Z-peak Subtracted Representation of Bhabha Scattering and Search for New Physics Effects at the NLC

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Introduction and Outline

- Z-peak subtracted representation ($f \neq e$) of $e^+e^- \to f\bar{f}$ at LEP2 and NLC energies
- Universal (AGC, TC) and non Universal (CT, ED) New Physics models
- Z-peak representation of Bhabha scattering $e^+e^- \to e^+e^-$

General Features of New Physics Effects off the Z Peak

- **At** the Z peak
  - Peskin - Takeuchi (S, T) or Altarelli - Barbieri ε_1, ε_3
  - Conditions for universality
    - box diagrams can be neglected
    - s channel γ exchange can be neglected

- **Off** the Z peak (LEP2, NLC, $\mu^+\mu^-$): Generic New Physics
  - Complicated dependence on the kinematical variables (s, θ)
  - box diagrams and s channel γ exchange are important

- **Off** the Z peak: Universal New Physics
  - **Only 3** functions $\delta_\gamma, \delta_s, \delta_Z$ of the energy (constants ?)

The Z-peak Subtracted Representation ($f \neq e$)

F.M. Renard and C. Verzegnassi, PRD52, 1369 (1995), PRD53, 1290 (1996)

– The general $e^+e^- \to f\bar{f}$ ($f \neq e$) scattering amplitude at one loop is the sum of an **effective photon** and an **effective Z amplitude** with couplings $g^{\gamma}_{Vj}(q^2,\theta)$, $g^{Z}_{Vj}(q^2,\theta)$, $g^{Z}_{Aj}(q^2,\theta)$ (j is the initial electron $j = e$ or the final fermion $j = f \neq e$)

$$\mathcal{A}(q^2,\theta) = \frac{i}{q^2}\bar{v}\gamma^{\mu} g^{(\gamma)}_{Ve}(q^2,\theta) u \cdot \bar{u}\gamma_{\mu} g^{(\gamma)}_{Vf}(q^2,\theta) v + \frac{i}{q^2 - M_Z^2 + iM_Z\Gamma_Z} \cdot$$
$$\bar{v}\gamma^{\mu}[g^{(Z)}_{Ve}(q^2,\theta) - g^{(Z)}_{Ae}(q^2,\theta)\gamma^5]u \cdot \bar{u}\gamma_{\mu}[g^{(Z)}_{Vf}(q^2,\theta) - g^{(Z)}_{Af}(q^2,\theta)\gamma^5]v$$

– Effective couplings ($\tilde{\Delta}_{\alpha,ef}$, R_{ef} and V_{ef} are **finite** and **gauge invariant**)

$$g^{\gamma}_{Ve}(q^2,\theta) = \sqrt{4\pi\alpha(0)}\ Q_e[1+\frac{1}{2}\tilde{\Delta}_{\alpha,ef}(q^2,\theta)]$$

$$g^{\gamma}_{Vf}(q^2,\theta) = \sqrt{4\pi\alpha(0)}\ Q_f[1+\frac{1}{2}\tilde{\Delta}_{\alpha,ef}(q^2,\theta)]$$

$$g^{\gamma}_{Ae}(q^2,\theta) = g^{\gamma}_{Af}(q^2,\theta) = 0$$

$$g^{Z}_{Ve} = \gamma_e^{\frac{1}{2}}\ I_{3e}\ \tilde{v}_e[1-\frac{1}{2}R_{ef}(q^2,\theta) - \frac{4\tilde{s}_e\tilde{c}_e}{\tilde{v}_e}|Q_f|V^{\gamma Z}_{ef}(q^2,\theta)]$$

$$g^{Z}_{Vf}(q^2,\theta) = \gamma_f^{\frac{1}{2}}\ I_{3f}\ \tilde{v}_f[1-\frac{1}{2}R_{ef}(q^2,\theta) - \frac{4\tilde{s}_e\tilde{c}_e}{\tilde{v}_f}|Q_f|V^{Z\gamma}_{ef}(q^2,\theta)]$$

$$g^{Z}_{Ae}(q^2,\theta) = \gamma_e^{\frac{1}{2}}\ I_{3e}[1-\frac{1}{2}R_{ef}(q^2,\theta)]$$

$$g^{Z}_{Af}(q^2,\theta) = \gamma_f^{\frac{1}{2}}\ I_{3f}[1-\frac{1}{2}R_{ef}(q^2,\theta)]$$

with the Z-**peak inputs**

$$\gamma_j^{\frac{1}{2}} = [\frac{48\pi\Gamma_j}{N_j M_Z(1+\tilde{v}_j^2)}]^{\frac{1}{2}} = \frac{e}{2sc} + \cdots$$

$$\tilde{v}_j = 1 - 4|Q_j|\tilde{s}_j^2$$

$\tilde{s}_j^2 = 1 - \tilde{c}_j^2$ is the **weak effective angle** measured through the forward-backward or polarization asymmetries in the final channel j, $\tilde{s}_e \equiv \tilde{s}_\mu \equiv \tilde{s}_\tau$

- The quantities $\tilde{\Delta}_{\alpha,ef}(q^2,\theta)$, $R_{ef}(q^2,\theta)$, $V_{ef}^{\gamma Z}(q^2,\theta)$, $V_{ef}^{Z\gamma}(q^2,\theta)$ contain all the q^2, θ dependent parts of the scattering amplitude due to SM or NP at one-loop.

- They are **finite, gauge independent** combinations of self-energies, vertices and boxes

– For an additional four fermion amplitude with Lorentz structure

$$\bar{v}(e^+)\gamma^\mu[a(q^2,\theta) - b(q^2,\theta)\gamma^5]u(e^-) \cdot \bar{u}(f)\gamma_\mu[c(q^2,\theta) - d(q^2,\theta)\gamma^5]v(f)$$

and a, b, c, d representing $\mathcal{O}(\alpha)$ effects, we have

$$\tilde{\Delta}_{\alpha,ef}(q^2,\theta) = \mathbf{q^2}\frac{[a(q^2,\theta) - b(q^2,\theta)\tilde{v}_e][c(q^2,\theta) - d(q^2,\theta)\tilde{v}_f]}{e^2 Q_e Q_f}$$

$$R_{ef}(q^2,\theta) = -(\mathbf{q^2} - \mathbf{M_Z^2})\frac{4\tilde{s}_e^2\tilde{c}_e^2 b(q^2,\theta)d(q^2,\theta)}{e^2 I_{3e} I_{3f}}$$

$$V_{ef}^{\gamma Z}(q^2,\theta) = -(\mathbf{q^2} - \mathbf{M_Z^2})\frac{[a(q^2,\theta) - b(q^2,\theta)\tilde{v}_e]2\tilde{s}_e\tilde{c}_e d(q^2,\theta)}{e^2 Q_e I_{3f}}$$

$$V_{ef}^{Z\gamma}(q^2,\theta) = -(\mathbf{q^2} - \mathbf{M_Z^2})\frac{[c(q^2,\theta) - d(q^2,\theta)\tilde{v}_f]2\tilde{s}_e\tilde{c}_e b(q^2,\theta)}{e^2 Q_f I_{3e}}$$

