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R_transport_matrices of the Fast Extraction Beam (FEB) of the AGS, and Beam Parameters at the Starting point of the AtR Line

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Abstract:

As part of the task to improve and further automate the "AtR BPM Application" we provide the theoretically calculated R_transport_matrices for the following beam line sections, which are shown schematically in Figure 1:

a) the Fast Extraction Beam section (FEB) of the AGS synchrotron. The FEB section starts at the middle of the G10_kicker and ends at the middle of the H10_septum.
b) the Drift Extraction Channel (DEC) section of the AGS synchrotron. The DEC section starts at the middle of the H10_septum, continues along the fringe field region of the H11,H12, and H13 AGS main magnets, and ends at the starting point of the AtR line.

The knowledge of these R_transport_matrices are needed in order to calculate the beam parameters at the beginning of the AtR line, which, in turn, are required to calculate the magnet settings of the U_line, that match the U_line into the W_line.
Also by incorporating these R_matrices into the model of the AtR line, the G10 kicker and the H10 septum are included in the AtR model therefore one can investigate any "jitter" of either the G10_kicker or H10_septum by looking at the trajectory of the beam in the AtR line.

INTRODUCTION

The AGS to RHIC (AtR) beam transport line, transports the extracted beam from the AGS to RHIC. As we mentioned earlier, and we repeat here, there are two basic requirements that the AtR beam transport line should satisfy; one is the "correct beam optics" of the AtR line, which relies on the proper magnet settings of the AtR line, and the other requirement is the stable beam trajectory in the AtR line. The stable beam trajectory relies on the good stability of the magnetic field generated by the AtR magnets and the various extraction devices, like the G10_kicker and H10_septum.
The first requirement, of a "correct beam optics", ensures proper matching of the transported beam with the lattice of the AtR line, especially the 20^o bend of the W_section, which consists of a FODO lattice, and the 90^o bends of the X and Y sections of the AtR line, which are also consist of FODO lattices. This proper beam matching will eliminate beam losses along the AtR line and also ascertain the correct beam parameters at the injection point of RHIC. This requirement, of the "correct magnet settings", can be tested by the use of the "AtR BPM Application" code.
We have to inform the reader that the magnet settings of the AtR line are based on:

a) the values of the beam parameters at the beginning of the AtR line.
b) the beam constraints imposed along the AtR line,
c) and the beam matching of the various beam sections of the AtR line, namely; matching of U_line to the W_line

matching of the W_line to the X and Y lines.
matching of the X and Y lines to the Injection points of RHIC.

These beam parameters at the beginning of the AtR line can be calculated theoretically and be compared with the measured ones. Since the theoretically calculated beam parameters are relatively accurate, this comparison will serve as a test that the measured beam parameters and beam emittance of in the AtR line are correct. In case that there is a discrepancy between the theoretical and experimental values of the beam parameters, it will indicate that either, the device which measures the beam parameters is malfunctioning or the beam extraction setup of the AGS has a major flaw.

The second requirement of the AtR line, which is the repeatability of the beam trajectory of the transported beam bunches, will ensure good beam injection repeatability into RHIC. Both of these requirements; the correct magnet settings, and the repeatability of the beam trajectory, can be tested, and subsequently satisfied, by the use of the automated version of the "AtR_BPM application".

This document will be dealing with:

a) the justification to provide the present write up for the theoretically calculated R_transfer_matrices mentioned earlier, and the beam parameters at the beginning of the AtR line
b) the step by step procedure utilized to calculate the R_transfer_matrices, and the beam parameters at the beginning of the AtR line.
c) Presentation of tables with the R_matrices of the "FEB" and "DEC" lines, and of the beam parameters at the beginning of the AtR line for various beam extraction settings of the AGS.

Why do we need a specific write-up for the calculation of the R_Matrices? Can one simply obtain these R_matrices from a "MAD_model" of the AGS and AtR lines?

A straightforward way to calculate the R_matrices of the various line sections of the FEB_AtR_line, is to generate a MAD model of the FEB_AtR_line, which can be partitioned in three beam lines according to the relation below.

{FEB_AtR_line}<=>{FEB_section} + {DEC_section} + {AtR_line} (See Figure 1)

Such a model can be easily generated for the FEB section and the AtR_line, since both lines consist of well described magnetic elements, like dipoles and quadrupoles.
The DEC section, however, is located inside the fringe field of the H11,H12 and H13 AGS main magnets and the R_matrices can only be calculated by the "raytrace" method which requires the knowledge of the magnetic field of the region where the DEC section is located.
Indeed the DEC line section is part of the area, where field maps, over the median plane of the AGS main magnets, have been generated[2]. These field maps can therefore be used to calculate the R_matrices of the DEC section by using the raytrace method.
Thus this document provides the R_transport_matrices of the "FEB" and "DEC" sections of the extraction line of the AGS, for various extraction settings of the AGS synchrotron.
The R_matrices are calculated by raytracing the extracted beam using the experimentally

measured field maps [2]. This document provides also the beam parameters at the beginning of the AtR line for various extraction settings of the AGS synchrotron.

Procedure on how to calculate the R_Matrices of the "FEB" and "DEC" Lines

In this section we provide details on how we calculated of the R_matrices of the FEB and DEC lines (see Fig. 1) of the AGS and also provide details on the calculations of the beam parameters at the beginning of the AtR line.
To remind the reader, the FEB section, shown schematically in Figure 1, starts from the middle of the G10_kicker, which is the first element of the FEB_section and ends at the middle of the H10_septum. The G10_kicker is represented by a "corrector magnet" of zero length, and its effect is included in the calculations of the R_matrix of the FEB_section. The H10_septum is nor included in the FEB_section.
The DEC section, shown schematically in Figure 1, starts from the middle of the H10_septum, which is the first element of the DEC_section, and ends at the starting point of the AtR line. The H10_septum is represented by a "corrector magnet" of zero length, and its effect is included in the calculations of the R_matrix of the DEC_section.
Thus the total "FEB_AtR_line" will be represented by the following model:

FEB_AtR_line={G10_kicker+FEB_matrix}+{H10_septum+DEC_matrix}+{AtR_line}

Two methods were used to calculate the R_matrices of the FEB_section; the first method utilizes a "MAD_model" of the AGS ring, and the second method utilizes "Raytracing" through the AGS magnets.
For reasons described above, the calculations of the DEC matrices were performed by the "Raytracing" method only.

Calculation of the "FEB" matrices using a "MAD model" of the AGS ring

In order to calculate the R_matrices of the FEB section by using the MAD code, we use a MAD model of the AGS that includes the following features:

a) The values of the physical quantities K1 and K2, which are required to represent the combined function main magnets of the AGS are incorporated in the MAD model as a function of the beam momentum. This functional dependence of the K1 and K2 is referred among the AGS personnel, as the "Ed Bleser's model of the AGS main magnets".
b) The AGS main magnets as they are represented in the "MAD_model" of the AGS, have been artificially split in the middle, and a kicker magnet of zero length has been placed in the middle. These kicker magnets are utilized in the optimization of the G10 and H10 extraction orbit bumps and provide a good approximation for the "back leg windings" settings, of the main magnets which are actually used to generate these local beam orbit bumps. The "back leg windings" are part of the FEB system [3]. In order to provide more accurate description of the local beam bumps of the extraction orbit, (following the optimization of the extraction orbit bumps which utilizes the

artificial kickers placed in the middle of the main magnets), we replace the strength of each artificial kicker that generated the G10 and H10 local beam bumps, by a magnet error (ΔK0, ΔK1, and ΔK2). Subsequently the local orbit bumps are further optimized by "trial and error" of the magnet error (ΔK0). This representation of the artificial kickers magnets by magnet errors is a more accurate description of the back leg windings of the main magnets which are actually used to generate these local orbit bumps of the extracted beam.

c) The strengths of both, the Tune Quadrupoles and Chromaticity Sextupoles are also included in the "MAD" Model of the FEB section.

