Identification of New Physics Scenarios in Fermion Pair Production at Polarized ILC

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Introduction

A Plethora of *New Physics* (NP) beyond the SM [conceptual problems]
It is generally expected that NP will manifest itself at future colliders either:

- **directly**, as in the case of new particle production (Z' and W' vector bosons, SUSY, Kaluza-Klein (KK) resonances...)

- **indirectly** through *deviations* of observables from SM predictions: typical case of NP interactions mediated by *heavy quanta exchanges* [$\Lambda \gg M_{W,Z}$] when collider energy is below production threshold.

In the case of **indirect** discovery, different NP scenarios may cause the same or similar experimental deviations.
Need for strategies to identify the source of corrections to SM predictions.

Proposed techniques:

- Monte Carlo-based analysis
  (*G. Pasztor, M. Perelstein*, hep-ph/0111471)

- Integrated cross sections weighted by Legendre polynomials
  (*T. Rizzo*, JHEP 0210 (2002))

- polarized Center–Edge Asymmetries [spin-1 *vs.* spin-2 exchange]
  (*P. Osland, N. Paver, A.A. Pankov*, Phys. Rev. D**68** (2003);
  A.A. Pankov, N. Paver, Phys. Rev. D **72** (2005))

- here: **combined χ^2 analysis of longitudinally polarized differential cross sections** for $e^+e^- \to \bar{f}f$
  (*A.A. Pankov, N. Paver, A.V. Tsytrinov*, Phys. Rev. D **73** (2006), hep-ph/0608285)

Outline

Phenomenology at the International Linear Collider (ILC) with e^- and e^+ polarized beams $\mathrm{E_{C.M.}} = 0.5 - 1\,\mathrm{TeV}$,
(see G.Moortgat-Pick et al., hep-ph/0507011)

- Fermion pair production:
  $e^+e^- \to l^+l^-$ $(l = e, \mu, \tau)$;
  $e^-e^- \to e^-e^-$
  $e^+e^- \to \bar{q}q$ $(q = c, b)$

- observables: polarized differential cross sections ($\mathrm{d}\sigma_{\mathrm{LL}}$, $\mathrm{d}\sigma_{\mathrm{RR}}$, $\mathrm{d}\sigma_{\mathrm{RL}}$, $\mathrm{d}\sigma_{\mathrm{LR}}$)

- individual NP scenarios

- sensitivity to Λ's

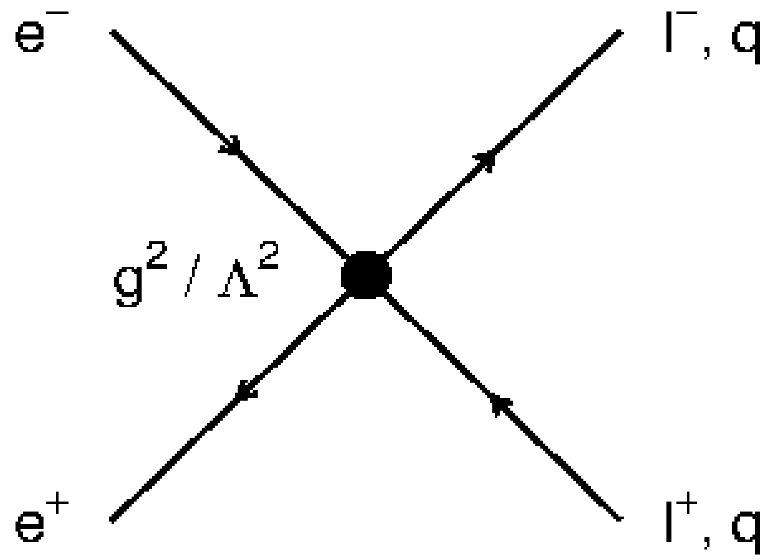
- rôle of beam polarization for identification reach enhancement

Nonstandard Scenarios

- Framework of effective Lagrangians (expansion in s/Λ^2)
- **CI**: Four-fermion contact interactions [compositeness]:

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

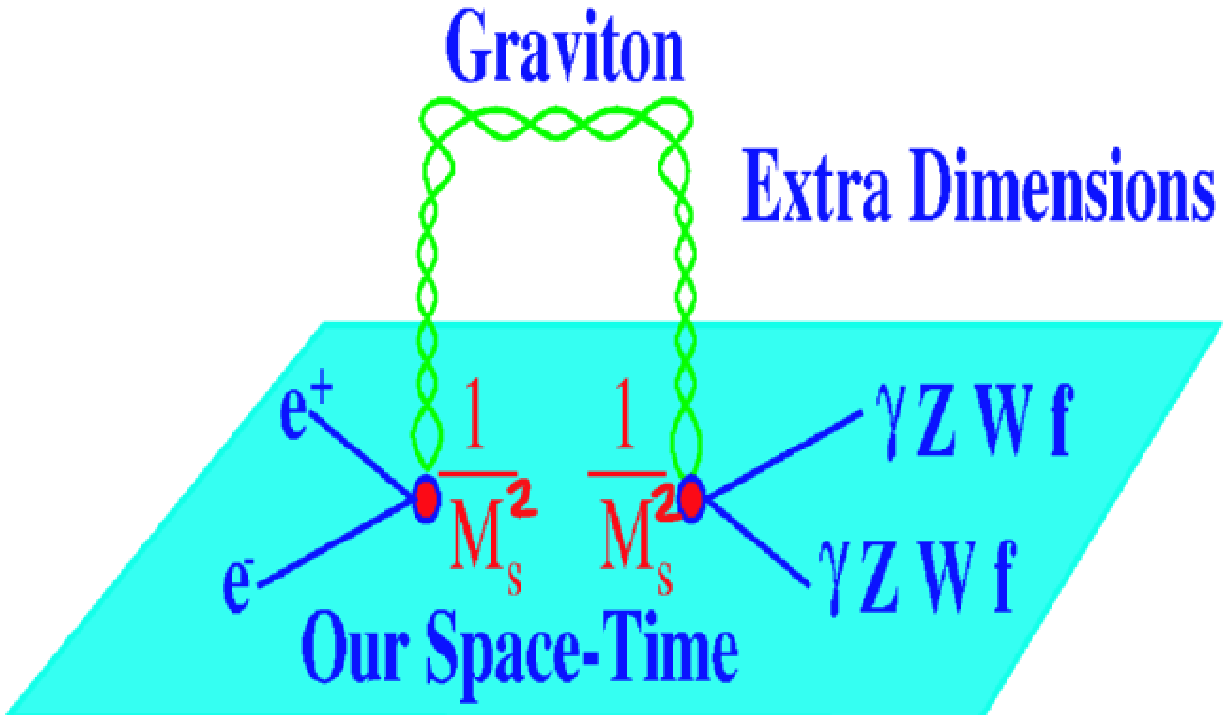
$$\eta_{\alpha\beta} = \pm 1, 0;\ \alpha, \beta = {\rm L}, {\rm R}.$$



- Can describe also exchanges of heavy Z', W', Leptoquarks, *etc.*
- Current limits on "compositeness scales" [Tevatron, LEP]:
  $\Lambda > 10 - 20\,{\rm TeV}$

- **ADD**: Gravity in "large" compactified extra dimensions (gauge hierarchy)

Gravity only can propagate in the full 4+N space



Effective Planck mass M_* *vs.* compactification radius R and Newton constant ($M_{\rm PL}$):

$$M_{\rm PL}(10^{16}\,{\rm TeV}) = M_*^{(1+N/2)} R^{(N/2)}$$

For $N \geq 2$, $R \leq {\rm mm}$: $M_* \sim {\rm TeV}$ (standard model cut-off)

In the 4-dimensional space: virtual exchange of tower of spin-2 massive graviton KK excitations (spectrum spaced by $1/R$).

Effective (contactlike) Lagrangian ($Hewett$ convention):

$$\mathcal{L}^{\mathrm{ADD}} = i\frac{4\lambda}{\Lambda_H^4} T^{\mu\nu} T_{\mu\nu}, \qquad \lambda = \pm 1$$

$T_{\mu\nu}$: energy-momentum tensor of SM particles

Λ_H: cut-off scale on KK summation (expected of TeV size).

Current lower limit: $\Lambda_H > 1.3\,\mathrm{TeV}$

- TeV^{-1}-scale extra dimensions

  Also SM gauge bosons may propagate in the additional dimensions: exchange of γ and Z KK excitations.
  Effective (contactlike) interaction:

$$\mathcal{L}^{\mathrm{TeV}} = -\frac{\pi^2}{3M_C^2}\left[Q_e Q_f (\bar{e}\gamma_\mu e)(\bar{f}\gamma^\mu f) + \right.$$

$$\left. +(g_{\mathrm{L}}^e \bar{e}_{\mathrm{L}}\gamma_\mu e_{\mathrm{L}} + g_{\mathrm{R}}^e \bar{e}_{\mathrm{R}}\gamma_\mu e_{\mathrm{R}}) \times (g_{\mathrm{L}}^f \bar{f}_{\mathrm{L}}\gamma^\mu f_{\mathrm{L}} + g_{\mathrm{R}}^f \bar{f}_{\mathrm{R}}\gamma^\mu f_{\mathrm{R}})\right].$$

  $M_C \gg M_{W,Z}$: inverse of the compactification radius

  Current limit [LEP2]: $M_C > 6.8\,\mathrm{TeV}$

Discovery reaches on Models

- $\mathrm{d}\sigma \propto |\mathrm{SM} + \mathrm{NewPhysics}|^2$

- **Deviations** of observables from the SM predictions:

$$\Delta(\mathcal{O}) = \frac{\mathcal{O}(SM+NP) - \mathcal{O}(SM)}{\mathcal{O}(SM)}, \qquad \mathcal{O} = \mathrm{d}\sigma/\mathrm{d}\cos\theta$$

- deviations must be compared to foreseen experimental uncertainties $\delta\mathcal{O}$ [statistical plus systematic]:

$$\chi^2(\mathcal{O}) = \sum_{\mathrm{bins}} \left(\frac{\Delta(\mathcal{O})^{\mathrm{bin}}}{\delta\mathcal{O}^{\mathrm{bin}}} \right)^2$$

- Assumption: no deviation from the SM is observed within the experimental accuracy.

