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KATTA ADRON KOLLAYDERIDA XE+XE VA PB+PB TO'QNASHUVLARIDA ZARYADLANGAN ZARRALARNING KO'NDALANG IMPULS TAQSIMOTLARINI IKKI KOMPONENTLI TSALLIS–HAGEDORN MODELI ORQALI TAVSIFLASH

Xudoyberdiyeva Shoxida Aliyevna
S. Azimov nomidagi Fizika-texnika instituti
Olimov Xusniddin Kosimovich
S. Azimov nomidagi Fizika-texnika institute, f.-m.f.d., prof.
Musayev Qobil Abdulvafayevich
S. Azimov nomidagi Fizika-texnika instituti, PhD
e-mail: xudoyberdiyevashohida676@gmail.com

Annotatsiya. *Mazkur ishda ikki komponentli model taklif etilgan bo'lib, ko'ndalang (radial) oqim kiritilgan termodinamik mos Tsallis funksiyasi hamda yuqori ko'ndalang impuls () qiymatlarida Hagedorn funksiyasining asimptotik ko'rinishini tavsiflovchi darajali funksiyasining yig'indisidan iborat ikki komponentli model (THMTF - Tsallis-Hagedorn model with transverse flow) qo'llanildi. Ko'ndalang (radial) oqim kiritilgan Tsallis–Hagedorn modeli (THMTF) deb nomlanuvchi ushbu ikki komponentli model funksiyasi ALICE kollaboratsiyasi tomonidan o'lchangan turli markaziyliklardagi =5.44 TeV energiyali Xe+Xe va = 2.76 va 5.02 TeV energiyali Pb+Pb to'qnashuvlarida hosil bo'lgan birlamchi zaryadlangan zarrachalarning markaziy jadallik sohasidagi spektrlarini o'rganilayotgan diapazonida yuqori aniqlikda tavsiflash imkonini berdi.*

Kalit so'zlar: *Katta adron kollayderi (KAK), zarralarning ko'ndalang impuls () taqsimotlari, ko'ndalang (radial) oqim kiritilgan Tsallis taqsimot funksiyasi, Hagedorn funksiyasi; ikki komponentli model funksiyasi; daraja ko'rsatkichi n; noekstensivlik parametri q; o'rtacha ko'ndalang tezlig, ; kinetik muzlash temperaturasi, T_0.*

АНАЛИЗ РАСПРЕДЕЛЕНИЙ ПОПЕРЕЧНОГО ИМПУЛЬСА ЗАРЯЖЕННЫХ ЧАСТИЦ В XE+XE И PB+PB СТОЛКНОВЕНИЯХ НА БОЛЬШОМ АДРОННОМ КОЛЛАЙДЕРЕ НА ОСНОВЕ ДВУХКОМПОНЕНТНОЙ МОДЕЛИ ЦАЛЛИСА–ХАГЕДОРНА

Аннотация. *В данной работе предложена двухкомпонентная модель (THMTF - Tsallis-Hagedorn model with transverse flow), представляющая собой сумму термодинамически согласованной функции Цаллиса с включённым поперечным (радиальным) потоком и функции обратного степенного закона (асимптотической формы функции Хагедорна при высоких значениях поперечного импульса ()). Данная двухкомпонентная модельная функция, называемая моделью Цаллиса–Хагедорна с поперечным потоком (THMTF), позволила с высокой точностью описать экспериментальные -спектры первичных заряженных частиц в центральной области быстрот, измеренных коллаборацией ALICE при различных центральностях Xe+Xe столкновений при =5.44 TeV и Pb+Pb соударений при = 2.76 и 5.02 TeV во всём измеренном диапазоне .*

Ключевые слова: *Большой адронный коллайдер (БАК), распределения поперечного импульса () частиц, поперечный поток в распределении Цаллиса; функция Хагедорна; двухкомпонентная модельная функция; показатель степени n; параметр неэкстенсивности, q; скорость поперечного потока, ; кинетическая температура замораживания, T_0.*

ANALYSIS OF TRANSVERSE MOMENTUM DISTRIBUTIONS OF CHARGED PARTICLES IN XE+XE AND PB+PB COLLISIONS AT THE LARGE HADRON COLLIDER WITHIN A TWO-COMPONENT TSALLIS–HAGEDORN FRAMEWORK

Abstract. *A thermodynamically consistent two-component approach, formed by combining the Tsallis distribution with incorporated transverse flow and an inverse power-law term (representing the asymptotic form of the Hagedorn function at very high transverse momentum ()), has been introduced to accurately reproduce the broad spectra of primary charged particles measured at midrapidity in high-energy heavy-ion collisions at the LHC across different collision centralities. This model, referred to as the Tsallis–Hagedorn model with transverse flow (THMTF), successfully describes the experimental midrapidity transverse momentum*

distributions of primary charged particles over the entire measured interval obtained by the ALICE Collaboration in various centrality classes of Xe+Xe collisions at =5.44 TeV and Pb+Pb collisions at = 2.76 and 5.02 TeV.

