Summary of L3 results from the November 1995 LEP run at 130-140 GeV

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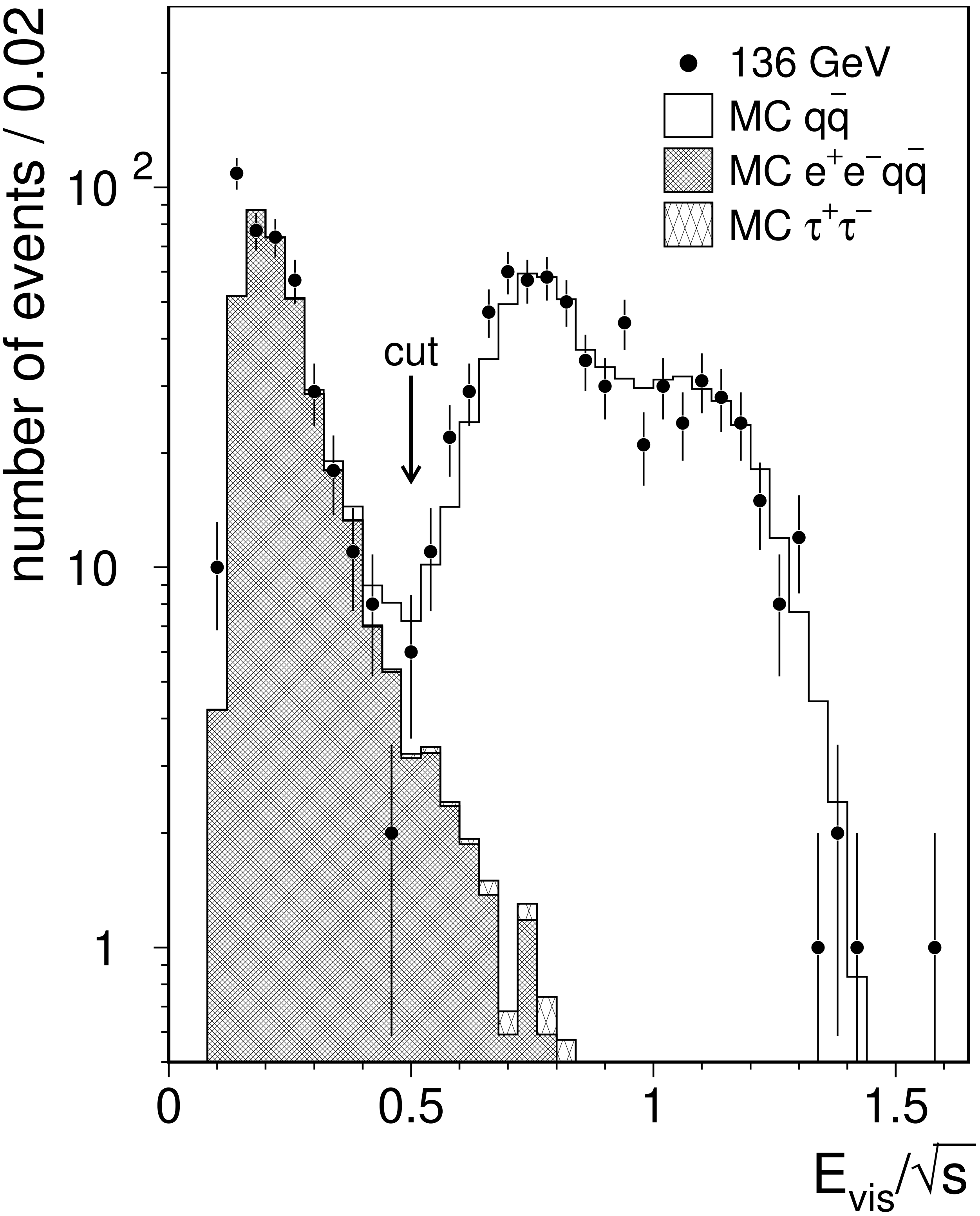
12 December 1995

Hadron Visible Energy Distribution



Hadron cross sections

We determine the cross section for $e^+e^- \to q\bar{q}$, including the radiative return to the Z events:

$\sqrt{s}$[GeV]	$\mathcal{L}$[pb^{-1}]	Events	$\sigma \pm \Delta\sigma_{stat.}$[pb]
130.3	2.754	921	341 ± 11
136.3	2.269	645	291 ± 12
140.0	0.047	11	233 ± 70

The total systematic uncertainty per measurement is estimated to be of order 1-1.3%, and is therefore small compared to the statistical errors

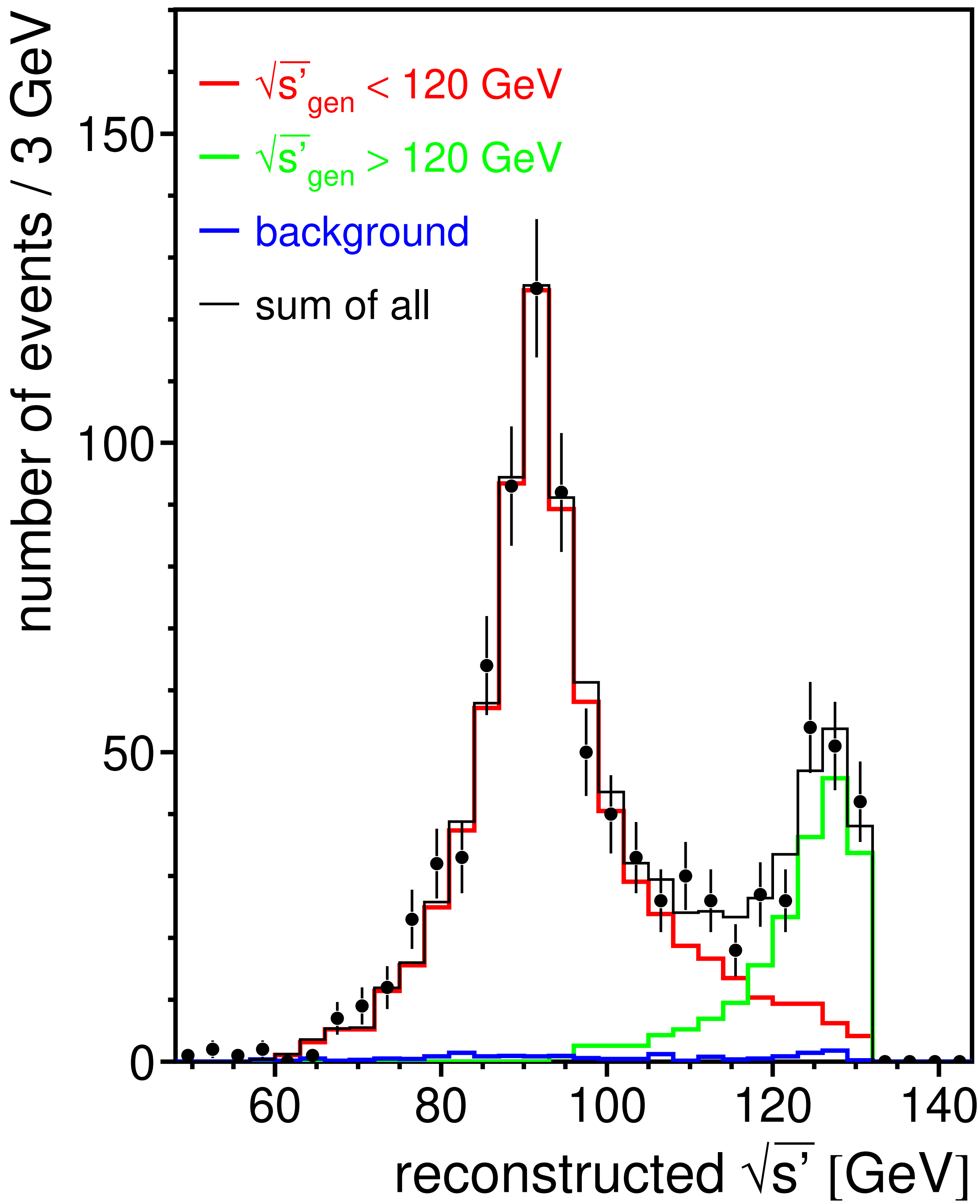
Separation of "full beam energy" and "return to Z" events

Determine an effective center of mass energy, s':

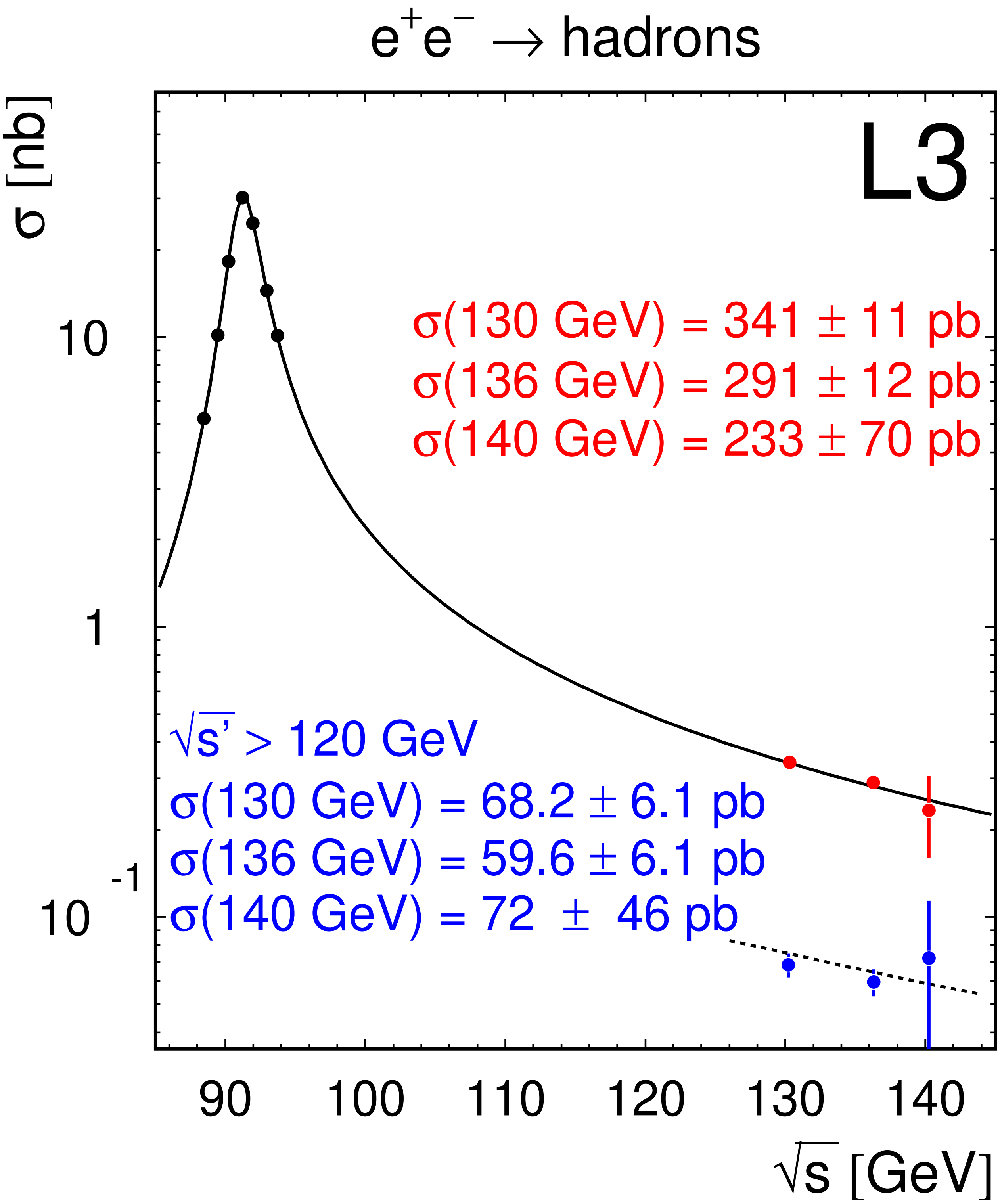
- Use measured energy of an isolated photon
- Perform a kinematic fit to two jets and missing energy to approximate the missing photon