- Constraints on Λ_H, Λ's [expected discovery reaches] from:

$$\chi^2(\mathcal{O}) \leq 3.84 \quad (95\% \text{ C.L.})$$

Experimental inputs:

Bhabha and Møller scattering ($|\cos\theta| < 0.9$, $\epsilon \simeq 100\%$, bin width: $\Delta\cos\theta = 0.2$);
$\mu^+\mu^-$, $\tau^+\tau^-$ ($|\cos\theta| < 0.98$, $\epsilon = 95\%$);
$\bar{c}c$ ($\epsilon = 35\%$); $\bar{b}b$ ($\epsilon = 60\%$)
radiative corrections included;
$\delta P^{\pm}/P^{\pm} = 0.2\%$, $\delta\mathcal{L}_{\text{int}}/\mathcal{L}_{\text{int}} = 0.5\%$.

95% C.L. discovery reaches (in TeV). Left and right entries refer to the polarization configurations $(|P^-|,|P^+|)$=(0,0) and (0.8,0.6), respectively. $\sqrt{s} = 0.5$ TeV, $\mathcal{L}_{\rm int} = 100 fb^{-1}$

Model	Process			
	$e^+e^- \to e^+e^-$	$e^+e^- \to l^+l^-$	$e^+e^- \to \bar{b}b$	$e^+e^- \to \bar{c}c$
Λ_H	4.1; 4.3	3.0; 3.2	3.0; 3.4	3.0; 3.2
Λ^{ef}_{VV}	76.2; 86.4	89.7; 99.4	76.1; 96.4	84.0; 94.1
Λ^{ef}_{AA}	47.4; 69.1	80.1; 88.9	76.7; 98.2	76.5; 85.9
Λ^{ef}_{LL}	37.3; 52.5	53.4; 68.3	63.6; 72.7	54.5; 66.1
Λ^{ef}_{RR}	36.0; 52.2	51.3; 68.3	42.5; 71.2	46.3; 66.8
Λ^{ef}_{LR}	59.3; 69.1	48.5; 62.8	51.3; 68.7	37.0; 57.7
Λ^{ef}_{RL}	$\Lambda^{ee}_{RL} = \Lambda^{ee}_{LR}$	48.7; 63.6	46.8; 60.1	52.2; 60.7
M_C	12.0; 13.8	20.0; 22.2	6.6; 10.7	10.4; 12.0

See also *S.Riemann, T.Rizzo, S.Godfrey.*

Distinction among the New Physics models

- expected identification reaches

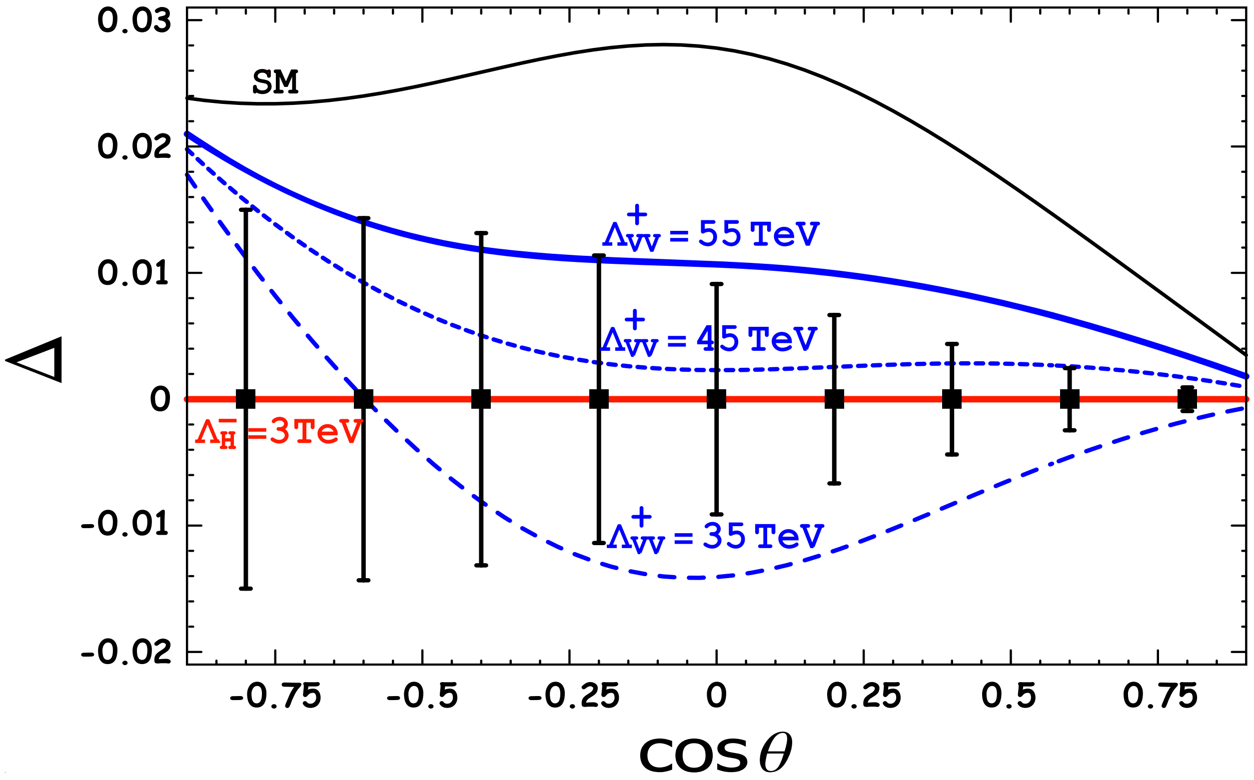
- Assumption: One of the models, say the ADD, is found consistent with experimental data with some value of Λ_H

