A composite Higgs at high q^2

Heather Logan
Carleton University

Pheno 2012 Symposium
University of Pittsburgh, May 7–9, 2012

Based on K. Hally and H.E.L., arXiv:1205.xxxx

Outline

Motivation

Minimal Composite Higgs model

Probing the Higgs at short wavelength: $e^+e^- \to ZH$

Prospects for measuring Z KK-mode couplings

Conclusions

Motivation

The hierarchy problem motivates new (Higgs-related) physics at the TeV scale:

- new particles + symmetry to cancel t, W, Z, ... loops
- Higgs is a composite object with size $\sim 1/\text{TeV}$

Composite Higgs solves the hierarchy problem because loop momentum integrals are cut off by a formfactor at the TeV scale.

Q: Can we probe this formfactor behavior directly in a collider process?

- Want to "hit the Higgs with a short-wavelength probe"
- Try $f\bar{f} \to ZH$: s-channel Z^* carries full c.m. energy

To study this, need a concrete, calculable composite Higgs model

Minimal Composite Higgs Model

Agashe, Contino & Pomarol, Nucl. Phys. B719, 165 (2005)

Warped 5D model, dual to composite Higgs by AdS/CFT

Light Higgs appears as zero mode of 5th component of a 5D gauge field: "gauge-Higgs unification"

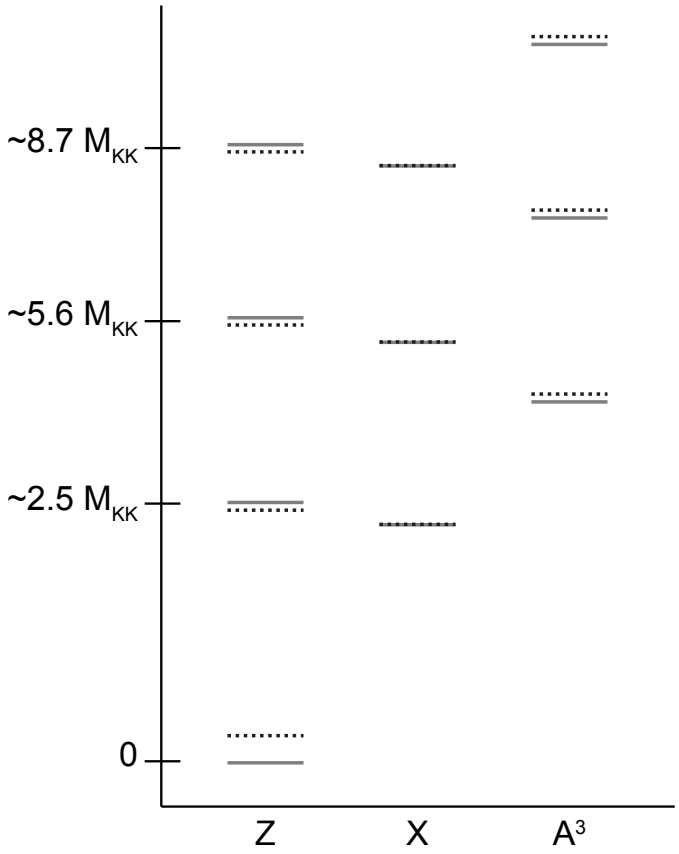
Electroweak gauge group:
- SO(5) x $U(1)_{B-L}$ in bulk
- broken to $SU(2)_L$ x $U(1)_Y$ on Planck brane, SO(4) x $U(1)_{B-L}$ on TeV brane $SO(4) \supset SU(2)_L \times SU(2)_R$

SO(5)/SO(4) coset gauge bosons $A_\mu^{\hat{a}}$ ($\hat{a} = 1...4$) are broken on both branes: only scalar 5th component $A_5^{\hat{a}}$ has a zero mode.

$A_5^{\hat{a}}$ ($\hat{a} = 1...4$) transforms as a Higgs doublet
- 3 Goldstones eaten by zero-mode $W^\pm$, Z
- 1 physical Higgs H; 5D profile peaked toward TeV brane

A short-wavelength probe of the Higgs

$f\bar{f} \to ZH$: new neutral gauge bosons contribute in s-channel.



