Fermionpair Cross-Sections and Lepton Asymmetries at LEP II

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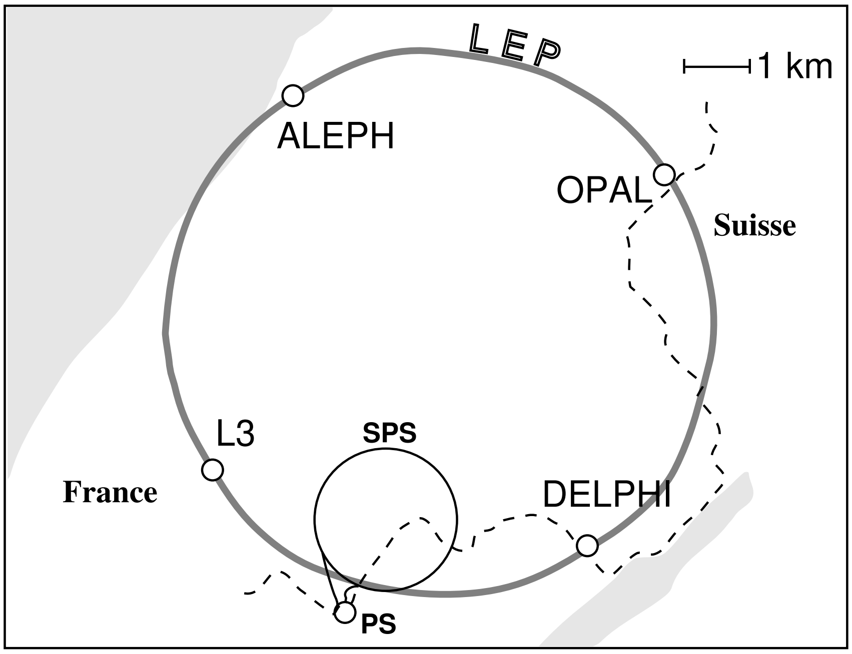
- Introduction
- Physical Background
- Event Selection
- Fermion-Pair Cross-Sections
- Lepton FB-Asymmetries
- Conclusion

Reference:
LEP Experiments: ALEPH, DELPHI, L3, OPAL
LEP Electroweak Working Group

Fermion-Pair Measurements at LEP II

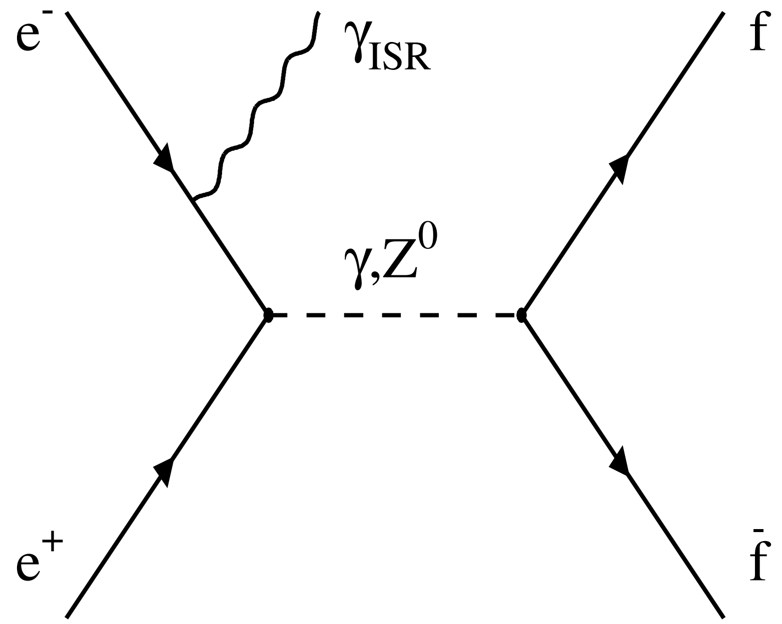


LEP II runs at 2 $\times$ LEP I beam energy

Motivation:
- Z-Mass improvement (J^{tot}_{had})
- SM lepton-universality
- Detector/Reconstruction checks

Characteristics:
- Low number of selected events
- Large radiative corrections
- New LEP operating-scheme

Fermion-Pair-Production

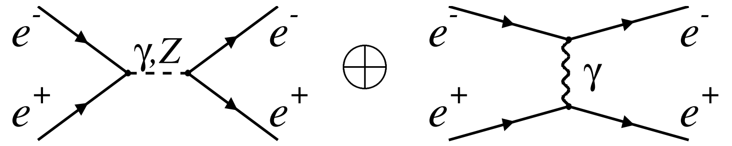


$e^+e^- \rightarrow q\,\bar{q}\,(\gamma)$

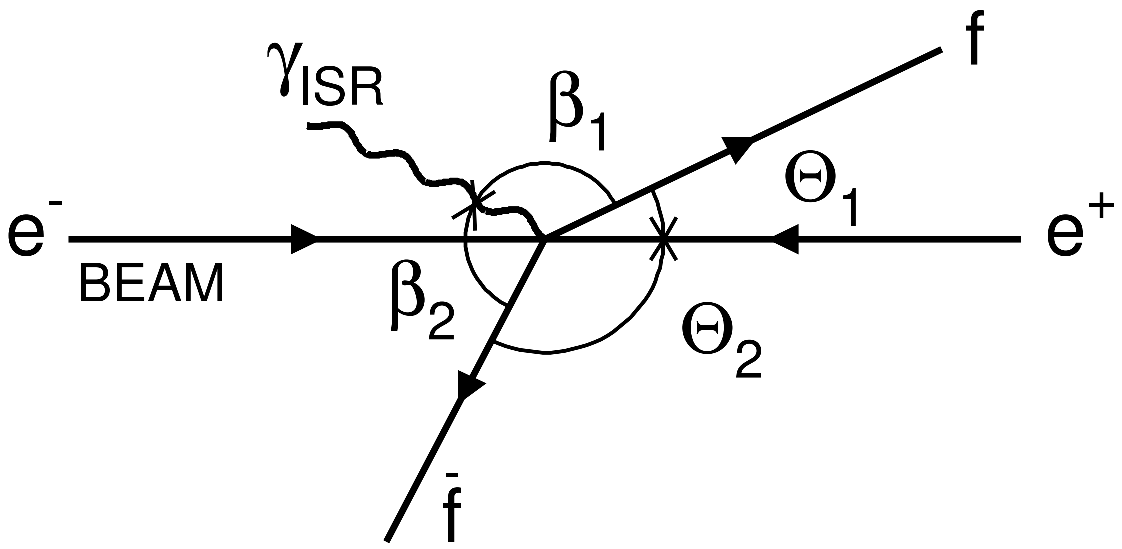
$e^+e^- \rightarrow \mu^+\mu^-\,(\gamma)$

$e^+e^- \rightarrow \tau^+\tau^-\,(\gamma)$

$e^+e^- \rightarrow e^+e^-\,(\gamma)$



Kinematics



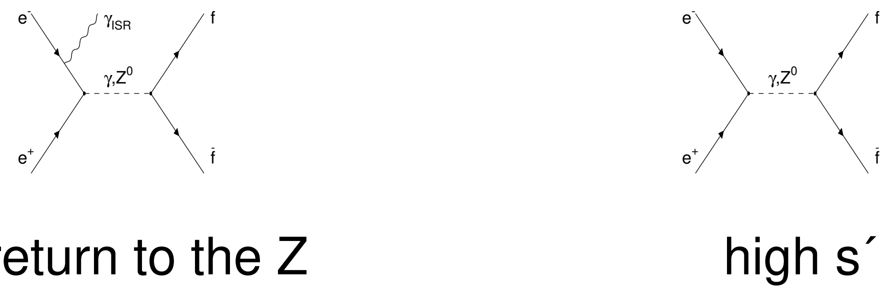
$\sqrt{\mathsf{s}} = \mathsf{E}_{\mathsf{e}^-} + \mathsf{E}_{\mathsf{e}^+} = 2\mathsf{E}_{\mathsf{BEAM}}$

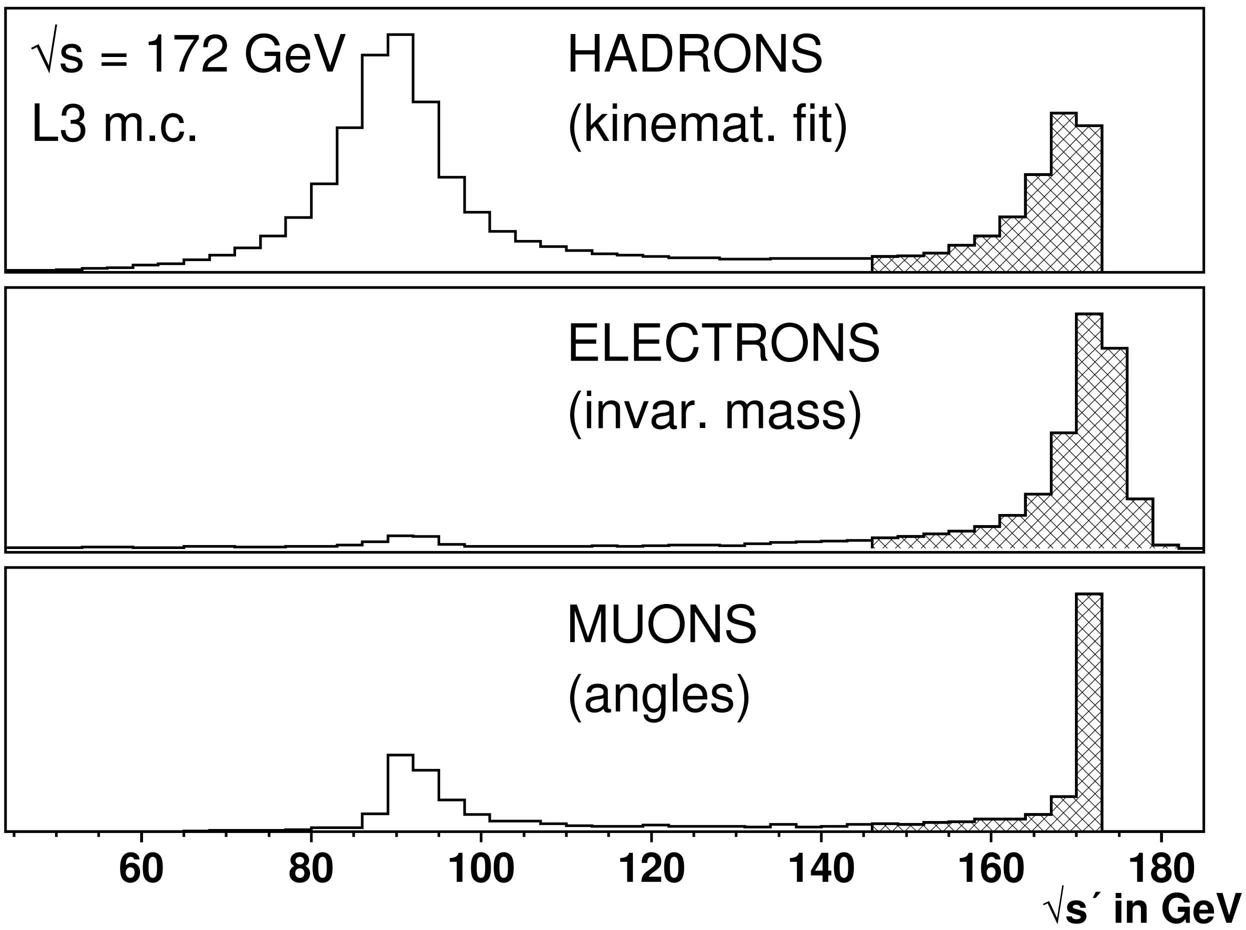
$\mathsf{s}' := \mathsf{M}^2(\mathsf{f}, \bar{\mathsf{f}}) = \mathsf{s} - 2\mathsf{E}_{\gamma_{\mathsf{ISR}}}\sqrt{\mathsf{s}}$

