DELPHI Collaboration

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Implementation of KK for DELPHI (DelKK version 4.14/6)

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Abstract

The implementation of the Monte Carlo event generator KK for DELPHI for the simulation of the process $e^+e^- \to f\overline{f}$ is discussed.

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1 Introduction

The KK Monte Carlo Events Generator [1] is a generator for $e^+e^- \rightarrow f\overline{f} + n\gamma$ for $f = \mu, \tau, u, d, s, c, b$, which is applicable at LEP I and LEP II energies. QED corrections are computed up to second order using the method of Coherent Exclusive Exponentiation (CEEX) [2] a development of the exclusive exponentiation method (EEX) of Yennie-Frautschi-Suura (YFS). Electroweak corrections are included using the DIZET library [3].

Compared to previous Monte Carlo event generators, such as KORALZ [4], KK includes a more complete treatment of QED corrections. The exact matrix elements are included for $e^+e^- \rightarrow f\overline{f}$ and two photons, and interference between initial state and final state radiation can be included naturally in the computation. Many of the improvements in KK are at the limit of what is observable experimentally in the different LEP experiments, but, nevertheless, need to be included in event simulations to control systematic uncertainties to better than the statistical precision of combined LEP measurements.

The implementation of QED and Electroweak corrections have been extensively studied by the authors of the program [2] and the predictions of the MC have be compared with other event generators and semi-analytic calculations as part of the LEP II Monte Carlo Workshop [5]. This generator is likely to be the primary generator for $e^+e^- \rightarrow f\overline{f}$ in other LEP collaborations, and it is also applicable to higher energy simulations.

For use in DELPHI, KK version 4.14 has been adapted to provide a generator for $\mu^+\mu^-$, $\tau^+\tau^-$ and $q\bar{q}$ final states, producing events in a format suitable for passing through DELSIM with fragmentation and hadronisation implemented in a variety of different hadronisation code. The implementation is called DelKK, here we describe the DelKK version 4.14/6.

In Section 2 the technical details of the implementation of interfaces between the various elements of DelKK are discussed. The means by which internal parameters can be set are discussed in Section 3. The output of DelKK is described briefly in Section 4. One important physics study which was performed during the setting up of DelKK is described in Section 5. The limitations of DelKK are discussed in Section 6. Conclusions are given in Section 7.

Details of where to find and how to modify, compile and run the code are given in Appendix A. The updated decay tables which have been implemented in the version of PYTHIA which is interfaced to KK in DelKK are given in Appendix B.

2 DelKK Interfaces

DelKK combines code for KK with a number of other codes. The following building blocks are used:

- KK version 4.14: generation of $f\overline{f}$ + ISR/FSR photons
- The DELPHI implementation of PYTHIA version 6.156 [6]: hadronisation - handling FSR for hadronic final states
  (τ-lepton decays in hadronic events are handled with TAUOLA interfaced to PYTHIA).
- ARIADNE version 4.08 [7]

- HERWIG version 6.201 [8]
- TAUOLA for τ-lepton decays in $\tau^+\tau^-$ events.

Interfaces have been developed to interface KK to the other elements of DelKK.

2.1 Interface to Hadronisation Models

The KK generator creates final state $f\overline{f}(n\gamma)$ systems from the initial e^+e^- system. For $e^+e^-\rightarrow\mu^+\mu^-$ this is all that needs to be done. However, for $\mathrm{q\bar{q}}$ final states it is necessary to hadronise the $\mathrm{q\bar{q}}$ system. The main interface between the $\mathrm{q\bar{q}}(n\gamma)$ system generated event-by-event by KK and the hadronisation model is the `HepEvt` record. This is rather flexible and allows one to change from one fragmentation model to another. The original version of KK version 4.14 was interfaced to JETSET 7.4 for the hadronisation. DelKK can be interfaced to PYTHIA 6.156, ARIADNE 4.08 and HERWIG 6.201. The details of the modification to KK needed to provide these interfaces are described below. Since the fragmentation code is rather cumbersome and potentially conflicting, it was decided to provide different executables for each fragmentation model, rather than provide a flag based selection of the different models while running a single executable.

The generation of random numbers in KK for the Monte Carlo technique is kept separate from the other elements of the event generation since KK has its own routines to generate random numbers. This means that it is possible to generate the same sequence of underlying events and apply different fragmentation models to these events by ensuring the KK events are generated with the same initial random number seeds.

There are a number of physics issues which span the interface between the $\mathrm{q\bar{q}}\gamma$ generation and the subsequent hadronisation: the choice of quark masses, and the interplay between gluon and photon radiation from the final state. The second of these is discussed in Section 5.

There are some issues which are purely to do with the hadronisation, the different options available to the user are discussed in this note.

PYTHIA

The use of PYTHIA version 6.156 for the fragmentation involved a number of changes to the existing KK code[1]

- PYTHIA `REAL` common arrays changed to `DOUBLE PRECISION`.
- Subroutines `LUname` changed to `PYname`.
- Introduction of Z/γ into `HepEvt` record in KK. This was handled by providing a more flexible means of recording the positions of particles inside the `HepEvt` record, which were originally hard-coded inside the FORTRAN file `HepEvt.f`.

In addition, the default masses of quarks inside the array `PMAS` of PYTHIA differ from those of KK. PYTHIA masses are forced to be equal by a call to `DELKK_SET_PYMASSES`.

[1]Following contact with the authors these modifications have been implemented in later versions of KK.

PYTHIA flags are set to the standard DELPHI tuned values [9], as applied to PYTHIA version 6.125, by a call to the subroutine TUNPY, and are dumped to ascii and html files via a call to DELKK_PYFLAGS_DUMP.

The event-by-event hadronisation of the $q\bar{q}$ system is made by a call to PYEXEC from the KK routine HepEvtHadronise.

ARIADNE and HERWIG

A number of small additional modifications were needed to interface KK to the ARIADNE and HERWIG fragmentation models.

Versions of the TUNPY and DELKK_PYFLAGS_DUMP routines were provided to allow tuning of the ARIADNE and HERWIG models and to provide appropriate dumps of the model parameters. Details of the tuning can be found from the webpages [10] and [11]. The routine HepEvtHadronise was modified to call AREXEC for ARIADNE and HW2FINTF for HERWIG. The modified routines are provided in separate FORTRAN files which are linked when the executable is built, along with the appropriate code for the hadronisation model.

Hadronisation Tuning and Decay Tables

A number of parameter are available to modify the basic hadronisation inside PYTHIA:

- The fragmentation parameter for events b/c quarks can be updated from the default PYTHIA parameters;
- BSW matrix elements can be used for semi-leptonic decays of hadrons containing b and c quarks;
- The decay tables can be updated compared to the PYTHIA defaults;
- The parameters controlling Bose-Einstein correlations between mesons can be modified

The values of the branching ratios used in the updated decay tables in the version of PYTHIA which has been interfaced to KK are given as tables in Appendix B.

2.2 Interface for τ-lepton Decays

KK version 4.14 is interfaced to TUAOLA to perform decays of τ-leptons in $e^+e^- \rightarrow \tau^+\tau^-$ events. This version has a complete spin density treatment of the the τ-lepton decays, taking into account longitudinal and transverse spin correlations between the τ-leptons.

However, in the limit that the τ-leptons can be treated as massless, $m_\tau^2/s \ll 1$ it is possible to make an approximation to the complete treatment: ignoring the transverse spin correlations, and identifying each τ-lepton as having a specific helicity. This approximation was used at LEP I, where events were generated with the KORALZ generator. For DELPHI, events were flagged as either right or left handed helicity, by marking a LH τ^- as a χ^- (a hypothetical 4^{th}-generation charged lepton) and a LH τ^+ as a χ^+. This information was passed through DELSIM and recorded on the DSTs. The generated events were used to fit the tau polarisation at LEP I to extract the weak mixing angle. Similar studies have been repeated at LEP II, also using event generated with KORALZ.

In the full spin-density treatment of KK it is not possible to assign a helicity to each event. Therefore, to generate events suitable for the measurement of the τ polarisation, modifications were needed to KK to interface to a version of TAUOLA using the helicity treatment. These were implemented with the help of Z. Was, one of the original authors of both KK and TAUOLA. The modifications involve

- Providing an interface to initialise the helicity version of TAUOLA This is done via a call in the routine `DELKKTAUOLA`. This calls the routine `TAUOLA` in `tauface_jetset.f` which itself calls routines in `tauola_photot_ini.f`, these files are in the KK subdirectory `zwtauola`. These routines are compiled and linked during the creation of the executable.

