

Discriminating Large Extra Dimensions at the ILC with Polarized Beams

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Non-standard scenarios described by effective interactions can manifest themselves indirectly, *via* corrections to the Standard Model cross sections. It should be desirable to identify at a given confidence level the source of such deviations among the different possible explanations. We here discuss the identification reach on gravity in extra dimensions from the four-fermion compositeness-inspired contact interactions and *viceversa*, using as basic observable the differential cross section of $e^+e^- \rightarrow \bar{f}f$ at the ILC, and emphasize the rôle of beams polarization in enhancing the identification sensitivity.

1. INTRODUCTION

New-physics scenarios (NP) based on very heavy virtual quanta exchanges can be described, below the direct production threshold, by effective, contact-interactions that can have only *indirect* signatures by contributing corrective terms to the Standard Model (SM) amplitudes, suppressed by some power of the ratio between the collider c.m. energy and the above mentioned characteristic high mass scales. These corrections will reveal themselves *via* deviations of the measured observables from the SM predictions or, in few specific cases, by the observation of processes forbidden by the SM.

In principle, different kinds of NP interactions may produce similar deviations and, consequently, it would be desirable to assess, for each non-standard model, not only the “discovery reach”, represented by the maximal value of the relevant mass scale below which a deviation can be observed at a given C.L. within the experimental accuracy but, also, the “identification reach”, defined as the upper limit of the mass range of values for which the model can be discriminated from the other potentially competing scenarios.

We will focus on the discrimination reach on the ADD models of gravity in large, compactified, extra spatial dimensions [1], with respect to the four-fermion contact interactions inspired by compositeness [2], and *viceversa*, looking at the differential cross sections of

$$e^+ + e^- \rightarrow \bar{f} + f, \quad (1)$$

with $f = l, q$ ($l = \mu, \tau$; $q = c, b$), at the ILC with longitudinally polarized beams [3, 4]. In Ref. [5], the identification reach on individual contact-interactions was studied by applying a Monte Carlo technique to lepton-pair production with unpolarized beams. Approach based on the polarized differential distributions for lepton pair production processes was proposed in [6]. We here discuss the benefits of longitudinal beams polarization in improving the identification reaches and consider also quark-pair production channels.

2. DIFFERENTIAL CROSS SECTIONS AND DEVIATIONS FROM THE SM

Neglecting all fermion masses with respect to the c.m. energy $\sqrt{s}$, the polarized differential cross section of processes (1) can be expressed as follows [7]:

$$\frac{d\sigma^{\text{pol}}}{dz} = \frac{1}{4} \left[(1 - P_1)(1 + P_2) \left(\frac{d\sigma_{\text{LL}}}{dz} + \frac{d\sigma_{\text{LR}}}{dz} \right) + (1 + P_1)(1 - P_2) \left(\frac{d\sigma_{\text{RR}}}{dz} + \frac{d\sigma_{\text{RL}}}{dz} \right) \right], \quad (2)$$

where $z = \cos \theta$ is the angle between the incoming and outgoing fermions in the c.m. frame and $(\alpha, \beta = \text{L, R})$:

$$\frac{d\sigma_{\alpha\beta}}{dz} = N_{\text{colors}} \frac{3}{8} \sigma_{\text{pt}} |\mathcal{M}_{\alpha\beta}|^2 (1 \pm z)^2. \quad (3)$$

P_1 and P_2 the degrees of longitudinal polarization of the electron and positron beams, respectively, and the ‘ $\pm$ ’ signs apply to the cases LL, RR and LR, RL, respectively.

