SECONDARY-PARTICLE YIELDS AT 200 GeV

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SUMMARY

The predictions of the Cocconi-Koester-Perkins, Trilling and Hagedorn-Ranft formulae are compared. It is concluded that the most reasonable predictions to use for studying the feasibility of experiments are the Hagedorn-Ranft yields.

Yields of $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$, Λ, and Σ^{+} for 200-GeV proton-proton collisions at angles up to 45 mrad are plotted. The reduction in yields expected from targets other than hydrogen requires further study.

Which Formula?

Estimates of secondary-particle yields have been made by Cocconi, Koester, and Perkins[1] (CKP), Trilling,[2] and Hagedorn and Ranft[3] (HR). Koester[4] in a report to the NAL 1967 Summer Study compared these models and recommended the use of the CKP formula. One of the principal reasons for this choice was the need for a computer to calculate the Hagedorn-Ranft spectra. Data are now available for 200-GeV incident protons, and it is, therefore, worth reconsidering which formula to use.

Does It Matter?

1. The CKP formula for pions is based on systematics observed in cosmic-ray data and on 30-GeV data. It makes no distinction between pions of different charge. At the CERN 300-GeV study,[5] it was recommended that for experimental fluxes, the following prescription should

be used. For

$$\left.\begin{array}{ll} \pi^{+} & \text{use } 2 \times \text{CKP} \\ \pi^{-} & \text{use } 1/2 \times \text{CKP} \\ K^{+} & \text{use } 1/10 \times \text{CKP} \end{array}\right\} \text{ to take into account observed differences in } \pi^{\pm} \text{ yields,}$$

where CKP is the mean π flux according to the CKP formula. This decision was based upon yields integrated over the whole angular range. The integrated CKP yields are the more conservative.

2. The Trilling formula is based on a semi-empirical model in which high-momentum secondaries arise from isobar decay and low-momentum particles come from an evaporation process. Cocconi[6] criticizes this formula on the grounds of lack of constancy of the transverse momentum distribution. The predicted yields differ appreciably at most momenta from CKP. CERN recommended the use of the Trilling yields for shielding calculations because of the high yields for high-momentum secondaries.

3. The model of Hagedorn and Ranft is based on a combination of thermodynamics of strong interactions at high energies and some simple kinematical considerations. The only published criticism of the model or its predictions is concerned with the π^{+} yields. The authors themselves point out that the π^{+} inelasticities which are predicted are higher than those indicated by cosmic-ray results. The HR predictions for all particles fit the 30-GeV data very well, and the model does not require the extrapolation of empirical fits to existing data to get 200-GeV yields.

It is not the purpose of this note to evaluate the validity of these models. All fit the existing data reasonably well. Because of the greater physics input and lesser dependence on curve fitting to existing (and inadequate) data the HR predictions are strongly favored. Here we shall compare the predictions themselves rather than the manner in which they are made. We shall see that the HR yields are generally lower than or comparable to the other yields in the momentum and angular ranges which are relevant for the charged-particle beams presently under discussion, and it is on these grounds that it is recommended that HR yields be used for beam fluxes.

π^+ Yields

It is not envisaged that secondary beams of momentum greater than 150 GeV/c will be constructed when the accelerator is running at 200 GeV. It would probably be more economical to increase the energy of the accelerator for experiments in the momentum range 150 to 190 GeV/c. Consequently, Hagedorn and Ranft's self-criticism of the high-momentum part of the π^+ spectrum is not relevant to present beam design. Apart from the dip for low momentum in the Trilling predictions, HR and Trilling are in good agreement in the momentum range, $0 < p < 150$ GeV/c, and angular range, $0 < \theta < 45$ mrads. At low momenta the CKP yields are significantly greater than HR.

The HR yields for π^+ at 0 and 10 mrads are compared with CKP and Trilling on the upper part of Fig. 1 and with $2 \times$ CKP on the lower part. If the only basis for deciding which formula to choose were conservatism, then the choice would be the HR yields.

π^- Yields

A comparison of HR, Trilling, CKP and 1/2 CKP (CERN recipe) is made for the π^- yields at 0° on Fig. 2. It certainly matters for π^- which formula is used. The HR yields are again the lowest of the four and not too different from 1/2 × CKP. It should be noted that the predicted inelasticities for π^- on the HR model agree with cosmic-ray data. The HR yields would again appear a reasonable choice.

K^+ Yields

The CERN recipe of 1/10 × CKP and HR are within a factor of two at 0° and at larger angles and lower momenta (Fig. 3). The greater disagreement for larger angles and momenta is not relevant to realistic beam design.

Proton Yields

No predictions are available for protons using the CKP formula. The HR and Trilling formula agree very well except at 0° where HR is a factor of two higher than Trilling (Fig. 4). The nucleon multiplicity predicted by the HR model is smaller than obtained in cosmic-ray measurements and the HR yields may be considered as lower limits.

Particle-Yield Estimates for NAL Beams

It is recommended that the HR yields be adopted for beam-flux estimations for the following reasons:

1. There is no criticism leveled at the HR predictions in the angular and momentum intervals of interest.

2. In most cases, the HR yields are comparable or lower and are, therefore, safer to use for studying the feasibility of experiments.

3. The HR model makes predictions over a much wider range of secondary particles.

Figures 5-12 show the HR predictions for $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$, Λ, and Σ^{+} for 200-GeV proton-proton collisions. Tabulated computer data are available for secondary momenta up to 200 GeV/c and angles up to 45 mrads.

Some interesting features of the data are:

(i) Significant yields of long-lived hyperons are available (Figs. 11 and 12).

(ii) For most beams non-zero degree production is just about as good as 0° for yields. The variation of $\pi^{\pm}$ yields $d^2N/dpd\Omega$ are plotted in Fig. 13 as a function of production angle. Fig. 14 shows the variation of $d^2N/dpd\theta$ with θ for $\pi^{\pm}$ of 50 and 100 GeV/c.

(iii) The contamination of unwanted particles in unseparated beams can be estimated. For example, at 10 mrads the π^{+}/K^{+} ratio varies in the range 6-9 for momenta between 25 and 100 GeV/c. At 25 GeV/c the p/π^{+} ratio is 1/15 but rises to 4/1 at 100 GeV/c. The π^{-}/K^{-} ratio is about 10/1 between 25 and 100 GeV/c, and the $\bar{p}/\pi^{-}$ ratio about 1/40.

Further Studies

The HR yields are for proton-proton collisions. Secondary beams, however, are produced from nuclei. Only the Trilling formula makes a distinction between target nuclei. The π^+ yields for p-p and p-Be are compared on Fig. 15. There is a reduction in yields varying between 1.0 and 2.0 by using a beryllium target. This reduction is due to the absorption of secondaries in the target and is based on observations using 30 GeV for protons. The reduction in yields when using a heavy target is worthy of further attention.

Acknowledgments

The computer program used for all the data displayed was made available by J. Ranft and run on the Rutherford Laboratory IBM 360/75. More extensive calculations can be made using the CERN CDC-6600 library programs W-129 and W-130. Many visitors to the Aspen Summer Study have contributed in plotting the data in the graphs.

REFERENCES

[1] Cocconi, Koester, and Perkins, Lawrence Radiation Laboratory UCRL-10022, 1961, p. 107; G. Cocconi, Proc. Argonne Users Group Meeting, Dec. 1961.

[2] G. Trilling, Lawrence Radiation Laboratory UCID-10148, UCRL-16830, 1964, p. 25, and UCRL-16000, Vol. I, XIII-1, 1965.

[3] R. Hagedorn and J. Ranft, CERN/ECFA 67/16, Vol. I, 1967, p. 70.

[4] L. Koester, NAL Summer Study Report EA-67-79, 1967.

[5]CERN/ECFA 67/16 Vol. I, 1967, p. 8.

[6]G. Cocconi, Lawrence Radiation Laboratory UCRL-16830, Vol. III, 1966, p. 17.

