p̄ Note # 503

DECELERATION ORBIT IMPROVEMENTS

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26 April 1991

I. Motivation

During the accelerator studies period of 12/90 - 1/91 much study time was dedicated to improving the E760 deceleration ramps. 4 general goals were in mind:

1) Reduce the relative orbit deviations from the nominal reference orbit as much as possible. This reduces the potential error in the orbit length calculation—which is the primary source of error in the beam energy calculation (see Pbar Note "BPM System Improvements").
2) Maximize the transverse apertures. This minimizes beam loss during deceleration and during accidental beam blow-ups.
3) Measure and correct lattice parameters. Knowledge of γ_T, η, Q_h, Q_v, and the dispersion in the straight sections allows for a more accurate energy calculation and reliable SYNCH calculations.
4) Minimize the coupling. This allows one to discern between horizontal and vertical tunes.

II. Deceleration Ramps

The E760 deceleration ramps consist of up to 64 momentum points above transition and up to 64 momentum points below transition. At each point the currents of 78 devices are defined (plus RF frequency, RF voltage, 2 skew quad polarity switches, 4 damper delay switches, and 2 Hall probe parameters). Deceleration between points is a linear interpolation. Another ramp table defines momentum as a function of time (Fig. 1). A subset of the 64 ramp points are denoted as "primary" ramp points, and in practice most ramp corrections are made at these primary points only. The currents at other ramp points are derived from a linear interpolation between primary points. An exception to this is the RF frequency, which must be corrected at every ramp point near transition and below transition since frequency is not proportional to momentum at low energies.

III. Studies

A. Closed Orbit Corrections

A horizontal reference orbit was chosen at P_{beam} = 8374Mev/c with an aperture of $A_H = 12\pi$ mm-mrad; and a vertical reference orbit was chosen at P_{beam} = 8834Mev/c with an aperture of $A_V = 10\pi$ mm-mrad (Fig. 2). It is required that this orbit be approximately centered in the machine, but more closely centered at A50 (interaction region) and A60 (2-4 momentum pickup). The 4-8 momentum pickup is at A20 and can be moved to be centered on the beam.

Orbits at other energies were adjusted so as to minimize the deviation from the reference orbit. Horizontal deviations were kept to $< \pm 5mm$, and vertical deviations were kept to $< \pm 2mm$. The RF frequency was adjusted to keep $\mid \Delta p/p \mid \leq .0001$. A typical difference orbit is shown in Fig. 3.

The general procedure used to correct orbits was the following. First a global orbit correction was made using P53 "FIX CLOSED ORBIT." This usually left a few excessively large local bumps which were then eliminated using P53 "4-BUMPS AND 3-BUMPS." Both these procedures were often iterated; and after a few corrections, the beam would be dumped, busses recycled, and new beam decelerated to the energy of interest. This was necessary to overcome the problem of hysterisis in the main dipole magnets. As beam momentum was lowered, "FIX CLOSED ORBITS" became less and less effective for horizontal corrections and eventually all corrections had to be made with local bumps. "FIX CLOSED ORBITS" was generally very effective in smoothing the vertical orbit and only occasionally was it necessary to make local bumps to smooth the vertical orbit. Fig. 4 shows the above-transition ramps for A:IB and A:BS310. The erratic nature of the BS310 ramp at the beginning of the ramp is typical of horizontal trims and shunts andhas two probable causes: saturation of the dipoles and large quadrupoles at high currents, and inadequate orbit correction software.

B. Apertures

After smoothing the orbits to the above criteria, the apertures were measured and typically found large enough such that no more corrections were necessary. Fig. 5 shows the horizontal and vertical apertures compared with the apertures obtained with the ramps used during the E760 run of 5/90 to 9/90. During E760 running, emittances are typically kept at about 1 π mm-mrad and during deceleration they typically grow to $\sim 4\pi$ mm-mrad. The dramatic drop in apertures just after transition is due to the large quadrupoles mis-steering the beam during transition crossing (no trims or shunts are ramped during transition crossing). This also reduces the momentum aperture from $> 1\%$ above transition to .75% below transition with the beam positioned only $\sim$ 9 Mev from the edge of the momentum aperture. For this reason, care must be taken when bunching the beam below transition. This problem would be greatly mitigated if the beam could be accurately and easily centered in the quadrupoles.

C. Tunes, chromaticity, γ_T, and Coupling

At each primary ramp point the tunes were adjusted using the mults shown in Fig. 6. These mults worked well at all energies. The tunes were kept at $Q_h = .614 \pm .003$ and $Q_v = .611 \pm .003$. Adjusting the tunes had some effect on the orbits and vice versa, therefore these two corrections often had to be repeated.