Procedure to calculate the R_matrices of the FEB section using the "MAD model"

In this section we describe the step by step procedure to calculate the R_matrices of the FEB section by using the MAD model.

1. Set up AGS for beam extraction using the "MAD_model" of AGS as described above:
   1.1 Main magnets of AGS are set to allow beam with the required "momentum at extraction" to circulate . The required "beam momentum at extraction" corresponds to the momentum of the beam which allows the beam to circulate at a radius of R_0=0.0 [mm]. The actual extraction momentum of the beam is achieved when the beam is moved to an outer radius, and also, the local beam extraction bumps "G10" and "H10" are energized.
   1.2 The Tune_Quadrupoles and Chromaticity_sextupoles are set to generate the required tunes $Q_{x,y}$ and chromaticities $\xi_{x,y}$. These required tunes and chromaticities are the tunes and chromaticities of the AGS synchrotron as measured with the beam just before extraction.
   1.3 The beam orbit is placed at the desired radius. At this desired radius the beam momentum is the actual beam momentum that the RHIC synchrotron desires during injection. Also while the beam circulates at the desired radius the local beam bumps G10 and H10 (see item 1.4 below) are energized.
   The local beam bumps for fast extraction are set to provide the required X_{cod} at the middle of the G10_kicker and the middle of the H10_septum [1,3] . The required closed orbit displacements are: $(X_{cod})_{\delta p/p=0}$ (at G10)=~61 [mm] and $(X_{cod})_{\delta p/p=0}$ (at H10)=~48 [mm]. These beam displacements at G10 and H10 have been calculated when the fast extraction system of the AGS was designed, and take into account the size of the beam at extraction so that the beam does not interact with any apertures. Also the beam displacements $(X_{cod})_{\delta p/p=0}$ (at G10) and $(X_{cod})_{\delta p/p=0}$ (at H10) should always be ~61 [mm] and ~61 [mm] respectively, independent of the average radius of the circulating beam.
   The meaning of the δp/p=0.0 is discussed in the rest of this section. In either the MAD code of the BEAM code, for the beam to be placed at

the desired extraction radius one must add a momentum dp/p to the required "beam momentum at extraction" . However in this write up we call the final momentum of the circulating beam at the extraction radius and with the extraction bumps energized as having a dp/p=0.0000

1.4 The following physical quantities, for the closed beam orbit, are recorded:

i. The beam parameters (β_{xy}, α_{xy}) at the location of the G10_kicker.

ii. The X_{cod} and X'_{cod} at the location of the G10 kicker for two different momenta of the central orbit, $\delta p/p=0$ and $\delta p/p=0.001$. It is required that $(X_{cod})_{\delta p/p=0}$ (at G10)=~61 [mm] and $(X_{cod})_{\delta p/p=0}$ (at H10)=~48 [mm] .

2. After the orbit is closed, we use the MAD model of the AGS section between the G10_kicker and the H10_septum: this section was defined earlier as the "FEB" section.

2.1 With the magnetic elements of the FEB section set as in item (1.) above and the beam's initial conditions same as those recorded in (1.4 above), we kick the beam with the G10_kicker. The strength of the G10_kicker should be such that the central ray of the beam, referred as "Extracted orbit" in Table 1., should have the required displacement $(X_{cod})_{\delta p/p=0}$, midway of the H10_septum. This central orbit displacement $(X_{cod})_{\delta p/p=0}$(at H10) is shown in Table 1. Record the values of $(X_{cod})_{\delta p/p=0}$(at H10) and $(X'_{cod})_{\delta p/p=0}$(at H10) midway of the H10 septum magnet.

Table 1: Central Orbit Displacements at H10_septum.

	$(X_{cod})_{\delta p/p=0}$ Bump Only "Closed orbit" [mm]	$(X_{cod})_{\delta p/p=0}$ Bump + G10kick "Extracted orbit" [mm]
UpStream H10	51.5	83.5
Midway of H10	48.0	77.5

2.2 The MAD code can now provide the 6x6 R_matrix of the FEB_section. We actually use the beam parameters at the beginning and end of the FEB section to calculate the matrix elements of the R matrix. This method includes the effect of the sextupoles on the beam which is laterally displaced at the location of the sextupoles.

2.3 Repeat task 2.1 but this time the central orbit should have increased momentum $\delta p/p=0.001$ and the starting coordinates at the middle of G10_kicker will be the coordinates $(X_{cod})_{dp/p=0.001}$(at G10) and $(X'_{cod})_{dp/p=0.001}$(at G10) which were recorded from section (1.4 ii above) . Record the output coordinates $(X_{cod})_{dp/p=0.001}$(at H10) and $(X'_{cod})_{dp/p=0.001}$(at H10). These coordinates will help determine the dispersion function $\eta_{x,y}$ at the starting point of AtR line.

In the next subsection we describe the procedure to calculate the R_matices of the FEB section using the "Raytrace" method.

Calculation of the "FEB" matrices using the "Raytrace" method

The procedure of calculating the R_matrices with the "Raytrace" method is similar to the method of using MAD, with two major differences:

a) It uses the "BEAM_model" [4] of the AGS ring, and
b) The AGS main magnets are described with the experimentally measured field maps [2].

Both features (a) and (b) above have been combined, in a modified version of the BEAM code[4]. A description, on how, the experimentally field maps of the main magnets, have been incorporated into the BEAM code, is given in Ref. [1].

Procedure to calculate the R_matrices of the FEB section using the "Raytrace" method

In this section we describe the step by step procedure to calculate the R_matrices of the FEB section by using the modified BEAM code for the AGS ring.

1. Set up AGS for beam extraction using the "BEAM model" of the AGS:

   1.1 Main magnets of AGS are set to allow a beam with the required "momentum at extraction" to circulate . The required "momentum at extraction" corresponds to the momentum of the beam which allows the beam to circulate at a radius of R_0=0.0 [mm]. The actual extraction momentum of the beam is achieved when the beam is moved to an outer radius and with the local beam extraction bumps "G10" and "H10" both energized.

   1.2 The Tune_Quadrupoles and Chromaticity_sectupoles are set to generate the required tunes $Q_{x,y}$ and chromaticities $\xi_{x,y}$.

   1.3 The beam orbit is placed at the desired radius, with the local beam bumps for fast extraction set to provide the required X_{cod} at the middle of the G10_kicker and H10_septum [1,3] for the closed orbit. The required closed orbit displacements are: $(X_{cod})_{\delta p/p=0}$ (at G10)=~61 [mm] and $(X_{cod})_{\delta p/p=0}$ (at H10)=~48 [mm].

