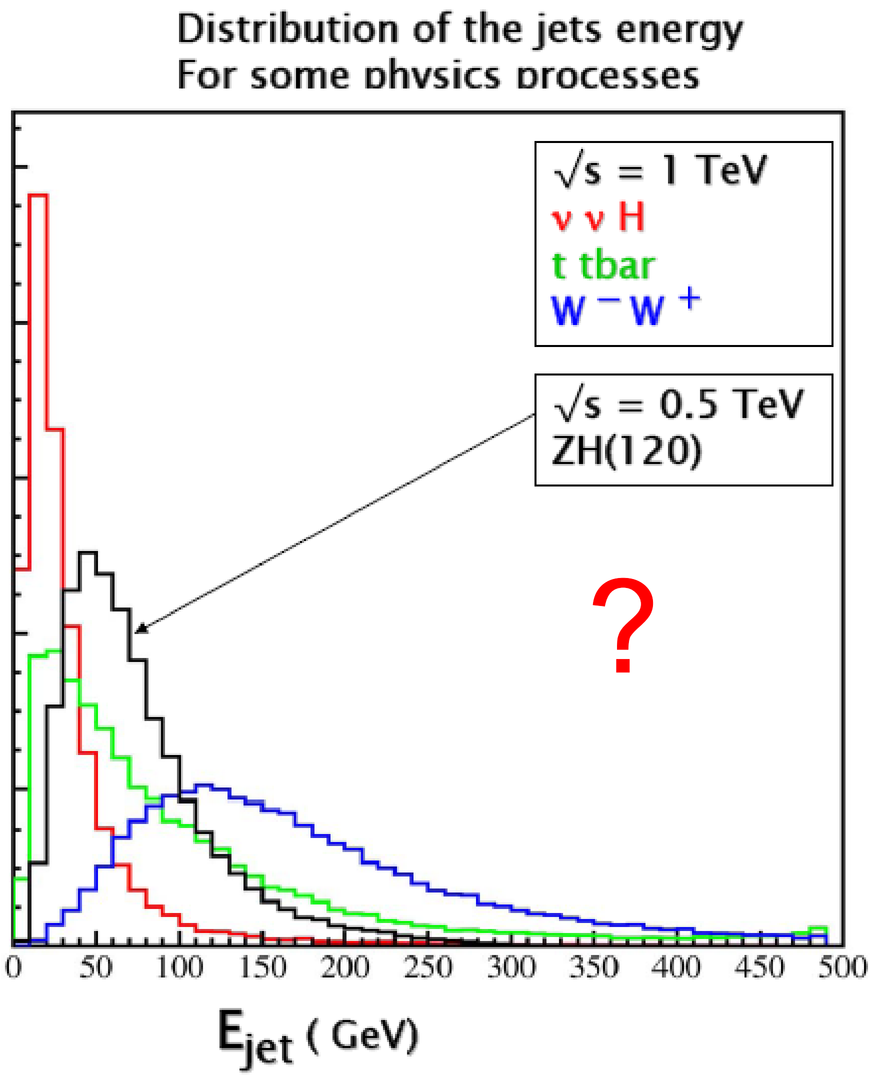
Jet Energy Studies at $\sqrt{s}$=1 TeV e^+e^- Colliders: A First Look

C.F. Berger & TGR
05/08

In order to know how well jet energies should/can be measured at higher energy colliders, we first need to know what the range of `interesting' jet energies is, i.e., what is the jet E spectrum??



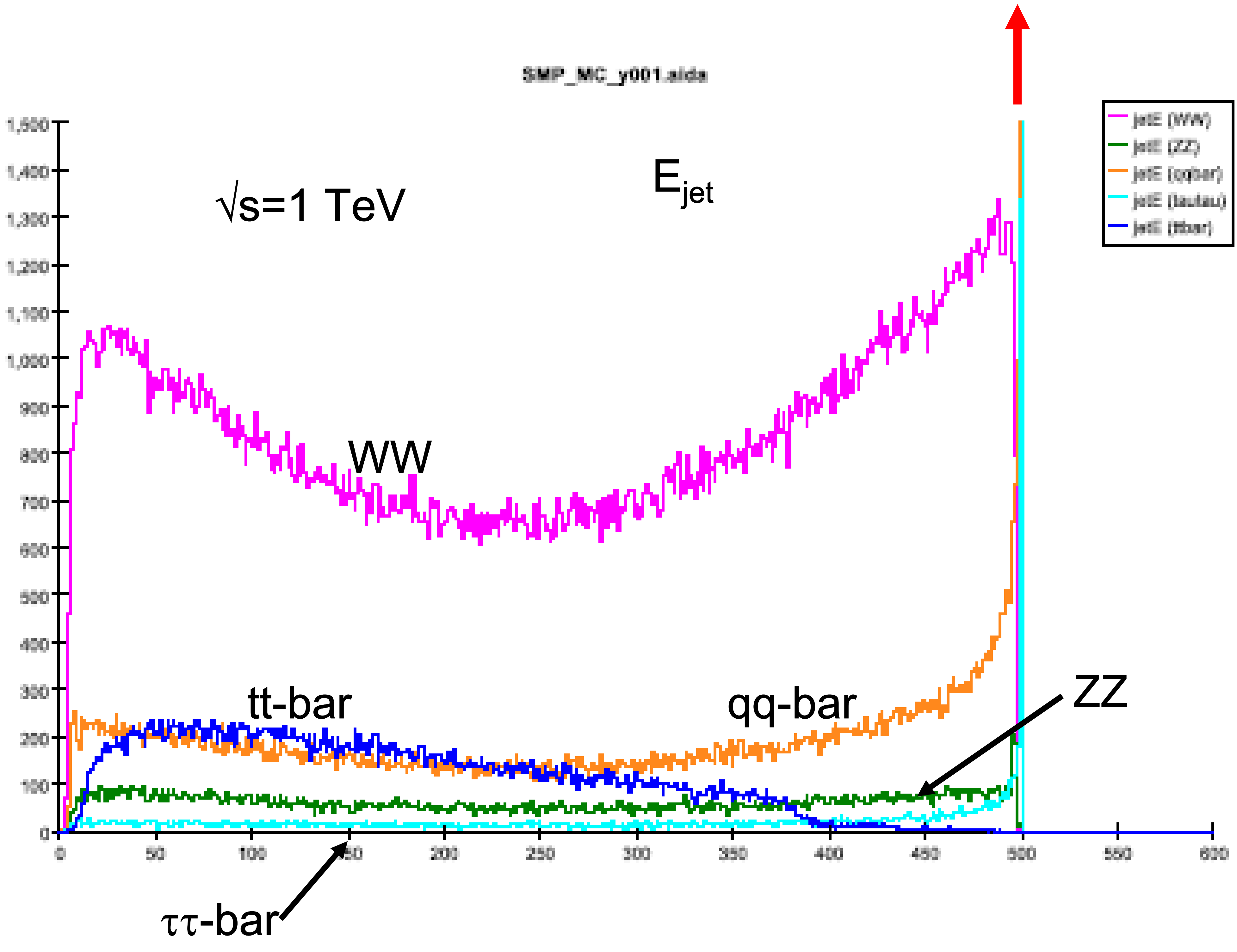
A very quick look at this was done at Snowmass a few years back…

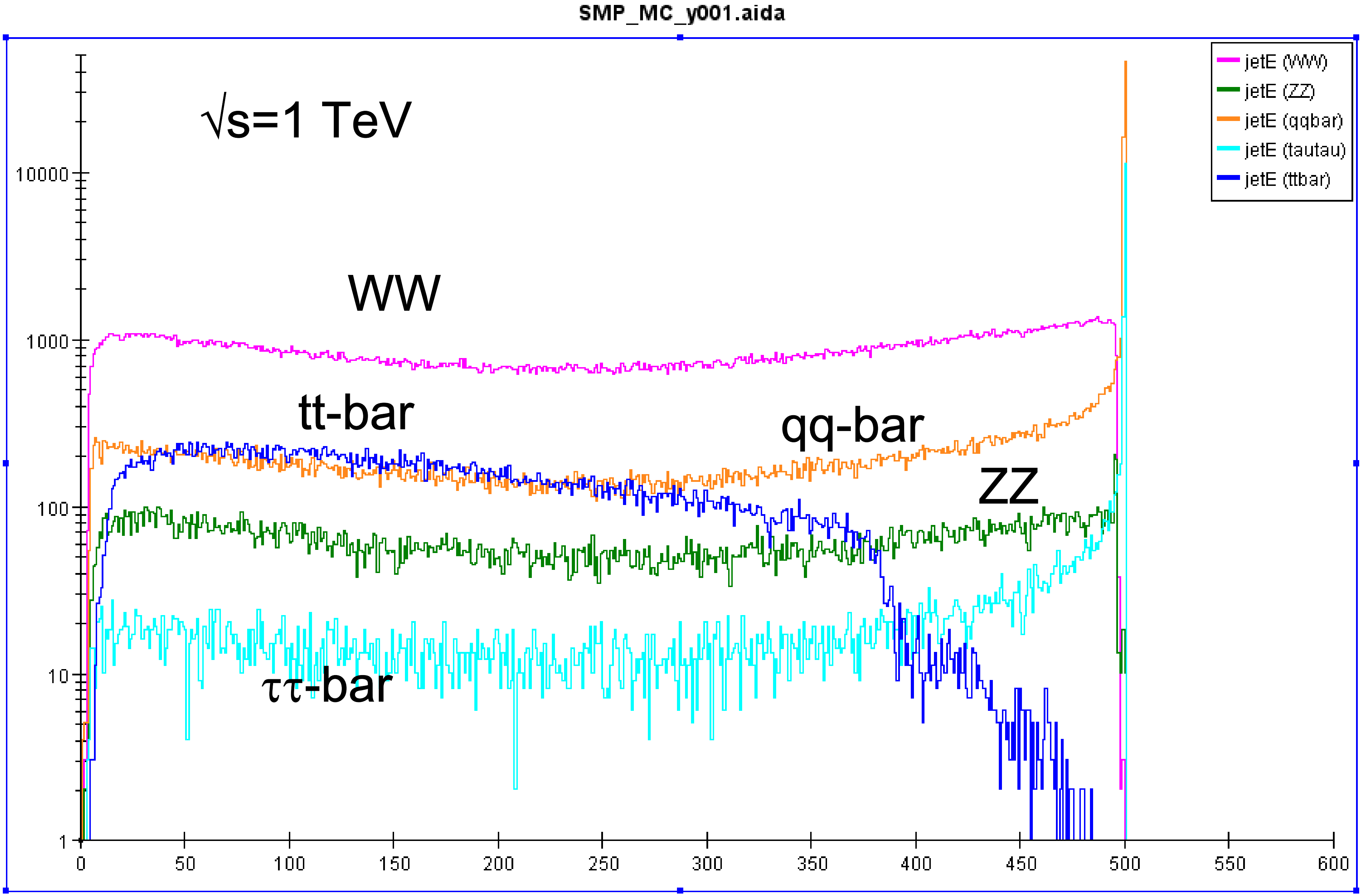
This is *rather* incomplete necessitating a more detailed look…

