Sherpa vs. DØ in Z + jets

[HERA and the LHC workshop]

Jan Winter [a]

CERN PH and
Institute for Theoretical Physics, Dresden University of Technology

Our aim for this workshop series: proving that the SHERPA MC is ready for LHC studies.

- validating the SHERPA (CKKW) approach against Tevatron data
- validating it against other ME PS merging approaches
- verifying that it gives reliable results in new (so far untested) channels
- making predictions : extrapolation to LHC energies
- MI model of SHERPA has been shown to work well (HERA/LHC proceedings)

Sorry...!!! SHERPA is still not a MC event generator for DIS scenarios.

[a] SHERPA authors: T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann, J. W.

Sherpa vs. DØ in Z + jets

Challenge: future (and present) hadron collider experiments.

- LHC: first re-discover SM physics
- LHC: these signals will be tomorrow's backgrounds
- LHC: tremendously large phase space for QCD radiation
- LHC: is a QCD machine → **Multijets**
- LHC physics: need to understand SM backgrounds

Model...!!! **Jet production** → **Jet evolution** → **Hadronization**

SHERPA: AMEGIC++'s MEs ← **CKKW** → **APACIC++ Shower** →

SHERPA: → **PYTHIA (phenomenological) Models**

Scope of this talk

- Central part: DØ analysis and its preliminary results
  - Brief description of the analysis
  - SHERPA version used in the analysis
  - The results
- A brief comment: detailed merging comparison has started
  - 1st results in proceedings hep-ph/0601012,13
  - Go for a second round.
- Status of SHERPA.

The Z/γ^*+jet-production DØ analysis

Names related with this analysis:

Henrik Nilsen

under supervision of Prof. Karl Jacobs, DØ group Freiburg.

Scope:

- Study accuracy of modelling associated jet production in Z/γ^* events
- MCs: PYTHIA and SHERPA
- Data: Fermilab Tevatron Run II, Oct 2002 - Nov 2005, int lum 950 pb^{-1}

Some details:

- e^-, e^+ with $p_T > 25$ GeV, $|\eta| < 2.5$, one central ℓ with $|\eta| < 1.1$
- variety of single and di-electron triggers, optimized likelihood function to separate real electrons from QCD jet production BG
- $70 \text{ GeV} \leq m^2(e^-, e^+) \leq 100 \text{ GeV}$
- jets according to DØ Run II cone algorithm, $p_T > 15$ GeV, $\Delta R_{\ell j} > 0.5$
- some more work to suppress fake jets and to avoid electron contamination
- Gaussian smearing of jet energies in MC events
- + data zero bias events overlayed to account for other $p\bar{p}$ in same beam crossing

The Z/γ^*+jet-production DØ analysis

PYTHIA:

- version 6.319 using CTEQ6L1 PDF
- tuned to match a ME prediction for $Z/\gamma^* + 1$ jet production
- UE model: TUNE A parameter set

SHERPA:

- version 1.0.6 with CTEQ6L PDF
- inclusive $Z/\gamma^* + 3$ jet sample, i.e. ME's up to 3 jets included
- internal separation cut $k_{T,0} = 20\ \mathrm{GeV}$
- UE model: default (set up according to data used for R. Field's TUNE A)

Processing:

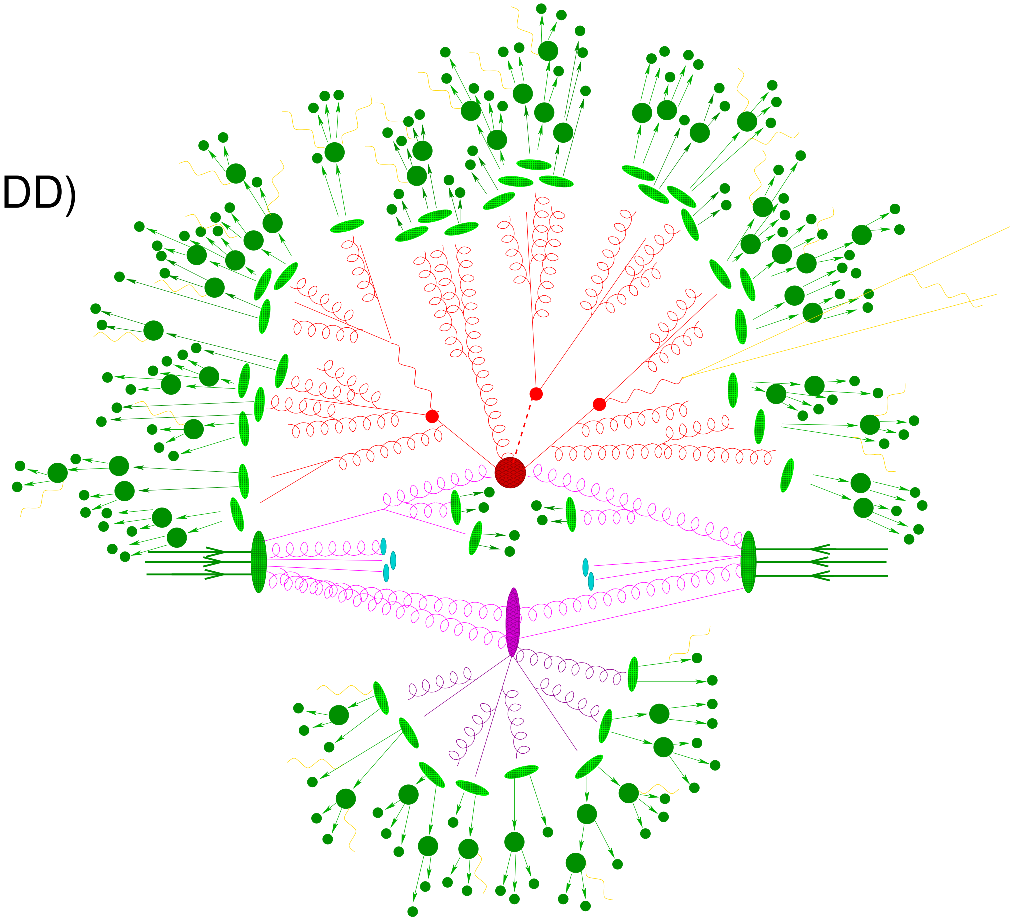
- full DØ detector simulation and reconstruction chain
- normalization is to total number of Z/γ^* events found in data sample
- systematic uncertainties: main contributions arise from jet energy scale and smearing of jet energies

SHERPA in the Z+jet-production DØ analysis

T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann and J. W., JHEP **0402** 056 (2004).

- **SHERPA version 1.0.6 has been used:**

- **ME generator AMEGIC++**
  (at tree level, provides HP and HD in SM, MSSM, ADD)

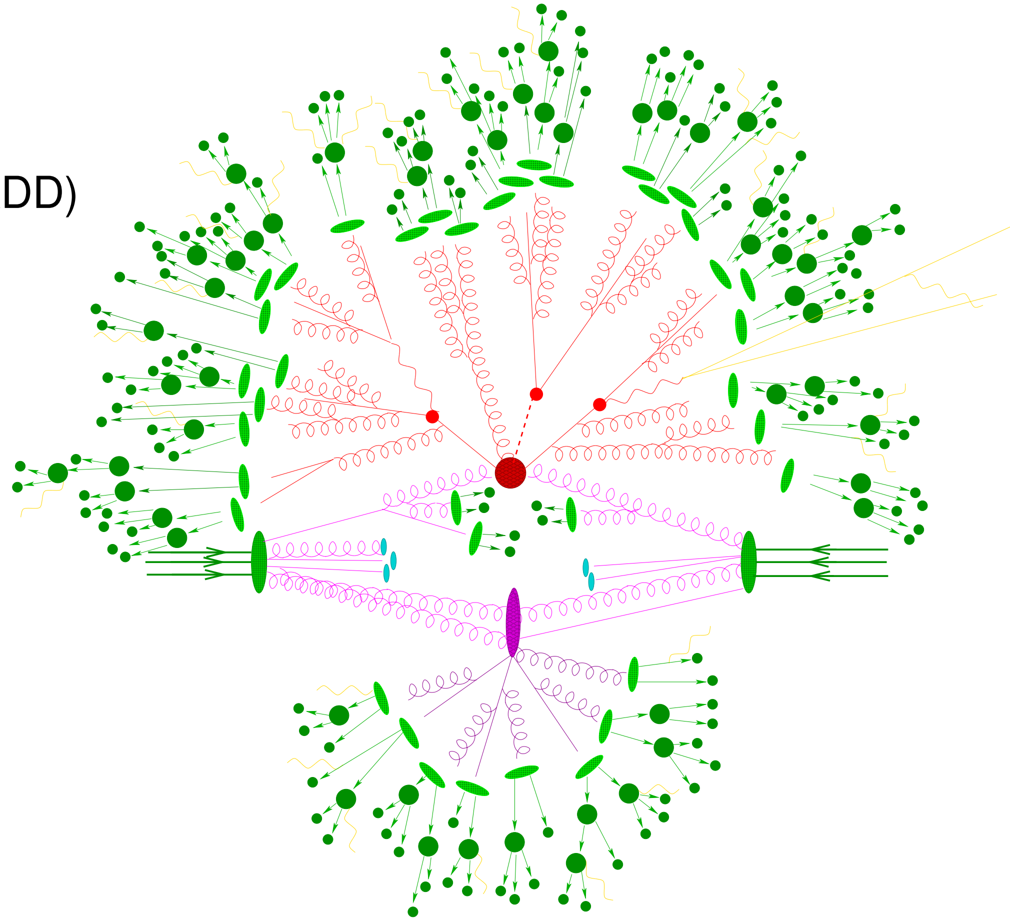


SHERPA in the Z+jet-production DØ analysis

T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann and J. W., JHEP **0402** 056 (2004).

➡ **SHERPA version 1.0.6 has been used:**

- **ME generator AMEGIC++**
  (at tree level, provides HP and HD in SM, MSSM, ADD)
- **IS and FS shower module APACIC++**
  (virtuality ordered, PYTHIA-like showers)

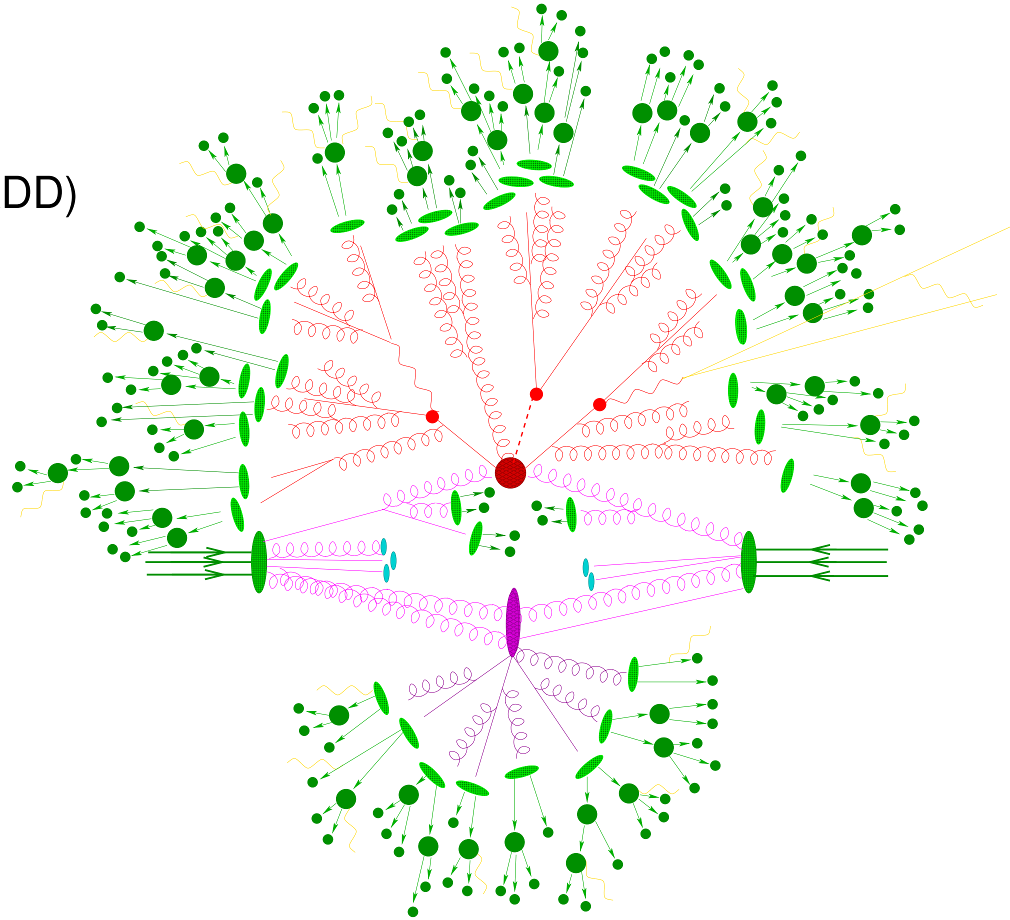


SHERPA in the Z+jet-production DØ analysis

T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann and J. W., JHEP **0402** 056 (2004).