- KK-modes $Z_\mu^{(n)}$ of Z-boson
- KK-modes $X_\mu^{(n)}$ of X (numerically small)

  X = combination of U(1)$_{B-L}$ and SU(2)$_R$ orthogonal to hypercharge
- KK-modes $A_\mu^{\hat{3}(n)}$ of coset gauge boson

  ($A_5^{\hat{3}} = G^0$; contribution is zero until after EWSB-induced mixing with $Z^{(n)}$)
- KK-modes of photon: do not couple to ZH

EWSB implemented through 5D gauge transformation

A short-wavelength probe of the Higgs

For simplicity we consider $e^+e^- \to ZH$: avoid parton densities

SM process: cross section $\propto 1/q^2$ at CM energies $\gg M_Z$

Goal: study dependence of cross section on q^2, including KK-mode contributions in s-channel.

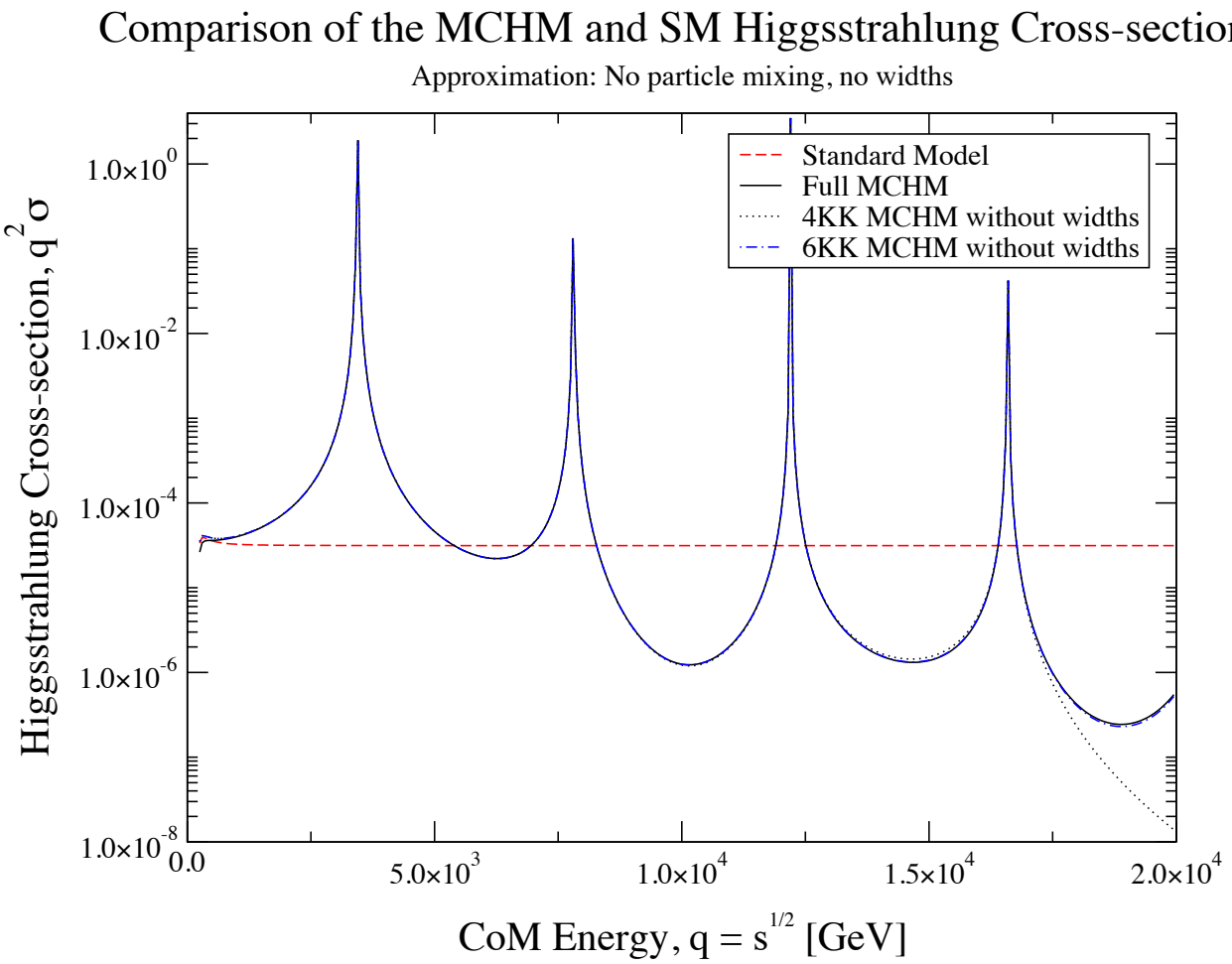
Approach:

- Calculate cross section in 5D theory using full 5D propagator
  - Hard to implement EWSB
  - Hard to implement KK-mode resonance widths
- Calculate cross section in 4D theory using KK-mode expansion
  - Have to truncate at finite KK number
  - Harder to understand underlying reason for cancellations

Fermion embedding: Medina, Shah, Wagner, Phys. Rev. D76, 095010 (2007)

Cross section I: 5D calculation

- Ignore EWSB-induced mixing and gauge KK-mode decay widths
- Compare to 4D fixed-KK-number calc.: agrees very well



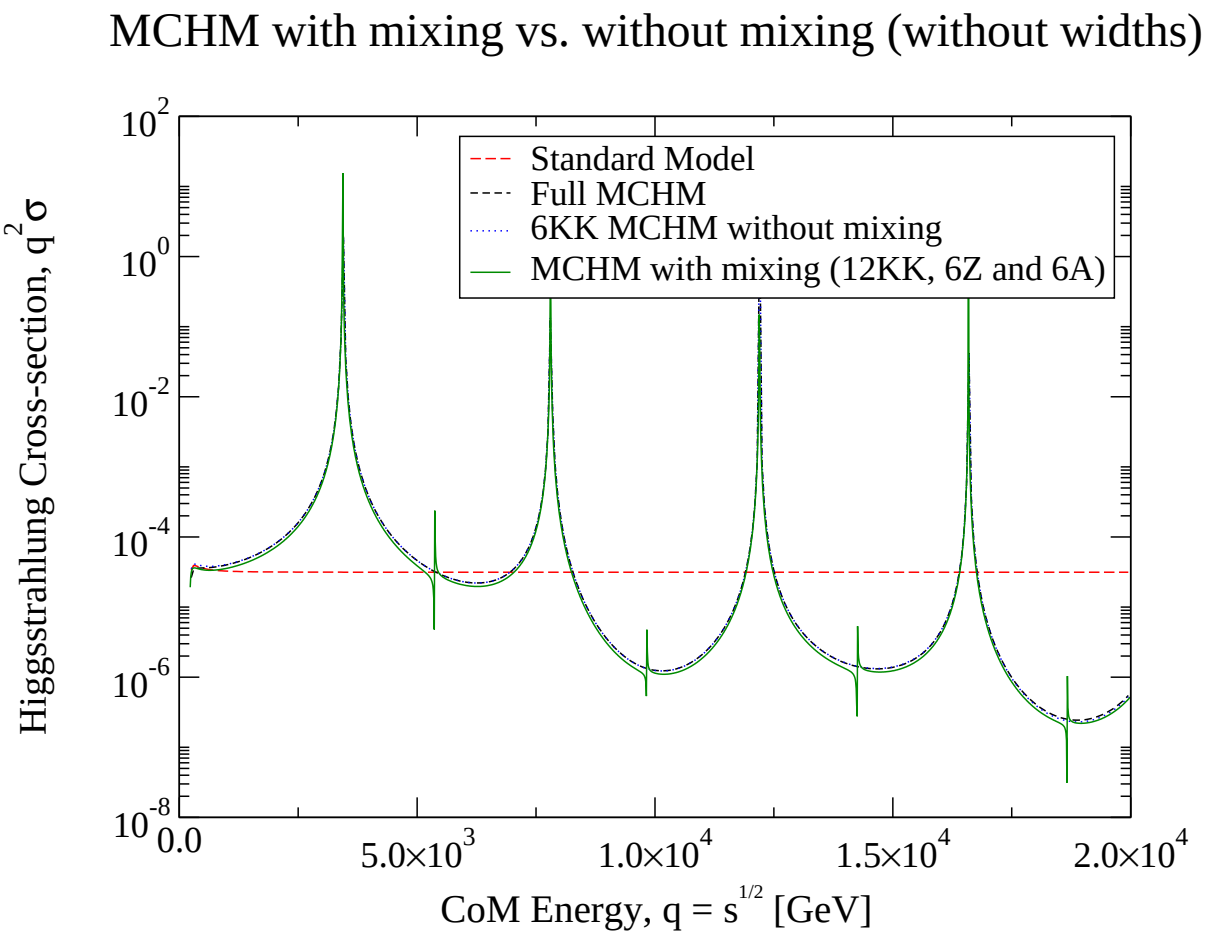
Plot: $\sigma \times q^2$
(SM is flat)

Peaks are $Z^{(n)}$
($X^{(n)}$ too small to see)

Note suppression...

