MadSpin

ERC miniworkshop

December 17, 2012

Pierre Artoisenet
NIKHEF

Who ?

- Pierre Artoisenet
- Rikkert Frederix
- Olivier Mattelaer
- Robbert Rietkerk

arXiv:1212.3460

Problem statement

- consider the generation of NLO events involving heavy resonances, e.g. p p > t t~ H

- procedure to generate the decay of the heavy resonances, in an efficient, accurate and generic way ?

Options for the decay

Simplest solution: let the parton shower do the decay

- no use of the production matrix elements
- spin correlation effects are lost
- very fast, but rather inaccurate in some cases

Complex solution: generate the process with only stable particles (ex: p p > l+ l- vl vl~ b b~)

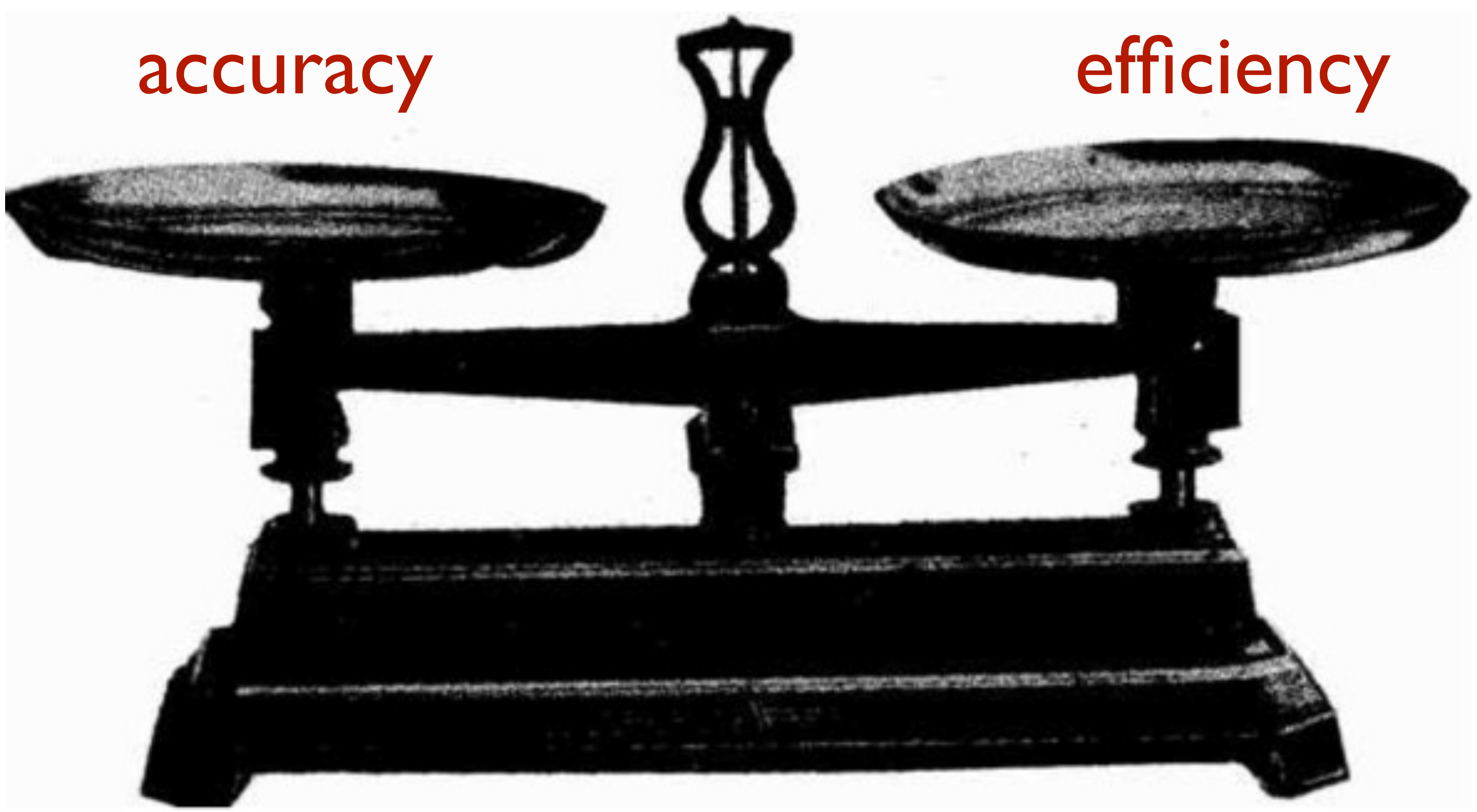
- include spin correlation effects, off-shell effects, non-resonant contributions ...
- requires complex mass scheme (or something similar) to deal with the intermediate resonances
- very accurate, but computationally very expensive

(needed for events away from the resonance region)

Options for the decay

Is there an intermediate solution ?

