Workshop on Radiative Corrections in K, D, and B Mesons

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Summary of Presentations and Discussions:

It has been recognized for a while and became more evident last year that the precisions anticipated by recent or currently running experiments on branching fraction, form factor, and moment measurements for B, D and K mesons will catapult radiative corrections to the fore. Such precision necessitates clear definition of the experimental measurements and comparison to theoretical predictions that incorporate radiative corrections to avoid significant systematic uncertainties on the underlying electroweak and QCD parameters of interest. The current theoretical tools for such a program, which range in age from 15 to 35 years, do not provide adequate accuracy.
The primary goal of this workshop were

1. to bring the situation to light within the theoretical and experimental community; and
2. to develop a strategy for improvement both of radiative simulation tools for use in MC generators and of specific analytic calculations for incorporation into theoretical form factor or moment predictions.

The program, individual presentations and additional information can be found in http://www.slac.stanford.edu/BFROOT/www/Public/Organization/2005/ workshops/radcorr2005/.

K Decays:

Precision measurements of K(2π), K(3π) and Ke3, Kμ3 have demonstrated sizable radiative effects on particle spectra, angular distributions, and effective mass distributions that lead to efficiency losses in standard analyses. Radiative effects impact the form factor measurements for Ke3, and Kμ3 decays by several standard deviations. The current version of PHOTOS reproduces the photon spectra quite well, but shows clear deviation from data in the angular distribution of the real photons.

Both BTEV and KLOE have developed new MC simulations based on two sets of calculations, see talks by Isidori, Gatti and Kessler. These new calculations include real and virtual photons, and treat both short and long distance effects. For Ke3 and Kμ3 comparisons with data show agreement at the level for better than 0.5%. KTEV has very large samples of events with the photon detected, $E\gamma > 10$ MeV, for K → π e ν γ, π μ ν γ as well as K → π π γ and π π π γ, that have been and could be further used to test MC simulations. Calculations indicate sizable effects on the isospin amplitudes in K → π π. During discussion there was some discussion that small discrepancies observed in Ke3γ for hard, non-collinear photons could be due to structure terms. Studies of radiative B and D decays should show enhanced effects.

D Decays

CLEO, and also BABAR and Belle, are planning precision measurements of hadronic and semileptonic D decays to the level of better that 1%. So far PHOTOS has been used to simulate radiative corrections. But it is known that the current version of PHOTOS does not treat all virtual photons correctly, and it is assumed that radiative effects do not impact the form factors and their q^2 dependence. Measurements will include decays like D → K π, π π, K π π , k π π π and D → K(*) e ν γ, K(*) μ ν, and π (η) e ν , π(η) μ ν. Much less theoretical work is done for D meson than for kaon decays. From BABAR and Belle sizable samples of clean two and three body hadronic decays exist, but the detection of low energy photons associated with these decays may be difficult due to background from π^0 and η decays. CLEO will collect in the coming year large samples of very clean events, for which the photon could be identified and measured.

B decays

BABAR and Belle expect to collect and reconstruct up to10,000 B → K π decays and other rare two- and three-body hadronic decays and also plan to improve measurements of exclusive and inclusive semileptonic B decays, both for b→ c l ν and u l ν transitions. Efficiency losses and changes in particle distributions and form factors due to radiative effects need to be better understood. Effects are expected to be larger for b→ u l ν transitions. PHOTOS predicts corrections of 15% at the high end of the electron spectrum, the uncertainties have not been quantified. These effects impact the event selection because they create tails in effective mass and energy distributions. Experimenters can provide hadronic mass and momentum distributions for comparison.

Simulation of Radiative Processes

Most experiments do not detect or identify a photon emitted in hadronic or semileptonic meson decays. In fact, there is little effort to identify those photons, unless there is a special physics interest in such measurements. In high energy kaon experiments, the photons can generally be measured, because they are boosted to high energy. In typical e+e- experiments near threshold, the photons are not identified, their low energy makes detection difficult, and the presence of many other π0 and η decays make identification possible only in fully reconstructed events. External bremsstrahlung in the detector, primarily from electrons, similarly leads to energy loss and the emission of photons at small angles. For some measurements these photons (not distinguishable from internal radiation) are identified and their energy is combined with the electron energy to correct for this loss on an event-by-event basis.

