MC Generators for Multiparticle Processes

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Outline

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Motivation

A number of physical problems involve measurements of exclusive cross sections of $e^+e^- \to$ hadrons at low energy:

- Determination of R in this energy range ($\sqrt{s} < 2$ GeV) is only possible in the exclusive approach, i.e., measuring specific final states and then summing their cross sections
- Knowledge of R gives an opportunity to calculate the LO and HO (not LBL) hadronic contributions to $(g-2)_\mu$, $\alpha(M_Z^2)$, estimate various QCD parameters (α_s, Λ_{QCD}, quark masses, condensates)
- Exclusive cross sections rather than total R are needed for resonance studies, e.g., 4π for the $\rho(1450, 1700, ...)$, $3/5\pi$ for the $\omega(1420, 1650)$
- Exclusive isovector cross sections are used for conserved vector current (CVC) tests, e.g., $4, 6\pi$, $\eta\pi^+\pi^-$, ...

This necessitates preparing corresponding Monte Carlo generators, first of all, for multiparticle final states

Final States and Intermediate Mechanisms

- $\pi^+\pi^-\pi^0$ – $\rho\pi$
- $\pi^+\pi^-\pi^+\pi^-$ – $a_1\pi$, $f_0\rho^0$, $a_2\pi$, $\pi'\pi$
- $\pi^+\pi^-\pi^0\pi^0$ – $a_1\pi$, $\omega\pi$, $f_0\rho^0$
- $\pi^+\pi^-\pi^+\pi^-\pi^0$ – $\omega\pi^+\pi^-$, $\eta\pi^+\pi^-$, $\phi\pi^+\pi^-$, $\rho^0\pi^+\pi^-\pi^0$
- $3\pi^+3\pi^-$ – $\rho^0(4\pi)^0$, $2\pi^+2\pi^-2\pi^0$ – $\rho^0 f_2(1270)$, $\omega\pi^+\pi^-\pi^0$, $\eta\pi^+\pi^-\pi^0$, ...
- $K^+K^-\pi^0$ – $\phi\pi^0$, $K^{*\pm}K^{\mp}$; $K^0_S K^{\pm}\pi^{\mp}$ – ,$K^{*0}K^0$, $K^{*\pm}K^{\mp}$
- $K^+K^-\pi^+\pi^-$ – $K^{*0}K^{\pm}\pi^{\mp}$, $\phi\pi^+\pi^-$, $(K\rho)K$
- Other final states observed: $K^+K^-\eta$, $K^+K^-\pi^0\pi^0$, $K^+K^-K^+K^-$, $K^+K^-2(\pi^+\pi^-)$, ...
- Interference effects should be taken into account

Production of Four Pions at CMD-2 – I

- There are two possible final states – $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-\pi^0\pi^0$ with two pairs and one pair of identical pions in the 1st and 2nd cases
- The amplitude of the process should be symmetric with respect to permutations of identical particles
- For example, for the $\pi_1^+\pi_2^-\pi_3^+\pi_4^-$ final state produced via ρf_0
  $\mathcal{A} \ = \ f_0(1,2)\rho(3,4) + f_0(1,4)\rho(2,3) + f_0(3,4)\rho(1,2) + f_0(2,3)\rho(1,4)$
- The $a_1^+\pi^-$ case with $a_1^+ \to \rho^0\pi^+$ and $\rho^0 \to \pi^+\pi^-$ gives even more – 8 combinations
- Additional difficulty – in some cases more than one Lorentz-invariant structure is needed to describe the process, so that new form factors arise

