V. Precyzyjne testy Modelu Standardowego w LEP, TeVatronie i LHC

V.1 WYNIKI LEP

$e^+e^- \rightarrow Z^0$

Calkowity przekroj czynny

MODEL STANDARDOWY

(1)

$$\sigma_f(s) = \frac{s}{(s-M_Z^2)^2 + s^2\Gamma_Z^2/M_Z^2}\left(\frac{12\pi\,\Gamma_e\Gamma_f}{M_Z^2} + I_f Q_f \frac{N_c(s-M_Z^2)}{s}\right) + \frac{4\pi}{3} N_c Q_f^2 \frac{\bar{\alpha}^2}{s}$$

$$\varrho = \frac{G_F^{NC}}{G_F^{CC}} = \frac{M_W^2}{M_Z^2\cos^2\theta_W} = 1 \qquad Q^2 = M_Z^2$$

$$\Gamma_f = \frac{N_c G_F M_Z^3}{6\sqrt{2}\,\pi}\left[\left(\bar{g}_{V_f}^2 + \bar{g}_{A_f}^2\right) + O(\varepsilon)\right] * \left[* \sqrt{1 - \frac{4m_f^2}{M_Z^2}}\right]$$

$$\sin^2\bar{\theta}_W = 1 - \frac{M_W^2}{\bar{\varrho} M_Z^2} \equiv \frac{\bar{e}^2}{\bar{g}^2} \qquad \overline{MS}$$

$$g_{A_f} = \sqrt{\bar{\varrho}}\; I_f^3$$

$$g_{V_f} = \sqrt{\bar{\varrho}}\left[I_f^3 - 2Q_f\sin^2\bar{\theta}_W\right]$$

$$\bar{\varrho} = 1 + \Delta\varrho = 1 + \frac{3\sqrt{2}\,G_F}{16\pi^2} m_t^2$$

$$A_f^{FB} = \frac{\sigma_F(f) - \sigma_B(f)}{\sigma_F(f) + \sigma_B(f)} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f$$

$$M_Z^2 = \frac{\pi\tilde{\alpha}}{\sqrt{2}\,\bar{\varrho}\, G_F \sin^2\bar{\theta}_W \cos^2\bar{\theta}_W}$$

$$Q^2 \equiv M_Z^2$$

$$\mathcal{A}_e = \frac{2\bar{g}_{V_e}\cdot\bar{g}_{A_e}}{g_{V_e}^2 + g_{A_e}^2}$$

$$M_W^2 = \frac{\pi\tilde{\alpha}}{\sqrt{2}\, G_F \sin^2\bar{\theta}_W}$$

$$\mathcal{A}_f = \frac{2\bar{g}_{V_f}\cdot\bar{g}_{A_f}}{g_{A_f}^2 + g_{V_f}^2}$$

$$\boxed{\sigma_0^{had} = \frac{12\pi}{M_Z^2}\frac{\Gamma_e\Gamma_{had}}{\Gamma_Z^2}}$$

ZALEŻNOŚĆ OD m_t^2

$$\Gamma_Z = \frac{G_F M_Z^3}{24\sqrt{2}\,\pi}\left[21.7 - 49.4\sin^2\bar{\theta}_W + 64.6\sin^4\bar{\theta}_W + N_\nu\right]$$

Np: $\boxed{\Gamma_Z \approx 2.65 + 0.172(N_\nu - 3)}$ $\quad \sin^2\bar{\theta}_W = 0.223$, $M_Z = 92.26$

$\boxed{\Gamma_Z = 2.50 + 0.172(N_\nu - 3)}$ $\quad \sin^2\bar{\theta}_W = 0.2302 \pm 0.0021$, $M_Z = 91.177$

Całkowity przekrój czynny $e^+e^-\to f\ \text{fbar}$

$$\sigma_f(s) = \frac{s}{(s-M_Z^2)^2 + s^2\Gamma_Z^2}\left(\frac{12\pi\Gamma_e\Gamma_f}{M_Z^2} + I_f Q_f \frac{N_C\left(s-M_Z^2\right)}{s}\right) + $$

$$+\frac{4\pi}{3} N_C Q_f \frac{\overline{\alpha}^2}{s}$$

$$\Gamma_f = N_C \frac{G_F M_Z^3}{6\sqrt{2}\pi}\left[\left(\overline{g_V}^2 + \overline{g_A}^2\right) + \mathbf{O}(\varepsilon)\right] * \sqrt{1-\frac{4m_f^2}{M_Z^2}}$$

$$\overline{g_V} = \sqrt{\overline{\rho}}\left(I_f^3 - 2Q_f \sin^2\theta_W\right); \quad \overline{g_A} = \sqrt{\overline{\rho}}\, I_f^3$$

$$\overline{\rho} = 1 + \Delta\rho = 1 + \frac{3\sqrt{2}G_F}{16\pi^2} m_t^2$$

Stałe sprzężenia

Kinematics

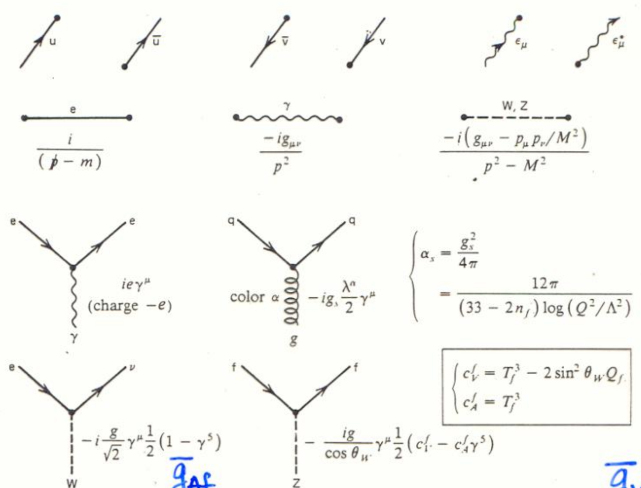
Lorentz invariant phase space ($P \to p_1 + \cdots p_n$)

$$dQ = (2\pi)^4 \delta^4 (P - p_1 - \cdots p_n) \prod_{i=1}^{n} \frac{d^3 p_i}{(2\pi)^3 2E_i}$$

Scattering: $\left.\frac{d\sigma}{d\Omega}\right|_{cm} = \frac{1}{64\pi^2 s} \frac{p_f}{p_i} |\mathcal{M}|^2$

Decay: $d\Gamma(A \to 1 + \cdots n) = \frac{|\mathcal{M}|^2}{2m_A} dQ.$

Feynman Rules for $-i\mathcal{M}$



$$\frac{i}{(\not p - m)} \qquad \frac{-ig_{\mu\nu}}{p^2} \qquad \frac{-i(g_{\mu\nu} - p_\mu p_\nu / M^2)}{p^2 - M^2}$$

$ie\gamma^\mu$ (charge $-e$) $\qquad$ color α $\; -ig_s \frac{\lambda^a}{2}\gamma^\mu$

$$\alpha_s = \frac{g_s^2}{4\pi} = \frac{12\pi}{(33 - 2n_f)\log(Q^2/\Lambda^2)}$$

$$-i\frac{g}{\sqrt{2}}\gamma^\mu \frac{1}{2}(1-\gamma^5) \qquad -\frac{ig}{\cos\theta_W}\gamma^\mu \frac{1}{2}(c_V^f - c_A^f \gamma^5)$$

$$c_V^f = T_f^3 - 2\sin^2\theta_W Q_f, \qquad c_A^f = T_f^3$$

g_{Af}	f	Q_f	$(T_f^3)_L$	$(T_f^3)_R$	g_{Vf}
1/2	u, c, t	$+\frac{2}{3}$	$\frac{1}{2}$	0	0.193
−1/2	d, s, b	$-\frac{1}{3}$	$-\frac{1}{2}$	0	−0.35
1/2	ν_e, ν_μ, ν_τ	0	$\frac{1}{2}$	—	0.5
−1/2	e, μ, τ	−1	$-\frac{1}{2}$	0	−0.27

$\sin^2\theta_W \simeq 0.23$, $g\sin\theta_W = e$, $G = \frac{\sqrt{2}g^2}{8M_W^2} \simeq 1.17 \times 10^{-5}\ \mathrm{GeV}^{-2}$

$\sin^2\theta_W = 0.2302$

Poprawki radiacyjne

DANE — POPRAWKI NA AKCEPTACJE, ZDOLNOŚĆ ROZDZIELCZĄ,....

DANE POPRAWIONE

FIT ➡ $M_Z, \Gamma_Z, \sigma^0, \Gamma_h, \Gamma_e, \Gamma_\mu, \Gamma_\tau, \Gamma_{inv}$, $\sin^2\theta_W, \ldots$

PRZEKROJE CZYNNE FIZYCZNE

POPRAWKI RADIACYJNE

PRZEKROJE BORNOWSKIE

$\boxed{\text{POPRAWKI RADIACYJNE}}$ — Ogromny postęp od 1974

* QED

DUŻE, ZALEŻNE OD CIĘĆ EXP.

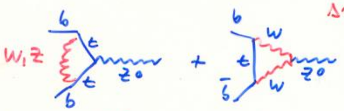
$$\sigma_f(s) = \int_0^1 dz\, H(z,s)\, \sigma_f^{BORN}(zs)$$

* NIE-QED, NIEFOTONOWE

↙ CIĘŻKI TOP DAJE WKŁAD DO $\Delta\rho$ (np.)

← ±NIE MA $\cancel{M_H^2}$ NA POZIOMIE 1 PĘTLI

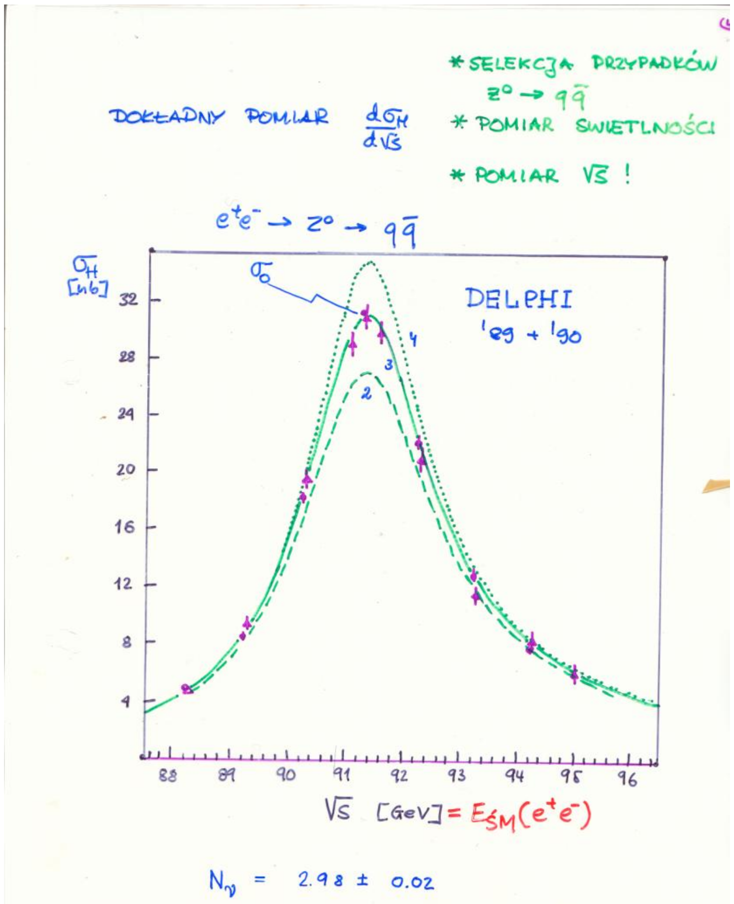
$\Delta r \approx 10^{-2} - 10^{-3}$



$\sim \frac{M_t^2}{M_W^2} + \ldots \ln \frac{M_t^2}{M_W^2}$ $\quad \cancel{M_H^2}$

GŁÓWNĄ CZĘŚĆ TYCH POPRAWEK MOŻNA ZAABSORBOWAĆ W $\alpha(Q^2)$, ρ.... → "IMPROVED BORN APPROXIMATION"

Pomiar calkowitego przekroju czynnego w LEP



1990

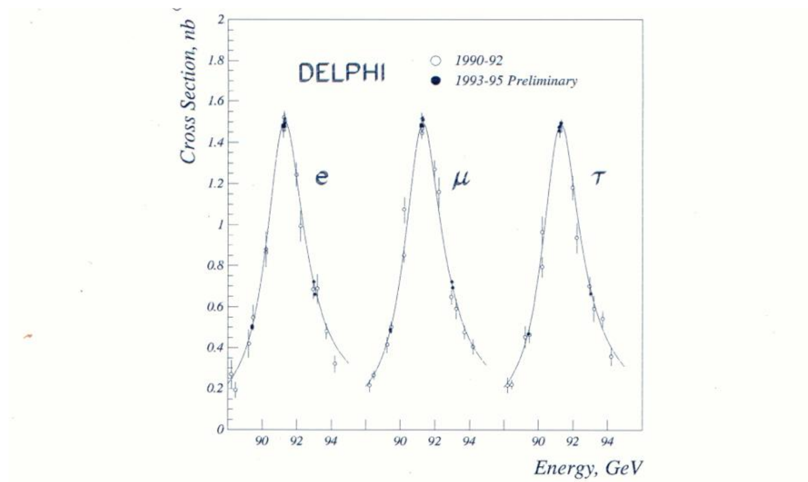
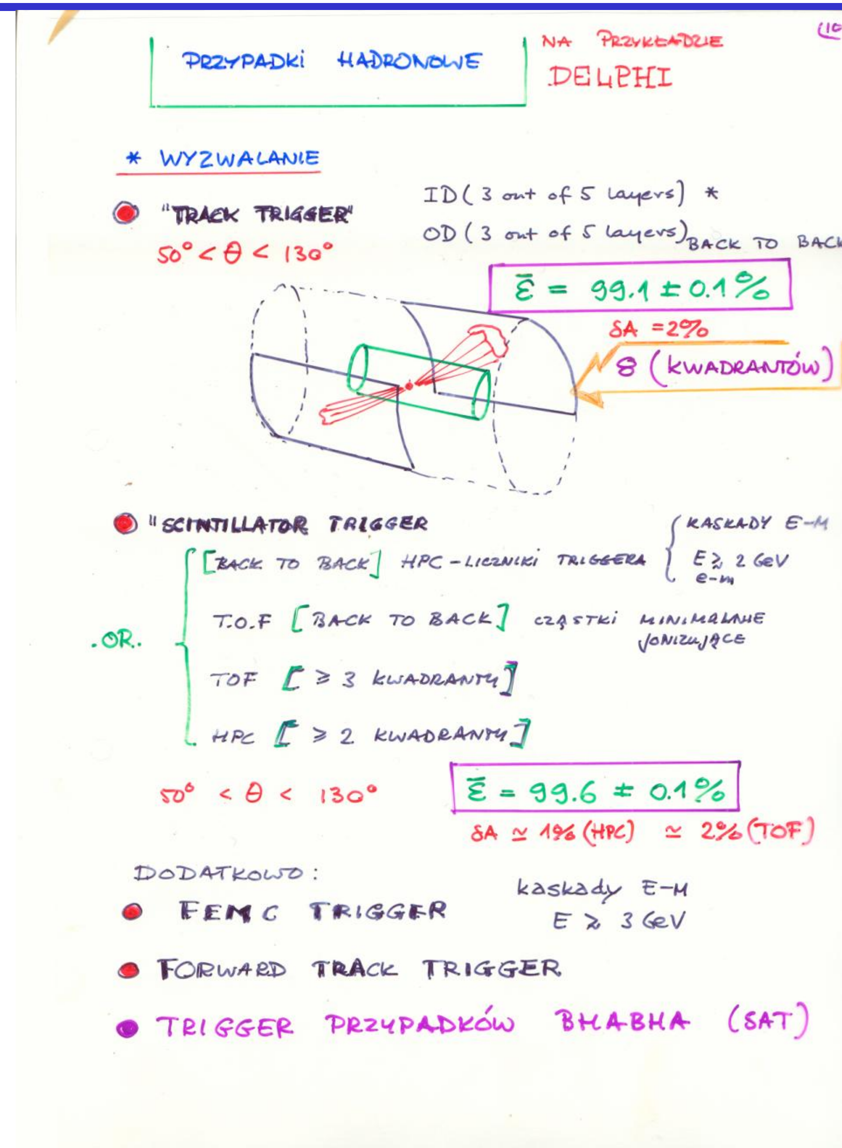


Figure 2.3: Leptonic cross sections as a function of centre-of-mass energy as measured by the DELPHI Collaboration [58]. The solid lines represents the MSM fit to the data.

