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THE NEW FAST EXTRACTION SYSTEM [NewFEB] AT THE AGS

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THE NEW FAST EXTRACTION SYSTEM [NewFEB] AT THE AGS

(The conceptual design of the new fast extraction system for the AGS g-2 experiment, RHIC injection and FEB)

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ABSTRACT

The AGS g-2 experiment (E821) requires new single-bunch multiple-extracted [SBME] beam from the AGS. Due to removal of the H5 and E5 kickers, neither the single bunch extraction [SBE] system nor the fast extracted beam [FEB] system will be available for the post-Booster era. As a result, the new FEB [NewFEB] system is proposed for both the g-2 experiment and RHIC injection. The NewFEB system will consist of a new fast multi-pulsing kicker at straight section G10 [FKG10] and an ejector septum magnet at H10 [SMH10] with local orbit bumps [BLWGH] generated by power backleg windings. This note is intended to define basic design parameters, to discuss possible options, and to provide guidelines for more detailed engineering design work [+].

[+] This note is an upgraded version of M. Tanaka, Muon g-2 Note No.31, and AD/Physics Note No.8, "The AGS g-2 Extraction System".

CHAPTER 1

I. INTRODUCTION

Since the present FEB and SBE systems [1] are no longer available for the post-Booster era due to removal of fast kickers FKE5 and FKH5 [2], the NewFEB syetem will serve as the AGS extraction system not just for the AGS g-2 experiment [3] but also for the Relativistic Heavy Ion Collider [RHIC] [4] and any future neutrino physics program.

For the g-2 experiment, which is now constructing a 14 m diameter 3 GeV/c superferric muon storage ring [μSR] with B=1.5 T in the old 80" buble chamber building, in order to measure the anomalous magnetic moment ($a_\mu = (g-2)/2$) with an error of 0.3 ppm, NewFEB must meet the following requirements:

(1) extract proton beam up to full energy;

(2) single (or double) bunch multiple extraction [SBME/DBME] at intervals of $2 < t < 10$ ms and at least up to six (or three) times per AGS cycle for the nominal operation (the μSR needs only one bunch per spill for μ injection and can take up to two bunches per spill for pion injection);

(3) extract up to $\sim 4.2 \times 10^{12}$ protons per bunch to the new V-target for 3.1 GeV/c pion production through the existing U-line;

(4) the remaining bunches, if any, have to be debunched and delivered to the East Area through the existing SEB channel (the g-2 experiment originally proposed two micropulses, three times per FEB cycle, i.e., three DBEs (50% of the beam) to the D-line during FEB (U-line) operation [5]);

(5) a fast kicker at 10 foot straight section G10 [FKG10] and an ejector septum magnet at H10 [SMH10] [6];

(6) can also deliver the SBE beam to the East Area through the SEB channel as the substitute of the existing SBE system as early as possible so that the FKE5 kicker can be removed and the SBE beam will be avialable without any interuption.

The AGS with the Booster [7] must also serve as an injector for the RHIC, which is now under construction. The circumference of the RHIC ring is 19/4 times larger than the AGS and its harmonic number at injection is 342 (=6x12x19/4) compared to 12 of the AGS. The present RHIC design [4] assumes that the AGS can accelerate a variable number of bunches per pulse and the FEB/SBE system can be used as the AGS extraction system for RHIC injection. The exact operation mode of RHIC injection has not yet been fixed [8]. There are several possible ways:

a) one may transfer all bunches (e.g., 12 for p, 3 for HI) in the AGS to RHIC in a single turn (FEB, box-car stacking),

b) individual bunches may be transfered one-by-one [SBME] into the waiting rf buckets or,

c) even the AGS may accelerate just single bunch per cycle.

The two rings (57 bunches/ring) are filled with HI one after another in two minutes (or longer for case c)) every 10 hours or so.

The schematic layouts of the AGS complex including RHIC and of the beam transfer lines from the AGS to μSR and to RHIC are shown in Fig.1a and 1b.

As the first step, we consider the NewFEB scheme which is capable of performing 1 to 12 SBEs per AGS cycle (with SEB) at ~ 8-10 ms intervals as the minimum requirement. In addition to SBME, the FKG10/SMH10 system should be able to perform normal FEB too. [+]

The rest of the note is organized as follows:

Chapter 2. - Machine and Beam Parameters
Chapter 3. - Fast Multipulsing Kicker
Chapter 4. - Kicker Pulser
Chapter 5. - Ejector Septum Magnet
Chapter 6. - Orbit Bumps
Chapter 7. - Simulation
Chapter 8. - Miscellaneous (Cost/Schedule/Responsibilities)

[+] In principle, we should build the NewFEB system as flexibly as possible by providing fully variable pulse width (no. of bunches) and multi-extraction (no. of spills) in one AGS cycle, including full FEB capability. However, in reality, we are usually forced to be conservative and build a simple system which is a kind of improved, modified or extended version of the existing working systems due to limited budget, manpower, time and other resources. In most cases, it turns out be the right choice.

CHAPTER 2

II. MACHINE PARAMETERS

II.A General

The AGS Booster, nearly completed, should soon be able to increase proton beam intensity in the AGS by a factor of 4 and to allow the AGS to accelerate heavy ions beyond Si(A=28) up to Au (A=197). The current machine parameters for the AGS are summarized in Table II.1a.

Table II.1a. AGS Parameters

Mean Radius	: R = 128.45·· [m]
Circumference	: C = 2·pi·R = 807.075·· [m]
Curvature	: rho = 85.17 [m]
Orbit Frequency	: frev = c/C = 371.7 [kHz]
Revolution Time	: trev = C/c = 2.692 [μs]
Typical Operation Energy	: 24.5 - 28.5 GeV for p 14.5 GeV/N for O and Si
Typical AGS Cycle	: 1.8 - 2.4 [s] for FEB 2.5 - 4.0 [s] for SEB
Typical Intensity	: $1.6\cdot10^{13}$ ppp $1.0\cdot10^{10}$ O/pulse 3.0·10 Si/pulse
Tune	: Qh = ~Qv = ~8.7
Beta Functions	: ßh_max=ßv_max = 22.5 [m] ßh_min=ßv_min = 10.5 [m]
Dispersion Function	: Dx_max = 2.20 [m]
# of Bunches	: Nb = 12 (= 3 for HI with Booster)
Bunch Shape	: triangular
Full Bunch Length	: tb = 35 ± 5 [ns]
Separation between centers of the bunches	: ts = 224 [ns] at top energy

Fig.2 shows the wall monitor display of the bunch structure in the AGS just after the third bunch extracted for the SBE operation.

In the following tables, we list the main design parameters for the AGS Booster, μSR and RHIC:

Table II.1b. AGS Booster Parameters

Mean Radius	: R = 32.11 [m]
Circumference	: C = 2·pi·R = 201.78 [m]
Curvature	: rho = 13.75 [m]
Extraction Energy	: 1.5 GeV for p
	: 72 MeV/N for Au
No. of Particles	: $0.5 \cdot 10^{13}$ ppb
	$0.8 - 0.4 \cdot 10^{10}$ ions/bunch
Tune	: Qh = ~Qv = ~4.8
Beta Functions	: ßh_max=ßv_max = 13.8 [m]
	ßh_min=ßv_min = 3.6 [m]
Dispersion Function	: Dx_max = 2.95 [m]
No. of Bunches	: Nb = 3/pulse
Reptition rate	: 4 pulses/AGS cycle for p
	1 HI
Normal. Emittance	: 10.0 [pi mm-mrad] for p
(en(95%))	2.3 Au
Bunch Area	: 0.07 [eV-sec/N]

(from [7])

Table II.1c. μSR Parameters

Mean Radius	: R = 7.0 [m]
Circumference	: C = 2·pi·R = 43.98 [m]
Orbit Frequency	: frev = c/C = 6.81 [MHz]
Revolution Time	: trev = C/c = 147 [ns]
μ Momentum	: pμ = 3.094 [GeV/c]
Lifetime	: tμ = 64.4 [μs]
Magnetic Field	: Bo = 1.47 [T]
Storage Aperture	: ø = 90.0 [mm]
Forcusing	: vertical by electric quads (pulsed 1 [ms], 38.7 [kV])
Injection	: pi->μ decay or μ
Protons on the V-target:	
Intensity	: $4.2 \cdot 10^{12}$ protons/bunch
Bunches	: single bunch /Fill
Fills/AGS Cycle	: variable (1 to 12)

(from [3])

Table II.1d RHIC Design Parameters

Mean Radius	: R = 610.176 [m]
Circumference	: C = 2·pi·R = 3833.852 [m]
Curvature	: rho = 243.241 [m]
Orbit Frequency	: frev = c/C = 77.25 [kHz]
Revolution Time	: trev = C/c = 12.78 [μs]
Operation Energy	: 28 - 250 GeV for p 10 - 100 GeV/N for HI
Luminosity (Av.)	: 1.5·10**31 [/cm**2/sec]for p 2·10**26 [/cm**2/sec] for Au-Au at top energy
Typical RHIC Cycle	
Filling Time	: < 1 [min] for each ring
Acceleration	: 1 [min]
Collision Mode	: ~ 10 [hr] at top energy
Transition Energy	: gamma-t = 24.7
No. of Bunches	: Nb = 57/Ring (upgrade x 2)

(from [4])

Expected extracted beam parameters from the AGS with the Booster for RHIC injection are listed below:

Table II.1e. Extracted Beam Parameters for RHIC Injection

	Proton	Silicon	Gold	
Charge/Mass No. :	+1/1	+14/28	+77/197	[Z/A]*
p :	29.0	14.5	11.3	[GeV/c/N]
en :	20.0	10.0	10.0	[mm-mrad]
dp/p :	±0.056	±0.084	±0.102	[%]
bunch length :	<17.	17.	17.	[ns]
bunch area :	0.3	0.3	0.3	[eV·sec/N]
No. ions/bunch :	100.	5.6	1.0	[10**9]

(from [4])

In the AGS the Au ions will be accelerated with 2 electrons in a filled K-shell (Au77+). The extracted Au beam will be fully stripped by passing through a stripping foil in the transfer line from the AGS to RHIC [ATR][8] before RHIC injection.

II.B Lattice and Beam Parameters at G10 and H10

For design purposes, we may assume that the maximum operational momentum is

(1) pmax = 30.0 [GeV/c], (24.5 < pnominal < 29.0 GeV/c),

the 95 % normalized transverse beam emittance, en = e·(p/m), with high intensity proton beam at high energy, is

(2) env(95) = enh(95) = 50 pi [mm-mrad],

where ev=eh= $6 \cdot sig^2 \cdot pi/ßx$, using xmax = v[e·ßx/pi] = 2.45·sig and sig is the standard deviation of the beam size [+], and the maximum total fractional momentum spread allowed is

(3) dp/p = $\pm$ 2.0 x 10^{-3}.

Fig.3 shows the half horizontal beam width (99%) as a function of momentum for various assumptions.

The real values of en(95) and dp/p for high intensity and high energy bunched proton beam in the AGS have not been measured well. It is assumed that 20 < en(95) < ~35 pi mm-mrad and $\pm$0.5 < dp/p < $\pm$1.2 x10^{-3} [9]. For RHIC injection, the expected values of en and dp/p are substantially lower than these values due to rather low intensity beam operation and the AGS Improvemnet Program as seen in Table II.d.

[+] AGS vertical betatron space available and admittance are ~70 mm and ~54 pi mm-mrad, respectively. The horizontal ones are ~116 mm and ~128 pi mm-mrad.

The relevant beam and lattice parameters [10] at straight section G10 and H10 are listed together with the parameters of the present FEB/SBE extraction magnets in the following table.

Table II.2. Beam and Lattice Parameters at G10 and H10

:	G10	{H05 }	H10
ßh [m] :	19.9–12.0 (15.5)	{22.1}	19.9–12.0 (15.5)
ßv [m] :	12.0–19.9 (15.5)	{10.5}	12.0–19.9 (15.5)
Dx [m] :	2.09–1.63 (1.86)	{2.17}	2.09–1.63 (1.86)
beam width (95%) for en=50 mm-mrad and dp/p=±2.0x10^{-3}			at p=28.5 GeV/c
2·v[eh·ßh/pi] [mm] :	11.5– 9.0	{12.1}	11.7– 9.1
2·v[ev·ßv/pi] [mm] :	9.0–11.5	{8.3}	9.1–11.7
2·Dx·dp/p [mm] :	8.4– 6.5	{8.7}	8.4– 6.5
	FKG10	**FKH05/E05**	**SMH10**
Aperture width [mm] :	w = ?	{31.8}	{62.7}
gap [mm]	g = ?	{12.7}	{25.4}
leff [m] :	?	{0.89}	{2.13}
ø [mrad] :	?	{1.13}	{22.0}

At 10-ft straight section ßh and ßv are rapidly changing as well as Dx while at 5-ft S.S.s ßh=˜ßmax, ßv=˜ßmin and Dx =˜Dmax as seen in Fig.4a and 4b.

CHAPTER 3

III. FAST MULTIPULSING KICKER MAGNET [FKG10]

III.A Kick [B·1]

The full horizontal beam width is usually defined either by

$$2\cdot\text{beam size} = 2\cdot\sqrt{[eh\cdot\beta h/pi + (Dx\cdot dp/p)^2]},$$

assuming that the dp/p distribution is symmetric and the transverse and longitudinal emittances are uncorrelated, or otherwise by

$$(= 2\cdot\sqrt{[eh\cdot\beta h/pi]} + 2\cdot Dx\cdot dp/p).$$

Hence, for p=28.5 GeV/c the maximum full beam width (95% emittance) with dp/p=±0.2% at H10 is

$$= 14.2\ [mm]\quad (\text{or } 19.9\ [mm])$$

using eh(95)=50·(m/p)=1.65 pi mm-mrad, ßh(H10)=19.9 m and Dx(H10)=2.09 m.

If we use 99% emittance, then we have

$$= 16.4\ [mm]$$

as seen in Fig.3.

Assuming that we need 1 mm separation and 1 mm safety margin at both sides of the septum of the ejector magnet [SMH10], and ~10 mm septum thickness[+], then the minimum separation of the circulating beam and the beam kicked by FKG10 at H10 is

$$\begin{aligned} dx(H10) &= \text{beam width} + \text{septum thickness} + \text{additional} \\ &= 16.4 + 10.0 + 4.0 \\ &= 30.4\ [mm] \end{aligned}$$

[+] If we choose a DC-mode for the ejctor magnet during the SMBE main magnet flattop (at max.~100 ms) rather than pulsing, we must increase the septum thickness from 2.3 mm to ~10 mm. See details in Chapter 5 for SMH10.

