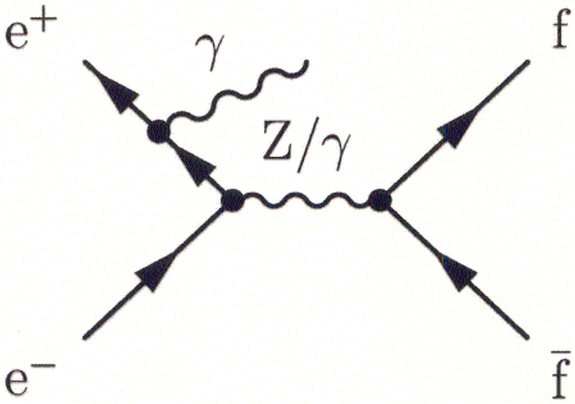
LEP II Beam Energy Measurement using Radiative Return Events



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Presentation of preliminary results on behalf of the LEP Collaborations

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Overview

- Motivation for a precise knowledge of the LEP beam energy ($E_{\rm b}$).
- The radiative return approach to $E_{\rm b}$ (first reported on by ALEPH in Phys. Lett. **B464** (1999) 339).
- Measurements by DELPHI, L3 and OPAL.
- Systematic studies.
- Results & LEP combination.
- Conclusion.

Why determine E_b accurately?

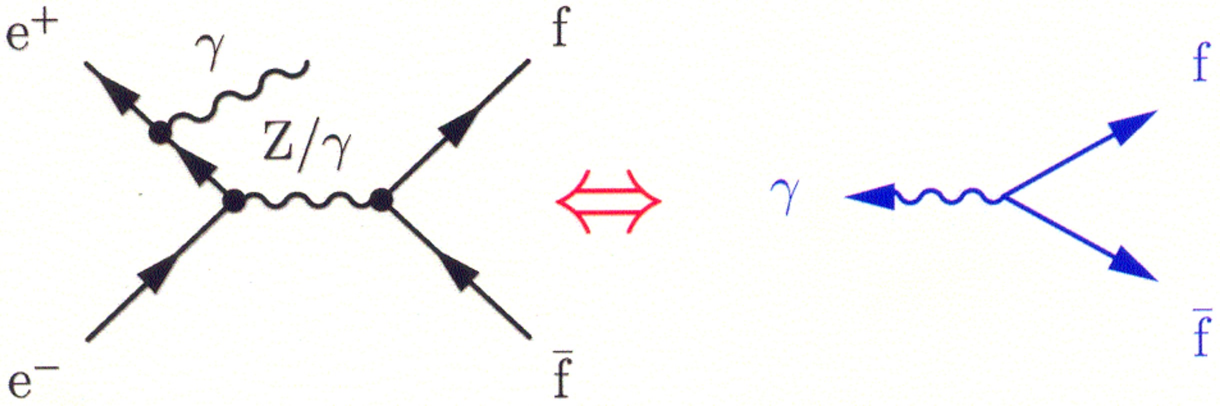
- Knowledge of E_b important for many *precision measurements* at LEP.
- Relevant for measurement of $\int \mathcal{L}\mathrm{d}t$ via Bhabha cross-section $\Rightarrow$ fundamental to all cross-section determinations.
- Vital for accuracy of m_W measurement; a principal objective of LEP $\mathrm{II} \longrightarrow$ resolution improved through kinematic fit constraints:

$$\frac{\Delta m_\mathrm{W}}{m_\mathrm{W}} = \frac{\Delta E_\mathrm{b}}{E_\mathrm{b}}.$$

- Standard LEP calibration relies on LEP I technique of resonant depolarisation at $E_\mathrm{b} \sim 40 - 60\ \mathrm{GeV}$, together with magnetic extrapolation to LEP II energies ($E_\mathrm{b} \sim 100\ \mathrm{GeV}$), assuming $E_\mathrm{b} = a + bB$ $\Rightarrow$ *indirect* determination: need to be confident it really works at $\sim 20\ \mathrm{MeV}$ level LEP claims.

Radiative Return Approach

- E_{b} measured *directly* by LEP experiments.
- Use radiative fermion-pair events and construct $\sqrt{s'}$ = centre-of-mass energy after initial state radiation (ISR) .



- $\sqrt{s'}$ sensitive to E^{LEP} through energy and momentum constraints in kinematic fits.
- Use ISR events with $\sqrt{s'} \sim m_{\mathrm{Z}}$ to reconstruct ‘pseudo’-Z peak in MC ($\sqrt{s}$ known *exactly*) and in data ($\sqrt{s}$ known *by measurement*).
- Attribute any relative shift to a discrepancy in the measurement of the beam energy (ΔE_{b}).

