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DISTRIBUTION OF THE SYNCHROTRON RADIATION FROM BENDING MAGNETS

This note describes the distribution of the synchrotron radiation from the bending magnets (BM) around the vacuum chamber, crotches, and absorbers in the storage ring of the Advanced Photon Source (APS).

The layout of a 26.5-m-long sector of the Chasman-Green lattice for the APS is shown in Fig. 1 with the locations of BM (M1, M2), crotches (C1, C2), and absorbers (A1-A4). There are additional absorbers near the locations of C1 and C2. The source of the BM beam line is the M2 magnet. Bending magnets M1 and M2 are of the same kind, being distinguished because of their different locations with respect to the straight section. The relevant storage-ring parameters used in this note, listed below, are for the maximum level of the radiation:

Positron Beam Energy	E = 7.0 GeV
Positron Beam Current	I = 300 mA
Magnetic Field of BM	B = 0.60 T
BM Length	L = 3.06 m
Bending Radius	ρ = 38.9611 m

The total radiation power from one BM is $1.267\ E^2B^2\ IL = 20.5$ kW. The radiation power density for a unit angle of 1 mrad in the horizontal direction is given by

$$P_D = 12.4\ E^4\ BI\ F(\gamma\psi)\ W/(\text{mrad})^2,$$

where $F(\gamma\psi)$ can be approximated by a normal distribution

$$F(\gamma\psi) = 0.4375\ e^{-\left(\frac{\gamma\psi}{0.608}\right)^2/2}.$$

Here $\gamma = E/m_oc^2$ and ψ is the vertical angle.

Figure 2 shows the distribution of the synchrotron radiation on the vacuum chamber wall when there are no crotches or absorbers. The radiation in the vertical axis is the integrated value over the vertical opening angle and per unit length along the vacuum chamber wall in the horizontal direction. The distance from the storage-ring orbit to the wall in the radial direction is 23.81 cm.

The distribution of the absorption by crotches and absorbers for the synchrotron radiation of Fig. 2 is shown in Fig. 3. It is assumed that the distance from the storage-ring orbit to the edges of the crotches and absorbers is 3 cm. The radiation from the M1 magnet is absorbed by C1 (64.5%), A1 (25%), and C2 region absorber (7.5%). Due to the slit opening for the insertion-device (ID) beam near the C1 crotch region, the remaining 3% of the M1 radiation goes to the ID beam line. (Detailed beam profile at C1 will be described in Fig. 6.) Here, 100% of the radiation from one BM at 7.0 GeV and 300 mA is 20.5 kW. The radiation from M1 does not hit the vacuum chamber directly in the arrangement of the sector shown in Fig. 1.

Because of the straight section (SS) and the extraction of a BM beam, the absorption of the M2 radiation is somewhat different from that of the M1 radiation. First, 87% of the M2 radiation will be absorbed by C2 (53.5%), C2 region absorber (8.5%), A2 (22%), and C1 region absorber (3%). Another 7.5% of the radiation goes to the BM beam line. The absorption of the remaining 5.5% of the M2 radiation is dependent on the use of the SS. (Further details of the BM beam and C2 will be described in Figs. 6 and 7).

When the SS is used for rf cavities or during the initial operation of the machine, the wall distance from the storage-ring orbit will be larger than 7 cm. In this case, the remaining 5.5% of the M2 radiation does not hit the wall at all. It is absorbed by A3 (4.5%) and A4 (1%).

When the SS is used for an ID, the distance from the storage ring orbit to the vacuum chamber wall in the present design is 3 cm. The distribution of the radiation along the ID vacuum chamber for this case is shown in Fig. 4. With the edge of the A2 absorber 3 cm away from the storage-ring orbit, the radiation is distributed all over the SS from −2.5 m to 2.7 m, as shown in Fig. 4. The maximum power density is less than 0.5 W/mm^2. The vertical width of the beam is on the order of 1 mm. The total amount of the power is 4.5% of the M2 radiation. The remaining 1% is absorbed by A4. The

4.5% radiation could be handled without difficulty in the present design of the SS vacuum system.

If the edge of A2 is 2 cm from the orbit, instead of 3 cm, the distribution of the dotted line in Fig. 4 is absorbed by A2, and only that of the solid line is distributed in the SS. This reduces the total power distribution in the SS to 2% of the M2 radiation.

