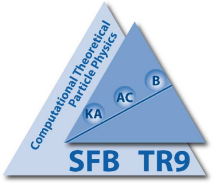
Status of our nnlo project

Tord Riemann, DESY, Zeuthen



4^{th} Meeting of the Working Group on Radiative Corrections and Monte Carlo Generators for Low Energies

Radio MonteCarlow

October 9-11, 2008, IHEP, Beijing, China

based on work with

S. Actis (RWTH Aachen), A. Arbuzov (JINR Dubna), M. Czakon (U. Würzburg), J. Gluza, K.Kajda, T. Sabonis (U. Katowice), M. Worek (Karlsruhe U.)

- Introduction: What is "our bhbhnnlo project" ?
- bhbhnnlo_hf (SA,MC,JG,TR)
- eemmnnlo_5p (JG,KK,TS,TR)
- bhbhnnlo_prs (MC,JG,TR,MW)
- bhbhnnlo_mc_prs (AA,JG,TR)
- Concluding Remarks

Introduction: What is "our nnlo project" ?

In Summer 2003, M. Czakon, J. Gluza, T.R. (and later also S. Actis) started a study of massive two-loop Bhabha scattering for the ILC project.

We got nice results (PRD71, NPB751, NPB786, PRL100, PRDxx), but failed so far with the crossed 2-loop box diagrams (as did others too),
while with another method these diagrams were evaluated (Penin PRL95) to the necessary accuracy
$\longrightarrow$ including all logarithmic terms plus the constant terms (in m_e^2/s and m_e^2/t).

But we gained some expertise on such calculations
and found out that important applications are at lower energy meson factories.

The research going on is what I call here
"our bhbhnnlo project" or shorter "our nnlo project".

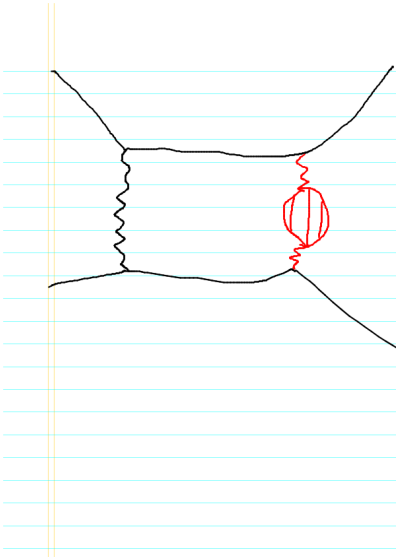
bhbhnnlo_hf

Bhabha scattering with heavy fermions and hadrons

The so-called $N_f = 1$ Bhabha scattering process knows only photons and electrons.

In fact, there are also effects due to leptons (or generally, heavy fermions) and hadrons. There is the running α_{QED} effect, but most complicated are the heavy two-loop boxes, which contribute at most to order $\ln^2\left(\frac{s}{m_f^2}\right)$, which is much smaller than the $\ln^2\left(\frac{s}{m_e^2}\right)$ from other diagrams.

This is solved quite recently, $\longrightarrow$ see J. Gluza's talk here at Sighad2008.

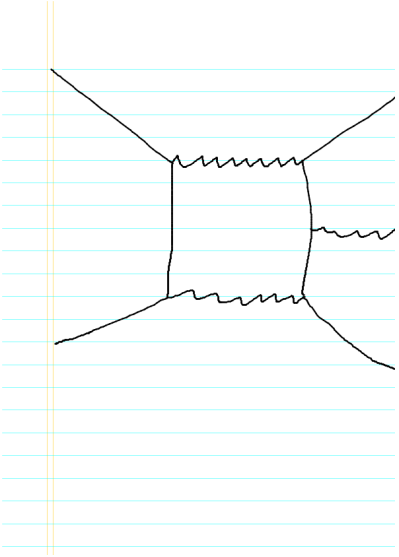


Sample diagram of $N_f > 1$ Bhabha scattering

Actis/Czakon/Gluza/T.R. PRL100 (dispersion approach)
Bonciani/Ferroglia/Penin PRL100 (diagrams)
also: Kühn/Uccirati arXiv:0807.1284 (dispersion approach)

eemmnnlo_5p – Radiative loop corrections

Gluza, Kajda, Sabonis, T.R. and thanks to H. Czyz



Among the non-leading NNLO corrections are the so-called radiative loop corrections, interfering with lowest order bremsstrahlung.
The main problems arise from the pentagon diagrams.
Tool for tensor reduction of 5-point functions to scalar boxes, vertices, self-energies:
K. Kajda et al., hexagon.m
see webpage http://prac.us.edu.pl/∼ gluza/hexagon/

