The POWHEG generator for Heavy Flavour production

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Outline

- Basics
- The POWHEG method
- Results for top

How to use it

Open the URL `http://moby.mib.infn.it/~nason/POWHEG/`

Open the `HeavyQuarks` directory. Content:

`AAAreadme`

`AAAreadme-Patches`

`POWHEG-hvq-patch1`

`POWHEG-hvq-patch2`

`POWHEG-hvq-patch3`

`POWHEG-hvq.tar.gz`

Download and execute `AAAreadme-Patches`, or read through it and follow the instruction.

The manual:

arXiv:0707.3081 The POWHEG-hvq manual version 1.0, (Frixione,Ridolfi,P.N.)

The paper:

JHEP 0709:126,2007 (Frixione,Ridolfi,P.N.)

For problems: mail to Paolo.Nason@mib.infn.it

Capabilities

- Generates heavy quark pair production events at NLO accuracy: $c\bar{c}$, $b\bar{b}$, $t\bar{t}$. Top quarks can be decayed, including spin correlations

- All events have weight 1.

- Can be used in conjunction with any shower Monte Carlo that complies with the Les Houches interface for user processes (all modern ones).
  Thus: `HERWIG`, `HERWIG++`, `PYTHIA`, `PYTHIA++`, `SHERPA`, etc.
  Example of interface to `PYTHIA` and `HERWIG` are explicitly provided.

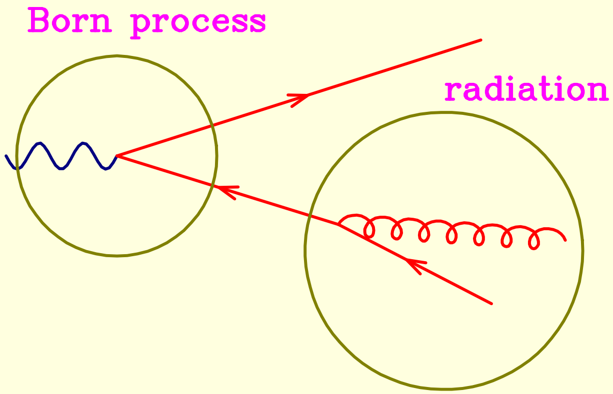
- Events can be written to a file, according to the Les Houches standard, or it can be directly linked to the Monte Carlo (at least for the fortran ones)

- Uses its own pdf package, or it can be interfaced to `LHAPDF`.

How does it work: the POWHEG method

NLO accuracy is achieved by generating the hardest radiation first, at NLO accuracy (POWHEG: Positive Weight Hardest Emission Generator)

A standard LO Monte Carlo start a shower with the Born cross section; then computes the probability of radiation from each leg of the process:



Given the Born event, a SMC generates QCD collinear radiation; thus, the Born cross section is really the inclusive cross section, at fixed kinematics for the short distance process. Radiation is generated according to the Sudakov form factor:

$$\Delta_t = \exp\left[-\int_t^{t_{\max}} \frac{dt}{t} \alpha_s(t) P(z)\, dz\, d\phi \right] \quad \text{(no radiation probability)}$$

At LO, inclusive cross section = Born cross section
Also: radiation in the small angle approximation

To go to NLO:

Inclusive cross section $\Longrightarrow$ NLO inclusive cross section. Positive if $\mathrm{NL} < \mathrm{LO}$

$\Phi_n = \text{Born variables}$
$\Phi_r = \text{radiation vars.}$

$$\bar{B}(\Phi_n) = B(\Phi_n) + \underbrace{\left[\overbrace{V(\Phi_n)}^{\text{INFINITE}} + \overbrace{\int R(\bar{\Phi}_n, \Phi_r)\, d\Phi_r}^{\text{INFINITE}} \right]}_{\text{FINITE!}}$$

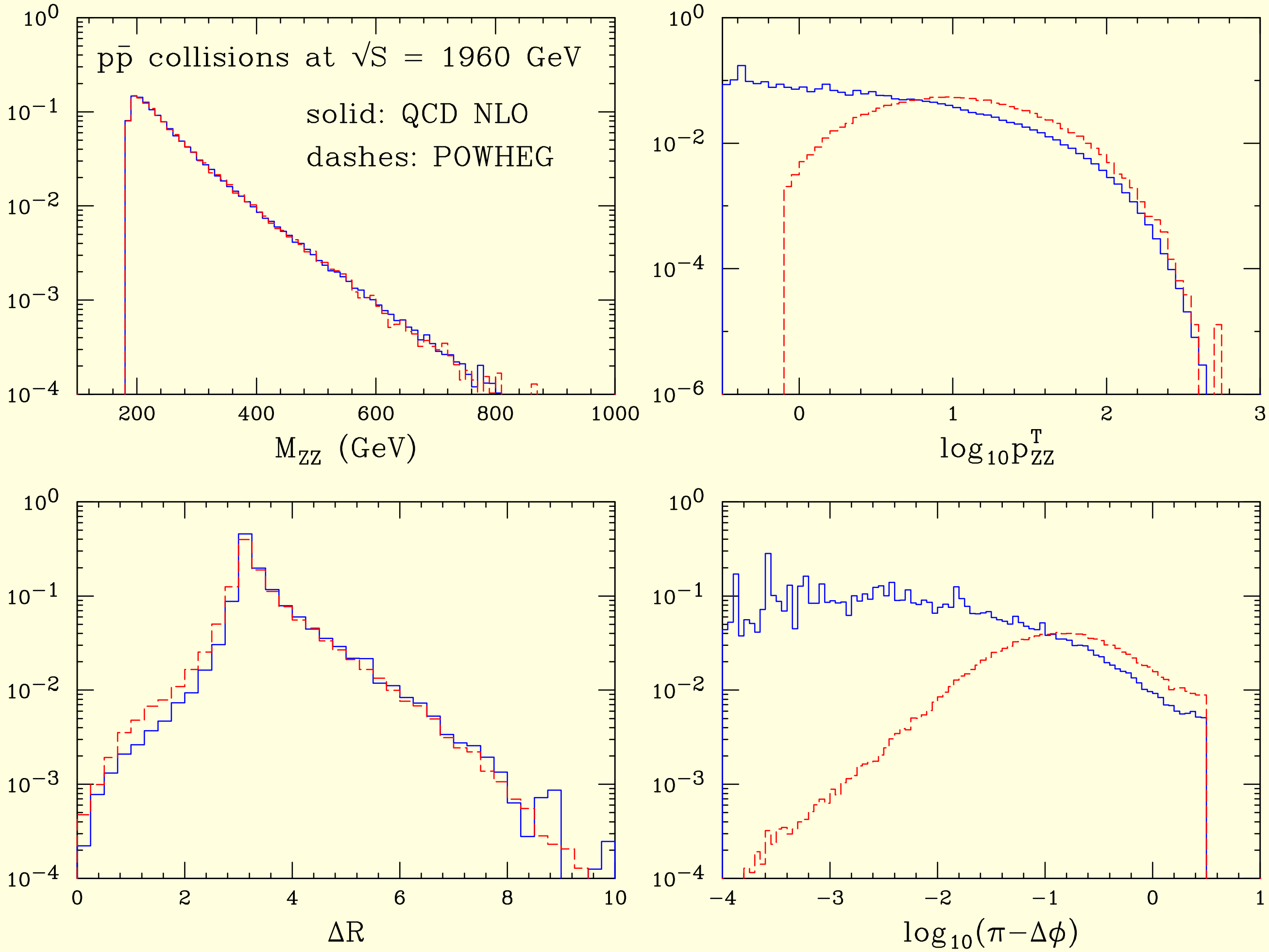
Sudakov form factor for hardest emission built from exact NLO real emission

$$\Delta_t = \exp\left[\underbrace{- \int \theta(t_r - t) \frac{R(\Phi_n, \Phi_r)}{B(\Phi_n)} d\Phi_r}_{\text{FINITE because of } \theta \text{ function}} \right]$$

with $t_r = k_T(\Phi_n, \Phi_r)$, the transverse momentum for the radiation.