Figure 5 shows the details of the absorption at A1 and A2. The z-axis is the storage-ring beam direction after each corresponding BM, and the x-axis is in the radial direction of the storage ring. The difference in direction of the arrows with units of mrad is the angle between the direction of the radiation and the z-axis. The absorbers make an angle of 60° with the z-axis. The M1 radiation between 25.5 and 5.9 mrad is absorbed by A1, which has a length of 12.6 cm and a width of 0.083 cm. Since the edge of A1 is 3 cm from the orbit, the radiation between 5.9 and 0 mrad goes through the A1 area. The beam cross section A and its radiation power P are listed. The figure also shows that the absorber A2 is not much different from A1.

The beam profiles at C1 and C2 are shown in Fig. 6. The y-axis represents the vertical direction in the storage ring. All other notations are the same as used in Fig. 5. At crotch area C1 the ID beam is near the initial direction of the M1 radiation. With a slit opening of ± 1 cm for the ID beam, small fractions of the M1 and M2 radiations go to the ID beam line as stray beams. The beam width from the M1 radiation varies from 0.026 cm at one end to 0.056 cm near the ID beam. The beam width from the M2 radiation is rather wide because of the long distance to M2.

The beam profile at the C2 area is similar to that at the C1 area, except for the extraction of the BM beam. Figure 6(b) shows that the BM beam is not in the direction of the initial M2 radiation. In order to avoid the end effects of the BM field, the center of the BM beam source is chosen 1/8 of the effective length from the end of the M2 magnet. The exact location of the BM beam and the radiation power density at the C2 area is shown in Fig. 7. The x-axis is the distance from the orbit in the radial direction. The beam below A in Fig. 7 goes through the C2 area. The crotch extends from A to B. The slit opening for the BM beam is between B and D with C as its center. The absorber at C2 area stops the radiation between D and E in Fig. 7, which is approximately 8.5% of the M2 radiation.

