SDC-92-221

SDC
SOLENOIDAL DETECTOR NOTES

STUDIES OF HEAVY $W'\mu\nu_\mu$ and $Z' \rightarrow \mu^+\mu^-$ PRODUCTION AND RADIATIVE DECAY

February 25, 1992

Steve Errede
University of Illinois

Steve Errede
Univ. Illinois
Feb. 25, 1992
SDC-92-221

Studies of Heavy $W' \rightarrow \mu\nu_\mu$ and $Z' \rightarrow \mu^+\mu^-$ Production and Radiative Decay

Abstract

This note summarizes recent studies of the impact/ramifications of inner bremsstrahlung in the radiative decays of W, Z and heavy W', Z' bosons, at the trigger and off-line event selection level.

Introduction

In the production and decay of W and Z bosons, and possible heavy W' and Z' bosons, the emission of hard photons from initial-state and final state (inner bremsstrahlung) can occur in the production and decay of such massive particles. These particular radiation processes have an electric dipole-like intensity pattern, in that the emitted photons are predominantly collinear with the incident quarks and outgoing final-state leptons (or quarks), with very steeply falling energy and angular distributions[1-4].

A modified version of the CDF radiative W/Z MC event generator, code originally written by Bob Wagner of Argonne [5], was used for studies of radiative *muonic* decays of W and Z bosons, and heavy W' and Z' bosons, with masses up to 5 TeV/c^2. This event generator was used to create MC data sets of $W \rightarrow \mu\ \nu_\mu$ and $Z \rightarrow \mu^+\mu^-$ as well as $W' \rightarrow \mu\ \nu_\mu$ and $Z' \rightarrow \mu^+\mu^-$ with statistics of 20K events per sample, per mass point. The event generation used a photon cutoff of $E_\gamma > 0.2\ GeV$. Studies of the fraction of radiative W and Z events above a given cutoff in energy were carried out, as well as energy-angle correlation

studies, both as a function of W' and Z' mass. These results were also studied as a function of cuts on the muon P_T (and MET - for the W, W' case), but were found to be essentially independent of such cuts. We therefore present here the results with no such cuts on muon P_T and MET.

Radiative $Z' \to \mu^+\mu^-$ Decay

Fig. 1 shows the inner bremsstrahlung fraction (defined as the # of events above a given photon energy cutoff E_{cut} to *all* Z' events) vs. Z' mass for radiative $Z' \to \mu^+\mu^-$ decay as generated by modified version of the CDF radiative W/Z MC program. Fig. 2 shows the inner bremsstrahlung fraction vs. the photon energy cutoff E_{cut} for Z' masses of $M_{Z'} = M_Z$, 0.2, 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 TeV/c^2. The lowest (highest) curve in Fig. 2 is for the lowest (highest) Z' mass.

Figs. 3 & 4 show the corresponding results of the same as those for figs 1 & 2, but where a cone cut requiring that the photon around either leg of the final state muons from $Z' \to \mu^+\mu^-$ decay be within $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.1$. Comparison of fig. 3 with fig. 1 shows that approximately 2/3 of radiative Z' events will have the photon contained within this angular region of one of the final state muons, independent of photon energy. Note that for large Z' masses, approximately 20-30% of the events are expected to be accompanied by a photon having $E_\gamma \geq 50\ GeV$! Almost *all* events at these masses emit photons of appreciable energy, particularly in comparison to the (minimum-ionizing) energy deposition signature in e.g. the EM and hadron calorimeters - *especially* the EM calorimeter, where the peak of the -dE/dX energy loss deposition for minimum-ionizing, non-showering particles is expected to be $\sim$ few $\times$ 100 MeV . Note that for standard-model $Z^0 \to \mu^+\mu^-$ decay, this MC simulation indicates that nearly 20% of all such events will have a photon emitted with $E_\gamma > 5.0\ GeV$.

Figs. 5 & 6 show the corresponding results of the same as those for figs 1 & 2, but where a muon "tower" cut is made, requiring that the photon be within the

same calorimeter tower as either of the two muons. The size of the calorimeter tower used was $\Delta\phi = \Delta\eta = 0.1$ Comparison of fig. 5 with fig. 1 shows that approximately 1/2 of radiative Z' events will have the photon contained within this angular region of one of the final state muons, independent of photon energy.

Figs. 7 & 8 show the corresponding results of the same as those for figs 1 & 2, but where a muon "border tower" cut is made, requiring that the photon be within the one of the eight "border towers" in the calorimeter surrounding the tower associated with either of the two muons. The size of the calorimeter tower used was $\Delta\phi = \Delta\eta = 0.1$ Comparison of fig. 7 with fig. 1 shows that approximately 15% of radiative Z' events will have the photon contained within this angular region of one of the final state muons, independent of photon energy.

The remainder of the final state radiation in Z' decay is emitted at angles larger than this, but still tends to be concentrated collinear with the muons, for a given photon energy. The photon angular distribution(s) are also not strongly energy-dependent.

Radiative $W' \rightarrow \mu\ \nu_\mu$ Decay

Fig. 9 shows the inner bremsstrahlung fraction (defined as the # of events above a given photon energy cutoff E_{cut} to *all* W' events) vs. W' mass for radiative $W' \rightarrow \mu\ \nu_\mu$ decay as generated by modified version of the CDF radiative W/Z MC program. Fig. 10 shows the inner bremsstrahlung fraction vs. the photon energy cutoff E_{cut} for W' masses of $M_{W'} = M_W$, 0.2, 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 TeV/c^2. The lowest (highest) curve in Fig. 10 is for the lowest (highest) W' mass.

Figs. 11 & 12 show the corresponding results of the same as those for figs 9 & 10, but where a cone cut requiring that the photon around the final state muon from $W' \rightarrow \mu\ \nu_\mu$ decay be within $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.1$. Comparison of fig. 11 with fig. 9 shows that approximately 2/3 of radiative

W' events will have the photon contained within this angular region of one of the final state muons, independent of photon energy. Note that for large W' masses, approximately 10-15% of the events are expected to be accompanied by a photon having $E_\gamma \geq 50\ GeV$! Note that this is in good agreement with expectations from $Z' \rightarrow \mu^+\mu^-$ - roughly 1/2 of the W' for the same mass Z' will have radiation at a given photon energy. Here again, a significant fraction of W' events at these large masses are expected to emit photons of appreciable energy. Note that for standard-model $W \rightarrow \mu\nu_\mu$ decay, this MC simulation indicates that approximately 8% of all such events will have a photon emitted with $E_\gamma > 5.0\ GeV$.

Figs. 13 & 14 show the corresponding results of the same as those for figs 1 & 2, but where a muon "tower" cut is made, requiring that the photon be within the same calorimeter tower that of the muon. The size of the calorimeter tower used was again $\Delta\phi = \Delta\eta = 0.1$ Comparison of fig. 13 with fig. 9 shows that approximately 1/2 of radiative W' events will have the photon contained within this angular region of the decay muon, independent of photon energy.

Figs. 15 & 16 show the corresponding results of the same as those for figs 9 & 10, but where a muon "border tower" cut is made, requiring that the photon be within the one of the eight "border towers" in the calorimeter surrounding the tower associated with the decay muon. The size of the calorimeter tower used was $\Delta\phi = \Delta\eta = 0.1$ Comparison of fig. 15 with fig. 9 shows again that approximately 15% of radiative W' events will have the photon contained within this angular region of the decay muon, independent of photon energy.

The remainder of the final state radiation in W' decay is emitted at angles larger than this but still tends to be concentrated collinear with muon, for a given photon energy. The photon angular distribution(s) are also not strongly energy-dependent.

Conclusions

These initial studies of the radiative decays of massive W' and Z' bosons (and/or any other heavy particles that may be produced at the SSC) indicate that the impact/ramifications of final-state radiation (inner bremsstrahlung) can be quite significant if associative trigger schemes (e.g. muon trigger + minium ionizing calorimeter signature) are not carefully thought through in detail. From first-hand experience on CDF in the measurement of W and Z masses (and their width), radiative effects must also must be carefully taken into account - not only for for their systematic (downward) shifts on the apparent masses, but also for their impact on the *fluctuations* of e.g. the assumed muon momentum resolution function associated with finite statistical sample(s) of events.

Acknowledgements

I wish to thank Bob Wagner of Argonne National Laboratory for sage advice, help and extremely useful/interesting discussions associated with using his radiative W/Z MC event generator in ways stranger than either of us ever originally believed possible!

References

[1] Berends, F. A. and R. Kleiss, Z. Phys. C27, 365 (1985).

[2] Berends, F. A., R. Kleiss, J. P. Revol, and J. P. Vaille, Z. Phys. C27, 155 (1985).

[3] G. Marchesini and B. Webber, Nucl. Phys. B310, 461 (1988).

[4] G. Bonvicini and L. Trentadue, Nucl. Phys. B, 1990.

[5] R.G. Wagner, Nucl. Phys. B, 1990.