Differential Unpolarized Cross Sections

$$\frac{d\sigma_{lf}}{dcos\theta} = \frac{4\pi}{3} N_f q^2 \{\frac{3}{8}(1+cos^2\theta)\mathbf{U_{11}} + \frac{3}{4}cos\theta\mathbf{U_{12}}\}$$

where (apart from α redefinition)

$$U_{11} = \gamma\gamma + (\gamma Z + ZZ)(1 + \mathbf{A_e A_f} + \mathbf{A_e} + \mathbf{A_f})$$

$$U_{12} = \gamma Z(1 + \mathbf{A_e A_f}) + ZZ(1 + \mathbf{A_e A_f} + \mathbf{A_e} + \mathbf{A_f})$$

$$U_{11} = \frac{\alpha^2(0)Q_f^2}{q^4}[1 + 2\tilde{\Delta}_{\alpha,lf}(q^2,\theta)]$$

$$+2[\alpha(0)|Q_f|]\frac{q^2 - M_Z^2}{q^2((q^2-M_Z^2)^2 + M_Z^2\Gamma_Z^2)}[\frac{3\Gamma_l}{M_Z}]^{1/2}[\frac{3\Gamma_f}{N_f M_Z}]^{1/2}\frac{\tilde{v}_l\tilde{v}_f}{(1+\tilde{v}_l^2)^{1/2}(1+\tilde{v}_f^2)^{1}}$$

$$\times[1 + \tilde{\Delta}_{\alpha,lf}(q^2,\theta) - R_{lf}(q^2,\theta) - 4\tilde{s}_l\tilde{c}_l\{\frac{1}{\tilde{v}_l}V_{lf}^{\gamma Z}(q^2,\theta) + \frac{|Q_f|}{\tilde{v}_f}V_{lf}^{Z\gamma}(q^2,\theta)\}]$$

$$+\frac{[\frac{3\Gamma_l}{M_Z}][\frac{3\Gamma_f}{N_f M_Z}]}{(q^2-M_Z^2)^2+M_Z^2\Gamma_Z^2}$$

$$\times[1-2R_{lf}(q^2,\theta)-8\tilde{s}_l\tilde{c}_l\{\frac{\tilde{v}_l}{1+\tilde{v}_l^2}V_{lf}^{\gamma Z}(q^2,\theta)+\frac{\tilde{v}_f|Q_f|}{(1+\tilde{v}_f^2)}V_{lf}^{Z\gamma}(q^2,\theta)\}]$$

$$U_{12} = \quad 2[\alpha(0)|Q_f|]\frac{q^2-M_Z^2}{q^2((q^2-M_Z^2)^2+M_Z^2\Gamma_Z^2)}[\frac{3\Gamma_l}{M_Z}]^{1/2}[\frac{3\Gamma_f}{N_f M_Z}]^{1/2}\frac{1}{(1+\tilde{v}_l^2)^{1/2}(1+\tilde{v}_f^2)^{1/2}}$$

$$\times[1+\tilde{\Delta}_{\alpha,lf}(q^2,\theta)-R_{lf}(q^2,\theta)]$$

$$+\frac{[\frac{3\Gamma_l}{M_Z}][\frac{3\Gamma_f}{N_f M_Z}]}{(q^2-M_Z^2)^2+M_Z^2\Gamma_Z^2}[\frac{4\tilde{v}_l\tilde{v}_f}{(1+\tilde{v}_l^2)(1+\tilde{v}_f^2)}]$$

$$\times[1-2R_{lf}(q^2,\theta)-4\tilde{s}_l\tilde{c}_l\{\frac{1}{\tilde{v}_l}V_{lf}^{\gamma Z}(q^2,\theta)+\frac{|Q_f|}{\tilde{v}_f}V_{lf}^{Z\gamma}(q^2,\theta)\}]$$

New Physics Contributions

- For a general one loop New Physics effect the form factors $\tilde{\Delta}_{\alpha,lf}$, R_{lf}, $V_{lf}^{\gamma Z}$ and $V_{lf}^{Z\gamma}$ are shifted

$$\tilde{\Delta}_{\alpha,lf}(q^2,\theta) \rightarrow \tilde{\Delta}_{\alpha,lf}(q^2,\theta) + \tilde{\Delta}_{\alpha,lf}^{NP}(q^2,\theta)$$

- Explicit θ dependent terms (e.g. from SUSY boxes) introduce **new** parameters (# of terms $\cos^N \theta$)
- Simplifications occur for **Universal New Physics**
  - independent on the final fermion family f
  - independent on θ

$$\tilde{\Delta}_{\alpha}^{UNP}(q^2) \quad R^{UNP}(q^2) \quad V^{UNP}(q^2)$$

- If the q^2 dependence is **factorized**, then measurements at different q^2 can be combined

Definition of the Three δ Parameters

– By construction

$$\tilde{\Delta}_{\alpha}^{UNP}(0) = R^{UNP}(M_Z^2) = V^{UNP}(M_Z^2) = 0$$

– We therefore introduce the three dimensionless functions $\delta_{z,s,\gamma}(q^2)$

$$R^{UNP}(q^2) = \frac{(q^2 - M_Z^2)}{M_Z^2}\,\delta_z \quad V^{UNP}(q^2) = \frac{(q^2 - M_Z^2)}{M_Z^2}\,\delta_s \quad \tilde{\Delta}_{\alpha}^{UNP}(q^2) = \frac{q^2}{M_Z^2}\,\delta_\gamma$$

– For large New Physics scales ($\Lambda^2 >> q^2$), we find typically $\delta_i(q^2) = (q^2)^{m_i}\hat{\delta}_i(q^2)$ and, in some cases, $\hat{\delta}_i(q^2) \simeq \hat{\delta}_i(0)$

– Non Universality can occur by a θ dependence, a final flavour dependence, both.

