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# ARIEL Front-End Design Note

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# Contents

# 1 Abstract

The present document describes the low energy radioactive ion beam (RIB) transport system (front-end) concept of the ARIEL facility. This concept includes the ARIEL-II phases of the project as well as future upgrades. The layout is presented as well as the operational functionality.

# 2 Introduction

ISAC is TRIUMF isotope separation on-line (ISOL) facility for RIB production and post-acceleration. The beam is produced in one of the two underground target stations at a time using up to 50 kW proton (100 μA at 500 MeV) from the cyclotron as driver beam.

The produced RIB is selected and transported at ground level where it can be directed to three different experimental areas: low energy (up to 60 keV, source potential up to 60 kV), medium energy (up to 1.8 MeV/u) or high energy (up to 18 MeV/u).

At present ISAC is a single user facility where only a single RIB beam can be delivered to one of the three experimental areas that collectively count a total of fifteen experimental stations (see Figure 1). The purpose of the AREL facility is to make ISAC a multi-user facility with three simultaneously delivered beams. The ARIEL front-end will be capable of delivering two simultaneous RIB beams, in addition to the RIB beam from ISAC.

The ARIEL separator and front-end facility, also referred as RIB transport system, connects the ARIEL targets to the existing ISAC-I LEBT (Low Energy Transport Line), the ISAC-I post accelerator chain (starting with the existing ISAC RFQ), as well as to the ISAC-II superconducting linac through a new accelerator path[1].

This facility includes the following elements: beam lines (with electrostatic and magnetic optical elements), pre-separator, medium[2] and high resolution separators, RFQ cooler, charge state breeder, laser ion source, RFQ, DTL and yield stations.

## 2.1 Purpose

This document presents the front-end design features that implement and satisfy the RIB transport system requirements written in document-123559 and related.

The document also includes functionality aspects required to achieve the operational requirements.

[1] The second accelerator path is out of the scope of the ARIEL-II project, but it is conceived as a future upgrade and therefore it is considered in the overall layout.

[2] The medium resolution separator (MRS) in out of the scope of the ARIEL-II project, but similarly to the second accelerator path it is conceived as a future upgrade and therefore it is considered in the overall layout.

## 2.2 Scope

The scope of this document covers the entire RIB transport system including the CANREB project components and future upgrades.

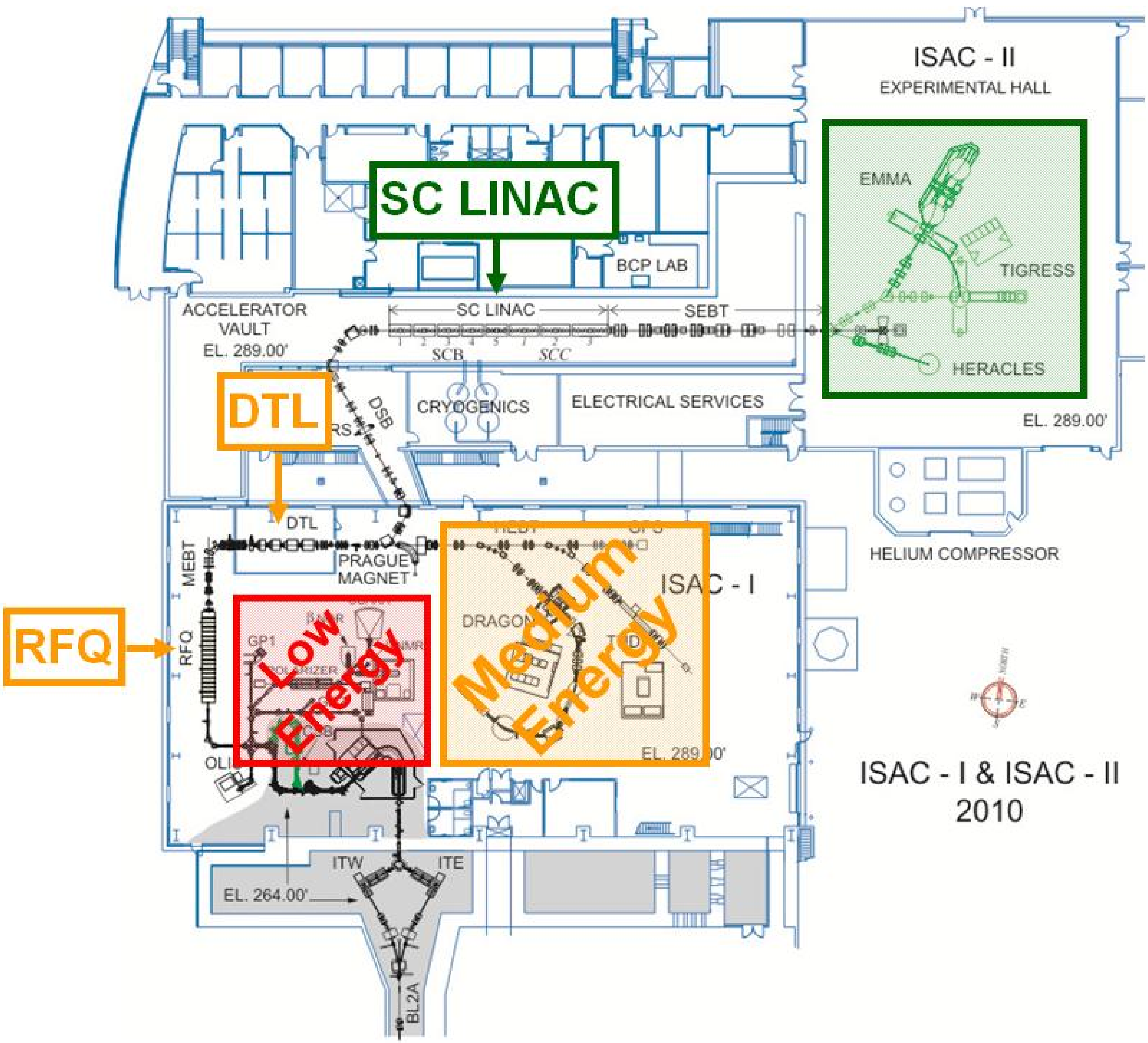


**Figure 1. Existing ISAC-I and ISAC-II facilities.**

## 2.3 Definitions and Abbreviations

The following Table 1 includes acronym used in the rest of the document[3].

| Acronym | Field | Meaning |
|---|---|---|
| G | Building | Ground level |
| B1 | Building | Power supply room level (first basement) |
| B2 | Building | Mass separator room level |
| HRS | Beam line | High Resolution Spectrometer |
| ISOL | Method | Isotope Separation On Line |
| ILE1 | Beam line | Low Energy line to 8PI (GRIFFIN), RADON-EDM |
| ILE2 | Beam line | Low Energy line to TITAN, BNMR, OSAKA, (GPS) |
| LEBT | Beam line | Low Energy Beam Transport |
| MRS | Beam line | Medium Resolution Spectrometer (not part of ARIEL-II phase) |
| RFQ1 | Accelerator | ISAC RFQ |
| RFQ2 | Accelerator | ARIEL RFQ (not part of the ARIEL-II phase) |
| RIB | Beam | Radioactive Ion Beam |
| RIB0 | Beam Line | ISAC vertical section |
| AVTE | Beam Line | ARIEL east vertical section |
| AVTW | Beam Line | ARIEL west vertical section |
| APTW | Source | ARIEL west target station for proton |
| AETE | Source | ARIEL east target station for electrons |

**Table 1. Acronyms used in this document.**

[3] These acronyms are not part of the ARIEL naming convention.

# 3 RIB transport system beam line concept

The front-end building is referred as RIB annex. It includes the mass separator room (B2), power supply room (B1) and ground level (G).

In this chapter the low energy beam line that connects the ARIEL target to the existing ISAC-I LEBT and RFQ1 as well as to the future ARIEL RFQ2 is presented from a concept layout and functionality point of view. This beam line is electrostatic.

The optics layout is based on standard proven optical modules that are operational in the ISAC-I LEBT beam lines for two decades. The basic modules are:

1. 1 meter long periodic section: composed of 2 electrostatic quadrupoles (see Figure 2, left module)
2. 90° degree bending section: composed of two electrostatic 45° spherical bender and six quadrupoles (see Figure 2, central module)
3. Cross: composed of two 90° degree bending sections connected by a cross of 12 quadrupoles (see Figure 2, right module)
4. Reverse polarity (not represented)

Other sections are necessary to transport or match the ARIEL beam into the ISAC beam lines.

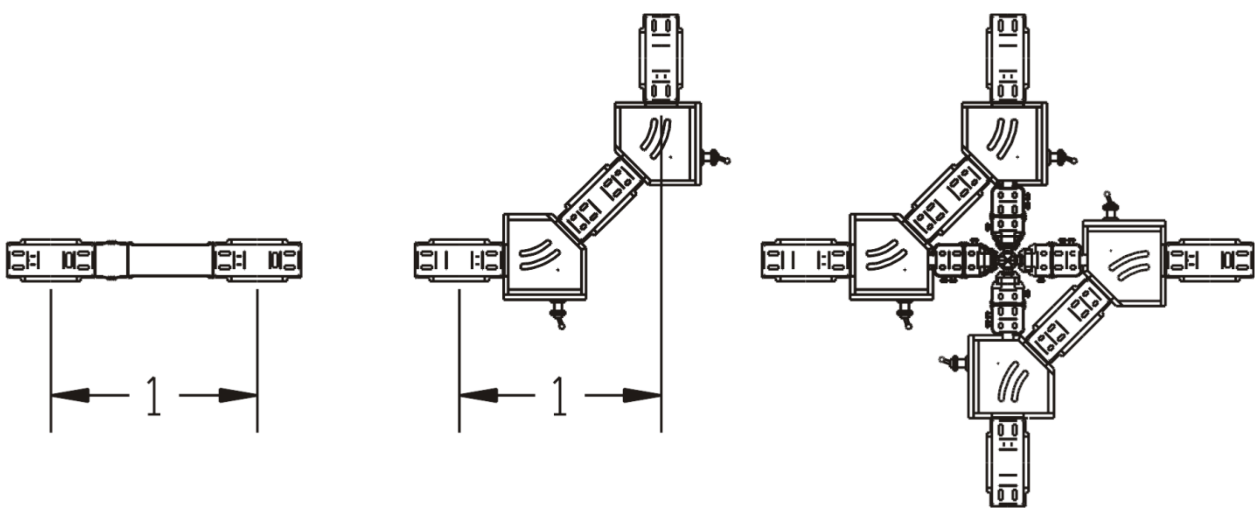


**Figure 2. ISAC electrostatic optics elements (from left to right): 1 m long straight section, 90° bender, cross.**

The front-end concept layout is presented by area starting from the target hall and ending at the ground level, going from the lower to the higher elevation.

All the beam lines layouts presented are located inside the new ARIEL building envelope according to architectural drawings.

All the coordinates are given in the absolute reference system (X,Y,Z) with the origin in the center of the cyclotron. The X, Y and Z coordinates are oriented respectively West-East, South-North and bottom-up.

## 3.1 Target Hall

Even though the target hall does not belong to the front-end building it contains beam lines that connect the target stations (APTW and AETE) to the mass separator room.

Figure 3 represents the optics layout in the target hall. Each target station has a dedicated pre-separator and electrostatic beam line in order to allow independent operations. The two pre-separators and relative beam lines are identical.

The pre-separator magnet has a bending angle is 112° and an assumed radius of curvature equals to 0.5 m. It is supposed to provide a resolving power of M/ΔM=300. Final design details of the pre-separator beam line will be presented in the relative design note (document number not yet available).

The beam line elevation in the target hall is presently Z=10.5 mm. The final elevation is determined by the geometry of the proton target located in the APTW.

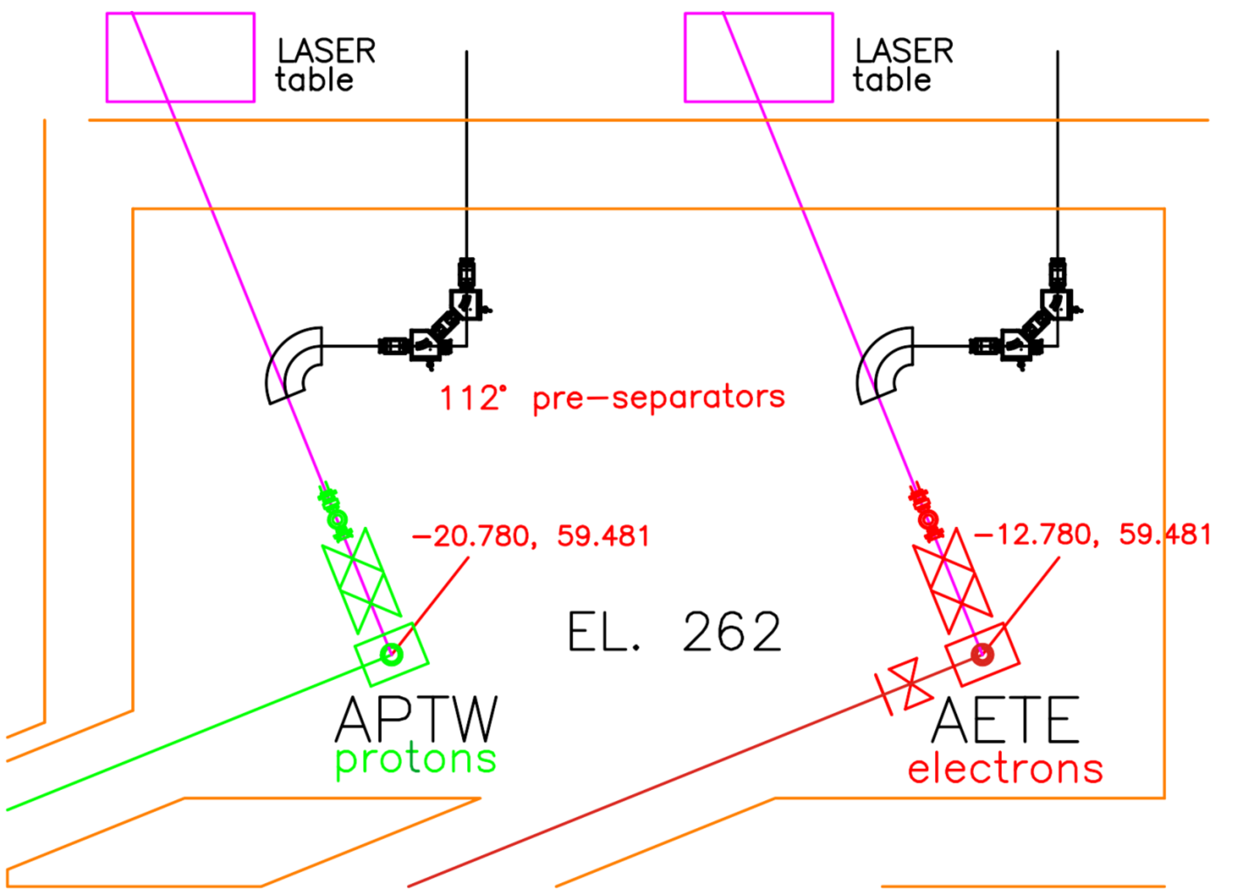


**Figure 3. Front-end conceptual beam line layout in the target hall.**

## 3.2 Mass separator room

The mass separator room optics layout is represented in Figure 2. This switchyard has the flexibility to allow the beam to be transported from either target station (APTW or AETE) to either vertical section (AVTE or AVTW) with different option (mode) as far as mass selection.

The beam from one of the targets can be further mass selected after the pre-separator by means of a medium resolution (MRS) or a high resolution (HRS) spectrometer with foreseen resolving power of respectively M/ΔM=5000 and M/ΔM=20000[4].

The beam can also be sent directly to one of vertical beam line after being mass selected only with the pre-separator by-passing the spectrometers (by-pass mode).

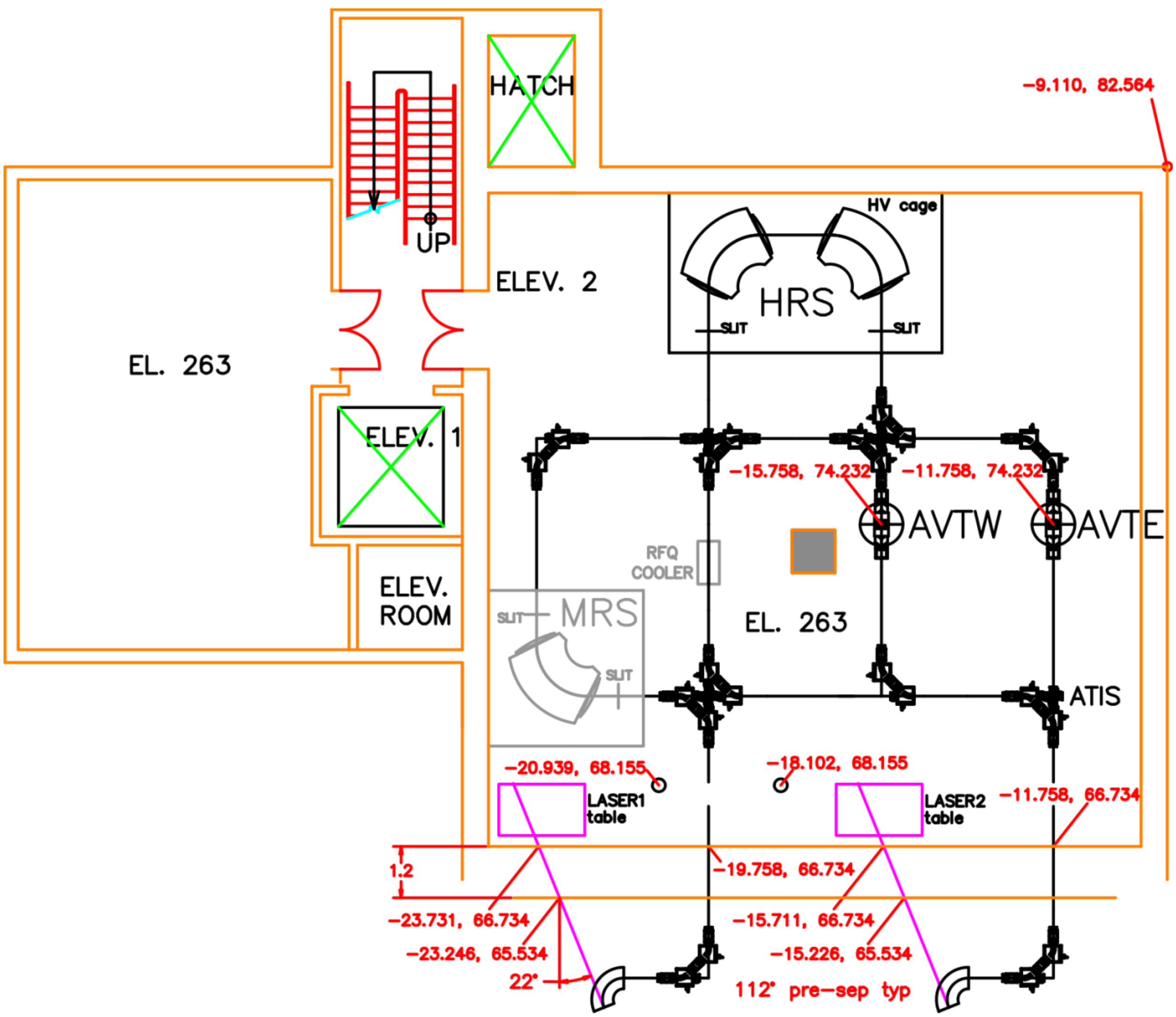


**Figure 4. Front-end conceptual beam lines layout in the mass separator room. The MRS is depicted in light grey since it is not part of the ARIEL-II project.**

[4] ARIEL High Resolution Separator: design note TRI-DN-14-06 document-109442

The following Table 2 includes all possible paths for two simultaneously transported beams from the target stations to the vertical sections.

| APTW | | | AETE | | |
|---|---|---|---|---|---|
| By-pass | MRS | HRS | By-pass | MRS | HRS |
| AVTW | | | | | |
| AVTE | | | AVTW | | |
| | AVTW | | AVTE | | |
| | AVTW | | | | AVTE |
| | AVTE | | AVTW | | |
| | AVTE | | | | AVTW |
| | | AVTW | AVTE | | |
| | | AVTW | | AVTE | |
| | | AVTE | AVTW | | |
| | | AVTE | | AVTW | |

**Table 2. Possible paths from the target stations to the ARIEL vertical transport lines.**

The beam line elevation in the mass separator room is Z=10.5 mm (same as in the target hall). The average elevation of the mass separator room floor is XXX, this translates into a 1.7 m beam line average height which allows walk-through under the beam lines in order to move to the different locations inside the mass separator room.

Both separators are foreseen to be electrically isolated on a high voltage platform. The high voltage cage enclosures are sketch in Figure 4.

An RFQ cooler is foreseen upstream of the HRS in order to reduce the beam transverse emittance and hence to increase the resolution.

Two laser tables are located at B1 level (room B1-08) to combine the laser beams from the LASER lab (at ground level) and then direct them first to the B2 level (mass separator room) and finally to the targets through the south wall.

A compact test ion source (ATIS) is installed at the south-east entrance of the switchyard to tune the beam lines with stable ion beam.

