Measurement of Fermion Pair Production above the Z Resonance with the L3 Detector at LEP

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on behalf of the L3 Collaboration

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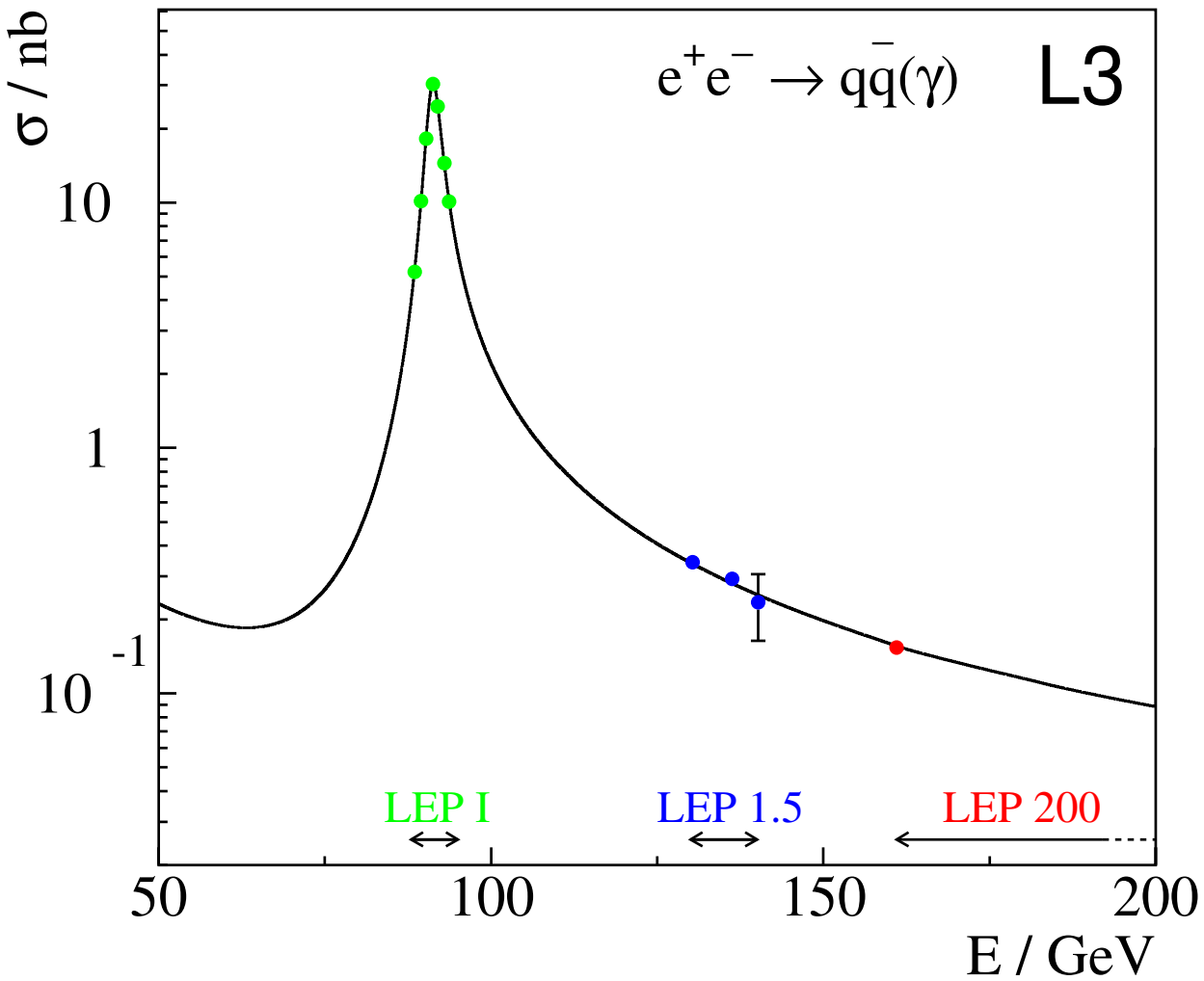
- LEP above the Z Resonance
- Measurement of σ and A_{fb} for
  $e^+e^- \longrightarrow q\overline{q}(\gamma)$ $\quad$ $e^+e^- \longrightarrow e^+e^-(\gamma)$
  $e^+e^- \longrightarrow \tau^+\tau^-(\gamma)$ $\quad$ $e^+e^- \longrightarrow \mu^+\mu^-(\gamma)$
- Determination of $j^{\mathrm{tot}}_{\mathrm{had}}$

LEP above the Z resonance

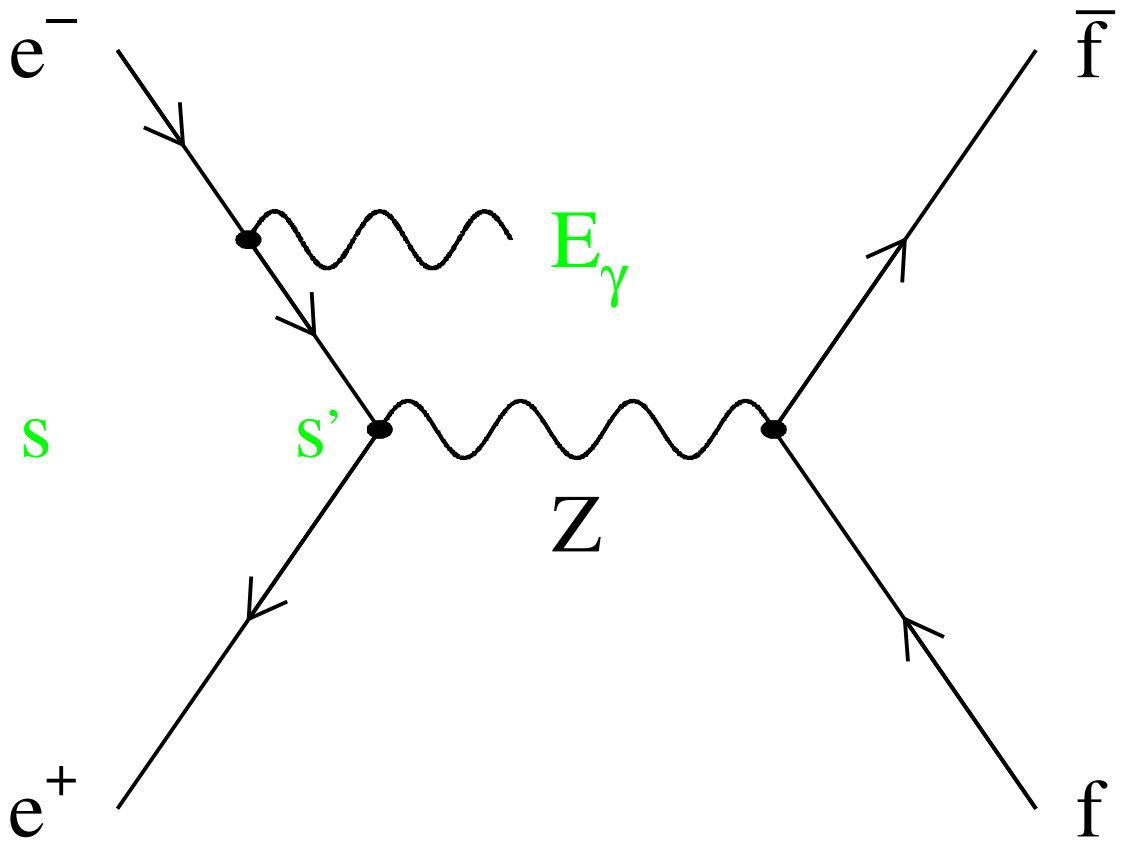
- Cross section for $f\overline{f}$–production
  $\Longrightarrow$ about 100 $\times$ smaller than at $\sqrt{s} \approx m_Z$



