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STRANGENESS PRODUCTION IN NUCLEAR BEAMS AT JINR

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Strange particles produced in nucleus-nucleus (A_P A_T) collisions provide very important probe of the highly excited matter. It has been argued that strangeness is a unique signature of quark gluon plasma (1). Such signals are expected to be very prominent in the case of QGP formation in the stopping (baryon-rich) regime[1] which could be realized at rather low energies of projectile nuclei ($E_P \sim 2 - 10$ A GeV) (2-5). The production of Λ-hyperons and K^0_S-mesons has been investigated at JINR using two 4π track detectors: the two-meter streamer spectrometer and propane bubble chamber with various targets inside feducial volumes (A_T=^{6}Li, ^{12}C, ^{20}Ne, Mg, Cu, Zr, Ta, Pb) exposed to nuclear beams (A_P=d, ^{4}He, ^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg) of the Dubna Synchrophasotron at momenta of 4.2–4.5 A GeV/c (7-13).

One might consider it to be a Nature's favour that the degree of randomization (thermalization) of hadronic matter in AA-collisions could be easily estimated looking at the Λ-hyperon peculiarities in their angular distributions which are known to be forward-backward peaked in the initial reaction NN$\rightarrow$ ΛNK due to the leading effect of baryonic diquark. It should be pointed out that this feature is less pronounced at higher energy because of a production of additional pions which wash out the mentioned angular asymmetry. This peculiarity being used in our experiments as a probe of the excited matter appeared to be fairly efficient. As can be seen from Fig.1 the "centrally" produced $\Lambda(K^0_S)$ particles are emitted near isotropically in contrast to the forward (backward) peaked emission from noncentral CC-collisions which reproduce the particular feature of initial NN-interactions.

Very similar regularities have been observed in angular distributions of $\Lambda(K^0_S)$ particle energies also in the CM-system ($dE^*_{\Lambda,K}/d\cos\theta^*$).

These effects, obtained first from our early Λ data and confirmed later by our K^0_S ones, suggest a full stopping with formation of a single thermalized source (fireball) in midrapidities of very central AA-collisions.

The study of Λ-hyperon polarization appears to be another profitable tool for examination of excited hadron matter. The polarization $\wp_\Lambda$ which is likely also due to the leading diquark effect,has been found to be rather large in pA-interactions for a high P_T-region. This parameter $\wp_\Lambda$ is expected to vanish for Λ's from central AA-collisions with a formation of a thermalized fireball.

We have seen some increase of $|\wp_\Lambda|$ when increasing P_T of Λ's from noncentral AA-collisions. As for centrally produced Λ's there is no polarization observed, within rather large errors though: $\Delta(\alpha\wp_\Lambda) \simeq 0.2$. Statistically richer

[1]This is not likely the case in baryon-free regime (6) predicted to be realized at much higher energies

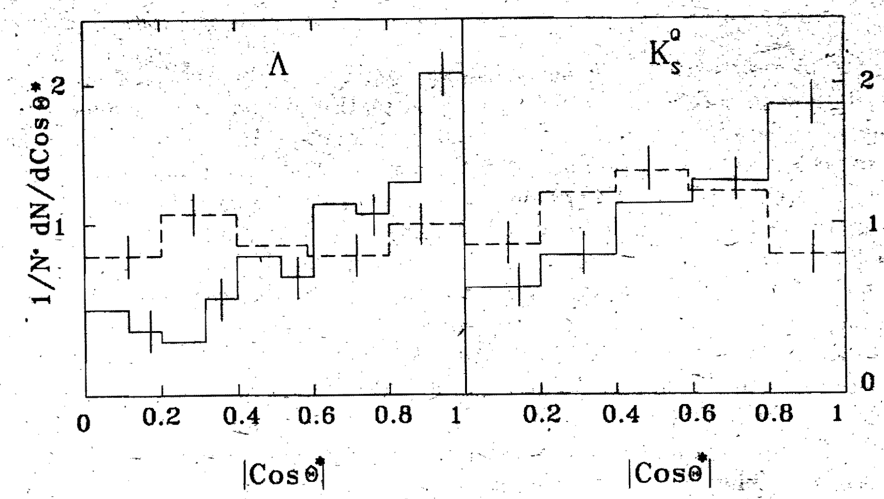

Figure 1: Folded (in Cos θ^*) angular distributions of Λ hyperons and K_S^0-mesons produced: in noncentral CC-collisions — solid lines, and in central ones — dashed lines.

data are needed for more significant results.[2] Anyhow the obtained data support the above suggestion derived from the analysis of angular distributions.

