SENSITIVITY TO CONTACT INTERACTIONS WITH POLARIZED ELECTRON AND POSITRON BEAMS

$e^+e^- \to \bar{f}f$ at $\sqrt{s} = 0.5$ TeV

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Outline:

- Model-independent constraints from polarized cross sections
- $P_e \neq 0$, $P_{\bar{e}} = 0$: role of δP_e
- $P_e \neq 0$, $P_{\bar{e}} \neq 0$: role of $P_{\bar{e}}$
- $P_e \neq 0$, $P_{\bar{e}} \neq 0$: role of $\delta P_{\bar{e}}$
- Final remarks

Contact Interaction (C.I.)

For the process

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

lowest-dimensional, contact four-fermion $eeff$ interaction Lagrangian with helicity conserving, flavor-diagonal fermion currents:

$$\mathcal{L} = \frac{g^2_{eff}}{\Lambda^2}\left[\eta_{\rm LL}\left(\bar{e}_{\rm L}\gamma_\mu e_{\rm L}\right)\left(\bar{f}_{\rm L}\gamma^\mu f_{\rm L}\right) + \eta_{\rm LR}\left(\bar{e}_{\rm L}\gamma_\mu e_{\rm L}\right)\left(\bar{f}_{\rm R}\gamma^\mu f_{\rm R}\right)\right.$$
$$\left. + \eta_{\rm RL}\left(\bar{e}_{\rm R}\gamma_\mu e_{\rm R}\right)\left(\bar{f}_{\rm L}\gamma^\mu f_{\rm L}\right) + \eta_{\rm RR}\left(\bar{e}_{\rm R}\gamma_\mu e_{\rm R}\right)\left(\bar{f}_{\rm R}\gamma^\mu f_{\rm R}\right)\right]$$

• Typical values (models) $\eta_{\alpha\beta} = \pm 1,\ 0$ $(\alpha, \beta = {\rm R}, {\rm L})$

• Conventionally: $g^2_{eff} = 4\pi$ (strong at $\sqrt{s} \sim \Lambda$)

• More general significance: parameterization of new physics at large $\Lambda \gg \sqrt{s}$ (Z', LQ, ...)

Example: very heavy $M_{Z'} \sim \sqrt{\alpha}\,\Lambda$

• $\Lambda_{\alpha\beta}$: standard for reach of new-physics searches

• Constraints on $\mathcal{L} \Leftrightarrow$ deviations from SM predictions in the relevant data.

• For each flavor: in *general*, σ, $A_{\rm LR}$, ... depend on *all* four independent C.I. couplings

Constraints on the C.I.

• Simplest procedure assumes non-zero value for only *one* C.I. coupling at a time ⇒ 1-parameter χ^2 fit.

• Completely model-independent procedure: simultaneously accounts for *all* non-zero *independent* C.I. couplings

• Avoid potential cancellations

• *Highly desirable*: disentangle individual effective C.I. couplings ⇒ general, and *separate*, constraints

• Longitudinally **Polarized** beams: *direct* access to *helicity cross sections*, dependent on *individual* C.I.

• Minimal set of free independent parameters in χ^2 analysis

• **Integrated** cross sections: possible advantage for limited statistics

Earlier references: Schrempp's, Wermes, Zeppenfeld; Cheung, Godfrey, Hewett; S. Riemann, talk in Sitges, Padova

Polarized cross sections

$$e^+ + e^- \to \bar{f} + f, \qquad (f \neq e, t;\, m_f \ll \sqrt{s})$$

- s-channel $\gamma, Z + \mathcal{L}$:

$$\frac{d\sigma}{d\cos\theta} = \frac{3}{8}\left[(1+\cos\theta)^2\,\sigma_+ + (1-\cos\theta)^2\,\sigma_-\right]$$

- Helicity cross sections:

$$\sigma_+ = \frac{1}{4}\left[(1+P_e)(1-P_{\bar{e}})\,\sigma_{\mathrm{RR}} + (1-P_e)(1+P_{\bar{e}})\,\sigma_{\mathrm{LL}}\right]$$
$$\sigma_- = \frac{1}{4}\left[(1+P_e)(1-P_{\bar{e}})\,\sigma_{\mathrm{RL}} + (1-P_e)(1+P_{\bar{e}})\,\sigma_{\mathrm{LR}}\right]$$

- measurable either by fit or suitable angular integration
- Helicity amplitudes ($\alpha, \beta = \mathrm{L}, \mathrm{R}$):

$$\sigma_{\alpha\beta} = [N_C]\,\frac{4\pi\alpha_{em}^2}{3s}\,|A_{\alpha\beta}|^2$$

$$A_{\alpha\beta} = (Q_e)_\alpha (Q_f)_\beta + g_\alpha^e\, g_\beta^f\, \chi_Z + \frac{s\eta_{\alpha\beta}}{\alpha_{em}\Lambda_{\alpha\beta}^2},$$

Determination of helicity cross sections

- Measurements at different longitudinal beams polarizations:

$$P_{\text{eff}} = \frac{P_e - P_{\bar{e}}}{1 - P_e P_{\bar{e}}} = \pm P$$

$$D = 1 - P_e P_{\bar{e}}$$

Helicity cross sections:

$$\begin{aligned}
\sigma_{\text{RR}} &= \frac{1}{D}\left[\frac{1+P}{P}\sigma_+(P) - \frac{1-P}{P}\sigma_+(-P)\right] \\
\sigma_{\text{LL}} &= \frac{1}{D}\left[\frac{1+P}{P}\sigma_+(-P) - \frac{1-P}{P}\sigma_+(P)\right] \\
\sigma_{\text{LR}} &= \frac{1}{D}\left[\frac{1+P}{P}\sigma_-(-P) - \frac{1-P}{P}\sigma_-(P)\right] \\
\sigma_{\text{RL}} &= \frac{1}{D}\left[\frac{1+P}{P}\sigma_-(P) - \frac{1-P}{P}\sigma_-(-P)\right]
\end{aligned}$$

- Electron-beam polarization is enough to disentangle $\sigma_{\alpha\beta}$
- Positron-beam polarization *can* increase the sensitivity to C.I.

- Sensitivity depends on luminosity L_{int}
- Depends on actual values of $P_e,\ \delta P_e,\ P_{\bar{e}},\ \delta P_{\bar{e}}$

Sensitivity to C.I.

For each $\sigma_{\alpha\beta}$ ($\alpha, \beta = \mathrm{R}, \mathrm{L}$):

$$\mathcal{S}(\sigma_{\alpha\beta}) = \frac{|\Delta\sigma_{\alpha\beta}|}{\delta\sigma_{\alpha\beta}}$$

- Deviation from SM prediction due to C.I. ($\sqrt{s} \ll \Lambda$):

$$\begin{aligned} \Delta\sigma_{\alpha\beta} &\equiv \sigma_{\alpha\beta} - \sigma_{\alpha\beta}^{SM} \\ &\simeq N_C\, \sigma_{\mathrm{pt}}\, 2\left(Q_e\, Q_f + g_\alpha^e\, g_\beta^f\, \chi_Z\right) \cdot \frac{s\eta_{\alpha\beta}}{\alpha_{em}\Lambda_{\alpha\beta}^2} \end{aligned}$$

- $\delta\sigma_{\alpha\beta}$ combines statistical *and* systematic uncertainties
- includes ΔP_e, $\Delta P_{\bar{e}}$
- independent individual couplings disentangled
- assessment of sensitivity ⇒ constraints on C.I. couplings:

$$\frac{\delta\sigma_{\alpha\beta}}{\sigma_{\alpha\beta}} \simeq \left(\frac{\delta\sigma_{\alpha\beta}}{\sigma_{\alpha\beta}}\right)^{\mathrm{SM}}$$