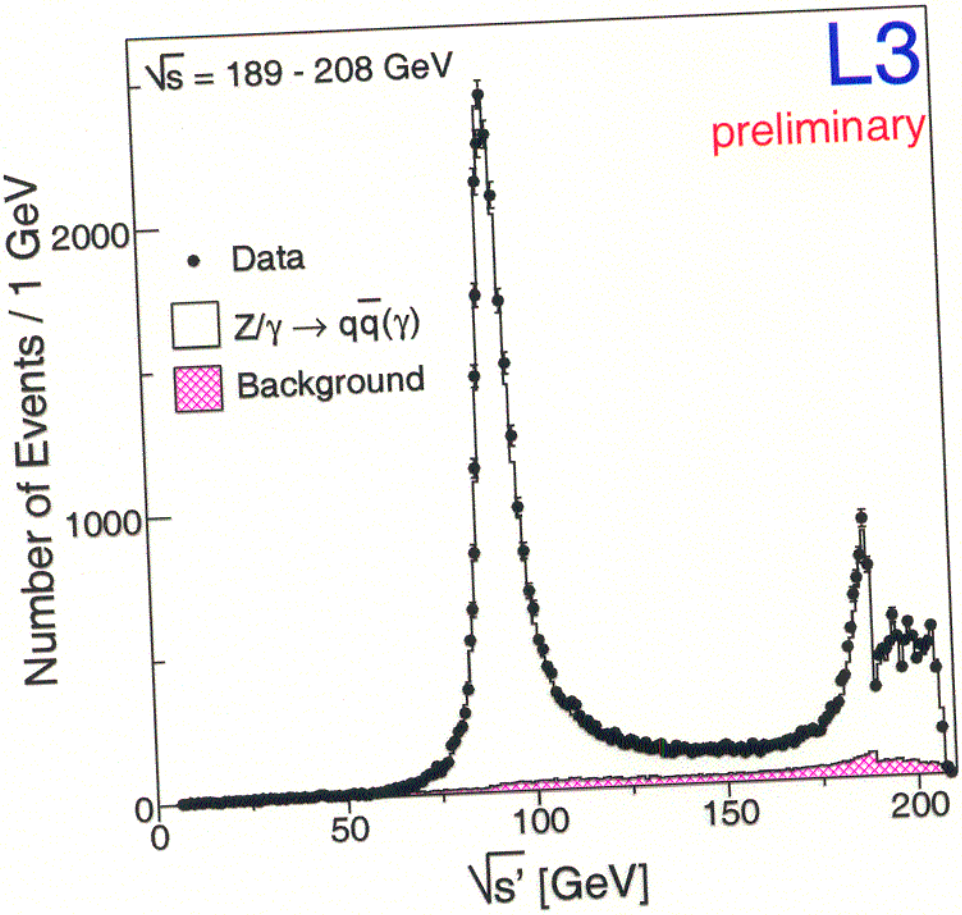
Reconstructed $\sqrt{s'}$ Distribution

- 1998–2000 L3 hadronic data ($627\ \mathrm{pb}^{-1}$):

  $E_\mathrm{b} \sim 94 - 104$ GeV.

- $\sqrt{s'}$ reconstructed from angles only:

$$\sqrt{\frac{s'}{s}} = \sqrt{\frac{\sin\chi_{q\gamma} + \sin\chi_{\bar{q}\gamma} - |\sin(\chi_{q\gamma} + \chi_{\bar{q}\gamma})|}{\sin\chi_{q\gamma} + \sin\chi_{\bar{q}\gamma} + |\sin(\chi_{q\gamma} + \chi_{\bar{q}\gamma})|}}.$$



