Re-Weighting in MG5_aMC

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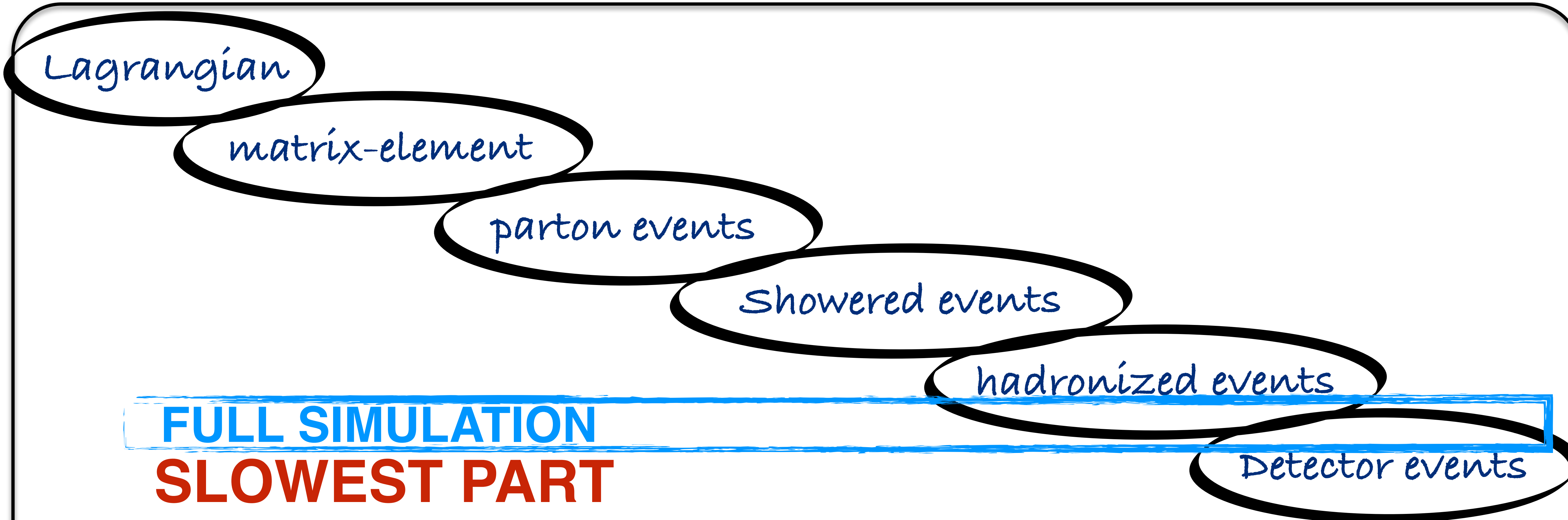
Re-Weighting

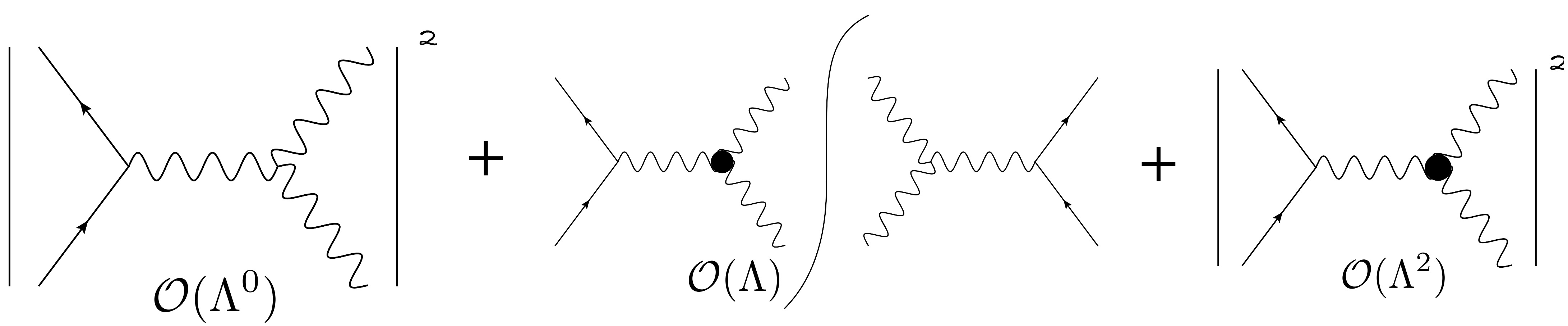
Reweighting are everywhere

- scale and pdf uncertainties (available both for LO and NLO computation)
- re-introduce top mass effect for Higgs processes
  - ➡ Higgs production [1110.1728]
  - ➡ Higgs pair mechanism [1401.7340]
  - ➡ ZH associated production [1503.01656]
- parameter scan (for coupling/lorentz)