➡ **SHERPA version 1.0.6 has been used:**

- **ME generator AMEGIC++**
  (at tree level, provides HP and HD in SM, MSSM, ADD)
- **IS and FS shower module APACIC++**
  (virtuality ordered, PYTHIA-like showers)
- **Combination of ME and PS according to CKKW**

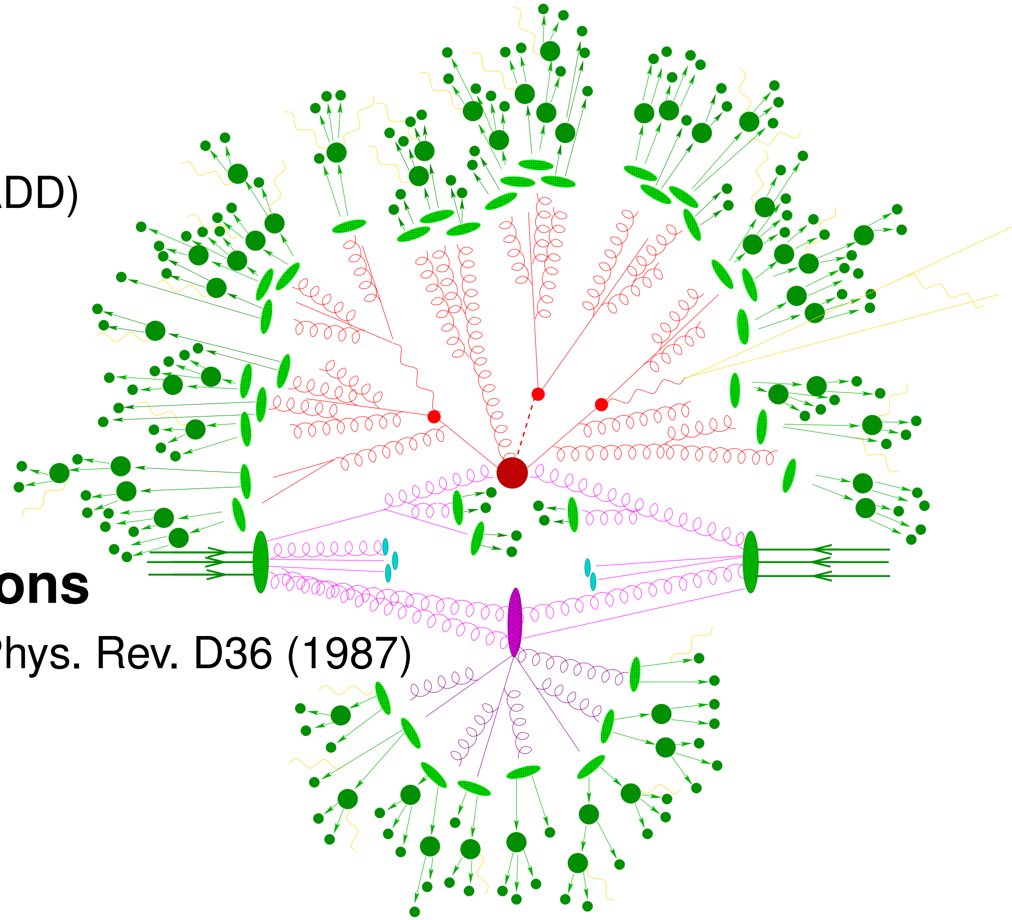


SHERPA in the Z+jet-production DØ analysis

T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann and J. W., JHEP **0402** 056 (2004).

➡ **SHERPA version 1.0.6 has been used:**

- **ME generator AMEGIC++**
  (at tree level, provides HP and HD in SM, MSSM, ADD)
- **IS and FS shower module APACIC++**
  (virtuality ordered, PYTHIA-like showers)
- **Combination of ME and PS according to CKKW**
- **Simulation of multiple parton interactions**
  main ideas based on T. Sjöstrand and M. van Zijl, Phys. Rev. D36 (1987)

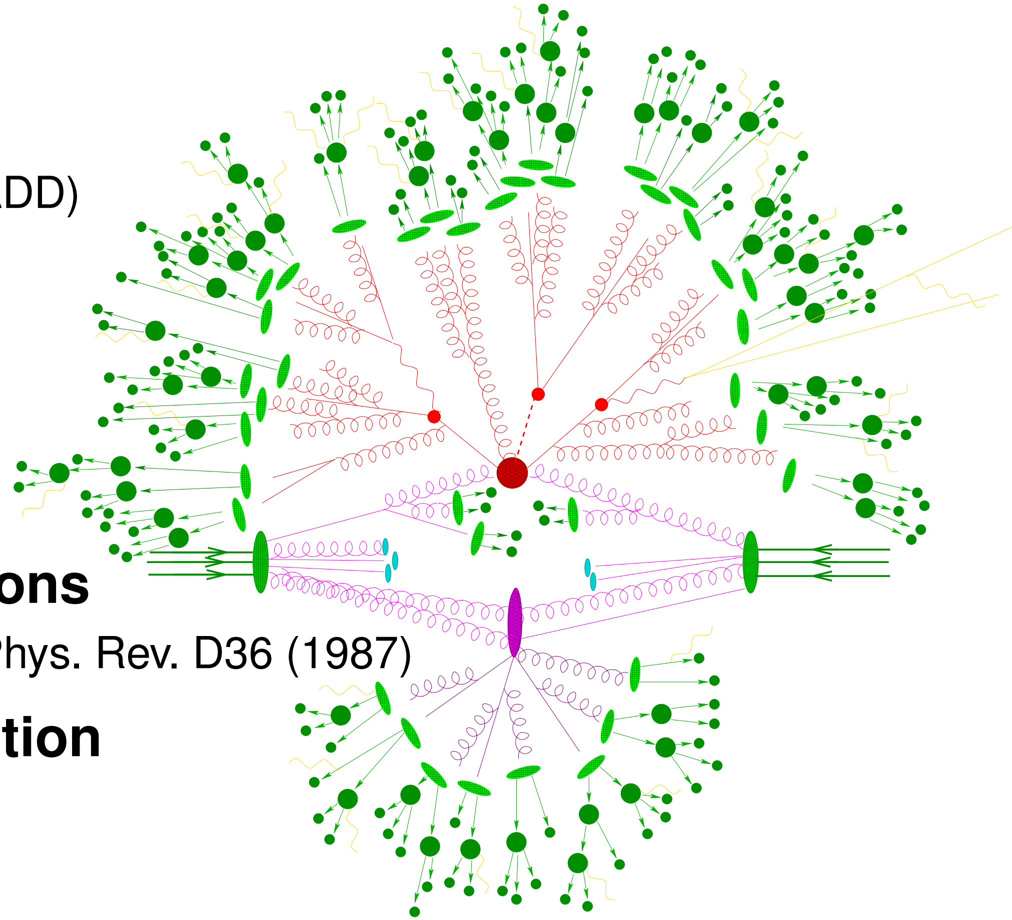


SHERPA in the Z+jet-production DØ analysis

T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann and J. W., JHEP **0402** 056 (2004).

➔ **SHERPA version 1.0.6 has been used:**

- **ME generator AMEGIC++**
  (at tree level, provides HP and HD in SM, MSSM, ADD)
- **IS and FS shower module APACIC++**
  (virtuality ordered, PYTHIA-like showers)
- **Combination of ME and PS according to CKKW**
- **Simulation of multiple parton interactions**
  main ideas based on T. Sjöstrand and M. van Zijl, Phys. Rev. D36 (1987)
- **Interface to PYTHIA's string hadronization**

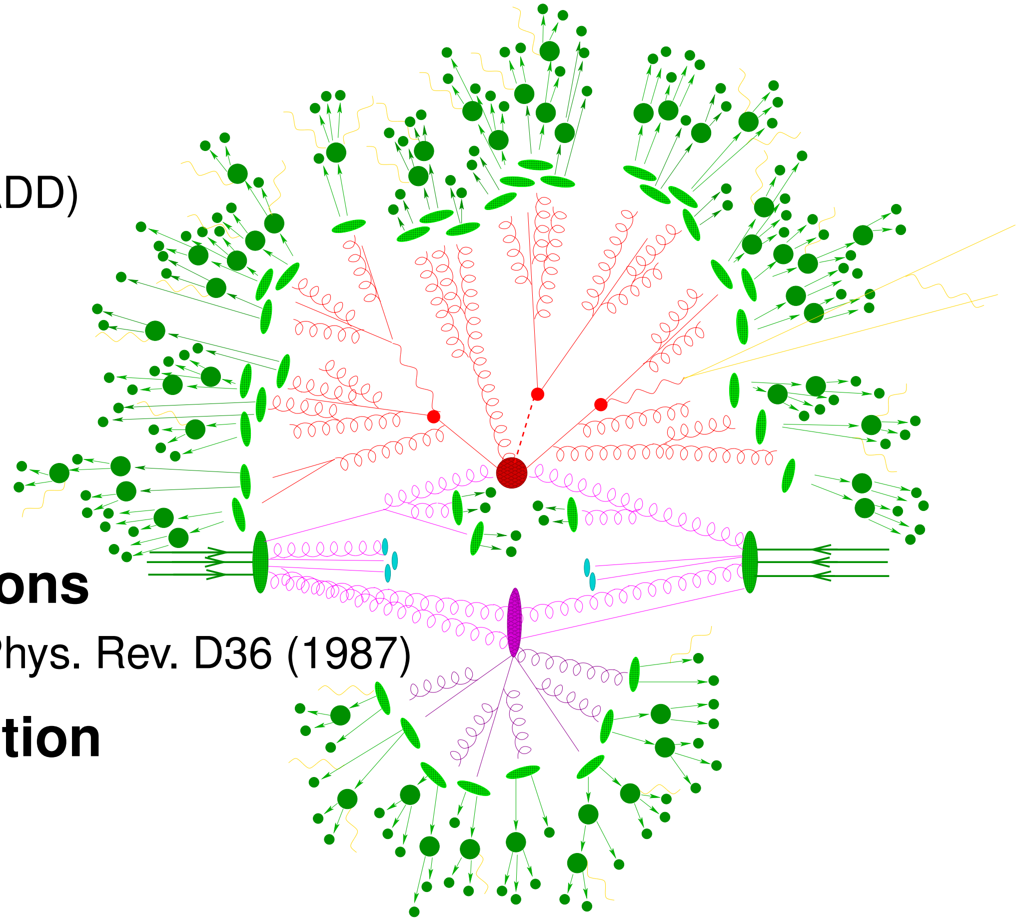


SHERPA in the Z+jet-production DØ analysis

T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann and J. W., JHEP **0402** 056 (2004).

➡ **SHERPA version 1.0.6 has been used:**

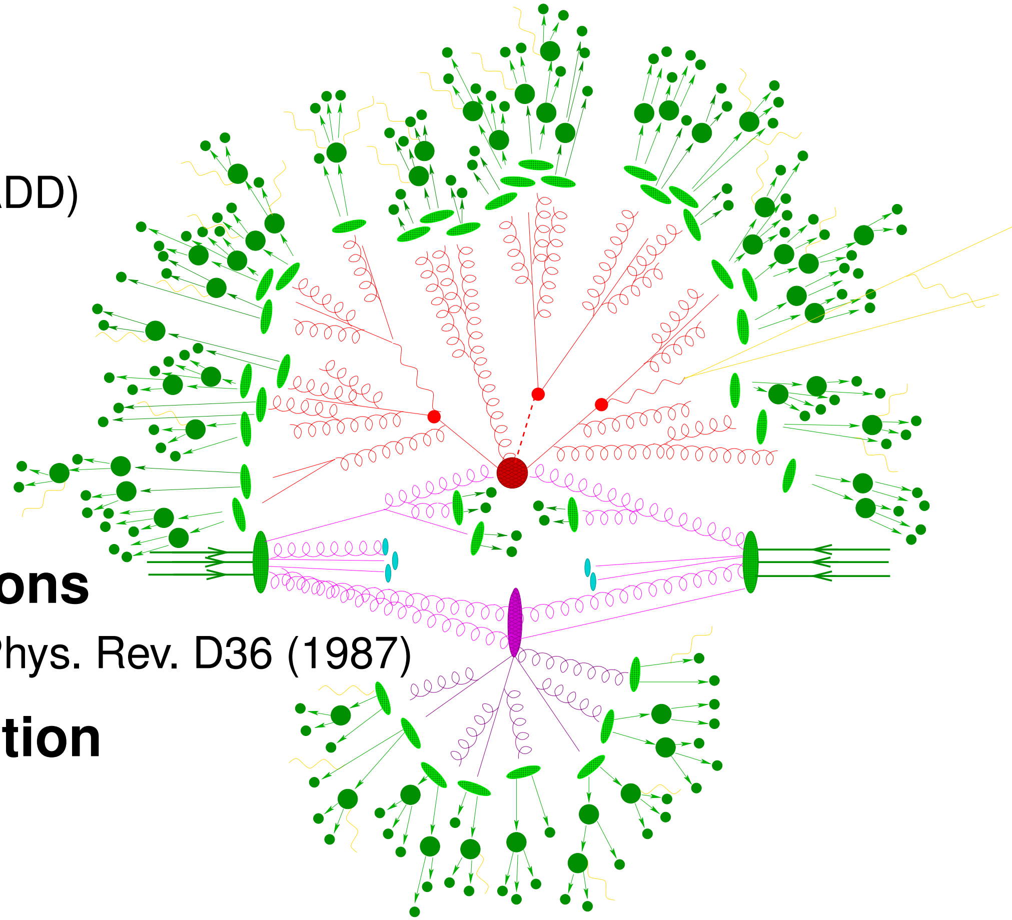
- **ME generator AMEGIC++**
  (at tree level, provides HP and HD in SM, MSSM, ADD)
- **IS and FS shower module APACIC++**
  (virtuality ordered, PYTHIA-like showers)
- **Combination of ME and PS according to CKKW**
- **Simulation of multiple parton interactions**
  main ideas based on T. Sjöstrand and M. van Zijl, Phys. Rev. D36 (1987)
- **Interface to PYTHIA's string hadronization**
- **Interface to PYTHIA's hadron decays**



SHERPA in the Z+jet-production DØ analysis

T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann and J. W., JHEP **0402** 056 (2004).