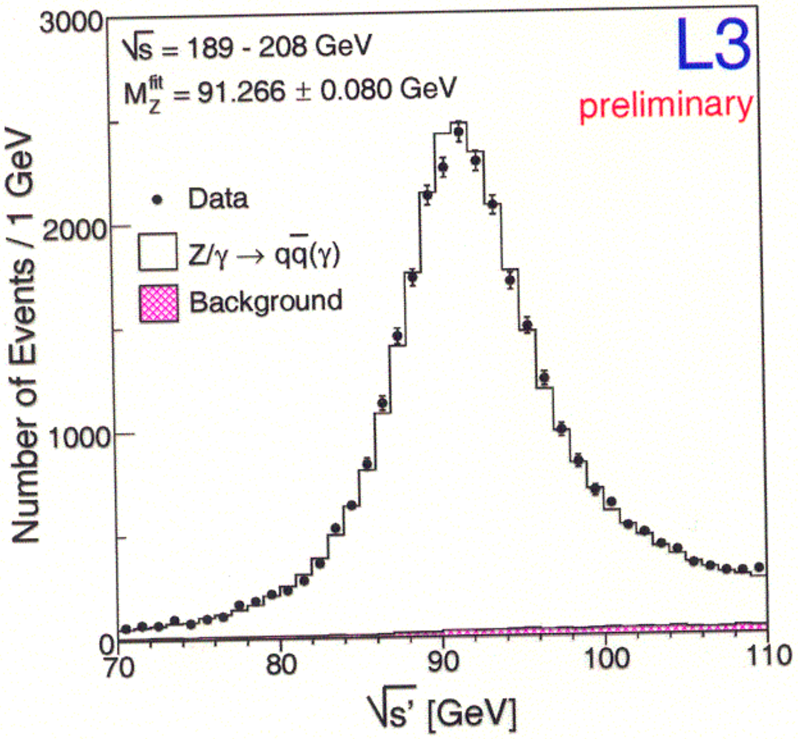
- Dominated by events under *radiative return* peak (≈ independent of E_b) and at full energy.

ΔE_b from $\mathrm{e^+e^-} \rightarrow \mathrm{q\bar{q}\gamma}$

(1) Re-weighting method (DELPHI, L3):

- Use knowledge of m_Z from LEP I.
- Re-weight Monte Carlo $\sqrt{s'}$ distribution with Breit-Wigner-like function $f(s', m_\mathrm{Z})$ assuming different $m_\mathrm{Z}^\mathrm{new}$:

$$w(s', m_\mathrm{Z}^\mathrm{new}) = \frac{f(s', m_\mathrm{Z}^\mathrm{new})}{f(s', m_\mathrm{Z}^\mathrm{LEP})}.$$



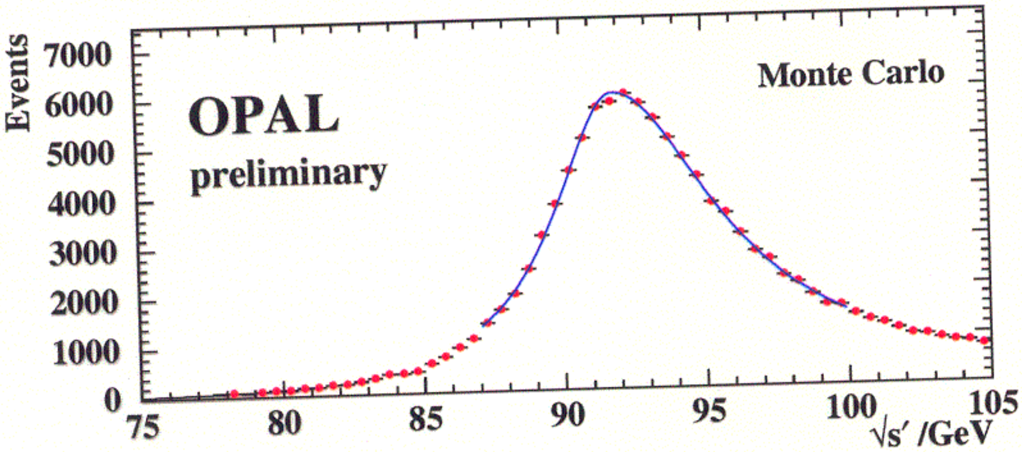
- Optimise agreement with data by varying $m_\mathrm{Z}^\mathrm{new}$