Z-peak Representation of the Bhabha Process

– The scattering amplitude at one loop is the sum of two (s-channel and t-channel) components

$$\mathcal{A}_{ee} = \mathcal{A}_s(q^2,\theta) + \mathcal{A}_t(q^2,\theta)$$

– Definition of effective couplings in the t-channel component

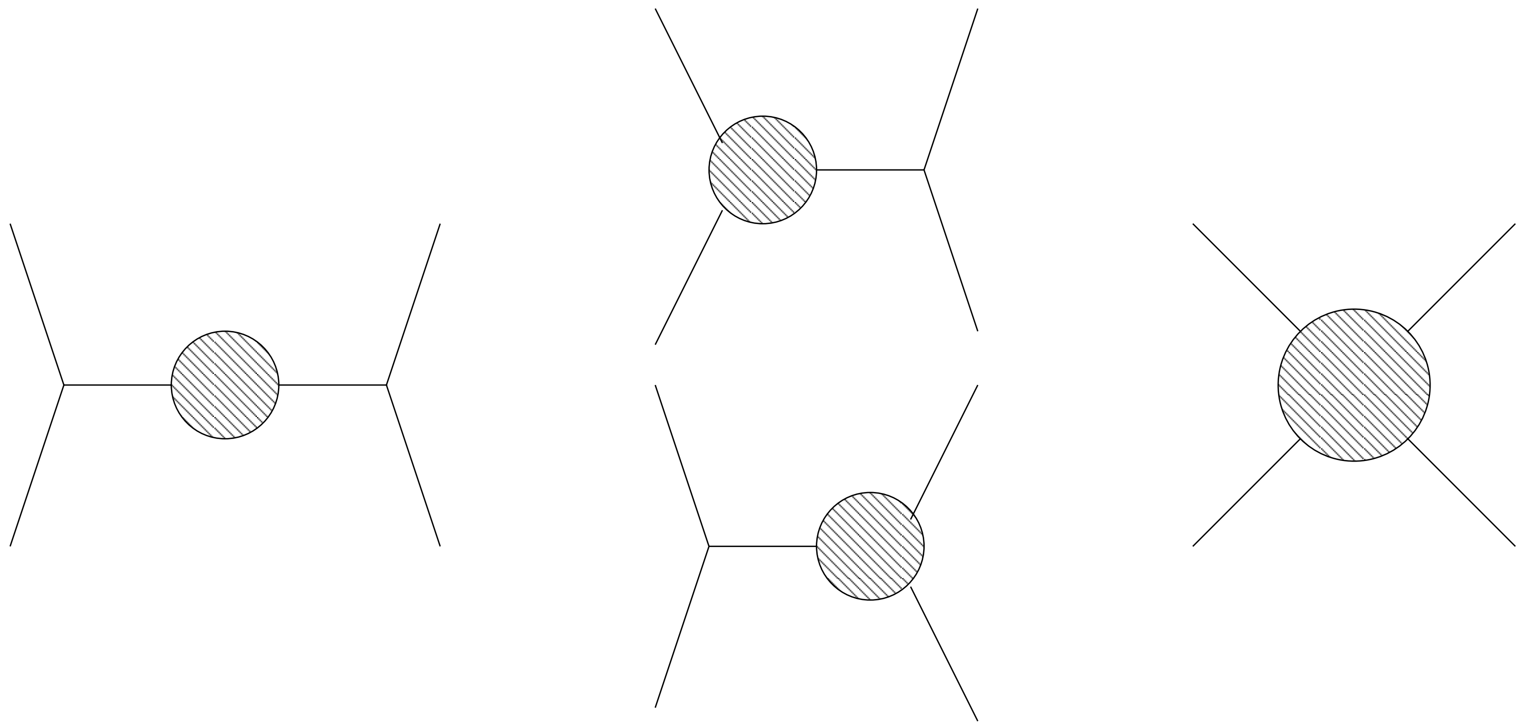
$$\mathcal{A}_t(q^2,\theta) = \frac{i}{t}\bar{v}\gamma^\mu \bar{g}^{(\gamma)}_{Ve}(q^2,\theta)v \cdot \bar{u}\gamma_\mu \bar{g}^{(\gamma)}_{Vf}(q^2,\theta) + \frac{i}{t-M_Z^2}.$$
$$\bar{v}\gamma^\mu[\bar{g}^{(Z)}_{Ve}(q^2,\theta) - \bar{g}^{(Z)}_{Ae}(q^2,\theta)\gamma^5] \cdot \bar{u}\gamma_\mu[\bar{g}^{(Z)}_{Vf}(q^2,\theta) - \bar{g}^{(Z)}_{Af}(q^2,\theta)\gamma^5]u$$

- t-channel effective couplings

$$\bar{g}^{\gamma}_{Ve}(q^2,\theta) = \sqrt{4\pi\alpha(0)}\ Q_e[1+\frac{1}{2}\overline{\Delta}_\alpha(q^2,\theta)]$$
$$\bar{g}^{Z}_{Ve}(q^2,\theta) = \gamma_e^{\frac{1}{2}}\ I_{3e}\ \tilde{v}_e[1-\frac{1}{2}\overline{R}(q^2,\theta) - \frac{4\tilde{s}_e\tilde{c}_e}{\tilde{v}_e}|Q_f|\overline{V}(q^2,\theta)]$$
$$\bar{g}^{Z}_{Ae}(q^2,\theta) = \gamma_e^{\frac{1}{2}}\ I_{3e}[1-\frac{1}{2}\overline{R}(q^2,\theta)] \tag{1}$$

- The new functions $\overline{\Delta}_\alpha(q^2,\theta)$, $\overline{R}(q^2,\theta)$ and $\overline{V}(q^2,\theta)$ are obtained from the s-channel by crossing $s \longleftrightarrow t$

$$q^2 \longrightarrow t = -\frac{q^2}{2}(1-cos\theta) \qquad cos\theta \longrightarrow 1+\frac{2q^2}{t}$$



A rotated copy of the same diagrams occur in $e^+e^- \to e^+e^-$

– General expression of the polarized Bhabha differential cross section (P and P' are the initial e^-, e^+ polarizations)

$$\frac{d\sigma}{dcos\theta} = (1 - PP')\frac{d\sigma^1}{dcos\theta} + \underbrace{(1 + PP')\frac{d\sigma^2}{dcos\theta}}_{\text{t channel only}} + (P' - P)\frac{d\sigma^P}{dcos\theta}$$

– unpolarized angular distribution: the only one relevant at LEP2

$$\frac{d\sigma}{dcos\theta} \equiv \frac{d\sigma^1}{dcos\theta} + \frac{d\sigma^2}{dcos\theta}$$

– LL-RR and LL+RR polarization asymmetries: specific of NLC

$$A_{LR}(q^2, \theta) = [\frac{d\sigma^P}{dcos\theta}]/[\frac{d\sigma}{dcos\theta}] \qquad A_{||}(q^2, \theta) = [\frac{d\sigma^2}{dcos\theta}]/[\frac{d\sigma}{dcos\theta}]$$

Parametrization of New Physics Effects in the Bhabha Observables

- General New Physics $\Longrightarrow$ duplication of the parameters
- Universal New Physics $\Longrightarrow$ the same set of three numbers
- General definition of δ, including contributions to Bhabha

$$R^{UNP}(z) = \frac{(z - M_Z^2)}{M_Z^2}\,\delta_Z$$

$$V^{UNP}(z) = \frac{(z - M_Z^2)}{M_Z^2}\,\delta_s$$

$$\tilde{\Delta}_\alpha^{UNP}(z) = \frac{z}{M_Z^2}\,\delta_\gamma$$

where $z = s, t$

Summary Table of Some Common New Physics Models

– AGC and TC are Universal

– CT are Universal in each flavour (e.g. $e^+e^- \to l\bar{l}$)

– For ED and SUSY, δ are functions of θ, not constants

– For SUSY, the condition $\Lambda^2 >> q^2$ is not interesting.