LEP I:	150 pb^{-1}	$\Rightarrow$	$3.5{\cdot}10^6 q\overline{q}$
LEP 1.5:	5.5 pb^{-1}	$\Rightarrow$	$1.7{\cdot}10^3 q\overline{q}$
LEP 200:	4.3 pb^{-1}	$\Rightarrow$	650 $q\overline{q}$

- Hard initial state bremsstrahlung

	140 GeV	(161 GeV)
$e^+e^- \longrightarrow q\overline{q}\gamma(\gamma)$:	80%	(70%)
$e^+e^- \longrightarrow \mu^+\mu^-\gamma(\gamma)$:	65%	(50%)

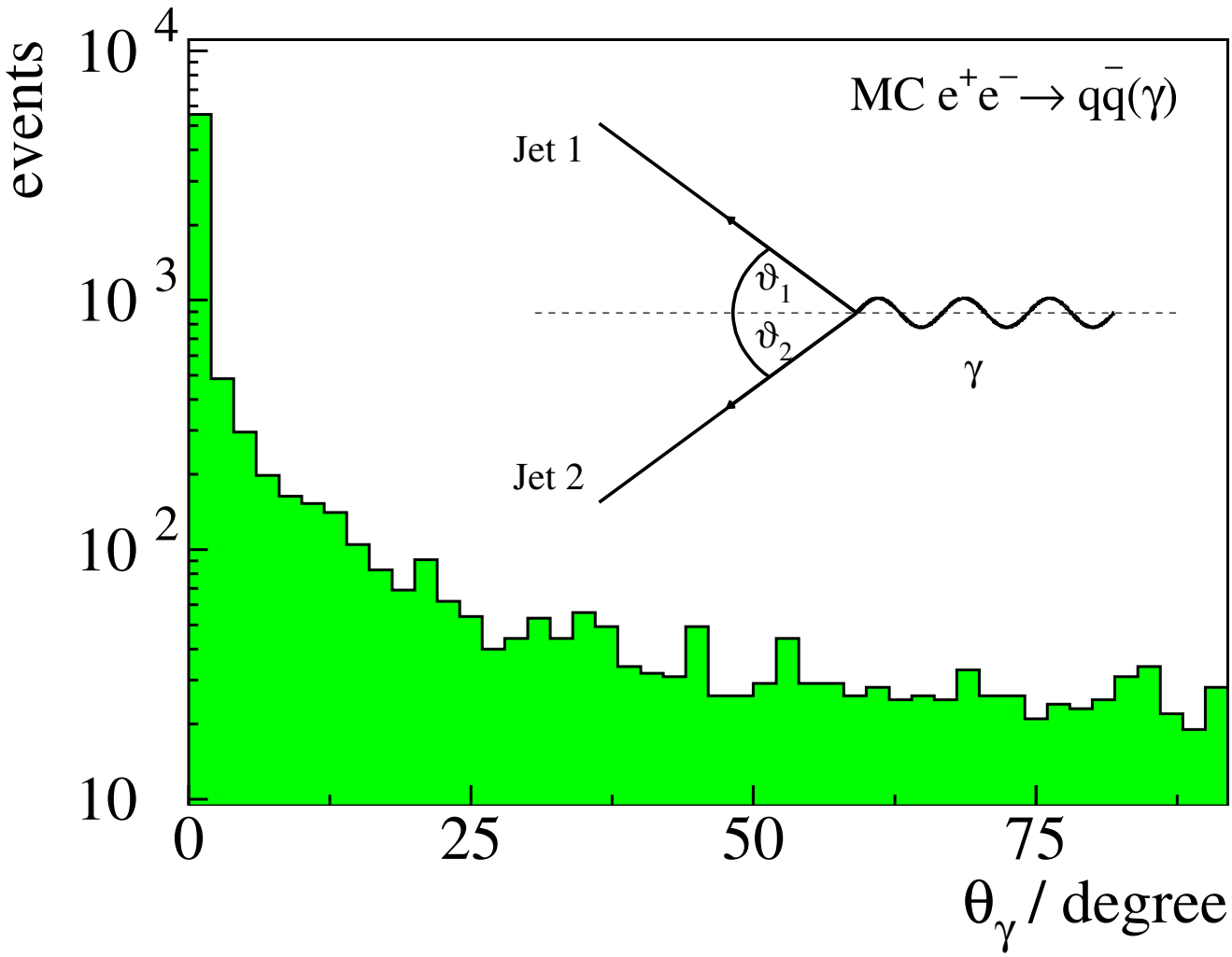


$$s' = s - 2 \cdot E_\gamma \cdot \sqrt{s}$$