- retain spin correlation effects & off-shell effects to a good accuracy,
- efficient generation of unweighted events



Intermediate solution

Frixione, Laenen, Motylinski, Webber

- generate NLO events keeping the resonances on-shell without the decay
- read the event file before the shower
- generate the virtuality of each resonance and reshuffle the momenta
- generate the kinematics of the decay
- reweight the event by the ratio $|M_{prod+decay}|^2/|M_{prod}|^2$

  or do secondary unweighting:

  keep generating decay configurations until

$$|M_{prod+decay}|^2/|M_{prod}|^2 > Rand() \times \left(|M_{prod+decay}|^2/|M_{prod}|\right)_{max}$$

Solution

Matrix elements:

- use tree-level matrix elements to calculate the weight of a decay configuration

  for H events: use the "real emission" matrix elements

  for S events: use the born matrix elements

- generation + evaluation of the matrix elements are fast

  ➜ efficient, spin correlation effects included to a very good accuracy (as we will see later)

Solution

Maximum weight for $|M_{prod+decay}|^2/|M_{prod}|^2$

- the maximum weight is independent of the production event and kinematics Frixione, Laenen, Motylinski, Webber
- estimated numerically by probing the phase space for the decay associated with the first few production events
- this estimate of the maximum weight is then used for the unweighting of the decay configurations for all production events

Generic implementation

PA, Frederix, Mattelaer, Rietkerk

- the code has been implemented in madgraph 5, and the corresponding module is called MADSPIN
- it takes advantage of the user-friendly interface inherent to mg5
- it can be used to generate the decay of any processes of which matrix elements are available in mg5
- it can take as an input any LHE event file, e.g. it can also decay hard events generated by POWHEG (up to a straightforward modification of the banner)

Validation

(1) Finite width effects:

- the Narrow Width Approximation (NWA) is used in the first place so that the generation of the production kinematics is factorized from the decay
- finite width effects are partly restored in the unweighting procedure for the decay

valid approximation ? ➜ comparisons at Leading order (finite width effects/non-resonant contributions are easy to calculate)

Validation

(1) Finite width effects:

example:

(1) p p > [w- > e- ve~][z > mu+ mu-]