$$s' = s - 2E_\gamma\sqrt{s}$$

Fit to s' distributions for 130 GeV Data

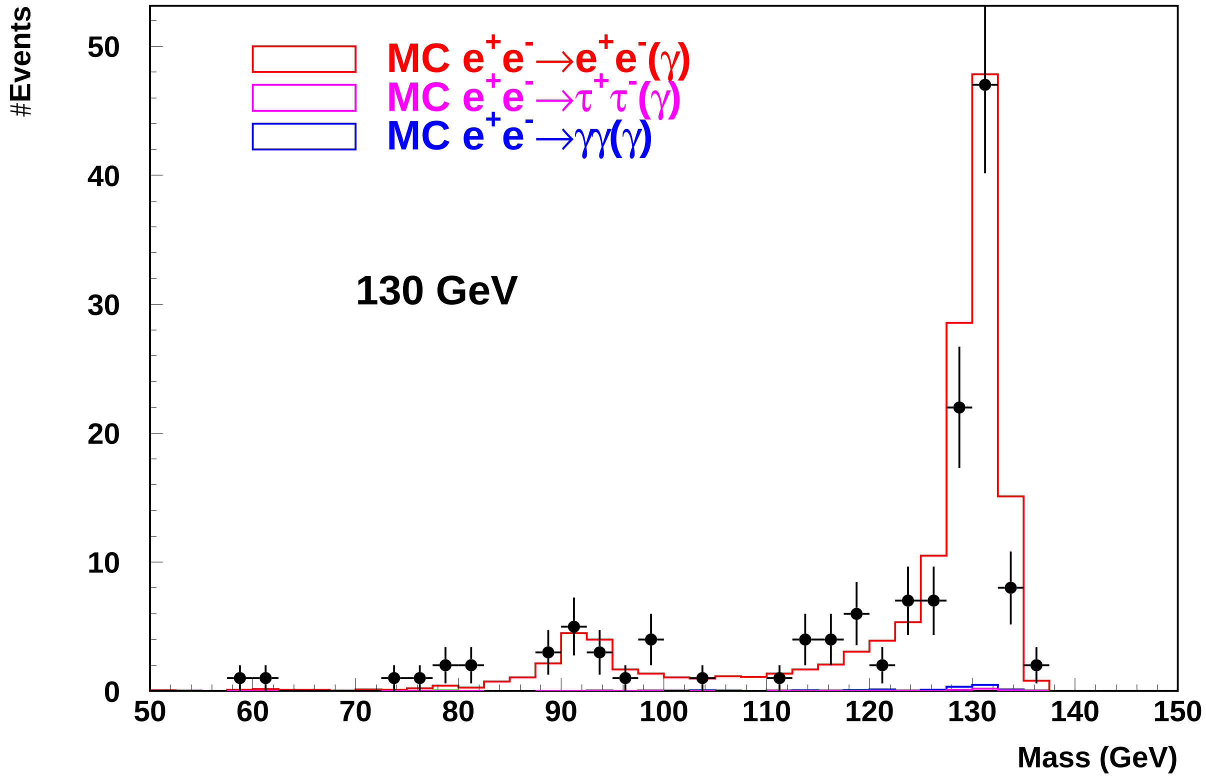


Hadron Cross Sections

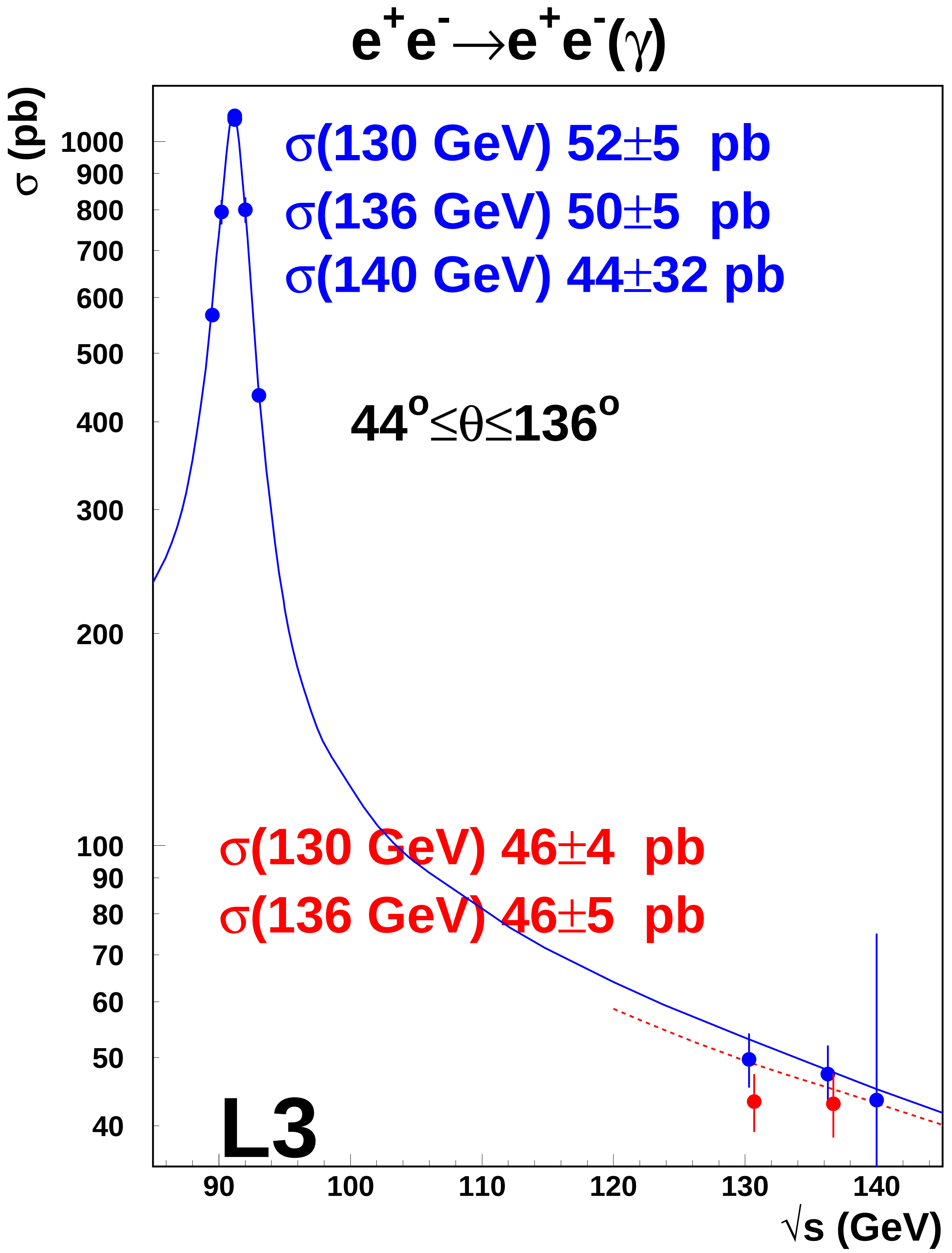


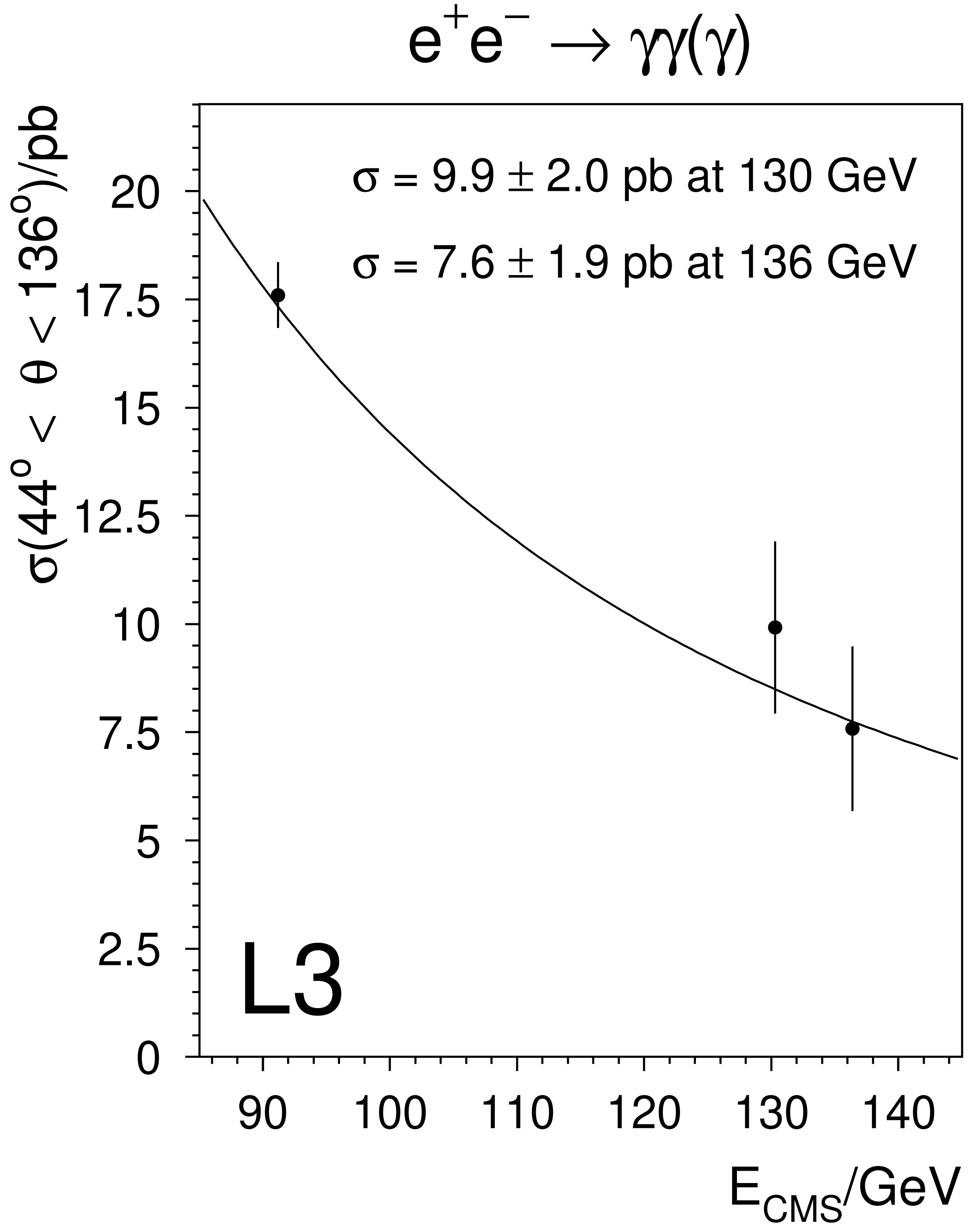
Bhabha Cross Sections

The BGO energy resolution combined with the TEC/SMD tracking make the selection of Bhabha events and the calculation of the effective center of mass energy straightforward:



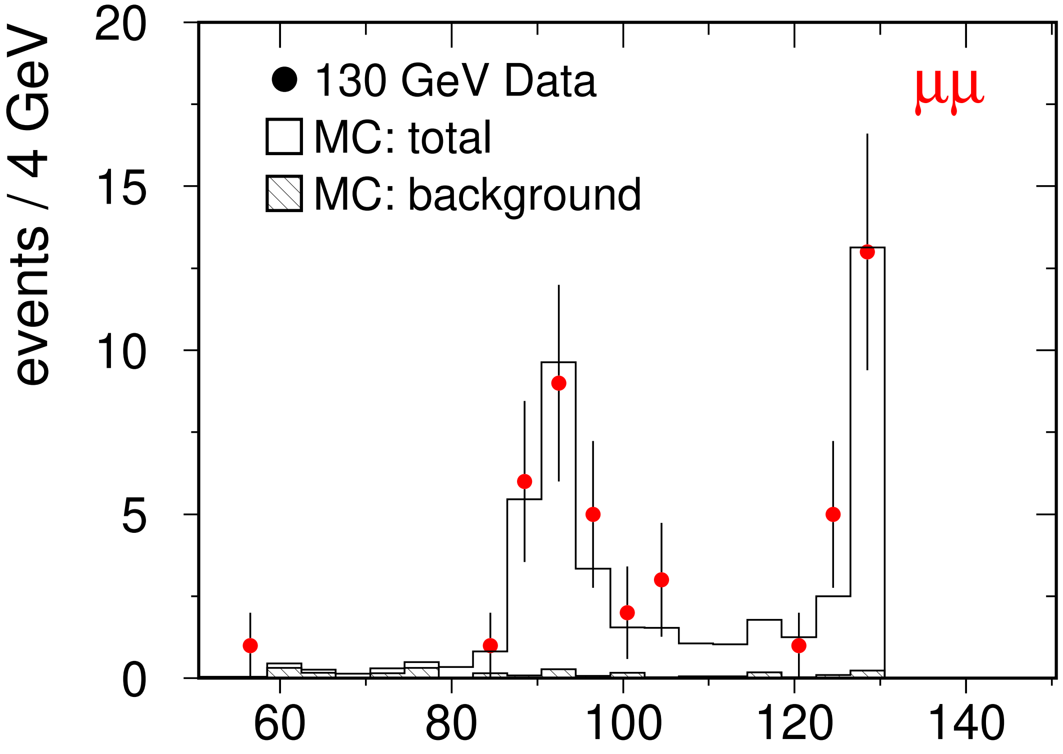
Bhabha Cross Sections

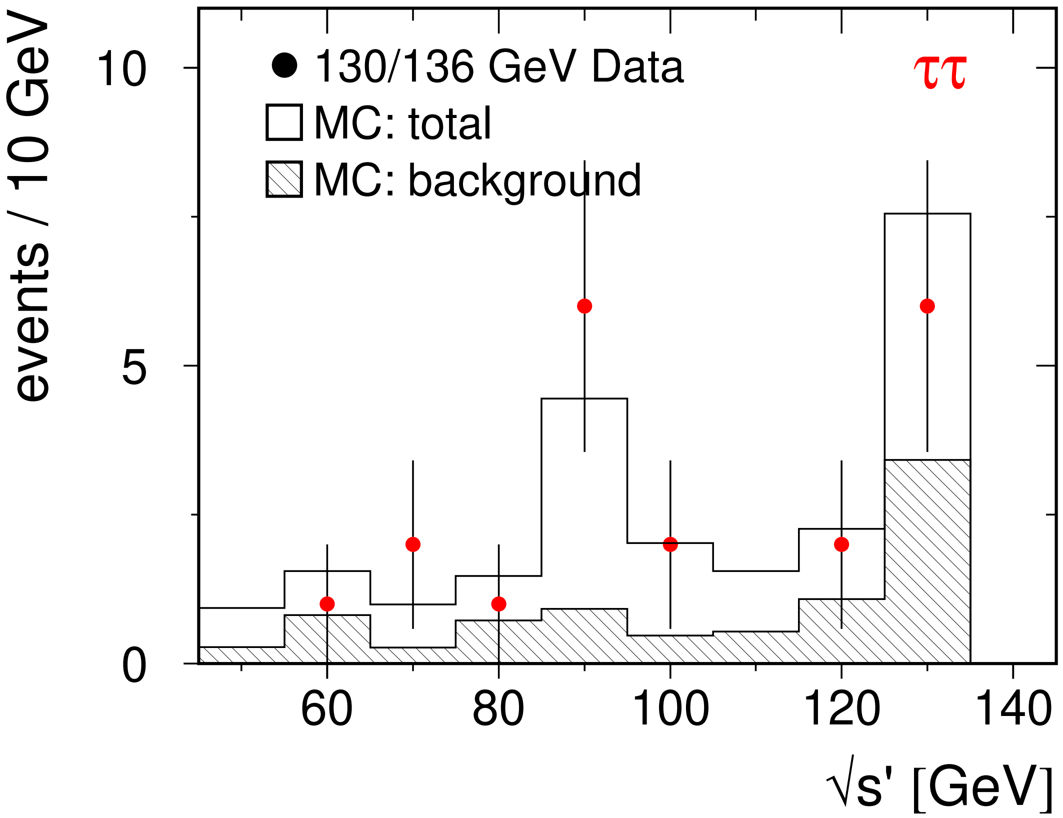




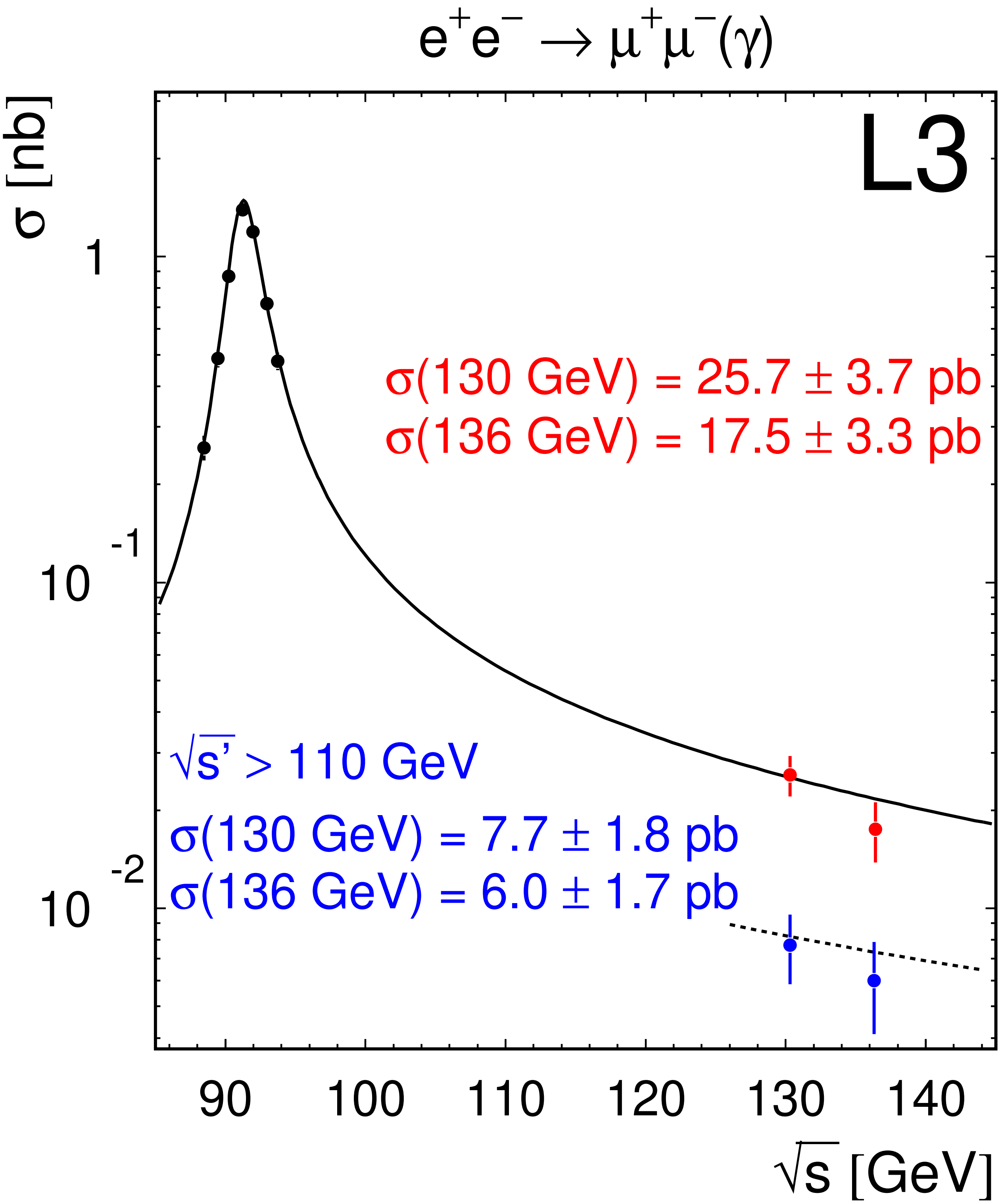
e+e− → γγ(γ)
σ = 9.9 ± 2.0 pb at 130 GeV
σ = 7.6 ± 1.9 pb at 136 GeV
σ(44° < θ < 136°)/pb
0
2.5
5
7.5
10
12.5
15
17.5
20
90
100
110
120
130
140
E_CMS/GeV
L3

