Z' searches at 1.5 and 3 TeV CLIC

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Z' Physics

There are many ideas that lead to TeV scale Z' in spectrum

Characterizing all possibilities is impossible and not needed.

Choose a simple Z' framework to illustrate how well (or not) a linear collider can do.

We chose to study the minimal anomaly free Z' model, that was recently emphasized by Salvioni, Villadoro, and Zwirner arxiv:0909.1320.

The Theory

If one charges SM fermions under a new U(1)' symmetry there are generally anomalies associated with uncanceled

U(1)'-U(1)'-U(1)', U(1)-graviton-graviton, etc.
charge anomalies

The exception to this is when SM fermions have charges that are linear combination of hypercharge and B-L.

$$J^{\mu}_{Z'} = [g'_Y Y_f + g'_{BL}(B-L)_f] \; \bar{f}\gamma^{\mu} f$$

$$\Delta\mathcal{L} = J^{\mu}_{Z'} Z'_{\mu}$$

Input parameters: $M_{Z'}$, g'_Y and g'_{BL}

The Observables

We focus on discerning Z' effects in muon pair production:

$$\sigma(e^+e^- \to \mu^+\mu^-)$$

The three observables we study are

$$\sigma_{tot} = \sigma_F + \sigma_B, \qquad A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}, \qquad A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}.$$

The observables σ_{tot} and A_{FB} are measured with respect to unpolarized electron and positron beams. The A_{LR} asymmetry is defined with respect to $+80\%$ and -80% polarized electron beams for σ_L and σ_R respectively. The positron beam is considered unpolarized.

"Backgrounds" and Cuts

Events with such hard photons have less e^+e^- center-of-mass energy available and so are much less sensitive to a Z'; therefore, we eliminate them by cuts on the energy and angles of the outgoing muons. In addition, other SM processes produce $\mu^+\mu^-$ final states. The most important of these additional contributions are listed in Table 1. At CLIC, beam-induced background $\mu^+\mu^-$ final state events are produced in the process $e^+e^- \to \gamma\gamma \to \mu^+\mu^-$. Both types of background events, SM and beam-induced, must be suppressed to preserve the purity of the $e^+e^- \to \mu^+\mu^-$ sample.

The detector angular acceptance is defined by $10° < \theta(\mu^\pm) < 170°$, θ is the angle of the μ^+ or the μ^- with respect to the beam. In this region the muons are measured with high efficiency and excellent momentum resolution. To suppress the beam-induced background, $e^+e^- \to \gamma\gamma \to \mu^+\mu^-$ and $e^+e^- \to \gamma\gamma \to$ hadrons, a cut on $P_T(\mu^\pm)$ is applied, $P_T(\mu^\pm) > 5$ GeV, where P_T is the transverse momentum. To reduce the hard photon events and the contributions of the SM background processes, additional cuts are applied:

- dimuon energy, $\mathrm{E}(\mu^+) + \mathrm{E}(\mu^-) > E_{\min}$,
- acoplanarity, $0° < \Delta\phi(\mu^+,\mu^-) < 5°$, where $\Delta\phi(\mu^+,\mu^-) \equiv |\phi_{\mu^+} - \phi_{\mu^-} - \pi|$ (that is, ϕ_{μ^+} must be nearly back-to-back to ϕ_{μ^-} in the azimuthal plane)
- angle of the dimuon missing momentum vector, $0 < \theta_{miss}(\mu^+,\mu^-) < 5°$ (that is, the missing momentum vector polar angle must be very close to beam)

Production Rates after Cuts

Process $\sqrt{s} = 1.4\,\text{TeV}$	$\sigma \times Br$ (fb) $10^\circ < \theta(\mu^\pm) < 170^\circ$ and $P_T(\mu^\pm) > 5$ GeV	$\sigma \times Br$ (fb) final selection cuts
$e^+e^- \to \mu^+\mu^-$	156	23.6
$e^+e^- \to \mu^+\mu^-\nu_e\nu_e$	44.7	0.002
$e^+e^- \to \mu^+\mu^-\nu_\mu\nu_\mu$	14.5	0.027
$e^+e^- \to \mu^+\mu^-e^+e^-$	1690	< 0.0001

