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The EPA Bending Magnet and its Representation in the Full Description of the Machine.

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Abstract.

Since EPA is a small machine and the bending magnets short, the fringe field effects are large and special attention has to be paid to the tracking of particles through the magnets. Here we describe the procedures making use of measured field tables in computer programs to determine the properties of the machine. footnote[1]

[1] A review of field tables since this note was first published led to updates of table 1C-E and table 2,as well as figures 2 and 3. Revision is indicated by :R. Simulation of field tables with measuring errors provided - for some field integrals - values with r.m.s. errors. This has been included in table 1C-E.

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1. INTRODUCTION.

Earlier studies of EPA had to be done with hard-edged magnets [1] or with a calculated fringe field [2]. The linear optics found with the latter data have already been described[3]. In these calculations the computed fringe field was fitted with expansions around the central axis of the magnet in the manner described in TRANSPORT[4]. With the arrival of a prototype magnet and later of the first of the series for the machine, measurements of the magnetic field in the median plane were able to be made by G.Suberlucq [5]. These measurements were then used to determine the basic closed orbit for the reference momentum and the matrix transformation for betatron oscillations through one magnet. This preliminary program, called here PREP, is described in Section 2. Here, except for one set of results, the full field table was used. The same full field table can be used in the program ORBIT[6] to study the whole machine. However, although the program can optimise a number of quantities, it cannot as yet match for a desired phase difference over a certain region. So for this reason, as before (ref.[2,3]) the special version of AGS (prepared by Risselada)[7] was then used to match the machine. With the values of the quadrupoles so found ORBIT was then run. This is described in Section 3. Although it is hoped that ORBIT gives a good description of EPA, because of the integration through the magnetic fields it is not suitable for modelling studies where a very quick answer is needed. For this reason a model using hard- edged elements was searched for which would give, as nearly as possible, the same values as ORBIT for a number of quantities. Sections 4,5,6,7 and 8 are devoted to this model.

2. PREP.

The exact equations of motion of a charged particle in a magnetic field have already been quoted in [2] where the results were given for the computed magnetic field supplied by D.Cornuet[8]. The nominal energy of EPA is 600 MeV. As particle tracking has revealed that the sextupole component of the magnet should be as small as possible for a maximum of the dynamic aperture, shimming was done by G.Suberlucq et al. to try to make it zero along the straight central axis of the magnet, which was excited to the fields needed for 600 MeV. From the measurements supplied, we were able to construct values of the vertical magnetic field on a grid of 1 cm^2 over the region of interest. By varying the strength of the field slightly, by a fraction of a %, we found by integration the basic closed orbit in the magnet so that it was centrally placed - the maximum excursion above the axis equal to the displacement below at the physical end of the magnet. The magnetic field of course extends some distance beyond this last position. The magnetic measurements had to be smoothed using CERN Library routines to try to get good values of second derivatives for use both when determining the field within a box of the grid, and for evaluating certain integrals along the curved closed orbit. This was not completely successful in the region of the physical end of the magnet but is believed to be adequate. The value of the maximum excursion above the axis was 13.612326mm (called x0). The value of the entrance coordinate at the edge of the measured fringe field was -.106548m(called x1). The origin of x is always the central straight axis of the magnet.(See Figure 1). There is still some fringe field at z=±1000mm.However,at this distance,we are already inside the adjacent elements.For this reason,although the first of the measured tables extended to ±1000mm(See Table 1A_prototype magnet),it was decided,in later measurements,to stop at ±750mm, which is about where the next elements are situated.It was felt that the fields(very small) so far out would not be realistic.For TABLE 1A,the earlier fitting of the magnetic field by expansions around x=0,was used in both PREP and ORBIT, but for TABLES 1B,C,D,E the full field table was used.As before[3], in order to prepare a model for use in AGS, small off-closed orbit trajectories were run in order to find matrix elements for the model described in [9].When EPA starts,the energy may not be 600MeV at the beginning. For this reason measurements were also made at 500MeV and at the later possible energy of 650MeV,and the same calculations made. In these cases,however, we were not free to choose x1. This was fixed at the 600 MeV value as the magnets will be fixed in position. As the magnets were shimmed for 600MeV,different values were found for sextupole components along the basic trajectories. For all cases from these calculations some key integrals were found,namely

$$\int B ds, \quad \int G ds, \quad \int SE ds$$

where s is measured along the path.B is the magnetic field,G is $dB/d\eta$ (where η is the direction in the horizontal plane at right angles to the basic trajectory),and SE is $d^2B/d\eta^2$. $\int B ds$ is of course fixed by the bend and is only a check on the integration. Some other integrals along the straight central axis, coordinate z, were also made. In addition the length of the trajectory was found. The model for linear optics used in AGS was described in [9], and from the data found here,the machine was again matched. The results from PREP are shown in the first parts of Tables 1.

3.ORBIT.

In ORBIT the representation of the bending magnet is just as in PREP. For the full field table the fields and their first and second derivatives at the mesh points are read in,already smoothed,as data. Runs were made at several momenta for all the cases for which we had field maps. For these at first the pure correcting sextupoles were inactive. We then obtained values for the chromaticity. This we have called

$$\xi_{PM} = \xi_{\text{Pure machine}}$$

$$= \xi_{NAT} + \xi_{SEXT} \text{ from bending magnets}$$

ξ_{NAT} is the chromaticity which would be found if there were no sextupoles present either in the magnets or as pure sextupoles. ξ_{NAT} can not be found directly with ORBIT since the field maps contain a sextupole component, although this is small at 600MeV.The synchrotron integrals, dispersion,etc. were calculated. Later runs then activated the pure sextupoles to correct the chromaticity.

All the results for the two magnets,prototype and the first element of the series (at the three energies) can be found in TABLE 1 A-E, along with those from the model which is described later.As the measured field used for TABLE 1A extended into the next element,artificially we had to use a negative drift length (L around -.27m) at each end of a magnet in order to be ready to enter the next element.Even with the field tables of ±750mm this effect has to be put in,but there it is much smaller (L around -.018852m for SERIES magnet at 600MeV).

Figure 3 shows the chromaticity (see Appendix A) of the 'pure' machine as a function of the sextupole component S in the bending magnet(see footnote[2]). The circles in fact represent slightly different machines, but the fact that the points lie on almost straight lines indicates that the differences are very small. As natural chromaticity of the machine one can deduce for the horizontal and the vertical planes:

$$\xi_{HNAT} = -1.36, \qquad \xi_{VNAT} = -1.60 \qquad :R$$

[2] Figure 4 indicates,in the working diagram, the tune shifts we have to expect without chromaticity correction.

The sensitivity of the chromaticity with respect to the sextupole component $S=(1/B\rho)\int(d^2B/d\eta^2)ds$ of the bending magnet can be seen to be

$$\Delta\xi_H = .34*S; \quad \Delta\xi_V = -1.26*S \qquad :R$$

The results from ORBIT runs are given in TABLES 1. By studying the detailed computer outputs one can see that the changes in I1 and I4 for off-momentum particles when the sextupoles are turned on are mainly due to the changes in the dispersion D.

4. WHY WE NEED A MODEL.

The simple matrix representation of our bending magnet has been very useful in the calculation of the linear optics, and allows us to tune the machine to any desired working point.However,for

simulation and studies of orbit distortions,beam dimensions (with ORBCOR[10], MAD[11], or PETROC[12])

calculation and quick tuning of chromaticities (with MAD or COMFORT[13])

on-line presentation of the lattice with correct characteristics of damping

study of the effects from nonlinear elements in the lattice, determining the dynamic aperture of the machine (e.g. tracking of particles using MAD or PATRICIA[14])

a model of the magnet is needed. It has to consist of magnet elements which are described by forces as functions of the space coordinates x and y (horizontal and vertical).

5. REQUIREMENTS of a MODEL.

The model should, for the 3 energies 500,600,and 650 MeV satisfy linear optics -provide the lattice functions previously found by using the PREP transform matrix,

provide a lattice with the same natural chromaticity as found by ORBIT,

allow tracking of particles with ,in the lattice, azimuthally correctly distributed non-linearities,

in its damping time characteristics not differ by more than ±10% from the characteristics of the "true" magnet,

be independent of machine-program specific features(e.g. be transportable from one program to another).

6. THE CONFIGURATION OF THE MODEL.

The magnet is treated as a transfer channel built of one ideal combined function magnet, (B),two adjacent quadrupoles (Q1,Q2),and a sextupole,(S), to take care of the intrinsic sextupole component (small at 600MeV) of the true magnet. Eight parameters $\beta_H, \alpha_H, \mu_H, D_H, D'_H, \beta_V, \alpha_V, \mu_V$ are fitted optimally to the values obtained from the runs made with the matrix obtained from PREP. In addition, the variables are tuned so as to provide chromaticities comparable to those found by ORBIT runs. Half of the configuration is shown in Figure 3. Referring to this figure's symbols

$$L/2 = \Sigma L_i + \Sigma D_j + LC/2 + D_0 + LS = \text{constant}.$$

The variables are: The gradients K,K1,K2,
the lengths L1,L2,LC/2,D1,D2,D3,
the end face rotation ϕ.

