Experimental Aspects of New Physics at TeV Scale & Precision Electroweak

Atul Gurtu

TIFR, Mumbai

Nature of LC measurements

Stand-alone:

Direct search for new & undiscovered particles with limited energy reach

Precision measurements of known processes to discover deviations from SM to reveal new physics even beyond direct energy reach

Guided by LHC:

Disentangle the LHC discoveries

Presentations in the five sessions on

New physics at TeV scale and precision electroweak

New Vector Boson related;

Use of polarized beams;

EW measurement related (TGC

W-pair prod., 3-gauge boson);

Loop calculations (ew mixing angle, 2-fermion, running α);

Special models (NCSM, Little Higgs);

ED/KK related (Higgsless model, UED, dark matter, graviton induced brem, Higgs pair prod, 5-D SM extn)

Experiment related:

Precision luminosity measurement, results on muon g-2.

Interesting and varied topics.

Cannot hope to present all. All talks are (will be) available on the WEB.

Hope to give you a flavor.

Plan of the talk

- Electroweak
- Contact interactions, Z' etc
- Theory to match
- Examples of importance of Polarization
- Extra dimensions
- Recent models (Little Higgs, Warped Higgsless)

Don't know how far I will get !

Importance of Precision Electroweak studies

SM: W,Z conceal Higgs field DOF

Thus:

➔Precision study of W, Z properties, & their production & decay characteristics will reveal nature of EWSB and test the internal consistencies within SM.

➔Deviations from SM will imply NEW PHYSICS.

➔Nature of deviations: which (or NEW) model.

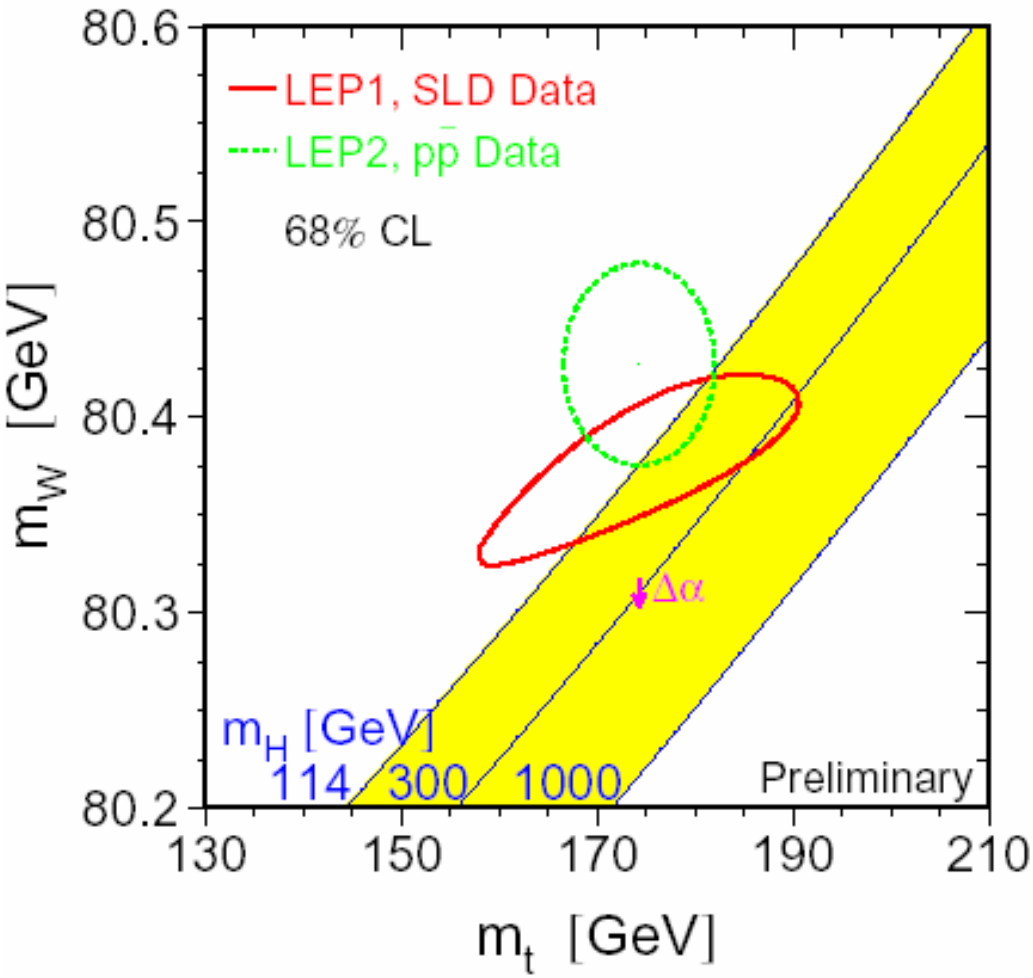
Precision Electroweak - masses

➔ M_z LEP: 2 MeV error

➔ M_W current: 34 MeV (dominated by LEP),
Tevatron-Run2: ~20-25 MeV,
LHC: ~15 MeV ? LC: ~5-10 MeV ?

➔ Mtop current: 4 GeV, Tevatron-Run2:
2-3 GeV, LHC: 1-2 GeV (?), LC: 100 MeV ?

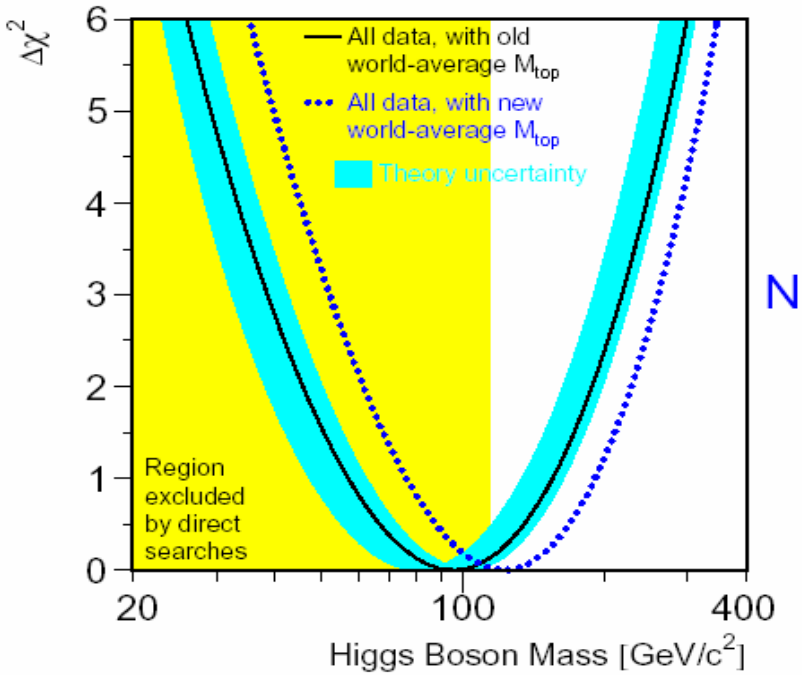
Importance of precise mass determinations



New top mass and M_{higgs}

Precision electroweak data:

Constrain M_H in the MSM



Old:

$$M_{top} = 174.3 \pm 5.1 \text{ GeV}$$

$$\log M_H = 1.98^{+0.21}_{-0.22}$$

$$M_H = 96^{+60}_{-38} \text{ GeV}$$

$$\text{or} < 219 \text{ GeV (95\% CL)}$$

New:

$$M_{top} = 178.0 \pm 4.3 \text{ GeV}$$

$$\log M_H = 2.07^{+0.20}_{-0.21}$$

$$M_H = 117^{+67}_{-45} \text{ GeV}$$

$$\text{or} < 251 \text{ GeV (95\% CL)}$$

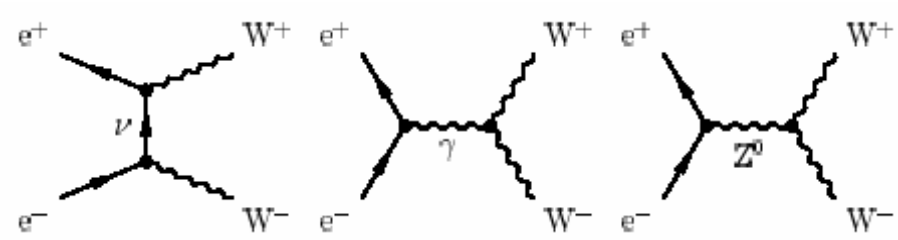
(Procedure as in hep-ex/0312023!)

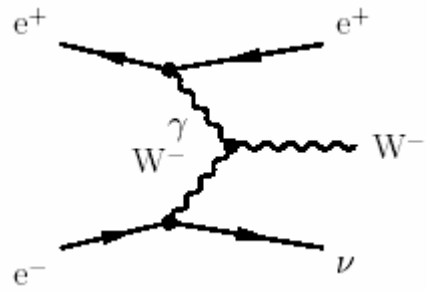
Precision Electroweak (contd)
Gauge Couplings

Specially sensitive to models of EWSB

At LC, will be measured with very high precision (10^{-4})

Measured using single/ pair production of Gauge bosons (W, Z, photon). Use σ, $d\sigma/d\cos\theta$.





