

OLIS Maintenance Summary by Oli S.

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TRIUMF

Abstract: Corrective maintenance of the ISAC offline ion source (OLIS) took place between January to March 2020, following the findings in TRI-BN-19-20. This report details the maintenance that was performed, what was found, what was corrected. In addition, the results of post-maintenance tuning sessions are recorded, as part of ongoing efforts to bring operational OLIS configurations in closer agreement with TRANSOPTR simulations and assumptions.

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Plan View

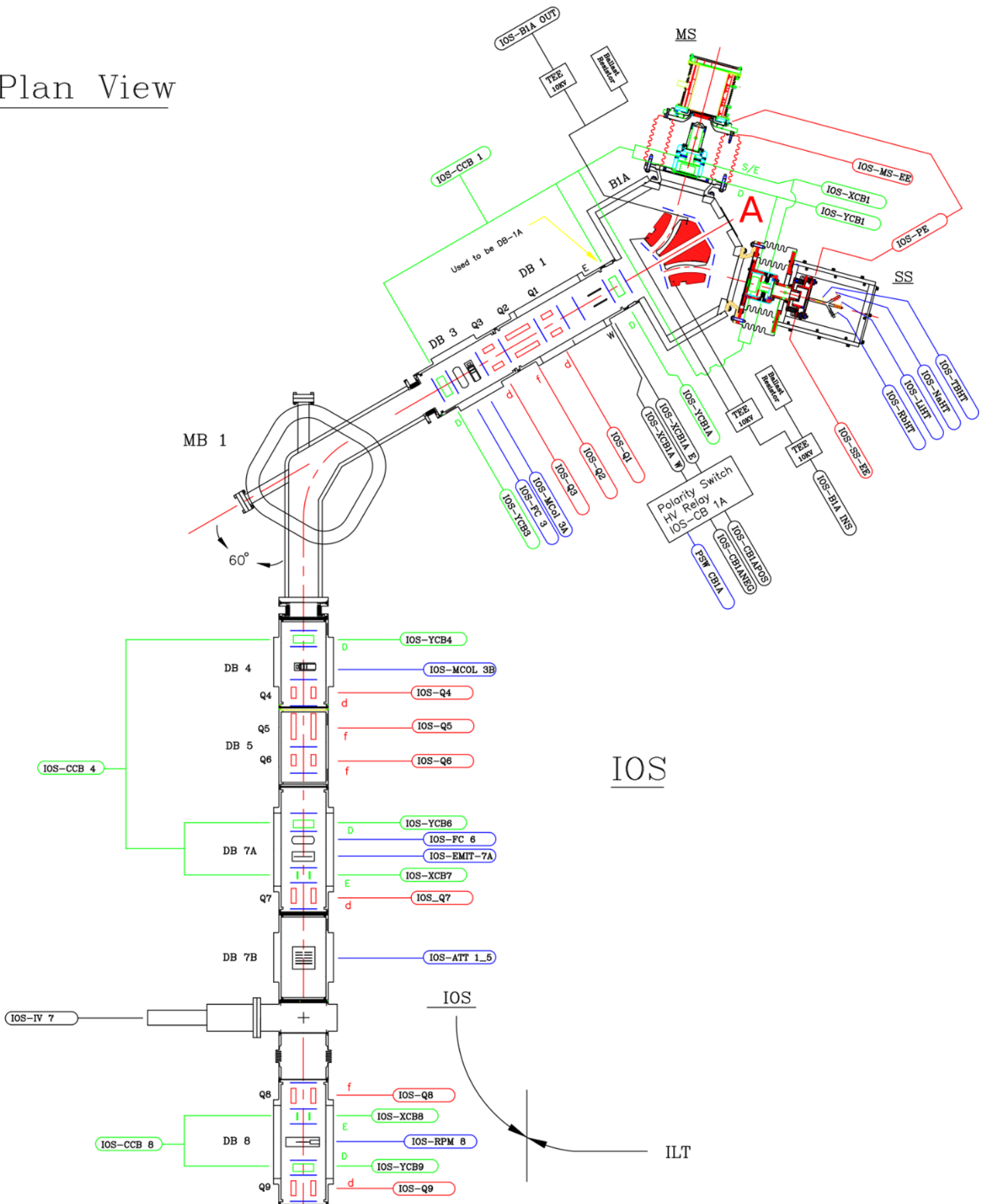


Figure 1: Sketch layout of the ISAC Offline Ion Source, showing transport optics, dipole magnet and 3-head attachment (top right). MCIS (not shown) connects to the 3-head bend at the location labeled A.