   1.4 The following physical quantities, of the closed beam orbit, are recorded:

      i. The beam parameters (β_{xy}, α_{xy}) at the location of the G10_kicker.
      ii. The X_{cod} and X'_{cod} at the location of the G10 kicker for two different momenta of the central orbit, $\delta p/p=0$ and $\delta p/p=0.001$. It is required that $(X_{cod})_{\delta p/p=0}$ (at G10)=~61 [mm] and $(X_{cod})_{\delta p/p=0}$ (at H10)=~48 [mm] (Distance is measured from the Optimum Closed Orbit (OCO)).

2. After the orbit is closed, we use the BEAM model of the section of the AGS between the middle of the G10_kicker and the middle of the H10_septum and we perform the following operations.

2.1 With the magnetic elements of the FEB section set as in item (1.) above, and the beam's initial conditions same as those recorded in (1.5), we kick the beam with the G10_kicker. The strength of the G10_kicker should be such that the central ray of the beam, which is referred as, "Extracted orbit" in Table 1., should have the required displacement $(X_{cod})_{\delta p/p=0}$ at the center of the H10_septum. This $(X_{cod})_{\delta p/p=0}$ displacement is shown in Table 1.
Record the values of $(X_{cod})_{\delta p/p=0}$(at H10) and $(X'_{cod})_{\delta p/p=0}$(at H10)
The BEAM code can now provide the Horizontal and Vertical 2x2 R_matrices of the FEB_section. The R_{16} and R_{26} matrix elements can also be computed.

2.2 Repeat task 2.1 but this time the central orbit should have an increased momentum of dp/p=0.001 and the starting coordinates will be the coordinates $(X_{cod})_{dp/p=0.001}$(at G10) and $(X'_{cod})_{dp/p=0.001}$(at G10) which were recorded from section (1.4 ii) . Record the output coordinates $(X_{cod})_{dp/p=0.001}$(at H10) and $(X'_{cod})_{dp/p=0.001}$(at H10). These coordinates will help determine the dispersion function $\eta_{x,y}$ at the starting point of AtR line.

In the next subsection we describe the procedure to calculate the R_matices of the DEC section using the "Raytracing" method.

Calculation of the "DEC" matrices using the "Raytracing" method

Although the DEC section does not include any lumped magnetic elements like dipoles, quadrupoles etc., it cannot be considered as a drift space because it is located in the fringe field region of the H11, H12 and H13 AGS main magnets which generate a field which is described by the magnetic field maps of the main magnets [2]. For this section of the line we use the "Raytrace method" to calculate the R_matrices.

Procedure to calculate the R_matrices of the DEC section using the Raytrace method

The Raytrace method is currently the only method used to calculate the R_matrices of the DEC section. The rest of this subsection is devoted in the procedure used to calculate the R_matrices in the DEC section.

In the earlier subsections which describe the procedure to calculate the R_matrices for the FEB section, we energized the G10_kicker to kick the central orbit of the beam, for the central orbit to acquire a displacement at the middle of the H10 straight section X_{cod}(at H10) =~77.5 [mm].

Now using the modified BEAM code or the modified RAYTRACE code which both have incorporated the measured field maps of the main AGS magnet as well as the field maps of the fringe fields, we excite the H10_septum to bend the central orbit of the beam outside of the AGS, and achieve a central orbit displacement at the middle of the H13 straight section of X_{cod}(at H13) =~450.5 [mm]. This point which is at a distance of 450.5 [mm] from the middle of the straight section (H13), is defined as the starting point of the AtR line. The direction of the central orbit at the beginning of the AtR line should be X'_{cod}(at H13) =~69.5 [mrad]. If the direction of the beam at the middle of the straight section H13 differs by more than ±1.0 mrad from the specified direction of 69.5 mrad, we should revisit the calculations of the FEB section, and if needed, we can change the strength of the G10_kicker. The possibility that the beam coordinates at H13 are not equal to {X,X'}={450.5 [mm], 69.5 [mrad]} when the beam position X, at H10 is 75 [mm] will indicate that the fringe fields generated by H11,H12 and H13 main magnets do not scale linearly with magnet current (beam momentum). The fringe field linearity however has been tested by raytracing in this fringe field region, beams of two different momenta of 24.3 GeV/c and 29.0 GeV/c.

With the central orbit extracted from the AGS and having the required trajectory in the DEC section, the modified BEAM or RAYTRACE codes can be used to calculate the R_matix in the DEC section.

Calculation of the beam parameters ($\alpha_{x,y}$, $\beta_{x,y}$) and ($\eta_{x,y}$, $\eta'_{x,y}$) at H13

With the central orbit extracted from the AGS and having the required trajectory in the DEC section, the modified BEAM or RAYTRACE codes can be used to calculate the R_matix in the DEC section.

With the R_matrices calculated, as described in the previous sections, the beam parameters at the starting point of the AtR line can be computed by using the relations:

$$\beta_x(H13)= (R_{11}R_{11})\,\beta_x(H10) - 2\,R_{11}\,R_{12}\,\alpha_x(H10) + (R_{12}\,R_{12})\gamma_x(H10)$$
$$\alpha_x(H13)=-(R_{11}R_{21})\,\beta_x(H10) +(1+2R_{11}R_{21})\alpha_x(H10) - (R_{12}R_{22})\,\gamma_x(H10)$$

$$\beta_y(H13)= (R_{33}R_{33})\,\beta_y(H10) - 2\,R_{33}\,R_{34}\,\alpha_y(H10) + (R_{34}\,R_{34})\gamma_y(H10)$$
$$\alpha_y(H13)=-(R_{33}R_{43})\,\beta_y(H10) +(1+2R_{33}R_{43})\alpha_y(H10) - (R_{34}R_{44})\,\gamma_y(H10)$$

The R_{ij} matrix elements appearing in the relations above correspond to the matrix elements of the line between the middle of the H10_septum and the starting point of the AtR line (H13 point). The dispersion functions η_x(H13) and η'_x(H13) are calculated using the following relations:

$$\eta_x(H13) = (X_{cod}(H13)_{\delta p/p=0.001} - X_{cod}(H13)_{\delta p/p=0.000})/0.001$$

$$\eta'_x(H13) = (X_{cod}(H13)_{\delta p/p=0.001} - X_{cod}(H13)_{\delta p/p=0.000})/0.001$$

The quantities $X_{cod}(H13)_{\delta p/p=0.000}$ and $X'_{cod}(H13)_{\delta p/p=0.000}$ are the displacement and direction respectively, of the central orbit which starts from the middle of the straight section H10 with specified coordinates $X_{cod}(H10)_{\delta p/p=0.000}$ and $X'_{cod}(H13)_{\delta p/p=0.000}$ and ends up at the middle of the straight section H13 after passing through the fringe field of the H11, H12 and H13 AGS main magnets.

The quantities $X_{cod}(H13)_{\delta p/p=0.001}$ and $X'_{cod}(H13)_{\delta p/p=0.001}$ are the displacement and direction respectively, of the central orbit which starts from the middle of the straight section H10 with specified coordinates $X_{cod}(H10)_{\delta p/p=0.001}$ and $X'_{cod}(H13)_{\delta p/p=0.001}$ and end up at the middle of the straight section H13 after passing through the fringe field of the H11, H12 and H13 AGS main magnets.

