals)
- The *n* and *n+1* body integral now are finite in 4 dimension
  - Can be integrated numerically

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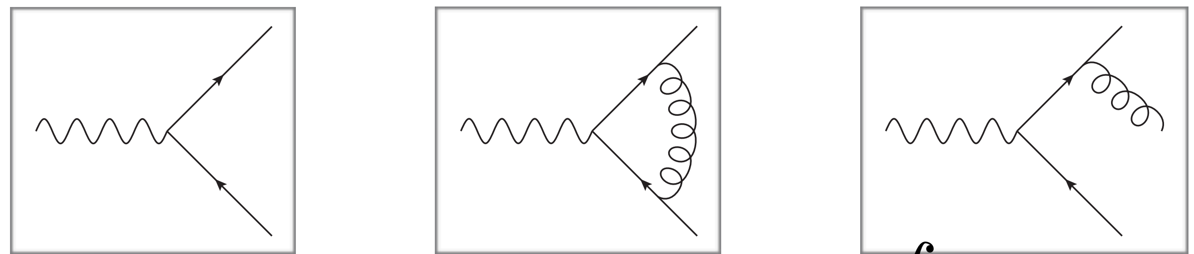

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How to do this in an efficient way?

The FKS subtraction

Frixione, Kunszt, Signer, arXiv:hep-ph/9512328

- Soft/collinear singularities arise in many PS regions
- Find parton pairs *i*, *j* that can give collinear singularities
- Split the phase space into regions with one collinear sing
  - Soft singularities are split into the collinear ones

$$|M|^2 = \sum_{ij} S_{ij} |M|^2 = \sum_{ij} |M|^2_{ij} \qquad \sum S_{ij} = 1$$

$$S_{ij} \to 1 \text{ if } k_i \cdot k_j \to 0 \qquad S_{ij} \to 0 \text{ if } k_{m\neq i} \cdot k_{n\neq j} \to 0$$

- Integrate them independently
  - Parallelize integration
  - Choose ad-hoc phase space parameterization
- Advantages:
  - # of contributions ~ n^2
  - Exploit symmetries: 3 contributions for `X Y > ng`

Loop ME evaluation: MadLoop

Hirschi et al. arXiv:1103.0621

- Load the NLO UFO model
- Generate Feynman diagrams to evaluate the loop ME
- Add R2/UV renormalisation counter terms
- Interface to CutTools or to tensor reduction programs (in progress)
- Check PS point stability (and switch to QP if needed)
- Improved with the OpenLoops method

  Cascioli, Maierhofer, Pozzorini arXiv:1111.5206
- And much more (can be used as standalone or external OLP via the BLHA, handle loop-induced processes, …)

Matching in MC@NLO

- Use suitable counterterms to avoid double counting the emission from shower and ME, keeping the correct rate at order α_s:

$$\frac{d\sigma_{MC@NLO}}{dO} = \underbrace{\left(\mathcal{B} + \mathcal{V} + \int d\Phi_1 MC\right) d\Phi_n \; I^n_{MC}(O)}_{\text{S-events}} + \underbrace{(\mathcal{R} - MC)\, d\Phi_n \; d\Phi_1 \; I^{n+1}_{MC}(O)}_{\text{H-events}}$$

- MC depends on the PSMC's Sudakov:

$$MC = \left| \frac{\partial\left(t^{MC}, z^{MC}, \phi\right)}{\partial \Phi_1} \right| \frac{1}{t^{MC}} \frac{\alpha_s}{2\pi} \frac{1}{2\pi} P\left(z^{MC}\right) \mathcal{B}$$

- Available for Herwig6, Pythia6 (virtuality-ordered), Herwig++, Pythia8 (in the new release)
- MC acts as local counterterm
- Some weights can be negative (unweighting up to sign)
  - Only affects statistics

MadGraph5_aMC@NLO

in collaboration with: R. Frederix, S. Frixione, F. Maltoni, O. Mattelaer, P. Torrielli, V. Hirschi, MZ

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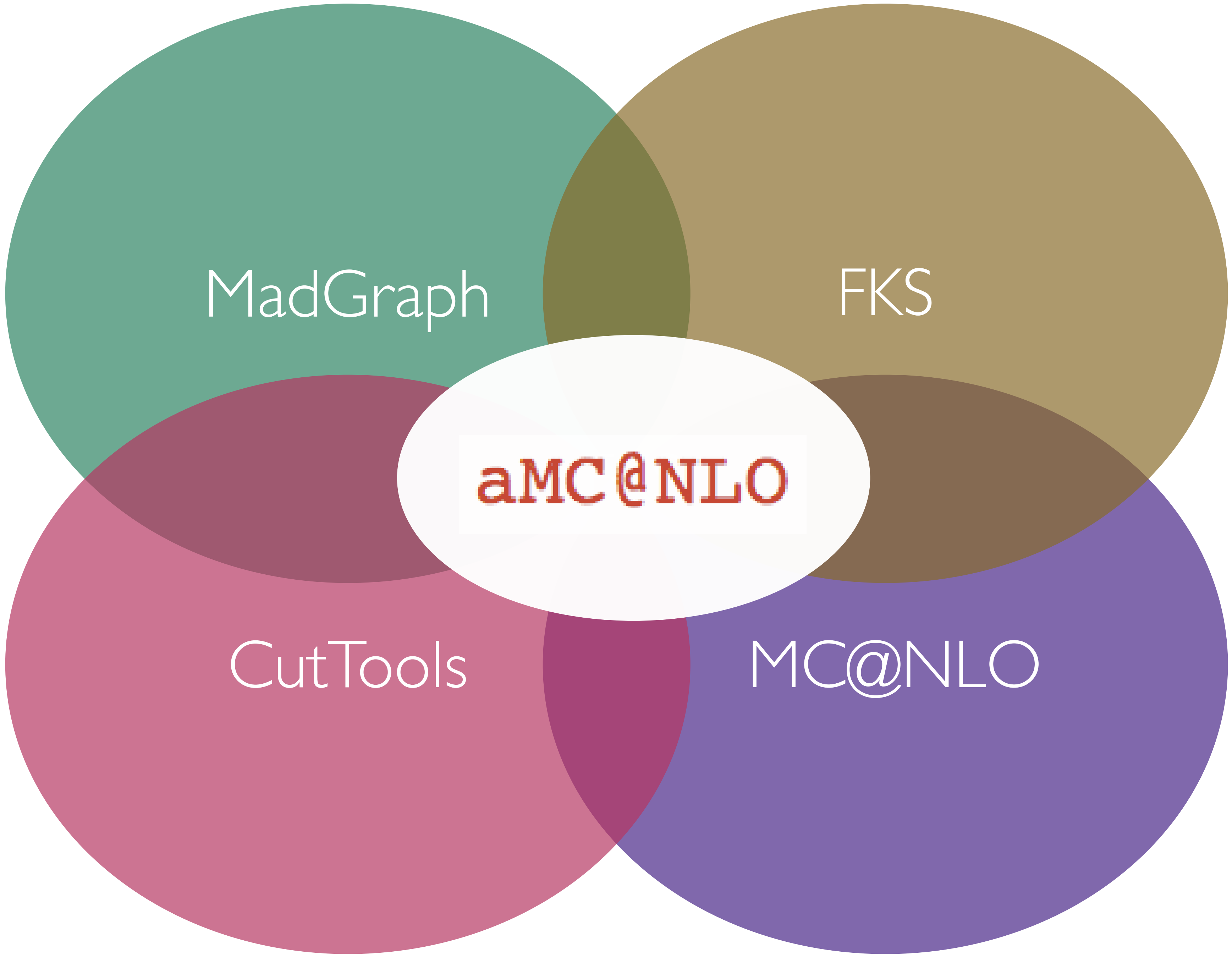

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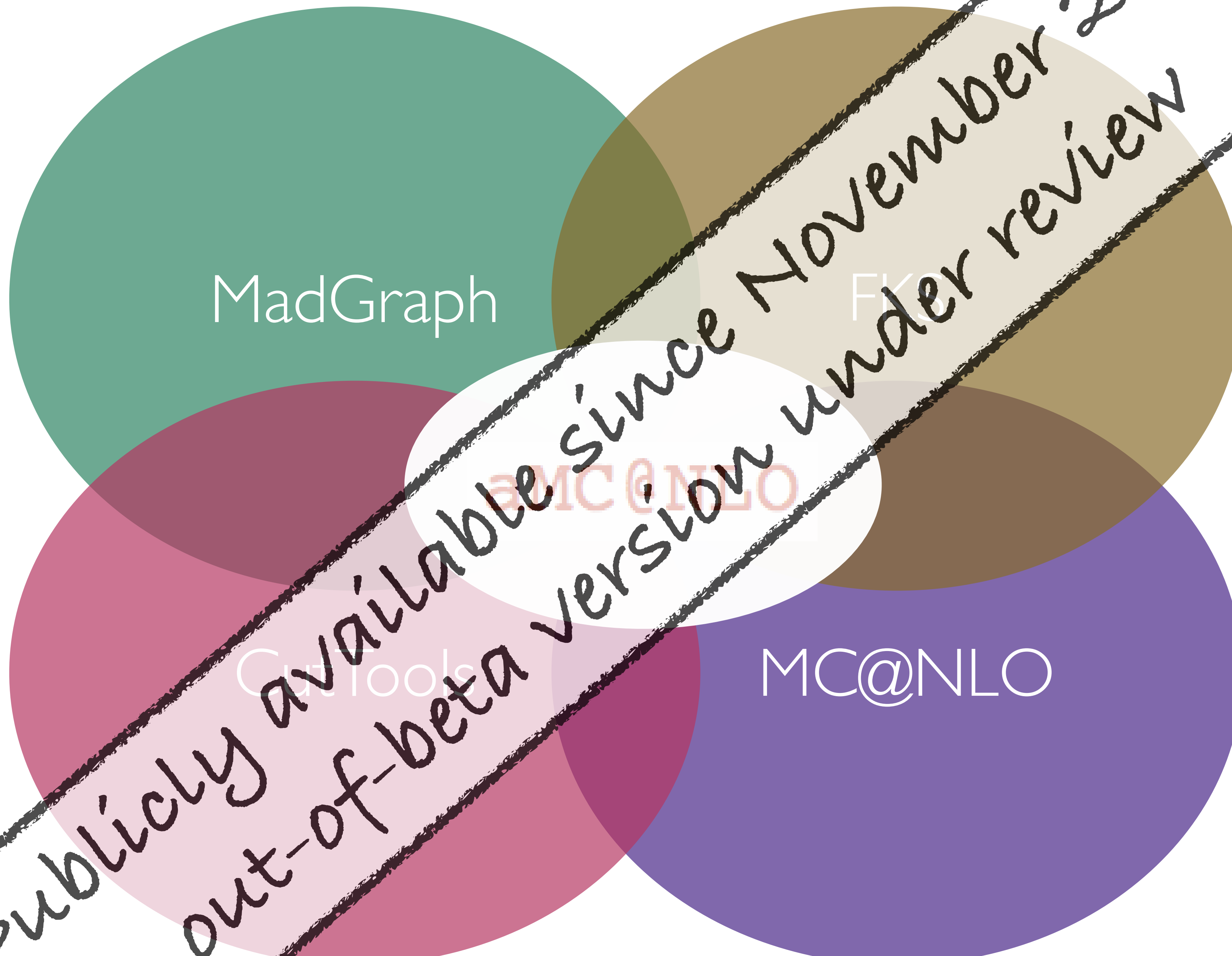