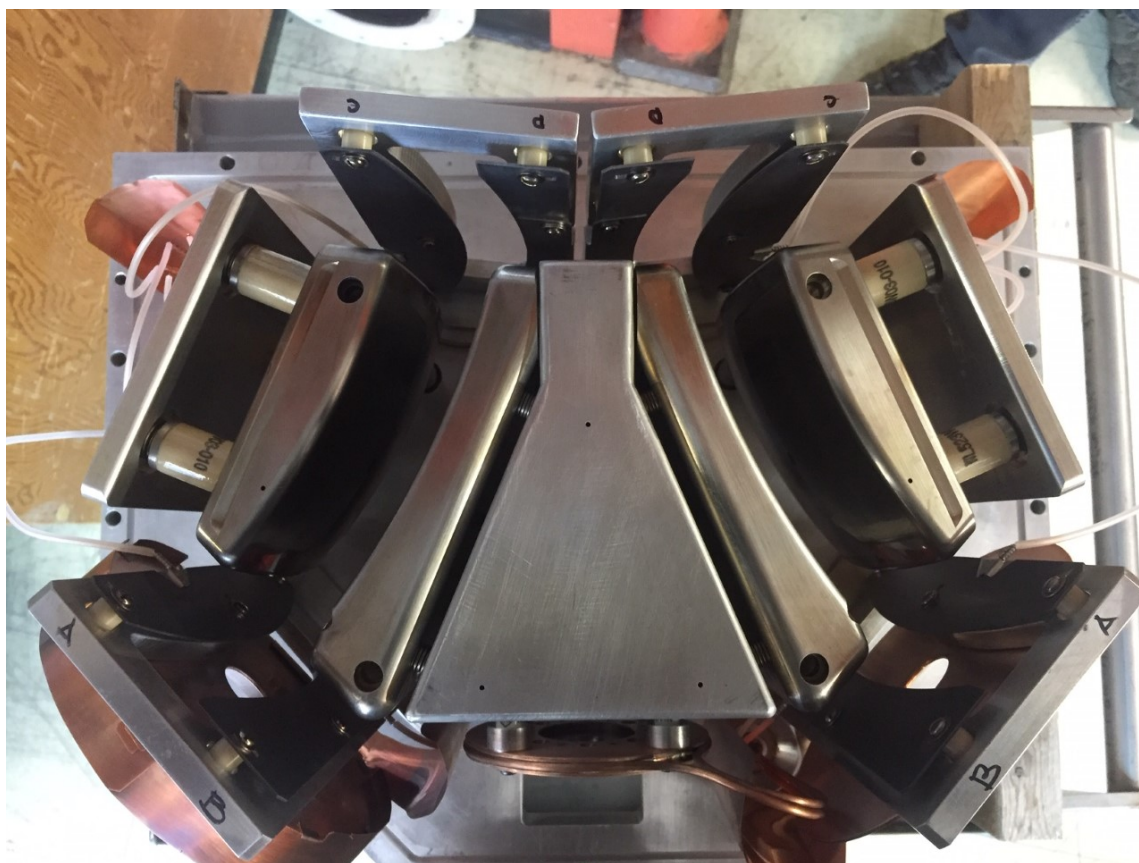


Figure 2: The OLIS spherical bender on the Stable Sources workbench. Note both sets of grounding electrodes have been opened to 1”.