The dependence of hadron matter excitation upon a collision centrality has been studied by estimating parameters $<P_T>_{\Lambda,K}$ and temperatures T_B extracted from Boltzmann-like spectra (or an inverse slope of invariant cross sections spectra T_0, treated often wrongfully as temperature).

Our early analysis **has** revealed a considerable rise of T_B with degree of centrality: from $T_\Lambda = (75 \pm 8)$MeV up to $T_\Lambda = (158 \pm 11)$MeV which corresponds to $T_0 \simeq 210$MeV. The same increase from $T_K = (73 \pm 11)$MeV up to $T_K = (162 \pm 8)$MeV has been observed when K_S^0 mesons have been used as "thermometer"(13).

It is very essential that the mentioned T values were obtained in 4πgeometry (over all rapidity region) and derived from Boltzmann-like spectra of Λ and K_S^0 particles with their isotropic emission from midrapidities in central AA-collisions. Therefore these values exhibit adequately a high excitation degree of a single source (fireball) created in midrapidities.

It should be also emphasized that strangeness "thermometers" work very well at our energies due to an absence of strange resonances which could distort T measurements at higher energies in the same manner as Δ's do at our energy when T values are extracted from pion spectra.

[2]Data from collisions of asymmetric nuclei are desirable in order to eliminate a cancellation effect of polarization being opposite in projectile and target fragmentation regions.

Coming back to our T data, one could conclude that they demonstrate a collective effect of the heating of hadronic matter (created fireball) up to temperatures being near critical ones predicted for a phase transition into QGP.

Such a fireball appeared to be not only very hot but also rather dense. We have observed in central AA-collisions a considerable portion of Λ's with anomalously large P_T, emitted (rescattered) from midrapidities: above 12% compared with $\sim$ 1% in noncentral ones (see Fig.2). Taking into account this effect some model dependent estimation can be obtained which gives for the baryonic density $\rho = (4 \pm 1)\rho_o$.

One of the most important **observations** made in our early experiment (9),was an enhancement of a $< \Lambda >/< \pi^- >$ ratio (by factor about 10 for $P_T(\Lambda)$>1 GeV/c) when going from peripherical AA-collisions to central ones. Such a P_T cutoff used to eliminate the background of Λ's from NN-interactions, has been supported by theoretical considerations which have argued in favour of the study of strange particles with anomalously high $P_T(E_T)$ in order to search for QGP (15).

A similar enhancement was observed later (17) at AGS (14.6 A GeV/c) for $< K^+ >/< \pi^+ >$ ratio (by factor of 2-3 at somewhat other P_T cutoffs).