Motivation

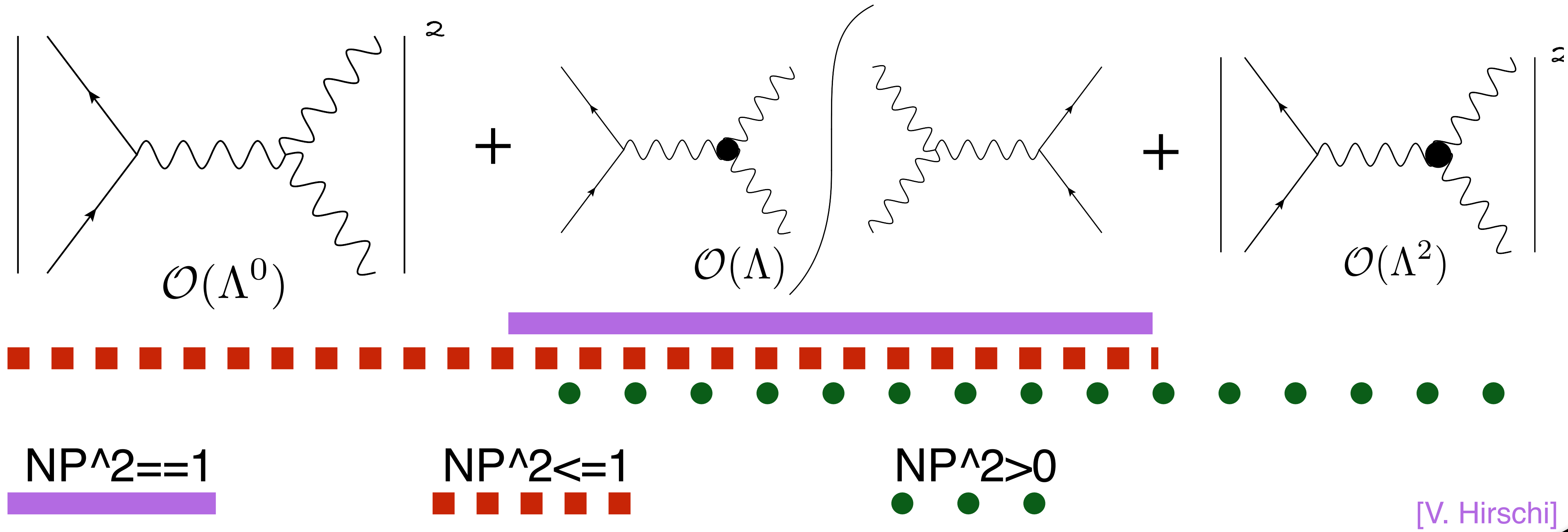


- Critical when interference are relevant



First Possibility

Interference alone



EFT Case

- The interference is the important part
- The difference between the full matrix-element and the SM plus interference is an estimation of one theoretical uncertainty
- We should report this error!