1 Spherical Bender Ground Electrodes

The 36° spherical bender was removed from the OLIS beamline and inspected by Stable Sources. Both sets of grounding electrodes had previously been closed to 0.5”, in an effort to minimize skimmer and downstream element power supply readback currents. Beam Physics and Stable Sources discussed this during SAS-0746 OLIS maintenance, as shown in an email below. All ground electrodes for the spherical bender were set to 1”.

Rick Baartman <baartman@triumf.ca>
Tue 2/4/2020 1:41 PM

[...]

In attached figure,
 d = skimmer-to-electrode distance (along reference trajectory path)
 b = half the electrode gap
 s = skimmer half aperture
 η -star = distance from electrodes end plane to skimmer plane

I measured accurately from my drawing, and found:

$d = 1 \text{ inch} = 25.4 \text{ mm}$
 $b = 3/4 \text{ inch} = 19 \text{ mm}$
 $s = 1/2 \text{ inch} = 12.7 \text{ mm}$
 η -star = $3/8 \text{ inch} = 9.5 \text{ mm}$

These correspond to the blue dot on the figure, which is from Wollniks "Electrostatic Prisms" in a book edited by Septier (1967)
<https://www.sciencedirect.com/science/article/pii/B9780126369021500111>

This figure was used to design the ISIS benders in 1972, and I used the same basic design for ISAC bender design. The ISAC benders have bend radius 254mm but the ISIS bend is 381mm, but the gaps and the skimmer configuration are the same dimensions between ISIS and ISAC.

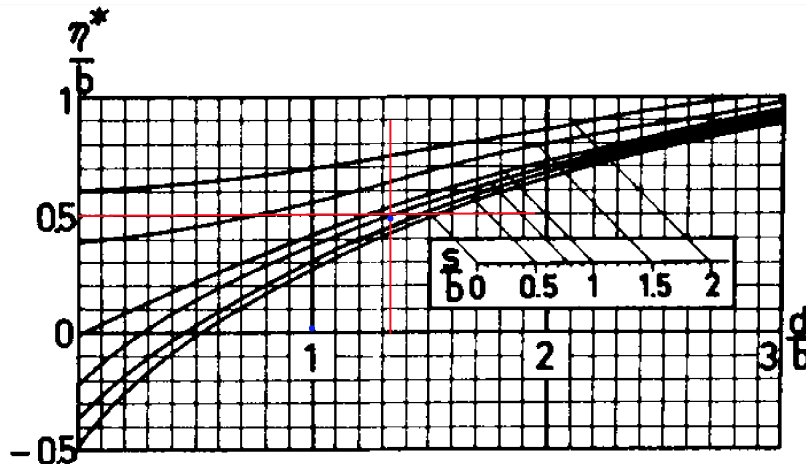


Figure 3: Wollnik's graph from Electrostatic Prisms, as annotated by Baartman.

