Using the GRACE-loop system for computing the electroweak corrections to top-pair production

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European Linear Collider Workshop 2016

Outline

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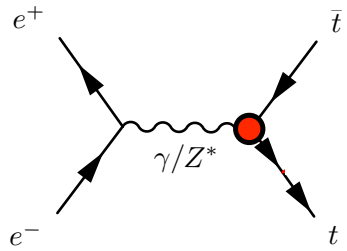
Window for New Physics

$t\bar{t} - Z\gamma$ anomalous coupling measurement — a way to search for New Physics at ILC



- QCD N^{3}LO correction is $\sim 0.1\%$.

  Kiyo et al NPB **8** 23 ('09); Hoang et al NPB **8** 13 ('09)

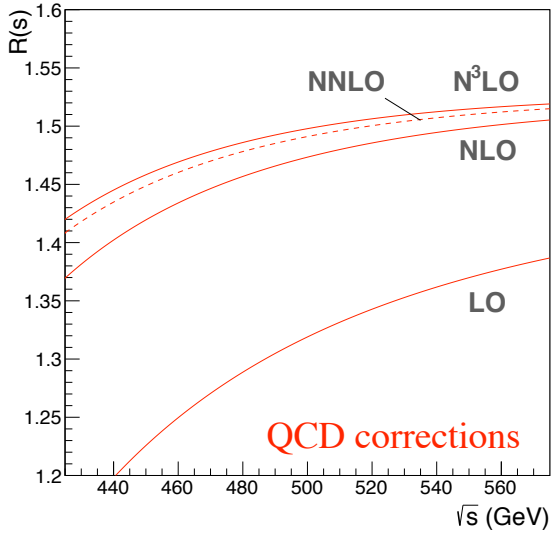
- EW NLO correction is 5% for cross section, 10% for A_{FB}.

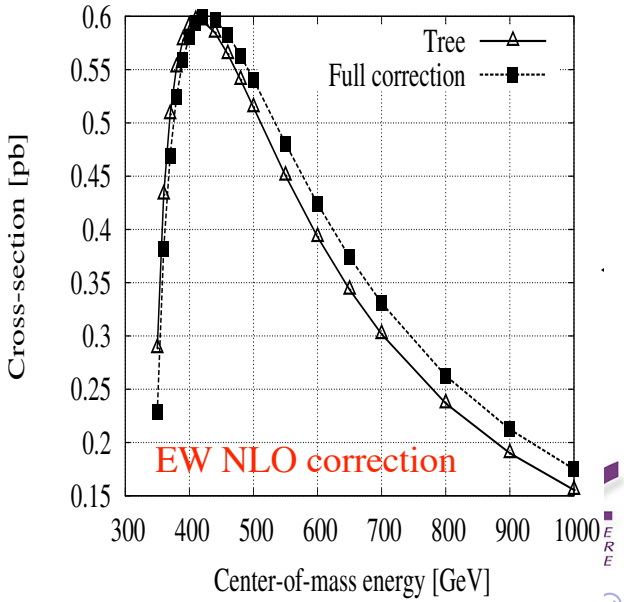
  Fleischer *et al.*, EPJC **31** 37 ('03); Khiem *et al.*, EPJC **73** 4 ('13)

- Experiment gives permil precision.

  Amjad *et al.*, EPJC **75** 10 ('15)

- Beyond SM theories can give relative deviation $> 5\%$ for coupling.



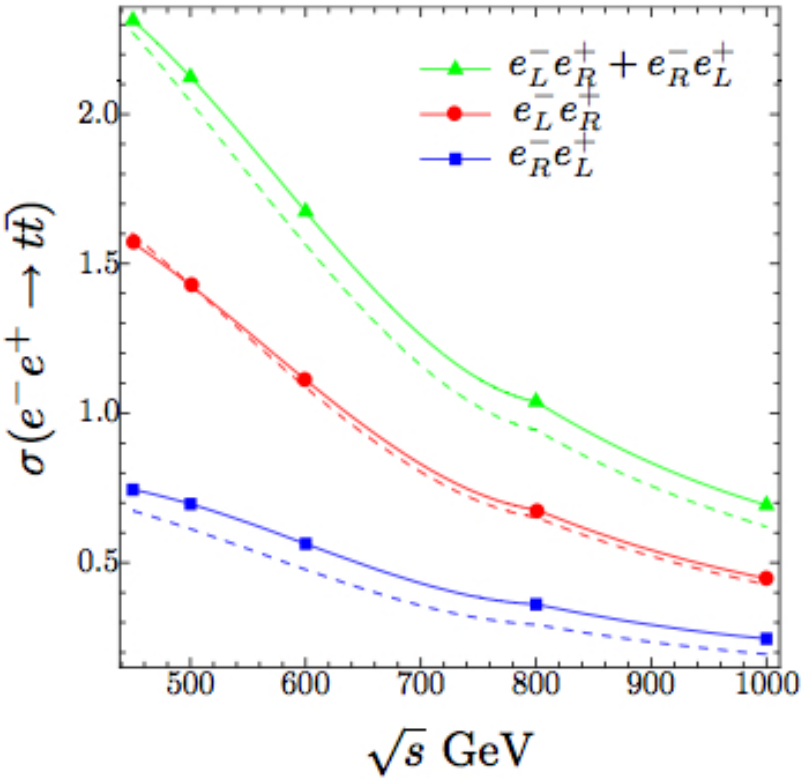


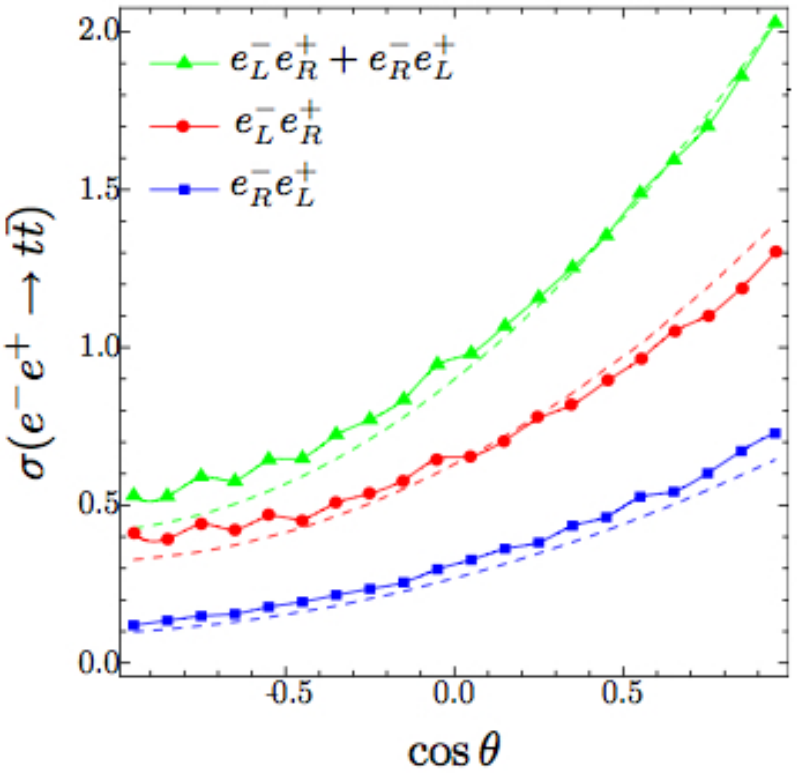
Spin correlation as a tool for precision