The beam lines and laser beam pipes penetration specifications from the target hall to the mass separator room are listed respectively in Table 3 and Table 4 . The Z coordinate is 10.5 mm. The coordinates are given at South and North faces of the wall between the target hall and the mass separator room. The bore diameter is also specified (in inches to match the beam pipe dimension).

| | ALTW beam line | | | ALTE beam line | | |
|---|---|---|---|---|---|---|
| | X(m) | Y (m) | ∅ (inches) | X (m) | Y (m) | ∅ (inches) |
| **South** | -19.778 | 65.534 | 8 | -11.758 | 65.534 | 8 |
| **North** | -19.778 | 66.734 | 8 | -11.758 | 66.734 | 8 |

**Table 3. Coordinates of the beam lines penetrations at the south wall of the mass separator room.**

| | LASER1 | | | LASER2 | | |
|---|---|---|---|---|---|---|
| | X (m) | Y (m) | ∅ (inches) | X (m) | Y(m) | ∅ (inches) |
| **South** | -23.246 | 65.534 | 8 | -15.266 | 65.534 | 8 |
| **North** | -23.731 | 66.734 | 8 | -15.711 | 66.734 | 8 |

**Table 4. Coordinates of the laser beam pipes penetrations at the south wall of the mass separator room.**

## 3.3 Power supply room

The two vertical beam lines and laser beam pipes (see Figure 5) cross the power supply room and penetrate both floor and ceiling.The beam line and laser penetration specifications from the mass separator room to the ground floor are listed respectively in Table 5 and Table 6.

| AVTE | | | AVTW | | |
|---|---|---|---|---|---|
| X (m) | Y (m) | ∅ (m) | X (m) | Y (m) | ∅ (m) |
| -15.758 | 74.232 | 1 | -11.758 | 74.232 | 1 |

**Table 5. Coordinate of the vertical beam lines inside the power supply room.**

| LASER1 | | | LASER2 | | |
|---|---|---|---|---|---|
| X (m) | Y (m) | ∅ (inches) | X (m) | Y (m) | ∅ (inches) |
| -20.939 | 68.155 | 12 | -18.102 | 68.155 | 12 |

**Table 6. Coordinate of the laser beam pipes inside the power supply room.**

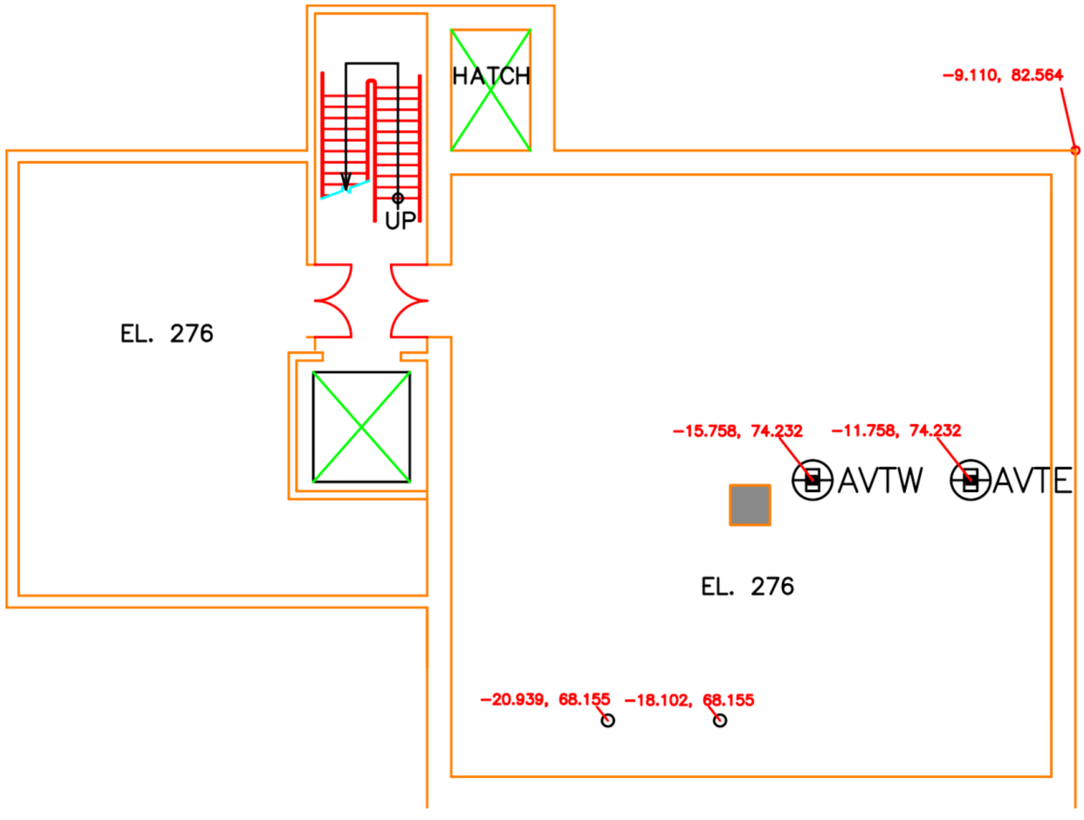


**Figure 5. Front-end optics in the power supply room.**

## 3.4 Ground floor

The front-end beam lines at ground level connect ARIEL to the existing ISAC facility as represented in Figure 6. The penetrations for the beam lines are present in the east wall of the ground level hall. Their locations are listed in Table 7 from south to north. The elevation of these penetrations is the beam line height. The bore diameter is also specified.

The beam coming from a vertical section (AVTE or AVTW) can be sent to the ISAC low energy experimental stations, or post accelerated. The post acceleration is achieved by means of the existing ISAC-I RFQ (RFQ1) or by means of a new future ARIEL RFQ (RFQ2). The latter is not part of the ARIEL-II project but it is considered for a future upgrade. This upgrade will not require any major change of the beam lines installed during the ARIEL-II project (see paragraph 5.4).

Since RFQ2 is foreseen to be optimized for $A/q \leq 9$ (rather than $A/q \leq 30$ for RFQ1), the beam must be charge bred before being injected in the accelerator. A new EBIS charge breeder for the ARIEL facility receiving beam from AVTE is located at ground floor in the north-east corner right upstream of the RFQ2 (see Figure 6).
The RFQ2 can also be fed from the ISAC facility (RIB0) using the existing charge state booster (CSB). The ground level switchyard (see Figure 6) integrated with the existing ISAC low energy

beam transport lines offer different options in term of three simultaneously delivered radioactive beams.

| X (m) | Y (m) | ∅ (m) |
|---|---|---|
| -9.72 | 72.232 | 1 |
| -9.72 | 70.109 | 1 |
| -9.72 | 68.109 | 1 |

**Table 7. East wall penetrations at ground level. The penetrations are listed from south to north.**

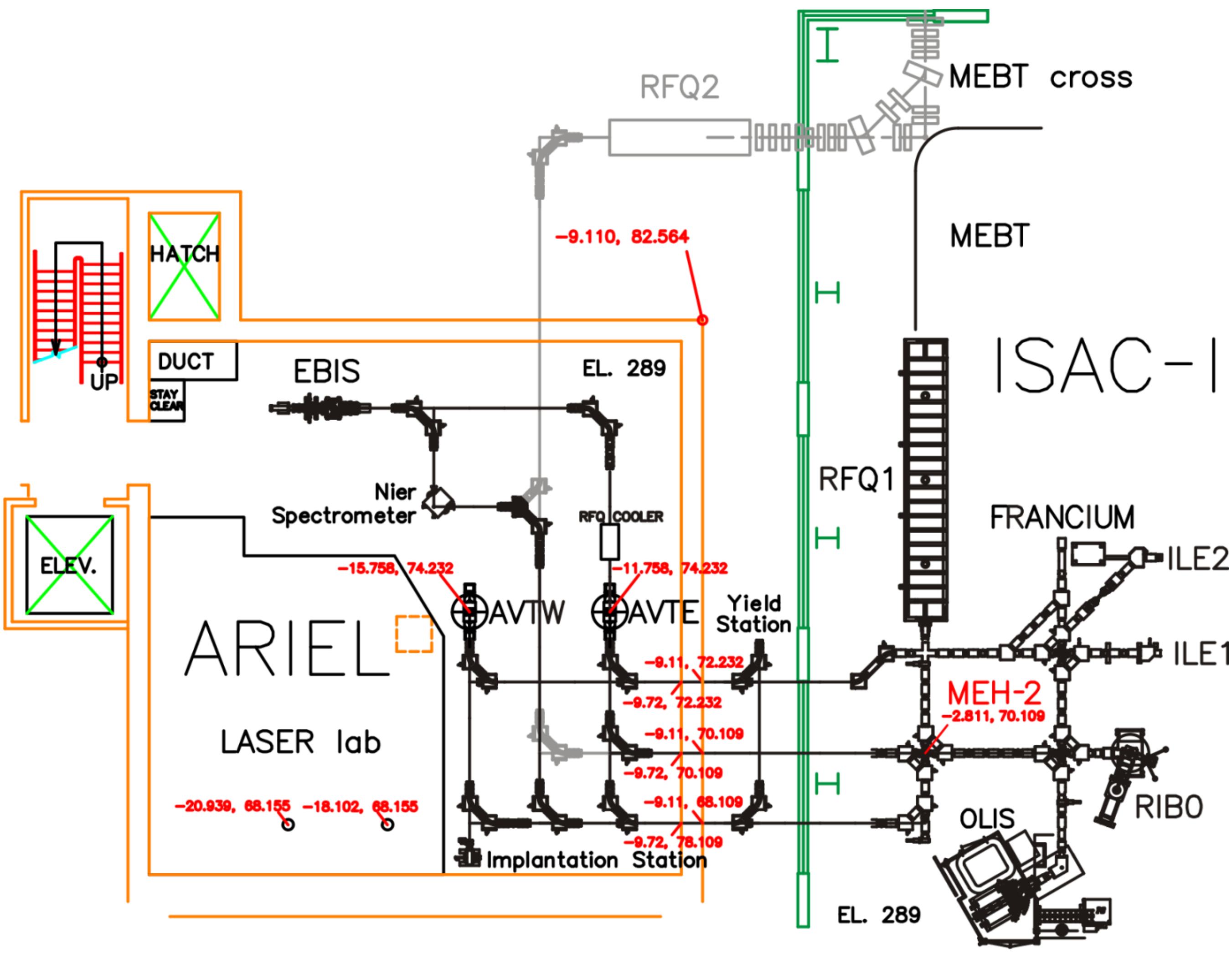


**Figure 6. Front-end conceptual layout at ground level. The RFQ2 and relative beam lines are depicted in light grey since it is not part of the ARIEL-II project.**

The different operational modes are listed in Table 8. The table is built based on two options, basic and extended (shown respectively in Figure 7 and Figure 8) for the G level switchyard.

In the basic layout the beam coming from AVTE can only be directed to MEBT/HEBT. As far as the ground level switchyard, we treat MEBT/HEBT as one destination since the distinction occurs in the MEBT cross (see Figure 6) where the beam can be directed to either MEBT or HEBT from either RFQ1 or RFQ2.

In the extended mode, by adding two extra benders (BD2 and BD5 in Figure 8) there is the possibility of sending the beam to either LEBT or MEBT/HEBT from either AVTE or AVTW. Table 8 show that adding just BD5 restricts to two the number of simultaneous RIB delivered, while adding just DB2 or DB2 and DB5 increases the delivery options (with some level of redundancy in case of target failure) for three simultaneous beams.

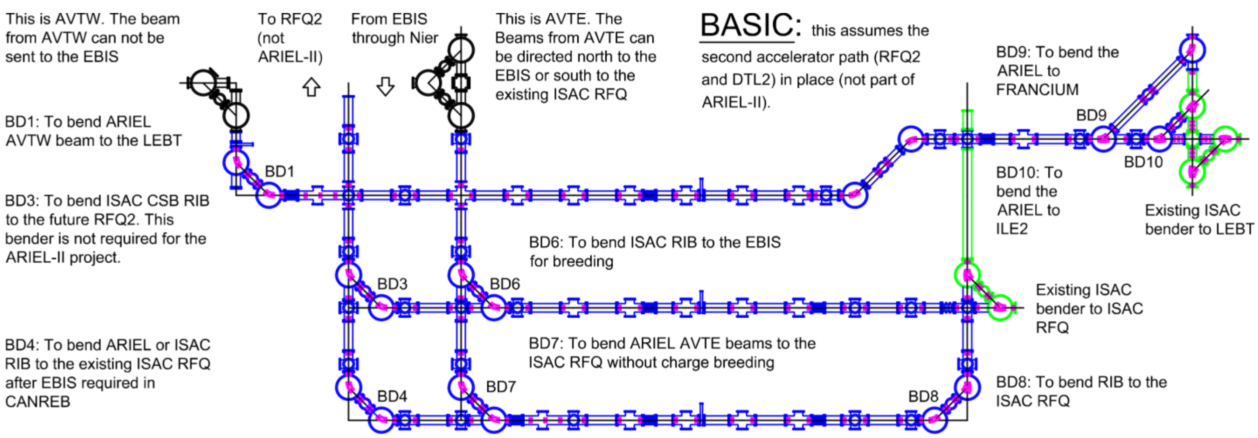


**Figure 7. Basic option for the ground level switchyard. In this case AVTE send the beam exclusively to the MEBT/HEBT while AVTW send the beam exclusively to the LEBT.**

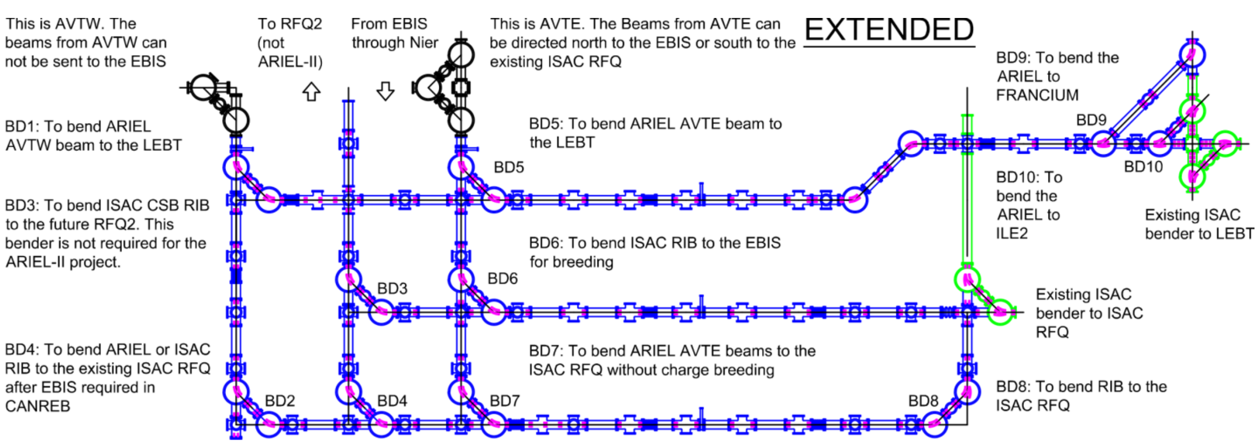


**Figure 8. Extended option for the ground level switchyard. In this both AVTE and AVTW can send the beam either to MEBT/HEBT or LEBT.**

| RIB0 (protons) | | | | AVTE (protons or electrons) | | | AVTW (electrons or proton) | | | Note |
|---|---|---|---|---|---|---|---|---|---|---|
| LEBT | MEBT or HEBT | | | LEBT | MEBT or HEBT | | LEBT | MEBT or HEBT | | |
| | 1+ | CSB | EBIS | | 1+ | EBIS | | 1+ | EBIS | |
| ✓ | | | | × | RFQ1 | | ✓ | × | × | BASIC |
| ✓ | | | | × | | RFQ2 | ✓ | × | × | BASIC |
| | RFQ1 | | | × | | RFQ2 | ✓ | × | × | BASIC |
| | | RFQ1 | | × | | RFQ2 | ✓ | × | × | BASIC |
| | | RFQ2 | | × | | RFQ1 | ✓ | × | × | BASIC |
| | | | RFQ2 | × | | | ✓ | × | × | ISAC beam through BD6<br>2/3 RIB's deliverable |
| ✓ | | | | × | | RFQ2 | | RFQ1 | | Adding only BD2 |
| ✓ | | | | ✓ | | | | × | × | Adding only BD5<br>2/3 RIB's deliverable |
| | RFQ1 | | | ✓ | | | | × | × | Adding only BD5<br>2/3 RIB's deliverable |
| | | RFQ1 | | ✓ | | | | × | × | Adding only BD5<br>2/3 RIB's deliverable |
| ✓ | | | | ✓ | | | | RFQ1 | | EXTENDED<br>Adding BD2 & BD5 |

**Table 8. Three simultaneously delivered radioactive beams operational mode.**

These modes have to combine with the possible modes given in Table 2. This combination gives ARIEL great flexibility of going from either target station to any of the ISAC-I or ISAC-II experimental station. Furthermore the MEBT switchyard downstream of the RFQs is going to further increase this flexibility for the medium and high energy experimental areas by allowing the acceleration path optimization through either RFQ1 or RFQ2.

The ground floor houses also the LASER lab in the south west corner. The laser beams in the lab are sent down to the mass separator room through the power supply room onto the two LASER tables. The ARIEL Yield station as well as the ARIEL implantation station is also located at ground level (see Figure 6).

The ISAC beam lines position in the absolute coordinate system is established; in particular monument MEH-2 (see Figure 6) coordinates are (-2811.2655, 70108.7354, 7906.9358).

The beam line elevation is Z=7907 mm (same as the existing ISAC-I beam lines). The average elevation of the ground level is 6230±10 mm, this implies an average beam height of 1.677 m. Such height allows for walkway under the beam lines in order to move to the different locations at the ground level.

# 4 Beam optics calculation of the

In this paragraph the beam optics calculation, including envelopes and beam line element position, are presented.

## 4.1 Optics modules

The modules presented in this paragraph are:

1. 1 meter long periodic section (standard): dimensions and operational parameters are listed in Table 9 while the beam envelope is represented in Figure 9.
2. AGTW/C/E/Y long periodic section (1123.26 mm long): this is to match the ISAC beam lines (monument MEH 2) in the N-S direction. Dimensions and operational parameters are listed in Table 9.
3. IGTA short periodic section (946.73 mm long): this is to match the ISAC beam lines (monument MEH 2) in the W-E direction. Dimensions and operational parameters are listed in Table 11.
4. 1 meter long reversing polarity section: dimensions and operational parameters are listed in Table 12 while the beam envelope is represented in Figure 10.
5. AGTN/S short reversing polarity section (946.73 mm): this is to match the ISAC beam lines (monument MEH 2) in the W-E direction. Dimensions and operational parameters are listed in Table 13 .
6. Crossing (low beta insertion) section: dimensions and operational parameters are listed in Table 14 while the beam envelope is represented in Figure 11. This module is also used for the pre-buncher in the AGTS section.
7. 90 degree bending section: dimensions and operational parameters are listed in Table 15 while the beam envelope is represented in Figure 12 (horizontal) and in Figure 13 (vertical).
8. 90 degree Y bending section: dimensions and operational parameters are listed in Table 15 while the beam envelope is represented in Figure 14.
9. ARIEL to ISAC LEBT dog-leg: dimensions and operational parameters are listed in Table 17 while the beam envelope is represented in Figure 15.
10. The pre-separator beam line will be presented in paragraph 5.1.

Each table includes the following parameters:

1. Aperture: this the transverse full aperture (diameter is given) of the optics element
2. Length: this is the total mechanical (electrode) length of the optics element
3. Maximum operation voltage: this is the maximum voltage required to transport a 60 kV beam.

4. Dimension s: this is the longitudinal accumulated reference trajectory from the beginning of the element
5. Relative coordinates (x,y,z): these are the right handed Cartesian coordinates of the middle points of the elements. The coordinates x and y are transverse while z is longitudinal (along the beam). At the B2 and ground level, both x and z are horizontal while y is vertical (pointing up). In the Vertical sections, both x and y are horizontal and z is vertical

Absolute coordinates (X,Z,Y) for all beam line elements, as well as EPIC names, are provided in the "ARIEL RIB transport optics layout" spreadsheet document-126944.

**Table 9. Characteristic of the 1 m long (standard) periodic section**

| element | Aperture (mm) | Length (mm) | Maximum Voltage (V) | s (mm) | x (mm) | y (mm) | z (mm) |
|---|---|---|---|---|---|---|---|
| Entrance point | - | - | - | 0 | 0 | 0 | 0 |
| Quadrupole | 50.8 | 50.8 | -2419 | 157 | 0 | 0 | 157 |
| Quadrupole | 50.8 | 50.8 | 2419 | 843 | 0 | 0 | 843 |
| Exit point | - | - | - | 1000 | 0 | 0 | 1000 |

**Table 10. Characteristic of the AGTW/C/E/Y long periodic section**

| element | Aperture (mm) | Length (mm) | Maximum Voltage (V) | s (mm) | x (mm) | y (mm) | z (mm) |
|---|---|---|---|---|---|---|---|
| Entrance point | - | - | - | 0 | 0 | 0 | 0 |
| Quadrupole | 50.8 | 50.8 | | 157 | 0 | 0 | 157 |
| Quadrupole | 50.8 | 50.8 | | 966.26 | 0 | 0 | 966.26 |
| Exit point | - | - | - | 1123.26 | 0 | 0 | 1123.26 |

**Table 11. Characteristic of the IGTA short periodic section**

| element | Aperture (mm) | Length (mm) | Maximum Voltage (V) | s (mm) | x (mm) | y (mm) | z (mm) |
|---|---|---|---|---|---|---|---|
| Entrance point | - | - | - | 0 | 0 | 0 | 0 |
| Quadrupole | 50.8 | 50.8 | | 157 | 0 | 0 | 157 |
| Quadrupole | 50.8 | 50.8 | | 789.73 | 0 | 0 | 789.73 |
| Exit point | - | - | - | 946.73 | 0 | 0 | 946.73 |

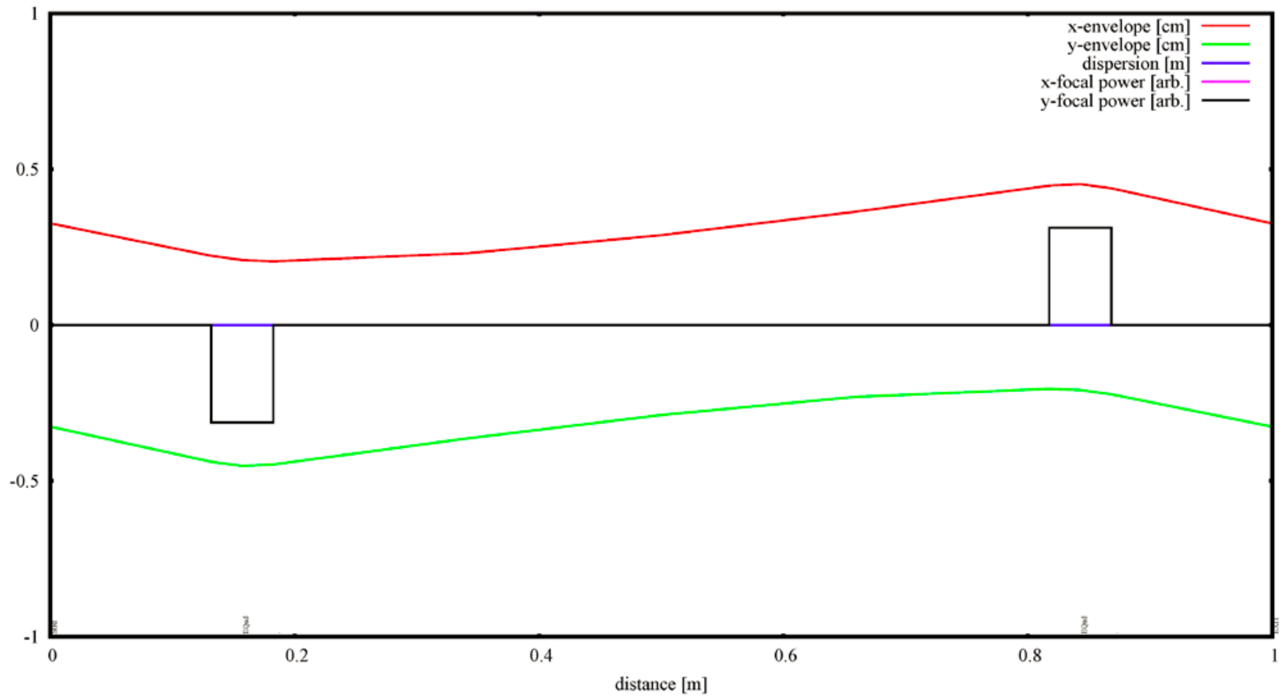


**Figure 9. Beam envelope of the 1 m long periodic section.**

**Table 12. Characteristic of the 1 m long reversing section**

| element | Aperture (mm) | Length (mm) | Maximum Voltage (V) | s (mm) | x (mm) | y (mm) | z (mm) |
|---|---|---|---|---|---|---|---|
| Entrance point | - | - | - | 0 | 0 | 0 | 0 |
| Quadrupole | 50.8 | 50.8 | 3123 | 157 | 0 | 0 | 157 |
| Quadrupole | 50.8 | 50.8 | -1907 | 314 | 0 | 0 | 314 |
| Quadrupole | 50.8 | 50.8 | -1907 | 686 | 0 | 0 | 686 |
| Quadrupole | 50.8 | 50.8 | 3123 | 843 | 0 | 0 | 843 |
| Exit point | - | - | - | 1000 | 0 | 0 | 1000 |