The chromaticity was only occasionally adjusted. The mults shown in Fig. 6 were used, although the horizontal and vertical are not at all decoupled with these mults. For the most part, the sextupoles are ramped down linearly with momentum

γ_T was adjusted by changing the LQ current a large amount and QT, QD, QF smaller amounts to maintain constant tune. The change in γ_T is given approximately by

$$d\gamma_T = (dLQ/60amps) \cdot P_{beam}/5174 \tag{1}$$

where P_{beam} is in Mev/c. Fig. 7 shows γ_T as a function of momentum.

An attempt was made to decouple the tunes at all energies, however below transition this became progressively more difficult (reason unknown). At 3594 Mev/c the tunes appear to be almost completely coupled. The 2 skew quads, SQ100, and SQ607, have polarity switches on them which can be changed during deceleration, but we were unable to find a polarity combination which eliminated coupling at low energies.

IV. Conclusions

The deceleration ramps generated during the 12/90 - 1/91 studies period should be adequate for the coming E760 run, and represent a small improvement over the previous set of ramps in orbit uniformity. A fairly complete library of measurements for these ramps is contained in the "E760 Ramps Notebook" generally kept at AP10.

Developing new ramps in the future would be greatly facilitated by an improved orbit correction Application Program. The orbit corrections were by far the most time-consuming part of this effort.

P81 BEAM DECELERATION IN THE ACCUMULATOR (II) ♦COPIES♦

```
*LX♦ X-A/D  X=TIME   Y=L:TESCAR, :QB15F ,T QA45  ,T QA45F
.... Eng-U  I= 0     I= 0       ,-50    ,-50     ,-50
One+ AUTO   F= 400   F= 1       , 50    , 50     , 50
```

momentum = 5174 mev time = 0secs

- -

READ FROM SCREEN WRITE TO SCREEN -<-1>+ A: -< 0>+ A: RETURN

	seconds	mom(Mev)		seconds	mom(Mev)		seconds	mom(Mev)		seconds	mom(Mev)
1	0	5174P	17	22	4754	33	54	4114	~~49~~	~~86~~	~~3474~~
2	1	5164	18	24	4714	34	56	4074	~~50~~	~~88~~	~~3434~~
3	2	5154	19	26	4674	35	58	4034P	~~51~~	~~90~~	~~3394~~
4	3	5134P	20	28	4634	36	60	3994	~~52~~	~~92~~	~~3354~~
5	4	5114	21	30	4594	37	62	3954	~~53~~	~~94~~	~~3314~~
6	5	5094	22	32	4554	38	64	3914	~~54~~	~~96~~	~~3274~~
7	6	5074	23	34	4514	39	66	3874	~~55~~	~~98~~	~~3234~~
8	7	5054	24	36	4474	40	68	3834	~~56~~	~~100~~	~~3194~~
9	8	5034	25	38	4434P	41	70	3794	~~57~~	~~102~~	~~3154~~
10	9	5014	26	40	4394	42	72	3754	~~58~~	~~104~~	~~3114~~
11	10	4994	27	42	4354	43	74	3714	~~59~~	~~106~~	~~3074~~
12	12	4954	28	44	4314	44	76	3674	~~60~~	~~108~~	~~3034~~
13	14	4914	29	46	4274	45	78	3634	~~61~~	~~110~~	~~2994~~
14	16	4874	30	48	4234	46	80	3594P	~~62~~	~~112~~	~~2954~~
15	18	4834P	31	50	4194	~~47~~	~~82~~	~~3554~~	~~63~~	~~114~~	~~2914~~
16	20	4794	32	52	4154	~~48~~	~~84~~	~~3514~~	~~64~~	~~116~~	~~2874~~

BELOW TRANSITION

P81 BEAM DECELERATION IN THE ACCUMULATOR (II) ♦COPIES♦

```
*LX♦ X-A/D  X=TIME   Y=L:TESCAR, :QB15F ,T QA45  ,T QA45F
.... Eng-U  I= 0     I= 0       ,-50    ,-50     ,-50
One+ AUTO   F= 400   F= 1       , 50    , 50     , 50
```