EW corrections depend on the initial state polarization

For $(e_L^- e_R^+)$ beam NLO EW correction is surprisingly small: $\lesssim 1\%$

Corrections were computed using GRACE [Khiem, Kou, Kurihara, Le Diberder, EPJC **73** 4 ('13)]





- Polarized beam option $(e^+e^-) = (\pm 0.8, \mp 0.3)$ is available at ILC

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Closer look at NLO electroweak corrections

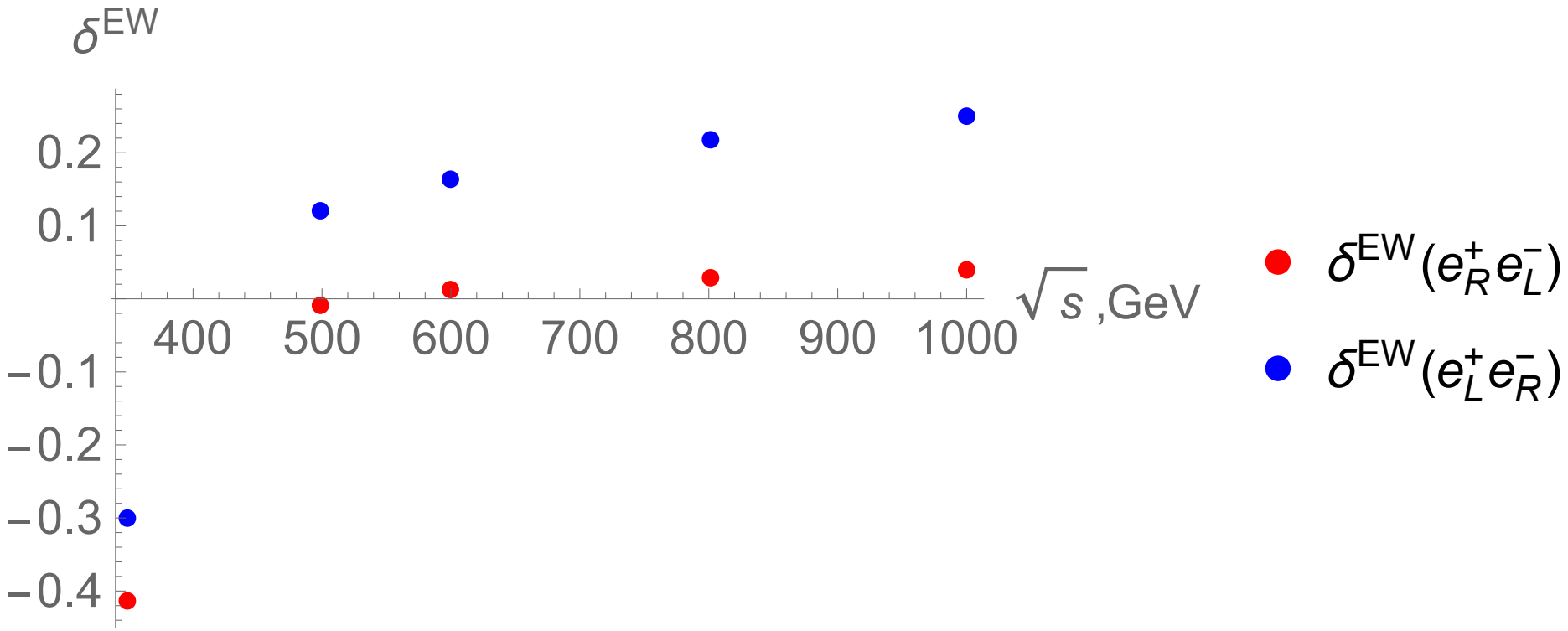


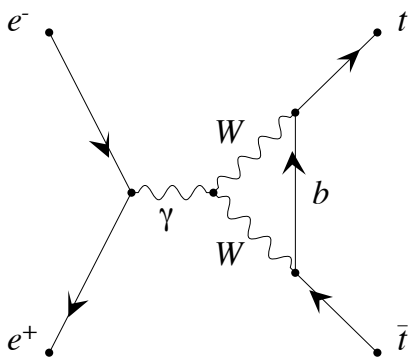
Figure 1: Center-of-mass energy dependence of the relative EW correction for different initial state polarizations.

Question:

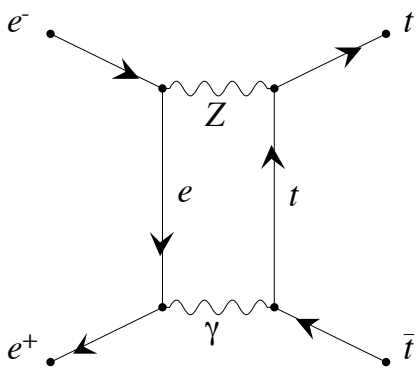
Why $\delta^{EW}(e_R^+ e_L^-)$ is so small?

