NEUTRINO COUNTING FROM $Z^0 \to \nu\bar{\nu}$ DECAYS AT e+e- STORAGE RINGS.

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Summary

We report on neutrino counting from $Z^0 \to \nu\bar{\nu}$ decay to estimate the number of fermion generations. A simple detector is outlined.

Our current belief is that the Z^0 exists at a mass around 93 GeV. Its width is given by summing over the partial widths for decays into the fundamental fermion pairs :

$$\Gamma_Z = \frac{G_F m_Z^3}{24\sqrt{2}\pi}[[1+(1-4\sin^2\theta)]N_\ell + 2N_\nu + 3[1+(1-4/3\sin^2\theta)^2]N_{-1/3} + 3[1+(1-8/3\sin^2\theta)^2]N_{2/3}]$$

N_ℓ, N_ν, $N_{-1/3}$, $N_{2/3}$ are the number of leptons, neutrinos, -1/3 and 2/3 quarks with masses $\lesssim 1/2\ m_Z$. For a weak mixing angle $\sin^2\theta=0.23$ one obtains

$$\Gamma_Z = (89\ \text{MeV})\times[1.01N_\ell + 2N_\nu + 4.5N_{-1/3} + 3.5N_{2/3}] \quad (1)$$

or simply writing as a sum of the partial widths

$$\Gamma_Z = \Gamma_\ell + \Gamma_{hadron} + \Gamma_\nu \quad (2)$$

with $\Gamma_\nu = 180\ \text{MeV} \times N_\nu$.

A determination of the number of neutrino species will give an estimate of the number of fermion generations, provided the neutrino masses are less than 1/2 the Z^0 mass. Present experimental limits for the number of neutrinos are $N_\nu < 6000$ from $K\pi\nu\bar{\nu}$ decays. From cosmological arguments one expects $N_\nu \leq 5$. Measurements of the $Z^0 \to \nu\bar{\nu}$ decays will allow to determine N_ν . Experimentally one cannot detect neutrinos , therefore indirect measurements are necessary. From eq. (2) follows:

$$N_\nu = \frac{1}{180\ \text{MeV}}[\Gamma_Z - \Gamma_{hadron} - \Gamma_\ell] \quad (3)$$

i.e. a measurement of Γ_Z, Γ_{had} and Γ_ℓ would determine N_ν . A precision well below 20 MeV is required for each quantity to obtain $\Delta N_\nu < 0.3$. This measurement is possible but requires a complete scan between about 80 to 110 GeV. Radiative effects are expected to distort the shape of the Z^0. Also the machine resolution has to be unfolded (500 MeV at SLC, 130 MeV at CESR II and 80 MeV at LEP). Great (although physically very interesting) complications are expected if the toponium or any other new flavour threshold coincides in mass with the Z^0. In summary it can be concluded that this method will allow rather quickly to determine N_ν with an error of a few families but a measurement of N_ν with $\Delta N_\nu < 0.3$ will need substantial time and a very good understanding of the detector, the storage ring resolution, and radiative effects.

Another alternative to count the number of neutrino species is to study the reaction :

$$e^+e^- \to Z^{0*} \to \gamma Z^0 \to \gamma\nu\bar{\nu} \quad (4)$$

This was suggested by [1,2] and analyzed for feasibility and background estimates by [3]. The experiment would be performed about 10 to 15 GeV above the Z^0 peak. One would search for a single high energy γ with $E \sim \text{sqrt}(s)-m_Z$ in the absence of any other interacting particle. Fig.1 shows the expected spectrum for m_Z=90 GeV and sqrt(s)= 105 GeV (from ref.3). The spectrum is a ' mirror image ' of the Z^0 sitting on a smooth background.

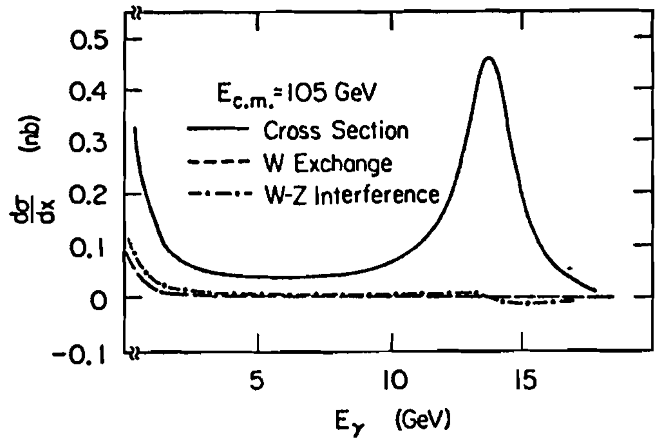

Fig.1 Differential cross section $d\sigma/dx$ versus the photon energy E_γ . The three curves are for the total cross section, the contribution from W exchange, and the WZ interference term (from ref.3). Contributions from background processes are not included. In practice this spectrum would sit on a steeply falling background spectrum.

The cross section is then a direct measure of N_ν . The choice of sqrt(s) of 10-15 GeV above the Z^0 is dictated by i) being well above the Z^0 in order not to be swamped by photons from single radiative Bhabha scattering and ii) being not too far above the Z^0 so that the cross section for $e^+e^- \to Z^{0*} \to \gamma Z^0$ is still significant.

