NLO + PARTON SHOWER: A NEW APPROACH

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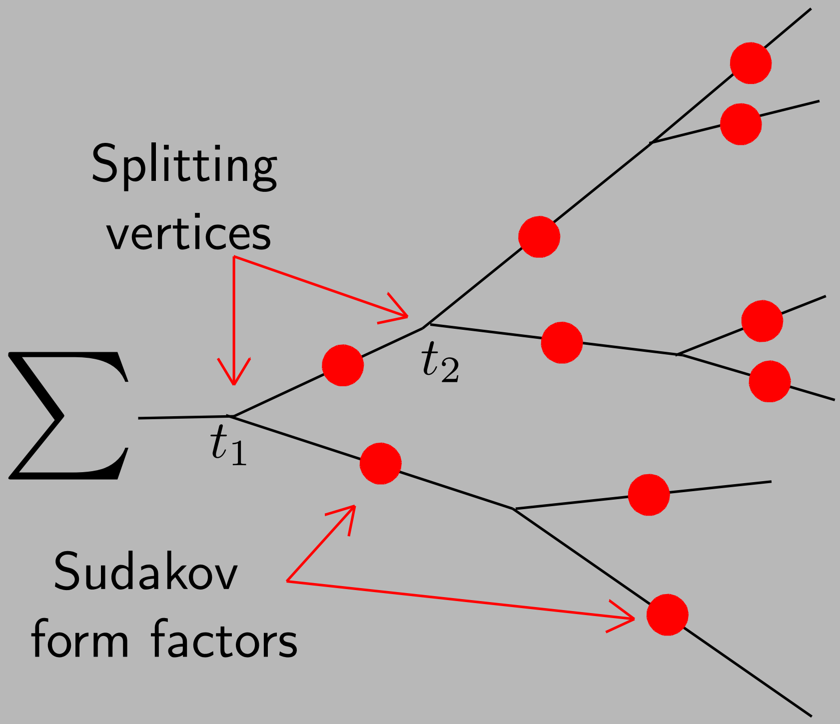
Motivations

SMC (Shower Monte Carlo) programs: normally accurate at LL level
Naturally interfaced to Born processes (i.e. Matrix Elements generators)
NLO calculations: many available results for collider processes

Positive NLO experience with QCD tests at colliders;
PS predictive for multiplicities and multiplicity distributions;
Natural extension: NLO+PS

What is a SMC



Splitting vertices are given,
in the collinear approximation, by

$$d\,p = \frac{\alpha}{2\pi} P(z) \frac{d\,t}{t}\, d\,z\, d\,\varphi$$

The Sudakov form factors are

$$\Delta = \exp\left[-\int_{t_2}^{t_1} \frac{\alpha}{2\pi} P(z) \frac{d\,t}{t}\, d\,z\, d\,\varphi \right]$$

Notice: $\Delta\, d\,p = -\,d\Delta$
Sudakov form factors are
uniformly distributed.

Uniformity of Sudakov form factors used for numerical implementations.

The Sudakov form factor are the sum of all virtual corrections in the collinear approximation. Notice that $0 < \Delta < 1$; Δ is referred to as the non-emission probability. Notice also that the inclusion of real and virtual corrections gives a net result of 1 (cancellation of collinear singularities in inclusive quantities).

The generation of a branching is analogous to the generation of the decay of a radioactive source:
if $p\,\delta t$ is the radiation probability in the interval δt,
the non radiation probability in the interval δt is $(1 - p\delta t) = \exp(-p\delta t)$.
The non-radiation probability in a finite interval is $\exp(-pt)$.
The probability for the first radiation is $\exp(-pt)\,p\delta t$ (an exact differential).
For a Monte Carlo implementation, generate a random number $0 < r < 1$ and solve $r = \exp(-pt)$ for t.

What is an NLO calculation

Typically (subtraction method) for an observable O

$$\begin{aligned}\langle O \rangle &= \int O\, d\,\sigma = \int O(\Phi_n)\,[B(\Phi_n) + V(\Phi_n)]\, d\,\Phi_n \\ &+ \int \Big[O(\Phi_{n+1}) R(\Phi_{n+1}) - O(\tilde{\Phi}_{n+1}) C(\Phi_{n+1}) \Big]\, d\,\Phi_{n+1}\end{aligned}$$

$\tilde{\Phi}_{n+1}$: singular $n+1$ body phase space point, function of Φ_{n+1}

- Soft case: $\tilde{\Phi}_{n+1}$ has a zero momentum parton
- Collinear case: $\tilde{\Phi}_{n+1}$ has two massless partons with parallel momenta

Near the singular limit $\tilde{\Phi}_{n+1} \approx \Phi_{n+1}$.

(In general, several singular regions, counterterms, $\tilde{\Phi}_{n+1}$ functions)

The singular configurations $\tilde{\Phi}_{n+1}$ have an underlying Born kinematics $\bar{\Phi}_n$, obtained by:

- Soft case: removing the zero momentum parton
- Final state collinear: merging the collinear partons
- Initial state collinear: removing the radiated collinear parton, and subtracting its momentum from initial state parton

Assume that we can parametrize the Φ_{n+1} phase space in terms of $(\bar{\Phi}_n, \Phi_r)$ where Φ_r are three more radiation variables. We have

$$\begin{aligned}\langle O \rangle &= \int O(\Phi_n)\left[B(\Phi_n) + V(\Phi_n)\right] d\,\Phi_n \\ &+ \int \left[O(\bar{\Phi}_n, \Phi_r) R(\bar{\Phi}_n, \Phi_r) - O(\bar{\Phi}_n) C(\bar{\Phi}_n, \Phi_r)\right] d\,\bar{\Phi}_n\, d\Phi_r\end{aligned}$$

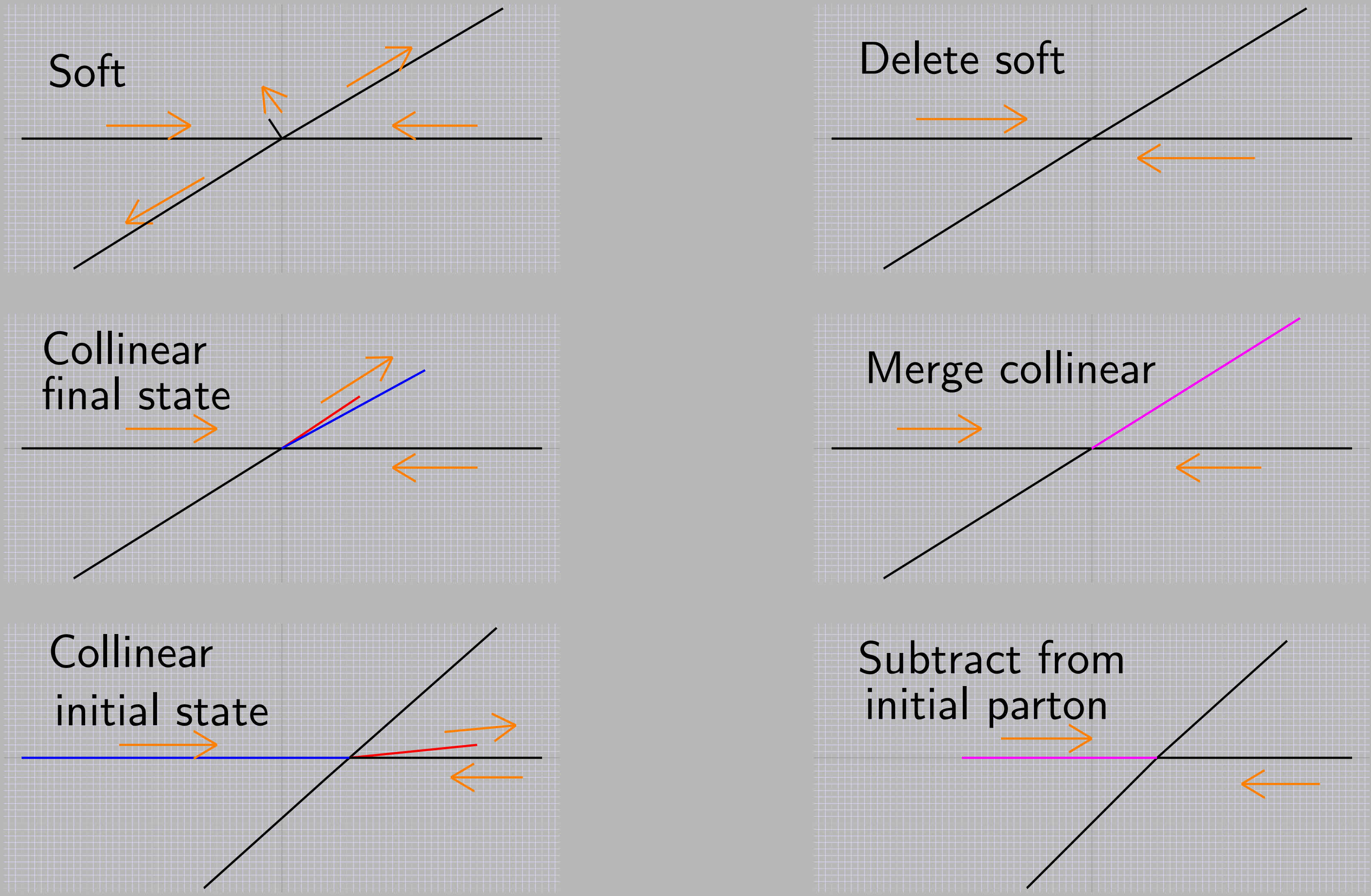
Defining the unregularized virtual $V_b(\Phi_n) = V(\Phi_n) - \int C(\Phi_n, \Phi_r)\, d\,\Phi_r$:

$$\langle O \rangle = \int O(\Phi_n)\left[B(\Phi_n) + V_b(\Phi_n)\right] d\,\Phi_n + \int O(\bar{\Phi}_n, \Phi_r) R(\bar{\Phi}_n, \Phi_r) d\,\bar{\Phi}_n\, d\Phi_r$$

which is the starting formula with divergent real and virtual corrections.

Singular configuration

Underlying Born



NLO in SMC

In SMC's: $\Phi_{n+1} = \Phi_{n+1}(\Phi_n, \Phi_r)$, with $\Phi_r = (t, z, \varphi)$ (momentum reshuffling).
The form of the mapping depends upon the implementation.
SMC cross section for first emission:

$$\langle O \rangle = \int B(\Phi_n) d\Phi_n \left\{ O(\Phi_n)\, \Delta_{t_{\rm min}} + \int_{t_{\rm min}} O(\Phi_n, \Phi_r)\, \Delta_t \frac{\alpha}{2\pi} P(z) \frac{dt}{t}\, dz\, d\varphi \right\}$$

with

$$\Delta_t = \exp\left[- \int_t \frac{\alpha}{2\pi} P(z) \frac{dt'}{t'}\, dz\, d\varphi \right]$$

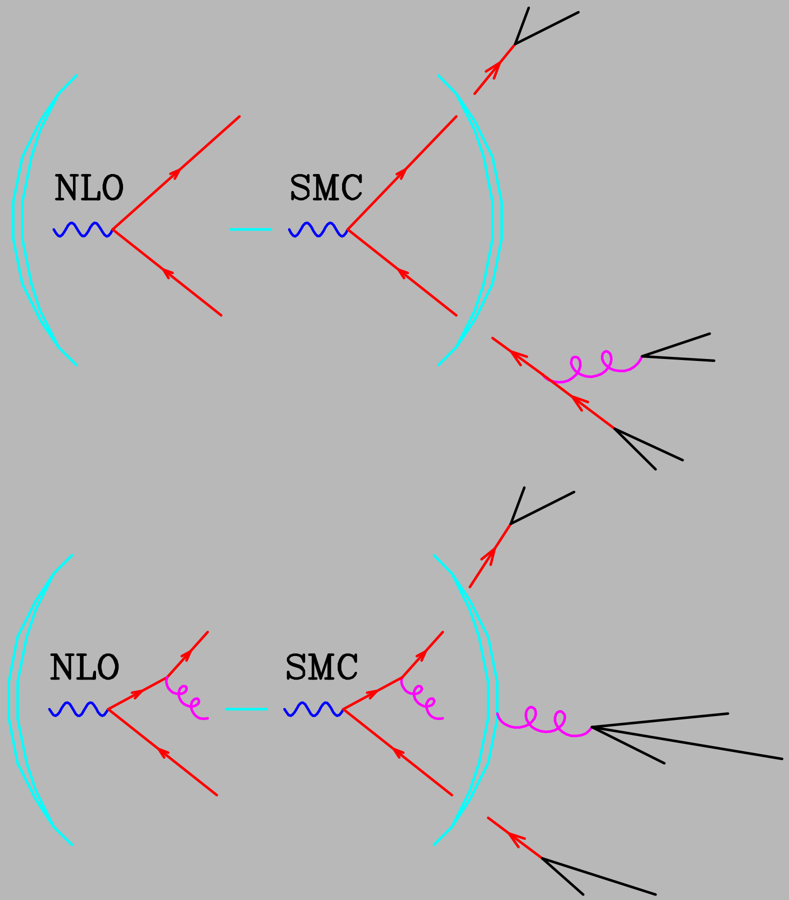
at $\mathrm{NLO_{SMC}}$ order (expand the above formula to $O(\alpha_S)$)

$$\langle O \rangle = \int B(\Phi_n) d\Phi_n \left\{ O(\Phi_n) + \int_{t_{\rm min}} [O(\Phi_n, \Phi_r) - O(\Phi_n)] \frac{\alpha}{2\pi} P(z) \frac{dt}{t}\, dz\, d\varphi \right\}$$

(of course, this is the inexact NLO correction implemented by the SMC)

How do we reach exact NLO accuracy?

MC@NLO (2002, Frixione+Webber)



Add difference between exact NLO and approximate (MC) NLO.

- Must use $(\bar{\Phi}, \Phi_r)$ of the MC
- Difference should be regular (if the MC is OK)
- Difference may be negative

Several collider processes already implemented: Vector Bosons, Vector Bosons pairs, Higgs, Heavy Quarks, Single Top.

MC@NLO

First viable (and useful) implementation of SMC+NLO.
No need to modify the shower program: straightforward to implement.
Drawbacks:

- Must use $(\bar{\Phi}, \Phi_r)$ of the SMC: SMC specific, needs the authors...
- $\mathrm{NLO} - \mathrm{NLO}_{\mathrm{SMC}}$ must be regular in the singular limit. Therefore:
  - SMC must implement correctly collinear singularities, also in the azimuthal dependence
  - SMC must implement correctly soft emission. If not, one must worry about the importance of the left over.
  - The matching in the subtraction is crucial and delicate
- Events with negative weights may be generated (undesirable feature). Physical distributions should turn out positive. However this may be difficult to prove for all cases.

POWHEG

Positive Weight Hardest Emission Generator

Method to generate the hardest emission first, with NLO accuracy, and independently of the SMC (P.N. 2004).

- SMC independent; no need of SMC expert; same calculation can be interfaced to several SMC programs with no extra effort
- SMC inaccuracies only affect next-to-hardest emissions; no matching problems
- As the name says, it generates events with positive weight

How it works

$$\begin{aligned}
\langle O\rangle &= \int O(\Phi_n)\,[B(\Phi_n)+V(\Phi_n)]\,d\,\Phi_n \\
&+ \int \left[O(\bar\Phi_n,\Phi_r)R(\bar\Phi_n,\Phi_r)-O(\bar\Phi_n)C(\bar\Phi_n,\Phi_r)\right]d\,\bar\Phi_n\,d\Phi_r \\
&= \int O(\Phi_n)\left[B(\Phi_n)+V(\Phi_n)+\int\ \{R(\bar\Phi_n,\Phi_r)-C(\Phi_n,\Phi_r)\}\,d\Phi_r\right]d\,\Phi_n \\
&+ \int R(\Phi_n,\Phi_r)[O(\Phi_n,\Phi_r)-O(\Phi_n)]\,d\,\Phi_n\,d\Phi_r
\end{aligned}$$

Define: $\bar B(\Phi_n)=B(\Phi_n)+V(\Phi_n)+\int\ \{R(\bar\Phi_n,\Phi_r)-C(\Phi_n,\Phi_r)\}\,d\Phi_r$, get:

$$\langle O\rangle=\int O(\Phi_n)\bar B(\Phi_n)\,d\,\Phi_n+\int R(\Phi_n,\Phi_r)[O(\Phi_n,\Phi_r)-O(\Phi_n)]\,d\,\Phi_n\,d\Phi_r$$

In $\mathrm{NLO}_{\mathrm{SMC}}$ was

$$\langle O\rangle=\int O(\Phi_n)B(\Phi_n)\,d\,\Phi_n+\int B(\Phi_n)\frac{\alpha}{2\pi}P(z)\frac{1}{t}[O(\Phi_n,\Phi_r)-O(\Phi_n)]\,d\,\Phi_n\,d\Phi_r$$

Thus: $\mathrm{NLO}_{\mathrm{SMC}} \leftrightarrow \mathrm{NLO}$: $B(\Phi_n) \leftrightarrow \bar{B}(\Phi_n)$, $B(\Phi_n)\frac{\alpha}{2\pi}P(z)\frac{1}{t} \leftrightarrow R(\Phi_n, \Phi_r)$

All order emission probability in SMC:

$$\langle O \rangle = \int B(\Phi_n) d\Phi_n \left\{ O(\Phi_n)\, \Delta_{t_{\min}} + \int_{t_{\min}} O(\Phi_n, \Phi_r)\, \Delta_t \frac{\alpha}{2\pi} P(z) \frac{1}{t}\, d\Phi_r \right\}$$

$$\Delta_t = \exp\left[- \int_t \frac{\alpha}{2\pi} P(z) \frac{1}{t'}\, d\Phi_{r'} \right]$$

All order emission probability in POWHEG:

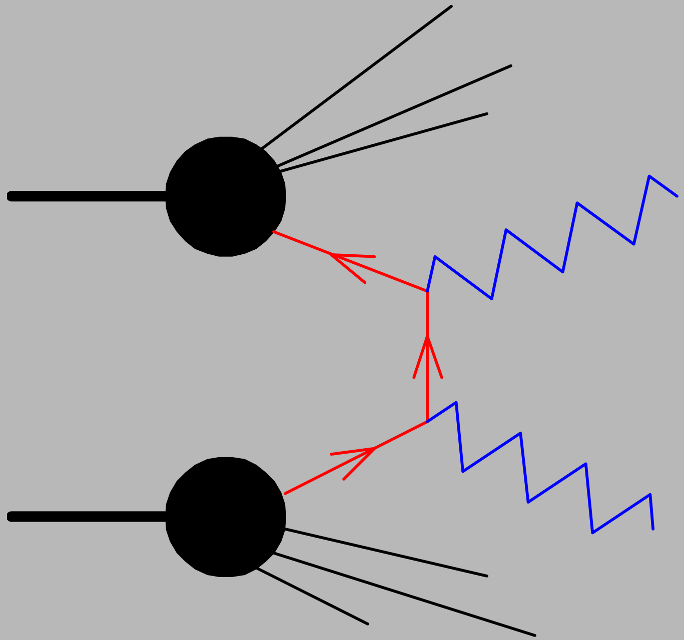
$$\langle O \rangle = \int \bar{B}(\Phi_n) d\Phi_n \left\{ O(\Phi_n)\, \Delta_{t_{\min}} + \int O(\Phi_n, \Phi_r) \Delta_{t_r} \frac{R(\Phi_n, \Phi_r)}{B(\Phi_n)} d\Phi_r \right\}$$

$$\Delta_t = \exp\left[- \int \theta(t_r - t) \frac{R(\Phi_n, \Phi_r)}{B(\Phi_n)} d\Phi_r \right]$$

with $t_r = k_T(\Phi_n \Phi_r)$, the transverse momentum for the radiation.
Positive if $\bar{B}$ is positive (i.e. $\mathrm{NL} < \mathrm{LO}$).

First example: ZZ production in hadron collisions

(Ridolfi, P.N.)



- NLO known
  (Mele,Ridolfi, P.N.)
- Intermediate complexity
- Hadrons in initial state
- Similar to WZ, WW, $Q\bar{Q}$

$\bar{\Phi}$ and Φ_r variables

$\bar{\Phi}$ variables: choose $M_{\rm zz}$, $Y_{\rm zz}$ and θ, where

- $M_{\rm zz}$: invariant mass of the ZZ pair
- $Y_{\rm zz}$: rapidity of ZZ pair
- θ: go in the (longitudinally) boosted frame where $Y_{\rm zz} = 0$.
  go to the ZZ rest frame with a transverse boost
  In this frame θ is the angle of a Z to the longitudinal direction.

Φ_r variables:

- $x = M_{\rm zz}/s$, (s is the invariant mass of the incoming parton system)
  $x \to 1$ is the soft limit
- y: cosine of the angle of the radiated parton to the beam direction in the partonic CM frame.
- ϕ: radiation azimuth.

Few tricks to do it

$$\bar{B}(\Phi) = B(\Phi) + V(\Phi) + \int d\Phi_r [R(\Phi,\Phi_r) - C(\Phi,\Phi_r)]$$

Seems to need one Φ_r integrations to get weight of each Φ point.

In fact, write

$$\tilde{B}(\Phi,\Phi_r) = N[B(\Phi) + V(\Phi)] + R(\Phi,\Phi_r) - C(\Phi,\Phi_r), \qquad N = \frac{1}{\int d\Phi_r} .$$

so that

$$\bar{B}(\Phi) = \int \tilde{B}(\Phi,\Phi_r) d\Phi_r .$$

Use standard procedures (SPRING-BASES, Kawabata)
to generate unweighted events for $\tilde{B}(\bar{\Phi},\Phi_r) d\Phi_r d\bar{\Phi}$.
discard Φ_r (same as integrating over it!).

$$\Delta(\Phi, p_T) = \exp\left[- \int \frac{R(\Phi, \Phi_r)}{B(\Phi)} \theta(k_T(\Phi, \Phi_r) - p_T) d\Phi_r \right],$$

Look for an upper bounding function;

$$\frac{R(\Phi, \Phi_r)}{B(\Phi)} \leq U(\Phi) = N \frac{\alpha_S(k_T)}{(1-x)(1-y^2)}$$

Generate x, y according to

$$\exp\left[- \int U(\Phi) \theta(k_T(\Phi, \Phi_r) - p_T) d\Phi_r \right]$$

accept the event with a probability

$$\frac{R(\Phi, \Phi_r)}{B(\Phi) U(\Phi)} \, .$$

If the event is rejected generate a new one for smaller p_T, and so on
(This procedure reconstructs the exact emission probability).
In the ZZ case, an event is generated with about six calls ro $R(\Phi, \Phi_r)$.

