

Z-pole studies for ILD?

Brief tour of the most critical physics aspects (EW focus)

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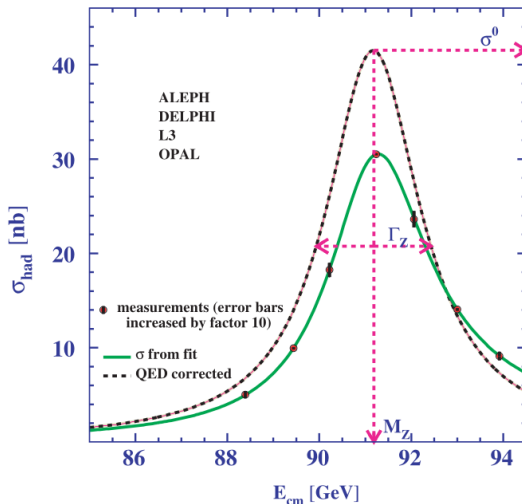
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- Overview with emphasis on electroweak physics. See LEP1/SLC Phys. Rep. 427 (2006) 257 for details.
- No full simulation studies to date for ILD@ILC at the Z nor for ILD@FCC-ee. Do both and compare performance!
- We really need to demonstrate amazingly good performance for multihadron acceptance including at forward angles to take advantage of FCC-ee statistics.

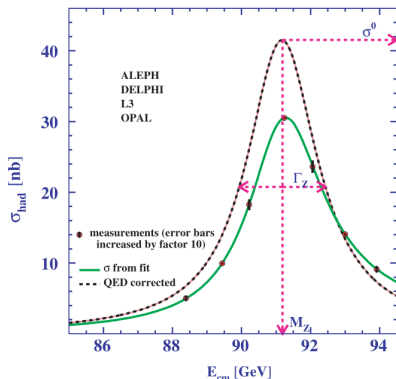
Z lineshape

At some level, the be all and end all case for extensive running at the Z.



Measure m_Z, Γ_Z, σ^0 for hadrons, dielectrons, dimuons, ditau, (dineutrinos).

Z lineshape



$$\sigma = \frac{N_{\text{sel}} - \mu_b}{\varepsilon \mathcal{L}} \quad \text{Need to control}$$

- Centre-of-mass energy
- Absolute luminosity
- Efficiency (also related to acceptance choice)
- Background
- Relative luminosity, efficiency, background, energy per scan point very important for Γ_Z .
- For each of the 4 channels including cross-channel contaminations.

$$\Gamma_Z = \Gamma_{\text{had}} + \Gamma_{\text{ee}} + \Gamma_{\mu\mu} + \Gamma_{\tau\tau} + \Gamma_{\text{inv}}$$

$$\sigma_{\text{ff}}^0 = \frac{12\pi}{m_Z^2} \frac{\Gamma_{\text{ee}} \Gamma_{\text{ff}}}{\Gamma_Z^2}$$

Bhabhas are especially important and more complicated (s, t and s-t interference)

Table 2.1

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

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

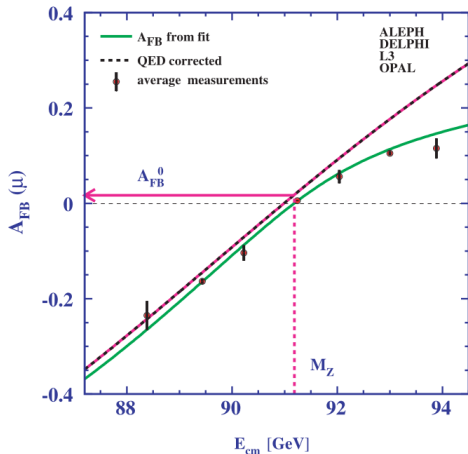
^aThe lepton selection efficiencies given by the experiments were in some cases quoted with respect to full acceptance in $\cos \theta$; for the purpose of comparison, they were corrected to the fiducial cuts in $\cos \theta$ actually used in the analyses, assuming a shape of the differential cross-section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

Asymmetries

Measurements of experimental asymmetries such as A_{FB} , A_{LR} , A_{LRFB} (last two require longitudinally polarized beam). Sensitive to the fermion-specific asymmetry parameters (related to L/R (V/A) couplings and the weak mixing angle).

$$A_f = \frac{g_L^2 - g_R^2}{g_L^2 + g_R^2}$$

Key experimental issue: Charge identification - so particularly curvature resolution of beam energy leptons near the edge of the tracking acceptance.



