Results of the L3 Experiment at 183 GeV

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On behalf of the L3 collaboration

Outline:

- W physics
- Fermion-pair production
- Tests of the Standard Model
- Tests of QCD and $\alpha_s(183\ \mathrm{GeV})$
- Searches for new particles

  Higgs bosons

  SUSY particles

1997 data sample:

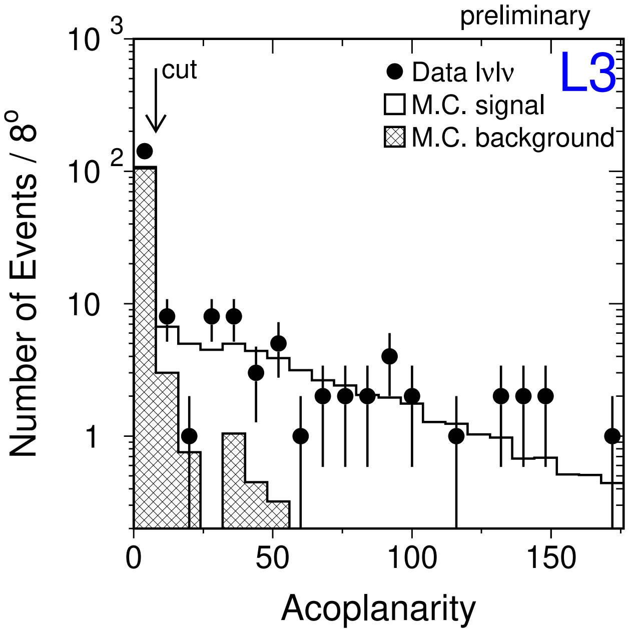
- $2.5\ \mathrm{pb}^{-1}$ at 91 GeV
- $7.0\ \mathrm{pb}^{-1}$ at 130/136 GeV
- $55.5\ \mathrm{pb}^{-1}$ at $181 - 184$ GeV "183 GeV"

All results still preliminary

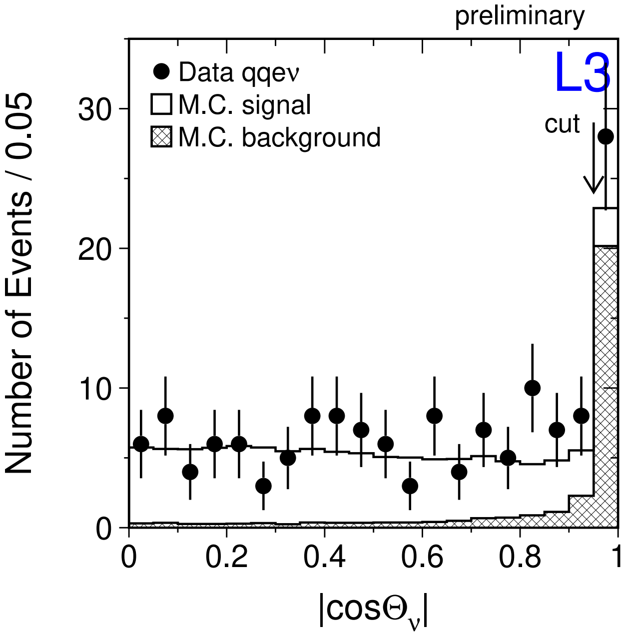
W pair cross section

Selection of W pairs:

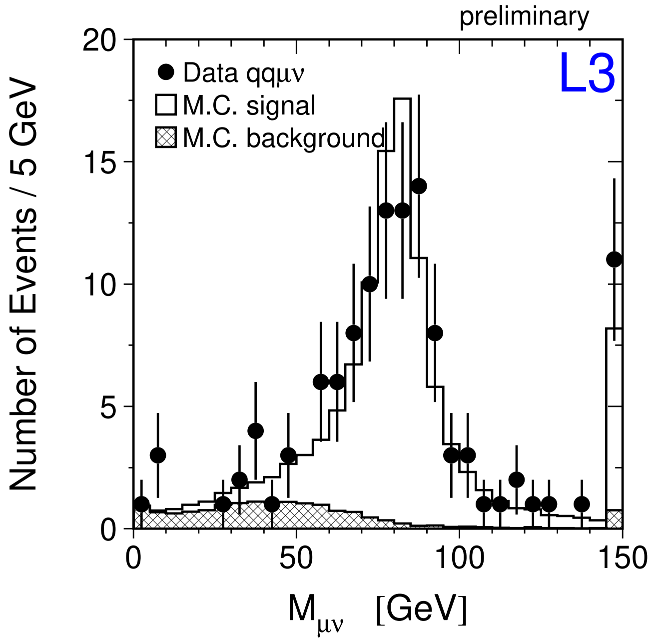
$e^+e^- \rightarrow \ell\nu\ell\nu(\gamma)$



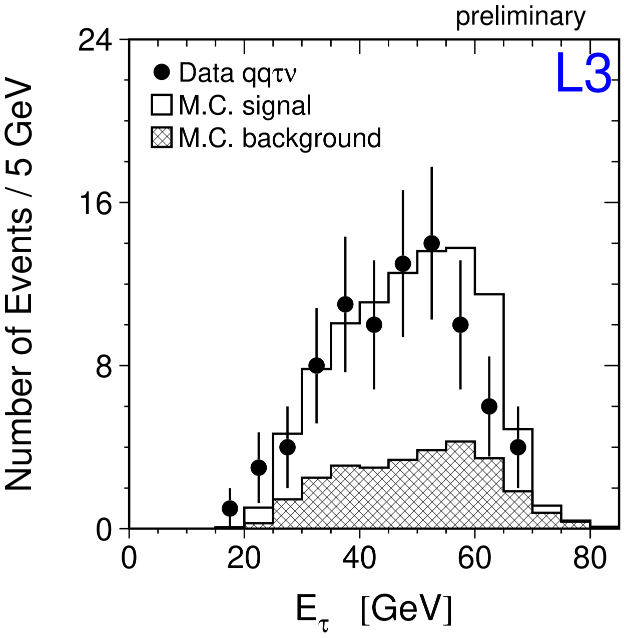
$e^+e^- \rightarrow qqe\nu(\gamma)$



$e^+e^- \rightarrow qq\mu\nu(\gamma)$

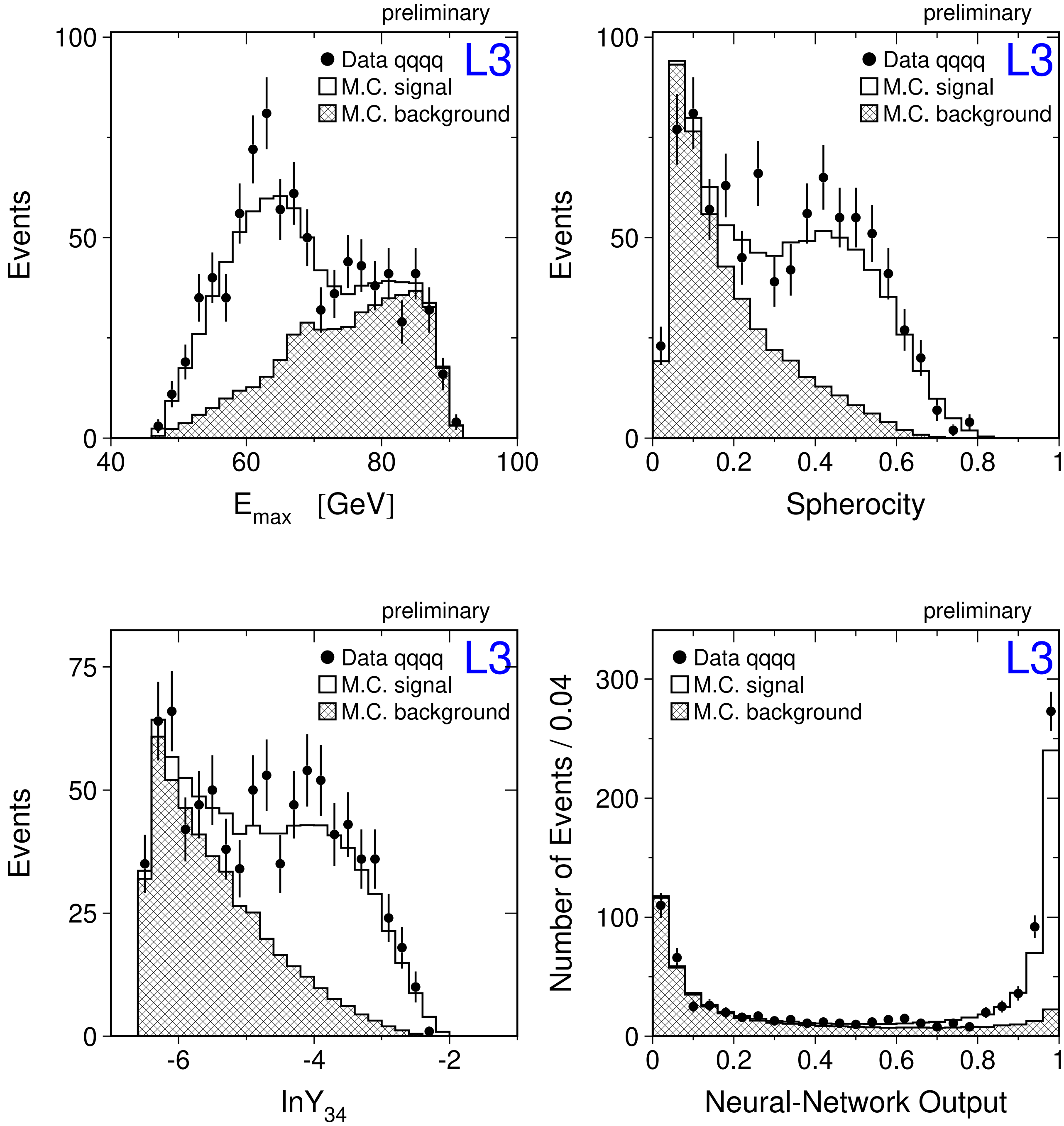


$e^+e^- \rightarrow qq\tau\nu(\gamma)$



Selection of $e^+e^- \to W^+W^- \to qqqq$ events

Neural-Network based on 8 input variables, e.g.:



Fit to NN output:

$$\sigma_{WW} = 8.25^{+0.46}_{-0.45} \text{ pb} \qquad \sigma_{e^+e^-\to q\bar{q}(\gamma)} = 102 \pm 6 \text{ pb}$$

Summary of cross section results:

Process	N_{data}	N_{bg}	σ(CC03) [pb]	σ_{SM} [pb]
$e^+e^- \rightarrow \ell\nu\ell\nu(\gamma)$	54	8.2	$1.53^{+0.25}_{-0.23} \pm 0.05$	1.67
$e^+e^- \rightarrow qqe\nu(\gamma)$	119	6.6	$2.46^{+0.26}_{-0.24} \pm 0.06$	2.30
$e^+e^- \rightarrow qq\mu\nu(\gamma)$	108	3.2	$2.34^{+0.25}_{-0.24} \pm 0.06$	2.30
$e^+e^- \rightarrow qq\tau\nu(\gamma)$	84	11.2	$1.87^{+0.34}_{-0.32} \pm 0.07$	2.30
$e^+e^- \rightarrow qqqq(\gamma)$	475	86.3	$8.25^{+0.46}_{-0.45} \pm 0.25$	7.17

840 WW events selected

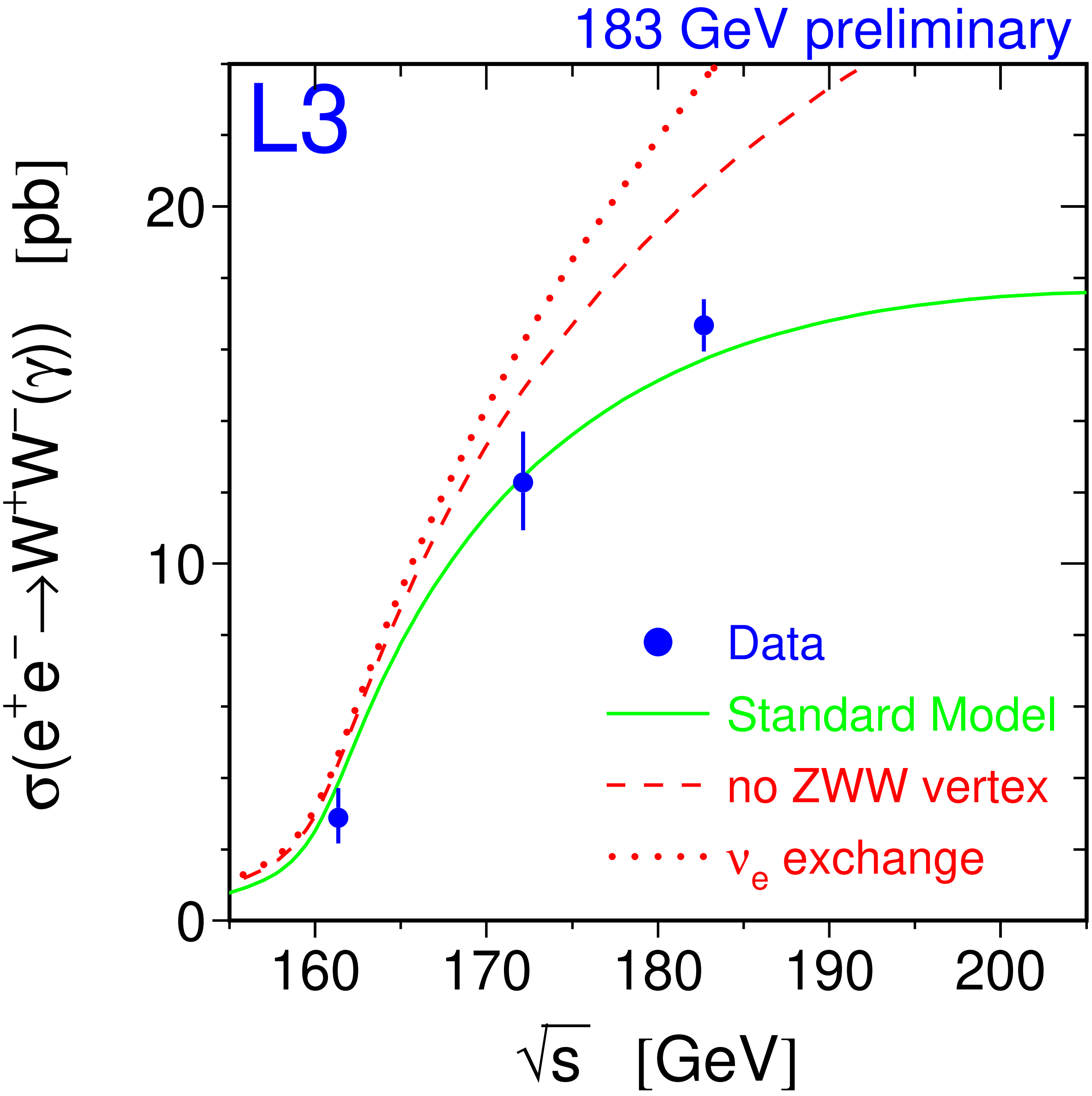
Results on W branching ratios:

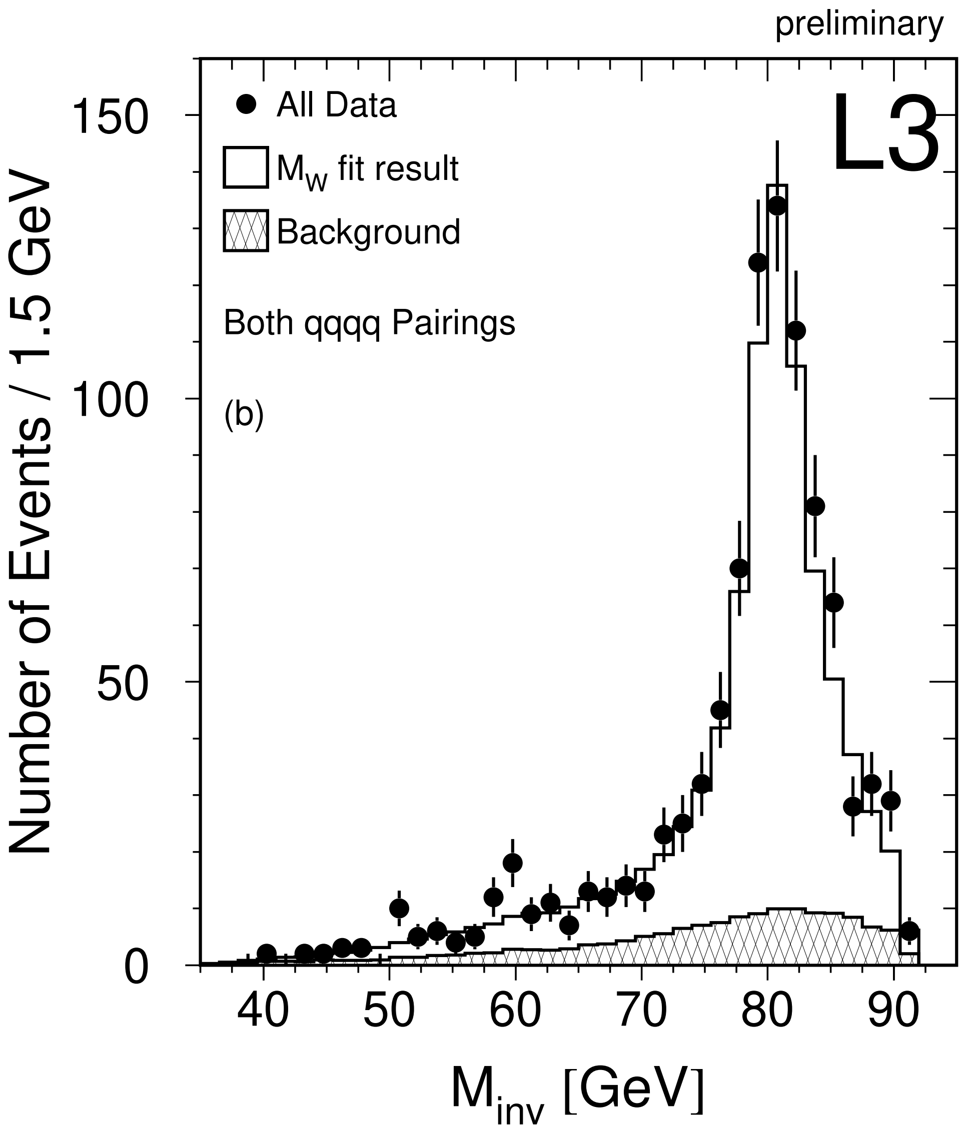
Parameter	Lepton Non-Universality	Lepton Universality	Standard Model
$B(W \rightarrow e\nu)$ [%]	$10.7 \pm 0.9 \pm 0.2$	—	
$B(W \rightarrow \mu\nu)$ [%]	$10.3 \pm 0.9 \pm 0.2$	—	
$B(W \rightarrow \tau\nu)$ [%]	$9.2 \pm 1.2 \pm 0.3$	—	
$B(W \rightarrow \ell\nu)$ [%]	—	$10.2 \pm 0.4 \pm 0.2$	10.8
$B(W \rightarrow qq)$ [%]	$69.7 \pm 1.3 \pm 0.4$	$69.5 \pm 1.3 \pm 0.4$	67.5
σ_{WW} [pb]	$16.50 \pm 0.67 \pm 0.30$	$16.60 \pm 0.66 \pm 0.30$	15.72

Using SM branching ratios

$$\sigma_{WW} = 16.66 \pm 0.66 \pm 0.30 \text{ pb} \qquad (\sqrt{s} = 183 \text{ GeV})$$

Cross section $e^+e^- \rightarrow W^+W^-(\gamma)$ between 161 and 183 GeV





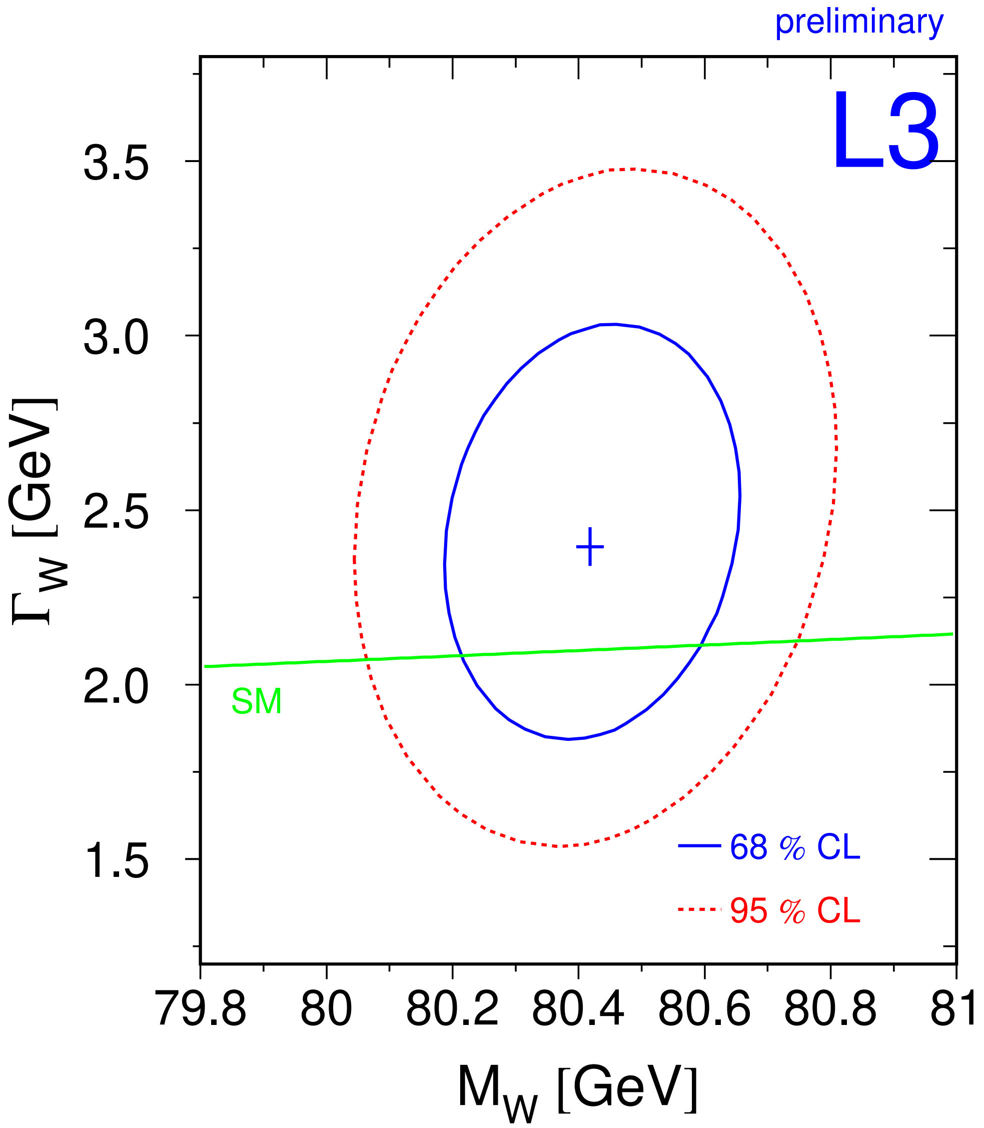
Reconstructed W mass (incl. 172 GeV data):

	m_W [GeV]
$e^+e^- \to qq\ell\nu(\gamma)$	$80.09 \pm 0.23 \pm 0.07$
$e^+e^- \to qqqq(\gamma)$	$80.59 \pm 0.19 \pm 0.13$
combined	$80.40 \pm 0.15 \pm 0.09$