SM with radiative corrections

- improved Born approximation
- initial/final state radiation; $\Delta \equiv \frac{E_\gamma}{E_{beam}} = 0.9$
- numerical analysis: program ZEFIT & ZFITTER (Riemann; Bardin), input $m_{top} = 175$ GeV and $m_H = 100$ GeV

Numerical inputs

Identification efficiencies (ϵ) and syst. uncertainties (δ^{sys}):

- $\epsilon = 100\%$ and $\delta^{sys} = 0.5\%$ for $e^+e^- \to \mu^+\mu^-$
- $\epsilon = 60\%$ and $\delta^{sys} = 1\%$ for $e^+e^- \to \bar{b}b$
- $\epsilon = 35\%$ and $\delta^{sys} = 1.5\%$ for $e^+e^- \to \bar{c}c$

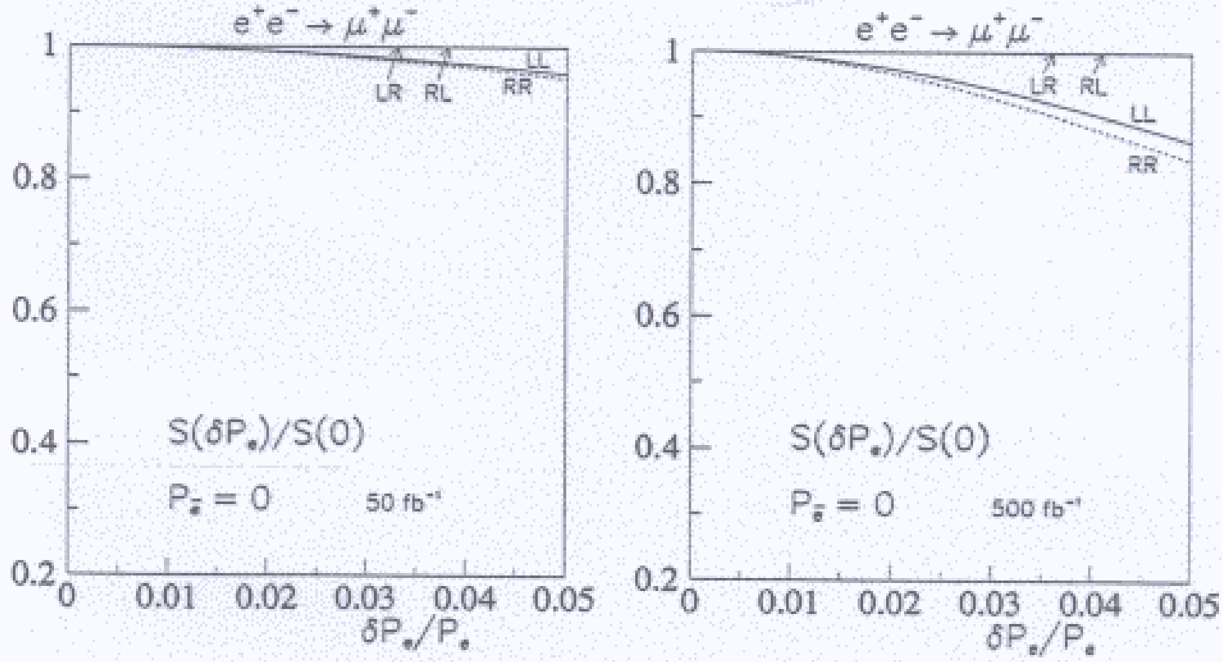
Luminosity

- $\sqrt{s} = 0.5\,\mathrm{TeV}$: $L_{int} = 50\,\mathrm{fb}^{-1}$
- $\sqrt{s} = 0.5\,\mathrm{TeV}$: $L_{int} = 500\,\mathrm{fb}^{-1}$
- $\frac{1}{2}L_{int}$ for each polarizations $P_{\mathrm{eff}} = \pm P$

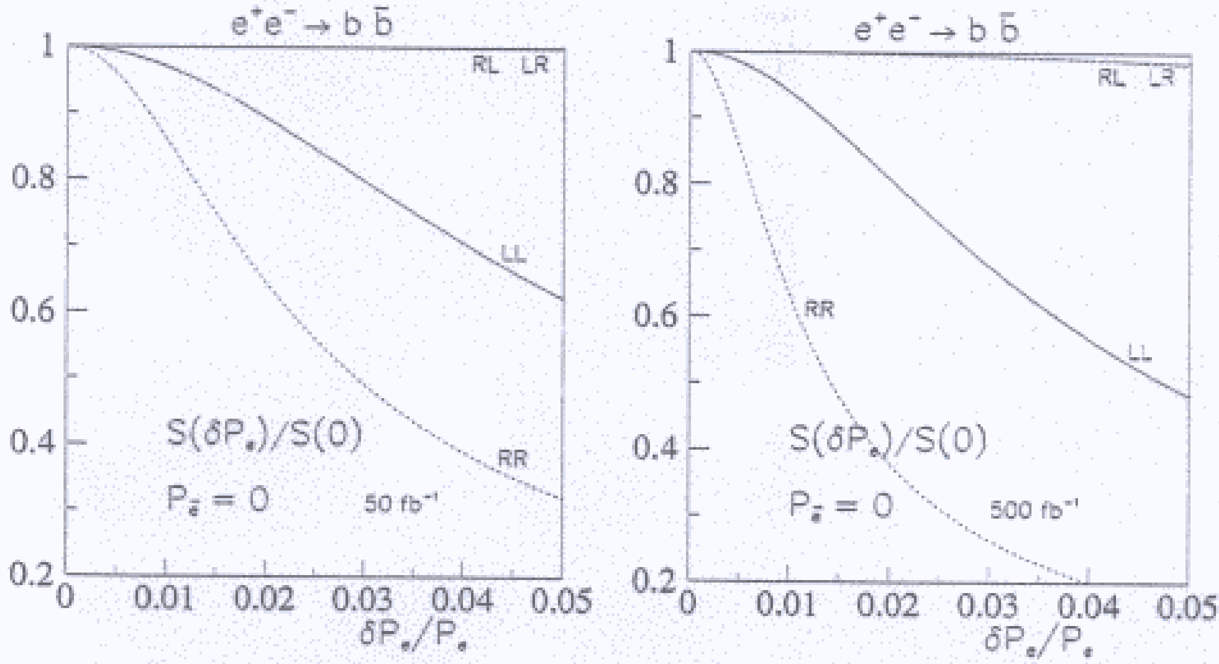
Longitudinal polarization

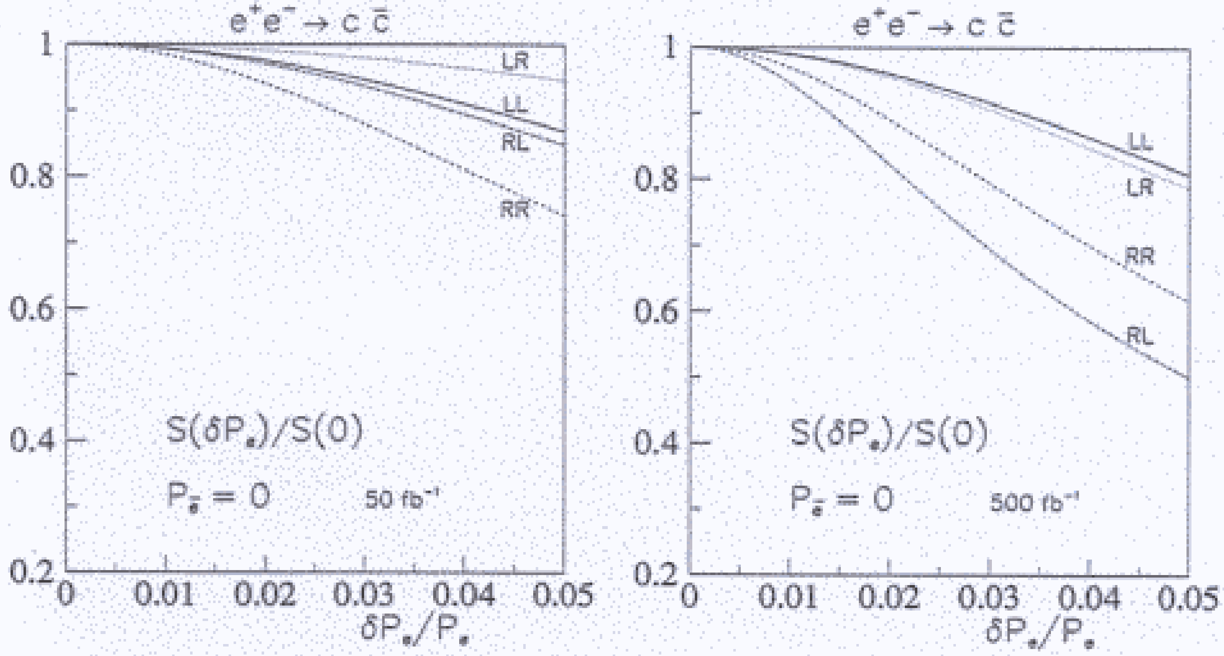
- $P_e = 0.9$, $\delta P_e/P_e = 0.5\%$ 0.8
- $P_{\bar{e}} = 0.6$, $\delta P_{\bar{e}}/P_{\bar{e}}$ varied