$\mathsf{E}_{\gamma_{\mathsf{ISR}}} = \sqrt{\mathsf{S}}\frac{|\sin(\beta_1+\beta_2)|}{\sin(\beta_1)+\sin(\beta_2)+|\sin(\beta_1+\beta_2)|}$

γ_{ISR} undetected: Assume in beampipe - take Θ_1, Θ_2

Effective Center of Mass Energy s'





S-Matrix Analysis

Photon Propagator massless

Z-Boson Propagator massiv (m_Z), instable (Γ_Z)

$$\frac{d\sigma}{d\cos\Theta} = \frac{4\pi\alpha^2}{3}\left\{ \frac{\left(\frac{\alpha(s)}{\alpha}Q_f\right)^2}{s} \quad \tfrac{3}{8}(1+\cos^2\Theta)\right.$$

$$+ \frac{s-m_Z^2}{(s-m_Z^2)^2+(\Gamma_Z m_Z)^2} \quad \left[J_f^{tot}\,\tfrac{3}{8}(1+\cos^2\Theta)+ \ J_f^{\mathrm{fb}}\cos\Theta\right]$$

$$\left. + \frac{s}{(s-m_Z^2)^2+(\Gamma_Z m_Z)^2} \quad \left[R_f^{tot}\,\tfrac{3}{8}(1+\cos^2\Theta)+ R_f^{\mathrm{fb}}\cos\Theta\right]\right\}$$

Standardmodel:

$$R_f^{tot} = \frac{9}{\alpha^2 m_Z^2}\Gamma_e\Gamma_f \qquad J_f^{tot} = \frac{G_F m_Z^2}{\sqrt{2}\pi\alpha}\overline{g}_{ve}\,\overline{g}_{vf}$$

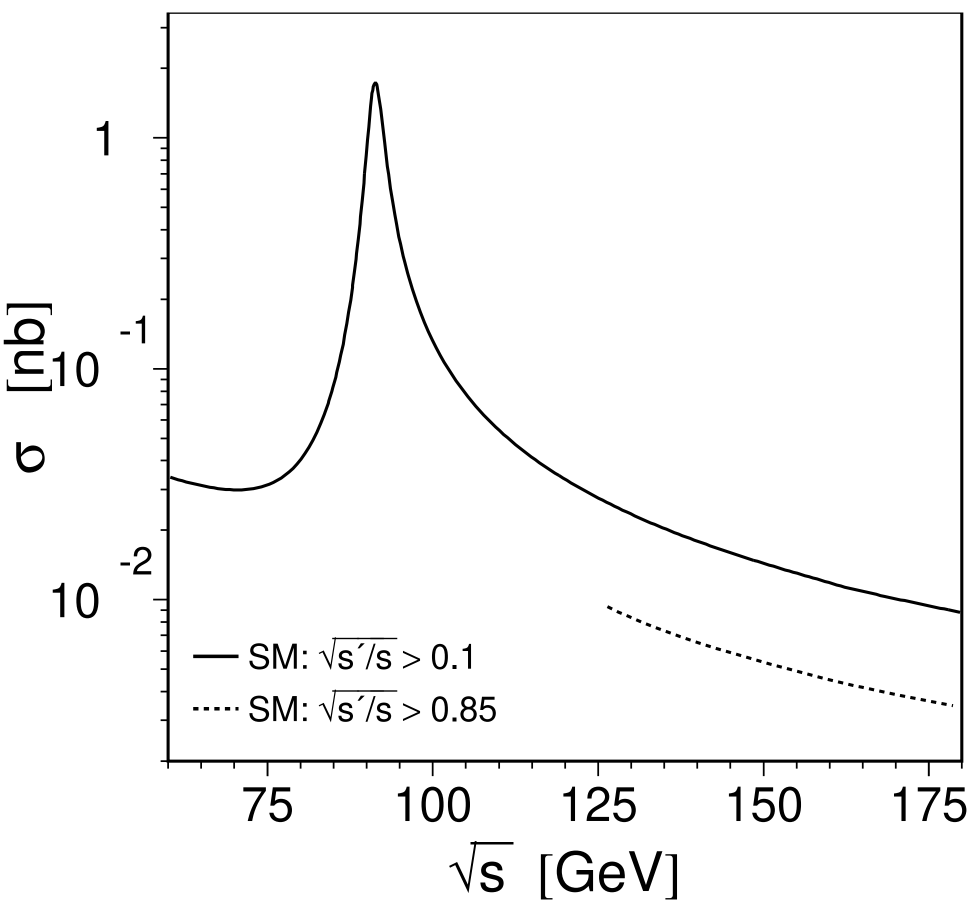
$$\Gamma_f = \frac{G_F m_Z^3}{6\pi\sqrt{2}}(\overline{g}_{vf}{}^2 + \overline{g}_{af}{}^2)$$

$$R_f^{\mathrm{fb}} = \frac{3G_F^2 m_Z^2}{8\pi\alpha^2}\overline{g}_{ve}\,\overline{g}_{ae}\,\overline{g}_{vf}\,\overline{g}_{af} \qquad J_f^{\mathrm{fb}} = \frac{3\sqrt{2}G_F}{8\alpha}\overline{g}_{ae}\,\overline{g}_{af}$$

Fermion-Pair-Cross-Section

$$\sigma_f^{tot} = \frac{4\pi\alpha^2}{3}\left\{\frac{\left(\frac{\alpha(s)}{\alpha}Q_f\right)^2}{s} + \frac{J_f^{tot}\,(s-m_Z^2) \quad + \quad R_f^{tot}\,s}{(s-m_Z^2)^2+(\Gamma_Z m_Z)^2}\right\}$$

Parametrisation from S-Matrix Analysis



Initial-state corrections: $\sigma(s) = \int_0^1 \sigma^0(\nu s) R(\nu s) d\nu$

LEP II Event Selection

Based on LEP I selections, but:

- Cross-section $\sim 10^{-2}$ of LEP I

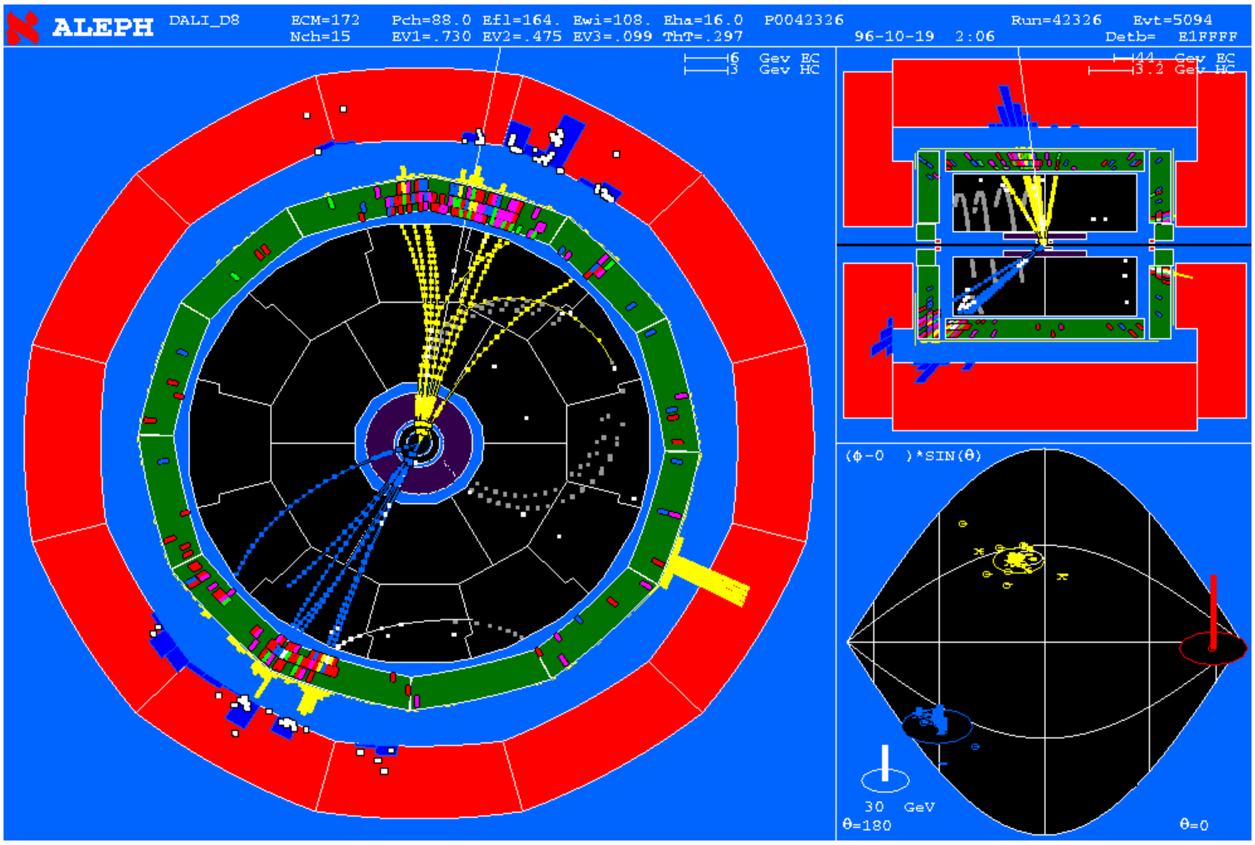
  $\Rightarrow$ higher non-interaction background
  (cosmic muons, beam - gas/wall)
  $\Rightarrow$ higher 2-photon collision background
  $(e^+e^- \to e^+e^- f\overline{f})$
  $\Rightarrow$ maximize acceptance
  (describe 'bad' runs in Real-Det.MC)