Feynman diagrams to the $e^+e^- \to t\bar{t}$ at 1-loop

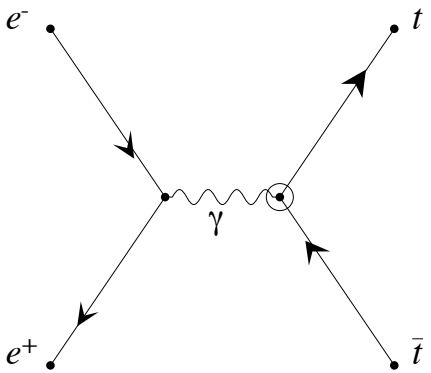
Graph 1



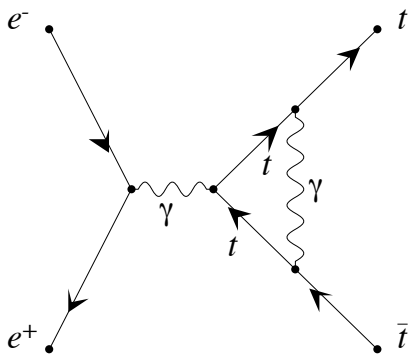
Graph 101



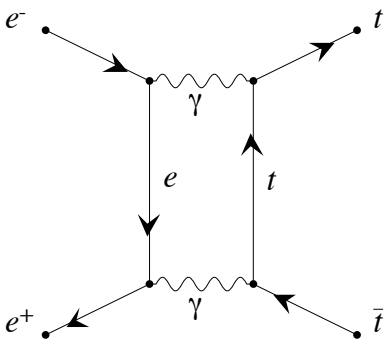
Graph 133



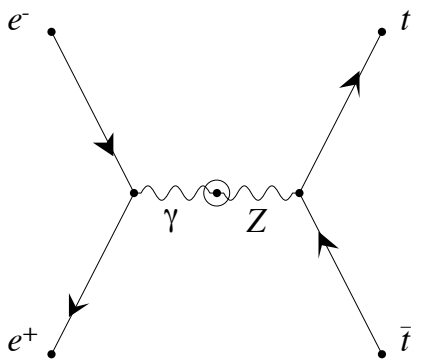
Graph 5



Graph 97



Graph 142



Individual EW corrections: vertex corrections

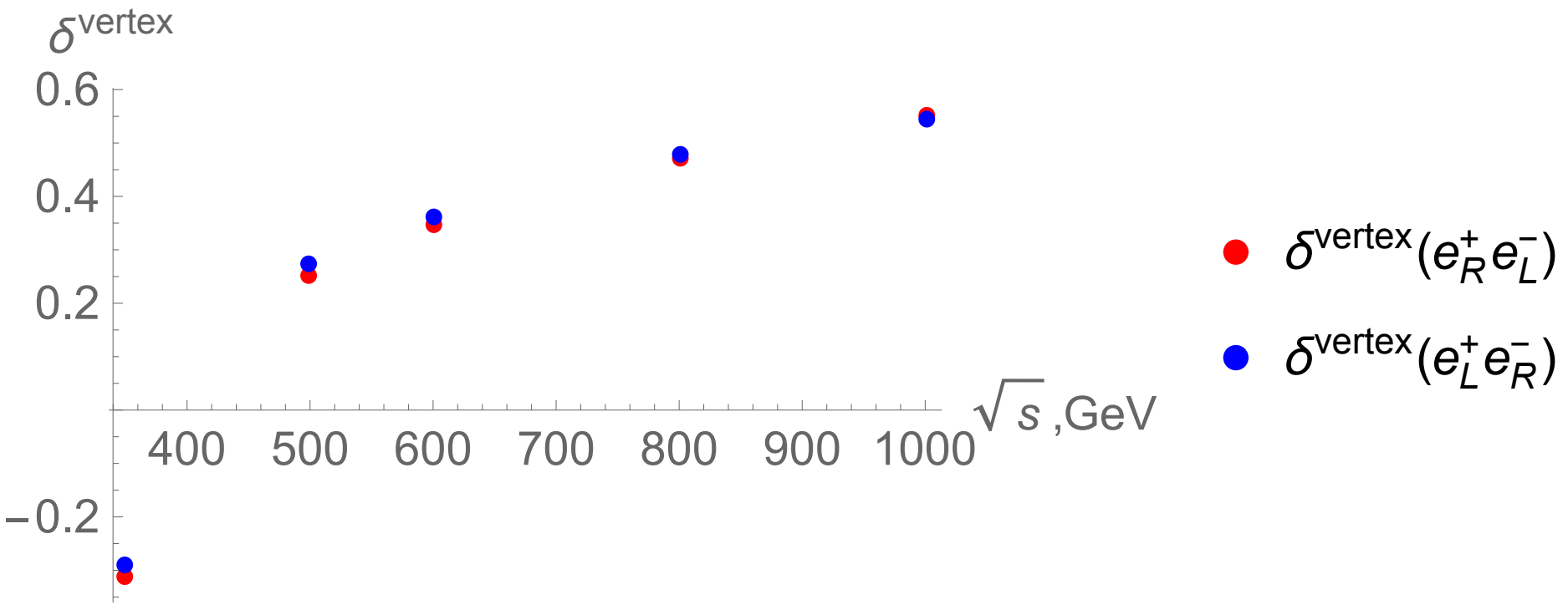


Figure 2: Relative vertex electroweak correction.

- Almost no dependence on polarization. The correction is positive.

Individual EW corrections: box corrections

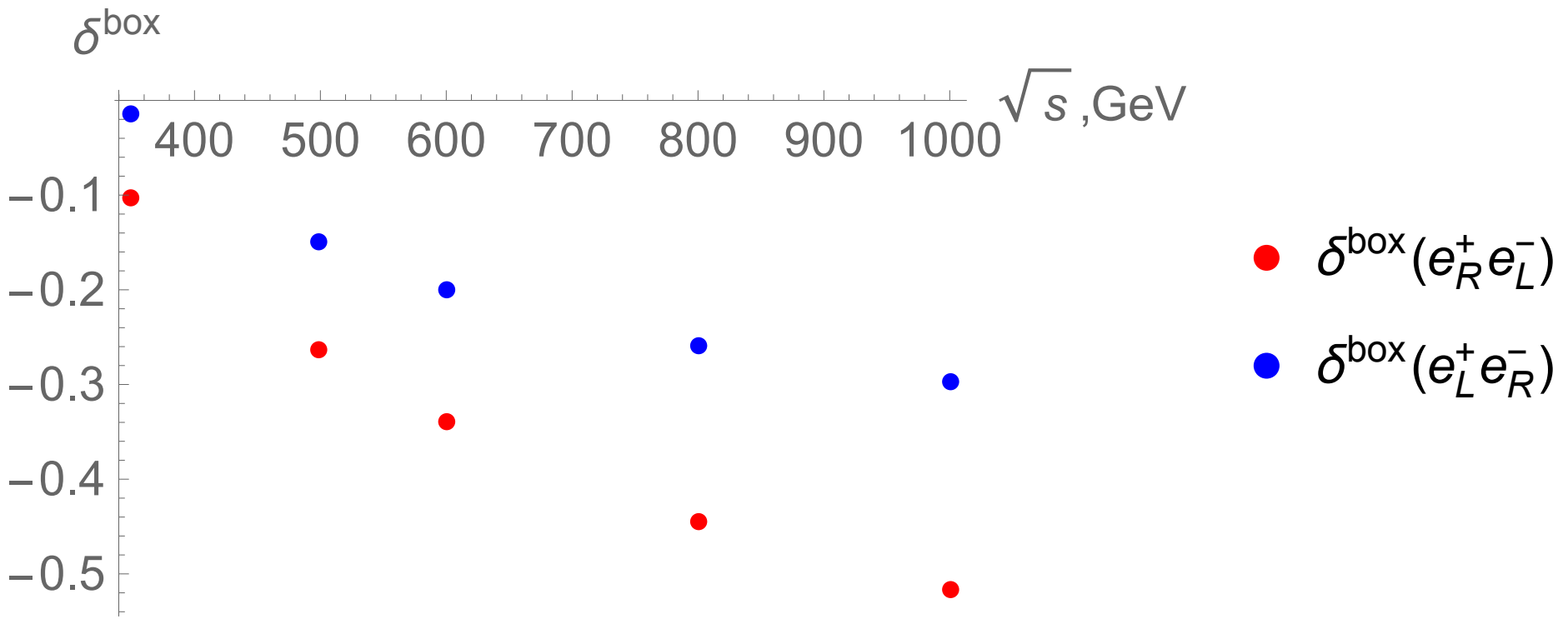


Figure 3: Relative EW correction coming from box diagrams.

Relative correction comes from both, vertex and box part, but...

All dependence on initial polarization comes from box diagrams. The correction is negative.