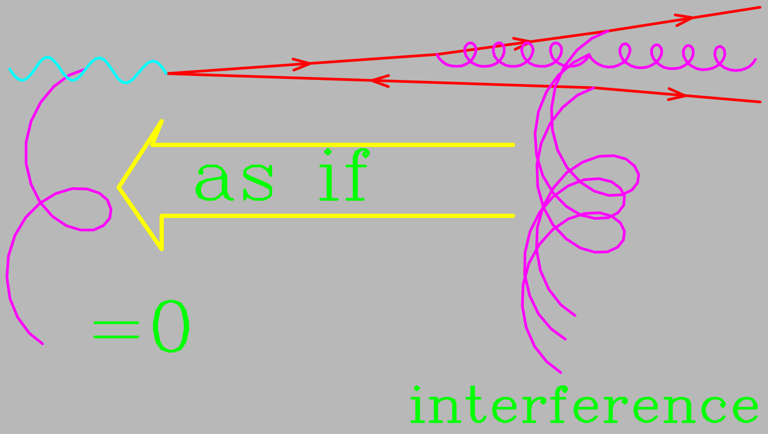
Interfacing to SMC's

For a p_T ordered SMC, nothing else needs to be done.
Use the standard Les Houches Interface for User's Processes (LHI):
put partonic event generated by POWHEG on the LHI;
Run the SMC in the LHI mode.
The LHI provides a facility to pass the p_T of the event to the SMC (SCALUP).
As far as the hardest emission is concerned, POWHEG guarantees:

- NLO accuracy of (integrated) shape variables
- Collinear, double-log, soft (large N_c) accuracy of the Sudakov FF.
  (In fact, corrections that exponentiates are obviously OK)

As far as subsequent (less hard) emissions, the output has the accuracy of the SMC one is using.

For angular ordered SMC's (i.e. HERWIG):



Angular ordering accounts

for soft gluon interference.

Intensity for photon jets $=0$

Intensity for gluon jets $=C_A$

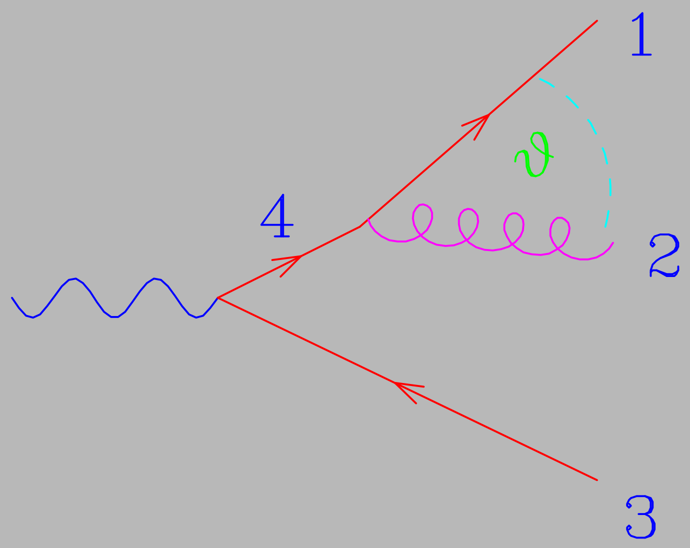
instead of $2C_F + C_A$

Consistent with a boosted jet pair, in the case of a photon jet.
In angular ordered SMC large angle soft emission is generated first.
Hardest emission (i.e. highest p_T) happens later.
Difficult to correct it explicitly.

Recipe for angular ordered showers

- Generate event with harderst emission
- Generate all subsequent emissions with a p_T veto equal to the hardest emission p_T
- Pair up the partons that are nearest in p_T
- Generate an angular ordered shower associated with the paired parton, stopping at the angle of the paired partons (truncated shower)
- Generate all subsequent (vetoed) showers

Example of truncated shower: e^+e^-



Nearby partons: 1,2

Truncated shower: 1,2 pair,

from maximum angle to θ

1 and 2 shower from θ to cutoff

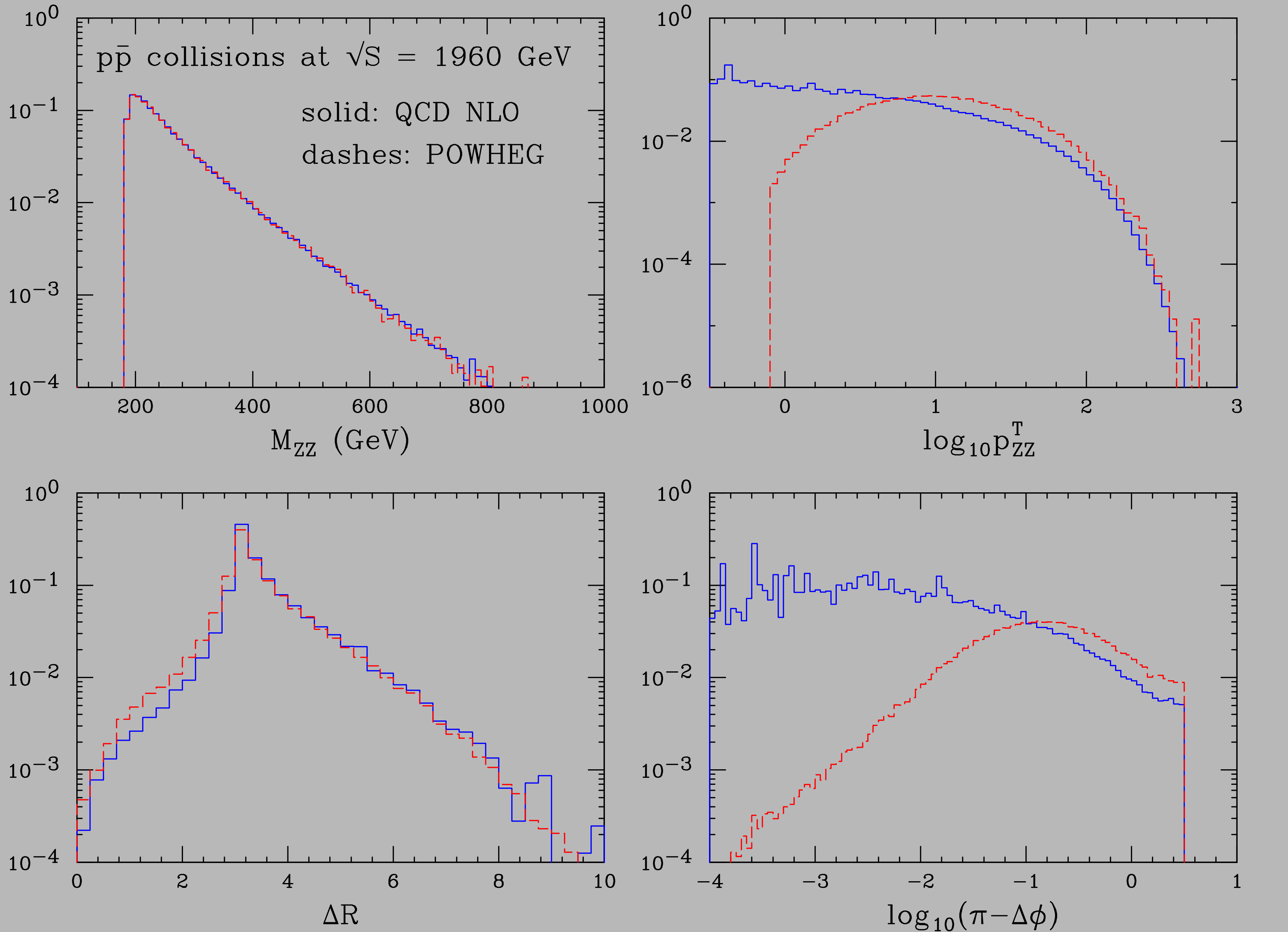
3 showers from maximum to cutoff

The truncated shower reintroduces coherent soft radiation from 1,2 at angles larger than θ (Angular ordered SMC's generate those earlier).

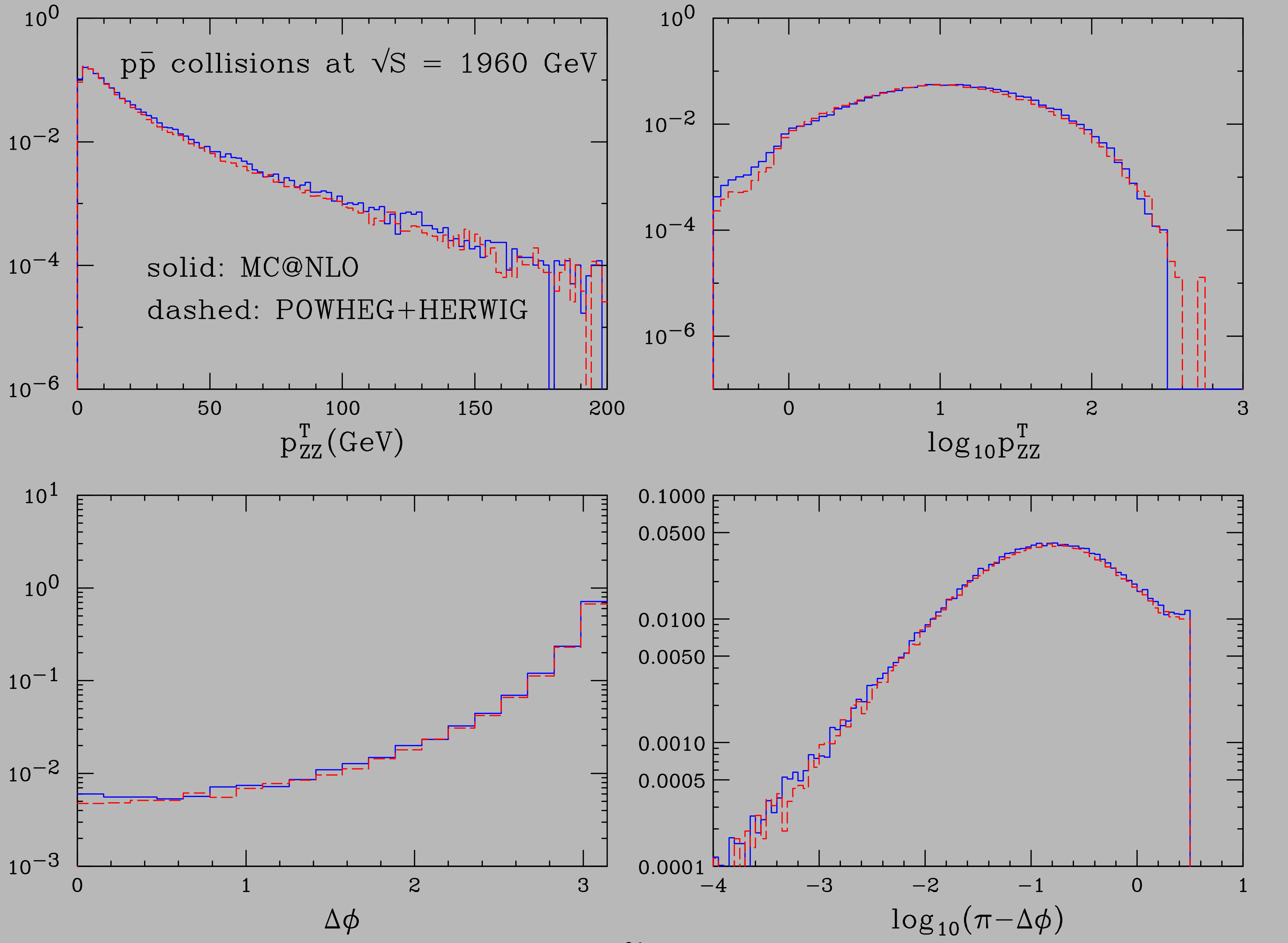
Truncated showers not yet implemented; work in progress with S. Frixione. (No evidence of effects from their absence up to now)

Results

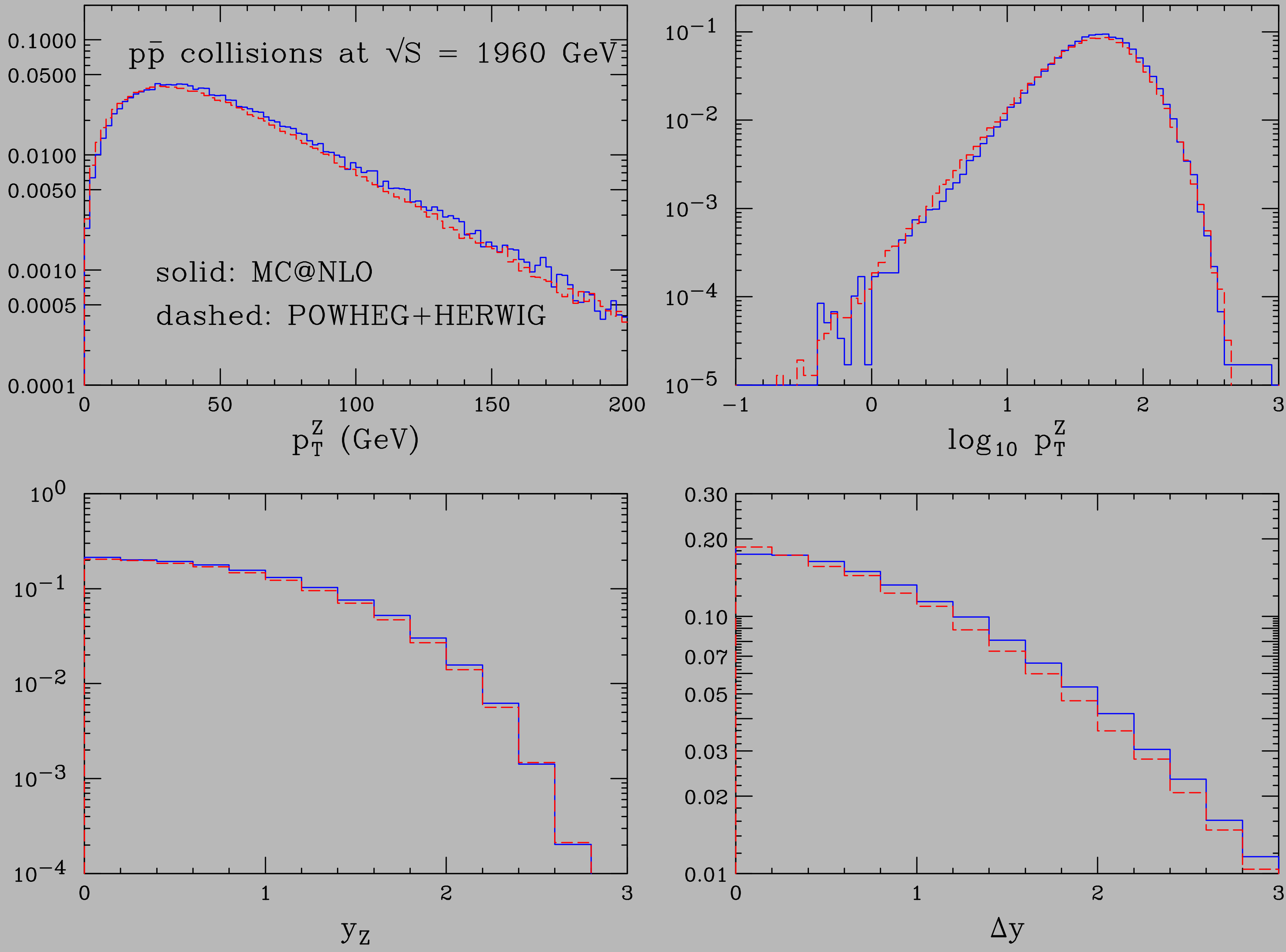
- We studied distributions for LHC and the TEVATRON
- We interfaced the output to both HERWIG and PYTHIA
- No truncated showers for now
- Haven't found yet significant differences from from MC@NLO



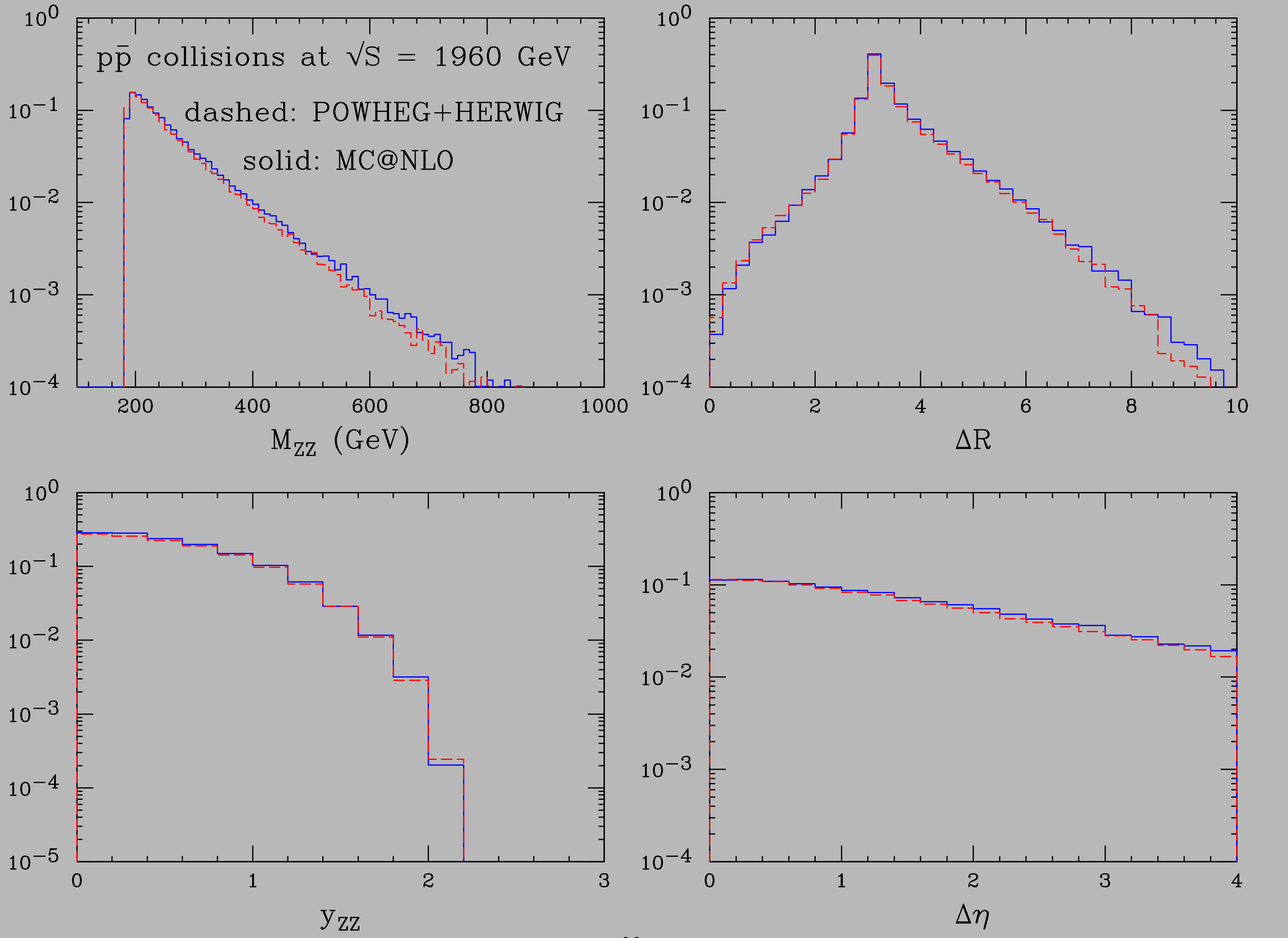
$p\bar{p}$ collisions at $\sqrt{S}$ = 1960 GeV
solid: QCD NLO
dashes: POWHEG
M_{ZZ} (GeV)
$\log_{10} p^T_{ZZ}$
ΔR
$\log_{10}(\pi - \Delta\phi)$