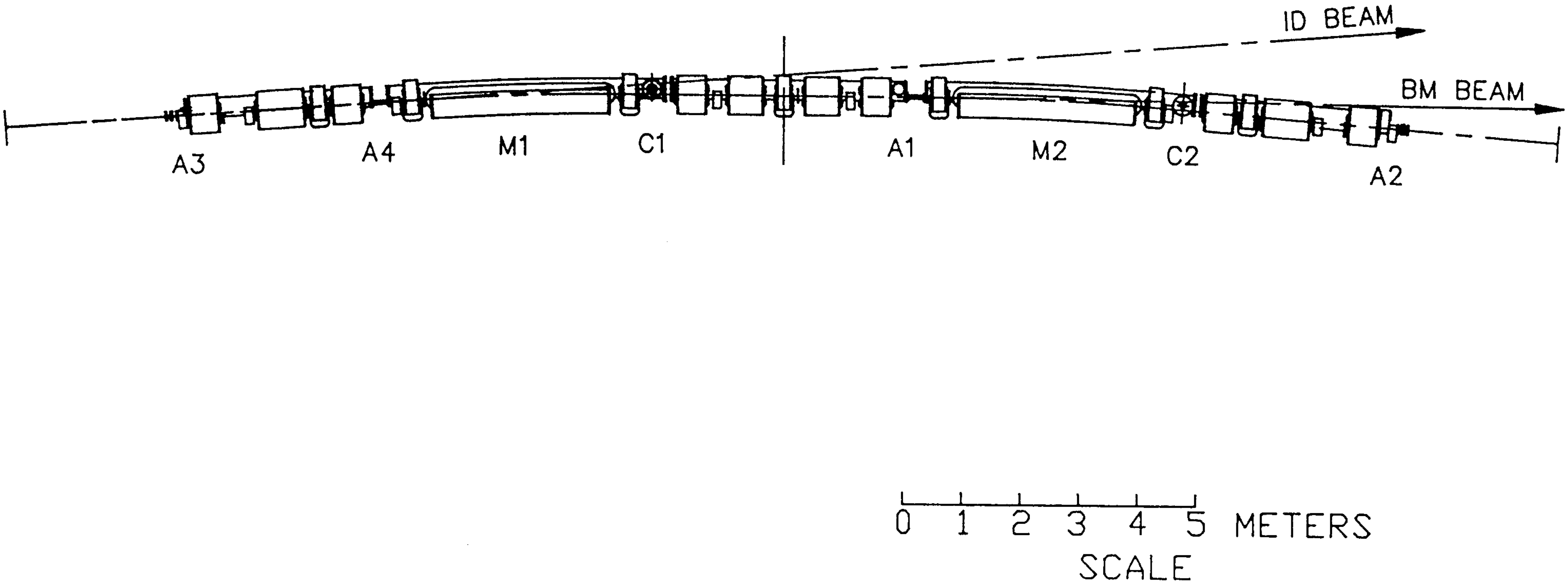

Fig. 1. Layout of a sector of the lattice. The straight sections of both ends are for an insertion device or rf cavities. Other relevant components are M1 and M2 (bending magnets), C1 and C2 (crotches), A1-A4 (absorbers).