Cancellation of vertex and box corrections for $e_R^+ e_L^-$

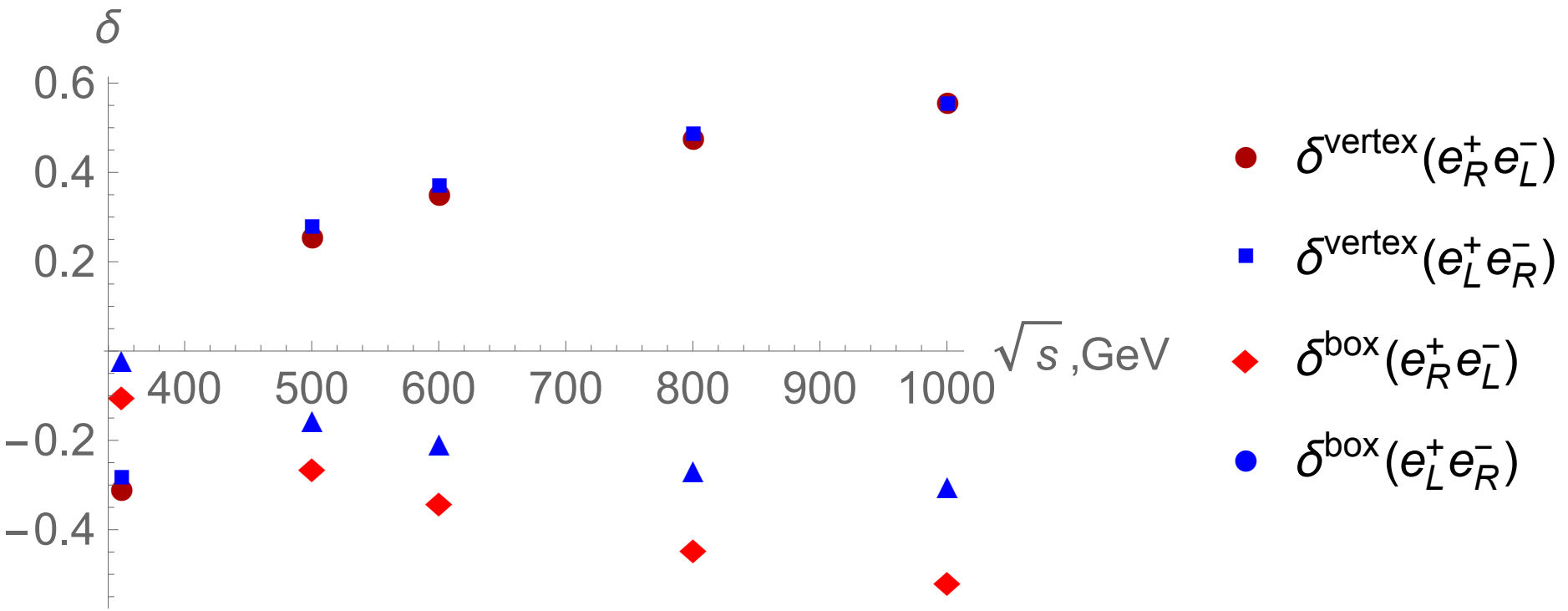


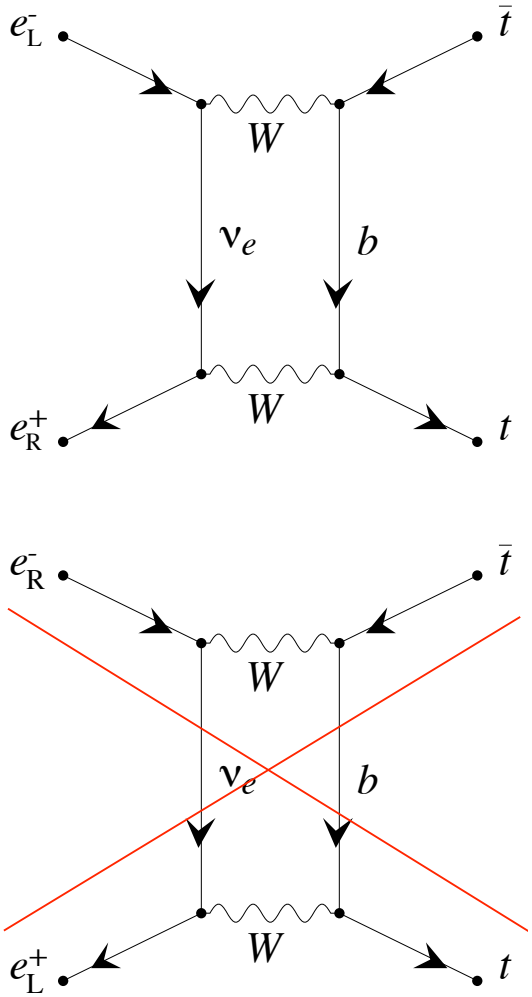
Figure 4: Box and vertex EW corrections.

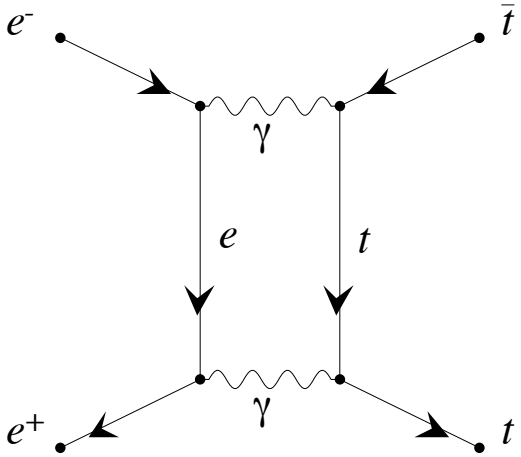
Accidental cancellation of vertex and box corrections

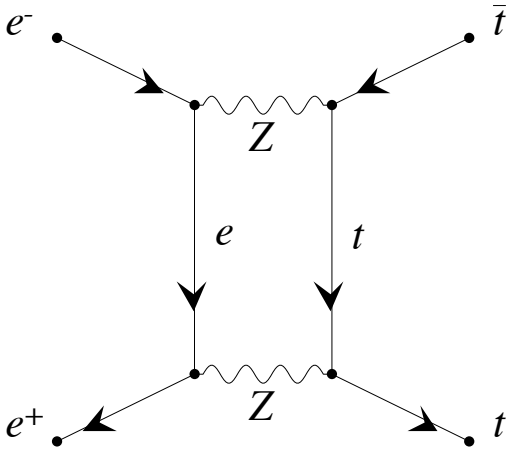
At 500GeV for $(e_R^+ e_L^-)$ the correction is $\delta \approx -0.8\%$.

Outline

Box Feynman diagrams to the $e^+e^- \to t\bar{t}$







- W box contribute only to $e^+_R e^-_L$ but not $e^+_L e^-_R$
- The photon and Z boxes are the present for both $e^+_R e^-_L$ and $e^+_L e^-_R$.

