One-loop electroweak corrections to Z+jet production [$e^+e^- \longrightarrow$ 3 jets]

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Outline

- ⋆ Motivations for ILC & LHC
- ⋆ Factorizable weak corrections
- ⋆ The complete EW one-loop calculation
  - calculation details
  - preliminary results (technical checks & physics)
- ⋆ Conclusions

Motivations

- ⋆ at e^+e^- colliders ($e^+e^- \to \gamma^*/Z \to$ 3 jets)
  - $e^+e^- \to$ 3 jets was the "golden" process for QCD measurements and tests at LEP
  - precise measurement of α_s ($\mathcal{O}(1\%)$ at LEP/SLC, $\mathcal{O}(0.1\%)$ at GigaZ)
  - EW effects can induce asymmetries in 3 jets observables
  - $\mathcal{O}(\alpha)$ EW RC roughly expected as large as NNLO QCD at high energies (Sudakov double-logs)
- ⋆ at hadron colliders ($pp \to \gamma^*/Z \to \ell^+\ell^-+$ jet)
  - measurement of PDFs via $p_\perp^{\gamma/Z}$ spectrum, in particular the gluon PDF
  - large effects of EW Sudakov logs in Z+jet observables, e.g. at high $p_\perp^Z$ where BSM physics can show up
  - detector calibration for jets measurements
- SM effects must be well under control to match the experimental accuracy and to disentangle SM from BSM physics

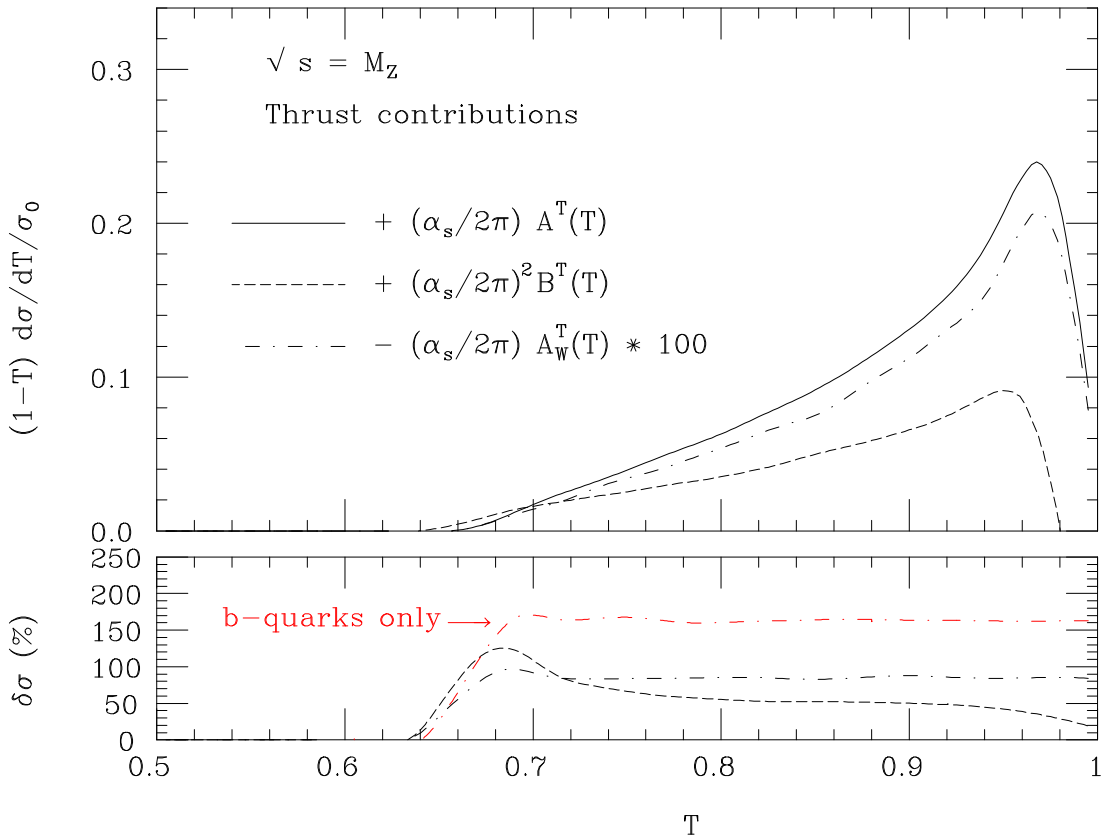
Literature

Restricting to EW corrections

- ⋆ Maina, Moretti, Ross, JHEP 0304:056 (2003)
  - factorizable weak corrections to $e^+e^- \to 3$ jets (no real & virtual QED, no RC connecting initial and final state), effects studied at $\sqrt{s} = M_Z$
- ⋆ Maina, Moretti, Ross, PLB 593 (2004), Erratum PLB 614 (2005)
  - purely weak corrections to $pp \to Z$ or $\gamma+$ jet at high $p_T^{\gamma/Z}$. γ and Z on-shell
- ⋆ Kuhn, Kulesza, Pozzorini, Schulze, PLB 609 (2005)
  - logarithmic weak corrections to $pp \to Z+$ jet (high $p_\perp^Z$) at one and two loop order with LL and NLL accuracy