Dimuon and Tau-pair Production

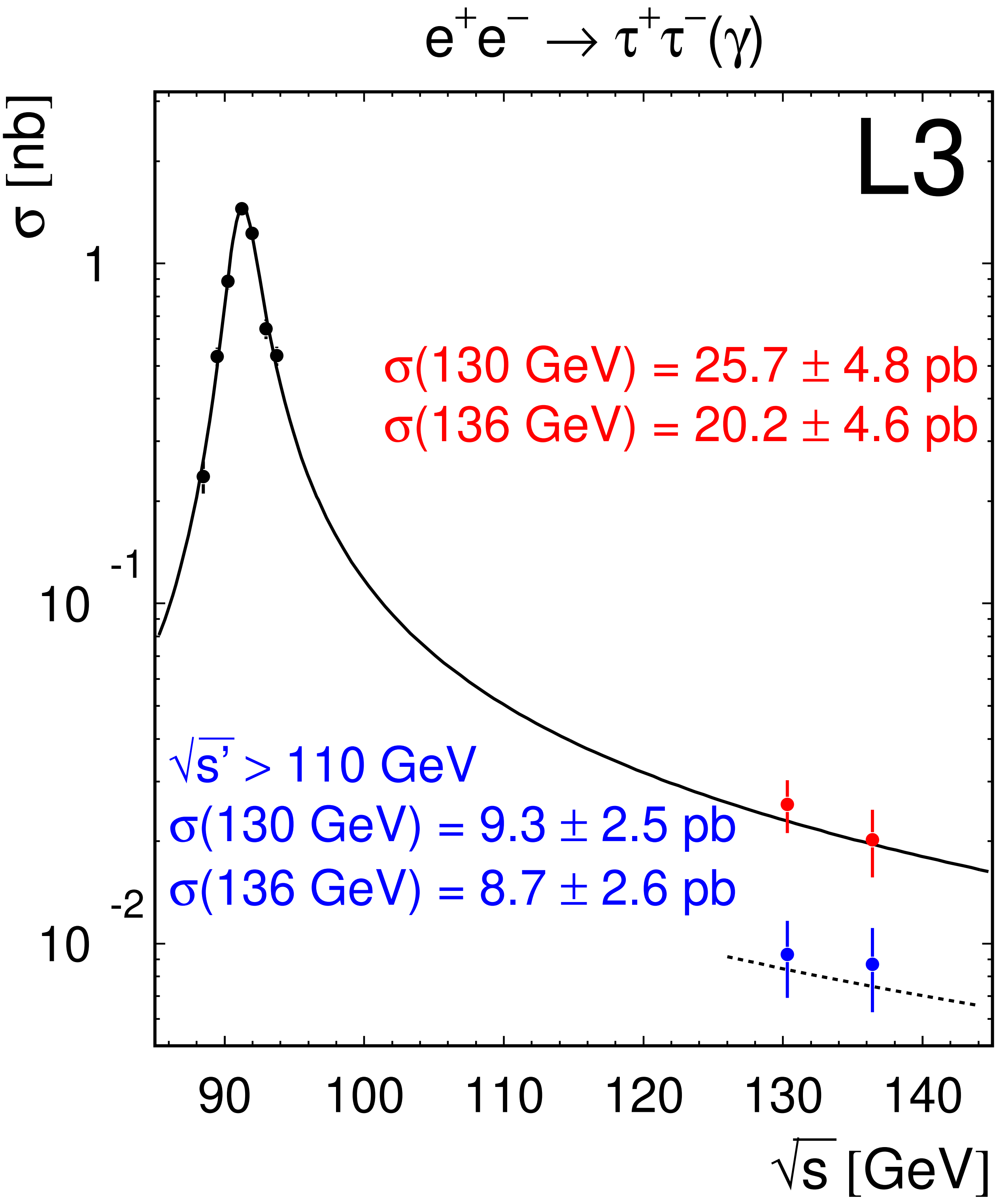




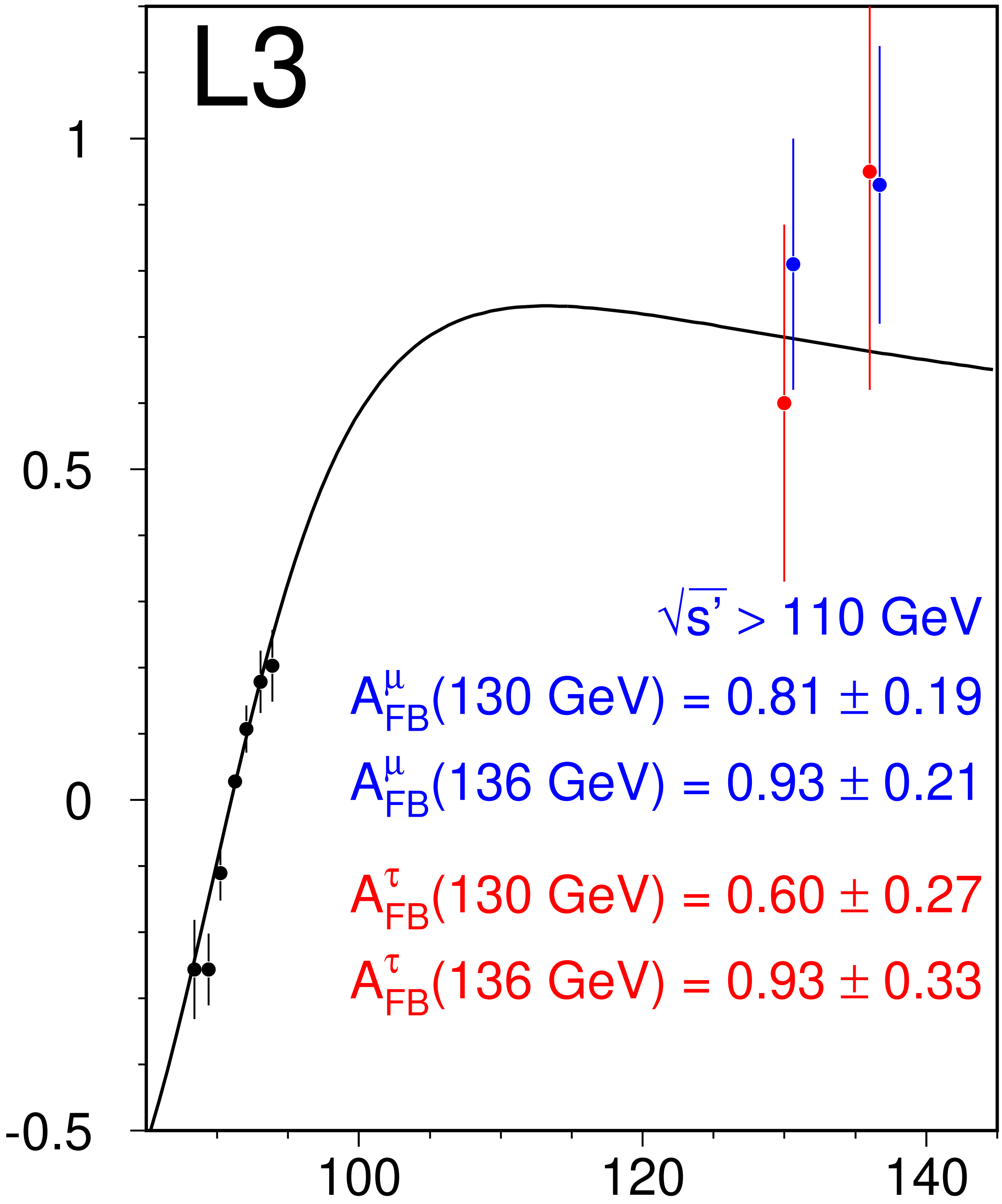
Dimuon cross sections



Tau-Pair Cross Sections



Lepton Forward-Backward Asymmetry



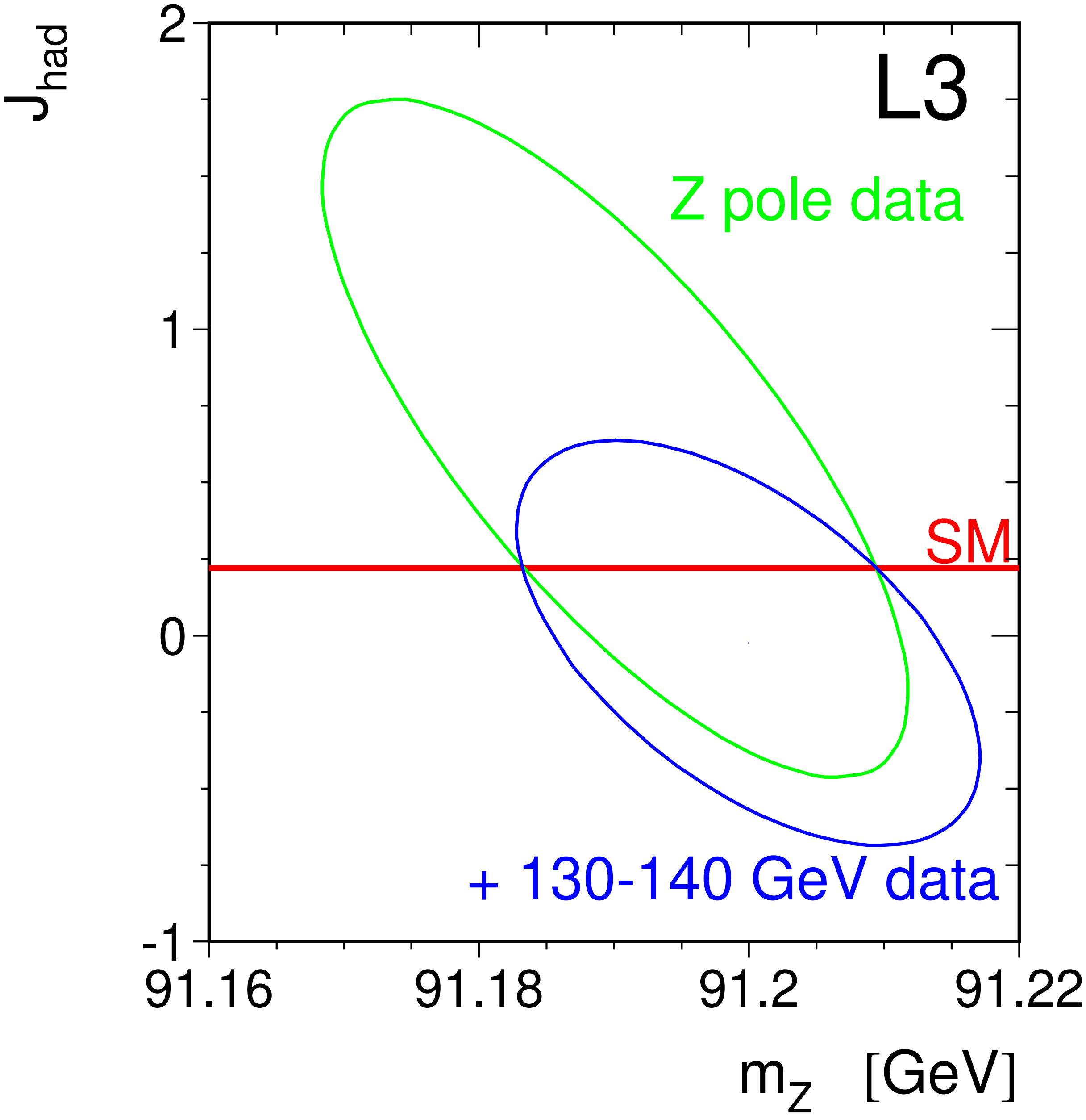
- At $\sqrt{s} = M_Z$ we use a standard model fit to determine the Electroweak parameters, such as M_Z
- Alternatively, we can make fewer theoretical assumptions as in the S-matrix ansatz
  - In this case the Interference terms between Z and γ exchange are free parameters.
  - We can leave them free and the uncertainty in j_{had} enters directly into the M_Z measurement, or
  - They can be fixed to the Standard Model values

From the 1990-1992 published L3 data we have:

	Standard Model fit	S-Matrix fit
M_Z[MeV]	91195 ± 9	91190 ± 14
j_{had}	0.2 FIXED	0.64 ± 0.73

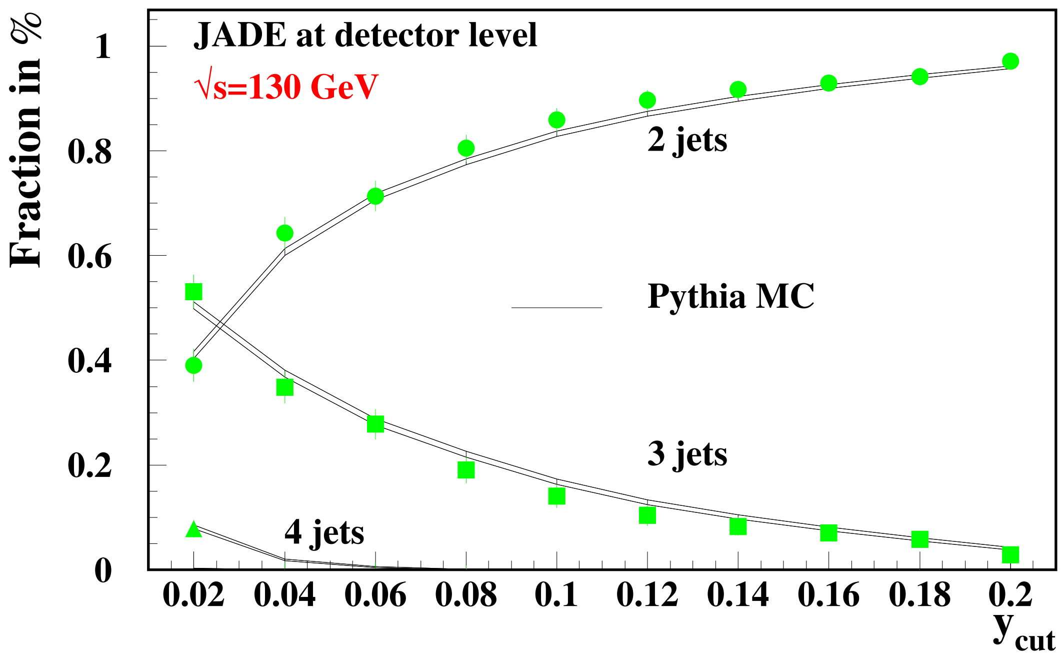
However,the 130 GeV data is much more sensitive to the interference term. After an s' cut the contributions to the full energy cross section are almost equal from Z and from γ exchange.

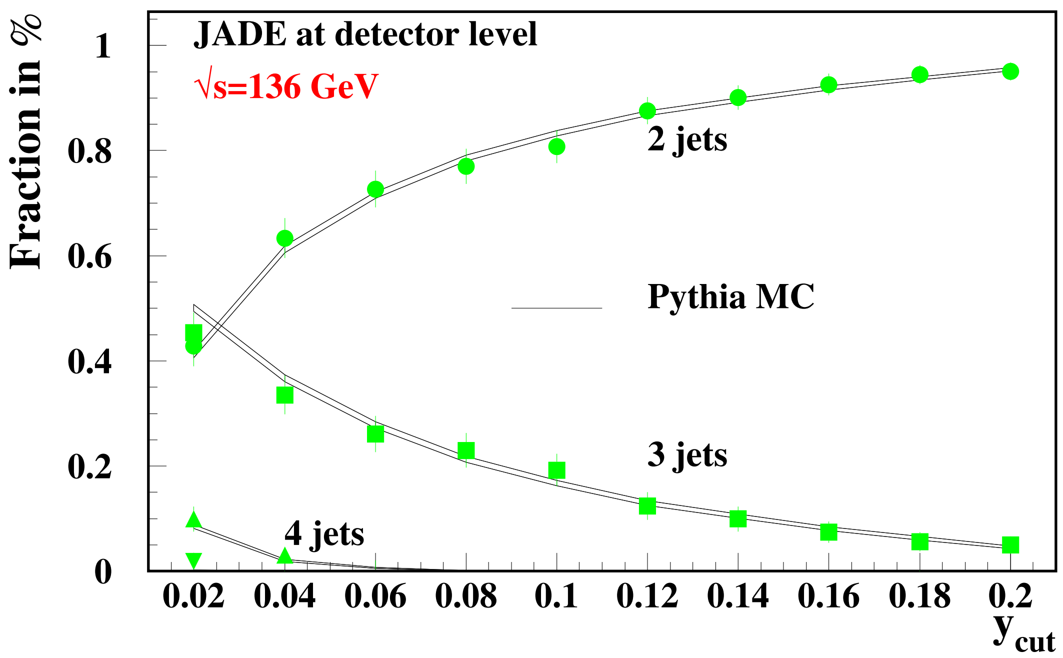
j_{had}



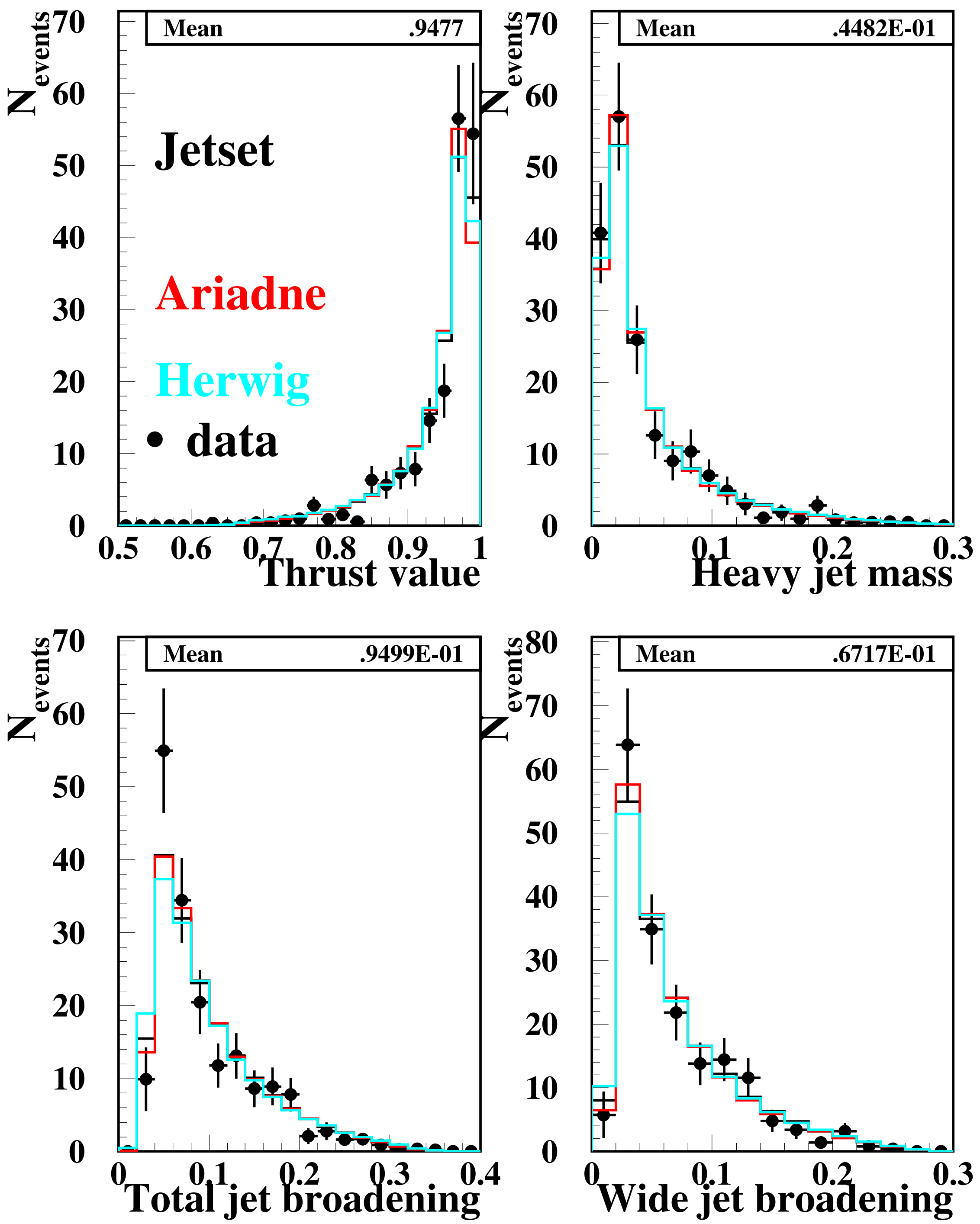
	1990 → 1992 published Z data + LEP1.4 data with s' cut
M_Z[MeV]	91200 ± 11
j_{had}	-0.02 ± 0.44
Correlation Coeff.	-0.57