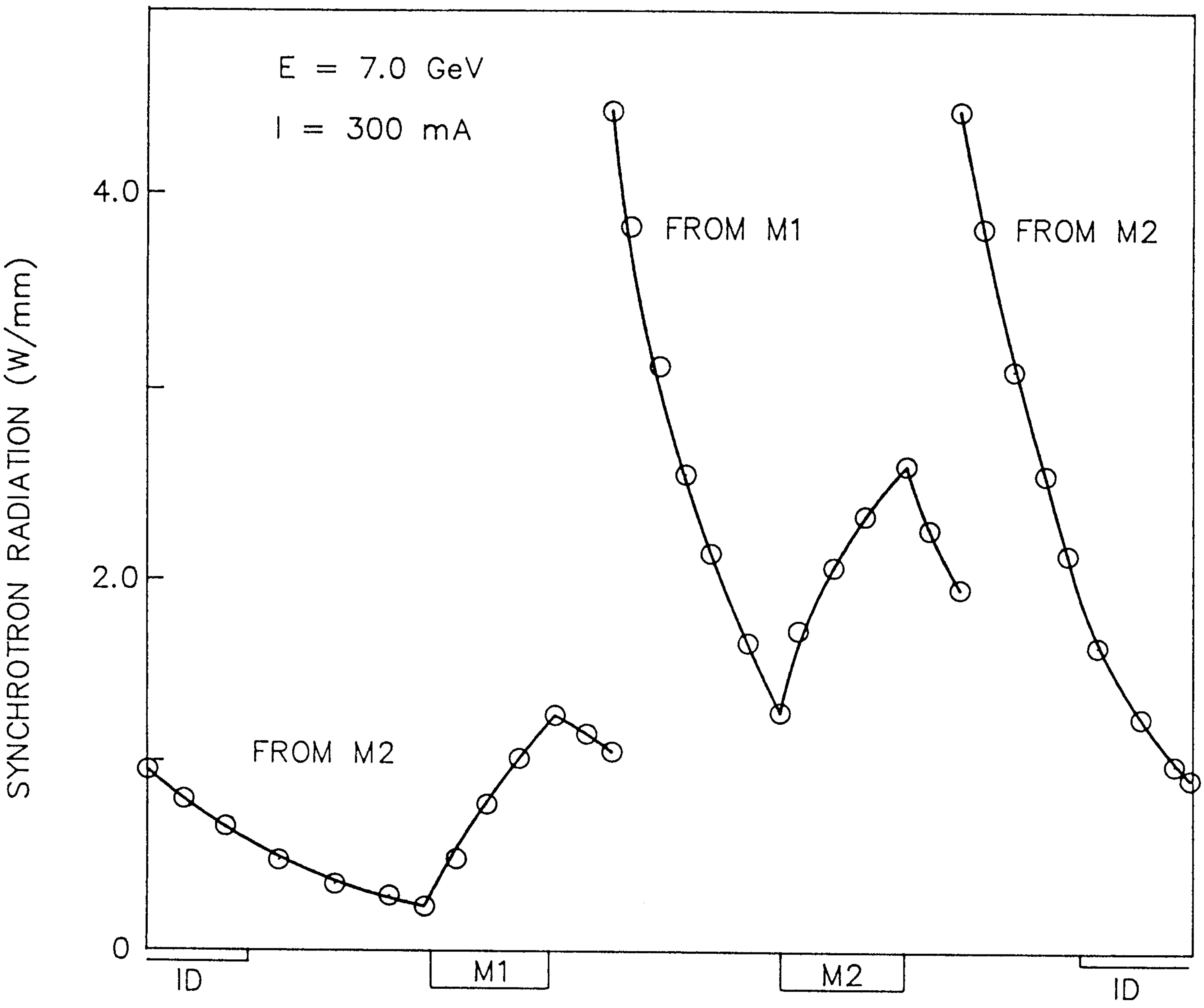

Fig. 2. Distribution of the bending magnet radiation on the vacuum wall chamber without crotches and absorbers. The distance from the storage-ring orbit to the wall in the radial direction is 23.8 cm.

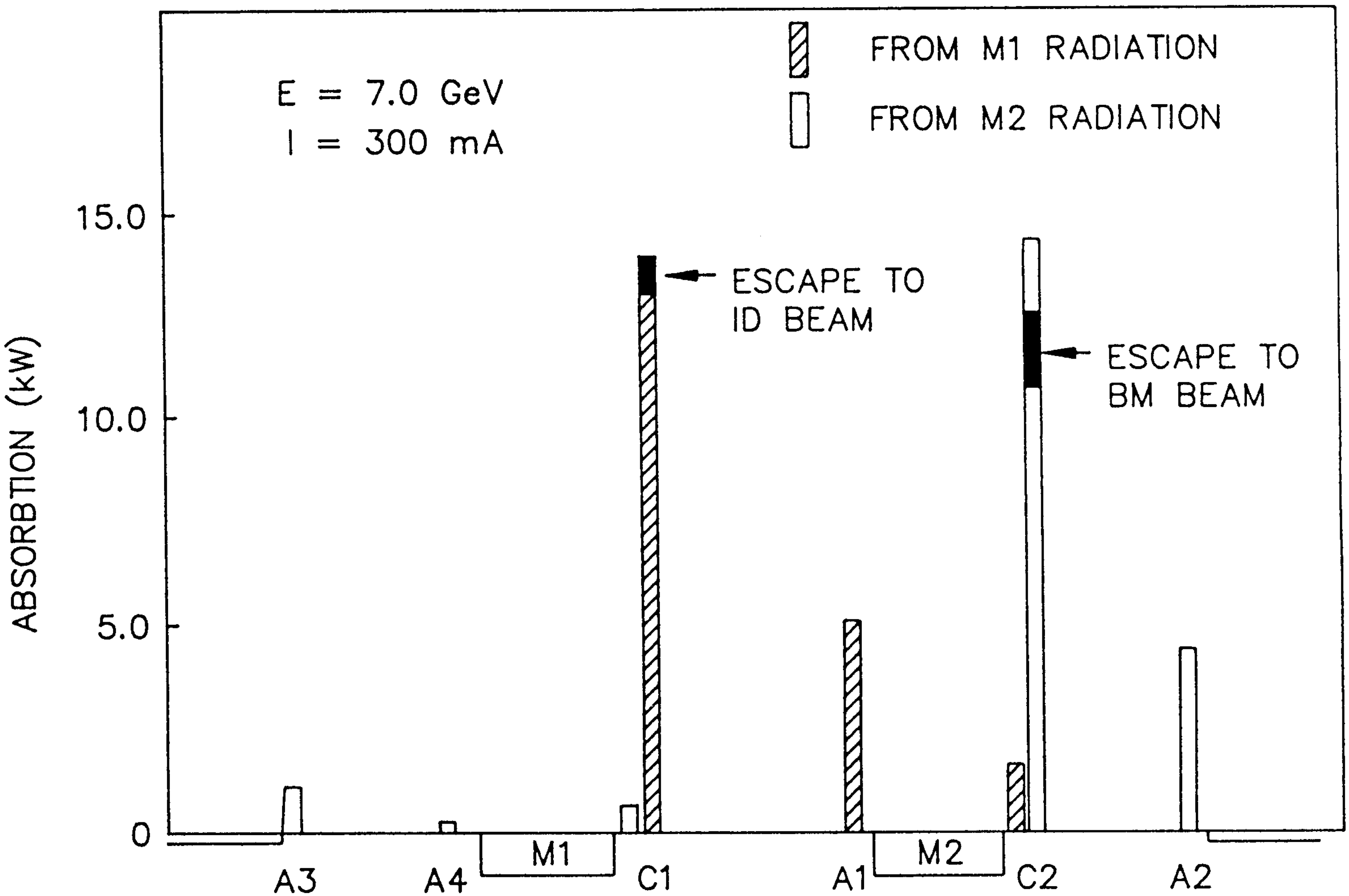

Fig. 3. Absorptions by the crotches and absorbers. The absorption by A3 depends on the use of the straight section.