Second Possibility

Re-Weighting

- Reuse the sample (Only one Full Sim)
- Change the weight of the events

$$W_{new} = \frac{|M_{new}|^2}{|M_{old}|^2} * W_{old}$$

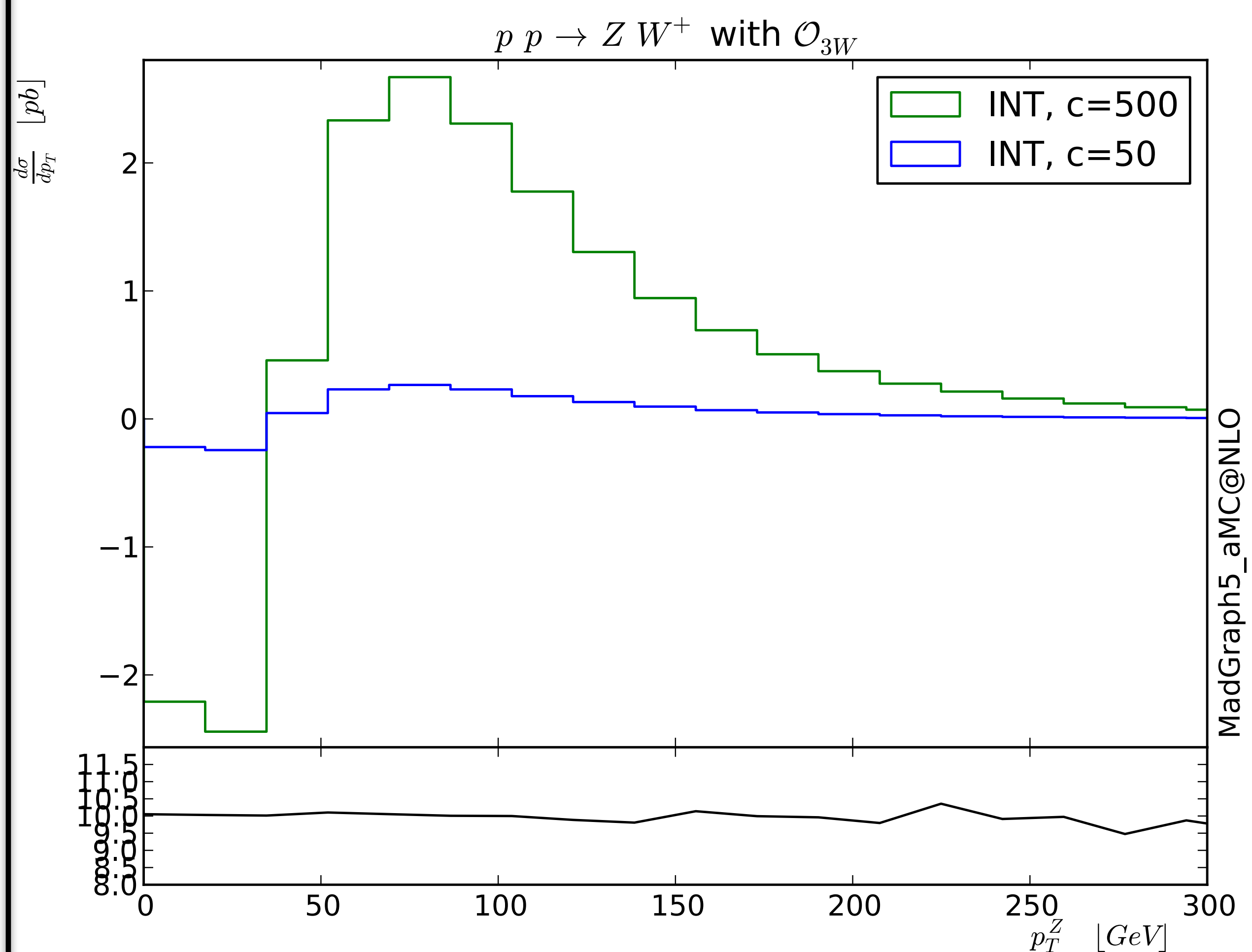
1405.0301
1404.7129

EFT case

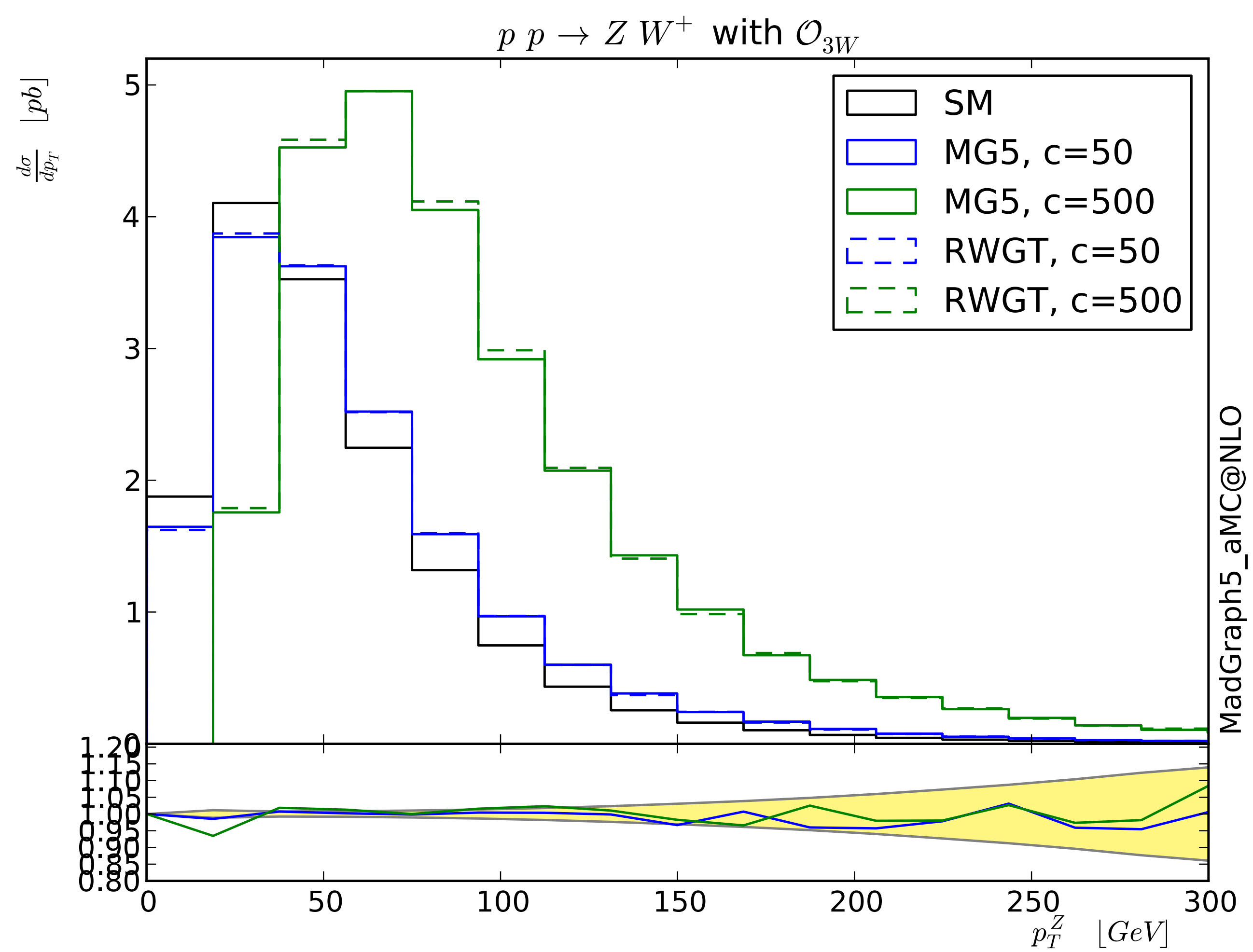
- The numerator should not be positive definite
    - can be SM + interference
    - so easy to estimate that theoretical uncertainty
    - NLO is tricky (See second part of the talk)