Losses due to radiative effects lead to changes in the energy and angular distributions, thus effecting variables like the hadronic effective mass and q^2 distributions. For inclusive hadronic mass distributions, the additional photons are added to the hadronic mass measurement.

It is obvious that more effort needs to be devoted to calculations of these effects for various processes. There was some not conclusive discussions on whether or not lattice and OPE calculations could in fact include radiative effects and predict moments with these radiative effects included. However, dynamical internal photons could be treated in analogy with methods used for gluons.

KLOR (hep-ph/0406006) and FFS were designed for K decays and have been tested against experimental distributions. There is agreements at the level of 0.3% or better. PHOTOS was designed for electroweak corrections to Z and W decays, and later adjusted to describe semileptonic K decays and more recently also semileptonic B decays. PHOTOS has recently been updated to version 2.13, which shows improvements for semileptonic K decays.

Matrix elements from such calculations can be introduced into various simulations, PHOTOS or other, and tested against measured distributions. As pointed out above such distributions can be provided by experiments, though not all experiments can detect the real photons (high energy experiments like KTEV can) and can provide four-vectors for all secondary particles for sufficiently clean samples of decays.

With the improved understanding of kaon decays, one would like to understand to what extent the calculations and simulations can be extrapolated to D and B decays. The q^2 range increases from 0.1 GeV^2 to 2 GeV^2 to 25 GeV^2 and many resonances of different spins contribute. It would be very beneficial to obtain estimates of the size of the expected effects so we can get an idea what the current uncertainties might be and which part of the calculations to focus on.

Home Work for Experimenters:

1. Compare observed distributions with existing MC simulations for two-body hadronic and semileptonic decays, based on simulations by PHOTOS or KLOR or others.
2. Provide distributions of momenta and effective masses for various particles in K, D and B decays. Where possible, measure properties of radiative processes in D and B decays directly.
3. Provide 4-vectors of secondary particles, including the photon in the rest frame of the decaying particle (contact P. Golonka or Z. Was for details).

To make use of this experimental information, the distributions should be in the rest frame of the decaying particle. Parameterizations for acceptance and external bremsstrahlung effects will likely be necessary for meaningful comparison with PHOTOS predictions.

It would be best if each experiment could provide the names of one or two contacts to coordinate the implementation of radiative corrections in the simulation of various decays.

Home Work for Theorists:

With the improved understanding of kaon decays, one would like to understand to what extent the calculations and simulations can be extrapolated to D and B decays. The q^2 range increases from 0.1 GeV^2 to 2 GeV^2 to 25 GeV^2 and many resonances of different spins contribute.

4. It would be very beneficial to obtain estimates of the size of the expected effects so that we can get an idea what the current uncertainties might be and which part of the calculations to focus on. This is of great interest to both D and B meson decays.
5. Calculate matrix elements for various processes, including all virtual corrections and potential q2 dependent form factor variations, for both two body hadronic, semileptonic and also radiative D and B decays.
   In this context review articles, similar to Gilman and Singleton (PRD41, 142, 1990), summarizing the structure of the decays for radiative hadronic and semileptonic processes would be helpful. A specific example of an exploratory study would be to compute the full Low's result for various radiative decay rates for comparison with and improvement of present Monte Carlo implementations.

Questions posed at the Workshop on Radiative Effects in K, D, and B Decays

- Which processes and measurements in weak decays of B, D and K mesons are affected by radiative processes?
- What is the precision of the measurements that can be achieved now and in the next few years?
- Are there selections (cuts) experimenters apply that affect such corrections (For instance a minimum photon energy that is detectable)? What effective photon cutoffs are implicit in reconstructed hadronic mass cuts?
- How can we best estimate the size of these effects?
- Do we distinguish soft, medium, and hard radiative processes? Radiation off electrons, muons, hadrons? Should we separate short-distance contributions (radiation off of quarks) from long-distance contributions (radiation off of final state particles), and how do we account for these two contributions?
- Which processes can be dealt with through a common approach? Like commonality between B, D, and K decays for classes of decays: Semileptonic, hadronic two- body, radiative penguins? Rare leptonic?
- What are the theoretical tools to calculate radiative effects? To what accuracy are they expected to work?
- Experimenters will need MC simulations of these processes, soft, medium and hard. What is needed to implement various effects? What exists? What is easy to do? What is harder and needs new input from analytical calculations? How do we best incorporate radiative effects when intermediate resonances are involved in a decay? How would radiation affect, for example, expected angular correlations between final state particles, e.g., between the pi-pi and l-nu systems in B,D -> rho+l+nu?
- What are the meaningful cross checks between simulation and calculations? And experiment?