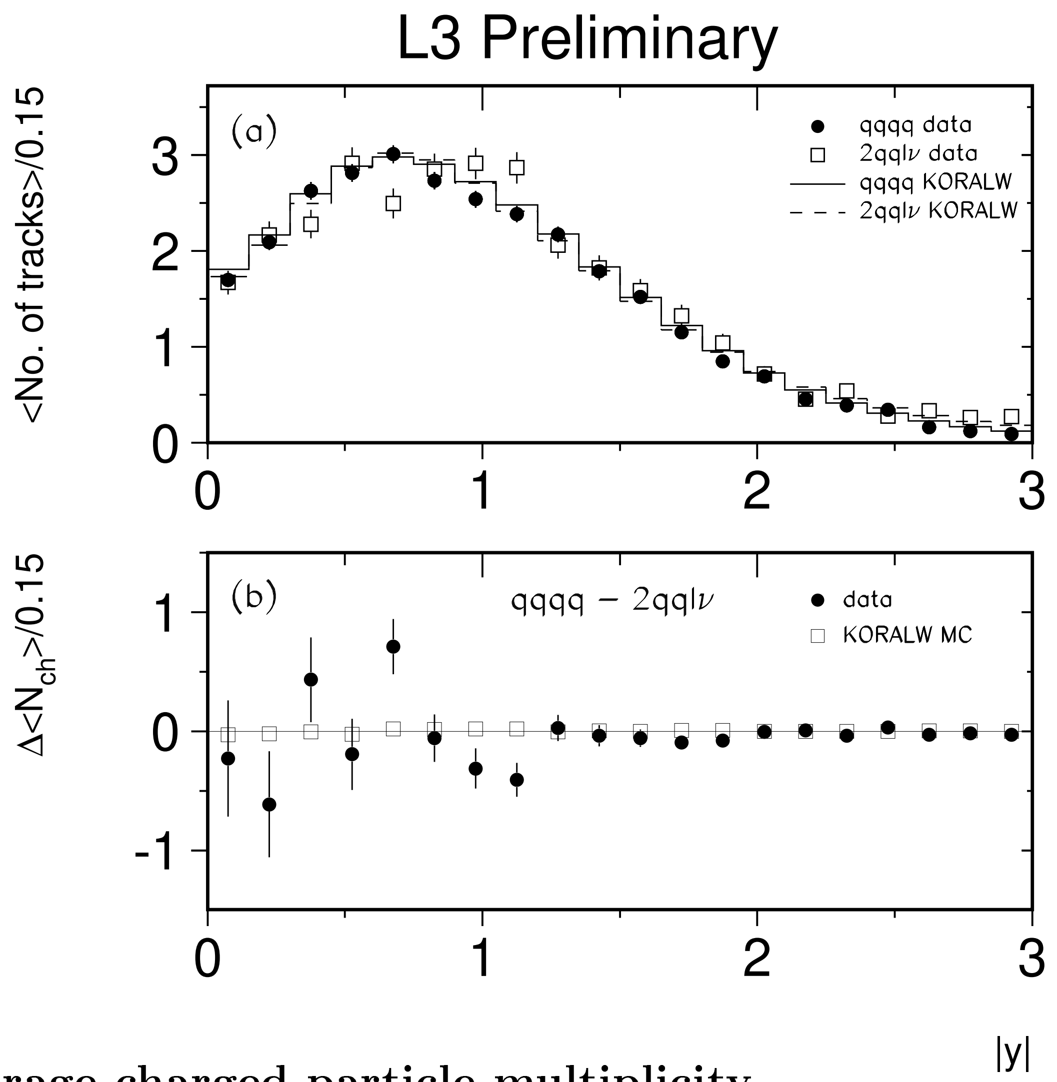
Combined with total cross section (161/172 GeV):

$$m_W = 80.44 \pm 0.16\,(\text{exp}) \pm 0.03\,(\text{LEP})\ \text{GeV}$$

Simultaneous fit for W mass and total width:



	Γ_W [GeV]
$e^+e^- \rightarrow qq\ell\nu(\gamma)$	$3.12 \pm 0.69 \pm 0.28$
$e^+e^- \rightarrow qqqq(\gamma)$	$1.85 \pm 0.46 \pm 0.33$
combined	$2.41 \pm 0.39 \pm 0.25$



Average charged particle multiplicity

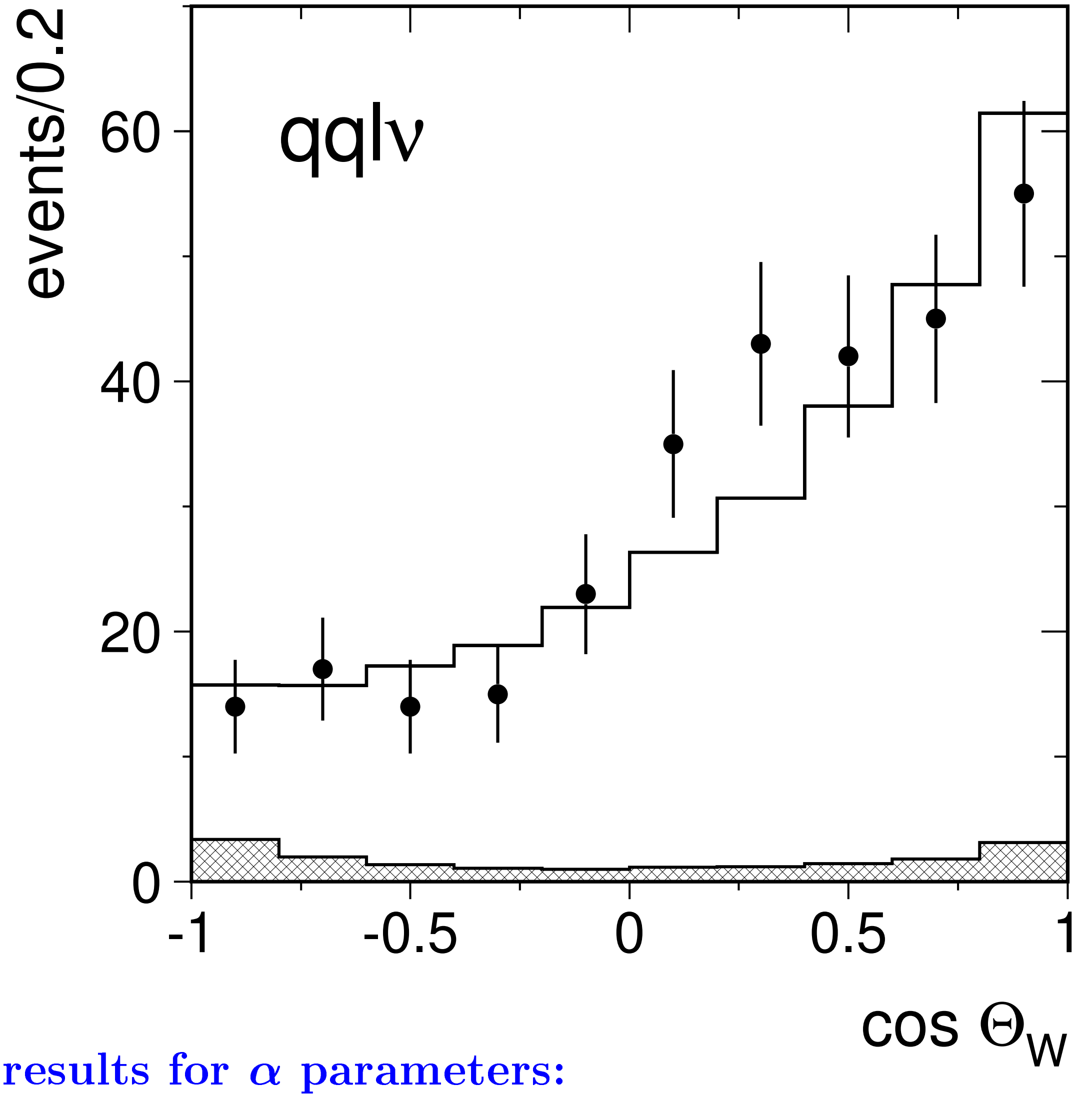
$$< N_{\rm ch}^{\rm qqqq} > \; = \; 36.1 \pm 0.4 \pm 0.8$$
$$< N_{\rm ch}^{{\rm qq}\ell\nu} > \; = \; 18.8 \pm 0.4 \pm 0.4$$

$$\Delta < N_{\rm ch} > \; = \; -1.5 \pm 0.8 \pm 0.5$$

Consistent with 0, i.e. both W in qqqq events fragment independently

From total and differential cross sections

e.g. angular distribution of W in $e^+e^- \to q q \ell \nu (\gamma)$ events



Fit results for α parameters:

$$\alpha_{W\Phi} = -0.12^{+0.11}_{-0.09} \pm 0.03$$
$$\alpha_{W} = -0.25^{+0.23}_{-0.15} \pm 0.06$$
$$\alpha_{B\Phi} = -0.43^{+0.31}_{-0.25} \pm 0.12$$

All consistent with Standard Model

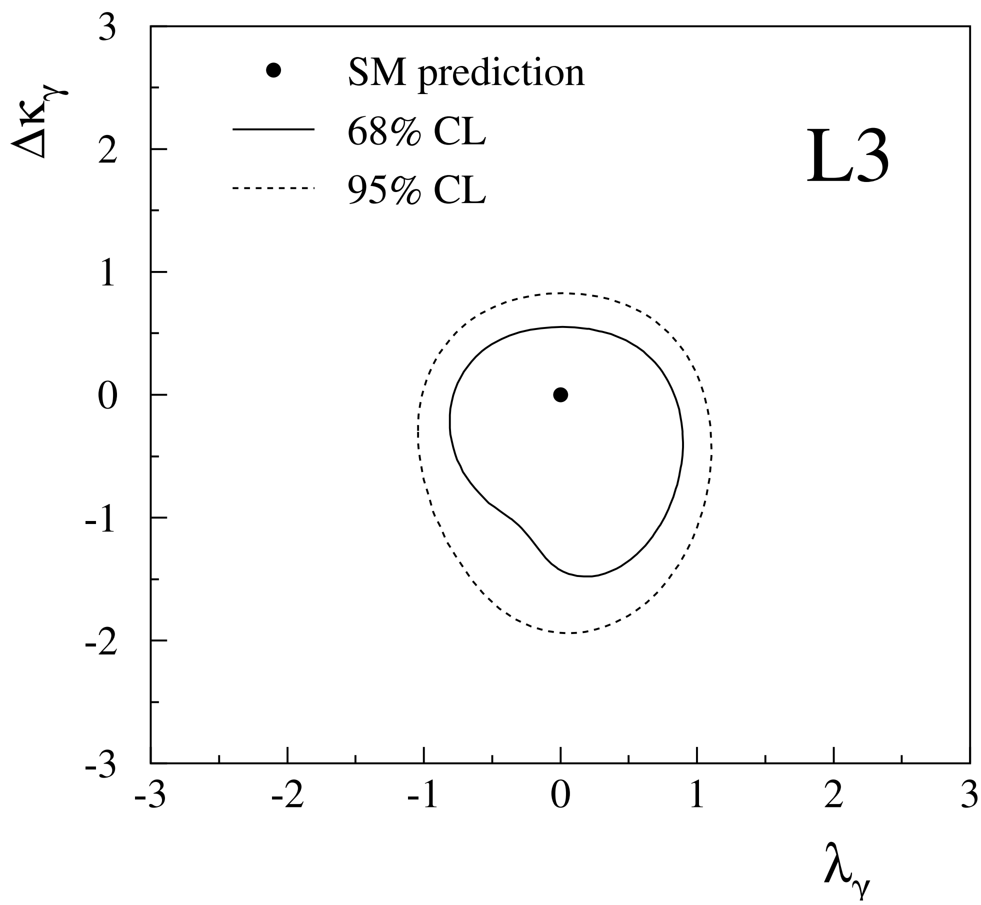
183 GeV result for $W \to q\bar{q}'$ channel (NN analysis)

Signal definition for $e^+e^- \to e\nu\, W$, $W \to q\bar{q}'$:
$|\cos\Theta_e| > 0.997$; $E_q, E_{\bar{q}'} > 15$ GeV

$$\sigma(e^+e^- \to e\nu\, W) \cdot BR(W \to q\bar{q}') = 0.37^{+0.18}_{-0.16} \pm 0.04 \text{ pb}$$

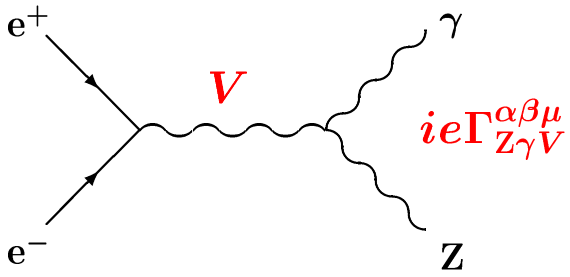
in agreement with expectation $\sigma^{SM} = 0.355$ pb

Limits on anomalous W couplings:
(from fit to NN output)



$$-0.86 < \Delta\kappa_\gamma < 0.38 \qquad 68\%\text{CL}$$
$$-0.65 < \lambda_\gamma < 0.76 \qquad 68\%\text{CL}$$

Anomalous ZZγ and Z$\gamma\gamma$ couplings



- 8 anamolous couplings h_i^V ($V = \mathrm{Z}, \gamma$)

$$h_i^V = \frac{h_{i0}^V}{(1 + s/\Lambda^2)^n}; \quad n = 3 \text{ for } i = 1, 3; \quad n = 4 \text{ for } i = 2, 4$$

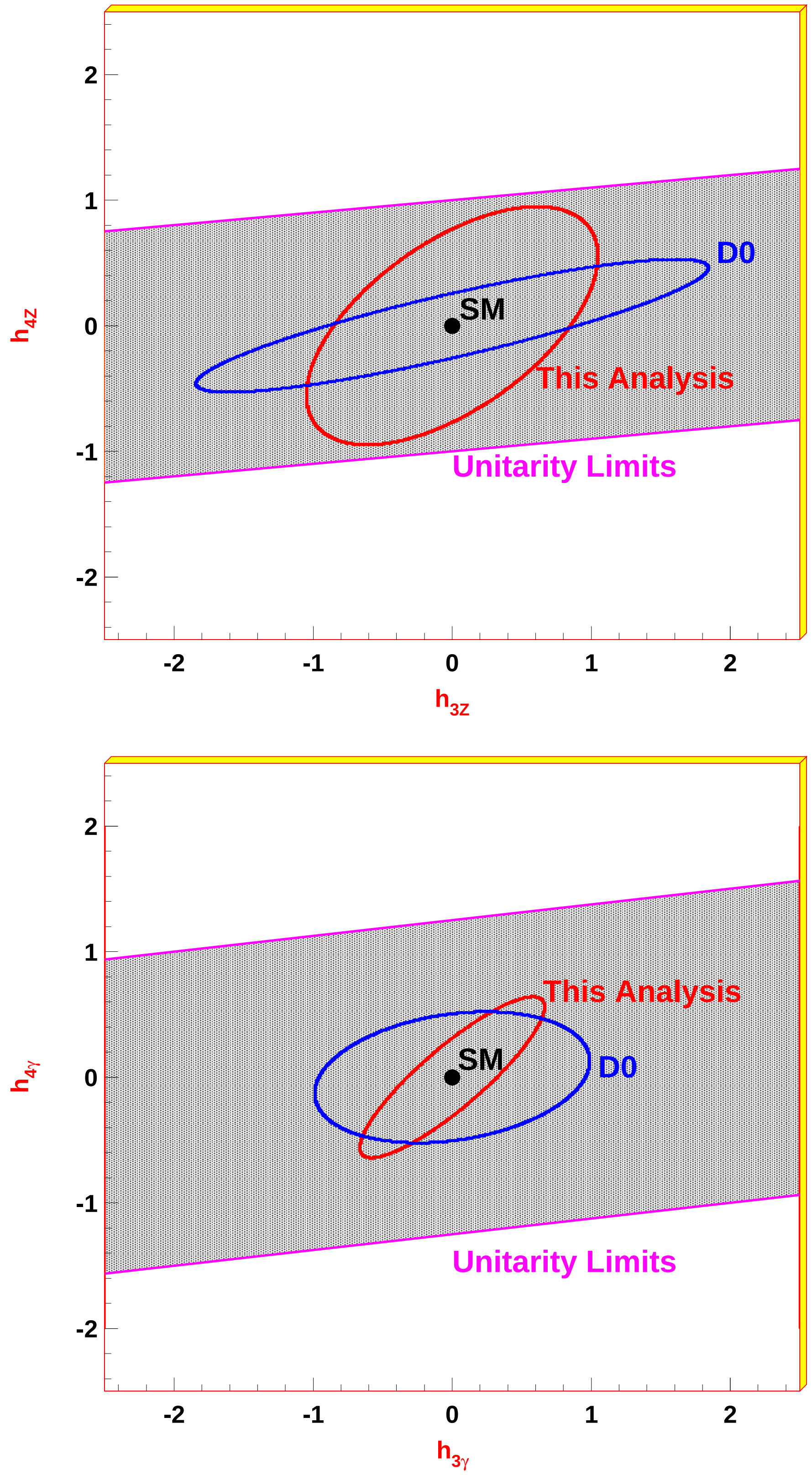
- Deviation from SM suppressed by $(p_\mathrm{Z}/E_\mathrm{Z})^n$
- Sensitivity increases with $\sqrt{s}$

- $\mathrm{e^+e^-} \to$ hadrons $+\,\gamma$
- $\mathrm{e^+e^-} \to \nu\bar{\nu}\gamma$

$14^\circ < \Theta_\gamma < 166^\circ$
$80\ \mathrm{GeV} < m_\mathrm{rec} < 110\ \mathrm{GeV}$

	$\mathrm{e^+e^-} \to \mathrm{q\bar{q}}\,\gamma$		$\mathrm{e^+e^-} \to \nu\bar{\nu}\gamma$	
$\sqrt{s}$ [GeV]	N_data	N_SM	N_data	N_SM
161	117	108	29	20
170	7	8	1	2
172	59	72	21	15
183	411	397	102	98

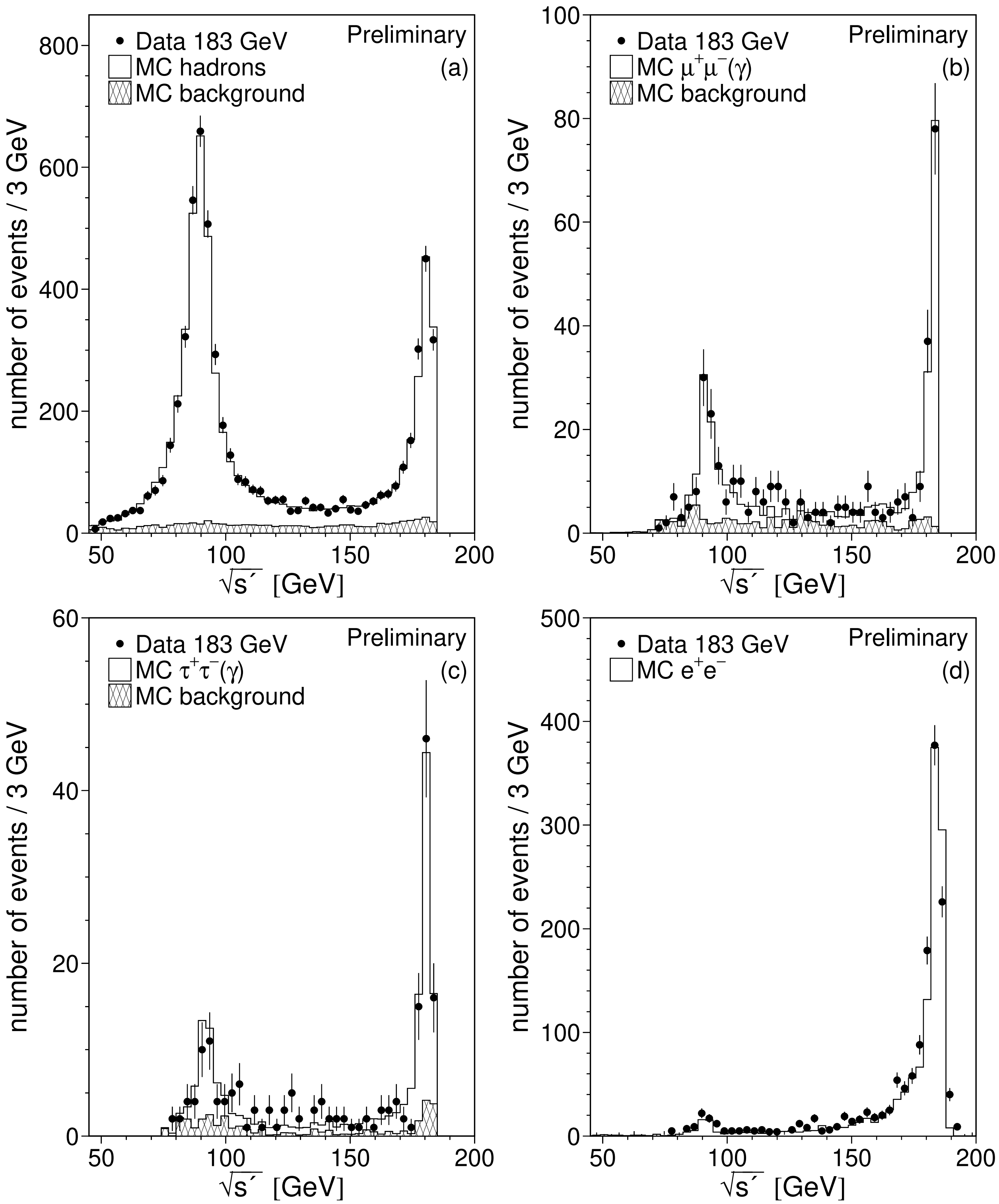
95% CL limits in the $h^V_{30} - h^V_{40}$ planes (CP conserving):