- Deviations of observables from the ADD model prediction due to other models (say, the **CI** ones):

$$\tilde{\Delta}(\mathcal{O}) = \frac{\mathcal{O}(CI) - \mathcal{O}(ADD)}{\mathcal{O}(ADD)}$$

- assess the level at which ADD is distinguishable from the other models

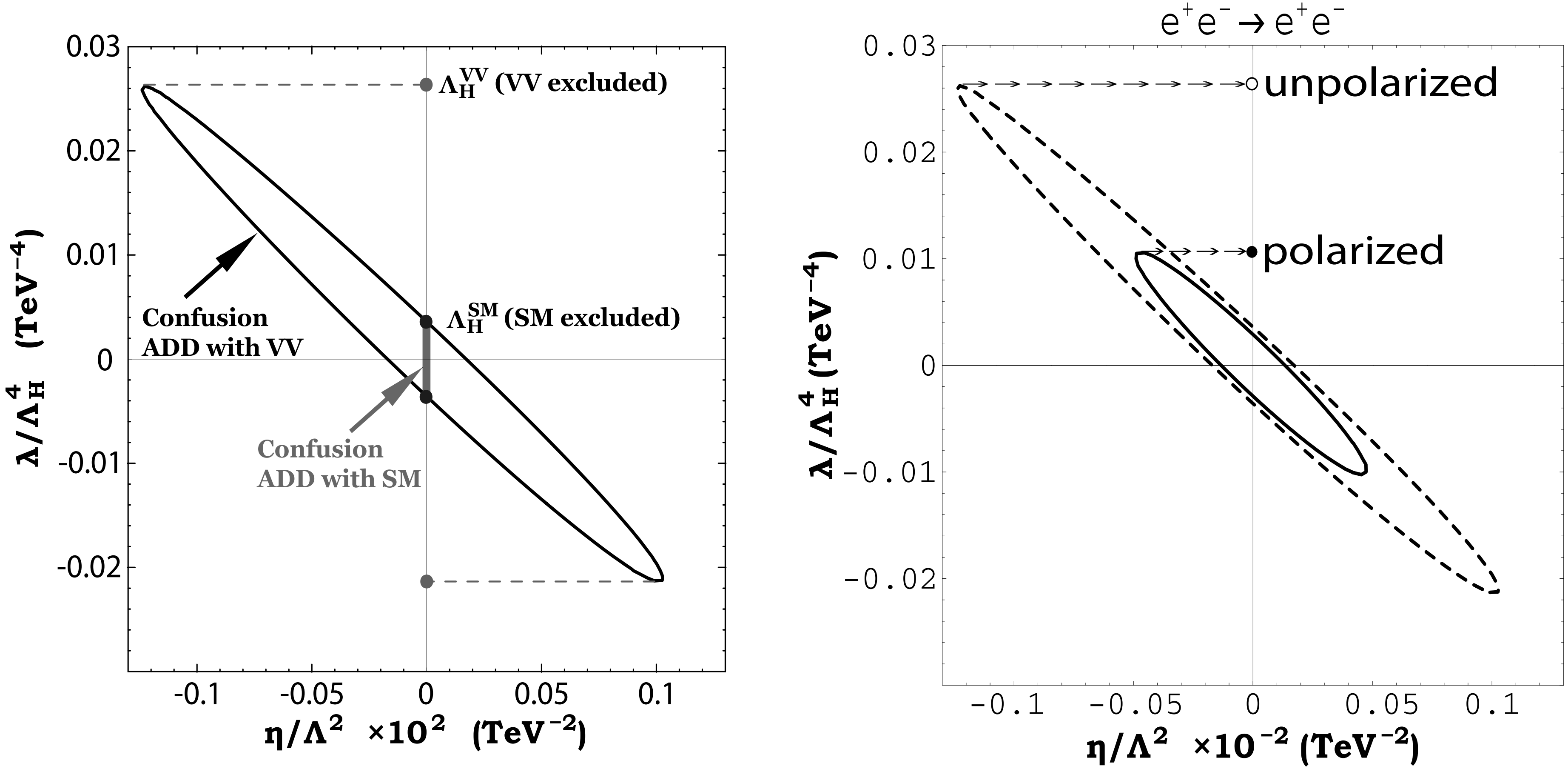
Example: CI=VV (ADD vs. VV)



- **Region of confusion** of ADD with VV model determined by:

$$\tilde{\chi}^2(\mathcal{O}) = \sum_{\text{bins}} \left(\frac{\tilde{\Delta}(\mathcal{O})^{\text{bin}}}{\tilde{\delta}\mathcal{O}^{\text{bin}}} \right)^2 \leq 3.84 \quad (95\% \text{ C.L.})$$

