Higgs plus jets with the POWHEG BOX

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Higgs generators now: `H`, `HJ`, `HJJ`;

`H`: Alioli,Oleari,Re,P.N. (2009)
`gg_H_quark-mass-effects`: Bagnaschi, Degrassi, Slavich,Vicini, (2012)

`HJ`, `HJJ`: Campbell,Ellis,Frederix,Oleari,Williams,P.N. 2012, using an Interface to `Madgraph` (everything but the virtual and the Born phase space R.Frederix, 2012), and virtuals from MCFM.

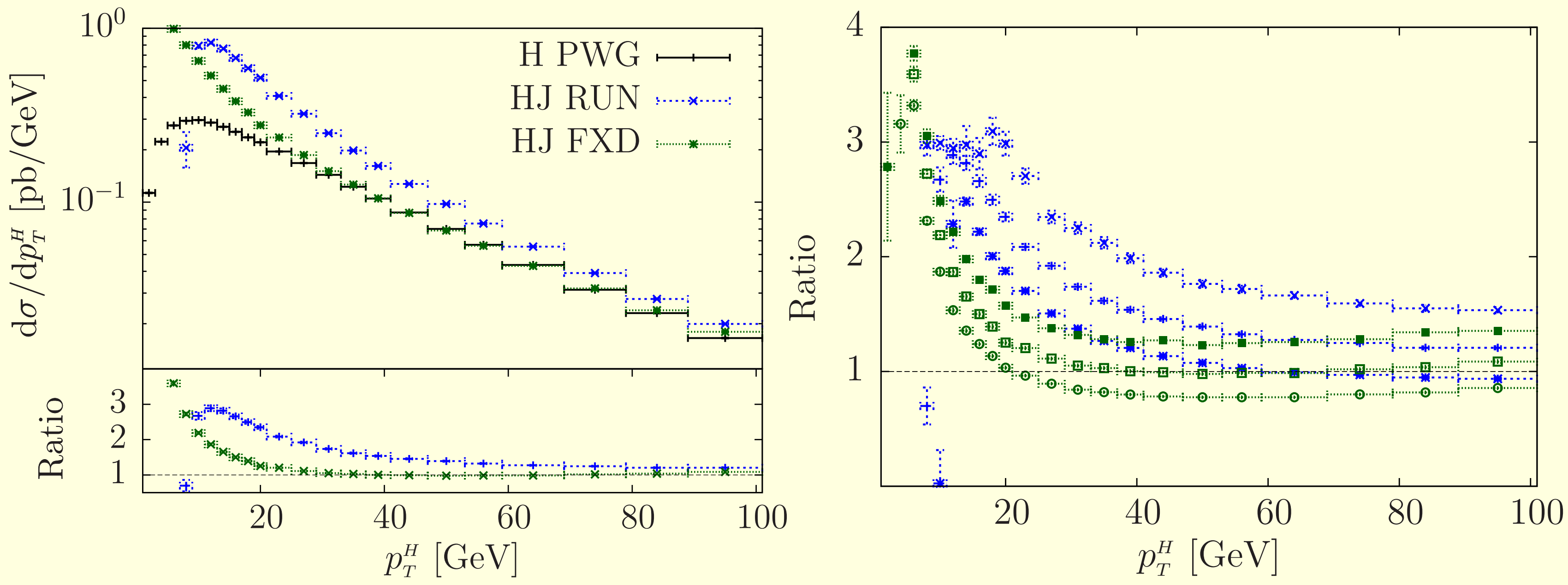
MINLO: Multi-scale Improved NLO

The MINLO procedure (Hamilton,Zanderighi,P.N. 2012) has been implemented and made public in the `POWHEG BOX`:

`svn://powhegbox.mib.infn.it/trunk/POWHEG-BOX/MINLO`

The purpose of this procedure is to improve the NLO computation of the inclusive cross section in the `POWHEG BOX` when regions of the phase space with widely different scales are approached.

The MINLO procedure achieves this by a suitable choices of the factorization and renormalization scales, and by exponentiating large Sudakof logarithms.



H PWG: `POWHEG` `gg_H` generator interfaced with `PYTHIA`, $M_H = 120\,\mathrm{GeV}$

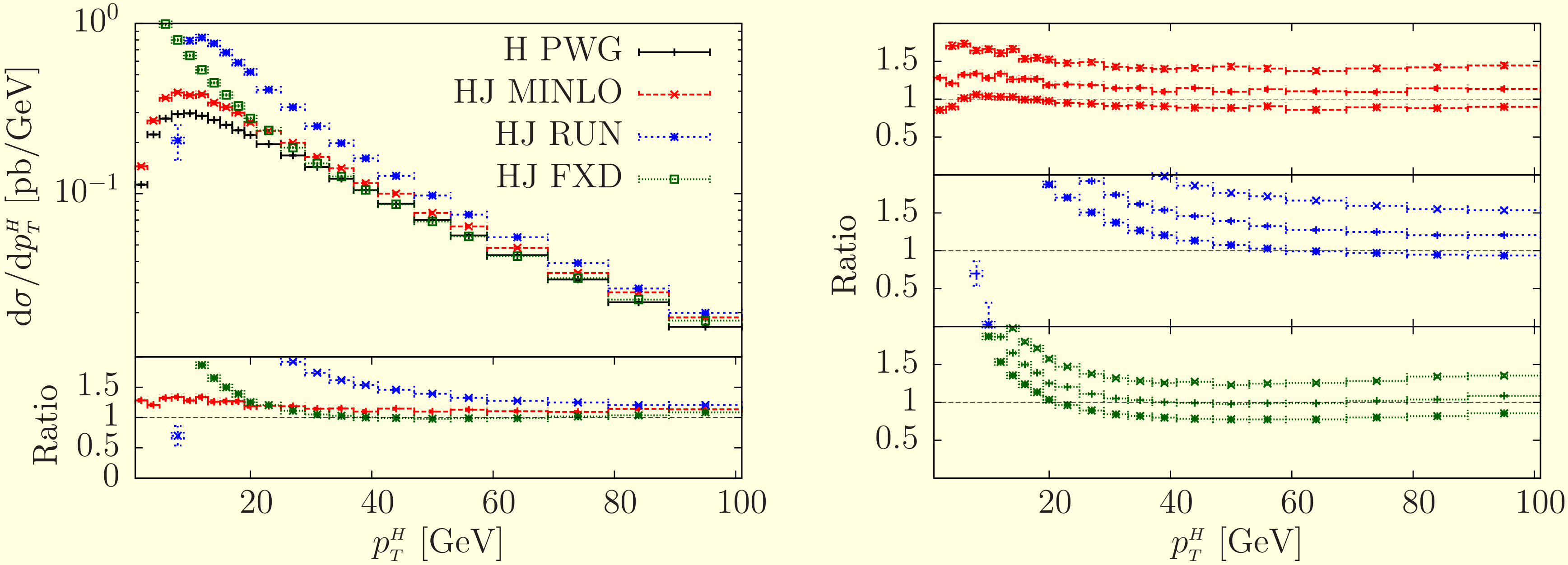
HJ RUN: `HJ` NLO calculation with $\mu_R = \mu_F = p_{\mathrm{T}}^{\mathrm{H}}$

HJ FXD: `HJ` NLO calculation with $\mu_R = \mu_F = m_{\mathrm{H}}$. (Ratios over H PWG)

- Error bands obtained varying μ_R and μ_F by a factor of two above and below their common central value, with the constraint $\frac{1}{2} \leqslant \frac{\mu_R}{\mu_F} \leqslant 2$.
- Bands don't overlap at $p_T \lesssim 30\,\mathrm{GeV}$.
- NLO shapes differ from LL resummed result (`POWHEG`) at small p_T.

In the standard POWHEG implementation of Hj production, the NLO computation of the Hj cross section suffers from large uncertainties due to scale choices, and, furthermore, does not have a good match with the H production POWHEG generator at small transverse momenta. This problem is easily tracked back to the fact that the Hj NLO calculation does not attempt to resum large logarithms of the jet transverse momentum, not even at the LO level.

MINLO HJ result



- H PWG: the (showered) `gg_H POWHEG BOX` result.
- RUN and FXD need a generation cut (or Born suppression) at small p_{T}. The `MINLO` result is instead FINITE (up to a cut-off $\approx\Lambda$)
- We can thrust the `MINLO` result at small p_{T} only as a LO result (see the widening of the `MINLO` uncertainty band at small p_{T}). However, at least we get a result that is sensible also at low p_{T} rather than divergent.

Scales and pdf uncertainties

Scales and pdf uncertainties are difficult to compute, if one must generate new Monte Carlo samples for each PDF set and scales choice.
It is desirable to have, associated with each event, a set of weights corresponding to different PDF and scale choices.

The `POWHEG BOX` provided since some time a primitive pdf reweighting facility, and no scales reweighting of the kind that is available in `aMC@NLO`.

We have now implemented scale and pdf reweighting in the `POWHEG BOX`.
(Hamilton,Re,P.N.)

How it works

Remember: the POWHEG BOX relies upon third parties matrix elements; it is difficult to track the coefficients of scale logs through them. So we do the following multi-stage procedure:

- Include with each generated event the value of the random seed used to compute the last phase space point, and the value of the integrand.
- Read the event file; for each event set the random seed to the stored value (to get the same phse space point), and compute the integrand again, with the desired new scale values or pdf set. Store the same event in a new file, appending to it the new weight

$$\text{new weight} = \text{old weight} \times \frac{\text{new integrand}}{\text{old integrand}}$$