Then, the deflection angle [ø] required at FKG10 is given by

$$\phi = \frac{dx(H10)}{\sqrt{\beta(G10)\cdot\beta(H10)}\cdot\sin(d\mu)}$$

$$= \frac{30.4}{\sqrt{15.5\cdot 15.5}\cdot\sin(4.524)}$$

$$= -2.00 \quad \text{[mrad]}$$

where $d\mu = \mu(H10)-\mu(G10) = Qh\cdot 2\cdot pi/12$ rad, the phase advance from FKG10 to SMH10. This corresponds to

$$\int Bdl = Bo\cdot leff = \phi\cdot pc/0.2998$$
$$= -0.19 \quad \text{[T-m]} \quad \text{at } p=28.5 \text{ GeV/c}$$

If we arbitrarily select the effective length of the FKG10 as 1.0,1.6,2.0 or 2.4 m [+], then the magnetic strength of the kicker should be

leff [m] :	{0.89}	1.0	1.6	2.0	2.4
-Bo [T] :	{0.214}	0.19	0.119	0.095	0.079

[+] The required power can be minimized by choosing leff as the maximum length available for the kicker at 10-ft straight section G10.

III.B Magnet Type

For the design of a fast multipulsing kicker magnet at G10 [FKG10], the following magnet types are available:

"C" type:
+ easier installation and service of vacuum chamber,
- bad magnetic symmetry (produces quadrupole components), (a lower field in the gap on the outside than on the inside).

Picture frame :
+ good symmetry up to high fields (2 T),i.e.,2-fold symmetry,
+ hard to be deformed by field,
+ excellent field uniformity,
- hard to use the gap (a full aperture magnet? At p=2.25 GeV/c (booster injection) e = 22 pi mm-mrad, so w x g must be > 45mmx45mm, N.B. physical AGS acceptance = 127mmx75mm),
- space for coils is limited.

The existing H5 and E5 kickers are "C"-type open magnets and the kicker magnet for the original FEB system was a full aperture (2"(v) x 5"(h)) ferrite magnet with a picture frame [11])

```
.-------------.                         .-------------------.
|      w      |                         |         w         |
|        _____[x]                       |                   |
| g [X]_____                  or        | [X]  ___g___  [X] |
|             [x]                       | [X]_____________[X]|
|_____________|                         |                   |
                                        |___________________|
```

III.C Physical Aperture

The minimum field region needed in the G10 kicker is

$$dx = 2\cdot\sqrt{[eh(99)\cdot\beta/pi + (Dx\cdot dp/p)^2]} + ? + \text{(additional space to ensure}$$
$$= 16.4 + 5 + g \text{ [mm]} \quad \text{the good field region, usually take g)}$$

$$dy = 2\cdot\sqrt{[ev(99)\cdot\beta v]} + ? \text{ (additional space)}$$
$$= 14.0 + 2$$
$$= 16.0 \text{ [mm]}$$

So the minimum physical aperture is

			{FKH5/E5}
w =	> 21.4 + g [mm]	=> 38.5 [mm]	{32 mm}
g =	> 16.0 [mm]	=> 17.0 [mm]	{13 mm}

N.B.- We may have to operate SBME at lower energy (e.g. p = 24.5 GeV/c).
- The vertical aperture [g] can be matched with the rapidly increasing vertical beta function [ßv] at G10.

If we built a full aperture fast multi-pulsing kicker, there would be some merits; however, it is unlikely due to its high cost (~$1.0 M) and R&D time. Therefore, we comsider a C-type ferrite magnet with a limited aperture.

III.D General Constraints [I,L,V]

The magnet current needed is given by

$$I = \frac{Bo \cdot g}{\mu o} = \frac{Bo \cdot g}{4 \cdot pi \cdot 10^{-7}},$$

where I[A],Bo[T],g[m],μo[W/A/M] and the corresponding total magnet inductance (single turn) is

$$Lmag = \mu o \cdot leff \cdot w/g.$$

Substituting g=17.0 mm and w=38.5 mm, we have

leff [m]	1.0	1.6	2.0	2.4
Bo [T]	0.19	0.12	0.095	0.079
I [kA]	2.57	1.60	1.29	1.07
Lmag [μH]	2.85	4.55	5.69	6.83

N.B. - Subdividing the FKG10 into N identical modules can reduce the impedance, voltage and power by 1/N.

The minimum charge voltage to perform the full field in t_rise = ~160 ns [+] is given by

$$V = Lmag \cdot \frac{dI}{dt} = Bo \cdot leff \cdot w/t\_rise$$
$$= 0.190 \cdot 3.85 \cdot 10^{-2}/1.6 \cdot 10^{-7}$$
$$= 45.7 \text{ [kV]}.$$

Since we have to add the additional stray inductance (~0.6 μH ?), V must be greater than 45.7 kV. e.g., the minimum voltage for the leff= 2.0 m case will be

$$= (5.7+0.6)[\mu H] \cdot 1290[A]/160[ns]$$
$$= 50.7 \text{ [kV]}$$

The peak power can be calculated by

$$W = V \cdot I = \frac{(Bo \cdot leff)^2 \cdot (w \cdot g)}{\mu o \cdot leff \cdot t}.$$

[+] FKG10 must be energized in the time interval between two successive circulating bunches. See Chapter 5.

CHAPTER 4

IV. KICKER PULSER

In order to achieve clean bunch-by-bunch extraction, the kicker pulse duration is the bunch reptition period and the fall time of the kicker magnetic field must be as rapid as the rise time as shown in Fig.2. The total length in the FKG10 kicker pulse is

$$
\begin{aligned}
T_o &= t_{rise} + t_{flat} + t_{fall} \\
&= 160 + 40 + 180 \\
&= 380 \text{ [ns] [+]},
\end{aligned}
$$

and the pulse waveform is essentially half sine. The recharge time must be an order of ~5 msec since SBE will repeat every 8 ms or so up to 12 times per AGS cycle.

A practical limit of the maximum pulse voltage on the magnet is ~40 kV and it is also desirable to keep V =~30 kV or less if we want to operate the thyratron in the air; therefore, the magnet will be subdivided into several [N] shorter modules and powered in parallel. e.g., for N=4 (leff=2.0 m),

$$
V = L_{mag}\cdot\frac{dI}{dt} = \underbrace{(5.69/N^2+0.6)}_{0.956}\cdot 1290\cdot N/160 = 30.8 \text{ [kV]}
$$

Substituting I=5.16 kA, we find the characteristic impedance of the pulse forming network (PFN) to be

$$
Z_o = V/I = 30.8/5.16 = 6.0 \text{ [Ohm]}.
$$

In principle, the total number of magnetic modules [N] is a matter of choice. However, it is usually chosen to give the required rise time and to minimize the flattop ripple.

The pulse current is generated by discharging an energy storage capacitor in the kicker magnet coil by a thyratron switch. The total inductance and capacitance of the PFN can be obtained by $T_o=\pi\cdot\sqrt{L\cdot C}/2$ and $Z_o=\sqrt{L/C}$.

[+] For single-turn fast extraction [FEB], the pulse duration is the revolution period (i.e., tflat=2.6 μs) and the fall time is arbitrary.

The pulser described here is a "mismatched" type similar to the FKH5/E5 pulser, and it has to be mounted on the magnet [11]. The FKE5 pulser for SBE has the following electrical parameters:

Table IV. the FKE05 pulser parameters

t_rise	:	180 [ns]
To(total width)	:	400 [ns]
Imax (half-sine)	:	2.8 [kA]
Lmag	:	1.0 [μH]
t_charge	:	70 [ms]
ø (p=24 GeV/c)	:	0.9 [mrad]
5 ns leading edge jitter		
5 % pulse undershoot		

(from [11])

If the pulser is to be mounted outside the ring due to the high radiation environment, it will have to be a "matched" PFN. The magnet is loaded with capacitance so it behaves like a transmission line of the correct impedance and the PFN/energy_storage voltage will be twice the maximum pulsing voltage on magnet (VPFN = 2·V) and it has to be oil insulated [12].

Is it possible to build a PFN which is capable of varying the pulse length on magnet between 0.4 and 2.8 μs so that any desired number of bunches can be extracted any desired times?

According to Fiander at CERN [13], at a moderate cost (~300 K$) we can build a simple fast kicker/PFN system which satisfies our requirements, including variable pulse length at least up to 1 μs without running into droop and "tail" problems. His design uses 3 short-circuited delay line magnet modules (3 x 0.8 m) fed from a 8.33 Ohm cable PFN to ~30 KV. Double ended PFN switching is required and the switch at the non-magnet end of PFN must be bi-directional. There are many kickers in the CERN PS of the same principle and they have quite similar performance and reliability records as the more conventional systems [13].

CHAPTER 5

V. EJECTION SEPTUM MAGNET

A new out-of-vacuumm septum magnet, SMH10 (Mark V), has been built for standard FEB operation and its magnetic properties have been intensively analysed [14].

Table V.1 Parameters of SMH10 (Mark V)

Eff. Septum Thickness	:	ws = 2.29 [mm]
incl. vac. ch. wall		(2.91)
Aperture Width	:	w = 62.7 [mm]
Gap	:	g = 25.4 [mm]
		(27.4)
Effective Length	:	leff= 221 [cm]
		(208)
Deflection	:	ø = 22 [mrad]
Pulse Type/Base	:	half sine / 1.2 [ms]
Rise Time	:	t = 0.7 [ms]
Cuurent	:	I = 21.3 [kA]
Field	:	B = 1.07 [T]
Filed Tolerance	:	pulse-to-pluse ± 0.5%

If we choose a DC mode for the ejector magnet during the SBME main magnet flattop (max. about 100 ms), then the septum thickness must be increased from the present value of 2.3 mm to ~10 mm. If it is water-cooled, the septum thickness of ~5 mm may be sufficient [15].

CHAPTER 6

VI. ORBIT BUMPS

Local orbit deformations are needed to move the circultating beam into the aperture of the fast kicker and also to bring the beam adjacent to the septum of the ejector magnet before turning on the kicker in order to avoid excess beam loss during injection, as the FKG10 is a C-type open magnet with a limited aperture placed ~50 mm away from the centeral orbit. These orbit bumps are generated by powering backleg windings on selected AGS main magnets so arranged that the tune shifts and stopbands at Qh = 8.5 are minimized [16]. The bumps have to be pulsed for each SBE or stay a DC mode during the SBME period in the AGS cycle.

VI.A Local Orbit Bump for the Ejector Magnet

There is an existing standard 3/2 lambda backleg winding local bump for FEB (FKH05/SMH10):

Table VI. Parameters of the BLWH07 bump

Name	:	BLWH07 (= FBLW = H5AA+H5BB)
Type	:	3/2 lambda, peak at H07
Location	:	G06/G07,G20/H01,H14/H15 & I08/I09
Polarity	:	− − + + + + − −
Magnet Type	:	F D D F F D D F
Turn	:	N = 5 (6) for long (short) magnets
t_rise	:	5.0 [ms]
Waveform	:	half-sine wave form with 10 ms base
ø	:	2 [mrad]
I	:	700 [A]

However, the BLWH07 cannot make a sufficient bump at G10 and also is not optimized for H10. Therefore, the BLWH07 will be shifted downstream by four magnets as shown in Fig.5 [+]:

BLWH11 : G10/G11,H04/H05,H18/H19 & I12/I13
− − + + + + − −

[+] The AGS lattice is anti-symmetric around 10-ft straight section.

VI.B A New Bump for the Fast Kicker

To maintain the perturbation of the AGS lattice minimum, we consider another 3/2 lambda (rather than 1/2 lambda) horizantal orbit bump with the opposite polarity for FKG10:

```
BLWG09  :  F08/F09,G02/G03,G16,G17 & H10/H11
              +   +   -   -   -   -    +   +
```

It appears that with the combination of BLWG09 and BLWH11, the beam kicked by FKG10 may hit the inside wall of the vacuum chamber around G13. If the bump is shifted upstream by two magnets, it may be possible to avoid the beam hitting the vacuum wall. However, there are some concerns about putting FKG10 inside due to possible radiation damage since at the AGS we occasionally dump the beam inward by turning off the RF. In addition, for an inward kick, making a bump outward and putting FKG10 outside would be better.

With a combination of BLWG09 (outside) and BLWH11, the beam can make it but the available space for the kicked beam is marginal around G17 as seen in Fig.6a and 6b. However, if we make the following adjustments:

```
                    BLWGH_A                        BLWGH_B
BLWGH: F08/F09,G02/G03,G16/G17 and H04/H05/,H18/H19,I12/I13
         -   -   +   +   ++  ++       ++  ++    +  +   -   -
```

eliminating G10/G11 and H10/H11 and doubling kicks at G16/G17 and H04/H05 [+], which is more like a two-lambda bump, as shown in Fig.7, then it works nicely as described in the next chapter. The tune shifts and stopbands caused by bumps are investigated for various configurations. The results are summarized in Fig.8.

VI.C Vertical Bumps

Due to the limited vertical aperture of the extraction magnets, there are presently two vertical bump magnets, one at F20 and another at I10, in order to make fine adjustments of the vertical beam position during extraction. There is a proposal to build a new vertical bump system with 10 magnets in straight section 07's [17].

[+] A hybrid bump BLWGH is suggested by Y.Y. LEE, hence is called Y.Y. bump.

CHAPTER 7

VII. SIMULATION OF THE NEWFEB EXTRACTION

In Fig.9, we show the location of basic elements of NewFEB extraction system; (1) hybrid backleg windings [BLWGH] to produce local orbit deformations which bring the circulating beam in to the aperture of the fast kicker [FKG10] and also adjacent to the septum of the ejector magnet [SMH10], (2) FKG10 to kick one bunch at a time and to make the bunch jump the sepetum, (3) SMH10 to kick the bunch further to eject from the ring.

To find out the extracted beam parameter with the optimal NewFEB set-up, the accelerator modelling program MAD [18] was used to simulate the NewFEB extraction. A simulation was performed with a simple model of the AGS which includes only quadrupolar and sextupolar components of the main combined function magnets and the extraction components.

First, we run MAD to obtain the desired closed orbit at FKG10 and SMH10 , making fine adjustments of BLWGH as shown in Fig.7.

Then, the particle with initial conditions [x,x′] at the beginning of straight section G10 [SSG10_us] is traced through the lattice and receives an appropriate kick by FKG10 and by SMH10 respectively up to the middle of s.s. H13 [SSH13_md], where the beam is about 43 cm away from the central orbit, free from the fringe field of the ring magnets.

The beam ejected by SMH10 passes at larger radial positions (x>10 cm) through two horizontally defocusing main magnets [MMH11,MMH12], where the average field drops by more than 50% but the gradient reduces more gradually. When the beam moves into the fringe filed of a focusing magnet at H13 [MMH13] at x > 25 cm, its gradient reverses sign and becomes defocusing. Since the fringe filed map for MMH13 is not available, the values calculated using the POISSON code [18] is used for simulation. Fig.10a and 10b show the AGS open defocusing and closed focusing main magnets with field lines. In Fig.11 we show the POISSON calculation results for the magnetic field and gradient as a function of x for the defocusing and focusing magnets.

