Monte Carlo Generators
I SPRACE Physics Analysis Workshop

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Overview

- High Energy Processes
- Monte Carlo generators roles, types and features
- A illustrative example: Z+jets production
- Practical examples:
  - Sherpa
  - Herwig++
- Last remarks

High Energy Processes

- Fundamental objects interact in a rather simple structure (tree level); However, we have corrections to this picture:

Perturbative

  - Bremsstrahlung-type corrections (specially QCD, due to large α_s and triple g vertex - Parton Shower - soft/collinear multiple emissions);
  - Multiple/Secondary interactions (Underlying Event)
  - Quark/gluons confinement - hadronization (fragmentation + decays) $\longrightarrow$ Model based!

Event Generators

- Objective: computers to generate events as detailed as it could be observed by a perfect detector.
- Factorize the problem into components: hard process $\longrightarrow$ bremsstrahlung $\longrightarrow$ hadronization
- Output - event - same average behaviour and fluctuation as real data
- Detector simulation - GEANT4 (see Marcia and Mauricio's talk) - ideally, output the same format recorded by the detector

Monte Carlo Generators Types

- General Purpose (GP) MC Generators:
  - Amplitudes of the processes
  - Algorithms for showering and hadronization
    - Ex: Pythia, Herwig++, Sherpa
- Specific Process MC Generators:
  - Calculate the amplitude of the processes
  - Give an output that can be fed in GP MC gen
    - Ex: Alpgen, Powheg, MadGraph

Jet Definitions

- The jet definition is fundamental in experimental and theoretical level - refer to number of jets in final state (ex. W+n jets, Z+n jets, ttbar+n jets)
- Algorithm types:
  - cone: maximize energy within a cone
  - cluster: identification and combination of nearest neighbour particles
  - CMS and ATLAS default is clustering anti-k_T algorithm

Parton Shower Approach

- QCD emissions populate collinear and soft phase-space regions - factorizes amplitude
- Describes the particle multiplicity growth
- Evolve partonic ensemble down to hadronization scale
- Provides input for hadronization models
- Ex: Sherpa's Catani-Seymour shower
- Limitations: LO process; doesn't populate high p_T emission; limit of large N_C.

Possible Improvements to PS

- Tree-level Matrix Element corrections for the first emissions (ME+PS merging) - gives cross sections in LO
    - CKKW, ME&TS (Sherpa), MLM (Alpgen, MadGraph)
- NLO QCD core processes and match to PS (NLO +PS matching)
    - MC@NLO, POWHEG

Z+jets Production - Features Example

- Motivation:
  - Background for new physics searches (SUSY, W', Z', Extra Dimensional excitations)
  - Important tests of the Standard Model (strong coupling constant, renormalization and factorization scales, PDFs)
  - Detector commissioning (absolute electromagnetic energy scale, tracker alignment and muon resolution)

General Features for Comparison

- Herwig++
  - LO hard process
  - Parton Shower + ME corrections
  - Z production

- Sherpa
  - LO hard process
  - Parton Shower + ME merging (improved CKKW)
  - Z + n jets production

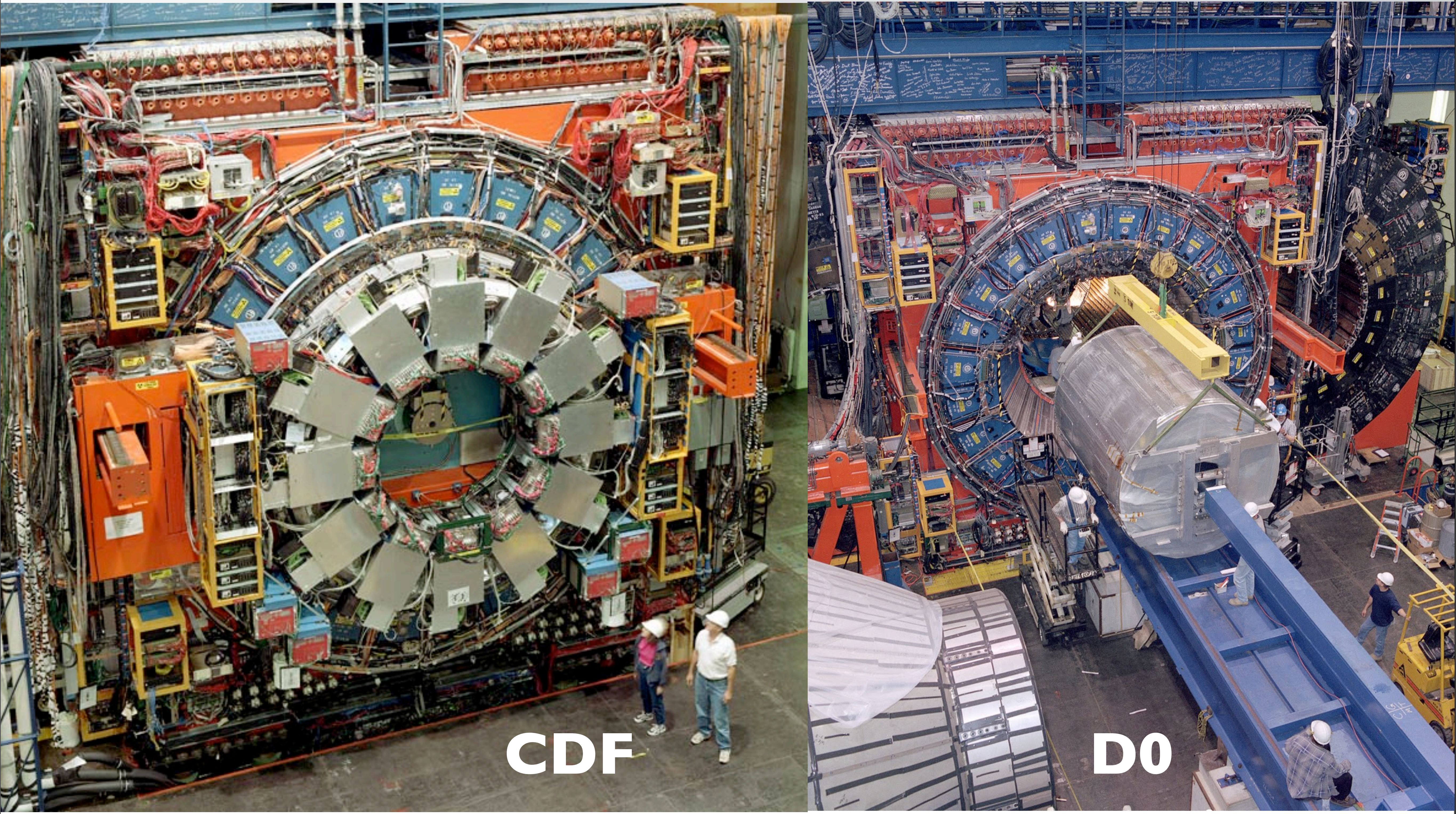
- POWHEG (Herwig++)
  - NLO hard process
  - LO showering (pT ordered)
  - Z production

Tevatron

Tevatron

Proton-antiproton collider, 1.96TeV center of mass energy (RunII; 1.8TeV RunI)

