Identifying sneutrino in lepton pair production at ILC with polarized beams

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Motivation

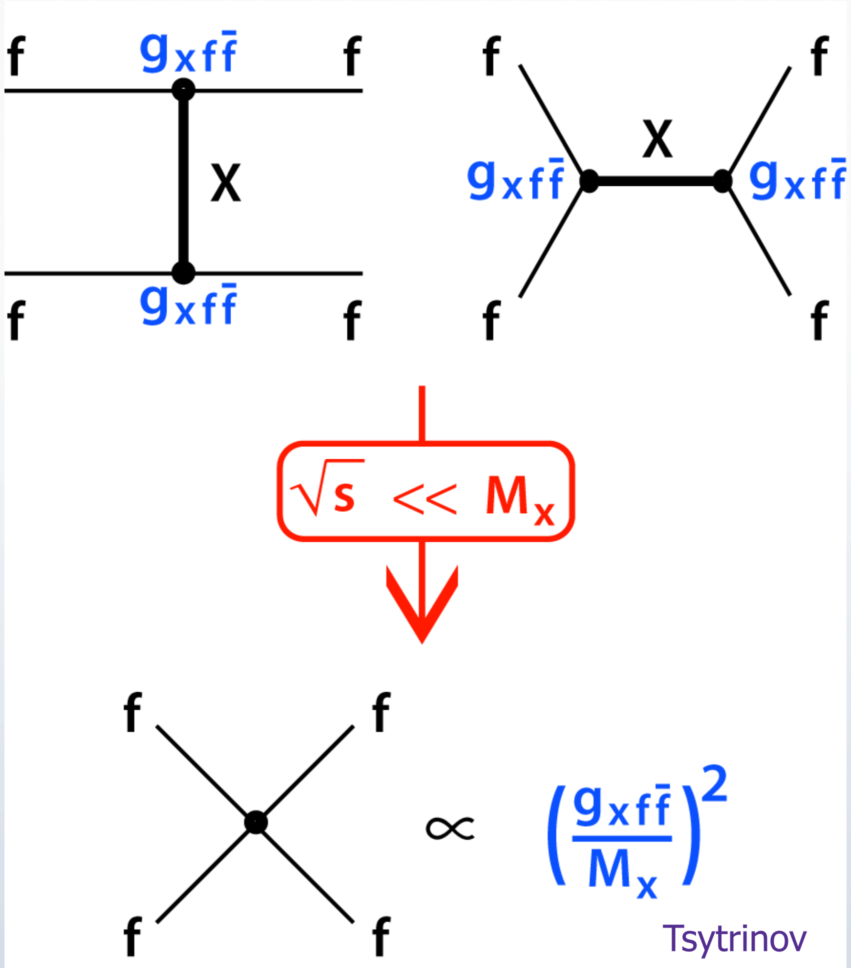
great hopes for New Physics manifestations at colliders: LHC or LC

direct: spectacular signatures of new particles X being produced directly

negative LHC searches push X masses up

indirect: deviations of SM processes from theoretical predictions

heavy X can contribute to the SM processes like f f -> f f



If X light, spectacular signals expected
easy to identify their origin

If heavy, their imprint can conveniently be parameterized in terms of contact interactions (CI)

Different BSM scenations may lead to similar effects:

- supersymmetry, RPC or RPV
- scalar or vector leptoquarks
- new gauge bosons,
- KK states,
- anomalous gauge couplings
- etc.

The origin more difficult to identify

Outline:

- Parametrization of NP effects
- Observables and numerical analysis
- Comparison with the LHC potential
- Concluding remarks

based on:
A.V. Tsytrinov, J.Kalinowski, P. Osland, A.A.Pankov
Sneutrino Identification in Lepton Pair Production at ILC with Polarized Beams
Physics Letters B 718 (2012) 94 [arXiv:1207.6234[hep-ph]]

Parametrization of NP effects

Differential cross section for $e^+ + e^- \to \mu^+ + \mu^-$ $z \equiv \cos\theta$

$$\frac{d\sigma^{CI}}{dz} = \frac{3}{8}\left[(1+z)^2\sigma_+^{CI} + (1-z)^2\sigma_-^{CI}\right]$$

$$\sigma_+^{CI} = \frac{1}{4}\left[(1-P^-)(1+P^+)\,\sigma_{LL}^{CI} + (1+P^-)(1-P^+)\,\sigma_{RR}^{CI}\right]$$

$$\sigma_-^{CI} = \frac{1}{4}\left[(1-P^-)(1+P^+)\,\sigma_{LR}^{CI} + (1+P^-)(1-P^+)\,\sigma_{RL}^{CI}\right]$$

$$\sigma_{\alpha\beta}^{CI} = \sigma_{pt}|\mathcal{M}_{\alpha\beta}^{CI}|^2$$

$$\sigma_{pt} \equiv \sigma(e^+e^- \to \gamma^* \to \mu^+\mu^-) = (4\pi\alpha_{em}^2)/(3s).$$