**Table 13. Characteristic of the AGTN/S short reversing section**

| element | Aperture (mm) | Length (mm) | Maximum Voltage (V) | s (mm) | x (mm) | y (mm) | z (mm) |
|---|---|---|---|---|---|---|---|
| Entrance point | - | - | - | 0 | 0 | 0 | 0 |
| Quadrupole | 50.8 | 50.8 | | 157 | 0 | 0 | 157 |
| Quadrupole | 50.8 | 50.8 | | 314 | 0 | 0 | 314 |
| Quadrupole | 50.8 | 50.8 | | 632,73 | 0 | 0 | 632.73 |
| Quadrupole | 50.8 | 50.8 | | 789.73 | 0 | 0 | 789.73 |
| Exit point | - | - | - | 946.73 | 0 | 0 | 946.73 |

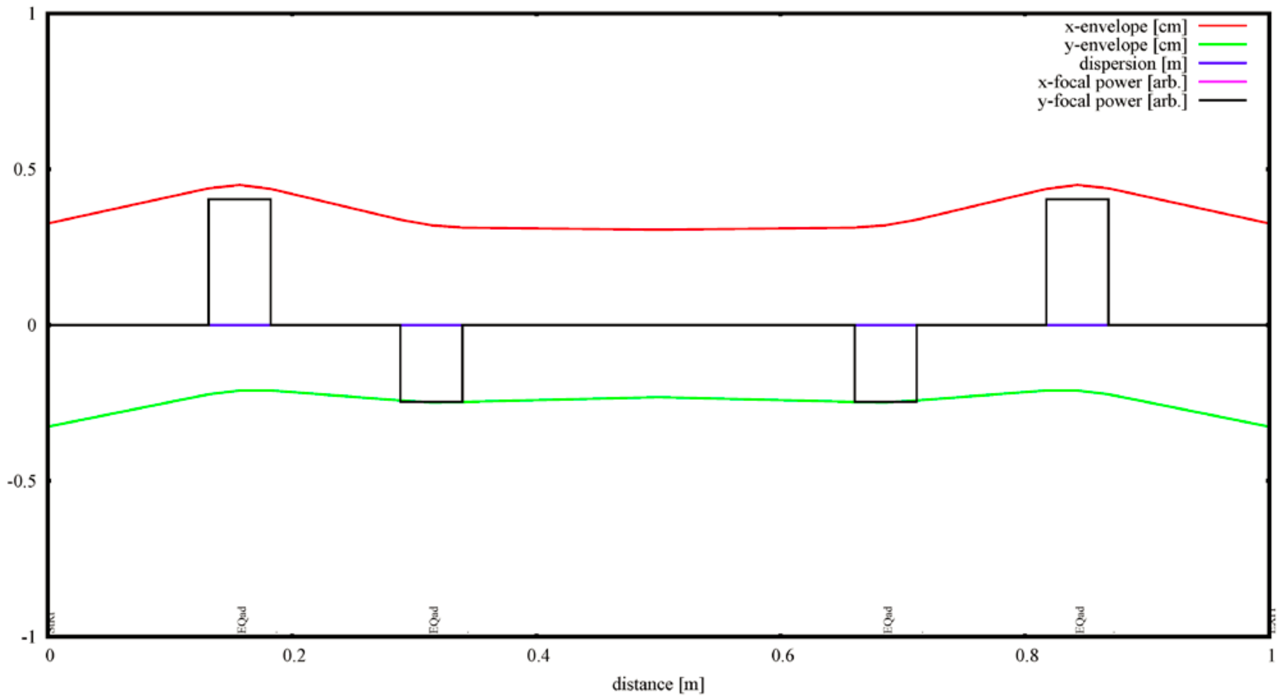


**Figure 10. Beam envelope of the 1 m long reversing section.**

**Table 14. Characteristic of the 2 m long crossing (low beta insertion) section. This module is also used for the pre-buncher in the AGTS section.**

| element | | Aperture (mm) | Length (mm) | Maximum Voltage (V) | s (mm) | x (mm) | y (mm) | z (mm) |
|---|---|---|---|---|---|---|---|---|
| ½ crossing | Entrance point | - | - | - | 0 | 0 | 0 | 0 |
| | Quadrupole | 50.8 | 50.8 | 2043 | 157 | 0 | 0 | 157 |
| | Quadrupole | 50.8 | 25.4 | -8882.3 | 673.1 | 0 | 0 | 673.1 |
| | Quadrupole | 50.8 | 38.1 | 8627 | 742.9 | 0 | 0 | 742.9 |
| | Quadrupole | 50.8 | 25.4 | -4347 | 812.8 | 0 | 0 | 812.8 |
| | Cross over point | - | - | - | 1000 | 0 | 0 | 1000 |
| ½ crossing | Quadrupole | 50.8 | 25.4 | -4347 | 1.1872 | 0 | 0 | 1.1872 |
| | Quadrupole | 50.8 | 38.1 | 8627 | 1.2571 | 0 | 0 | 1.2571 |
| | Quadrupole | 50.8 | 25.4 | -8882.3 | 1.3269 | 0 | 0 | 1.3269 |
| | Quadrupole | 50.8 | 50.8 | 2043 | 1.8431 | 0 | 0 | 1.8431 |
| | Exit point | - | - | - | 2000 | 0 | 0 | 2000 |

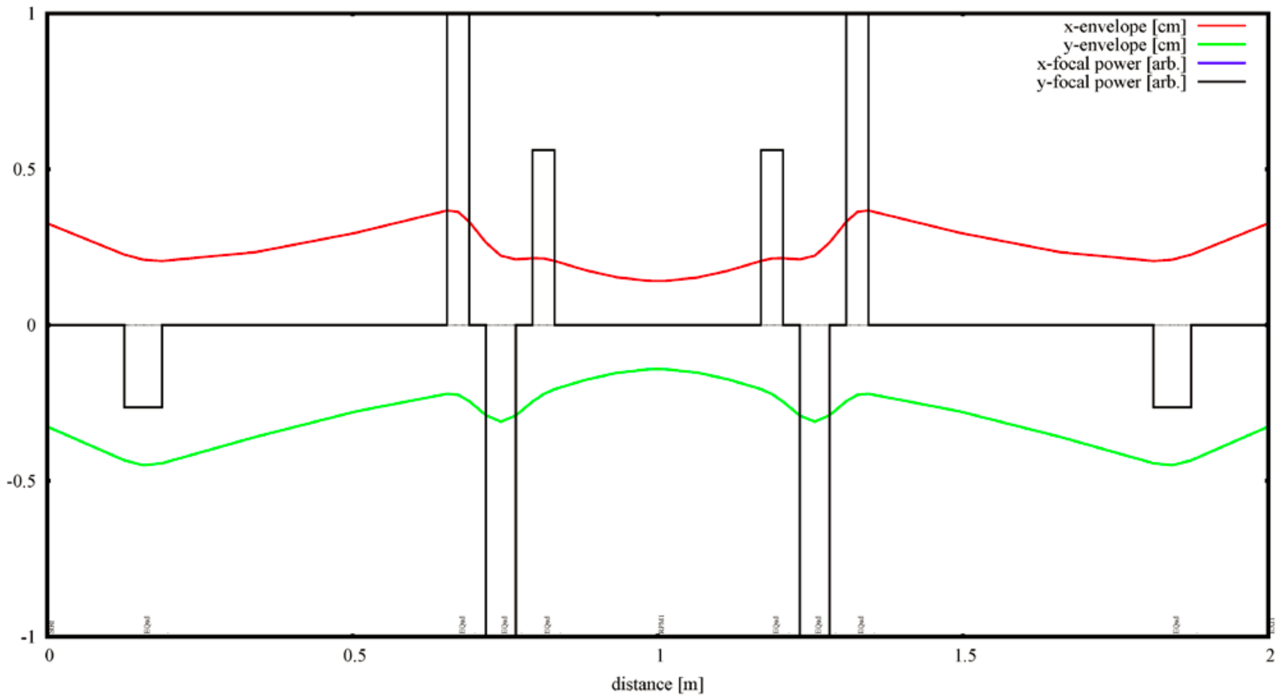


**Figure 11. Beam envelope of the crossing (low beta insertion) 2 meter long section.**

**Table 15. Characteristic of the 90 degree bender for both horizontal and vertical bending direction.**

| element | Aperture (mm) | Length (m) | Bending radius (mm) | Bending angle (deg) | Maximum Voltage (V) | s (mm) | x (mm) | y (mm) | z (mm) |
|---|---|---|---|---|---|---|---|---|---|
| entrance point | - | - | - | - | - | 0 | 0 | 0 | 0 |
| Quadrupole | 50.8 | 50.8 | - | - | -929 | 157 | 0 | 0 | 157 |
| | - | - | - | - | - | 268.2 | 0 | 0 | 268.2 |
| Bender | - | - | 254 | 45 | - | 368 | 19.33 | 0 | 364.5 |
| | - | - | - | - | - | 467.7 | 74.4 | 0 | 447.8 |
| Quadrupole | 50.8 | 38.1 | - | - | 4589 | 659.9 | 210.3 | 0 | 583.7 |
| Quadrupole | 50.8 | 25.4 | - | - | -1655 | 729.8 | 259.7 | 0 | 633.1 |
| Quadrupole | 50.8 | 25.4 | - | - | -1655 | 881.4 | 366.9 | 0 | 740.3 |
| Quadrupole | 50.8 | 38.1 | - | - | 4589 | 951.2 | 416.3 | 0 | 789.7 |
| | - | - | - | - | - | 1143.4 | 552.2 | 0 | 925.6 |
| Bender | - | - | 254 | 45 | - | 1243.1 | 634.6 | 0 | 980.7 |
| | - | - | - | - | - | 1342.9 | 731.8 | 0 | 1000 |
| Quadrupole | 50.8 | 50.8 | - | - | -929 | 1454.1 | 843 | 0 | 1000 |
| exit point | - | - | - | - | - | 1611.1 | 1000 | 0 | 1000 |

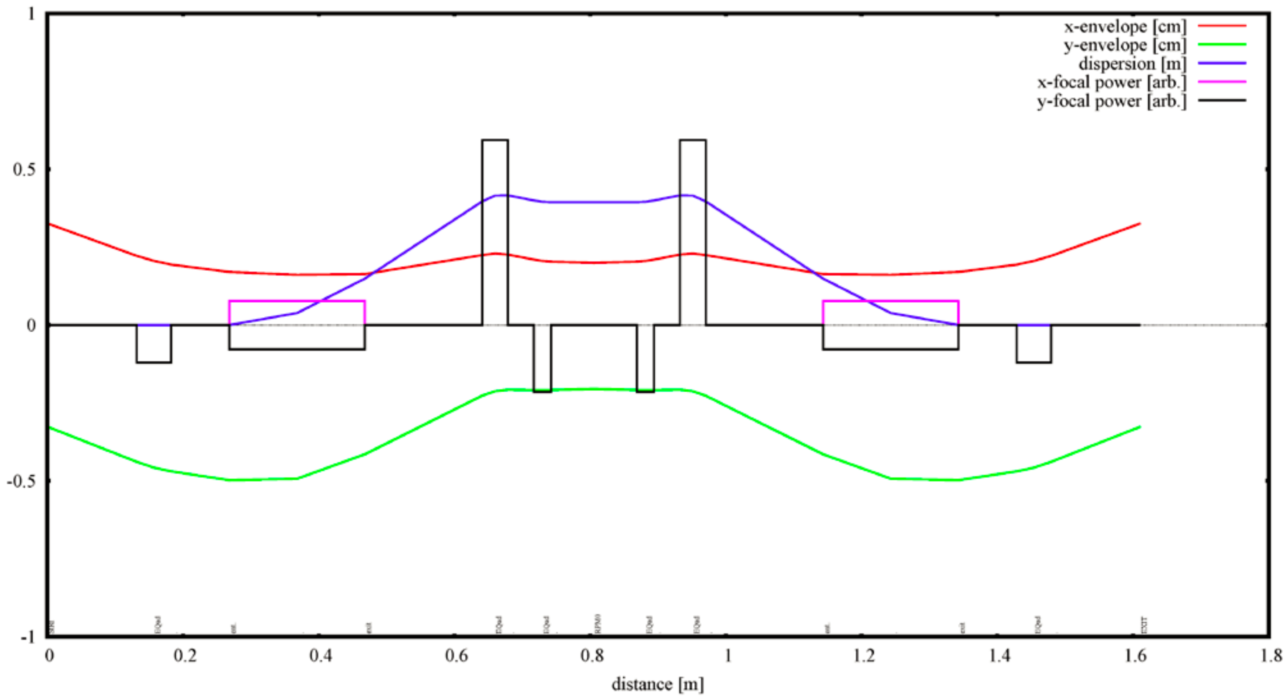


**Figure 12. Beam envelope of the 90 degree bender in the horizontal plane.**

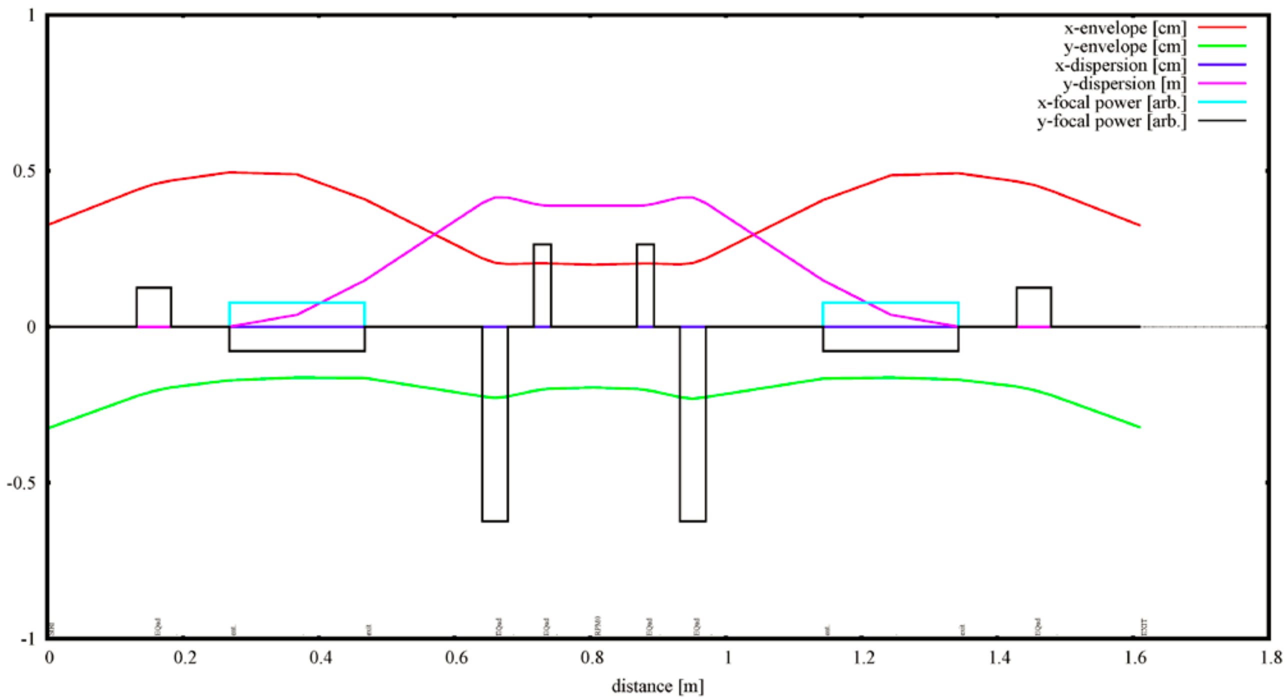


**Figure 13. Beam envelope of the 90 degree bender in the vertical plane.**

**Table 16. Characteristic of the 90 degree Y bender**

| element | Aperture (mm) | Length (mm) | Bending radius (mm) | Bending angle (deg) | Maximum Voltage (V) | s (mm) | x (mm) | y (mm) | z (mm) |
|---|---|---|---|---|---|---|---|---|---|
| entrance point | - | - | | | | 0 | 0 | 0 | 0 |
| Quadrupole | 50.8 | 50.8 | | | | 157 | 0 | 0 | 157 |
| | - | - | | | | 182.4 | 0 | 0 | 182.4 |
| Bender | - | - | 254 | 45 | | 367.99 | 19.33 | 0 | 365.44 |
| | - | - | | | | 467.73 | 74.39 | 0 | 447.85 |
| Quadrupole | 50.8 | 38.1 | | | | 593.28 | 163.17 | 0 | 536.62 |
| Quadrupole | 50.8 | 25.4 | | | | 663.13 | 212.56 | 0 | 586.01 |
| Quadrupole | 50.8 | 25.4 | | | | 810.9 | 317.05 | 0 | 690.5 |
| Quadrupole | 50.8 | 38.1 | | | | 880.75 | 366.44 | 0 | 739.89 |
| | - | - | | | | 1094.57 | 517.64 | 0 | 891.09 |
| Bender | - | - | 254 | 36 | | 1174.37 | 581.93 | 0 | 937.80 |
| | - | - | | | | 1254.17 | 657.51 | 0 | 962.36 |
| Deflector | - | 50.8 | | 9 | | 1494.79 | 895.17 | 0 | 1000 |
| exit point | - | - | | | | 1599.62 | 1000 | 0 | 1000 |

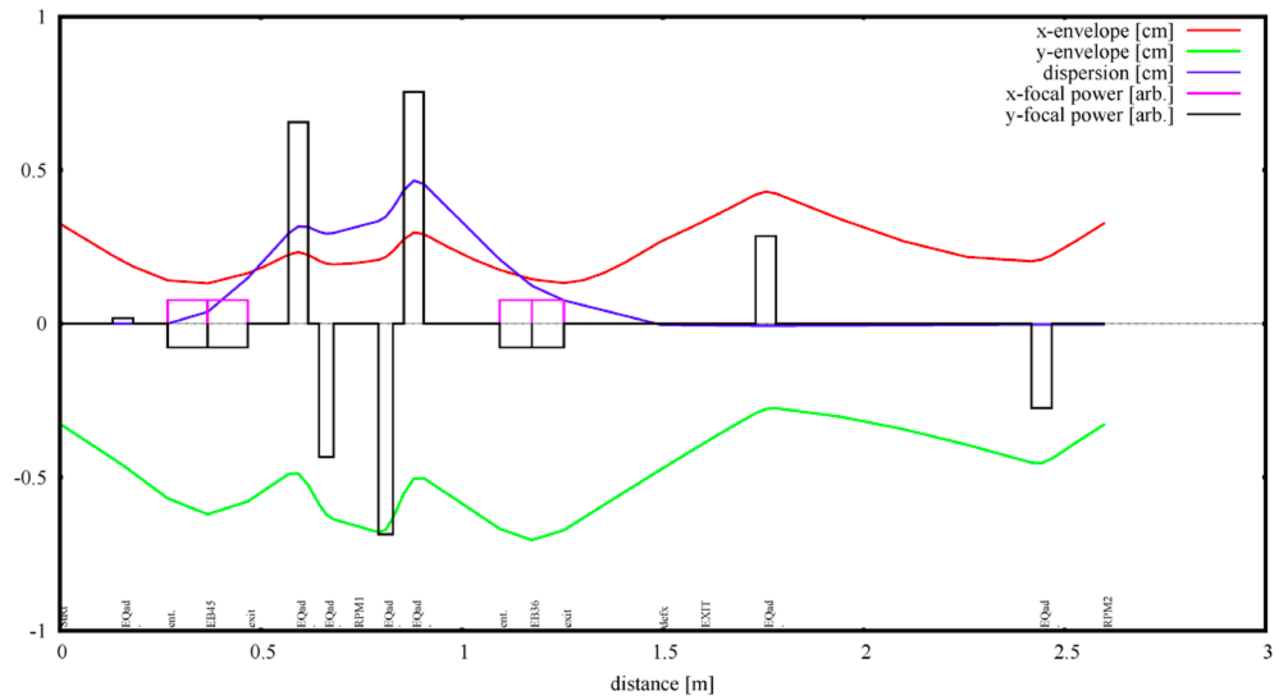


**Figure 14. Beam envelope of the 90 degree Y bender in the horizontal plane. This envelope includes also a downstream periodic module.**

**Table 17. Characteristic of the ARIEL to ISAC LEBT dog-leg**

| element | Aperture (mm) | Length (mm) | Bending radius (mm) | Bending angle (deg) | Maximum Voltage (V) | s (mm) | x (mm) | y (mm) | z (mm) |
|---|---|---|---|---|---|---|---|---|---|
| entrance point | - | - | | | | 0 | 0 | 0 | 0 |
| Quadrupole | 50.8 | 50.8 | | | | 157 | 0 | 0 | 157 |
| Quadrupole | 50.8 | 50.8 | | | | 314 | 0 | 0 | 314 |
| Quadrupole | 50.8 | 50.8 | | | | 509.19 | 0 | 0 | 509.19 |
| Quadrupole | 50.8 | 50.8 | | | | 666.19 | 0 | 0 | 666.19 |
| | - | - | | | | 954.79 | 0 | 0 | 954.79 |
| Bender | - | - | 254 | 45 | | 1054.54 | 19.33 | 0 | 1051.99 |
| | - | - | | | | 1154.28 | 74.39 | 0 | 1134.4 |
| Quadrupole | 50.8 | 50.8 | | | | 1433.52 | 271.84 | 0 | 1331.84 |
| Quadrupole | 50.8 | 38.1 | | | | 1594.82 | 385.90 | 0 | 1445.90 |
| Quadrupole | 50.8 | 38.1 | | | | 1747.83 | 494.10 | 0 | 1554.10 |
| Quadrupole | 50.8 | 50.8 | | | | 1909.13 | 608.16 | 0 | 1668.16 |
| | - | - | | | | 2188.37 | 805.61 | 0 | 1865.61 |
| Bender | - | - | 254 | 45 | | 2288.12 | 860.67 | 0 | 1948.01 |
| | - | - | | | | 2387.86 | 880 | 0 | 2045.21 |
| Quadrupole | 50.8 | 50.8 | | | | 2676.46 | 880 | 0 | 2333.81 |
| Quadrupole | 50.8 | 50.8 | | | | 2833.46 | 880 | 0 | 2490.81 |
| Quadrupole | 50.8 | 50.8 | | | | 3028.65 | 880 | 0 | 2686 |
| Quadrupole | 50.8 | 50.8 | | | | 3185.65 | 880 | 0 | 2843 |
| exit point | - | - | | | | 3342.65 | 880 | 0 | 3000 |

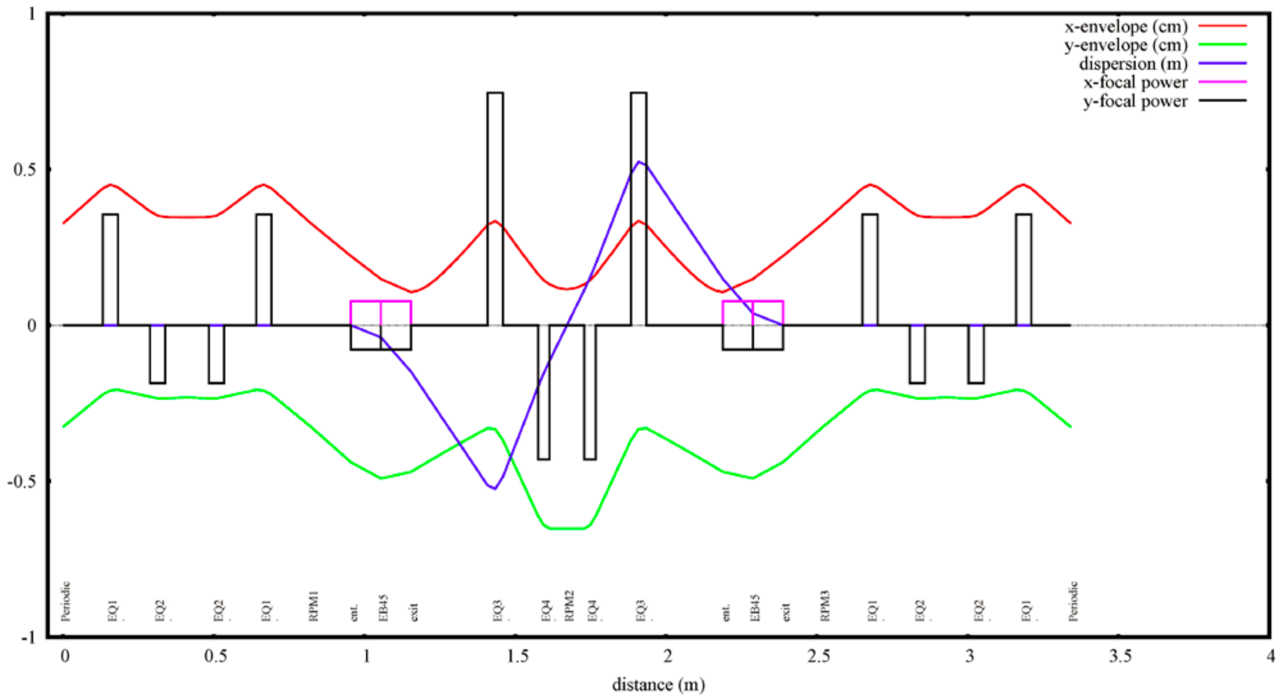


**Figure 15. ARIEL to ISAC LEBT dog-leg.**

## 4.2 EBIS injection line and Nier separator beam line

The EBIS injection line belongs to the AGTE section (see Table 39) while the Nier separator beam line belongs to the AGTC section (see Table 38). The EBIS injection line includes the RFQ cooler and the relative matching sections.
Details of the optics calculations for these sections are presented in the “Low Energy Beam Transport Line for the CANREB Charge State Breeder” document-116897.