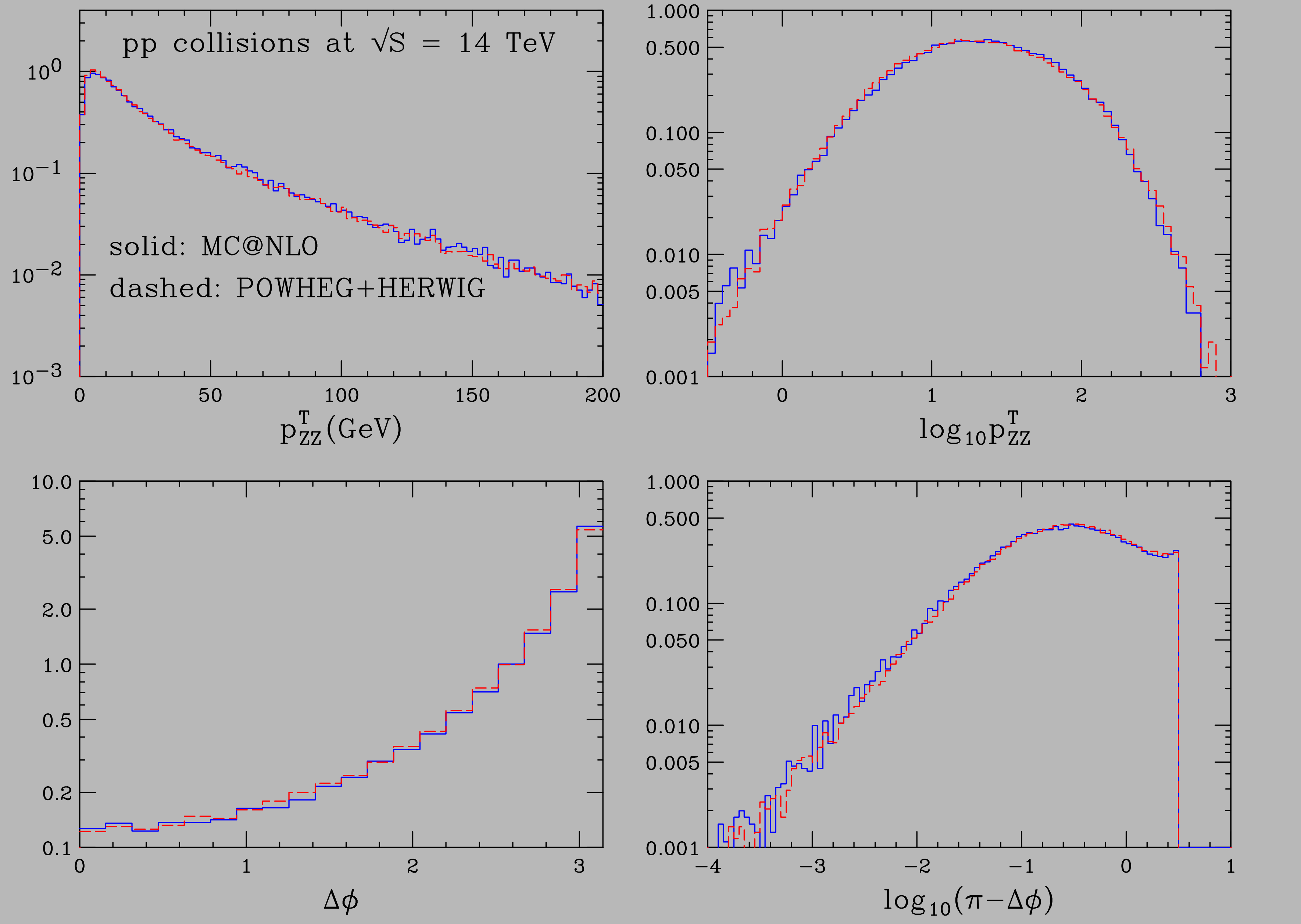


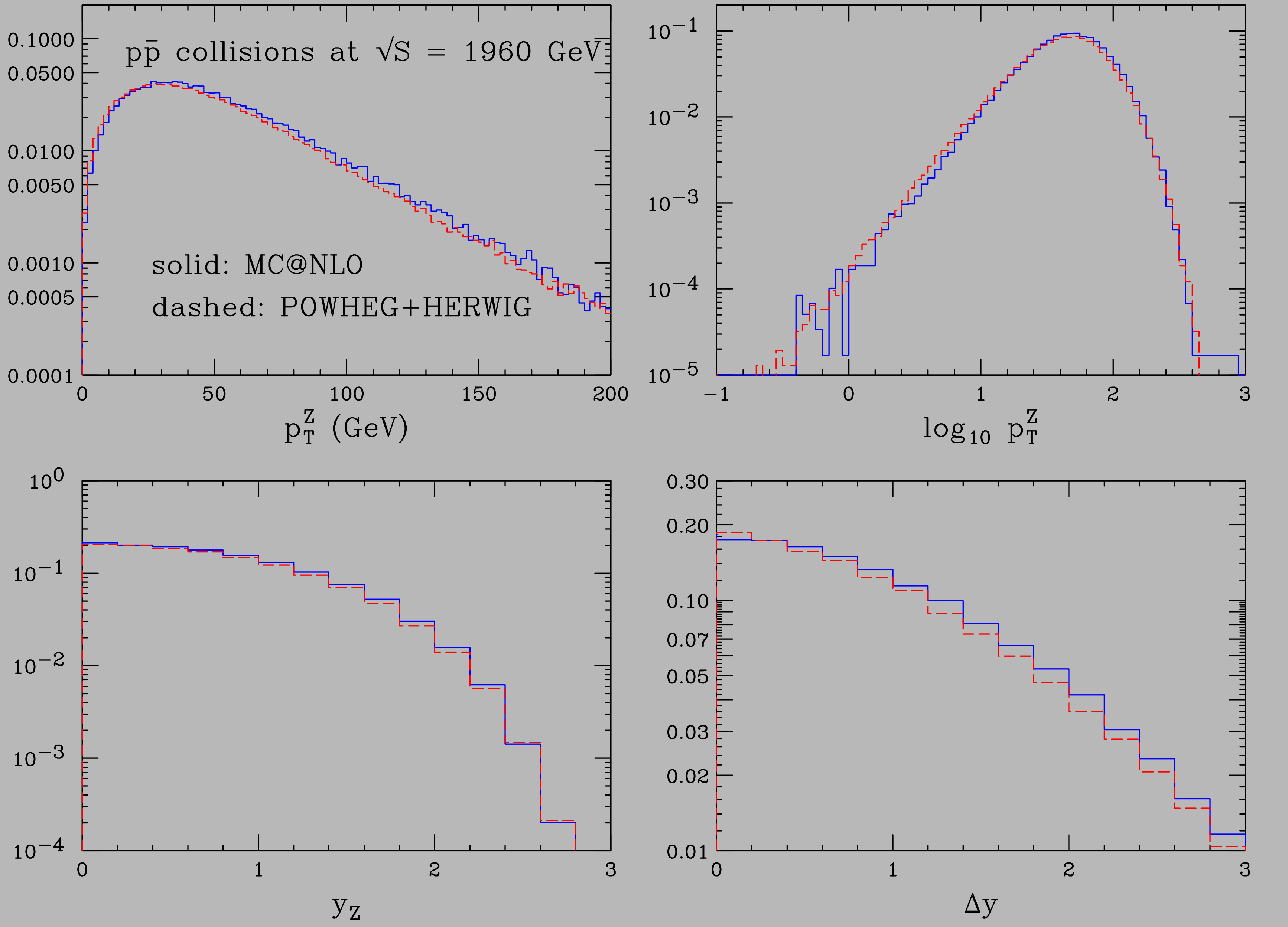
$p\bar{p}$ collisions at $\sqrt{S}$ = 1960 GeV
solid: MC@NLO
dashed: POWHEG+HERWIG
p^T_{ZZ}(GeV)
$\log_{10} p^T_{ZZ}$
$\Delta\phi$
$\log_{10}(\pi-\Delta\phi)$



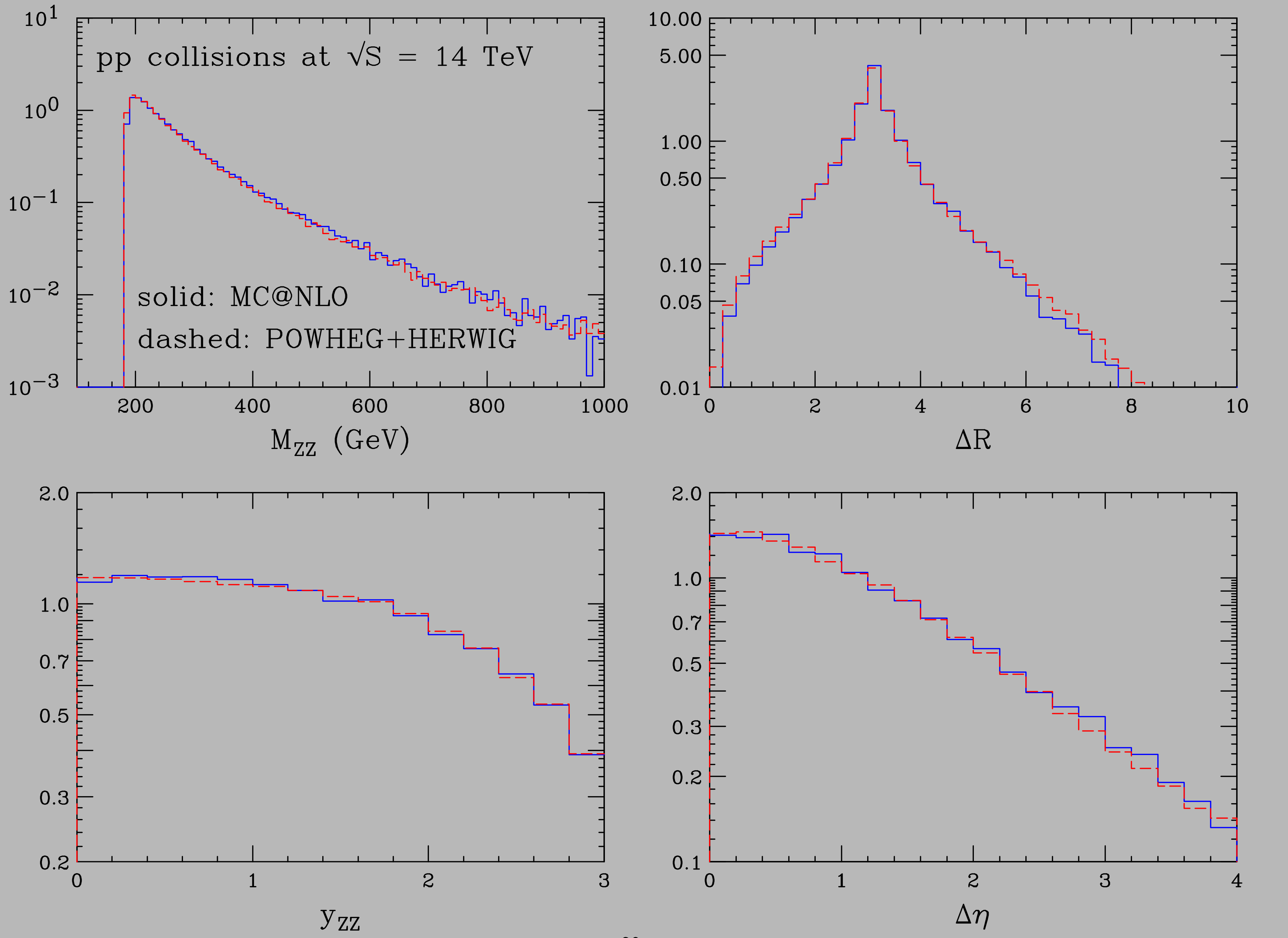
0.1000
0.0500
0.0100
0.0050
0.0010
0.0005
0.0001
pp̄ collisions at √S = 1960 GeV
solid: MC@NLO
dashed: POWHEG+HERWIG
0
50
100
150
200
p_T^Z (GeV)
10^−1
10^−2
10^−3
10^−4
10^−5
−1
0
1
2
3
log_10 p_T^Z
10^0
10^−1
10^−2
10^−3
10^−4
0
1
2
3
y_Z
0.30
0.20
0.10
0.07
0.05
0.03
0.02
0.01
0
1
2
3
Δy

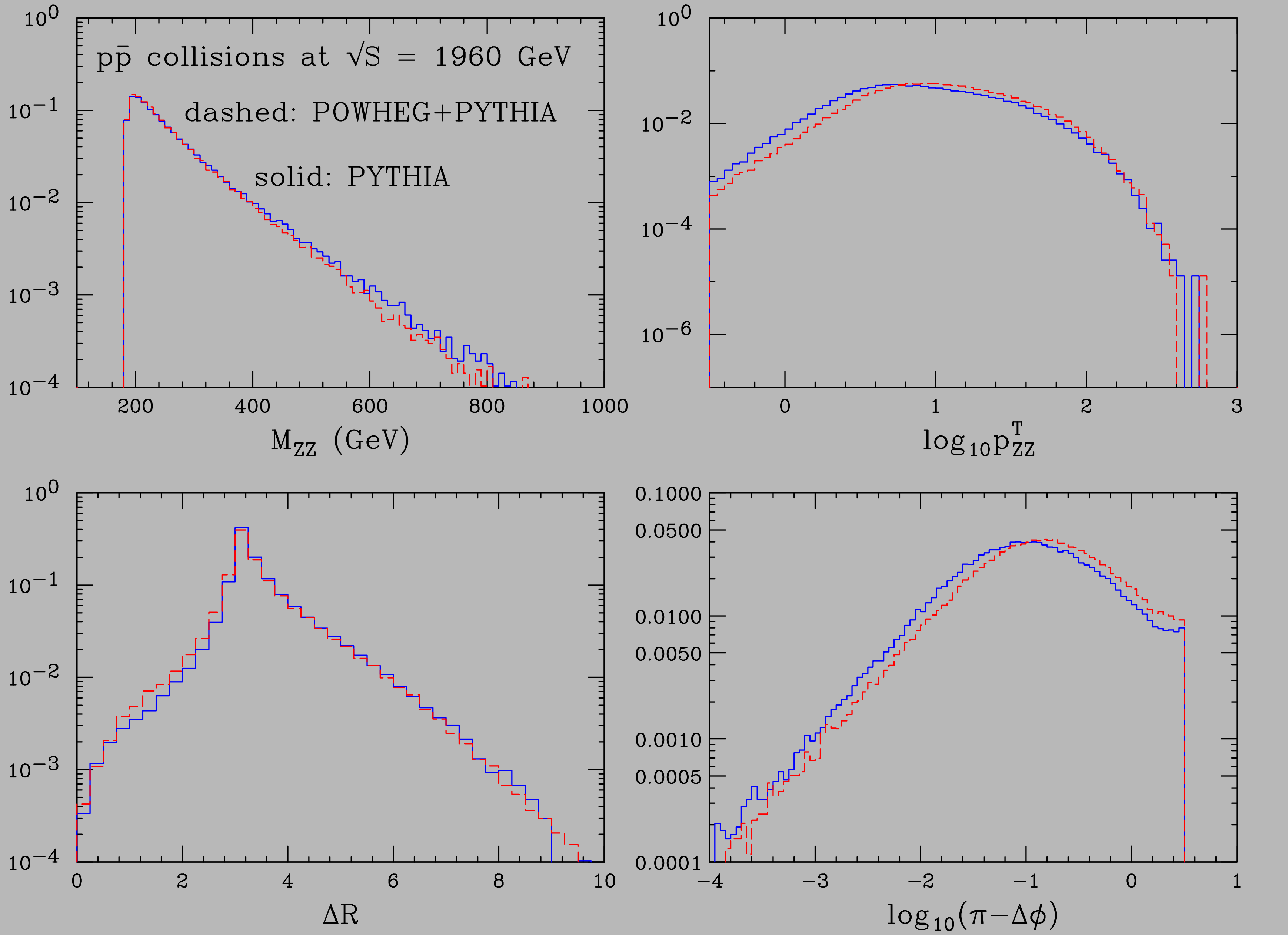

pp̄ collisions at √S = 1960 GeV
dashed: POWHEG+HERWIG
solid: MC@NLO
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
200
400
600
800
1000
M_{ZZ} (GeV)
0
2
4
6
8
10
ΔR
0
1
2
3
y_{ZZ}
0
1
2
3
4
Δη


pp collisions at √S = 14 TeV
solid: MC@NLO
dashed: POWHEG+HERWIG
10^0
10^{-1}
10^{-2}
10^{-3}
0
50
100
150
200
p^T_{ZZ}(GeV)
1.000
0.500
0.100
0.050
0.010
0.005
0.001
0
1
2
3
$\log_{10} p^T_{ZZ}$
10.0
5.0
2.0
1.0
0.5
0.2
0.1
0
1
2
3
$\Delta\phi$
1.000
0.500
0.100
0.050
0.010
0.005
0.001
−4
−3
−2
−1
0
1
$\log_{10}(\pi-\Delta\phi)$

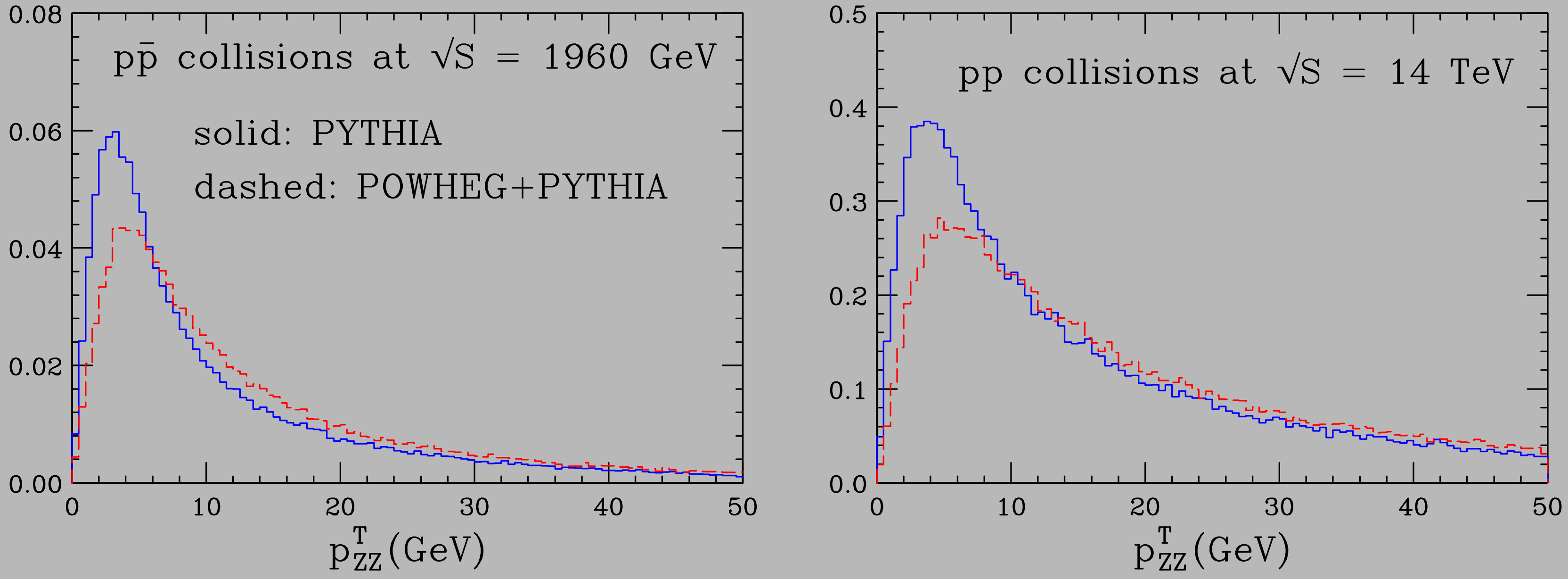


$p\bar{p}$ collisions at $\sqrt{S}$ = 1960 GeV
solid: MC@NLO
dashed: POWHEG+HERWIG
0.1000
0.0500
0.0100
0.0050
0.0010
0.0005
0.0001
0
50
100
150
200
p_T^Z (GeV)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
−1
0
1
2
3
$\log_{10} p_T^Z$
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
1
2
3
y_Z
0.30
0.20
0.10
0.07
0.05
0.03
0.02
0.01
0
1
2
3
Δy


pp collisions at √S = 14 TeV
solid: MC@NLO
dashed: POWHEG+HERWIG
M_ZZ (GeV)
ΔR
y_ZZ
Δη



$p\bar{p}$ collisions at $\sqrt{S}$ = 1960 GeV
dashed: POWHEG+PYTHIA
solid: PYTHIA
M_{ZZ} (GeV)
$\log_{10} p^T_{ZZ}$
ΔR
$\log_{10}(\pi - \Delta\phi)$



$p\bar{p}$ collisions at $\sqrt{S}$ = 1960 GeV
solid: PYTHIA
dashed: POWHEG+PYTHIA
0.08
0.06
0.04
0.02
0.00
0
10
20
30
40
50
p^T_{ZZ}(GeV)
pp collisions at $\sqrt{S}$ = 14 TeV
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
p^T_{ZZ}(GeV)

Accuracy of the Sudakov Form Factor

POWHEG's Sudakov FF has the form (with $c \approx 1$)

$$\Delta_t = \exp\left[-\int_t^{Q^2} \frac{d k_T^2}{k_T^2} \frac{\alpha_S(c\, k_T^2)}{\pi} \left\{ A \log\frac{M^2}{k_T^2} + B \right\} \right]$$

We know that the NLL Sudakov form factor has the form

$$\Delta_t^{\mathrm{NLL}} = \exp\left[-\int_t^{Q^2} \frac{d k_T^2}{k_T^2} \frac{\alpha_S(k_T^2)}{\pi} \left\{ \left(A_1 + A_2 \frac{\alpha_s(k_T^2)}{\pi} \right) \log\frac{M^2}{k_T^2} + B \right\} \right]$$

provided the colour structure of the process is sufficiently simple ($\leqslant 3$ coloured legs). Can use this to fix c in POWHEG's Sudakov FF.
(Suggested in (Catani, Webber, Marchesini, 1991) for HERWIG)
$\geqslant 4$ coloured legs: exponentiation only holds in LL, or large N_c

Summarizing:
POWHEG Sudakov is: always LL accurate,
NLL accurate for $\leqslant 3$ coloured legs, NLL accurate in leading N_c in all cases.

Some topics on general formulation of POWHEG

Frixione, Oleari, P.N., work in progress

Extension to the general case only a matter of bookkeeping;
POWHEG is fully general, can be applied in any subtraction framework.

We look in details at POWHEG in

- the FKS (Frixione, Kunszt, Signer)
- the CS (Catani, Seymour) subtraction frameworks.

Flavour separation

There are several allowed flavour structures in the n body process. A flavour structure is a flavour assignment to the incoming and outgoing partons.
The B and V contributions are labelled by the flavour structure index f_b.

There are several allowed flavour structures in the $n+1$ body process.
Thus R is labelled by a flavour structure index f_r.
Each component R_{f_r} has several singularity regions. We thus write

$$R = \sum_{\alpha_r} R^{\alpha_r}$$

where each R^{α_r} has a specif flavour structure, and is singular in only one singular region. This partition of R is trivial to perform:

- FKS provides specific kinematic functions S_{α_r}, with $\sum_{\alpha_r} S_{\alpha_r} = 1$ that suppress all but one singular regions.
- in CS one can use instead $S_{\alpha_r} = C_{\alpha_r} / (\sum_{\alpha_r} C_{\alpha_r})$ where C_{α_r} are the dipole subtraction terms.

$\bar{B}$ carries an f_b index;
Sudakov FF also carries an f_b index:

$$\Delta^{f_b}(\Phi_n, p_T) = \exp\left\{ - \sum_{\alpha_r \in \{\alpha_r | f_b\}} \int \frac{\left[d\Phi_r \, R(\Phi_n, \Phi_r) \theta(k_T - p_T)\right]_{\alpha_r}}{B^{f_b}(\Phi_n)} \right\}$$

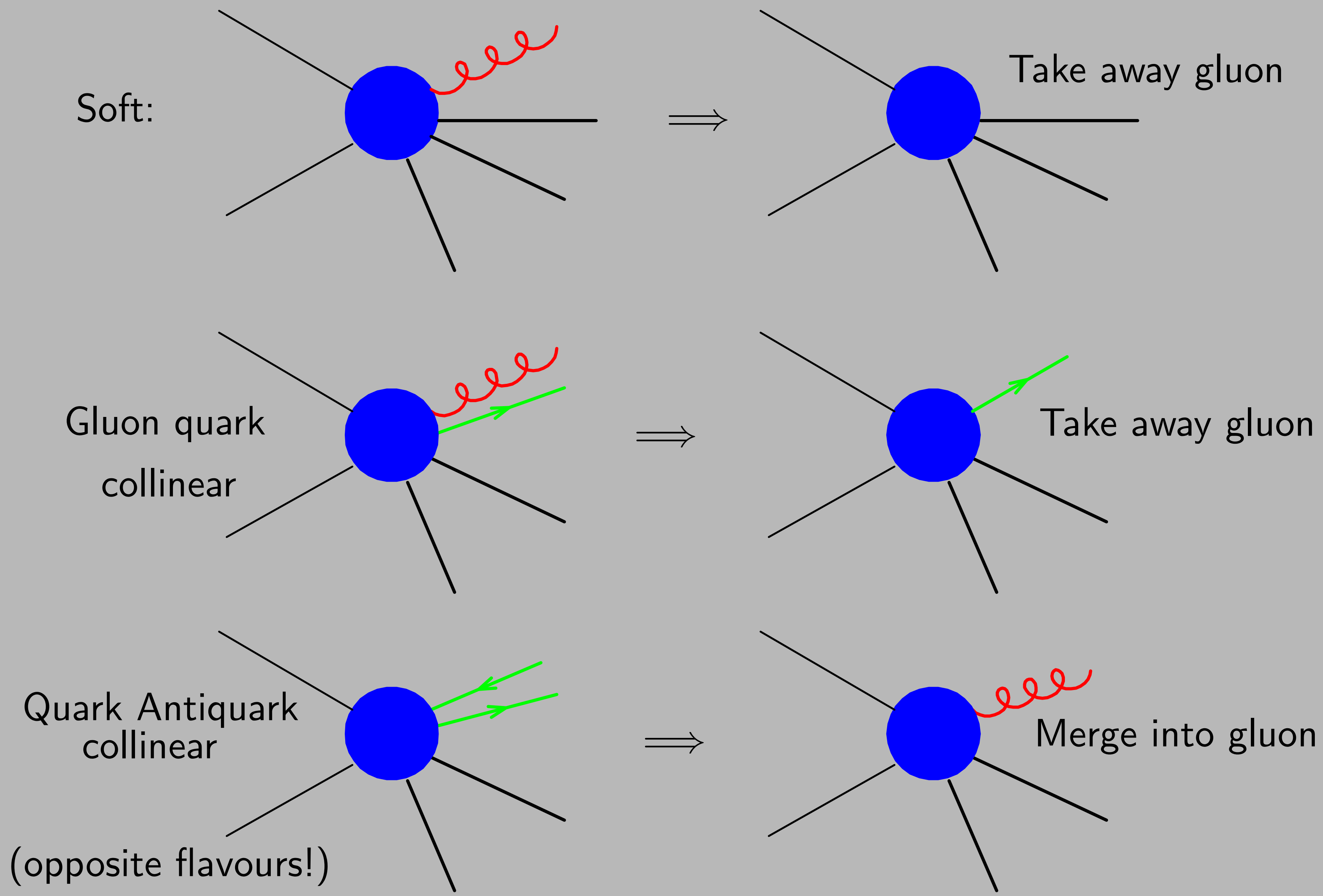
or

$$\Delta^{f_b}(\Phi_n, p_T) = \prod_{\alpha_r \in \{\alpha_r | f_b\}} \exp\left\{ - \sum \int \frac{\left[d\Phi_r \, R(\Phi_n, \Phi_r) \theta(k_T - p_T)\right]_{\alpha_r}}{B^{f_b}(\Phi_n)} \right\}$$

where

- $\{\alpha_r | f_b\}$ is the set of all singular regions having the underlying Born configuration with flavour structure f_b.
- $[\ldots]_{\alpha_r}$ means that everything inside is relative to the α_r singular term: thus R is R_{α_r}, the parametrization (Φ_n, Φ_r) is the one appropriate to the α_r singular region

The last expression is closer to typical SMC's, with each emission considered independently.