DELPHI 1993-95

Martinez et.al. CERN-EP/98-027

Pomiar przekroju czynnego w LEPie byl "prosty"

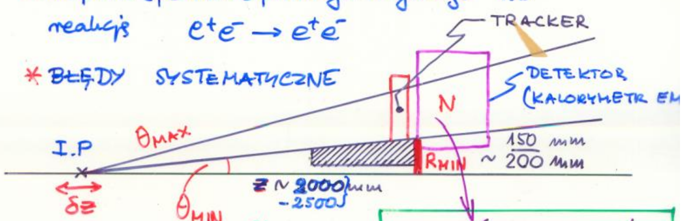


Pomiar swietlnosci

POMIAR ŚWIETLNOŚCI

* Poprzez {obliczenia / pomiar} przekroju czynnego na reakcję $e^+e^- \to e^+e^-$

* BŁĘDY SYSTEMATYCZNE



δL_{stat} ← WYBÓR PRZYPADKÓW

$$N(\theta_{min},\theta_{max}) = L \cdot \sigma(\theta_{min},\theta_{max})$$

$$\sigma(\theta_{min},\theta_{max}) = \int_{\theta_{min}}^{\theta_{min}} \frac{d\sigma}{d\cos\theta}\, d\cos\theta \sim A\left[\frac{1}{\theta^2_{min}} - 1/\theta^2_{max}\right]$$

$$\frac{\delta\sigma}{\sigma} \approx 2\cdot\frac{\delta\theta_{min}}{\theta_{min}} \approx 2\,\frac{\delta z}{z}$$

$1\% = \frac{\delta\sigma}{\sigma} \to$ $\boxed{\delta R_{MIN} \approx 1\ mm,\quad \delta z \approx 10\ mm}$

MINIMALIZACJA δR_{MIN} — 1° DOKŁADNE USTAWIENIE KAL. VS I.P δz

δR_{MIN}:
- pomiar toru $e^\pm$ przed kalorymetrem (Ⓧ, OPAL)
- maska ołowiana o dobrze znanych wymiarach przed kalorymetrem ($\Delta\phi$)
- b. dobra znajomość geometrii detektora

δz:
- naprzemienne wyzwalanie na e^+ i e^- (Ⓧ)

A: $\phi = 12$ cm

B: $\phi = 13$ cm

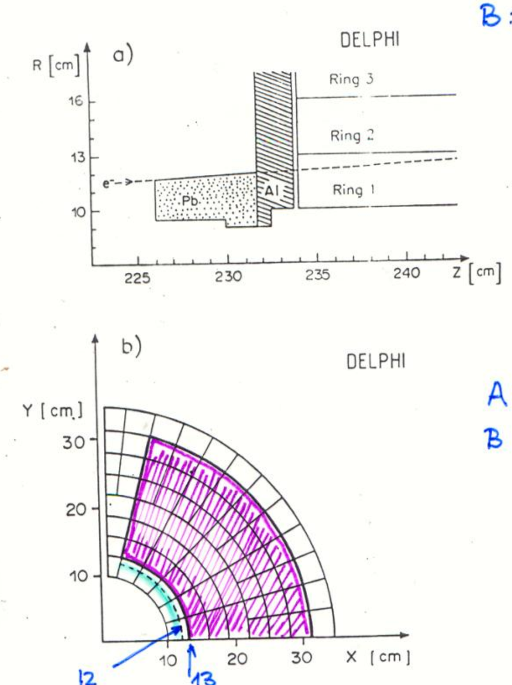


Fig. 1. The small angle tagger calorimeter. (a) Side view showing the 12 cm lead mask in front of calorimeter 2. (b) Segmentation of calorimeter in one quadrant. The border of the acceptance in calorimeter 2 is indicated by a thick line (dashed line for 12 cm mask).

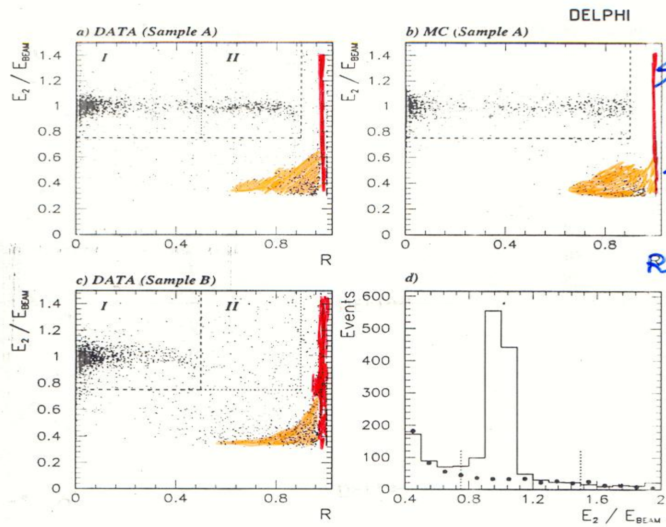
A: ≤ XI. 89

B: XII 89, 1990

Przypadki Bhabba- wyzwalanie i precyzja pomiaru swietlnosci

DELPHI

Volume 241, number 3 PHYSICS LETTERS B 17 May 1990



e przechodzące przez dziurę w masce;
e UDERZAJĄCE W MASKĘ

$R = \frac{E_1 \text{ warstwa}}{E_2}$

Fig. 2. (a)–(c) Distribution of the energy ratio E_2/E_{beam} versus the energy fraction R (see text for the definition of R). (d) shows E_2/E_{beam} of sample A (continuous line) and B (dots) for $0.5<R<0.9$ normalized to the same luminosity.

The visible cross section for the luminosity events formed. The visible cross sections at this energy were

WYZWALANIE

1. $(E_1 > 15) * (E_2 > 15)$ KOPLANARNE $(\Delta\phi = 180 \pm 20°)$
   $\varepsilon \geq 99.9\%$ $\delta\varepsilon \sim 0.6\%$
2. $(E_1 > 35) * (E_2 > 35)$
3. $(E_1 > 15)$ OR $(E_2 > 15)$ ← TYLKO PRZEZ CZĘŚĆ CZASU!

$\left(\frac{\delta L}{L}\right)_{syst} = 1.7\%$ DLA DANYCH Z 1990!
2.4% Z 1989!

PRZEWIDYWANIA MODELU STANDARDOWEGO I POPRAWKI PROMIENISTE

Obserwable elektroslabe

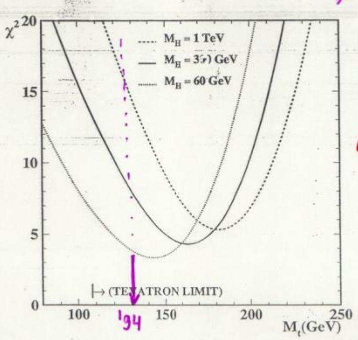
LEP EXPERIMENTS 1993

measurement	result
a) LEP	
line-shape and lepton asymmetries:	
M_Z	91.187 ± 0.007 GeV
Γ_Z	2.489 ± 0.007 GeV
σ_h^0	41.56 ± 0.14 nb
R_ℓ	20.763 ± 0.049
$A_{FB}^{0,\ell}$	0.0158 ± 0.0018
+ correlation matrix (Table 9)	
τ polarization asymmetries:	
$\mathcal{A}_\tau$	0.139 ± 0.014
$\mathcal{A}_e$	0.130 ± 0.025
b and c quark results:	
$A_{FB}^{0,b}$	0.099 ± 0.006
$A_{FB}^{0,c}$	0.075 ± 0.015
$\Gamma_{b\bar{b}}/\Gamma_{had}$	0.2200 ± 0.0027
$q\bar{q}$ charge asymmetry:	
$\sin^2\theta_{eff}^{lept}$ from $\langle Q_{FB}\rangle$	0.2320 ± 0.0016
b) $p\bar{p}$ and νN	
M_W/M_Z (UA2)	0.8813 ± 0.0041
M_W (CDF)	79.91 ± 0.39
$1 - M_W^2/M_Z^2(\nu N)$	0.2256 ± 0.0047

'94 ± 0.004 ± 0.003

Table 23: Summary of measurements included in the combined analysis of Standard Model parameters. Section a) summarizes LEP averages, section b) electroweak precision tests from hadron colliders and νN-scattering.

$N_\nu = 2.998 \pm 0.002$



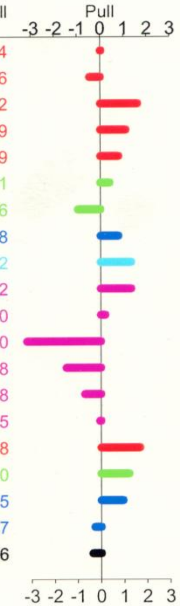
CDF ($\bar{p}p$)

$m_t = 174 \pm 17$ GeV

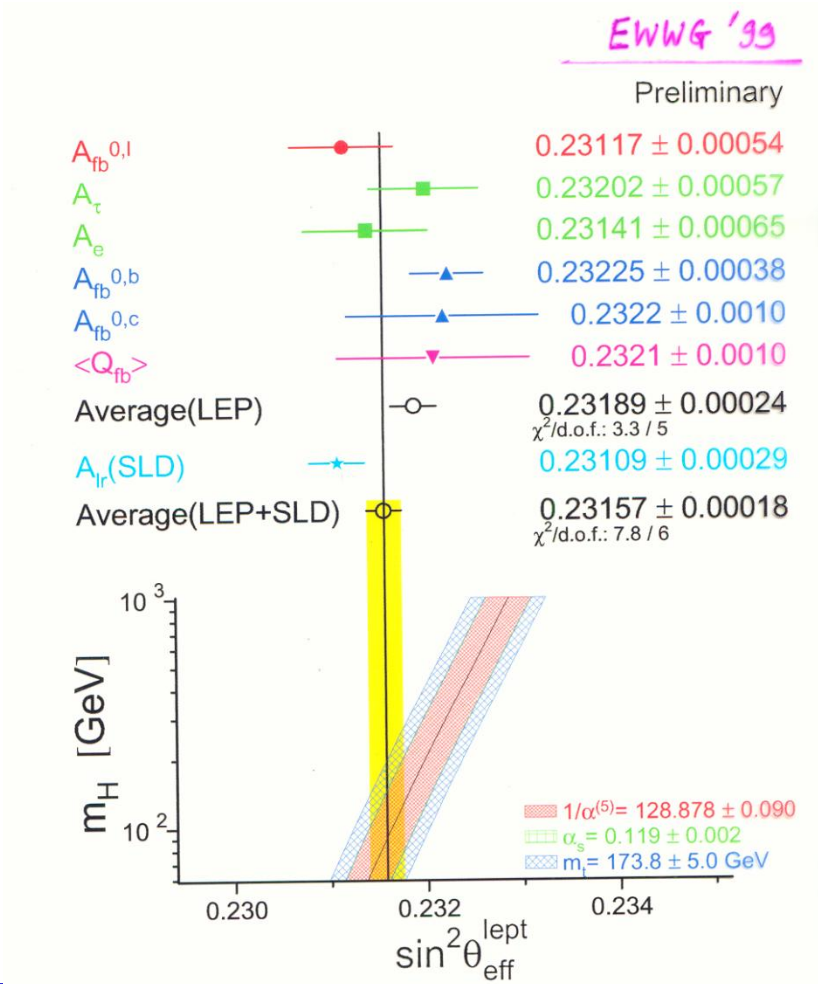
Figure 5: The χ^2 curves for the Standard Model fit in Table 24, column 3 to the electroweak precision measurements listed in Table 23 as a function of M_t for three different Higgs mass values spanning the interval $60 < M_H$ (GeV) < 1000.

Winter 2001

	Measurement	Pull
m_Z [GeV]	91.1875 ± 0.0021	.04
Γ_Z [GeV]	2.4952 ± 0.0023	-.46
σ^0_{hadr} [nb]	41.540 ± 0.037	1.62
R_l	20.767 ± 0.025	1.09
$A_{fb}^{0,l}$	0.01714 ± 0.00095	.79
A_e	0.1498 ± 0.0048	.41
A_τ	0.1439 ± 0.0041	-.96
$\sin^2\theta_{eff}^{lept}$	0.2322 ± 0.0010	.78
m_W [GeV]	80.446 ± 0.040	1.32
R_b	0.21664 ± 0.00068	1.32
R_c	0.1729 ± 0.0032	.20
$A_{fb}^{0,b}$	0.0982 ± 0.0017	-3.20
$A_{fb}^{0,c}$	0.0689 ± 0.0035	-1.48
A_b	0.921 ± 0.020	-.68
A_c	0.667 ± 0.026	-.05
A_l	0.1513 ± 0.0021	1.68
$\sin^2\theta_W$	0.2255 ± 0.0021	1.20
m_W [GeV]	80.452 ± 0.062	.95
m_t [GeV]	174.3 ± 5.1	-.27
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.36



LEP/SLC Rozne metody wyznaczania $\sin^2\theta_W$



Precyzyjne testy i poprawki radiacyjne

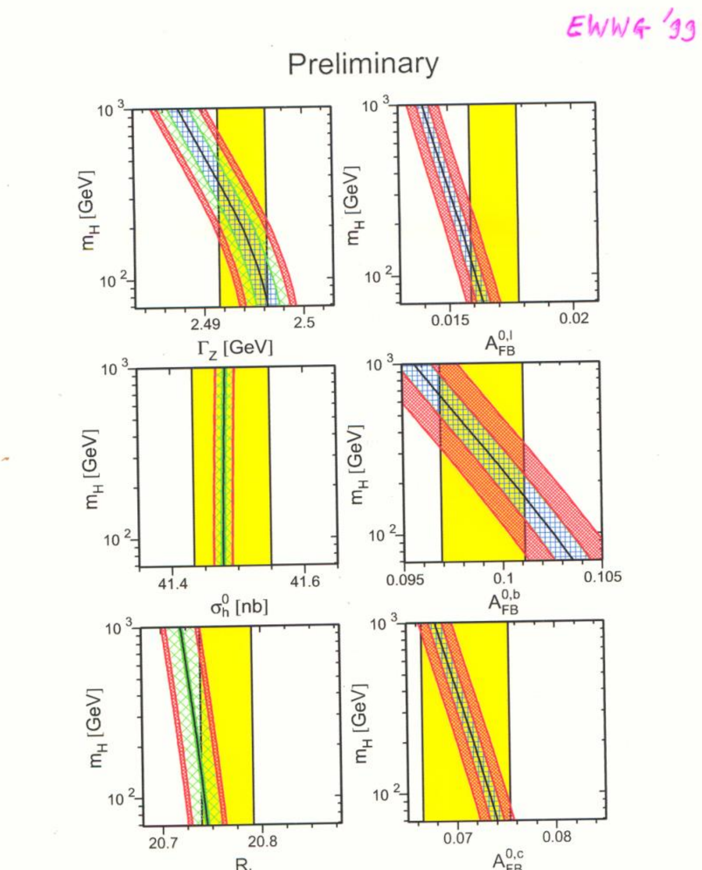


Figure 13: Comparison of LEP-I measurements with the Standard Model prediction as a function of m_H. The measurement with its error is shown as the vertical band. The width of the Standard Model band is due to the uncertainties in $\alpha(m_Z^2)$, $\alpha_s(m_Z^2)$ and m_t. The total width of the band is the linear sum of these effects. See Figure 14 for the definition of these uncertainties.

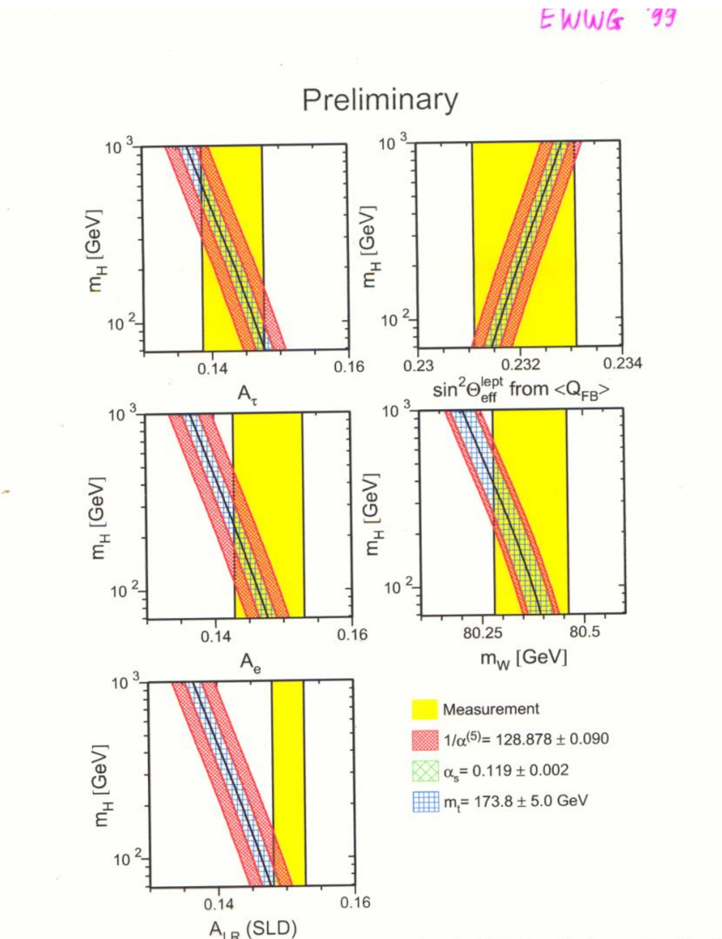


Figure 14: Comparison of LEP-I measurements with the Standard Model prediction as a function of m_H (*c.f.* Figure 13). Also shown is the comparison of the SLD measurement of A_{LR} with the Standard Model.