The concept: P.N. 2004
General formulation of the method: Frixione,Oleari,P.N. 2007

Effect: smooth smearing of low p_T region, compared to fixed order NLO accurate high p_T region (Shower MC fail there)



Processes implemented in POWHEG

- $hh \to ZZ$ (Ridolfi, P.N., 2006)
- $e^+e^- \to \mathrm{hadrons}$, (Latunde-Dada,Gieseke,Webber, 2006),
  $e^+e^- \to t\bar{t}$, including top decays at NLO (Latunde-Dada,2008),
- $hh \to Q\bar{Q}$ (Frixione, Ridolfi, P.N., 2007)
- $hh \to Z/W$ (Alioli,Oleari,Re,P.N.; Hamilton,Richardson,Tully, 2008;)

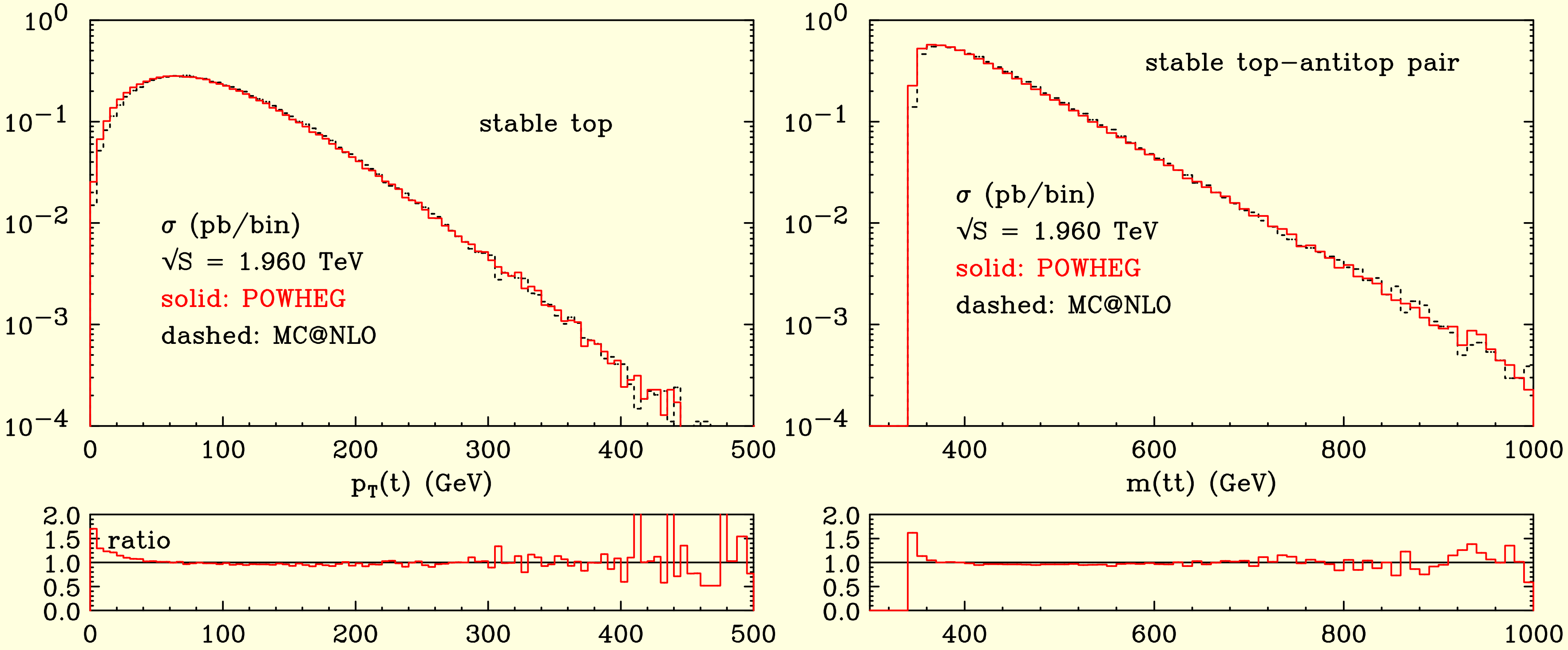
To appear soon:

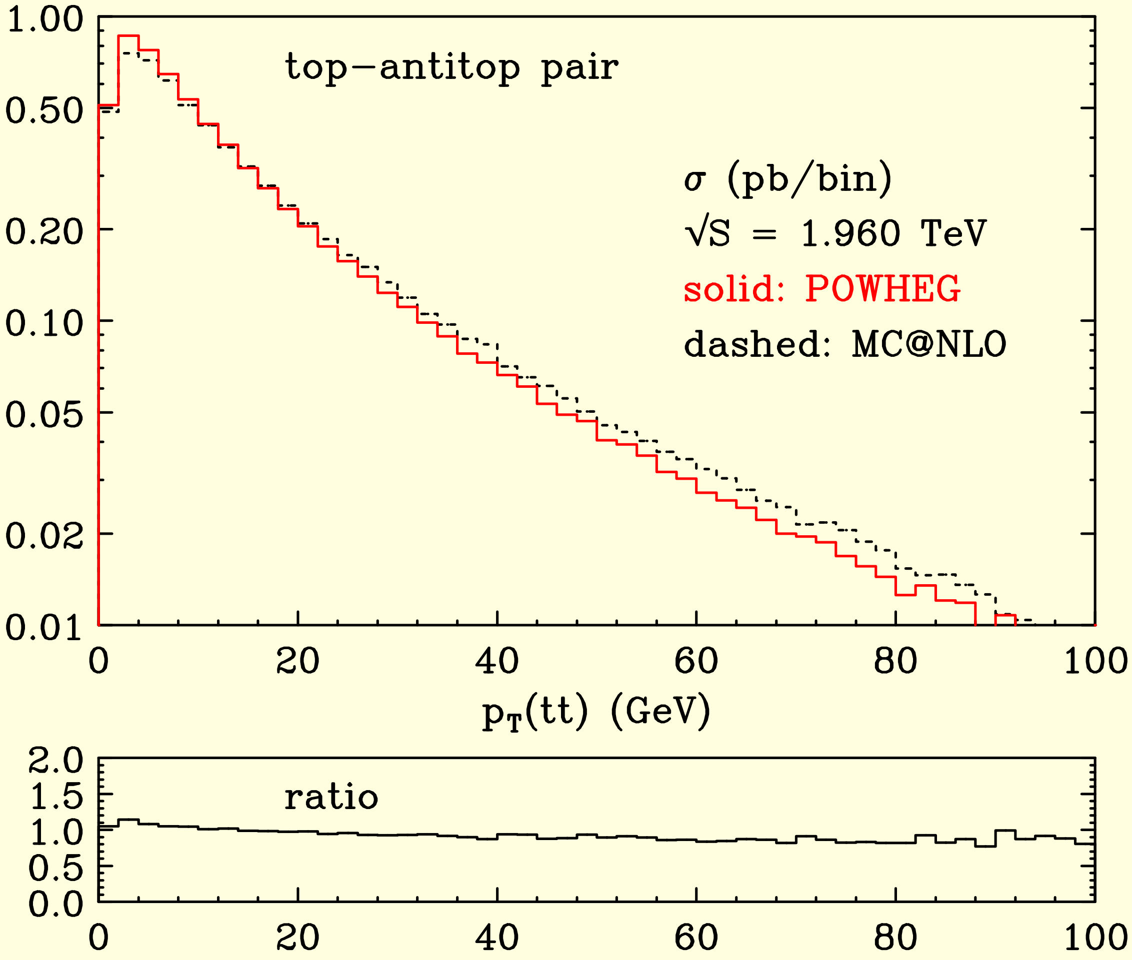
- Higgs production (Alioli,Oleari,Re,P.N.; Hamilton etal)
- Single top production (Alioli,Oleari,Re,P.N.)
- $hh \to Z/W + 1\mathrm{jet}$ (Alioli,Oleari,Re,P.N.)

