Monte Carlo fits to existing data and predictions of QCD (background) rates for an e^+e^- collider

Jon Butterworth (University College London)

Matthew Wing (Bristol University)

- Introduction and strategy
- Details of fitting procedure and best fits
- Features and trends
- Predictions for a linear collider
- Summary and outlook

Introduction

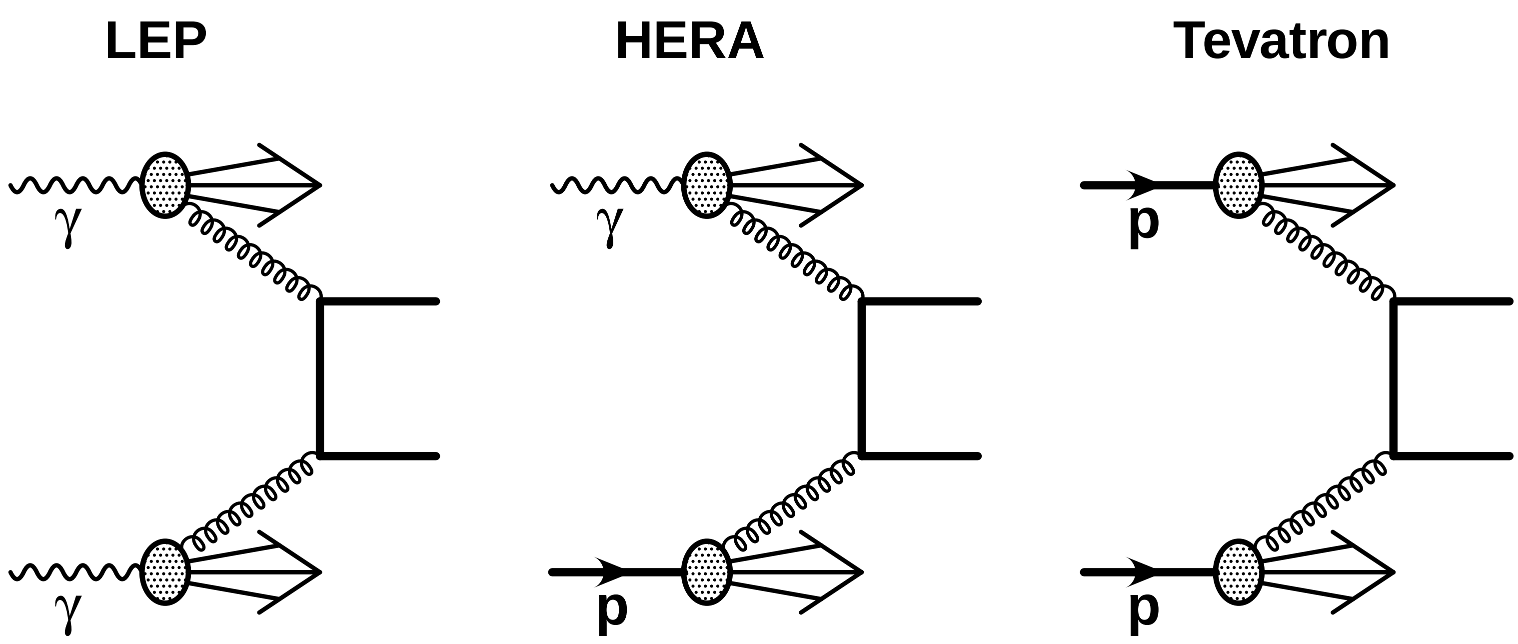
Why study QCD?

- It is a fundamental part of the Standard Model.
- It is a background to signals for new physics.

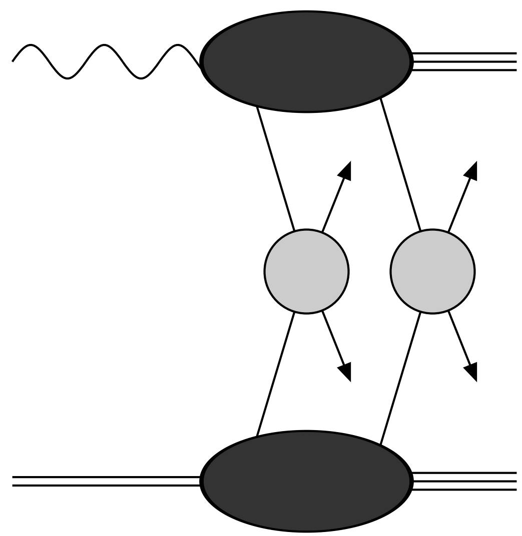
Have a lot of data on QCD from HERA, LEP and Tevatron.

- What have we learnt from the current data?
- How will this help us for future experiments?

Relevance of previous data



- Obvious how the Tevatron results relate to the LHC and LEP results relate to an FLC...
- Photon structure also being probed at HERA (higher scales).
- Remnant-remnant interactions exist at all colliders.
- HERA and LEP can turn them “on” or “off”.



Strategy

Have compared HERWIG 6.4, PYTHIA 6.206 with (fit to) current data sets.

This checks the consistency of current data and provides reliable MC for future colliders.

Using over 20 papers (mainly from HERA) to test the MC.

Varied many parameters not already constrained by LEP tunes (by eye rather than complete tune.)

Using JetWeb facility which is a WWW interface database for MC tuning.

J. M. Butterworth, S. Butterworth, "JetWeb: A WWW Interface and Database for Monte Carlo Tuning and Validation" `hep-ph/0210404`, `http://jetweb.hep.ucl.ac.uk/`

Details of fitting

Have chosen independent data sets spanning a large kinematic range

HERA jet photoproduction (γp) data:

- **large range in scale; 4 $< E_T^{\text{jet}} <$ 80 GeV**
- **inclusive, dijet and trijet events.**

LEP $\gamma\gamma$ jet data:

- **different centre-of-mass energies: 130 $< E_{\text{CM}} <$ 209 GeV**

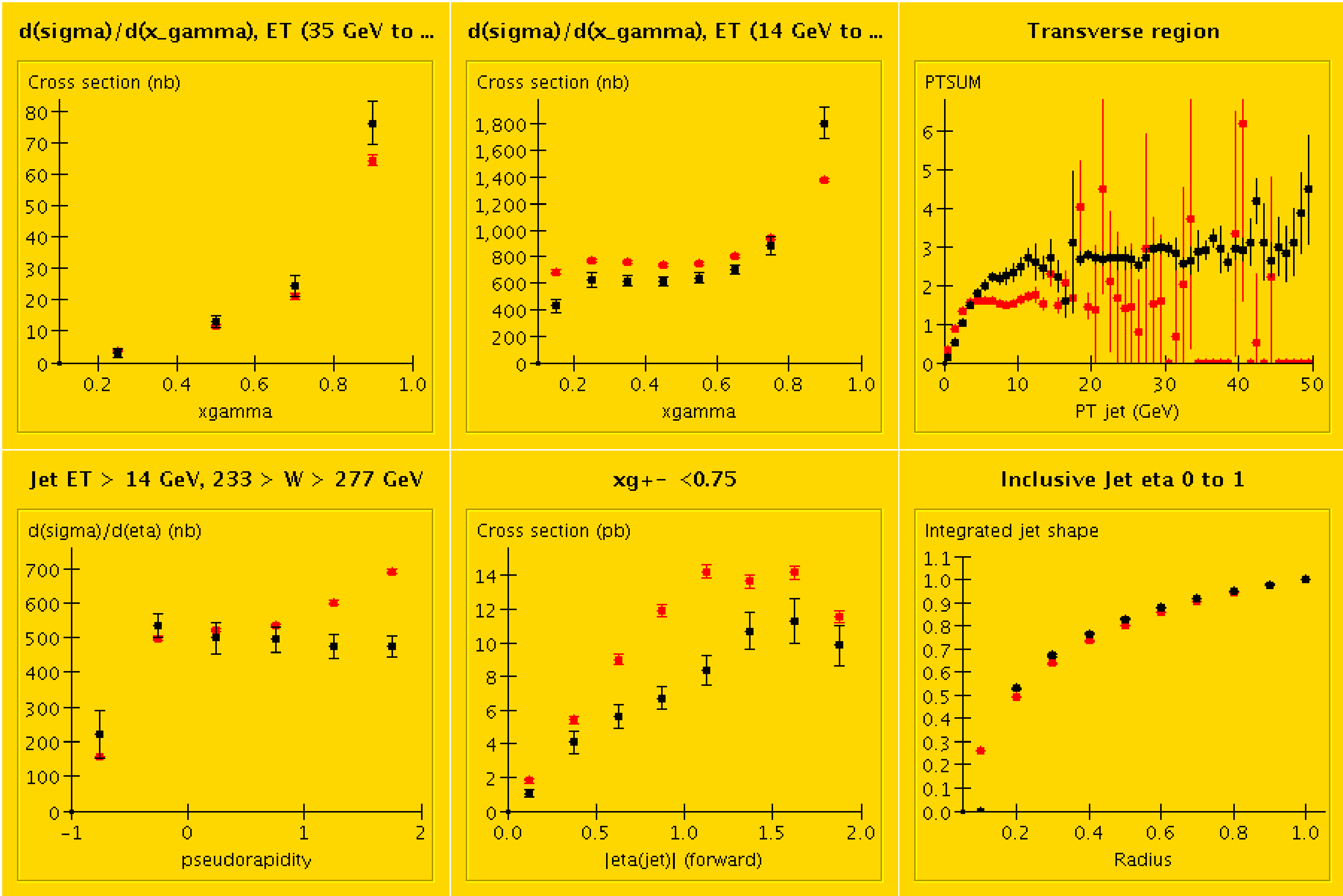
Tevatron data:

- **strong dependency on underlying event**

Including all measurements underestimates χ^2; systematics are correlated between years, e.g. jet resolution, model uncertainty.

Have made some choices of the data to be used.

A bad (default) HERWIG fit - 405 (SUE, $p_T^{\mathrm{min}} = 3$ GeV)