Keywords: *Large hadron collider (LHC), transverse momentum distributions () of particles, Tsallis distribution with transverse flow; Hagedorn function; two-component model function; power index, n; non-extensivity parameter, q; transverse flow velocity,; kinetic freeze-out temperature, T_0.*

Kirish

Yuqori energiyali to‘qnashuvlarda hosil bo‘lgan adronlarning ko‘ndalang impuls spektrlari kichik ko‘ndalang impuls (p_{T}) diapazonda eksponensial xususiyatlarini, yuqori p_{T}diapazonda esa g‘alayonlashgan kvant xromodinamikasi (pQCD) nazariyasida darajali taqsimotni namoyon etadi.

Eksponensial va darajali taqsimot xususiyatlarini o‘zida mujassamlashtirgan eng keng qo‘llaniladigan modellardan biri Tsallis taqsimot funksiyasi hamda uning turli ko‘rinishlarini o‘z ichiga oladi [1–23]. Shu bilan birga, Kvant xromodinamikasi (QCD) asosida ishlab chiqilgan darajali Hagedorn taqsimot funksiyasi yuqori energiyali nuklon-nuklon to‘qnashuvlarida hosil bo‘ladigan zarrachalarning p_{T} spektrlarining yuqori p_{T} diapazonini yuqori aniqlik bilan tavsiflash imkonini beradi [24,25]. Turli darajali (power-law) yoki Tsallis taqsimotiga asoslangan modellar faqat jami to‘qnashuvlarda va zarralar soni kam bo‘lgan proton-proton to‘qnashuvlarida, shuningdek zarralar soni kam bo‘lgan periferik proton-yadro va yadro-yadro to‘qnashuvlarida p_{T}spektrlarini yuqori aniqlik bilan tavsiflash imkonini beradi.

Mazkur tadqiqotda taklif qilingan ikki komponentli model funksiyasi ko‘ndalang (radial) oqim kiritilgan Tsallis–Hagedorn modeli (THMTF - Tsallis-Hagedorn model with transverse flow) yordamida ALICE kollaboratsiyasi tomonidan o‘lchangan $\sqrt{s_{nn}}$ =5.44 TeV energiyali turli markaziylikdagi Xe+Xe to‘qnashuvlarida [26] hamda $\sqrt{s_{nn}}$ = 2.76 va 5.02 TeV energiyali turli markaziylikdagi Pb+Pb to‘qnashuvlarida [27] markaziy jadallik sohasida birlamchi zaryadlangan zarrachalarning p_{T} spektrlari keng ko‘ndalang impuls sohasida eng katta o’lchangan p_{T} qiymatlarigacha batafsil tahlil qilinadi.

Eksperimental ma’lumotlar va ikki komponentli Tsallis–Hagedorn modeli

Olib borilgan tadqiqotda ALICE kollaboratsiyasi tomonidan o‘lchangan turli markaziyliklardagi $\sqrt{s_{nn}}$ = 2.76, 5.02 TeV energiyali Pb+Pb va $\sqrt{s_{nn}}$ =5.44 TeV energiyali Xe+Xe to‘qnashuvlarida hosil bo‘lgan birlamchi zaryadlangan zarrachalarning ko‘ndalang impuls spektrlari batafsil tahlil qilindi. Ushbu spektrlar markaziy jadallik sohasida ($|\eta| < 0.8$) joylashgan bo‘lib, to‘qqizta markaziylik intervali uchun o‘lchangan va p_{T} diapazoni Pb+Pb to‘qnashuvlari uchun $0.15 < p_{\mathrm{T}} < 15$ GeV/c va Xe+Xe to‘qnashuvlari uchun $0.15 < p_{\mathrm{T}} < 50$ GeV/c oralig‘ini qamrab oladi. Tahlil qilingan turli markaziylikdagi $\sqrt{s_{nn}}$ =5.44 TeV energiyali Xe+Xe to‘qnashuvlari hamda $\sqrt{s_{nn}}$ = 2.76 va 5.02 TeV energiyali Pb+Pb to‘qnashuvlarining markaziy jadallik sohalari uchun ishtirokchi nuklonlar sonining o‘rtacha qiymatlari $\langle N_{part}\rangle$ va zaryadlangan zarrachalar sonining psevdojadallik bo‘yicha o‘rtacha zichligi $\langle dN_{ch}/d\eta\rangle$ [26–28] 1-jadvalda ko’rsatilgan.