Supersymmetry is most attractive BSM scenario

- no compelling argument for R-parity conservation
- assume lepton number violation

$$W_{\not R} = \frac{1}{2}\lambda_{ijk}L_iL_jE_k + \lambda'_{ijk}L_iQ_jD_k + \mu'_iL_iH_u \text{ + soft terms}$$

- non-zero $\lambda_{131}\lambda_{232}$ implies s-channel $\tilde{\nu}_\tau$ contribution to

$$e^+ + e^- \rightarrow \mu^+ + \mu^-$$

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The goal: identify the s-channel sneutrino exchange at a Linear Collider

The tool: use both beams polarized

other examples: see A.Pankov today at 15:10

The helicity amplitudes

$$\mathcal{M}^{\rm CI}_{\alpha\beta} = \mathcal{M}^{\rm SM}_{\alpha\beta} + \Delta_{\alpha\beta}$$

new physics

s-channel sneutrino exchange does not interfere with gamma/Z

$$\frac{{\rm d}\sigma^{\tilde\nu}}{{\rm d}z} = \frac{3}{8}\left[(1+z)^2\sigma^{\rm SM}_{+} + (1-z)^2\sigma^{\rm SM}_{-} + 2\,\frac{1+P^-P^+}{2}\,(\sigma^{\tilde\nu}_{\rm RL} + \sigma^{\tilde\nu}_{\rm LR})\right]$$

$$\sigma^{\tilde\nu}_{\rm RL}(=\sigma^{\tilde\nu}_{\rm LR}) = \sigma_{\rm pt}\,|\mathcal{M}^{\tilde\nu}_{\rm RL}|^2,\ \mathcal{M}^{\tilde\nu}_{\rm RL} = \mathcal{M}^{\tilde\nu}_{\rm LR} = \tfrac{1}{2}\,C^s_{\tilde\nu}\chi^s_{\tilde\nu}$$

$$C^s_{\tilde\nu}\,\chi^s_{\tilde\nu} = \frac{\lambda_{131}\lambda_{232}}{4\pi\alpha_{\rm em}}\,\frac{s}{s - M^2_{\tilde\nu_\tau} + iM_{\tilde\nu_\tau}\Gamma_{\tilde\nu_\tau}}$$

KRSZ hep-ph/9703436

The parametrisation equally valid for many different models of CI

$$\mathcal{M}^{\rm CI}_{\alpha\beta} = \mathcal{M}^{\rm SM}_{\alpha\beta} + \Delta_{\alpha\beta}$$

new physics

Model	$\Delta_{\alpha\beta}$
composite fermions [1]	$\pm \frac{s}{\alpha_{\rm em}} \frac{1}{\Lambda^2_{\alpha\beta}}$
extra gauge boson Z' [2–5]	$g'^{\,e}_{\alpha}\, g'^{\,f}_{\beta}\, \chi_{Z'}$
AGC ($f = \ell$) [10]	$\Delta_{\rm LL} = s \left(\frac{\tilde{f}_{DW}}{2 s^2_W} + \frac{2 \tilde{f}_{DB}}{c^2_W} \right), \; \frac{\Delta_{\rm RR}}{2} = \Delta_{\rm LR} = \Delta_{\rm RL} = s \frac{4 \tilde{f}_{DB}}{c^2_W}$
TeV-scale extra dim. [15, 16]	$-(Q_e Q_f + g^e_\alpha\, g^f_\beta)\, \frac{\pi^2\, s}{3\, M^2_C}$
ADD model [11, 13]	$\Delta_{\rm LL} = \Delta_{\rm RR} = f_G\,(1 - 2\,z),\; \Delta_{\rm LR} = \Delta_{\rm RL} = -f_G\,(1 + 2\,z)$
R-parity violating SUSY [7, 8] ($\tilde{\nu}$ exchange in t-channel)	$\Delta_{\rm LL} = \Delta_{\rm RR} = 0,\; \Delta_{\rm LR} = \Delta_{\rm RL} = \frac{1}{2}\, C^t_{\tilde{\nu}}\, \chi^t_{\tilde{\nu}}$