Tevatron



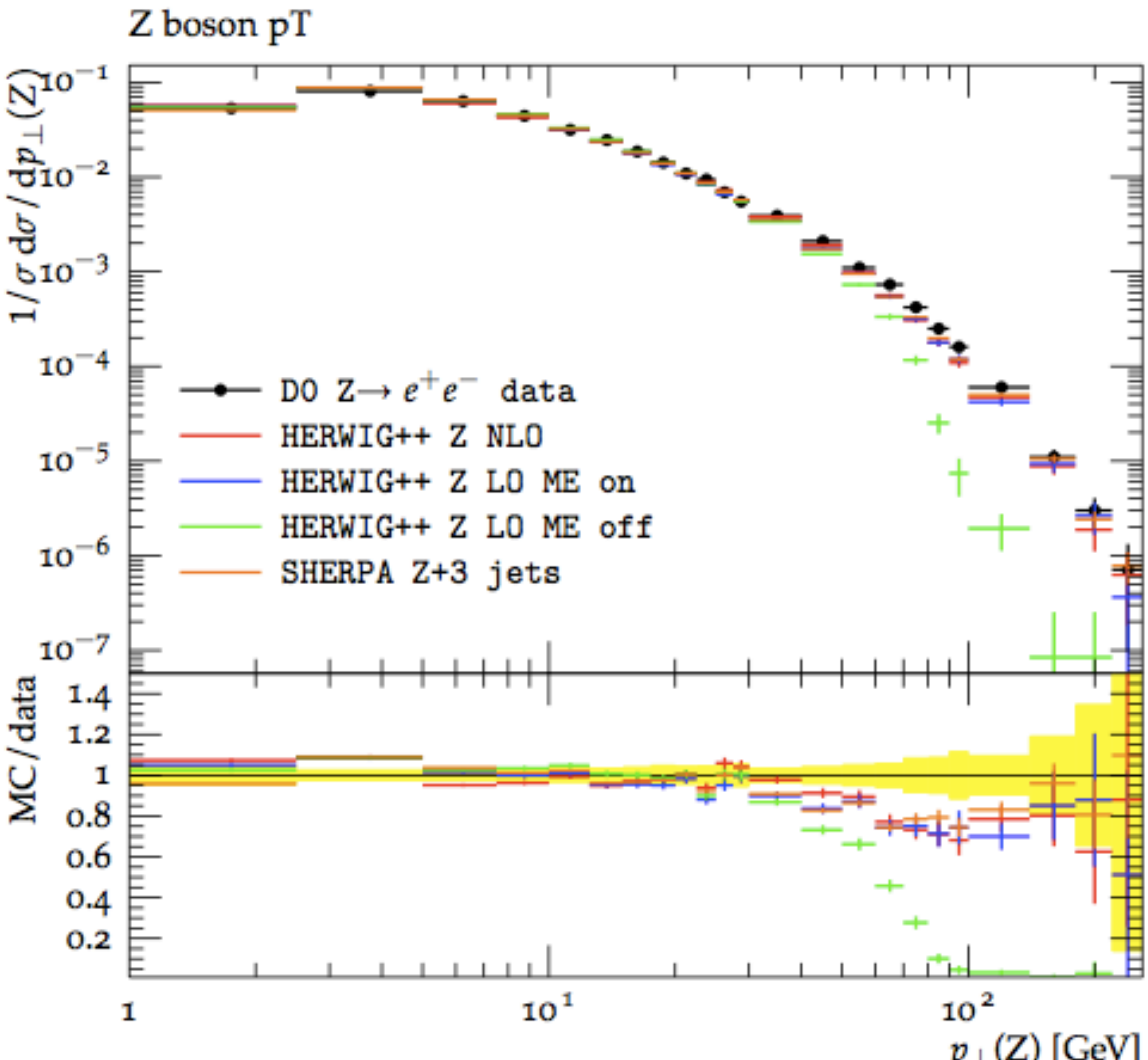
Tevatron Data Comparisons

- Compare the generator with Tevatron data:
  - NLO + PS merging
  - Parton Shower + ME corrections
  - Multiple Parton Interaction (MPI) models
  - Parton Distribution Functions (PDFs)

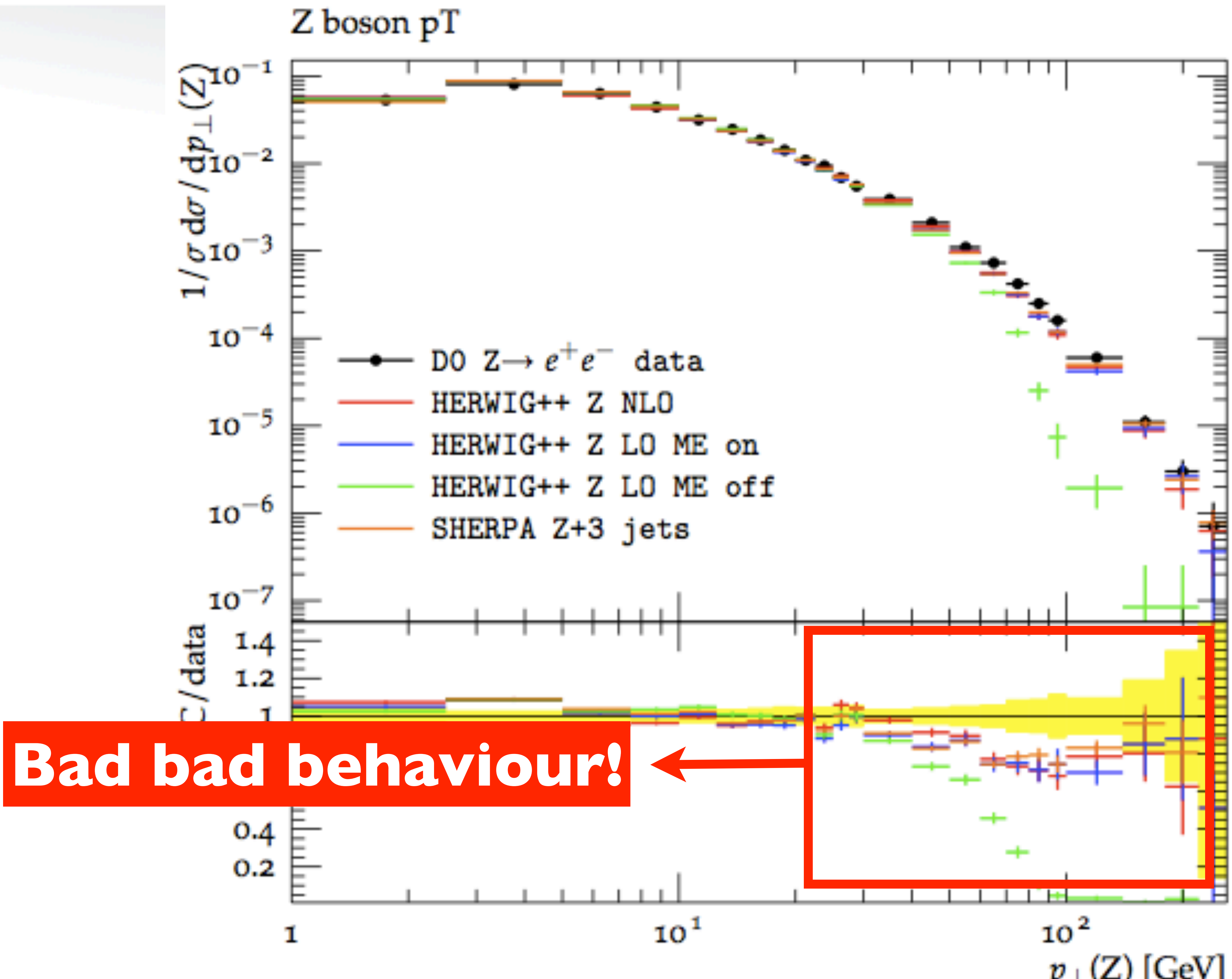
Z Transverse Momentum

- Generated by momentum balance against initial state radiation and parent's parton in incoming hadrons
- At generator level, generated from hard matrix element (high p_T), PS or Underlying Event (low p_T)
- Important generator tuning - fix interplay of ISR and MPI in generating UE activity

