Acceptance/Selection Issues for PEW at $\sqrt{s} \approx M_{\mathrm{Z}}$

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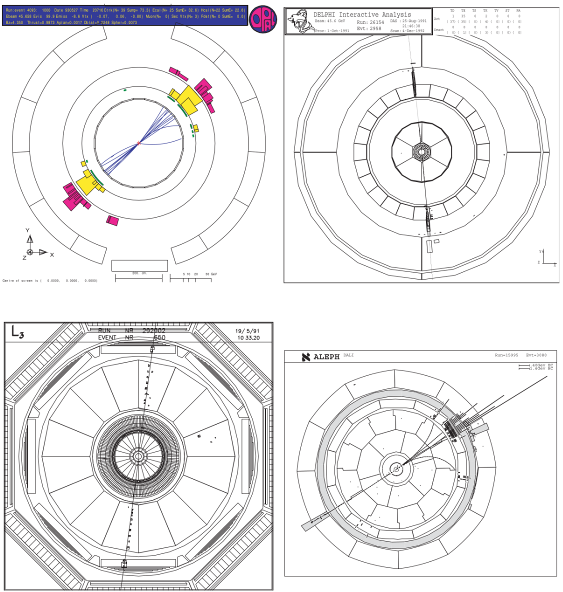
Main goal: measure $\sigma_{\mathrm{f\bar{f}}}(\sqrt{s})$ for $\mathrm{f} = \mathrm{q}, \mathrm{e}, \mu, \tau$ as function of $\sqrt{s}$.

1. Center-of-mass energy knowledge, $\sqrt{s}$
2. Numerator event counts, N_{sel}
3. Selection efficiency within acceptance, ε
4. Acceptance, A
5. Background, N_{bkg}
6. Normalization, $\mathcal{L}$

$$\sigma(\sqrt{s}) = \frac{N_{\mathrm{sel}} - N_{\mathrm{bkg}}}{\varepsilon \, A \, \mathcal{L}}$$

The four channels: multihadrons ($q\bar{q}$), e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$

The ALEPH, DELPHI, L3, OPAL and SLD Collaborations / Physics Reports 427 (2006) 257–454



LEP selections (Physics Reports)

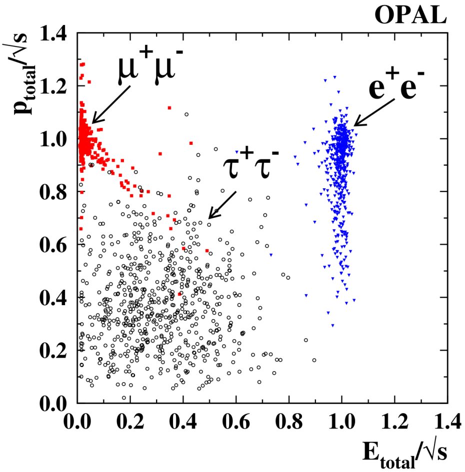
Ideal acceptances, selection efficiencies[a] and background contribution at the peak of the resonance (1994 data)