- Replacing the standard KK routines which handle τ-leptons with versions which skip the spin density treatment of TAUOLA. The modified routines are `Tauface.f` and `Taupair_new.f` in the KK subdirectory `zwKK2f`. These routines are compiled and linked during the creation of the executable. A dummy version of this routine is linked for other final states and for the spin-density treatment of τ-lepton decays.

- Providing an interface to call the helicity treatment version of TAUOLA which is done by a call to TAUOLA in the routine `DELKKTAUOLA`.
  TAUOLA then uses its internal routines to estimate the helicities of the τ-leptons given the effective centre of mass energy in the ultra-relativistic approximation and produce the appropriate decays using routines in the standard version of TAUOLA. The helicities of the τ-leptons are stored in a common block.

- Calling a routine, `DELKKTAUPOL`, to mark the generated τ-leptons as having either right or left handed helicity as in the DELPHI version of KORALZ according to the helicity as stored above.

The interface was tested against KORALZ and good agreement was found for distribution of the energy of charged pions from $\tau \to \pi\nu$ events which are particularly sensitive to the τ polarisation.

The user has the option of making an executable with the full spin density treatment or with the helicity treatment for the τ-lepton decays.

It should be noted that in the versions used to generate events for physics analyses the random number generator for TAUOLA was not initialised with a new random seed for each run, so that in $\tau^+\tau^-$ events the same sequence of τ decays are found. The impact of this on the determination of the efficiency of the $e^+e^-\to\tau^+\tau^-$ analysis has been studied. Due to the large number of the individual subsamples of $e^+e^-\to\tau^+\tau^-$ events generated and because the kinematics of the decays are randomised over the different samples, the bias on the efficiency estimated from these simulated event samples is found to be negligible.

3 DelKK parameters

In setting up DelKK a number of KK parameters have been changed from the default values set internally by KK. Some of these can be considered as DELPHI recommended

IFRM	Final state
1	down quarks
2	up quarks
3	strange quarks
4	charm quarks
5	beauty quarks
10	inclusive quarks
13	muons
15	tau leptons

Table 1: *The final state fermions generate for different settings of the DelKK flag* `IFRM`.

values. They can be changed by modifying input files, for which it is necessary to understand the KK internal parameters. Other changes are hard-coded into the DelKK code. In addition some KK parameters can be changed by the user at run time via a title file by simply setting different flags.

The parameters of KK are set in the following order:

1. Default KK parameters are read in from the KK default parameter file
2. Default DELPHI values for certain KK parameters are read in from a file
3. User choice of parameters are read in from a title file
4. A number of parameters which are hard coded in DelKK are set

Details of the locations of the relevant files are give in Appendix A.

3.1 Title Cards

Final State Fermions Index

The final state fermions to be generated in a given run can be set through the flag `IFRM` in the title cards file. The choices are summarised in Table 1.

Run Number

The run number for a given run can be set through the flag `NRUN` in the title cards file. This is used to generate a random seed for the random number generators used inside the generator.

Numbers of Events

The number of events to generate in a given run can be set through the flag `NEVT` in the title cards file.

Centre-of-Mass Energy

The centre-of-mass energy for the e^+e^- collisions in a given run can be set through the flag `ECMS` in the title cards file.

Final State Radiation for Quarks

The treatment of final state radiation for $e^+e^- \to q\bar{q}$ can be set by the DelKK flag `KQSR`.

-1: FSR in PYTHIA with FSR correction to KK total cross-section

0: FSR in PYTHIA (no FSR correction to KK total cross-section)

1: FSR in KK

Each of these settings changes various KK flags to produce the appropriate output. After studies, discussed in Section 5, it was decided that the preferred choice should be `-1` for the large scale generation of events for most physics analyses.

Initial and Final State QED Interference

The treatment of the interference between initial and final state QED radiation can be set by the DelKK flag `KINT`.

0: ISR⊗FSR is switched off

1: ISR⊗FSR is switched on

Each of these settings changes the KK flag `KeyInt` to produce the appropriate output. For quark final states, when the final state radiation is not generated in KK, the interference is hard-coded to be off.

Hadronisation

Hadronisation of q$\bar{\text{q}}$ events is controlled by the flag `KHAD`.

0: Hadronisation is off

1: Hadronisation is on

b/c Fragmentation

Fragmentation in events with b/c quarks in PYTHIA is controlled by the flag `KBCF`

0: no updates to the fragmentation parameters

0402: use update version 0402 of b/c quark fragmentation parameters

BSW Matrix Elements

The use of BSW matrix elements for semi-leptonic b and c decays [12] in PYTHIA is steered by the flag `KBSW`

0: BSW matrix elements are not used

1: BSW matrix elements are used

	Masses (GeV/c^2)			
quark	DelKK	KK	PYTHIA	PDG
d	0.010	0.100	0.0099	0.005-0.015
u	0.005	0.100	0.0056	0.002-0.008
s	0.200	0.200	0.199	0.100-0.300
c	1.300	1.300	1.350	1.0 - 1.6
b	4.800	4.500	5.000	4.1 - 4.5
t	175.0	175.0	175.0	174.3 ± 5.1

Table 2: *Values of quark masses used in DelKK, the default KK quark masses, the default values inside the* `PMAS` *array in PYTHIA version 6.125 (in PYTHIA version 6.156 the default quark masses in the* `PMAS` *array are the constituent quark masses) and the PDG preferred values [13].*

Decay Tables

It is possible to use updated decay tables used in PYTHIA with the flag `KDCY`

0: no updates to the decays tables

0402: use update version 0402 of the decay tables

The settings for the updated decay tables are given for reference in Appendix B.

Bose-Einstein Correlations

A numbers of flags control the treatment Bose-Einstein correlations in PYTHIA, `MSTJ51, MSTJ52, MSTJ53, MSTJ54, PRJ92, PRJ93, PRJ94` These set the PYTHIA parameters `MSTJ(51), MSTJ(52), MSTJ(53), PARJ(92), PARJ(93)` and `PARJ(94)`. See documentation for PYTHIA [6] for more details. Specific tunings can be switch on using the flag `TUNE`

0: no specific tuning

1: specific tuning for exponential parameterisation

2: specific tuning for Gaussian parameterisation

3.2 DELPHI Input Parameters

Quark Masses

The quark masses used inside DelKK are given in Table 2. The values have been chosen to provide a more-or-less consistent set of masses to those used in previous generations of DELPHI events with PYTHIA version 6.125. These values are set in the input file `DelKK.inp`.

3.3 Hard-coded parameters

Minimum Invariant Mass for Fermion Production

The minimum invariant mass for which fermions are generated is set by the KK parameter VMAX. This is hard-coded to be equivalent to 2 GeV/c^2.

Below this invariant mass KK would not give an accurate description of the hadronic invariant mass spectrum, which would require similar modifications to those described in [14].

In fact, the region between 2 GeV/c^2 and the b-quark resonances could also be improved following [14].

However, this region of phase-space was covered in previous samples of simulated events without explicit implementation of resonant particle production. Thus it was decided to cover this regions with the DelKK event generation in this way without an improved treatment of the resonances in this region[2].

Minimum Invariant Mass for CEEX computation

KK can generate events using either the CEEX or the older style EEX approaches to the generation of photons. It is possible to adjust the minimum invariant mass of the $f\overline{f}$ system for which events are generated with the CEEX scheme. Below this invariant mass the weights of events are computed using the EEX scheme.

For electrons, muons and taus DelKK uses the default KK minimum invariant masses for CEEX scheme. For quarks, with KQSR=-1, the minimum invariant mass is hard-coded to be 20 GeV. This would, in principle, allow matching to code [14] treating low mass resonances. For KQSR=1, the default KK values are used.

Minimum Invariant Mass for Hadronisation

The minimum invariant mass for which quarks are hadronised by PYTHIA is set by the KK parameter HadMin. This is hard-coded to be equivalent to 2 GeV/c^2.