0.4 0.5%



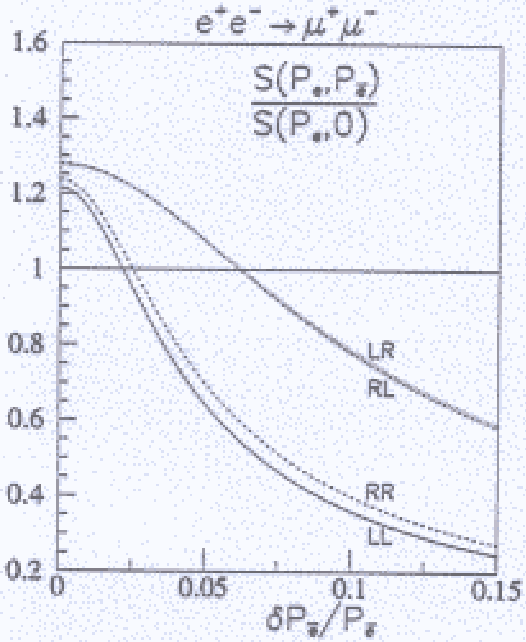
$P_e = 0.9$; $P_{\bar e} = 0$; $\delta P_e / P_e$ varied

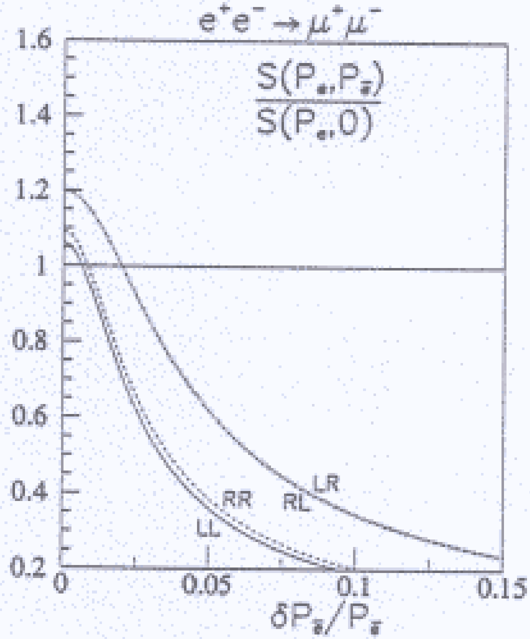




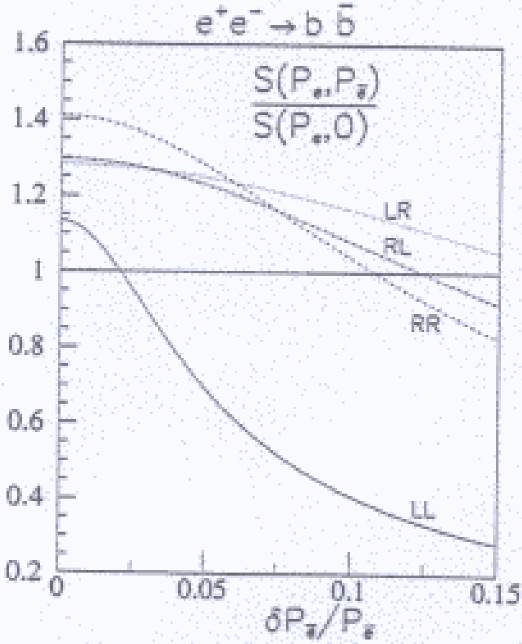
$P_e = 0.9$; $P_{\bar{e}} = 0$; $\delta P_e / P_e$ varied

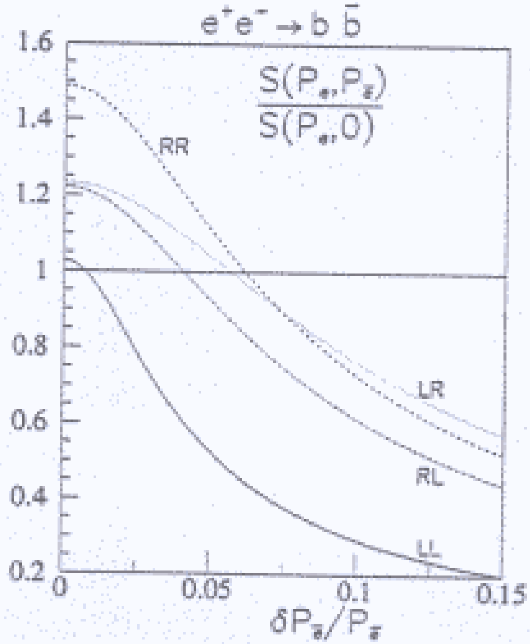
$L_{int} = 50\ fb^{-1}$ $L_{int} = 500\ fb^{-1}$