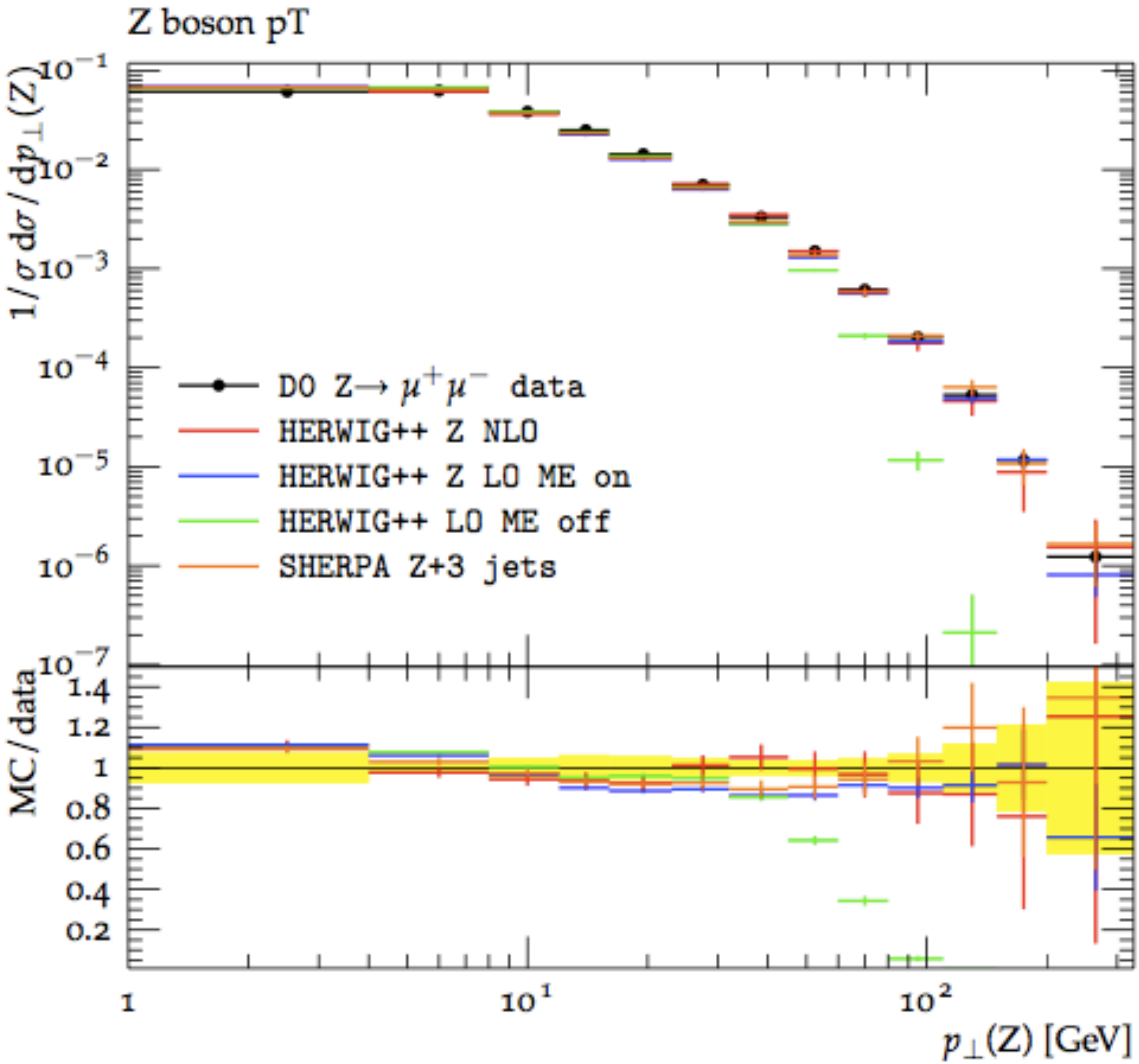
Z Transverse Momentum



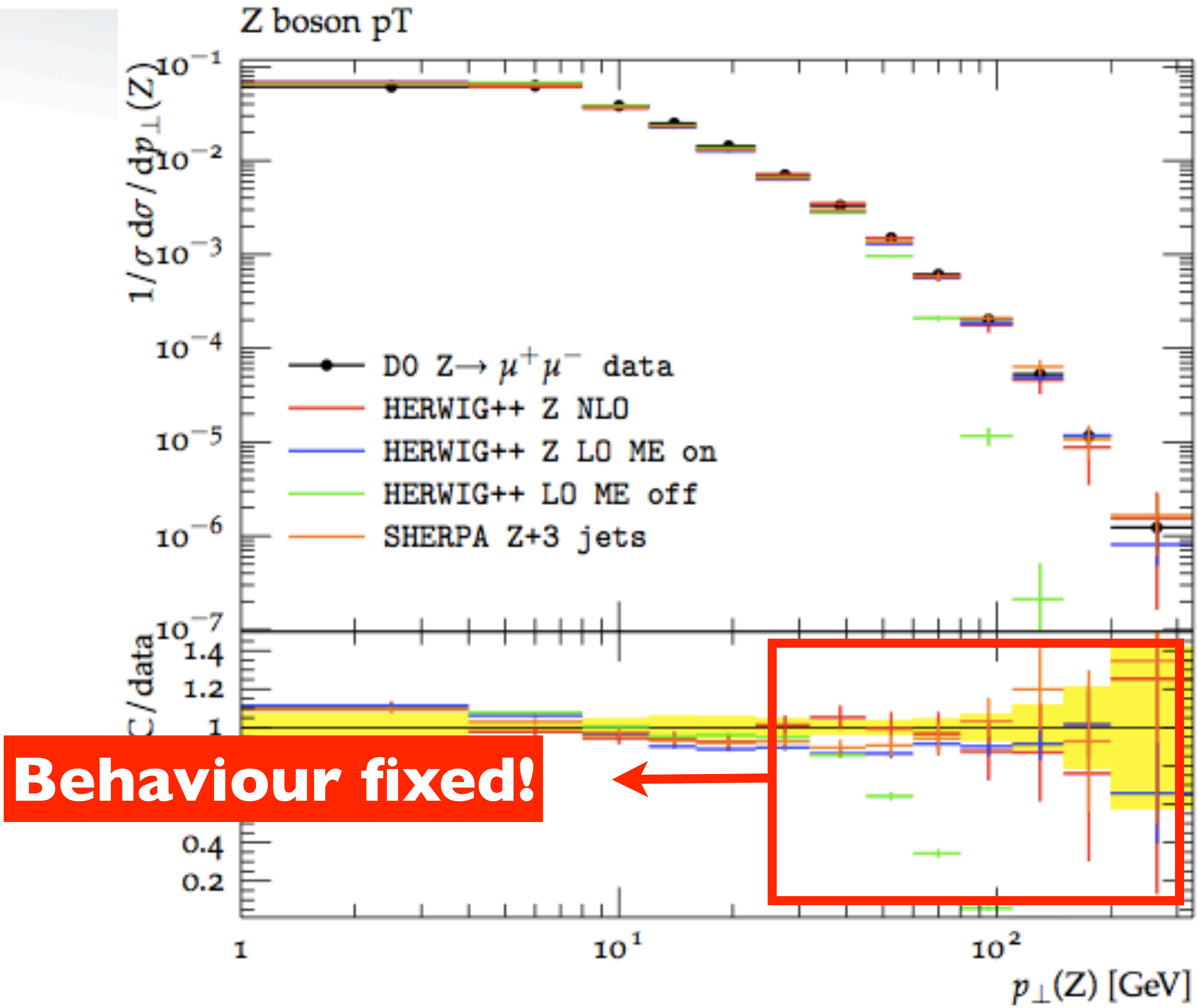
Z Transverse Momentum



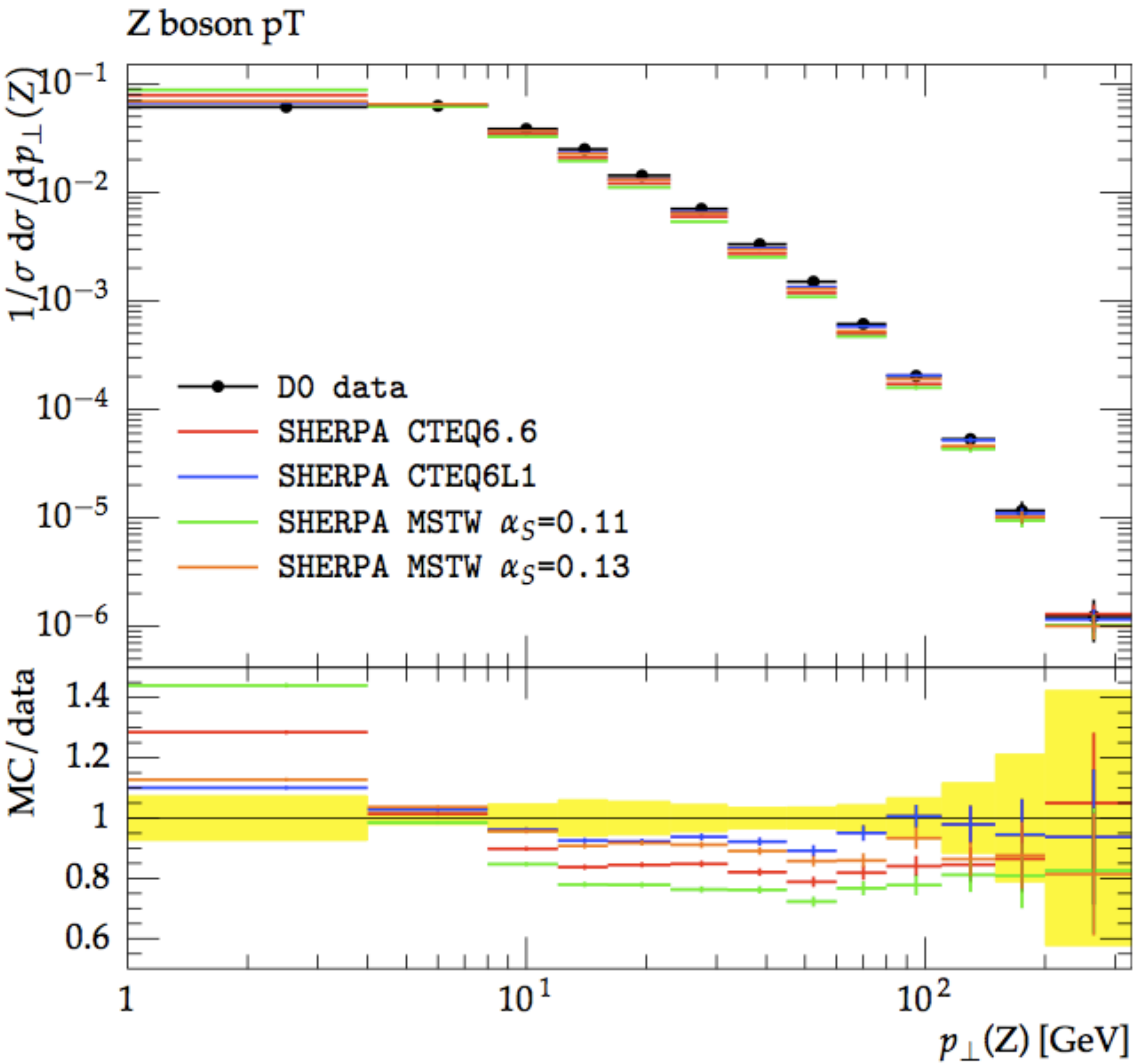
Z Transverse Momentum



Z Transverse Momentum

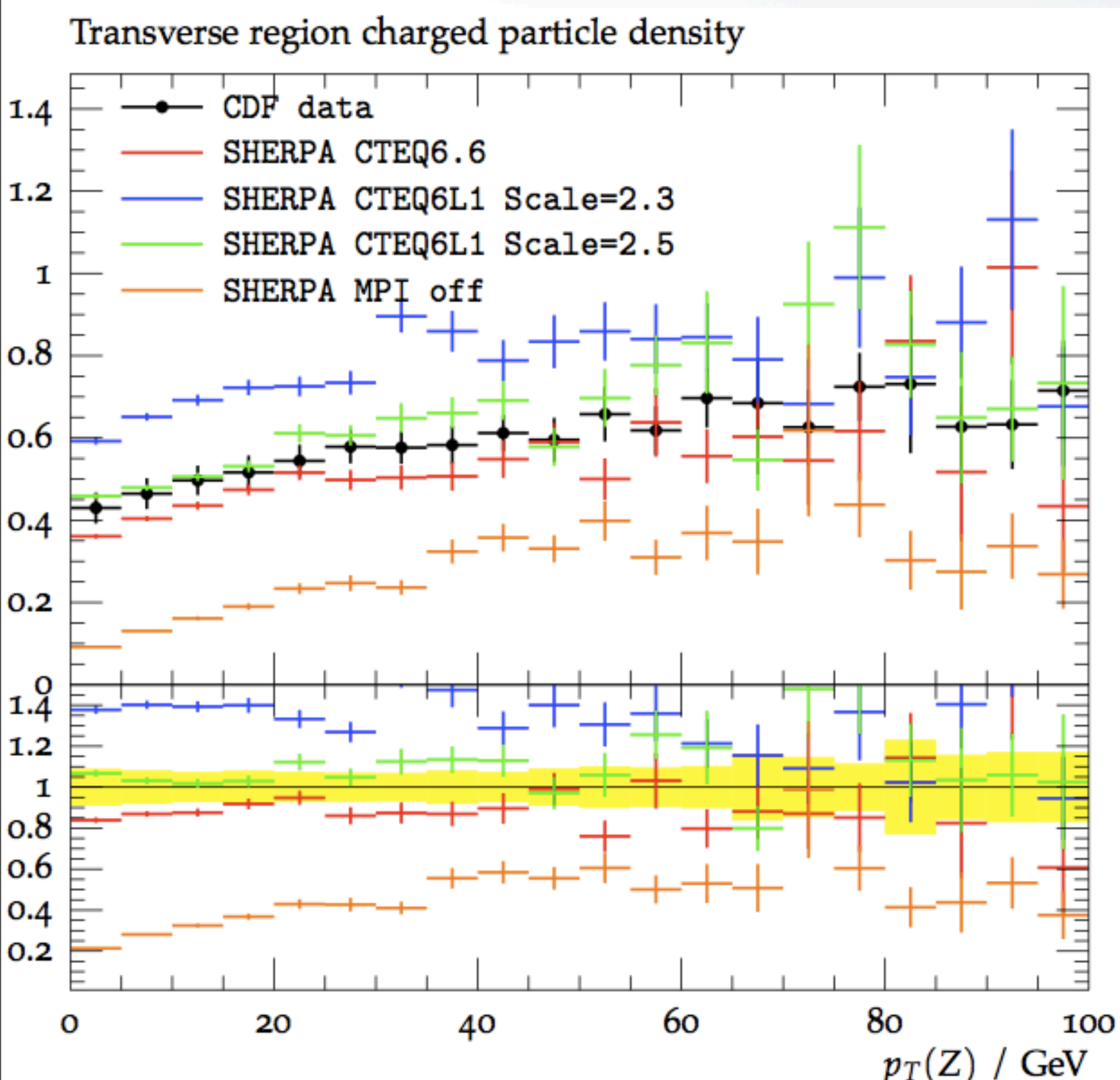


