Discriminating graviton effects via centre-edge asymmetry

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- A Plethora of New Physics
- The centre-edge asymmetry A_{CE}
- Applications

(with P. Osland and A. Pankov)

Various New Physics possibilities

- Composite models
- Heavy Z' exchanges
- Scalar and vector leptoquarks
- Sneutrino exchange
- Anomalous Gauge Couplings (AGC)
- Exchange of gauge boson KK towers
- Virtual KK graviton exchange (ADD)

Framework of effective Lagrangians
(expansion in s/Λ^2)
Deviations of cross sections from SM predictions
Study process ($f \neq e, t$)

$$e^+ + e^- \to f + \bar{f}$$

Mini-review of ADD [Hewett & Spirupulu, hep-ph/0205106]

Effective Lagrangian:

$$\mathcal{L} = i\frac{4\lambda}{M_H^4} T_{\mu\nu} T^{\mu\nu} + \text{h.c.}$$

Divergent sum over graviton exchange truncated 'naively':

$$\mathcal{M} \sim \frac{i\pi}{M_{\text{Pl}}} \sum_{\vec{n}=1}^{\infty} \frac{1}{s - m_{\vec{n}}^2} \to \frac{\lambda}{M_H^4}$$

Contact interaction terminology

Helicity cross sections:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}z} = \frac{1}{4}\left(\frac{\mathrm{d}\sigma_{\mathrm{LL}}}{\mathrm{d}z} + \frac{\mathrm{d}\sigma_{\mathrm{RR}}}{\mathrm{d}z} + \frac{\mathrm{d}\sigma_{\mathrm{LR}}}{\mathrm{d}z} + \frac{\mathrm{d}\sigma_{\mathrm{RL}}}{\mathrm{d}z}\right)$$

$z \equiv \cos\theta$

$$\frac{\mathrm{d}\sigma_{\alpha\beta}}{\mathrm{d}z} = N_C \frac{\pi\alpha^2_{\mathrm{e.m.}}}{2s} |\mathcal{M}_{\alpha\beta}|^2 (1 \pm z)^2$$

Helicity amplitudes:

$$\mathcal{M}_{\alpha\beta} = \mathcal{M}^{\mathrm{SM}}_{\alpha\beta} + \Delta_{\alpha\beta} = Q_e Q_f + g^e_\alpha g^f_\beta \chi_Z + \Delta_{\alpha\beta}$$

$\chi_Z = s/(s - M_Z^2 + iM_Z\Gamma_Z) \approx s/(s - M_Z^2)$

$g^f_{\mathrm{L}} = (I^f_{3L} - Q_f s^2_W)/s_W c_W$

$g^f_{\mathrm{R}} = -Q_f s_W/c_W$

$s^2_W = 1 - c^2_W \equiv \sin^2\theta_W$

Parametrization of the $\Delta_{\alpha\beta}$ functions in different models ($\alpha, \beta = \mathrm{L}, \mathrm{R}$)

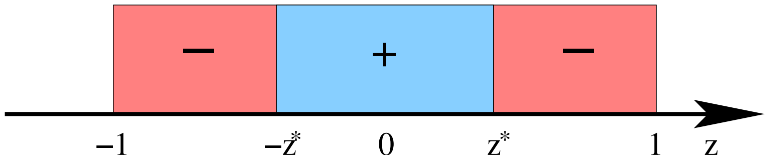
Model	$\Delta_{\alpha\beta}$
composite fermions	$\pm \frac{s}{\alpha_{\mathrm{e.m.}}} \frac{1}{\Lambda^2_{\alpha\beta}}$
extra gauge boson Z'	$g'^{\,e}_{\alpha}\, g'^{\,f}_{\beta}\, \chi_{Z'}$
AGC ($f = \ell$)	$\Delta_{\mathrm{LL}} = s \left(\frac{\tilde{f}_{DW}}{2 s_W^2} + \frac{2 \tilde{f}_{DB}}{c_W^2} \right)$ $\frac{\Delta_{\mathrm{RR}}}{2} = \Delta_{\mathrm{LR}} = \Delta_{\mathrm{RL}} = s \frac{4 \tilde{f}_{DB}}{c_W^2}$
TeV-scale extra dim.	$(Q_e Q_f + g^e_\alpha\, g^f_\beta)\, \frac{\pi^2}{3\, M_C^2}$
ADD model	$\Delta_{\mathrm{LL}} = \Delta_{\mathrm{RR}} = f_G\, (1 - 2\, z)$ $\Delta_{\mathrm{LR}} = \Delta_{\mathrm{RL}} = -f_G\, (1 + 2\, z)$

