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SIMULATION OF e^+e^- PAIR PRODUCTION AND DETECTION IN THE ALICE EXPERIMENT

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Simulation of e^+e^- pair production in PbPb interactions at LHC energy and of registration in the ALICE detector has been done. An influence of external γ-conversions on e^+e^- combinatorial background is studied. Some details for selection cuts to improve the signal-to-background ratio are considered.

The investigation has been performed at the Laboratory of High Energies, JINR.

Моделирование рождения и детектирования e^+e^--пар в эксперименте ALICE

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Проведено моделирование рождения e^+e^--пар в PbPb-взаимодействиях при энергии LHC и регистрации их в детекторе установки ALICE. Изучено влияние внешней гамма-конверсии на e^+e^- комбинаторный фон. Рассмотрены некоторые детали выбора критериев, улучшающих отношение сигнал-фон.

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1. Introduction

The important role of leptonic pair investigations in heavy ion collisions is discussed elsewhere. This possibility was considered also for the ALICE experiment and special Monte Carlo study has been done [1] to decide some problems for a selection of the vector meson decays to e^+e^- final states. The most problem is the high combinatorial background which relates to the Dalitz decays or external γ-conversions and is essentially proportional to the square of number of e^+e^- pairs. This difficulty is made worse by an impossibility to recognize and remove a large part of Dalitz decays and γ-conversions because of a loss of e^+ or e^- from the decay pairs (as a consequence of the detector acceptance, tracking efficiency and particle identification).

In this paper we studied particularly an influence of the external conversions, since only some suppositions about ones have been discussed in the ALICE LoI [1]. Besides, we present some details for the selection cuts which were used in order to improve the signal-to-background ratio (S/B).

2. Rates of the γ-Conversions

To obtain a rate of γ-conversions, we used the GEANT-based program [2] for simulation of the ITS (Inner Tracking System) of the ALICE. Also, the HIJING code [3] has been chosen to generate an event of PbPb central collision at an energy of 6.3 A TeV. The event contained 79000 particles and gammas in all phase space, with charge particle density of $dN/dy \simeq 5000$ at $y = 0$. We cutted charge particle momenta from $p \geq 0.03$GeV/c and found 11122 γ and e^+/e^- (54 e^+e^- pairs) from the primary vertex of an interaction in the ITS rapidity region of $-1 \leq y \leq 1$.

The ITS simulation package [2] contains geometry decks with five cylindrical silicon detectors (silicon layers of 300 μm thickness, a mechanical supporting system and a cooling system). Besides, the beam-pipe has been put to the GEANT geometry (Be, a radius of 4 cm, a thickness of 0.2 cm, a radiation length of 0.56% of X0). By requiring a hit at the nearest position from the primary vertex, photon conversions were restricted to the beam-pipe and the first silicon detector (pixels). We note, that the radiation length of the pixel detector has been taken equal to 0.52% of X0 (0.32% for the silicon and 0.2% for the electronics) because a gas coolant and the beam-pipe as a support are assumed in this case. The e^+/e^--tracks at a momentum of $p \geq 0.03$ GeV/c were selected as above.

The simulation result for numbers of the conversions is presented in Table 1. One can see from this that the e^+/e^- conversion number (101) is near the same as one produced in the primary vertex. But, of course, a large rate of conversions can be recognized by the following signs:

- a secondary vertex (conversion point) of the e^+e^- pair,
- a non-zero impact parameter of the single track,
- a double pulse-heigt of the hit as a consequence of double dE/dx for close pairs which do not open up in the weak field (0.2 T).

The most problem for the first and second signs is a very high charge particle space density near the vertex. A rate of the recognized conversions depends on the track reconstruction algorithm and may be assumed reasonably of $(60 \div 80)$%. We found also that a mean distance between e^+ and e^- is near 1 mm at the first silicon layer, when a photon converts inside the beam-pipe. It means that the third sign (double dE/dx) is realized only when the conversion point is inside the first silicon layer ($\simeq$ 50% of the conversions). We note that an additional difficulty of such a method is also an existence of only one hit-point with a double pulse-height for a $e^+(e^-)$-track. According to Table 1, $10 \div 20$ conversion pairs remain unrecognized, $(20 \div 40)$% from the amount of 54 e^+e^--pairs produced in primary vertex.