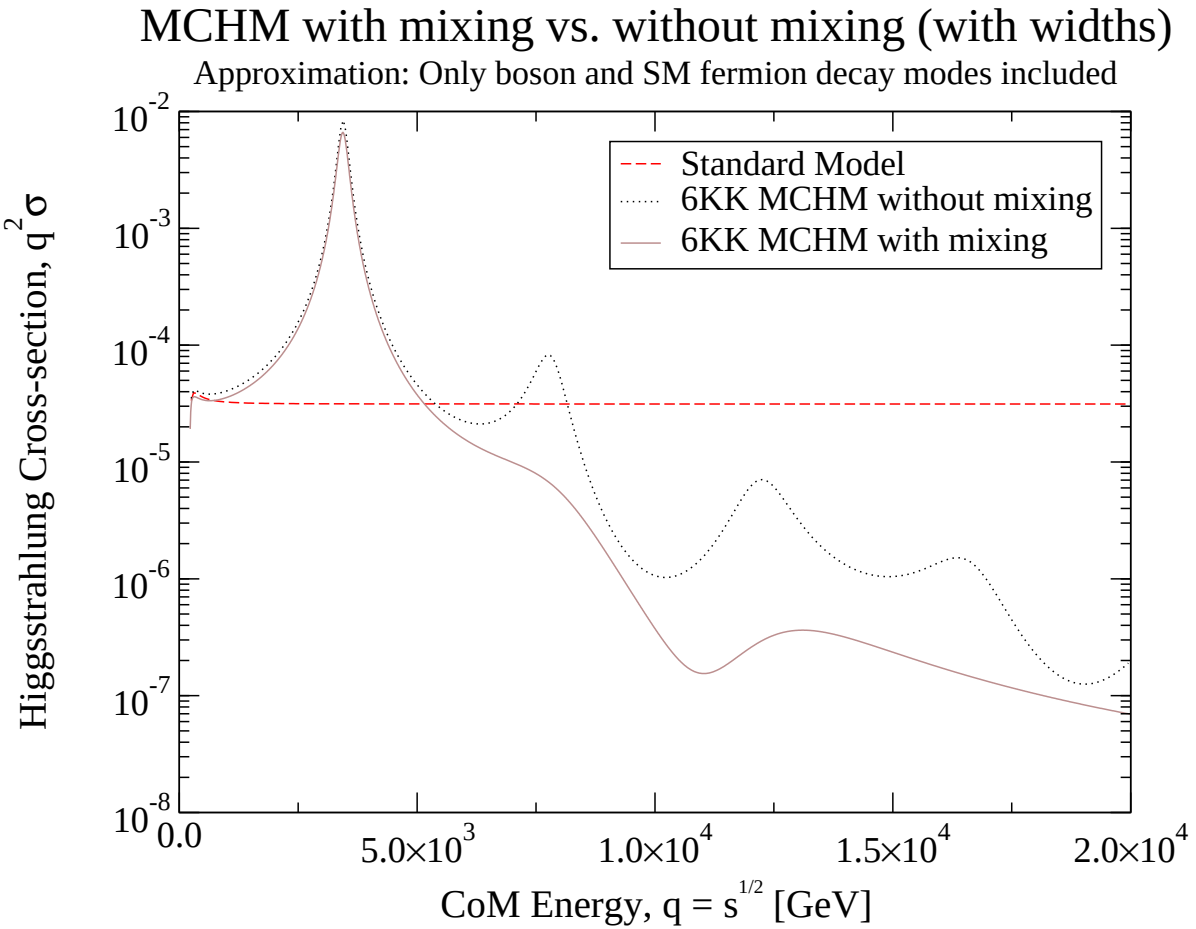
Cross section II: 4D calculation; implementation of mixing

- Include EWSB-induced mixing: effects are small
- Slight shift in overall cross section; $A^{\hat{3}}$ KK-modes appear



Cross section III: 4D calculation; implementation of widths

- Gauge KK-mode widths computed including decays to all lighter gauge/Higgs bosons, but only SM (zero-mode) fermions
- EWSB-induced mixing opens new decay modes for $Z^{(n\geq 2)}$



Note suppression!