- $\tilde{f} = f/m_t^2$ (f_{DW} and f_{DB} parametrize new-physics effects associated with the SU(2) and hypercharge currents)

- M_C is the compactification scale

- $f_G = \lambda\, s^2/(4\pi\alpha_{\mathrm{e.m.}} M_H^4)$ parametrizes strength associated with massive graviton exchange

Centre Edge Asymmetry



$$A_{\mathrm{CE}} = \frac{\sigma_{\mathrm{CE}}}{\sigma}$$

$$\sigma_{\mathrm{CE}} = \left[\int_{-z^*}^{z^*} - \left(\int_{-1}^{-z^*} + \int_{z^*}^{1}\right)\right] \frac{\mathrm{d}\sigma}{\mathrm{d}z}\,\mathrm{d}z$$

$$\sigma = \int_{-1}^{1} \frac{\mathrm{d}\sigma}{\mathrm{d}z}\,\mathrm{d}z$$

Decompose cross section:

$$\sigma = \sigma^{\mathrm{SM}} + \sigma^{\mathrm{INT}} + \sigma^{\mathrm{NP}}$$

"SM", "INT" and "NP" refer to "Standard Model", "Interference" and (pure) "New Physics" contributions.

$$A_{\mathrm{CE}} = \frac{\sigma^{\mathrm{SM}}_{\mathrm{CE}} + \sigma^{\mathrm{INT}}_{\mathrm{CE}} + \sigma^{\mathrm{NP}}_{\mathrm{CE}}}{\sigma^{\mathrm{SM}} + \sigma^{\mathrm{INT}} + \sigma^{\mathrm{NP}}}$$

Explicitly:

$$\begin{aligned}
\sigma^{\mathrm{SM}}_{\mathrm{CE}} =& \sigma_0 \frac{1}{4}\left[(\mathcal{M}^{\mathrm{SM}}_{\mathrm{LL}})^2 + (\mathcal{M}^{\mathrm{SM}}_{\mathrm{RR}})^2 + (\mathcal{M}^{\mathrm{SM}}_{\mathrm{LR}})^2 + (\mathcal{M}^{\mathrm{SM}}_{\mathrm{RL}})^2\right] \\
& \times \frac{4}{3}\left[z^*(z^{*2}+3) - 2\right], \\
\sigma^{\mathrm{INT}}_{\mathrm{CE}} =& \sigma_0\, 2\, f_G \frac{1}{4}\left[\mathcal{M}^{\mathrm{SM}}_{\mathrm{LL}} + \mathcal{M}^{\mathrm{SM}}_{\mathrm{RR}} - \mathcal{M}^{\mathrm{SM}}_{\mathrm{LR}} - \mathcal{M}^{\mathrm{SM}}_{\mathrm{RL}}\right] 4z^*(1 - z^{*2}), \\
\sigma^{\mathrm{NP}}_{\mathrm{CE}} =& \sigma_0\, f_G^2 \frac{4}{5}\left[4z^{*5} + 5z^*(1 - z^{*2}) - 2\right]
\end{aligned}$$

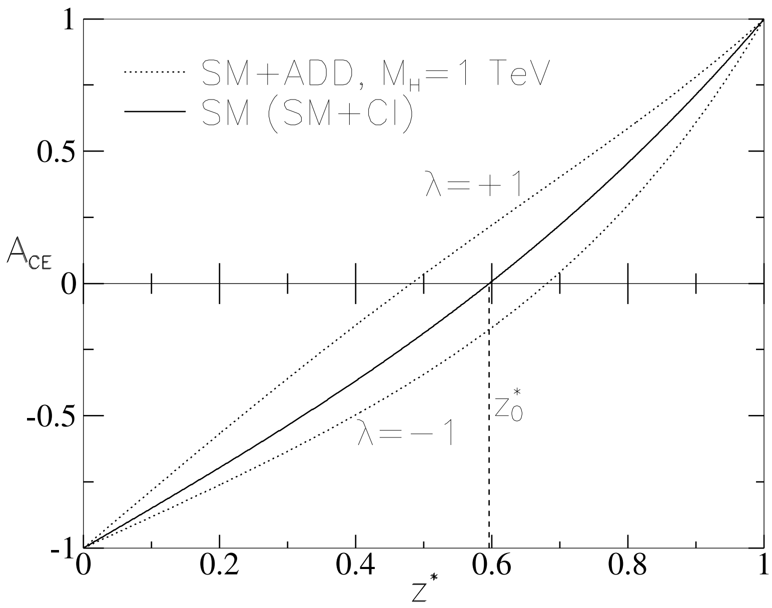
$$\sigma_0 = N_C \frac{\pi \alpha^2_{\mathrm{e.m.}}}{2s}$$