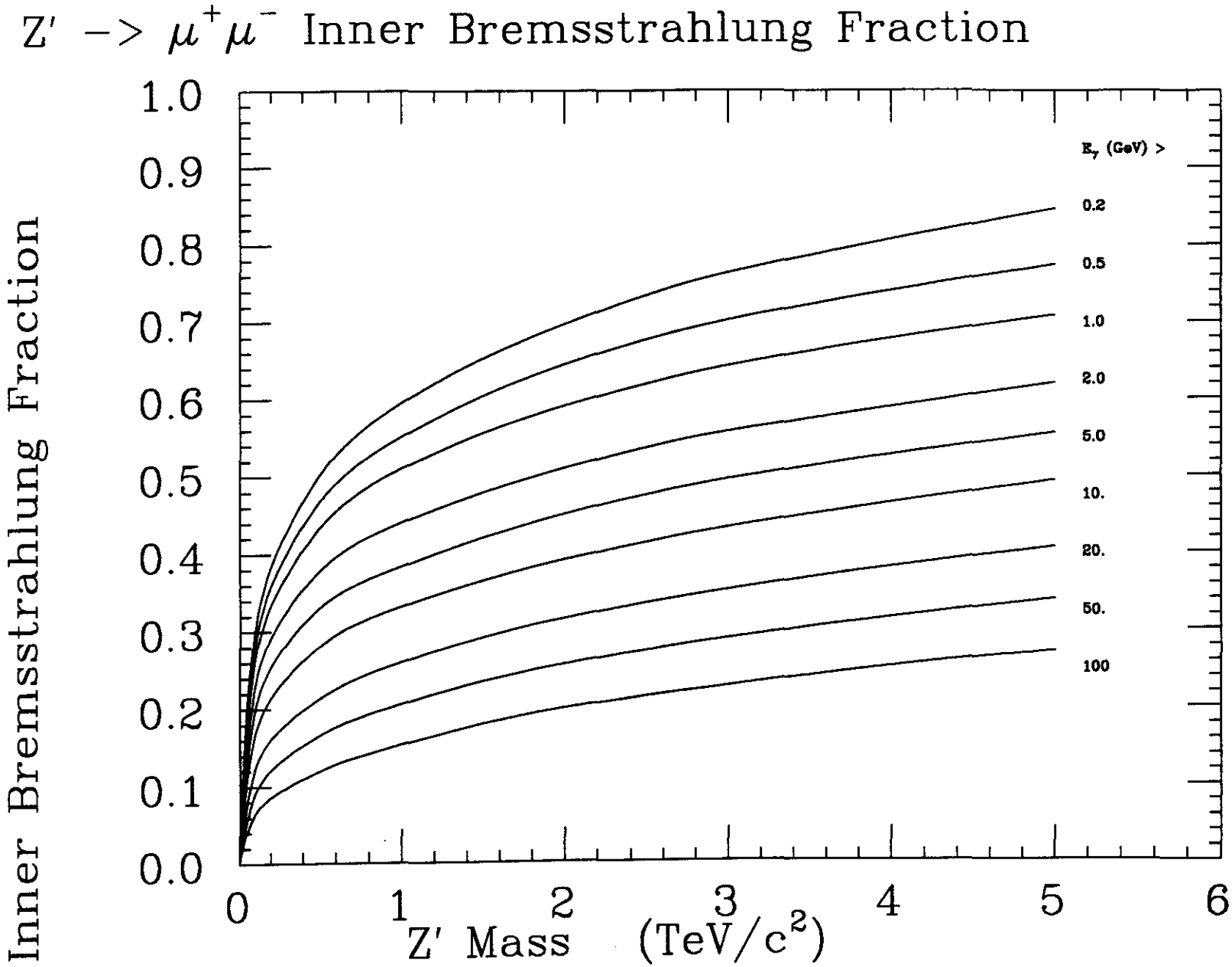

Z' -> μ+μ- Inner Bremsstrahlung Fraction
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
Z' Mass (TeV/c²)
Eγ (GeV) >
0.2
0.5
1.0
2.0
5.0
10.
20.
50.
100

Fig 1

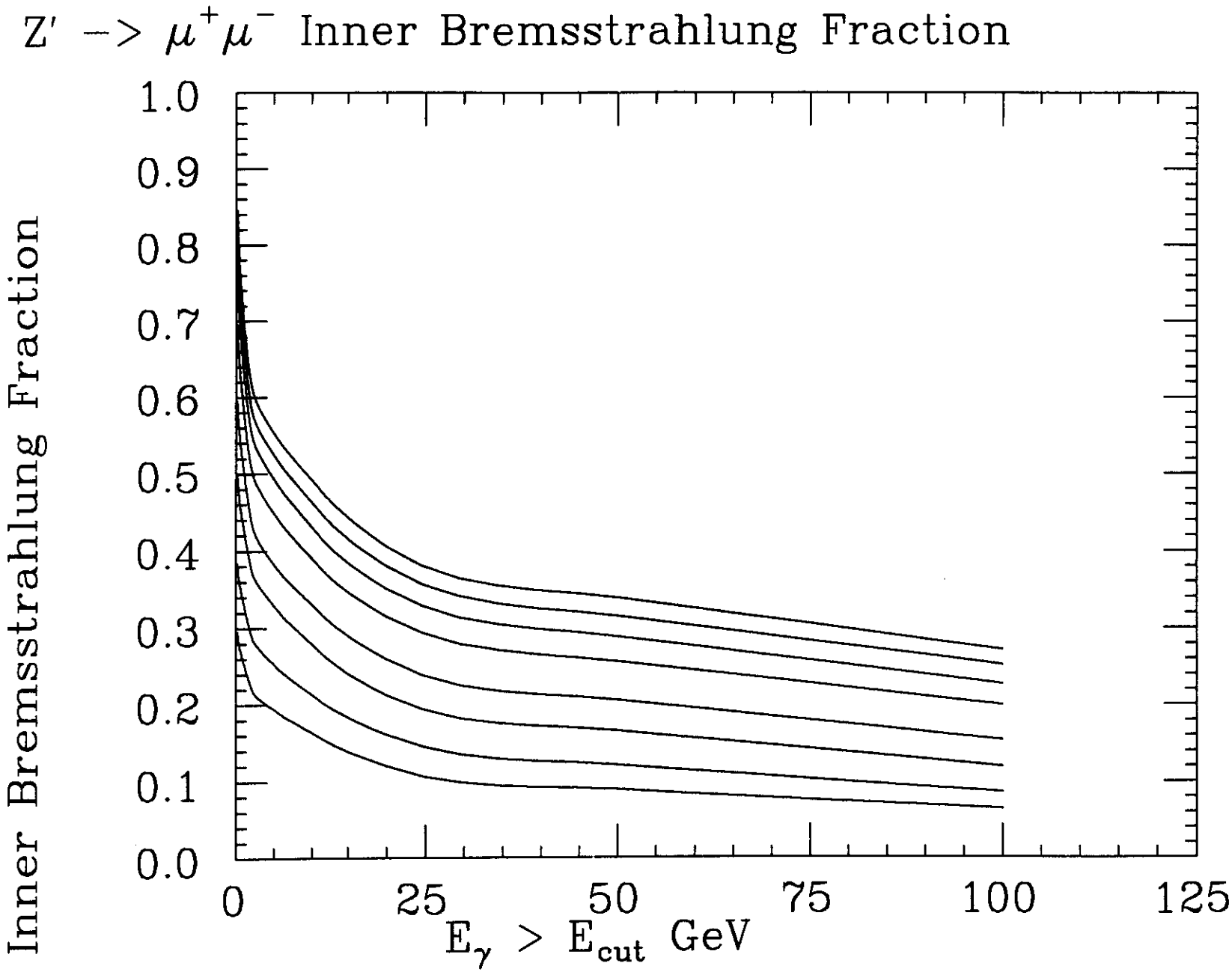

Z′ -> μ+μ− Inner Bremsstrahlung Fraction
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
Eγ > Ecut GeV

