Studying new physics with precision electroweak observables in multi-TeV e^+e^- collisions

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[1]based on work done with Marco Battaglia (CERN & UCSC)

Exploring BSM physics indirectly

- With the LHC on, we're all hoping to see many signals of New Physics soon. Already in 2011?
- Standard scenario: one/several new resonances seen at the LHC, but can't tell what exactly they are / measure their couplings . . .
  An e^+e^- machine could be necessary to disentangle different models.
- A complementary case - what if we NP is round the corner of LHC reach?
- It is well-known that some processes are sensitive to mass scales far beyond $\sqrt{s}$. But how well can we measure the properties of a several-TeV new resonance?

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Z-primes . . .

- Focus on a simple, clean possibility: new massive neutral bosons, or Z's
- Incomplete list of (well-known) motivations. Theory:
  1. GUTs with rank > 4 gauge groups ($SO(10)$, E_6 . . .)
  2. String models phenomenological realizations
  3. ADD Extra Dimensions
  4. Strong EW breaking - Composite/Little Higgs - Warped Extra Dimensions
- And Experiment: "contact interaction" $e^+e^- \to f\bar{f}$, clean signal, sensitive to an $M_{Z'} \gg \sqrt{s}$. . .

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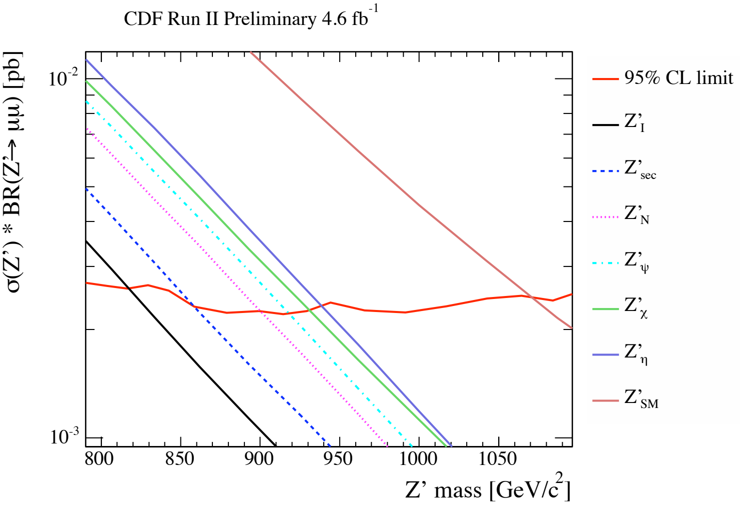
Z': where are we now?



Models

Many different scenarios out there . . . I will focus on some of them. Aim:

- See generic collider sensitivity in different cases
- See how well model parameters can be constrained
- Contrast two different approaches

1. The "standard" case, typically GUT-inspired. Couplings are usually universal, at least in the quark sector, mainly to avoid large FCNCs.
2. The "composite" case, from dynamical EW symmetry breaking. Top physics can become fundamental!

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This analysis

- Preliminary study based on Born cross-sections (however, ISR not so important in this case after judicious cuts are made; other RC sizable, but do not change the magnitude of the effects)
- Precision observables: cross-sections, A_{FB} and A_{LR} are used. Impact of polarization is considered. μ, b, t fermion pairs as final states.
- Experimental efficiency & stat. errors estimated with realistic simulations (still preliminary). Error/Efficiency in %:

%	$\mu^+\mu^-$	$b\bar{b}$	$t\bar{t}$
$\delta\sigma$	1 / 85	1.8 / 75	0.8 / 80
δA_{FB}	1 / 85	5.5 / 40	1.5 / 20
δA_{LR}	1 / 85	5.5 / 40	1.4 / 20

The Models Part I: "standard" Z'

- Widely studied in the literature. I will focus on three cases:

The Models Part I: "standard" Z'

- Sequential Z': really just a standard benchmark, not a realistic model

The Models Part I: "standard" Z'