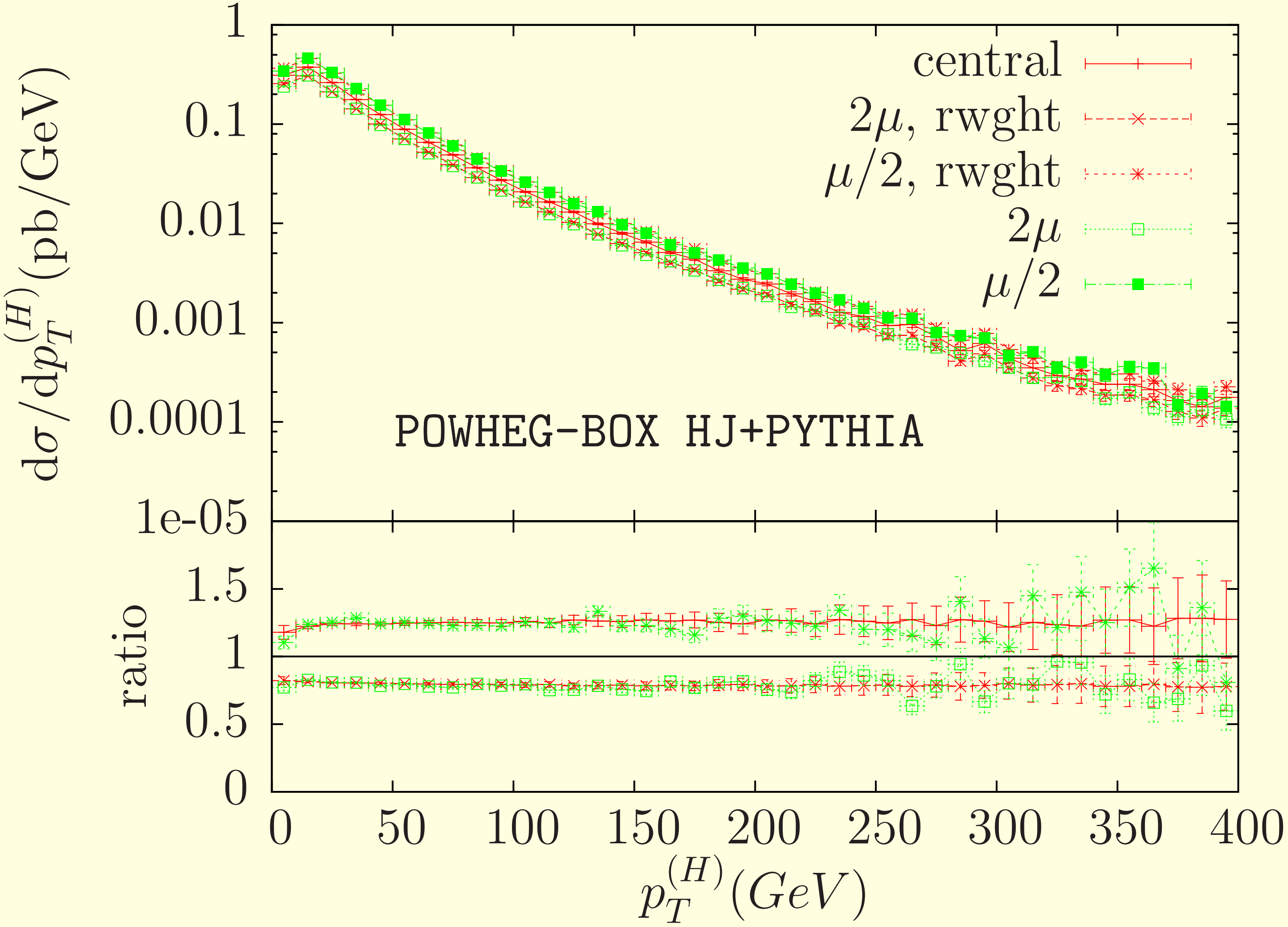
The procedure can be repeated as many times as one like, appendig to each event as many new weights as one likes.

How it looks

```
<event>
     13 320000  1.00000E+00  7.55201E+01 -1.00000E+00  1.32196E-01
      21    -1     0     0   502   503  0.000000000E+00  0.000000000E+00  2.541357439E+02  2.541357439E+02  0.000000000E+00  0.00000E+00  9.000E+00
      21    -1     0     0   504   505  0.000000000E+00  0.000000000E+00 -4.038831662E+02  4.038831662E+02  0.000000000E+00  0.00000E+00  9.000E+00
       6     2     1     2   502     0  1.264725057E+02 -1.714959634E+01  1.426298903E+02  2.574639028E+02  1.722061913E+02  0.00000E+00  9.000E+00
      -6     2     1     2     0   505 -5.236398848E+01  3.168283322E+01 -1.387258735E+02  2.293473789E+02  1.720742951E+02  0.00000E+00  9.000E+00
      21     1     1     2   504   503 -7.410851721E+01 -1.453323688E+01 -1.536514390E+02  1.712076284E+02  1.907348633E-06  0.00000E+00  9.000E+00
      24     2     3     3     0     0  1.124848494E+02 -7.726549391E+00  2.893166297E+01  1.424214097E+02  8.206263407E+01  0.00000E+00  9.000E+00
       5     1     3     3   502     0  1.398765633E+01 -9.423046952E+00  1.136982273E+02  1.150424932E+02  4.800000000E+00  0.00000E+00 -1.000E+00
     -24     2     4     4     0     0 -5.945165693E+01  5.404154111E+01 -2.987203972E+01  1.178918093E+02  8.093918871E+01  0.00000E+00  9.000E+00
      -5     1     4     4     0   505  7.087668448E+00 -2.235870789E+01 -1.088538338E+02  1.114555696E+02  4.800000000E+00  0.00000E+00  1.000E+00
     -11     1     6     6     0     0  4.753838319E+01 -4.076446196E+01  3.024215238E+01  6.954298683E+01  5.110000000E-04  0.00000E+00  1.000E+00
      12     1     6     6     0     0  6.494646617E+01  3.303791257E+01 -1.310489409E+00  7.287842286E+01  0.000000000E+00  0.00000E+00 -1.000E+00
      11     1     8     8     0     0 -1.056933235E+01  2.227732252E+01 -5.038255908E+01  5.609271026E+01  5.110000000E-04  0.00000E+00 -1.000E+00
     -12     1     8     8     0     0 -4.888232458E+01  3.176421859E+01  2.051051936E+01  6.179909906E+01  0.000000000E+00  0.00000E+00  1.000E+00
#rwgt           1           1   236.22329425426454                1          14          0
#new weight,renfact,facfact,pdf1,pdf2   1.0905908061313441       0.50000000000000000       0.50000000000000000            21100       21100  lha
#new weight,renfact,facfact,pdf1,pdf2  0.91488851756586331        1.0000000000000000       0.50000000000000000            21100       21100  lha
#new weight,renfact,facfact,pdf1,pdf2   1.2187689698521500       0.50000000000000000        1.0000000000000000            21100       21100  lha
#new weight,renfact,facfact,pdf1,pdf2   1.0697449892035478        1.0000000000000000        2.0000000000000000            21100       21100  lha
#new weight,renfact,facfact,pdf1,pdf2  0.83614889468182263        2.0000000000000000        1.0000000000000000            21100       21100  lha
#new weight,renfact,facfact,pdf1,pdf2  0.88271219160050818        2.0000000000000000        2.0000000000000000            21100       21100  lha
</event>
```

The #rwgt line contains the integrand and random number seeds, and is generated in the first run.
The #new weight ... lines are generated in subsequent (cheep!) runs, where only a single call to the cross section is made for each event.

Example: reweighted compared to direct



Various added features

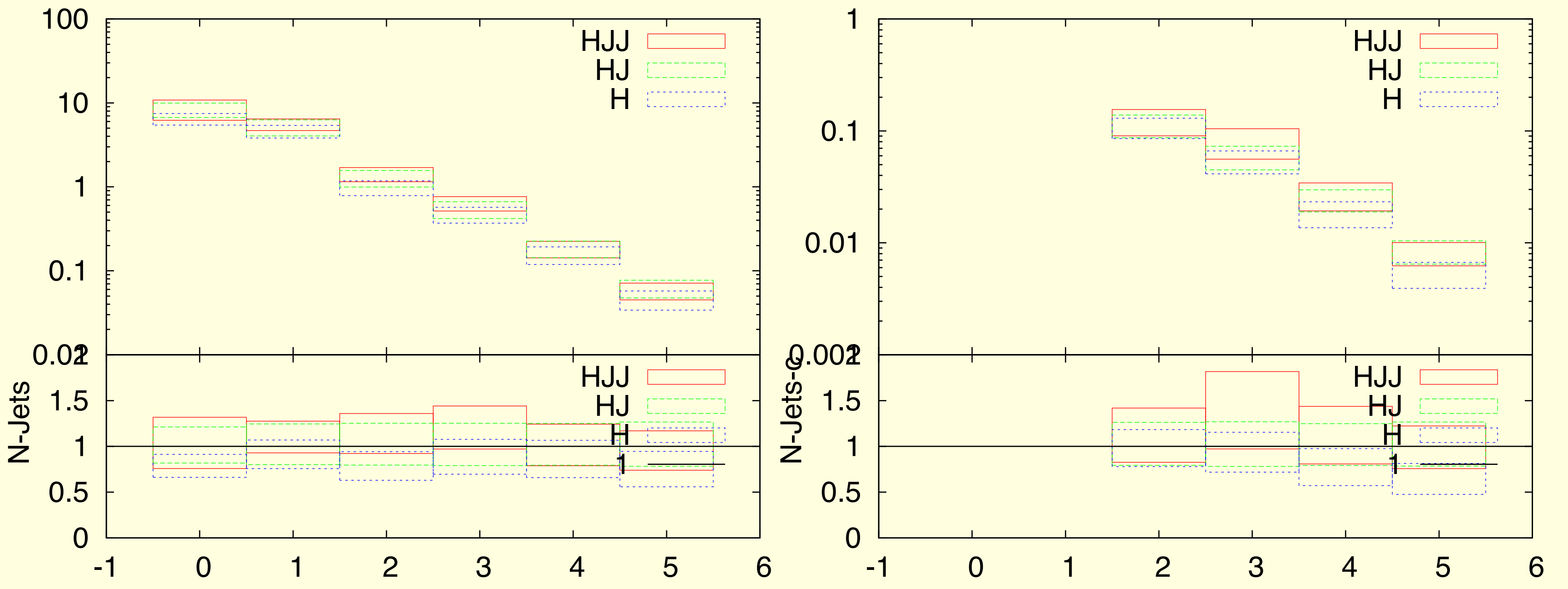
- MiNLO
- Reweighting
- Fast $\tilde{B}$ generation (from W^+W^+jj code,
  Melia, Rontsch,Zanderighi,P.N. 2011
- Parallelize importance sampling grid training (all other aspects of preparation runs are already parallelized)
- ...

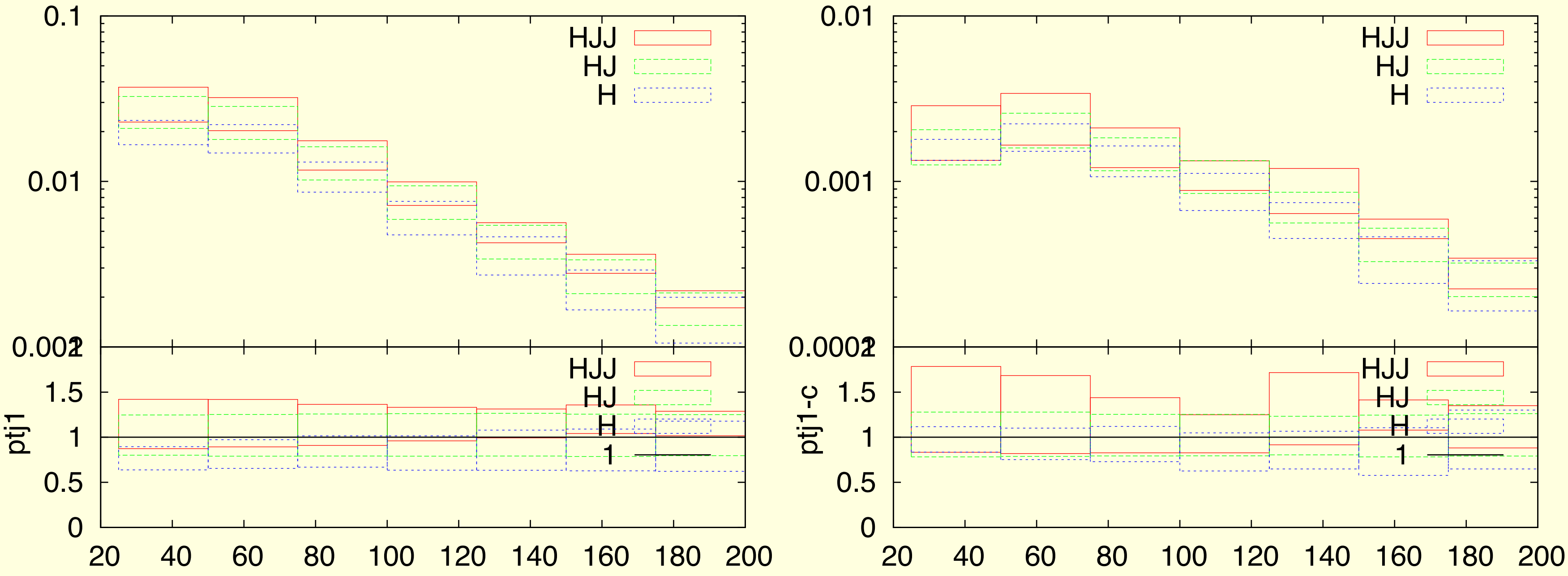
All these features are available in the SVN trunk distribution, but they are not yet merged together. Time for a new version, including all these new features ..