	ALEPH	DELPHI	L3	OPAL
$q\bar{q}$ *Final state*				
Acceptance	$s'/s > 0.01$	$s'/s > 0.01$	$s'/s > 0.01$	$s'/s > 0.01$
Efficiency (%)	99.1	94.8	99.3	99.5
Background (%)	0.7	0.5	0.3	0.3
e^+e^- *Final state*				
Acceptance	$-0.9 < \cos\theta < 0.7$	$\lvert\cos\theta\rvert < 0.72$	$\lvert\cos\theta\rvert < 0.72$	$\lvert\cos\theta\rvert < 0.7$
	$s' > 4m_\tau^2$	$\eta < 10°$	$\eta < 25°$	$\eta < 10°$
Efficiency (%)	97.4	97.0	98.0	99.0
Background (%)	1.0	1.1	1.1	0.3
$\mu^+\mu^-$ *Final state*				
Acceptance	$\lvert\cos\theta\rvert < 0.9$	$\lvert\cos\theta\rvert < 0.94$	$\lvert\cos\theta\rvert < 0.8$	$\lvert\cos\theta\rvert < 0.95$
	$s' > 4m_\tau^2$	$\eta < 20°$	$\eta < 90°$	$m_{f\bar{f}}^2/s > 0.01$
Efficiency (%)	98.2	95.0	92.8	97.9
Background (%)	0.2	1.2	1.5	1.0
$\tau^+\tau^-$ *Final state*				
Acceptance	$\lvert\cos\theta\rvert < 0.9$	$0.035 < \lvert\cos\theta\rvert < 0.94$	$\lvert\cos\theta\rvert < 0.92$	$\lvert\cos\theta\rvert < 0.9$
	$s' > 4m_\tau^2$	$s' > 4m_\tau^2$	$\eta < 10°$	$m_{f\bar{f}}^2/s > 0.01$
Efficiency (%)	92.1	72.0	70.9	86.2
Background (%)	1.7	3.1	2.3	2.7

[a] The lepton selection efficiencies given by the experiments were in some cases quoted with respect to full acceptance in $\cos\theta$; for the purpose of comparison, they were corrected to the fiducial cuts in $\cos\theta$ actually used in the analyses, assuming a shape of the differential cross-section according to $(1+\cos^2\theta)$.

η is the acollinearity angle.

Leptonic Channels



With excellent momentum resolution and calorimetry should normally be easily separable.

LEP systematics (Physics Reports)

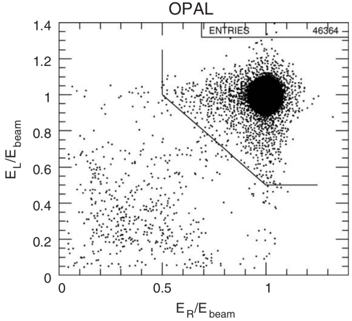
Experimental systematic errors for the analyses at the Z peak

	ALEPH			DELPHI		
	1993	1994	1995	1993	1994	1995
$\mathscr{L}^{exp}$	0.067%	0.073%	0.080%	0.24%	0.09%	0.09%
σ_{had}	0.069%	0.072%	0.073%	0.10%	0.11%	0.10%
σ_{e}	0.15%	0.13%	0.15%	0.46%	0.52%	0.52%
σ_{μ}	0.11%	0.09%	0.11%	0.28%	0.26%	0.28%
σ_{τ}	0.26%	0.18%	0.25%	0.60%	0.60%	0.60%
A_{FB}^{e}	0.0006	0.0006	0.0006	0.0026	0.0021	0.0020
A_{FB}^{μ}	0.0005	0.0005	0.0005	0.0009	0.0005	0.0010
A_{FB}^{τ}	0.0009	0.0007	0.0009	0.0020	0.0020	0.0020
	L3			OPAL		
	1993	1994	1995	1993	1994	1995
$\mathscr{L}^{exp}$	0.086%	0.064%	0.068%	0.033%	0.033%	0.034%
σ_{had}	0.042%	0.041%	0.042%	0.073%	0.073%	0.085%
σ_{e}	0.24%	0.17%	0.28%	0.17%	0.14%	0.16%
σ_{μ}	0.32%	0.31%	0.40%	0.16%	0.10%	0.12%
σ_{τ}	0.68%	0.65%	0.76%	0.49%	0.42%	0.48%
A_{FB}^{e}	0.0025	0.0025	0.0025	0.001	0.001	0.001
A_{FB}^{μ}	0.0008	0.0008	0.0015	0.0007	0.0004	0.0009
A_{FB}^{τ}	0.0032	0.0032	0.0032	0.0012	0.0012	0.0012

The errors are relative for the cross-sections and absolute for the forward–backward asymmetries. None of the common errors discussed in Section 2.4 are included here.