Observables and numerical analysis

processes with polarized beams

$$e^+e^- \to \mu^+\mu^-$$

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

observables

for discovery: differential cross sections $\frac{\mathrm{d}\sigma^{\tilde{\nu}}}{\mathrm{d}z}$

for identification: double beam polarization asymmetry

$$A_{\mathrm{double}} = \frac{\sigma(P_1,-P_2)+\sigma(-P_1,P_2)-\sigma(P_1,P_2)-\sigma(-P_1,-P_2)}{\sigma(P_1,-P_2)+\sigma(-P_1,P_2)+\sigma(P_1,P_2)+\sigma(-P_1,-P_2)}$$

Rizzo '99, Osland, Pankov, Paver '03

details of the analysis

- initial- and final-state radiation included using ZFITTER and ZEFIT

D.Bardin ea, S.Riemann

- one-loop EW corrections by means of improved Born

M.Consoli ea

- avoid radiative Z-return by demanding $\Delta = E_\gamma / E_{\text{beam}} = 0.9$

- LC energy: 0.5 and 1 TeV

- integrated luminosity: 500/fb with error 0.5%

- muon identification efficiency: 95% with error 0.5%

- beam polarization: electrons 80%, positrons 60% with error 0.5%

discovery reach in $e^+e^- \to \mu^+\mu^-$

- relative deviation of observables

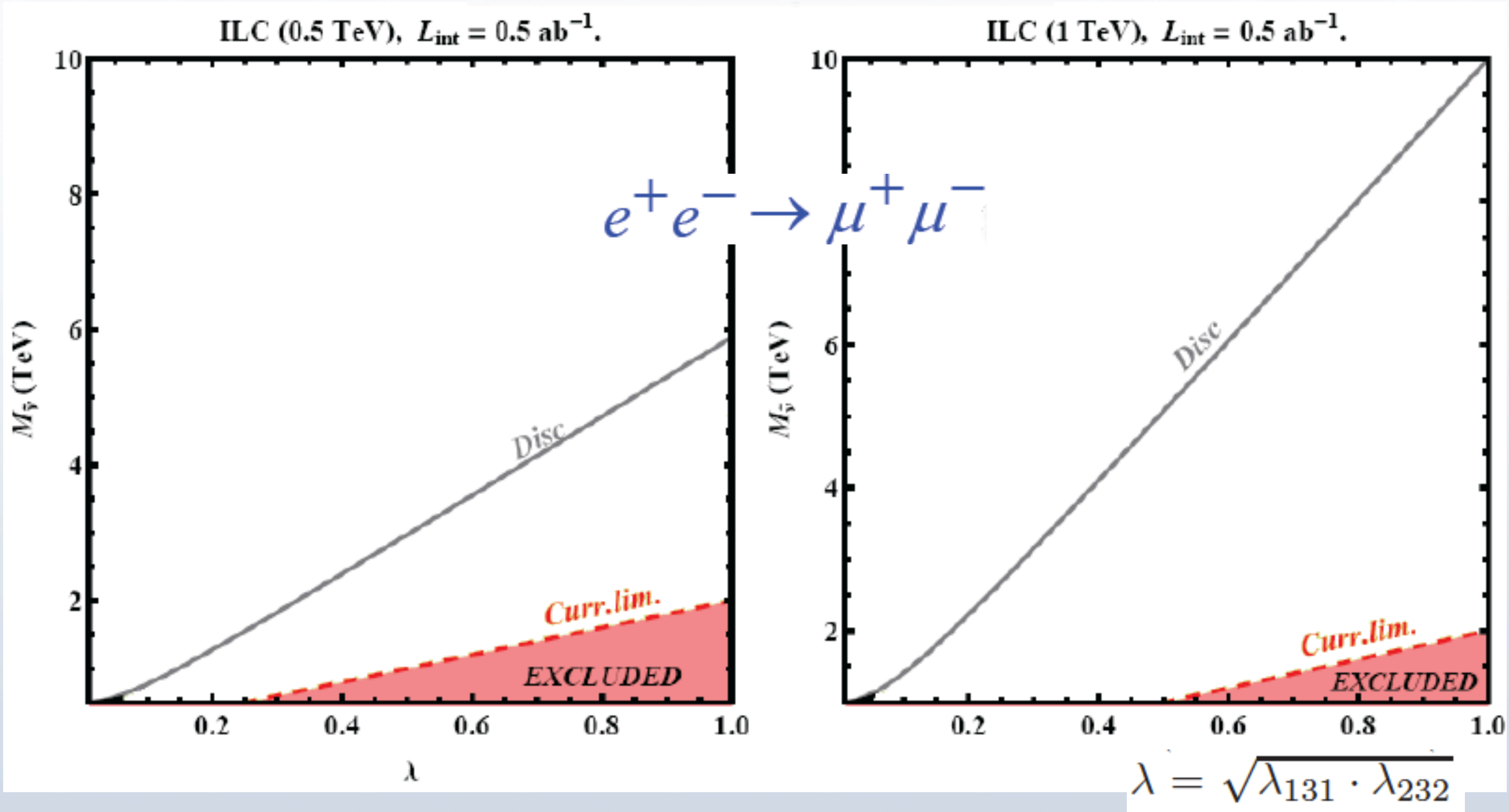
$$\Delta O = \frac{O(SM+NP) - O(SM)}{O(SM)}$$