Electroweak corrections coming from box diagrams

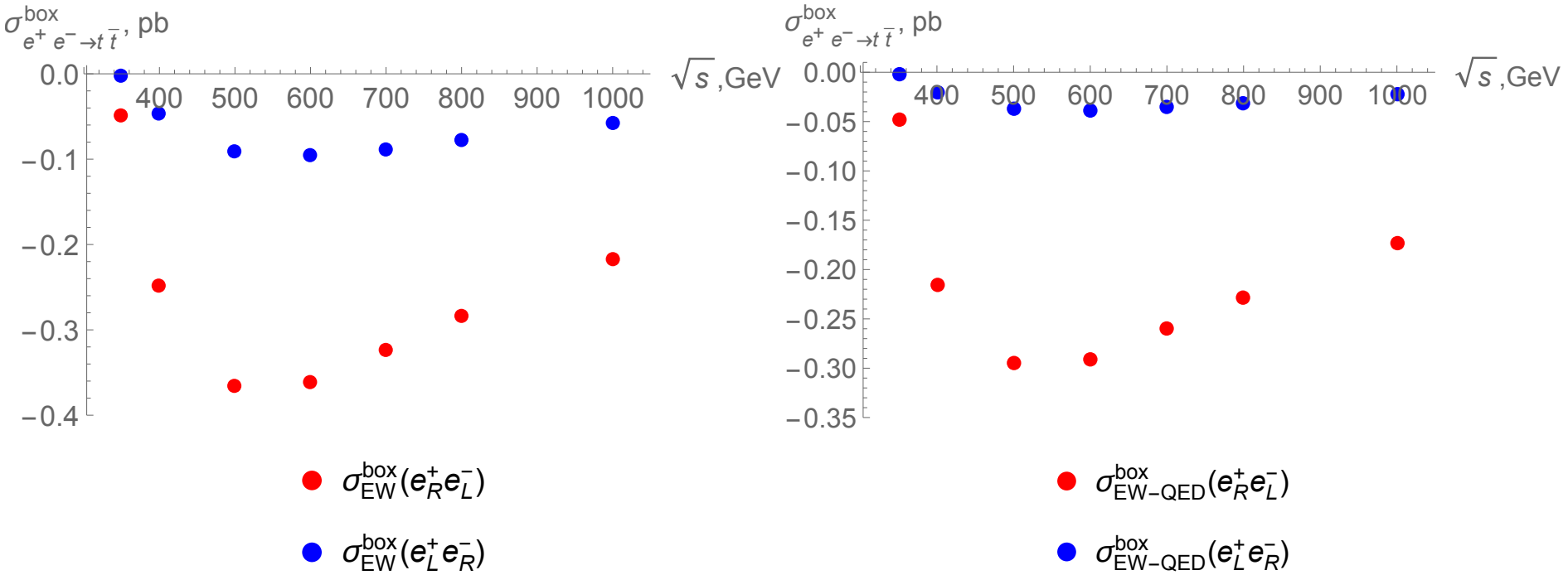


Figure 5: Total EW(on the left) and "weak"(on the right) box correction to the $e^+e^- \to t\bar{t}$ depending on the initial polarization.

- $e^+_R e^-_L$: W and Z contribution
- $e^+_L e^-_R$: only Z contribution

W boson contribution

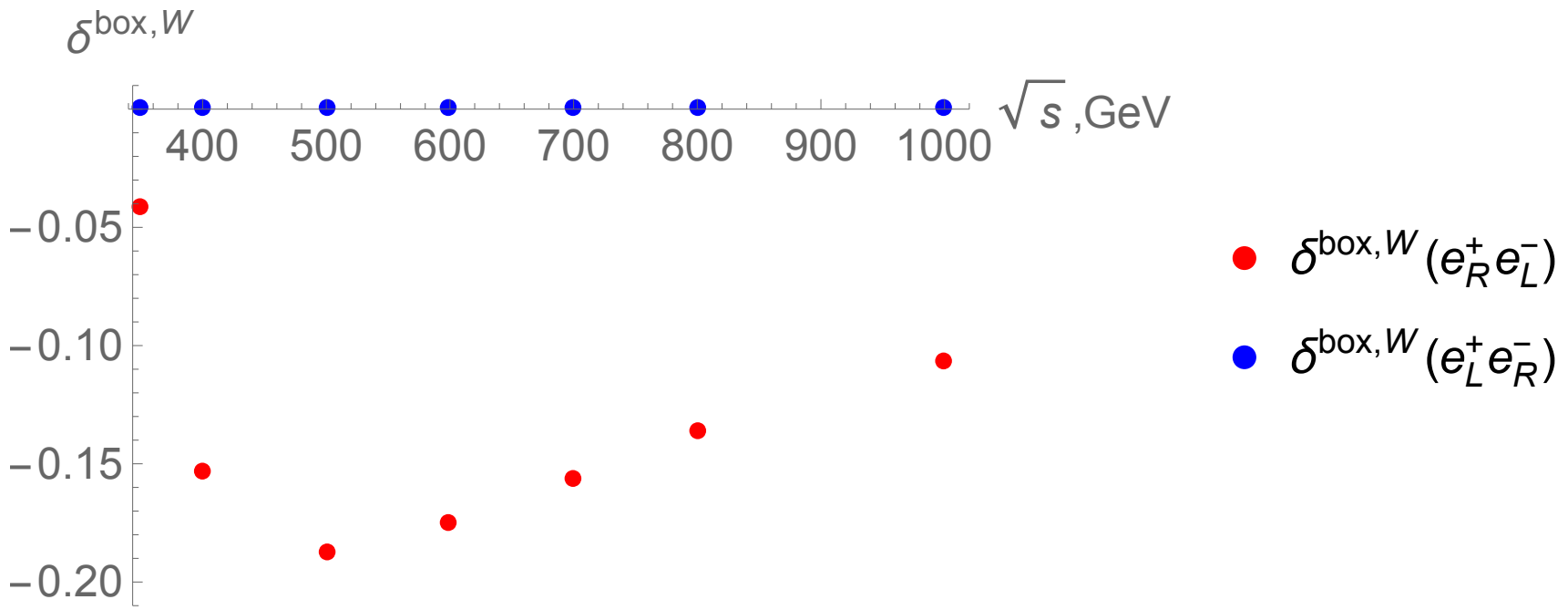


Figure 6: W box contribution to the $e^+e^- \to t\bar{t}$.

$\delta^{EW}(e_R^+ e_L^-)$ is larger principally because of W box contribution.

Parametrization of EW box corrections

Just for testing our result...

We will try to fit the σ^{box} energy dependence using existing theories.

Box diagrams contain double logarithms as a main contribution and single logarithms as subleading terms:[1]

- Single logarithms $\ln \frac{s}{m^2_{Z,W}}$ come from the analogue of QED collinear divergencies.
- Double logarithms $\ln^2 \frac{s}{m^2_{Z,W}}$ come from the analogue of QED divergences that are of IR and collinear origin.

[1] **M. Beccaria, P. Ciafaloni, D.Comelli, F. Renard Phys. Rev.D (2000)** .