Publicly available since November 2013
out-of-beta version under review

Full automation (and extreme simplicity)

- Start the MG5/aMC@NLO shell

```
$./bin/mg5_aMC
```

- Generate the process

```
> generate p p > t t~ b b~ [QCD]
```

- Write the code

```
> output my_ttbb_nlo
```

- Launch the event generation/fixed order computation

```
> launch
```

Improvements in the new version

- Interface with Pythia8
- FxFx merging (semi-automatic)
- Package shipped with FJcore
  - No external dependencies (LHAPDF optional)
- HTML monitoring
- Speed improvements:
  - Split event generation
  - Smarter virtual integration
    - MC over helicities
    - "Virt-Tricks": reduce the number of calls to MadLoop, learning from the points which have already been thrown

Speed improvement

MadGraph5 2.0.0beta3

```
Summary:
Process p p > t t~ [QCD]
Run at p-p collider (4000 + 4000 GeV)
Total cross-section: 1.770e+02 +- 1.7e+00 pb
Ren. and fac. scale uncertainty: +13.5% -13.0%
Number of events generated: 10000
Parton shower to be used: HERWIG6
Fraction of negative weights: 0.16
Total running time : 12m 12s

DEBUG:
Number of loop ME evaluations: 168120
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Total running time :  17h 0m
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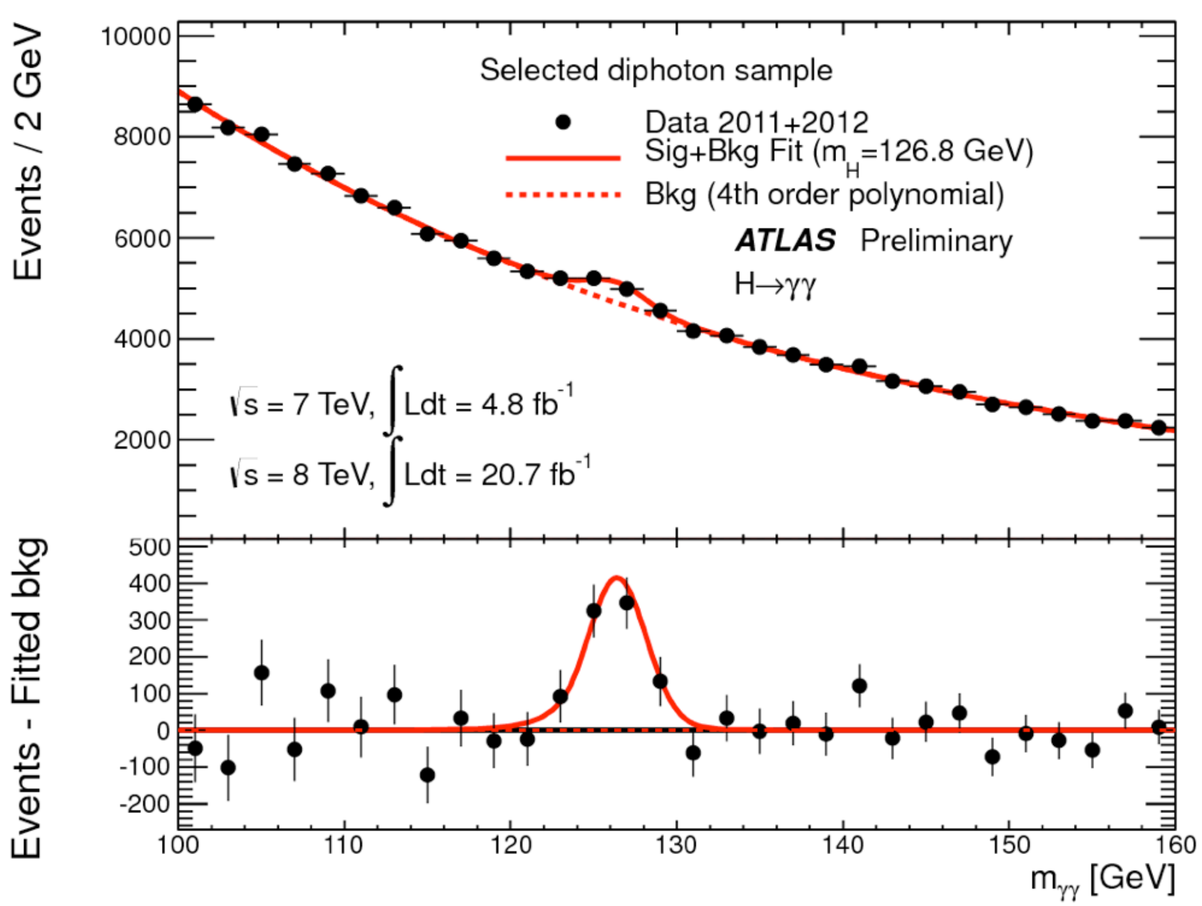
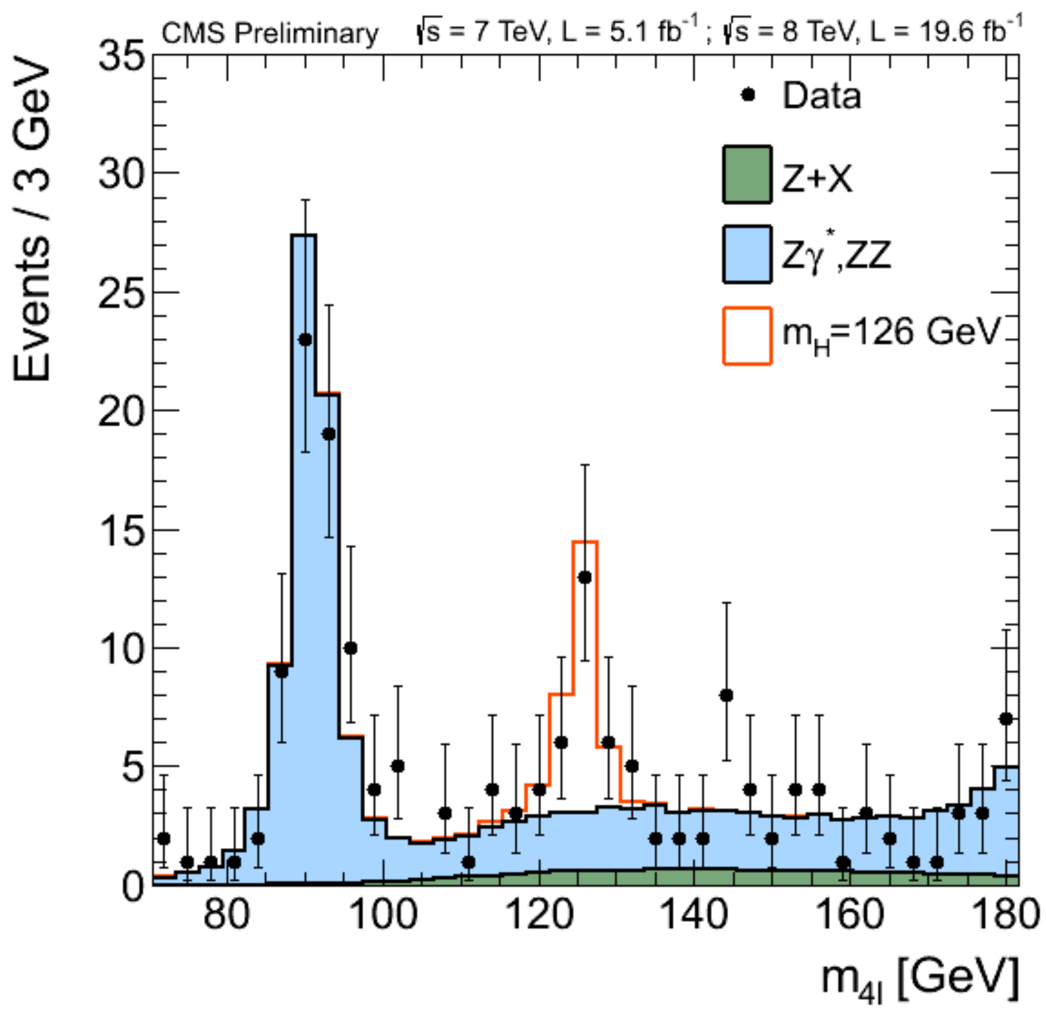
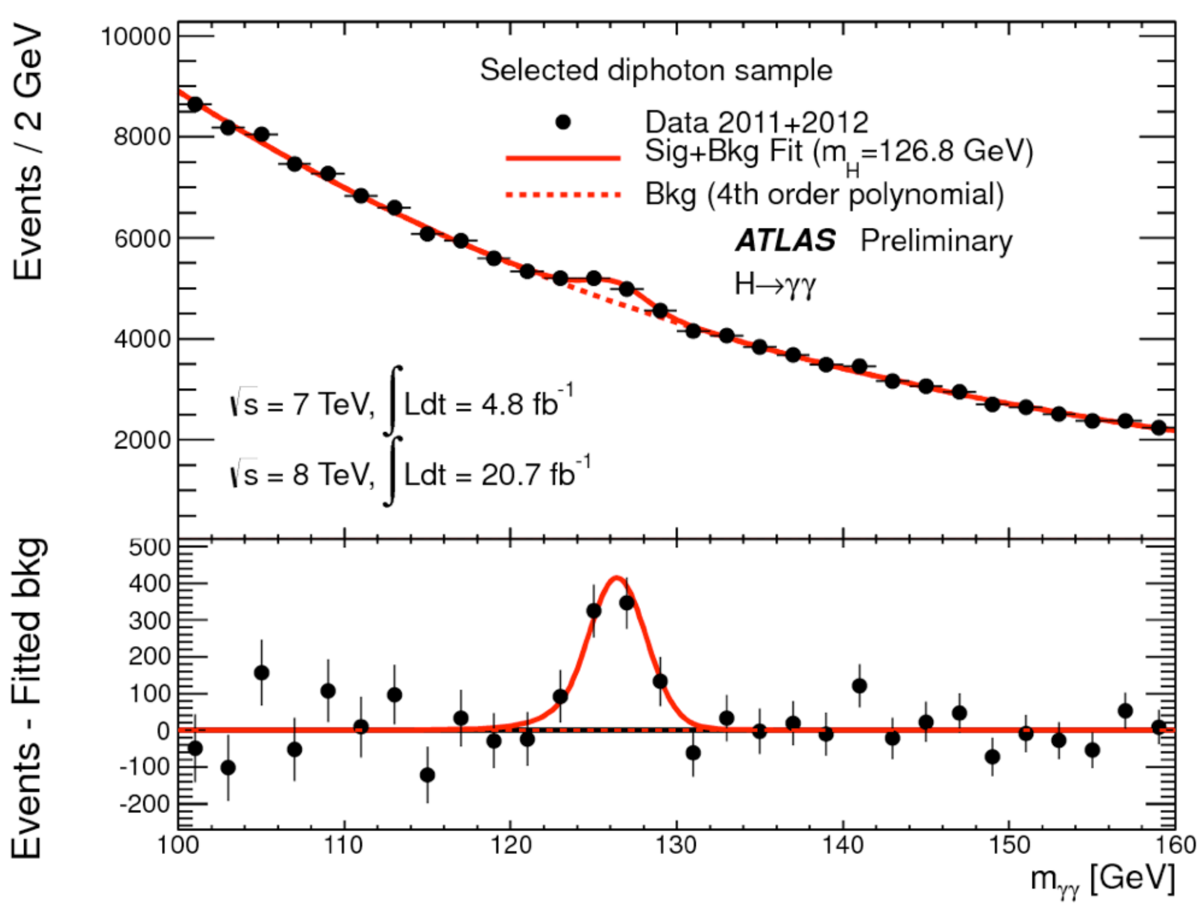
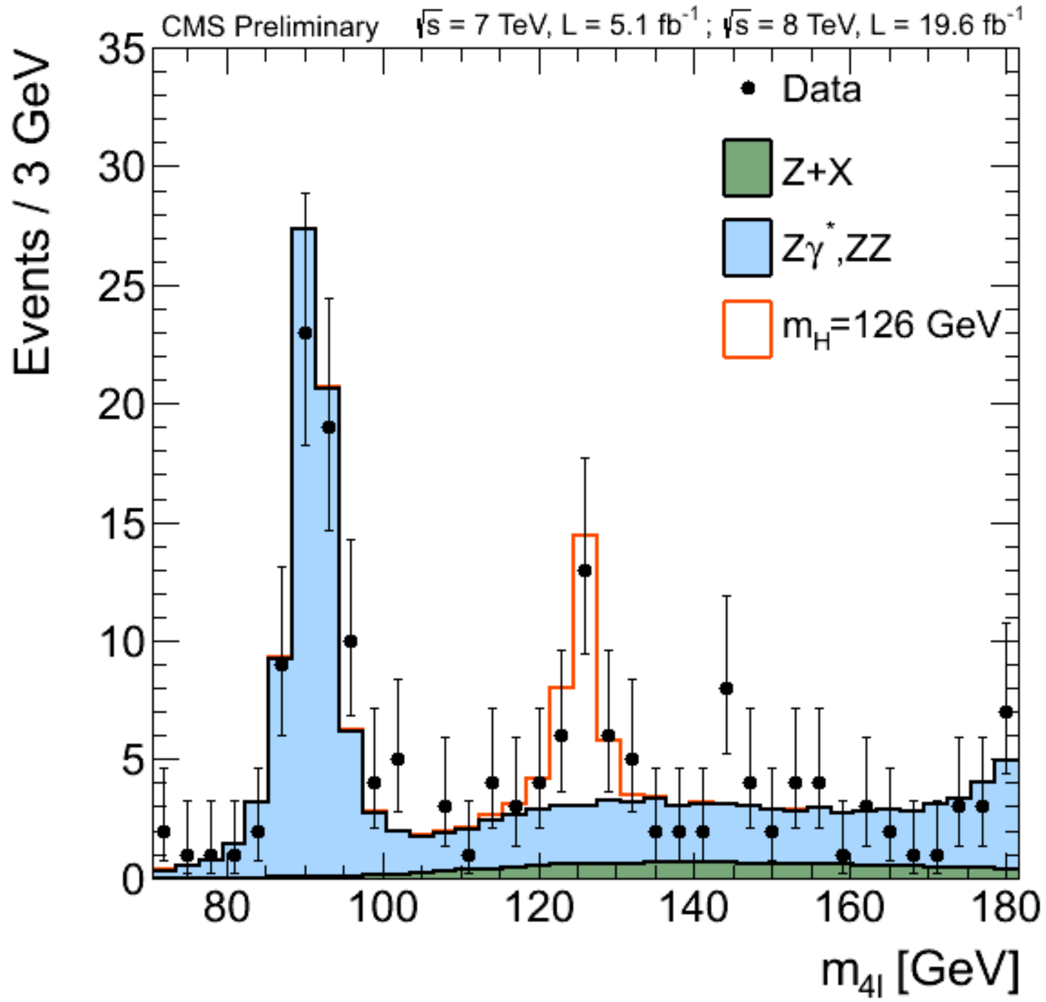
Studying the Higgs boson properties with aMC@NLO





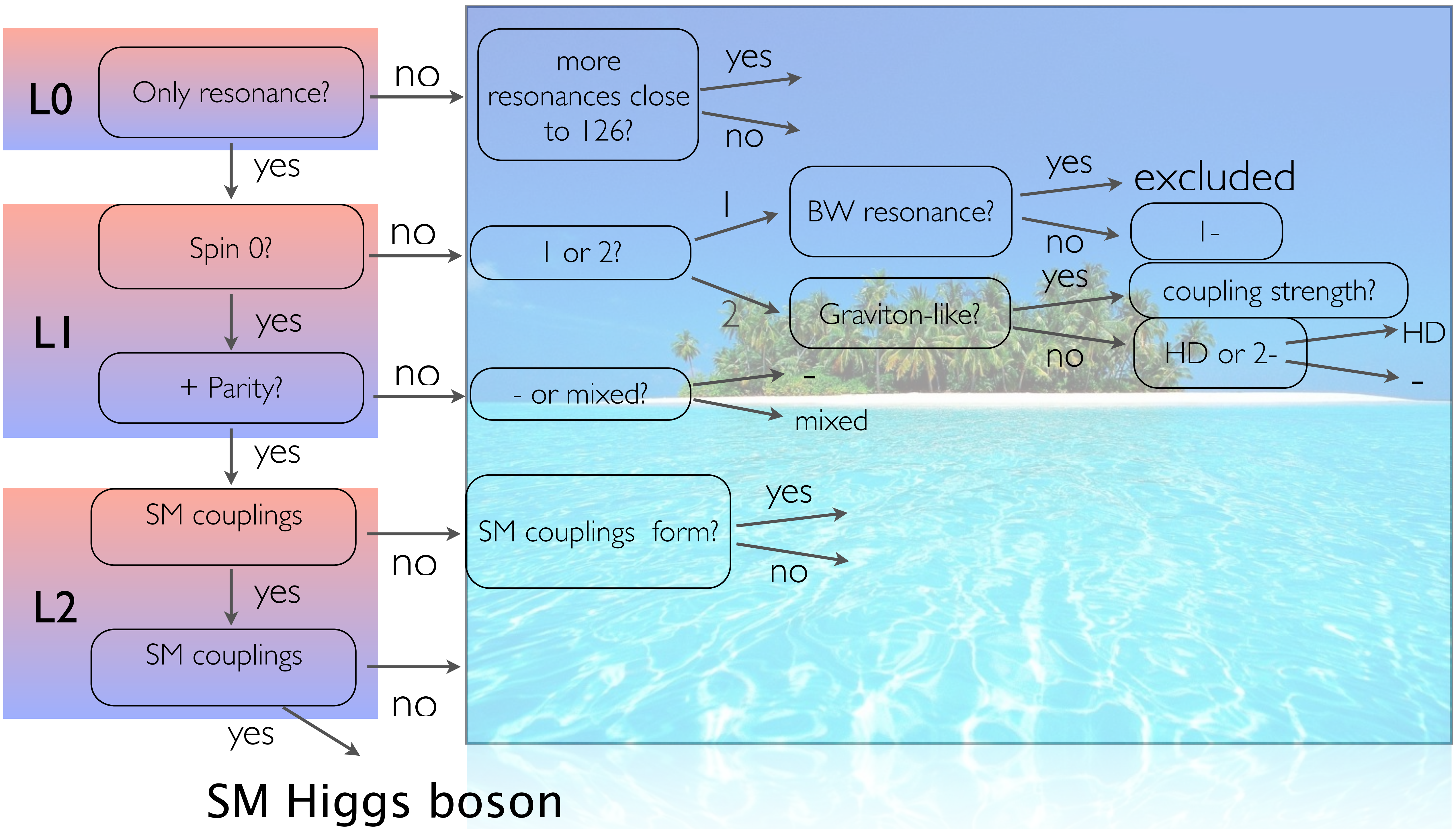
Studying the Higgs boson properties with aMC@NLO





What is that peak??

One year ago…


L0
Only resonance?
no
yes
L1
Spin 0?
no
yes
+ Parity?
no
yes
L2
SM couplings
no
yes
SM couplings
no
yes
SM Higgs boson
more resonances close to 126?
yes
no
1 or 2?
1
2
BW resonance?
yes
excluded
no
1-
Graviton-like?
yes
coupling strength?
no
HD or 2-
HD
-
- or mixed?
-
mixed
SM couplings form?
yes
no

Higgs Characterization

P. Artoisenet, P. de Aquino, F. Demartin, R. Frederix, S. Frixione, F. Maltoni, M. K. Mandal, P. Mathews, K. Mawatari, V. Ravindran, S. Seth, P. Torrielli, MZ, arXiv:1306.6464 + YR3