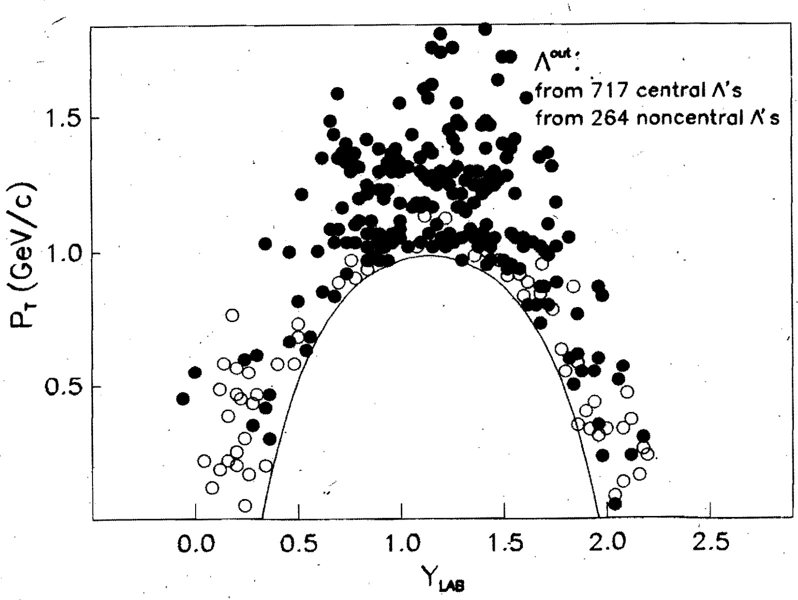

Figure 2: P_T-Y_L plot for commulative Λ hyperons produced: in non central HeLi CC-collisions selected from 264 Λ's (open circles) and in central CNe, ONe, CCu, CZr, MgMg collisions from 717 Λ's (black circles) at momenta 4.2 - 4.5 A GeV/c outside kinematical limits for NN interactions, outlined by solid lines

Such a strangeness enhancement was seen also at SPS CERN (200 A GeV) for Λ, $\bar{\Lambda}$, K^0_S and $K^\pm$ particles (18). [3]

The most significant effects found in Dubna experiments are summarized in Fig.3 which illustrates dependences of main characteristics of produced Λ-hyperons upon the degree of nuclear collision centrality (upon the number of projectile nucleons-participants <Q>).

To examine a further dependence of hadron matter excitation upon the total released energy, a study has been performed with an analysis of P_T spectrum of Λ's from very central MgMg collisions (15) which involve a twofold number of nucleons (with twice as great released energy) than central CC collisions. The value of T_B=137±9 MeV has been found from the mentioned analysis which does not differ within errors from T_B=158±11 MeV obtained for central CC collisions.

This gives an indication that the temperature stops to raise and seems to go to a plateau.

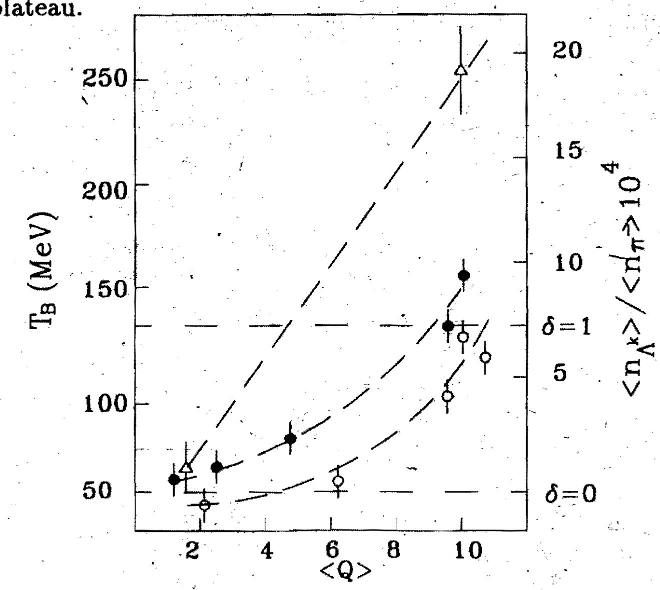

Figure 3: Dependences upon collision centrality (i.e., upon <Q> – average number of projectile nucleons-participants) of the following parameters: – the degree of flattening δ which is δ=0 for the peaked distribution from pp→ ΛK^+p and δ=1 for the isotropic distribution (open circles); – the Boltzman temperature T_B (black circles); – the relative yield $<\Lambda>/<\pi^->$ of Λ hyperons with P_T >1GeV/c (triangles).

[3]Our comparison of central AA collisions with peripherical ones seems to be more adequate than with pp and pA ones (used in (17,18)), in respect to an account for rescatterings, Fermi motion, etc.