Jet Multiplicities

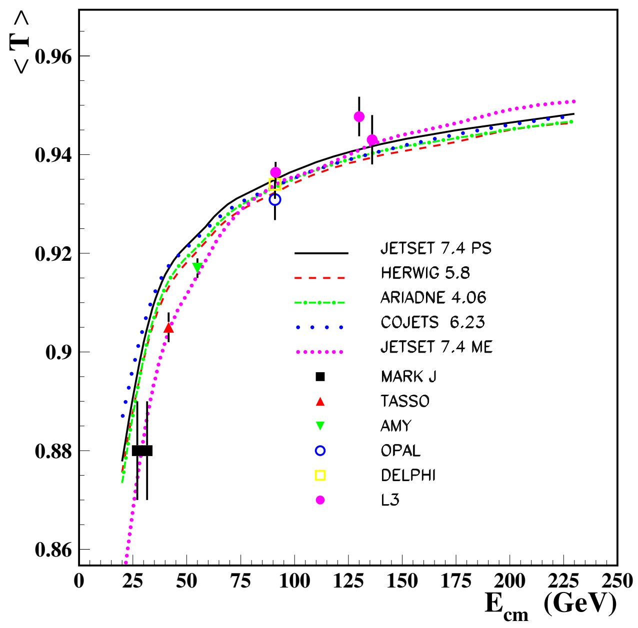




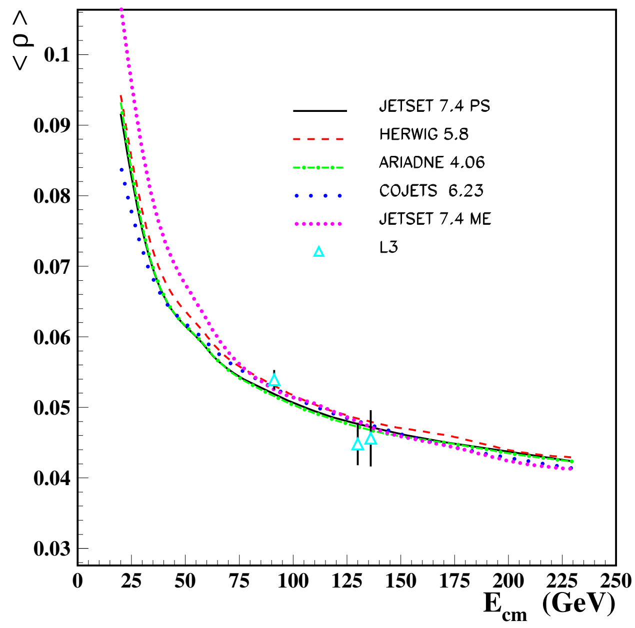
Comparisons with QCD Models at particle level



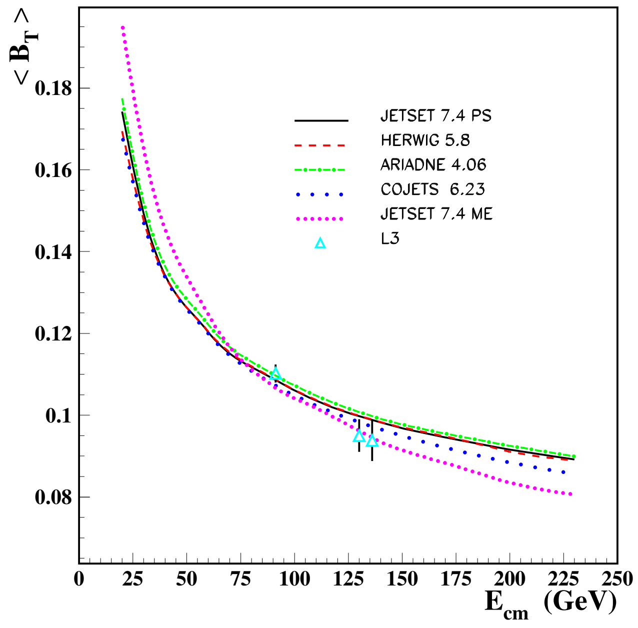
Event Shape Variables



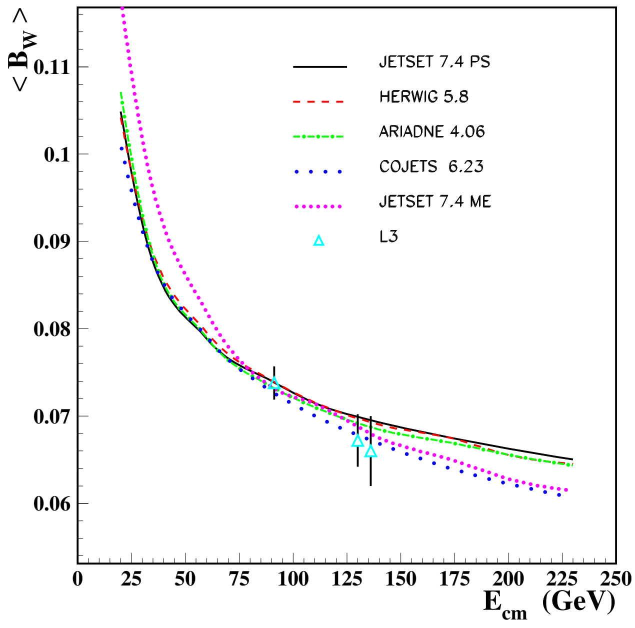
THRUST



HEAVY JET MASS



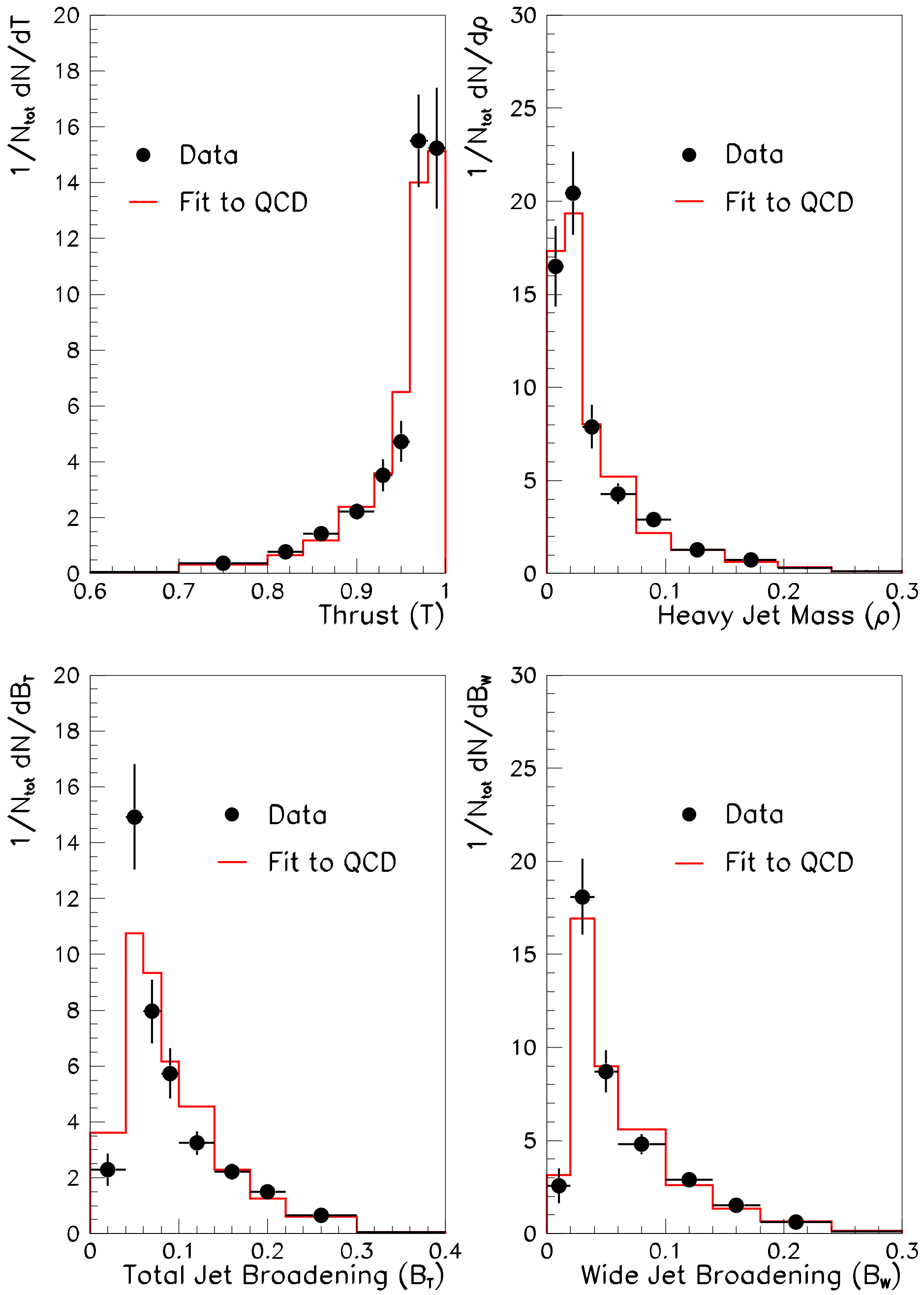
TOTAL JET BROADENING



WIDE JET BROADENING

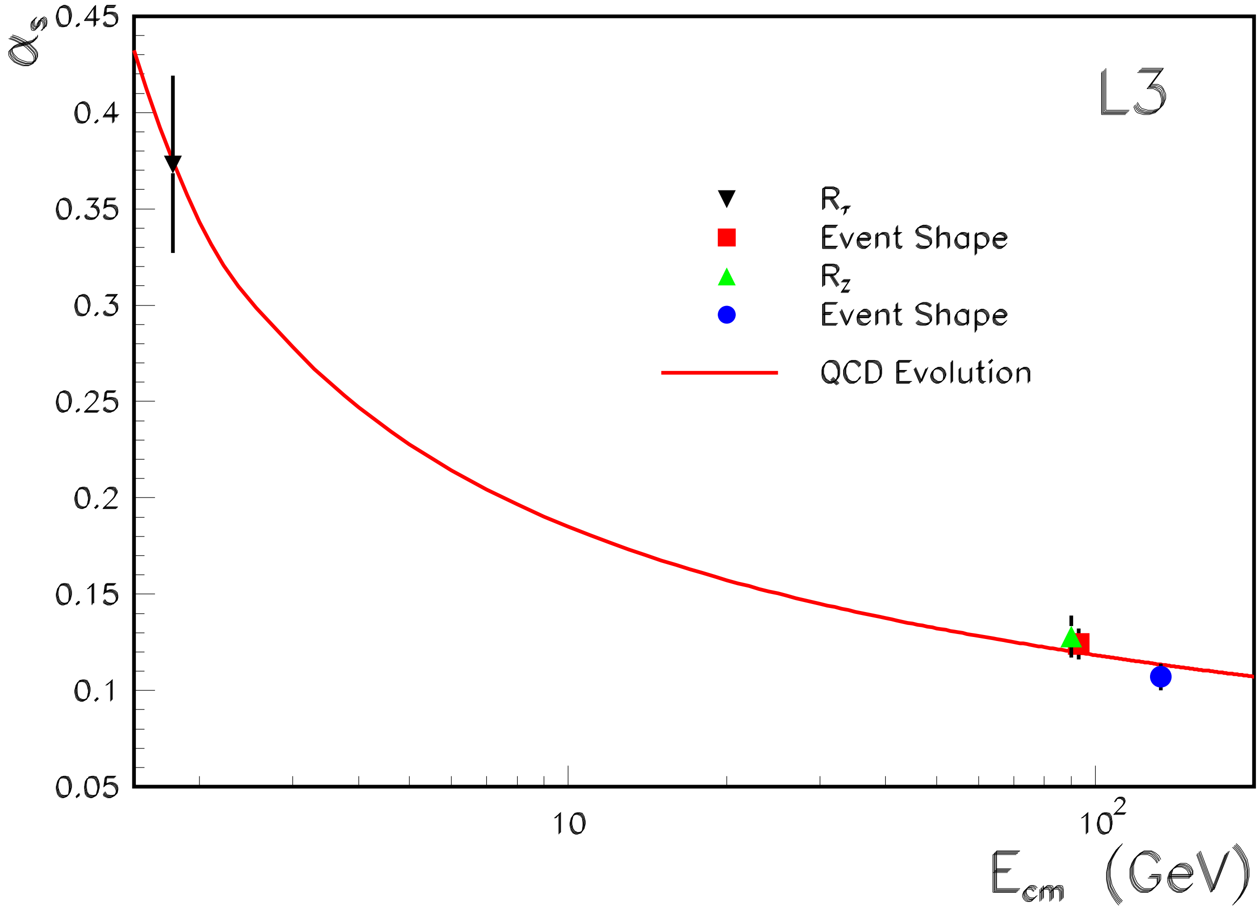
Fitting Event Shape Variables for α_s

Using a 2nd order and re-summed QCD description we can fit the measured event shape variables to extract α_s.



$$\alpha_s(133\ \mathrm{GeV}) = 0.107 \pm 0.005(\mathrm{Expt.}) \pm 0.006(\mathrm{Theory})$$

Running of α_s



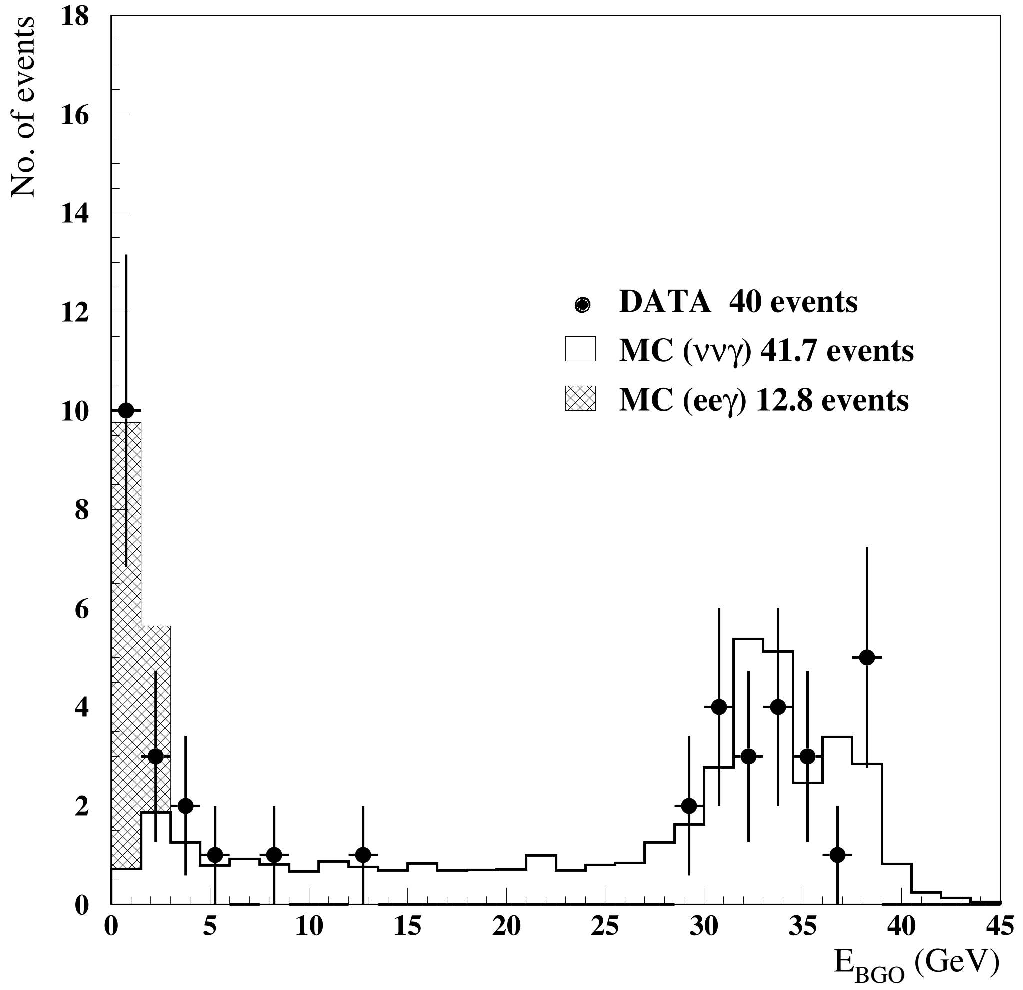
The energy dependence of the strong coupling constant

