QED, EW and hadronic corrections for Bhabha event generators

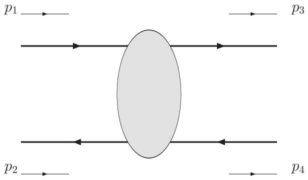
Janusz Gluza

University of Silesia, Katowice

FCC Week 2015, Washington, 24th March 2015

Kinematical Regions for Bhabha

Two regions where the Bhabha-scattering cross section is large and QED dominated



$$s = (p_1+p_2)^2 = 4E^2 > 4m_e^2, \quad t = (p_1-p_3)^2 = -4\,(E^2-m_e^2)\sin^2\frac{\theta}{2} < 0$$

- $\sqrt{s} \sim 10^2$ GeV $\Rightarrow$ small θ
- SABS $\Rightarrow \mathcal{L}$ at LEP, ...

  $\sim$ a few degrees

- $\sqrt{s} \sim$ 1-10 GeV $\Rightarrow$ large θ
- LABS $\Rightarrow \mathcal{L}$ at KLOE, ...

  $\theta \sim 55^0 - 125^0$

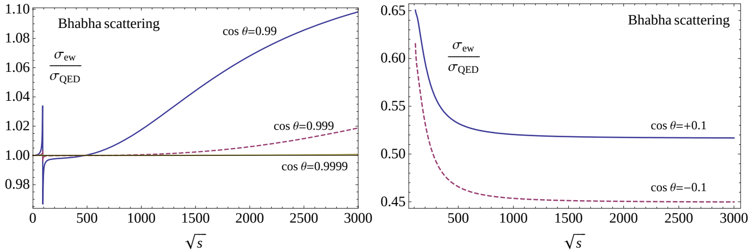
Theoretical accuracy and MC generators

How much theory to put into MC generators? (speed, efficiency, approximations,...)

The answer depends on:

- physics needs
- experimental setup (e.g. small, large angles)

Ratio of electroweak to QED Bhabha scattering cross-section at large and small angles as a function of CoM



Rough estimation, tree level calculation, no cuts etc,
PRD78 (2008) 085019

$$\cos(\theta) = 0.9999 \quad \rightarrow \quad \theta = 0.8^{o}$$

$$PRD78(2008)085019 \cos(\theta) = 0.999 \quad \rightarrow \quad \theta = 2.5^{o}$$

$$\cos(\theta) = 0.99 \quad \rightarrow \quad \theta = 8^{o}$$

$$\cos(\theta) = 0.1 \quad \rightarrow \quad \theta = 84^{o}$$

Dominant electroweak corrections for LABS

1. One loop corrections; Consoli NPB160 (1979) 208; [Greco, Lo Presti, Caffo, Gatto, Remiddi, Böhm, Tobimatsu, Shimizu, Denner, Hollik, Berends, Kleiss, Bardin, Riemann - see ref. in PRD78 (2008) 085019]
2. *Two-loop electroweak corrections to high energy large-angle Bhabha scattering*
A.A. Penin, G. Ryan, JHEP 1111 (2011) 081

"... We have computed the dominant two-loop electroweak corrections to high-energy wide-angle Bhabha scattering. The corrections can be as large as 10% in one loop and 1% in two loops. Our result completes the perturbative analysis of the Bhabha scattering necessary for the luminosity determination at the ILC"

FCC/ILC estimations: small-angle Bhabha scattering

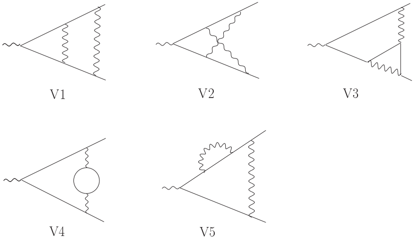
ILC: 31-63 mrad: 1.78-3.61 deg

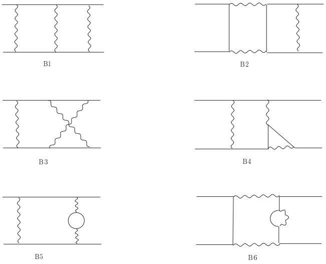
$\rightarrow$ FCC?

Eternal dilemma:
What is needed beyond dominating, resummed logarithmic terms to balance between efficiency and accuracy?
$\rightarrow$ E.g. nonlogarithmic $\mathcal{O}(\alpha^2)$ fixed order massive QED terms?

Fortunately, we know them all since LEP II finished its job. So we can estimate what is needed!