Results

In this section we will present the results from the calculations.
The results are summarizes in the Table 2 below. The first six columns of the Table 1 correspond to the extraction setting of the AGS synchrotron.
a) column 1: The rigidity of the central momentum of the circulating beam at R=0.0 [mm]. This rigidity corresponds to the setting of the AGS main magnets during extrtaction.
b) column 2: Average Extraction radius of the circulating beam just before extraction. The local beam bumps at the middle of the G10_kicker and the middle of the H10_septum are set to provide $(X_{cod})_{\delta p/p=0}$ (at G10)=~61 [mm] and $(X_{cod})_{\delta p/p=0}$ (at H10)=~48 [mm] independent of the average beam radius.
c) columns 3,4: Tune Quadrupoles set for specific tunes.
d) columns 5,6: Chromaticity sextupoles set for specific chromaticities.
e) column 7: The name of the Table_Xi which contains results corresponding to the extraction settings of the AGS as shown in the first six columns of Table 1. The Tables_Xi contain information like the beam parameters at the beginning of the AtR line an the R_matrices of the "FEB" and "DEC" sections.
f) column 8: The column under the name "comments" helps the reader to group together the Tables_Xi in order to find how the beam parameters at the beginning of the AtR line, vary as the extraction setting of the AGS vary.

Table 2: This Table provides the names of the Tables (column 7) generated for the various extraction settings of the AGS

Brho[T.m]	R_0 [mm]	IQx [A]	IQy [A]	ISx [A]	ISy [A]	Table	Comments
81.055	-2.1	0.0 8.656	0.0 8.741	0.0 -23.9	0.0 4.6	X1	Bare_AGS VaryExtraction Radius
81.055	-4.7	0.0 8.621	0.0 8.748	0.0 -24.1	0.0 4.7	X2	Bare_AGS VaryExtraction Radius
81.055	-7.3	0.0 8.586	0.0 8.755	0.0 -24.3	0.0 4.8	X3	Bare_AGS VaryExtraction Radius
81.055	-2.1	339 8.757	-130 8.751	104 -28.4	80 4.6	X4	No Bare AGS X4 compare X5
81.055	-4.7	339 8.718	-130 8.768	104 -28.4	80 4.6	X5	No Bare AGS X4 compare X5
88.233	-4.89	330 8.584	-210 8.689	120 -36.1	100 7.0	X6	Au 2008 Extraction
68.570	-4.7	120 8.629	-90 8.689	80 -27.3	60 1.8	X7	D 2008 Extraction

Each Table_Xi is included in this section below, and the explanation of each physical quantity included in each Table_Xi is given below.

Row 1: Designates the computer code used in the calculations, (MAD) or (BEAM)
Row 2: The central momentum of the circulating beam in GeV/c at R=0 [mm]. This corresponds to specified AGS main magnets setting which is always the same during the extraction process.
Row 3: The amount of the momentum increase added to the momentum of the beam shown in Row 2. This momentum increase takes the circulating beam to the specified radius at beam extraction.
Row 4: The radius of the circulating beam. The reason that the radius of the circulating beam for dp/p=0 is R?0 [mm] in both the MAD and BEAM calculations, instead of R=0 [mm] is due to the increase of the beam path of the circulating beam when the extraction local beam bumps are energized.
Row5 to 8: The settings of the tune quadrupoles and chromaticity sextupoles in [A]
Row 9, 10: The strength of the backleg winding of the G10 and H10 local beam bumps. Each of the local bump (G10 or H10) is generated by a set of backleg windings placed at specific main magnets and connected in series. G10 or H10 is energized by a single power supply. For more details about the configuration of the G10 and H10 local beam bumps see Ref [1,3]
Rows 11,12: The values of the X_{cod}(G10) and X'_{cod}(G10) of the circulating beam midway of the G10_kicker.
Rows 13,14: The values of the horizontal and vertical beam parameters of the circulating beam midway of the G10_kicker.
Rows 15, 20: Same as the corresponding rows 9 through 14 but for middle of the H10_septum
Rows 21,24: The Horizontal and Vertical Tunes and chomaticities during the circulating beam, before extraction.
Row 25: The strength of the G10_kicker required to place the X_{cod} extracted beam at H10 at 77.5 [mm].
Rows 26,27: The values of the X_{cod}(H10) and X'_{cod}(H10) of the extracted beam at the middle of the H10_septum.
Rows 28,29: The values of the horizontal and vertical beam parameters of the extracted beam at the middle of the H10_septum.
Row 30: The value of the horizontal phase advance in units of 2π from the middle of the G10_kicker to the middle of the H10_septum.
Rows 31,33: Same as in rows 28 to 30 but for the vertical.

The rest of the Tables_Xi show:
a) the R_matrices of the FEB_section, which is defined from the middle of the G10_kicker to the middle of the H10_septum,
b) the R_matrices of the DEC_section, which is defined from the middle of the H10_septum to the beginning of the AtR line.

c) the beam coordinates of the extracted beam and the parameters at the beginning of the AtR line.

Comments on comparing the various Tables_Xi

1. The tables X1,X2,X3 can be used to obtain information on the R_matrices and on how the beam parameters at the beginning of the AtR line vary as a function of extraction radius. (Beam rigidity=81.055 [T.m] and Bare AGS)
2. The tables X4 and X5 provide the same information as item 1 above but for for Non Bare AGS. The tune quadrupoles and the chromaticity Sextupoles of the BEAM code were set to provide same tunes and chromaticities as in MAD code.
3. The tables X6 and X7 provide the same information on the extraction beam parameters for the Au2008 and D2008 run. The same set currents were used for the tune quadrupoles and chromaticity sextupoles of the MAD and BEAM codes. Therefore the tunes and chromaticities as derived from the MAD code are not equal to those as derived from the BEAM code. No measured tunes and chromaticities for the Au2008 and D2008 run at this time. The fact that MAD code and the BEAM code do not provide the same tunes and chromaticities under the same settings of the AGS is a major issue under investigation.

Further development of the "AtR BPM Application"

In this section we propose two methods to further automate the "AtR BPM Application"

1. The calculations of a number of R_matrices and of extraction beam parameters as a function of the extraction setup of the AGS can generate a data base of R_matrices and beam parameters which can be called once the extraction settings of the AGS are known. Subsequently an optimization will follow to properly match the beam from the U_line to the W_line and also to satisfy the beam constraints of the U_line. This optimization will set the values of the various quadrupoles of the U_line.
2. An alternative method of automating the extraction setup as well as the "AtR BPM Application" is to read into a code the AGS settings at extraction and automate the procedure we describe in this note of how to calculate the R_matrices and the beam parameters at the beginning of the AtR line. Subsequently an optimization will follow to properly match the beam from the U_line to the W_line. This optimization will set the values of the various quadrupoles of the U_line.

References

[1] N. Tsoupas, et. al. "Closed Orbit Calculations at AGS and Extraction Beam Parameters at H13" AD/RHIC/RD-75

[2] R. Thern, Provided the experimentally measured field maps for the AGS main magnets. A description of the field maps is provided in Ref. [1].

[3] N. Tsoupas, et. al. "Fast Extracted Beam (FEB) for the g-2 Experiment" CA/AP/54

[4] G. H. Morgan, "Fortran IV Version of 'BEAM' the AGS Orbit Computing Program" AGS Internal Repot.
C. J. Gardner, Private Communication.