$$\chi^2 = \sum_{\{P^-,P^+\}} \sum_{bins} \left(\frac{\Delta O^{bin}_{pol}}{\delta O^{bin}_{pol}} \right)^2$$

$\chi^2_{CL} = 3.84$ **95% C.L.** in $M_{\tilde{\nu}},\ \lambda$ plane

- observables: differential cross sections $\dfrac{\mathrm{d}\sigma^{\tilde{\nu}}}{\mathrm{d}z}$
  - in 10 bins with |z|<0.99
  - and for polarized beams $(P^-, P^+) = (+0.8, +0.6); (-0.8, -0.6)$

The discovery reach calculated from the angular distribution



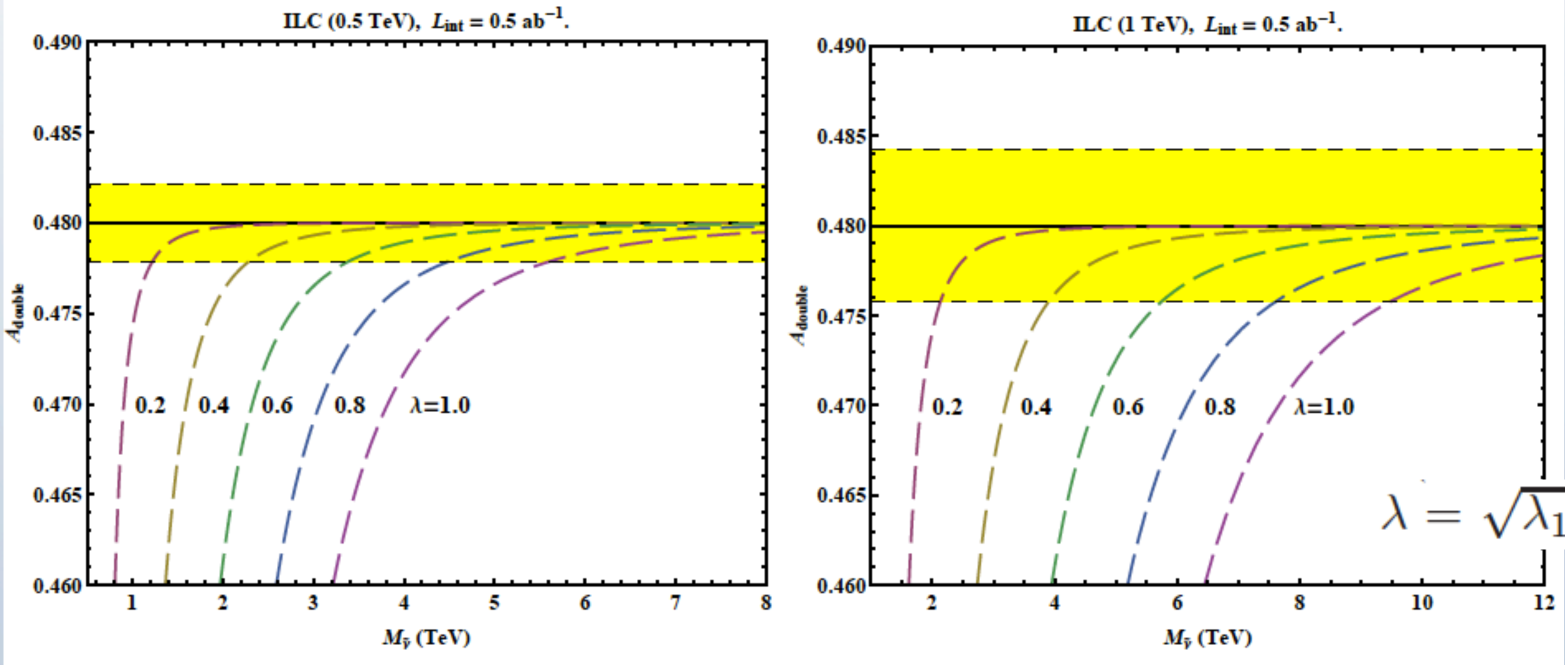
current limits from LE data: Kao ea, 0910.4980, Bhattacharyya ea, 11096183