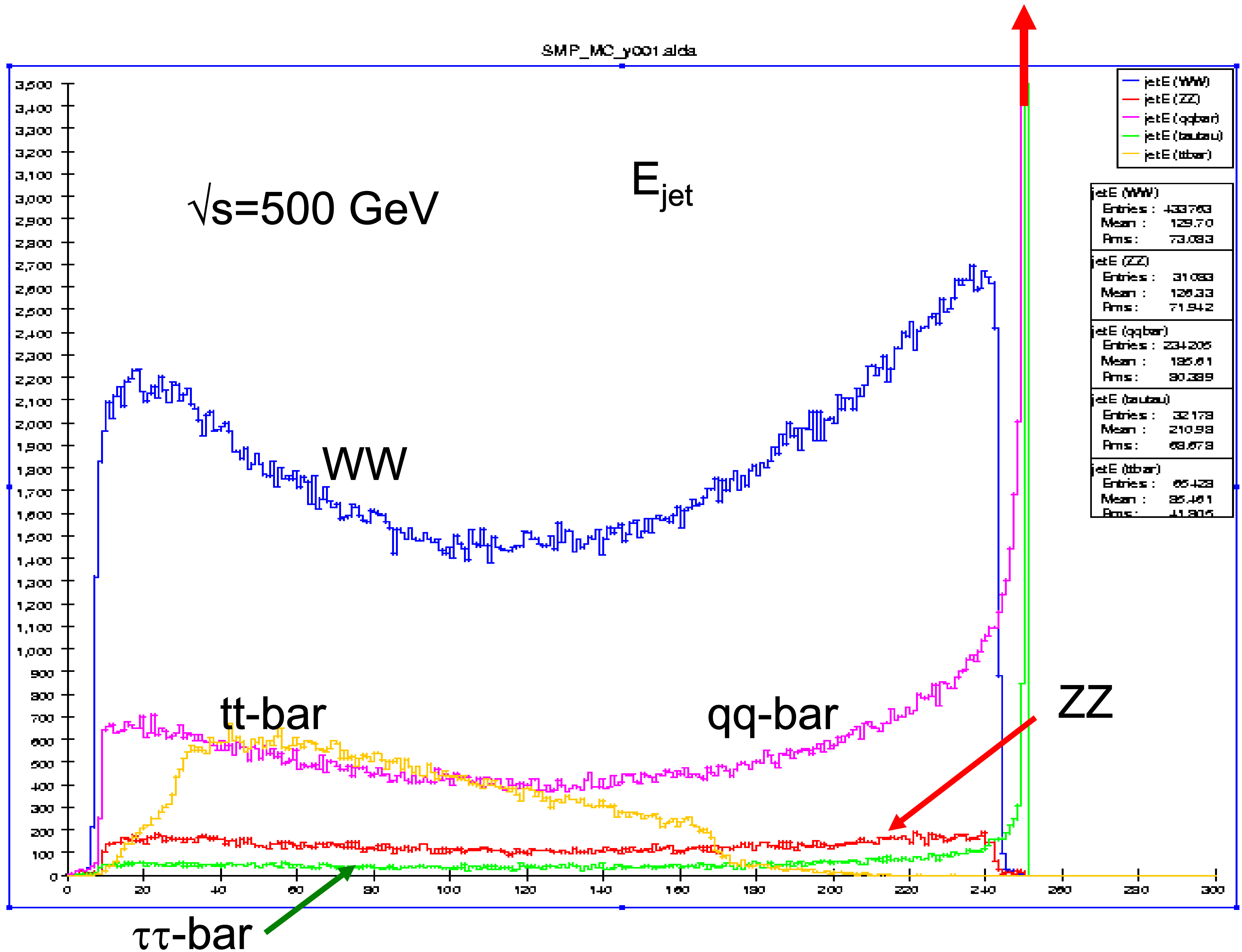
Brient (Snowmass'05)

So we will first look at a number of SM & non-SM processes and compare their jet energy distributions at the parton level at 500 GeV and 1 TeV. This will be done first using PYTHIA6.324 turning off QCD, ISR/FSR, fragmentation, hadronization and all detector effects.

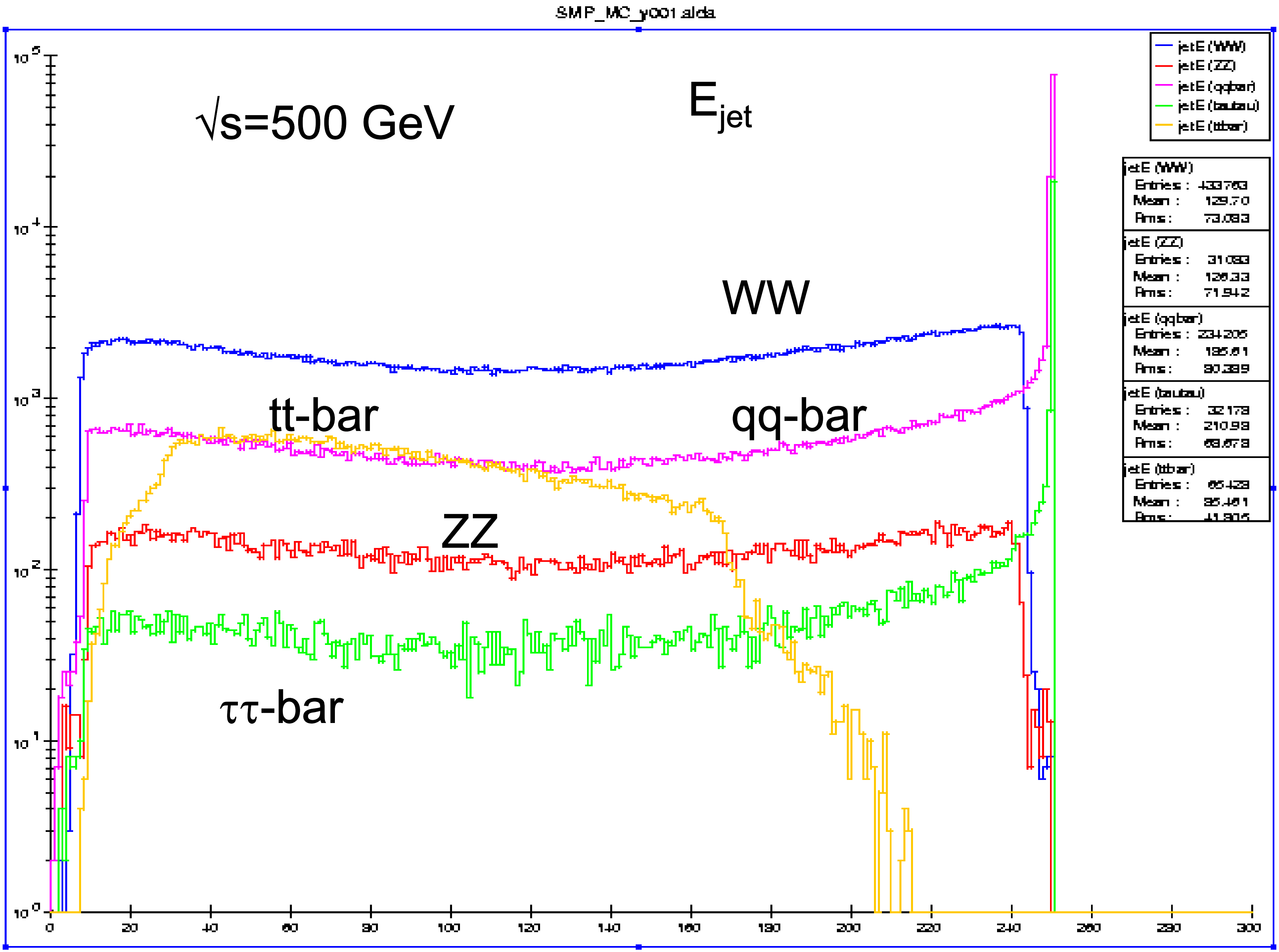
For the SM, these distributions are quite similar at these two energies .


SMP_MC_y001.aida
√s=1 TeV
E_jet
WW
tt-bar
qq-bar
ZZ
ττ-bar
jetE (WW)
jetE (ZZ)
jetE (qqbar)
jetE (tautau)
jetE (ttbar)
0
50
100
150
200
250
300
350
400
450
500
550
600
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
1,300
1,400
1,500


SMP_MC_y001.aida
√s=1 TeV
WW
tt-bar
qq-bar
ZZ
ττ-bar
jetE (WW)
jetE (ZZ)
jetE (qqbar)
jetE (tautau)
jetE (ttbar)
10000
1000
100
10
1
0
50
100
150
200
250
300
350
400
450
500
550
600

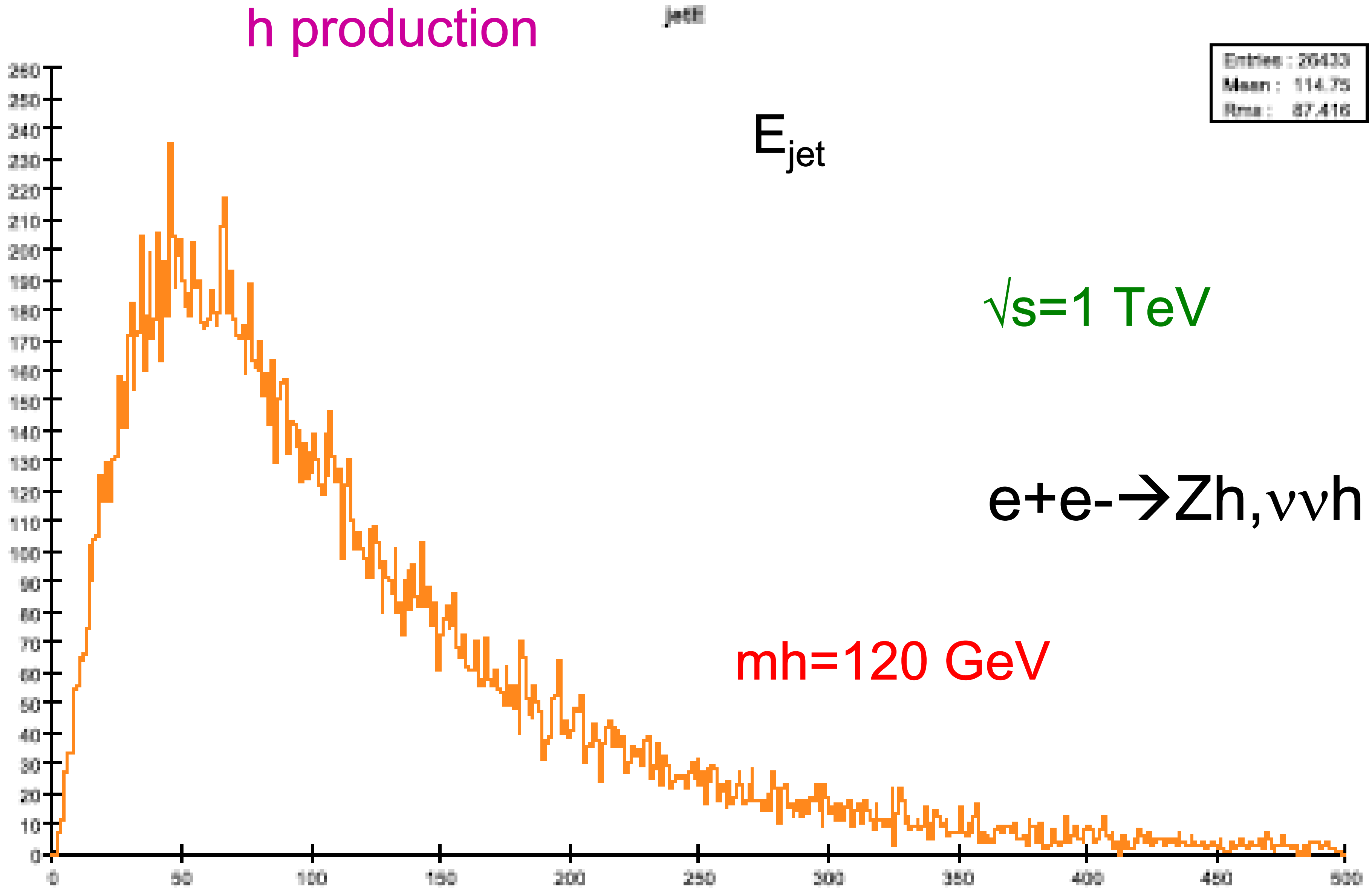


SMP_MC_y001.aida
√s=500 GeV
E_jet
WW
tt-bar
qq-bar
ZZ
ττ-bar
jetE (WW)
jetE (ZZ)
jetE (qqbar)
jetE (tautau)
jetE (ttbar)