Examples EFT

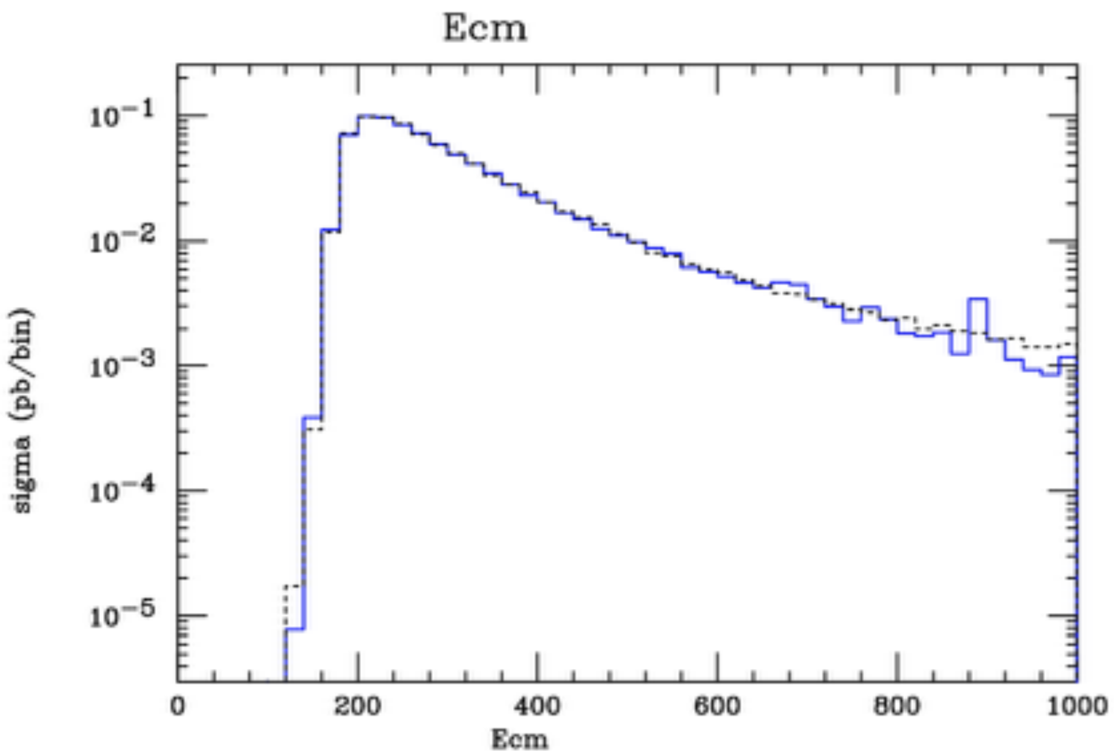
Interference contribution



Re-Weighting (by SM+Interference)



Re-Weighting Limitation



$$\Delta\sigma_{new} = \frac{\sigma_{new}}{\sigma_{old}} \Delta\sigma_{new} + \mathrm{Var}_{wgt}\, \sigma_{old}$$

- statistical uncertainty can be enhanced by the re-weighting
- better to have wgt<1

- You need to have the same phase-space (more exactly a subset)
- Mass scan are possible only in special case
  - only for internal propagator
  - for small mass variation (order of the width)

Caution

LHE Additional information

Helicity

- Partial helicity distribution are not correct with the full re-weighting

- Solution $$W_{new} = \frac{|M^h_{new}|^2}{|M^h_{orig}|^2} W_{orig},$$

Now the default (@LO)

Leading color information

- modify the shower so not suitable.

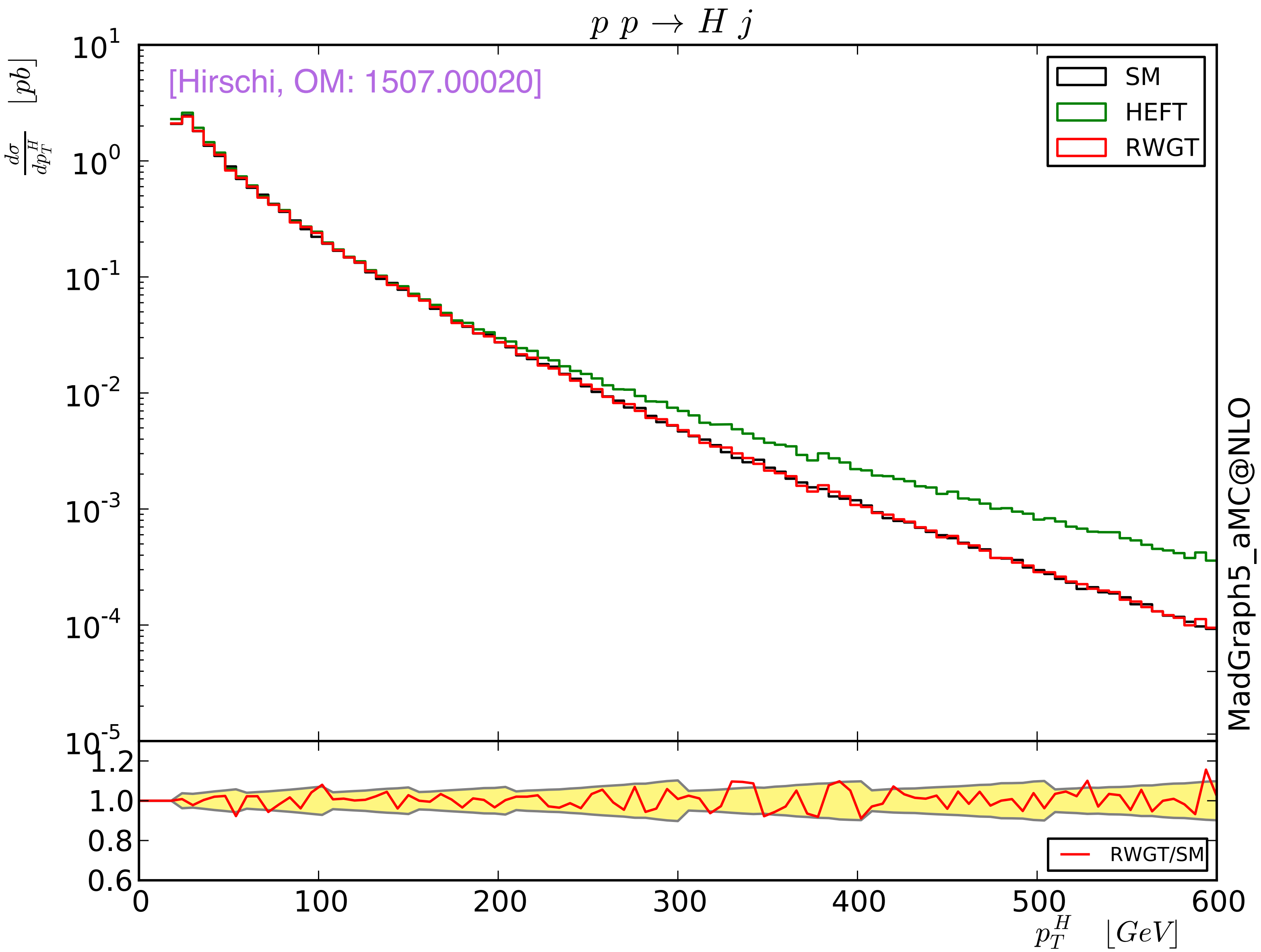
Intermediate particle

- modify the shower so not suitable.

