DETERMINATION OF THE NUMBER OF LIGHT NEUTRINO SPECIES

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S. Mele. ***The Measurement of the Number of Light Neutrino Species at LEP***. Adv.Ser.Direct.High Energy Phys. 23 (2015).

- LEP – первые пучки 14 июля, 1989. Набор данных на $E^{*} \sim 90$ GeV $\sim m_Z$.
- Около середины октября ALEPH, DELPHI, L3, OPAL публикуют результаты по изучению характеристик Z-бозона.
- Один из пяти Z-бозонов, полученных на LEP распадается на «**легкие нейтрино**»: $m_\nu < m_Z/2$.

ALEPH Collab. D. Decamp et al. Phys. Lett. B 231 (1989).

- Максимум сечения распада Z-бозона на любое детектируемое конечное состояние *F*:

$$\sigma_F^{\text{peak}} = \frac{12\pi}{m_Z^2}\frac{\Gamma_{ee}\Gamma_F}{\Gamma_Z^2}(1-\delta_{\text{rad}}) \equiv \sigma_F^0(1-\delta_{\text{rad}}),$$

- где

$$\Gamma_Z = N_\nu \Gamma_{\nu\nu} + 3\Gamma_{ee} + \Gamma_{\text{had}}.$$

- Отбирались события

$$e^+e^- \to Z \to \text{hadrons}$$

$$e^+e^- \to Z \to e^+e^-$$

(Bhabha рассеяние)

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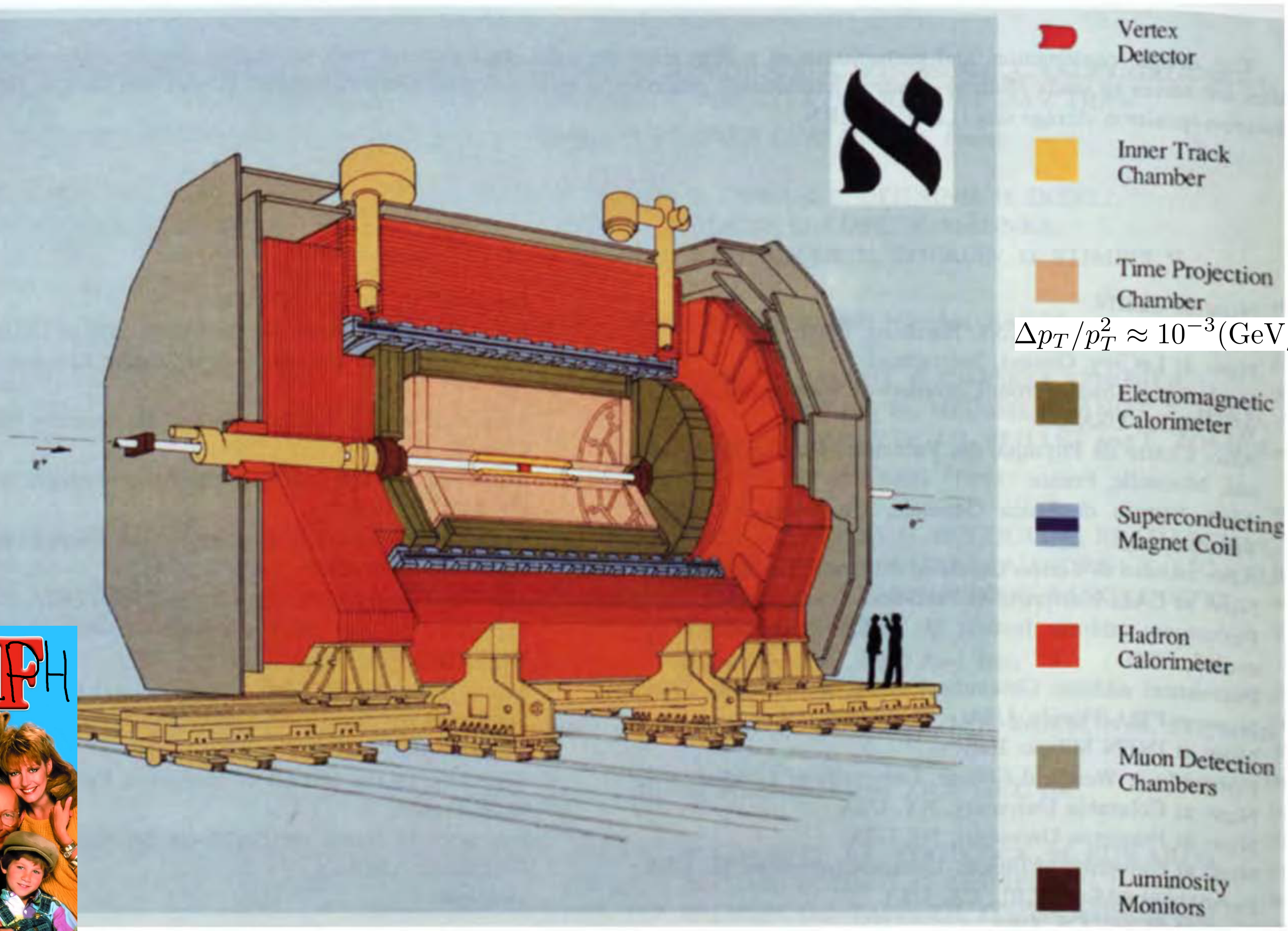
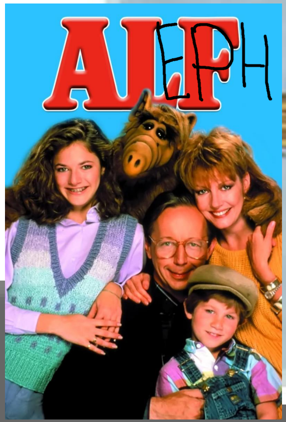


