Fermion Pair Production at LEP2

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- Measurement of cross sections and asymmetries for

$e^+e^- \longrightarrow q\overline{q}(\gamma)$ $e^+e^- \longrightarrow b\overline{b}(\gamma)$ $e^+e^- \longrightarrow c\overline{c}(\gamma)$

$e^+e^- \longrightarrow e^+e^-(\gamma)$ $e^+e^- \longrightarrow \tau^+\tau^-(\gamma)$ $e^+e^- \longrightarrow \mu^+\mu^-(\gamma)$

- Interpretation of the Measurements
  – S-Matrix
  – running $\alpha_{\rm QED}$
  – Z′
  – Contact interactions

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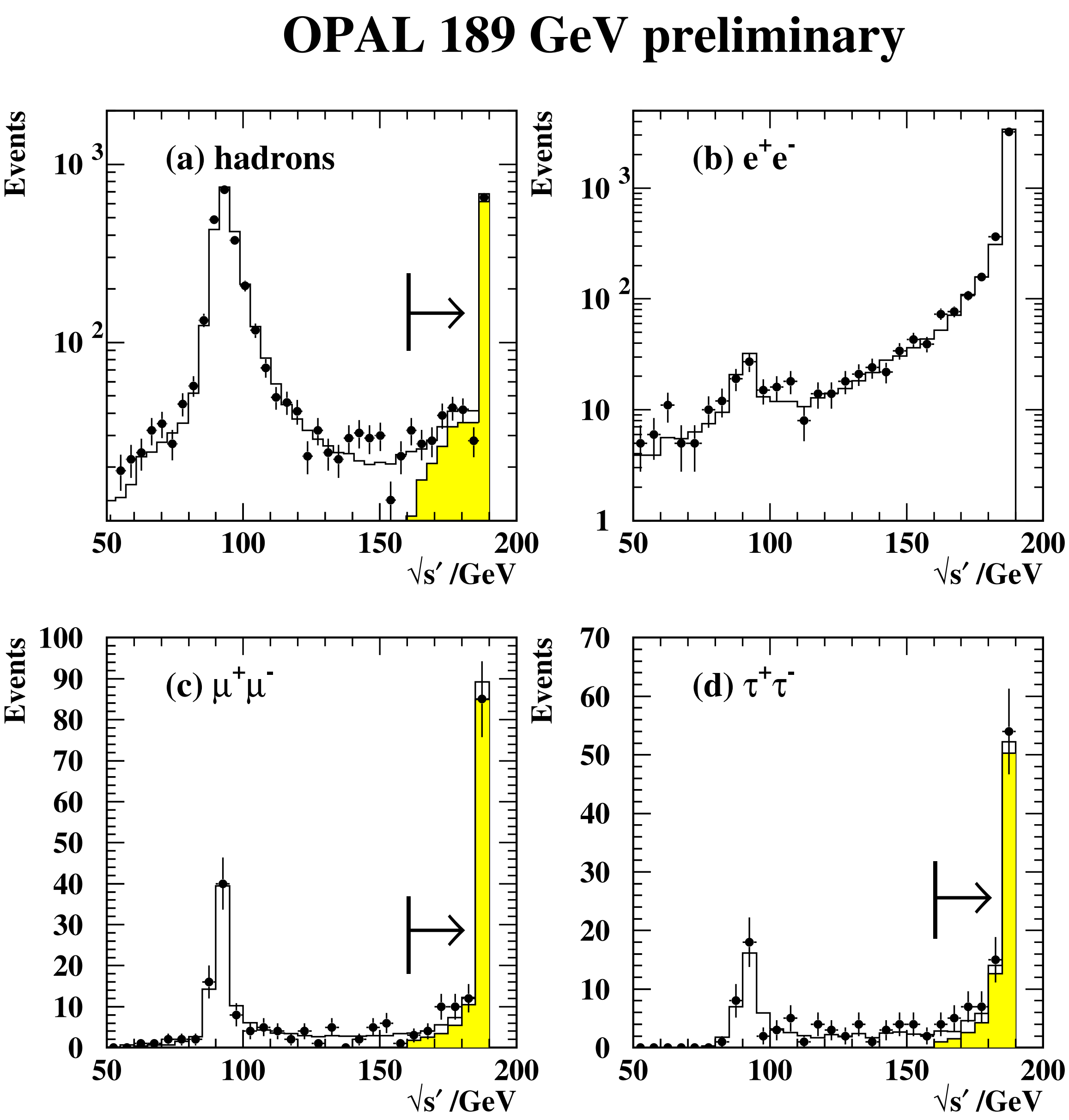
- Data from all four LEP experiments up to 189 GeV – mostly preliminary

Year	$\sqrt{s}$ [GeV]	$\mathcal{L}$/Exp. [pb^{-1}]	qq stat.err. [%]
1995 & 1997	130	~ 6	2.2/4.7
1995 & 1997	136	~ 6	2.5/5.3
1996	161	~ 10	2.6/5.8
1996	172	~ 10	2.8/5.8
1997	183	~ 55	1.3/2.9
1998	189	30-40 (150)	(0.8/1.7)

- Measurements for two event classes:
  - Inclusive events with $\sqrt{s'/s} > 0.1$ or $\sqrt{s'}$ >75 GeV
  - Non-radiative events with $\sqrt{s'/s} > 0.85 - 0.9$

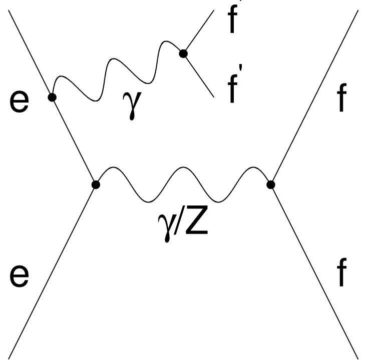
- Non-radiative events give limits for new physics



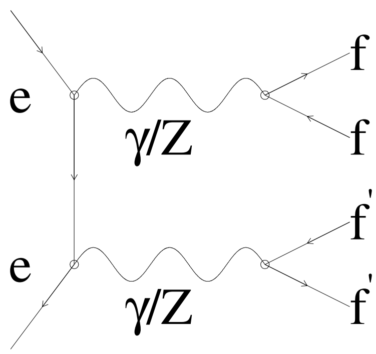
- from measured γ or e^+e^- $(\Delta\sqrt{s'}/\sqrt{s'} \approx 4\%)$
- from jet/particle angles $(\Delta\sqrt{s'}/\sqrt{s'} \approx 15\%)$
- from kinematic fit $(\Delta\sqrt{s'}/\sqrt{s'} \approx 10\%)$

But! Interference between ISR and FSR makes $\sqrt{s'}$ meaningless. Often $\sqrt{s'}$ actually means $m_{f\bar{f}}$.

