Distinguishing New Physics Scenarios at ILC with Polarized Beams

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Outline:

- Variety of New Physics Scenarios
- 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 distributions
- Discovery and identification reach
- Rôle of beam polarization in enhancing the identification reach

Introduction

It is generally expected that NP beyond the SM will manifest itself at future colliders such as the LHC and ILC either:

- **directly**, as in the case of new particle production, e.g., Z' and W' vector bosons, SUSY or Kaluza-Klein (KK) resonances, or
- **indirectly** through *deviations* of observables from the SM predictions.

In the case of **indirect** discovery many different NP scenarios may lead to the **same** or **very similar** experimental signatures.

These NP scenarios predict *new particle exchanges* which can lead to **CI** below direct production threshold.

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)
- etc.

($T.Rizzo$, hep-ph/0208027)

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

Proposed techniques:

- Monte Carlo best fits (*G.Pasztor & M.Perelstein*, hep-ph/0111471)
- Integrated cross sections weighted by Legendre polynomials (*T.Rizzo*, hep-ph/0208027)
- Transverse polarization (*T.Rizzo*, hep-ph/0211374, 0306283)
- Center–Edge Asymmetries:

- $A_{\rm CE}$ and $A_{\rm CE,FB}$ at ILC
  ($P.Osland$, $N.Paver$ & $A.A.P.$, hep-ph/0304123; $N.Paver$ & $A.A.P.$, hep-ph/0501170)

- $A_{\rm CE}$ at LHC
  ($E.W.Dvergsnes$, $P.Osland$, $N.Paver$ & $A.A.P.$, hep-ph/0410402, 0401199)

Here, we will consider the problem of how to **distinguish** the potential New Physics scenarios from each other at the ILC by using **polarized differential distributions** in $e^+e^- \to \bar{f}f$

($N.Paver$, $A.V.Tsytrinov$ & $A.A.P.$, hep-ph/0512131 and some recent results).

Indirect New Physics Effects

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

- "Conventional" (dim-6) four-fermion contact interactions (**CI**), effective Lagrangians

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

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

Definition of four-fermion CI models

CI model	η_{LL}	η_{RR}	η_{LR}	η_{RL}
LL	± 1	0	0	0
RR	0	± 1	0	0
LR	0	0	± 1	0
RL	0	0	0	± 1
VV	± 1	± 1	± 1	± 1
AA	± 1	± 1	∓ 1	∓ 1

- ADD scenario [hep-ph/9803315]

  Virtual exchange of the graviton KK excitation states is governed by the effective Lagrangian (similar to dim-8 CI):

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

  where Λ_H is the cut-off scale (convention of *Hewett*), $\lambda = \pm 1$.

  Introduce UV cut-off when summing over KK states:

$$\mathcal{M} \sim \sum_{\vec{n}=1}^{\infty} \frac{G_{\mathrm{N}}}{M^2 - m_{\vec{n}}^2} \to -\frac{\lambda}{\pi \Lambda_H^4}.$$

Leptonic processes:

$$e^+ + e^- \to e^+ + e^-,$$

$$e^- + e^- \to e^- + e^-,$$

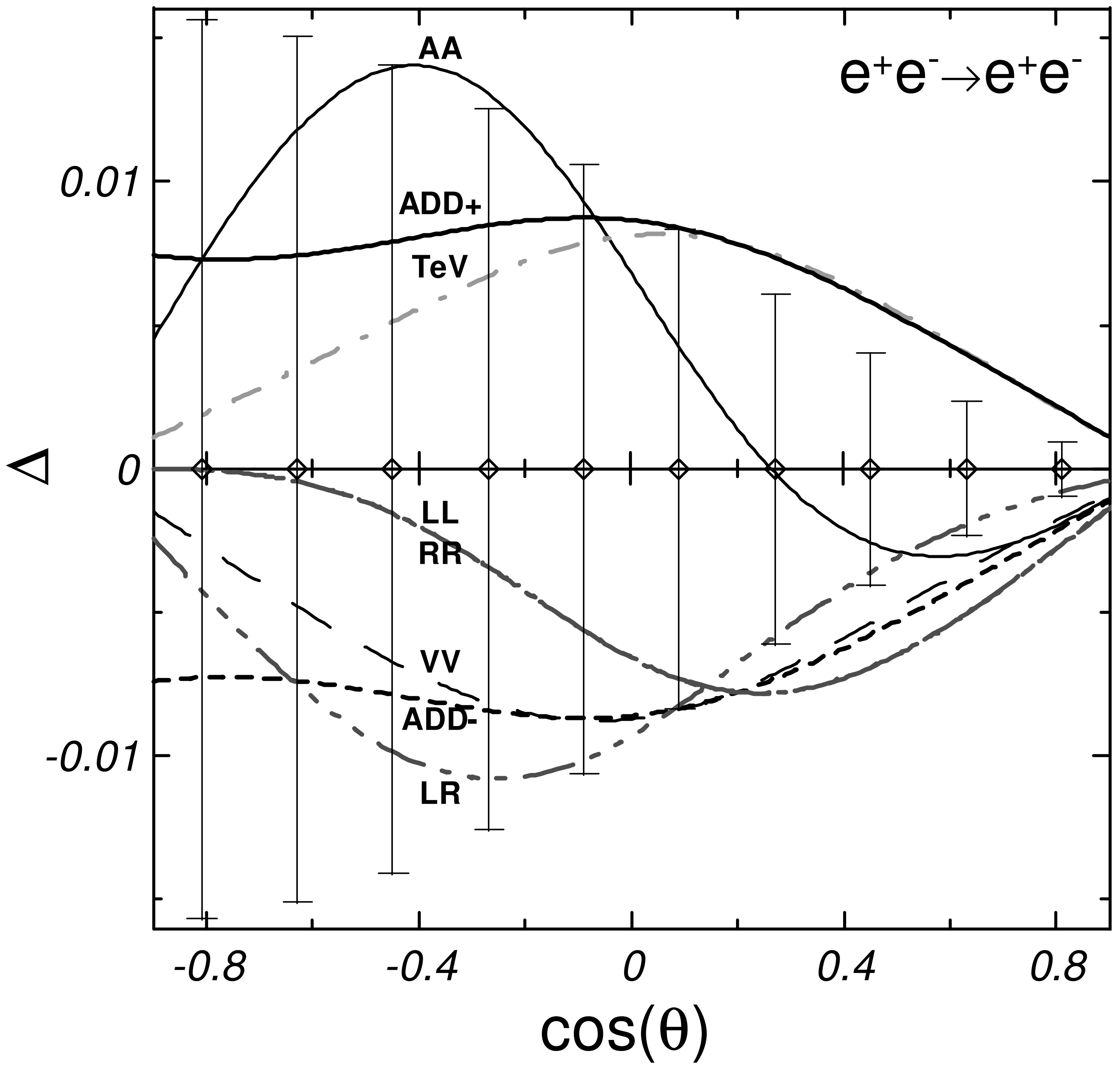
$$e^+ + e^- \to l^+ + l^-,$$
$$l = \mu,\ \tau.$$