Single Photon Events

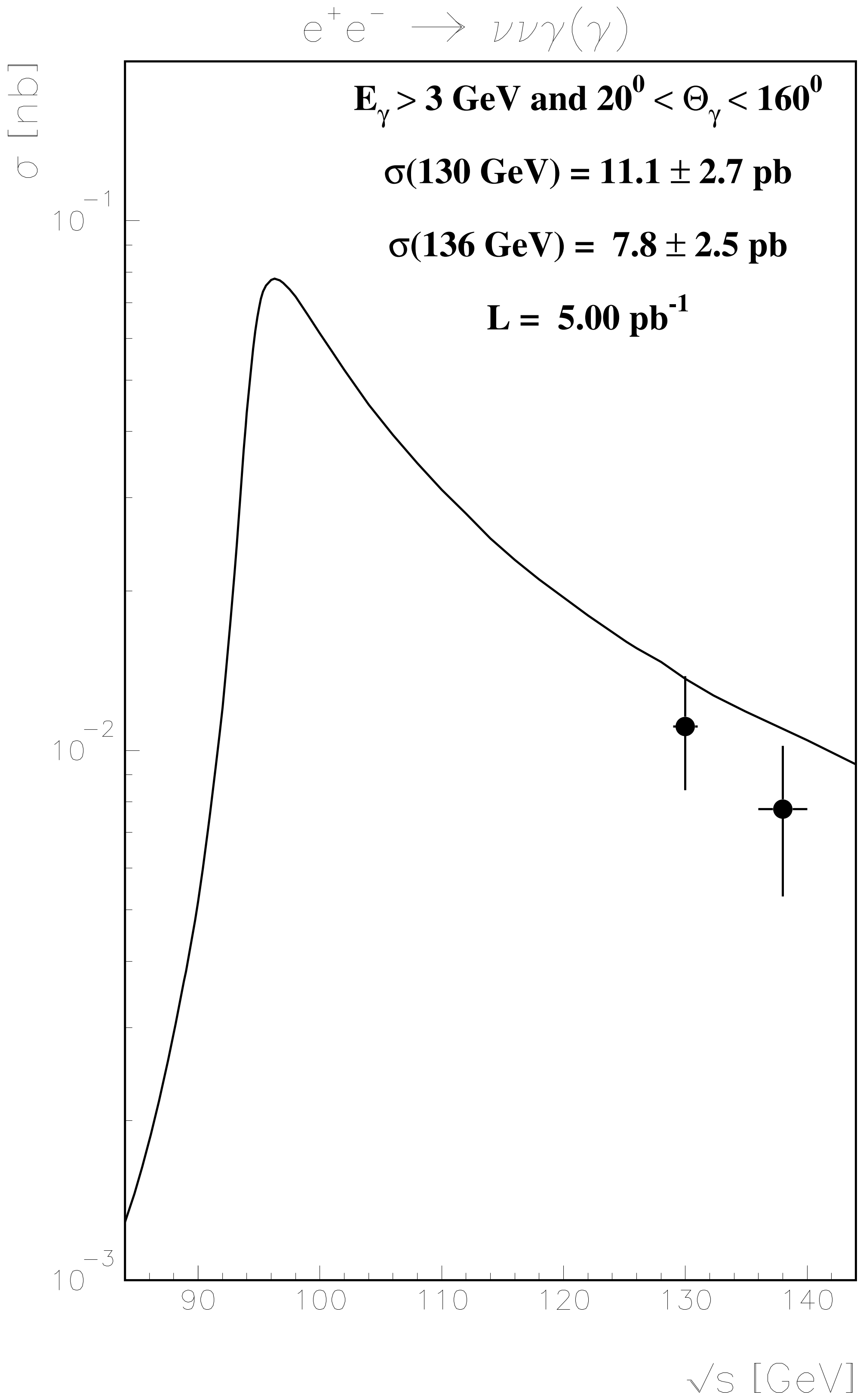
We search for photons in the angular and energy ranges:

- $45^\circ < \theta_\gamma < 135^\circ$, $E_\gamma > 1$ GeV.
- $20^\circ < \theta_\gamma < 35^\circ$ and $145^\circ < \theta_\gamma < 160^\circ$, $E_\gamma > 10$ GeV.

- Efficiency within fiducial cuts: $56 \pm 0.5\%$
- Trigger efficiency uncertainty: $< 2\%$
- Veto efficiency against noise: $96.7 \pm 0.5\%$

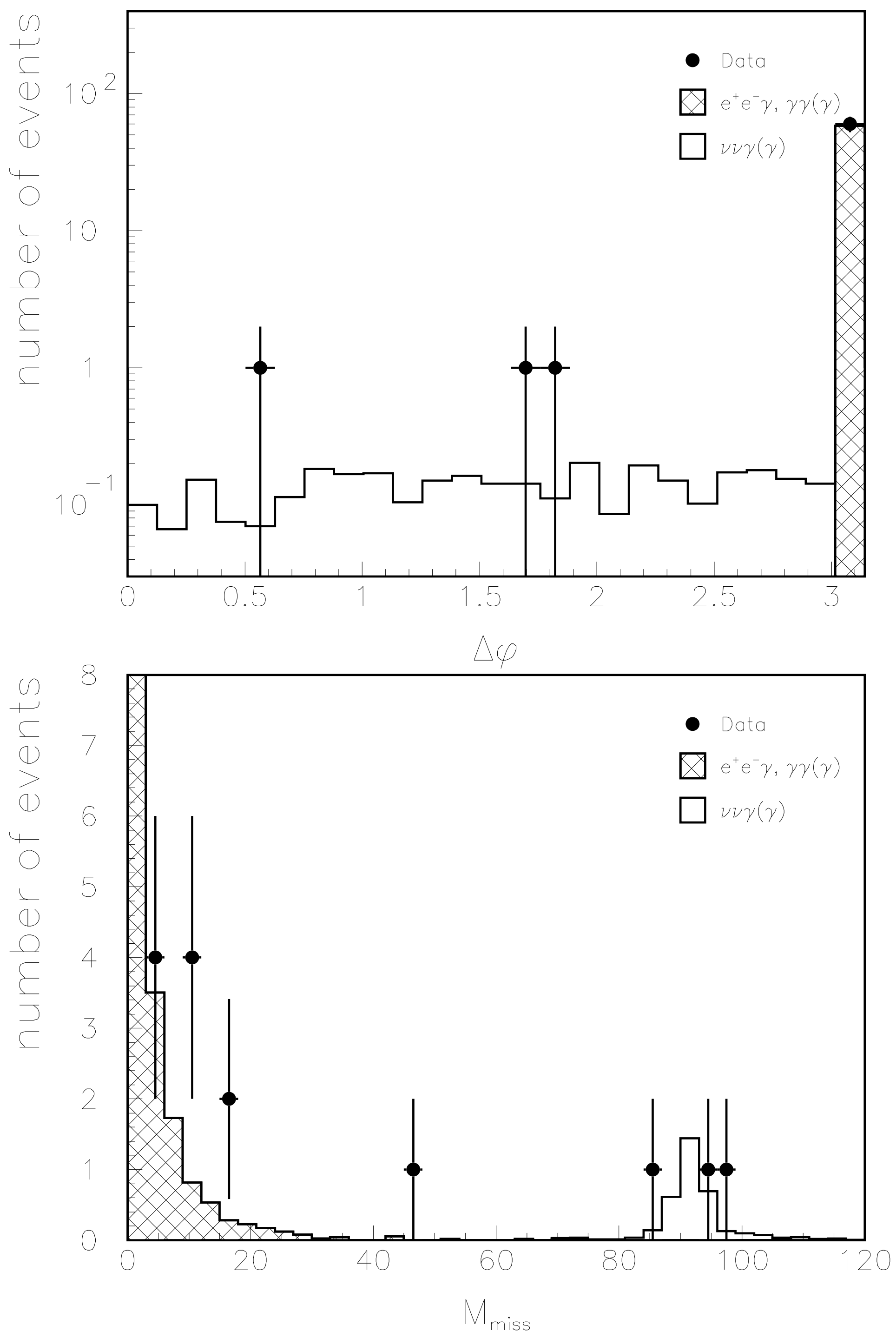


Single Photon Events



Double Photon Events

Requiring a second photon of at least 2 GeV we find three events consistent with $e^+e^- \to \nu\nu\gamma\gamma$. The MC expectation is also three events.



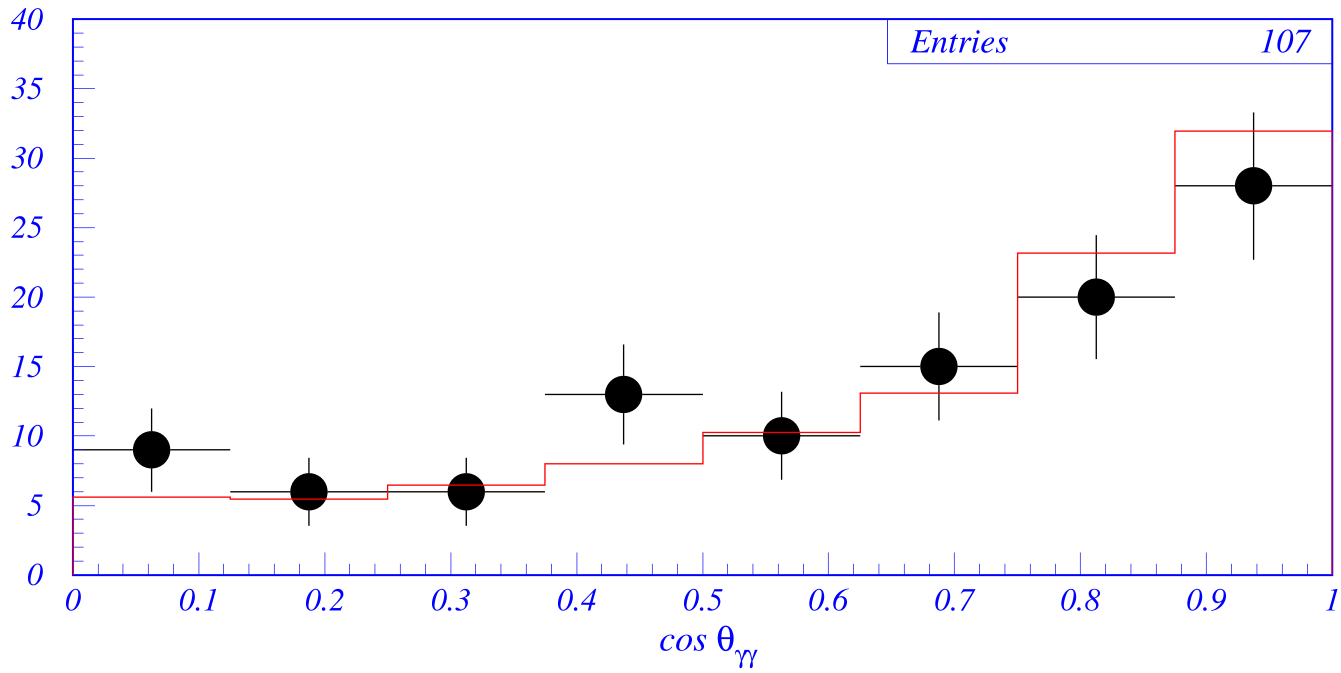
QED Studies, $e^+e^- \to \gamma\gamma(\gamma)$ events.

- $\mathcal{L} = 4.95\text{pb}^{-1}$
- Two or more photons of at least 1 GeV, $\Sigma E_\gamma > 0.5\sqrt{s}$
- Acceptance in the angular range $(16^\circ < \theta < 164^\circ) = (88.2 \pm 0.4)\%$
- Number of $\gamma\gamma(\gamma)$ events selected = 107

$$\sigma(16^\circ < \theta < 164^\circ) = 24.3 \pm 2.4\text{pb}$$

$$(\sigma_{QED} = 24.0\text{pb at } \sqrt{s} = 133 \text{ GeV})$$

$$(ee(\gamma)\text{background} \simeq 1\%)$$



QED Deviations

QED deviations can be introduced by modifying the angular distributions expected from QED with the introduction of cut-off parameters, Λ:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}\Big|_{QED}(1 + f(\Lambda, \cos\theta)) \cdot \epsilon(\cos\theta)$$

The fit is in terms $1/\Lambda^4$ and yields:

$$\frac{1}{\Lambda^4_{FIT}} = \left(0.98^{+1.34}_{-1.12}\right) \cdot 10^{-9}\ \mathrm{GeV}^{-4}$$

$\rightarrow$ NO QED DEVIATIONS

We can interpret this in terms of 95% Confidence Limits:

$\Lambda_+ > 131$ GeV (compared to 149 GeV in our last QED paper [1])

$\Lambda_- > 167$ GeV (was 143 GeV)

$\Lambda_6 > 535$ GeV (A contact interaction scale parameter) (was 602 GeV)

and

$m^*_e > 115$ GeV (was 146 GeV)

The $5\mathrm{pb}^{-1}$ at 130 GeV yield about the same QED limits as LEP I

[1] CERN PPE/95-41, Phy.Lett. **B353, 1995, p.136-144**

Multiphoton events

Following the observation of a spectacular 4 photon event we have looked more carefully at the 3 and 4 photon events in the LEP130 and LEP I data.

LEP130 3-photon events

Using the same cuts as defined in our previous paper:

- $E_{\gamma 1}, E_{\gamma 2}, E_{\gamma 3} > 5$ GeV
- Angle between pairs of photons, $\alpha_{ij} > 15°$
- Angle sum, $\Sigma\alpha_{ij} > 350°$

$\Rightarrow$ We observe 1 event in data, with 3.3 expected

Relaxing the photon energy cut to 2 GeV:

$\Rightarrow$ We observe 2 events in data, with 4.8 expected

Multiphoton events

LEP130 4-photon events

With the requirement for there to be 4 photons each of at least 3 GeV and at least one of them with an energy above 10 GeV and observed in the barrel $(cos\theta < 0.7)$:

$\Rightarrow$ We observe 1 event in data, with 0.1 expected

LEP I 4-photon events

With the above cuts;

$\Rightarrow$ We observe 0 events in data, with 2 expected

and with a relaxed photon energy cut of 1 GeV:

$\Rightarrow$ We observe 3 events in data, with 4 expected

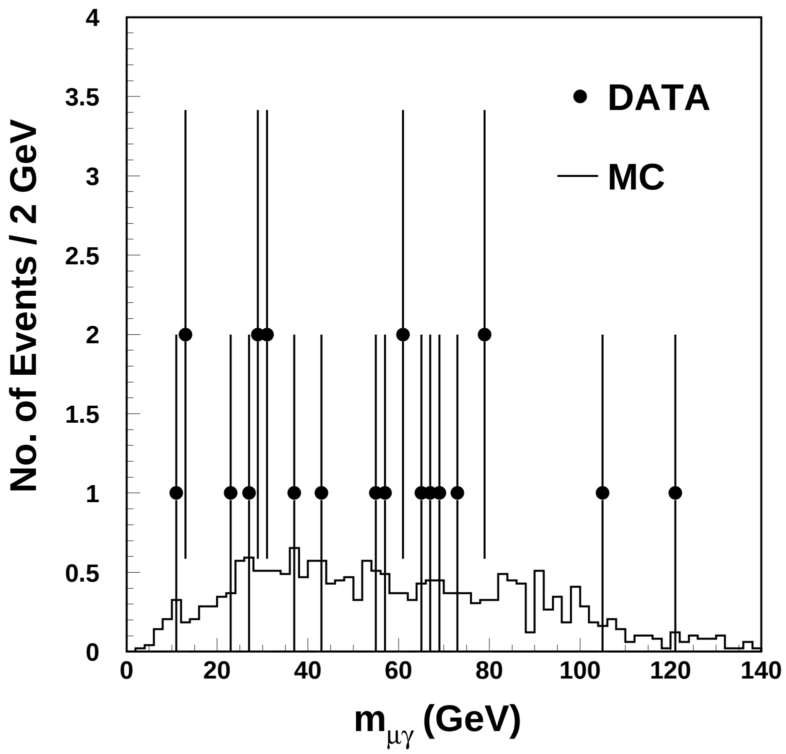
We conclude that we observe such events in total at about the predicted rate from QED. Though the 130 GeV event was certainly remarkable!

A natural consequence of composite models would be the existence of excited states ℓ^* of the known leptons ℓ.

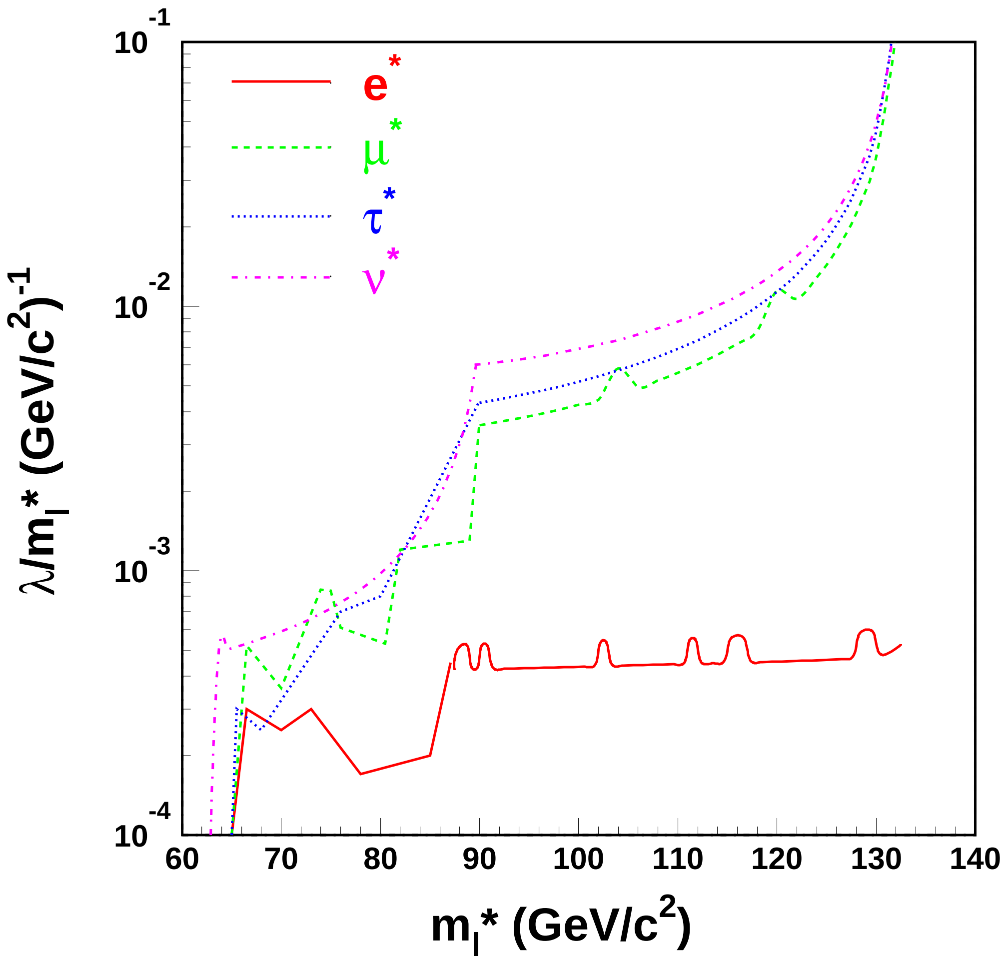
We consider both pair production, $(e^+e^- \rightarrow \ell^*\ell^*)$ and single production $(e^+e^- \rightarrow \ell^*\ell)$.