If deviation observed, the identification from double beam polarization

$$A_{\rm double} = \frac{\sigma(P_1,-P_2)+\sigma(-P_1,P_2)-\sigma(P_1,P_2)-\sigma(-P_1,-P_2)}{\sigma(P_1,-P_2)+\sigma(-P_1,P_2)+\sigma(P_1,P_2)+\sigma(-P_1,-P_2)}$$

for all CI in the Table $A^{\rm SM}_{\rm double} = A^{\rm CI}_{\rm double} = P_1 P_2 = 0.48$

while for s-channel $\tilde{\nu}$ $A^{\tilde{\nu}}_{\rm double} - A^{\rm SM}_{\rm double} \propto -P_1 P_2 \, |C^s_{\tilde{\nu}} \chi^s_{\tilde{\nu}}|^2 < 0$

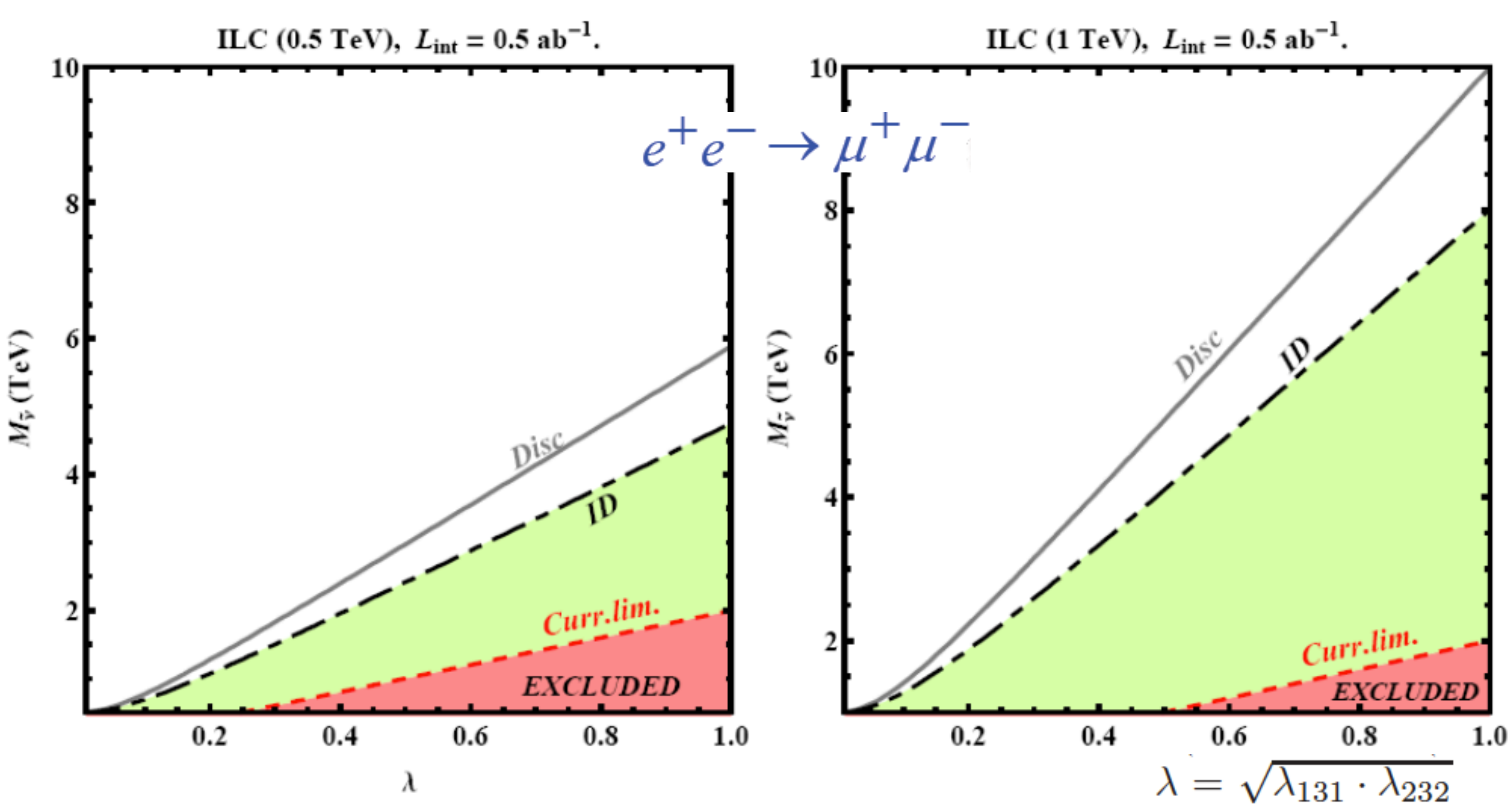


$\lambda = \sqrt{\lambda_{131} \cdot \lambda_{232}}$

again chi2 analysis

$$\chi^2 = \left(\frac{\Delta A_{double}}{\delta A_{double}}\right)^2$$

$e^+e^- \to \mu^+\mu^-$



$\lambda = \sqrt{\lambda_{131} \cdot \lambda_{232}}$

since λ_{131} assumed non-zero, s- and t-channel $\tilde{\nu}_\tau$ contribution to Bhabha