1-jadval. Tahlil qilingan turli markaziylikdagi $\sqrt{s_{nn}}$ =5.44 TeV energiyali Xe+Xe to‘qnashuvlari hamda $\sqrt{s_{nn}}$ = 2.76 va 5.02 TeV energiyali Pb+Pb to‘qnashuvlarining markaziy jadallik sohalari uchun ishtirokchi nuklonlar sonining o‘rtacha qiymatlari $\langle N_{part}\rangle$ va zaryadlangan zarrachalar sonining psevdojadallik bo‘yicha o‘rtacha zichligi $\langle dN_{ch}/d\eta\rangle$ [26–28].

To‘qnashuv markaziyligi	Xe+Xe to‘qnashuvlari uchun $\sqrt{s_{nn}}$ =5.44 TeV		Pb+Pb to‘qnashuvlari uchun $\sqrt{s_{nn}}$=2.76 TeV		Pb + Pb to‘qnashuvlari uchun $\sqrt{s_{nn}}$ = 5.02 TeV	
	$\langle N_{part}\rangle$	$\langle dN_{ch}/d\eta\rangle$	$\langle N_{part}\rangle$	$\langle dN_{ch}/d\eta\rangle$	$\langle N_{part}\rangle$	$\langle dN_{ch}/d\eta\rangle$
0-5%	236±2	1167±26	382±14	1601±60	383 ± 11	1943 ± 56
5-10%	207±2	939±24	328±13	1294±49	331 ± 10	1587 ± 47
10-20%	165±2	706±17	260±10	966±37	262 ± 7	1180 ± 31
20-30%	118±3	478±11	187±7	649±23	188 ± 5	786 ± 20
30-40%	82±3	315±8	130±5	426±15	131 ± 4	512 ± 15
40-50%	55±3	198±5	87±3	261±9	87 ± 4	318 ± 12
50-60%	34±2	118±3	54±2	149±6	54 ± 3	183 ± 8
60-70%	20±2	65±2	31±2	76±4	31 ± 2	96 ± 6
70-80%	11±1	32±1	16±2	35±2	16 ± 2	45 ± 3

Tsallis funksiyasining [5–7, 10] quyidagi varianti kimyoviy potensial nol bo’lgan ($\mu\approx 0$ TeV energiyali to‘qnashuvlar uchun xos holat) va markaziy jadallik (<y>=0) sohasida hisoblangan bo‘lib, bosim, temperatura, zarracha soni, energiya va entropiya zichliklari uchun asosiy termodinamik bog‘lanishlarni to‘liq qanoatlantiradi:

$$\frac{d^2N}{2\pi N_{ev} p_{\mathrm{T}} dp_{\mathrm{T}} dy} = C_q \cdot m_{\mathrm{T}} \cdot \left(1 + (q-1)\cdot\frac{m_{\mathrm{T}}}{T}\right)^{-q/(q-1)}, \qquad (1)$$

Bu yerda C_q — normallashtirish parametri, N_{ev} — noelastik to‘qnashuvlar soni, $m_T = \sqrt{p_T^2 + m_0^2}$ ko‘ndalang massa, m_0 — adronning tinch massasi, T — tizimning effektiv temperaturasi, q esa tizimning noekstensivlik parametri hisoblanadi. Tsallis taqsimotining fundamental parametri q tizim temperaturasining fluktuatsiyalarini $q - 1 = \frac{Var(T)}{<T>^2}$ munosabat orqali ifodalaydi.

(1)-tenglamada effektiv temperatura T tizimdagi xaotik termal harakat hamda kollektiv ko‘ndalang radial oqimni o‘z ichiga oladi. Ushbu omillarni ajratib ko‘rsatish maqsadida Tsallis taqsimot funksiyasiga ko‘ndalang oqim tezligi kiritilishi lozim. Buning uchun $m_T \to \langle\gamma_T\rangle\,(m_T - p_T\langle\beta_T\rangle)$, almashtirish amalga oshiriladi, bu yondashuv ilk bor [29] da taklif etilgan bo‘lib, natijada termodinamik jihatdan mos va ko‘ndalang oqimni o‘z ichiga olgan quyidagi Tsallis funksiyasi (2-tenglama) hosil qilinadi:

$$\frac{d^2N}{2\pi N_{ev} p_T dp_T dy} = C_q \cdot \langle\gamma_T\rangle \cdot (m_T - p_T \cdot \langle\beta_T\rangle) \left(1 + \langle\gamma_T\rangle \cdot \frac{(q-1)\cdot(m_T - p_T\cdot\langle\beta_T\rangle)}{T_0}\right)^{-q/(q-1)}. \quad (2)$$

Bu yerda $m_T \to \langle\gamma_T\rangle(m_T - p_T\langle\beta_T\rangle)$ almashtirish [29] ga ko‘ra Lorens almashtirishining ifodasi bo‘lib, u zarrachalar tizimini ko‘ndalang tekislikdagi o‘rtacha oqim tezligi $\langle\beta_T\rangle$ bilan birga harakatlanuvchi mos sanoq sistemasiga o‘tkazishni ifodalaydi, bunda tizimda kollektiv ko‘ndalang oqim mavjudligi faraz qilinadi.