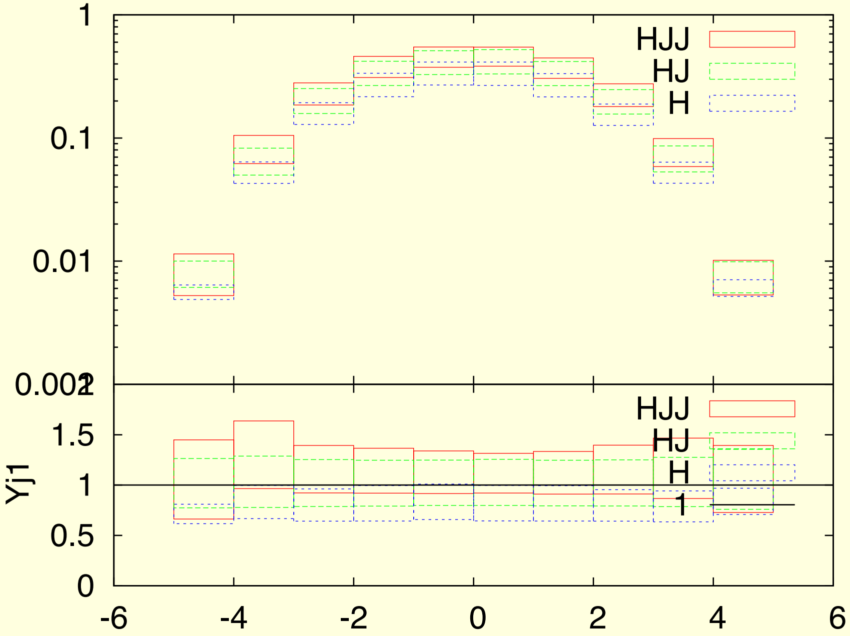
Results for Higgs plus jets

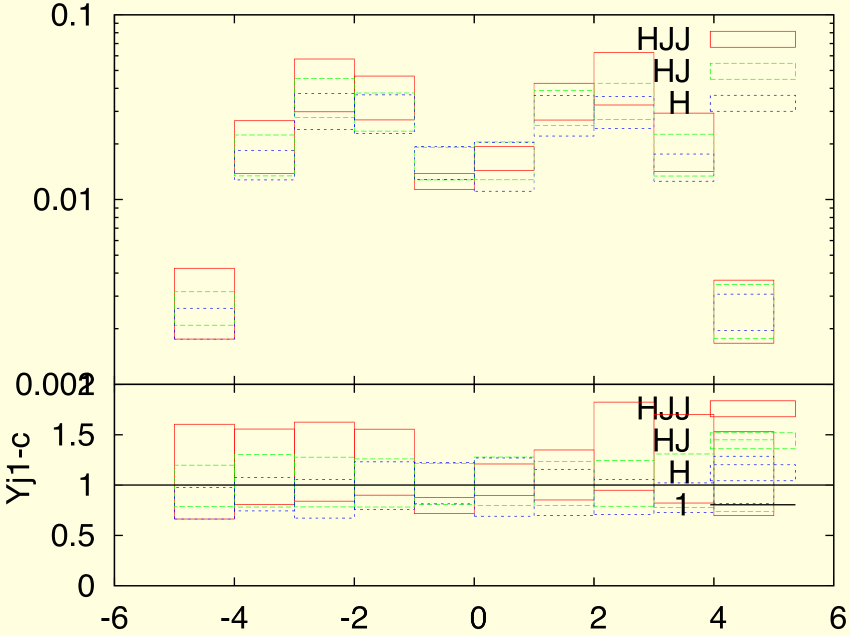
- Results with `H`, `HJ`, `HJJ` generators.
- 800M events for each.
- Scale variation by a factor of 2 above and below central value
- MST2008nlo, 8 TeV, $M_{\mathrm{H}} = 125\,\mathrm{GeV}$.
- Shower at parton level from `PYTHIA`, `PYTUNE(320)`
- Cuts and plots as agreed
- Comparison with full hadron level.

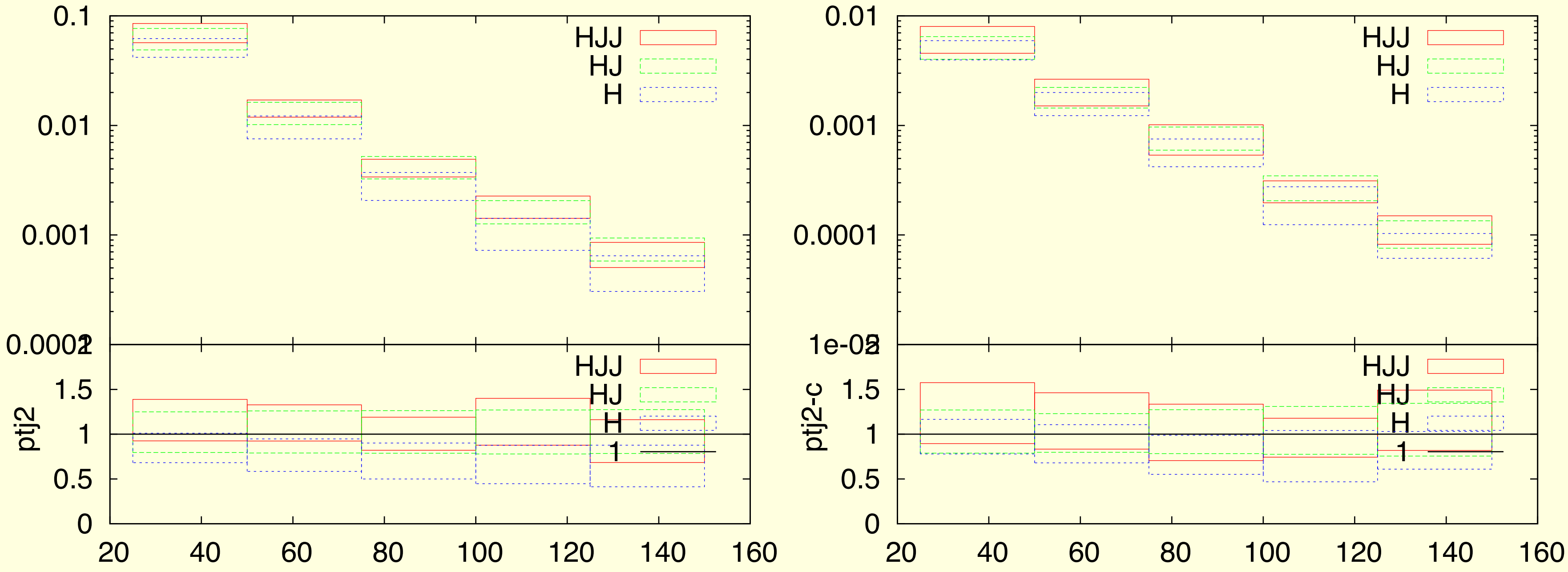
Comparison of the H, HJ and HJJ generators at parton level