Weak factorizable RC at $\sqrt{s} = M_Z$

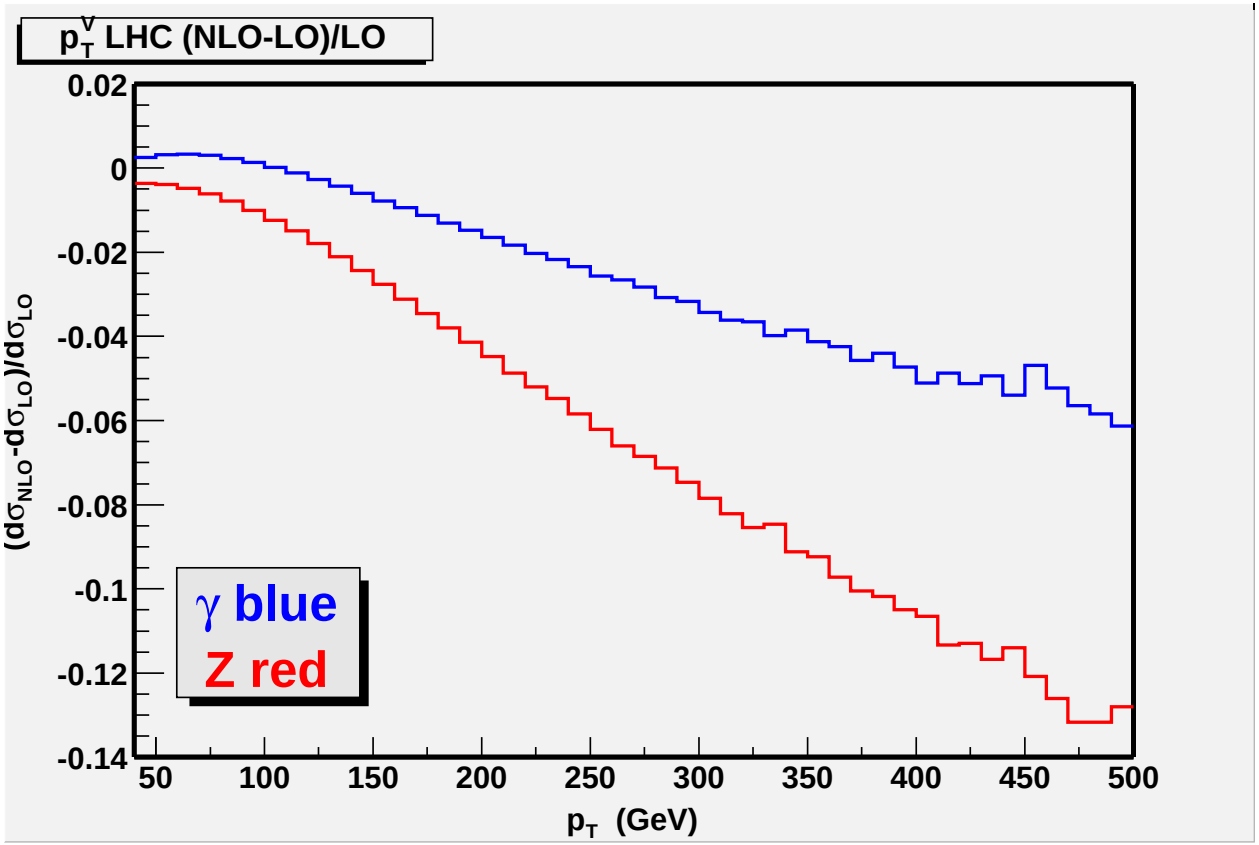
Maina et al., PLB



- weak corrections have a $\mathcal{O}(1\%)$ effect, which could be not negligible for α_s determination at GigaZ at the 0.1% level
- larger effect for the $b\bar{b}$ sub-sample (due to top in the loops)

Weak RC to γ/Z+jet

Maina et al., JHEP



- large corrections ($\mathcal{O}(10\%)$) in the high boson $p_\perp$ tail, where SM is a background to new physics signatures

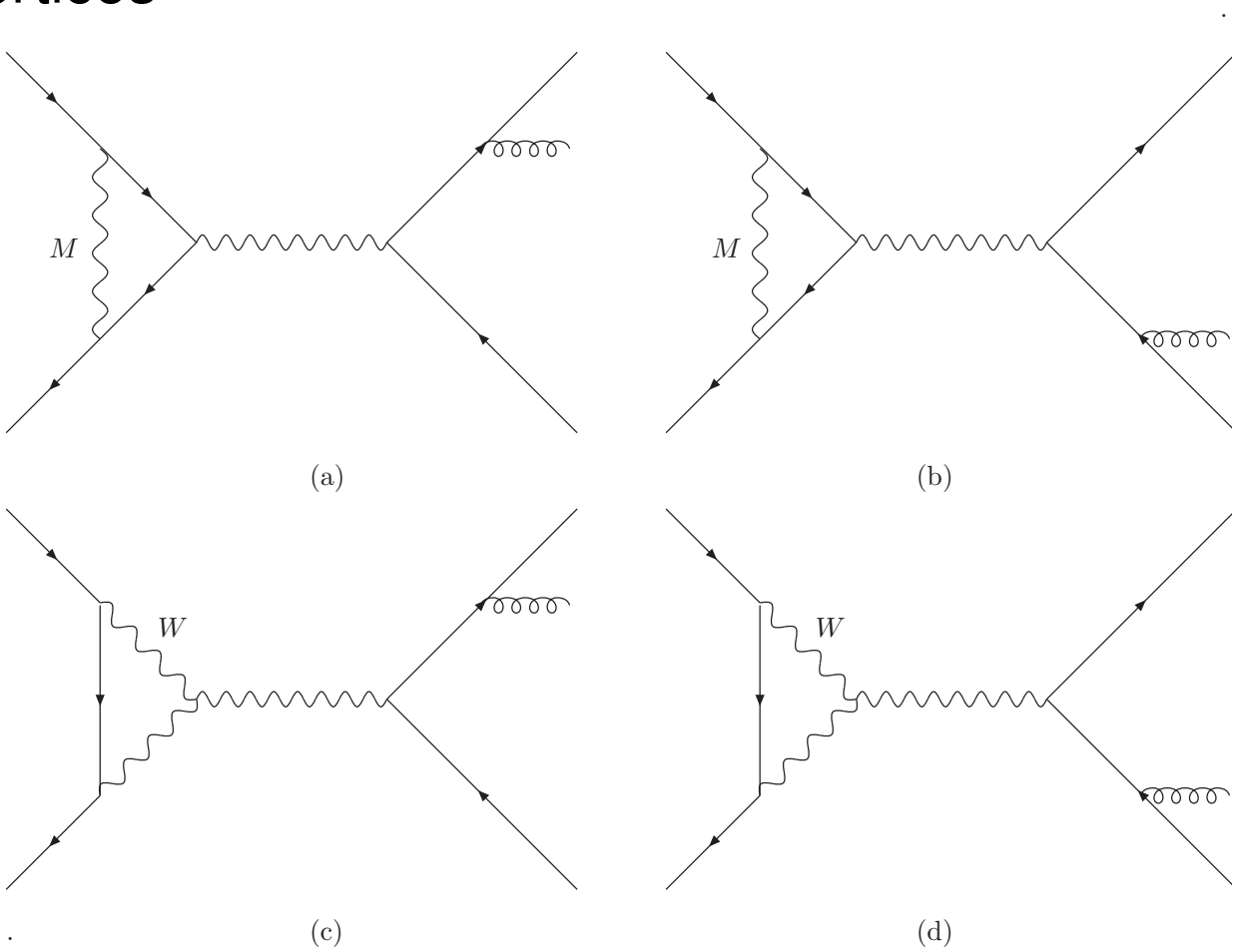
Complete 1-loop EW RC to $e^+e^- \to 3$ jets

- we calculated the complete 1-loop EW corrections to $e^+e^- \to 3$ jets
  - QED can give a sizeable effect if realistic event selection criteria are considered
  - non-factorizable RC can be not negligible far from M_Z
  - non-factorizable RC can have a not trivial impact on asymmetries
- by crossing symmetry, EW RC to $pp \to \ell^+\ell^- +$ jet are straighfordwardly obtained
- the precise control of SM effects is mandatory for precision physics and new physics searches