SMP_MC_y001.aida
√s=500 GeV
E_jet
WW
tt-bar
qq-bar
ZZ
ττ-bar
jetE (WW)
jetE (ZZ)
jetE (qqbar)
jetE (tautau)
jetE (ttbar)
jetE (WW) Entries : 433763 Mean : 129.70 Rms : 73.083
jetE (ZZ) Entries : 31083 Mean : 126.33 Rms : 71.942
jetE (qqbar) Entries : 234205 Mean : 185.61 Rms : 80.389
jetE (tautau) Entries : 32178 Mean : 210.98 Rms : 68.678
jetE (ttbar) Entries : 65428 Mean : 85.461
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300

h production

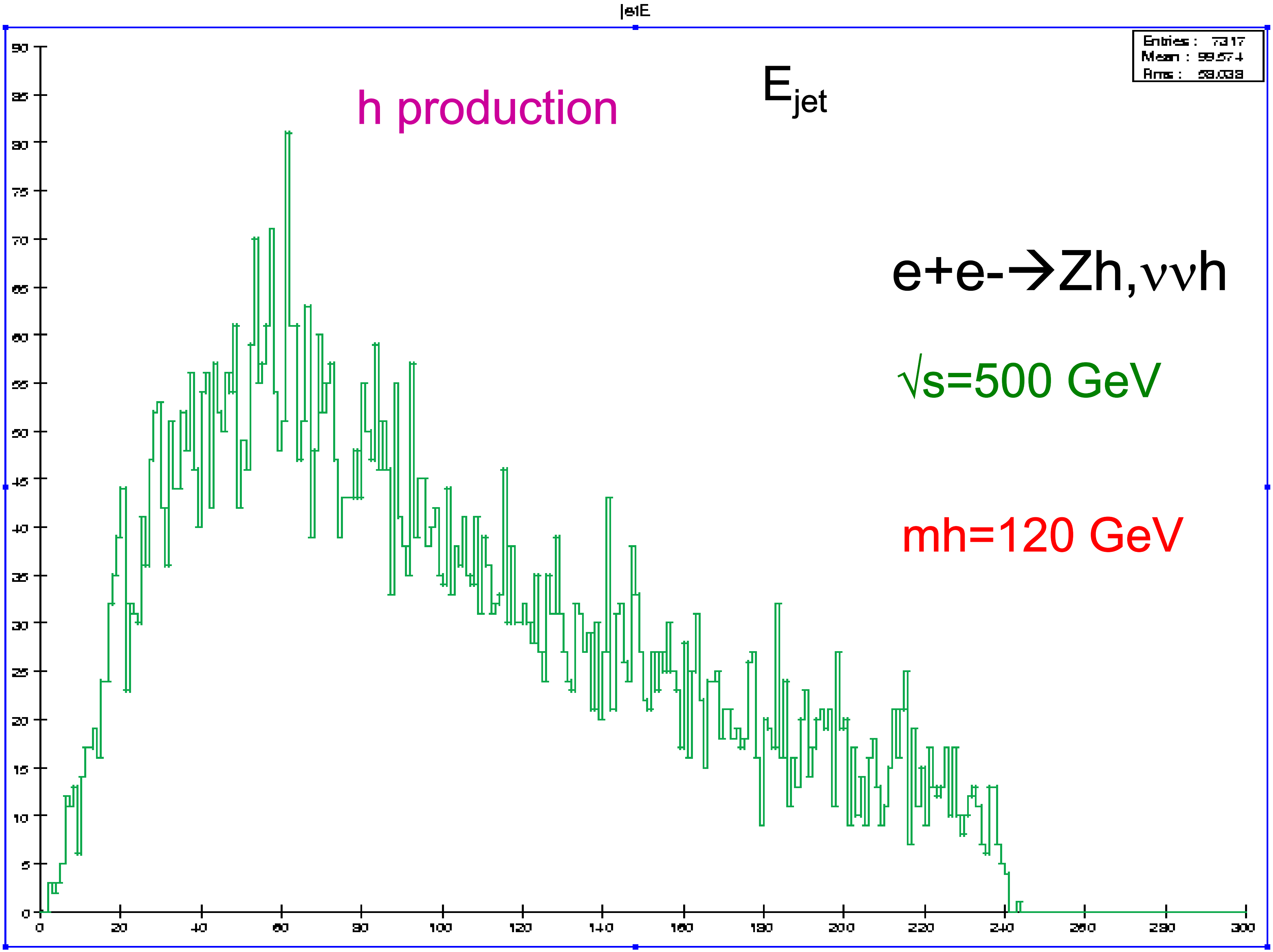


E_{jet}

$\sqrt{s}$=1 TeV

e+e-→Zh,ννh

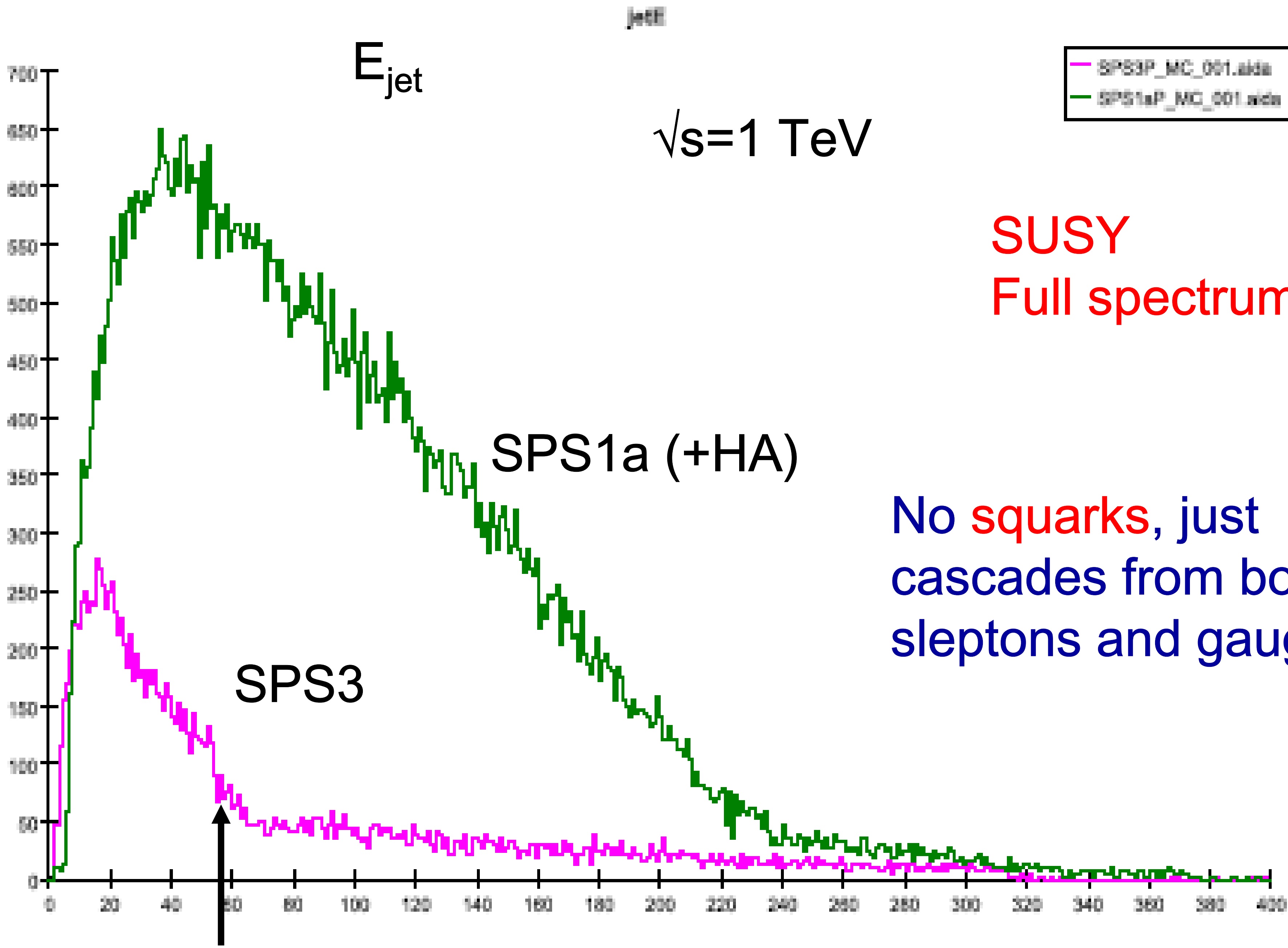
mh=120 GeV


jetE
Entries : 7317
Mean : 99.574
Rms : 53.038
h production
E_{jet}
e+e-→Zh,ννh
√s=500 GeV
mh=120 GeV
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90

When we look at SUSY production we see substantial model dependence as well as strong differences between the 500 GeV and 1 TeV jet energy spectra as new particle thresholds have been crossed….

However, the jets are relatively soft in all cases.