According to sec. 1, the reduced helicity amplitudes appearing in Eq. (3) can be expanded into the SM part represented by γ and Z exchanges, plus corrections depending on the considered NP model:

$$\mathcal{M}_{\alpha\beta} = \mathcal{M}_{\alpha\beta}^{\text{SM}} + \Delta_{\alpha\beta}(\text{NP}). \quad (4)$$

The examples explicitly considered here are the following ones:

a) The ADD large extra dimensions scenario [1], where only gravity can propagate in extra dimensions, and correspondingly a tower of graviton KK states occurs in the four-dimensional space [8, 9]. In the parameterization of Ref. [10], the (z -dependent) deviations can be expressed as [11]:

$$\Delta_{\text{LL}}(\text{ADD}) = \Delta_{\text{RR}}(\text{ADD}) = f_G(1 - 2z), \quad \Delta_{\text{LR}}(\text{ADD}) = \Delta_{\text{RL}}(\text{ADD}) = -f_G(1 + 2z), \quad (5)$$

where $f_G = \lambda s^2 / (4\pi\alpha_{\text{e.m.}}\Lambda_H^4)$, $\lambda = \pm 1$, Λ_H being a phenomenological cut-off on the integration on the KK spectrum.

b) Gravity in TeV^{-1} -scale extra dimensions, where also the SM gauge bosons can propagate there, parameterized by the “compactification scale” M_C [12, 13]:

$$\Delta_{\alpha\beta}(\text{TeV}) = - \left(Q_e Q_f + g_\alpha^e g_\beta^f \right) \pi^2 / (3 M_C^2). \quad (6)$$

c) The four-fermion contact-interaction scenario (CI) [2] where, with $\Lambda_{\alpha\beta}$ the “compositeness” mass scales ($\eta_{\alpha\beta} = \pm 1$):

$$\Delta_{\alpha\beta}(\text{CI}) = \eta_{\alpha\beta} s / (\alpha_{\text{e.m.}} \Lambda_{\alpha\beta}^2). \quad (7)$$

In cases *b)* and *c)* the deviations are z -independent, whereas in the case *a)* they introduce extra z -dependence in the angular distributions. The consequence is that the ADD contribution to the integrated cross sections is tiny, because the interference with the SM amplitudes vanishes in these observables. Current experimental lower bounds on the mass scales M_H and M_C are reviewed, e.g., in Ref. [14] ($M_H > 1.1 - 1.3 \text{ TeV}$, $M_C > 6.8 \text{ TeV}$), while those on Λ_s , of the order of 10 TeV, are detailed in Ref. [15].

3. DERIVATION OF THE IDENTIFICATION REACHES

Let us assume one of the models, for example the ADD model (5), to be the “true” one, i.e., to be consistent with data for some value of Λ_H . To estimate the level at which it may be discriminated from other, in principle competing NP scenarios (“tested” models), for any values of the relevant mass parameters, say example one of the four-fermion CI models (7), we introduce relative deviations of the differential cross section (denoted by $\mathcal{O}$) from the ADD predictions due to the CI in each angular bin, and a corresponding χ^2 function:

$$\Delta(\mathcal{O}) = \frac{\mathcal{O}(\text{CI}) - \mathcal{O}(\text{ADD})}{\mathcal{O}(\text{ADD})}; \quad \chi^2(\mathcal{O}) = \sum_{\text{bins}} \left(\frac{\Delta(\mathcal{O})^{\text{bin}}}{\delta\mathcal{O}^{\text{bin}}} \right)^2. \quad (8)$$

Here, $\delta\mathcal{O}$ s represent the expected relative uncertainties, which combine statistical and systematic ones, the former one being related to the ADD model prediction. Consequently, the χ^2 of Eq. (8) is a function of λ/Λ_H^4 and the considered η/Λ^2 , and we can determine the “confusion” region in this parameter plane where also the corresponding CI model may be considered as consistent with the ADD predictions at the chosen confidence level, so that an unambiguous identification of ADD cannot be made. We choose $\chi^2 < 3.84$ for 95% C.L..

For the numerical analysis, we consider an ILC with $\sqrt{s} = 0.5$ TeV time-integrated luminosity $\mathcal{L}_{\text{int}}$ from 100 fb^{-1} up to 1000 fb^{-1} ; reconstruction efficiencies 95% for l^+l^- , 60% for $b\bar{b}$ and 35% for $c\bar{c}$. We divide the angular range, $|z| < 0.98$ in ten bins. To account for the major systematic uncertainties, we assume $\delta\mathcal{L}_{\text{int}}/\mathcal{L}_{\text{int}} = 0.5\%$, and $|P_1| = 0.8$ and $|P_2| = 0.6$ with $\delta P_1/P_1 = \delta P_2/P_2 = 0.2\%$. Specifically, we consider the four polarized cross sections with the configurations $(P_1, P_2) = (0.8, -0.6)$ and $(-0.8, 0.6)$, and combine them into the χ^2 also accounting for their mutual statistical correlations.