Table 1. The conversion number from the simulation

γ-conversion pairs	Single e^+ from conversion pairs	Single e^- from conversion pairs
33	17	18

3. Simulation of e^+e^- Pair Production

Next we used the SHAKER code [4] to generate production and e^+e^- mode decays (two-and-three-body decays) of the π^0, η, ρ^0, ω, ϕ, J/φ and Drell-Yan pairs in central PbPb collision at 6.3 A TeV. The particle numbers and ratios and the weights for particle p_T-distributions were taken just the same as in Refs. [1,5]. Also, the special parametrizations [1] of tracking efficiency and pion rejection have been put for the detector simulation (it should be noted that more realistic parametrizations are now under study). The rapidity region, $-1 \leq y \leq 1$, was considered.

Additional Dalitz pairs have been generated instead of γ-conversions, since an absence of a special conversion generator in the SHAKER code. To justify such a simplification, we emphasize a very small difference between transverse momentum spectra (at $p \geq 0.03$ GeV/c) of the conversions ($\langle p_T \rangle \simeq 0.126$ GeV/c) and Dalitz pairs ($\langle p_T \rangle \simeq 0.130$ GeV/c). Besides, a zero effective mass and very small angle between e^+ and e^- have been imitated for the conversion pairs at the step of cut-1 (see below), because of important role of these characteristics for the background rejection. The rates of the conversions were taken from the simulation described in Section 2. We added 10 and 20 conversion pairs per event (to the 52 Dalitz ones) for an oprimistic and pessimistic versions, repectively.

4. Results of the SHAKER Simulation

As a result of the SHAKER simulation (100 K events), the S/B values are presented in Tables 2 and 3 for three different variants:

- without the conversion e^+e^- pairs,
- with 10 conversions per event (in addition to 52 Dalitz pairs),
- with 20 conversions per event.

Table 2. Results of the SHAKER simulation for the ρ^0, ω region of m_{ee}

	S/B		S	
	At m_{ee} of 070 ÷ 0.84 GeV/c^2	At m_{ee} of 0.76 ÷ 0.84 GeV/c^2	At m_{ee} of 0.70 ÷ 0.84 GeV/c^2	At m_{ee} of 0.76 ÷ 0.80 GeV/c^2
No conversions	0.0018	0.0058	1433	1100
10 conversions per event	0.0013	0.0036	1433	1010
20 conversions per event	0.0010	0.0027	1403	1010

Table 3. Results of the SHAKER simulation for the ϕ region of m_{ee}

	S/B		S	
	At m_{ee} of 0.95 ÷ 1.10 GeV/c^2	At m_{ee} of 1.00 ÷ 1.04 GeV/c^2	At m_{ee} of 0.95 ÷ 1.10 GeV/c^2	At m_{ee} of 1.00 ÷ 1.04 GeV/c^2
No conversions	0.0021	0.0073	530	490
10 conversions per event	0.0016	0.0054	534	485
20 conversions per event	0.0012	0.0040	537	492

Table 4. The same as in Table 2 (for 20 conversions) with the cuts 1 ÷ 4 (see text)

Cuts	S/B		S	
	At m_{ee} of 0.70 ÷ 0.84 GeV/c^2	At m_{ee} of 0.76 ÷ 0.80 GeV/c^2	At m_{ee} of 0.70 ÷ 0.84 GeV/c^2	At m_{ee} of 0.76 ÷ 0.80 GeV/c^2
1	0.005	0.0015	350	246
2	0.008	0.0021	133	97
3	0.004	0.0109	59	42
4	0.059	0.158	55	42

Table 5. The same as in Table 3 (for 20 conversions) with the cuts 1 ÷ 4 (see text)

Cuts	S/B		S	
	At m_{ee} of 0.95 ÷ 1.10 GeV/c^2	At m_{ee} of 1.00 ÷ 1.04 GeV/c^2	At m_{ee} of 0.95 ÷ 1.10 GeV/c^2	At m_{ee} of 1.00 ÷ 1.04 GeV/c^2
1	0.006	0.022	145	132
2	0.008	0.028	67	62
3	0.020	0.069	40	37
4	0.038	0.132	31	29

The numbers of e^+e^- pairs from ρ^0-, ω- and ϕ-resonances (S) are shown also. All results are presented for different regions of e^+e^- effective mass (m_{ee}) and after the cuts for the tracking efficiency and pion rejection [1] and for an acceptance restriction ($\theta = 90° \pm 40°$).