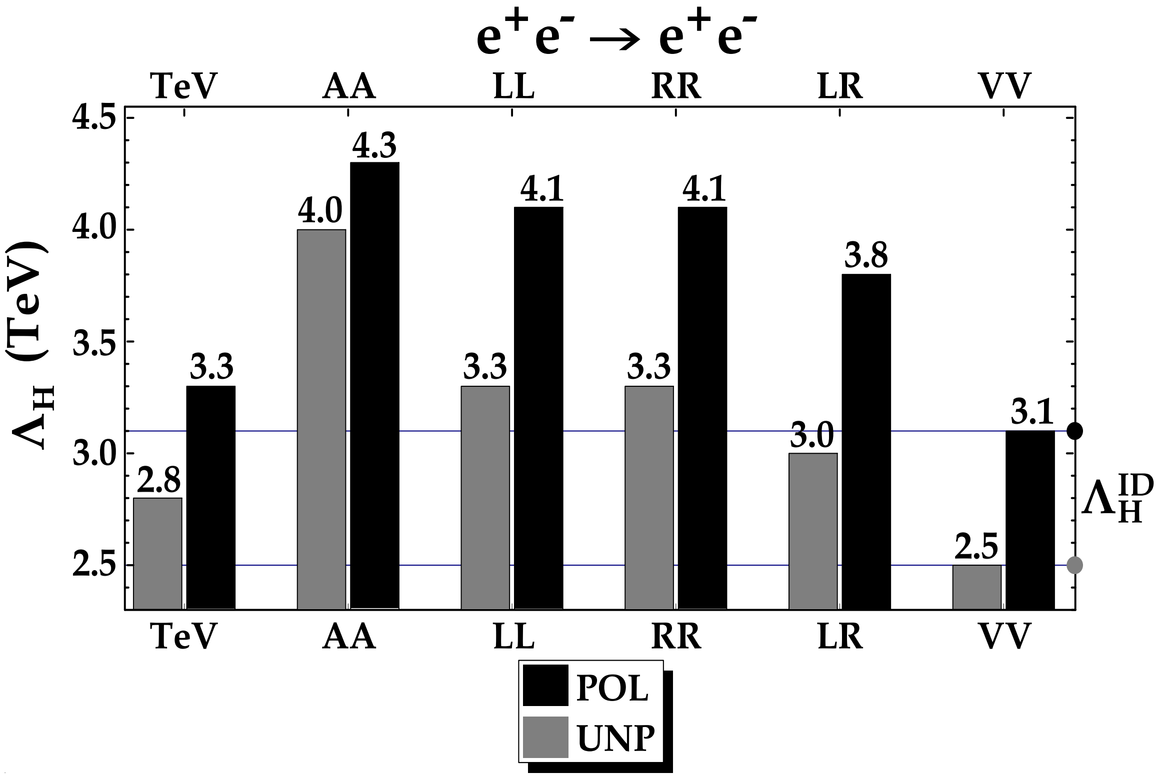
$\mathcal{L}_{e^+e^-} = 100 \text{ fb}^{-1}$, $\sqrt{s} = 0.5$ TeV.

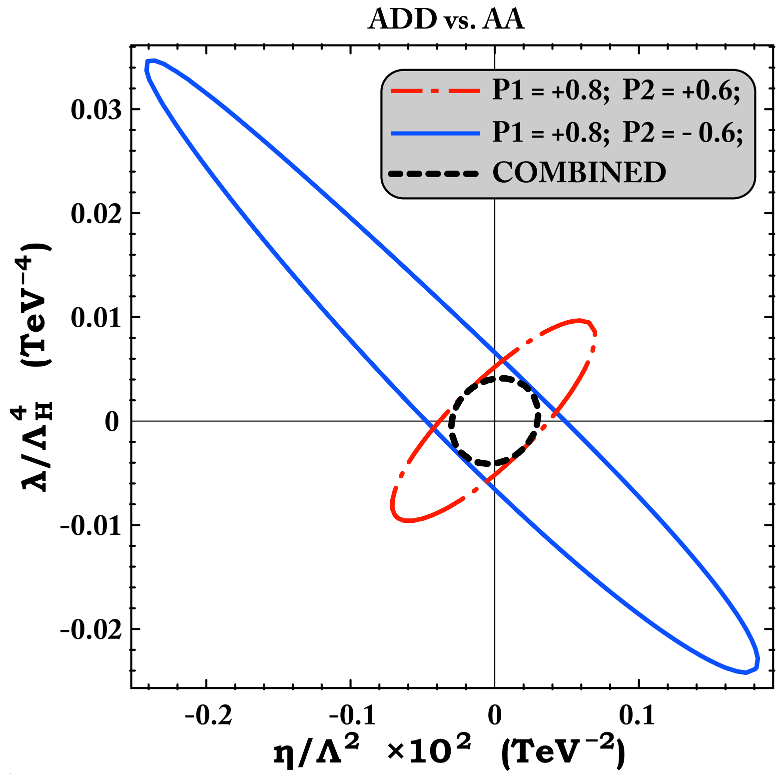


One can find a maximal absolute value of the scale parameter λ/Λ_H^4 for which the VV model hypothesis is expected to be **excluded** at the 95% C.L. for **any value of the CI parameter** η/Λ_{VV}.

We call this Λ_H^{VV} as **exclusion reach** of the VV model.