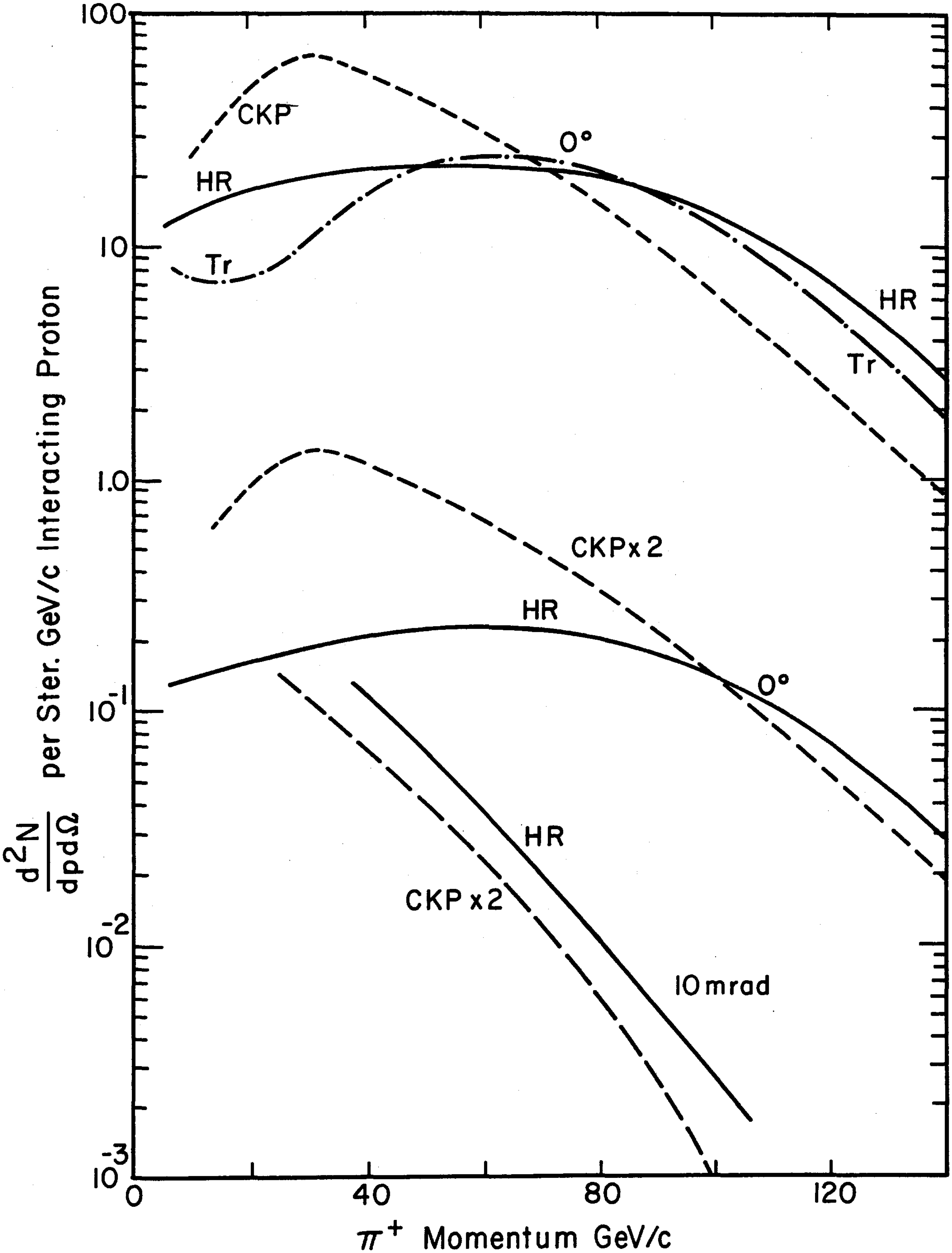


Fig. 1. π^+ yields at 0° and 10 mrad for 200-GeV proton-proton collisions

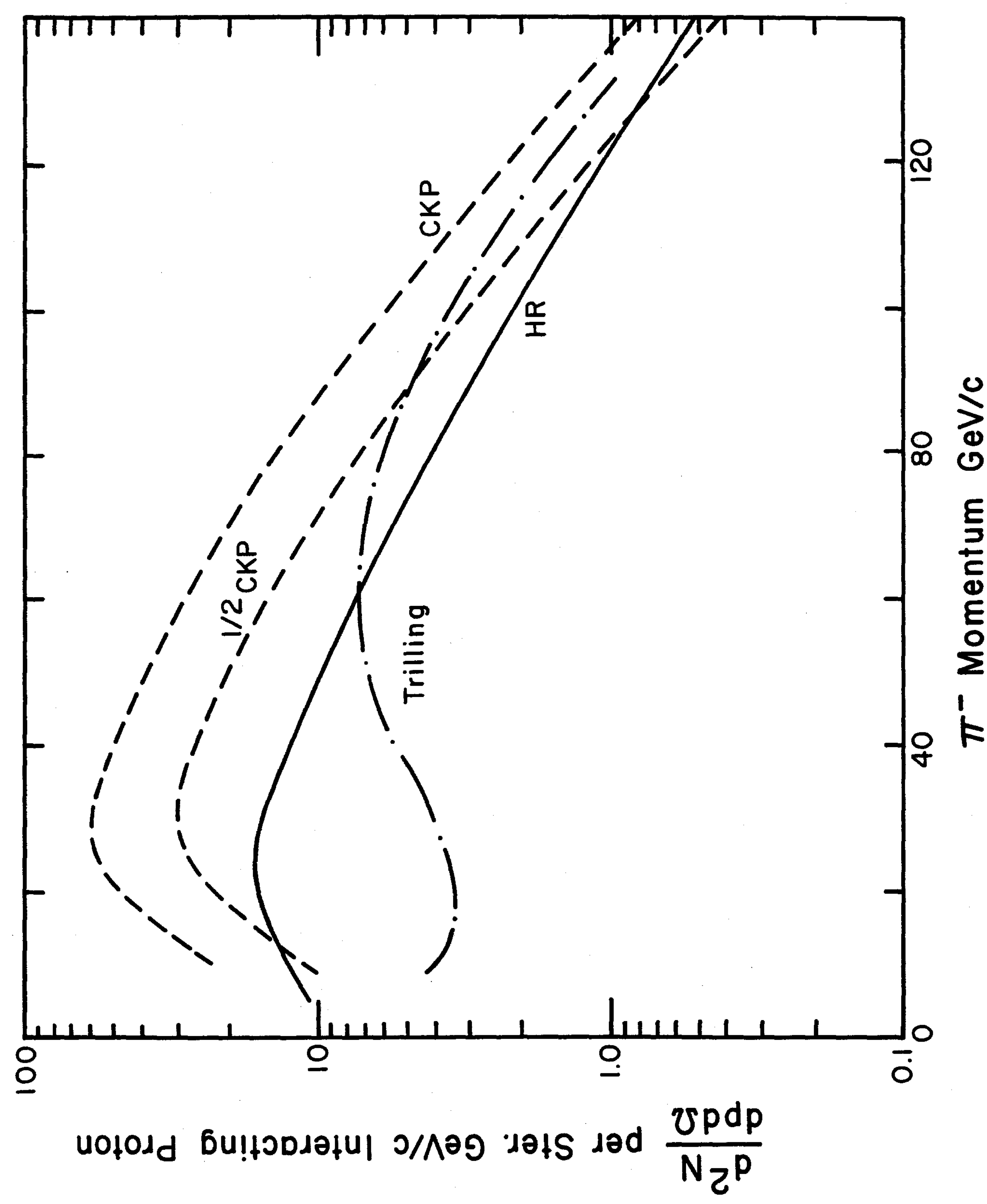


Fig. 2. π^- yields at 0° for 200-GeV p-p collisions according to CKP, Trilling, and HR.