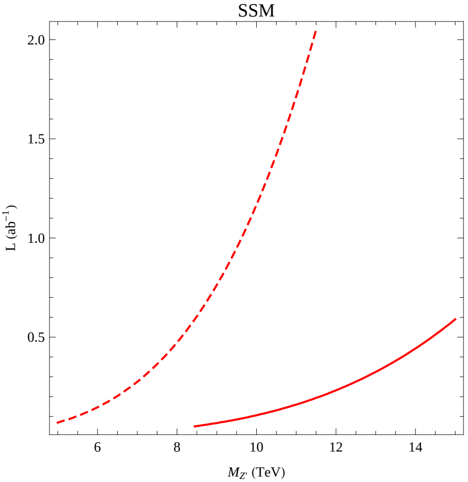

Figure: 95% exclusion plot for SSM, L_{int} vs. Mass. The dashed line corresponds to $\sqrt{s} = 1$ TeV, the continuous one to $\sqrt{s} = 1$ TeV

The Models Part I: "standard" Z'

- E_6-based Z': classic GUT-inspired scenario
- The SM gauge group is embedded in E_6. Fermions are promoted to fundamental **27**'s.
- Symmetry breaking in steps: $E_6 \to SU(10) \otimes U(1)_\psi \to SU(5) \otimes U(1)_\chi \otimes U(1)_\psi$
- Fermion reps break as $\mathbf{27} \to \mathbf{16} + \mathbf{10} + \mathbf{1} \to (\mathbf{10} + \mathbf{5}^* + \mathbf{1}) + (\mathbf{5} + \mathbf{5}^*) + \mathbf{1}$
- Usual phenomenological assumption: GUT scale at $\sim 10^{15}$ TeV, but a superposition of Z_χ and Z_ψ is pushed down to the TeV scale. A possibility, not a necessity!

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- The Z' interaction:

$$\mathcal{L}_{int} = i\sqrt{\frac{5}{3}} g \frac{s_\theta}{c_\theta} Z'_\mu \, \bar{f} \left(\gamma^\mu c_{\theta_6} Q^f_{\chi\,(L,R)} + s_{\theta_6} Q^f_{\psi\,(L,R)} \right) f$$

- Fermion charges $Q^f_{\chi\,(L,R)}$ and $Q^f_{\psi\,(L,R)}$ completely determined by the theoretical structure
- The mixing angle θ_6 distinguishes different models

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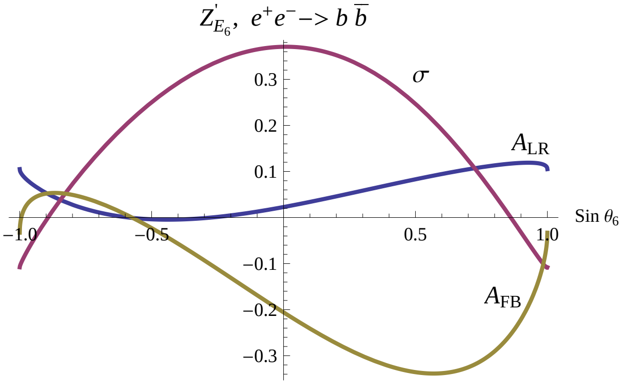

Figure: $|\mathcal{O}_{Z'} - \mathcal{O}_{SM}|/\mathcal{O}_{SM}$ vs. θ_6 in the E_6 model. $M_{Z'}$ is fixed at 5 Tev, $\sqrt{s} = 3$ TeV

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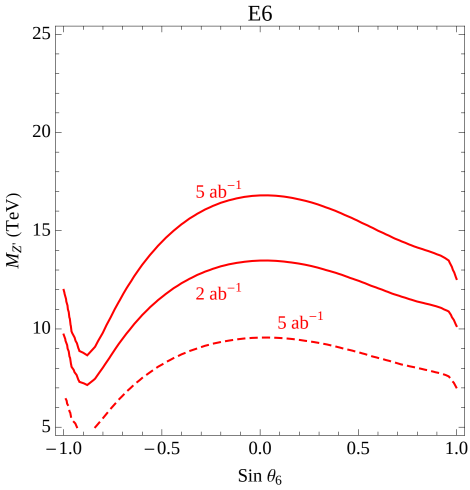

