String Physics at CLIC

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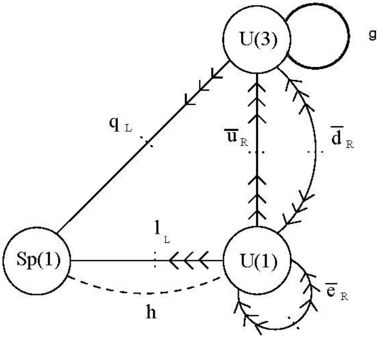
L. A. Anchordoqui, W. Z. Feng, H. Goldberg, XH and T. R. Taylor, arXiv:1012.3466 [hep-ph], to appear in PRD

Compact LInear Collider

Compact LInear Collider (CLIC) is a proposed linear accelerator of e^+ and e^-. CLIC aims at multi-TeV collision energy with high-luminosity $\mathcal{L}_{e^+e^-} \sim 8 \times 10^{34}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. The collider design has been optimized for $\sqrt{s} = 3$ TeV, with a possible upgrade path to $\sqrt{s} = 5$ TeV. The collision of γ and γ can also be realized. It can complement measurements at LHC.

Standard Model from Intersecting D-branes

This is an open string theory with M_s at TeV and Dp-branes wrapping around some $p-3$-cycles of T^6. Here is a picture of the minimal quiver Standard Model †,



†D. Berenstein and S. Pinansky, Phys. Rev. D **75**, 095009 (2007)

Particle Contents

Table: Chiral fermion spectrum of the $U(3)_a \times Sp(1)_L \times U(1)_c$ D-brane model.

Name	Representation	$Q_{U(3)}$	$Q_{U(1)}$	Q_Y
U_i	$(\bar{3}, 1)_1$	-1	1	$-\frac{2}{3}$
D_i	$(\bar{3}, 1)_{-1}$	-1	-1	$\frac{1}{3}$
L_i	$(1, 2)_1$	0	1	$-\frac{1}{2}$
E_i	$(1, 1)_{-2}$	0	-2	1
Q_i	$(3, 2)_0$	1	0	$\frac{1}{6}$

The hypercharge is given by $Q_Y \equiv \frac{1}{6} Q_{U(3)} - \frac{1}{2} Q_{U(1)}$.

Amplitudes for $\gamma\gamma$ and e^+e^- Scattering

We compute the following amplitudes with either $\gamma\gamma$ or e^+e^- as incoming states.

$\gamma\gamma$ Channel:

- $\gamma\gamma \to \gamma\gamma$, $\gamma\gamma \to Z^0Z^0$, $\gamma\gamma \to W^+W^-$, $\gamma\gamma \to gg$
- $\gamma\gamma \to F\bar{F}$

e^+e^- Channel:

- $e^+e^- \to \gamma\gamma$, $e^+e^- \to Z^0Z^0$, $e^+e^- \to Z^0\gamma$, $e^+e^- \to W^+W^-$
- $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$, $e^+e^- \to \nu\bar{\nu}$, $e^+e^- \to q\bar{q}$

$\gamma\gamma \to F\bar{F}$ Amplitude

The string amplitude involving the two initial gauge bosons (associated the same stack) carrying opposite helicities is,

$$\begin{aligned}\mathcal{M}(A_1^-, A_2^+, F_3^-, \bar{F}_4^+) &= 2\,g^2 \frac{\langle 13\rangle^2}{\langle 32\rangle\langle 42\rangle}\left[\frac{t}{s} V_t (T^{a_1} T^{a_2})_{\alpha_3\alpha_4}\right. \\ &+ \left.\frac{u}{s} V_u (T^{a_2} T^{a_1})_{\alpha_3\alpha_4}\right] .\end{aligned}$$

where the Veneziano form factors $V_t \equiv V(s,t,u)$, $V_u \equiv V(t,u,s)$ are defined by,

$$V(s,t,u) = \frac{s\,u}{tM_s^2} B(-s/M_s^2, -u/M_s^2) = \frac{\Gamma(1-s/M_s^2)\,\Gamma(1-u/M_s^2)}{\Gamma(1+t/M_s^2)}.$$

Resonance from Regge Excitation

Near $s = M_s^2$, we have a pole term from Regge excitations,

$$V_t \rightarrow \frac{u}{s - M_s^2} \,, \qquad V_u \rightarrow \frac{t}{s - M_s^2} \,.$$