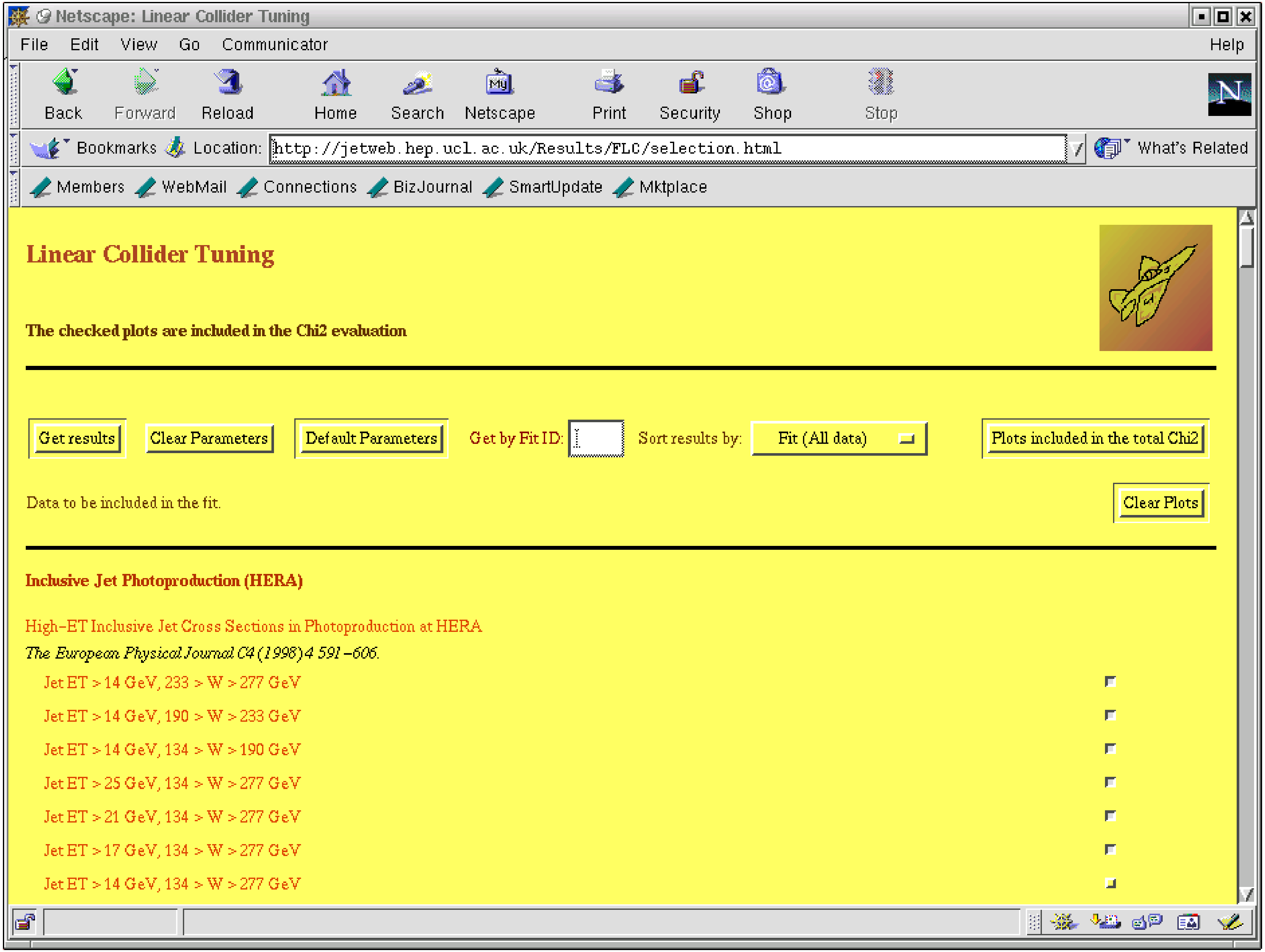
Monte Carlos used for fitting

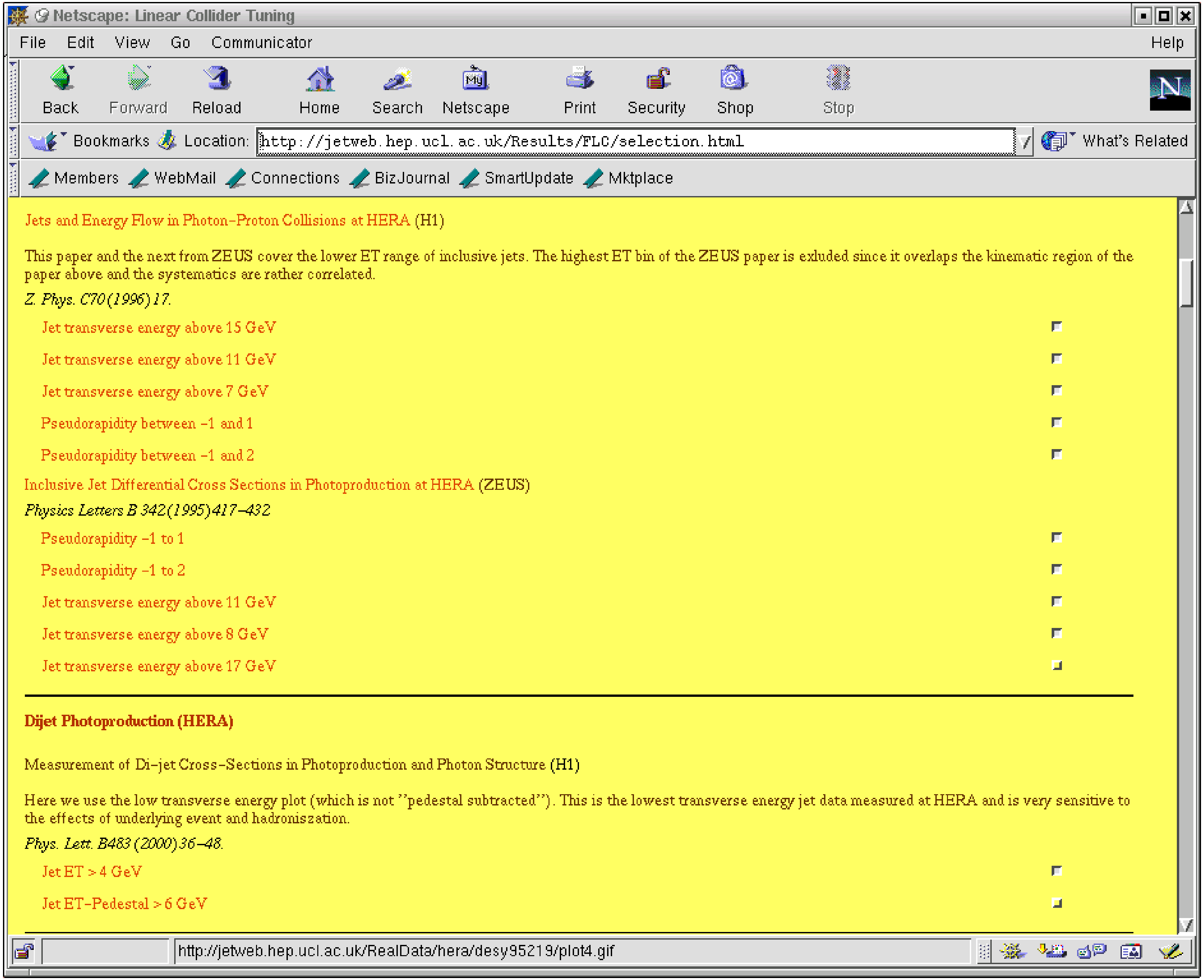
Currently have used HERWIG and PYTHIA:

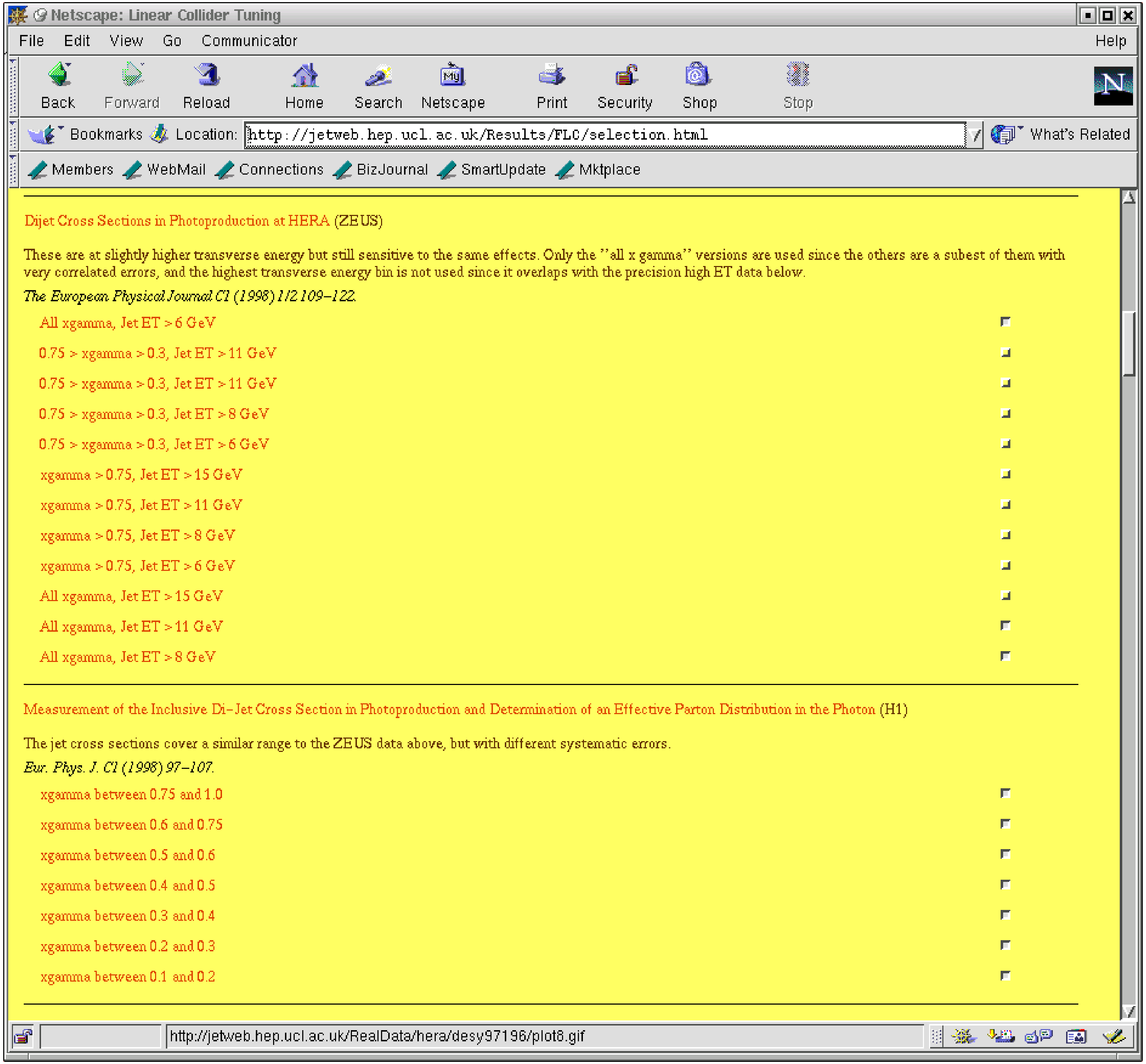
- **Minimum transverse momentum of hard scatters.**
- **Underlying event model.**
- **Proton and photon PDFs.**
- **Intrinsic transverse momenta in photon and proton.**
- **Proton and photon radius.**
- **Free normalisation.**
- **...**

Specifically in PYTHIA:

- **Minimum transverse momentum of secondary scatters.**
- **Maximum parton virtuality in space-like showers.**


Netscape: Linear Collider Tuning
File Edit View Go Communicator Help
Back Forward Reload Home Search Netscape Print Security Shop Stop
Bookmarks Location: http://jetweb.hep.ucl.ac.uk/Results/FLC/selection.html
What's Related
Members WebMail Connections BizJournal SmartUpdate Mktplace
Linear Collider Tuning
The checked plots are included in the Chi2 evaluation
Get results
Clear Parameters
Default Parameters
Get by Fit ID:
Sort results by:
Fit (All data)
Plots included in the total Chi2
Data to be included in the fit.
Clear Plots
Inclusive Jet Photoproduction (HERA)
High-ET Inclusive Jet Cross Sections in Photoproduction at HERA
The European Physical Journal C4 (1998) 4 591-606.
Jet ET > 14 GeV, 233 > W > 277 GeV
Jet ET > 14 GeV, 190 > W > 233 GeV
Jet ET > 14 GeV, 134 > W > 190 GeV
Jet ET > 25 GeV, 134 > W > 277 GeV
Jet ET > 21 GeV, 134 > W > 277 GeV
Jet ET > 17 GeV, 134 > W > 277 GeV
Jet ET > 14 GeV, 134 > W > 277 GeV


Netscape: Linear Collider Tuning
File Edit View Go Communicator Help
Back Forward Reload Home Search Netscape Print Security Shop Stop
Bookmarks Location: http://jetweb.hep.ucl.ac.uk/Results/FLC/selection.html What's Related
Members WebMail Connections BizJournal SmartUpdate Mktplace
Jets and Energy Flow in Photon-Proton Collisions at HERA (H1)
This paper and the next from ZEUS cover the lower ET range of inclusive jets. The highest ET bin of the ZEUS paper is exluded since it overlaps the kinematic region of the paper above and the systematics are rather correlated.
Z. Phys. C70 (1996) 17.
Jet transverse energy above 15 GeV
Jet transverse energy above 11 GeV
Jet transverse energy above 7 GeV
Pseudorapidity between -1 and 1
Pseudorapidity between -1 and 2
Inclusive Jet Differential Cross Sections in Photoproduction at HERA (ZEUS)
Physics Letters B 342(1995)417-432
Pseudorapidity -1 to 1
Pseudorapidity -1 to 2
Jet transverse energy above 11 GeV
Jet transverse energy above 8 GeV
Jet transverse energy above 17 GeV
Dijet Photoproduction (HERA)
Measurement of Di-jet Cross-Sections in Photoproduction and Photon Structure (H1)
Here we use the low transverse energy plot (which is not "pedestal subtracted"). This is the lowest transverse energy jet data measured at HERA and is very sensitive to the effects of underlying event and hadronisation.
Phys. Lett. B483 (2000) 36-48.
Jet ET > 4 GeV
Jet ET-Pedestal > 6 GeV
http://jetweb.hep.ucl.ac.uk/RealData/hera/desy95219/plot4.gif



Netscape: Linear Collider Tuning

File Edit View Go Communicator Help

Back Forward Reload Home Search Netscape Print Security Shop Stop

Bookmarks Location: http://jetweb.hep.ucl.ac.uk/Results/FLC/selection.html What's Related

Members WebMail Connections BizJournal SmartUpdate Mktplace

Dijet Cross Sections in Photoproduction at HERA (ZEUS)

These are at slightly higher transverse energy but still sensitive to the same effects. Only the "all x gamma" versions are used since the others are a subest of them with very correlated errors, and the highest transverse energy bin is not used since it overlaps with the precision high ET data below.

The European Physical Journal C1 (1998) 1/2 109–122.

