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# MC Study on R-parity violating neutralino decays into hadrons at 184 GeV

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# 1 Introduction

One of the major candidates for the LSP in the MSSM is the lightest neutralino $\chi_1^0$. In the R-parity conserving scenario the lowest threshold SUSY-process

$$e^+e^- \to \chi_1^0\chi_1^0$$

is invisible because the $\chi_1^0$ is stable. This is not the case when R-parity ($R = (-1)^{3B+2S+L}$) is violated. The most general gauge- and SUSY-invariant Lagrangean includes the following R-parity violating Yukawa coupling terms :

$$\mathcal{L}_{RPV} = \lambda_{ijk}L_iL_jE_k^c + \lambda_{ijk}^{'}L_iQ_jD_k^c + \lambda_{ijk}^{''}U_i^cD_j^cD_k^c$$

The first two terms violate lepton number L and the third terms violate baryon number B. The stability of the proton restricts RPV scenarios : L and B can not be simultaneously violated.

## 1.1 The leptonic terms

These final states include four charged leptons and two neutrinos.

## 1.2 The semileptonic terms

These final states include :

- four quark jets + two neutrinos
- four quark jets + one neutrino + one charged lepton
- four quark jets + two charged leptons

## 1.3 The hadronic terms

These final states include six quark jets.

## 2 The hadronic case

### 2.1 MC simulation at $\sqrt{s} = 184GeV$

- sil3v210 and rel3v211 installed in Budapest on SGI

#### 2.1.1 Signal events

- SUSYGEN (eglrv205) used
- The 18 R-parity breaking hadronic decay channnels of the neutralinos are equally mixed together
- 3000 $e^+e^- \to \chi_1^0\chi_1^0 \to hadrons$
  $m_{\chi_1^0} = 73.8GeV$
  $(M = 150GeV, \mu = -91GeV, m_0 = 1000GeV, \tan\beta = 2)$
- 3000 $e^+e^- \to \chi_1^0\chi_1^0 \to hadrons$
  $m_{\chi_1^0} = 62.4GeV$
  $(M = 250GeV, \mu = 91GeV, m_0 = 1000GeV, \tan\beta = 35)$

#### 2.1.2 Backround events

- 3000 $e^+e^- \to u\bar{d}d\bar{u}, u\bar{d}s\bar{c}, c\bar{s}d\bar{u}, c\bar{s}s\bar{c}$ events generated by EXCALIBUR (egwbv205). These final states are dominantly produced through $WW$
- 3000 $e^+e^- \to u\bar{u}u\bar{u}, u\bar{u}d\bar{d}, ...b\bar{b}b\bar{b}$ events generated by EXCALIBUR (egwbv205). These final states are dominantly produced through $ZZ$
- 3000 $e^+e^- \to WW \to all$ events generated by KORALW (egwkv205). This sample is used to cross check EXCALIBUR.
- 3000 $e^+e^- \to q\bar{q}$ events generated by PYTHIA (egqpv211).

### 2.2 Analysis

- dvn files were used
- some "ususal" cuts are applied (see below for details)
- jets were defined on clusters (SRC) by the Durham algorythm
- to improve momentum resolution 4C kinematic fit was applied on the jets (fitted parameters : $E$, $p_x$, $p_y$, $p_z$)
- WW and ZZ deselection, two methods tried :
  - mass sum windows based on 4C fitted jet momenta
    $\chi^2_{mass} = (m_{12} - m_W)^2/\sigma_W^2 + (m_{34} - m_W)^2/\sigma_W^2$
    the pairing of the least $\chi^2_{mass}$ is chosen
    on $M_{sum} = m_{12} + m_{34}$ cut is applied
    $M_{sum}$ of the two other combinations are also checked (cut on $M_{sum,2}$ $M_{sum,3}$)
  - mass sum windows based on 5C fit (equal mass constraint)

### 2.3 Problems

The interface between SUSYGEN and PYTHIA is not clear. One expects three quark jets from a neutralino, but the HEP listing contains a quark and a diquark turning to a string. This could be, however, a technical thing but comparing the distributions of $WW$ and $\chi\chi$ one finds no difference apart from the kinematical ones stemming from the different masses of the neutralinos and the gauge bosons. The $y$ distributions, (e.g. $y_{34}$, $y_{56}$ ) of the jet finding algorithm are the same (for four and six jet events), while those for $q\bar{q}$ (i.e. two jet) events are totally different.

### 2.4 Selection criteria

- $N_{trk} > 10$ - high multiplicity
- $N_{src} > 30$ - high multiplicity
- $E_{vis}/E_{cm} > 0.70$ - no missing energy
- $M_{event}/E_{cm} > 0.75$ - exclude $Z\gamma$
- $N_{jet} \geq 4$ if $y_{cut} = 0.008$ - 4 jets
- $E_{jet,EM}/E_{jet} < 0.85$ if $y_{cut} = 0.008$ for every jet - 4 jets
- chose $y_{cut}$ to have exactly 4 jets - 4 jets
- every jet must have tracks
- 4C kinematic fit of the four jets , $C.L. > 0.01$
- $|\cos\theta_{jet,beam}| < 0.99$, $E_{jet} > 0.05\sqrt{s}$ - jet quality
- $E_{jet,max} - E_{jet,min} < 0.3\sqrt{s}$ - kinematics
- $M_{2jet,min} > 0.18\sqrt{s}$ - kinematics
- $\cos\theta_{2jet,max} > -0.95$ - kinematics
- $M_{sum} < 140.$ or $M_{sum} > 180.$ - exclude WW
- $M_{sum} < 180.$ - exclude ZZ
- $M_{sum,2} < 140.$ or $M_{sum} > 180.$ - exclude WW second combination
- $M_{sum,3} < 140.$ or $M_{sum} > 180.$ - exclude WW third combination
- 5C kin. fit : $C.L. < 0.01$ or $M_{sum} < 140.$ or $M_{sum} > 180.$
- $M_{sum} < 180.$