Table 1: SM $e^+e^- \to \mu^+\mu^-$ processes, cross sections times branching ration ($\sigma \times Br$) with angular and P_T cuts, and with final selection cuts, at 1.4 TeV

Other Considerations

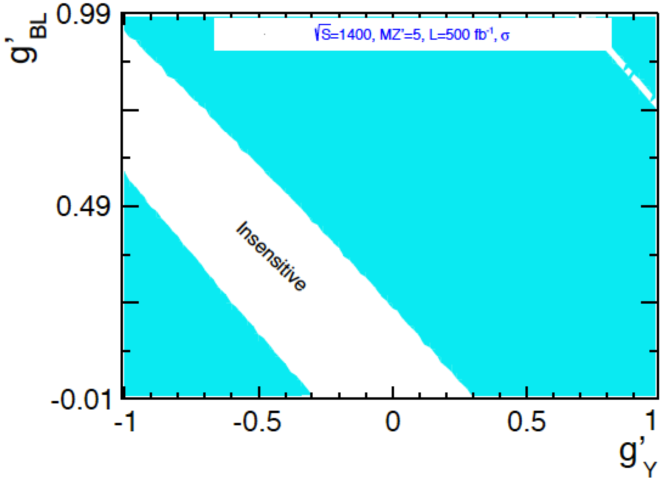
- error on σ from $\mu^{\pm}$ reconstruction and identification efficiency: $\Delta\sigma/\sigma = 1\%$
- error on A_{FB} from $\mu^{\pm}$ charge confusion: $\Delta A_{FB}/A_{FB} = 1\%$
- error on σ from luminosity determination: $\Delta\sigma/\sigma = 0.5\%$
- error on A_{LR} from polarization measurement: $\Delta A_{LR}/A_{LR} = 1\%$

Methodology of Z' Discovery Potential

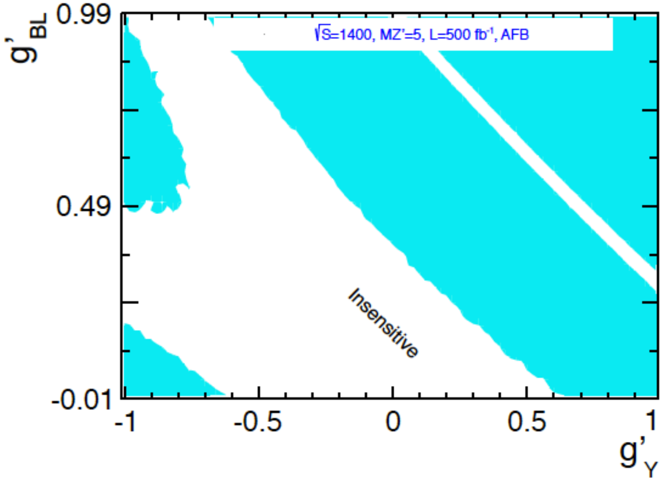
To estimate the Z' discovey potential, the SM predictions of the observables $\sigma(SM)$, $A_{FB}(SM)$ and $A_{LR}(SM)$ as well as the AFZ$'$ predictions of the observables $\sigma(\mathrm{AFZ}')$, $A_{FB}(\mathrm{AFZ}')$ and $A_{LR}(\mathrm{AFZ}')$ are computed for different values of $M_{Z'}$, g'_Y and g'_{BL}. For each observable the χ^2 is computed, defined as the difference between the SM value and the AFZ$'$ value:

$$\chi^2_\sigma = \frac{(\sigma(\mathrm{SM})-\sigma(\mathrm{AFZ}'))^2}{\Delta\sigma(\mathrm{SM})^2}, \quad \chi^2_{A_{FB}} = \frac{(A_{FB}(\mathrm{SM})-A_{FB}(\mathrm{AFZ}'))^2}{\Delta A_{FB}(\mathrm{SM})^2}, \quad \chi^2_{A_{LR}} = \frac{(A_{LR}(\mathrm{SM})-A_{LR}(\mathrm{AFZ}'))^2}{\Delta A_{LR}(\mathrm{SM})^2} \qquad (3)$$