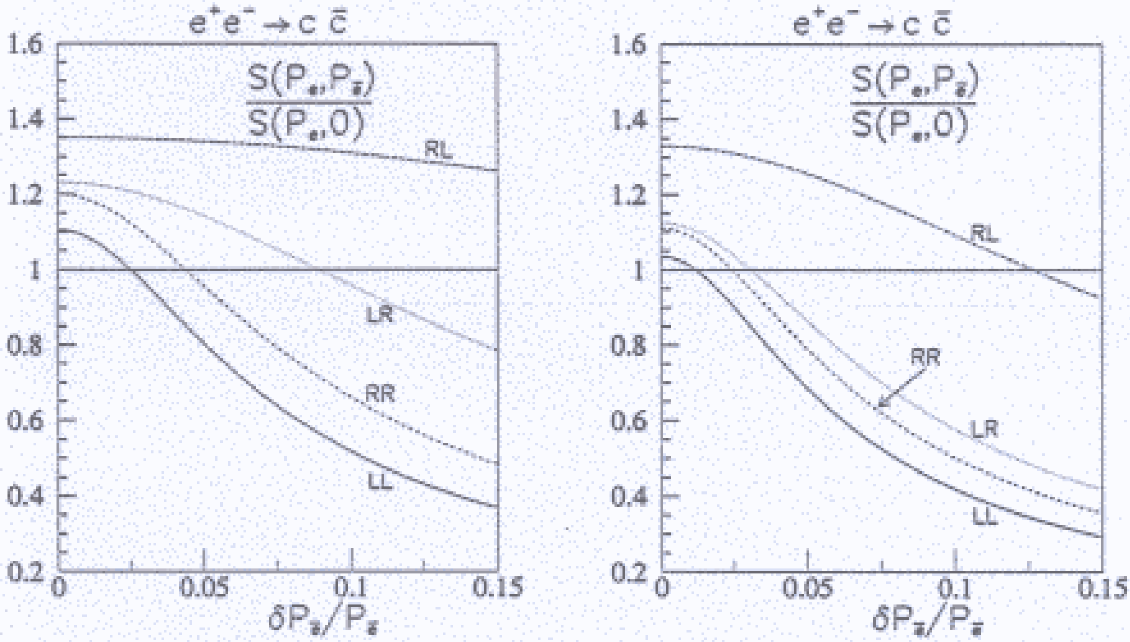




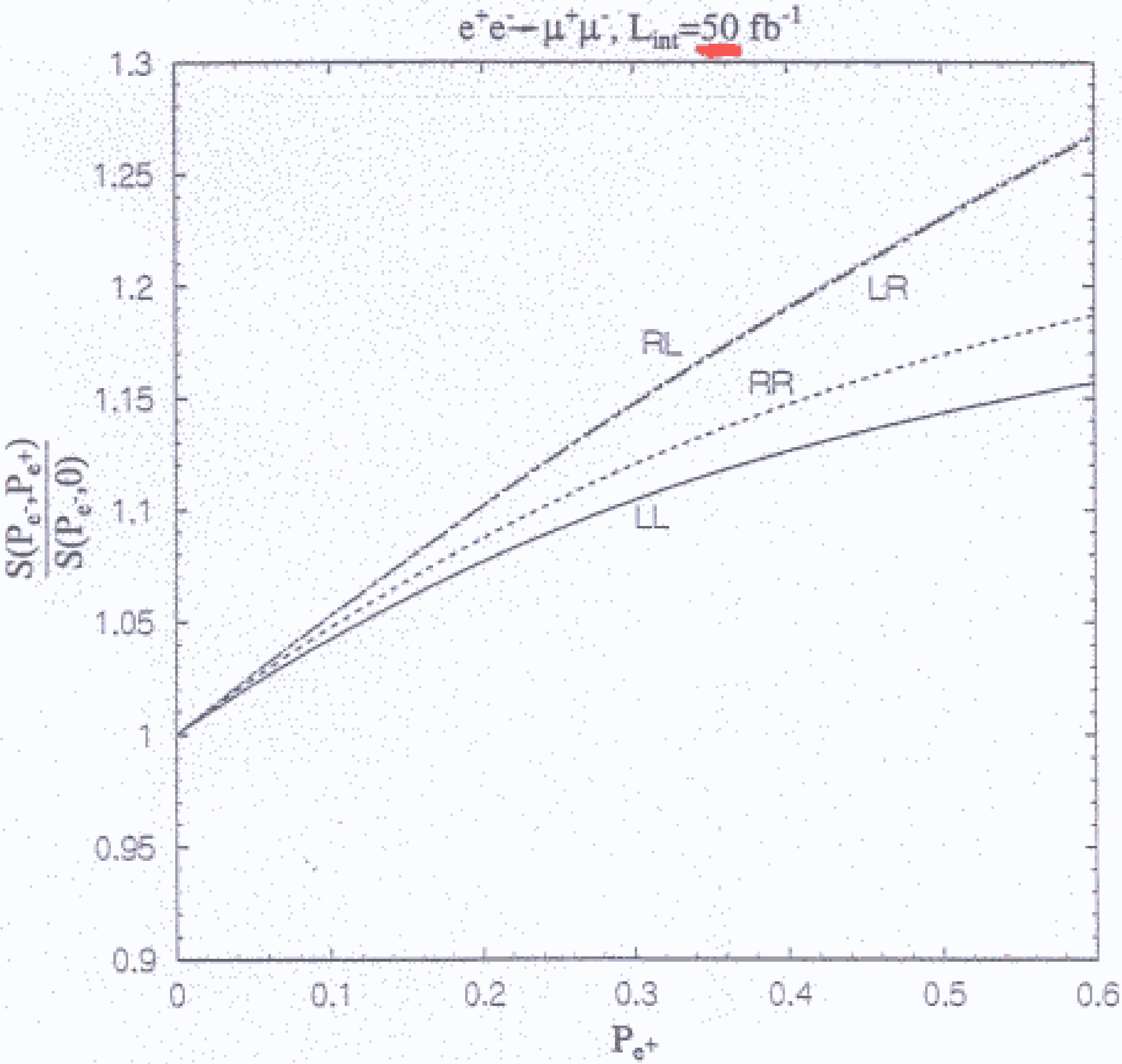
$P_e = 0.9$; $\delta P_e / P_e = 0.5\%$; $P_{\bar{e}} = 0.6$; $\delta P_{\bar{e}} / P_{\bar{e}}$ varied