### 2.5 Conclusions

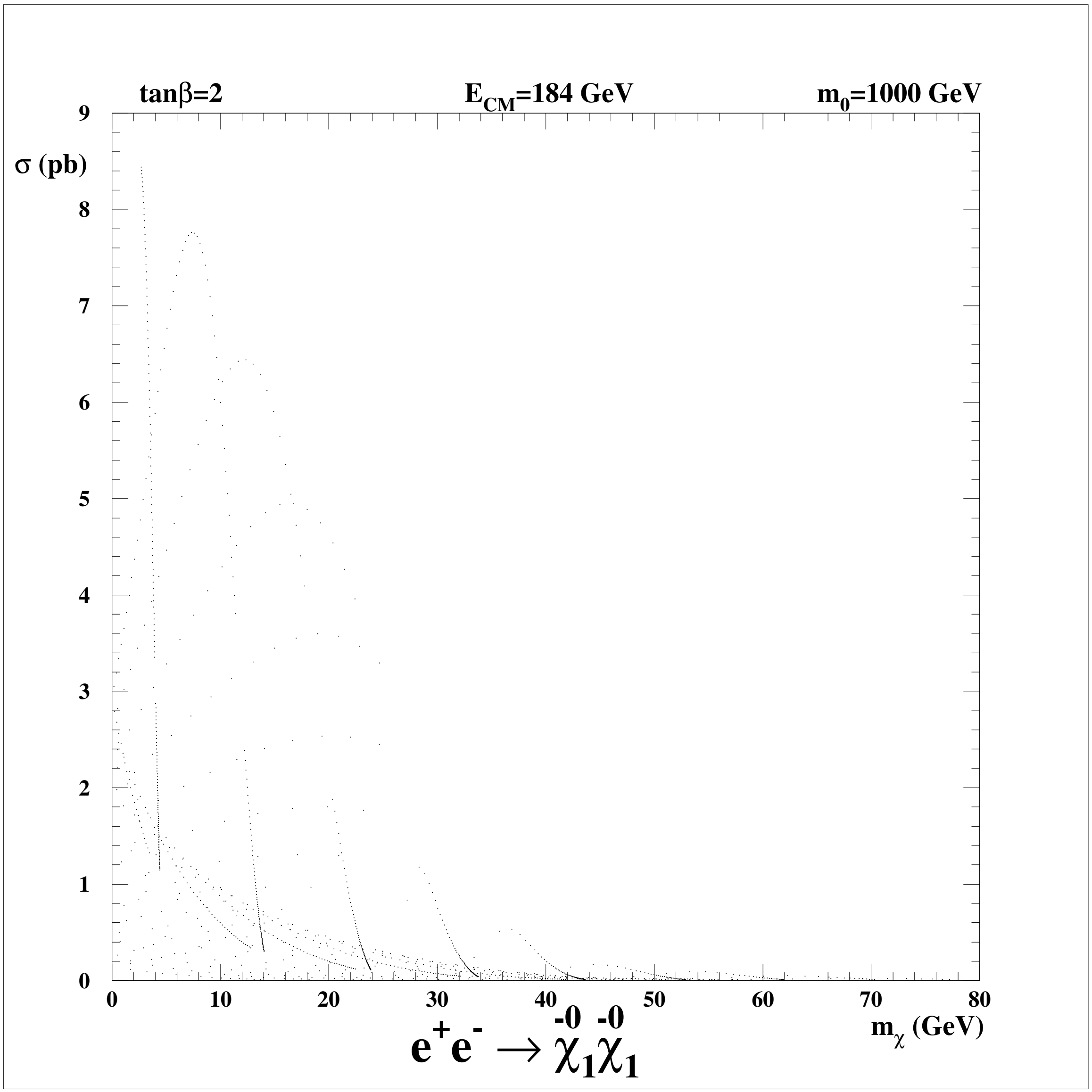
- it is hard to select the signal, the efficiency is low
- try other methods (e.g. 6C kinematic fit for WW deselection)
- include other backgrounds (e.g. $\gamma\gamma$)
- neutralino mass scan is necessary
- to understand better $\chi^0 \to 3jets$ on generator level
- leptonic and semileptonic decays are under study