➡ **SHERPA version 1.0.6 has been used:**



- **ME generator AMEGIC++**
  (at tree level, provides HP and HD in SM, MSSM, ADD)
- **IS and FS shower module APACIC++**
  (virtuality ordered, PYTHIA-like showers)
- **Combination of ME and PS according to CKKW**
- **Simulation of multiple parton interactions**
  main ideas based on T. Sjöstrand and M. van Zijl, Phys. Rev. D36 (1987)
- **Interface to PYTHIA's string hadronization**
- **Interface to PYTHIA's hadron decays**

➡ **Sherpa is the event generation framework:**

- initialization of the different phases - interplay of the various stages -
- steering the event generation -

SHERPA in the Z+jet-production DØ analysis

➡ **Brief note: CKKW is implemented within SHERPA in full generality.**

S. Catani, F. Krauss, R. Kuhn and B. Webber, JHEP **0111** 063 (2001)

F. Krauss, JHEP **0208** 015 (2002)

Strategy:

- Divide multijet phase space into two regimes.
  - apply cut $Q_{\mathbf{sep}}$ on MEs to regularize divergencies.
  - implies large, unphysical $Q_{\mathbf{sep}}$ dependence for fixed multiplicity.
  - jet production through the tree level MEs.
  - jet evolution down to fragmentation scale through the PS.
- Reweight MEs by a combined coupling and Sudakov weight to get exclusive samples at given resolution scale $Q_{\mathbf{sep}}$.
- Veto on PS configurations that are already included through higher order ME.
- Reweighting and vetoing eliminate/sizeably reduce the $Q_{\mathbf{sep}}$ dependence.

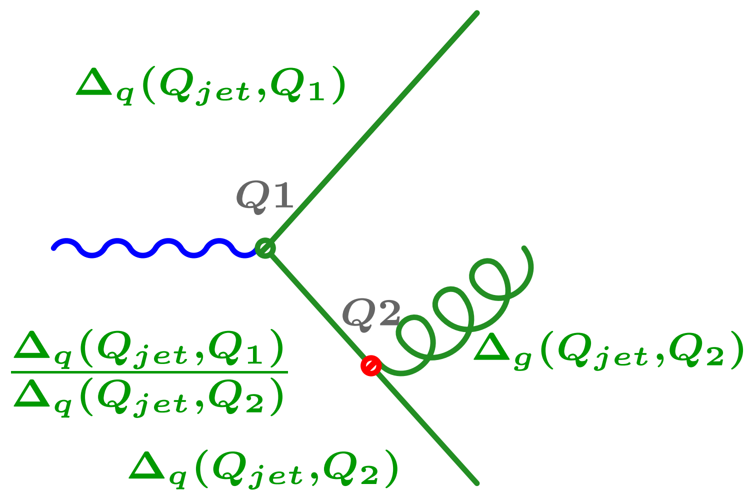
SHERPA in the Z+jet-production DØ analysis

➔ **Brief note: CKKW is implemented within SHERPA in full generality.**

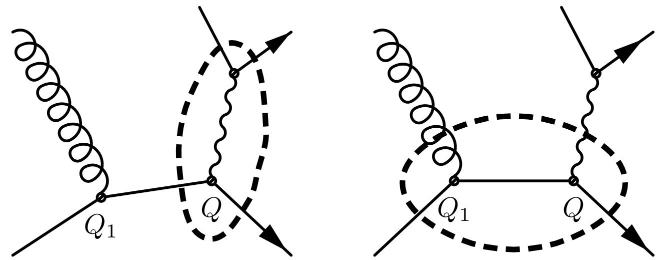
S. Catani, F. Krauss, R. Kuhn and B. Webber, JHEP **0111** 063 (2001)

F. Krauss, JHEP **0208** 015 (2002)

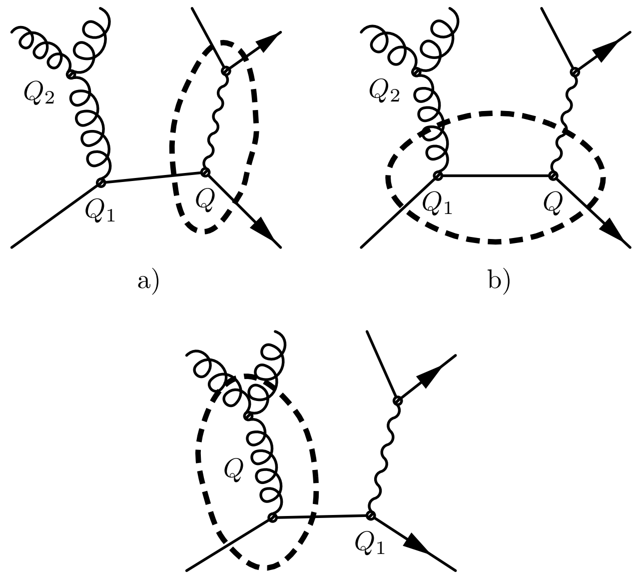
Visualization:



$$W = \Delta_g(Q_{jet},Q_2)\left[\Delta_q(Q_{jet},Q_1)\right]^2 \frac{\alpha_s(Q_2)}{\alpha_s(Q_{jet})}$$



a) b)



a) b) c)

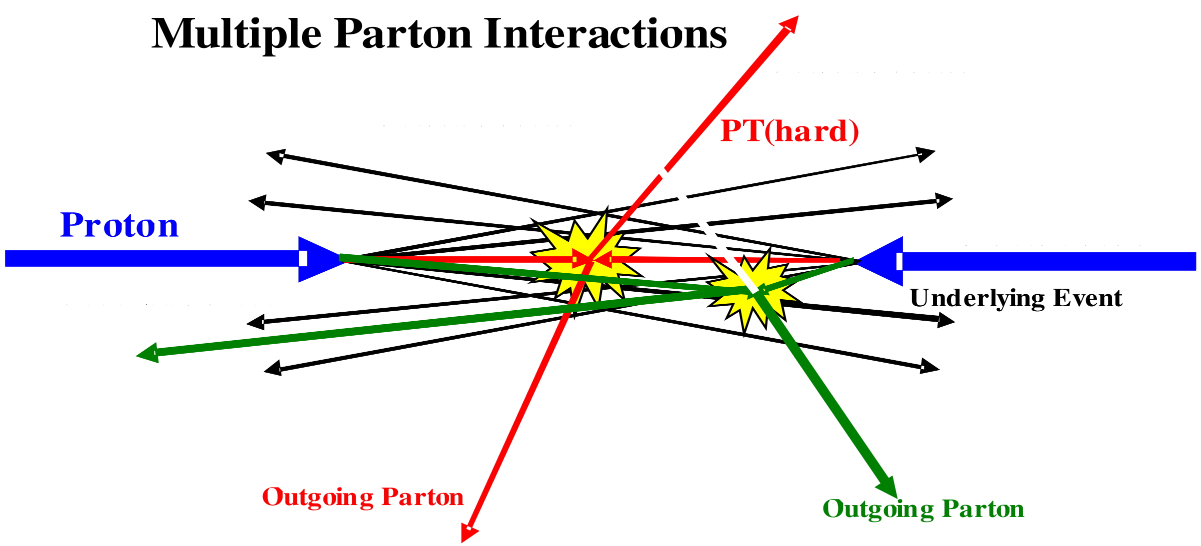
SHERPA in the Z+jet-production DØ analysis

➔ **Brief note: SHERPA uses MI model mainly based on Sjöstrand/Zijl ansatz.**

- 1st results have been presented in the “HERA and the LHC” proceedings: hep-ph/0601012,13

AMISIC++ has been set up to also work with the CKKW merging of SHERPA.

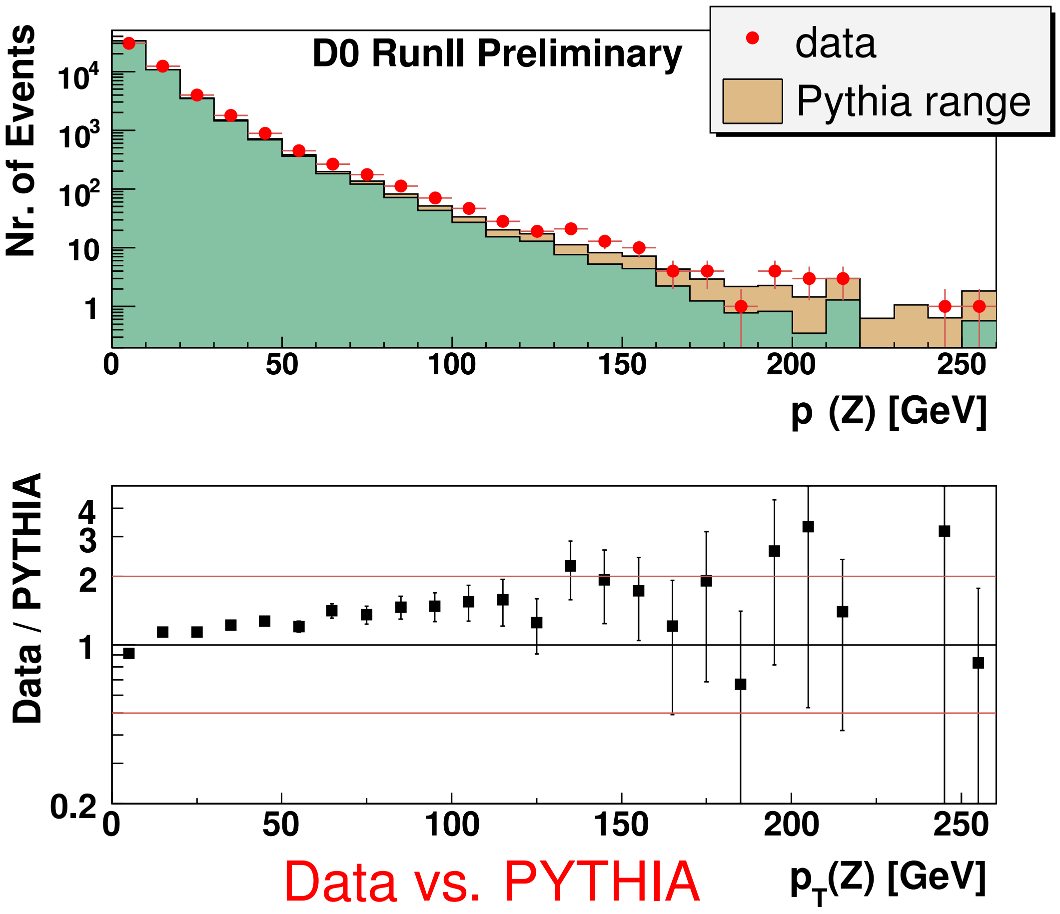
- HPs with FS multiplicities different from two require unique definition of the MI start scale.
- Employ k_T jet clustering algorithm to identify the last QCD node of the HP that needs to be clustered.
- Its $p_\perp^2$ defines the start scale for the MI evolution, and also the veto scale for the subsequent PS,
- since PSs are attached to the secondary interactions initiated at the QCD scale $\mu^2_{\rm QCD} = 2stu/(s^2+t^2+u^2)$.

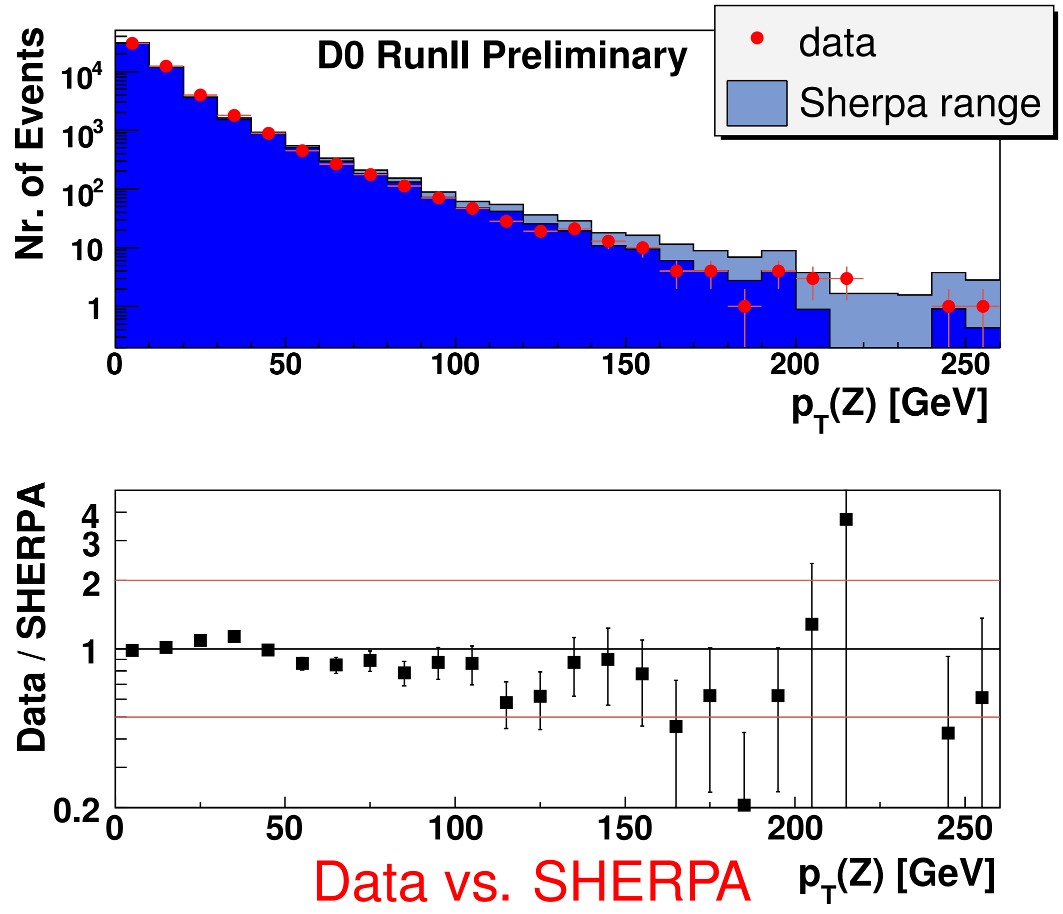


Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

→ The transverse momentum of the e^+e^- system.