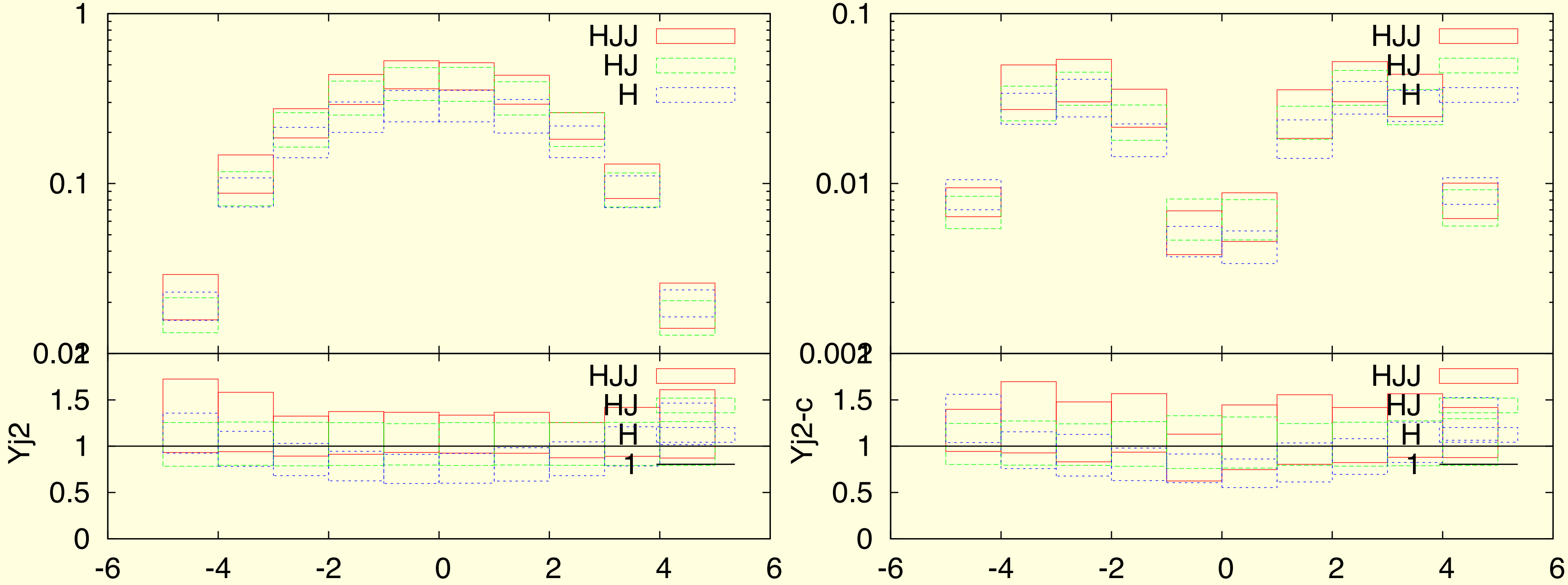


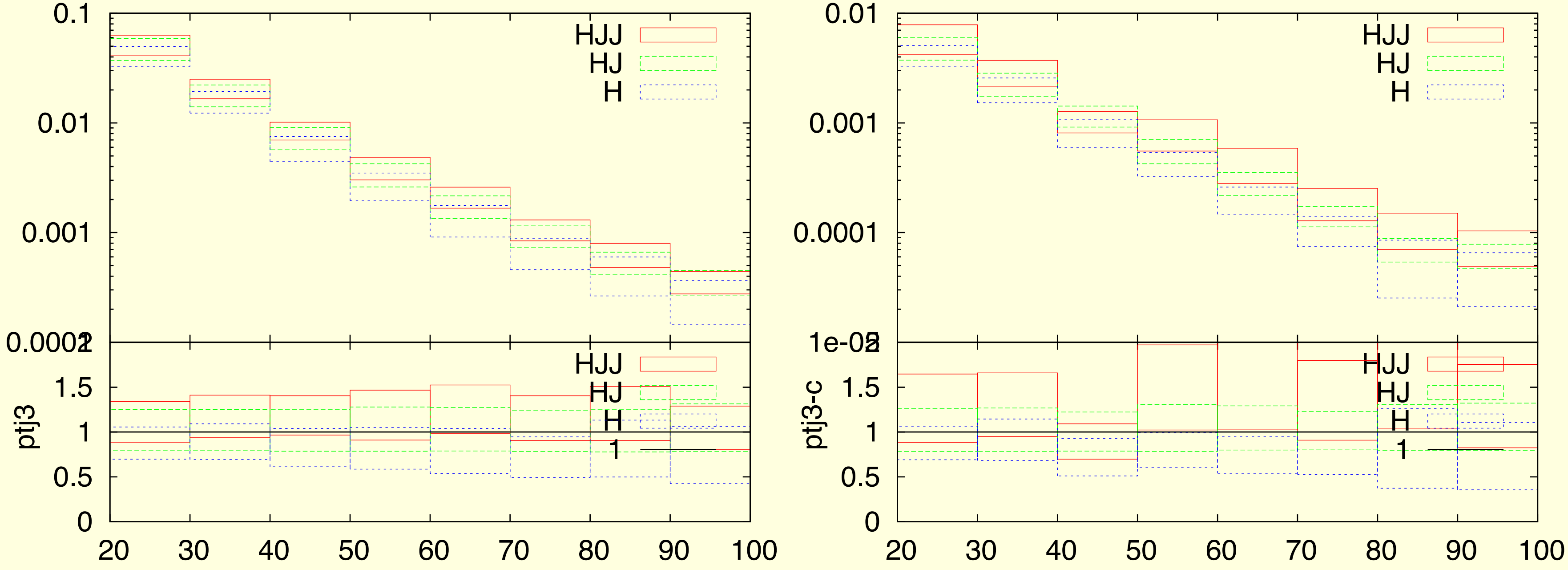

0.1
0.01
0.002
HJJ
HJ
H
2
1.5
1
0.5
0
ptj1
1
20
40
60
80
100
120
140
160
180
200
0.01
0.001
0.0002
ptj1-c


HJJ
HJ
H
1
0.1
0.01
0.002
2
1.5
0.5
0
Yj1
-6
-4
-2
6
4


HJJ
HJ
H
1
0.1
0.01
0.002
2
1.5
0.5
0
Yj1-c
-6
-4
-2
6
4


HJJ
HJ
H
1
ptj2
ptj2-c
0.1
0.01
0.001
0.0002
1e-05
0.0001
2
1.5
1
0.5
0
20
40
60
80
100
120
140
160


HJJ
HJ
H
1
Yj2
Yj2-c


HJJ
HJ
H
1
ptj3
ptj3-c
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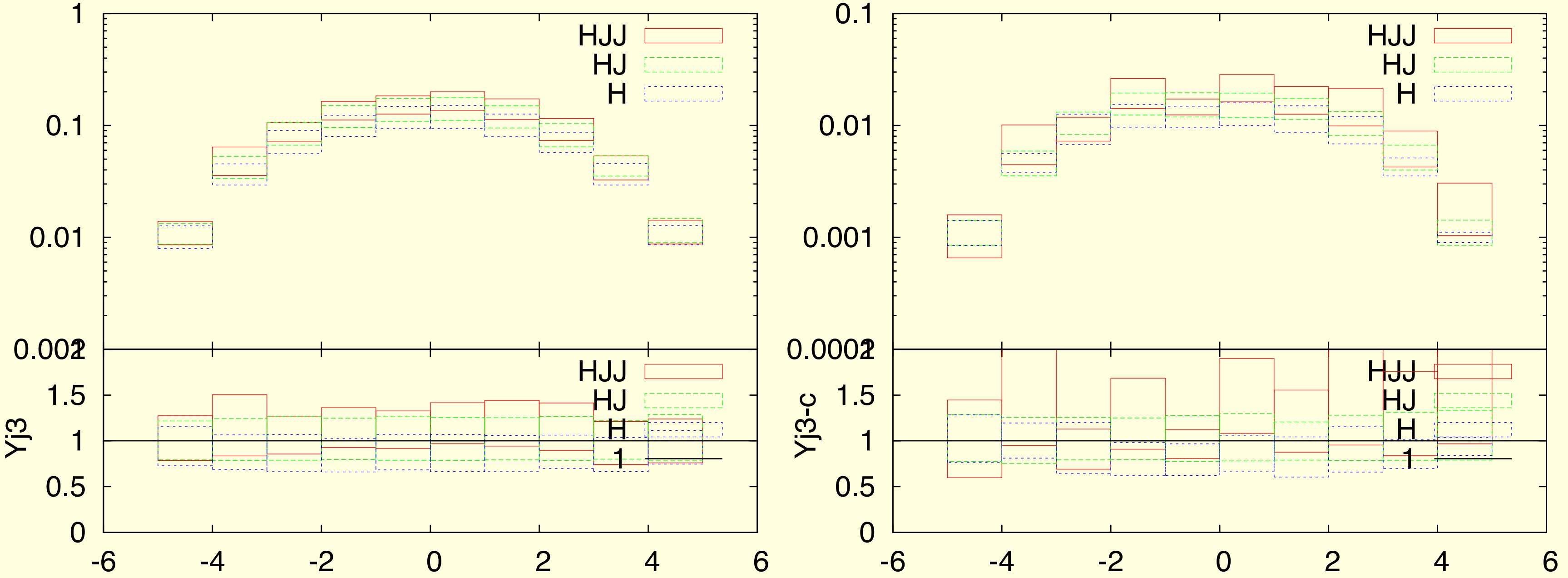
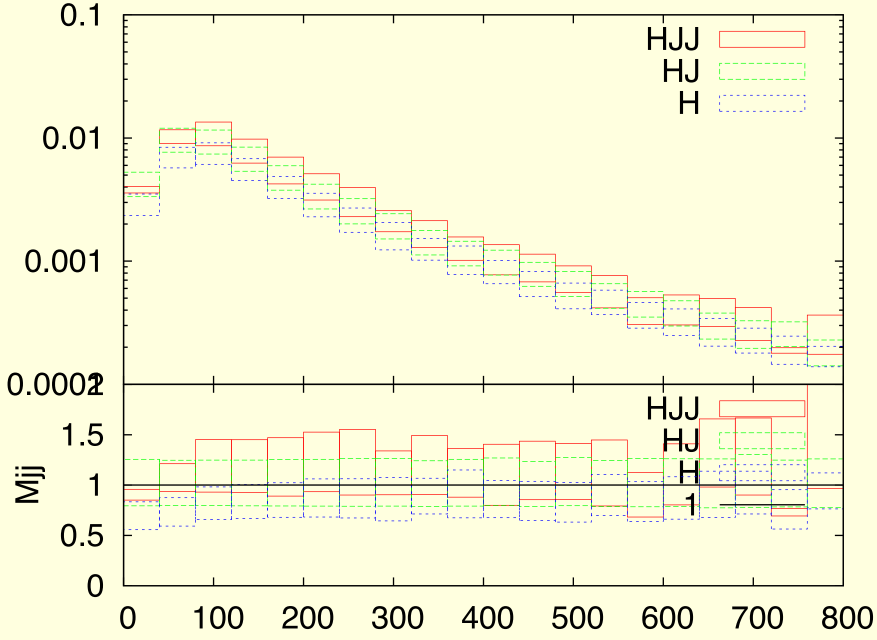
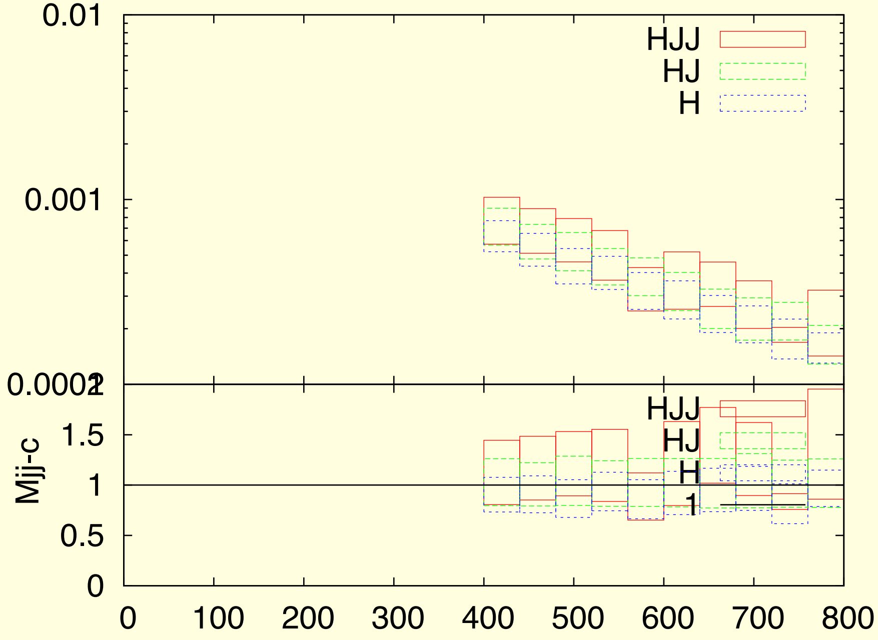
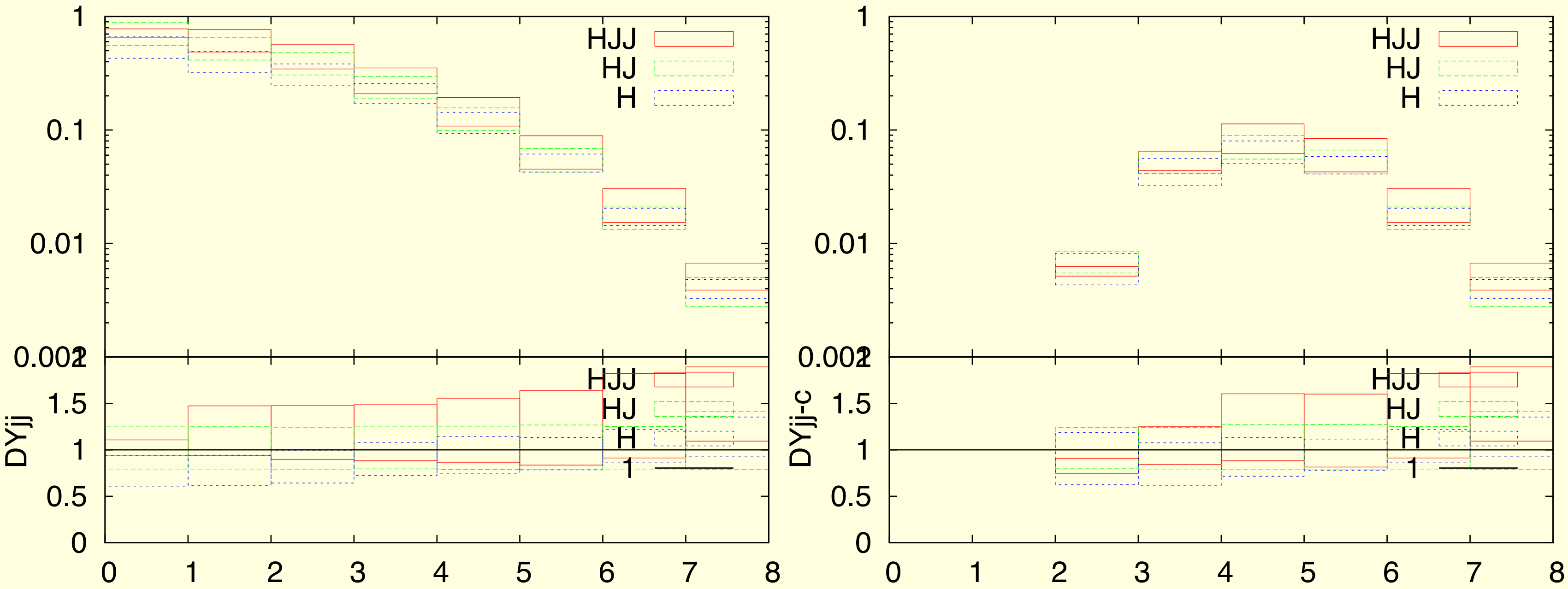
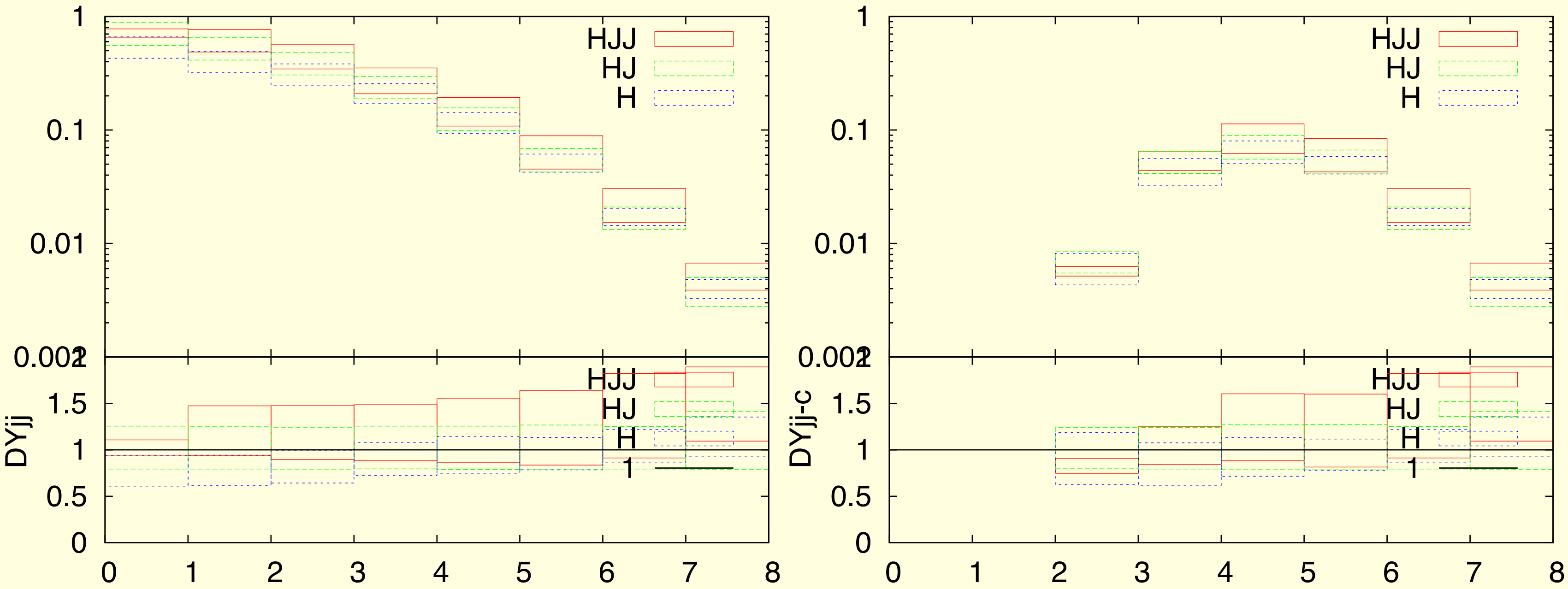
0.01
0.001
0.0001
1e-05
20
30
40
50
60
70
80
90
100