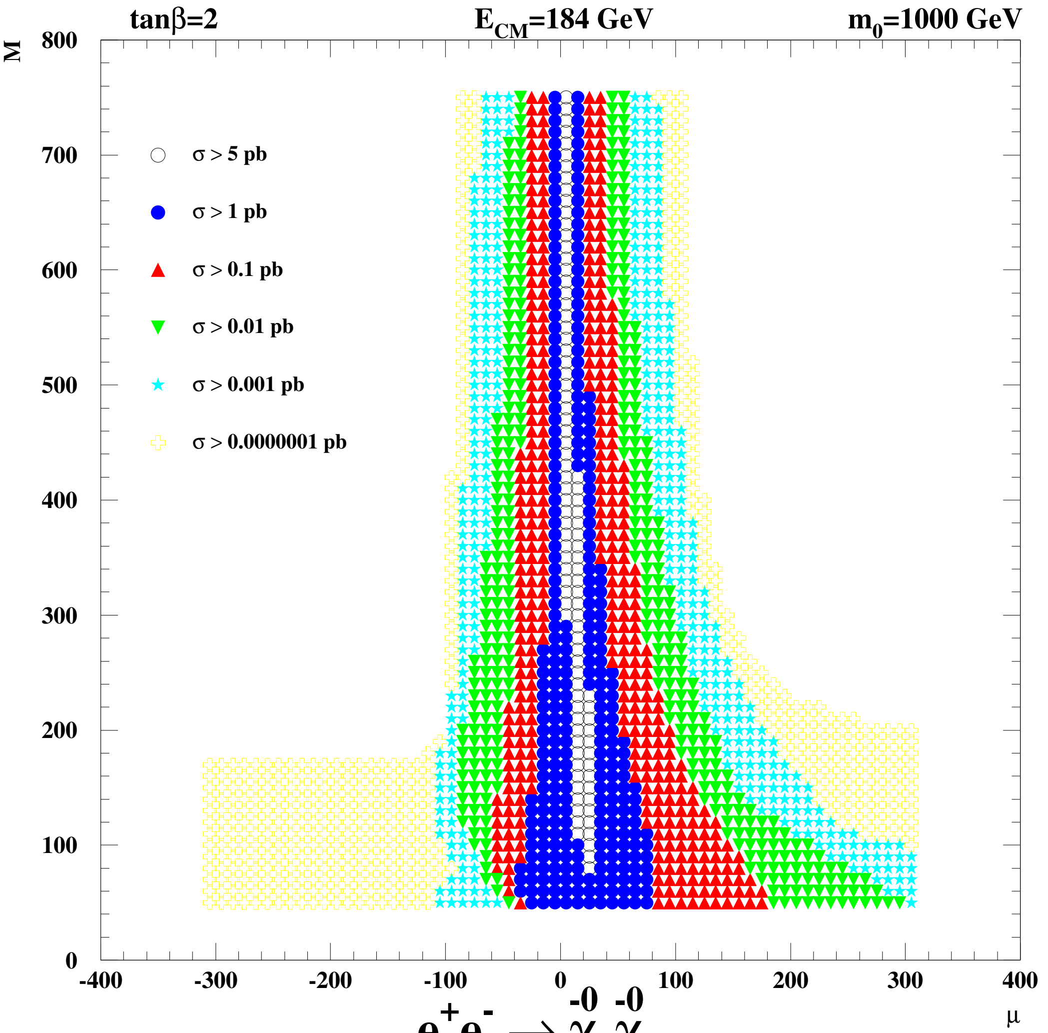
| *Process* | $q\bar{q}q\bar{q}$ *(WW)* | $q\bar{q}q\bar{q}$ *(ZZ)* | $\chi^0_0\chi^0_0$ *(74 GeV)* | $\chi^0_0\chi^0_0$ *(62 GeV)* | $WW$ $(\to X)$ | $q\bar{q}$ |
|---|---|---|---|---|---|---|
| Cross section | 6.6 pb | 0.93 pb | (0.25 pb) | (0.66 pb) | 16 pb | 99 pb |
| $N_{expect}(75pb^{-1})$ | 495 | 70 | (19) | (50) | 1200 | 7425 |
| $N_{expect}(160pb^{-1})$ | 1056 | 149 | (40) | (106) | 2560 | 15840 |
| *Generator* | XBUR | XBUR | SGEN | SGEN | KRLW | PYTH |
| *All* | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 |
| $N_{trk}$ | 2997 | 2950 | 3000 | 3000 | 2649 | 2805 |
| $N_{src}$ | 2997 | 2918 | 3000 | 3000 | 2475 | 2564 |
| $E_{vis}$ | 2816 | 2401 | 2817 | 2809 | 1720 | 1039 |
| $M_{event}$ | 2650 | 2174 | 2615 | 2606 | 1418 | 910 |
| $N_{jet}$ | 1966 | 1085 | 2043 | 1893 | 939 | 64 |
| $E_{jet,EM}$ | 1966 | 1085 | 2043 | 1893 | 939 | 64 |
| $4jets$ | 1966 | 1085 | 2043 | 1892 | 939 | 64 |
| $tracks$ | 1929 | 1065 | 1956 | 1787 | 910 | 30 |
| $4Cfit$ | 1648 | 884 | 1579 | 1425 | 743 | 24 |
| $\theta_{beam}, E_{jet}$ | 1638 | 875 | 1554 | 1406 | 739 | 24 |
| $E_{max} - E_{min}$ | 1521 | 804 | 1351 | 1103 | 672 | 16 |
| $M_{2jet}$ | 1102 | 592 | 1058 | 919 | 482 | 6 |
| $\theta_{2jet}$ | 916 | 374 | 873 | 681 | 405 | 5 |
| $M_{sum}$ $(\chi^2_{mass})$ | 44 | 30 | 102 | 169 | 17 | 1 |
| $M_{sum}$ | 44 | 27 | 101 | 168 | 17 | 0 |
| $M_{sum,2}$ | 12 | 6 | 39 | 72 | 2 | 0 |
| $M_{sum,3}$ | 0 | 0 | 1 | 0 | 0 | 0 |
| $M_{sum}$ $(5Cfit)$ | 665 | 275 | 672 | 586 | 298 | 4 |
| $M_{sum}$ | 634 | 266 | 653 | 562 | 283 | 4 |