Soft:
Take away gluon
Gluon quark
collinear
Take away gluon
Quark Antiquark
collinear
(opposite flavours!)
Merge into gluon

Work in progress: Heavy Flavour Production

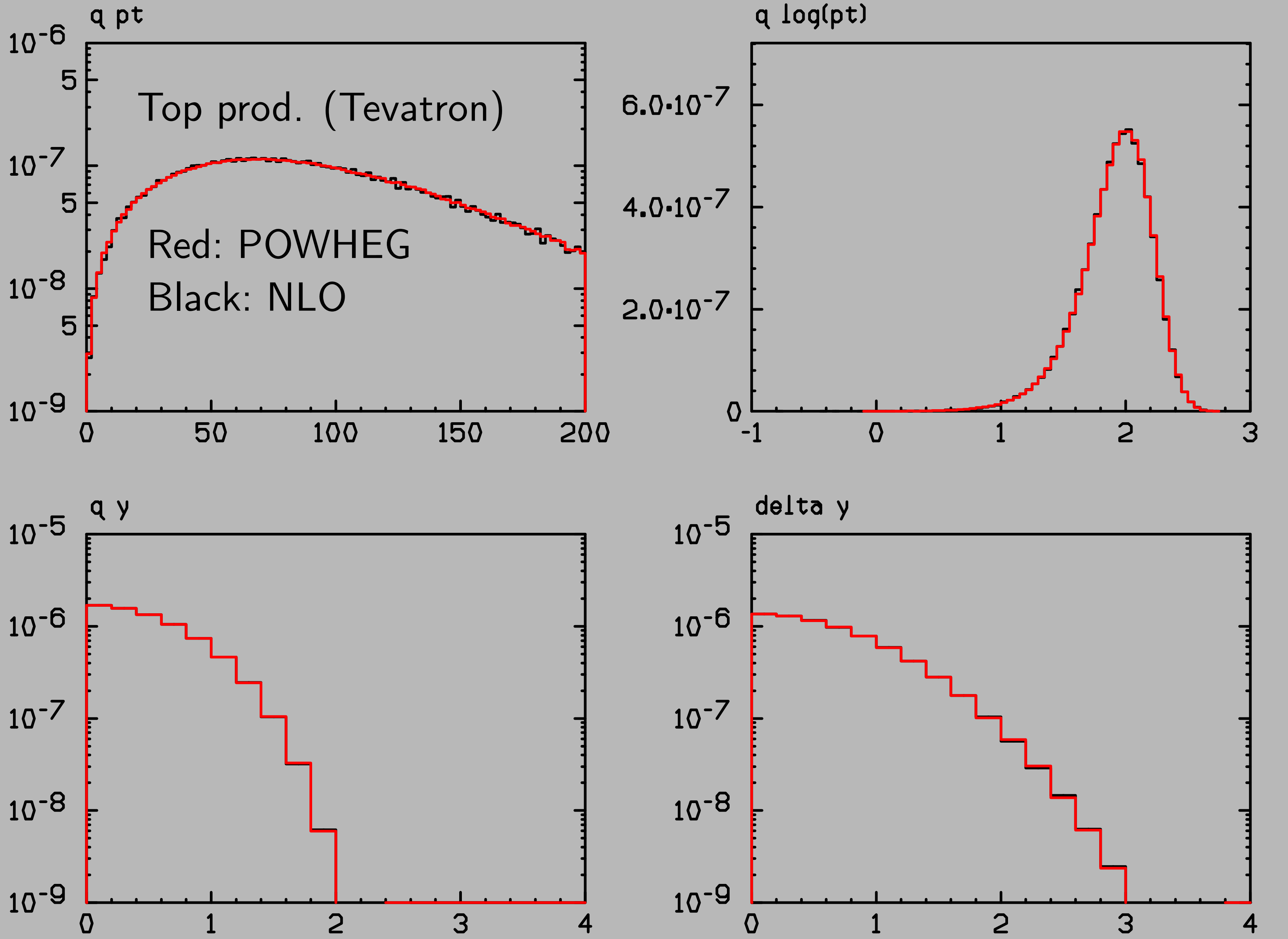
with S. Frixione, M. Mangano and G. Ridolfi

NLO calculation much more complex than in ZZ production.
However, POWHEG implementation is as easy.
Detailed soft structure of HVQ production hidden in the ratio R/B.

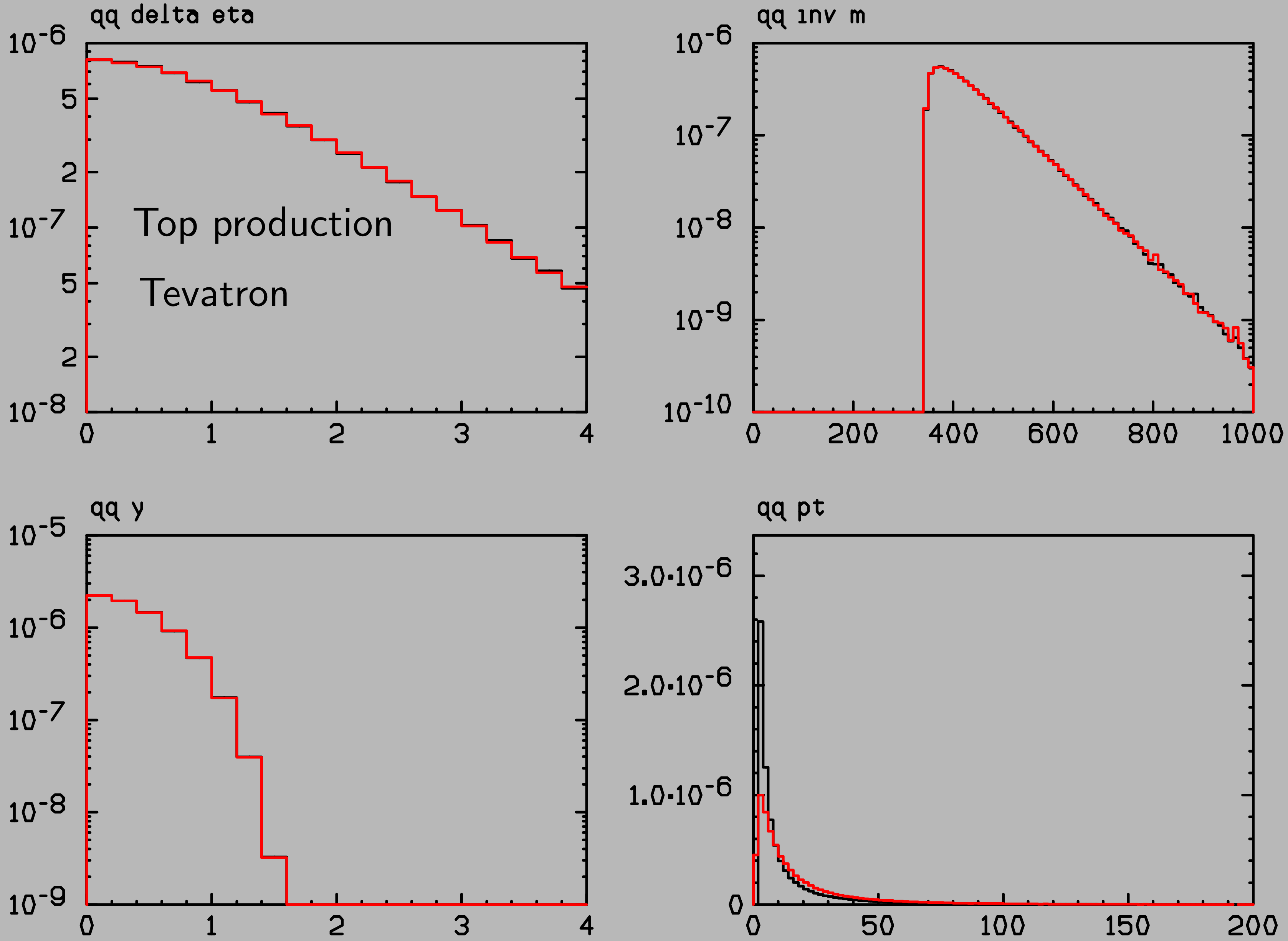
Status:

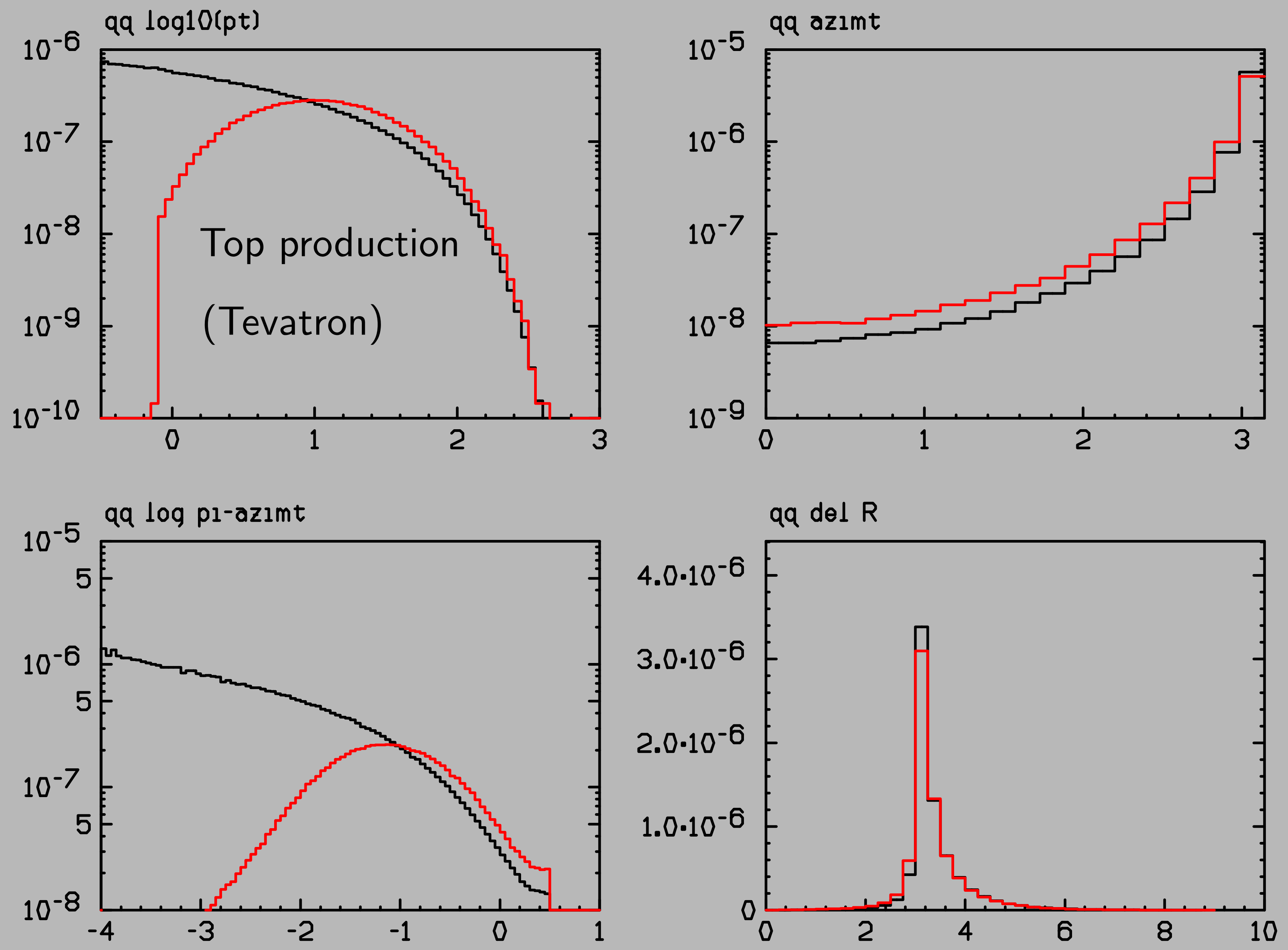
- POWHEG Generator ready and working
- LHI interface under work

Some raw plots follow ...

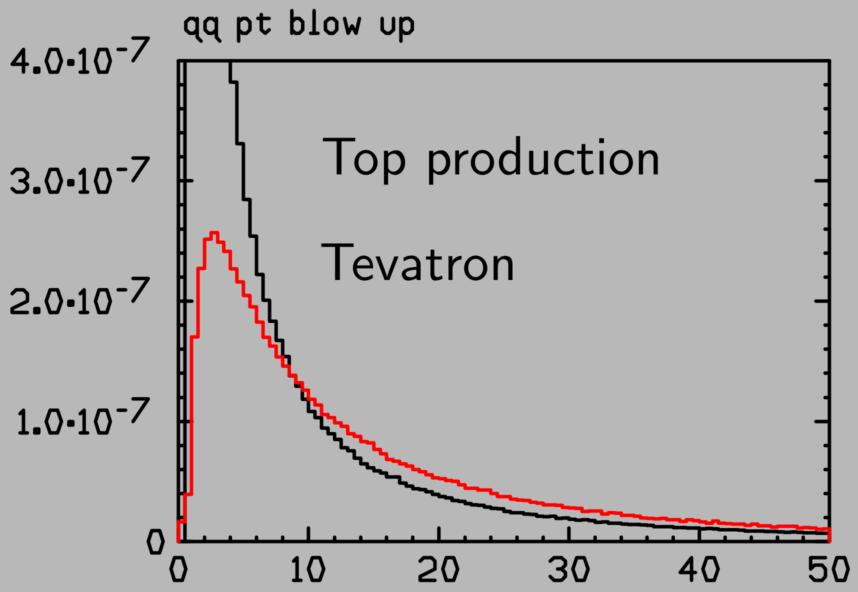


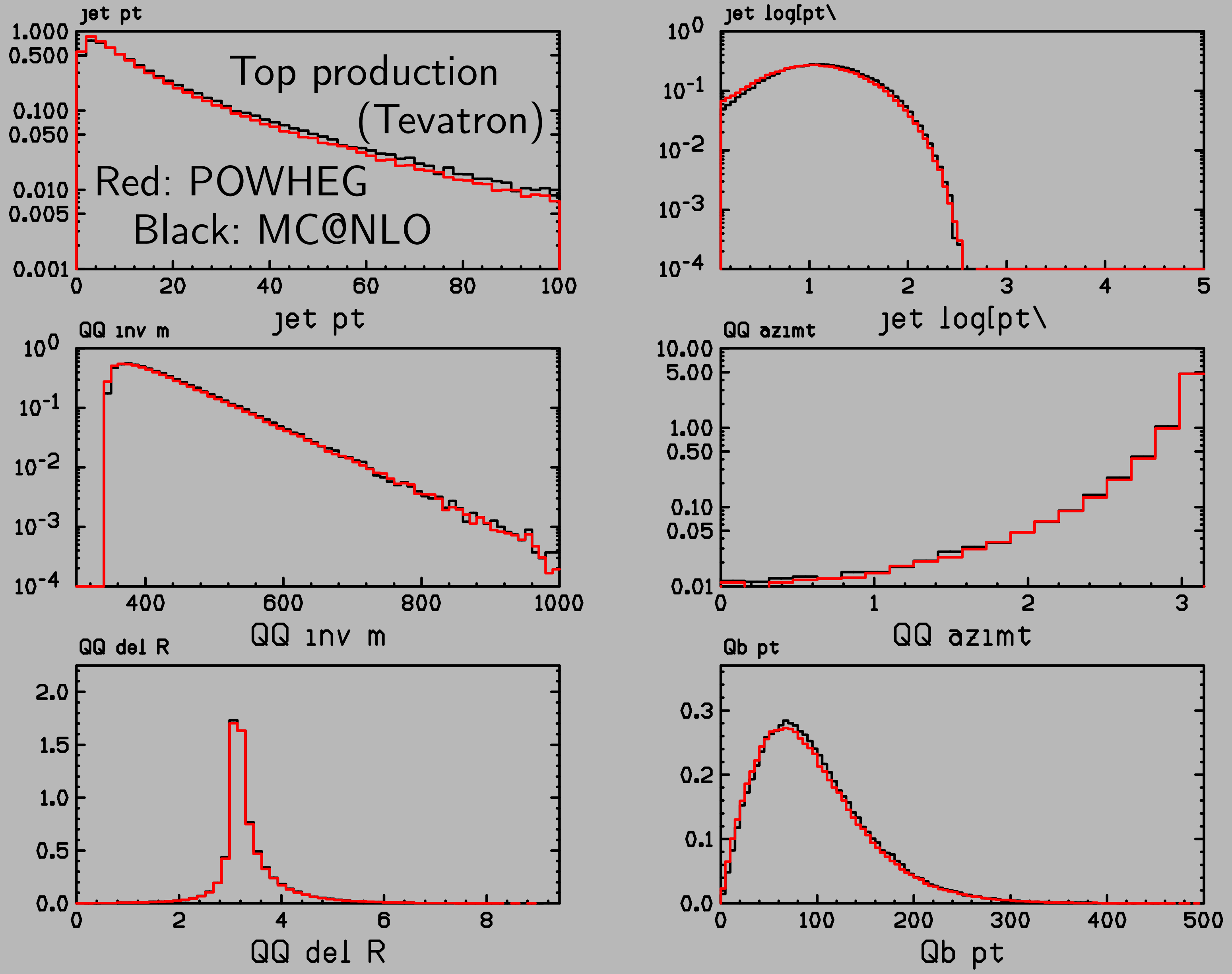
q pt
Top prod. (Tevatron)
Red: POWHEG
Black: NLO
q log(pt)
q y
delta y


qq delta eta
Top production
Tevatron
qq inv m
qq y
qq pt
10-6
5
2
10-7
5
2
10-8
0
1
2
3
4
10-6
10-7
10-8
10-9
10-10
0
200
400
600
800
1000
10-5
10-6
10-7
10-8
10-9
0
1
2
3
4
3.0·10-6
2.0·10-6
1.0·10-6
0
0
50
100
150
200



qq log10(pt)
Top production
(Tevatron)
qq azimt
qq log pi-azimt
qq del R


qq pt blow up
4.0·10-7
3.0·10-7
2.0·10-7
1.0·10-7
0
0
10
20
30
40
50
Top production
Tevatron



jet pt
Top production
(Tevatron)
Red: POWHEG
Black: MC@NLO
1.000
0.500
0.100
0.050
0.010
0.005
0.001
0
20
40
60
80
100
jet pt
jet log[pt\
10^0
10^-1
10^-2
10^-3
10^-4
1
2
3
4
5
jet log[pt\
QQ inv m
10^0
10^-1
10^-2
10^-3
10^-4
400
600
800
1000
QQ inv m
QQ azimt
10.00
5.00
1.00
0.50
0.10
0.05
0.01
0
1
2
3
QQ azimt
QQ del R
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
QQ del R
Qb pt
0.3
0.2
0.1
0.0
0
100
200
300
400
500
Qb pt

M. Treccani
Frascati,
23 Maggio 2006

ALPGEN & MC@NLO

Processo: $t\bar{t} + 1$ jet

- S. Frixione and B. R. Webber, "The MC@NLO 3.2 event generator" hep- ph/0601192

  General approach: S. Frixione and B. R. Webber, JHEP **0206** (2002) 029 [hep- ph/0204244];

  $t\bar{t}$ production: S. Frixione, P. Nason and B. R. Webber, JHEP **0308** (2003) 007[hep- ph/0305252].