Fig 2

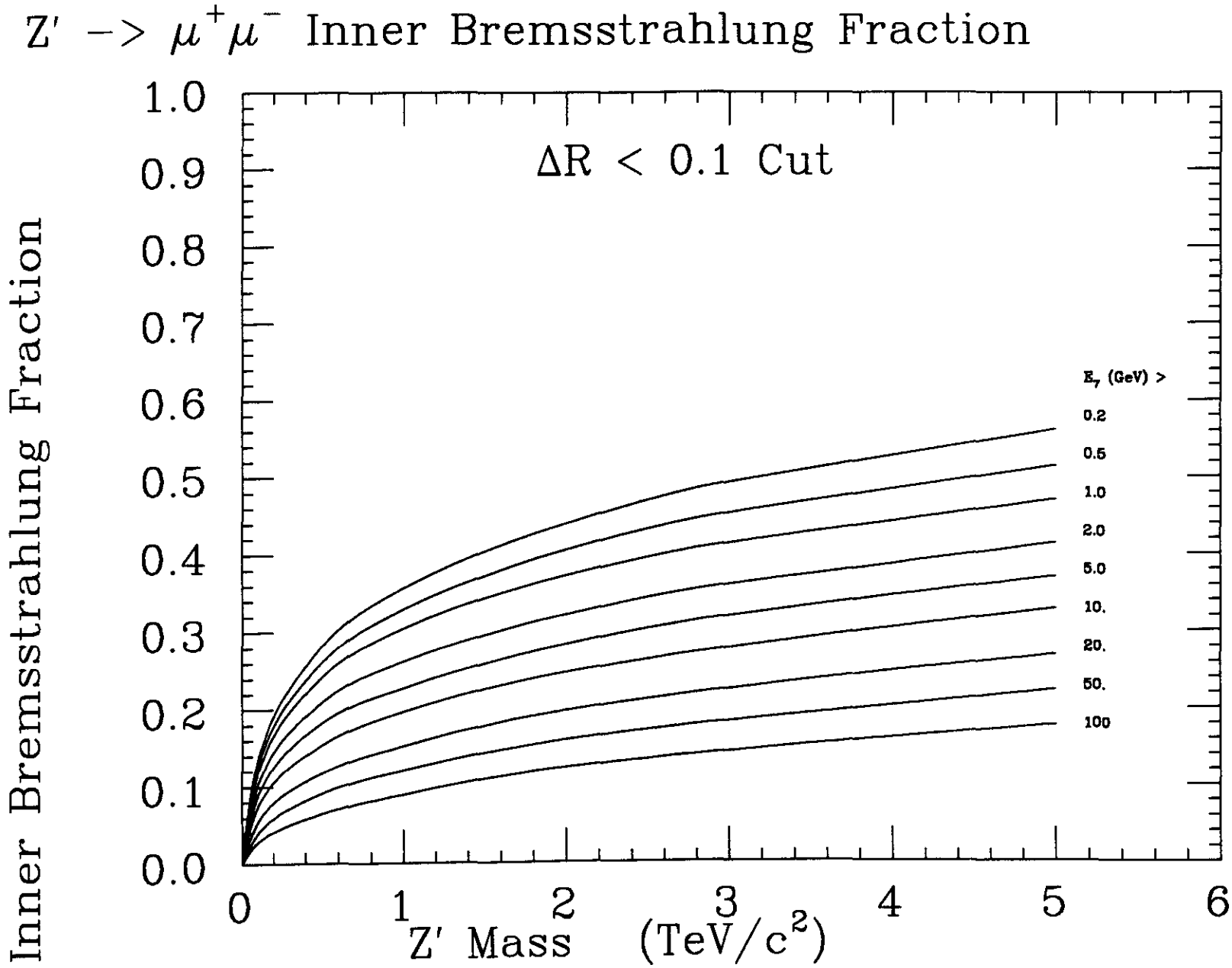

Z' -> μ+μ- Inner Bremsstrahlung Fraction
ΔR < 0.1 Cut
Inner Bremsstrahlung Fraction
Z' Mass (TeV/c²)
E_γ (GeV) >
0.2
0.5
1.0
2.0
5.0
10.
20.
50.
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
1
2
3
4
5
6

Fig 3

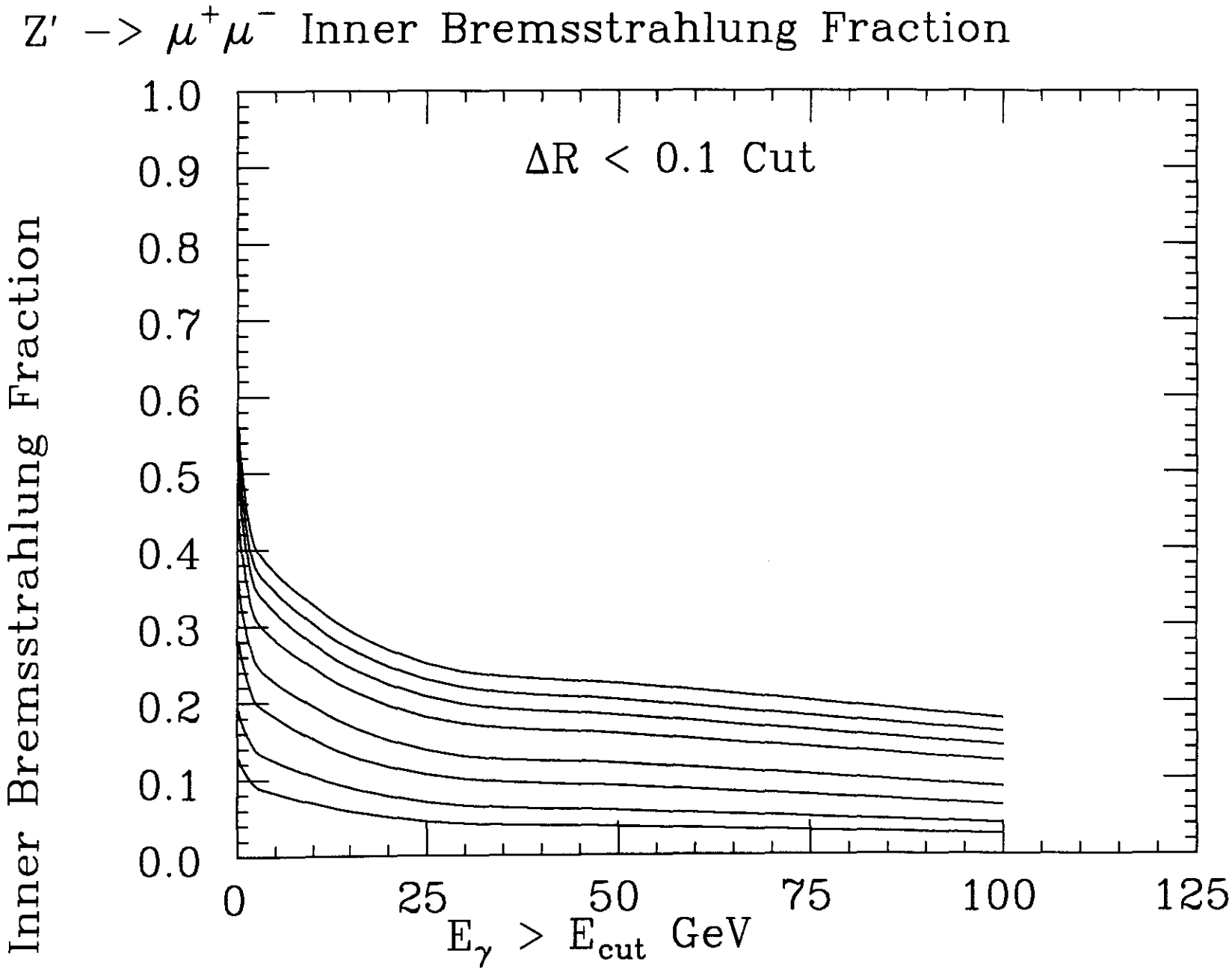

Z' -> μ+μ- Inner Bremsstrahlung Fraction
ΔR < 0.1 Cut
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
Eγ > Ecut GeV