$$\frac{d\sigma^{\tilde{\nu}}}{dz} = \frac{\pi\alpha_{em}^2}{8s}\Big[(1+z)^2\{(1-P^-)(1+P^+)\,|f_{LL}^s + f_{LL}^t|^2 + (1+P^-)(1-P^+)\,|f_{RR}^s + f_{RR}^t|^2\}$$
$$+(1-z)^2\{(1-P^-)(1+P^+)\,|f_{LR}^s|^2 + (1+P^-)(1-P^+)\,|f_{RL}^s|^2\}$$
$$+4\,(1+P^-P^+)\{|f_{LR}^t|^2 + |f_{RL}^t|^2\}\Big]$$

with

$$f_{LL}^s = 1 + (g_L^e)^2\chi_Z, \qquad f_{RR}^s = 1 + (g_R^e)^2\chi_Z,$$
$$f_{LR}^s = 1 + g_L^e g_R^e \chi_Z + \frac{1}{2}C_{\tilde{\nu}}\chi_{\tilde{\nu}}^t, \qquad f_{RL}^s = 1 + g_R^e g_L^e \chi_Z + \frac{1}{2}C_{\tilde{\nu}}\chi_{\tilde{\nu}}^t,$$
$$f_{LL}^t = \frac{s}{t} + (g_L^e)^2\chi_Z^t, \qquad f_{RR}^t = \frac{s}{t} + (g_R^e)^2\chi_Z^t,$$
$$f_{LR}^t = \frac{s}{t} + g_L^e g_R^e \chi_Z^t + \frac{1}{2}C_{\tilde{\nu}}\chi_{\tilde{\nu}}^s, \qquad f_{RL}^t = \frac{s}{t} + g_R^e g_L^e \chi_Z^t + \frac{1}{2}C_{\tilde{\nu}}\chi_{\tilde{\nu}}^s,$$

