Evidence for hadronic deconfinement in $\bar{p}$-$p$ collisions at 1.8 TeV

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Abstract

We have measured deconfined hadronic volumes, $4.4 < V < 13.0$ fm$^3$, produced by a one dimensional (1D) expansion. These volumes are directly proportional to the charged particle pseudorapidity densities $6.75 < dN_c/d\eta < 20.2$. The hadronization temperature is $T = 179.5 \pm 5$ (syst) MeV. Using Bjorken's 1D model, the hadronization energy density is $\epsilon_F = 1.10 \pm 0.26$ (stat) GeV/fm$^3$ corresponding to an excitation of $24.8 \pm 6.2$ (stat) quark-gluon degrees of freedom.

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The observation of high total multiplicity, high transverse energy, non jet, isotropic events \[1\] led Van Hove \[2\] and Bjorken \[3\] to conclude that high energy density events are produced in high energy $\bar{p}$-p collisions \[4\]. These events have a far greater cross section than jet production. In these events the transverse energy is proportional to the number of low transverse momentum particles. This basic correspondence can be explored over a wide range of the charged particle pseudorapidity density $dN_c/d\eta$ in $\bar{p}$-p collisions at center of mass energy $\sqrt{s} = 1.8$ TeV. The various measurements from the Fermilab quark-gluon plasma search experiment E-735 have already been published. In this letter, we present for the first time a coherent picture based on the relationship between the volume $V$, temperature $T$, energy density $\epsilon_F$, and pions per fm$^3$ $n_\pi$ emitted from $V$. Spectra of identified particles, $\pi$, K, $\varphi$, $p$, $\bar{p}$, $\Lambda^0$, $\bar{\Lambda}$, $\Xi^-$, $\bar{\Xi}^-$ are used to extract the $V$, $\epsilon_F$, and $n_F$ values and to determine the strange quark content and relative yields of the hadrons.

Previously the various individual measurements did not provide an overall understanding of these $\bar{p}$-p collisions. Prompted by the new analysis of the initial collision, we have developed a self-consistent picture of hadronic deconfinement. This letter discusses: (1) The role of parton-parton (gluon) scattering; (2) The volume at decoupling, resulting from the one dimensional longitudinal expansion; (3) The number of pions per fm$^3$ emitted by the source; (4) The hadronization temperature of the source; (5) The hadronization energy density of the source; (6) The number of quark-gluon degrees of freedom in the source; (7) The deconfined volumes and plasma lifetimes, estimates of initial energy densities and temperatures.

Experiment E-735 \[5\] was located at the CΦ interaction region of the Fermi National Accelerator Laboratory (FNAL). The $\bar{p}$-p interaction region was surrounded by a cylindrical drift chamber which in turn was covered by a single layer hodoscope including endcaps. This system measured the total charged particle multiplicity $10 < N_c < 200$ in the pseudorapidity range $|\eta| < 3.25$. A magnetic spectrometer with tracking chambers and time of flight counters, provided particle identified momenta spectra in the range $0.1 < p_t < 1.5$ GeV/c. The spectrometer covered $-0.37 < \eta < +1.00$ with $\Delta \varphi \sim 20^\circ$ ($\varphi$ is the azimuthal angle around the beam direction).

(1) Recently the E-735 collaboration has analyzed the charged particle multiplicity distributions arising from $p$-p and $\bar{p}$-p collisions over a range of center of mass energies $0.06 \leq \sqrt{s} \leq 1.8$ TeV \[6\]. Results at 1.8 TeV support the presence of double ($\sigma_2$) and triple ($\sigma_3$) parton interactions. These processes increase the non-single diffraction cross section (NSD) from $\sim 32$ mb at $\sqrt{s} = 0.06$ TeV to $\sim 48$ mb at $\sqrt{s} = 1.8$ TeV. The variation of the double encounter and triple encounter cross sections $\sigma_2$ and $\sigma_3$ with center of mass energy $\sqrt{s}$ is shown in Fig. 1.
FIG. 1. Comparison of the cross sections for single, double, and triple encounter collisions which increase $\sigma_{\text{NSD}}$ above 32 mb as a function of $\sqrt{s}$.