Fig. 1 (left panel) shows as an example the “confusion region” between the ADD and the VV models, resulting from the process $e^+e^- \rightarrow \bar{b}b$, with the above inputs and $\mathcal{L}_{\text{int}} = 100 \text{ fb}^{-1}$, both for unpolarized and polarized beams. The figure shows that a maximal absolute value of the λ/Λ_H^4 (equivalently, a minimal value of Λ_H) can be found,

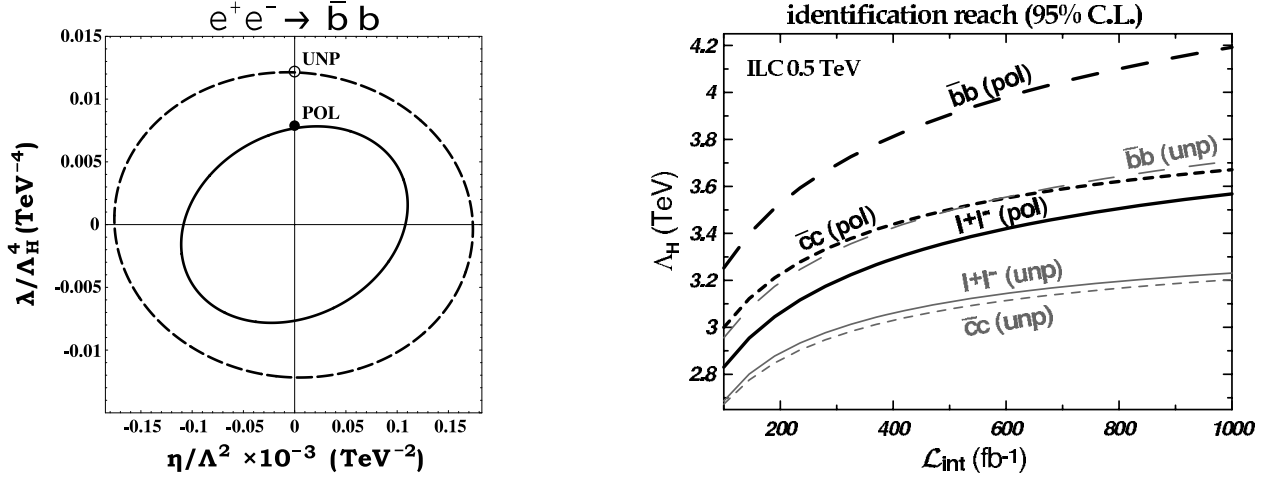


Figure 1: Left panel: confusion region (95% C.L.) for ADD and VV models from $e^+e^- \rightarrow \bar{b}b$ with $\mathcal{L}_{\text{int}} = 100 \text{ fb}^{-1}$. Right panel: identification reach on Λ_H in the ADD model *vs.* $\mathcal{L}_{\text{int}}$ obtained from all processes (1) with unpolarized and polarized beams.

