Identification of Large Extra Spatial Dimensions at the LC

N. Paver
University of Trieste

Stanford, 18-23 March, 2005

- A Plethora of New Physics
- Center-edge asymmetries $A_{\rm CE}$ and $A_{\rm CE,FB}$
- Applications
- LC vs. LHC

(with 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)

Energy may be below relevant high mass scales

- Framework of effective Lagrangians (expansion in s/Λ^2)

  Indirect manifestations: Deviations of cross sections from SM predictions

- Identify/constrain the source of indirect effects

Study process ($f \neq e, t$)

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

Contact interaction terminology

Helicity cross sections ($z \equiv \cos\theta$):

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

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

Helicity amplitudes ($\alpha, \beta = \mathrm{L}, \mathrm{R}$):

$$\mathcal{M}_{\alpha\beta} = \overbrace{Q_e Q_f + g_\alpha^e\, g_\beta^f\, \chi_Z}^{\mathcal{M}_{\alpha\beta}^{\mathrm{SM}}} + \Delta_{\alpha\beta}$$

SM :

$$\frac{\mathrm{d}\sigma}{\mathrm{d}z} = \frac{3}{8}\sigma \cdot \left(1 + z^2\right) + \sigma_{\mathrm{FB}} \cdot z,$$

where

$$\sigma = \int_{-1}^{1} \frac{\mathrm{d}\sigma}{\mathrm{d}z}\mathrm{d}z, \qquad \sigma_{\mathrm{FB}} = \left(\int_0^1 - \int_{-1}^0\right)\frac{\mathrm{d}\sigma}{\mathrm{d}z}\mathrm{d}z.$$

Different Scenarios

ADD scenario ('large' extra dimensions)
Effective Lagrangian (Hewett parametrisation):

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

M_H: cut-off of sum over KK states ($\lambda = \pm 1$).

Amplitudes deviations are z-dependent

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

$f_G = \lambda\, s^2/(4\pi\alpha_{\text{e.m.}} M_H^4)$:
strength of massive, spin-2, graviton exchange.

Contact interactions scenario (CI) (heavy quanta exchanges) [Eichten et al., Rückl]

Effective Lagrangian ($\alpha, \beta = \mathrm{L}, \mathrm{R}$):

$$\mathcal{L}^{CI} = 4\pi \sum_{\alpha,\beta} \frac{\eta_{\alpha\beta}}{\Lambda^2_{\alpha\beta}} \left(\bar{e}_\alpha \gamma_\mu e_\alpha\right) \left(\bar{f}_\beta \gamma^\mu f_\beta\right),$$

Amplitudes deviations z-independent:

$$\Delta^{\mathrm{CI}}_{\alpha\beta} = \pm \frac{s}{\alpha_{\mathrm{e.m.}}} \frac{1}{\Lambda^2_{\alpha\beta}}$$

Scalar exchange in t-channel (R-parity violation $\tilde{\nu}$ [Rizzo, Kalinowski et al.]:

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

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

z-independent in the contact limit

z-dependence next order in $1/m^2_{\tilde{\nu}}$.

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.	$(Q_e Q_f + g^e_\alpha\, g^f_\beta)\, \frac{\pi^2\, s}{3\, M_C^2}$
ADD model	$\Delta_{\mathrm{LL}} = \Delta_{\mathrm{RR}} = f_G\,(1 - 2\,z)$ $\Delta_{\mathrm{LR}} = \Delta_{\mathrm{RL}} = -f_G\,(1 + 2\,z)$
$\tilde{\nu}$ exchange	$\Delta_{\mathrm{LL}} = \Delta_{\mathrm{RR}} = 0$ $\Delta_{\mathrm{LR}} = \Delta_{\mathrm{RL}} = \frac{1}{2}\, C^t_{\tilde{\nu}}\, P^t_{\tilde{\nu}}$

- Suitable observables to help dividing the set of possible models into distinct subclasses

- Center-edge asymmetries A_{CE} and $A_{\mathrm{CE,FB}}$ to uniquely identify graviton exchange in ADD scenario in $e^+e^- \to \bar{f} f$ at LC.

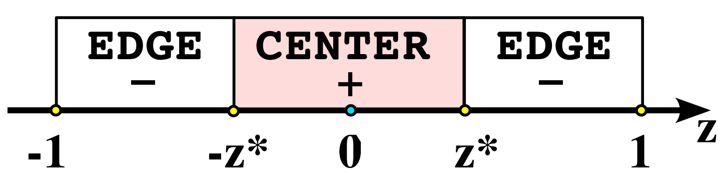
Center-Edge Asymmetry $A_{\rm CE}$

P. Osland, A. Pankov, and N. P., hep-ph/0304123

$$A_{\mathsf{CE}}(e^+e^- \to \bar{f}f) = \frac{\sigma_{\mathsf{CE}}}{\sigma},$$

where $(0 \leq z^* \leq 1)$

$$\begin{aligned}\sigma_{\mathsf{CE}} &= \sigma_{\mathsf{C}} - \sigma_{\mathsf{E}} = \\ &= \left[\int_{-z^*}^{z^*} - \left(\int_{-1}^{-z^*} + \int_{z^*}^{1}\right)\right] \frac{\mathrm{d}\sigma}{\mathrm{d}z}\,\mathrm{d}z,\end{aligned}$$



Sensitive to $z \equiv \cos\theta$-even terms only

- **SM**

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

Independent of s, flavour, longitudinal polarization

- **CI**

Same angular dependence as in the SM: $\mathrm{SM} \to \mathrm{CI}$

$$A_{\mathrm{CE}}^{\mathrm{CI}} = \frac{1}{2} z^* (z^{*2} + 3) - 1, \ (= \mathrm{A}_{\mathrm{CE}}^{\mathrm{SM}})$$

Deviation from SM:

$$\Delta A_{\mathrm{CE}}^{\mathrm{CI}}(z^*) = A_{\mathrm{CE}}^{\mathrm{CI}}(z^*) - A_{\mathrm{CE}}^{\mathrm{SM}}(z^*) = 0\,(!!).$$

$A_{\mathrm{CE}}^{\mathrm{SM}}(z_0^*) = A_{\mathrm{CE}}^{\mathrm{CI}}(z_0^*) = 0$:

$z_0^* = (\sqrt{2} + 1)^{1/3} - (\sqrt{2} - 1)^{1/3} \simeq 0.60 \ (\theta \simeq 53^\circ)$

- **ADD scenario**

$$\Delta A_{\rm CE}^{\rm ADD} = A_{\rm CE}^{\rm ADD} - A_{\rm CE}^{\rm SM} \neq 0$$