- All xgamma, Jet ET > 6 GeV
- 0.75 > xgamma > 0.3, Jet ET > 11 GeV
- 0.75 > xgamma > 0.3, Jet ET > 11 GeV
- 0.75 > xgamma > 0.3, Jet ET > 8 GeV
- 0.75 > xgamma > 0.3, Jet ET > 6 GeV
- xgamma > 0.75, Jet ET > 15 GeV
- xgamma > 0.75, Jet ET > 11 GeV
- xgamma > 0.75, Jet ET > 8 GeV
- xgamma > 0.75, Jet ET > 6 GeV
- All xgamma, Jet ET > 15 GeV
- All xgamma, Jet ET > 11 GeV
- All xgamma, Jet ET > 8 GeV

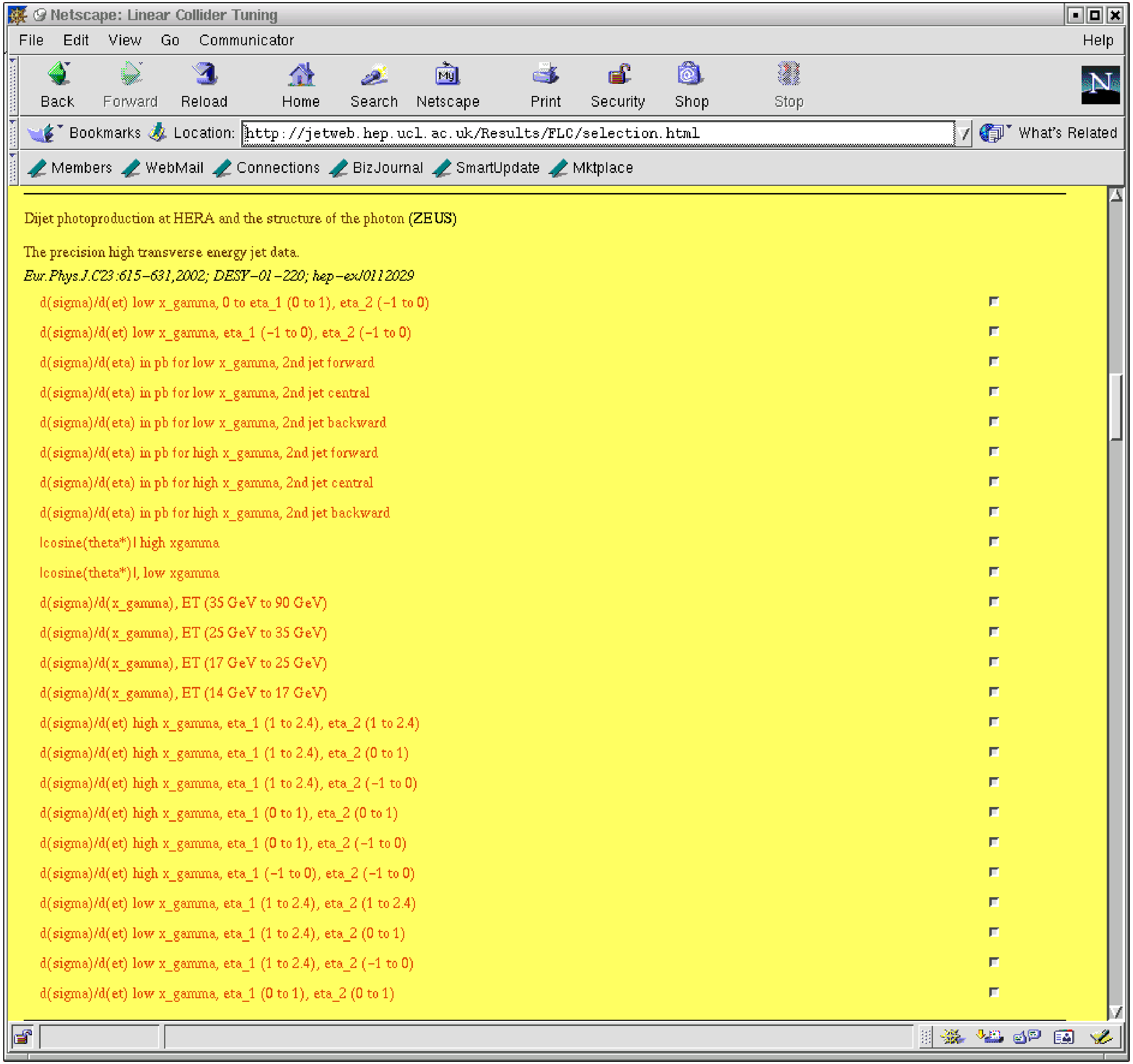
Measurement of the Inclusive Di-Jet Cross Section in Photoproduction and Determination of an Effective Parton Distribution in the Photon (H1)

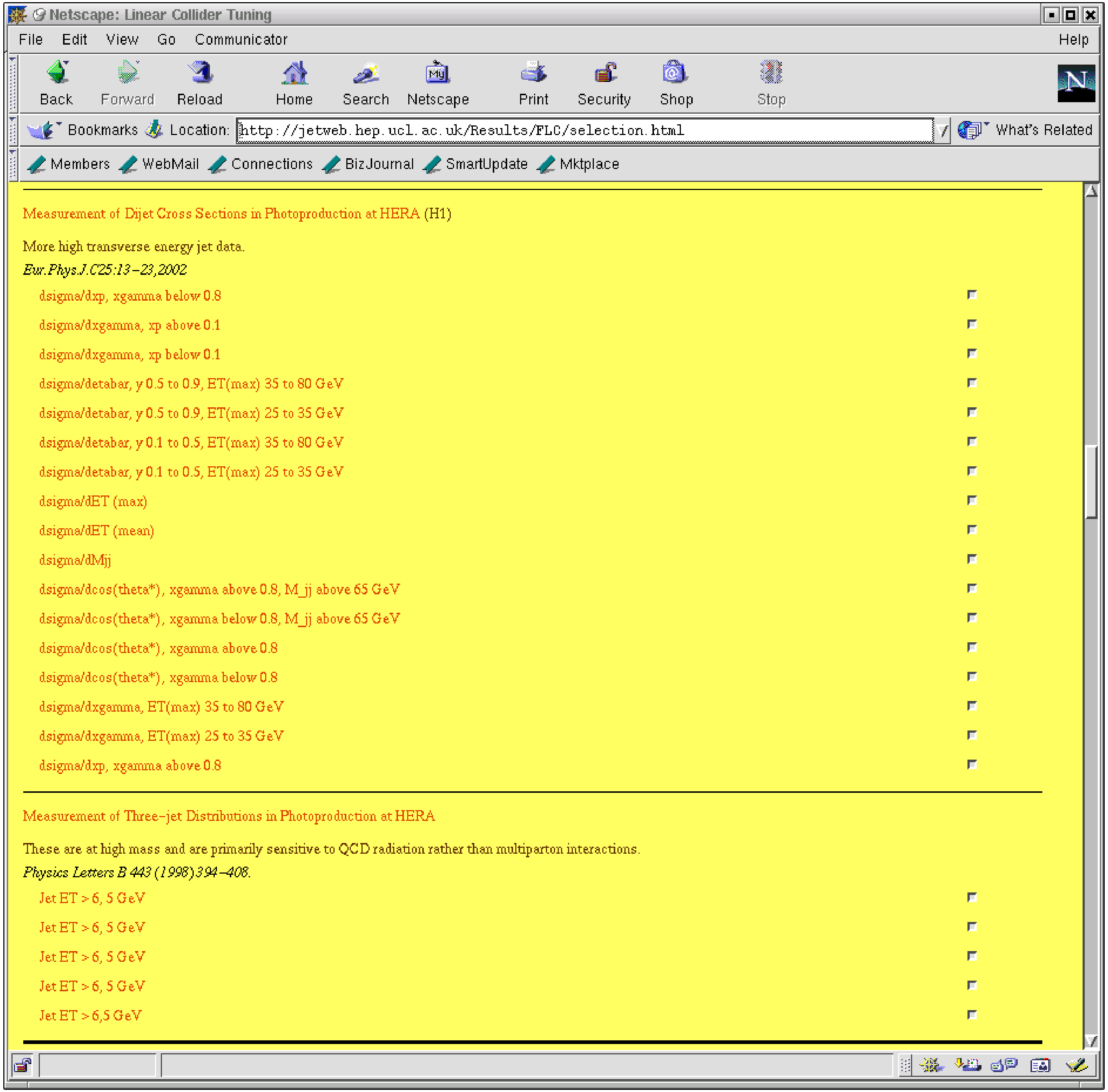
The jet cross sections cover a similar range to the ZEUS data above, but with different systematic errors.

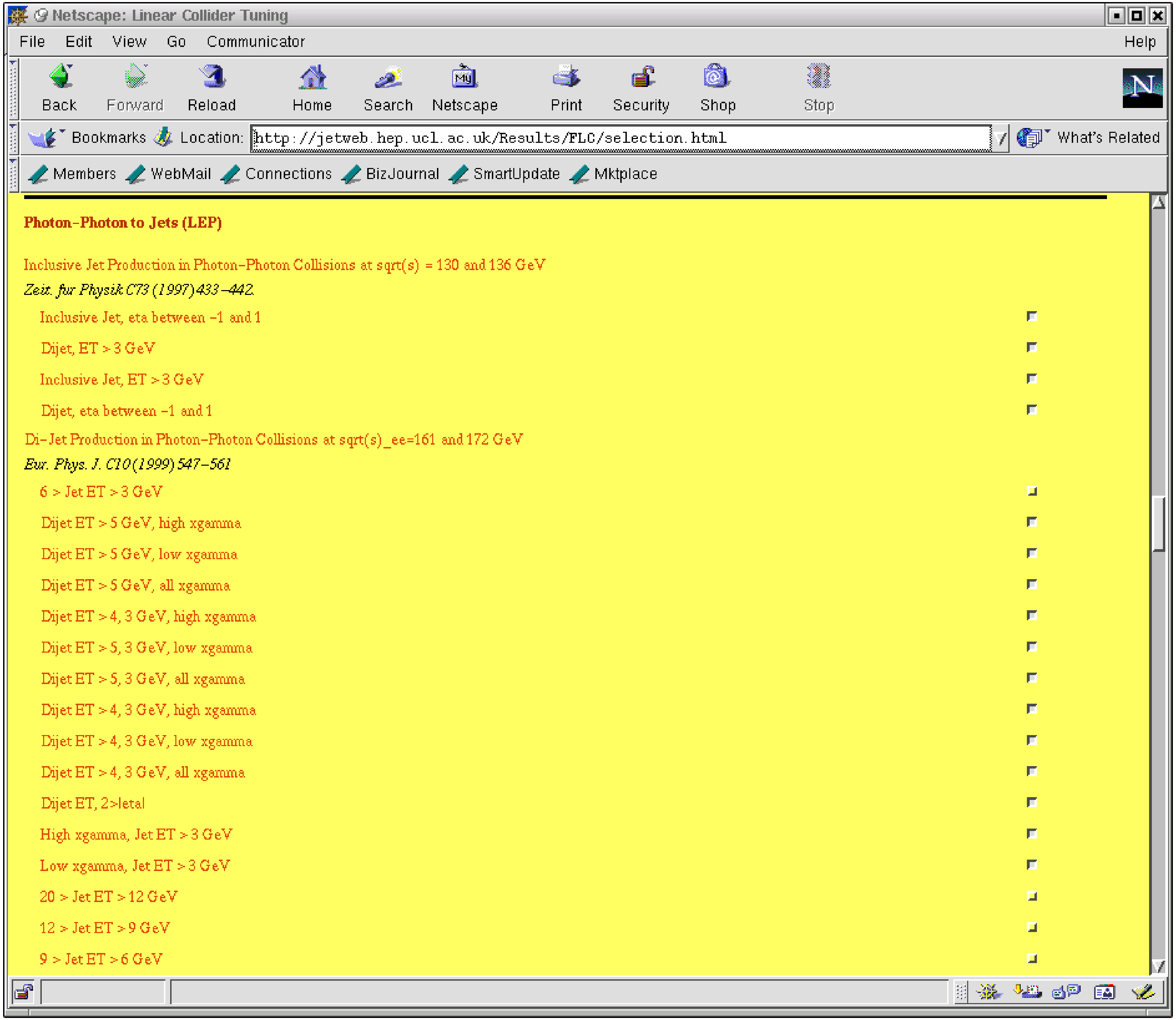
Eur. Phys. J. C1 (1998) 97–107.