momentum = 8834 mev time = 0secs

- -

READ FROM SCREEN WRITE TO SCREEN -<-1>+ A: -< 0>+ A: RETURN

	seconds	mom(Mev)		seconds	mom(Mev)		seconds	mom(Mev)		seconds	mom(Mev)
1	0	8834P	17	32	8194	33	76	7314	49	139	6054
2	2	8794P	18	34	8154	34	79	7254P	50	143	5974
3	4	8754	19	36	8114	35	83	7174	51	147	5894
4	6	8714	20	38	8074P	36	87	7094	52	151	5814P
5	8	8674P	21	40	8034	37	91	7014	53	155	5734
6	10	8634	22	43	7974	38	95	6934	54	159	5654
7	12	8594	23	46	7914	39	99	6854	55	163	5574
8	14	8554P	24	49	7854	40	103	6774P	56	167	5494
9	16	8514	25	52	7794	41	107	6694	57	171	5414
10	18	8474	26	55	7734P	42	111	6614	58	175	5334P
11	20	8434	27	58	7674	43	115	6534	59	179	5254
12	22	8394	28	61	7614	44	119	6454	60	183	5174P
13	24	8354P	29	64	7554	45	123	6374	~~61~~	~~187~~	~~5094~~
14	26	8314	30	67	7494	46	127	6294P	~~62~~	~~191~~	~~5014~~
15	28	8274	31	70	7434	47	131	6214	~~63~~	~~195~~	~~4934~~
16	30	8234	32	73	7374	48	135	6134	~~64~~	~~199~~	~~4854~~

ABOVE TRANSITION

FIG. 1: Deceleration ramp tables showing momentum vs. time; "primary" ramp points are denoted by "P"

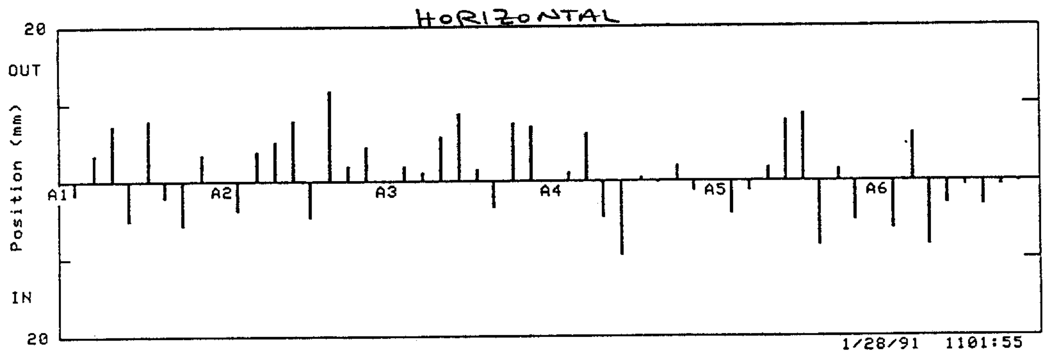
ACCUMULATOR CLOSED ORBIT (HORIZONTAL)

A:R1LLFS 52.624 A:R3HLFB .2495869
A:IBEAM .0032
RECORD 169 CO Date/Time: 1/11/91 0202:38 NEW E760 REF FILE- HORIZ. ONLY!
AVG OVER 20 FRAMES (20 20 20 20 20 20)
Deltap/p = 0

CONSOLE LOCATION 14; AP10 28-JAN-1991 11:02

BEAM POSITIONS (mm)

A1Q1	-1.59	A2Q14	-3.81	A3Q1	2.06	A4Q14	1	A5Q1	-4.26	A6Q14	-6.22
A1Q3	3.4	A2Q11	3.81	A3Q3	1.06	A4Q11	6.22	A5Q3	-1.26	A6Q11	6.22
A1Q4	7.23	A2Q10	5.02	A3Q4	5.74	A4Q10	-4.62	A5Q4	1.73	A6Q10	-8.24
A1Q6	-4.93	A2Q8	7.73	A3Q6	8.77	A4Q8	-9.65	A5Q6	7.76	A6Q8	-2.93
A1Q8	7.73	A2Q6	-4.6	A3Q8	1.4	A4Q6	.4	A5Q8	8.77	A6Q6	-.59
A1Q10	-2.21	A2Q4	11.72	A3Q10	-3.41	A4Q4	-.26	A5Q10	-8.24	A6Q4	-3.26
A1Q11	-5.82	A2Q3	2.06	A3Q11	7.43	A4Q3	2.06	A5Q11	1.4	A6Q3	-.59
A1Q14	3.41	A2Q1	4.4	A3Q14	7.03	A4Q1	-1.26	A5Q14	-5.02	A6Q1	-.26



ACCUMULATOR CLOSED ORBIT (VERTICAL)

A:R1LLFS 52.82441 A:R3HLFB 96.69649
A:IBEAM 2.812
RECORD 168 CO Date/Time: 12/14/90 2026:21 NEW E760 REF FILE FOR ORBIT CORR
AVG OVER 40 FRAMES (20 20 20 20 20 20)

CONSOLE LOCATION 14; AP10 28-JAN-1991 11:01

BEAM POSITIONS (mm)