Constraints are: Fixed length L (see above) and
implicitly the C-S invariant, as well as
the natural chromaticity of such a set.

7.PROCEDURES (programs) APPLIED TO ARRIVE AT THE FINAL PARAMETERS (K......,ϕ) OF THE MODEL.

To get from the measured field values of the magnet to its presentation in a lattice program implies several steps:

a) The tracking program PREP provides a transfer matrix together with the length LC of a hypothetical combined function magnet in hard-edged approximation[9].

b) The introduction of the matrix and LC into the special version of AGS[7] allows the matching of EPA - with the help of the six available quadrupole families - to the desired working points with some additional constraints.

c) The resulting quadrupole forces are used in ORBIT to track particles with Δp not equal to zero through a complete machine in order to deduce chromaticity. In addition, knowing D the calculation of the synchrotron integrals becomes possible.

d) The matrix,chromaticities and the synchrotron integrals are now used to find the model.

d_1) First the transfer channel "model magnet" is matched so that it becomes in its transfer characteristics identical to the transfer matrix of PREP.

d_2) The resulting model is introduced into a lattice program (MAD or COMFORT) where the chromaticity is obtained.

d_3) This process is repeated for different end-face rotation angles ϕ to find the minimum difference between the natural chromaticity deduced from ORBIT runs and the one resulting from the model. Detailed information can be found in Tables 3,4,5.

d_4) After this tuning of the model with respect to linear optics and natural chromaticity, the sextupole component of the magnet's magnetic field which remains after shimming and which was calculated as an integrated effect by PREP, is added via the sextupole of the model. This gives the complete representation of the true magnet.

8. CHROMATICITY AND DAMPING TIMES AS A FUNCTION OF THE END-FACE ROTATION ϕ.

A model magnet with parallel end-faces (in our case $\phi = 11.25^{\circ}$) provides - together with its adjacent optical neighbours Q1,Q2 - natural chromaticities of

$$\xi_H = -1.13, \quad \xi_V = -2.35 \text{ (Table 5,run 2).}$$

ORBIT, however, gives

$\xi_H = -1.36$, $\xi_V = -1.6$ (see Fig.3) :R

Trials to coax the chromaticity values of the model to those of ORBIT by
1)adjusting Q1 and Q2
2)varying ψ, the fringe field correction angle[4]-for the chosen ensemble of elements in the model- did not lead to satisfying results. Rotation of the end-faces of the magnet had to be applied.

8.1 Chromaticity as a function of end-face rotation ϕ.

A rough approximation for $\xi = f(\phi)$ can be deduced from the Hardt-Jaeger-Moehl formalism [15] (see also APPENDIX A). For the vertical plane one finds

$$\Delta\xi \approx -(h/4\pi Q)\sum_i \{(\beta_1+\beta_2)_i - (2K/h)(D_1\beta_1+D_2\beta_2)_i\} * \tan\phi$$

where i = 1-16 (summation over all bending magnets),
1,2 means at entry and exit of the magnet,
$h = 1/\rho$ and $K = (1/B\rho)(dB/dx)$.
Starting the variation of ϕ at the magnet with parallel end- faces ($\phi = 11.25^\circ$,run 2 in Table 5) one finds

$$\Delta\xi_V \approx -6.4 \tan\Delta\phi$$

Decreasing ϕ leads to a lowering of ξ_V(tot) and an increase of ξ_H(tot).
The change of chromaticity due to the neighbouring quadrupoles Q1 and Q2 counteracts to some extent the desired decrease of ξ_V with $\Delta\phi$. Figure 4 shows the variation of ξ_V and ξ_H over a range of ϕ from -8 to +15 degrees. The optimum angle ϕ is between .6 and -3.5°. At these extreme values ξ_V and ξ_H respectively fit the values found by ORBIT.
$\phi = 0$ has been chosen; for this angle ξ_H and ξ_V(model) differ by -5% and +2% from the ORBIT values.
From run 8 (ϕ=0) of Table 5 one can deduce:

	ξ_{NAT}	=	$\xi_{NATBending}$	+	$\xi_{NAT(rest)}$
H:	-1.33	=	+.21		-1.54
V:	-1.64	=	-1.67		+0.03

which shows that horizontally the major part of the chromaticity stems from the quadrupoles in the ring; vertically it is the bending magnet which provides nearly all. This is true as long as the sextupole component of the magnet can be neglected. This is the case for 600MeV where $S = -.12m^{-2}$.

8.2 Damping times and their ratio as a function of ϕ.

At the design stage of EPA [16] choosing a magnet with parallel end-faces and an approximate gradient,allowed one to fix $\tau_{x,y,\varepsilon}$ = 34,70,70 ms at 600MeV. For the true magnet ORBIT finds 34,70,72. Without imposing any special constraint on the model it provides 34,69,71 ms. The reason for the good agreement is that the loss of damping from the reduction of ϕ at the end-faces is nearly compensated by the increase of the gradient K in the inner part of the magnet. From the Helm-Lee-Morton formalism[17](see also Appendix A):

$$\tau_x \propto (I_2-I_4)^{-1}, \quad \tau_\varepsilon \propto (2I_2+I_4)^{-1}$$

where I_2, I_4 are the synchrotron radiation integrals. Now

$$I_2 = \sum_i l_i/\rho_i$$

which is,to a good approximation, constant against variations in ϕ.Also

$$I_4 = f(K,l,D,\phi)$$

$$\approx (1/\rho^3)\Sigma((D_1+D_2)/2)_i*(1+2\rho^2K-2(\rho/l)\tan\phi)$$

As long as the variation of $(1/\rho^3)$ with ϕ can be neglected, the relation:

$$\rho*K - (1/l)\tan\phi = \text{constant}$$

provides invariance of τ_x,τ_ε with respect to end-face rotations. When ϕ varies from 11.25° to 0°, I_4 changes only from -4.09 to -3.78(see Table 5,runs 2,8). Applying the approximation for I_4 given above yields:

$I_4(\phi=11.25^\circ, l=.623, K=-.474, \Sigma(\ )=11.04\text{(Table3)})=-4.15$

$I_4(\phi=0, \quad l=.618, K=-.649, \Sigma(\ )=11.04) \quad =-3.87$

Keeping K = constant =-.474 would have led to $I_4 \approx -2.34$. The change of I_4 (-4.15 $\rightarrow$ -2.34) due to the change of ϕ has been 85% compensated by the increase of K.

The small change of ΔI_4 = .31 changes τ_x,τ_ε by 3% and -8% respectively, and their ratio τ_x/τ_ε by 13% only. So in the model the constraint $\rho*K-(1/\rho)\tan\phi$ =constant did not need to be applied.

APPENDIX A. Definitions and Formulae.

$\xi_{TOT} = \xi_{NAT} + \xi_{SEXT}$

$\xi_{NAT} = \xi_{NAT}$ from bending magnet

$+\xi_{NAT}$ from rest of EPA

$\xi_{SEXT} = \xi_{SEXT}$ from correcting sextupoles

$+ \xi_{SEXT}$ intrinsic to the true bending magnet

$\xi_{PM} = \xi_{pure\ machine}$

$= \xi_{NAT} + \xi_{SEXT}$ from bending magnet

Sextupole component S:

$S = (1/B\rho)\int S'(s)ds$, $S' = (d^2B(s)/d\eta^2)$

Chromaticity from sextupoles is then[15]

$$\Delta\xi_{H,V} = \pm(1/4\pi Q_{H,V}) \int S' D(s)\beta_{H,V}(s)ds$$

for which a good approximation is, as long as D(s) and β(s) are smooth functions:

$$\Delta\xi_{H,V} = \pm(1/4\pi Q_{H,V})\sum_{i=1}^{16} \langle D*\beta_{H,V}\rangle_i * S$$

where < > denotes average values.