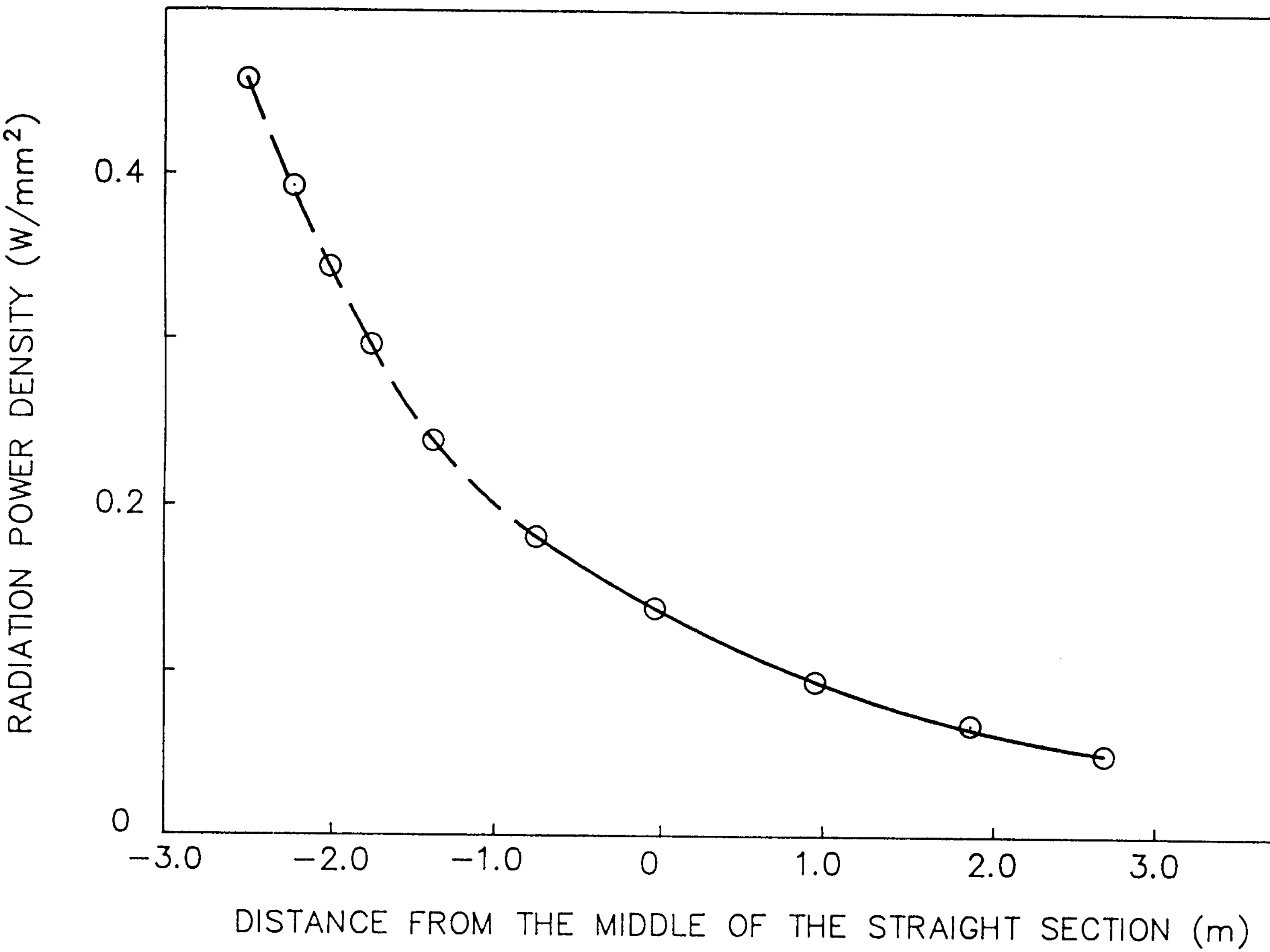

Fig. 4. Radiation power-density distribution in the straight section for the wall distance from the storage-ring orbit of 3 cm. When the edge of A2 is 3 cm from the orbit, the radiation extends through the whole straight section. When the edge is 2 cm from the orbit, the radiation extends only to the solid curve. The density is averaged within the vertical angle of ± 0.075 mrad.