$\Delta p_T / p_T^2 \approx 10^{-3} (\mathrm{GeV}/c)^{-1}$



ALEPH Collab. D. Decamp et al. Phys. Lett. B 231 (1989).

- Два метода отбора событий: 1) адронные события по трекам в TPC; 2) распад Z на адроны и пары τ по энергии в калориметрах;
- Всего 3112 события по трекам TPC, 3320 событий по калориметрическому методу.

ALEPH Collab. D. Decamp et al. Phys. Lett. B 231 (1989).

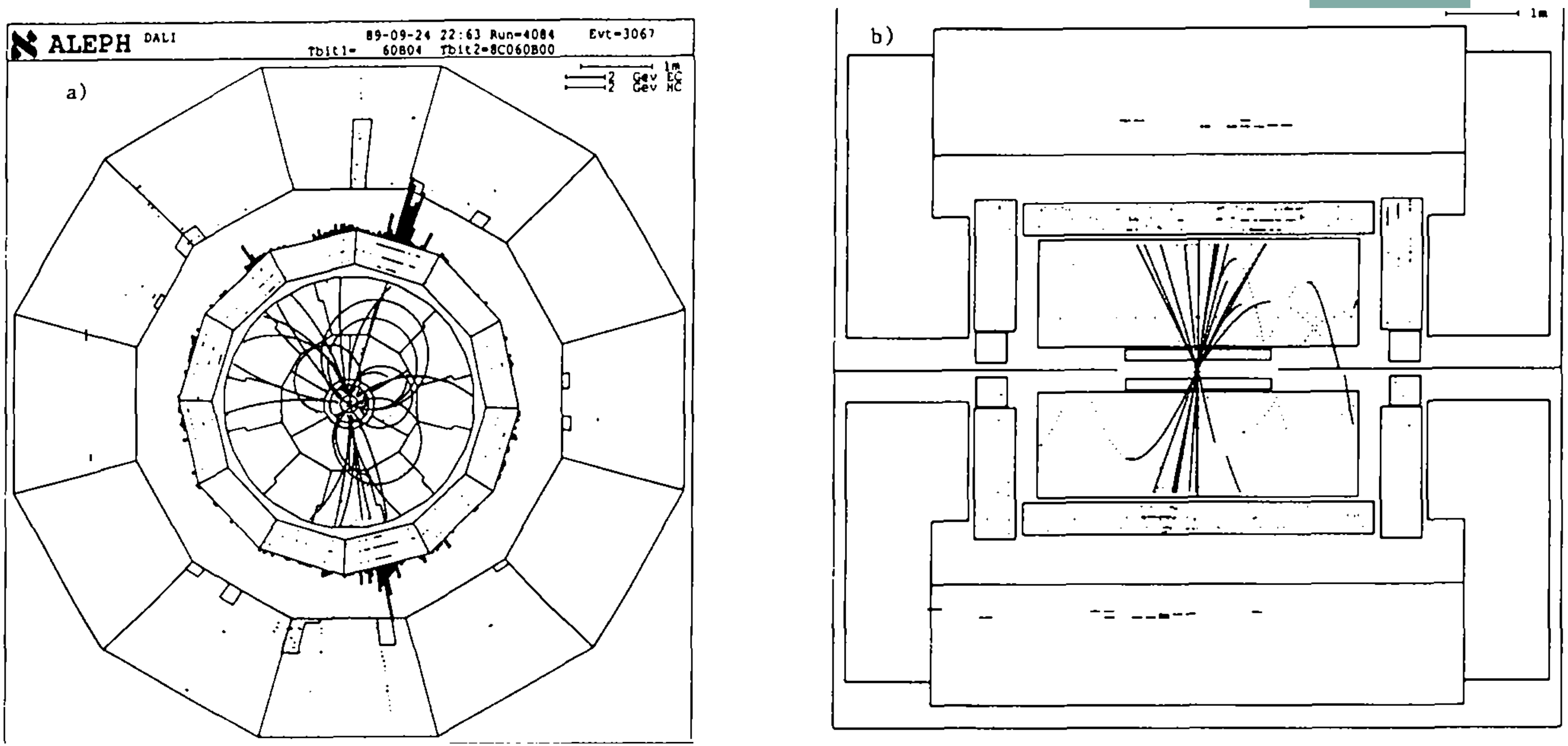
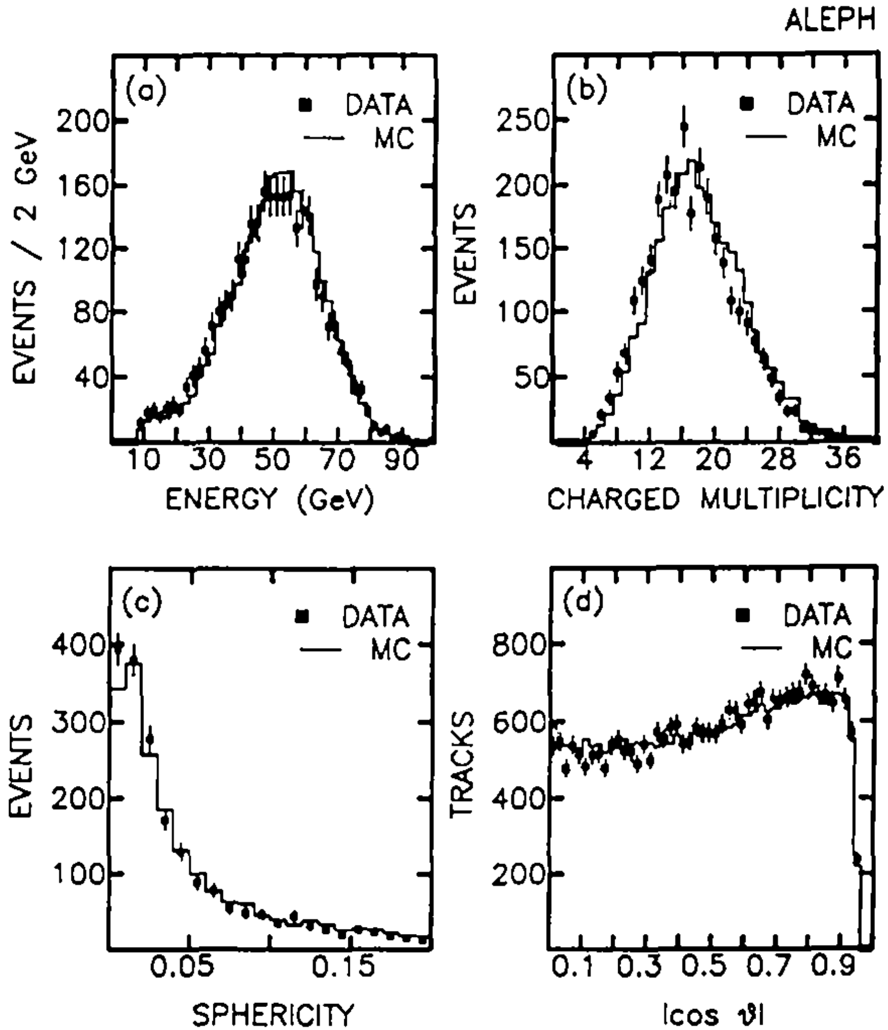