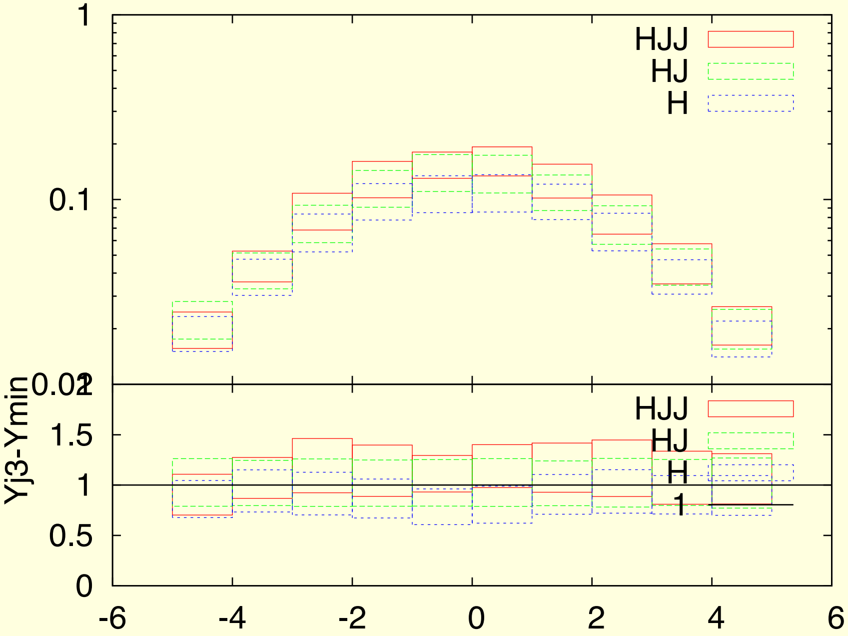

HJJ
HJ
H
1
Yj3
Yj3-c
1
0.1
0.01
0.001
0.0001
2
1.5
0.5
0
-6
-4
-2
0
2
4
6


HJJ
HJ
H
1
Mjj
0.1
0.01
0.001
0.0002
0
0.5
1
1.5
2
0
100
200
300
400
500
600
700
800

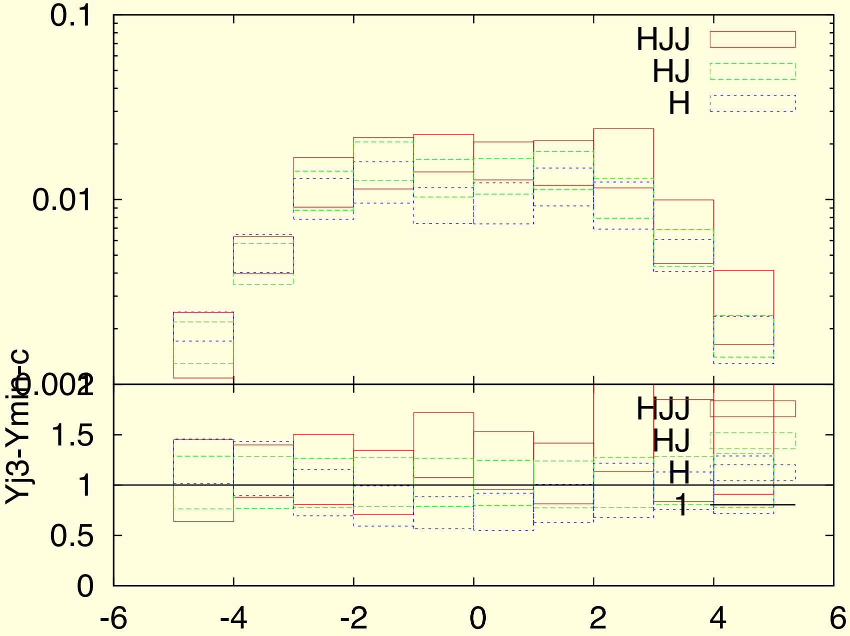

HJJ
HJ
H
1
Mjj-c
0.01
0.001
0.0002
0
0.5
1
1.5
2
0
100
200
300
400
500
600
700
800


HJJ
HJ
H
1
DYjj
DYjj-c
0.1
0.01
0.002
1.5
0.5
0 1 2 3 4 5 6 7 8


HJJ
HJ
H
1
DYjj
DYjj-c
1
0.1
0.01
0.002
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8