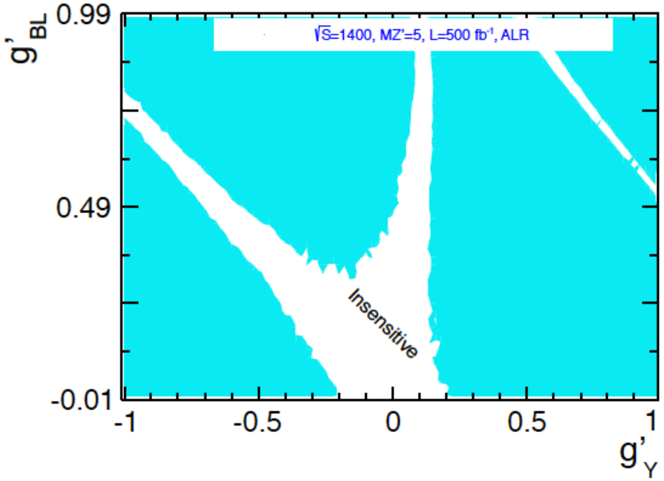
where $\Delta\sigma(\mathrm{SM})$, $\Delta A_{FB}(\mathrm{SM})$ and $\Delta A_{LR}(\mathrm{SM})$ are the experimental errors on the measurement of the SM observables. The theory computational errors are negligible in comparison.