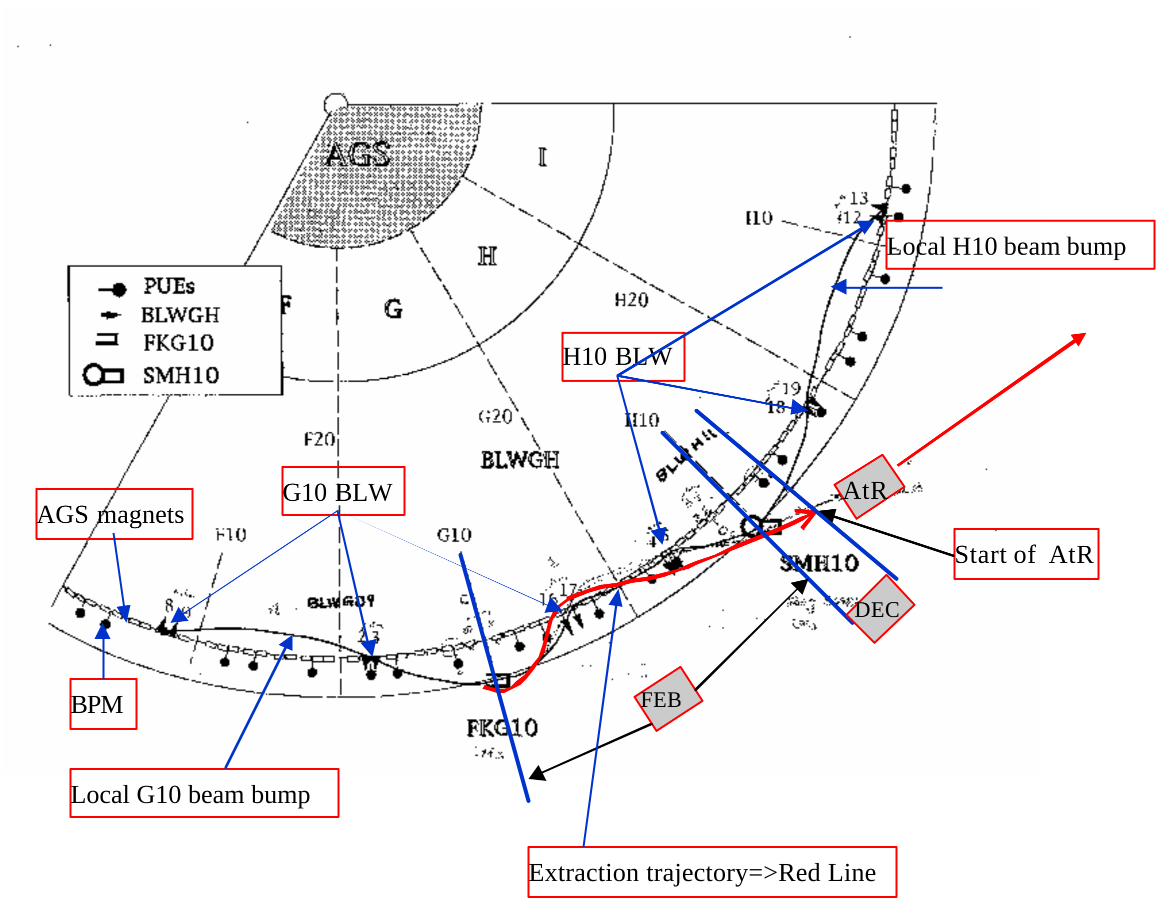


Figure 1: Schematic diagram of the section of the AGS ring which includes the Fast Extracted Beam region. The very small boxes located along an arc are the AGS main magnets. The black dots which are close to the AGS magnets are the Beam Position Monitors BPM's of the AGS ring. The G10_kicker is the "FKG10" and the H10_septum is the "SMH10". The Back Leg Windings for the G10 and H10 orbit bumps The black solid line designates the circulating beam just before extraction with the local bumps activated. The red line is the extracted beam trajectory which continues down the AtR line. The span of the "FEB" beam line

sections and of the "DEC" line section which are discussed in the text, are shown in the figure.

Table X1

# Set#	(MAD)	(MAD)	(BEAM)	(BEAM)
p[GeV/c]	24.3		24.3	
delp/p	0.000	0.001	0.000	0.001
R [mm]	-2.06	-3.87	2.33	4.2
IQH[A]	0.0		0.0	
IQV[A]	0.0		0.0	
ISH[A]	0.0		0.0	
ISV[A]	0.0		0.0	
Circulating Beam just before extraction				
B_G10[mrad]	-1.051		0.985	
B_H10[mrad]	-0.723		0.943	
XcodG10[mm]	-61.01	-62.466	61.2374	62.4897
X'codG10[mrad]	5.875	5.942	-5.79334	-5.85844
bx_G10[m]	15.924	15.891	16.142	16.222
ax_G10	1.322	1.315	1.3172	1.3184
by_G10[m]	15.334	15.328	15.007	14.980
ay_G10	-1.334	-1.332	-1.2746	-1.2681
XcodH10[mm]	-48.012	-49.294	47.8429	49.3193
X'codH10[mrad]	3.239	3.368	-2.96914	-3.12399
bx_H10[m]	17.028	17.140	17.007	17.025
ax_H10	1.386	1.391	1.3973	1.4012
by_H10[m]	14.271	14.275	14.365	14.395
ay_H10	-1.185	-1.185	-1.2124	-1.2189
Qx	8.6559	8.6319	8.69767,	8.67249
Qy	8.7411	8.7459	8.75388	8.75899
Xx	-23.92	-24.05	-24.313	-25.187
Xy	4.56	4.64	4.714	5.109
Extraction				
K_G10[mrad]	1.839		-1.840	
XcodH10[mm]	-77.50	-79.970	77.4879	79.8659
X'codH10[mrad]	5.168	5.436	-4.90060	-5.39909
bx_H10[m]	17.774	17.905	17.9636	18.2344
ax_H10	1.449	1.456	1.4135	1.4009
phx	0.709	0.707		
by_H10[m]	13.728	13.736	13.4929	13.3891
ay_H10	-1.163	-1.163	-1.1367	-1.1201
phy	0.723	0.724		

R_Matrix from G10 to H10

R11 R12	-1.61976	-16.26844	1.6157	-16.445
R21 R22	0.16951	1.08511	0.16377	1.0480
R16 R26	-2.470	0.268	-2.401	0.253
R33 R34	1.08434	-14.30052	1.0608	-14.084
R43 R44	0.17532	-1.38994	0.17171	-1.3371

R_Matrix from H10 to H13 Using beam

R11	R12	2.2899	14.527
R21	R22	0.26409	2.1120
R16	R26	0.1521	0.0149
R33	R34	0.050164	6.2662
R43	R44	-0.15799	0.19918

Beam Parameters at H13 Using Beam

XcodH13[mm]	450.6762
X'codH10[mrad]	69.374
bx_H13[m]	35.3760
ax_H13	-3.7250
ex[m]	-1.398
e'x	-0.1077
by_H13[m]	7.4187
ay_H13	1.0089