The Hardt-Jaeger-Moehl[15] formalism provides:

$$\Delta\xi_V = -\frac{1}{4\pi Q_V}\Big\{\int_{s_1}^{s_2} k\beta ds - \int_{s_1}^{s_2} rD\beta ds - \int_{s_1}^{s_2} hD(k+\gamma) ds$$

$$+\left[tg\,\theta(h\beta + 2Dk\beta) - h tg^2\theta(\beta D' - 2\alpha D - h D\beta\, tg\,\theta) - \beta hD' - \tau h\beta D\right]\Big|_{"1"}$$

$$+\left[tg\,\theta(h\beta + 2Dk\beta) + h tg^2\theta(\beta D' - 2\alpha D + h D\beta\, tg\,\theta) + \beta hD' - \tau h\beta D\right]\Big|_{"2"}\Big\}$$

$$\Delta\xi_H = -\frac{1}{4\pi Q_H}\Big\{\int_{s_1}^{s_2} (h^2-k)\beta ds + \int_{s_1}^{s_2} rD\beta ds + \int_{s_1}^{s_2} h(2kD\beta + 2D'\alpha - D\gamma) ds$$

$$+\left[-tg\theta\; h\beta + 2Dk\beta) + h tg^2\theta\;(\beta D' - 2\alpha D + hD\beta\; tg\theta) + \tau h\beta D\right]\Big|_{"1"}$$

$$+\left[-tg\theta(h\beta + 2Dk\beta) - h tg^2\theta\;(\beta D' - 2\alpha D - hD\beta\; tg\,\theta) + \tau h\beta D\right]\Big|_{"2"}\Big\}$$

where s_1 = beginning of the central part (H = 1)

s_2 = end " " " " "

"1" = entrance of the fringe region (H = 0)

"2" = exit " " " "

θ = entrance or exit angle of the trajectory

$\frac{1}{\tau\cos^3\theta}$ = radius of curvature of the end faces

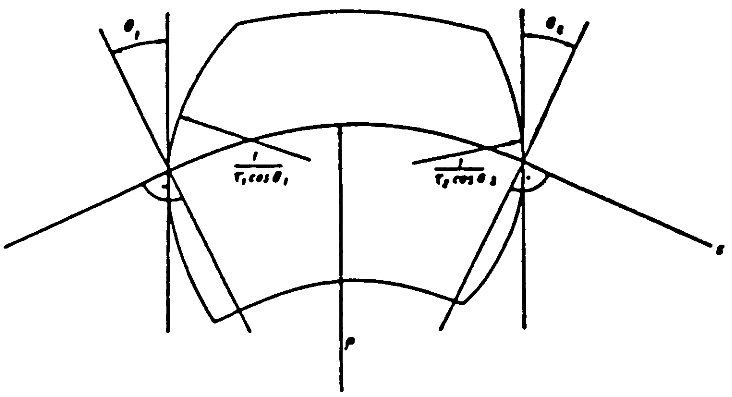
$h = \frac{1}{\rho}$ = curvature of the reference orbit

$k = -\frac{1}{B\rho}\frac{\partial B_z(0,0,S)}{\partial x}$ is the quadrupole component } of the magnet profile

$r = -\frac{1}{B\rho}\frac{\partial^2 B_z(0,0,S)}{\partial x^2}$ is the sextupole component } of the magnet profile

D, D' are the dispersion function and its derivative

α, β, γ are the Twiss functions.



The Helm-Lee-Morton[17] formalism provides:

$$I_4 = \int (1-2n)*D/\rho^3 ds$$

$$= \sum_i [(l_i/\rho_i^3)\langle D\rangle_i - 2l_i\langle(n*D/\rho^3)\rangle_i]$$

For the non-normal boundary magnet this becomes:

$$\sum_i [(l_i/\rho_i^3)\langle D\rangle_i$$

$$-2l_i\{(n/\rho_i^3)\langle D\rangle_i+(1/2l_i\rho_i^2)*W\}],$$

where

$$W = (D_1\tan\phi_1 + D_2\tan\phi_2)_i$$

Also l_i, ρ_i = length and curvature of the i^{th} segment,

$\langle D\rangle_i$ is average of D over the length of the i^{th} segment,

D_1, D_2, ϕ_1, ϕ_2 are the values at entrance and exit of the segment, and

$n = -(\rho/B)(\delta B/\delta\rho)$

APPENDIX B.

TABLE 1A. Prototype magnet.Field table 1. Measured fields fitted by expansions. Range of measurements ±1000mm.

In the succeeding tables the full field measurements were used. Range of measurements ±750mm.

TABLE 1B. Prototype magnet.Field table 2.

TABLE 1C. Series magnet. Field table for 500 MeV.

TABLE 1D. Series magnet. Field table for 600 MeV.

TABLE 1E. Series magnet. Field table for 650 MeV.

TABLE 2. Summary of results for the 3 energies 500,600 and 650 MeV.

TABLE 3. Typical Twiss values (vertical plane) at the bending magnets when the machine is matched to $Q_H = 4.46$, $Q_V = 4.38$.

TABLE 4. The linear model matched with respect to the PREP transfer matrix at different end-face angles ϕ.

TABLE 5. Chromaticity and damping times as a function of ϕ, no sextupoles on.

DATASET 5 : PROTOTYPE MAGNET, FIELDTABLE 1 (17.10.84)

MAGNET DATA		
CENTRAL FIELD B0(X=0,Y=0,Z=0)=	1.39758	[T]
CENTRAL GRADIENT G0(0,0,0)=	-1.18456	[T/M]
CENTRAL SEXTUPOLE S0(0,0,0)=	1.80000	[T/M*2]
INTEGRAL BDZ=	.785152	[TM]
INTEGRAL BDS=	.785938	[TM]
BENDING MAGNET LENGTH=		[MM]
INTEGRAL (DB/DX)DZ =INT G(0,0,Z)DZ=	-.542352	[T]
INTEGRAL (DB/D(ETA))DS=	-1.03022	[T]
GRADIENT MAGNET LENGTH=		[MM]
INTEGRAL (D*2(B)/DX*2)DZ =INT S(0,0,Z)DZ= SET ZERO		[T/M]
INTEGRAL (D*2(B)/D(ETA*2))DS=	2.07400	[T/M]
TRACKING RANGE D/2=Z2-Z1=	1000.0	[MM]
TRAJECTORY LENGTH LT=	2031.0	[MM]
PROJECTION OF LC OF AGS MODEL ON Z ,LM=	584.8	[MM]
MAGN. LENGTH OF AGS MODEL , LC=	588.6	[MM]

ELEMENTS OF TRANSFERMATRIX W.R.T. AGS MODEL :

H11= 1.0793526
H12= .5926173
H21= .2784277
H13= .1159663
H23= .4068982
V11= .8519299
V12= .5692197
V21= -.4817392

SYNCHROTRON INTEGRALS, SEXTUPOLES OFF

DP/PO	-.005	.000	+.005	+.01
I1=	4.109	4.235	4.356	4.474
I2=	4.020	3.958	3.899	3.843
I3=	2.702	2.640	2.580	2.522
I4=	-4.502	-4.138	-3.786	-3.444
I5=	2.020	1.970	1.943	1.925

AGS QH= 4.460 QV= 4.380
BETAHMAX= 16.26 [M] BETAVMAX= 14.52 [M] DXMAX= 2.303 [M]

ORBIT QH= 4.458 QV= 4.387
BETAHMAX= 17.39 [M] BETAVMAX= 13.45 [M] DXMAX= 2.398 [M]
CHROMAT. DQ/Q0:DP/PO H= -.98 V= -3.00

Table 1 A

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DATASET 7 : PROTOTYPE MAGNET, FIELDTABLE 2 (11.12.84)
---------------------------------------------------------
MAGNET DATA
CENTRAL FIELD B0(X=0,Y=0,Z=0)=                               1.40044     [ T    ]
CENTRAL GRADIENT G0(0,0,0)=                                 -1.18675     [T/M   ]
CENTRAL SEXTUPOLE S0(0,0,0)=                                 1.8313      [T/M*2]
INTEGRAL BDZ=                                                 .785132    [TM    ]
INTEGRAL BDS=                                                 .785942    [TM    ]
BENDING MAGNET LENGTH=                                                   [MM    ]
INTEGRAL (DB/DX)DZ =INT G(0,0,Z)DZ=                          -.540506    [T     ]
INTEGRAL (DB/D(ETA))DS=                                     -1.022676    [T     ]
GRADIENT MAGNET LENGTH=                                                  [MM    ]
INTEGRAL (D*2(B)/DX*2)DZ =INT S(0,0,Z)DZ= SET ZERO                       [T/M   ]
INTEGRAL (D*2(B)/D(ETA*2))DS=                                0.500904    [T/M   ]
TRACKING RANGE D/2=Z2-Z1=                                 750.0          [MM    ]
TRAJECTORY LENGTH LT=                                    1521.698        [MM    ]
PROJECTION OF LC OF AGS MODEL ON Z ,LM=                   585.29         [MM    ]
MAGN. LENGTH OF AGS MODEL , LC=589.07        SET TO 589.10               [MM    ]
DISTANCE X1 FROM BASIS D TO CENTRE OF MAGNET(X=0) -106.536               [MM    ]
MAX. DISTANCE X0 OF TRAJECTORY FROM CENTRE OF MAGN. 13.593               [MM    ]

ELEMENTS OF TRANSFERMATRIX W.R.T. AGS MODEL :
H11= 1.0780271
H12=  .5926933
H21=  .2735424
H13=  .1160104
H23=  .4067420
V11=  .8528856
V12=  .5697871
V21= -.4783996

SYNCHROTRON INTEGRALS, SEXTUPOLES OFF
DP/P0              -.01                  .00                   +.01
I1=                3.696                4.245                  4.617
I2=                4.087                3.963                  3.847
I3=                2.773                2.648                  2.529
I4=               -4.493               -4.094                 -3.602
I5=                2.105                2.004                  1.987

SYNCHROTRON INTEGRALS, SEXTUPOLES ON (FS= 17.16,SD=-12.94 [T/M*2])
DP/P0              -.01                 .0                     +.01
I1=                4.837                 .                     3.496
I2=                4.093                 .                     3.852
I3=                2.779                 .                     2.534
I4=               -5.601                 .                    -2.560
I5=                2.023                 .                     1.996

AGS      QH= 4.460 QV= 4.380
         BETAHMAX= 16.91 [M] BETAVMAX= 14.54 [M] DXMAX=        2.303 [M]

ORBIT    QH= 4.458 QV= 4.382
         BETAHMAX= 16.87 [M] BETAVMAX= 14.54 [M] DXMAX=        2.304 [M]
         CHRO. DQ/Q0:DP/P0: H=-1.274,V=-1.97(.5T/M SEXT.IN BENDINGMAG.)