$$\begin{aligned}
\sigma^{\mathrm{SM}} =& \sigma_0 \frac{1}{4}\left[(\mathcal{M}^{\mathrm{SM}}_{\mathrm{LL}})^2 + (\mathcal{M}^{\mathrm{SM}}_{\mathrm{RR}})^2 + (\mathcal{M}^{\mathrm{SM}}_{\mathrm{LR}})^2 + (\mathcal{M}^{\mathrm{SM}}_{\mathrm{RL}})^2\right] \frac{8}{3}, \\
\sigma^{\mathrm{INT}} =& 0, \qquad \sigma^{\mathrm{NP}} = \sigma_0\, f_G^2 \frac{8}{5}
\end{aligned}$$

Note that, at $z^* = 0$ and 1, $\sigma_{\mathrm{CE}} = \mp\sigma$, respectively.

Centre Edge Asymmetry in SM

$$A_{\mathrm{CE}}^{\mathrm{SM}} = \frac{\sigma_{\mathrm{CE}}^{\mathrm{SM}}}{\sigma^{\mathrm{SM}}} = \frac{1}{2} z^* \left(z^{*2} + 3\right) - 1.$$



Independent of s, flavour, longitudinal polarization

Zero of $A_{\mathrm{CE}}^{\mathrm{SM}}(z^*)$:

$$z_0^* = (\sqrt{2}+1)^{1/3} - (\sqrt{2}-1)^{1/3} = 0.596$$

$\theta = 53.4^\circ$ (solid curve in Fig.)

Graviton Exchange

Graviton exchange in the ADD model:

$$\Delta A_{\mathrm{CE}} = A_{\mathrm{CE}} - A_{\mathrm{CE}}^{\mathrm{SM}}$$

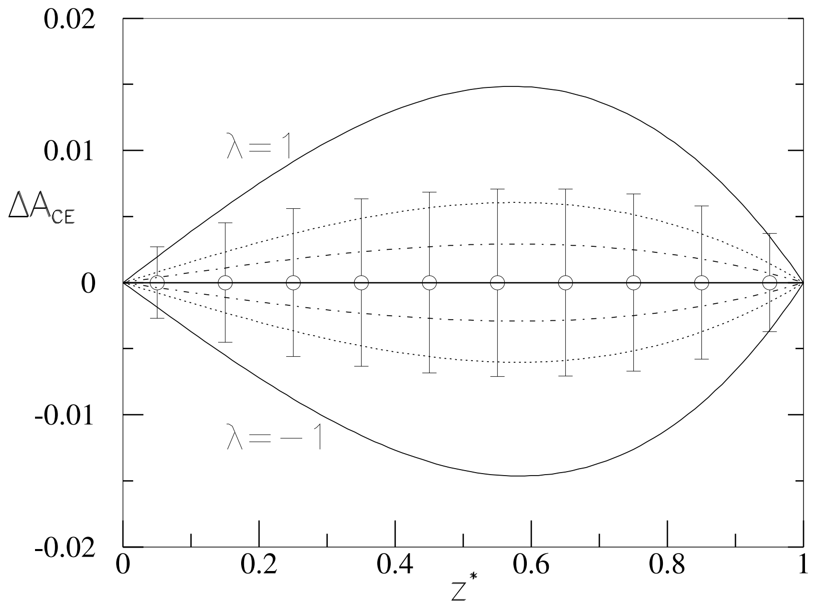
$\sigma_{\mathrm{CE}}^{\mathrm{INT}}$ produces largest deviation

Interference terms only:

$$\Delta A_{\mathrm{CE}} \simeq f_G \frac{\mathcal{M}_{\mathrm{LL}}^{\mathrm{SM}} + \mathcal{M}_{\mathrm{RR}}^{\mathrm{SM}} - \mathcal{M}_{\mathrm{LR}}^{\mathrm{SM}} - \mathcal{M}_{\mathrm{RL}}^{\mathrm{SM}}}{\left[(\mathcal{M}_{\mathrm{LL}}^{\mathrm{SM}})^2 + (\mathcal{M}_{\mathrm{RR}}^{\mathrm{SM}})^2 + (\mathcal{M}_{\mathrm{LR}}^{\mathrm{SM}})^2 + (\mathcal{M}_{\mathrm{RL}}^{\mathrm{SM}})^2\right]} \times 3\, z^* \,(1 - {z^*}^2)$$

Depends on flavour of final state f

Working at point z^* where SM contribution vanishes, this effect of graviton exchange can be isolated.