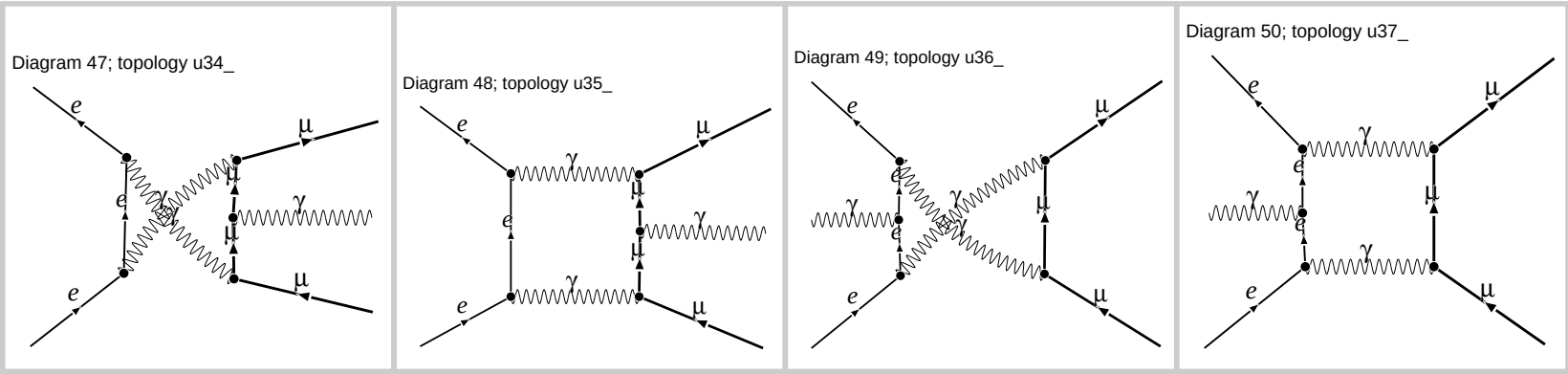
Status: We aim at automatic Fortran code generation for phase space integrations

- with DIANA, Fleischer/Tentyukov – creation of all diagrams
- with hexagon.m and LoopTools/FF, Hahn/vanOldenborgh and FORM, Vermaseren and Mathematica – treatment of the tensor loop integrals, and evaluation of the matrix elements with trace and helicity methods
- with PHOKHARA, Rodrigo/Czyz/Kühn/Szopa/Grzelinska/Nowak – Monte Carlo phase space integration foreseen

We look first at the reaction

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

with a resolved photon.
This has nothing to do with Bhabha scattering, but is a part of the Bhabha contributions and of physical interest by itself.



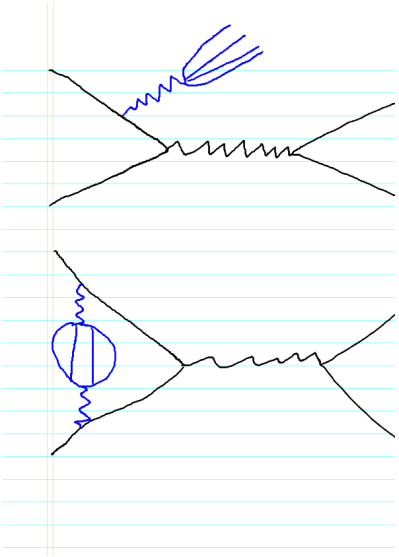
Four 5-point diagrams obtained using DIANA, Fleischer/Tentyukov.

bhbhnnlo_prs (Arbuzov, Gluza, T.R.)