Figure: 95 % C.L. M'_Z vs. θ_6 exclusion in the E_6 model, with no beam polarization included. Dashed lines are at $\sqrt{s} = 1$ TeV, continuous ones at $\sqrt{s} = 3$ TeV

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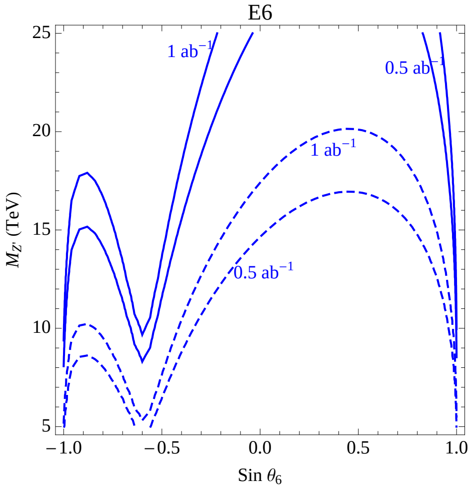

Figure: 95 % C.L. M'_Z vs. θ_6 exclusion in the E_6 model, with polarization taken into account. Dashed lines are at $\sqrt{s} = 1$ TeV, continuous ones at $\sqrt{s} = 3$ TeV

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- Minimal Z': ineresting semi-model-independent approach
- No exotics except the Z' + some (3+) ν_Rs.
- Anomaly cancellation
- Generation-independent couplings
- Automatical inclusion of mass and kinetic $Z - Z'$ mixing
- Includes several well studied models: Z'_{LR}, Z'_Y, Z'_{B-L}, Z'_χ
- New neutral interaction term:

$$\mathcal{L}_{int} = i\, g_Z Z'_\mu\, \bar{f}\,(\gamma^\mu \tilde{g}_Y Y + \tilde{g}_{BL}(B-L))\, f$$

Just 3 parameters!

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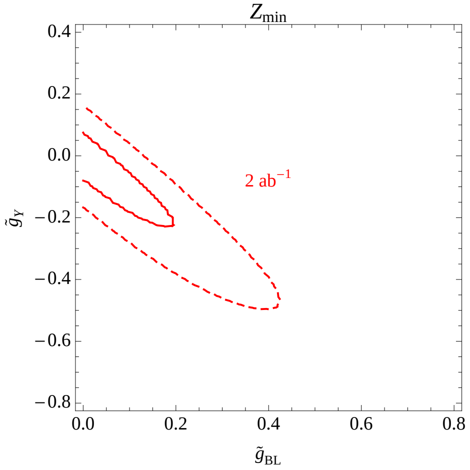

Figure: 95 % C.L. $\tilde{g}_{BL}$ vs. $\tilde{g}_Y$ exclusion in the Z_{min} model with $M_{Z'} = 5$ TeV and no beam polarization included. Dashed lines are at $\sqrt{s} = 1$ TeV, continuous ones at $\sqrt{s} = 3$ TeV

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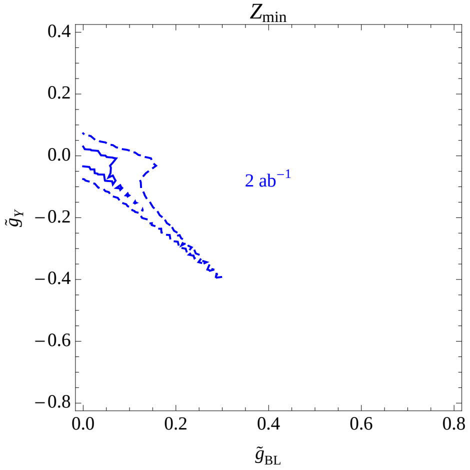