Table 1: The number of events remaining after the cuts applied

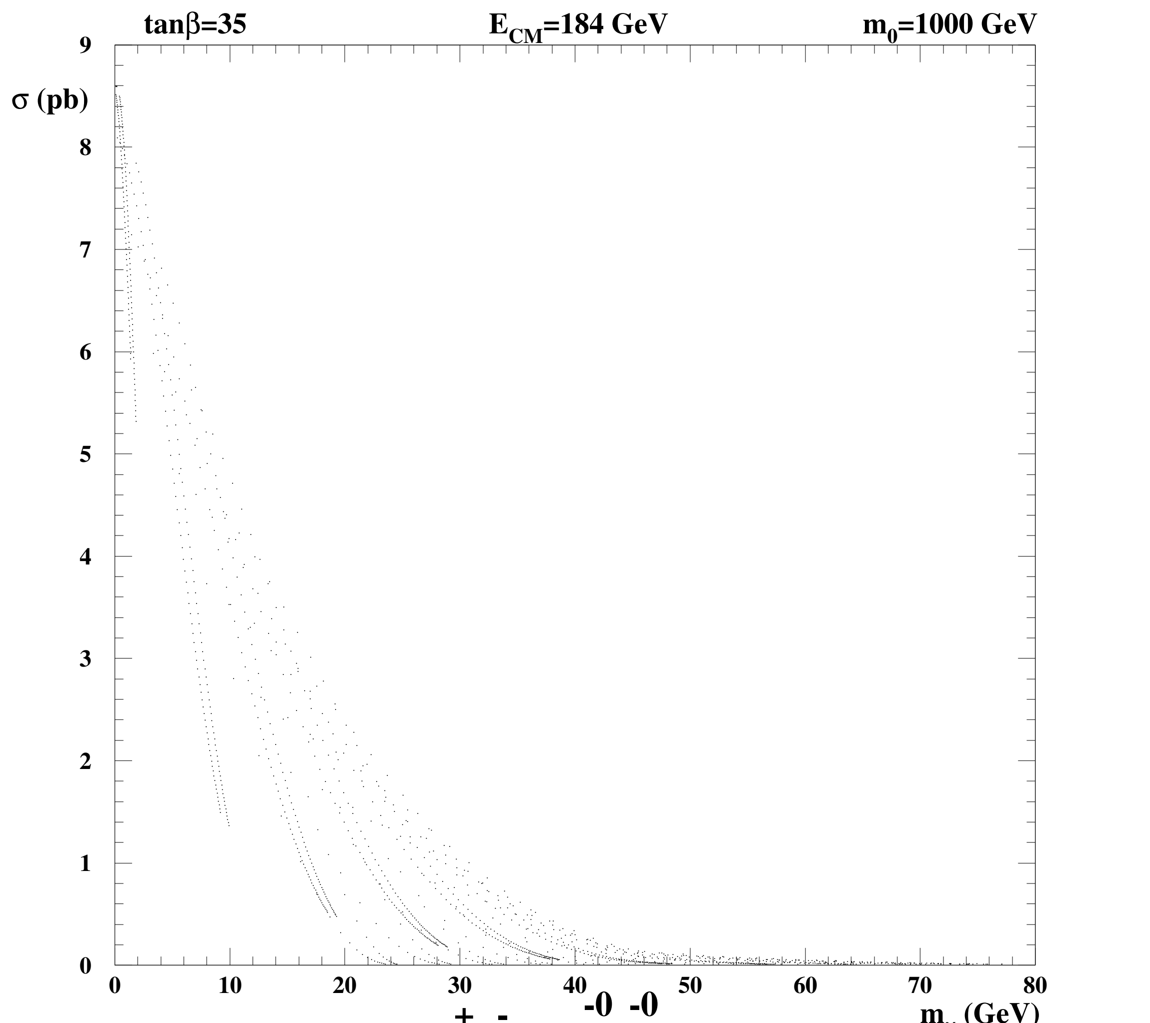
| *Process* | $q\bar{q}q\bar{q}$ *(WW)* | $q\bar{q}q\bar{q}$ *(ZZ)* | $\chi^0_0\chi^0_0$ *(74 GeV)* | $\chi^0_0\chi^0_0$ *(62 GeV)* | $WW$ $(\rightarrow X)$ | $q\bar{q}$ |
|---|---|---|---|---|---|---|
| Cross section | 6.6 pb | 0.93 pb | (0.25 pb) | (0.66 pb) | 16 pb | 99 pb |
| $N_{expect}(75pb^{-1})$ | 495 | 70 | (19) | (50) | 1200 | 7425 |
| $N_{expect}(160pb^{-1})$ | 1056 | 149 | (40) | (106) | 2560 | 15840 |
| *Generator* | XBUR | XBUR | SGEN | SGEN | LWW | PYTH |
| *All* | 1056 | 149 | 100% | 100% | 2560 | 15840 |
| $N_{trk}$ | 1055 | 147 | 100% | 100% | 2260 | 14810 |
| $N_{src}$ | 1055 | 145 | 100% | 100% | 2112 | 13538 |
| $E_{vis}$ | 991 | 119 | 93.9% | 93.6% | 1468 | 5486 |
| $M_{event}$ | 933 | 108 | 87.2% | 86.9% | 1210 | 4805 |
| $N_{jet}$ | 692 | 54 | 68.1% | 63.1% | 801 | 338 |
| $E_{jet,EM}$ | 692 | 54 | 68.1% | 63.1% | 801 | 338 |
| $4jets$ | 692 | 54 | 68.1% | 63.1% | 801 | 338 |
| $tracks$ | 679 | 53 | 65.2% | 59.6% | 777 | 158 |
| $4Cfit$ | 580 | 44 | 52.6% | 47.5% | 634 | 127 |
| $\theta_{beam}, E_{jet}$ | 577 | 43 | 51.8% | 46.9% | 631 | 127 |
| $E_{max} - E_{min}$ | 535 | 40 | 45.0% | 36.8% | 573 | 84 |
| $M_{2jet}$ | 388 | 29 | 35.3% | 30.6% | 411 | 32 |
| $\theta_{2jet}$ | 322 | 19 | 29.1% | 22.7% | 346 | 26 |
| $M_{sum}$ $(\chi^2_{mass})$ | 15 | 1.5 | 3.4% | 5.6% | 15 | 5 |
| $M_{sum}$ | 15 | 1.3 | 3.4% | 5.6% | 15 | 0 |
| $M_{sum,2}$ | 4 | 0.3 | 1.3% | 2.4% | 1.7 | 0 |
| $M_{sum,3}$ | 0 | 0 | 0.03% | 0 | 0 | 0 |
| $M_{sum}$ $(5Cfit)$ | 234 | 14 | 22.4% | 19.5% | 254 | 21 |
| $M_{sum}$ | 223 | 13 | 21.8% | 18.7% | 241 | 21 |