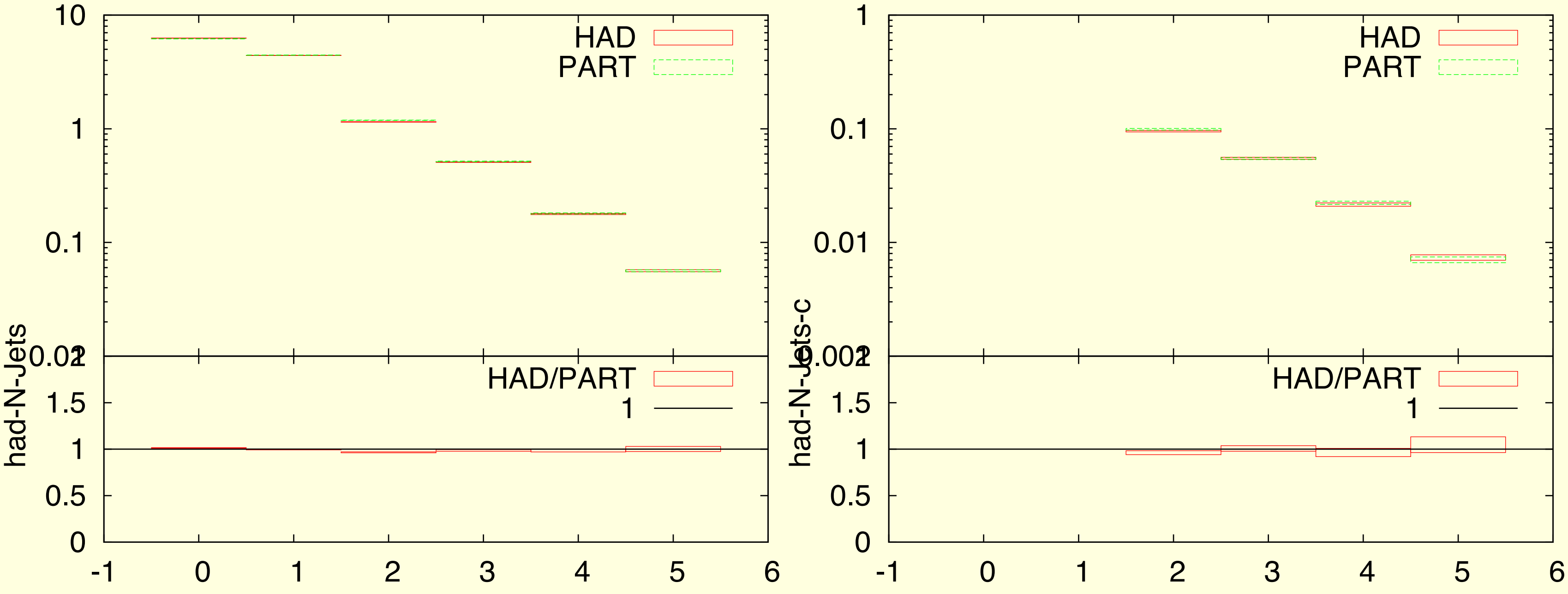


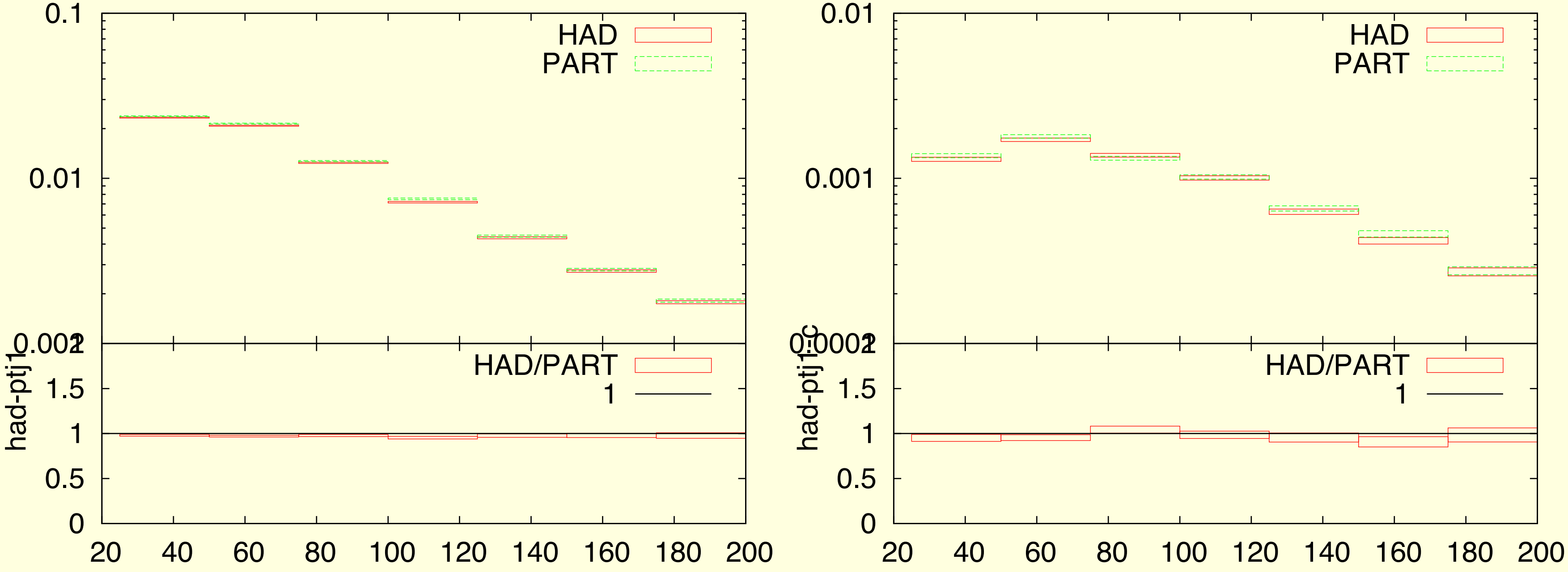
HJJ
HJ
H
Yj3-Ymin
1

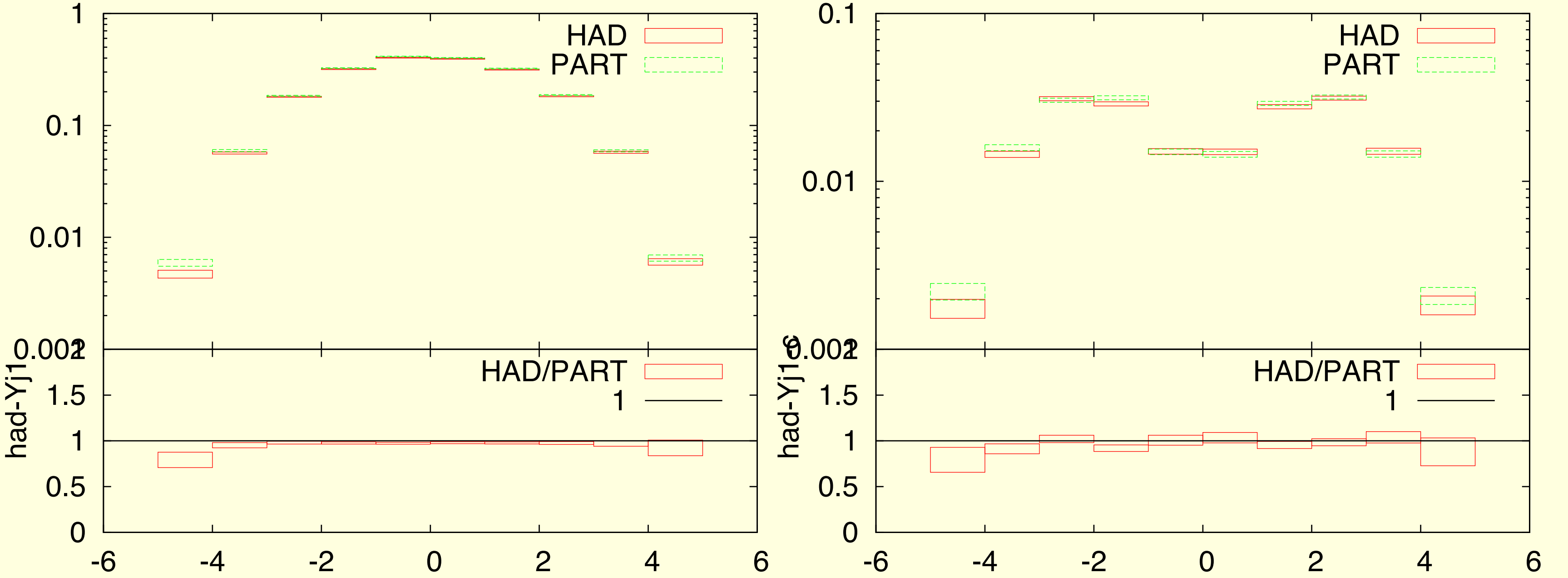


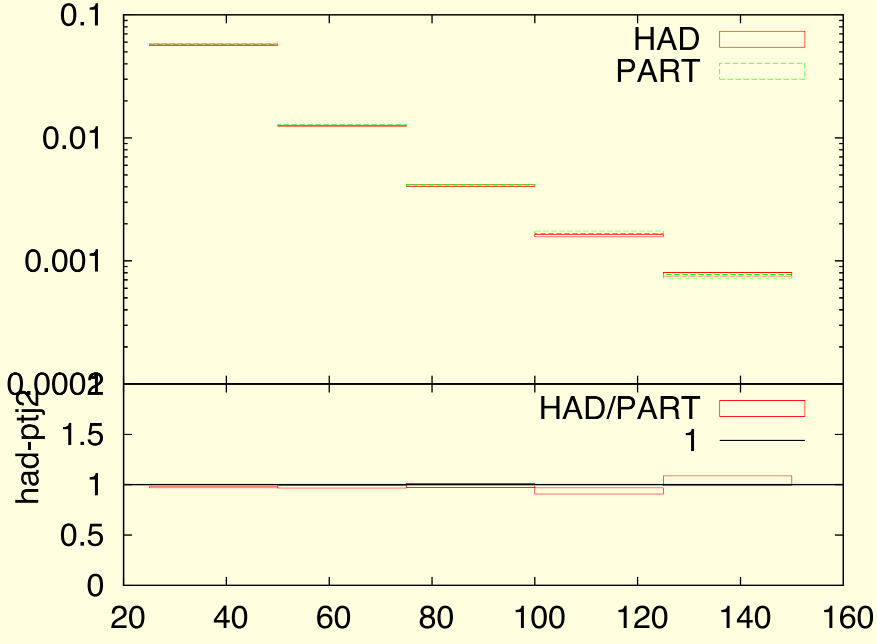
HJJ
HJ
H
Yj3-Ymin-c
1

Comparison of fully hadronized result wrto parton level

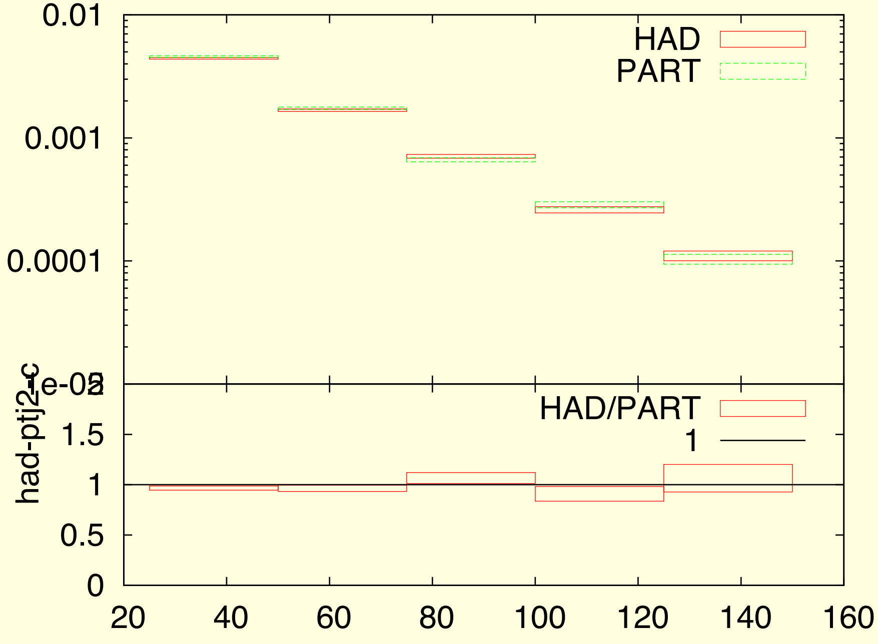



HAD
PART
HAD/PART
1
had-ptj1
had-ptj1-c
0.1
0.01
0.001
0.002
0.0002
2
1.5
1
0.5
0
20
40
60
80
100
120
140
160
180
200