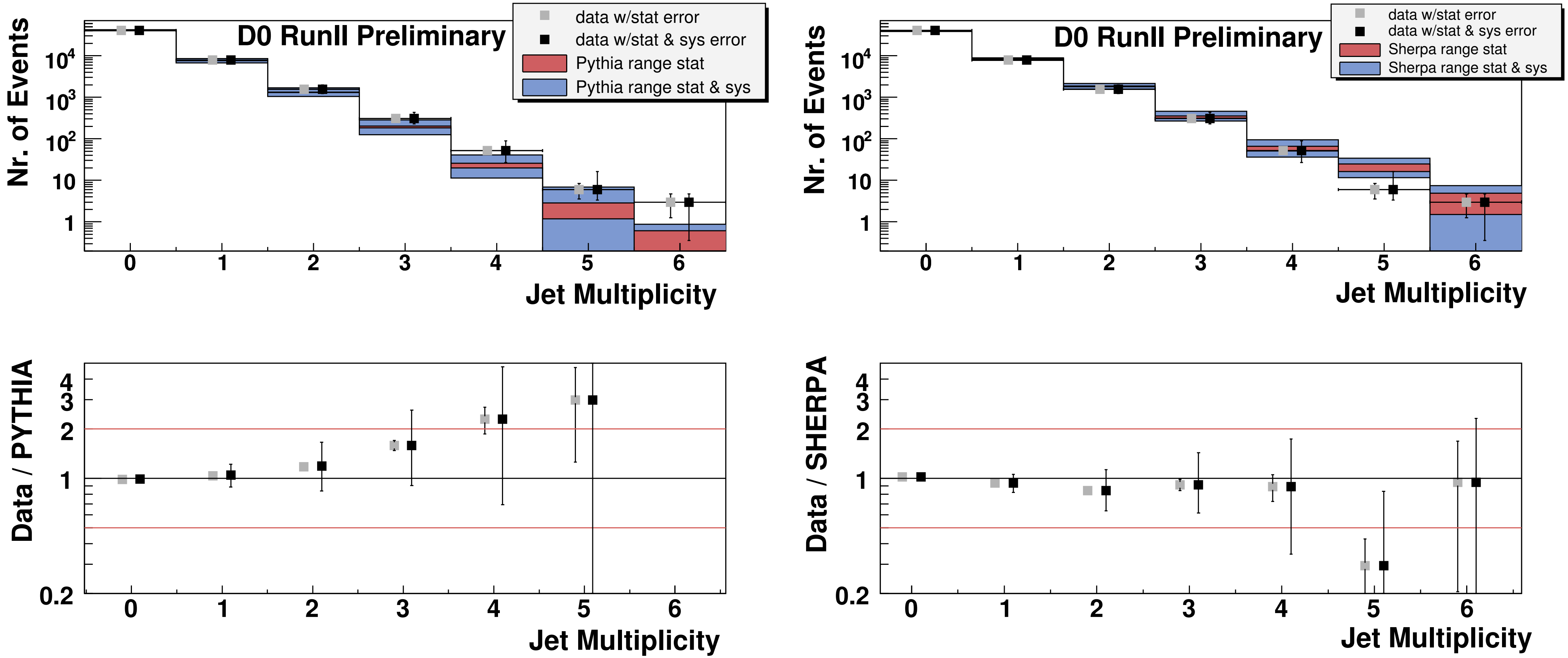


- Shaded ranges: MC statistics, central value $\pm 1\sigma$.
- Di-electron system has to balance the p_T of the jet system.

Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

➡ Jet multiplicity, data vs. PYTHIA (left) and SHERPA (right).

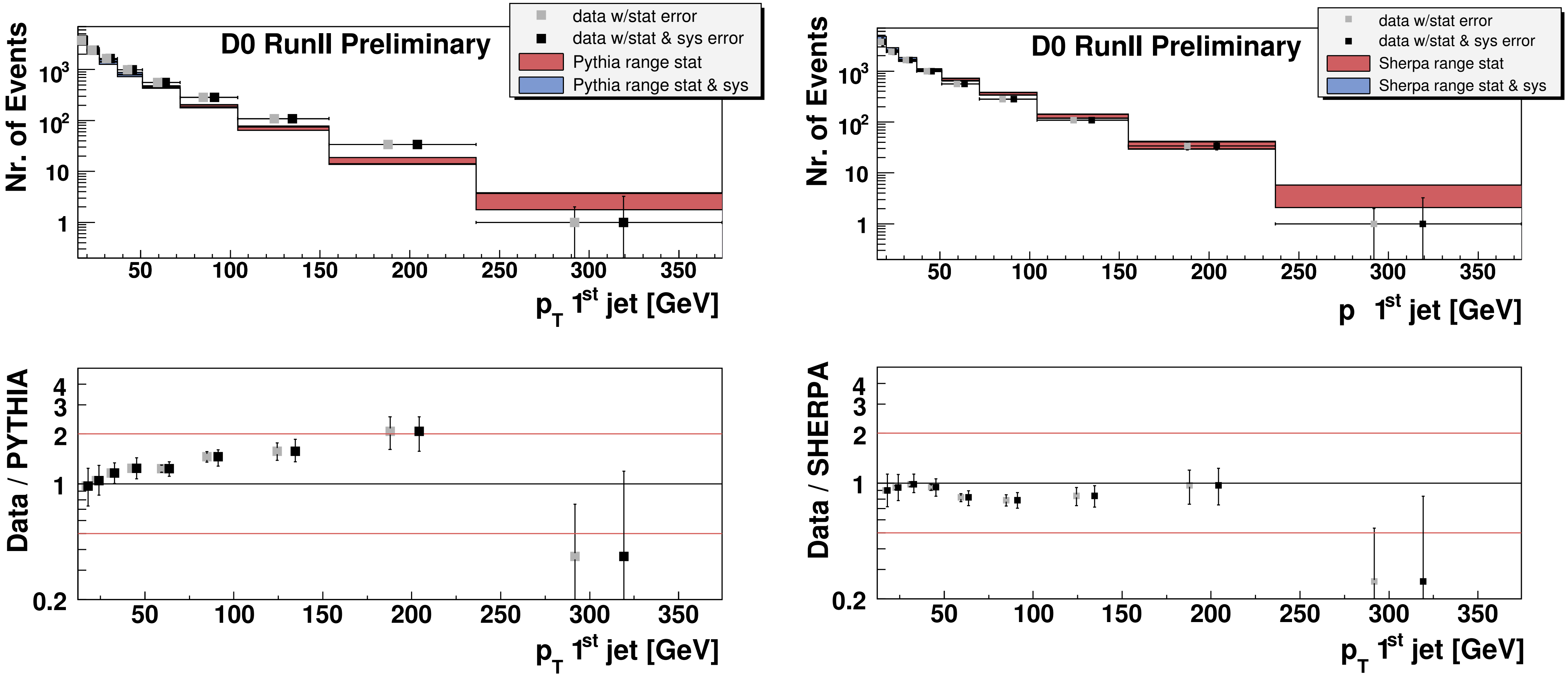


- MC predictions are normalized to total number of events observed in data.
- large systematic uncertainties arise from low p_T jets $\Rightarrow$ both predictions are in agreement with data.

Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

➡ Jet spectra: 1st jet, data vs. PYTHIA (left) and SHERPA (right).

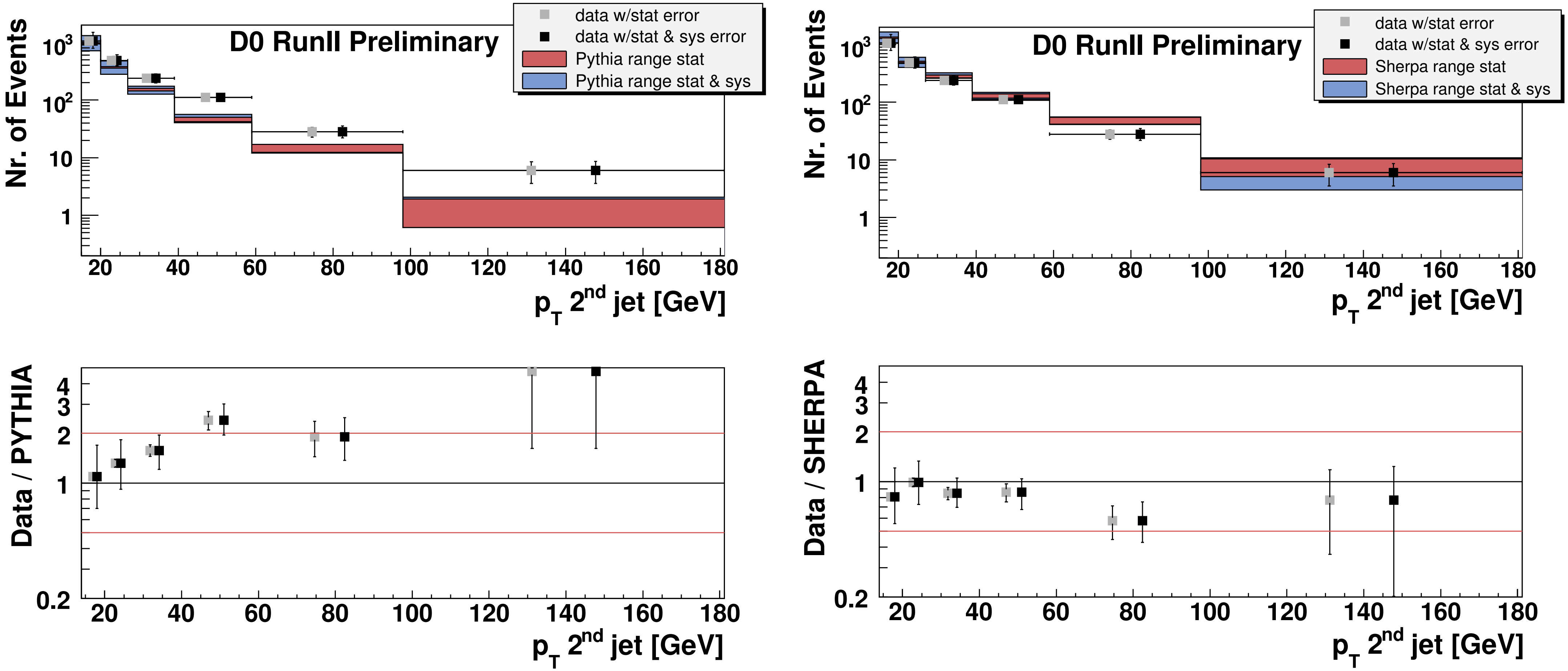


- PYTHIA: clear, positive slope in the ratio; lack of hard jets
- SHERPA: for most bins, prediction consistent with data if syst. errors included
- SHERPA: predictions are too hard around $80\ \mathrm{GeV}$

Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

➡ Jet spectra: 2nd jet, data vs. PYTHIA (left) and SHERPA (right).

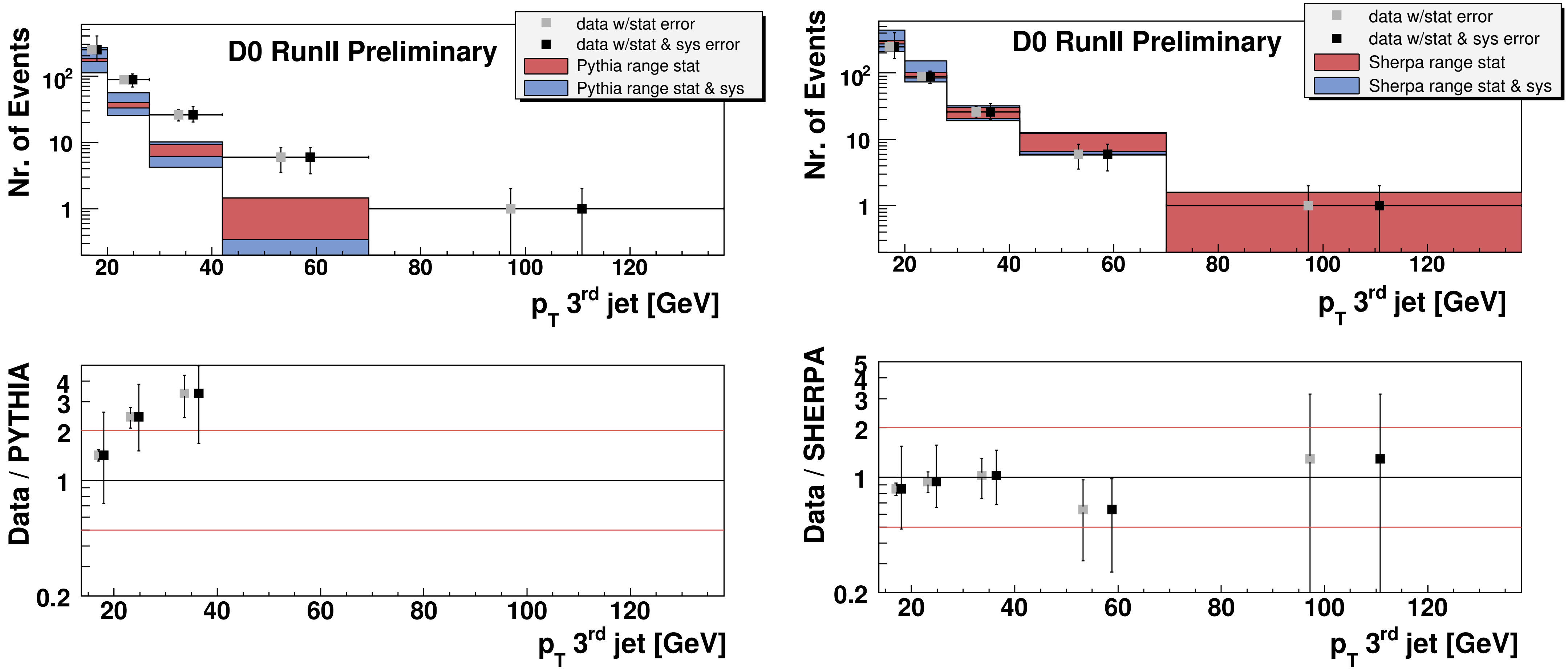


- PYTHIA: slope in the ratio gets increased.
- SHERPA: as before, nearly consistent with data, the $80\ \mathrm{GeV}$ problem!

Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

➡ Jet spectra: 3rd jet, data vs. PYTHIA (left) and SHERPA (right).