4 Output of DelKK

Records of the parameters set inside KK and the fragmentation models are provided by calls to the following subroutines

- DELKK_KKFLAGS_DUMP
- DELKK_PYFLAGS_DUMP

Variants of DELKK_PYFLAGS_DUMP exist for each of the different hadronisation interfaces.

DELSIM formatted output of events from DelKK is provided by the subroutine DELKKWRITE. As well as saving the Lund output for particles at the different stages of event generation the following extra information is written as comment lines in the output

- Version identifiers

[2] Later versions of KK do include a treatment of low mass resonances following [14].

- Weights
- Information about hadronisation

Further details can be found in Appendix A.3.

At the end of event generation DelKK writes the total cross-section to `STDOUT`.

5 Physics Studies

A number of physics studies were made during the development of DelKK, here we report one such study which was particularly important.

An important issue for hadronic events is whether the interplay between FSR photons and gluon radiation is more important than the effects of ISR⊗FSR interference. This was studied by examining the distortion of the $\sqrt{s'}$ spectrum under various different treatments of FSR and ISR⊗FSR interference.

Three samples of events were generated for $\mu^+\mu^-$ and inclusive $q\bar{q}$ final states:

- `DelKK0`: FSR in PYTHIA with no ISR⊗FSR interference
- `DelKK1`: FSR in KK with ISR⊗FSR interference
- `DelKK2`: FSR in KK with no ISR⊗FSR interference

By studying the differences between the samples `DelKK0` and `DelKK2` is is possible to assess the importance of mixing the generation of FSR photons and gluons, and by comparing samples `DelKK1` and `DelKK2` is is possible to asses the importance of the ISR⊗FSR interference. The muons acted as a control sample in this study.

The effects of switching between the different options was studies in 4 regions of $\sqrt{s'}/\sqrt{s}$:

- $(0.20 < \sqrt{s'}/\sqrt{s} < 0.40)$ below the Z
- $(0.40 < \sqrt{s'}/\sqrt{s} < 0.60)$ around the Z
- $(0.60 < \sqrt{s'}/\sqrt{s} < 0.85)$ above the Z
- $(0.85 < \sqrt{s'}/\sqrt{s} < 1.00)$ non-radiative peak

In each region two fractional changes in the partial cross-sections of samples where computed:

$$\mathrm{FSR} = \frac{\sigma(\texttt{DelKK0}) - \sigma(\texttt{DelKK2})}{\sigma(\texttt{DelKK2})},$$

which, for $q\bar{q}$ final states, measured the importance of the interplay between FSR photon and gluon radiation and differences due to the different procedures for generating FSR. In the case of $\mu^+\mu^-$ final states, where there is no gluon radiation the differences are due solely to the different procedures for generating FSR; and

$$\mathrm{INT} = \frac{\sigma(\texttt{DelKK1}) - \sigma(\texttt{DelKK2})}{\sigma(\texttt{DelKK2})},$$

which measured the importance of the treatments of ISR$\otimes$FSR interference.

At the time of the studies, switching off FSR in KK and into PYTHIA caused a change in the total cross-section calculation, which is inappropriate. Therefore, before computing the ratios of the partial cross-sections the cross-sections of the DelKK0 samples where rescaled by the ratios of the total cross-sections:

$$\frac{\sigma_{tot}(\texttt{DelKK2})}{\sigma_{tot}(\texttt{DelKK0})}.$$

Of the regions studied the most revealing is the non-radiative peak. In the region around the Z the effect of ISR$\otimes$FSR interference should be negligible. In the regions just above and below the Z peak the statistics in the samples used for the studies were rather low.

In the non-radiative peak region switching between FSR in KK and PYTHIA has very little effect for $\mu^+\mu^-$ final states as expected, while the changes due to ISR$\otimes$FSR interference are of the size expected. For $q\bar{q}$ final states the pure effect of changing the FSR generation from KK to PYTHIA should be even smaller than for $\mu^+\mu^-$ due to the smaller quark charges. Thus, comparing DELKK0 to DELKK2 gives sensitivity to the interplay between FSR photons and gluon radiation.

For inclusive $q\bar{q}$ final states, the change due to ISR$\otimes$FSR are smaller than for muons, as expected - since the interference for a given final state is proportional to the charge of the final state fermions, which makes the expected effect somewhat weaker for individual quarks compared to muons, and in addition there is some cancellation between different quark species.

The effect of the interplay between FSR photons and gluons is found to be larger than the ISR$\otimes$FSR effect, which is also the case around the Z.

For a sample of events drawn for the inclusive $q\bar{q}$ sample containing primary $b\bar{b}$ pairs the effects of ISR$\otimes$FSR interference and the photon-gluon interplay seem to be of similar sizes - but the statistics of the comparison are rather limited.

These findings are summarised in Figure 1.

As a result of these limited studies it was decided that for the production of $q\bar{q}$ pairs for DELPHI with DelKK it was more important to have the FSR generated in PYTHIA than to have the ISR$\otimes$FSR interference from KK.

These studies were rather limited in scope. To draw much firmer conclusions concerning the relative importance of ISR$\otimes$FSR interference and the interplay between FSR photon radiation and gluon radiation the authors suggest more studies be performed - investigating more observables, with high statistics, and making dedicated studies of different quark species with similar statistics to those used for muons.

6 Limitations of DelKK

It goes without saying, that all Monte Carlo programs represent an approximation to what really happens in particle physics experiments - and have their own inherent strengths and limitations.

Two main limitations are obvious in DelKK, one of which is purely technical the second has an impact on the physics that can be simulated.