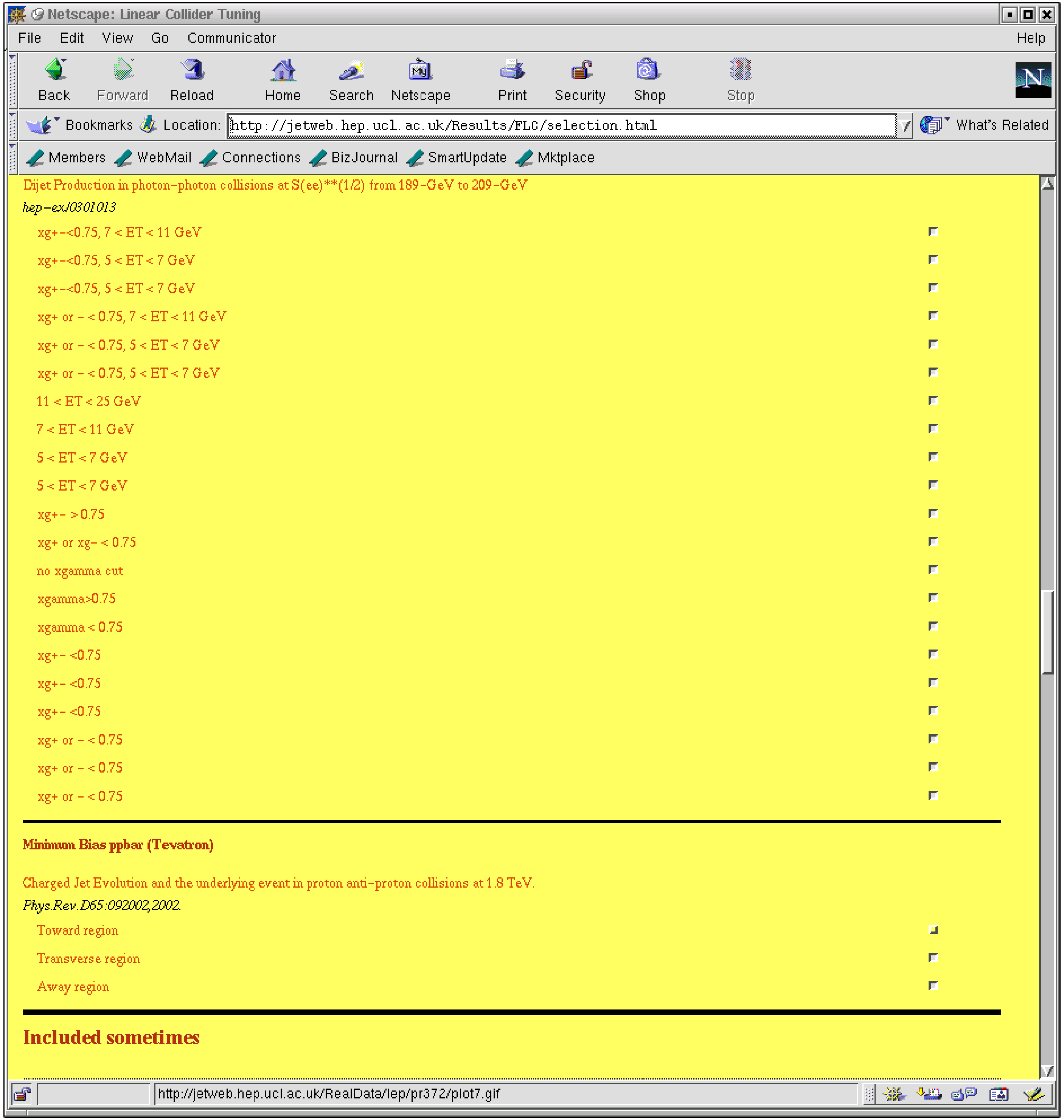
- xgamma between 0.75 and 1.0
- xgamma between 0.6 and 0.75
- xgamma between 0.5 and 0.6
- xgamma between 0.4 and 0.5
- xgamma between 0.3 and 0.4
- xgamma between 0.2 and 0.3
- xgamma between 0.1 and 0.2

http://jetweb.hep.ucl.ac.uk/RealData/hera/desy97196/plot8.gif


Netscape: Linear Collider Tuning
File Edit View Go Communicator Help
Back Forward Reload Home Search Netscape Print Security Shop Stop
Bookmarks Location: http://jetweb.hep.ucl.ac.uk/Results/FLC/selection.html
What's Related
Members WebMail Connections BizJournal SmartUpdate Mktplace
Dijet photoproduction at HERA and the structure of the photon (ZEUS)
The precision high transverse energy jet data.
Eur.Phys.J.C23:615-631,2002; DESY-01-220; hep-ex/0112029
d(sigma)/d(et) low x_gamma, 0 to eta_1 (0 to 1), eta_2 (-1 to 0)
d(sigma)/d(et) low x_gamma, eta_1 (-1 to 0), eta_2 (-1 to 0)
d(sigma)/d(eta) in pb for low x_gamma, 2nd jet forward
d(sigma)/d(eta) in pb for low x_gamma, 2nd jet central
d(sigma)/d(eta) in pb for low x_gamma, 2nd jet backward
d(sigma)/d(eta) in pb for high x_gamma, 2nd jet forward
d(sigma)/d(eta) in pb for high x_gamma, 2nd jet central
d(sigma)/d(eta) in pb for high x_gamma, 2nd jet backward
|cosine(theta*)| high xgamma
|cosine(theta*)|, low xgamma
d(sigma)/d(x_gamma), ET (35 GeV to 90 GeV)
d(sigma)/d(x_gamma), ET (25 GeV to 35 GeV)
d(sigma)/d(x_gamma), ET (17 GeV to 25 GeV)
d(sigma)/d(x_gamma), ET (14 GeV to 17 GeV)
d(sigma)/d(et) high x_gamma, eta_1 (1 to 2.4), eta_2 (1 to 2.4)
d(sigma)/d(et) high x_gamma, eta_1 (1 to 2.4), eta_2 (0 to 1)
d(sigma)/d(et) high x_gamma, eta_1 (1 to 2.4), eta_2 (-1 to 0)
d(sigma)/d(et) high x_gamma, eta_1 (0 to 1), eta_2 (0 to 1)
d(sigma)/d(et) high x_gamma, eta_1 (0 to 1), eta_2 (-1 to 0)
d(sigma)/d(et) high x_gamma, eta_1 (-1 to 0), eta_2 (-1 to 0)
d(sigma)/d(et) low x_gamma, eta_1 (1 to 2.4), eta_2 (1 to 2.4)
d(sigma)/d(et) low x_gamma, eta_1 (1 to 2.4), eta_2 (0 to 1)
d(sigma)/d(et) low x_gamma, eta_1 (1 to 2.4), eta_2 (-1 to 0)
d(sigma)/d(et) low x_gamma, eta_1 (0 to 1), eta_2 (0 to 1)


Netscape: Linear Collider Tuning
File Edit View Go Communicator Help
Back Forward Reload Home Search Netscape Print Security Shop Stop
Bookmarks Location: http://jetweb.hep.ucl.ac.uk/Results/FLC/selection.html
What's Related
Members WebMail Connections BizJournal SmartUpdate Mktplace
Measurement of Dijet Cross Sections in Photoproduction at HERA (H1)
More high transverse energy jet data.
Eur.Phys.J.C25:13–23,2002
dsigma/dxp, xgamma below 0.8
dsigma/dxgamma, xp above 0.1
dsigma/dxgamma, xp below 0.1
dsigma/detabar, y 0.5 to 0.9, ET(max) 35 to 80 GeV
dsigma/detabar, y 0.5 to 0.9, ET(max) 25 to 35 GeV
dsigma/detabar, y 0.1 to 0.5, ET(max) 35 to 80 GeV
dsigma/detabar, y 0.1 to 0.5, ET(max) 25 to 35 GeV
dsigma/dET (max)
dsigma/dET (mean)
dsigma/dMjj
dsigma/dcos(theta*), xgamma above 0.8, M_jj above 65 GeV
dsigma/dcos(theta*), xgamma below 0.8, M_jj above 65 GeV
dsigma/dcos(theta*), xgamma above 0.8
dsigma/dcos(theta*), xgamma below 0.8
dsigma/dxgamma, ET(max) 35 to 80 GeV
dsigma/dxgamma, ET(max) 25 to 35 GeV
dsigma/dxp, xgamma above 0.8
Measurement of Three-jet Distributions in Photoproduction at HERA
These are at high mass and are primarily sensitive to QCD radiation rather than multiparton interactions.
Physics Letters B 443 (1998) 394–408.
Jet ET > 6, 5 GeV
Jet ET > 6, 5 GeV
Jet ET > 6, 5 GeV
Jet ET > 6, 5 GeV
Jet ET > 6,5 GeV


Netscape: Linear Collider Tuning
File Edit View Go Communicator Help
Back Forward Reload Home Search Netscape Print Security Shop Stop
Bookmarks Location: http://jetweb.hep.ucl.ac.uk/Results/FLC/selection.html
What's Related
Members WebMail Connections BizJournal SmartUpdate Mktplace
Photon-Photon to Jets (LEP)
Inclusive Jet Production in Photon-Photon Collisions at sqrt(s) = 130 and 136 GeV
Zeit. fur Physik C73 (1997) 433-442.
Inclusive Jet, eta between -1 and 1
Dijet, ET > 3 GeV
Inclusive Jet, ET > 3 GeV
Dijet, eta between -1 and 1
Di-Jet Production in Photon-Photon Collisions at sqrt(s)_ee=161 and 172 GeV
Eur. Phys. J. C10 (1999) 547-561
6 > Jet ET > 3 GeV
Dijet ET > 5 GeV, high xgamma
Dijet ET > 5 GeV, low xgamma
Dijet ET > 5 GeV, all xgamma
Dijet ET > 4, 3 GeV, high xgamma
Dijet ET > 5, 3 GeV, low xgamma
Dijet ET > 5, 3 GeV, all xgamma
Dijet ET > 4, 3 GeV, high xgamma
Dijet ET > 4, 3 GeV, low xgamma
Dijet ET > 4, 3 GeV, all xgamma
Dijet ET, 2>|eta|
High xgamma, Jet ET > 3 GeV
Low xgamma, Jet ET > 3 GeV
20 > Jet ET > 12 GeV
12 > Jet ET > 9 GeV
9 > Jet ET > 6 GeV


Netscape: Linear Collider Tuning

File Edit View Go Communicator Help

Back Forward Reload Home Search Netscape Print Security Shop Stop

Bookmarks Location: http://jetweb.hep.ucl.ac.uk/Results/FLC/selection.html What's Related

Members WebMail Connections BizJournal SmartUpdate Mktplace

Dijet Production in photon-photon collisions at S(ee)**(1/2) from 189-GeV to 209-GeV

hep-ex/0301013

- xg+-<0.75, 7 < ET < 11 GeV
- xg+-<0.75, 5 < ET < 7 GeV
- xg+-<0.75, 5 < ET < 7 GeV
- xg+ or - < 0.75, 7 < ET < 11 GeV
- xg+ or - < 0.75, 5 < ET < 7 GeV
- xg+ or - < 0.75, 5 < ET < 7 GeV
- 11 < ET < 25 GeV
- 7 < ET < 11 GeV
- 5 < ET < 7 GeV
- 5 < ET < 7 GeV
- xg+- > 0.75
- xg+ or xg- < 0.75
- no xgamma cut
- xgamma>0.75
- xgamma < 0.75
- xg+- <0.75
- xg+- <0.75
- xg+- <0.75
- xg+ or - < 0.75
- xg+ or - < 0.75
- xg+ or - < 0.75

Minimum Bias ppbar (Tevatron)

Charged Jet Evolution and the underlying event in proton anti-proton collisions at 1.8 TeV.

Phys.Rev.D65:092002,2002.