Normalization

Need a calculable QED process with known cross-section for luminosity measurement. LEP approach: count small angle Bhabhas.



$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{2s}\left[\frac{1+\cos^4\frac{\theta}{2}}{\sin^4\frac{\theta}{2}} - 2\frac{\cos^4\frac{\theta}{2}}{\sin^2\frac{\theta}{2}} + \frac{1+\cos^2\theta}{2}\right]$$

Cross-section of 79 nb for OPAL Si-W luminometer defined acceptance. (larger than $\sigma_Z(vis) \approx 34$ nb).

Need exquisite control of inner-most polar angle measurement. Experimental uncertainty of 0.034%.

Some observations on LEP approach

- All four channels (and detectors) are different!
- Fiducial acceptance cuts are used for the leptonic channels.
- Hadronic channel. Accounts for 88% of visible Z decays. Efficiency quoted for 4π acceptance.
- $\mathrm{e}^+\mathrm{e}^-$ channel. Limit acceptance to limit t-channel and s-t interference contributions.
- $\tau\tau$ channel. Lowest efficiency and highest background (mostly $\mu^+\mu^-$ contamination).

Remarks on e^+e^- channel

- It would seem appropriate to do a more differential measurement that extends the acceptance to the t-channel dominated region. This would allow a more explicit check of the t/s+t contribution.
- Puts more and more emphasis on polar angle measurement precision.

Remarks on $\mu^+\mu^-$ channel

- Design detector with **odd** number of sectors/wire planes! (ie. azimuthally back-to-back tracks should not have correlated reconstruction inefficiencies like OPAL).
- Residual background with a modern detector should be very small.

Remarks on $\tau^+\tau^-$ channel

- Modern detectors should be able to more effectively use vertexing in event selection.

Remarks on multihadronic channel

- I suspect this is the most challenging channel.
- Efficiency depends on reconstruction of hadronic jets below the tracker acceptance in the forward calorimetry region. Dominant uncertainty of 0.066% for OPAL.
- Puts an emphasis on hermeticity and forward region design.
- Important backgrounds from dileptons ($\tau\tau$) and mostly multi-peripheral (and non-resonant) $\mathrm{e^+e^- \to e^+e^- q\bar{q}}$ (51 ± 7 pb).
- Need full detector level simulations to assess?

Can the non-resonant background be predicted? Or does it need to be measured? (I suspect the latter).

Normalization'

- Need a calculable QED process with known cross-section for luminosity measurement.
- Small angle Bhabhas are great for statistics (79 nb), and an obvious choice for *relative* luminosity measurement for FCC-ee.
- With Tera-Z type statistics, one can think of using an alternative for *absolute* luminosity.

One alternative is $\mathrm{e}^+\mathrm{e}^- \rightarrow \gamma\gamma$,

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{s} \frac{1 + \cos^2\theta}{\sin^2\theta}$$

- Cross-section of 41 pb for $20^\circ < \theta < 160^\circ$.
- See C Calame et al. (arXiv:1906.08056).
- Major issue is $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{e}^+\mathrm{e}^-$ background rejection ($\sigma = 2.6$ nb).
- Less sensitive than small angle Bhabhas to forward angle acceptance understanding (very similar to numerator events).
- Potentially theoretically smaller uncertainties.

Omissions

In this brief talk, I focused on the core Z lineshape observables and neglected,

- asymmetries
- tau polarization
- neutrino channel $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$
- identified hadronic decays ($b\bar{b}$, $c\bar{c}$ etc)

which are all obviously important related topics.

Summary

- Initial superficial look at some of the relevant issues based on LEP PR.
- I had planned a more in-depth review and comparison, but this is what I have for today.
- Will do this certainly for the $\mathrm{e}^+\mathrm{e}^- \to \mu^+\mu^-$ channel which has synergies with on-going center-of-mass energy measurement studies.
- Obviously we would like to go far beyond what was already done at LEP, but that is the foundation to build from.

Backup Slides