# MC Generators for Multiparticle Processes

Simon Eidelman

Budker Institute of Nuclear Physics,
Novosibirsk, Russia

## Outline

1. Multiparticle $e^+e^-$
2. CMD-2 experience
3. Ideas for future

## 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 $\rho f_0$
  $\mathcal{A} = f_0(1,2)\rho(3,4) + f_0(1,4)\rho(2,3) + f_0(3,4)\rho(1,2) + f_0(2,3)\rho(1,2)$
- 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

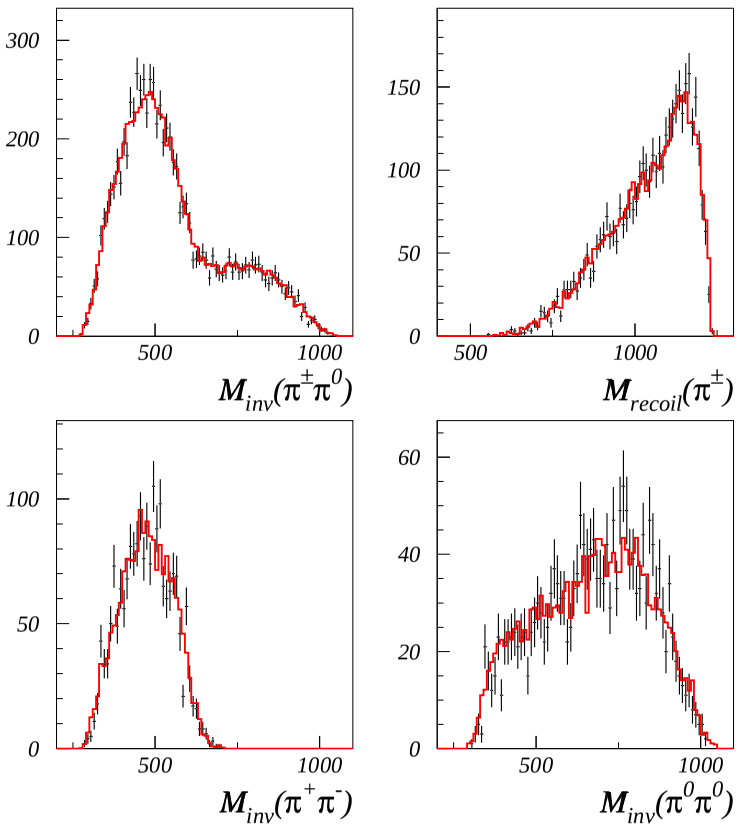
## Production of Four Pions at CMD-2 – II

| 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 |

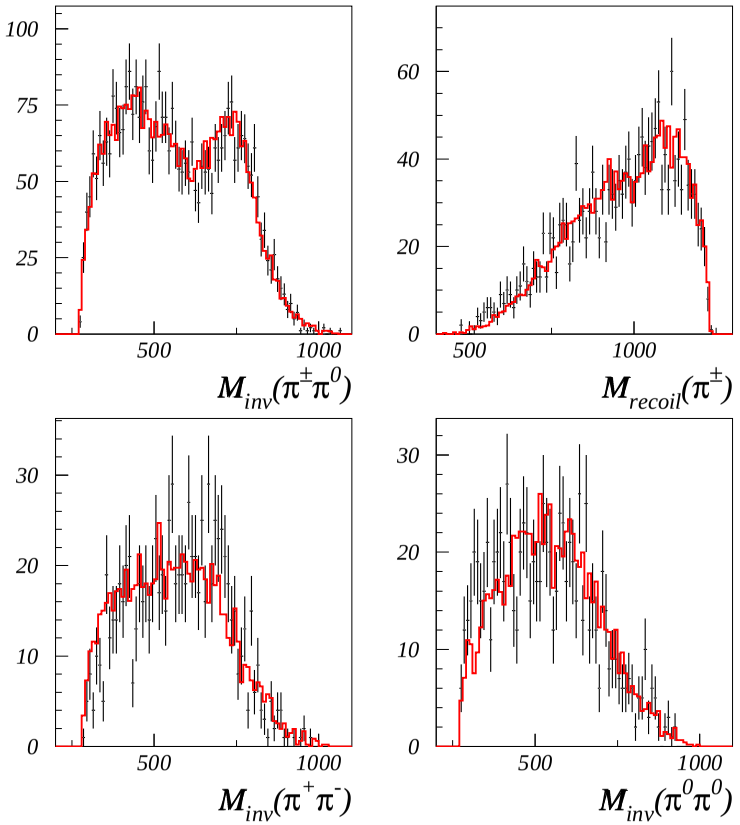
## Production of Four Pions at CMD-2 – III

