A status of electroweak/QCD radiative corrections on a top quark pair production at the open-top region

Kurihara, Y. (KEK)

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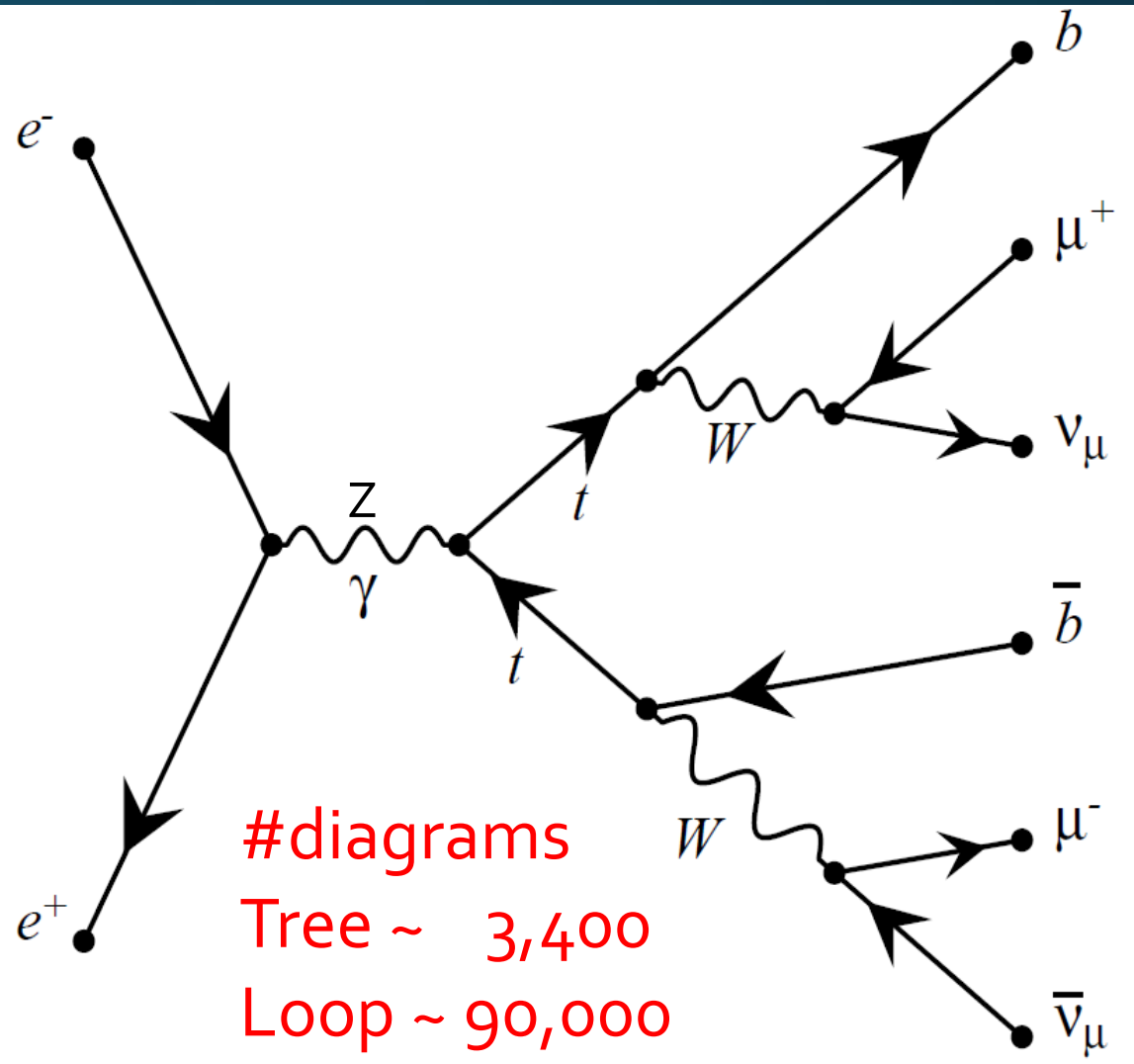
  - Process: $e^+ e^- \to t \bar{t} \to b \bar{b} f \bar{f} f \bar{f}$ @ ILC ($\sqrt{s}$>500 GeV)
- Full $O(\alpha)$ electroweak corrections w/ beam polarization effects
- Higher order re-summation of the photonic effect (Radiator method)
- QCD corrections on the top quark production and its decay
- Summary