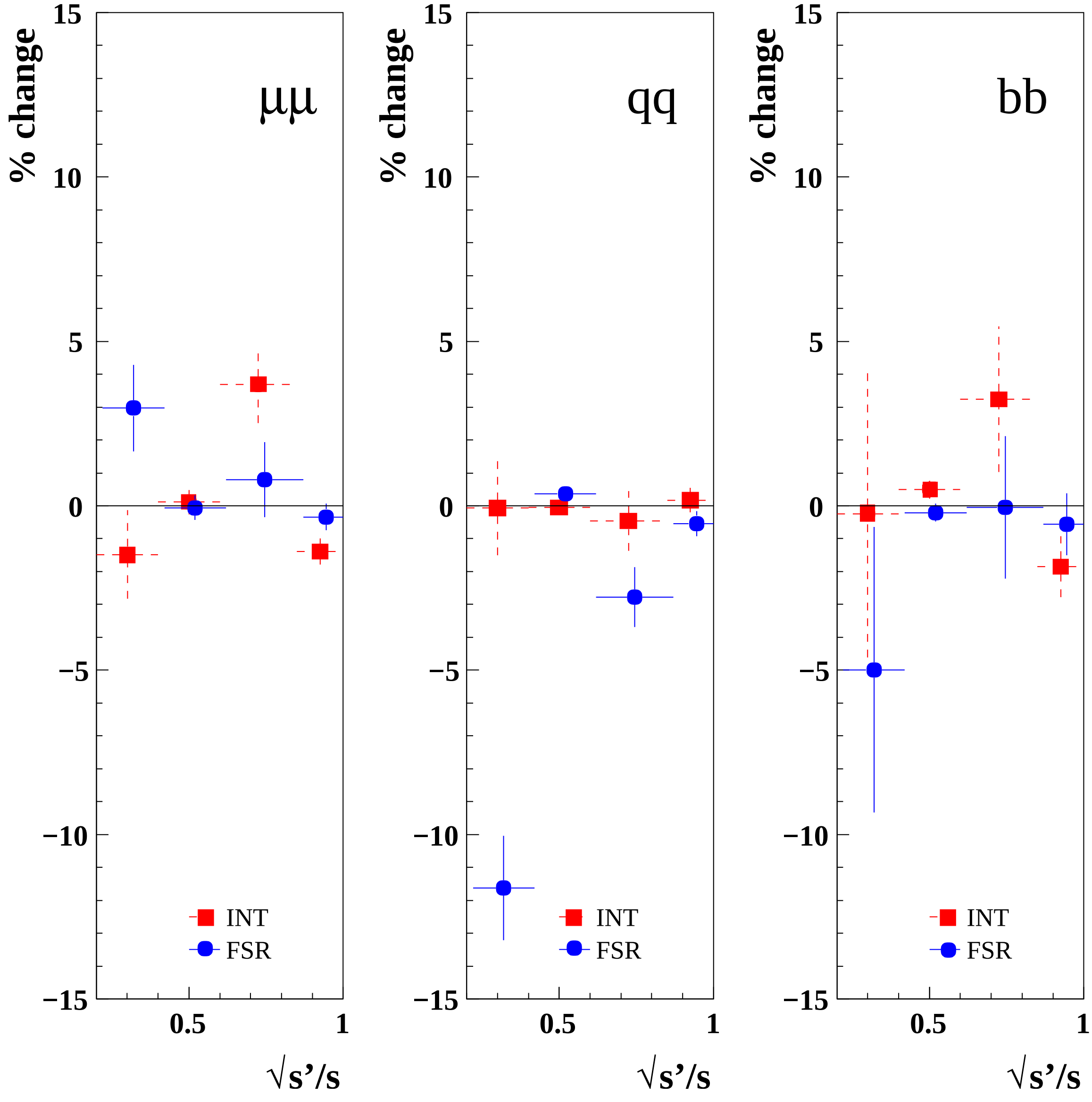

Figure 1: Changes in the partial cross-sections in 4 ranges of $\sqrt{s'}/\sqrt{s}$ for $\mu^+\mu^-$, $q\bar{q}$ and $b\bar{b}$ final states due to treatments of ISR⊗FSR interference and FSR photon-gluon interplay as described in the text.

The technical limitation, is that in stitching together the various different elements in DelKK it was decided to not mix different interfaces in a single executable, in order to avoid potential conflicts. This means that to cover a wide range of final states and wide range of different hadronisation schemes and treatments of τ decays a large number of individual executables are required. Avoiding having several interfaces in one executable reduces the total size of each individual executable. However, since large sections of the code are common between executables, the total disk space occupied by the executables is maybe larger than necessary. Perhaps more serious than the amount of disk space occupied by the executables, is the careful handling which is needed in compiling and running the executables and bookkeeping during event simulation.

The main physical limitation of DelKK is the inability to have both the interplay between FSR photons and gluons and ISR⊗FSR interference in $\mathrm{q\bar{q}}$ events. But this is not a new limitation, since existing generators did not include the ISR⊗FSR interference. However, it means that one of the major improvements of KK could not be capitalised on for $\mathrm{q\bar{q}}$ final states.

7 Conclusions

The technical implementation of DelKK has been presented. Showing how various Monte Carlo programs for the hadronisation and τ decays have been interfaced to the original version of KK.

Those internal parameters which have been modified, or are modifiable by the user of DelKK, from the original values set in KK have been discussed and the means by which user modifiable parameters can be adjusted are described.

The Appendices to this document give details on how to use DelKK and give the modified decay tables implemented inside the version of PYTHIA which has been interfaced to KK.

KK itself represents a genuine improvement on previous Monte Carlo programs for the generation of $e^+e^- \to f\overline{f}$ final states - particularly in its ability to take into account ISR⊗FSR interference. Many of the improvements in KK are at the limit of what is observable experimentally at LEP, but nevertheless need to be included in event simulation to control systematic uncertainties to better than the statistical precision of the combined LEP measurements. Unfortunately, for $\mathrm{q\bar{q}}$ final states it was not possible to retain all the improvements of KK and still have the important interplay between FSR photons and gluons. It was decided to generate $e^+e^- \to q\overline{q}$ events with FSR photons generated in PYTHIA, thereby, retaining the important interplay between FSR photons and gluon radiation.

Acknowledgements

The authors would like to thank Z. Was and S. Jadach, the original authors of KK for very helpful discussions during the implementation of DelKK.

A Using DelKK

A.1 Location of the Code

The code for DelKKcan be found at:

- `/afs/cern.ch/delphi/tasks/generators/kk`

in the following files[3]

- `README`: Update information
- `DelKKMake.job`: Perl script to make an executable of the program DelKK
- `DelKKRUN.job`: Perl script to run the program DelKK
- `DelKK.f`: main program to interface to KK and produce events with output in DELSIM format
- `DelKK.inp`: input file setting KK parameters
- `DelKK.tit`: title card read by delherw.f (on fort.19) updates some KK parameters

and subdirectories

- `KK-v4-14`: original source code for KK
- `pythia6156`: source code for PYTHIA 6.156
- `ariadne408`: source code for ARIADNE 4.08
- `herwig6201`: source code for HERWIG 6.201
- `delfor`: modified versions of original KK files
- `inputs`: KK2f_defaults input file for KK
- `plots`: collections of plots showing performance of DelKK

A.2 Compilation and Execution of the Code

DelKK.tit

1. Copy this file to your local directory
2. Edit the title cards to select the options you want

DelKK.inp

1. Only copy and change this during development if you want to adjust parameters which are not available via `DelKK.tit`

[3] later versions of the code will have strings inserted in to the original names.

DelKKMake.job

1. Copy this to you user directory
2. Set the variables (default values are shown)

```
## Name of Job: $JOBNAME
$JOBNAME   = "DelKK";

## Name of directory for working: $WORKDIR
$WORKDIR   = "$SCRATCH_WEEK";

## Name of directory for source code (DelKK.f) for wrapper to KK
$SOURCEDIR = "/afs/cern.ch/delphi/tasks/generators/kk";
```

3. Run the script DelKKMake.job options are

```
-j jobname       name of job
-f final_state   make executable appropriate for final state specified
                 valid final states: mm = mu+mu-
                                     tt = tau+tau-
                                     qq = hadrons
-t treatment      use a particular treatment for a final state
                    for mm
                      kk = kk [default]
                    for qq
                      py6156 = pythia 6.156 [default]
                      ar408 = ariadne 4.08
                      hw6201 = herwig 6.201
                    for tt
                      spin = (KK) tau decays with spin density [default]
                      hel  = (koralz) tau decays with helicity
```

The executable will be called

```
${JOBNAME}_${FinalState}_${Treatment}_${OpSys}.exe
```

where OpSys is the operating system on which the executable is compiled.

DelKKRun.job

1. Copy this to you user directory
2. Set the variables (default values are shown)

```
## Name of Job: $JOBNAME
$JOBNAME   = "DelKK";

## Name of directory for working: $WORKDIR
$WORKDIR   = "$SCRATCH_WEEK";

## Name of directory for output: $OUTPUTDIR
$OUTPUTDIR = "$SCRATCH_WEEK";

## Name of directory for Lund output: $LUNDOUTPUTDIR
$LUNDOUTPUTDIR = "$SCRATCH_WEEK";

## Direcory containing executable: $KKEXEDIR
$KKEXEDIR = "/afs/cern.ch/delphi/tasks/generators/kk/";

## Name of executable: $KKEXEFILE
$KKEXEFILE = "DelKK_${FinalState}_${OpSys}.exe";

## Name of title file for KK: $KKTITFILE
$KKTITFILE = "/afs/cern.ch/delphi/tasks/generators/kk/
                                   ${JOBNAME}_${FinalState}.tit";

## Name of input file for KK: $KKINPFILE
$KKINPFILE = "/afs/cern.ch/delphi/tasks/generators/kk/DelKK.inp";
```

3. Run the script DelKKMake.job options are

```
-j jobname       name of job
-f final_state   make executable appropriate for final state specified
                 valid final states: mm = mu+mu-
                                     tt = tau+tau-
                                     qq = hadrons
-t treatment     use a particular treatment for a final state
                   for mm
                     kk = kk [default]
                   for qq
                     py6156 = pythia 6.156 [default]
                     ar408 = ariadne 4.08
                     hw6201 = herwig 6.201
                   for tt
                     spin = (KK) tau decays with spin density [defualt]
                     hel  = (koralz) tau decays with helicity
-d               run exe in debug mode
-r run number    sets run number in title file if calls to
                 SetRunNumber and PrepareTitleFile are uncommented
```

4. this script can be submitted to batch.