Precision Electroweak (contd)
Gauge Couplings at LEP

Common set: $[g_1^z, \kappa_z, \kappa_\chi, \lambda_z, \lambda_\chi]$,

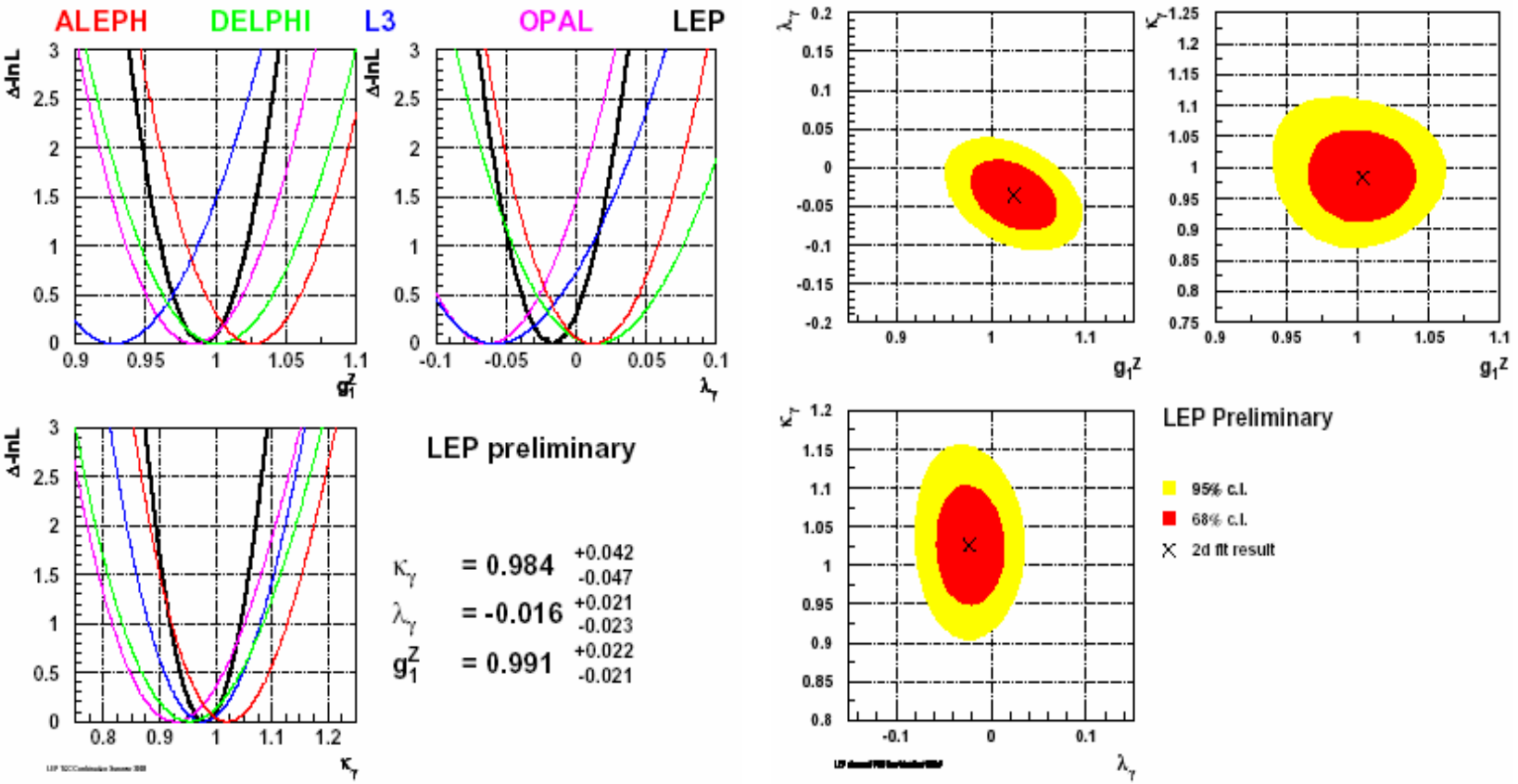
SM: CP- conserving

$g_1^z = \kappa_z = \kappa_\chi = 1; \quad \lambda_z = \lambda_\chi = 0$

SM: not C or P- conserving

g_5^z, g_4^z, $\tilde{\kappa}_z$, $\tilde{\kappa}_\chi$

Precision Electroweak (contd)
Charged TGC's at LEP



Expectations at LC (TESLA-TDR), comparison of Colliders

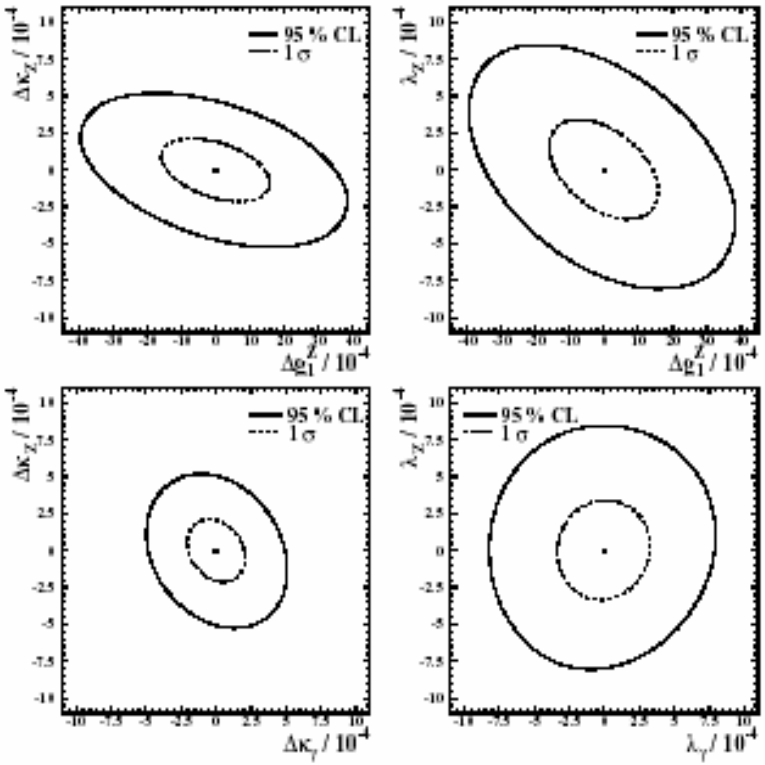


Figure 5.1.5: 1σ and 95% c.l. (2D) contours for Δg_1^Z-$\Delta\kappa_Z$, Δg_1^Z-λ_Z, $\Delta\kappa_\gamma$-$\Delta\kappa_Z$ and λ_γ-λ_Z in the 5-parameter fit ($\sqrt{s} = 800$ GeV, $\mathcal{L} = 1000\,\mathrm{fb}^{-1}$, $\mathcal{P}_{e^-} = 0.8$, $\mathcal{P}_{e^+} = 0.6$). For the combinations not shown the correlations are small.

coupling	error $\times 10^{-4}$	
	$\sqrt{s} = 500$ GeV	$\sqrt{s} = 800$ GeV
C,P-conserving, SU(2) × U(1) relations:		
Δg_1^Z	2.8	1.8
$\Delta\kappa_\gamma$	3.1	1.9
λ_γ	4.3	2.6
C,P-conserving, no relations:		
Δg_1^Z	15.5	12.6
$\Delta\kappa_\gamma$	3.3	1.9
λ_γ	5.9	3.3
$\Delta\kappa_Z$	3.2	1.9
λ_Z	6.7	3.0
not C or P conserving:		
g_5^Z	16.5	14.4
g_4^Z	45.9	18.3
$\tilde{\kappa}_Z$	39.0	14.3
$\tilde{\lambda}_Z$	7.5	3.0

Table 5.1.1: *Results of the single parameter fits (1σ) to the different triple gauge couplings. For $\sqrt{s} = 500$ GeV $\mathcal{L} = 500\,\mathrm{fb}^{-1}$ and for $\sqrt{s} = 800$ GeV $\mathcal{L} = 1000\,\mathrm{fb}^{-1}$ has been assumed. For both energies $\mathcal{P}_{e^-} = 80\%$ and $\mathcal{P}_{e^+} = 60\%$ has been used.*

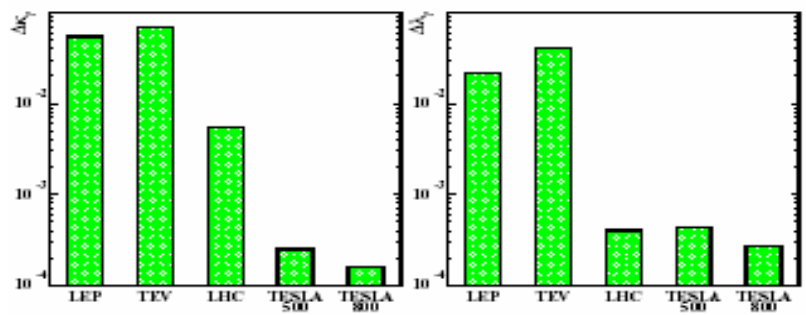


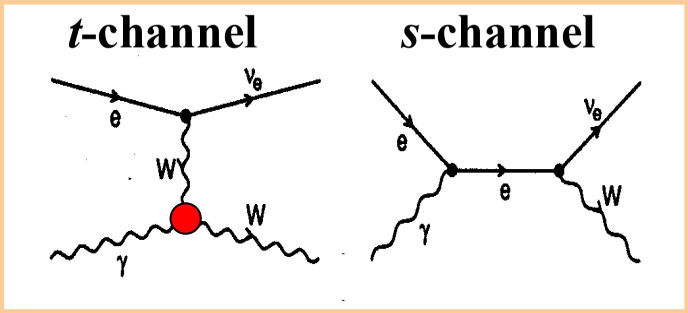
Figure 5.1.6: *Comparison of $\Delta\kappa_\gamma$ and $\Delta\lambda_\gamma$ at different machines. For LHC and TESLA three years of running are assumed (LHC: 300 fb^{-1}, TESLA $\sqrt{s} = 500$ GeV: 900 fb^{-1}, TESLA $\sqrt{s} = 800$ GeV: 1500 fb^{-1}).*