A1Q1	5.94	NO PU	NO MUX	A3Q1	2.59	NO PU	NO MUX	A5Q1	-.06	NO PU	NO MUX
A1Q2	1.93	A2Q14	.65	A3Q2	2.26	A4Q14	-.6	A5Q2	-2.06	A6Q14	-.78
A1Q5	-1.5	A2Q13	1.72	A3Q5	6.27	A4Q13	1.9	A5Q5	-4.06	A6Q13	-1.86
A1Q7	-.06	A2Q9	.26	A3Q7	-4.73	A4Q9	-1.73	A5Q7	-3.73	A6Q9	2.26
A1Q9	-1.73	A2Q7	-2.73	A3Q9	1.59	A4Q7	7.28	A5Q9	1.26	A6Q7	-6.07
A1Q13	-.6	A2Q5	.59	A3Q13	-.24	A4Q5	-1.4	A5Q13	.47	A6Q5	3.59
A1Q14	.65	A2Q2	1.26	A3Q14	.29	A4Q2	1.26	A5Q14	.65	A6Q2	-1.06
NO PU	NO MUX	A2Q1	3.93	NO PU	NO MUX	A4Q1	1.93	NO PU	NO MUX	A6Q1	2.26

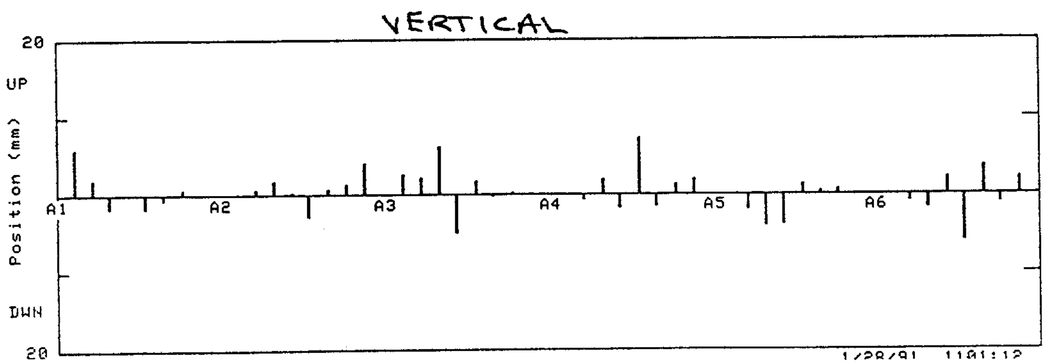


FIG. 2: The horizontal and vertical reference orbits used in making orbit corrections

CONSOLE LOCATION 08; AP10 18-DEC-1990 06:54

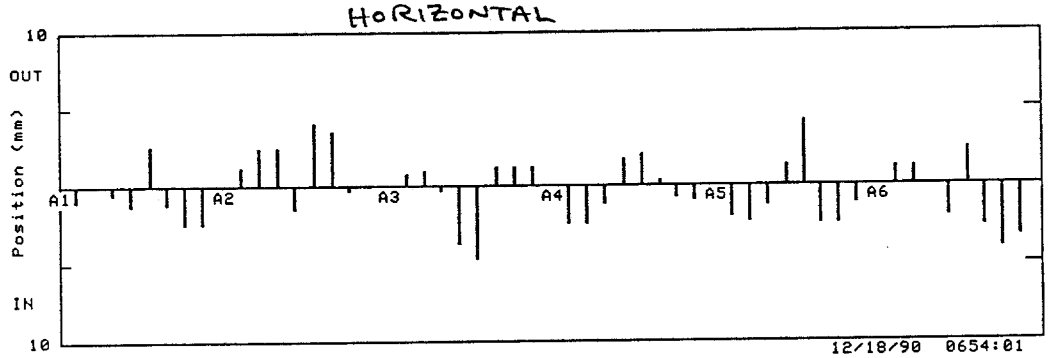
ACCUMULATOR CLOSED ORBIT (HORIZONTAL)

A:R1LLFS 52.792 A:R3HLFB 258.8615
A:IBEAM 4.57
CO Date/Time: 12/18/90 0653:52
AVG OVER 20 FRAMES (20 20 20 20 20 20) FILE 168 HAS BEEN SUBTRACTED
Deltap/p = 0

BEAM POSITIONS (mm)

A1Q1	-1	A2Q14	1.21	A3Q1	.67	A4Q14	-2.4	A5Q1	-2.01	A6Q14	1.21
A1Q3	0	A2Q11	2.41	A3Q3	1	A4Q11	-2.41	A5Q3	-2.33	A6Q11	1.21
A1Q4	-.5	A2Q10	2.41	A3Q4	-.33	A4Q10	-1.2	A5Q4	-1.32	A6Q10	0
A1Q6	-1.34	A2Q8	-1.5	A3Q6	-3.67	A4Q8	1.69	A5Q6	1.33	A6Q8	-2
A1Q8	2.47	A2Q6	3.99	A3Q8	-4.65	A4Q6	1.99	A5Q8	4.07	A6Q6	2.33
A1Q10	-1.21	A2Q4	3.53	A3Q10	1.21	A4Q4	.33	A5Q10	-2.41	A6Q4	-2.67
A1Q11	-2.41	A2Q3	-.33	A3Q11	1.21	A4Q3	-.66	A5Q11	-2.41	A6Q3	-3.99
A1Q14	-2.41	A2Q1	0	A3Q14	1.21	A4Q1	-1	A5Q14	-1.2	A6Q1	-3.34