Zaleznosci miedzy m_t, m_W, m_H

2001

Test of the Standard Model

Use electroweak measurements at LEP1 and SLC $\Rightarrow$ indirect determination of m_{top} and M_W and constraint on M_H

$$\mathrm{Log}(M_H) = 1.94^{+0.34}_{-0.37}$$

$$M_H = 87^{+119}_{-43}\ \mathrm{GeV}$$

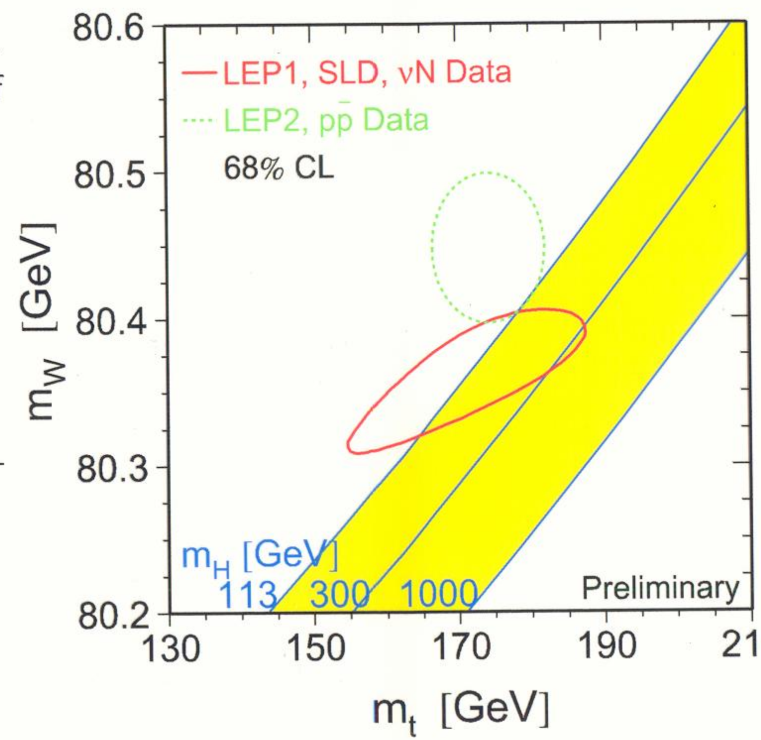
$$m_{top} = 168.3^{+11.9}_{-9.3}\ \mathrm{GeV}$$

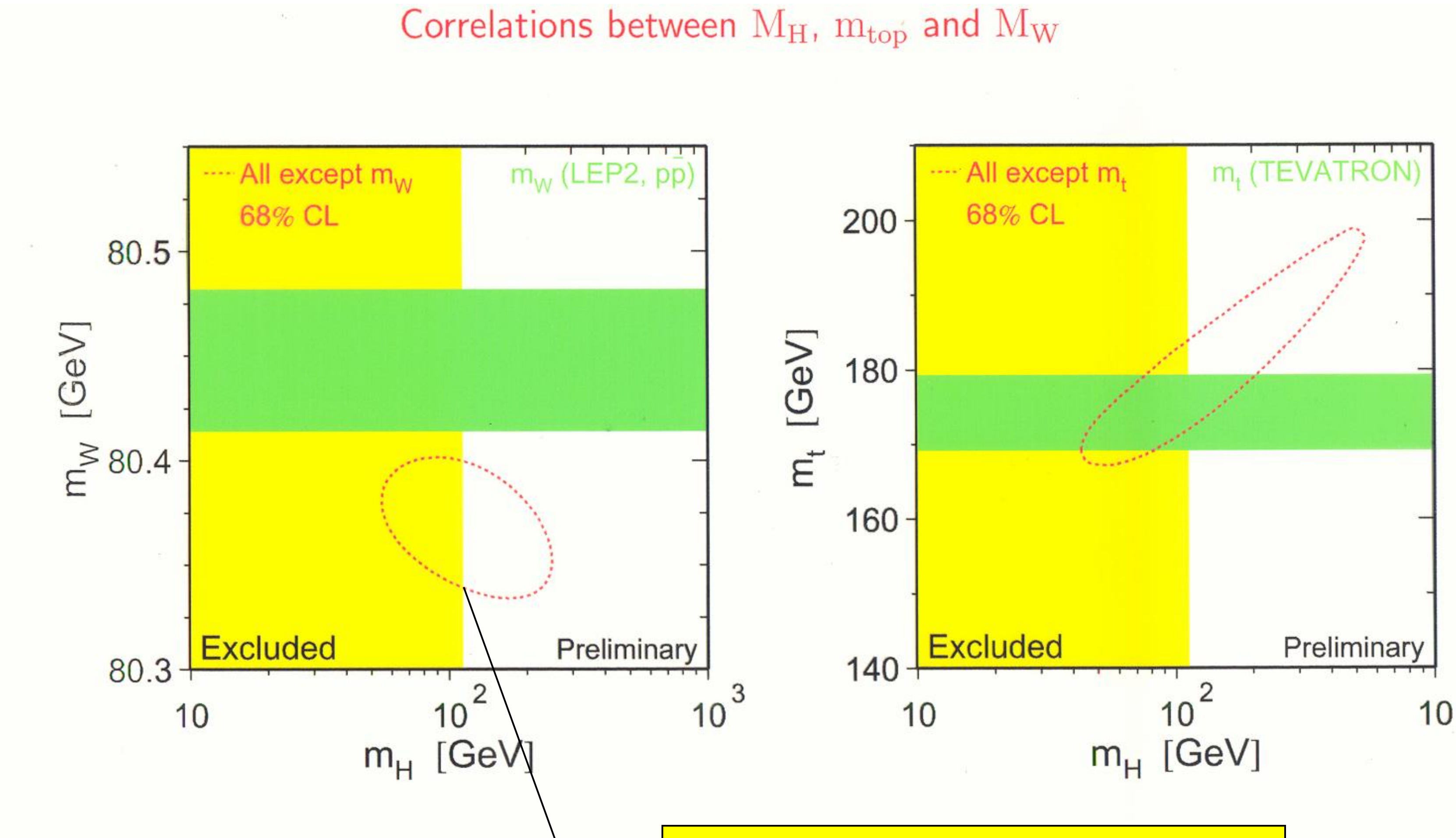
$$M_W = 80.357 \pm 0.033\ \mathrm{GeV}$$

Good agreement with the direct measurements:

$$m_{top} = 174.3 \pm 5.1\ \mathrm{GeV}$$

$$M_W = 80.448 \pm 0.034\ \mathrm{GeV}$$





$m_H > 114.5$ GeV/c^2

Masa Higgsa z globalnego dopasowania

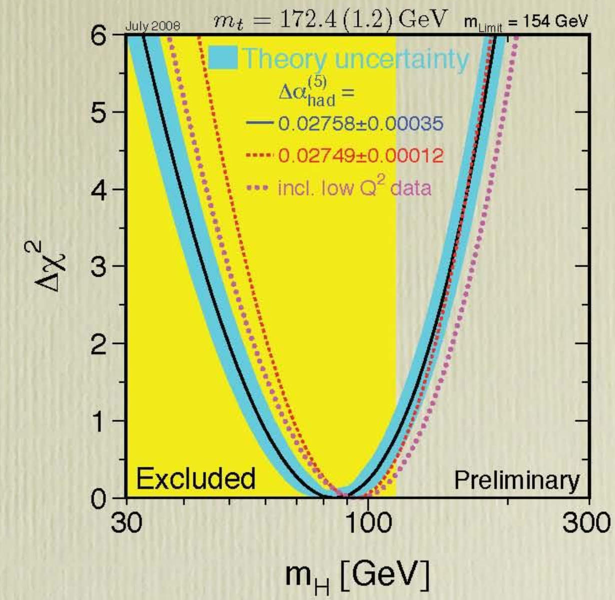
Global fit to the Higgs Model

[from the LEP EWWG]

The dependence upon the Higgs mass is logarithmic and comes in through loop effects

On the whole the Standard Model performs rather well, with a clear indication for a light Higgs

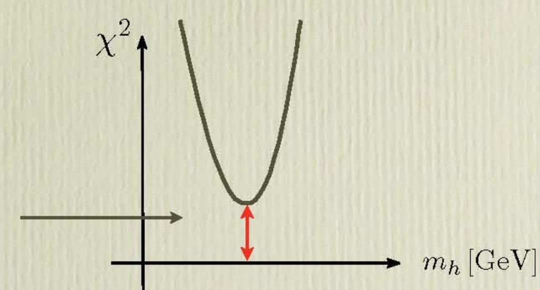
$m_h \lesssim 154\,\mathrm{GeV} \quad @\ 95\%\,\mathrm{CL}$



yet the fit is not entirely satisfactory:

P~4.5% $\qquad \dfrac{\chi^2_{min}}{ndf}(all) = \dfrac{28.0}{17}$

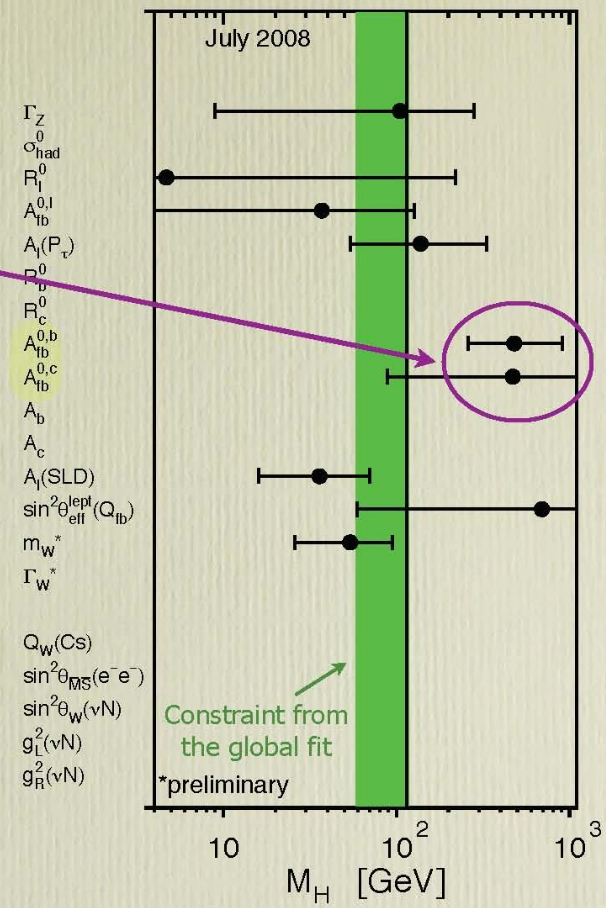
P~15% $\qquad \dfrac{\chi^2_{min}}{ndf}(only - high) = \dfrac{18.2}{13}$



Globalne dopasowanie i masa Higgsa

Best fit $m_h = 87^{+36}_{-27}$ GeV is the result of a tension between leptonic and hadronic asymmetries

Only the hadronic asymmetries (and the NuTeV result) push for a high Higgs mass



removing $A^{0,b}_{\rm fb}$ from the fit gives a better χ^2 but also :

$$m_h = 55^{+30}_{-20}\ \mathrm{GeV}$$

RÓŻNICZKOWE PRZEKROJE CZYNNE I ASYMETRIE

Rozniczkowe przekroje czynne i pomiar asymetrii

RÓŻNICZKOWE PRZEKROJE CZYNNE w e^+e^-

Oddziaływania elektromagnetyczne $\leftrightarrow$ prąd wektorowy

$$J_f^\mu = \bar{\psi}_f \gamma^\mu \psi_f \qquad \mathcal{P}: \; J_f^\mu \leftrightarrow -J_f^\mu, \quad A_\mu^{(*)} \leftrightarrow -A^{\mu(*)}$$

$$\mathcal{L}_{int} \propto -e^2 A_\mu^{(*)} J_f^\mu \qquad \mathcal{L}_{int} \leftrightarrow \mathcal{L}_{int}$$

rzeczywiste bądź wirtualne

Oddziaływania słabe z Z^0

$$\mathcal{L}_{int} \propto Z_\mu^{(*)} J_W^\mu \qquad \mathcal{P}: \; Z_\mu^{(*)} \leftrightarrow \pm Z_\mu^{(*)}, \quad J_{vf}^\mu \leftrightarrow -J_{vf}^\mu, \quad J_{af}^\mu \leftrightarrow +J_{af}^\mu$$

$$J_W^\mu = \bar{\psi}_f (\gamma^\mu \underline{v_f} - \gamma^\mu \gamma_5 \underline{a_f}) \psi_f = J_{vf}^\mu + J_{af}^\mu$$

$\frac{d\sigma}{d\cos\theta}$ parzysta

$\frac{d\sigma}{d\cos\theta}$ nieparzysta

$$A_\mu^{(*)} = \bar{\psi} \gamma_\mu^\mu \psi \, \frac{1}{k^2}$$

$$Z_\mu^* = \bar{\psi}(v\gamma_\mu - a\gamma_\mu\gamma_5)\psi \, \Pi(M_Z)$$

$$\frac{d\sigma}{d\cos\theta_f} = A\underbrace{(1+\cos^2\theta)}_{\int_{-1}^{1} d\cos\theta (\,) \neq 0} + \underbrace{B\cos\theta}_{\int_{-1}^{1} = 0}$$

W PRZYPADKU NIESPOLARYZOWANYM

- wymiana γ $V \cdot V$
- Dla Z^0 $(V\cdot V + A\cdot A)_e \cdot (V\cdot V + AA)_f$
- interferencja γZ $Q_f \, V_e \, V_f$

- Interferencja $\gamma \cdot Z$ $\Big\}$ $(V\cdot A + A\cdot V)$
- Interferencja $Z - Z$ $\Big\}$ $A\cdot V \cdot (A^2+V^2)$ etc....

Zależność od skrętności (polaryzacji) początkowych e^+ i e^- i/lub końcowego fermionu f

NIESPOLARYZOWANE e^+ i e^-

$$\frac{d\sigma_f}{d\cos\theta} = \frac{\pi\bar{\alpha}^2}{2s}\Big\{ Q_f^2 (1+\cos^2\theta) + $$

$$- 8 Q_f \, \chi(M_Z)\big(v_e v_f (1+\cos^2\theta) + 2 a_e a_f \cos\theta \big) + $$

$$+ 16 \chi^2(M_Z)\big((v_e^2 + a_e^2)(v_f^2 + a_f^2)(1+\cos^2\theta) + 8 v_e v_f a_e a_f \times \cos\theta \big) \Big\}$$

$$\chi(M_Z) = g \, \frac{s * M_Z}{s - M_Z^2} = \left(\frac{G_F}{8\sqrt{2}\pi\alpha}\right) \frac{s \cdot M_Z}{s - M_Z^2}$$

SPOLARYZOWANE e^+ (h^+) i e^- (h_-)

$$\frac{d\sigma_f(h_+, h_-)}{d\cos\theta} = (1 - h_+ h_-)\,\sigma_1 + (h^- - h^+)\,\bar{\sigma}_2$$

relat. e^+, e^- $\begin{cases} h^+ \sim 1 \\ h_- \sim -1 \\ h_f \sim -1 \end{cases}$

$$\sigma_1 = \frac{1}{2}\frac{d\sigma_f}{d\cos\theta}$$

$$\bar{\sigma}_2 = \frac{\pi\alpha^2}{2s}\chi(M_Z)\Big\{ 4 Q_f \big(v_f a_e (1+\cos^2\theta) + 2 a_f v_e \cos\theta \big) + $$

$$- 16\, \chi(M_Z)\big(v_e a_e (a_f^2 + v_f^2)(1+\cos^2\theta) + 2 a_f v_f (a_e^2 + v_e^2)\cos\theta \big) \Big\}$$

Asymetrie w rozpadach Z^0

ASYMETRIE W e^+e^-

Asymetria przód-tył A^f_{FB}

$$A^f_{FB} = \frac{\int_0^1 d\cos\theta \frac{d\sigma_f}{d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d\sigma_f}{d\cos\theta}}{\int_0^1 \frac{d\sigma_f}{d\cos\theta} d\cos\theta + \int_{-1}^0 \frac{d\sigma_f}{d\cos\theta} d\cos\theta} = \frac{F-B}{F+B}$$

$$A^f_{FB} = \frac{\frac{3}{2}\chi\left(4Q_f a_e a_f + 32 v_e a_e v_f a_f \chi\right)}{\left(Q_f^2 - 8 Q_f \chi v_e v_f + 16\chi^2 (a_e^2 + v_e^2)(v_f^2 + a_f^2)\right)} \quad \leq \pm 3/4$$

Asymetria polaryzacyjna A^f_{pol} $(\tau^\pm)$

$$A^f_{pol} = \frac{\int_{-1}^{1} d\sigma_f (h_f = -1) - \int_{-1}^{1} d\sigma_f (h_f = +1)}{\int_{-1}^{1} d\sigma_f (h_f = -1) + \int_{-1}^{1} d\sigma_f (h_f = +1)} = \frac{\sigma_{fL} - \sigma_{fR}}{\sigma_{fL} + \sigma_{fR}}$$

Asymetria lewo-prawo A^f_{LR}

$$e^-_{L,R} + e^+ \to f$$

SPOLARYZOWANA WIĄZKA e^- (SLC)

$$A^f_{LR} = \frac{\int_{-1}^{1} \sigma_L f - \int_{-1}^{1} \sigma_R f}{\int_{-1}^{1} \sigma_L f + \int_{-1}^{1} \sigma_R f}$$

Asymetrie w e^+e^-

ASYMETRIE W e^+e^-

Asymetria przód - tył A^f_{FB}

$$A^f_{FB} = \frac{\int_0^1 d\cos\theta \frac{d\sigma_f}{d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d\sigma_f}{d\cos\theta}}{\int_0^1 \frac{d\sigma_f}{d\cos\theta} d\cos\theta + \int_{-1}^0 \frac{d\sigma_f}{d\cos\theta} d\cos\theta} = \frac{F-B}{F+B}$$

$$A^f_{FB} = \frac{\frac{3}{2}\chi(4Q_f a_e a_f + 32 v_e a_e v_f a_f \chi)}{(Q_f^2 - 8 Q_f \chi v_e v_f + 16\chi^2(a_e^2+v_e^2)(v_f^2+a_f^2))} \leq |\pm 3/4|$$

Asymetria polaryzacyjna A^f_{pol} $(\tau^\pm)$

$$A^f_{pol} = \frac{\int_{-1}^1 d\sigma_f(h_f=-1) - \int_{-1}^1 d\sigma_f(h_f=+1)}{\int_{-1}^1 d\sigma_f(h_f=-1) + \int_{-1}^1 d\sigma_f(h_f=+1)} = \frac{\sigma_{fL} - \sigma_{fR}}{\sigma_{fL} + \sigma_{fR}}$$

Asymetria lewo-prawo A^f_{LR}

$$e^-_{L,R} + e^+ \to f$$

SPOLARYZOWANA WIĄZKA e^- (SLC)

$$A^f_{LR} = \frac{\int_{-1}^1 \sigma_L^f - \int_{-1}^1 \sigma_R^f}{\int_{-1}^1 \sigma_L^f + \int_{-1}^1 \sigma_R^f}$$

Z

Pomiar asymetrii przod-tyl w rozpadach $Z^0 \to b\bar{b}$ w LEPie

- Selekcja rozpadow Z→bbar
- Odrzucenie tla od innych rozpadow

P.Abreu et.al. Z.f.Phys. C65 (1995) 587

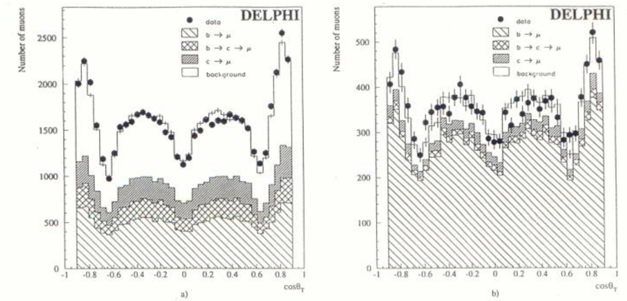


Fig. 5. $\cos\theta_T$ distributions for events from the muon sample in the low- and high-p_t regions below **a)** and above **b)** 1.6 GeV/c

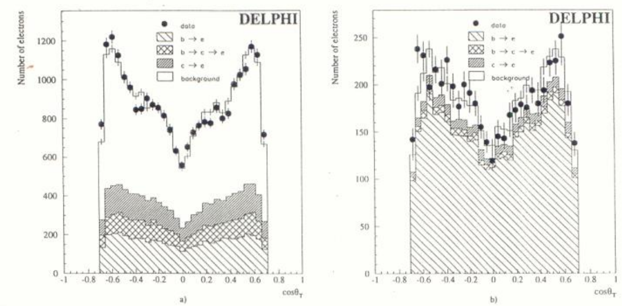


Fig. 6. $\cos\theta_T$ distribution for events from the electron sample in the low- and high-p_t regions below **a)** and above **b)** 1.6 GeV/c