Interference terms only:

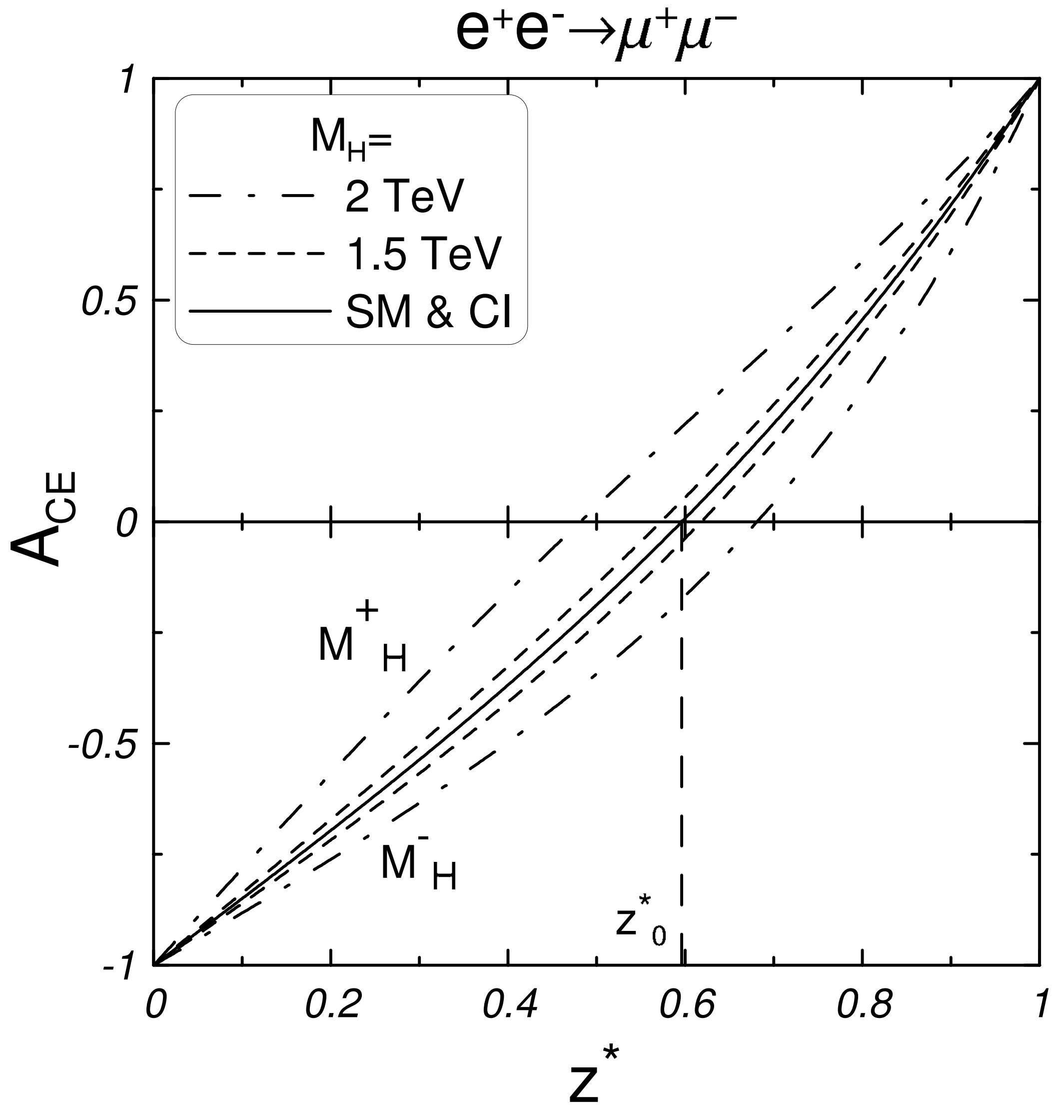
$$\Delta A_{\rm CE}^{\rm ADD} \simeq f_G \cdot \frac{\mathcal{M}_{\rm LL}^{\rm SM} + \mathcal{M}_{\rm RR}^{\rm SM} - \mathcal{M}_{\rm LR}^{\rm SM} - \mathcal{M}_{\rm RL}^{\rm SM}}{\left[(\mathcal{M}_{\rm LL}^{\rm SM})^2 + (\mathcal{M}_{\rm RR}^{\rm SM})^2 + (\mathcal{M}_{\rm LR}^{\rm SM})^2 + (\mathcal{M}_{\rm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

At z_0^*, where $A_{\rm CE}^{\rm SM} = 0$: maximal effect.

Dependent on the flavour of final state f

Conclusions from $A_{\rm CE}$:

- Conventional CI-like interactions ‘filtered’ out for all z^*
- Can tune z^* such as SM and CI contributions vanish



$e^+e^- \to \mu^+\mu^-$
M_H=
2 TeV
1.5 TeV
SM & CI
M^+_H
M^-_H
z^*_0
A_{CE}
z^*
1
0.5
0
-0.5
-1
0
0.2
0.4
0.6
0.8
1

Center-Edge Forward-Backward Asymmetry $A_{\rm CE,FB}$

A. Pankov and N. P., hep-ph/0501170

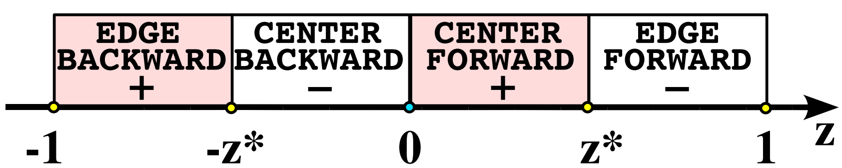
$$A_{\textsf{CE,FB}}(e^+e^- \to \bar{f}f) = \frac{\sigma_{\textsf{CE,FB}}}{\sigma},$$