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

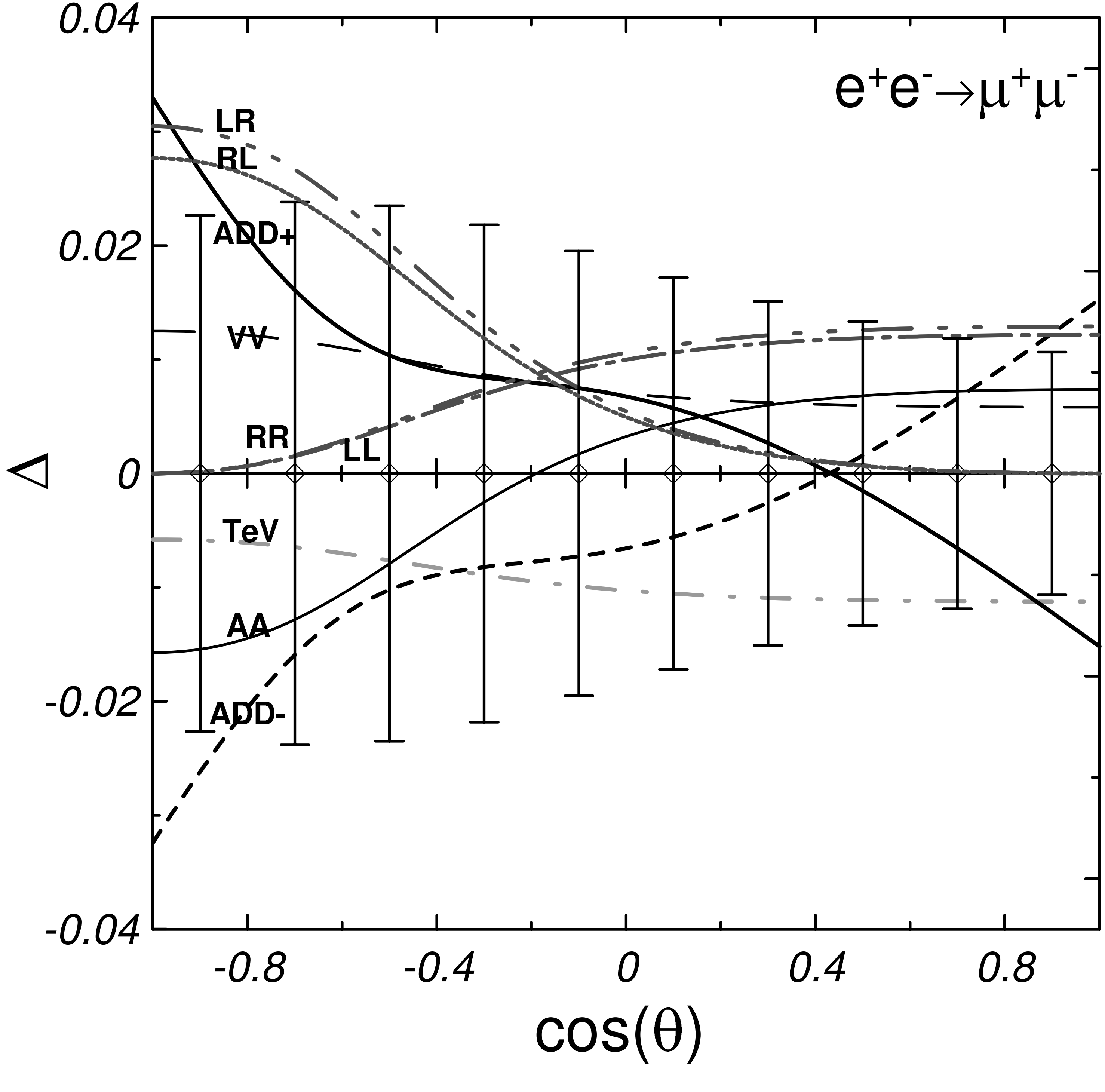
Deviations of observables from the SM predictions

$$\Delta(\mathcal{O}) = \frac{\mathcal{O}(SM+NP) - \mathcal{O}(SM)}{\mathcal{O}(SM)},$$

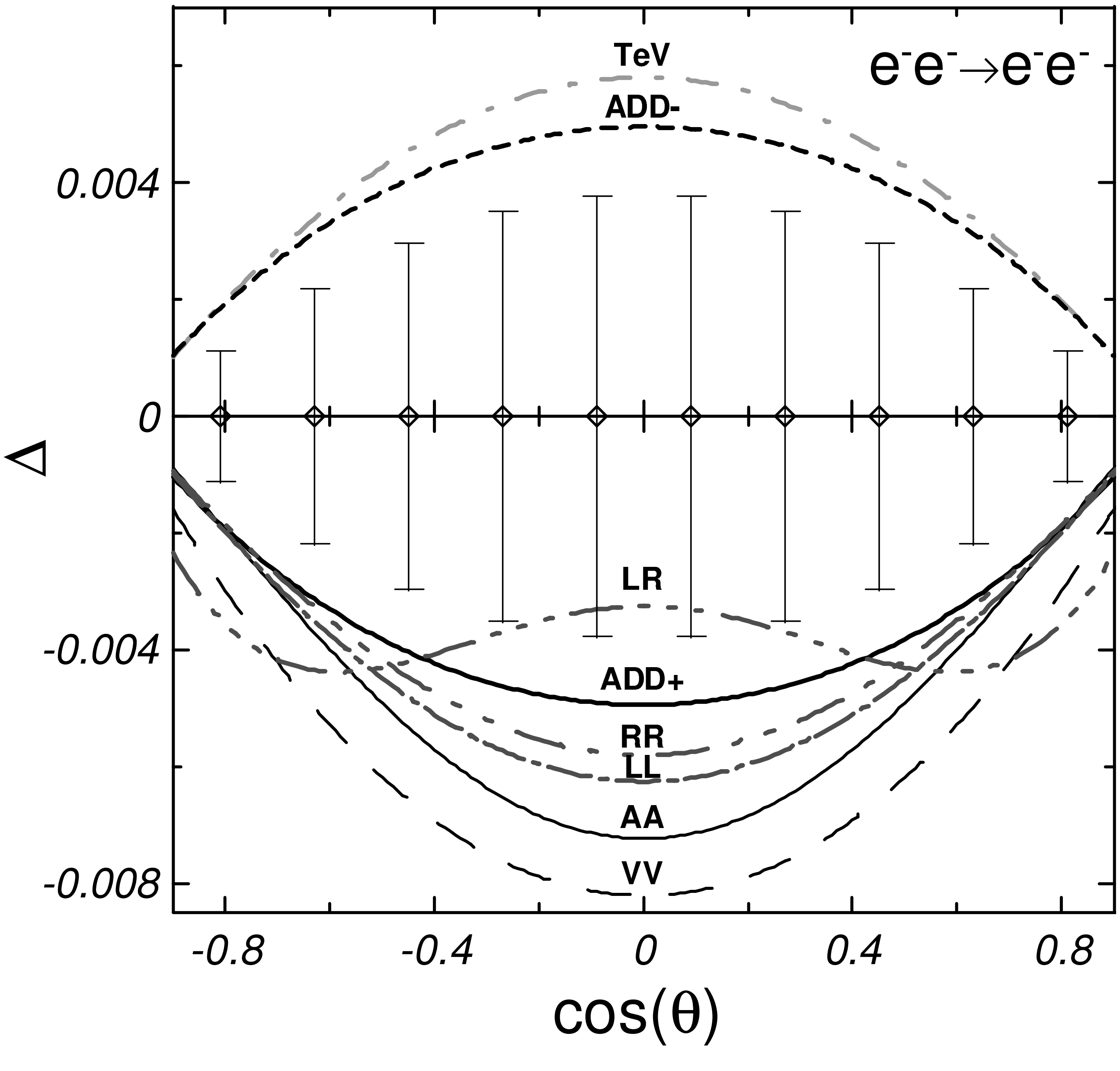
where $\mathcal{O} = \mathrm{d}\sigma / \mathrm{d}\cos\theta$.