The multiplicity distribution is made up of three contributions corresponding to single, double and triple parton-parton collisions. Our work on multiparton interactions shows that the increase in the $p-p$ inelastic cross section with energy is nearly completely accounted for by the increase in multiparton interactions. Previously this increase in the $p-p$ inelastic cross section was ascribed to copious minijet production [7]. As the energy is increased, a decreasing fraction of the center of mass energy appears in the NSD part of the inelastic cross section. This may be due to the decrease of the Feynman $x$ of the partons involved in these collisions. It is thus likely that gluons become more involved with increasing energy leading to rapid thermalization [8].

(2) To measure the hadronization volume $V$, pion HBT (Hanbury Brown, Twiss) correlation measurements were made as a function of both $P_{\pi\pi} = \vec{p}_1 + \vec{p}_2$ the total momentum of the pion pair and of $dN_c/d\eta$. The $P_{\pi\pi}$ momentum dependent results are shown in Table I [2]. $R_G$ is the Gaussian radius parallel to the beam, $\tau$ the Gaussian lifetime, and $\lambda$ the chaoticity parameter. The lifetime $\tau$ can be viewed as a measure of the radius perpendicular to the beam [11]. The increase of $R_G$ and $\tau$ with decreasing $P_{\pi\pi}$ is the characteristic signature for the expansion of the pion source [10]. The dependence of $R_G$ and $\tau$ on $dN_c/d\eta$ is shown in Table II [9]. A clear increase of $R_G$ with $dN_c/d\eta$ is evident. The dependence of $R_G$ and $\tau$ on $P_{\pi\pi}$ and $dN_c/d\eta$ is consistent with a one dimensional (1D) longitudinal expansion of the pion source. The effect of a 1D expansion on the Bose Einstein correlation has been calculated for a massless relativistic ideal gas [12]. This calculation provides correction factors $\ell_R$ and $\ell_\tau$ to our values of $R_G$ and $\tau$ obtained from the HBT analysis. Both $\ell_R$ and $\ell_\tau$ are a function of $P_{\pi\pi}$ and $\Delta \eta$, where $\Delta \eta$ is the spectrometer aperture. The cylindrical volume $V$ of the pion source is $V = \pi(\ell_\tau \tau)^2 2 \ell_R R_G$ where $R_G$ varies with $dN_c/d\eta$ and $\ell_\tau \tau$ reaches an asymptotic value for the larger $dN_c/d\eta$ values. From our data $R_G = e + h dN_c/d\eta$ where $e = (0.0788 \pm 0.013)$ fm and $h = (0.0730 \pm 0.011)$ fm and $\chi^2/\text{NDF} = 3.09/4.00$ as shown in
Fig. 2. We neglect $\epsilon$ since $h \, dN_c/d\eta$ is 6 to 20 times larger than $\epsilon$. The cylindrical volume becomes,

$$V = \pi \ell^2 \tau^2 \ell_R h \, dN_c/d\eta$$  \hspace{1cm} (1)$$

FIG. 2. Dependence of the Gaussian radius $R_G$ on $dN_c/d\eta$. The gluon diagram indicates that two gluons are required to form two pions.

The largest measured value of $\tau = 0.95$ fm is used to evaluate $V$. We estimate the $\ell$ factors using the extrapolation procedure ($P_{\pi\pi} \to 0$) outlined in Ref. [12]. (See in particular Fig.4 and Eq.(7) in Ref [12]). For our $P_{\pi\pi}$ values and a 1D expansion, $\ell_r = 1$ independent of $P_{\pi\pi}$. For the data in Table II $\ell_R = 1.56$. Thus $V = (0.645 \pm 0.130) dN_c/d\eta$ fm$^3$ and the range of $V$ is $4.4 \pm 0.9 < V < 13.0 \pm 2.6$ fm$^3$ for $6.75 < dN_c/d\eta < 20.2$.

(3) We assume that for $dN_c/d\eta > 6.75$ the system is above the deconfinement transition. The hot thermalized system expands, cools and then hadronizes. We attribute all of the measured volume to the expansion before hadronization. We neglect the subsequent expansion of the hadronic phase. Following Bjorken’s derivation, we further assume that hydrodynamics of a massless relativistic ideal gas can describe the 1D expansion and that the observed number of pions/fm$^3$ are proportional to the entropy density $s$ at hadronization. To estimate the pions/fm$^3$ emitted by the source, the Bjorken 1D boost invariant equation becomes

$$s \propto n_\pi = \frac{3/2}{A \, 2 \, \mathcal{T}} \, dN_c/d\eta$$  \hspace{1cm} (2)$$

