Referee report

on proposal of JINR participation in the project «Search for light dark matter at SPS CERN» (**02-1-1096-2020/2022**)

Astronomical observations over the past century have shown that 27% of the Universe is made of dark matter. Since dark matter has only been detected through its gravitational interactions, several of its properties, including the mass of dark matter particles and their interactions with standard model (SM) particles, remain completely unknown. While the weakly interacting massive particle with mass of order the electroweak scale is arguably the most popular candidate at this time, the possibility that dark matter could be light of order 100 MeV has attracted much attention recently. Some models postulate a neutral scalar dark matter particle χ with mass 1–10 MeV, which annihilates to produce electron/positron pairs $\chi\chi$–>ee. The excess positrons produced in this annihilation reaction could be responsible for the bright 511 keV line emanating from the center of the Galaxy, as more conventional astrophysical explanations have failed to explain both the intensity and shape of this line. Another unexplained effect is, so-called 8Be anomaly (Feng etal, PRL, 2016) There exists two particles that mediate χ annihilation: a neutral vector boson (sub-GeV dark photon) A' with mass $m_{A'}$ ~ 10–100 MeV, and a heavy fermion F with mass >100 GeV. The A' boson is needed to explain the relic dark matter density, while the F fermion is necessary to account for the observed rate of positron annihilation in the galactic center. This carries the fundamental sense of experimental search for dark matter mediators, where this search is the important low-energy test of SM and the method to look for New Physics. One of the most promising reactions are the A' production in the bremsstrahlung process e- Z -> e- Z A', followed by the *invisible* A' -> $\chi\chi$ or *visible* A'-> e+ e-,… decays. NA64 experiment is specially designed for a direct search for these decays at the CERN SPS. In this search no any assumption on the nature of these decays is used.

In the presence the light dark states, the A' would predominantly *decay invisibly* into those particles. NA64 experiment is specially designed for a direct search for the A' -> $\chi\chi$ decay at the CERN SPS. The occurrence of A' produced in this reaction would appear as an excess of events whose signature in a single e-m shower in the target accompanied by the significant missing energy above those expected from backgrounds. The feasibility study shows that a sensitivity for the search of the *A'* -> $\chi\chi$ decay mode in branching fraction Br(A') = $\sigma(e^-Z \to e^-Z\ A')/\sigma(e^-Z \to e^-\ Z\ \gamma)$ following by A' -> $\chi\chi$, at the level below a few *ppb* could be achieved.

The NA-64 experiment has also a capability to search for the decays A' -> e+ e- of massive dark photons A' into e+e- pairs. If A's with the γ - A' mixing strength in the range 10-5 $\leq \varepsilon \leq$ 10-3 and masses MA' $\leq$ 100 MeV exist, they could be observed through the *visible decay* A' -> e+ e-. The experimental signature of this process - the two-shower energy deposition in the detector - has never been experimentally tested before. The feasibility study of the experimental setup shows that a sensitivity for the search of the A' -> $e^+ e^-$ decay mode in branching fraction Br(A') = $\sigma(e^-Z \to e^-Z\ A')/\sigma(e^-Z \to e^-\ Z\ \gamma)$ at the level below a few *ppb* could be achieved.

These searches would allow to cover a significant fraction of the yet unexplored parameters space for the A' -> $\chi\chi$ (first run 12.10-09.11.16, second 2017-18) and A' -> e+ e- (first run 22.09-

01.10.17, second 2017) decay modes. The results of the first runs are well published and have high level of citations. The collaboration set new limits (comparing with other experiments) on the $\gamma - A'$ mixing strength and exclude the invisible A' with a mass $\lesssim 100$ MeV as an explanation of the muon $g_\mu - 2$ anomaly. The future plans include much higher statistics allowing to probe the most popular sub_GeV dark matter models.

The purpose of the current project is the continuation of significant participation and contribution of the JINR physicists to NA64. This international group includes scientists from JINR, Russia and abroad.

Summarizing, and taking into account undoubtedly valuable expected scientific results, I recommend to extend the participation of the JINR team in experiment NA64 for the period of 2020-2022.

Leading scientific researcher, BLTP JINR

Doctor of Science in physics and mathematics

A.E. Dorokhov

Dubna, March 20, 2019