Diagrams

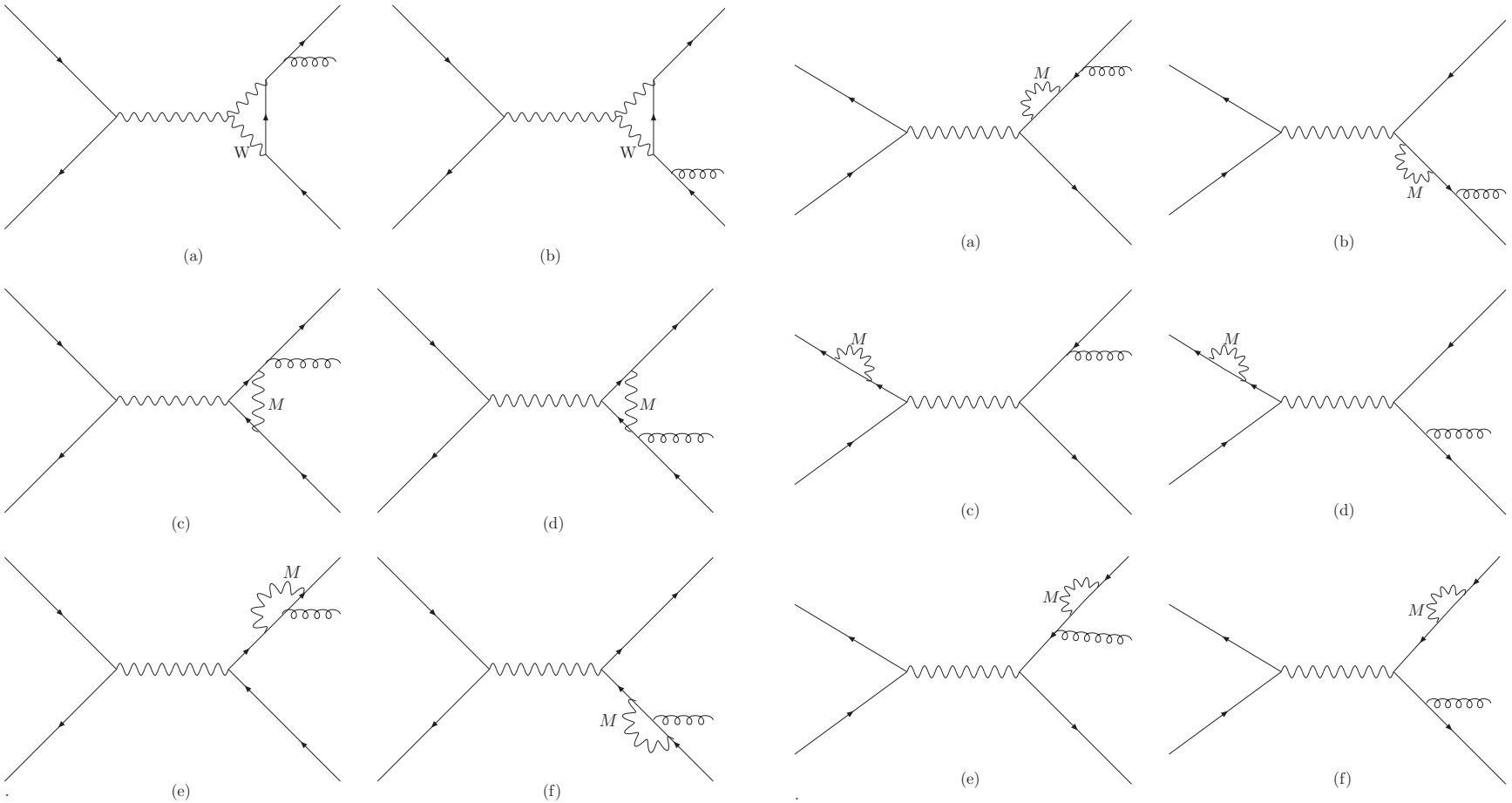
The 1-loop diagrams to be evaluated are:

- e^+e^- vertices



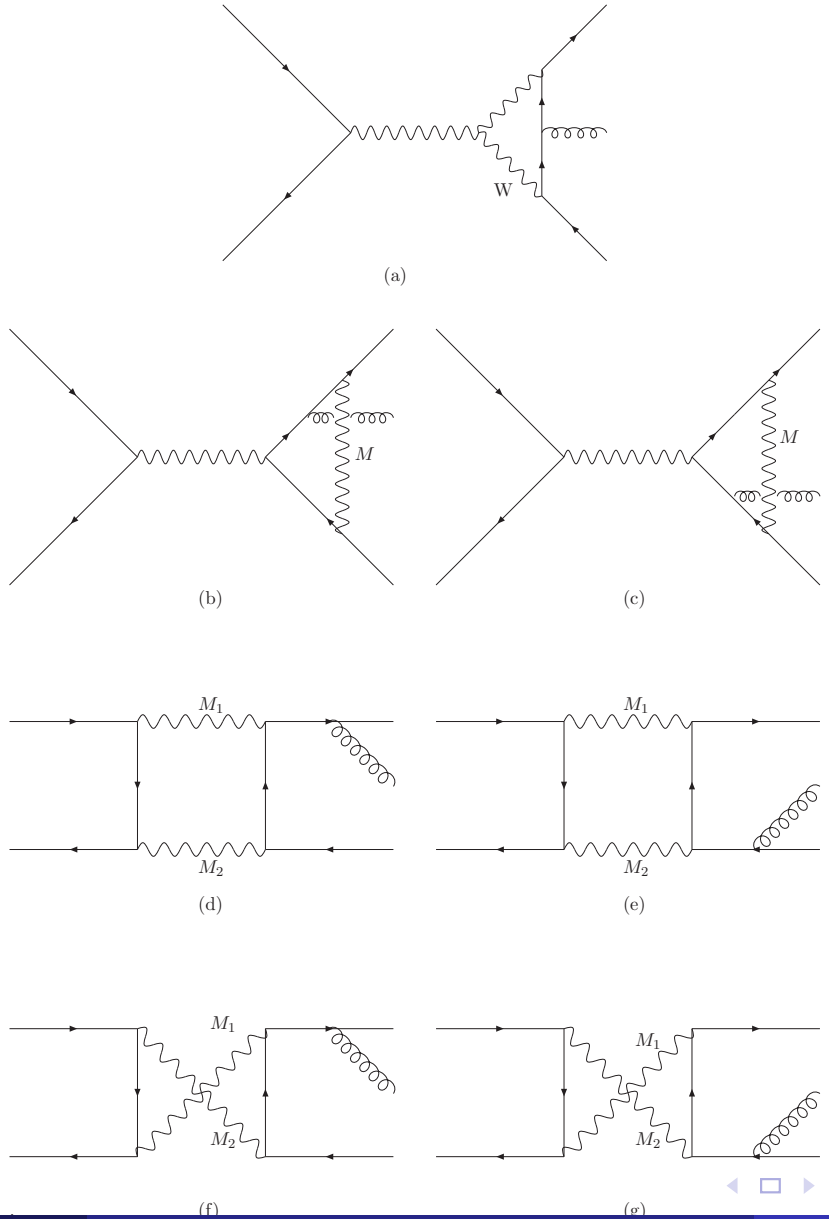
Diagrams

- $q\bar{q}$ and gluon vertices and fermion self-energies



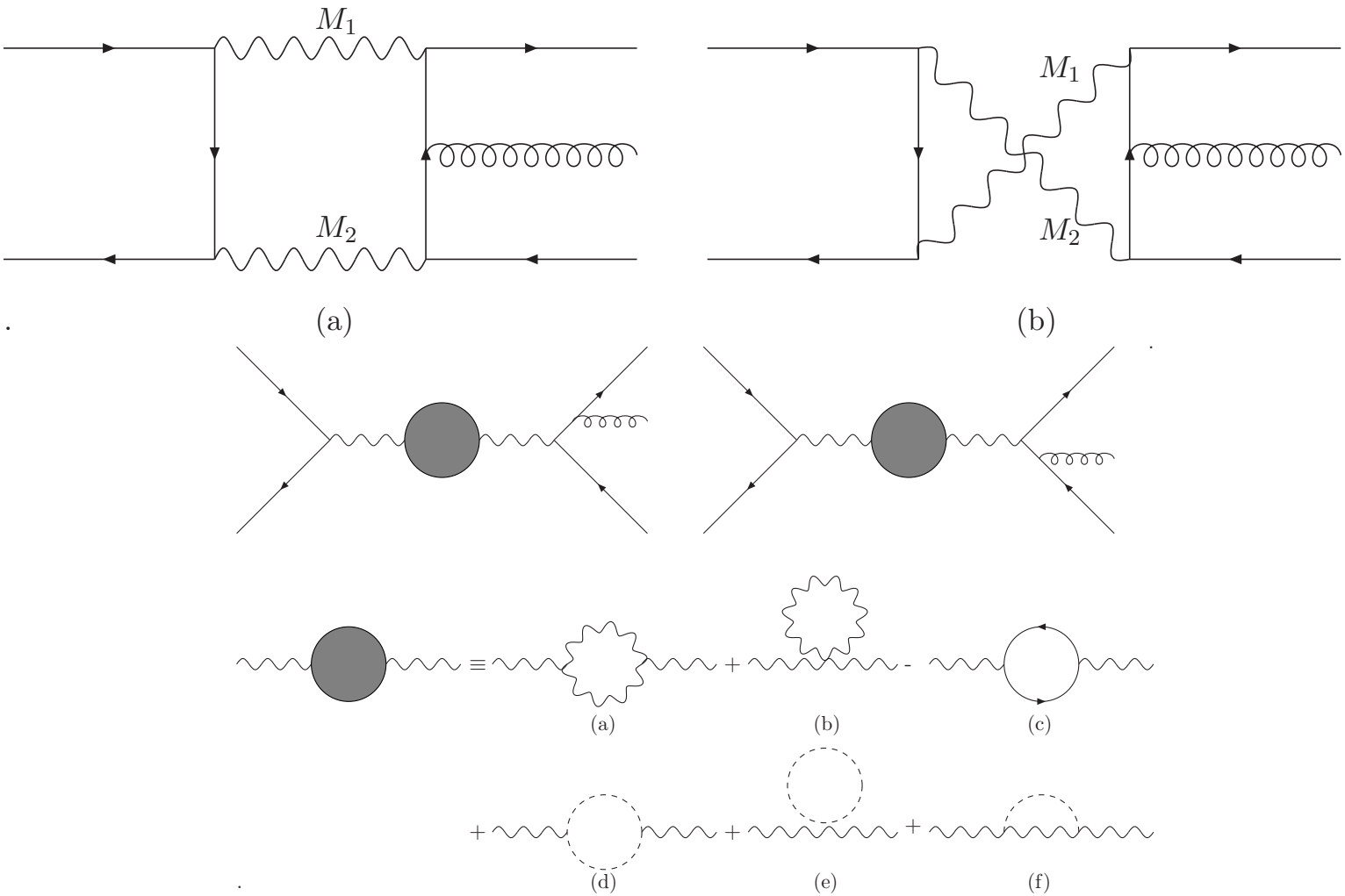
Diagrams

- box diagrams (factorizable and not factorizable)



Diagrams

- pentagons and gauge-bosons self-energies



Calculation details

- the calculation has been performed in the limit $m_{ext}^2/s \to 0$
- collinear singularities cured with a small fermion & quark mass
- infrared divergencies regularized with a finite photon mass λ
- virtual corrections
  - ⋆ amplitudes evaluated with helicity techniques and manipulated with **FORM** (Vermaseren)
  - ⋆ two independend calculations
  - ⋆ up to 4-point functions: reduction of tensor integrals with Passarino-Veltman reduction
  - ⋆ 5-point functions, reduction according to PV or to Denner-Dittmaier (as coded in a our own library or in **LoopTools** (Hahn))
  - ⋆ so far, good agreement among different implementations
- also the squared amplitude for the real emission process $e^+e^- \to q\bar{q}g\gamma$ has been calculated
  - ⋆ with **ALPHA** (Moretti & Caravaglios)
  - ⋆ with **MADGRAPH** (Maltoni, Stelzer et al.)

Cross section calculation

As usual, the cross section is split into two parts

- $e^+e^- \to q\bar{q}g$

$$\sigma_{2\to3} = \int d\Phi_3 \left(|\mathcal{M}_0|^2 + 2\Re[\mathcal{M}_0^* \mathcal{M}_\alpha^{virt}(\lambda)] \right)$$

- $e^+e^- \to q\bar{q}g\gamma$

$$\sigma_{2\to4} = \int_{\lambda<\omega} d\Phi_4 |\mathcal{M}_\alpha^{real}|^2 =$$

$$\int_{\lambda<\omega<k_0} d\Phi_4 |\mathcal{M}_\alpha^{real}|^2 + \int_{k_0<\omega} d\Phi_4 |\mathcal{M}_\alpha^{real}|^2 = \delta_s(\lambda, k_0)\sigma_0 + \sigma_{2\to4}^{hard}(k_0)$$

- $\sigma_{2\to3} + \sigma_{2\to4} \equiv \sigma^{SV}(k_0) + \sigma^{hard}(k_0)$ has to be independent from the unphysical parameters λ and k_0
- the integral over $2 \to 3$ and $2 \to 4$ phase space is performed with a Monte Carlo generator

Results

- all the results are preliminary
- test simulation for an e^+e^- collider running at $\sqrt{s} = 300$ GeV
- cuts & parameters:
  - ⋆ momenta clustered into jets according to the Durham algorithm, i.e. if $y_{ij} < y_{min}$, where

$$y_{ij} = 2\frac{\min(E_i^2, E_j^2)(1 - \cos\theta_{ij})}{s}$$

  - ⋆ photon (in $2 \to 4$) recombined according to the same algorithm
  - ⋆ at least 3 "hadronic" jets requested
  - ⋆ $y_{min} = 0.005, \quad 30° < \theta_{\text{jets}} < 150°, \quad M_{3\text{ jets}} > 0.75\sqrt{s}$
  - ⋆ $\alpha_s = 0.118, \quad \alpha_{em} = 1/128, \quad M_Z = 91.18$ GeV, $\quad M_W = 80.4$ GeV
- summed over final state quarks ($q\bar{q} = u\bar{u}, d\bar{d}, c\bar{c}, s\bar{s}, b\bar{b}$)
- the effect of the weak factorizable corrections far from the Z peak is shown for comparison purpose only

Cross sections and technical checks

- integrated cross sections

	σ (pb)	δ (%)
Born	0.73836(3)	
complete $\mathcal{O}(\alpha)$	0.7200(2)	-2.48
$\mathcal{O}(\alpha)$ weak fact.	0.7146(1)	-3.22