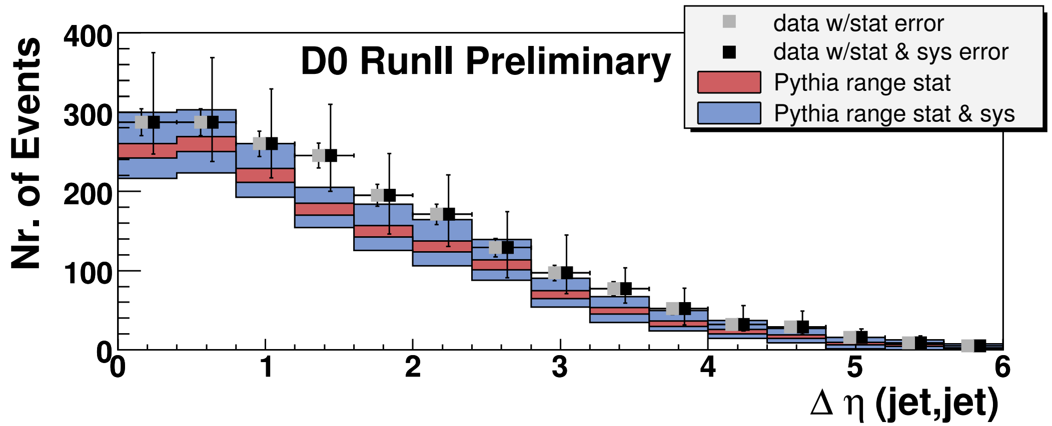


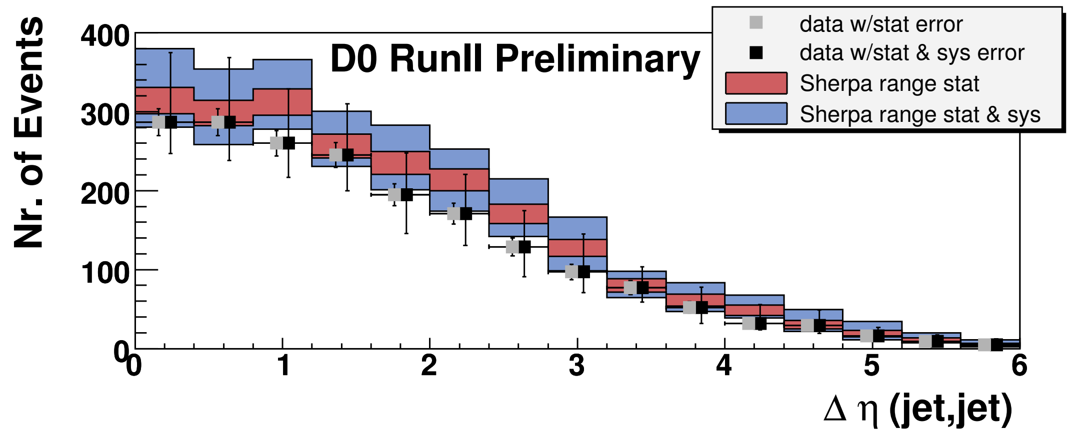
- With the same pattern as before.

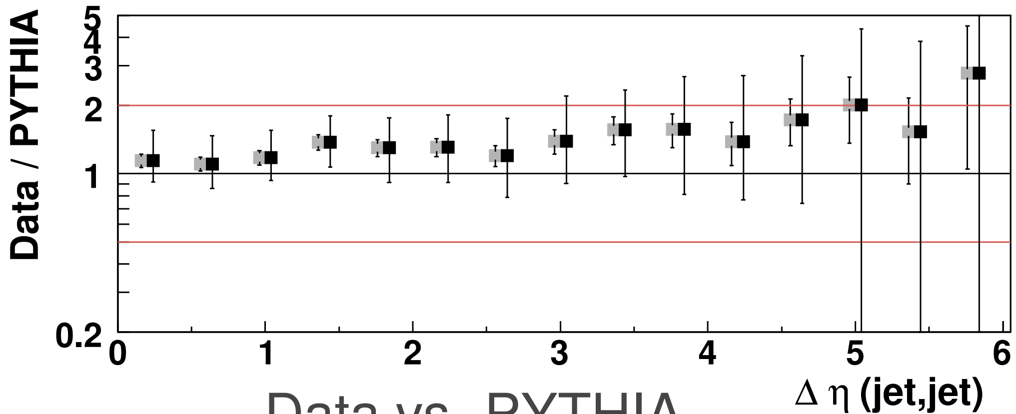
Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

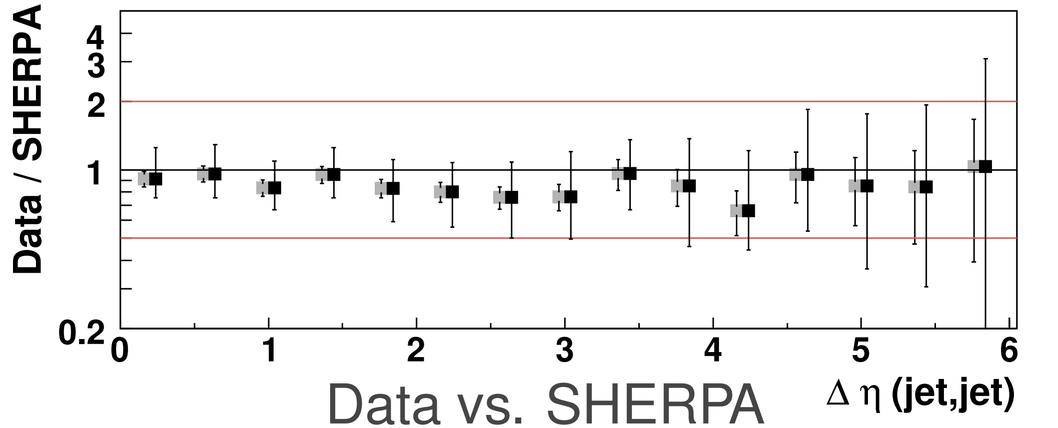
➡ Eta difference between the two hardest jets in incl $Z/\gamma^* + 2$ jets.







Data vs. PYTHIA



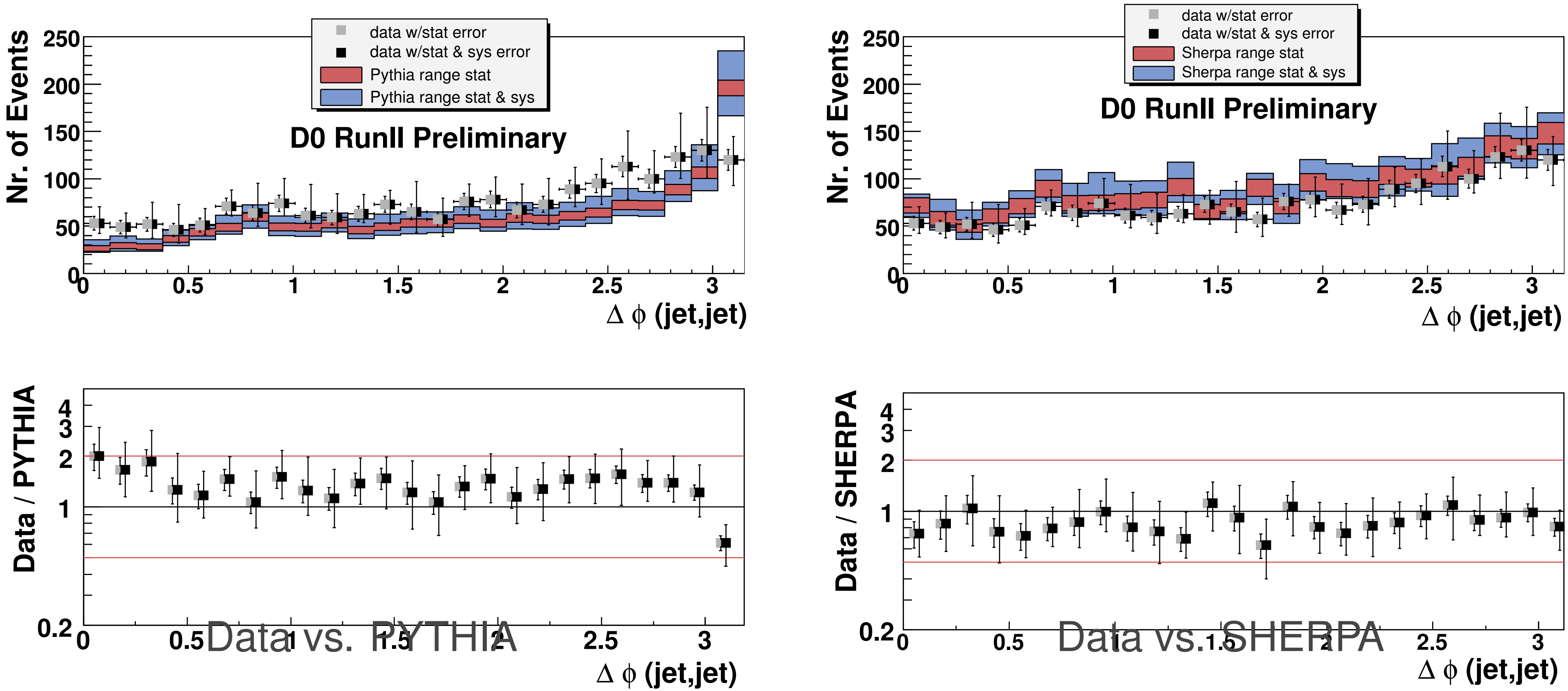
Data vs. SHERPA

- Studying **angular correlations**; these should fall into the **domain of ME.**
- Both predictions are consistent with the data.

Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

➜ Phi difference between the two hardest jets in incl $Z/\gamma^* + 2$ jets.



Data vs. PYTHIA

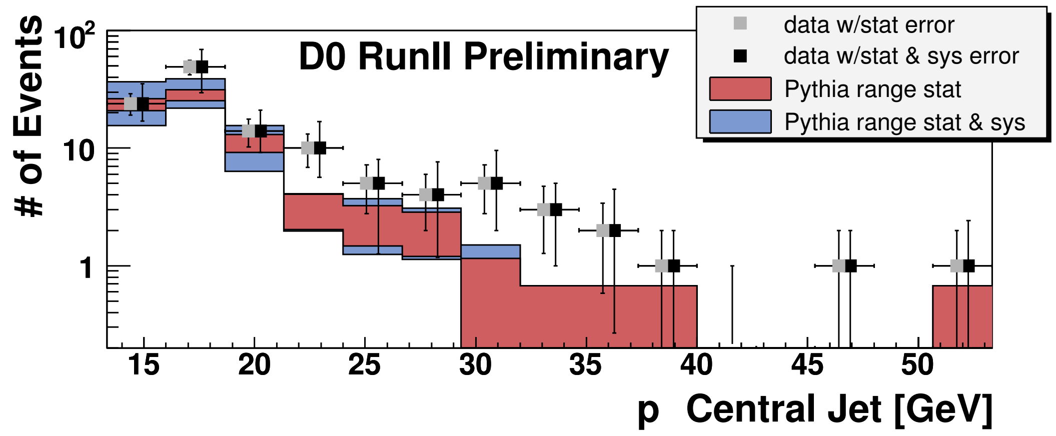
Data vs. SHERPA

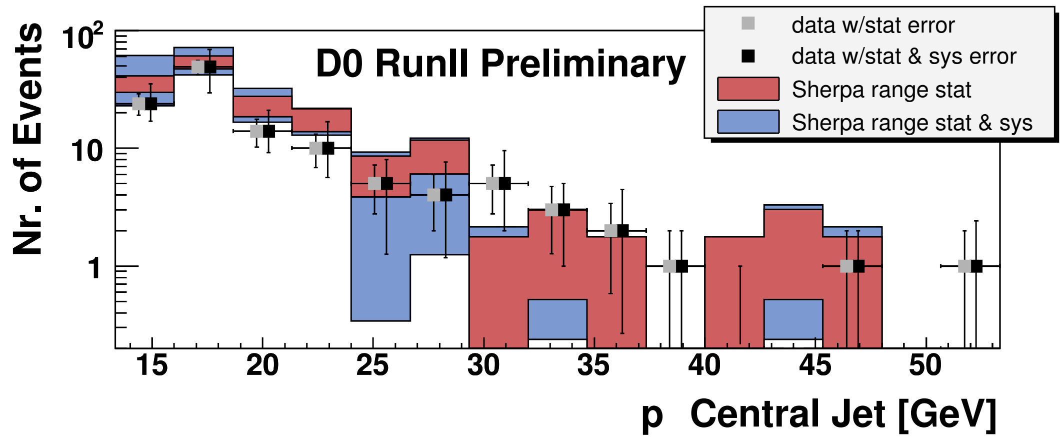
- Overall normalization is still in agreement with data within the errors.
- SHERPA predicts shape that allows for consistency with straight line at 1.
- PYTHIA has problems in the lowest and highest (their UE model?) $\Delta\phi$ bins.