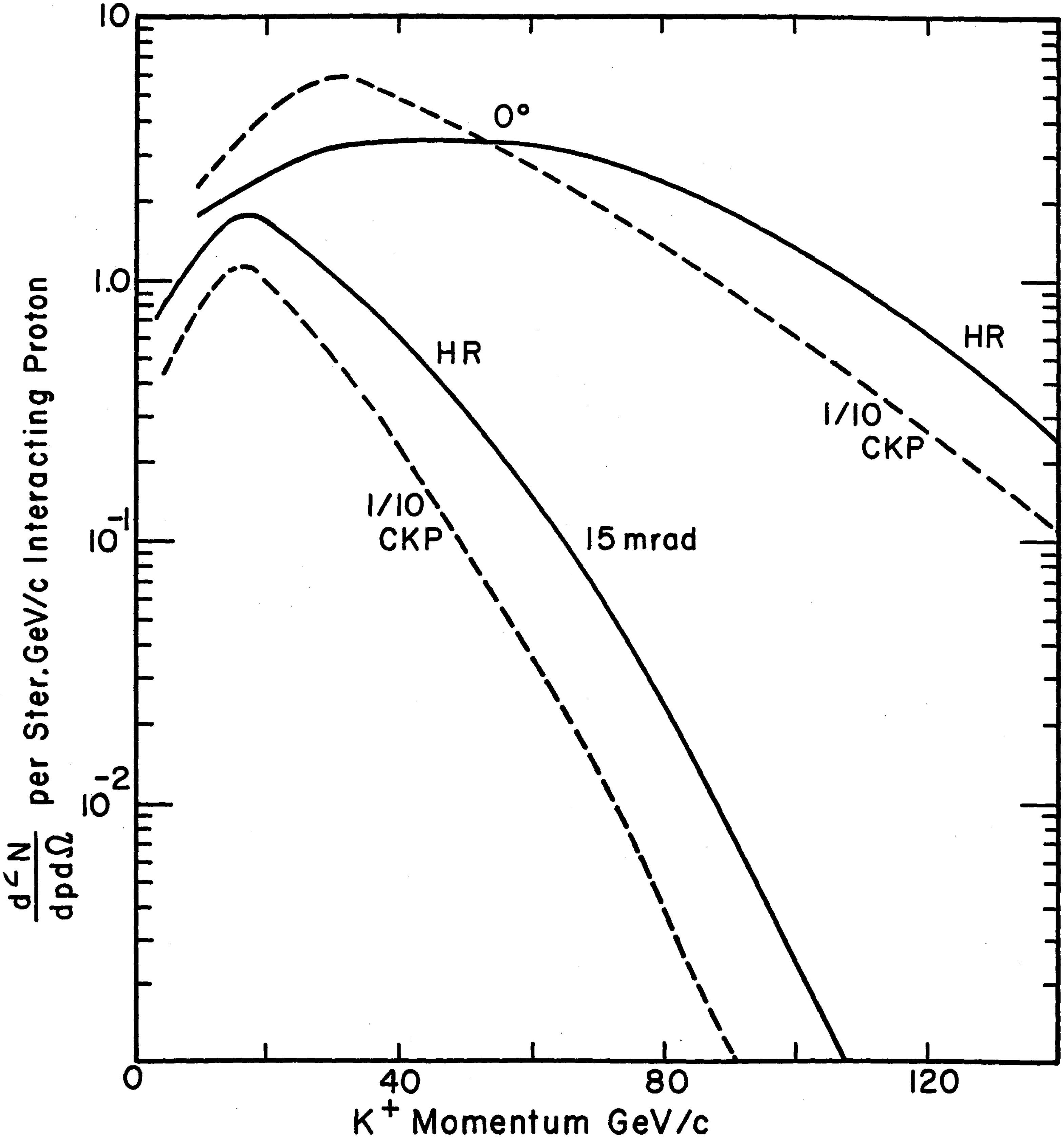


Fig. 3. K^+ yields at 0° and 15 mrad for 200-GeV p-p collisions according to 1/10 CKP and HR.