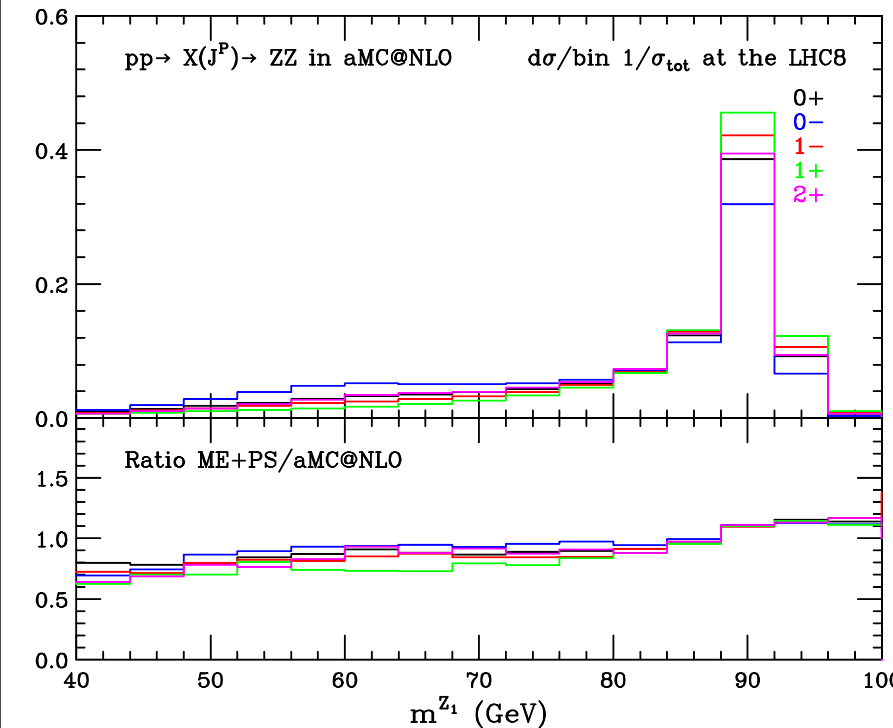
- Effective field theory approach
  - The "Higgs" is the first particle from NP
  - Agnostic on NP details (encoded in cutoff Λ)
- Keep lowest dimension operators for spin 0, 1, 2 hypotheses (CP +/- or mixed)
- Extra QCD radiation can be consistently incorporated (MLM or aMC@NLO, but virtuals had to be coded by hand)
- Study `zz`, `ww`, γγ final states, keeping all angular correlations

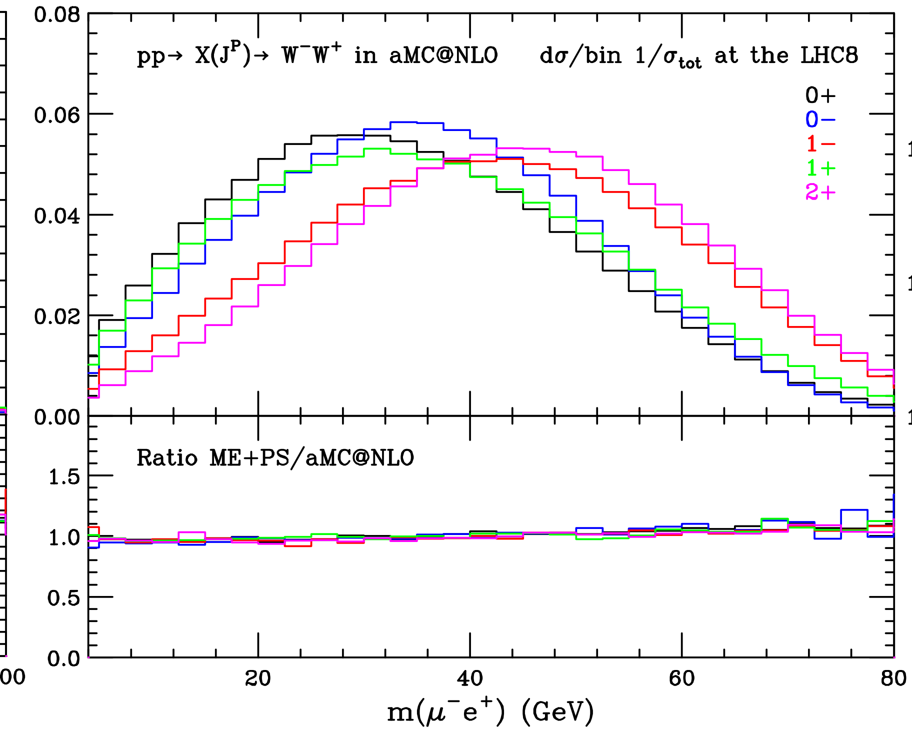
Results:

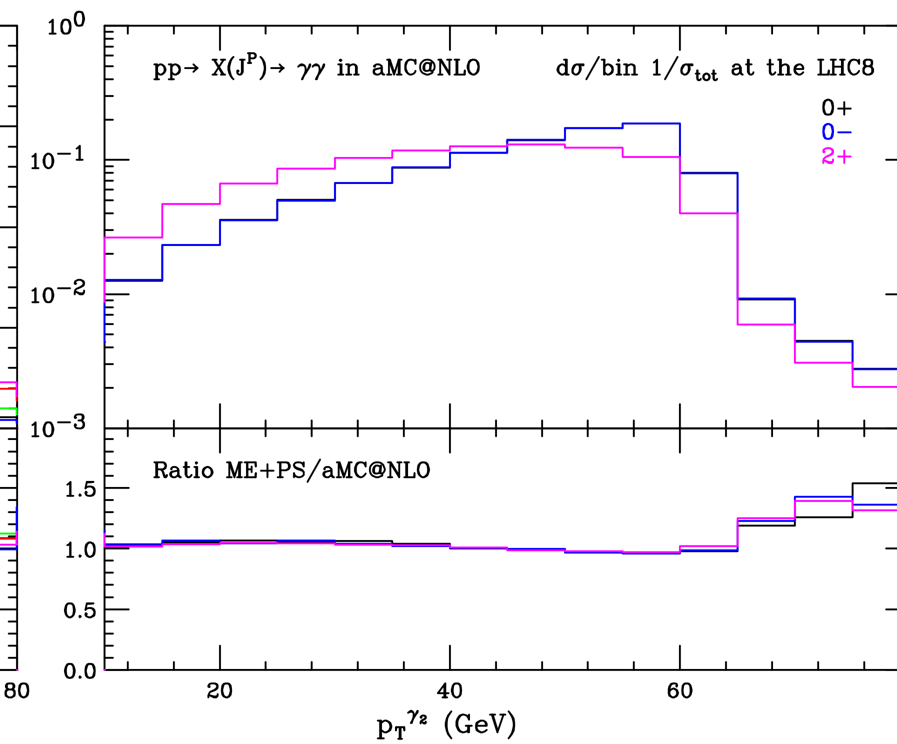
ZZ

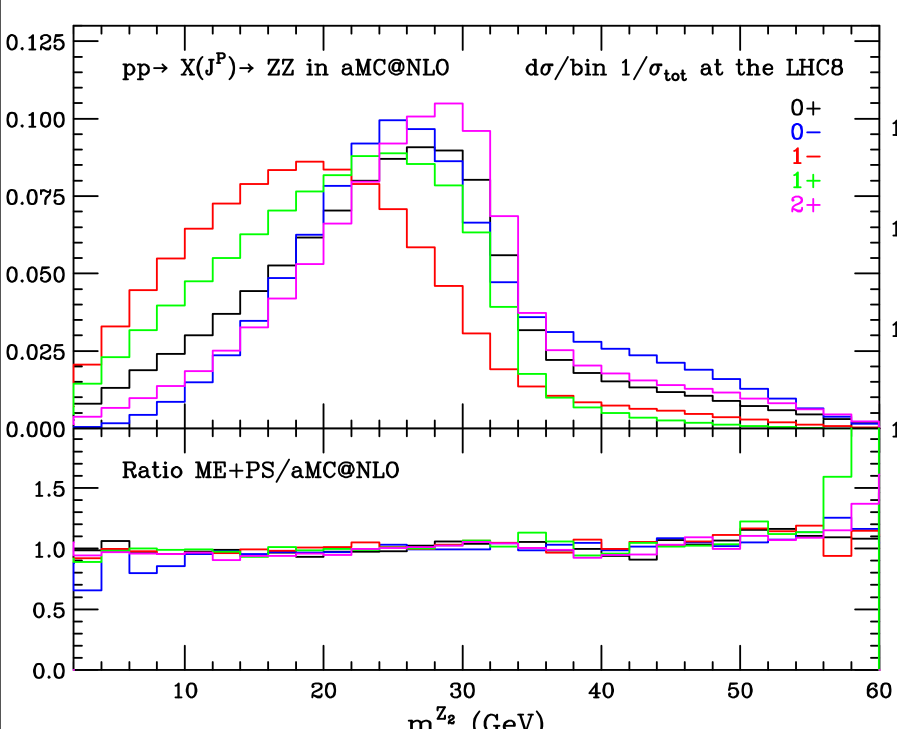
WW

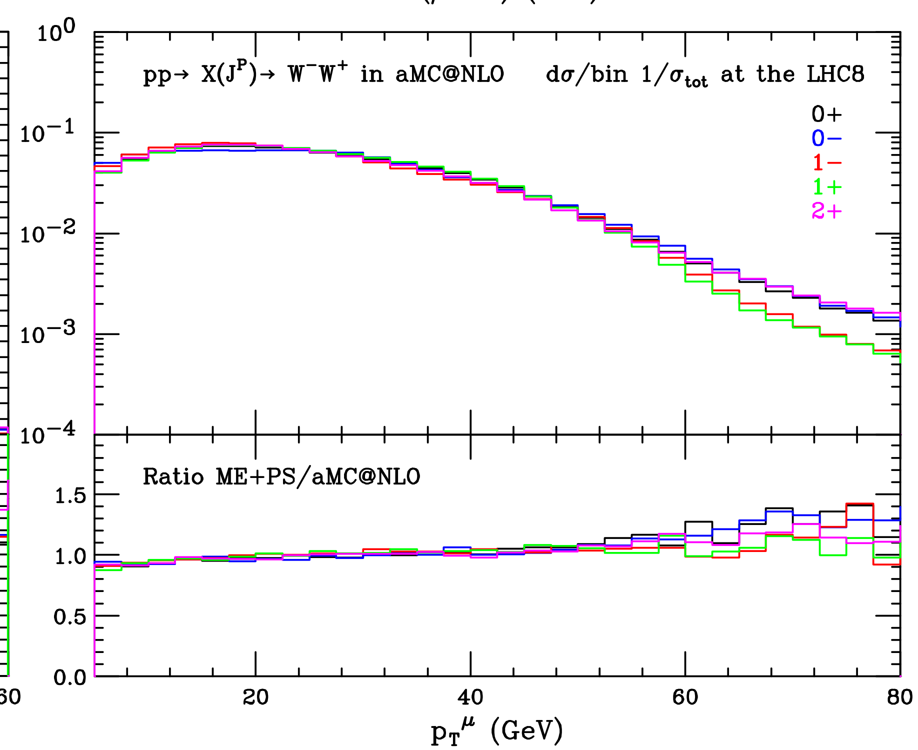
γγ

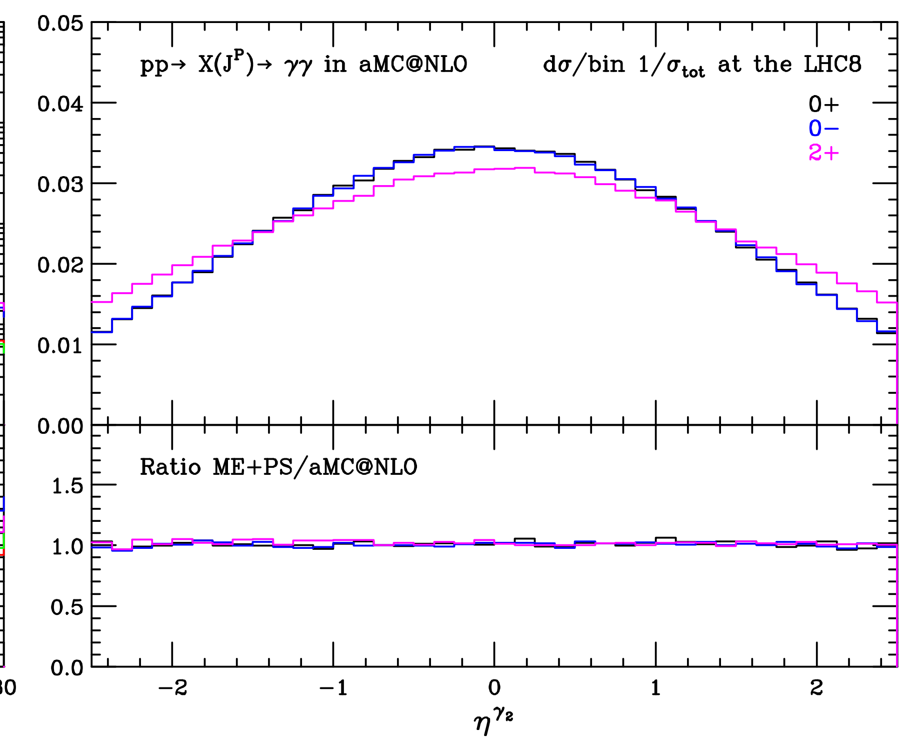




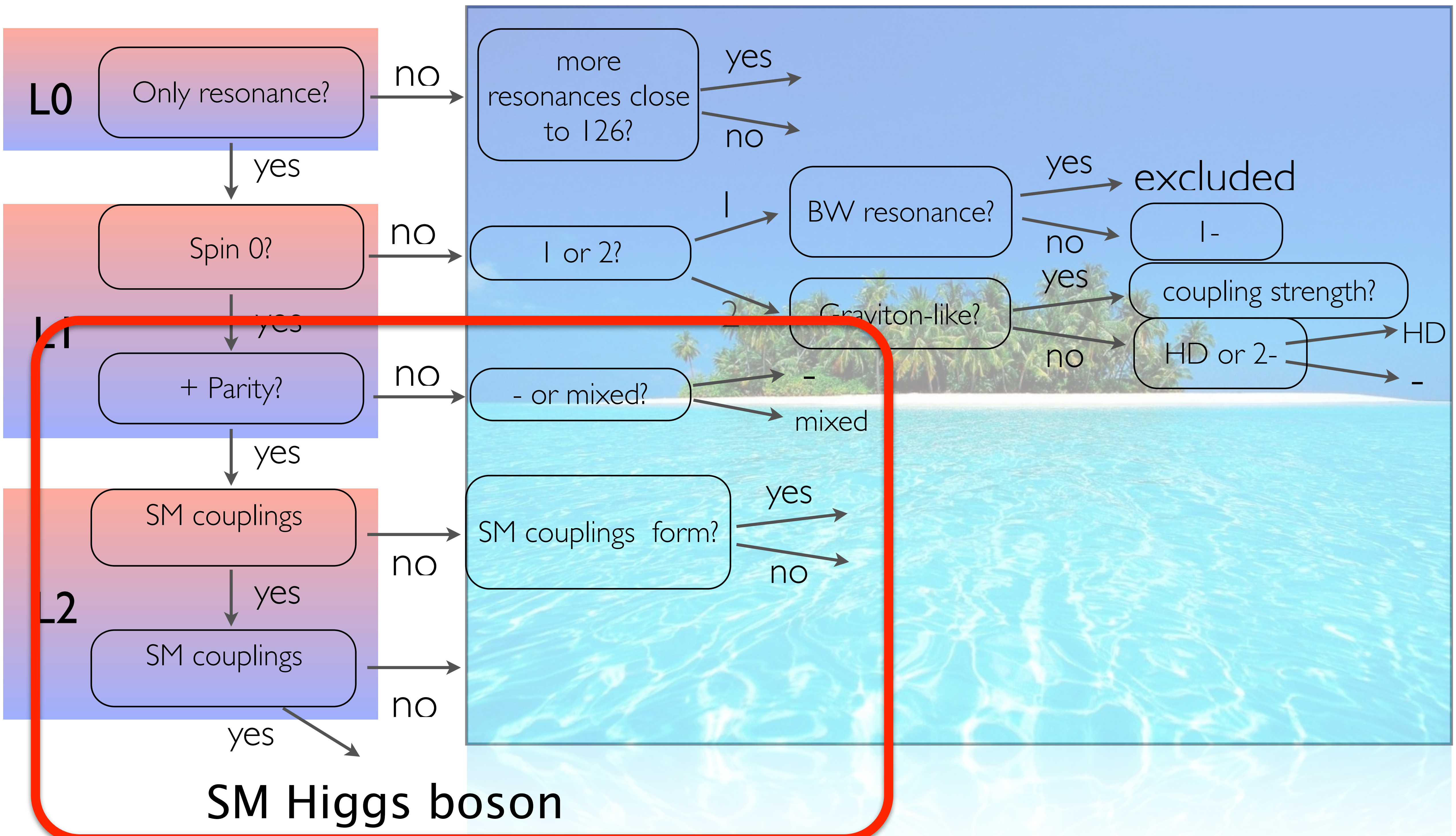








Today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+ Parity?
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yes
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-
mixed
L2
SM couplings
no
yes
SM couplings form?
yes
no
SM couplings
no
yes
SM Higgs boson

Higgs characterization in VBF and VH

F. Maltoni, K. Mawatari, MZ, arXiv:1311.1829 + F. Demartin for HC model @NLO

- VBF and VH can provide additional information about the nature of the Higgs boson
- Build a NLO HiggsCharacterization model (in preparation) so that one can generate the full NLO process automatically
  - Easy for VBF and VH, the Higgs does not couple to QCD particles (just add the *HVV* vertices)
- Focus on the spin-0 hypothesis, probe possible anomalous couplings

Spin-0 *HVV* lagrangian

$$
\begin{aligned}
\mathcal{L}_0^V = \Big\{ & c_\alpha \kappa_{\rm SM} \big[\tfrac{1}{2} g_{HZZ}\, Z_\mu Z^\mu + g_{HWW}\, W^+_\mu W^{-\mu}\big] \\
& - \frac{1}{4}\big[c_\alpha \kappa_{H\gamma\gamma} g_{H\gamma\gamma}\, A_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{A\gamma\gamma} g_{A\gamma\gamma}\, A_{\mu\nu} \widetilde{A}^{\mu\nu}\big] \\
& - \frac{1}{2}\big[c_\alpha \kappa_{HZ\gamma} g_{HZ\gamma}\, Z_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{AZ\gamma} g_{AZ\gamma}\, Z_{\mu\nu} \widetilde{A}^{\mu\nu}\big] \\