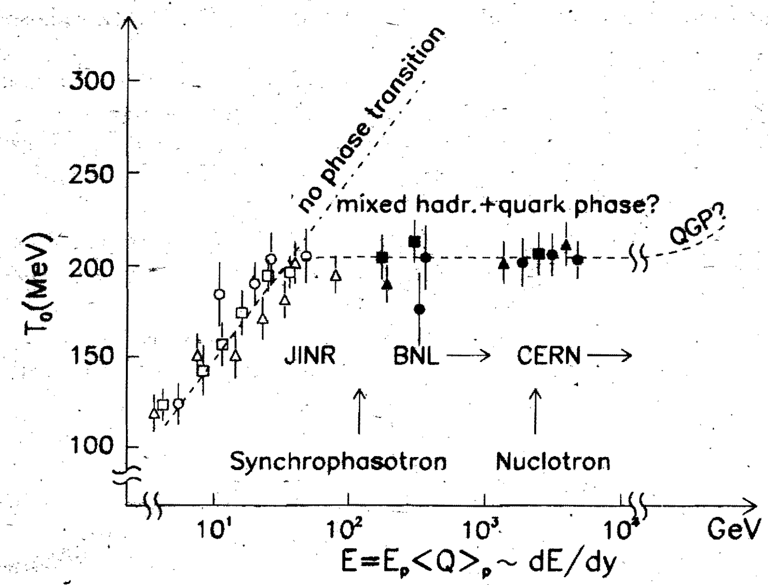

Figure 4: Inverse slope parameters T_0 versus $E=E_P <Q>$: open circles, open triangles and open sqares— K^0_S, Λ and proton JINR data; black circles, black triangles and black squares — neutral (charged) kaons, Λ and proton data of BNL (17) and CERN (18). To make an adequate comparision, the T_0 parameters (not the Boltzmann temperatures T_B) are shown on this figure, because T_B values are not given in CERN papers.

The recent data of the experiments at AGS BNL (17) and SPS CERN (18) have supported the evidence for such a plateau extending to much higher energies as could be seen from Fig.4.

This chain of the revealed effects, mentioned above is predicted as signals of a stopping, thermalization and heating of hadronic matter with a formation of a dense strangeness abundant fireball(mixed phase) via first order transition. Possibilities of such a transition under conditions (stopping, density, temperature, energy) similar to our ones have been considered in many theoretical papers. Nevertheless, even being confirmed by data of other groups, these results need more detailed comparative analyses and looking for possible alternative interpretations (besides QGP) to make final conclusions.

Anyway our data and other similar ones could be treated as a strong evidence for a creation of a hot and dense fireball (possibly mixed phase) in violent AA-collisions. This provides favourable conditions to search for Metastable Exotic Multihypernuclear Objects(MEMO's) (19) and Strange Quark Matter (SQM) states which are predicted to be considerably enhanced in such a fireball due to expected strangeness enrichment (20). Such an investigation being of great importance itself might give a proof of the QGP (mixed phase) formation (21).

At the first stage of this investigation we are looking for H-dihyperon (the ground SQM state) and few baryon MEMO's by re-analyzing anomalous events which have been detected in an open (4π) geometry from central AA-collisions in streamer chambers and recorded in DST but failed to be fitted as decays of "usual" strange particles. The requirement of a coexistence with 3 double hypernuclei, observed by now, provides the most probable properties of H-particle (22): M_H=2.220–2.231 GeV/c^2 and $\tau \sim 0.1 - 10$ ns with the main decay mode H$\rightarrow \Sigma^-$ p (23) followed by $\Sigma^- \rightarrow$ n π^-.

Some computer programs have been elaborated for analyses of data:

- the program of the kinematical reconstruction of H-decays to determine masses and to identify H-particles by fitting;

- the code for the simulations of H production from a hot midrapidity fireball with a subsequent H decay in fiducial volumes of chambers to obtain detection efficiencies and H yields (their upper limits), which depend on the parameters T_B, τ, A_P/A_T and E_P.

We have carefully re-analyzed (24) data, obtained by the use of our streamer spectrometer, with $2.1 \cdot 10^4$ extremely central MgMg- collisions detected ($\sigma_{centr}/\sigma_{tot}=4\cdot 10^{-4}$). Amongst ~1200 identified Λ and $K^0{}_s$ decays and ~100 conversions $\gamma \rightarrow e^+e^-$, a small sample of "anomalous" V^0 events (~20) was revealed. After an additional analysis the latter appeared to be e^+e^- pairs with one exception.
This V^0 event is characterized by rather large open angle and enhanced track density of the negatively charged secondary which **cannot** be an electron or pion. Being fitted as $H \rightarrow \Sigma^-$p this event exhibits M_H= 2228 $\pm$ 2 MeV/c^2, which falls into the narrow gap of expected H mass mentioned above.
Kinematical parameters of the considered event are also in good agreement with those predicted by thermodynamical models (see Fig.5).