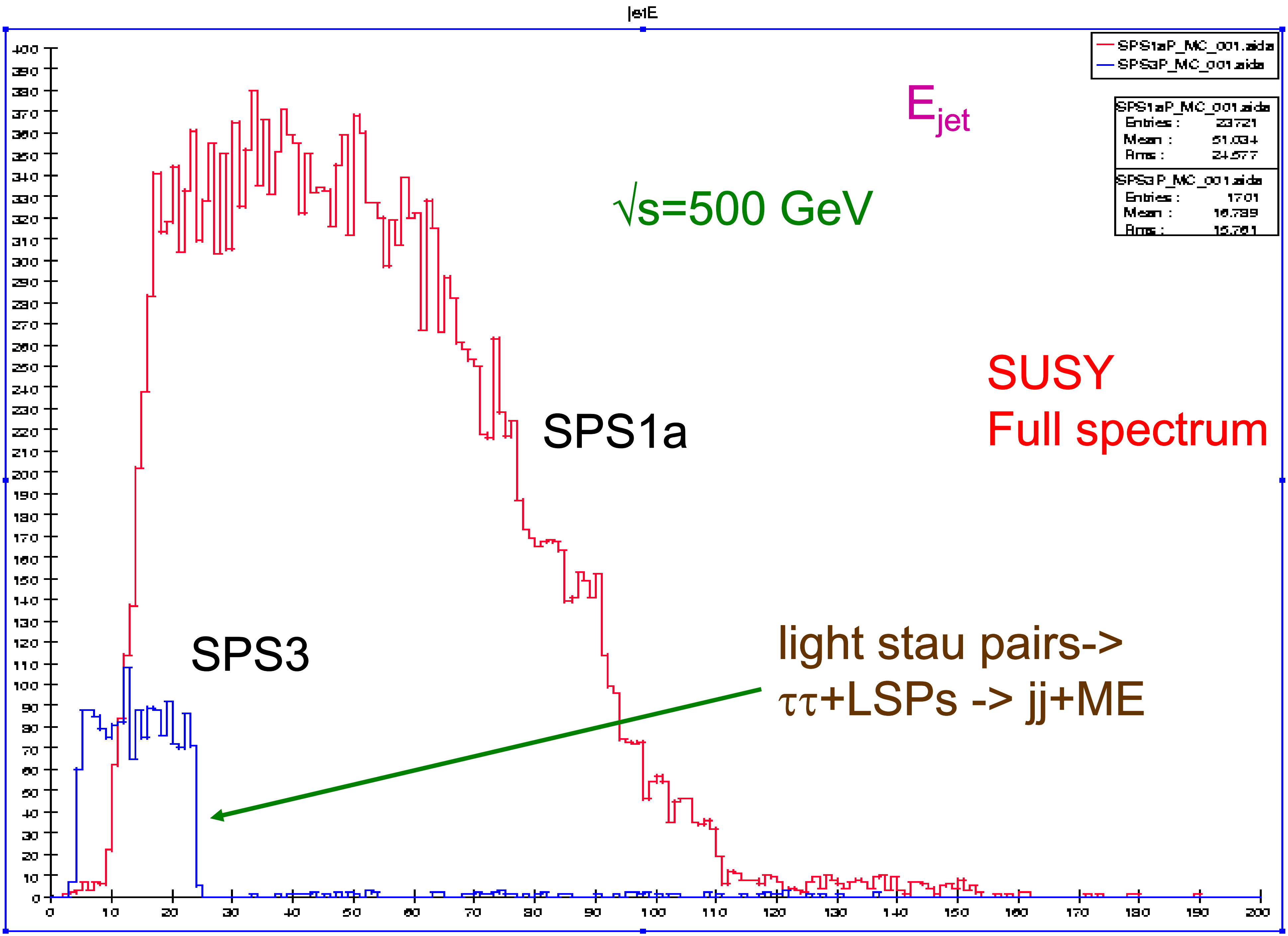
We limit ourselves to 3 SPS models…none of which have accessible squarks.



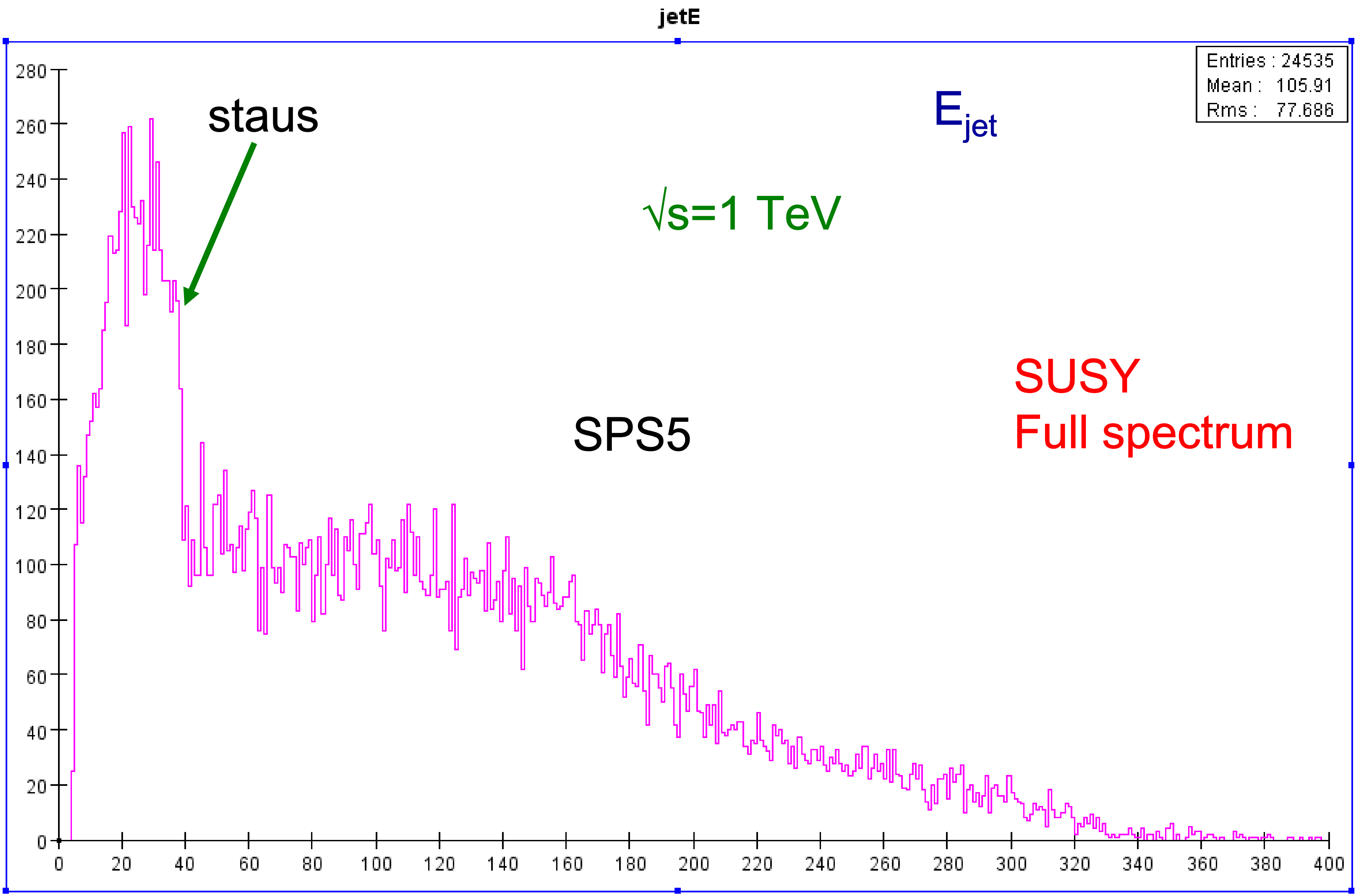
Interesting structure??