## 4.3 Pre-separator beam lines

The eats target station (AETE) pre-separator beam line belongs to ALTE (see Table 18) while the west target station (APTW) pre-separator beam line belongs to ALTW (see Table 19).

Details of the optics calculations for these sections are presented in the “ARIEL Pre-separator” document-129911.

## 4.4 High Resolution Separator (HRS)

Details of the optics calculations for the high resolution separator (HRS) section are presented in the “Design Note TRI-DN-14-06 ARIEL high resolution separator” document-109442.

# 5 Beam optics layout for the RIB transport

In the present chapter we are going to list the sequence of the optics module for all the beam line section at different levels.

As already mentioned in the previous chapter, the absolute coordinates (X,Z,Y) for all beam line elements are provided in the "ARIEL RIB transport optics layout" spreadsheet document-126944.

## 5.1 Target hall beam line optics

Each target station has a dedicated pre-separator beam line with a dipole magnet followed by a 90° degree electrostatic bending section configured to be achromatic so the dispersion created by the magnet will be compensated by the electrostatic bender. The two beam lines are identical.

The EPICS acronym that identifies the beam line elements downstream of the APTW and AETE target stations are respectively ALTW (ARIEL Low Transport West) and ALTE (ARIEL Low Transport East).

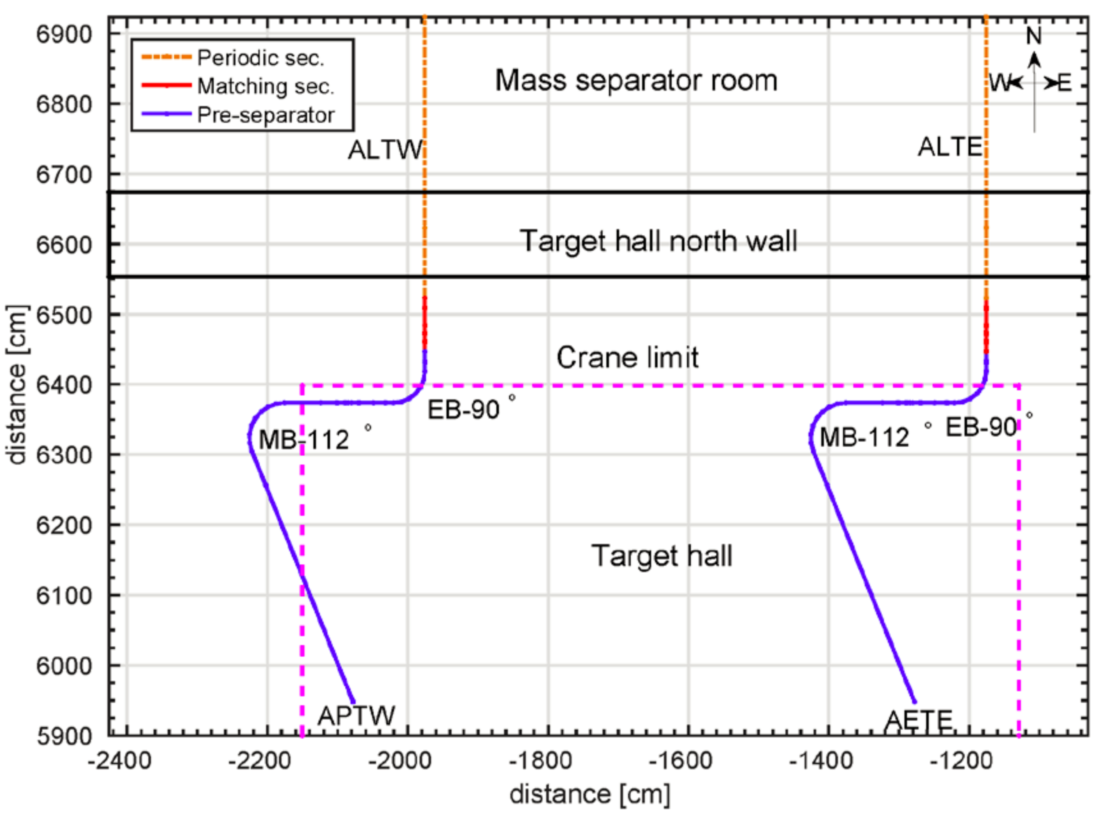


**Figure 16. Layout of the beam transport line inside the target hall. The circle represents the target location. The APTW and AETE transport line are conceptual identical but has slightly different dimension.**

**Table 18. ALTE beam transport line optics elements in the target hall.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Marching | ALTE | Q1 | Q1 | |
| | ALTE | Q2 | Q2 | |
| | ALTE | Q3 | Q3 | |
| | ALTE | Q4 | Q4 | |
| Periodic | ALTE | Q5 | Q5 | |
| | ALTE | Q6 | Q5 | |
| Matching | ALTE | Q7 | Q7 | |
| | ALTE | Q8 | Q8 | |
| | ALTE | Q9 | Q9 | |
| | ALTE | Q10 | Q10 | |
| Pre-separator Magnet | ALTE | MB0 | MB0 | |
| Matching | ALTE | Q11 | Q11 | |
| | ALTE | Q12 | Q12 | |
| | ALTE | Q13 | Q11 | |
| Bending | ALTE | Q14 | Q14 | |
| | ALTE | B1 | B1 | This is a 90 degree electrostatic bender |
| | ALTE | Q15 | Q14 | |
| Matching | ALTE | Q16 | Q16 | |
| | ALTE | Q17 | Q17 | |
| | ALTE | Q18 | Q18 | |
| | ALTE | Q19 | Q19 | |

**Table 19. ALTW beam transport line optics elements in the target hall.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Marching | ALTW | Q1 | Q1 | |
| | ALTW | Q2 | Q2 | |
| | ALTW | Q3 | Q3 | |
| | ALTW | Q4 | Q4 | |
| Periodic | ALTW | Q5 | Q5 | |
| | ALTW | Q6 | Q5 | |
| Matching | ALTW | Q7 | Q7 | |
| | ALTW | Q8 | Q8 | |
| | ALTW | Q9 | Q9 | |
| | ALTW | Q10 | Q10 | |
| Pre-separator Magnet | ALTW | MB0 | MB0 | |
| Matching | ALTW | Q11 | Q11 | |
| | ALTW | Q12 | Q12 | |
| | ALTW | Q13 | Q11 | |
| Bending | ALTW | Q14 | Q14 | |
| | ALTW | B1 | B1 | This is a 90 degree electrostatic bender |
| | ALTW | Q15 | Q14 | |
| Matching | ALTW | Q16 | Q16 | |
| | ALTW | Q17 | Q17 | |
| | ALTW | Q18 | Q18 | |
| | ALTW | Q19 | Q19 | |

## 5.2 Mass separator room beam line optics

The first section of the beam transport line in the mass separator room is located downstream of the last element listed in Table 18 and Table 19.

Figure 17 represents the layout of the mass separator room (B2 level) electrostatic switchyard. The right picture represents an early variant of the switchyard when the medium resolution separator is not in place. The fully electrostatic by-pass loop in place of the MRS allows beam from APTW to be sent to the experimental stations while the beam from AETE is sent through the HRS. The beam line vacuum envelope has been modelled based on commercially available components as explained in paragraph 8.

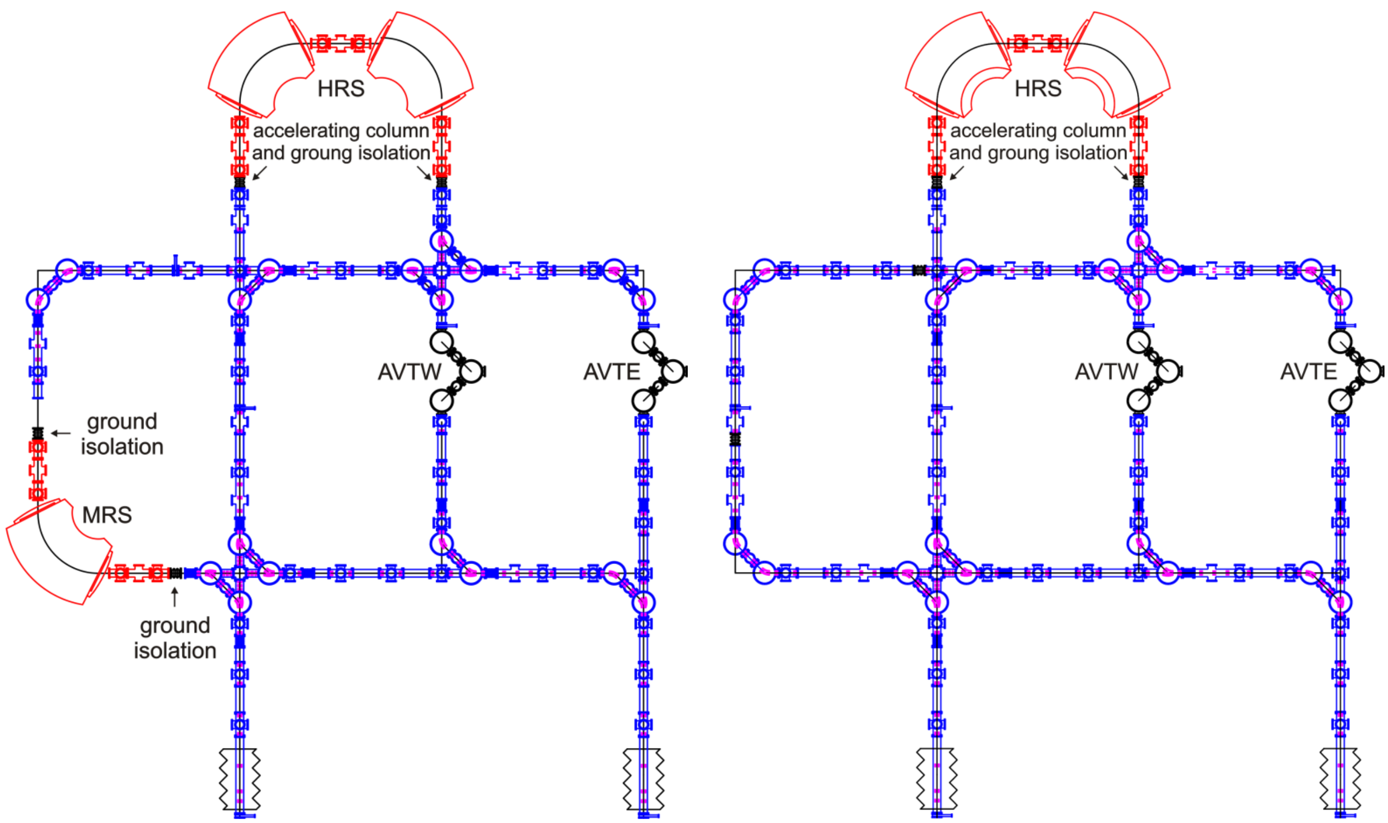


**Figure 17. Mass separator room switchyard layout with (left) and without (right) the medium resolution separator (MRS). Until the MRS will be in installed, a fully electrostatic by-pass loop is in place to allow beam from APTW to be sent to the experimental stations while the beam from AETE is sent through the HRS.**

The mass separator room optics elements are listed in the different tables. Each table contains all the elements inside a section of the full switchyard identified by a specific EPICS acronym. Such acronyms are represented in Figure 18. Epics acronyms are (in alphabetical order):

- AHRS: ARIEL lower (level) transport through HRS
- AHRSN: ARIEL lower (level) transport from HRS to North (branching into ALTN)
- ALTC: ARIEL Lower (level) Transport Central
- ALTE: ARIEL Lower (level) Transport East
- ALTN: ARIEL Lower (level) Transport North
- ALTNC: ARIEL Lower (level) Transport North-Central
- ALTNS: ARIEL Lower (level) Transport from North to South (branching into ALTNC)
- ALTS: ARIEL Lower (level) Transport South
- ALTSW: ARIEL Lower (level) Transport from South to West (branching into ALTW)
- ALTW: ARIEL Lower (level) Transport West
- ALTWM: ARIEL Lower (level) Transport from West to MRS (branching into MRS)
- ALTWN: ARIEL Lower (level) Transport from West to North (branching into ALTN)
- AMRS: ARIEL lower (level) Transport through MRS

The tables contain also information about the connection in series of quadrupoles within the same section. In general, quadrupoles that belong to different sections are not connected in series unless otherwise specified in the note.

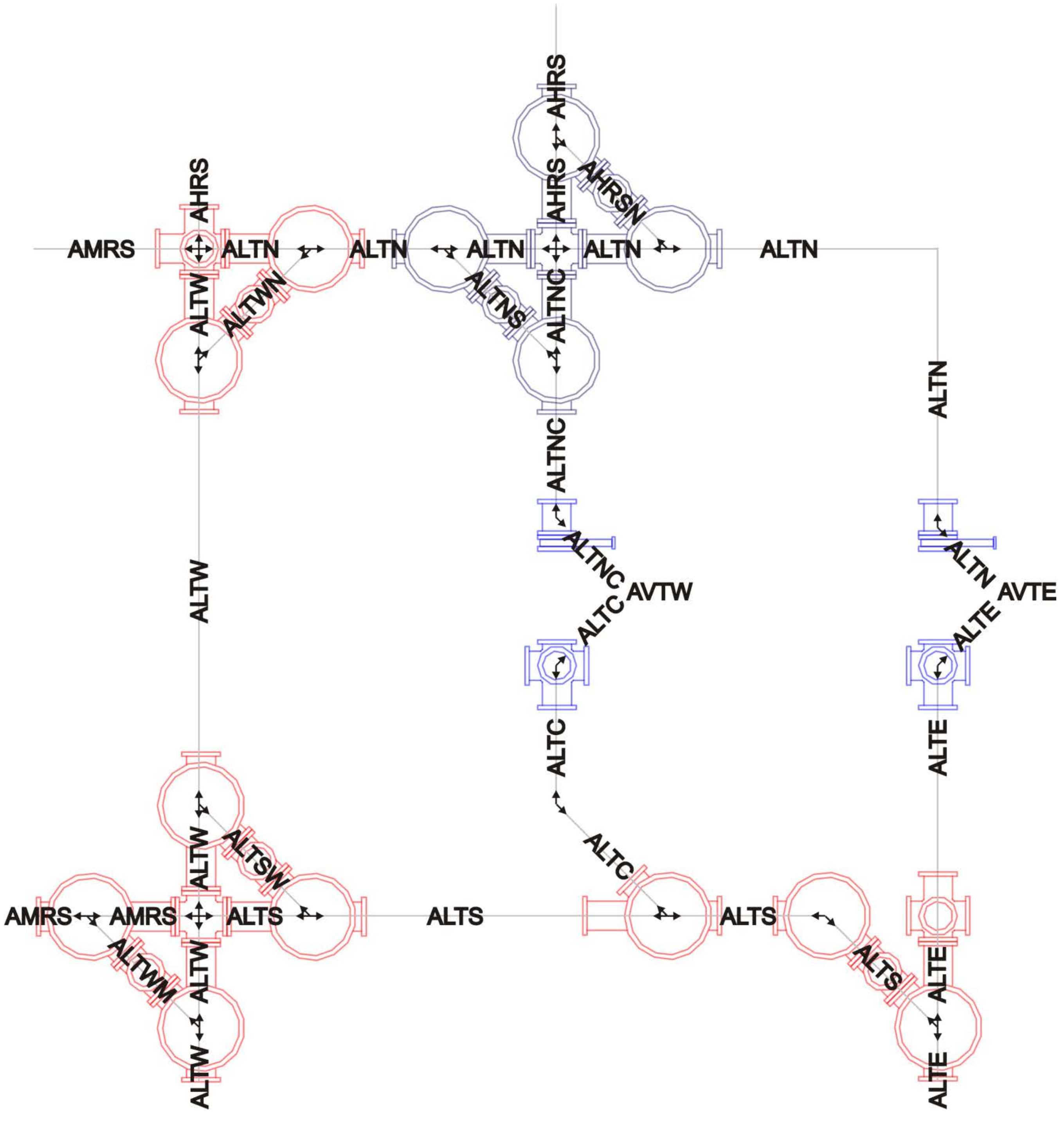


**Figure 18. EPICS acronyms in the mass separator room electrostatic switchyard.**

**Table 20. AHRS beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Periodic | AHRS | Q1 | ALTW:Q49 | |
| | AHRS | Q2 | ALTW:Q49 | |
| HRS matching in | AHRS | Q3 | Q3 | This is the HRS matching section |
| | AHRS | Q4 | Q4 | |
| | AHRS | Q5 | Q4 | |
| | AHRS | Q6 | Q3 | |
| HRS | AHRS | Q7 | Q7 | This is the HRS edge correcting quadrupole |
| | AHRS | MB1 | MB1 | This is the first HRS magnet |
| | AHRS | MLTP | MLTP | This is the multi-poles of the HRS |
| | AHRS | MB2 | MB2 | This is the second HRS magnet |
| | AHRS | Q8 | Q8 | |
| HRS matching out | AHRS | Q9 | Q9 | |
| | AHRS | Q10 | Q10 | |
| | AHRS | Q11 | Q11 | |
| | AHRS | Q12 | Q12 | |
| Crossing | AHRS | Q13 | Q13 | This is also the first quadrupole of the AHRSN bender and it is independent |
| | AHRS | Q14 | Q14 | This is the power supply pair for ALTCN:Q3 |
| | AHRS | Q15 | Q15 | This is the power supply pair for ALTCN:Q2 |
| | AHRS | Q16 | Q16 | This is the power supply pair for ALTCN:Q1 |
| | ALTNC | Q1 | AHRS:Q16 | |
| | ALTNC | Q2 | AHRS:Q15 | |
| | ALTNC | Q3 | AHRS:Q13 | |
| | ALTNC | Q4 | Q4 | This is also the last quadrupole of the ALTNS bender and it is independent |

**Table 21. AHRSN beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AHRS | Q13 | Q13 | This cannot be paired with the last quadrupole of the bender because we can cross the beams |
| | AHRSN | B1 | B1+ B1- | |
| | AHRSN | Q1 | Q1 | |
| | AHRSN | Q2 | Q2 | |
| | AHRSN | Q3 | Q2 | |
| | AHRSN | Q4 | Q1 | |
| | AHRSN | B4 | B4+ B1- | |
| | ALTN | Q16 | Q16 | This cannot be paired with the first quadrupole of the bender because we can cross the beams |

**Table 22. ALTC beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | ALTS | Q12 | Q12 | |
| | ALTC | B1 | B1+ B1- | |
| | ALTC | Q1 | Q1 | |
| | ALTC | Q2 | Q2 | |
| | ALTC | Q3 | Q2 | |
| | ALTC | Q4 | Q1 | |
| | ALTC | B4 | B4+ B1- | |
| | ALTC | Q5 | ALTS:Q12 | |
| Periodic | ALTC | Q6 | Q6 | |
| | ALTC | Q7 | Q6 | |
| Periodic | ALTC | Q8 | Q6 | |

**Table 22. ALTC beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| | ALTC | Q9 | Q6 | |
| Y Bender | ALTC | Q10 | Q10 | These PS are in common with ALTNC:Q5 |
| | ALTC | B10 | B10+ B10- | |
| | ALTC | Q11 | Q11 | These PS are in common with ALTNC:Q6 |
| | ALTC | Q12 | Q12 | This is also the power supply of ALTNC:Q7 |
| | ALTC | Q13 | Q12 | This is also the power supply of ALTNC:Q8 |
| | ALTC | Q14 | Q11 | This is also the power supply of ALTNC:Q9 |
| | ALTC | B14 | B14+ B10- | This is half of the Y bender in common with ALTNC. |
| | AVTW | D1 | D1 | This is the deflector in common with ALTNC |

**Table 23. ALTE beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Periodic | ALTE | Q23 | Q23 | |
| | ALTE | Q24 | Q23 | |
| Periodic | ALTE | Q25 | Q23 | |
| | ALTE | Q26 | Q23 | |
| Periodic | ALTE | Q27 | Q27 | |
| | ALTE | Q28 | Q27 | |
| Periodic | ALTE | Q29 | Q27 | |
| | ALTE | Q30 | Q27 | |
| Periodic | ALTE | Q31 | Q31 | This is also the first quad of ALTS and it must be independent from the upstream periodic |
| | ALTE | Q32 | Q31 | |
| Periodic | ALTE | Q33 | Q33 | |
| | ALTE | Q34 | Q33 | |
| Periodic | ALTE | Q35 | Q33 | |
| | ALTE | Q36 | Q33 | |

**Table 23. ALTE beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Reversing | ALTE | Q37 | Q37 | |
| | ALTE | Q38 | Q38 | |
| | ALTE | Q39 | Q38 | |
| | ALTE | Q40 | Q37 | |
| Y Bender | ALTE | Q41 | Q41 | This is the power supply for ALTN:Q29 |
| | ALTE | B41 | B41+<br>B41- | These PS are in common with ALTN:B29 |
| | ALTE | Q42 | Q42 | This is also the power supply of ALTN:Q30 |
| | ALTE | Q43 | Q43 | This is also the power supply of ALTN:Q31 |
| | ALTE | Q44 | Q43 | This is also the power supply of ALTN:Q32 |
| | ALTE | Q45 | Q42 | This is also the power supply of ALTN:Q33 |
| | ALTE | B45 | B45+<br>B41- | This is half of the Y bender in common with ALTN. |
| | AVTE | D1 | D1 | This is the deflector in common with ALTN |