where $A$ is the transverse area and $\mathcal{T}$ is the proper time [13]. The collisions occur at longitudinal coordinate $z = 0$ and time $t = 0$. Eq. (2) describes an isentropic expansion $s(\mathcal{T})/s(\mathcal{T}_0) = \mathcal{T}_0/\mathcal{T}$ and

$$\mathcal{T} = (t^2 - z^2)^{1/2}$$  \hspace{1cm} (3)$$
where \( T_0 \) is the initial proper time when thermalization has occurred. For a relativistic massless ideal gas above the phase transition the maximum expansion velocity, responsible for most of the longitudinal expansion, is likely to be the sound velocity, \( v_s^2 = 1/3 \) \[13\]. The expansion time \( t = z/v_s = \ell_R R_G/v_s \) and \( T = (3z^2 - z^2)^{1/2} = \sqrt{2} z \). We note that \( T_f \) is the proper time at hadronization.

\[
T_f = \sqrt{2} \ell_R R_G = \sqrt{2} \ell_R h \frac{dN_c}{d\eta}
\]

and Eqn. (2) becomes

\[
n_{\pi} = \frac{3/2}{\pi \tau^2} \frac{dN_c/d\eta}{2 \ell_R h} \frac{1/\sqrt{2}}{dN_c/d\eta} = \frac{3/2}{\pi \tau^2} \frac{1/\sqrt{2}}{2 \ell_R h}
\]

where \( 1/\sqrt{2} \) is the effective \( \Delta \eta \) slice. Thus \( n_{\pi} \) is independent of \( dN_c/d\eta \) and one obtains

\[
n_{\pi} = 1.64 \pm 0.33 \text{ (stat) pions fm}^{-3}
\]

This \( n_{\pi} \) value indicates that the deconfinement transition occurs at a definite entropy density. Since \( s \propto n_{\pi} \) is constant we can directly evaluate \( n_{\pi} \) using the total number of pions emitted divided by the total volume for the data set in Table I. We choose the lowest \( P_{\pi\pi} \) value where \( \tau = 0.95 \text{ fm}, R_G = 1.2 \text{ fm}, \) and \( \ell_R = 1.43 \). Here the average pseudo-rapidity density is \( <dN_c/d\eta> = 14.4 \) and Eqns. (2) and (4) become

\[
n_{\pi} = \frac{3/2}{\pi \tau^2} \frac{dN_c/d\eta}{2 \ell_R R_G} \frac{1/\sqrt{2}}{dN_c/d\eta} = 1.57 \pm 0.25 \text{ (stat) pions fm}^{-3}
\]

which has a smaller statistical error than (6).

(4) The negative particle \( p_t \) spectrum is used to measure the temperature. A slope parameter \( b^{-1} \) is obtained from a fit of the invariant cross section \( d^2N_{c}/dy d^2p_t \) to the function \( A \exp(-bp_t) \) for \( 0.15 \leq p_t \leq 0.45 \text{ GeV/c} \) \[14\]. The \( b^{-1} \) value is constant to \( \pm 1\% \) for \( 6.75 < dN_c/d\eta < 20.2 \). Transverse flow has not been seen in \( p-p \) reactions at lower energies \[15,16\]. In heavy ion reactions the transverse flow is attributed to final state interactions of the hadrons which presumably are not important in \( \bar{p}-p \) collisions. The fact that \( R_G \) increases by a factor of three and \( b^{-1} \) remains constant to \( \pm 1\% \), suggests that the transverse flow is negligible. The components \( \sigma_2, \sigma_3 \) in the NSD cross section indicate that the parton-parton mean free paths are shorter in high energy collisions. Since gluon-gluon interactions dominate in the initial encounters, early thermalization \( \sim 0.5 \text{ fm/c} \) when \( T \sim 200 \text{ MeV} \) is likely \[8\]. We interpret \( b^{-1} = T = 179.5 \pm 5 \text{ MeV (syst)} \) as the hadronization temperature. We neglect the expansion of the hadronic phase following hadronization i.e. decoupling is associated with hadronization. The systematic error estimate is based on possible kaon \( (K_0^0) \) misidentification in the negative particle spectrum at low \( p_t \). We have not made a correction for the effect of resonance decays on the negative particle \( p_t \) spectrum. We note that the negative particle temperature is significantly higher than the temperature based on the spectra of identified pions which include resonance particle decay pions \( (T\lesssim168 \text{ MeV}) \). A hadronization inverse slope parameter \( T_m \) can be estimated from our measurement of the relative yields of mesons and hyperons as shown in Fig. 3, using all the events with \( dN_c/d\eta > 6.75 \). The hadron yield versus rest mass inverse slope parameters indicates 162 <
$T_m < 173$ MeV. Similar $T_m \sim 168$ MeV values, based on thermal model analyses of hadron yield ratios, have been seen in high energy $\bar{p}$ p, p p, $e^+e^-$ and heavy ion reactions [17]. This has been interpreted as evidence for a universal limiting temperature $T_m$ for hadrons, the Hagedorn temperature [18].