$M_H = 2$ (solid), 2.5 (dotted)

3 TeV (dash-dotted)

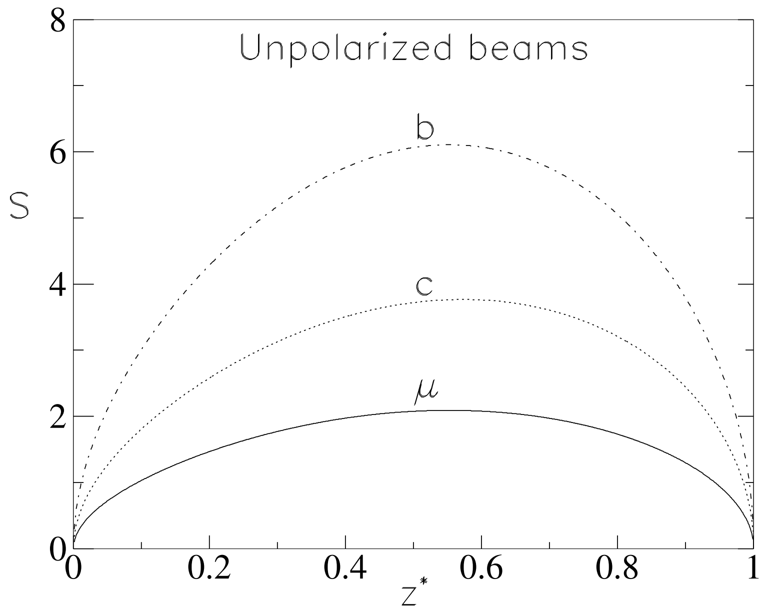
$\lambda = \pm 1$ and $\sqrt{s} = 0.5$ TeV

$\mathcal{L}_{\text{int}} = 50$ fb^{-1}

At the point z_0^* where $A_{\text{CE}}^{\text{SM}}$ vanishes, the effect is maximal

Sensitivity

$$\mathcal{S} = \frac{|\Delta A_{\text{CE}}|}{\delta A_{\text{CE}}}$$



$M_H = 2$ TeV, $\mathcal{L}_{\text{int}} = 50\text{fb}^{-1}$, $\lambda = 1$,
$\sqrt{s} = 500$ GeV.
Rec. efficiency: $\epsilon_{\mu,\tau} = 100\%$; $\epsilon_c = 60\%$;
$\epsilon_b = 80\%$
Max of $\mathcal{S}$ at $z^*_{\text{max}} \approx 1/\sqrt{3} = 0.577$ ($\theta = 54.7°$),
close to $z^*_0 = 0.596$ ($\theta = 53.4°$)
Smooth behaviour around z^*_0

Centre Edge Asymmetry for CI

$$A_{\rm CE}^{\rm SM+CI} = \frac{\sigma_{\rm CE}^{\rm SM+CI}}{\sigma^{\rm SM+CI}}$$

with

$$\sigma_{\rm CE}^{\rm SM+CI} = \sigma_0 \frac{1}{4}\left[(\mathcal{M}_{\rm LL})^2 + (\mathcal{M}_{\rm RR})^2 + (\mathcal{M}_{\rm LR})^2 + (\mathcal{M}_{\rm RL})^2\right] \times \frac{4}{3}\left[z^*(z^{*2}+3) - 2\right]$$

$$\sigma^{\rm SM+CI} = \sigma_0 \frac{1}{4}\left[(\mathcal{M}_{\rm LL})^2 + (\mathcal{M}_{\rm RR})^2 + (\mathcal{M}_{\rm LR})^2 + (\mathcal{M}_{\rm RL})^2\right] \frac{8}{3}$$