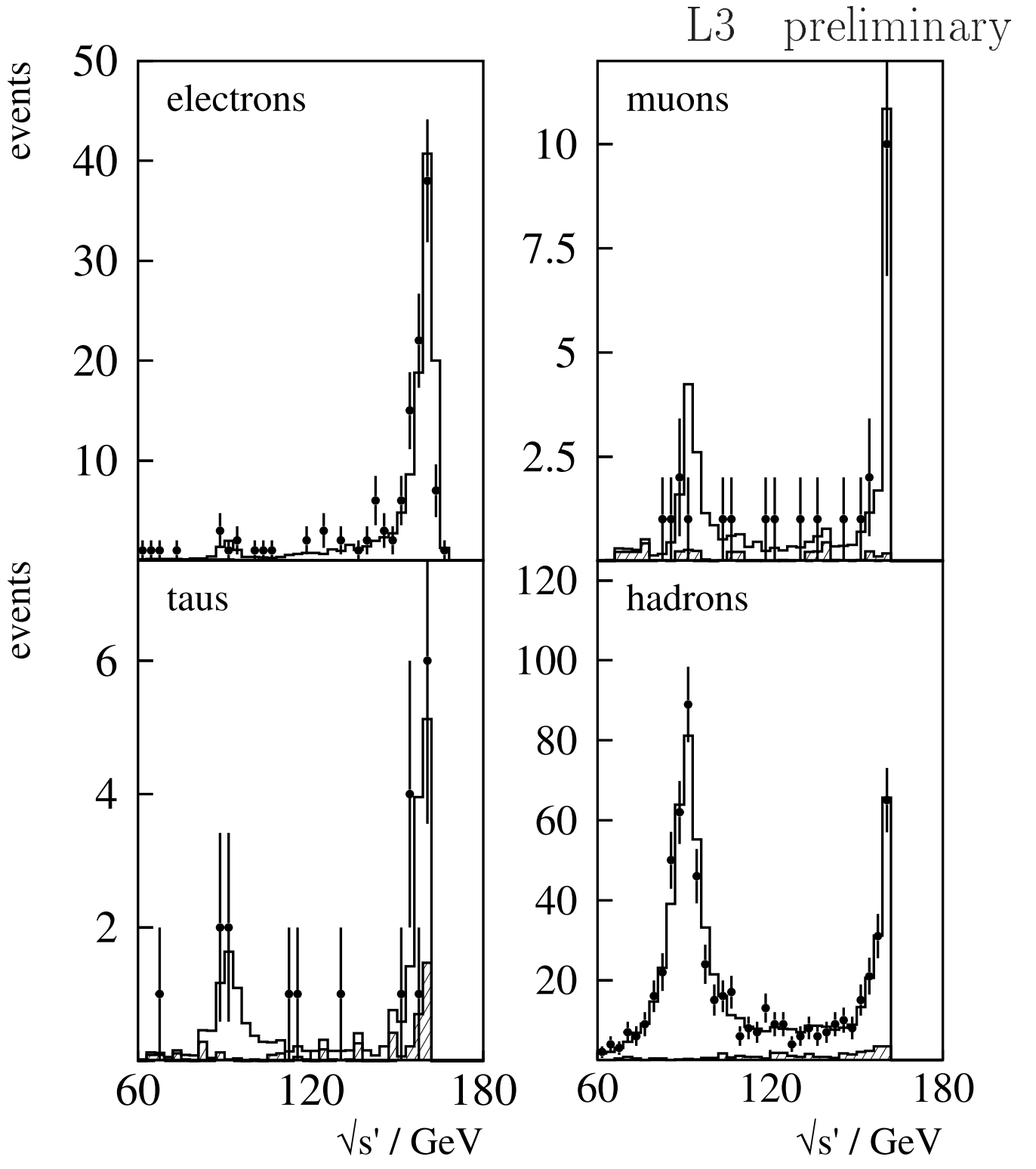
Determination of the effective CMS energy $\sqrt{s'}$:

- direct measurement from final state (Bhabhas)
- observation of the hard photon in the detector
- reconstruction from particle/jet directions assuming $\theta_\gamma = 0$

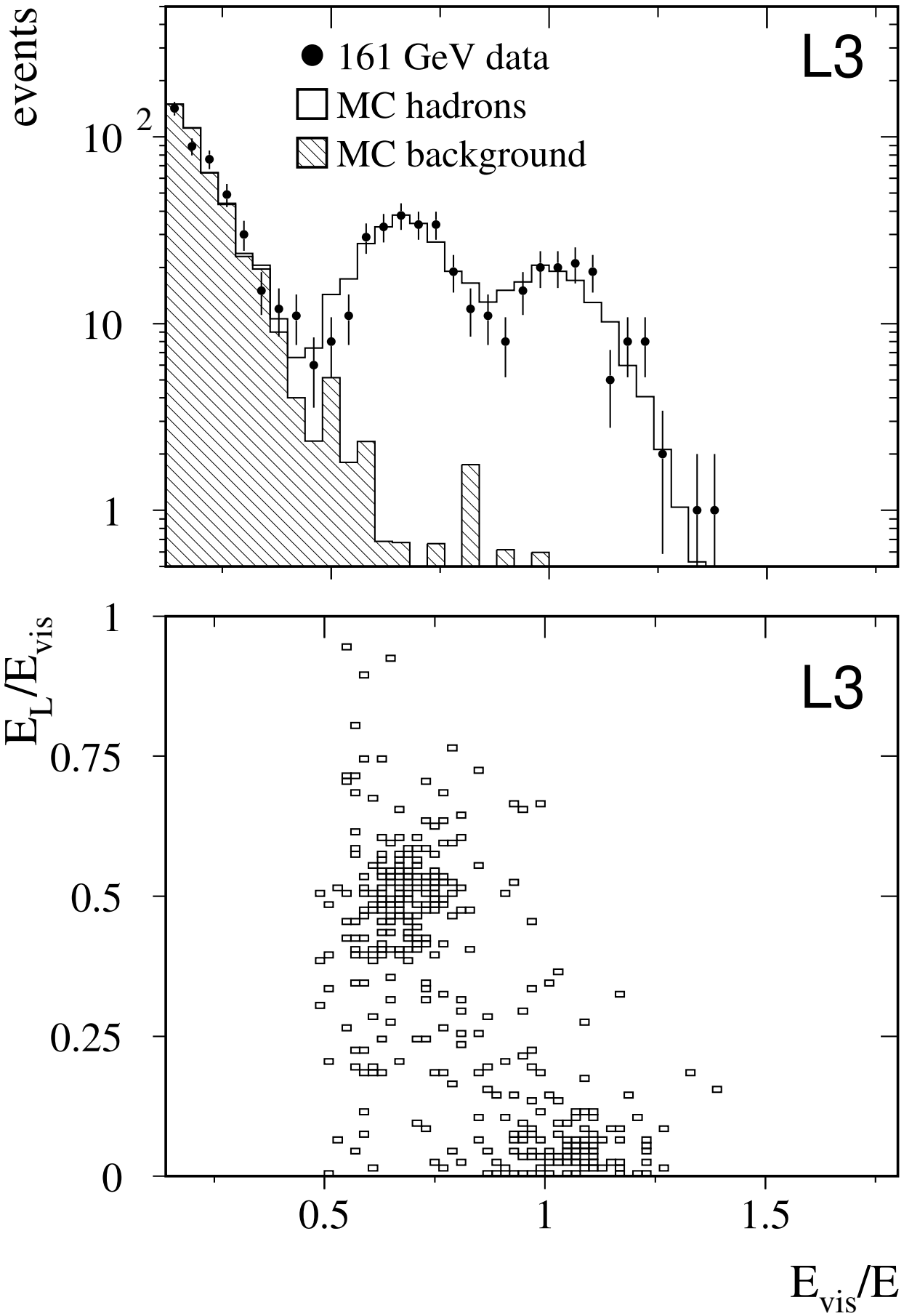
$$E_\gamma^{rec} = E_{CMS} \cdot \frac{|\sin(\vartheta_1 + \vartheta_2)|}{\sin\vartheta_1 + \sin\vartheta_2 + |\sin(\vartheta_1 + \vartheta_2)|}$$