Table 2: The number of events remaining after the cuts applied

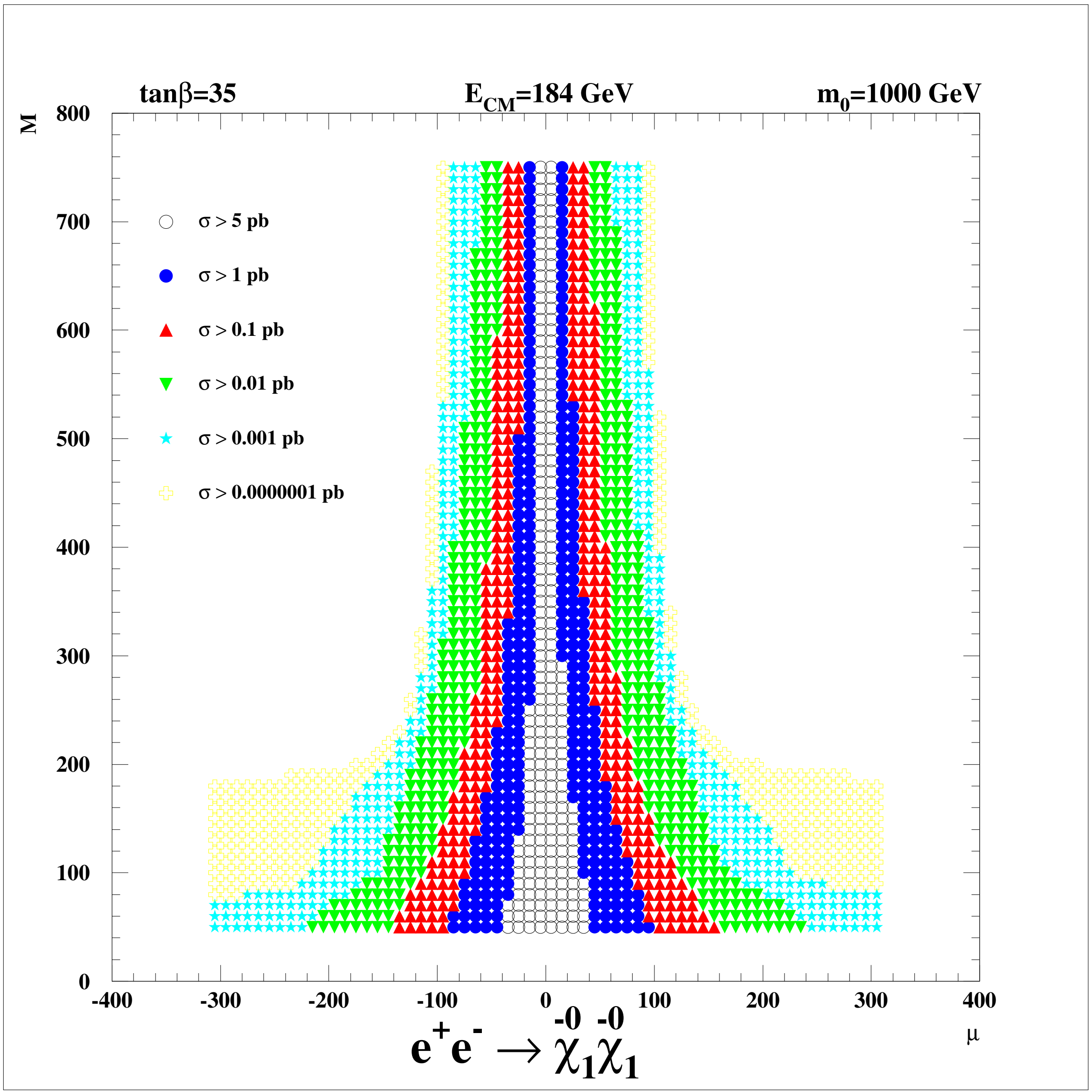

tanβ=2
E_CM=184 GeV
m_0=1000 GeV
σ (pb)
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
70
80
m_χ (GeV)
e+e- → χ1-0 χ1-0