- ALPGEN:
  - Generazione: $P^t_{min} = 30\, GeV$, $\Delta R = 0.7$
  - Matching: $E^t_{min} = 30\, GeV$, $\Delta R = 0.7$

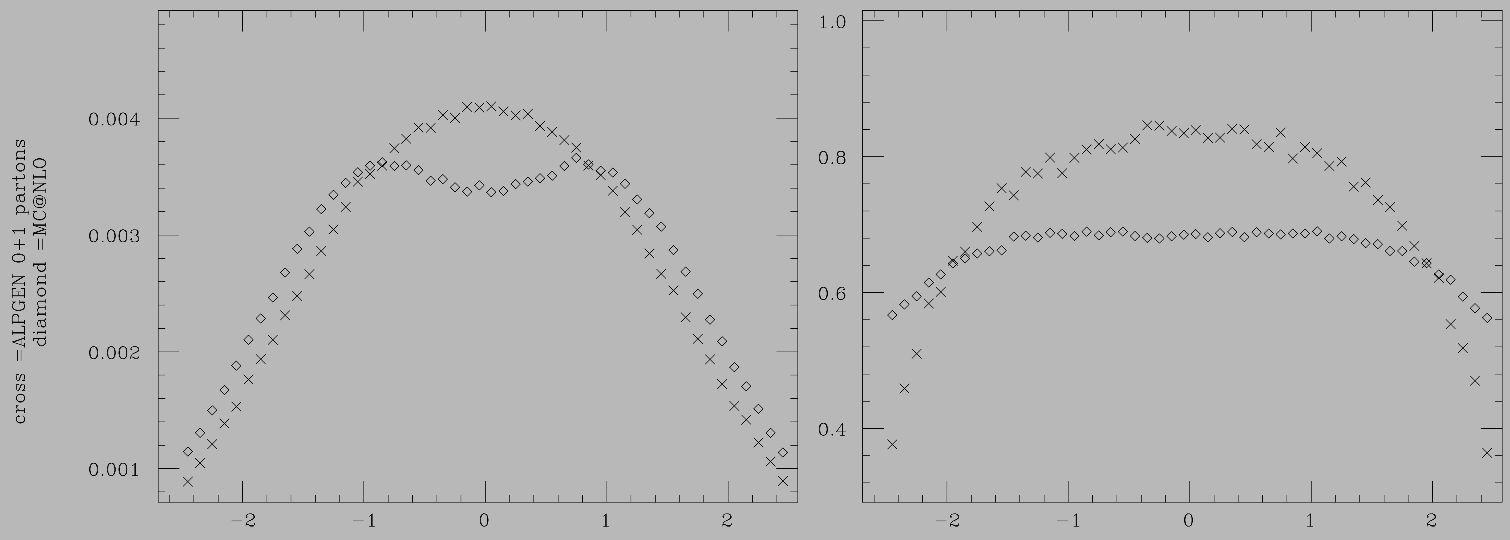
Definizione dei jet per l'analisi:

$TeVatron\ E^t_{min} = 15\, GeV,\ \Delta R = 0.4$ $\qquad$ $LHC\ E^t_{min} = 20\, GeV,\ \Delta R = 0.5$

Confronto tra ALPGEN e MC@NLO$\rightarrow$ introdurre il K- factor

$TeVatron \qquad K = 1.45 \qquad\qquad LHC \qquad K = 1.57$

Extra-radiazione, Y del jet leading

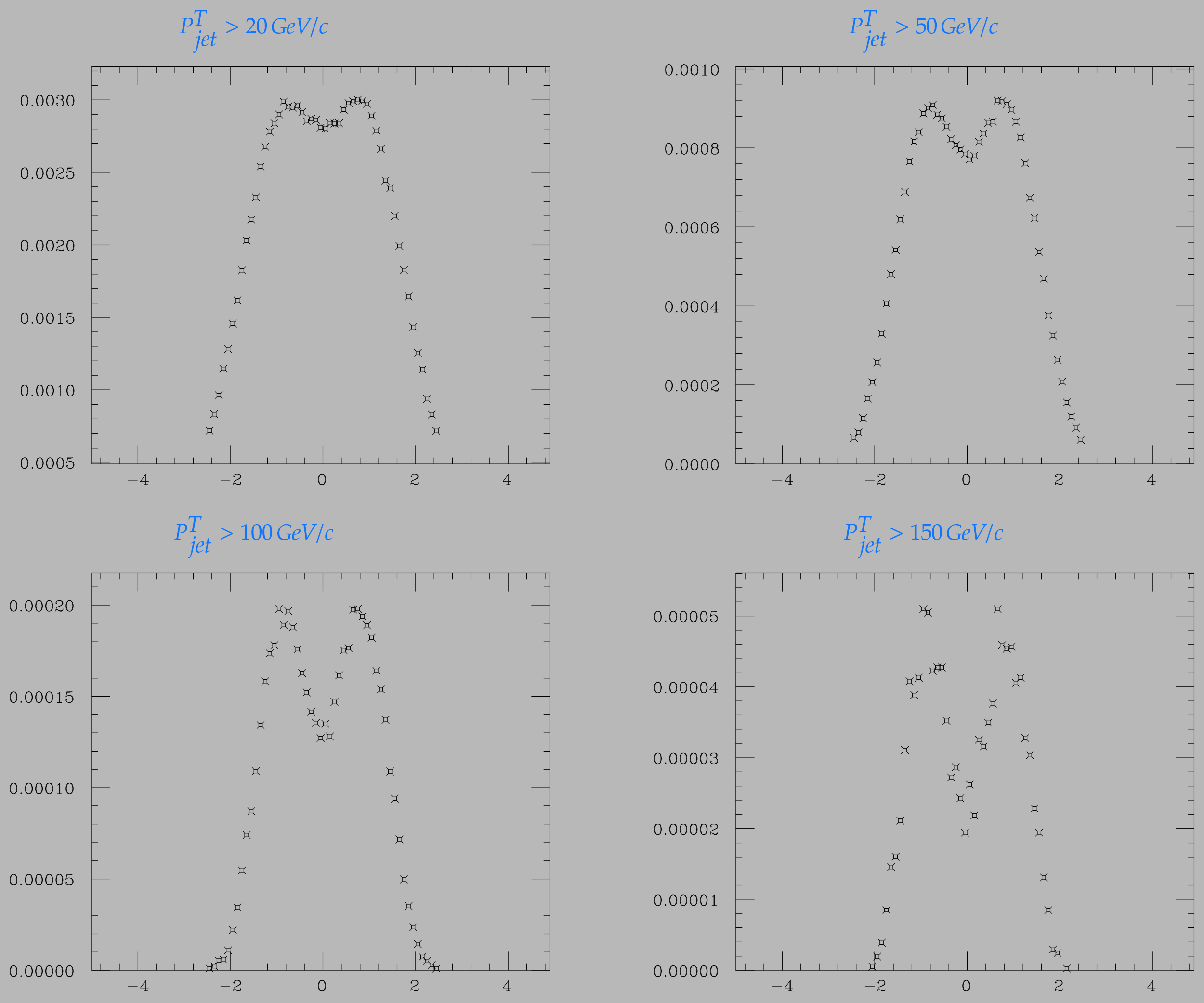


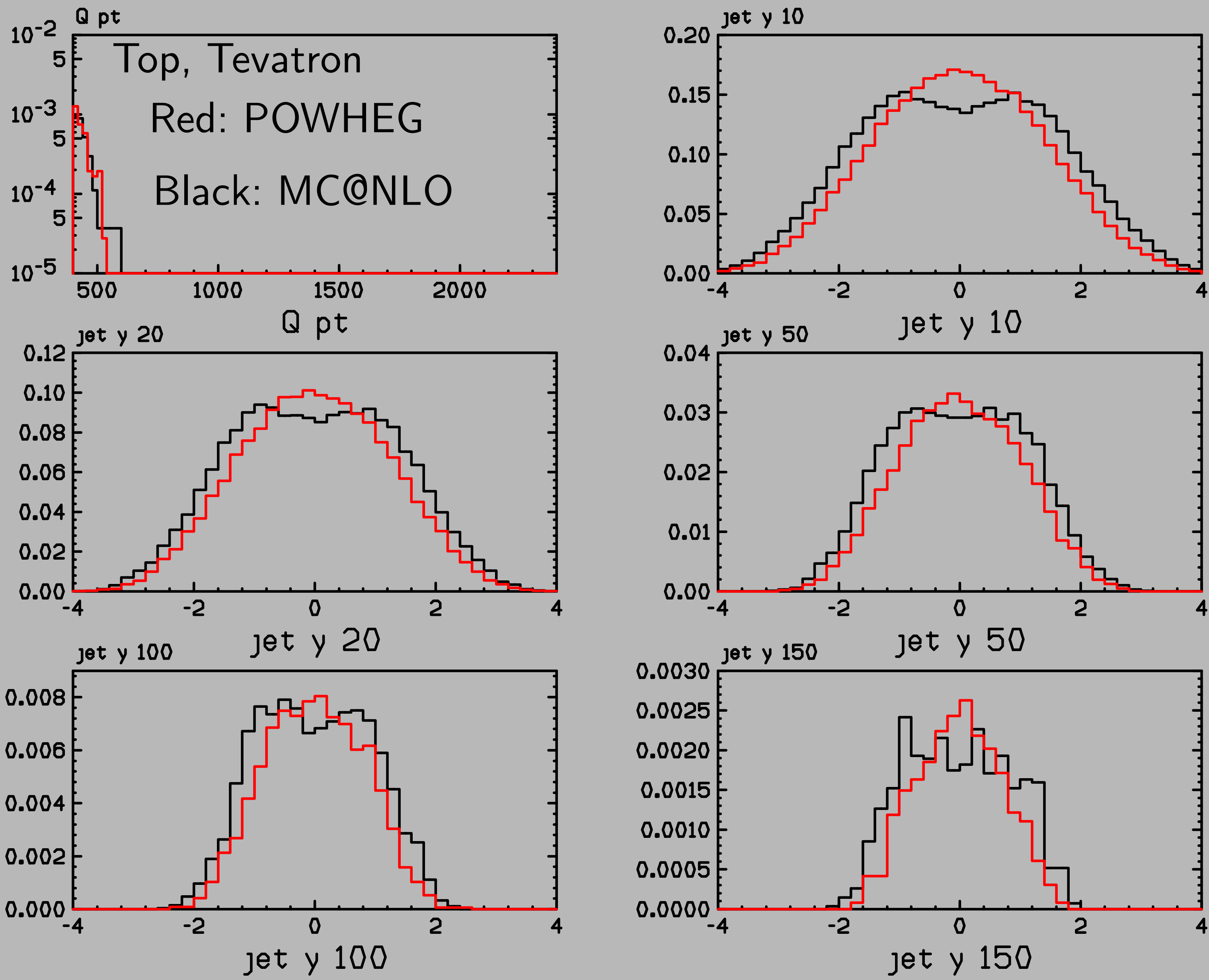
TeVatron LHC

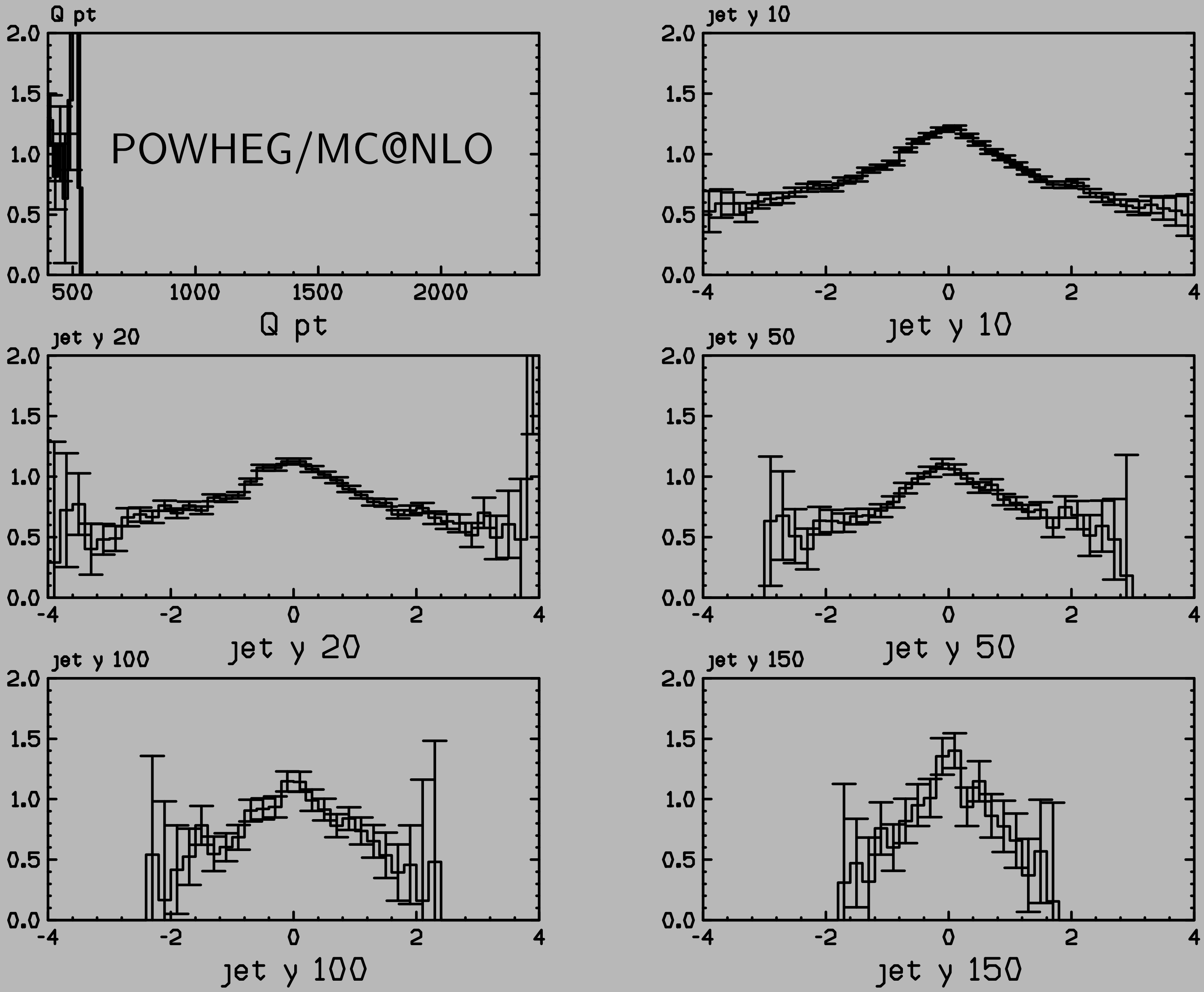
Struttura differente sia TeVatron che LHC

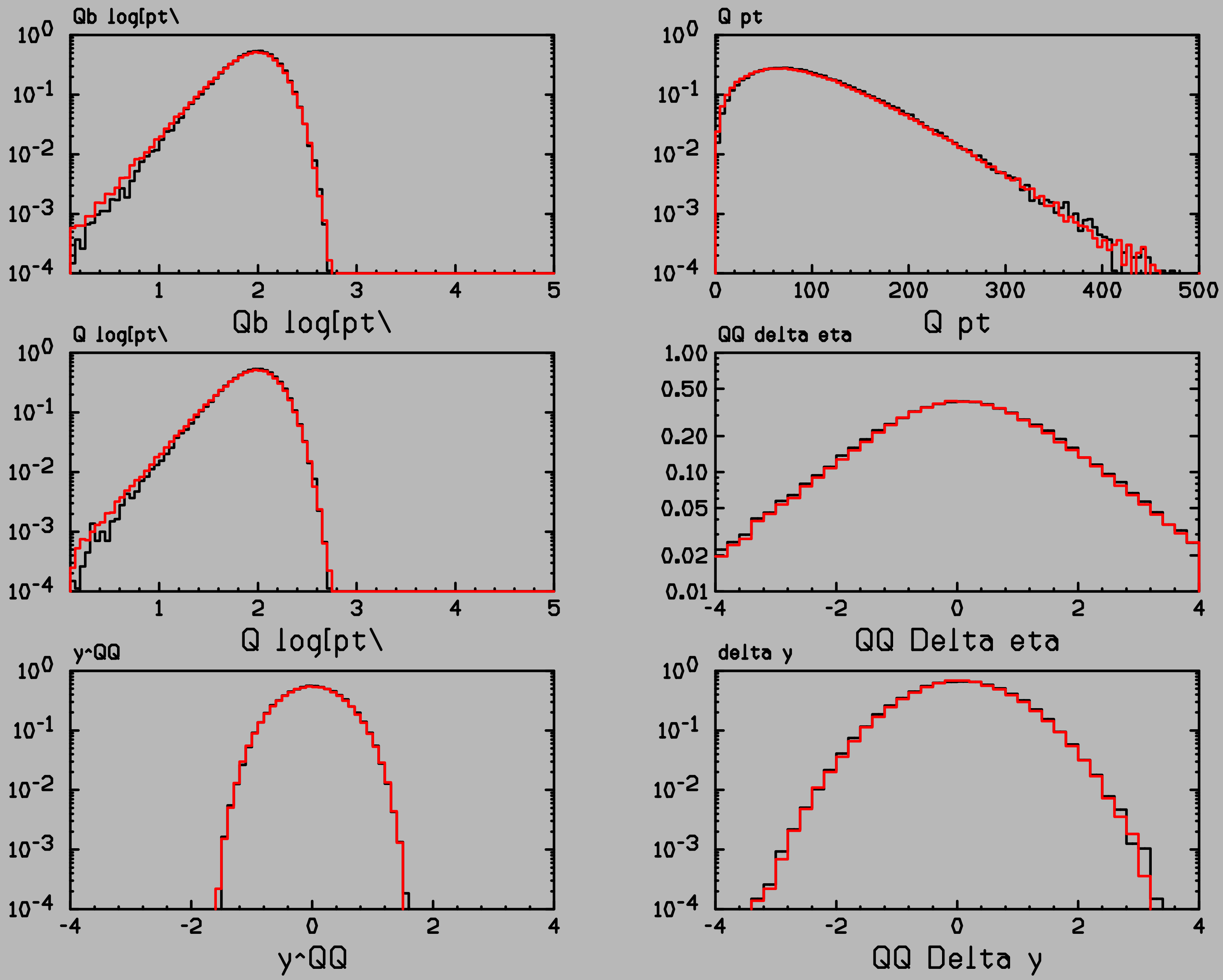
TeVatron effetto maggiore, studiamo i contributi parziali

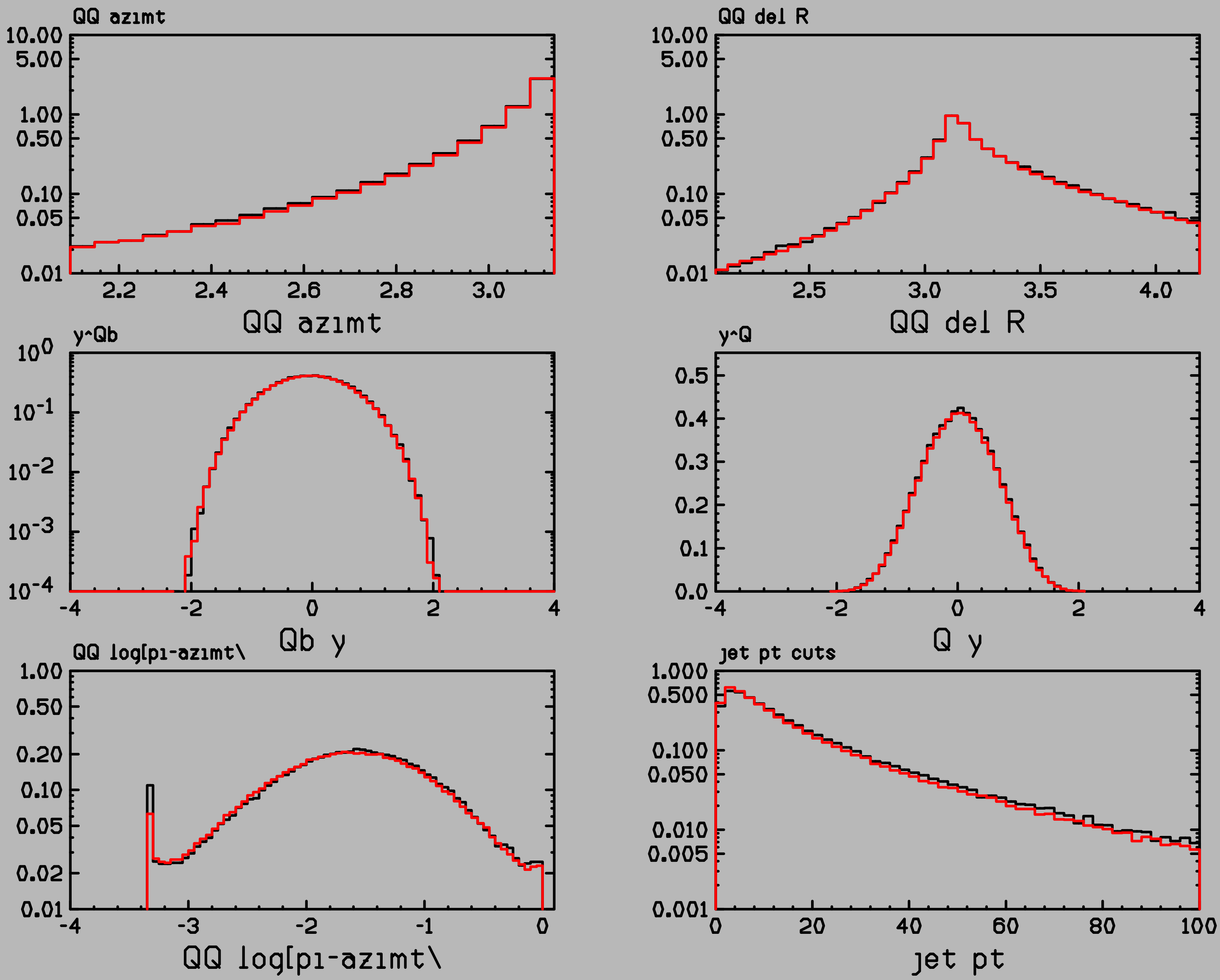
Jet da extra-radiazione, Y_{jet}, HERWIG



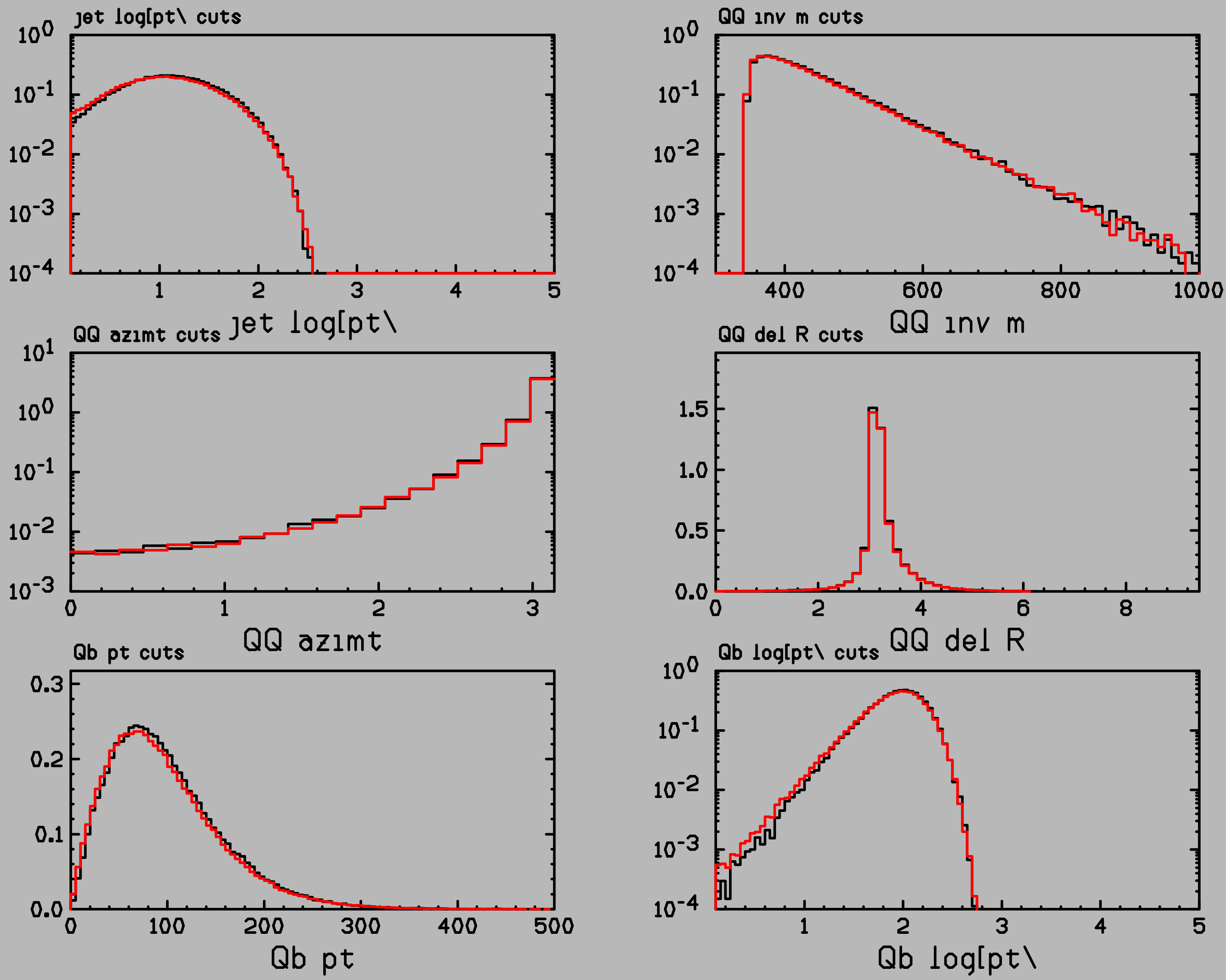

Q pt
Top, Tevatron
Red: POWHEG
Black: MC@NLO
Q pt
jet y 10
jet y 10
jet y 20
jet y 20
jet y 50
jet y 50
jet y 100
jet y 100
jet y 150
jet y 150