with mg5 + MadSpin

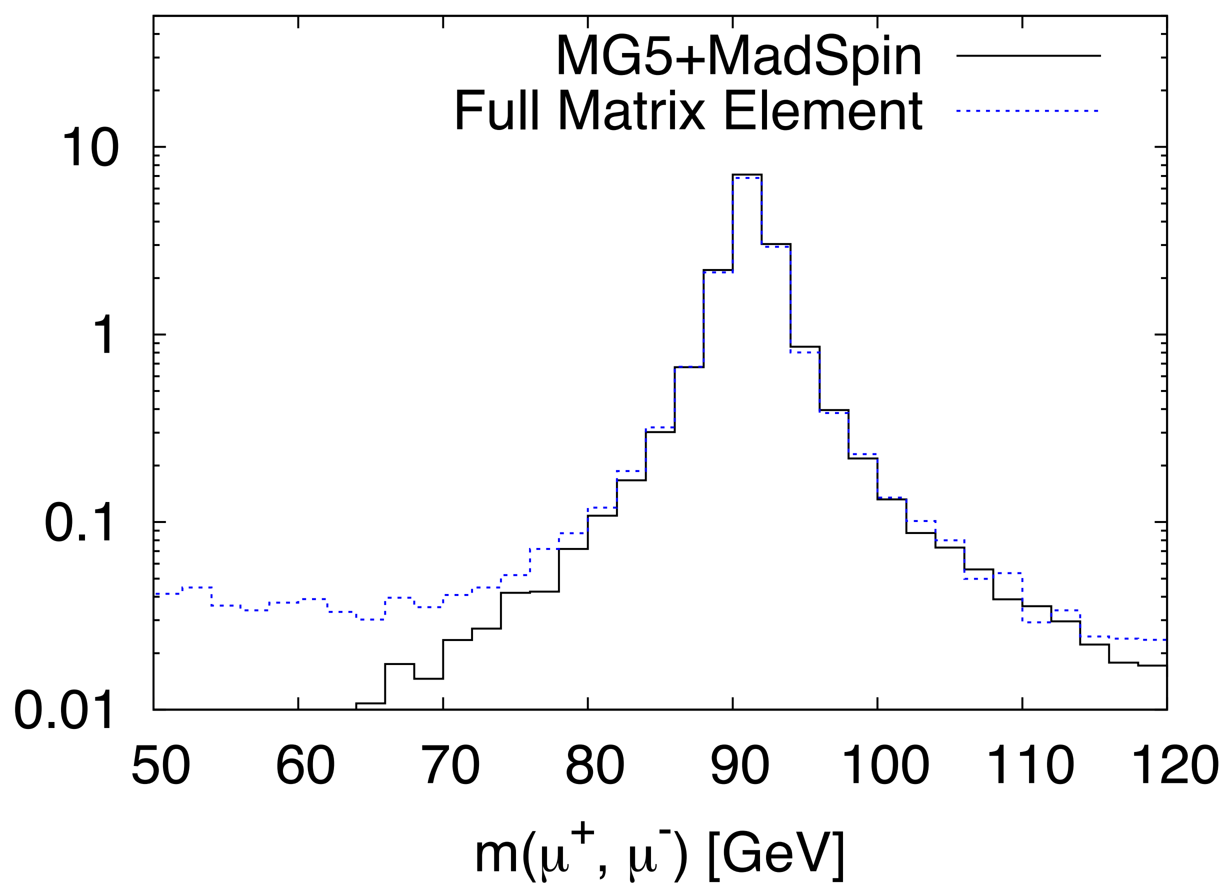
versus

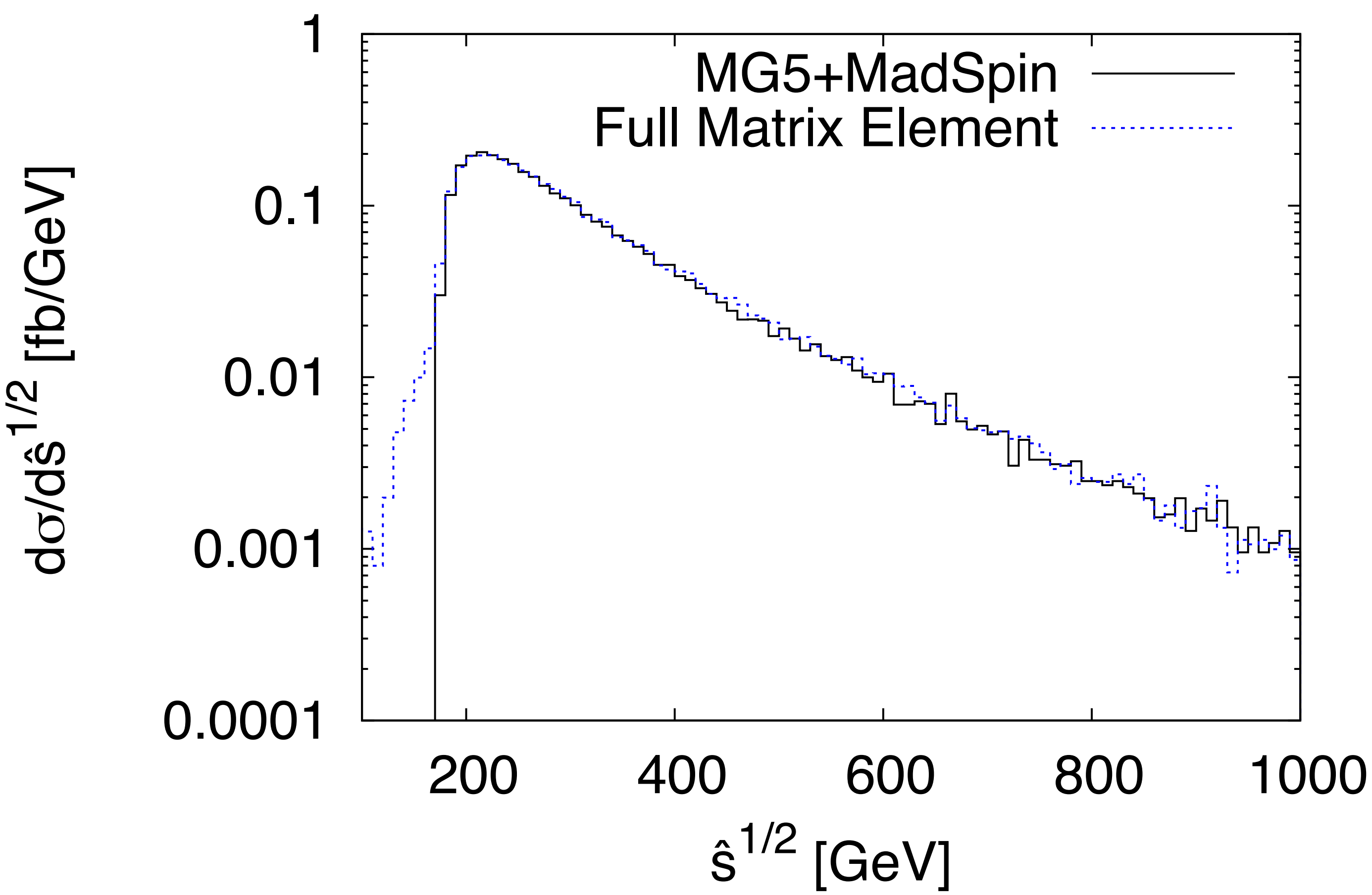
(2) p p > e- ve~ mu+ mu-

with mg5 (no NWA, include non-resonant contributions)