**Table 24. ALTN beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Periodic | ALTN | Q1 | Q1 | ALTN:Q2 PS used as reference |
| | ALTN | Q2 | Q1 | |
| Reversing | ALTN | Q3 | Q3 | |
| | ALTN | Q4 | Q4 | |
| | ALTN | Q5 | Q4 | |
| | ALTN | Q6 | Q3 | |
| Periodic | ALTN | Q7 | Q7 | |
| | ALTN | Q8 | Q7 | |

**Table 24. ALTN beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Crossing | ALTN | Q9 | Q9 | This is also the first quadrupole of the ALTNS bender and it is independent |
| | ALTN | Q10 | Q10 | |
| | ALTN | Q11 | Q11 | |
| | ALTN | Q12 | Q12 | |
| | ALTN | Q13 | Q12 | |
| | ALTN | Q14 | Q11 | |
| | ALTN | Q15 | Q10 | |
| | ALTN | Q16 | Q16 | This is also the last quadrupole of the AHRSN bender and it is independent |
| Reversing | ALTN | Q17 | Q17 | |
| | ALTN | Q18 | Q18 | |
| | ALTN | Q19 | Q18 | |
| | ALTN | Q20 | Q17 | |
| Periodic | ALTN | Q21 | Q21 | |
| | ALTN | Q22 | Q21 | |
| Bender | ALTN | Q23 | Q23 | |
| | ALTN | B23 | B23+ B23- | |
| | ALTN | Q24 | Q24 | |
| | ALTN | Q25 | Q25 | |
| | ALTN | Q26 | Q25 | |
| | ALTN | Q27 | Q24 | |
| | ALTN | B27 | B27+ B23- | |
| | ALTN | Q28 | Q23 | |

ALTN continues

**Table 24. ALTN beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Y Bender | ALTN | Q29 | ALTE:Q41 | This uses the power supply of ALTE:Q41 |
| | ALTN | B29 | ALTE:B41+<br>ALTE:B41- | This uses the power supplies of ALTE:B4 |
| | ALTN | Q30 | ALTE:Q42 | |
| | ALTN | Q31 | ALTE:Q43 | |
| | ALTN | Q32 | ALTE:Q43 | |
| | ALTN | Q33 | ALTE:Q42 | |
| | ALTN | B33 | ALTE:B45+<br>ALTE:B41- | This is half of the Y bender in common with ALTE. |
| | AVTE | D1 | D1 | This is the deflector in common with ALTE |

**Table 25. ALTNC beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Crossing | AHRS | Q13 | Q13 | This is also the first quadrupole of the AHRSN bender and it is independent |
| | AHRS | Q14 | Q14 | |
| | AHRS | Q15 | Q15 | |
| | AHRS | Q16 | Q16 | |
| | ALTNC | Q1 | AHR:Q16 | |
| | ALTNC | Q2 | AHR:Q15 | This is the power supply for AHRS:Q15 |
| | ALTNC | Q3 | AHR:Q14 | This is the power supply for AHRS:Q14 |
| | ALTNC | Q4 | Q4 | This is also the last quadrupole of the ALTNS bender and it is independent |

**Table 25. ALTNC beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Y Bender | ALTNC | Q5 | ALTC:Q10 | |
| | ALTNC | B5 | ALTC:B10+ ALTC:B10- | |
| | ALTNC | Q6 | ALTC:Q11 | |
| | ALTNC | Q7 | ALTC:Q12 | |
| | ALTNC | Q8 | ALTC:Q12 | |
| | ALTNC | Q9 | ALTC:Q11 | |
| | ALTNC | B9 | ALTC:B14+ ALTC:B10- | This is half of the Y bender in common with ALTC. |
| | AVTW | D1 | D1 | This is the deflector in common with ALTC |

**Table 26. ALTNS beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | ALTN | Q9 | Q9 | This cannot be paired with the last quadrupole of the bender because we can cross the beams. |
| | ALTNS | B1 | B1+ B1- | |
| | ALTNS | Q1 | Q1 | |
| | ALTNS | Q2 | Q2 | |
| | ALTNS | Q3 | Q2 | |
| | ALTNS | Q4 | Q1 | |
| | ALTNS | B4 | B4+ B1- | |
| | ALTNC | Q4 | Q4 | This cannot be paired with the first quadrupole of the bender because we can cross the beams. |

**Table 27. ALTS beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | ALTE | Q31 | Q31 | This belongs to ALTE (see Table 23) |
| | ALTS | B1 | B1+ B1- | |
| | ALTS | Q1 | Q1 | |
| | ALTS | Q2 | Q2 | |
| | ALTS | Q3 | Q2 | |
| | ALTS | Q4 | Q1 | |
| | ALTS | B4 | B4+ B1- | B1- PS belongs to ALTE:B3- |
| | ALTS | Q5 | Q32 | This is the power supply for ALTE:Q31 |
| Periodic | ALTS | Q6 | Q6 | |
| | ALTS | Q7 | Q6 | |
| Reversing | ALTS | Q8 | Q8 | |
| | ALTS | Q9 | Q9 | |
| | ALTS | Q10 | Q9 | |
| | ALTS | Q11 | Q8 | |
| Periodic | ALTS | Q12 | Q12 | This is also the first quadrupole of the ALTC bender |
| | ALTS | Q13 | Q12 | |
| Periodic | ALTS | Q14 | Q12 | |
| | ALTS | Q15 | Q12 | |
| Periodic | ALTS | Q16 | Q16 | |
| | ALTS | Q17 | Q16 | |
| Periodic | ALTS | Q18 | Q16 | |
| | ALTS | Q19 | Q16 | |

ALTS continues

**Table 27. ALTS beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Crossing | ALTS | Q20 | Q20 | This is also the first quadrupole of the ALTSW bender and it is independent |
| | ALTS | Q21 | Q21 | This is also the power supply for AMRS:Q3 |
| | ALTS | Q22 | Q22 | |
| | ALTS | Q23 | Q23 | |
| | AMRS | Q1 | ALTS:Q23 | |
| | AMRS | Q2 | ALTS:Q22 | |
| | AMRS | Q3 | ALTS:Q21 | |
| | AMRS | Q4 | Q4 | This is also the last quadrupole of the ALTSM bender and it is independent |

**Table 28. ALTSW beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | ALTS | Q20 | Q20 | This cannot be paired with the last quadrupole of the bender because we can cross the beams. |
| | ALTSW | B1 | B1+ B1- | |
| | ALTSW | Q1 | Q1 | |
| | ALTSW | Q2 | Q2 | |
| | ALTSW | Q3 | Q2 | |
| | ALTSW | Q4 | Q1 | |
| | ALTSW | B4 | B4+ B1- | |
| | ALTW | Q38 | Q38 | This cannot be paired with the first quadrupole of the bender because we can cross the beams. |

**Table 29. ALTW beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Periodic | ALTW | Q23 | Q23 | |
| | ALTW | Q24 | Q23 | |
| Periodic | ALTW | Q25 | Q23 | |
| | ALTW | Q26 | Q23 | |
| Periodic | ALTW | Q27 | Q27 | |
| | ALTW | Q28 | Q27 | |
| Periodic | ALTW | Q29 | Q27 | |
| | ALTW | Q30 | Q27 | |
| Crossing | ALTW | Q31 | Q31 | This is also the first quadrupole of the ALTWM bender and it is independent |
| | ALTW | Q32 | Q32 | |
| | ALTW | Q33 | Q33 | |
| | ALTW | Q34 | Q34 | |
| | ALTW | Q35 | Q34 | |
| | ALTW | Q36 | Q33 | |
| | ALTW | Q37 | Q32 | |
| | ALTW | Q38 | Q38 | This is also the last quadrupole of the ALTSW bender and it is independent |
| Reversing | ALTW | Q39 | Q39 | |
| | ALTW | Q40 | Q40 | |
| | ALTW | Q41 | Q40 | |
| | ALTW | Q42 | Q39 | |
| Periodic | ALTW | Q43 | Q43 | |
| | ALTW | Q44 | Q43 | |
| Periodic | ALTW | Q45 | Q43 | |
| | ALTW | Q46 | Q43 | |
| Periodic | ALTW | Q47 | Q47 | |
| | ALTW | Q48 | Q47 | |

**Table 29. ALTW beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Periodic | ALTW | Q49 | Q49 | This is also the first quadrupole of the ALTWN bender |
| | ALTW | Q50 | Q49 | |

**Table 30. ALTWM beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | ALTW | Q31 | Q31 | This cannot be paired with the last quadrupole of the bender because we can cross the beams. |
| | ALTWM | B1 | B1+ B1- | |
| | ALTWM | Q1 | Q1 | |
| | ALTWM | Q2 | Q2 | |
| | ALTWM | Q3 | Q2 | |
| | ALTWM | Q4 | Q1 | |
| | ALTWM | B4 | B4+ B1- | |
| | AMRS | Q4 | Q4 | This cannot be paired with the first quadrupole of the bender because we can cross the beams. |

**Table 31. ALTWN beam transport line optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | ALTW | Q49 | Q49 | This cannot be paired with the last quadrupole of the bender because we can cross the beams. |
| | ALTWN | B1 | B1+ B1- | |
| | ALTWN | Q1 | Q12 | |
| | ALTWN | Q2 | Q13 | |
| | ALTWN | Q3 | Q13 | |
| | ALTWN | Q4 | Q12 | |
| | ALTWN | B4 | B4+ B1- | |
| | ALTN | Q2 | Q2 | This cannot be paired with the first quadrupole of the bender because we can cross the beams. |

**Table 32. AMRS beam transport line optics elements in the mass separator room. The medium resolution separator (MRS) is not included in this table but it is replaced by an extra electrostatic bender.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Crossing | ALTS | Q20 | Q20 | This is also the first quadrupole of the ALTSW bender and it is independent |
| | ALTS | Q21 | Q21 | |
| | ALTS | Q22 | Q22 | |
| | ALTS | Q23 | Q23 | |
| | AMRS | Q1 | ALTS:Q23 | |
| | AMRS | Q2 | ALTS:Q22 | |
| | AMRS | Q3 | ALTS:Q21 | |
| | AMRS | Q4 | Q4 | This is also the last quadrupole of the ALTWM bender and it is independent |

**Table 32. AMRS beam transport line optics elements in the mass separator room. The medium resolution separator (MRS) is not included in this table but it is replaced by an extra electrostatic bender.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Reversing | AMRS | Q5 | Q39 | |
| | AMRS | Q6 | Q40 | |
| | AMRS | Q7 | Q40 | |
| | AMRS | Q8 | Q39 | |
| Periodic | AMRS | Q9 | Q9 | |
| | AMRS | Q10 | Q9 | |
| Bender | AMRS | Q11 | Q11 | |
| | AMRS | B11 | B11+ B11- | |
| | AMRS | Q12 | Q12 | |
| | AMRS | Q13 | Q13 | |
| | AMRS | Q14 | Q13 | |
| | AMRS | Q15 | Q12 | |
| | AMRS | B15 | B15+ B11- | |
| | AMRS | Q16 | Q16 | |
| Reversing | AMRS | Q17 | Q17 | |
| | AMRS | Q18 | Q18 | |
| | AMRS | Q19 | Q18 | |
| | AMRS | Q20 | Q17 | |
| Periodic | AMRS | Q21 | Q9 | |
| | AMRS | Q22 | Q9 | |
| Periodic | AMRS | Q23 | Q9 | |
| | AMRS | Q24 | Q9 | |
| Periodic | AMRS | Q25 | Q25 | |
| | AMRS | Q26 | Q25 | |

AMRS continues

**Table 32. AMRS beam transport line optics elements in the mass separator room. The medium resolution separator (MRS) is not included in this table but it is replaced by an extra electrostatic bender.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AMRS | Q27 | Q11 | |
| | AMRS | B27 | B27+ B27- | |
| | AMRS | Q28 | Q12 | |
| | AMRS | Q29 | Q13 | |
| | AMRS | Q30 | Q13 | |
| | AMRS | Q31 | Q12 | |
| | AMRS | B31 | B31+ B27- | |
| | AMRS | Q32 | Q16 | |
| Periodic | AMRS | Q33 | Q33 | |
| | AMRS | Q34 | Q33 | |
| Periodic | AMRS | Q35 | Q33 | |
| | AMRS | Q36 | Q33 | |
| Periodic | AMRS | Q37 | Q33 | |
| | AMRS | Q38 | Q33 | |

## 5.3 Vertical section beam line optics

The two vertical sections (AVTE and AVTW) are represented in Figure 19. The nomenclature used for them is represented in Figure 20. The tables with the components for each vertical line follow (Table 33 for AVTE, Table 36 for AVTW).

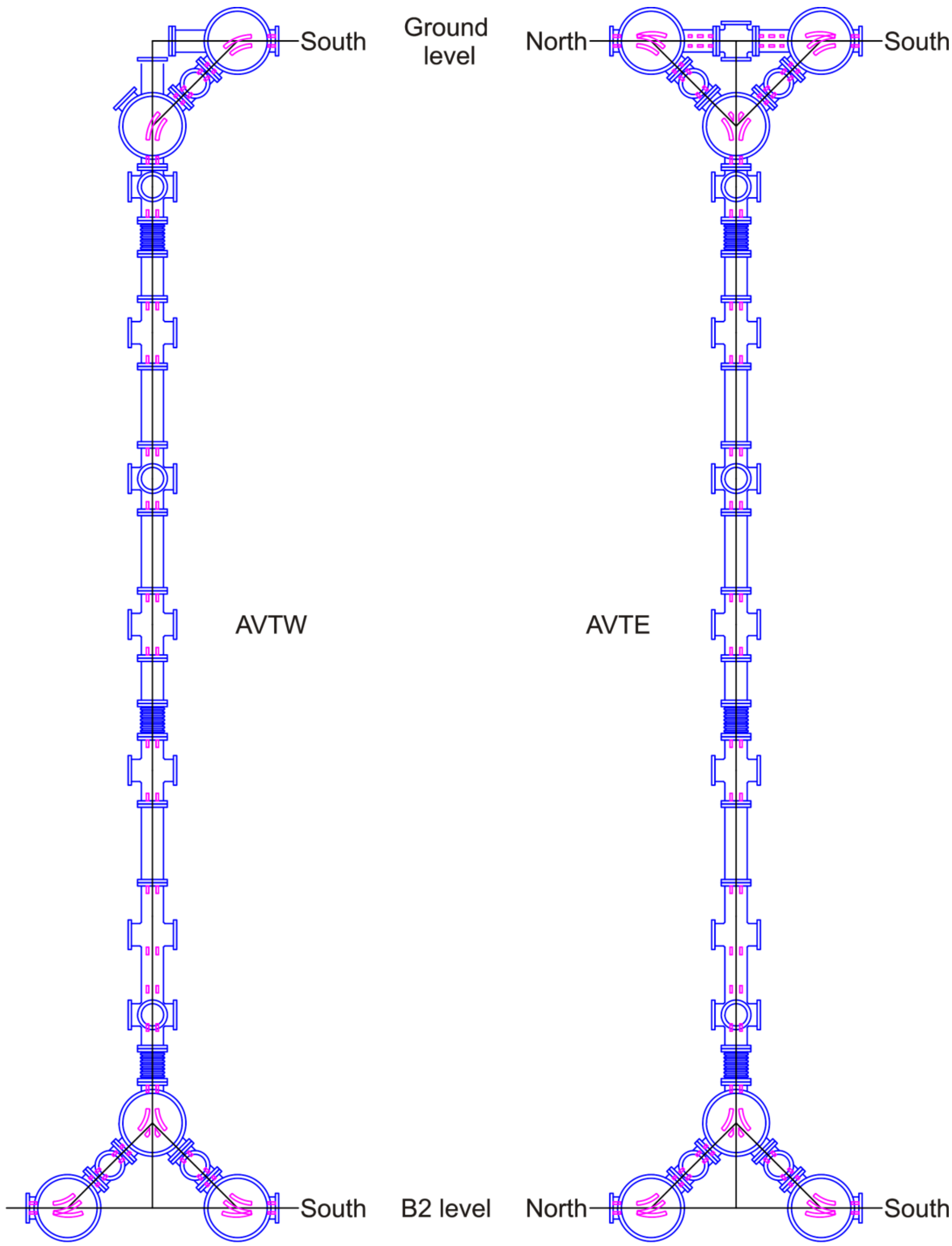


**Figure 19. Vertical section layout from lower level to ground level.**

The EPICS acronyms for the vertical transport beam line include:

- AVTE: ARIEL Vertical Transport East
- AVTEN: ARIEL Vertical Transport East to horizontal North (branching into AGTE)
- AVTES: ARIEL Vertical Transport East to horizontal South (branching into AGTE)
- AVTW: ARIEL Vertical Transport West
- AVTWS: ARIEL Vertical Transport West to horizontal South (branching into AGTW)

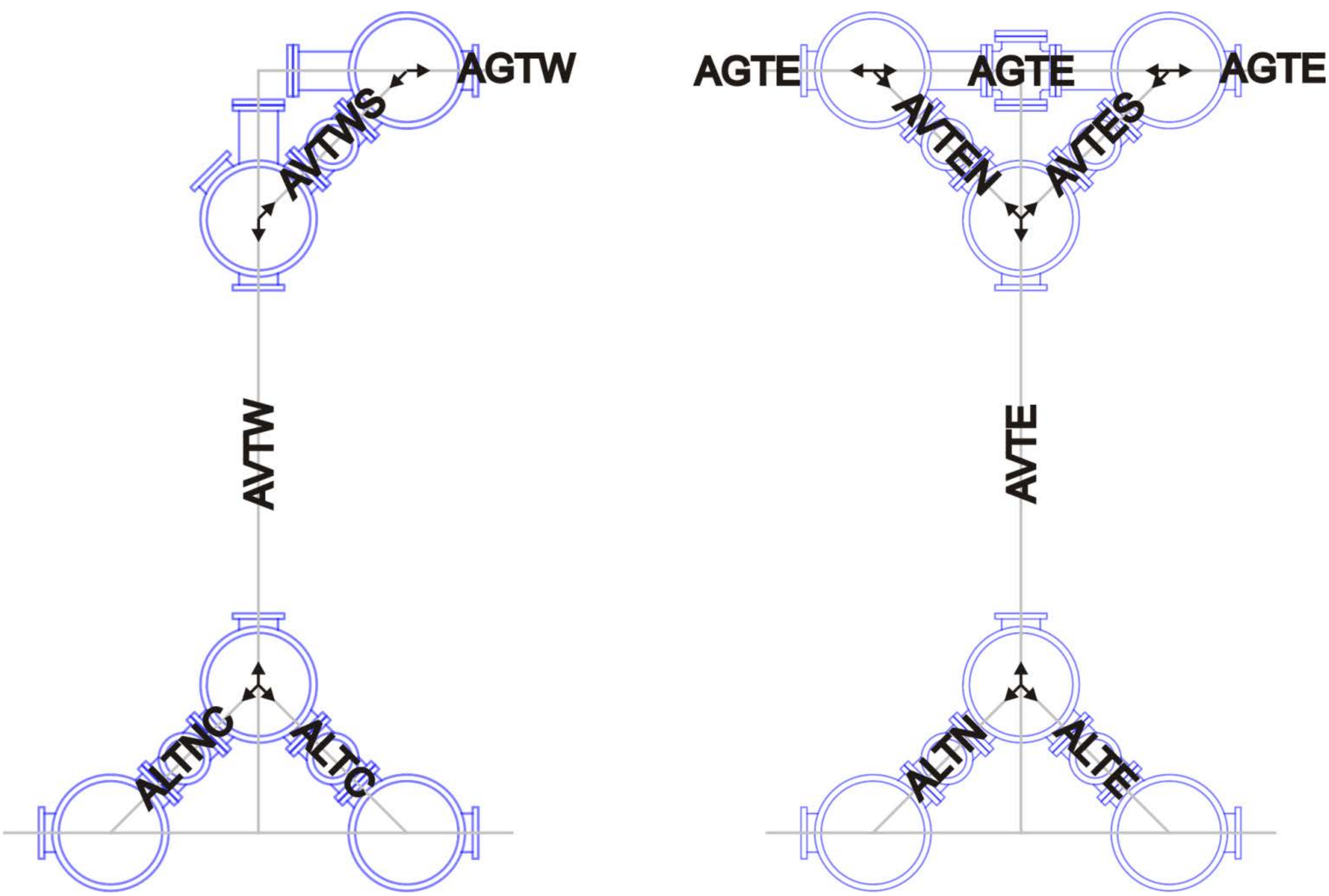


**Figure 20. Vertical sections nomenclature.**

**Table 33. AVTE beam transport line optics elements in the east vertical section.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Y Bender | ALTE | Q41 | Q41 | |
| | ALTE | B41 | B41+ B41- | |
| | ALTE | Q42 | Q42 | |
| | ALTE | Q43 | Q43 | |
| | ALTE | Q44 | Q43 | |
| | ALTE | Q45 | Q42 | |
| | ALTE | B45 | B45+ B41- | |
| | AVTE | D1 | D1 | |
| AVTE/W Short Reversing | AVTE | Q1 | Q1 | |
| | AVTE | Q2 | Q2 | |
| | AVTE | Q3 | Q2 | |
| | AVTE | Q4 | Q1 | |
| Periodic | AVTE | Q5 | Q5 | |
| | AVTE | Q6 | Q5 | |
| Periodic | AVTE | Q7 | Q5 | |
| | AVTE | Q8 | Q5 | |
| Periodic | AVTE | Q9 | Q5 | |
| | AVTE | Q10 | Q5 | |
| Periodic | AVTE | Q11 | Q11 | |
| | AVTE | Q12 | Q11 | |
| Periodic | AVTE | Q13 | Q11 | |
| | AVTE | Q14 | Q11 | |

AVTE continues

**Table 33. AVTE beam transport line optics elements in the east vertical section.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Y Bender | AVTE | D2 | D2 | |
| | AVTES | B1 | B1+ B1- | |
| | AVTES | Q1 | Q1 | |
| | AVTES | Q2 | Q2 | |
| | AVTES | Q3 | Q2 | |
| | AVTES | Q4 | Q1 | |
| | AVTES | B4 | B4+ B1- | |
| | AGTE | Q14 | AGTE:Q14 | |

**Table 34. AVTEN beam transport line optics elements in the east vertical section.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Y Bender | AVTE | D2 | D2 | |
| | AVTEN | B1 | B1+ B1- | |
| | AVTEN | Q1 | Q1 | |
| | AVTEN | Q2 | Q2 | |
| | AVTEN | Q3 | Q2 | |
| | AVTEN | Q4 | Q1 | |
| | AVTEN | B4 | B4+ B1- | |
| | AGTE | Q21 | AGTE:Q14 | |

**Table 35. AVTES beam transport line optics elements in the east vertical section.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Y Bender | AVTE | D2 | D2 | |
| | AVTES | B1 | B1+ B1- | |
| | AVTES | Q1 | Q1 | |
| | AVTES | Q2 | Q2 | |
| | AVTES | Q3 | Q2 | |
| | AVTES | Q4 | Q1 | |
| | AVTES | B4 | B4+ B1- | |
| | AGTE | Q14 | AGTE:Q14 | |

**Table 36. AVTW beam transport line optics elements in the east vertical section.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Y Bender | ALTC | Q10 | Q10 | |
| | ALTC | B10 | B10+ B10- | |
| | ALTC | Q11 | Q11 | |
| | ALTC | Q12 | Q12 | |
| | ALTC | Q13 | Q12 | |
| | ALTC | Q14 | Q11 | |
| | ALTC | B14 | B14+ B10- | |
| | AVTW | D1 | D1 | |
| AVTE/W Short Reversing | AVTW | Q1 | Q1 | |
| | AVTW | Q2 | Q2 | |
| | AVTW | Q3 | Q2 | |
| | AVTW | Q4 | Q1 | |
| Periodic | AVTW | Q5 | Q5 | |
| | AVTW | Q6 | Q5 | |
| Periodic | AVTW | Q7 | Q5 | |
| | AVTW | Q8 | Q5 | |

**Table 36. AVTW beam transport line optics elements in the east vertical section.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Periodic | AVTW | Q9 | Q5 | |
| | AVTW | Q10 | Q5 | |
| Periodic | AVTW | Q11 | Q11 | |
| | AVTW | Q12 | Q11 | |
| Periodic | AVTW | Q13 | Q11 | |
| | AVTW | Q14 | Q11 | |
| Bender | AVTW | Q15 | Q15 | |
| | AVTWS | B1 | B1+ B1- | |
| | AVTWS | Q1 | Q1 | |
| | AVTWS | Q2 | Q2 | |
| | AVTWS | Q3 | Q2 | |
| | AVTWS | Q4 | Q1 | |
| | AVTWS | B4 | B4+ B1- | |
| | AGTW | Q1 | AVTW:Q15 | |

**Table 37. AVTWS beam transport line optics elements in the east vertical section.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AVTW | Q15 | Q15 | |
| | AVTWS | B1 | B1+ B1- | |
| | AVTWS | Q1 | Q1 | |
| | AVTWS | Q2 | Q2 | |
| | AVTWS | Q3 | Q2 | |
| | AVTWS | Q4 | Q1 | |
| | AVTWS | B4 | B4+ B1- | |
| | AGTW | Q1 | AVTW:Q15 | |

## 5.4 Ground level beam line optics

The optics presented in this paragraph refers to the extended version of the ARIEL front-end where the additional bender BD2 and BD5 are installed (see Figure 8). The configuration considered take into account also the future upgrade (see Figure 21). The various phases of the ARIEL-II project are presented in the following paragraph 6. They are just a subset of the configuration presented in this paragraph.