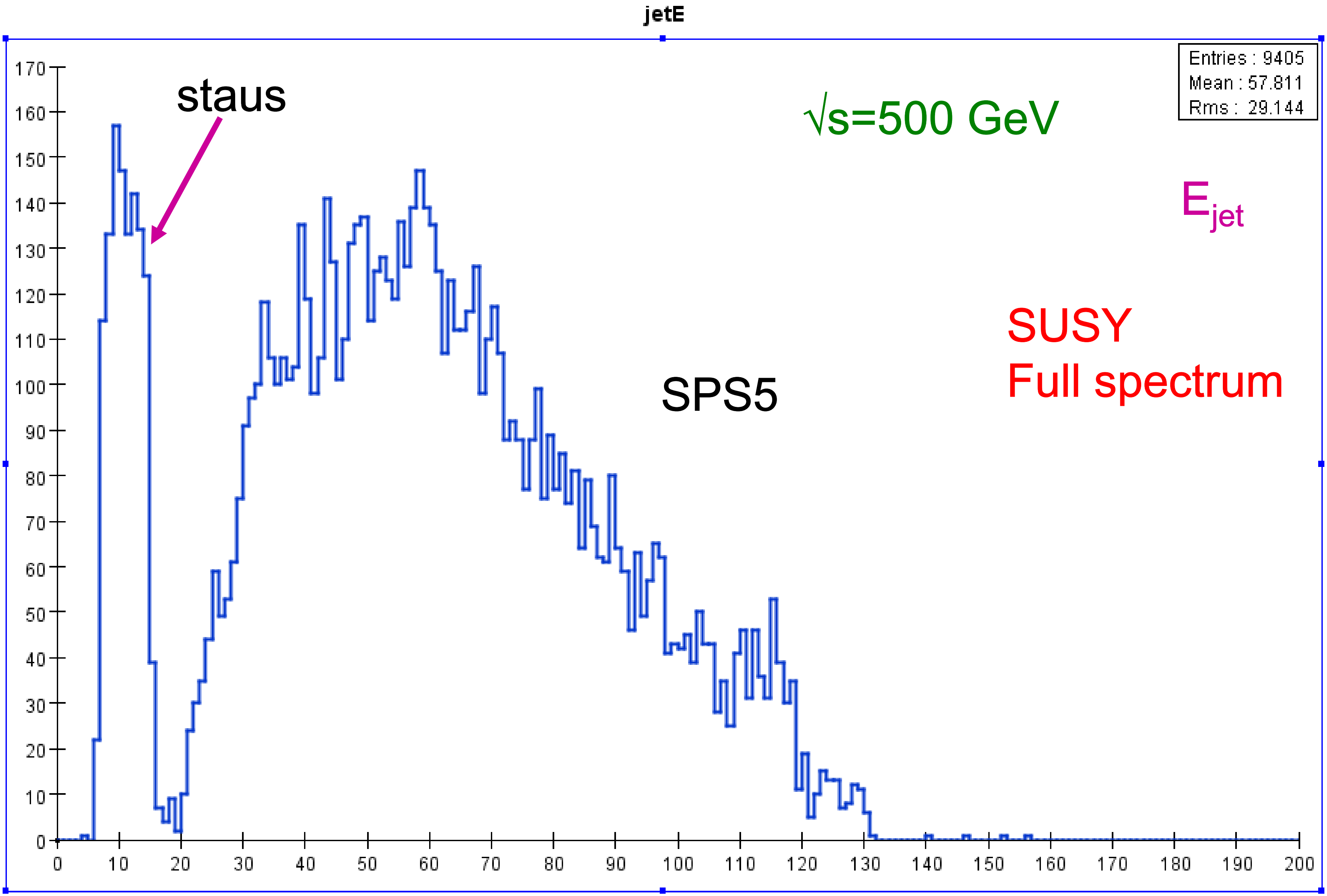
SUSY
Full spectrum

No squarks, just cascades from both sleptons and gauginos



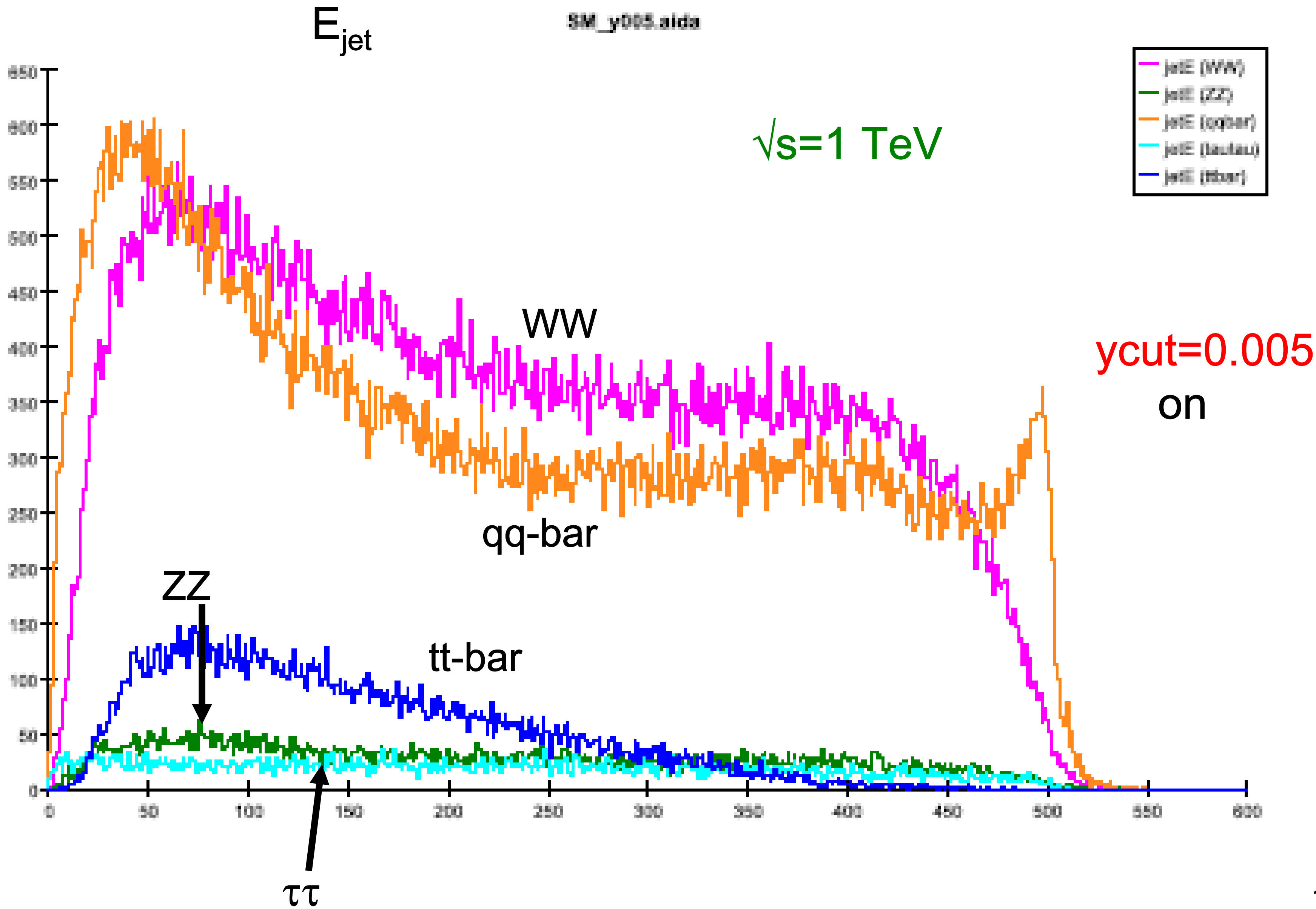
jet1E
SPS1aP_MC_001.aida
SPS3P_MC_001.aida
E_{jet}
SPS1aP_MC_001.aida
Entries : 23721
Mean : 51.034
Rms : 24.577
SPS3P_MC_001.aida
Entries : 1701
Mean : 16.739
Rms : 15.761
√s=500 GeV
SUSY
Full spectrum
SPS1a
SPS3
light stau pairs->
ττ+LSPs -> jj+ME


jetE
Entries : 24535
Mean : 105.91
Rms : 77.686
staus
E_{jet}
√s=1 TeV
SPS5
SUSY
Full spectrum
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400

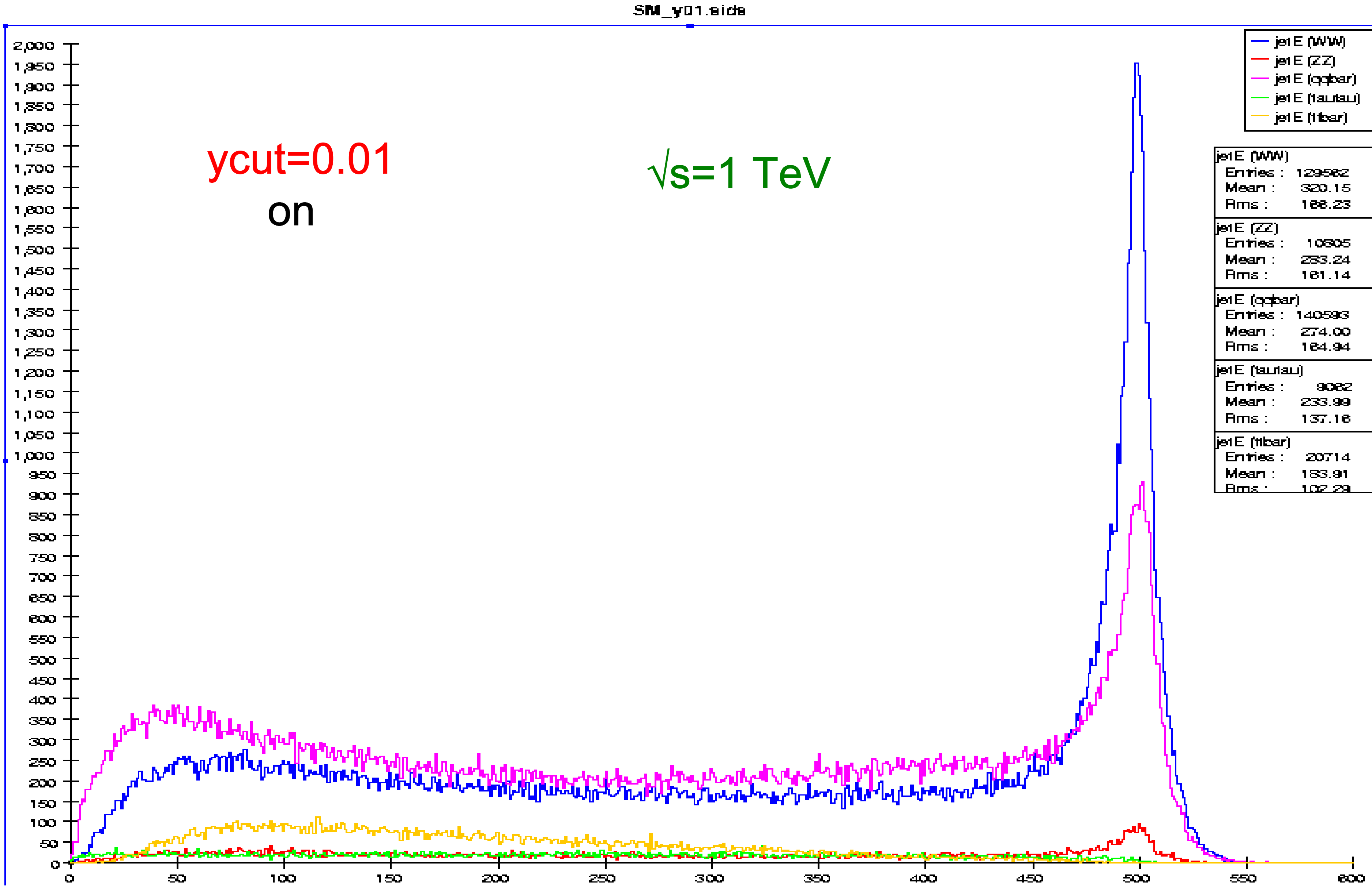

jetE
Entries : 9405
Mean : 57.811
Rms : 29.144
staus
√s=500 GeV
E_{jet}
SUSY
Full spectrum
SPS5
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

It is perhaps instructive to compare these parton level results to those obtained including ISR/FSR, QCD, fragmentation, hadronization and detector effects. We use will use the sidaug05/Godzilla version of lcsim.org fast MC…

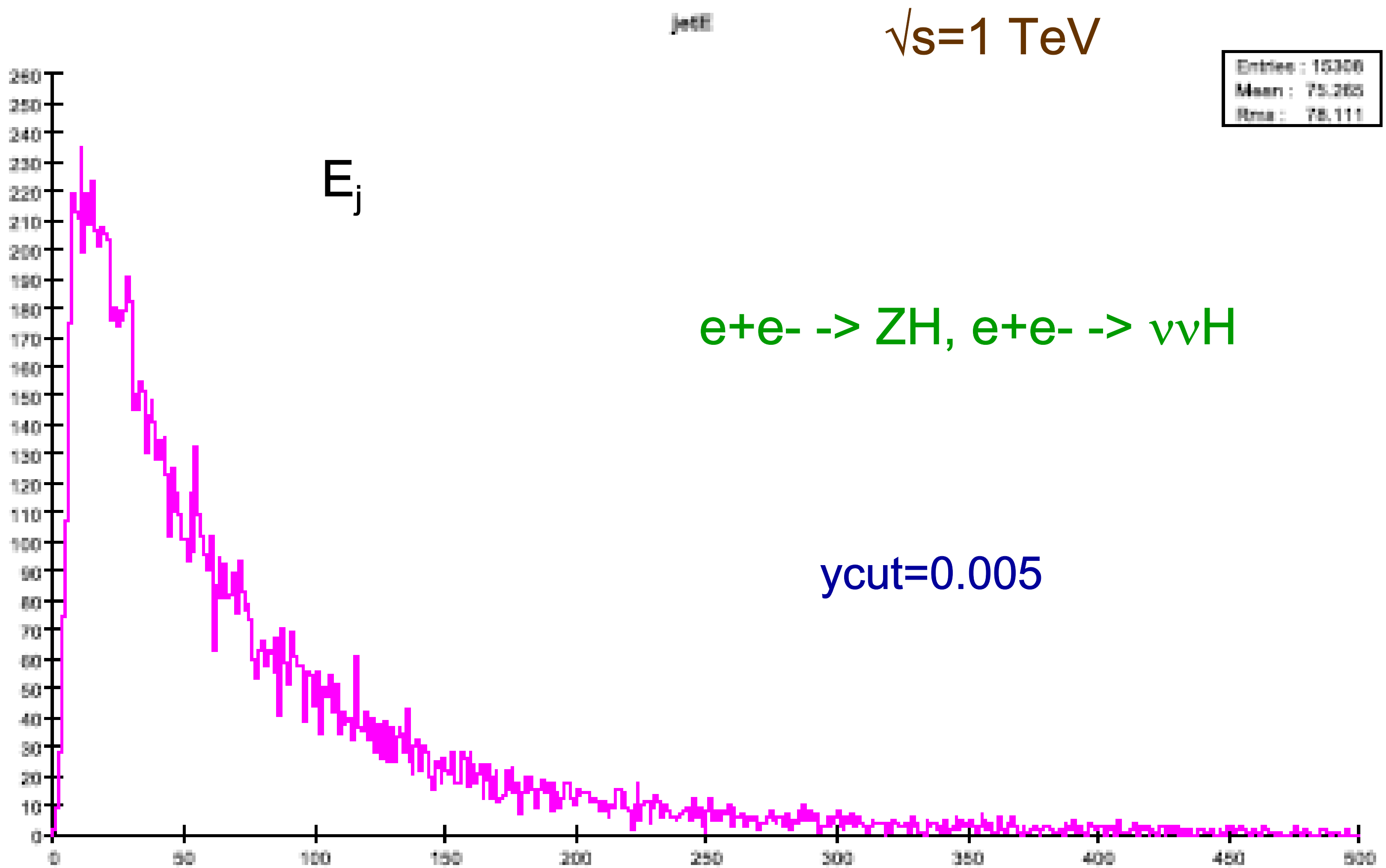
The result for the SM is given by this plot :