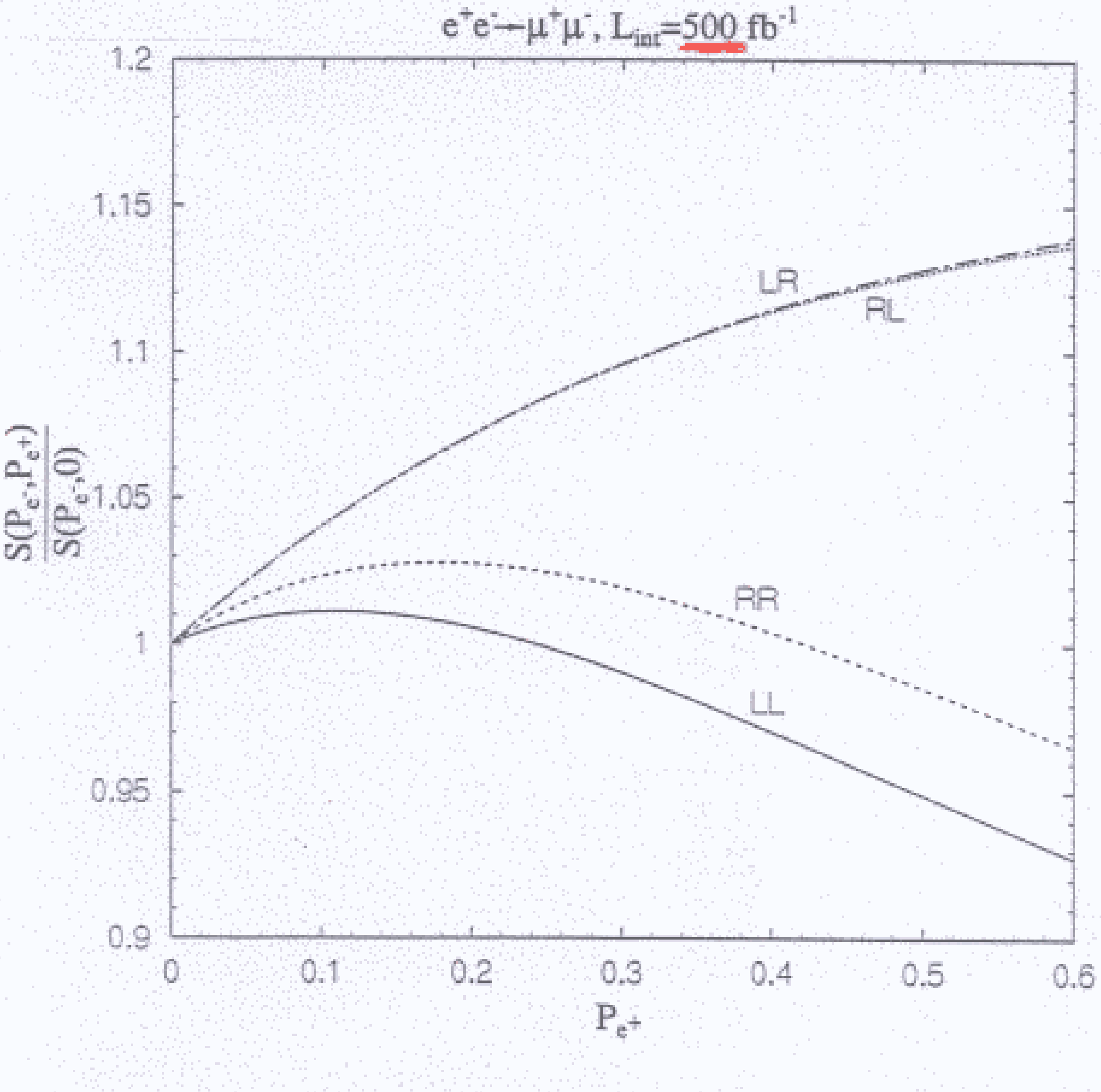




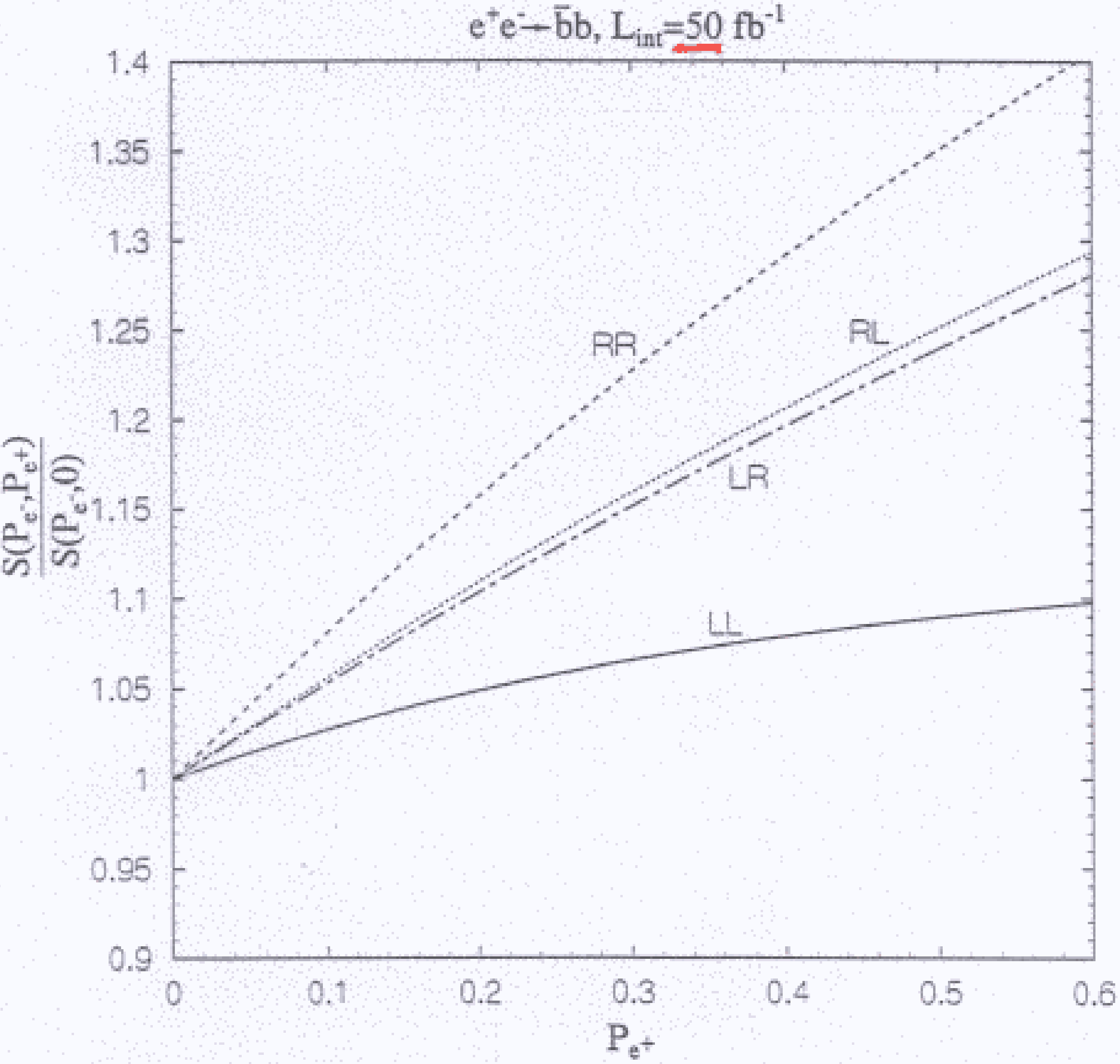
$P_e = 0.9$; $\delta P_e/P_e = 0.5\%$; $P_{\bar{e}} = 0.6$; $\delta P_{\bar{e}}/P_{\bar{e}}$ varies



$P_e = 0.9$; $\delta P_e / P_e = 0.5\%$; $\delta P_{\bar{e}} / P_{\bar{e}} = 1\%$