Validation

(1) Finite width effects:





Validation

(2) Spin correlation effects:

- no information from the one-loop amplitude is used to calculate the weight of a decay configuration
- NLO correction in the decay itself is also neglected
- this is the price to pay to preserve the efficiency

valid approximation ? ➜ compare distributions of events against the results from a “predictor” which include spin correlation effects at a higher accuracy

Validation

(2) Spin correlation effects:

example: pp > tt~ @NLO

(1) aMC@NLO+MadSpin+Herwig

- ☑ generation of unweighted events, shower included ➜ very convenient for pheno analysis
- ☐ spin correlations included at tree-level acc. only

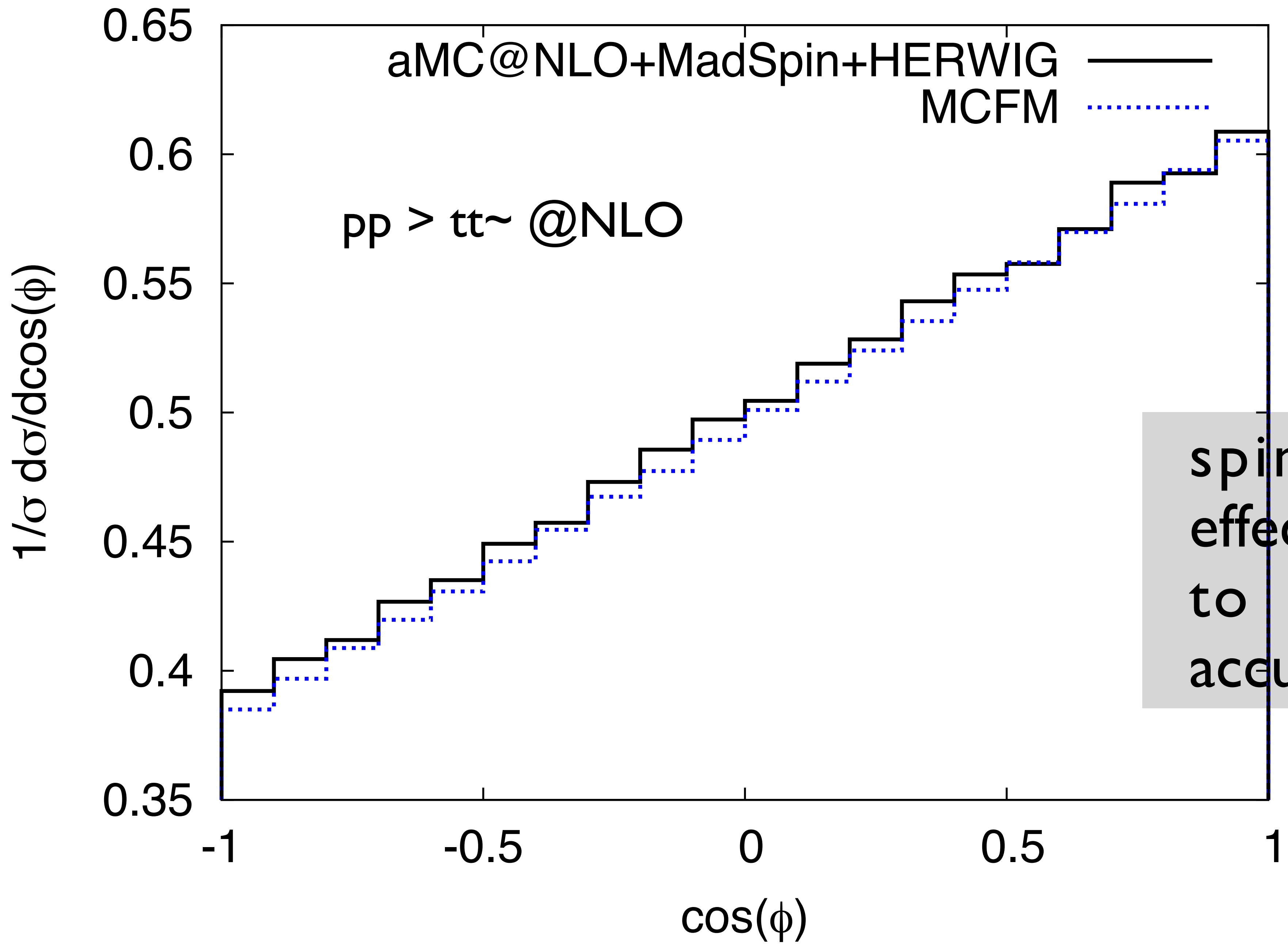
(2) MCFM

- ☐ fixed-order results, no unweighted events
- ☑ virtual corrections in the production and in the decay are included to weight the decay configurations

complementary tools: use predictions from (2) to validate some approximations made in (1)