Table X2

# Set#	(MAD)	(MAD)	(BEAM)	(BEAM)
p[GeV/c]	24.3		24.3	
delp/p	0.0015	0.0025	0.0015	0.0025
R [mm]	-4.684	-6.512	4.9285	6.7447
IQH[A]	0.0		0.0	
IQV[A]	0.0		0.0	
ISH[A]	0.0		0.0	
ISV[A]	0.0		0.0	
Circulating Beam just before extraction				
B_G10[mrad]	-1.012		0.948	
B_H10[mrad]	-0.692		0.899	
XcodG10[mm]	-61.05	-62.635	60.9970	62.4116
X'codG10[mrad]	5.776	5.862	-5.69743	-5.78184
bx_G10[m]	15.854	15.781	16.174	16.184
ax_G10	1.311	1.300	1.3164	1.3180
by_G10[m]	15.320	15.313	15.000	15.030
ay_G10	-1.328	-1.326	-1.2693	-1.2723
XcodH10[mm]	-47.994	-49.396	47.9640	49.5280
X'codH10[mrad]	3.300	3.431	-3.06490	-3.21698
bx_H10[m]	17.126	17.288	16.984	17.077
ax_H10	1.390	1.398	1.3956	1.4006
by_H10[m]	14.320	14.321	14.428	14.360
ay_H10	-1.190	-1.190	-1.2211	-1.2145
Qx	8.621031	8.596836	8.66255	8.64211
Qy	8.747782	8.752583	8.75982	8.76038
Xx	-24.10	-24.23	-22.429	-20.437
Xy	4.68	4.76	2.416	0.554
Extraction				
K_G10[mrad]	1.850		-1.842	
XcodH10[mm]	-77.514	-80.021	77.5012	79.9651
X'codH10[mrad]	5.199	5.471	-4.95838	-5.21589
bx_H10[m]	17.968	18.083	18.0033	18.1667
ax_H10	1.458	1.467	1.4145	1.3999
phx	0.704	0.704		
by_H10[m]	13.802	13.787	13.5429	13.4651
ay_H10	-1.168	-1.167	-1.1418	-1.1241
phy	0.725	0.725		

R_Matrix from G10 to H10

R11	R12	-1.63012	-16.20584	-1.6256	-16.405
R21	R22	0.16847	1.06138	0.16283	1.0280
R16	R26	-2.523	0.273	-2.464	0.2575
R33	R34	1.08434	-14.30052	1.0677	-14.124
R43	R44	0.17532	-1.38994	0.1715	-1.332

R_Matrix from H10 to H13 Using beam

R11 R12	2.2880	14.520
R21 R22	0.26367	2.110
R16 R26	0.1528	0.0150
R33 R34	0.051236	6.2703
R43 R44	-0.15785	0.20001

Beam Parameters at H13 Using Beam

XcodH13[mm]	450.6532
X'codH10[mrad]	69.37962
bx_H13[m]	35.4013
ax_H13	-3.7231
ex[m]	-1.646
e'x	-0.1362
by_H13[m]	7.4582
ay_H13	1.0146

Table X3

# Set#	1(MAD)	1(MAD)	1(BEAM)	1(BEAM)
p[GeV/c]	24.3		24.3	
delp/p	0.0030	0.0040	0.0030	0.0040
R [mm]	-7.3361	-9.1826	7.5382	9.3676
IQH[A]	0.0		0.0	
IQV[A]	0.0		0.0	
ISH[A]	0.0		0.0	
ISV[A]	0.0		0.0	
Circulating Beam just before extraction				
B_G10[mrad]	-0.970		0.912	
B_H10[mrad]	-0.660		0.846	
XcodG10[mm]	-61.108	-62.804	61.0863	62.6244
X'codG10[mrad]	5.689	5.791	-5.63935	-5.73939
bx_G10[m]	15.723	15.537	16.187	16.202
ax_G10	1.294	1.271	1.3183	1.3166
by_G10[m]	15.304	15.296	15.038	15.032
ay_G10	-1.322	-1.320	-1.2727	-1.2707
XcodH10[mm]	-48.102	-49.610	47.7821	49.4283
X'codH10[mrad]	3.359	3.493	-3.12865	-3.27965
bx_H10[m]	17.298	17.596	17.030	17.109
ax_H10	1.399	1.416	1.3970	1.3998
by_H10[m]	14.366	14.364	14.389	14.378
ay_H10	-1.195	-1.194	-1.2164	-1.2154
Qx	8.585995	8.561649	8.63386	8.61009
Qy	8.754538	8.759449	8.75977	8.76388
Xx	-24.29	-24.43	-21.986	-23.776
Xy	4.79	4.89	2.229	4.104
Extraction				
K_G10[mrad]	1.853		-1.842	
XcodH10[mm]	-77.501	-80.075	77.5012	79.9651
X'codH10[mrad]	5.219	5.497	-4.95838	-5.21589
bx_H10[m]	18.099	18.167	18.0033	18.1667
ax_H10	1.468	1.469	1.4145	1.3999
phx	0.704	0.702		
by_H10[m]	13.833	13.853	13.5429	13.4651
ay_H10	-1.172	-1.167	-1.1418	-1.1241
phy	0.725	0.726		

R_Matrix from G10 to H10

R11 R12	-1.63655	-16.16952	-1.6329	-16.354
R21 R22	0.16770	1.04585	0.16175	1.0075
R16 R26	-2.574	0.278	-2.517	0.2613
R33 R34	1.09266	-14.37079	1.0730	-14.165
R43 R44	0.17467	-1.38211	0.17114	-1.3272

R_Matrix from H10 to H13 Using beam

R11 R12	2.2870	14.518
R21 R22	0.26359	2.111

R16	R26	0.1528	0.0149
R33	R34	0.051925	6.2716
R43	R44	-0.15779	0.1999

Beam Parameters at H13 Using Beam

XcodH13[mm]	450.2426
X'codH10[mrad]	69.32804
bx_H13[m]	35.5953
ax_H13	-3.7471
ex[m]	-1.860
e'x	-0.161
by_H13[m]	7.4314
ay_H13	1.0145

Table X4

# Set#	1(MAD)	1(MAD)	1(BEAM)	1(BEAM)
p[GeV/c]	24.3		24.3	
delp/p	0.000	0.001	0.000	0.001
R [mm]	-2.1	-3.9	2.4	4.2
IQH[A]	339.0		300.0	
IQV[A]	-130.0		-200.0	
ISH[A]	104.0		100.0	
ISV[A]	80.0		80.0	
B_G10[mrad]	-0.998		0.940	
B_H10[mrad]	-0.677		0.928	
XcodG10[mm]	-61.03	-61.538	61.1593	61.4625
X'codG10[mrad]	6.189	6.150	-5.96154	-5.93491
bx_G10[m]	15.563	15.454	15.833	15.758
ax_G10	1.361	1.338	1.3469	1.3248
by_G10[m]	18.215	18.170	17.558	17.628
ay_G10	-1.674	-1.669	-1.5604	-1.5633
XcodH10[mm]	-48.00	-48.908	47.8522	49.2846
X'codH10[mrad]	3.260	3.405	-3.01732	-3.21570
bx_H10[m]	20.716	21.090	20.679	20.980
ax_H10	1.775	1.803	1.7779	1.8045
by_H10[m]	12.401	12.461	12.484	12.506
ay_H10	-1.078	-1.084	-1.1186	-1.1245
Qx	8.757	8.72815	8.77925	8.75164
Qy	8.751	8.755847	8.77420	8.77852
Xx	-28.36	-28.618700	-27.028	-27.612
Xy	4.61	4.650659	4.138	4.318
Extraction				
K_G10[mrad]	1.484		-1.720	
XcodH10[mm]	-77.50	-78.370	77.4617	79.8659
X'codH10[mrad]	5.45	5.563	-5.15319	-5.39909
bx_H10[m]	19.772	20.160	20.1222	20.6362
ax_H10	1.743	1.776	1.6931	1.7120
phx	0.714	0.710		
by_H10[m]	13.181	13.237	12.7951	12.7135
ay_H10	-1.150	-1.154	-1.1241	-1.1096
phy	0.716	0.717		