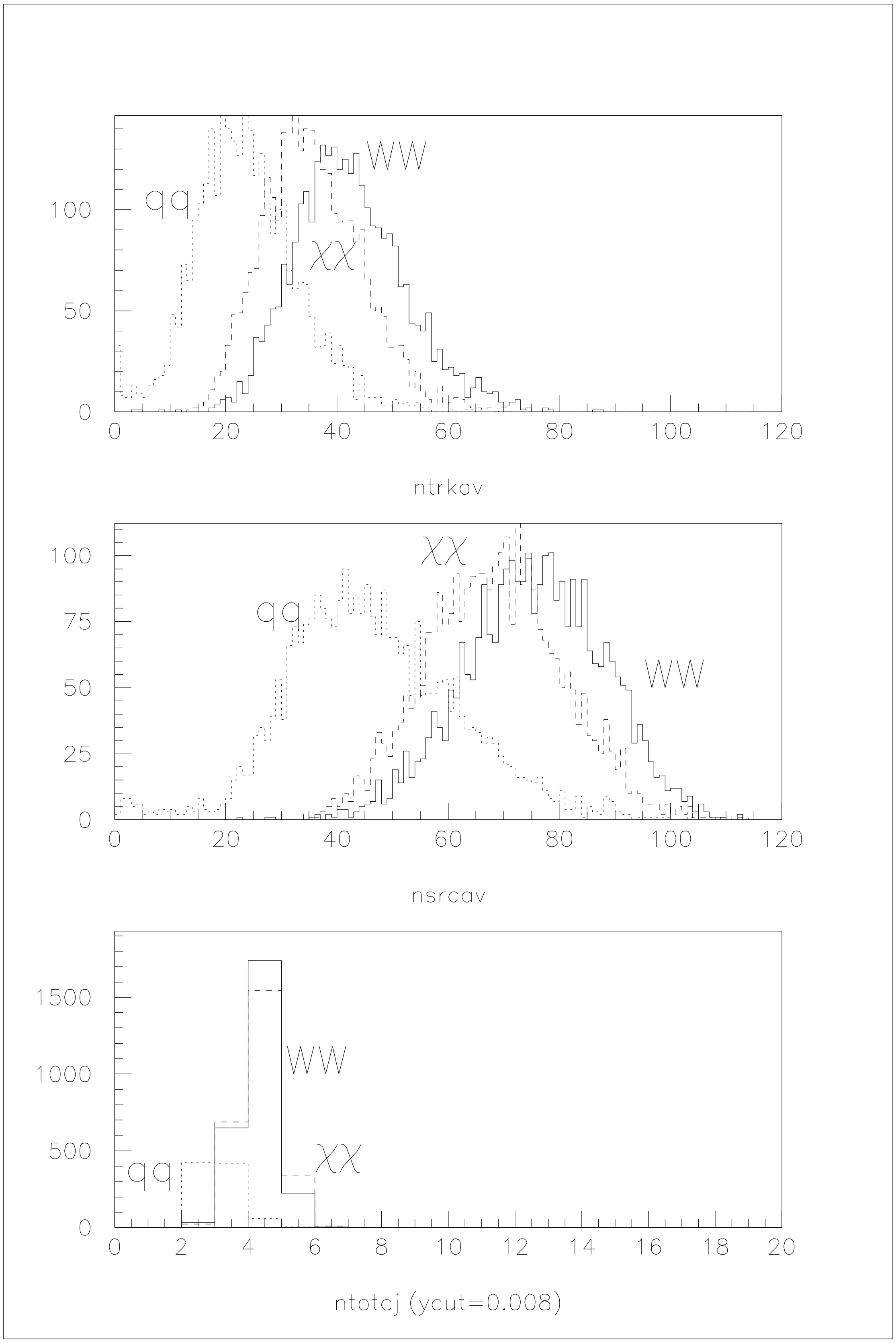


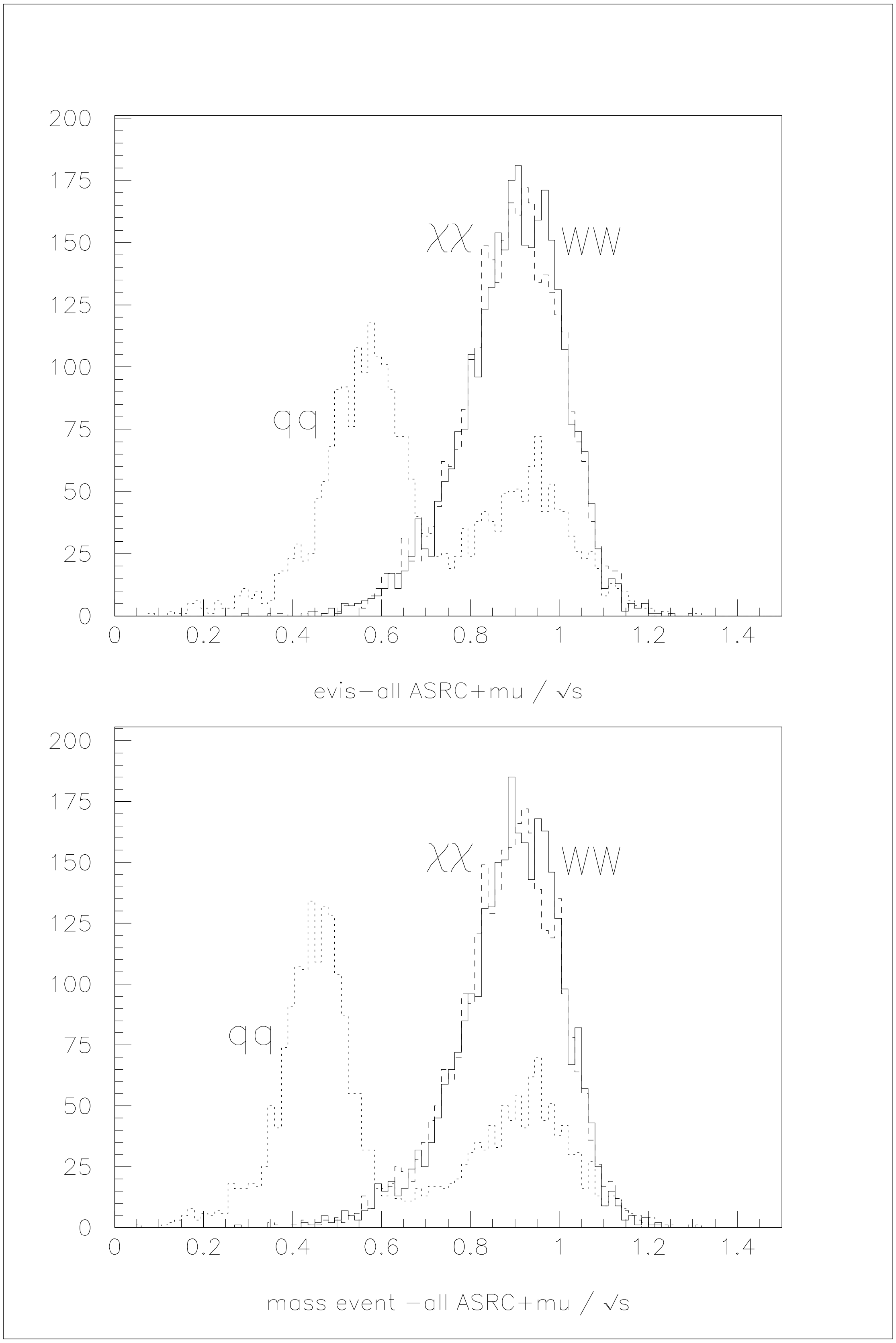

$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$$



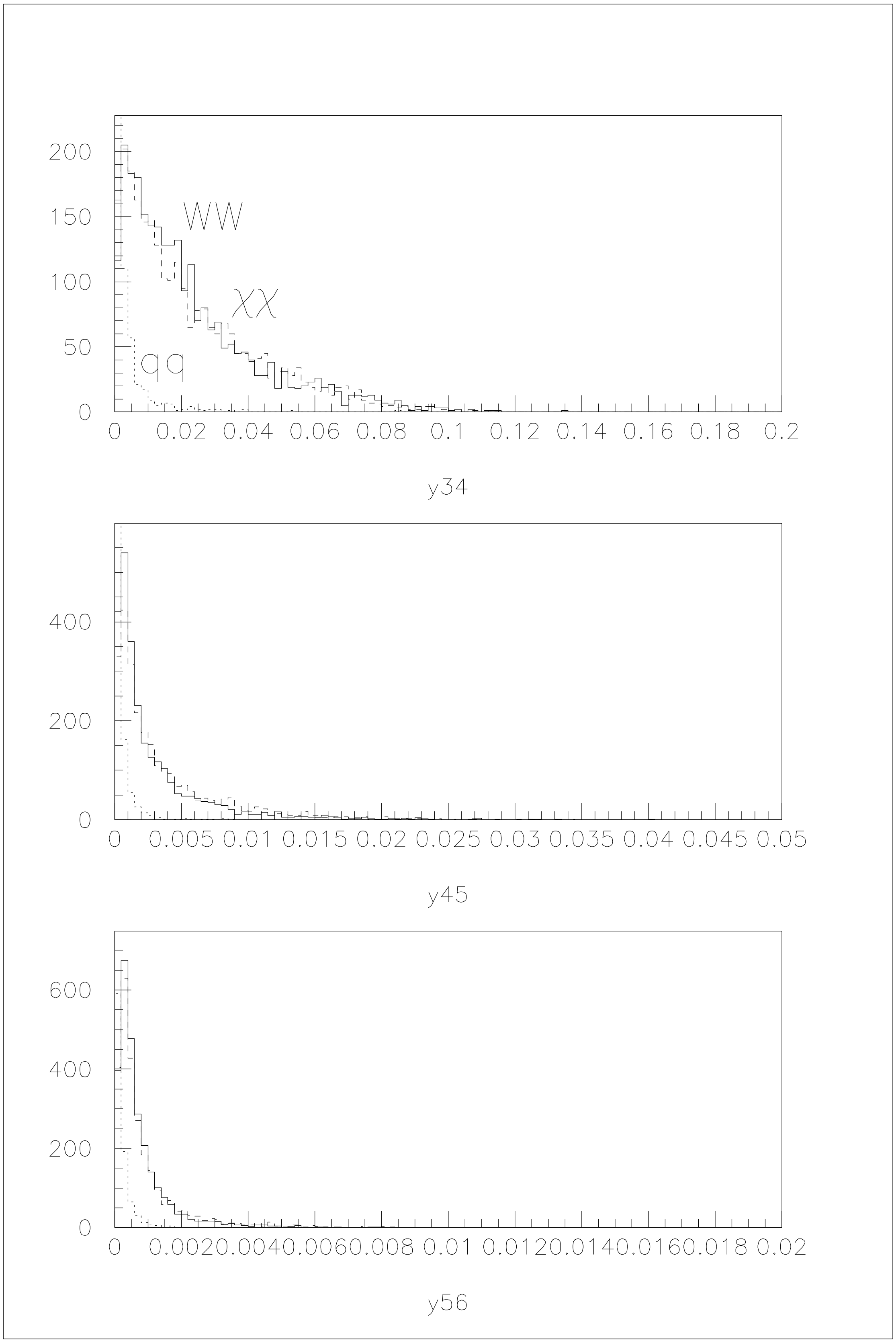

$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$