The simulation results from SSG10_us to SSH13_md, the beginning of the U-line are shown in Fig.12 and summarized in the following table:

```
p       = 28.5 [GeV/c]
BLWGH_A =  2.0 [mrad/pair]
     _B =  1.6 [mrad/pair]
FKG10   =  1.6 [mrad]
SMH10   = 20.0 [mrad]
```

Table VII.1. (x,x') and (Dx, DX') from G10 to H13

FKG10/SMH10:	Off		On			
Position	x[mm]	x'[mrad]	x[mm]	x'[mrad]	Dx[m]	DX'[rad]
SSG10_us	72.7	-5.6	72.7	-5.6	1.32	-0.069
FKG10_us	69.8	-5.6	69.8	-5.6	1.29	-0.067
_ds	58.5	-5.6	56.9	-7.2	1.16	-0.067
SSG20_md	5.9	0.6	-13.6	0.2	2.67	0.205
SSH10_us	52.5	-3.1	81.5	-4.8	1.35	-0.106
_ds	45.9	-3.1	92.7	15.2	1.11	-0.126
MMH11_us	44.5	-3.1	99.7	15.2	1.05	-0.126
_ds	42.6	1.1	141.4	27.0	0.87	-0.007
MMH12_us	43.2	1.1	157.9	27.0	0.85	-0.007
_ds	49.8	5.6	230.3	46.3	0.88	0.107
MMH13_us	53.2	5.6	258.6	46.3	0.92	0.107
_ds	58.9	-0.9	389.1	63.8	1.14	0.190
SSH13_md	58.2	-0.9	437.7	63.8	1.24	0.190

Table VII.2a and VII.2b show more complete outputs from MAD for circulating beam and extracted beam with the NewFEB system.

Since the g-2 μSR uses the secondary pions from the V-target, the small variations of these extracted beam parameters do not directly influence the beam parameters at μSR injection. Due to its high intensity operation it is important that the NewFEB system can achieves a high extraction efficiency for the g-2 experiment to minimizes beam losses. However, for RHIC injection any change (pulse-to-pulse and/or cycle-to-cycle) of the AGS extracted bunch beam parameters (x, x', p, dp/p, Twiss parameters, etc.) will directly influence the beam parameters at RHIC injection, hence its performance [8][20]. So reliablilty of the system and stability/reproducibility of the extracted beam parameters are more crucial in this case. More complete and realistic simulations of the NewFEB extraction and beam transfer to RHIC will be needed in order to specify details of the NewFEB system components as well as the overall required AGS peformance as the injector for RHIC.

In order to assess the validity of modeling the NewFEB extraction, we also simulated fast extraction with the present FEB system using the same method. Table II.3 shows the extracted beam parameters found at SSH13_md for FEB and NewFEB by MAD together with the previous calculations by Weng [1] using the AGS Beam program and values measured by Thern [9] using the SEM in 1985 for FEB.

Table VII.3. Extracted Beam Parameters at SSH13_md

	FEB (FKH05/SMH10/BLWH07)			NewFEB
	Ref. [1]	Ref.[9]	This	This
alpha_x :	-5.67	-4.78 ± 0.58	-5.84	-5.75
ßh [m] :	57.46	37.59 ± 4.60	47.13	46.37
alpha_y :	0.987	1.05 ± 0.04	0.837	0.833
ßv [m] :	3.7	8.05 ± 0.17	3.60	3.64
Dx [m] :	2.46	....	2.15	1.24
Dx' [rad] :	0.295	....	0.302	0.190

Our results for the FEB system using MAD are in reasonable agreement both with Ref.[1] and Ref.[2]. We find that the NewFEB results are quite similar to the FEB results except Dx and Dx' though these values are rather sensitive to exact setting values for extraction parameters, especially to fine tuning of the orbit bumps.

Table. VII.2a Circulating BEAM with Y.Y. Bump

AGS NewFEB SYSTEM - BLWGH(Y.Y. BUMP) (Vax) "MAD" VERSION: 6.01/03 RUN: 14-MAR-9 14:08:12
LINEAR LATTICE PARAMETERS FOR BEAM LINE: "RGNFEB ", RANGE = "#S / #E"
DELTA(P)/P = 0.000000 SYMM = F PAGE 1

ELEMENT SEQUENCE				HORIZONTAL							VERTICAL						
POS. NO.	ELEMENT NAME	OCC. NO.	DIST [M]	BETAX [M]	ALFAX [1]	MUX [2PI]	X(CO) [MM]	PX(CO) [.001]	DX [M]	DPX [1]	BETAY [M]	ALFAY [1]	MUY [2PI]	Y(CO) [MM]	PY(CO) [.001]	DY [M]	DPY [1]
1	DSG10	1	0.524	21.752	1.716	4.644	69.756	-5.620	1.287	-0.069	10.426	-0.050	0.008	0.000	0.000	0.000	0.000
2	FKG10	1	2.524	15.614	1.353	4.661	58.516	-5.620	1.160	-0.069	11.012	-0.243	0.038	0.000	0.000	0.000	0.000
3	DSG10	2	3.048	14.246	1.258	4.667	55.572	-5.620	1.127	-0.069	11.293	-0.293	0.045	0.000	0.000	0.000	0.000
4	DS	1	5.054	12.299	-0.226	4.692	49.464	-0.565	1.128	0.064	10.581	0.624	0.074	0.000	0.000	0.000	0.000
5	BWG11	1	5.054	12.299	-0.226	4.692	49.464	-0.565	1.128	0.064	10.581	0.624	0.074	0.000	0.000	0.000	0.000
6	D2S	1	5.664	12.607	-0.278	4.699	49.119	-0.565	1.167	0.064	9.869	0.544	0.083	0.000	0.000	0.000	0.000
7	DS	2	7.670	16.919	-2.010	4.722	52.847	4.340	1.438	0.214	6.621	0.965	0.122	0.000	0.000	0.000	0.000
8	D2T	1	8.280	19.479	-2.191	4.727	55.492	4.340	1.566	0.214	5.553	0.787	0.138	0.000	0.000	0.000	0.000
9	FLC	1	10.667	24.980	0.097	4.744	58.055	-2.242	1.880	0.046	4.519	-0.317	0.221	0.000	0.000	0.000	0.000
10	MG13	1	10.667	24.980	0.097	4.744	58.055	-2.242	1.880	0.046	4.519	-0.317	0.221	0.000	0.000	0.000	0.000
11	DS07	1	11.102	24.903	0.080	4.747	57.081	-2.242	1.901	0.046	4.840	-0.422	0.236	0.000	0.000	0.000	0.000
12	SXH	1	11.757	24.816	0.053	4.751	55.612	-2.242	1.932	0.046	5.498	-0.582	0.256	0.000	0.000	0.000	0.000
13	DS07	2	12.191	24.778	0.036	4.754	54.638	-2.242	1.953	0.046	6.050	-0.688	0.268	0.000	0.000	0.000	0.000
14	FLC	2	14.579	18.778	2.248	4.771	42.284	-7.871	1.846	-0.144	13.235	-2.582	0.313	0.000	0.000	0.000	0.000
15	D2L	1	15.188	16.158	2.051	4.776	37.486	-7.871	1.763	-0.144	16.597	-2.935	0.320	0.000	0.000	0.000	0.000
16	DLA	1	17.576	11.378	0.132	4.806	23.113	-4.444	1.704	0.081	26.958	-0.991	0.337	0.000	0.000	0.000	0.000
17	MG15	1	17.576	11.378	0.132	4.806	23.113	-4.444	1.704	0.081	26.958	-0.991	0.337	0.000	0.000	0.000	0.000
18	D2H	1	18.338	11.229	0.063	4.816	19.727	-4.444	1.769	0.081	28.510	-1.047	0.341	0.000	0.000	0.000	0.000
19	D2H	2	19.100	11.184	-0.005	4.827	16.341	-4.444	1.834	0.081	30.148	-1.103	0.345	0.000	0.000	0.000	0.000
20	DLA	2	21.487	15.150	-1.806	4.858	7.540	-3.098	2.339	0.344	27.279	2.192	0.358	0.000	0.000	0.000	0.000
21	BWG16	1	21.487	15.150	-1.806	4.858	7.540	-1.098	2.339	0.342	27.279	2.192	0.358	0.000	0.000	0.000	0.000
22	D2L	2	22.097	17.456	-1.978	4.864	6.871	-1.098	2.548	0.342	24.687	2.062	0.362	0.000	0.000	0.000	0.000
23	FLC	3	24.484	22.379	0.107	4.882	3.450	-1.703	3.023	0.044	21.641	-0.673	0.379	0.000	0.000	0.000	0.000
24	BWG17	1	24.484	22.379	0.107	4.882	3.450	0.297	3.023	0.042	21.641	-0.673	0.379	0.000	0.000	0.000	0.000
25	DS03	1	24.906	22.297	0.088	4.885	3.575	0.297	3.041	0.042	22.221	-0.701	0.382	0.000	0.000	0.000	0.000
26	QDH	1	25.586	22.197	0.058	4.890	3.777	0.297	3.069	0.042	23.206	-0.747	0.387	0.000	0.000	0.000	0.000
27	DS03	2	26.008	22.157	0.038	4.893	3.902	0.297	3.087	0.042	23.848	-0.775	0.390	0.000	0.000	0.000	0.000
28	FLC	4	28.396	16.711	2.031	4.912	4.056	-0.170	2.803	-0.275	35.799	-4.676	0.403	0.000	0.000	0.000	0.000
29	D2T	2	29.005	14.349	1.844	4.918	3.952	-0.170	2.636	-0.275	41.736	-5.066	0.406	0.000	0.000	0.000	0.000
30	DS	3	31.012	10.243	0.333	4.946	3.989	0.208	2.351	-0.014	54.322	-0.793	0.412	0.000	0.000	0.000	0.000
31	BWG19	1	31.012	10.243	0.333	4.946	3.989	0.208	2.351	-0.014	54.322	-0.793	0.412	0.000	0.000	0.000	0.000
32	D2S	2	31.622	9.877	0.267	4.955	4.116	0.208	2.342	-0.014	55.299	-0.811	0.414	0.000	0.000	0.000	0.000
33	DS	4	33.628	11.173	-0.955	4.987	4.952	0.639	2.568	0.243	48.164	4.132	0.420	0.000	0.000	0.000	0.000
34	BWG20	1	33.628	11.173	-0.955	4.987	4.952	0.639	2.568	0.243	48.164	4.132	0.420	0.000	0.000	0.000	0.000
35	MG20	1	33.628	11.173	-0.955	4.987	4.952	0.639	2.568	0.243	48.164	4.132	0.420	0.000	0.000	0.000	0.000
36	D10	1	35.152	14.480	-1.215	5.006	5.927	0.639	2.938	0.243	36.443	3.560	0.426	0.000	0.000	0.000	0.000
37	D10	2	36.676	18.581	-1.476	5.021	6.901	0.639	3.307	0.243	26.465	2.988	0.434	0.000	0.000	0.000	0.000
38	FS	1	38.682	21.042	0.329	5.037	7.485	-0.067	3.487	-0.066	19.923	0.478	0.448	0.000	0.000	0.000	0.000
39	BWH01	1	38.682	21.042	0.329	5.037	7.485	-0.067	3.487	-0.066	19.923	0.478	0.448	0.000	0.000	0.000	0.000
40	D2S	3	39.292	20.660	0.297	5.041	7.444	-0.067	3.447	-0.066	19.362	0.441	0.453	0.000	0.000	0.000	0.000

41	FS	2	41.299	16.065	1.843	5.058	6.603	-0.757	3.014	-0.359	21.606	-1.630	0.469	0.000	0.000	0.000	0.000
42	D2T	3	41.908	13.920	1.676	5.065	6.141	-0.757	2.796	-0.359	23.655	-1.733	0.473	0.000	0.000	0.000	0.000
43	DLC	1	44.296	10.259	-0.005	5.098	5.110	-0.126	2.327	-0.044	25.444	1.054	0.488	0.000	0.000	0.000	0.000
44	DS03	3	44.718	10.280	-0.046	5.105	5.057	-0.126	2.308	-0.044	24.569	1.019	0.491	0.000	0.000	0.000	0.000
45	QDV	1	45.398	10.388	-0.112	5.115	4.971	-0.126	2.278	-0.044	23.221	0.963	0.495	0.000	0.000	0.000	0.000
46	DS03	4	45.819	10.500	-0.153	5.122	4.918	-0.126	2.260	-0.044	22.424	0.928	0.498	0.000	0.000	0.000	0.000
47	DLC	2	48.207	15.136	-1.962	5.153	5.292	0.447	2.501	0.251	13.572	2.433	0.519	0.000	0.000	0.000	0.000
48	BWH04	1	48.207	15.136	-1.962	5.153	5.292	2.047	2.501	0.249	13.572	2.433	0.519	0.000	0.000	0.000	0.000
49	D2L	3	48.817	17.647	-2.158	5.159	6.539	2.047	2.651	0.249	10.796	2.122	0.527	0.000	0.000	0.000	0.000
50	FLA	1	51.204	23.423	-0.036	5.177	10.328	1.054	2.893	-0.048	5.120	0.467	0.582	0.000	0.000	0.000	0.000
51	BWH05	1	51.204	23.423	-0.036	5.177	10.328	2.654	2.893	-0.050	5.120	0.467	0.582	0.000	0.000	0.000	0.000
52	MH05	1	51.204	23.423	-0.036	5.177	10.328	2.654	2.893	-0.050	5.120	0.467	0.582	0.000	0.000	0.000	0.000
53	DSH05	1	51.521	23.451	-0.050	5.179	11.169	2.654	2.877	-0.050	4.848	0.392	0.592	0.000	0.000	0.000	0.000
54	FKH05	1	52.411	23.574	-0.088	5.185	13.531	2.654	2.830	-0.050	4.339	0.180	0.623	0.000	0.000	0.000	0.000
55	DSH05	2	52.728	23.634	-0.102	5.188	14.372	2.654	2.814	-0.050	4.249	0.104	0.635	0.000	0.000	0.000	0.000
56	MH05	2	52.728	23.634	-0.102	5.188	14.372	2.654	2.814	-0.050	4.249	0.104	0.635	0.000	0.000	0.000	0.000
57	FLA	2	55.116	18.368	2.102	5.205	18.497	0.723	2.354	-0.323	6.406	-1.088	0.714	0.000	0.000	0.000	0.000
58	D2L	4	55.725	15.915	1.923	5.211	18.938	0.723	2.156	-0.323	7.858	-1.296	0.728	0.000	0.000	0.000	0.000
59	DLC	3	58.113	11.607	0.045	5.240	23.407	3.106	1.682	-0.079	12.755	-0.562	0.764	0.000	0.000	0.000	0.000
60	DS07	3	58.547	11.584	0.007	5.246	24.757	3.106	1.647	-0.079	13.263	-0.607	0.770	0.000	0.000	0.000	0.000
61	SXV	1	59.202	11.612	-0.049	5.255	26.791	3.106	1.593	-0.079	14.102	-0.674	0.777	0.000	0.000	0.000	0.000
62	DS07	4	59.637	11.671	-0.087	5.261	28.141	3.106	1.557	-0.079	14.707	-0.719	0.782	0.000	0.000	0.000	0.000
63	DLC	4	62.024	16.260	-2.010	5.290	39.874	6.946	1.603	0.128	14.345	0.856	0.807	0.000	0.000	0.000	0.000
64	D2T	4	62.634	18.825	-2.198	5.296	44.107	6.946	1.677	0.128	13.347	0.782	0.814	0.000	0.000	0.000	0.000
65	FS	3	64.640	24.393	-0.397	5.310	53.436	2.201	1.784	-0.014	13.001	-0.599	0.839	0.000	0.000	0.000	0.000
66	D2S	4	65.250	24.895	-0.426	5.314	54.777	2.201	1.774	-0.014	13.770	-0.663	0.847	0.000	0.000	0.000	0.000
67	FS	4	67.256	22.149	1.706	5.327	53.883	-3.078	1.605	-0.152	19.994	-2.629	0.867	0.000	0.000	0.000	0.000
68	BWH10	1	67.256	22.149	1.706	5.327	53.883	-3.078	1.605	-0.152	19.994	-2.629	0.867	0.000	0.000	0.000	0.000
69	DSH10	1	67.713	20.628	1.625	5.331	52.477	-3.078	1.537	-0.152	22.478	-2.810	0.870	0.000	0.000	0.000	0.000
70	SMH10	1	69.847	14.496	1.248	5.350	45.910	-3.078	1.218	-0.152	36.271	-3.654	0.882	0.000	0.000	0.000	0.000
71	DSH10	2	70.304	13.393	1.168	5.356	44.504	-3.078	1.150	-0.152	39.692	-3.835	0.884	0.000	0.000	0.000	0.000
72	MH10	1	70.304	13.393	1.168	5.356	44.504	-3.078	1.150	-0.152	39.692	-3.835	0.884	0.000	0.000	0.000	0.000
73	DS	5	72.311	11.649	-0.243	5.382	42.554	1.104	0.976	-0.026	47.265	0.316	0.891	0.000	0.000	0.000	0.000
74	BWH11	1	72.311	11.649	-0.243	5.382	42.554	1.104	0.976	-0.026	47.265	0.316	0.891	0.000	0.000	0.000	0.000
75	D2S	5	72.920	11.979	-0.298	5.390	43.227	1.104	0.960	-0.026	46.888	0.302	0.893	0.000	0.000	0.000	0.000
76	DS	6	74.927	16.270	-1.977	5.414	49.823	5.576	1.020	0.093	37.208	4.195	0.900	0.000	0.000	0.000	0.000
77	D2T	5	75.536	18.792	-2.161	5.420	53.221	5.576	1.073	0.093	32.280	3.890	0.903	0.000	0.000	0.000	0.000
78	FLC	5	77.924	24.360	0.042	5.437	58.903	-0.925	1.173	-0.006	22.700	0.468	0.918	0.000	0.000	0.000	0.000
79	BWH13	1	77.924	24.360	0.042	5.437	58.903	-0.925	1.173	-0.006	22.700	0.468	0.918	0.000	0.000	0.000	0.000
80	D2H	3	78.686	24.320	0.010	5.442	58.199	-0.925	1.169	-0.006	22.018	0.427	0.923	0.000	0.000	0.000	0.000
81	MH13	1	78.686	24.320	0.010	5.442	58.199	-0.925	1.169	-0.006	22.018	0.427	0.923	0.000	0.000	0.000	0.000
82	D2H	4	79.448	24.328	-0.021	5.447	57.494	-0.925	1.165	-0.006	21.399	0.386	0.929	0.000	0.000	0.000	0.000