- ISR radiation 'return to the Z'

  $\Rightarrow$ Acollinear events

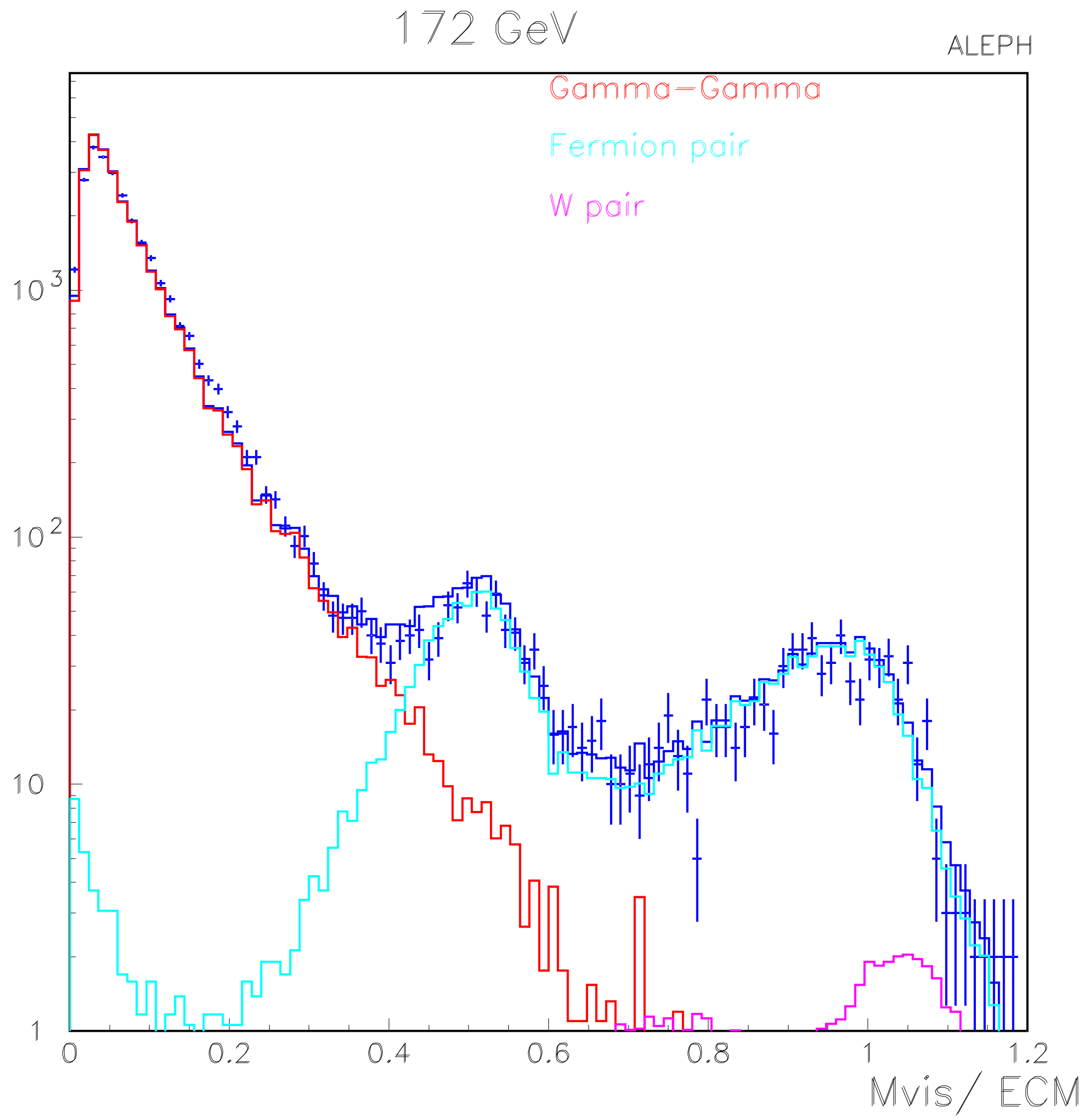
- New physical 'background' W^+W^-

$e^+e^- \longrightarrow q\bar{q}(\gamma)$ **(Aleph)**

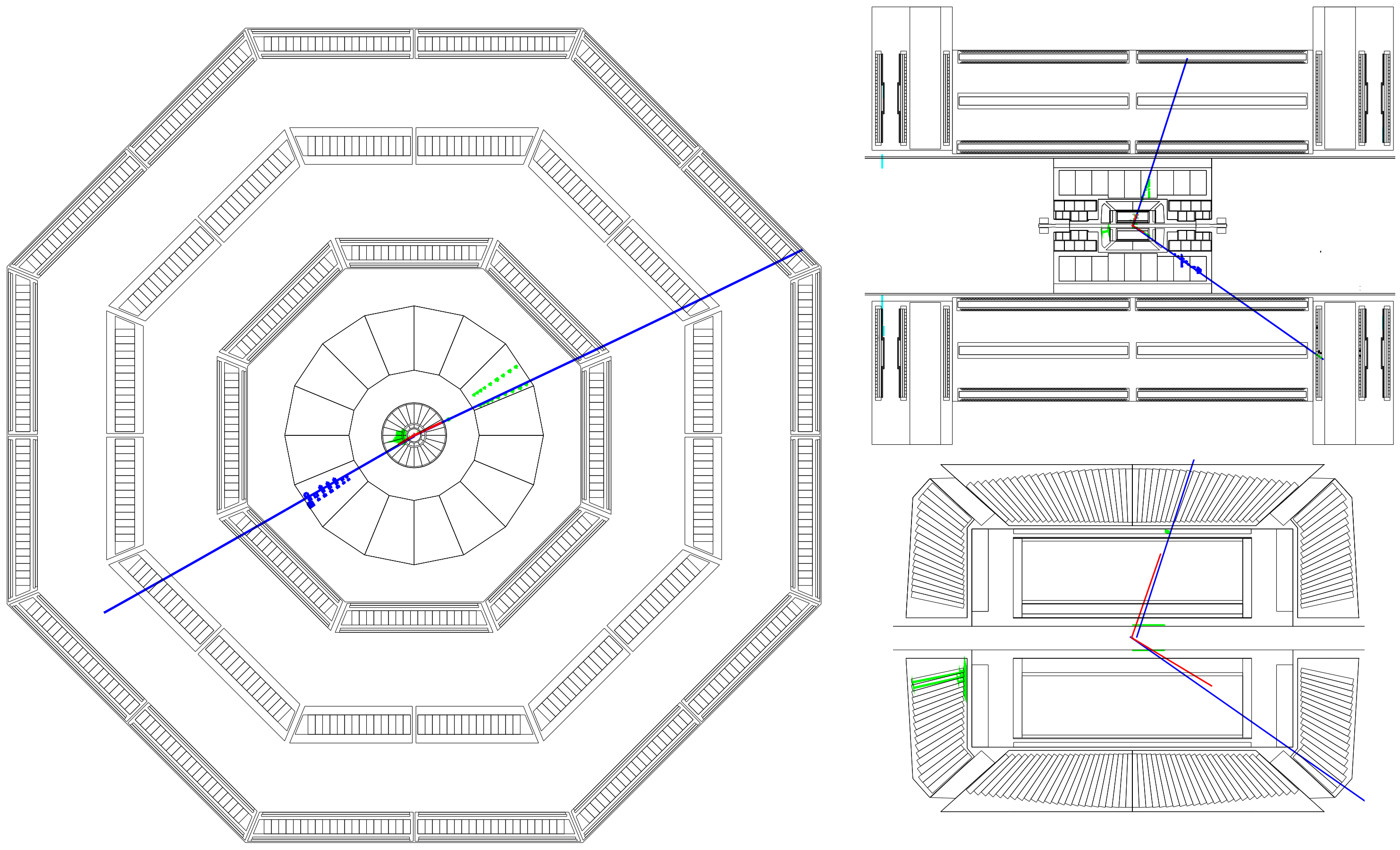


$N_{track} \geq 5$
Visible Mass $M_{vis} \geq 50GeV$
Identify ISR-photon in (3^{rd}) el.m. jet
Recluster rest into 2 jets (JADE)

Efficiency 98%   Background 17% (high s')