Parametrization of EW box corrections

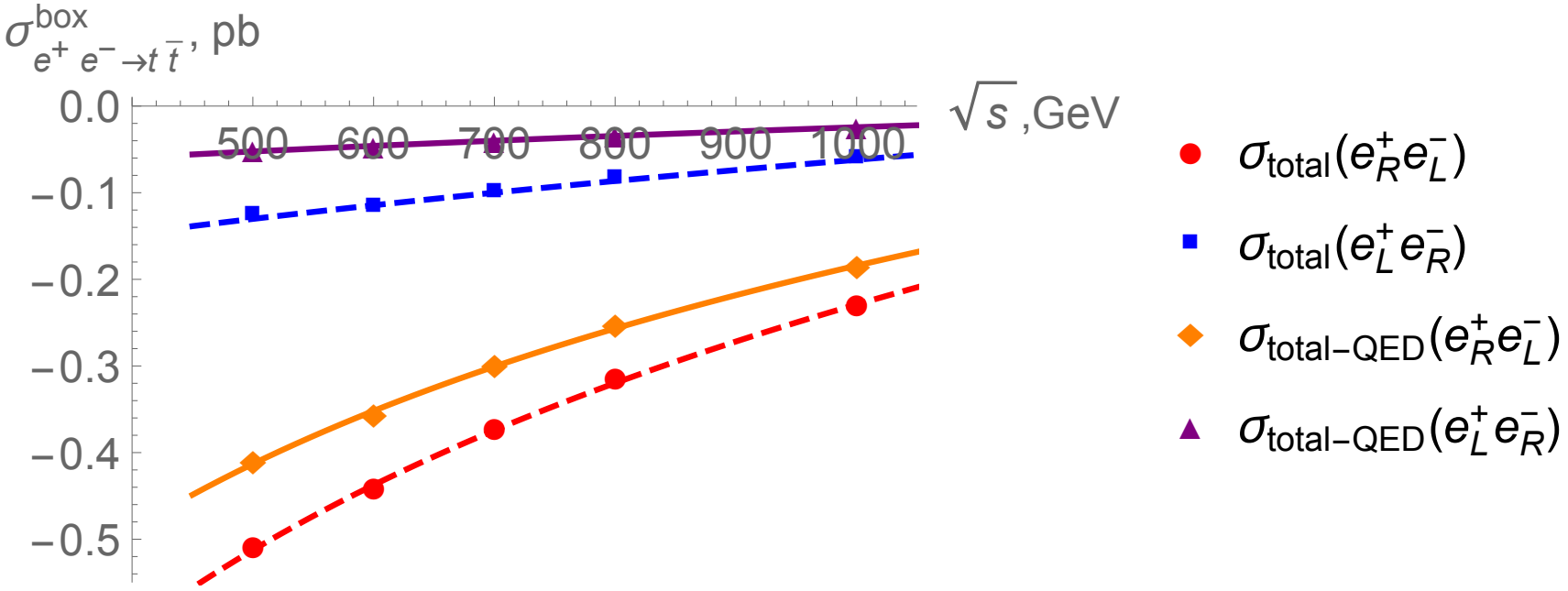


Figure 7: Total and weak box correction to the $e^+e^- \to t\bar{t}$ fitted with double log: $\sigma \sim const + \left(\ln \frac{s}{M^2_{W,Z}}\right)^2$.

- The double-log-dependence fits well the box contributions computed with the GRACE program. [2]

[2] Here we divided the cross-section by $\sqrt{1-\frac{4m_t^2}{s}}$ in order to cancel phase space effects near $t\bar{t}$ threshold.

Outline

Forward–backward asymmetry at NLO

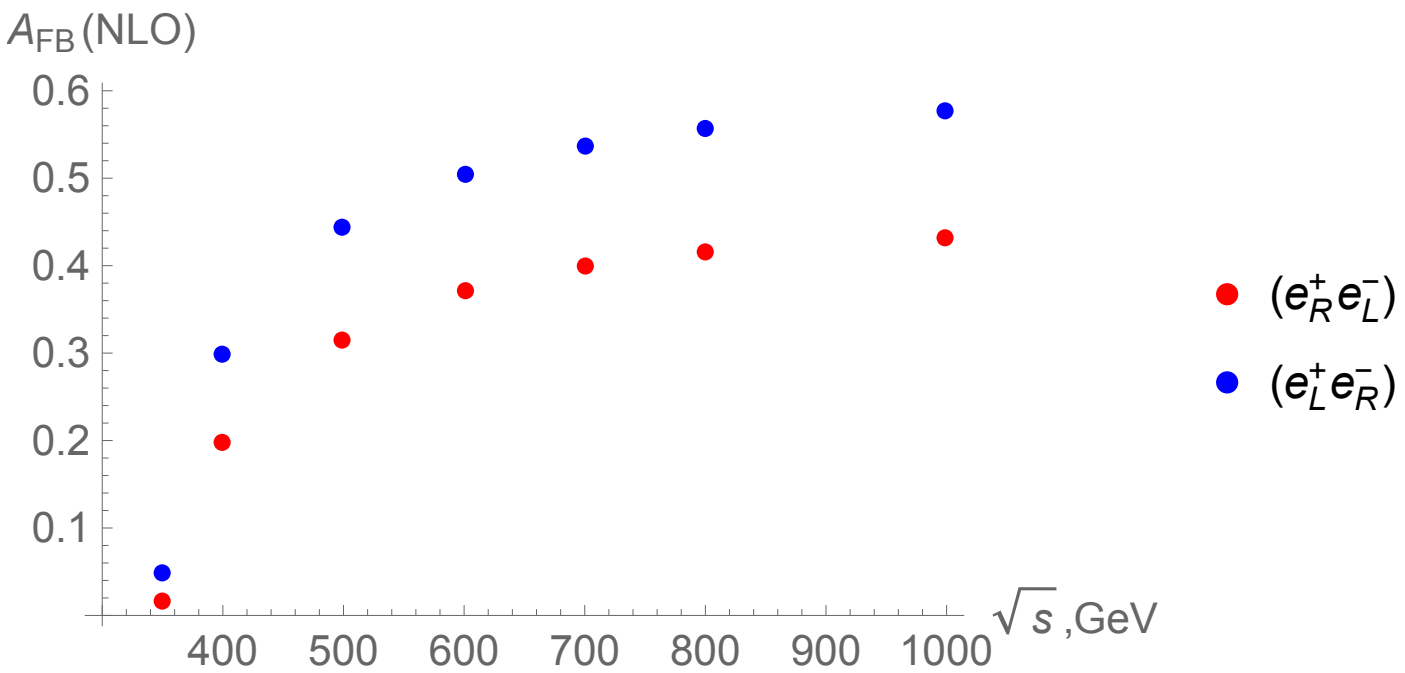


Figure 8: Forward–backward asymmetry at NLO for different initial polarizations

$$A_{FB} = \frac{\sigma(0^\circ \leq \theta_t \leq 90^\circ) - \sigma(90^\circ \leq \theta_t \leq 180^\circ)}{\sigma(0^\circ \leq \theta_t \leq 90^\circ) + \sigma(90^\circ \leq \theta_t \leq 180^\circ)}$$