Model	Universal	θ	f	m
AGC	X			
TC	X			
CT			X	
ED		X	X	1
(SUSY)		X	X	?

Universal New Physics I: Anomalous gauge couplings

A. Blondel, F. M. Renard, L. Trentadue and C. Verzegnassi PRD 54 (1996)

dim=6, $SU(2) \times U(1)$ and CP conserving operators, linear Higgs (Hagiwara et al., PRD 48 (1993)

	W^2	Z^2	AZ	A^2	W^2Z	W^2A	W^4	W^2Z^2	W^2ZA	W^2A^2	Z^4
DW	x	x	x	x	x	x	x	x	x	x	
DB		x	x	x							
BW		x	x	x	x	x					
Φ,1		x									
WWW					x	x	x	x	x	x	
W					x	x	x	x	x		
B					x	x					

$e^+e^- \to f\bar{f}$ versus $e^+e^- \to W^+W^-$ at LEP2

- The effect of the “tree level” operators parametrized by f_{DW}, f_{DB}, f_{BW} and $f_{\Phi,1}$ receives contributions from the “one loop” operators, e.g.

$$
\begin{aligned}
f_{DW}^r &= f_{DW} - \frac{1}{192\pi^2}\left(f_W \log\frac{\Lambda^2}{M_W^2} + \frac{f_B - f_W}{4}\log\frac{M_H^2}{M_W^2}\right) \\
f_{DB}^r &= f_{DB} - \frac{1}{192\pi^2}\left(f_B \log\frac{\Lambda^2}{M_W^2} - \frac{f_B - f_W}{4}\log\frac{M_H^2}{M_W^2}\right)
\end{aligned}
$$

- The couplings f_{DW}, f_{DB}, f_{BW} and $f_{\Phi,1}$ are well constrained by amplitudes with external fermions at LEP1 and LEP2. Results from a 500 pb^{-1} @ 175 GeV conventional 4 parameters fit

	DW	DB	BW	Φ,1	WWW	W	B
$f\bar{f}$	0.22	1.9	0.46	0.042			
W^+W^-	2.1	12	1.5	0.19	10	7.1	46

– If they are excluded from $e^+e^- \to f\bar{f}$ then we can study

$$\frac{i\mathcal{L}}{g_{WWV}} = g_1^V V_\mu (W^{-\mu\nu} W_\nu^+ - W^{+\mu\nu} W_\nu^-) + \kappa_V V^{\mu\nu} W_\mu^- W^+ \nu + \frac{\lambda_V}{M_W^2} V^{\mu\nu} W_\nu^{+\rho} W_{\rho\mu}^-$$

with ($SU(2) \times U(1)$ gives $g_1^\gamma = 1$, $\lambda_Z = \lambda_\gamma = \lambda$ and trades κ_Z)

$$\begin{aligned} \Delta\kappa_\gamma &= (f_B + f_W)\frac{M_W^2}{2\Lambda^2} \\ \Delta g_1^Z &= f_W \frac{M_Z^2}{2\Lambda^2} \\ \lambda &= f_{WWW}\frac{3M_W^2 g^2}{2\Lambda^2} \end{aligned}$$

LEP2 experimental results (C. Sbarra, Moriond 2000)

$$\Delta\kappa_\gamma = 0.021^{+0.063}_{-0.059}, \qquad \Delta g_1^Z = -0.024^{+0.024}_{-0.024}, \qquad \lambda_\gamma = -0.016^{+0.026}_{-0.026}$$

- Z-peak subtracted analysis: 2 parameters, f_{DW} and f_{DB}; they give q^2 dependent contributions.
- Expression of the δ parameters in terms of f_{DW} and f_{DB}

$$\delta_z = 8\pi\alpha\frac{M_Z^2}{\Lambda^2}\left(\frac{\tilde{c}_l^2}{\tilde{s}_l^2}f_{DW} + \frac{\tilde{s}_l^2}{\tilde{c}_l^2}f_{DB}\right), \quad \delta_s = 8\pi\alpha\frac{M_Z^2}{\Lambda^2}\left(\frac{\tilde{c}_l}{\tilde{s}_l}f_{DW} - \frac{\tilde{s}_l}{\tilde{c}_l}f_{DB}\right),$$

$$\delta_\gamma = -8\pi\alpha\frac{M_Z^2}{\Lambda^2}\left(f_{DW} + f_{DB}\right),$$

They satisfy the linear constraint:

$$\boxed{\delta_z - \frac{1-2\tilde{s}_l^2}{\tilde{s}_l\tilde{c}_l}\delta_s + \delta_\gamma = 0}$$

Universal New Physics II: Models of Technicolor type

R. S. Chivukula, F. M. Renard and C. Verzegnassi PRD 547 (1998)

- Strongly coupled Vector and Axial resonances. 2 parameters (ratios F/M^2)
- The Z-peak scheme leads naturally to the use of non perturbative dispersion relations
- δ parameters

$$\delta_z = M_Z^2 \frac{\pi\alpha}{\tilde{s}_l^2 \tilde{c}_l^2} \left((1-2\tilde{s}_l^2)^2 \frac{F_V^2}{M_V^4} + \frac{F_A^2}{M_A^4} \right),$$

$$\delta_s = M_Z^2 \frac{2\pi\alpha}{\tilde{s}_l \tilde{c}_l} (1-2\tilde{s}_l^2) \frac{F_V^2}{M_V^4}, \quad \delta_\gamma = -4\pi\alpha M_Z^2 \frac{F_V^2}{M_V^4}.$$

Again, we have a linear constraint in the $(\delta_z, \delta_s, \delta_\gamma)$ space:

$$\boxed{\delta_s = -\left(\frac{1-2\tilde{s}_l^2}{2\tilde{s}_l \tilde{c}_l}\right) \delta_\gamma} \qquad \delta_{z,s} > 0 \qquad \delta_\gamma < 0$$