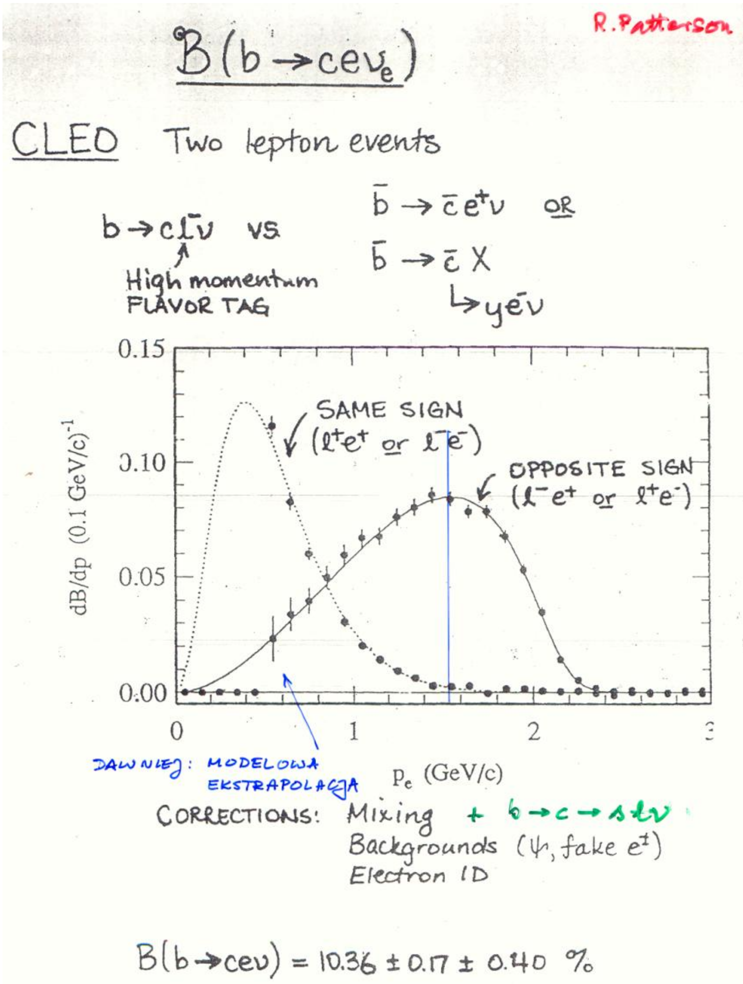
Table 1. Classes definition and composition of the lepton samples in different kinematical domains. (p_{tin} corresponds to the transverse momentum when the lepton is included in the jet. The p_t cuts are in GeV/c)

Type of process "x"		Value of their asymmetry A^x_{FB}	Composition of the samples in % for $l=\mu$ No cut	$p_t > 1.6$	$p_{tin} > 1$	for $l=e$ No cut	$p_t > 1.6$	$p_{tin} > 1$
f_b :	$b \to l^-$ $b \to \tau \to l^-$ $b \to \bar{c} \to l^-$ $b \to \bar{c} \to \tau^- \to l^-$	$A^{b\bar{b},exp}_{FB}$	31.9	75.3	72.3	29.7	78.8	76.0
f_{bc} :	$\bar{b} \to \bar{c} \to l^-$ $\bar{b} \to \bar{c} \to \tau^- \to l^-$	$-A^{b\bar{b},exp}_{FB}$	11.3	3.8	5.7	8.6	3.4	4.9
f_c :	$\bar{c} \to l^-$ $\bar{c} \to \tau^- \to l^-$	$-A^{cc}_{FB}$	15.1	6.0	4.7	12.0	5.2	4.2
f_{bg} :	Total Background	A^{bg}_{FB}	41.7	14.9	17.3	49.7	12.6	14.9
Number of data candidates			58633	13214	12921	30971	5379	5426

OZNACZANIE DŻETÓW B

- Za pomocą leptonów o dużych pędach (p_L lub p_t)
- Za pomocą detektorów wierzchołka

Znaczenie (tagowanie) dżetów b za pomocą leptonów



Metoda polega na znalezieniu wewnątrz dżetu leptonu o dużym pędzie lub pędzię poprzecznym do osi dżetu.

Oś dżetu jest wybrana poprzez jeden z algorytmów szukania dżetów np. używając zmiennej thrust T:

$$T = \max_{|\vec{n}|=1} \frac{\sum |\vec{n} \cdot \vec{p}_i|}{\sum |\vec{p}_i|}$$

$$1/2 < T < 1$$

Oznaczanie dżetów b za pomocą detektorów wierzchołka

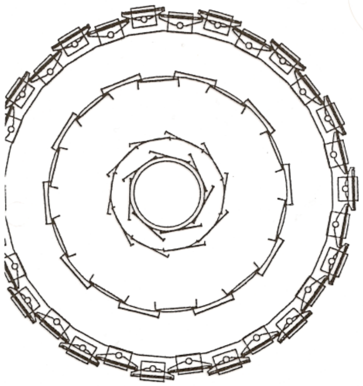
EPS - BRUSSELS C.TRONCON

Comparison of Vertex Detectors

Experiment	SLD-VXD3	CDF-SVXII	CLEOIII	DELPHI	H1-CST
layers	3	5	4	3	2
radii [cm]	2.8, 3.8, 4.8	2.4, 4.1, 6.5, 8.3, 10.2	2.5, 3.75, 7.5, 12.	6.3 (ds), 9 (ss), 10.9 (ds)	5.75, 9.7
active length [cm]	16	96	variable $\cos(\theta)$=.93	22.7, 22.7, 27.3	35
barrels	1	3	1	1	1
ϕ modularity	12, 16, 20	12	7, 10, 20, 30	24	12, 18
detectors	96	720	566	288	180
strip pitch rphi [μm] z [μm]	20 (CCD) 20 (CCD)	60, 62, 60, 60, 65 150, 133, 60, 150, 65	50 *n-side* 100 *p-side*	25 49.5, 99, 150; 42	25 88
readout pitch rphi [μm] z [μm]	20 (CCD) 20 (CCD)	60, 62, 60, 60, 65 150, 133, 60, 150, 65	50 100	50 49.5, 99, 150; 42, 84	50 88
detector area [cm^2]	8.0 × 1.6	7.8× (1.7, 2.5, 3.9, 4.7, 5.9)	5.12 × 2.56	8.0 × 1.9, 6 × 1.9 (ds) 5.8 × 2.6 (ss) 5.8 × 3.2 (ds)	5.63 × 3.20
detectors/ladder	2	4	4-12	4	6
S/N	20	14 (expect.)	48 - 15 (expect.)	13-18 (meas.)	15 (expect.)
spatial resolution $R\phi$[μm] z [μm]	5 6			7.6 9	
asymptotic I.P. resolution $R\phi$ [μm] z [μm]	*9 (exp.)*, 13 *14 (exp.)*, 35	~15	~15	20 (meas.) 39 (meas.)	~90 in 1995 ~60 1996

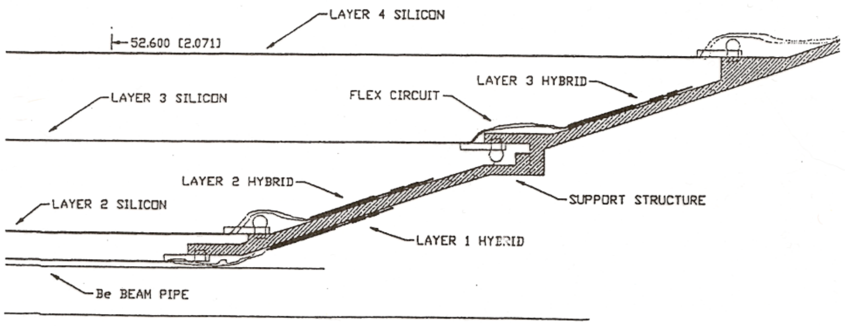
at 1 GeV/c

CLEO 3 SILICON VERTEX DETECTOR



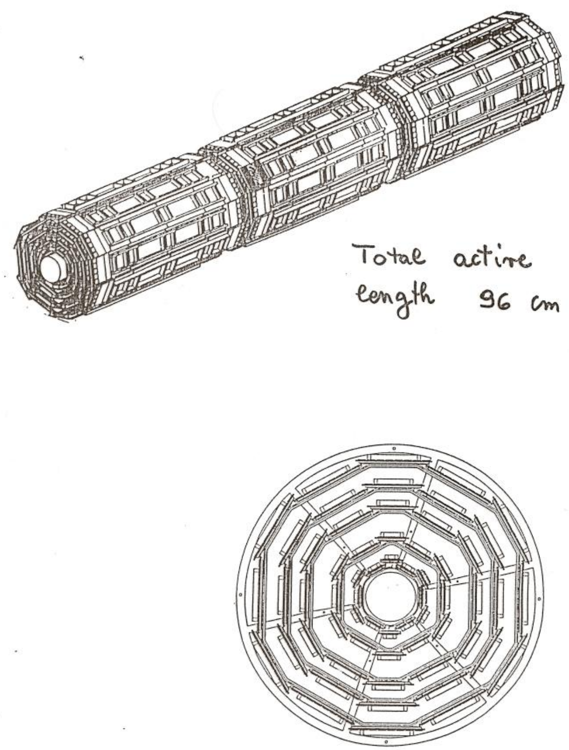
Layer	r (cm)	# detectors in ϕ	# detectors in Z	Σ
1	2.4	7 or 8	3 or 4	28
2	3.75	10	4	40
3	7.5	20	8	160
4	12.0	30	12	360

Σ 588 detectors



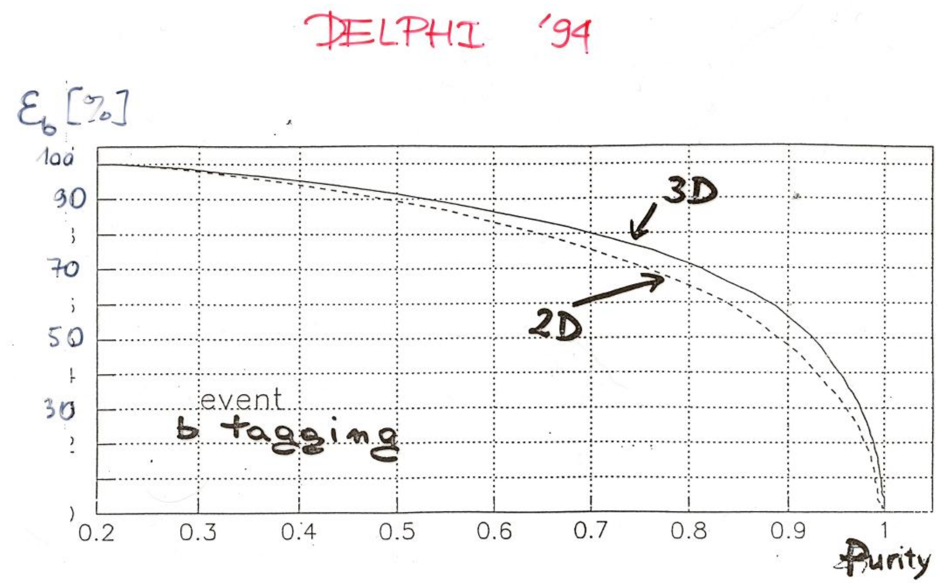
VTX detectors

CDF SVX II



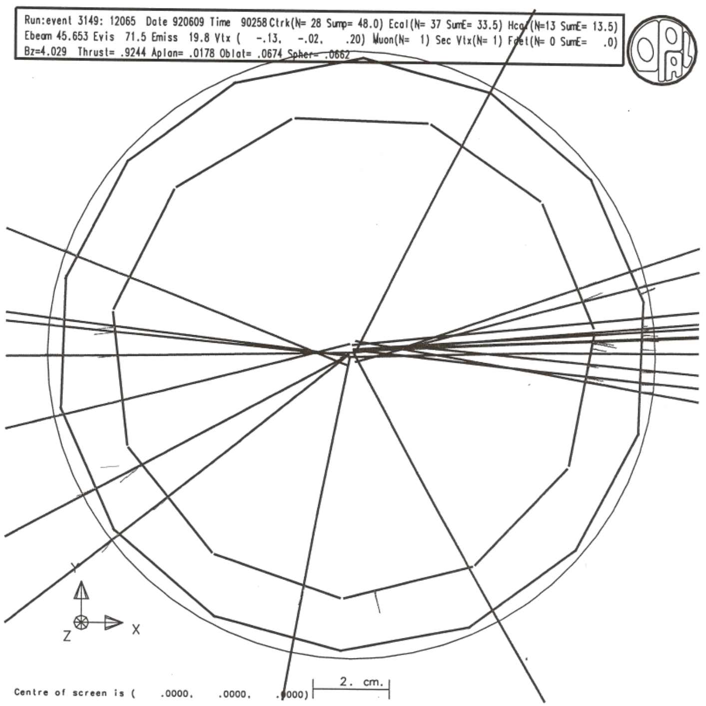
Tracks	4 layers SVX II	5 Layers SVX II
ε_t	97 ± 1%	99 ± 1%
axial purity	93 ± 1%	95 ± 1%
stereo purity	82 ± 1%	90 ± 1%

CDF - SVX II



Poszukiwanie wtórnego wierzchołka

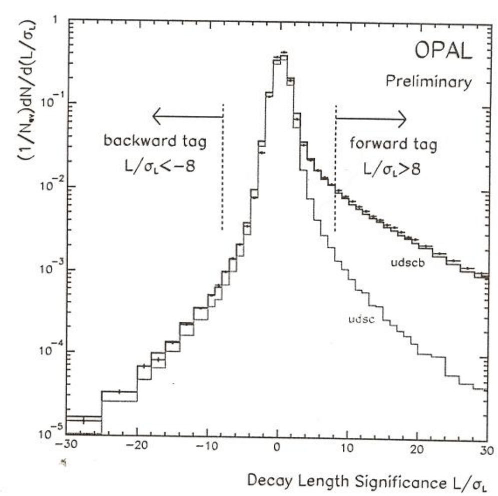
Double Lifetime Tagged Event



Secondary Vertex b Flavour Tag

Used by OPAL

- Reconstruct secondary vertices from tracks in each jet
- Reject vertices with fewer than four tracks
- Construct physics signed decay length significance



- Folded tag: subtract statistically backwards vertices from forwards vertices → reduces resolution uncertainties

Oznaczanie dżetów b

Impact Parameter Probability b Flavour Tag

- Construct "no-lifetime" probability for tracks with physics-signed impact parameter $b > 0$:

$$\mathcal{P}_T = \int_b^{\infty} \mathcal{R}(x)\,\mathrm{d}x$$

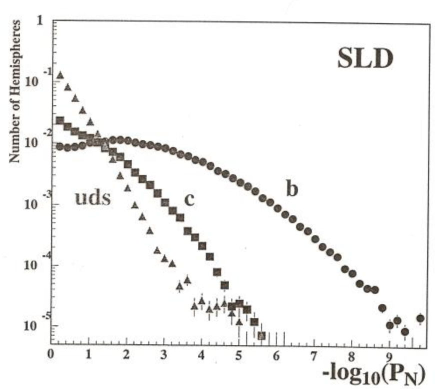
resolution function $\mathcal{R}$ measured from $b < 0$ distribution

- Construct joint probability for "no-lifetime" in the hemisphere:

$$\mathcal{P}_N \equiv \Pi \sum_{j=0}^{N-1} \frac{(-\ln \Pi)^j}{j!}$$

where

$$\Pi \equiv \prod_{i=1}^{N} (\mathcal{P}_T)_i$$



Used by ALEPH, DELPHI, SLD

POMIAR R_B=BR($Z^0 \rightarrow$B BBAR) W LEPIE

Metoda pomiaru R_b i R_c

METODA POMIARU R_b i R_c

- $e^+e^- \to Z^0 \to b\bar{b}$
- $e^+e^- \to Z^0 \to c\bar{c}$

• MUSIMY WYBRAĆ PRZYPADKI $b\bar{b}$ LUB $c\bar{c}$.
• EFEKTYWNOŚĆ WYBORU i CZYSTOŚĆ PRÓBEK MUSZĄ BYĆ DOBRZE ZNANE

METODY WYBORU PRÓBKI $b\bar{b}$

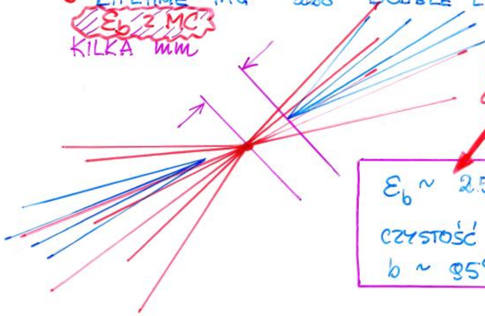
NIE POZWALA NA WYBRANIE CZYSTYCH $c\bar{c}$

• "LIFETIME TAG" albo "DOUBLE LIFETIME TAG"

ε_b Z MC

KILKA mm

ε_b Z DANYCH!



$\varepsilon_b \sim 25\%$
CZYSTOŚĆ PRÓBKI $b \sim 95\%$

• LEPTON (e,μ) O DUŻYM $(\gtrsim 1\text{-}2\ \mathrm{GeV/c})$ p_T WZGLĘDEM OSI DŻETU (OŚ T, S, ...)

$BR(\overset{(-)}{b} \to \ell^{\pm}\nu_\ell X) \approx 10\%$ ← ZNAJOMOŚĆ WIDMA $\ell^{\pm}$

$\varepsilon_b \sim 10\%$
CZYSTOŚĆ $\sim 90\%$

Widma $\ell^{\pm}$ z $b \to D^{**}\ell\nu$, $D^0\pi\ell\nu \ldots$ są inne ?