where

$$\sigma_{\textsf{CE,FB}} = \sigma_{\textsf{C,FB}} - \sigma_{\textsf{E,FB}},$$

$$\sigma_{\textsf{C,FB}} = \sigma_{\textsf{C,F}} - \sigma_{\textsf{C,B}},$$

$$\sigma_{\textsf{E,FB}} = \sigma_{\textsf{E,F}} - \sigma_{\textsf{E,B}}.$$



Sensitive to $z \equiv \cos\theta$-odd terms only

- **SM**

$$A_{\rm CE,FB}^{\rm SM}(z^*) = A_{\rm FB}^{\rm SM} \cdot (-1 + 2z^{*2})$$

- **CI**

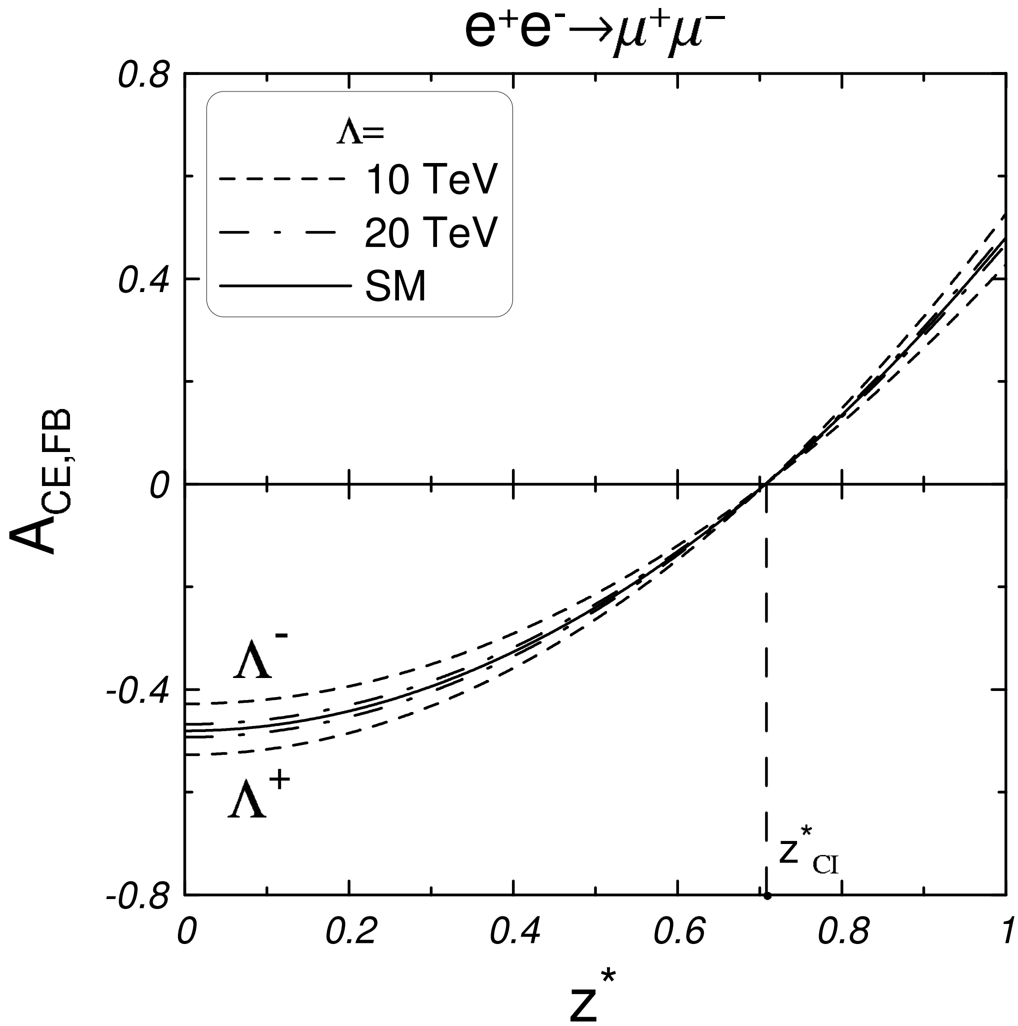
Same angular dependence as in the SM: $\rm SM \to CI$

$$A_{\rm CE,FB}^{\rm CI} = A_{\rm FB}^{\rm CI} \cdot (-1 + 2\, z^{*2}).$$

Deviation from SM:
For general z^*: $\Delta A_{\rm CE,FB}^{\rm CI} \neq 0$
At $z_{\rm CI}^* = 1/\sqrt{2} \simeq 0.71$ ($\theta = 45°$):

$$A_{\rm CE,FB}^{\rm SM}(z_{\rm CI}^*) = A_{\rm CE,FB}^{\rm CI}(z_{\rm CI}^*) = 0$$

No deviation from the SM induced by CI at $z^* = z_{\rm CI}^*$



e+e-→μ+μ-
0.8
0.4
0
-0.4
-0.8
Λ=
10 TeV
20 TeV
SM
A_CE,FB
Λ-
Λ+
z*_CI
0
0.2
0.4
0.6
0.8
1
z*

- **ADD scenario**

$$A^{\rm ADD}_{\rm CE,FB} = \frac{\sigma^{\rm SM}_{\rm CE,FB} + \sigma^{\rm INT}_{\rm CE,FB} + \sigma^{\rm NP}_{\rm CE,FB}}{\sigma^{\rm SM} + \sigma^{\rm INT} + \sigma^{\rm NP}} \cong$$

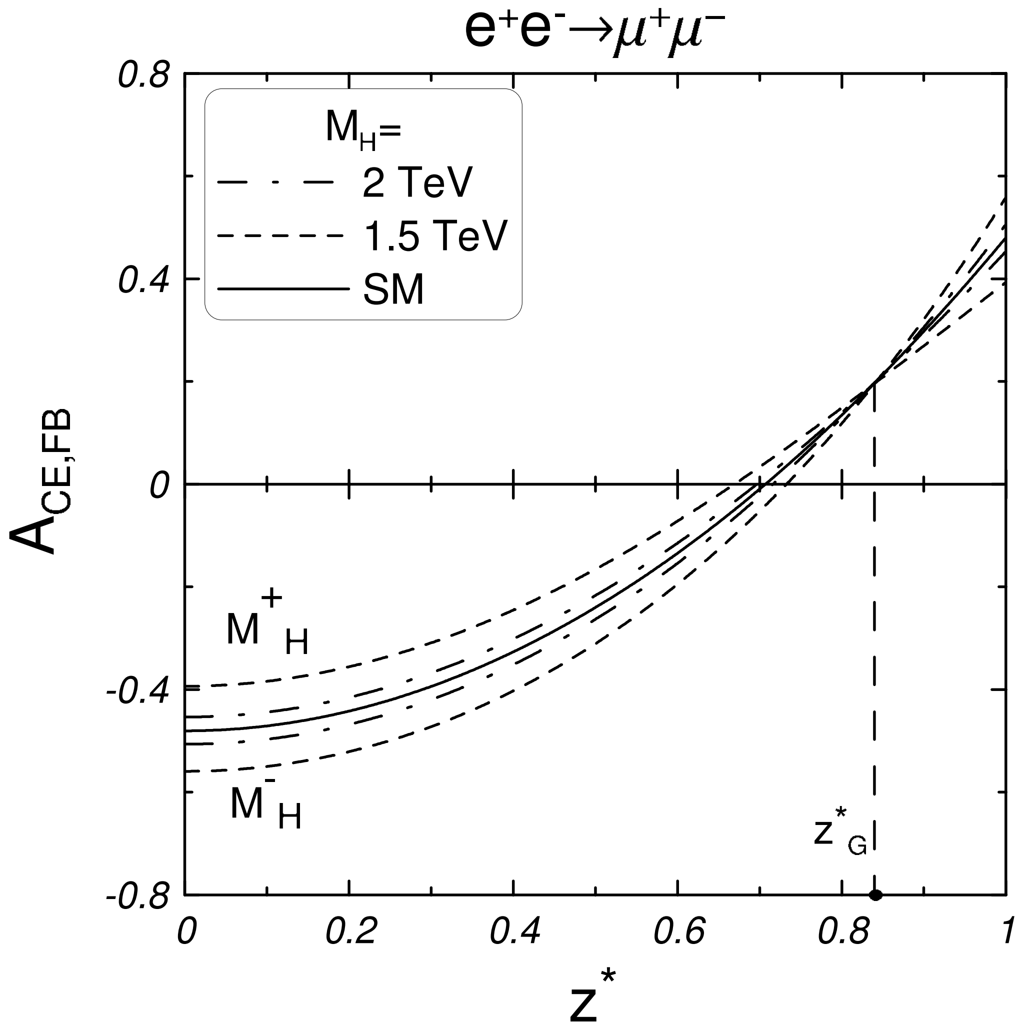
$$\cong \frac{\left(-1 + 2{z^*}^2\right)\sigma^{\rm SM}_{\rm FB} + \left(-1 + 2{z^*}^4\right)\sigma^{\rm INT}_{\rm FB}}{\sigma^{\rm SM}}$$