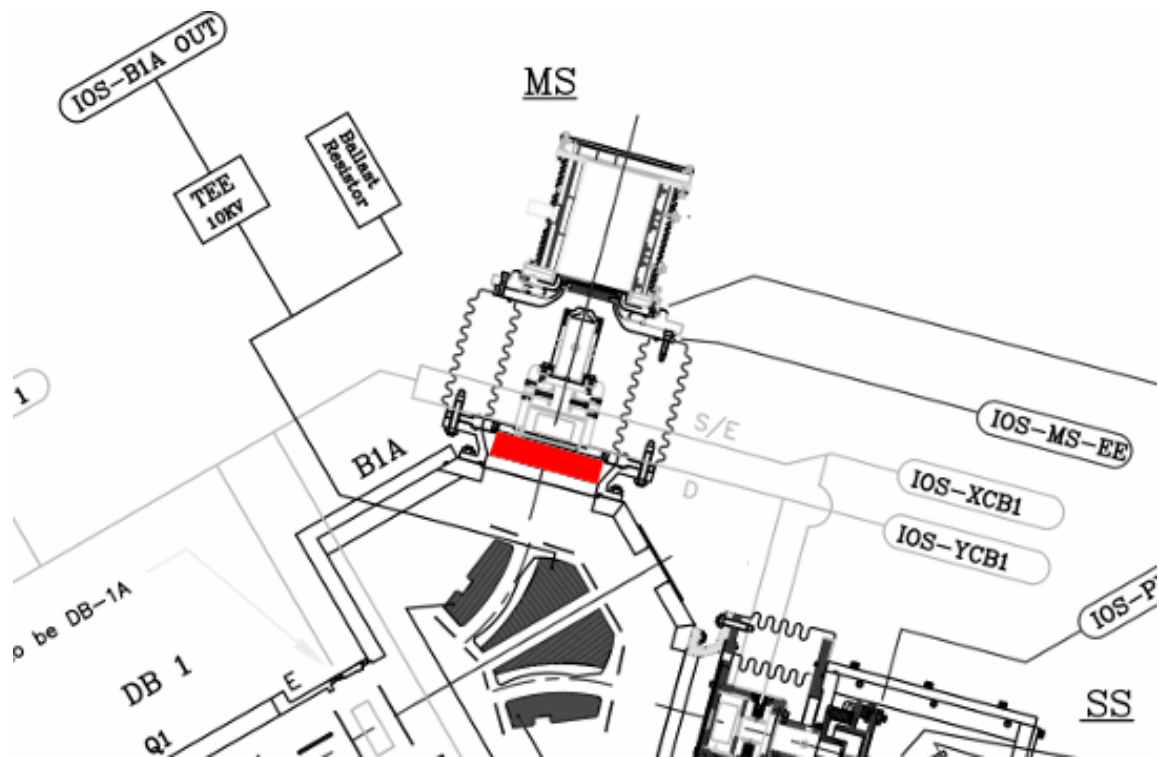


Figure 4: Location (red) of the new MWS protect collimator.

2 New MWS Protect Collimator

Initial microwave source (MWS) tuning after SAS-0476 OLIS maintenance and alignment checks were completed had found high power supply readback currents on elements up to IOS:FC3. This is likely due to increased transmission across IOS:B1A, after the spherical bender's ground electrodes were opened back up to 1". To counter this, a two-segment Ta collimator has been installed upstream of IOS:B1A, the 36° bender, facing the microwave source.

The collimator aperture is 0.5", the same horizontal constraint previously imposed by the ground electrodes. Figure 4 shows its location, Figure 5 shows the as-installed device. Note current readback connections the top of Fig. 5, which provide a relative current signal to EPICS. The previous configuration featured a 0.75" copper aperture, shown in Figure 6.