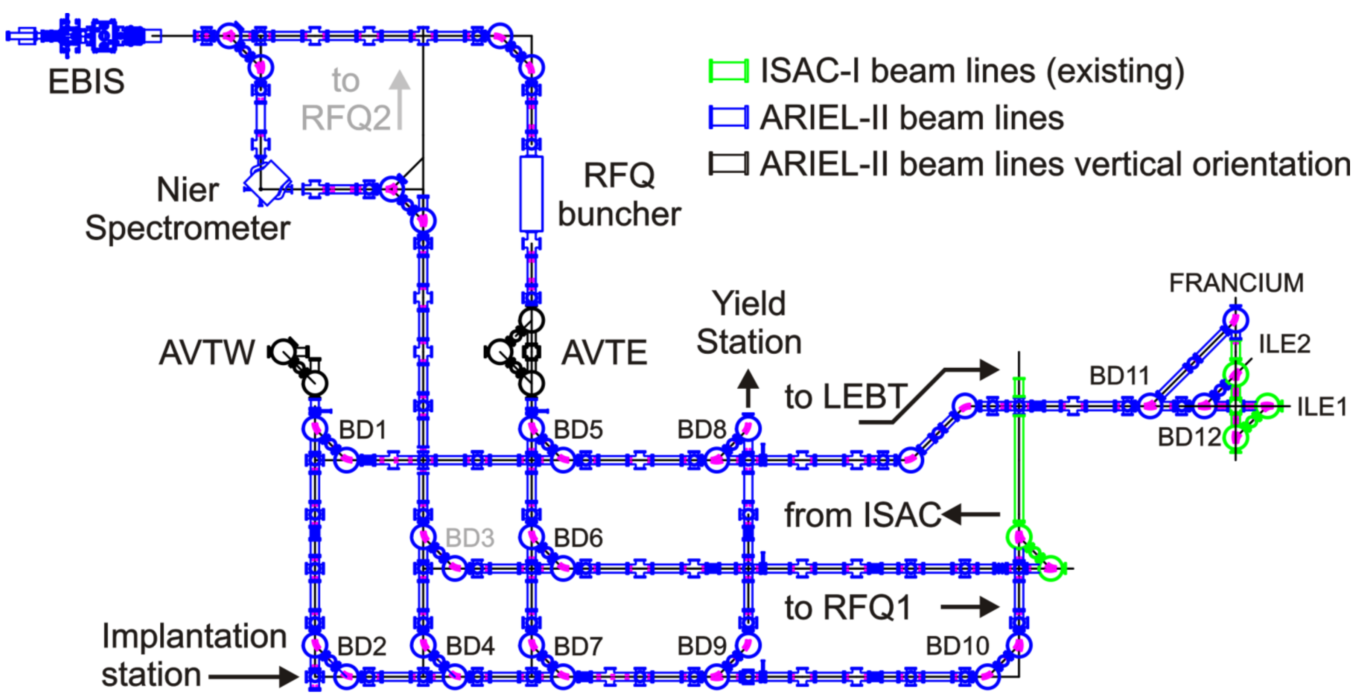


**Figure 21. Ground level beam transport line beyond ARIEL-II. The final beam line configuration of the ARIEL-II project differs only for the position of the BD3 bender (in line with BD2 and BD7).**

The EPICS acronyms for the ground level beam transport are represented in Figure 22 and they include:

- AGTC: ARIEL Ground (level) Transport Central
- AGTE: ARIEL Ground (level) Transport East
- AGTEN: ARIEL Ground (level) Transport (from) East (to) North (branching into AGTN)
- AGTN: ARIEL Ground (level) Transport North
- AGTNI: ARIEL Ground (level) Transport (from) North (to) ILE (branching into ISAC ILE)
- AGTNY: ARIEL Ground (level) Transport (from) North (to) Yield (branching into AGTY)
- AGTS: ARIEL Ground (level) Transport South
- AGTW: ARIEL Ground (level) Transport West
- AGTY: ARIEL Ground (level) Transport (to) Yield (station)
- IGTA: ISAC Ground (level) Transport (to) ARIEL
- IGTAE: ISAC Ground (level) Transport (to) ARIEL East (branching into AGTE)
- AGTNF: ARIEL Ground (level) Transport (from) North (to) FRANCIUM

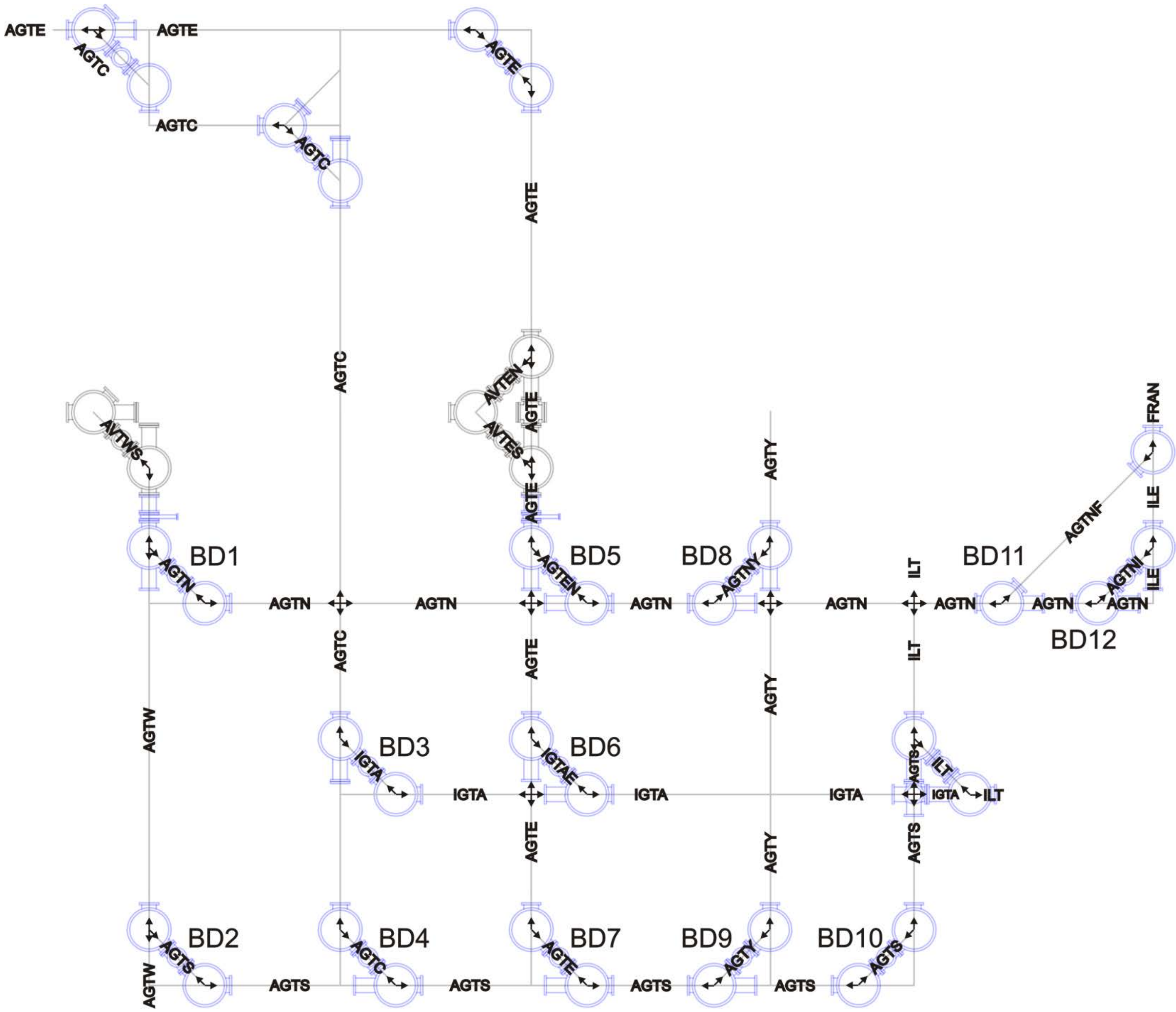


**Figure 22. Ground level beam line nomenclature.**

**Table 38. AGTC beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| EBIS output matching | AGTE | Q48 | Q48 | |
| | AGTE | Q47 | Q47 | |
| | AGTE | Q46 | Q46 | |
| | AGTE | Q45 | Q45 | |
| EBIS/Nier Y Bender | AGTE | D44 | D44 | |
| | AGTC | B1A | B1A+ B1A- | |
| | AGTC | B1B | B1B+ B1B - | |
| | AGTC | Q1 | Q1 | |
| Nier input matching | AGTC | Q3 | Q3 | |
| | AGTC | Q4 | Q4 | |
| | AGTC | Q5 | Q5 | |
| | AGTC | Q6 | Q6 | |
| NIER | AGTC | MB0 | MB0 | This is the Nier spectrometer dipole magnet |
| Nier output matching | AGTC | Q7 | Q7 | |
| | AGTC | Q8 | Q8 | |
| | AGTC | Q9 | Q9 | |
| | AGTC | Q10 | Q10 | |
| Bender | AGTC | Q11 | Q23 | |
| | AGTC | B11 | B11+ B11- | |
| | AGTC | Q12 | Q24 | |
| | AGTC | Q13 | Q25 | |
| | AGTC | Q14 | Q25 | |
| | AGTC | Q15 | Q24 | |
| | AGTC | B15 | B15+ B11- | |
| | AGTC | Q16 | Q23 | |

**Table 38. AGTC beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Reversing | AGTC | Q17 | Q17 | |
| | AGTC | Q18 | Q18 | |
| | AGTC | Q19 | Q18 | |
| | AGTC | Q20 | Q17 | |
| Periodic | AGTC | Q21 | Q21 | |
| | AGTC | Q22 | Q21 | |
| Periodic | AGTC | Q23 | Q21 | |
| | AGTC | Q24 | Q21 | |
| Periodic | AGTC | Q25 | Q25 | |
| | AGTC | Q26 | Q25 | |
| AGTW/C/E/Y Long periodic | AGTC | Q27 | Q25 | |
| | AGTC | Q28 | Q25 | |
| Periodic | AGTC | Q29 | Q29 | |
| | AGTC | Q30 | Q29 | |
| Periodic | AGTC | Q31 | Q29 | |
| | AGTC | Q32 | Q29 | |
| Bender | AGTC | Q33 | Q33 | |
| | AGTC | B33 | B33+ B33- | |
| | AGTC | Q34 | Q34 | |
| | AGTC | Q35 | Q35 | |
| | AGTC | Q36 | Q35 | |
| | AGTC | Q37 | Q34 | |
| | AGTC | B37 | B37+ B33- | |
| | AGTS | Q9 | AGTS:Q6 | |

**Table 39. AGTE beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AGTS | Q13 | Q13 | |
| | AGTE | B1 | B1+ B1- | |
| | AGTE | Q1 | Q1 | |
| | AGTE | Q2 | Q2 | |
| | AGTE | Q3 | Q2 | |
| | AGTE | Q4 | Q1 | |
| | AGTE | B4 | B4+ B1- | |
| | AGTE | Q5 | AGTS:Q10 | |
| Periodic | AGTE | Q6 | Q6 | |
| | AGTE | Q7 | Q6 | |
| Periodic | AGTE | Q8 | Q6 | |
| | AGTE | Q9 | Q6 | This is also the last quadrupole of the IGTAE bender |
| AGTW/C/E/Y Long periodic | AGTE | Q10 | Q10 | |
| | AGTE | Q11 | Q10 | |
| Periodic | AGTE | Q12 | Q12 | |
| | AGTE | Q13 | Q12 | This is also the first quadrupole of the AGTEN bender |
| Crossing | AGTE | Q14 | Q14 | This is also the last quadrupole of the AVTES bender |
| | AGTE | Q15 | Q15 | |
| | AGTE | Q16 | Q16 | |
| | AGTE | Q17 | Q17 | |
| | AGTE | Q18 | Q17 | |
| | AGTE | Q19 | Q16 | |
| | AGTE | Q20 | Q15 | |
| | AGTE | Q21 | Q14 | This is also the last quadrupole of the AVTEN bender |

**Table 39. AGTE beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| RFQ IN Matching | AGTE | Q22 | Q22 | |
| | AGTE | Q23 | Q23 | |
| | AGTE | Q24 | Q24 | |
| | AGTE | Q25 | Q25 | |
| RFQ buncher | AGTE | RFQ1 | RFQ1 | |
| RFQ OUT Matching | AGTE | Q26 | Q26 | |
| | AGTE | Q27 | Q27 | |
| | AGTE | Q28 | Q28 | |
| | AGTE | Q29 | Q29 | |
| Bender | AGTE | Q30 | Q30 | |
| | AGTE | B30 | B30+ B30- | |
| | AGTE | Q31 | Q31 | |
| | AGTE | Q32 | Q32 | |
| | AGTE | Q33 | Q32 | |
| | AGTE | Q34 | Q31 | |
| | AGTE | B34 | B34+ B30- | |
| | AGTE | Q35 | Q30 | |
| Periodic | AGTE | Q36 | Q36 | |
| | AGTE | Q37 | Q36 | |
| Periodic | AGTE | Q38 | Q36 | |
| | AGTE | Q39 | Q36 | |
| Periodic | AGTE | Q40 | Q40 | |
| | AGTE | Q41 | Q40 | |

AGTE continues

**Table 39. AGTE beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| EBIS input Matching | AGTE | Q42 | Q42 | |
| | AGTE | Q43 | Q43 | |
| | AGTE | Q44 | Q44 | |
| | AGTE | D44 | D44 | |
| | AGTE | Q45 | Q45 | |
| | AGTE | Q46 | Q46 | |
| | AGTE | Q47 | Q47 | |
| | AGTE | Q48 | Q48 | |

**Table 40. AGTEN beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AGTE | Q13 | AGTE:Q12 | This cannot be paired with the last quadrupole of the bender because we can cross the beams. |
| | AGTEN | B1 | B1+ B1- | |
| | AGTEN | Q1 | Q1 | |
| | AGTEN | Q2 | Q2 | |
| | AGTEN | Q3 | Q2 | |
| | AGTEN | Q4 | Q1 | |
| | AGTEN | B4 | B1+ B4- | |
| | AGTN | Q13 | AGTN:Q10 | This cannot be paired with the first quadrupole of the bender because we can cross the beams. |

**Table 41. AGTN beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AGTW | Q2 | Q2 | |
| | AGTN | B1 | B1+ B1- | |
| | AGTN | Q1 | Q1 | |
| | AGTN | Q2 | Q2 | |
| | AGTN | Q3 | Q2 | |
| | AGTN | Q4 | Q1 | |
| | AGTN | B4 | B1+ B4- | |
| | AGTN | Q5 | AGTW:Q10 | |
| Periodic | AGTN | Q6 | Q6 | |
| | AGTN | Q7 | Q6 | |
| Periodic | AGTN | Q8 | Q6 | |
| | AGTN | Q9 | Q6 | |
| Periodic | AGTN | Q10 | Q10 | |
| | AGTN | Q11 | Q10 | |
| Periodic | AGTN | Q12 | Q10 | |
| | AGTN | Q13 | Q10 | |
| AGTN/S Short Reversing | AGTN | Q14 | Q14 | |
| | AGTN | Q15 | Q15 | |
| | AGTN | Q16 | Q15 | |
| | AGTN | Q17 | Q14 | |
| Periodic | AGTN | Q18 | Q18 | |
| | AGTN | Q19 | Q18 | |
| Periodic | AGTN | Q20 | Q20 | This is also the first quadrupole of the AGTNY bender. |
| | AGTN | Q21 | Q20 | |
| Periodic | AGTN | Q22 | Q22 | |
| | AGTN | Q23 | Q22 | |
| Periodic | AGTN | Q24 | Q22 | |
| | AGTN | Q25 | Q22 | |

**Table 41. AGTN beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| AGTN dogleg | AGTN | Q26 | Q26 | |
| | AGTN | Q27 | Q27 | |
| | AGTN | Q28 | Q27 | |
| | AGTN | Q29 | Q26 | |
| | AGTN | B29 | B29+ B29- | |
| | AGTN | Q30 | Q30 | |
| | AGTN | Q31 | Q31 | |
| | AGTN | Q32 | Q31 | |
| | AGTN | Q33 | Q30 | |
| | AGTN | B33 | B33+ B29- | |
| | AGTN | Q34 | Q26 | |
| | AGTN | Q35 | Q27 | |
| | AGTN | Q36 | Q27 | |
| | AGTN | Q37 | Q26 | |
| Periodic | AGTN | Q38 | Q36 | |
| | AGTN | Q39 | Q36 | |
| Periodic | AGTN | Q40 | Q36 | |
| | AGTN | Q41 | Q36 | |
| Periodic | AGTN | Q42 | Q36 | This is also the first quadrupole of the AGTNF bender. |
| | AGTN | Q43 | Q36 | |

AGTN continues

**Table 41. AGTN beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Crossing | AGTN | Q44 | Q44 | This is also the first quadrupole of the AGTNI bender. |
| | AGTN | Q45 | Q45 | |
| | AGTN | Q46 | Q46 | |
| | AGTN | Q47 | Q47 | |
| | AGTN | Q48 | Q47 | |
| | AGTN | Q49 | Q46 | |
| | AGTN | Q50 | Q45 | |
| | ILE1 | Q5 | Q5 | Existing ISAC device |

**Table 42. AGTNI beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AGTN | Q44 | Q42 | |
| | AGTNI | B1 | B1+ B1- | |
| | AGTNI | Q1 | Q1 | |
| | AGTNI | Q2 | Q2 | |
| | AGTNI | Q3 | Q2 | |
| | AGTNI | Q4 | Q1 | |
| | ILE2 | B1 | | Existing ISAC device |
| | ILE2 | Q1 | | Existing ISAC device |

**Table 43. AGTNY beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AGTN | Q20 | Q20 | This cannot be paired with the last quadrupole of the bender because we can cross the beams. |
| | AGTNY | B1 | B1+ B1- | |
| | AGTNY | Q1 | Q1 | |
| | AGTNY | Q2 | Q2 | |
| | AGTNY | Q3 | Q2 | |
| | AGTNY | Q4 | Q1 | |
| | AGTNY | B4 | B4+ B1- | |
| | AGTY | Q13 | AGTY:Q10 | This cannot be paired with the first quadrupole of the bender because we can cross the beams. |

**Table 44. AGTS beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AGTW | Q10 | Q10 | |
| | AGTS | B1 | B1+ B1- | |
| | AGTS | Q1 | Q1 | |
| | AGTS | Q2 | Q2 | |
| | AGTS | Q3 | Q2 | |
| | AGTS | Q4 | Q1 | |
| | AGTS | B4 | B4+ B1- | |
| | AGTS | Q5 | AGTW:Q10 | |
| Periodic | AGTS | Q6 | Q6 | |
| | AGTS | Q7 | Q6 | |
| Periodic | AGTS | Q8 | Q6 | |
| | AGTS | Q9 | Q6 | |

**Table 44. AGTS beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Periodic | AGTS | Q10 | Q10 | |
| | AGTS | Q11 | Q10 | |
| Periodic | AGTS | Q12 | Q10 | |
| | AGTS | Q13 | Q10 | |
| AGTN/S Short Reversing | AGTS | Q14 | Q14 | |
| | AGTS | Q15 | Q15 | |
| | AGTS | Q16 | Q15 | |
| | AGTS | Q17 | Q14 | |
| Periodic | AGTS | Q18 | Q18 | |
| | AGTS | Q19 | Q18 | |
| Periodic | AGTS | Q20 | Q20 | |
| | AGTS | Q21 | Q20 | |
| Periodic | AGTS | Q22 | Q22 | |
| | AGTS | Q23 | Q22 | |
| Periodic | AGTS | Q24 | Q22 | |
| | AGTS | Q25 | Q22 | |
| Crossing (pre-buncher) | AGTS | Q26 | Q26 | |
| | AGTS | Q27 | Q27 | |
| | AGTS | Q28 | Q28 | |
| | AGTS | Q29 | Q29 | The ARIEL pre-buncher for the ISAC-I RFQ (RFQ1) is located in the middle between Q29 and Q30 |
| | AGTS | Q30 | Q29 | |
| | AGTS | Q31 | Q28 | |
| | AGTS | Q32 | Q27 | |
| | AGTS | Q33 | Q26 | |

AGTS continues

**Table 44. AGTS beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AGTS | Q34 | Q34 | |
| | AGTS | B34 | B34+ B34- | |
| | AGTS | Q35 | Q35 | |
| | AGTS | Q36 | Q36 | |
| | AGTS | Q37 | Q36 | |
| | AGTS | Q38 | Q35 | |
| | AGTS | B38 | B38+ B34- | |
| | AGTS | Q39 | Q34 | |
| Periodic | AGTS | Q40 | Q41 | |
| | AGTS | Q41 | Q41 | |
| Periodic | AGTS | Q42 | Q42 | |
| | ILT | Q47 | Q47 | Existing ISAC device |

**Table 45. AGTW beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AVTW | Q15 | Q15 | |
| | AVTWS | B1 | B1+ B1- | |
| | AVTWS | Q1 | Q1 | |
| | AVTWS | Q2 | Q2 | |
| | AVTWS | Q3 | Q2 | |
| | AVTWS | Q4 | Q1 | |
| | AVTWS | B4 | B4+ B1- | |
| | AGTW | Q1 | AVTW:Q15 | |
| Periodic | AGTW | Q2 | Q2 | |
| | AGTW | Q3 | Q2 | |
| AGTW/C/E/Y Long periodic | AGTW | Q4 | Q4 | |
| | AGTW | Q5 | Q4 | |