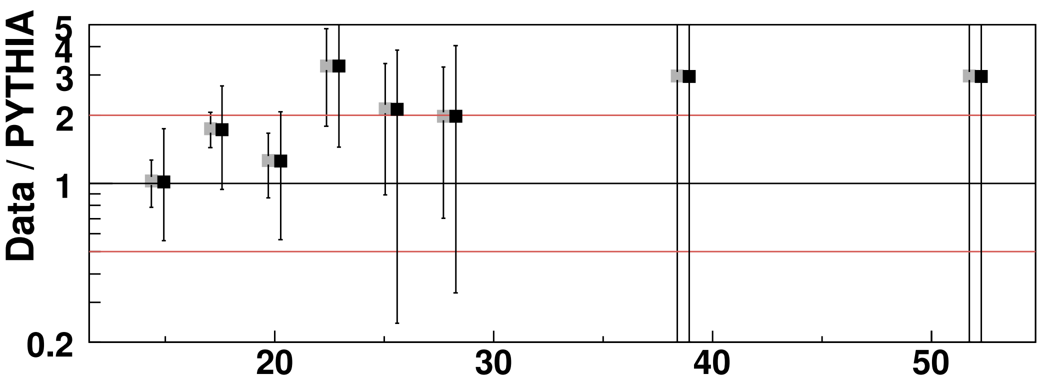
Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

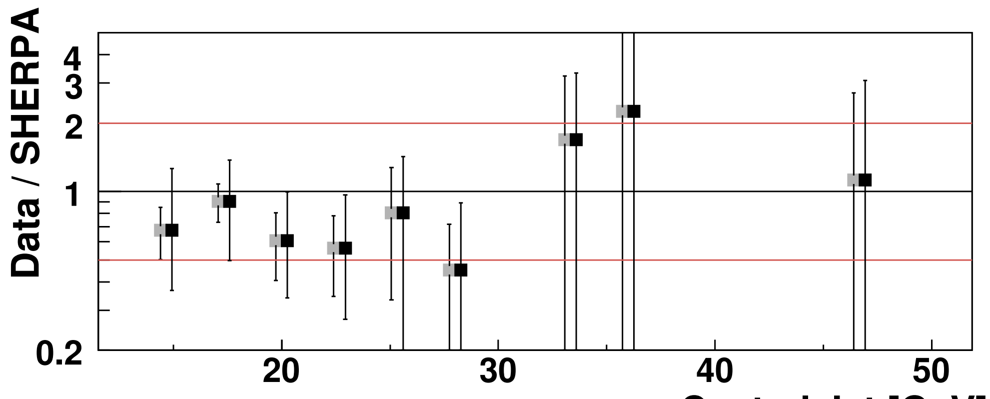
➡ Transverse momentum of the third jet under the central-jet condition.







Data vs. PYTHIA



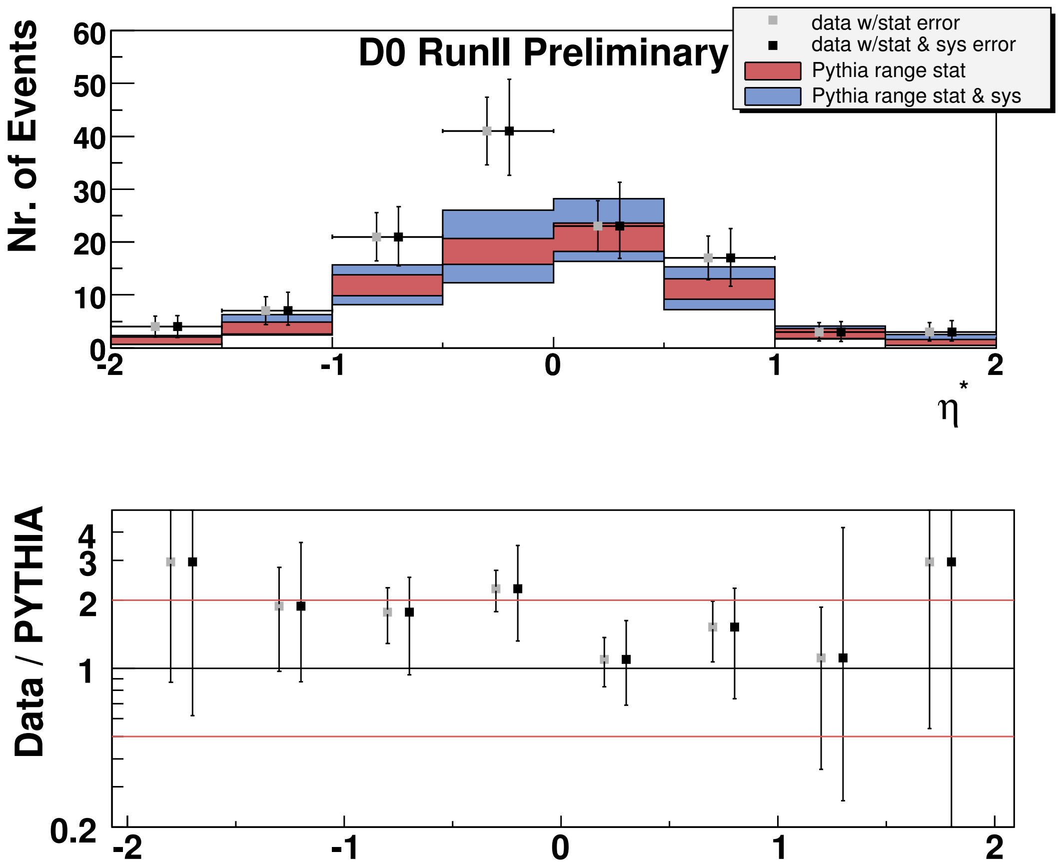
Data vs. SHERPA

- Central-jet studies according to Zeppenfeld ideas:
  $|\eta_1 - \eta_2| > 2.0$ and $\eta_{1,2} < \eta_3 < \eta_{2,1}$.

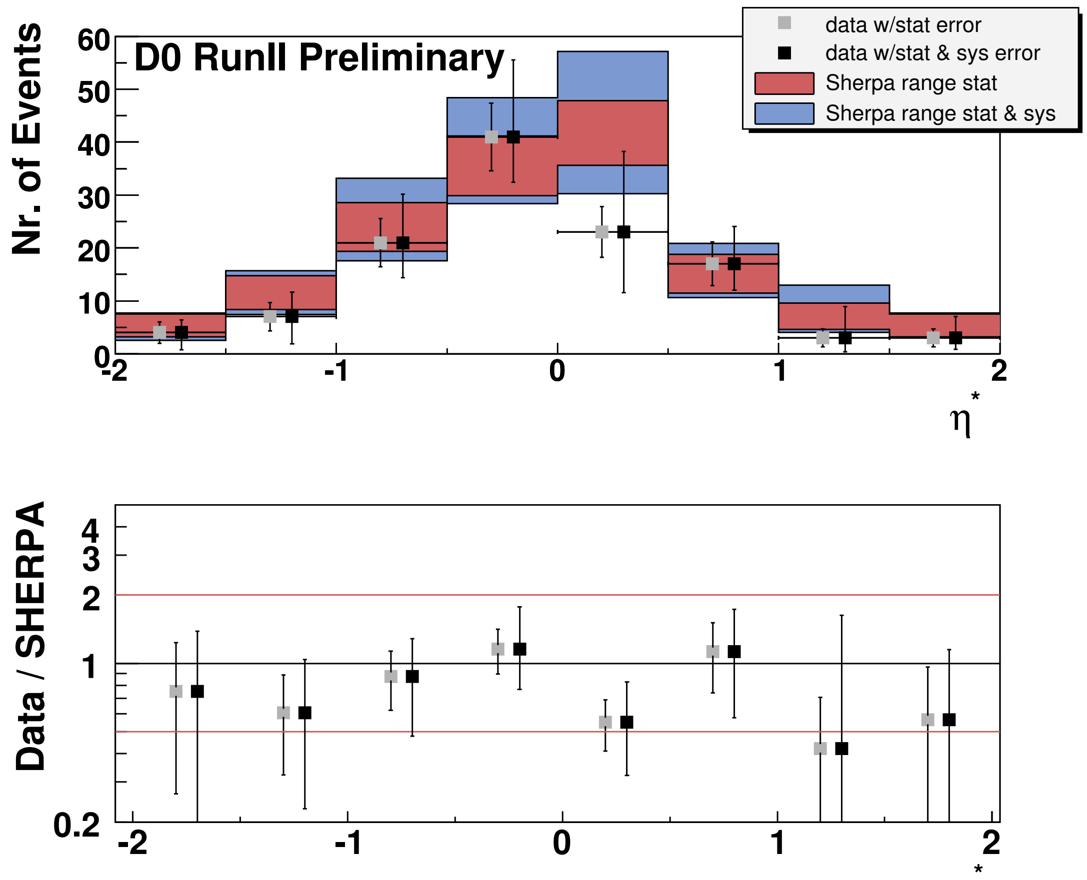
Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

➜ Eta of third jet using the Zeppenfeld definition.



Data vs. PYTHIA



Data vs. SHERPA

- Number of events passing tagging criteria might be too low, for PYTHIA even worse.

$$\eta^* = \eta_3 - \frac{\eta_1 + \eta_2}{2}$$

Preliminary DØ results in Z+jet-production

The DØ collaboration, DØ note 5066-CONF

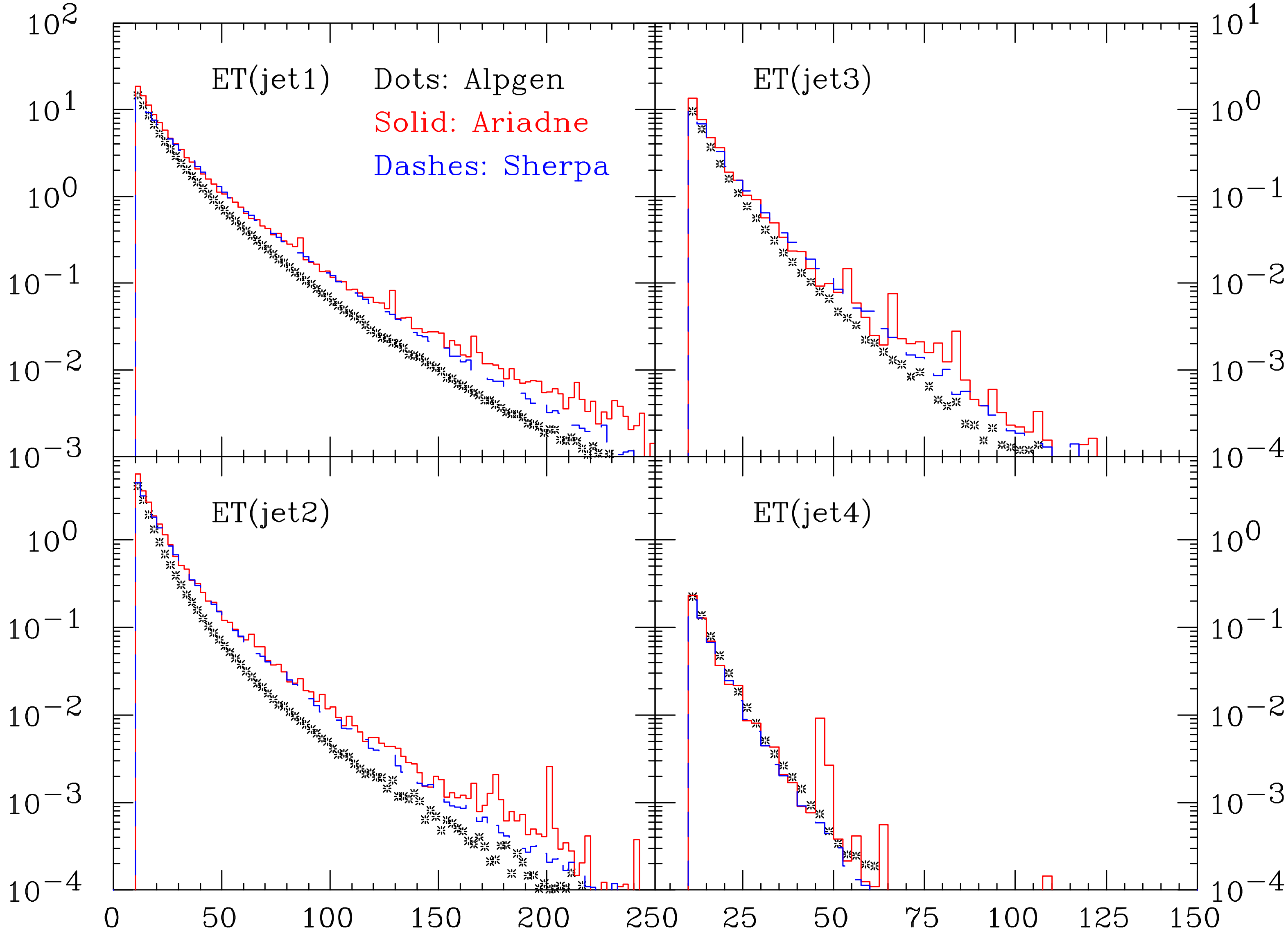
➡ **Conclusions from our point of view:**

- First of all, many thanks go to ...
- SHERPA has been passed through a full detector simulation and it worked.
- Our implemented MI model reasonably/smoothly fits into the CKKW machinery of SHERPA.
- For characteristics,
  multijets ⇒ jet multiplicities and spectra,
  angular correlations,
  we have been expected to describe them well, we succeeded.
- Global normalization seems to be sufficient.

Merging approach comparison between ...