Deviation from SM:

$$\Delta A^{\rm ADD}_{\rm CE,FB} = (-1 + 2{z^*}^4) A^{\rm INT}_{\rm FB}$$

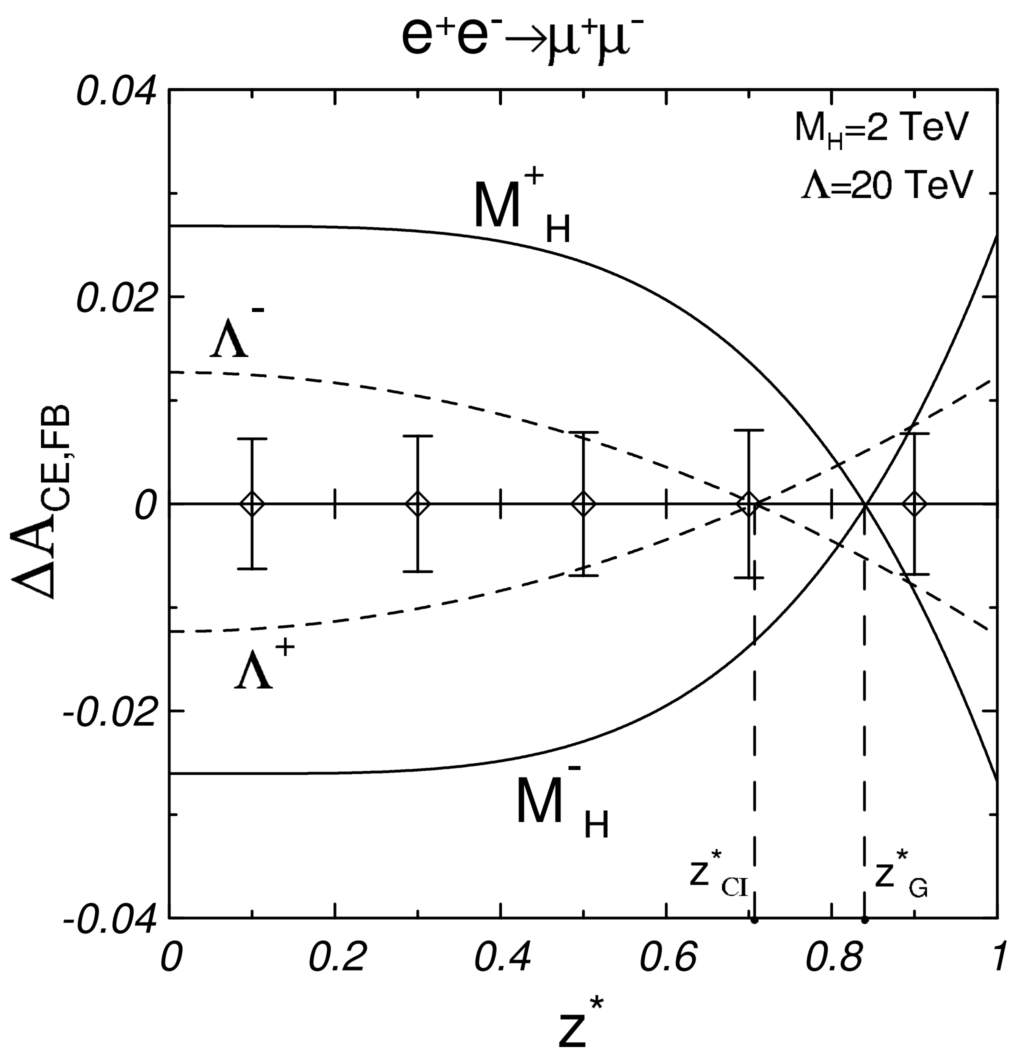
At $z^* = z^*_{\rm G} = 2^{-1/4} \simeq 0.84$ $(\theta \simeq 33^\circ)$:

$$\Delta A^{\rm ADD}_{\rm CE,FB}(z^*_{\rm G}) = 0$$



e+e-→μ+μ-
M_H=
2 TeV
1.5 TeV
SM
A_CE,FB
M+H
M-H
z*G
z*
0.8
0.4
0
-0.4
-0.8
0
0.2
0.4
0.6
0.8
1

Conclusions about $A_{\rm CE,FB}$



- $z^* \approx z^*_{\rm G}$: maximal sensitivity to 4-fermion CI, least contamination from ADD;

- $z^* \approx z^*_{\rm CI}$: maximal sensitivity to ADD, least contamination from CI; may be combined with $A_{\rm CE}$ for identification reach

Identification reaches

- With $\mathcal{O} = A_{\rm CE}, A_{\rm CE,FB}$:

$$\chi^2 = \frac{(\Delta\mathcal{O}^f)^2}{(\delta\mathcal{O}^f)^2}$$

$\delta\mathcal{O}$ = foreseen experimental uncertainty

- Constraints on M_H, Λ:

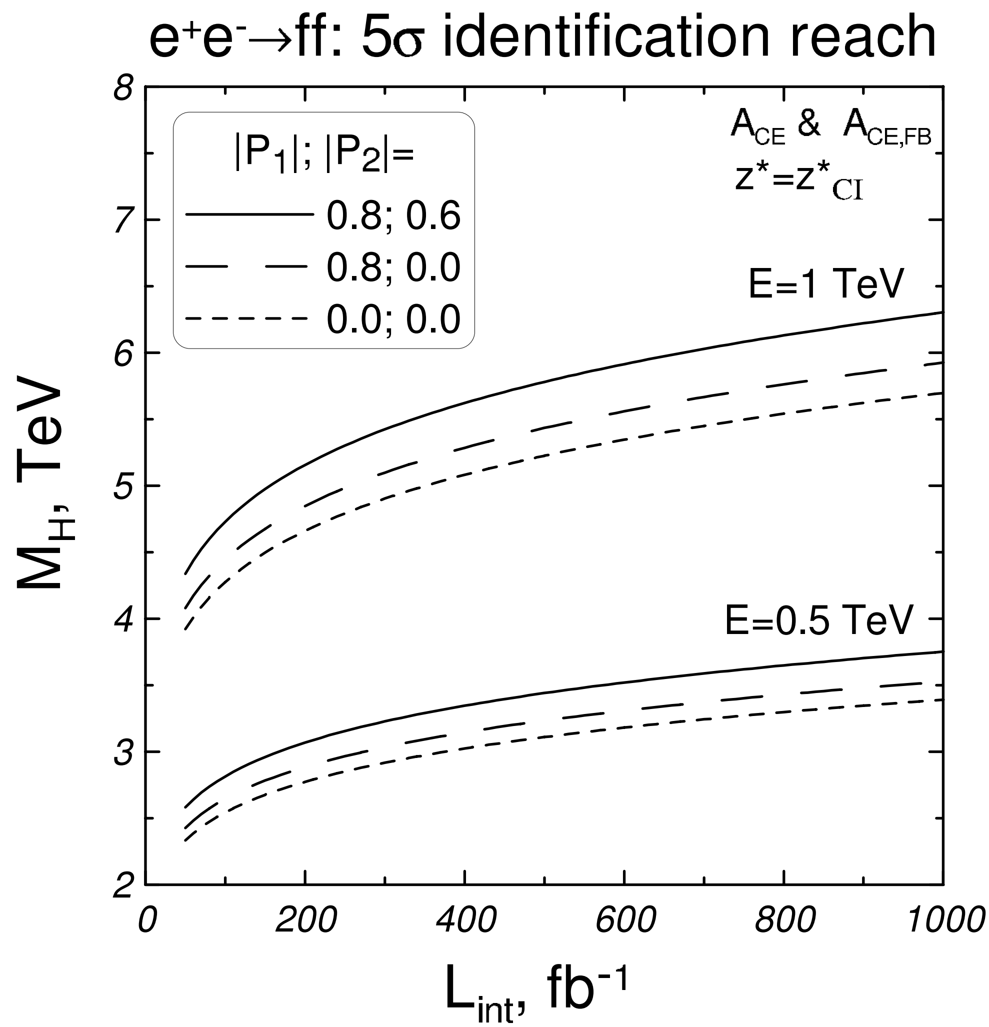
$$\chi^2 \leq \chi^2_{\rm CL}$$

- Systematic uncertainties ($|P_1| = 0.80$, $|P_2| = 0.60$):

$$\frac{\Delta\mathcal{L}_{\rm int}}{\mathcal{L}_{\rm int}} = \frac{\Delta P_1}{P_1} = \frac{\Delta P_2}{P_2} = 0.5\%$$

- $\theta_0 \leq \theta \leq 180^\circ - \theta_0$, with $\theta_0 = 10^\circ$

Identification reach on M_H



Current limit: $M_H \geq 1.28$ TeV (Tevatron, LEP)

Maximal sensitivity to ADD (no contamination from CI)

Scales as $(s^3\mathcal{L}^{\rm int})^{1/8}$

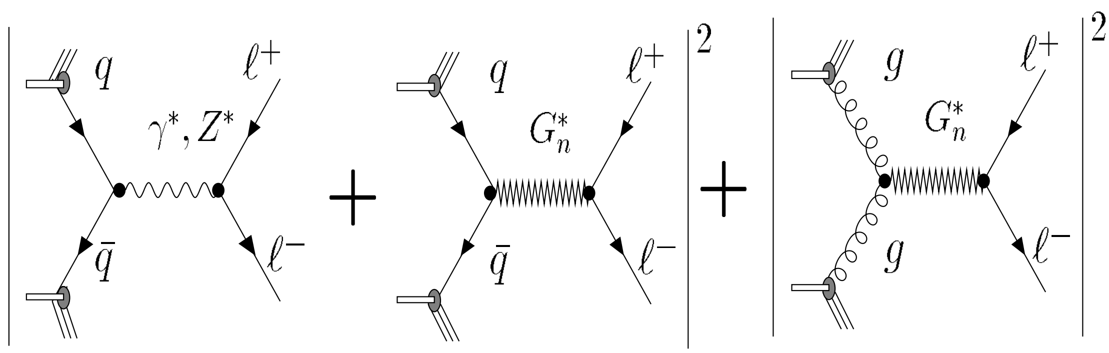
$A_{\rm CE}$ at the LHC

Drell-Yan process (E.W. Dvergsnes, P. Osland, A. Pankov, N. P., hep-ph/0401199)