172 GeV
ALEPH
Gamma−Gamma
Fermion pair
W pair
10^3
10^2
10
1
0
0.2
0.4
0.6
0.8
1
1.2
Mvis/ ECM

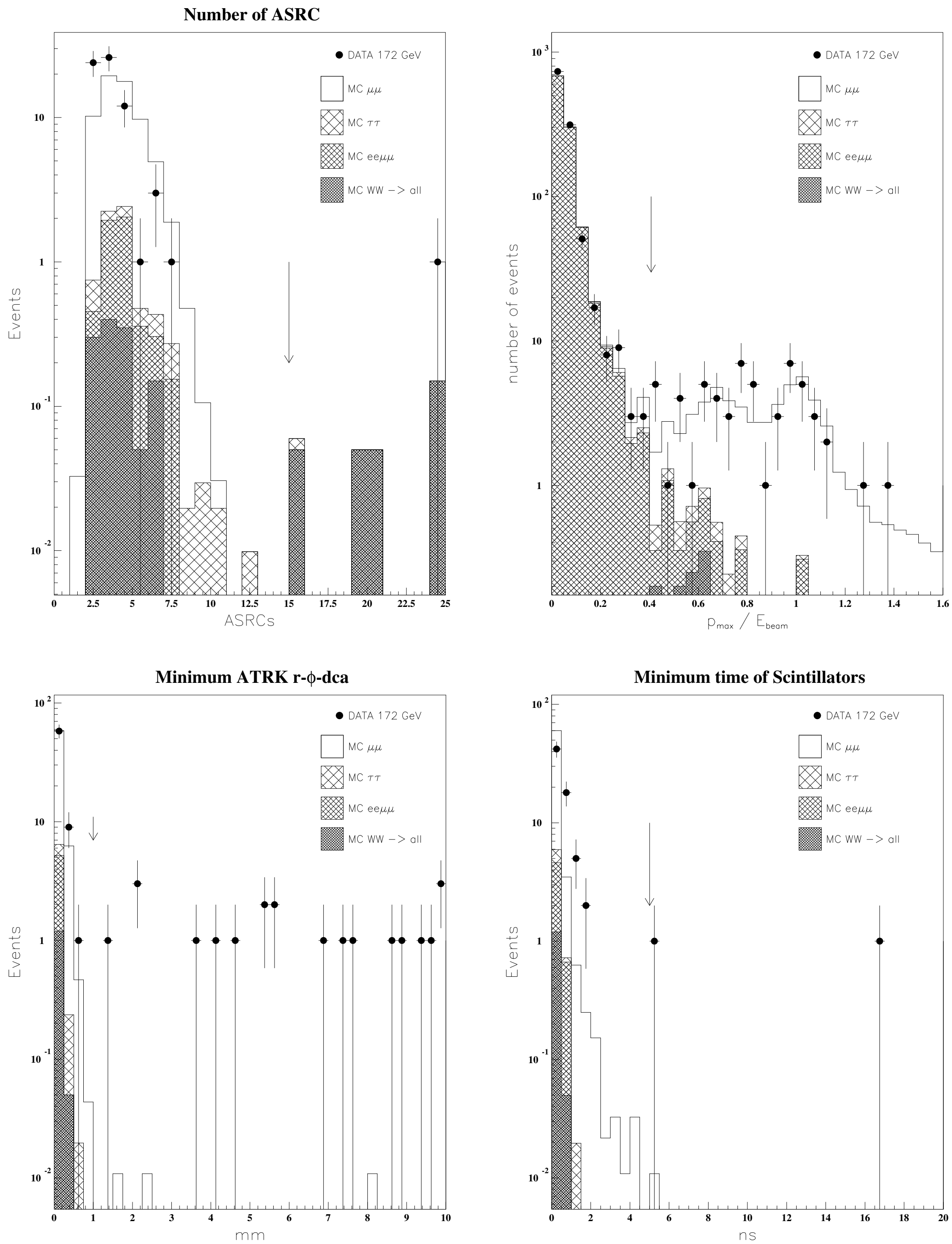
$e^+e^- \longrightarrow \mu^+\mu^-(\gamma)$ **(L3)**



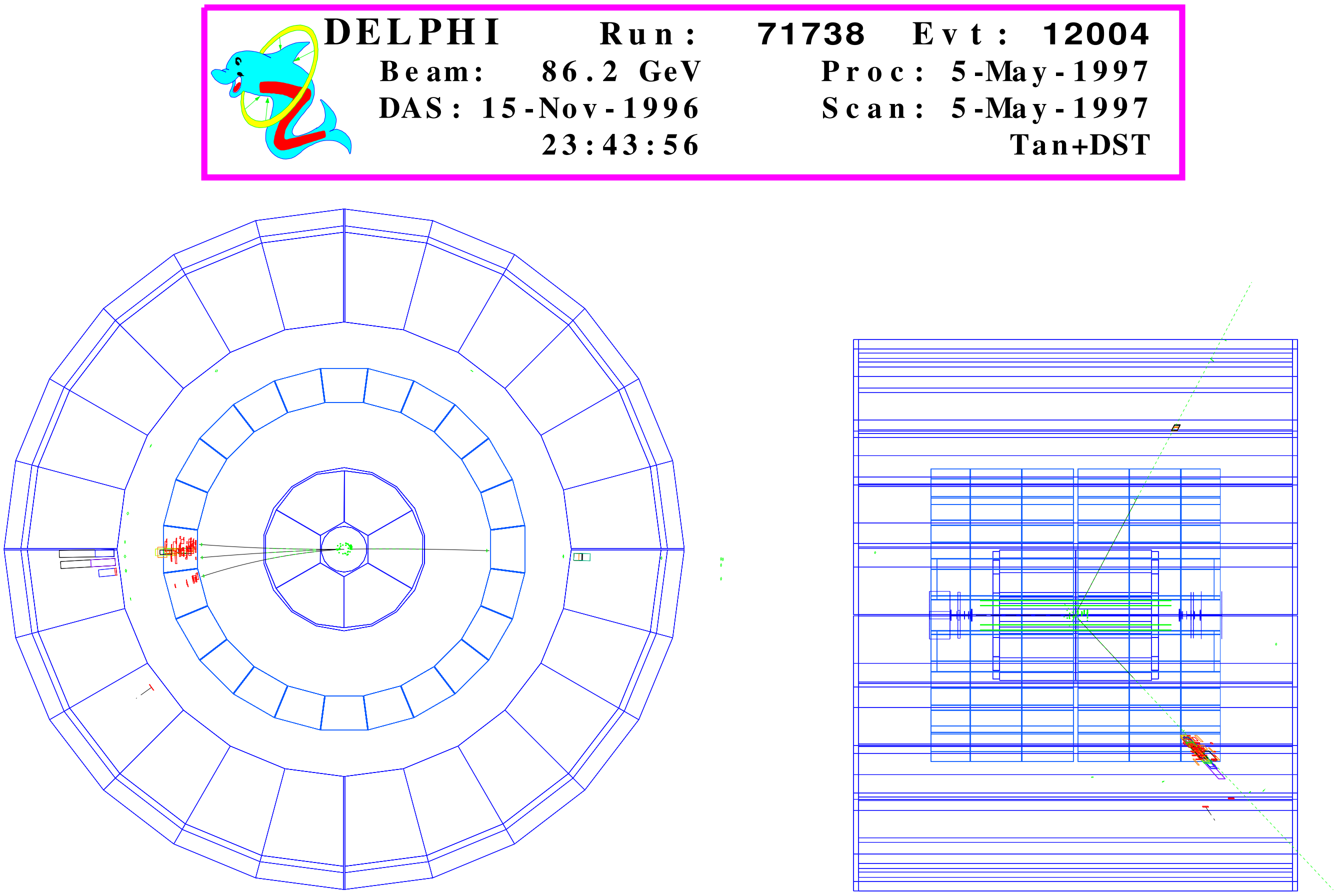
2 Muon-tracks/MIPs within $|\cos\Theta| < 0.9$
$P^{max}_{MUON} > 35 GeV$ track in time from vertex
Identify ISR-photon as isolated el.m cluster

Efficiency 60% - 73% Background 10% - 15%

L3 di-muon selection distributions



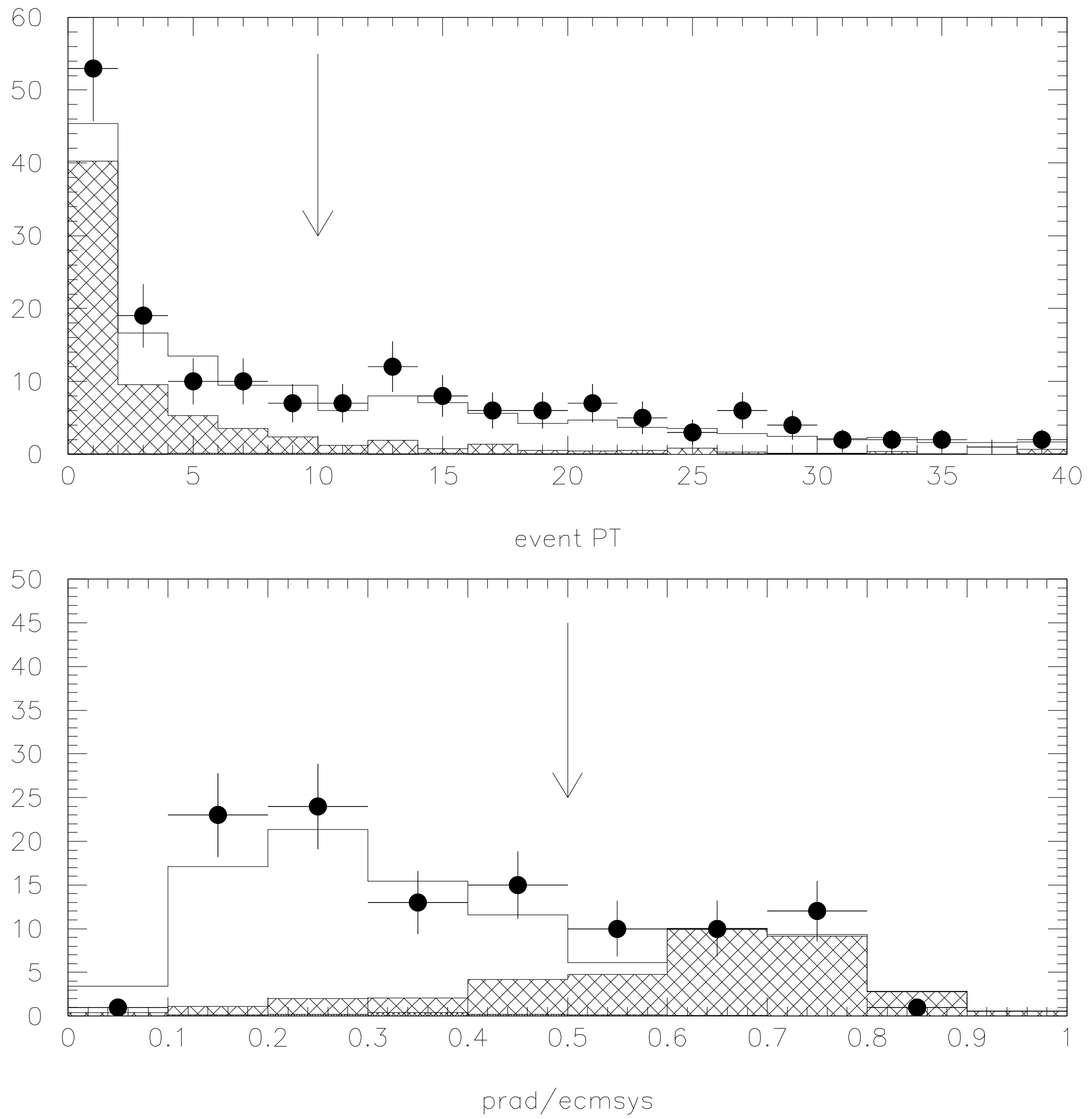
$e^+e^- \to \tau^+\tau^-(\gamma)$ **(Delphi)**