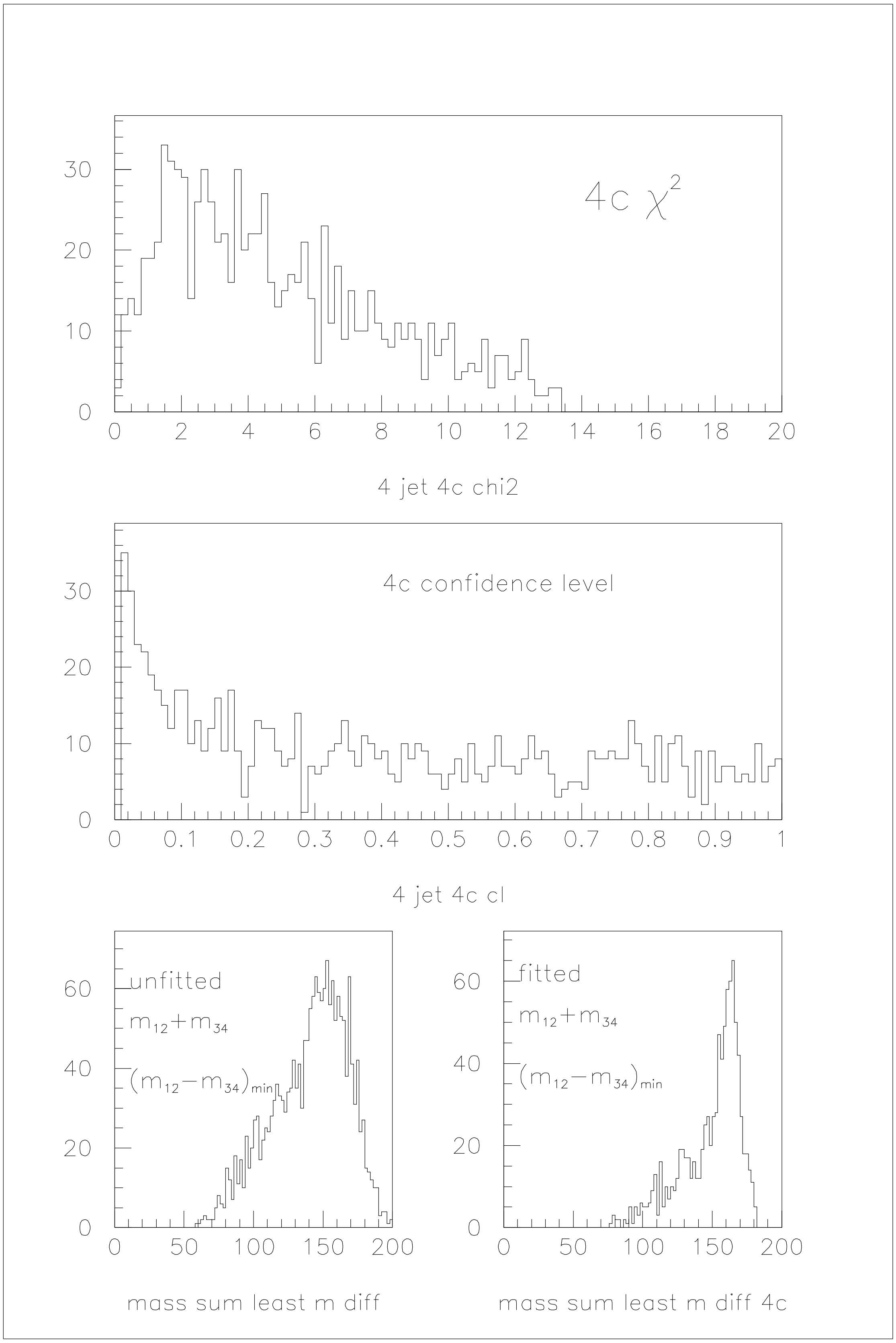

tanβ=35
E_CM=184 GeV
m_0=1000 GeV
M
μ
σ > 5 pb
σ > 1 pb
σ > 0.1 pb
σ > 0.01 pb
σ > 0.001 pb
σ > 0.0000001 pb
$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$