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

## 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

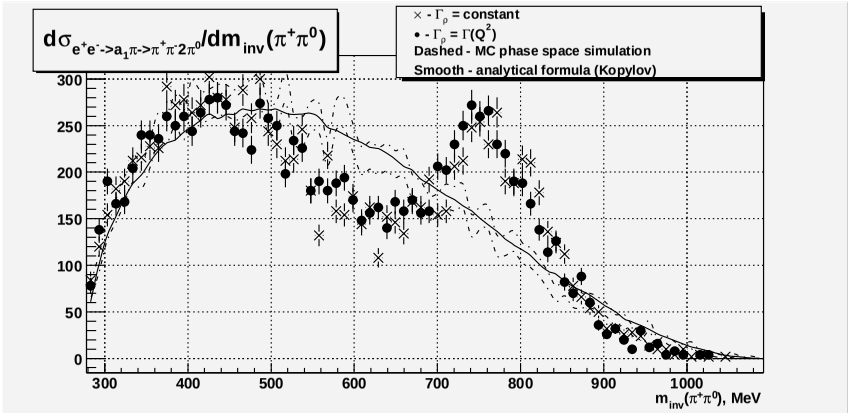
A new code has been created to generate multiparticle processes:

- 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

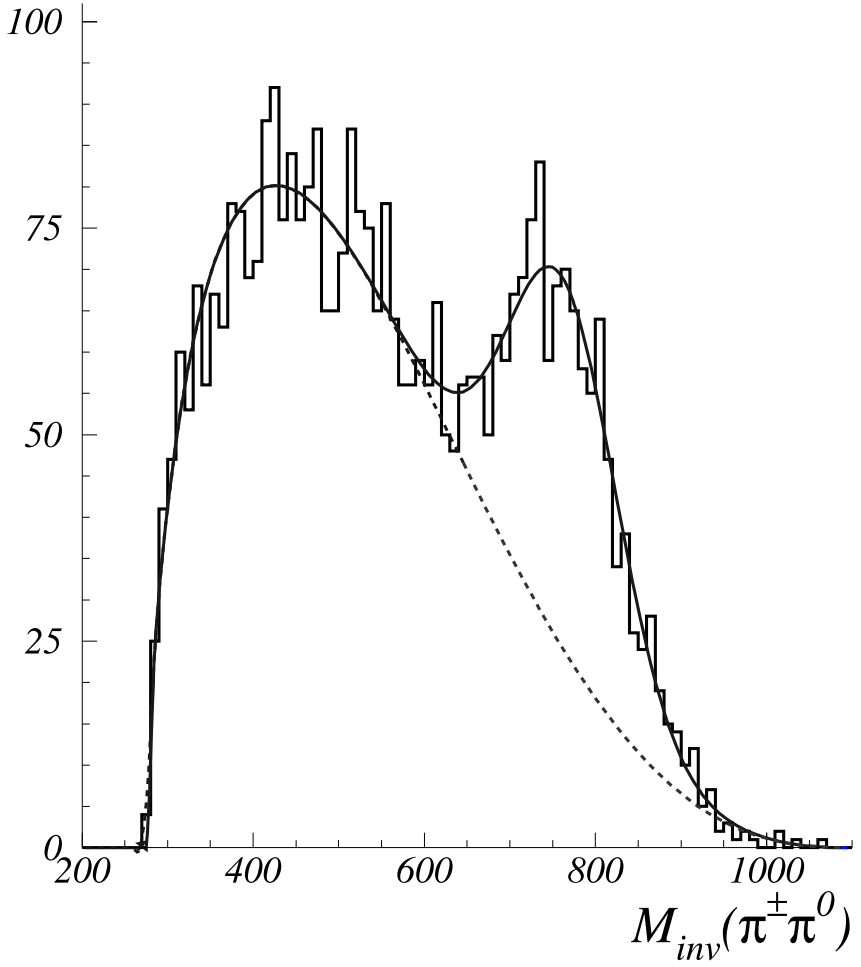
Additional checks are in progress. We hope to use it for CMD-III.

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

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




$a_1\pi$ – Monte Carlo




$a_1\pi$ – data

## 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 ($2\pi$, $4\pi$, $\omega\pi$, ...) CVC can be used to add more information from high-statistics $\tau$ data
- Hard work is needed to prove that MC generators for multiparticle processes are not limiting the precision of $R$