Yuqori energiyali nuklon–nuklon to‘qnashuvlarida adronlarning ko‘ndalang impuls spektrlari yuqori p_T diapazoni QCD ga asoslangan teskari darajali Hagedorn funksiyasi yordamida yuqori aniqlik bilan tavsiflanadi [22,24,25]:

$$\frac{d^2N}{2\pi N_{ev} p_T dp_T dy} = C_n \cdot \left(1 + \frac{p_T}{P_0}\right)^{-n}. \quad (3)$$

Ushbu ifodada C_n— fitlash doimiysi bo‘lib, kinetik muzlash bosqichidagi tizim hajmiga proporsionaldir, n va P_0 esa adron hosil bo‘lishning asosiy mexanizmlarini ifodalovchi erkin parametrlar sifatida talqin qilinadi. P_0 parametri xarakterli impuls masshtabi sifatida qaralib, adron hosil bo‘lish jarayonida yumshoq (termal/eksponensial) mexanizmlaridan qattiq (perturbativ/darajali) mexanizmlarga o‘tish sodir bo‘ladigan muayyan impuls diapazonini belgilaydi.

Ko‘ndalang impulsning katta qiymatlarida Hagedorn funksiyasi o‘zining asimptotik limitida oddiy teskari darajali funksiyaga aylanadi va quyidagi ko‘rinishda ifodalanadi:

$$\frac{d^2N}{2\pi N_{ev} p_T dp_T dy} = C_n \cdot \left(\frac{p_T}{P_0}\right)^{-n}. \quad (4)$$

Yuqori energiyali og‘ir ion to‘qnashuvlarining turli markaziylik intervallarida o‘lchangan keng p_T diapazonidagi markaziy jadallik sohasidagi zaryadlangan zarrachalar spektrlarini yuqori aniqlik bilan tavsiflash maqsadida termodinamik jihatdan mos, ko‘ndalang (radial) oqim kiritilgan Tsallis funksiyasi (2-tenglama) hamda oddiy teskari darajali funksiyaning (4-tenglama) yig‘indisidan iborat quyidagi ikki komponentli model funksiyasi (5-tenglama) taklif etiladi:

$$\frac{d^2N}{2\pi N_{ev} p_T dp_T dy} =$$

$$= \theta(x_{thr} - p_T)\cdot C_q \cdot \langle\gamma_T\rangle \cdot (m_T - p_T \cdot \langle\beta_T\rangle) \cdot \left(1 + \langle\gamma_T\rangle \cdot \frac{(q-1)\cdot(m_T - p_T\cdot\langle\beta_T\rangle)}{T_0}\right)^{-q/(q-1)} + \theta(p_T - x_{thr})\cdot C_n \cdot \left(\frac{p_T}{P_0}\right)^{-n}, \quad (5)$$

bu yerda $\theta(x)$— Heaviside funksiyasi bo‘lib, $\theta(x) = 0$ agar $x < 0$, va $\theta(x) = 1$ agar $x > 0$ qiymatlarni qabul qiladi. (5)-tenglamada keltirilgan ushbu yangi ikki komponentli model funksiyasi mazkur tadqiqotda ko‘ndalang (radial) oqim kiritilgan Tsallis–Hagedorn modeli (THMTF) sifatida yuritiladi. x_{thr}parametri esa modelning birinchi va ikkinchi hadlariga mos keluvchi p_T diapazonlari orasidagi optimal chegaraviy qiymatni aniqlaydi.

(5)-tenglamada $x_{thr} = 5$ GeV/c qiymatining tanlanishi adronlarning $p_T$spektrlarini ikkita alohida diapazonda tavsiflash imkonini beradi: $p_T \leq 5$ GeV/c sohada ko‘ndalang (radial) oqim kiritilgan termodinamik jihatdan mos Tsallis funksiyasi (2-tenglama), $p_T > 5$ GeV/c sohada esa teskari darajali funksiya (4-tenglama) adronlarning $p_T$spektrlarini tavsiflaydi. O‘lchangan markaziy jadallik sohasidagi spektrlar uchun THMTF modeli (6)-tenglama ko‘rinishida yoziladi:

$$\frac{d^2N}{N_{ev} dp_T dy} =$$

$$= \theta(x_{thr} - p_T)\cdot 2\pi\cdot p_T \cdot C_q \cdot \langle\gamma_T\rangle \cdot (m_T - p_T \cdot \langle\beta_T\rangle) \cdot \left(1 + \langle\gamma_T\rangle \cdot \frac{(q-1)\cdot(m_T - p_T\cdot\langle\beta_T\rangle)}{T_0}\right)^{-q/(q-1)} + \theta(p_T - x_{thr})\cdot 2\pi\cdot p_T \cdot C_n \cdot \left(\frac{p_T}{P_0}\right)^{-n} \quad (6).$$