Fig 4

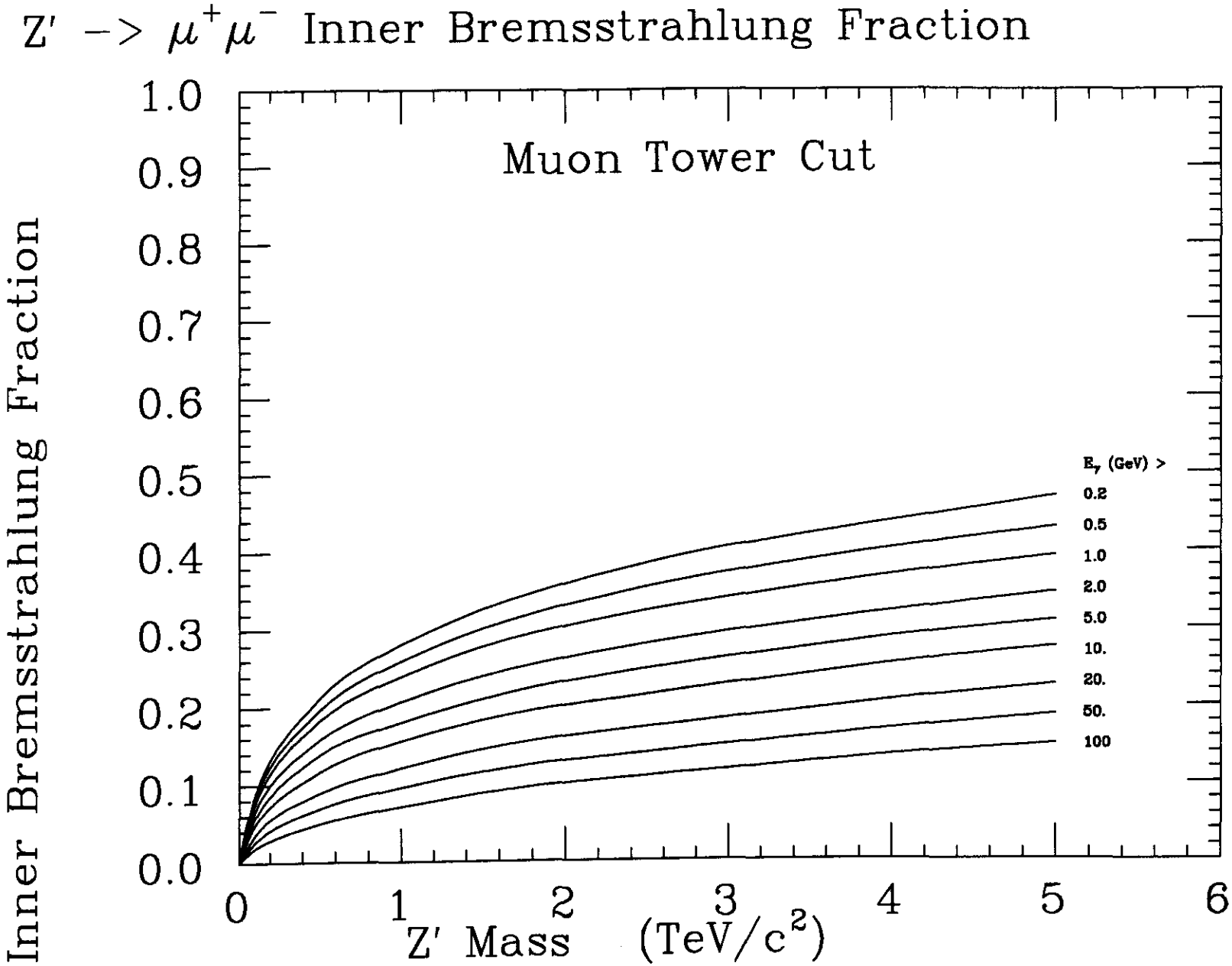

Z' -> $\mu^+\mu^-$ Inner Bremsstrahlung Fraction
Muon Tower Cut
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
Z' Mass (TeV/c^2)
E_γ (GeV) >
0.2
0.5
1.0
2.0
5.0
10.
20.
50.
100

Fig 5

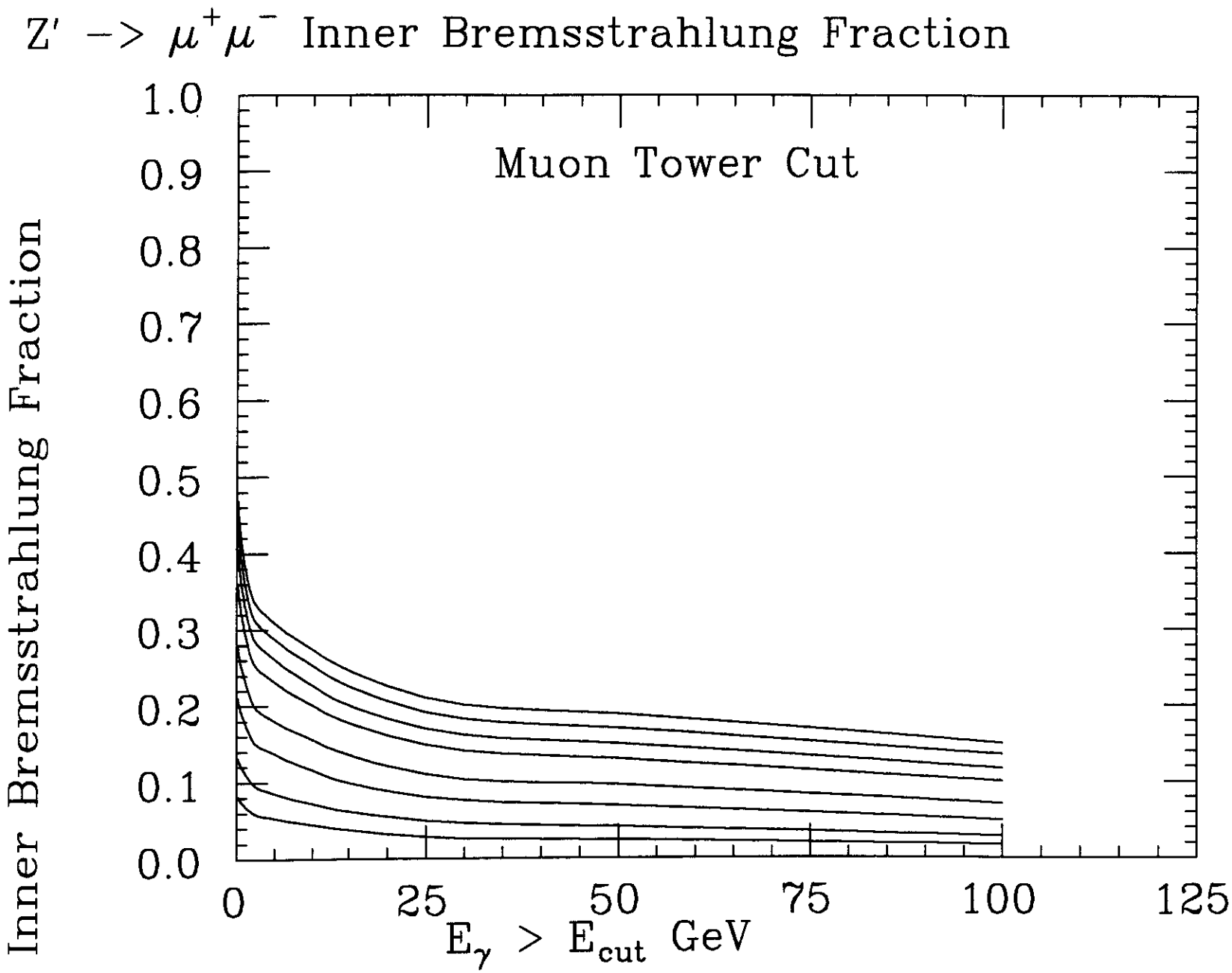

Z' -> $\mu^+\mu^-$ Inner Bremsstrahlung Fraction
Muon Tower Cut
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
$E_\gamma > E_{cut}$ GeV

Fig 6

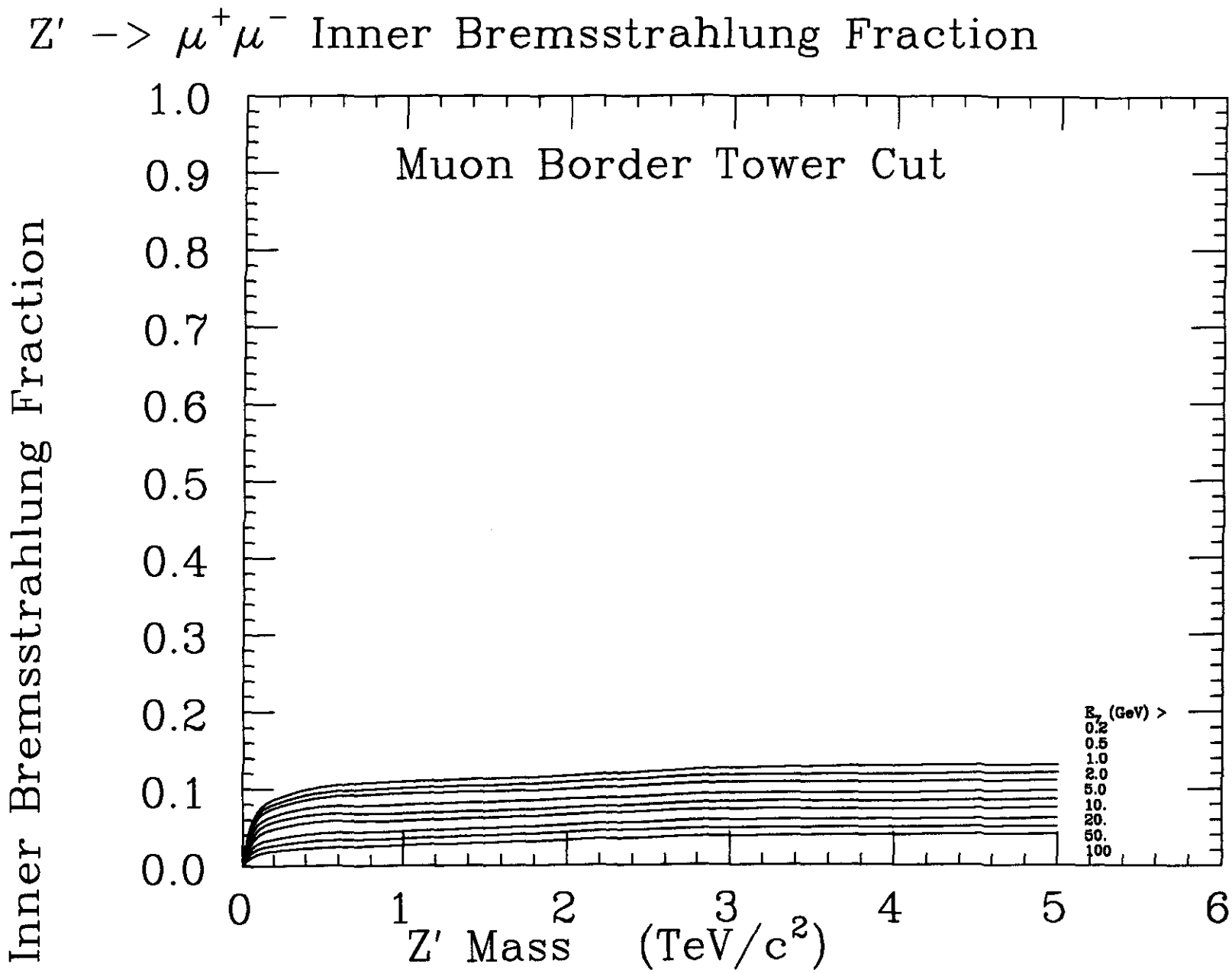

Z' -> μ+μ- Inner Bremsstrahlung Fraction
Muon Border Tower Cut
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
Z' Mass (TeV/c²)
E_T (GeV) >
0.2
0.5
1.0
2.0
5.0
10.
20.
50.
100