for which the “tested” VV model hypothesis is expected to be excluded at the 95% C.L. for any value of the CI parameter η/Λ^2 . We denote the corresponding ADD mass scale parameter as Λ_H^{VV} and call it “exclusion reach” of the VV model. The same procedure can be applied to all other types of effective contact interaction models considered in Eqs. (7) and (6), and leads to the corresponding “exclusion reaches” Λ_H^{AA} , Λ_H^{RR} , Λ_H^{LL} , Λ_H^{LR} , Λ_H^{RL} and Λ_H^{TeV} . As the final step, the “identification reach” on the ADD scenario can be defined as the minimum of the Λ_H “exclusion reaches”, $\Lambda_H^{\text{ID}} = \min\{\Lambda_H^{\text{VV}}, \Lambda_H^{\text{AA}}, \Lambda_H^{\text{RR}}, \Lambda_H^{\text{LL}}, \Lambda_H^{\text{LR}}, \Lambda_H^{\text{RL}}, \Lambda_H^{\text{TeV}}\}$. Clearly, $\Lambda_H < \Lambda_H^{\text{ID}}$ allows to exclude *all* composite-like CI models as well as the TeV^{-1} gravity model. The results of this kind of analysis for all processes (1) with unpolarized beams as well as polarized beams, and the corresponding “identification reach” on Λ_H , are shown in Fig. 1 (right panel).

The simple, χ^2 -based procedure outlined above can be applied in turn to all individual processes, sources of the corrections in Eqs. (7) and (6), and distinction reaches on the relevant mass parameters can be derived analogously. In Fig. 2 we show, as examples, the results for the compactification scale M_C and the CI compositeness scale Λ_{VV} . One can notice, from both Figs. 1 and 2, the essential rôle of beam polarization in increasing the discrimination sensitivity on the different NP scenarios.

In conclusion, we have developed a specific approach based on the differential polarized cross sections to search for and identify spin-2 graviton exchange with uniquely distinct signature. Fig. 1 (right panel) shows that, of the three considered processes, $\bar{b}b$ pair production process definitely has the best identification sensitivity on the scale Λ_H characterizing the ADD model for gravity in “large” compactified extra dimensions. As one can see, in the polarized case, the identification reach ranges from 3.3 TeV to 4.2 TeV, depending on on luminosity.

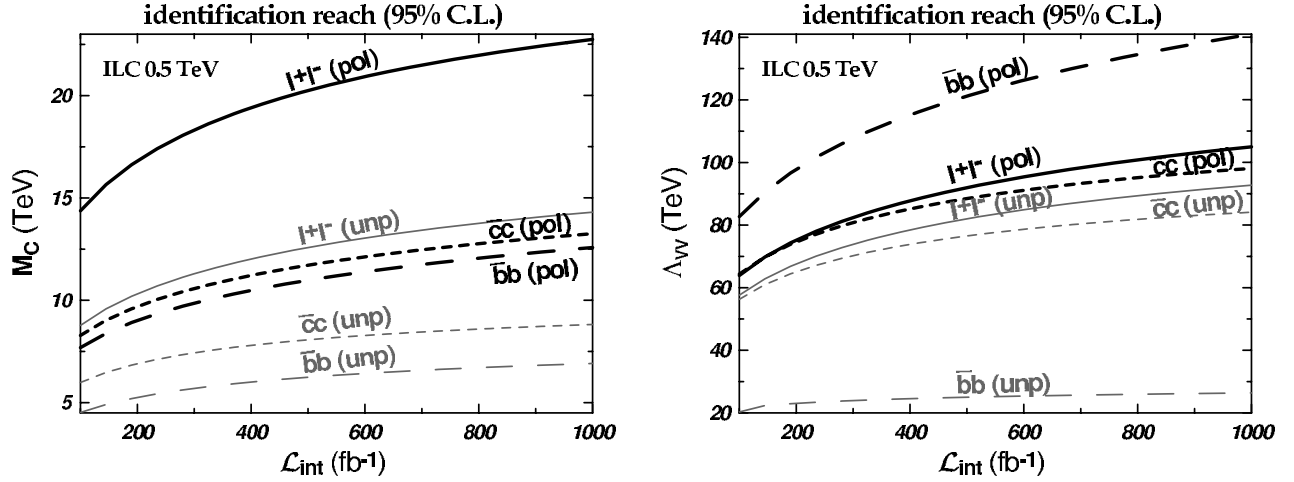


Figure 2: 95% CL identification reach on the cutoff scale M_C in the TeV model (left panel) and Λ_{VV} in the VV model (right panel) as a function of the integrated luminosity obtained from the fermion pair production processes with unpolarized and both polarized beams at ILC(0.5 TeV).

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