Table VII.2b Extracted BEAM

AGS NewFEB SYSTEM - SSG10US to SSH13DS (Vax) "MAD" VERSION: 6.01/03 RUN: 14-MAR-9 14:57:13
LINEAR LATTICE PARAMETERS FOR BEAM LINE: "EXNFEB ", RANGE = "#S / #E"
DELTA(P)/P = 0.000000 SYMM = F PAGE 1

ELEMENT SEQUENCE				H O R I Z O N T A L							V E R T I C A L						
POS. NO.	ELEMENT NAME	OCC. NO.	DIST [M]	BETAX [M]	ALFAX [1]	MUX [2PI]	X(CO) [MM]	PX(CO) [.001]	DX [M]	DPX [1]	BETAY [M]	ALFAY [1]	MUY [2PI]	Y(CO) [MM]	PY(CO) [.001]	DY [M]	DPY [1]
1	DSG10	1	0.524	21.752	1.716	0.004	69.756	-5.620	1.287	-0.069	11.429	-1.029	0.008	0.000	0.000	0.000	0.000
2	FKG10	1	2.524	15.614	1.353	0.021	56.916	-7.220	1.162	-0.067	16.267	-1.390	0.031	0.000	0.000	0.000	0.000
3	DSG10	2	3.048	14.246	1.258	0.027	53.134	-7.220	1.130	-0.067	17.773	-1.484	0.036	0.000	0.000	0.000	0.000
4	DS	1	5.054	12.294	-0.224	0.052	43.460	-2.576	1.138	0.066	20.353	0.286	0.052	0.000	0.000	0.000	0.000
5	BWG11	1	5.054	12.294	-0.224	0.052	43.460	-2.576	1.138	0.066	20.353	0.286	0.052	0.000	0.000	0.000	0.000
6	D2S	1	5.664	12.599	-0.276	0.059	41.890	-2.576	1.180	0.066	20.024	0.254	0.057	0.000	0.000	0.000	0.000
7	DS	2	7.670	16.883	-1.998	0.082	40.718	1.390	1.461	0.217	15.623	1.791	0.075	0.000	0.000	0.000	0.000
8	D2T	1	8.280	19.428	-2.178	0.087	41.565	1.390	1.592	0.217	13.539	1.627	0.081	0.000	0.000	0.000	0.000
9	FLC	1	10.667	24.827	0.124	0.104	39.217	-3.311	1.914	0.044	9.943	0.010	0.116	0.000	0.000	0.000	0.000
10	MG13	1	10.667	24.827	0.124	0.104	39.217	-3.311	1.914	0.044	9.943	0.010	0.116	0.000	0.000	0.000	0.000
11	DS07	1	11.102	24.728	0.106	0.107	37.778	-3.311	1.934	0.044	9.954	-0.034	0.123	0.000	0.000	0.000	0.000
12	SXH	1	11.757	24.607	0.079	0.111	35.609	-3.311	1.965	0.044	10.041	-0.100	0.133	0.000	0.000	0.000	0.000
13	DS07	2	12.191	24.546	0.061	0.114	34.171	-3.311	1.985	0.044	10.146	-0.143	0.140	0.000	0.000	0.000	0.000
14	FLC	2	14.579	18.452	2.256	0.131	22.070	-6.594	1.867	-0.151	14.578	-1.876	0.173	0.000	0.000	0.000	0.000
15	D2L	1	15.188	15.825	2.055	0.137	18.051	-6.594	1.779	-0.151	16.980	-2.065	0.179	0.000	0.000	0.000	0.000
16	DLA	1	17.576	10.946	0.172	0.167	4.117	-5.345	1.702	0.073	22.457	-0.012	0.198	0.000	0.000	0.000	0.000
17	MG15	1	17.576	10.946	0.172	0.167	4.117	-5.345	1.702	0.073	22.457	-0.012	0.198	0.000	0.000	0.000	0.000
18	D2H	1	18.338	10.738	0.101	0.178	0.044	-5.345	1.762	0.073	22.501	-0.046	0.203	0.000	0.000	0.000	0.000
19	D2H	2	19.100	10.639	0.029	0.190	-4.028	-5.345	1.821	0.073	22.596	-0.080	0.208	0.000	0.000	0.000	0.000
20	DLA	2	21.487	14.243	-1.674	0.222	-17.942	-6.578	2.307	0.332	17.495	2.018	0.227	0.000	0.000	0.000	0.000
21	BWG16	1	21.487	14.243	-1.674	0.222	-17.942	-4.578	2.307	0.330	17.495	2.018	0.227	0.000	0.000	0.000	0.000
22	D2L	2	22.097	16.383	-1.837	0.228	-20.732	-4.578	2.511	0.330	15.142	1.842	0.233	0.000	0.000	0.000	0.000
23	FLC	3	24.484	20.869	0.135	0.248	-28.372	-1.676	2.962	0.033	11.036	0.034	0.264	0.000	0.000	0.000	0.000
24	BWG17	1	24.484	20.869	0.135	0.248	-28.372	0.324	2.962	0.031	11.036	0.034	0.264	0.000	0.000	0.000	0.000
25	DS03	1	24.906	20.764	0.114	0.251	-28.235	0.324	2.974	0.031	11.023	-0.004	0.270	0.000	0.000	0.000	0.000
26	QDH	1	25.586	20.631	0.081	0.257	-28.014	0.324	2.995	0.031	11.071	-0.066	0.280	0.000	0.000	0.000	0.000
27	DS03	2	26.008	20.571	0.060	0.260	-27.877	0.324	3.008	0.031	11.142	-0.104	0.286	0.000	0.000	0.000	0.000
28	FLC	4	28.396	15.390	1.906	0.280	-23.382	3.355	2.699	-0.280	15.680	-1.969	0.316	0.000	0.000	0.000	0.000
29	D2T	2	29.005	13.178	1.723	0.287	-21.338	3.355	2.526	-0.280	18.196	-2.159	0.322	0.000	0.000	0.000	0.000
30	DS	3	31.012	9.338	0.313	0.317	-16.482	1.563	2.212	-0.033	23.670	-0.392	0.337	0.000	0.000	0.000	0.000
31	BWG19	1	31.012	9.338	0.313	0.317	-16.482	1.563	2.212	-0.033	23.670	-0.392	0.337	0.000	0.000	0.000	0.000
32	D2S	2	31.622	9.001	0.241	0.328	-15.530	1.563	2.191	-0.033	24.166	-0.422	0.341	0.000	0.000	0.000	0.000
33	DS	4	33.628	10.256	-0.907	0.362	-13.816	0.172	2.358	0.205	21.456	1.684	0.354	0.000	0.000	0.000	0.000
34	BWG20	1	33.628	10.256	-0.907	0.362	-13.816	0.172	2.358	0.205	21.456	1.684	0.354	0.000	0.000	0.000	0.000
35	MG20	1	33.628	10.256	-0.907	0.362	-13.816	0.172	2.358	0.205	21.456	1.684	0.354	0.000	0.000	0.000	0.000
36	D10	1	35.152	13.431	-1.177	0.383	-13.554	0.172	2.670	0.205	16.739	1.412	0.367	0.000	0.000	0.000	0.000
37	D10	2	36.676	17.432	-1.448	0.399	-13.292	0.172	2.981	0.205	12.852	1.139	0.384	0.000	0.000	0.000	0.000
38	FS	1	38.682	19.994	0.255	0.415	-11.684	1.405	3.114	-0.073	11.102	-0.211	0.411	0.000	0.000	0.000	0.000
39	BWH01	1	38.682	19.994	0.255	0.415	-11.684	1.405	3.114	-0.073	11.102	-0.211	0.411	0.000	0.000	0.000	0.000
40	D2S	3	39.292	19.703	0.223	0.420	-10.828	1.405	3.068	-0.073	11.394	-0.269	0.420	0.000	0.000	0.000	0.000

41	FS	2	41.299	15.523	1.724	0.438	-7.063	2.287	2.651	-0.332	15.385	-1.848	0.445	0.000	0.000	0.000	0.000
42	D2T	3	41.908	13.517	1.568	0.445	-5.669	2.287	2.447	-0.332	17.744	-2.023	0.451	0.000	0.000	0.000	0.000
43	DLC	1	44.296	10.228	-0.067	0.479	-0.750	1.928	1.989	-0.056	22.791	0.105	0.469	0.000	0.000	0.000	0.000
44	DS03	3	44.718	10.303	-0.109	0.485	0.063	1.928	1.965	-0.056	22.710	0.087	0.472	0.000	0.000	0.000	0.000
45	QDV	1	45.398	10.496	-0.175	0.496	1.374	1.928	1.925	-0.056	22.613	0.057	0.477	0.000	0.000	0.000	0.000
46	DS03	4	45.819	10.661	-0.217	0.502	2.187	1.928	1.901	-0.056	22.573	0.038	0.480	0.000	0.000	0.000	0.000
47	DLC	2	48.207	15.710	-2.088	0.533	7.308	2.460	2.055	0.193	16.995	2.079	0.498	0.000	0.000	0.000	0.000
48	BWH04	1	48.207	15.710	-2.088	0.533	7.308	4.060	2.055	0.192	16.995	2.079	0.498	0.000	0.000	0.000	0.000
49	D2L	3	48.817	18.382	-2.296	0.539	9.783	4.060	2.170	0.192	14.577	1.888	0.504	0.000	0.000	0.000	0.000
50	FLA	1	51.204	24.640	-0.082	0.556	17.728	2.443	2.341	-0.044	10.128	0.140	0.537	0.000	0.000	0.000	0.000
51	BWH05	1	51.204	24.640	-0.082	0.556	17.728	4.043	2.341	-0.046	10.128	0.140	0.537	0.000	0.000	0.000	0.000
52	MH05	1	51.204	24.640	-0.082	0.556	17.728	4.043	2.341	-0.046	10.128	0.140	0.537	0.000	0.000	0.000	0.000
53	DSH05	1	51.521	24.696	-0.095	0.558	19.009	4.043	2.326	-0.046	10.050	0.108	0.542	0.000	0.000	0.000	0.000
54	FKH05	1	52.411	24.898	-0.131	0.563	22.607	4.043	2.281	-0.046	9.937	0.019	0.557	0.000	0.000	0.000	0.000
55	DSH05	2	52.728	24.985	-0.144	0.565	23.889	4.043	2.265	-0.046	9.935	-0.013	0.562	0.000	0.000	0.000	0.000
56	MH05	2	52.728	24.985	-0.144	0.565	23.889	4.043	2.265	-0.046	9.935	-0.013	0.562	0.000	0.000	0.000	0.000
57	FLA	2	55.116	19.567	2.204	0.582	29.914	0.889	1.887	-0.259	13.583	-1.650	0.596	0.000	0.000	0.000	0.000
58	D2L	4	55.725	16.991	2.021	0.587	30.456	0.889	1.728	-0.259	15.696	-1.817	0.603	0.000	0.000	0.000	0.000
59	DLC	3	58.113	12.491	0.034	0.615	36.973	4.695	1.354	-0.056	20.295	0.073	0.623	0.000	0.000	0.000	0.000
60	DS07	3	58.547	12.477	-0.001	0.620	39.012	4.695	1.327	-0.056	20.241	0.051	0.627	0.000	0.000	0.000	0.000
61	SXV	1	59.202	12.512	-0.053	0.629	42.087	4.695	1.287	-0.056	20.195	0.019	0.632	0.000	0.000	0.000	0.000
62	DS07	4	59.637	12.573	-0.088	0.634	44.127	4.695	1.260	-0.056	20.188	-0.003	0.635	0.000	0.000	0.000	0.000
63	DLC	4	62.024	17.445	-2.138	0.661	62.117	10.716	1.315	0.119	15.297	1.854	0.656	0.000	0.000	0.000	0.000
64	D2T	4	62.634	20.170	-2.332	0.666	68.648	10.716	1.381	0.119	13.146	1.677	0.663	0.000	0.000	0.000	0.000
65	FS	3	64.640	26.067	-0.418	0.680	83.032	3.386	1.494	0.006	9.393	0.306	0.693	0.000	0.000	0.000	0.000
66	D2S	4	65.250	26.593	-0.445	0.684	85.096	3.386	1.496	0.006	9.063	0.235	0.703	0.000	0.000	0.000	0.000
67	FS	4	67.256	23.671	1.808	0.696	83.700	-4.755	1.395	-0.106	10.289	-0.882	0.737	0.000	0.000	0.000	0.000
68	BWH10	1	67.256	23.671	1.808	0.696	83.700	-4.755	1.395	-0.106	10.289	-0.882	0.737	0.000	0.000	0.000	0.000
69	DSH10	1	67.713	22.056	1.726	0.699	81.528	-4.755	1.349	-0.106	11.132	-0.961	0.744	0.000	0.000	0.000	0.000
70	SMH10	1	69.847	15.512	1.341	0.717	92.721	15.245	1.111	-0.126	16.022	-1.330	0.770	0.000	0.000	0.000	0.000
71	DSH10	2	70.304	14.324	1.259	0.722	99.686	15.245	1.046	-0.126	17.274	-1.409	0.774	0.000	0.000	0.000	0.000
72	MH10	1	70.304	14.324	1.259	0.722	99.686	15.245	1.046	-0.126	17.274	-1.409	0.774	0.000	0.000	0.000	0.000
73	DS	5	72.311	12.472	-0.272	0.747	141.441	27.020	0.874	-0.007	19.535	0.358	0.791	0.000	0.000	0.000	0.000
74	BWH11	1	72.311	12.472	-0.272	0.747	141.441	27.020	0.874	-0.007	19.535	0.358	0.791	0.000	0.000	0.000	0.000
75	D2S	5	72.920	12.835	-0.324	0.755	157.910	27.020	0.854	-0.007	19.120	0.323	0.796	0.000	0.000	0.000	0.000
76	DS	6	74.927	17.627	-2.218	0.777	230.350	46.278	0.882	0.107	14.441	1.832	0.815	0.000	0.000	0.000	0.000
77	D2T	5	75.536	20.456	-2.423	0.782	258.555	46.278	0.919	0.107	12.320	1.648	0.822	0.000	0.000	0.000	0.000
78	MGH13FR	1	77.924	38.036	-5.191	0.796	389.074	63.823	1.144	0.190	5.180	1.188	0.869	0.000	0.000	0.000	0.000
79	BWH13	1	77.924	38.036	-5.191	0.796	389.074	63.823	1.144	0.190	5.180	1.188	0.869	0.000	0.000	0.000	0.000
80	D2H	3	78.686	46.374	-5.751	0.799	437.703	63.823	1.241	0.190	3.639	0.833	0.897	0.000	0.000	0.000	0.000
81	MH13	1	78.686	46.374	-5.751	0.799	437.703	63.823	1.241	0.190	3.639	0.833	0.897	0.000	0.000	0.000	0.000
82	D2H	4	79.448	55.565	-6.311	0.801	486.331	63.823	1.337	0.190	2.640	0.479	0.937	0.000	0.000	0.000	0.000