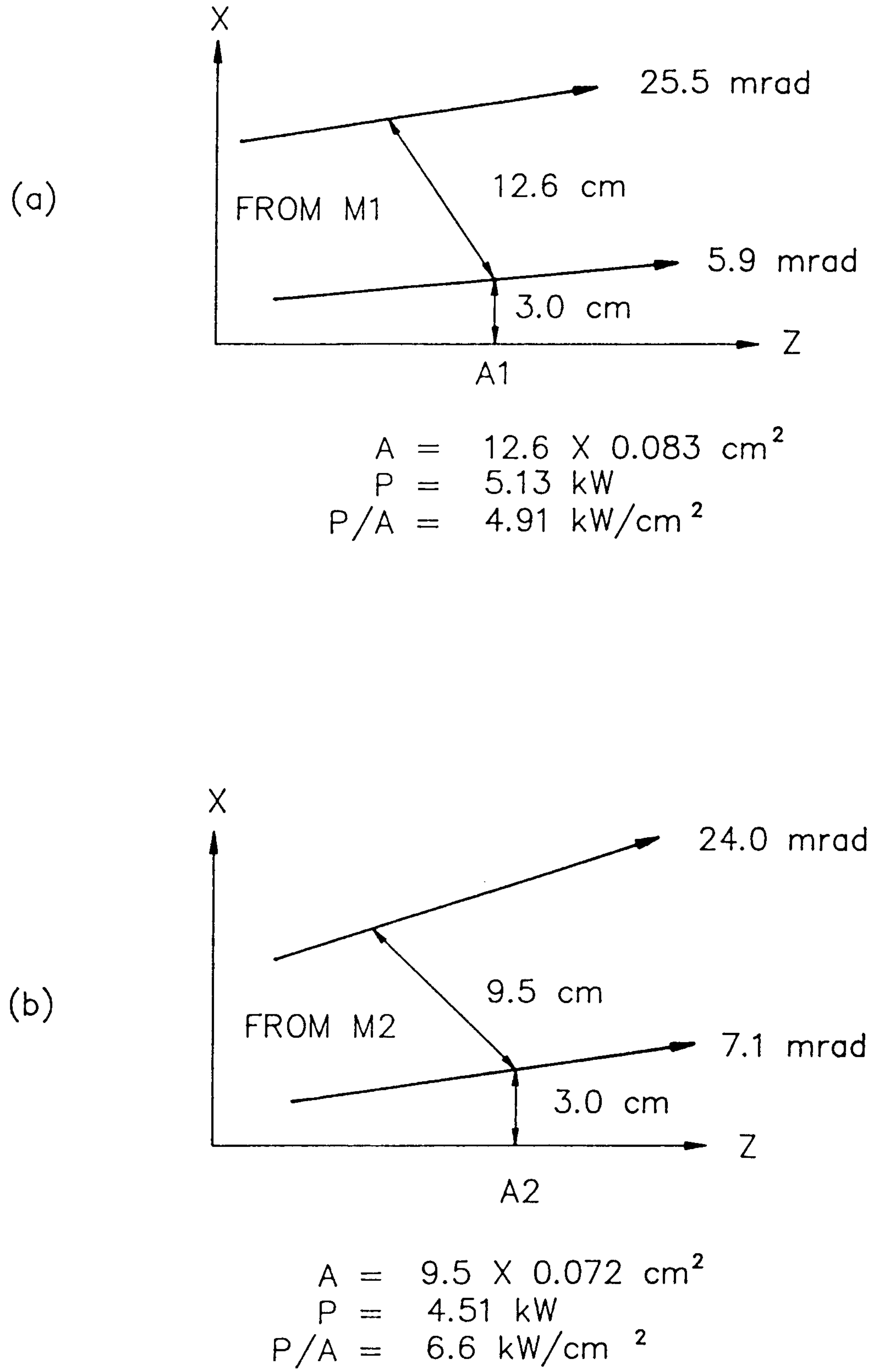

Fig. 5. Synchrotron radiation beam profile, total power, average power density at the absorbers of A1 and A2. It is assumed that the absorbers are 3 cm from the orbit and tilted 60°. Here, A and P are the beam cross section and radiation power, respectively. (The figures are not in scale.)