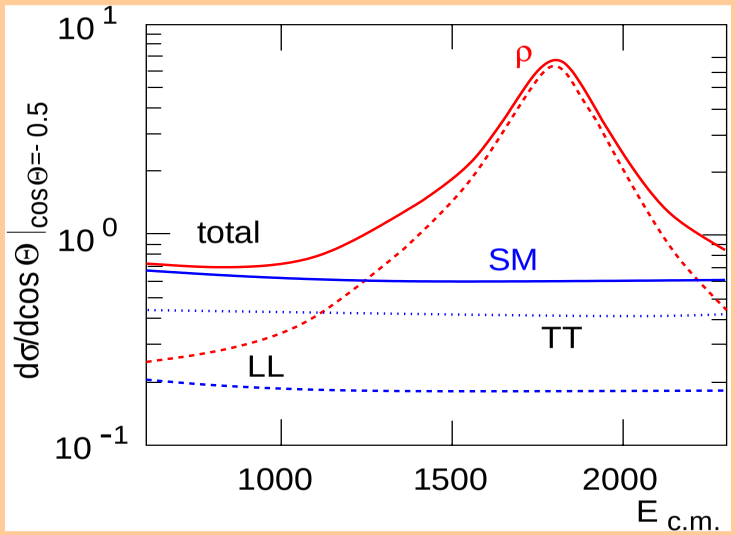
e.g.
W - couplings at an $e\gamma$ collider & comparison with e+e- and $\gamma\gamma$ colliders

K.Mönig, J.Sekaric
DESY - Zeuthen

Overview

$e^-\gamma \rightarrow \nu_e W^-$ $\sqrt{S} = 450GeV$

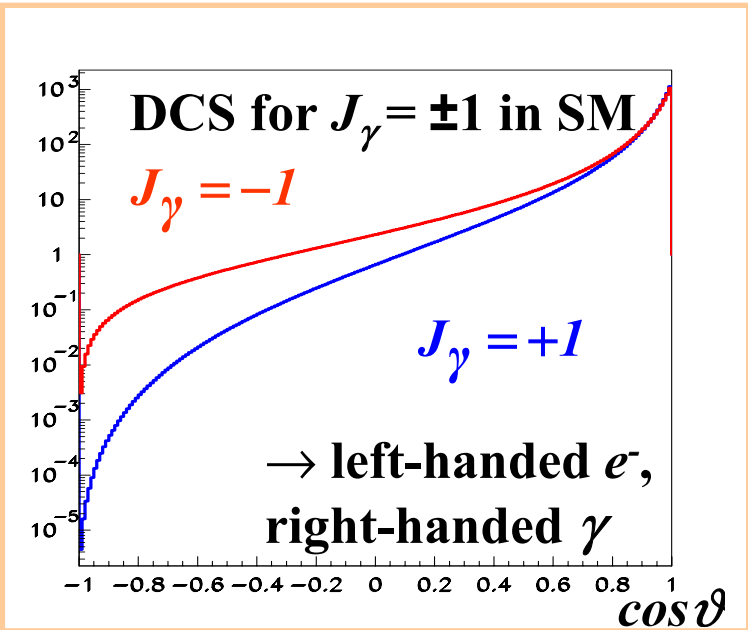




Vector 'ρ'-like resonance in $e^+e^- \rightarrow W^+W^-$

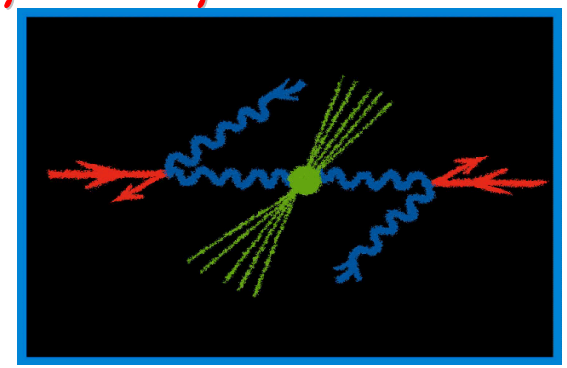
Deviations from SM TGC values → *test of EW theory, probe of some possible extensions → new physics beyond the SM*

- precision measurements of deviations from its SM values (anomalous TGC)



In order to estimate the precision of measurement of TGC :

- Signal ($\gamma e^- \rightarrow \nu W$) sample (background, pile-up) (WHIZARD – W. Kilian & CIRCE2 – T. Ohl, variable energy spectra, polarized beams)
- Response of a detector simulated with SIMDET V4
- *W*s are reconstructed from *hadronic final states*
- *Estimated errors* of measurement of κ_γ and λ_γ parameters, obtained by fit (binned χ^2) for
  real ($e\gamma$- *collider*) and
  parasitic ($\gamma\gamma$- *collider*) $e\gamma$-mode
- Estimation of *systematic errors*



Comparison …

with $\gamma\gamma$ and e^+e^- colliders

	$E_{e\gamma}$= 450 GeV $\int L\Delta t$=110 fb^{-1}	$E_{\gamma\gamma}$= 400 GeV $\int L\Delta t$=110 fb^{-1}	E_{ee}= 500 GeV $\int L\Delta t$=500 fb^{-1}
ΔL	0.1%	0.1%	Acc *
$\Delta\kappa_\gamma \cdot 10^{-4}$	10.0/11.0	(6.7)	3.6
$\Delta\lambda_\gamma \cdot 10^{-4}$	4.9/6.7	(6.0)	11.0

( ) – fixed beam energy, 2D fit, generator level

• – generator level

• Demonstration of 10^{-4} to 10^{-3} capability of LC

Quartic gauge couplings in a strongly interacting heavy Higgs model

Michael Beyer:

e+e- → WWZ, ZZZ

Carried out SIMDET simulation, preliminary results on ability to obtain parameter values (α_4, α_5).

Further studies in progress.

Precision Electroweak: using di-fermion production

Cross section and asym. measurements:
- all agree with SM predictions

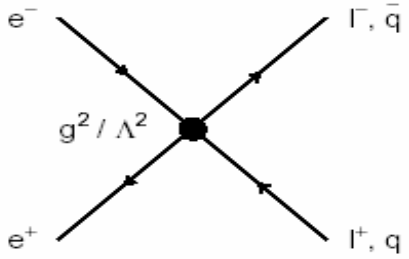
- Contact interaction scale can be used to place limits on mass of Z', scale of gravity or mass of lepto-quarks or other new physics.

case of Z' is very important as additional Z bosons exist in many new physics scenarios (E6, Little Higgs and Higgsless models).

(Sabine Riemann, A. Freitas, W. Kilian, T. Rizzo, … – this conf.)

Contact Interactions

Contact interactions (C.I.) to describe interactions beyond the SM at $\sqrt{s} \ll \Lambda$



$$\mathcal{L}_{CI} = \sum_{L,R} \eta_{i,j} \frac{g^2}{\Lambda^2} \left(\bar{u}_{F,i}\gamma^\mu u_{F,i}\right)\left(\bar{u}_{f,j}\gamma_\mu f_{f,j}\right)$$

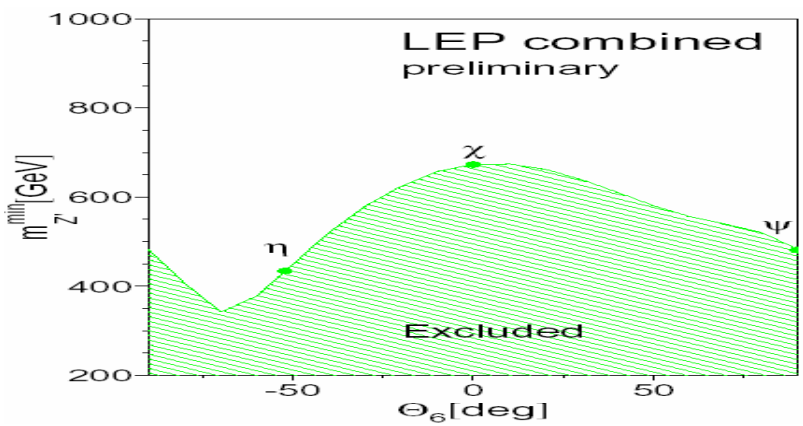
$$\frac{d\sigma}{d\cos\Omega} \propto \sum_{i,j=L,R} \rho_{ij}|A_{ij}|^2 \text{ with } A_{ij} \sim A_{ij}^{SM} + \frac{\eta_{ij}\cdot s}{\Lambda^2}$$

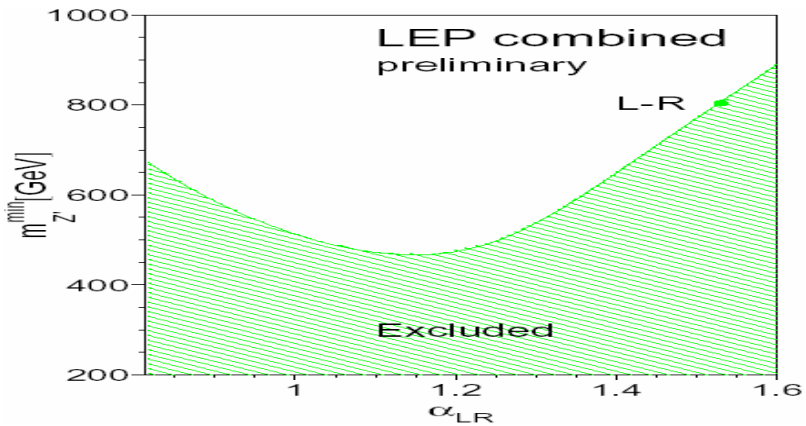
$$\rho_{LL,RR} = (1+\cos\theta)^2$$
$$\rho_{LR,RL} = (1-\cos\theta)^2$$

		LHC Λ [TeV]				LC Λ [TeV]				
model		LL	RR	LR	RL	LL	RR	LR	RL	
eeqq:	Λ_+	20.1	20.2	22.1	21.8	64	24	92	22	Gupta, Jain, Mondal, PRD**62**(2000)095003
	Λ_-	33.8	33.7	29.2	29.7	63	35	92	24	
ee$\mu\mu$:	Λ_+					90	88	72	72	SR, LC-TH-2001-007,
	Λ_-					90	88	72	72	Babich et al., hep-ph/0107159
eeee:	Λ_+					44.9	43.4	52.4	52.4	D. Bourilkov, hep-ph/0305125
	Λ_-					43.5	42.1	50.7	50.7	Pankov, Paver, hep-ph/0209058

LC: $\sqrt{s} = 500$ GeV

LEP – Z' mass limit





Fits made to Z' from E6 GUT & L-R symmetric Models and for Sequential SM (same couplings as SM).