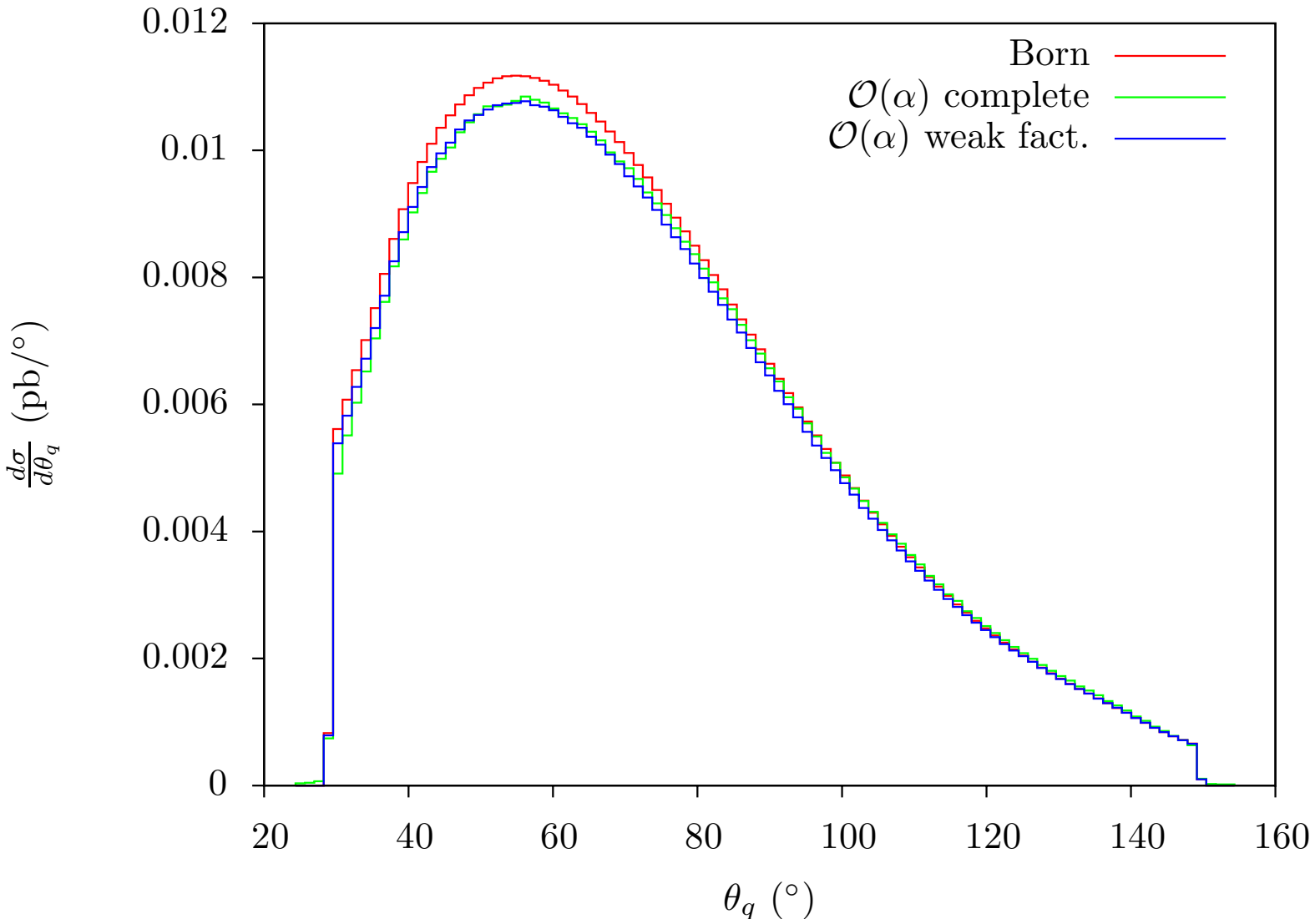
- independence of σ^{SV} from the photon mass (λ)

λ^2 (GeV^2)	10^{-5}	10^{-10}	10^{-15}
σ^{SV} (pb)	0.2863(2)	0.2866(2)	0.2866(2)

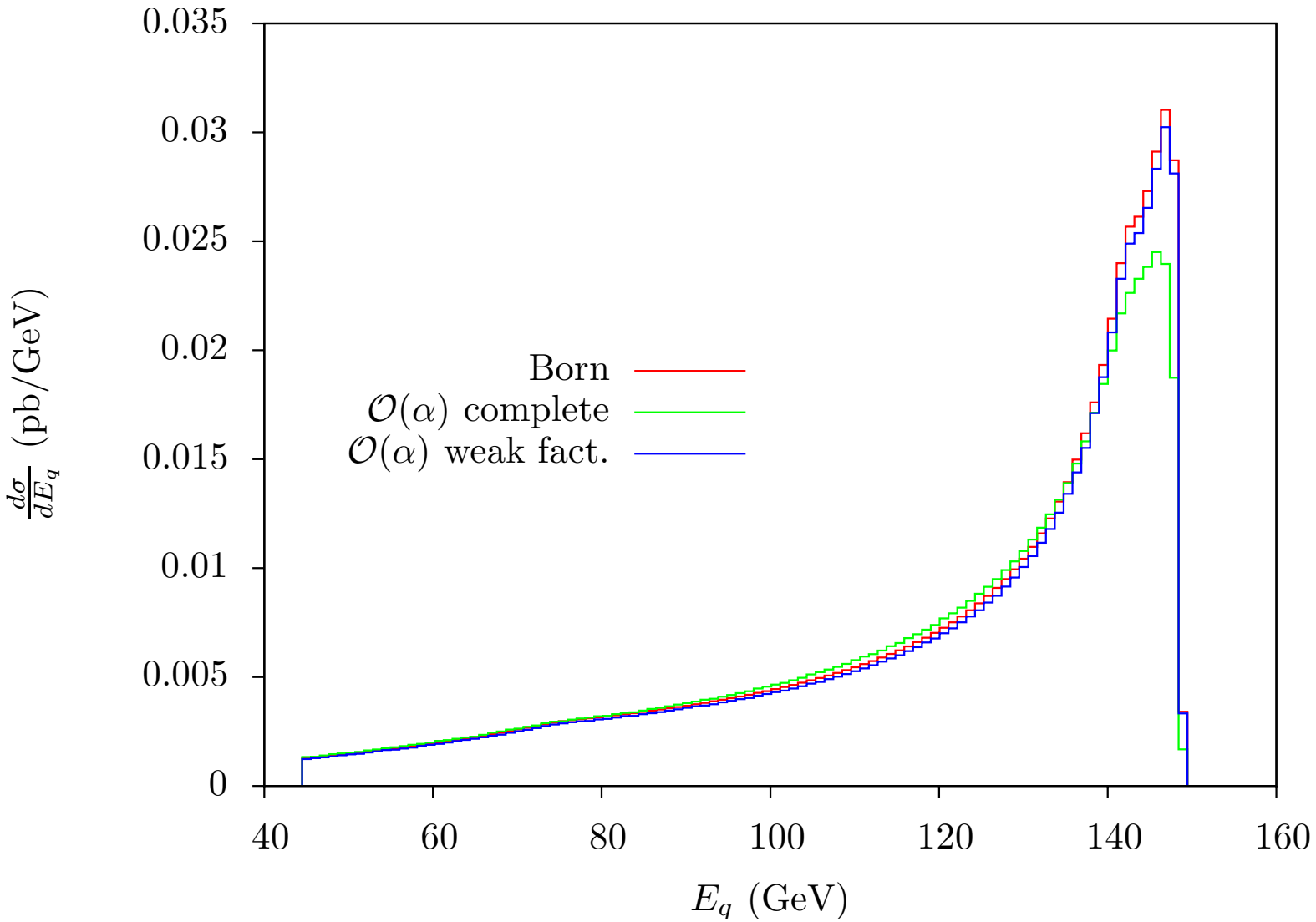
- independence of σ^{real} from the soft-hard separator (k_0)