**Table 45. AGTW beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Periodic | AGTW | Q6 | Q2 | |
| | AGTW | Q7 | Q2 | |
| Periodic | AGTW | Q8 | Q2 | |
| | AGTW | Q9 | Q2 | |
| Periodic | AGTW | Q10 | Q10 | |
| | AGTW | Q11 | Q10 | |
| Implantation Station Matching | AGTW | Q12 | Q12 | |
| | AGTW | Q13 | Q13 | |
| | AGTW | Q14 | Q14 | |
| | AGTW | Q15 | Q15 | |

**Table 46. AGTY beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | AGTS | Q20 | Q20 | |
| | AGTY | B1 | B1+ B1- | |
| | AGTY | Q1 | Q1 | |
| | AGTY | Q2 | Q2 | |
| | AGTY | Q3 | Q2 | |
| | AGTY | Q4 | Q1 | |
| | AGTY | B4 | B4+ B1- | |
| | AGTY | Q5 | AGTS:Q20 | |
| Periodic | AGTY | Q6 | Q6 | |
| | AGTY | Q7 | Q6 | |
| Periodic | AGTY | Q8 | Q6 | |
| | AGTY | Q9 | Q6 | |
| AGTW/C/E/Y Long periodic | AGTY | Q10 | Q10 | |
| | AGTY | Q11 | Q10 | |

**Table 46. AGTY beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Periodic | AGTY | Q12 | Q10 | |
| | AGTY | Q13 | Q10 | |
| Yield Station Matching | AGTY | Q14 | Q14 | |
| | AGTY | Q15 | Q15 | |
| | AGTY | Q16 | Q16 | |
| | AGTY | Q17 | Q17 | |

**Table 47. IGTA beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Periodic | ILT | Q42 | Q42 | Existing ISAC device |
| | IGTA | Q1 | Q25 | |
| Periodic | IGTA | Q2 | Q2 | |
| | IGTA | Q3 | Q2 | |
| Periodic | IGTA | Q4 | Q2 | |
| | IGTA | Q5 | Q2 | |
| Periodic | IGTA | Q6 | Q3 | |
| | IGTA | Q7 | Q3 | |
| Periodic | IGTA | Q8 | Q8 | |
| | IGTA | Q9 | Q8 | |
| Periodic | IGTA | Q10 | Q8 | |
| | IGTA | Q11 | Q8 | |
| Periodic | IGTA | Q12 | Q12 | |
| | IGTA | Q13 | Q12 | |
| Periodic | IGTA | Q14 | Q12 | |
| | IGTA | Q15 | Q12 | |
| IGTA Short Periodic | IGTA | Q16 | Q16 | |
| | IGTA | Q17 | Q16 | |

**Table 47. IGTA beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Periodic | IGTA | Q18 | Q18 | |
| | IGTA | Q19 | Q18 | |
| Periodic | IGTA | Q20 | Q18 | |
| | IGTA | Q21 | Q18 | |
| Bender | IGTA | Q22 | Q22 | |
| | IGTA | B22 | B22+ B22- | |
| | IGTA | Q23 | Q23 | |
| | IGTA | Q24 | Q24 | |
| | IGTA | Q25 | Q24 | |
| | IGTA | Q26 | Q23 | |
| | IGTA | B26 | B26+ B22- | |
| | AGTC | Q29 | Q29 | |

**Table 48. IGTAE beam transport line optics elements at ground level.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | IGTA | Q18 | Q18 | |
| | IGTAE | B1 | B1+ B1- | |
| | IGTAE | Q1 | Q1 | |
| | IGTAE | Q2 | Q2 | |
| | IGTAE | Q3 | Q2 | |
| | IGTAE | Q4 | Q1 | |
| | IGTAE | B4 | B4+ B1- | |
| | AGTE | Q9 | AGTE:Q6 | |

# 6 ARIEL-II project installation phases

The RIB transport system beam lines are going to be installed in three phases described in the following paragraphs.

## 6.1 Phase-1

Phase-1 installation, also referred as AETE to β-NMR, aims at delivering beam from the electron target station to the ISAC low energy experimental area using only the pre-separator magnet for mass selection.

This phase foresees the installation of the following beam line sections (see Figure 23):

1. Target hall and B2 level
    a. ALTC
    b. ALTE up to Q31
    c. ALTS up to Q12
2. Vertical section:
    a. AVTW
    b. AVTWS
3. G level:
    a. AGTN
    b. AGTNI
    c. AGTNY (if yield station required for AETE beams)
    d. AGTY from Q13 to Q17 (if yield station required for AETE beams)

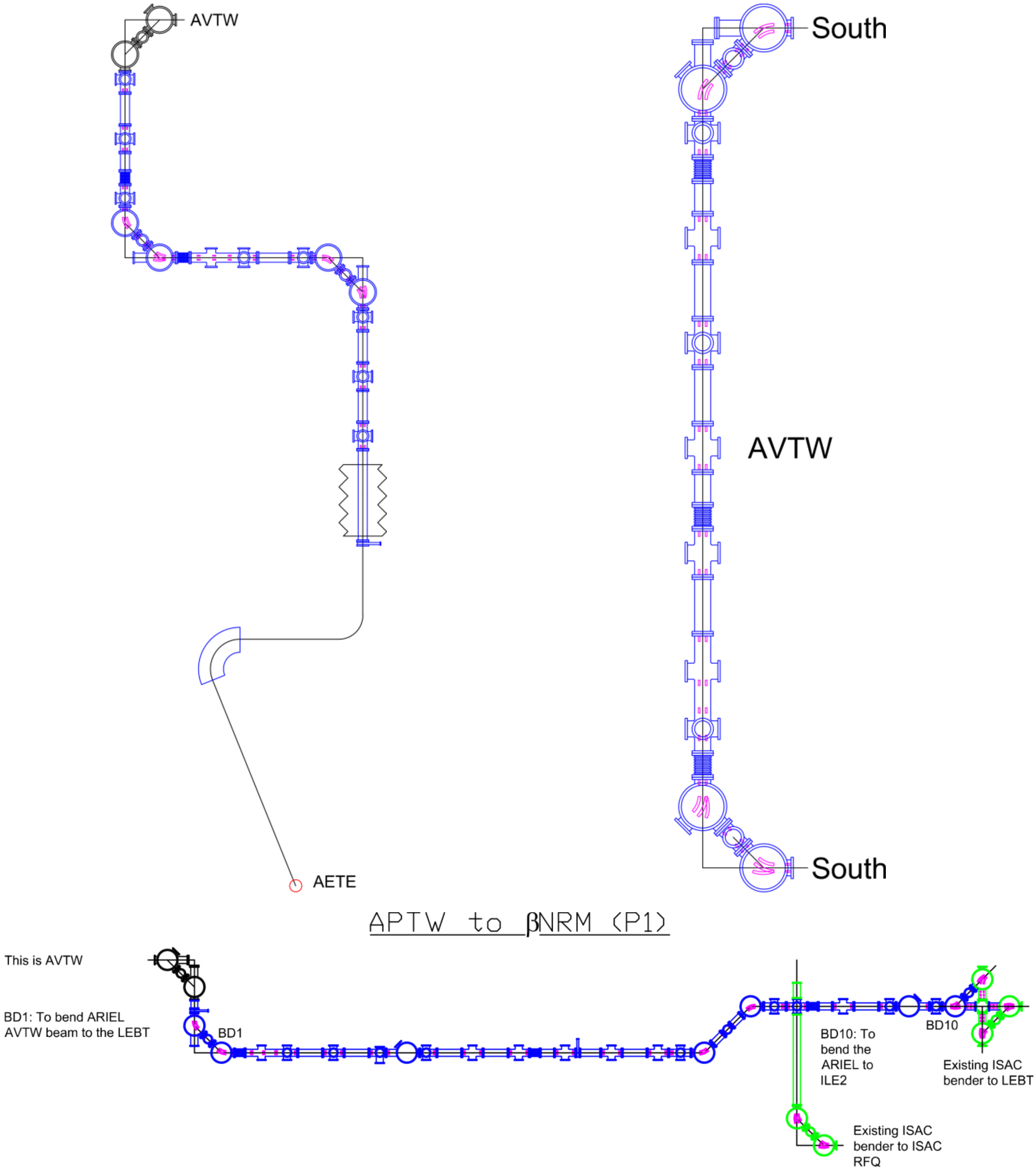


**Figure 23. Phase-1 beam lines layout: Target hall and B2 level (top left), Vertical section (top right) and G level (bottom)**

## 6.2 Phase-3

Phase-3 installation (there is no installation in the phase 2 of the ARIEL-II project as far as RIB transport system) aims at delivering AETE beam through the HRS to low or medium/high energy and charge breeding ISAC beam with the EBIS for medium/high energy post acceleration.

This phase foresees the installation of the following beam line sections (see Figure 24) in addition to the one installed in Phase-1:

1. Target hall and B2 level
   a. AHRS
   b. AHRSN (if charge breeding required for AETE beams)
   c. ALTN from Q16 (if charge breeding required for AETE beams)
   d. ALTNC
   e. ALTS up to Q20
   f. ALTSW
   g. ALTW from Q38
2. Vertical section:
   a. AVTE (if charge breeding required for AETE beams)
   b. AVTEN (if charge breeding required for AETE beams)
3. G level:
   a. AGTE from Q6
   b. AGTNC
   c. AGTW up to Q10
   d. AGTS
   e. AGTNY (unless already installed in Phase-1)
   f. AGTY (completion if partially installed in Phase-1)
   g. IGTA up to Q18
   h. IGTAE

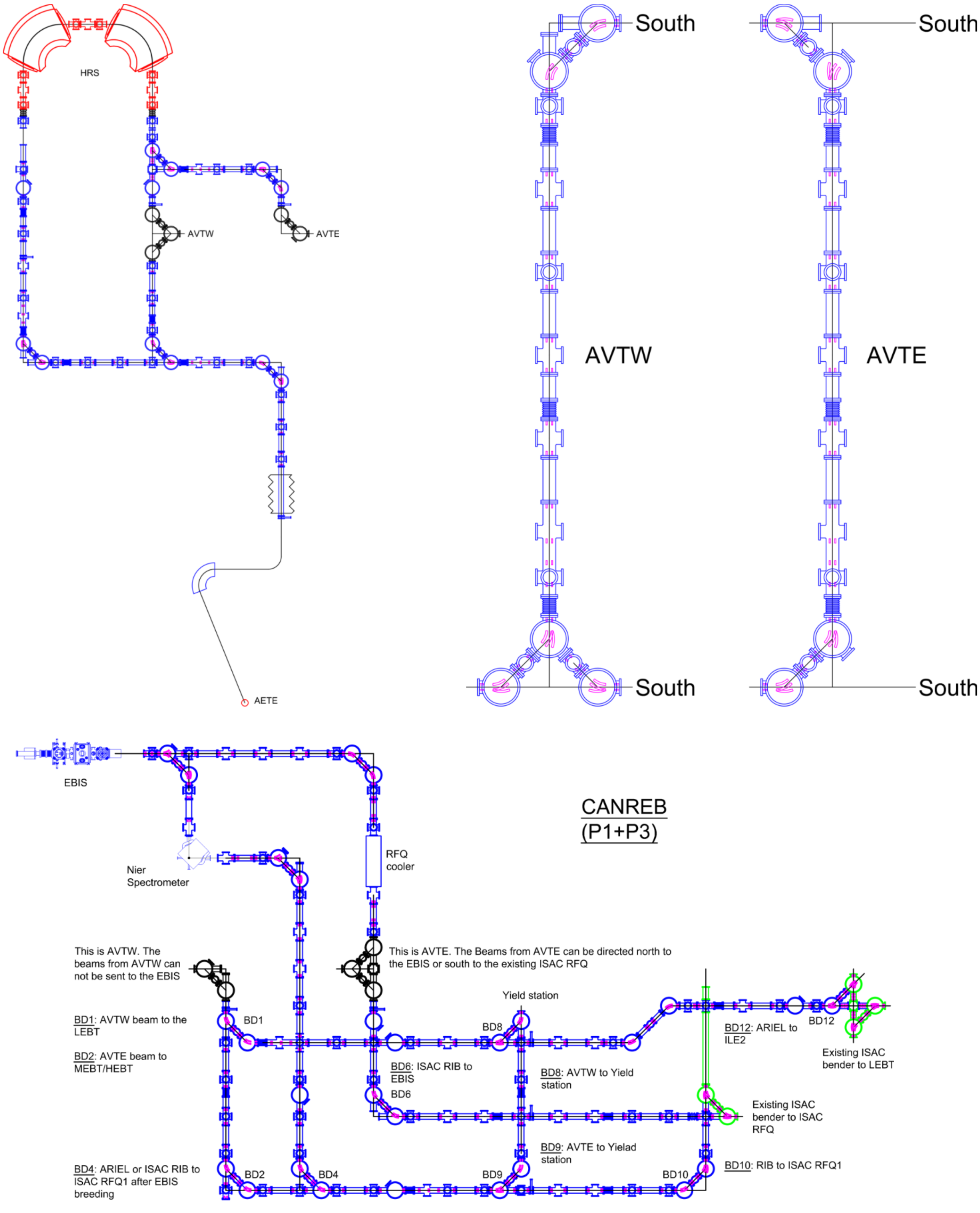


**Figure 24. Phase-3 beam lines layout: Target hall and B2 level (top left), Vertical line (top right) and G level (bottom)**

## 6.3 Phase-4

Phase-4 installation is the completion of the RIB transport system. In fact some of the sections included in this phase (like ALTWM) and in Phase-3 (like ALTSW) are going to be pre-installed during the prototype development (see chapter 9).
This phase foresees the installation of the following beam line sections (see Figure 25) in addition to the one installed in Phase-3:

A. Target hall and B2 level
   a. AHRSN (unless already installed in Phase-3)
   b. ALTE from Q32
   c. ALTN up to Q15 (or in full unless already partially installed in Phase-3)
   d. ALTS from Q21
   e. ALTW up Q37
   f. ALTWN
   g. ALTWM
   h. AMRS
B. Vertical section:
   a. AVTE (unless already installed in Phase-3)
   b. AVTEN (unless already installed in Phase-3)
   c. AVTES
C. G level:
   a. AGTE up to Q6
   b. AGTW from Q11 (implantation station)
   c. IGTA from Q19
   d. AGTNF

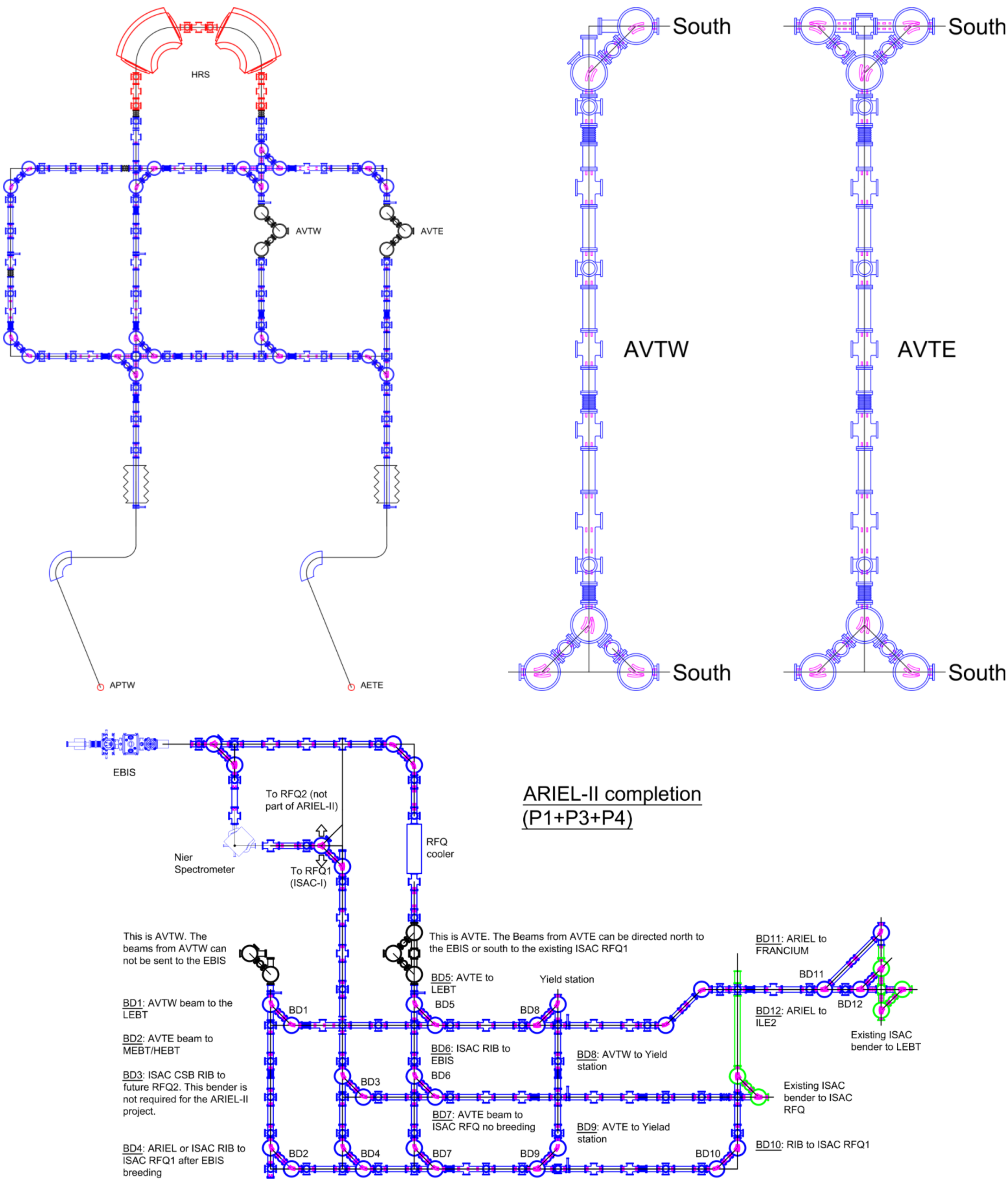


**Figure 25. Phase-4 beam lines layout: Target hall and B2 level (top left), Vertical line (top right) and G level (bottom)**

# 7 Grounding layout

The medium and high resolution separators (respectively MRS and HRS) must reference the same ground shared by the two ARIEL target stations. Figure 26 represents the conceptual design of the mass separator room switchyard ground. Two ground levels are identified: target stations ground (red) and building ground (blue). Ground isolation (ceramic insulator) preliminary locations are also identified. Specific details of the grounding are described in the "ARIEL RIB Signal Reference Electrical Grounding" document-120821.

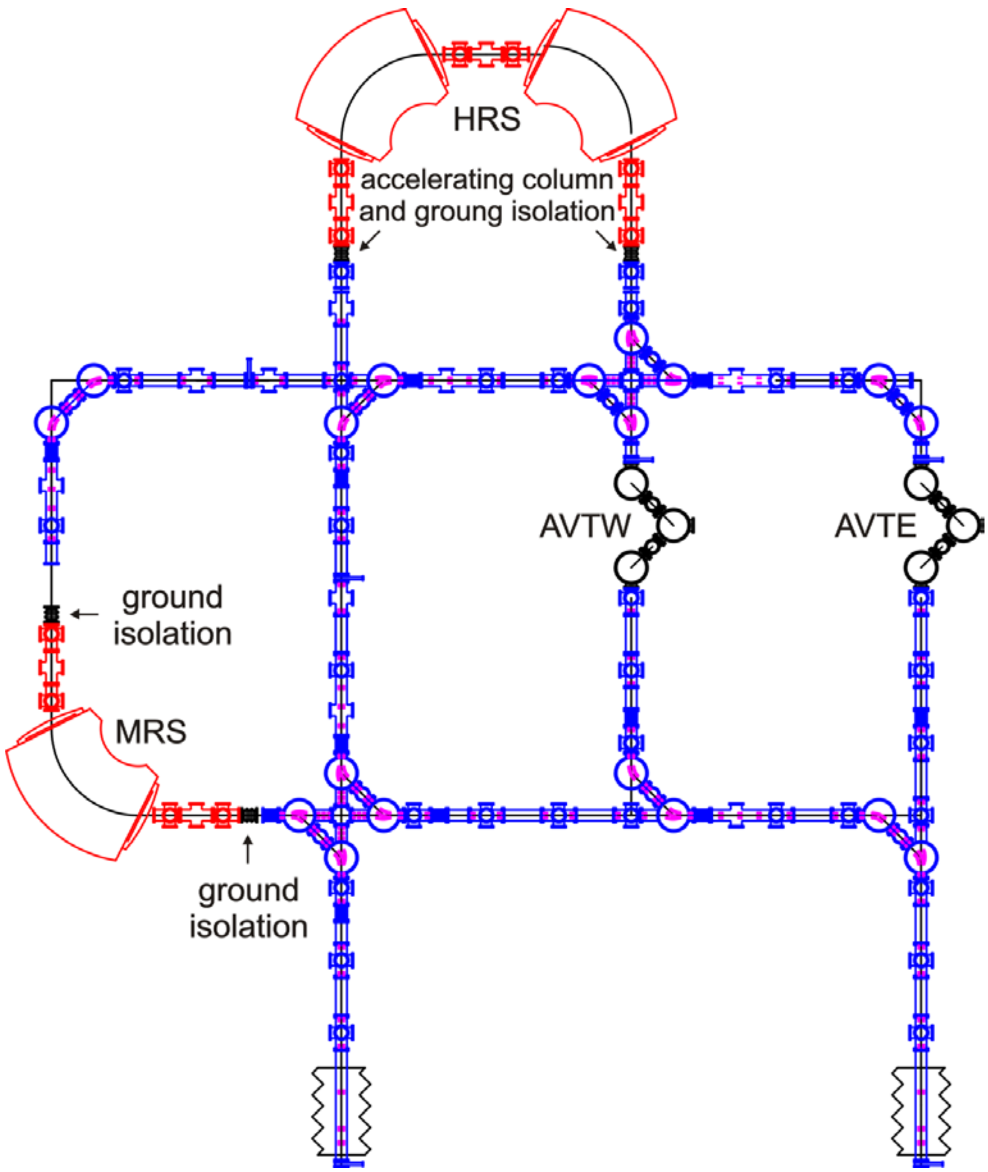


**Figure 26. Grounding concept of the ARIEL mass separator room switchyard. The ARIEL target station ground is identified in red while the building ground is identified in blue.**

# 8 Vacuum envelope

The required vacuum is $10^{-8}$ Torr. This is to reduce beam losses due to interaction with the residual gas. For a 11Li beam at 2 keV/u a $10^{-6}$ Torr gives a 20% loss in 50 m of beam line while $10^{-8}$ Torr gives a 0.2% beam loss (based on design note TRI-DN-98-07 [1]).

The vacuum envelope is intended to be composed of few building blocks as represented in Figure 27. These building blocks are customized starting from commercially available components. They use a 6 inches tube with an 8 inches Conflat® flanges and copper gasket seals. Ports are included to insert diagnostic, high voltage feed trough and vacuum equipment (pumps and gauges).

Figure 28 represents the beam line portion that connect the APTW target station to the ISAC low energy beam transport line via the AVTW vertical section. The same building blocks of Figure 27 are used to build the section while more details are given.

Both representations (Figure 28 and Figure 27) belong to an early design developed to establish the concept and they are intended for explanation only.