Fig 7

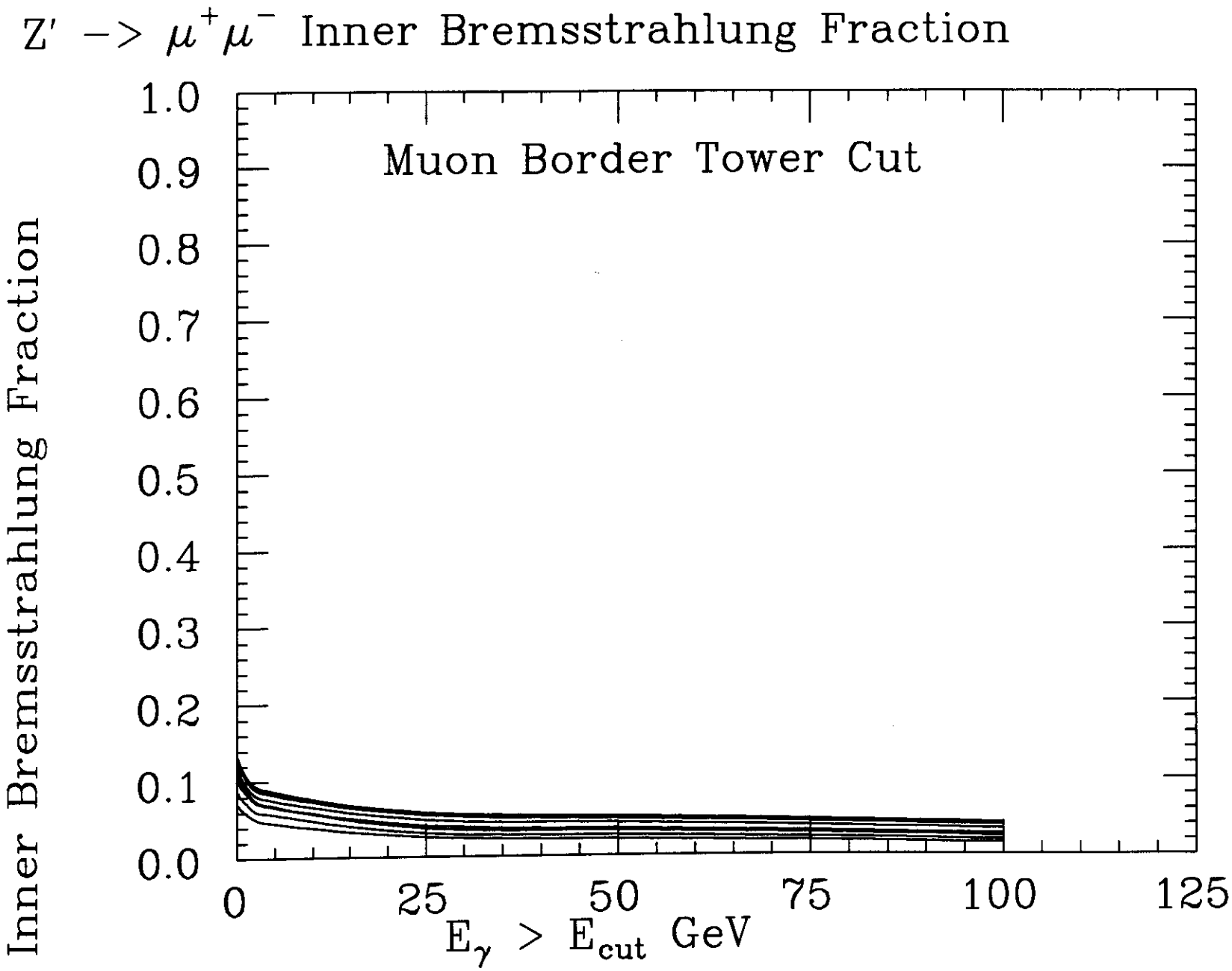

Z' -> $\mu^+\mu^-$ Inner Bremsstrahlung Fraction
Muon Border Tower Cut
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
$E_\gamma > E_{cut}$ GeV

Fig 2

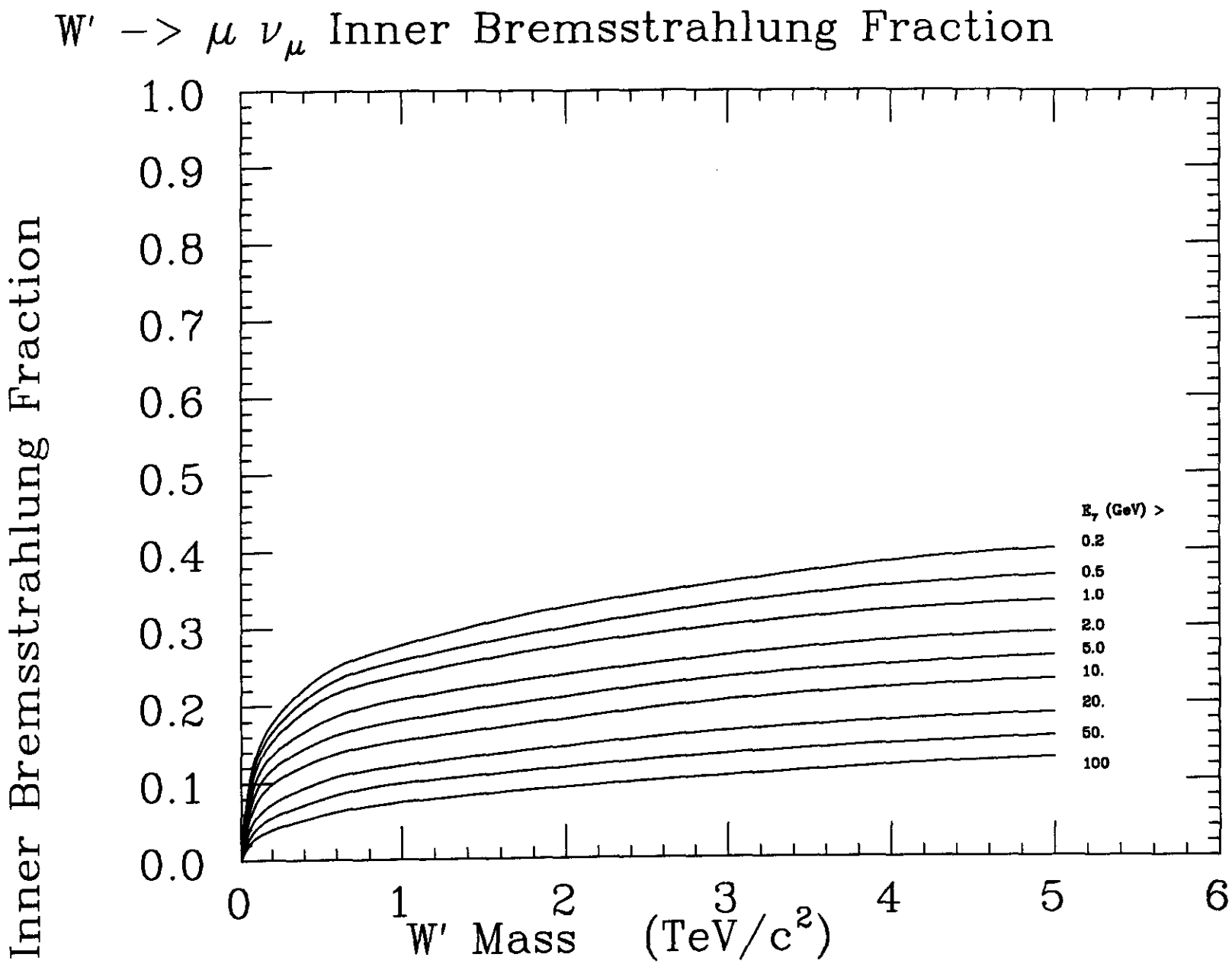

W' -> μ ν_μ Inner Bremsstrahlung Fraction
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
W' Mass (TeV/c²)
E_γ (GeV) >
0.2
0.5
1.0
2.0
5.0
10.
20.
50.
100