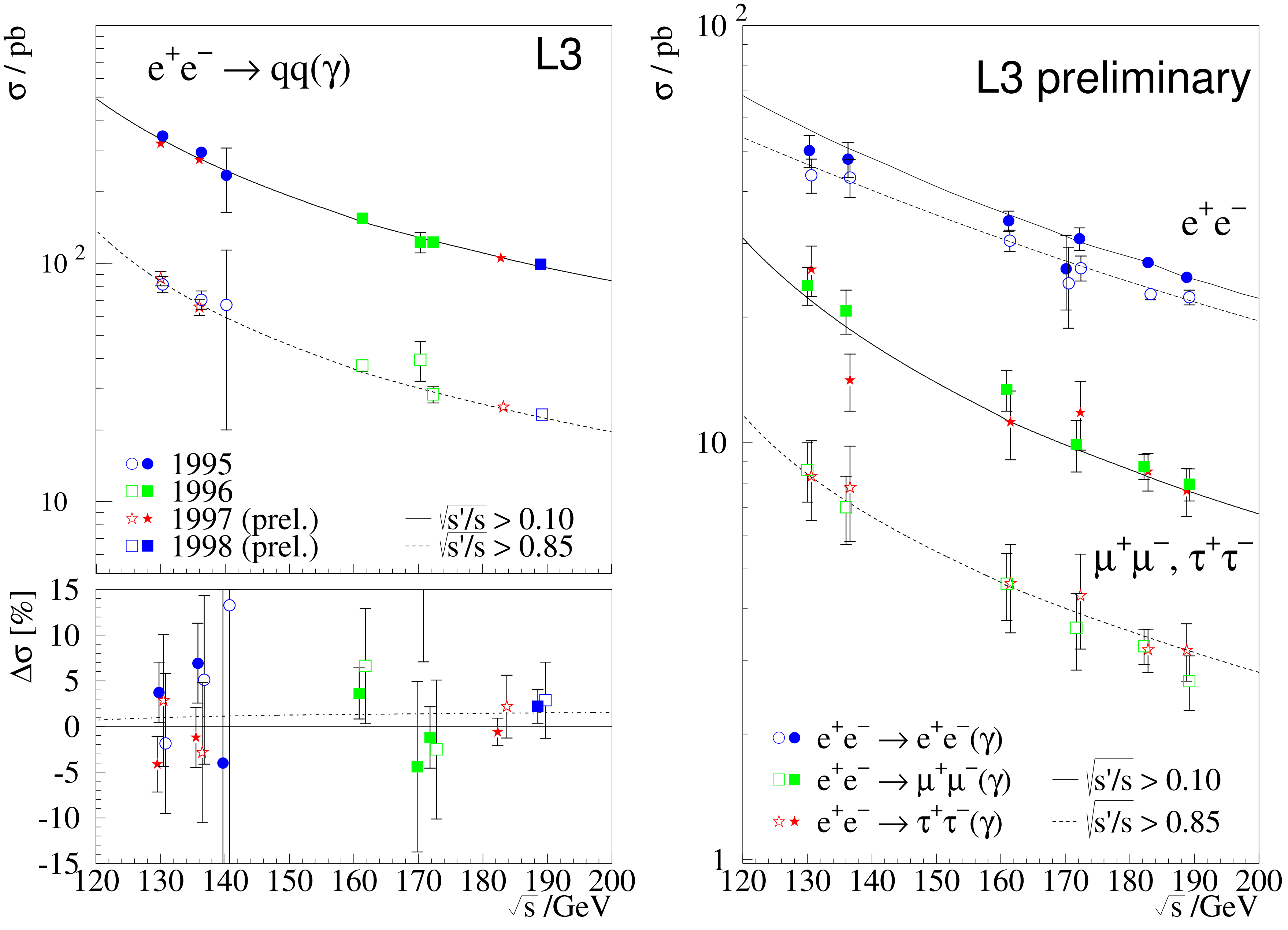
- include or not ISR/FSR interference
  - total effect is 1-2% for $\sqrt{s'/s} > 0.85$, predominantly for large $|\cos(\vartheta_f)|$.
  - OPAL corrects to 'no-interference' ($\mathcal{O}(\alpha)$)
  - ALEPH reduces the effect by cutting on $|\cos(\vartheta_f)|$
- 4-fermion events