GAMMA TRANSITION =  5.5153(AGS), 5.4410(ORB)


DAMPING PARTITION NUMBERS :
JX=  2.03
JE=  0.97
DJX/DE/E: SEXT. OFF= -8.15, SEXT. ON= -35.19

DAMPING TIME CONSTANTS :
TAUX=                                                        34.22 [MS   ]
TAUY=                                                        69.58 [MS   ]
TAUE=                                                        71.95 [MS   ]
```

Table 1 B

:R

```
DATASET 9 : SERIE MAGNET NO.1 . FIELDTABLE 3: 500 MEV (JUN85)
-----------------------------------------------------------
MAGNET DATA - REVISED MARCH 1986
CENTRAL FIELD B0(X=0,Y=0,Z=0)=        M:1.1609941        1.1617100 [T     ]
CENTRAL GRADIENT G0(0,0,0)=           M:-0.990973       -0.990992  [T/M   ]
CENTRAL SEXTUPOLE S0(0,0,0)=          M:1.78             1.69414   [T/M*2]
INTEGRAL BDZ=                         M:.65356           .654220   [TM    ]
INTEGRAL BDS=                                            .654956   [TM    ]

INTEGRAL (DB/DX)DZ =INT G(0,0,Z)DZ= M:-.46239           -.462900   [T     ]
INTEGRAL (DB/D(ETA))DS=                                 -0.867060  [T     ]

INTEGRAL (D*2(B)/DX*2)DZ =INT S(0,0,Z)DZ= SET ZERO M               [T/M   ]
INTEGRAL (D*2(B)/D(ETA*2))DS=                            0.28688   [T/M   ]
TRACKING RANGE D/2=Z2-Z1=                              750.0       [MM    ]
TRAJECTORY LENGTH LT=                                 1521.680     [MM    ]
PROJECTION OF LC OF AGS MODEL ON Z ,LM=                586.666     [MM    ]
MAGN. LENGTH OF AGS MODEL ,LC=                         590.448     [MM    ]
DISTANCE X1 FROM BASIS D TO CENTRE OF MAGNET(X=0) -106.548         [MM    ]
MAX. DISTANCE X0 OF TRAJECTORY FROM CENTRE OF MAGN. 13.503         [MM    ]
CIRCUMFERENCE OF EPA=                               125663.214     [MM    ]
ELEMENTS OF TRANSFERMATRIX W.R.T. AGS MODEL :
H11= 1.0810005
H12=  .5944441
H21=  .2834486
H13=  .1163174
H23=  .4072015
V11=  .8500136
V12=  .5707717
V21= -.4861429

RESULTS FROM SIMULATION OF ERRORS ( GENERATION OF 20 FIELDTABLES )
RMS VALUES FOR DISPLACEMENTS [M] :
DELX=.00002, DELXI=.00005, DELZ=.0002, DELZI=.0001
RMS VALUES FOR HALL PROBE ERRORS [DELTAB/B] :
DELB1=.0001 FOR .09 [T] <= B, DELB2=.0015 FOR .09>B>=.005 [T]
RMS VALUE  FOR HALL PROBE ERROR  [DELTAB IN [T]] :
DB3=.0003 [T] FOR .005 [T] > B

INTEGRAL (DB/D(ETA))DS=                         -.86755 +-.00373   [T     ]
INTEGRAL (D*2B/D(ETA*2))DS=                      .14 +-.49         [T/M   ]
DIST. X1 FROM BASIS D TO CENTRE OF MAG.(X=0)= -106.54 +-.06        [MM    ]

 SYNCHROTRON INTEGRALS. SEXTUPOLES OFF
 DP/P0       -0.009          0.000           0.01
 I1=          3.968          4.224           4.552
 I2=          4.072          3.960           3.843
 I3=          2.755          2.643           2.524
 I4=         -4.706         -4.161          -3.611
 I5=          2.034          1.976           1.956

 SYNCHROTRON INTEGRALS. SEXTUPOLES ON (FS=14.74,DS=-9.284[T/m*2])
 DP/P0       -0.01           0.              0.01
 I1=          5.241           .              3.403
 I2=          4.090           .              3.849
 I3=          2.774           .              2.530
 I4=         -6.078           .             -2.521
 I5=          2.058           .              1.959

ORBIT        QH=4.4581  QV= 4.3791
             BETAHMAX= 15.22[m]  BETAVMAX= 13.38[m] DXMAX= 2.301[m]
             CHRO. DQ/Q0:DP/P0: H=-1.305, V=-1.813 (.2869 T/m SEXT.in
                                                    BENDING MAGNET)

 GAMMA TRANSITION  =   5.454 (ORBIT )

 DAMPING PARTITION NUMBERS:
 JX= 2.05
 JE= 0.95
 DJX/DE/E:  SEXT.OFF=-11.39, SEXT. ON= -41.55

 DAMPING TIME CONSTANTS:
 TAUX=                           58.66  [ms]
 TAUY=                           120.3  [ms]
 TAUE=                           126.7  [ms]
```

Table 1 C

:R

```
DATASET 9 : SERIE MAGNET NO.1 , FIELDTABLE 3: 600 MEV (JUN85)
--------------------------------------------------------------
MAGNET DATA - REVISED MARCH 1986
CENTRAL FIELD B0(X=0,Y=0,Z=0)=      M:1.40291          1.40180    [T     ]
CENTRAL GRADIENT G0(0,0,0)=         M:-1.188099       -1.191000   [T/M   ]
CENTRAL SEXTUPOLE S0(0,0,0)=        M:1.72             1.83830    [T/M*2]
INTEGRAL BDZ=                       M:.78518            .785100   [TM    ]
INTEGRAL BDS=                                           .785946   [TM    ]

INTEGRAL (DB/DX)DZ =INT G(0,0,Z)DZ= M:-.548188         -.55054    [T     ]
INTEGRAL (DB/D(ETA))DS=                               -1.032700   [T     ]

INTEGRAL (D*2(B)/DX*2)DZ =INT S(0,0,Z)DZ= SET ZERO M              [T/M   ]
INTEGRAL (D*2(B)/D(ETA*2))DS=                          0.013120   [T/M   ]
TRACKING RANGE D/2=Z2-Z1=                            750.0        [MM    ]
TRAJECTORY LENGTH LT=                               1521.702      [MM    ]
PROJECTION OF LC OF AGS MODEL ON Z ,LM=              584.987      [MM    ]
MAGN. LENGTH OF AGS MODEL ,LC=                       588.762      [MM    ]
DISTANCE X1 FROM BASIS D TO CENTRE OF MAGNET(X=0) -106.548        [MM    ]
MAX. DISTANCE X0 OF TRAJECTORY FROM CENTRE OF MAGN. 13.601        [MM    ]
CIRCUMFERENCE OF EPA=                             125663.568      [MM    ]
ELEMENTS OF TRANSFERMATRIX W.R.T. AGS MODEL :
H11= 1.0793829
H12=  .5924985
H21=  .2786136
H13=  .1159592
H23=  .4069602
V11=  .8515336
V12=  .5693606
V21= -.4828054

RESULTS FROM SIMULATION OF ERRORS ( GENERATION OF 20 FIELDTABLES )
RMS VALUES FOR DISPLACEMENTS [M] :
DELX=.00002, DELXI=.00005, DELZ=.0002, DELZI=.0001
RMS VALUES FOR HALL PROBE ERRORS [DELTAB/B] :
DELB1=.0001 FOR .09 [T] <= B, DELB2=.0015 FOR .09>B>=.005 [T]
RMS VALUE  FOR HALL PROBE ERROR  [DELTAB IN [T]] :
DB3=.0003 [T] FOR .005 [T] > B