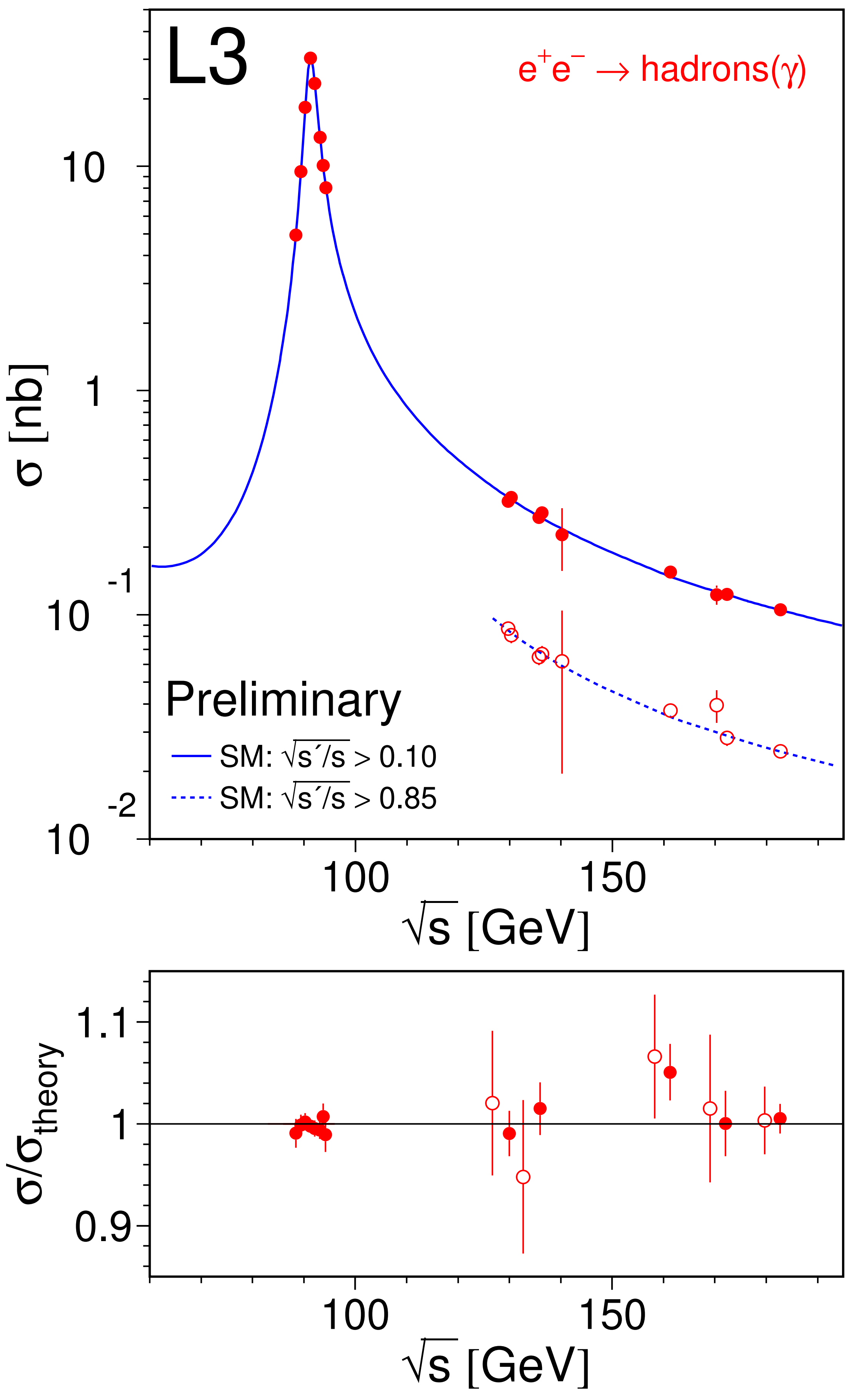


Large improvement compared to our LEP I result

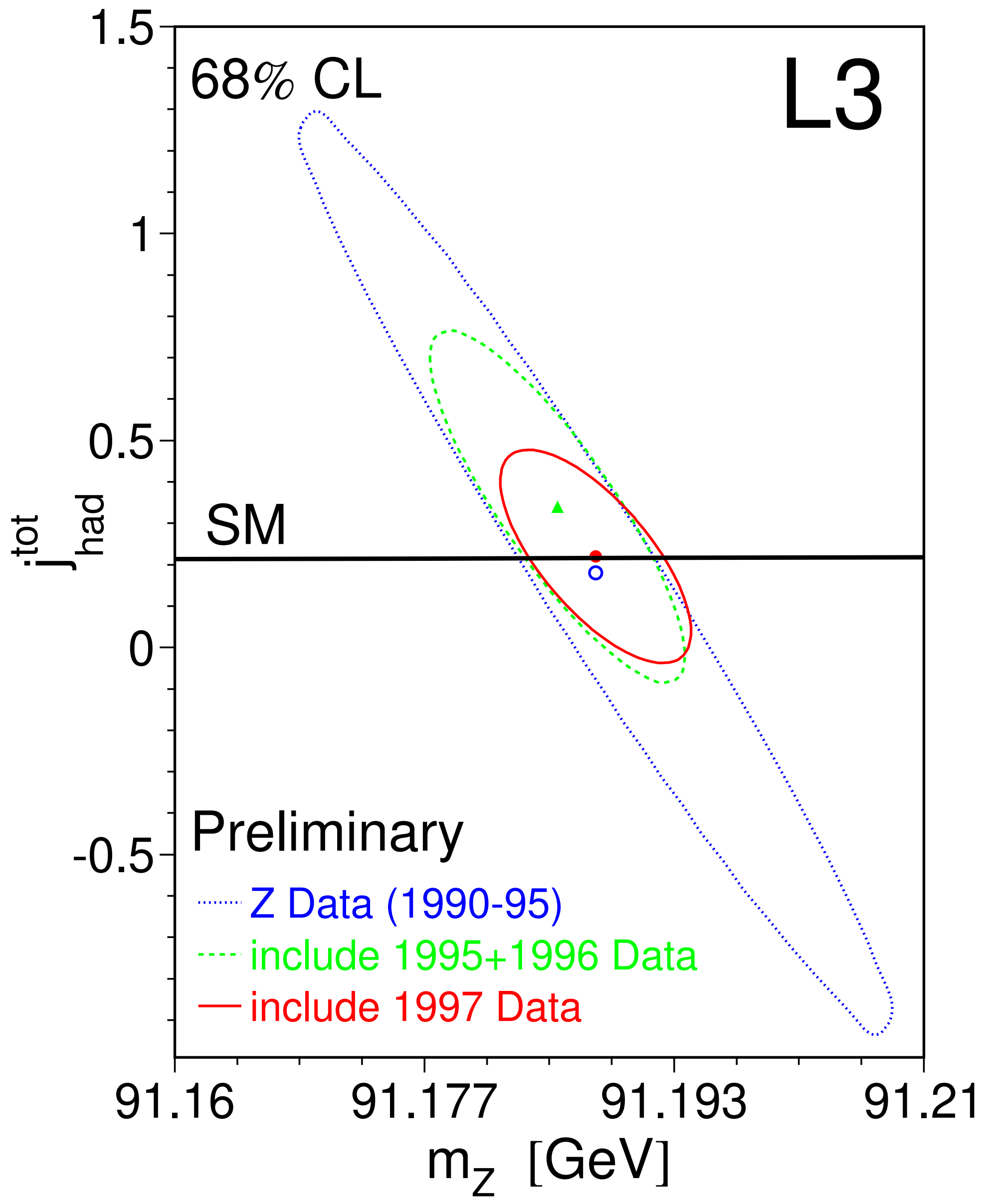
$$e^+e^- \to Z/\gamma \to f\bar{f}(\gamma)$$

Reconstructed effective centre-of-mass energy $\sqrt{s'}$:



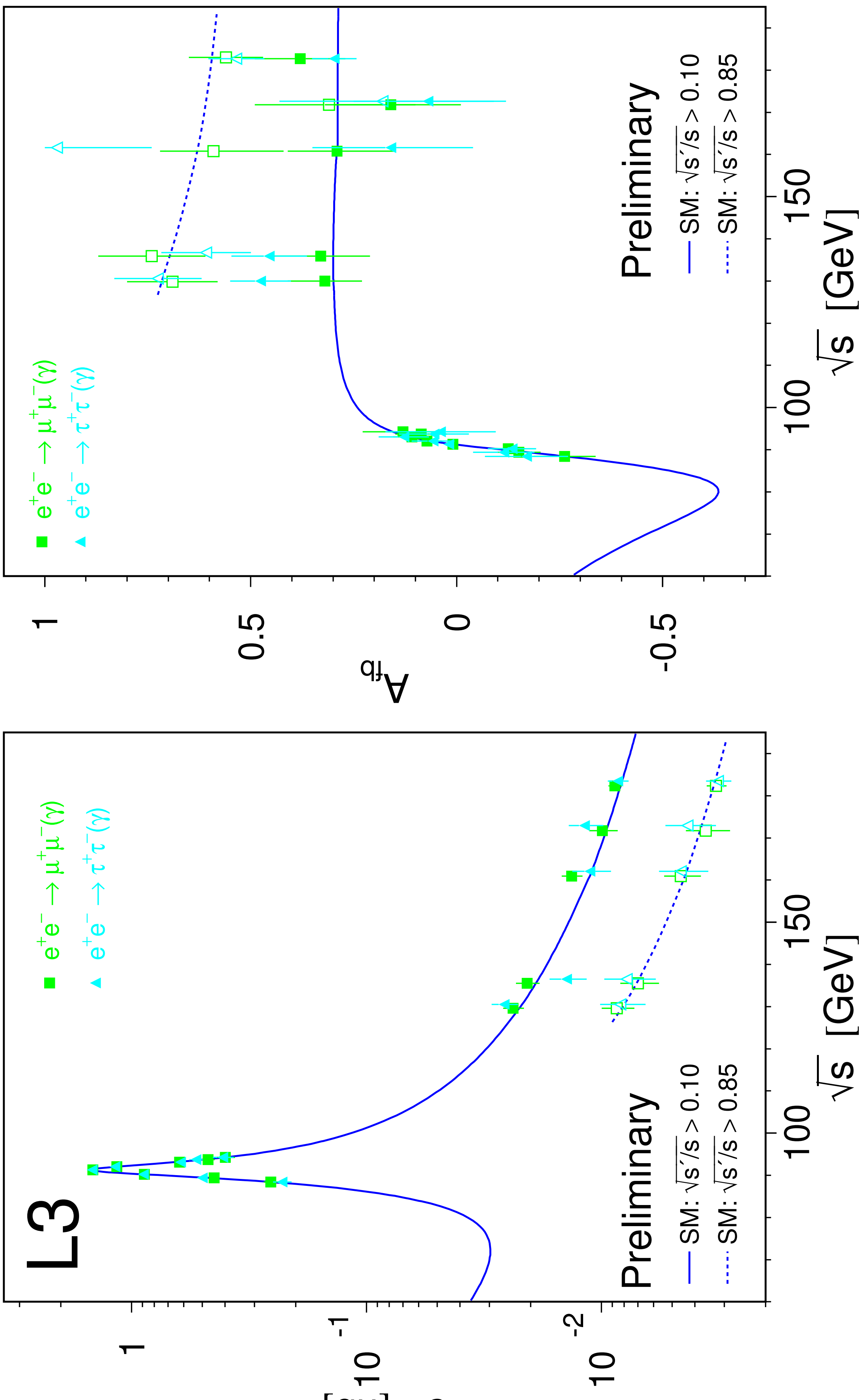

L3
$e^+e^- \rightarrow$ hadrons(γ)
Preliminary
SM: $\sqrt{s'/s} > 0.10$
SM: $\sqrt{s'/s} > 0.85$
σ [nb]
10
1
10^{-1}
10^{-2}
100
150
$\sqrt{s}$ [GeV]
σ/σ_{theory}
1.1
1
0.9
100
150
$\sqrt{s}$ [GeV]

Hadronic γZ interference term:

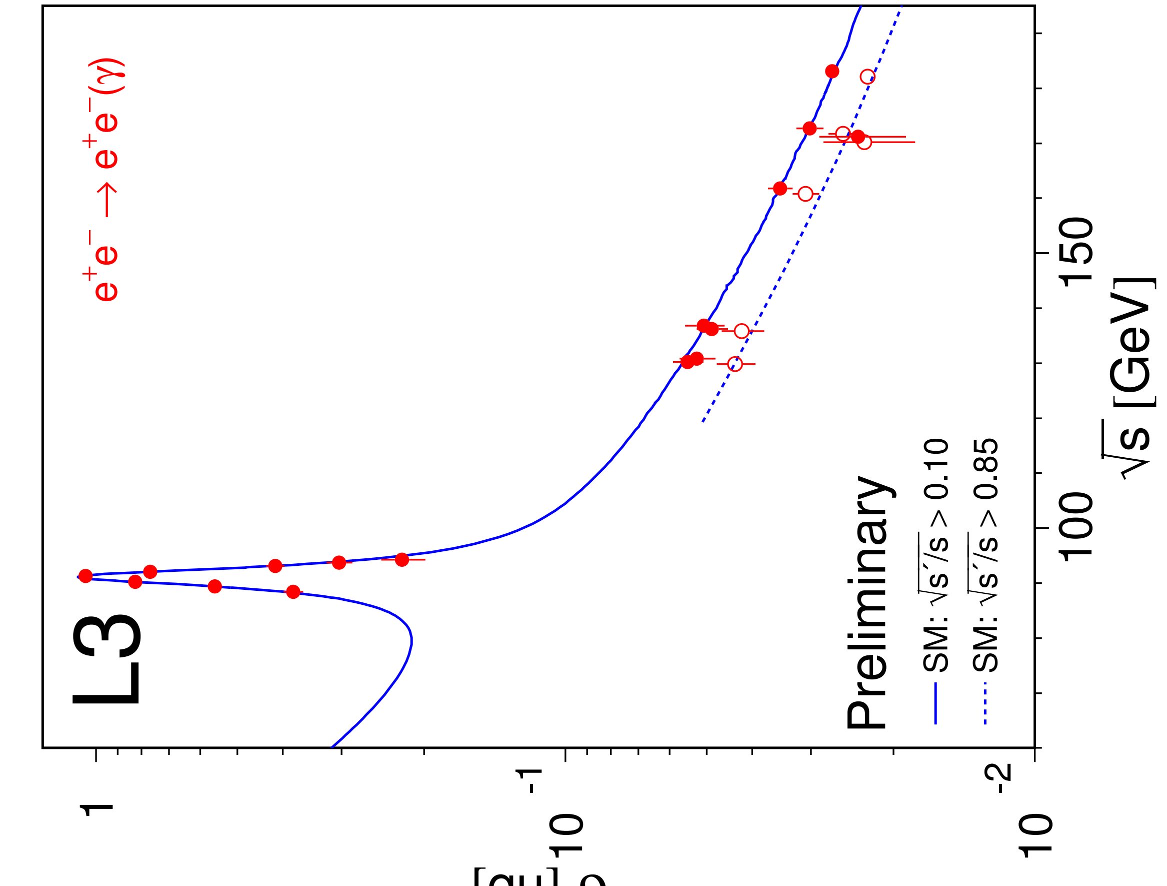


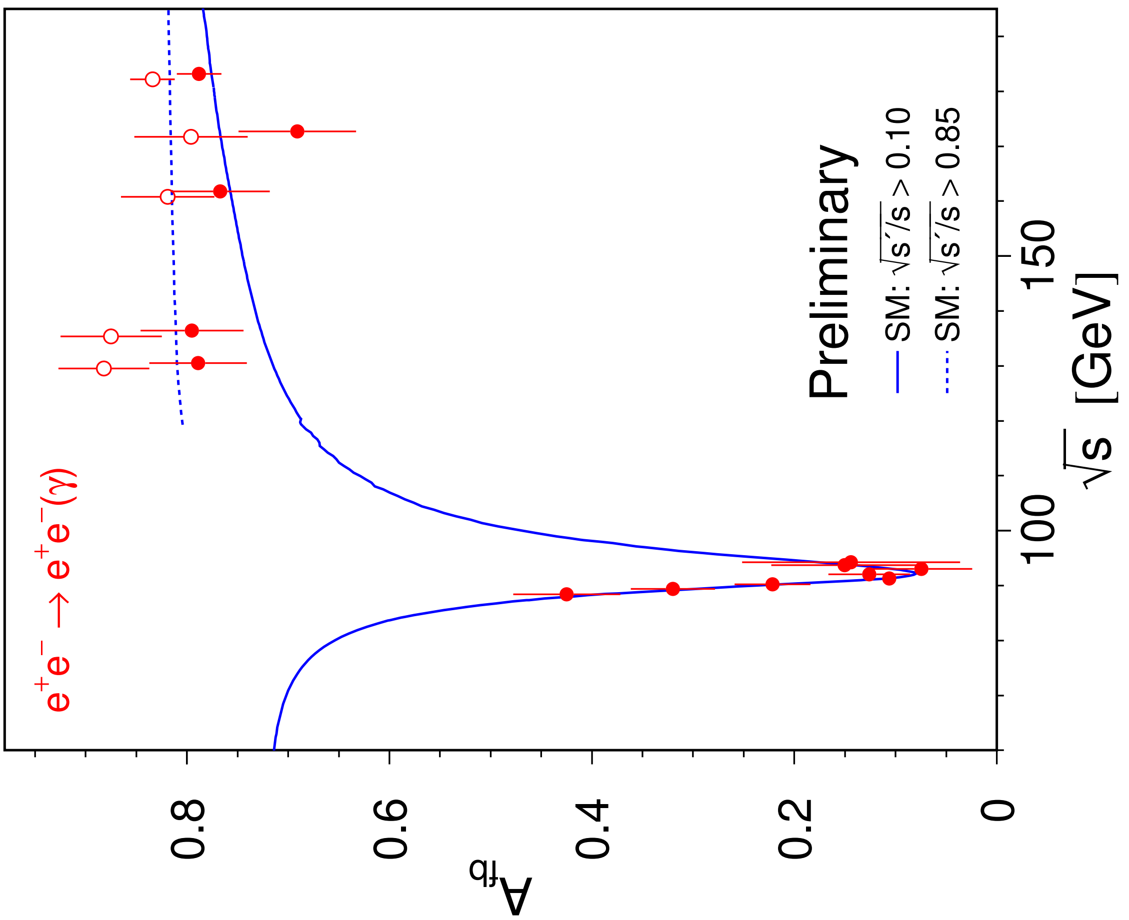
Fits in S-matrix framework:

	$j^{\rm tot}_{\rm had}$	m_Z [MeV]
LEP I	0.18 ± 0.73	$91\,188 \pm 13$
$\sqrt{s} \leq 183$ GeV	0.22 ± 0.17	$91\,188 \pm 4.2$
Standard Model	0.21	


L3
Preliminary
$e^+e^- \to \mu^+\mu^-(\gamma)$
$e^+e^- \to \tau^+\tau^-(\gamma)$
SM: $\sqrt{s'/s} > 0.10$
SM: $\sqrt{s'/s} > 0.85$
σ [nb]
A_{fb}
$\sqrt{s}$ [GeV]
1
10^{-1}
10^{-2}
0.5
0
-0.5
100
150

$(44^\circ < \Theta_{e^+}, \Theta_{e^-} < 136^\circ)$



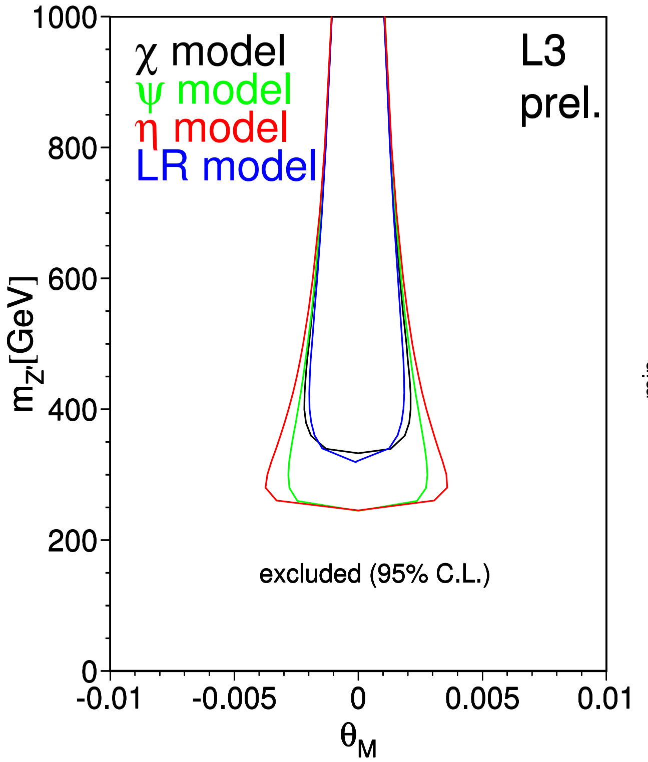


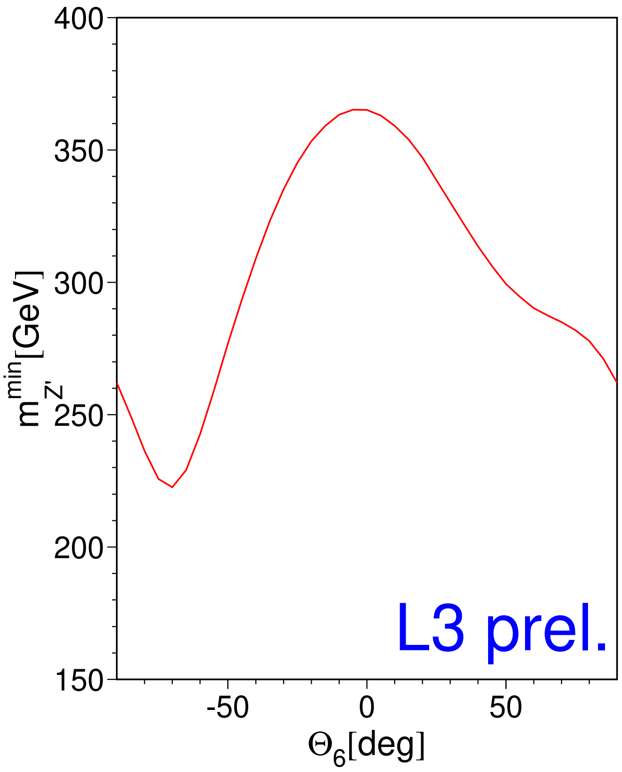
Additional heavy boson Z′:

– mass $m_{Z'}$
– Z′ couplings
– $Z - Z'$ mixing Θ_M

Consider LR and E_6 models:

χ, ψ, η : $\Theta_6 = 0, \frac{\pi}{2}, -\arctan\sqrt{\frac{5}{3}}$





Sequential Standard Model
($\Theta_M = 0$, SM couplings)

$m_{Z'} > 805$ GeV   (95% CL)