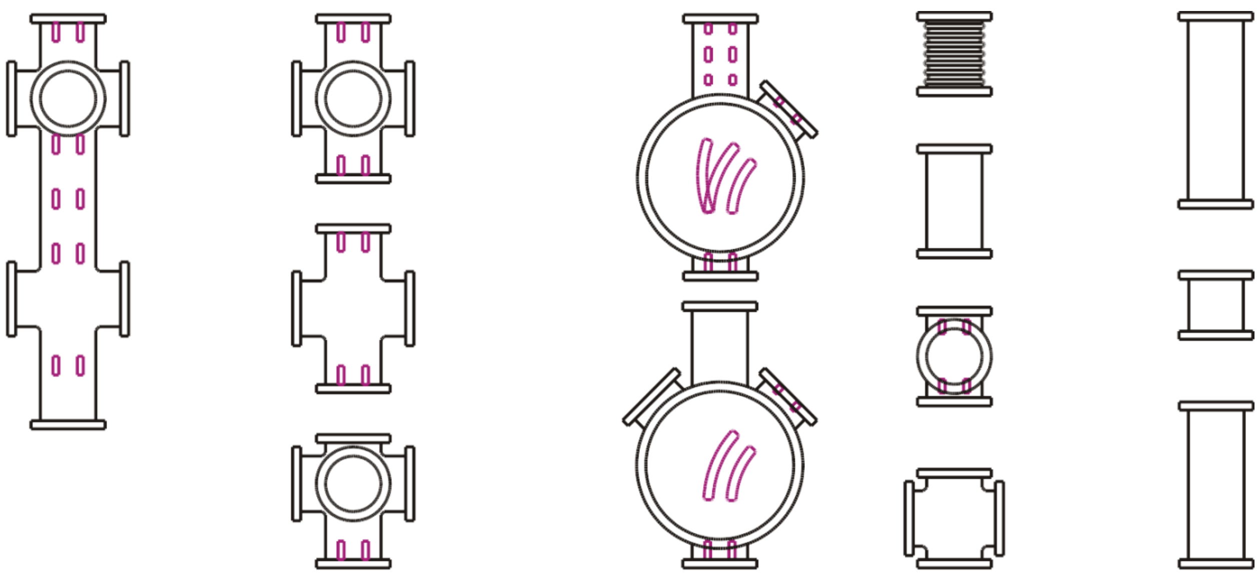

**Figure 27. Beam line vacuum envelope components.**

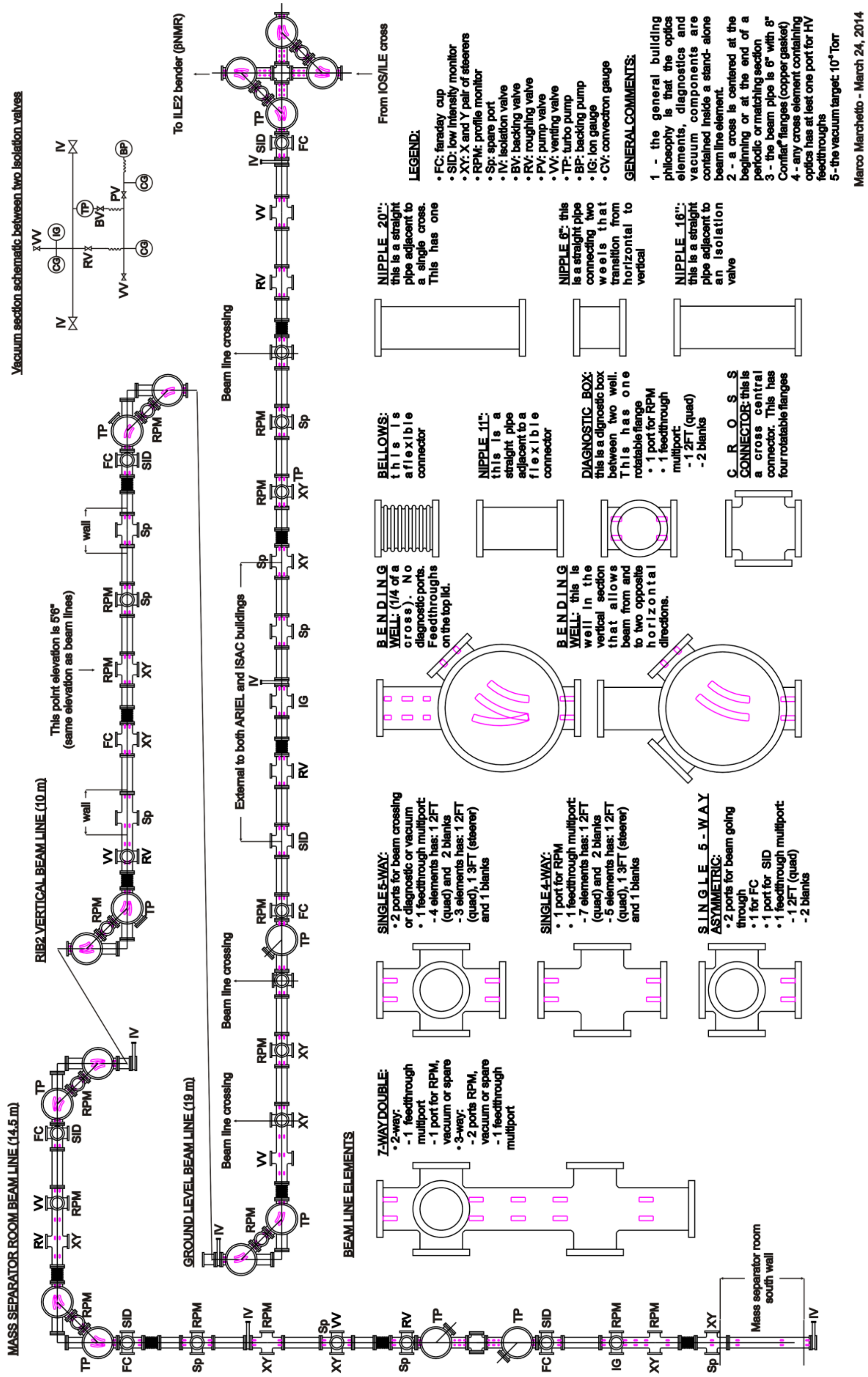


**Figure 28. Beam line details of the beam line connecting APTW to LEBT via AVTW.**

# 9 Prototype section

In order to validate the mechanical design of the vacuum envelope, a prototype section is going to be built and installed prior to Phase-1. The prototype section is a subset of the beam line in the mass separator room (see green enclosure in Figure 29) and it contains the optics elements listed in Table 49.

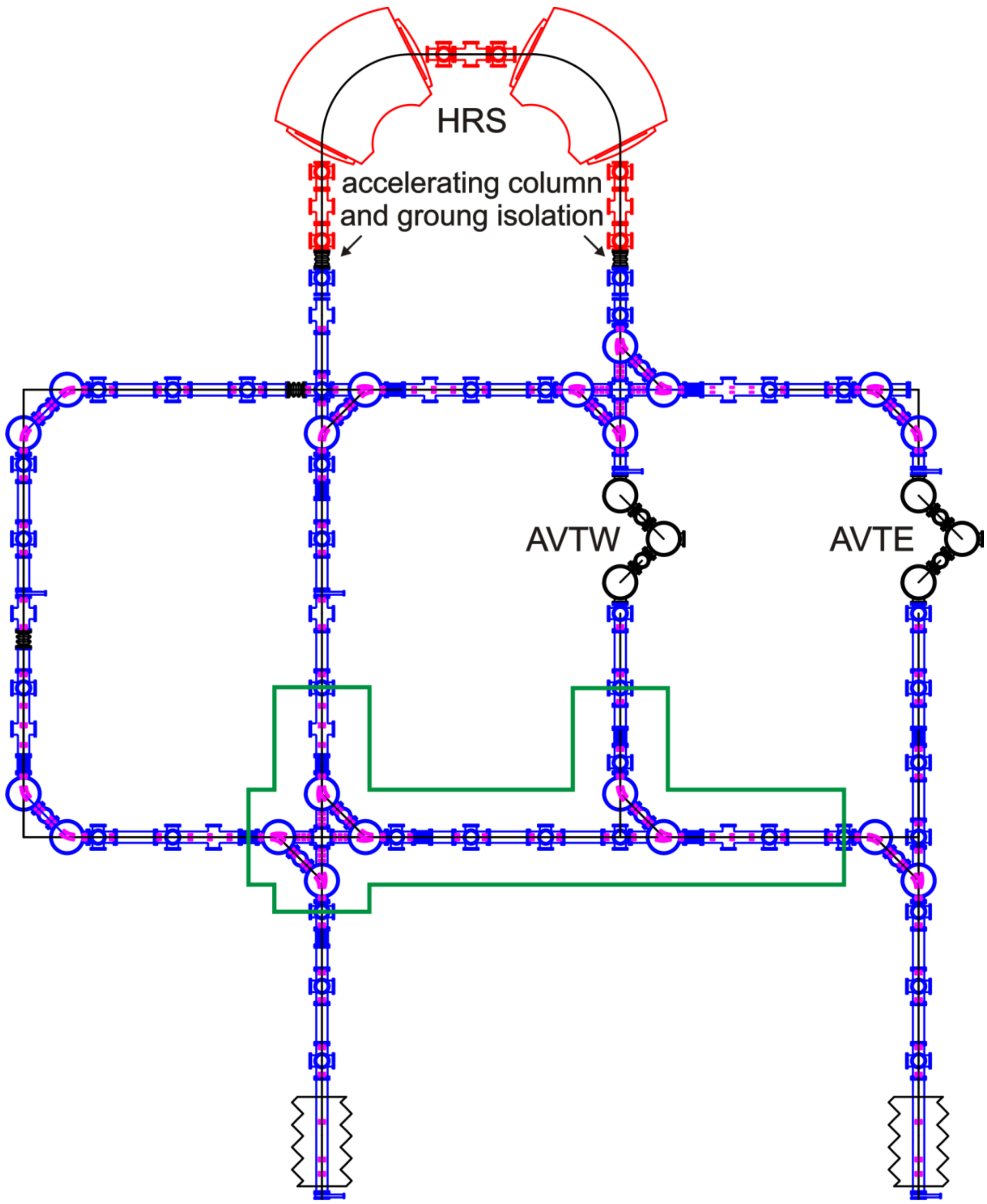


**Figure 29. Prototype section (within green boundaries) in the mass separator room.**

**Table 49. Prototype section optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Bender | ALTS | Q12 | Q12 | |
| | ALTC | B1 | B1+ B1- | |
| | ALTC | Q1 | Q1 | |
| | ALTC | Q2 | Q2 | |
| | ALTC | Q3 | Q2 | |
| | ALTC | Q4 | Q1 | |
| | ALTC | B4 | B4+ B1- | |
| | ALTC | Q5 | ALTS:Q12 | |
| Periodic | ALTC | Q6 | Q6 | |
| | ALTC | Q7 | Q6 | |
| Periodic | ALTS | Q6 | Q6 | |
| | ALTS | Q7 | Q6 | |
| Reversing | ALTS | Q8 | Q8 | |
| | ALTS | Q9 | Q9 | |
| | ALTS | Q10 | Q9 | |
| | ALTS | Q11 | Q8 | |
| Periodic | ALTS | Q12 | Q12 | This is also the first quadrupole of the ALTC bender |
| | ALTS | Q13 | Q12 | |
| Periodic | ALTS | Q14 | Q12 | |
| | ALTS | Q15 | Q12 | |
| Periodic | ALTS | Q16 | Q16 | |
| | ALTS | Q17 | Q16 | |
| Periodic | ALTS | Q18 | Q16 | |
| | ALTS | Q19 | Q16 | |

Prototype section continues

**Table 49. Prototype section optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Crossing | ALTS | Q20 | Q20 | This is also the first quadrupole of the ALTSW bender and it is independent |
| | ALTS | Q21 | Q21 | This is also the power supply for AMRS:Q3 |
| | ALTS | Q22 | Q22 | |
| | ALTS | Q23 | Q23 | |
| | AMRS | Q1 | ALTS:Q23 | |
| | AMRS | Q2 | ALTS:Q22 | |
| | AMRS | Q3 | ALTS:Q21 | |
| | AMRS | Q4 | Q4 | This is also the last quadrupole of the ALTSM bender and it is independent |
| Bender | ALTS | Q20 | Q20 | This cannot be paired with the last quadrupole of the bender because we can cross the beams. |
| | ALTSW | B1 | B1+ B1- | |
| | ALTSW | Q1 | Q1 | |
| | ALTSW | Q2 | Q2 | |
| | ALTSW | Q3 | Q2 | |
| | ALTSW | Q4 | Q1 | |
| | ALTSW | B4 | B4+ B1- | |
| | ALTW | Q38 | Q38 | This cannot be paired with the first quadrupole of the bender because we can cross the beams. |
| Crossing | ALTW | Q31 | Q31 | This is also the first quadrupole of the ALTWM bender and it is independent |
| | ALTW | Q32 | Q32 | |
| | ALTW | Q33 | Q33 | |
| | ALTW | Q34 | Q34 | |
| | ALTW | Q35 | Q34 | |
| | ALTW | Q36 | Q33 | |
| | ALTW | Q37 | Q32 | |
| | ALTW | Q38 | Q38 | This is also the last quadrupole of the ALTSW bender and it is independent |

**Table 49. Prototype section optics elements in the mass separator room.**

| Section type | Element EPICS name | | PS series | Note |
|---|---|---|---|---|
| Reversing | ALTW | Q39 | Q39 | |
| | ALTW | Q40 | Q40 | |
| | ALTW | Q41 | Q40 | |
| | ALTW | Q42 | Q39 | |
| Bender | ALTW | Q31 | Q31 | This cannot be paired with the last quadrupole of the bender because we can cross the beams. |
| | ALTWM | B1 | B1+ B1- | |
| | ALTWM | Q1 | Q1 | |
| | ALTWM | Q2 | Q2 | |
| | ALTWM | Q3 | Q2 | |
| | ALTWM | Q4 | Q1 | |
| | ALTWM | B4 | B4+ B1- | |
| | AMRS | Q4 | Q4 | This cannot be paired with the first quadrupole of the bender because we can cross the beams. |

# 10 Diagnostics

A layout of the diagnostic for the B2 level and the vertical section is represented respectively in Figure 30 and Figure 31.

The absolute location and EPICS name for the diagnostic is going to be provided in the "ARIEL RIB transport diagnostic layout" spreadsheet document-130097.

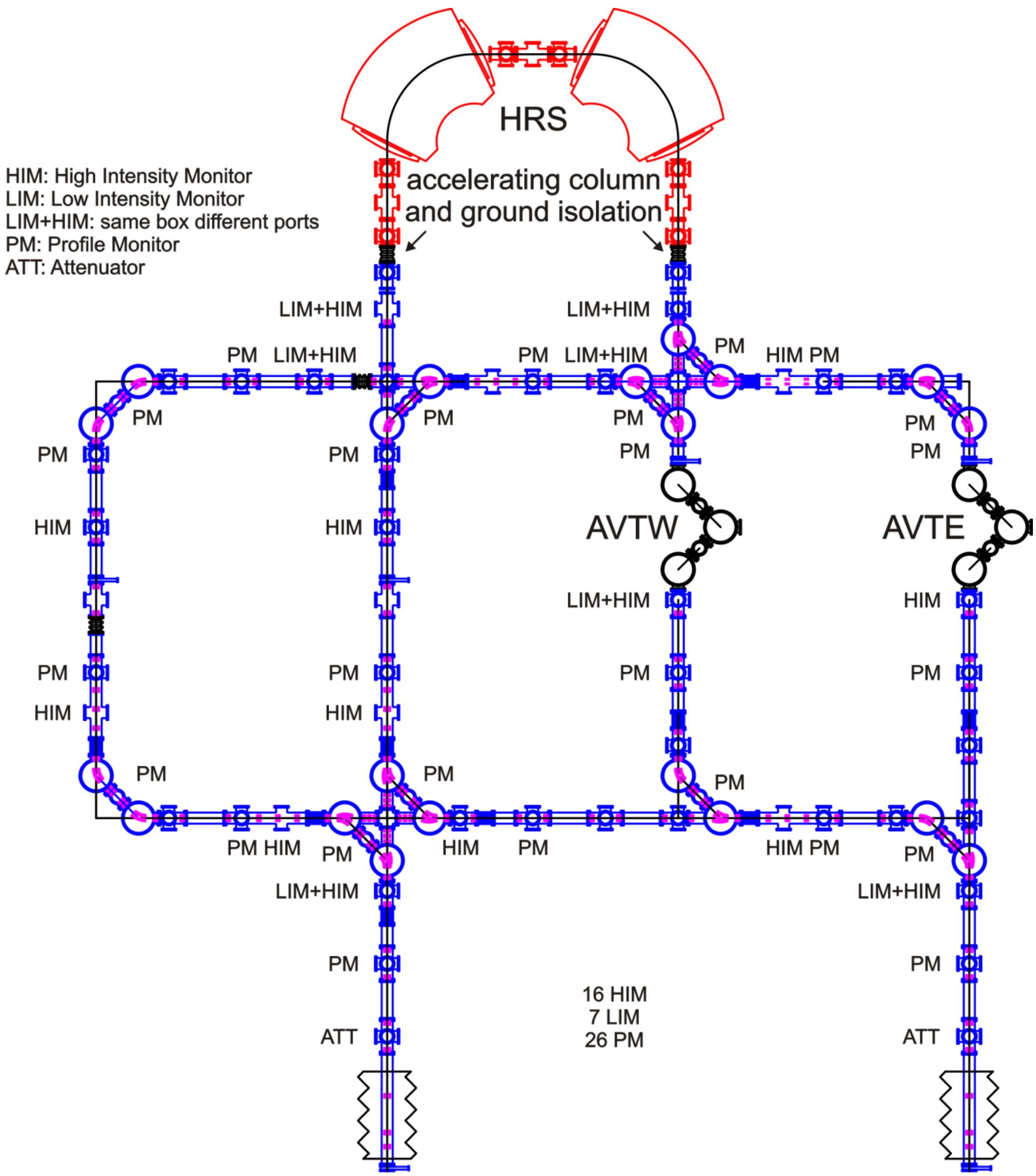


**Figure 30. Preliminary layout of the diagnostic at B2 level.**

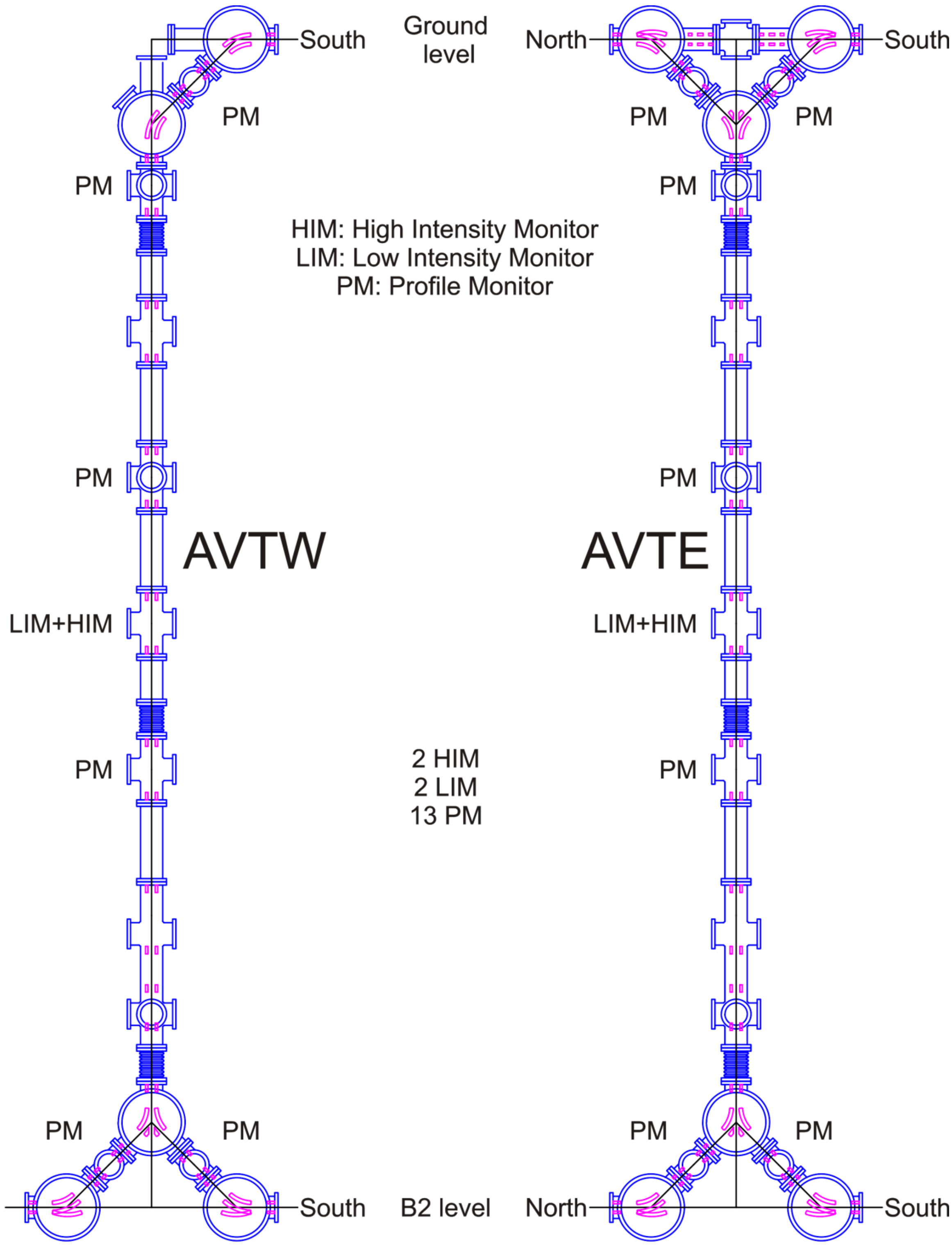


**Figure 31. Preliminary layout of the diagnostic in the vertical section.**

# 11 Electrical and mechanical tolerances

The electrical and mechanical tolerances of the beam line elements are based on the design note TRI-DN-97-11 [2] . Here we report the tolerances (converted to mm) from the summary table presents in that document:

**Table 50. Electrical and mechanical tolerances of the electrostatic optic elements: $\Delta x$ is the tolerance in the transverse position, $\Delta z$ is the tolerance in the longitudinal position, $\psi$ is the roll angle and $\Delta V$ is the tolerance on the voltage.**

| Element | $\Delta x$[5] (mm) | $\Delta z$ (mm) | $\psi$ (mrad) | $\Delta V$ (V) |
|---|---|---|---|---|
| Periodic Cell Doublet | 0.51 | 15.24 | 10 | 28 |
| Periodic Cell Quads | 0.33 | 15.24 | 10 | 10 |
| Quads in the Bend Section | 0.20 | 8.64 | 10 | 33 |
| Cross Triplet | 0.38 | 4.83 | 10 | |
| Cross Triplet Quads | 0.18 | 4.83 | 10 | 30 |
| 45º Electrostatic Bends | 0.36 | 8.64 | 1.4 | 2.5 |

The relative tolerance on the electrostatic quadrupole aperture is $\pm 10^{-3}$. For a standard quadrupole with aperture of 50.8 mm the tolerance is circa ±50 μm.

The tolerance on the electrostatic corrector (steerer) is ±0.5 mm.

[5] Same as $\Delta y$.

# 12 Works Cited

[1] R. Baartman, "Vacuum Requirements in ISAC for ISAC2," TRIUMF internal note, TRI-DN-98-07.

[2] R. Baartman, "Tolerances in the LEBT optics," TRIUMF internal note, TRI-DN-97-11.