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Multi-particle Production in High-Energy Proton-Nucleus Interaction

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In this report, an interpretation for multiplicity and angular distribution of emitted charged particles in high-energy proton-nucleus inelastic collision are given through the hypothesis of contracting space.

Three marvellous phenomena are presented high-energy proton-nucleus interaction as follows,

1) The inealstic cross section for proton-nucleus(with mass number A) interaction is obtained as follows,

$$\sigma_A = \sigma_p A^{2/3} + 0.1 \pm 0.01 ,$$

σ_p : cross section of p-p inelastic interaction

2) $$R_A = \frac{\langle n_s \rangle_A \text{ (mean multiplicity of p-A interaction for thin track)}}{\langle n_s \rangle_p \text{ (mean multiplicity of p-p interaction)}}$$

= lower value than results computed though two fireball or intranuclear cascade models

3) $f_{p-A}(y) \simeq f_{p-p}(y)$ in the forward direction independently of A

f(y): rapidity distribution

In the case that the proton with nearly light velocity pass through the nucleus(very condensed matter) for very short time of 10^{-23}sec, it leads a strong suspicion that the mean free path length is given as $\frac{1}{\sigma_p N}$, where, N means nucleon density in nucleus.

In first stage, a trial of explanation is made from the standpoint of two center model which the incident proton turns into one exited center in the forward direction and induces several target nucleons to exite in backward after collsion due to the phenomenon of 3).

It seems to be considered that the front target nucleon conseals the rear one for incident proton, that is, the more position is rear the more target size contracts apparently. This state becomes to show the circular frustum as probability space. And, the low value of R_A can be explained through the

probability space. However, this consideration is inconsistent with the phenomenon of 1). Therefore, the circular frustum space are considered as the existence space.

Here exist two unknown constants for the interaction within the circular frustum space as follows,

1) The function expressed generating line of circular frustum is unknown. The exponential law was taken for succesive contraction of nucleon size as the intuitive speculation. The contraction factor in area of nucleon size at the position of

$e^{-2\zeta\lambda}$ λ : distance passed through nucleus in one mean free path unit

ζ :perpendicular contraction coefficient in length of nucleon size to incident direction per one mean free path

2) The ratio of length for one nucleon size to one mean free pass, η, is unknown.

Then, it might be necessary to consider the space with dimension of length in addition to the phase space with momentum and energy.

The mean multiplicity of particles emitted from the exited target nucleon at λ, $\langle n\rangle_\lambda$, is given from assumption mean multiplicity is proportion to the volume of contracted nucleon as follows

$$\langle n\rangle_\lambda = \frac{\langle n_s\rangle_p}{2} e^{-2\zeta\lambda} \qquad (1)$$

Consequently, R_A is shown as the follwing formula:

$$R_A = \frac{\langle n_s\rangle_A}{\langle n_s\rangle_p} = \frac{1}{\langle n_s\rangle_p}\left\{\frac{\langle n_s\rangle_p}{2} + \frac{\langle n_s\rangle_p}{2}\int_0^{\bar{L}_A} e^{-2\zeta\lambda}\,d\lambda\right\} \qquad (2)$$

and, $\bar{L}_A$(mean length passed through nucleus A) $= \eta\cdot\frac{4}{3}A^{1/3}$ (3)

Namely, $$R_A = \frac{1}{2}\left\{1 + \frac{1}{2\zeta}\left(1 - e^{-2\zeta\eta\frac{4}{3}A^{1/3}}\right)\right\} \qquad (4)$$

Recently, the exact experimental value[5] of $\langle n_s\rangle_A$ of Al, Cu, Pb targets was given by Ogata(one of the repoters) from the analysis for the emulsion cloud chmber(each metal sheets with 500 μ thickness; FUJI-ET7B emulsion coating to 50 μ thickness on the both side of meta-acryl base 800 μ thickness) exposed to 200 GeV proton beam at FNAL.

Experimental results: $R_{Al}=1.72 \pm 0.13$, $R_{Cu}=1.97 \pm 0.17$.

We obtained $\zeta = 0.10$ and $\eta = 0.84$ by solving the simultaneous equation of two unknown from formula (4). Since $\sigma_p = 32$mb at 200 GeV incident proton, the nucleon radius is estimated as 1.1 fermi at this energy region.

Florian et al[1] presented the value of $\langle n_s \rangle_A$ for targets of W (Ag,Br) and (C,N,O) groups by using of the loading emulsion exposed to 200 Gev proton beam. These values are plotted as $\langle n_s \rangle_A$ versus A in Fig.1 (⊥ : Ogata's; ⊥ : Florian's). The experimental plots excepted the points of Al and Cu show a reasonable agreement for the curve obtained from (4) (solid line). According this model, $R_A < 3$ for any mass number.