R-parity violating scalar neutrino exchange

L and B violating terms in superpotential

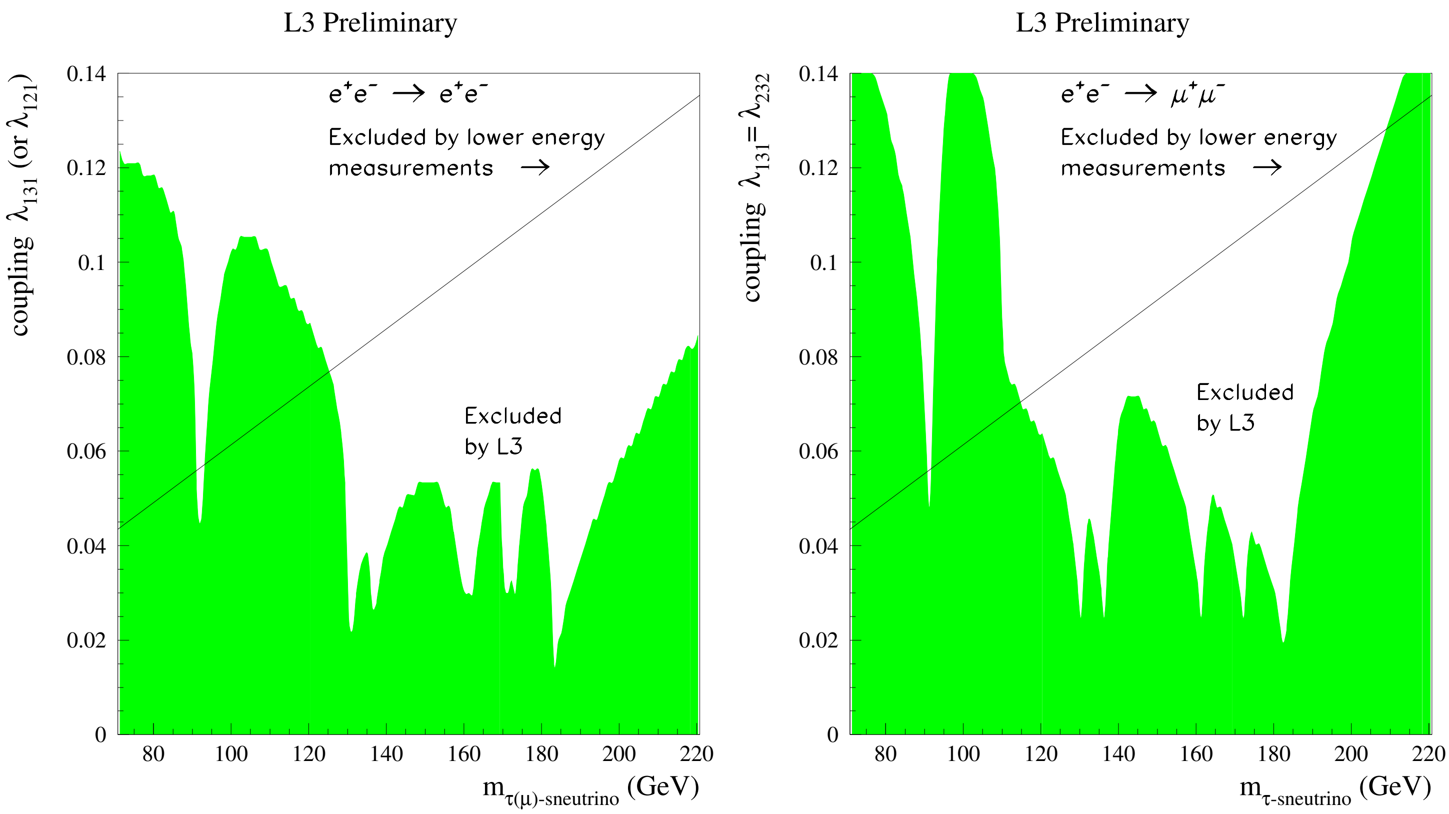
$$W_{\not R} = \lambda_{ijk}\, L_L^i\, L_L^j\, \bar{E}_R^k + \lambda'_{ijk} L_L^i\, Q_L^j\, \bar{D}_R^k + \ldots$$

$\lambda_{ijk}^{(\prime)} \neq 0$ only for $i \neq j$

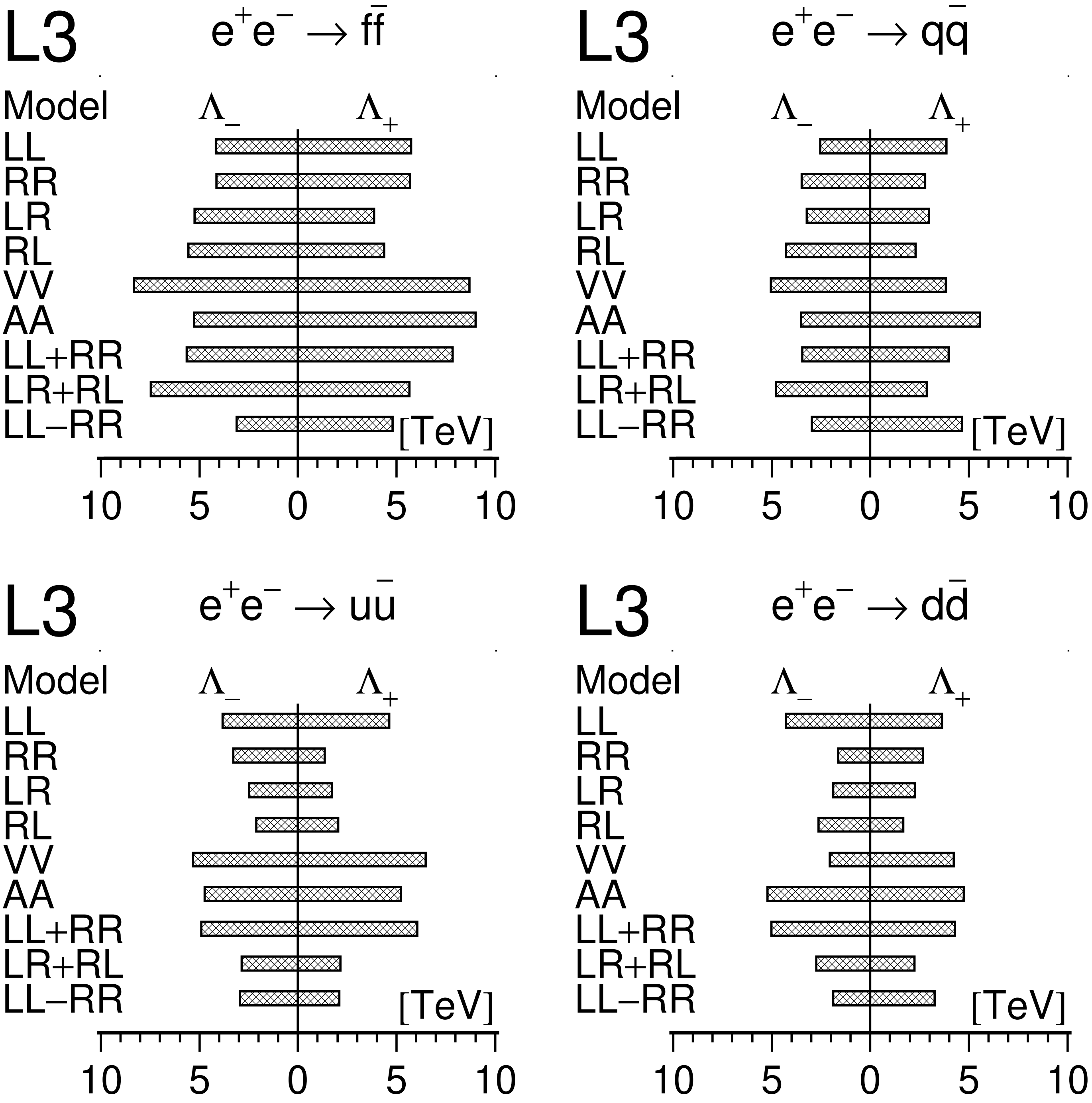
9(27) independent Yukawa couplings $\lambda\,(\lambda')$

- λ_{121} or $\lambda_{131} \neq 0$
  $\tilde{\nu}_\mu,\ \tilde{\nu}_\tau$ exchange in $e^+e^- \to e^+e^-(\gamma)$
- $\lambda_{131} = \lambda_{232} \neq 0$
  $\tilde{\nu}_\tau$ exchange in $e^+e^- \to \mu^+\mu^-(\gamma)$

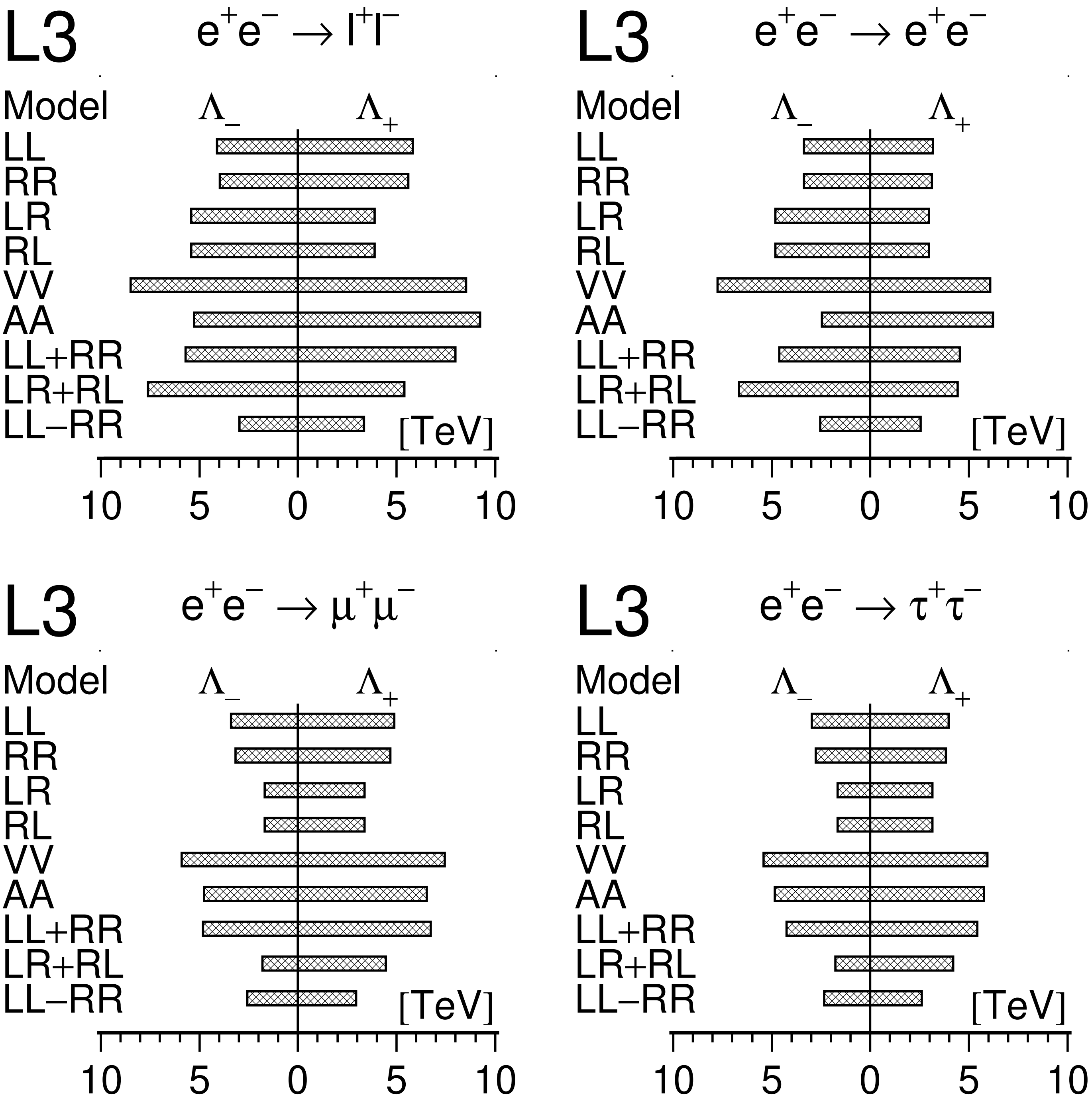
Exclusion in $\lambda - m_{\tilde{\nu}}$ plane (95% CL):



Combined and hadronic final states



Leptonic final states



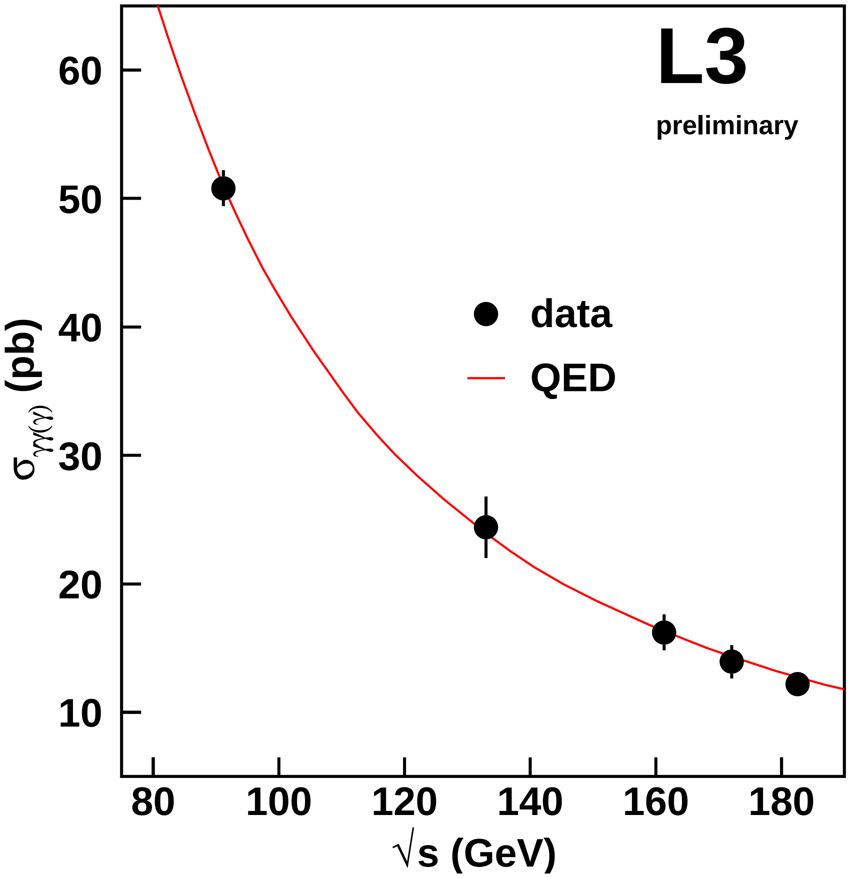
Study of $e^+e^- \to n\,\gamma$ $(n \geq 2)$ at $\sqrt{s} = 183$ GeV

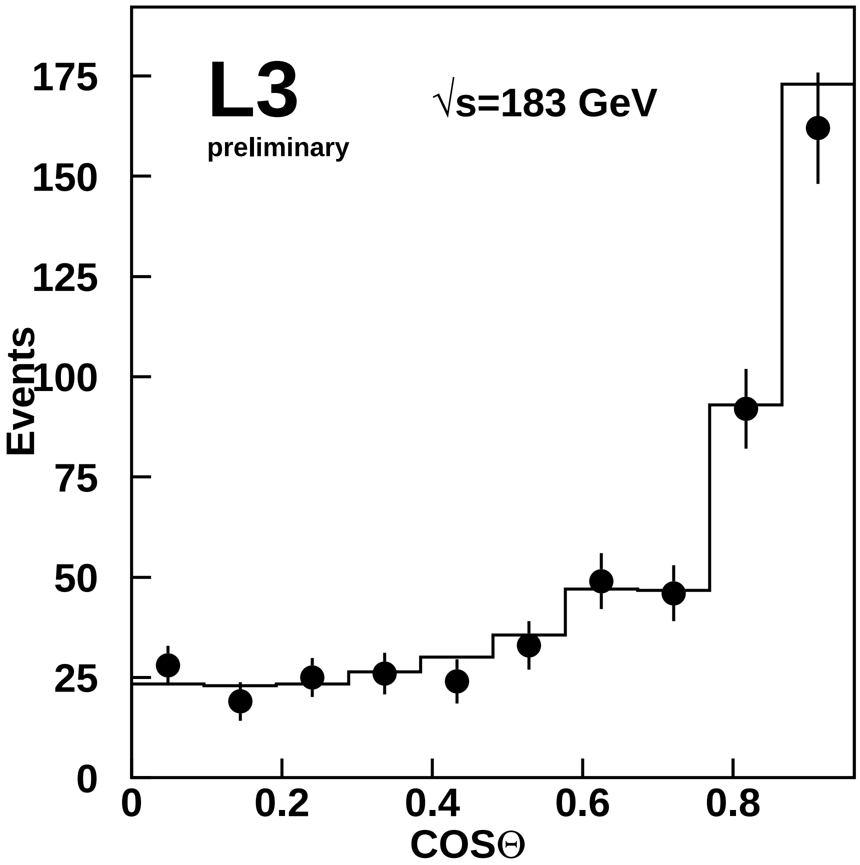
- $16^\circ < \Theta_\gamma < 164^\circ$, $E_\gamma \geq 1$ GeV, $\sum E_\gamma \geq \sqrt{s}/2$

Events	observed	expected
$2\,\gamma$	473	490
$3\,\gamma$	30	30
$4\,\gamma$	1	–
Total	504	520

Measured cross section at $\sqrt{s} = 183$ GeV:

$$\sigma(e^+e^- \to n\,\gamma) = 12.20 \pm 0.53 \pm 0.26 \text{ pb}$$





From total and differential cross section limits (95% C.L.) on

- QED cut-off parameter:

$$\Lambda_+ > 262 \text{ GeV}$$
$$\Lambda_- > 245 \text{ GeV}$$

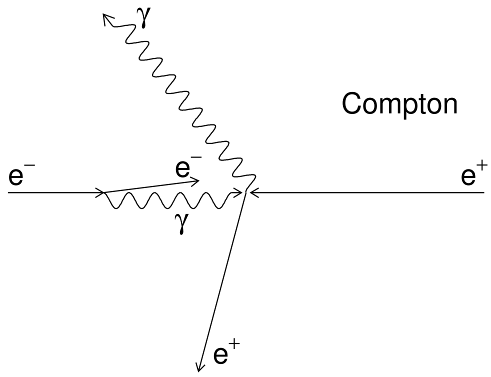
- Contact interaction scales:

$$\Lambda > 1064 \text{ GeV}$$
$$\Lambda' > 603 \text{ GeV}$$

- Excited electron, $\lambda = 1$:

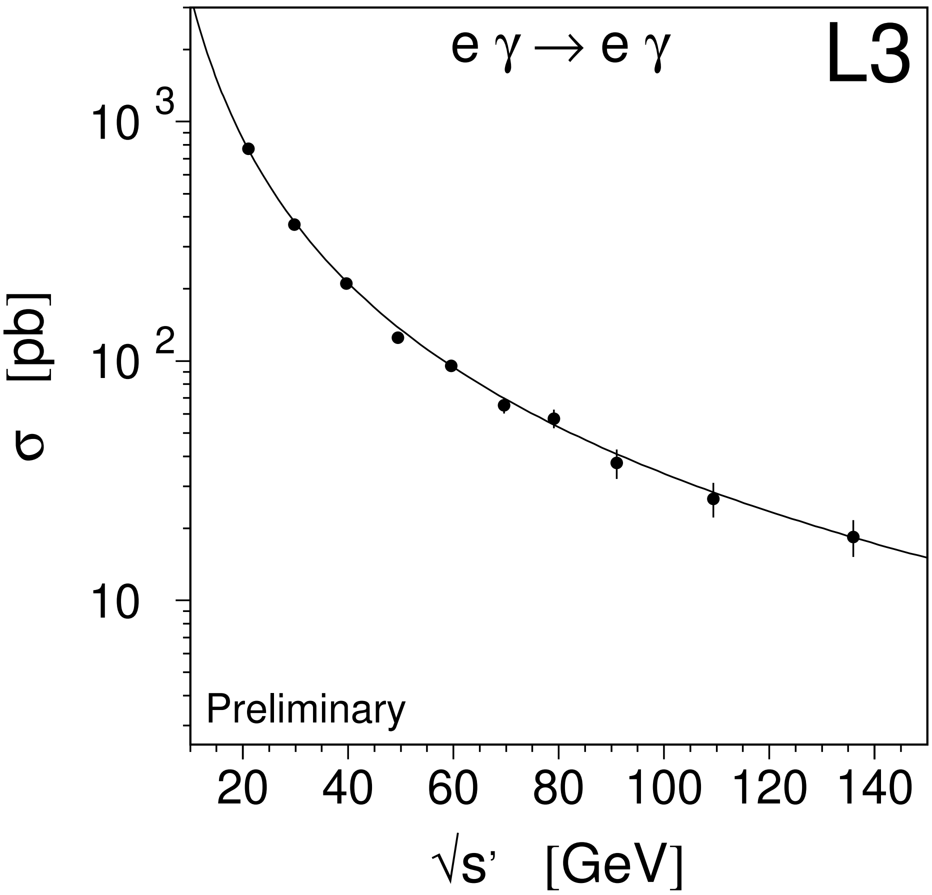
$$m_{e^*} > 246 \text{ GeV} \qquad (\text{L} - \text{R})$$
$$m_{e^*} > 180 \text{ GeV} \qquad (\text{L or R})$$

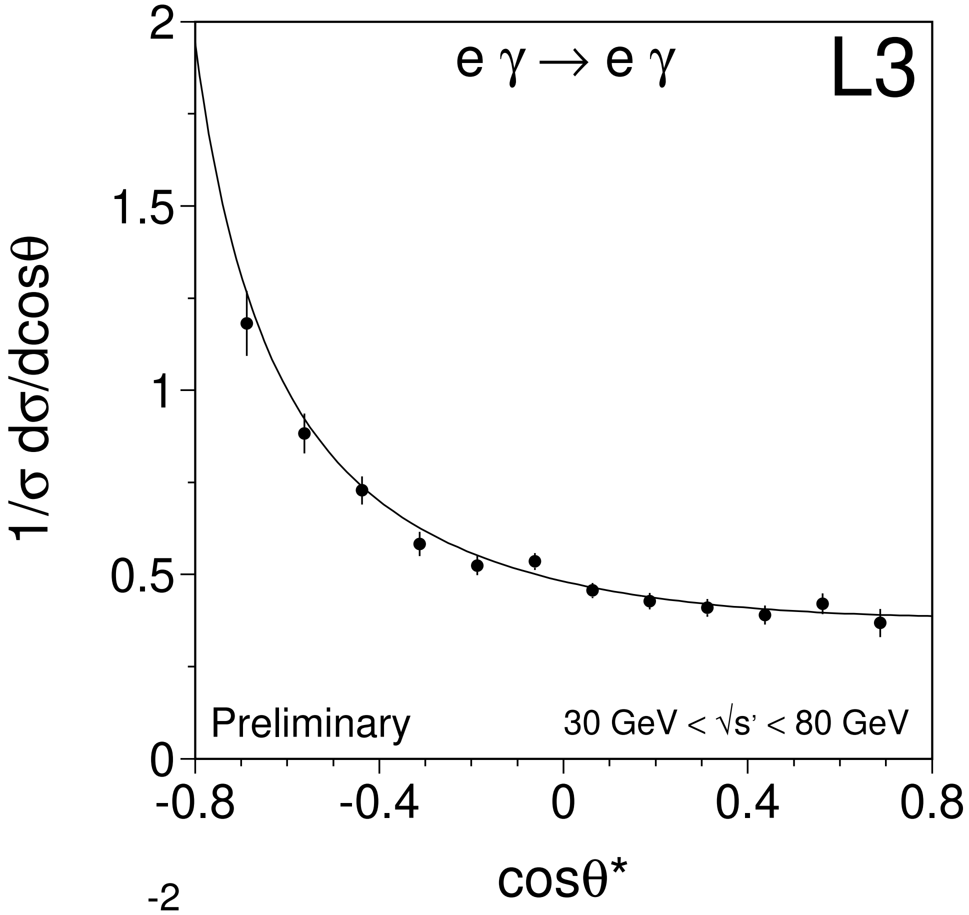
$$e^{\pm}\gamma \rightarrow e^{\pm}\gamma$$