AA
e⁺e⁻→e⁺e⁻
0.01
ADD+
TeV
Δ
0
LL
RR
VV
ADD-
-0.01
LR
-0.8
-0.4
0
0.4
0.8
cos(θ)



0.04
0.02
0
-0.02
-0.04
-0.8
-0.4
0
0.4
0.8
Δ
cos(θ)
e⁺e⁻→μ⁺μ⁻
LR
RL
ADD+
VV
RR
LL
TeV
AA
ADD-



e⁻e⁻→e⁻e⁻
TeV
ADD-
LR
ADD+
RR
LL
AA
VV
0.004
0
-0.004
-0.008
Δ
-0.8
-0.4
0
0.4
0.8
cos(θ)

Discovery Reach:

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

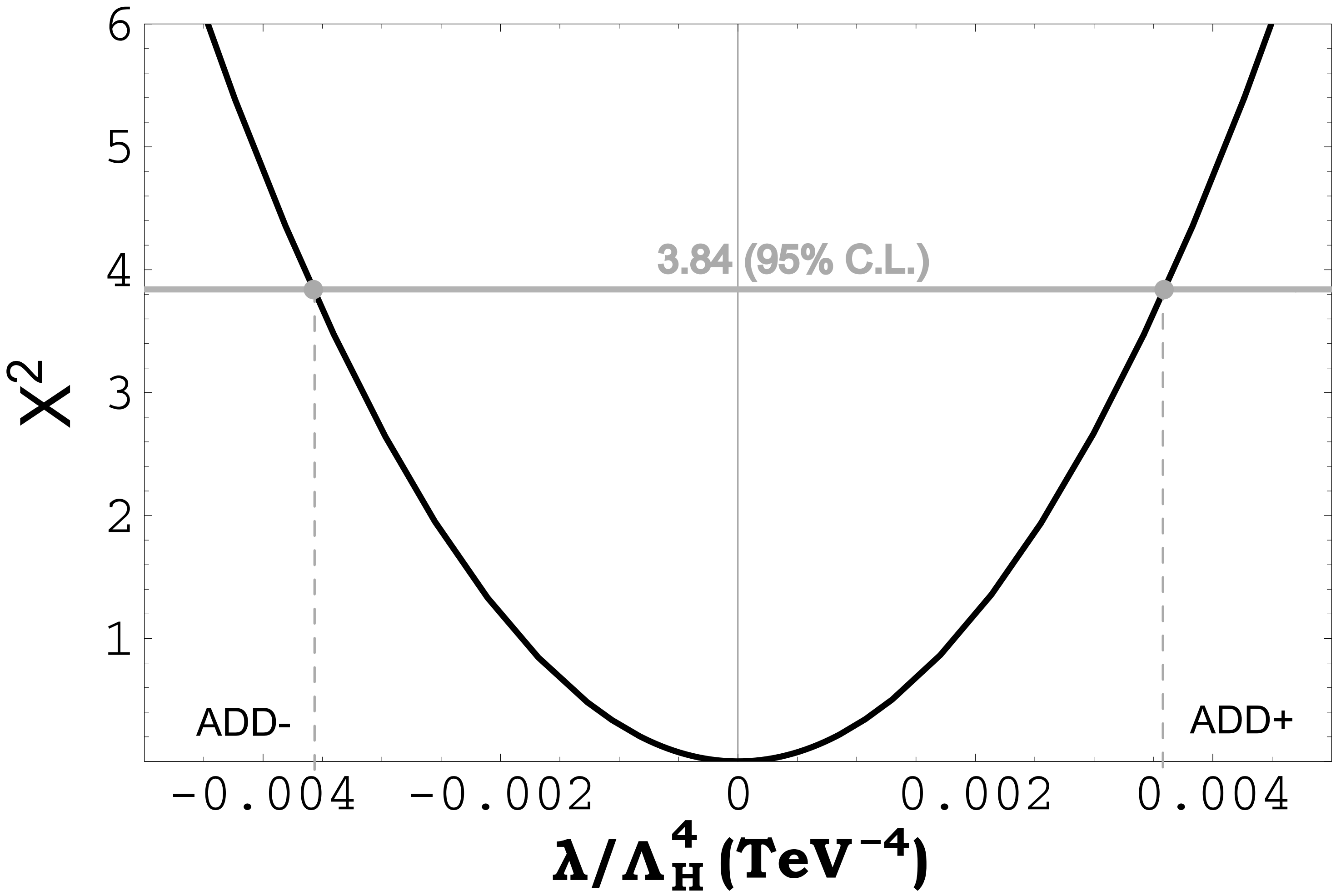


Table 1: Discovery reach on Λ's (95% C.L.) at $\sqrt{s} = 0.5$ TeV and $\mathcal{L}_{\rm int}(e^+e^-) = 100\ fb^{-1}$.

$e^+e^- \to e^+e^-$	$(\lvert P^-\rvert, \lvert P^+\rvert)$ (0,0);	(0.8,0);	(0.8,0.6)
Λ_H (TeV)	4.1;	4.2;	4.3
Λ_{VV} (TeV)	76.2;	80.8;	86.4
Λ_{AA} (TeV)	47.4;	49.1;	69.1
Λ_{LL} (TeV)	37.3;	45.5;	52.5
Λ_{RR} (TeV)	36.0;	44.7;	52.2
Λ_{LR} (TeV)	59.3;	61.6;	69.1
Λ_{RL} (TeV)	$\Lambda_{RL} = \Lambda_{LR}$		
TeV^{-1}-model:			
M_C (TeV)	12.0;	12.8;	13.8

Experimental inputs:

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

Table 2: Discovery reach on Λ's (95% C.L.) at $\sqrt{s} = 0.5$ TeV and $\mathcal{L}_{\rm int}(e^+e^-) = 100\ fb^{-1}$.

$e^+e^- \to l^+l^-$ $l = \mu, \tau$	$(\lvert P^-\rvert, \lvert P^+\rvert)$ (0,0);	 (0.8,0);	 (0.8,0.6)
Λ_H (TeV)	3.0;	3.0;	3.2
Λ_{VV} (TeV)	89.7;	90.7;	99.4
Λ_{AA} (TeV)	80.1;	81.1;	88.9
Λ_{LL} (TeV)	53.4;	60.5;	68.3
Λ_{RR} (TeV)	51.3;	60.0;	68.3
Λ_{LR} (TeV)	48.5;	55.0;	62.8
Λ_{RL} (TeV)	48.7;	55.6;	63.6
TeV^{-1}-model:			
M_C (TeV)	20.0;	20.3;	22.2

Table 3: Discovery reach on Λ's (95% C.L.) at $\sqrt{s} = 0.5$ TeV and $\mathcal{L}_{\rm int}(e^-e^-) \approx \frac{1}{3}\mathcal{L}_{\rm int}(e^+e^-)$; reduction in luminosity of the e^-e^- mode due to anti-pinching in the interaction region.

$e^-e^- \to e^-e^-$	$(\lvert P_1^-\rvert, \lvert P_2^-\rvert)$ (0,0);	(0.8,0);	(0.8,0.8)
Λ_H (TeV)	3.8;	4.0;	4.1
Λ_{VV} (TeV)	64.0;	68.8;	71.5
Λ_{AA} (TeV)	58.0;	62.0;	64.9
Λ_{LL} (TeV)	43.9;	52.4;	55.2
Λ_{RR} (TeV)	42.3;	52.3;	55.4
Λ_{LR} (TeV)	20.1;	22.1;	31.5
Λ_{RL} (TeV)	$\Lambda_{RL} = \Lambda_{LR}$		
TeV^{-1}-model:			
M_C (TeV)	11.7;	12.5;	12.9

Conclusion: Discovery reach agree with recent estimates obtained by *S.Riemann, T.Rizzo, S.Godfrey, D.Bourilkov*