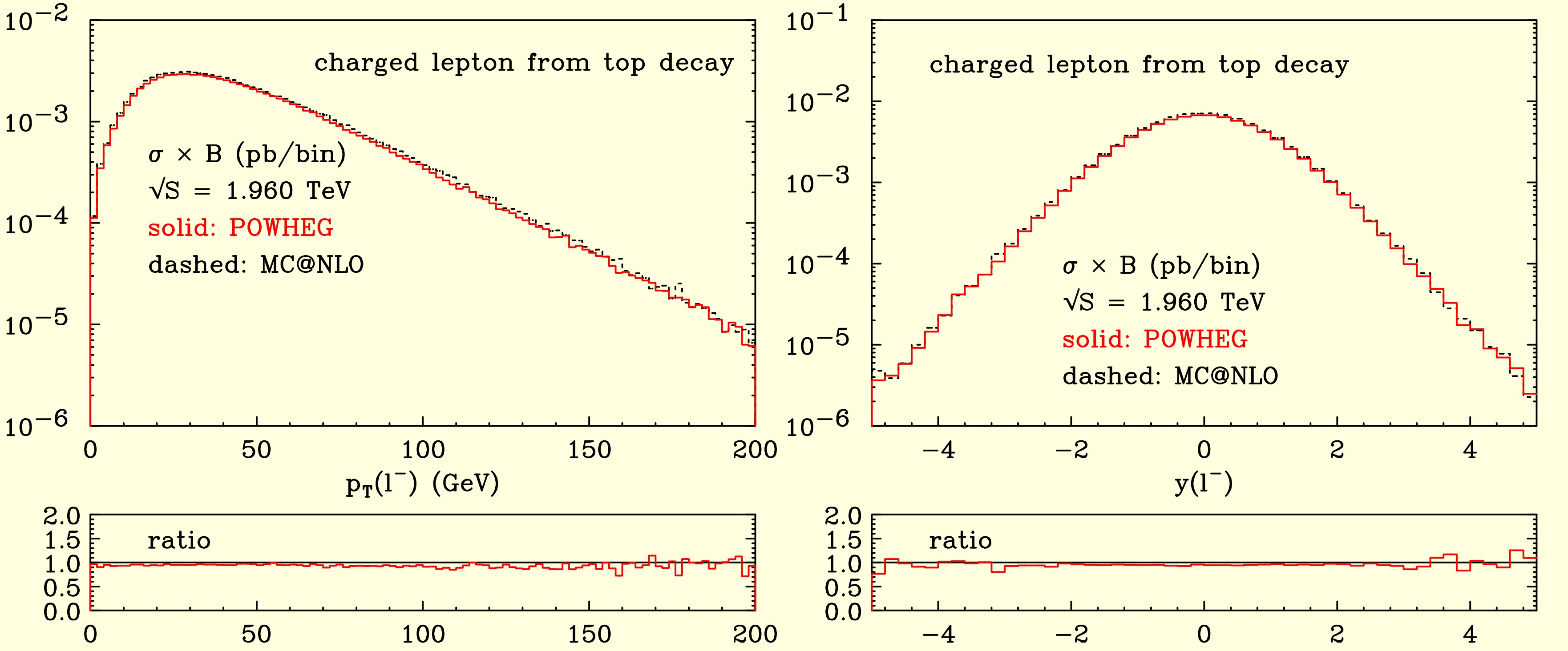
While working on $hh \to Z/W + 1\mathrm{jet}$, we realized that this process is already complex enough, so that a general framework for the implementation of a POWHEG generator for any NLO process can be setup.

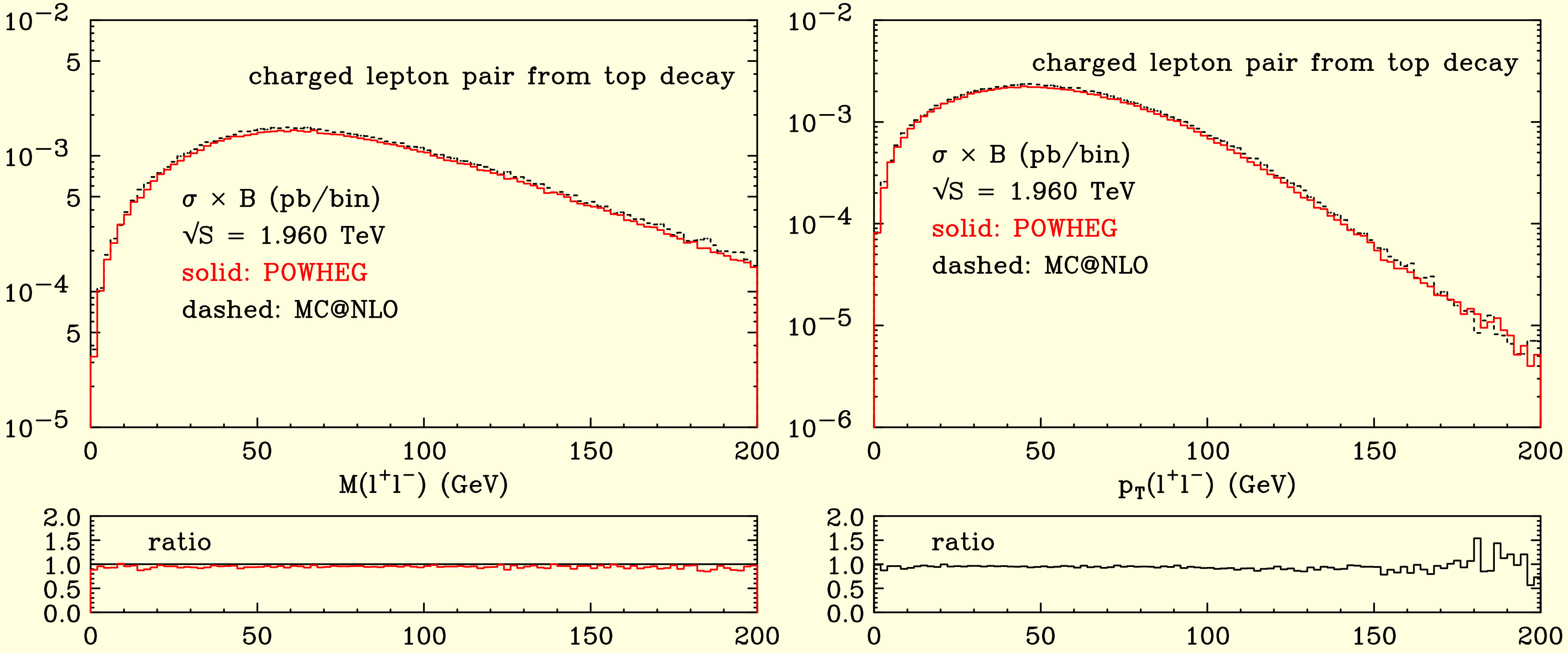
Results: comparison with MC@NLO

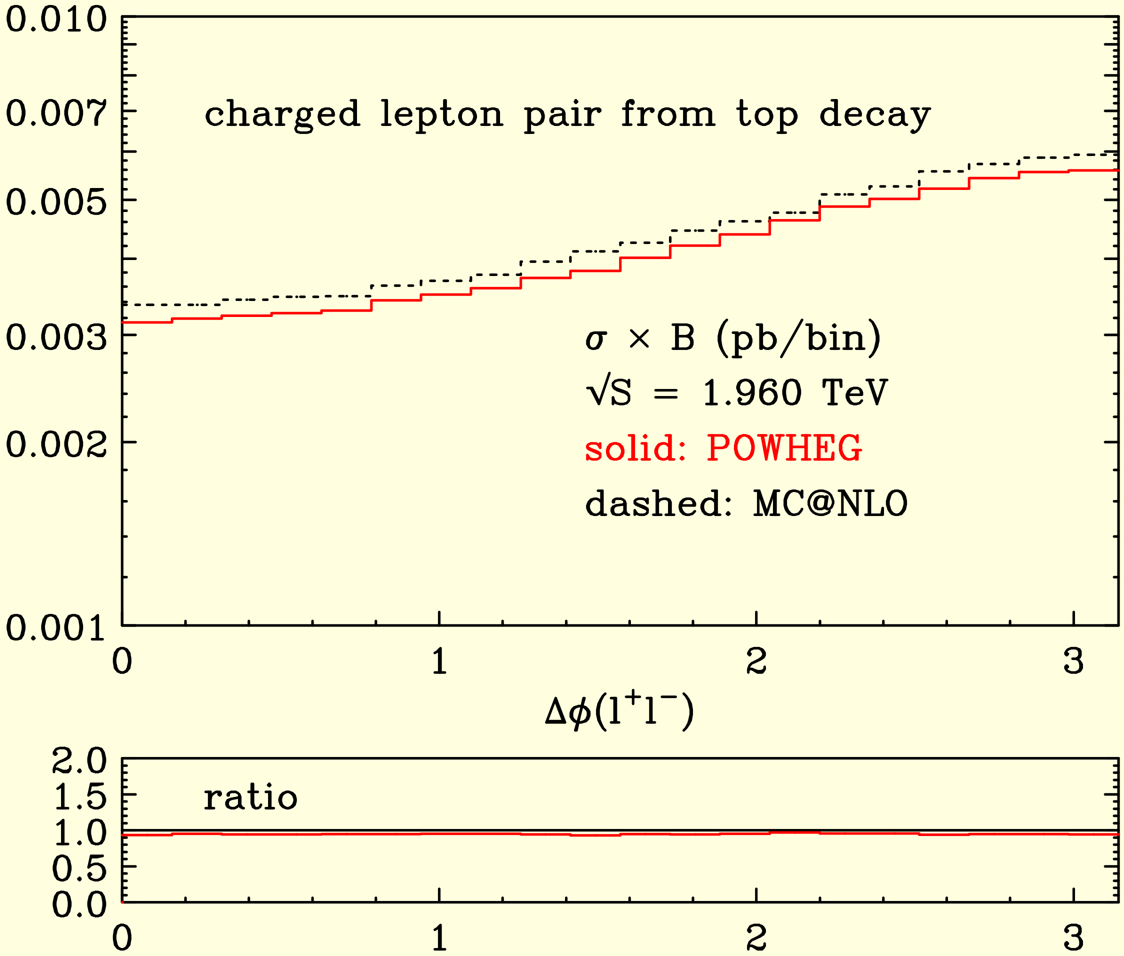
Tevatron




top−antitop pair
σ (pb/bin)
√S = 1.960 TeV
solid: POWHEG
dashed: MC@NLO
1.00
0.50
0.20
0.10
0.05
0.02
0.01
0
20
40
60
80
100
p_T(tt) (GeV)
ratio
2.0
1.5
1.0
0.5
0.0