A.3 Format of Output

The output from DelKK is in the following format.

$$\begin{array}{llllllllll} n, \\ k(1,1), & \ldots & k(1,5), & p(1,1), & \ldots & p(1,5), & v(1,1), & \ldots & v(1,5), \\ \vdots \\ k(n,1), & \ldots & k(n,5), & p(n,1), & \ldots & p(n,5), & v(n,1), & \ldots & v(n,5), \end{array}$$

where k, p and v are standard Lund arrays. The first n-6 groups of k, p, v are the simulation history prepared by KK and the fragmentation model. The subsequent 6 lines are comment lines, which all start with K(i,1)=21, which are added in DelKK.
In the first comment line contains the following

$$\begin{array}{l} k(i,3) = 103 \\ p(i,1) = 4.14 \\ p(i,2) = 4.14 \\ p(i,3) = 6.0 \\ p(i,4) = 6.156 \end{array}$$

The next three comment lines contain information about weights from KK,

$$\begin{array}{lll} p(i+1,1) = \texttt{WtMain} & p(i+2,1) = \texttt{WtMain} & p(i+3,1) = \texttt{WtMain} \\ p(i+1,2) = \texttt{WtCEEX2} & p(i+2,2) = \texttt{WtCEEX2NoIntf} & p(i+3,2) = \texttt{WtEEX3} \\ p(i+1,3) = \texttt{WtCEEX1} & p(i+2,3) = \texttt{WtCEEX1NoIntf} & p(i+3,3) = \texttt{WtEEX2} \\ p(i+1,4) = \texttt{WtCEEX0} & p(i+2,4) = \texttt{WtCEEX0NoIntf} & p(i+3,4) = \texttt{WtEEX1} \\ & & p(i+3,5) = \texttt{WtEEX0} \end{array}$$

Where `WtMain` gives the Main weight for an event, `WtCEEX`N gives the weight for an events with the CEEX scheme at order $N\alpha$ in the QED corrections, `WtCEEX`N`NoIntf` gives the weight for an event at order $N\alpha$ for the CEEX scheme ignoring ISR$\otimes$FSR interference and `WtEEX`N gives the weight for the event under the EEX scheme at order $N\alpha$.

The final two lines contain parameters important for the identifying the hadronisation scheme

$$\begin{array}{ll} p(i+4,1) = \texttt{XHAD} & p(i+5,1) = \texttt{MSTU(90)} \\ p(i+4,2) = \texttt{KBCK} & p(i+5,2) = \texttt{MSTU(91)} \\ p(i+4,3) = \texttt{KDCY} & p(i+5,3) = \texttt{MSTU(92)} \\ p(i+4,4) = \texttt{KWSB} & p(i+5,4) = \texttt{PARU(91)} \\ & p(i+5,5) = \texttt{PARU(92)} \end{array}$$

B Updated Decay Tables

Particle	BF	Daughters	Mode
443	0.06	11	0
	0.06	13	0
	0.88	82	12
10443	0.324	443, 211	0
	0.184	443, 111, 111	0
	0.027	443, 221	0
	0.093	10441, 22	0
	0.087	20443, 22	0
	0.078	445, 22	0
	0.0028	441, 22	0
	0.00015	331, 22	0
	0.0088	11	0
	0.0103	13	0
	0.19998	82	12
10413	0.33	423, 211	0
	0.17	413, 111	0
	0.33	421, 211, 111	0
	0.17	411, 211	0
10423	0.33	413	0
	0.17	423, 111	0
	0.33	411, 111	0
	0.17	421, 211	0
10433	0.25	413	0
	0.25	423, 321	0
	0.08	411, 111	0
	0.17	411, 321	0
	0.08	421, 321, 111	0
	0.17	421, 211	0
10411	0.666	421, 211	0
	0.334	411, 111	0
10421	0.666	411	0
	0.334	421, 111	0
10431	0.5	411	0
	0.5	421, 321	0
20413	0.43	423, 211	0
	0.22	413, 111	0
	0.23	421, 211, 111	0
	0.12	411, 211	0
20423	0.43	413	0
	0.22	423, 111	0
	0.23	411, 111	0
	0.12	421, 211	0
20433	0.5	413	0
	0.5	423, 321	0
415	0.22	423, 211	0
	0.11	413, 111	0
	0.38	421, 211	0
	0.19	411, 111	0
	0.067	423, 211, 111	0
	0.033	413, 211	0
425	0.22	413	0
	0.11	423, 111	0
	0.38	411	0
	0.19	421, 111	0
	0.067	413, 111	0
	0.033	423, 211	0
435	0.05	413	0
	0.05	423, 321	0
	0.45	411	0
	0.45	421, 321	0
10513	0.57	523	0
	0.28	513, 111	0
	0.1	523, 111	0
	0.05	513, 211	0
10523	0.57	513, 211	0
	0.28	523, 111	0
	0.1	513, 211, 111	0
	0.05	523, 211	0
10533	0.5	513, 311	0
10533	0.5	523	0
10511	0.63	521	0
	0.31	511, 111	0
	0.04	523, 111	0
	0.02	513, 211	0
10521	0.63	511, 211	0
	0.31	521, 111	0
	0.04	513, 211, 111	0
	0.02	523, 211	0
10531	0.5	511, 311	0
	0.5	521	0
20513	0.63	523	0
	0.31	513, 111	0
	0.04	521, 111	0
	0.02	511, 211	0
20523	0.63	513, 211	0
	0.31	523, 111	0
	0.04	511, 211, 111	0
	0.02	521, 211	0
20533	0.5	513, 311	0
	0.5	523	0

Particle	BF	Daughters	Mode
515	0.31	523	0
	0.15	513, 111	0
	0.31	521	0
	0.15	511, 111	0
	0.05	523, 111	0
	0.03	513, 211	0
525	0.31	513, 211	0
	0.15	523, 111	0
	0.31	511, 211	0
	0.15	521, 111	0
	0.05	513, 211, 111	0
	0.03	523, 211	0
535	0.17	513, 311	0
535	0.17	523	0
	0.33	511, 311	0
	0.33	521	0
413	0.683	421, 211	0
	0.31	411, 111	0
	0.007	411, 22	0
423	0.636	421, 111	0
	0.364	421, 22	0
541	0.05	-15, 16	0
	0.005	12, 441	42
	0.02	12, 443	42
	0.01	12, 531	42
	0.03	12, 533	42
	0.025	12, 4	42
	0.01	12, 3	42
	0.005	14, 441	42
	0.02	14, 443	42
	0.01	14, 531	42
	0.03	14, 533	42
	0.025	14, 4	42
	0.01	14, 3	42
	0.01	16, 4	42
	0.04	-531, 211	0
	0.02	-531, 213	0
	0.03	-533, 211	0
	0.15	-533, 213	0
	0.13	4	26
	0.06	4, 4	42
	0.05	2, 4	42
	0.12	2, 4	42
	0.03	2, 4	11
	0.0275	-1, 2, 3	42
	0.066	-1, 3, 2	42
	0.0165	-1, 2, 3	11
411	0.0033	-11, 12, 111	42
	0.0017	-11, 12, 221	42
	0.0007	-11, 12, 331	42
	0.004	-11, 12, 113	42
	0.0038	-11, 12, 223	42
	0.00035	-11, 12, 211	42
	0.00035	-11, 12, 111, 111	42
	0.097	-11, 12	42
	0.06	-11, 12	42
	0.0026	-11, 12	42
	0.0005	-11, 12	42
	0.0016	-11, 12	42
	0.0016	-11, 12	42
	0.0033	-13, 14, 111	42
	0.0017	-13, 14, 221	42
	0.0007	-13, 14, 331	42
	0.004	-13, 14, 113	42
	0.0038	-13, 14, 223	42
	0.00035	-13, 14, 211	42
	0.00035	-13, 14, 111, 111	42
	0.097	-13, 14	42
	0.06	-13, 14	42
	0.0026	-13, 14	42
	0.0005	-13, 14	42
	0.0016	-13, 14	42
	0.0016	-13, 14	42
	0.0025	111, 211	0
	0.0008	111, 213	0
	0.0075	221, 211	0
	0.001	221, 213	0
	0.0004	331, 211	0
	0.0004	331, 213	0
	0.0004	113, 211	0
	0.0004	113, 213	0
	0.0004	211, 223	0
	0.0004	213, 223	0
	0.0067	211, 333	0
	0.01	333, 213	0
	0.0274	-311, 211	0
	0.066	-311, 213	0
	0.022	211	0
	0.021	213	0
	0.081	-311, 20213	0