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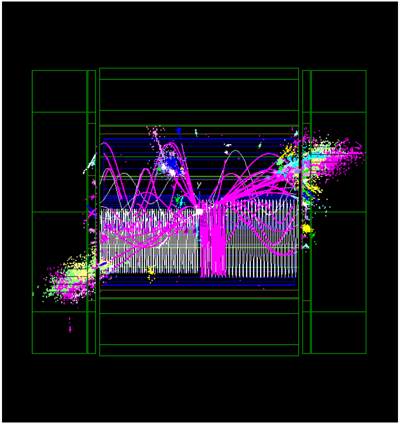
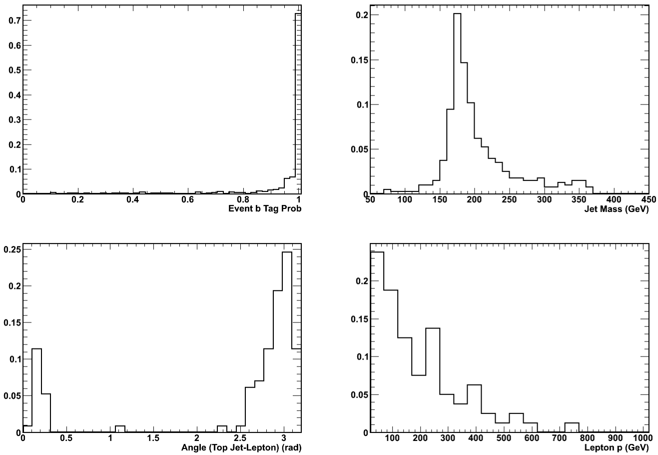
Interlude: bottoms and tops



$b\bar{b}$ event reconstruction simulation in detector model CLIC_ILD

Interlude: bottoms and tops

Top charge reconstruction, $e^+e^- \to t\bar{t}$; $t \to bW^+ \to bl^+\bar{\nu}_l$



Interlude: bottoms and tops

- If we're looking at fermion pairs $\rightarrow \mu^+\mu^-$ the easiest channel
- The expected detector performance, however, is such that it is interesting to extend the analysis to tops and bottoms
- Theoretically, it is interesting to check realistic scenario where couplings to the 3^{rd} generation of quarks are either favoured or disfavoured

Models Part II: composite Z'

- One good motivation to look at tops: Warped Extra Dimensions, dual to composite Higgs sector / Strong EW breaking
- A minimal well-studied model is based on $SU(2) \otimes SU(2) \otimes U(1)$ symmetry on a slice of AdS_5
- The top mostly a composite → preferential coupling to the extra gauge bosons → greatly enhanced production

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Let's see it in more detail ...

Models Part II: composite Z'

- Contrary to GUTs, the model naturally “lives” in the 1-10 TeV range (the full structure has to be taken into consideration: considerably harder calculation!)
- A relatively easy-to-study version is based on “maximal deconstruction”, with the 5^{th} dimension discretized to just two points!
- On the 1^{st} point there lives an SM-like (without a Higgs) “elementary” sector, on the 2^{nd} a “composite” $SU(2) \otimes SU(2) \otimes U(1)$ explicitly broken gauge theory. Both are purely 4D. The two sectors “talk” via mass mixing: mass eigenstes generally superpositions
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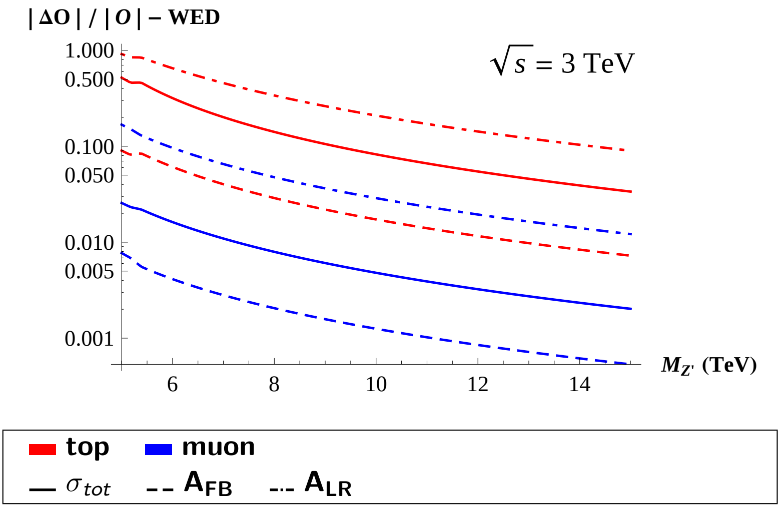
- The model contains 3 heavy neutral bosons $\rightarrow$ Z's.
- Approximate interaction Lagrangian:

$$\begin{aligned}\mathcal{L}^{Z'}_{int.} = \; & igW^3_{L\mu}\,\bar{f}\gamma^\mu T^3_L Q_L(f)\,f \\ & + ig' B^*_\mu\,\bar{f}\gamma^\mu Y\,Q_{(L,R)}(f)\,f \\ & + i\frac{g'}{\sin\theta_1}\tilde{B}_\mu\,\bar{f}\gamma^\mu Y \sin^2\varphi_{f\,L,R}\,f;\end{aligned}$$

$$Q_{(L,R)}(f) = (\sin^2\varphi_{f\,L,R}\cot\theta_2 - \cos^2\varphi_{F\,L}\tan\theta_2)$$

- The ϕ and θ are fermionic/bosonic mixing angles, indicating the degree of compositeness (depends on the Yukawas for fermions). θs are quite small; $\phi \simeq 0$ for every fermion except t_R, $\phi \simeq \pi/2$

Models Part II: composite Z'



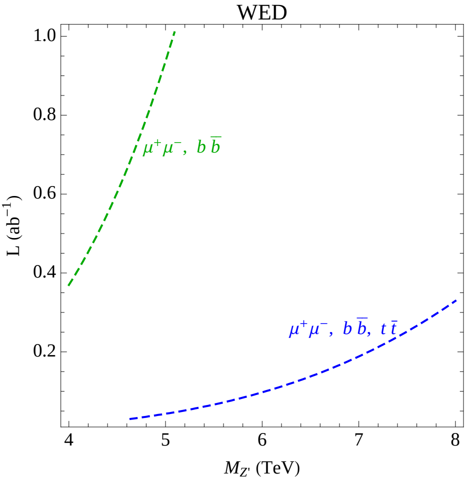


Figure: 95 % C.L. L_{int} vs. $M_{Z'}$ exclusion in the $W.E.D.$ model, at $\sqrt{s} = 1$ TeV

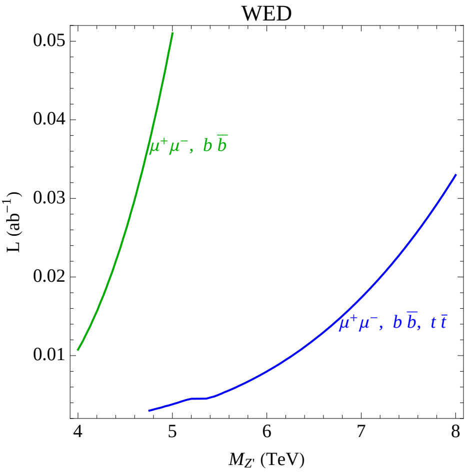


Figure: 95 % C.L. L_{int} vs. $M_{Z'}$ exclusion in the $W.E.D.$ model, at $\sqrt{s} = 3$ TeV

Conclusions

- Multi-TeV e^+e^- collider indirect sensitivity well beyond 10 TeV
- Good potential in discriminating between models
- Polarization is fundamental in several scenarios
- Important to look at different fermionic channels (top!)