Z' model:	chi	psi	eta	L-R	SSM
Mass limit:	673	481	434	804	1787 GeV

Z' Limits at the LC

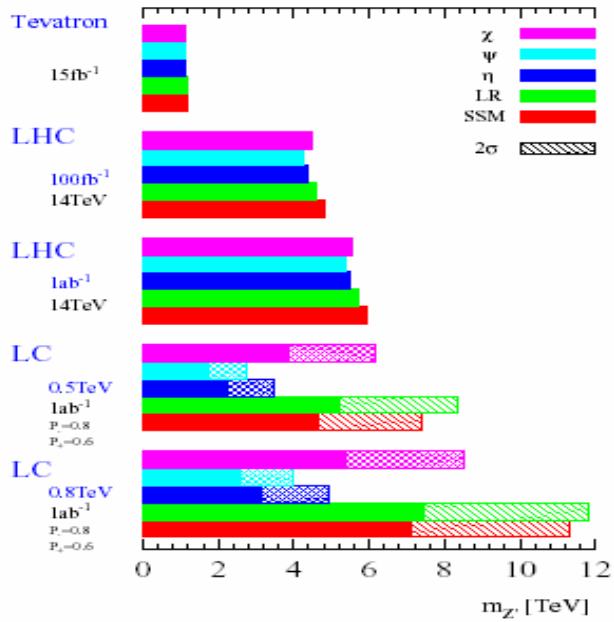
Most likely indirect Z′ search at LC

- derive Z′ couplings $\frac{g^f_{L,R}}{M_{Z'}}$
- observables: σ_{tot}, A_{FB}, A_{LR}, A^{FB}_{LR}
- search for contact terms:
  in case of Z′ one finds:

$$\frac{\eta^{ef}_{LL}}{\Lambda^2}\frac{\eta^{ef}_{RR}}{\Lambda^2} = \frac{\eta^{ef}_{LR}}{\Lambda^2}\frac{\eta^{ef}_{RL}}{\Lambda^2}$$

$$\sim \frac{g^e_L}{M_{Z'}}\frac{g^f_L}{M_{Z'}}\frac{g^e_R}{M_{Z'}}\frac{g^f_R}{M_{Z'}}$$

- model-dependent search within various new gauge boson scenarios



LHC: see Godfrey, hep-ph/0201093

Assumptions:

- $\mathcal{L}_{int} = 1ab^{-1}$, $\Delta\mathcal{L}_{int} = 0.2\%$
- $P_- = 0.8$, $P_+ = 0.6$, $\Delta P_- = \Delta P_+ = 0.5\%$
- Δsys(lept)=0.2%, Δsys(had)=0.1%

What if Z' has very weak couplings to fermions ?

A. Freitas:

→Very narrow, energy scan would miss it (washed out by Ecm spread due to ISR, beamstrahlung).

→ Use radiative return method (tag hard γ): reconstruct recoil jet-jet or $\mu\mu$ system

→ Need very good mom./energy resolution

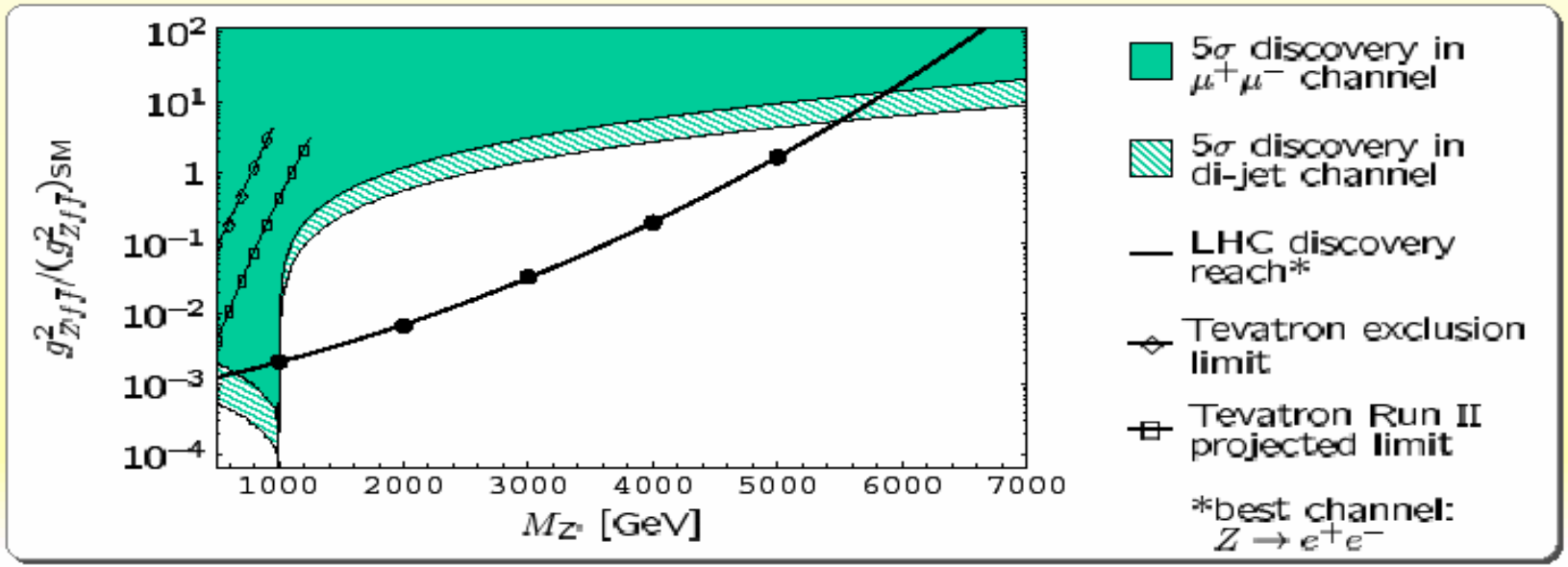
Results: Weakly coupled Narrow Z'

Comparison with hadron colliders

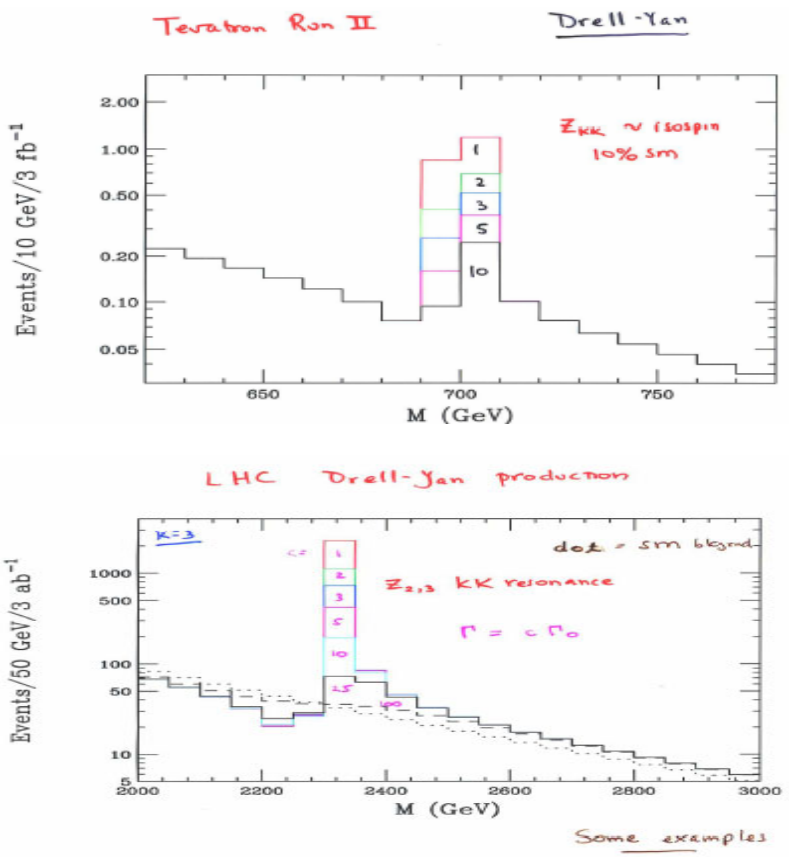
Combination of searches with radiative-return method for $M_{Z'} < \sqrt{s}$ and contact-interaction method for $M_{Z'} > \sqrt{s}$:

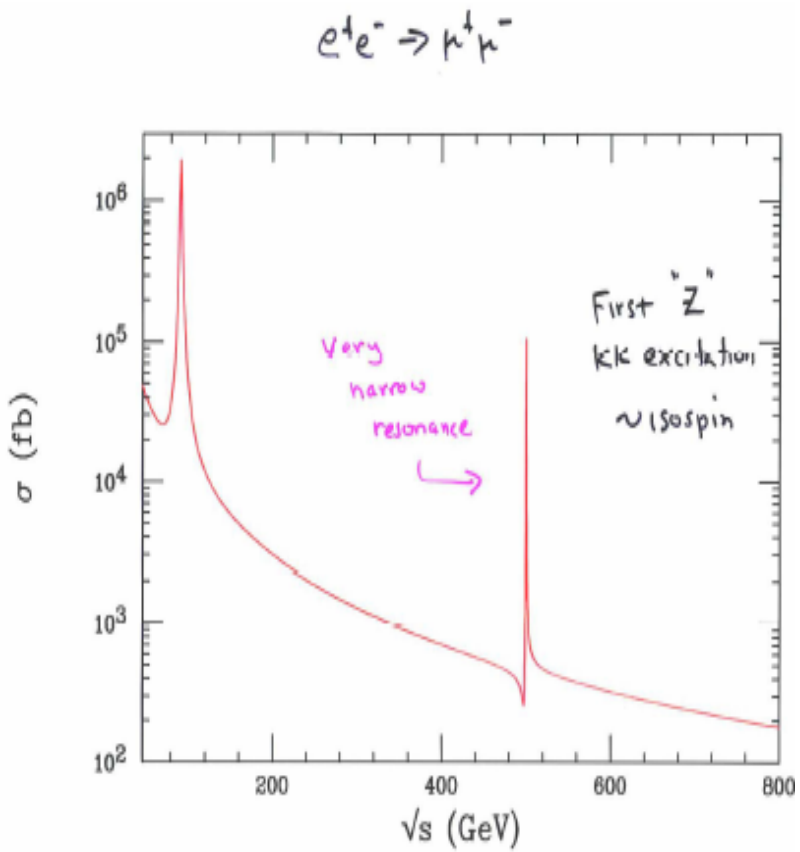
Sensitivity to high masses $M_{Z'}$, but only moderate coupling strength $g^2_{Z'f\bar{f}}/(g^2_{Zf\bar{f}})_{SM}$

Example for BR = BR_{SM}: $\sqrt{s} = 1000$ GeV, $\int \mathcal{L} = 1000$ fb^{-1}

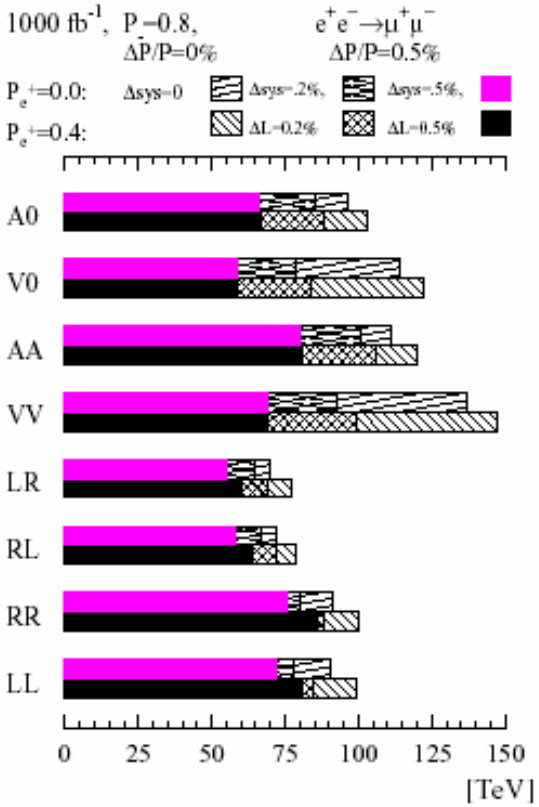


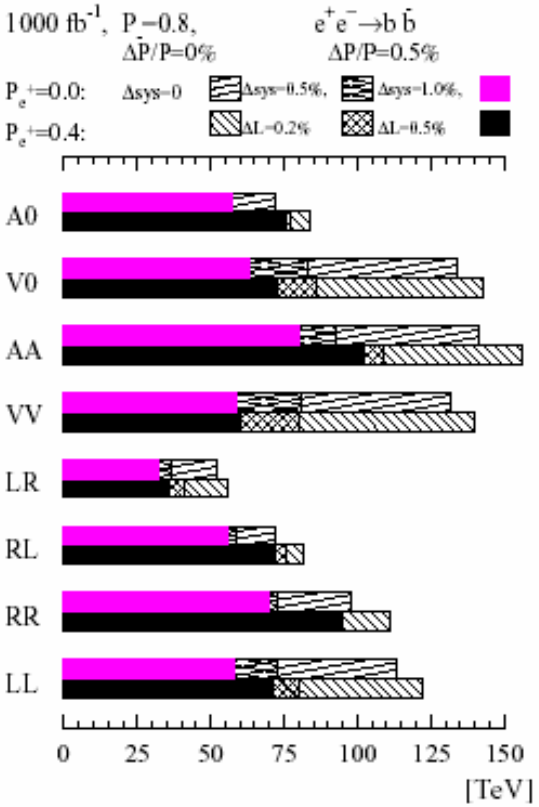
Context of Higgsless model with Z' like KK excitations (T. Rizzo et al)





Lepto-quark searches at a 500 GeV LC





ED - Estimate of M_H limits using di-fermion data at 500 GeV LC

M_D, fundamental scale of higher dimensional theory
$[M^2(Pl) = V_\delta M_D^{2+\delta}]$, V_δ = vol. of compactfied dimensions.

(In general M_H, scale relevant to graviton exchange is not equal to M_D).

Limit on M_H (TeV) for L_{int} = 1 ab^{-1} at 500 GeV	P(e+) = 0.6	0.0
e+e- → μμ	4.1	3.8
→ bb	5.0	4.4
→ cc	5.1	4.4
Combined	5.6	5.0

P=0.6 at 800 GeV
M_H limit ~8 TeV

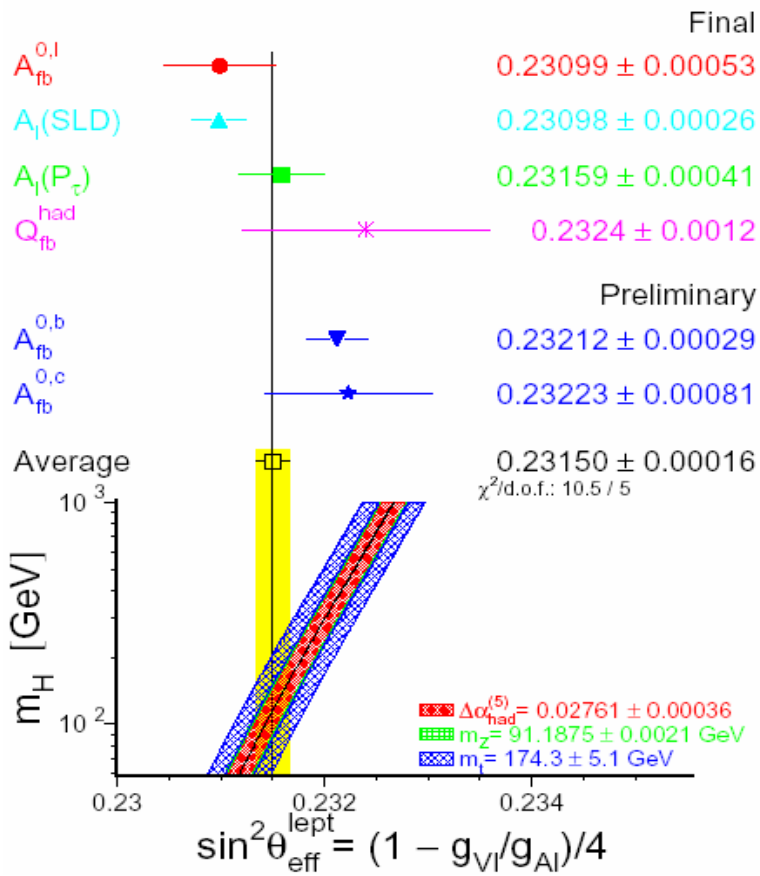
Conclusion: Power of di-fermion study

"Fermion pair production is sensitive to most of new phenomena. The combination of different final states, angular distributions and helicity amplitudes can be exploited to disentangle the source of new physics up to a multiple of available c.m. energies."

Precision Electroweak (contd)

Also solve left-over puzzle from LEP: disagreement in measured EW angle from different asyms.

'Cleaner' Measurements
➔TOO LOW M_{higgs} value



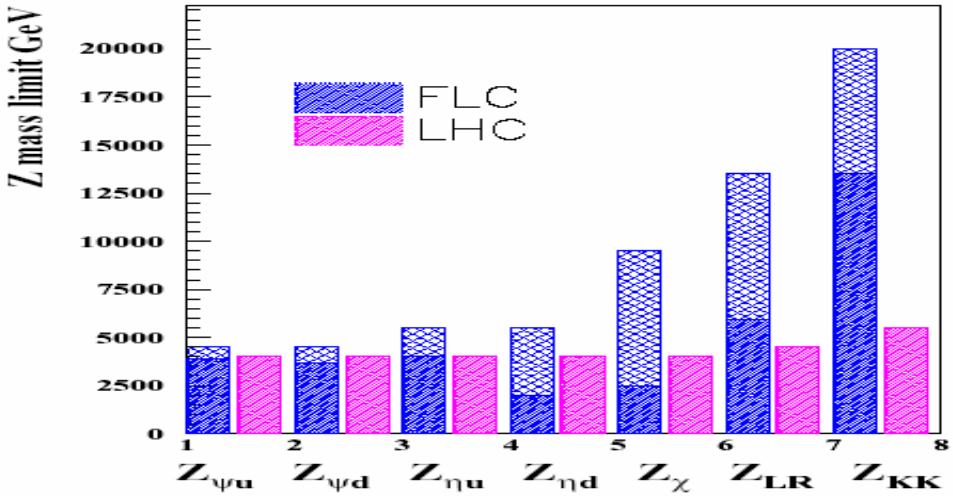
Precision electroweak, Giga-Z, W-threshold runs

- Giga-Z: 10^9 Z in 100 days run → partial widths, ew mixing angle, b, c- quark studies
- W-threshold → W-mass

	LEP/SLC/Tev [19]	TESLA
$\sin^2\theta^{\ell}_{eff}$	0.23146 ± 0.00017	± 0.000013
lineshape observables:		
M_Z	91.1875 ± 0.0021 GeV	± 0.0021 GeV
$\alpha_s(M_Z^2)$	0.1183 ± 0.0027	± 0.0003
$\Delta\rho_\ell$	$(0.55 \pm 0.10) \cdot 10^{-2}$	$\pm 0.05 \cdot 10^{-2}$
N_ν	2.984 ± 0.008	± 0.004
heavy flavours:		
$\mathcal{A}_b$	0.898 ± 0.015	± 0.001
R_b^0	0.21653 ± 0.00069	± 0.00014
M_W	80.436 ± 0.038 GeV	± 0.008 GeV

Z' searches: comparison of LHC with LC (GigaZ + high energy)

LHC and LC (GigaZ and 'high energy'):



Theory to match

3 interesting talks:

T. Riemann: automatized Calculation of 2f production with aITALC for higher precision calculations

M. Awramik: NNLO corrections to the effective weak mixing angle. Need a precision of ~10^{-5} to match Giga-Z LC results.

