

High-energy Bhabha scattering

LEP Trieste
2000

A. Arbuzov

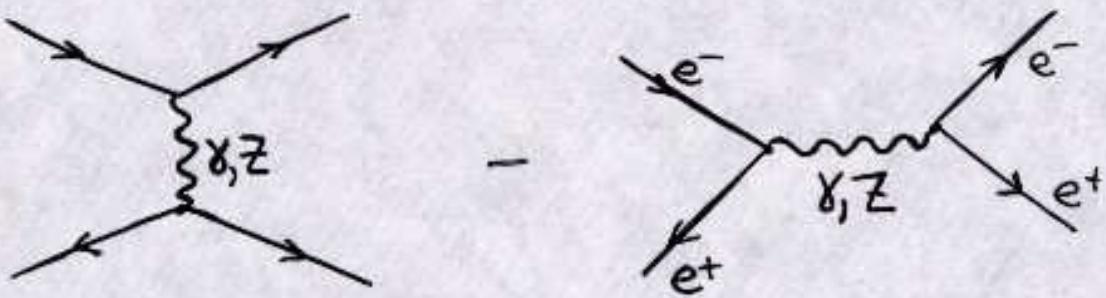
Torino U. & INFN

(on leave of absence
from JINR, Dubna)

Plan

1. Bhabha scattering in general
2. Small-Angle Bhabha Scattering (SABS) at LEP1
3. LABS at LEP and flavour factorier
4. LABSMC event generator
5. Bhabha and Møller processes at future colliders
6. Outlook

Introduction



high energy $\rightarrow E_{\text{beam}} \gg m_e$

Main features

- infinite cross section
- "good" experimental signature
- "good" theoretical description

almost pure QED
 only log mass effects (but very important)
 perturbative calculations
 some EW and hadronic effects

Accuracy of Bhabha description

(3)

theoretical

- radiative corrections
- backgrounds

technical

- precision of Monte Carlo and semi-analytical codes
- possible bugs and misinterpretations of experimental conditions

Sources of RC

- one-loop QED
- one-loop EW + effective EW couplings
- vacuum polarization by e, μ, τ , hadrons
- two-loop QED (including pair production)
- higher order QED (Leading log approximation, exponentiation)

Small-Angle Bhabha Scattering at LEP1

- enormous precision of experiment $\sim 0.05\%$
 - calibration of beam energy
 - high statistics
 - clear signature
- Importance of error (and absolute value) of luminosity definition for SM parameters
- small angles - few degrees $1^\circ < \theta < 6^\circ$
 \Rightarrow great advantage in calculations : $\theta^2 \ll 1$

Theory: Yellow Report 96-01 (S. Jadach, O. Nicodemi, conv.
 Phys. Lett. B 383 (A.A. et al))

Common conclusion of several groups

BHLUMI, SABSPV, BRAGEN95, NLLBMA, OLDBIS, ...

Theoretical uncertainty of SABS at LEP1

source	error '96	BHLUMI '99
missing $O(L^2 L, \alpha^2)$ photonic RC	0.1% *	0.027% **
missing $O(L^3 L^3)$	0.015%	0.015%
vacuum polarization	0.04%	0.04%
light pairs	0.03% *	0.03%
Z-exchange	0.015%	0.015%
<u>total</u>	<u>0.11%</u>	0.061%

* NLLBMA contained $O(\alpha^2 L)$ and $e^+ e^-$ pairs, BUT semi-analytical

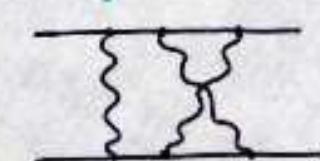
* can not be checked analytically; has never been confronted quantitatively to other calculations

$$\left(\frac{\alpha}{\pi}\right)^2 \sim 6 \cdot 10^{-6}, \quad L = \ln\left(\frac{-t}{m_e^2}\right) \sim 15 \Rightarrow \left(\frac{\alpha}{\pi}\right)^2 L \sim 10^{-9}$$

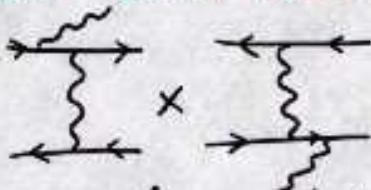
New MC LABSMC can be used also at small angles. Comparisons with BHLUMI for integrated and differential distributions are in progress.