$2k_0/\sqrt{s}$	10^{-3}	10^{-4}	10^{-5}
σ_{real} (pb)	0.4892(2)	0.4895(2)	0.4896(2)

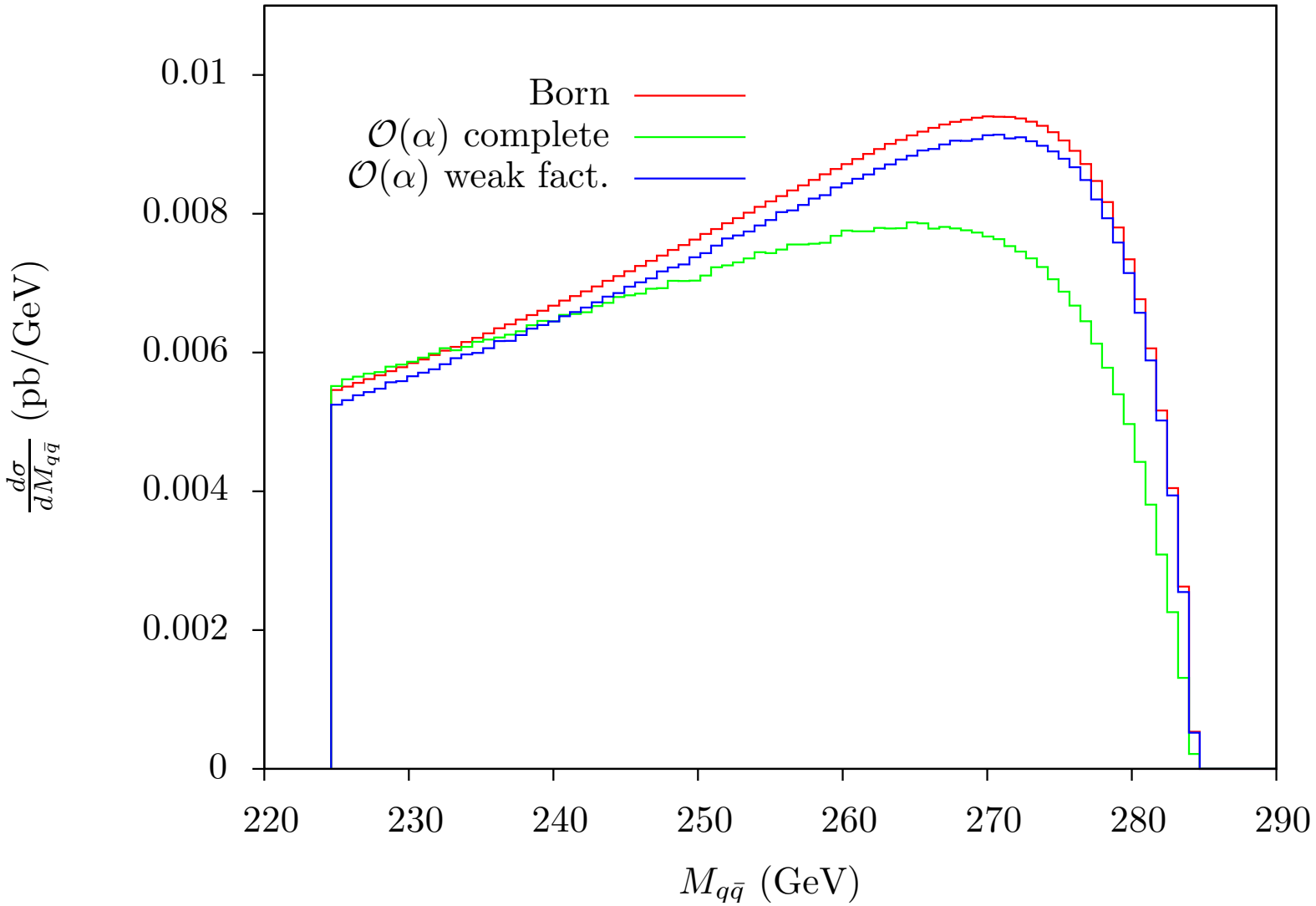
Quark angle


0.012
0.01
0.008
0.006
0.004
0.002
0
20
40
60
80
100
120
140
160
$\frac{d\sigma}{d\theta_q}$ (pb/°)
θ_q (°)
Born
$\mathcal{O}(\alpha)$ complete
$\mathcal{O}(\alpha)$ weak fact.