One should note that the R_A caluculated for hydrogen target is obtained as 1.002. This fact means that the nucleon is self-consistent for the value of R_A within the experimental error; The equivalent condition is satisfied as follows,

$$\int_0^{L_1} e^{-2\zeta\lambda} d\lambda = 1 \qquad (5)$$

The distribution of $f_{p-A}(y)$ is discussed through the two fireball model and or the adaptation of limiting fragmentation hypothesis.[2]

If it is consider that the distribution of n_s for p-p interaction is approximately expressed by Poisson type and the number of particle emitted from one center, n, is appeared independently to another center, the distribution of n is also represented as Poisson type with the mean value of $\frac{\langle n_s \rangle_p}{2}$.

Therefore, the distribution of n at λ in nuclear matter, $f(n, \lambda)$, is expressed by (1) as follows,

$$f(n, \lambda) = \frac{\left(\frac{\langle n_s \rangle_p}{2} e^{-2\zeta\lambda}\right)^n}{n!} e^{-\frac{\langle n_s \rangle_p}{2} e^{-2\zeta\lambda}} \qquad (6)$$

In the case of two fireball model, two assumptions are made as follows,

i) isotropic particle emission in fireball rest system; The rapidity distrbution of $\mathrm{sech}^2(y)$ from the approximation of $y \simeq -\ln \tan \theta/2$ (θ : emission angle)

ii) M^2(fireball mass) $\ll S_p$(squared value of total energy in center of mass system for p-nucleon interaction : CMS_p), due to small value of $\frac{\langle n_s \rangle_p}{2}$.

Since the mean value of S_A for incident proton and collective target of nucleons is nearly obtained $S_p \frac{4}{3} A^{1/3}$, it is considered that S_A is approximately divided into $\frac{4}{3} A^{1/3}$ equal parts with S_p in CMS of succesive fireball(or incident proton)-target nucleon interaction from ii).

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1) J.R. Florian et al, 1973 Meeting of the Division of Particle and Fields, Berkely, August

2) J. Benecke et al, Phys. Rev. 188 (1969) 2159

Therefore, the Lorentz factor of fireball in CMSp is obtained through the assumption of ii) as follows,

$$\gamma_f \simeq \frac{\sqrt{S_p}}{2M_f}, \quad f\text{: forward dorection} \; ; \quad \gamma_b \simeq \frac{\sqrt{S_p}}{2M_f}, \quad b : \text{backward} \tag{7}$$

The mean value of M for n is obtained from the assumption of i) and charge independence for pion as the following formula:

$$\overline{M}(n) = \left\{\sqrt{\left(\langle P_\perp\rangle_\pi \times \frac{4}{\pi}\right)^2 + m_\pi^2} \times \frac{3}{2} \times (n-0.5)\right\} + \sqrt{\left(\langle P_\perp\rangle_p \times \frac{4}{\pi}\right)^2 + m_p^2} \tag{8}$$

$\langle P_\perp\rangle$: mean transversal momentum π : pion p: proton

numerical value of 0.5: emission rate of proton by considering charge exchage[3] and ratio of number for proton to nutron in nucleus

Therefore, $f_{p-A}(y_c)$ in CMS_p are obtained by using of formula (6) and rapidity transformation as follows,

$$\begin{aligned} f_{p-A}(y_c) &\simeq \sum_{n=1}^{\infty}\left\{\int_0^{\bar{\lambda}_1} n f(n,\lambda)\, d\lambda \cdot \operatorname{sech}^2\left(y - \frac{1}{2}\frac{1+\bar{\beta}_f(n)}{1-\bar{\beta}_f(n)}\right) \right. \\ &\quad \left. + \int_0^{\bar{\lambda}_A} n f(n,\lambda)\, d\lambda \operatorname{sech}^2\left(y + \frac{1}{2}\frac{1+\bar{\beta}_b(n)}{1-\bar{\beta}_b(n)}\right)\right\} \\ &= f_{p-p}(y) + \sum_{n=1}^{\infty}\int_{\bar{\lambda}_1}^{\bar{\lambda}_A} \quad '' \quad d\lambda \end{aligned} \tag{9}$$

$\bar{\beta}(n)$: mean value of ratio of velocity for fireball with n to light.

The calculated $f_{p-p}(y)$ is substituted by the experimental one.

The caluculated results are in approximate agreement with experimental one for W by Florian[1] et al in the part of backward direction normalizing the calculated $f_{p-p}(y)$ to the experimental one.[4] The calculated was compared the computed by Fishbane et al[5] through incherent production model.