Introduction

Introduction

Threshold : M_t, Γ_t measurements
Open top : Precise measurement

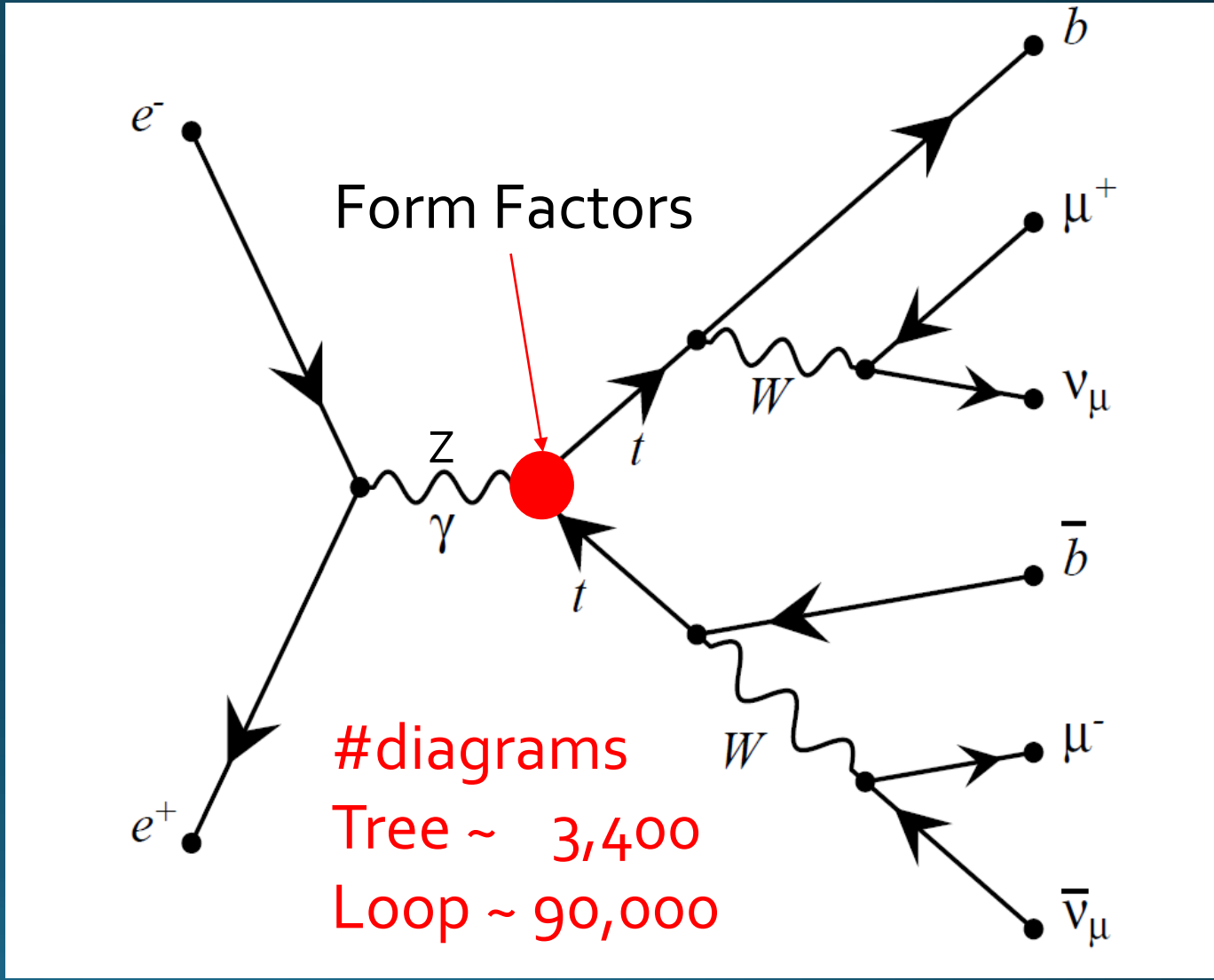


#diagrams
Tree ~ 3,400
Loop ~ 90,000

Introduction

Threshold : M_t, Γ_t measurements
Open top : Precise measurement

BSM

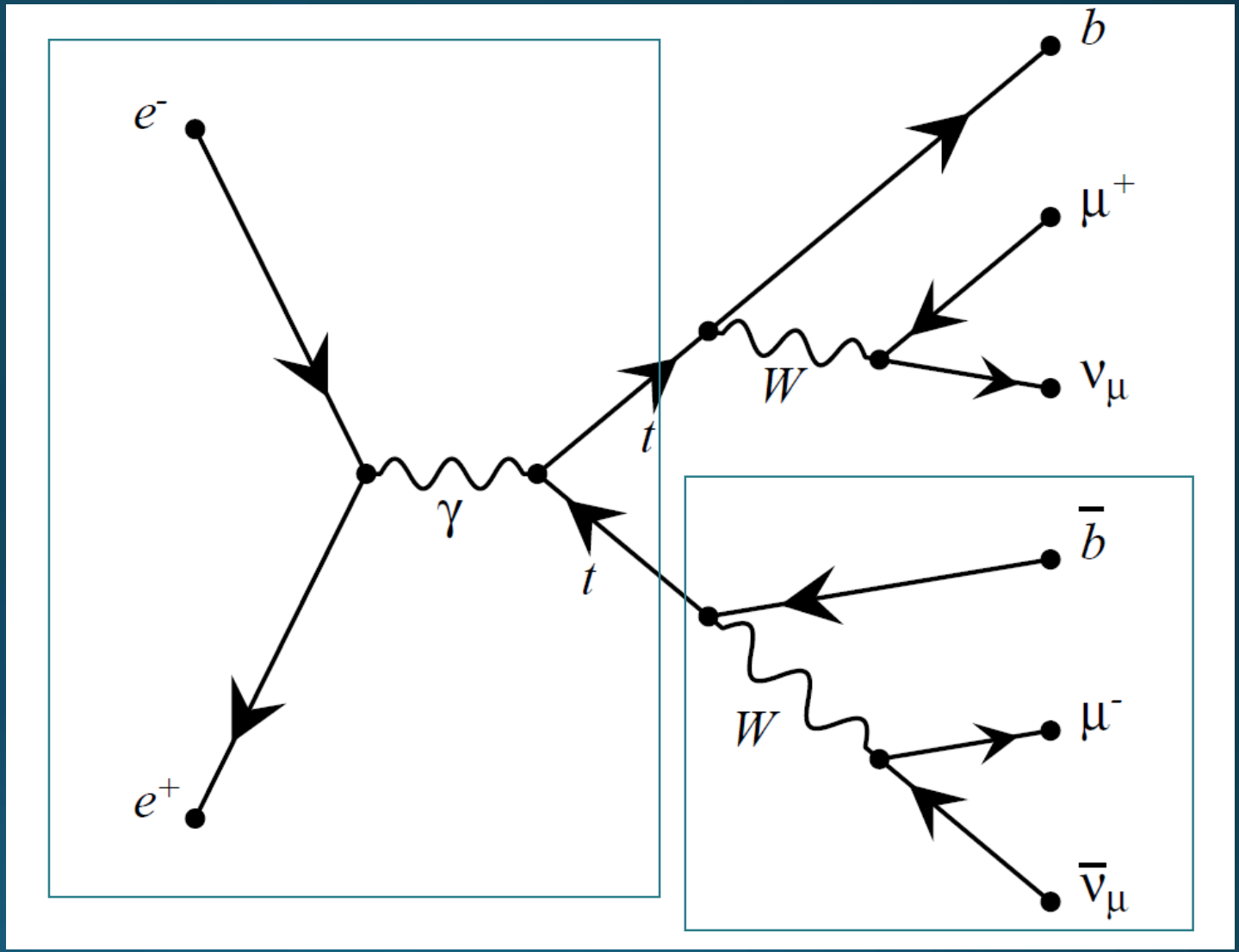


P. H. Khiem, E. Kou, Y. Kurihara, F. Le Diberder, Probing New Physics using top quark polarization in the $e^+e^- \to t\bar{t}$ process at future Linear Colliders, 2015. arXiv:1503.04247.

Introduction

Narrow width approx.

Double-pole approx.



#diagrams
Tree ~ 4
Loop ~ 150

#diagrams
Tree ~ 2
Loop ~ 80

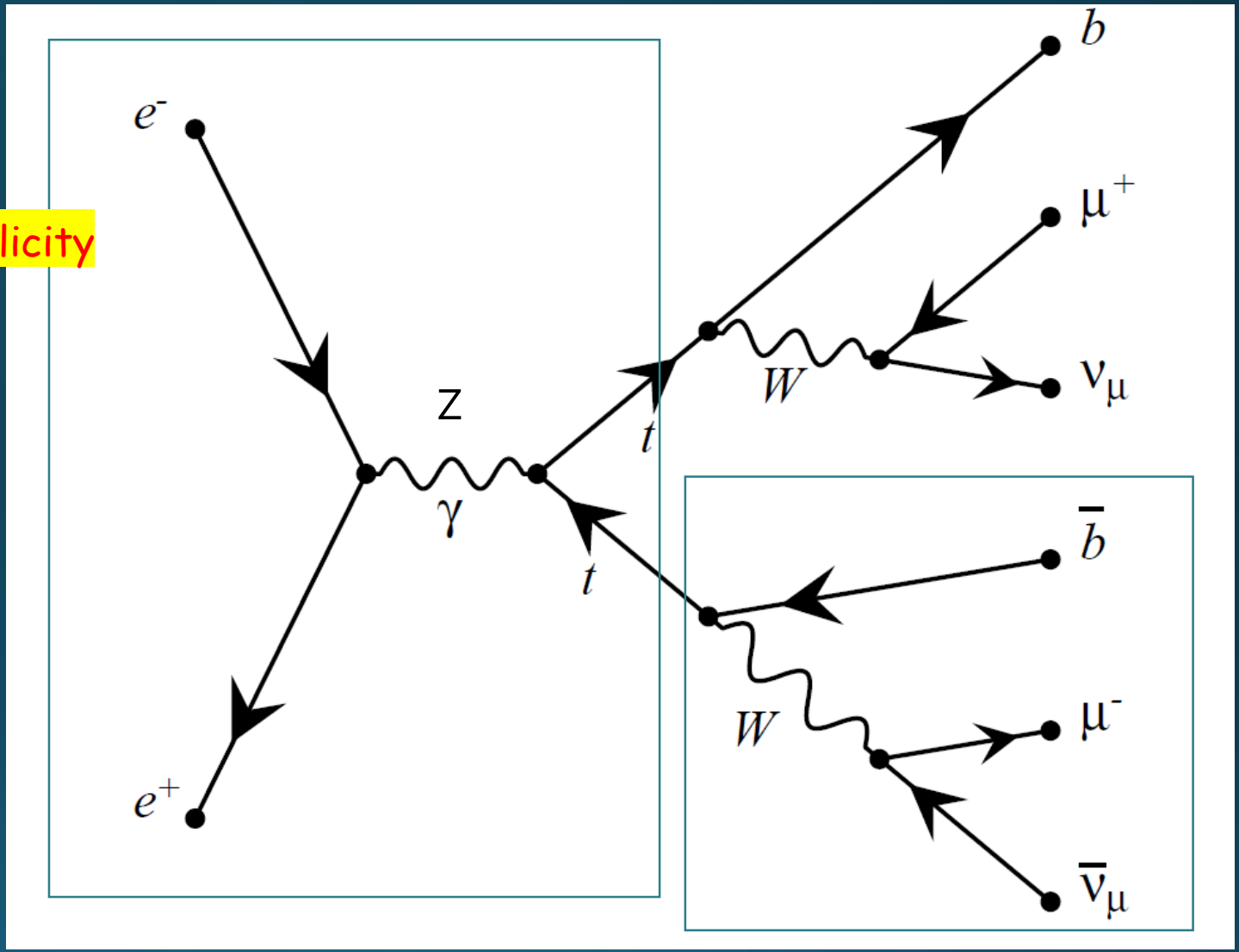
Introduction

Narrow width approx.

For simplicity

Double-pole approx.