LABS

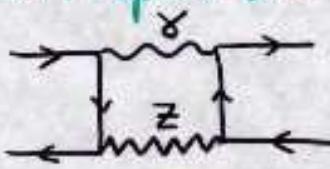
Many "additional" contributions in respect to SABS



two-loop boxer



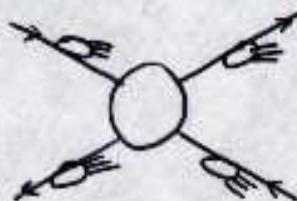
up-down interference



EW boxer

Scheme

1. Born level, including Z -exchange
2. $O(\alpha)$ photonic RC (incl. Z -exch.)
3. vacuum polarization \leq
 0.04% for $Q^2 \sim 1 \text{ GeV}$
 0.1% for LEP2
4. $O(\alpha^n L^n)$ photonic RC: electron structure functions



$$\text{vacuum polarization} = \text{---} \times \text{---}$$

$$G^{LLA} = \int \int dz_1 dz_2 D(z_1) D(z_2) \tilde{f}(z_1 z_2) \int dy_1 \int dy_2 f(y_1) f(y_2)$$

$$D(z) = \delta(1-z) + \sum_{n=1}^{\infty} \frac{1}{n!} \left[\frac{d}{dz} (L-1) \right]^n P^{(n)}(z)$$

- exponentiation \leftrightarrow order-by-order SF
- $m=5$ (see A.A. hep-ph/9908361)
- argument of L : $L = \ln(\frac{s}{m_e^2})$ or $L = \ln(\frac{-t}{m_e^2})$ or ?
- V.Antonelli, E.Kuraev, B.Shaikhatdenov, hep-ph/0905331

LABSMC
 semi-analytical — Monte Carlo

Comparison with Fig. 21 YR 96-01

Ecm	BHWIDE	TOPAZ0	BHAGENE3	UNIBAB	SABSPV	BHAGEN95	<u>LABSMC</u>
175	35.257	35.455	34.690	34.498	35.740	35.847	35.337
190	29.899	30.024	28.480	29.189	30.270	30.352	29.941
205	25.593	25.738	24.690	25.976	25.960	26.007	25.687
175	39.441	40.487	39.170	39.521	40.240	40.505	40.029
190	33.698	34.336	32.400	33.512	34.100	34.331	33.954
205	28.929	29.460	27.840	28.710	29.280	29.437	29.178

LEP2 MC workshop, 2f -group

#observables according to "preliminary notes":

17-36 (Bhabha), 77-78 ($e^+e^- \gamma$)

17	ALEPH realistic exclusive ES1:	108.24	pb
19	DELPHI — / / — : ES :	23.297	
23	L3 realistic inclusive ES :	209.03	
24	OPAL — / / — : ES :	110.01	
27	ALEPH idealized exclusive ES1:	111.27	
29	DELPHI — / / — ES :	18.456	
32	L3 idealized inclusive ESL :	25.187	
34	OPAL — / / — ES :	111.94	

5. One-loop EW RC $\overline{\text{83}} \overline{\text{32}} + \dots$

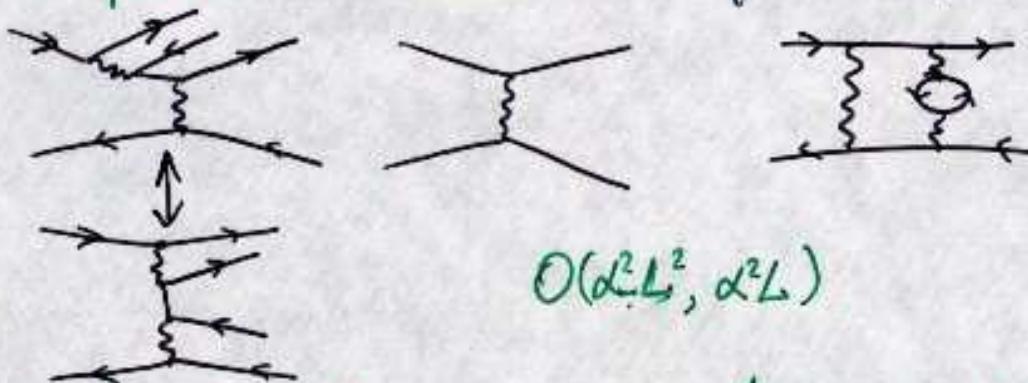
(absent for flavour factories)

+ effective EW couplings (see LEP1)

ALIBABA \leftrightarrow **DIZET** (see ZFITTER description
hep-ph/0908453)

6. Pair production

- e^+e^- pairs: A.A. et al. Nucl. Phys. B 474, Yad. Fiz. '97



- hadronic pairs: approximation via $R(s)$, but a parametrization of R is missing...