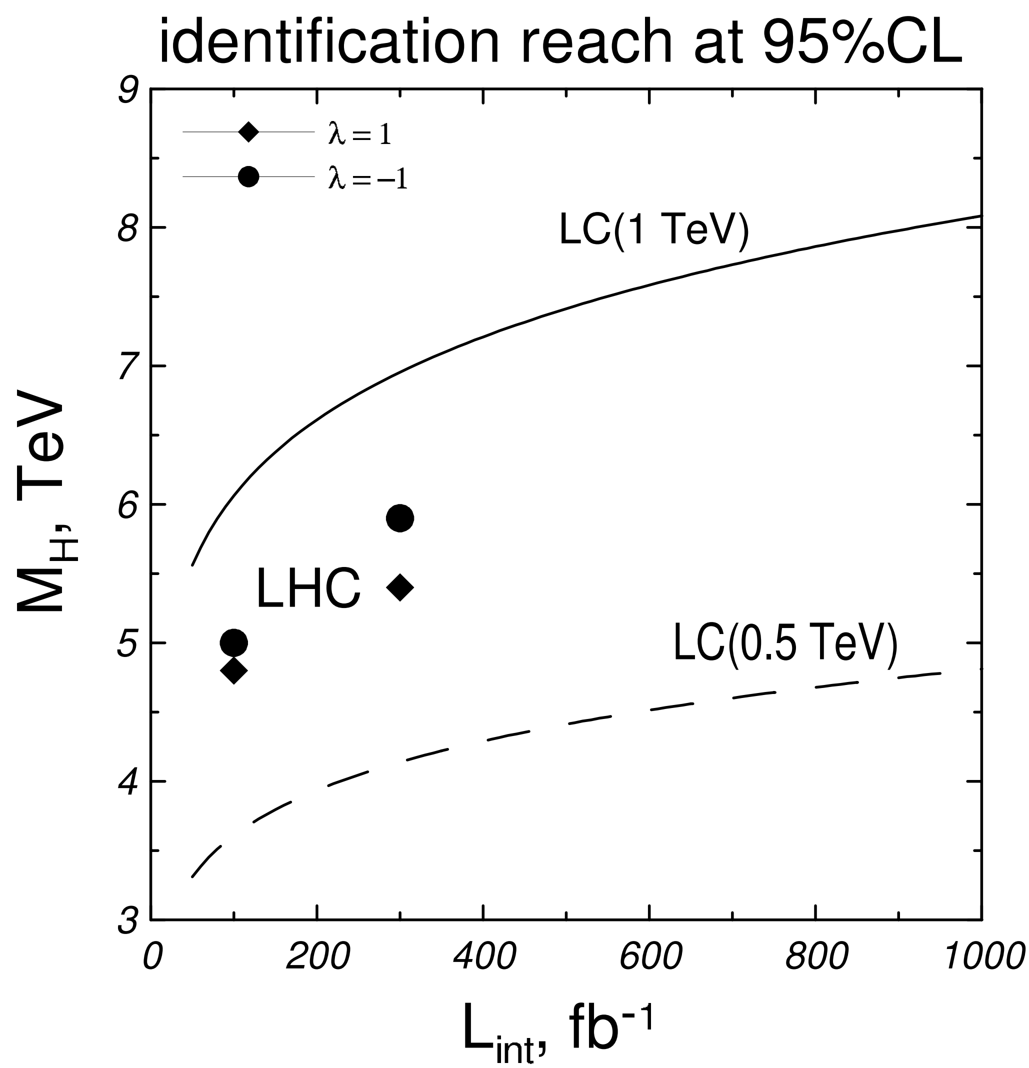
$$p + p \to l^+ l^- + X, \qquad (l = e, \mu)$$

Sub-processes:

SM $q\bar{q} \to \gamma, Z \to l^+ l^-$
ADD $q\bar{q} \to G_n \to l^+ l^-,\ gg \to G_n \to l^+ l^-$