QCD corrections

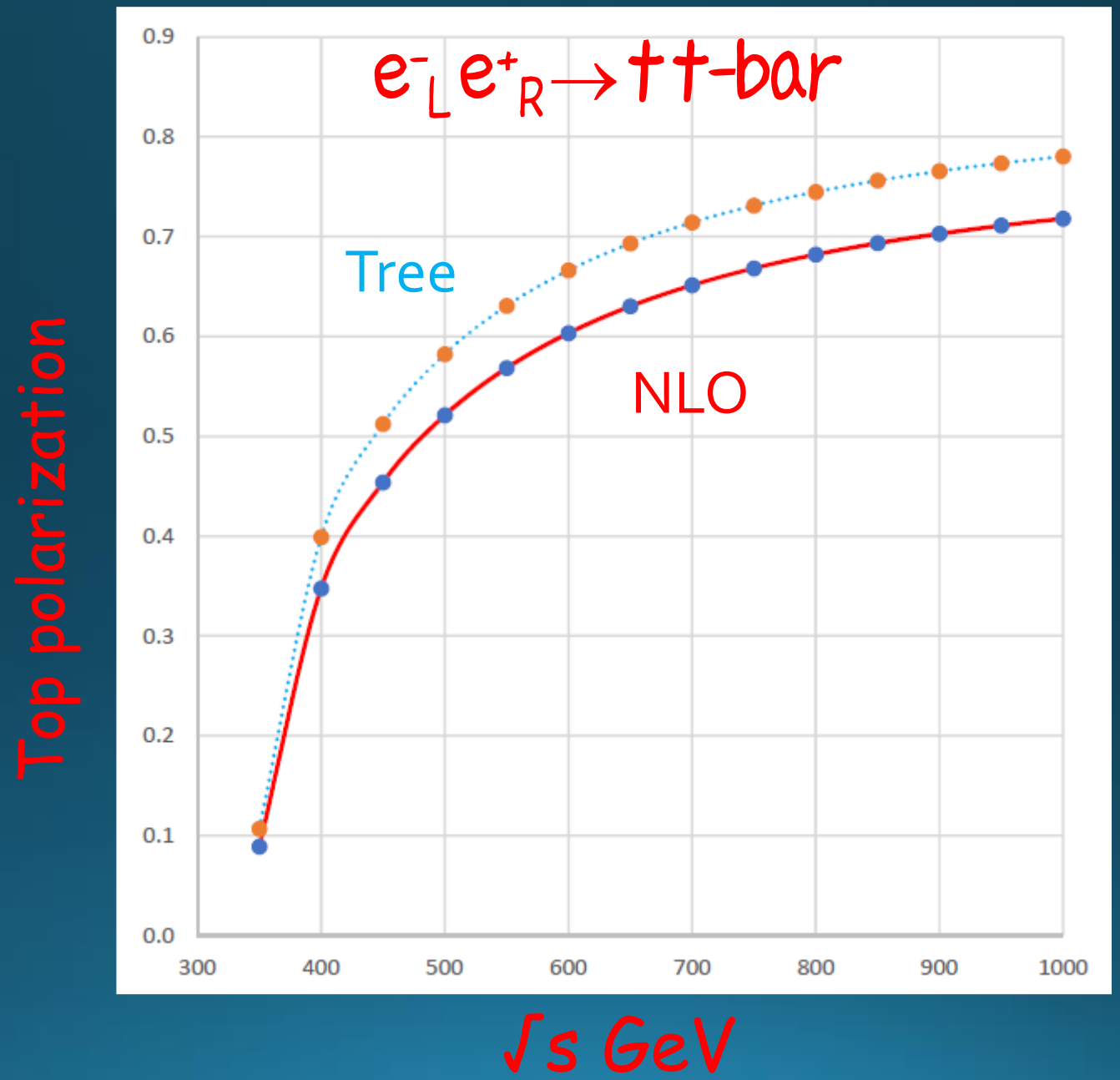


#diagrams
Tree ~ 4
Loop ~ 150

#diagrams
Tree ~ 2
Loop ~ 80

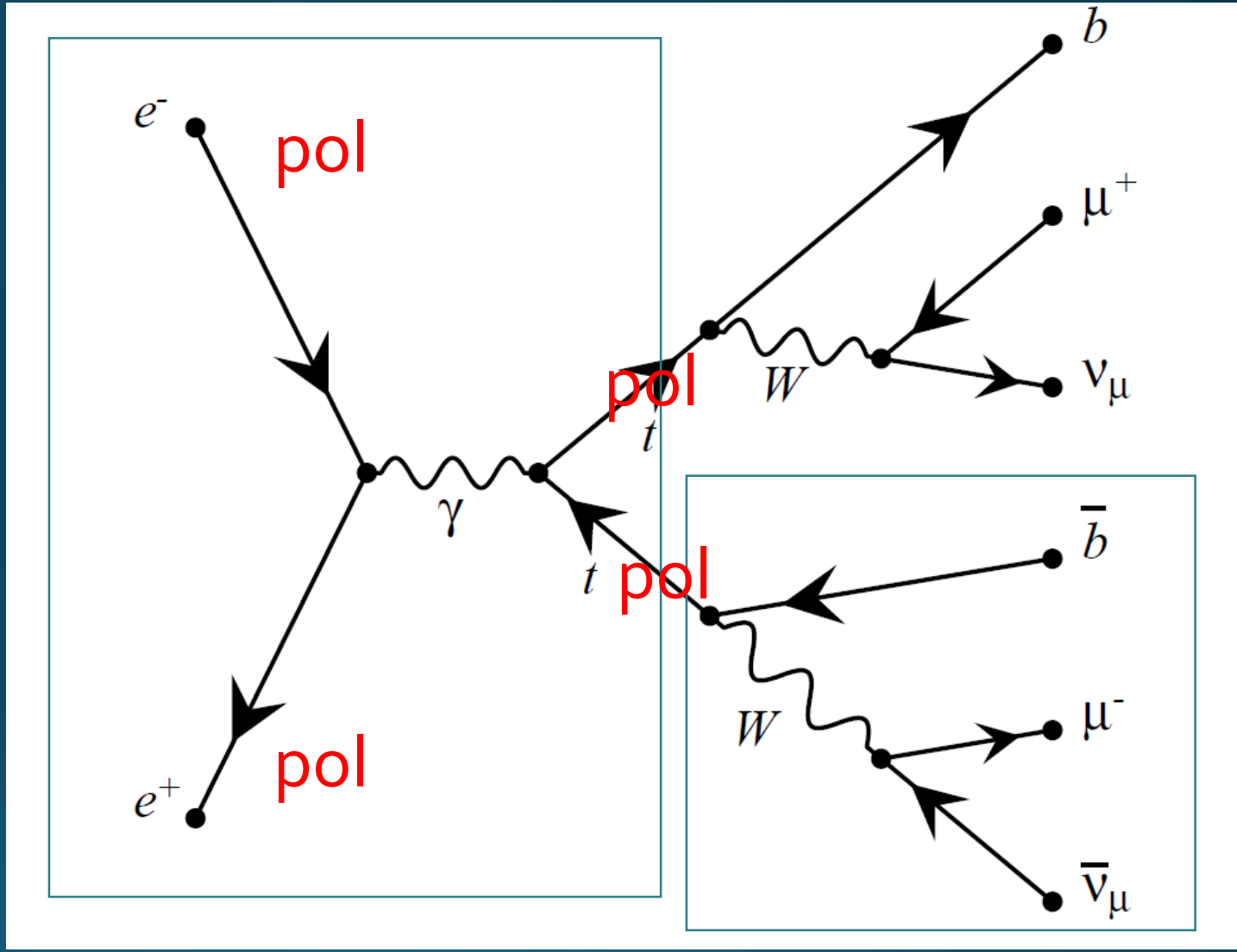
Introduction

$$Top\ Pol. = \frac{top(L)}{top(L) + top(R)}$$



Narrow width approx.

Double-pole approx.