& - \frac{1}{4}\big[c_\alpha \kappa_{Hgg} g_{Hgg}\, G^a_{\mu\nu} G^{a,\mu\nu} + s_\alpha \kappa_{Agg} g_{Agg}\, G^a_{\mu\nu} \widetilde{G}^{a,\mu\nu}\big] \\
& - \frac{1}{4}\frac{1}{\Lambda}\big[c_\alpha \kappa_{HZZ}\, Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ}\, Z_{\mu\nu} \widetilde{Z}^{\mu\nu}\big] \\
& - \frac{1}{2}\frac{1}{\Lambda}\big[c_\alpha \kappa_{HWW}\, W^+_{\mu\nu} W^{-\mu\nu} + s_\alpha \kappa_{AWW}\, W^+_{\mu\nu} \widetilde{W}^{-\mu\nu}\big] \\
& - \frac{1}{\Lambda} c_\alpha \big[\kappa_{H\partial\gamma}\, Z_\nu \partial_\mu A^{\mu\nu} \kappa_{H\partial Z}\, Z_\nu \partial_\mu Z^{\mu\nu} \\
& \qquad + \big(\kappa_{H\partial W} W^+_\nu \partial_\mu W^{-\mu\nu} + h.c.\big)\big] \Big\} X_0 \,, \qquad (1)
\end{aligned}
$$

Spin-0 *HVV* lagrangian

SM

$$
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& - \frac{1}{4} \big[c_\alpha \kappa_{Hgg} g_{Hgg}\, G^a_{\mu\nu} G^{a,\mu\nu} + s_\alpha \kappa_{Agg} g_{Agg}\, G^a_{\mu\nu} \widetilde{G}^{a,\mu\nu} \big] \\
& - \frac{1}{4} \frac{1}{\Lambda} \big[c_\alpha \kappa_{HZZ}\, Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ}\, Z_{\mu\nu} \widetilde{Z}^{\mu\nu} \big] \\
& - \frac{1}{2} \frac{1}{\Lambda} \big[c_\alpha \kappa_{HWW}\, W^+_{\mu\nu} W^{-\mu\nu} + s_\alpha \kappa_{AWW}\, W^+_{\mu\nu} \widetilde{W}^{-\mu\nu} \big] \\
& - \frac{1}{\Lambda} c_\alpha \big[\kappa_{H\partial\gamma}\, Z_\nu \partial_\mu A^{\mu\nu} \kappa_{H\partial Z}\, Z_\nu \partial_\mu Z^{\mu\nu} \\
& \qquad + \left(\kappa_{H\partial W} W^+_\nu \partial_\mu W^{-\mu\nu} + h.c. \right) \big] \Big\} X_0 \,, \qquad (1)
\end{aligned}
$$

Spin-0 *HVV* lagrangian

SM

HD

$$
\begin{aligned}
\mathcal{L}_0^V = \Big\{ & c_\alpha \kappa_{\rm SM} \big[\tfrac{1}{2} g_{HZZ}\, Z_\mu Z^\mu + g_{HWW}\, W_\mu^+ W^{-\mu}\big] \\
& - \frac{1}{4}\big[c_\alpha \kappa_{H\gamma\gamma} g_{H\gamma\gamma}\, A_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{A\gamma\gamma} g_{A\gamma\gamma}\, A_{\mu\nu} \widetilde{A}^{\mu\nu}\big] \\
& - \frac{1}{2}\big[c_\alpha \kappa_{HZ\gamma} g_{HZ\gamma}\, Z_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{AZ\gamma} g_{AZ\gamma}\, Z_{\mu\nu} \widetilde{A}^{\mu\nu}\big] \\