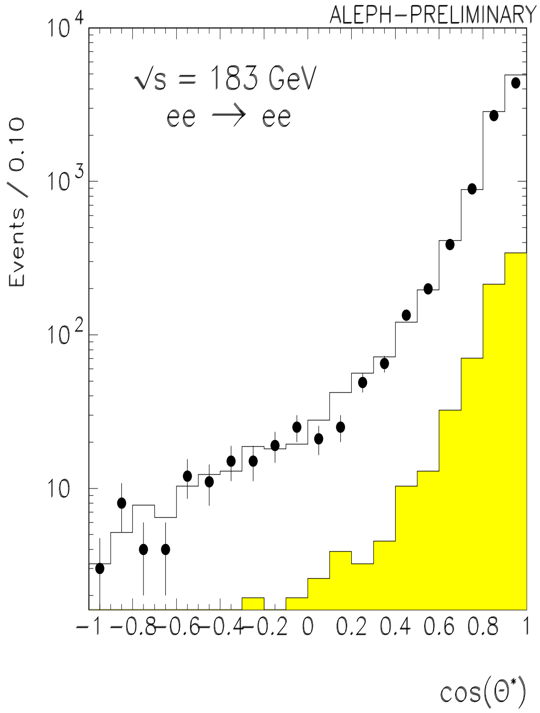
- New process: Z pair production

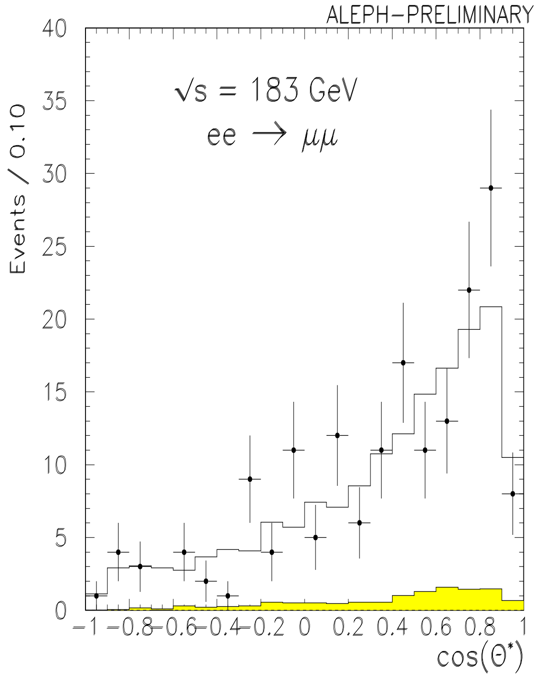


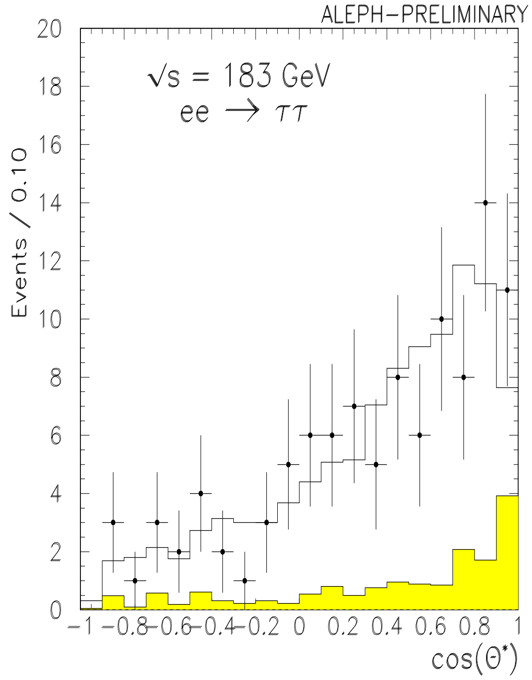
Cross Sections



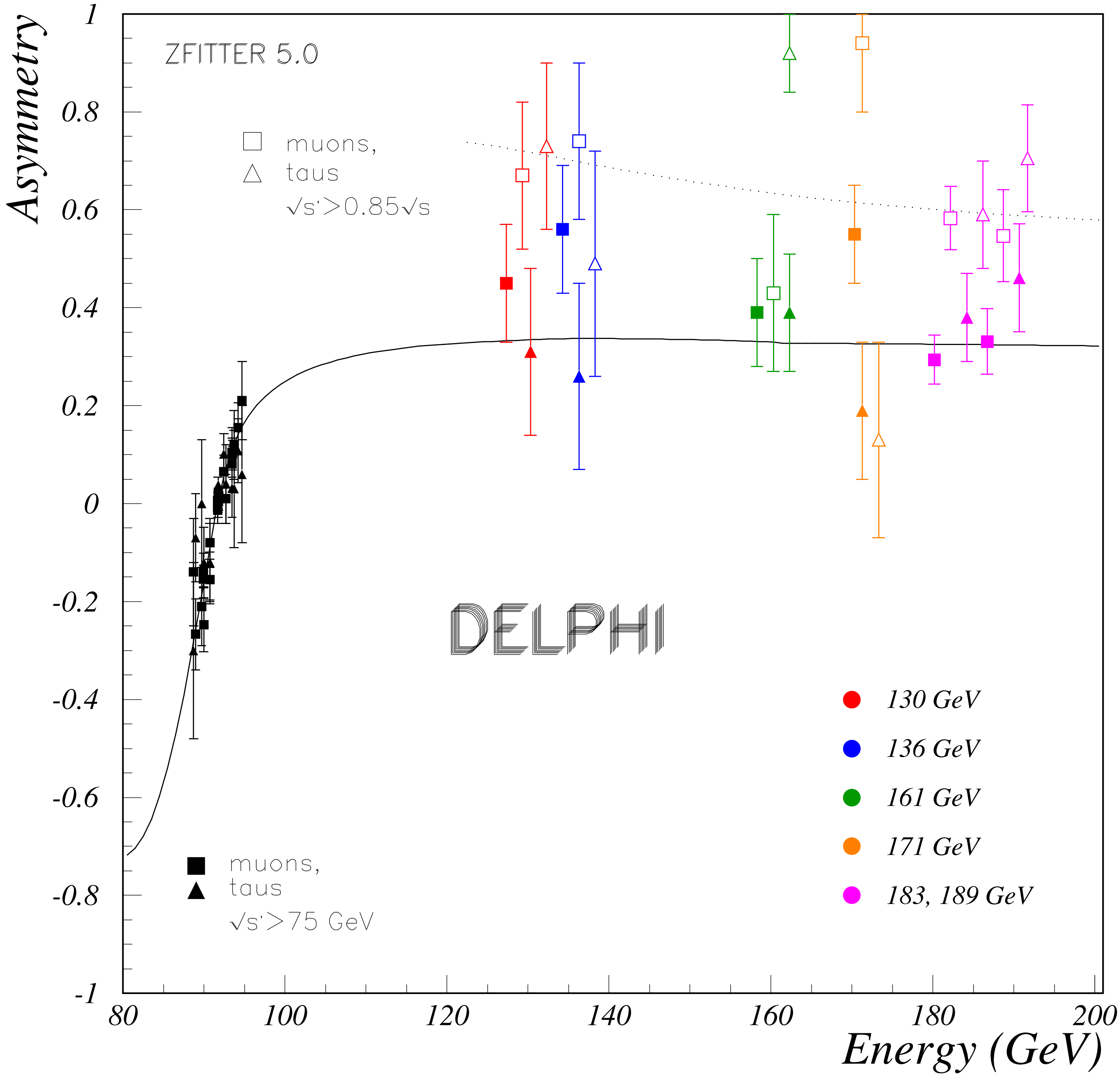
Differential Cross Section



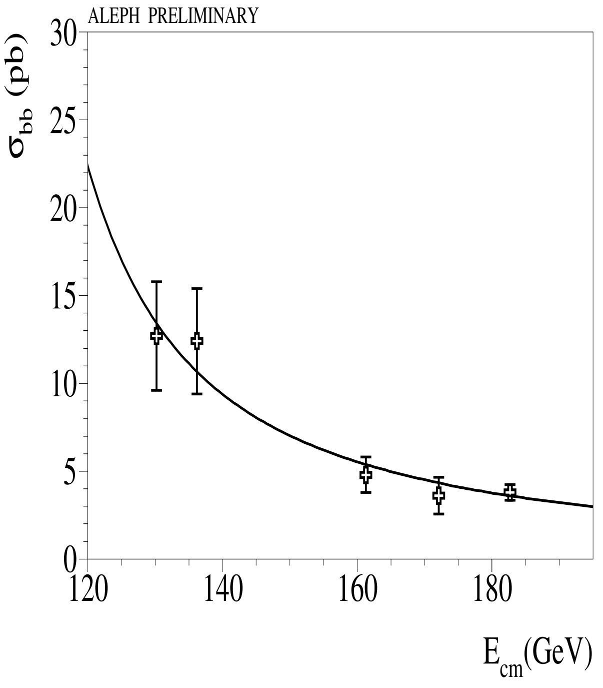