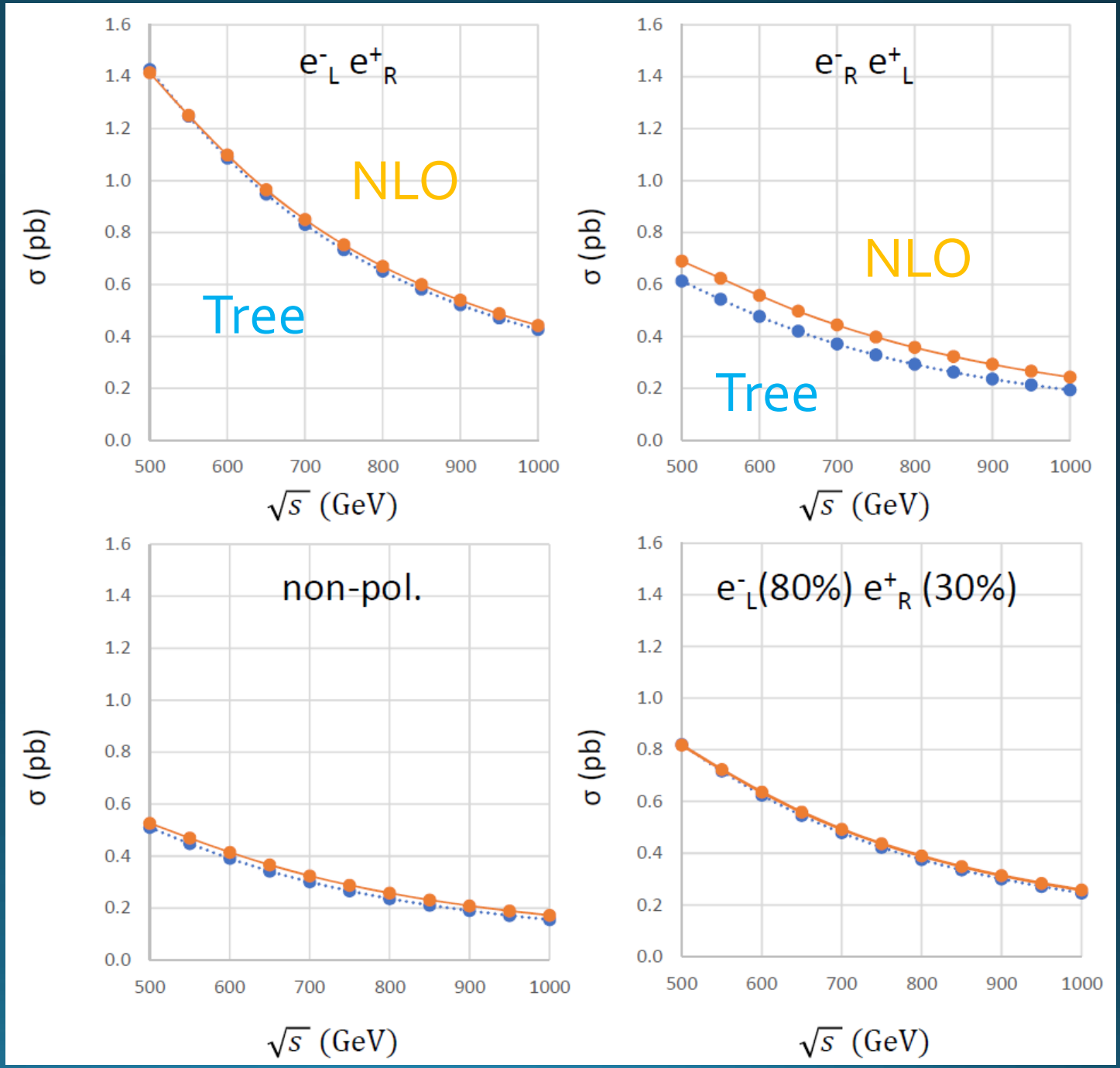
#diagrams
Tree ~ 4
Loop ~ 150

#diagrams
Tree ~ 2
Loop ~ 80

O(α) ELWK corrections

O(α) ELWK correction

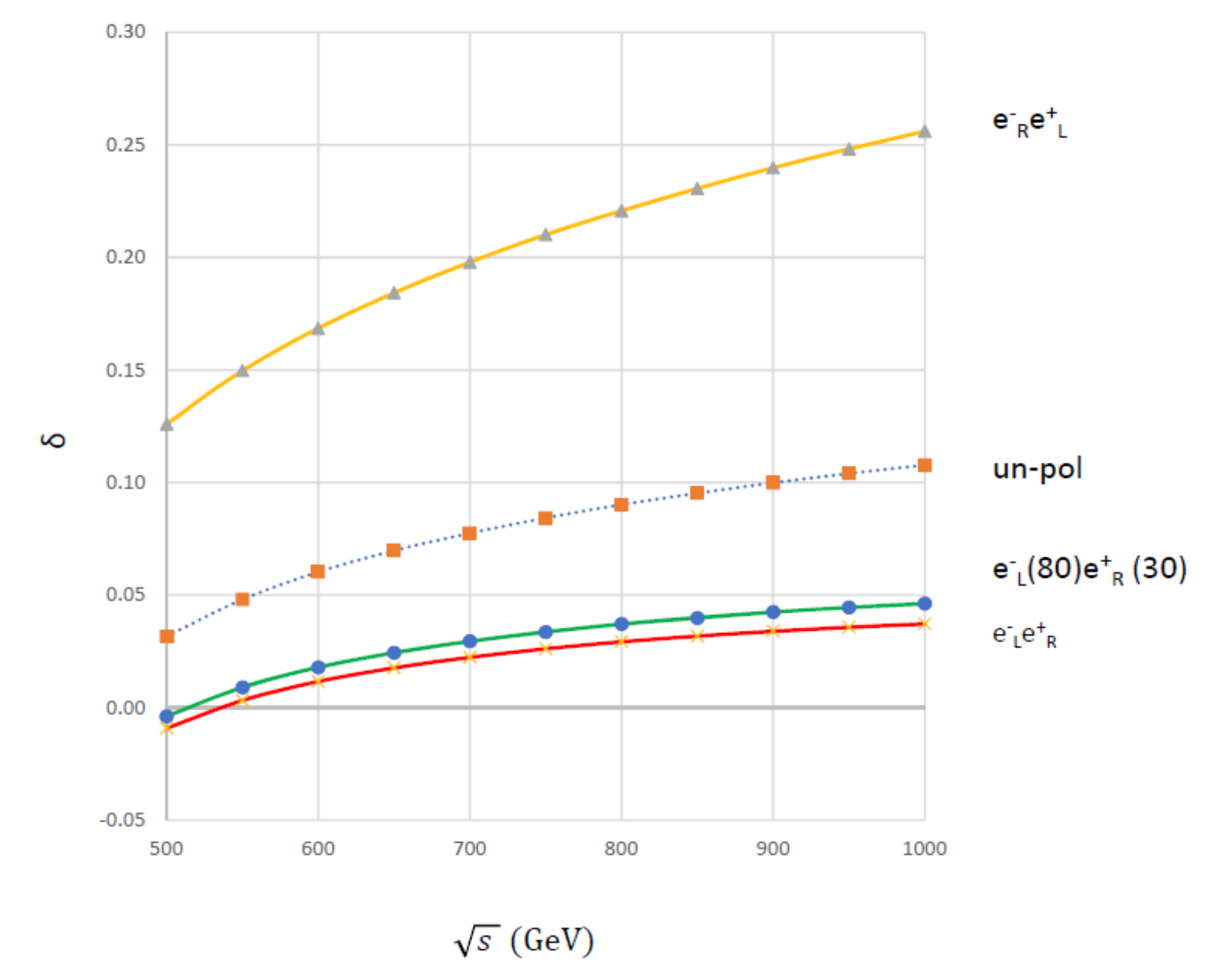
Total cross sections



O(a) ELWK correction

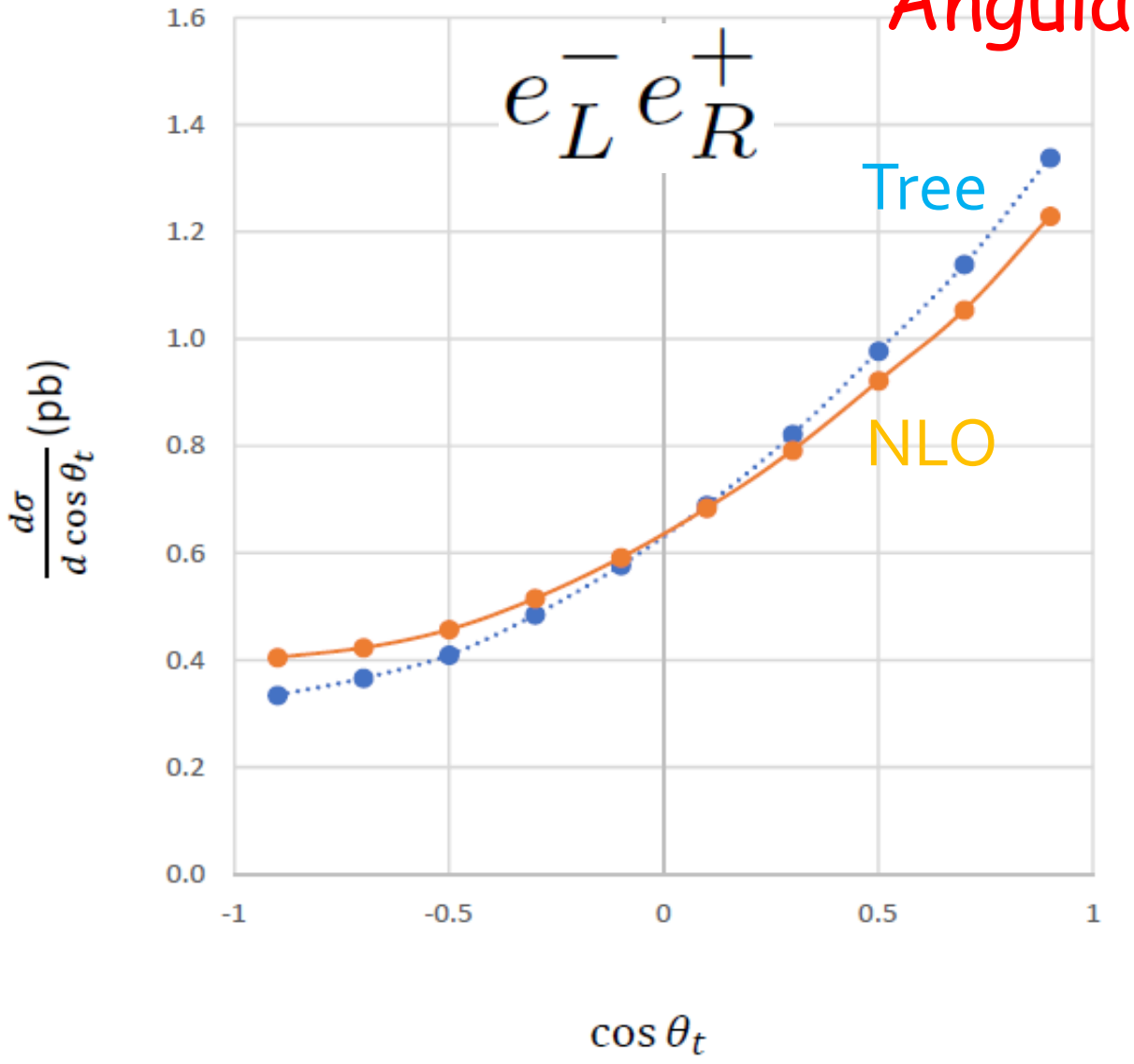
$$\delta = (\sigma_{NLO} - \sigma_{Tree})/\sigma_{Tree}$$