Non Universal New Physics I: Contact Interactions

E. Eichten, K. Lane, M. Peskin, PRL 50 (1983)

- Composite models or any generic virtual NP effect with a high intrinsic scale (e.g., higher vector boson exchanges, satisfying chirality conservation)
- Interaction Lagrangian for $(i\bar{i} \to f\bar{f})$

$$\begin{aligned}\mathcal{L} \quad = \quad & k_{if}\frac{4\pi}{\Lambda^2}\{\eta_{LL}(\bar{\Psi}^i_L\gamma^\mu\Psi^i_L)(\bar{\Psi}^f_L\gamma_\mu\Psi^f_L) + \eta_{RR}(\bar{\Psi}^i_R\gamma^\mu\Psi^i_R)(\bar{\Psi}^f_R\gamma_\mu\Psi^f_R) \\ & +\eta_{RL}(\bar{\Psi}^i_R\gamma^\mu\Psi^i_R)(\bar{\Psi}^f_L\gamma_\mu\Psi^f_L) + \eta_{LR}(\bar{\Psi}^i_L\gamma^\mu\Psi^i_L)(\bar{\Psi}^f_R\gamma_\mu\Psi^f_R)\}\end{aligned}$$

  where
  $k_{if} = \frac{1}{2}$ for $i \equiv f$, $k_{if} = 1$ otherwise; $\Psi_L = (1-\gamma^5)/2\ \Psi$, $\Psi_R = (1+\gamma^5)/2\ \Psi$; η_{ab} are phase factors defining the chirality structure of the interaction.
- Specific applications can be considered for pure chiral cases $(ij) = LL$ or RR or LR or RL (keeping only one $\eta_{ij} = \pm 1$), as well as for mixed cases like VV $(\eta_{LL} = \eta_{RR} = \eta_{RL} = \eta_{LR} = \pm 1)$, AA $(\eta_{LL} = \eta_{RR} = -\eta_{RL} = -\eta_{LR} = \pm 1)$, VA $(\eta_{LL} = -\eta_{RR} = \eta_{RL} = -\eta_{LR} = \pm 1)$, AV $(\eta_{LL} = -\eta_{RR} = -\eta_{RL} = \eta_{LR} = \pm 1)$;

- δ parameters

$$\delta_{\gamma,ef} = \frac{\pi M_Z^2}{e^2 Q_e Q_f \Lambda^2}[\eta_{LL}(1-v_e)(1-v_f) + \eta_{RR}(1+v_e)(1+v_f)$$
$$+\eta_{RL}(1+v_e)(1-v_f) + \eta_{LR}(1-v_e)(1+v_f)]$$
$$\delta_{Z,ef} = -\frac{4\tilde{s}_e^2\tilde{c}_e^2\pi M_Z^2}{e^2 I_{3e} I_{3f}\Lambda^2}[\eta_{LL} + \eta_{RR} - \eta_{RL} - \eta_{LR}]$$
$$\delta_{s,ef}^{\gamma Z} = -\frac{2\tilde{s}_e\tilde{c}_e\pi M_Z^2}{e^2 Q_e I_{3f}\Lambda^2}[\eta_{LL}(1-v_e) - \eta_{RR}(1+v_e) + \eta_{RL}(1+v_e) - \eta_{LR}(1-v_e)]$$
$$\delta_{s,ef}^{Z\gamma} = -\frac{2\tilde{s}_e\tilde{c}_e\pi M_Z^2}{e^2 Q_f I_{3e}\Lambda^2}[\eta_{LL}(1-v_f) - \eta_{RR}(1+v_f) - \eta_{RL}(1-v_f) + \eta_{LR}(1+v_f)$$

- Since there is a single parameter, the bounds on $\delta_{Z,s,\gamma}$ translates into a bound on the New Physics coupling

Non Universal New Physics II: Extra Dimensions

N. Arkani-Hamed, S. Dimopoulos, G. Dvali, PLB 429 (1998), PLB 436 (1998)

– Arkani-Hamed, Dimopoulos, Dvali model ($M_{Pl} \sim 10^{19}$GeV, $M_S \sim 10^2$GeV)

$$M_{Pl}^2 \sim M_S^{n+2}\ R^n$$

– $n = 1$, $R \sim$ solar system;
$n = 2$, $R = 0.1 - 1$mm

– Coupling to KK modes

$$\frac{1}{M_{Pl}} \times \#\ \text{modes} \sim \frac{1}{M_S}$$

– Lorentz structure of the matrix element

$$\frac{\lambda}{\Lambda^4}[\bar{e}\gamma^\mu e \bar{f}\gamma_\mu f (p_2 - p_1).(p_4 - p_3) - \bar{e}\gamma^\mu e \bar{f}\gamma^\nu f (p_2 - p_1)_\nu (p_4 - p_3)_\mu]$$

– δ parameters

$$\delta_{z,ef} = -(\frac{\lambda M_Z^2 q^2}{\Lambda^4})\frac{4\tilde{s}_l^2\tilde{c}_l^2}{e^2 I_{3e} I_{3f}}$$

$$\delta_{s,ef}^{\gamma Z} = (\frac{\lambda M_Z^2 q^2}{\Lambda^4})\frac{2\tilde{s}_l\tilde{c}_l\tilde{v}_l}{e^2 Q_e I_{3f}}$$

$$\delta_{s,ef}^{Z\gamma} = (\frac{\lambda M_Z^2 q^2}{\Lambda^4})\frac{2\tilde{s}_l\tilde{c}_l\tilde{v}_f}{e^2 Q_f I_{3e}}$$

$$\delta_{\gamma,ef} = (\frac{\lambda M_Z^2 q^2}{\Lambda^4})\frac{(\tilde{v}_l\tilde{v}_f - 2cos\theta)}{e^2 Q_e Q_f}$$

– The q^2 factor is purely kinematical and a consequence of the higher dimension of the interaction Lagrangian

– The term term proportional to $cos\theta$ gives a contribution in the t-**channel** with **large interference** effects **with** the standard **photon exchange** amplitude.

Definition of the Observables

- Non Bhabha: σ_l, σ_5, $A_{FB,l}$, $A_{LR,l}$ @ $\sqrt{s} = 500$ GeV, $\mathcal{L} = 500\ fb^{-1}$