We search for decays of the type:

- $e^* \rightarrow e\gamma$
- $\mu^* \rightarrow \mu\gamma$
- $\tau^* \rightarrow \tau\gamma$
- $\nu^* \rightarrow \nu\gamma$ and $\nu^* \rightarrow e$W.



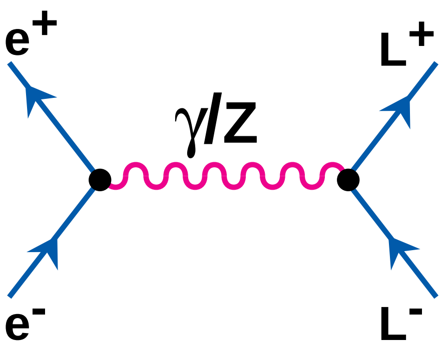
Excited Lepton Limits

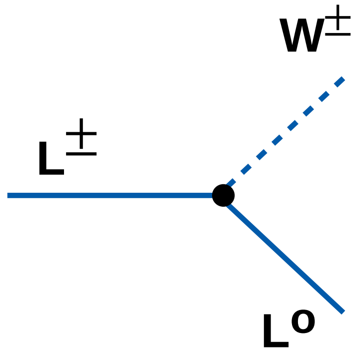


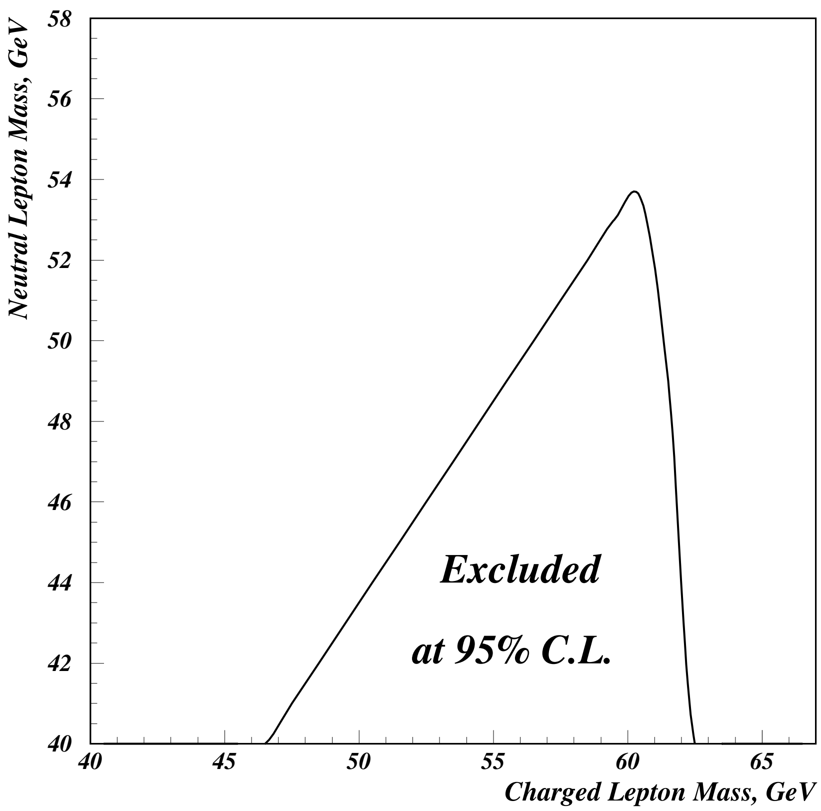
The upper limit of the coupling constant λ/m_{ℓ^*} at 95% C.L. as a function of m_{ℓ^*}.

Charged Heavy Leptons

Search for sequential charged heavy leptons decaying to stable neutral partners:

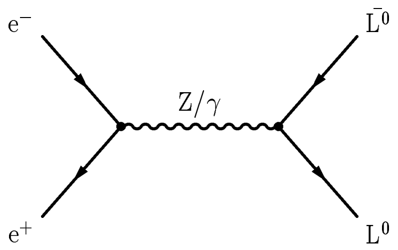


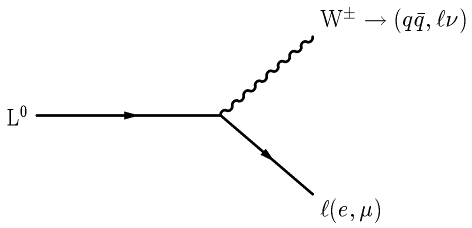




Neutral Heavy Leptons

Search for unstable sequential neutral heavy leptons:



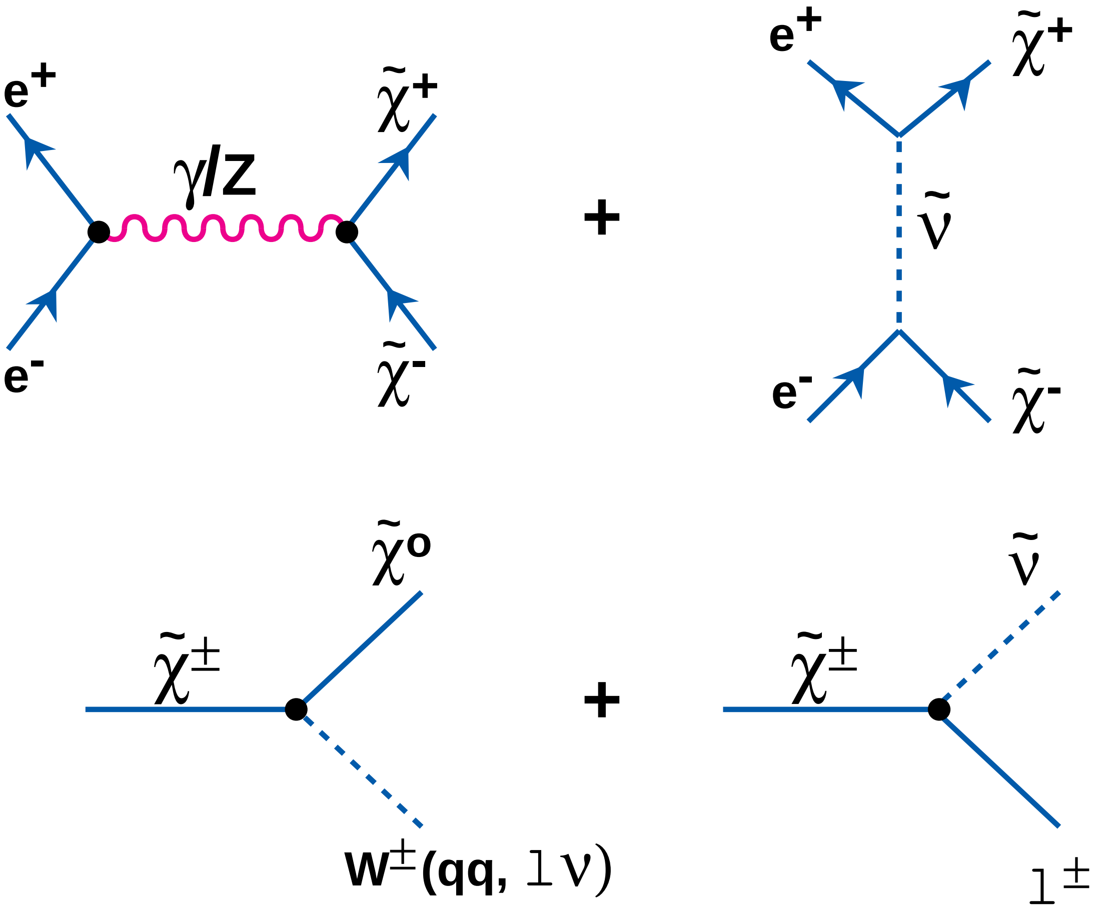


We observe no candidate events in the data.

$\Rightarrow$ 95% C.L. limits:

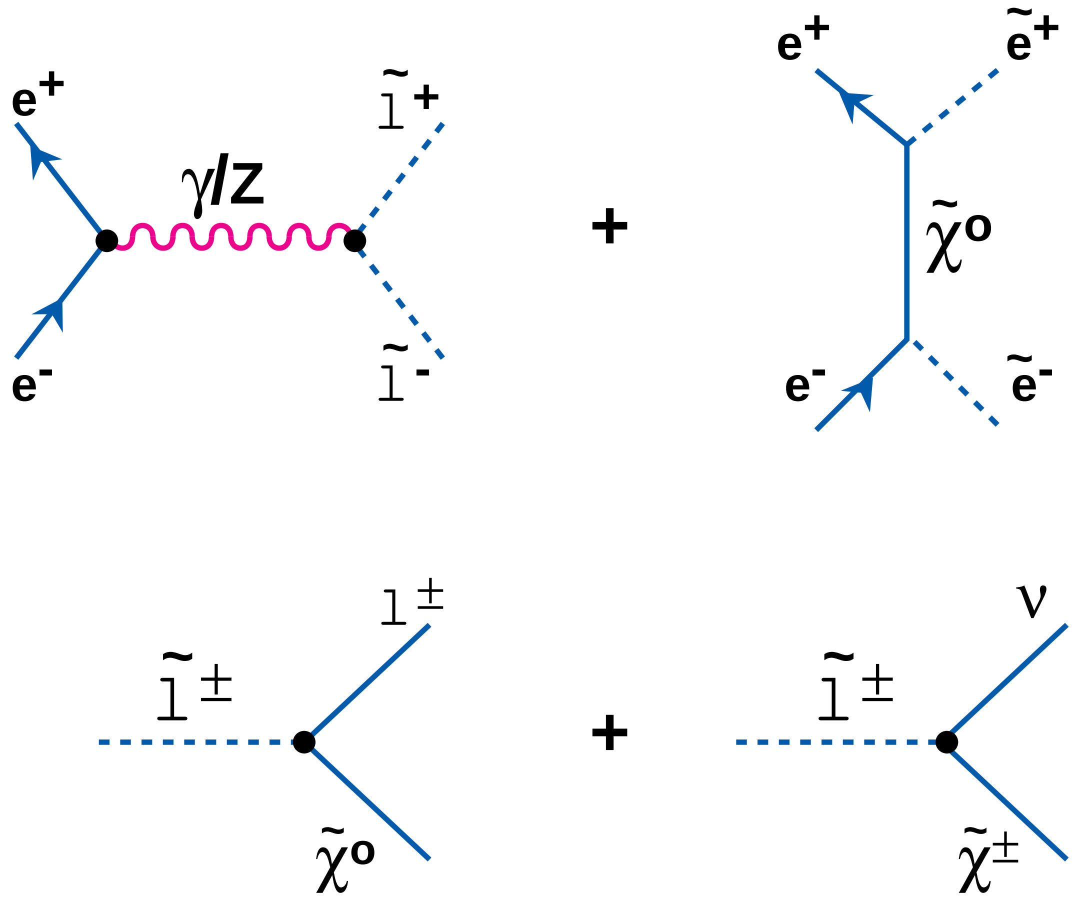
- DIRAC TYPE HEAVY LEPTONS
  - muon channel: $m_{L^0} > 58.9$ GeV
  - electron channel: $m_{L^0} > 60.2$ GeV
- MAJORANA TYPE HEAVY LEPTONS
  - muon channel: $m_{L^0} > 48.1$ GeV
  - electron channel: $m_{L^0} > 49.5$ GeV
- LEP I LIMITS
  - Dirac type: $m_{L^0} > 46.4$ GeV
  - Majorana type: $m_{L^0} > 45.1$ GeV

Chargino Production and Decay



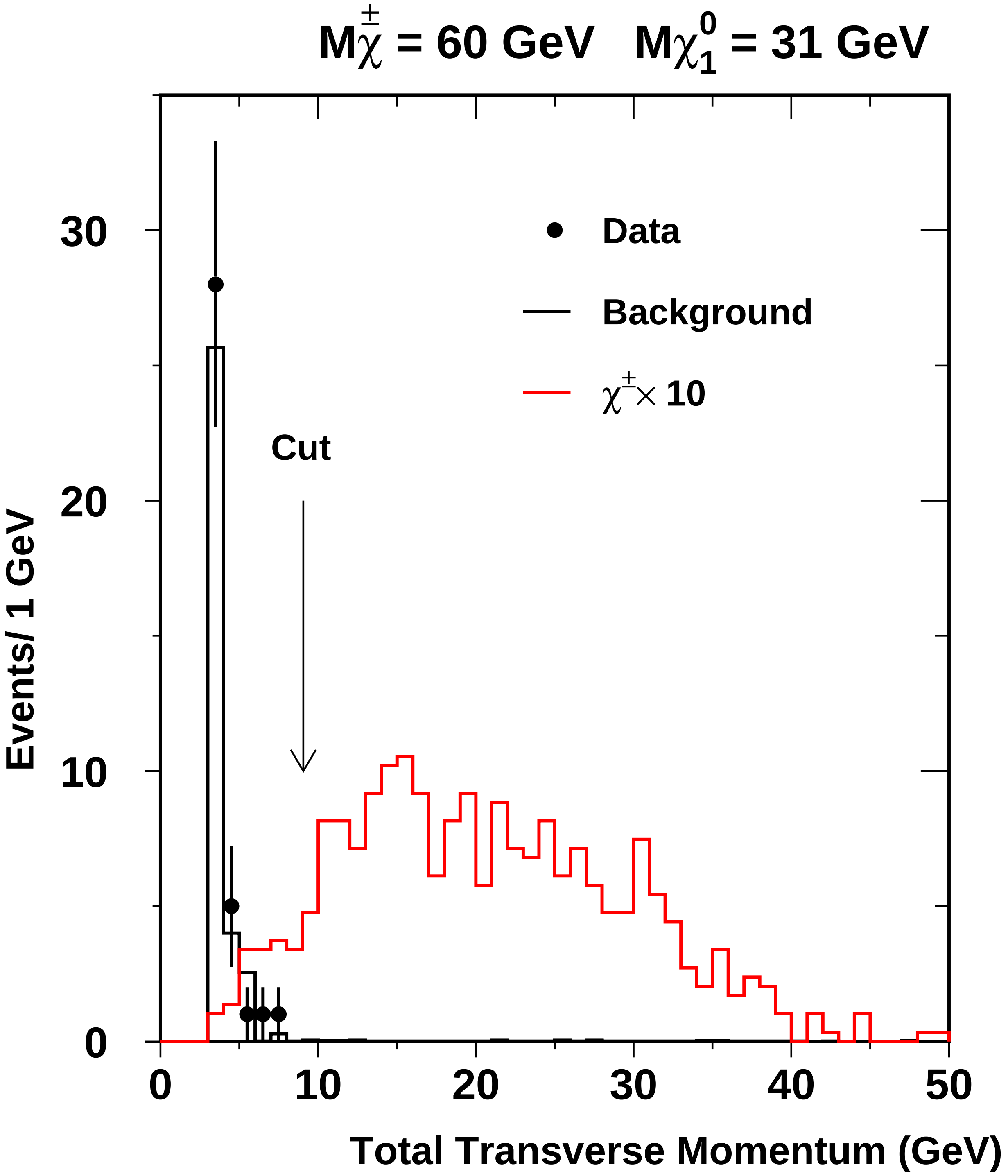
- Since gauginos couple with the $\tilde{\nu}$ whereas higgsinos do not, the contributions of the two production mechanisms depend on the field content of the chargino.
- The decay $\tilde{\chi}^{\pm} \rightarrow \tilde{\nu}\ell^{\pm}$ has not been included in the analysis. Thus the results are only valid for $M_{\tilde{\nu}} > M_{\tilde{\chi}^{\pm}}$.
- We make the assumption that $M_{\tilde{\chi}^0_2} > M_{\tilde{\chi}^{\pm}}$ and that only the $\tilde{\chi}^0_1$ is accessible in $\tilde{\chi}^{\pm}$ decays.