CHAPTER 8

VIII. MISCELLANEOUS

Work on detailed engineering design/review, schedule and manpower/cost estimates for the NewFEB AIP project has not yet started due to the budgetary and manpower constraints from the Booster project.

VIII.A Cost Estimates

A very rough cost estimate for the NewFEB project was previouesly done in conjunction with the BNL g-2 project, which started in FY1989.

Table VIII. Rough Cost Estimates

System	Item	[k$]	Subtotal
FKG10	- Magnet	164	
	- PS/PFN	320	484
SMH10	- Magnet	100	
	- PS	114	214
H.Bumps	- Blwdg	40	
	- PS	200	240
V.Bumps	- Magnet	48	
	- PS	50	98
Monitors	- Beam Loss	15	
	- Orbit	83	98
Control	- Hardware	90	
	- Software	53	143
Others	- Vacuum	20	
	- Installation	55	75
	Total	1,352	1,352

(from [3], Cost Estimate, 1.6 AGS Extraction Systems)

This estimate does not assume any labor from the operating budget. The total figure, ~$1.35M, does not include any spare FKG10 and SMH10.

VIII.B Schedule

We are hoping that some engineering design work on the NewFEB system can start soon and the basic design can be fixed as soon as possible. Fig. 13 shows a tentative schedule [+].

NewFEB Milstones (Mar. 1991 Baseline)

April	1991	: Engineering design starts.
June	1993	: Extraction and transfer line test
October	1993	: Beam to the V-target and to the μSR
January	1994	: the g-2 experiment run
April	1995	: Partial RHIC injection test
April	1997	: First collision at RHIC

VIII.C Responsibilities

Conceptual Design : Phys/Inj&Ext and Beam Dynamics.

- detailing and updating the overall design
- study of the RHIC requirements
- operational aspect as the injector etc
- tracking NewFEB->U-line->ATR->RHIC
- measurements on beam parameters in the AGS with Booster

Mechanical Design : M. E.

- FKG10 P. Cameron,...
- SMH10 E. Rodger,...
- BLWGH ?

Electrical Design : E. E.

- FKG10 Pulser S.Y. Zhang, W.Zhang, W. Frey, ...
- SMH10 PS PS group

Control System : Accelerator Controls Section

- Hardware
- Software

Beam Instruments : Phys/Diagnostic

- Loss Monitors R. Witkover
- Beam Profile
- Position Monitor
- Intensity Monitor

[+] It should be noted that the annual AGS summer shutdown time is only available for equipment installation since the AGS complex usually runs from October to June for its physics program.

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Th. Sluyters, A. Soukas, R. Thern ....

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REFERENCES

[1] W.T. Weng, "The New Fast Extraction System", BNL 51310 and "The AGS New Fast Extraction System and the Single Bunch Extraction Test", IEEE NS-30, No.4 (1983).

[2] M. Tanaka, "AGS Extraction System Modifications and Upgrades due to the AIP", 6-March-1990 AGS/AD Memorandum.

[3] AGS Proposal #821," A New Precision Measurements of the Muon g-2 Value at the Level of 0.35 PPM", 08-October-1986.

G. Bunce, "Muon g-2 Cost Estimate, AGS 821", 4-Feb-1988 Memo.

[4] BNL52195, "Conceptual Design on the Relativistic Heavy Ion Collider", May-1989.

[5] G. Bunce, "g-2 experiment extraction from AGS", 2-March-1987 memo.

[6] M. Tanaka, 31-January-1989 AGS/AD Extraction Group Mimutes.

[7] The Booster Design Manual, January-1990.

[8] J. Claus and H. Foelsche, "Beam Transfer from AGS to RHIC", RHIC Tech. Note No. 47 (1988)

[9] R. Thern, "Measurement of Twiss parameters and Emittance in the U-line", AGS Studies Report #193 (1985).
R. Thern, "Measurement of Emittance vs. Intensity in the U-line", AGS Studies Report #197 (1986).

[10] E. D. Courant, "Precision Computation of AGS Orbit Parameters", ADD/EDC-28 (1958).

E. Auerbach, "Computer Models of the AGS, I", AGS/AD/Tech. Note #297.

[11] W.T. Weng et al., "The AGS Fast Kicker Magnet Systyem", IEEE, NS-28, No.3 (1981)

W. Frey, S. Ghoshroy and J.C. Cottingham, "H5 fast Kicker Magnet Pulser", BNL 31427.
W.W. Frey, "Single Bunch Kicker Pulser", IEEE NS-30, No.4 (1983).

[12] E.B. Forsyth and C. Lasky, "The Fast Beam Extraction System of the Alternating Gradient Synchrotron", BNL 910 (T-373).

[13] D. Fiander, Private communication.
D. Fiander et al., "Kickers and Septa at the PS Complex, CERN", CERN/PS 88-58 [RF].

[14] E. Rodger and V. Badea, "Magnetic Properties in the H-10 Magnet", AD/Booster Tech. Note #148 (1989).
M.A. Goldman, "Magnetostatic Analysis of the AGS H-10 Septum

Magnet", AGS/AD/Tech. Note #343 (1990)

[15] E. Rodger, Private communication.

[16] M.Q. Barton and J. Faure, "Improved Calculations of Properties of the Slow Extracted Beam", AADD-131 (1967).

[17] E. Bleser, "Vertical Bump Magnets", 10-July-1989 AGS/AD Memo.

[18] F.C. Iselin and J. Niederer, "The MAD Program - User's Reference Manual", CERN/LEP-TH/88-38.

[19] M.T. Menzel and H.K. Stokes, "User's Guide for the POISSON/SUPERFISH Group of Codes", LA-UR-87-115.

[20] J. Xu, "The Influence of the AGS Beam Parameters on the Beam Parameters at the RHIC Injection Point", AD/RHIC/RD-14 (1990).