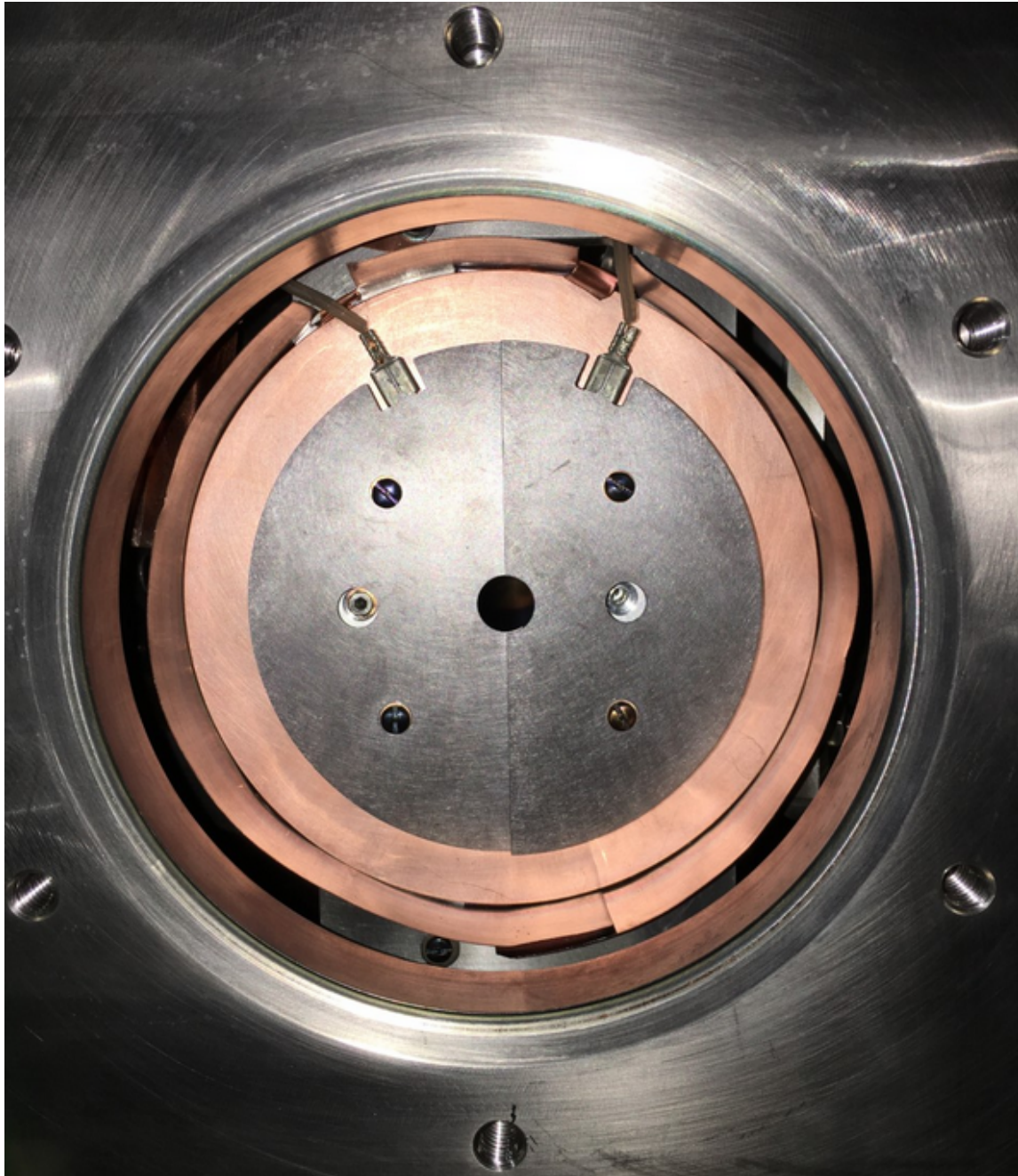


Figure 5: Two-segment Ta collimator installed upstream of IOS:B1A, the 36° bender, facing the microwave source. Note current readback connections the top, which provide a relative current signal to EPICS. The collimator is installed in the red area shown in Figure 4.



Figure 6: Original MWS-facing copper aperture on the exterior surface of IOS:B1A, shown in Figure 4.