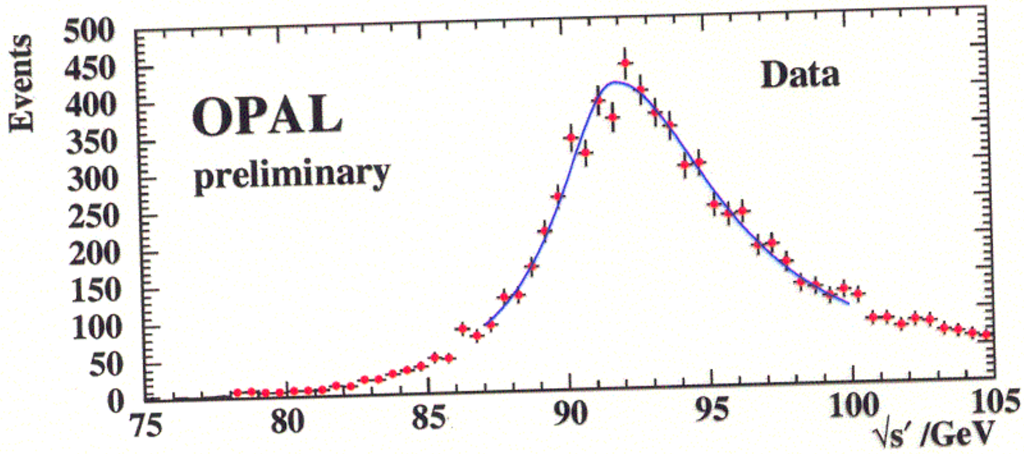
$$\Rightarrow \Delta E_\mathrm{b} = -E_\mathrm{b}\left(\frac{m_\mathrm{Z}^\mathrm{new} - m_\mathrm{Z}^\mathrm{LEP}}{m_\mathrm{Z}^\mathrm{LEP}}\right).$$

ΔE_{b} from $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{q}\bar{\mathrm{q}}\gamma$

(2) Fit method (OPAL):

- Fit Breit-Wigner-like function to $\sqrt{s'}$ distribution in MC (at *known* $\sqrt{s}$) around 'pseudo'-Z peak.
- Fit same function to $\sqrt{s'}$ distribution in data as a function of $\Delta E_{\mathrm{b}} = E_{\mathrm{b}}^{\mathrm{OPAL}} - E_{\mathrm{b}}^{\mathrm{LEP}}$, allowing normalisation/peak position (M^*) to vary.



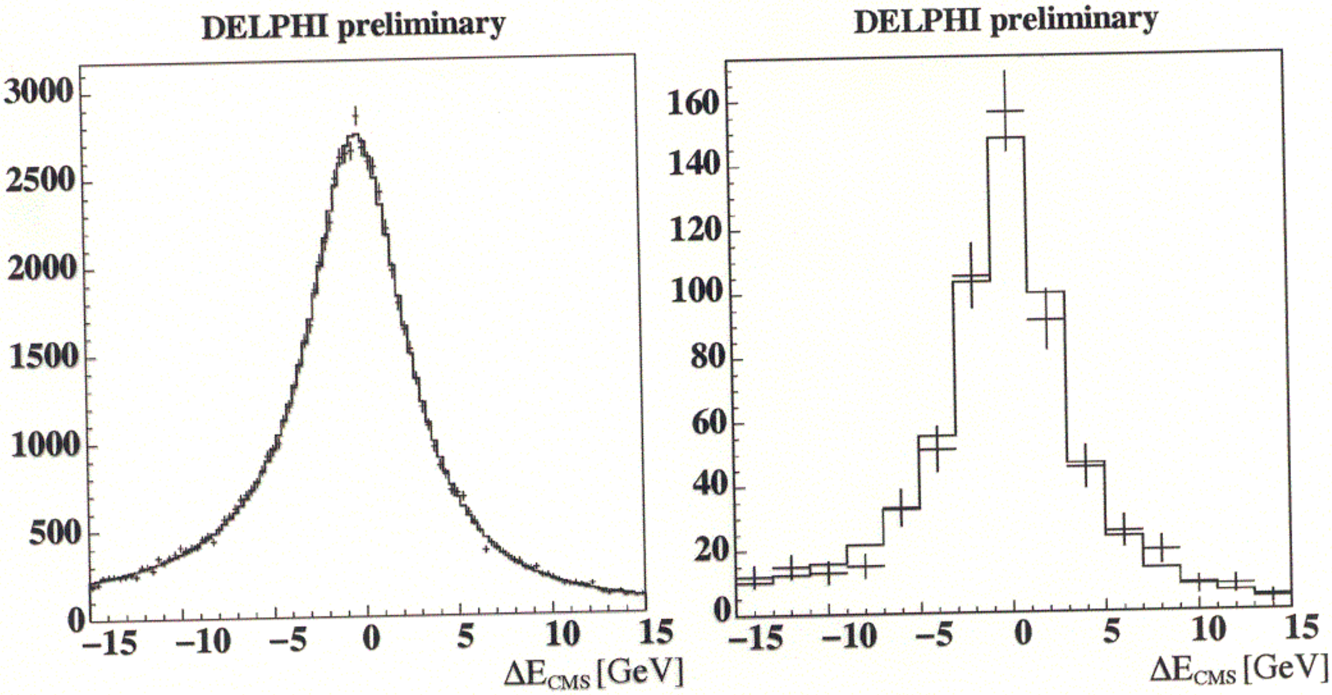


- Extract ΔE_{b} from $M^*_{\mathrm{data}}(\Delta E_{\mathrm{b}}) = M^*_{\mathrm{MC}}$.