Fig 9

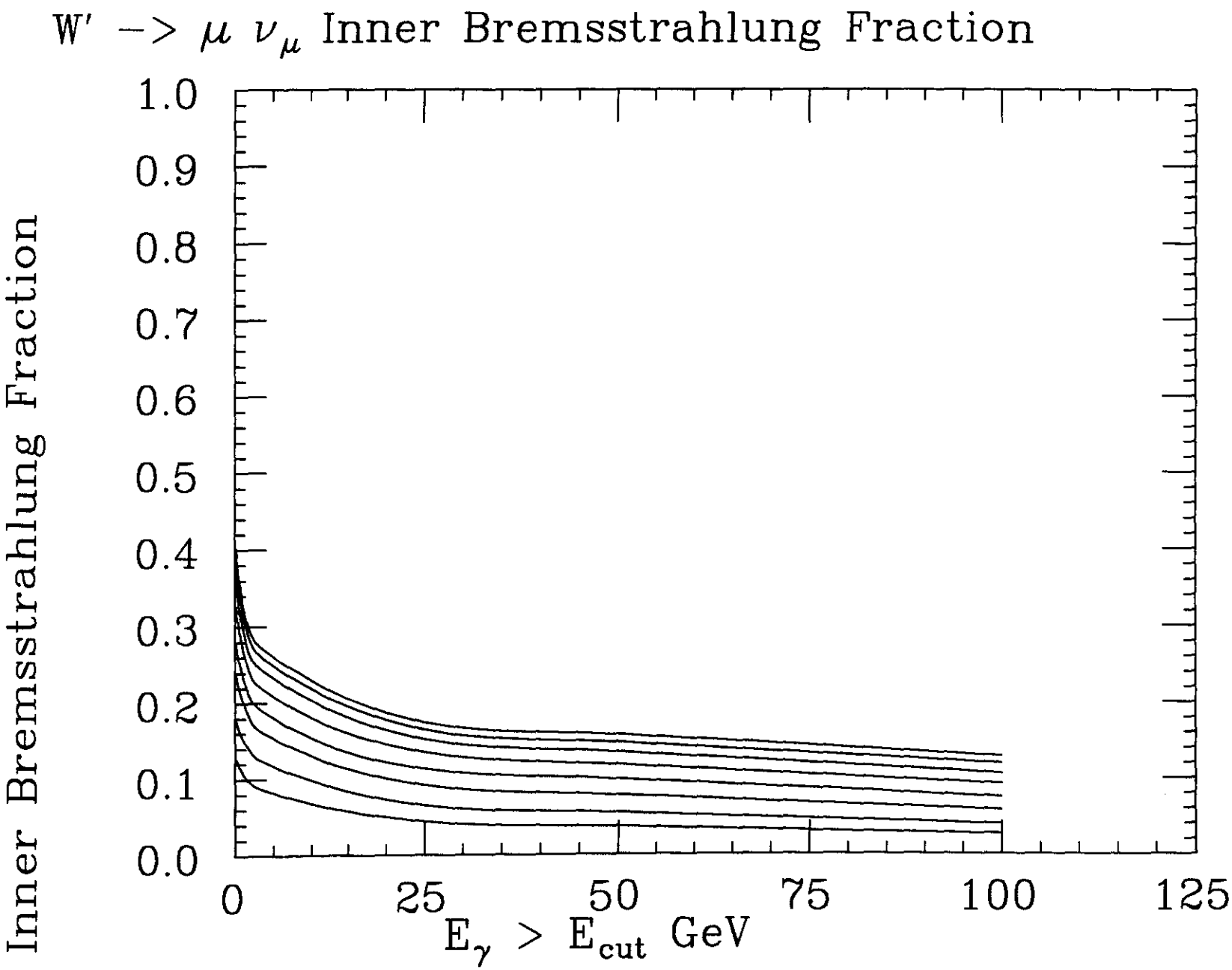

W' -> μ ν_μ Inner Bremsstrahlung Fraction
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
E_γ > E_cut GeV

Fig. 10

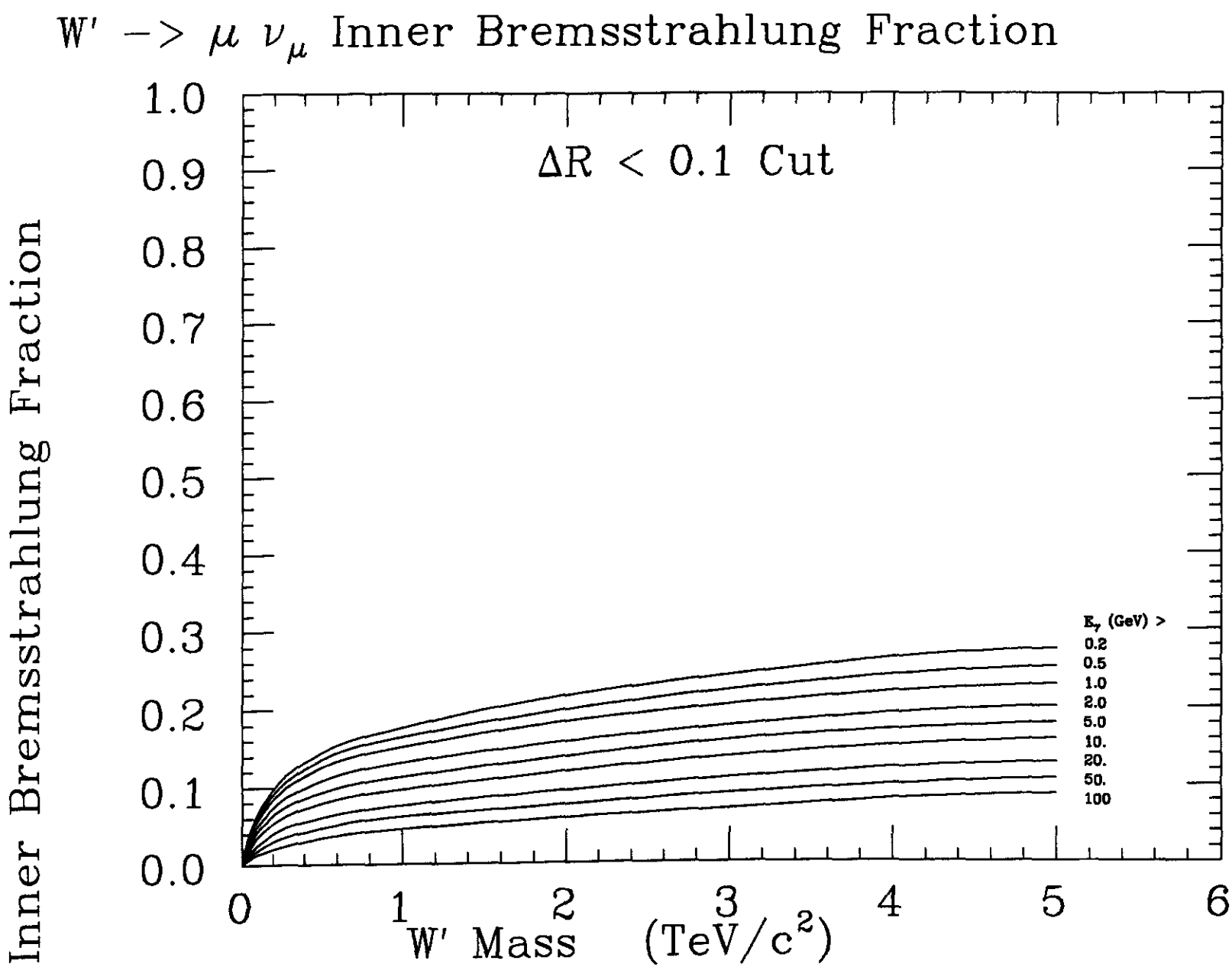

W' -> μ ν_μ Inner Bremsstrahlung Fraction
ΔR < 0.1 Cut
Inner Bremsstrahlung Fraction
W' Mass (TeV/c²)
E_γ (GeV) >
0.2
0.5
1.0
2.0
5.0
10.
20.
50.
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
1
2
3
4
5
6