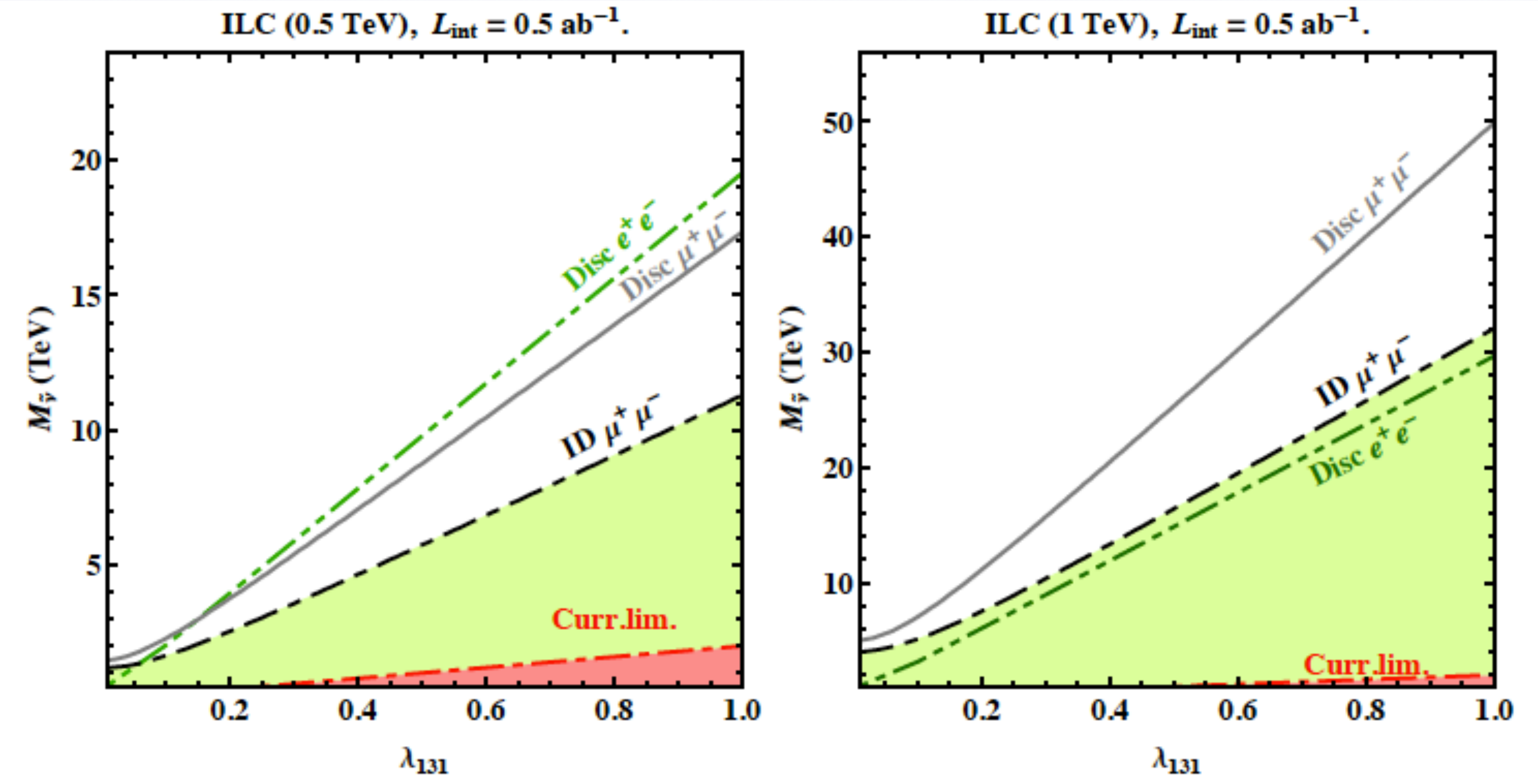
$$C_{\tilde{\nu}} = \frac{\lambda_{131}^2}{4\pi\alpha_{em}} \qquad \chi_i^t = s/(t - M_i^2)$$

KRSZ hep-ph/9703436

for numerics:

- discovery: angular distribution in 10 bins with |z|<0.9
- unique identification not possible

Bhabha discovery reach



for comparison with muons $\lambda_{232} = 0.5 \times M_{\tilde{\nu}}/\mathrm{TeV}$ is used