Validation

(2) Spin correlation effects: example of a validation plot



spin correlation effects reproduced to a very good accuracy

ϕ : angle between the direction of the muon in the t rest frame and the direction of the anti-muon in the anti-t rest frame

Application

process : p p > t t~ H @ NLO

- use aMC@NLO to generate the events without the decay

- decay the events before the shower

- shower the events

Application

standalone mode of madpsin:

```
./madspin
 ...
MadSpin>import event_file.lhe.gz
 ...
INFO: process: p p > t t~ H
 ...
MadSpin>decay t > b w+ , w+ > mu+ vm
MadSpin>decay t~ > b~ w- , w- > mu- vm~
MadSpin>decay h > b b~
MadSpin>launch
```

- you can also use multiparticle tags, e.g. w+ > j j
- in case of identical resonances you can specify distinct decay channels

Application

```
INFO: decay channels for w+ :
INFO:          BR                       d1   d2
INFO:     1.111202e-01                  vm   mu+
INFO:     1.110388e-01                  vt   ta+
INFO:     1.111202e-01                  ve   e+
INFO:     3.333605e-01                  u    d~
INFO:     3.333605e-01                  c    s~
INFO:
INFO: decay channels for t :
INFO:          BR                       d1   d2
INFO:     1.000000e+00                  w+   b
```

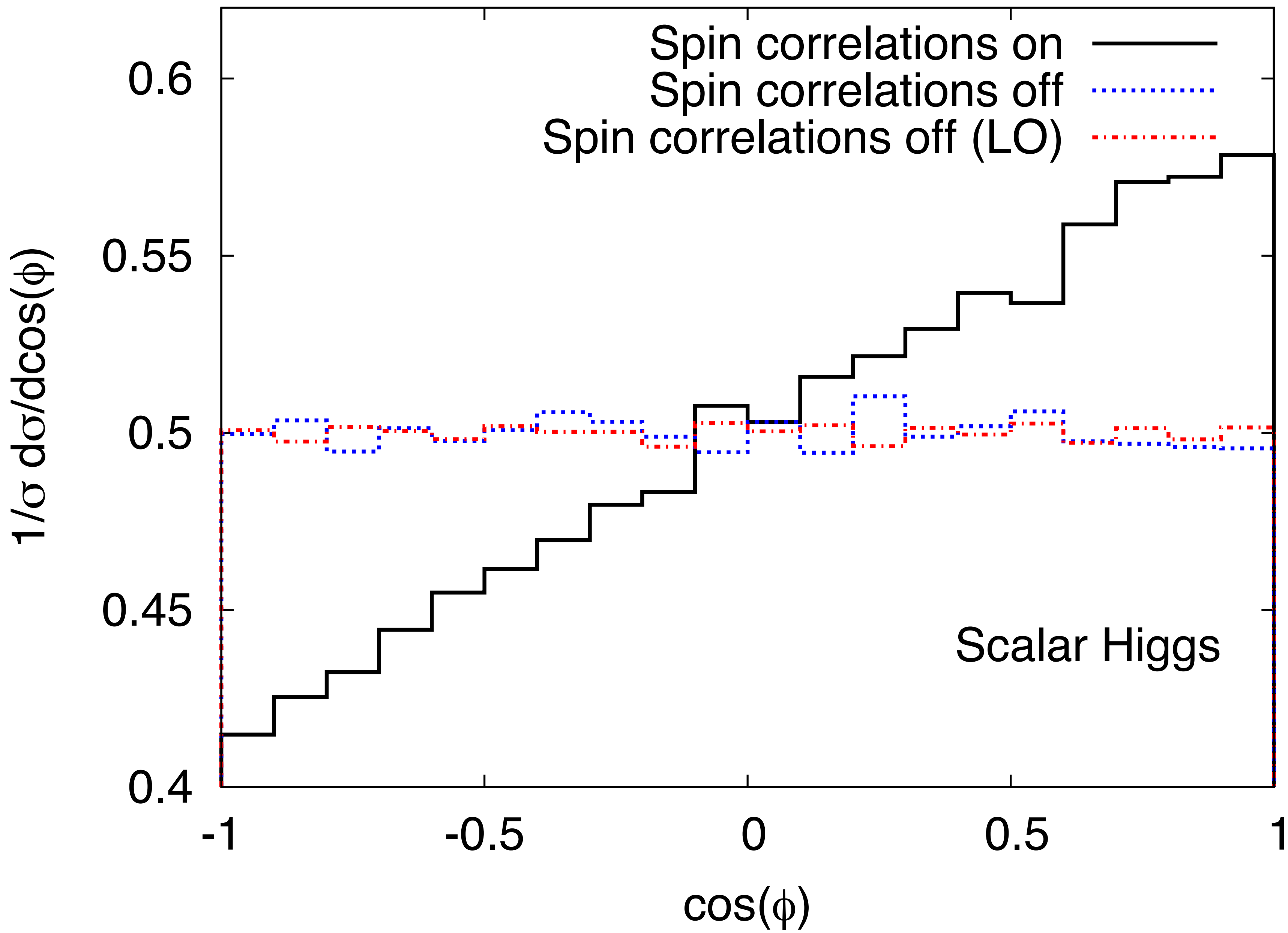
- branching fractions are automatically calculated at LO (analytic formulae or numerical estimates)
- if several decay channels (multi-particle tags), each channel is weighted by the proper (LO) branching fraction