& - \frac{1}{4}\big[c_\alpha \kappa_{Hgg} g_{Hgg}\, G^a_{\mu\nu} G^{a,\mu\nu} + s_\alpha \kappa_{Agg} g_{Agg}\, G^a_{\mu\nu} \widetilde{G}^{a,\mu\nu}\big] \\
& - \frac{1}{4}\frac{1}{\Lambda}\big[c_\alpha \kappa_{HZZ}\, Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ}\, Z_{\mu\nu} \widetilde{Z}^{\mu\nu}\big] \\
& - \frac{1}{2}\frac{1}{\Lambda}\big[c_\alpha \kappa_{HWW}\, W^+_{\mu\nu} W^{-\mu\nu} + s_\alpha \kappa_{AWW}\, W^+_{\mu\nu} \widetilde{W}^{-\mu\nu}\big] \\
& - \frac{1}{\Lambda} c_\alpha \big[\kappa_{H\partial\gamma}\, Z_\nu \partial_\mu A^{\mu\nu} \kappa_{H\partial Z}\, Z_\nu \partial_\mu Z^{\mu\nu} \\
& \qquad + \left(\kappa_{H\partial W} W_\nu^+ \partial_\mu W^{-\mu\nu} + h.c.\right)\big] \Big\} X_0 \,, \qquad (1)
\end{aligned}
$$

Spin-0 *HVV* lagrangian

SM

HD

0^+

$$\begin{aligned}\mathcal{L}_0^V = \Big\{ & c_\alpha \kappa_{\rm SM} \big[\tfrac{1}{2} g_{HZZ}\, Z_\mu Z^\mu + g_{HWW}\, W^+_\mu W^{-\mu}\big] \\ & - \frac{1}{4}\big[c_\alpha \kappa_{H\gamma\gamma} g_{H\gamma\gamma}\, A_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{A\gamma\gamma} g_{A\gamma\gamma}\, A_{\mu\nu} \widetilde{A}^{\mu\nu}\big] \\ & - \frac{1}{2}\big[c_\alpha \kappa_{HZ\gamma} g_{HZ\gamma}\, Z_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{AZ\gamma} g_{AZ\gamma}\, Z_{\mu\nu} \widetilde{A}^{\mu\nu}\big] \\ & - \frac{1}{4}\big[c_\alpha \kappa_{Hgg} g_{Hgg}\, G^a_{\mu\nu} G^{a,\mu\nu} + s_\alpha \kappa_{Agg} g_{Agg}\, G^a_{\mu\nu} \widetilde{G}^{a,\mu\nu}\big] \\ & - \frac{1}{4}\frac{1}{\Lambda}\big[c_\alpha \kappa_{HZZ}\, Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ}\, Z_{\mu\nu} \widetilde{Z}^{\mu\nu}\big] \\ & - \frac{1}{2}\frac{1}{\Lambda}\big[c_\alpha \kappa_{HWW}\, W^+_{\mu\nu} W^{-\mu\nu} + s_\alpha \kappa_{AWW}\, W^+_{\mu\nu} \widetilde{W}^{-\mu\nu}\big] \\ & - \frac{1}{\Lambda} c_\alpha \big[\kappa_{H\partial\gamma}\, Z_\nu \partial_\mu A^{\mu\nu} \kappa_{H\partial Z}\, Z_\nu \partial_\mu Z^{\mu\nu} \\ & \qquad + \big(\kappa_{H\partial W} W^+_\nu \partial_\mu W^{-\mu\nu} + h.c.\big)\big]\Big\} X_0 \,, \qquad (1)\end{aligned}$$

