NEUTRINO COUNTING FROM SINGLE PHOTON EVENTS

JEAN FAY
Institut de Physique Nucléaire
IN2P3/CNRS and Université Claude Bernard
Lyon, France

ABSTRACT

The number of light neutrino species can be determined, at LEP, directly from the radiative process $e^+e^- \rightarrow \nu\bar{\nu}\gamma$. New results are presented, obtained by ALEPH, using 1990 and 1991 data collected at 7 center of mass energies from 88.25 to 94.25 GeV, and by L3, with all data collected in 1992 at the Z peak (E_{CM} = 91.3 GeV).

Introduction

The number of fermion families, which can be determined from the number of light neutrinos N_ν, is among the most important parameters in the Standard Model (SM).

An indirect determination of N_ν has been made at LEP through the analysis of the Z lineshape, subtracting the visible partial widths Γ_h, Γ_l from the total width Γ_z.

A direct method for measuring the Z width into neutrinos, and thus for counting the number of light neutrino types, is based on the measurement of the cross section for the radiative process $e^+e^- \rightarrow \nu\bar{\nu}\gamma$. The signature of such events is a single photon arising from initial state radiation.

The Indirect Method

In this method, from a global fit of hadronic cross sections, making the assumption of lepton universality, 4 parameters are extracted : M_z, Γ_z, σ_0^h, R_h, where

$$\sigma_0^h = \frac{12\pi\Gamma_e\Gamma_h}{M_z^2\Gamma_z^2} \text{ and } R_h = \frac{\Gamma_h}{\Gamma_l}$$

As

$$N_\nu = \frac{\Gamma_{inv}}{\Gamma_l}\left(\frac{\Gamma_l}{\Gamma_\nu}\right)_{SM} \text{ and } \Gamma_{inv} = \Gamma_z - \Gamma_h - 3\Gamma_l$$

one gets

$$N_\nu = \left(\frac{\Gamma_l}{\Gamma_\nu}\right)_{SM} \left(\sqrt{\frac{12\pi R_h}{M_z^2\sigma_0^h}} - R_h - 3\right)$$

A compilation of the 4 LEP experiments [1] gives the following result:

$$N_\nu = 2.980 \pm 0.027$$

The systematic error reads:

$$\Delta N_\nu = 7.5\,\frac{\Delta\sigma_0}{\sigma_0} + 0.145\,\Delta R + 0.16\,\Delta M_z$$

where M_z is in GeV.

The main contribution comes from the first term, the error on the hadronic cross section which depends mainly on the systematic error on the luminosity.

The Direct Method

In the Standard Model, the cross section of the reaction $e^+e^- \rightarrow \gamma + nothing$ is dominated by the decay amplitude of the Z into light neutrino pairs with a small contribution arising from the interference with W exchange amplitudes.

The differential cross section can be written as [2]:

$$\frac{d^2\sigma}{dE_\gamma d\cos\theta_\gamma} = H(E_\gamma, \cos\theta_\gamma, s)\sigma_0(s') \qquad (1)$$

where H is a radiator function for a photon of energy E_γ at angle θ_γ with respect to the beam axis, s is the square of the center of mass energy and $s' = s(1 - 2E_\gamma/\sqrt{s})$. In lowest order, σ_0 is given by:

$$\sigma_0(s) = \frac{12\pi}{M_Z^2}\frac{s\Gamma_e N_\nu \Gamma_\nu}{(s - M_Z^2)^2 + s^2\Gamma_Z^2/M_Z^2} + W\ terms \quad (2)$$

The measurement is optimally carried out at energies a few GeV above the Z mass, where initial state photon radiation brings the e^+e^- center of mass energy down to the Z resonance. So, contrary to most other processes, the cross section does not peak at the resonance, but slightly above, depending on the photon energy. However the cross section can still be substantial at the Z peak and allows a meaningful measure of the number of neutrino families. In these conditions, the photons have low energies with a rapidly falling spectrum, requiring the two following experimental conditions to be realized:

- the capacity to trigger the detector on low energy single photons,
- a good hermiticity at very low angles to reject the background which increases rapidly in this region.

Backgrounds

These come from any process in which particles escape detection with only one photon detected in the fiducial volume.