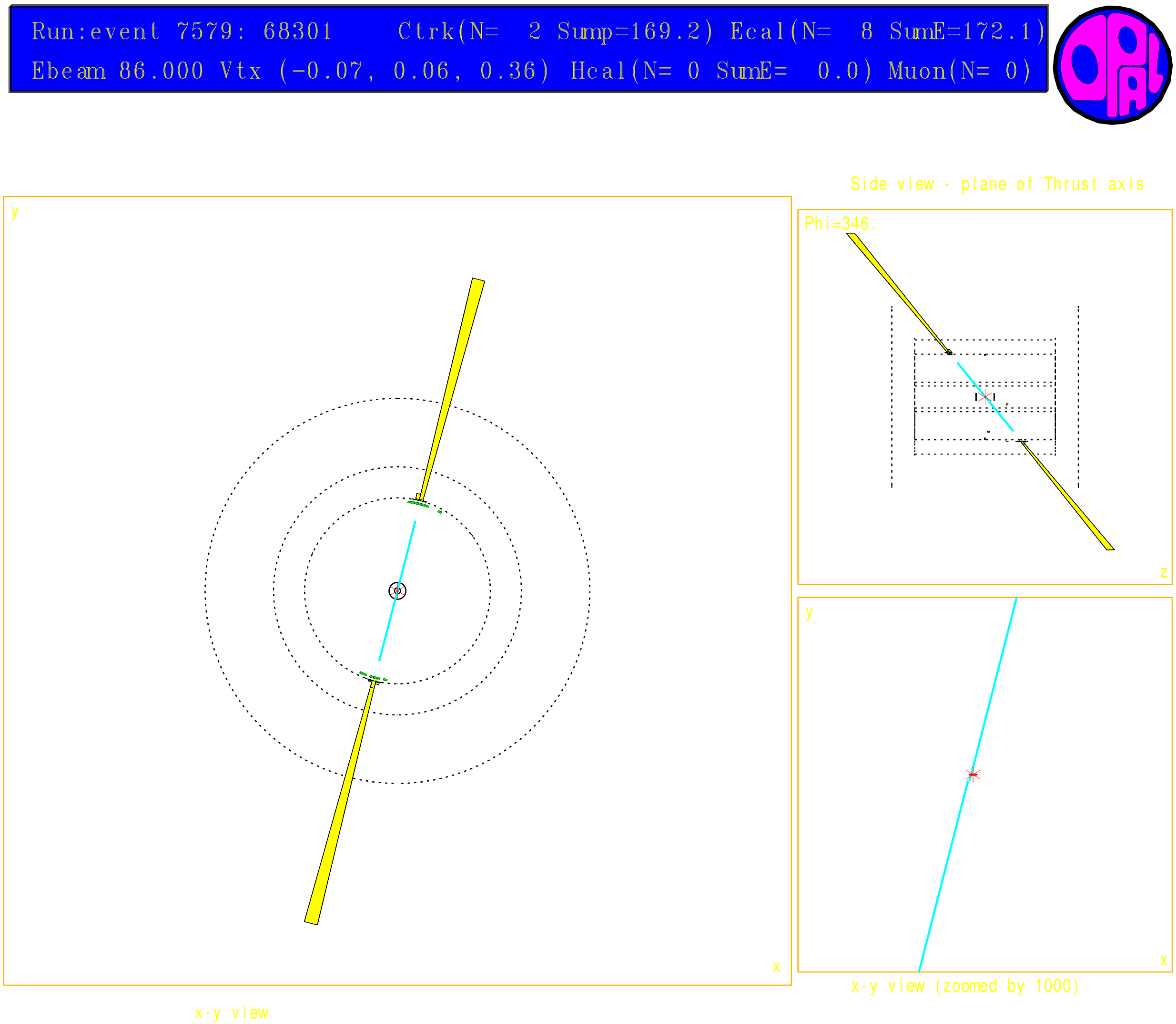
1-(1,2,3) topology within $|\cos\Theta_{thr}| < 0.9$
leading track from vertex with $p > 6GeV$
$0.5^\circ < \xi_{acol} < 1rad$
$p_{trans} > 1GeV$
reject $ee, \mu\mu$ events

Efficiency 45% Background 9%

DELPHI tau-pair selection distributions



$e^+e^- \longrightarrow e^+e^-(\gamma)$ (Opal)



$E^{tot}_{ECAL} > 50\%\sqrt{S}$ within $|\cos\Theta| < 0.7$
El.m. cluster with charged track
$\Theta_{acol} < 10^\circ$ (instead of s' cut)

Efficiency 99.4% Background 1.3%

L3 $\sqrt{s'}$ distributions

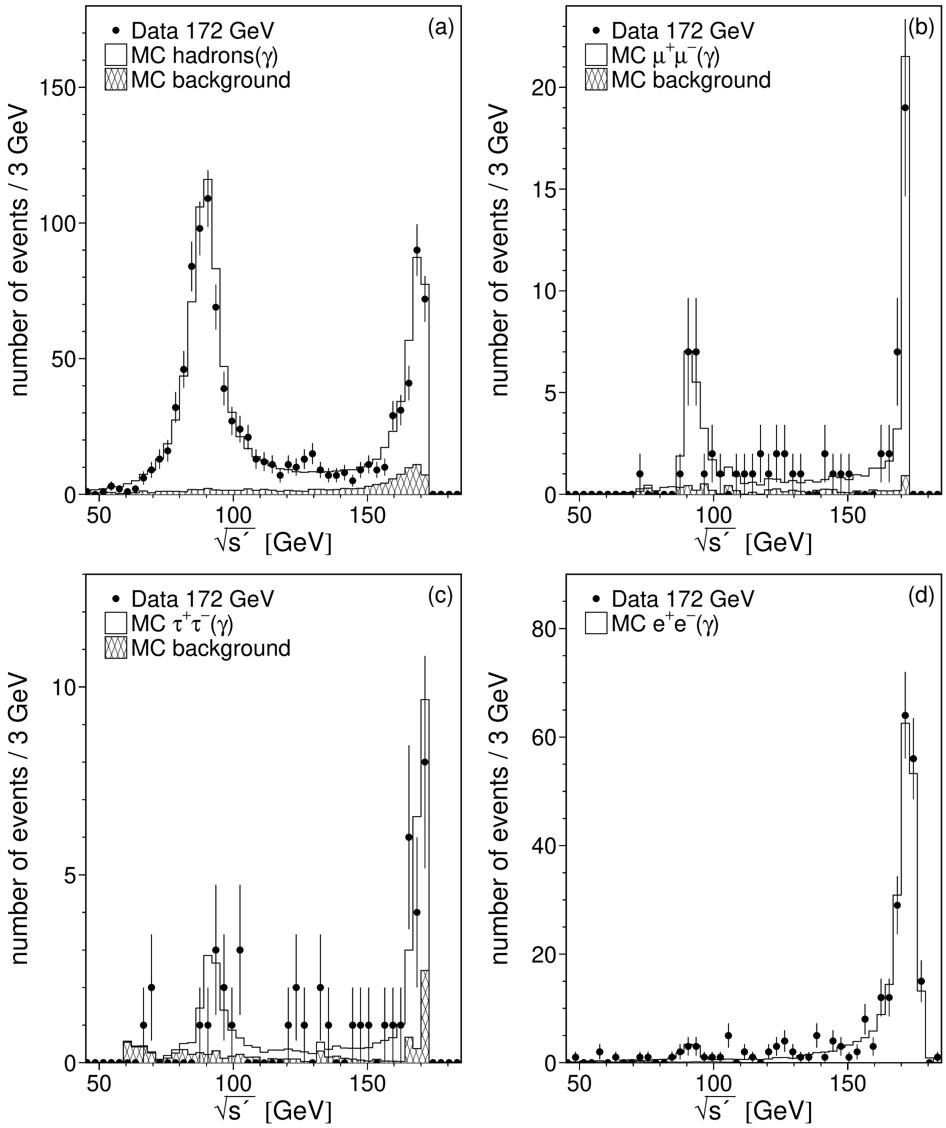


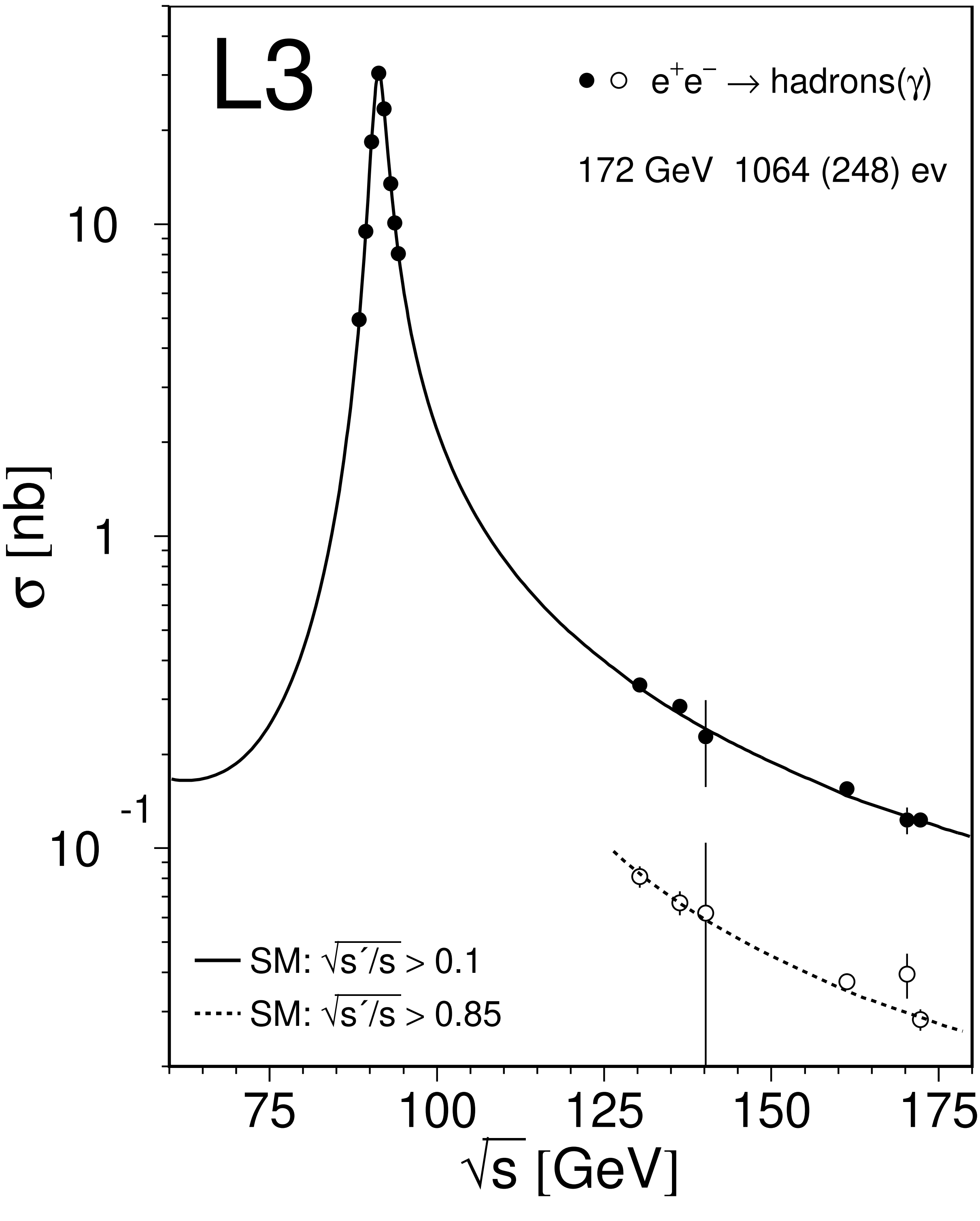
Figure 2: The reconstructed effective centre–of–mass energy, $\sqrt{s'}$, for the selection of (a) $e^+e^- \to$ hadrons(γ) events, (b) $e^+e^- \to \mu^+\mu^-(\gamma)$ events, (c) $e^+e^- \to \tau^+\tau^-(\gamma)$ events and (d) $e^+e^- \to e^+e^-(\gamma)$ events.