Spin-0 *HVV* lagrangian

SM

HD

0^+ 0^-

$$
\begin{aligned}
\mathcal{L}_0^V = \Big\{ & c_\alpha \kappa_{\rm SM} \big[\tfrac{1}{2} g_{HZZ}\, Z_\mu Z^\mu + g_{HWW}\, W^+_\mu W^{-\mu} \big] \\
& - \frac{1}{4} \big[c_\alpha \kappa_{H\gamma\gamma} g_{H\gamma\gamma}\, A_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{A\gamma\gamma} g_{A\gamma\gamma}\, A_{\mu\nu} \widetilde{A}^{\mu\nu} \big] \\
& - \frac{1}{2} \big[c_\alpha \kappa_{HZ\gamma} g_{HZ\gamma}\, Z_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{AZ\gamma} g_{AZ\gamma}\, Z_{\mu\nu} \widetilde{A}^{\mu\nu} \big] \\
& - \frac{1}{4} \big[c_\alpha \kappa_{Hgg} g_{Hgg}\, G^a_{\mu\nu} G^{a,\mu\nu} + s_\alpha \kappa_{Agg} g_{Agg}\, G^a_{\mu\nu} \widetilde{G}^{a,\mu\nu} \big] \\
& - \frac{1}{4} \frac{1}{\Lambda} \big[c_\alpha \kappa_{HZZ}\, Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ}\, Z_{\mu\nu} \widetilde{Z}^{\mu\nu} \big] \\
& - \frac{1}{2} \frac{1}{\Lambda} \big[c_\alpha \kappa_{HWW}\, W^+_{\mu\nu} W^{-\mu\nu} + s_\alpha \kappa_{AWW}\, W^+_{\mu\nu} \widetilde{W}^{-\mu\nu} \big] \\
& - \frac{1}{\Lambda} c_\alpha \big[\kappa_{H\partial\gamma}\, Z_\nu \partial_\mu A^{\mu\nu} \kappa_{H\partial Z}\, Z_\nu \partial_\mu Z^{\mu\nu} \\
& \qquad + \left(\kappa_{H\partial W} W^+_\nu \partial_\mu W^{-\mu\nu} + h.c. \right) \big] \Big\} X_0 \,, \qquad (1)
\end{aligned}
$$

Spin-0 *HVV* lagrangian

SM

HD

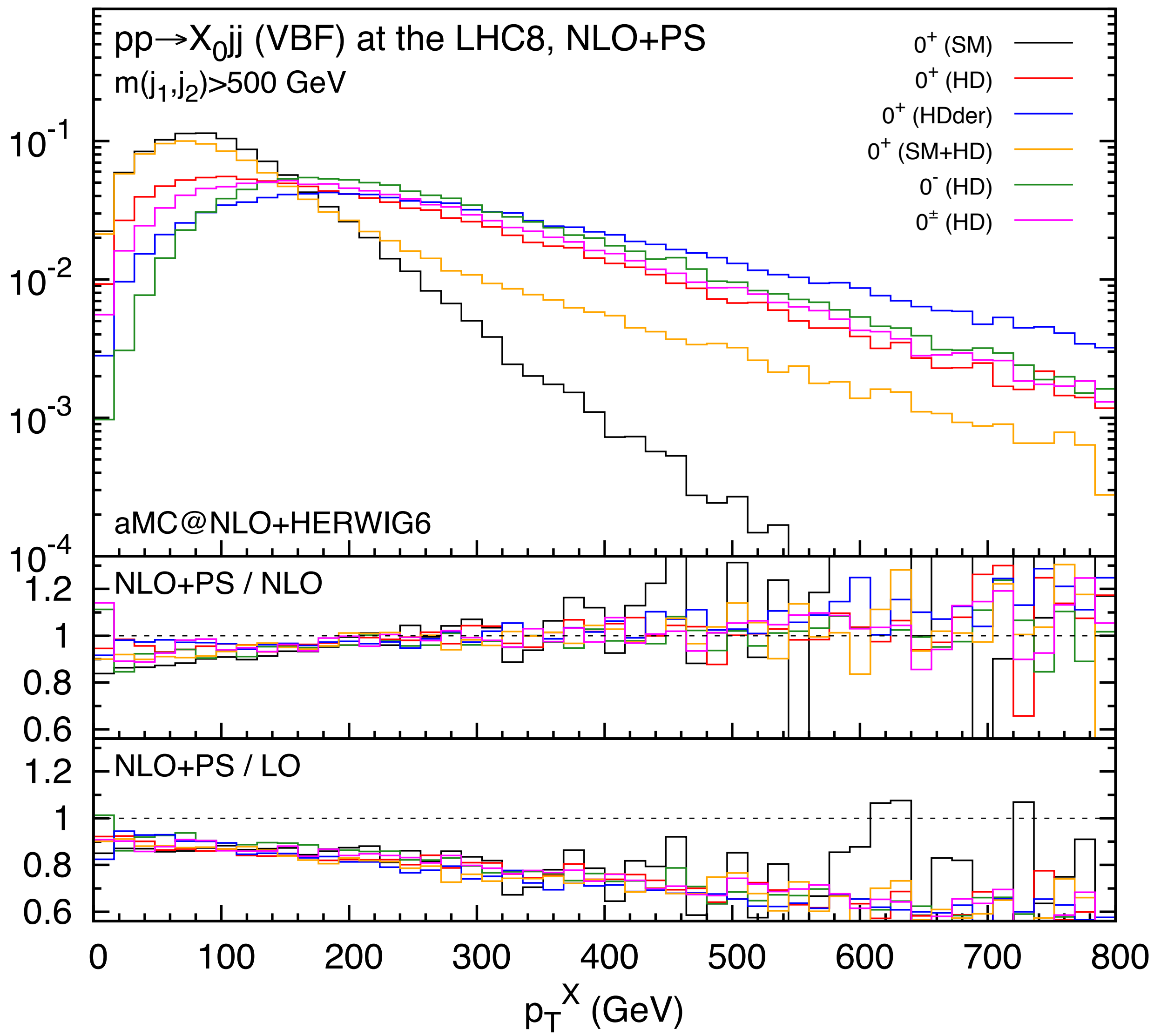
0+

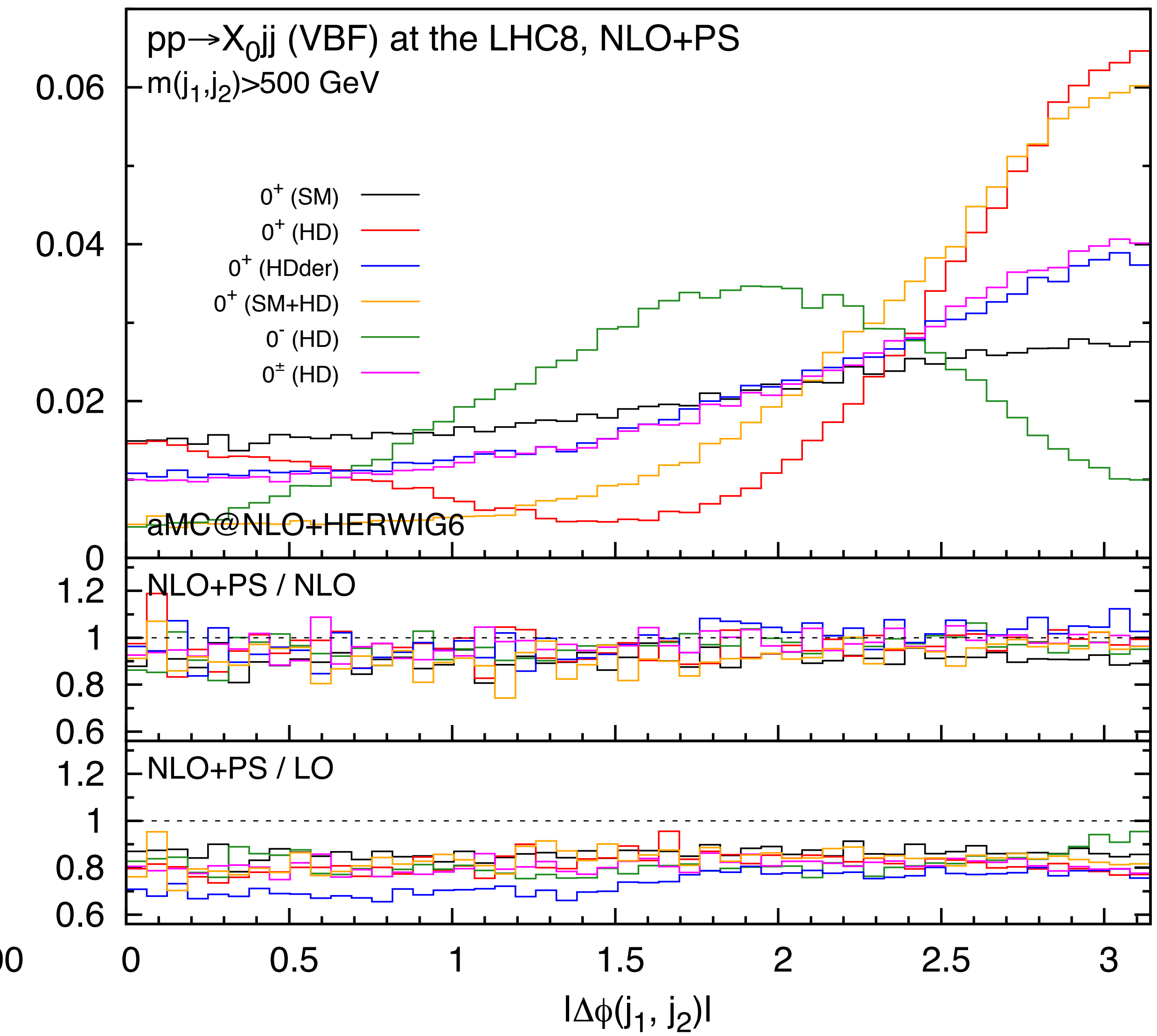
0-

$$
\begin{aligned}
\mathcal{L}_0^V = \Big\{ & c_\alpha \kappa_{\rm SM} \big[\tfrac{1}{2} g_{HZZ}\, Z_\mu Z^\mu + g_{HWW}\, W^+_\mu W^{-\mu} \big] \\
& - \frac{1}{4} \big[c_\alpha \kappa_{H\gamma\gamma} g_{H\gamma\gamma}\, A_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{A\gamma\gamma} g_{A\gamma\gamma}\, A_{\mu\nu} \widetilde{A}^{\mu\nu} \big] \\
& - \frac{1}{2} \big[c_\alpha \kappa_{HZ\gamma} g_{HZ\gamma}\, Z_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{AZ\gamma} g_{AZ\gamma}\, Z_{\mu\nu} \widetilde{A}^{\mu\nu} \big] \\