INTEGRAL (DB/D(ETA))DS=                        -1.03320 +-.00440  [T     ]
INTEGRAL (D*2B/D(ETA*2))DS=                      -.16 +-.58       [T/M   ]
DIST. X1 FROM BASIS D TO CENTRE OF MAG.(X=0)= -106.54 +-.06       [MM    ]
 SYNCHROTRON INTEGRALS, SEXTUPOLES OFF
 DP/P0      -0.01          0.000          0.01
 I1=         3.744         4.239          4.611
 I2=         4.090         3.966          3.849
 I3=         2.777         2.653          2.533
 I4=        -4.524        -4.136         -3.653
 I5=         2.058         1.991          1.984

 SYNCHROTRON INTEGRALS, SEXTUPOLES ON (FS=17.90,DS=-9.808[T/m*2])
 DP/P0      -0.01          0.             0.01
 I1=         4.962          .             3.430
 I2=         4.096          .             3.855
 I3=         2.784          .             2.539
 I4=        -5.721          .            -2.547
 I5=         2.027          .             1.975


 ORBIT      QH=4.456    QV= 4.380

            BETAHMAX= 15.26[m]  BETAVMAX= 14.47[m] DXMAX= 2.302[m]
            CHRO. DQ/Q0:DP/P0: H=-1.362, V=-1.608 (.01312 T/m SEXT.in
                                                  BENDING MAGNET)

  GAMMA TRANSITION  =   5.4445 (ORBIT )

  DAMPING PARTITION NUMBERS:
  JX= 2.04
  JE= 0.96
  DJX/DE/E:  SEXT.OFF=-7.85, SEXT. ON= -36.78

  DAMPING TIME CONSTANTS:
  TAUX=                           34.03  [ms]
  TAUY=                           69.51  [ms]
  TAUE=                           72.61  [ms]
```

Table 1 D

:R

```
DATASET 9 : SERIE MAGNET NO.1 , FIELDTABLE 3: 650 MEV (JUN85)
------------------------------------------------------------
MAGNET DATA -  REVISED MARCH 1986
CENTRAL FIELD B0(X=0,Y=0,Z=0)=        M:1.52565         1.52474    [T     ]
CENTRAL GRADIENT G0(0,0,0)=           M:-1.272823      -1.27567    [T/M   ]
CENTRAL SEXTUPOLE S0(0,0,0)=          M:1.383           1.32132    [T/M*2]
INTEGRAL BDZ=                         M:.850574          .850520   [TM    ]
INTEGRAL BDS=                                            .851440   [TM    ]

INTEGRAL (DB/DX)DZ =INT G(0,0,Z)DZ= M:-.58085           -.585600   [T     ]
INTEGRAL (DB/D(ETA))DS=                                -1.104200   [T     ]

INTEGRAL (D*2(B)/DX*2)DZ =INT S(0,0,Z)DZ= SET ZERO M               [T/M   ]
INTEGRAL (D*2(B)/D(ETA*2))DS=                          -0.460000   [T/M   ]
TRACKING RANGE D/2=Z2-Z1=                          750.0           [MM    ]
TRAJECTORY LENGTH LT=                             1521.718         [MM    ]
PROJECTION OF LC OF AGS MODEL ON Z ,LM=            583.769         [MM    ]
MAGN. LENGTH OF AGS MODEL ,LC=                     587.536         [MM    ]
DISTANCE X1 FROM BASIS D TO CENTRE OF MAGNET(X=0) -106.548         [MM    ]
MAX. DISTANCE X0 OF TRAJECTORY FROM CENTRE OF MAGN. 13.671         [MM    ]
CIRCUMFERENCE OF EPA=                           125663.820         [MM    ]
ELEMENTS OF TRANSFERMATRIX W.R.T. AGS MODEL :
H11= 1.0773366
H12=  .5909129
H21=  .2717769
H13=  .1156826
H23=  .4066817
V11=  .8537091
V12=  .5685518
V21= -.4769673

RESULTS FROM SIMULATION OF ERRORS ( GENERATION OF 20 FIELDTABLES )
RMS VALUES FOR DISPLACEMENTS [M] :
DELX=.00002, DELXI=.00005, DELZ=.0002, DELZI=.0001
RMS VALUES FOR HALL PROBE ERRORS [DELTAB/B] :
DELB1=.0001 FOR .09 [T] <= B, DELB2=.0015 FOR .09>B>=.005 [T]
RMS VALUE  FOR HALL PROBE ERROR  [DELTAB IN [T]] :
DB3=.0003 [T] FOR .005 [T] > B

INTEGRAL (DB/D(ETA))DS=                      -1.10480 +-.00470    [T     ]
INTEGRAL (D*2B/D(ETA*2))DS=                    -.60 +-.64          [T/M   ]
DIST. X1 FROM BASIS D TO CENTRE OF MAG.(X=0)= -106.54 +-.06        [MM    ]
 SYNCHROTRON INTEGRALS. SEXTUPOLES OFF
 DP/P0       -0.01          0.000           0.01
 I1=          3.627          4.246           4.730
 I2=          4.092          3.969           3.852
 I3=          2.781          2.658           2.538
 I4=         -4.270         -4.046          -3.741
 I5=          2.062          1.991           2.008

 SYNCHROTRON INTEGRALS. SEXTUPOLES ON (FS=19.48,DS=-10.07[T/m*2])
 DP/P0        -0.01         0.              0.01
 I1=          4.850          .              3.512
 I2=          4.098          .              3.858
 I3=          2.787          .              2.544
 I4=         -5.436          .             -2.621
 I5=          2.012          .              1.975


 ORBIT        QH=4.460   QV= 4.3773
              BETAHMAX= 15.28[m]  BETAVMAX= 13.40[m] DXMAX= 2.304[m]
              CHRO. DQ/Q0:DP/P0: H=-1.418, V=-1.404 (-.46  T/m SEXT.in
                                                      BENDING MAGNET)

  GAMMA TRANSITION  =   5.440 (ORBIT )

