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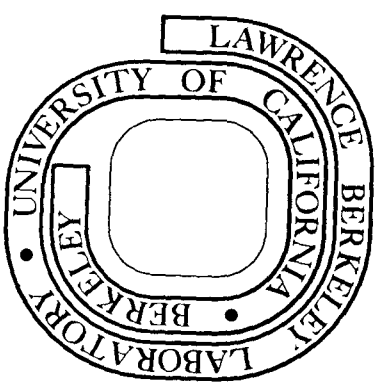

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LBL-7749

^{12}C ON ^{12}C AT 800 MeV/n; ONE FIREBALL OR TWO ?

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ABSTRACT

We demonstrate that a two-fireball model can explain the proton and pion inclusive spectra for collision between light ions at relativistic energies. For heavier ions, the one-fireball model is recovered.

[Relativistic heavy ions; fireball; proton and pion spectra]

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†Permanent address

The fireball model predicts, with a fair degree of success, inclusive spectra for collision of Ne on U, Pb, etc. at relativistic energies. For the basics of this model, relevant for this letter, see Refs. 1 and 2.

Data for lighter ions have become available in recent times. Preliminary data for ^{12}C on ^{12}C at 800 MeV/n have existed for more than a year.[3] Data analysis for Ne on NaF and Ar on Ar is nearing completion.

These data have shown strong deviations from the fireball model as developed in Refs. 1 and 2. From now on we will call this model the one-fireball model. We will show that a simple extension of the one-fireball model idea -- two fireballs[5] rather than one -- fits the data on lighter ions. When heavier ions are involved, our two-fireball model essentially coalesces into the one-fireball model.

The basic premise of the one-fireball model is the following. For a given impact parameter b there will be an overlap between the target and the projectile. This overlap region forms the fireball. After collision, the overlapping regions of the target and the projectile fuse together and come to rest in the c.m. of the fireball. The available kinetic energy before the collision goes into creating thermal motion after the collision. Particles are then emitted isotropically in the rest frame of the fireball. Because the c.m. of the fireball is moving in the lab, the inclusive spectrum measured in the lab will, in general, be anisotropic. For collisions between unequal masses the c.m. velocity of the fireball in the lab is generally a function of b. It is possible to include particle productions (pions, deltas, etc.) and composites (d, ^3He, ^3H, etc.) in the formulation using the law of chemical equilibrium.[6]

A justification for this procedure has been advanced.[7]

For collision between identical ions, the c.m. of the fireball is independent of the impact parameter and coincides with the c.m. of the target and the projectile. Inclusive spectrum measured in the c.m. is therefore predicted to be isotropic. Figure 1 shows that for ^{12}C on ^{12}C, the measured proton inclusive cross-section is strongly anisotropic; at 30° the cross-section is approximately five/six times higher than at 90°. Further, although the protons are highly anisotropic, pions are only mildly so.

We find that the following simple extension of the one-fireball model reproduces these characteristics of the data. Let P_a^i, E_a^i be the momentum and energy respectively of the overlapping part of the projectile before collision in the c.m. of the fireball. After the collision

$$P_a^f = (1 - y)P_a^i \tag{1}$$

The factor y is unity in the one-fireball model if the projectile hits the target at all. We think that it is more realistic to consider y as a function of b. The idea is that if the overlapping part of the projectile does not meet enough number of nucleons on its way, it will be slowed down but not completely stopped. Similar arguments apply for the overlapping part of the target. A theoretical derivation of y is very difficult and we will not attempt it here. The simple assumption made here is that

$$\begin{aligned} y &= 1 \qquad \text{if} \qquad n_{ab} \geq n_0 \\ &= \frac{n_{ab}}{n_0} \qquad \text{if} \qquad n_{ab} < n_0 \end{aligned} \tag{2}$$

where n_{ab} is the initial number of nucleons participating in the collision. Our first guess was $n_0 = 16$ and this already gives a reasonable fit. This value is used in the calculation of Fig. 1. For ^{12}C on ^{12}C this choice generates the one-fireball model only for $b < 2$ fm; for higher values of b, the overlapping parts of the projectile and the target continue in their paths after collision but with reduced momentum (two fireballs). Because of symmetry we must have $E_a^f = E_a^i$; thus the excess energy after slowing down is dumped as thermal energy. Particles are then emitted isotropically in the rest frame of each fireball.