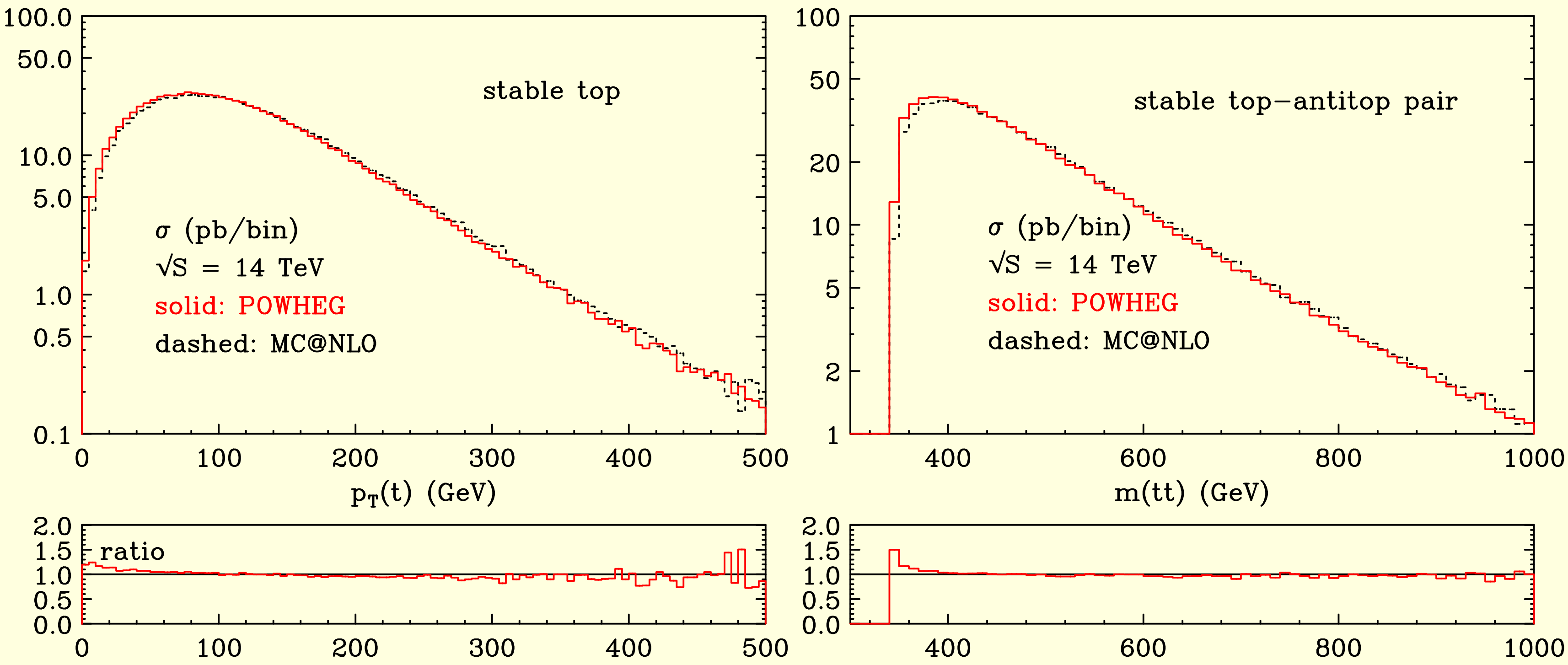

charged lepton from top decay
σ × B (pb/bin)
√S = 1.960 TeV
solid: POWHEG
dashed: MC@NLO
$p_T(l^-)$ (GeV)
ratio
charged lepton from top decay
σ × B (pb/bin)
√S = 1.960 TeV
solid: POWHEG
dashed: MC@NLO
$y(l^-)$
ratio


charged lepton pair from top decay
σ × B (pb/bin)
√S = 1.960 TeV
solid: POWHEG
dashed: MC@NLO
M(l+l−) (GeV)
ratio
charged lepton pair from top decay
σ × B (pb/bin)
√S = 1.960 TeV
solid: POWHEG
dashed: MC@NLO
pT(l+l−) (GeV)
ratio

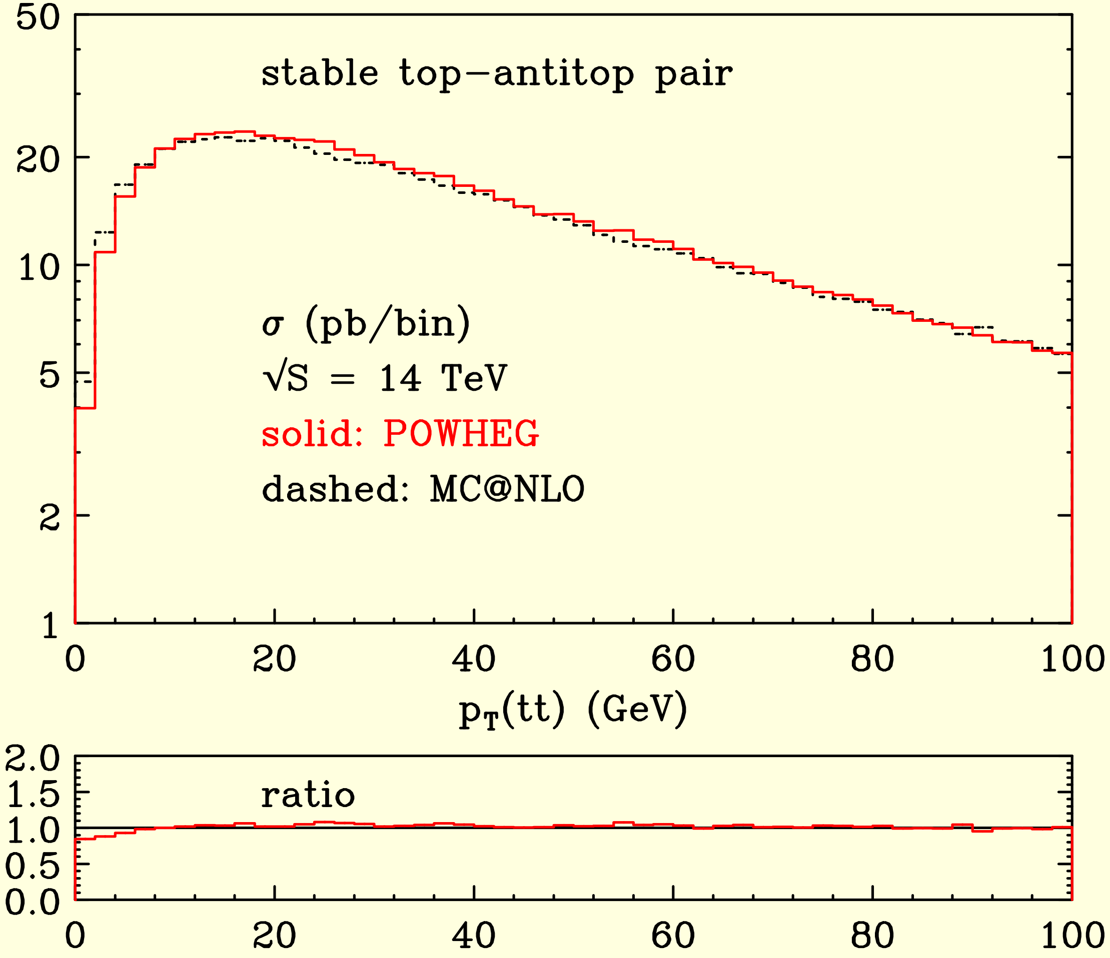


charged lepton pair from top decay
σ × B (pb/bin)
√S = 1.960 TeV
solid: POWHEG
dashed: MC@NLO
0.010
0.007
0.005
0.003
0.002
0.001
0
1
2
3
Δφ(l+l−)
ratio
2.0
1.5
1.0
0.5
0.0