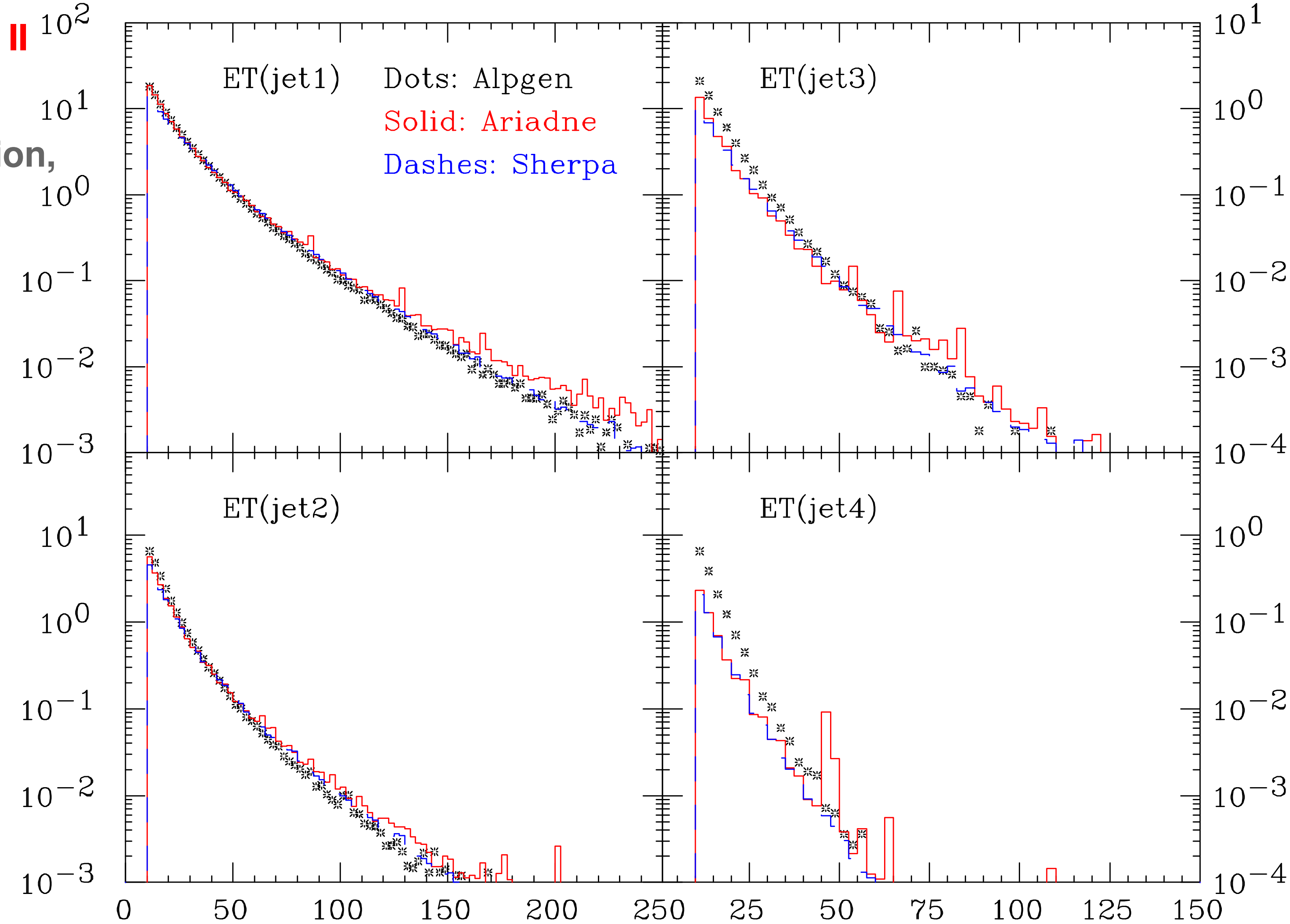
- the MLM, LL and SHERPA ME-PS-merging has started: **hep-ph/0602031.**

- E_T jet spectra at Tevatron Run II



Merging approach comparison between ...

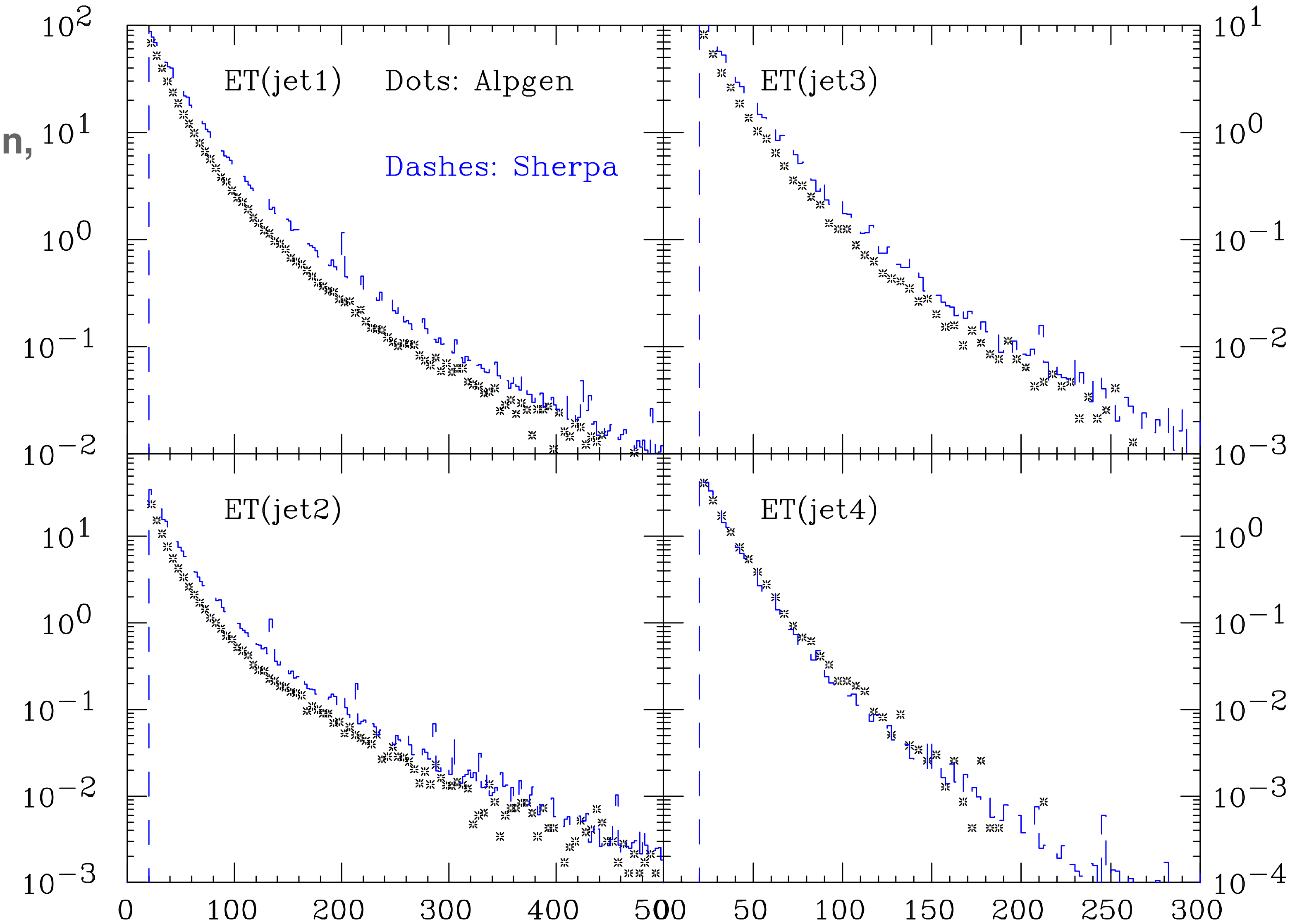
- the MLM, LL and SHERPA ME-PS-merging has started: **hep-ph/0602031.**
  - E_T jet spectra at Run II
    Alpgen $\mu_R \times 0.5$
  - impact of scale variation, a 1st estimate of scale uncertainties



Merging approach comparison between ...

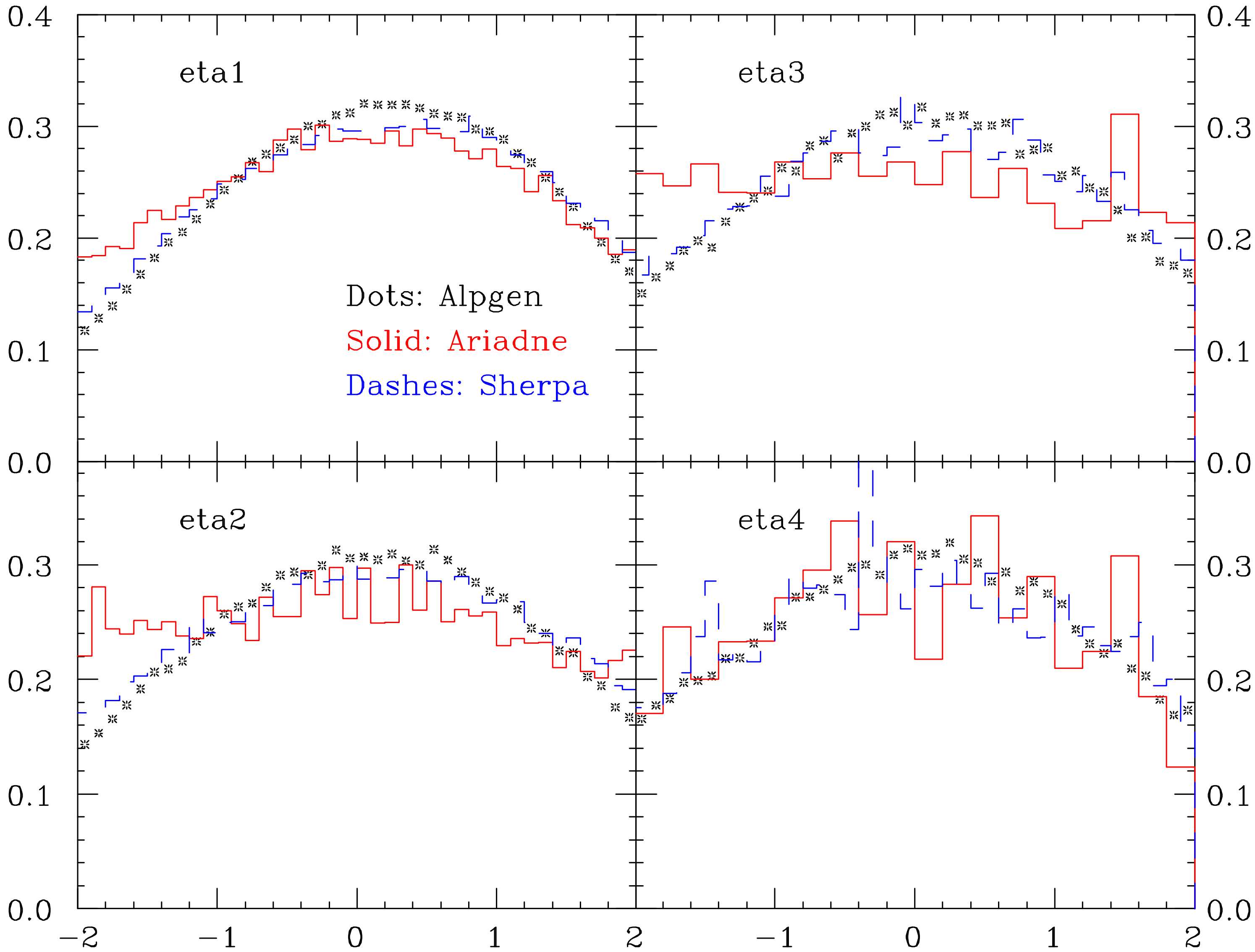
➡ the MLM, LL and SHERPA ME-PS-merging has started: **hep-ph/0602031.**

- E_T jet spectra at the LHC
- impact of scale variation, a 1st estimate of scale uncertainties
- similar pattern wrt Tevatron



Merging approach comparison between ...

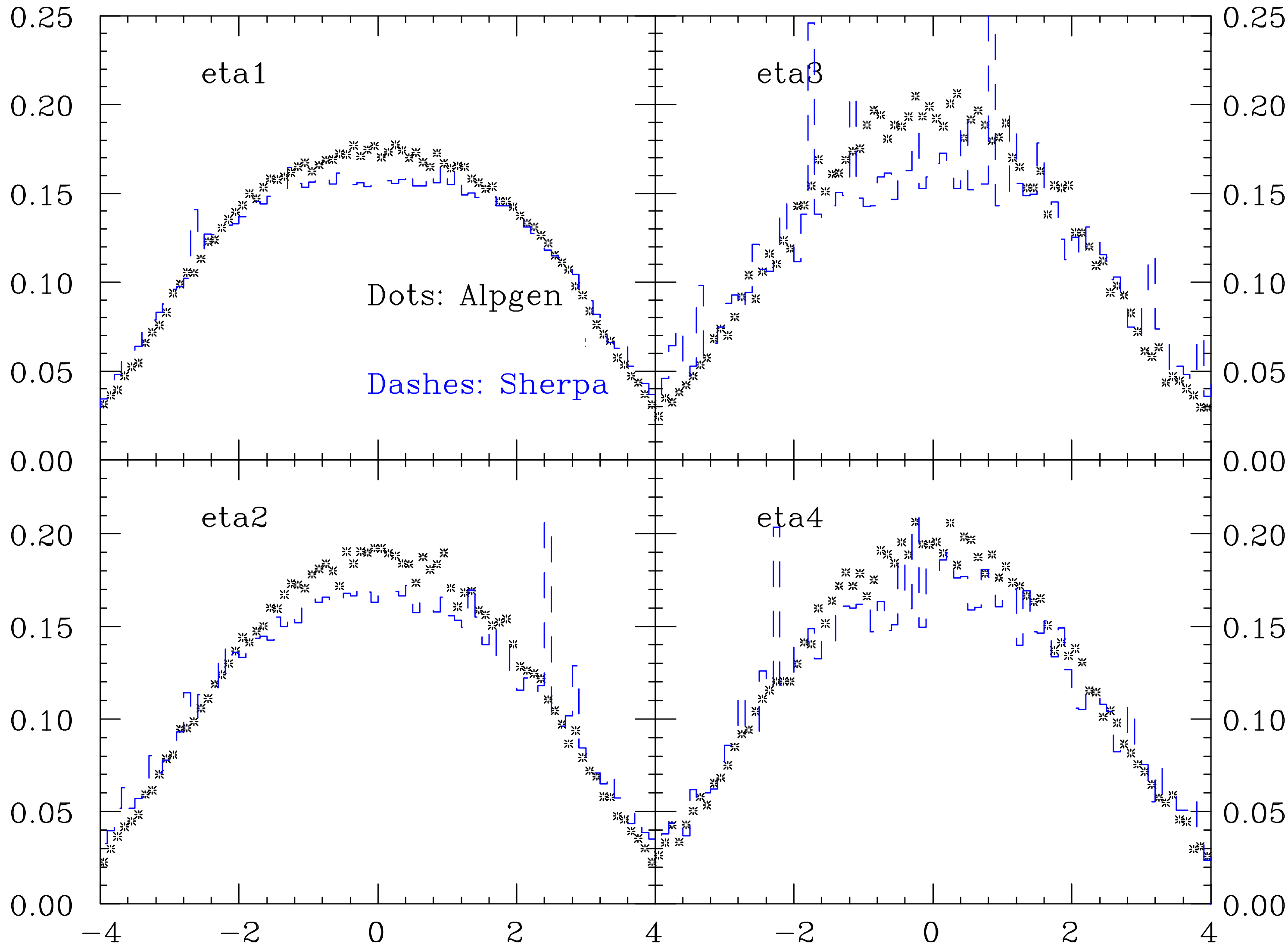
- the MLM, LL and SHERPA ME-PS-merging has started: **hep-ph/0602031.**
  - η jet spectra at Tevatron Run II
  - impact of scale variation, a 1st estimate of scale uncertainties
  - similar pattern wrt Tevatron
  - broadening of jet ηs in ARIADNE



Merging approach comparison between ...