HORIZONTAL



CONSOLE LOCATION 08; AP10 18-DEC-1990 06:54

@6214 @6214

ACCUMULATOR CLOSED ORBIT (VERTICAL)

A:R1LLFS 52.792 A:R3HLFB 258.8615
A:IBEAM 4.57
CO Date/Time: 12/18/90 0653:52
AVG OVER 20 FRAMES (20 20 20 20 20 20) FILE 168 HAS BEEN SUBTRACTED

BEAM POSITIONS (mm)

A1Q1	-.34	NO PU	NO MUX	A3Q1	.34	NO PU	NO MUX	A5Q1	-1	NO PU	NO MUX
A1Q2	-.34	A2Q14	-.71	A3Q2	0	A4Q14	.71	A5Q2	-1.34	A6Q14	-.18
A1Q5	-.48	A2Q13	-.9	A3Q5	-1.34	A4Q13	.72	A5Q5	.66	A6Q13	.18
A1Q7	1.65	A2Q9	0	A3Q7	1.33	A4Q9	-1.33	A5Q7	0	A6Q9	0
A1Q9	.33	A2Q7	1	A3Q9	-1.33	A4Q7	.68	A5Q9	-.67	A6Q7	.33
A1Q13	.36	A2Q5	-.33	A3Q13	.89	A4Q5	-1	A5Q13	.18	A6Q5	-.33
A1Q14	0	A2Q2	.67	A3Q14	.36	A4Q2	.33	A5Q14	0	A6Q2	0
NO PU	NO MUX	A2Q1	.67	NO PU	NO MUX	A4Q1	0	NO PU	NO MUX	A6Q1	0