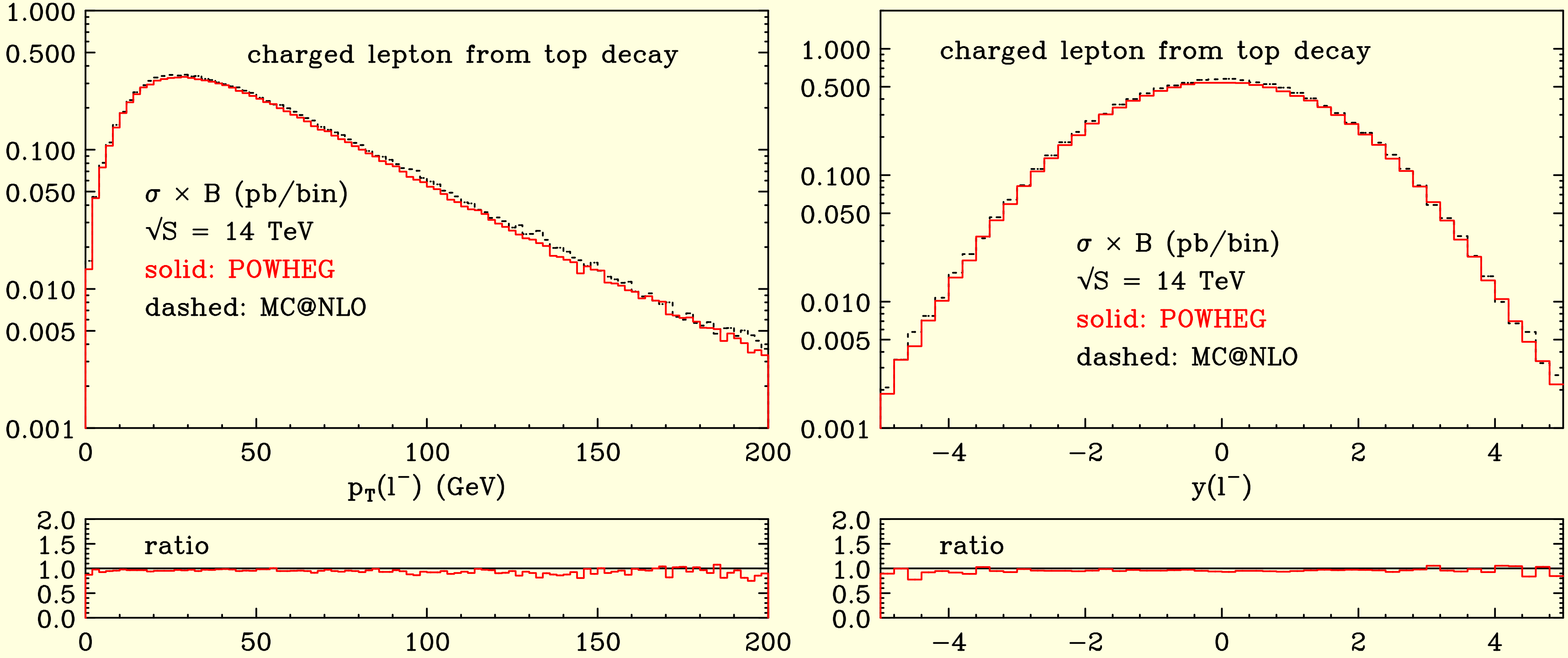
LHC

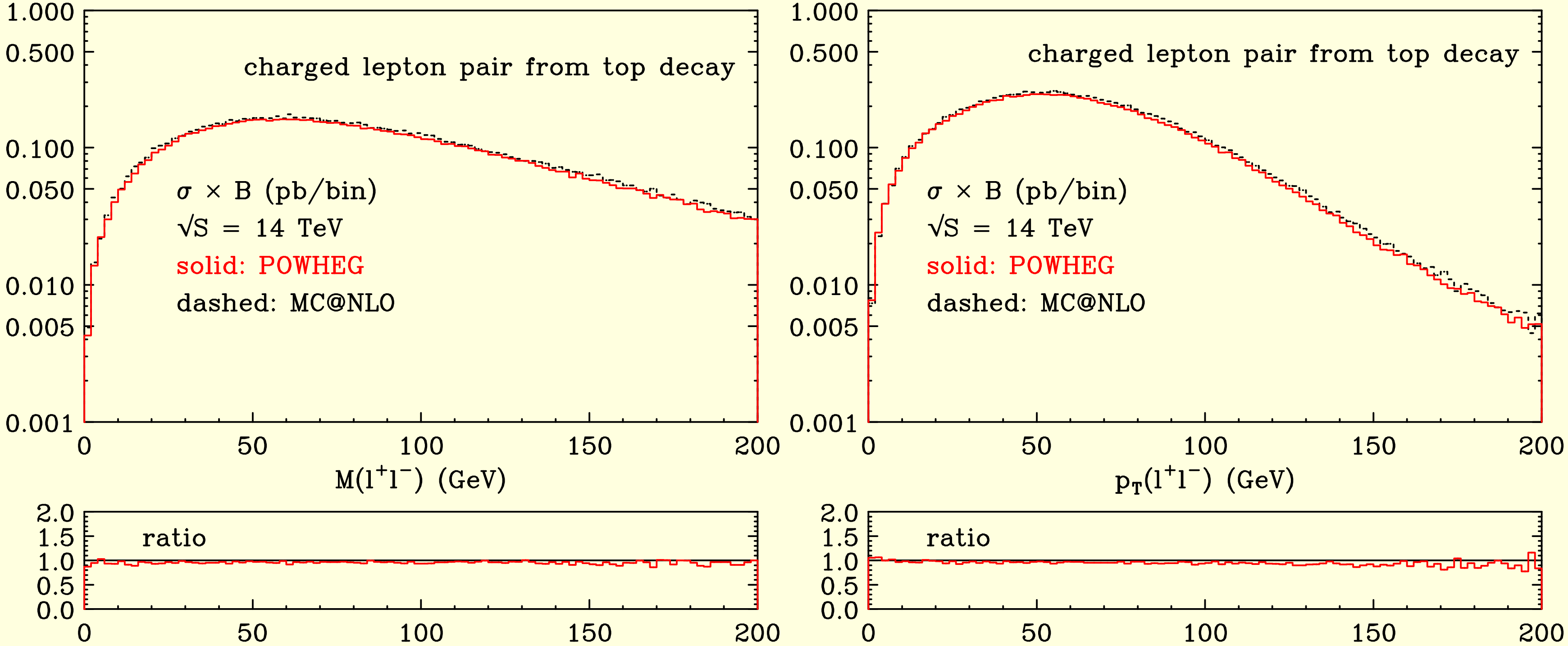


stable top
σ (pb/bin)
√S = 14 TeV
solid: POWHEG
dashed: MC@NLO
p_T(t) (GeV)
ratio
stable top−antitop pair
σ (pb/bin)
√S = 14 TeV
solid: POWHEG
dashed: MC@NLO
m(tt) (GeV)

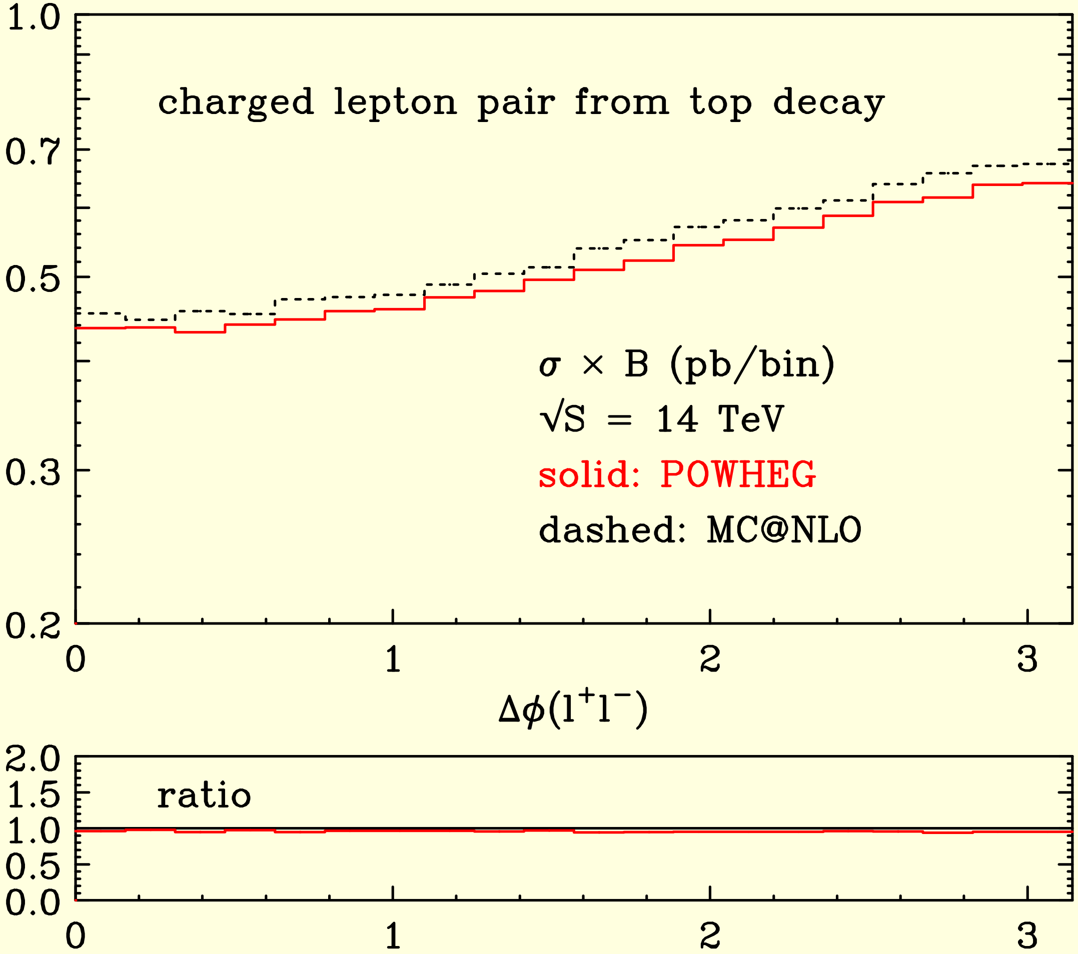


stable top−antitop pair
σ (pb/bin)
√S = 14 TeV
solid: POWHEG
dashed: MC@NLO
50
20
10
5
2
1
0
20
40
60
80
100
p_T(tt) (GeV)
ratio
2.0
1.5
1.0
0.5
0.0
0
20
40
60
80
100