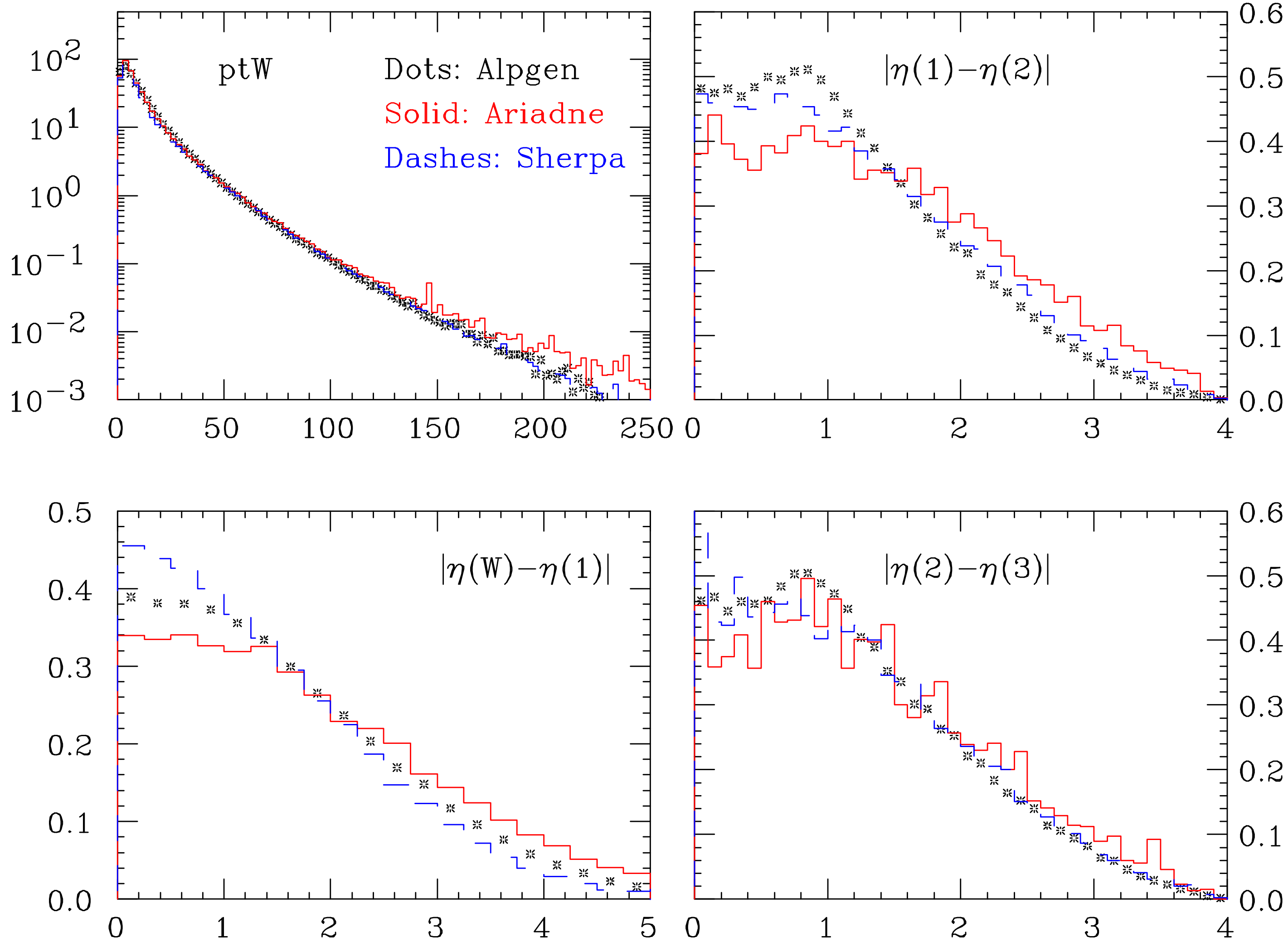
➡ the MLM, LL and SHERPA ME-PS-merging has started: **hep-ph/0602031.**

- η jet spectra at the LHC
- impact of scale variation, a 1st estimate of scale uncertainties
- similar pattern wrt Tevatron
- broadening of jet ηs in ARIADNE
- again similar pattern wrt Tevatron
- once tuned to Tevatron data, same extrapolation to LHC can be expected



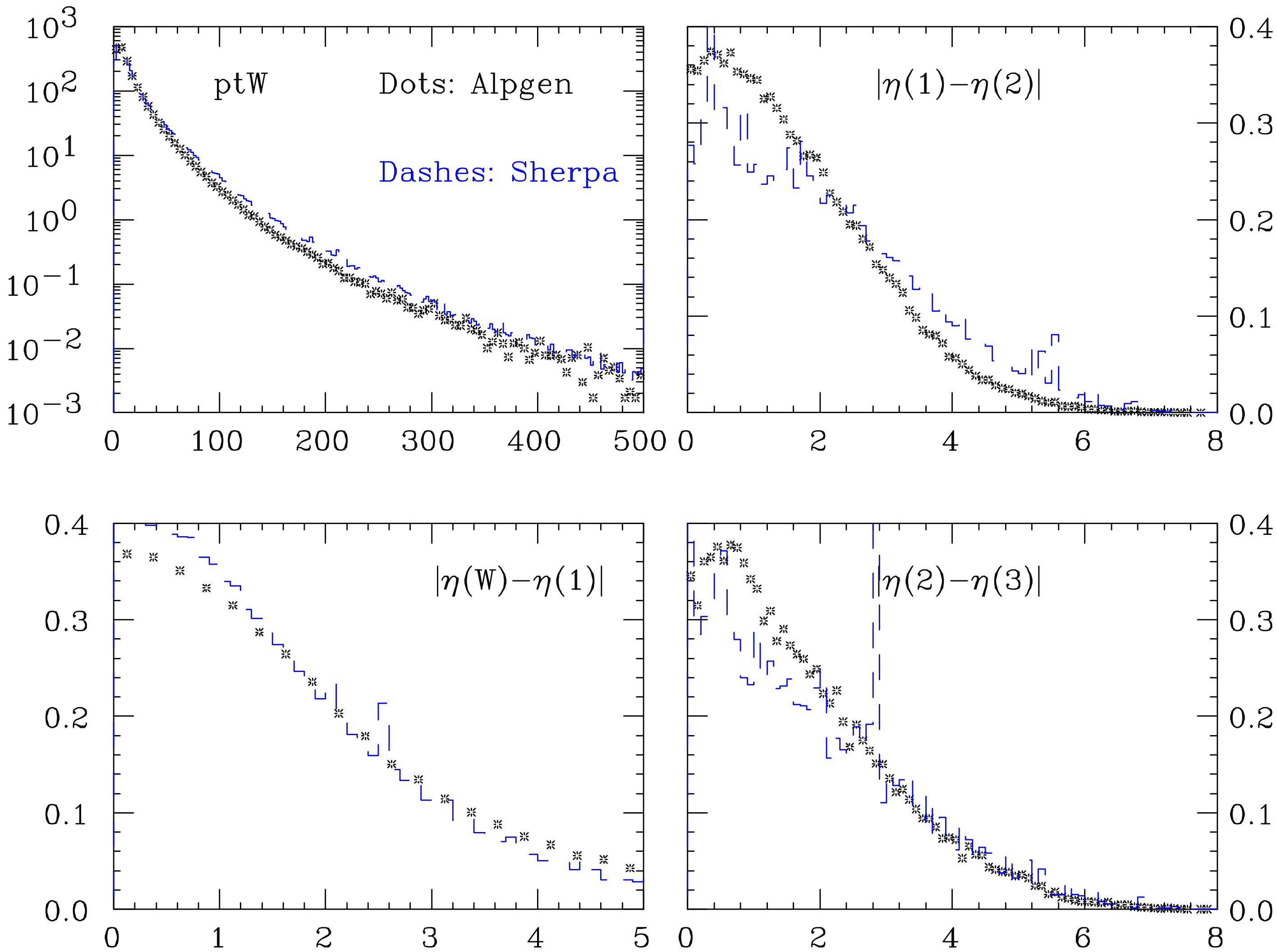
Merging approach comparison between ...

- the MLM, LL and SHERPA ME-PS-merging has started: **hep-ph/0602031.**
  - $p_T(W)$ and $\Delta\eta$ spectra at Tevatron Run II
  - impact of scale variation, a 1st estimate of scale uncertainties
  - similar pattern wrt Tevatron
  - broadening of jet ηs in ARIADNE
  - again similar pattern wrt Tevatron
  - once tuned to Tevatron data, same extrapolation to LHC can be expected



Merging approach comparison between ...

- the MLM, LL and SHERPA ME-PS-merging has started: **hep-ph/0602031.**
  - $p_T(W)$ and $\Delta\eta$ spectra at the LHC
  - impact of scale variation, a 1st estimate of scale uncertainties
  - similar pattern wrt Tevatron
  - broadening of jet ηs in ARIADNE
  - again similar pattern wrt Tevatron
  - once tuned to Tevatron data, same extrapolation to LHC can be expected

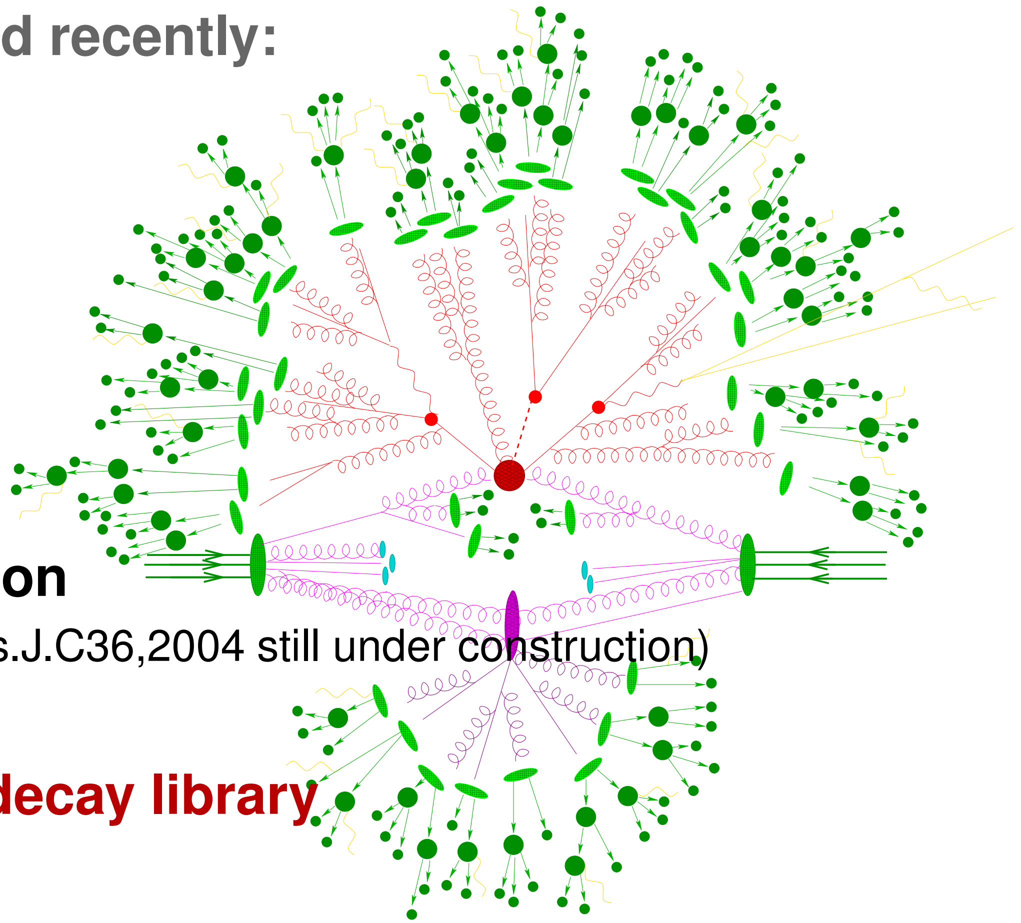


  - exploring differences of the merging approaches is essential to assess systematic uncertainties of multijet calculations
- **2nd round:** more observ. (correlations, intrajet ch.), scale variat., residual param. depend.

Current SHERPA version: http://www.sherpa-mc.de/

T. Gleisberg, S. Höche, F. Krauss, A. Schälicke, S. Schumann and J. W., JHEP **0402** 056 (2004).

- **SHERPA version 1.0.8 has been released recently:**



- **ME generator AMEGIC++**
- **IS/FS shower module APACIC++**
- **Combination of ME and PS according to CKKW**
- **Multiple interactions module AMISIC++**
- **Interface to PYTHIA's string hadronization**
  (cluster-model implementation of J.W. et al., Eur.Phys.J.C36,2004 still under construction)
- **Interface to PYTHIA's hadron decays**
  Own hadron-decay framework and tau decay library

- **More new features:**

- revised SUSY sector (SUSY comparison: K. Hagiwara et al., Phys. Rev. D73, 055005 (2006)), including SLHA interface
- decay chain treatment for heavy unstable particles in MEs
- revised CKKW sector (QCD jets, VBF)
- simply a number of bug fixings