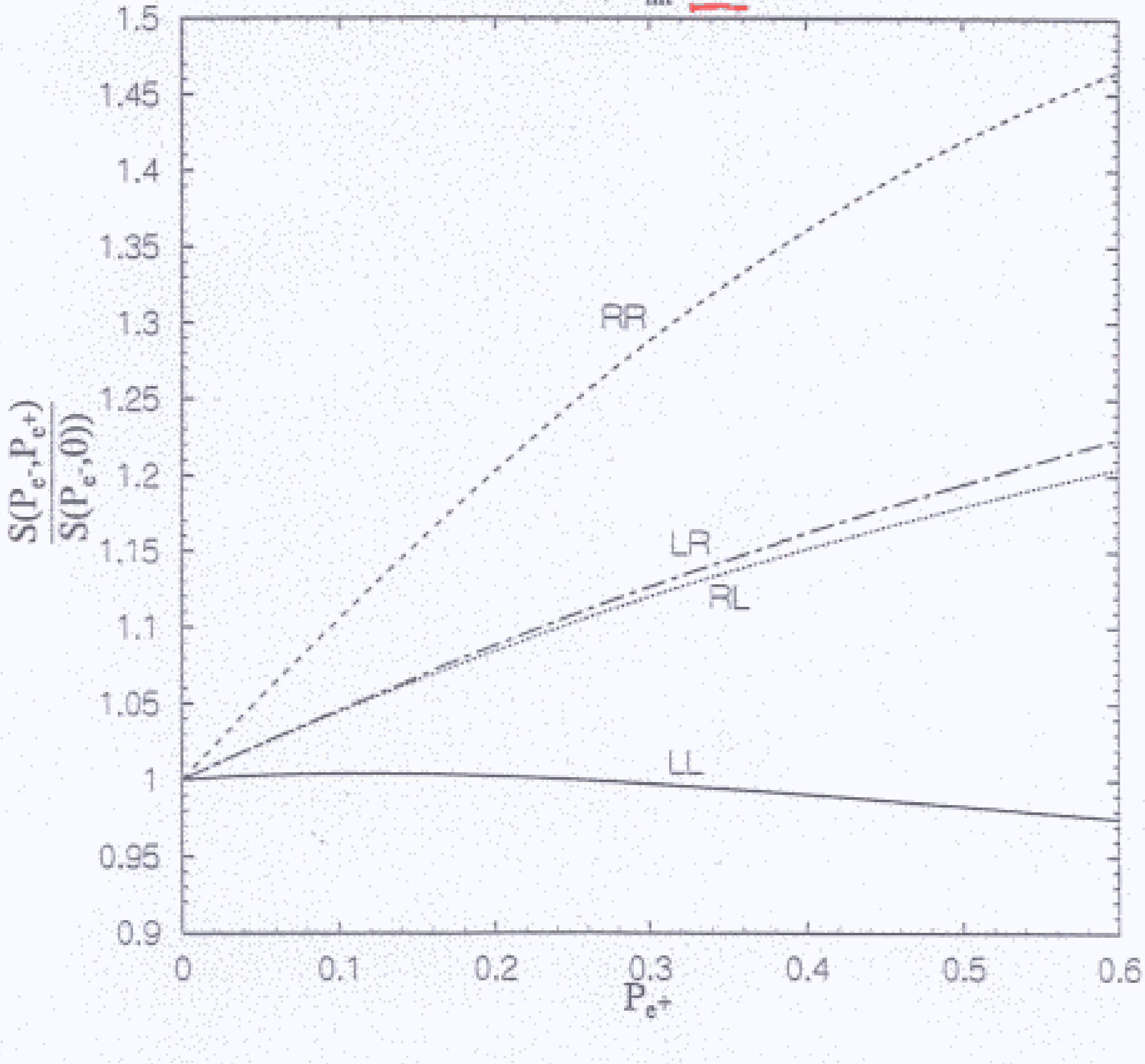


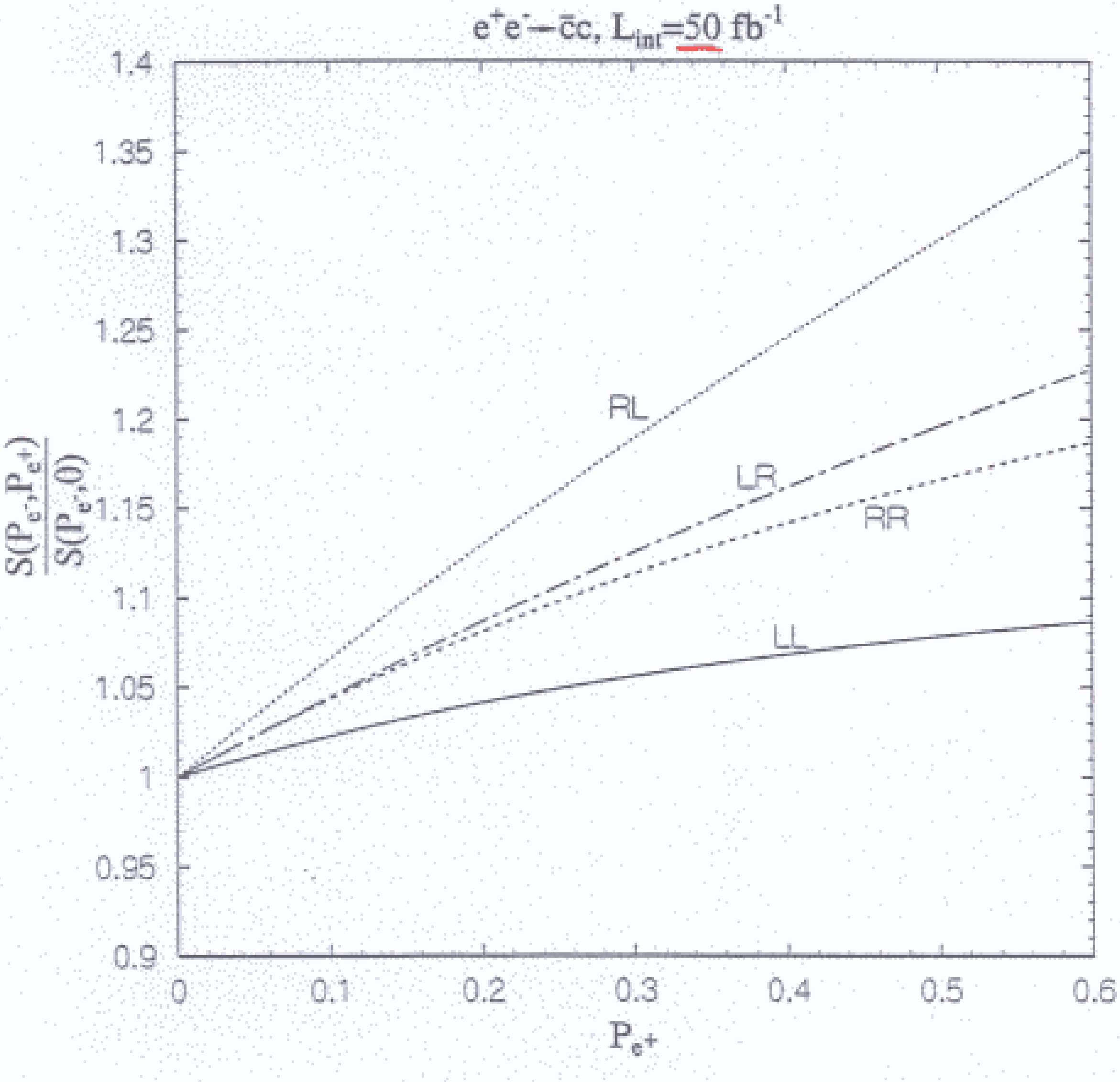
$e^+e^- \to \mu^+\mu^-$, L_{int}=500 fb^{-1}
$\frac{S(P_{e^-},P_{e^+})}{S(P_{e^-},0)}$
1.2
1.15
1.1
1.05
1
0.95
0.9
0
0.1
0.2
0.3
0.4
0.5
0.6
P_{e^+}
LR
RL
RR
LL



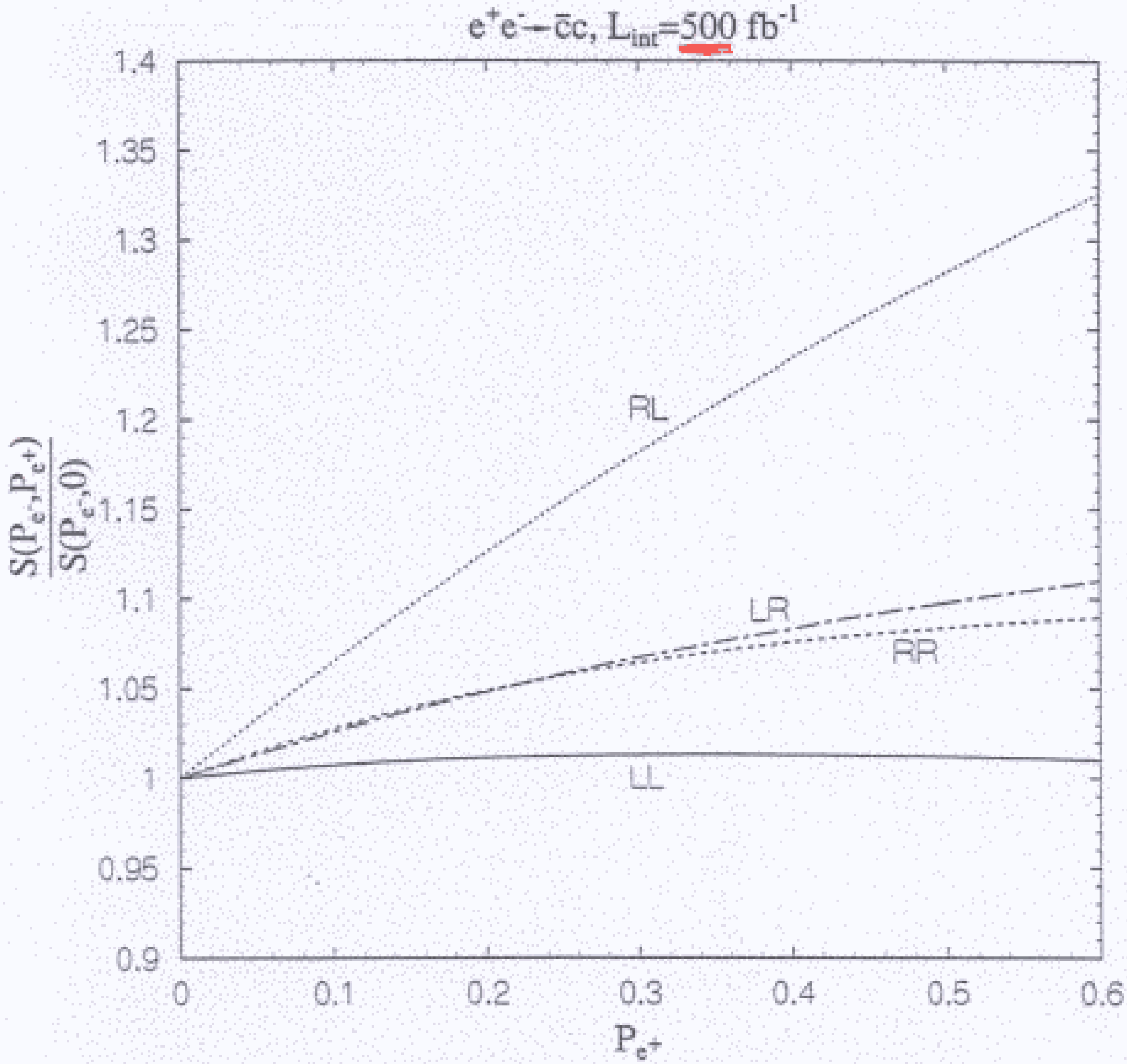
$e^+e^- \to \bar{b}b$, L_{int}=50 fb^{-1}
$\frac{S(P_{e^-},P_{e^+})}{S(P_{e^-},0)}$
P_{e^+}
RR
RL
LR
LL
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0
0.1
0.2
0.3
0.4
0.5
0.6