VERTICAL

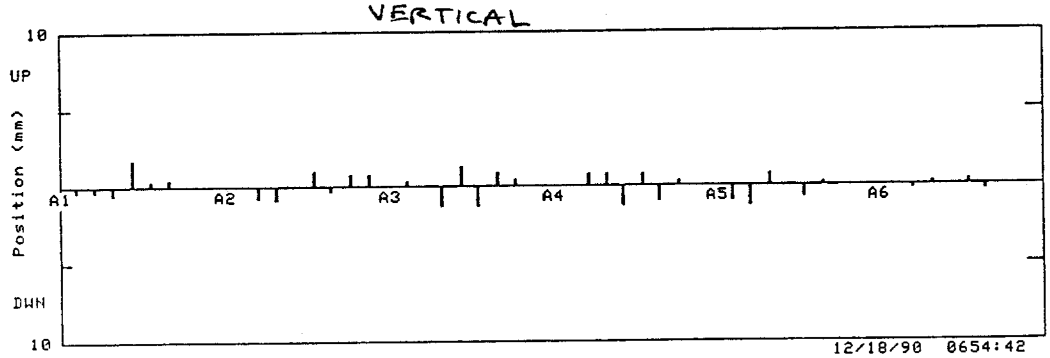


FIG. 3: A typical difference orbit; beam momentum = 6214 Mev/c

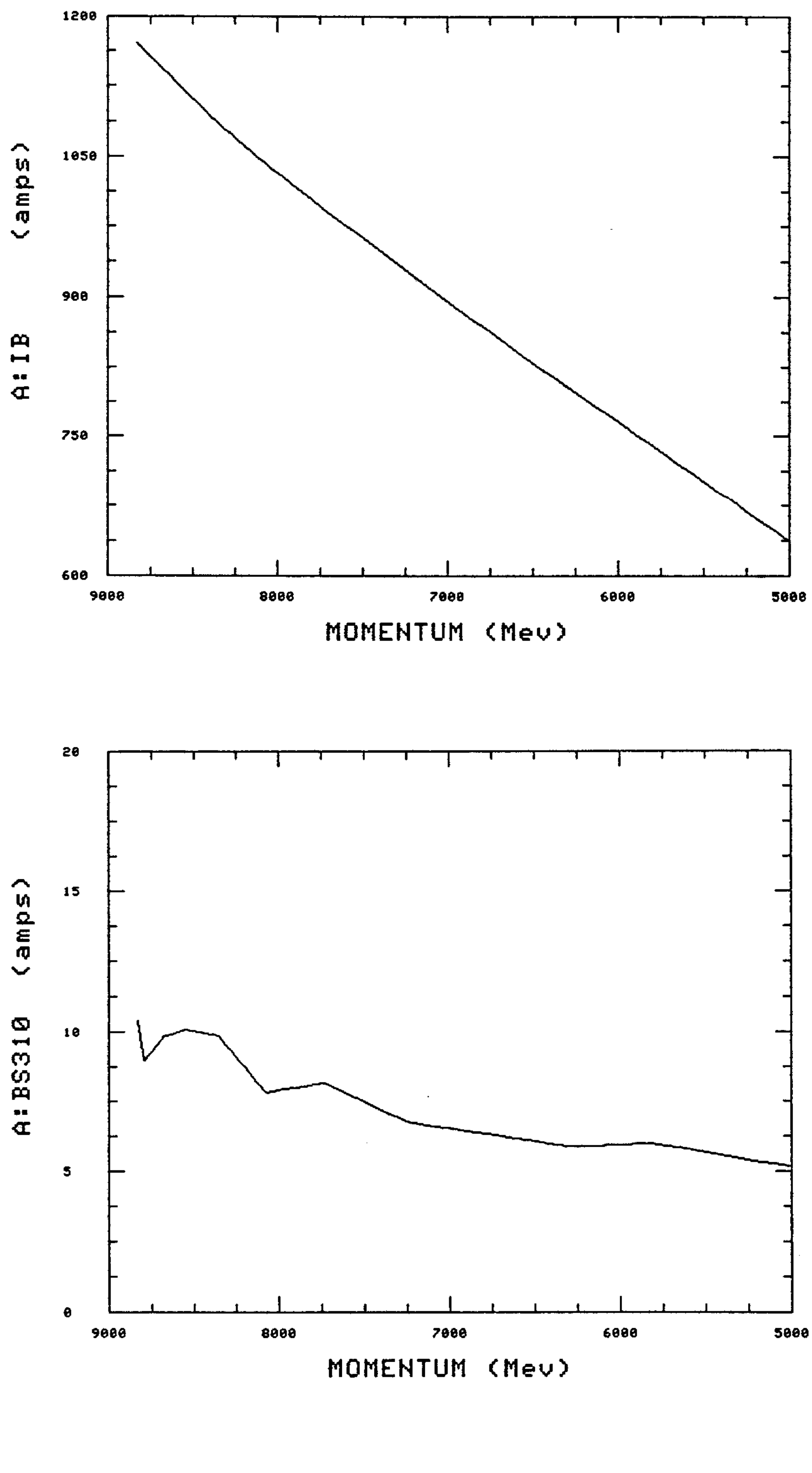
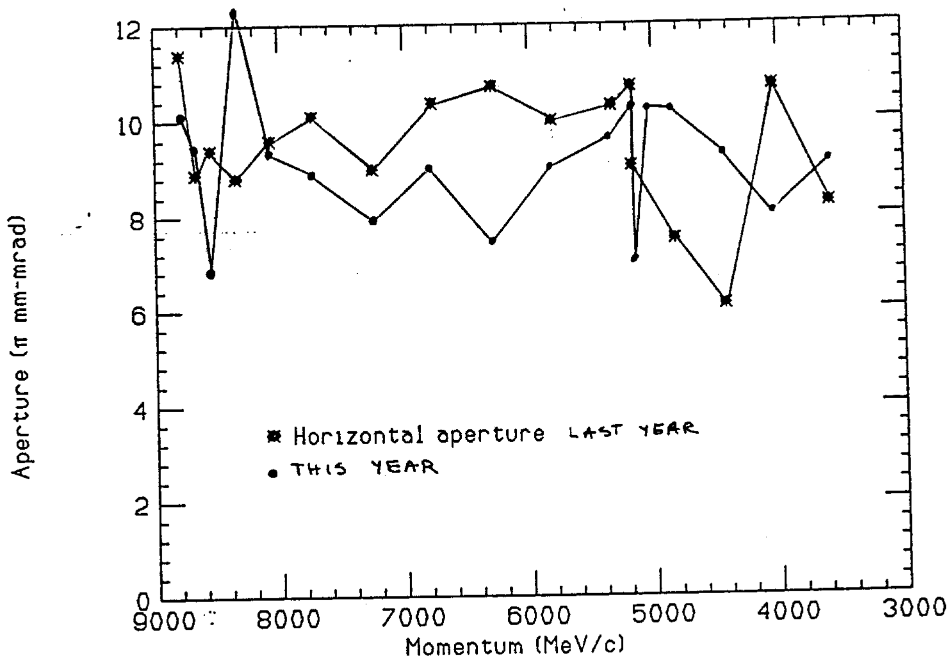


FIG. 4: Bend bus current as a function of beam momentum; shunt current as a function of momentum