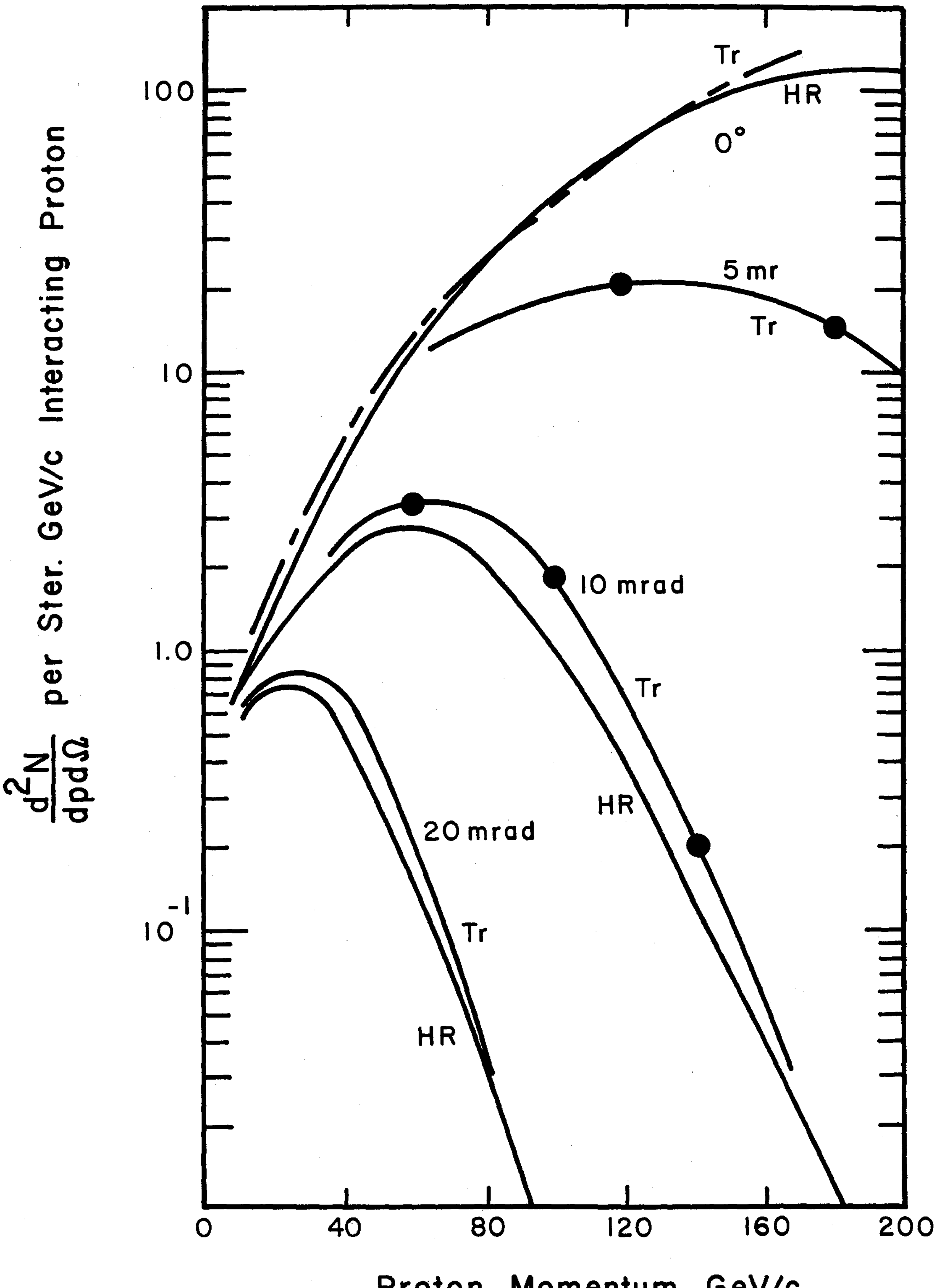


Fig. 4. Proton yields at 0°, 5, 10, 20 mrad for 200-GeV p-p collisions

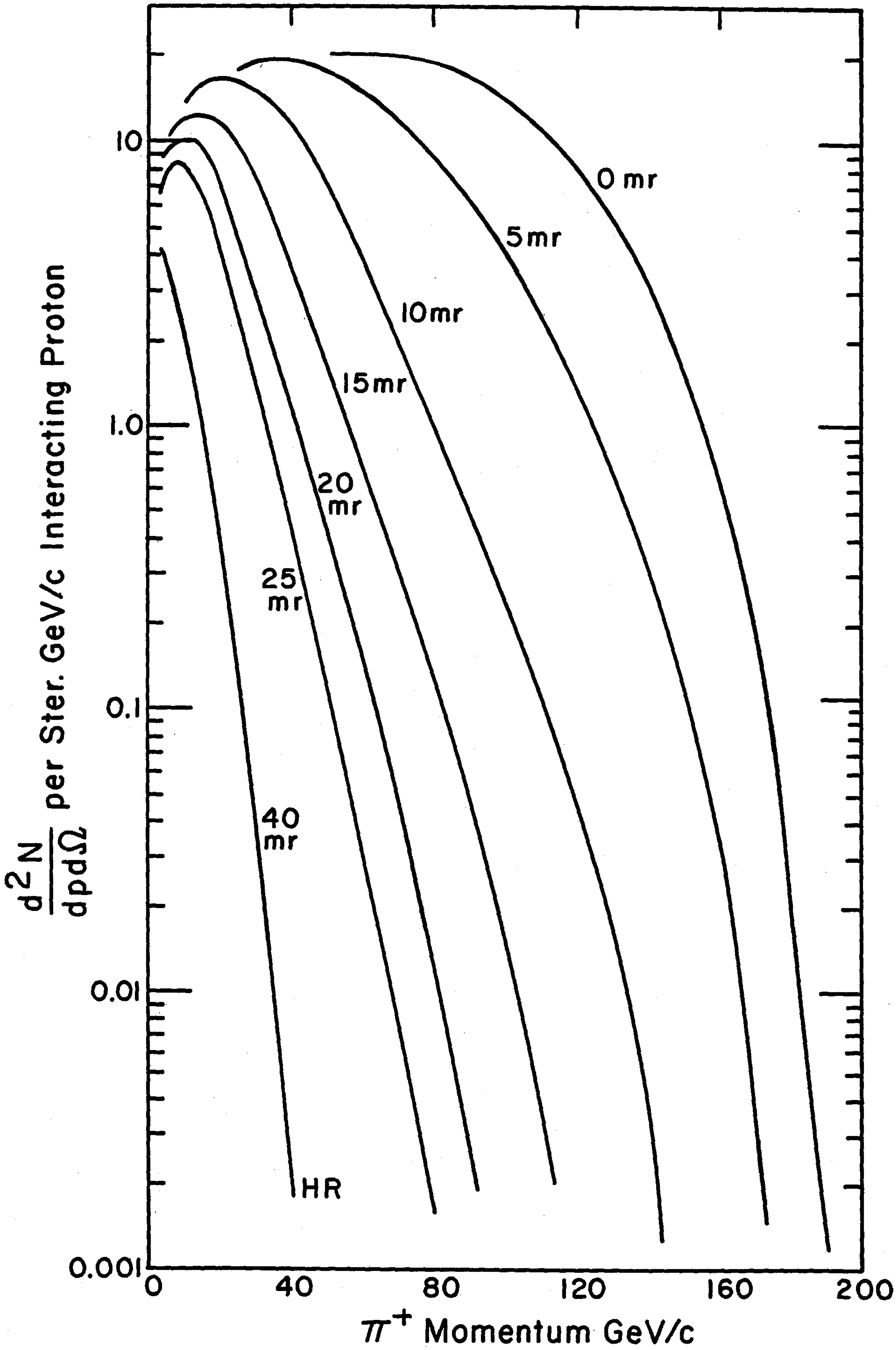


Fig. 5. π^+ yields according to HR for 200-GeV p-p collisions for

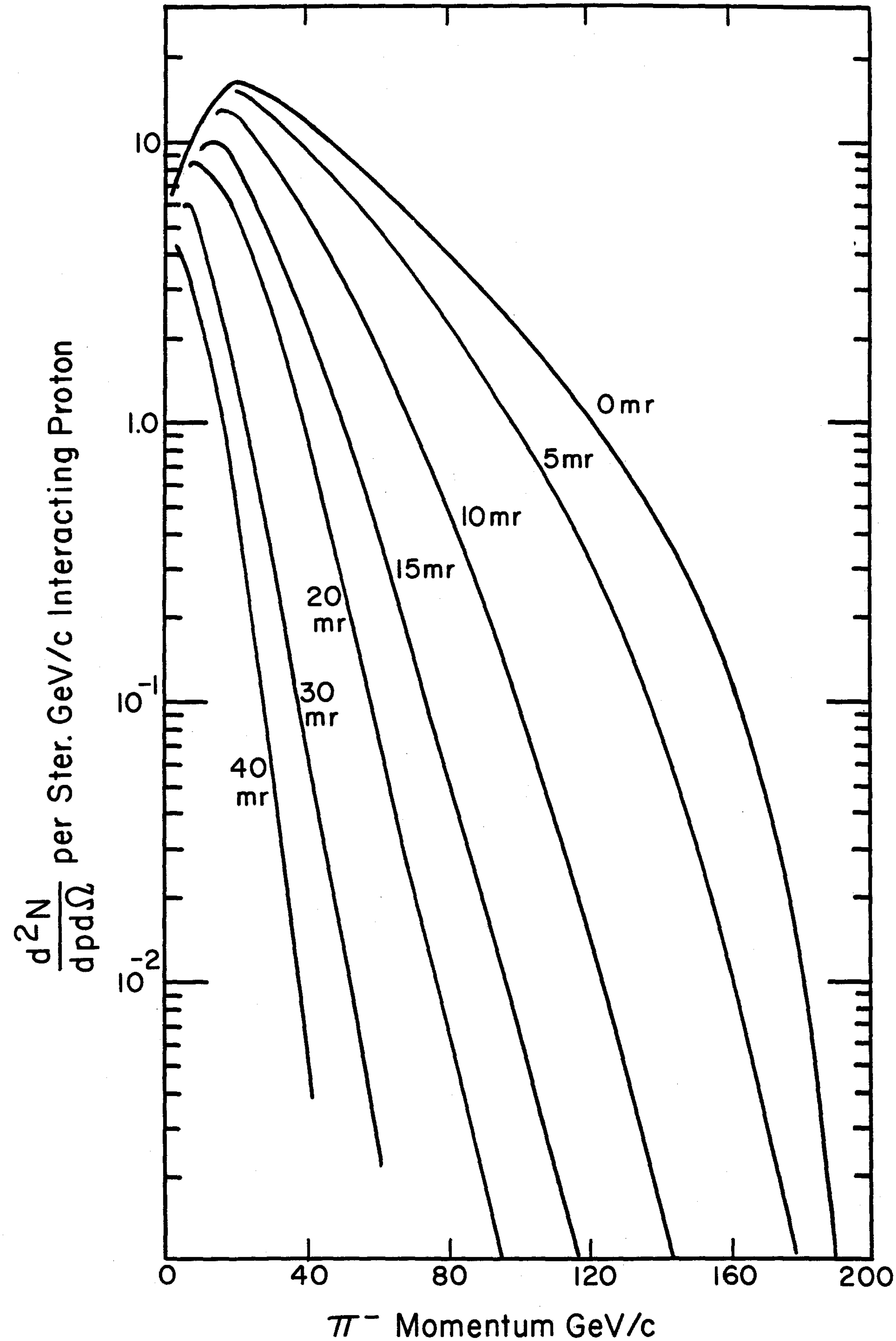


Fig. 6. π^- yields according to HR, as a function of production angle 200 GeV p-p production