Particle	BF	Daughters	Mode
411	0.042	211	0
	0.034	211	0
	0.008	-311, 321	0
	0.0006	-311, 323	0
	0.0051	321	0
	0.026	-313, 323	0
	0.0024	-211, 211, 211	0
	0.0012	211, 111, 111	0
	0.005	-211, 211, 211, 111	0
	0.0033	213, 211	0
	0.0025	-213, 211, 211	0
	0.0025	113, 211, 111	0
	0.0005	213, 211	0
	0.0005	213, 213	0
	0.0005	213, 113, 111	0
	0.001	113, 113, 211	0
	0.0005	223, 211, 113	0
	0.0004	223, 213, 111	0
	0.0003	223, 213, 211	0
	0.0003	223, 113, 211, 111	0
	0.013	-311, 211, 111	0
	0.001	-311, 211, 113	0
	0.0002	-311, 211, 221	0
	0.0002205	-311, 211, 211, 221	0
	0.0001025	-311, 211, 111, 111, 221	0
	0.0001505	-311, 211, 22, 113	0
	1.5E-05	-311, 211, 22, 223	0
	1.1E-05	-311, 211, 22, 22	0
	5.E-07	-311, 211, 111, 111, 111	0
	0.0275	-311, 211, 223	0
	0.001	-311, 213, 111	0
	0.0097	-311, 213, 211	0
	0.0097	-311, 113, 211, 111	0
	0.035	-313, 211, 111	0
	0.019	-313, 213, 111	0
	0.0077	-313, 211, 113	0
	0.001	-313, 211, 221	0
	0.059	-321, 211, 211	0
	0.0007	-321, 211, 211, 113	0
	0.007	-321, 213, 211	0
	0.01	-321, 213, 211, 111	0
	0.015	-323, 211, 211	0
	0.0046	321, 211	0
	0.0006	-311, 311, 211	0
	0.0004	-313, 311, 211	0
	0.0004	-311, 313, 211	0
	0.031	-311, 321	0
	0.0006	-311, 211, 211	0
	0.0025	-313, 211, 211	0
	0.003	-321, 211, 211, 111	0
421	0.0024	-11, 12	42
	0.0029	-11, 12	42
	0.0003	-11, 12, 111	42
	0.038	-11, 12	42
	0.024	-11, 12	42
	0.0002	-11, 12	42
	0.0006	-11, 12	42
	0.0006	-11, 12	42
	0.001	-11, 12	42
	0.0024	-13, 14	42
	0.0029	-13, 14	42
	0.0003	-13, 14, 111	42
	0.038	-13, 14	42
	0.024	-13, 14	42
	0.0002	-13, 14	42
	0.0006	-13, 14	42
	0.0006	-13, 14	42
	0.001	-13, 14	42
	0.0009	111, 111	0
	0.0006	111, 221	0
	0.0003	111, 331	0
	0.007	111, 113	0
	0.0078	113, 113	0
	0.0002	111, 223	0
	0.001	111, 333	0
	0.0019	113, 333	0
	0.0004	221, 333	0
	0.001	221, 221	0
	0.0012	221, 223	0
	0.0017	333, 223	0
	0.0205	-311, 111	0
	0.0068	-311, 221	0
	0.0166	-311, 331	0
	0.0046	-311, 10221	0
	0.00428	-311, 113	0
	0.0083	-311, 333	0
	0.02	-311, 223	0
	0.001	311	0
	0.028	111	0
	0.016	-313, 113	0
	0.019	221	0
	0.0075	331	0
	0.011	-313, 223	0
	0.003	-313, 333	0
	0.002	-313, 311	0
	0.002	-313, 313	0

Particle	BF	Daughters	Mode
421	0.0026036	-313, 211	0
	0.0013018	-313, 111, 111	0
	0.0003174	-313, 211, 111, 111	0
	0.0001288	-313, 211, 211	0
	0.0001058	-313, 321	0
	5.152E-05	-313, 130, 130	0
	5.152E-05	-313, 310, 310	0
	2.3E-05	-313, 221, 221	0
	1.38E-05	-313, 111, 111, 111, 111	0
	0.004278	-313, 211	0
	0.002139	-313, 111, 111	0
	0.0002415	-313, 321	0
	0.00012075	-313, 130, 130	0
	0.00012075	-313, 310, 310	0
	0.0016	211	0
	0.0005	211, 211	0
	0.004	213	0
	0.0012	-213, 211	0
	0.001	-213, 213	0
	0.0401	-321, 211	0
	0.046	211	0
	0.094	-321, 213	0
	0.059	-323, 213	0
	0.00454	321	0
	0.0034	-321, 323	0
	0.0018	321	0
	0.004	-323, 323	0
	0.0104	-10323, 211	0
	0.011	-10321, 211	0
	0.0794	-321, 20213	0
	0.005	-321, 211, 111	0
	0.0189	-321, 211, 211	0
	0.0051	-321, 211, 113	0
	0.02	-321, 213, 111	0
	0.0193	-323, 213, 111	0
	0.026	-321, 211, 223	0
	0.0197	-311, 111, 223	0
	0.005	-321, 211, 221	0
	0.007	-321, 211, 331	0
	0.00428	-311, 211	0
	0.037	-311, 213	0
	0.0075	-311, 111, 111	0
	0.004	-311, 321	0
	0.0049	-311, 321	0
	0.001	-311, 311	0
	0.0024	311, 211	0
	0.0032	313, 211	0
	0.0017	-313, 321	0
	0.021	-311, 211, 111	0
	0.0373	-321, 211, 111, 111	0
	0.001	-313, 111, 111, 111	0
	0.0152	-313, 211, 111	0
	0.001	-313, 211, 111	0
	0.0002	-321, 211, 111, 111, 111	0
	0.0043	-311, 211, 211	0
	0.02	-311, 211, 111, 111	0
431	0.02	-15, 16	0
	0.054	-11, 12, 221	42
	0.02	-11, 12, 331	42
	0.0188	-11, 12, 333	42
	0.0026	-11, 12, 311	42
	0.0026	-11, 12, 313	42
	0.004	-11, 12, 321	42
	0.005	-11, 12, 311	42
	0.054	-13, 14, 221	42
	0.02	-13, 14, 331	42
	0.0188	-13, 14, 333	42
	0.0026	-13, 14, 311	42
	0.0026	-13, 14, 313	42
	0.004	-13, 14, 321	42
	0.005	-13, 14, 311	42
	0.019	221, 211	0
	0.075	221, 213	0
	0.025	221, 211, 113	0
	0.008	221, 213, 111	0
	0.005	221, 213, 111, 111	0
	0.005	221, 213, 211	0
	0.027	331, 211	0
	0.1	331, 213	0
	0.01	331, 213	0
	0.005	331, 211, 113	0
	0.01	331, 213, 111	0
	0.005	331, 211, 111, 111, 111	0
	0.005	331, 211, 211, 111	0
	0.035	333, 211	0
	0.065	333, 211, 111	0
	0.013	333, 211, 211	0
	0.013	333, 111, 211, 111	0
	0.001	333, 211, 111, 111, 111	0
	0.001	333, 211, 211, 111	0
	0.01	10221, 211	0
	0.02	10221, 213	0
	0.005	10221, 211, 211	0
	0.008	10221, 213, 111	0
	0.001	10221, 211, 111, 111, 111	0
	0.004	10221, 211, 211, 111	0