ΔE_b from $e^+e^- \to \ell^+\ell^-\gamma$

Fit method (DELPHI: $\ell = \mu$; OPAL: $\ell = e, \mu, \tau$):

- Define $x \equiv \sqrt{\frac{s'}{s}}$.
- Construct $\Delta E_{\rm cms} = \frac{m_Z}{x} - \sqrt{s}$ for each event.
- Fit Breit-Wigner-like function to distribution of $\Delta E_{\rm cms}$ in Monte Carlo and in data:



- Extract relative difference in peaks:

$$\Rightarrow \Delta E_b = \frac{1}{2}(\Delta E_{\rm cms}^{\rm data} - \Delta E_{\rm cms}^{\rm MC}).$$

Systematic Studies

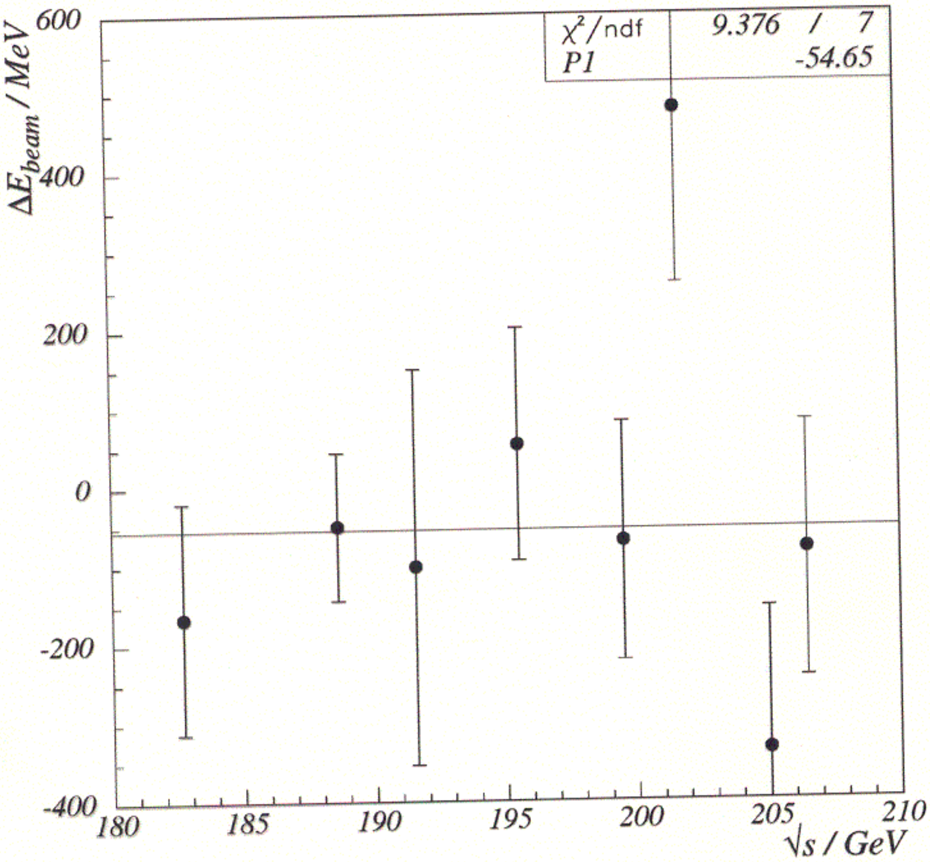
- Motivated by m_{W} systematics; dominated by *detector modelling* and quark *fragmentation*.

Experiment	Dominant systematics /MeV		Total /MeV
DELPHI($q\bar{q}\gamma$)	Data/MC tracking mismatch	60	65
	Angular scale	20	
L3($q\bar{q}\gamma$)	Jet energies	46	75
	Angular scale	40	
OPAL($q\bar{q}\gamma$)	Fragmentation	61	70
	Jet/photon energies/angles	29	
DELPHI($\mu^+\mu^-\gamma$)	Angular scale	24	27
OPAL($e^+e^-\gamma$)	MC stats	52	78
	Angular scale	43	
OPAL($\mu^+\mu^-\gamma$)	Angular scale	20	22
OPAL($\tau^+\tau^-\gamma$)	Angular scale	140	148

- ISR modelling in $\mathcal{KK}2f$ MC, backgrounds, fit parameters give only small uncertainties.