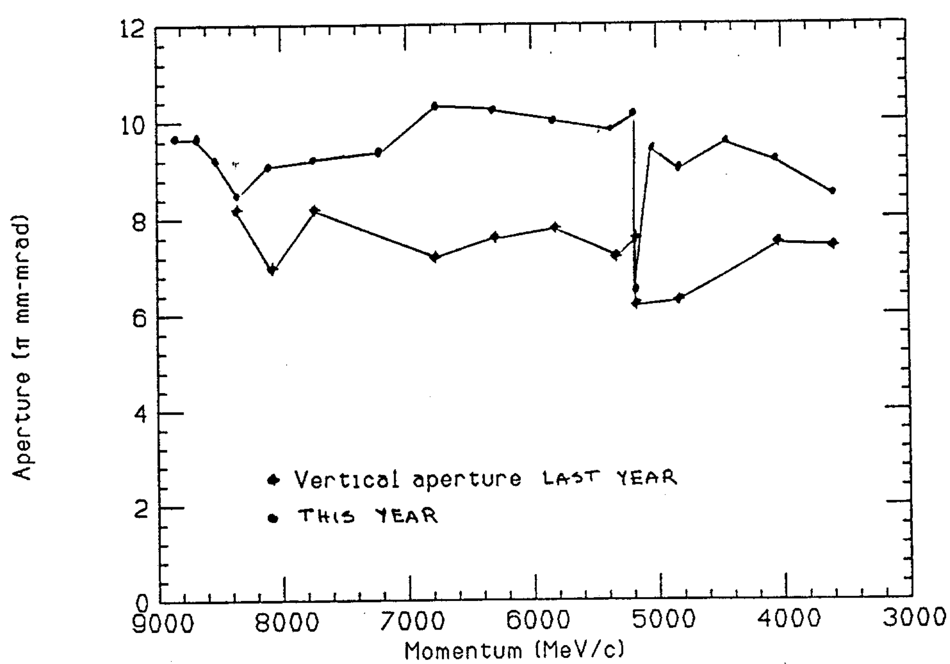


FIG. 5: Horizontal and vertical apertures as a function of momentum, as compared to previous deceleration ramps

CONSOLE LOCATION 16; MCR-N1   26-APR-1991 12:59
Main color TV

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P79  TUNES, GAMMAT, COUPLING        SET     D/A    A/D   Eng-U ♦COPIES♦
-<FTP>+ *LX♦ X-A/D  X=TIME      Y=L:CGAUSS,L T2CHIP,B ELCWSP,B WLCWSP
COMMAND ---- Eng-U  I= 0        I= 140     , 0       , 90      , 90
-< 1>+  One+ AUTO   F= 1200     F=-140     , 80      , 130     , 130
params MULTS  apert  cool'n radmon gasdet stackn paux.. bumps

 MULT:4         HOR TUNE QT .00446
-A:LQ*-.021     ACCUMULATOR LARGE QUA  0          * 0         Amp  *T.
-A:QT*.225      ACCUMULATOR QUAD TRIM  0          * .0003     Amp  *T.
-A:QDF*-.051    ACCUMULATOR QUAD DF B  0          *-.0007     Amp  *T.
-A:QSD*2        QDF DEFOCUSIN SHUNT          0      *  .065   AMP

 MULT:4         VER TUNE QT -.03448
-A:QT*-.03      ACCUMULATOR QUAD TRIM  0          * .0003     Amp  *T.
-A:QDF*.041     ACCUMULATOR QUAD DF B  0          *-.0007     Amp  *T.
-A:QSF1*.623    QDF   FOCUSIN SHUNT # 1      0      *  0      AMP
-A:LQ*.008      ACCUMULATOR LARGE QUA  0          * 0         Amp  *T.

-A:SQ607*.1     SKEW QUAD  100AMP          35.69  *  20 -95AMP  *TL
-A:SQ607R       SQ607 POLARITY REVERSAL      0               VOLT    +
-A:SQ100*.1     SKEW QUAD  200AMP          3.064  *  20 -95AMP  *TL
-A:SQ100R       SQ100 POLARITY REVERSAL      0               VOLT    +

-A:LQ*.01       ACCUMULATOR LARGE QUA  0          * 0         Amp  *T.