Mazkur tadqiqot doirasida yangi taklif etilgan ko‘ndalang oqim kiritilgan Tsallis–Hagedorn modeli funksiyasi (6-tenglama) yordamida ALICE kollaboratsiyasi tomonidan o‘lchangan markaziy jadallik sohasidagi birlamchi zaryadlangan zarrachalarning ko‘ndalang impuls sohasidagi p_T spektrlari eng yuqori p_T qiymatlarigacha tavsiflandi.

Tahlil va natijalar

$\sqrt{s_{nn}}$=5.44 TeV energiyali Xe+Xe va $\sqrt{s_{nn}}$ = 2.76 va 5.02 TeV energiyali Pb+Pb to‘qnashuvlarining turli markaziyliklarida birlamchi zaryadlangan zarrachalarning markaziy jadallik sohasidagi p_T spektrlarini $0.5 \leq p_T \leq 15$ GeV/c diapazonda ikki komponentli Tsallis–Hagedorn modeli (6-tenglama) yordamida minimal χ^2 fitlash natijasida olingan parametrlar qiymatlari 2-jadvalda taqdim qilingan. $\sqrt{s_{nn}}$=5.44 TeV energiyali Xe+Xe to‘qnashuvlarining turli

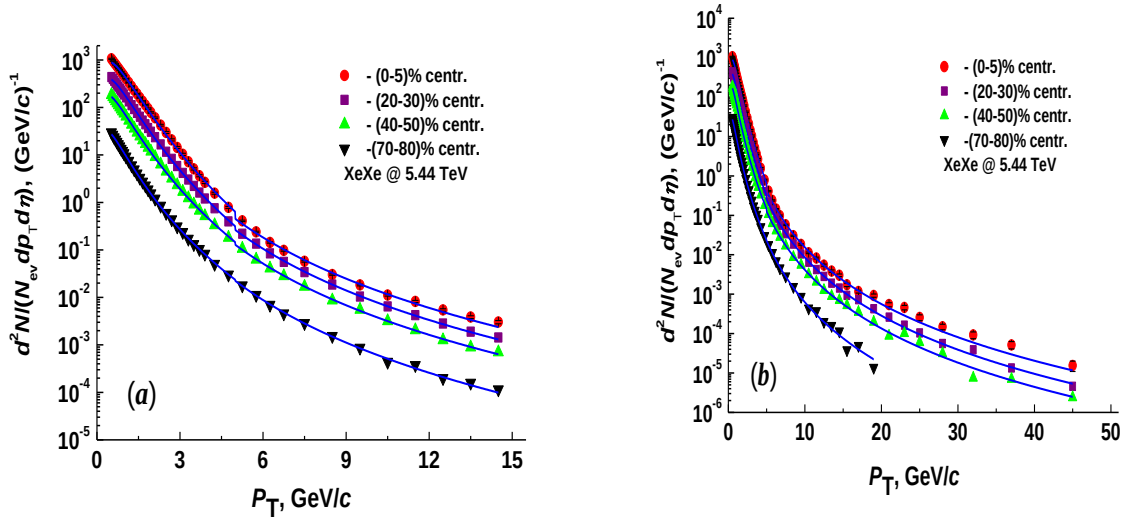
markaziyliklarida markaziy jadallik sohasidagi birlamchi zaryadlangan zarrachalarning eksperimental p_T spektrlarini $0.5 \le p_T \le 15$ GeV/c hamda $0.5 \le p_T \le 50$ GeV/c diapazonlarida ikki komponentli Tsallis–Hagedorn modeli (6-tenglama) yordamida minimal χ^2 fitlash orqali olingan fitlash egri chiziqlari 1-rasmda keltirilgan. 2-jadval shuni ko'rsatadiki, Xe+Xe hamda Pb+Pb to'qnashuvlarining markaziylik darajasining oshishi bilan daraja parametri n kamayadi, P_0 parametri esa ortadi. Buni to'qnashuvlar markaziyligi oshishi bilan birlamchi yuqori energiyali qattiq parton-parton to'qnashuvlari ehtimolligi va sonini ortishi hamda hosil bo'gan tegishli yuqori impulsli adronlar sonini va ularni p_T spektrlardagi ulushini ko'payishi bilan izohlasa bo'ladi. Bu esa o'z navbatida zarralarning p_T spektrlarini qattiqlashuviga olib keladi. Shuningdek, Xe+Xe hamda Pb+Pb to'qnashuvlarining markaziylik darajasining oshishi bilan ko'ndalang oqimning o'rtacha tezligi muntazam ravishda oshib boradi. Undan tashqari, 2-jadvaldan Xe+Xe hamda Pb+Pb to'qnashuvlarining markaziyligi oshishi bilan noekstensivlik q parametrini muntazam ravishda kamayib borishi kuzatildi. Bu esa to'qnashuvlar markaziyligi oshishi bilan hosil bo'lgan issiq va zich materiyaning termalizatsiya darajasining ko'payishini ko'rsatadi.