R_Matrix from G10 to H10

R11	R12	-1.75339	-17.03986	1.7551	-17.263
R21	R22	0.19285	1.30382	0.18268	1.227
R16	R26	-2.427	0.257	-2.404	0.245
R33	R34	1.21130	-15.14267	1.1812	-14.802
R43	R44	0.19166	-1.57037	0.18604	-1.4847

R_Matrix from H10 to H13

R11	R12	2.2903	14.528
R21	R22	0.26419	2.1125

R16	R26	0.156	0.0154
R33	R34	0.050012	6.2652
R43	R44	-0.15802	0.19890

Beam Parameters at H13

bx_H13[m]	33.4364
ax_H13	-3.3830
ex[m]	-0.722
e'x	-0.013
by_H13[m]	7.6818
ay_H13	0.9825

Table X5

# Set#	1(MAD)	1(MAD)	1(BEAM)	1(BEAM)
p[GeV/c]	24.3		24.3	
delp/p	0.0015	0.0025	0.0015	0.0025
R [mm]	-4.7	-6.5	4.9763	6.7464
IQH[A]	339.0		300.0	
IQV[A]	-130.0		-200.0	
ISH[A]	104.0		100.0	
ISV[A]	80.0		80.0	
B_G10[mrad]	-0.980		0.923	
B_H10[mrad]	-0.656		0.884	
XcodG10[mm]	-61.00	-61.918	60.9820	61.7596
X'codG10[mrad]	6.056	6.070	-5.87059	-5.89526
bx_G10[m]	15.417	15.270	15.759	15.587
ax_G10	1.331	1.300	1.3231	1.3014
by_G10[m]	18.077	18.044	17.550	17.659
ay_G10	-1.660	-1.657	-1.5581	-1.5751
XcodH10[mm]	-48.090	-49.223	47.9930	49.5041
X'codH10[mrad]	3.377	3.518	-3.16471	-3.34386
bx_H10[m]	21.659	21.090	20.952	21.400
ax_H10	1.845	1.803	1.8016	1.8305
by_H10[m]	12.547	12.587	12.592	12.531
ay_H10	-1.09	-1.097	-1.1320	-1.1186
Qx	8.717978	8.714968	8.73942	8.71177
Qy	8.768184	8.758003	8.77960	8.78302
Xx	-28.411278	-28.723916	-27.749	-27.646
Xy	4.581765	4.670417	3.442	3.411
Extraction				
K_G10[mrad]	1.720		-1.720	
XcodH10[mm]	-77.58	-80.061	77.4820	79.8659
X'codH10[mrad]	5.75	5.791	-5.25624	-5.39909
bx_H10[m]	20.226	20.273	20.1222	20.6362
ax_H10	1.782	1.780	1.6931	1.7120
phx	0.709	0.708		
by_H10[m]	13.327	13.429	12.7951	12.7135
ay_H10	-1.164	-1.172	-1.1241	-1.1096
phy	0.717	0.717		

R_Matrix from G10 to H10

R11	R12	-1.76603	-17.07584	-1.7676	-17.238
R21	R22	0.19115	1.28203	0.18132	1.2025
R16	R26	-2.486	0.263	-2.468	0.251
R33	R34	1.21803	-15.18889	1.1889	-14.861
R43	R44	0.19145	-1.56638	0.18578	-1.481

R_Matrix from H10 to H13

R11	R12	2.2888	14.524
R21	R22	0.26396	2.1119

R16	R26	0.1566	0.0156
R33	R34	0.050865	6.2678
R43	R44	-0.15793	0.19918

Beam Parameters at H13

bx_H13[m]	33.6497
ax_H13	-3.3877
ex[m]	-1.212
e'x	-0.0915
by_H13[m]	7.6960
ay_H13	0.9899

Table X6

# Set#	1(MAD)	1(MAD)	1(BEAM)	1(BEAM)
p[GeV/c]	26.452		26.452	
delp/p	0.0015	0.0025	0.0015	0.0025
R [mm]	-4.89	-6.73	4.9520	6.74
IQH[A]	330.0		330.0	
IQV[A]	-210.0		-210.0	
ISH[A]	120.0		120.0	
ISV[A]	100.0		-100.0	
B_G10[mrad]	-1.055		0.950	
B_H10[mrad]	-0.659		0.900	
XcodG10[mm]	-61.017	-62.829	60.9928	61.9493
X'codG10[mrad]	6.041	6.147	-5.84059	-5.88798
bx_G10[m]	13.445	12.986	15.729	15.559
ax_G10	0.801	0.487	1.2861	1.2542
by_G10[m]	17.971	17.932	18.211	18.222
ay_G10	-1.506	-1.504	-1.6390	-1.6458
XcodH10[mm]	-47.925	-49.012	47.7788	49.4357
X'codH10[mrad]	3.626	3.744	-3.22135	-3.40253
bx_H10[m]	28.681	38.649	22.271	22.938
ax_H10	2.264	3.054	1.9121	1.9602
by_H10[m]	12.004	12.029	12.246	12.272
ay_H10	-0.976	-0.980	-1.1250	-1.1232
Qx	8.583494	8.545375	8.69804	8.66670
Qy	8.688998	8.696075	8.80833	8.81539
Xx	-36.069879	-41.783562	-30.652	-31.336
Xy	6.958385	7.047489	6.258	7.068
Extraction				
K_G10[mrad]	1.780		-1.720	
XcodH10[mm]	-77.569	-80.061	77.5316	80.1205
X'codH10[mrad]	5.428	5.791	-5.25509	-5.50674
bx_H10[m]	27.059	20.273	21.8586	22.8062
ax_H10	2.294	1.780	1.8184	1.8489
phx	0.669	0.708		
by_H10[m]	12.433	13.429	12.5977	12.5144
ay_H10	-1.002	-1.172	-1.1141	-1.0921
phy	0.712	0.717		

R_Matrix from G10 to H10

R11	R12	-1.68356	-16.65640	-1.8261	-17.443
R21	R22	0.16805	1.06863	0.17912	1.1634
R16	R26	-2.385	0.267	-2.5889	0.2517
R33	R34	1.02039	-14.523651	1.12425	-15.016
R43	R44	0.17107	-1.45482	0.18951	-1.4855

R_Matrix from H10 to H13

R11	R12	2.2886	14.523
R21	R22	0.26387	2.1114
R16	R26	0.1566	0.0156

R33	R34	0.050902	6.2687
R43	R44	-0.15730	0.19950

Beam Parameters at H13

XcodH13[mm]	450.4427
X'codH10[mrad]	69.34723
bx_H13[m]	35.1662
ax_H13	-3.4864
ex[m]	-1.60
e'x	-0.121
by_H13[m]	7.7344
ay_H13	0.9702