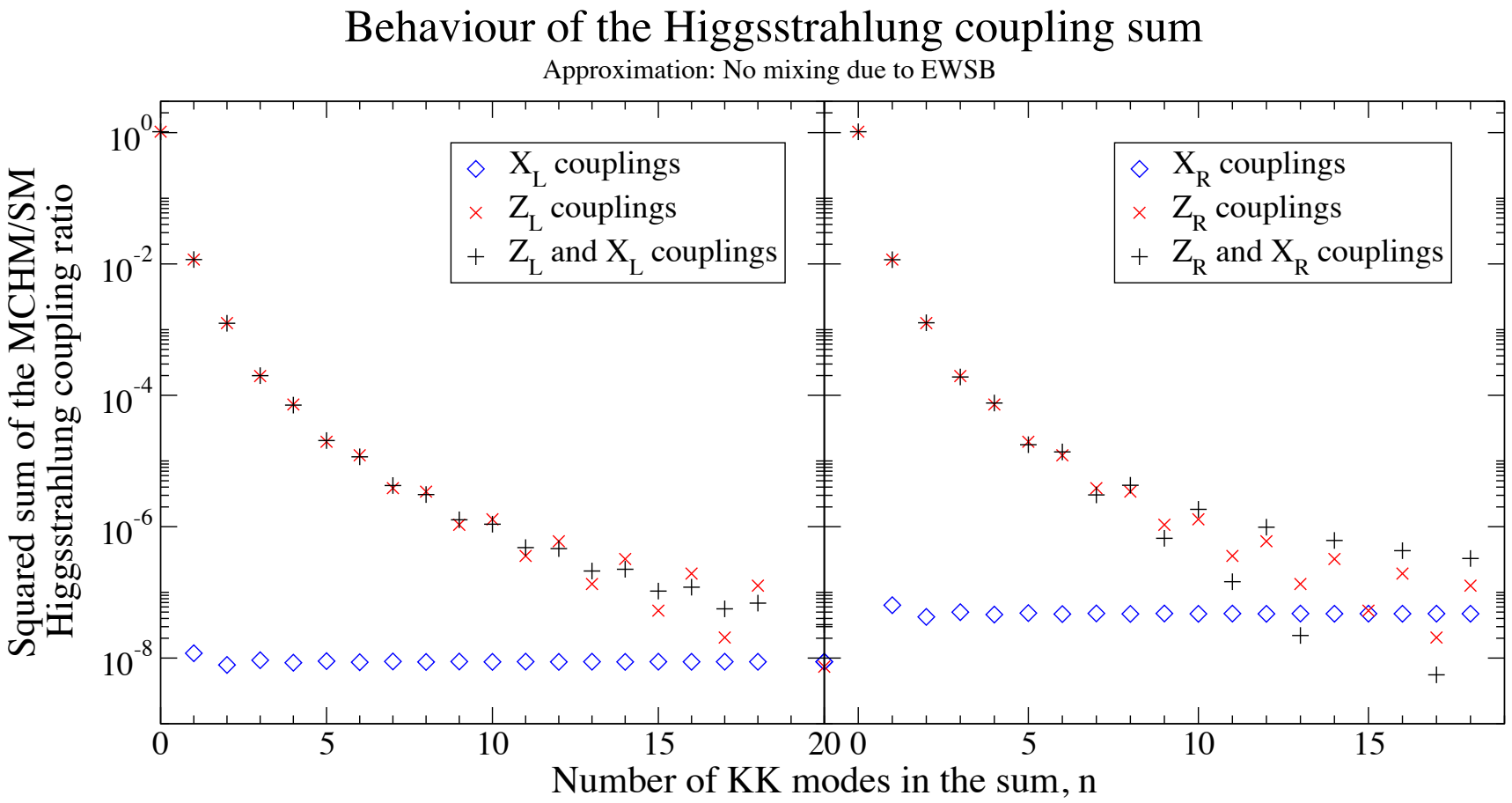
Where does the cross section suppression come from?