(a) Total cross-section $\sigma(e^+e^- \to \mu^+\mu^-)$

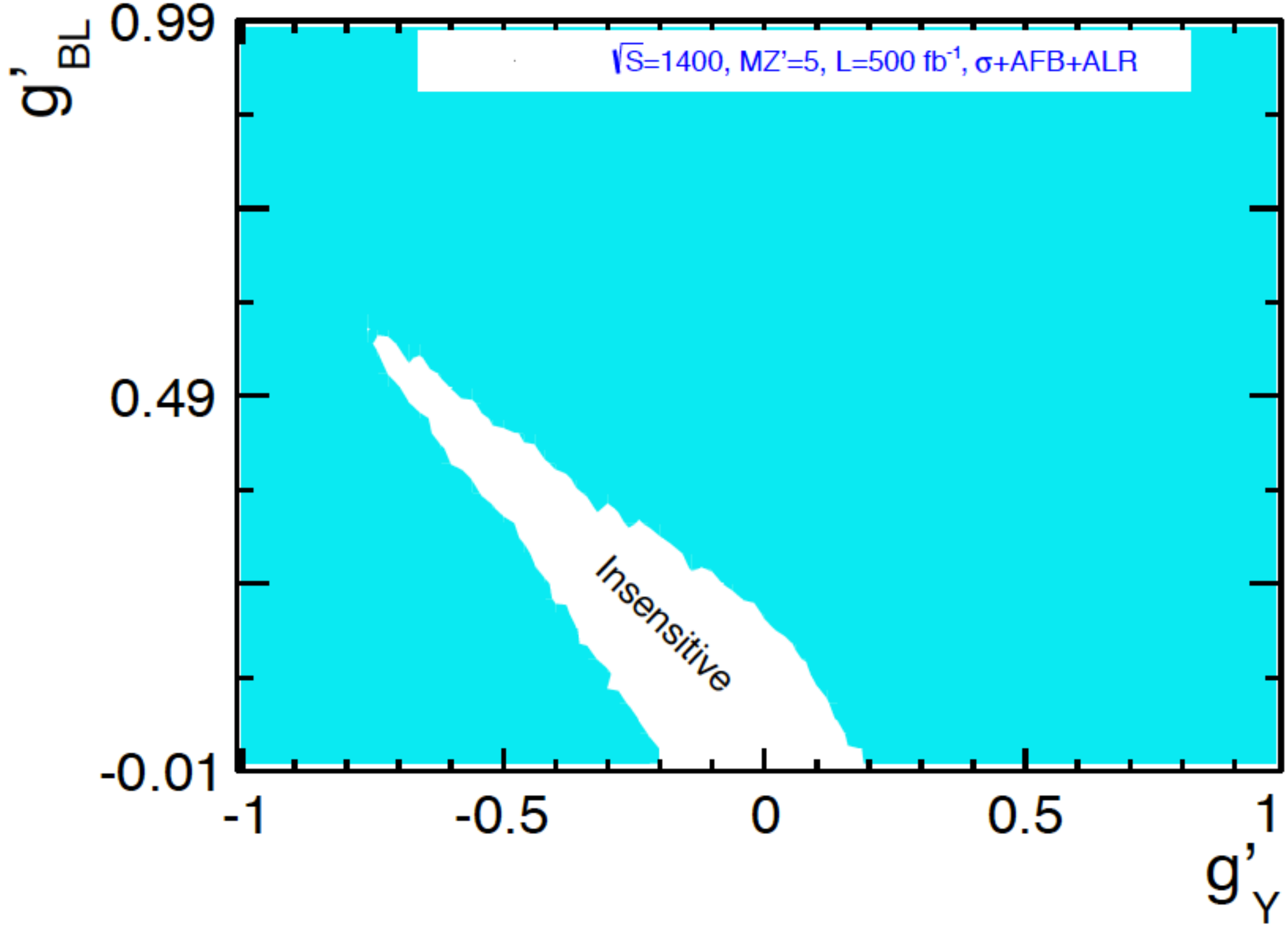


(b) Forward-Backward asymmetry

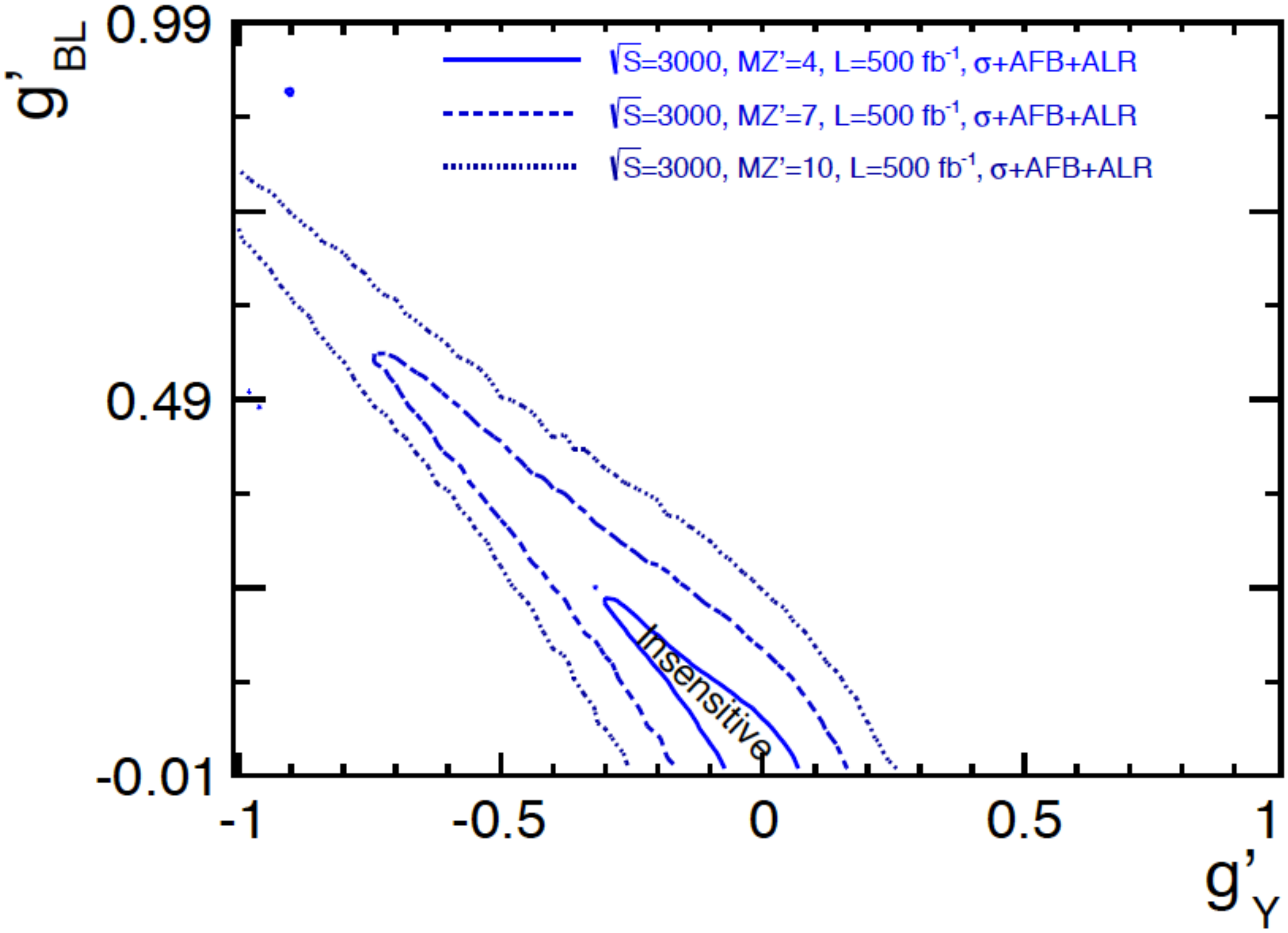


(c) Left-Right asymmetry