Production of Four Pions at CMD-2 – II

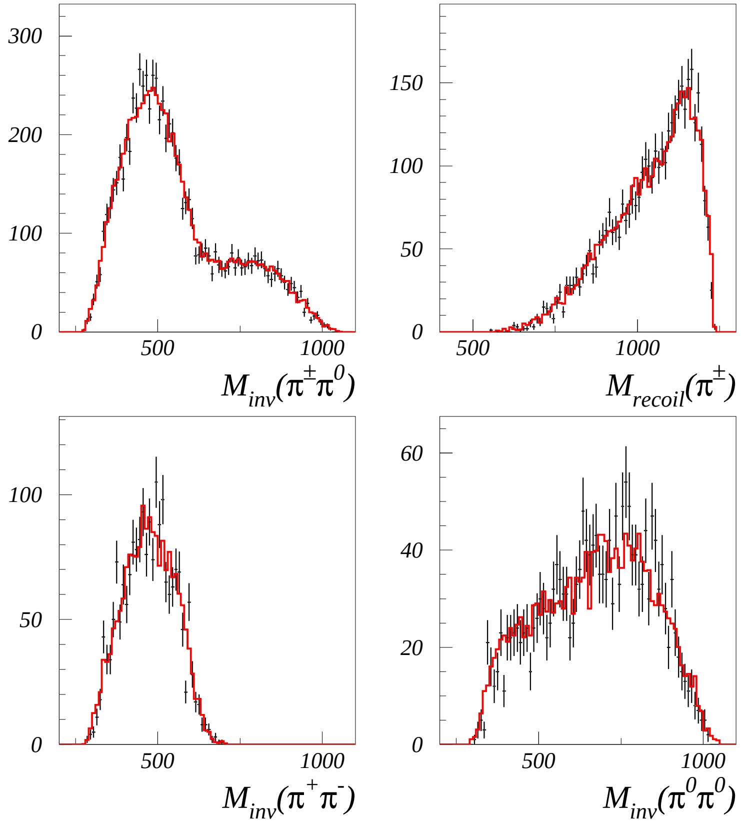
Mechanism	$\pi^+\pi^-\pi^+\pi^-$	$\pi^+\pi^-\pi^0\pi^0$
$a_1(1260)\pi$	8	4
$a_2(1320)\pi$	8	4
$\omega\pi$	–	6
$h_1(1170)\pi$	–	6
$\rho^+\rho^-$	–	8
$\pi'(1300)\pi$	8	4
$f_0\rho$	4	1

The number of combinations for various mechanisms

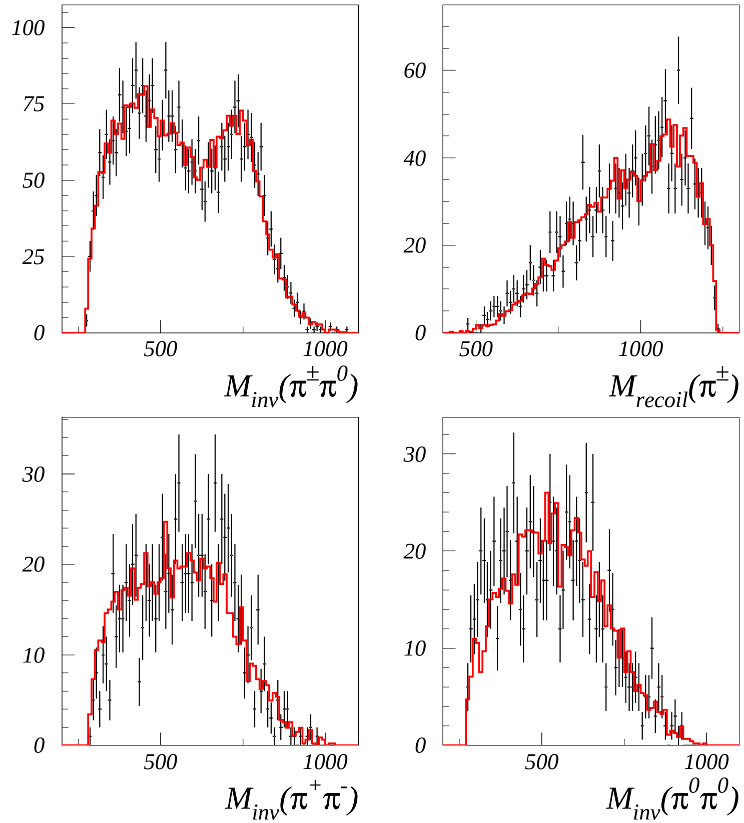
Production of Four Pions at CMD-2 – III

1. At the first stage of analysis it was shown that the $\pi^+\pi^-\pi^+\pi^-$ is dominated by the $a_1(1260)\pi$ intermediate mechanism
2. Two mechanisms contribute to the $\pi^+\pi^-\pi^0\pi^0$ final state – $a_1\pi$ and $\omega\pi$
3. The nominal model is an $a_1\pi + \omega\pi$ combination.
   We also studied possible admixtures of all other modes one by one
   - $a_1\pi + \omega\pi + \rho f_0$
   - $a_1\pi + \omega\pi + h_1\pi$
   - $a_1\pi + \omega\pi + a_2\pi$
   - $a_1\pi + \omega\pi + \pi'\pi$
   - $a_1\pi + \omega\pi + \rho^+\rho^-$
4. Each mechanism has its weight – in general a complex form factor