1-rasmning (a) va (b) qismlaridan ko'rinib turibdiki, (6)-tenglamadagi ko'ndalang oqim kiritilgan Tsallis–Hagedorn modeli funksiyasi $\sqrt{s_{nn}}$ =5.44 TeV energiyali Xe+Xe to'qnashuvlarining turli markaziylik intervallarida markaziy jadallik sohasidagi birlamchi zaryadlangan zarrachalarning eksperimental p_T spektrlarini har ikkala p_T = 0.5–15 GeV/c va p_T = 0.5–50 GeV/c fitlash oralig'ida yuqori aniqlik bilan tavsiflaydi.

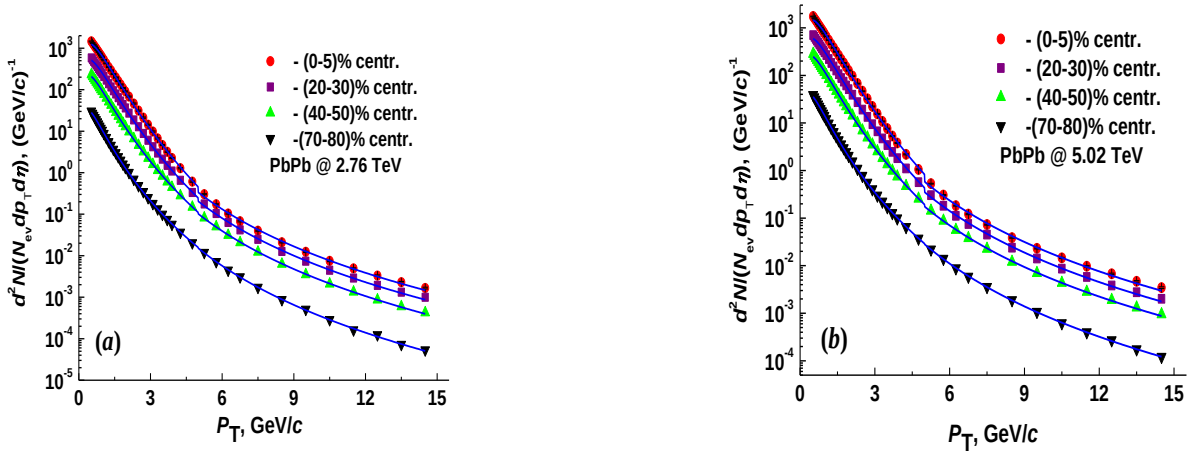
2-jadval. $\sqrt{s_{nn}}$ =5.44 TeV energiyali Xe+Xe va $\sqrt{s_{nn}}$ = 2.76 va 5.02 TeV energiyali Pb+Pb to'qnashuvlarining turli markaziyliklarida birlamchi zaryadlangan zarrachalarning markaziy jadallik sohasidagi $p_T$spektrlarini $0.5 \le p_T \le 15$ GeV/c diapazonda ikki komponentli Tsallis–Hagedorn modeli (6-tenglama) yordamida minimal χ^2 fitlash natijasida olingan parametrlar qiymatlari taqdim qilingan.