charged lepton from top decay
σ × B (pb/bin)
√S = 14 TeV
solid: POWHEG
dashed: MC@NLO
$p_T(l^-)$ (GeV)
ratio
charged lepton from top decay
σ × B (pb/bin)
√S = 14 TeV
solid: POWHEG
dashed: MC@NLO
$y(l^-)$
ratio



charged lepton pair from top decay
σ × B (pb/bin)
√S = 14 TeV
solid: POWHEG
dashed: MC@NLO
M(l+l−) (GeV)
ratio
charged lepton pair from top decay
σ × B (pb/bin)
√S = 14 TeV
solid: POWHEG
dashed: MC@NLO
pT(l+l−) (GeV)
ratio


charged lepton pair from top decay
σ × B (pb/bin)
√S = 14 TeV
solid: POWHEG
dashed: MC@NLO
1.0
0.7
0.5
0.3
0.2
0
1
2
3
Δφ(l⁺l⁻)
ratio
2.0
1.5
1.0
0.5
0.0

Very good agreement in $t\bar{t}$ observables.

Small, not well understood discrepancies near $t\bar{t}$ threshold.

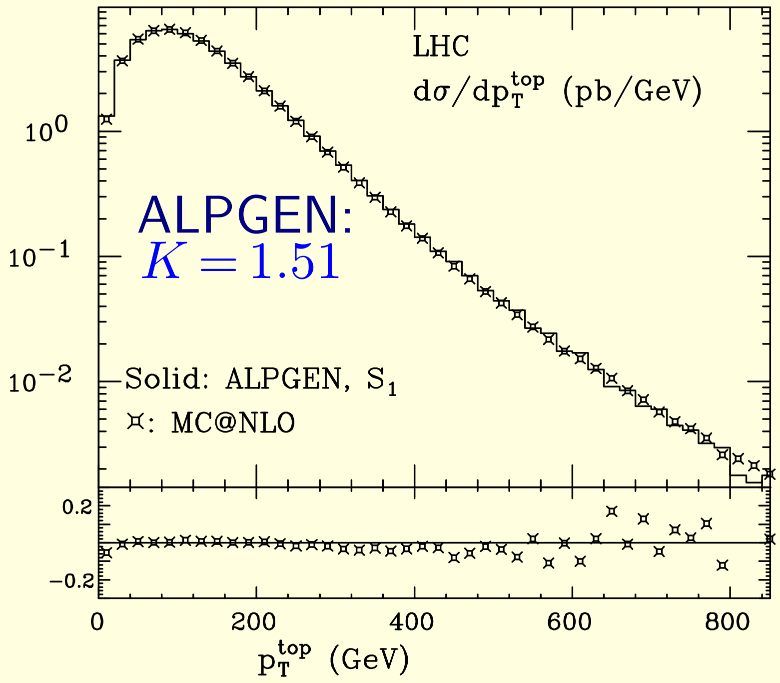
More significant discrepancies found by the ALPGEN team

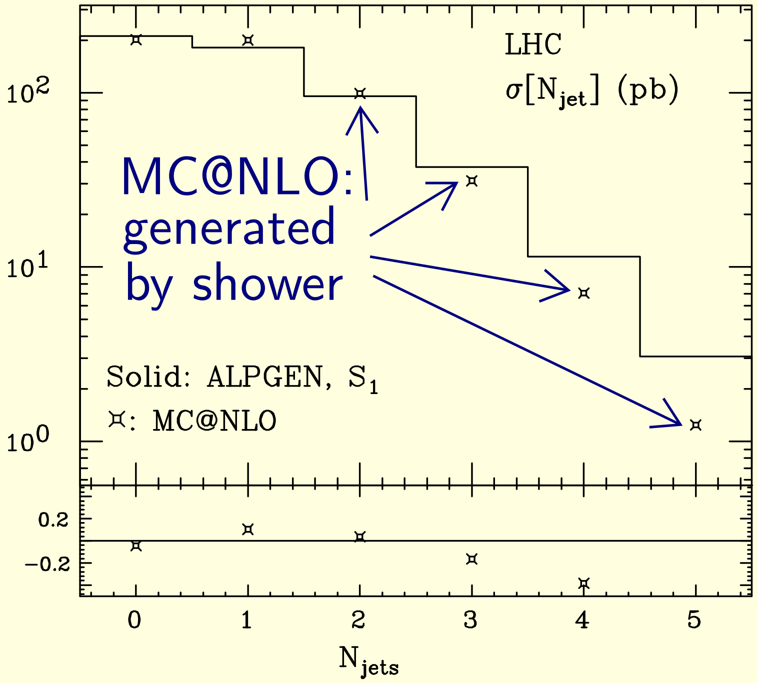
ALPGEN can generate samples of $t\bar{t} + n\,\mathrm{jets}$; can be compared to NLO+PS;

expect:

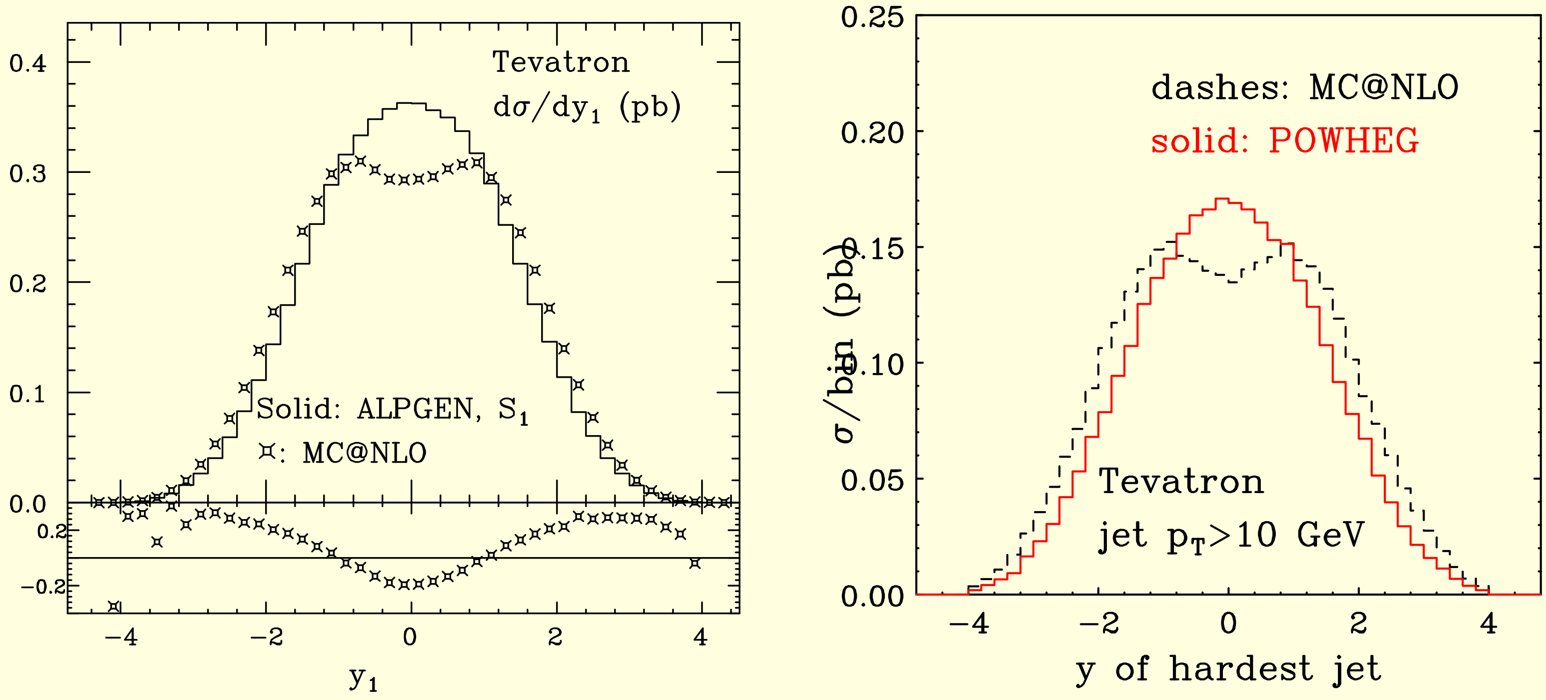
- Disadvantage: worse normalization (no NLO)
- Advantage: better high jet multiplicities (exact ME)