Fig 11

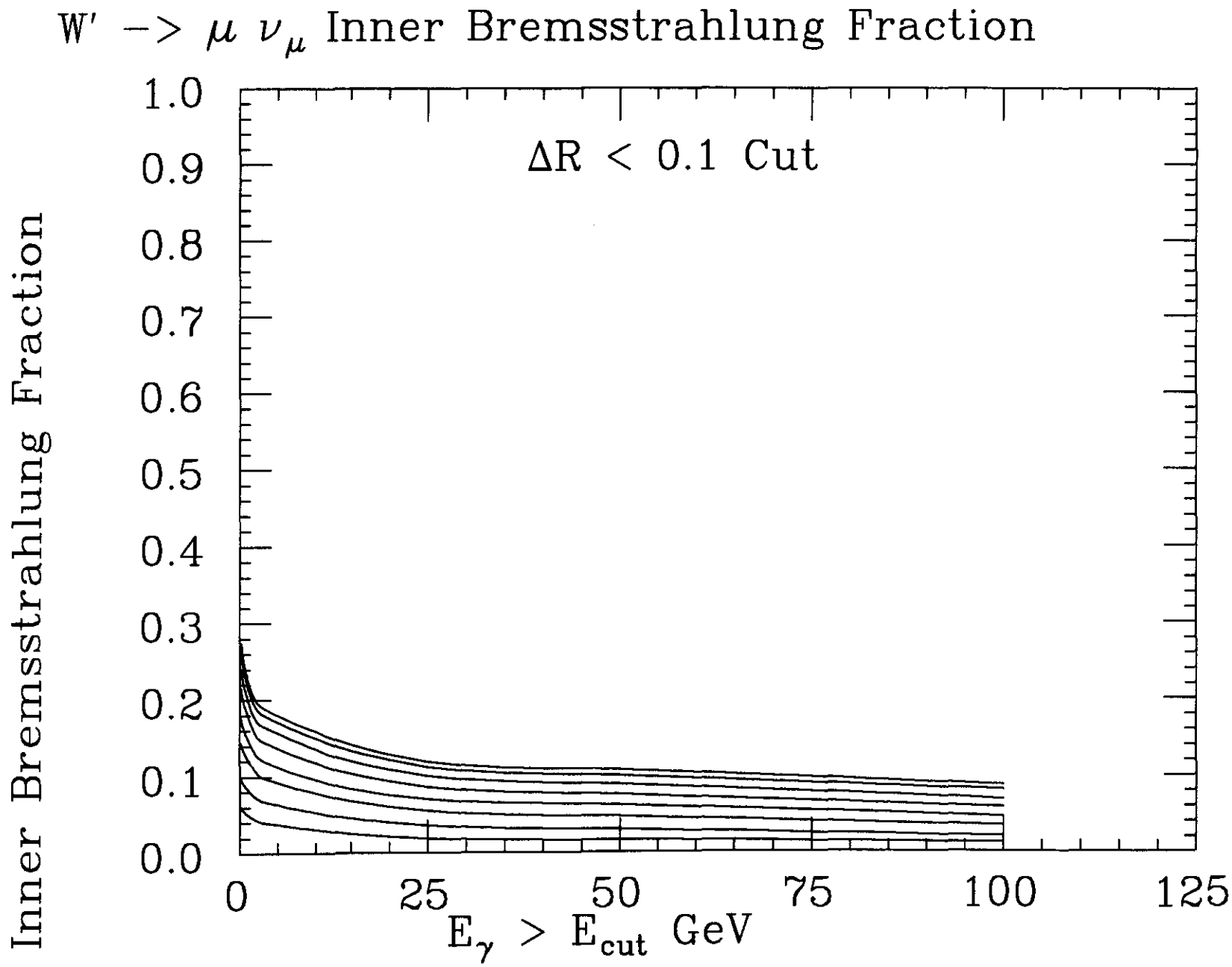

W' -> μ ν_μ Inner Bremsstrahlung Fraction
ΔR < 0.1 Cut
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
E_γ > E_cut GeV

FIG 12

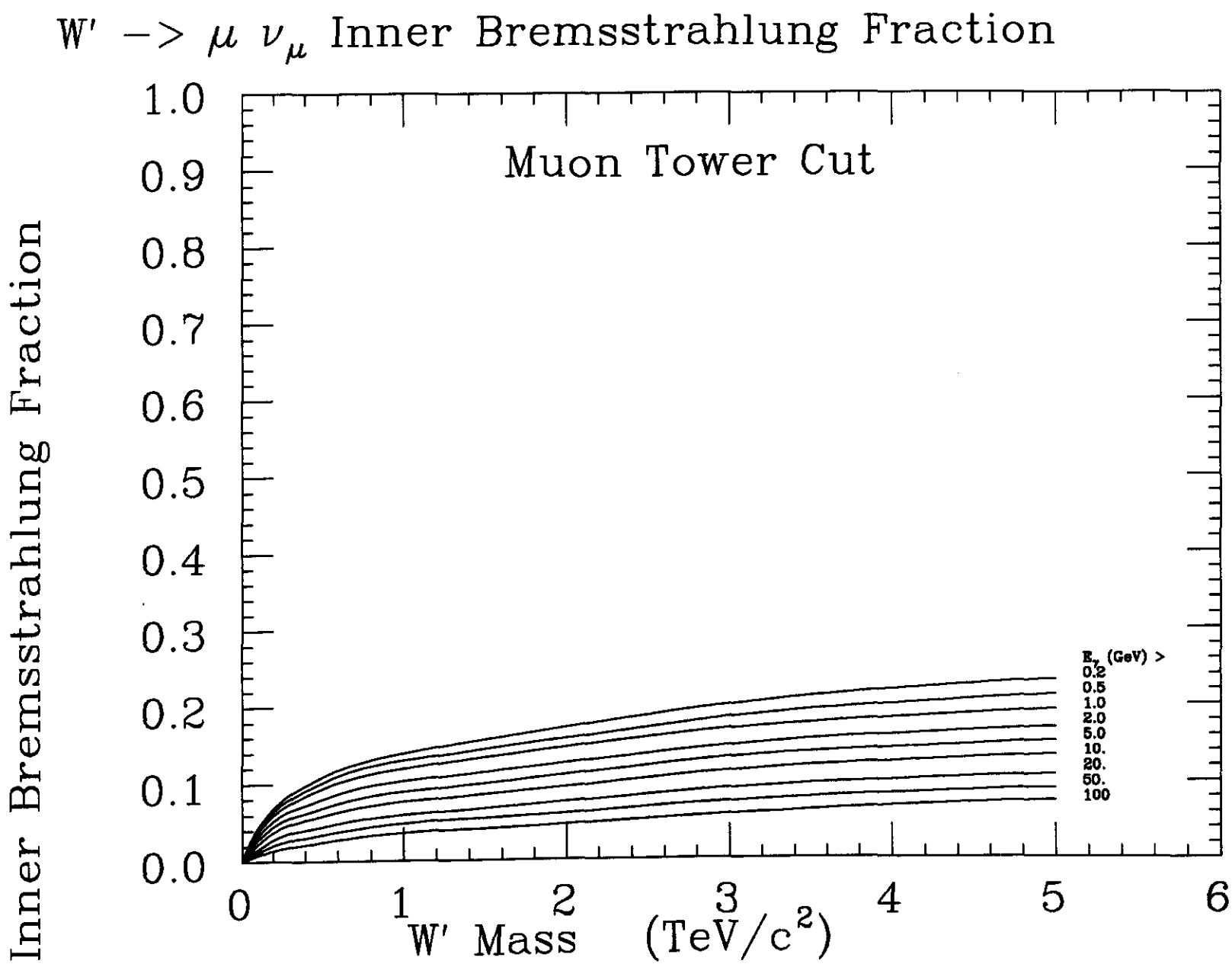

W' -> μ ν_μ Inner Bremsstrahlung Fraction
Muon Tower Cut
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
W' Mass (TeV/c²)
E_γ (GeV) >
0.2
0.5
1.0
2.0
5.0
10.
20.
50.
100

Fig 13

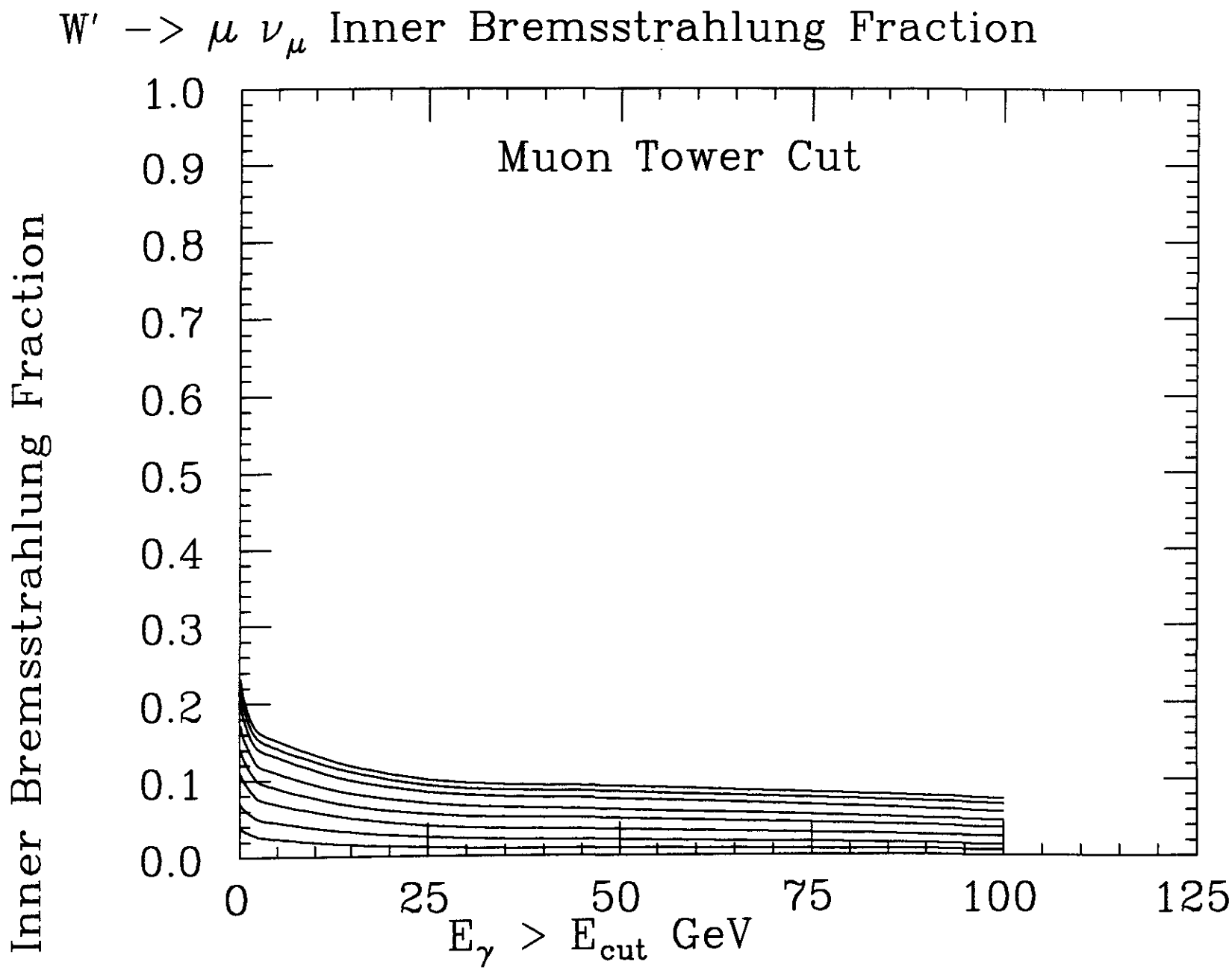

W' -> μ ν_μ Inner Bremsstrahlung Fraction
Muon Tower Cut
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
E_γ > E_cut GeV