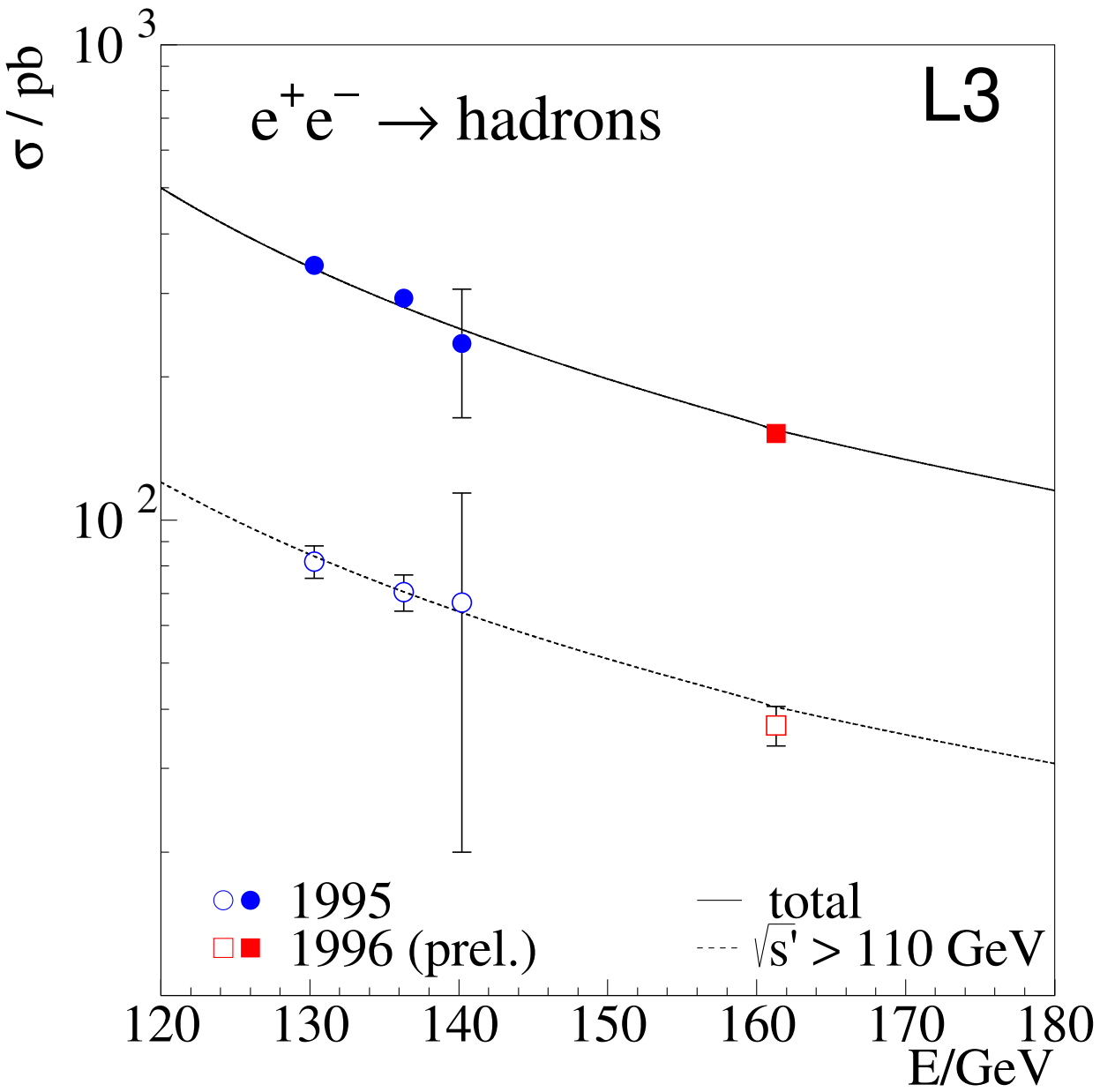
The reconstructed $\sqrt{s'}$ at 161 GeV



Visible energy in hadronic events



The Hadronic Cross Section

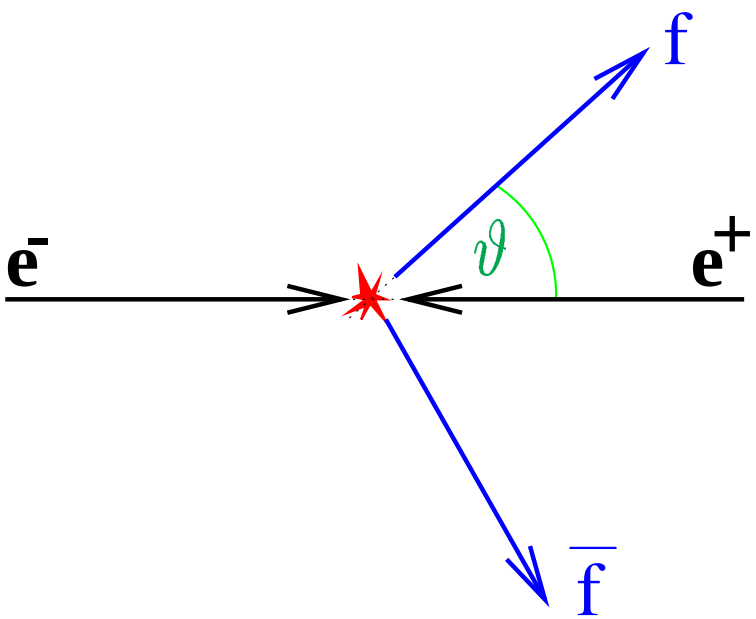


$\sqrt{s}$ [GeV]	$\mathcal{L}$ [pb^{-1}]	σ_{tot} [pb]	σ_{110} [pb]
130.3	2.74	343 ± 11	81.8 ± 6.4
136.3	2.25	293 ± 12	70.5 ± 6.2
140.2	0.05	235 ± 71	67 ± 47
161.3	4.31	152 ± 6	37 ± 3.5