7. $O(\alpha^2 L)$ photonic RC $\stackrel{(2)}{\approx} L - 1.4 \cdot 10^{-4}$

there are some results:

- 2 real hard collinear photons
- 2 soft
- 1 hard + 1 soft/virt

problems

two-loop boxes

hoper

W.L.van Neerven hep-ph/0003043
E.A. Kuraev & co

Numerical illustration

Yellow Report 96-01: LABS at LEP1 (2)

TOPAZ \emptyset , BHWIDE, BHAGENE3, UNIBAB, BHAGEN95
up to 2% difference

specific situation: interplay of s- and t-channels.

LEP2 predictions in YR96-01 are spread in 2%
as well, but "physics" is different: t-channel

LEP2 Monte Carlo work shop

they ask up to 1.3 per mille for LABS

<http://www.dft.unito.it/giampieri/lep2.html>

BHWIDE \leftrightarrow LABSMC \leftarrow too few

$$\begin{array}{ccc} 0.5\% & & 0.2\% \\ \downarrow & & \downarrow \\ ? & & 0.3\% ? \end{array}$$

- considerable difference in EW
- pair RC
- technical precision

LABSMC

189 GeV, $|C| < 0.96$

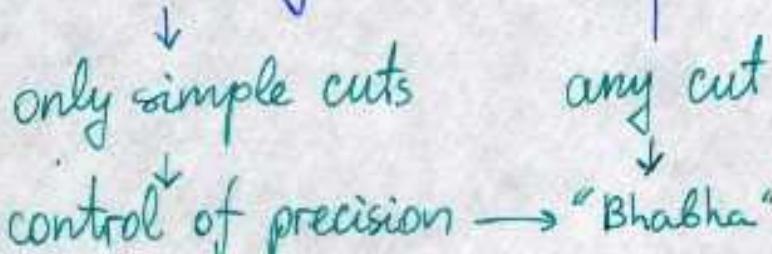
QED Born pure t-channel	- 332.39 pb	
QED Born	- 316.79	
EW Born*	- 301.74	
EW "improved" Born	- 301.29	
Born + vac. pol.	- 334.87	
Corr. only photons	- 332.30	"Aleph 3"
+ $O(\alpha^2 L^2)$ pairs	- 332.35	118.78 $\pm 0.3\%$
+ double-photon	- 336.18	119.13 $\pm 0.4\%$
		119.57

Uncertainties

$O(\alpha^2 L)$	0.1% (0.15%?)
vac. pol.	0.1%
pairs	0.05% (?)
EW	?

LABSMC code A.A. hep-ph/9907298, 9910280,
LEP2 MC w.sh.

semi-analytical \rightarrow MC



Flavour factories

C.M. Carloni Calame et al BABAYAGA (0.5%)

DAΦNE, BEPC/BES, KEKB, PERII, VEPP-2M

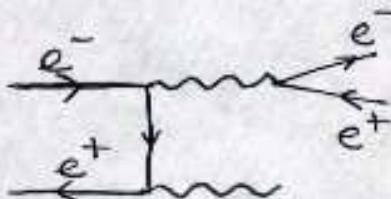
- to pay attention to resonances (ψ)
 - importance of FSR in presence of strong magnetic field
 - specific treatment of pairs
-

Future colliders $e^+e^- \mu^+\mu^- (e^-e^-)$
LABS (Møller)

- beam energy spread (e^+e^-) luminosity
 - polarization
 - $t\bar{t}$ threshold ?
 - precision requirements ?
-

Special kinematics

- radiative Bhabha with tagged photon
- extremely small angles $\theta \sim m_e/E_{beam}$
- "annihilation into photons"



QED \rightarrow Bhabha \rightarrow SM \rightarrow Bhabha $\xrightarrow{?} NP$

M. Beccaria et al. hep-ph/0002101

D. Bourilkov hep-ph/0002172, 9907380

• • •

Searcher for new physics by means
of Bhabha (see "the main features")

LEP2 \rightarrow already some constrains on NP

Table IV from [L]

	w/o Bhabha	with all Bhabha (2% err)	with Bhabha exact
Λ_u	4.1	4.2	4.4
$\Lambda_{\bar{u}}$	3.8	3.9	4.2
Λ_v	6.3	6.8	7.5
$\Lambda_{\bar{v}}$	5.8	6.0	6.1
Λ_{eD}	0.89	1.2	1.4

Outlook

- experimental accuracy \leftrightarrow accuracy required from theory
- theory is retarded
- permil precision on LABS should be achieved
- 2-loop Boxer - a challenge
- LEP2 MC WS - a step forward ?
- Bhabha "grows up"