L.Trentadue: Proposal to determine running of α_{QED} using small angle Bhabha scattering

Importance of both beams polarization, and transverse pol.

G. Moortgat-Pick & S.D. Rindani:

Apart from the general desirability of BOTH beams polarized,

there are cases where TRANSVERSE polarization is essential to disentangle the physics or determine a coupling.

⇒ However sensitiv to one specific TGC only with trans. pol. via optimal observable method Diehl, Nachtmann, Nagel'03

reparametrisation and taking linear combinations → 'error minimisatio

⇒ one specific coupling $\tilde{h}_{\pm} = Im(g_1^R \pm \kappa_R)/\sqrt{2}$ only sensitiv to $P_T P_T$

	unpol	long (80%,0)	long (80%,60%)	trans (80%, 60%)
$\tilde{h}_-$	11	4.5	2.5	3.7
$\tilde{h}_+$	–	–	–	3.2

⇒ other results comparable simulation results

Need of transverse polarization in LC studies

3 specific examples:

- CP violation in $e^+e^- \to t\bar{t}$ in the presence of chirality-violating scalar S and tensor T contact interactions
  (in collaboration with B. Ananthanarayan
  hep-ph/0309260, LC-TH-2001-099)
- CP violation in $e^+e^- \to \gamma Z$ with chirality-preserving anomalous triple gauge couplings $\gamma\gamma Z$ and γZZ
  (in collaboration with B. Ananthanarayan, A. Bartl, R.K.Singh
  hep-ph/0404106)
- $e^+e^- \to t\bar{t}$ with scalar leptoquark intermediate states, both chirality preserving and chirality violating couplings
  (in preparation)

Minimal 5D Extensions of SM

R. Rueckl: Non-universal 5D model.

Studied effects on SM processes.

Determined Compactification scale by fitting EW data.

LEP data: 4-6 TeV (shifts higgs mass upward by 40-50 GeV)

TESLA: 15-25 TeV (syst errs incl.)

$$\mathcal{O}^{\mathrm{5DSM}} = \mathcal{O}^{\mathrm{SM}} \left(1 + \Delta_{\mathcal{O}}^{\mathrm{5DSM}} \right)$$

$\mathcal{O}^{\mathrm{SM}}$: standard model prediction including radiative corrections

$\Delta_{\mathcal{O}}^{\mathrm{5DSM}}$: tree level effects in compactified 5D extensions (to $O(m_Z^2/M^2)$, $M = 1/R$)

- shifts in couplings and masses of the SM gauge bosons
- virtual exchange of heavy KK modes

  $\rightarrow$ modification of SM relations between ew. parameters

input parameters (α, M_Z, G_F)

LEP1 (precision observables) and LEP2 (fermion-pair, W-pair production) data
Particle Data Group, Electroweak Working Group

one-parameter fit excluding (including) $e^+e^- \to e^+e^-$ and $e^+e^- \to W^+W^-$:

SU(2)$\times$U(1) in bulk (brane Higgs):	6.4 (6.9) TeV
SU(2)$\times$U(1) in bulk (bulk Higgs):	5.5 (6.0) TeV
U(1) in bulk:	5.0 (5.4) TeV
SU(1) in bulk:	4.5 (4.8) TeV

multi-parameter fit using ZFITTER (D. Bardin et al.):

SU(2)$\times$U(1) in bulk (brane Higgs):	5.4 TeV
SU(2)$\times$U(1) in bulk (bulk Higgs):	5.2 TeV
U(1) in bulk:	3.6 TeV
SU(2) in bulk:	4.3 TeV

Minimal Universal Extra dimensions – study at CLIC

A. De Roeck: Minimal UED model, d=4+1 (Cheng, Schmaltz, Matchev)

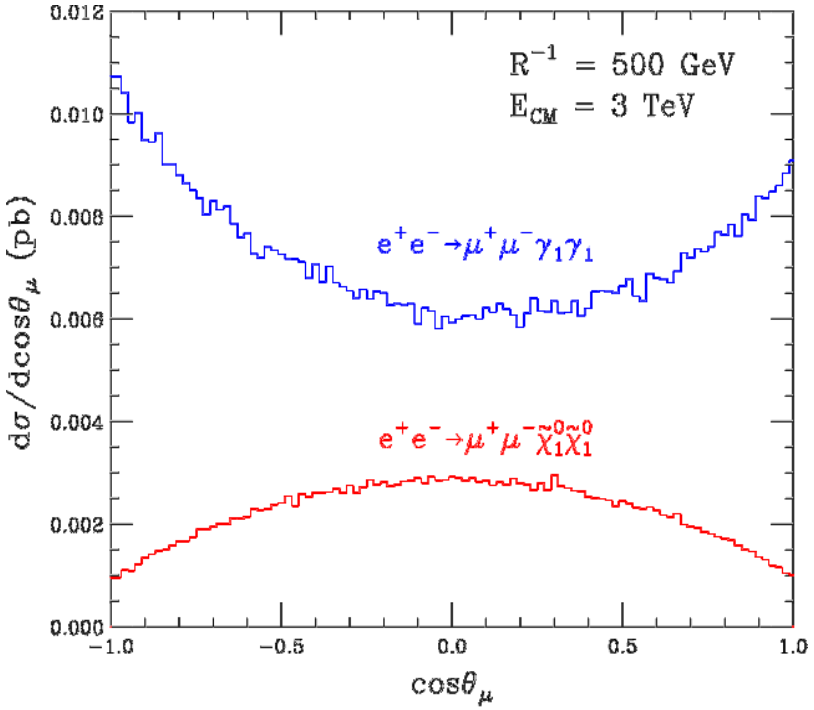
→ KK partners for all particles and LKP (Lightest KK Particle) dark matter candidate.

→ Signatures very much like SUSY; could be discovered at LHC. Would need LC for proper interpretation of the signal.

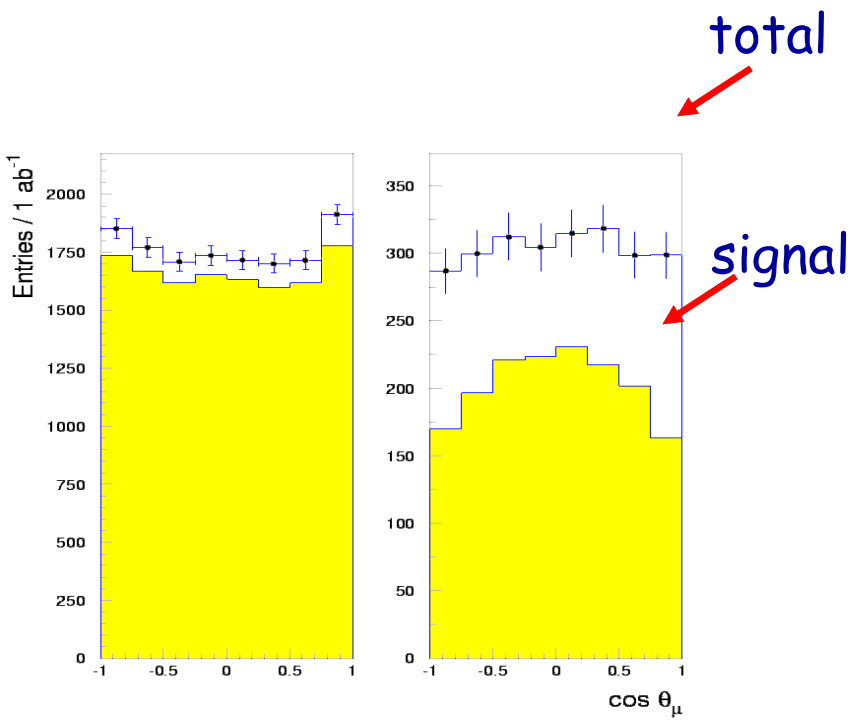
Comparison: angular distributions of muons

Production polar angle θ of the decay muons

If mass difference $M_{\mu 1}$ -$M_{\gamma 1}$ small ⇒ correlation between muons & parer



Theoretical prediction



After detector simulation
χ^2 fit: can distinguish UED from SUSY at 5σ with 350 fb^{-1} at $\sqrt{s}$= 3 TeV

Higgs pair production in ED models

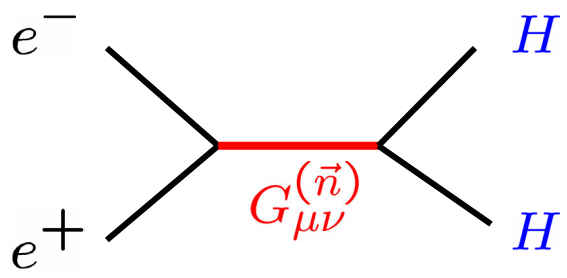
N. Okada: ADD scenario.