Comparison ALPGEN-MC@NLO carried out in detail
(Mangano, Moretti,Piccinini,Treccani, Nov.06)





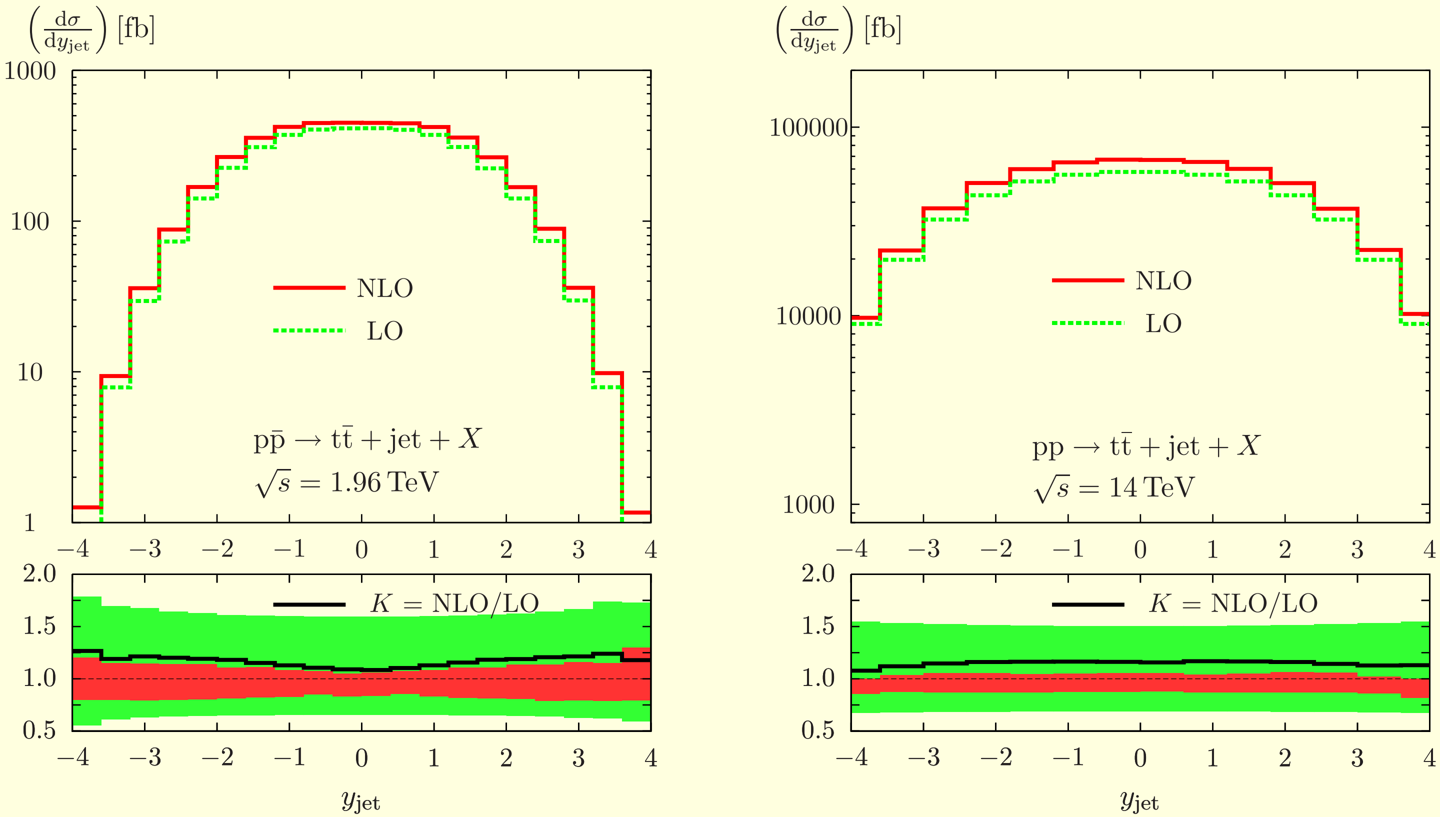
Results as expected but for 1 observable



POWHEG's distribution as in ALPGEN (i.e., no dip);

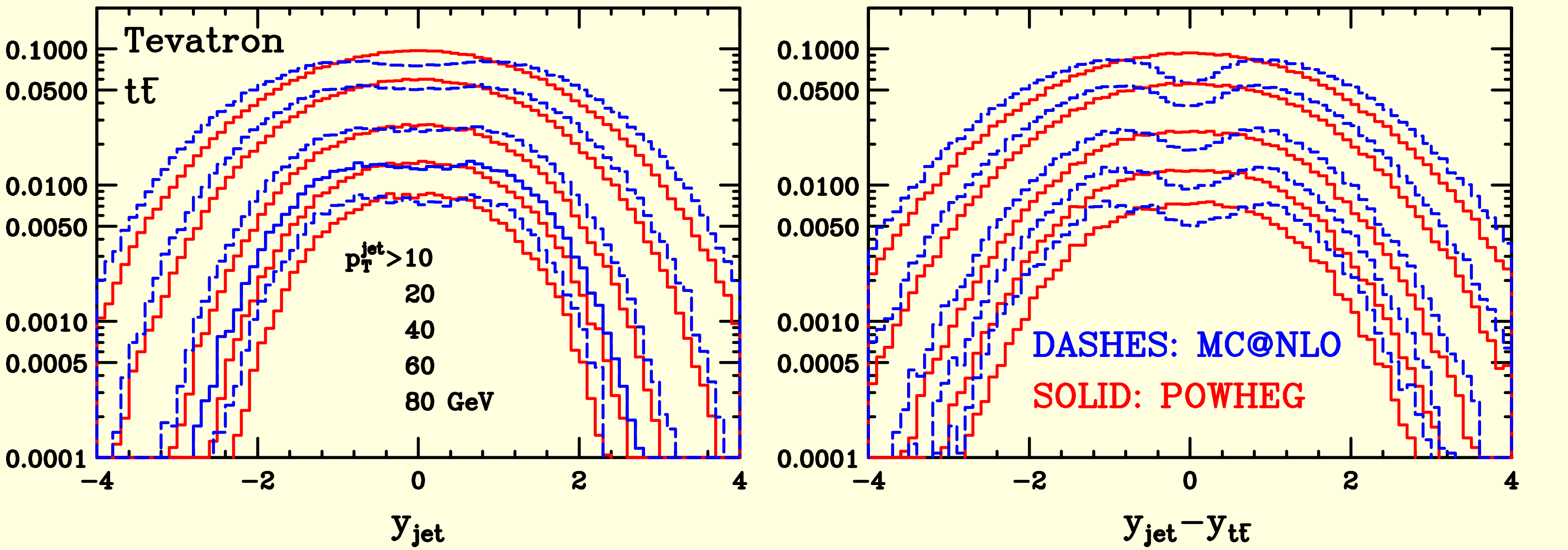
Notice: size of discrepancy can be attributed to different treatment of higher order terms. Is this "feature" really there?