Absolute/Relative Luminosity

3 approaches under consideration

- ① Small angle Bhabha scattering (SABS). Same as LEP. But $\sigma < \sigma_Z$ for FCC-ee.
- ② $e^+e^- \rightarrow \gamma\gamma$. Use whole detector. Statistics limited (σ at most 100 pb at Z)
- ③ $e^+e^- \rightarrow e^+e^-\ell^+\ell^-$ ($\ell = e, \mu$). VERY large potentially observable cross-section at the Z. (1 μb .)

I discussed possibility 3 at the FCC-ee Luminometry workshop. Events basically consist of only one or two VERY soft prompt leptons. The underlying physics is dominated by the QED multiperipheral process ($\gamma\gamma \rightarrow \ell^+\ell^-$) - basically the inverse of process 2.

Using process 3?

Would likely benefit greatly from being able to take data with a low B-field. Arguably this is also beneficial for Z to hadrons which is the main channel for normalizing Z branching ratios (like R_e , R_μ , R_τ). Maybe an excellent systematic check would be to show the stability of the Z pole observables with detector B-field.

Physics backgrounds for Z counting

- Ignoring/neglecting machine backgrounds, the most important physics background is two-photon production of hadrons, dielectrons, dimuons, ditaus.
- Leptons under good theoretical control, but hadrons not so much.
- Additionally in general low multiplicity hadronic Z decays were never measured at LEP before because of underlying $\tau^+\tau^-$ and two-photon production of hadrons.
- Should also include radiative return (to very low invariant mass hadronic systems), ie. $e^+e^- \rightarrow q\bar{q}\gamma$. Not clear that the B-factory generators work at the Z pole in this respect.
- Would be good to have as many experimental handles as possible to control. One way would be to use beam polarization

Z branching fractions / branching ratios

- Relative measurements of event rate ratios can take advantage of the very high luminosity without needing absolute luminosity precision.
- Particularly important is $R_\ell = \Gamma_{\text{had}}/\Gamma_\ell$. Sensitive to α_S . Here I think the main experimental issue is controlling the hadronic efficiency/acceptance (others disagree).

Tau polarization in $Z \rightarrow \tau^+ \tau^-$

Taus have a special role. Measure tau polarization vs $\cos \theta_\tau$ and extract A_e and A_{tau} using all possible decay modes.

$$Z \rightarrow \nu \bar{\nu}$$

- Can be tested using Γ_{inv} from essentially $\Gamma_Z - \Gamma_{\text{vis}}$
- Can also be measured using $e^+e^- \rightarrow \nu \bar{\nu} \gamma$ where the ISR photon makes the neutrinos visible. Includes some t-channel W-related contributions for ν_e .
- Interesting to measure ratios of lepton-pair to neutrino-pairs in events with photons especially at higher $\sqrt{s}$. (although leptons have FSR contributions too..)

Detector Thoughts

AVOID BACK-TO-BACK DETECTOR WEAKNESSES AT DESIGN STAGE!

Example: OPAL jet chamber. 24 sectors in azimuth. For $e^+e^- \rightarrow \mu^+\mu^-$, one of the primary systematics was associated with tracking inefficiencies for muons near the anode plane of each jet-chamber sector. The cathode planes were not so pretty either.

Easy solution - odd number of sectors.

ILD example?

Back-to-back in θ gaps in ECAL modules. Azimuth is OK, although performance is definitely not ϕ symmetric.

The claim that different readout deadtimes between say dileptons and multihadrons causes a counting bias seems just plain wrong to me. As long as all detectors are synchronized and only say "ready for trigger" in a coordinated way there seems no issue?

Please review critically statements made and repeated ad infinitum with little justification.

- Understanding better the capabilities of a polarized Z lineshape scan is important for comparing different accelerators. Never really worked out properly.
- Needs work on the standard measurement/pseudo-observable (PO) ansatz to fully value polarized observables. Issue is that the LEP1 emphasis has been to deconvolve the QED radiation to get POs that are Z specific (with no photon contribution).
- Better approach may be to convolve the theory with QED predictions to get experimentally observable predictions.

Summary

- I have highlighted some of the primary electroweak measurements at the Z.
- Many other interesting things to do - for example tau mass, tau-neutrino mass, tau lifetime, lepton universality tests, running of α .
- Key systematic issues are luminosity, center-of-mass energy, efficiencies, background control.
- Detector can also help with center-of-mass energy with precision momentum scale.
- Detector does not need to be super precise - systematic control more important.