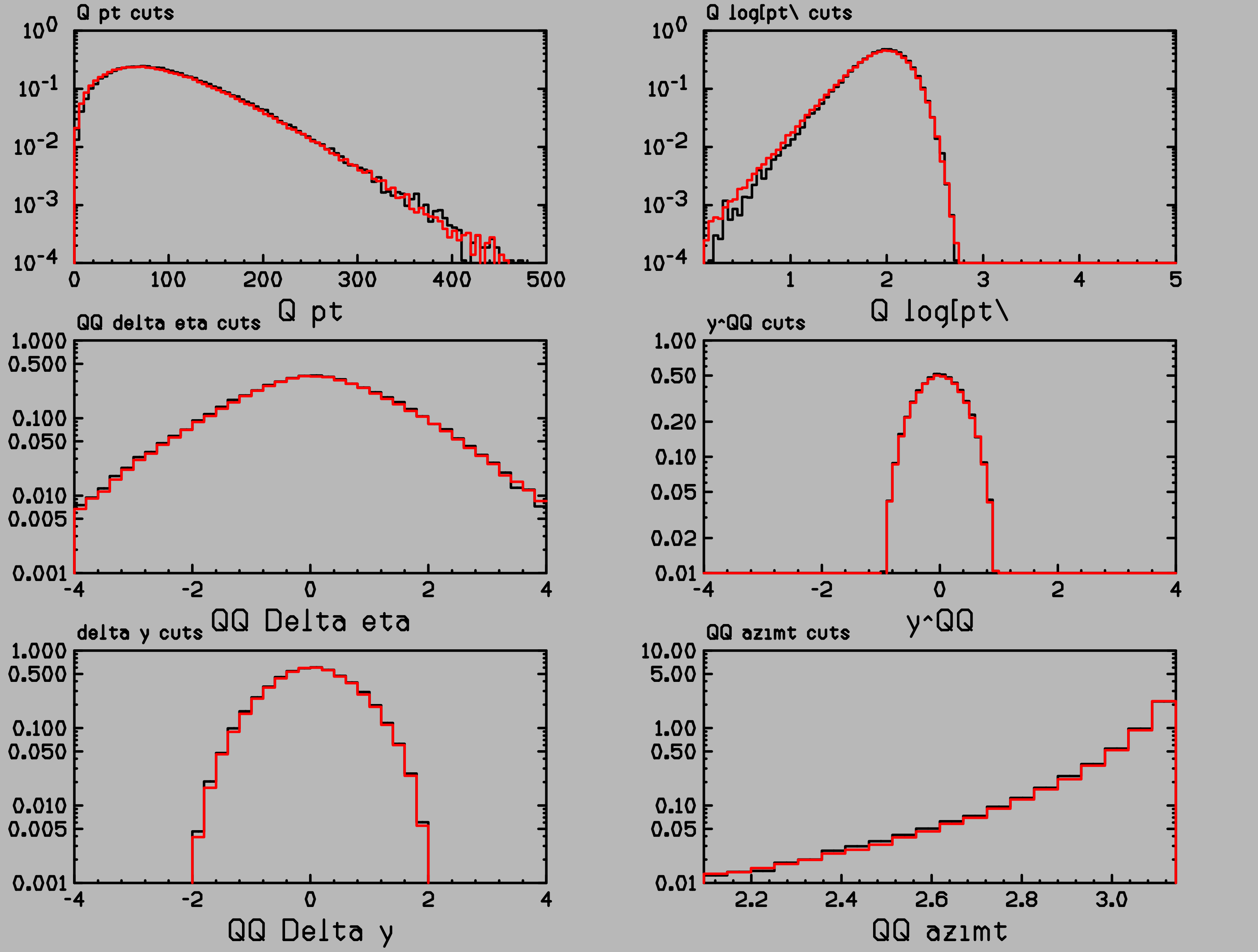

POWHEG/MC@NLO
Q pt
jet y 10
jet y 20
jet y 50
jet y 100
jet y 150
0.0
0.5
1.0
1.5
2.0
500
1000
1500
2000
-4
-2
0
2
4


Qb log[pt\
Qb log[pt\
Q pt
Q pt
Q log[pt\
Q log[pt\
QQ delta eta
QQ Delta eta
y^QQ
y^QQ
delta y
QQ Delta y

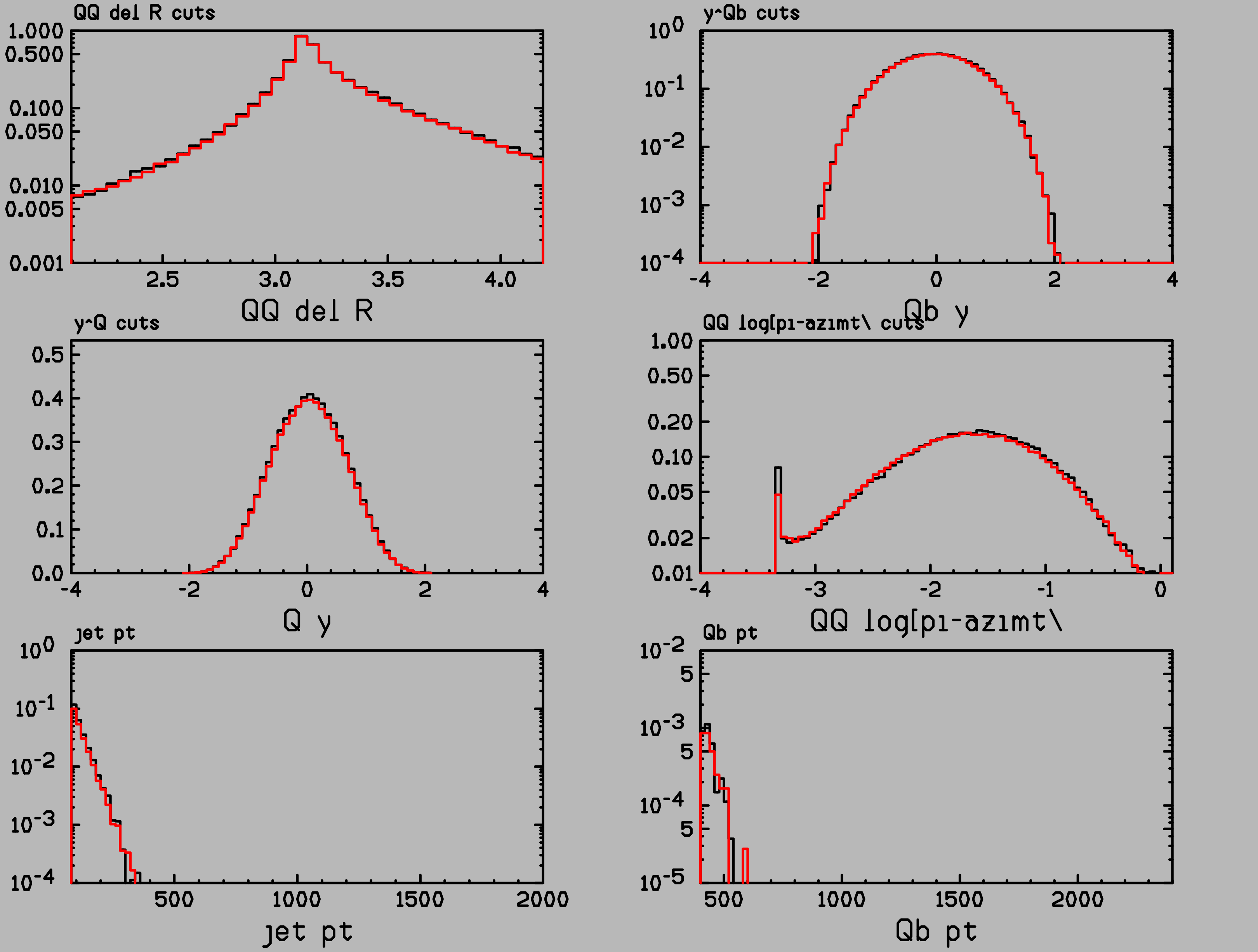


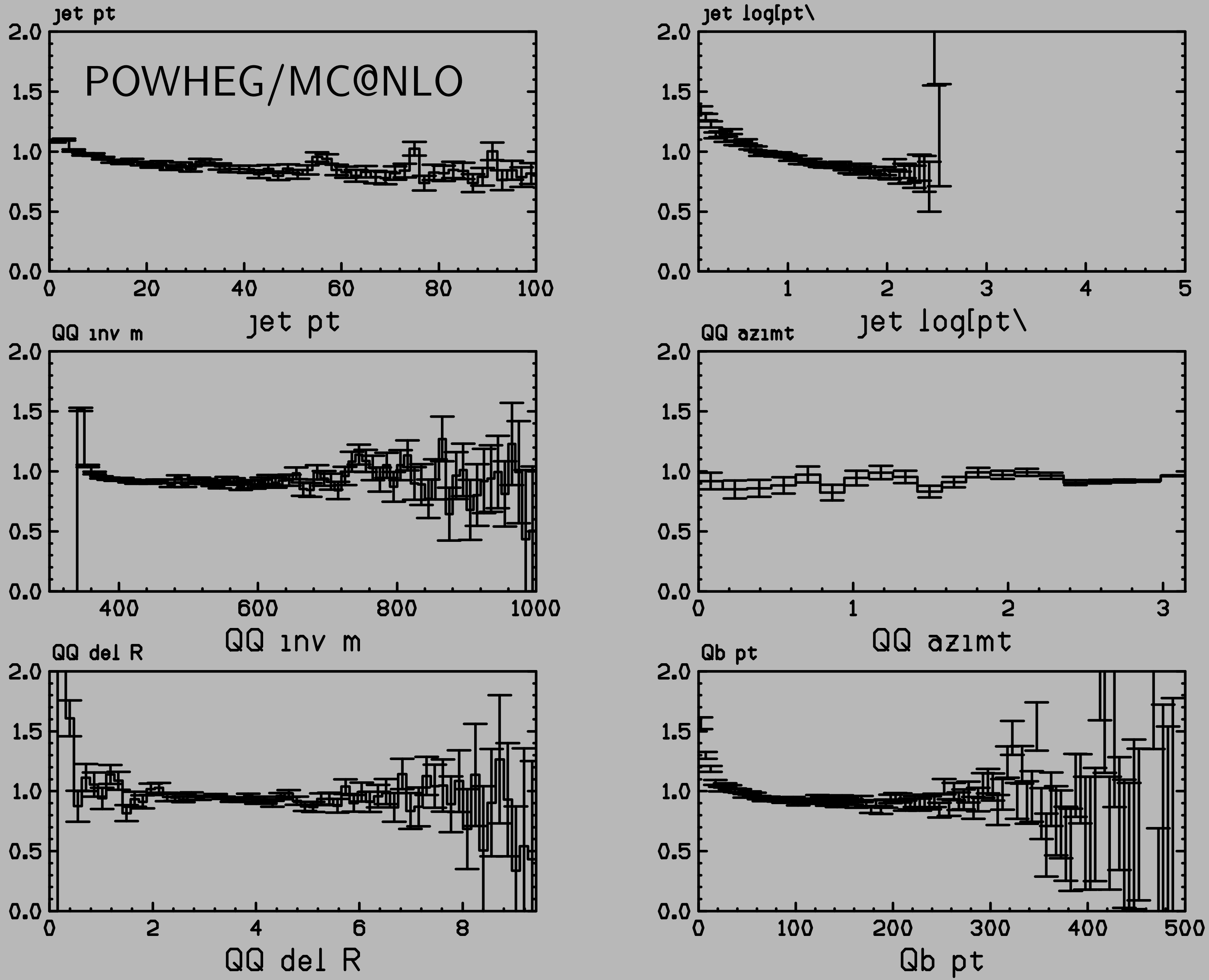
QQ azimt
QQ del R
y^Qb
y^Q
QQ log[pi-azimt\
jet pt cuts
QQ azimt
QQ del R
Qb y
Q y
QQ log[pi-azimt\
jet pt


jet log[pt\ cuts
jet log[pt\
QQ inv m cuts
QQ inv m
QQ azimt cuts
QQ azimt
QQ del R cuts
QQ del R
Qb pt cuts
Qb pt
Qb log[pt\ cuts
Qb log[pt\

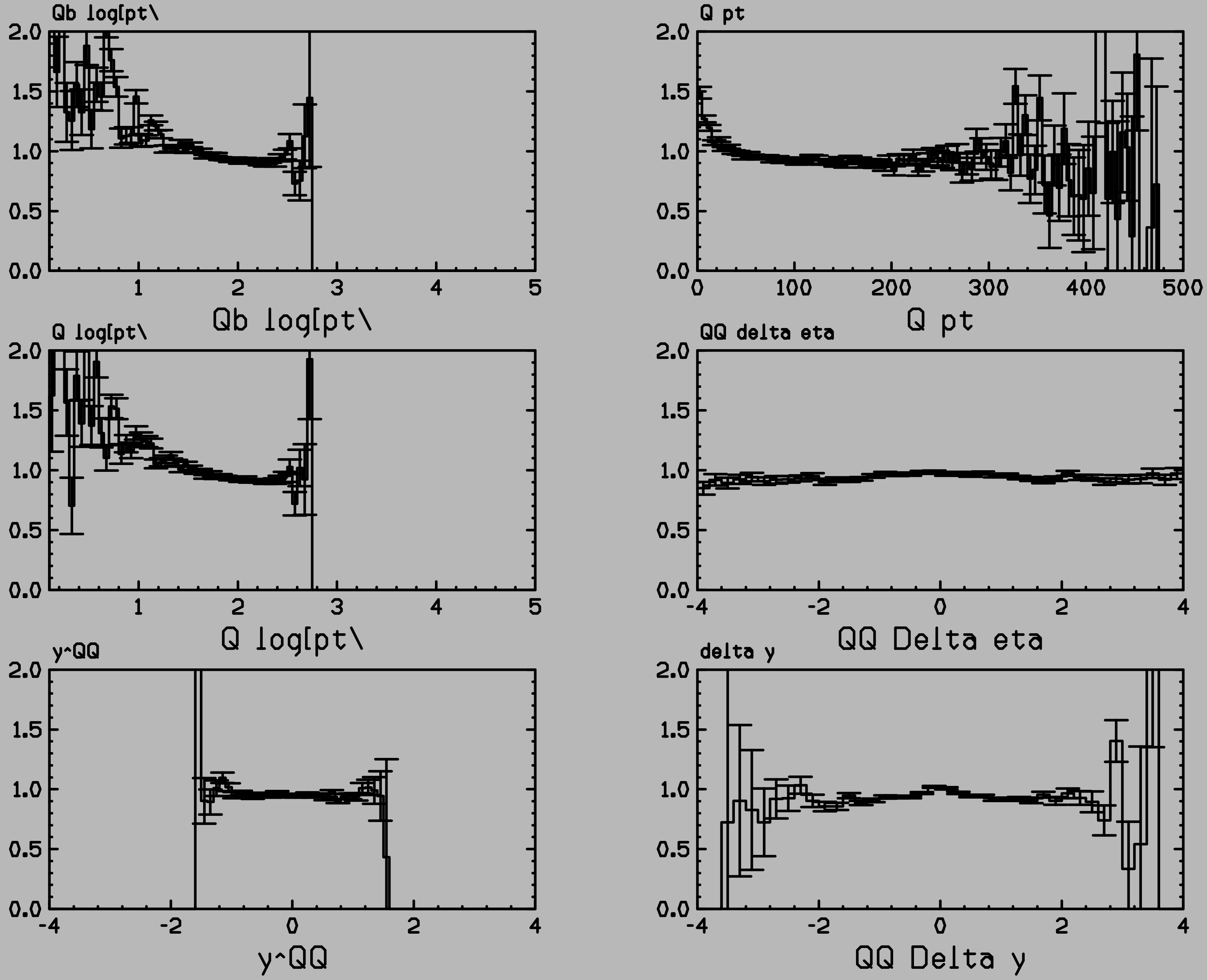


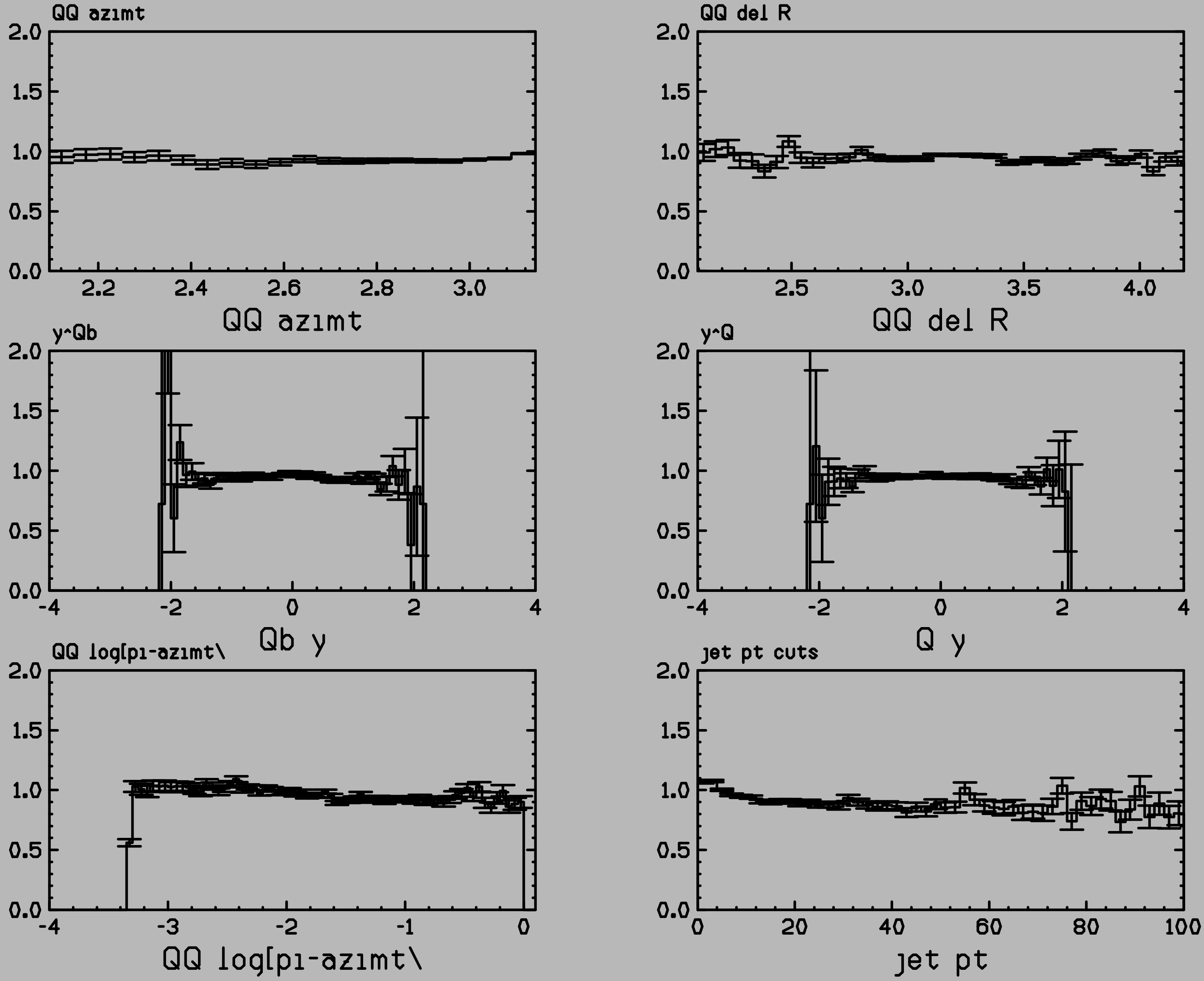
Q pt cuts
10^0
10^-1
10^-2
10^-3
10^-4
0
100
200
300
400
500
Q pt
Q log[pt\ cuts
1
2
3
4
5
Q log[pt\
QQ delta eta cuts
1.000
0.500
0.100
0.050
0.010
0.005
0.001
-4
-2
0
2
4
QQ Delta eta
y^QQ cuts
1.00
0.50
0.20
0.10
0.05
0.02
0.01
y^QQ
delta y cuts
QQ Delta y
QQ azimt cuts
10.00
5.00
2.2
2.4
2.6
2.8
3.0
QQ azimt

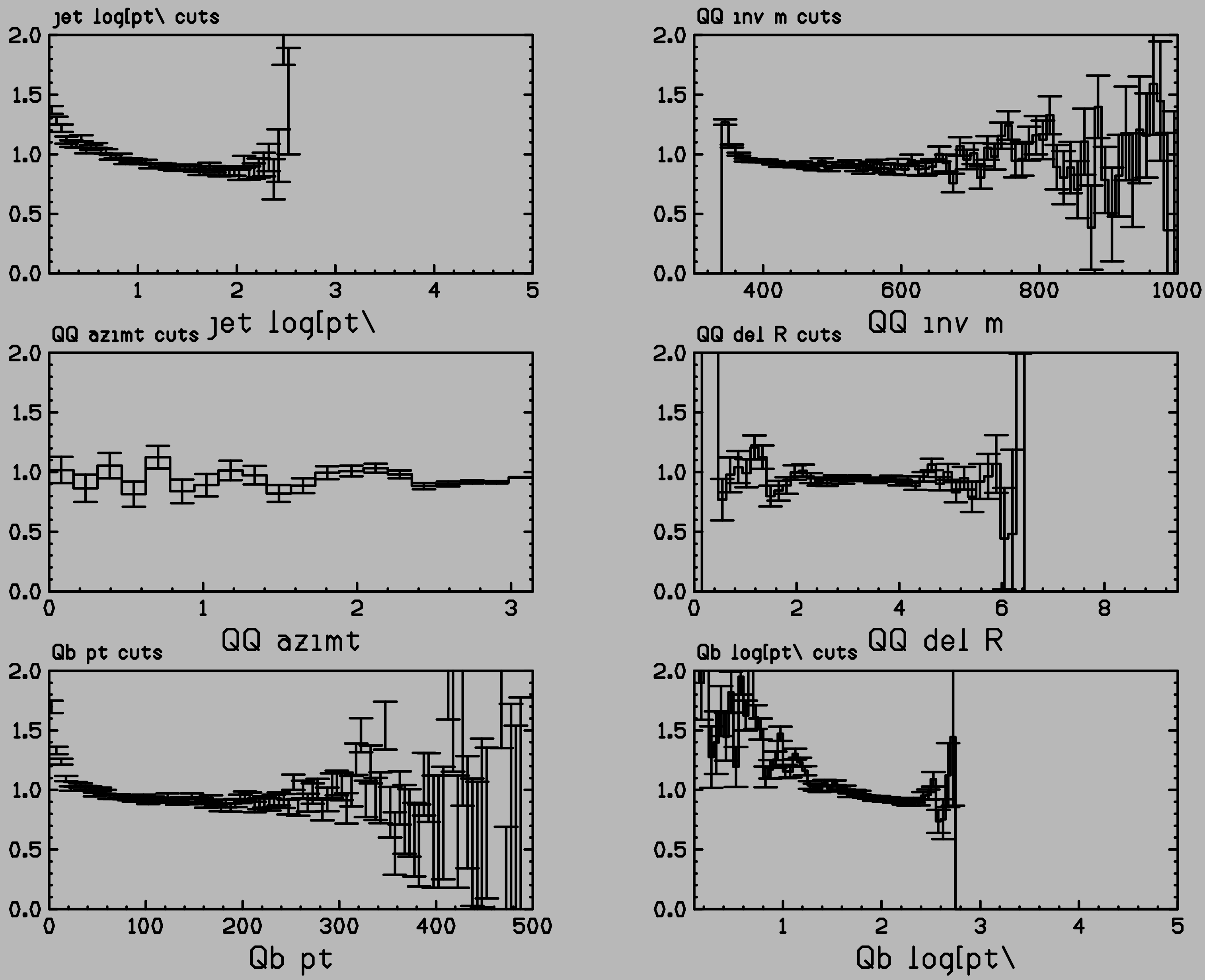

QQ del R cuts
QQ del R
y^Qb cuts
Qb y
y^Q cuts
Q y
QQ log[pi-azimt\ cuts
QQ log[pi-azimt\
jet pt
jet pt
Qb pt
Qb pt