NNLO photonic, fermionic $N_f = 1, 2$ and hadronic topologies

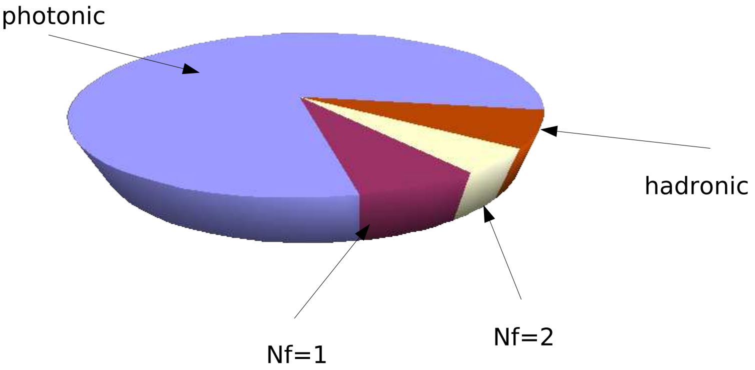




2-loop boxes for Bhabha process

- SE loop insertions (without photonic line) are so called fermionic diagrams, rest represents photonic.
- Closed fermionic loop can be muon, tau, top or hadron structures
- In general, box B5 is a 4-scale problem: $m_e, m_f, s, t(u)$.

Status: main pieces of the 2-loop virtual Bhabha cake



Remarkable: photonic, $N_f = 1, N_f = 2$ and hadronic NNLO corrections doubly (triply) cross-checked, last results:
J.M. Henn and V. A. Smirnov, "Analytic results for two-loop master integrals for Bhabha scattering I",
JHEP **1311** (2013) 041

Literature

Photonic corrections:

- [Penin '05]

Electrons in SE loops

- [Bonciani,Ferroglia ,Mastrolia,Remiddi,van der Bij '05] $\Rightarrow$ full m_e dep.
- [Actis, JG, Czakon, Riemann '07] $\Rightarrow$ full m_e dep.
- [Becher-Melnikov '07] $\Rightarrow m_e^2 << s, t$

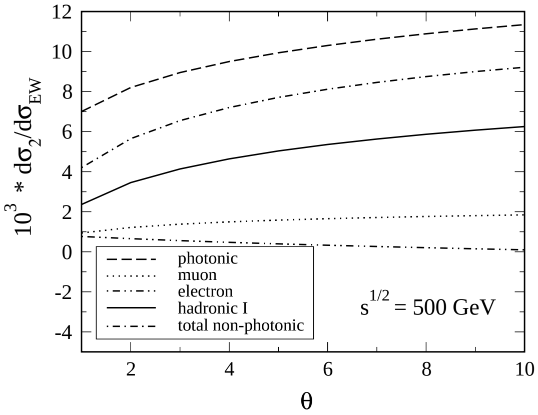
Muon, tau in SE loops

- [Becher-Melnikov '07] $\Rightarrow m_e^2 << m_f^2 << s, t, u$
- [Actis, JG, Czakon, Riemann '07] $\Rightarrow m_e^2 << m_f^2 << s, t, u$
- [Bonciani, Ferroglia, Penin '07] $\Rightarrow m_e^2 << m_f^2, s, t, u$

Hadrons in SE loops, dispersion relations

- [Actis, JG, Czakon, Riemann '08] $\Rightarrow m_e^2 << m_f^2, s, t, u$
- [Kuhn, Ucciratti '09] $\Rightarrow m_e^2 << m_f^2, s, t, u$

Cut dependent results, Actis, Czakon, JG, Riemann, PRD2008



We need more, to estimate role of calculated higher order virtual corrections, physical conditions must be applied through MC generators, including also real radiation, pair emissions...

Available MC generators

- BHLUMI v.4.04: Jadach, Placzek, Richter-Was, Was: CPC 1997
- NLLBHA: Arbuzov, Fadin, Kuraev, Lipatov, Merenkov, Trentadue: NPB 1997, CERN 96-01
- SAMBHA: Arbuzov, Haidt, Matteuzzi, Paganoni, Trentadue: hep-ph/0402211
- BabaYaga: Calame, Montagna, Nicrosini, Piccinini, http://www2.pv.infn.it/ hepcomplex/babayaga.html

BHLUMI was a main tool at LEP. It can be certainly used for FCC (SMABS).
BabaYaga is presently the main tool for luminosity at flavor factories.

BabaYaga MC generator, recent studies

NNLO leptonic and hadronic corrections to Bhabha scattering and luminosity monitoring at meson factories,
JHEP 1107:126,2011

C. Carloni Calame, (Southampton U.)
H. Czyz, (Silesia U.)
J. Gluza, (Silesia U.)
M. Gunia, (Silesia U.)
G. Montagna, (Pavia U. & INFN, Pavia)
O. Nicrosini, F. Piccinini, (INFN, Pavia)
T. Riemann, (DESY, Zeuthen)
M. Worek, (Wuppertal U.)