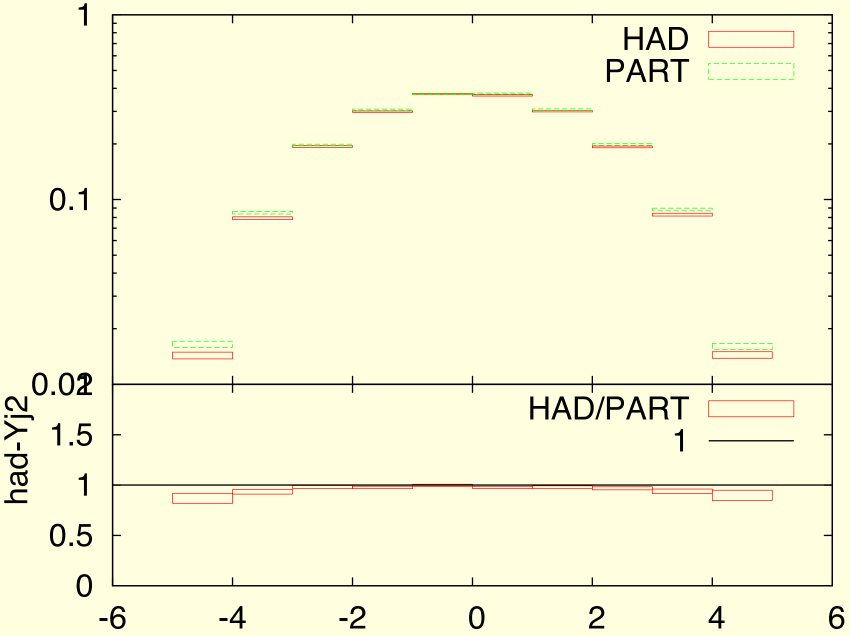

HAD
PART
HAD/PART
1
had-Yj1
had-Yj1-6

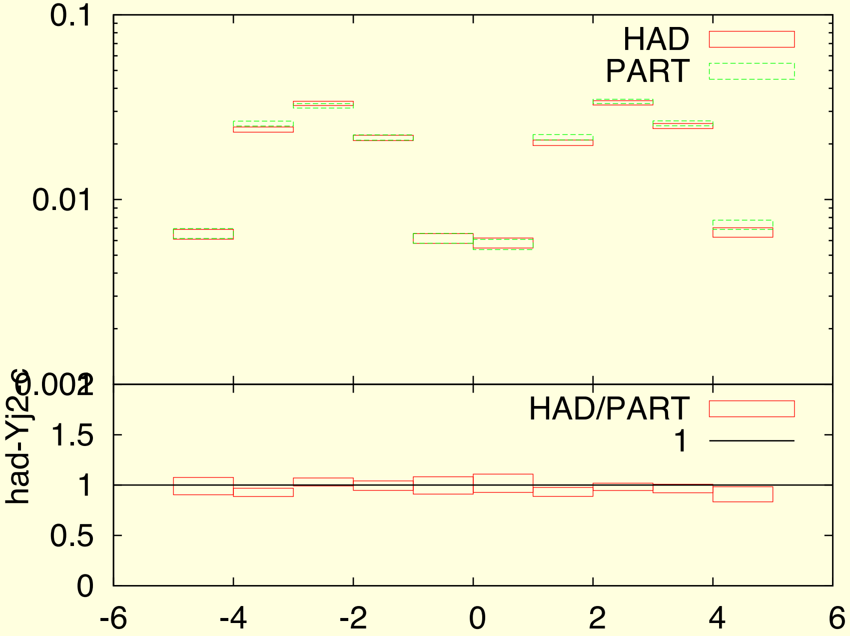


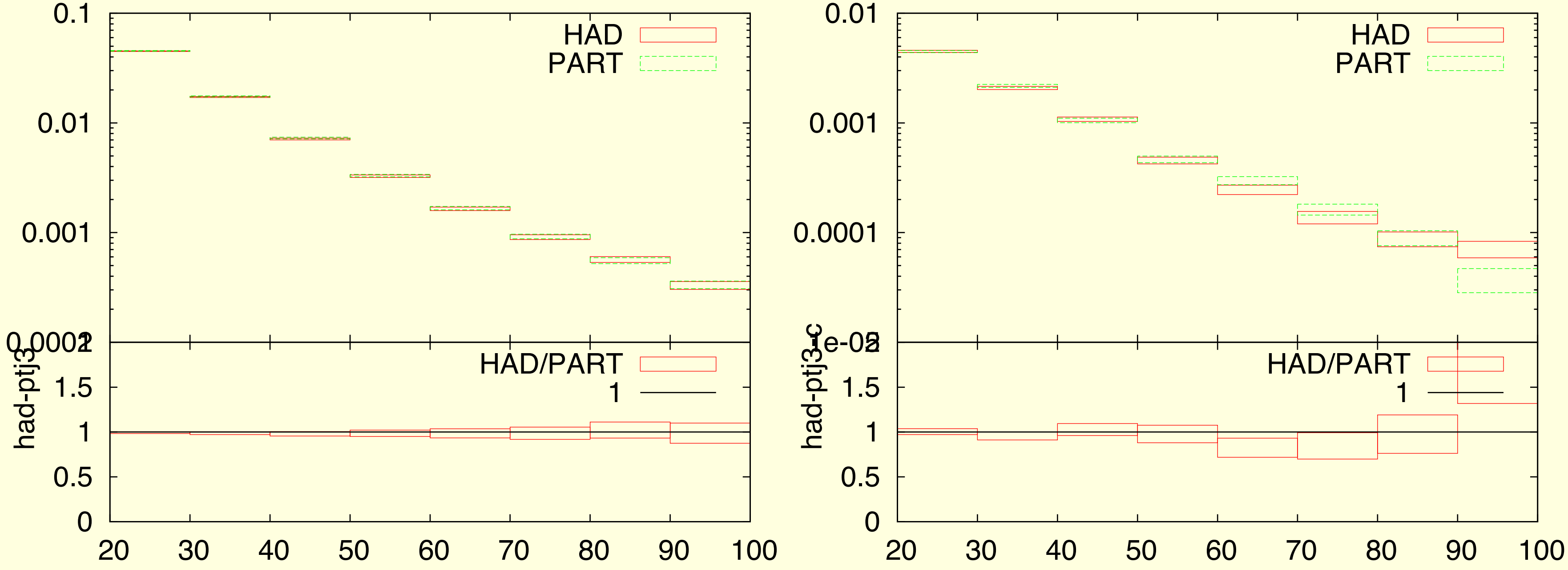
0.1
0.01
0.001
0.0001
HAD
PART
had-ptj2
2
1.5
1
0.5
0
HAD/PART
1
20
40
60
80
100
120
140
160



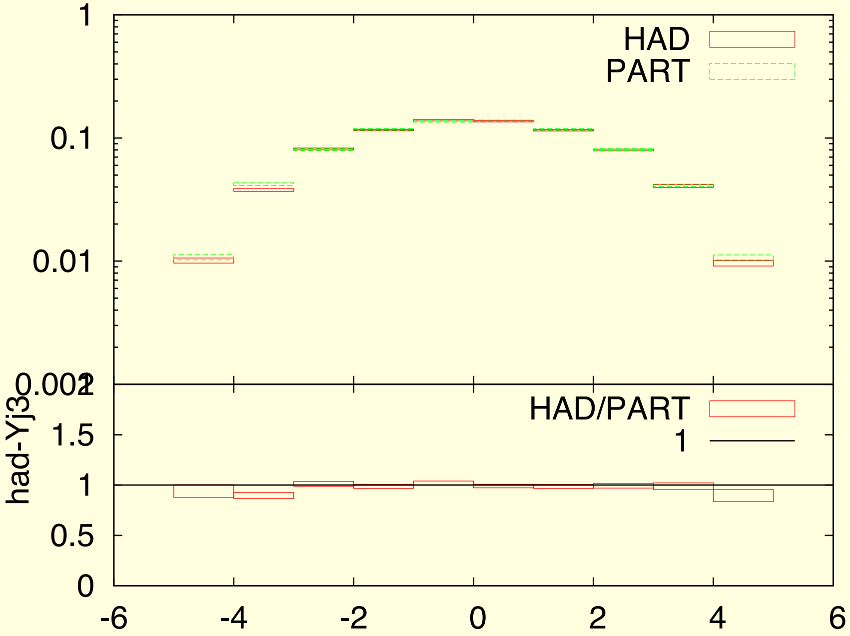
0.01
0.001
0.0001
1e-05
HAD
PART
had-ptj2-c
2
1.5
1
0.5
0
HAD/PART
1
20
40
60
80
100
120
140
160