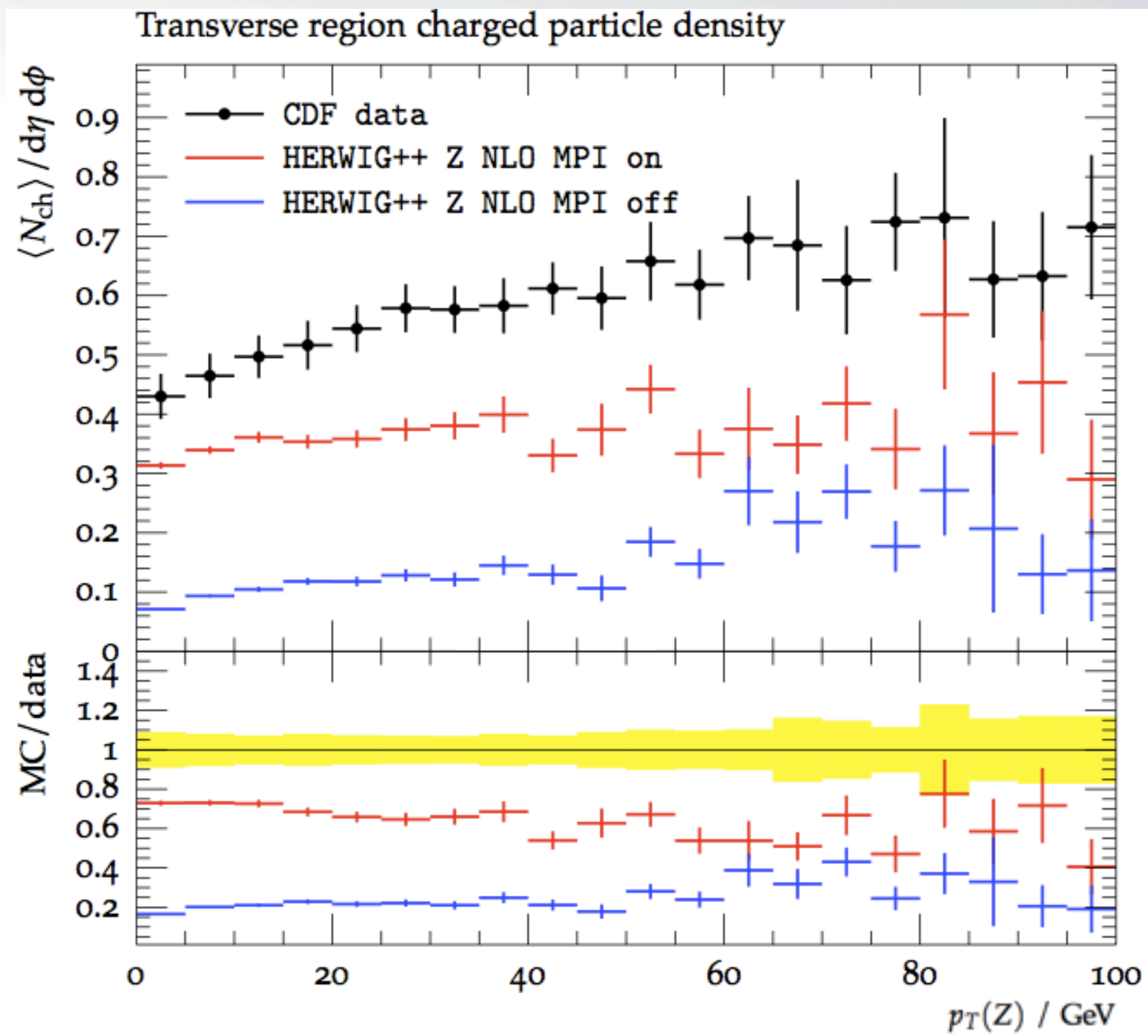
PDF Choice



Z boson pT
D0 data
SHERPA CTEQ6.6
SHERPA CTEQ6L1
SHERPA MSTW α_S=0.11
SHERPA MSTW α_S=0.13
$1/\sigma\, d\sigma/dp_\perp(Z)$
MC/data
$p_\perp(Z)$ [GeV]

Multiple Parton Interaction



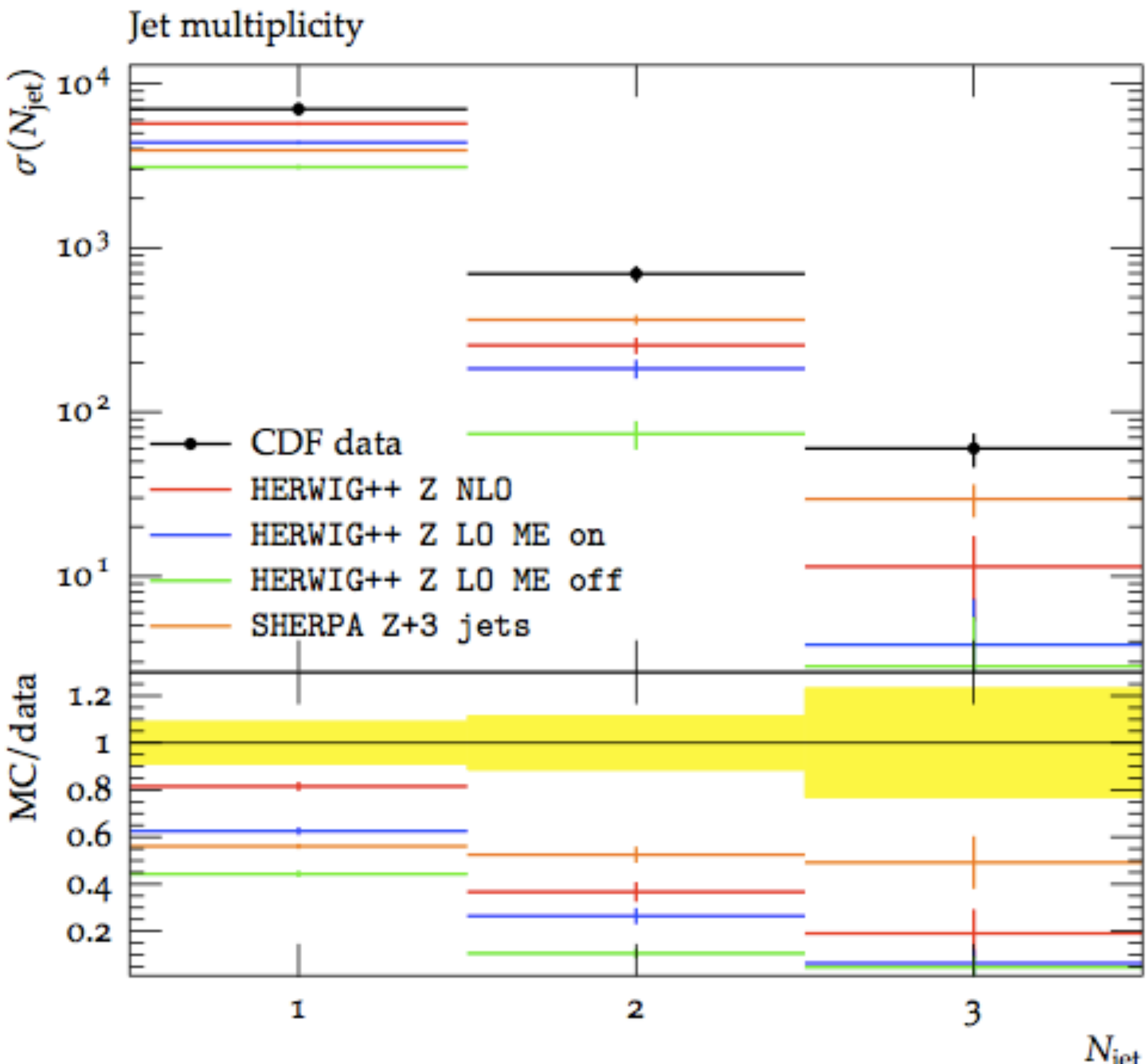