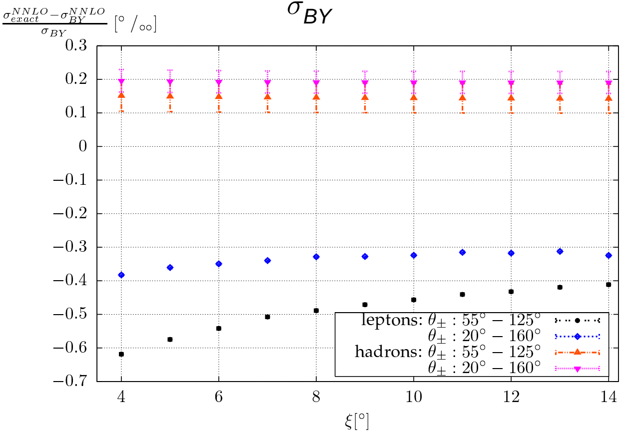
To be done analogously for FCC!

- calculation of the virtual (determined by the package bha_nnlo_hf) and real corrections (Monte Carlo generators EKHA RA, BHAGHEN–1PH+... and HELAC–PHEGAS) at NNLO for Bhabha scattering
- discussion of the numerical results for energies and with realistic cuts used at the Φ factory Dafne, at the B factories PEP-II and at KEK and at the charm/τ factory BEPC II, Beijing
- comparison complete calculations with approximate ones realized in the MC generator BabaYaga

It has been checked that BabaYaga MC generator is sufficient for precise low-energy studies, up to 10.56 GeV (Babar), and aiming at 1 per-mille level.

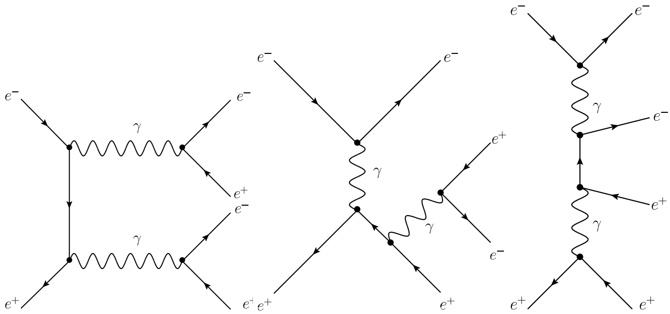
Example for KLOE, JHEP 1107 (2011) 126

$$\frac{\sigma_{exact}^{NNLO} - \sigma_{BY}^{NNLO}}{\sigma_{BY}}$$



C. Carloni Calame, H. Czyz, J. Gluza, M. Gunia, G. Montagna, O. Nicrosini, F. Piccinini, T. Riemann, M. Worek

Real electron pairs



Samples of the 36 diagrams contributing to $e^+e^- \to e^+e^-(e^+e^-)$, as calculated by M. Worek using Helac-Phegas code.

Conclusions for FCC

1. MC generators exist (e.g. BHLUMI and BabaYaga), used successfully for many studies, however at energies and configurations different than that which will be needed for FCC
2. Virtual corrections at NNLO level are known
3. Influence of missing NNLO terms in existing MC generators should be studied for FCC energies assuming some realistic FCC conditions, real pair emissions and real radiation.

Open questions:

1. influence of pentagon diagrams,
2. stable and efficient libraries (e.g. PJFRY should be used (!) in MC generators)
3. influence of weak corrections (LABS)

MC generators radiative working group for FCC studies is needed


www.lnf.infn.it/wg/sighad/

Working Group on Rad. Corrections and MC Generators for Low Energies

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Meetings

Monte Carlo Codes

Comparisons between Generators and num. Codes

Working Group on Rad. Corrections and MC Generators for Low Energies

The aim of this Working Group is to bring together theorists and experimentalists in order to discuss the current status of radiative corrections and Monte Carlo generators at low energies. These radiative corrections and MC generators are crucial for the measurement of the R-ratio (both with IS and energy scan), as well as the determination of luminosity.

The sixteenth meeting will take place in Frascati, on November 18/19 2014.

The fifteenth meeting took place in Mainz, on April 11 2014.

The fourteenth meeting took place in Frascati, on September 13 2013, as a satellite meeting of the PHIPSI13 conference in Rome.

The thirteenth meeting took place at ECT* Trento, on April 11/12 2013.

The twelfth meeting took place in Mainz, on September 27/28 2012.

The eleventh meeting took place in Frascati, on April 16/17 2012.

The tenth meeting took place in Novosibirsk, on September 23 2011, as a satellite meeting of the PHIPSI11 conference.