- Toward region
- Transverse region
- Away region

Included sometimes

http://jetweb.hep.ucl.ac.uk/RealData/lep/pr372/plot7.gif

Details of best fits for PYTHIA

PYTHIA, fit 246, $\chi^2/\text{dof} = 2.4$

CTEQ5L/SaS2D, $p_T^{\text{min}} = 3$ GeV, PARP(67) = 2.0, UE $= 3$, $p_T^{\text{min2}} = 1.6$ GeV, PARP(85) = 1.0, PARP(86) = 1.0, PARP(90) = 0.0, scale factor = 1.3

PYTHIA, fit 325, $\chi^2/\text{dof} = 2.5$

CTEQ5L/SaS2D, $p_T^{\text{min}} = 3$ GeV, PARP(67) = 1.0, UE $= 4$, $p_T^{\text{min2}} = 1.9$ GeV, PARP(84) = 0.5, k_T^p = 0.0, scale factor = 1.4

PYTHIA, fit 319, $\chi^2/\text{dof} = 2.5$

CTEQ5L/SaS2D, $p_T^{\text{min}} = 3$ GeV, PARP(67) = 1.0, UE $= 3$, $p_T^{\text{min2}} = 1.7$ GeV, PARP(85) = 1.0, PARP(86) = 1.0, PARP(90) = 0.0, scale factor = 1.4

(cf default: PYTHIA, fit 761, $\chi^2/\text{dof} = 9.9$)

Simulation of underlying event, multiple scatters and parton showering

Details of best fits for HERWIG

HERWIG, fit 689, $\chi^2/\mathrm{dof} = 2.7$

CTEQ5L/SaS2D, $p_T^{\mathrm{min}} = 3$ GeV, SUE+JIMMY, PRSOF = 0.1, $R_p = R_p/\sqrt{3}$, scale factor = 1.65

HERWIG, fit 359, $\chi^2/\mathrm{dof} = 2.9$

CTEQ4L/SaS2D, $p_T^{\mathrm{min}} = 3$ GeV, JIMMY, $R_p = R_p/\sqrt{3}$, scale factor = 1.7
(NB, fit 493 with CTEQ5L, $\chi^2/\mathrm{dof} = 3.23$)

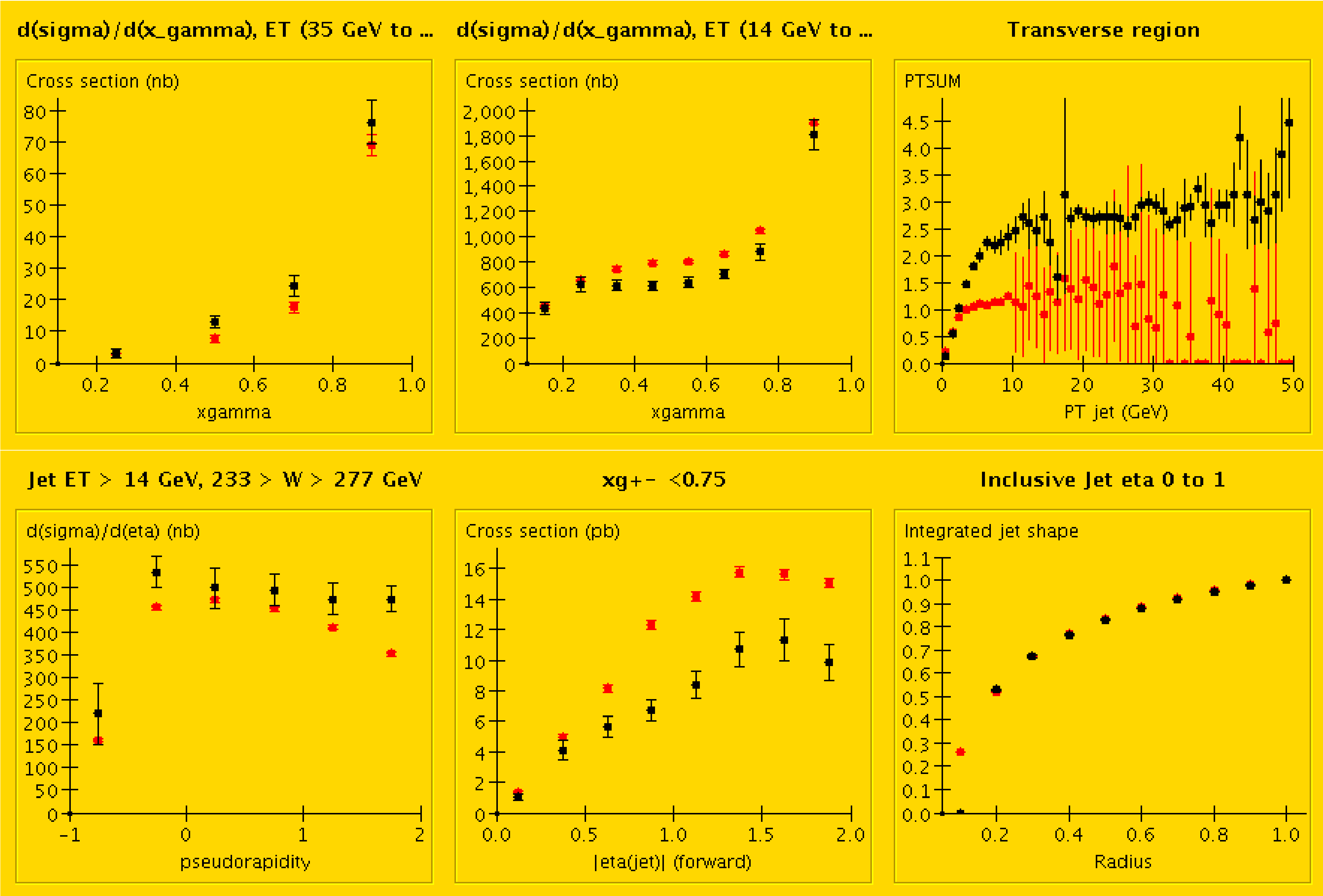
HERWIG, fit 720, $\chi^2/\mathrm{dof} = 3.0$

CTEQ5L/SaS2D, $p_T^{\mathrm{min}} = 3$ GeV, SUE+JIMMY, PRSOF = 0.01, $R_p = R_p/\sqrt{3}$, $R_\gamma = R_\gamma/\sqrt{3}$, scale factor = 1.7

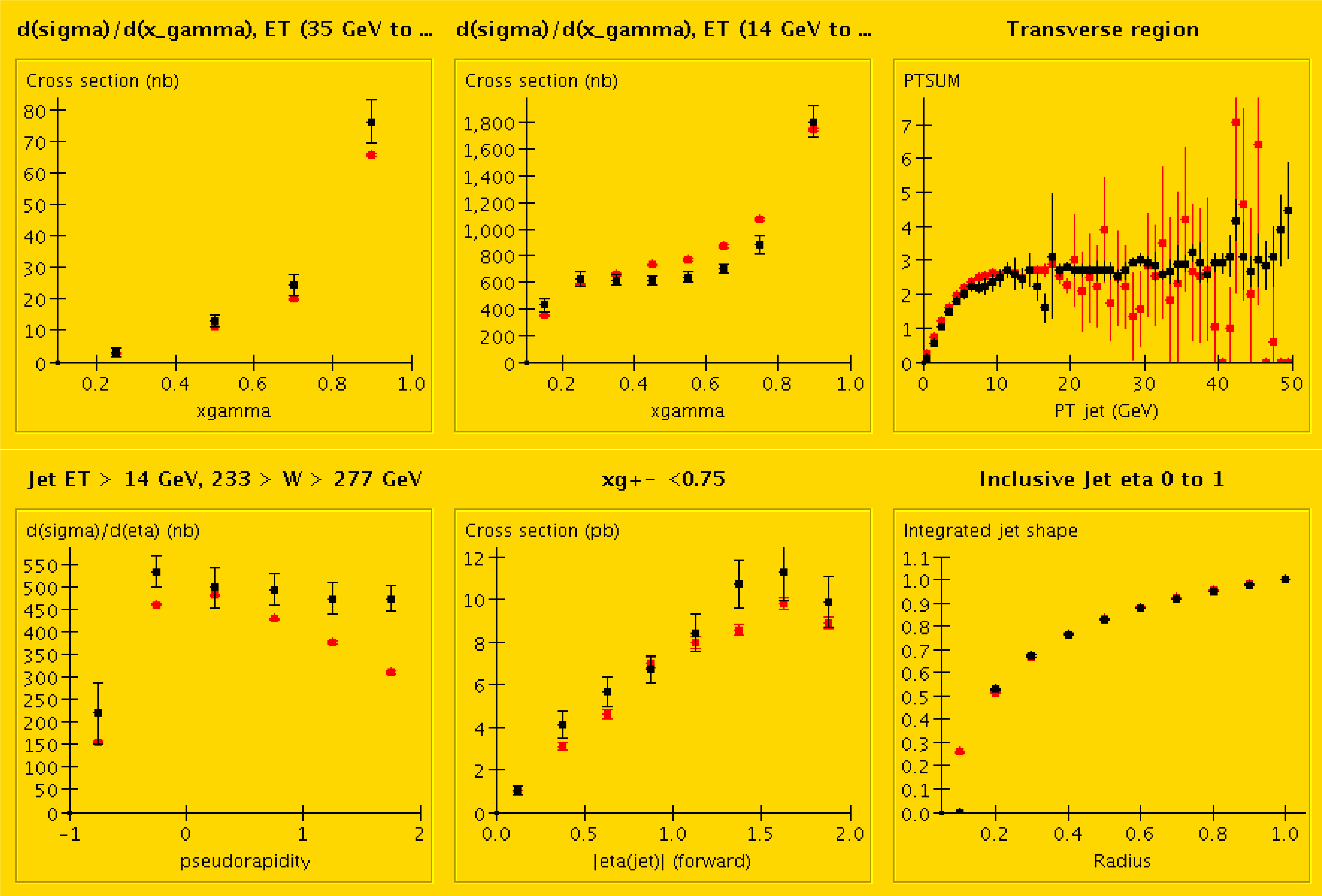
(*cf* default: HERWIG, fit 373/405, No UE/SUE, $\chi^2/\mathrm{dof} = 6.3/4.9$)

Simulation of underlying event, multiparton interactions and radii of colliding particles

A bad (default) PYTHIA fit - 761



The best PYTHIA fit - 246



Sensitivity to PARP(67) in PYTHIA

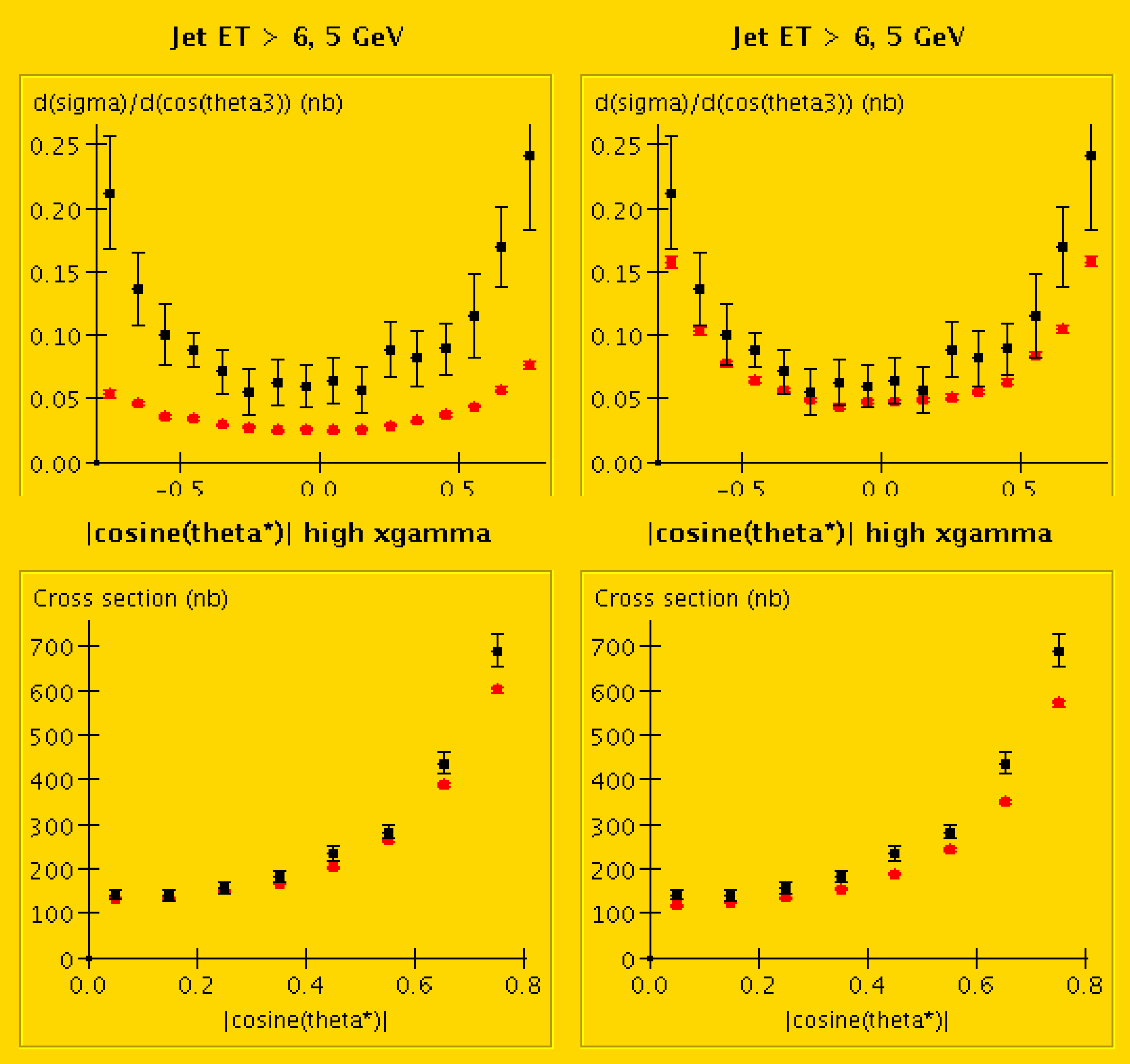
Sensitivity to the maximum parton virtuality in space-like showers is seen:

Fit ID	PARP(67)		scale factor	χ^2, 3jets	χ^2, high E_T	χ^2, all data
244	0.5		1.45	7.8	2.6	3.0
73	1.0		1.4	4.8	2.2	2.7
246	2.0		1.3	3.0	2.4	2.4
250	4.0		1.15	1.5	4.0	2.9

Current default is 1.0 and previous default was 4.0

Description of data varying PARP(67) in PYTHIA

Fit 244, PARP(67) = 0.5 Fit 250, PARP(67) = 4.0



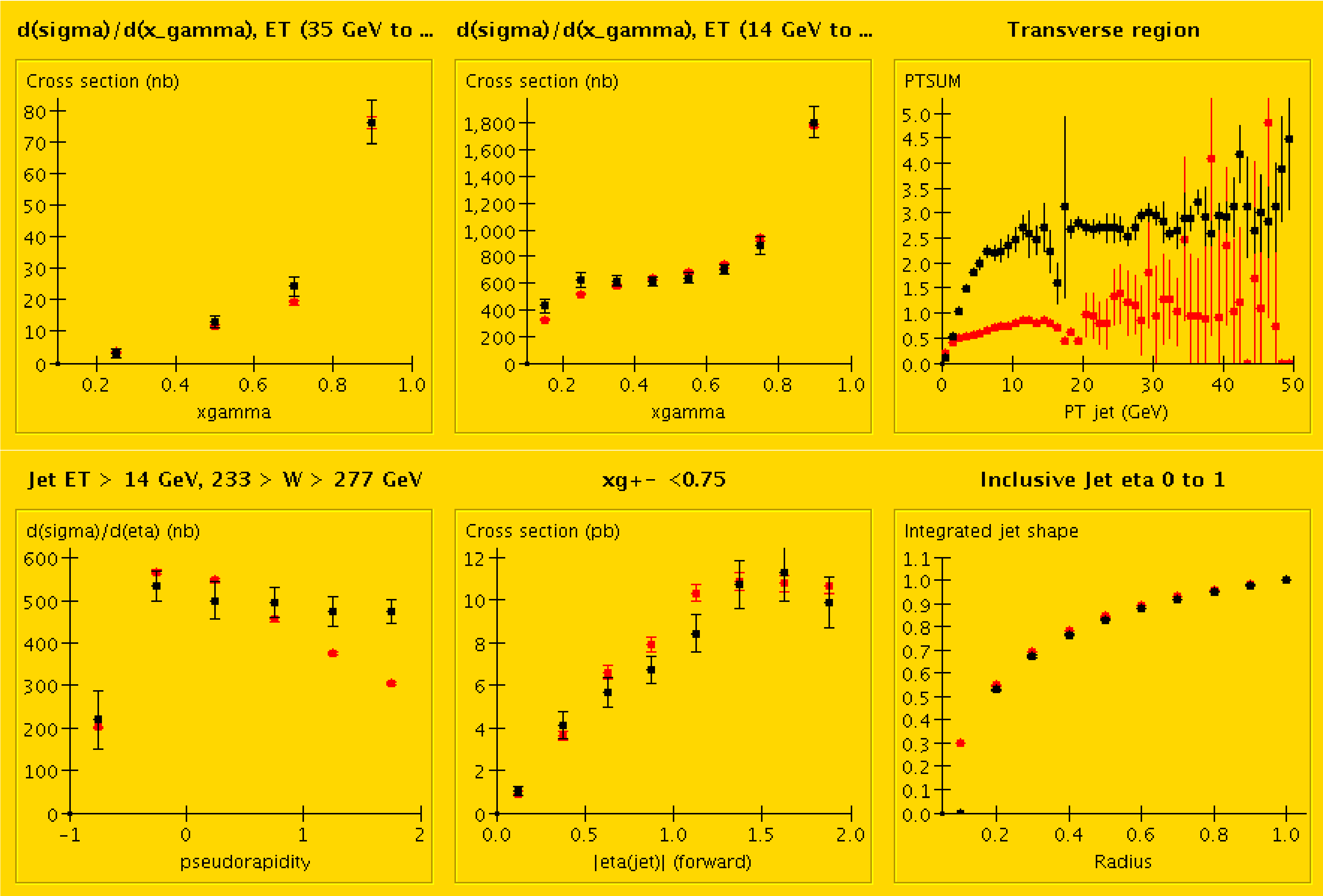
Fit 246, PARP(67) = 2.0 Fit 250, PARP(67) = 4.0

This is not tuneable in HERIWG

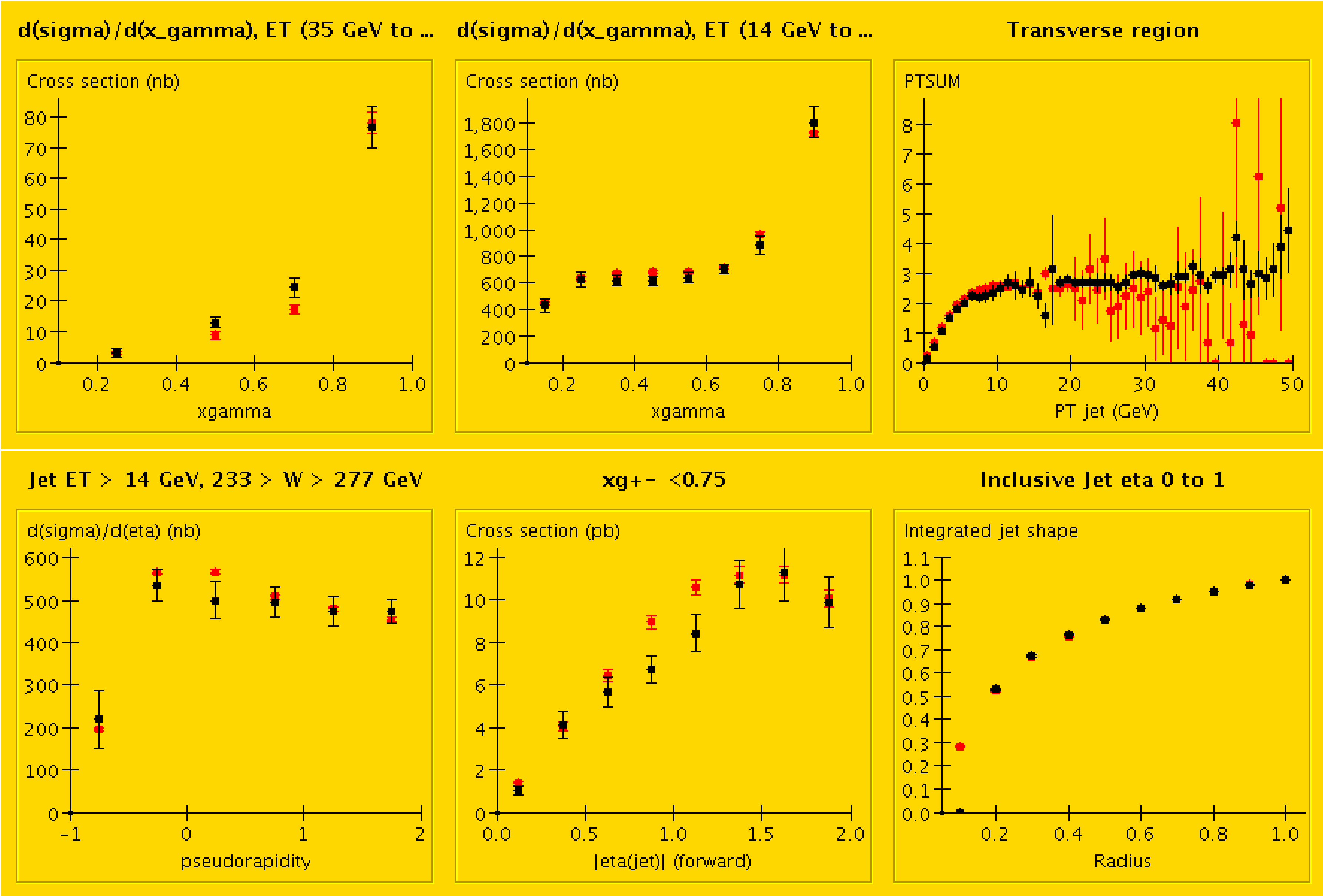
Best HERWIG fit gets the 3 jet distributions right (χ^2/dof = 1.1)

A variable to focus on

Another bad (default) HERWIG fit - 373



The best HERWIG fit - 689



Results for a e^+e^- linear collider

Have used these fits and predicted $\gamma\gamma$ rates at a future linear collider.

Can have two direct photons, one direct and one resolved or two resolved photons producing jets.

Large QCD production rate up to high energies and masses.

Demonstration of this procedure for $\sqrt{s} = 500$ GeV.

Applies for 800 GeV. Should apply for other energies and other colliders, e.g. LHC or $\gamma\gamma$.

(Default) HERWIG predictions at 500 GeV

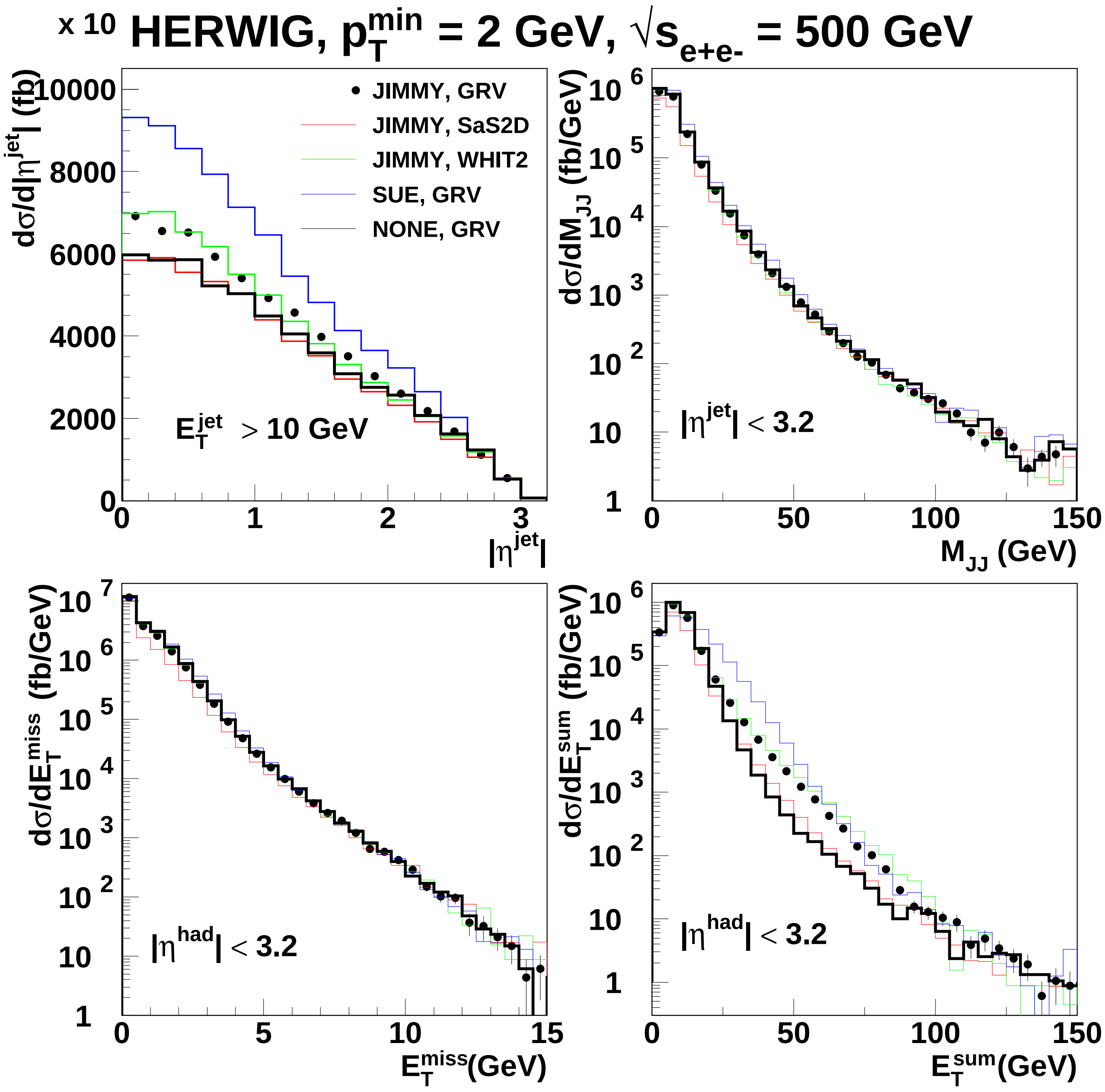
Default HERWIG prediction used with changes in underlying event and photon PDF.