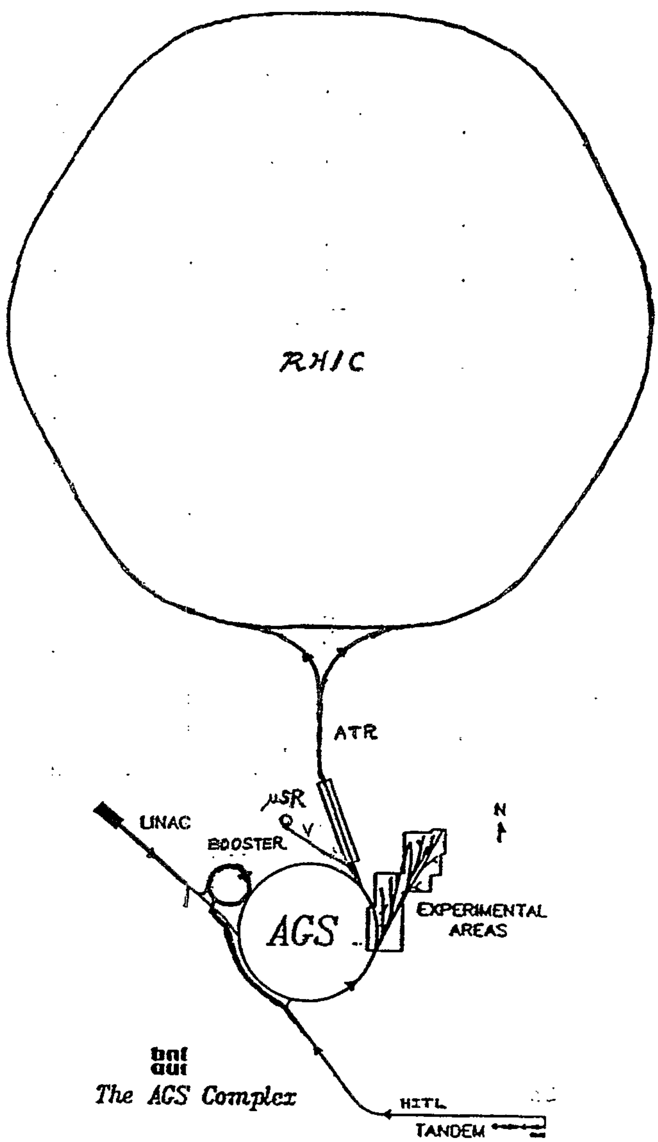

Fig. 1a Schematic layout of the AGS complex

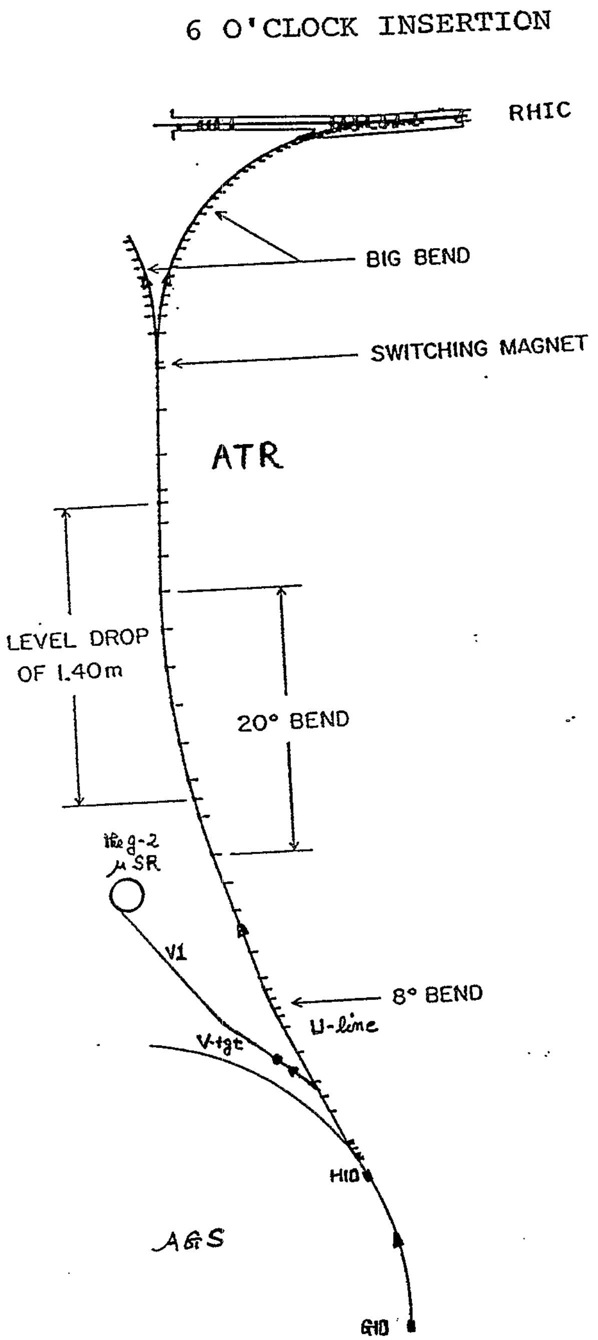

Fig. 1b Schematic layout of the transferlines

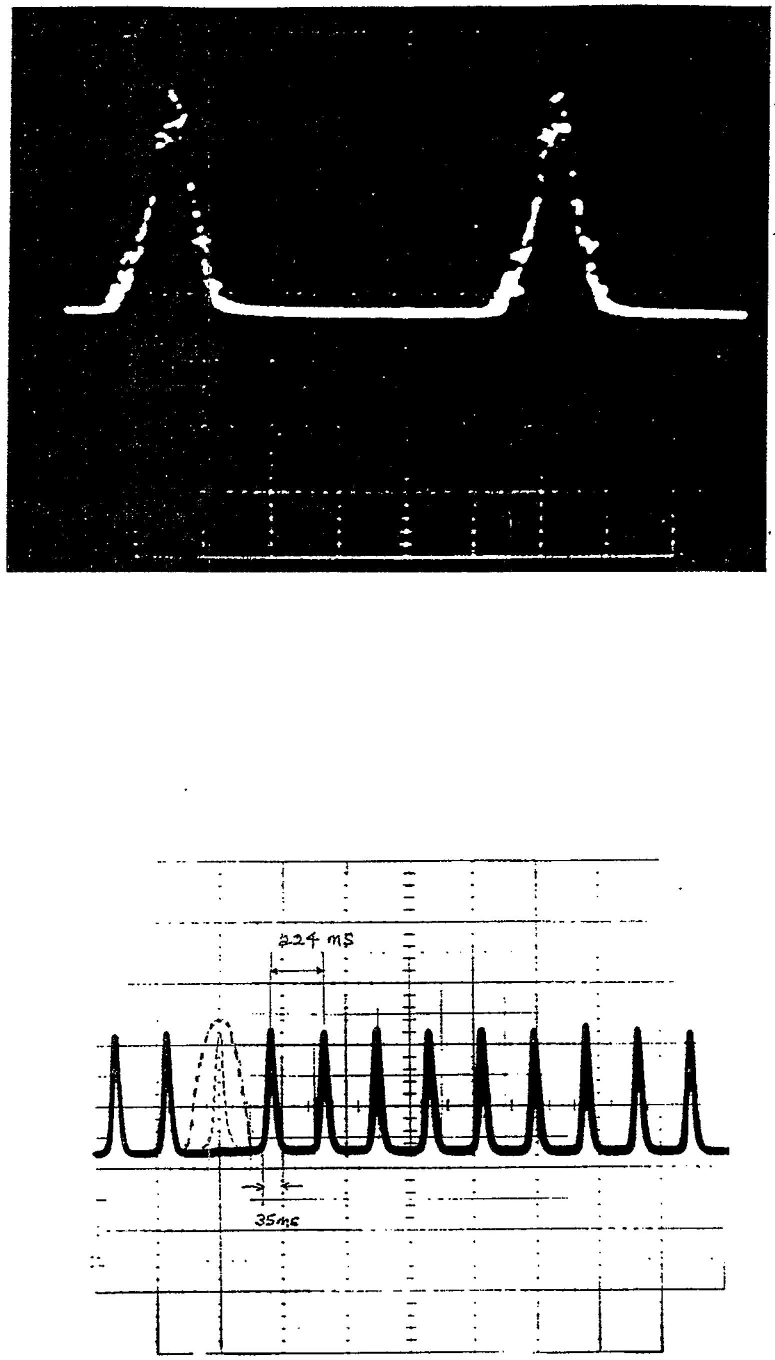

Fig. 2 Display of the bunch structure in the AGS

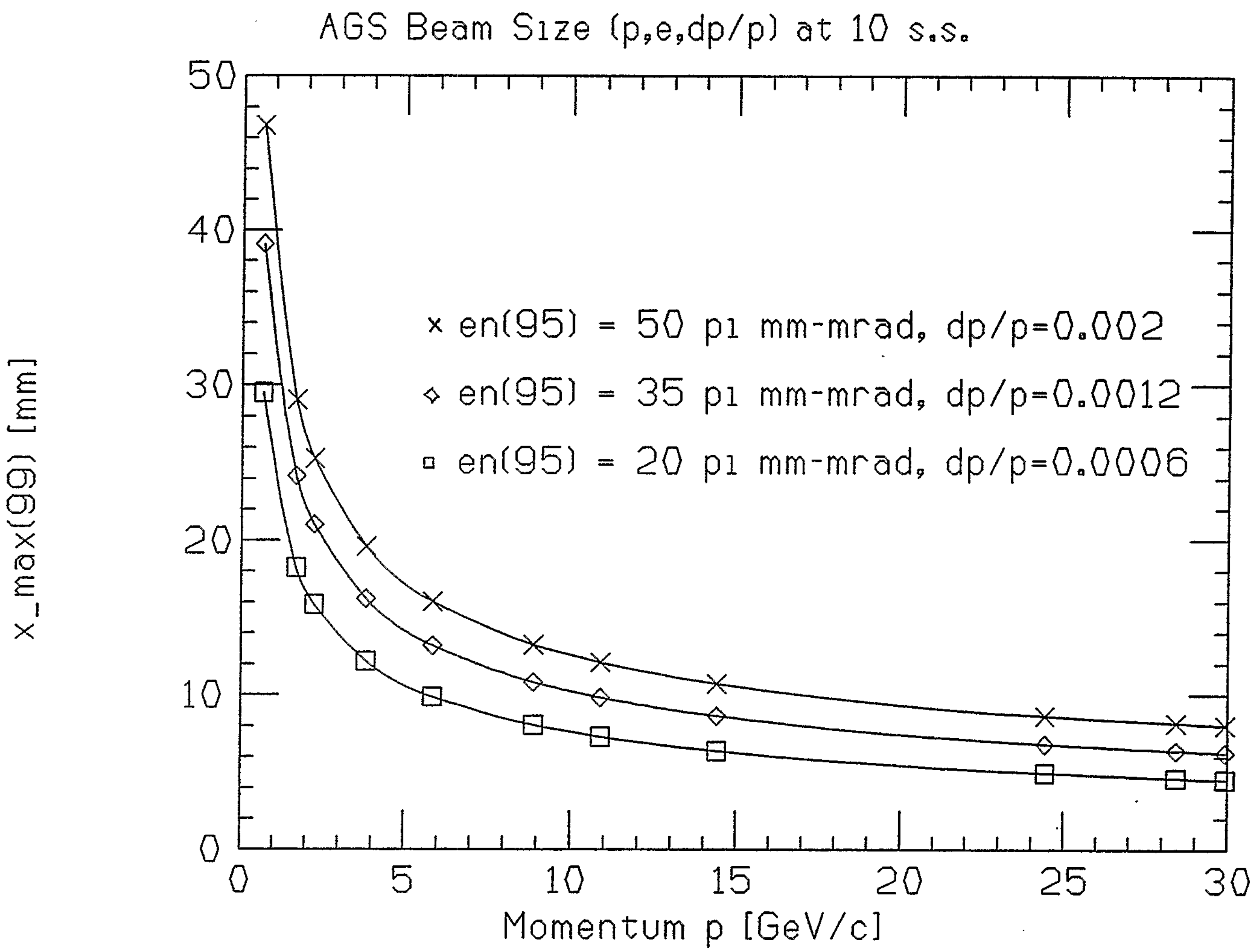

Fig. 3 Half horizontal beam width (99%)