Distinction among the New Physics models

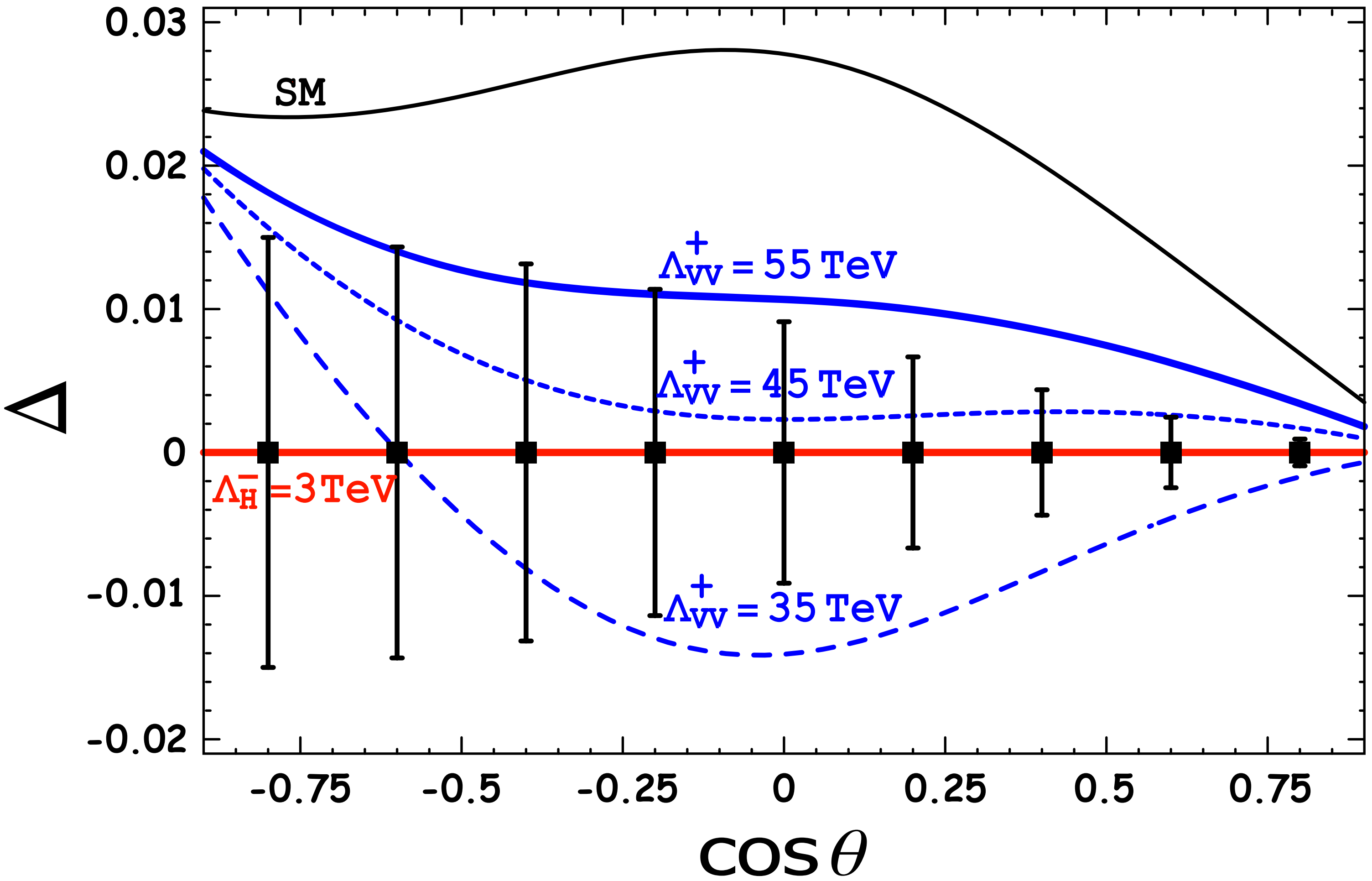
Assumption: One of a model, e.g. ADD is consistent with experimental data with some Λ_H.

Deviations of observables from the ADD model prediction:

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

where $\mathcal{O} = \mathrm{d}\sigma/\mathrm{d}\cos\theta$.

Example: CI=VV (ADD vs. VV)



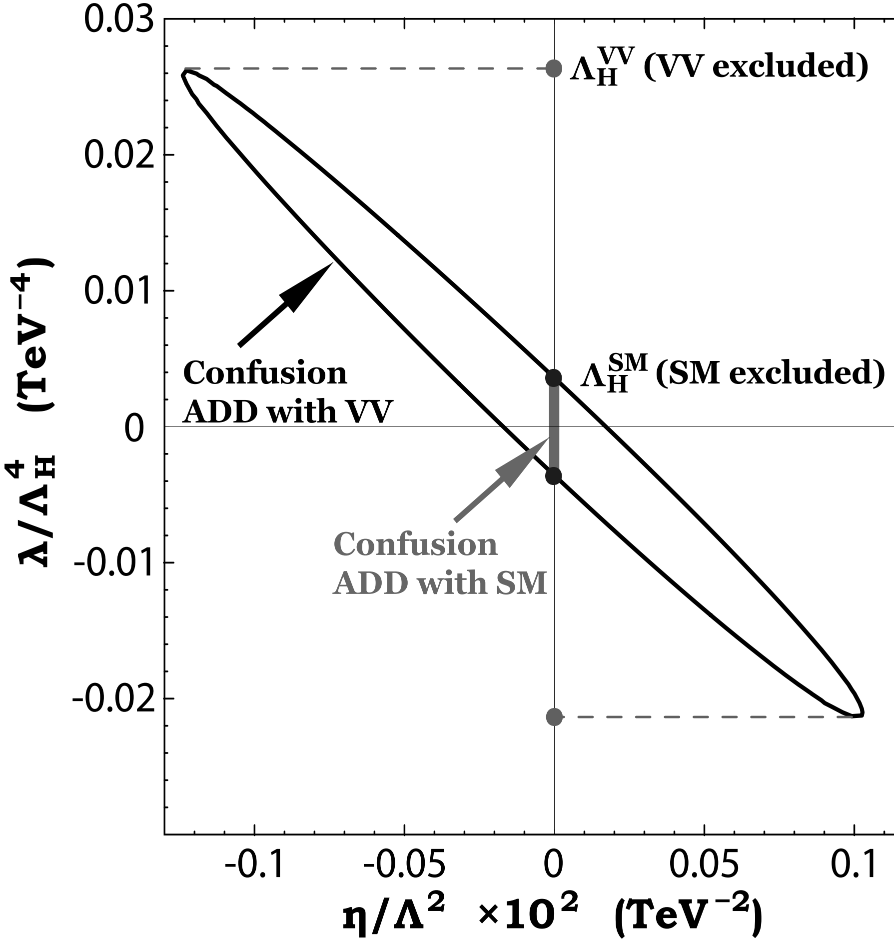
Confusion of ADD with VV:

Let us assess the level at which ADD is distinguishable from other ones (CI=VV & SM).