Application

```
INFO: Total number of events: 1000
INFO: Average number of trial points
per production event: 5.607
INFO: Number of subprocesses 8
INFO: Decayed events have been written in
event_file_decayed.lhe.gz
```

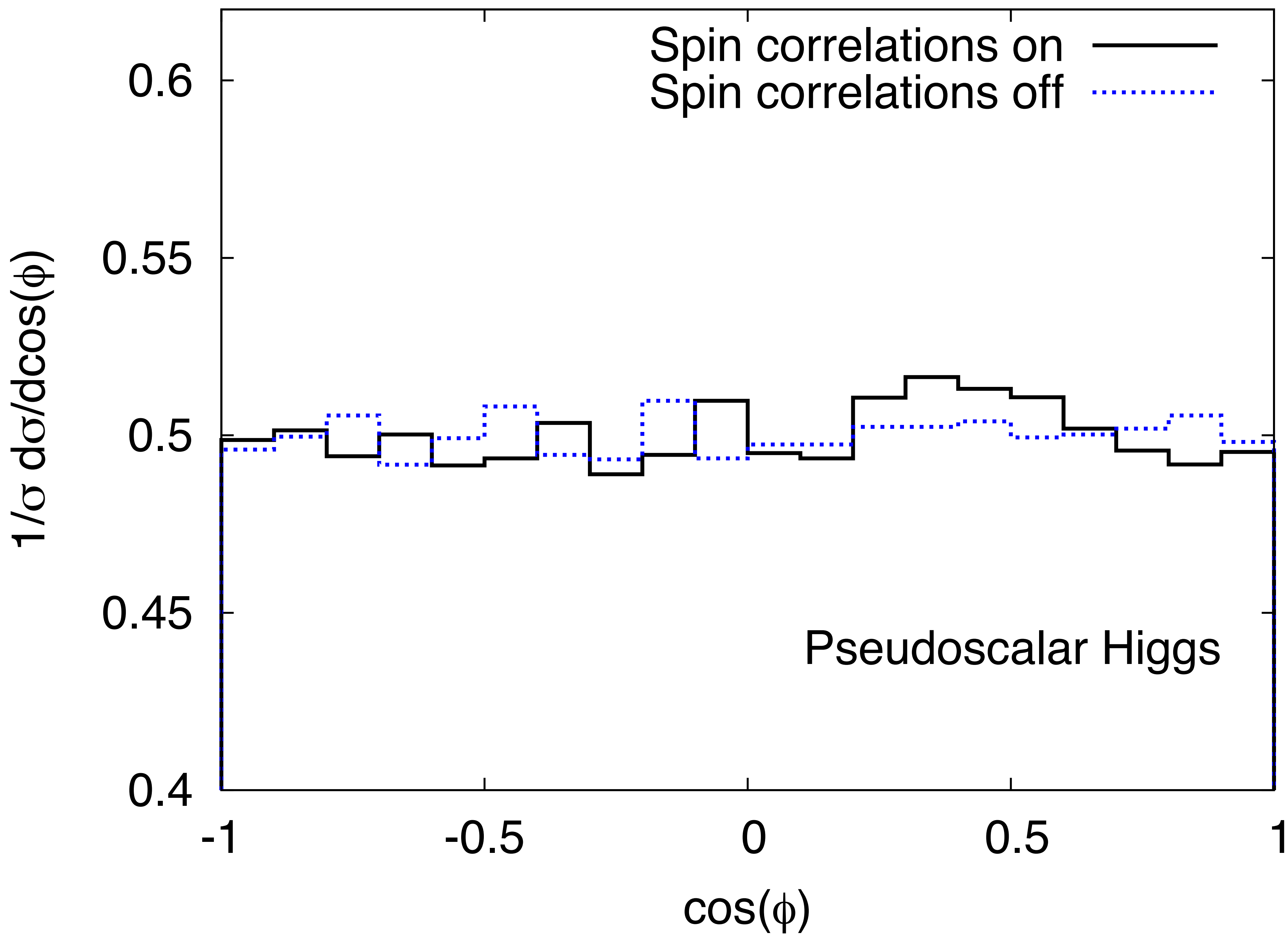
Application

- $\cos\phi$ distribution, H = scalar



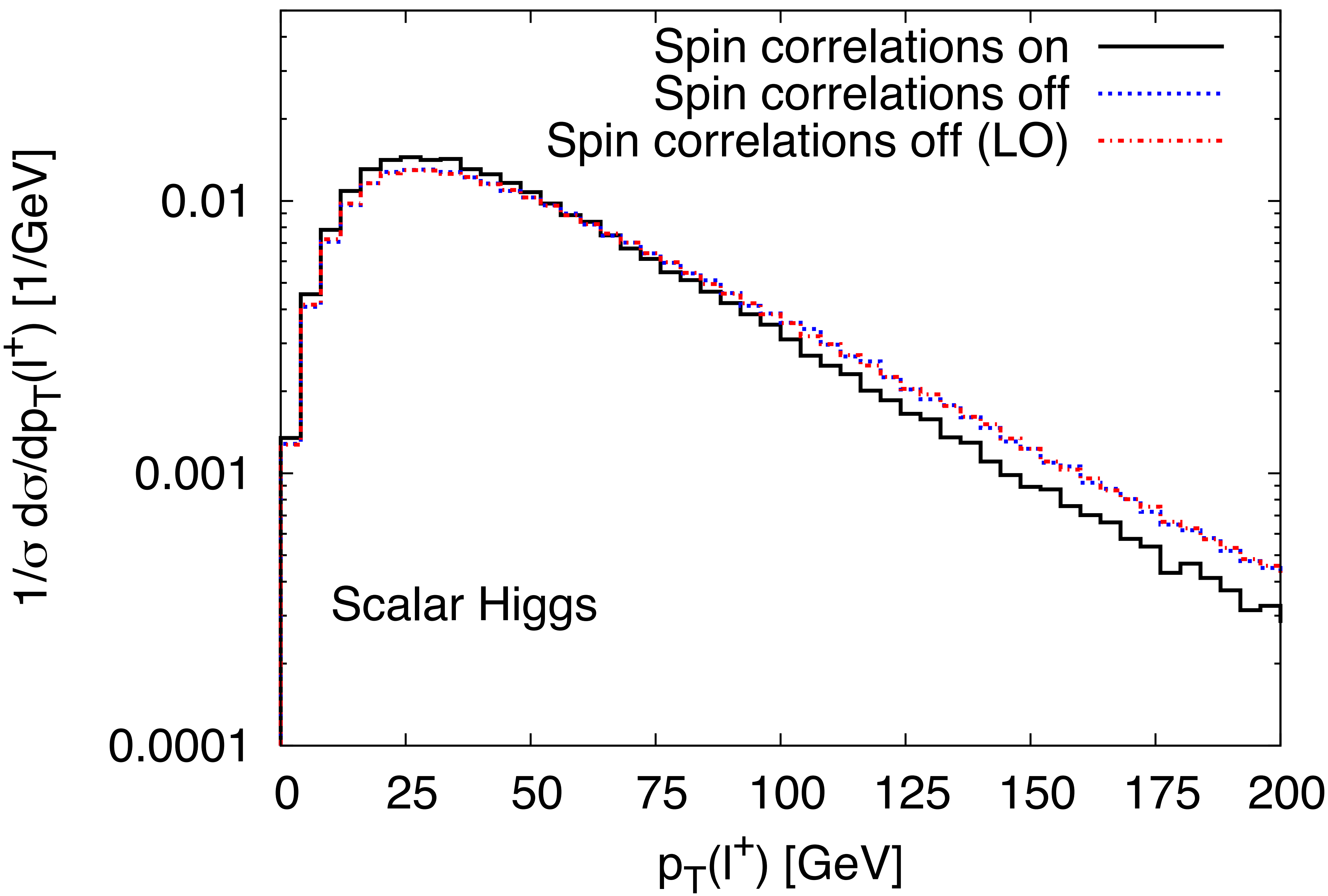
Application

- $\cos\phi$ distribution, H = pseudo scalar



Application

- pT distribution of the positively-charged lepton



possible improvements

- grouping of matrix elements into subprocesses

already optimized in the decay, but not yet optimized for the production

ex: p p > w+ j j

```
INFO: Total number of events: 1000
INFO: Average number of trial points per production event: 6.803
INFO: Number of subprocesses 54
```