$e^+e^- \to bb$, L_{int}=500 fb^{-1}





e⁺e⁻→c̄c, L_int=50 fb⁻¹
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0
0.1
0.2
0.3
0.4
0.5
0.6
RL
LR
RR
LL
S(P_e-,P_e+) / S(P_e-,0)
P_e+



$e^+e^- \to \bar{c}c$, L_{int}=500 fb^{-1}
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0
0.1
0.2
0.3
0.4
0.5
0.6
RL
LR
RR
LL
$\frac{S(P_{e^-},P_{e^+})}{S(P_{e^-},0)}$
P_{e^+}

Reach on Λ

- χ^2 analysis data for $\sigma_{\alpha\beta}$:

• Suppose *no deviation* is observed within the expected experimental uncertainty:

• Define $\chi^2 = \left(\frac{\Delta\sigma_{\alpha\beta}}{\delta\sigma_{\alpha\beta}}\right)^2$

• apply the criterion: $\chi^2 < \chi^2_{\rm crit}$

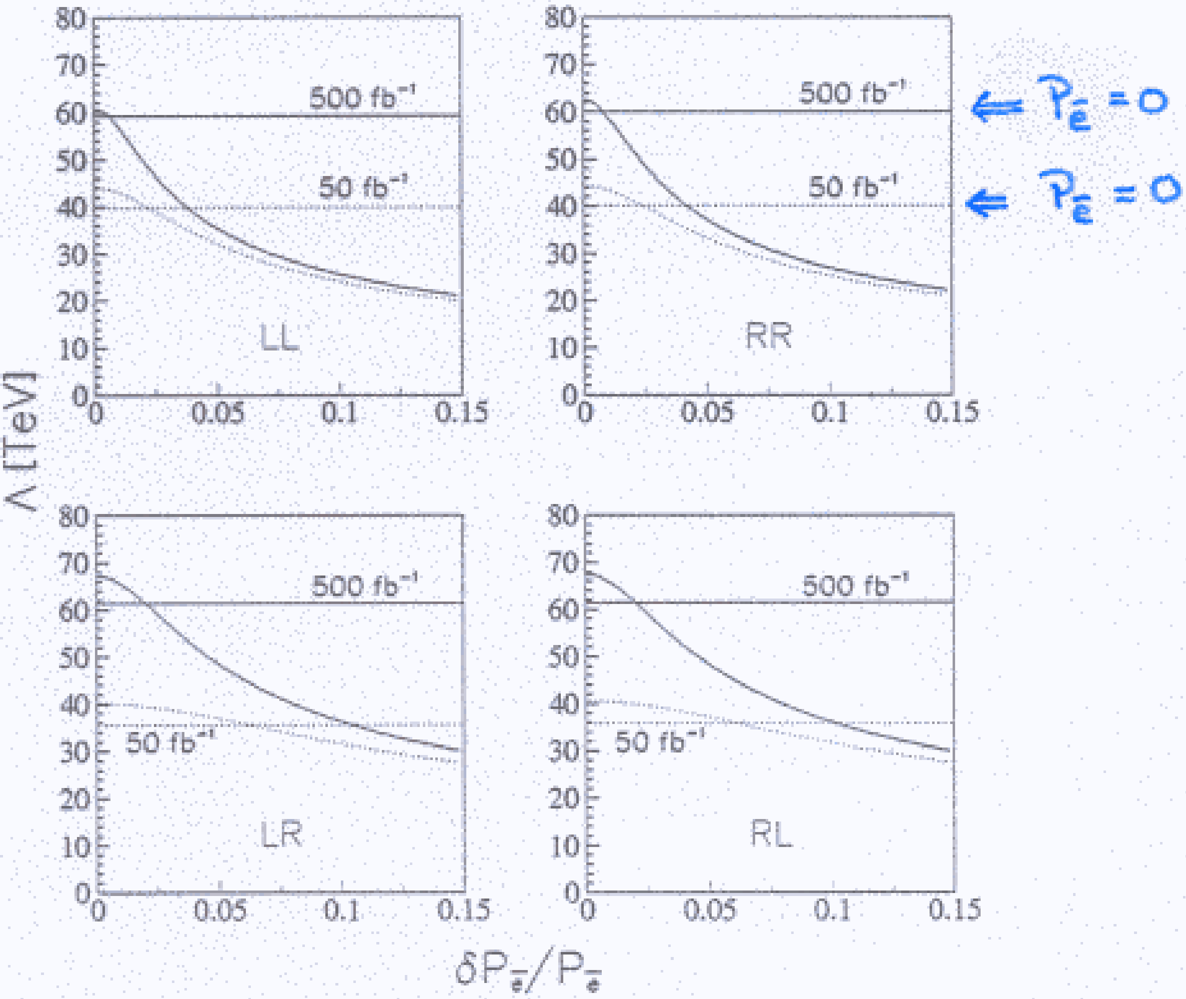
• $\chi^2_{\rm crit}$ specifies the desired 'confidence' level

• typical $\chi^2_{crit} = 3.84$ for 95% C.L. with a one-parameter fit.