![Relative meson and hyperon yields versus rest mass](image)

**FIG. 3.** Relative meson and hyperon yields versus rest mass [19,20]. For the mesons, the inverse slope parameter $T_m = 162 \pm 5$ MeV, and for the hyperons $T_m = 173 \pm 12$ MeV.

(5) We can also use the average measured energies to estimate the hadronization energy density $\epsilon_F$ [19]. Since $\epsilon_F = 3/4 \, T \, s_F$, $\epsilon_F$ is also constant versus $dN_c/d\eta$ [13],

$$\epsilon_F = \frac{\sum_h F_h \times (m_h)_\perp \times 1/\sqrt{2}}{\pi \tau^2 \times 2 \times \ell_R \times \hbar}$$  \hspace{1cm} (8)

where $(m_h)_\perp = (m_h^2 + p_t^2)^{1/2}$ is the average transverse mass of hadron $h$, $F_h$ is a hadron abundance factor which also accounts for the neutral hadrons of each species. We have determined $F_h$ for $\pi, K, \varphi, p, n, \Lambda^0, \Xi$, etc. For $\tau = 0.95$ fm, $\ell_R = 1.56$, $h=0.073$, $\epsilon_F$ becomes

$$\epsilon_F = 1.10 \pm 0.26 \text{ (stat) GeV/fm}^3$$  \hspace{1cm} (9)

(6) We can estimate the average number $n_c$ of constituents in volume $V$ at temperature $T$, for a system without boundaries [21]

$$n_c = V \frac{G(T) \, 1.202 \, (kT)^3}{\pi^2 \, \hbar^3 \, c^3}$$  \hspace{1cm} (10)

where $G(T)$ are the number of degrees of freedom (DOF). For a pion gas $G(T) = 3$, $V = 1$ fm$^3$, and $T = 179.5$ MeV. The average number of pions (pion gas) in the source is $n_\pi = 0.28$. 
pions/fm$^3$. We observe 1.57 pions/fm$^3$, emitted from the source at temperature $T = 179.5$ MeV, which requires many more DOF.

For a quark-gluon plasma $G(T) = G_g(T) + G_q(T) + G_{ar{q}}(T) = 16 + 21/2 (f)$ where $f$ are the number of quark flavors \[13\]. $G_g(T)$ are the gluon DOF; $G_q(T)$, $G_{ar{q}}(T)$ are the quark, antiquark DOF. We assume that pion emission from the source can be determined by the number of constituents in the source at hadronization, that one pion is a quark antiquark $(q, \bar{q})$ pair and that two gluons (2$g$) are required to produce two pions (see insert Fig. 2).

$$n_\pi = n_g + (n_q + n_{\bar{q}})/2$$

(11)

Our data indicates that $\sim 6\%$ strange quarks are present at hadronization \[19,20\]. Thus we use $f = 2$ to evaluate Eqn. (10) where $V = 1$ fm$^3$ and,

$$n_\pi = (1 + 2 \times 21/64)G_g \times 16.1 \ T^3 \ (GeV)$$

(12)

where $G_g$ are the effective number of gluon DOF. For $n_\pi = 1.57$/fm$^3$ and $T = 0.1795$ GeV, we obtain $G_g = 10.18$. The total number of DOF are,

$$G(T) = n_g + n_q + n_{\bar{q}} = (1 + 21/16)G_g = 23.5 \pm 6 \ DOF$$

(13)

nearly eight times the DOF for a pion gas. A second method for estimating the DOF is to use the energy density and temperature at hadronization. For the isentropic expansion, the energy $E$ in the volume $V$ at temperature $T$ is \[21]\n
$$E = V \frac{G(T) \ \pi^2 \ k^4}{30 \ h^3 \ c^3} \ T^4.$$

(14)

For $\epsilon_F = 1.10 \pm 0.22 \ (stat) \ GeV/fm^3$ and $T = 179.5 \pm 5$ MeV, we find $G(T) = 24.8 \pm 6.2$ (stat) quark gluon DOF, in good agreement with the DOF using the number of constituents (Eq. 13).