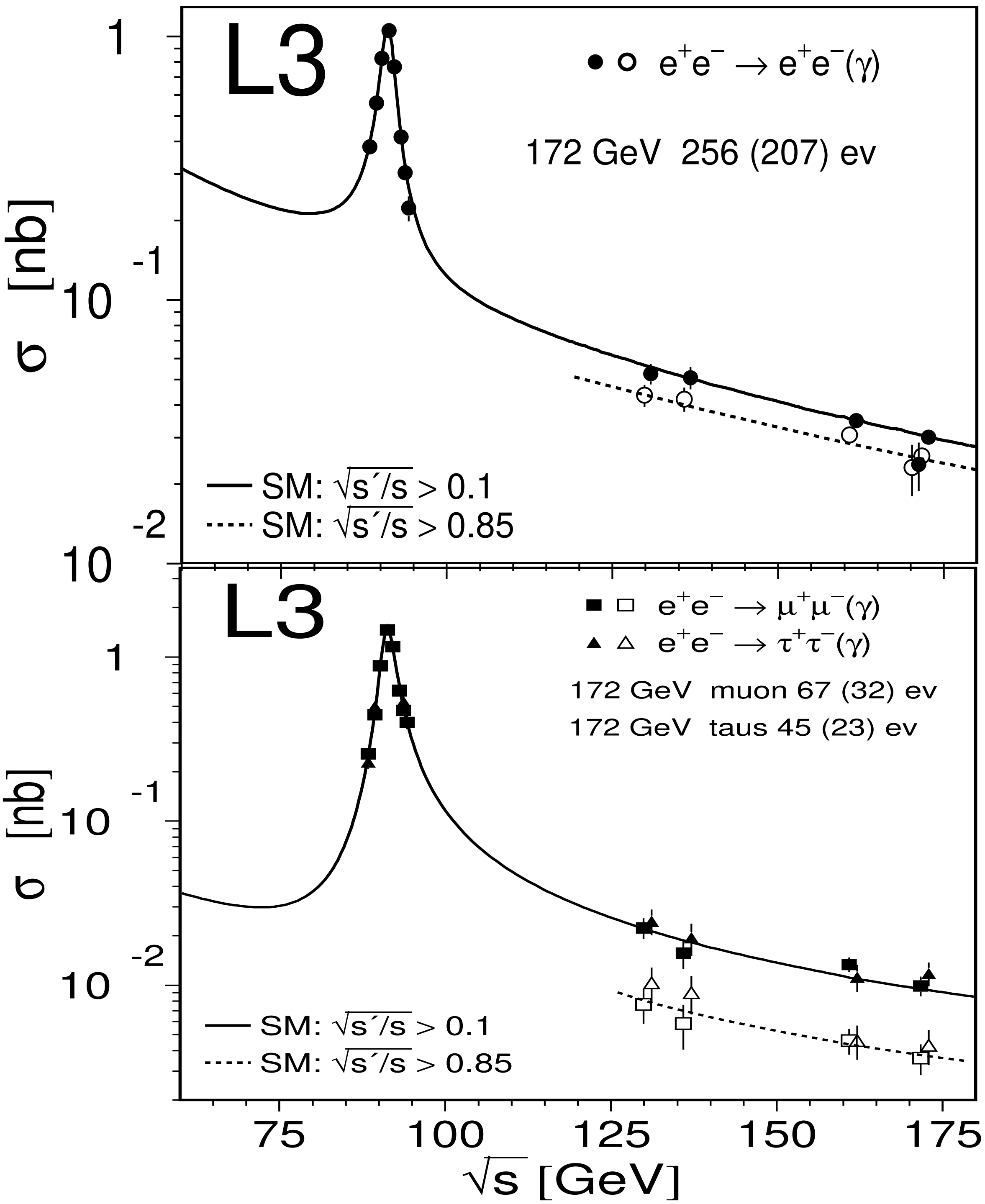
Fermion-Pair Cross-Section

N	Selected events from Data
$\mathcal{L}$	On tape Luminosity (QED small-angle Bhabha-scattering)
ϵ	Detector- $\times$ selection-efficiency (from 'real-detector' MC)
N_{bg}	Estimated background (from real MC, $\mathcal{L}$ and SM x-sec.) (cosmics from DCA-sidebands)

$$\Longrightarrow \qquad \sigma^{tot} = \frac{N - N_{bg}}{\epsilon \cdot \mathcal{L}}$$

At LEP II the statistical error dominates


L3
● ○ $e^+e^- \rightarrow$ hadrons(γ)
172 GeV 1064 (248) ev
10
1
10^{-1}
σ [nb]
SM: $\sqrt{s'/s} > 0.1$
SM: $\sqrt{s'/s} > 0.85$
75
100
125
150
175
$\sqrt{s}$ [GeV]


L3
e⁺e⁻ → e⁺e⁻(γ)
172 GeV 256 (207) ev
σ [nb]
SM: √s′/s > 0.1
SM: √s′/s > 0.85
L3
e⁺e⁻ → μ⁺μ⁻(γ)
e⁺e⁻ → τ⁺τ⁻(γ)
172 GeV muon 67 (32) ev
172 GeV taus 45 (23) ev
σ [nb]
SM: √s′/s > 0.1
SM: √s′/s > 0.85
√s [GeV]

Forward-Backward Asymmetry

$$A_{fb} := \frac{\int_0^1 \frac{d\sigma}{d\cos\Theta} d\cos\Theta - \int_{-1}^0 \frac{d\sigma}{d\cos\Theta} d\cos\Theta}{\int_0^1 \frac{d\sigma}{d\cos\Theta} d\cos\Theta + \int_{-1}^0 \frac{d\sigma}{d\cos\Theta} d\cos\Theta}$$

(measured in Lab. frame)

$$\frac{d\sigma}{d\cos\Theta} \propto (1+\cos^2\Theta) + \frac{3}{8} A_{fb} \cos\Theta$$