With this modification, the rest of the calculation proceeds exactly as in Ref. 2. We include the production of pions and deltas using the thermodynamic formulation. The deltas decay into appropriate pions and nucleons. For pion production, a freeze-out density has to be assumed. In accordance with a recent calculation[8] this is taken to be 0.12 fm^{-3}. The reasons for the difference in anisotropy of the protons and the pions are twofold: (a) pions are lighter, and (b) pions are produced mostly at low values of b.

We now return to a discussion of Eq. (2). One could also try

$$y = \left(\frac{n_{ab}}{n_0}\right)^{\nu} \qquad \text{if} \qquad n_{ab} < n_0$$

The choice of Eq. (2) is thus one of simplicity -- one that does an adequate job. Accepting Eq. (2) from this viewpoint, it is obvious that n_0 primarily determines the anisotropy of the proton spectrum. Larger n_0 will lead to more anisotropic proton spectra. This is demonstrated in Fig. 2 which shows that the constant is determined to better than 25% by existing data. We expect n_0 to be a function of the incident energy

but for a given incident energy per nucleon, it should be independent of the mass number of the projectile for the identical projectile target case. Thus the same value of $n_0 \approx 16$ should reproduce data for ^{20}Ne on ^{20}Ne at 800 MeV/n. The theoretical prediction is compared with experiment in Fig. 3. With heavier projectiles, the anisotropy in the proton spectrum will decrease. For ^{20}Ne on ^{20}Ne at 800 MeV/n, the factor between the proton spectrum at 30° and that at 90° is about two/three. For Ar on Ar our calculation predicts that the factor will drop to less than two.

We note that our theoretical predictions for pion spectra are too high compared to experiments by about a factor of two to three. The numerical value for the freeze-out density[8] used in the calculation affects the normalization of the pion spectrum most directly. A higher value would yield better agreement for pions while the proton spectrum would remain essentially unchanged. However, many modifications of the model proposed here are possible which will affect details of agreement.

The firestreak model[9,8] applied to light ion reactions also produces an anisotropic proton spectrum. However, the fit to the data is much worse than what is achieved in the two-fireball model. Lastly, it is possible to formulate a hydrodynamical description[10] which will produce anisotropy in proton and pion spectra.

I am very much indebted to S. Nagamiya for informing me of experimental results prior to publication. I wish to thank G. Westfall for making available to me the firestreak model predictions. I also wish to thank P.Siemens, J.I.Kapusta, M.Gyulassy, Y.Karant, R.Landau, and N.K.Glendenning for discussion. This work was carried out under the auspices of the U.S.Department of Energy and is also supported in part by the N.R.C. of Canada and the Quebec Department of Education.

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FIGURE CAPTIONS

Fig. 1. Theoretical calculations for proton spectrum (A = 90°, B = 60°, C = 90°) and pion spectrum (a = 90°, b = 60°, c = 90°) compared with experimental results for ^{12}C on ^{12}C at 800 MeV/n. All results are in the c.m.

Fig. 2. Calculation of proton spectrum anisotropy for ^{12}C on ^{12}C at 800 MeV/n as a function of n_0 (Eq. 2); (a,A) corresponds to spectrum at 30° and 90° respectively for n_0 = 16; (b,B) for n_0 = 24; (d,D) for n_0 = 30. All calculations are in the c.m.

Fig. 3. Same as in Fig. 1 except for Ne on NaF.