Slepton Production and Decay

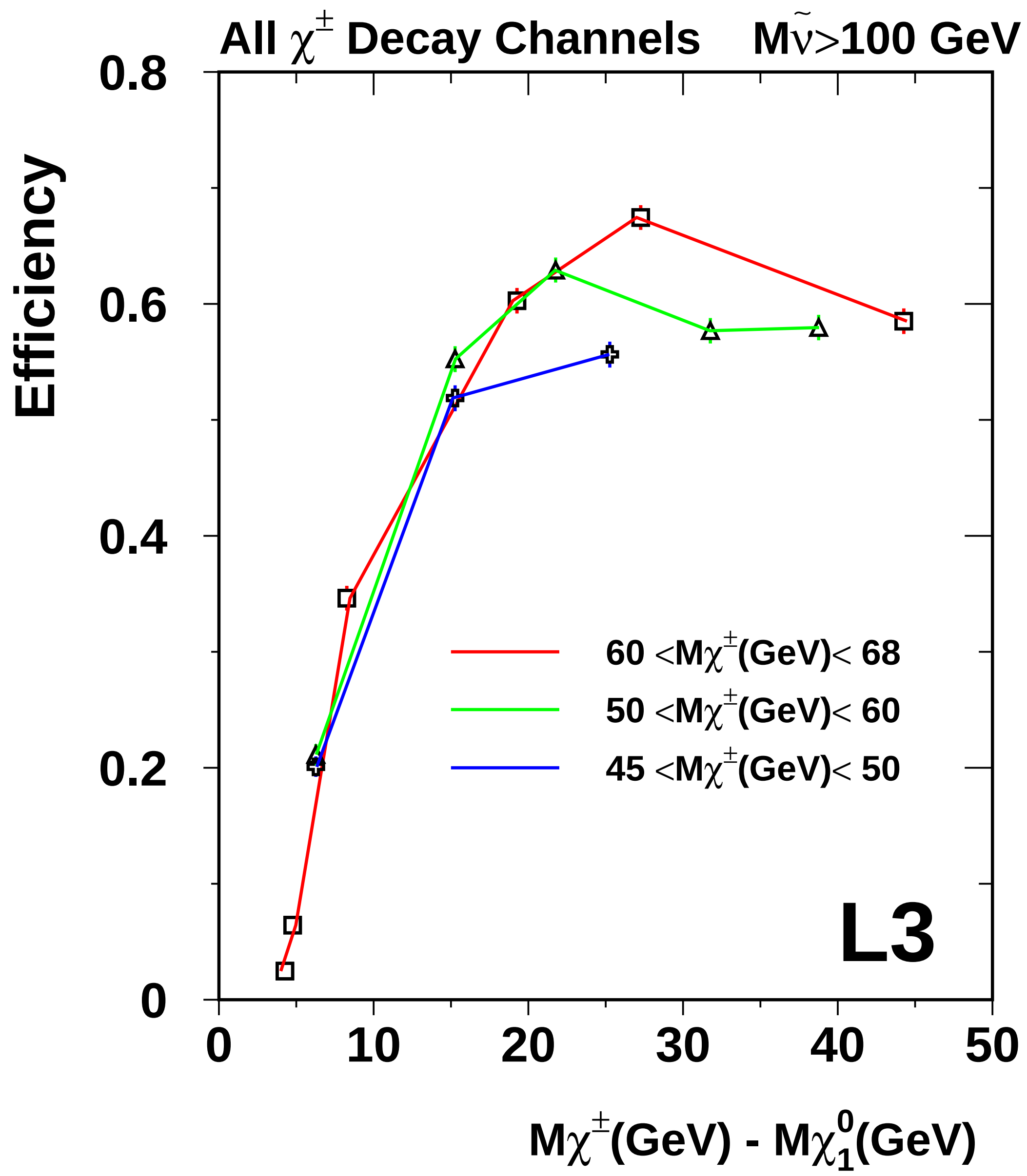


- We make the assumptions that $M_{\tilde{\chi}^0_2} > M_{\tilde{\ell}}$ and that for most values of the parameter space the decay $\tilde{\ell}^\pm \to \ell^\pm \tilde{\chi}^0_1$ dominates.
- The slepton signatures are essentially the same as the leptonic chargino decays, and we use the same analysis to search for them.

Search for Charginos , cut example



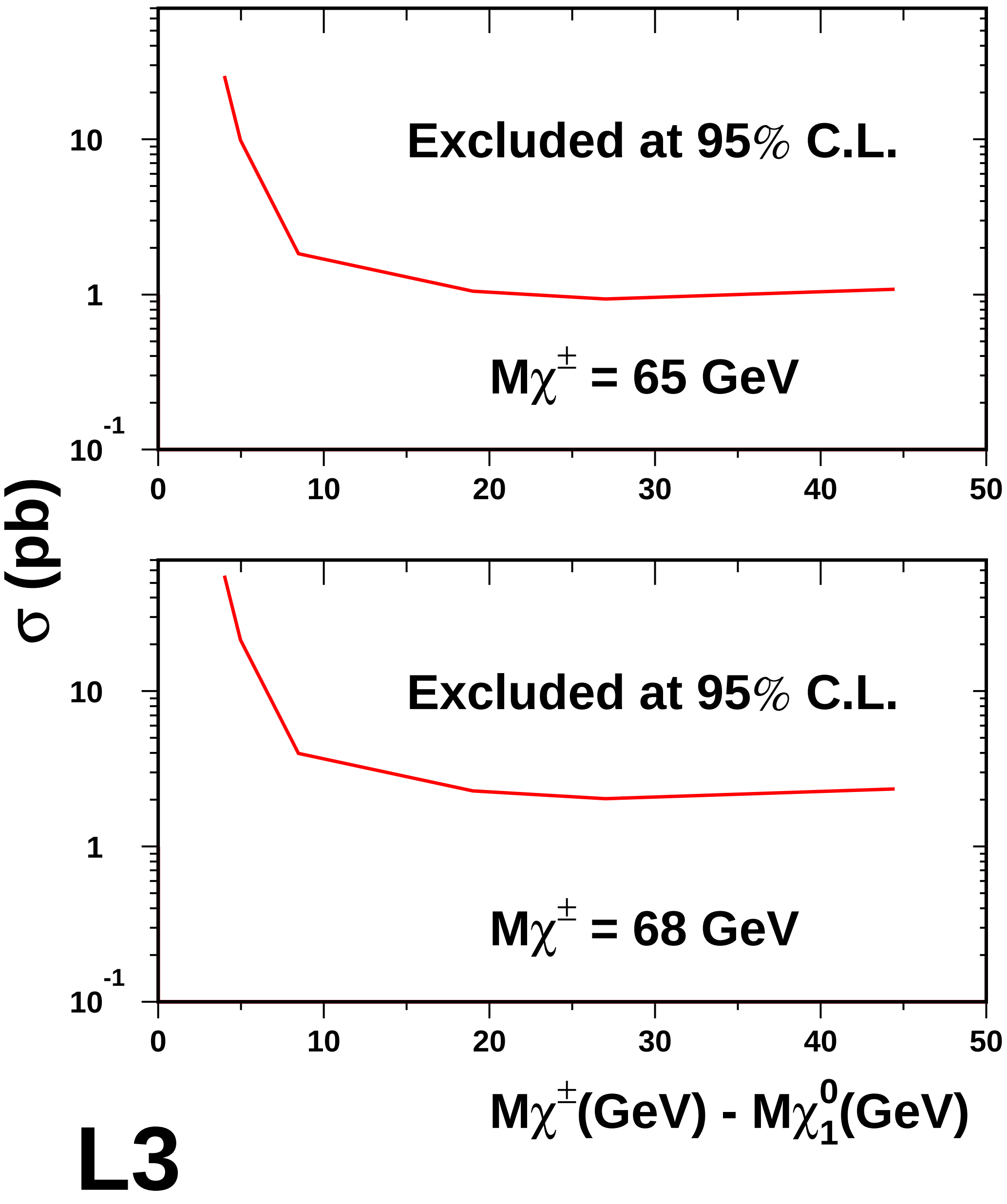
Search for Charginos



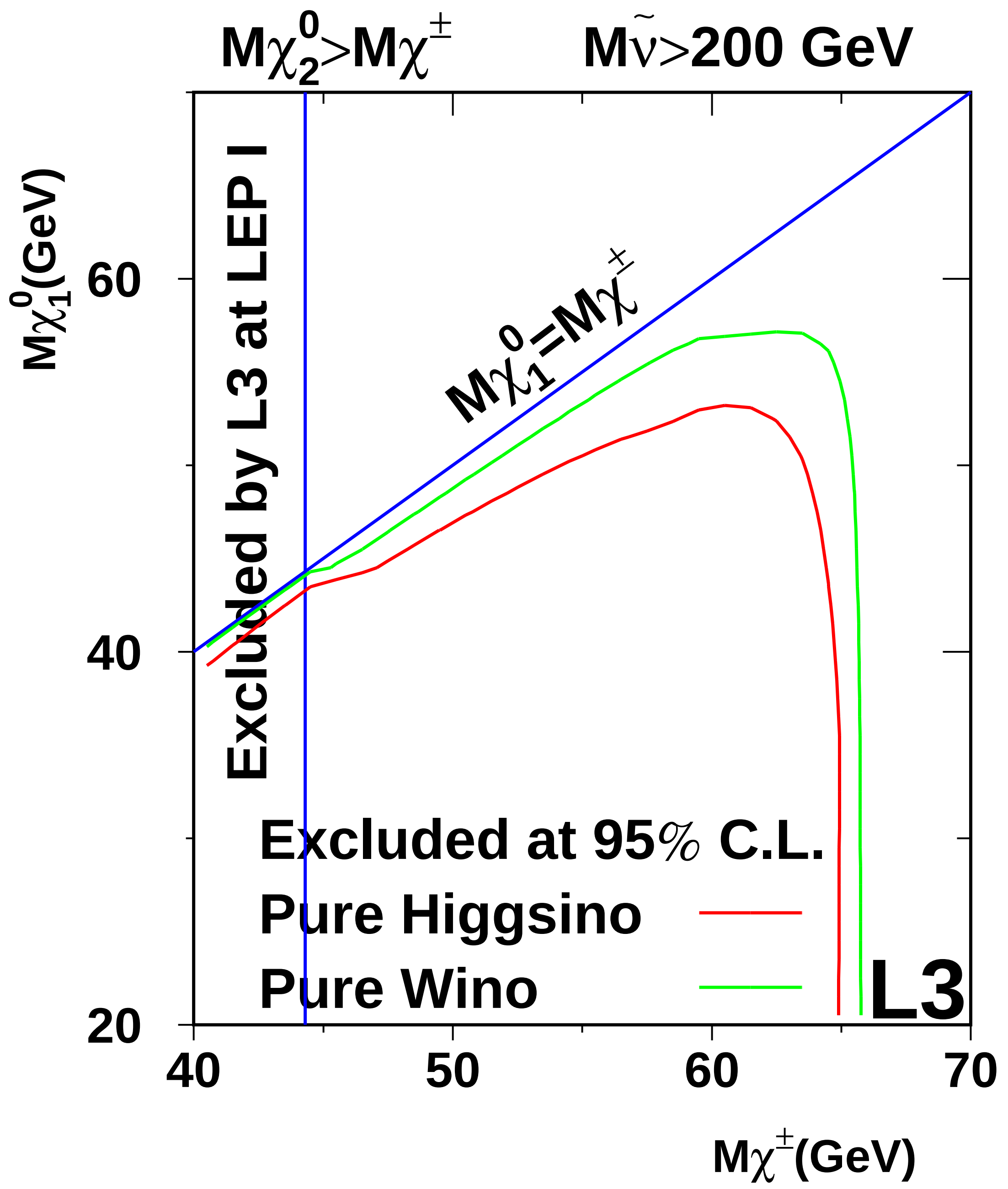
Combined Selection and Trigger efficiency for Charginos

Search for Charginos

We find no Chargino candidates in our data, thus our experimental results are cross section limits for Chargino production.

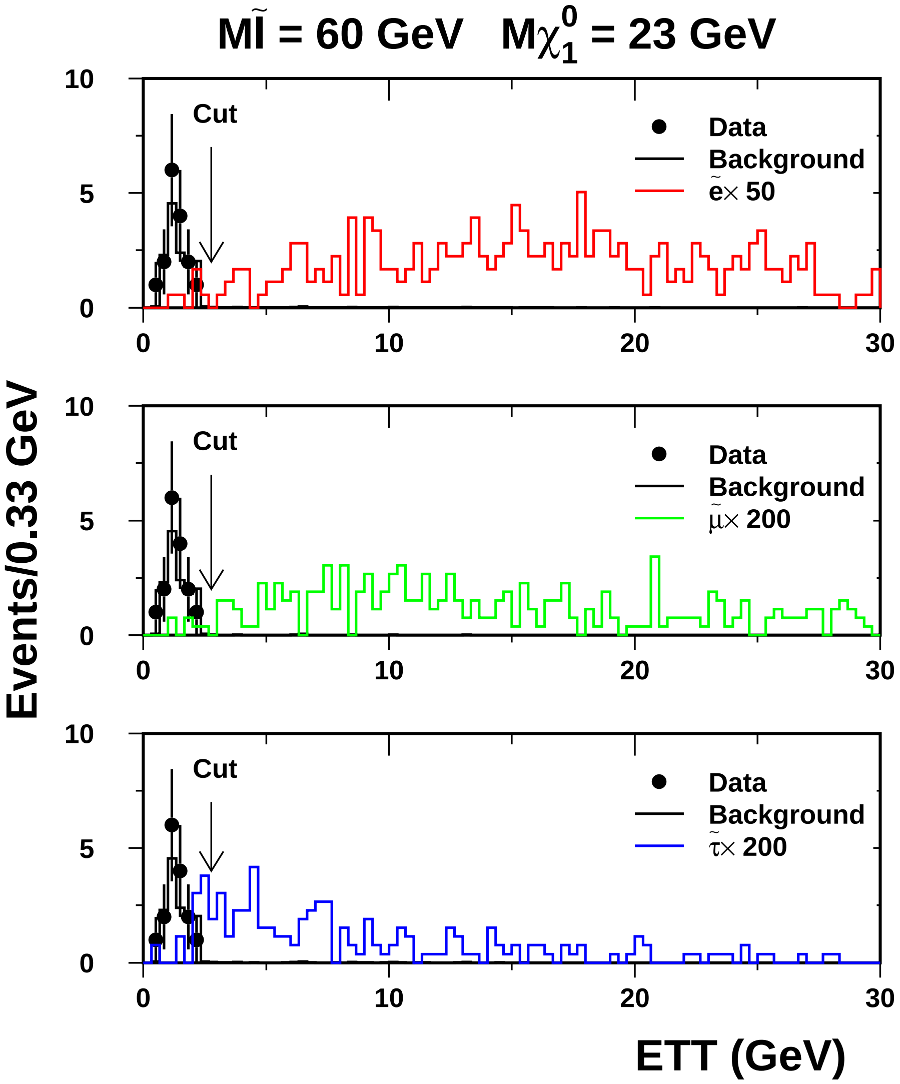


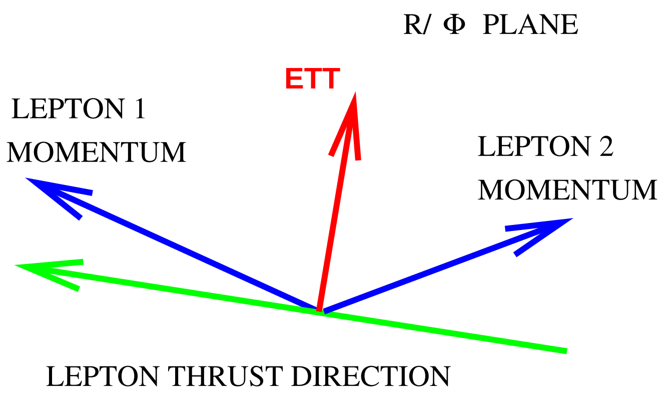
Search for Charginos



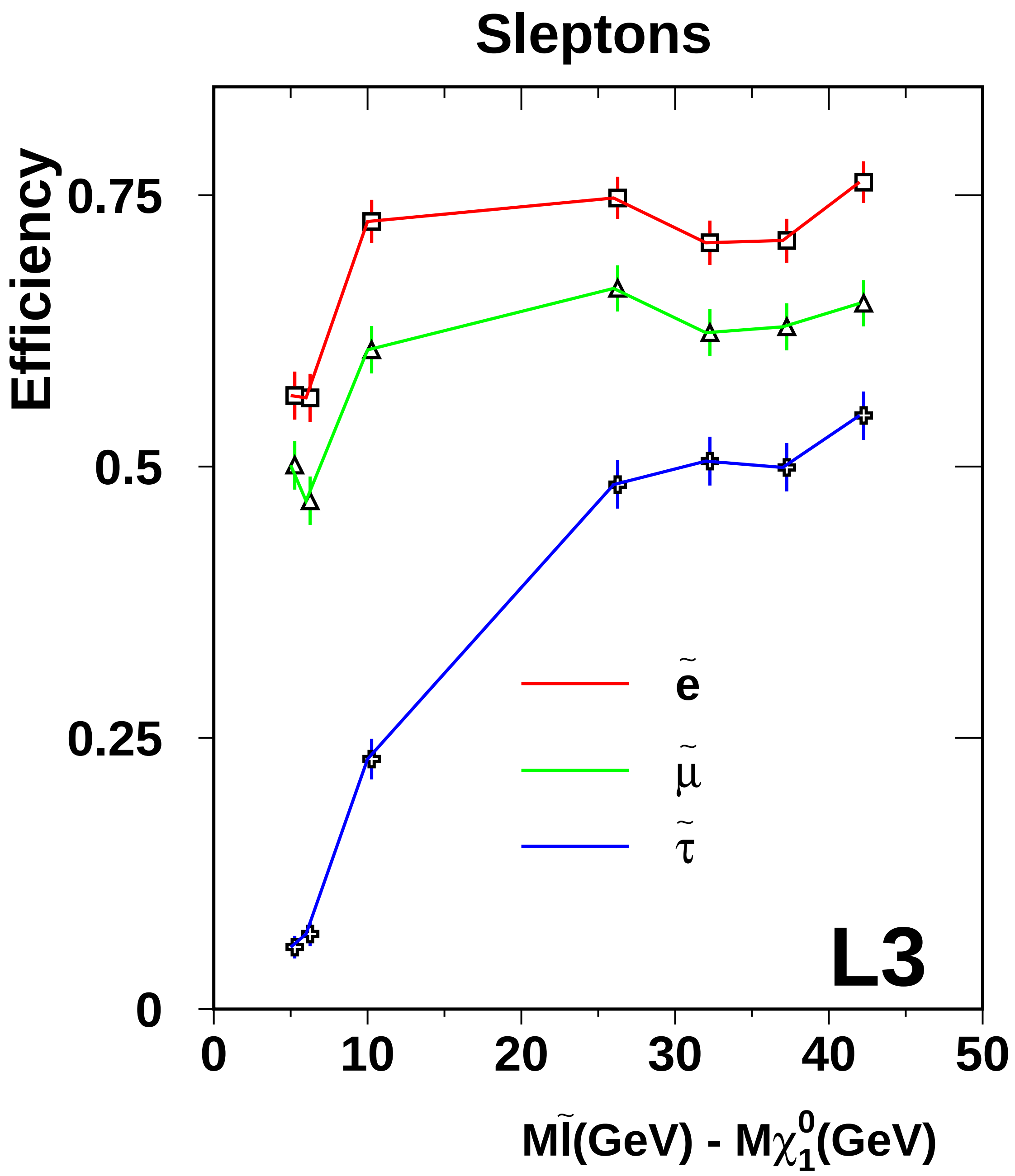
Chargino-Neutralino exclusion plot in the MSSM

The Slepton selection is identical to that used for the leptonic decays of the Charginos.