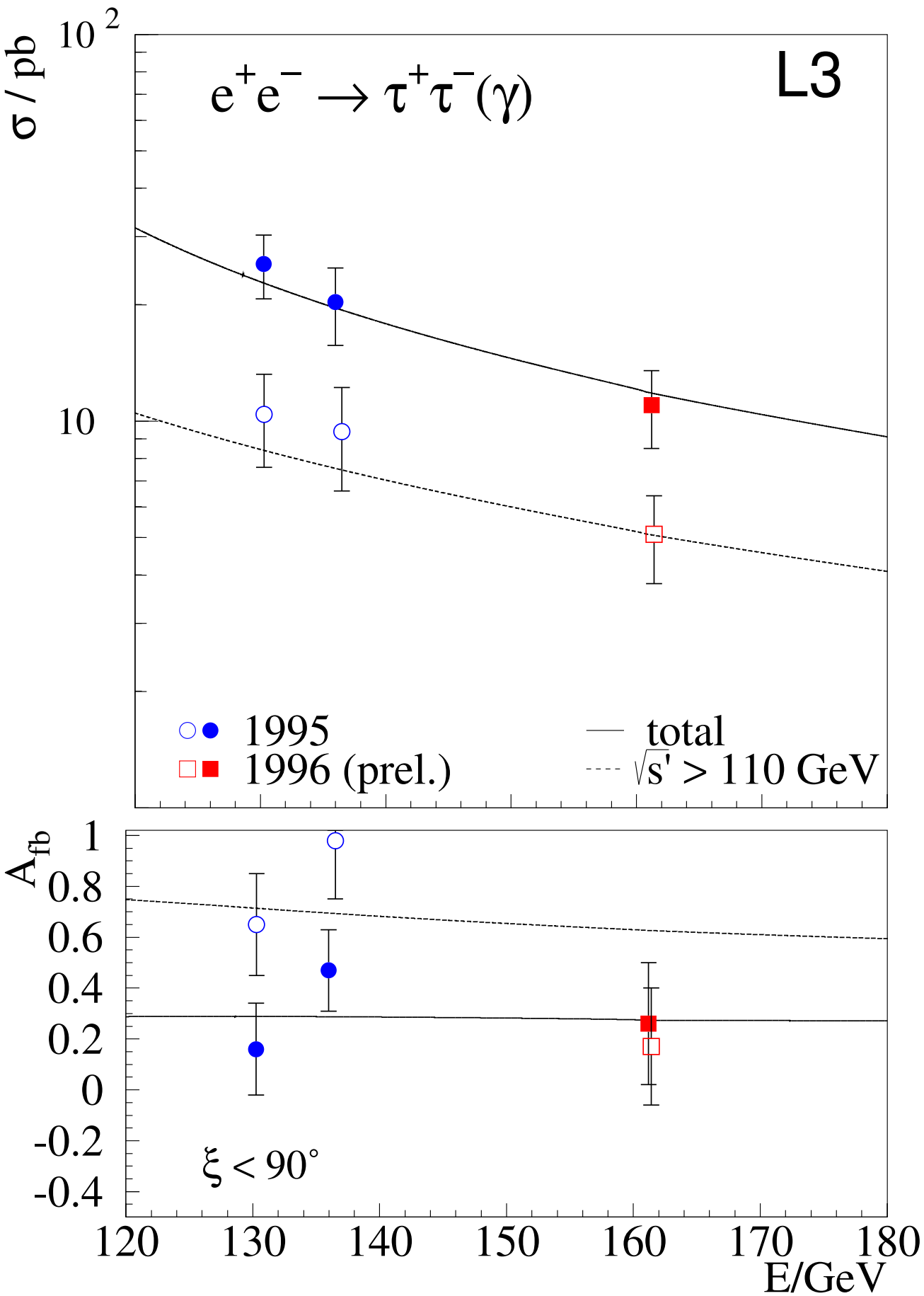
Leptonic Cross Sections and Charge Asymmetries