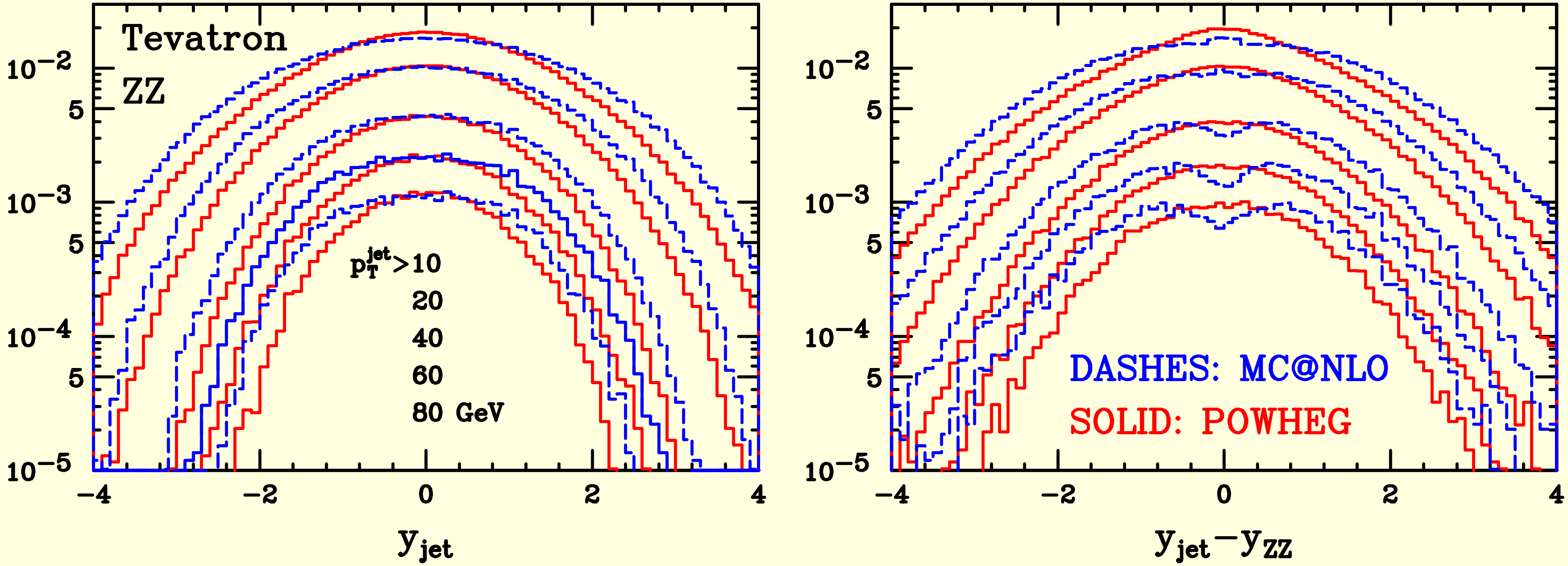
$pp \rightarrow t\bar{t} + \mathrm{Jet}$ at NLO (Dittmaier, Uwer, Weinzierl) agrees with ALPGEN and POWHEG



Recent studies show same problem in Z/W, ZZ, and higgs production.

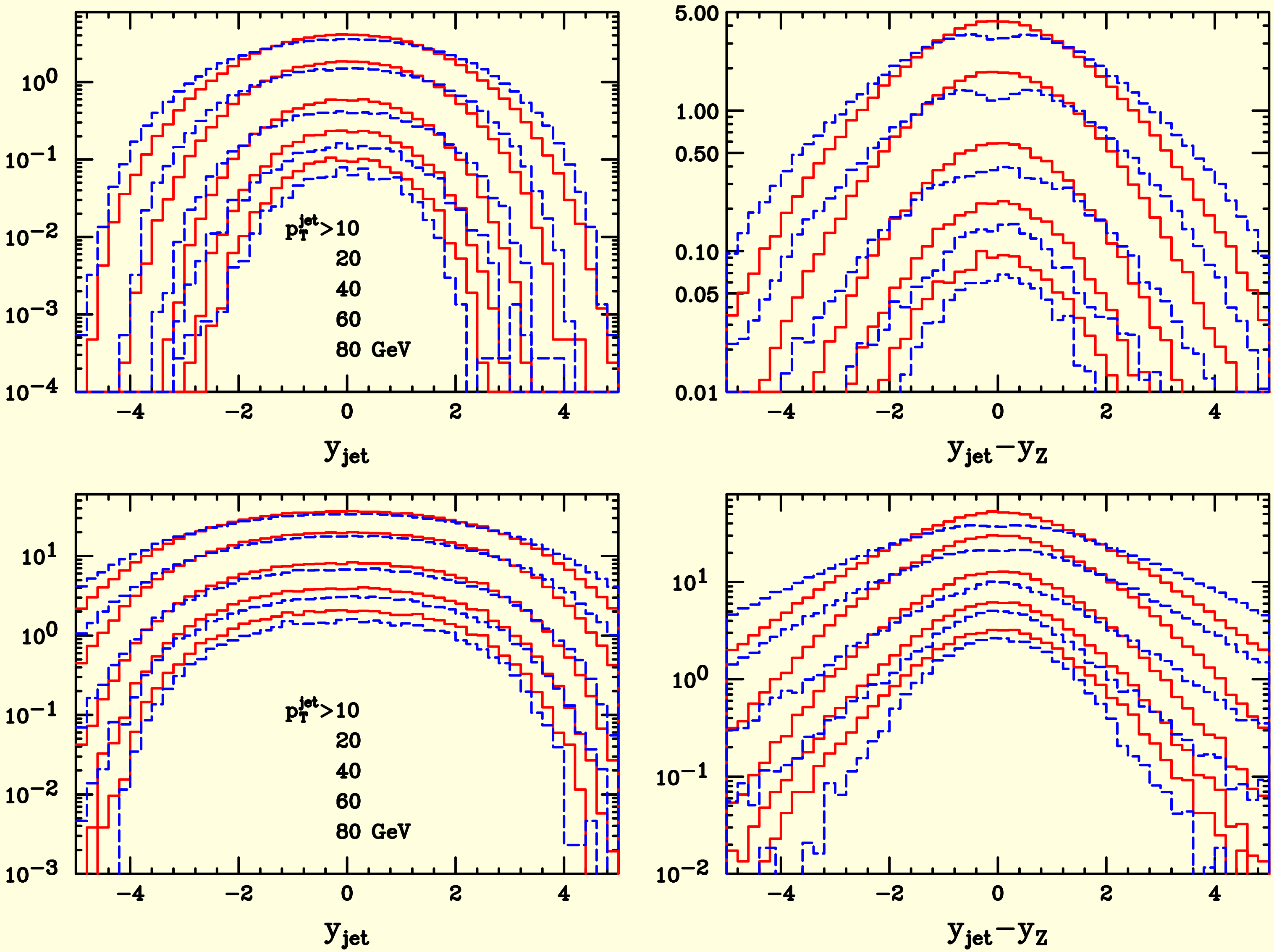
Furthermore, the "dip" is more pronounced if one plots the rapidity of the jet minus the rapidity of the heavy sistem:



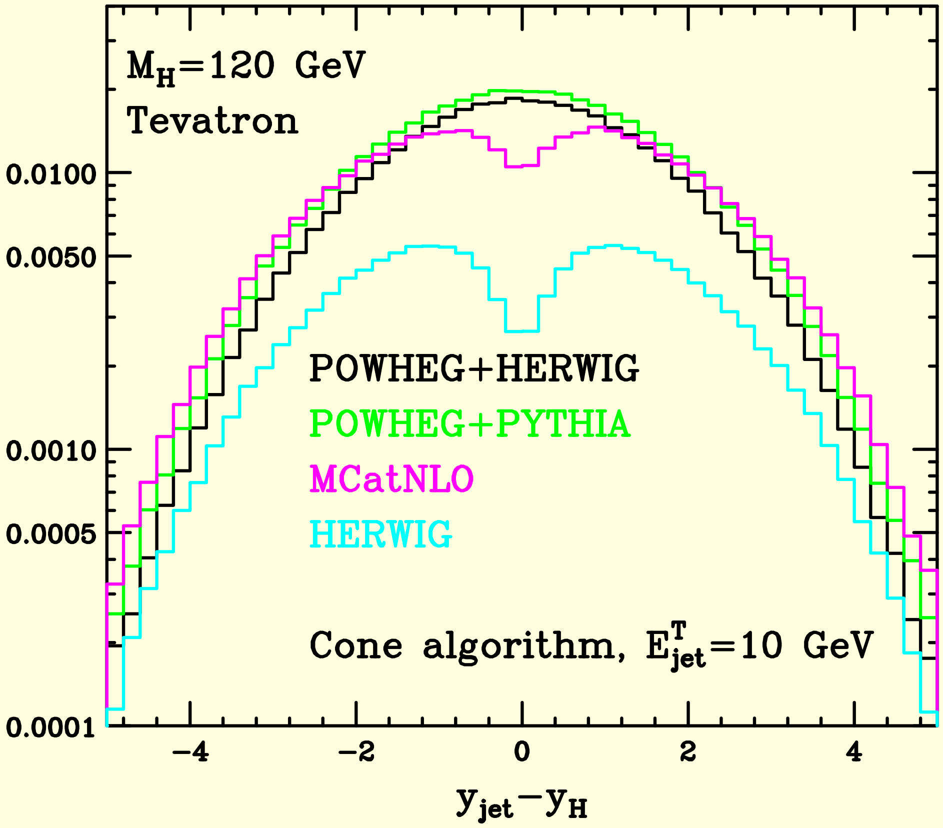

Tevatron
ZZ
p_T^{jet}>10
20
40
60
80 GeV
DASHES: MC@NLO
SOLID: POWHEG
y_{jet}
$y_{jet}-y_{ZZ}$

Tev

LHC



Origin of the problem: HERWIG radiation leaves an empty region, not properly filled by MC@NLO



Conclusions

- POWHEG-hvq: sound method for generating NLO $Q\bar{Q}$ events and shower them
- Works with your favorite Shower MC
- Compares favourably with MC@NLO
- No speed issues for top production