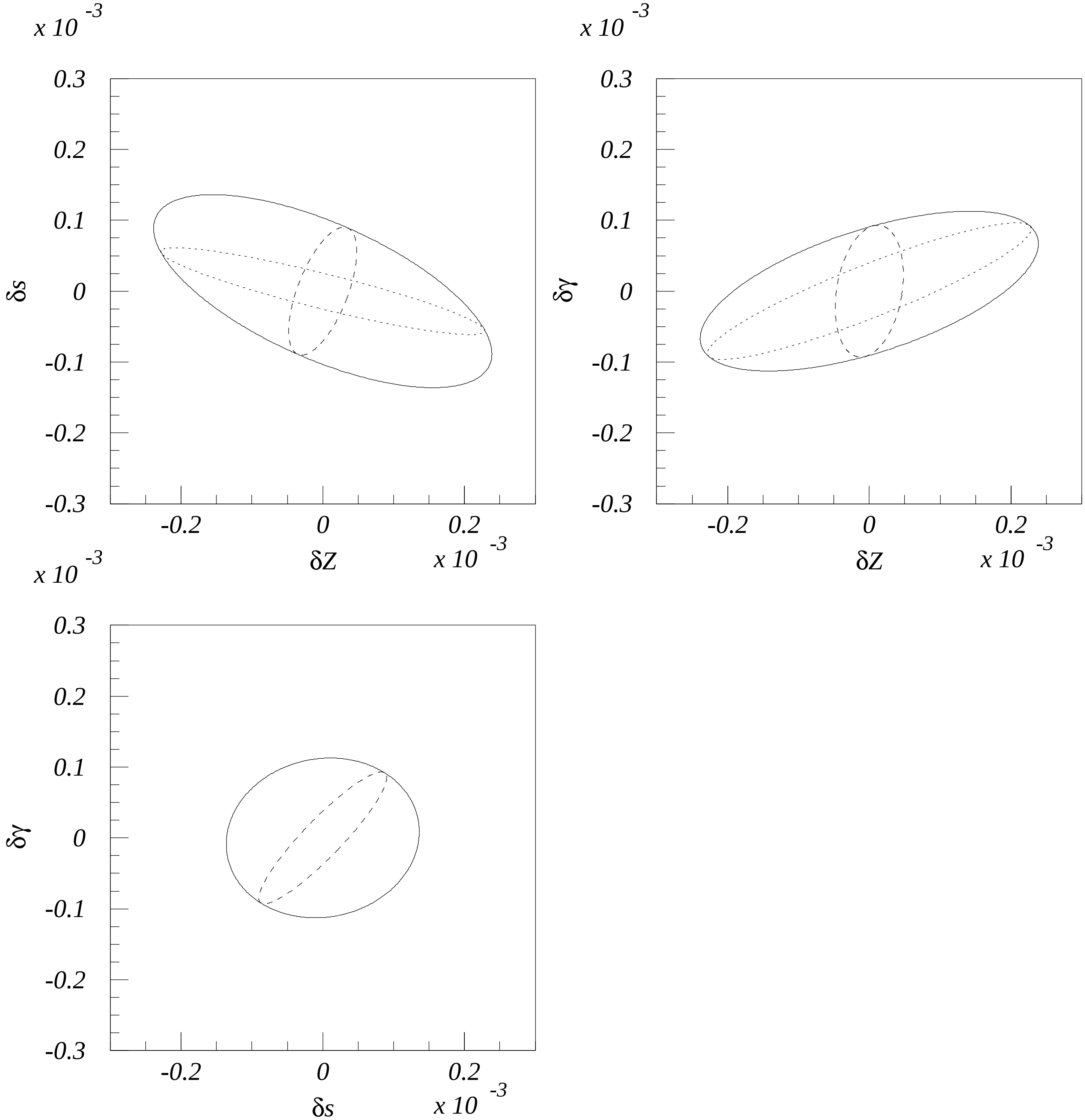
- Bhabha: σ, A_{LR}, $A_{||}$ in 9 angular bins $-0.9 < \cos\theta_{e^-} < 0.9$

- The theoretical error: situation at LEP2
  - For the non Bhabha observables, $\varepsilon_{th} < \varepsilon_{exp}$ is $< 1\%$, dominated by large QED corrections.

  - For the Bhabha cross section, $\varepsilon_{th} \simeq 2\%$ larger than the experimental error in the very forward cone.