Region of confusion of ADD with VV model:

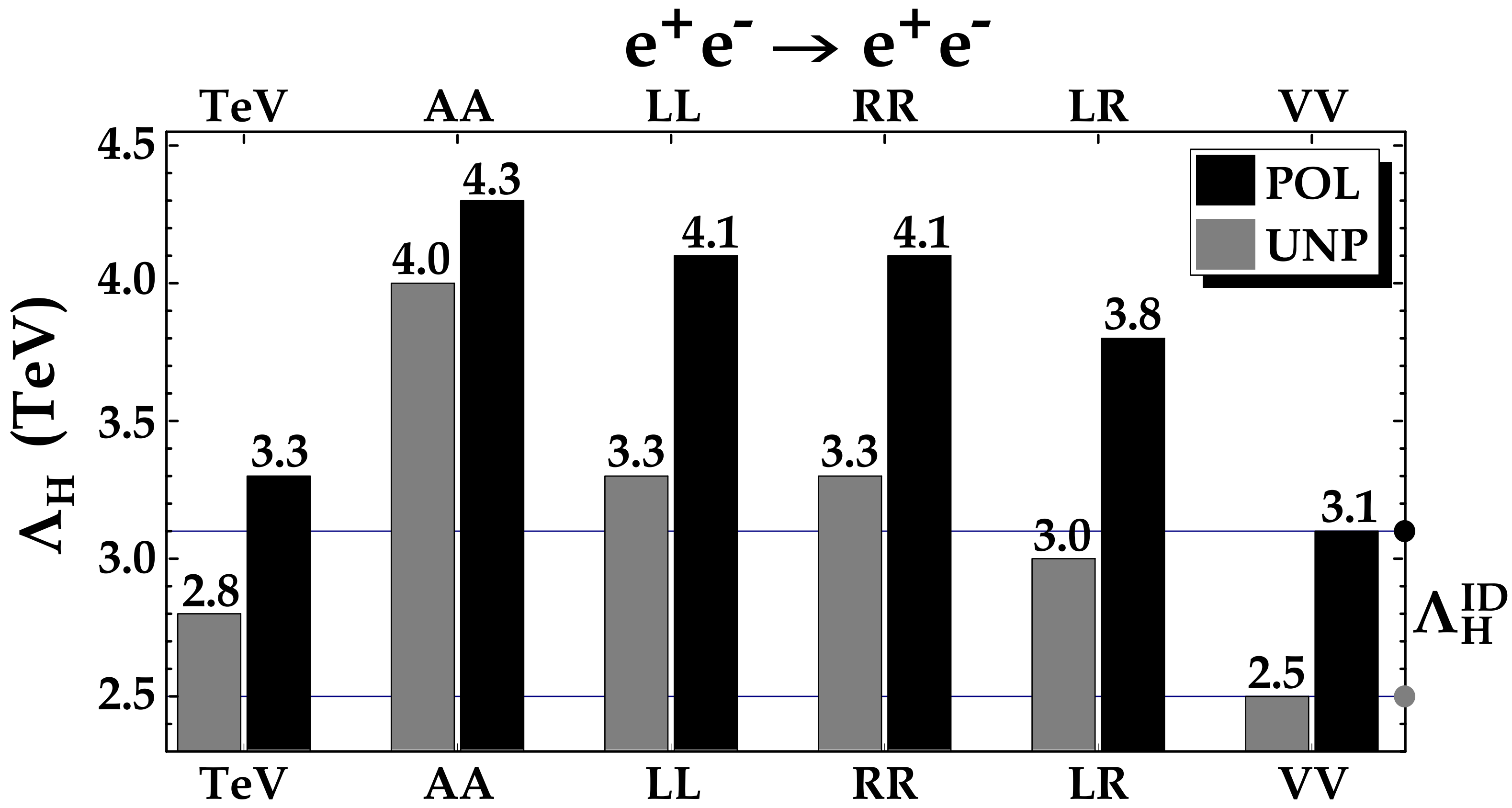
$$\chi^2(\mathcal{O}) = \sum_{\text{bins}} \left(\frac{\Delta(\mathcal{O})^{\text{bin}}}{\delta\mathcal{O}^{\text{bin}}} \right)^2 \leq 3.84 \quad (95\%\ C.L.)$$

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



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: $\Lambda_H^{\rm VV}$, ...

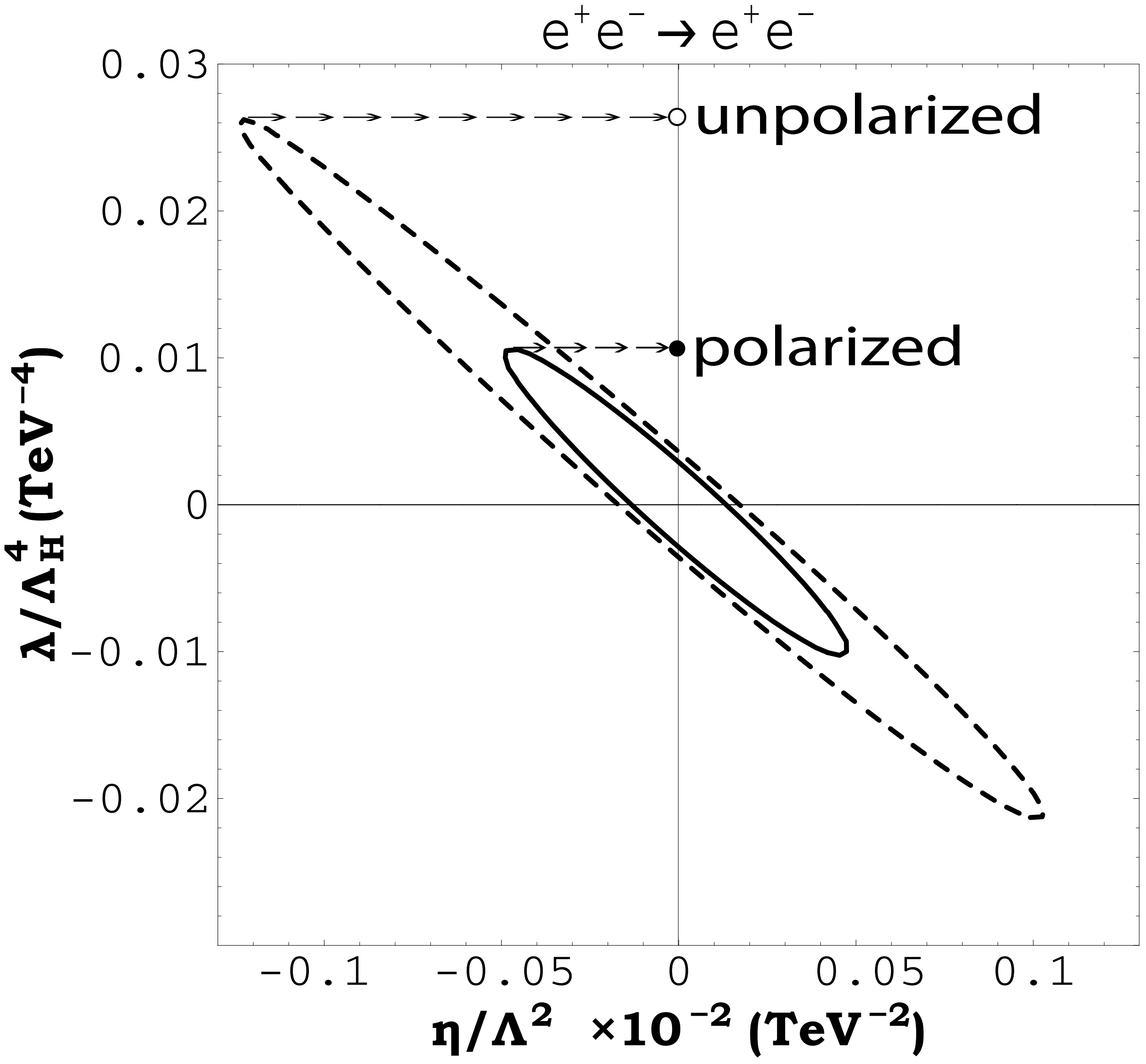
Identification reach:

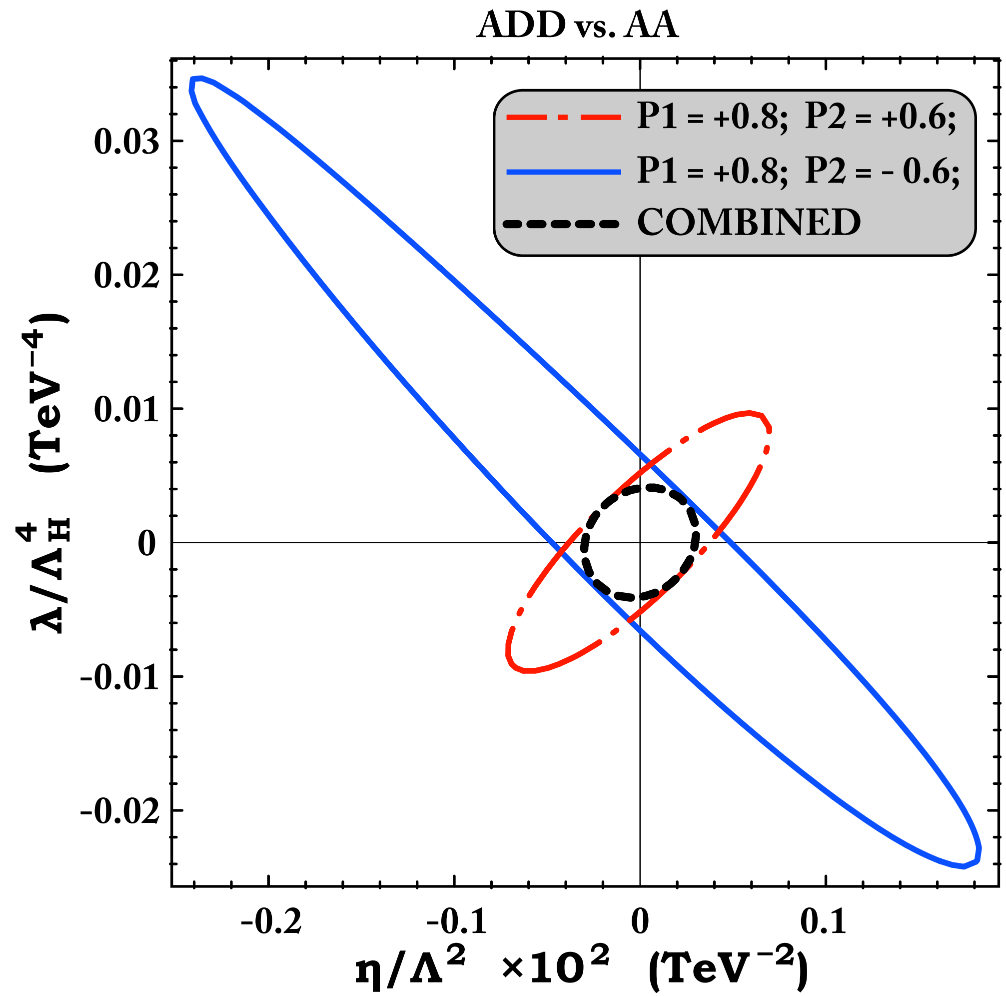
$$\Lambda_H^{\rm ID} = min\{\Lambda_H^{\rm VV}, \Lambda_H^{\rm AA}, \Lambda_H^{\rm RR}, \Lambda_H^{\rm LL}, \Lambda_H^{\rm LR}, \Lambda_H^{\rm TeV}\}$$

$\rightarrow \Lambda_H^{\rm ID} = 2.5(3.1)$ TeV.