Radiative Bhabha scattering

The dominant background comes from the low Q^2 radiative Bhabha scattering when both electrons escape detection in the beam pipe or any inactive region. The detection of scattered electrons down to very small angle (θ_{veto}) by the luminosity detector is then particularly important.

Figure 1 shows the variation of signal and background cross section versus the detected energy threshold, E_{thr}, together with the variation of the ratio signal/background for different values of the minimum detection angle, θ_{veto}.

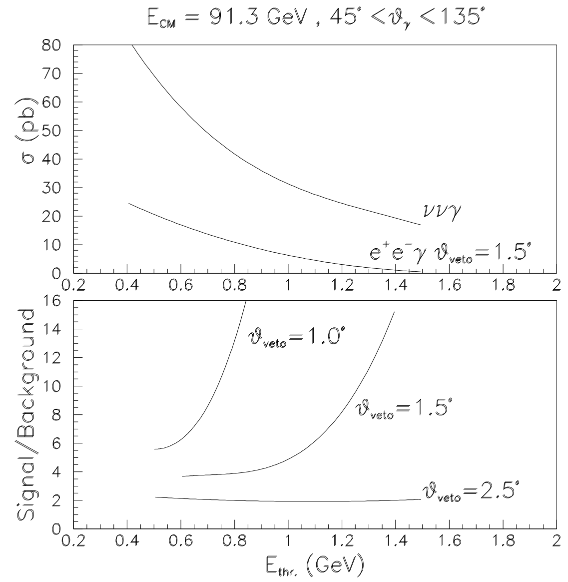

Figure 1: Signal and background cross sections and the ratio signal/background for different θ_{veto}

The contributions to this background process can be computed with the TEEG Monte Carlo [4]. The predictions of this generator are checked on a large sample of events with a single electron in the electromagnetic detector, which arise from the reactions $e^+e^- \rightarrow e^+e^-\gamma$ and $e^+e^- \rightarrow e^+e^-\ e^+e^-$ [2,3]

Other backgrounds

Smaller backgrounds come from e^+e^- annihilation into three photons $e^+e^- \rightarrow \gamma\gamma\gamma$, two-photon production of resonances ($e^+e^- \rightarrow e^+e^-$ X, where X is a π^0, η, η', a_2 or f_2), $e^+e^-\gamma$, $\mu^+\mu^-\gamma$ and $\tau^+\tau^-\gamma$ final states.

The cosmic ray contribution is negligible for ALEPH (interaction time must lie within 150 ns from beam crossing). For L3, an upper limit can be computed[2] and this effect is included in the systematic error.

Beam gas or beam wall effects are negligible for both experiments when requiring the photon direction to point to the vertex.

Single Photon Selection

The selection of the Z $\rightarrow \nu\bar{\nu}\gamma$ candidates aims at identifying events with:

a) a neutral electromagnetic energy deposit in the electromagnetic calorimeter (Ecal).
For ALEPH, the lead/wire chambers calorimeter covers a fiducial volume of $42.3° < \theta < 137.7°$; the electromagnetic cluster energy must exceed 1.5 GeV. The L3 calorimeter is made of BGO crystals; the energy deposit in Ecal must be greater than 1 GeV, at a polar angle between 45° and 135°.

b) no other activity in the detector apart from that which is consistent with noise:

- no charged track
- no energy in luminosity monitors which define the minimum angle at which particles can be detected (θ_{veto} = 2.6° for ALEPH and 1.5° for L3)
- no energy in the hadronic calorimeter
- no other energy measured in Ecal
- no muon track (only for L3)

	$\int \mathcal{L}$ dt (pb^{-1})	Data	predicted Events	
			$\nu\bar{\nu}\gamma$	Background
ALEPH				
1990	5.3	152	109.0	49.2
1991	10.4	248	164.2	90.9
L3				
1992	20.8	451	376.3	68.0

Table 1: Luminosity, observed and expected number of events.

After applying all the selection cuts, one obtains the event samples shown in table 1 together with the integrated luminosity, the number of candidates expected from $\nu\bar{\nu}\gamma$ for 3 neutrino families and the total number of background events. The energy spectrum of the single photon candidates for L3 is shown in figure 2 together with the Monte Carlo prediction for the signal expected from 3 light neutrino families and the backgrounds.