Fig. 1. A hadronic Z decay in the ALEPH detector: (a) x–y view; (b) r–z view.

ALEPH Collab. D. Decamp et al. Phys. Lett. B 231 (1989).



$$\epsilon_{\text{cal}} = 0{,}974 \pm 0{,}006$$

$$\epsilon_{\text{TPC}}^{\text{peak}} = 0{,}975 \pm 0{,}006$$

Fig. 2. Properties of charged tracks in hadronic events and comparison with simulations. In each plot, the solid points represent data and the lines represent the simulation normalized to the data: (a) distribution of the charged-track energy sum per event; (b) charged-track multiplicity distribution; (c) sphericity distribution for events where the sphericity axis had a polar angle such that $|\cos\vartheta_{\text{sph}}| < 0.8$; and (d) polar angle distribution for charged tracks.

ALEPH Collab. D. Decamp et al. Phys. Lett. B 231 (1989).

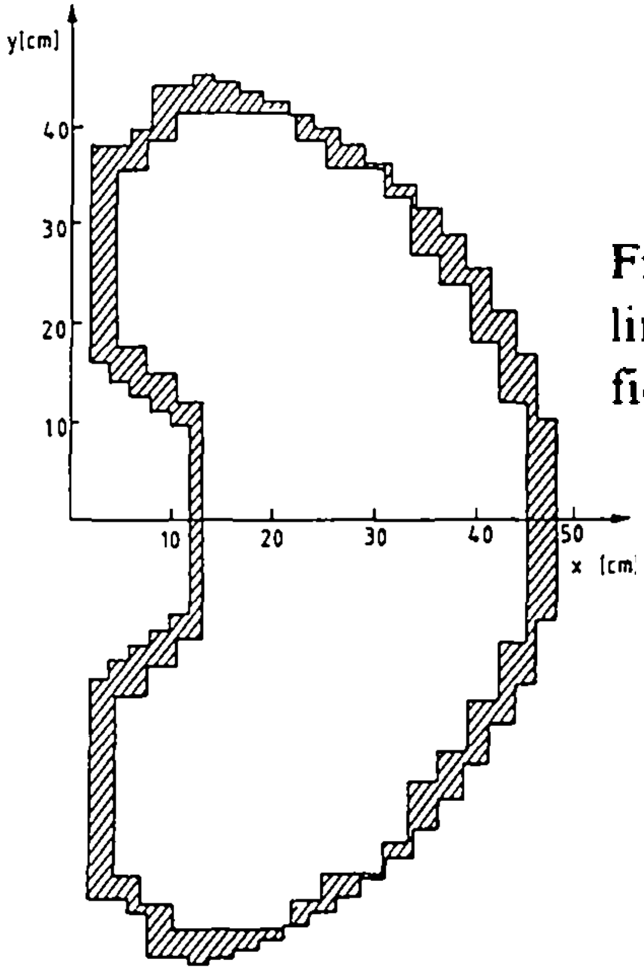


Fig. 3. End view of the Luminosity Calorimeter, showing the tower limits; the shaded area represent the towers excluded from the fiducial area.