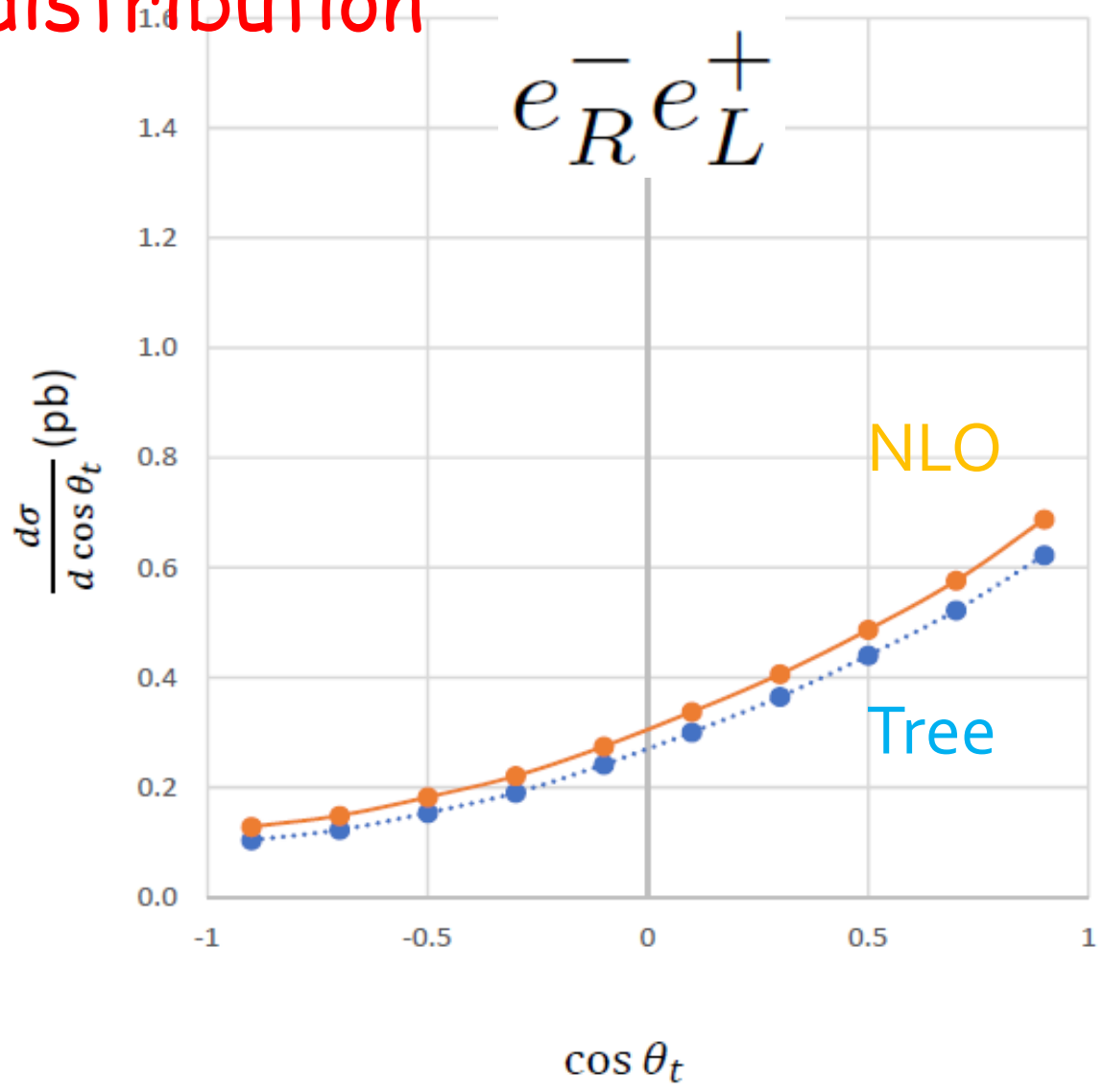
Total cross sections



O(α) ELWK correction

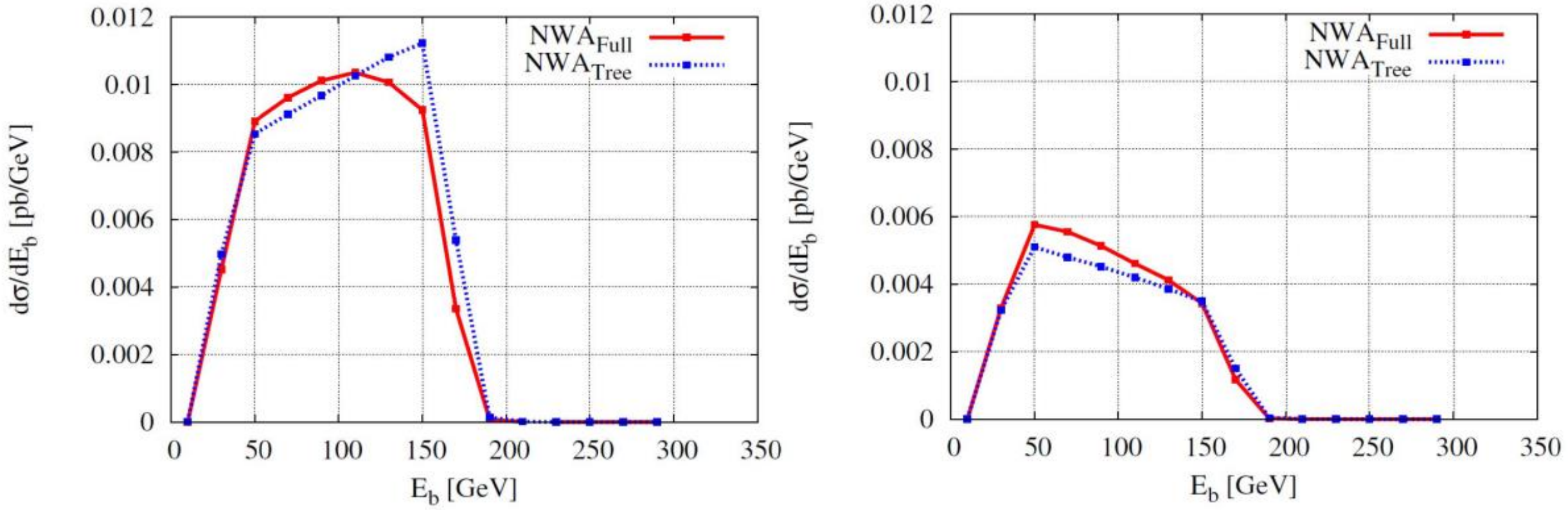
Angular distribution





O(α) ELWK correction

$e^-_L e^+_R$ 6-body final process $e^-_R e^+_L$

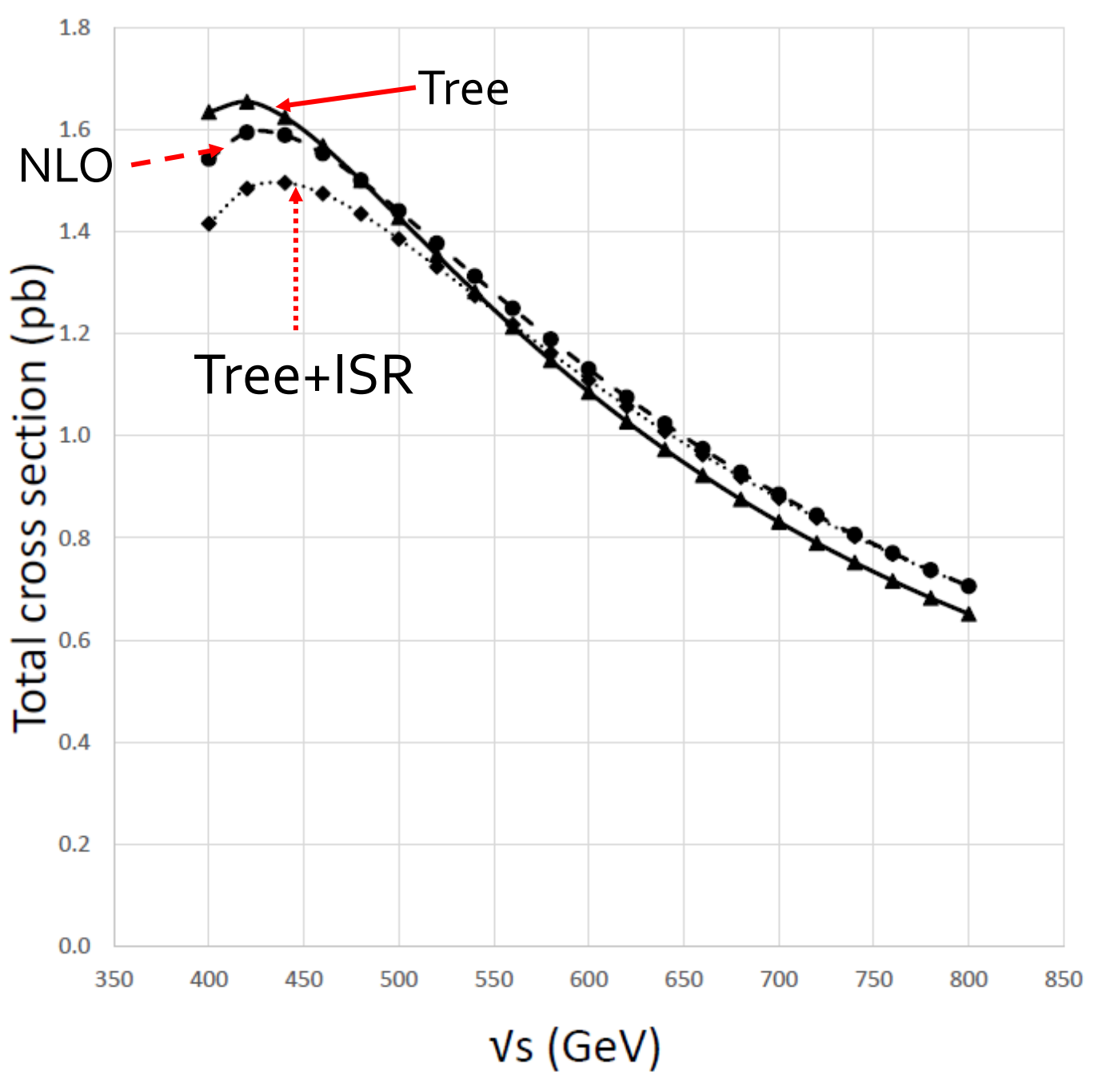


$\bar{b}$-quark energy

ISR re-summation

ISR re-summation

The ISR correction gives a main correction



ISR re-summation

$$\sigma_{NLO;fixed} = \sigma_{Loop} + \sigma_{Soft} + \sigma_{Hard} + \sigma_{Tree}$$

λ
(photon mass)

k_c

ISR re-summation

$$\sigma_{NLO;fixed} = \sigma_{Loop} + \sigma_{Soft} + \sigma_{Hard} + \sigma_{Tree}$$

$$\sigma_{NLO;ISR} = (\sigma_{Loop} - \sigma_{Tree}\delta_{ISL}) + \tilde{\sigma}^{final}_{Soft} + \sigma_{Hard} + \sigma_{ISR}$$

λ
(photon mass)

k_c

ISR re-summation

$$\sigma_{NLO;fixed} = \sigma_{Loop} + \sigma_{Soft} + \sigma_{Hard} + \sigma_{Tree}$$

$$\sigma_{NLO;ISR} = (\sigma_{Loop} - \sigma_{Tree}\delta_{ISL}) + \widetilde{\sigma}^{final}_{Soft} + \sigma_{Hard} + \sigma_{ISR}$$

$$\sigma_{ISR} = \int_0^{k_c^2/s} dx_1 \int_0^{1-x1} dx_2 \; D(x_1, s) D(x_2, s) \sigma_{Tree}(s x_1 x_2))$$

ISR re-summation

Radiator

$$D(1-x,s)^2 = H(x,s) = \Delta_2 \beta x^{\beta-1} - \Delta_1 \beta \left(1 - \frac{x}{2}\right) + \frac{\beta^2}{8}\left[-4(2-x)\log x - \frac{1+3(1-x)^2}{x}\log(1-x) - 2x\right]$$

$$\beta = \frac{2\alpha}{\pi}\left(\log\frac{s}{m_e^2} - 1\right),$$

$$\Delta_2 = 1 + \delta_1 + \delta_2, \qquad \Delta_1 = 1 + \delta_1$$

$$\delta_1 = \frac{\alpha}{\pi}\left(\frac{3}{2}L + \frac{\pi^2}{3} - 2\right), \qquad \delta_2 = \left(\frac{\alpha L}{\pi}\right)^2\left(-\frac{1}{18}L + \frac{119}{72} - \frac{\pi^2}{3}\right)$$

ISR re-summation

$$\sigma_{NLO;fixed} = \sigma_{Loop} + \sigma_{Soft} + \sigma_{Hard} + \sigma_{Tree}$$

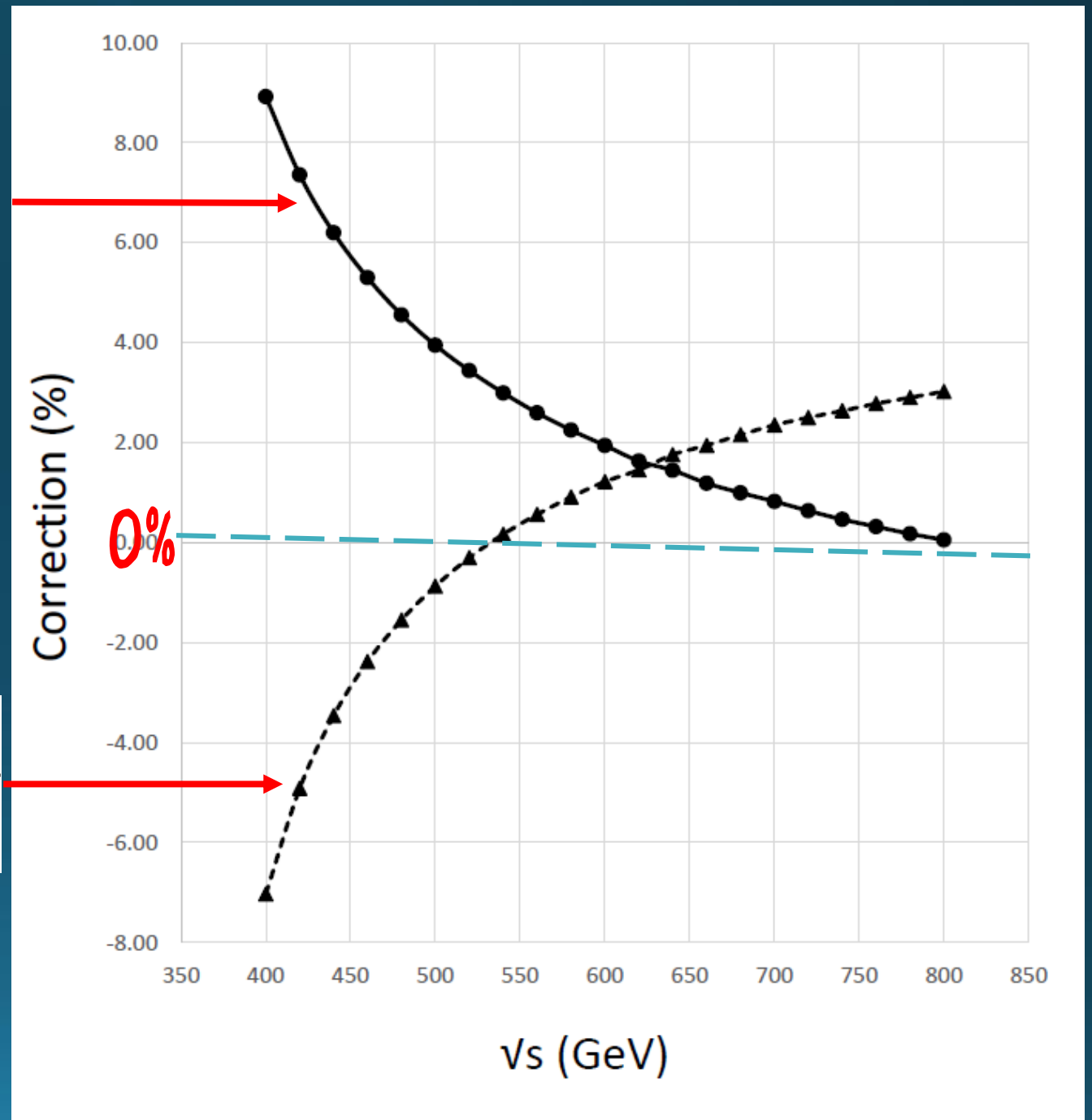
$$\sigma_{NLO;ISR} = (\sigma_{Loop} - \sigma_{Tree}\delta_{ISL}) + \widetilde{\sigma}^{final}_{Soft} + \sigma_{Hard} + \sigma_{ISR}$$

$$\delta_{ISL} = \frac{2\alpha}{\pi}\left(-(L-1)\log\frac{m_e}{\lambda} - \frac{1}{4}L^2 + \frac{3}{4}L + \frac{\pi^2}{3} - 1\right)$$