N_{tot} = LICZBA $Z^0 \to$ hadrony

DOUBLE TAG

N_b = LICZBA ZNALEZIONYCH DŻETÓW b

(JEŻELI ZNALEZIONO 2 DŻETY b W 1 PRZYPADKU ≡ LICZYMY 2 RAZY)

N_{bb} = LICZBA PRZYPADKÓW, W KTÓRYCH OBA DŻETY BYŁY ROZPOZNANE JAKO b.

$$\varepsilon_b = \frac{2N_{bb}}{N_b}$$

EFEKTYWNOŚĆ ZNALEZIENIA DŻETU b

$$R_b = \frac{N_b}{2N_{tot}\varepsilon_b} = \frac{N_b^2}{4N_{tot}N_{bb}}$$

• AKCEPTACJE N_{tot} i N_b SĄ W PRZYBLIŻENIU RÓWNE

• ZANIEDBUJEMY KORELACJE

• OBECNOŚĆ TŁA KOMPLIKUJE OBRAZ
→ DOMINUJĄCYM TŁEM JEST $Z^0 \to c\bar{c}$

Metoda pomiaru R_b i R_c

Uwzględniając korelacje

$N_t \equiv N$ "tagowanych", znaczonych dżetów

$N_{tt} \equiv N$ przypadków z 2 znaczonymi dżetami

$$R_t = \frac{N_t}{N_{tot}} = R_b \cdot \varepsilon_b + R_c\, \varepsilon_c + (1 - R_b - R_c)\, \varepsilon_{uds}$$

$$R_{tt} = \frac{N_{tt}}{N_{tot}} = R_b\, \varepsilon_{b\bar{b}} + R_c\, \varepsilon_{c\bar{c}} + (1 - R_c - R_b)\, \varepsilon_{uds\,\overline{uds}}$$

$$= R_b \left(\varepsilon_b^2 + \rho_b (\varepsilon_b - \varepsilon_b^2) \right) + R_c\, \varepsilon_c^2 + (1 - R_b - R_c)\, \varepsilon_{uds}^2$$

ε_b DUŻE ($\sim 20\%$)

ε_c, ε_{uds} małe → zaniedbujemy (ε_i^2) korelację

↓

ROZWIĄZUJEMY SZUKAJĄC R_b i ε_b

ZAKŁADAJĄC np R_c^{SM}

DELPHI '95

ε_c, ρ_b, ε_{uds} z symulacji

$(1.7 \pm 0.03 \pm 0.16) \times 10^{-2}$

$(-0.26 \pm 0.15 \pm 0.09) \times 10^{-2}$

$(0.323 \pm 0.006 \pm 0.024) \times 10^{-2}$

$\Delta R_b = -0.13 (R_c - R_c^{SM})$

$R_b = 0.2224 \pm 0.0027 \pm 0.0034 \pm 0.018 (R_c)$

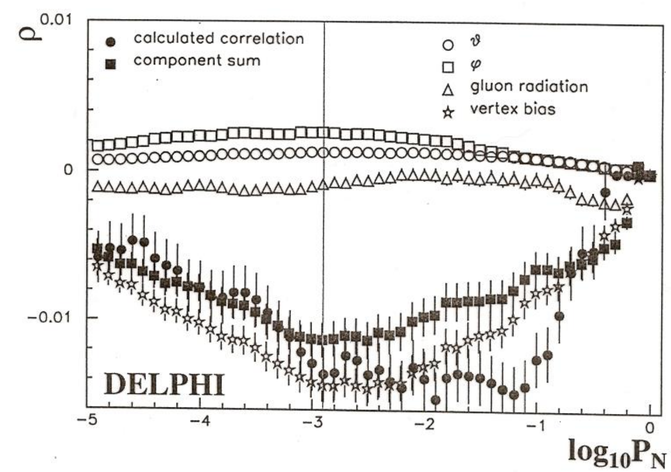
$\varepsilon_b = 0.201 \pm 0.003$ (MC : 0.195)

Total efficiency correlation ρ:

$$\rho = \frac{(C_b(\varepsilon^b)^2 - \varepsilon^b)}{(\varepsilon^b - (\varepsilon^b)^2)}$$

typically:

- ρ −1% to −2% for IP probability tag
- ρ +0.2% for secondary vertex tag



Systematics from statistics, residual MC-data differences

Metoda pomiaru R_b i R_c

METODY WYBORU PRÓBKI $c\bar{c}$

- WYBÓR $D^{*\pm}$ O DUŻYM PĘDZIE W JEDNYM Z DŻETÓW ($b \to D^{*\pm}$ małe)

  O LIFETIME / p_T^{ℓ} / KSZTAŁT PRZYPADKU SĄ KRYTERIAMI POMOCNICZYMI c/b

$f(c \to D^{*\pm})$ NIE JEST DOBRZE ZNANE

CZYSTY SYGNAŁ $D^{*\pm} \to D^0 \pi_S^{\pm}$!

- D^0 LUB $D^{\pm}$

WYŻSZE TŁO, ALE LEPIEJ ZNANE $f(c \to D^{0\pm})$

- PRÓBKA $Z^0 \to b\bar{b}$ JEST INKLUZYWNA
- PRÓBKA ($Z^0 \to D^{*\pm}_X, D^{0\pm}_X$) JEST EKSKLUZYWNA.
- WYZNACZENIE $Z^0 \to c\bar{c}$ WYMAGA WIĘC ZNAJOMOŚCI $f(c \to D^{*\mp})$ LUB $f(c \to D^{\pm 0})$ I STOSUNKÓW ROZGAŁĘZIEŃ (np z CLEO)

$$R_c = \frac{N(D^*)}{N_{tot}(hadr)} \frac{1}{f(c \to D^*)}$$

ZANIEDBANIE PRODUKCJI NP Σ_c, (barionów powab...

POWODUJE PODWYŻSZENIE $f(c \to D^*)$, A WIĘC $R_c \searrow$

Charm Systematics

Production fractions

- Tagging probability of different c hadron species differs (lifetime)
- From D^+ to Λ_c^+, typically factor four difference
- Take from CLEO and ARGUS measurements

$$f(D^0) : f(D^+) : f(D_s^+) : f(\Lambda_c^+) =$$
$$0.557 : 0.248 : 0.120 : 0.075$$

- Variations according to CLEO/ARGUS errors

$f(D^0)$ ± 0.053; $f(D^+)$ ± 0.037;
$f(D^0 + D^+)$ ± 0.070; $f(D_s^+)$ ± 0.050

- LEP measurements now competitive: consistent with above numbers (see talk by M.Hauschild)

Decay multiplicity

MARK III measurements (Phys.Lett.B263(1991)1)

- D^0,D^+,D_s^+ mean charged decay multiplicities and distributions
- $B(D \to K^0 (\text{or } \overline{K}^0) X)$

Add a large error on mean charge multiplicity for unmeasured Λ_c^+ (± 0.5 on mean about JETSET prediction)

Metoda pomiaru R_b i R_c

DELPHI

LEPTON TAG

- $b \to \begin{pmatrix} B_d^{\pm} \\ B_d^0 \\ B_s^0 \\ \Lambda_b \ldots \\ B^{**} \end{pmatrix} \to \begin{pmatrix} D^{**} \ell \nu \\ D^{0\pm} \ell \nu \\ \underbrace{D^{\pm}\pi}_{D^*} \ell \nu \end{pmatrix}$ SYMULACJA a'la Isgur-Wise...

$\frac{D^{**}}{D^0 + D^* + D^{**}} \sim 32\%$ CLEO

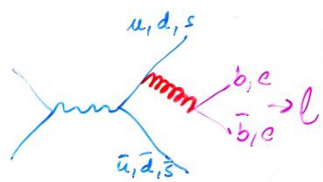
ZAMIAST 11% z ISGW

- 1) $b \to \ell^- X$

2) $b \to \tau^- X \to \ell^- X$
$b \to \bar{c} X \to \ell^- X$

3) $b \to c X \to \ell^+ X$

4) $c \to \ell^+ X$
$c \to \tau^+ X \to \ell^+ X$



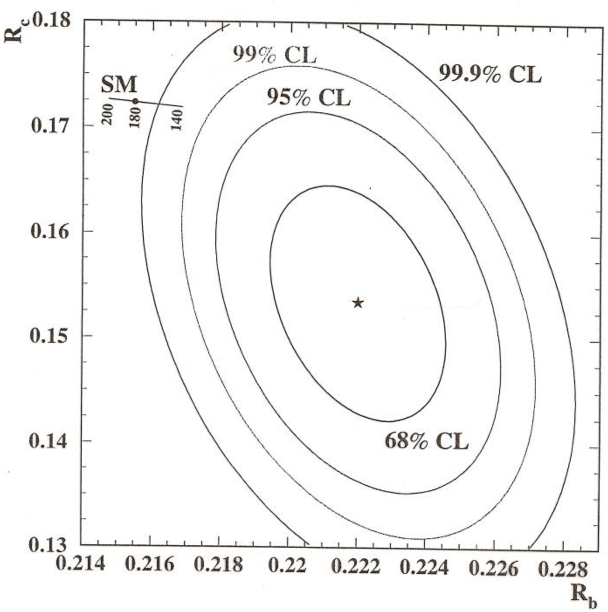
5) $J/\psi \to \mu\mu,\ ee$
$c\bar{c},\ b\bar{b} \to \ell$ $c\bar{c}$ albo $b\bar{b}$ w KASKADZIE

6) lekkie hadrony $\to \ell$
lekkie hadrony błędnie zidentyfikowane jako $\ell^{\pm}$

Wynik R_b i R_c

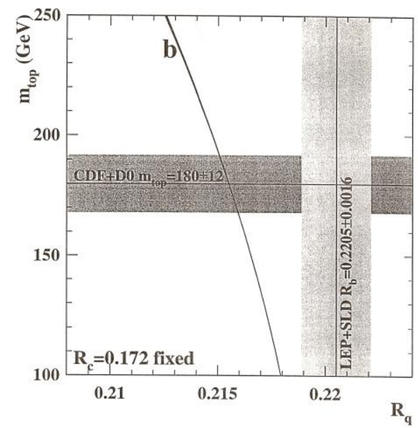
Antykorelacja dwóch mierzonych wielkości

Comparison with Standard Model: R_c vs. R_b



$\Delta\chi^2$ between best fit with Standard Model R_b and R_c ($m_{top} = 180$ GeV, $R_b = 0.2155, R_c = 0.172$), and best overall fit, is 16.0

Comparison with Standard Model: R_c Fixed



Standard Model predictions from ZFITTER 4.9:
m_{Z^0}=91.1888 GeV, 60 GeV < m_H < 1000 GeV,
$\alpha_s(m_{Z^0})$=0.12, $\alpha(m_{Z^0})$=1/128.67

For $m_{top} = 180 \pm 12$ GeV, Standard Model prediction
$R_b = 0.2155 \pm 0.0005$

SLC: ASYMETRIA POLARYZACYJNA

(Tylko) taon jest swoim własnym polarymetrem

NIESPOLARYZOWANE e^+, e^-
MIERZYMY POLARYZACJĘ
h_f KOŃCOWEGO FERMIONU

relatywistycznego f
$h_f \sim -1$

$$\frac{d\sigma_f(h_f)}{d\cos\theta} = \sigma_1 + h_f\,\sigma_2$$

$$\sigma_1 = \frac{1}{2}\frac{d\sigma_f}{d\cos\theta}$$

σ_2 otrzymujemy z $\bar{\sigma}_2$ przez zamianę stałych sprzężenia
$(v_e, a_e) \leftrightarrow (v_f, a_f)$

$$\sigma_2 = \frac{\pi\alpha^2}{2s}\,\chi(M_Z)\Big\{4Q_f\big(v_e a_f(1+\cos^2\theta) + 2a_e v_f\cos\theta\big) +$$

$$- 16\,\chi(M_Z)\big(v_f a_f(v_e^2+a_e^2)(1+\cos^2\theta) + 2a_e v_e(v_f^2+a_f^2)\cos\theta\big)\Big\}$$

POLARYZACJA $\tau^{\pm}$

$$\frac{d\sigma_f}{d\cos\theta} = \sigma_1 + h_f\,\sigma_2$$

$$\mathbb{P}_f = \langle h_f \rangle = -\mathbb{P}_{\bar f} = -\langle h_{\bar f}\rangle = \frac{\sigma_2}{\sigma_1} = \mathbb{P}_f(s, \cos\theta)$$

$$\mathbb{P}_\tau^0 = -\,\frac{\mathcal{A}_\tau(1+\cos^2\theta) + 2\mathcal{A}_e\cos\theta}{1+\cos^2\theta + 2\mathcal{A}_\tau\mathcal{A}_e\cos\theta}$$

ZANIEDBANE γ, γ-Z, poprawki radiacyjne.

$\sim -\mathcal{A}_\tau$

Pomiar $\tau \to e\nu\bar\nu,\ \mu\nu\bar\nu,\ \pi\nu,\ \rho\nu,\ a_1\nu,\ \pi\nu$, $K\nu$

Rozkład kątowy cząstki naładowanej jest skorelowany ze spinem τ

Przykładowo: $x_i = \dfrac{p_i}{p_{beam}} = \dfrac{p_i}{E_{beam}}$

- $\tau^- \to \begin{pmatrix} e^- \\ \mu^- \end{pmatrix} \bar\nu_{e,\mu}\,\nu_\tau$ 3-CIAŁOWY BR ~17%

$$\frac{1}{N_\ell}\frac{dN_\ell}{dx_\ell} = \frac{1}{3}\left[5 - 9x_\ell^2 + 4x_\ell^3 + \mathbb{P}_\tau(1 - 9x_\ell^2 + 8x_\ell^3)\right]$$

(+ efekty poprawek radiacyjnych)

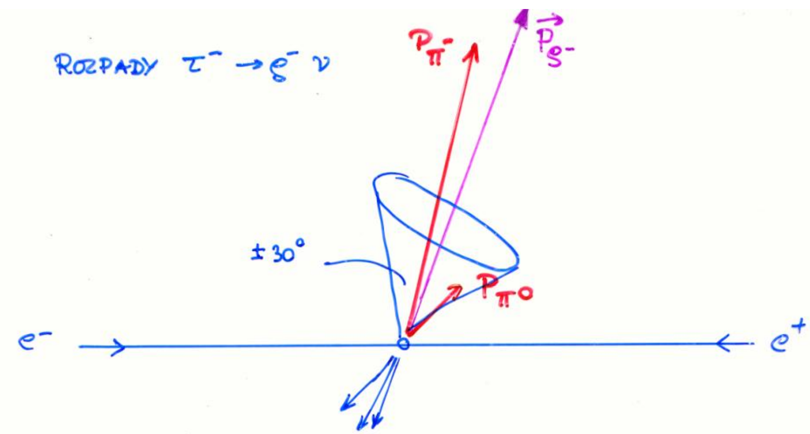
- $\tau^- \to \begin{pmatrix} \pi^- \\ K^- \end{pmatrix} \nu_\tau$ ROZPAD 2-CIAŁOWY BR ~ 11% ($7\cdot10^{-3}$)

$$\frac{1}{N_\pi}\frac{dN_\pi}{dx_\pi} = 1 + \mathbb{P}_\tau(2x_\pi - 1)$$

- $\tau^- \to \rho^-\nu_\tau$, $\rho^- \to \pi^-\pi^0$ ROZPAD 2-CIAŁOWY BR ~ 22%

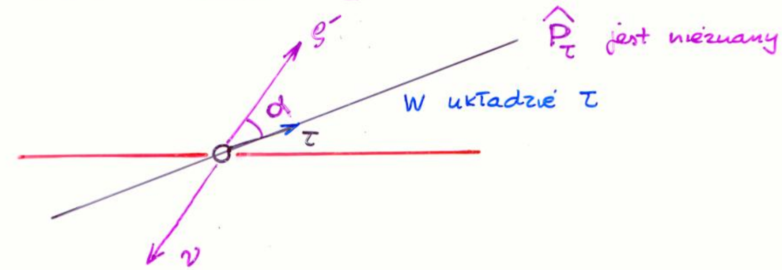
Y.S. Tsai Phys. Rev D4 (1971) 2821
D13 (1976) 771 (erratum)

ROZPADY $\tau^- \to \rho^-\nu$

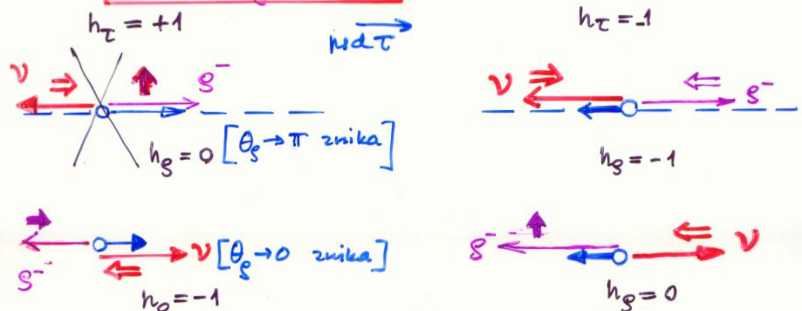


$$|\vec{P}_{\rho^-}|^{max} = E_{beam} \qquad x_\rho = \frac{P_\rho}{E_{beam}}$$

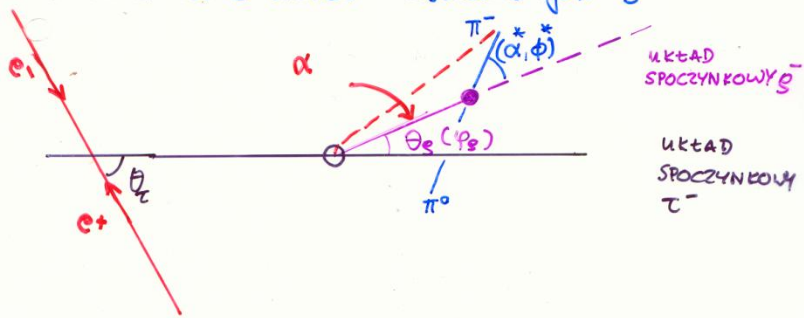
$$|\vec{P}_\tau| = E_{beam} = \frac{M_Z}{2}$$



POLARYZACJA τ cd



→ Wkład od 2 stanów skrętnościowych ρ^-



$$|M|^2 \propto \cos^2\alpha^*(1+P\cos\theta_\rho) + \frac{m_\rho^2}{m_\tau^2}\sin^2\alpha^*(1-P\cos\theta_\rho) +$$

$$-2\frac{m_\rho}{m_\tau}P\sin\theta_\rho\sin\alpha^*\cos\alpha^*\cos\phi^* \leftarrow$$ ZCAŁKOWANE PO KĄTACH

$$\boxed{\frac{1}{N_\rho}\frac{dN_\rho}{d\cos\theta_\rho} = 1 + P_\tau\, a\cos\theta_\rho} \qquad a = \frac{m_\tau^2 - 2m_\rho^2}{m_\tau^2 + 2m_\rho^2} \approx 0.46$$

W układzie spoczynkowym taonu

$$\cos\theta_\rho = \frac{2x_\rho - 1 - m_\rho^2/m_\tau^2}{1-(m_\rho/m_\tau)^2} \qquad \cos\alpha = \frac{m_\rho}{\sqrt{m_\rho^2 - 4m_\pi^2}}\,\frac{E_{\pi^-}-E_{\pi^0}}{|\vec{P}_{\pi^-}+\vec{P}_{\pi^0}|}$$

DELPHI, Z. Phys. C55 (1992) 555

$\tau^\pm \to \rho\,\nu$

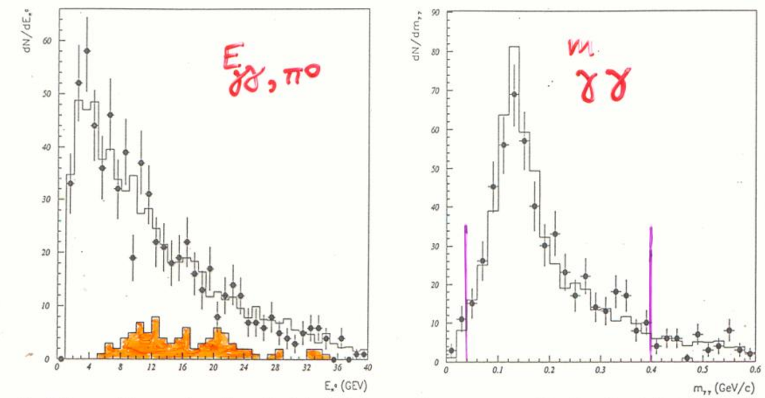


Fig. 7. Energy of the neutral particle produced in the decay $\tau^- \to \rho^-\nu_\tau$, $\rho \to \pi\pi^0$ for data (points with error bars) and Monte Carlo simulation (solid line); the shaded area corresponds to the contribution of the energetic π^0 (the two photons are not resolved into two neutrals but identified using the first three layers of the HPC)

Fig. 8. Invariant mass of the π^0 candidates (with the two resulting photons identified as two separate neutral particles in the HPC) for data (points with error bars) and Monte Carlo simulation (solid line)

$BR(\tau^- \to \rho^-\nu) = (22.4 \pm 0.8 \pm 1.3)\%$; $P_\tau = -0.24 \pm 0.09 \pm 0.07$

τ^- ~700 przyp.