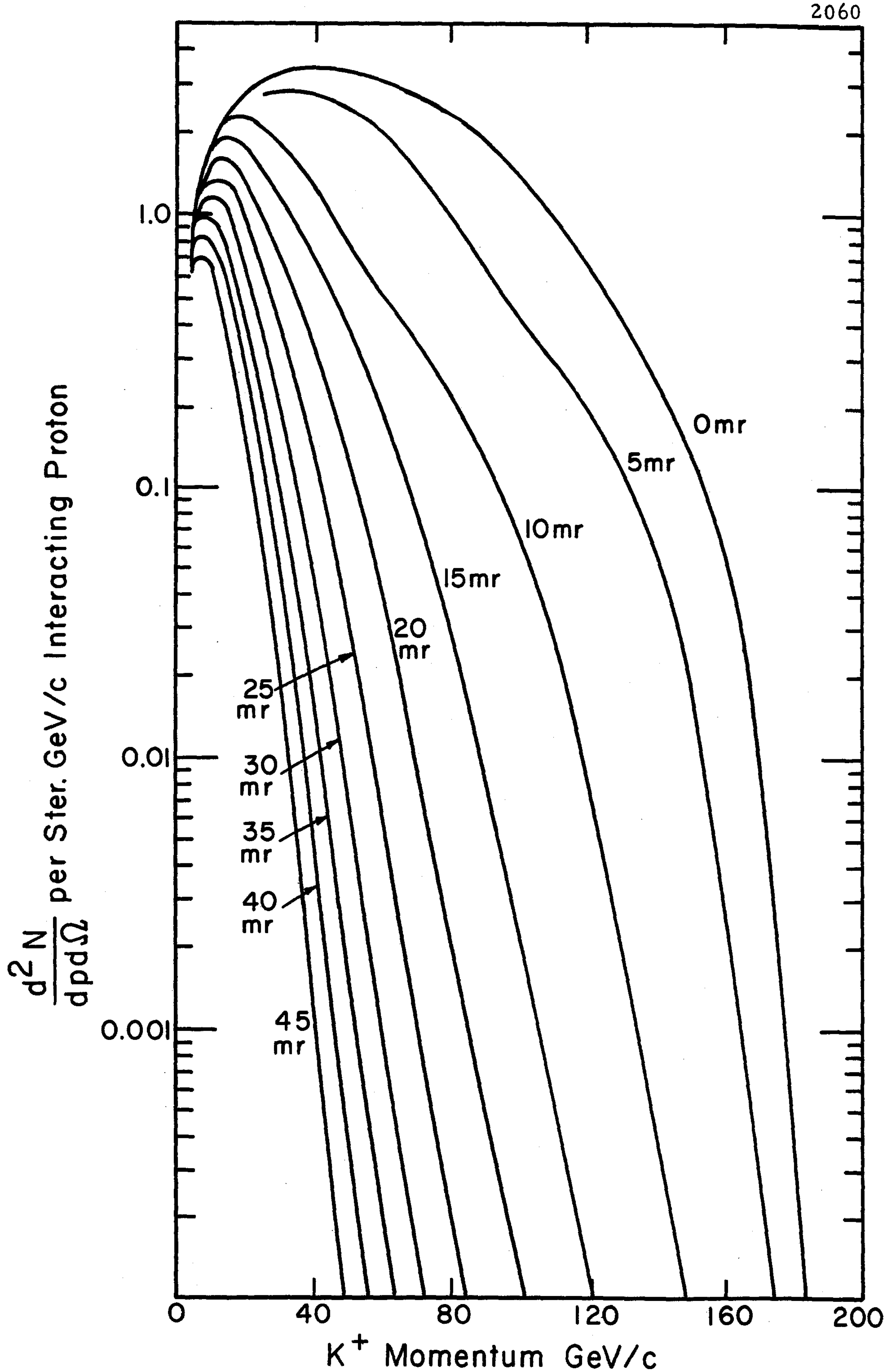


Fig. 7. K^+ yields (HR) as a function of production angle. 200 GeV p-p

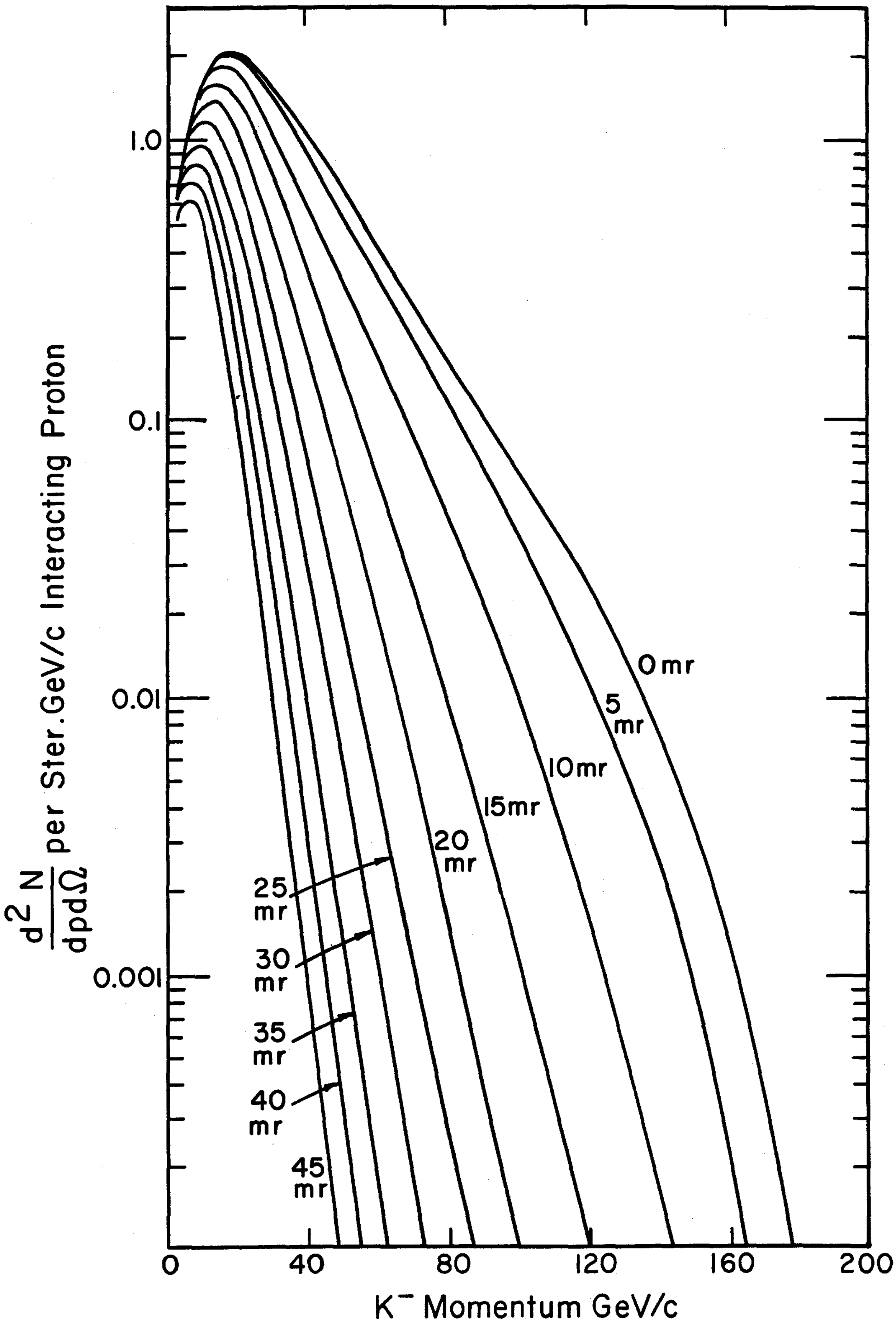


Fig. 8. K^- yields (HR) as a function of production angle. 200 GeV p-p production

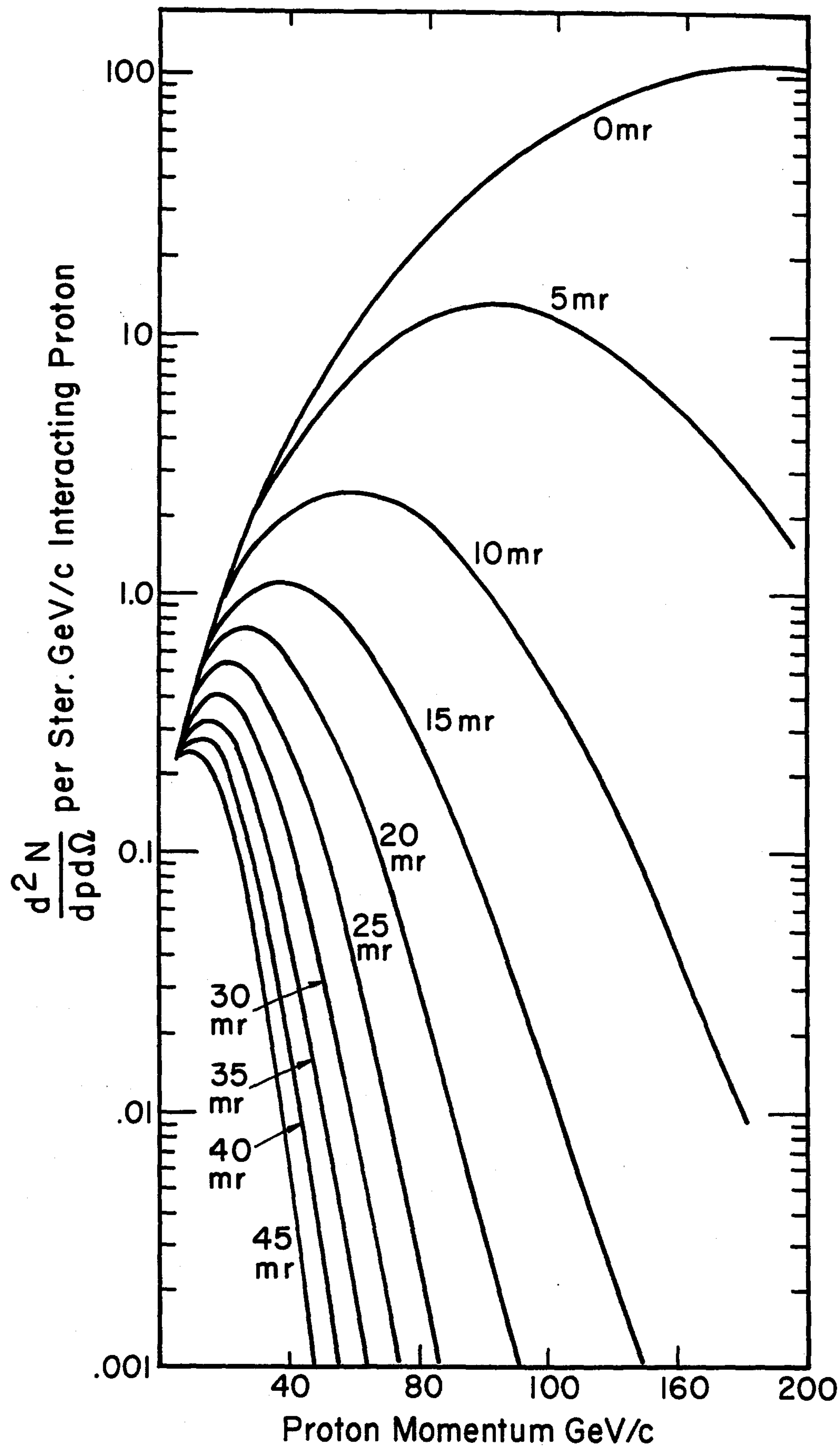


Fig. 9. Proton yields (HR) as a function of production angle. 200 GeV p-p production