ISR re-summation

$$\delta_{weak} = \frac{\sigma_{NLO;ISR} - \sigma_{ISR}}{\sigma_{ISR}}$$

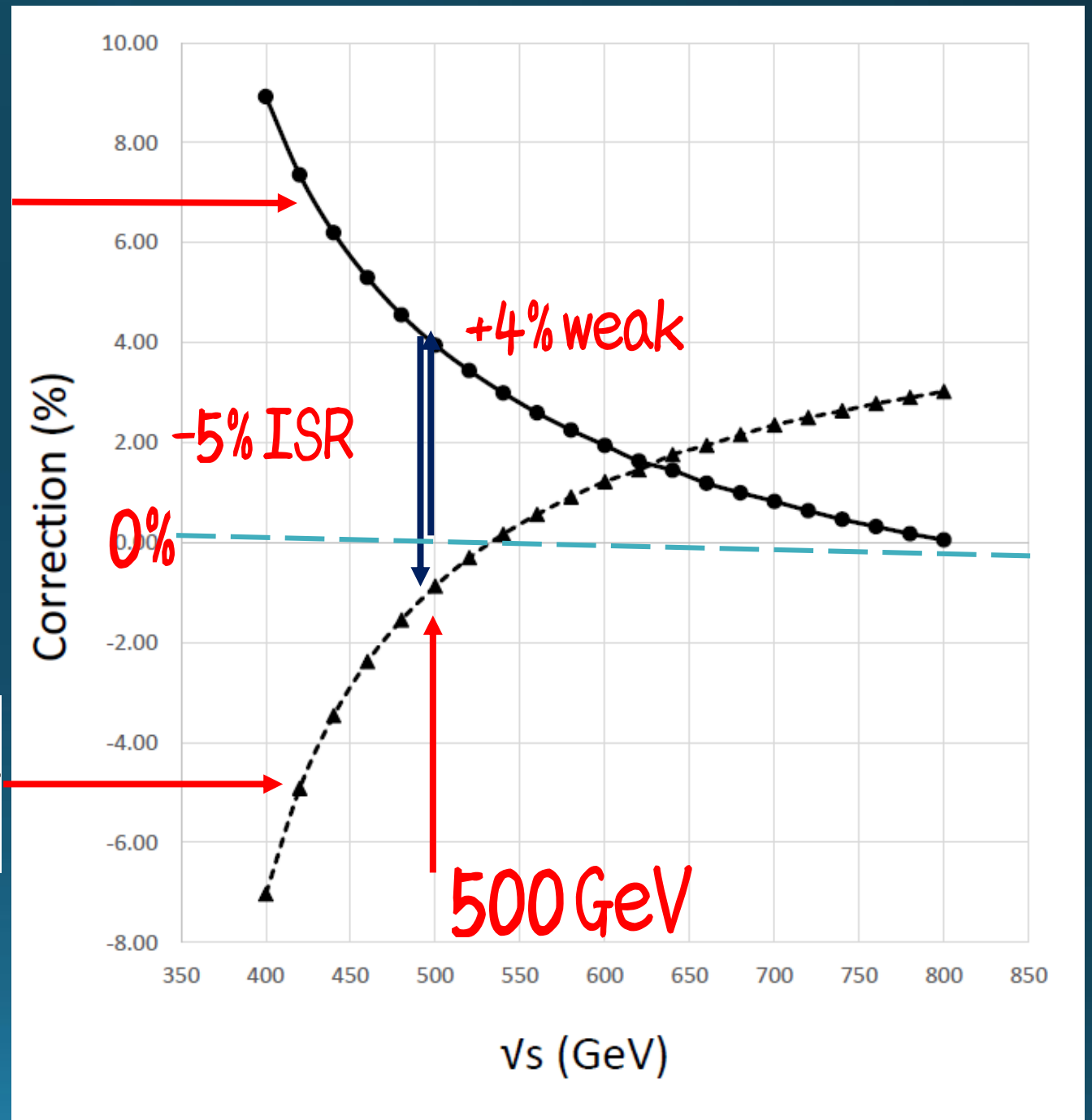
$$\delta_{NLO} = \frac{\sigma_{NLO;fixed} - \sigma_{Tree}}{\sigma_{Tree}}$$



ISR re-summation

$$\delta_{weak} = \frac{\sigma_{NLO;ISR} - \sigma_{ISR}}{\sigma_{ISR}}$$

$$\delta_{NLO} = \frac{\sigma_{NLO;fixed} - \sigma_{Tree}}{\sigma_{Tree}}$$



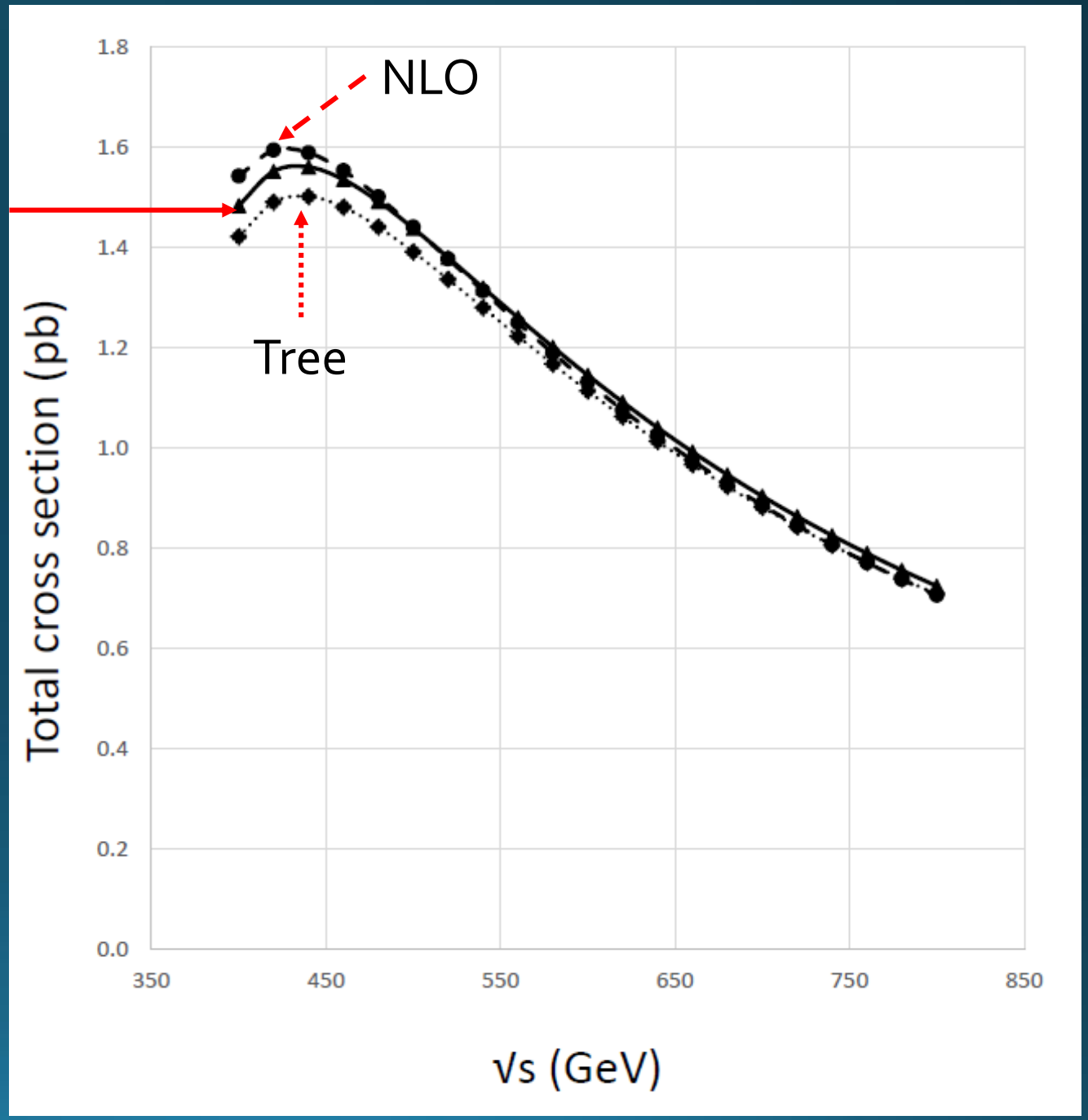
ISR re-summation

Improved Born

$$\sigma_{imp} = \int_0^1 dx_1 \int_0^{1-x_1} dx_2 \; D(x_1, s) D(x_2, s) \; \sigma_{Tree}\left(\alpha\left(s x_1 x_2\right); s x_1 x_2\right)$$