It stands to reason that a single observed candidate **cannot** be treated as an evidence for the existence of the H dihyperon. However this provides possibilities to estimate an upper limit of production cross sections of a metastable (rather short-lived) H particle which escapes usually a detection in mass spectrometric experiments. Such an estimation gives: $\sigma \leq 0.12$ μb if τ=1ns and $\sigma \leq 0.36$ μb if τ=10ns (under our conditions mentioned above).

Our further plans in this research field are connected with a development of the new approach which has been proposed (25,26) and successfully realized at JINR (27). This will make possible to increase data taking rates (sensitivities) by a factor of 10^{3}–10^{4}, using an elaborated detector system (28) with a fast coordinate spectrometer in heavy nucleus beams of our new superconducting facility–Nuclotron (5–6 A GeV).

Summing up it should be concluded that strangeness demonstrates to be a very efficient probe of an excited matter in our energy region, with fairly prominent signals which becomes more ambiguous at higher energies.

On the other hand I would like to oppose the wide-spread statement "the higher–the better" when considering projectile energies wanted for QGP formation, and adduce weighty arguments in favour of the baryon-rich regime at several GeV per nucleon:
—many models predict QGP creation at as low energies as 2–5 A GeV for some EoS;
—the alternative fundamental phenomenon (besides the deconfinement) is expected to cause QGP formation– the chiral symmetry restoration with its predicted high density/low temperature effects;
—such processes could more adequately reproduce (simulate) astrophysical phenomena (Big Bang, neutron star evolution, supernouva explosion);
—the strangeness (flavour) enhancement as QGP signature should be more pronounced within a high density enviroment due to the Pauli principle;
—the background contributions to studied QGP signals (e.g. from hadronic gas) are much smaller due to lower energies of secondaries.

Two last points make very favourable the effect/background ratio especially for sub-near threshold effects at the Nuclotron energies as the processes of the production of $\bar{\Lambda}$, Ξ, Ω, ϕ-meson, H-dihyperon which are planned to be studied as possible QGP signals.

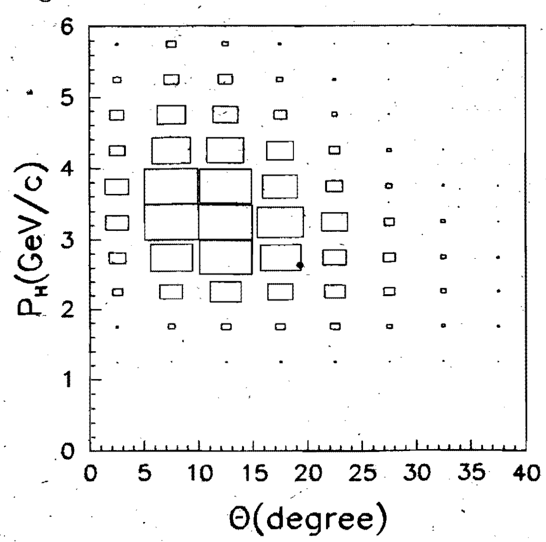

Figure 5: The expected angular and momentum distributions of H dihyperons produced within a fireball (T_B=150 MeV) in central MgMg-collisions (the black circle–the detected event).

I believe most of physicists to be convinced now that more concerted approaches are necessary to attack efficiently as complicated problems as the QGP and strange matter, using not only distinct signatures but also different phase trajectories to reach QGP (mixed phase) with a following adequate comparision of data obtained at various energies.

I am very grateful to all my colleagues who participated in the mentioned Dubna experiments giving data analyzed in this work.

