The possibility of finding the P-symmetry breaking decay of the charged a_0 meson

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Abstract

The spatial parity (P) violation in strong interactions have never been observed experimentally. One can include a P-breaking term in the QCD Lagrangian. Thus, there can be a local violation of P-symmetry in the medium with high temperature and large topological fluctuations [1]. As a consequence, some hadrons would decay in channels that forbidden by the global parity conservation [2]. In this work we investigate the possibility of observing such process: decay of a charged a_0 meson into charged pion and photon [3]. We study an invariant-mass spectrum of $\pi^{\pm}-\gamma$ pairs produced in PYTHIA Monte Carlo generator with enabled $a_0^{\pm} \rightarrow \pi^{\pm}+\gamma$ decay channel. To distinguish the peak of mentioned decay from the background the mixed-event subtraction, kinematic cuts and Dalitz plots analysis was used. As a result we have estimated minimal number of pp collision events for significant signal of the P-breaking decay.

Symmetry breaking in strong interaction

The QCD Lagrangian

$$\mathcal{L}_{QCD} = -\frac{1}{4}G^{\mu\nu,a}G^a_{\mu\nu} + \bar{q}(i\gamma^{\mu}D_{\mu} - \hat{m}_q)q, \qquad (1)$$

$$D_{\mu} = \partial_{\mu} - iG^a_{\mu}\lambda^a, \quad G^a_{\mu\nu} = \partial_{\mu}G^a_{\nu} - \partial_{\nu}G^a_{\mu} + gf^{abc}G^b_{\mu}G^c_{\nu}$$

can be supplemented by the θ-term that breaks the P symmetry:

$$\Delta\mathcal{L}_{\theta} = \theta\frac{g^2}{32\Pi^2}Tr\left(G^{\mu\nu}\epsilon_{\mu\nu\alpha\beta}G^{\alpha\beta}\right) \qquad (2)$$

with a very small value $\theta \lesssim 10^{-9}$. One of the possible theories considers violation as a local breaking due to large topological fluctuations at high temperature and generation of configurations of nontrivial topological charge. The evolution of topological charge in a finite space region leads to nonzero chiral chemical potential μ_5. As one of the consequences, $a_0^{\pm}$ meson may decay by the forbidden channel: $a_0^{\pm} \rightarrow \pi^{\pm}+\gamma$ [3]. If $\mu_5 = 500\ MeV$ and $|\vec{q}| = 128\ MeV$, estimated (from [4]) branching ratio for that mode is 0.001%.

Decays of a_0 meson

There are several decay chains of $a_0^{\pm}$ that lead to the final pair of $\pi^{\pm}$ meson and γ particle [5]. $a_0^{\pm} \rightarrow \eta+\pi^{\pm}$ is the dominant channel (90%). Then η meson can decay into 2γ (39.4%), $\pi^{+}+\pi^{-}+\pi^{0}$ (23%) or $3\pi^0$ (32.6%). There is 4.29% chance that η decays into several particles with only one γ (mostly $\pi^{+}+\pi^{-}+\gamma$).
π^0 mostly decays into 2γ (98.8%). Thus, γ, that has $a_0^{\pm}$ in ancestors, was probably produced by η or π^0 mesons. It can be detected as stripes at $M_{\gamma\gamma} = 135\ MeV$ (π^0) and $548\ MeV$ (η) at the Dalitz plot (Fig. 1). The second $a_0^{\pm}$ decay channel, $K^{\pm}+K^0$ (10%), produces low rate of $\pi^{\pm}-\gamma$ pairs.