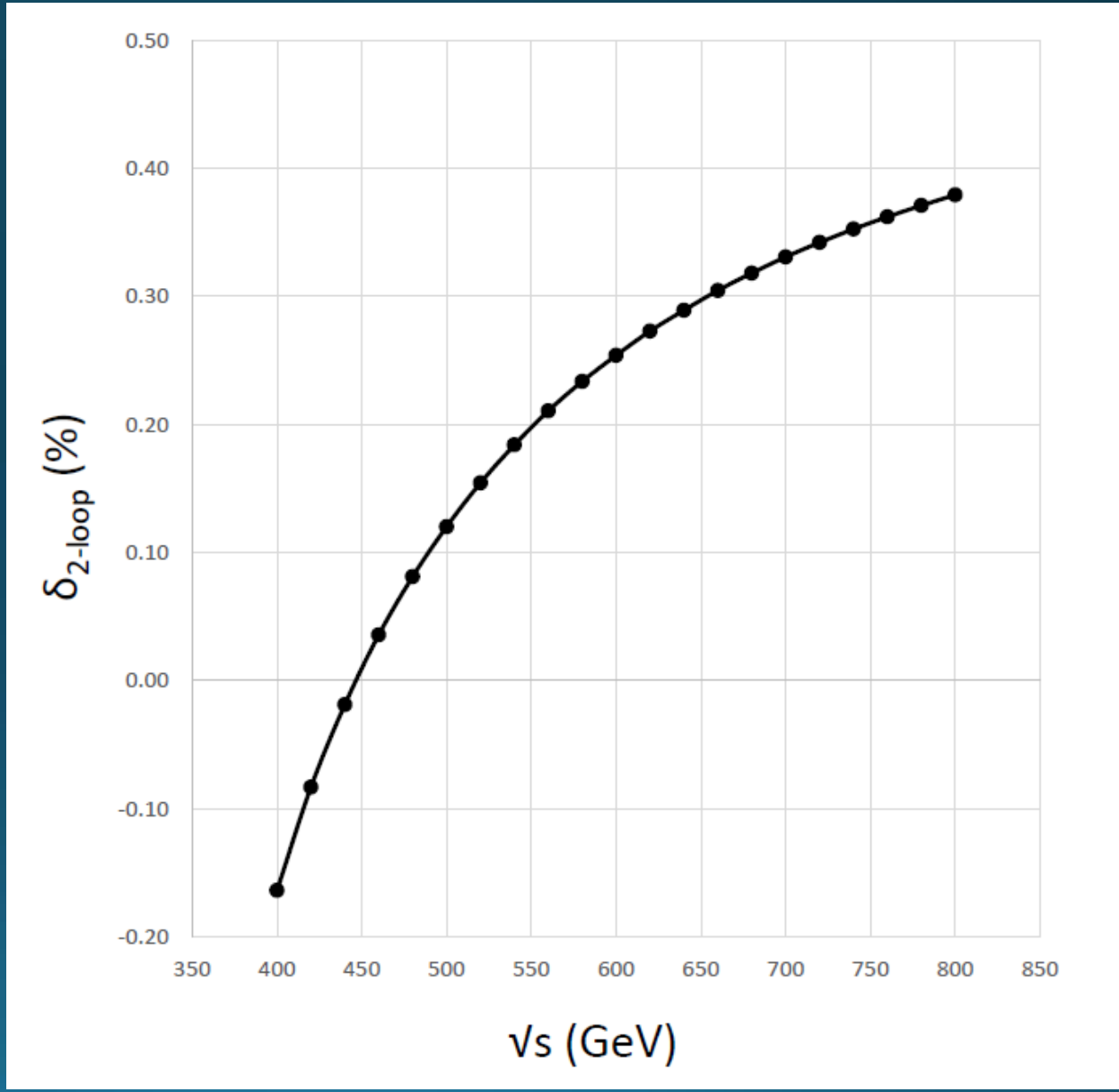
$$\alpha\left(|q^2|\right) = \frac{\alpha\left(\mu^2\right)}{1 - \frac{\alpha(\mu^2)}{3\pi} \log\left(\frac{|q^2|}{\mu^2}\right)}$$

$$\sin^2\theta_W = \frac{\pi\alpha\left(|q^2|\right)}{\sqrt{2} G_F m_W^2}$$



ISR re-summation

$$\delta_{2-loop} = \frac{\sigma_{ISR} - \sigma_{ISR}^{(1)}}{\sigma_{ISR}^{(1)}}$$

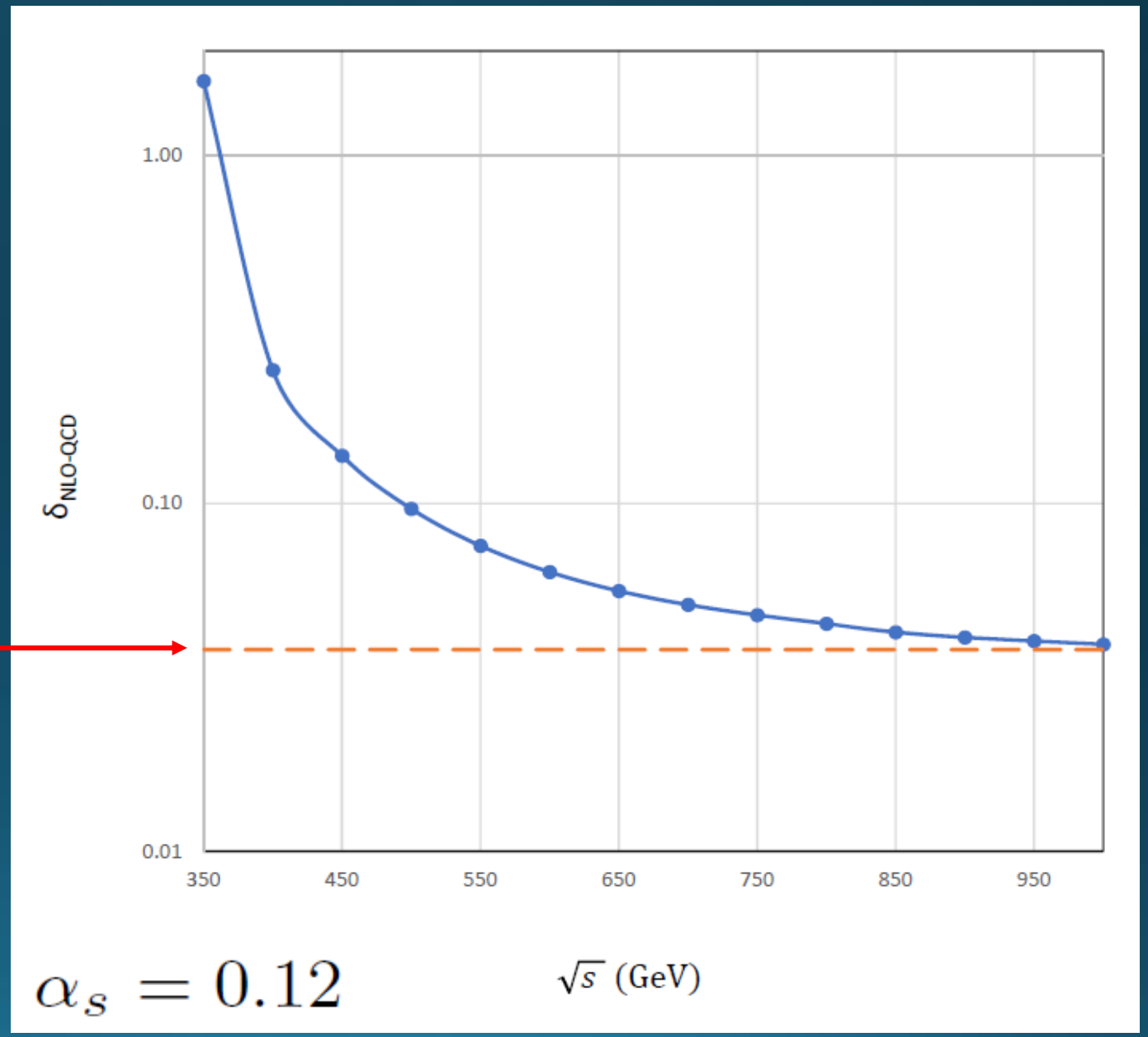


QCD corrections

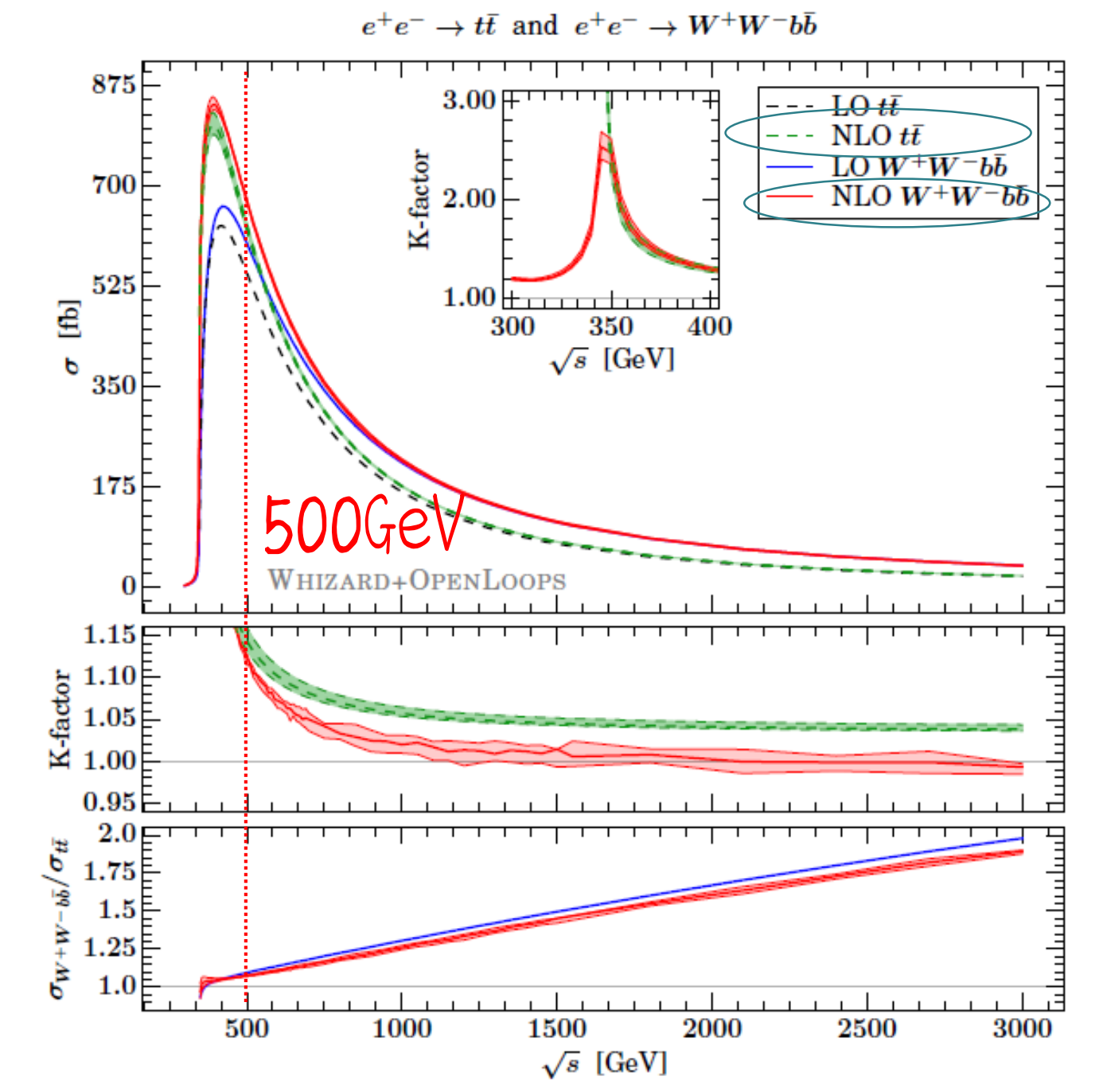
QCD Correction

Total cross sections w/ a QCD correction on a t-pair production only

$$\alpha_s/\pi \simeq 3.8\%$$



NLO QCD correction w/ double-pole approx.