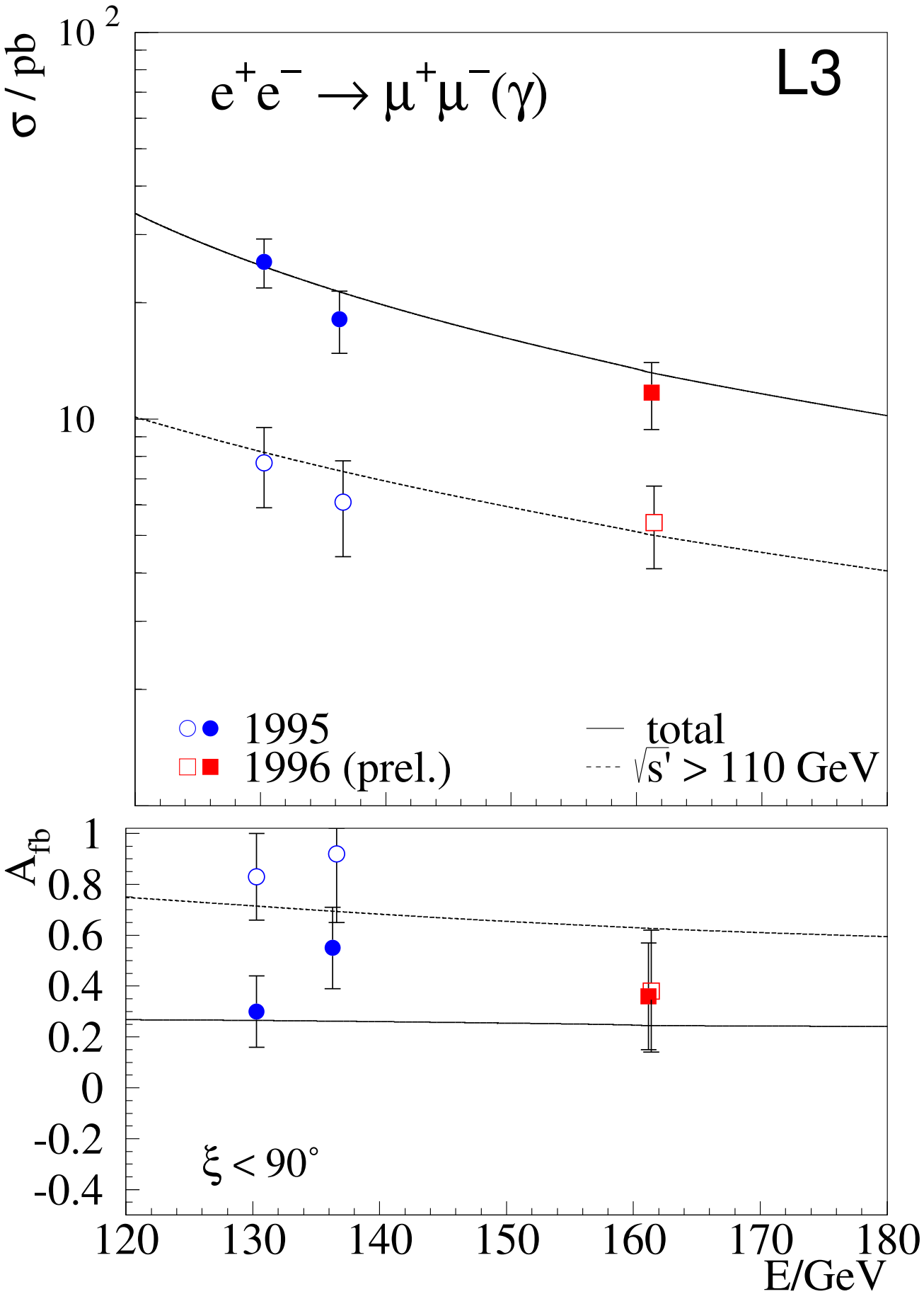
$$A_{fb} = \frac{\sigma_f - \sigma_b}{\sigma_f + \sigma_b}$$

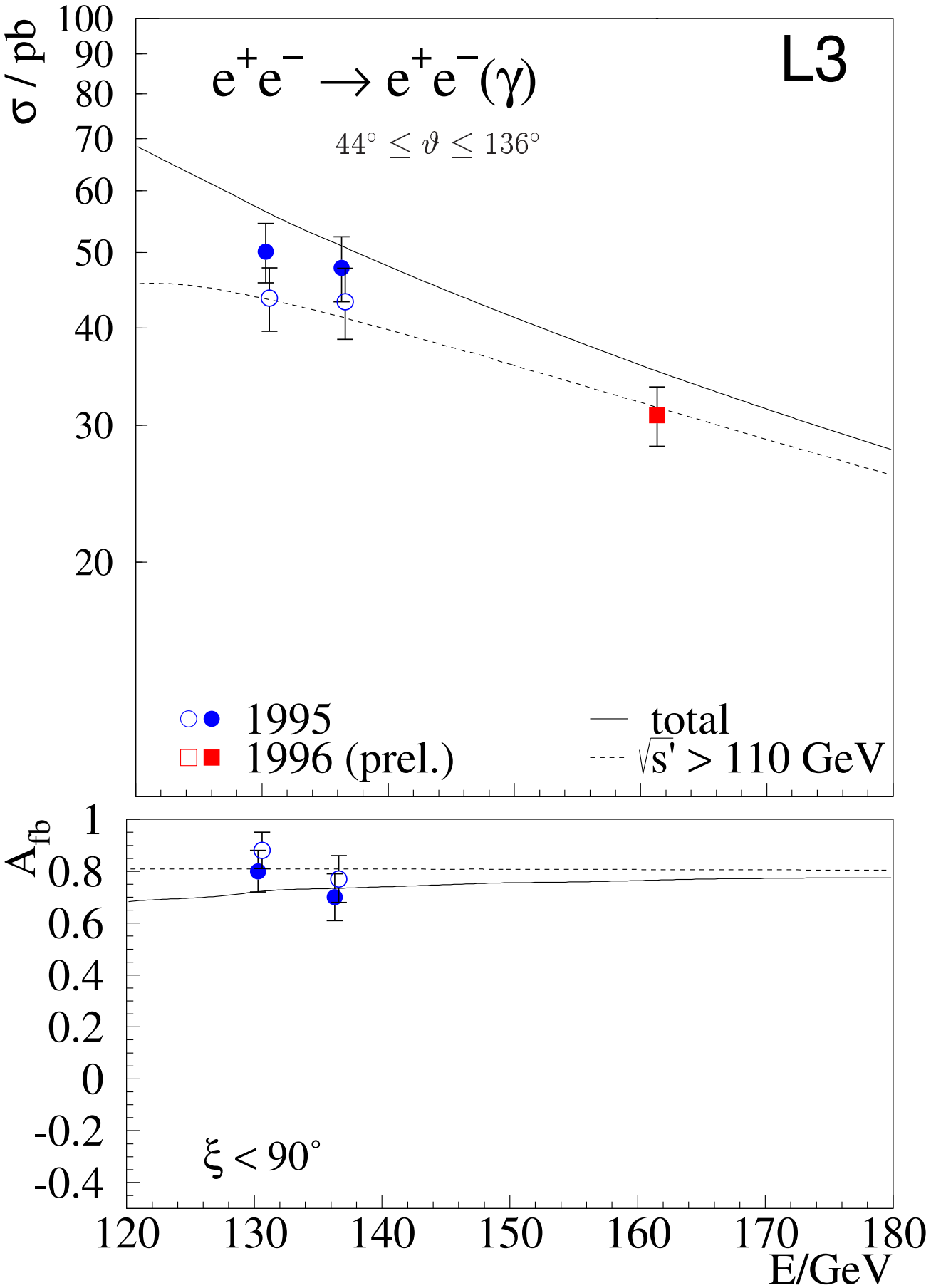
- Forward means $\vartheta < 90$ degrees