The adaptation of limiting fragmentation for the contracting space is more simple than two fireball as follows,

$$f_{p-A}(y) = \sum_{n=1}^{\infty}\int_0^{\bar{\lambda}_1} n f(n,\lambda)\, d\lambda \cdot f_{p,f}(n,y) + \sum_{n=1}^{\infty}\int_0^{\bar{\lambda}_A} n f(n,\lambda)\, d\lambda\, f_{p,b}(n,y) \tag{10}$$

$f_p(y, n)$: rapidity distribution for limiting fragments of one proton corresponding to n in p-p interaction

In the present stage, it is assumed that $f_p(y, n = n_s/2)$ is nearly same as the one side of experimental $f_{p-p}(y, n_s)$.[6,7] In Fig. 4, the first term in formula (10) was normalized with the experimental $f_{p-p}(y)$ in the forward direction. Though we could not obtain good data of $f_{p-p}(y, n_s)$ ($f(y,n_s \geq 4)$ is obtained from only negative pion), it seems that the calculated distribution shows the agreement with the experimental result in the fragment region of of target nucleons around the position of y= 0 as shown in Fig. 2.

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3) D.R.O. Morrison, Fourth International Conference on High Energy Collison (Stony Brook Series) Oxford, April, 1972
4) G. Charlton et al,1972 International Conference on High Energy Physics Chicago, August
5) P.M. Fishbane et al, Phys. Rev. Letters, 29 (1972) 685
6) S.Barish et al, Phys, Rev. D 9 (1974) 1171
7) Y. Cho et al, Phys. Rev. Letters 31 (1973) 413