ID reach for ADD model





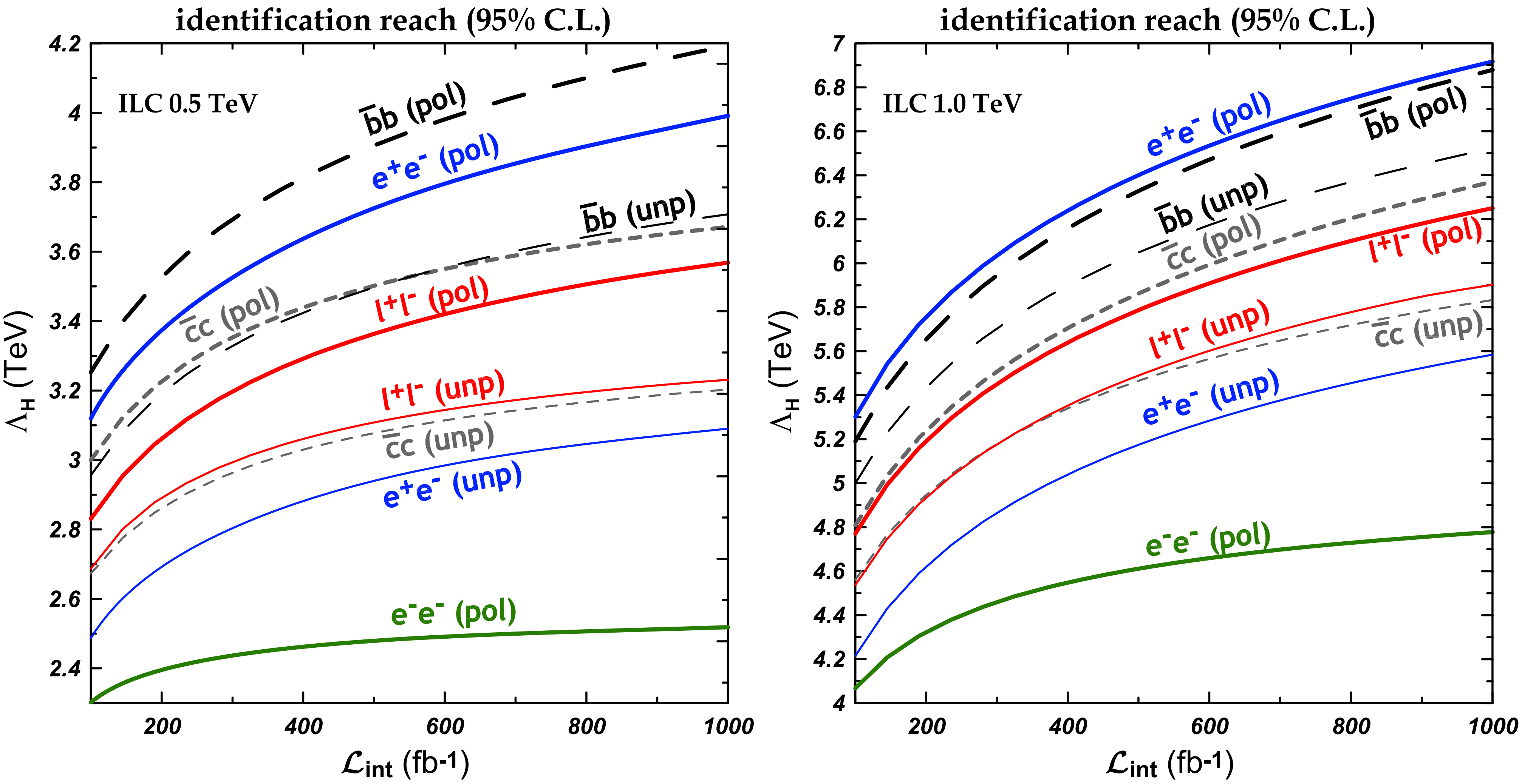
Exclusion reach: Λ_H^{VV}, ...

Identification reach:

$$\Lambda_H^{\mathrm{ID}} = min\{\Lambda_H^{\mathrm{VV}}, \Lambda_H^{\mathrm{AA}}, \Lambda_H^{\mathrm{RR}}, \Lambda_H^{\mathrm{LL}}, \Lambda_H^{\mathrm{LR}}, \Lambda_H^{\mathrm{TeV}}\}$$