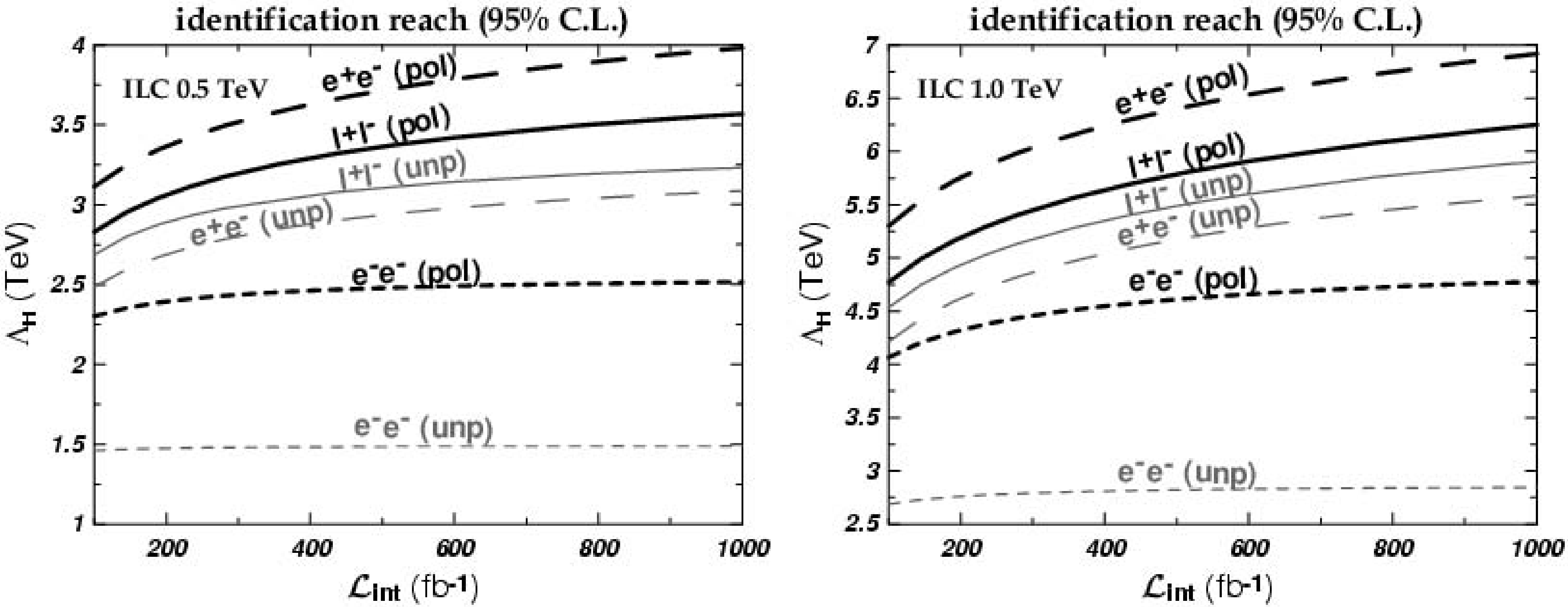
Role of polarization

Exclusion reach: ADD vs. VV



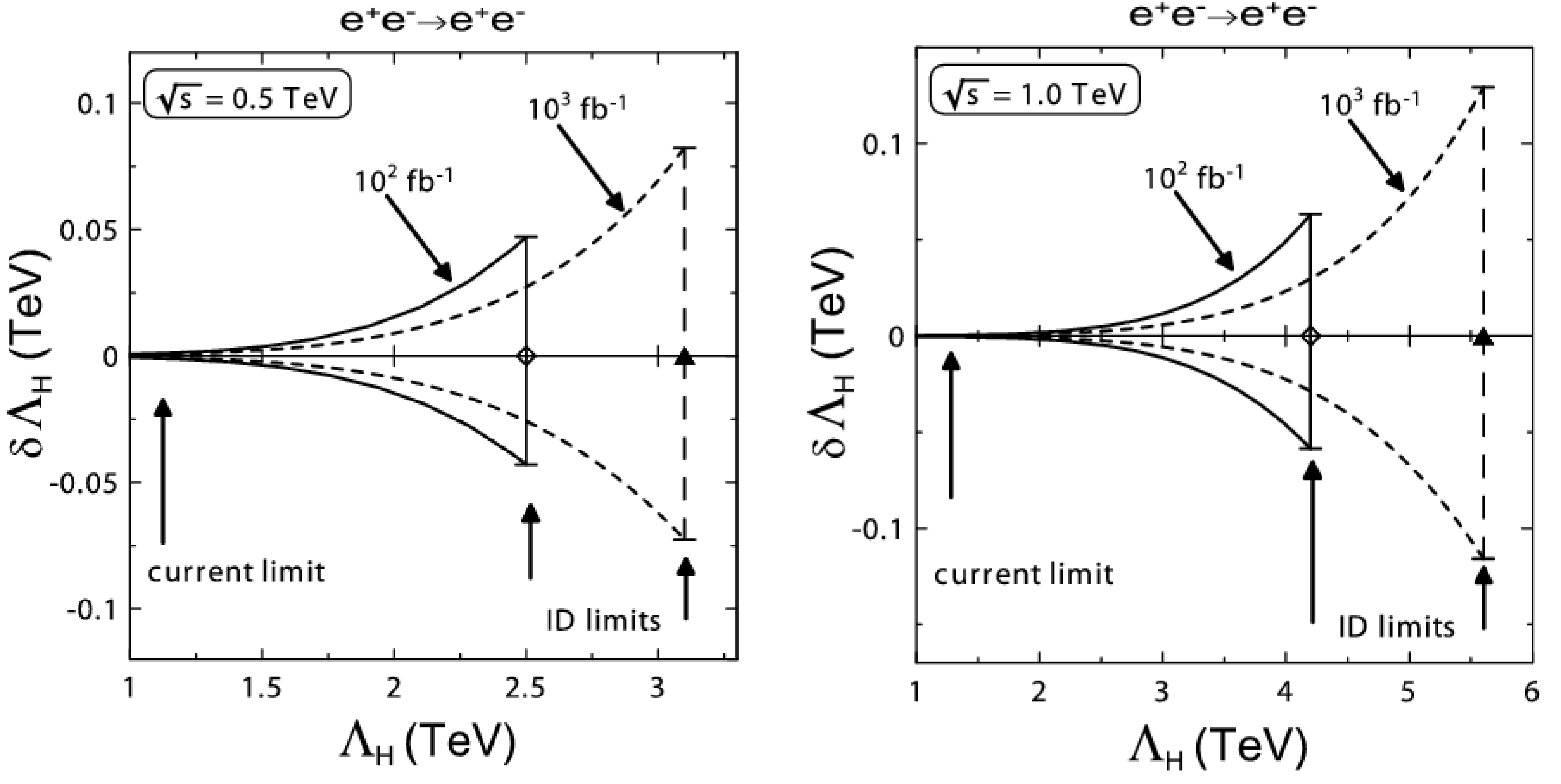


ADD vs. AA
P1 = +0.8; P2 = +0.6;
P1 = +0.8; P2 = - 0.6;
COMBINED
0.03
0.02
0.01
0
-0.01
-0.02
-0.2
-0.1
0
0.1
λ/Λ_H^4 (TeV^{-4})
$\eta/\Lambda^2 \times 10^2$ (TeV^{-2})

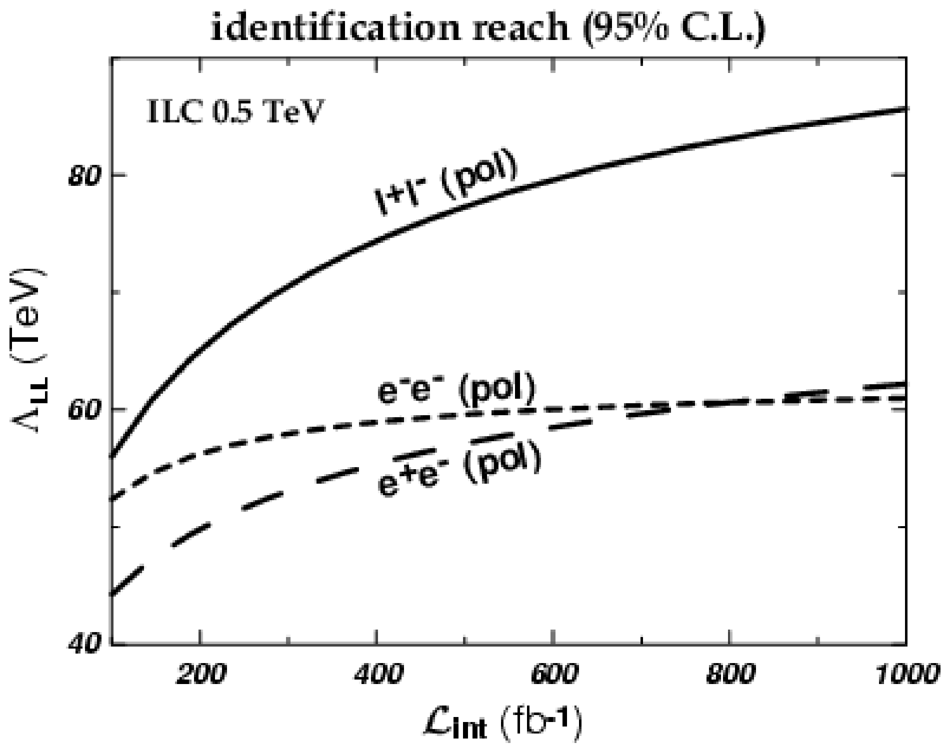


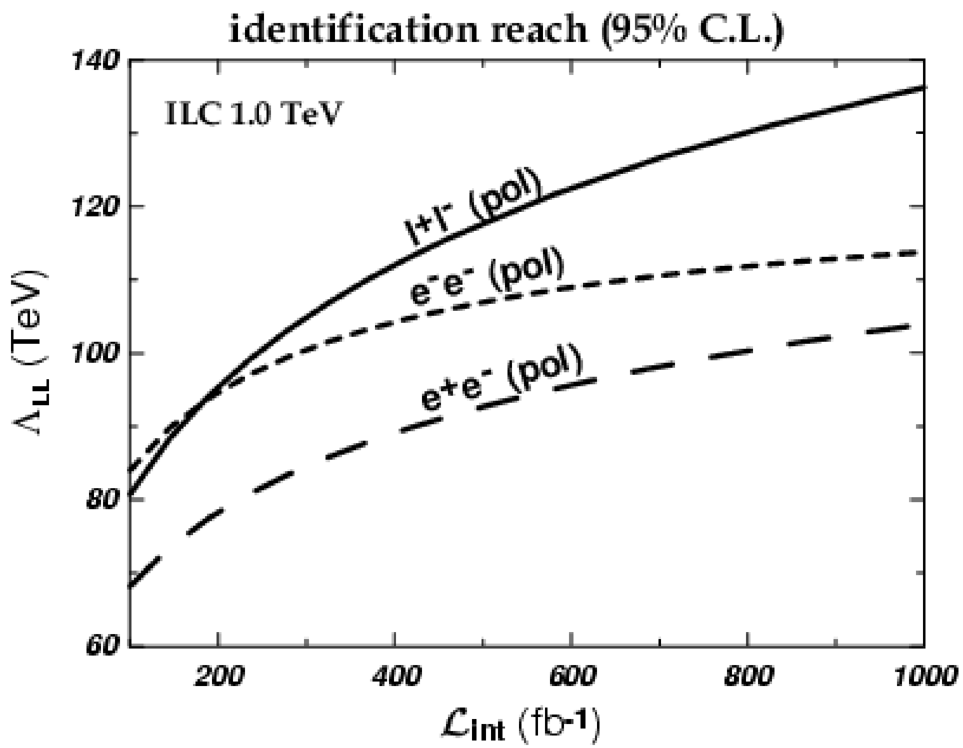
identification reach (95% C.L.)
ILC 0.5 TeV
e+e- (pol)
l+l- (pol)
l+l- (unp)
e+e- (unp)
e-e- (pol)
e-e- (unp)
Λ_H (TeV)
ℒ_int (fb-1)
identification reach (95% C.L.)
ILC 1.0 TeV
e+e- (pol)
l+l- (pol)
l+l- (unp)
e+e- (unp)
e-e- (pol)
e-e- (unp)
Λ_H (TeV)
ℒ_int (fb-1)