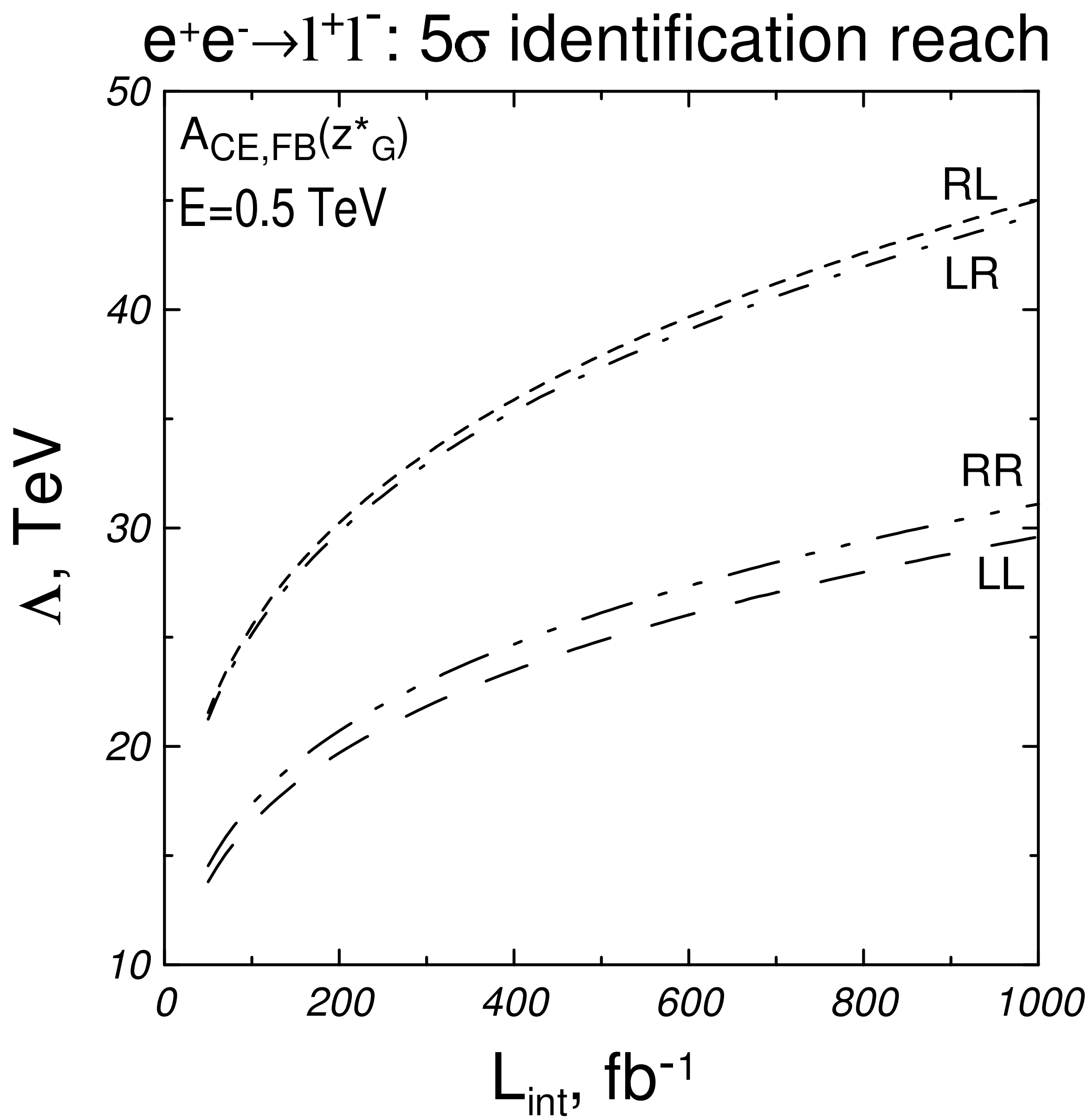
LC vs. LHC

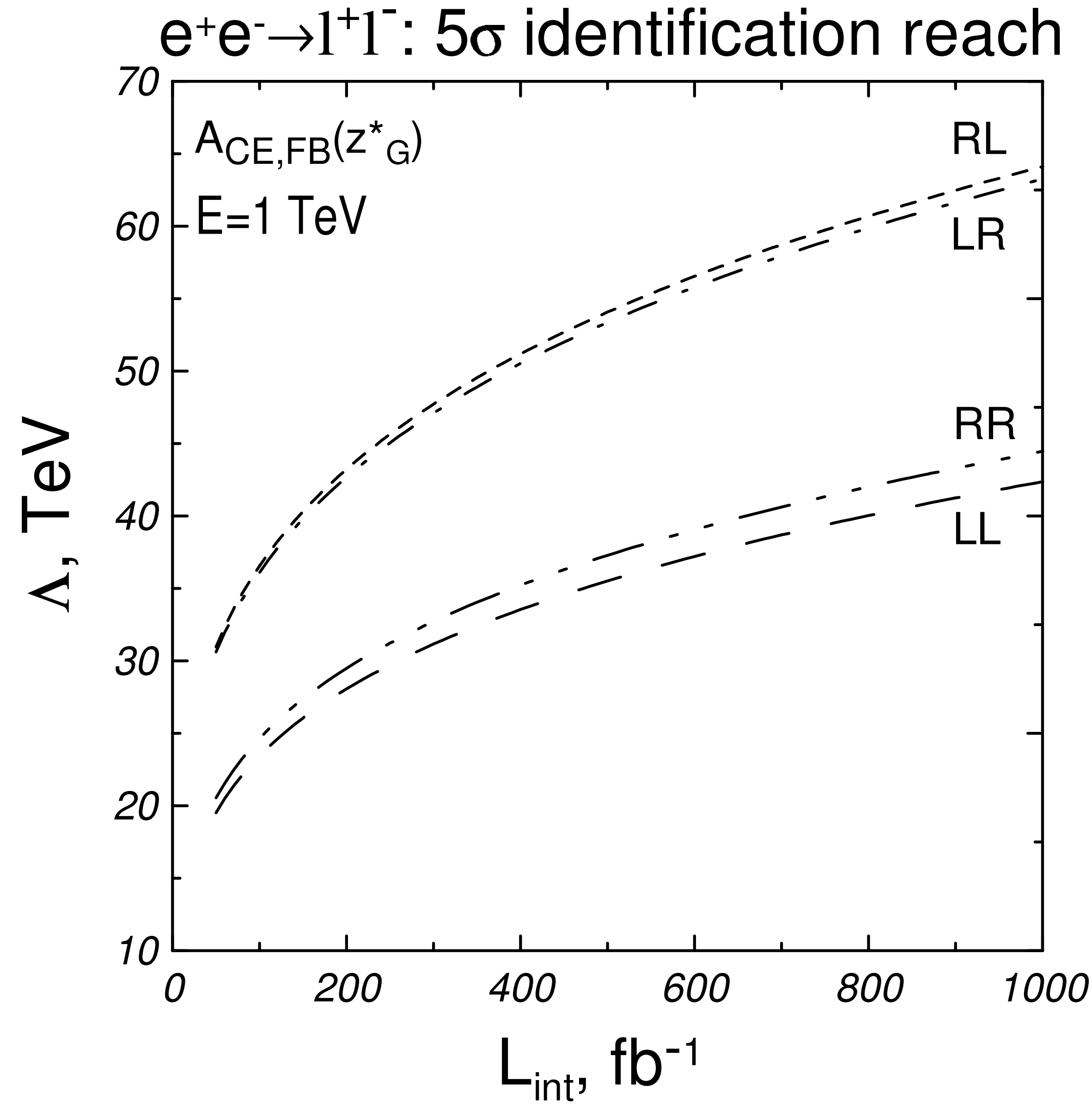


identification reach at 95%CL
λ = 1
λ = −1
LC(1 TeV)
LHC
LC(0.5 TeV)
M_H, TeV
L_int, fb^-1
9
8
7
6
5
4
3
0
200
400
600
800
1000