ALEPH Collab. D. Decamp et al. Phys. Lett. B 231 (1989).

Относительные ошибки

Table 1
Summary of systematic errors in the luminosity measurement.

transverse and longitudinal shower profile	±0.005
energy scale	±0.002
energy resolution and cell-to-cell calibration	±0.007
external alignment and beam parameters	±0.002
internal alignment and inner radius	±0.010
description of material	±0.005
higher order radiative effects	±0.01
total uncertainty:	±0.02

ALEPH Collab. D. Decamp et al. Phys. Lett. B 231 (1989).

$$\sigma_{\text{lum}}(E = 91{,}0\ \text{GeV}) = (31{,}12 \pm 0{,}45_{\text{exp}} \pm 0{,}31_{\text{th}})\ \text{nb}$$

D. Decamp et al, **1990**

$$\sigma_{\text{lum}}(E) = \sigma_{\text{lum}}(91\ \text{GeV}) \cdot \left(\frac{91\ \text{GeV}}{E}\right)^2 + \text{EW effects corrections}$$

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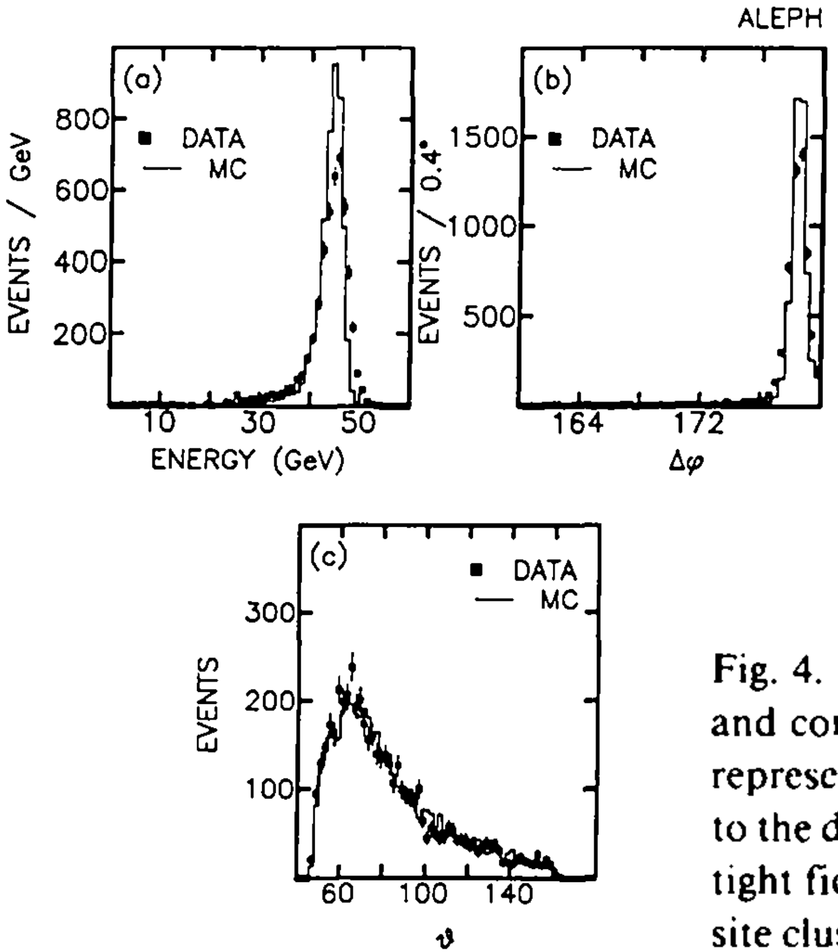

Efficiencies vary with the run, ranging from 0.98 to 1.00 with an average value of 0.997 ± 0.002.