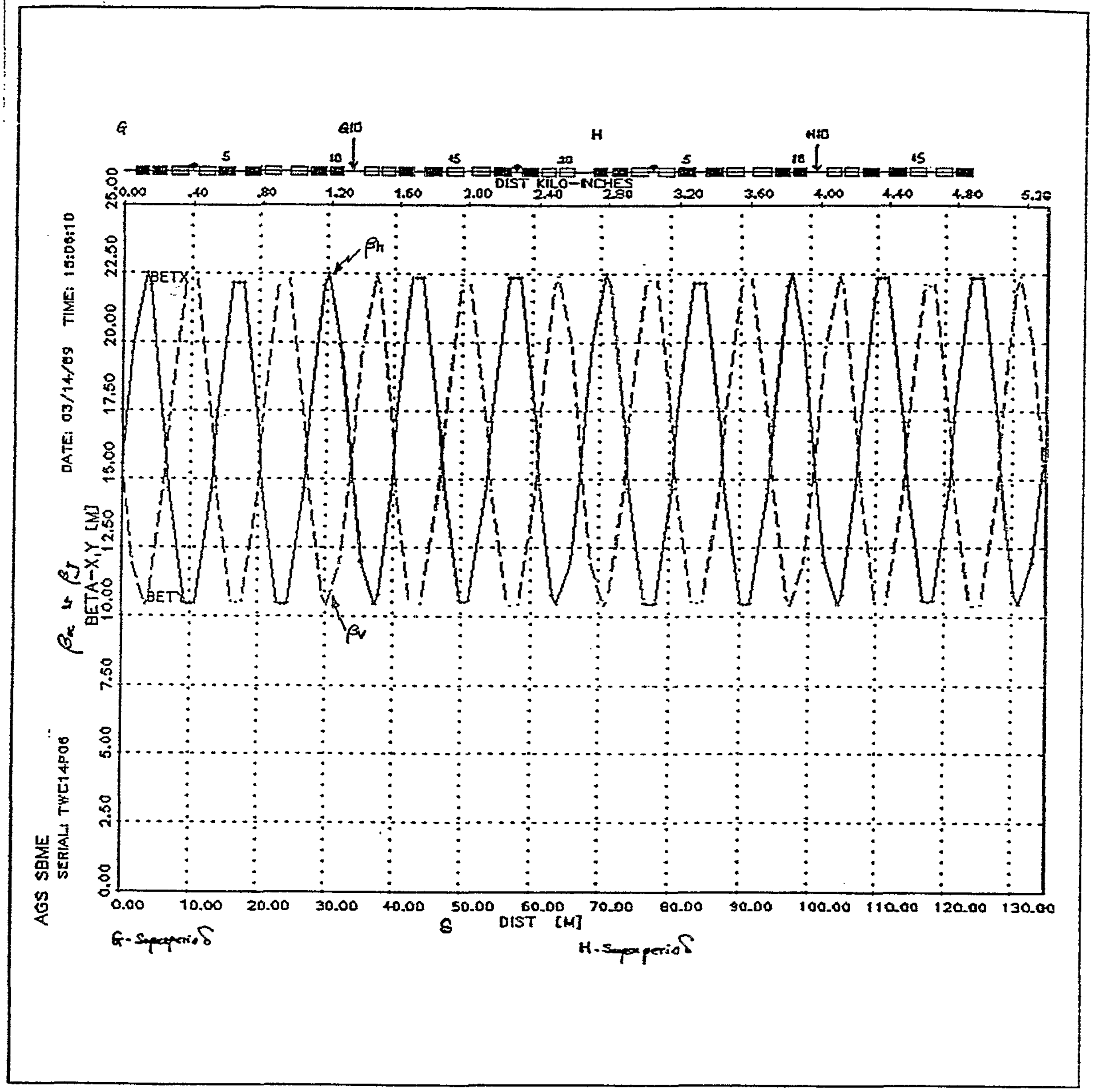

Fig. 4a Beta functions $\beta_h(s)$ and $\beta_v(s)$

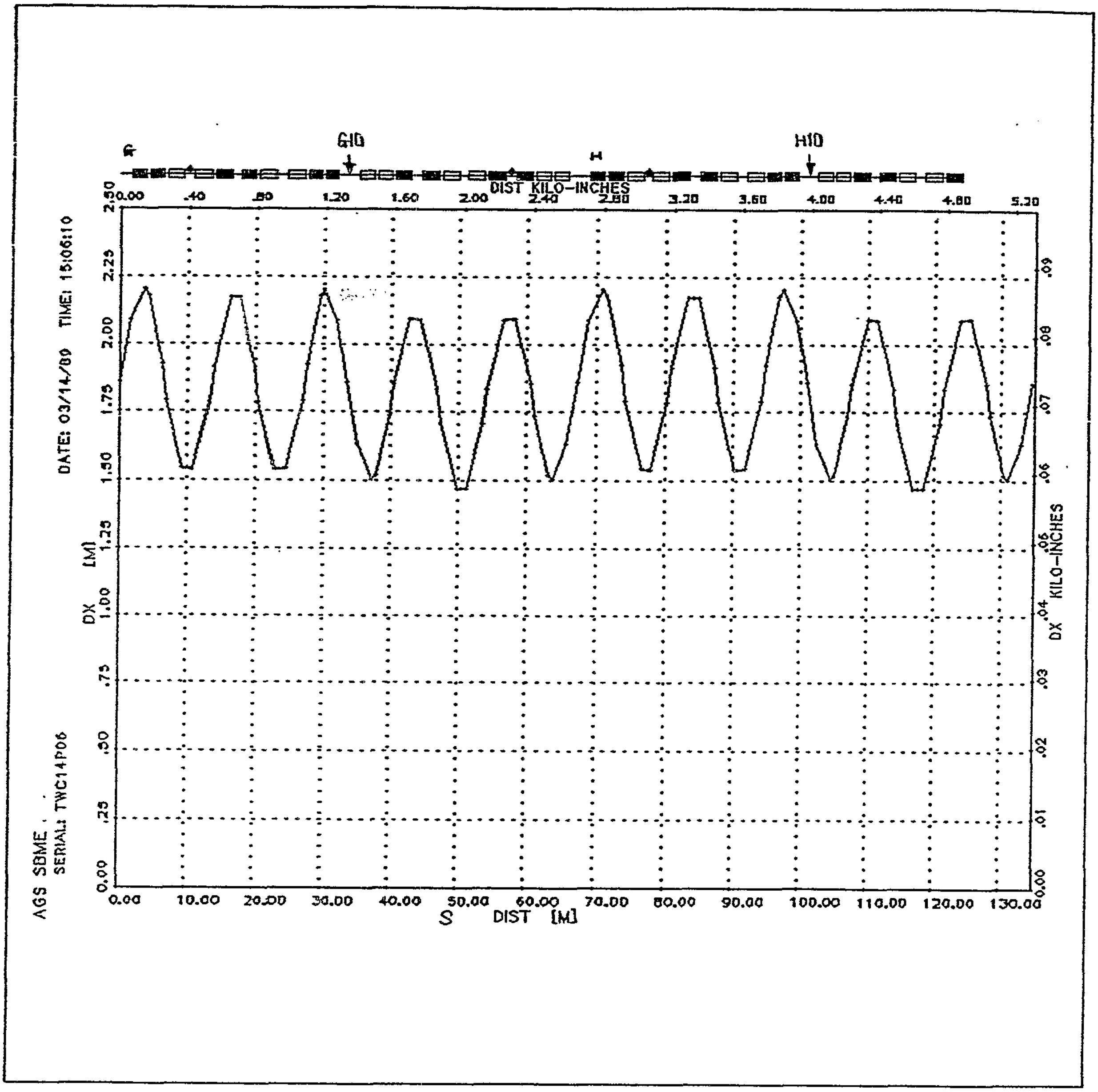

Fig. 4b Dispersion function $D_x(s)$

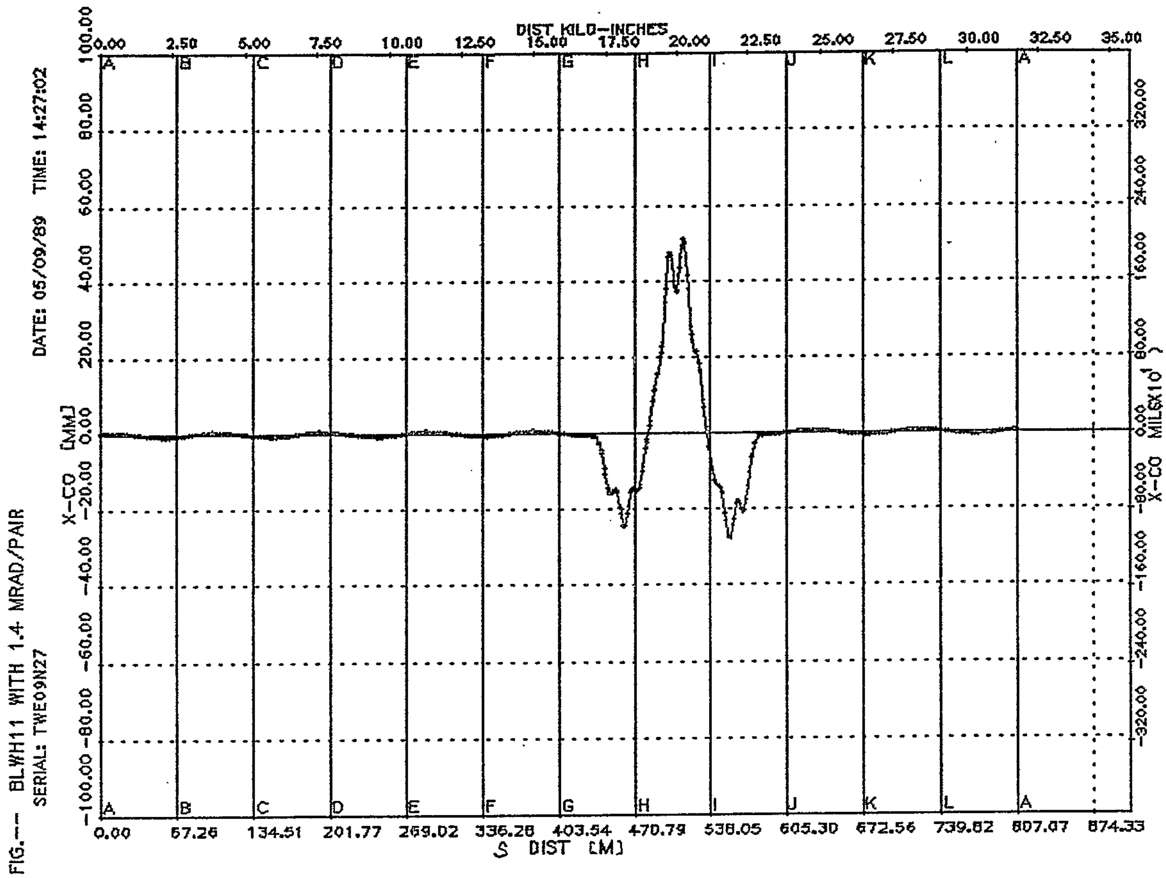

Fig. 5 BLWH11 - 3/2 lambda orbit bump for SMH10

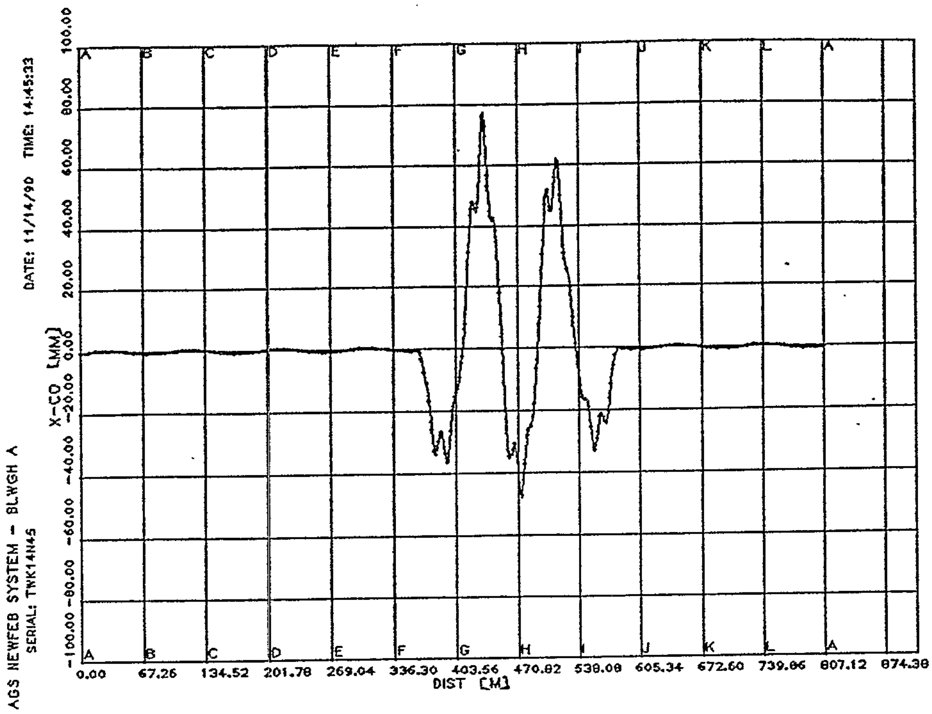

Fig. 6a BLWG09 + BLWH11 for FKG10/SMH10

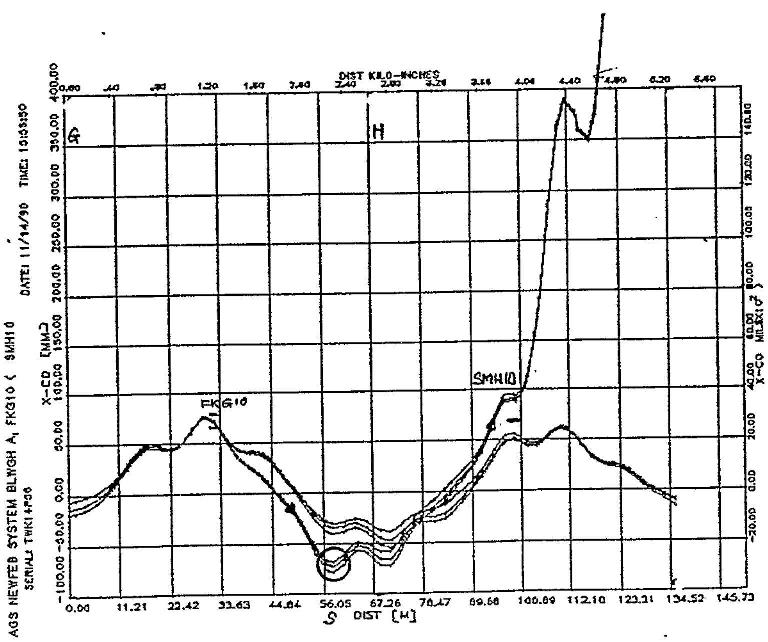

Fig. 6b BLWG09 + BLWH11 with FKG0/SMH10 on

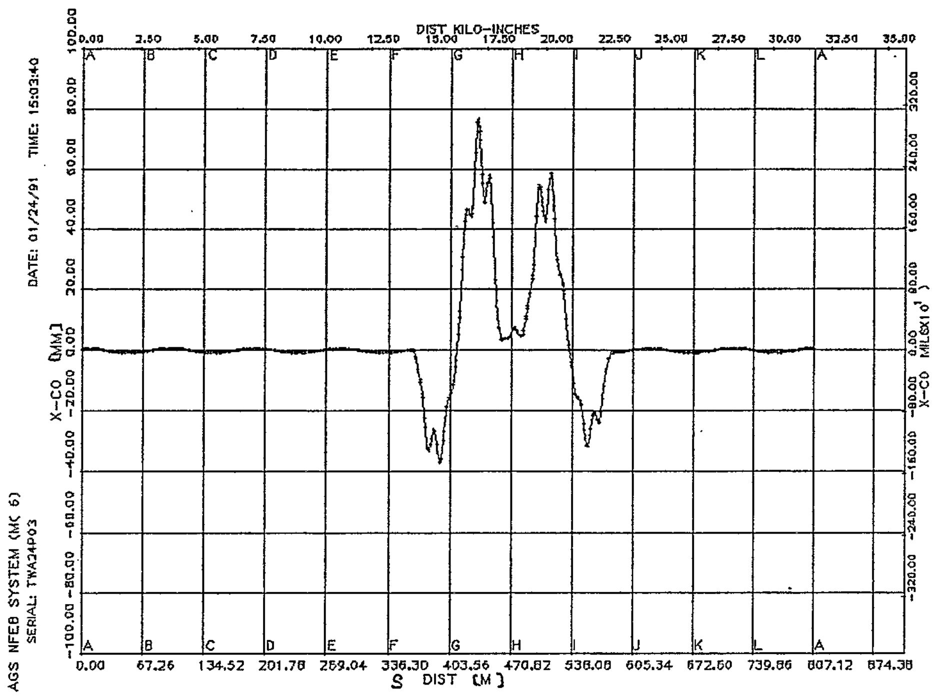

Fig. 7 BLWGH (Y.Y. Bump) for NewFEB

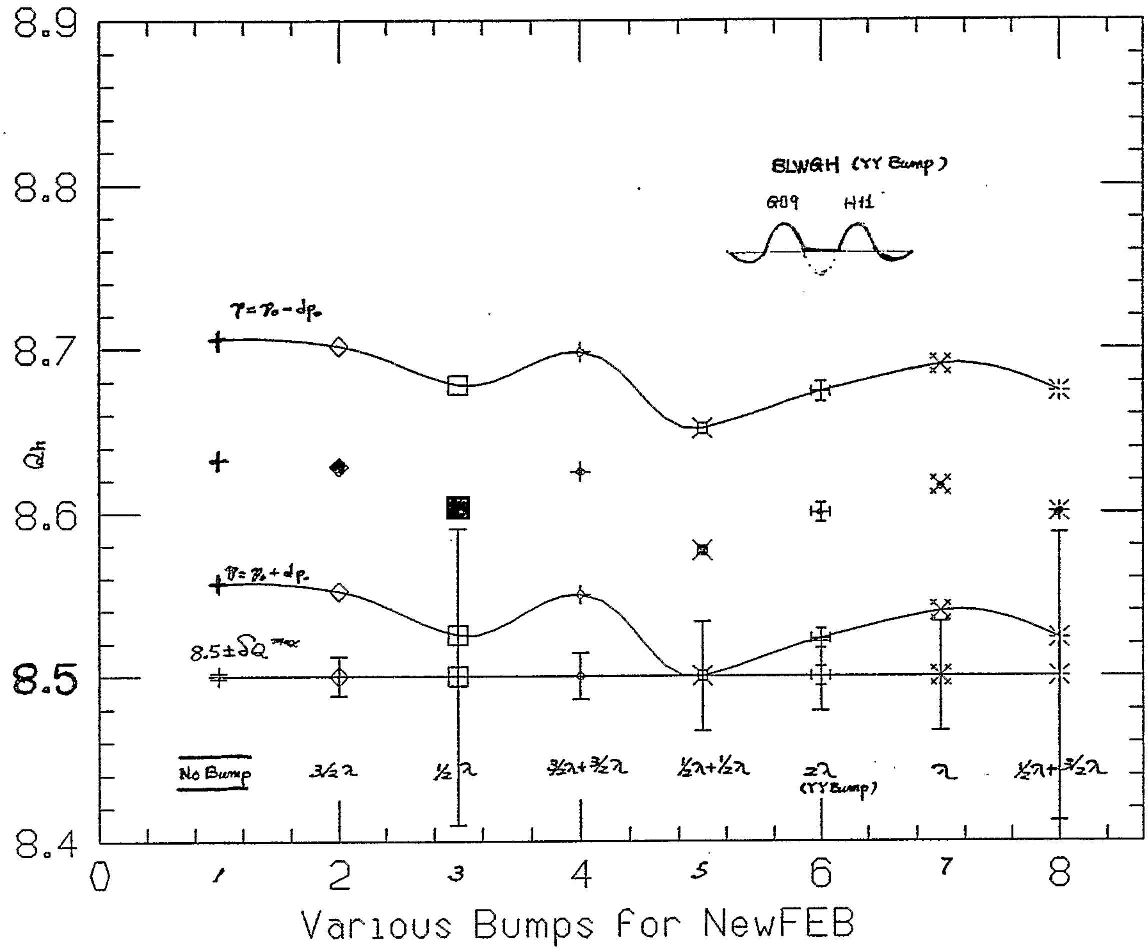

Fig. 8 Tune shift and stopband width for various bumps