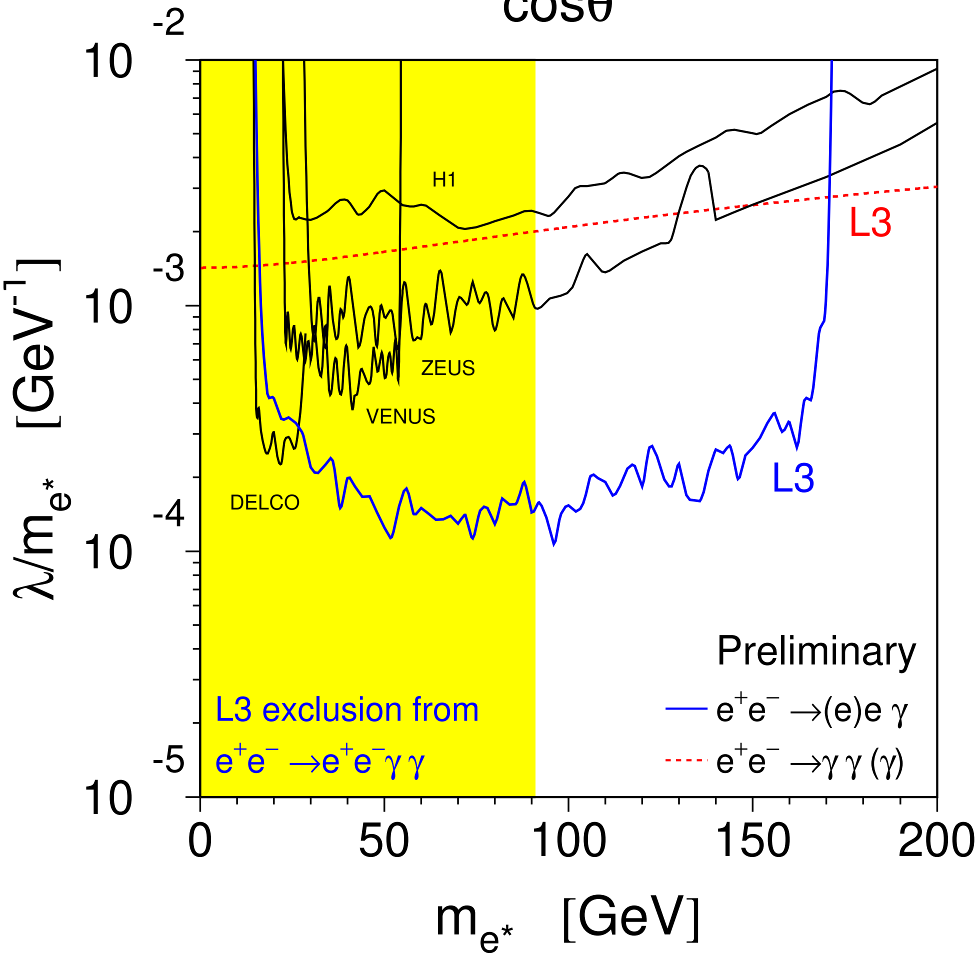
Electron & photon inside $|\cos\Theta| < 0.94$
Scattering angle in $e^{\pm}\gamma$ system $|\cos\Theta^{*}| < 0.8$
$\sum p_{\perp} < 0.15 E_{b}$

4641 events selected ($\sqrt{s} \leq 183$ GeV)
Cross section as function of energy





Differential cross section

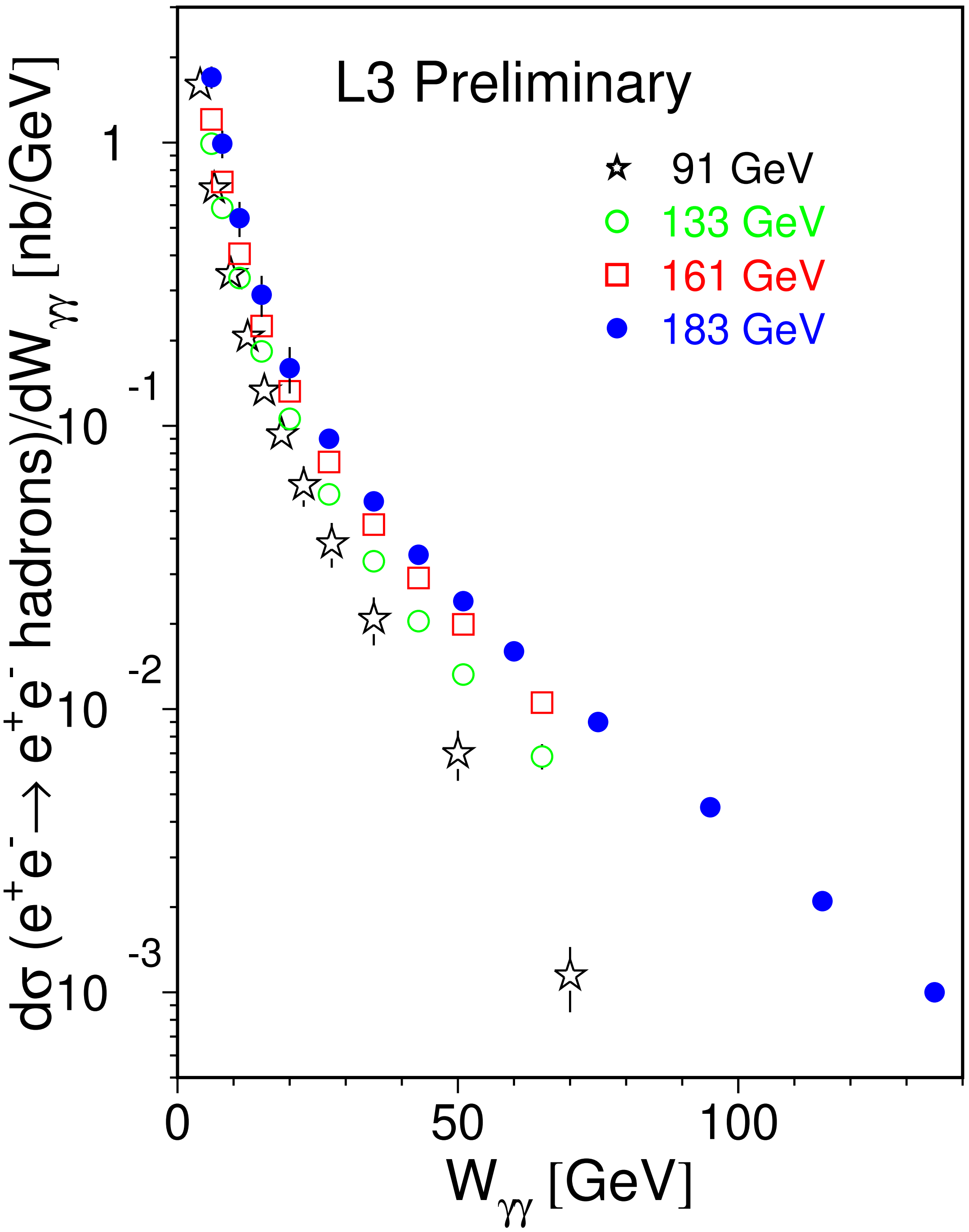


Limits on excited electron

(95% CL)

Measurement of the inclusive cross section $e^+e^- \rightarrow e^+e^-$ hadrons

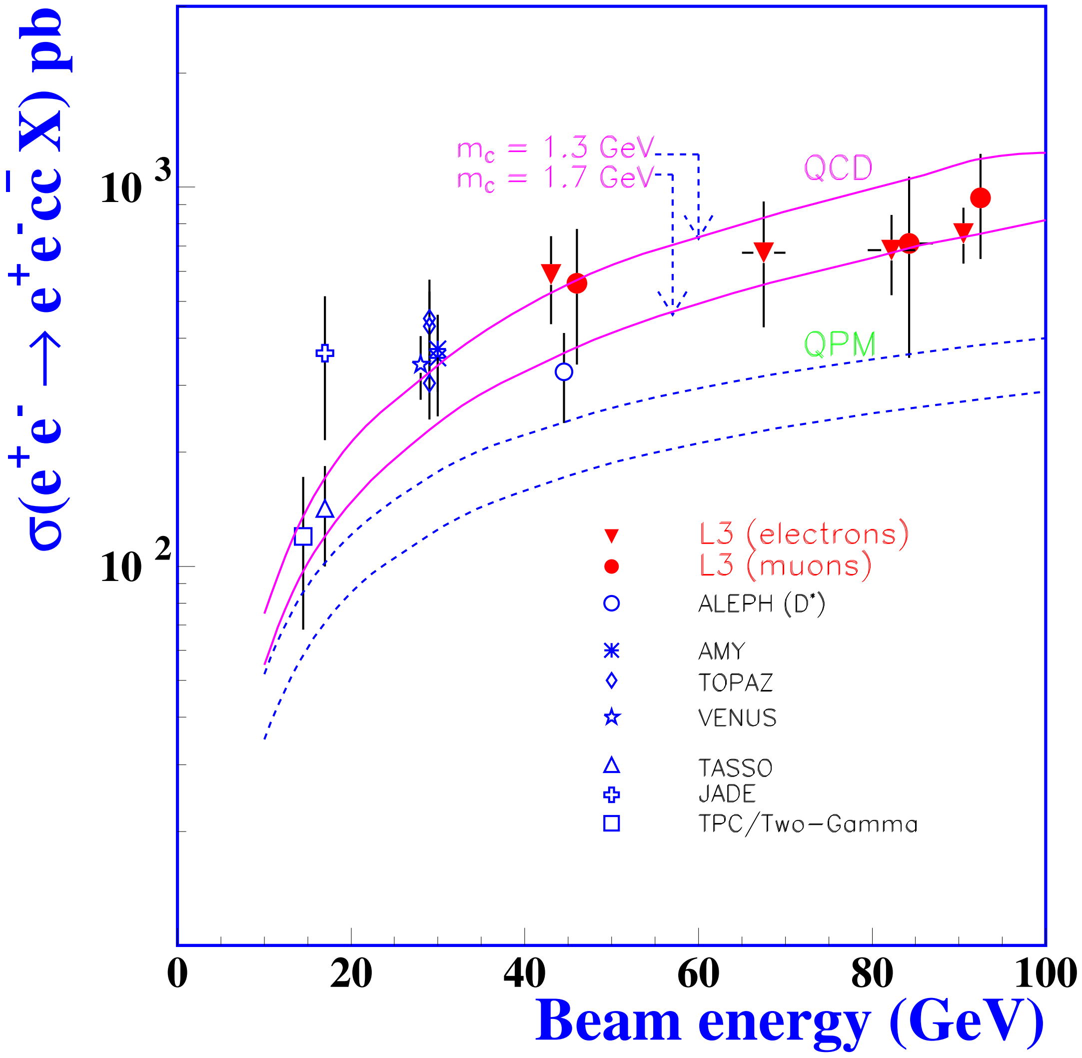
Unfolding of W_{vis} to obtain $W_{\gamma\gamma}$



Inclusive charm production in $\gamma\gamma$ collisions

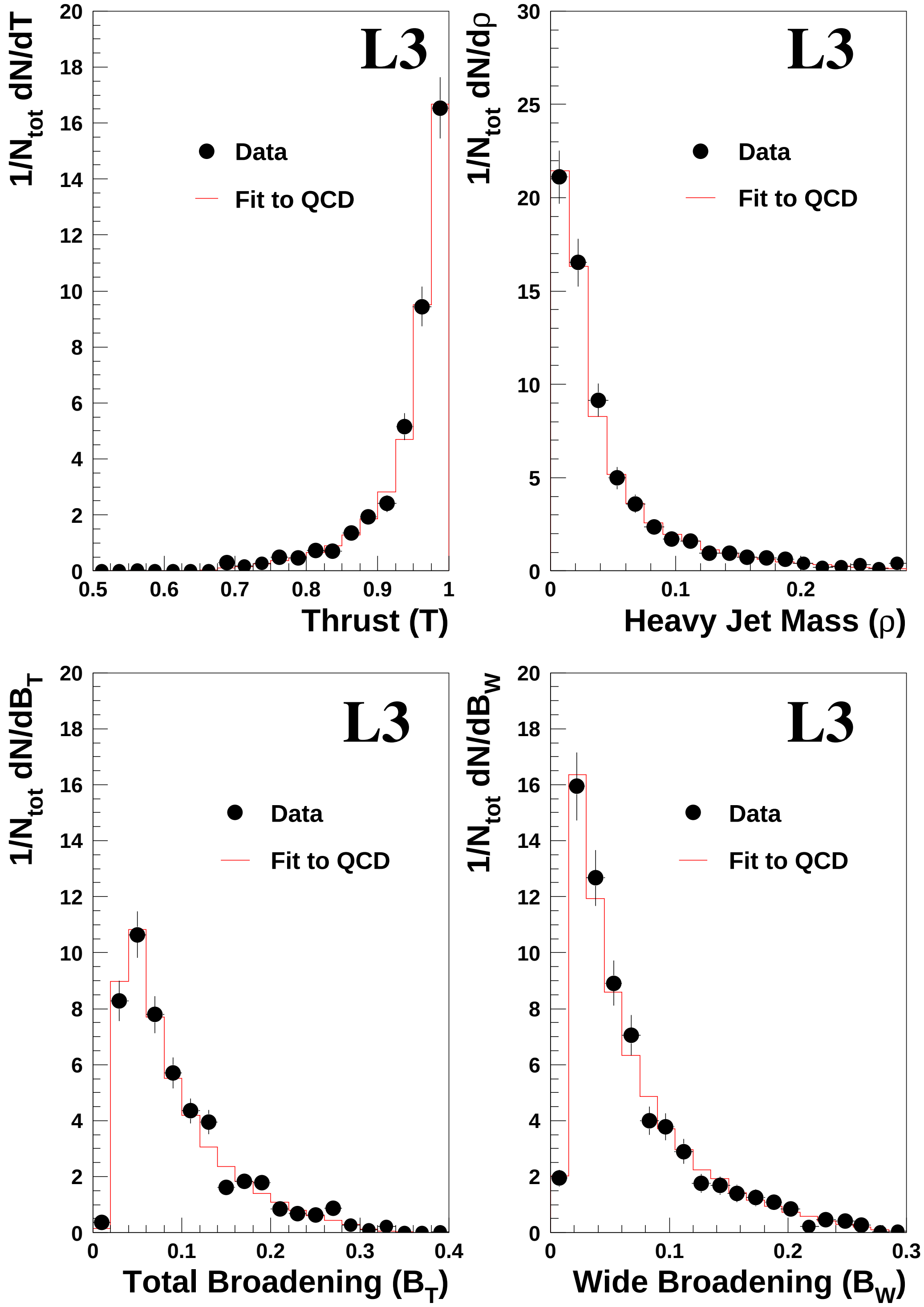
From $e^+e^- \to e^+e^-$ hadrons select low energy leptons:
$p_e > 0.5$ GeV; 2 GeV $< p_\mu < 0.2E_b$

301 electron and 52 muon candidates at $\sqrt{s} = 183$ GeV
Cross section $e^+e^- \to e^+e^- c\bar{c}X$:



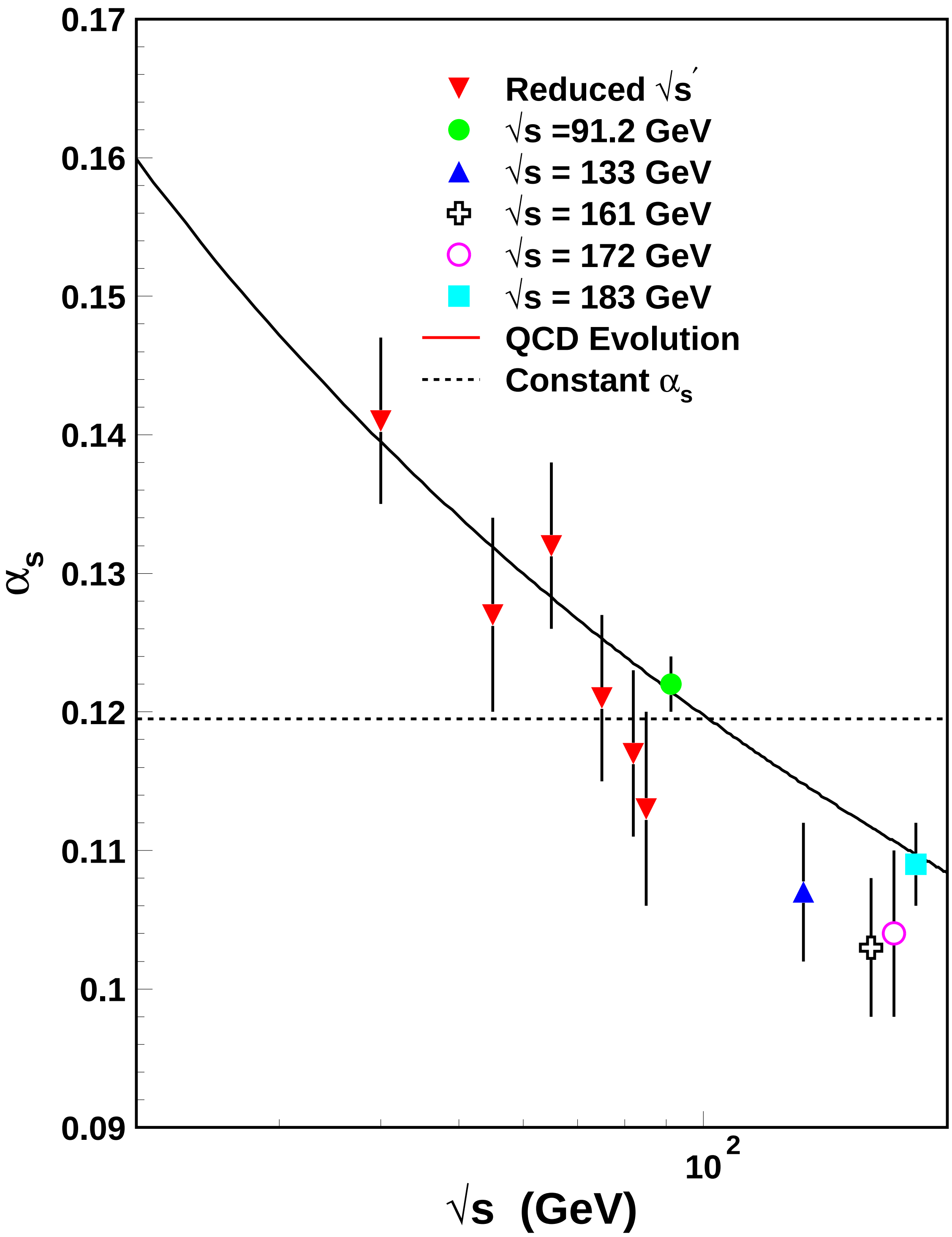
- **Test of QCD**
- **Gluon content of photon**
- **Constrain charm quark mass**

Determination of α_s from hadronic event shape variables



$$\alpha_s(183\ \mathrm{GeV}) = 0.109 \pm 0.002\,(\mathrm{exp}) \pm 0.005\,(\mathrm{th})$$

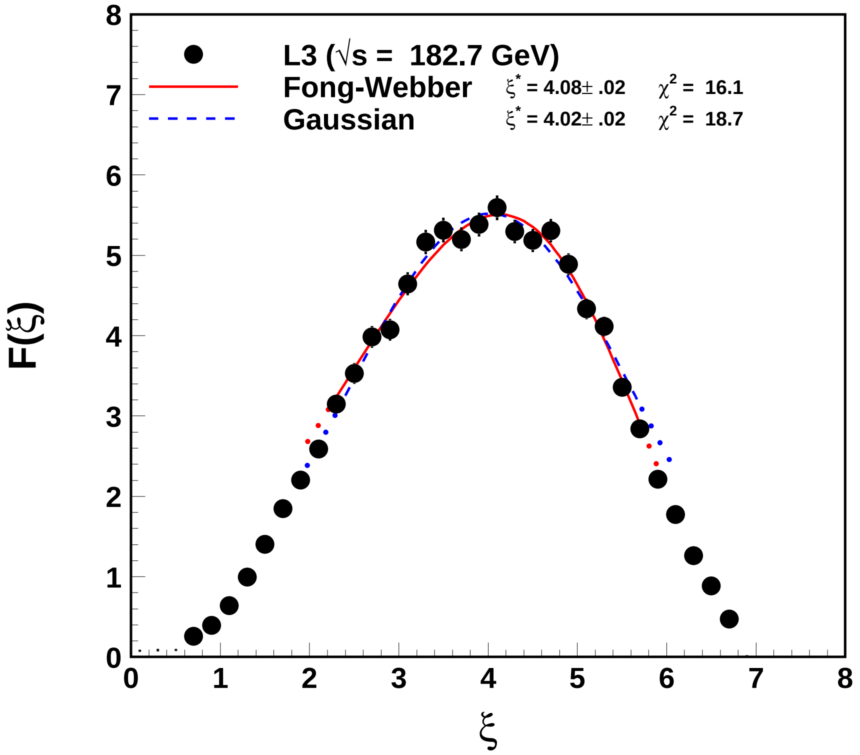
Evolution of α_s (experimental errors only):