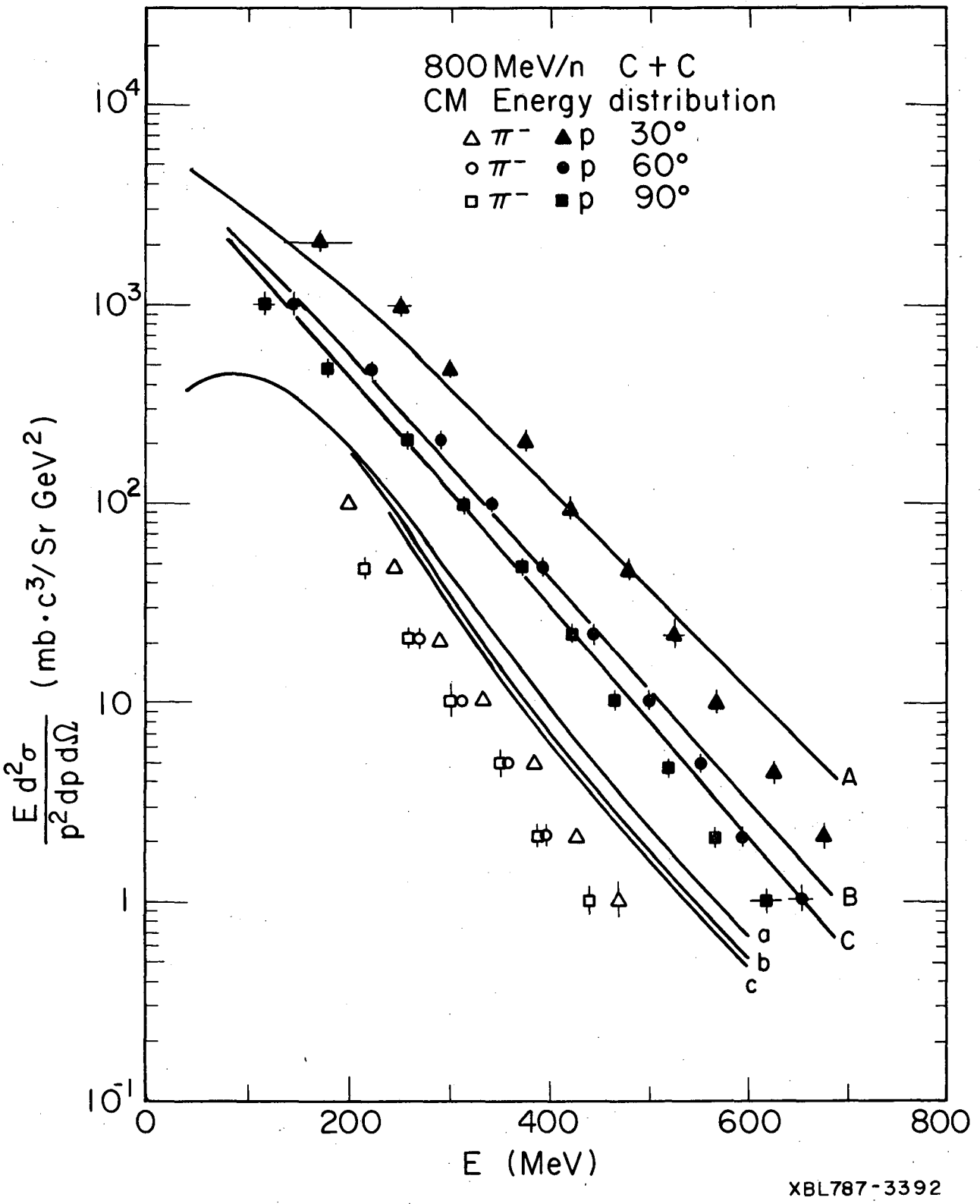
800 MeV/n C + C
CM Energy distribution
△ π⁻ ▲ p 30°
○ π⁻ ● p 60°
□ π⁻ ■ p 90°
$\frac{E\,d^2\sigma}{p^2 dp\,d\Omega}$ (mb · c³/Sr GeV²)
10⁴
10³
10²
10
1
10⁻¹
0
200
400
600
800
E (MeV)
A
B
C
a
b
c
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Figure 1