& - \frac{1}{4} \big[c_\alpha \kappa_{Hgg} g_{Hgg}\, G^a_{\mu\nu} G^{a,\mu\nu} + s_\alpha \kappa_{Agg} g_{Agg}\, G^a_{\mu\nu} \widetilde{G}^{a,\mu\nu} \big] \\
& - \frac{1}{4} \frac{1}{\Lambda} \big[c_\alpha \kappa_{HZZ}\, Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ}\, Z_{\mu\nu} \widetilde{Z}^{\mu\nu} \big] \\
& - \frac{1}{2} \frac{1}{\Lambda} \big[c_\alpha \kappa_{HWW}\, W^+_{\mu\nu} W^{-\mu\nu} + s_\alpha \kappa_{AWW}\, W^+_{\mu\nu} \widetilde{W}^{-\mu\nu} \big] \\
& - \frac{1}{\Lambda} c_\alpha \big[\kappa_{H\partial\gamma}\, Z_\nu \partial_\mu A^{\mu\nu} \kappa_{H\partial Z}\, Z_\nu \partial_\mu Z^{\mu\nu} \\
& \qquad + \big(\kappa_{H\partial W} W^+_\nu \partial_\mu W^{-\mu\nu} + h.c. \big) \big] \Big\} X_0 \,, \qquad (1)
\end{aligned}
$$

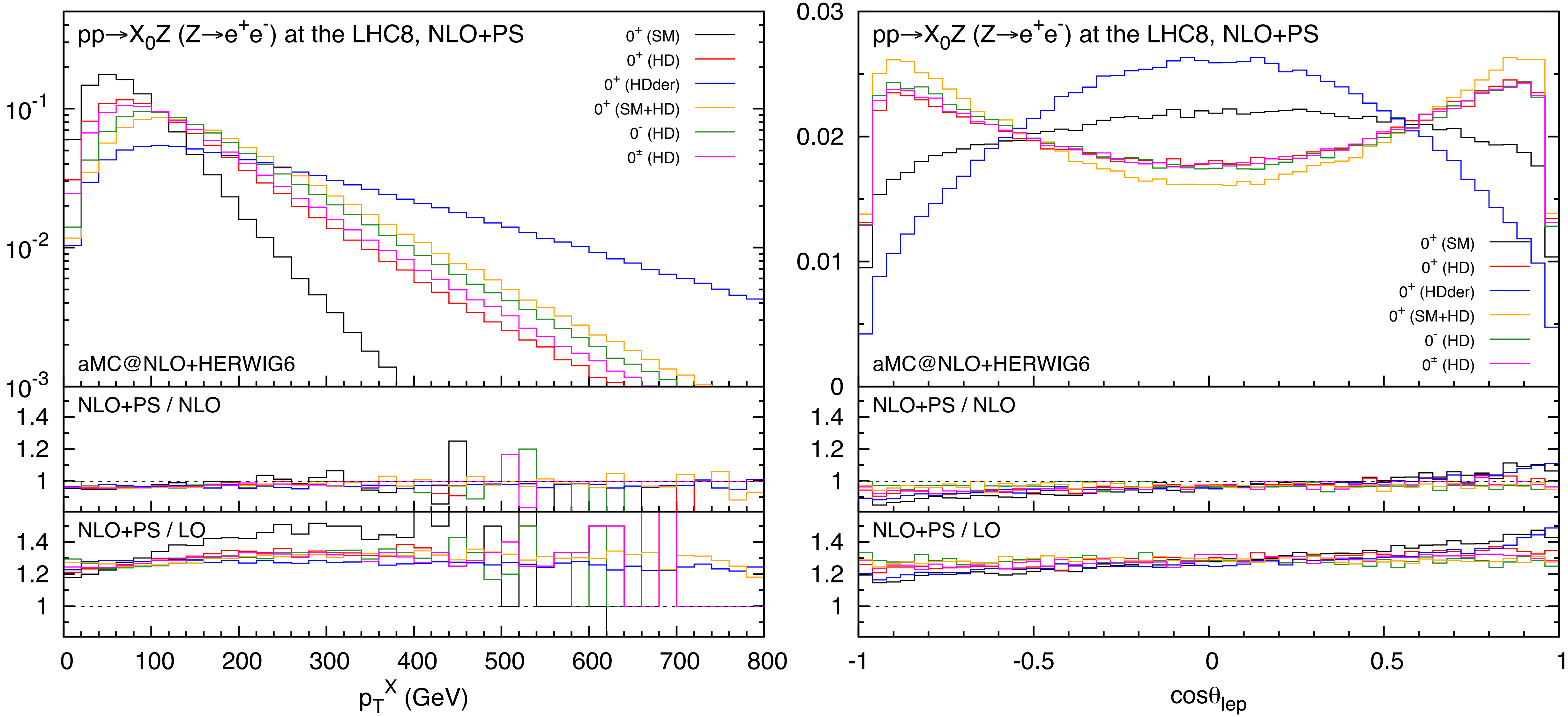
0+Der

VBF:


pp→X0jj (VBF) at the LHC8, NLO+PS
m(j1,j2)>500 GeV
0+ (SM)
0+ (HD)
0+ (HDder)
0+ (SM+HD)
0- (HD)
0± (HD)
aMC@NLO+HERWIG6
NLO+PS / NLO
NLO+PS / LO
pTX (GeV)


pp→X0jj (VBF) at the LHC8, NLO+PS
m(j1,j2)>500 GeV
0+ (SM)
0+ (HD)
0+ (HDder)
0+ (SM+HD)
0- (HD)
0± (HD)
aMC@NLO+HERWIG6
NLO+PS / NLO
NLO+PS / LO
|Δφ(j1, j2)|

VH:


pp→X_0Z (Z→e^+e^-) at the LHC8, NLO+PS
0^+ (SM)
0^+ (HD)
0^+ (HDder)
0^+ (SM+HD)
0^- (HD)
$0^\pm$ (HD)
aMC@NLO+HERWIG6
NLO+PS / NLO
NLO+PS / LO
p_T^X (GeV)
cosθ$_{lep}$

Probing the Higgs self coupling: HH production with aMC@NLO

MadGraph_aMC@NLO collaboration + E.Vryonidou, in preparation

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- All HH production channels but ggF (WIP) can be generated automatically within aMC@NLO
- Scale and PDF uncertainties (in %) computed from reweighting

σ[fb]	$\sqrt{s}=8$ TeV (LO)	NLO	$\sqrt{s}=13$ TeV (LO)	NLO	$\sqrt{s}=14$ TeV (LO)	NLO
$HHjj$	(0.436^{+12}_{-10})	$0.479^{+1.8+2.8}_{-1.8-2.0}$	$(1.543^{+9.4}_{-8.0})$	$1.684^{+1.4+2.6}_{-0.9-1.9}$	$(1.839^{+8.9}_{-7.7})$	$2.017^{+1.3+2.5}_{-1.0-1.9}$
$t\bar{t}HH$	(0.265^{+41}_{-27})	$0.177^{+4.7+3.2}_{-19-3.3}$	(1.027^{+37}_{-25})	$0.792^{+2.8+2.4}_{-10-2.9}$	(1.245^{+36}_{-25})	$0.981^{+2.3+2.3}_{-9.0-2.8}$