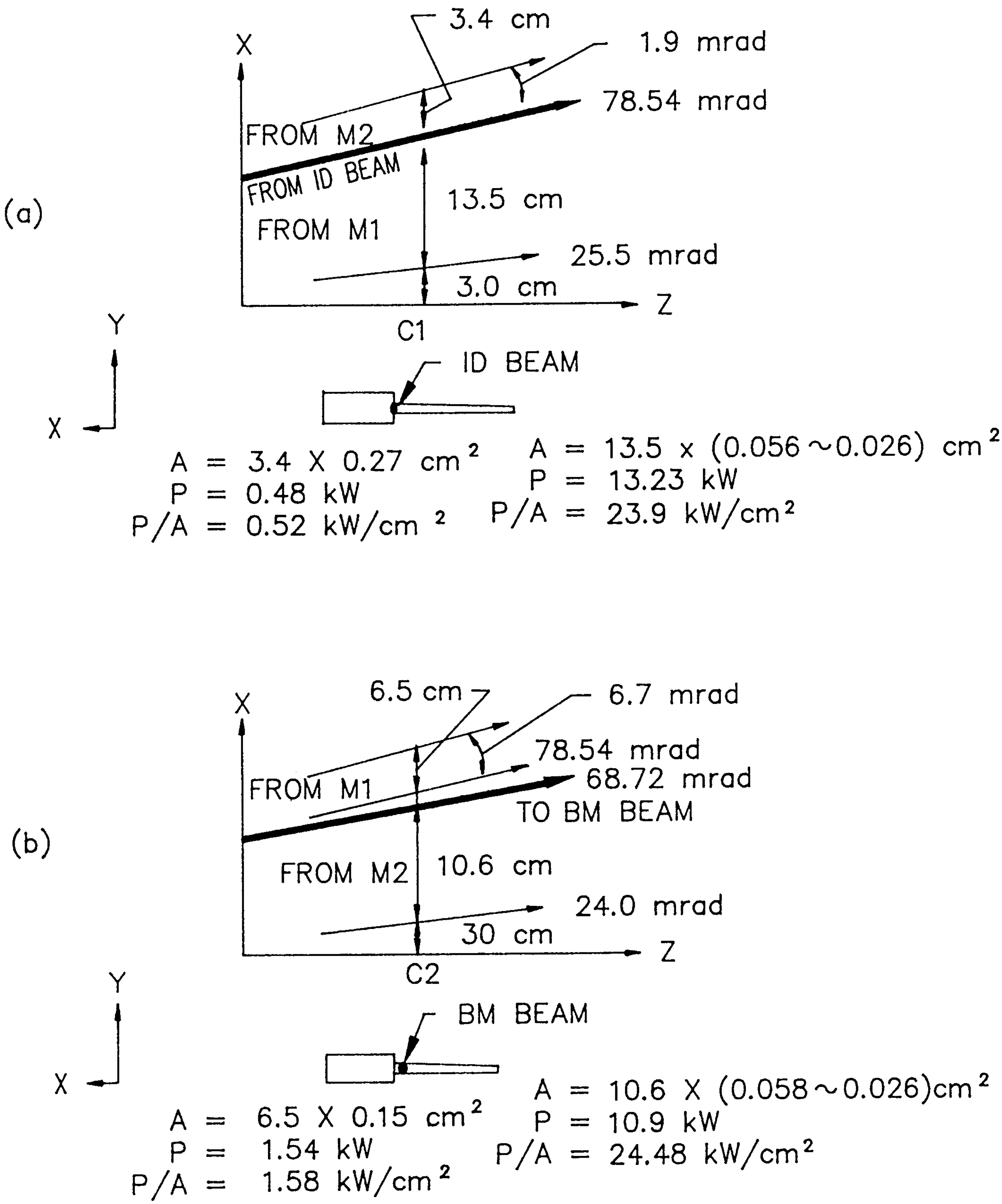

Fig. 6. Synchrotron radiation beam profile, total power, average power density at the crotches of C1 and C2. The locations and directions of the ID and BM beams are also shown. (The figures are not in scale.)