(7) Two Lorentz contracted nucleons collide at $t = 0, z = 0$ and the thermalized constituents are assumed to emerge at $T_0$. Suppose we choose $T_0 = 1.0$ fm/c. For a given expansion velocity, the data determines the hadronization proper time $T_i$ and 1.09 < $T_f$ < 3.25 fm/c. For 6.75 < $dN_c/d\eta$ < 20.2, the deconfined volumes $V$, determined by the data, range between 4.4 < $V$ < 13.0 fm$^3$. For $dN_c/d\eta > 6.75$ and using $G(T)$ from Eq. (14)

$$\epsilon/T^4 = \pi^2/30 \ G(T) = 8.15 \pm 2.0 (stat)$$

(15)

in general agreement with lattice gauge calculations \[22\]. The ratio of the initial temperature $T_i$ to the final $T_f$ is $T_i/T_f = (T_f/T_0)^{1/3}$ and 185 < $T_i$ < 266 MeV. The ratio of the initial energy density $\epsilon_i$ to the final energy density $\epsilon_f$ is $\epsilon_i/\epsilon_f = (T_f/T_0)^{4/3}$ and $\epsilon_i$ is 1.23 < $\epsilon_i$ < 5.30 GeV/fm$^3$ for 6.75 < $dN_c/d\eta$ < 20.2. Note a different choice of $T_0$ would change the $T_i$ and $\epsilon_i$ estimates.

In summary, the HBT analysis and the constant temperature versus $dN_c/d\eta$ are consistent with a model in which a pion source undergoes a 1D expansion with total longitudinal dimension 2 $l_R R_G$ directly proportional to $dN_c/d\eta$. We have used the Bjorken 1D model to analyze our data. We find that there is a unique hadronization entropy density and temperature at which the pions are produced independent of $dN_c/d\eta$. We have used phase space
estimates of the average number of thermalized constituents in volume $V$ at temperature $T$ and the measured energy density $\epsilon_F$ to compute the number of DOF in the source. However, we note that reducing the average expansion velocity from $v^2 = 1/3$ to $v^2 = 1/5$ reduces the DOF estimate by 30%. Then the lower limit for the DOF is $16.6\pm4.2$, still substantially larger than the pion gas DOF of 3. This lower limit allows a more conservative argument that quark-gluon constituents are present in the large deconfined volumes. Our estimate of the number of DOF in the source ($23.5\pm6, 24.8\pm6.2$) is in general agreement with those expected for a quark-gluon plasma. The $n_\pi, \epsilon_F$, and $T$ values characterize the quark-gluon to hadron thermal phase transition. We expect that these hadronization conditions will be observed in $p$-$p$ collisions at the CERN Large Hadron Collider where higher pseudorapidity density $dN_c/d\eta$ values will produce even larger deconfined volumes and longer plasma lifetimes.