Xe+Xe to'qnashuvlari uchun $\sqrt{s_{nn}}$ =5.44 TeV						
To'qnashuv markaziyligi	**$\langle\beta_T\rangle$ (fitlash)**	***q***	***T*₀, MeV**	***n***	***P*₀ (GeV/*c*)**	***χ2/n.d.f.* (*n.d.f.*)**
(0-5)%	0.61	1.095±0.003	92±2	5.93±0.10	2.44±0.05	4.85 (38)
(5-10)%	0.60	1.106±0.003	87±2	5.93±0.10	2.40±0.04	2.21 (38)
(10-20)%	0.58	1.107±0.003	89±2	5.93±0.10	2.33±0.04	1.87 (38)
(20-30)%	0.55	1.106±0.002	93±2	5.98±0.06	2.25±0.04	1.63 (38)
(30-40)%	0.52	1.111±0.002	94±2	5.93±0.08	2.11±0.04	1.48 (38)
(40-50)%	0.48	1.117±0.002	93±1	5.99±0.06	1.99±0.03	0.81 (38)
(50-60)%	0.40	1.123±0.002	98±2	6.02±0.07	1.86±0.03	0.76 (38)
(60-70)%	0.33	1.125±0.001	104±1	6.06±0.07	1.74±0.03	0.70 (38)
(70-80)%	0.22	1.131±0.001	109±2	6.09±0.08	1.60±0.03	0.41 (38)
Pb+Pb to'qnashuvlari uchun $\sqrt{s_{nn}}$=2.76 TeV						
To'qnashuv markaziyligi	**$\langle\beta_T\rangle$ (fitlash)**	***q***	***T*₀, MeV**	***n***	***P*₀ (GeV/*c*)**	***χ2/n.d.f.* (*n.d.f.*)**
(0-5)%	0.60	1.082±0.002	94±2	6.09±0.09	2.37±0.04	5.72 (38)
(5-10)%	0.58	1.085±0.002	96±2	6.14±0.08	2.36±0.04	5.03 (38)
(10-20)%	0.58	1.088±0.002	94±2	6.14±0.07	2.30±0.04	4.55 (38)
(20-30)%	0.55	1.093±0.002	96±2	6.12±0.07	2.20±0.04	3.33 (38)
(30-40)%	0.52	1.098±0.002	96±2	6.18±0.08	2.11±0.04	2.44 (38)
(40-50)%	0.47	1.104±0.001	97±1	6.21±0.05	1.99±0.03	1.57 (38)
(50-60)%	0.40	1.111±0.001	100±1	6.23±0.05	1.84±0.03	1.32 (38)
(60-70)%	0.33	1.119±0.001	100±1	6.30±0.05	1.71±0.03	0.92 (38)
(70-80)%	0.24	1.125±0.001	104±1	6.35±0.06	1.57±0.03	0.92 (38)
Pb + Pb to'qnashuvlari uchun $\sqrt{s_{nn}}$ = 5.02 TeV						
To'qnashuv markaziyligi	**$\langle\beta_T\rangle$ (fitlash)**	***q***	***T*₀, MeV**	***n***	***P*₀ (GeV/*c*)**	***χ2/n.d.f.* (*n.d.f.*)**
(0-5)%	0.60	1.085±0.003	98±2	5.95±0.10	2.56±0.05	13.16 (38)
(5-10)%	0.59	1.086±0.002	100±2	5.96±0.09	2.52±0.05	11.41 (38)
(10-20)%	0.58	1.089±0.002	100±2	5.96±0.09	2.45±0.04	11.31 (38)
(20-30)%	0.57	1.094±0.002	98±2	5.97±0.10	2.35±0.04	8.77 (38)
(30-40)%	0.53	1.099±0.002	100±2	5.97±0.10	2.24±0.04	7.84 (38)
(40-50)%	0.49	1.106±0.002	101±2	5.97±0.10	2.09±0.04	5.80 (38)

(50-60)%	0.43	1.101±0.001	101±1	6.01±0.05	1.94±0.03	3.88 (38)
(60-70)%	0.33	1.121±0.001	106±1	6.03±0.05	1.78±0.03	2.92 (38)
(70-80)%	0.22	1.128±0.001	112±1	6.11±0.08	1.65±0.03	2.40 (38)



1-rasm. $\sqrt{s_{nn}}$=5.44 TeV energiyali Xe+Xe to‘qnashuvlarining turli markaziylik intervallari uchun markaziy jadallik sohasidagi birlamchi zaryadlangan zarrachalarning eksperimental p_T spektrlarini (belgilar) ikki komponentli Tsallis–Hagedorn modeli (6-tenglama) yordamida minimal χ^2 fitlash orqali olingan fitlash egri chiziqlari (uzluksiz ko‘k chiziqlar) keltirilgan. (a) qismida $0.5 \le p_T \le 15$ GeV/c diapazondagi natijalar, (b) qismida esa $0.5 \le p_T \le 50$ GeV/c diapazondagi natijalar keltirilgan. Vertikal xatolik chiziqlari statistik va sistematik xatoliklarning yig‘indisini ifodalaydi, ularning qiymatlari belgilar o‘lchamiga yaqin.



2-rasm. $\sqrt{s_{nn}}$ = 2.76 va 5.02 TeV energiyali Pb+Pb to‘qnashuvlarining turli markaziylik intervallari uchun markaziy jadallik sohasidagi birlamchi zaryadlangan zarrachalarning eksperimental p_T spektrlarini (belgilar) ikki komponentli Tsallis–Hagedorn modeli (6-tenglama) yordamida minimal χ^2 fitlash orqali olingan fitlash egri chiziqlari (uzluksiz ko‘k chiziqlar) keltirilgan. (a) qismida $\sqrt{s_{nn}}$ = 2.76 (b) qismida esa $\sqrt{s_{nn}}$= 5.02 TeV to’qnashuv energiyasi uchun natijalar keltirilgan. Vertikal xatolik chiziqlari statistik va sistematik xatoliklarning yig‘indisini ifodalaydi, ularning qiymatlari belgilar o‘lchamiga yaqin.