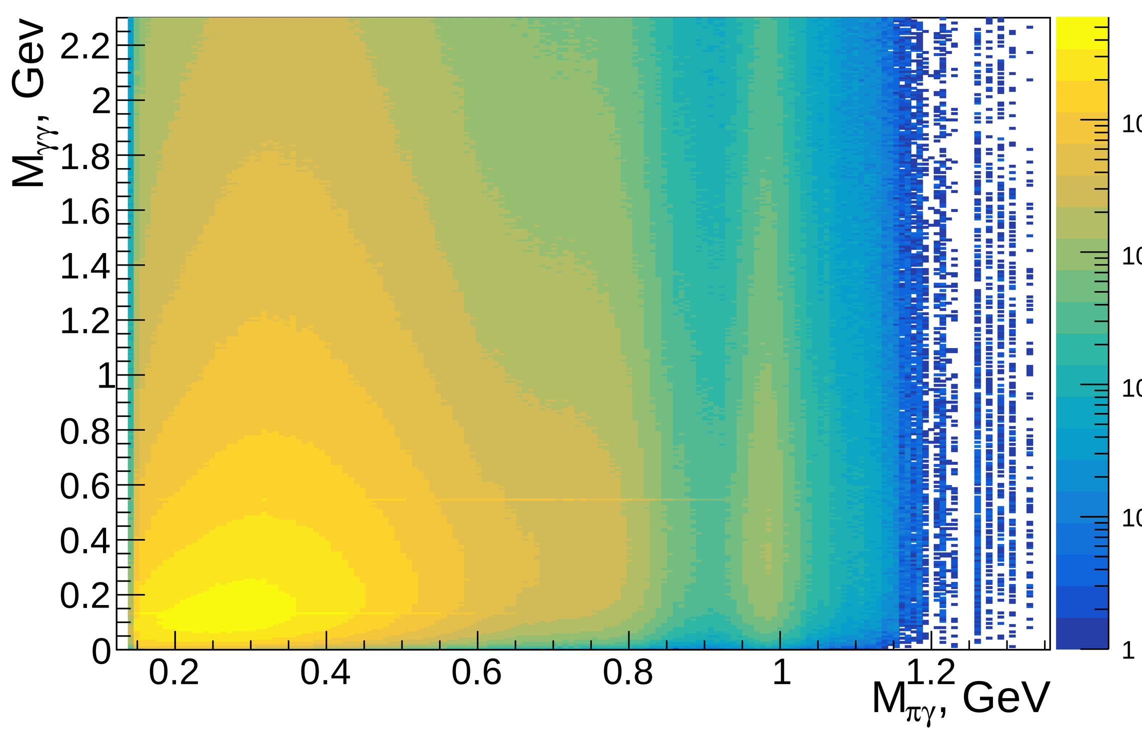

Fig. 1: Dalitz plot for the products of a_0 decays. The branching ratio of ($a_0^{\pm} \rightarrow \pi^{\pm}+\gamma$) is 5%.

Analysis of generated data

- To distinguish the correlated signal from the combinatorial background we used the event mixing technique.
- $\pi^{\pm}-\gamma$ pairs produced directly from a_0 most likely have the opposite azimuthal direction. Taken this into account, we applied the following selection criteria: $\Delta\varphi_{\pi^{\pm},\gamma} > \frac{\Pi}{2}$.
- There is the contribution of γ produced by π_0 or η. To suppress it, we rejected γ particles if they had in the same event a second γ, so that in combination $M_{\gamma\gamma}$ was close to the mass of π_0 or η (γ cut).

When all corrections and selections are applied, the remain spectrum contains only $\pi^{\pm}-\gamma$ pairs produced by decay chains without participation of π_0 and η mesons (Fig. 2).