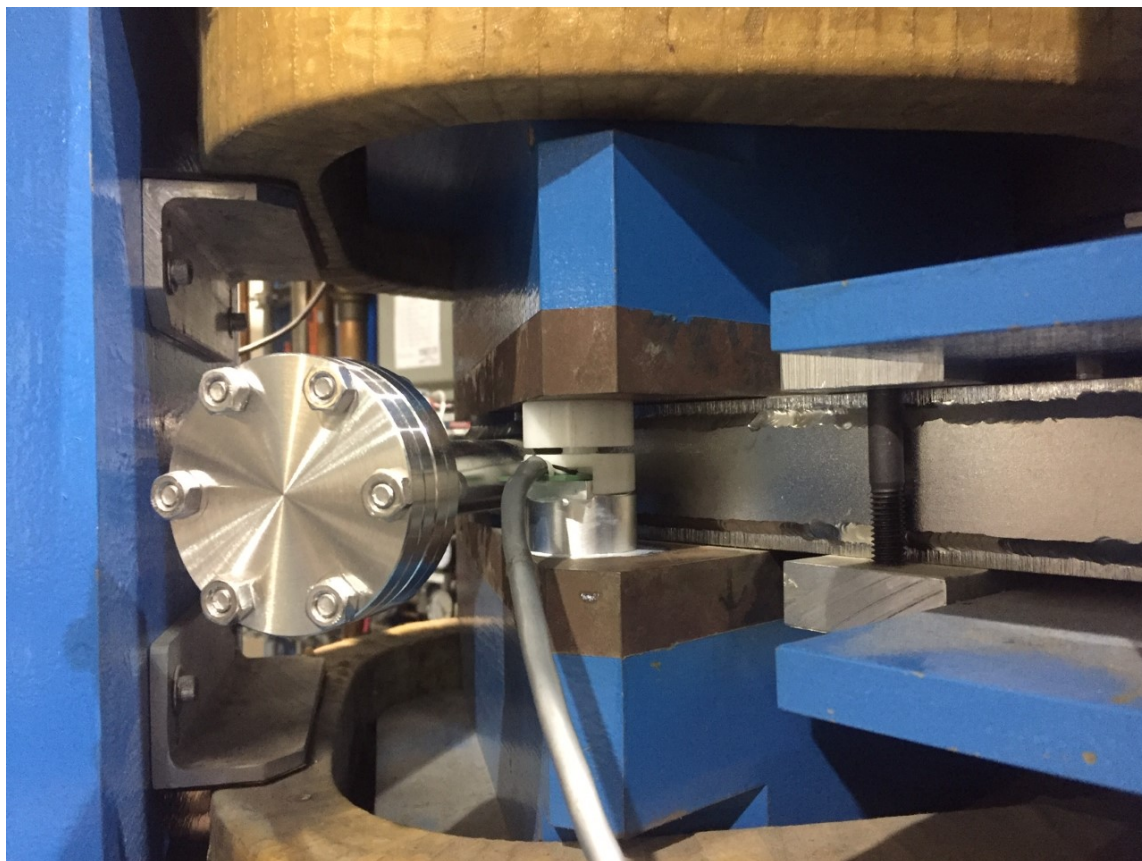


Figure 7: New OLIS dipole Hall probe, installed February 2020. Note the probe is now equidistant to the pole faces.

3 New Hall Probe Mount

Per TRI-DN-19-20, the Hall probe plastic mounting structure has been replaced with a new one which holds the probe midway between both pole faces. This is shown in Figure 7.

4 IOS:Q2 re-positioning

It was confirmed by Stable Sources that IOS:Q2 was 0.54" off its intended design position. The quadrupole has been re-located to its intended design location, equidistant from the Q1 and Q3 skimmer plates.

5 9° X-Deflector Skimmer Correction

The OLIS optics were removed from the beamline by Stable Sources and moved to the Meson Hall extension during late January 2020, where their dimensions were measured. During this time, it was observed by M. Marchetto that the molybdenum skimmers both upstream and downstream of the 2" long 9° x-deflector, which follows the spherical bender and first y-correction bender, were of the incorrect design. These are shown in Figures 8 & 9.

As a consequence of the close proximity of the y-steerer and the x-deflector, the current beamline optical mounting frame only allows a single skimmer electrode between both devices. It is likely that the previous implementation was a compromise, though it was pointed out by Marchetto that the as-found configuration exposed both x-deflector plates to beam, well before it had crossed the initial skimmer. This is significant for two reasons.

First, the x-deflector plates run with a voltage of about 10% the source bias and both electrodes have an opposite polarity. An incorrect skimmer configuration may, amongst other effects, produce an unwanted vertical electric field component. This would likely disrupt the local beam envelope and may be a significant contributing factor for the observation that most, if not all, MWS and SIS operational OLIS tunes ran both x-deflector plates off-theory and asymmetrically. Second, the central skimmer's configuration likely extended the effective length of the x-deflector, also changing its effect upon the beam, compared to the tune computation's theoretical assumption. The downstream x-deflector skimmer is also incorrect, having a circular aperture. This can also potentially change the overall properties of the deflector and may have also contributed to the OLIS tune anomalies.