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REFERENCES

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[1] UA1 collaboration, Phys. Lett. B 123 (1983) 115; Physics Letters 107B (1981) 320.
[2] L. Van Hove, Phys. Lett. B 118 (1982) 138.
[3] J. D. Bjorken, Fermilab Pub. 82/44-THY.
[4] L. McLerran, Rev. Mod. Phys. 58 (1986) 1021.
[5] E-735 proposal. Search for a deconfined quark-gluon plasma phase, Fermilab P-735 (1983).
[6] T. Alexopoulos, et al., (E-735 collaboration) Phys. Lett. B 435 (1998) 453; W. D. Walker, private communication.
[7] X. N. Wang, Phys. Rep. 280 (1977) 287.
[8] B. Müller and A. Trayanov, Int. J. Mod. Phys. C5 (1994) 113; W. Pöschel and B. Müller, Phys. Rev. D 60 (1999) 114505.
[9] T. Alexopoulos, et al., (E-735 collaboration) Phys. Rev. D 48 (1993) 1931.
[10] E. V. Shuryak, Phys. Lett. 44B (1973) 387; G. Cocconi, Phys. Lett. 49B (1974) 459.
[11] R. M. Weiner, Physics Reports 127 (2000) 249.
[12] B. R. Schlei, et al., Phys. Lett. B 293 (1992) 275.
[13] J. D. Bjorken, Phys. Rev. D 27 (1983) 140.
[14] T. Alexopoulos, et al., (E-735 collaboration), Phys. Lett. B 336 (1994) 599.
[15] A. T. Laasanen, et al., Phys. Rev. Lett. 38 (1977) 1.
[16] I. Bearden, et al. (NA44 Collaboration). Phys. Rev. Lett. 78 (1977) 2080.
[17] U. Heinz, Nucl. Phys. 685 (2001) 414c.
[18] R. Hagedorn and J. Rafelski, Phys. Lett. 97B (1980) 136.
[19] T. Alexopoulos, et al., (E-735 collaboration), Phys. Rev. D 46 (1992) 2773; Phys. Rev. D 48 (1993) 984.
[20] T. Alexopoulos, et al., (E-735 collaboration), Z. Phys. C67 (1995) 411.
[21] R. K. Pathria, Statistical Mechanics, Pergamon Press, Ltd, 1972, p 187f.
[22] F. Karsch, et al., Phys. Lett. B 478 (2000) 249.
TABLE I. Fitted values of radius $R_G$, lifetime $\tau$, and chaoticity $\lambda$ in the Gaussian parameterization with respect to $q_t$ and $q_0$. Values are a function of average two-pion total momentum $P_{\pi\pi}$ or average two-pion transverse momentum $P_t$. The total momentum interval containing the data is listed in column 1. Momentum is in GeV/c. The errors are statistical.

| $P_{\pi\pi}$ | $\langle P_{\pi\pi}\rangle$ | $R_G$ (fm) | $\tau$ (fm) | $\lambda$ | $\langle P_t\rangle$ |
|--------------|----------------------------|------------|-------------|------------|-----------------|
| 0.2-0.5      | 0.404                      | 1.20±0.05  | 0.95±0.06   | 0.24±0.01  | 0.369           |
| 0.2-0.7      | 0.503                      | 1.05±0.08  | 0.71±0.05   | 0.25±0.01  | 0.462           |
| 0.5-1.0      | 0.708                      | 0.80±0.07  | 0.67±0.07   | 0.23±0.02  | 0.650           |
| 0.7-1.2      | 0.900                      | 0.60±0.06  | 0.64±0.05   | 0.26±0.03  | 0.832           |
| 0.9-1.7      | 1.175                      | 0.58±0.06  | 0.53±0.07   | 0.26±0.02  | 1.087           |
| >1.0         | 1.403                      | 0.48±0.06  | 0.45±0.05   | 0.21±0.02  | 1.285           |
| >1.2         | 1.600                      | 0.43±0.06  | 0.41±0.06   | 0.23±0.02  | 1.479           |
TABLE II. Fitted values of the (longitudinal) radius $R_G$ (transverse) lifetime $\tau$ and corrected chaoticity $\lambda$ in the Gaussian parameterization with respect to $q_t$ and $q_0$. Values are a function of the average charged multiplicity per unit of pseudorapidity. Charged particle multiplicity intervals containing the data are listed in column 1. The errors are statistical.

| $N_c$  | $\langle dN_c/d\eta \rangle$ | $R_G$ (fm) | $\tau$ (fm) | $\lambda$ |
|--------|-----------------------------|------------|-------------|---------|
| 0-60   | 6.75                        | 0.62 ± 0.09 | 0.53 ± 0.07 | 0.39 ± 0.05 |
| 0-80   | 9.00                        | 0.70 ± 0.09 | 0.65 ± 0.06 | 0.32 ± 0.03 |
| 60-100 | 12.5                        | 1.00 ± 0.08 | 0.86 ± 0.12 | 0.25 ± 0.01 |
| 80-120 | 15.5                        | 1.10 ± 0.10 | 0.89 ± 0.12 | 0.23 ± 0.01 |
| 100-240| 18.2                        | 1.52 ± 0.14 | 0.99 ± 0.15 | 0.21 ± 0.02 |
| 120-240| 20.17                       | 1.86 ± 0.35 | 0.88 ± 0.20 | 0.19 ± 0.03 |