KK gravitons either direct observation or via indirect KK mediated process.

Studied higgs pair production. Both Higgs → bb; 4b final state.

Cross section & its angular distribution allows identification of spin-2 KK indirectly.

Virtual KK graviton mediated process



Sum over infinite tower of KK modes

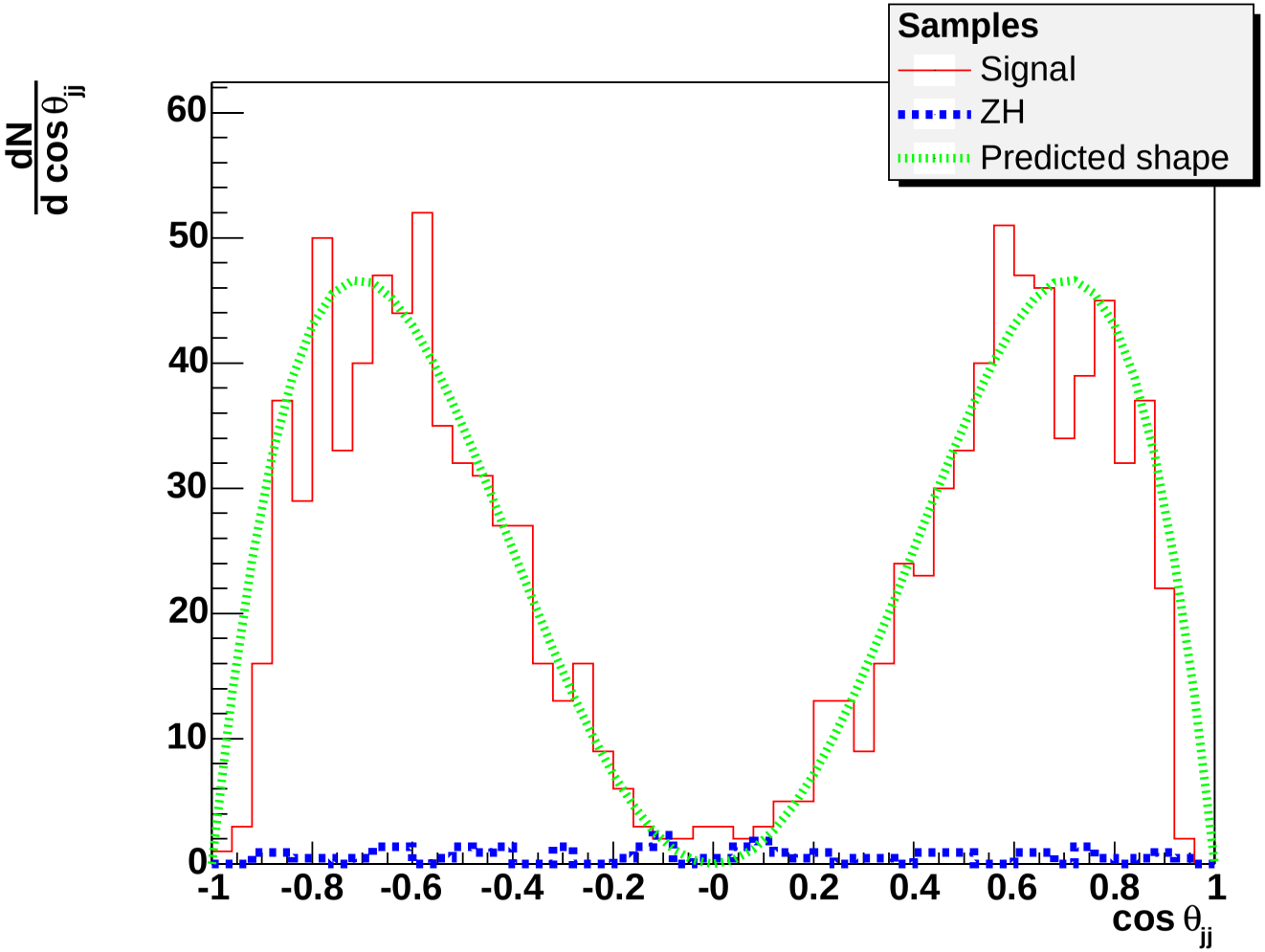
$$\sum_{\vec{n}} \frac{1}{s - \left(m_{KK}^{(\vec{n})}\right)^2} \to \infty \quad (\text{for } \delta \geq 2)$$

Need regularization

Naïve: Cut Off by $m_{KK}^{MAX} \sim M_{4+\delta}$

$$\boxed{\frac{4\pi\lambda}{M_S{}^4}} = -\frac{8\pi}{M_P^2} \sum_{\vec{n}} \frac{1}{s - \left(m_{KK}^{(\vec{n})}\right)^2}; \qquad \lambda = \pm 1$$

Reconstruction of Angular Distribution (after selection)



integrated luminosity 500 fb^{-1}

Little Higgs Model

(Arkani-Hamed, Cohen, Georgi, 2001, …)

Higgs doublet part of pseudo-Goldstone bosons multiplet associated with a global sym. at scale Λ in multi-TeV range → protects lightness of Higgs fields.

Characteristic scale of Goldstone multiplet F, is given by $F \sim 4\pi$ v(**EW** scale ~250 GeV) ~ $\Lambda/4\pi$

Addl particles introduced:

extra vector bosons, scalars, fermions whose properties arranged to ensure at least one light higgs.

Others have masses of order F (many TeV), hence unobserved so far.

Little Higgs: what signals ?

W. Kilian (talk + hep-ph/0311095) and

Gi-Chol Cho:

If new particles beyond LC reach

Check for indirect effects in precision measurement, e.g., Oblique correction variables S,T,U.

If discovered how to distinguish from other scenarios (e.g. E6 Z')

Little Higgs observables

Results: LEP Observables (Littlest Higgs)

Caveat: Direct *and* indirect effects of contact interactions

- Conventionally, S, T, U are calculated using G_F as reference scale

Shift in effective Fermi coupling:

$$G_F = \frac{1}{v^2}(1 - \alpha\Delta T + \delta) \qquad \text{with} \qquad \delta = c^4 \frac{v^2}{F^2}$$

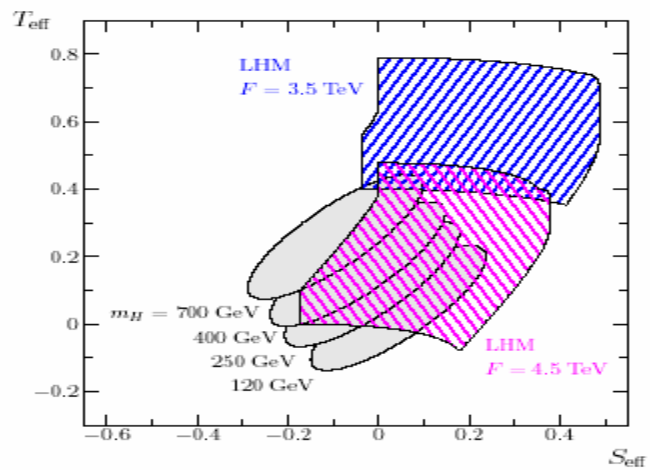
$\Rightarrow$ modified effective parameters

$$S_{\text{eff}} = \Delta S$$

$$T_{\text{eff}} = \Delta T - \frac{1}{\alpha}\delta$$

$$U_{\text{eff}} = \frac{4 s_w^2}{\alpha}\delta$$

$\Rightarrow$ Partial cancellation in T, positive U
due to nonvanishing δ ($SU(2)_c$-conserving)



Identifying Little Higgs signals – need for precision measurement of all kinds of couplings

New observables: Linear Collider

- Triple gauge couplings:

$$\Delta g_\gamma = \Delta\kappa_\gamma = 0$$

$$\Delta g_Z = \Delta\kappa_Z = 2M_Z^2 \frac{c^2(c^2 - s^2)}{g^2 F^2}$$

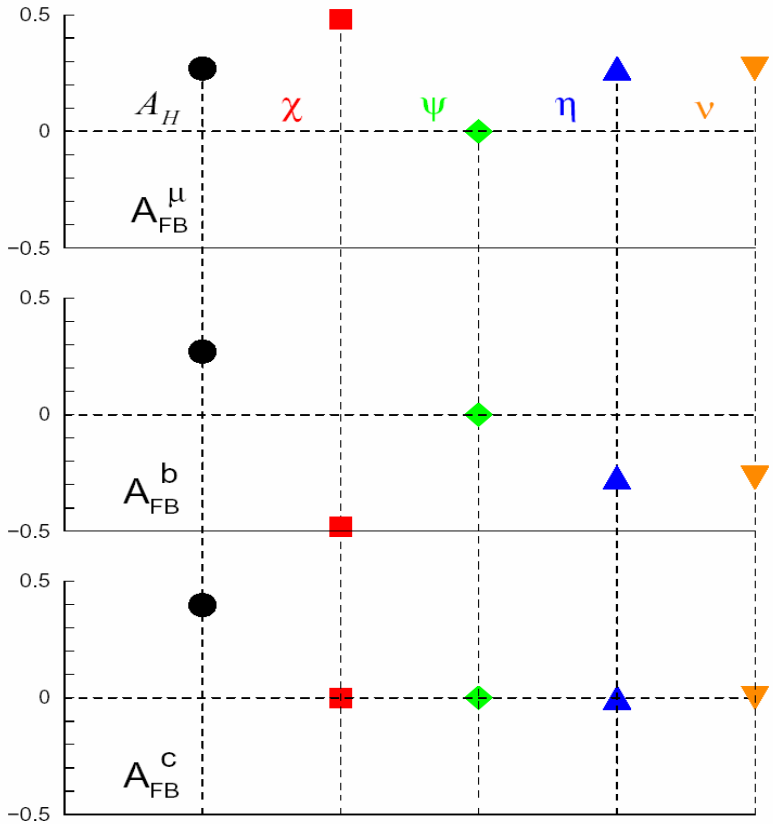
  (equals ΔS correction, but triplet part only)