Z + Jets Total Cross Section

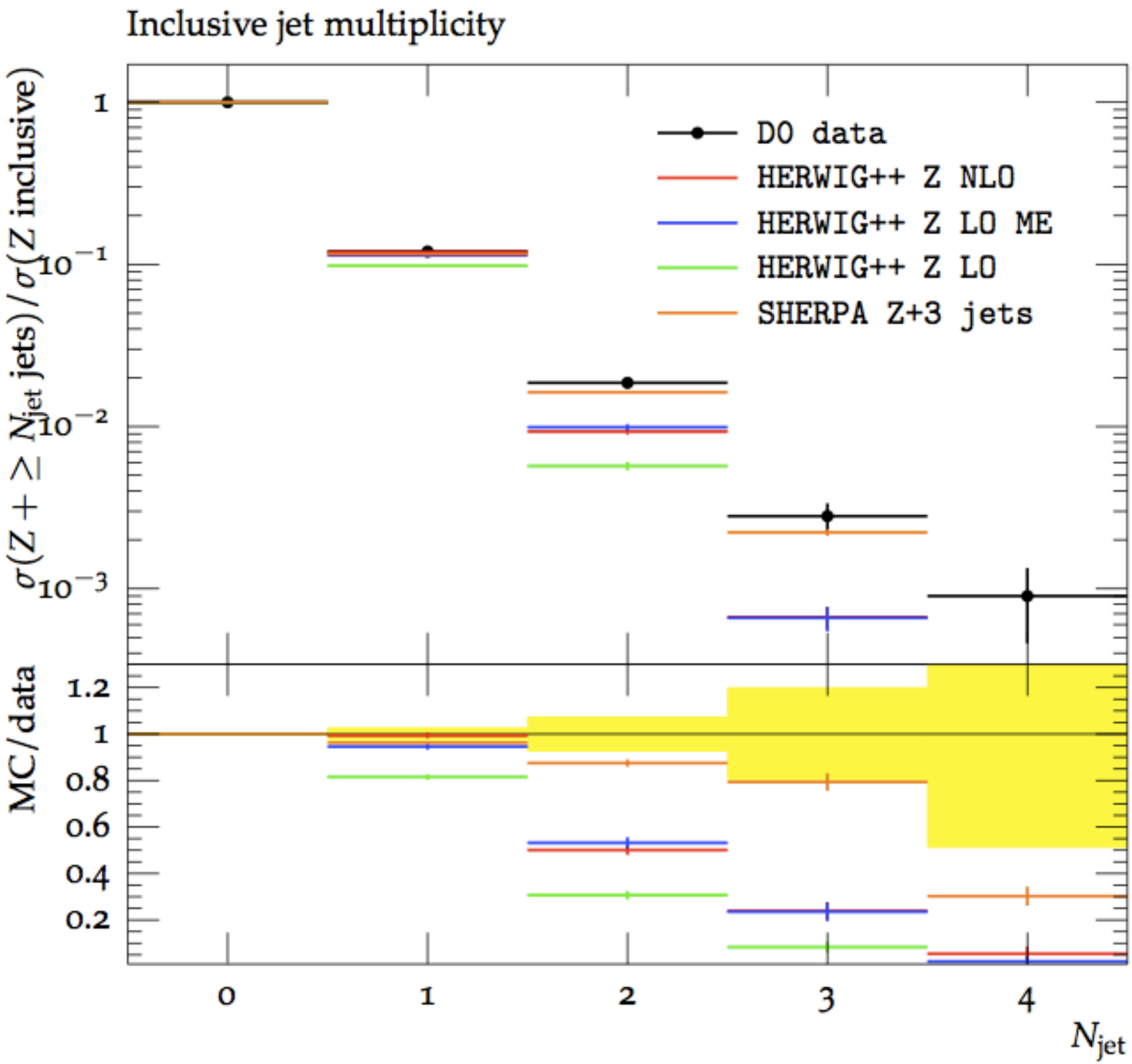
	Total σ_Z [pb]	Uncertainty [pb]
CDF data	256.0	2.1
HERWIG++ LO ME on	185.1	0.7
HERWIG++ LO ME off	185.2	0.7
HERWIG++ NLO	230.4	0.9
SHERPA Z + 1 jet	171.5	0.3
SHERPA Z + 3 jets	172.6	0.4