• systematic *vs* statistical uncertainties

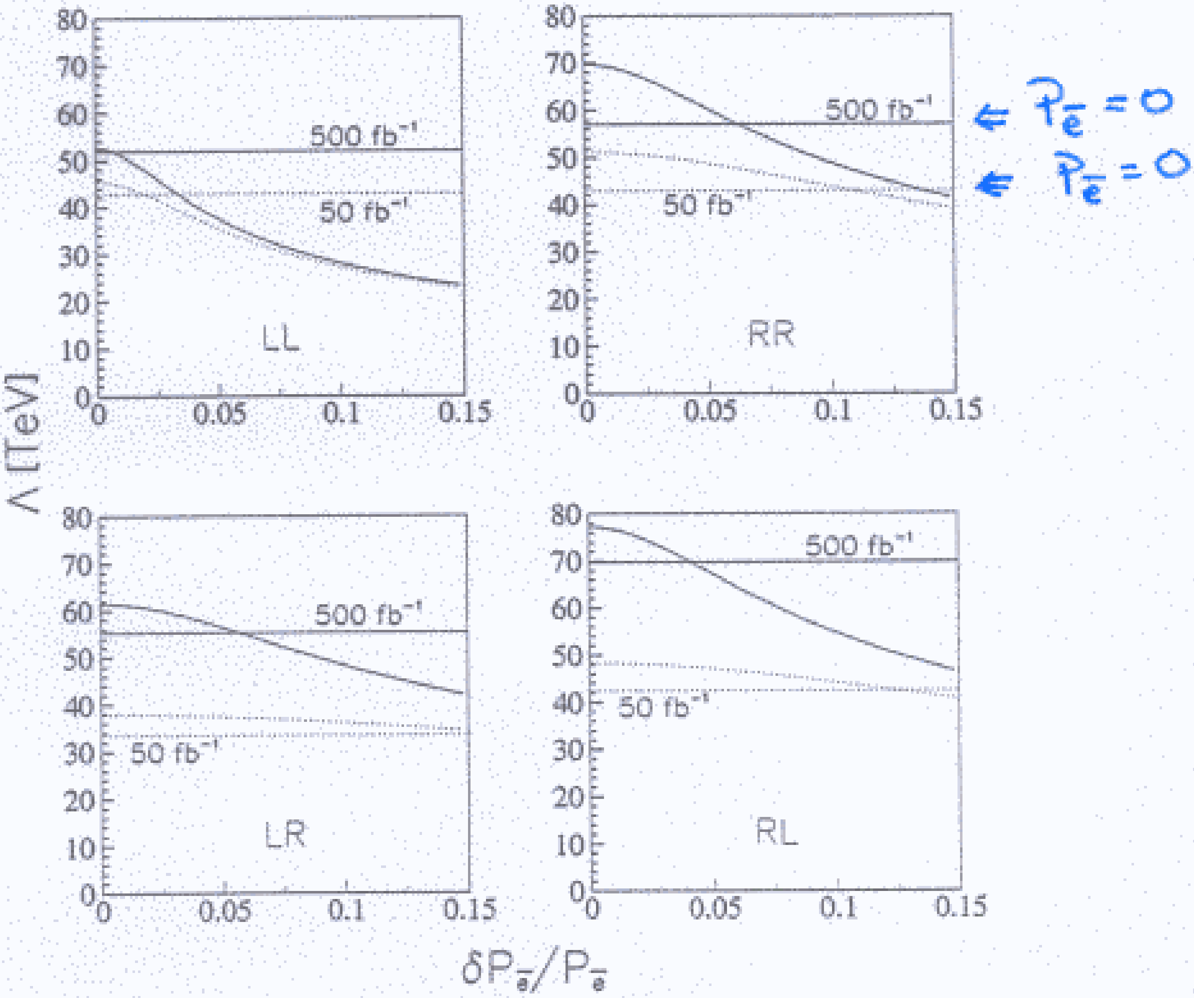
$$\Lambda \sim (L_{\rm int} \times s)^{1/4} \times \left[1 + \left(\delta^{sys}/\delta^{stat}\right)^2\right]^{-1/4}$$

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

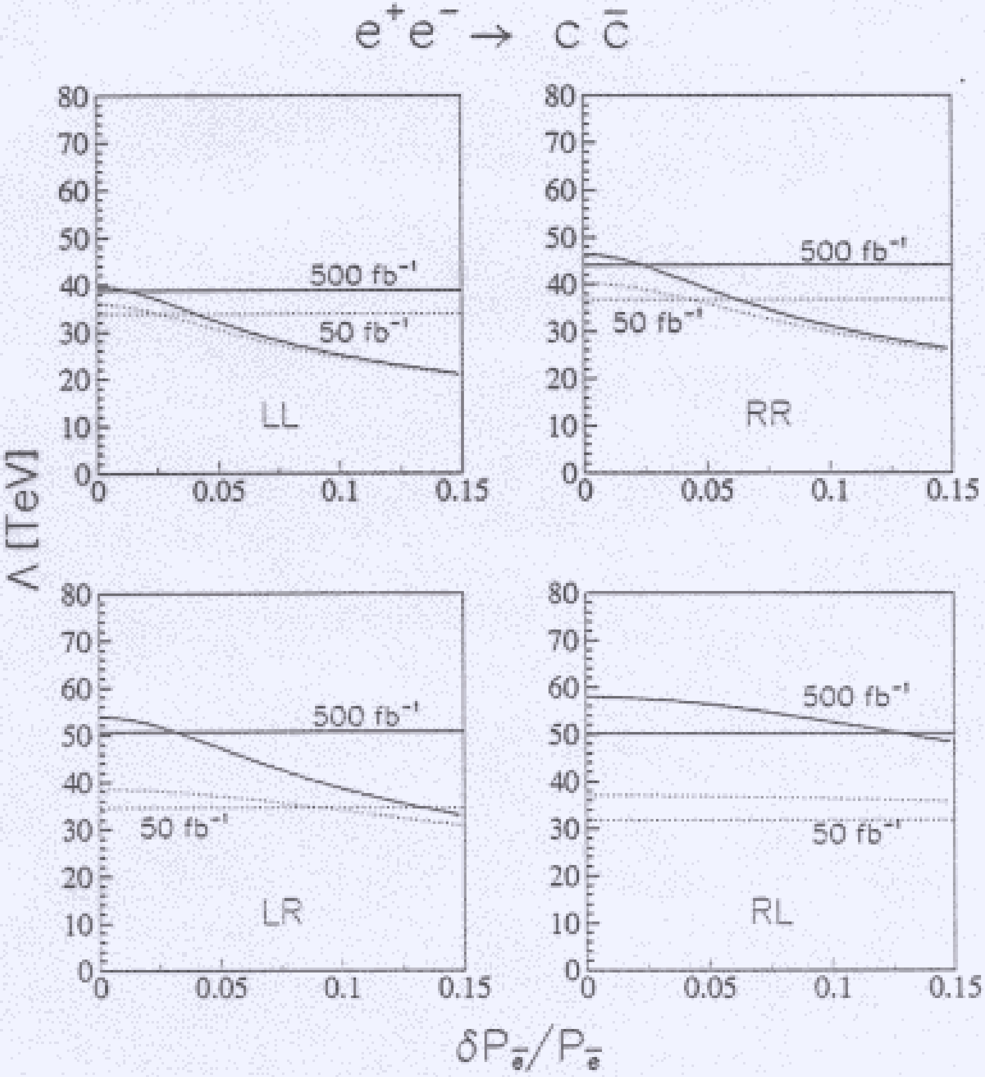


$P_e = 0.9$; $P_{\bar{e}} = 0.6$; $\delta P_e / P_e = 0.5\%$

$e^+e^- \to b\,\bar{b}$



$P_e = 0.9$; $\delta P_e / P_e = 0.5\,\%$; $P_{\bar{e}} = 0.6$



$e^+e^- \to c\,\bar{c}$
Λ [TeV]
$\delta P_{\bar{e}}/P_{\bar{e}}$
500 fb⁻¹
50 fb⁻¹
LL
RR
LR
RL

Final remarks

• Model-independent analysis of C.I. based on "optimal" polarized observables σ_+ and σ_- for $P_{\rm eff} = \pm P$

• individual couplings disentangled *via* helicity cross sections

• electron polarization is a *necessity*

• benefit of positron polarization depends on $P_{\bar{e}}$ *and* $\delta P_{\bar{e}}$

• at higher luminosity: $\delta P_{\bar{e}}$ (and δP_e) increasingly important (w.r.t. δ^{stat})

For the chosen inputs:

• dominant uncertainty for $\Lambda_{\rm RL}$ and $\Lambda_{\rm LR}$: δ^{stat}

• uncertainty for $\Lambda_{\rm LL}$ and $\Lambda_{\rm RR}$: δ^{sys} and δ^{stat} can compete

• for $\delta P_e \simeq \delta P_{\bar{e}} \simeq 0.5\%$: reach on Λ can be improved by 5-30% by e^+ polarization

• depending on flavor: $\Lambda_{\alpha\beta} > (50 - 150) \times \sqrt{s}$

• best sensitivity for $\bar{b}b$ final state, worst for $\bar{c}c$

• need for more detailed expectations on δ^{exp}