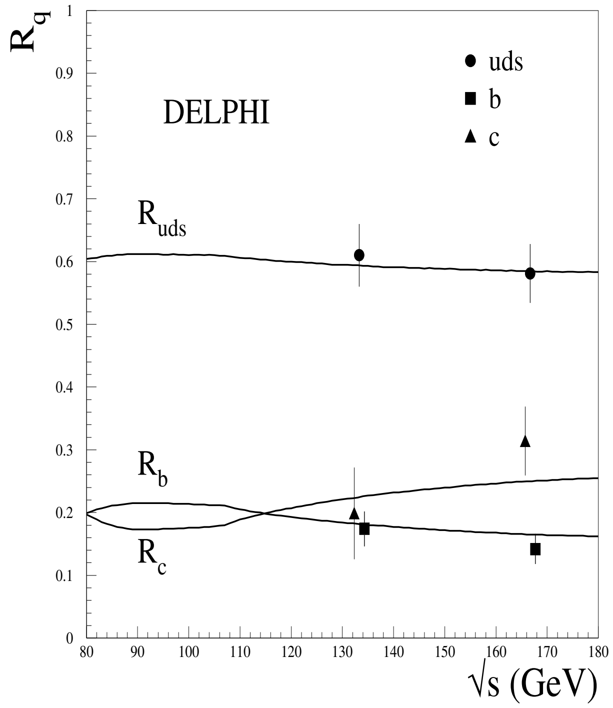


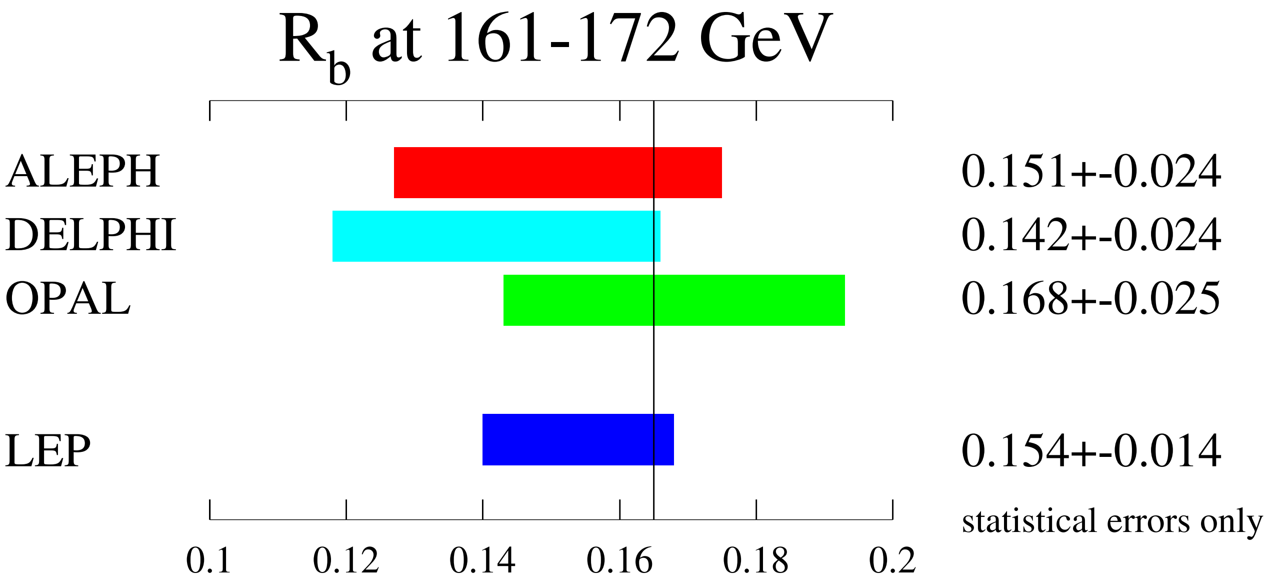
- Measured by counting or fit



- ALEPH, DELPHI, OPAL give results for $b\bar{b}$, $c\bar{c}$
- $\varepsilon_b = 40 - 78\%, p_b = 75 - 95\%$
  $\varepsilon_c = 15 - 35\%, p_c = 40 - 55\%$