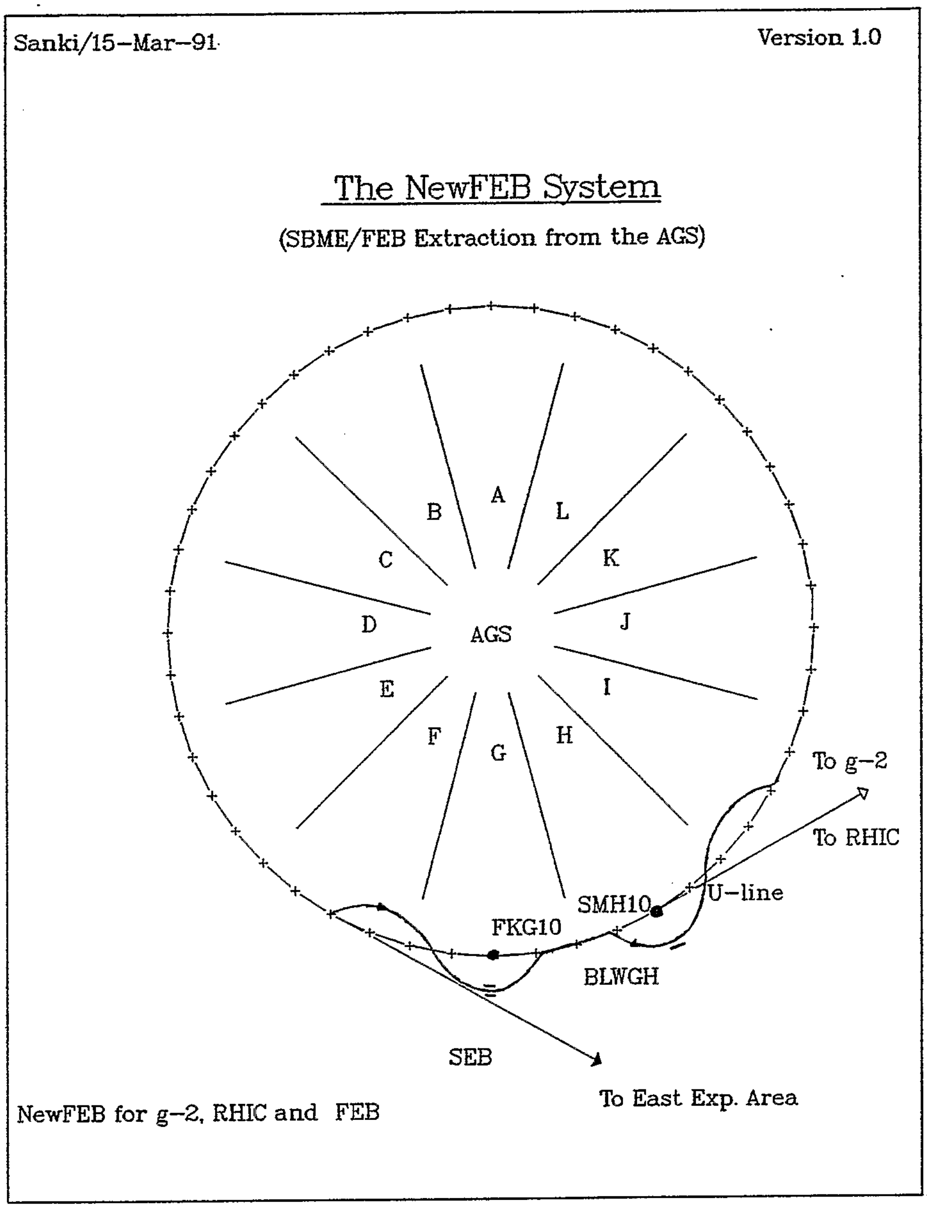

Fig. 9 Schematic layout of the NewFEB components

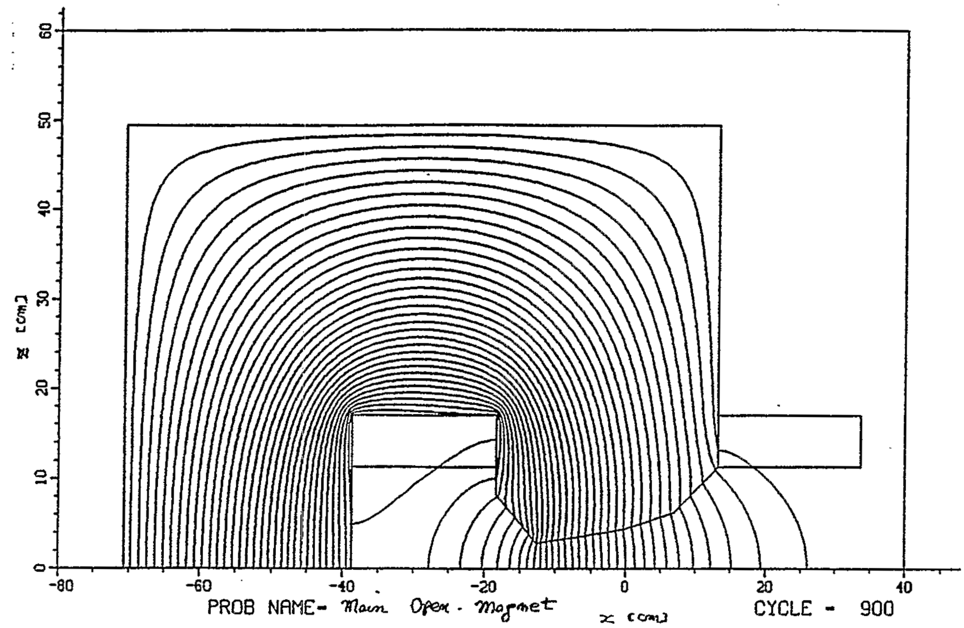

Fig. 10a The AGS open focusing magnet with field lines

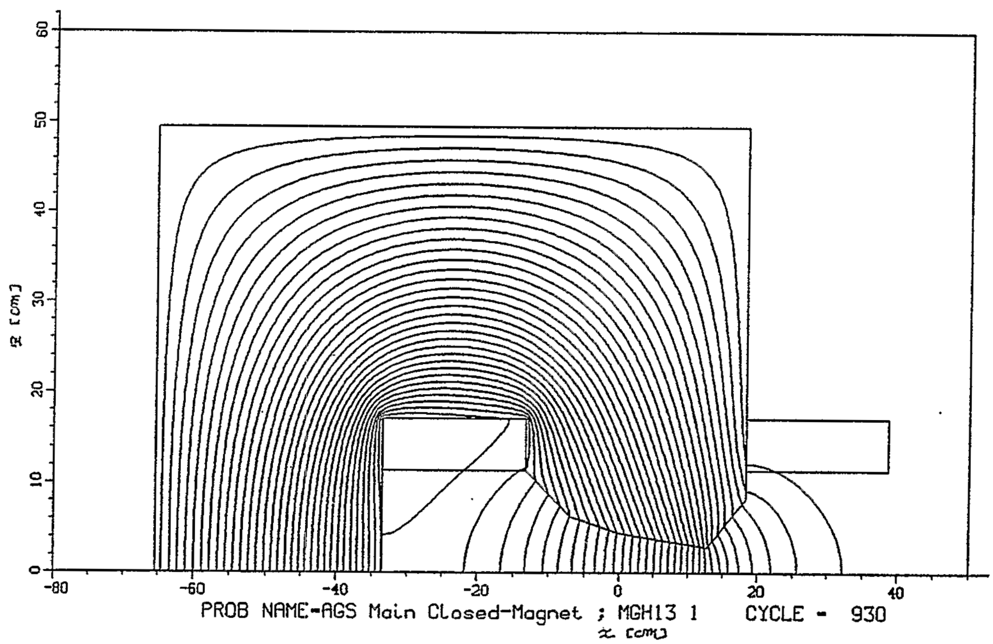

Fig. 10b The AGS closed defocusing magnet with field lines

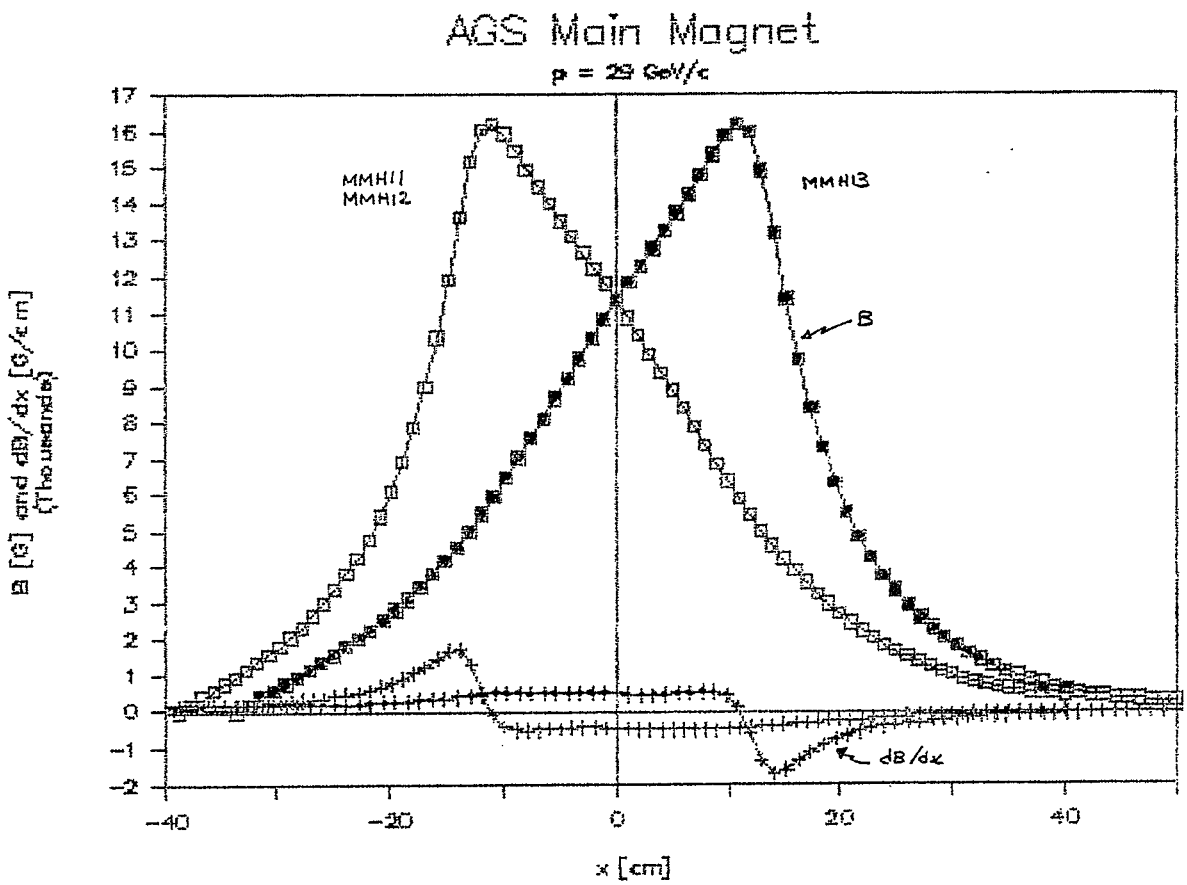

Fig. 11 The AGS main magnet field and gradient

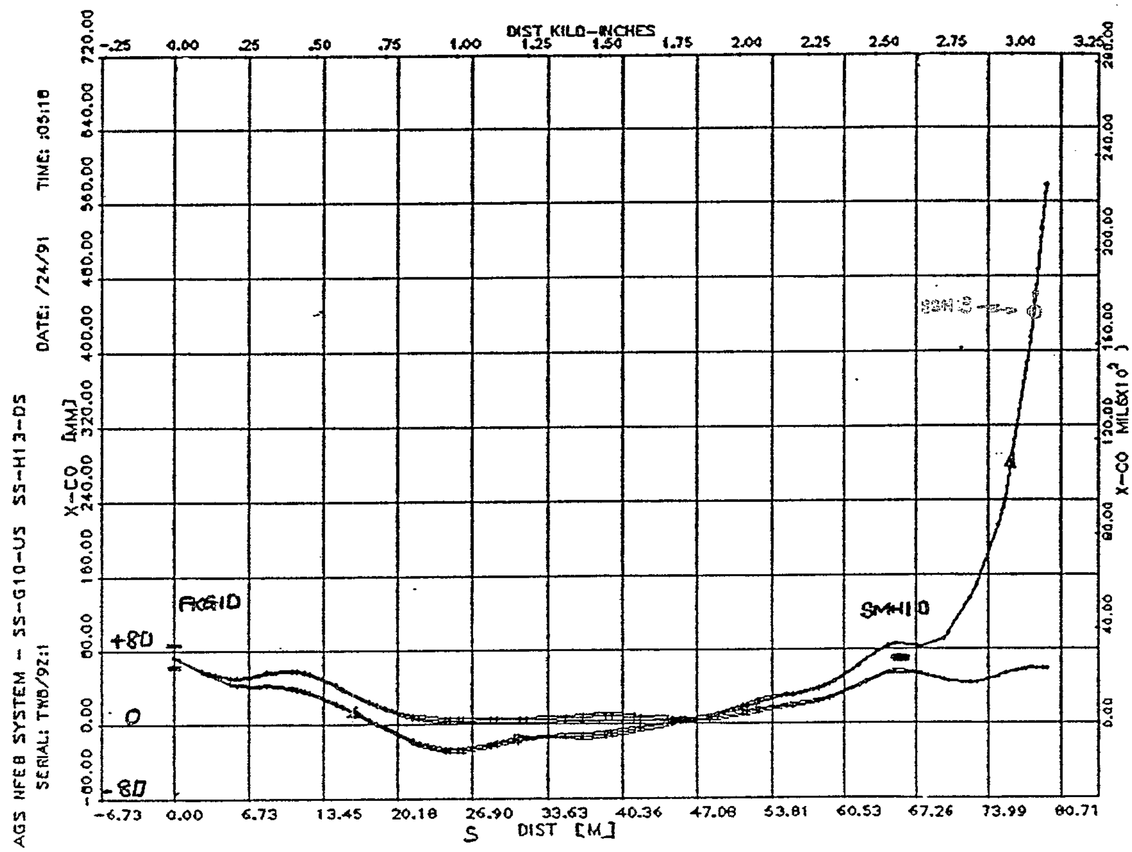

Fig. 12 Extracted and circulated beam with the NewFEB system

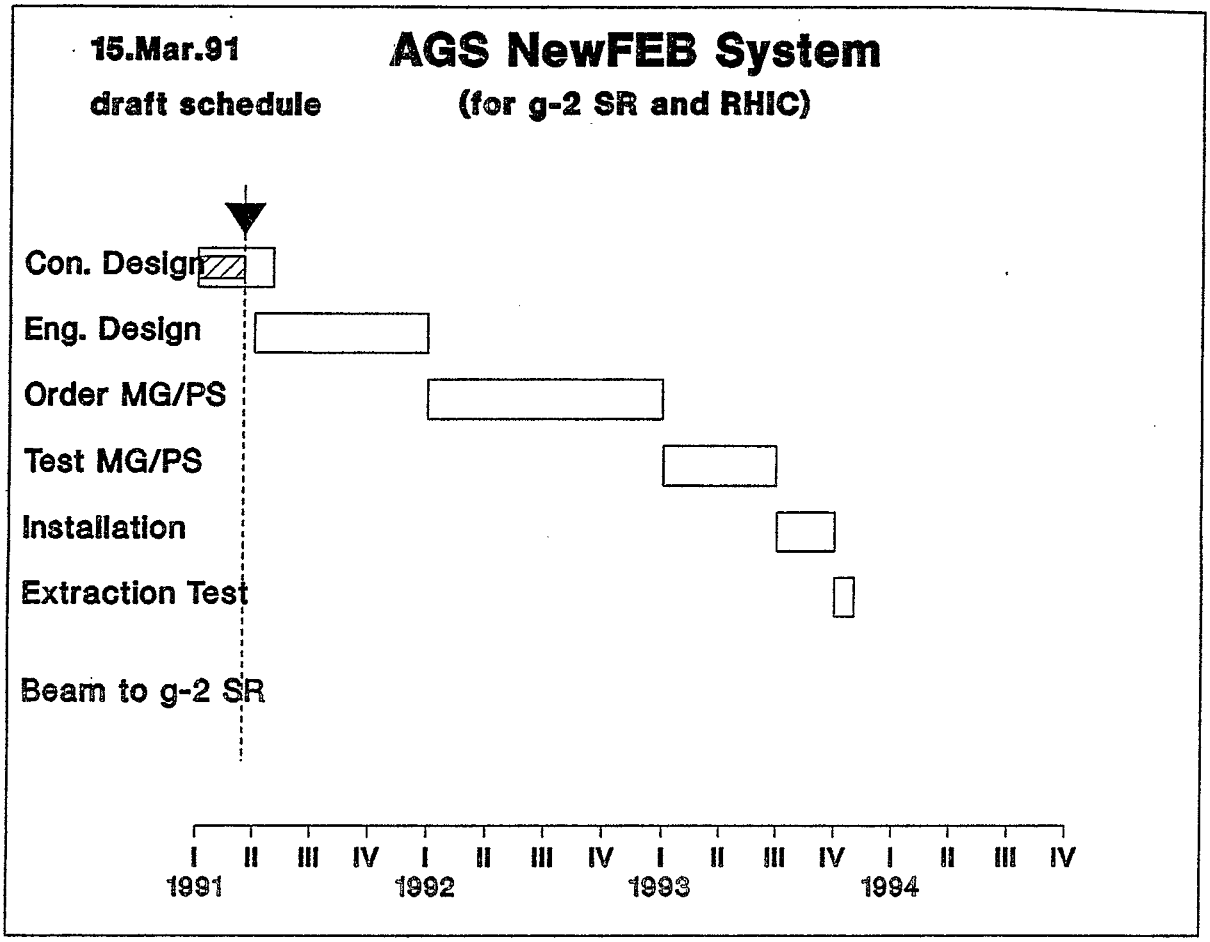

Fig. 13 Tentative Schedule for the NewFEB System