Resolving Power on Λ_H

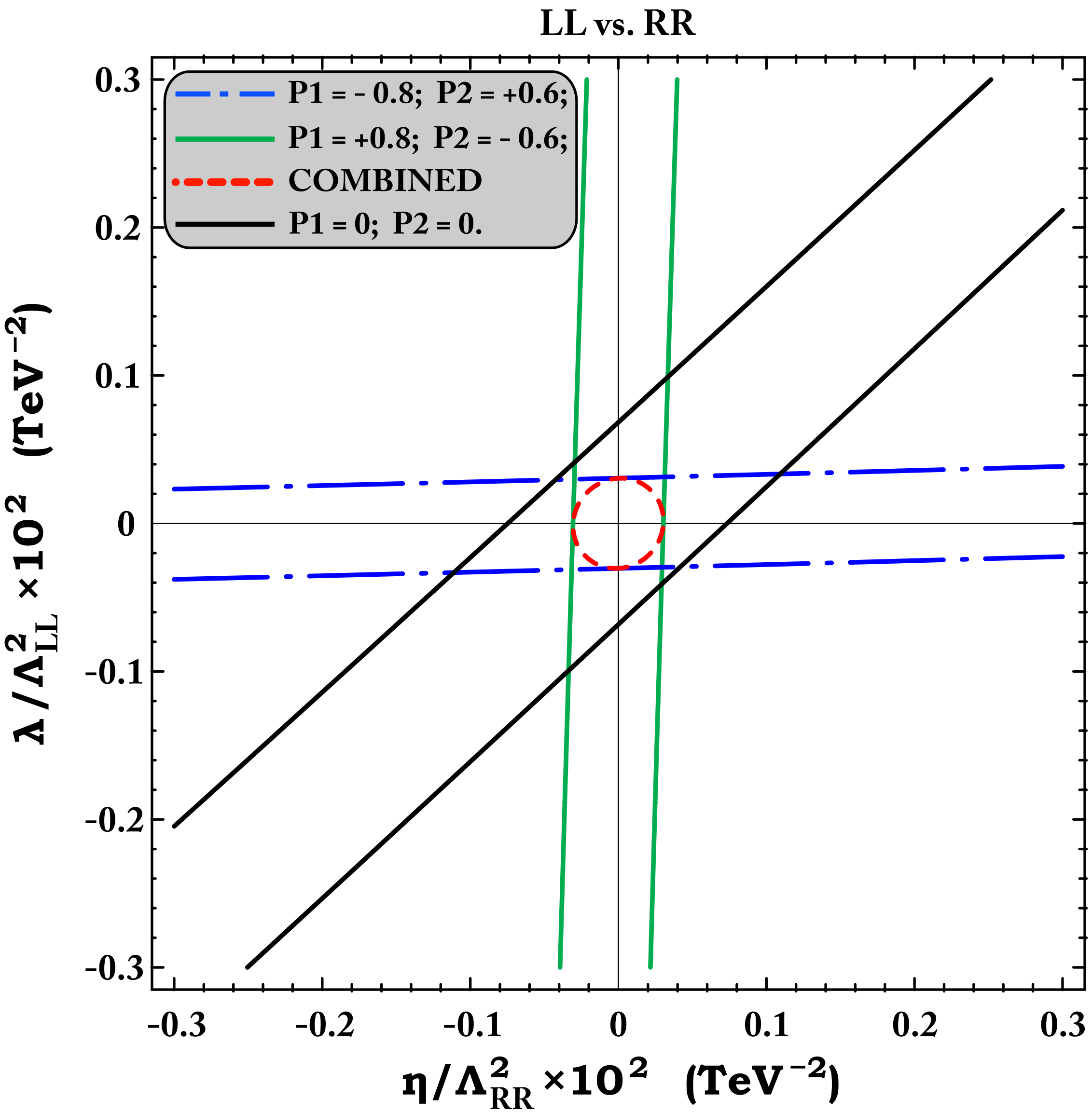


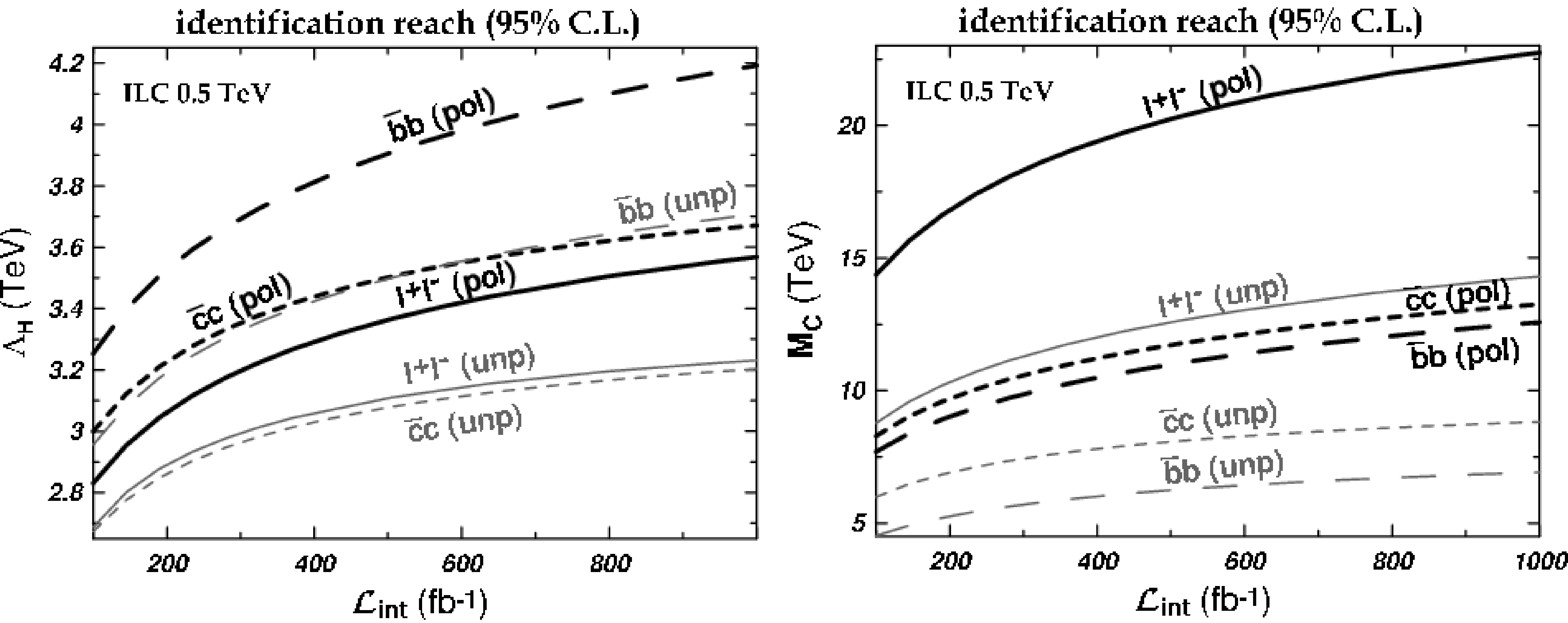
ID reach for CI models





Role of polarization





identification reach (95% C.L.)
ILC 0.5 TeV
$\bar{b}b$ (pol)
$\bar{b}b$ (unp)
$\bar{c}c$ (pol)
l+l- (pol)
l+l- (unp)
$\bar{c}c$ (unp)
Λ_H (TeV)
4.2
4
3.8
3.6
3.4
3.2
3
2.8
200
400
600
800
$\mathcal{L}_{int}$ (fb-1)
identification reach (95% C.L.)
ILC 0.5 TeV
l+l- (pol)
l+l- (unp)
$\bar{c}c$ (pol)
$\bar{b}b$ (pol)
$\bar{c}c$ (unp)
$\bar{b}b$ (unp)
M_C (TeV)
20
15
10
5
200
400
600
800
1000
$\mathcal{L}_{int}$ (fb-1)

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.