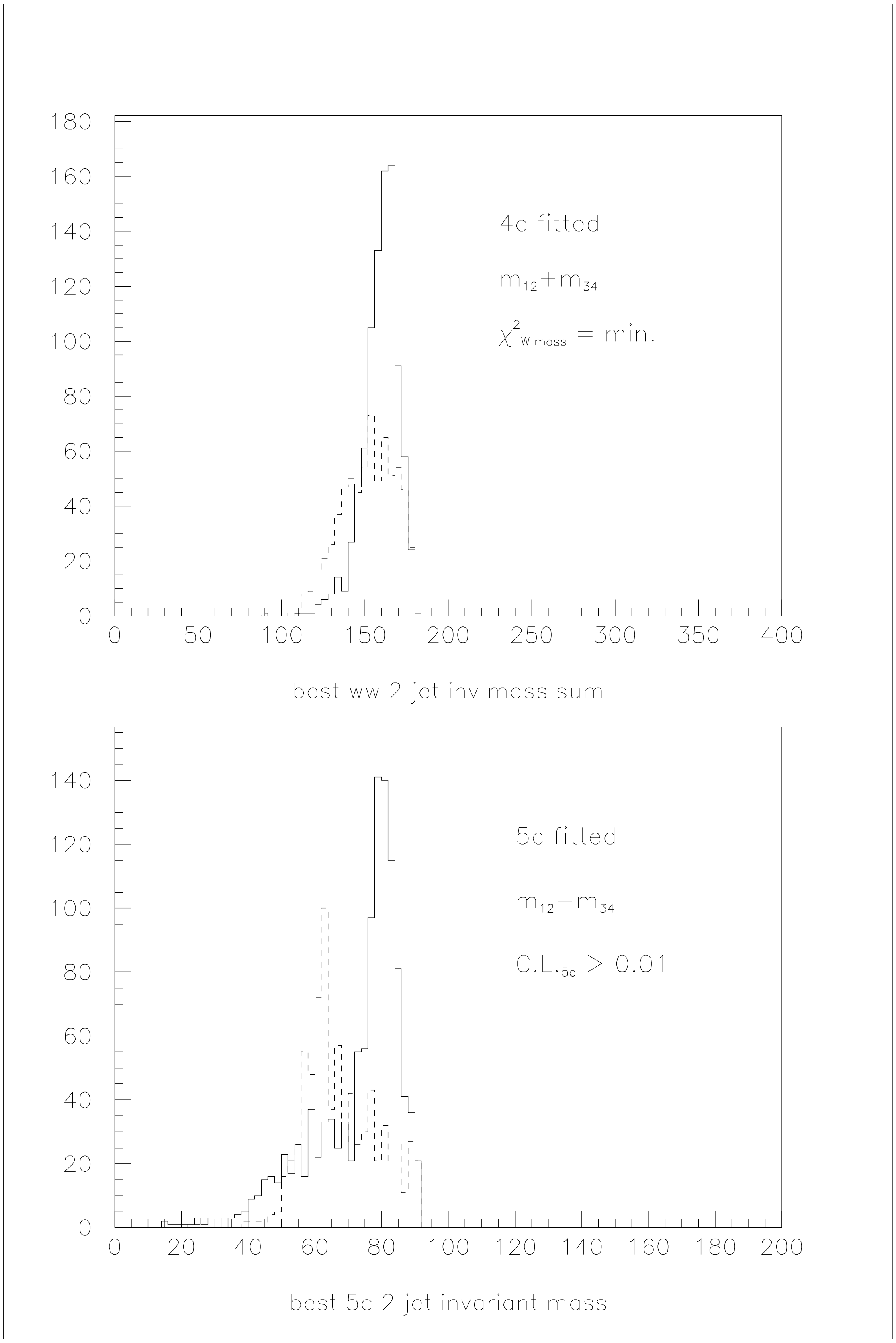

qq
WW
χχ
0
50
100
0
20
40
60
80
100
120
ntrkav
qq
χχ
WW
0
25
50
75
100
0
20
40
60
80
100
120
nsrcav
WW
qq
χχ
0
500
1000
1500
0
2
4
6
8
10
12
14
16
18
20
ntotcj (ycut=0.008)



200
175
150
125
100
75
50
25
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
χχ
WW
qq
evis−all ASRC+mu / √s
200
175
150
125
100
75
50
25
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
χχ
WW
qq
mass event −all ASRC+mu / √s


200
150
100
50
0
WW
χχ
qq
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
y34
400
200
0
0 0.005 0.01 0.015 0.02 0.025 0.03 0.035 0.04 0.045 0.05
y45
600
400
200
0
0 0.0020.0040.0060.008 0.01 0.0120.0140.0160.018 0.02
y56


4c $\chi^2$
4 jet 4c chi2
4c confidence level
4 jet 4c cl
unfitted
$m_{12}+m_{34}$
$(m_{12}-m_{34})_{min}$
mass sum least m diff
fitted
$m_{12}+m_{34}$
$(m_{12}-m_{34})_{min}$
mass sum least m diff 4c


180
160
140
120
100
80
60
40
20
0
0 50 100 150 200 250 300 350 400
4c fitted
$m_{12}+m_{34}$
$\chi^2_{W\,mass}$ = min.
best ww 2 jet inv mass sum
140
120
100
80
60
40
20
0
0 20 40 60 80 100 120 140 160 180 200
5c fitted
$m_{12}+m_{34}$
C.L.$_{5c}$ > 0.01
best 5c 2 jet invariant mass