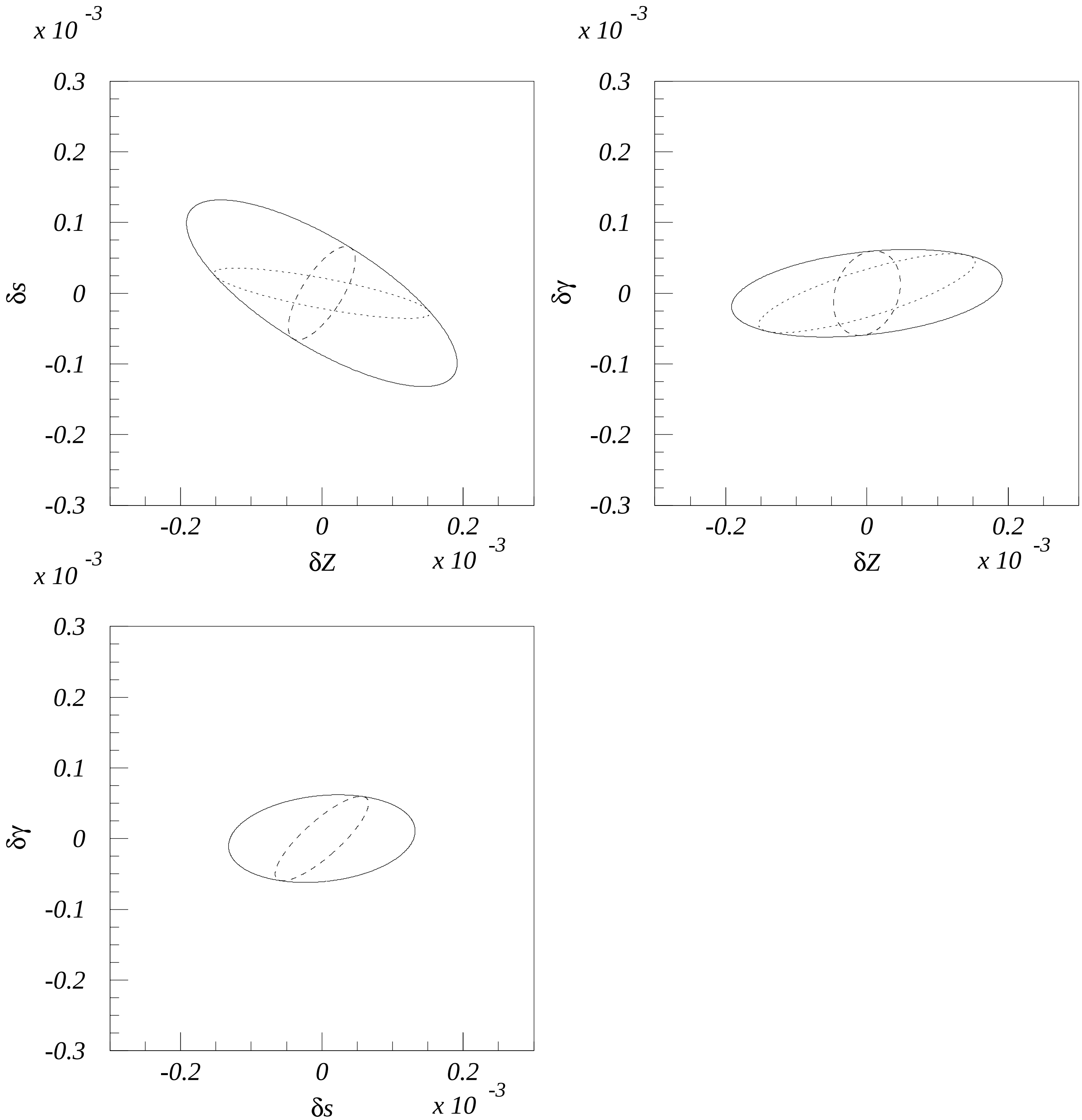
Bounds on δ

without Bhabha



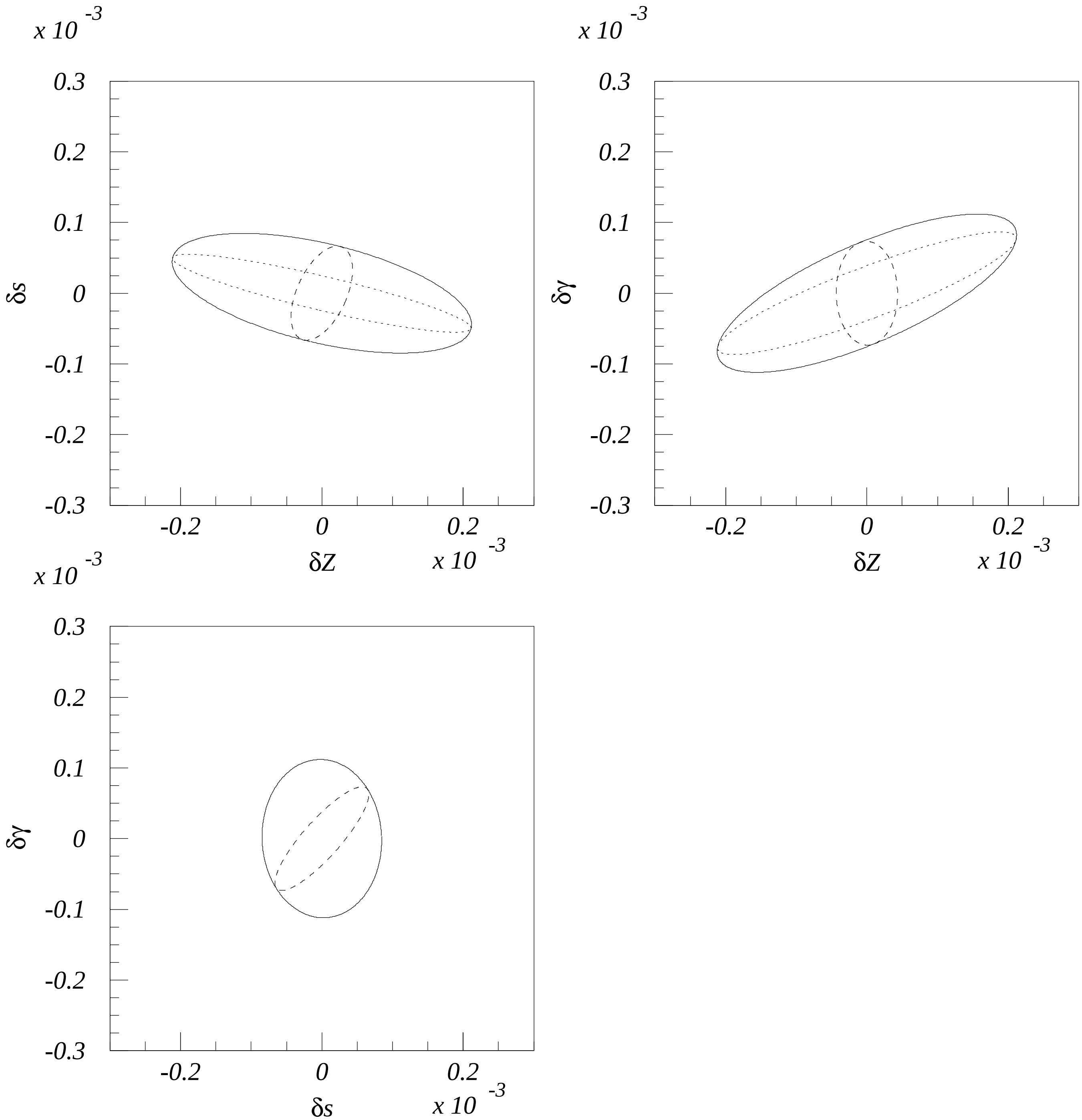
Bounds on δ

with unpolarized Bhabha σ



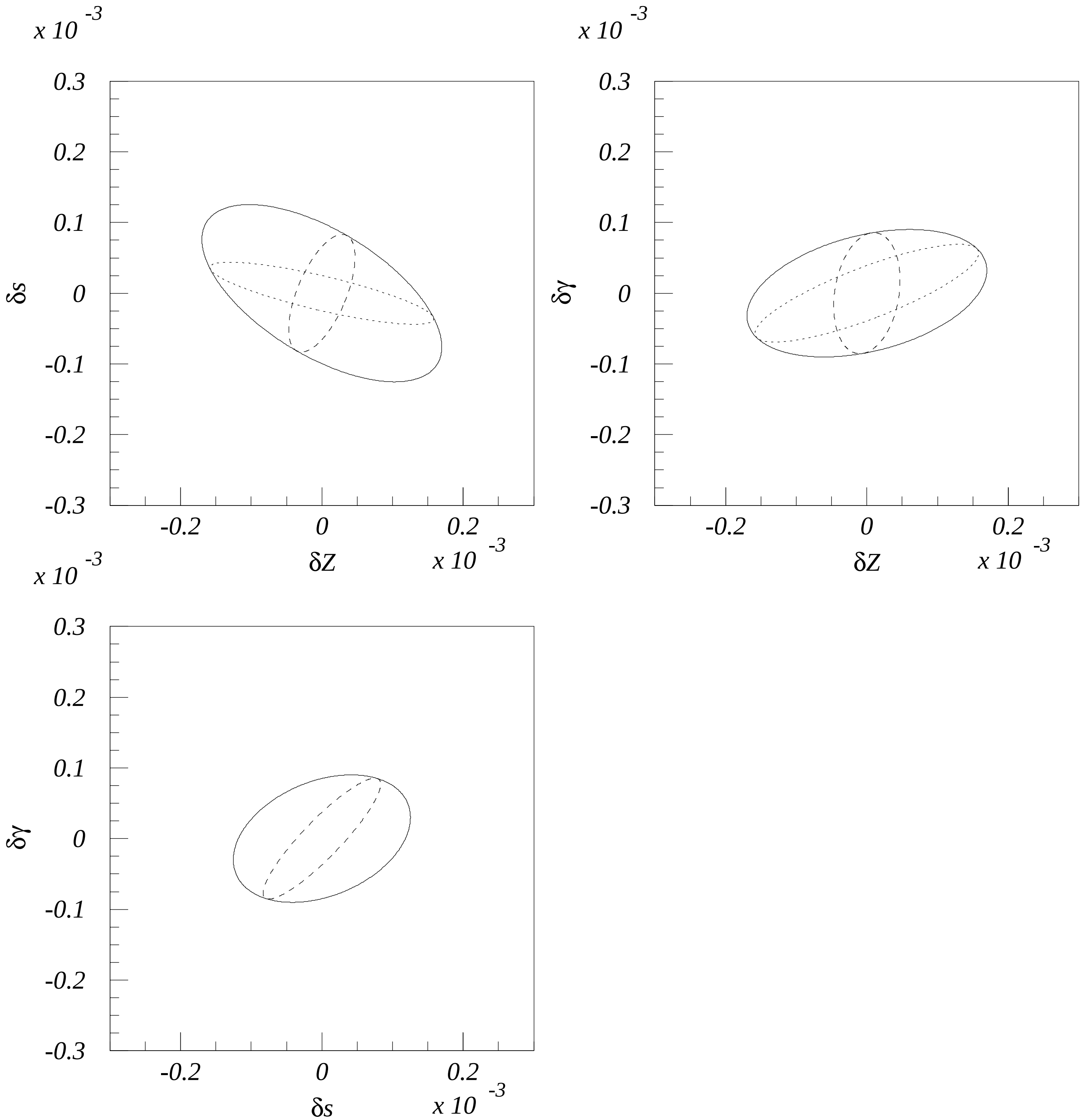
Bounds on δ

with Bhabha A_{LR}

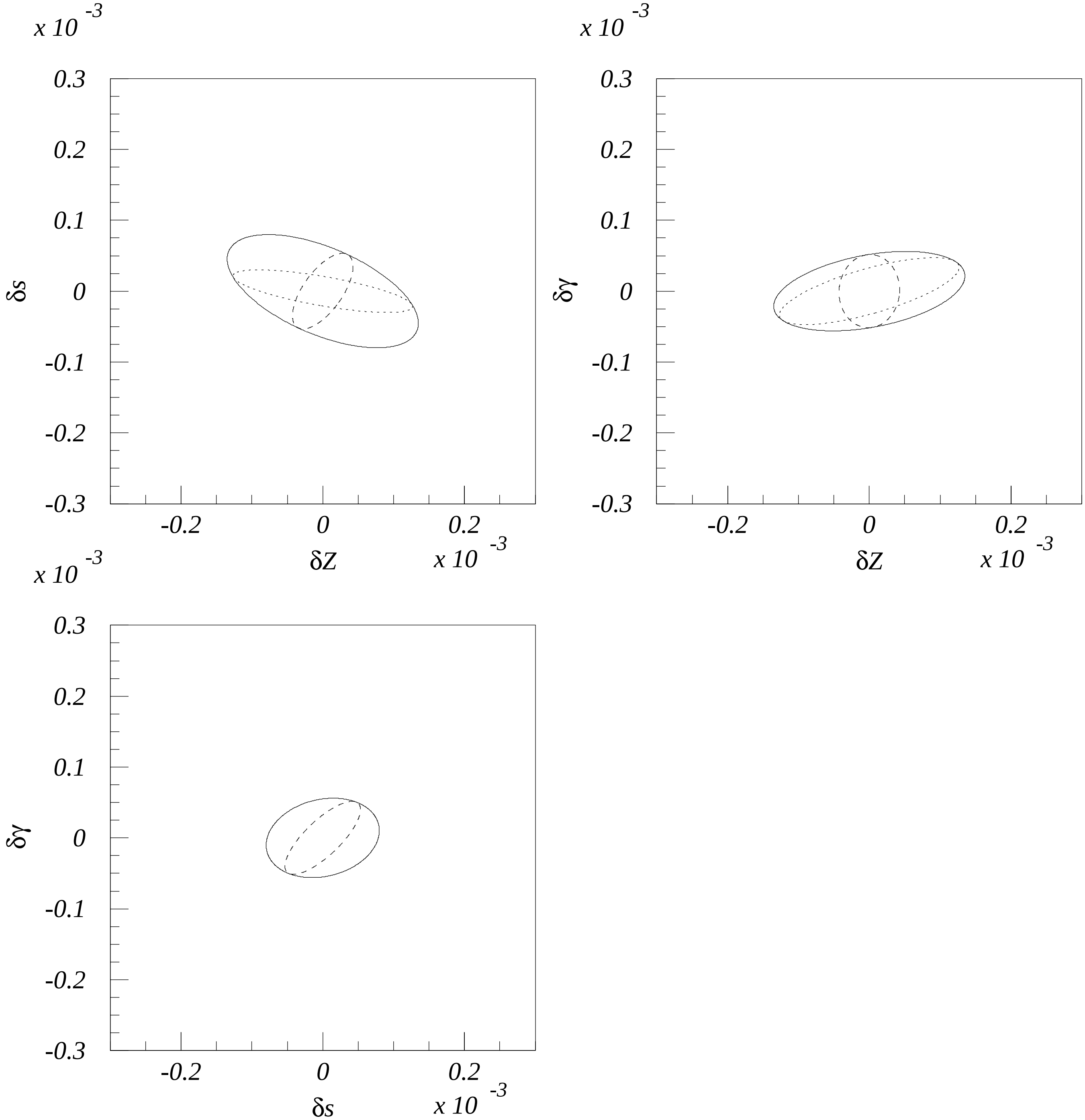


Bounds on δ

with Bhabha || asymmetry



Bounds on δ
with all Bhabha observables



Bounds on δ

Present Data

	without Bhabha	with all Bhabha	σ	A_{LR}	$A_{\|\|}$	forw.	back.
$10^4\ \delta_Z$	2.4	1.3	1.9	2.1	1.7	1.6	1.7
$10^4\ \delta_s$	1.4	0.8	1.3	**0.85**	1.3	**0.82**	1.3
$10^4\ \delta_\gamma$	1.1	0.56	**0.62**	1.1	0.9	**0.65**	0.82

Bounds on Non Universal New Physics

	without Bhabha	with all Bhabha	σ	A_{LR}	$A_{\|\|}$	forw.	back.
Λ_{LL}	85	94	89	89	87	93	85
Λ_{RR}	84	92	87	88	85	92	84
Λ_{LR}	66	120	120	66	87	110	110
Λ_{RL}	81	130	120	81	94	110	110
Λ_{VV}	120	150	150	120	120	150	140
Λ_{AA}	110	140	130	110	120	120	130
Λ_{AV}	130	130	130	130	130	130	130
Λ_{VA}	71	90	71	90	71	90	71
Λ_{ED}	3.3	5.7	5.7	3.3	3.6	5.6	4.5

Conclusions

- Simple parametrization of New Physics Effects in $e^+e^- \rightarrow f\bar{f}$ at present and future energies

- Exploitation of the Z-peak inputs in an automatic fashion for conventional observables and also for Bhabha

- Important Role of Bhabha scattering as a complementary measurement (such as A_{LR} available at NLC) and as a probe for certain New Physics models