Forward–backward asymmetry at NLO

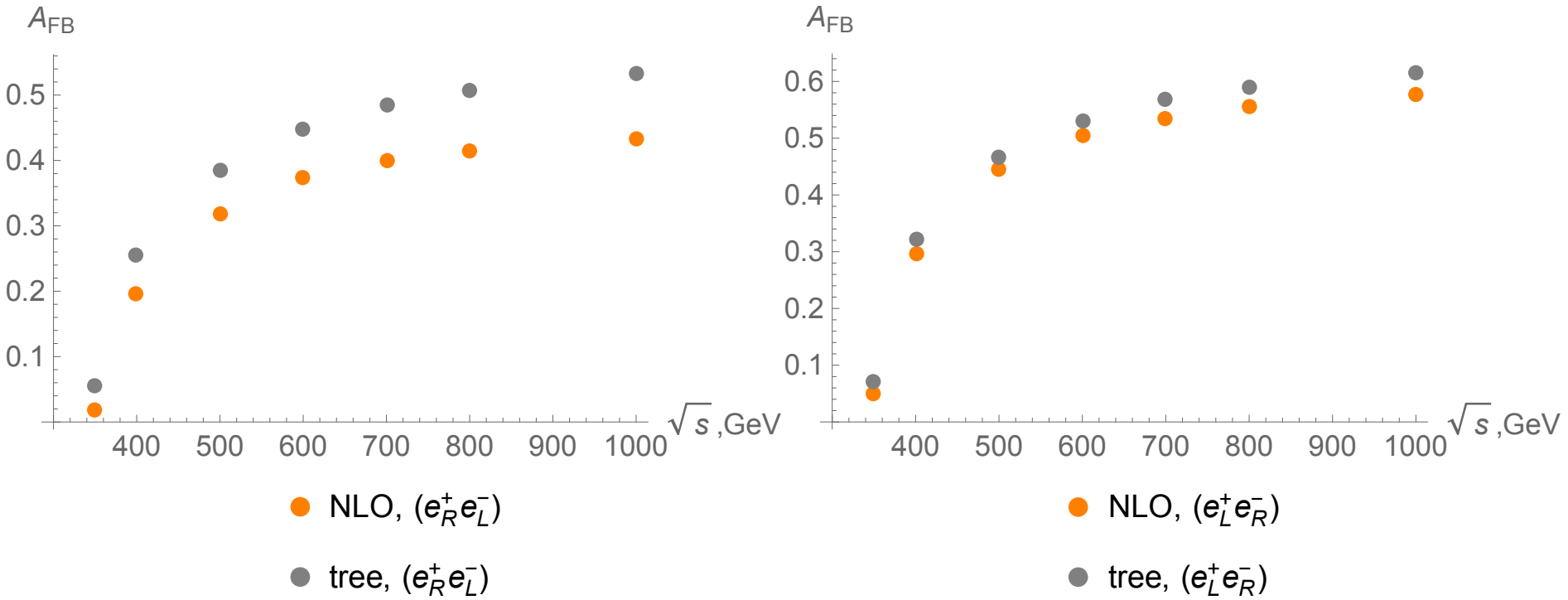


Figure 9: A_{FB} at NLO compared to the tree level result

- Correction to the A_{FB} for $(e_R^+ e_L^-)$ initial state becomes much larger with energy than for $(e_L^+ e_R^-)$.

Separate contributions to A_{BF}

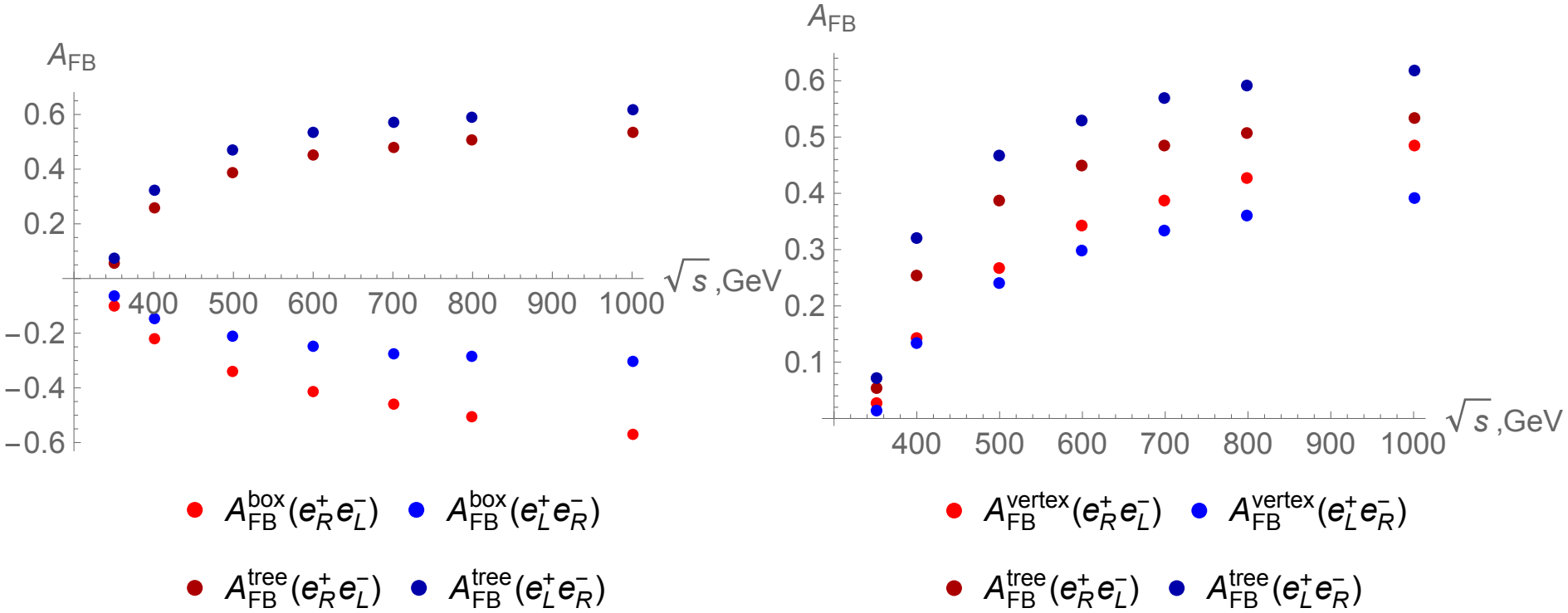
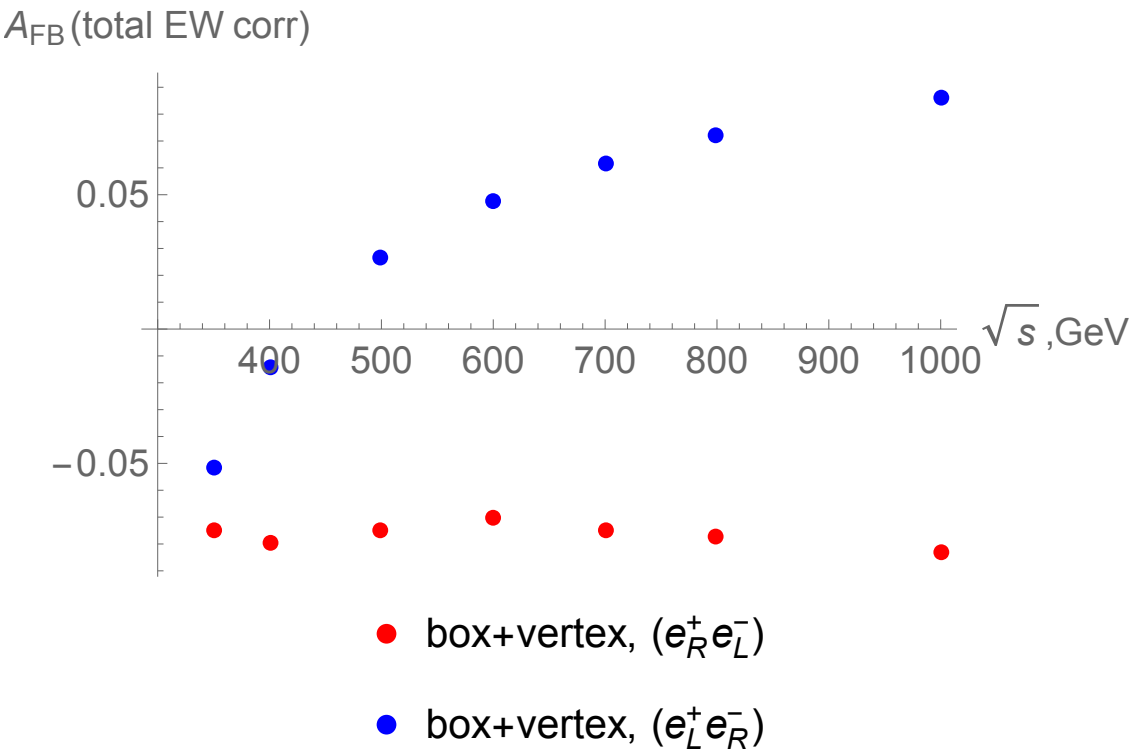