Identify the fermion via negative charge
$\Rightarrow$ Charge-confusion

A_{fb} by counting: $$A_{fb} = \frac{N^f - N^b}{N^f + N^b}$$

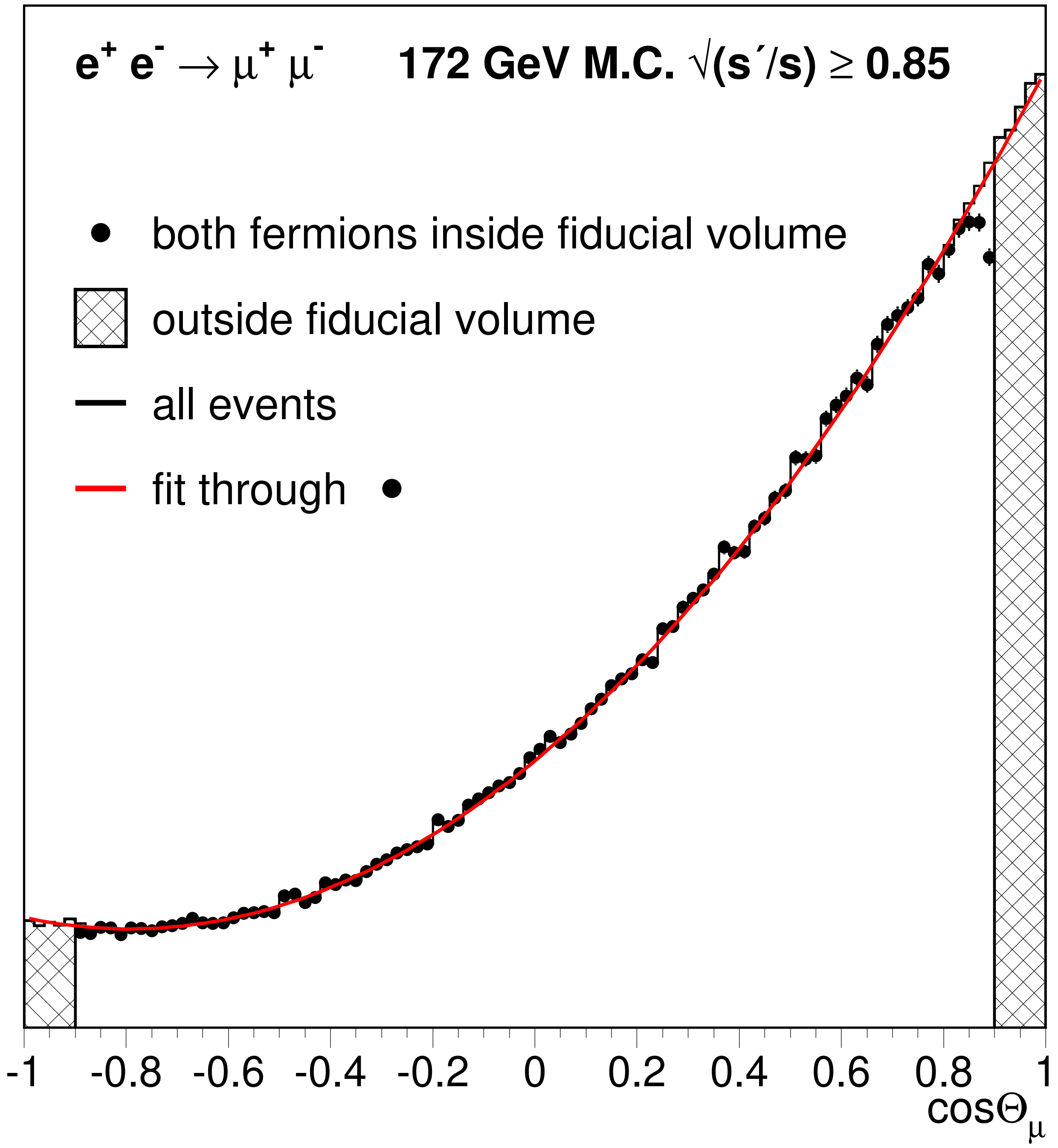
global corrections for

- Charge confusion
- Fiducial volume cut
- Detector acceptance
- Background

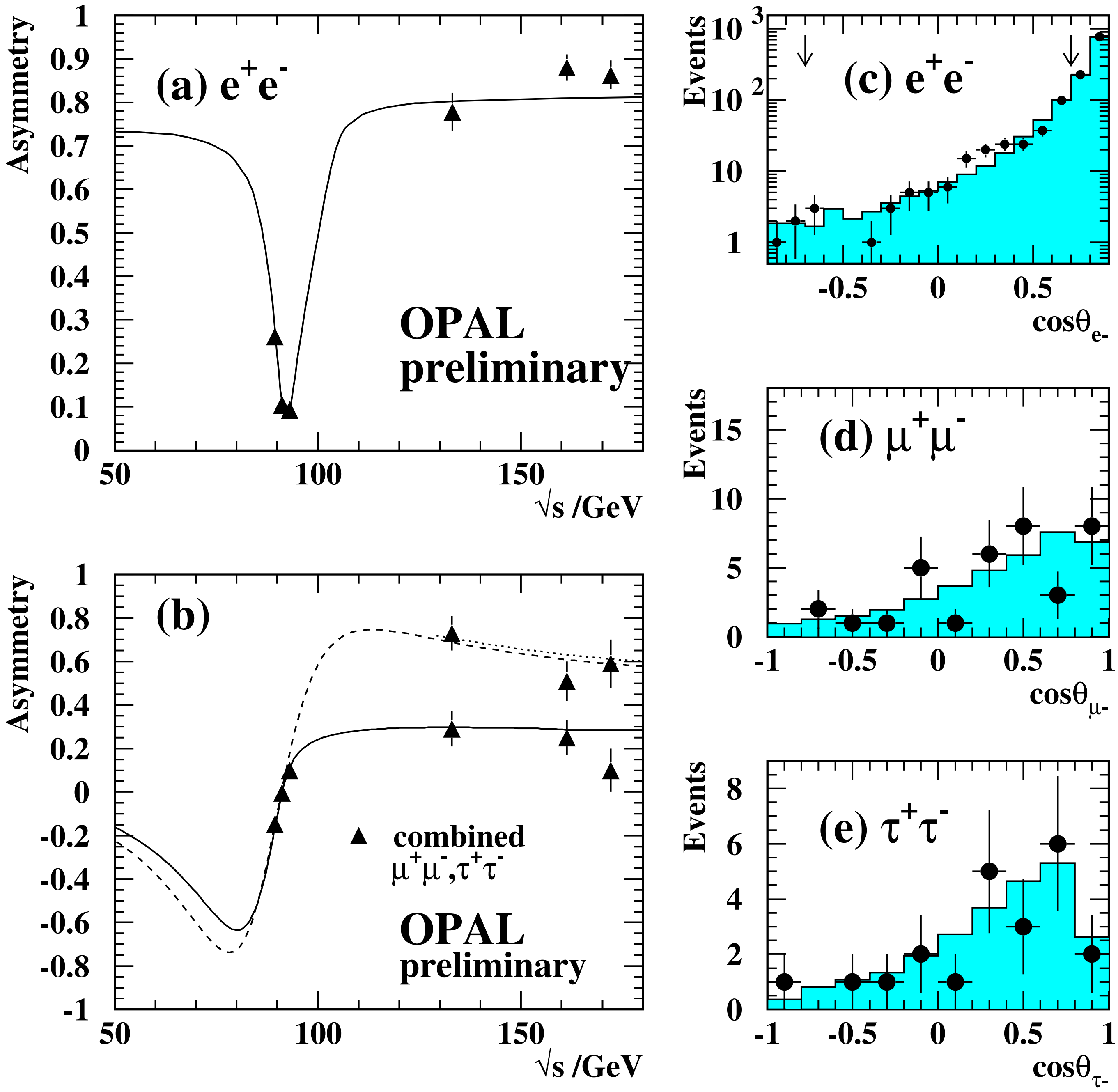
A_{fb} from $\dfrac{d\sigma}{d\cos\Theta}$ fit:

$+$ $\cos\Theta$ dependent corrections cancel
$+$ charge confusion and background corrections on event to event basis
\- Correction-factor for total sample needed

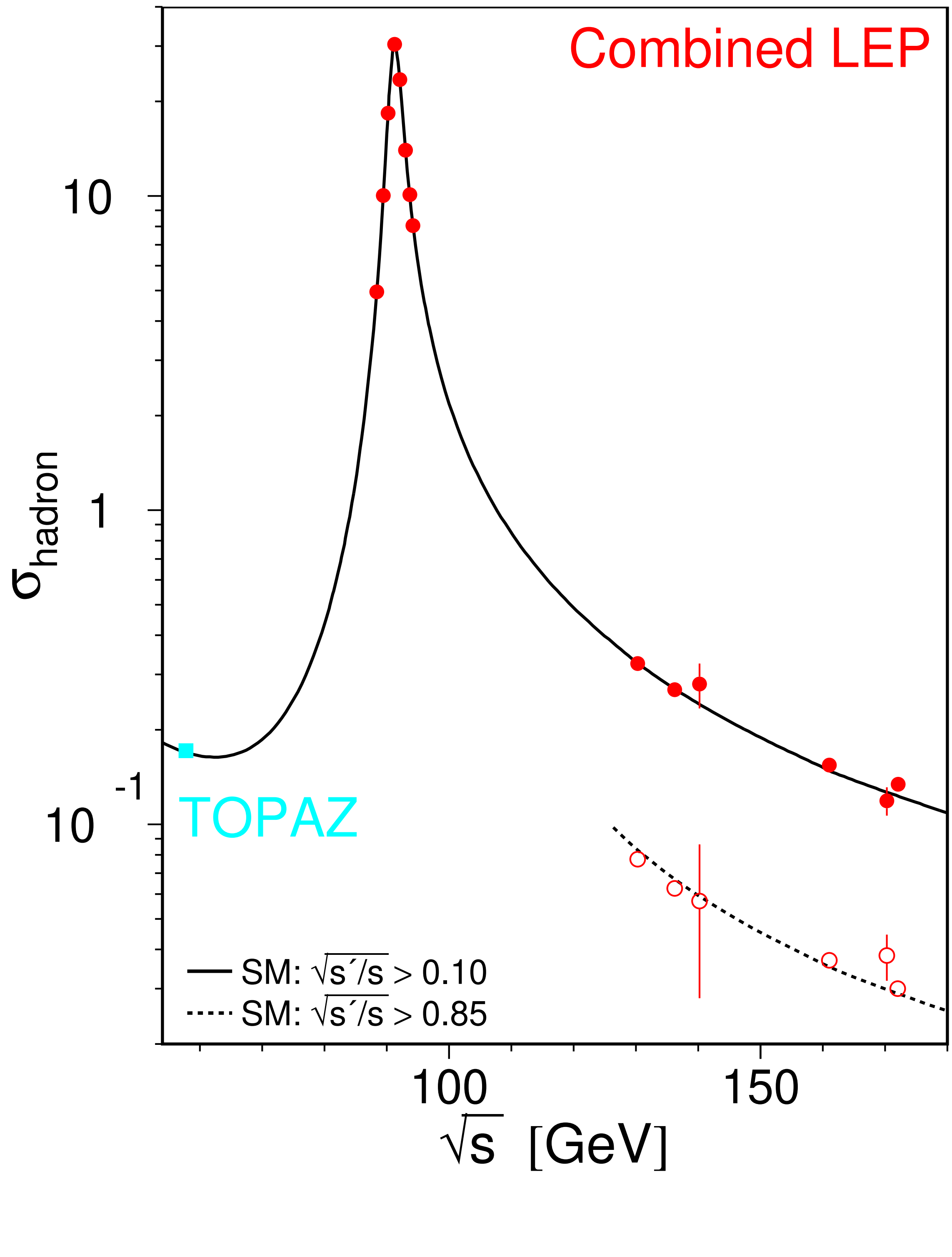
Log-likelihood fit to $\dfrac{d\sigma}{d\cos\Theta}$