Fig 14

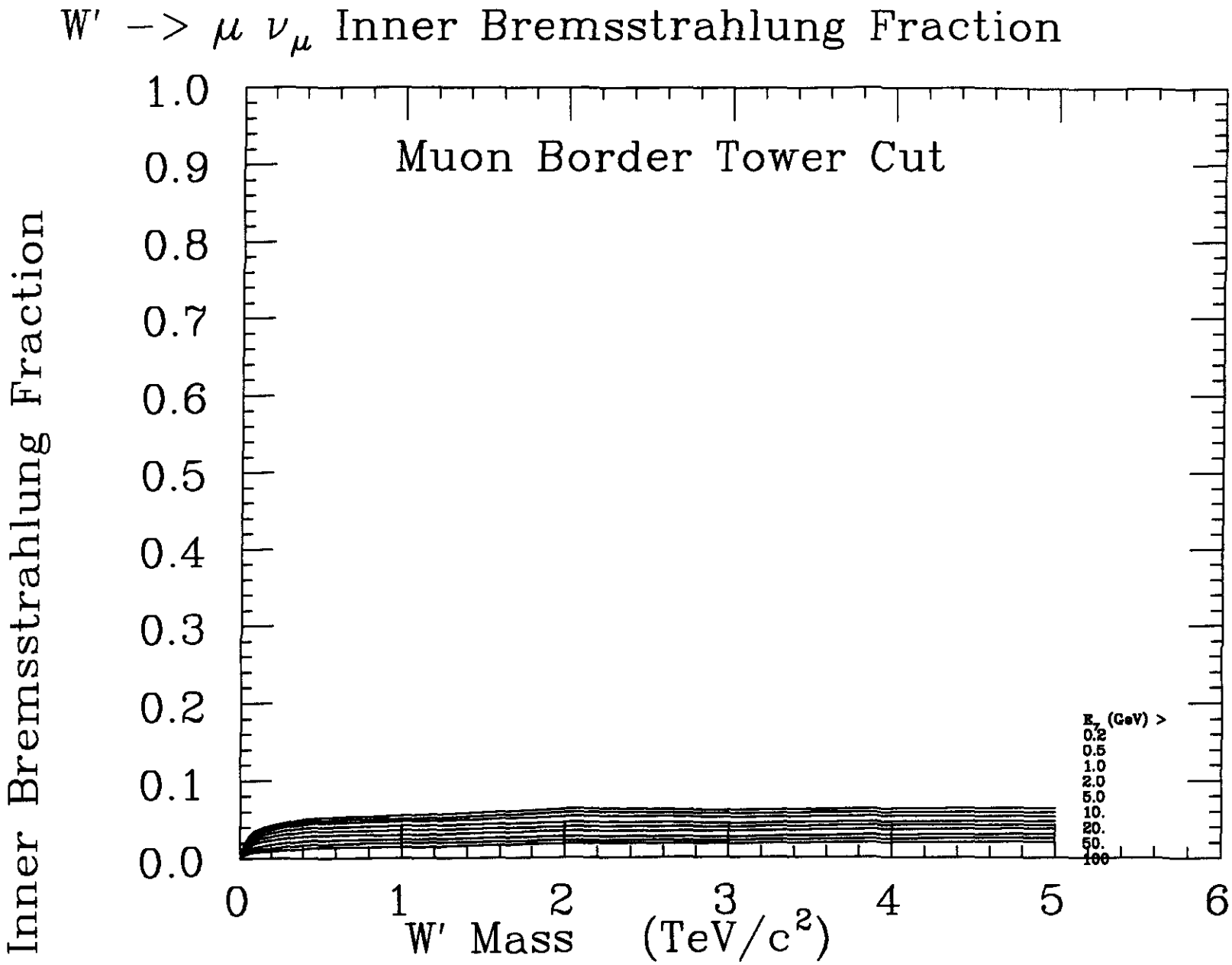
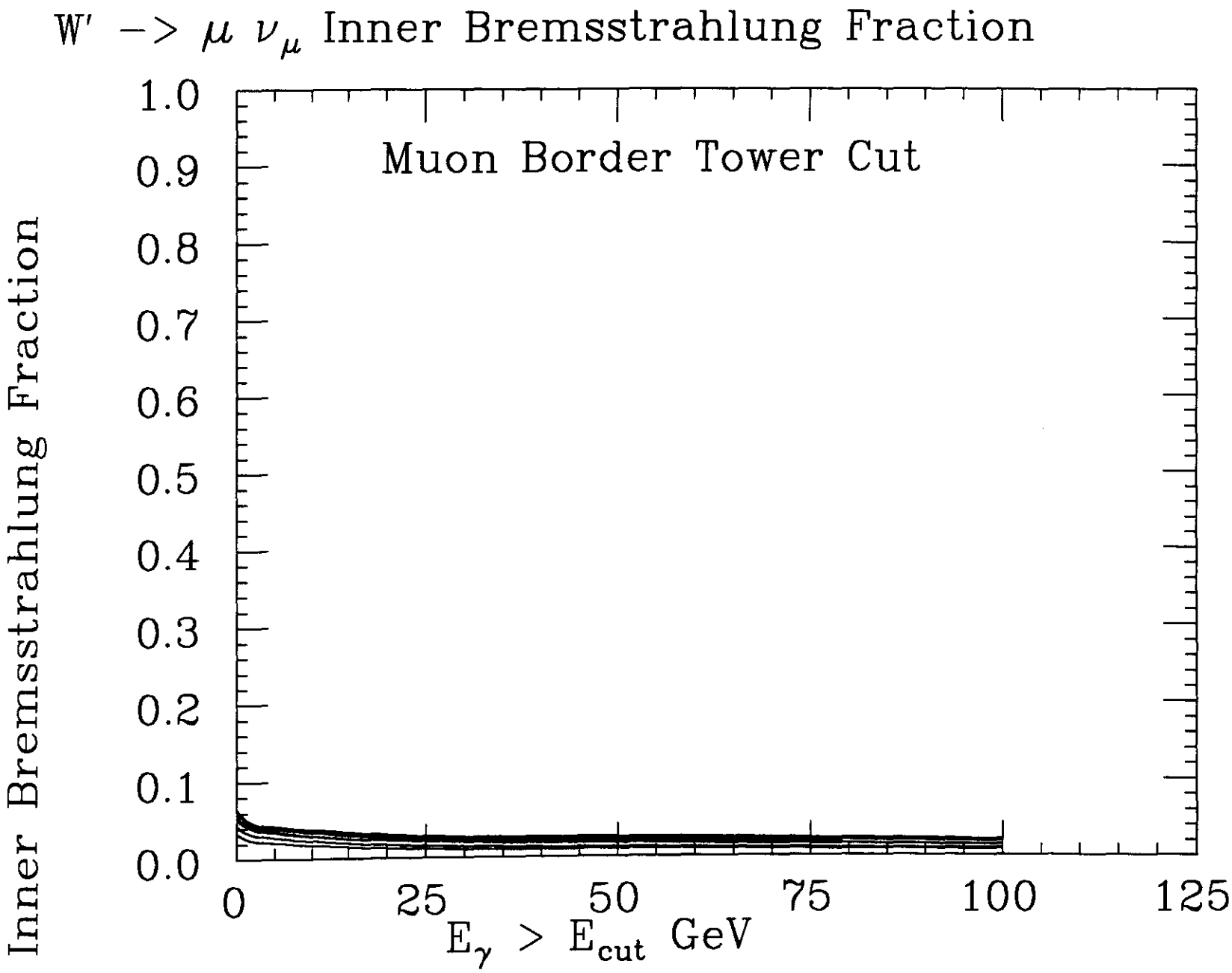

W' -> μ ν_μ Inner Bremsstrahlung Fraction
Muon Border Tower Cut
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
W' Mass (TeV/c²)
E_T (GeV) >
0.2
0.5
1.0
2.0
5.0
10.
20.
50.
100

Fig 15


W' -> μ ν_μ Inner Bremsstrahlung Fraction
Muon Border Tower Cut
Inner Bremsstrahlung Fraction
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
E_γ > E_cut GeV

Fig