Consider product of $e^+e^-Z^{(n)}$ and $Z^{(n)}Z^{(0)}H$ couplings

(gauge couplings times a 5D profile integral)

For $q^2 \gg M^{(n)2}$, $\sigma \propto |\sum$ product of couplings$|^2$: cancellation!

$Z^{(0)}$: $+1$; $Z^{(1)}$: -1.1; $Z^{(2)}$: $+0.10$; ...

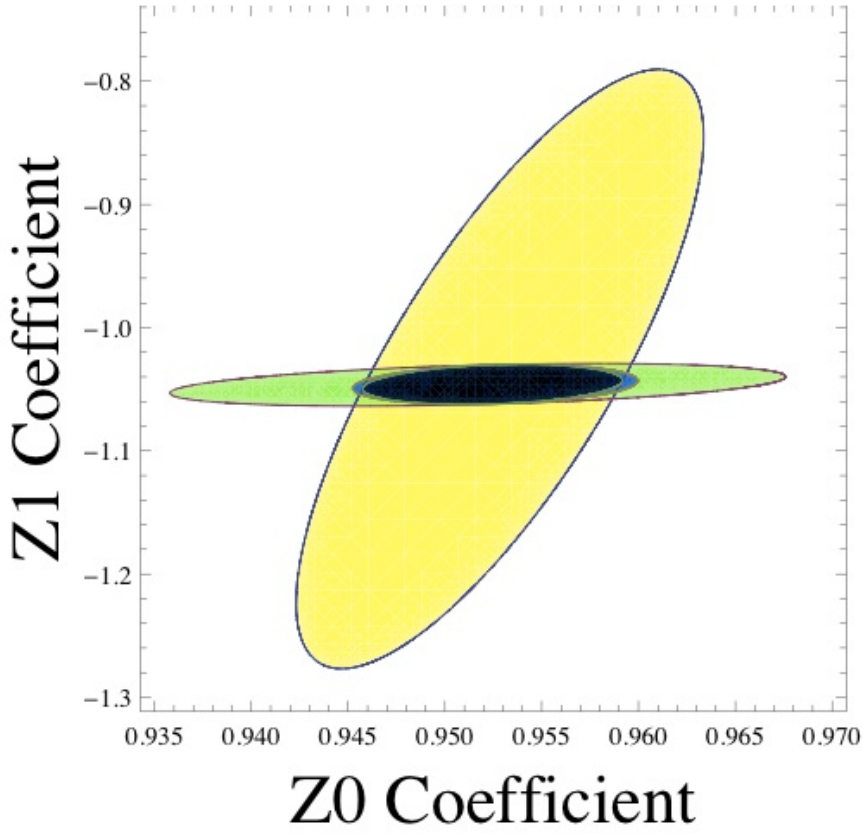


Measuring the Z KK mode couplings

Cross section at multiple q^2 values $\Rightarrow$ extract $Z^{(n)}$ couplings

- χ^2 fit for $Z^{(0)}$ and $Z^{(1)}$ couplings based on cross section counting statistics only