Results from DELPHI

- 1997–2000 $q\bar{q}\gamma$ data:



$$\Rightarrow \Delta E_{\mathrm{b}} = -55 \pm 53 \pm 65\ \mathrm{MeV}.$$

- 1997–2000 $\mu^+\mu^-\gamma$ data:

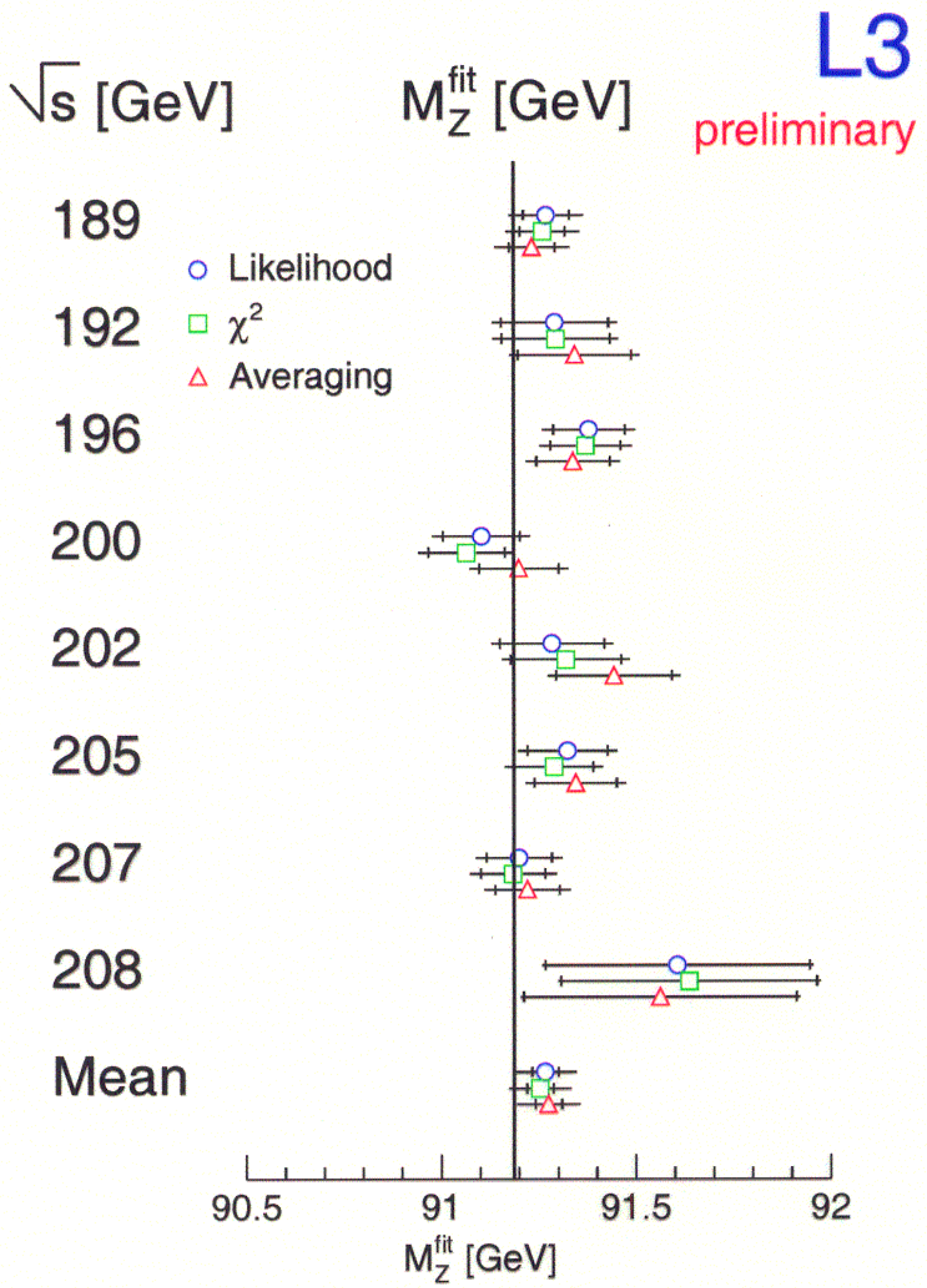
$$\Rightarrow \Delta E_{\mathrm{b}} = +113 \pm 75 \pm 27\ \mathrm{MeV}.$$