Figure 10: Box and vertex correction contribution to A_{FB}, compared to the tree asymmetry.

Total correction



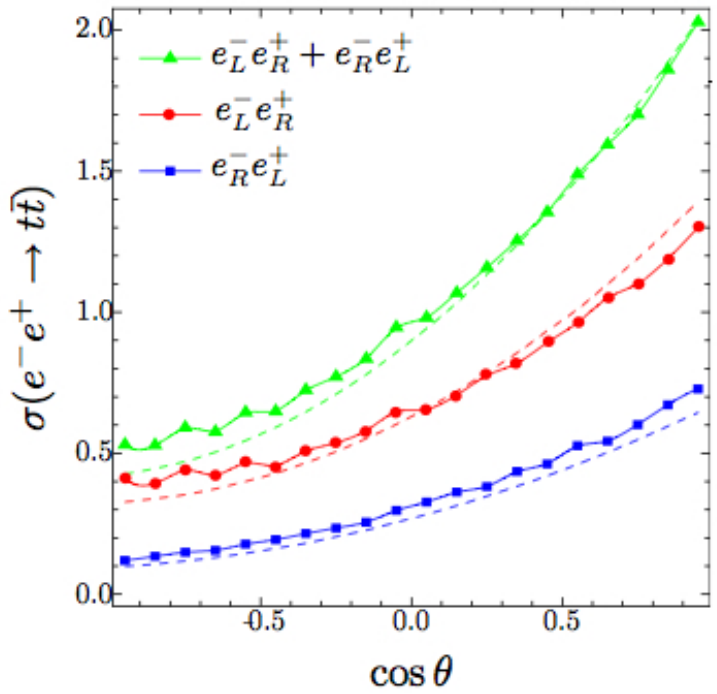


Figure 11: Total EW correction contribution to forward–backward asymmetry

[Khiem, Kou, Kurihara, Le Diberder, EPJC **73** 4 ('13)]

- Almost no energy dependence for $(e_R^+ e_L^-)$ initial state.

Outline

Summary

- EW NLO correction strongly depends on polarization.
  - We found in this work, the main reason seems to be the different W contributions to box diagrams.
- For $(e_R^+ e_L^-)$ initial state, especially, at 500 GeV the NLO correction accidentally cancel, which results in a very small NLO contribution: $\delta \sim 1\%$ level
- Vertex and box corrections are both large ($\gtrsim 20\%$), but for $(e_R^+ e_L^-)$ they cancel each other.
  - Because of extra W contribution.
- $\delta^{EW}_{e_R^+ e_L^-}(500\text{GeV}) \approx 0.8\% \rightsquigarrow$ polarized beam is useful at ILC since New Physics might be at $\gtrsim 5\%$.
  - Note that QCD corrections up to N^{3}LO and experimental precision are $\sim 0.1\%$
- Although for $(e_R^+ e_L^-)$ the δ^{EW} is tiny, there is a significant negative contribution to A_{FB}.

Here I presented preliminary results, work is still in progress!

Backup: What is GRACE?

GRACE is an automatic computation system for calculating High Energy Physics processes at tree and one-loop level.

- One can obtain full set of the Feynman diagrams for the specific process.
- Wide range of kinematics is available for computation.
- Using the generated fortran code one can calculate amplitudes and cross-sections.
- The gauge invariance can be checked.
- The cross section is computed by Monte Carlo integration package BASES.
- The events are simulated by event generation package SPRING.

Backup: Algorithm

For getting the values of physical observables of the specific process we have to...

1. Create an input file: initial & final state, kinematics type.
2. Generate the fortran code.
3. Modify the fortran files if setting the specific kinematic parameters, polarization, ... is needed.
4. Compile the fortran code.

- Output of generated executables gives cross-section, check of the the gauge independence, and generated events.

Backup: In the result

NLO cross-section of the $e_R^+ e_L^- \to t\bar{t}$ process.

```
 Convergency Behavior for the Integration Step
-------------------------------------------------------------------------------
<- Result of each iteration -> <- Cumulative Result -> < CPU time >
IT Eff R_Neg Estimate Acc % Estimate(+- Error )order Acc % ( H: M: Sec )
-------------------------------------------------------------------------------
1 100100.00 -6.647E-01 0.027 -6.647040(+-0.001819)E-01 0.027 0:07:08.26
2 100100.00 -6.645E-01 0.027 -6.646174(+-0.001283)E-01 0.019 0:10:42.88
3 100100.00 -6.645E-01 0.027 -6.645904(+-0.001043)E-01 0.016 0:14:16.04
4 100100.00 -6.648E-01 0.027 -6.646396(+-0.000898)E-01 0.014 0:17:48.01
5 100100.00 -6.645E-01 0.027 -6.646023(+-0.000803)E-01 0.012 0:21:23.94

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