- Acollinearity less than 90 degrees


σ / pb
10 2
10
$e^+e^- \to \tau^+\tau^-(\gamma)$
L3
1995
1996 (prel.)
total
$\sqrt{s'} > 110$ GeV
A_{fb}
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
$\xi < 90°$
120
130
140
150
160
170
180
E/GeV


σ / pb
10^2
10
$e^+e^- \to \mu^+\mu^-(\gamma)$
L3
1995
1996 (prel.)
total
$\sqrt{s'} > 110$ GeV
A_{fb}
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
$\xi < 90°$
120
130
140
150
160
170
180
E/GeV

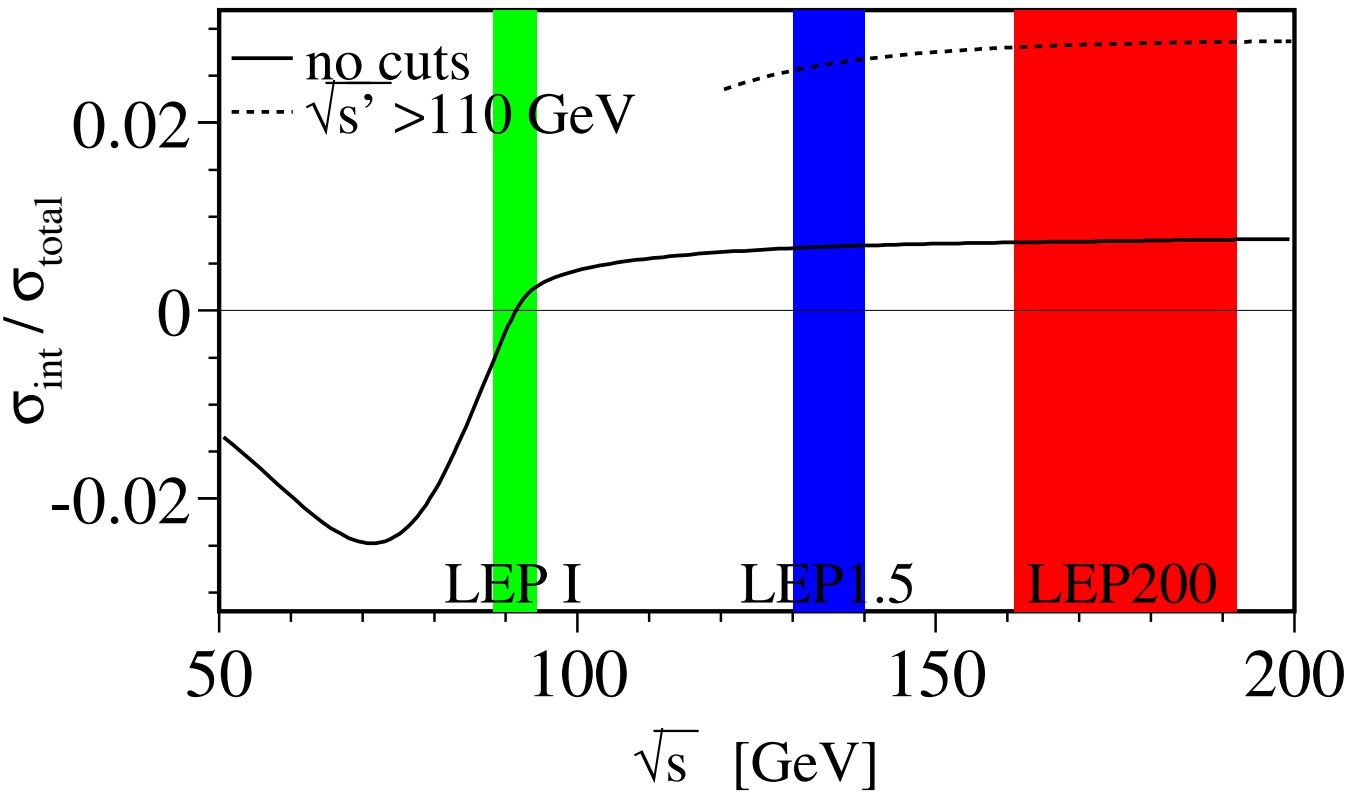

σ / pb
100
90
80
70
60
50
40
30
20
$e^+e^- \to e^+e^-(\gamma)$
L3
$44^\circ \leq \vartheta \leq 136^\circ$
1995
1996 (prel.)
total
$\sqrt{s'} > 110$ GeV
A_{fb}
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
$\xi < 90^\circ$
120
130
140
150
160
170
180
E/GeV