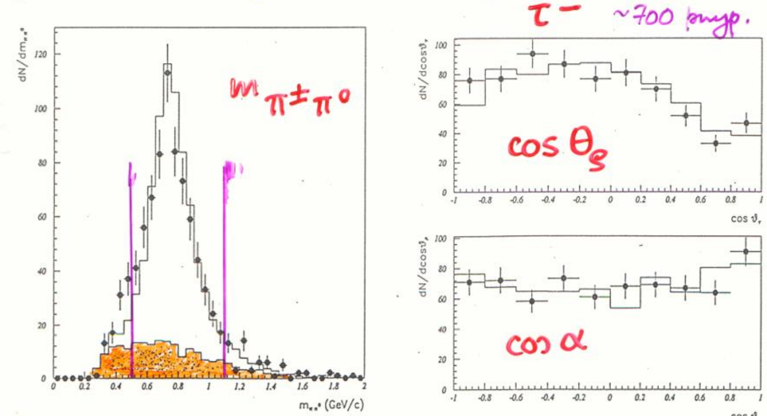


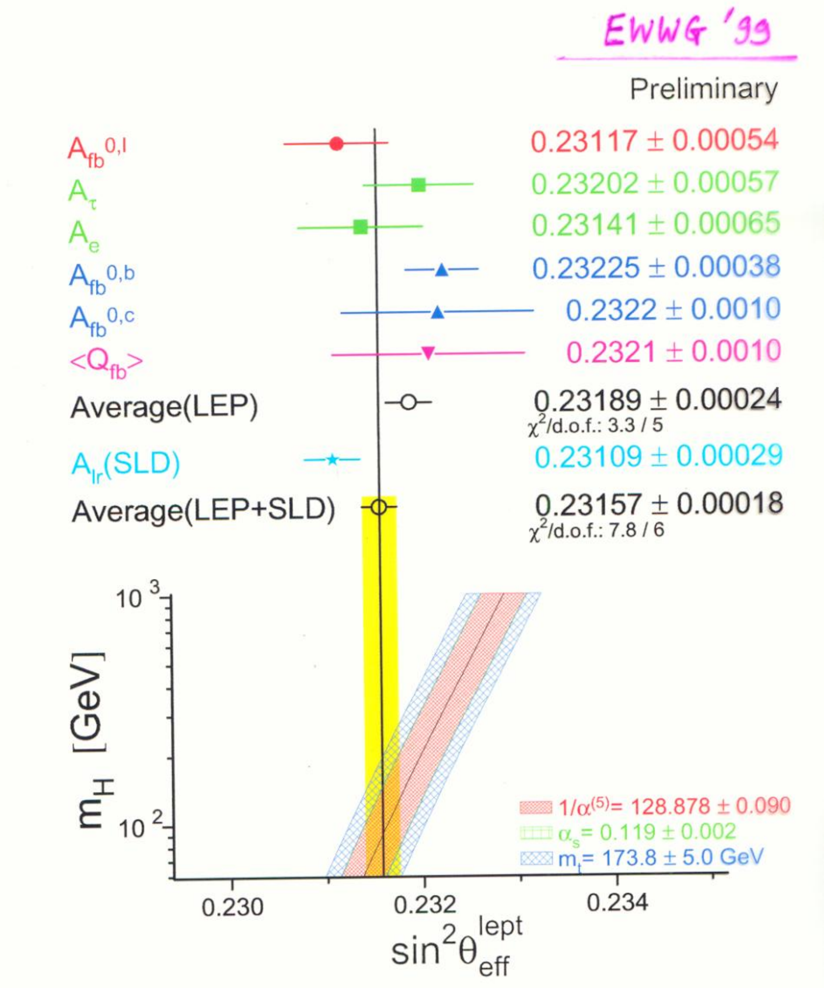
Fig. 9. Invariant mass of the ρ candidates for data (points with error bars) and Monte Carlo simulation (solid line) after the cut on π^0 mass. The shaded area corresponds to the background

Fig. 10. Raw distributions of $\cos\theta_\rho$ and $\cos\theta_\pi$ in $\tau^- \to \rho^-\nu_\tau$ events. The data are the points with error bars. The Monte Carlo prediction for $P_\tau = -0.16$ is superimposed

V.2 $\sin^2\Theta_W$ z oddziaływań neutrin (Tevatron)

LEP/SLC Rozne metody wyznaczania $\sin^2\theta_W$

LEP/SLC

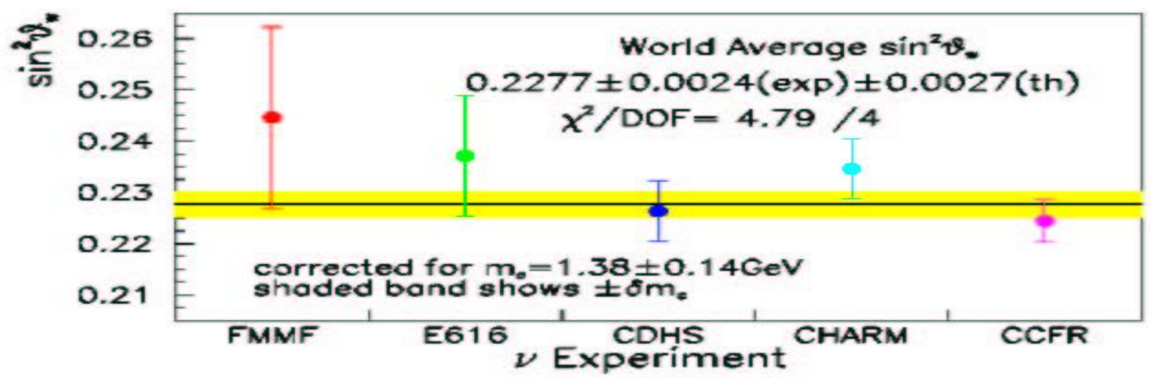


- Pomiar NUTEV „ciągnie" kąt Weiberga do dołu.
- Jest to pomiar przy niższych energiach i obarczony innymi błędami systematycznymi.

1.Zestawienie wyników $\sin^2 \theta_W$ z eksperymentów neutrinowych

$$\sin^2 \theta_W^{\text{on-shell}} \equiv 1 - \frac{M_W{}^2}{M_Z{}^2} = 0.2277 \pm 0.0036$$

$$\Rightarrow M_W = 80.14 \pm 0.19 GeV$$



NuTeV: $\sin^2 \theta^{\text{on-shell}}_W = 0.2277 \pm 0.0013 \pm 0.0009$

Wynik N1uTeV (PRL 88,091802,2002)

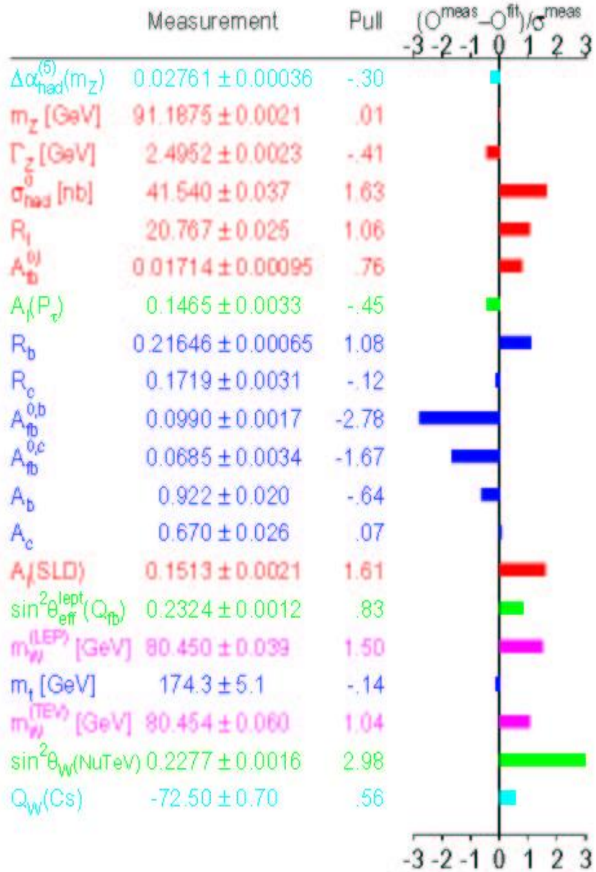
$$\sin^2 \theta^{on\text{-}shell}{}_W = 0.2277 \pm 0.0013 \pm 0.0009$$

$$-0.00022\left(\frac{m_t{}^2 - (175\,\mathrm{GeV})^2}{(50\,\mathrm{GeV})^2}\right) +$$

$$+0.00023 \times \ln\left(\frac{m_H}{150\,\mathrm{GeV}}\right)$$

LEP EWWG:

$$\sin^2 \theta_W = 0.2227 \pm 0.0004$$



(Courtesy M. Grunewald, LEPEWWG)

Without NuTeV: $\chi^2/\mathrm{dof} = 21.5/14$, probability of 9.0%

With NuTeV: $\chi^2/\mathrm{dof} = 30.5/15$, probability of 1.0%

Upper m_{Higgs} limit weakens slightly

Precyzyjne testy MS + wyniki NuTeV

Precyzyjny pomiar $s^2{}_W$ poprzez

$$R_\nu = \frac{\sigma^{NC}{}_\nu}{\sigma^{CC}{}_\nu}$$

$$R_\nu = g_L{}^2 + g_R{}^2\, r$$

$$R_{\bar\nu} = g_L{}^2 + \frac{g_R{}^2}{r}$$

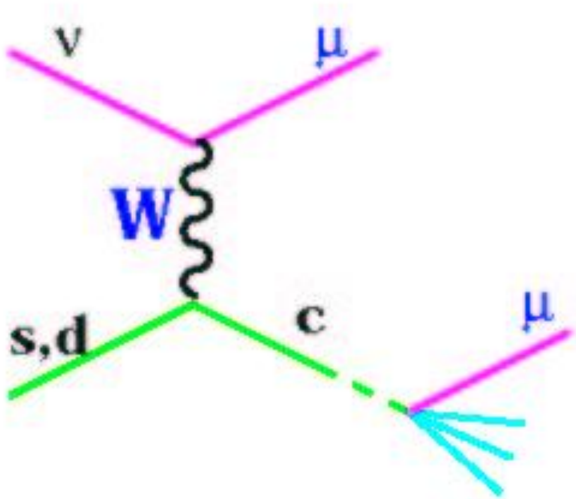
gdzie

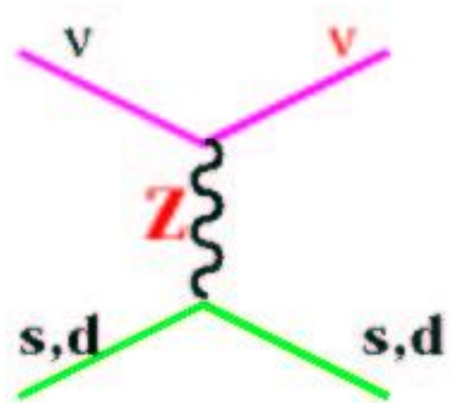
$$r = \frac{\sigma^{CC}{}_{\bar\nu}}{\sigma^{CC}{}_\nu} \approx \frac{1}{2}$$

oraz w przybliżeniu:

$$\boxed{\begin{aligned} g_L{}^2 &\approx \frac{1}{2} - \sin^2\theta_W + \frac{5}{9}\sin^4\theta_W \\ g_R{}^2 &\approx \frac{5}{9}\sin^4\theta_W \end{aligned}}$$

Produkcja cząstek powabnych tylko w próbce *CC*





Dokładniej...

Mierzymy stosunek przekrojów czynnych na NC do przekrojów na CC dla neutrin i antyneutrin. Przekroje czynne zależą od scałkowanych po

{x, Q^2} funkcji struktury. Dokładna analiza wymaga więc symulacji rozkładów wielkości mierzalnych używając f.s. W NuTeV używano f.s zmierzonych przez CCFR, poprawianych (i dostrajanych) na (do) wiele(u) efektów m.i.:

- poprawki na nieizoskalarność żelaznej tarczy,
- stosunek d/u
- efekty wyższych twistów,
- morze kwarków dziwnych,
- tłumienie produkcji cz. powabnych w CC,
- ewolucje f.s dla małych Q^2 (nie mierzonych przez CCFR).

Te poprawki i dostrojenia są niezbędne i kluczowe.

Co się mierzy w eksprymentach neutrinowych?

W wiązkach neutrin i neutrin mierzymy:

$$\mathbf{R_{exp}} = \frac{\#\,\text{krótkich przypadków}}{\#\,\text{długich przypadków}} = \frac{\#\,\text{kandydatów NC}}{\#\,\text{kandydatów CC}}$$

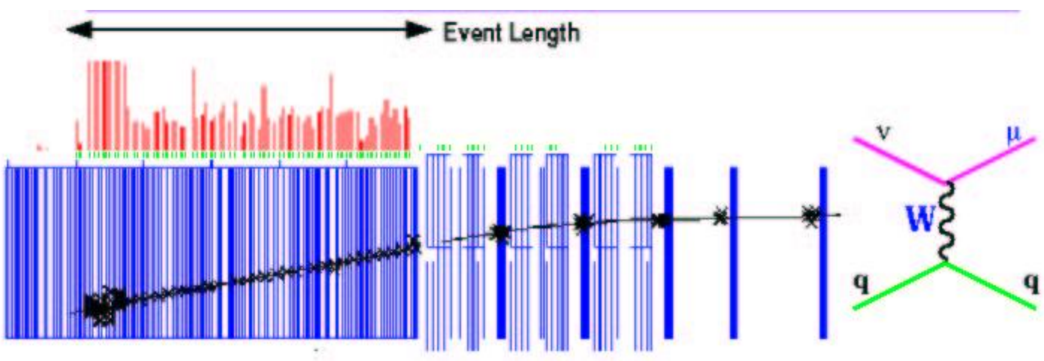
NuTeV zmierzył

dla neutrin (1.6×10^6 przypadków): **0.3916 ± 0.0007**

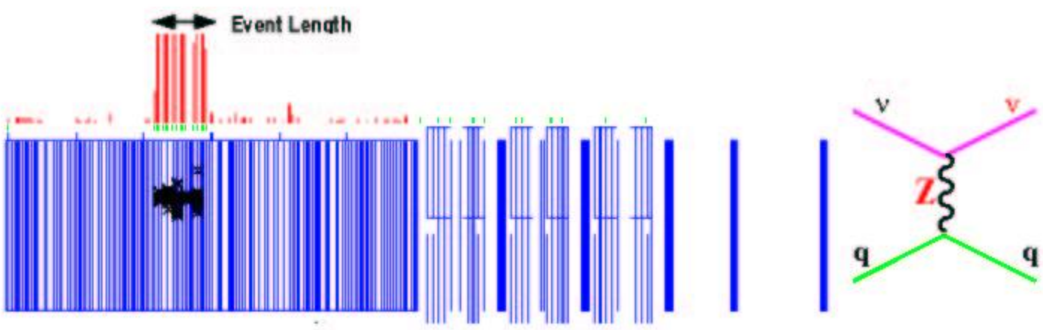
dla antyneutrin (0.36×10^6 przypadków): **0.4050 ± 0.0016**

$\sin^2\theta_W$ otrzymujemy z w/w poprzez szczegółowy rachunki MC (widmo padających neutrin, przekroje czynne i f.s., detektor).