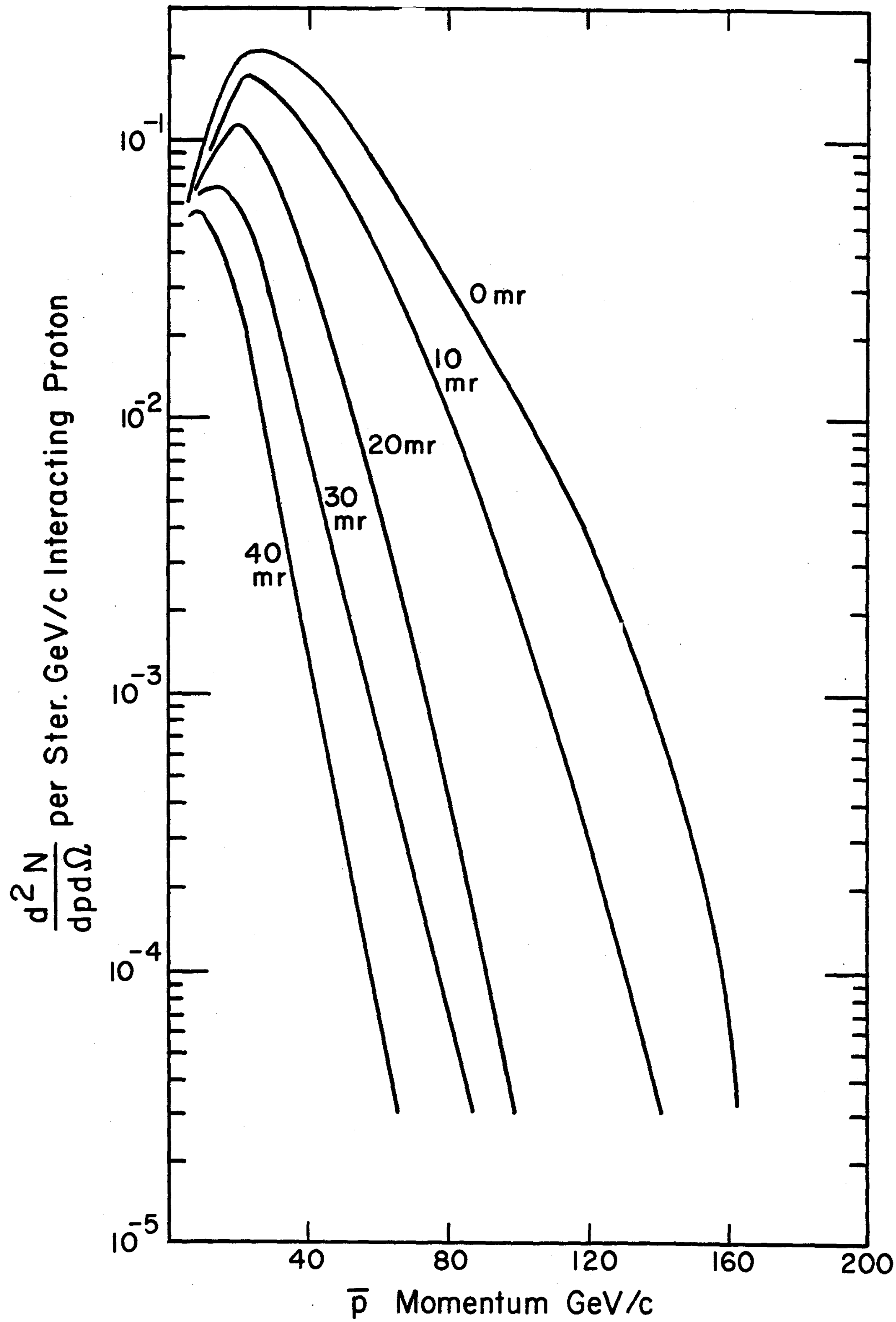
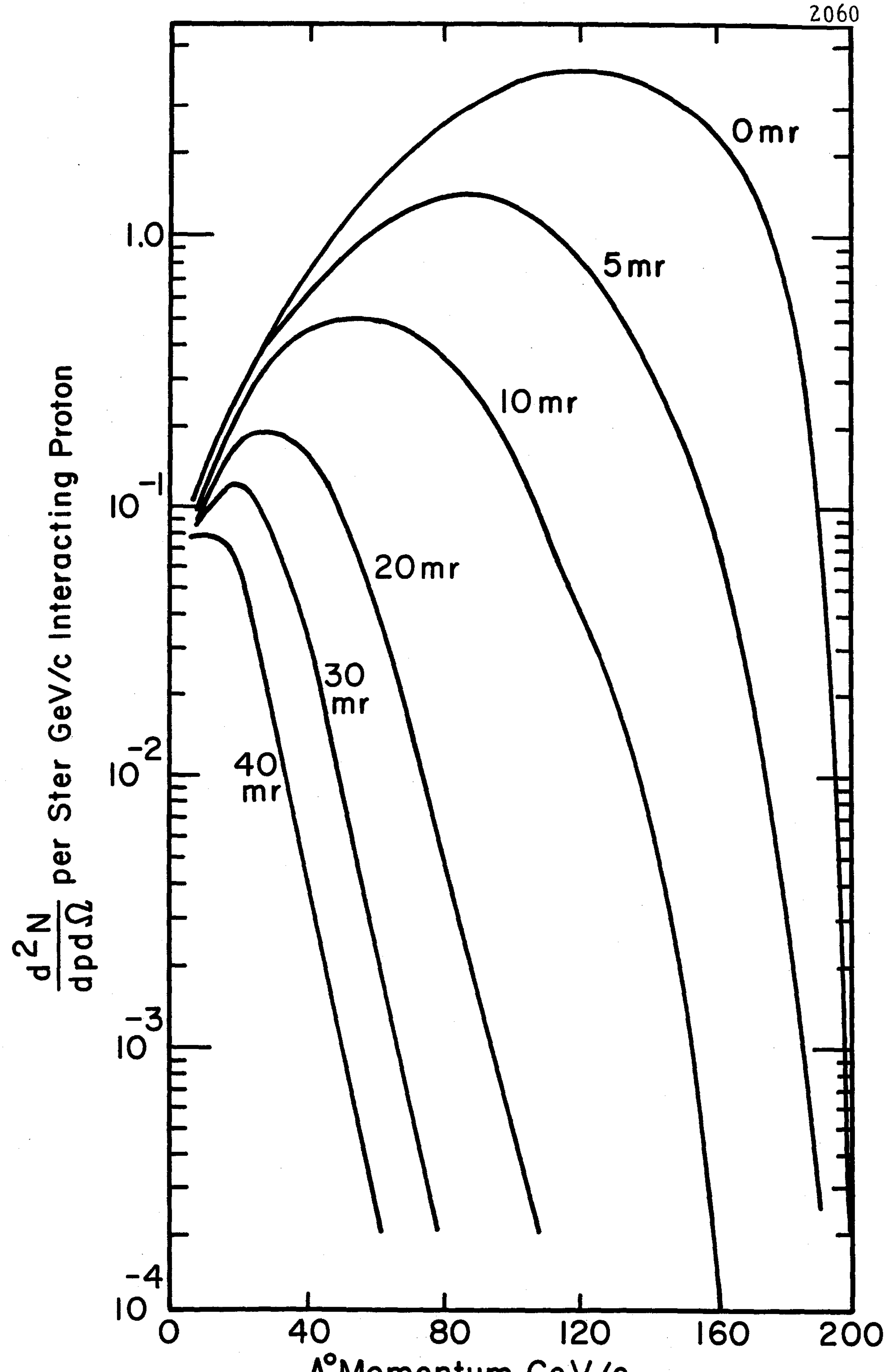
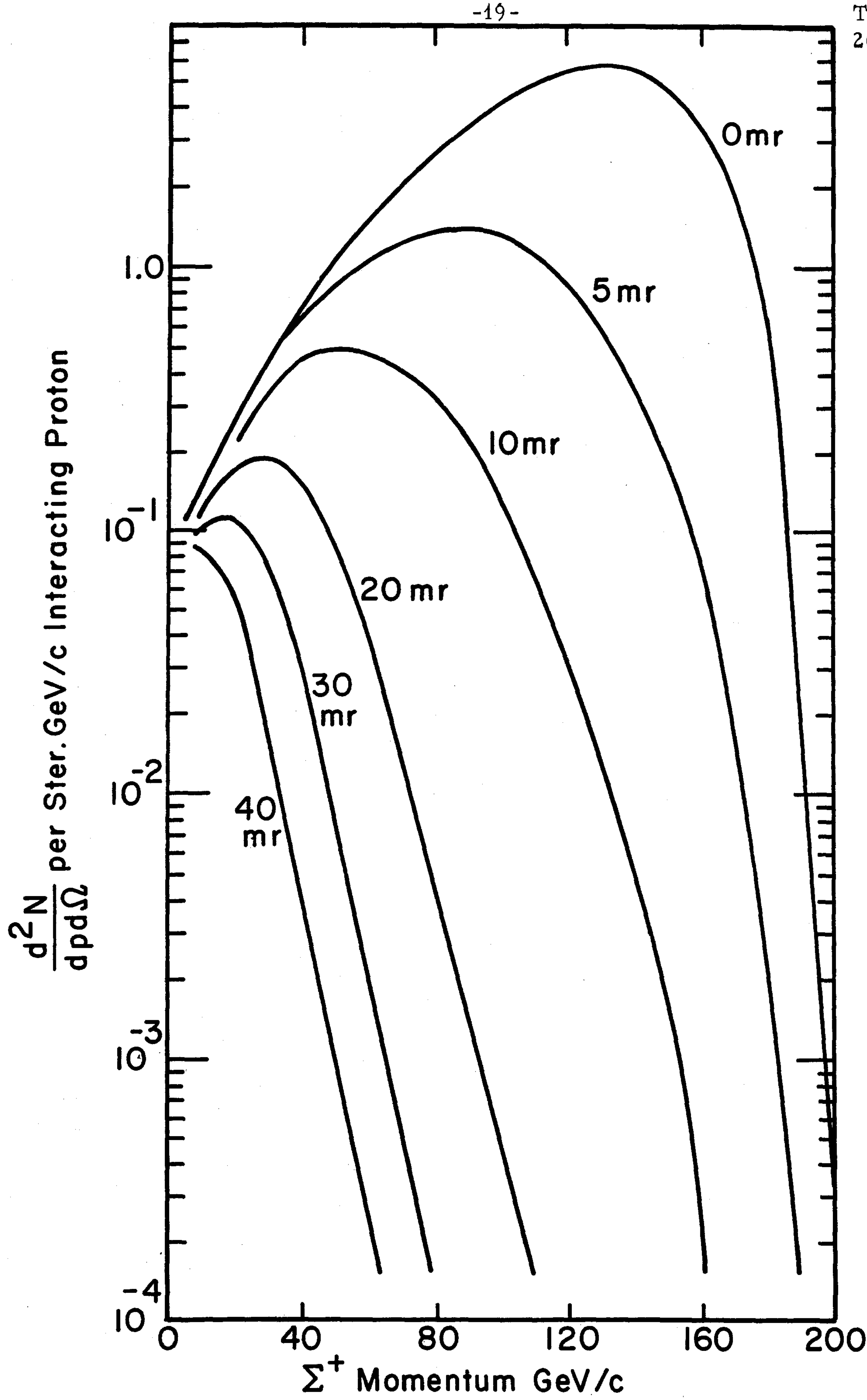