Limits on Λ

$l = \mu, \tau$



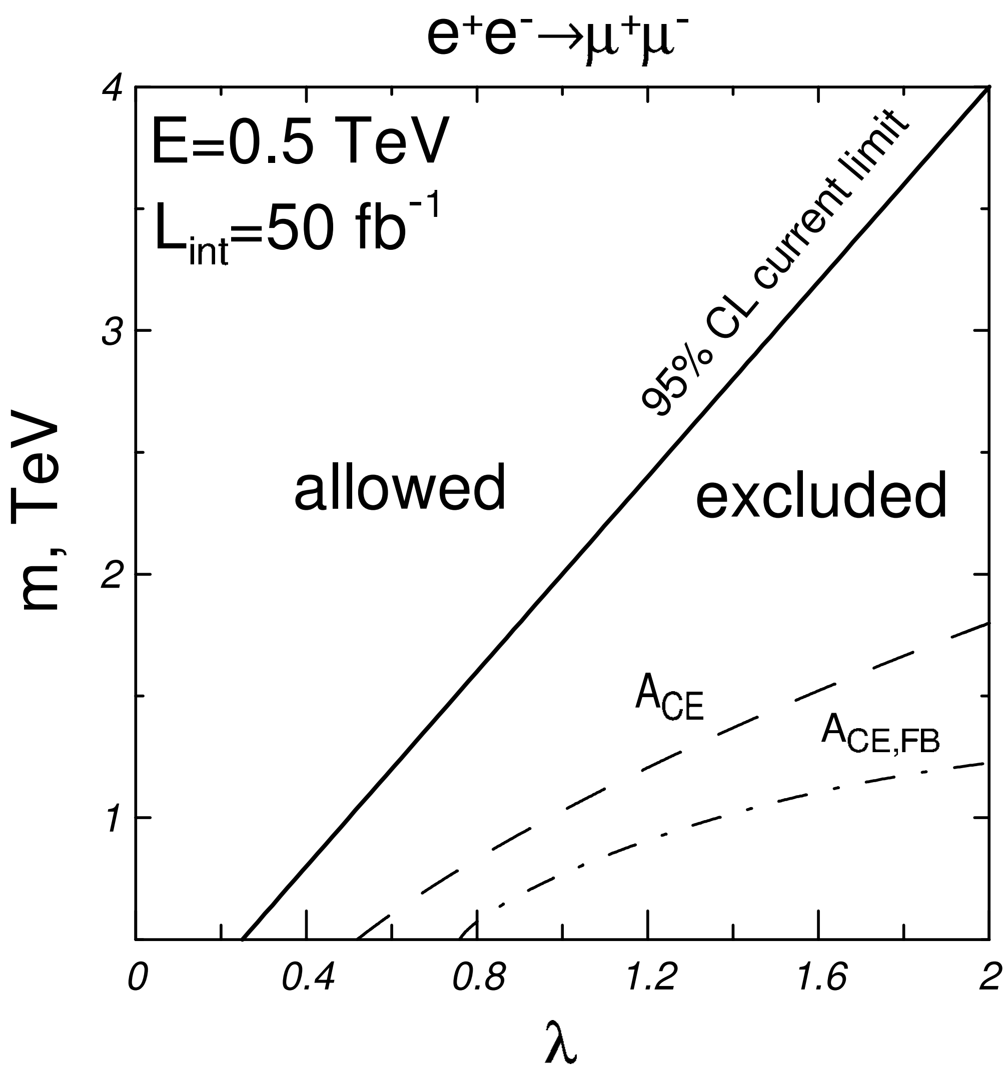


Maximal sensitivity to CI (no contamination from ADD)

Scales as $(s\mathcal{L}_{\rm int})^{1/4}$

Sneutrino exchange

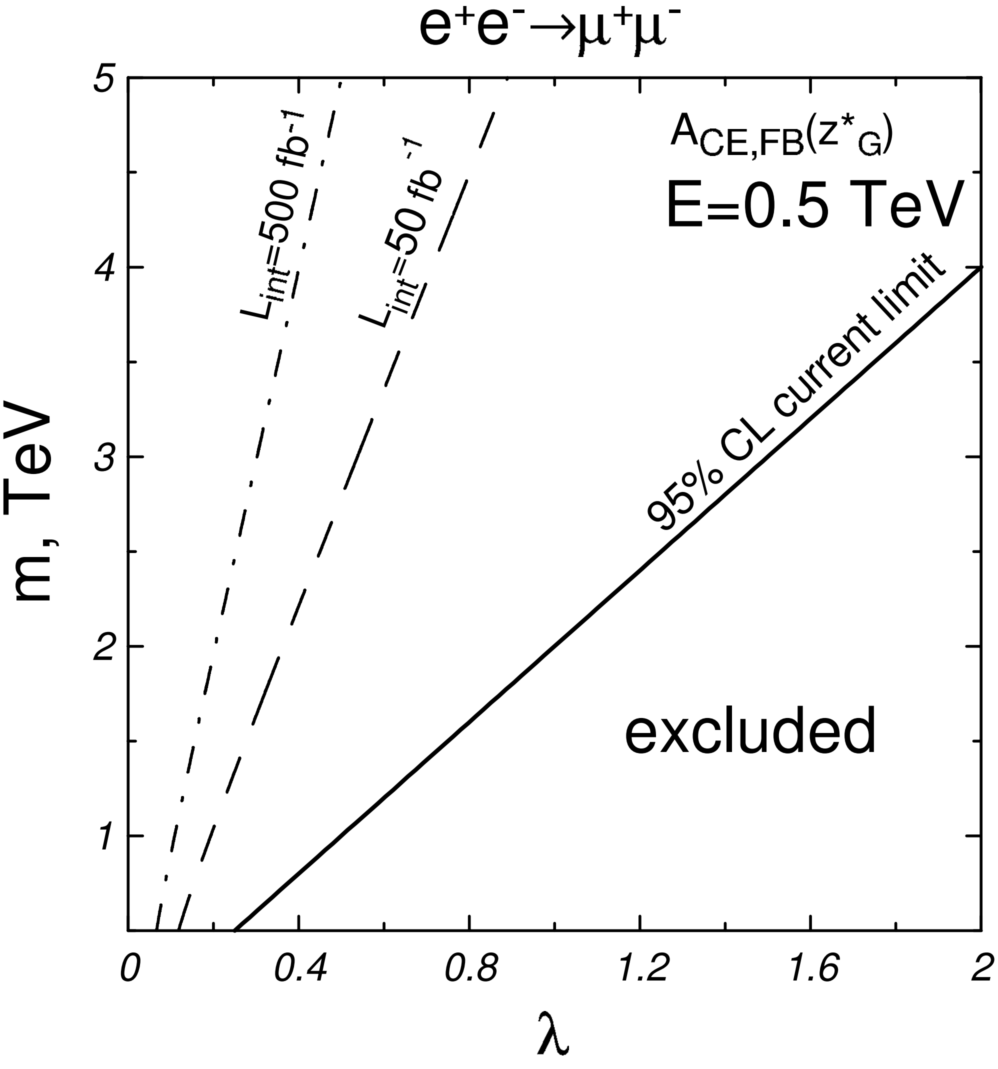
$A_{\mathrm{CE,FB}}(z^*_{\mathrm{CI}})$; $A_{\mathrm{CE}}(z^*_0)$:



Negligible sensitivity to $\tilde{\nu}$ exchange:
unambiguous identification of ADD

Translation from bounds on Λ:

$$\frac{m_{\tilde{\nu}}}{\lambda} \sim \frac{\Lambda}{\sqrt{8\pi}}$$



Summary

- If New Physics effects are discovered, it is crucial to have good search strategies to determine its origin.

- We have considered the problem of how to distinguish the potential New Physics scenarios from each other at the LC by using $A_{\rm CE}$ and $A_{\rm CE,FB}$.

- The Center–Edge Asymmetries offer a possibility of easily discriminating spin-1 from spin-2 exchanges.

- $A_{\rm CE}$ and $A_{\rm CE,FB}$ are complementary:

  $A_{\rm CE} \to \rm ADD$ within wide range of z^* (no $\rm CI$)
  $A_{\rm CE,FB} \to \rm ADD$ at $z^*_{\rm CI}$ (no $\rm CI$)
  $A_{\rm CE,FB} \to \rm CI$ at $z^*_{\rm G}$ (no $\rm ADD$)

- LC: 5σ ident. reach on $M_H = 3.5 - 5.8$ TeV at $\sqrt{s} = 0.5 - 1$ TeV and $\mathcal{L}_{\rm int} = 500\, fb^{-1}$