W^+HH	$(0.111^{+4.0}_{-3.9})$	$0.145^{+2.1+2.5}_{-1.9-1.9}$	$(0.252^{+1.4}_{-1.7})$	$0.326^{+1.7+2.1}_{-1.2-1.6}$	$(0.283^{+1.1}_{-1.3})$	$0.364^{+1.7+2.1}_{-1.1-1.6}$
W^-HH	$(0.051^{+4.2}_{-4.0})$	$0.069^{+2.1+2.6}_{-1.9-2.2}$	$(0.133^{+1.5}_{-1.7})$	$0.176^{+1.6+2.2}_{-1.2-2.0}$	$(0.152^{+1.1}_{-1.4})$	$0.201^{+1.7+2.2}_{-1.1-1.8}$
ZHH	$(0.098^{+4.2}_{-4.0})$	$0.130^{+2.1+2.2}_{-1.9-1.9}$	$(0.240^{+1.4}_{-1.7})$	$0.315^{+1.7+2.0}_{-1.1-1.6}$	$(0.273^{+1.1}_{-1.3})$	$0.356^{+1.7+1.9}_{-1.2-1.5}$
$tjHH(\cdot 10^{-3})$	$(5.919^{+1.8}_{-3.0})$	$6.432^{+4.1+3.7}_{-2.1-4.1}$	$(26.54^{+0.0}_{-1.0})$	$33.78^{+4.6+2.7}_{-2.6-3.1}$	$(32.97^{+0.0}_{-1.4})$	$42.38^{+4.5+2.5}_{-2.5-2.9}$

Probing the Higgs self coupling: HH production with aMC@NLO

MadGraph_aMC@NLO collaboration + E.Vryonidou, in preparation

- All HH production channels but ggF (WIP) can be generated automatically within aMC@NLO
- Scale and PDF uncertainties (in %) computed from reweighting

σ[fb]	$\sqrt{s} = 8$ TeV (LO)	NLO	$\sqrt{s} = 13$ TeV (LO)	NLO	$\sqrt{s} = 14$ TeV (LO)	NLO
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$t\bar{t}HH$	(0.265^{+41}_{-27})	$0.177^{+4.7+3.2}_{-19-3.3}$	(1.027^{+37}_{-25})	$0.792^{+2.8+2.4}_{-10-2.9}$	(1.245^{+36}_{-25})	$0.981^{+2.3+2.3}_{-9.0-2.8}$
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W^-HH	$(0.051^{+4.2}_{-4.0})$	$0.069^{+2.1+2.6}_{-1.9-2.2}$	$(0.133^{+1.5}_{-1.7})$	$0.176^{+1.6+2.2}_{-1.2-2.0}$	$(0.152^{+1.1}_{-1.4})$	$0.201^{+1.7+2.2}_{-1.1-1.8}$
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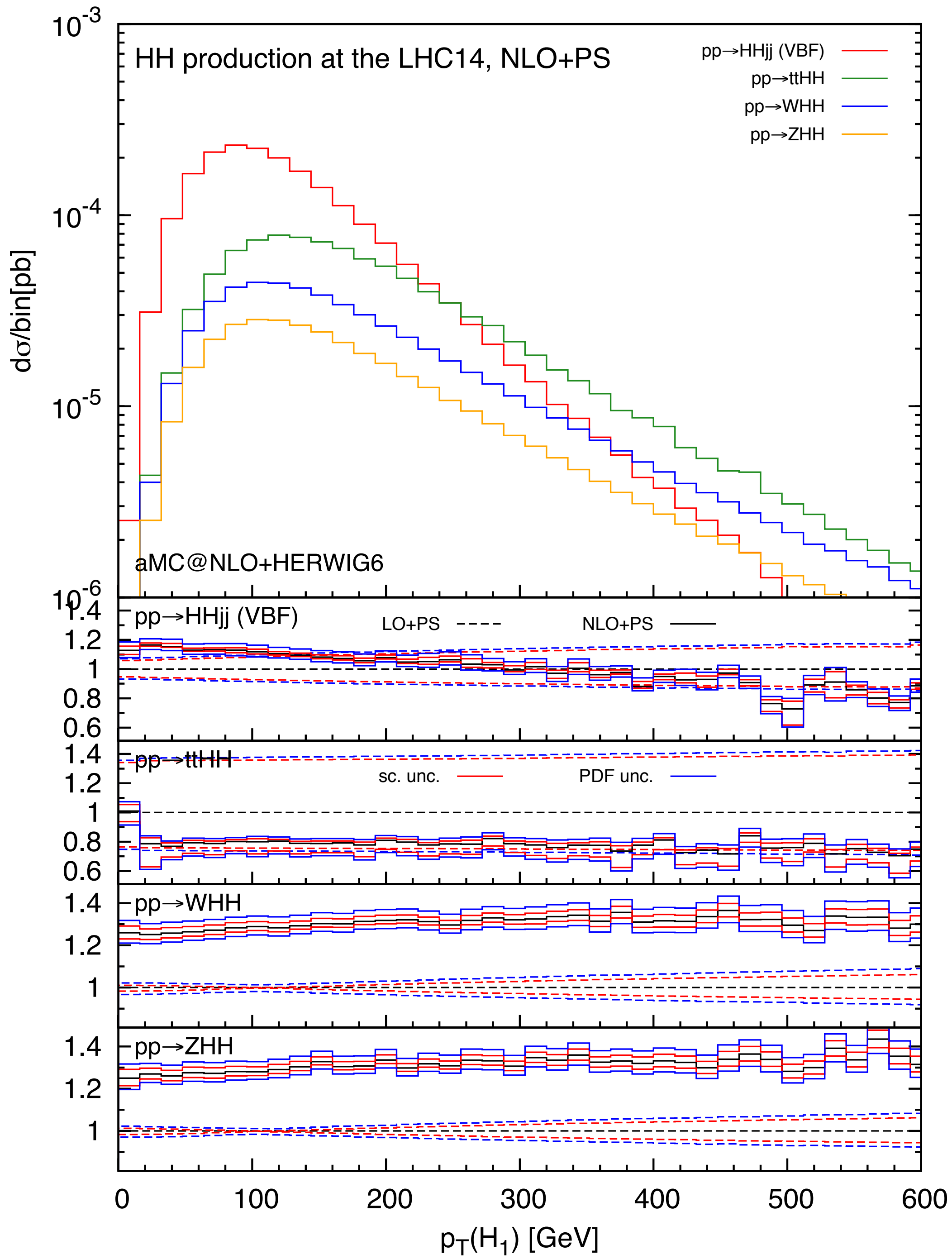
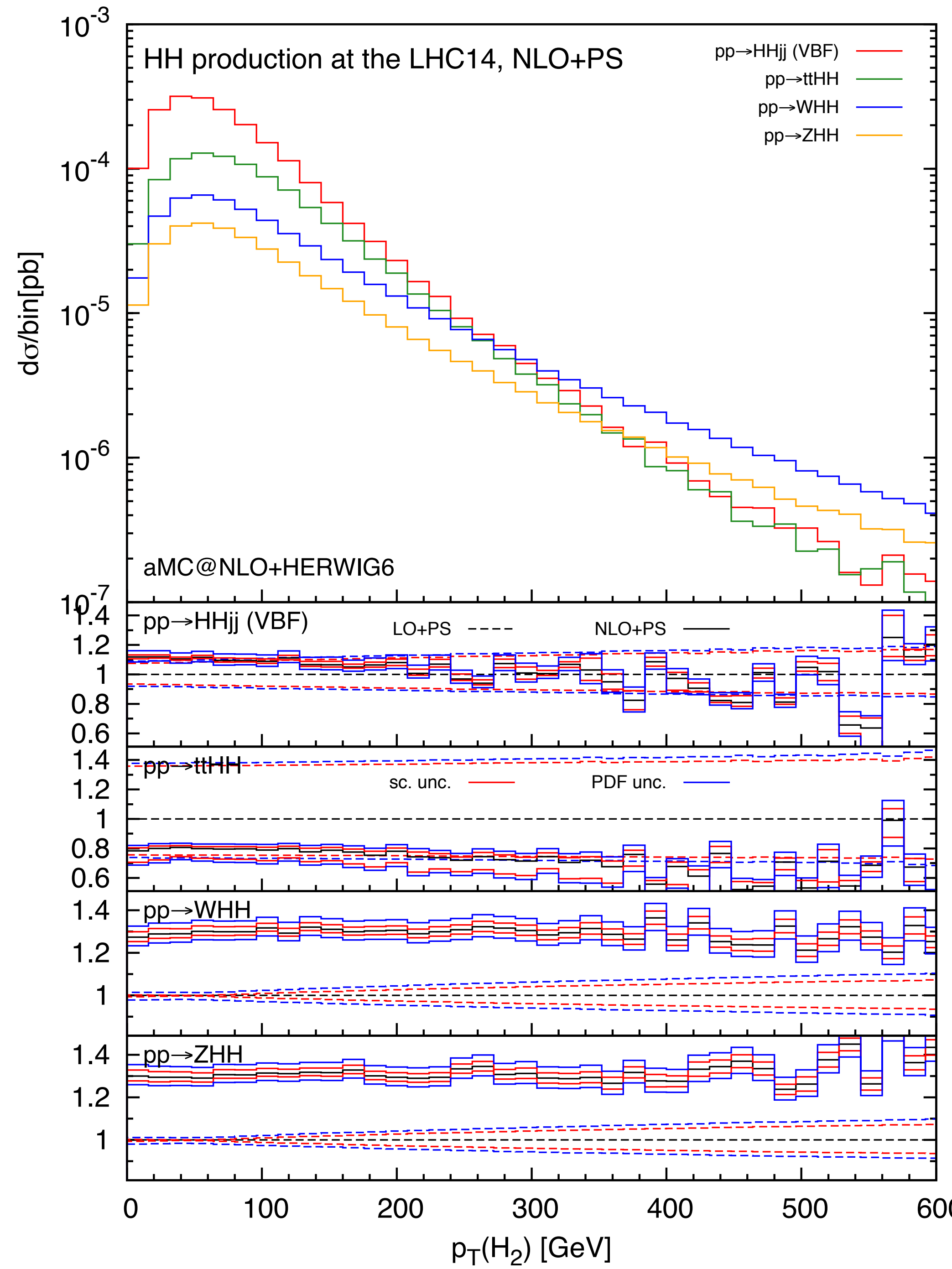
Probing the Higgs self coupling: HH production with aMC@NLO

MadGraph_aMC@NLO collaboration + E.Vrionidou, in preparation





Conclusions

- The MadGraph5_aMC@NLO package can perform matched/merged LO/NLO computations in a fully automatic way
- Code is stable, first non-beta release out soon with several improvements
- Sample application: studying the nature and couplings of the Higgs boson
  - HC model @NLO in preparation
  - All "easy" HH production channels can be computed automatically, ggF WIP
- Website: http://amcatnlo.cern.ch