But this result now depends on the value ycut…

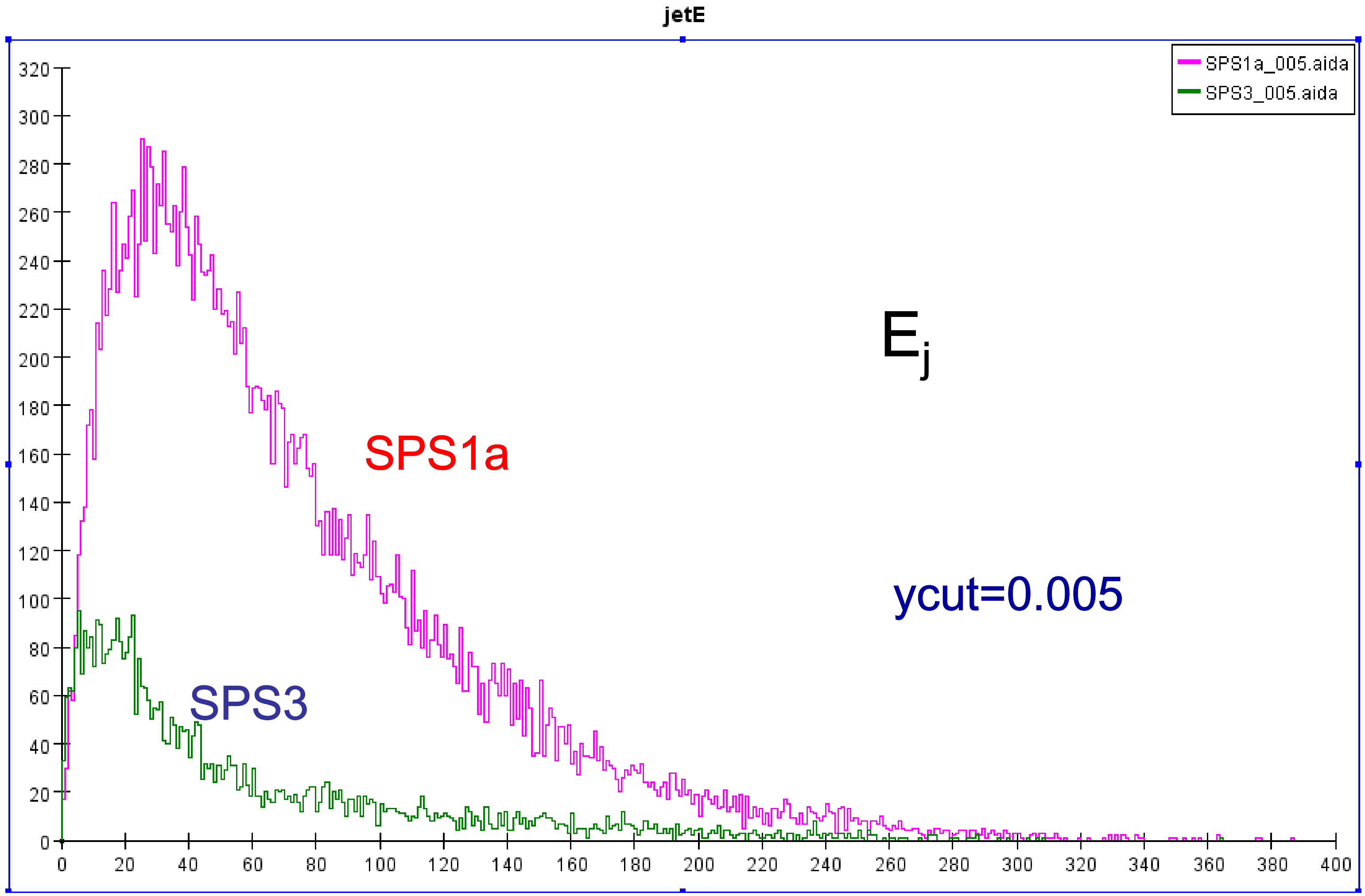


New Physics: Higgs (120 GeV) production -> mostly soft jets as W*W* is dominant



SUSY: SPS1a & SPS3

√s=1 TeV *JUST* a bit too small to make squark pairs
so jets arise from slepton and gaugino cascade decays…
-> jets are relatively soft

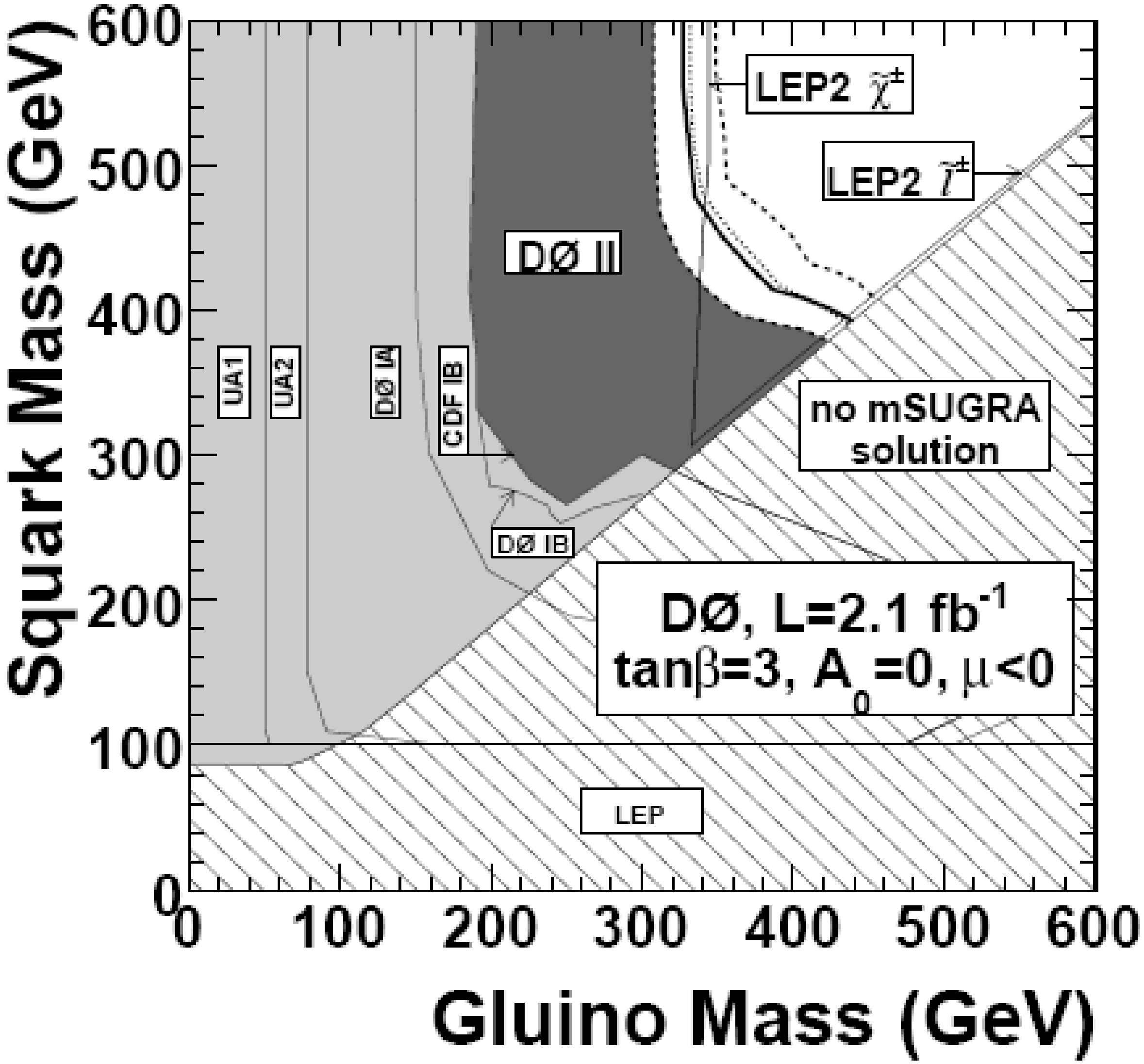


Jet-wise, the production of new colored objects which decay to quarks and/or gluons can lead to important new signals

The most obvious case of this is squark production… which has NOT been well studied at any realistic level for ILC…

The jet E spectrum from these new states depends on the mass spectrum details.

Some new physics scenarios may demand good jet energy resolution at higher energies, e.g., it is unlikely that squarks will be encountered at a 500 GeV machine but they may occur at 1 TeV…



This is for MSUGRA showing > 380 GeV squarks are still allowed. However, in GENERAL, the MSSM may allow even smaller mass values (I'll let you know).

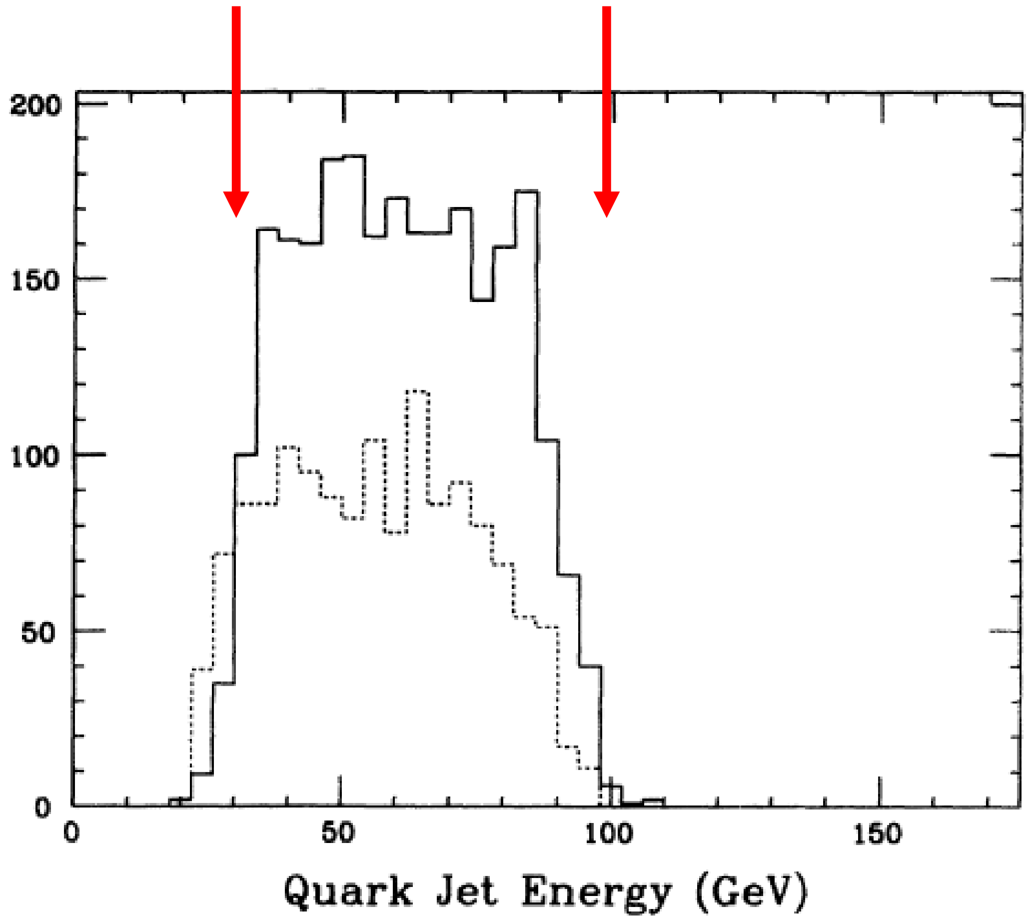
However, their in-accessibility at 500 GeV means their masses will be quite poorly known after ILC500.