  DAMPING PARTITION NUMBERS:
  JX= 2.02
  JE= 0.98
  DJX/DE/E:  SEXT.OFF=-3.625, SEXT. ON= -32.375

  DAMPING TIME CONSTANTS:
  TAUX=                          27.05 [ms]
  TAUY=                          54.63 [ms]
  TAUE=                          55.71 [ms]
```

Table 1 E

:R

TABLE 2. SUMMARY of the RESULTS for the 3 ENERGIES 500,600,650 MeV.

Energy(MeV)	500	600	650	
	H11=1.0810005	H11=1.0793829	H11=1.0773366	
	H12= .5944441	H12= .5924985	H12= .5909129	
	H21= .2834486	H21= .2786136	H21= .2717769	
Matrix	H13= .1163174	H13= .1159592	H13= .1156826	PREP
	H23= .4072015	H23= .4069602	H23= .4066817	
	V11= .8500136	V11= .8515336	V11= .8537091	
	V12= .5707717	V12= .5693606	V12= .5685518	
	V21=-.4861429	V21=-.4828054	V21=-.4769673	
LC [m]	.59045	.58876	.58754	
SEXT* [T/m]	.29	.01312	-.46	

$Q_{H,V}$	4.4614,4.3800	4.4601,4.3800	4.4611,4.3800	
$\beta_{H,V}$max[m]	16.19,14.34	16.48,14.49	16.51,14.53	
$D_x$ma x [m]	2.29	2.30	2.30	
QFW [m^{-2}]	-1.10458262	-1.10699649	-1.10688462	
QFC [m^{-2}]	.02120095	.06964026	.08294285	
QFL [m^{-2}]	-1.38267778	-1.37548425	-1.37293891	AGS,matched
QFN [m^{-2}]	- .56741475	- .56713222	- .56720738	
QFI [m^{-2}]	- .53293977	- .53262991	- .53286830	
QDN [m^{-2}]	.56911615	.56920927	.56930300	

:R

$Q_{H,V}$	4.458 ,4.379	4.456,4.380	4.460,4.377	
$\beta_{H,V}$max[m]	15.22,14.44	15.26,14.47	15.28,14.51	
$D_x$max[m]	2.301	2.302	2.304	ORBIT
ξ_H/ξ_V	-1.305/-1.813	-1.362/-1.608	-1.418/-1.404	
t_x-t_y-t_e	59-120-127	34-70-73	27-55-56	

:R				
B[L] [m]	.620285	.618582	.618538	
B[K1][m^{-2}]	-.728010	-.688051	-.650488	
rot ϕ**[mrad]	0	0	0	
Q1R(L*K1)[m^{-1}]	.01374*(-2.28743)	.01764*(-2.23267)	.02093*(-2.32916)	
Q2R(L*K1)[m^{-1}]	.00882*(-.348371)	.00932*(-.48796)	.00931*(-.563352	
D1R[L][m]	.1069	.05533	.03334	MODEL MAGNET
D2R[L][m]	.01351	.01204	.01177	MAD NOTATION
D3R[L] [m]	.28887	.33837	.35737	
DOR[L] [m]	.000001	.000001	.000001	
SYB(L*K2)[m^{-2}]	9E-6*9.55E3	9E-6*.36E3	9E-6*(-11.8E3)	

:R				
$Q_{H,V}$	4.46,4.38	4.46,4.38	4.46,4.38	
$\beta_{H,V}$max[m]	15.21,14.31	15.22,14.36	15.29,14.45	
$D_x$max [m]	2.30	2.30	2.30	MAD
ξ_H/ξ_V	-1.279/-1.335	-1.335/-1.644	-1.415/1.359	

ξ_H/ξ_V	-3.20/+4.74	-1.39/-1.48	-1.47/-1.19	
ξ_H/ξ_VNAT	-1.33/-1.64	-1.34/-1.64	-1.34/-1.64	COMFORT
SF/SD [m^{-2}]	-4.14/-3.70	-2.63/+1.52	-2.68/+1.28	
t_x-t_y-t_e[ms]	59-117-116	34-69-71	27-54-53	

* SEXT = $\int(d^2B/d\eta^2)ds$ [T/m],

** magnet end-face rotation,

K2[m^{-3}] = $(2B\rho*L(SYB))^{-1}$*SEXT

SF = $-(1/B\rho)\int(d^2B/d\eta^2)ds$