Recent Progress (2.3.3)

1. Include the re-weighting by a given helicity (as default)
2. Allow to change model
   - ➡ "change model NAME"
3. Allow to change process
   - ➡ change process XXX [—add]
   - ➡ allow loop-induced re-weighting
4. easier syntax for scan in re-weighting
   - ➡ set mt scan:[100,200,300]

Loop induced



proc_card

```
import model heft
generate p p > h j
output
launch
```

reweight_card

```
change model loop_sm
change process g g > H g [sqrvirt=QCD]
change process g u > H u [sqrvirt=QCD] —add
change process g u~ > H u~ [sqrvirt=QCD] —add
change process g d~ > H d~ [sqrvirt=QCD] —add
change process g c > H c [sqrvirt=QCD] —add
change process g c~ > H c~ [sqrvirt=QCD] —add
change process g s > H s [sqrvirt=QCD] —add
change process g s~ > H s~ [sqrvirt=QCD] —add
launch
~/Cards/param_card_loop_sm.dat
```

NLO ReWeighting

MC@NLO

$$\frac{d\sigma_{\mathrm{NLOwPS}}}{dO} = \left[d\Phi_m (B + \int_{\mathrm{loop}} V + \int d\Phi_1 MC) \right] I_{\mathrm{MC}}^{(m)}(O)$$

$$+ \left[d\Phi_{m+1} (R - MC) \right] I_{\mathrm{MC}}^{(m+1)}(O)$$

LHE

- "S-events" (which have m body kinematics)
- "H-events" (which have m+1 body kinematics)

Re-Weighting

- "S-events" need to be re-weight by the born/virtual + counter-term
- "H-events" need to be re-weight by the real + counter-term
- The counter-term might not have the same kinematic

NLO Reweighting

LO/Kamikaze Reweighting

- Reweight the S event by the born
- Reweight the H event by the real
- No guarantee of NLO accurate
- available in repolo and MG5_aMC

NLO Reweighting

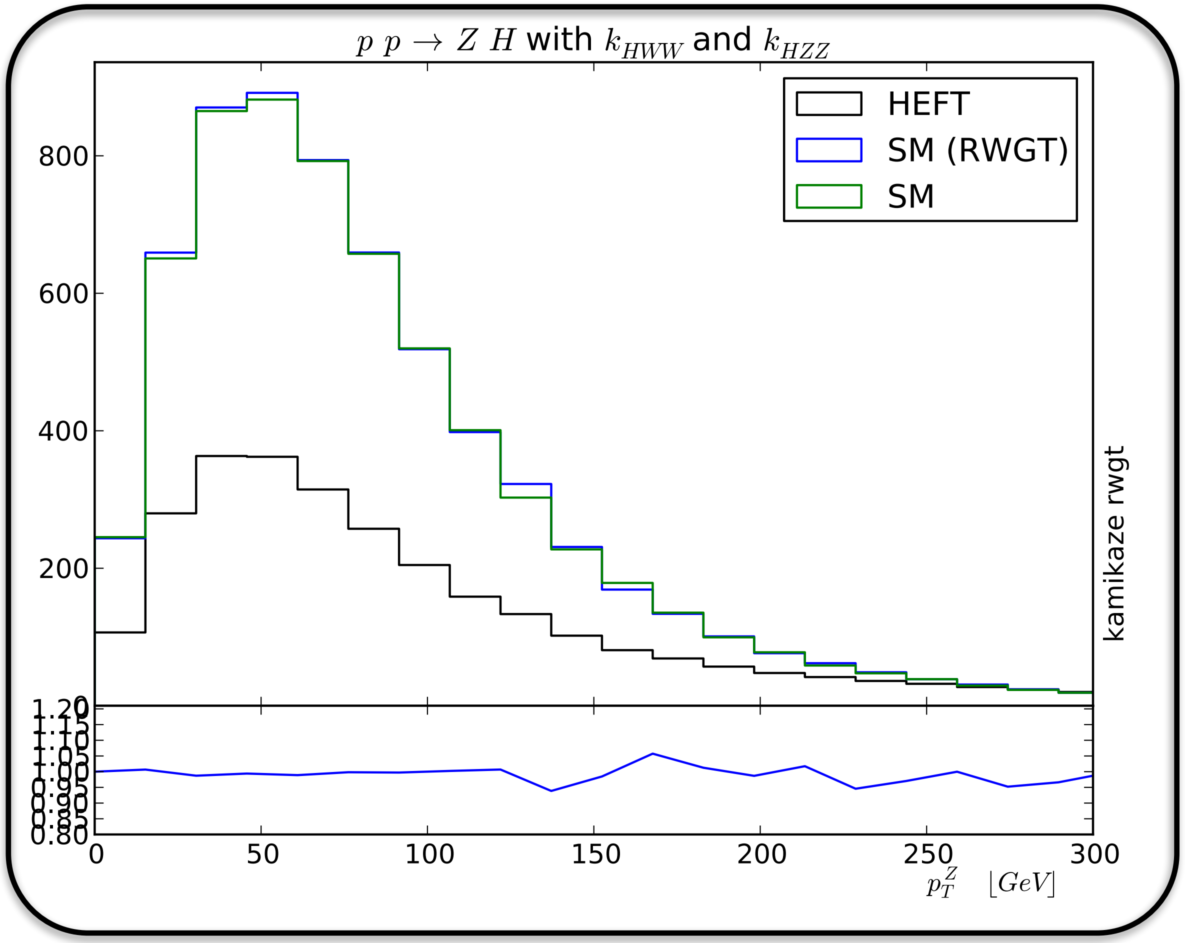
- Keep the kinematics of each counter event
- Reweight each piece accordingly (including the virtual reweighting)
- Recombine to give the weight
- not yet released in MG5_aMC