Fig. 1

Dependence on Mass Number to Mean Multiplicity at 200 GeV Incident Proton

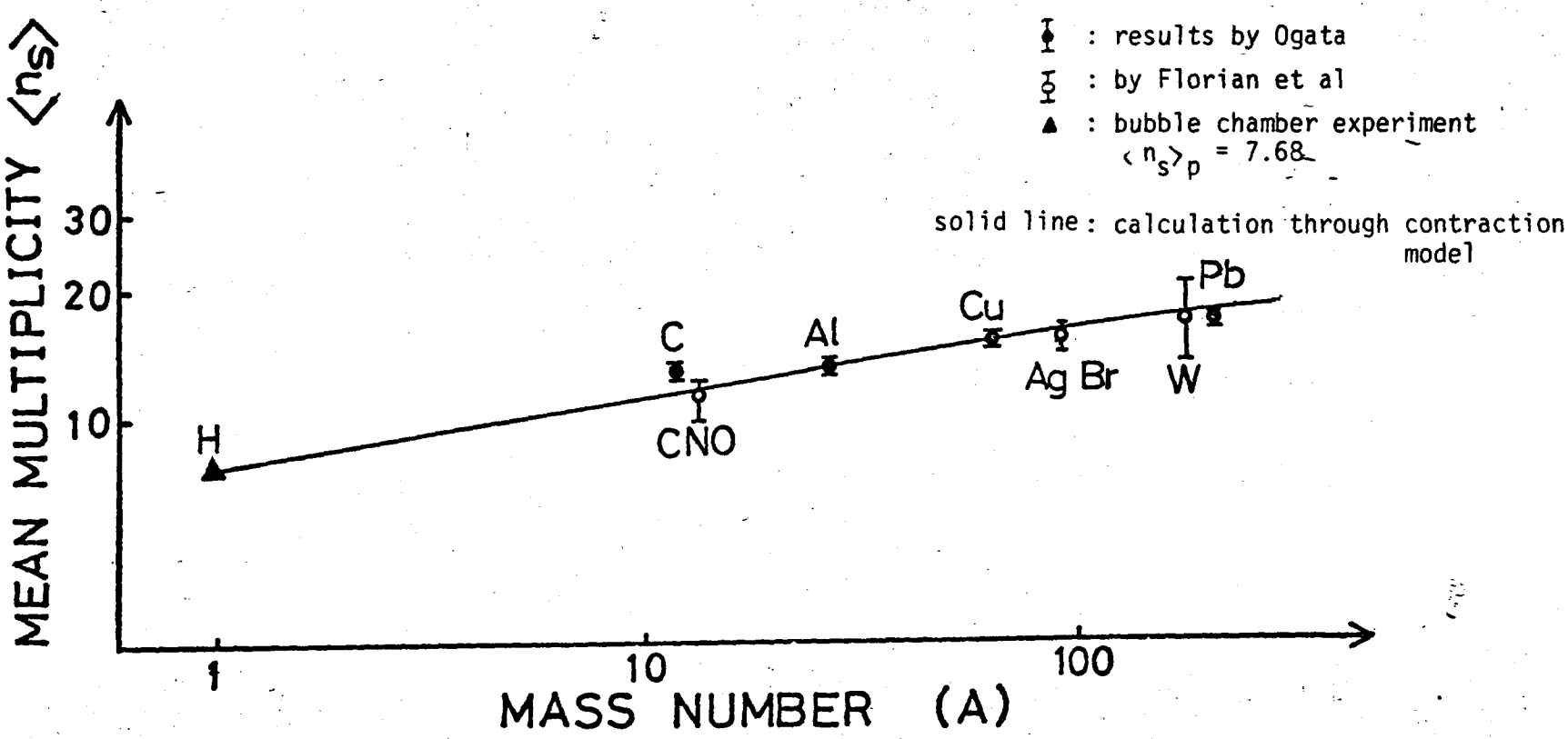
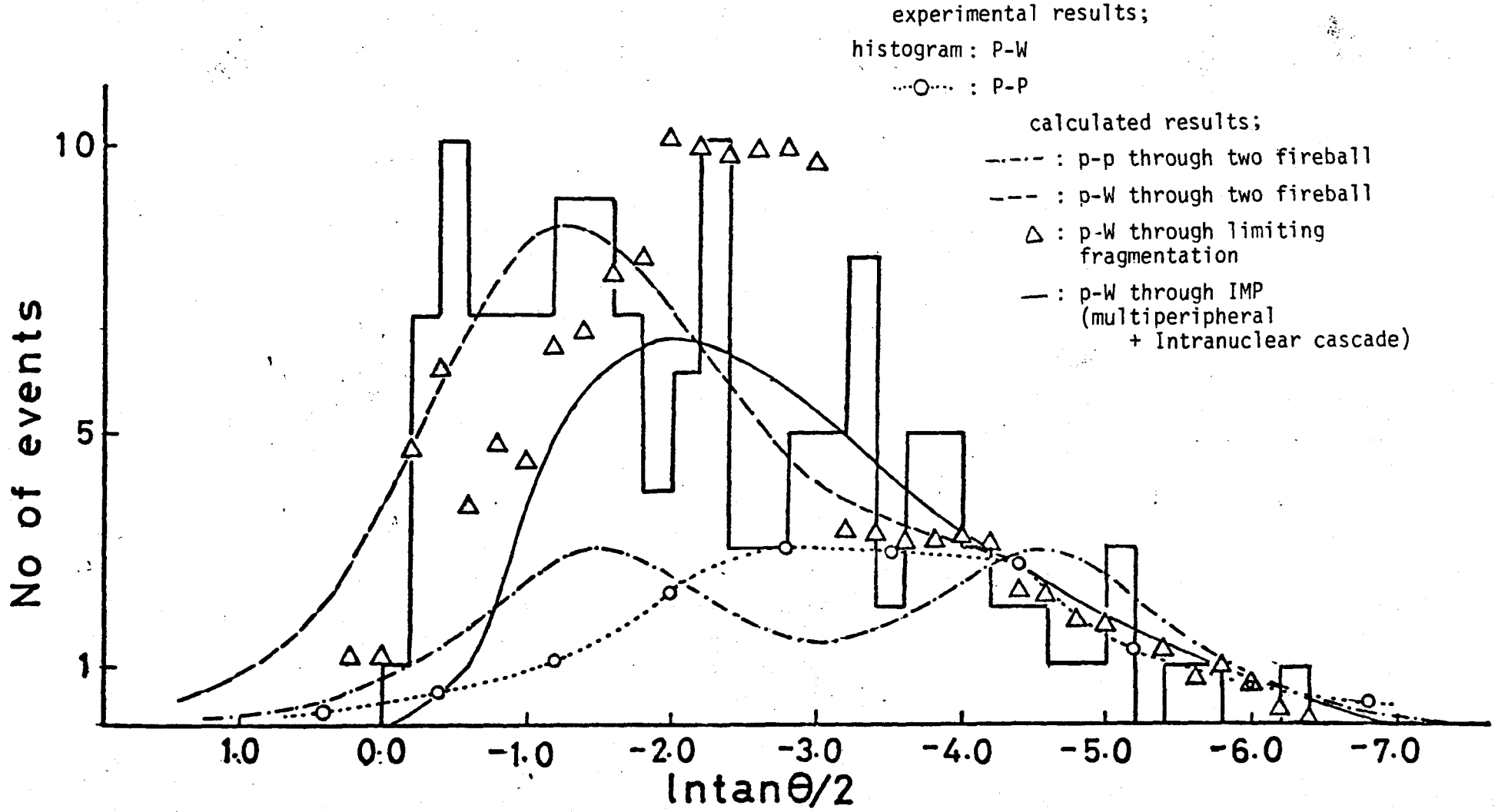


Fig. 2

Rapidity Distributions of 200 GeV Proton-Proton and Tungsten Nucleus Intreaction