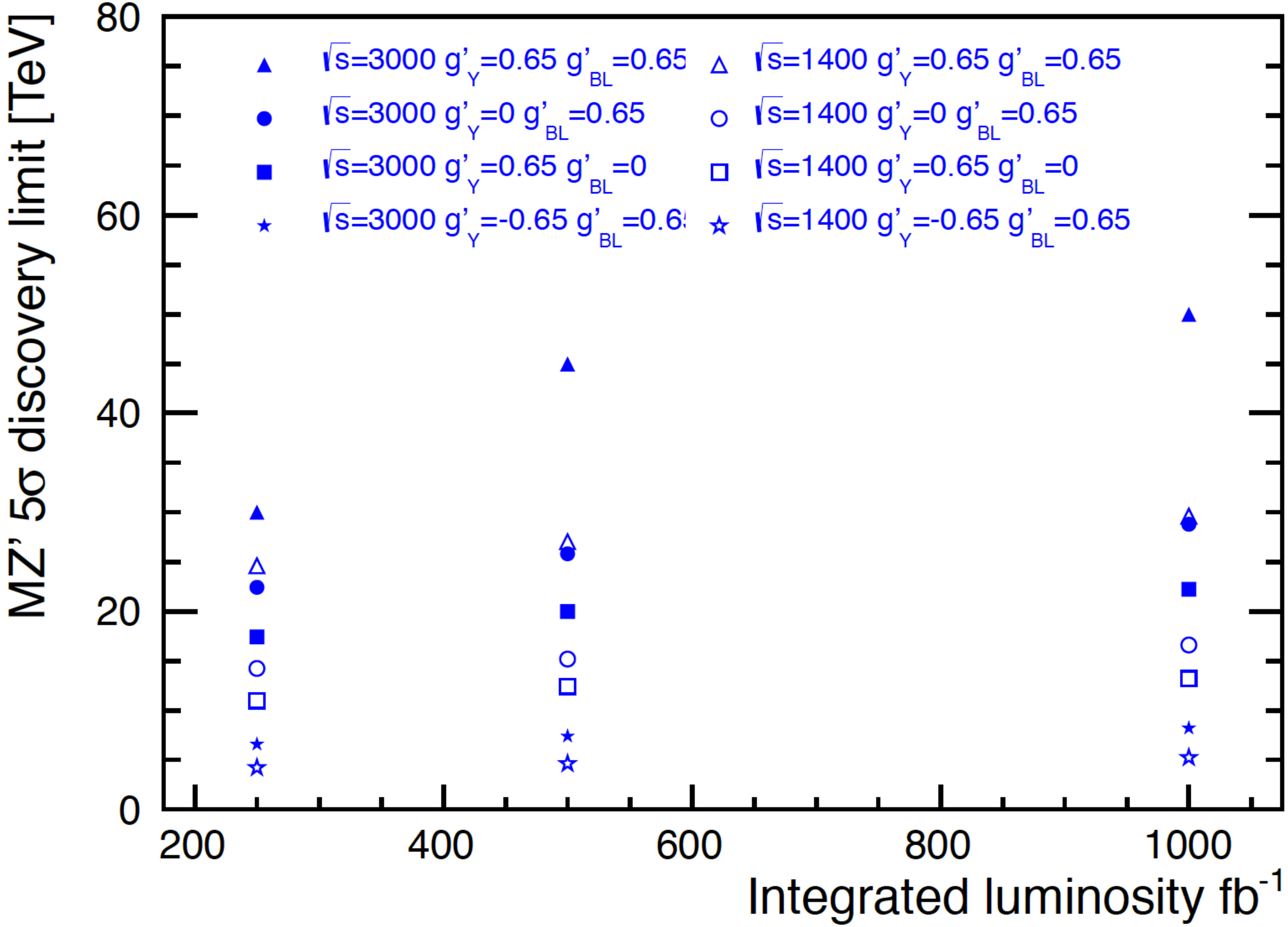
Figure 1: 5σ discovery potential in (g'_Y, g'_{BL}) plane, $M_{Z'} = 5\,\text{TeV}$, L=500 fb^{-1} and $\sqrt{s} = 1.4\,\text{TeV}$, determined from different observables, (a) total cross-section σ, (b) forward-backward asymmetry A_{FB}, and (c) left-right asymmetry A_{LR}.



√S=1400, MZ'=5, L=500 fb-1, σ+AFB+ALR
Insensitive
g'BL
0.99
0.49
-0.01
-1
-0.5
0
0.5
1
g'Y