Table X7

# Set#	1(MAD)	1(MAD)	1(BEAM)	1(BEAM)
p[GeV/c]	20.557		20.557	
delp/p	0.0015	0.0025	0.0015	0.0025
R [mm]	-4.7	-6.5	4.8357	6.63
IQH[A]	120.0		120.0	
IQV[A]	-90.0		-90.0	
ISH[A]	80.0		80.0	
ISV[A]	60.0		-60.0	
B_G10[mrad]	-1.038		0.950	
B_H10[mrad]	-0.645		0.855	
XcodG10[mm]	-60.99	-62.646	61.1503	62.3536
X'codG10[mrad]	6.094	6.184	-5.96899	-6.03627
bx_G10[m]	13.829	13.562	14.708	14.669
ax_G10	1.002	0.929	1.1941	1.1770
by_G10[m]	17.557	17.540	17.634	17.576
ay_G10	-1.486	-1.483	-1.5475	-1.5399
XcodH10[mm]	-48.085	-49.201	47.9456	49.4391
X'codH10[mrad]	3.592	3.715	-3.25548	-3.41960
bx_H10[m]	22.928	24.384	20.914	21.259
ax_H10	1.835	1.952	1.7441	1.7735
by_H10[m]	12.681	12.695	12.811	12.851
ay_H10	-1.039	-1.040	-1.1263	-1.1333
Qx	8.628875	8.601389	8.69699	8.67352
Qy	8.73241	8.734280	8.80935	8.80924
Xx	-27.253863	27.734676	-24.968	-23.468
Xy	1.750805	1.802543	0.481	-0.113
Extraction				
K_G10[mrad]	1.810		-1.790	
XcodH10[mm]	-77.48	-80.061	77.4672	80.1205
X'codH10[mrad]	5.480	5.791	-5.28817	-5.50674
bx_H10[m]	21.630	21.656	20.1972	20.6997
ax_H10	1.817	1.810	1.6856	1.7022
phx	0.693	0.692		
by_H10[m]	13.199	13.294	13.1560	13.1172
ay_H10	-1.080	-1.088	-1.1332	-1.1257
phy	0.716	0.716		

R_Matrix from G10 to H10

R11	R12	-1.61202	-16.19775	-1.6743	-16.527
R21	R22	0.16926	1.08039	0.17571	1.1372
R16	R26	-2.322	0.272	-2.416	0.2644
R33	R34	1.07533	-14.87680	1.1874	-15.049
R43	R44	0.17288	-1.46180	0.18283	-1.4749

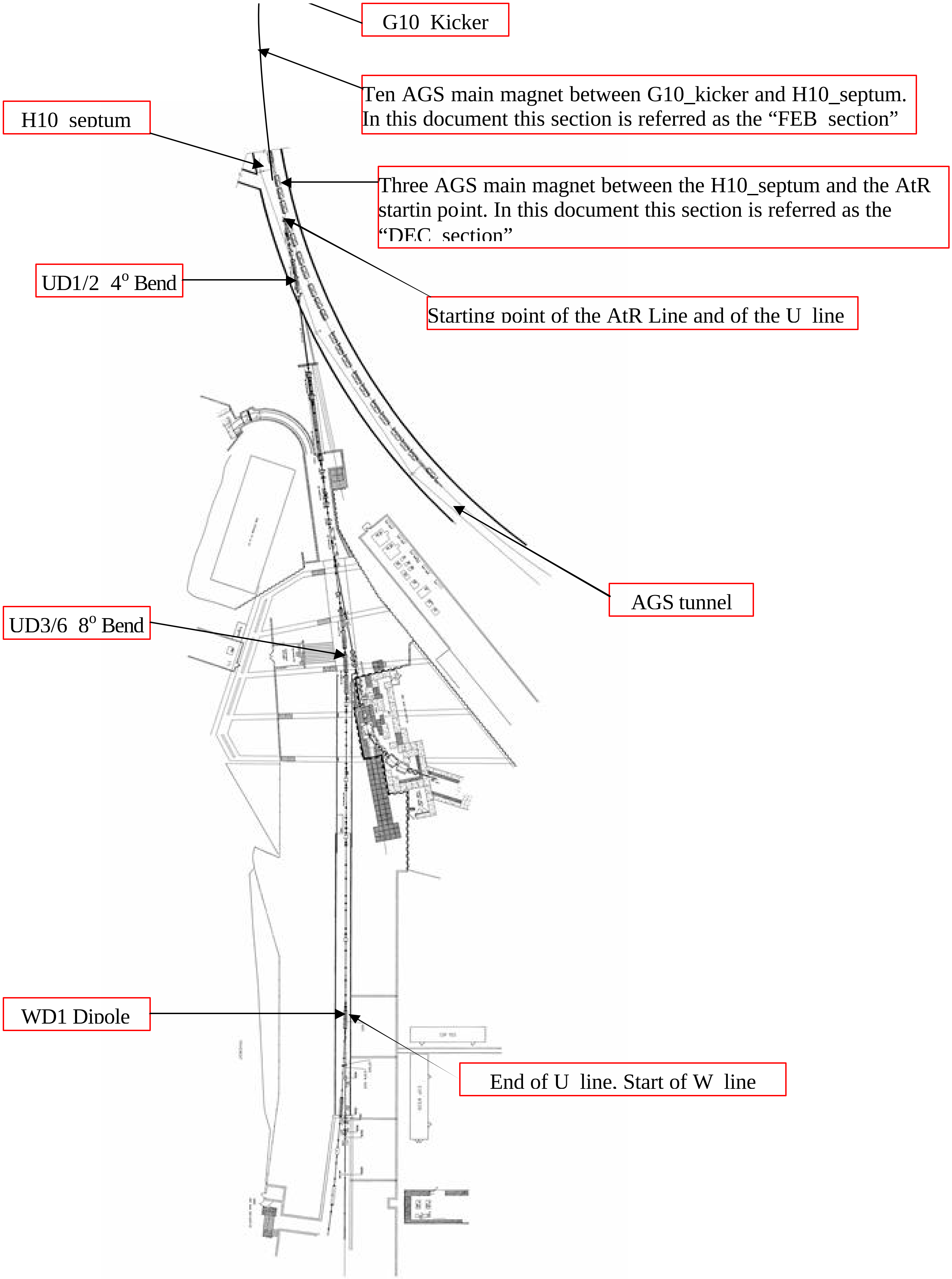
R_Matrix from H10 to H13

R11	R12	2.2893	14.527
R21	R22	0.26417	2.1131

R16 R26	0.1568 0.0155
R33 R34	0.050816 6.2658
R43 R44	-0.15799 0.19844

Beam Parameters at H13

XcodH13[mm]	450.1035
X'codH10[mrad]	69.30331
bx_H13[m]	33.8736
ax_H13	-3.4299
ex[m]	-1.35
e'x	-0.096
by_H13[m]	7.5726
ay_H13	1.0001


G10 Kicker
Ten AGS main magnet between G10_kicker and H10_septum.
In this document this section is referred as the “FEB section”
H10 septum
Three AGS main magnet between the H10_septum and the AtR startin point. In this document this section is referred as the “DEC section”
UD1/2 4° Bend
Starting point of the AtR Line and of the U line
AGS tunnel
UD3/6 8° Bend
WD1 Dipole
End of U line. Start of W line