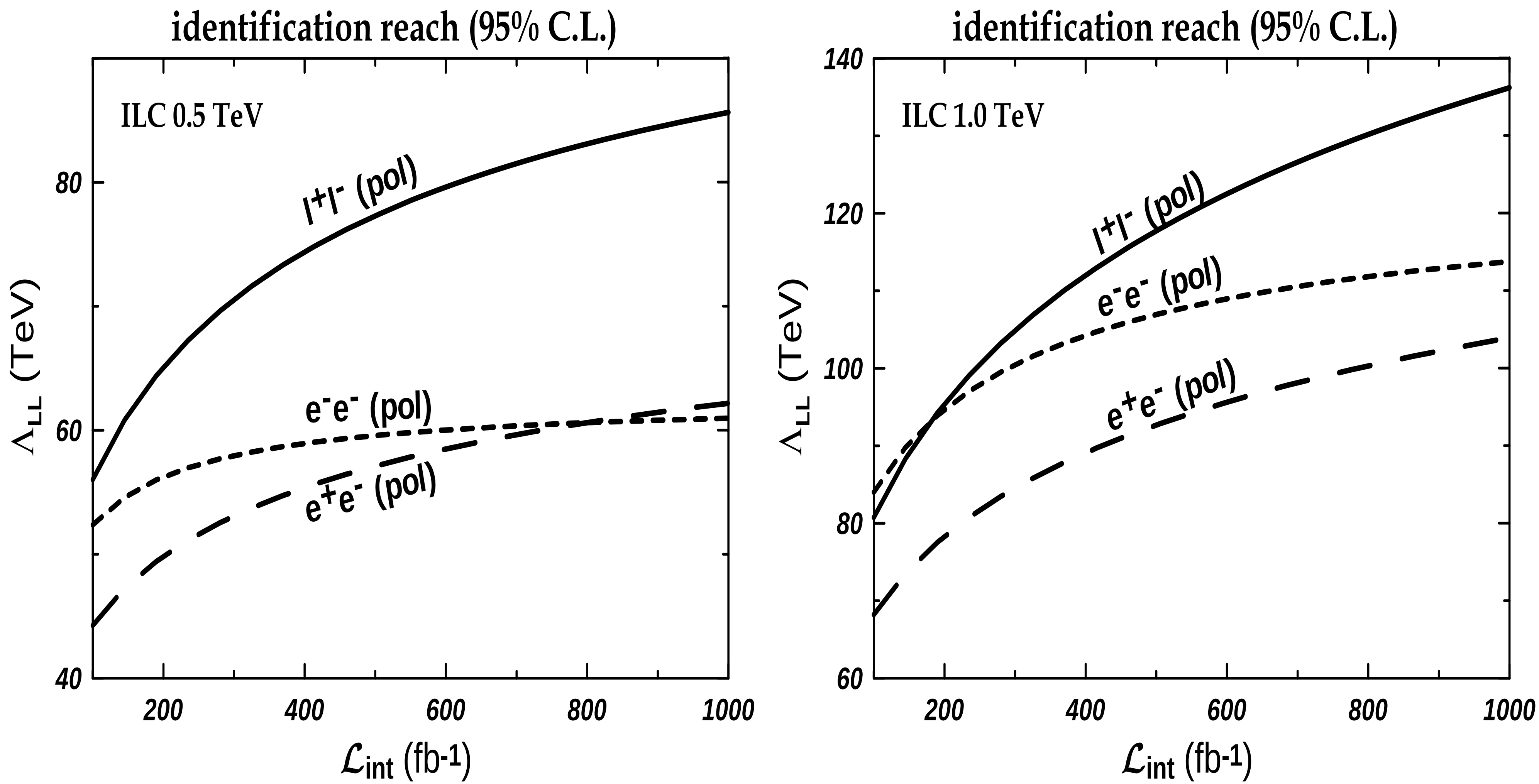
$$\to \Lambda_H^{\mathrm{ID}} = 2.5(3.1)\ \mathrm{TeV}.$$