In principle most of the proposed detectors for LEP, CESR II or the SLC are able to do this experiment if they are equipped with a reasonably good gamma calorimeter of large solid angle coverage and a small angle luminosity monitor and provided one is willing to spend a substantial integrated luminosity on neutrino counting alone. Difficulties arise from i) the need for precision measurement of the luminosity and ii) the modest detector discrimination power against background.

For a $N_\nu < 0.3$ the luminosity has to be measured with an absolute precision of $\Delta L < 0.5 \times \Delta N_\nu / N_\nu$, i.e. better than 5% for N_ν=3 (1.5% for N_ν=10) This is not trivial with today's standard luminosity monitors because of alignment problems at very low measurment angles and the $1/\theta^4$ dependence of the Bhabha cross section at small angles. Interference effects of the Z^0 will influence the Bhabha cross section on the percent level.

There exist four dominant background reactions:
i) ee $\to$ eeγ with both electrons undetected
ii) ee $\to$ $\gamma\gamma\gamma$ with both high energy γ's undetected
iii) beam gas $\to \gamma X$ with X undetected
beam wall $\to \gamma X$ with X undetected
iv) 2 photon processes with both electrons undetected and only one final state γ (or 2 overlapping γ's) observed.

Nearly all proposed detectors have large gaps or low detection efficiencies in the forward/backward direction, making the rejection of background i)-iv) difficult. Particularly the large facilities with unshielded beampipes of up to 4 m length and γ calorimeters with very modest ability to measure the γ direction are vulnerable to beam gas and beam wall interactions.

Therefore a simple dedicated and small volume detector might be best suited for neutrino counting in the early phase of Z^0 studies. The basic setup consists of a γ calorimeter covering the region $\theta_{\gamma min} < \theta < \pi - \theta_{\gamma min}$ in polar angle and a veto calorimeter covering the remaining polar angle down to θ_{min} (as given by the beam pipe diameter). For the most critical backgrounds, i)and ii), the inability to detect either electrons or the high energy γ's below θ_{min} limits the range for the detection of a γ (from $\gamma\nu\bar{\nu}$) to angles far away from the beam pipe .Table 1 shows correlations between $\theta_{\gamma min}$, θ_{min} and expected cross sections for N_ν =3 and for the following parameters $\sqrt{s}$ =105 GeV, M_Z=90 GeV, E_γ =14$\pm$2.5 GeV and less than 15% background contribution from i),ii). Additional neutrino species would increase the cross section by about 1/3.

Table 1: Correlation between θ_{min} and $\theta_{\gamma min}$ and the cross section for N =3

θ_{min}	$\theta_{\gamma\ min}$	σ(pb)
1.2°	10°	35
2.5°	20°	25
3.5°	30°	19
5.°	45°	13

For a normalization error in luminosity measurements of 5% it would be necessary to collect data for an integrated luminosity of $\gtrsim 4.10^4$ nb^{-1} i.e.approximately 2 months with an average luminosity of 1.10^{31} $cm^{-2}sec^{-1}$. This is a lower limit as the Z^0 induced peak might sit on substantial background from iii) and the error from the subtraction has to be included. It should be mentioned that one might use the shape of the angular distribution of the γ to disentangle the background if the vertex resolution from the γ direction measurement is within a few cm.

Finally we would like to summarize the basic elements of a practical detector

i)a γ calorimeter of modest energy resolution but high 2 γ separation and good γ direction determination. This calorimeter would extend from 30° < θ < 150° and would have full azimuthal coverage.

ii)a modest but highly efficient charged particle detector in front of the γ calorimeter

iii)a very simple, but highly efficient veto calorimeter (a few layers of lead-scintillation counters) covering the area between 5° < θ < 30° and full azimuthal coverage.

iv) a high quality luminosity monitor covering 2.5° < θ <5.5° and with full azimuthal coverage, acting also as an event trigger veto.

The approximate radius of the γ calorimeter is given by the 2γ separation for π^0's up to 14 GeV. The calorimeter would allow to cross check the small angle luminosity monitor with large angle Bhabhas by running for short time well below the Z^0 mass. It should be mentioned that with modest trigger modifications one would record at the same time the QED reaction ee $\rightarrow\gamma\gamma$. Although the rates are rather small, this reaction would provide an independent and best measurement of the luminosity.

The γ calorimeter could consist of lead cylinders interleaved with proportional tubes with cathode strip-read out oriented orthogonally and at 45° with respect to the sense wire. The tubes could operate in the limited streamer mode making readout simple. Reading out all layers separately would provide information of shower directions.

The energy resolution of the em calorimeter is not critical for $\sigma/E \lesssim 15\%/\sqrt{E}$, E in GeV. The trigger is straight forward.

Normalization using the reaction ee $\rightarrow \gamma Z^0 \rightarrow \gamma\mu\mu$ (or γee) would require additional absorber material and tracking chambers and the ability to measure muon momenta.

<u>References</u>

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