Fig. 10. Antiproton yields (HR) as a function of production angle.


$\frac{d^2N}{dp\,d\Omega}$ per Ster GeV/c Interacting Proton
1.0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0 mr
5 mr
10 mr
20 mr
30 mr
40 mr
0
40
80
120
160
200
Λ° Momentum GeV/c


$\frac{d^2N}{dpd\Omega}$ per Ster. GeV/c Interacting Proton
1.0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
40
80
120
160
200
Σ^+ Momentum GeV/c
0mr
5mr
10mr
20mr
30 mr
40 mr

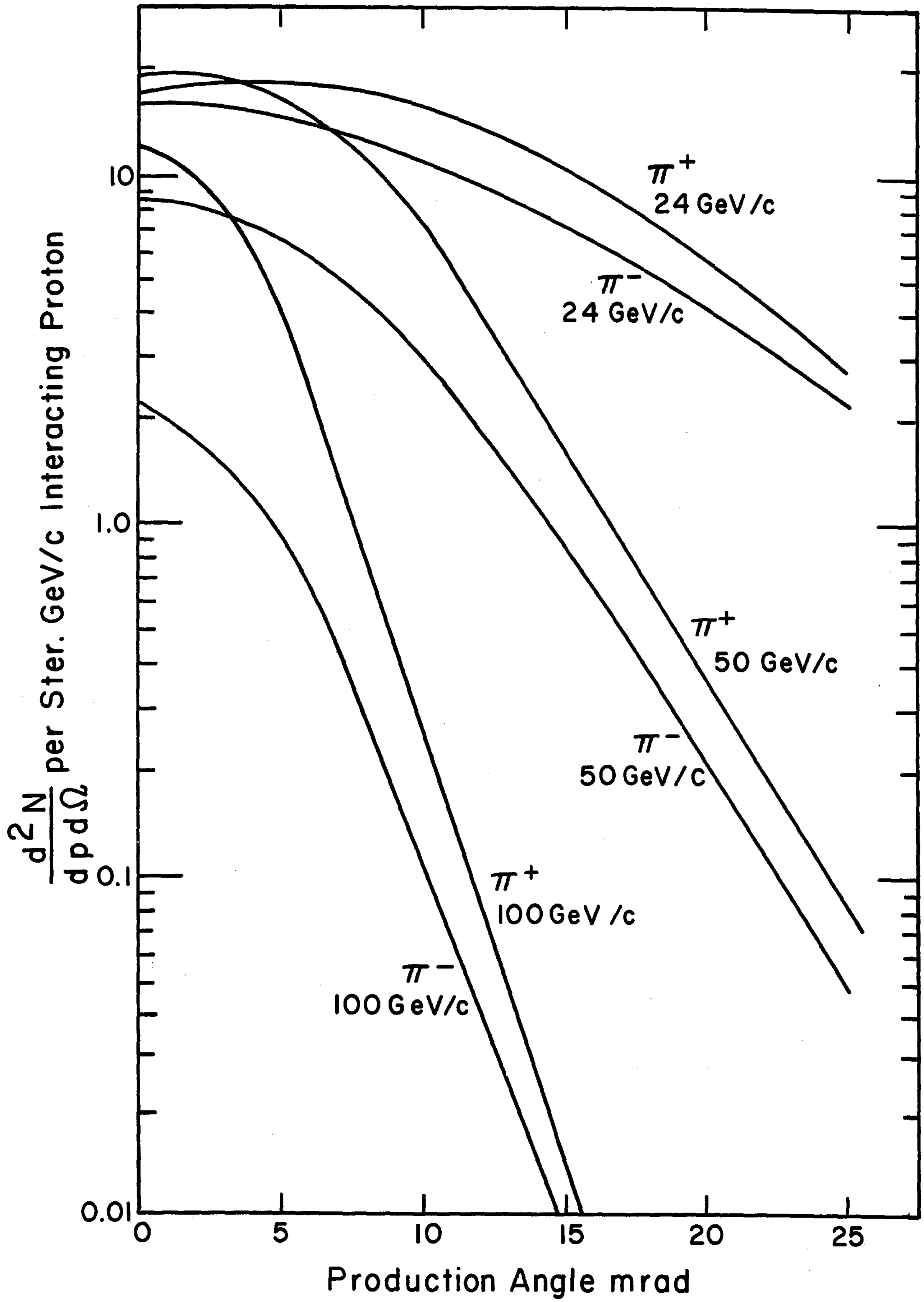


Fig. 13. Total yields at 25, 50, 100 GeV/c as a function of production

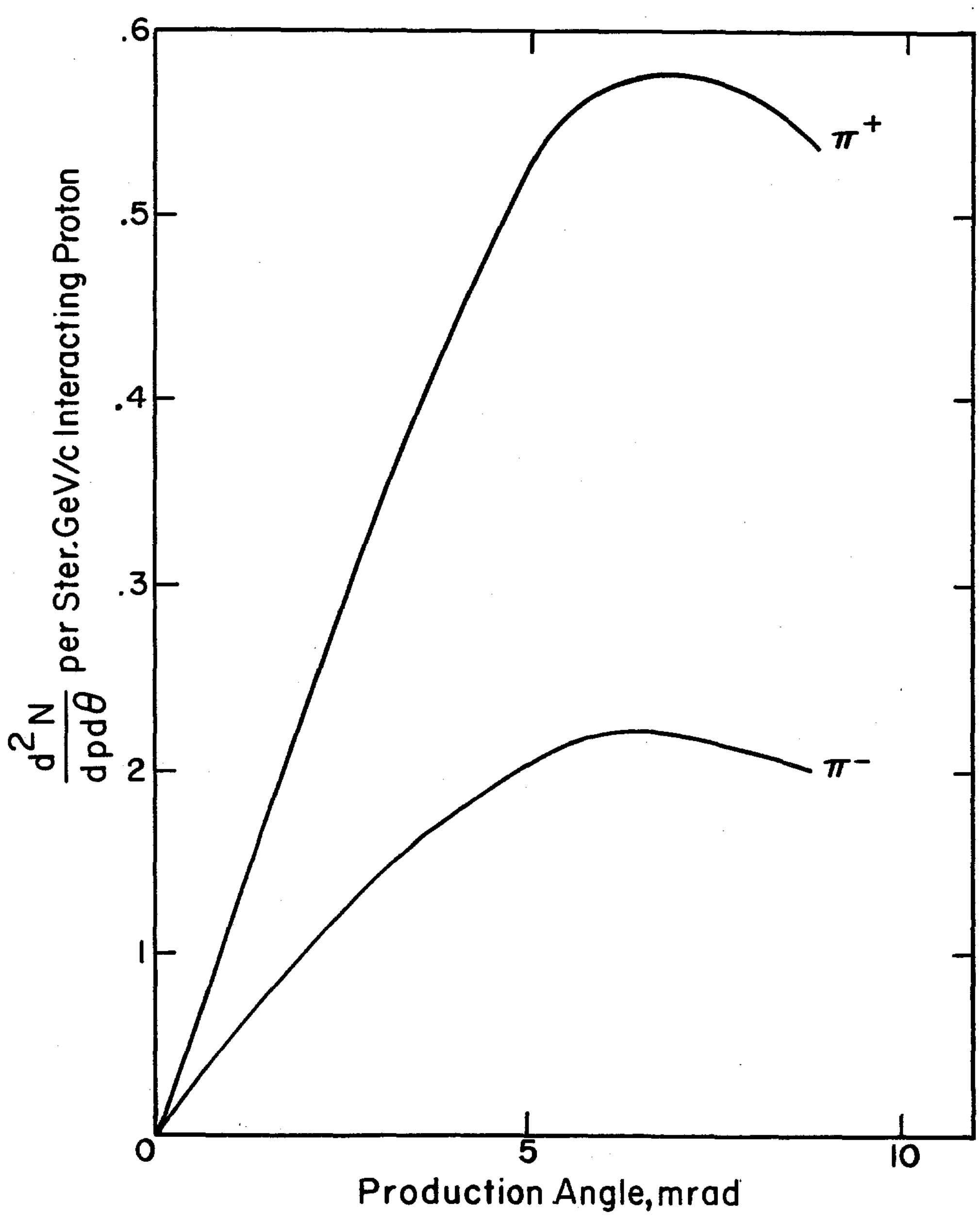


Fig. 14(a). $\pi^{\pm}$ yields per unit angle at 50 GeV/c as a function of production angle.