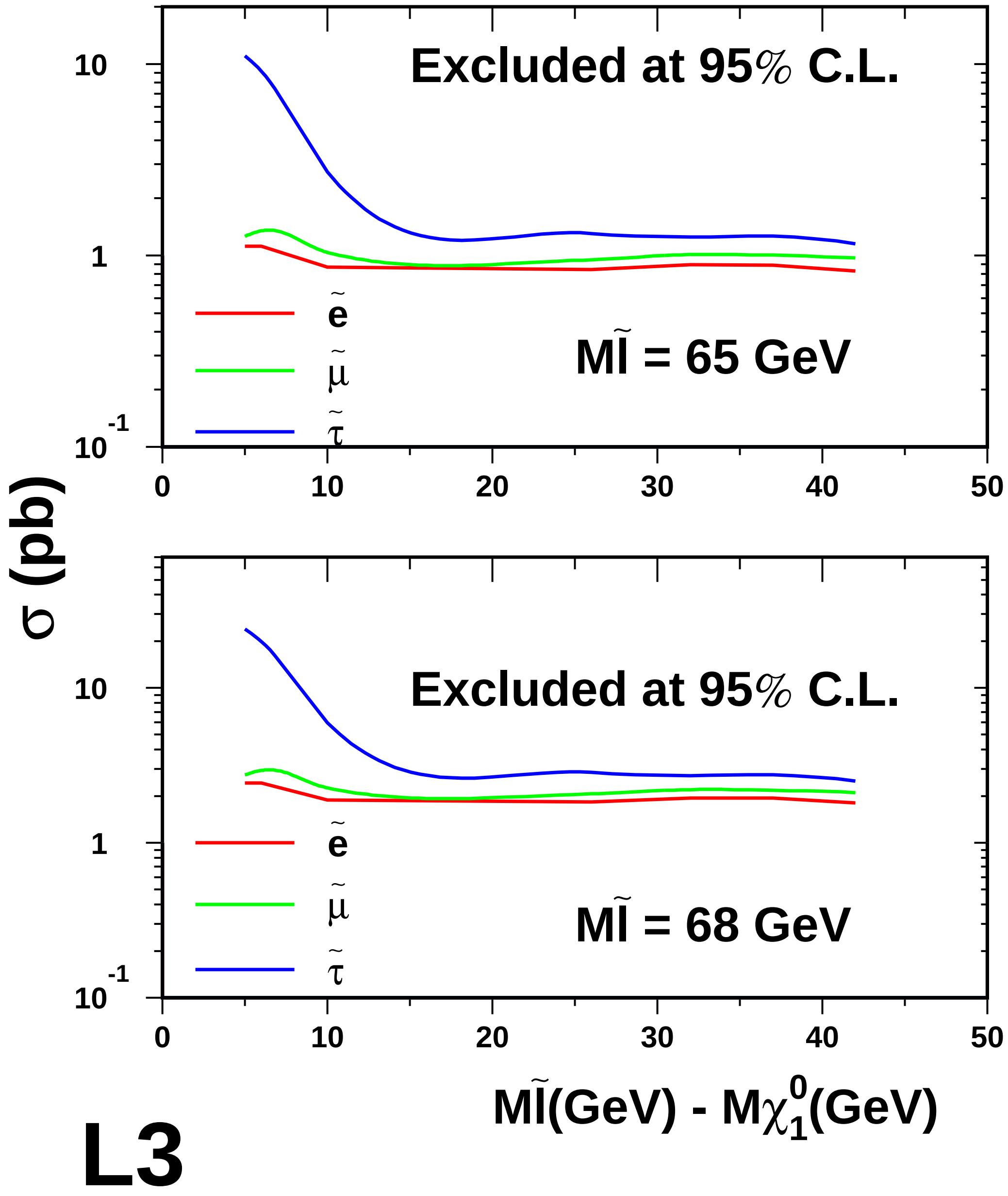


Search for Sleptons



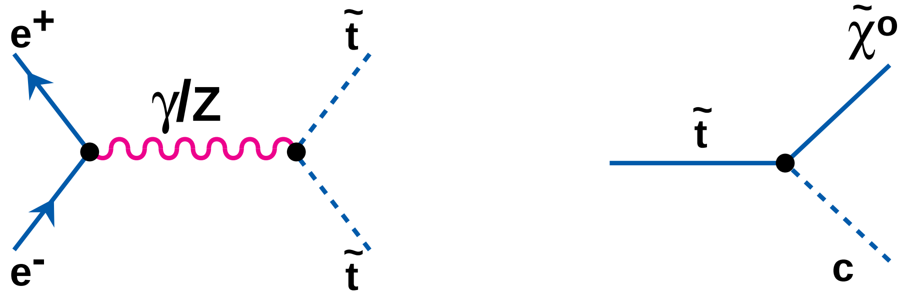
Combined Selection and Trigger efficiency for Sleptons

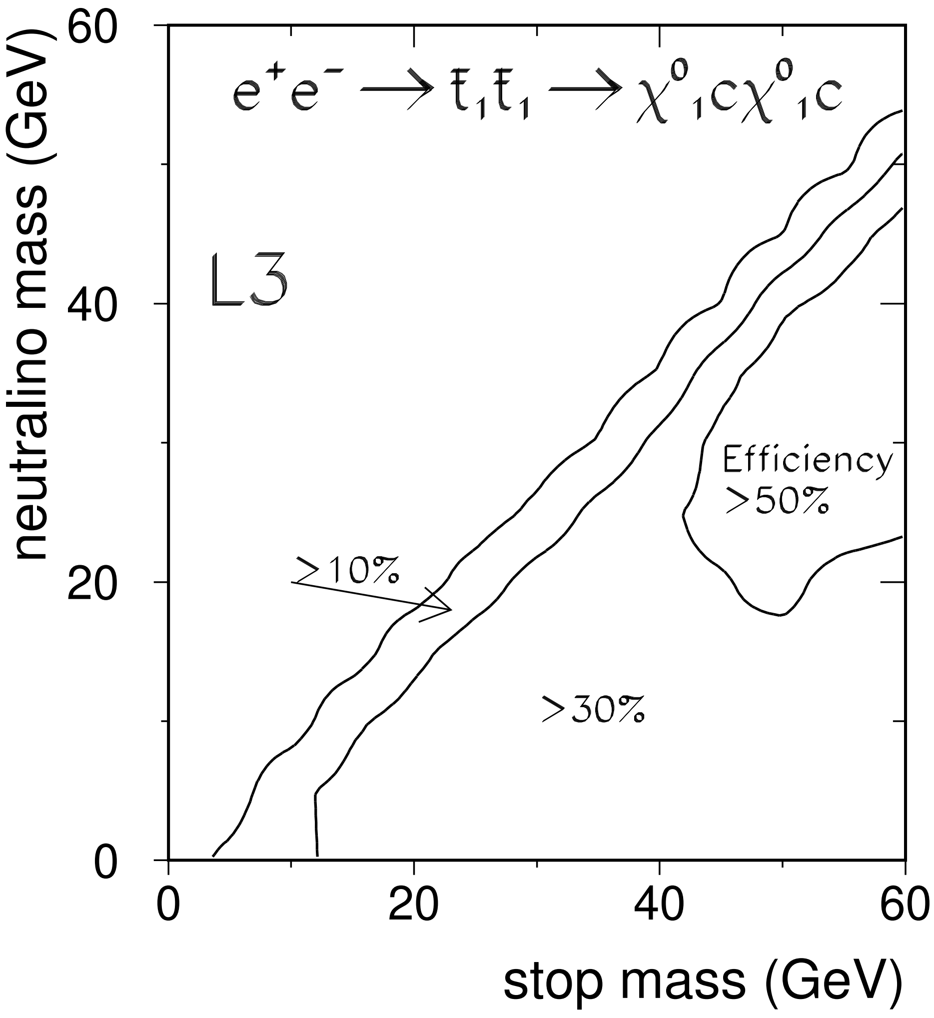
Search for Sleptons



Cross-section limits for Sleptons

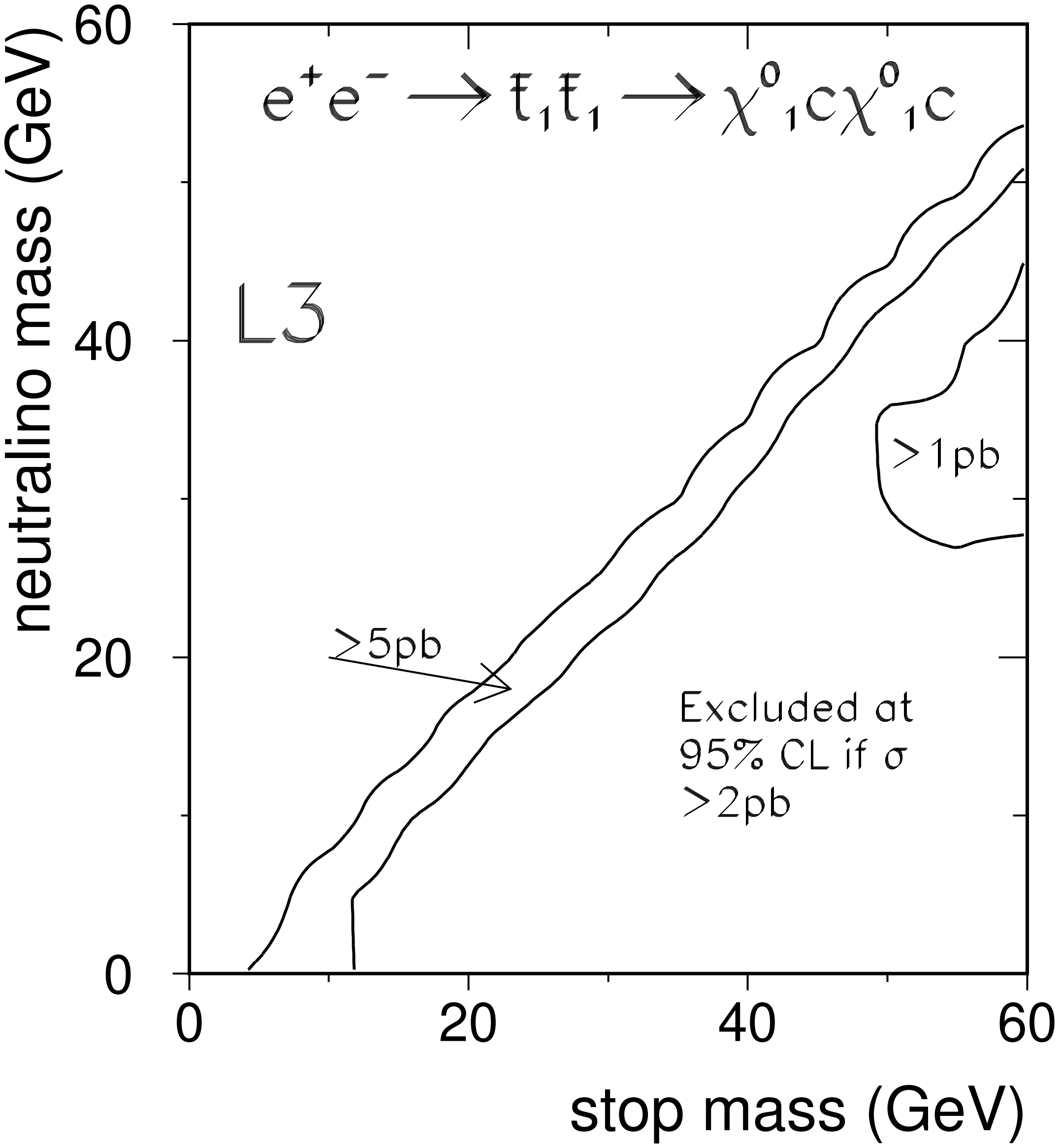
Search for Scalar top





Efficiency of the Scalar top search as a function of Stop and Neutralino masses

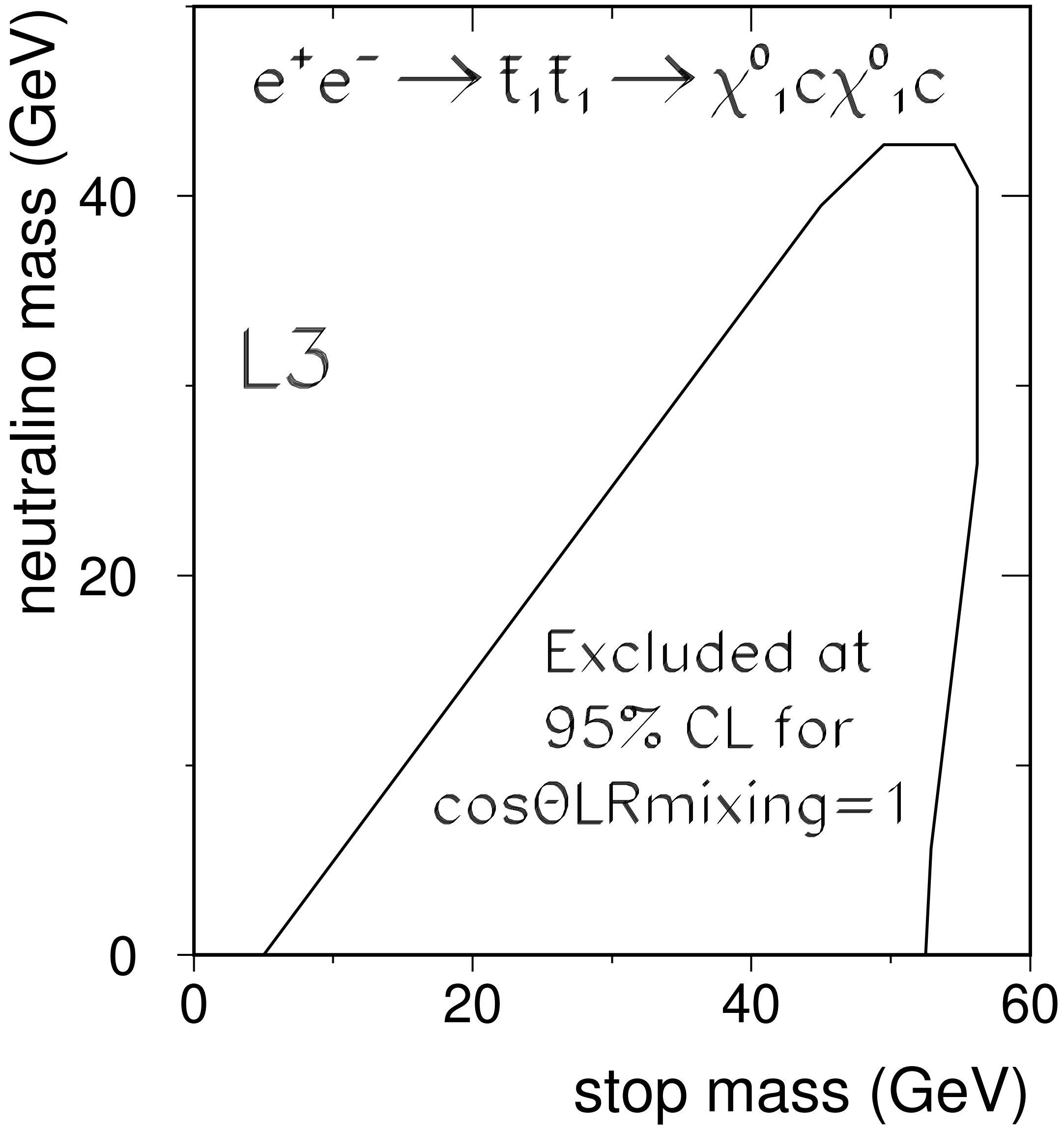
Search for Scalar top



Cross section limits from the LEP1.4 run as a function of the Stop and Neutralino masses

Search for Scalar top

We search for the lighter mass eigenstate, $\tilde{t}_1 = \tilde{t}_L \cos\theta + \tilde{t}_R \sin\theta$, where θ is a mixing angle, whose choice is a free parameter. Under the condition that this mixing angle is 0, pure $\tilde{t}_1 = \tilde{t_L}$, we can exclude at 95% C.L. the following region in the Stop-Neutralino mass plane.



Summary

- All fermion pair cross sections have been measured, both the full cross-sections and after removal of the return to Z events.
- Event shape distribution in data and MC are in good agreement and the evolution with $\sqrt{s}$ agrees with predictions. The strong coupling constant has been measured and its value is consistent with the running of α_s.
- The LEP1.4 cross sections can be used to greatly improve the constraints on the hadronic interference term, j_{had}.
- Events of the type $e^+e^- \rightarrow \nu\nu\gamma$ and $\nu\nu\gamma\gamma$ have been found and their cross sections measured.
- No deviations from QED have been observed, and the coupling/mass limits for excited lepton searches have been extended to 130 GeV
- The lower limits on the mass of neutral heavy leptons have been extended with respect to LEP I
- No candidates for Charginos, Sleptons or Scalar-top particles have been observed and limits on all three have been extended up to close to the kinematic limits.

This glimpse of the data to come has been very exciting and we look forward to the next four years of LEP II