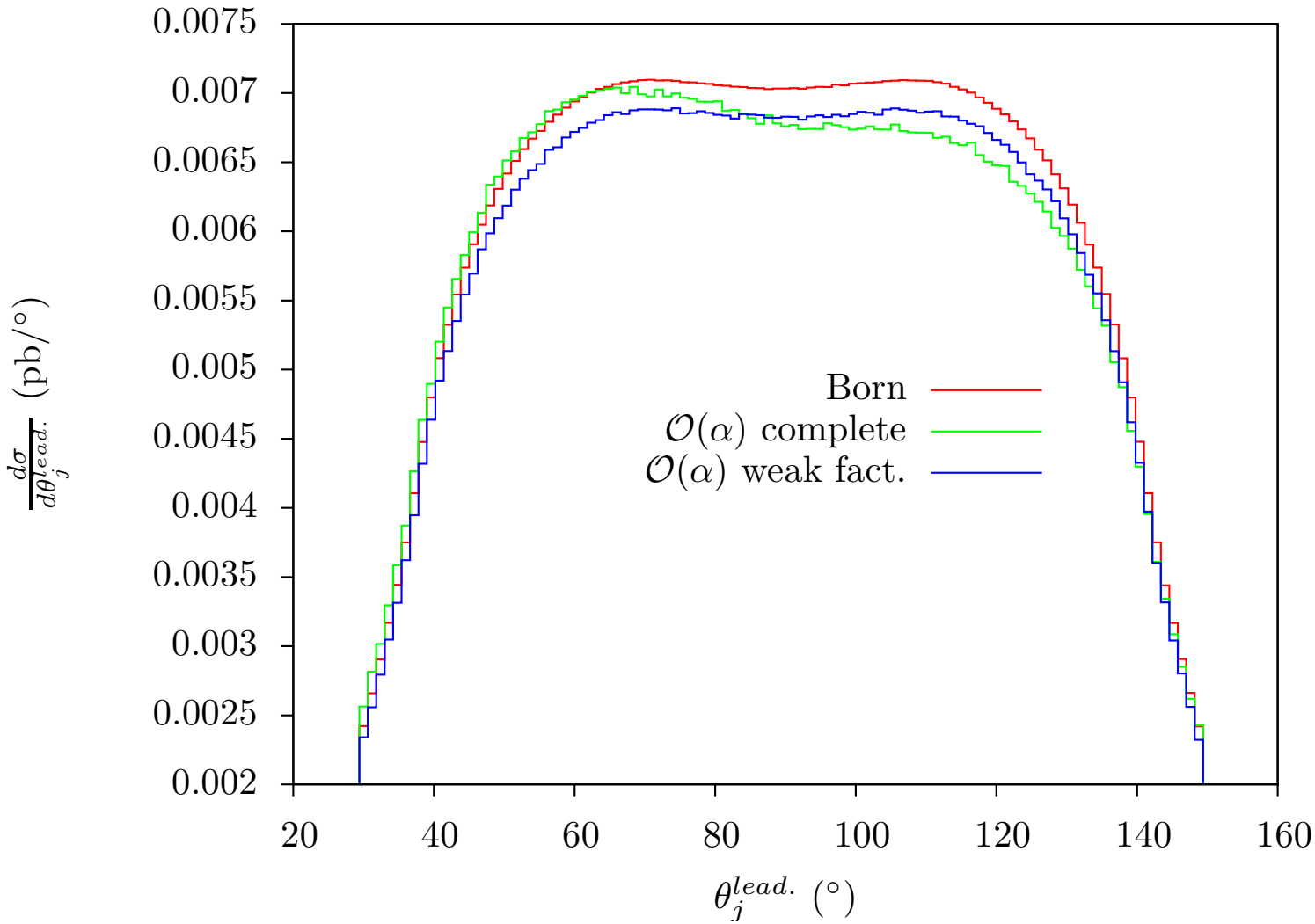
Quark energy



$q\bar{q}$ invariant mass

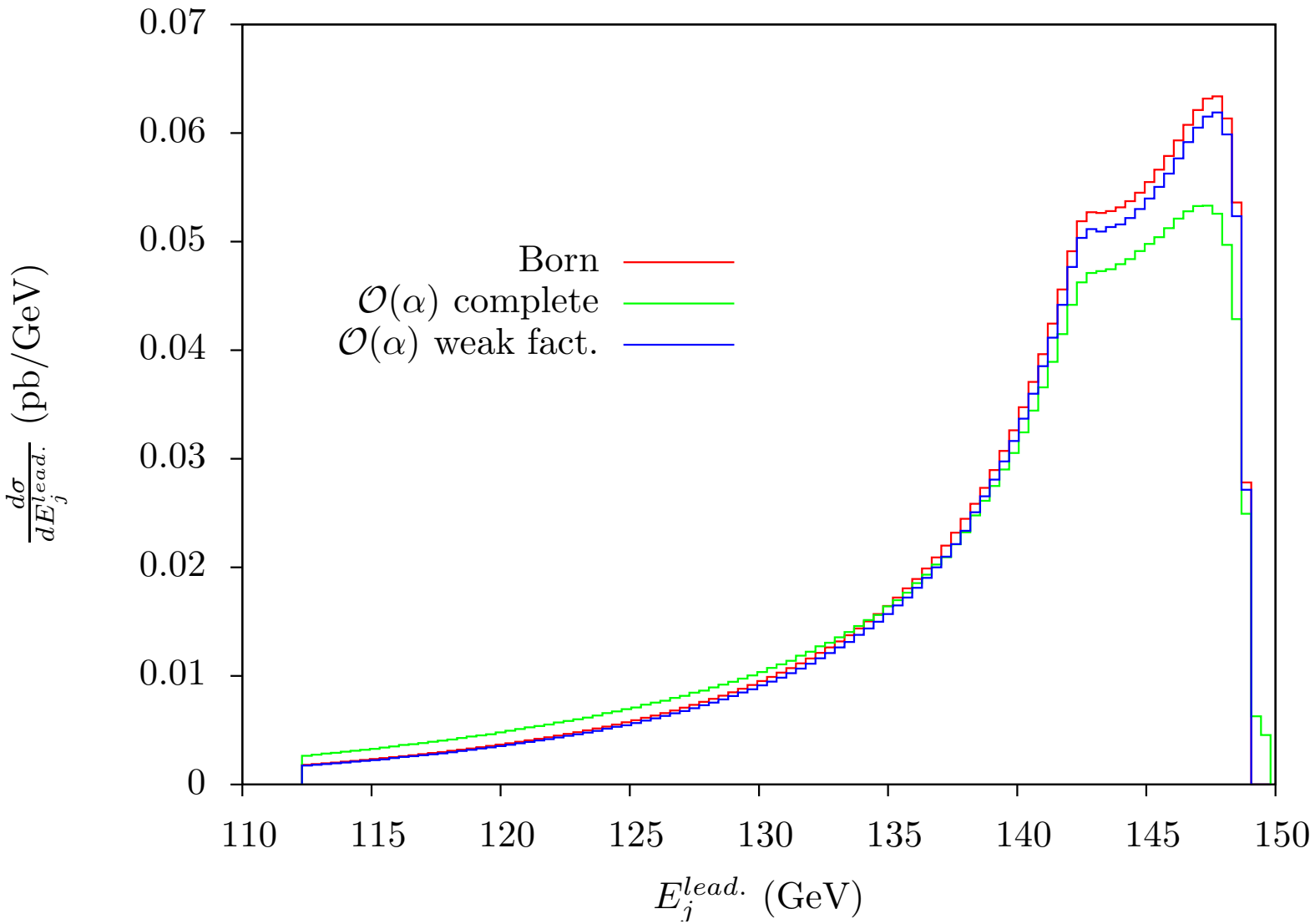


Leading jet angle

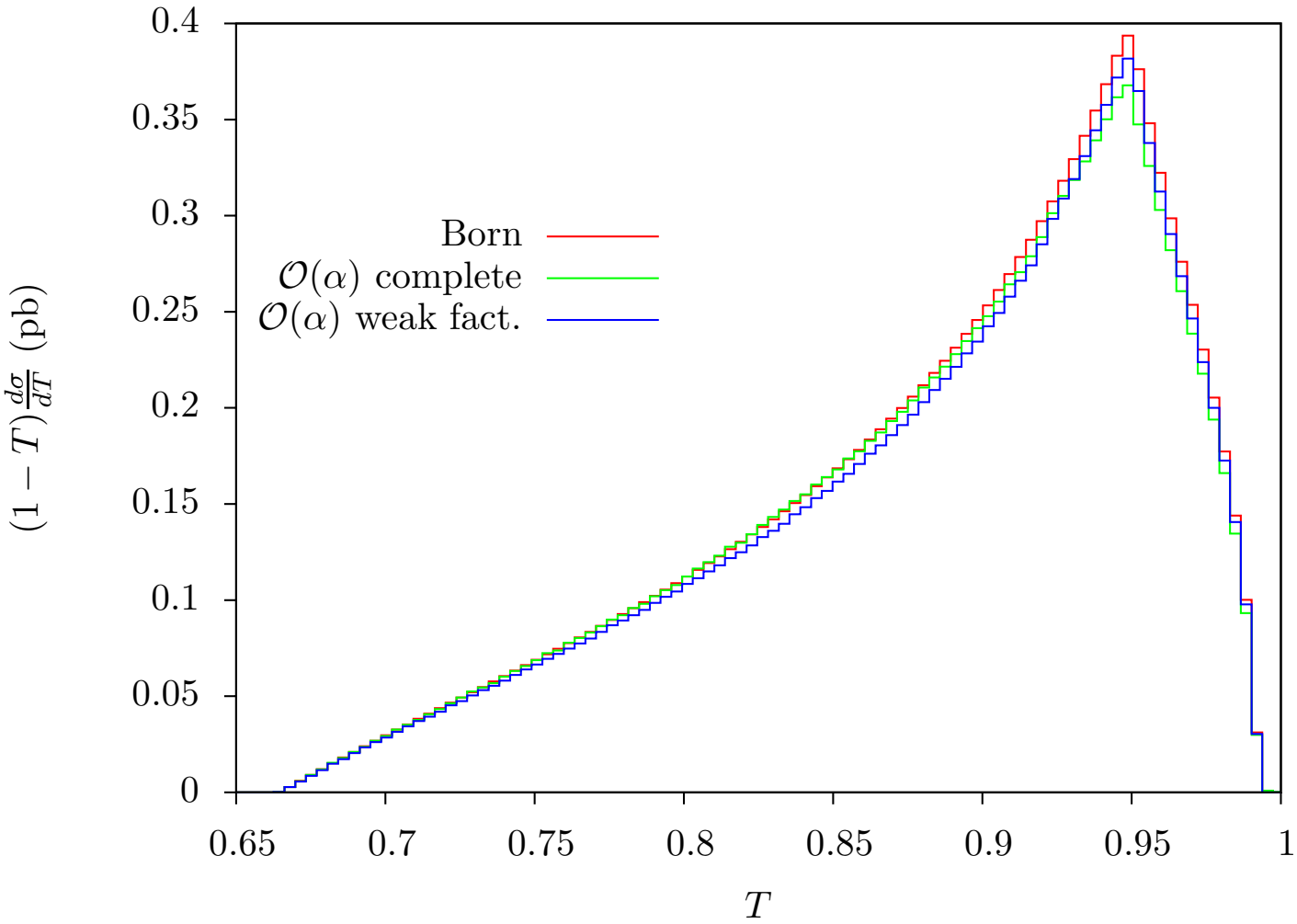


- asymmetry induced by photonic real corrections

Leading jet energy

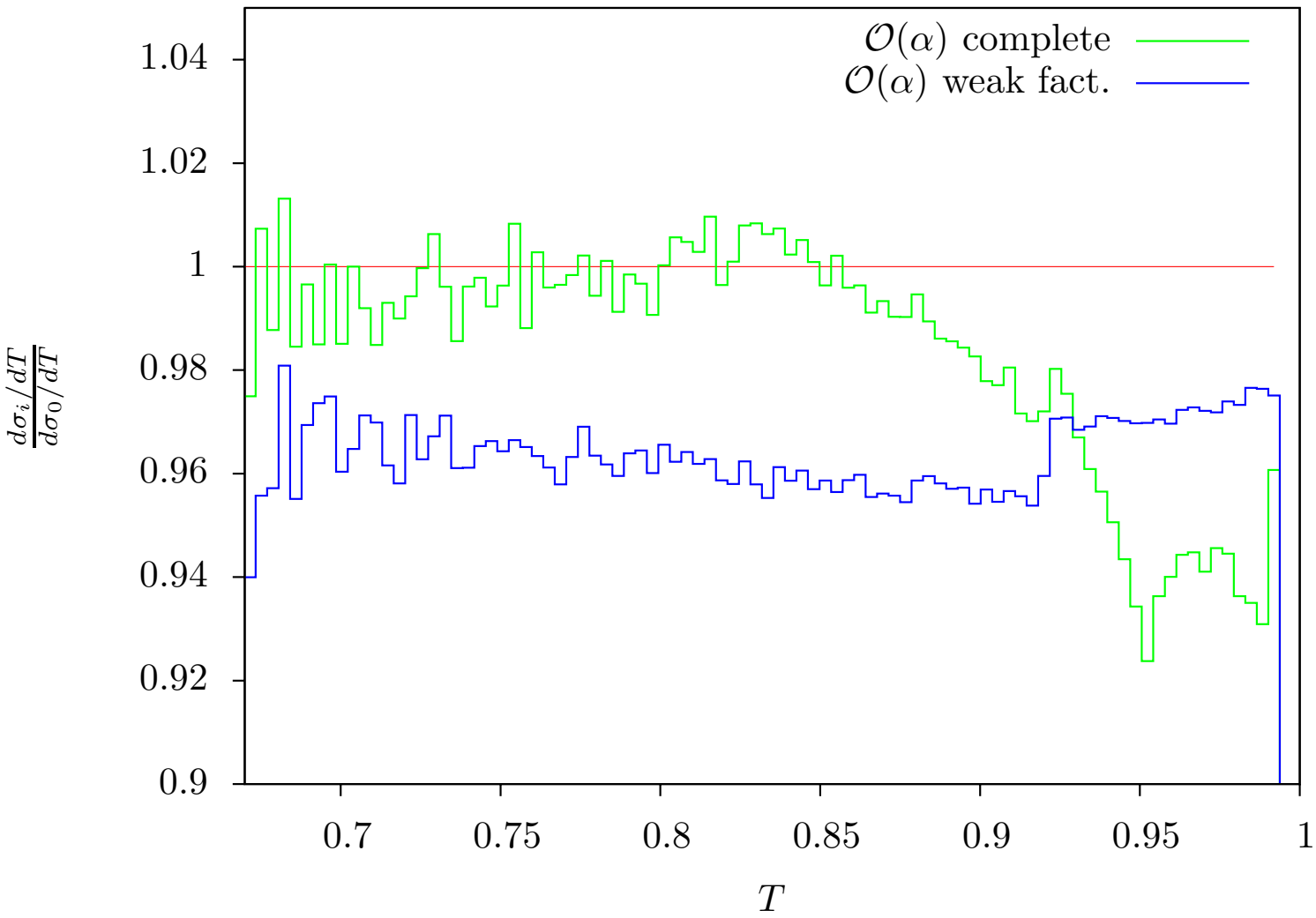


Thrust



$$T = \max \frac{\sum_i |\vec{p}_i \cdot \vec{n}_T|}{\sum_i |\vec{p}_i|}$$

Thrust



- effects at some 1% level on thrust distribution. Non-trivial effect of QED + non-factorizable weak corrections

Conclusions

- ⋆ the complete one-loop EW corrections to $e^+e^- \to 3$ jets have been calculated
  - each contribution calculated independently twice
  - so far, good agreement between different implementations
  - the calculation is implemented in a Monte Carlo event generator
- ⋆ at 300 GeV, weak factorizable and weak non-factorizable + QED corrections give effects of the same size, e.g. on thrust distribution
- ⋆ EW RC are expected to be even more relevant in presence of polarized beams, unlike QCD RC
- ⋆ these corrections are important in view of precision physics and BSM searches at ILC
- ⋆ work in progress:
  - further (technical & stability) checks
  - inclusion of ISR higher-order (avoiding double counting) and *beamstralhung* effects
  - conclude the phenomenological study for $e^+e^- \to 3$ jets
  - crossing the process to study EW RC to Z+jet at hadron colliders