All “reasonable” parameter settings.

Large spread in predictions, even at high energies.

How accurately do we know QCD production?

Not very well!

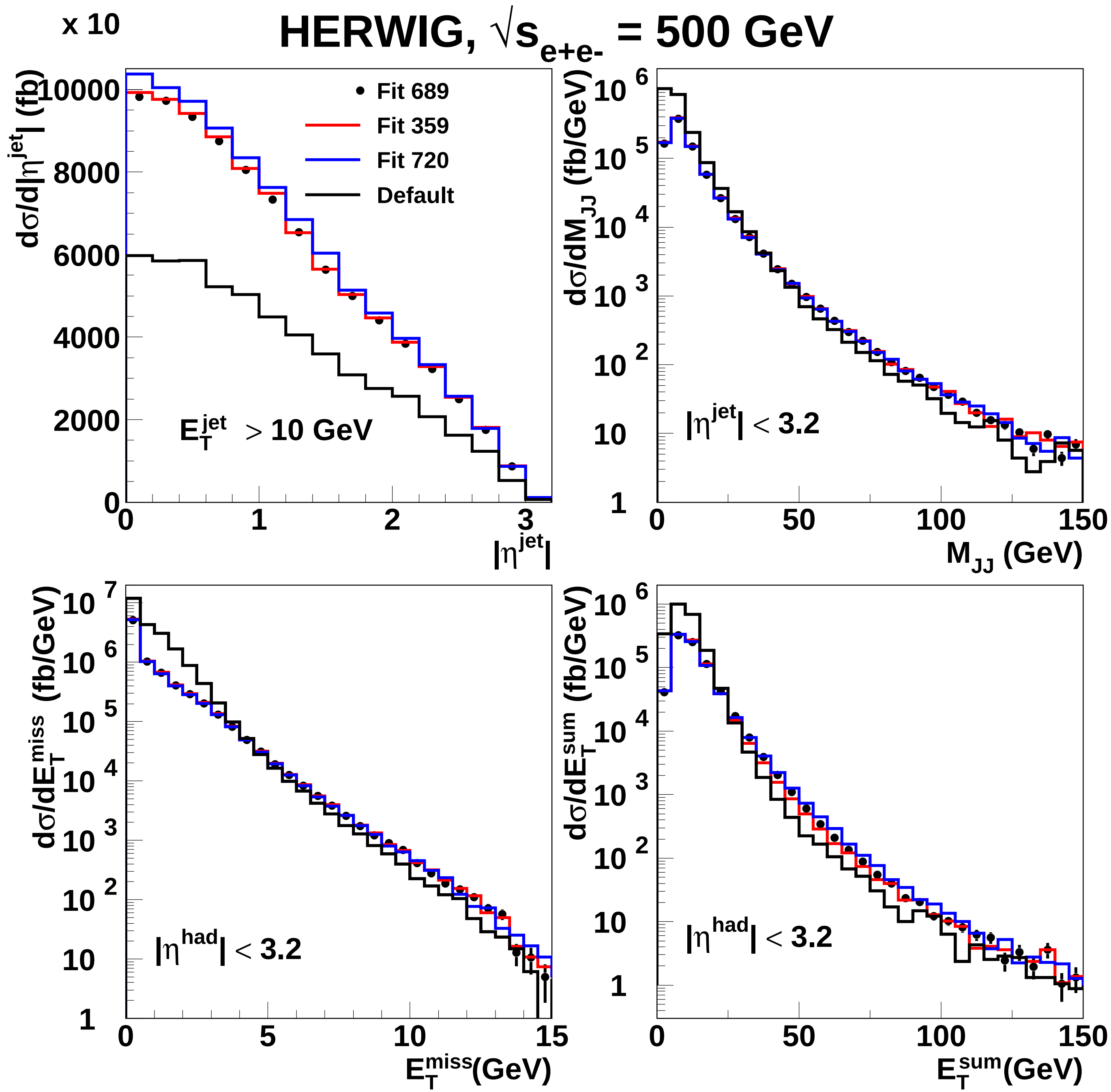


(Fitted) HERWIG predictions at 500 GeV

Predictions significantly different from default

Note increased cross sections at high energies

Reduced spread in predictions



(Fitted) predictions at 500 GeV

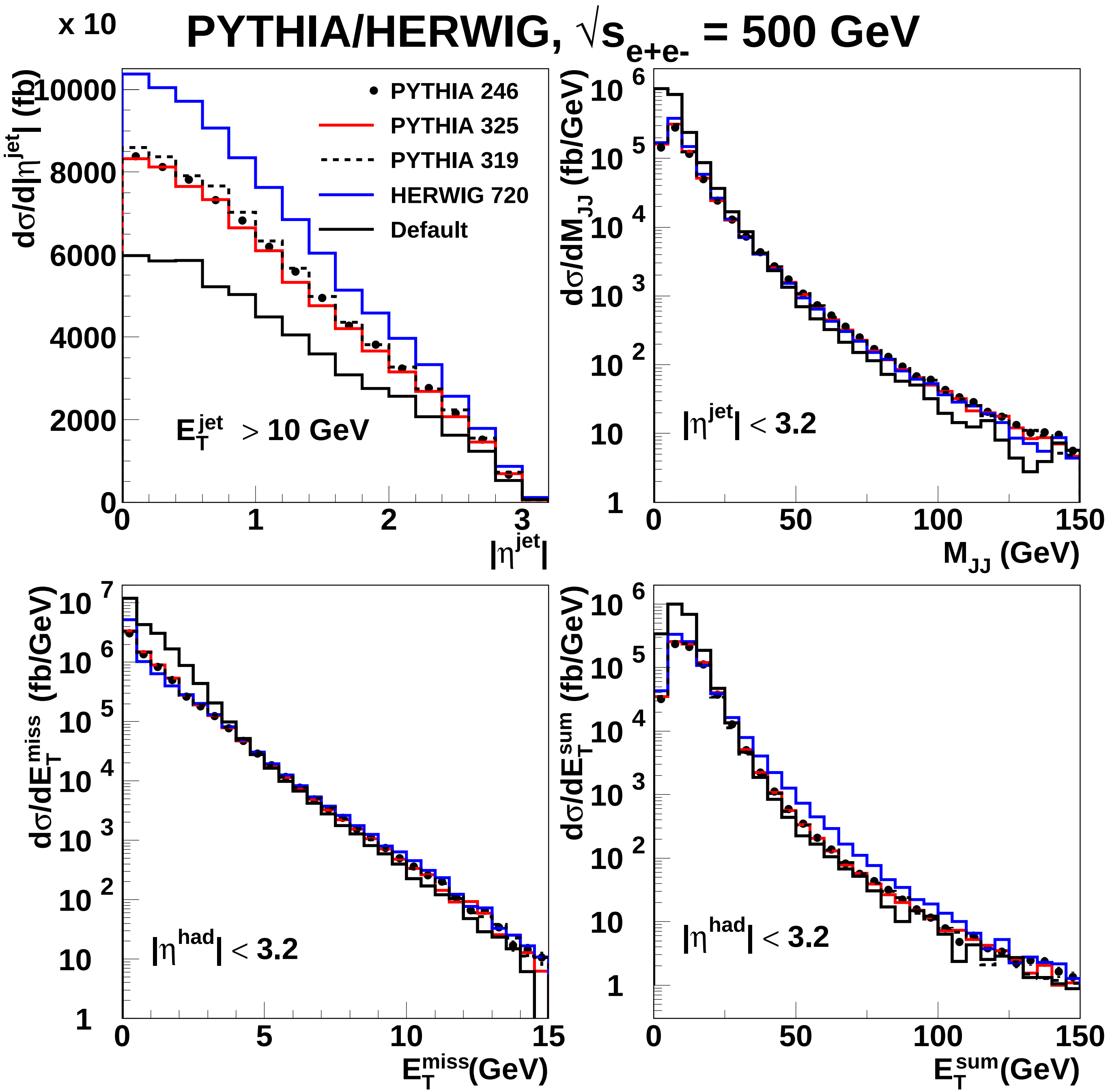
Predictions from PYTHIA cluster together

Similar to PYTHIA, but use of model leads to not insignificant difference...

...but closer to the tuned than default HERWIG

At high energies, similar cross section to HERWIG

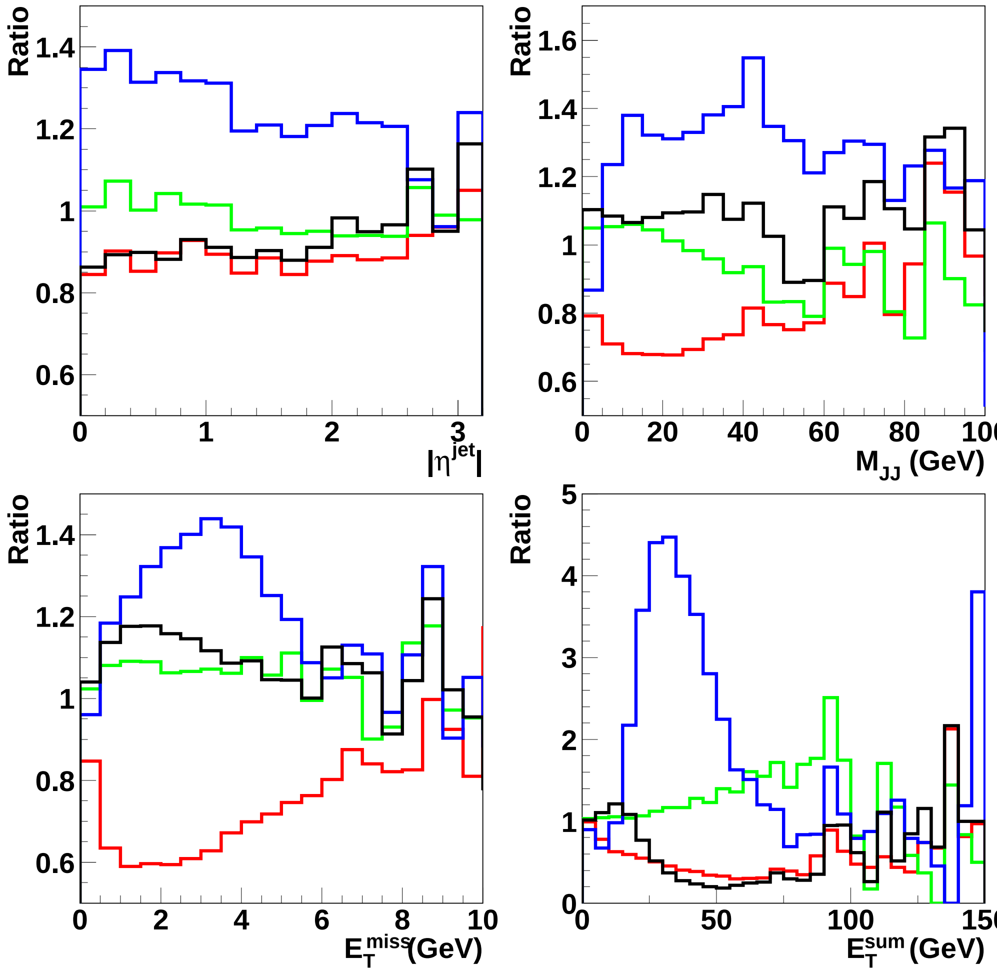
Now have six very different predictions giving us a good estimation of the uncertainty