ID reach for ADD model



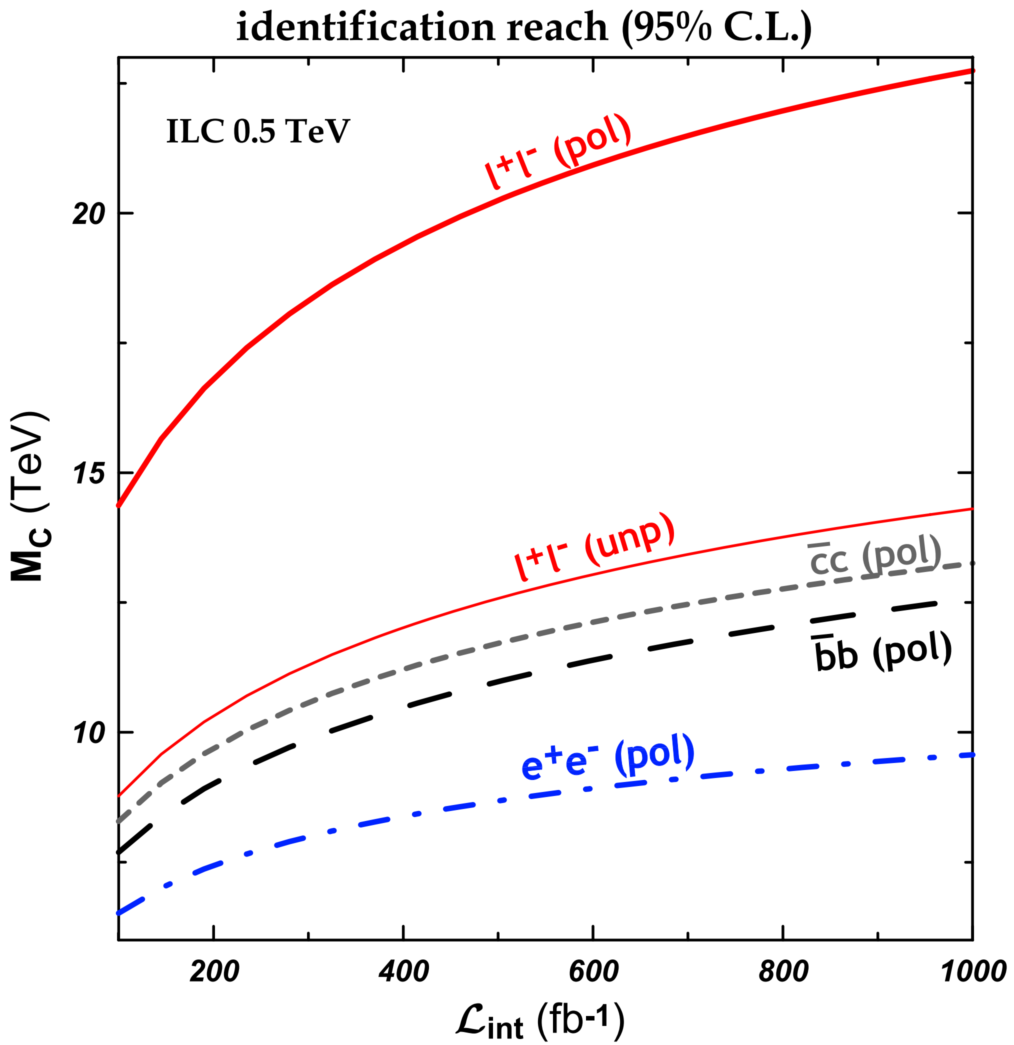
Current limit: $\Lambda_H > 1.3$ TeV

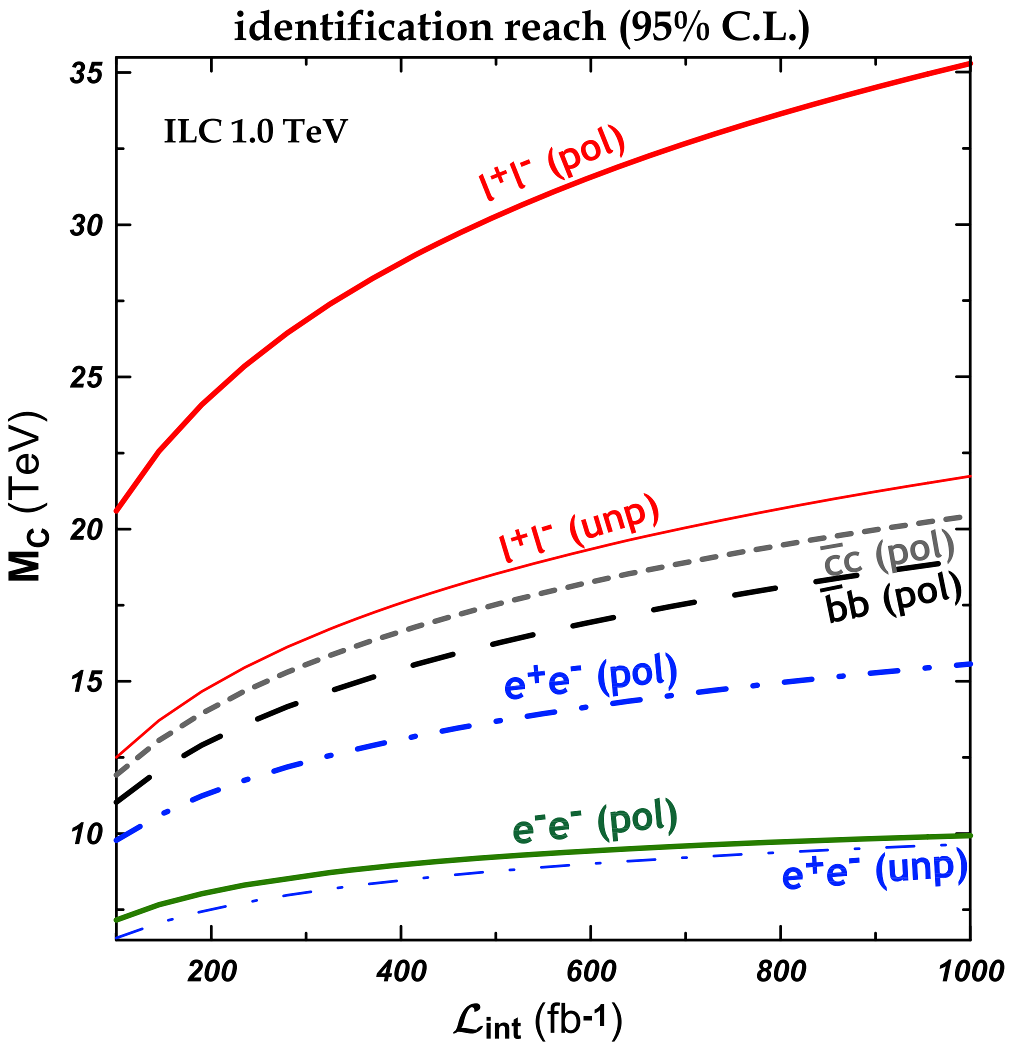
ID reach for CI models



Current limit: $\Lambda_{LL} > 15$ TeV

ID reach for TeV^{-1} model





Current limit: $M_C > 6.8$ TeV

Conclusions

- 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 ILC by using polarized differential distribution for fermion pair production processes.

- Identification reach (95% CL) at ILC:

  - ADD: $\Lambda_H = 3.1 - 6.9$ TeV depending on the ILC energy and luminosity
  - TeV^{-1}: $M_C = 15 - 35$ TeV
  - VV: $\Lambda_{VV} = 62 - 160$ TeV
  - AA: $\Lambda_{AA} = 70 - 170$ TeV
  - LL: $\Lambda_{LL} = 55 - 135$ TeV
  - RR, LR and RL: $\Lambda = 57 - 142$ TeV

- Polarization is quite important, in particular in case of CI models.