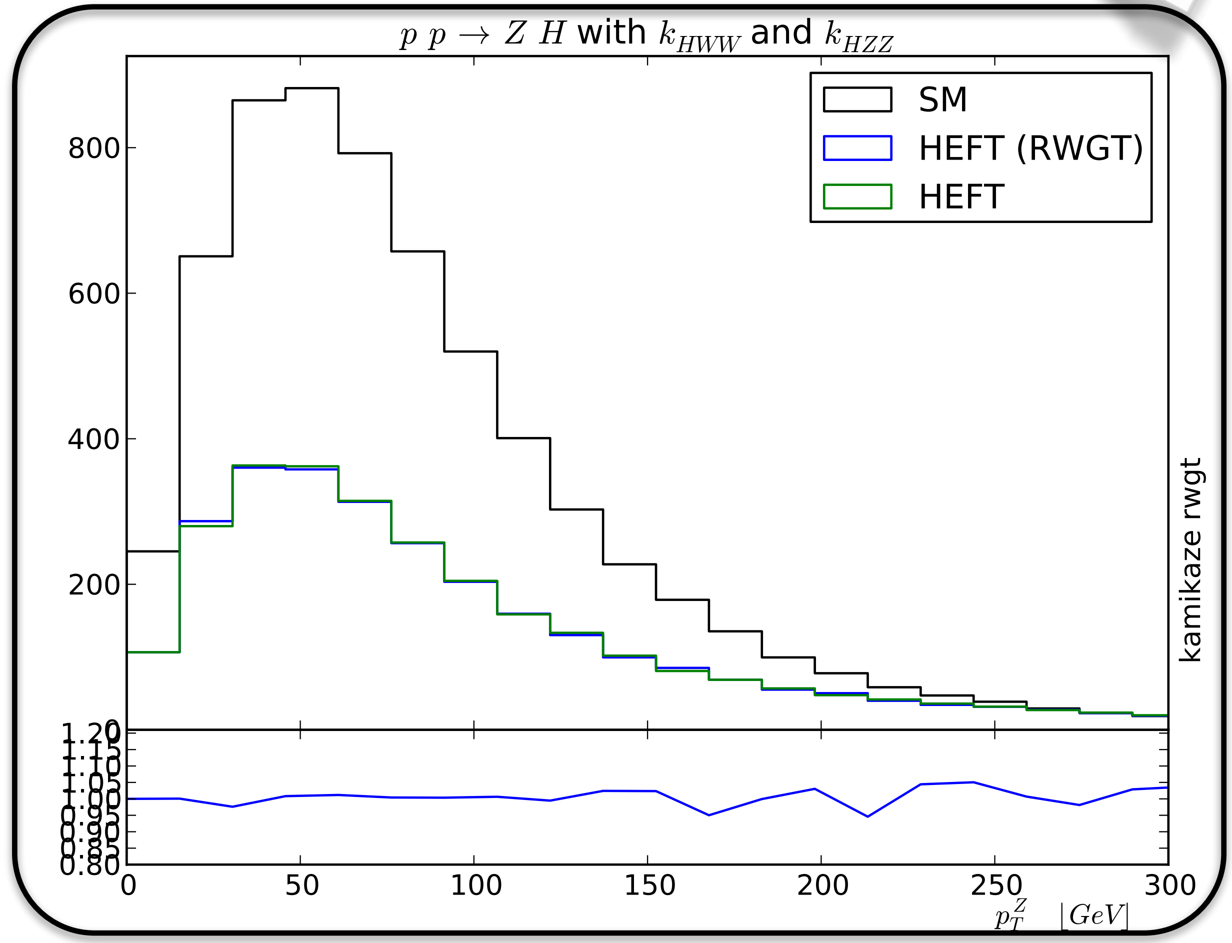
MCFM method

Example @NLO

Preliminary

LO/Kamikaze re-weighting



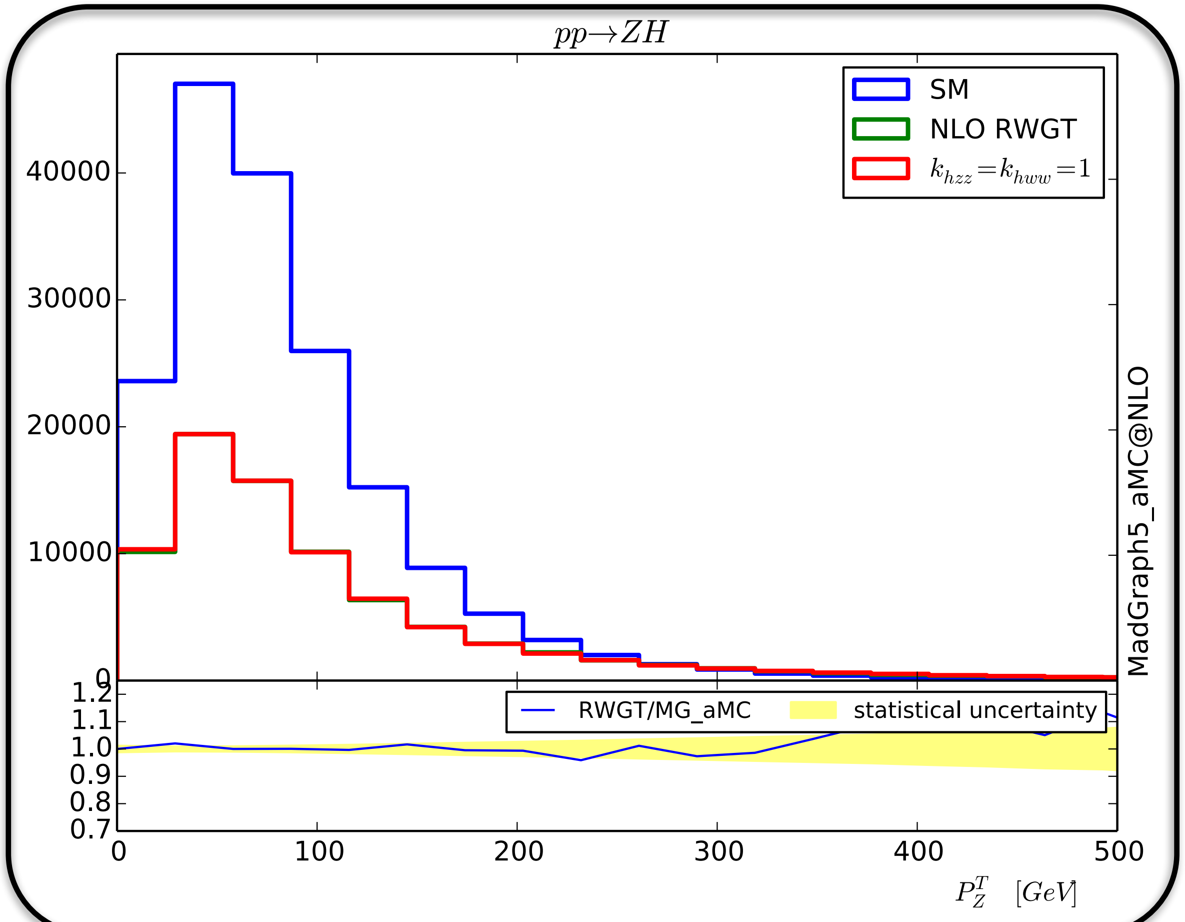