Squark masses will be poorly determined even *after* LHC & ILC500…

	m_{SPS1a}	LHC	LC	LHC+LC		m_{SPS1a}	LHC	LC	LHC+LC
h	111.6	0.25	0.05	0.05	H	399.6		1.5	1.5
A	399.1		1.5	1.5	$H+$	407.1		1.5	1.5
χ_1^0	97.03	4.8	0.05	0.05	χ_2^0	182.9	4.7	1.2	0.08
χ_3^0	349.2		4.0	4.0	χ_4^0	370.3	5.1	4.0	2.3
$\chi_1^\pm$	182.3		0.55	0.55	$\chi_2^\pm$	370.6		3.0	3.0
$\tilde{g}$	615.7	8.0		6.5					
$\tilde{t}_1$	411.8		2.0	2.0					
$\tilde{b}_1$	520.8	7.5		5.7	$\tilde{b}_2$	550.4	7.9		6.2
$\tilde{u}_1$	551.0	19.0		16.0	$\tilde{u}_2$	570.8	17.4		9.8
$\tilde{d}_1$	549.9	19.0		16.0	$\tilde{d}_2$	576.4	17.4		9.8
$\tilde{s}_1$	549.9	19.0		16.0	$\tilde{s}_2$	576.4	17.4		9.8
$\tilde{c}_1$	551.0	19.0		16.0	$\tilde{c}_2$	570.8	17.4		9.8
$\tilde{e}_1$	144.9	4.8	0.05	0.05	$\tilde{e}_2$	204.2	5.0	0.2	0.2
$\tilde{\mu}_1$	144.9	4.8	0.2	0.2	$\tilde{\mu}_2$	204.2	5.0	0.5	0.5
$\tilde{\tau}_1$	135.5	6.5	0.3	0.3	$\tilde{\tau}_2$	207.9		1.1	1.1
$\tilde{\nu}_e$	188.2		1.2	1.2					

Table 5.25: Errors for the mass determination in SPS1a, taken from [146]. Shown are the nominal parameter values and the error for the LHC alone, the LC alone, and a combined LHC+LC analysis. All values are given in GeV.

E.g., the simple squark -> q χ two-body decay leads to the familiar `table' structure. The rate depends on the specifics of the mass spectrum and the beam polarization.



$\delta m/m \sim \delta E/E$

For m ~ 400 GeV and $\delta E/E$=5% , δm ~ 10 GeV?? which is not too much of an improvement !!

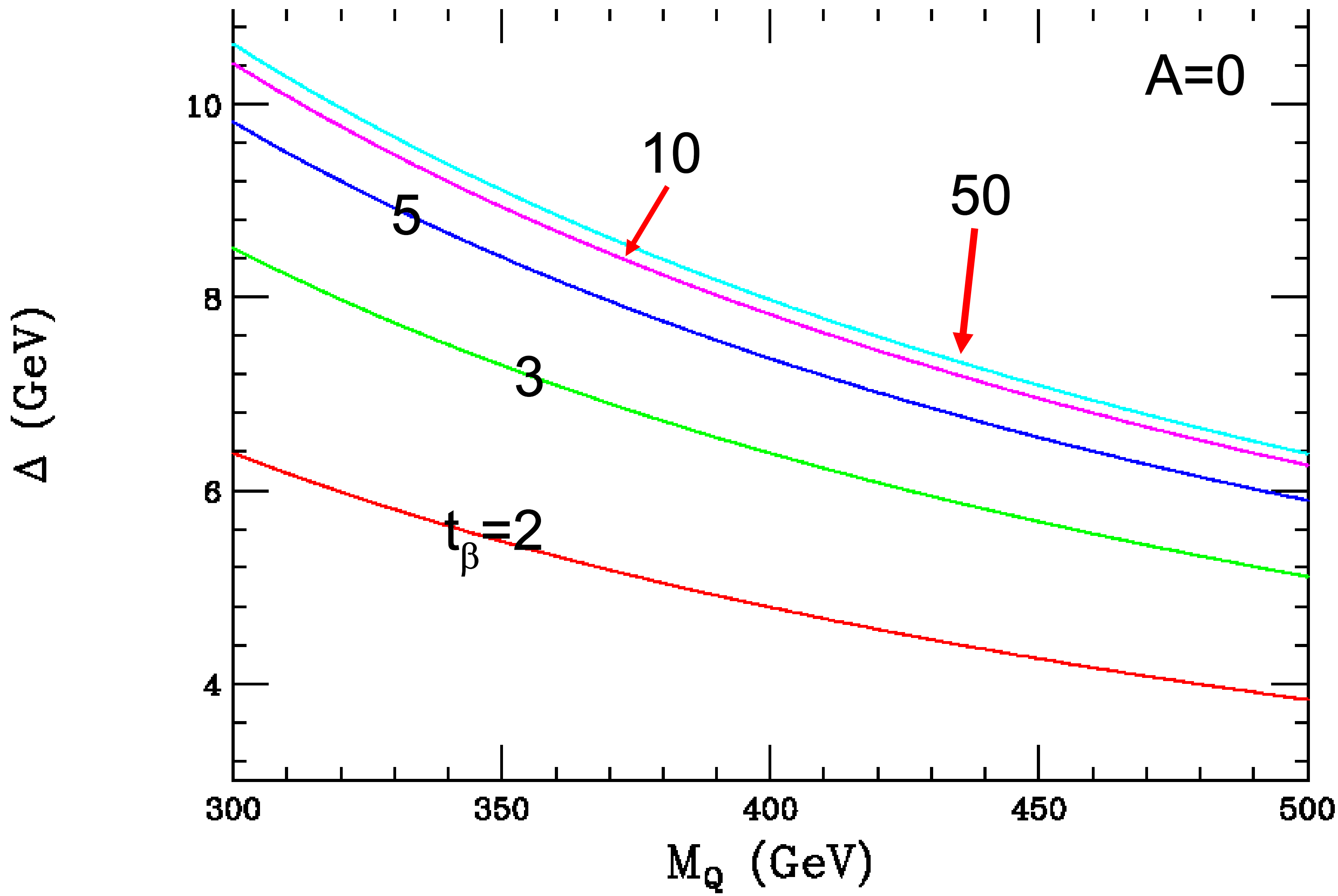
Problem ???

The end points tell us the squark mass

Feng & Finnell '93

d_L-u_L squark mass splitting

Can this be measured??? Jet E resolution will be important

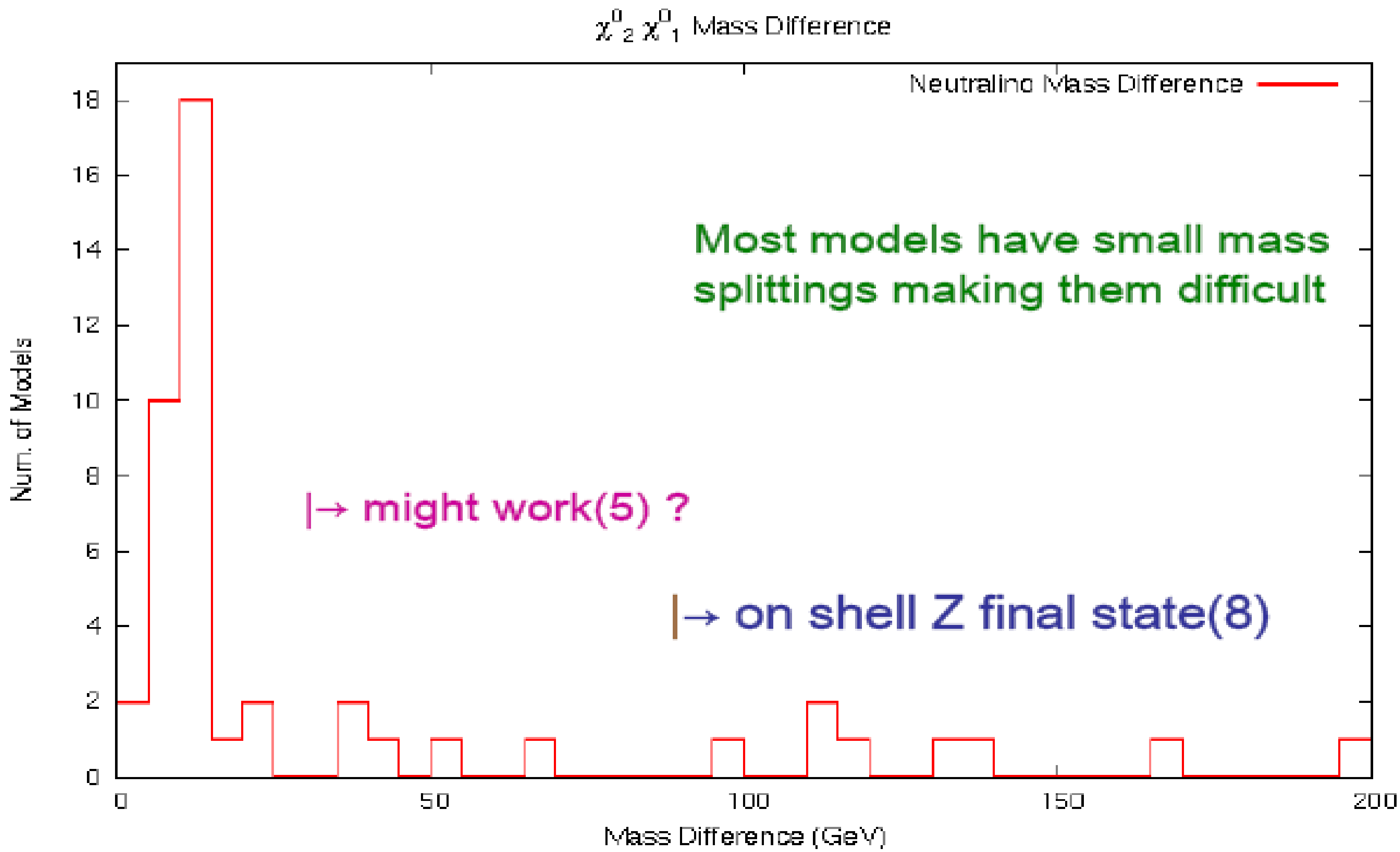


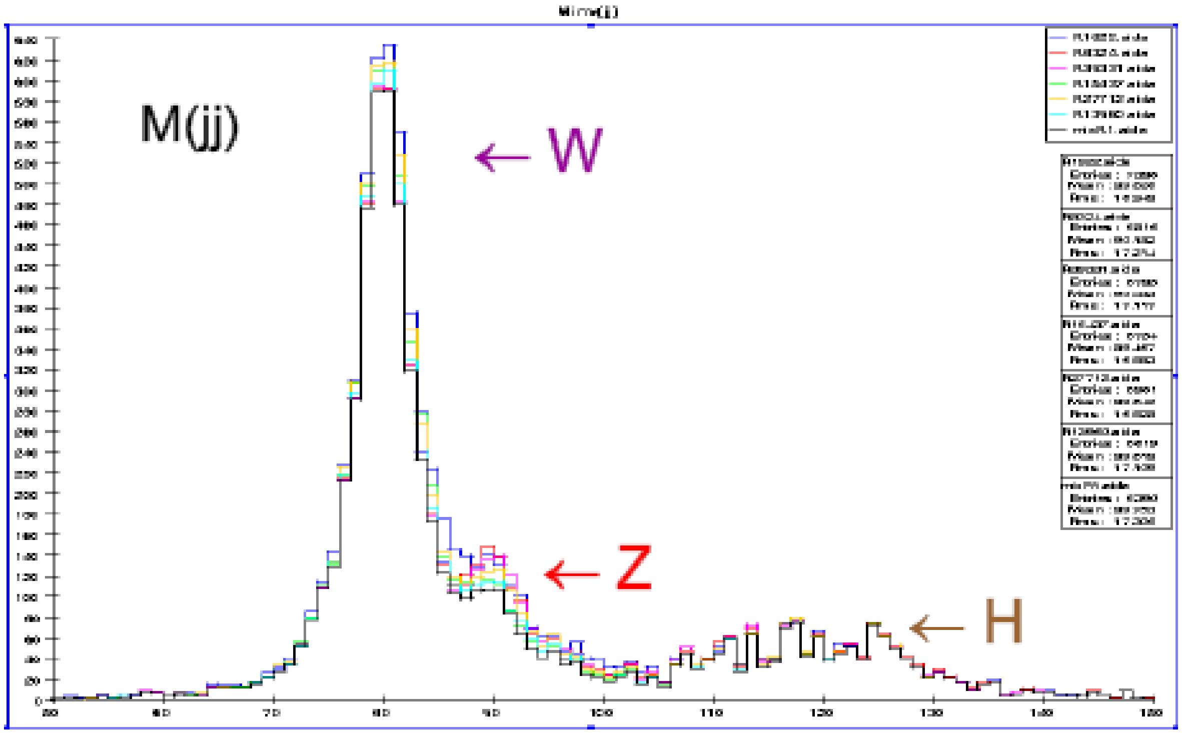
Some (more) SUSY Energy Resolution Issues

…part of a much larger analysis..