One can see from Tables 2 and 3 that ratios are too small and an influence of the conversions is significant enough. In order to improve the S/B ratio we applied a number of successive cuts (step by step) for the e^+e^- effective mass and some kinematic variables of kinematic e^+ and e^- from the e^+e^--pairs. First of all, the cuts from the LoI [1] have been used. An order of the cuts is following:

1. All e^+ and e^- forming pairs of $m_{ee} \le 100$ MeV/c^2 are discarded if the opening angle between the e^+ and e^- is less than 26° ($\cos(\theta) \ge 0.9$).

2. All e^+ and e^- with the $m_{ee} \le 150$ MeV/c^2 are removed from the next step.

3. In the next step, we remove e^+ and e^- which are outside the fiducial area of $90° \pm 40°$ or have a p_T below 450 MeV/c.

4. Finally, we form the invariant mass of all pairs with $p_T(\text{pair}) \ge 1$ GeV/c.

The results of the cuts $1 \div 4$ are shown in Tables 4 and 5 for the 100 K SHAKER events with 20 conversions (per event).

Table 6. The S/B values after the cut 3 (see text) at the p_T cut of 600 MeV/c

	At m_{ee} of $0.70 \div 0.84$ GeV/c^2	At m_{ee} of $0.76 \div 0.80$ GeV/c^2	At m_{ee} of $0.95 \div 1.10$ GeV/c^2	At m_{ee} of $1.00 \div 1.04$ GeV/c^2
No conversions	0.18	0.42	0.08	0.30
10 conversions per event	0.13	0.40	0.07	0.32
20 conversions per event	0.10	0.29	0.05	0.17

Table 7. The same as in Table 6 at the p_T cut of 750 MeV/c

	At m_{ee} of $0.70 \div 0.84$ GeV/c^2	At m_{ee} of $0.76 \div 0.80$ GeV/c^2	At m_{ee} of $0.95 \div 1.10$ GeV/c^2	At m_{ee} of $1.00 \div 1.04$ GeV/c^2
No conversions	0.36	0.96	0.20	0.77
10 conversions per event	0.27	0.77	0.13	0.51
20 conversions per event	0.24	0.64	0.11	0.40

Table 8. The same as in Table 2 with the optimized cuts (see text)

	S/B		*S*	
	At m_{ee} of 0.70 ÷ 0.84 GeV/c^2	At m_{ee} of 0.76 ÷ 0.80 GeV/c^2	At m_{ee} of 0.70 ÷ 0.84 GeV/c^2	At m_{ee} of 0.76 ÷ 0.80 GeV/c^2
10 conversions per event	0.26	0.69	45	33
20 conversions per event	0.21	0.60	39	30
20 conversions per event for 3×10^6 events	0.18	0.51	1168	865

Table 9. The same as in Table 3 with the oprimized cuts (see text)

	S/B		*S*	
	At m_{ee} of 0.95 ÷ 1.10 GeV/c^2	At m_{ee} of 1.00 ÷ 1.04 GeV/c^2	At m_{ee} of 0.95 ÷ 1.10 GeV/c^2	At m_{ee} of 1.00 ÷ 1.04 GeV/c^2
10 conversions	0.13	0.41	27	25
20 conversions per event	0.10	0.31	25	23
20 conversions per event for 3×10^6 events	0.10	0.34	744	691

It is seen from Tables 4 and 5 that the cuts 1 and 3 are the most effective ones (the *S/B* increases by a factor of 5 ÷ 6) and cuts 2 and 4 rather weakly affect the *S/B* value but, however, cut 2 decreases near 2 ÷ 2.5 times the resonance numbers. Next we checked punctually the optimization of cuts 1 ÷ 4. We found that cut 1 is optimized enough, however, because of combinatorial effect an amount of 0.3% of Dalitz pairs remains only after this cut action and practically single e^+ and e^- come to the next step (cut 2). This is a main reason of the low efficiency of cut 2, and the situation is not improved by a change of the limit near the value of 150 MeV/c^2. Further it was found that the *S/B* ratio is very sensitive to the limit in cut 3. This effect is seen from Tables 6 and 7, where the *S/B* values are presented after an action of cut 3 at the p_T limit of 600 MeV/c and 750 MeV/c, respectively, and for different numbers of the conversion e^+e^- pairs.