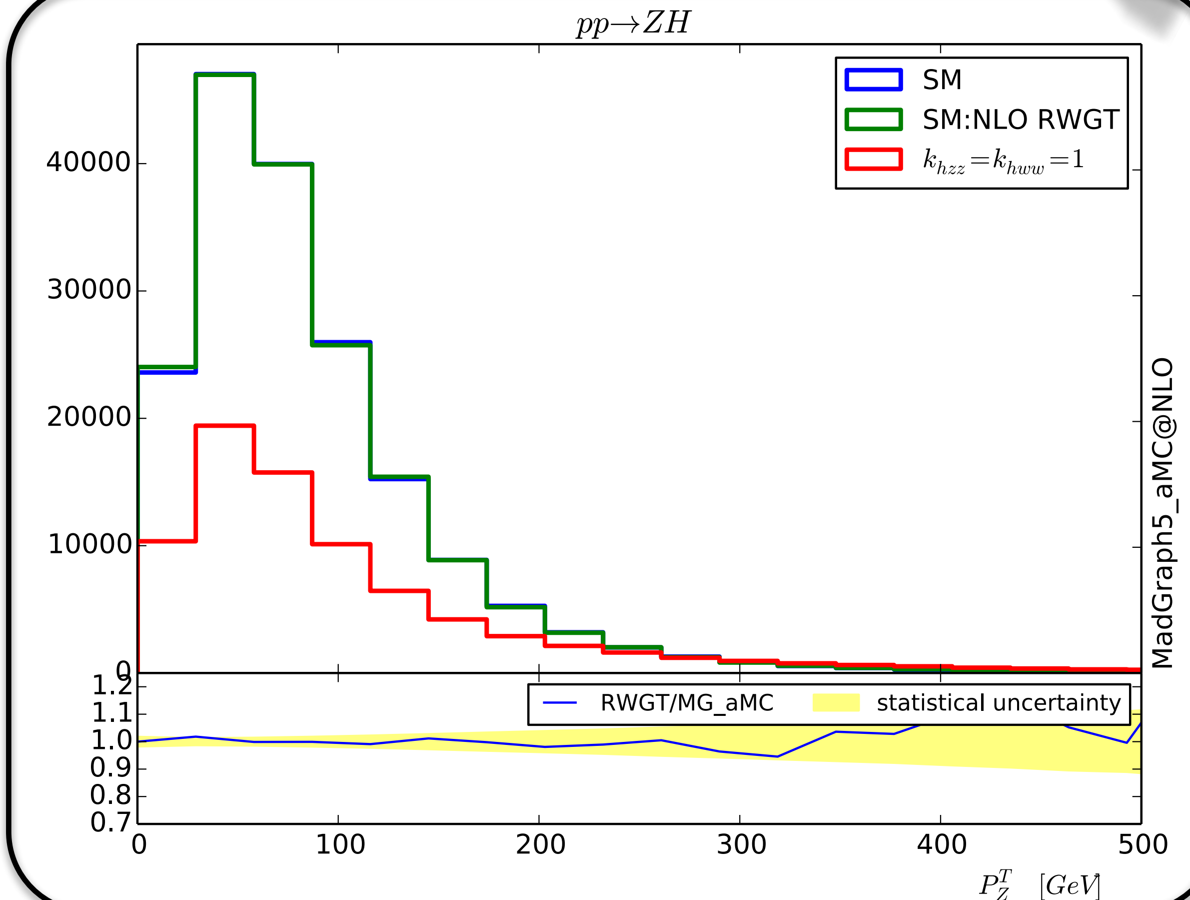
- Works very well for EW EFT
  - Since the QCD/EW effect are factories
  - Same principle as for MadSpin