- DELPHI combined:

$$\Rightarrow \Delta E_{\mathrm{b}} = +34 \pm 47 \pm 37\ \mathrm{MeV}.$$

Results from L3

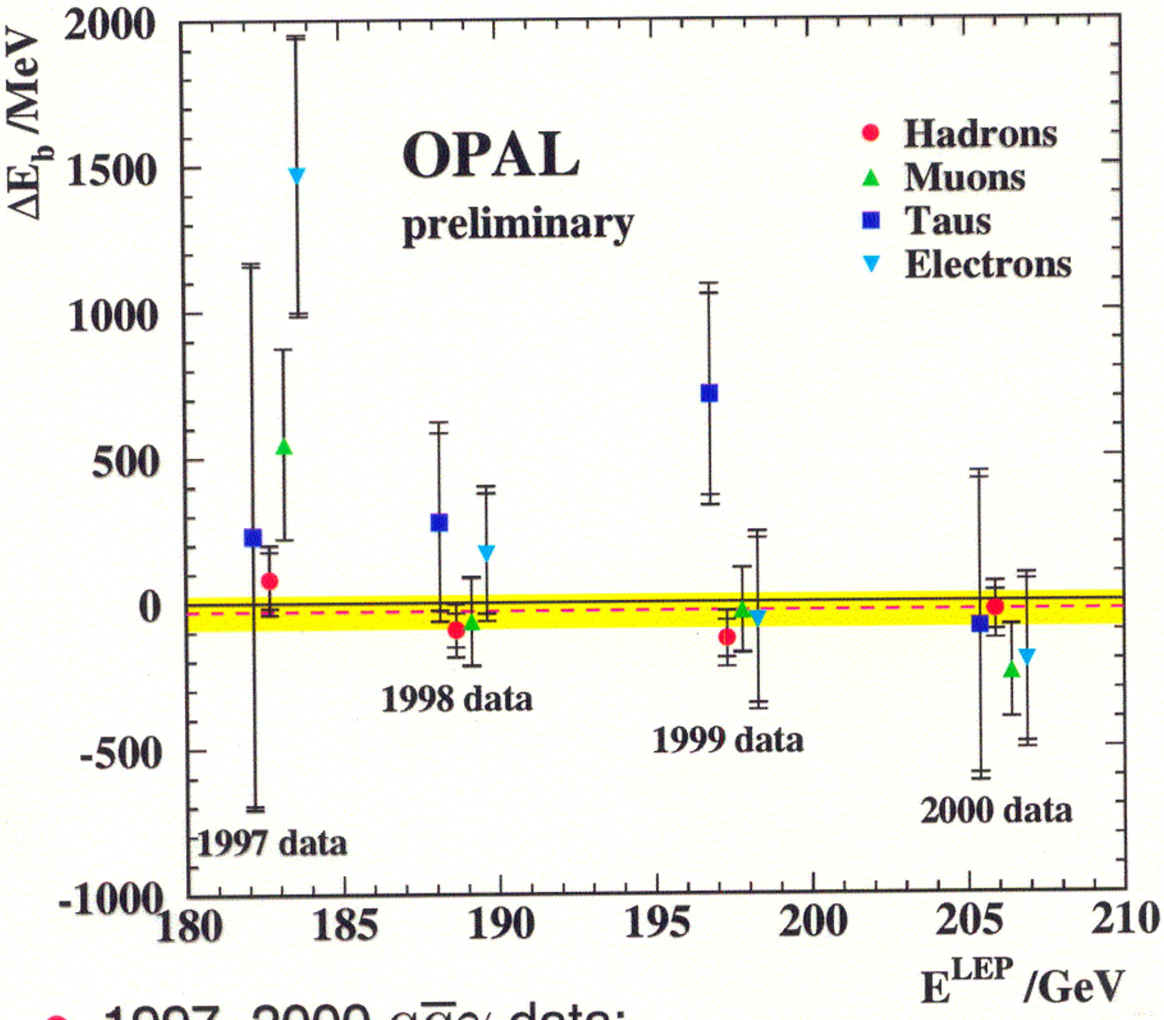
- 1998–2000 $q\bar{q}\gamma$ data:



$$\Rightarrow \Delta m_Z = +76 \pm 34 \pm 72 \text{ MeV}$$

$$\Rightarrow \Delta E_b = -83 \pm 37 \pm 75 \text{ MeV}.$$

Results from OPAL



- 1997–2000 $q\bar{q}\gamma$ data:

$$\Rightarrow \Delta E_{\mathrm{b}} = -65 \pm 34 \pm 70\ \mathrm{MeV}.$$

- 1997–2000 $\ell^+\ell^-\gamma\ (\ell = \mathrm{e}, \mu, \tau)$ data:

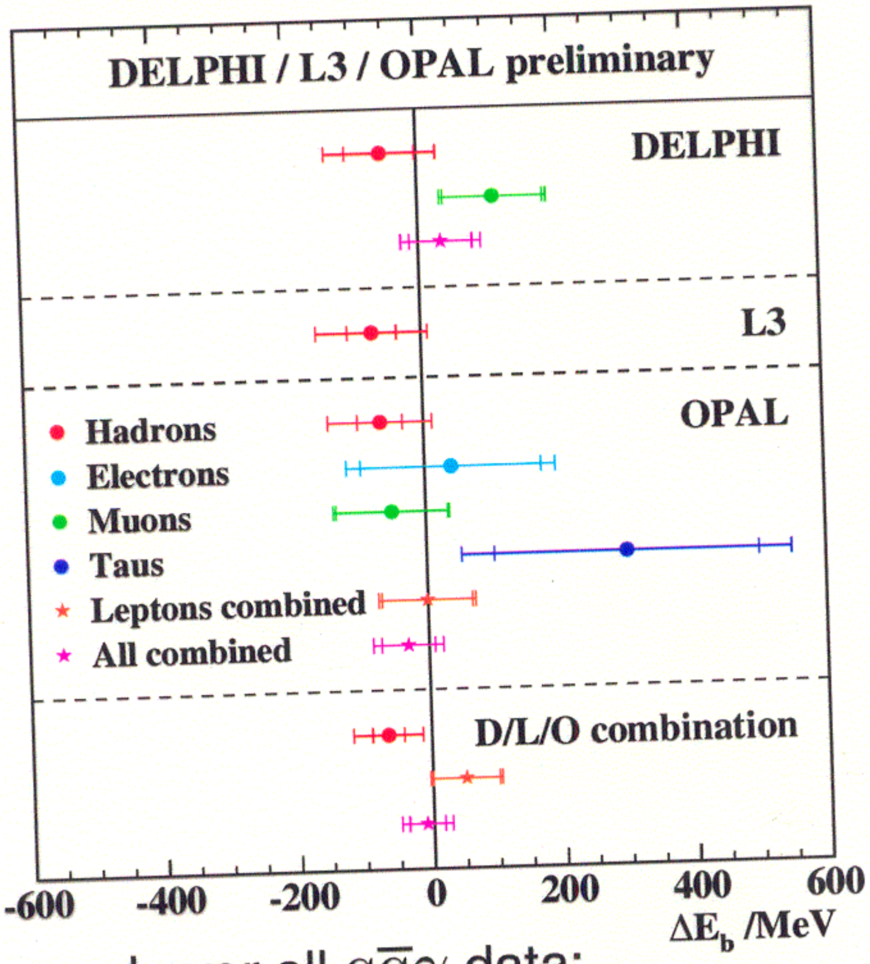
$$\Rightarrow \Delta E_{\mathrm{b}} = -1 \pm 68 \pm 26\ \mathrm{MeV}.$$

- OPAL combined:

$$\Rightarrow \Delta E_{\mathrm{b}} = -31 \pm 40 \pm 36\ \mathrm{MeV}.$$

Combination

- Summary of all radiative return results:



- Averaged over all $q\bar{q}\gamma$ data:

$$\Rightarrow \Delta E_{\rm b} = -65 \pm 24 \pm 45 \text{ MeV}.$$

- Averaged over all $\ell^+\ell^-\gamma$ data:

$$\Rightarrow \Delta E_{\rm b} = +51 \pm 50 \pm 19 \text{ MeV}.$$

- Averaged over all data:

$$\Rightarrow \Delta E_{\rm b} = -10 \pm 27 \pm 26 \text{ MeV}.$$

Conclusions

- Beam energy from radiative returns is *entirely consistent* with standard LEP calibration
  ⇒ good news for LEP calibration team;
  ⇒ good news for $m_{\rm W}$ determination.
- Radiative return systematics $\sim$ uncertainty on magnetic extrapolation.
- Approach works with/without *circulating* beams
  ⇒ potential method for evaluating $E_{\rm b}$ at a high-statistics future linear collider.