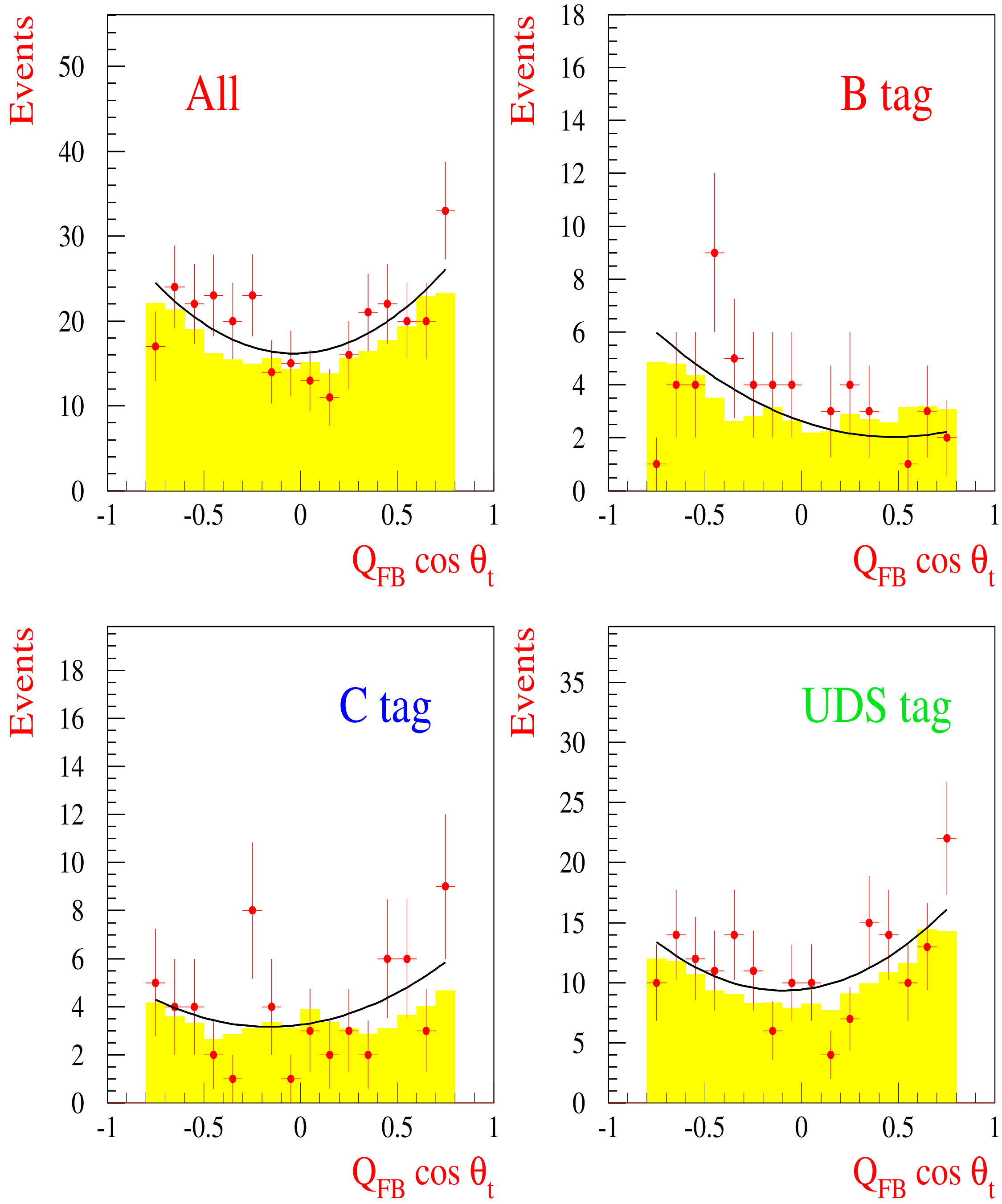




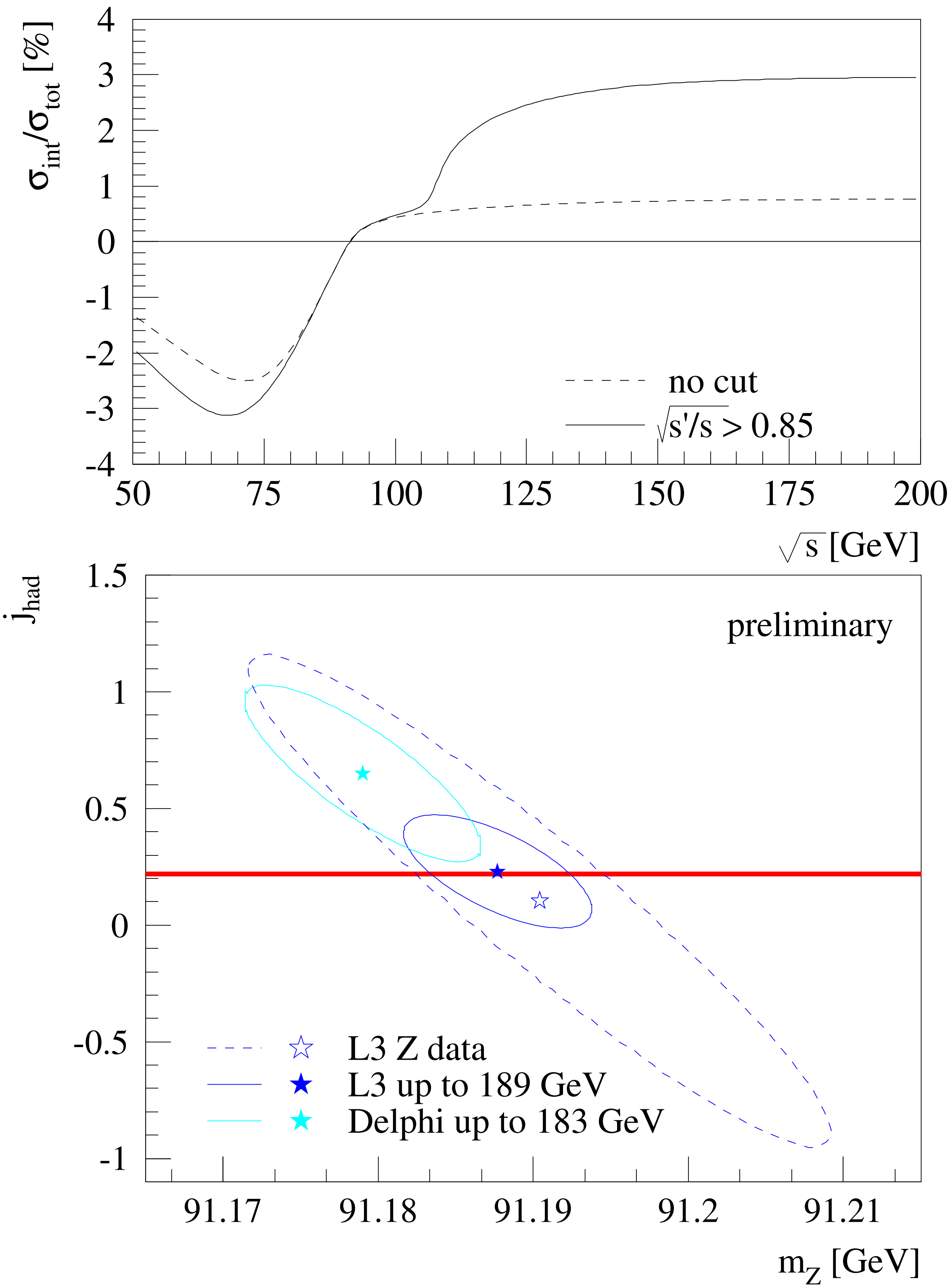


- measure $< Q_{FB} >$ (ALEPH)
- fit A^b_{FB}, A^c_{FB} to ang. distrib. (DELPHI,OPAL)