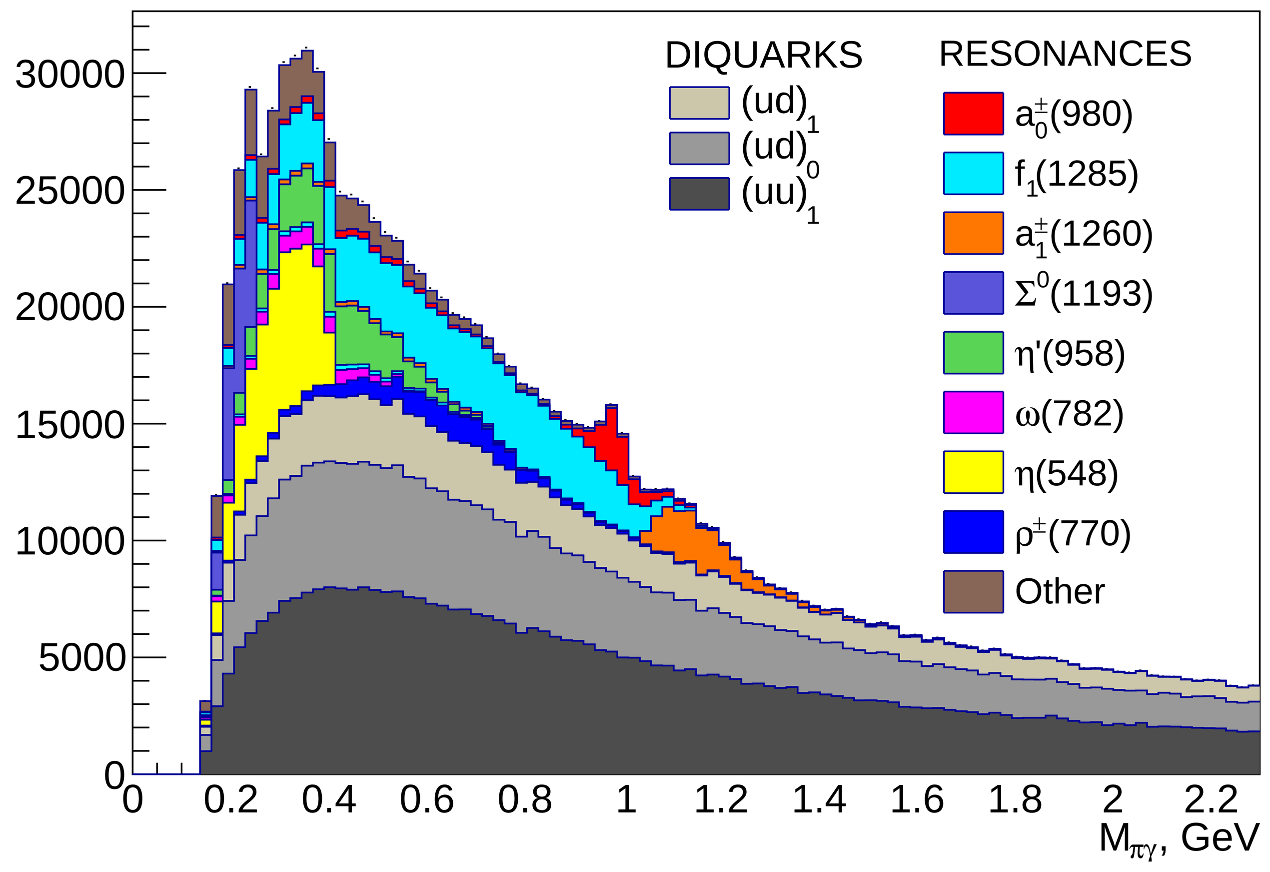

Fig. 2: The composition of invariant-mass spectrum after γ cut. The branching ratio of ($a_0^{\pm} \rightarrow \pi^{\pm}+\gamma$) is 5%.

The main contribution in the background arises due to the correlations that occurs from diquarks in PYTHIA. There is a peak produced by direct $a_1^{\pm} \rightarrow \pi^{\pm}+\gamma$ decay near the region of a_0 mass. Apart of that peak all particular spectra are smooth around 0.98 GeV.
The analysis was applied for the data generated in PYTHIA8 Monte Carlo simulator with $\sqrt{s} = 13TeV$ and enabled $a_0^{\pm} \rightarrow \pi^{\pm}+\gamma$ decay channel (Fig. 3). There was 10 millions events for branching ratio = 5% as a test and 60 millions for branching ratio = 0.001% as more realistic scenario.

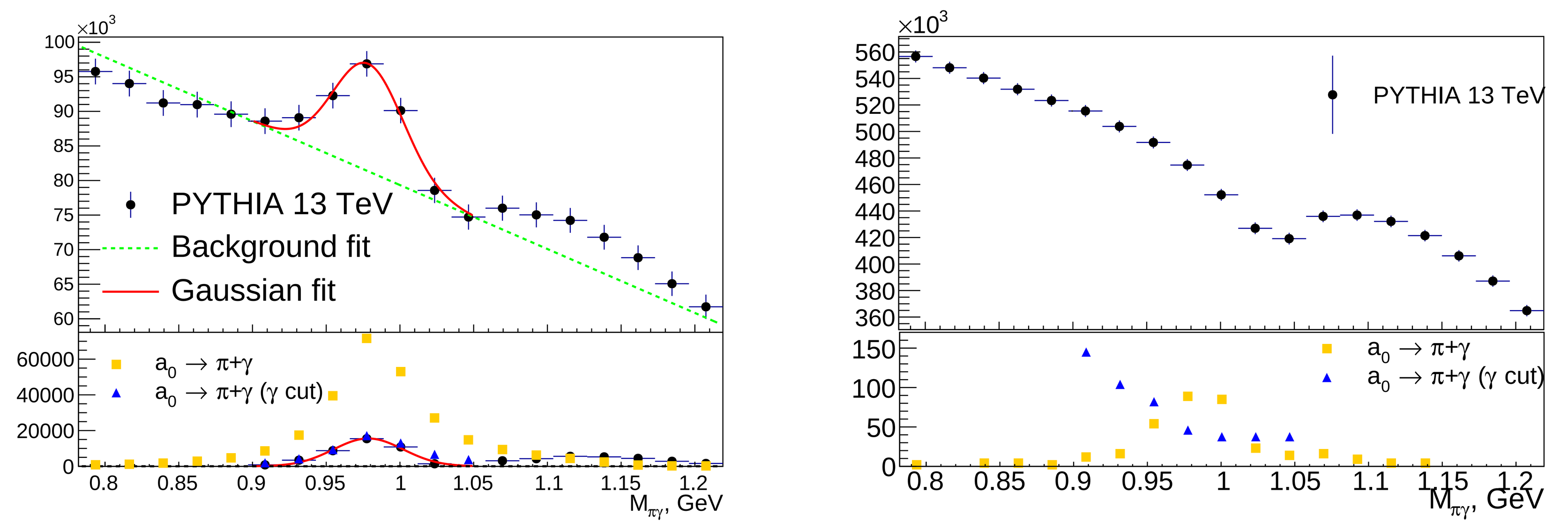

Fig. 3: Analysis of spectra with branching ratio of ($a_0^{\pm} \rightarrow \pi^{\pm}+\gamma$) left: 5%, right: 0.001%. Black markers simulate data in experiment, blue correspond all decays of $a_0^{\pm}$ which produce $\pi^{\pm}+\gamma$ pairs selected after γ cut and orange shows true yield from the desired decay.

Conclusion

In the case of low branching ratio (realistic = 0.001%) minimal number of events to detect the $a_0^{\pm} \rightarrow \pi^{\pm}+\gamma$ decay is 10^{12}. Unideal effectivity of γ registration, contamination of $\eta \rightarrow \pi^{+}+\pi^{-}+\gamma$ decays and closeness of $a_1(1260)$ peak will reduce the chances.

References

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