BIBLIOGRAPHY:

RADIATIVE CORRECTIONS TO K-E-3-NEUTRAL DECAYS AND THE DELTA-I=1/2 RULE. (ERRATUM).
By E.S. Ginsberg. 1968.
Published in Phys.Rev.171:1675,1968, Erratum-ibid.174:2169,1968

RADIATIVE CORRECTIONS TO THE K-L-3 +- DALITZ PLOT. (ERRATUM).
By E.S. Ginsberg. 1969.
Published in Phys.Rev.162:1570,1967, Erratum-ibid.187:2280,1969

RADIATIVE CORRECTIONS TO K-MU-3 DECAYS.
By E.S. Ginsberg (Technion),. 1970.
Published in Phys.Rev.D1:229-239,1970

RADIATIVE CORRECTIONS AND SEMILEPTONIC B DECAYS.
By David Atwood, William J. Marciano (Brookhaven),. BNL-43638,
Published in Phys.Rev.D41:1736,1990

RADIATIVE NONLEPTONIC KAON DECAYS.
By G. D'Ambrosio (CERN), G. Ecker (Vienna U.), G. Isidori (INFN, Rome & Rome U.), H. Neufeld (Vienna U.),.
Published in 2nd DAPHNE Physics Handbook:265-313 (QCD183:L15:1995) e-Print Archive: hep-ph/9411439

RADIATIVE FOUR MESON AMPLITUDES IN CHIRAL PERTURBATION THEORY.
By G. D'Ambrosio (INFN, Naples & Naples U.), G. Ecker (Vienna U.), G. Isidori (Frascati), H. Neufeld (Vienna U.),Published in Phys.Lett.B380:165-170,1996
e-Print Archive: hep-ph/9603345

K ---> PI PI PHENOMENOLOGY IN THE PRESENCE OF ELECTROMAGNETISM.
By Vincenzo Cirigliano, John F. Donoghue, Eugene Golowich (Massachusetts U., Amherst),
Published in Eur.Phys.J.C18:83-95,2000
e-Print Archive: hep-ph/0008290

RADIATIVE CORRECTIONS TO K(L3) DECAYS.
By V. Cirigliano (Vienna U. & Valencia U., IFIC), M. Knecht (Marseille, CPT), H. Neufeld, H. Rupertsberger (Vienna U.), P. Talavera (Marseille, CPT).

Published in Eur.Phys.J.C23:121-133,2002
e-Print Archive: hep-ph/0110153

RADIATIVE CORRECTIONS IN K0(L3) DECAYS.
By Troy C. Andre (Chicago U., EFI & Chicago U.),. EFI-04-17, Jun 2004. 16pp.
Submitted to Phys.Rev.D   e-Print Archive: hep-ph/0406006

ELECTROWEAK RADIATIVE CORRECTIONS TO B ---> S GAMMA.
By Andrzej Czarnecki, William J. Marciano (Brookhaven),.
BNL-HET-98-11, Apr 1998. 8pp.
Published in Phys.Rev.Lett.81:277-280,1998
e-Print Archive: hep-ph/9804252

PHOTOS: A UNIVERSAL MONTE CARLO FOR QED RADIATIVE CORRECTIONS. VERSION 2.0.
By Elisabetta Barberio (CERN & Siegen U.), Zbigniew Was (CERN & Cracow, INP),. CERN-TH-7033-93, Oct 1993. 22pp.
Published in Comput.Phys.Commun.79:291-308,1994

PHOTOS: A UNIVERSAL MONTE CARLO FOR QED RADIATIVE CORRECTIONS IN DECAYS.
By Elisabetta Barberio, Bob van Eijk, Zbigniew Was (CERN),.
CERN-TH-5857-90, Sep 1990. 22pp.
Published in Comput.Phys.Commun.66:115-128,1991

QED BREMSSTRAHLUNG IN SEMILEPTONIC B AND LEPTONIC TAU DECAYS.
By E. Richter-Was (CERN & Jagiellonian U.),. CERN-TH-6746-92, Dec 1992. 17pp.
Published in Phys.Lett.B303:163-169,1993