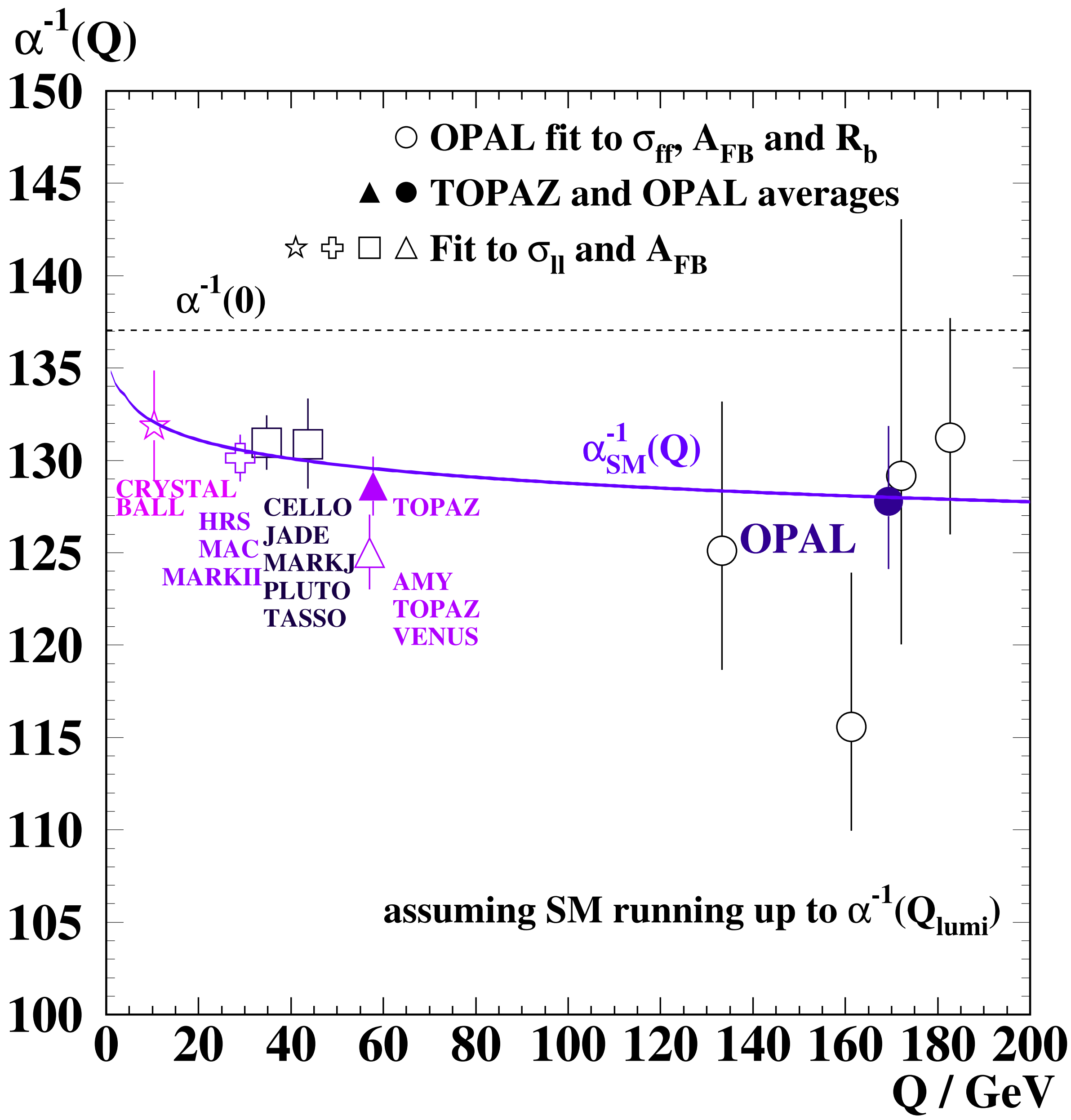
DELPHI preliminary $\sqrt{s} = 161 - 172$ GeV



- Measure Interferenz between γ and Z (j_{had})
- Reduce correlation and errors on m_{Z}



- At 130-183 GeV γ- is 2-4 $\times$ Z-Xch. for μ, τ and $\sqrt{s'} \approx \sqrt{s}$
- Do χ^2 fit to non-radiative σ and A_{FB} varying only α_{QED}



Additional heavy vector Boson:

$$\mathcal{L} = eA_\mu J^\mu_\gamma + gZ_\mu J^\mu_Z + g' Z'_\mu J^\mu_{Z'}$$

Mixing angle θ_M:

$$\rho_f \to \rho_f \left(1 + \frac{m^2_{Z'}}{m^2_Z} \sin^2\theta_M\right)$$

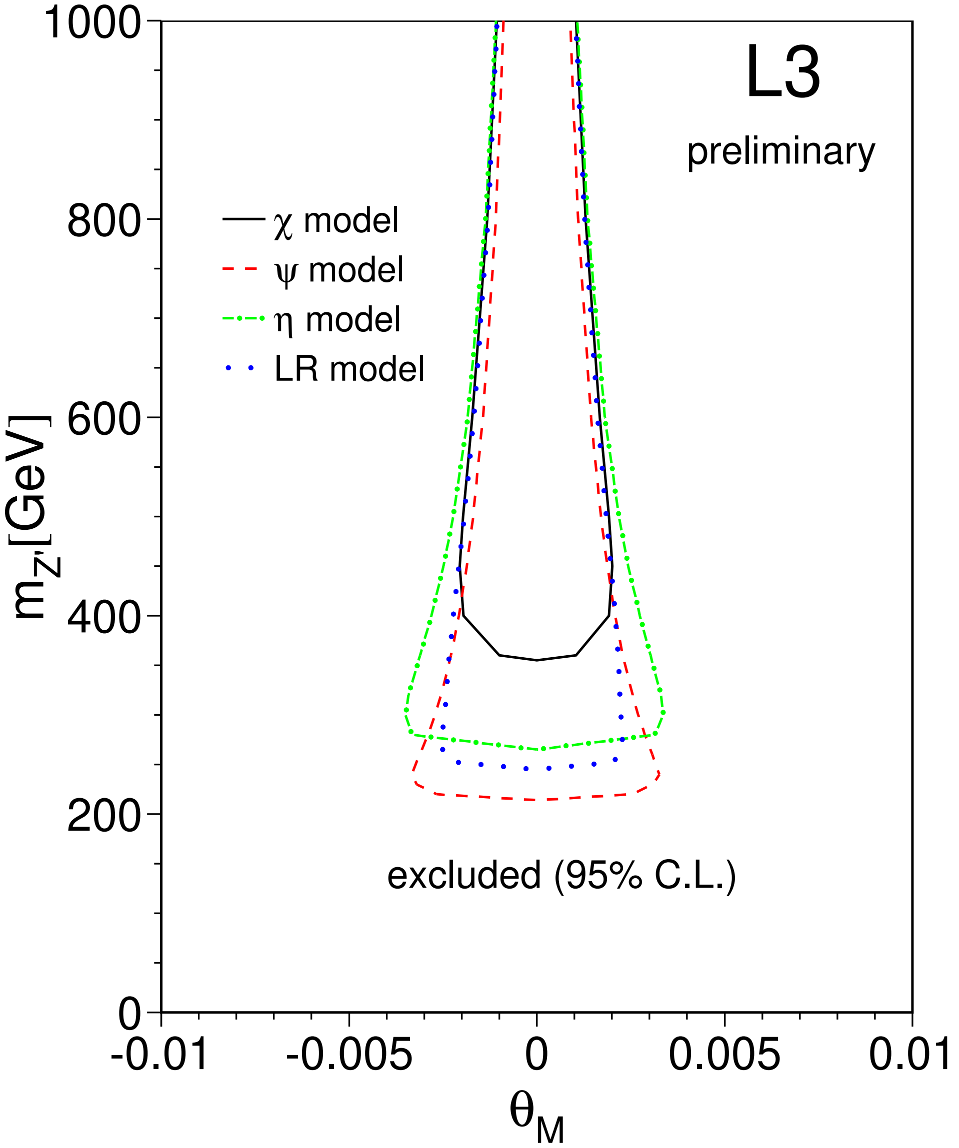
Couplings a'_f, v'_f:

$$a^f_Z = \cos\theta_M \cdot a_f + \sin\theta_M \cdot a'_f \cdot \frac{g'}{g}$$

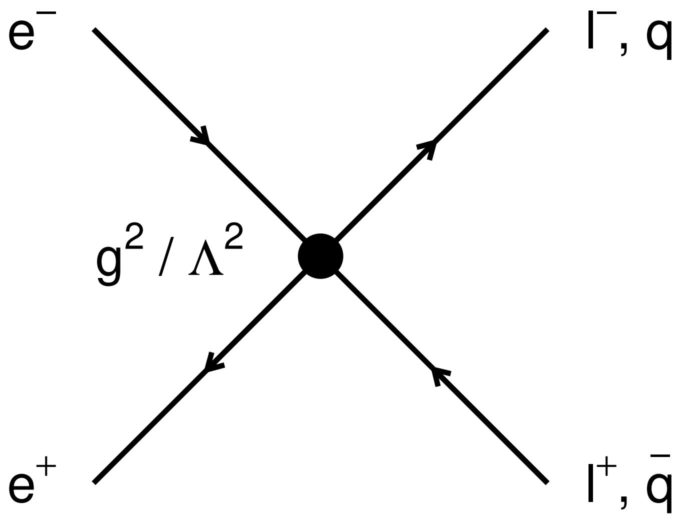
$$a^f_{Z'} = \cos\theta_M \cdot a'_f - \sin\theta_M \cdot a_f \cdot \frac{g}{g'}$$

$$v^f_Z = \cos\theta_M \cdot v_f + \sin\theta_M \cdot v'_f \cdot \frac{g'}{g}$$

$$v^f_{Z'} = \cos\theta_M \cdot v'_f - \sin\theta_M \cdot v_f \cdot \frac{g}{g'}$$



	$m_{Z'}^{min}$ [GeV]		
Z′ Model	DELPHI	L3	CDF
χ	315	390	595
ψ	330	230	590
η	240	285	620
LR	270	250	630
SSM	–	820	690