Example @NLO

Preliminary

Correct NLO re-weighting





- Works as well
- Ensure NLO accuracy
  - Usual comment on Reweighting error

NLO Error

Durham University

Preliminary

Naively

$$\Delta\sigma_{new} = \frac{\sigma_{new}}{\sigma_{old}}\Delta\sigma_{new} + \mathrm{Var}_{wgt}\,\sigma_{old}$$

Problem

- How to evaluate the variance?
  - ➡ Use the global weight
  - ➡ Make one variance for the each pieces? and multiply by the relative contribution
- Virt-tricks handling
  - ➡ MG5_aMC uses sometimes an approximate to the loop
  - ➡ We correct that by a specific reweighting (B+V) but induces an additional error

Comparison

- **Both works well** for EFT
- NLO ReWeighting is
  - Theoretical **NLO accurate**
  - Requires **larger file** (need the additional information)
  - **Much slower** to run. ~10 times slower than generating the dedicated sample
- LO/Kamikaze Reweighting is
  - **Not NLO** accurate (in general)
  - **Compatible** with **old production** (no need of extra information)
  - **Easier error estimate**

- I Recommend LO/Kamikaze for EFT

Conclusion

- allows to reuse the same shower / event reconstruction -> huge gain in efficiency
- are no bullet proof
  - ➡ additional error
  - ➡ need the same phase-space
  - ➡ some shower related information
- available both for LO and NLO generation
  - ➡ correct NLO reweighting works!
  - ➡ LO reweighting for NLO sample still recommended

Why does it works

without un-weighting

$$\sigma_{orig} = \sum_{i=1}^{N} W^i_{orig},$$
$$= \sum_{i=1}^{N} f_1(x_1^i) \cdot f_2(x_2^i) \cdot |M^i_{orig}|^2 \cdot d\Omega$$

$$\sigma_{new} = \sum_{i=1}^{N} W^i_{new}$$
$$= \sum_{i=1}^{N} f_1(x_1^i) \cdot f_2(x_2^i) \cdot |M^i_{new}|^2 \cdot d\Omega$$
$$= \sum_{i=1}^{N} W^i_{orig} \cdot \frac{|M^i_{new}|^2}{|M^i_{orig}|^2}$$

unweighting case

unweighted sample

$$\begin{aligned}\sigma_{orig} &= \sum_{i=1}^{N} W^i_{orig}, \\ &= \max_i(W^i_{orig}) \sum_{i=1}^{N} \frac{W^i_{orig}}{\max_i(W^i_{orig})}, \\ &\approx \sum_{i=1}^{N} \max_i(W^i_{orig}) Acc_i\end{aligned}$$

$$\begin{aligned}\sigma_{new} &= \sum_{i=1}^{N} W^i_{new}, \\ &= \max_i(W^i_{orig}) \sum_{i=1}^{N} \frac{W^i_{new}}{\max_i(W^i_{orig})}, \\ &= \max_i(W^i_{orig}) \sum_{i=1}^{N} \frac{W^i_{new}}{W^i_{orig}} \frac{W^i_{orig}}{\max_i(W^i_{orig})}, \\ &\approx \sum_{i=1}^{N} \max_i(W^i_{orig}) Acc_i \cdot \frac{|M_{new}|^2}{|M_{orig}|^2}\end{aligned}$$

Why does it work

$$\sigma^h_{orig} = \sum_{i=1}^{N} W^i_{orig} P^i_{h,orig},$$
$$= \sum_{i=1}^{N} W^i_{orig} \frac{|M^h_{orig}|^2}{\sum_{\tilde{h}} |M^{\tilde{h}}_{orig}|^2},$$

$$\sigma^h_{new} = \sum_{i=1}^{N} W^i_{new} P^i_{h,new},$$
$$= \sum_{i=1}^{N} W^i_{new} \frac{|M^h_{new}|^2}{\sum_{\tilde{h}} |M^{\tilde{h}}_{new}|^2},$$
$$= \sum_{i=1}^{N} W^i_{orig} \frac{\sum_{\tilde{h}} |M^{\tilde{h}}_{new}|^2}{\sum_{h'} |M^{h'}_{orig}|^2} \frac{|M^h_{new}|^2}{\sum_{\tilde{h}} |M^{\tilde{h}}_{new}|^2},$$
$$= \sum_{i=1}^{N} W^i_{orig} \frac{1}{\sum_{h'} |M^{h'}_{orig}|^2} \frac{|M^h_{new}|^2}{1},$$
$$= \sum_{i=1}^{N} W^i_{orig} \frac{|M^h_{orig}|^2}{\sum_{h'} |M^{h'}_{orig}|^2} \frac{|M^h_{new}|^2}{|M^h_{orig}|^2},$$
$$= \sum_{i=1}^{N} W^i_{orig} P^i_{h,orig} \frac{|M^h_{new}|^2}{|M^h_{orig}|^2}.$$