- Higgs boson couplings:
  Anomalous ZZH, WWH vertices, sensitive to coefficient of $\mathrm{Tr}\,[V_\mu V^\mu]$
  (nonvanishing if heavy vectors decouple, contains piece due to nonlinear representation)
- Corrections to Higgs Yukawa couplings, extra $HHf\bar{f}$ terms (sensitive to scalar sector)
- Higgs contact terms: $f\bar{f}HW$, $f\bar{f}HZ$
  $\Rightarrow$ include these in analysis of Higgs couplings
- Anomalous $t\bar{t}Z$ and $t\bar{b}W$ couplings (sensitive to heavy-top chirality)
- Modified quartic couplings $HHWW$, $HHZZ$
- Modified Higgs self-coupling HHH

Distinguishing between Little Higgs Z' and E6 Z'

- LHC has a detectability of TeV *Z'* boson in some class of models
- What can LC do if LHC find a *Z'* boson (< 1TeV)?
  - If *Z'* mass is smaller than the CM energy of LC, it can be produced in *s*-channel
- Can LC tell us that if discovered Z' boson is in Littlest Higgs model or SUSY E6 models?

Signal cross section + FB asymmetry measurements



	A_H	χ	ψ	η	ν
A_{FB}^{μ}	0.27	0.48	0	0.27	0.27

	A_H	χ	ψ	η	ν
A_{FB}^{b}	0.27	-0.48	0	-0.27	-0.27

	A_H	χ	ψ	η	ν
A_{FB}^{c}	0.397	0	0	0	0

ED – Warped Higgsless Model

Talks by Tom Rizzo, Christophe Grojean

Try to do what Higgs does without it.

Randall-Sundrum framework:

Gravity localised in a 5-D non-factorizable geometry based on a slice of AdS_5.

Warped Higgsless Model - 2

Goal is to have a model consistent with

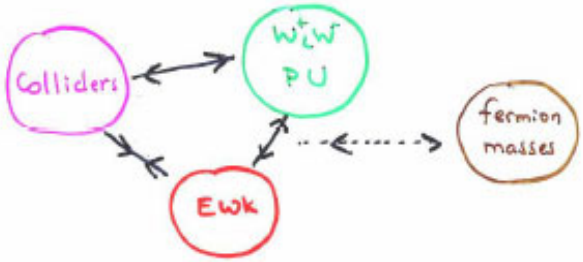
1 existing precision EW data

2 Limits on Z' from current data (compactification leads to KK tower of states which should show up as Z/W excitations)

3 Unitarity in high energy WW scattering

Doing all the above simultaneously is difficult.

TENSION HEADACHE:



Why? w/o a Higgs the SM violates unitarity in $W_L^+W_L^-$ scattering at $\sqrt{s} \simeq 1.8$ TeV

$\therefore$ We need some KK's lighter than this to contribute to $W_L^+W_L^-$ scattering to get P.U.

But: they can't have (yet) showed up at the Tevatron (or via LEPII contact int. searches, etc)

And: light KK's usually imply a 'disruption' of good SM EWK results

Examples: The 3 $\sin^2\theta$'s ... at tree level in the SM ..

$\sin^2\theta_{OS} \equiv 1 - M_W^2/M_Z^2$

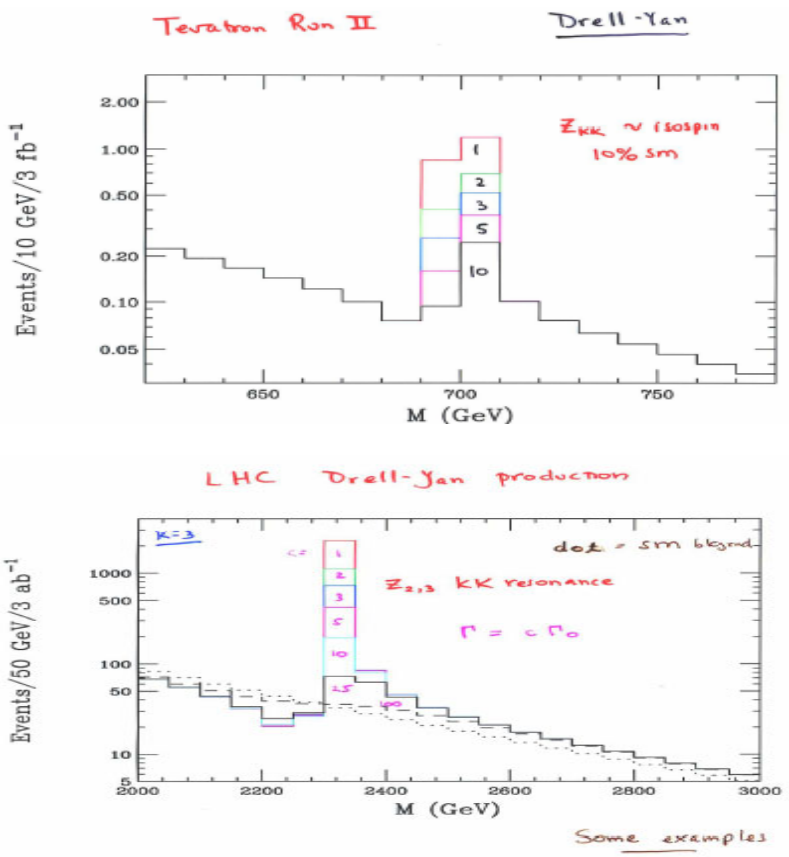
$\sin^2\theta_{eff} \equiv e^2/g_{f\bar{f}V}^2$

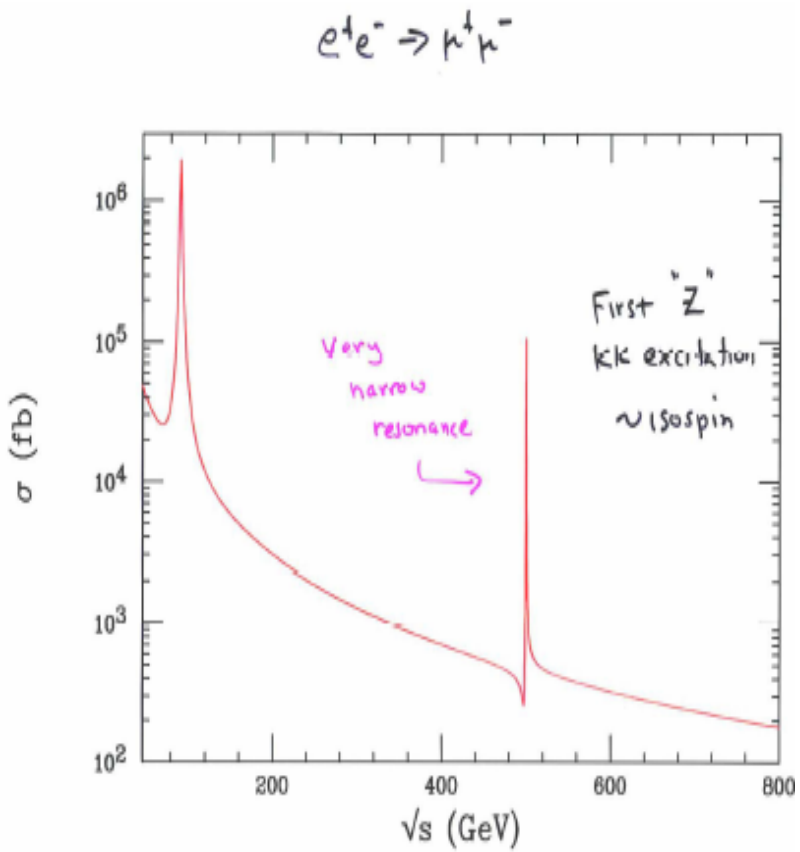
$\sin^2\theta_{eff}$ at the Z-pole

ARE all the same ... differ at loop order

$\Rightarrow$ Here they differ at tree level if M_W/M_Z are inputs

Context of Higgsless model with Z' like KK excitations (T. Rizzo et al)





Conclusions – Warped Higgsless Model

(1) Higgsless models offer a potential method of EW symmetry breaking w/ a Higgs using extra dimensions

(2) The simplest models examined so far do not have all the required features + even they are not yet fully explored

(3) Many (All ?) of the desired properties of a succesful model have been identified → most likely signature

→ light Z/W-like KK states w/ small fermion couplings

→ → Visible at LHC, LC (or even TeV ??)

(4) A lot more work is needed to see if this idea can really work...

Final Remarks – New Physics, EW measurements sessions

- Many studies presented
- At LC most important will be PRECISION EW measurements (for Model Independent conclusions)
- High theoretical precision needed to match measurements – progress in this.
- Need for PRECISION detector to fully exploit the capabilities of the LC
- Status of models given – need more work

Universal Extra Dimensions

- The framework is all fields live in all dimensions:
  - Quarks & Gluons
  - Leptons
  - Photons and Gauge Bosons
  - Higgs
  - Gravity
- This is unlike the "brane world" scenario where everything except gravity is stuck to some point.
- This universality implies a translational invariance along the 5th dimension, and thus conservation of momentum in that direction.
- The result is a stable particle, necessary to have a dark matter candidate.

Universal ED's in Cosmology (Dark Matter)

Tim Tait:

Lightest KK Particle as Dark matter candidate.