Comparison with the LHC reach

Osland, Pankov, Paver, Tsytrinov 1008.1389

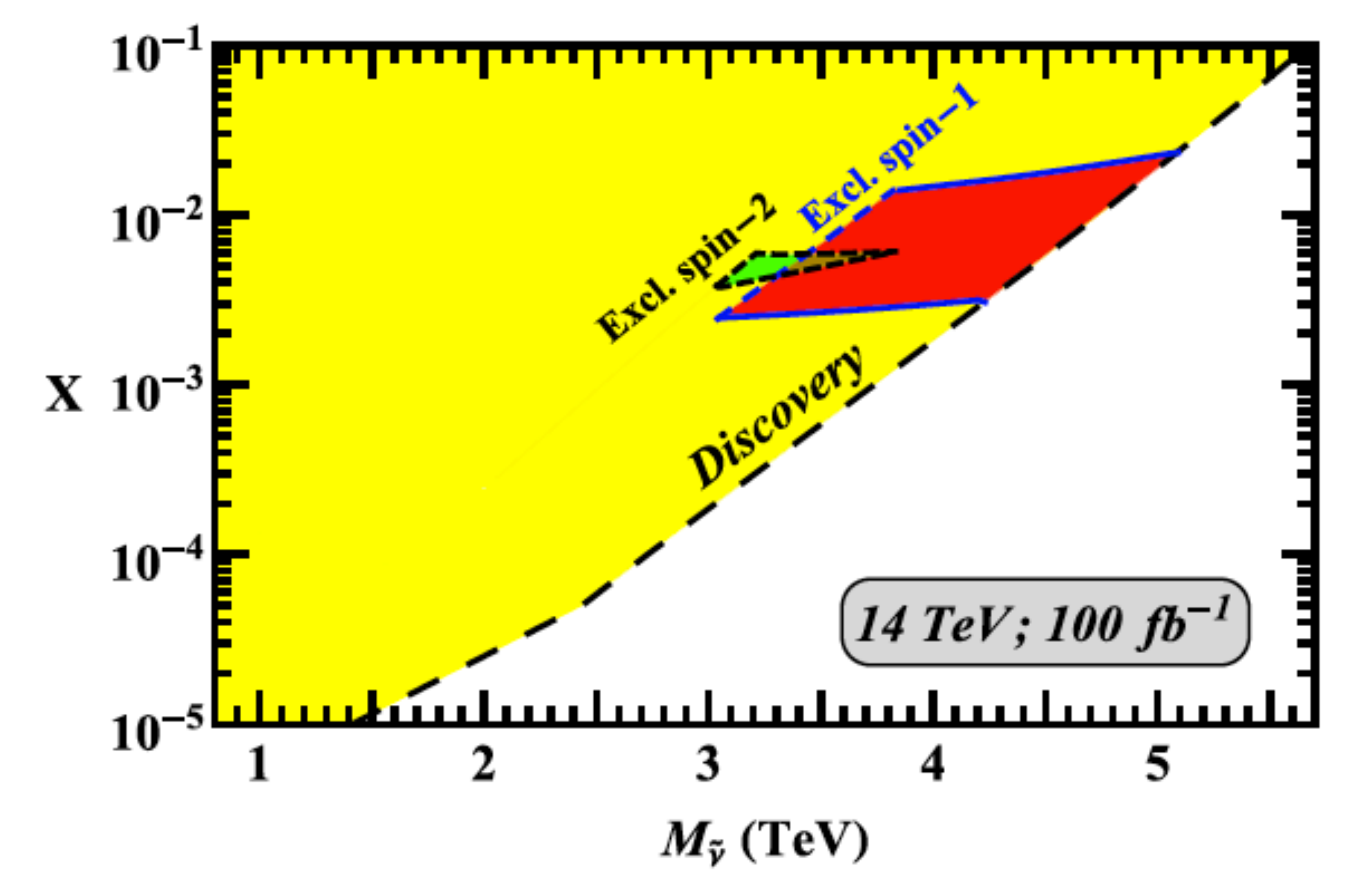
$$p + p \to l^+ l^- + X \qquad (l = e, \mu)$$

$$\frac{d\sigma}{dz} = \int_{M_R - \Delta M/2}^{M_R + \Delta M/2} dM \int_{-Y}^{Y} \frac{d\sigma}{dM\, dy\, dz}\, dy$$

using center-edge asymmetry for spin discrimination

$$\sigma_{\rm CE} \equiv \left[\int_{-z^*}^{z^*} - \left(\int_{-z_{\rm cut}}^{-z^*} + \int_{z^*}^{z_{\rm cut}} \right) \right] \frac{\mathrm{d}\sigma}{\mathrm{d}z}\, \mathrm{d}z$$

$$X = (\lambda')^2 B_l$$



Excl. spin−1
Excl. spin−2
Discovery
X
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1
2
3
4
5
$M_{\tilde{\nu}}$ (TeV)
14 TeV; 100 fb^{-1}

Conclusions

- If NP discovered good search strategies needed to determine origin
- We considered R-parity violating supersymmetry
  - indirect s-channel spin-0 sneutrino can unambigiously be identified at a LC
  - crucial role played by polarized beams of electrons AND positrons

    ⇒ discovery reach 0.5 (1) TeV LC down to $\lambda/M_{\tilde{\nu}} > 0.17\ (0.10)$

    $M_{\tilde{\nu}}$ in TeV

    ⇒ identification reach down to $\lambda/M_{\tilde{\nu}} > 0.21\ (0.13)$

➔ other examples: see Pankov's talk