Fig. 4. Properties of luminosity events passing selection criteria and comparison with simulations. In each plot, the solid points represent data and the lines represent the simulation normalized to the data: (a) shower energy distribution for events passing the tight fiducial cut; (b) azimuthal separation $\Delta\phi$ of the two opposite clusters; (c) polar angle distribution.

ALEPH Collab. D. Decamp et al. Phys. Lett. B 231 (1989).

Table 2
Event numbers and cross-section as a function of centre-of-mass energy. The overall systematic error of ±2% in the cross-sections is not included.

Energy GeV	Selection from TPC tracks			Selection by calorimeters		
	N_{had}	N_{lumi}	σ_{had} (nb)	$N_{had}+N_\tau$	N_{lumi}	$\sigma_{had}+\sigma_\tau$ (nb)
89.263	120	443	9.00 ± 0.92	134	450	9.89 ± 0.97
90.265	406	715	18.43 ± 1.14	445	736	19.62 ± 1.17
91.020	656	668	31.29 ± 1.72	678	669	32.28 ± 1.76
91.266	1156	1295	28.16 ± 1.14	1243	1309	29.96 ± 1.19
92.260	258	377	21.11 ± 1.72	268	374	22.10 ± 1.78
92.519	125	247	15.52 ± 1.71	142	260	16.75 ± 1.76
93.264	391	883	13.36 ± 0.82	410	889	13.92 ± 0.84

$$\sigma_{\rm had} = \frac{N_{\rm TPC,\,cal}}{\epsilon_{\rm TPC,\,cal}} \frac{\sigma_{\rm lum}}{N_{\rm lum}}$$

$$\sigma_{\rm lum}(E) = \sigma_{\rm lum}(91\ {\rm GeV}) \cdot \left(\frac{91\ {\rm GeV}}{E}\right)^2 + \text{EW effects corrections}$$

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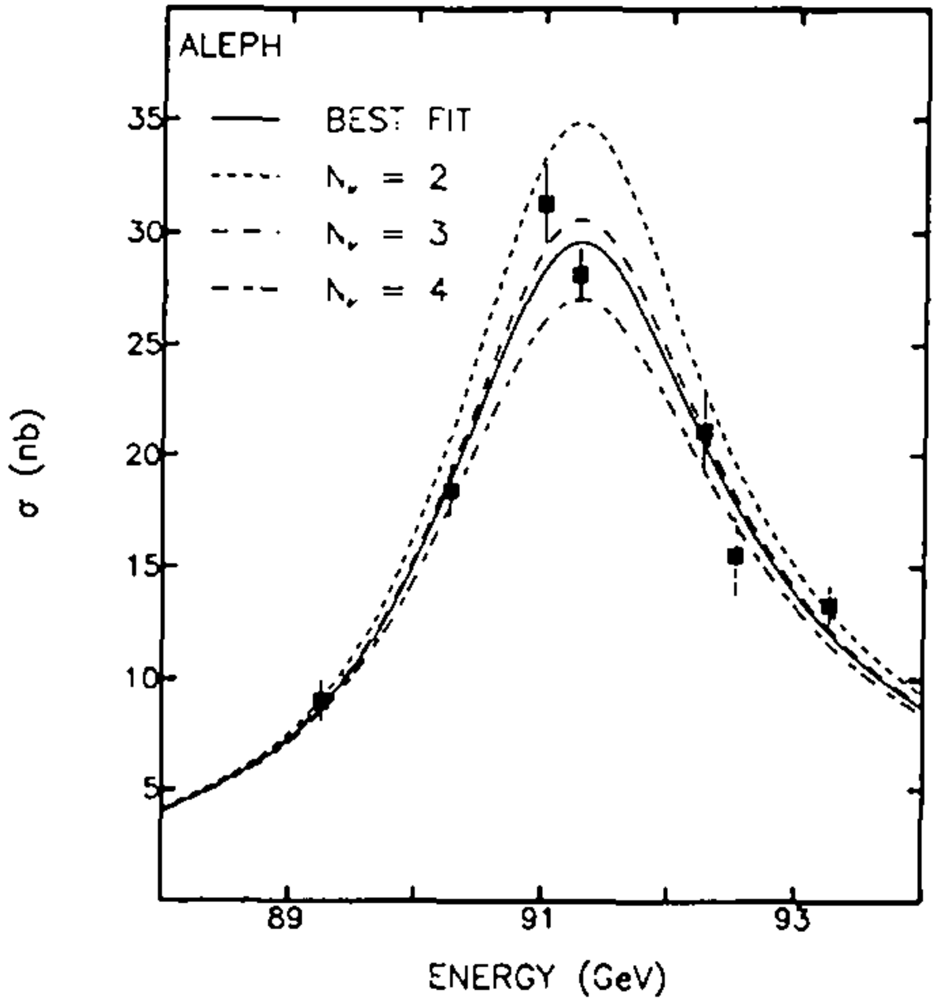