Particle	BF	Daughters	Mode
431	0.003	321, 211	0
	0.035	-311, 321	0
	0.065	-311, 323	0
	0.0325	321	0
	0.08	-313, 323	0
	0.0086	-321, 321, 211	0
	0.0086	-311, 321, 111	0
	0.01	-321, 321, 213	0
	0.009	-311, 311, 211	0
	0.01	-311, 321, 113	0
	0.01	-311, 311, 211	0
	0.0075	-321, 311, 211, 213	0
	0.0021	-311, 321, 111, 111	0
	0.0021	-313, 321, 111, 111	0
	0.002	321, 211, 211	0
	0.002	-321, 311, 211, 211, 111	0
	0.0018	-311, 311, 211, 211	0
	0.0018	-311, 311, 211, 111, 111	0
4122	0.028	-11, 12, 3, 2101	42
	0.007	-11, 12, 3, 2103	42
	0.028	-13, 14, 3, 2101	42
	0.007	-13, 14, 3, 2103	42
	0.53	2, 3, 2101	11
4122	0.2	2, 3201	11
	0.1	2, 3203	11
	0.1	3, 2203	11
4132	0.02	-11, 12, 3, 3101	42
	0.005	-11, 12, 3, 3103	42
	0.02	-13, 14, 3, 3101	42
	0.005	-13, 14, 3, 3103	42
	0.54	2, 3, 3101	11
	0.21	3, 3201	11
	0.1	3, 3203	11
	0.1	2, 3303	11
4232	0.028	-11, 12, 3, 3201	42
	0.007	-11, 12, 3, 3203	42
	0.028	-13, 14, 3, 3201	42
	0.007	-13, 14, 3, 3203	42
	0.93	2, 3, 3201	11
4332	0.018	-11, 12, 3, 3303	42
	0.018	-13, 14, 3, 3303	42
	0.964	2, 3, 3303	11
511	0.020952	12	42
	0.050976	12	42
	0.01188	12	42
	0.015552	12	42
	0.00648	12	42
	0.00216	12	42
	0.002	12, 1	42
	0.020952	14	42
	0.050976	14	42
	0.01188	14	42
	0.015552	14	42
	0.00648	14	42
	0.00216	14	42
	0.002	14, 1	42
	0.00625	16	42
	0.01275	16	42
	0.0019760479	16	42
	0.00258682635	16	42
	0.00107784431	16	42
	0.000359281437	16	42
	0.001	16, 1	42
	0.001	443, 311	0
	0.000437	10443, 311	0
	0.000471	20443, 311	0
	9.E-05	445, 311	0
	0.00049	441, 311	0
	0.0015	443, 313	0
	0.0006555	10443, 313	0
	0.0007065	20443, 313	0
	0.000135	445, 313	0
	0.000735	441, 313	0
	0.0012	443, 321	0
	0.0005244	10443, 321	0
	0.0005652	20443, 321	0
	0.000108	445, 321	0
	0.000588	441, 321	0
	0.0006	443, 311, 111	0
	0.0002622	10443, 311, 111	0
	0.0002826	20443, 311, 111	0
	5.4E-05	445, 311, 111	0
	0.000294	441, 311, 111	0
	0.00382	443, 1	23
	0.00166934	10443, 1	23
	0.00179922	20443, 1	23
	0.0003438	445, 1	23
	0.0018718	441, 1	23
	0.109676892	2, 1	42
	0.263224541	2, 1	42
	0.0658061352	2, 1	11
	0.005772468	2, 1	42
	0.0138539232	2, 1	42
	0.0034634808	2, 1	11
	0.009	2, 1	42
	0.006	2, 1	42

Particle	BF	Daughters	Mode
511	0.0092	431, 1	23
	0.0092	433, 1	23
	0.00115	431	0
	0.00345	431	0
	0.00345	431	0
	0.00575	431	0
	0.00115	433	0
	0.00345	433	0
	0.00345	433	0
	0.00575	433	0
	0.013	431	0
	0.009	431	0
	0.009	433	0
	0.023	433	0
	0.008	421, 321, 1	42
	0.008	411, 311, 1	42
	0.032	423, 321, 1	42
	0.032	413, 311, 1	42
	0.055	-4122, 2203, 1	11
	0.011	-4232, 4201, 1	11
	0.011	-4132, 4101, 1	11
521	0.020952	12	42
	0.050976	12	42
	0.01188	12	42
	0.015552	12	42
	0.00648	12	42
	0.00216	12	42
	0.002	12, 2	42
	0.020952	14	42
	0.050976	14	42
	0.01188	14	42
	0.015552	14	42
	0.00648	14	42
	0.00216	14	42
	0.002	14, 2	42
	0.00625	16	42
	0.01275	16	42
	0.0019760479	16	42
	0.00258682635	16	42
	0.00107784431	16	42
	0.000359281437	16	42
	0.001	16, 2	42
	0.001	443, 321	0
	0.000437	10443, 321	0
	0.000471	20443, 321	0
	9.E-05	445, 321	0
	0.00049	441, 321	0
	0.0015	443, 323	0
	0.0006555	10443, 323	0
	0.0007065	20443, 323	0
	0.000135	445, 323	0
	0.000735	441, 323	0
	0.0012	443, 321, 111	0
	0.0005244	10443, 321, 111	0
	0.0005652	20443, 321, 111	0
	0.000108	445, 321, 111	0
	0.000588	441, 321, 111	0
	0.0006	443, 311, 211	0
	0.0002622	10443, 311, 211	0
	0.0002826	20443, 311, 211	0
	5.4E-05	445, 311, 211	0
	0.000294	441, 311, 211	0
	0.00382	443, 2	23
	0.00166934	10443, 2	23
	0.00179922	20443, 2	23
	0.0003438	445, 2	23
	0.0018718	441, 2	23
	0.109676892	2, 2	42
	0.263224541	2, 2	42
	0.0658061352	2, 2	11
	0.005772468	2, 2	42
	0.0138539232	2, 2	42
	0.0034634808	2, 2	11
	6.40872688E-19	2, 2	11
	0.009	2, 2	42
	0.006	2, 2	42
	0.0092	431, 2	23
	0.0092	433, 2	23
	0.00115	431	0
	0.00345	431	0
	0.00345	431	0
	0.00575	431	0
	0.00115	433	0
	0.00345	433	0
	0.00345	433	0
	0.00575	433	0
	0.013	431	0
	0.009	431	0
	0.009	433	0
	0.023	433	0
	0.008	421, 321, 2	42
	0.008	411, 311, 2	42
	0.032	423, 321, 2	42
	0.032	413, 311, 2	42
	0.055	-4122, 2203, 2	11
	0.011	-4232, 4201, 2	11
	0.011	-4132, 4101, 2	11

Particle	BF	Daughters	Mode
531	0.020952	12	42
	0.050976	12	42
	0.01188	12	42
	0.015552	12	42
	0.00648	12	42
	0.00216	12	42
	0.002	12, 3	42
	0.020952	14	42
	0.050976	14	42
	0.01188	14	42
	0.015552	14	42
	0.00648	14	42
	0.00216	14	42
	0.002	14, 3	42
	0.00625	16	42
	0.01275	16	42
	0.0019760479	16	42
	0.00258682635	16	42
	0.00107784431	16	42
	0.000359281437	16	42
	0.001	16, 3	42
	0.0005	443, 221	0
	0.0002185	10443, 221	0
	0.0002355	20443, 221	0
	4.5E-05	445, 221	0
	0.000245	441, 221	0
	0.0005	443, 331	0
	0.0002185	10443, 331	0
	0.0002355	20443, 331	0
	4.5E-05	445, 331	0
	0.000245	441, 331	0
	0.0015	443, 333	0
	0.0006555	10443, 333	0
	0.0007065	20443, 333	0
	0.000135	445, 333	0
	0.000735	441, 333	0
	0.0012	443, 321	0
	0.0005244	10443, 321	0
	0.0005652	20443, 321	0
	0.000108	445, 321	0
	0.000588	441, 321	0
	0.0006	443, 311	0
	0.0002622	10443, 311	0
	0.0002826	20443, 311	0
	5.4E-05	445, 311	0
	0.000294	441, 311	0
	0.00382	443, 3	13
	0.00166934	10443, 3	13
	0.00179922	20443, 3	13
	0.0003438	445, 3	13
	0.0018718	441, 3	13
	0.109676892	2, 3	42
	0.263224541	2, 3	42
	0.0658061352	2, 3	11
	0.005772468	2, 3	42
	0.0138539232	2, 3	42
	0.0034634808	2, 3	11
	0.009	2, 3	42
	0.006	2, 3	42
	0.0092	431, 3	23
	0.0092	433, 3	23
	0.00115	431	0
	0.00345	431	0
	0.00345	431	0
	0.00575	431	0
	0.00115	433	0
	0.00345	433	0
	0.00345	433	0
	0.00575	433	0
	0.013	431	0
	0.009	431	0
	0.009	433	0
	0.023	433	0
	0.008	421, 321, 3	42
	0.008	411, 311, 3	42
	0.032	423, 321, 3	42
	0.032	413, 311, 3	42
	0.055	-4122, 2203, 3	11
	0.011	-4232, 4201, 3	11
	0.011	-4132, 4101, 3	11
5122	0.108	-12, 11, 4, 2101	42
	0.002	-12, 11, 2, 2101	42
	0.108	-14, 13, 4, 2101	42
	0.002	-14, 13, 2, 2101	42
	0.025	-16, 15, 4, 2101	42
	0.001	-16, 15, 4, 2101	42
	0.001	443, 3122	0
	0.000437	10443, 3122	0
	0.000471	20443, 3122	0
	9.E-05	445, 3122	0