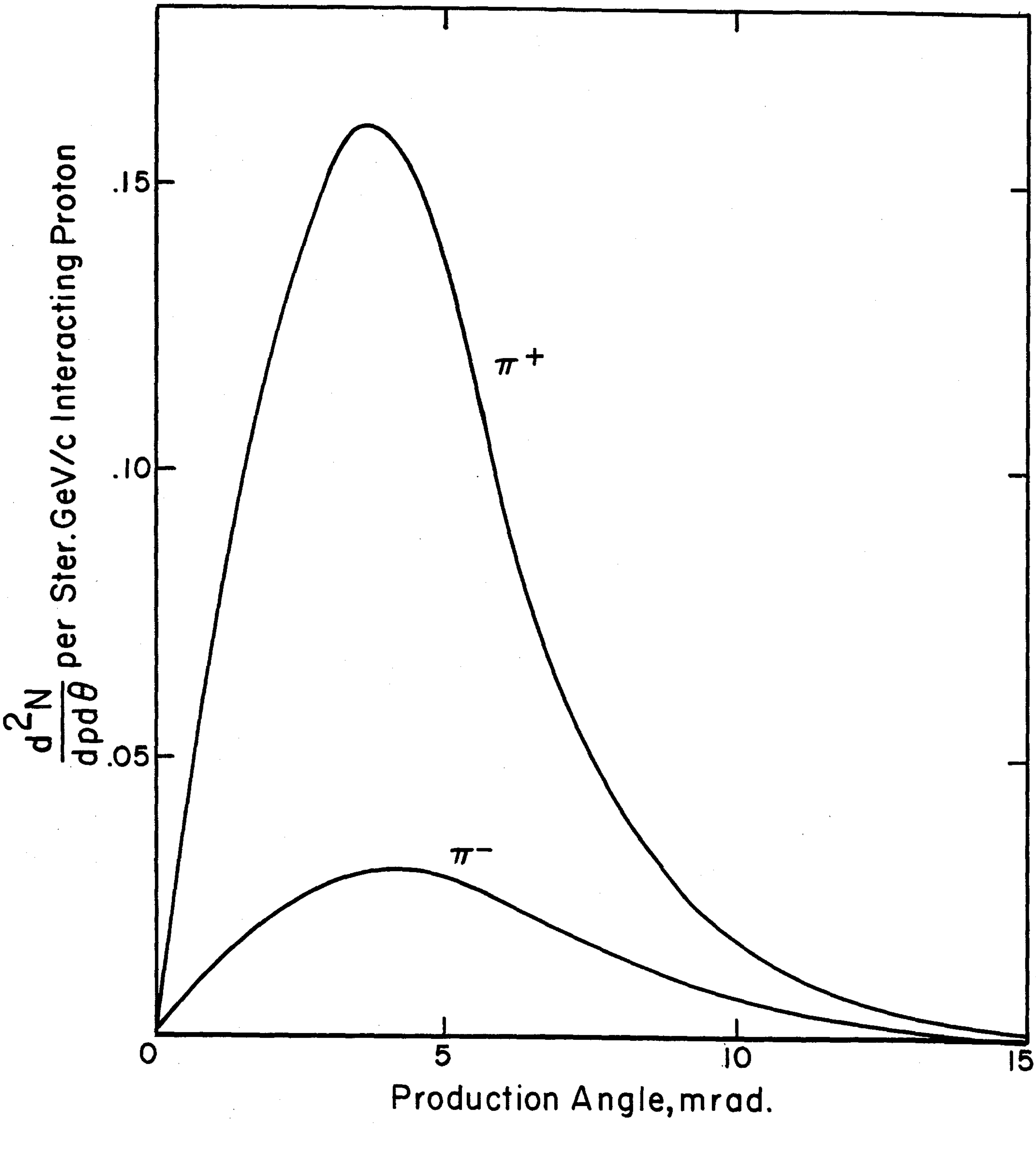


Fig. 14(b). $\pi^{\pm}$ production yields per unit angle at 100 GeV/c, as a function of production angle.

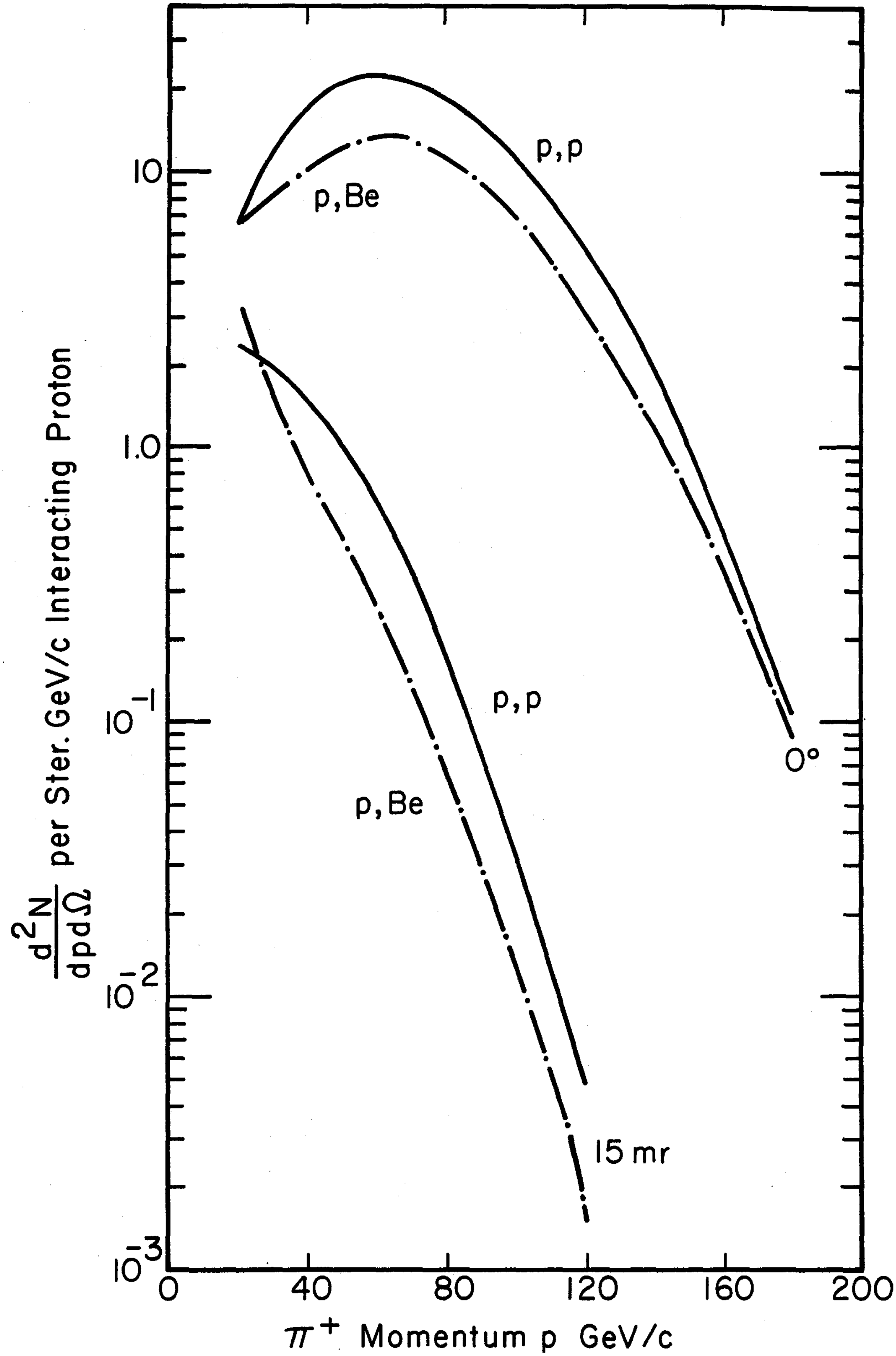


Fig. 15. π^+ yields at 0° and 15 mrad according to the Trilling model