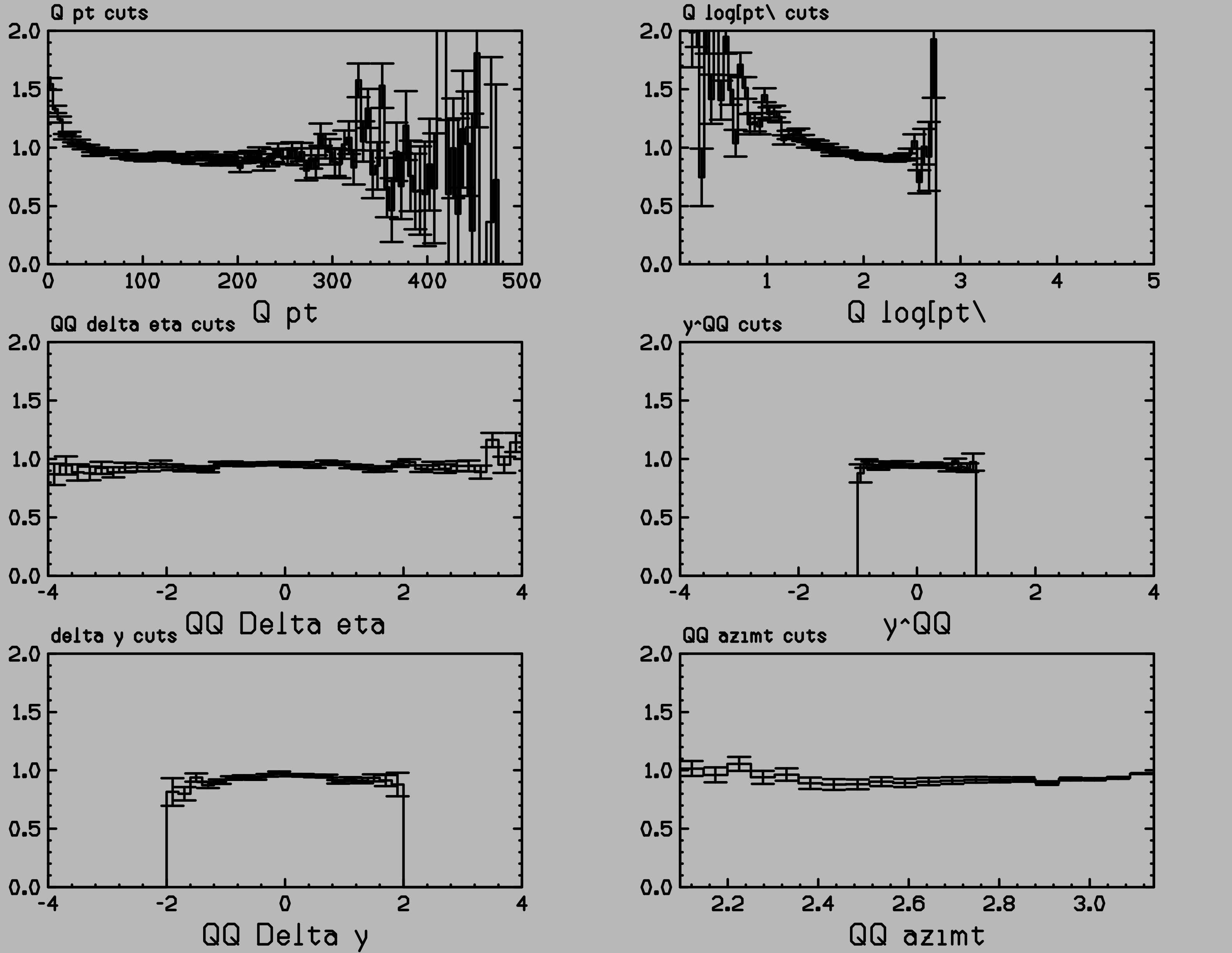


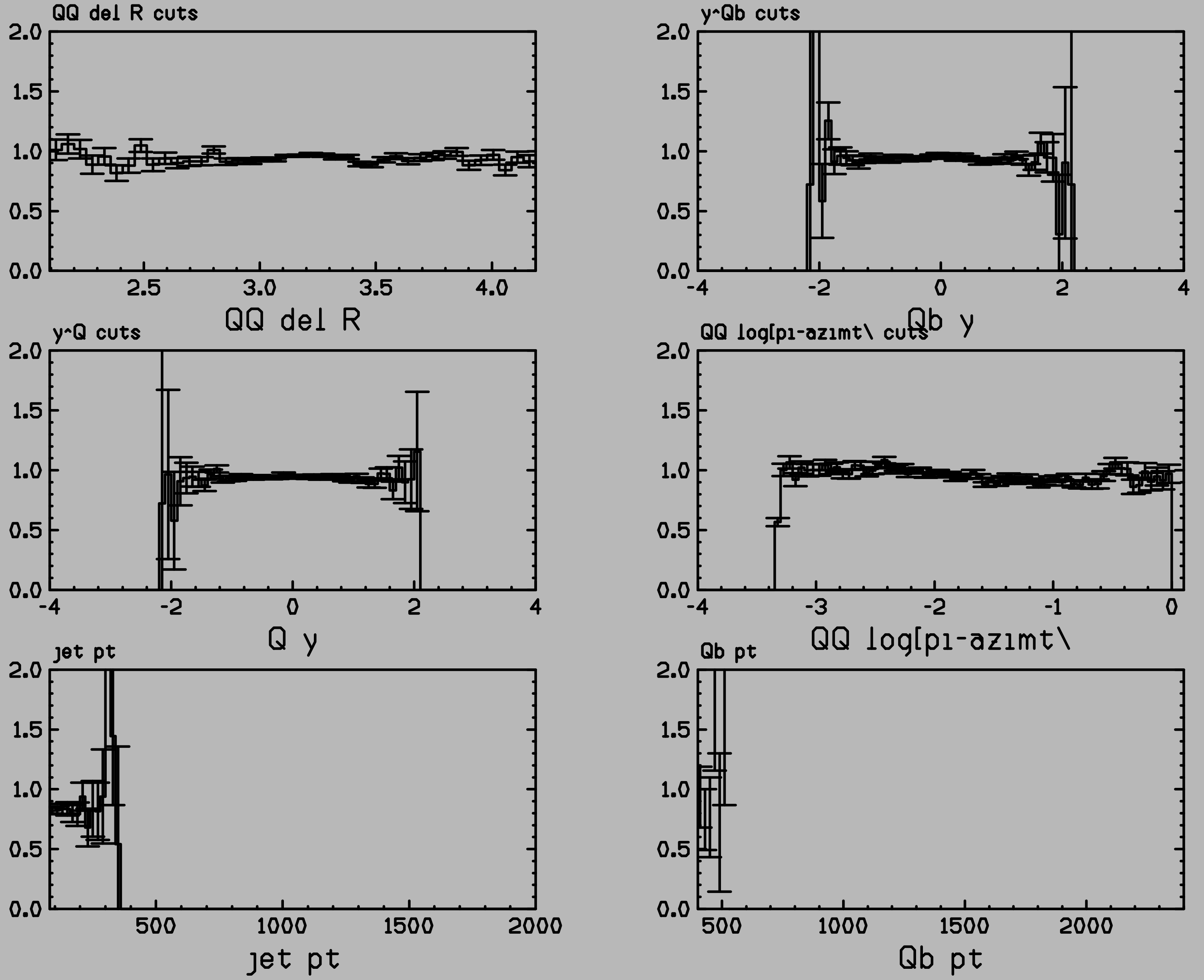
jet pt
POWHEG/MC@NLO
jet log[pt\
QQ inv m
QQ azimt
QQ del R
Qb pt

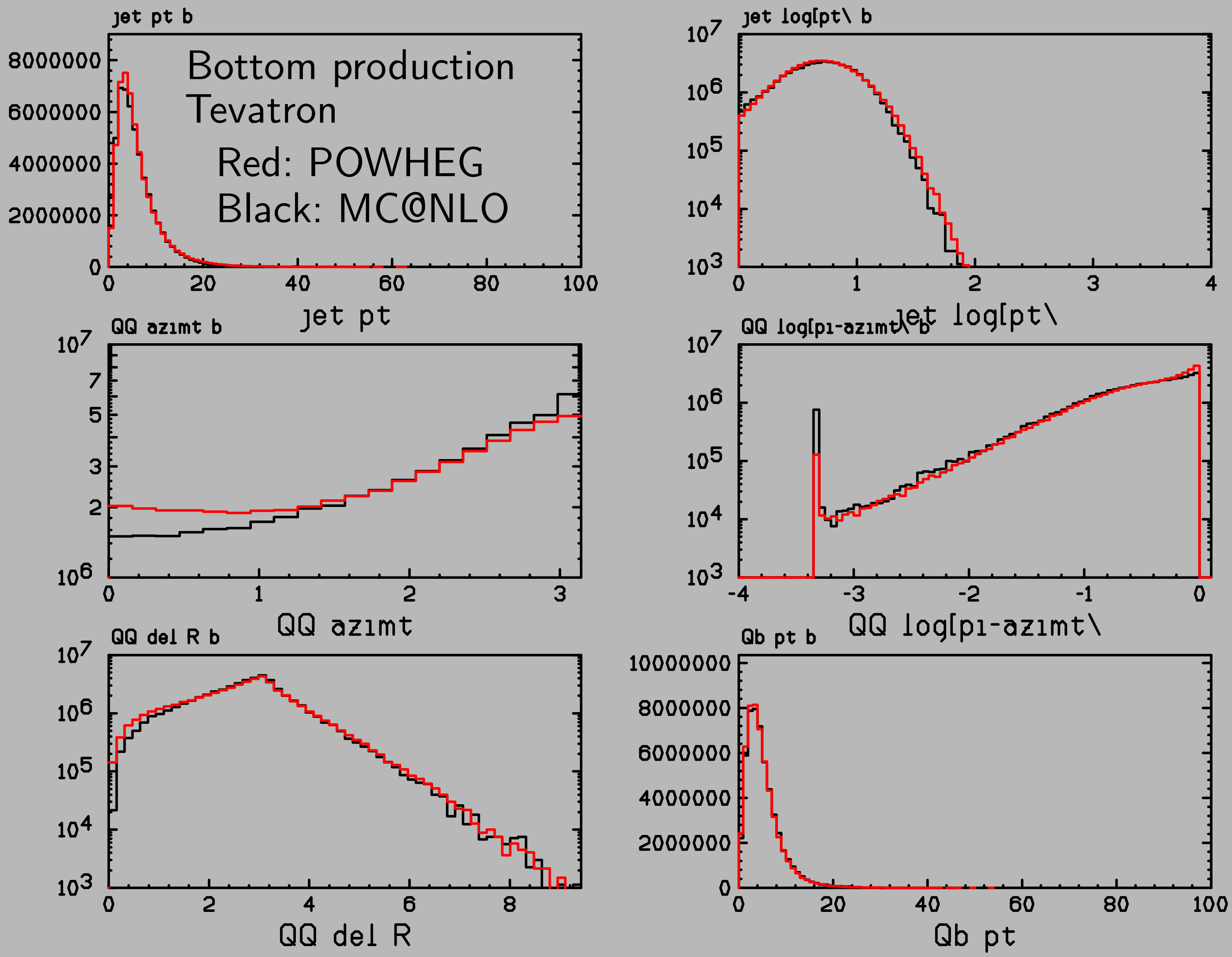

Qb log[pt\
Qb log[pt\
Q pt
Q pt
Q log[pt\
Q log[pt\
QQ delta eta
QQ Delta eta
y^QQ
y^QQ
delta y
QQ Delta y

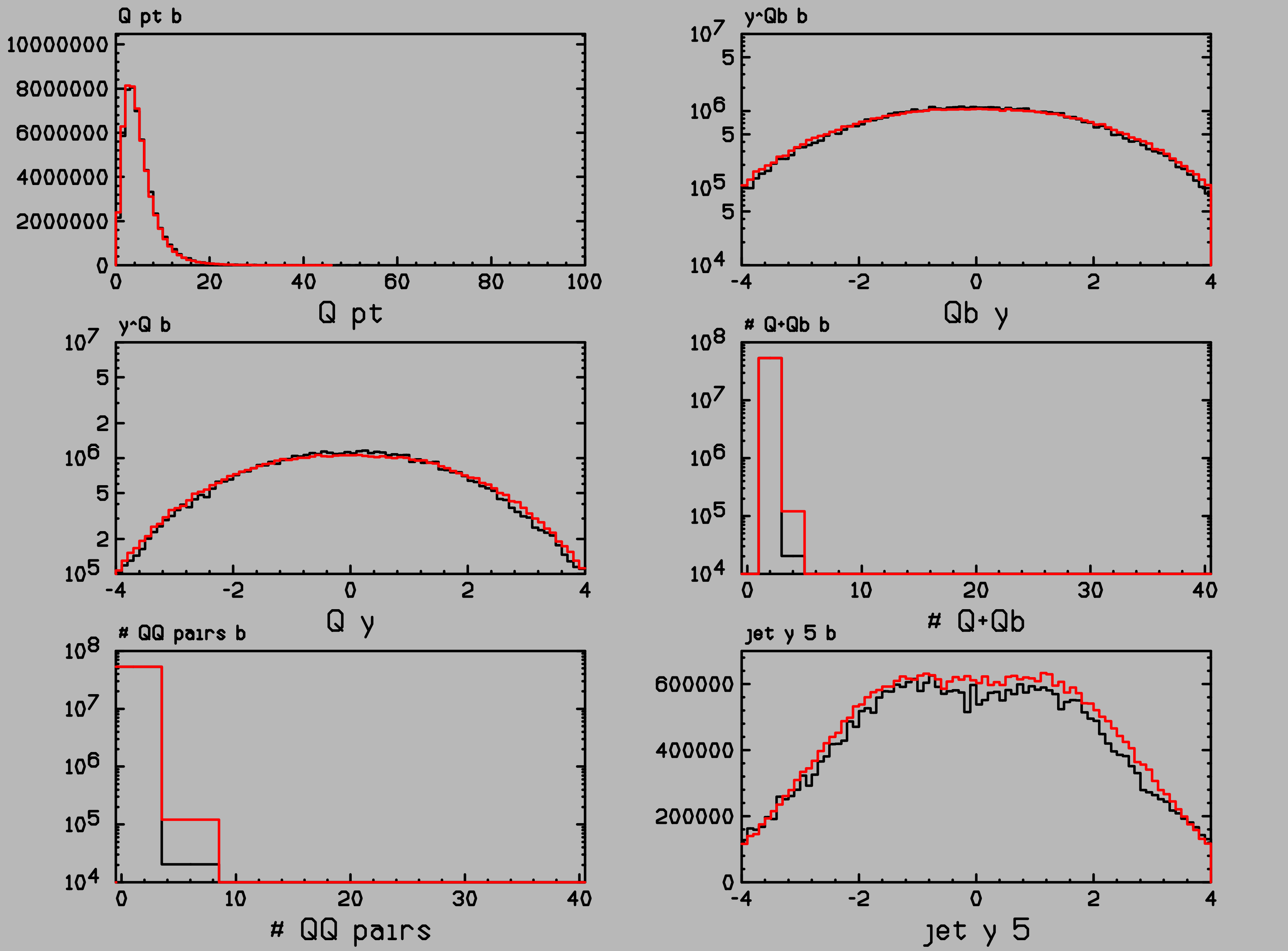

QQ azımt
2.0
1.5
1.0
0.5
0.0
2.2
2.4
2.6
2.8
3.0
QQ azımt
QQ del R
2.5
3.0
3.5
4.0
QQ del R
y^Qb
-4
-2
0
2
4
Qb y
y^Q
Q y
QQ log[pı-azımt\
-3
-1
QQ log[pı-azımt\
jet pt cuts
20
40
60
80
100
jet pt

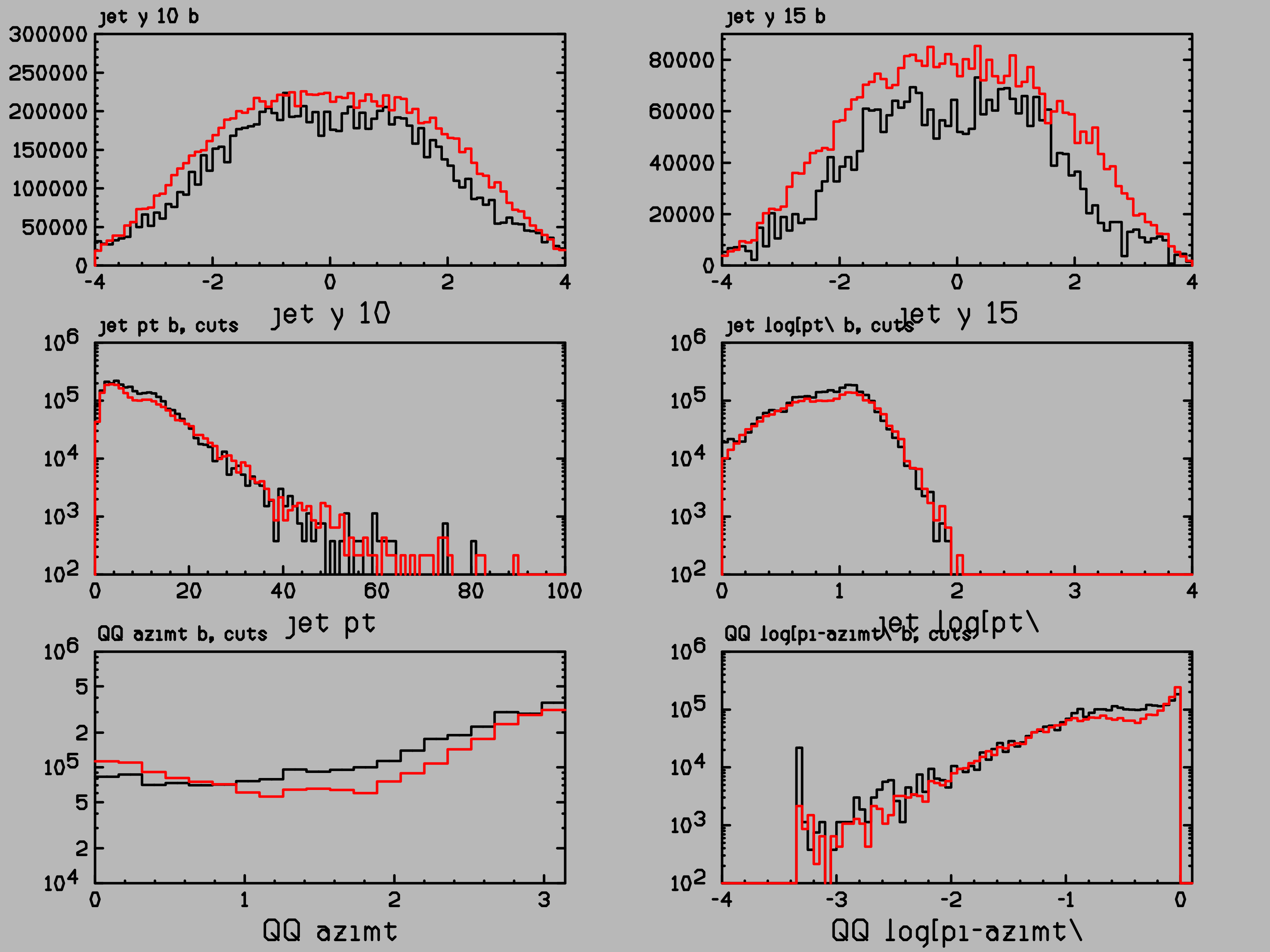

jet log[pt\ cuts
jet log[pt\
QQ inv m cuts
QQ inv m
QQ azimt cuts
QQ azimt
QQ del R cuts
QQ del R
Qb pt cuts
Qb pt
Qb log[pt\ cuts
Qb log[pt\


Q pt cuts
Q pt
Q log[pt\ cuts
Q log[pt\
QQ delta eta cuts
QQ Delta eta
y^QQ cuts
y^QQ
delta y cuts
QQ Delta y
QQ azımt cuts
QQ azımt

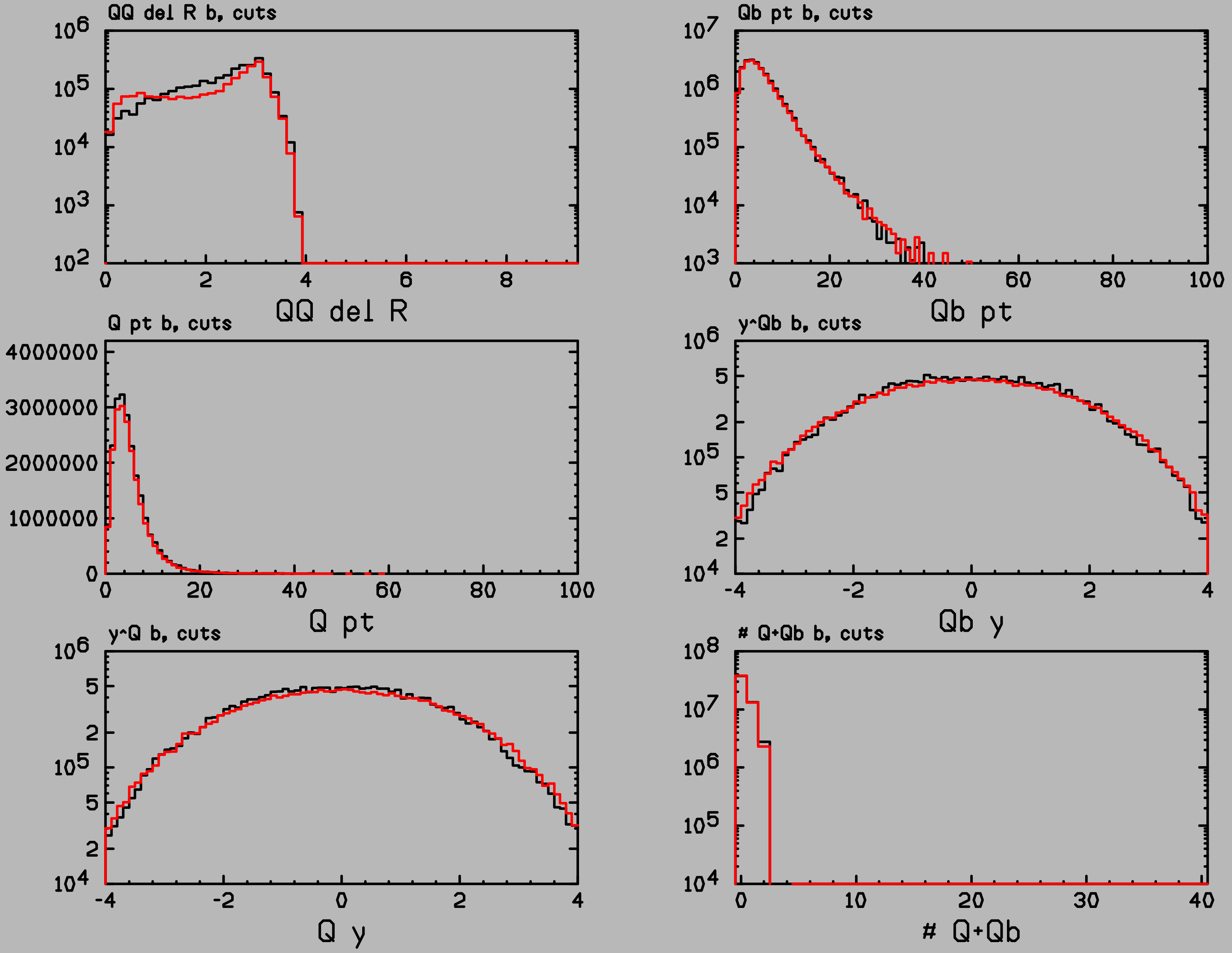

QQ del R cuts
QQ del R
y^Qb cuts
Qb y
y^Q cuts
Q y
QQ log[pı-azımt\ cuts
QQ log[pı-azımt\
jet pt
jet pt
Qb pt
Qb pt