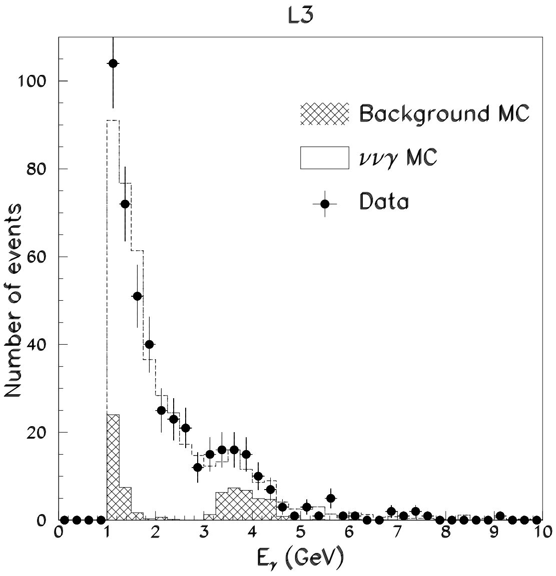

Figure 2: Energy spectrum of the single photons along with the Monte Carlo predictions.

The number of light neutrino families is extracted by performing a maximum likelihood fit to the number of candidates shown in table 1. One uses Poisson probabilities calculated as a function of the expected number of signal plus background events. From these fits, the number of light neutrino families is found to be:

ALEPH: 1990 + 1991 data

$$N_\nu = 2.68 \pm 0.20 \pm 0.20$$

L3: 1992 data

$$N_\nu = 3.00 \pm 0.16 \pm 0.08$$

ALEPH corrected cross sections are shown in figure 3 as a function of the center of mass energy along with the expectations for N_ν= 2,3 and 4.

Conclusions

Both methods are valuable means to measure the number of neutrino families. They are different: the indirect method measures the "unseen" width (non-hadronic, non-leptonic), the single photon method measures directly the "invisible" cross section $\sigma_{inv} \propto N_\nu \Gamma_\nu$.

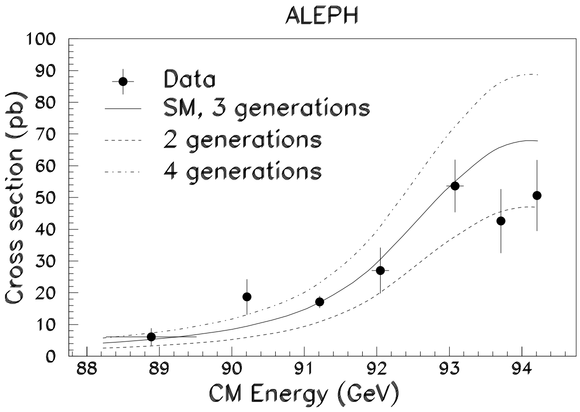

Figure 3: Corrected experimental cross sections for the $\nu\bar{\nu}\gamma$ (γ) process as a function of center of mass energy for $E_\gamma >$ 1.5 GeV and $|\cos\theta| < 0.74$. The predictions for 2, 3, 4 neutrino families are shown for comparison.

Systematic errors on the measurement are different. The line shape method depends mainly on the accuracy of the luminosity measurement. The single photon systematic errors depends on various factors which all can be reduced with increased statistics (better determination of the trigger efficiency, the cosmic ray contamination and the background subtraction). These improvements should make the direct method systematic error quite competitive with the indirect method.

The direct method not only is an independent measure of the number of generations but gives in addition two specific observables which are of interest for tagging possible new physics:

- the photon energy spectrum
- the cross section versus $\sqrt{s}$

It should be pointed out that in order to bring the statistical error to the level of the ultimate systematic error, high luminosity above the peak and/or a decrease of the energy threshold (together with a further decrease of the minimum θ_{veto} angle) are needed.

References

[1] J. Lefrançois, *these proceedings*.
[2] L3 Collaboration, O. Adriani et al., *Phys Lett.* **B 292** (1992) 463 and references therein.
[3] ALEPH Collaboration, D. Buskulic et al., *Phys Lett.* **B 313** (1993) 520.
[4] D. Karlen, *Nucl. Phys.* **B 289** (1987) 23.