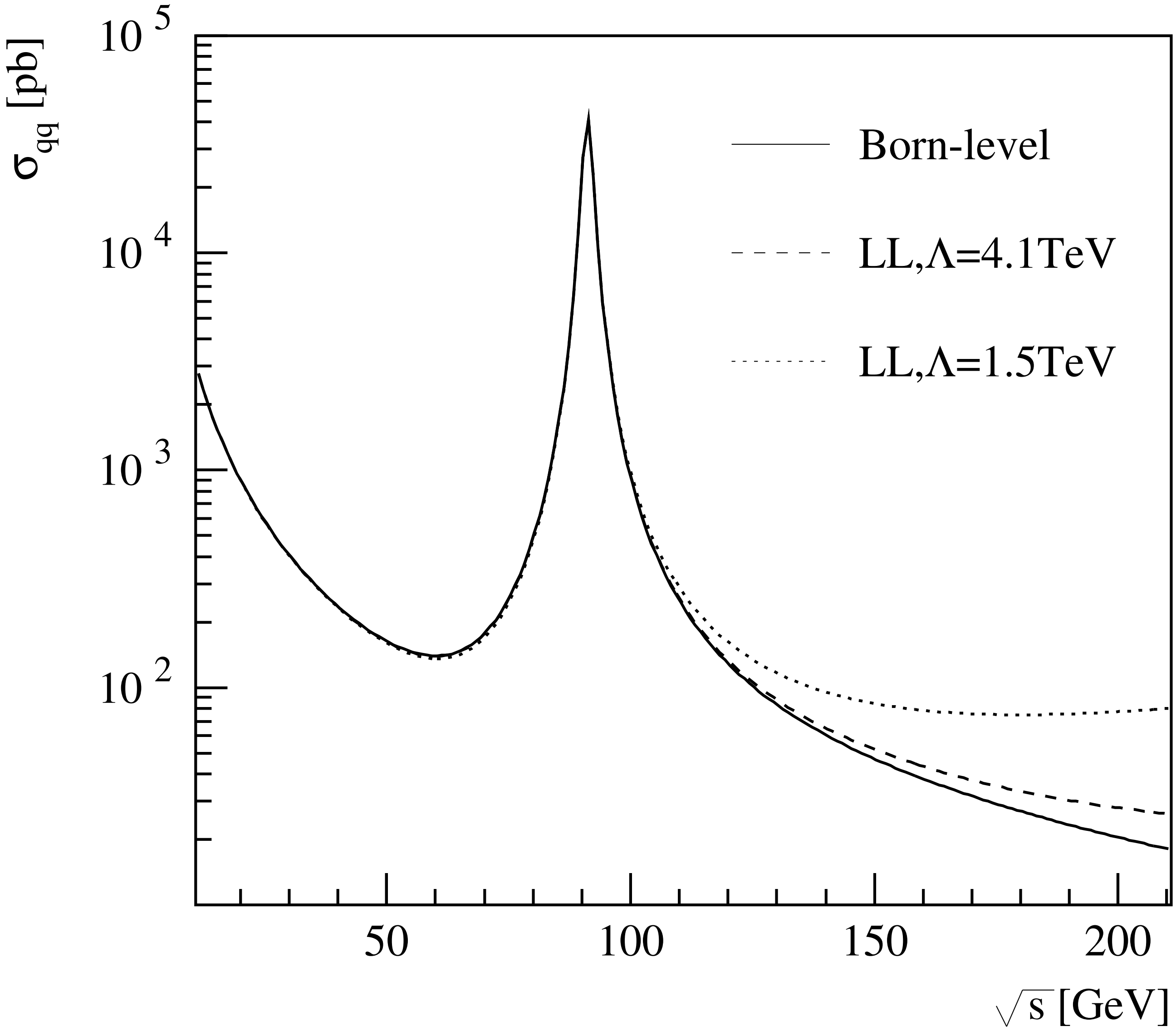


$$\mathcal{L} = \frac{1}{1+\delta_{ef}} \sum_{i,j=\mathrm{L,R}} \eta_{ij} \frac{g^2}{\Lambda_{ij}^2} (\bar{\mathrm{e}}_i \gamma^\mu \mathrm{e}_i)(\bar{f}_j \gamma_\mu f_j),$$

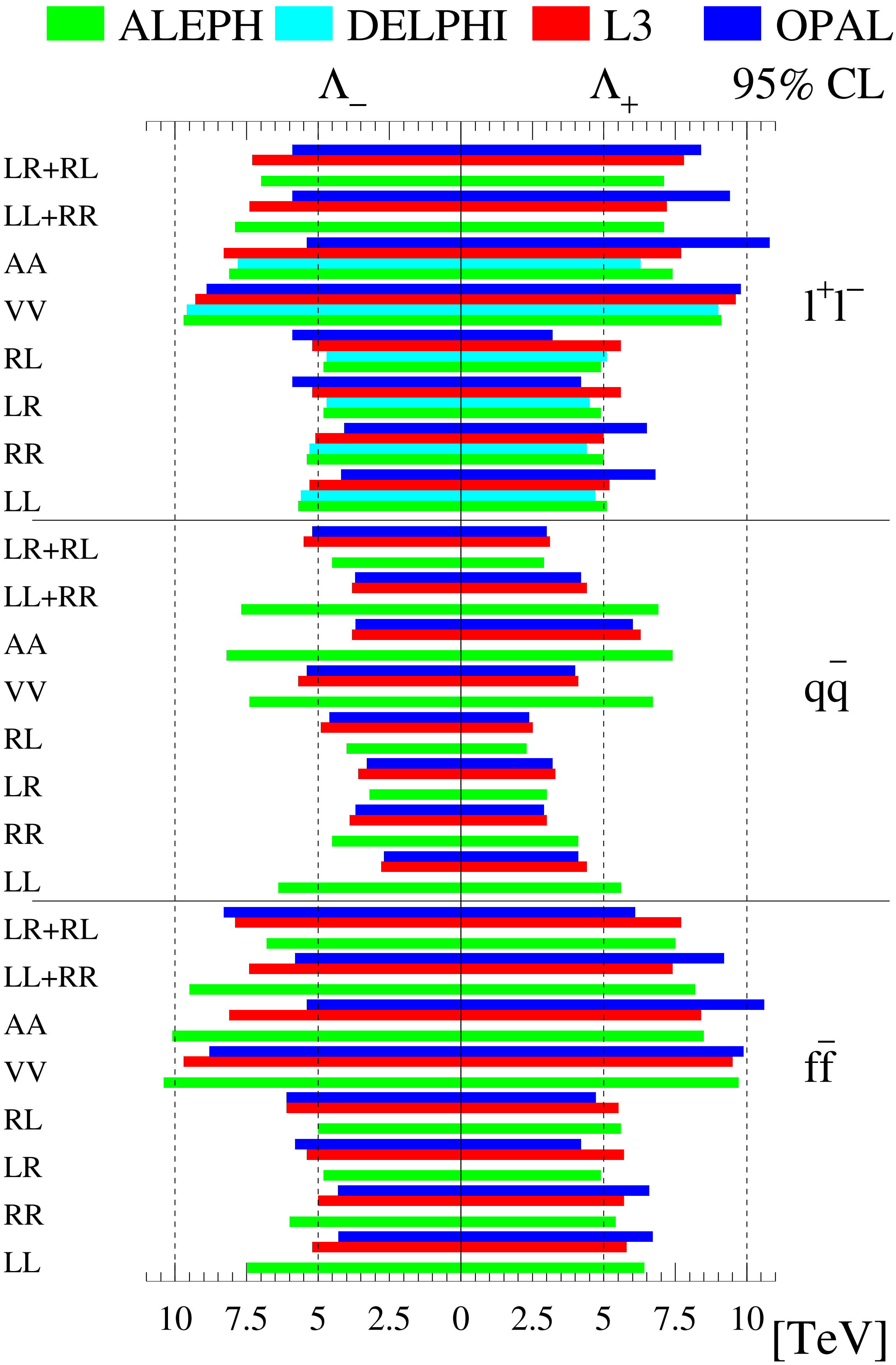
g Coupling, by convention $g^2/4\pi = 1$
η_{ij} Helicity amplitudes, choose $|\eta_{ij}| = 0, 1$

Λ Energy scale

$$\frac{d\sigma}{d\cos\theta} = \frac{d\sigma^{\mathrm{SM}}}{d\cos\theta} + c_{\mathrm{int}}(s,\cos\theta)\frac{1}{\Lambda^2} + c_{\mathrm{ci}}(s,\cos\theta)\frac{1}{\Lambda^4}.$$



$\Rightarrow$ LogL-Fit to σ and $A_{fb} = (\sigma_f - \sigma_b)/\sigma$



ALEPH DELPHI L3 OPAL
Λ₋ Λ₊ 95% CL
LR+RL
LL+RR
AA
VV
RL
LR
RR
LL
l⁺l⁻
qq̄
ff̄
10 7.5 5 2.5 0 2.5 5 7.5 10 [TeV]

- Cross section and asymmetry measurements at 130-183 GeV in good agreement with SM predictions
- Preliminary results from 189 GeV also consistent with SM
- Further improvement on m_{Z}, j_{had} within S–Matrix Ansatz
- α_{QED} is running as predicted
- Mass of a Z' must be higher than 240 GeV (SSM: 820 GeV)
- Energy scale for new (contact) interactions constraint to values above 5-10 TeV
- Further $\mathcal{L}$ increases precision significantly, higher $\sqrt{s}$ gives better sensitivity