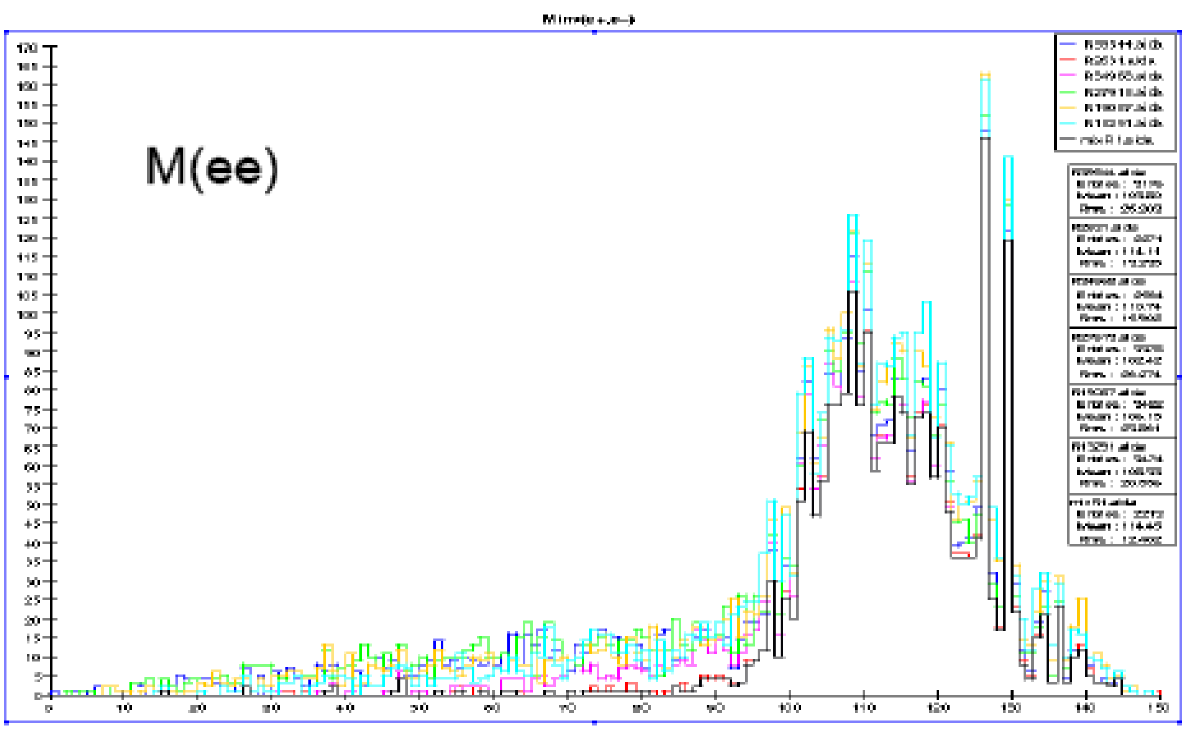
arXiv:0712:2965

$\chi_2^0\ \chi_1^0$ Analysis : most models accessible at 500 GeV have a smallish mass splitting and will be tough…look for an on/off-shell Z in jj, ee, and $\mu\mu$



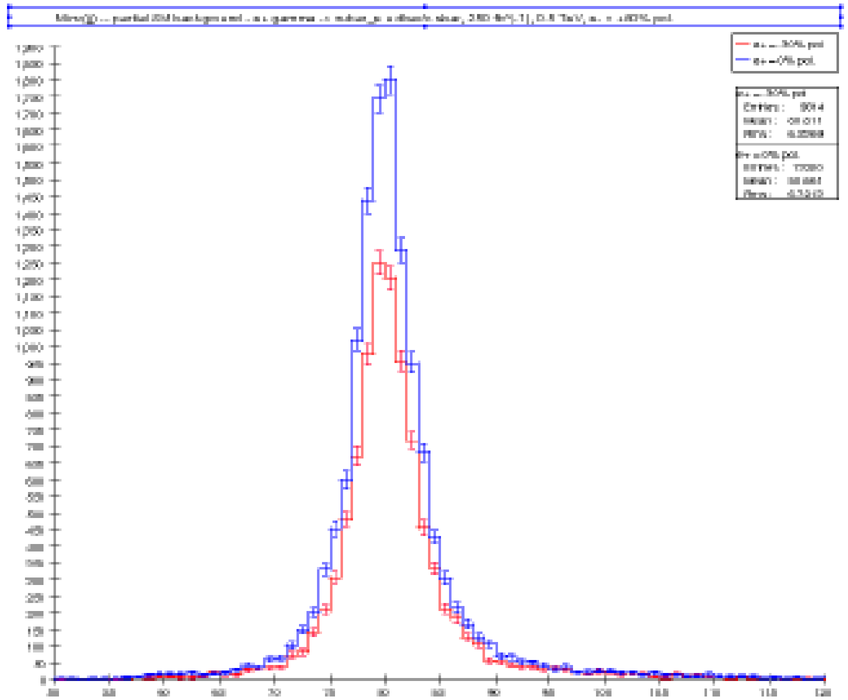


In the jj channel we *do* see an excess at the Z (5 models) but also a huge W peak from both backgrounds as well as from other sparticles such as the charginos… we also see the Higgs.

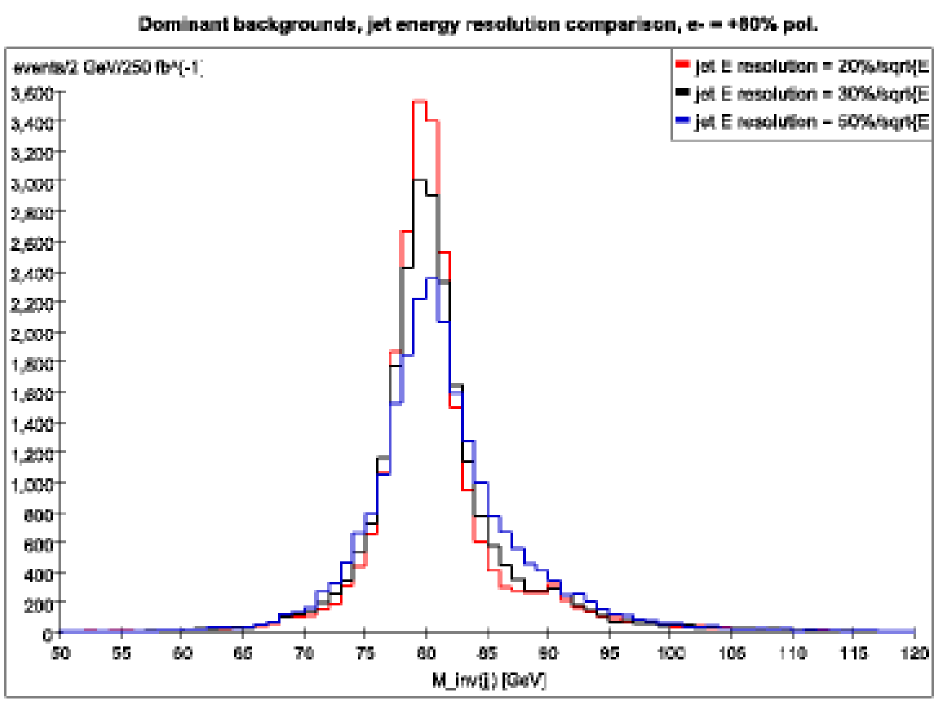


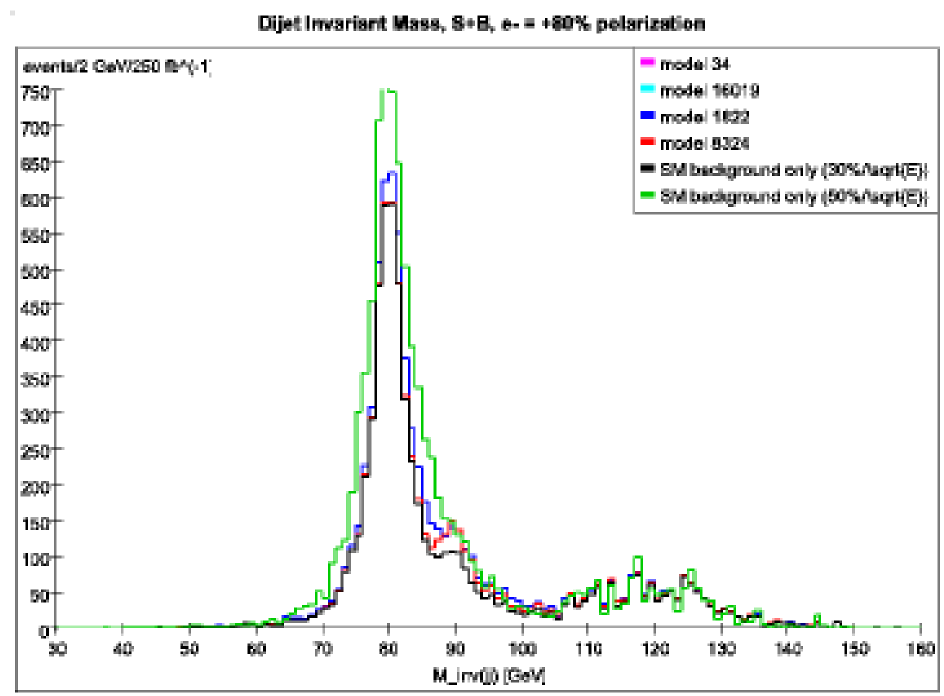
This signal can be cleaned up with better mass resolution and/or positron polarization

In the ee channel we have mostly fakes..



Here we see the response to both positron polarization and changes in the jet energy resolution…these changes are necessary to improve this channel





Summary

- The jet energy distributions for important SM processes such as WW, ZZ, tt-bar, qq-bar and $\tau+\tau-$ are generally similar (scaled by $\sqrt{s}$, of course) but do show some visible kinematic differences

- Light Higgs production shows some moderate differences due to kinematic changes and the increase in the contribution from WW fusion when going to 1 TeV.

- Jet energies from SUSY decays are both model dependent and are much more sensitive to the collider energy due to the opening of new thresholds. Generally, these jets are soft relative to $\sqrt{s}/2$ due to the large ME , etc., since they arise solely from gaugino/slepton cascade decays *in these models*.

Summary (cont.)

- Squark pair production has not been well studied for ILC & may present new demands on jet energy resolution but will also likely lead to relatively soft jets. The likelihood of squark pairs being accessible at 1 TeV in the general MSSM is reasonably high.

- Better energy resolution would be somewhat useful in the reduction of W backgrounds in some SUSY searches such as $\chi_2^0\chi_1^0$ production in the jj +ME channel…but this may be compensated for with sufficient positron polarization.