The corrections to Bhabha scattering from electron pair emission diagrams are at most of order $\ln^3\left(\frac{s}{m_e^2}\right)$ and compensate against irreducible vertices by one order, resulting in a net $\ln^2\left(\frac{s}{m_e^2}\right)$ effect; see

A.Arbuzov, E.Kuraev, N.Merenkov, L.Trentadue, Phys.Atom.Nucl.60(1997)

The same for heavy fermions may also be evaluated, following the method described in PAN60.



This is what Andrej Arbuzov is currently looking at.
One might expect the most leading terms to agree with the electron pairs' effect, but others might deviate.
One may also look at the hadronic case, but then to some extent numerically.

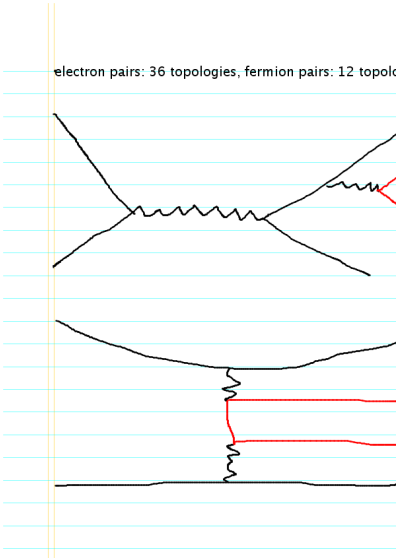
Pair corrections with bhbhnnlo_MC_prs

M. Czakon, J. Gluza, T.R., M. Worek

Thanks to M. Worek's engagement, there are first results for event generation of Bhabha scattering with additional unresolved electron or muon pairs at $\sqrt{s} = 1.02, 10, 91$ GeV.

No cuts on the unresolved particles, but acceptance cuts on electron energy E_{min}, production angles $\theta_{\pm}$, acollinearity $\xi_{\max}$.

All particles are massive and observed, so there are no true singularities.



- **At low energies, logarithms are not enhanced at all**
- **There are diagrams with quite different kinematics**
- **then, realistic cuts play a crucial role**
- **$\longrightarrow$ use HELAC-PHEGAS, Kanaki/Papadopulos/Worek/Cafarella webpage**
  http://helac-phegas.web.cern.ch/helac-phegas/

Sample results (I)

Particle	$20^\circ < \theta_\pm < 160^\circ$	$55^\circ < \theta_\pm < 125^\circ$
e	**2.22595**	**0.30969**

Table 1: *Contribution of electron pair corrections to the cross section of Bhabha scattering (in nb), for KLOE/DAΦNE center-of-mass energy* $\sqrt{s} = 1.02$ *GeV. Statistical errors below* 0.5 %

Particle	$20^\circ < \theta_\pm < 160^\circ$	$55^\circ < \theta_\pm < 125^\circ$
e	**0.0890437**	**0.0103023**
μ	**0.725999**$\times 10^{-3}$	**0.175093**$\times 10^{-3}$
u	**0.350995**$\times 10^{-3}$	**0.944359**$\times 10^{-4}$
d (s)	**0.873300**$\times 10^{-4}$	**0.236085**$\times 10^{-4}$

Table 2: *Contributions of electron, muon and light quark pair corrections to the cross section of Bhabha scattering (in nb), for BABAR/PEP-II & BELLE/KEKB center-of-mass energy* $\sqrt{s} = 10$ *GeV. Statistical errors well below* 0.5 %.

Summary

- We have started to study so far unimportant NNLO cross-section contributions: At 10^{-3} to 10^{-4} some of them may become of interest
- The heavy fermion or hadron corrections to Bhabha scattering are publicly available as a Fortran package
- The MC program for real pair corrections to Bhabha scattering based on HELAC/PHEGAS is ready for use
- An analytical study of the heavy soft pair corrections to Bhabha scattering is under way, but not easy to finish.
- The radiative loop corrections to muon pair production are under development, and those for Bhabha scattering might be studied afterwards
- We hope to learn from this workshop
  – Which NNLO contributions look important/interesting also to our collegues ?
  – Which pieces of our ongoing studies might find the way into the write-up of the working group ?
  – Cuts ...