The mass spectrum of the Regge excitations are $M = \sqrt{n} M_s$. At each n level, Regge excitations have the spins ranging from $S = 0$ to $S = n + 1$, $(S \leq 1 + \alpha' M^2)$. The amplitude is

$$\mathcal{M}(A_1^-, A_2^+, F_3^-, \bar{F}_4^+) \rightarrow 2\, g^2\, \mathcal{D}^{1234} \frac{\langle 13 \rangle^2}{\langle 32 \rangle \langle 42 \rangle} \frac{tu}{M_s^2 (s - M_s^2)}$$

Resonance Scattering Amplitude

The $\gamma\gamma \to e_R^+ e_L^-$ amplitude is ($\kappa^2 \simeq 0.02$),

$$\begin{aligned}\mathcal{M}(\gamma\gamma \to e_R^+ e_L^-) &= (1-\kappa^2)\cos\theta_W{}^2\,\mathcal{M}(BB \to e_R^+ e_L^-) \\ &= 4g_c^2(1-\kappa^2)\cos\theta_W{}^2\;\frac{\langle 13\rangle^2}{\langle 32\rangle\langle 42\rangle}\frac{tu}{M_s^2(s-M_s^2)}\end{aligned}$$

The square amplitude with the Breit-Wigner form is,

$$|\mathcal{M}(\gamma\gamma \to e^+ e^-)|^2 = 5\,(1-\kappa^2)^2\,C_W^4\,\frac{4g_c^4}{M_s^4}\,\left[\frac{ut(u^2+t^2)}{(s-M_s^2)^2+(\Gamma_{B^*}^{J=2}\;M_s)^2}\right],$$

Cross Section

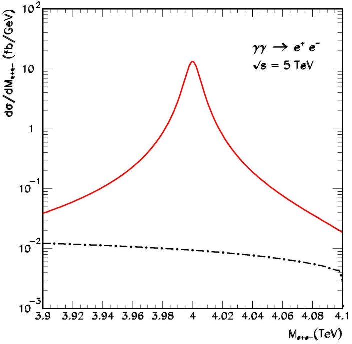
The cross section can be obtained by folding with the photon distribution function,

$$
\begin{aligned}
\frac{d\sigma}{dM_{e^+e^-}} &= \sqrt{s}z^3 \left[\int_{-Y_{\max}}^{0} dY \; f_{\gamma/e}(x_a) \;\; f_{\gamma/e}(x_b) \times \right. \\
&\quad \int_{-(y_{\max}+Y)}^{y_{\max}+Y} dy \; \frac{d\hat{\sigma}}{d\hat{t}}\bigg|_{\gamma\gamma\to e^+e^-} \; \frac{1}{\cosh^2 y} \\
&+ \int_{0}^{Y_{\max}} dY \; f_{\gamma/e}(x_a) \; f_{\gamma/e}(x_b) \times \\
&\quad \left. \int_{-(y_{\max}-Y)}^{y_{\max}-Y} dy \; \frac{d\hat{\sigma}}{d\hat{t}}\bigg|_{\gamma\gamma\to e^+e^-} \; \frac{1}{\cosh^2 y} \right],
\end{aligned}
$$

where $z^2 = M^2_{e^= e^-}/s$.

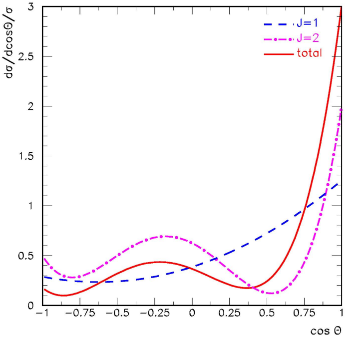
$\gamma\gamma \to e^+e^-$ Cross Section

Differential cross section $d\sigma/dM_{e^+e^-}$ *vs.* $M_{e^+e^-}$ for $M_s = 4$ TeV and $\sqrt{s} = 5$ TeV



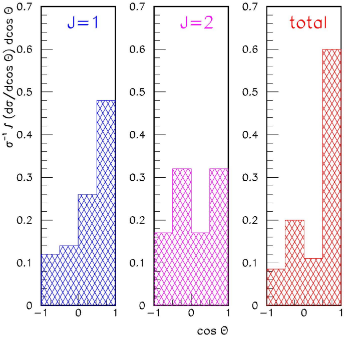
Normalized Angular Distribution of $e^+e^- \to \mu^+\mu^-$

Normalized angular distributions of Regge recurrences with spin 1, 2, and total in the $e^+e^- \to \mu^+\mu^-$ channel.



Binned Angular Distribution of $e^+e^- \to \mu^+\mu^-$

Binned angular distributions of Regge recurrences with spin 1, 2, and total in the $e^+e^- \to \mu^+\mu^-$ channel.



Conclusions

We study the contributions from Regge excitations to the scatterings of e^+e^- and $\gamma\gamma$ and show that the stringy corrections can be observed at CLIC.