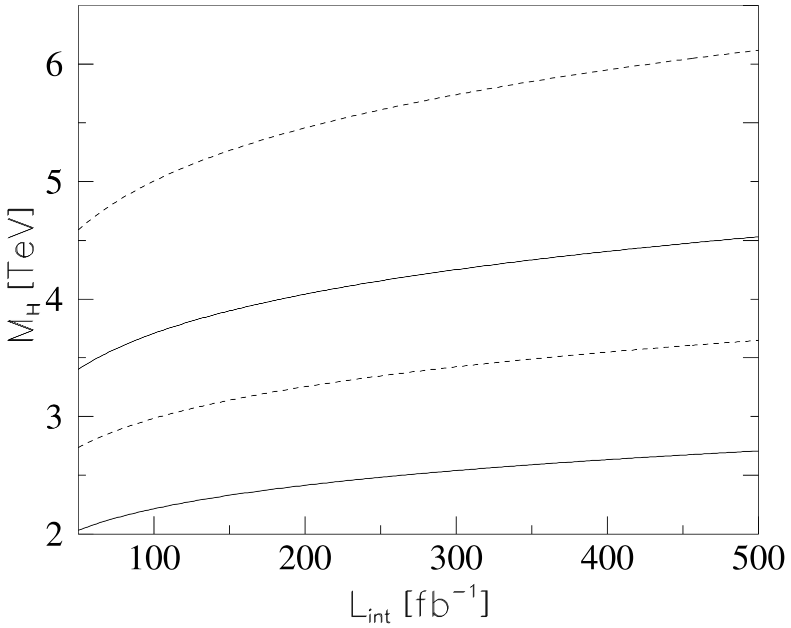
$$A_{\rm CE}^{\rm SM+CI} = \frac{1}{2} z^* \left(z^{*2} + 3\right) - 1$$

THIS IS THE SAME RESULT AS IN SM

Reason: Vector couplings

Conventional “contact-like” interactions “filtered” out

5σ Reach on M_H (summed over μ, τ, b, c):



Solid: unpolarized

Dashed: $P = 0.8$, $\bar{P} = -0.6$

$\delta\mathcal{L}_{\rm int}/\mathcal{L}_{\rm int} = \delta P/P = \delta\bar{P}/\bar{P} = 0.5\%$

$z_{\rm cut} = 0.985$ (10°) $[-z_{\rm cut} \leq z \leq z_{\rm cut}]$

Top down: $\sqrt{s} = 1$ TeV, 0.5 TeV

Sneutrino exchange

Example of scalar exchange

t-channel $\tilde{\nu}$ exchange [Rizzo]:

$$\Delta_{\mathrm{LL}} = \Delta_{\mathrm{RR}} = 0, \qquad \Delta_{\mathrm{LR}} = \Delta_{\mathrm{RL}} = \frac{1}{2} C_{\tilde{\nu}} P^t_{\tilde{\nu}}$$

$P^t_{\tilde{\nu}} = s/(t - m^2_{\tilde{\nu}})$, $C_{\tilde{\nu}} = \lambda^2/4\pi\alpha_{\mathrm{e.m.}}$

Define polarization configurations:

$(P, \bar{P})_{\mathrm{L}} \equiv (-P_1, P_2)$; $(P, \bar{P})_{\mathrm{R}} \equiv (P_1, -P_2)$:

$$\sigma_{\mathrm{CE,LR}} = \left[\int_{-z_0^*}^{z_0^*} - \left(\int_{-1}^{-z_0^*} + \int_{z_0^*}^{1} \right) \right] \left(\frac{\mathrm{d}\sigma_{\mathrm{L}}}{\mathrm{d}z} - \frac{\mathrm{d}\sigma_{\mathrm{R}}}{\mathrm{d}z} \right) \mathrm{d}z$$

$$\begin{aligned} \Delta(\mathrm{d}\sigma_{\mathrm{LR}}) &\equiv (\mathrm{d}\sigma_{\mathrm{L}} - \mathrm{d}\sigma_{\mathrm{R}}) - (\mathrm{d}\sigma^{\mathrm{SM}}_{\mathrm{L}} - \mathrm{d}\sigma^{\mathrm{SM}}_{\mathrm{R}}) \\ &\propto (\mathcal{M}^{\mathrm{SM}}_{\mathrm{LR}} - \mathcal{M}^{\mathrm{SM}}_{\mathrm{RL}}) C_{\tilde{\nu}} P^t_{\tilde{\nu}} = 0 \end{aligned}$$

since $\mathcal{M}^{\mathrm{SM}}_{\mathrm{LR}} = \mathcal{M}^{\mathrm{SM}}_{\mathrm{RL}}$ for $f = \mu, \tau$

$\sigma_{\mathrm{CE,LR}}$ unaltered by t-channel $\tilde{\nu}$ exchange

However: $\Delta\sigma^{G}_{\mathrm{CE,LR}} \neq 0$

Summary

- The Centre-Edge asymmetry is based on integrated cross sections
- Results on M_H rather stable in z_{cut} near 1
- Can tune parameter z^* such that SM and CI contributions vanish
- $b\bar{b}$ channel most sensitive
- 5σ reach on M_H: 4-6 TeV 500 fb^{-1}
- Work on Drell-Yan processes in progress