Krótkie i długie przypadki

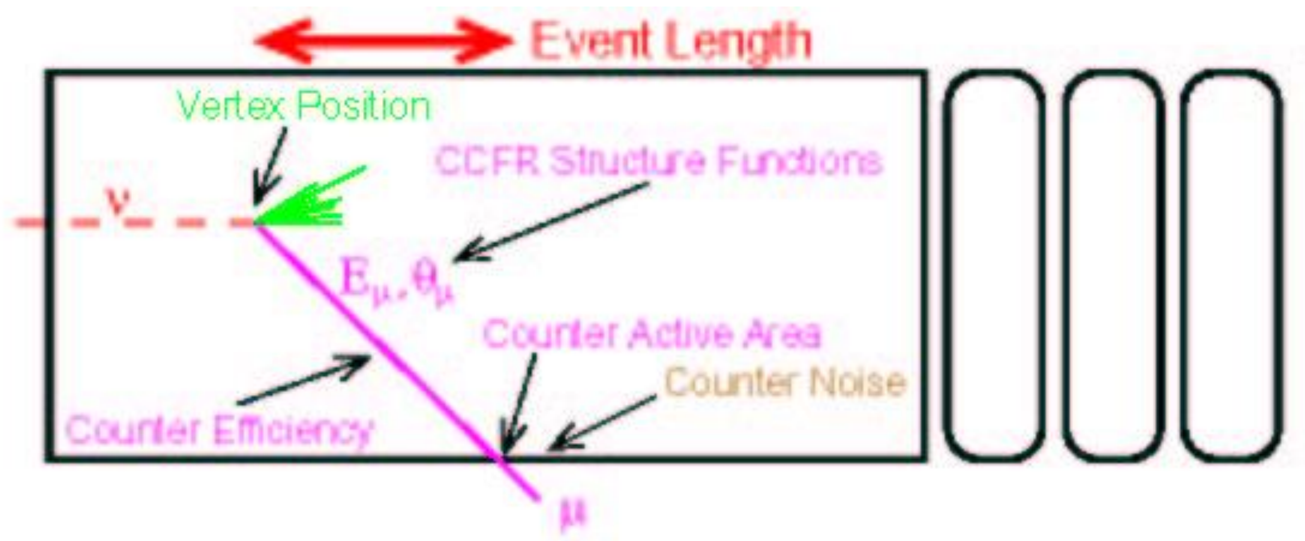


CC: Neutrina albo antyneutrina mionowe

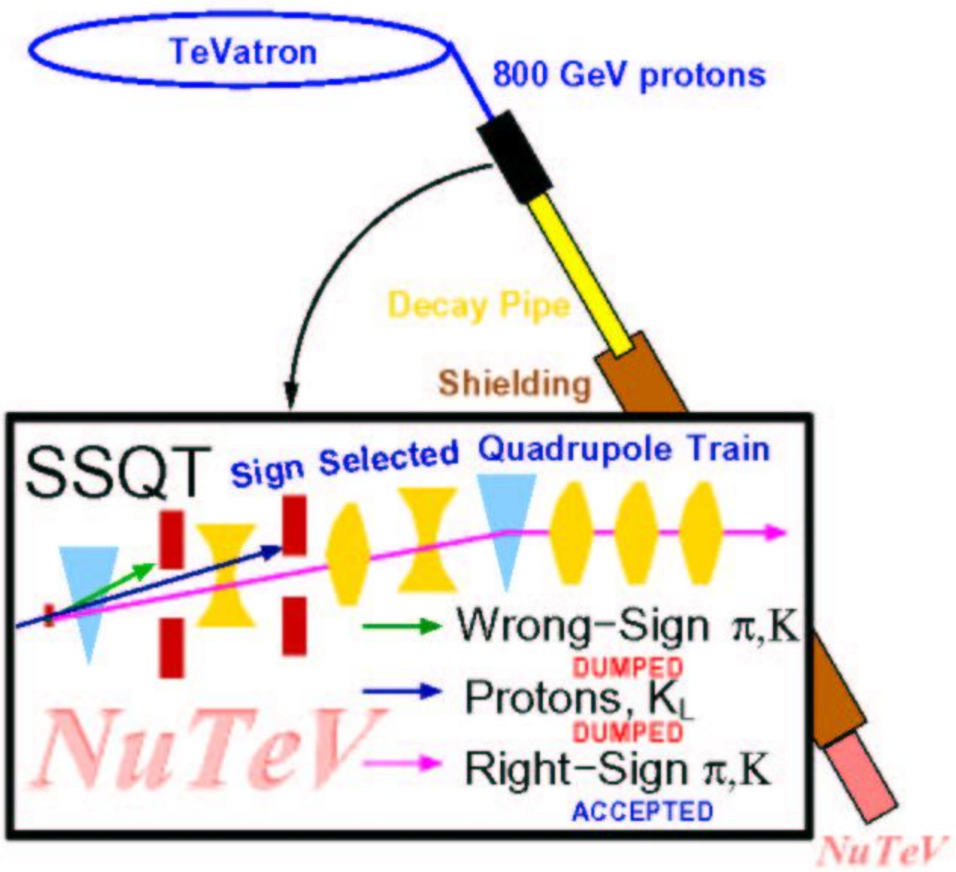


Nie rozróżniamy NC neutrin mionowych i (NC+CC) elektronowych. Nie rozróżniamy neutrin od antyneutrin.

Model oddziaływań CC i NC w detektorze służy do wyznacznenia R^{ν} i $R^{\nu bar}$ z mierzonych R^{ν}_{exp} i $R^{\nu bar}_{exp}$

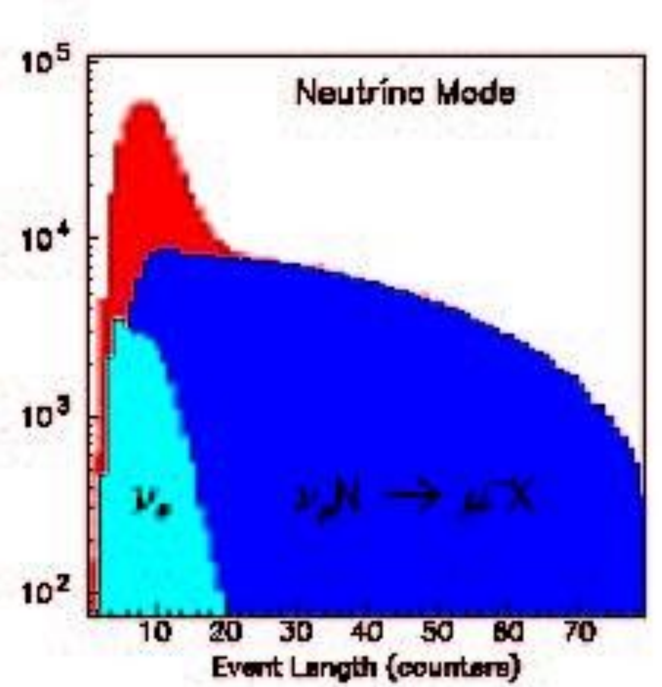


WIĄZKA NEUTRIN W FNAL

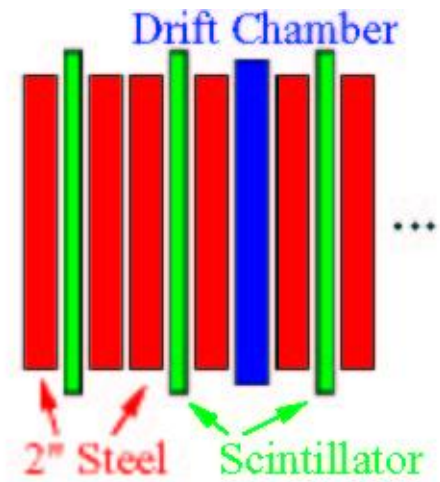


WIĄZKA NEUTRIN W FNAL contd.

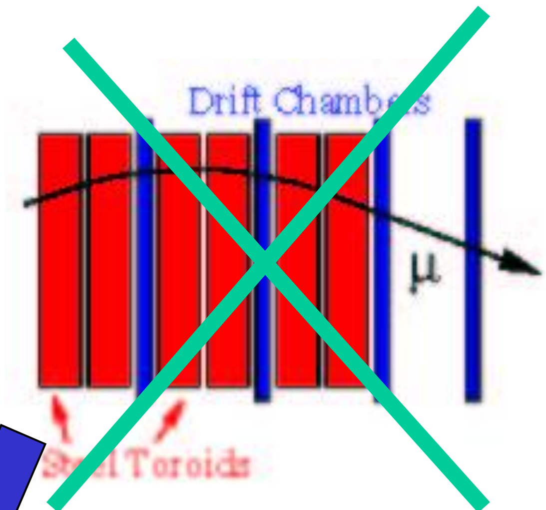
Skład wiązki neutrinowej w funkcji długości przypadku

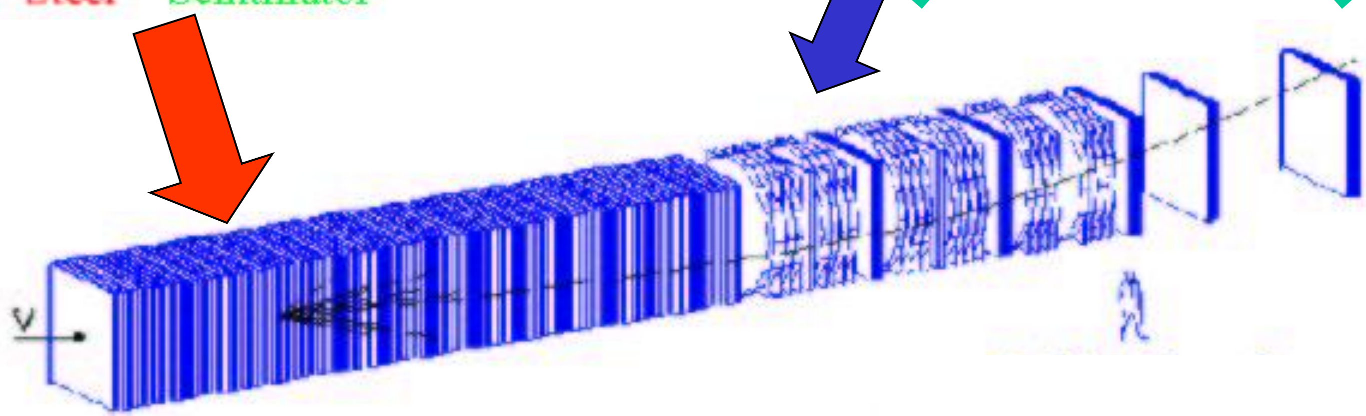


Detektor NuTeV



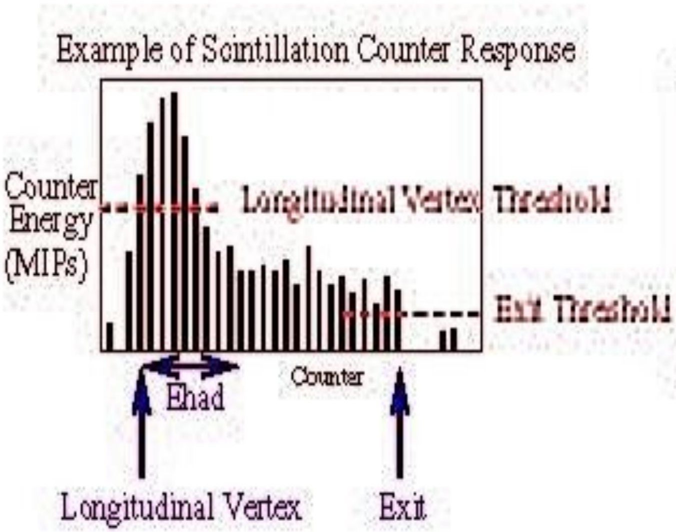
Dlugość 18 m
$3 \times 3\ m^2$
Masa tarczy 690 t

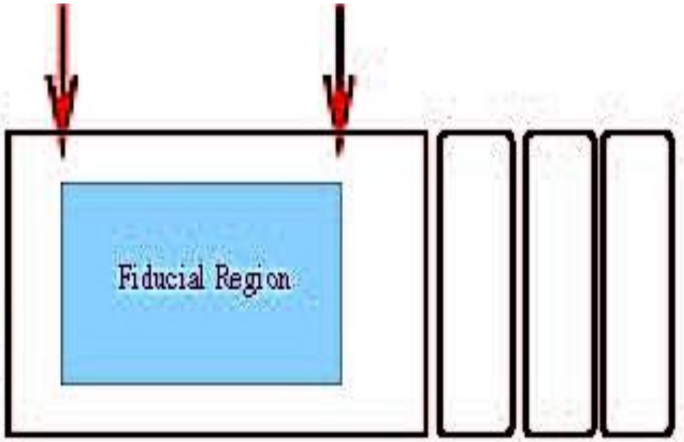




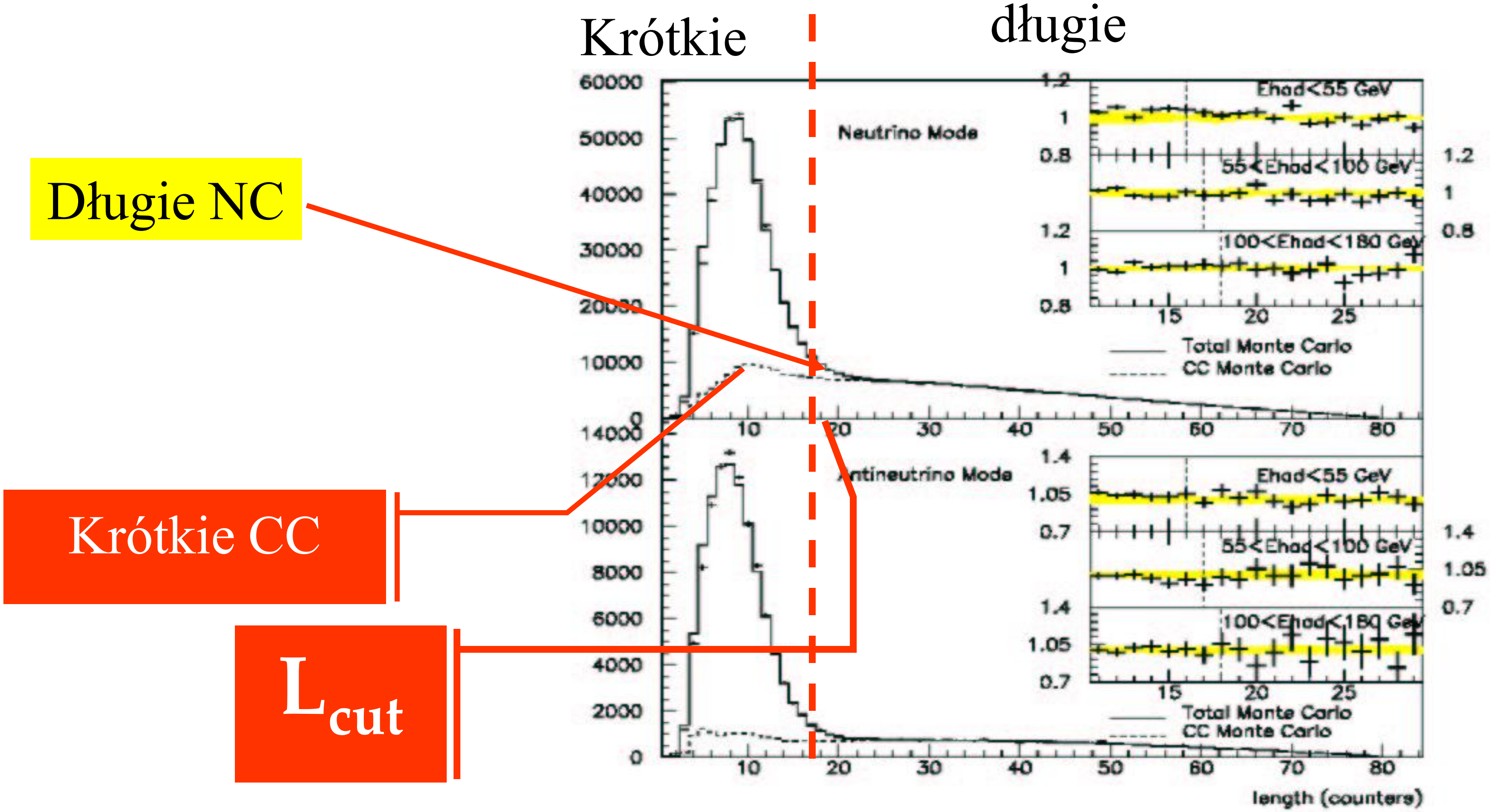
ANALIZA cd.

Selekcja przypadków





ANALIZA


Krótkie
długie
Długie NC
Krótkie CC
L_{cut}
Neutrino Mode
Antineutrino Mode
Ehad<55 GeV
55<Ehad<100 GeV
100<Ehad<180 GeV
Total Monte Carlo
CC Monte Carlo
length (counters)

ANALIZA cd.

Zmienne, których używano w analizie:

- energia hadronowa,
- położenie wierzchołka oddziaływania wzdłuż kalorymetru,
- położenie wierzchołka oddziaływania w pł. poprzecznej,
- koniec przypadku,
- długość przypadku.

Stabilność wyniku analizowano ze względu na w/w zmienne. Niewielkie niestabilności posłużyły do wyznaczenia poprawek i błędów systematycznych wyniku.

ANALIZA cd.

Poprawki obliczone metodami MC:

Effects in Monte Carlo that relate $R^{\overset{(-)}{\nu}}$ to $R^{\overset{(-)}{\nu}}_{\mathrm{exp}}$

Effect	$\delta R^{\nu}_{\mathrm{exp}}$	$\delta R^{\overline{\nu}}_{\mathrm{exp}}$
Short CC Background	−0.068	−0.026
Electron Neutrinos	−0.021	−0.024
Long NC	+0.0028	+0.0029
Counter Noise	+0.0044	+0.0016
Counter Efficiency	−0.0008	−0.0008
Longitudinal Vertex Offset	−0.0015	−0.0010
Heavy m_c	−0.0010	−0.0024
R_L	−0.0026	−0.0092
EM Radiative Correction	+0.0074	+0.0109
Weak Radiative Correction	−0.0005	+0.0058
High Q^2 "Longexit"	+0.00021	−0.00035
d/u	−0.00023	−0.00023
Higher Twist	−0.00012	−0.00013
Intrinsic Charm Sea	−0.00005	+0.00004

Recall: R^{ν}_{exp} and $R^{\overline{\nu}}_{\mathrm{exp}}$ measured to a precision of 0.0012 and 0.0026, respectively

ANALIZA cd.