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REFERENCES

1. J.Rafelski, Mueller B., *Phys.Rev.Lett.*,**48** , 1066 (1982).
2. T.Biro, J.Zymanyi, *Phys.Lett.***B113**, 6 (1982).
3. H.Stoecker,*Nucl.Phys.***A418**, 587 (1984).
4. M.Gyulassy, LBL-16895, Berkeley (1984).
5. N.Glendening, *Nucl.Phys.***A512**, 737, (1990).
6. T.Matsui et al., *Phys.Rev.***D34**, 2047 (1986).
7. M.Anikina et al., *Phys.Rev.Lett.***50**, 1971 (1982); *Z.Phys.***C25**,1 (1986).
8. E.Okonov, JINR D2-82-568, Dubna (1982);JINR P-1-86-312, Dubna (1986).
9. M.Gazdzicki, K.Iovchev, E.Kladnitskaya, E.Okonov, E.Skrzypczak, JINR E1-85-989, Dubna (1985); Z.Phys.**C33**, 895 (1986).
10. E.Okonov, *Modern Developments in Nuclear Physics*, World Scientific Pub.Co., Singapore, 1988, pp.166-176.
11. M.Anikina et al.,JINR E1-85-578, Dubna (1985).
12. D.Armutlijski et al.,*Sov.Nucl.Phys.***43**, 366 (1986).
13. V.Boldea et al.,*Sov.Nucl.Phys.***47**, 451 (1988).
14. K.Iovchev, E.Kladnitskaya and E.Okonov, JINR Rap.Com.**7**, 27, Dubna (1990).
15 M.Danos and J.Rafelski,*Phys.Lett.***B192**, 492 (1987).
16. S.Avramenko et al.,JINR P1-91-235, Dubna (1991).
17 T.Abbot et al.,*Phys.Rev.Lett.***64**, 847 (1990); ibid **66**, 1567 (1991).
18 .J.Bartke et al.,*Z.Phys.* **C48**, 191 (1990); P.Seyboth, *Nucl.Phys.***A544**, 293 (1993).
19 .J.Schaffner,C.Greiner and H.Stoecker,*Phys.Rev.***C46**,322(1992).
20 .C.Greiner et al.,*Quark Matter-93*, North-Holland Pub.,1994,pp 157-166.
21.C.Greiner,D.Rischke,H.Stoecker and P.Koch,*Phys.Rev.***D38**,2797(1989).
22. R.Dalitz et al.,*Proc.Royal Soc.Lon.***A426**,1(1989); S.Aoki et al.,DFNU-91-07(1991).
23 .J.Donoghue, E.Golowich and B.Holstein, *Phys.Rev.***D34**,3434(1987).
24. E.Okonov, V.Pechenov,I.Chernov, JINR B2-1-95-4, Dubna (1994).
25. M.Podgoretski, JINR-8309,81(1974).
26. E.Okonov, JINR-8309,104(1974); see also JINR B1-7113,Dubna(1973), JINR P1-87-191,Dubna(1987), JINR E1-90-591,Dubna(1991).
27. S.Avramenko et al.,JINR D1-88-691,Dubna(1988);*Nuov.Cim.***A102**,95 (1989).
28. D.Mikhalev,E.Okonov,A.Parfenov, JINR B2-1-95-2, Dubna (1995).

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Окунов Э.О. E1-95-89

Рождение странности в ядерных пучках в ОИЯИ

Проанализированы особенности рождения странных частиц, наблюдавшиеся в экспериментах с тяжелыми ионами при импульсе ~4 А ГэВ/с. Обнаруженные коллективные эффекты указывают на рандомизацию (термализацию) вещества, его значительный разогрев с образованием обогащенного странностью файербола (смешанной фазы?) в центральных столкновениях ядер. Была сделана оценка верхнего предела сечения образования Н-дигиперона в этих условиях. Коротко рассмотрены перспективы и преимущества использования странности в качестве эффективного пробника для изучения вещества с большой барионной плотностью на нуклотроне ЛВЭ ОИЯИ (~6 А ГэВ/с).

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Okonov E.O. E1-95-89

Strangeness Production in Nuclear Beams at JINR

Peculiar features of strange particle production observed in heavy ion experiments at ~4 A GeV/c are analyzed. The found collective effects suggest randomization (thermalization), considerable heating and formation of a dense strangeness abundant fireball (mixed phase?) in central nuclear collisions. Under these conditions an upper limit of production cross sections of metastable (short-lived) H dihyperon is estimated from these experiments. Some prospects and advantages of using strangeness as an efficient probe of a baryon-rich matter at the Nuclotron of LHE JINR (~6 A GeV/c) are briefly outlined.

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

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