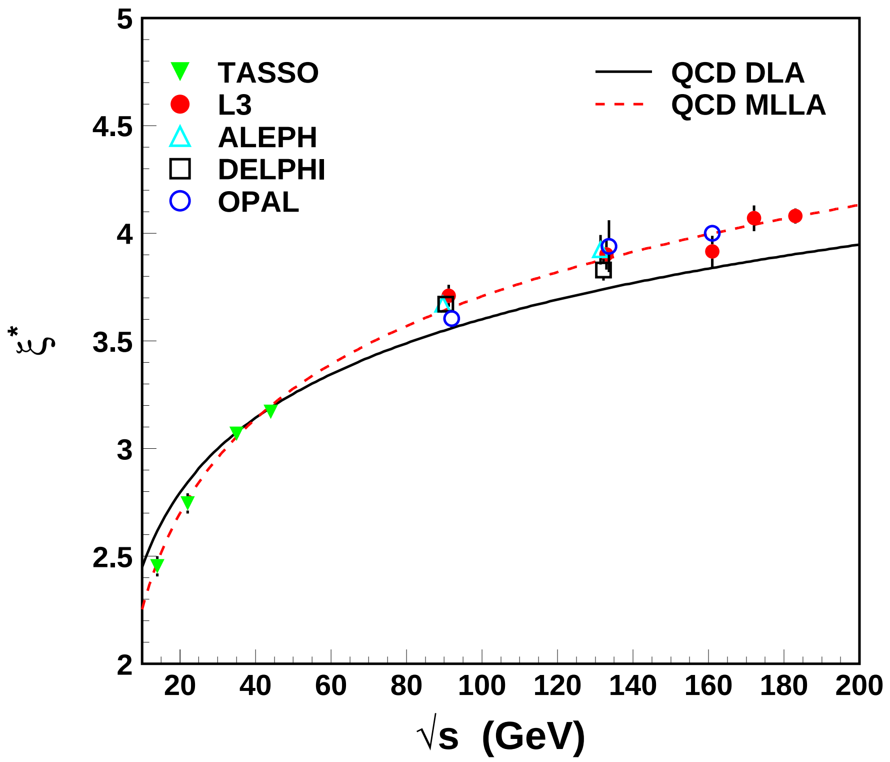
From fit to 11 measurements

$$\alpha_s(m_Z) = 0.1215 \pm 0.0016\,(\mathrm{exp}) \pm 0.0066\,(\mathrm{th})$$

Charged particle spectrum $\xi = -\log x_p$ in hadronic events



Evolution of peak position

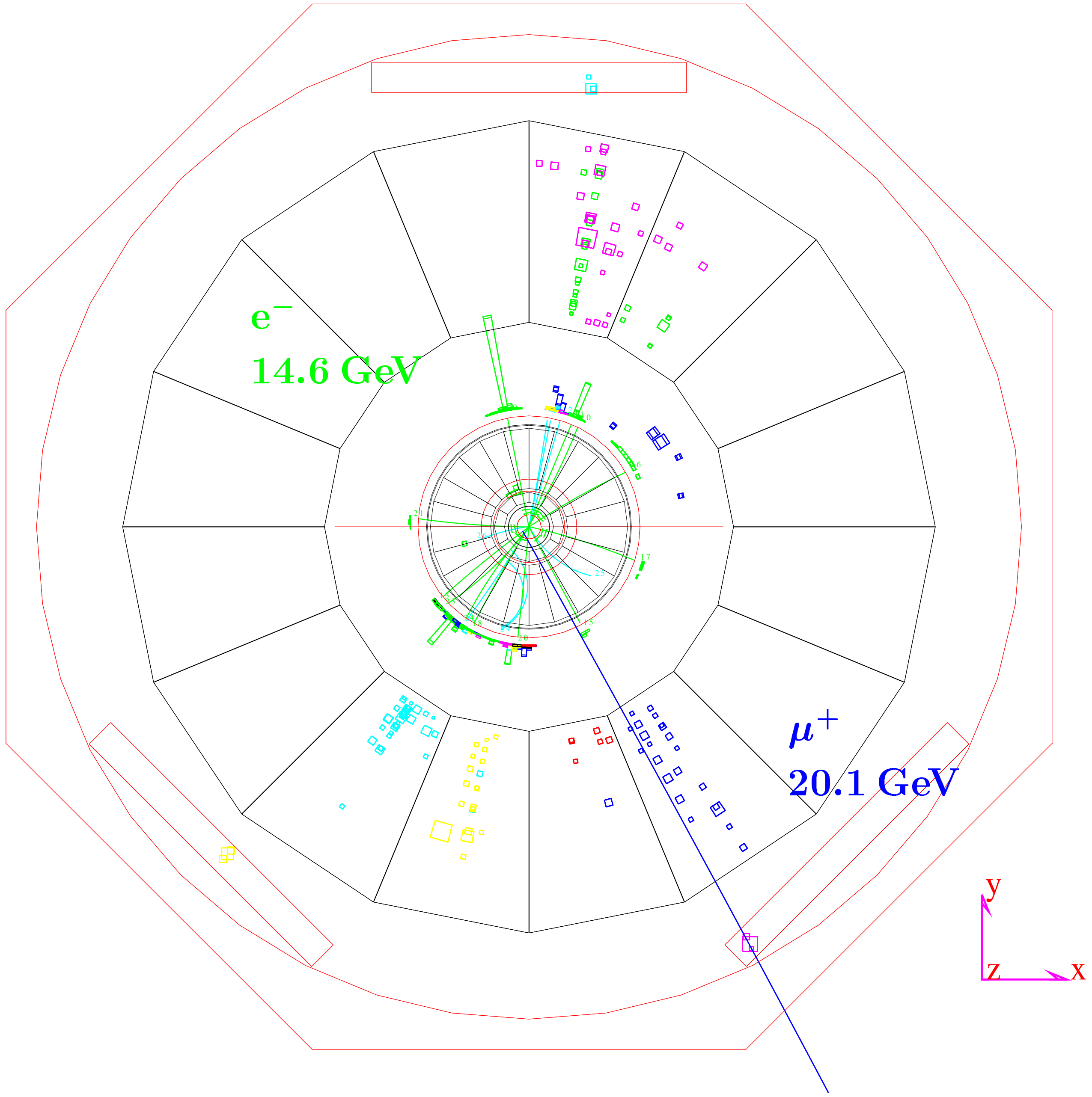


$$\xi^*(183\ \text{GeV}) = 4.08 \pm 0.02 \pm 0.03$$

Search for Heavy Leptons

Candidate event $e^+e^- \rightarrow L^0\,\bar{L}^0$, $L^0 \rightarrow \tau^\pm W^\mp$

Run # **690011** **Event #** **3606** Total Energy : 126.44 GeV



$$m_{jj} = 90.3 \text{ GeV} \qquad m_{\tau\tau} = 91.2 \text{ GeV}$$

Nice $e^+e^- \rightarrow ZZ \rightarrow q\bar{q}\,\tau^+\tau^-$ candidate!

Summary of results:

(95% CL lower mass limits)

- Neutral heavy leptons $e^+e^- \to L^0\,\bar{L}^0$

		Dirac	Majorana
$L^0 \to e^\pm\,W^{\mp *}$	m_{L^0}	> 86.3 GeV	> 72.5 GeV
$L^0 \to \mu^\pm\,W^{\mp *}$	m_{L^0}	> 87.7 GeV	> 74.9 GeV
$L^0 \to \tau^\pm\,W^{\mp *}$	m_{L^0}	> 75.4 GeV	> 63.9 GeV

- Charged heavy leptons $e^+e^- \to L^+\,L^-$

$L^\pm \to \nu_\ell\,W^{\pm *}$ $\quad m_{L^\pm} > 85$ GeV

$L^\pm \to L^0\,W^{\pm *}$ $\quad m_{L^\pm} > 90.5$ GeV $\quad (\Delta m > 15$ GeV)

- Stable charged heavy leptons

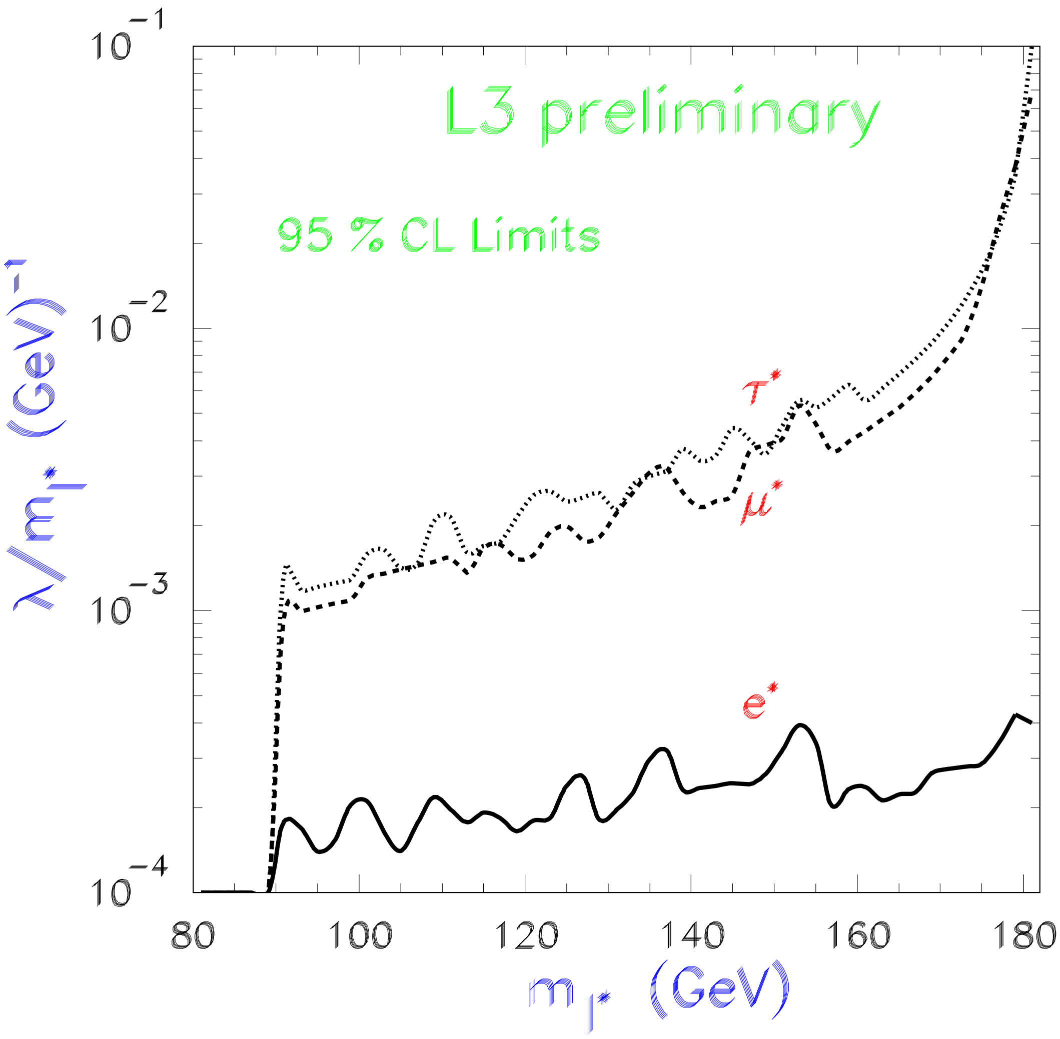
$$m_{L^\pm} > 90.5 \text{ GeV}$$

Limits (95% CL) on excited electron, muon and tau

- **Pair production ($f = f'$)**

$$m_{e^*} > 91.1 \text{ GeV}$$
$$m_{\mu^*} > 91.1 \text{ GeV}$$
$$m_{\tau^*} > 91.0 \text{ GeV}$$

- **Single production**

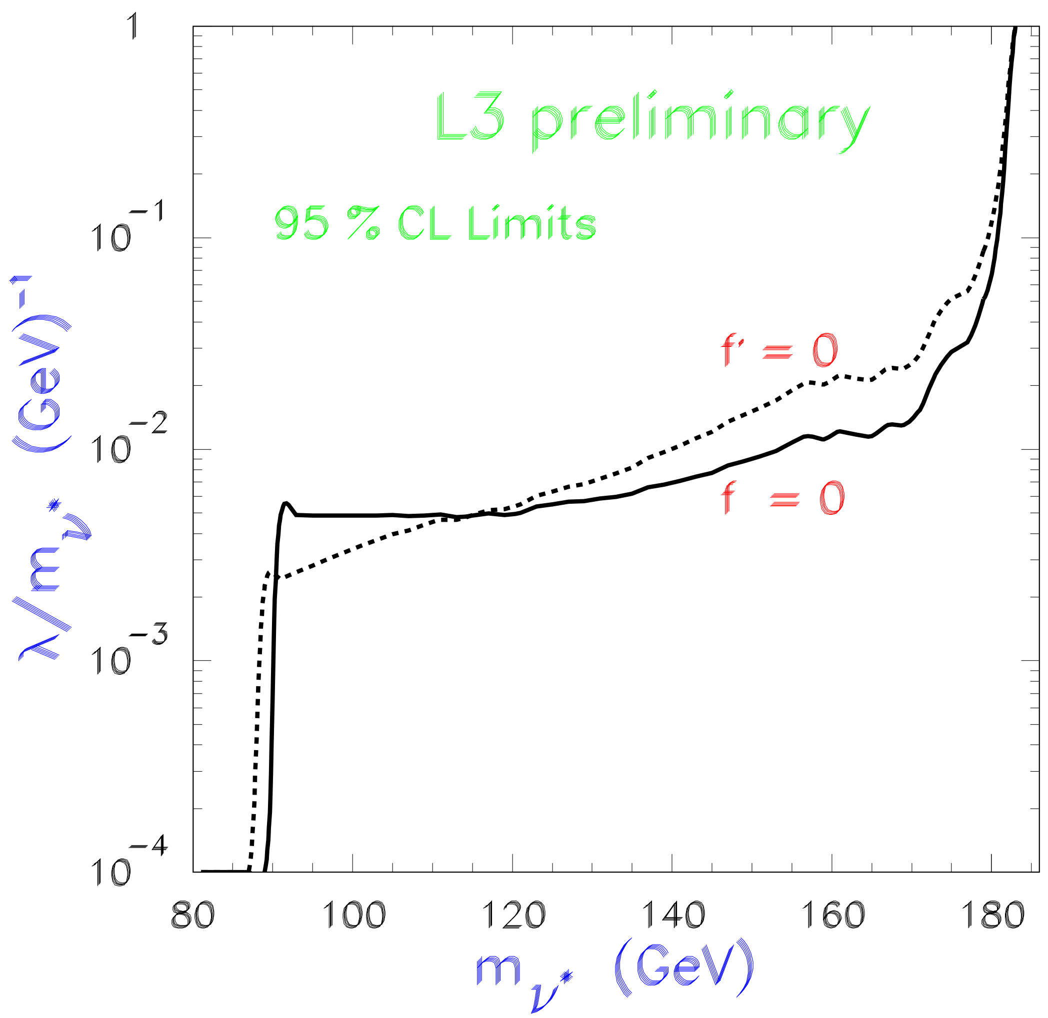


Limits (95% CL) on excited neutrinos

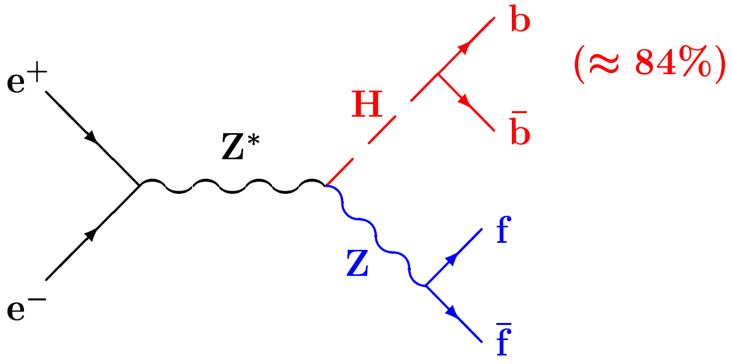
- **Pair production**

$$m_{\nu^*} > 89.5 \text{ GeV} \qquad f = -f'$$
$$m_{\nu^*} > 90.0 \text{ GeV} \qquad f = 0$$
$$m_{\nu^*} > 88.1 \text{ GeV} \qquad f' = 0$$

- **Single production**



The Standard Model Higgs boson



(+ small contribution from WW fusion diagram)

6 HZ decay channels event topologies:

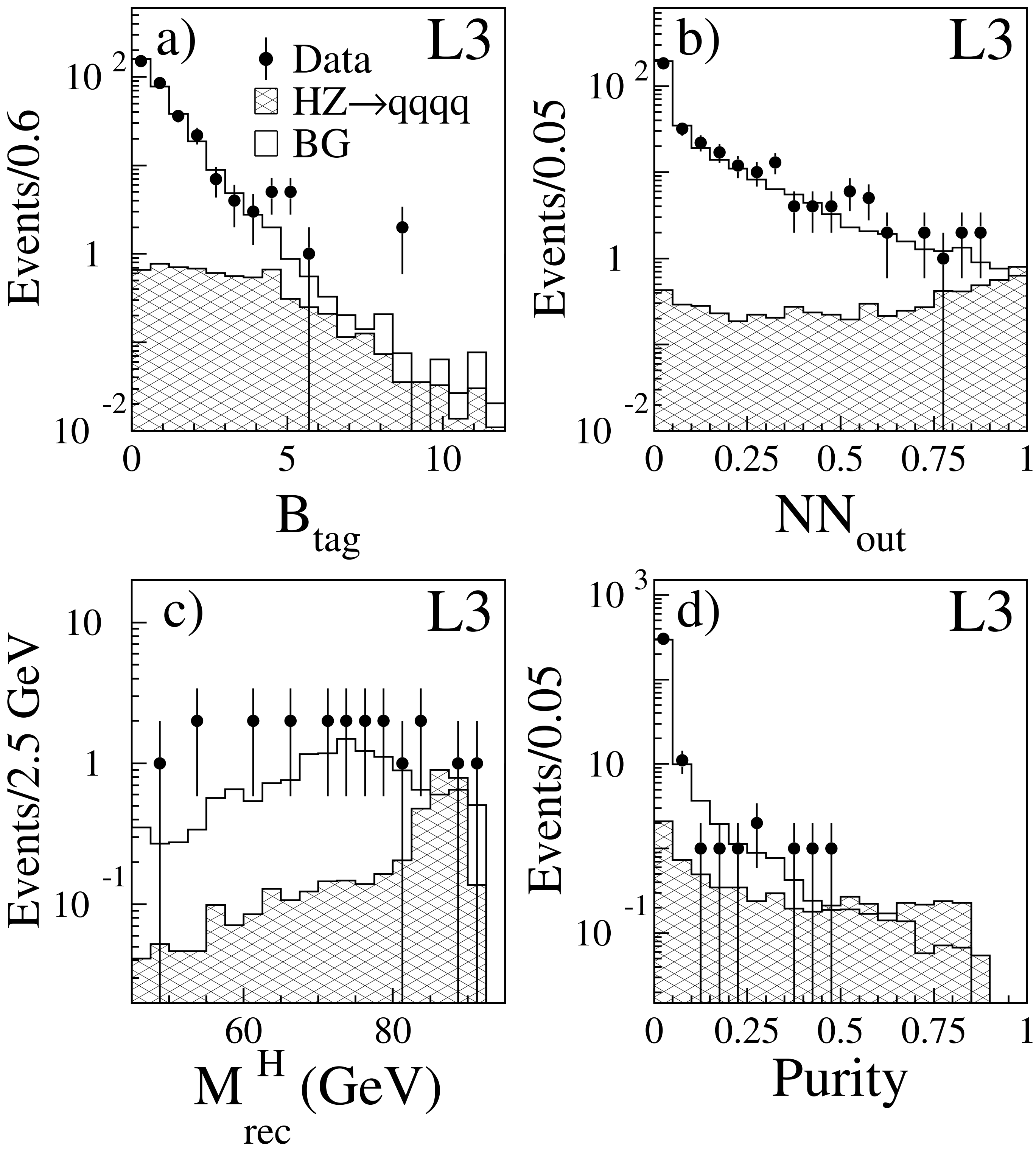
- loose preselection
- neural network, checked by cut based analysis
  $BR(H \to \mathrm{b\bar{b}}) = 84\% \Rightarrow$ b-tagging
  some efficiency kept for other hadronic H decays
- kinematic fit using m_Z $\Rightarrow M^\mathrm{H}_\mathrm{rec}$
- build discriminant variable (purity)

After preselection:

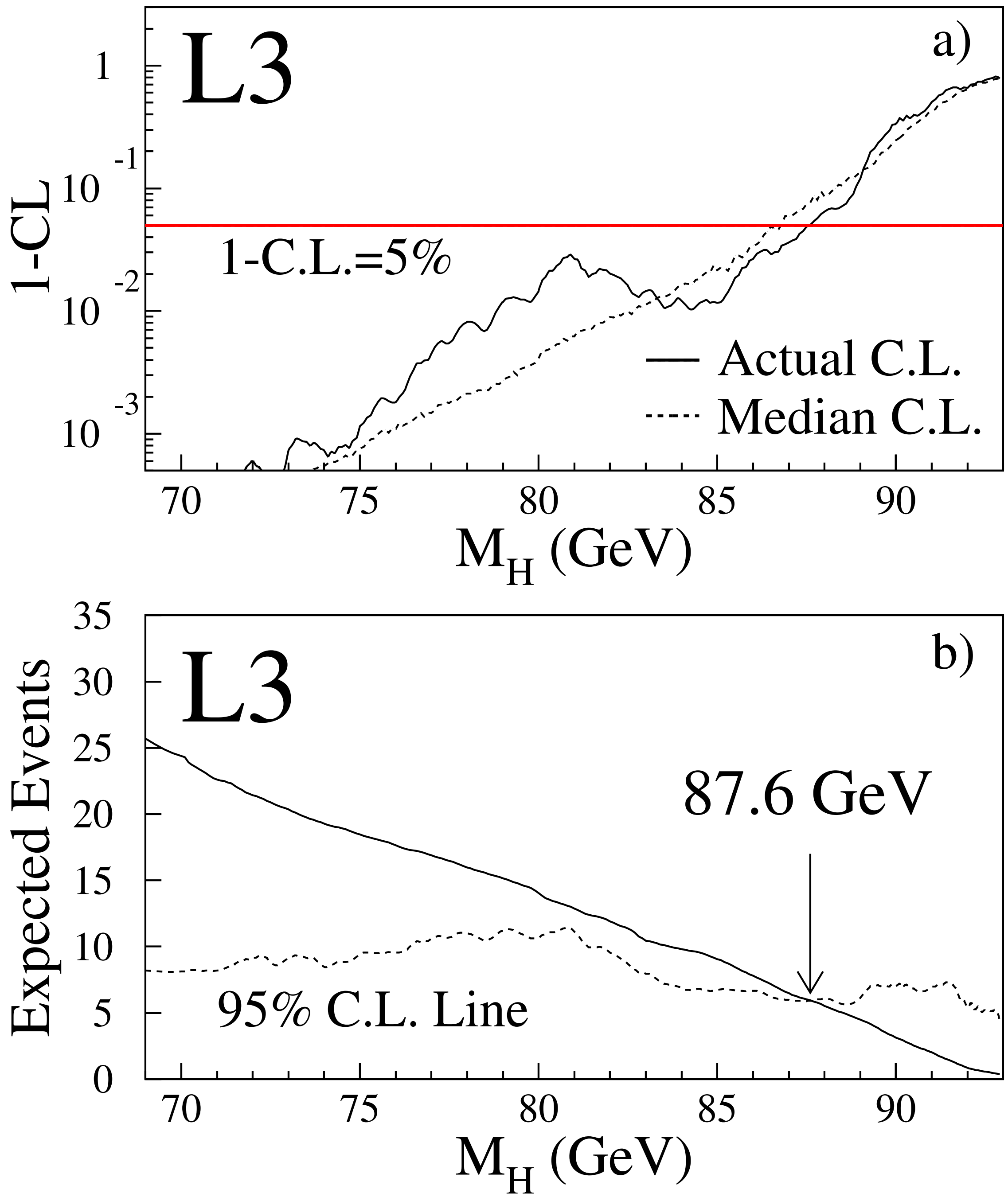
Final state		Efficiency for m_H [GeV]				BG	DATA
H	Z	80	85	87	90		
$q\bar{q}$	$q\bar{q}$	0.65	0.66	0.65	0.66	315	321
$q\bar{q}$	$\nu\bar{\nu}$	0.76	0.75	0.74	0.71	50.4	56
$q\bar{q}$	$\mathrm{e^+e^-}$	0.78	0.80	0.75	0.77	5.4	6
$q\bar{q}$	$\mu^+\mu^-$	0.44	0.45	0.45	0.48	1.4	2
$q\bar{q}$	$\tau^+\tau^-$	0.15(0.06)	0.14(0.08)	0.15(0.08)	0.14(0.08)	0.7	0
$\tau^+\tau^-$	$q\bar{q}$	0.19(0.06)	0.17(0.07)	0.16(0.09)	0.16(0.09)	1.7	1