- NLO - better prediction cross section (90% of data value)
- LO Herwig++ slightly better than Sherpa (72% against 67% of data value)

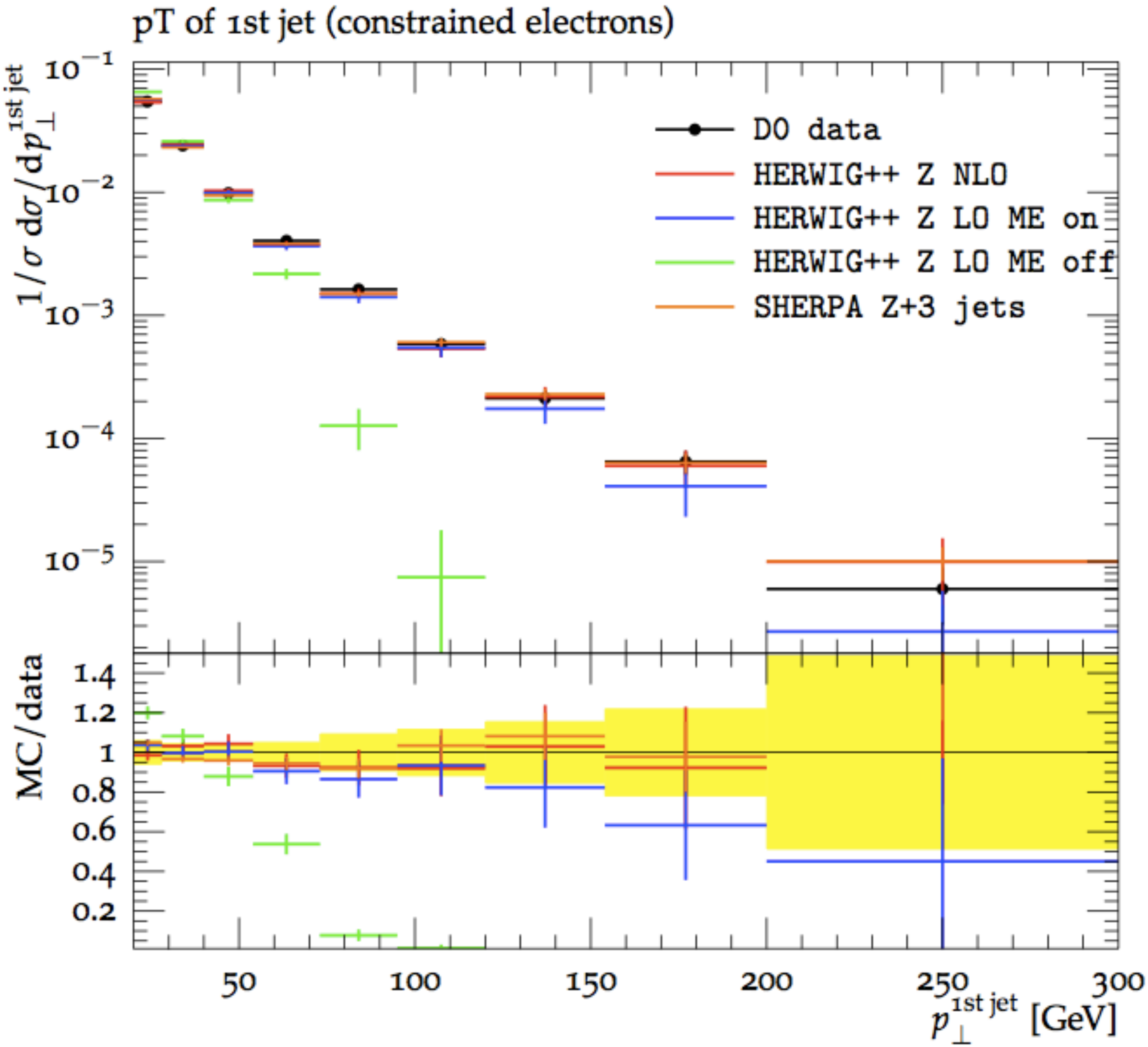
Jet Multiplicity



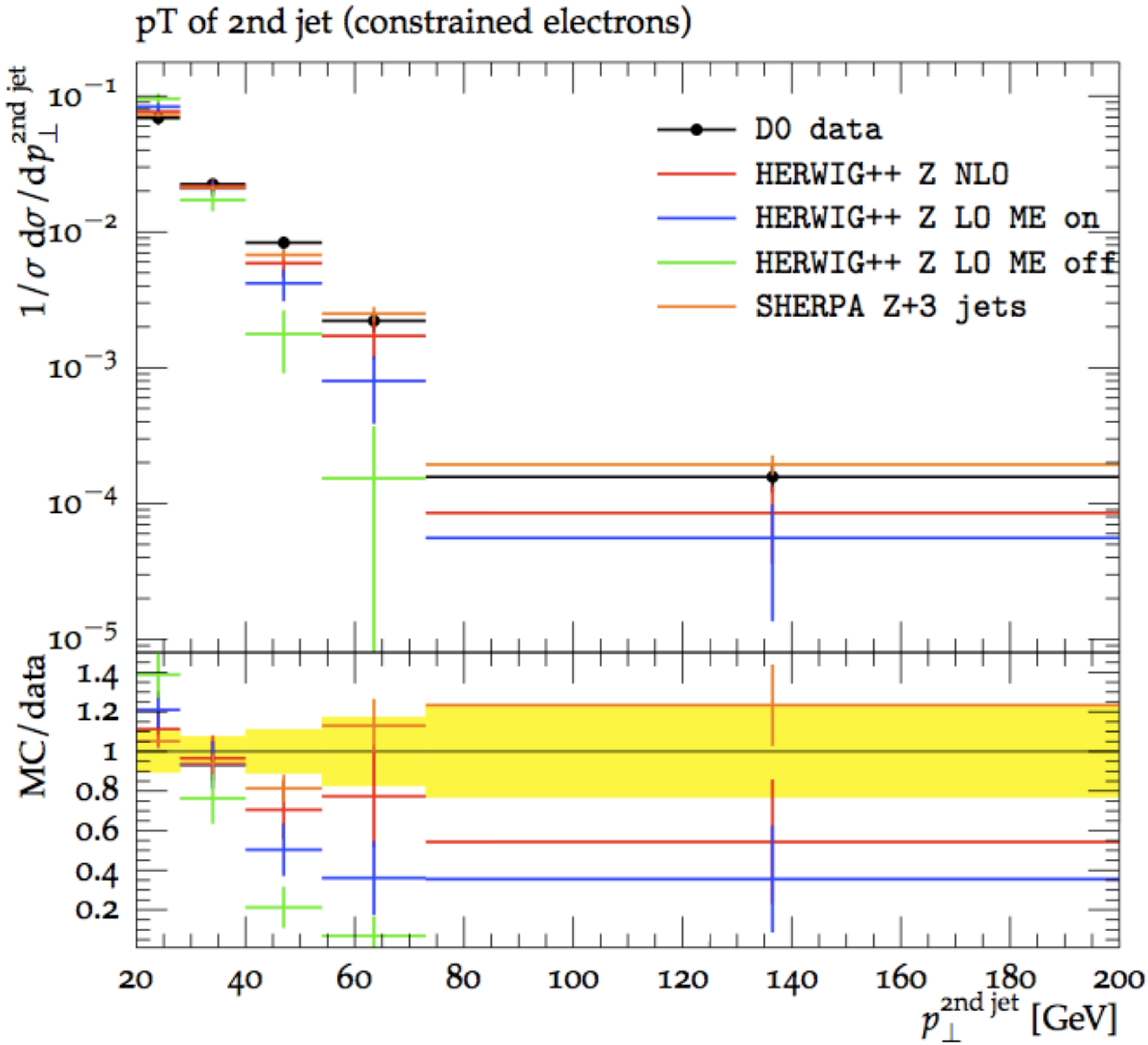
Ratios of Jet Cross Section



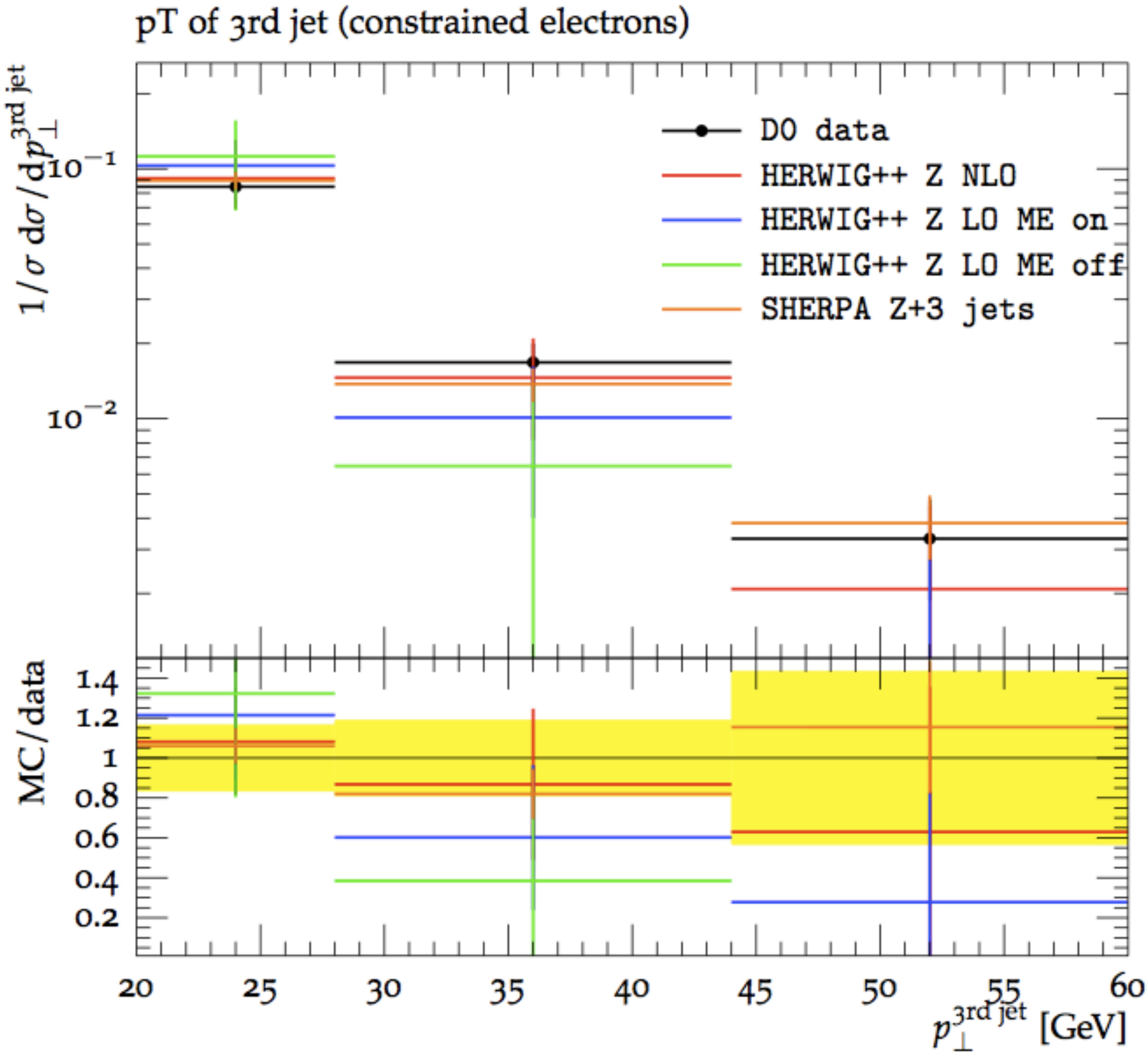
Jets Transverse Momentum



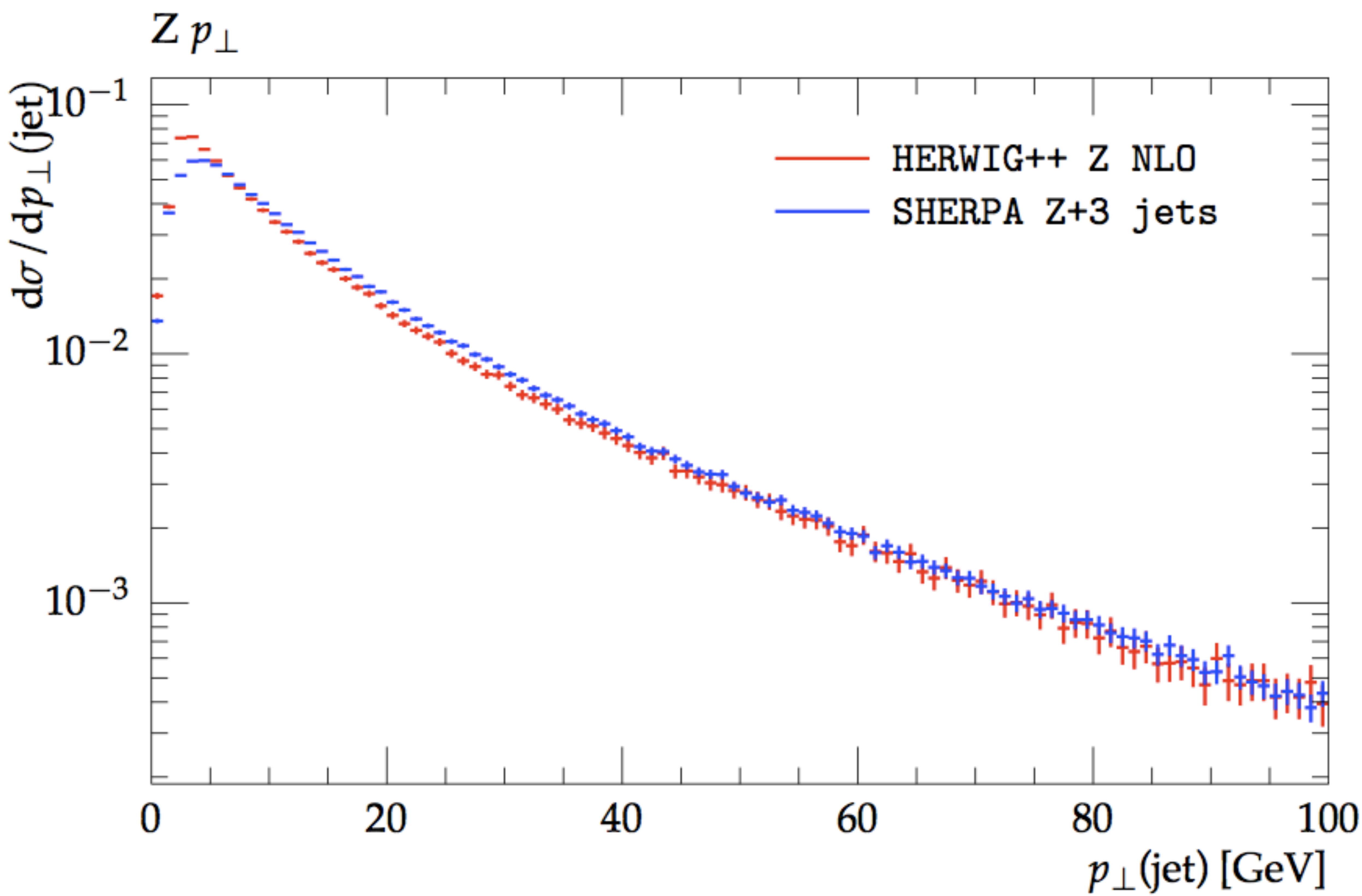
Jets Transverse Momentum



Jets Transverse Momentum

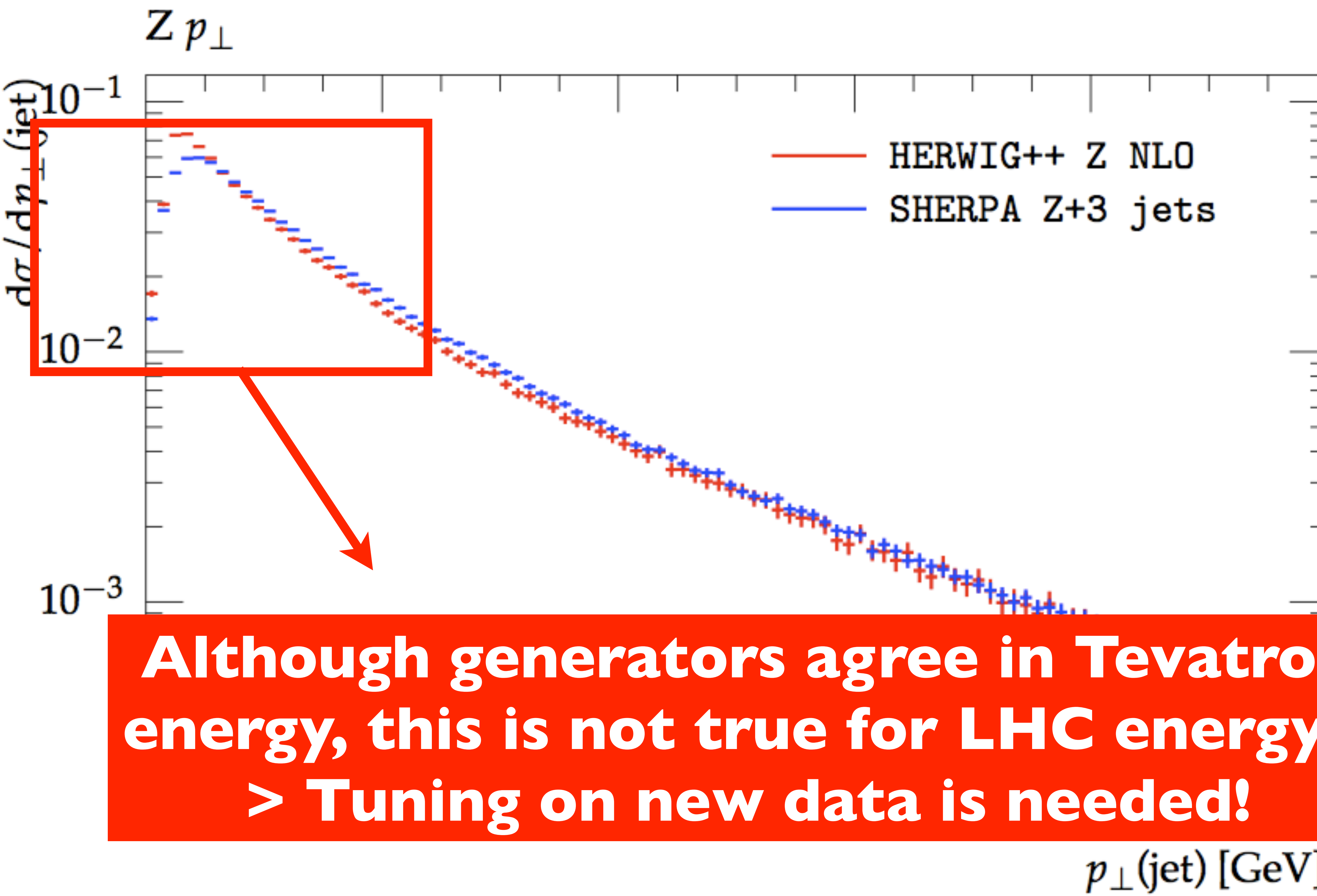


LHC Energy



Z $p_\perp$
$d\sigma/dp_\perp$(jet)
10^{-1}
10^{-2}
10^{-3}
HERWIG++ Z NLO
SHERPA Z+3 jets
0
20
40
60
80
100
$p_\perp$(jet) [GeV]

LHC Energy



Although generators agree in Tevatron energy, this is not true for LHC energy -> Tuning on new data is needed!

MC Remarks

- MC is a very helpful tool for theory insights and for data analysis
- There are several parameters that must be tuned for better description of colliders data
- There are several generators with different purposes and models implemented

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- **Now, how do I run these generators?**

Practical Example - Sherpa

- General Purpose generator
- Installation, physics and manual: http://sherpa-mc.de/
- Contact: info@sherpa-mc.de
- They are very helpful to help with any questions about installation and running, but check the manual and FAQ first!

Basic Installation - From Manual

2.1 Installation

Sherpa is distributed as a tarred and gzipped file named `Sherpa-<version>.tar.gz`, and can be unpacked in the current working directory with