-A:QT*.01       ACCUMULATOR QUAD TRIM  0          * .0001     Amp  *T.
```

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P79  CHROMATICITY  MULTS          SET      D/A    A/D   Eng-U ♦COPIES♦
-<FTP>+ *LX♦ X-D/A  X=B:HL21   Y=B:HL21   ,M ABTHR ,           ,
COMMAND ---- Eng-U  I=-10      I=-10      ,-2       ,-10       ,-10
-< 3>+  r_14 Auto   F= 10      F= 10      , 10      , 10       , 10
params MULTS  apert  cool'n radmon gasdet stackn paux.. bumps

 MULT:2        HORIZ CHROM
-A:SEX10*1.16 Q10 SEX    600A/100V SEX      392.4   *   20 -95AMP   *TL
-A:SEX12*2.28 Q12 SEX    600A/100V SEX      422.5   *   20 -95AMP   *TL


 MULT:2        VERT CHROM
-A:SEX10*1.16 Q10 SEX    600A/100V SEX      392.4   *   20 -95AMP   *TL
-A:SEX12*3.29 Q12 SEX    600A/100V SEX      422.5   *   20 -95AMP   *TL
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FIG. 6: Tune mults and chromaticity mults

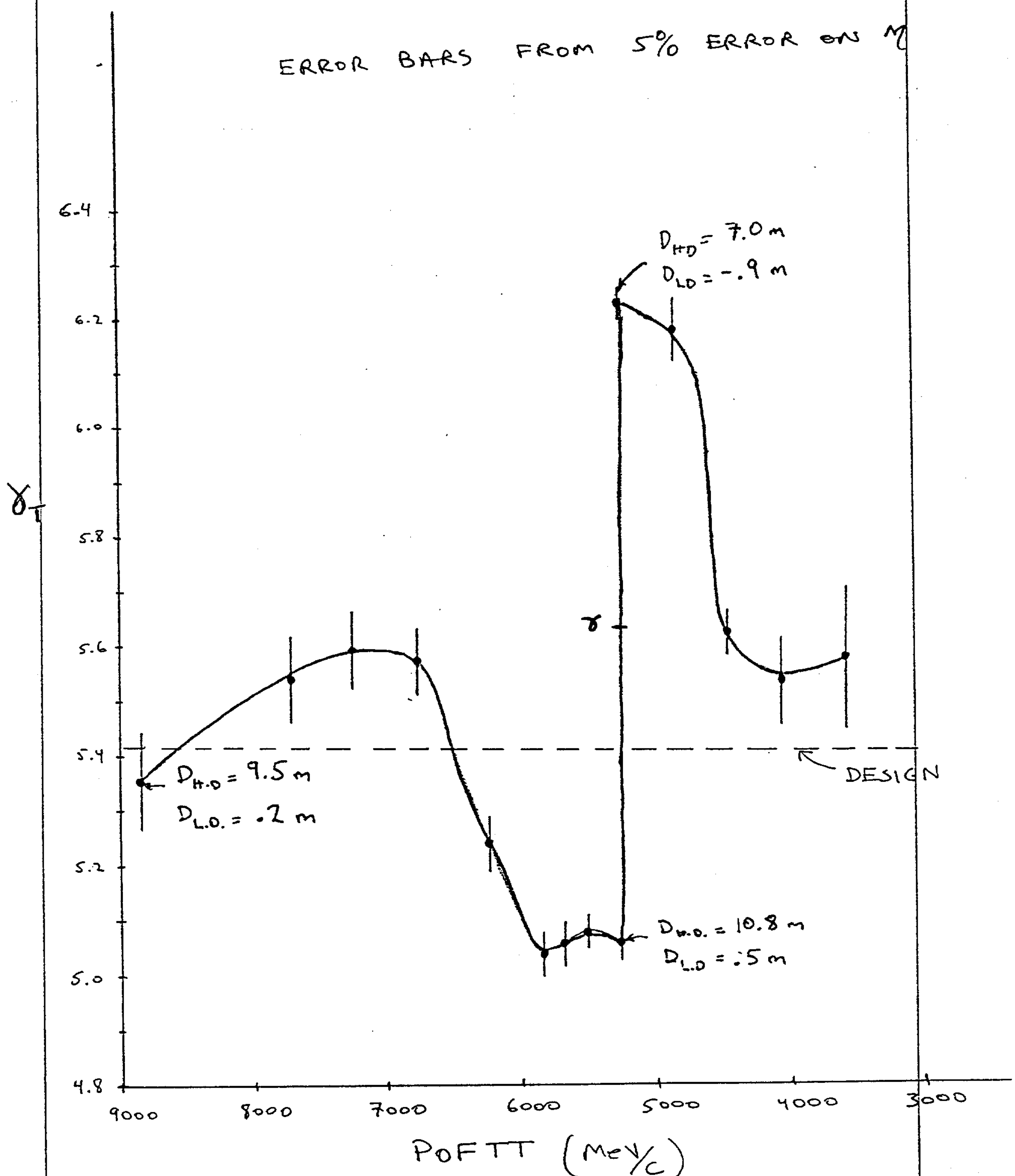

FIG. 7: Transition gamma as a function of beam energy; also shown are the dispersions at the straight sections