Plot: 95% CL region



$M_{Z^{(1)}} = 3437$ GeV

Assume 500 fb^{-1} at each center-of-mass energy

Yellow: 500 GeV + 1 TeV

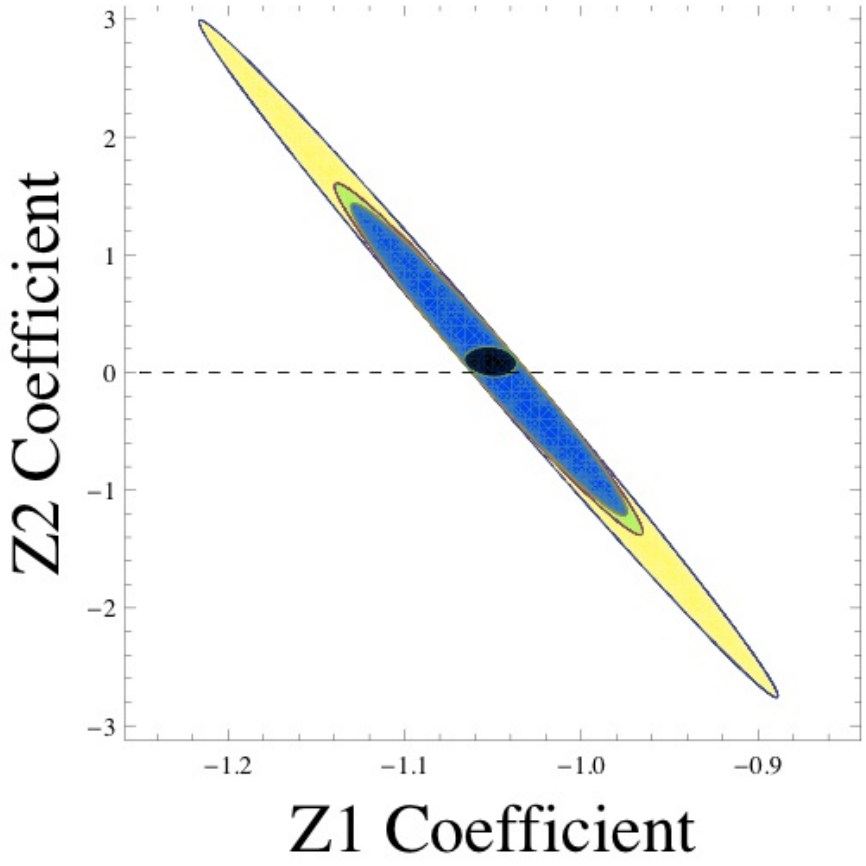
Green: 1 TeV + 3 TeV

Blue: 500 GeV + 3 TeV

Black: 500 GeV + 1 TeV + 3 TeV

Measuring the Z KK mode couplings

- Assume $Z^{(0)}$ coupling to Higgs is well-measured elsewhere (e.g., Higgs decays)



$M_{Z^{(1)}} = 3437$ GeV
$M_{Z^{(2)}} = 7804$ GeV
$\Gamma_{Z^{(2)}}/M_{Z^{(2)}} = 0.56$

Yellow: 500 GeV + 3 TeV

Green: 1 TeV + 3 TeV

Blue: 500 GeV + 1 TeV + 3 TeV

Black: 500 GeV + 1 TeV + 3 TeV + 5 TeV

Assume 500 fb^{-1} at each center-of-mass energy.

Conclusions

Expect compositeness of a composite Higgs to be revealed when probed at short wavelength.

Minimal Composite Higgs model (warped 5D AdS/CFT):

- $e^+e^- \to ZH$ cross section exhibits a formfactor-like suppression starting at $\sqrt{s} > M_{KK}$

- 4D picture: this is due to progressive cancellations among the contributions of successive Z KK modes

May be able to probe cancellation up to 2nd Z KK mode at CLIC

BACKUP SLIDES

Parameters and masses

$\ln(kL_1)$	$c_1^{(q_3)}$	$c_2^{(q_3)}$	$c_3^{(q_3)}$	c_{light}	$M_1^{(q_3)}$	$M_2^{(q_3)}$
30	0.24	-0.41	-0.58	0.70	2.3	0.5

v	M_H	$k = 1/L_0$	$M_{\text{KK}} = 1/L_1$
250.218 GeV	131.6 GeV	1.497×10^{16} GeV	1401 GeV

	Mass before EWSB			Mass after EWSB		
KK order	Z [TeV]	X [TeV]	$A^{\hat{3}}$ [TeV]	Z [TeV]	X [TeV]	$A^{\hat{3}}$ [TeV]
0	0	–	–	0.09118	–	–
1	3.442	3.368	5.367	3.437	3.368	5.372
2	7.809	7.732	9.826	7.804	7.732	9.831
3	12.199	12.121	14.249	12.194	12.121	14.254
4	16.595	16.515	18.661	16.590	16.515	18.667

Event numbers used for counting statistics

$\sqrt{s}$ (TeV)	σ_{tot} (fb)	N_S [500 fb^{-1}]	$\sqrt{N_S}$	$\Delta\sigma_{\text{tot}}$ (fb)
0.5	52.91	26,455	163	0.3253
1	13.90	6,947	83	0.1667
3	21.51	10,752	104	0.2074
5	0.5819	291	17	0.03412