```
tar -zxf Sherpa-<version>.tar.gz .
```

To guarantee successful installation, the following tools should have been made available on the system: `make`, `autoconf`, `automake` and `libtool`. Furthermore, a C++ and FORTRAN compiler must be provided. Compilation and installation proceed through the following commands

```
./configure

make install
```

Running Examples

- Runcards automatically in directory <prefix>/share/SHERPA-MC/Examples
- To run the program: <prefix>/bin/Sherpa

```
(run){
  EVENTS = 2500000
  OUTPUT = 2
  BATCH_MODE = 3
  EVENT_MODE = HepMC
  HEPMC2_GENEVENT_OUTPUT = out.events
  FILE_SIZE = 2500001
}(run)

(isr){
  PDF_SET = cteq6l1
  PDF_GRID_PATH = CTEQ6Grid
}(isr)

(beam){
  BEAM_1 =  2212; BEAM_ENERGY_1 = 3500;
  BEAM_2 =  2212; BEAM_ENERGY_2 = 3500;
  K_PERP_MEAN_1 = 1.4
  K_PERP_SIGMA_1 = 0.8
  K_PERP_MEAN_2 = 1.4
  K_PERP_SIGMA_2 = 0.8
}(beam)
```

```
(processes){
  Process 93 93 -> 11 -11 93{3}
  Order_EW 2;
  CKKW sqr(30/E_CMS)
  Integration_Error 0.02 {6};
  End process;
}(processes)

(selector){
  Mass 11 -11 60 110
}(selector)

(me){
  ME_SIGNAL_GENERATOR = Internal Comix
}(me)

(mi){
  MI_HANDLER = Amisic  # None or Amisic
  SCALE_MIN = 2.5
}(mi)
```

A More Complex Run Card

- Open in my own computer :)

Practical Example - Herwig++

- General Purpose generator
- Installation: http://projects.hepforge.org/herwig/trac/
- Physics and manual: http://arxiv.org/abs/0803.0883
- Contact: herwig@projects.hepforge.org