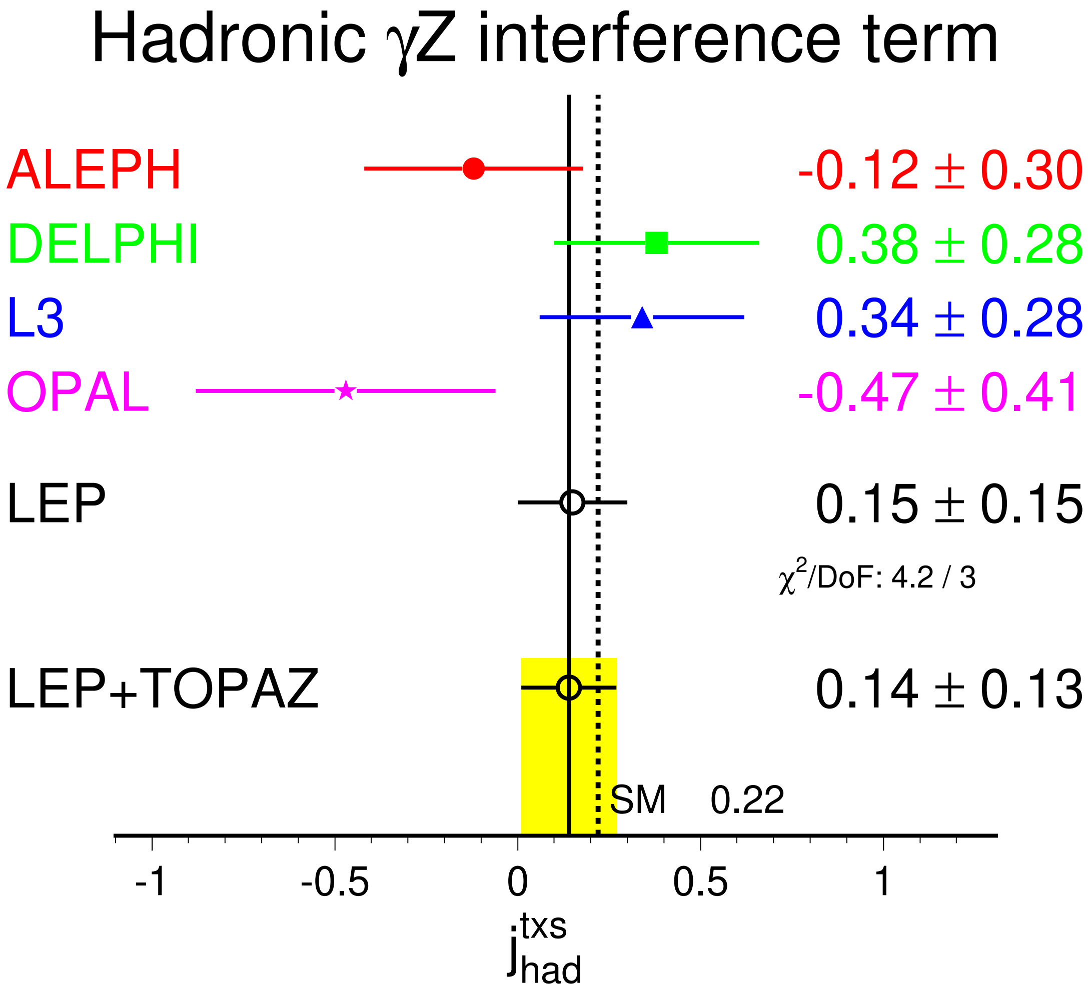


Opal preliminary Lepton-Asymmetries



LEP I + II combined results



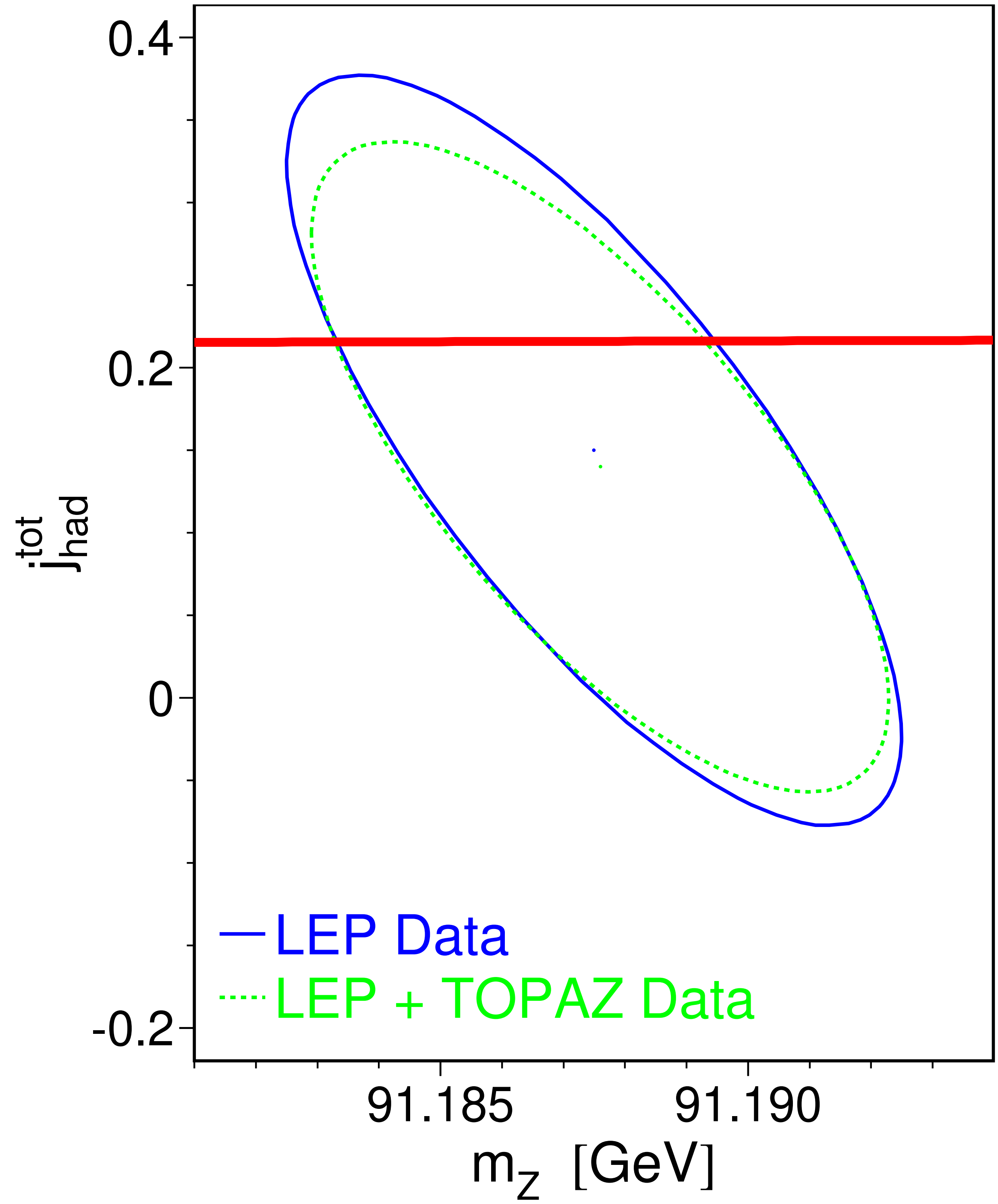


$$SM: \quad J_f^{tot} = \frac{G_F\, m_Z^2 \frac{\alpha(s)}{\alpha}}{\sqrt{2}\pi\alpha} Q_e Q_f\, \bar{g}_{ve}\, \bar{g}_{vf}$$

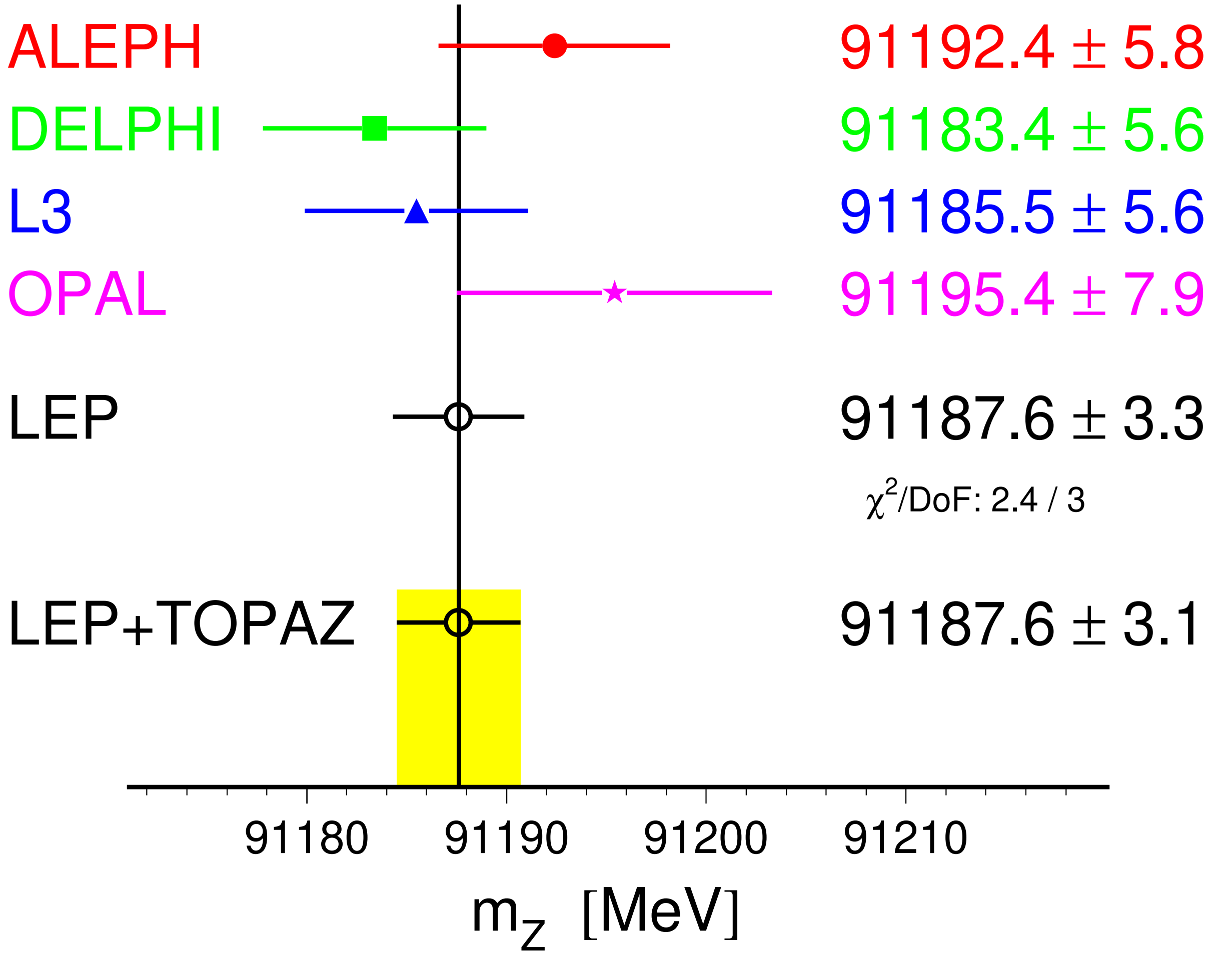
$$\bar{g}_{vf} = \bar{g}_{af}\ (1 - 4Q_f \sin^2\Theta_W)$$

$$J_{had}^{tot} = 3 \sum_{f=duscb} J_f^{tot}$$

$J_{had}^{tot} - m_Z$ correlation



Z-Boson Mass [MeV], S-Matrix



LEP I: $m_Z = 91186.3 \pm 1.9 MeV$ (J_{had}^{tot} fixed)

(Brussels 95)

$m_Z = 91189.3 \pm 6.2 MeV$ (J_{had}^{tot} free)

Conclusions

- In 1996 LEP successfully operated above W-threshhold
  $10pb^{-1}$ at 161 GeV
  $11pb^{-1}$ at 172 GeV
- Fermion-pair measurements in good agreement with SM
- Z-mass measurement improved with J_{had}^{tot}

We look forward to 1997 with $100pb^{-1}$ at 184 GeV

Published 1996 LEP Fermion-Pair Data:

OPAL Collab., K. Ackerstaff *et al., Production of Fermion-pair Events in* e^+e^- *Collisions at 161 GeV Centre-of-mass Energy*, CERN-PPE/96-156, submitted to Phys.Lett. B.

L3 Collab., M. Acciari *et al., Measurement of Hadron and Lepton-Pair Production at* $161GeV < \sqrt{s} < 172GeV$ *at LEP*, CERN-PPE/97-52, submitted to Phys.Lett. B.