TABLE 3. TYPICAL TWISS VALUES (VERTICAL PLANE) at the BENDING MAGNETS WHEN the MACHINE IS MATCHED TO $Q_H = 4.46$, $Q_V = 4.38$.

i	D_1	D_2	D_1'	D_2'	β_1	β_2
1	0.	.11	0.	.41	12.05	14.52
2	1.11	1.54	.40	1.18	8.06	4.99
3	1.54	1.11	-1.18	- .40	4.9	7.94
4	.11	0.	- .41	0.	14.39	11.97
Σ	2.76	2.76				

i	α_1	α_2	$(\beta_1+\beta_2)$	'A'	'B'	'C'
1	-5.38	1.55	26.57	1.60	-.17	-5.89
2	1.00	3.78	13.05	16.63	-4.71	-2.66
3	-3.72	-1.00	12.84	16.36	-4.62	-2.61
4	-1.56	5.33	26.36	1.58	-.17	-5.90
Σ		78.82	36.17			

i = number of bending magnet in first quadrant

1,2 = entry and exit of the pole faces of the bending magnet part of the model.

Also $'A' = \beta_1 D_1 + \beta_2 D_2$

$'B' = \alpha_1 D_1 - \alpha_2 D_2$

$'C' = \beta_1 D_1' - \beta_2 D_2'$

MAD03600,17/10.85,11.50

TABLE 4. THE LINEAR MODEL MATCHED WITH RESPECT TO THE PREP TRANSFER MATRIX AT DIFFERENT END-FACE ANGLES ϕ.

RUN	$\phi(^o)$	FCT	D1R(L)	D2R(L)	Q1R(L)	Q2R(L)
2	11.25	.14D-3	.0855428	.0194161	.0704268	.0531434
1	15.00	.15D-3	.0318465	.00981382	.0762341	.0245223
3	10.	.13D-3	.0862281	.0210958	.0773011	.053150
4	8.	.11D-3	.0154154	.0539729	.0218606	.0381925
5	6.	.11D-3	.0116351	.0577398	.0413123	.0335068
		(.11D-3	.0020001	.274847	.0266487	.0903239
6	4.	.95D-4	.0783244	.00781526	.00966224	.00934678
7	2.	.93D-4	.0383055	.00548428	.00688513	.0186873
8	0.	.93D-4	.0135054	.00504645	.00548654	.0290548
9	-2.	.94D-4	.001	.00100612	.00125166	.0500324
10	-4.	.94D-4	.00100058	.00102838	.00150064	.0486117
11	-6.	.94D-4	.00100058	.00102838	.00150064	.0486117
12	-8.	.94D-4	.0010000	.00100612	.00125166	.0500324

where FCT = Penalty Function at Matching.

RUN	B(L)	B(K1)	Q1R(K1)	Q2R(K1)
2	.622726	-.474031	.0726259	.190303
1	.626409	-.458320	.750906	-.127437
3	.621296	-.486418	-.169462	.332888
4	.620082	-.557801	-.388972	.326993
5	.619591	-.558777	-.686094	.301141
	.618817	-.559986	-1.60495	.0252053)
6	.618096	-.636931	.0556537	-1.85896
7	.617848	-.648285	-.090392	-1.87543
8	.617968	-.649091	-.0954495	-1.96357
9	.618134	-.649993	-.179399	-2.21740
10	.618278	-.664790	-.187671	-2.26002
11	.618523	-.680658	-.195007	-2.34528
12	.618994	-.698077	-.228279	-2.61522

TABLE 5. CHROMATICITY AND DAMPING TIMES AS A FUNCTION OF ϕ, NO SEXTUPOLES ON.

		CHROMATICITIES total		inner part $\Delta\xi$		from end-faces $\Delta\xi$		from Q1,Q2 $\Delta\xi$	
RUN	ϕ	ξ_H	ξ_V	H	V	H	V	H	V
1	15	-1.06	-2.58	-.24	.01	.85	-2.93	-.14	.29
2	11.25	-1.13	-2.35	-.24	.01	.69	-2.49	-.04	.08
3	10.	-1.15	-2.28	-.23	.00	.64	-2.35	-.01	-.02