The rise of the p_T limit from 450 MeV/c up to 750 MeV/c increases the S/B ratio by a factor of $5 \div 7$. But, it should be noted that the resonance numbers decrease near two times. We note also that cut 4 does not practically change the S/B values in this case. To optimize the S/B ratios and resonance numbers cuts 2 and 4 have been removed and the p_T limit (in cut 3), equal to 750 MeV/c, has been chosen. The final results for the optimized cuts are shown in Tables 8 and 9 for 10^5 events and 3×10^6 events (for 20 conversions).

Figure 1 shows the effective mass distribution of pairs e^+e^- (from resonances and background) at the optimized cuts for 3×10^6 events. Figure 2 shows the contribution, where both e^+ and e^- come from one resonance (ρ^0, ω, ϕ). The results of the fits (Gaussian — for the resonances and exponential — for the background) are shown as well.

Table 10 presents extrapolated values of S and $S/\sqrt{B}$ (the significance) to the amount of 5×10^7 events.

Table 10. Extrapolated values of S and $S/\sqrt{B}$ (siginficance) to the amount of 5×10^7 events

	S	$S/\sqrt{B}$
At m_{ee} of $0.76 \div 0.80$ GeV/c^2	14420	85
At m_{ee} of $1.00 \div 1.04$ GeV/c^2	11520	63

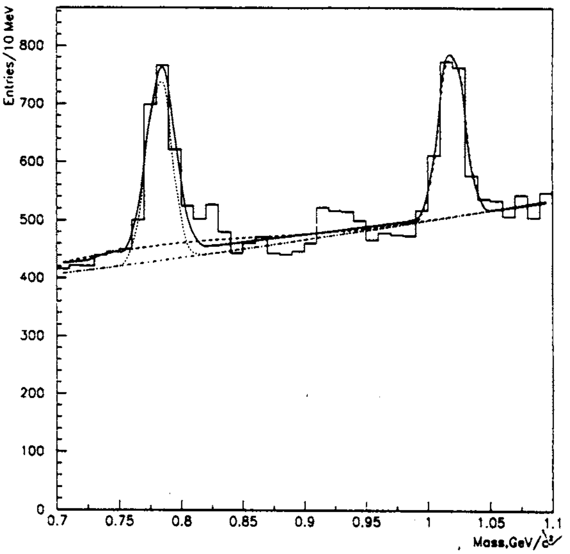

Fig.1. Effective mass distribution of e^+e^- pairs from the ρ^0, ω, ϕ resonances and background at the optimized cuts (see text). The curves are the results of fits: Gaussian — for the resonances and exponential — for the background

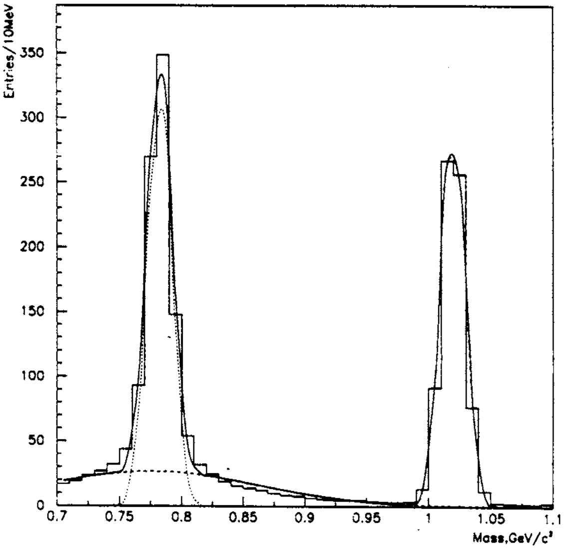

Fig.2. Effective mass distribution of pairs where both e^+ and e^- come from one of the resonances (ρ^0, ω or ϕ). The curves are the results of Gaussian fits

5. Conclusion

The results presented in this paper show that the external γ-conversion decreases the signal-to-background ratio (S/B) by a factor of $1.5 \div 2$ for the ω and ϕ resonances. But, on the other hand, the optimization of the selection cuts allows one to increase S/B value by factors of $5 \div 6$. Finally, we obtained the signal-to-background ratio of $S/B \simeq 0.5$ and 0.3 for ω and ϕ mesons, respectively, at the oprimized selection cuts.

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