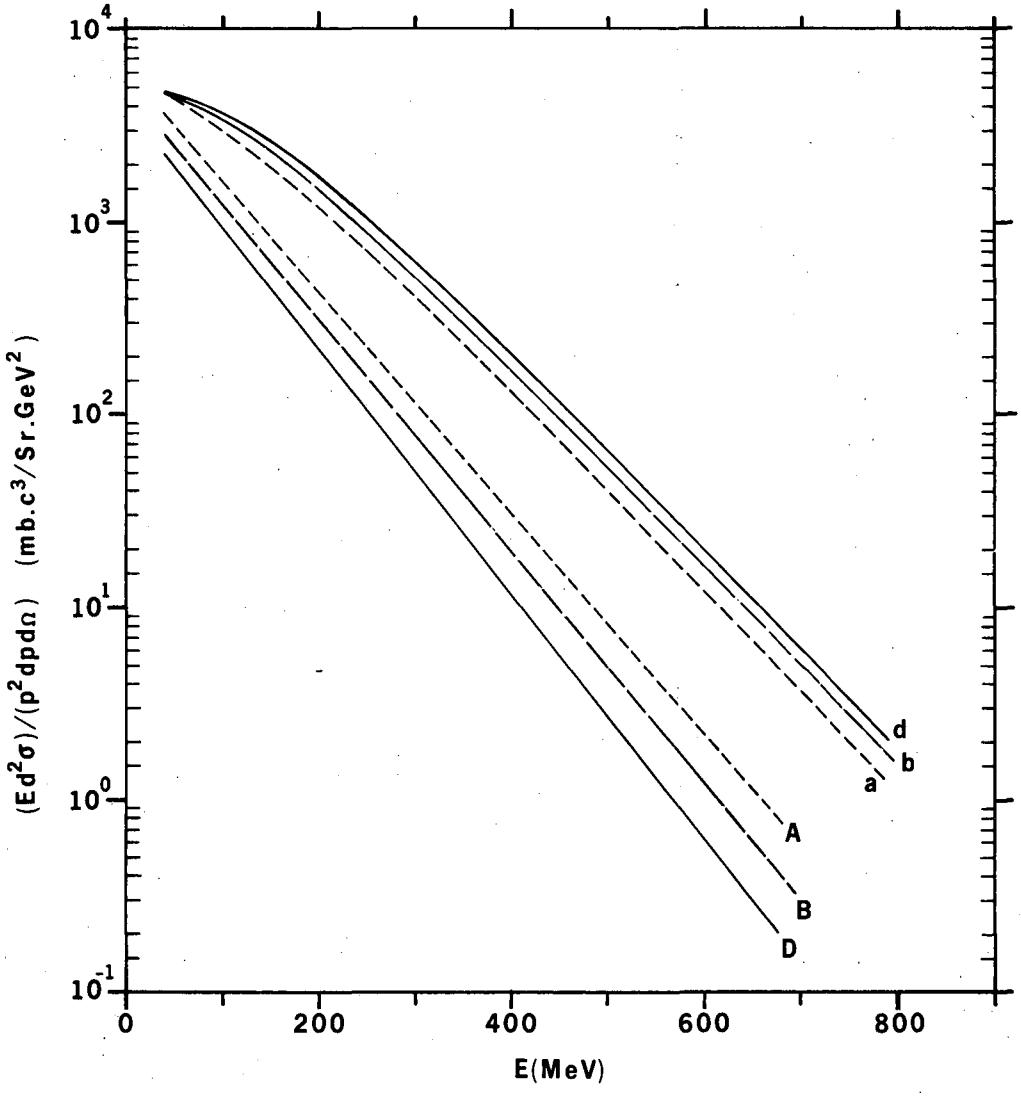

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Figure 2

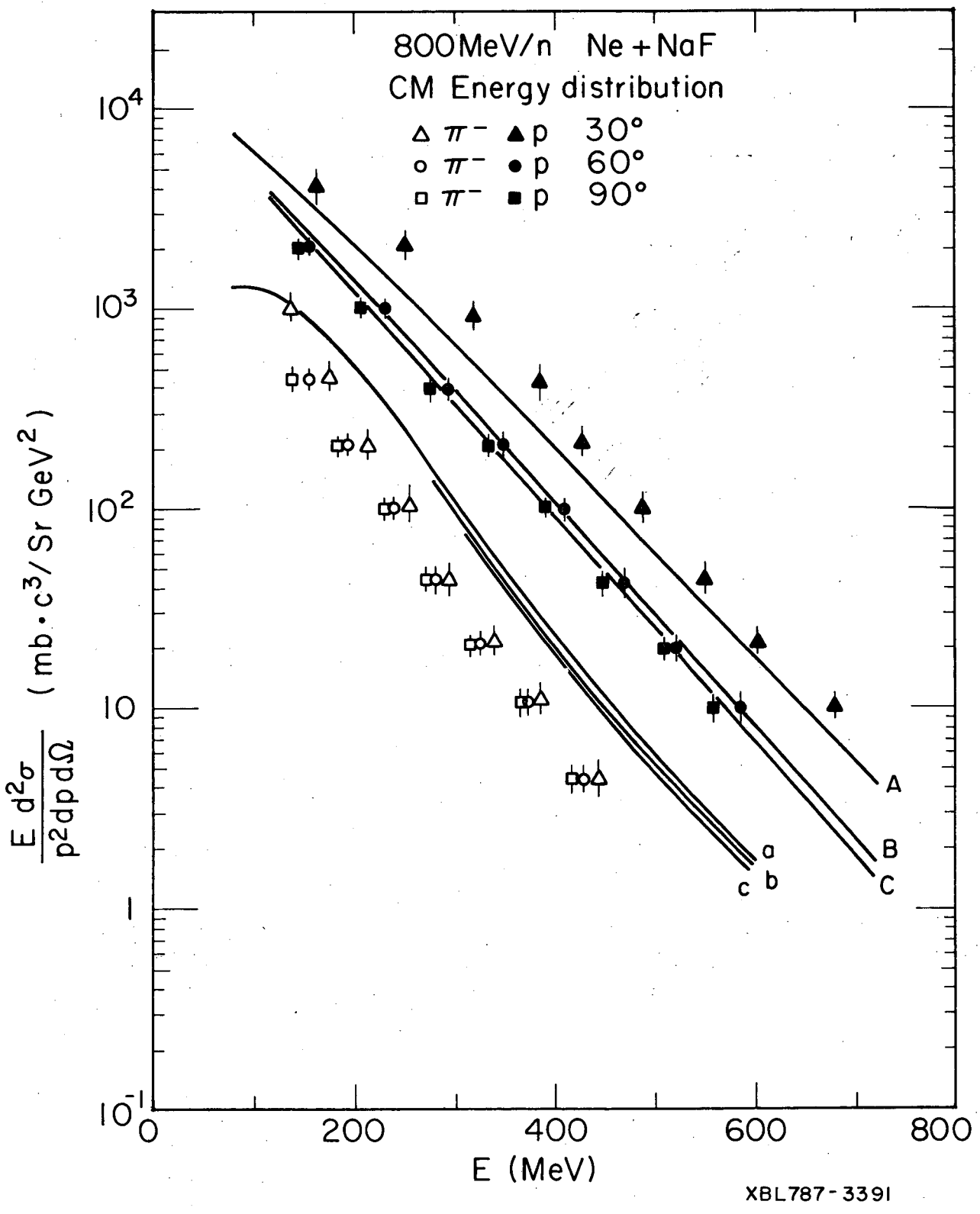
800MeV/n Ne + NaF
CM Energy distribution
△ π⁻ ▲ p 30°
○ π⁻ ● p 60°
□ π⁻ ■ p 90°
$\frac{E\,d^2\sigma}{p^2 dp\,d\Omega}$ (mb·c³/Sr GeV²)
10⁴
10³
10²
10
1
10⁻¹
0
200
400
600
800
E (MeV)
A
B
C
a
b
c
XBL787-3391

Figure 3

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

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