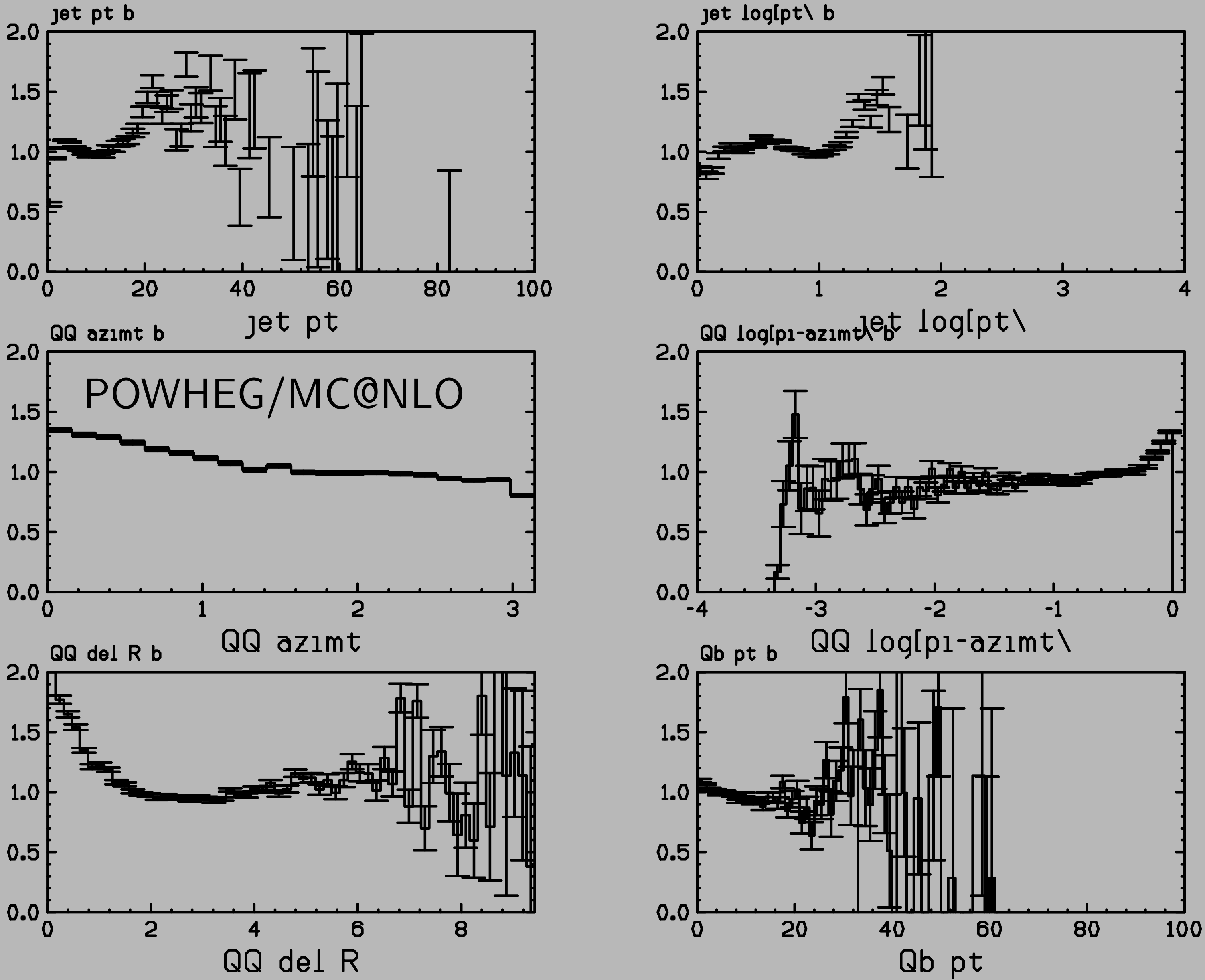

jet pt b
Bottom production
Tevatron
Red: POWHEG
Black: MC@NLO
jet pt
jet log[pt\ b
jet log[pt\
QQ azımt b
QQ azımt
QQ log[pı-azımt\ b
QQ log[pı-azımt\
QQ del R b
QQ del R
Qb pt b
Qb pt

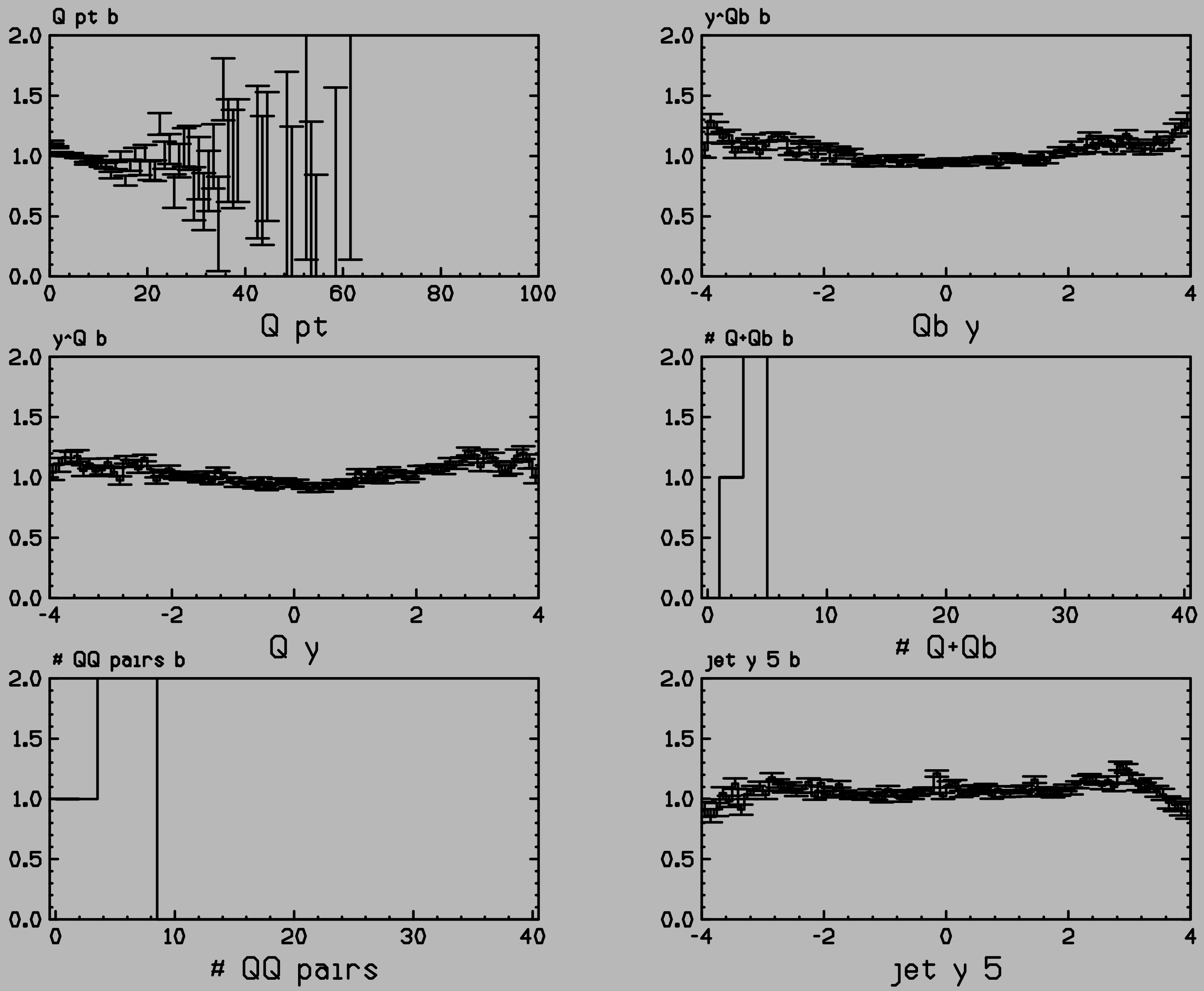

Q pt b
Q pt
y^Qb b
Qb y
y^Q b
Q y
Q+Qb b
Q+Qb
QQ pairs b
QQ pairs
jet y 5 b
jet y 5

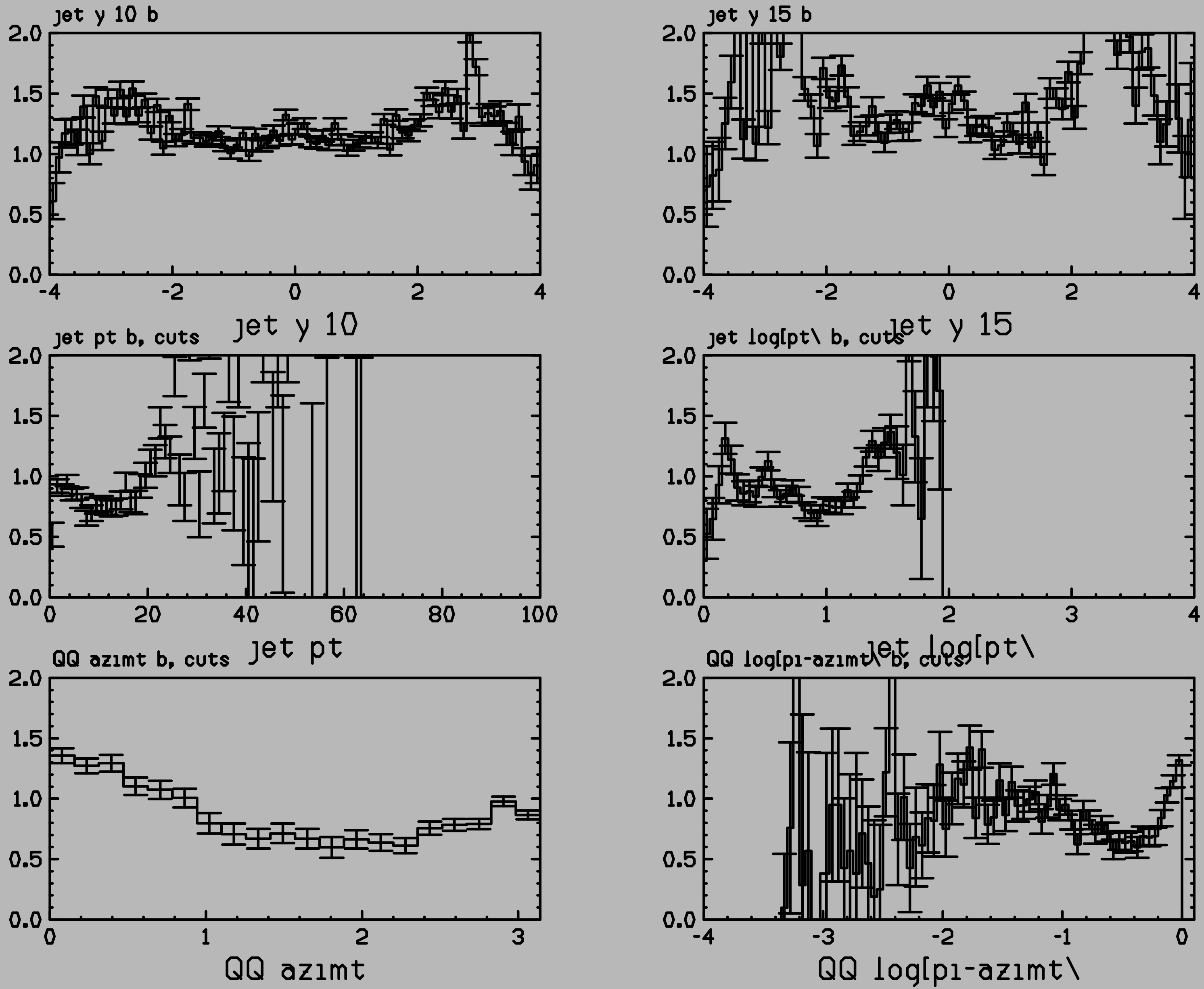


jet y 10 b
jet y 10
jet y 15 b
jet y 15
jet pt b, cuts
jet pt
jet log[pt\ b, cuts
jet log[pt\
QQ azımt b, cuts
QQ azımt
QQ log[pı-azımt\ b, cuts
QQ log[pı-azımt\

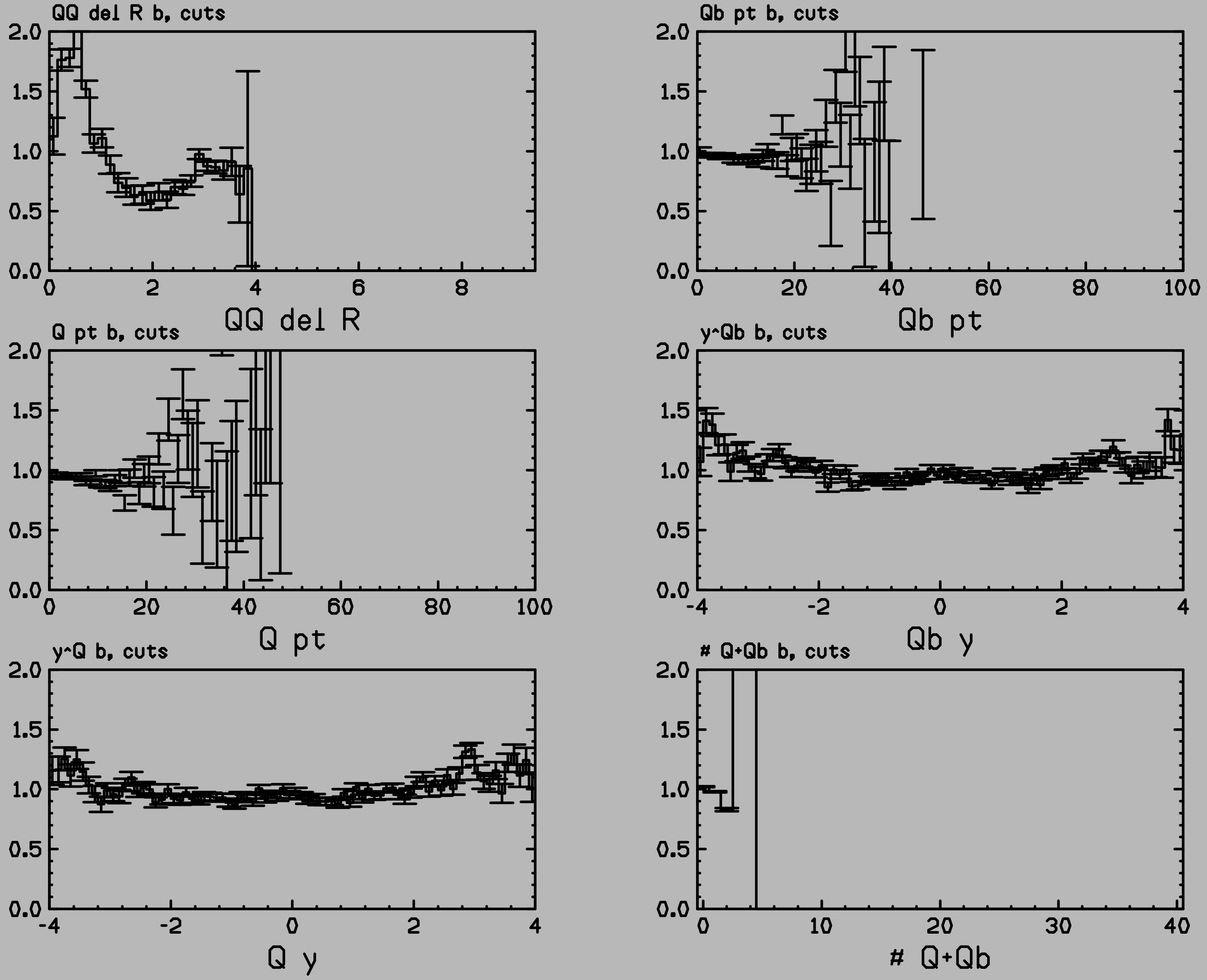

QQ del R b, cuts
QQ del R
Qb pt b, cuts
Qb pt
Q pt b, cuts
Q pt
y^Qb b, cuts
Qb y
y^Q b, cuts
Q y
Q+Qb b, cuts
Q+Qb

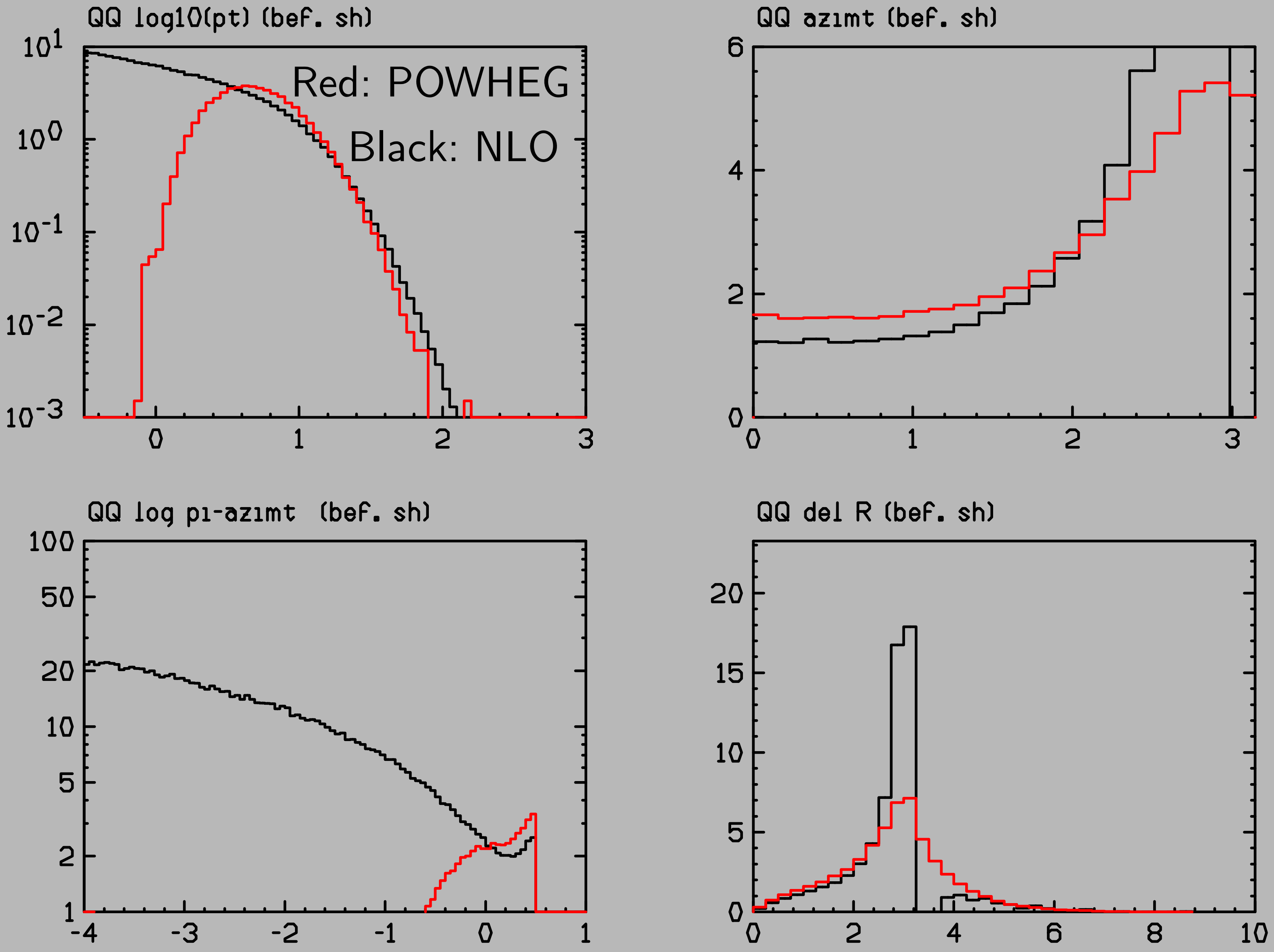

jet pt b
jet pt
jet log[pt\ b
jet log[pt\
QQ azimt b
POWHEG/MC@NLO
QQ azimt
QQ log[pi-azimt\ b
QQ log[pi-azimt\
QQ del R b
QQ del R
Qb pt b
Qb pt


Q pt b
Q pt
y^Qb b
Qb y
y^Q b
Q y
Q+Qb b
Q+Qb
QQ pairs b
QQ pairs
jet y 5 b
jet y 5



jet y 10 b
jet y 10
jet y 15 b
jet y 15
jet pt b, cuts
jet pt
jet log[pt\ b, cuts
jet log[pt\
QQ azimt b, cuts
QQ azimt
QQ log[pi-azimt\ b, cuts
QQ log[pi-azimt\


QQ del R b, cuts
QQ del R
Qb pt b, cuts
Qb pt
Q pt b, cuts
Q pt
y^Qb b, cuts
Qb y
y^Q b, cuts
Q y
Q+Qb b, cuts
Q+Qb


QQ log10(pt) (bef. sh)
Red: POWHEG
Black: NLO
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
0
1
2
3
QQ azımt (bef. sh)
6
4
2
0
0
1
2
3
QQ log pı-azımt (bef. sh)
100
50
20
10
5
2
1
-4
-3
-2
-1
0
1
QQ del R (bef. sh)
20
15
10
5
0
0
2
4
6
8
10

Conclusions and Perspective

- POWHEG is a viable method for interfacing NLO and SMC
- It is easy to implement, does not require new NLO computations
- Does not require committment to specific SMC implementations
- Its output is closer to traditional SMC's: positive weighted events
- To get it going, we will implement a number of processes: vector bosons and boson pairs, Higgs, Heavy Flavour, etc.
- We collect and publish material to make it easy for others to implement POWHEG with their NLO calculation