possible improvements

- improving the integration techniques

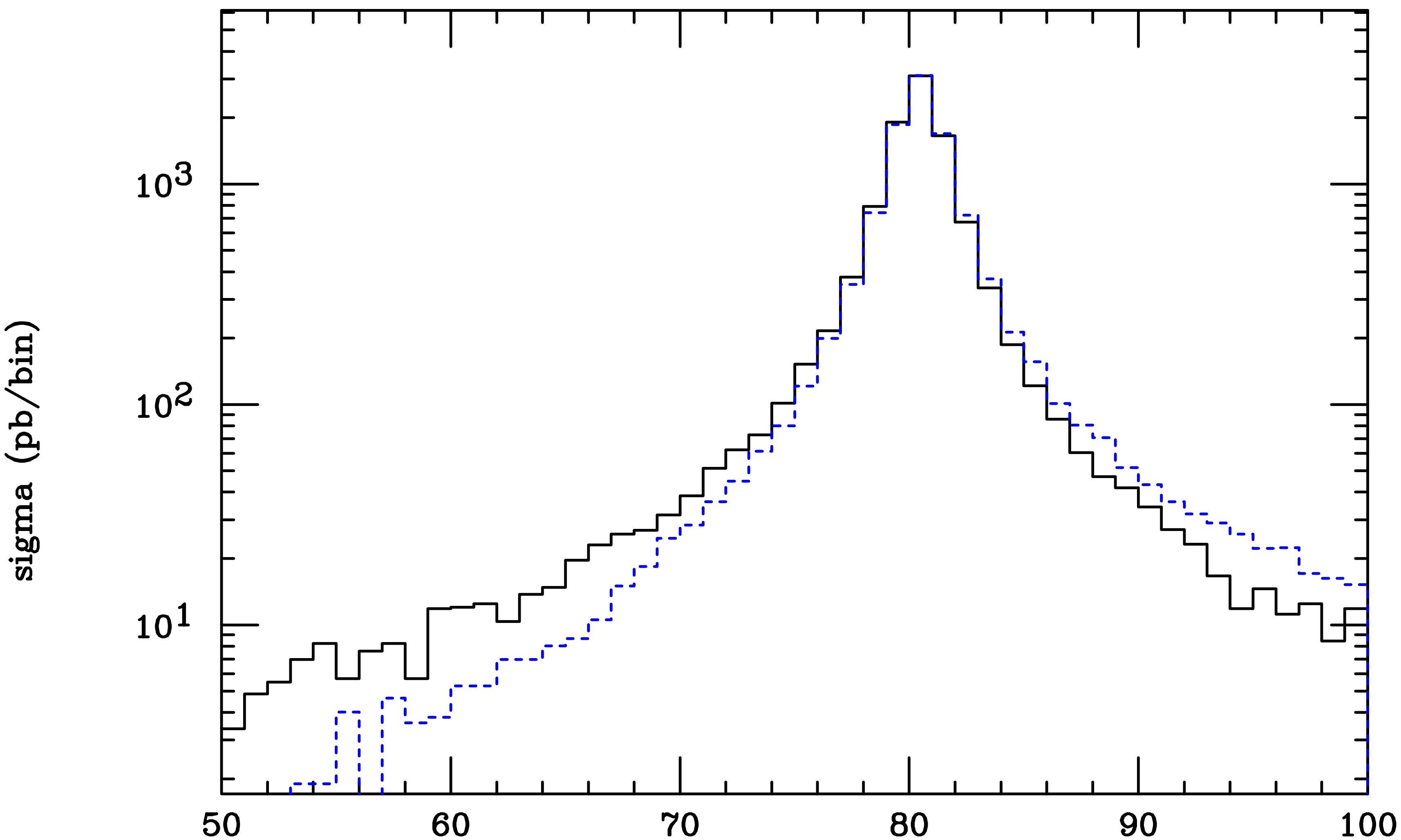
currently: simple Monte Carlo integration, not adaptive (no grid)

ex: p p > h , h > ZZ > 4 leptons   [mh = 125 GeV]

possible improvements

- accounting for the PDF weight

may be important for 2 > 1 processes, e.g. p p > w



Conclusion

- MadSpin is a new tool to handle the decay of heavy resonances
- it is implemented in the madgraph5 framework, and hence takes advantage of the mg5 user-friendly interface and flexibility
- efficient way to generate unweighted events, also shows a good accuracy (validated for top pair and single top production)
- the paper is out, and the code is now integrated the in aMCatNLO code