STATYSTYKA

	Short (NC) Events	Long (CC) Events
ν	457K	1167K
$\bar{\nu}$	101K	250K

	$R_{\mathrm{exp}} \equiv$ Short Events/Long Events
ν	$0.3916 \pm 0.0007(\mathrm{stat})$
$\bar{\nu}$	$0.4050 \pm 0.0016(\mathrm{stat})$

ANALIZA cd.

Wynik

z dokładnością

do 0.7%

(syst. 0.4%)

$$\sin^2 \theta^{\text{on-shell}}_W = 0.2277 \pm 0.0013 \pm 0.0009$$

$$-0.00022 \left(\frac{m_t^2 - (175\,\text{GeV})^2}{(50\,\text{GeV})^2} \right) +$$

$$+0.00023 \times \ln\left(\frac{m_H}{150\,\text{GeV}} \right)$$

ANALIZA cd.

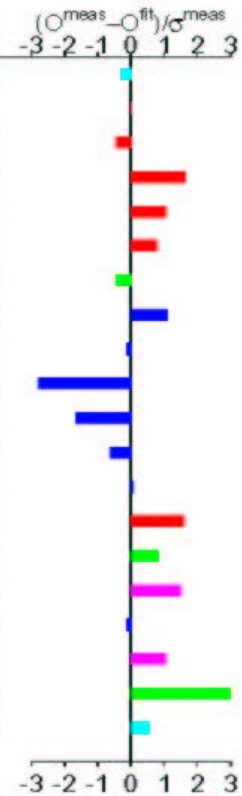
Niepewności systematyczne

0.1%=0.00022

SOURCE OF UNCERTAINTY	$\delta\sin^2\theta_W$	δR^{ν}_{exp}	$\delta R^{\bar\nu}_{exp}$
Data Statistics	0.00135	0.00069	0.00159
Monte Carlo Statistics	0.00010	0.00006	0.00010
TOTAL STATISTICS	0.00135	0.00069	0.00159
$\nu_e, \bar\nu_e$ Flux	0.00039	0.00025	0.00044
Energy Measurement	0.00018	0.00015	0.00024
Shower Length Model	0.00027	0.00021	0.00020
Counter Efficiency, Noise, Size	0.00023	0.00014	0.00006
Interaction Vertex	0.00030	0.00022	0.00017
TOTAL EXPERIMENTAL	0.00063	0.00044	0.00057
Charm Production, $s(x)$	0.00047	0.00089	0.00184
Charm Sea	0.00010	0.00005	0.00004
$\sigma^{\bar\nu}/\sigma^{\nu}$	0.00022	0.00007	0.00026
Radiative Corrections	0.00011	0.00005	0.00006
Non-Isoscalar Target	0.00005	0.00004	0.00004
Higher Twist	0.00014	0.00012	0.00013
R_L	0.00032	0.00045	0.00101
TOTAL MODEL	0.00064	0.00101	0.00212
TOTAL UNCERTAINTY	0.00162	0.00130	0.00272

Wynik NuTeV a inne pomiary

	Measurement	Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.30
m_Z [GeV]	91.1875 ± 0.0021	.01
Γ_Z [GeV]	2.4952 ± 0.0023	-.41
σ^0_{had} [nb]	41.540 ± 0.037	1.63
R_l	20.767 ± 0.025	1.06
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.76
$A_l(P_\tau)$	0.1465 ± 0.0033	-.45
R_b	0.21646 ± 0.00065	1.08
R_c	0.1719 ± 0.0031	-.12
$A^{0,b}_{fb}$	0.0990 ± 0.0017	-2.78
$A^{0,c}_{fb}$	0.0685 ± 0.0034	-1.67
A_b	0.922 ± 0.020	-.64
A_c	0.670 ± 0.026	.07
A_l(SLD)	0.1513 ± 0.0021	1.61
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	.83
$m_W^{(LEP)}$ [GeV]	80.450 ± 0.039	1.50
m_t [GeV]	174.3 ± 5.1	-.14
$m_W^{(TEV)}$ [GeV]	80.454 ± 0.060	1.04
$\sin^2\theta_W$(NuTeV)	0.2277 ± 0.0016	2.98
Q_W(Cs)	-72.50 ± 0.70	.56



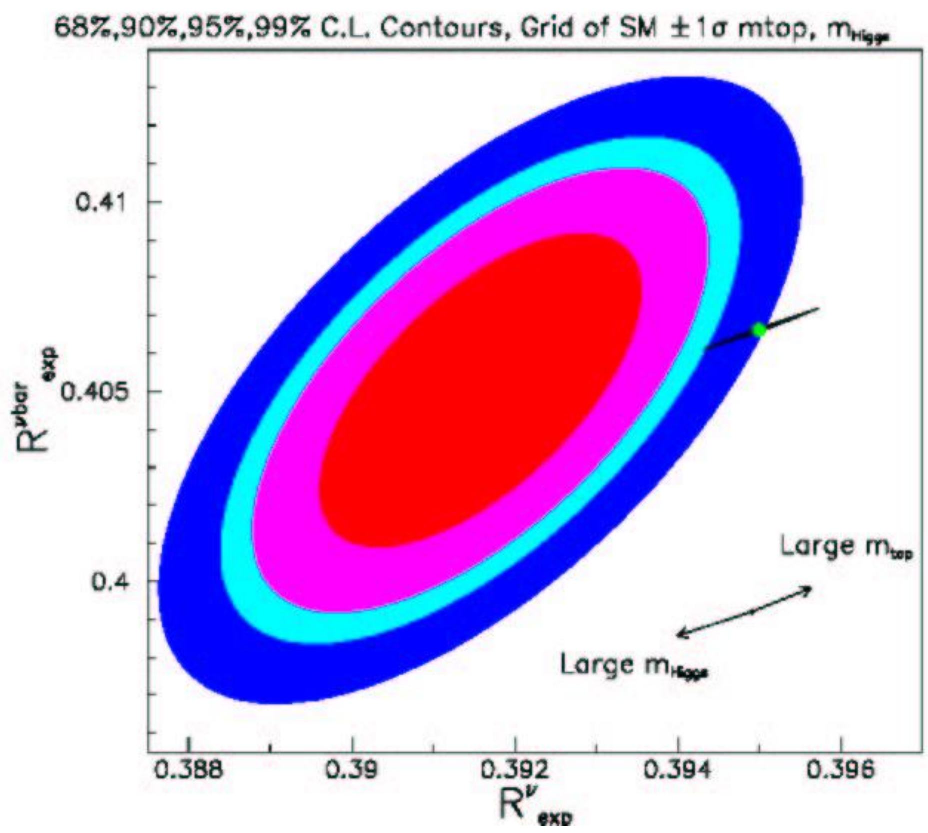
(Courtesy M. Grunewald, LEPEWWG)

Without NuTeV: $\chi^2/\text{dof} = 21.5/14$, probability of 9.0%

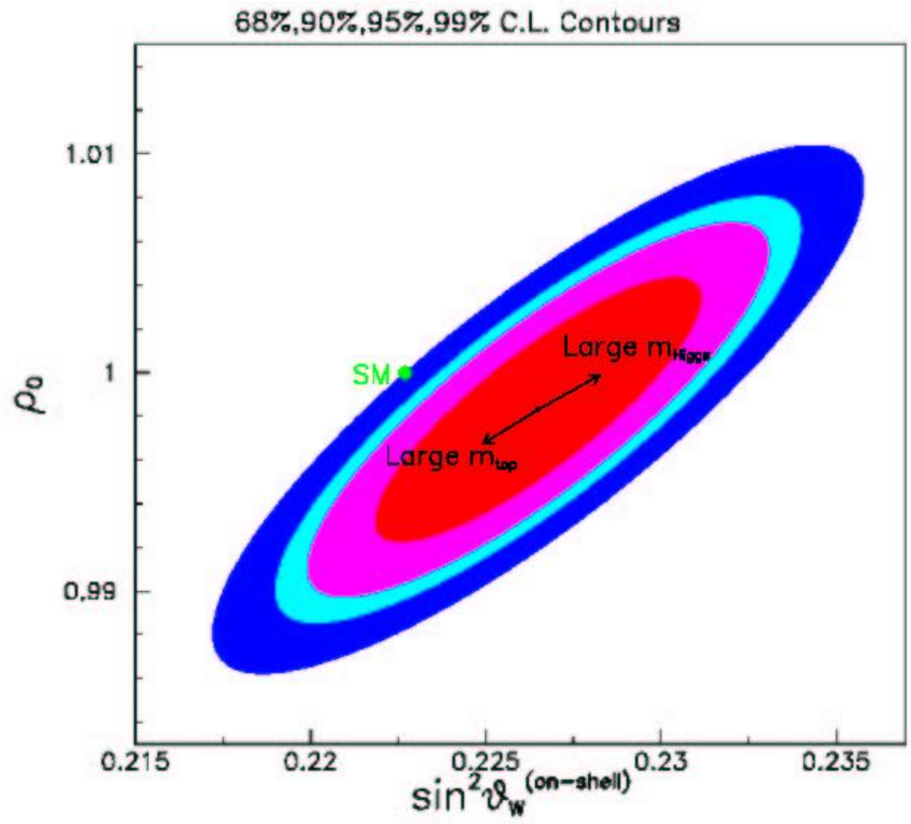
With NuTeV: $\chi^2/\text{dof} = 30.5/15$, probability of 1.0%

Upper m_{Higgs} limit weakens slightly

Wynik NuTeV a inne pomiary

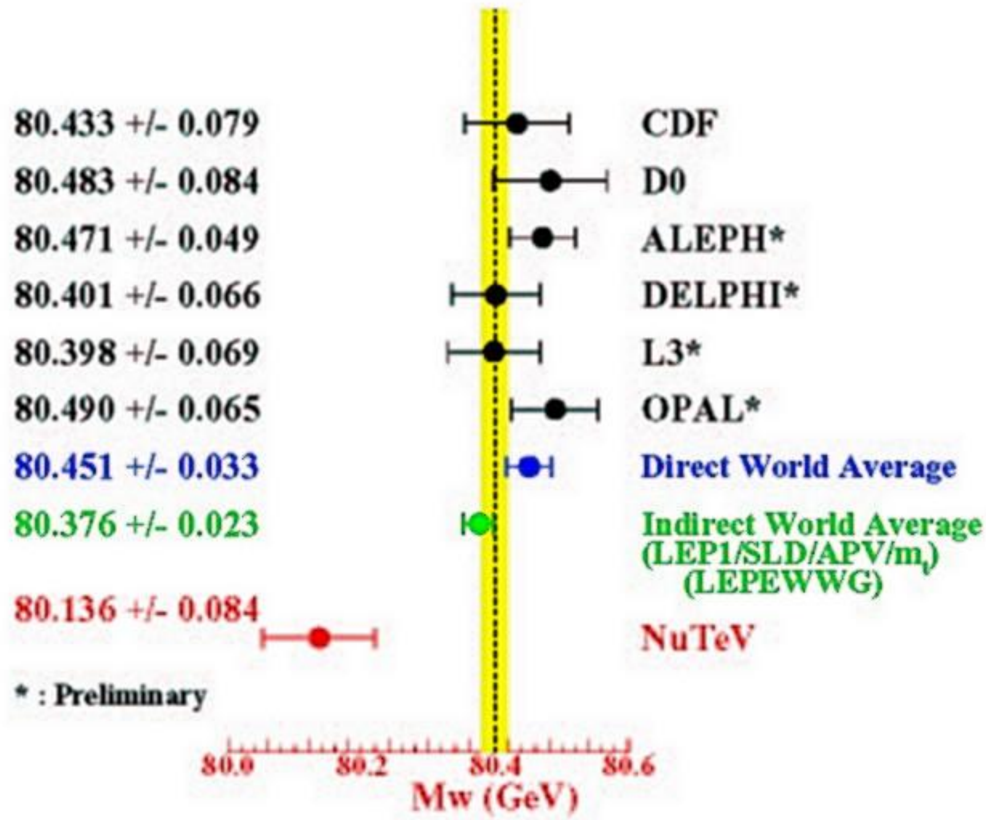


Wynik NuTeV a inne pomiary

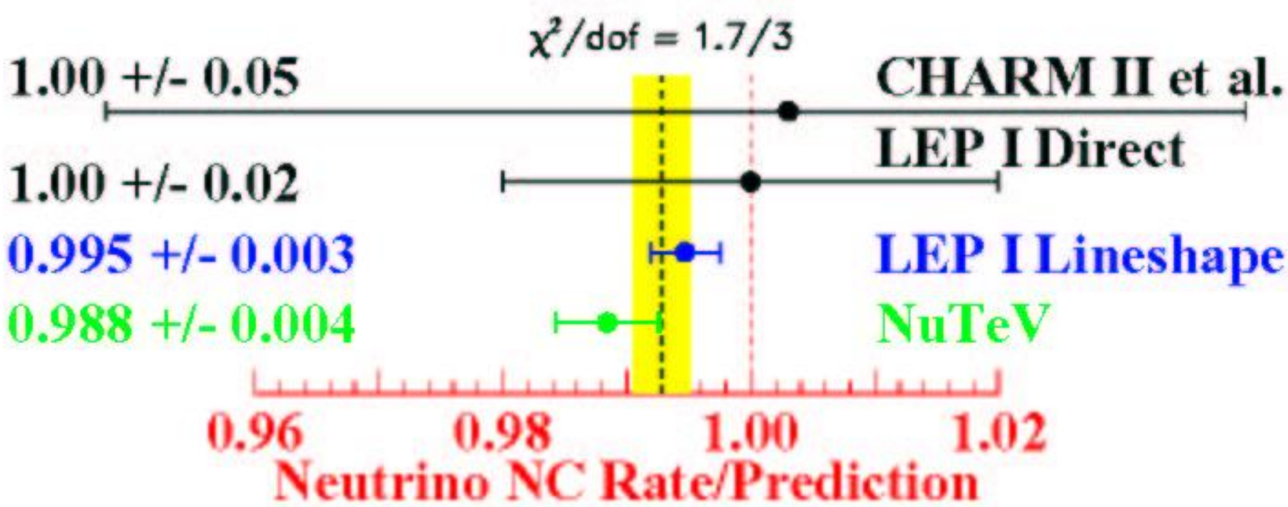


Wynik NuTeV a inne pomiary

M_W



Porównanie pomiarów ρ



ANALIZA cd.

Poprawki wprowadzone do danych na podstawie pomocniczych pomiarów:

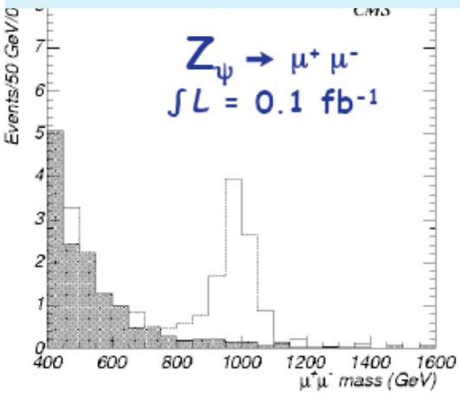
Corrections Applied to Data

Effect	$\delta R^{\nu}_{\text{exp}}$	$\delta R^{\bar{\nu}}_{\text{exp}}$
Cosmic Ray Background	-0.0036	-0.019
Beam μ Background	$+0.0008$	$+0.0012$
Vertex Efficiency	$+0.0008$	$+0.0010$

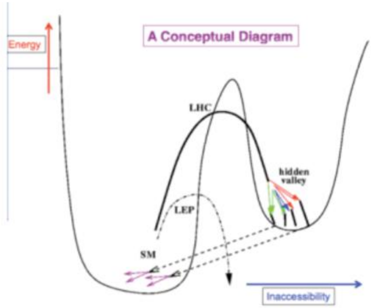
V.3 TEVATRON I LHC

Fizyka elektrosłaba (bez fizyki ciężkich zapachów)

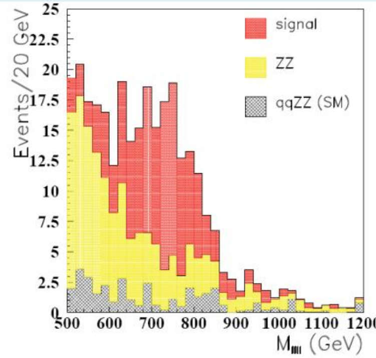
New Gauge Bosons?



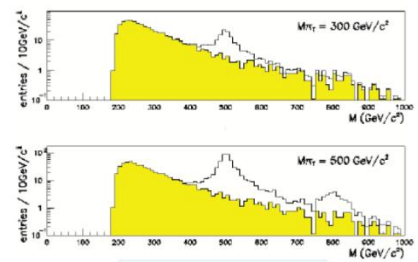
Hidden Valleys?



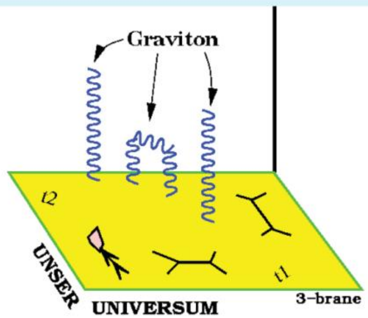
ZZ/WW resonances?



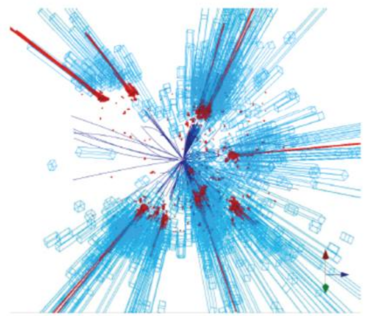
Technicolor?



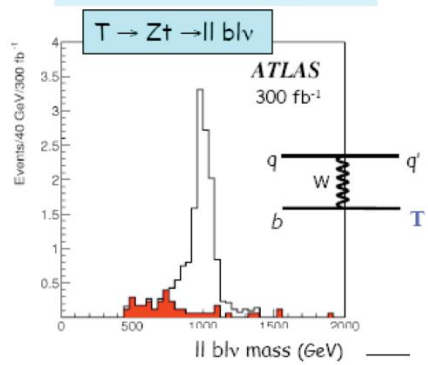
Extra Dimensions?



Black Holes???



Little Higgs?



Split Susy?

PYTHIA R-hadron event from ATLSIM