Particle	BF	Daughters	Mode
5122	0.00049	441, 3122	0
	0.0015	443, 3212	0
	0.0006555	10443, 3212	0
	0.0007065	20443, 3212	0
	0.000135	445, 3212	0
	0.000735	441, 3212	0
	0.0012	443, 2212	0
	0.0005244	10443, 2212	0
	0.0005652	20443, 2212	0
	0.000108	445, 2212	0
	0.000588	441, 2212	0
	0.0006	443, 2112	0
	0.0002622	10443, 2112	0
	0.0002826	20443, 2112	0
	5.4E-05	445, 2112	0
	0.000294	441, 2112	0
	0.00382	443, 3, 2101	13
	0.00166934	10443, 3, 2101	13
	0.00179922	20443, 3, 2101	13
	0.0003438	445, 3, 2101	13
	0.0018718	441, 3, 2101	13
	0.109676892	-2, 1, 4, 2101	42
	0.263224541	-2, 4, 1, 2101	42
	0.0658061352	-2, 1, 4, 2101	11
	0.005772468	-2, 3, 4, 2101	42
	0.0138539232	-2, 4, 3, 2101	42
	0.0034634808	-2, 3, 4, 2101	11
	0.009	-2, 1, 2, 2101	42
	0.006	-2, 2, 1, 2101	42
	0.023	-431, 4, 2101	23
	0.023	-433, 4, 2101	23
	0.013	-431, 4122	0
	0.009	-431, 4214	0
	0.009	-433, 4122	0
	0.023	-433, 4214	0
	0.008	-421, 4, 2101	42
	0.008	-411, 4, 2101	42
	0.032	-423, 4, 2101	42
	0.032	-413, 4, 2101	42
	0.077	4122, 2101	11
5132	0.108	-12, 11, 4, 3101	42
	0.002	-12, 11, 2, 3101	42
	0.108	-14, 13, 4, 3101	42
	0.002	-14, 13, 2, 3101	42
	0.025	-16, 15, 4, 3101	42
	0.001	-16, 15, 4, 3101	42
	0.001	443, 3312	0
	0.000437	10443, 3312	0
	0.000471	20443, 3312	0
	9.E-05	445, 3312	0
	0.00049	441, 3312	0
	0.0015	443, 3314	0
	0.0006555	10443, 3314	0
	0.0007065	20443, 3314	0
	0.000135	445, 3314	0
	0.000735	441, 3314	0
	0.0012	443, 3122	0
	0.0005244	10443, 3122	0
	0.0005652	20443, 3122	0
	0.000108	445, 3122	0
	0.000588	441, 3122	0
	0.0006	443, 3112	0
	0.0002622	10443, 3112	0
	0.0002826	20443, 3112	0
	5.4E-05	445, 3112	0
	0.000294	441, 3112	0
	0.00382	443, 3, 3101	13
	0.00166934	10443, 3, 3101	13
	0.00179922	20443, 3, 3101	13
	0.0003438	445, 3, 3101	13
	0.0018718	441, 3, 3101	13
	0.109676892	-2, 1, 4, 3101	42
	0.263224541	-2, 4, 1, 3101	42
	0.0658061352	-2, 1, 4, 3101	11
	0.005772468	-2, 3, 4, 3101	42
	0.0138539232	-2, 4, 3, 3101	42
	0.0034634808	-2, 3, 4, 3101	11
	0.009	-2, 1, 2, 3101	42
	0.006	-2, 2, 1, 3101	42
	0.023	-431, 4, 3101	23
	0.023	-433, 4, 3101	23
	0.013	-431, 4132	0
	0.009	-431, 4314	0
	0.009	-433, 4132	0
	0.023	-433, 4314	0
	0.008	-421, 4, 3101	42
	0.008	-411, 4, 3101	42
	0.032	-423, 4, 3101	42
	0.032	-413, 4, 3101	42
	0.077	4122, 3101	11

Particle	BF	Daughters	Mode
5232	0.108	-12, 11, 4, 3201	42
	0.002	-12, 11, 2, 3201	42
	0.108	-14, 13, 4, 3201	42
	0.002	-14, 13, 2, 3201	42
	0.025	-16, 15, 4, 3201	42
	0.001	-16, 15, 4, 3201	42
	0.001	443, 3322	0
	0.000437	10443, 3322	0
	0.000471	20443, 3322	0
	9.E-05	445, 3322	0
	0.00049	441, 3322	0
	0.0015	443, 3324	0
	0.0006555	10443, 3324	0
	0.0007065	20443, 3324	0
	0.000135	445, 3324	0
	0.000735	441, 3324	0
	0.0012	443, 3222	0
	0.0005244	10443, 3222	0
	0.0005652	20443, 3222	0
	0.000108	445, 3222	0
	0.000588	441, 3222	0
	0.0006	443, 3212	0
	0.0002622	10443, 3212	0
	0.0002826	20443, 3212	0
	5.4E-05	445, 3212	0
	0.000294	441, 3212	0
	0.00382	443, 3, 3201	13
	0.00166934	10443, 3, 3201	13
	0.00179922	20443, 3, 3201	13
	0.0003438	445, 3, 3201	13
	0.0018718	441, 3, 3201	13
	0.109676892	-2, 1, 4, 3201	42
	0.263224541	-2, 4, 1, 3201	42
	0.0658061352	-2, 1, 4, 3201	11
	0.005772468	-2, 3, 4, 3201	42
	0.0138539232	-2, 4, 3, 3201	42
	0.0034634808	-2, 3, 4, 3201	11
	0.009	-2, 1, 2, 3201	42
	0.006	-2, 2, 1, 3201	42
	0.023	-431, 4, 3201	23
	0.023	-433, 4, 3201	23
	0.013	-431, 4232	0
	0.009	-431, 4324	0
	0.009	-433, 4232	0
	0.023	-433, 4324	0
	0.008	-421, 4, 3201	42
	0.008	-411, 4, 3201	42
	0.032	-423, 4, 3201	42
	0.032	-413, 4, 3201	42
	0.077	4122, 3201	11

Particle	BF	Daughters	Mode
5332	0.108	-12, 11, 4, 3303	42
	0.002	-12, 11, 2, 3303	42
	0.108	-14, 13, 4, 3303	42
	0.002	-14, 13, 2, 3303	42
	0.025	-16, 15, 4, 3303	42
	0.001	-16, 15, 4, 3303	42
	0.0025	443, 3334	0
	0.0010925	10443, 3334	0
	0.0011775	20443, 3334	0
	0.000225	445, 3334	0
	0.001225	441, 3334	0
	0.0012	443, 3322	0
	0.0005244	10443, 3322	0
	0.0005652	10443, 3322	0
	0.000108	445, 3322	0
	0.000588	441, 3322	0
	0.0006	443, 3312	0
	0.0002622	10443, 3312	0
	0.0002826	20443, 3312	0
	5.4E-05	445, 3312	0
	0.000294	441, 3312	0
	0.00382	443, 3, 3303	13
	0.00166934	10443, 3, 3303	13
	0.00179922	20443, 3, 3303	13
	0.0003438	445, 3, 3303	13
	0.0018718	441, 3, 3303	13
	0.109676892	-2, 1, 4, 3303	42
	0.263224541	-2, 4, 1, 3303	42
	0.0658061352	-2, 1, 4, 3303	11
	0.005772468	-2, 3, 4, 3303	42
	0.0138539232	-2, 4, 3, 3303	42
	0.0034634808	-2, 3, 4, 3303	11
	0.009	-2, 1, 2, 3303	42
	0.006	-2, 2, 1, 3303	42
	0.023	-431, 4, 3303	23
	0.023	-433, 4, 3303	23
	0.013	-431, 4332	0
	0.009	-431, 4334	0
	0.009	-433, 4332	0
	0.023	-433, 4334	0
	0.008	-421, 4, 3303	42
	0.008	-411, 4, 3303	42
	0.032	-423, 4, 3303	42
	0.032	-413, 4, 3303	42
	0.077	4122, 3303	11

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