Example: HZ $\rightarrow q\bar{q}q\bar{q}$

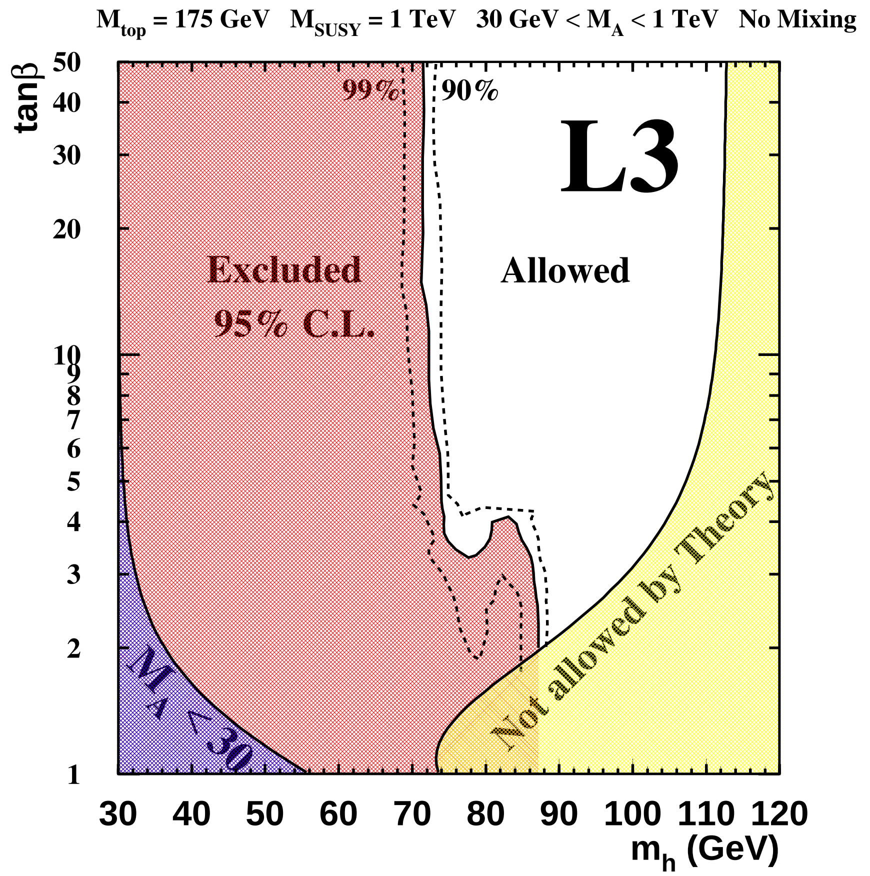
(Signal distributions for $m_{\mathrm{H}} = 87$ GeV)

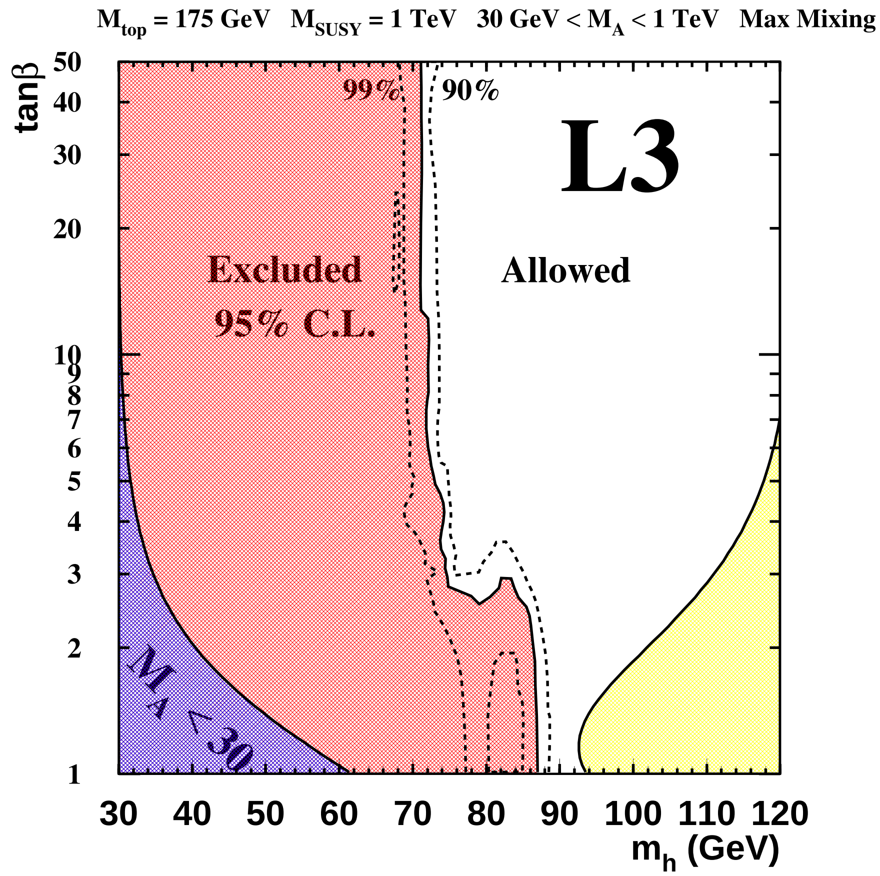


Result of SM Higgs search:



$m_{\mathrm{H}} > 87.6$ GeV (95% CL)





$m_h > 71$ GeV

(95% CL)

Search for Supersymmetric Particles

- R-parity conservation
- $\tilde{\chi}_1^0$ is LSP
- missing energy, missing mass, acoplanarity

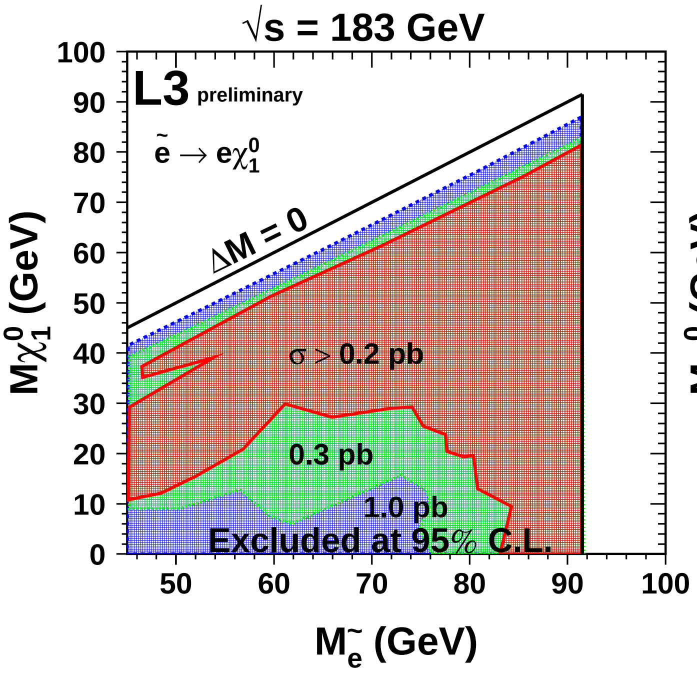
Topologies: 2 leptons, lepton + hadrons, purely hadronic
3 different $\Delta M = M_{sp} - M_{\tilde{\chi}_1^0}$ ranges

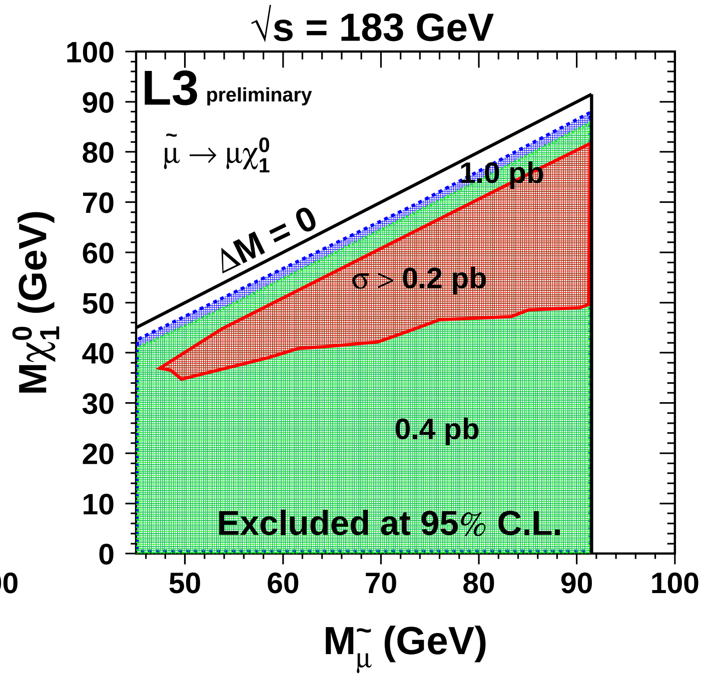
27 different selections, logical “OR”
Summary of SUSY particle search:

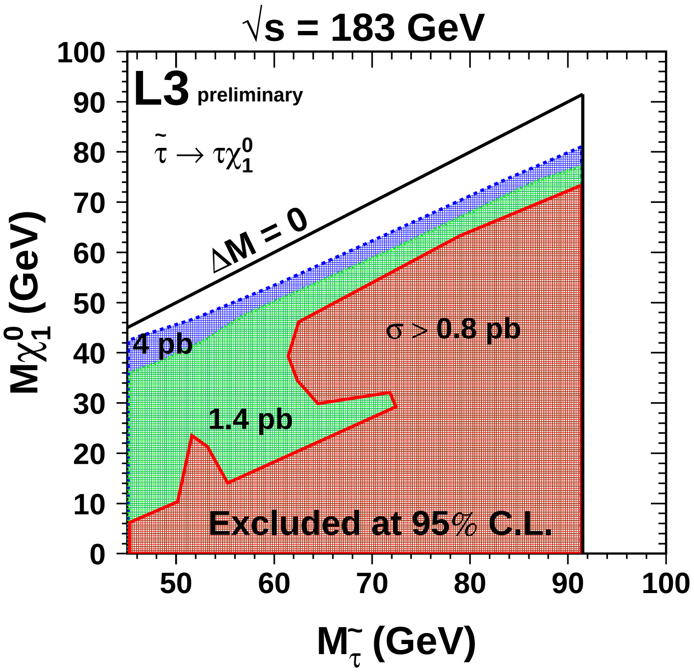
	N_{data}	N_{bkgd}
$\tilde{e}$	3	7.1 ± 1.5
$\tilde{\mu}$	4	6.4 ± 1.8
$\tilde{\tau}$	8	7.9 ± 2.8
$\tilde{\chi}_1^\pm$, $\tilde{\chi}_1^0$	15	20.2 ± 7
Overall	27	32.4 ± 9

⇒ no evidence for SUSY
⇒ limits on cross sections, masses, MSSM parameter

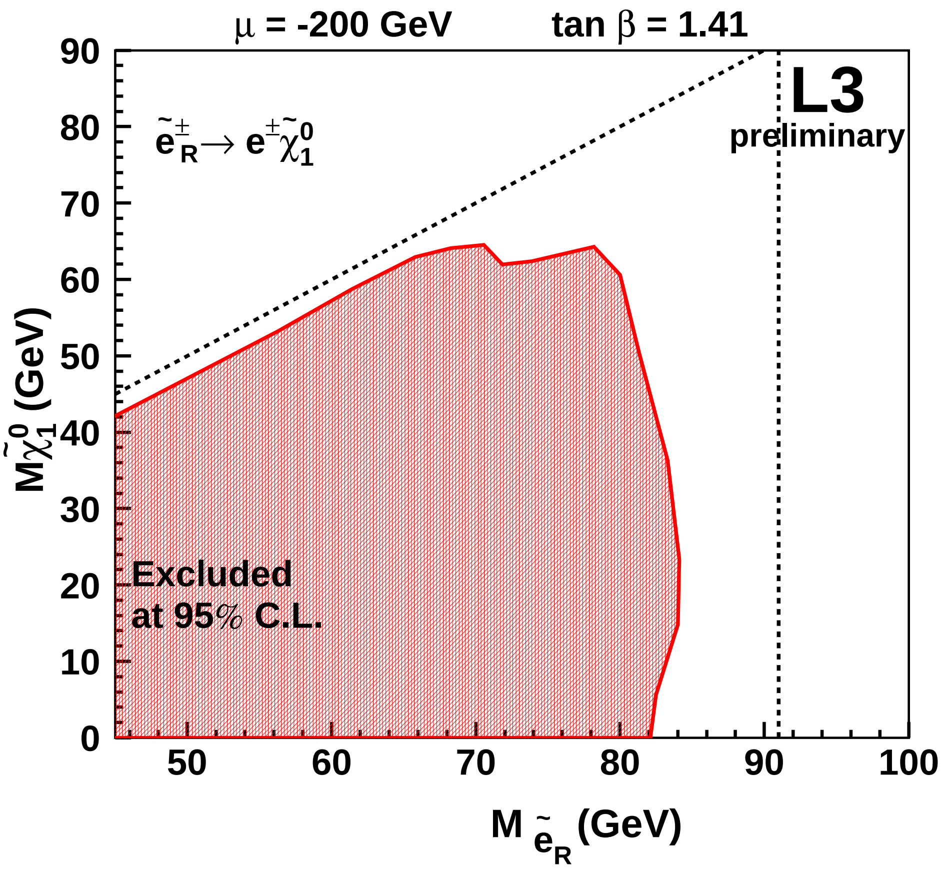
Upper limits on production cross sections for scalar leptons $e^+e^- \to \tilde{\ell}^+\tilde{\ell}^-$ ($\sqrt{s} = 183$ GeV)

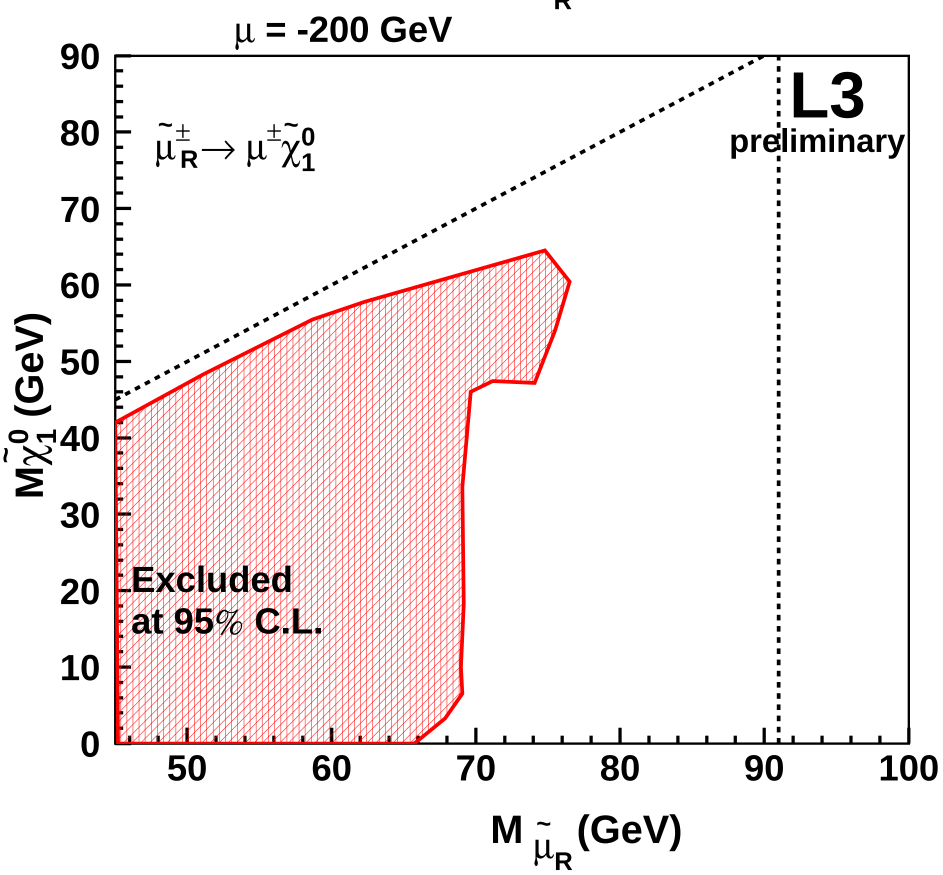




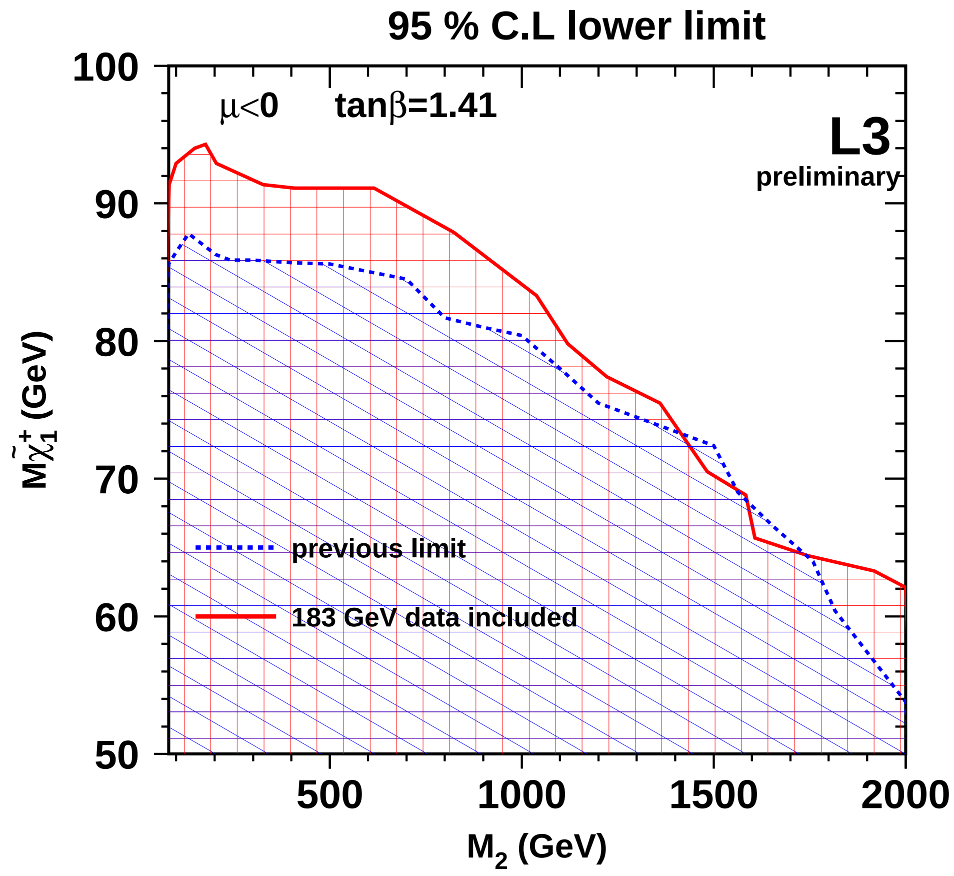


Mass limits for $\tilde{e}^{\pm}_{R}$ and $\tilde{\mu}^{\pm}_{R}$ from cross section limits



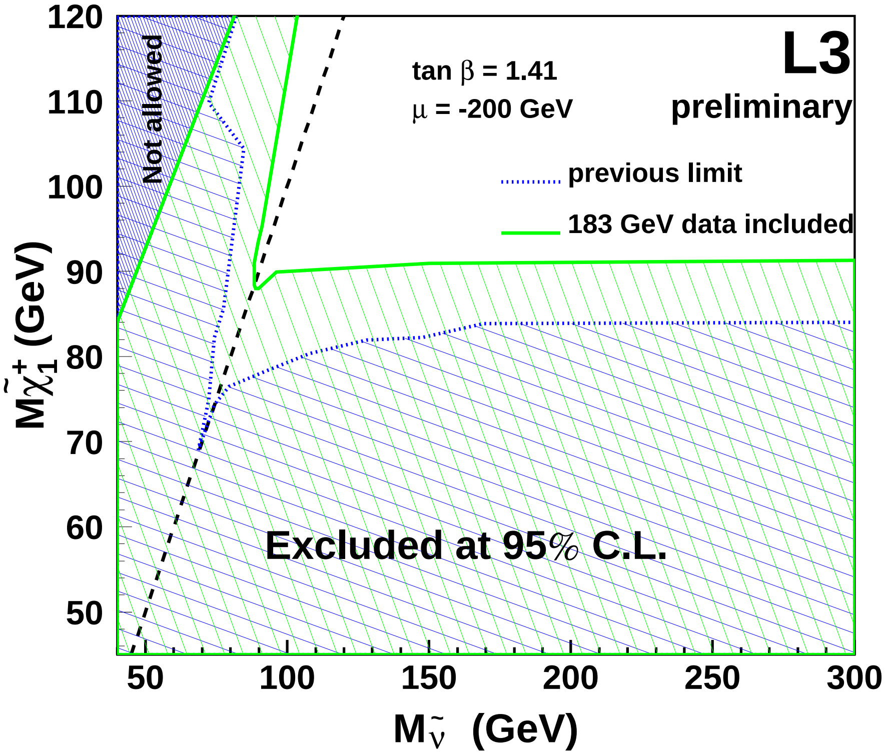


Limits on the chargino mass in the MSSM:



Higgsino-like $\tilde{\chi}_1^{\pm}$

$(M_2 \gg |\mu|)$

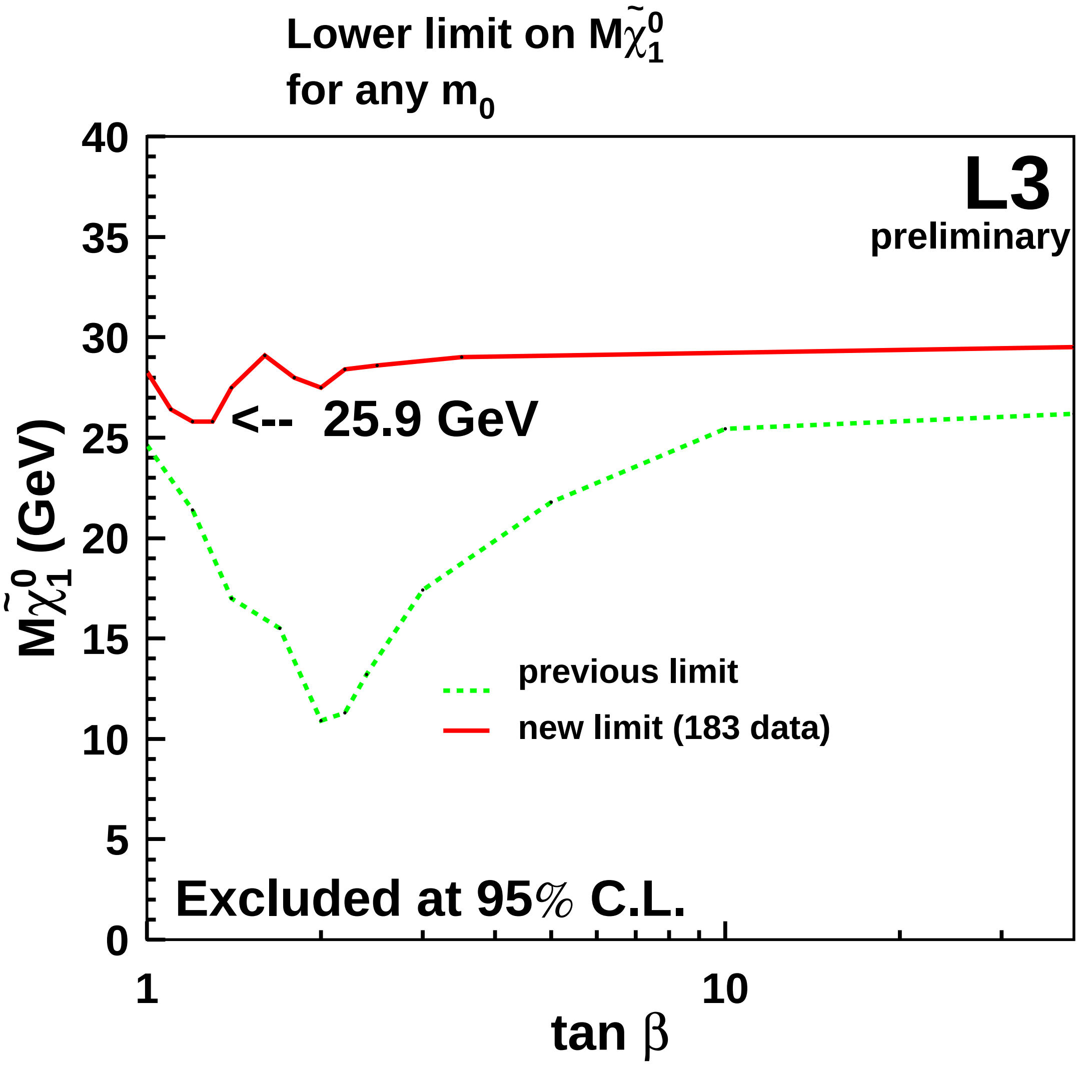


Gaugino-like $\tilde{\chi}_1^{\pm}$

$(M_2 \ll |\mu|)$

Mass limits on the lightest neutralino $\tilde{\chi}_1^0$

Combined search for scalar leptons, chargino and neutralino:

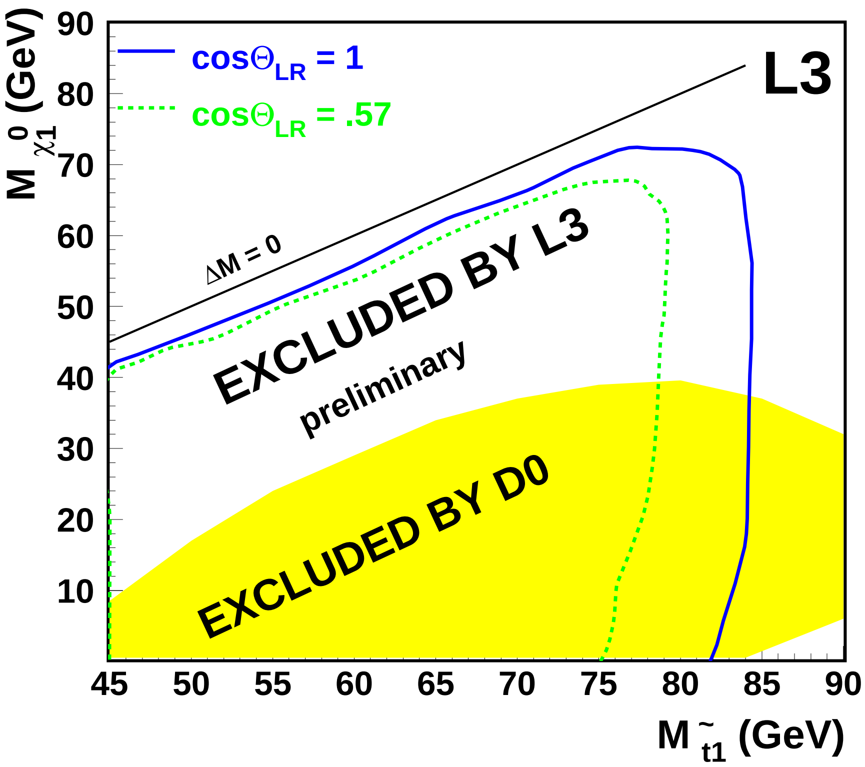


$$m_{\tilde{\chi}_1^0} > 25.9 \text{ GeV} \qquad (\tan\beta \geq 1)$$

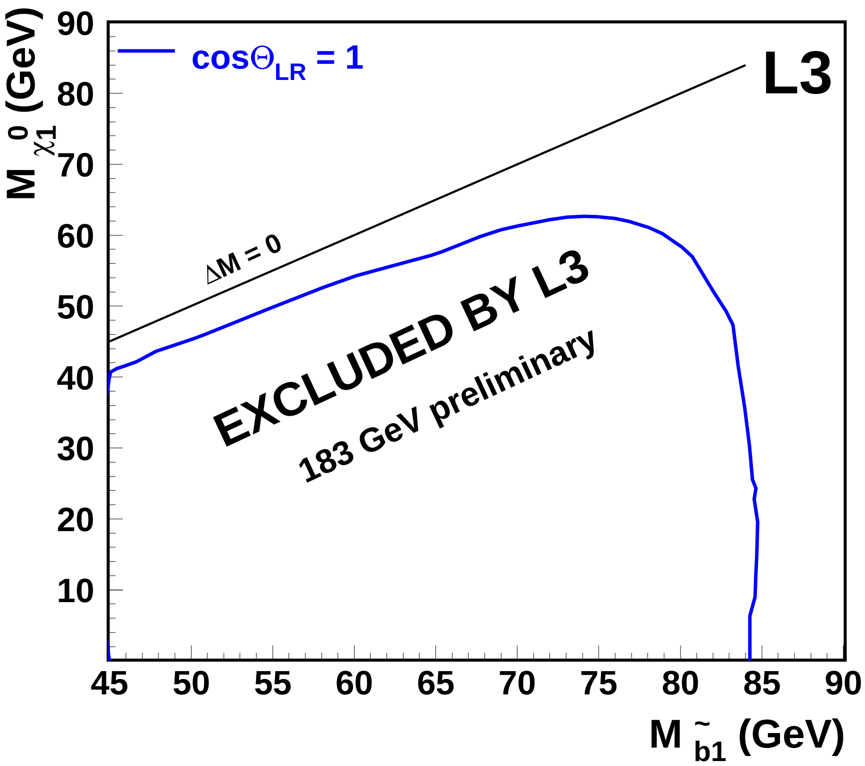
Will improve by including 161/172 GeV data and MSSM Higgs search

- For large m_0 (≥ 200 GeV): $m_{\tilde{\chi}_1^0} > 30.1$ GeV

Search for scalar quarks

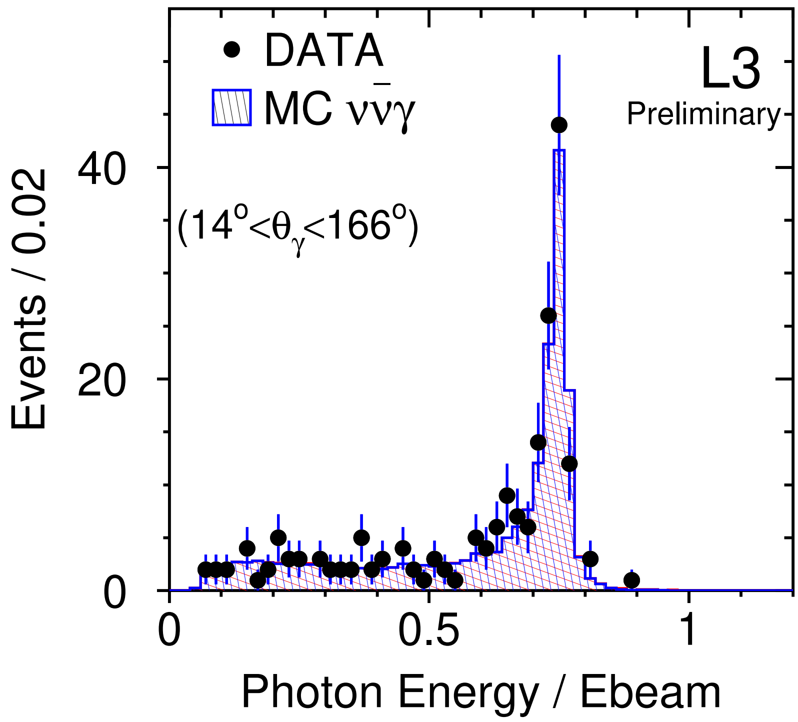


Scalar top:
($\sqrt{s} = 161 - 183$ GeV)
$N_{\mathrm{data}} = 3$
$N_{\mathrm{bkgd}} = 4.3$



Scalar bottom:
($\sqrt{s} = 183$ GeV)
$N_{\mathrm{data}} = 2$
$N_{\mathrm{bkgd}} = 3.0$

Single photon energy spectrum at $\sqrt{s} = 183$ GeV

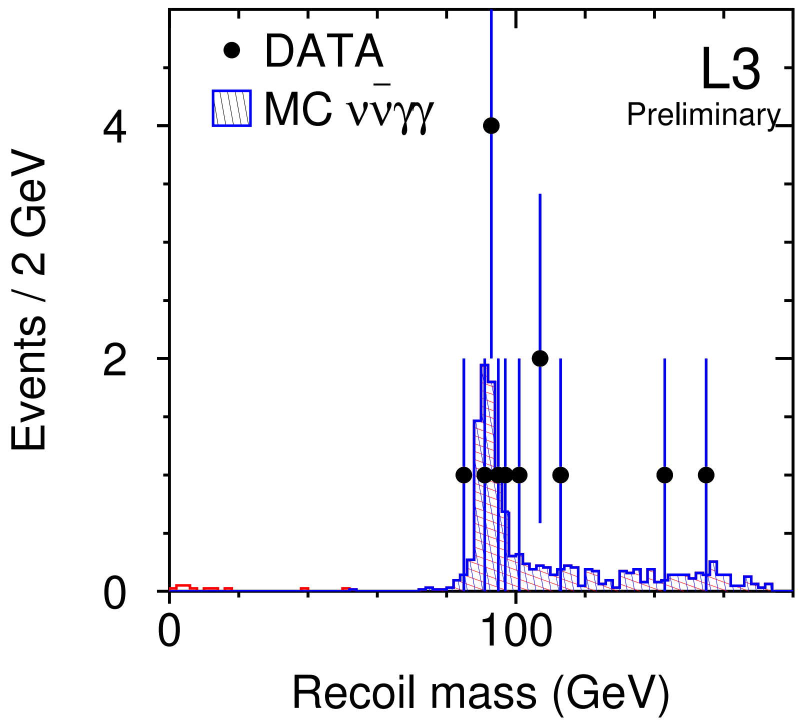


$E_\gamma > 5$ GeV:

$N_{\text{data}} = 193$

$N_{\text{exp}} = 193.4$

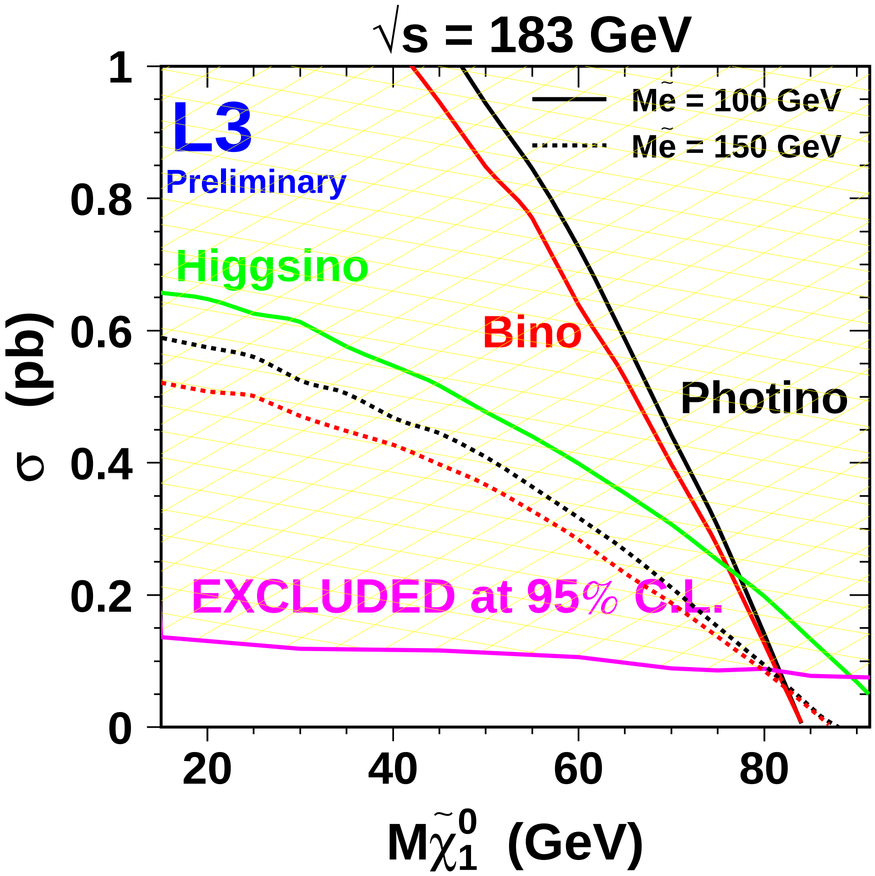
Di-photon recoil mass:



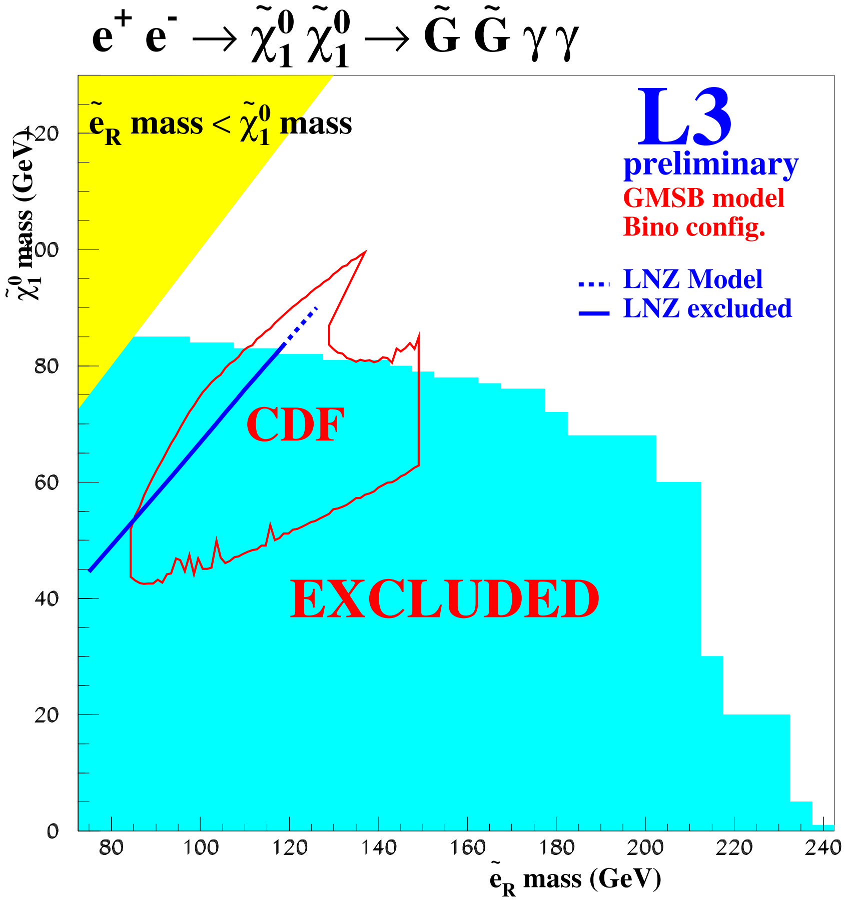
$E_\gamma > 5$ GeV,
$\Sigma p_\perp > 3$ GeV,
acopl. $> 2.4^\circ$:

$N_{\text{data}} = 14$

$N_{\text{exp}} = 13.4$



Cross section limit
$e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_1 \to \tilde{G}\tilde{G}\,\gamma\gamma$



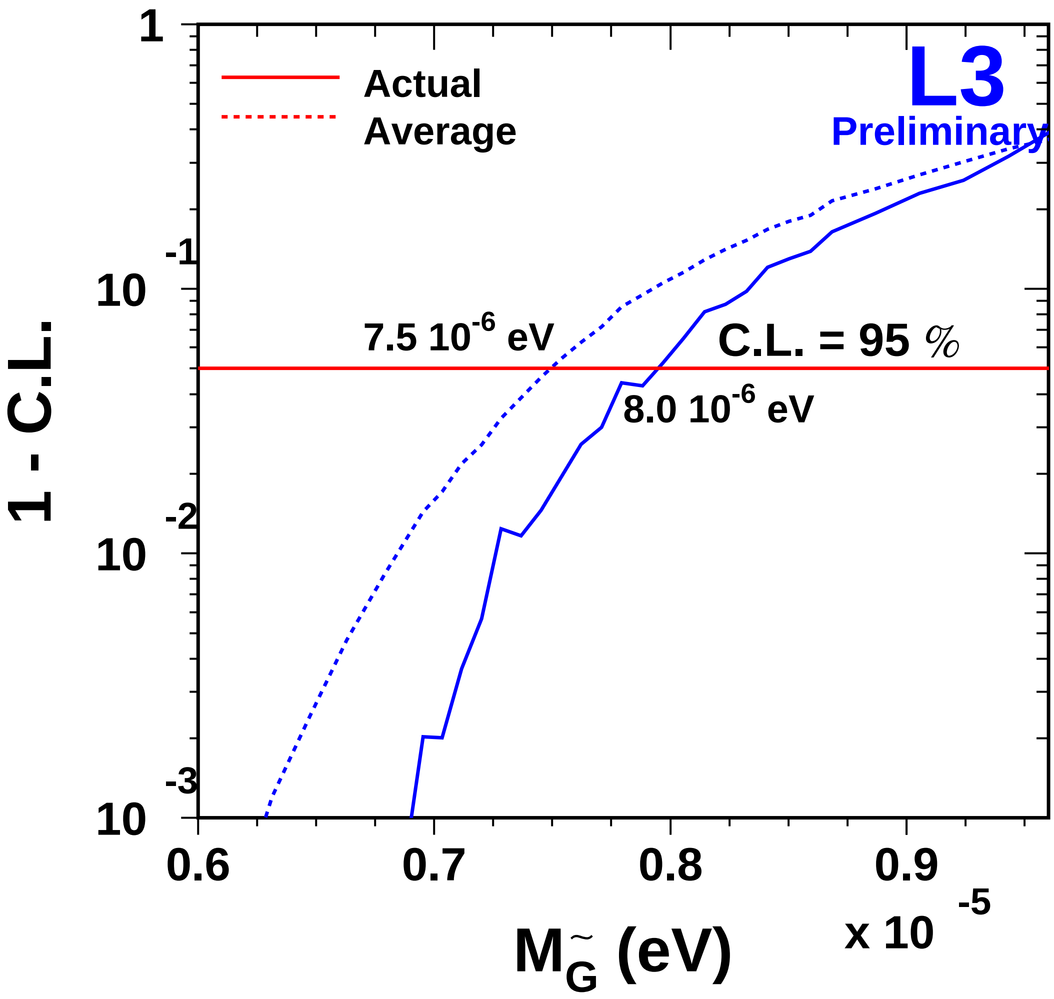
Gravitino interpretation of CDF event almost ruled out

Mass limit on superlight gravitino:

$$e^+e^- \to \tilde{G}\tilde{G}\gamma$$

$$\sigma_{\tilde{G}\tilde{G}\gamma} = \frac{\alpha\, s^3}{320\pi^2|F|^4} I(E_\gamma, \cos\Theta_\gamma)$$

Assume other SUSY particles $m_{\mathrm{SUSY}} > \sqrt{s}$



$$m_{\tilde{G}} > 8.0\,10^{-6}\ \mathrm{eV}$$

Lower limit on SUSY breaking scale:

$$\sqrt{F} > 181.9\ \mathrm{GeV}$$

- W pair cross section at 183 GeV
  $\sigma_{\mathrm{WW}} = 16.66 \pm 0.66 \pm 0.30$ pb
- W mass (LEP II combined)
  $m_{\mathrm{W}} = 80.44 \pm 0.16\,(\mathrm{exp}) \pm 0.03\,(\mathrm{LEP})$
- Measurements of fermion-pair production lead to improved limits on new physics
- Studies of eγ and $\gamma\gamma$ scattering at high energies
- Hadronic event shapes in agreement with QCD
  $\alpha_{\mathrm{s}}(183\ \mathrm{GeV}) = 0.109 \pm 0.002\,(\mathrm{exp}) \pm 0.005\,(\mathrm{th})$
- Searches for Higgs bosons result in improved mass limits:
  $m_{\mathrm{H}} > 87.6$ GeV
  $m_{\mathrm{h}} > 71$ GeV
- No sign for Supersymmetry
  $m_{\tilde{\chi}^0_1} > 25.9$ GeV for any m_0

- Congratulations and thanks to the accelerator divisions for the excellent performance in 1997
- L3 is looking forward to collect high luminosity at even higher energies