4	8.	-1.18	-2.20	-.22	-.03	.59	-2.24	-.01	-.002
5	6.	-1.22	-2.06	-.22	-.03	.50	-1.97	-.005	-.01
6	4.	-1.26	-1.95	-.20	-.07	.44	-1.83	+.005	-.009
7	2.	-1.30	-1.79	-.20	-.08	.35	-1.57	.01	-.18
8	0.	-1.33	-1.64	-.20	-.08	.26	-1.29	.15	-.30
9	-2.	-1.37	-1.48	-.20	-.08	.17	-1.01	.21	-.41
10	-4.	-1.41	-1.32	-.19	-.09	.09	-0.74	.26	-.50
11	-6.	-1.45	-1.15	-.19	-.09	.00	-0.58	.30	-.59
12	-8.	-1.49	-0.97	-.18	-.10	-.09	-0.19	.30	-.58

	B-MAGNET [m]	[m^{-2}]	SYNCHROTRON INTEGRALS					DAMPING TIMES [ms] τ		
RUN	B[L]	B[K1]	I1	I2	I3	I4	I5	x	y	e
1	.626	-.458	4.23	3.94	2.47	-4.56	1.90	32	70	83
2	.623	-.474	4.23	3.96	2.50	-4.09	1.92	34	70	72
3	.621	-.486	4.23	3.97	2.51	-4.00	1.93	35	69	70
4	.621	-.558	4.23	3.98	2.52	-4.28	1.94	33	69	75
5	.620	-.559	4.23	3.98	2.52	-3.97	1.94	35	69	69
6	.618	-.637	4.23	3.99	2.54	-4.31				

$\Delta\xi_{H,V}$ for the inner part and the end-faces has been summed up numerically from COMFORT runs.

$\Delta\xi_{H,V}$ resulting from the auxiliary quadrupoles Q1,Q2 is calculated with:

$$\Delta\xi_H = -(1/4\pi Q_H)\{Q1R[K1] * Q1R[L] * \Sigma\beta_{1,H} + Q2R[K1] * Q2R[L] * \Sigma\beta_{2,H}\}$$

$$\Delta\xi_V = (1/4\pi Q_V)\{Q1R[K1] * Q1R[L] * \Sigma\beta_{1,V} + Q2R[K1] * Q2R[L] * \Sigma\beta_{2,V}\}$$

QiR[K1],QiR[L] are taken from TABLE 4.
$\Sigma\beta_{i(H,V)}$ come from RUN 2(ϕ=11.25°)

Numerically,

$\Sigma\beta_{1,H}/4\pi Q_H = 2.54$,
$\Sigma\beta_{2,H}/4\pi Q_H = 2.65$,
$\Sigma\beta_{1,V}/4\pi Q_V = 5.35$,
$\Sigma\beta_{2,V}/4\pi Q_V = 5.15$

where $\beta_i = \beta$ at Q_i.

APPENDIX C.

Figure 1. Schematic drawing of magnet for ORBIT1.

Figure 2. Schematic drawing of model.

Figure 3. Chromaticity results from ORBIT2 runs.

Figure 4. $Q = f(\xi_s)$ at different energies.

Figure 5. Chromaticity as a function of end-face rotation ϕ.

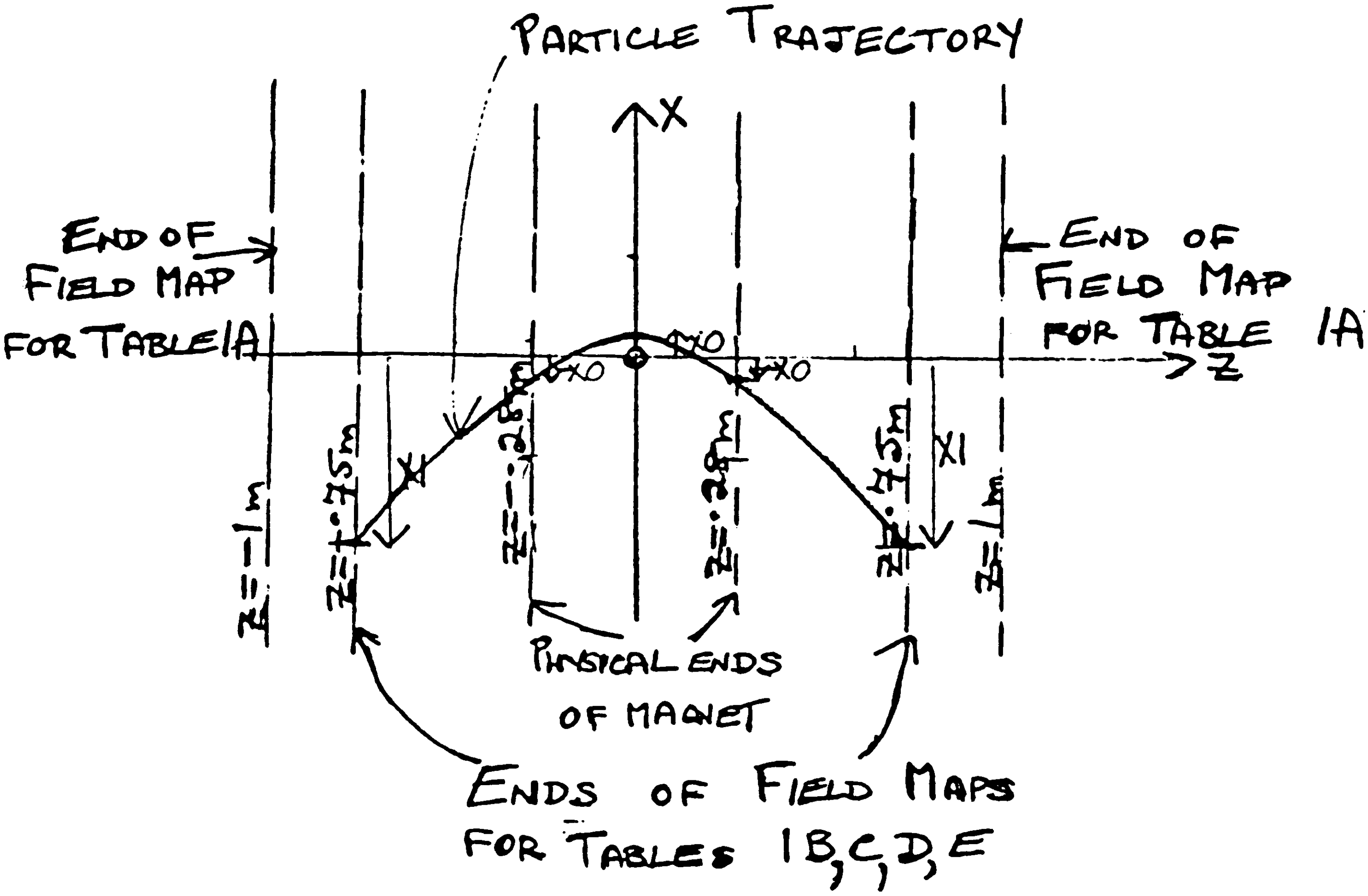
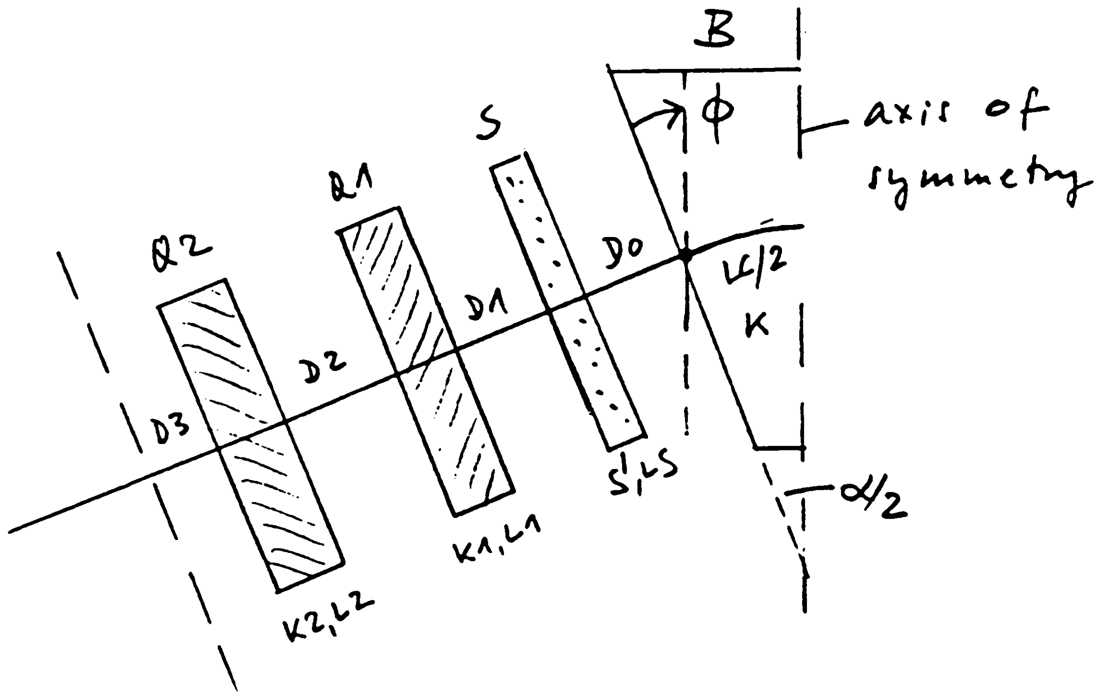


FIGURE 1. SCHEMATIC DRAWING OF MAGNET FOR ORBIT1



where $L/2 = \sum L_i + \sum D_j + LC/2 + D_0 + LS = \text{const.}$

FIGURE 2. SCHEMATIC DRAWING OF MODEL

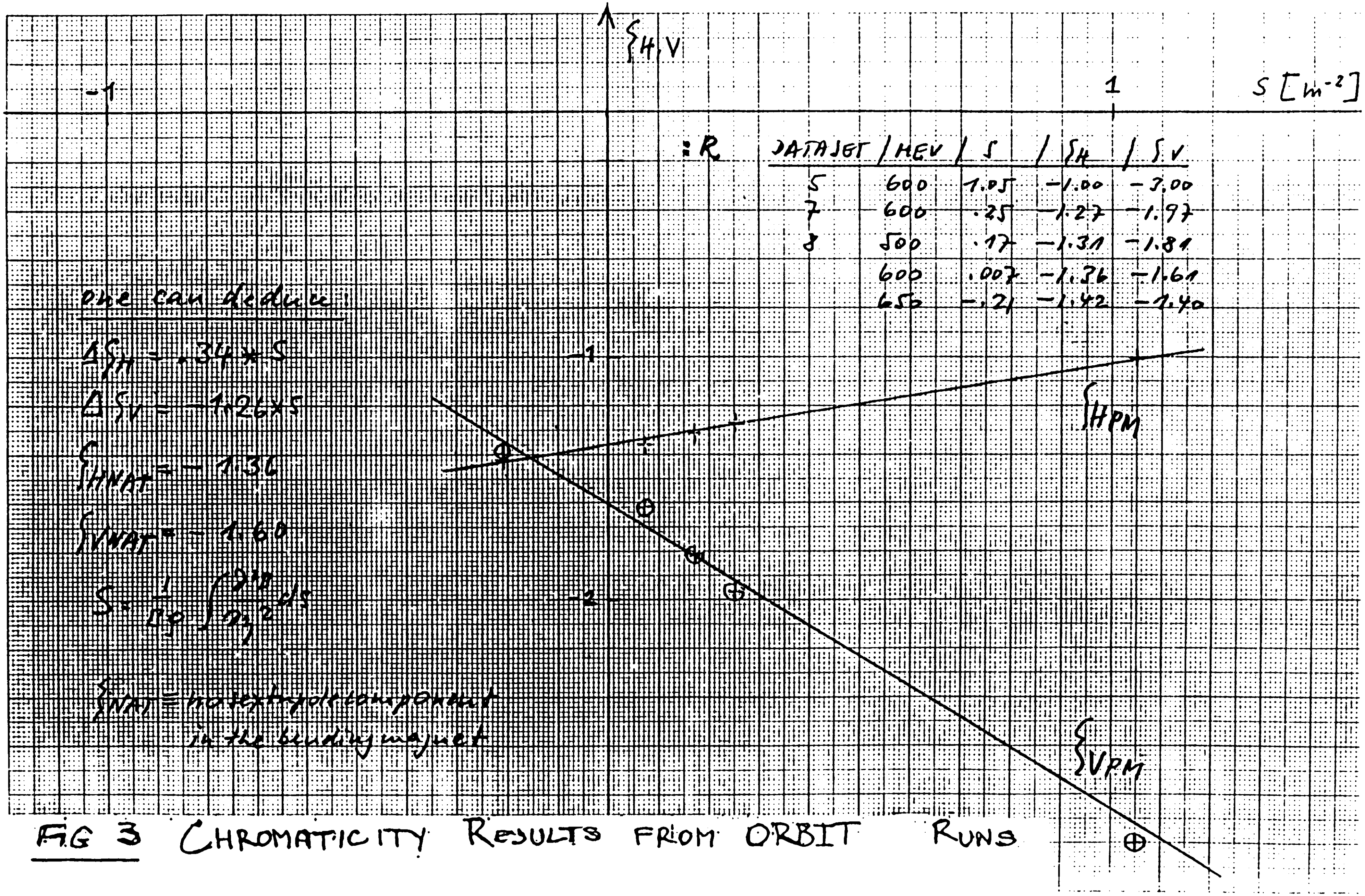


FIG 3 CHROMATICITY RESULTS FROM ORBIT RUNS

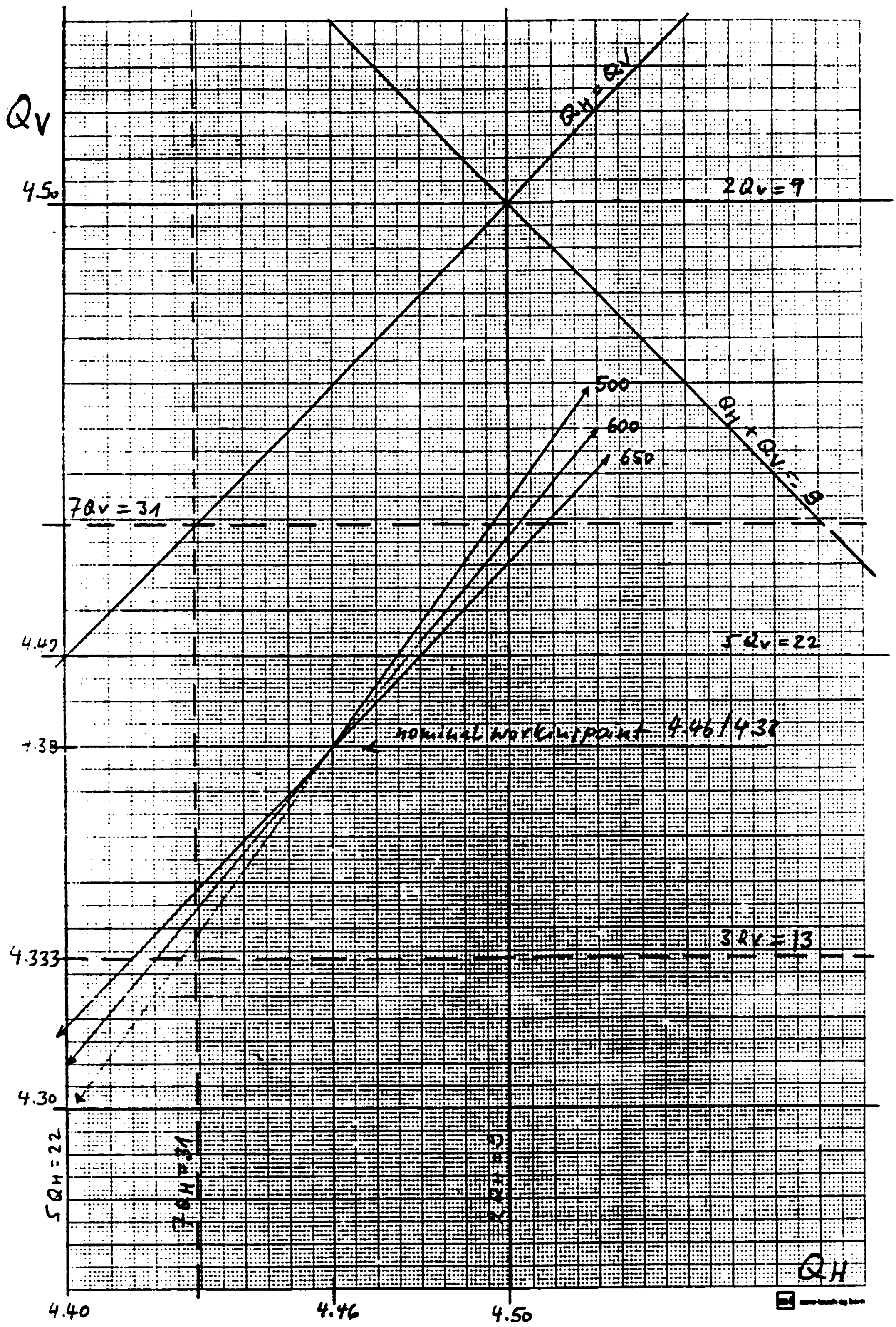


Fig 4: $Q = f(\xi_s)$ at different energies

$\Delta p = \pm 1\% * p_0$: R

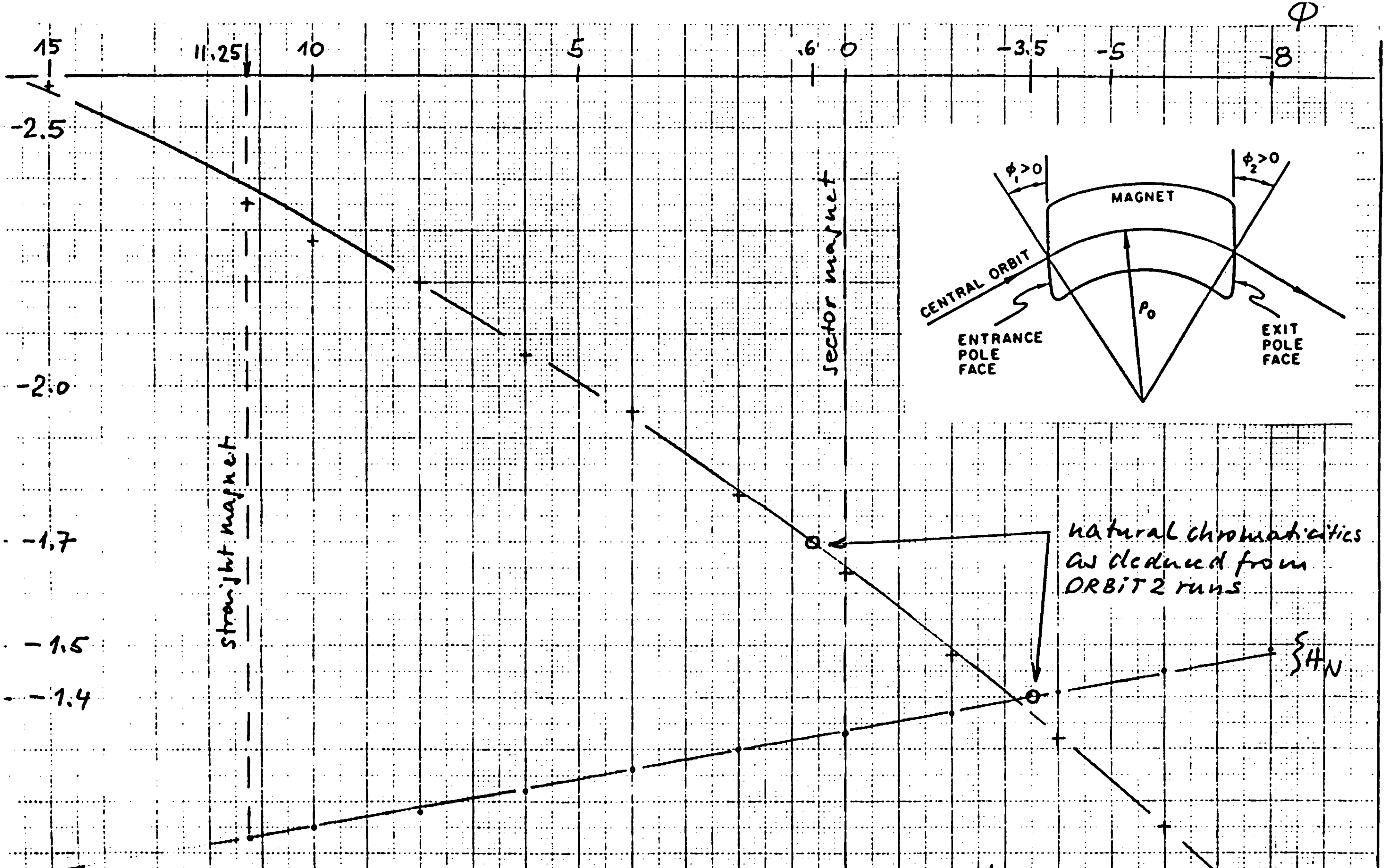


FIG.5: Chromaticity as function of endface rotation Φ
for every Φ, linear matching was done, no sextupoles were in

APPENDIX D. REFERENCES.

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