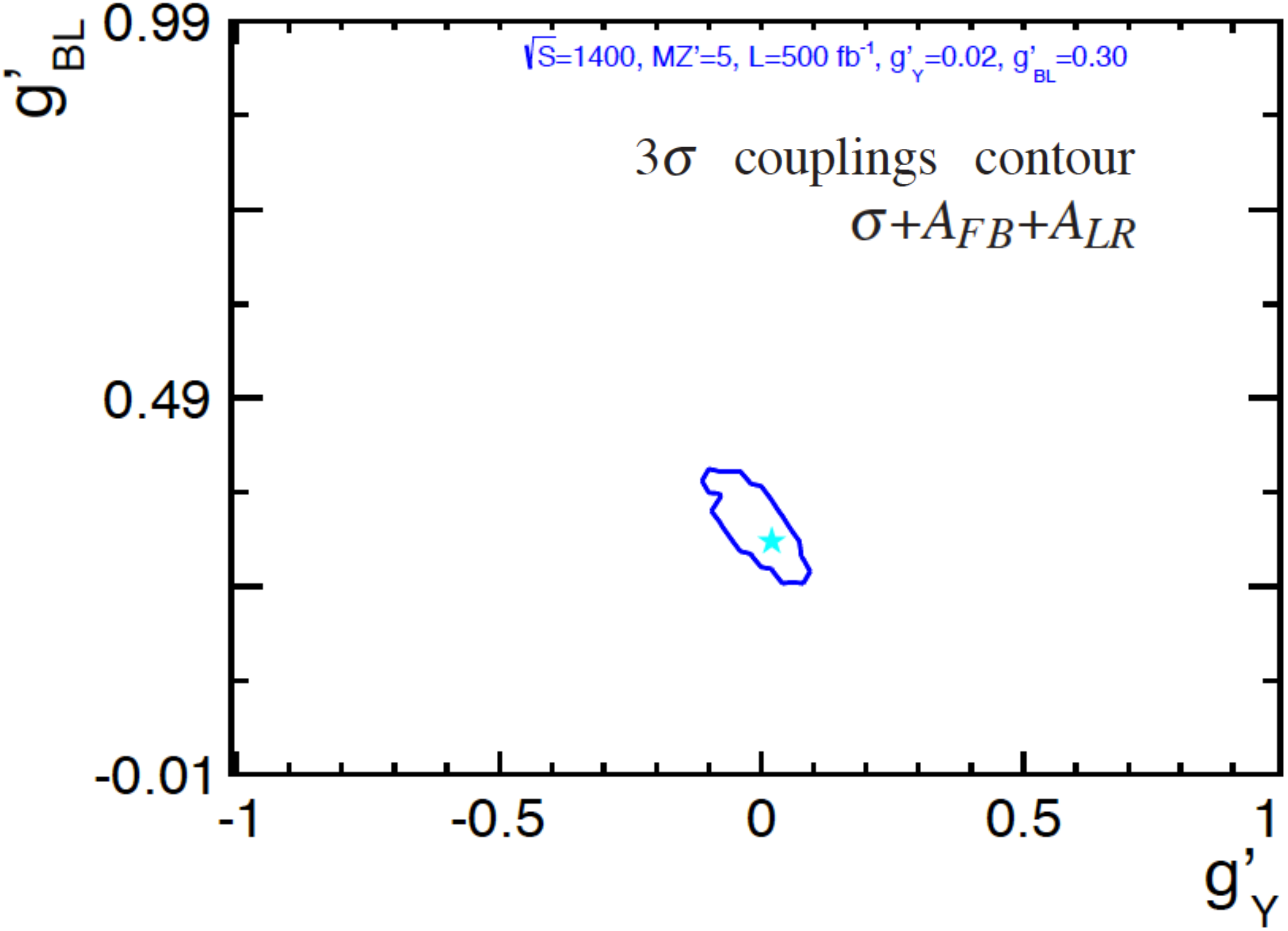


g'_{BL}
0.99
0.49
-0.01
$\sqrt{S}$=3000, MZ'=4, L=500 fb^{-1}, σ+AFB+ALR
$\sqrt{S}$=3000, MZ'=7, L=500 fb^{-1}, σ+AFB+ALR
$\sqrt{S}$=3000, MZ'=10, L=500 fb^{-1}, σ+AFB+ALR
Insensitive
-1
-0.5
0
0.5
1
g'_Y



MZ' 5σ discovery limit [TeV]
Integrated luminosity fb-1
√s=3000 g'Y=0.65 g'BL=0.65
√s=3000 g'Y=0 g'BL=0.65
√s=3000 g'Y=0.65 g'BL=0
√s=3000 g'Y=-0.65 g'BL=0.6
√s=1400 g'Y=0.65 g'BL=0.65
√s=1400 g'Y=0 g'BL=0.65
√s=1400 g'Y=0.65 g'BL=0
√s=1400 g'Y=-0.65 g'BL=0.65
0
20
40
60
80
200
400
600
800
1000

Determining the Couplings with Assumed Model



Conclusions

1.4 TeV and 3.0 TeV colliders have several complementary observables by which to find evidence for new physics from Z'.

Mass reach of Z' (i.e., BSM signal discerned) depends on the relative g'_Y and g'_{BL} couplings but could extend to 60 GeV (30 TeV) for 3 TeV (1.4 TeV) CLIC for perturbative coupling values.

Precision tests of the Z' model couplings can be performed.