$$\sigma_{\rm had} = \sigma^0_{\rm had} \frac{s\Gamma_Z^2}{(s - m_Z^2)^2 + s^2\Gamma_Z^2/m_Z^2}(1 + \delta_{\rm rad}(s))\Big|_{s=E^2}$$

$$\sigma^0_{\rm had} = \frac{12\pi}{m_Z^2}\frac{\Gamma_{ee}\Gamma_{\rm had}}{\Gamma_Z^2}$$

$$M_Z = (91.174 \pm 0.055_{\rm exp} \pm 0.045_{\rm LEP})\ {\rm GeV}\ .$$

Fig. 5. The cross-section for $e^+e^- \to$ hadrons as a function of centre-of-mass energy and result of the three parameter fit.

ALEPH Collab. D. Decamp et al. Phys. Lett. B 231 (1989).

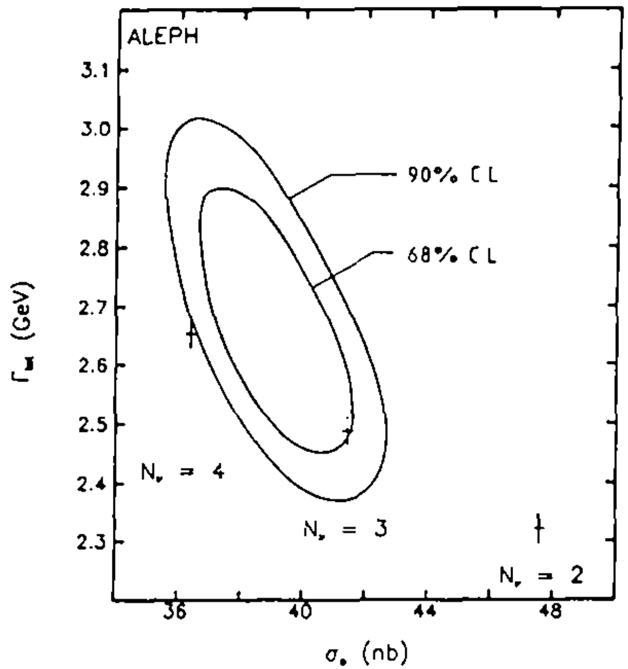

Fig. 6. The total width versus the peak hadronic cross-section, with 68% and 90% CL experimental contours. The standard model prediction for 2, 3 or 4 species of neutrinos is also shown, with its theoretical error.

$$\Gamma_{ee}, \Gamma_{\nu\nu}, \Gamma_{\text{had}}$$

Из СМ с ошибкой в ~1%:

Table 4
Standard model partial widths of the Z in MeV for the measured value of M_Z; $\alpha_s = 0.12 \pm 0.02$ and $\sin^2\vartheta_w = 0.230 \pm 0.006$ have been used as input.