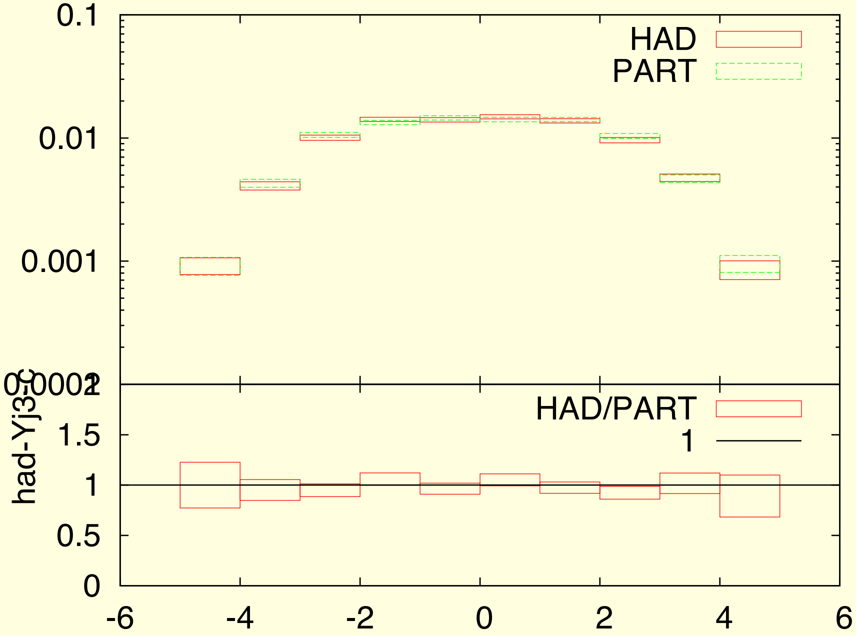

HAD
PART
HAD/PART
1
had-Yj2
1
0.1
0.01
2
1.5
1
0.5
0
-6
-4
-2
0
2
4
6

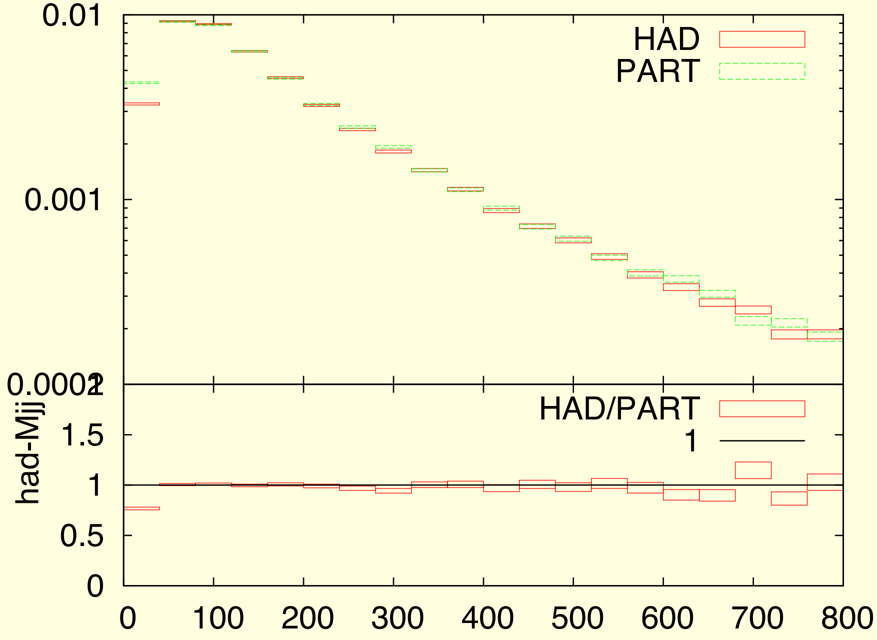

HAD
PART
HAD/PART
1
had-Yj2-6
0.1
0.01
0.001
2
1.5
1
0.5
0
-6
-4
-2
0
2
4
6

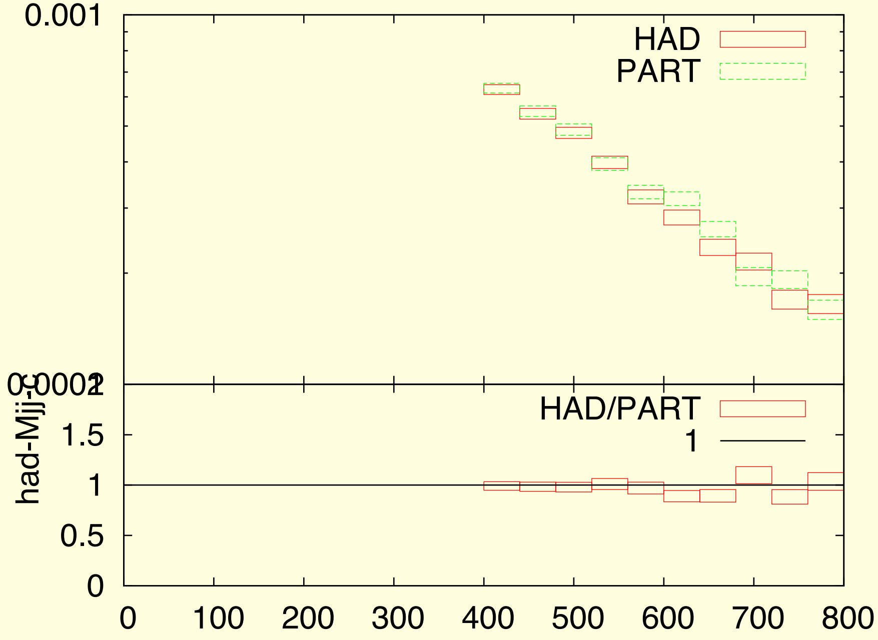


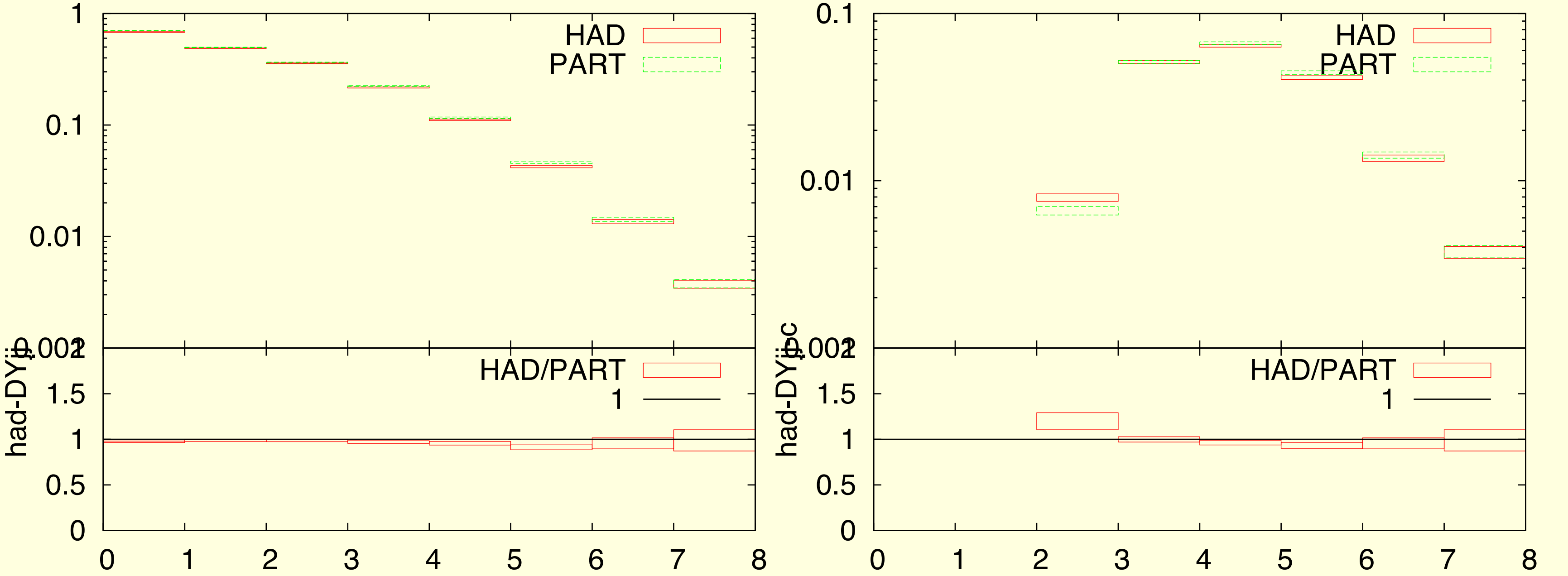
HAD
PART
HAD/PART
1
had-ptj3
had-ptj3-c

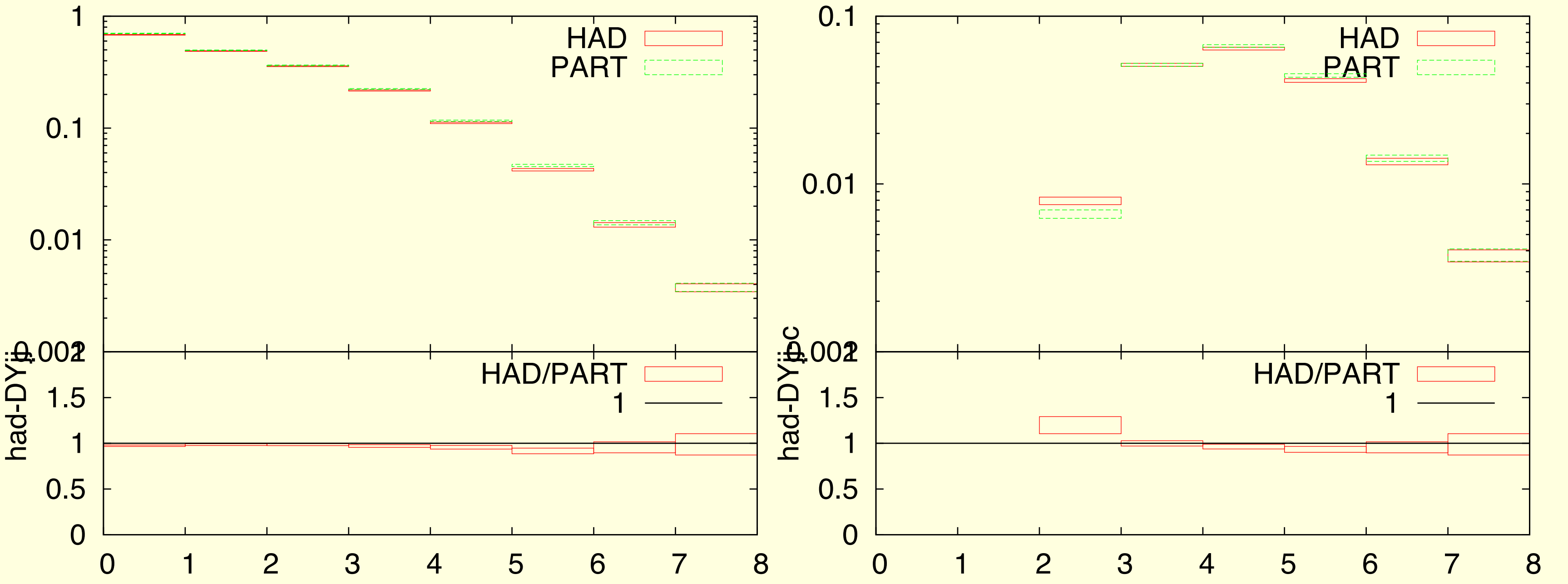

HAD
PART
HAD/PART
1
had-Yj3
1
0.1
0.01
0.001
2
1.5
1
0.5
0
-6
-4
-2
0
2
4
6

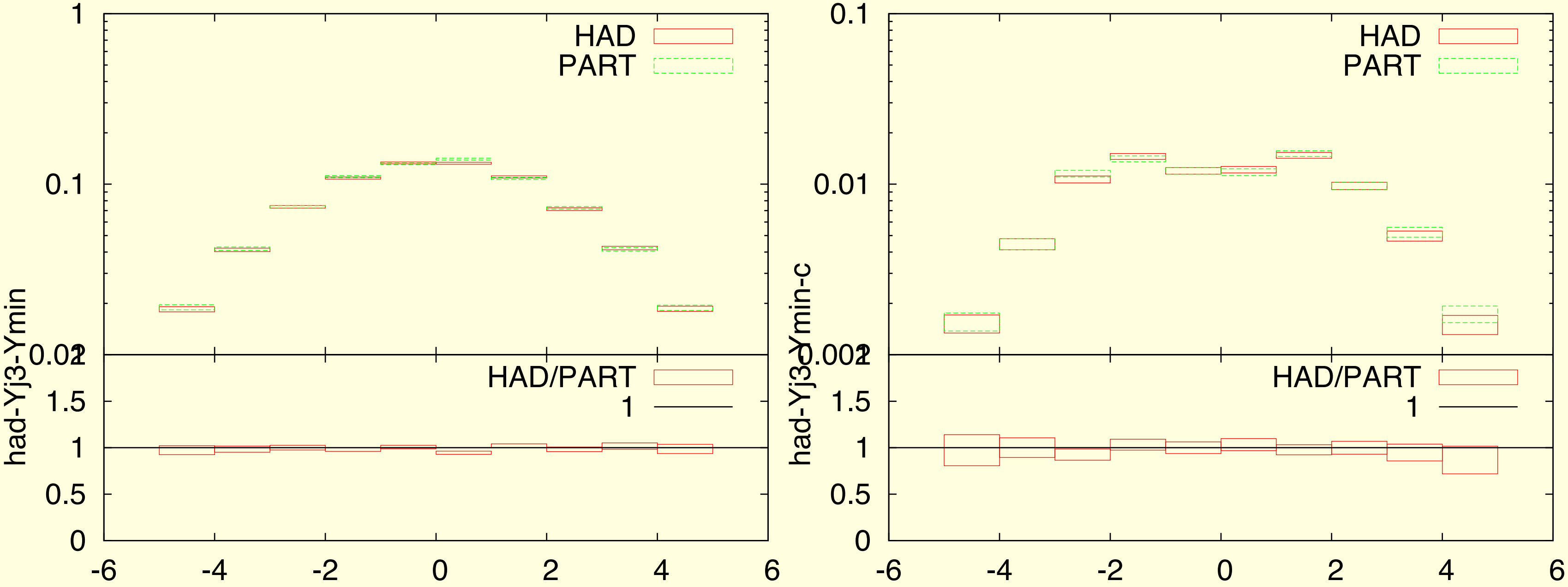

HAD
PART
HAD/PART
1
had-Yj3-C
0.1
0.01
0.001
0.0001
2
1.5
1
0.5
0
-6
-4
-2
0
2
4
6


0.01
0.001
0.0002
HAD
PART
HAD/PART
1
had-Mjj
2
1.5
1
0.5
0
0
100
200
300
400
500
600
700
800


0.001
0.0002
HAD
PART
HAD/PART
1
had-Mjj-c
2
1.5
1
0.5
0
0
100
200
300
400
500
600
700
800


HAD
PART
HAD/PART
1
had-DYjjb
had-DYjjbc
0.1
0.01
0.002
1.5
0.5


HAD
PART
HAD/PART
1
had-DYjjb
had-DYjjbc
HAD
PART
HAD/PART
1


HAD
PART
HAD/PART
1
had-Yj3-Ymin
had-Yj3-Ymin-c