Determination of $j^{\mathrm{tot}}_{\mathrm{had}}$

$$\sigma = \sigma_\gamma + \sigma_Z + \sigma_{int}$$

At $\sqrt{s} \approx m_Z$

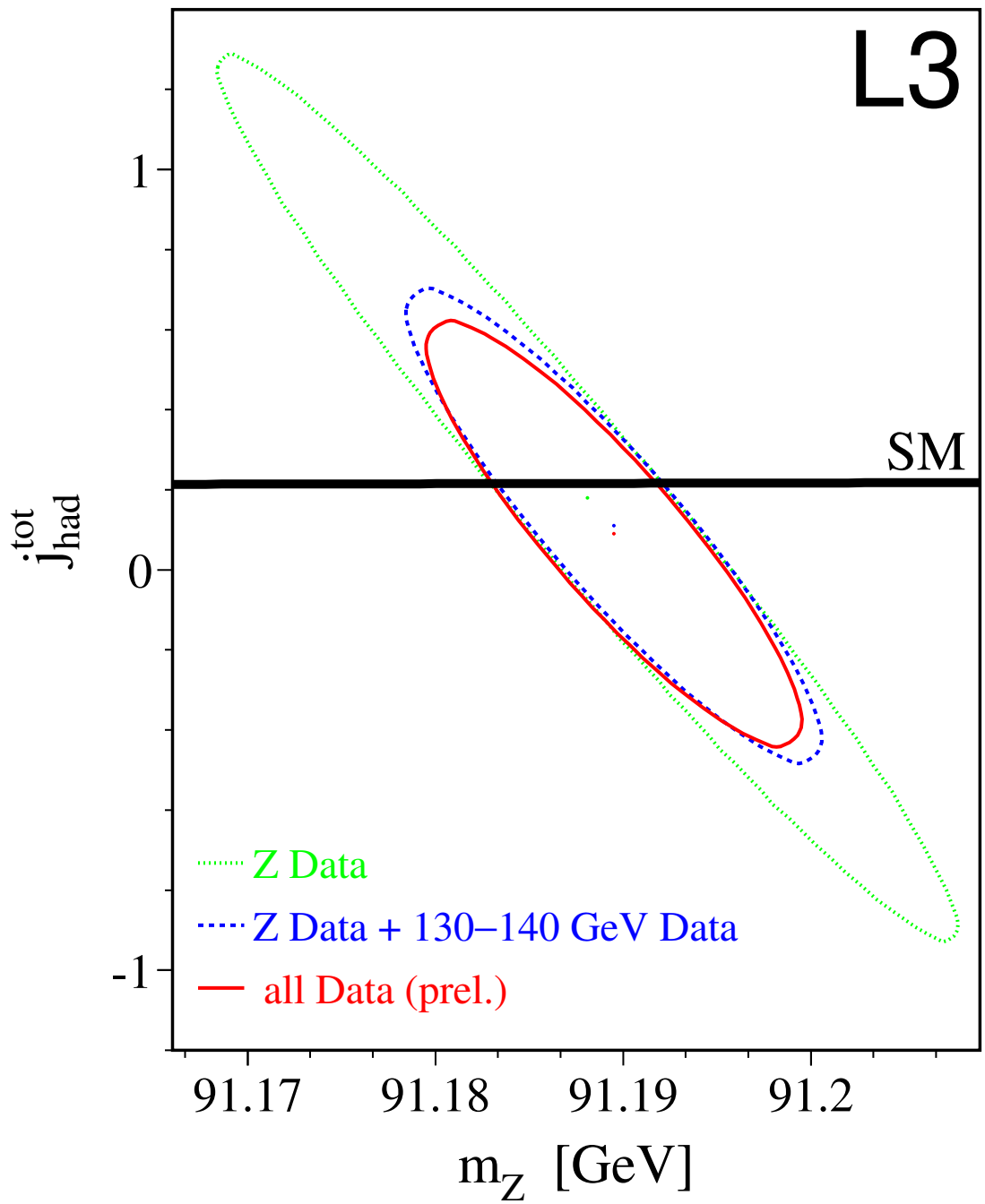
- insensitive to σ_{int} since $|\sigma_{int}(m_Z)| \ll \sigma(m_Z)$
- $\Longrightarrow$ σ_{int} fix to SM value $j^{\mathrm{tot}}_{\mathrm{had}} = 0.22$



At $\sqrt{s} > m_Z$

- sensitivity to σ_{int} higher
- further enhancement by cut on $\sqrt{s'} > 110$ GeV

data used	$j^{\mathrm{tot}}_{\mathrm{had}}$	m_Z [MeV]
Z-pole	0.18 ± 0.73	$91188 \pm 3 \pm 13$
+ 130-140 GeV	0.11 ± 0.39	$91189 \pm 3 \pm 7$
all (prel.)	0.09 ± 0.35	$91189 \pm 3 \pm 6$



Conclusions

- LEP was successfully operated at 130-140 GeV and 161 GeV allowing the first measurements of $e^+e^- \rightarrow f\bar{f}$ above the Z pole
- The measured cross sections and forward backward asymmetries are in good agreement with the standard model
- Using the framework of an S-matrix ansatz the determination of the γ/Z interference and the Z mass can be improved

- Check the standard model with higher precision and at higher energies

$e^+e^- \longrightarrow e^+e^-(\gamma)$			
$\sqrt{s}$ [GeV]	$\mathcal{L}$ [pb^{-1}]	σ [pb]	A_{fb}
130.3	2.68	50.1 ± 4.4	0.80 ± 0.08
		43.7 ± 4.1	0.88 ± 0.07
136.3	2.29	47.8 ± 4.6	0.70 ± 0.09
		43.2 ± 4.5	0.77 ± 0.09
161.3	4.11	30.9 ± 2.7	

$e^+e^- \longrightarrow \mu^+\mu^-(\gamma)$			
$\sqrt{s}$ [GeV]	$\mathcal{L}$ [pb^{-1}]	σ [pb]	A_{fb}
130.3	2.54	25.5 ± 3.7	$0.30\ ^{+0.14}_{-0.15}$
		7.7 ± 1.8	$0.83\ ^{+0.16}_{-0.22}$
136.3	2.25	18.1 ± 3.3	$0.55\ ^{+0.14}_{-0.17}$
		6.1 ± 1.7	$0.92\ ^{+0.08}_{-0.27}$
161.3	4.22	11.7 ± 2.3	$0.36\ ^{+0.21}_{-0.21}$
		5.4 ± 1.3	$0.38\ ^{+0.24}_{-0.24}$

$e^+e^- \longrightarrow \tau^+\tau^-(\gamma)$			
$\sqrt{s}$ [GeV]	$\mathcal{L}$ [pb^{-1}]	σ[pb]	A_{fb}
130.3	2.54	25.5 ± 4.8	$0.16\ ^{+0.16}_{-0.21}$
		10.4 ± 2.8	$0.65\ ^{+0.15}_{-0.25}$
136.3	2.25	20.3 ± 4.6	$0.47\ ^{+0.14}_{-0.18}$
		9.4 ± 1.7	$0.98\ ^{+0.02}_{-0.23}$
161.3	4.22	11.0 ± 2.5	$0.26\ ^{+0.20}_{-0.20}$
		5.1 ± 1.3	$0.17\ ^{+0.23}_{-0.23}$

Lowest order:

$$\sigma = \sigma_\gamma + \sigma_Z + \sigma_{int}$$

$$\sigma_Z = \frac{12\pi}{m_Z^2}\frac{\Gamma_e\Gamma_f}{\Gamma_Z^2}\frac{s\Gamma_Z^2}{(s-m_Z^2)^2+s^2\Gamma_Z^2/m_Z^2}$$

$$\sigma_\gamma = \frac{4\pi\alpha^2}{3s}q_e^2q_f^2N_C^f$$

$$\sigma_{int} = \frac{4\pi\alpha^2}{3}J_f\frac{s-m_Z^2}{(s-m_Z^2)^2+s^2\Gamma_Z^2/m_Z^2}$$

with

$$J_f = \frac{G_F m_Z^2}{\sqrt{2}\pi\alpha}q_eq_fg_V^eg_V^f$$

S–Matrix:

$$\sigma = \frac{4}{3}\pi\alpha^2\left[\frac{g_f}{s}+\frac{sr_f+(s-\overline{m}_Z^2)j_f}{(s-\overline{m}_Z^2)^2+\overline{m}_Z^2\overline{\Gamma}_Z^2}\right]$$