Γ_{ee} (MeV)	83.5 ± 0.5
Γ_ν (MeV)	166.5 ± 1.0
Γ_{had} (MeV)	1737 ± 22

$$\sigma^0_{\text{had}} = \frac{12\pi}{m_Z^2} \frac{\Gamma_{ee}\Gamma_{\text{had}}}{\Gamma_Z^2}$$

$$\Gamma_Z = N_\nu \Gamma_{\nu\nu} + 3\Gamma_{ee} + \Gamma_{\text{had}}$$

$$N_\nu = 3.27 \pm 0.24_{\text{stat}} \pm 0.16_{\text{sys}} \pm 0.05_{\text{th}}$$

ALEPH Collab. D. Decamp et al. Phys. Lett. B 231 (1989).

$$N_\nu = 3.27 \pm 0.30$$

The demonstration that there is a third neutrino confirms that the τ neutrino is distinct from the e and μ neutrinos. The absence of a fourth light neutrino indicates that the quark–lepton families are closed with the three which are already known, except for the possibility that higher order families have neutrinos with masses in excess of ~ 30 GeV.

ALEPH Collab. D. Decamp et al. Phys. Lett. B 235 (1990).

- 1990 г. — тот же анализ, улучшен детектор и понимание систематических ошибок.

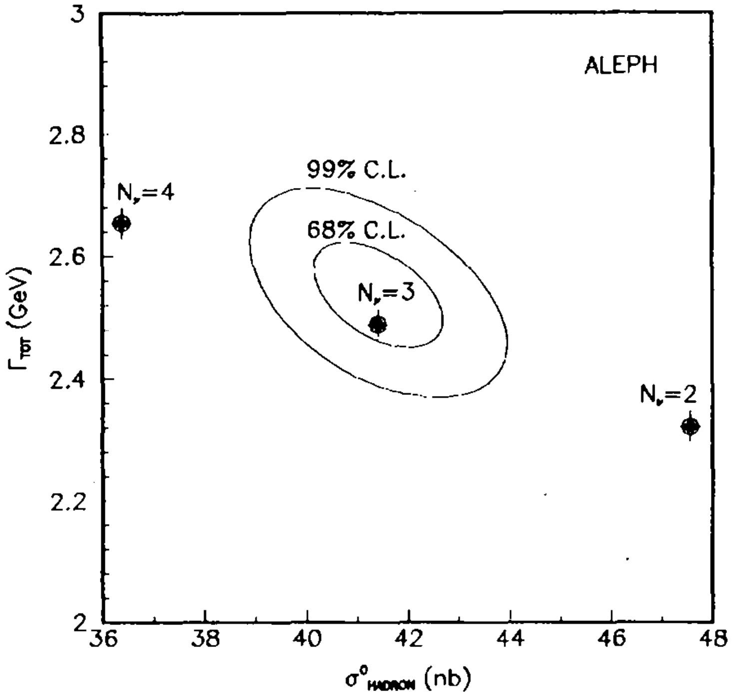

Fig. 5. Contours of constant χ^2 in the $\sigma^0_{had}-\Gamma_Z$ plane, and the standard model predictions for $N_\nu=2$, 3 and 4.

In the frame of the standard model, the statistically most powerful way to obtain the number of neutrino families is not from the measurement of the width, but from the peak cross-section, σ^0_{had}. the data are refitted with only N_ν and M_Z as parameters. Since the mass determination is independent of the absolute cross-section and the width, M_Z changes only slightly in this fit. We find

$$M_Z = 91.175 \pm 0.027 \pm 0.030 \text{ GeV},$$

$$N_\nu = 3.01 \pm 0.15 \text{ (exp.)} \pm 0.05 \text{ (theor.)}.$$

The theoretical uncertainty is due to uncertainties in the partial width calculation and is discussed in our previous letter [5]. The χ^2 of this fit is 11.3 for 9 degrees of freedom. The agreement with the earlier results [1–5], which give an average of $N_\nu = 3.13 \pm 0.25$, is good.


ВСЁ!