B.C. Nejad, et al., JHEP12 (2016) 075

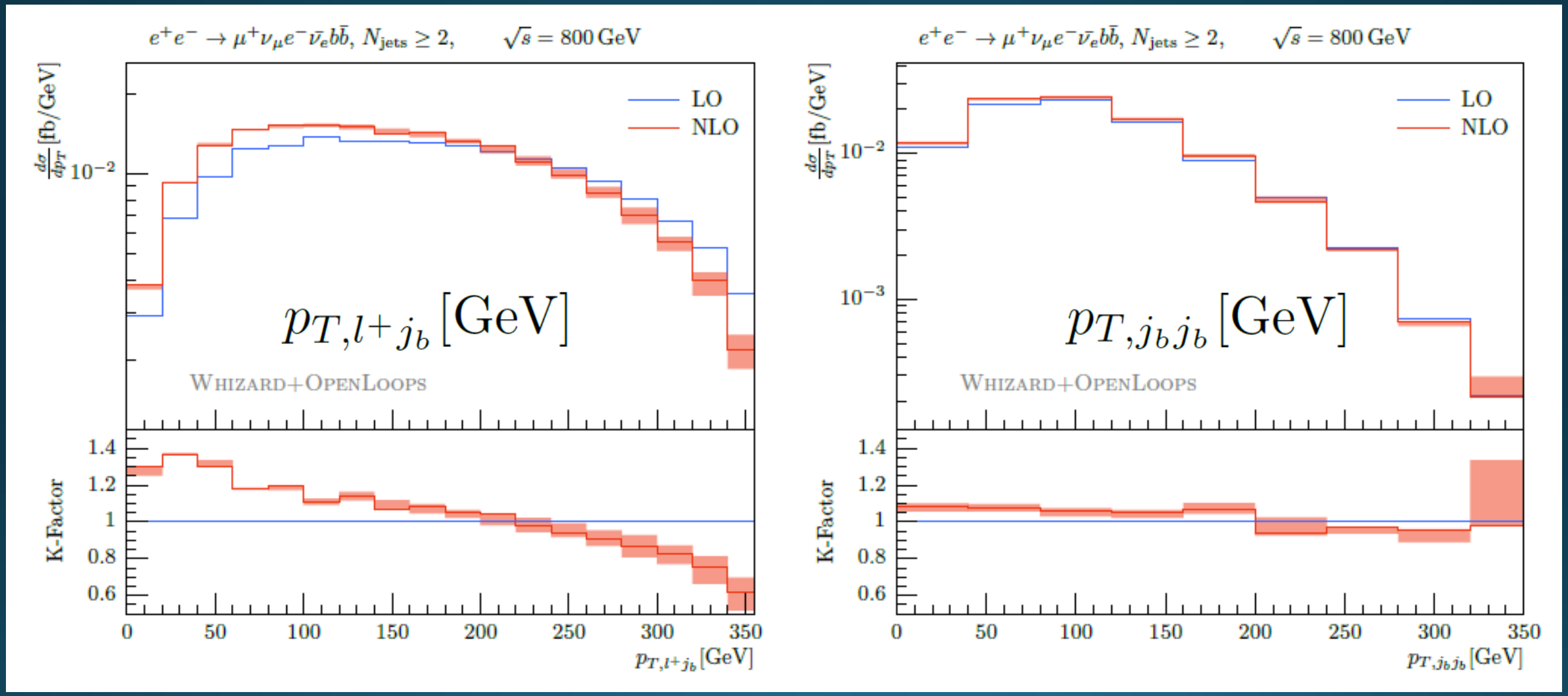
NLO QCD correction w/ double-pole approx.

	$e^+e^- \to t\bar{t}$			$e^+e^- \to W^+W^-b\bar{b}$		
$\sqrt{s}$ [GeV]	$\sigma^{\rm LO}$[fb]	$\sigma^{\rm NLO}$[fb]	K-factor	$\sigma^{\rm LO}$[fb]	$\sigma^{\rm NLO}$[fb]	K-factor
500	548.4	$627.4^{+1.4\%}_{-0.9\%}$	1.14	600.7	$675.1^{+0.4\%}_{-0.8\%}$	1.12
800	253.1	$270.9^{+0.8\%}_{-0.4\%}$	1.07	310.2	$320.7^{+1.1\%}_{-0.7\%}$	1.03
1000	166.4	$175.9^{+0.7\%}_{-0.3\%}$	1.06	217.2	$221.6^{+1.1\%}_{-1.0\%}$	1.02
1400	86.62	$90.66^{+0.6\%}_{-0.2\%}$	1.05	126.4	$127.9^{+0.7\%}_{-1.5\%}$	1.01
3000	19.14	$19.87^{+0.5\%}_{-0.2\%}$	1.04	37.89	$37.63^{+0.4\%}_{-0.9\%}$	0.993

		$\sqrt{s} = 800$ GeV			$\sqrt{s} = 1500$ GeV		
$P(e^-)$	$P(e^+)$	$\sigma^{\rm LO}$[fb]	$\sigma^{\rm NLO}$[fb]	K-factor	$\sigma^{\rm LO}$[fb]	$\sigma^{\rm NLO}$[fb]	K-factor
0%	0%	253.7	272.8	1.075	75.8	79.4	1.049
−80%	0%	176.5	190.0	1.077	98.3	103.1	1.049
80%	0%	176.5	190.0	1.077	53.2	55.9	1.049
−80%	30%	420.8	452.2	1.074	124.9	131.0	1.048
−80%	60%	510.7	548.7	1.074	151.6	158.9	1.048
80%	−30%	208.4	224.5	1.077	63.0	66.1	1.049
80%	−60%	240.3	258.9	1.077	72.7	76.3	1.049

B.C. Nejad, et al., JHEP12 (2016) 075

NLO QCD correction w/ double-pole approx.

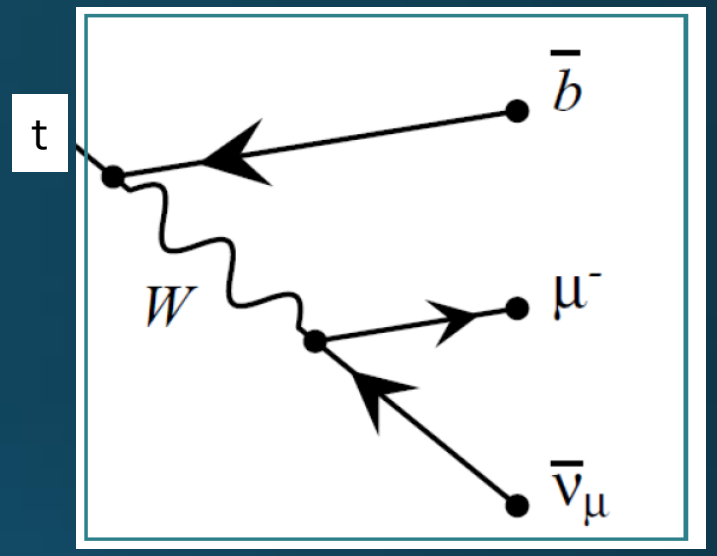


B.C. Nejad, et al., JHEP12 (2016) 075

NLO QCD correction for top decay

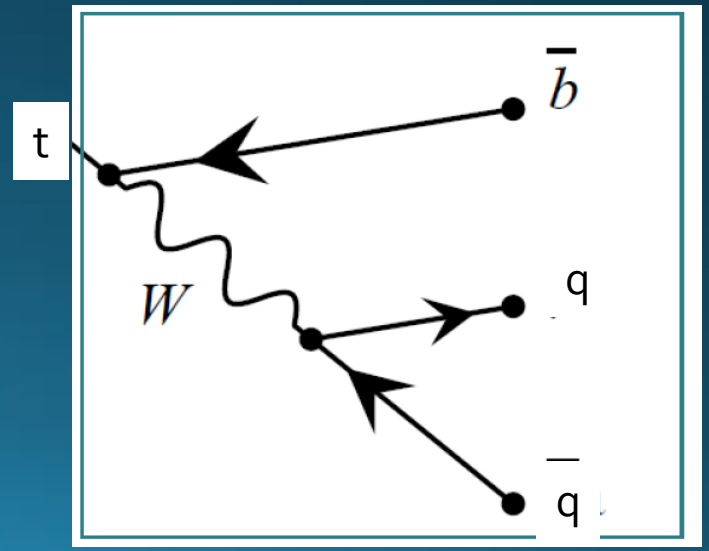
Semi leptonic

	OCSM
$\Gamma^{(0)}_{\text{lept}}$ / GeV	0.1610645(3)
$\delta^{(1),\text{QCD}}_{\text{lept}}$ /%	−9.379(3)
$\delta^{(1),\text{EW}}_{\text{lept}}$ /%	1.335(2)
$\Gamma^{\text{NLO}}_{\text{lept}}$ / GeV	0.148108(6)



Hadronic

	OCSM
$\Gamma^{(0)}_{\text{hadr}}$ / GeV	0.48319351(5)
$\delta^{(1),\text{QCD}}_{\text{hadr}}$ /%	−5.58(2)
$\delta^{(1),\text{EW}}_{\text{hadr}}$ /%	1.2896(5)
$\Gamma^{\text{NLO}}_{\text{hadr}}$ / GeV	0.46248(9)



L. Oggero, Ph.D thesis

Summary:

- Numerical precision of Full ELWK correction under controlled ~ $\mathcal{O}(0.1\%)$
- Corr.(Full)=~10% mainly comes from ISR.
- "pure weak correction" <~ 4%
- 2-loop ISR effect is small < 0.5%
- QCD corrections are still important.