- They are very helpful to help with any questions about installation and running, but check the manual and FAQ first!

Herwig++ really quick installation guide

ThePEG

Download ThePEG, then

```
$ tar xjvf ThePEG-*.tar.bz2
$ cd ThePEG*
$ ./configure --prefix=/path/where/ThePEG/should/be/installed
$ make
$ make check
$ make install
```

Herwig++

Download Herwig++, then

```
$ tar xjvf Herwig++-*.tar.bz2
$ cd Herwig++*
$ ./configure --prefix=/path/where/Herwig++/should/be/installed --with-thepeg=/path/where/ThePEG/is/installed
$ make
$ make check
$ make install
```

From Herwig++ version 2.1 CLHEP is only required if you are using additional external packages, such as KtJet, which require it. The core Herwig++ and ThePEG code no longer depends on it.

If that was too quick, have a look at the more detailed user guides.

Running Examples

- Example input files automatically in directory: <path>/share/Herwig++
- Show input example on my laptop.
- To run:

```
Herwig++ read Collider.in
Herwig++ run -N no_of_events Collider.run
```

- The default parameters can be found in:

```
HERWIGPATH/share/Herwig++/defaults
```

A Lesson to be Learned

- Read the manual!
- Read the manual!
- Read the manual!
- Run the examples
- Contact the developers if the problems persist - in most big collaboration generators, the answers come in the same day

Acknowledgements

- MCnet UCL and IPPP-Durham group (Emily Nurse, Frank Siegert, Frank Krauss, Peter Richardson, Jon Butterworth) and Gavin Hesketh (CERN)

- Thank you for the attention