$\sqrt{s_{nn}}$ = 2.76 va 5.02 TeV energiyali Pb+Pb to‘qnashuvlarining turli markaziylik intervallarida markaziy jadallik sohasidagi birlamchi zaryadlangan zarrachalarning eksperimental p_T spektrlarini ikki komponentli Tsallis–Hagedorn modeli (6-tenglama) yordamida minimal χ^2 fitlash orqali olingan fitlash egri chiziqlari 2-rasmda keltirilgan. 2-rasmning (a) va (b) qismlaridan ko‘rinib turibdiki, ko’ndalang oqim kiritilgan Tsallis–Hagedorn modeli funksiyasi $\sqrt{s_{nn}}$=2.76 va 5.02 TeV energiyali Pb+Pb to‘qnashuvlarining turli markaziylik intervallarida markaziy jadallik sohasida hosil bo‘lgan birlamchi zaryadlangan zarrachalarning eksperimental p_T spektrlarini 0.5–15 GeV/c diapazonida yetarlicha yaxshi tavsiflaydi.

Xulosa

Mazkur tadqiqot doirasida katta adron kollayderida Xe+Xe va Pb+Pb to‘qnashuvlarida markaziy jadallik sohasida hosil bo’gan zaryadlangan zarralarning eksperimental ko’ndalang impuls taqsimotlari taklif etilgan yangi, ko’ndalang oqim kiritilgan Tsallis–Hagedorn model funktsiyasi yordamida juda yaxshi tavsiflandi. Tavsiflash natijasida olingan ushbu model parametrlarining Xe+Xe va Pb+Pb to‘qnashuvlari markaziyligiga ($\langle N_{part} \rangle$ va $\langle \frac{dN_{ch}}{d\eta} \rangle$ larga) hamda to’qnashuv energiyasiga ($\sqrt{s_{nn}}$) bog‘liqligi tizimli ravishda tahlil qilindi.

Xe+Xe hamda Pb+Pb to‘qnashuvlarining markaziylik darajasining oshishi bilan Tsallis–Hagedorn model funktsiyasining daraja parametri n kamayishi, P_0 parametrini esa ortishi kuzatildi. Bu esa to’qnashuvlar markaziyligi oshishi bilan birlamchi yuqori energiyali qattiq parton-parton to’qnashuvlari ehtimolligi va sonini ortishi hamda hosil bo’gan tegishli yuqori impulsli adronlar sonini va ularni p_T spektrlardagi ulushini ko’payishi bilan izohlanadi. Xe+Xe hamda Pb+Pb to‘qnashuvlarining markaziylik darajasining oshishi bilan ko’ndalang oqimning o’rtacha tezligi muntazam ravishda oshib borishi kuzatildi. Undan tashqari, Xe+Xe hamda Pb+Pb to’qnashuvlarining markaziyligi oshishi bilan noekstensivlik q parametrini muntazam ravishda kamayib borishi aniqlandi. Bu esa to’qnashuvlar markaziyligi oshishi bilan hosil bo’lgan issiq va zich materiyaning termalizatsiya darajasining ko’payishidan dalolat beradi.

Mazkur tadqiqotda Katta adron kollayderidagi yuqori energiyali Xe+Xe va Pb+Pb to‘qnashuvlari uchun aniqlangan daraja ko‘rsatkichi $n \approx 6$ ning o‘rtacha qiymatidan kelib chiqib, $n = 2 \cdot n_\alpha - 4$ munosabat asosida tahlil qilingan to‘qnashuvlarda sochilishda ishtirok etuvchi partonlarning o‘rtacha soni n_α=5 deb baholandi. KAK dagi ushbu to‘qnashuvlarda asosiy zaryadlangan adronlarning katta qismini zaryadlangan pionlar (~85%) va kaonlar (~10%) tashkil etishini inobatga olgan holda, n_α=5 qiymati yuqori p_T adronlar hosil bo’lishining ustun mexanizmi sifatida g + q → mezon + q hamda g + g → mezon + g turidagi glyuon fragmentatsiyasi (parchalanishi) jarayonlariga (reaktsiyalariga) mos keladi (bu yerda g – glyuon, q esa kvark). Ushbu natijalar oldingi tadqiqotlar bilan mos bo‘lib, yuqori energiyali KAK to‘qnashuvlarida, ayniqsa markaziy jadallik sohasida, yuqori ko’ndalang impulsli mezonlar hosil bo’lishida glyuon fragmentatsiyasi (parchalanishi) jarayonlari eng asosiy rol o‘ynashini hamda eng katta hissa qo’shishini ko’rsatadi.

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