Illustrations of Monte Carlo for $e^+e^- \to \pi^+\pi^-2\pi^0$



$\omega\pi$ enriched



$a_1\pi$ enriched

SND Experience

- A set of processes studied almost the same as at CMD-2, SND has their own generators
- Has additionally studied various 3- and 4-body QED final states: $e^+e^- \to e^+e^-\gamma,\ \mu^+\mu^-\gamma,\ 3\gamma,\ e^+e^-e^+e^-,\ e^+e^-\mu^+\mu^-,\ e^+e^-\gamma\gamma$ with corresponding MC generators based on E. Kuraev's studies

Experience of BaBar

- EVA-based event generator is used
- The list of the processes follows
- The processes with HC, among them vector-pseudoscalar (VP) and vector-scalar (VS) are simulated with proper hadronic currents
- Most of other modes are generated using uniform phase space (PS) distribution
- For tagged ISR measurements the dependence of the detection efficiency on hadron system dynamics is low

Processes simulated at BaBar – I

Process	C	Process	C
$\mu^+\mu^-$	EM	$K^0_S K^\pm \pi^\mp$	H
$\pi^+\pi^-$	H	$K^+K^-\pi^0$	H
$\pi^+\pi^-\pi^+\pi^-$	H	$p\bar{p}$	H
$\pi^+\pi^-\pi^0\pi^0$	H	$\eta\pi^+\pi^-$	H
$\pi^+\pi^-\pi^0$	H	$\pi^0\phi(K^+K^-)$	H
K^+K^-	H	$\eta\phi(K^+K^-)$	H
$K^0_S K^0_L$	H	$\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$	PS

Processes simulated at BaBar – II

Process	C	Process	C
$\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$	PS	$K_S^0K_L^02\pi^0$	PS
$\pi^+\pi^-\pi^0\pi^0\pi^0\pi^0$	PS	$K_S^0K_L^02\pi^0$	PS
$K^+K^-\pi^+\pi^-$	PS	$K^+K^-K^+K^-$	PS
$K^+K^-2\pi^0$	PS	$K^+K^-K_S^0K_S^0$	PS
$K_S^0K_S^0\pi^+\pi^-$	PS	$K^+K^-K_S^0K_L^0$	PS
$K_S^0K_S^02\pi^0$	PS	$p\bar{p}\pi^+\pi^-$	PS
$K_S^0K_L^0\pi^+\pi^-$	PS	$p\bar{p}2\pi^0$	PS

Future

- We expect much higher precision and higher energy $\Rightarrow$ new requirements for both experiment and analysis
- Higher precision imposes special constraints on the description of physical processes, i.e. on the amplitudes and form factors
- Interference effects demand additional form factors: $\mathcal{A}(4\pi) = \mathcal{A}(a_1\pi) + f(s)\mathcal{A}(f_0\rho)$
- Higher precision appears due to higher statistics $\Rightarrow$ we can use data for studying dynamics of various processes and better model their description needed for the MC input
- Higher energy results in a rich variety of physics so that new mechanisms arise and new particles are produced
- $f_0 = f_0(600),\ f_0(980),\ f_0(1370),\ \ldots,\ \rho = \rho(770),\ \rho(1450),\ \ldots$

"New" Monte Carlo

A new code has been created to generate multiparticle processes:

- The matrix element (m.e.) of each final state is written manually in the Lorentz-invariant form
- The code automatically calculates the m.e. squared and prepares a subroutine for MC generation
- Permutations of identical particles are done automatically
- Interference of different mechanisms can be on/off
- We started working on a library of different mechanisms

Additional checks are in progress. We hope to use it for CMD-III.

D.Anipko, SE, A.Pak, hep-ph/0308209, both students gone

New "automatic" ideas needed (K. Kolodziej)

Instead of Conclusions

- Radiative corrections (ISR) – some approximation with some "reasonable" energy and angular distribution of a photon emitted by initial e^+e^- followed by the Lorentz boost of the hadronic final state
- Radiative corrections (FSR) – PHOTOS?
- For some modes ($2\pi,\ 4\pi,\ \omega\pi,\ \ldots$) CVC can be used to add more information from high-statistics τ data
- Hard work is needed to prove that MC generators for multiparticle processes are not limiting the precision of R
- What about generators for $\gamma\gamma \to$ hadrons?
- Needed for BESIII, CMD-3, SND + ISR at BABAR and Belle and for planned DAFNE-II, Super-$\tau - c$ factory