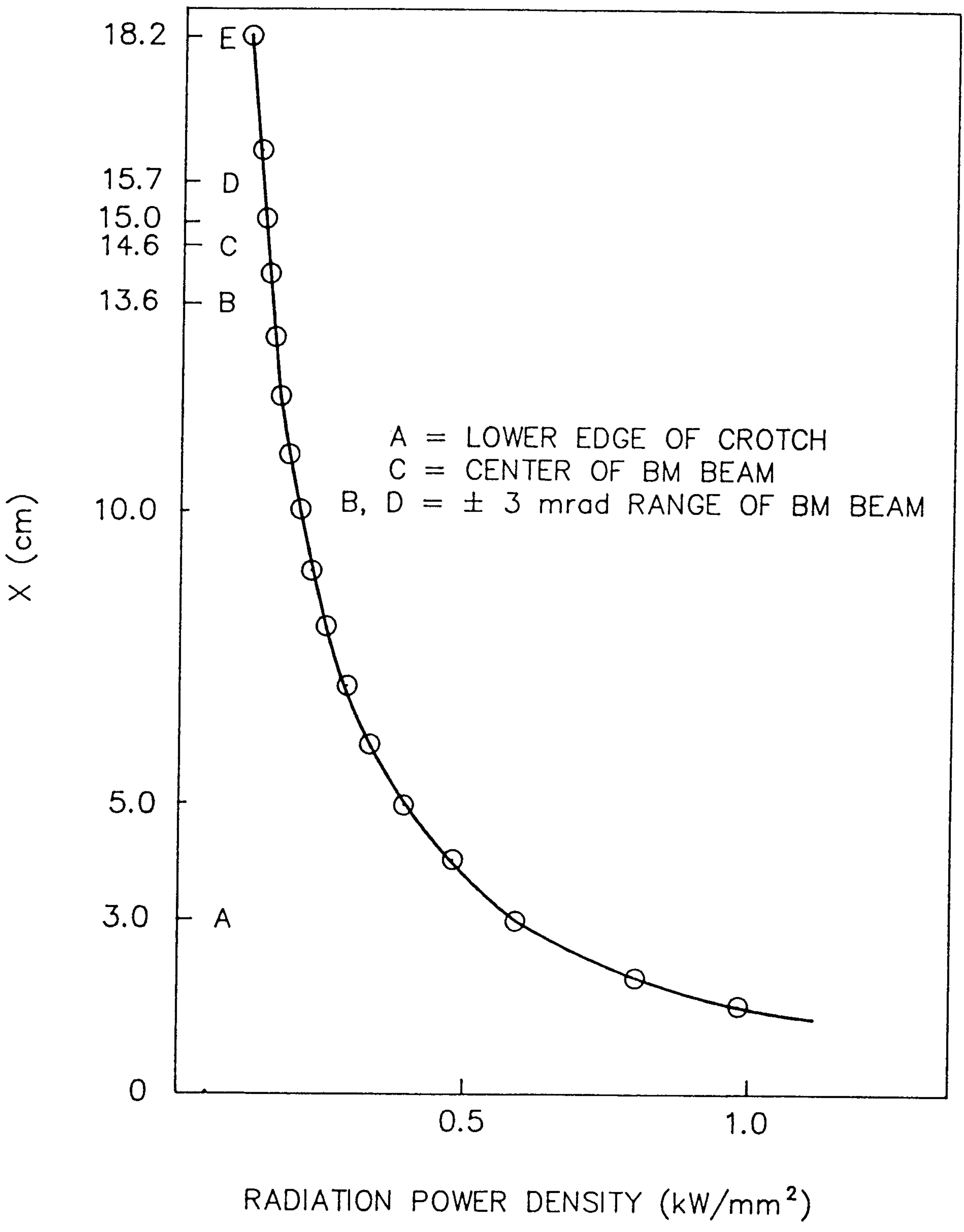

Fig. 7. Radiation power density and the location of the BM beam at crotch area C2. The B2 radiation extends from A to E. The BM beam has a divergence angle of ±3 mrad, which is between B and D with C as its center. Below A, the beam goes through to absorber A2.