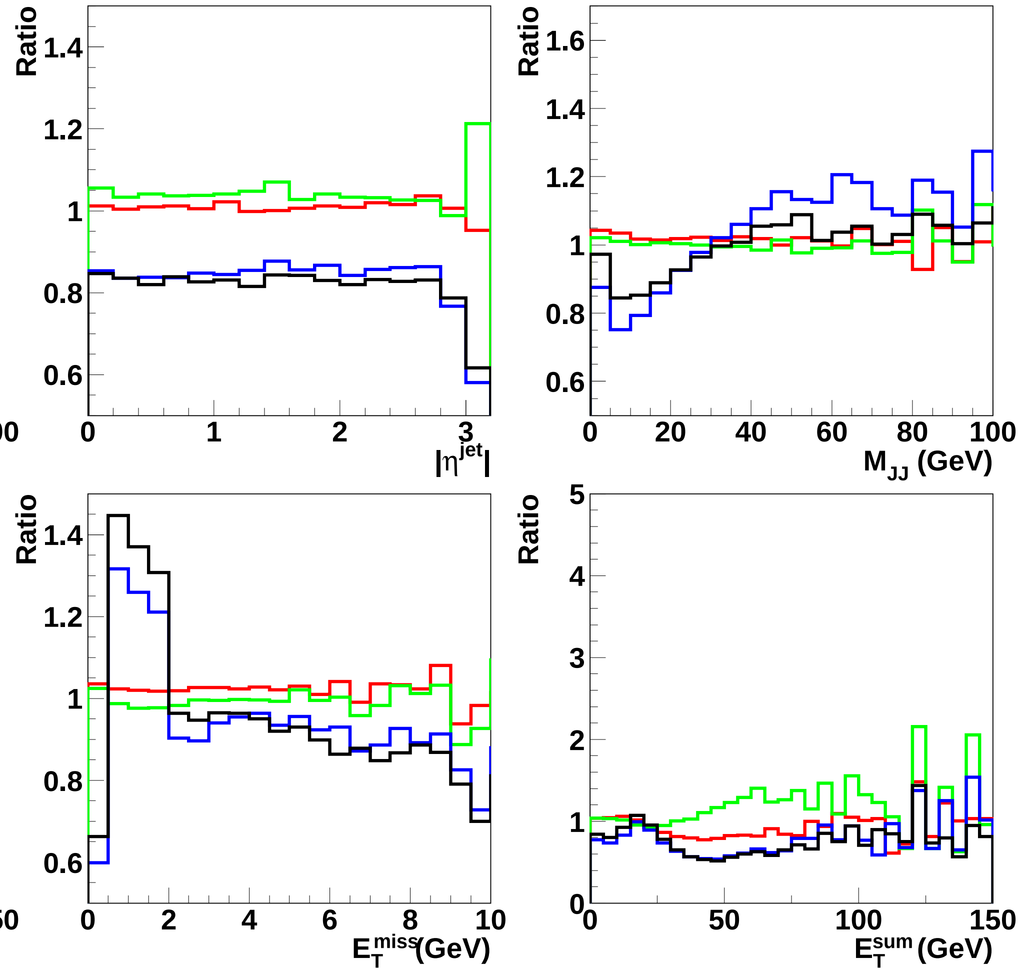
Spread in tuned predictions at 500 GeV

Choose "central" MC prediction and calculate how much other predictions differ.

HERWIG defaults, $\sqrt{s}_{e+e-}$ = 500 GeV



HERWIG/PYTHIA fits, $\sqrt{s}_{e+e-}$ = 500 GeV



Five HERWIG predictions $\leftrightarrow$ three HERWIG, two PYTHIA predictions.

Significant reduction in spread in predictions.

Conclusions

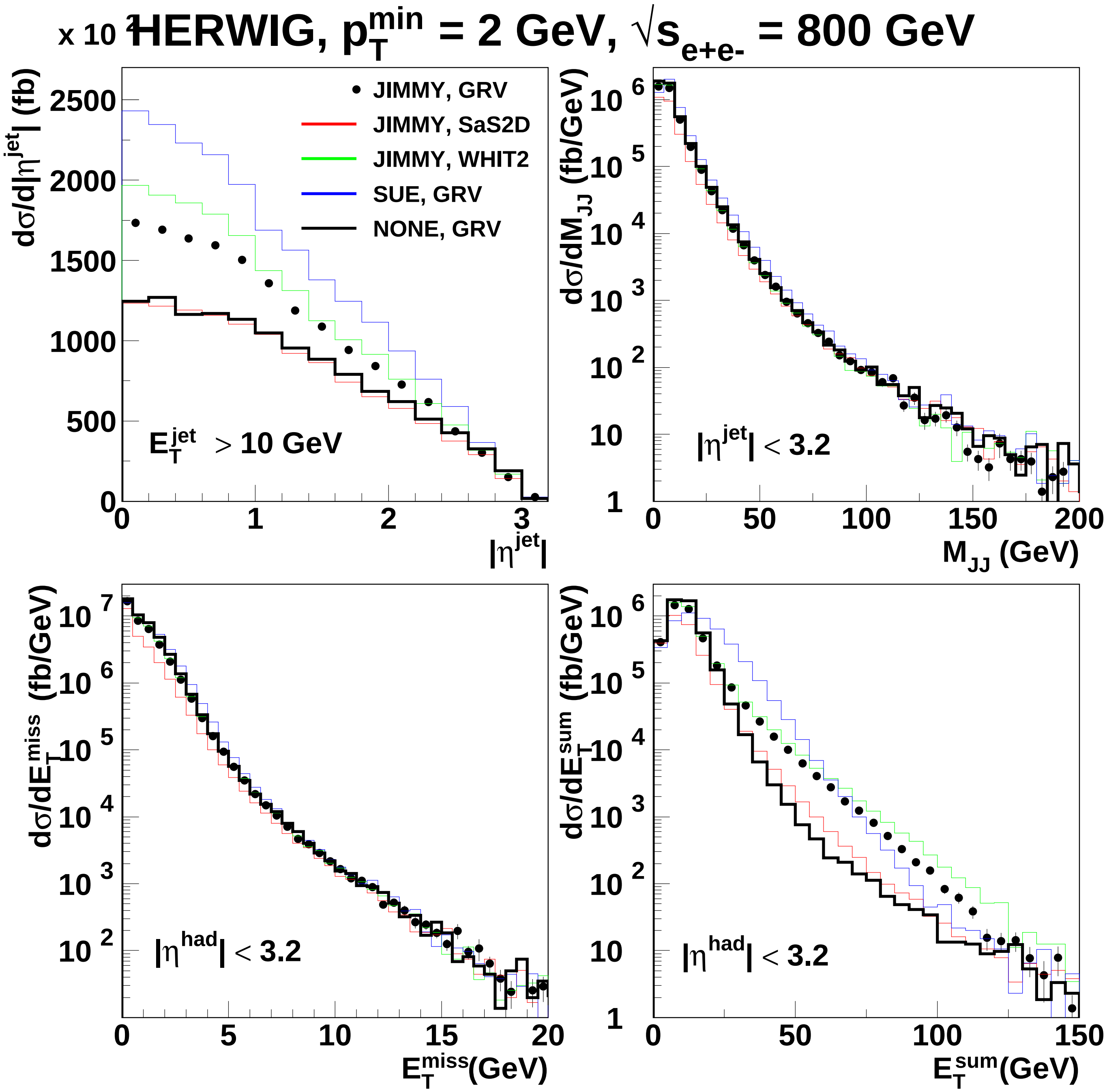
We are able to change the parameters in the MC to better describe a wide range of different data.

Have made a careful selection of relevant data for this procedure.

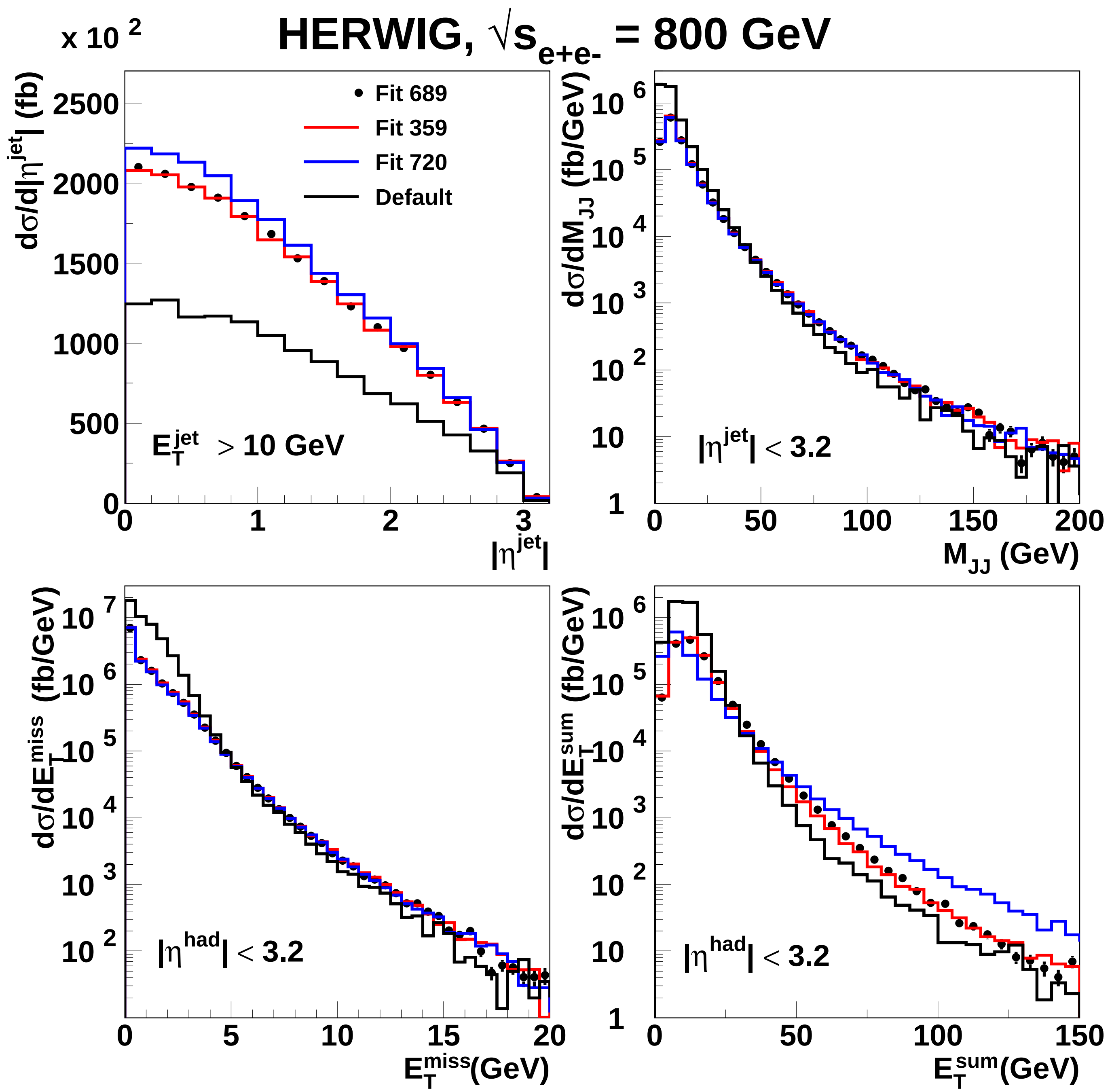
These improved MCs give a significantly reduced spread in predictions for a future linear collider.

Fits can always be improved, with new data, different parameters, etc., but the general proof of principle has been achieved which will be written up soon.

For more information, see:
http://jetweb.hep.ucl.ac.uk/Results/FLC/index.html



HERWIG, p_T^{min} = 2 GeV, $\sqrt{s_{e+e-}}$ = 800 GeV
x 10 ^2
$d\sigma/d|\eta^{jet}|$ (fb)
JIMMY, GRV
JIMMY, SaS2D
JIMMY, WHIT2
SUE, GRV
NONE, GRV
E_T^{jet} > 10 GeV
$|\eta^{jet}|$
$d\sigma/dM_{JJ}$ (fb/GeV)
$|\eta^{jet}| < 3.2$
M_{JJ} (GeV)
$d\sigma/dE_T^{miss}$ (fb/GeV)
$|\eta^{had}| < 3.2$
E_T^{miss}(GeV)
$d\sigma/dE_T^{sum}$ (fb/GeV)
$|\eta^{had}| < 3.2$
E_T^{sum}(GeV)


HERWIG, √s_e+e- = 800 GeV
x 10^2
dσ/d|η^jet| (fb)
Fit 689
Fit 359
Fit 720
Default
E_T^jet > 10 GeV
|η^jet|
dσ/dM_JJ (fb/GeV)
|η^jet| < 3.2
M_JJ (GeV)
dσ/dE_T^miss (fb/GeV)
|η^had| < 3.2
E_T^miss(GeV)
dσ/dE_T^sum (fb/GeV)
|η^had| < 3.2
E_T^sum(GeV)

Implementation of Beamstrahlung in PYTHIA

Beamstrahlung not available in PYTHIA for $\gamma\gamma \rightarrow$ QCD processes.

Could implement into PYTHIA as done in HERWIG.

Easier to extract weights from HERWIG by considering a cross section with beamstrahlung on and off.

A 2D grid in the energy fractions ($\log_{10}(E_\gamma/E_e)$) of the two virtual photons was formed.

A weight was then found as the ratio of cross sections in each bin in the grid.

Direct, single-resolved and double-resolved events used to span all phase space.

Performed separately for 500 and 800 GeV.

Testing of Beamstrahlung weights

Found for a given set of HERWIG parameters.

(Trivial) retest on HERWIG sample with same settings.

Apply to a sample of direct photon-photon collisions.

Parameters changed ($p_T^{\rm min}$, PDF) and weight applied $\rightarrow$

Energy fractions and other complicated distributions reproduced exactly.

Confidence in weighting procedure $\Rightarrow$ use in PYTHIA.