For these reasons, this was further discussed by the Beam Physics group during its weekly meetings. The central skimmer's orientation is correct for IOS:YCB1, however this device typically operates with a common plate voltage of roughly 300 V, an order of magnitude less than XCB1AW/E. As such, it was decided that given the design constraint of a single central skimmer common to both devices, it was better to rotate the central skimmer 90° with respect to the upstream YCB1 skimmer, visible at the bottom of Figure 9.

Both skimmers were also replaced with tantalum duplicates of the upstream YCB1 skimmer, which possesses a narrower aperture and further restricts the solid angle from which the x-deflector plates are exposed to the beam axis. The narrower aspect is also intended to reduce any unwanted vertical field components.

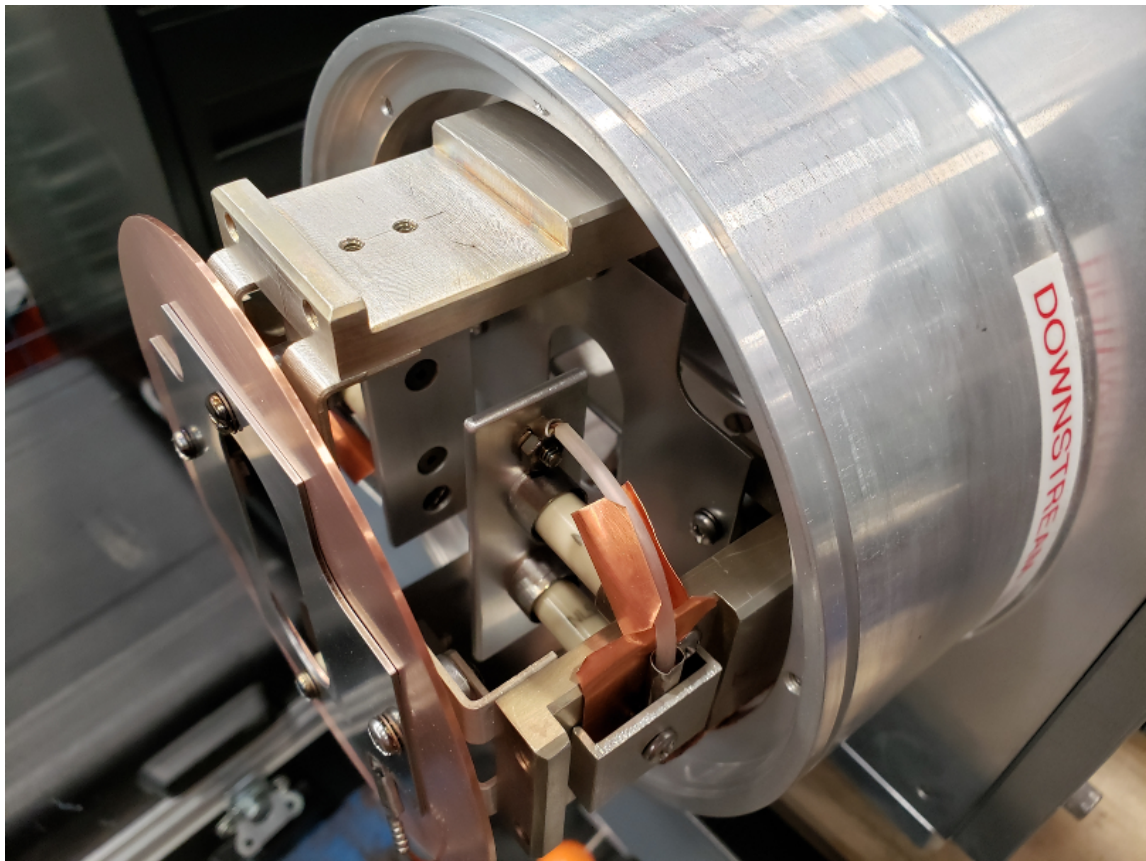


Figure 8: Steerer assembly containing IOS:YCB1 (center) and IOS:XCB1AW/E (right, only partially visible). The upstream molybdenum skimmer for the 9° x-deflector can be seen behind the vertical plates of IOS:YCB1. Note the assembly is tilted 90° on the workbench. **Photo courtesy of M. Marchetto.**

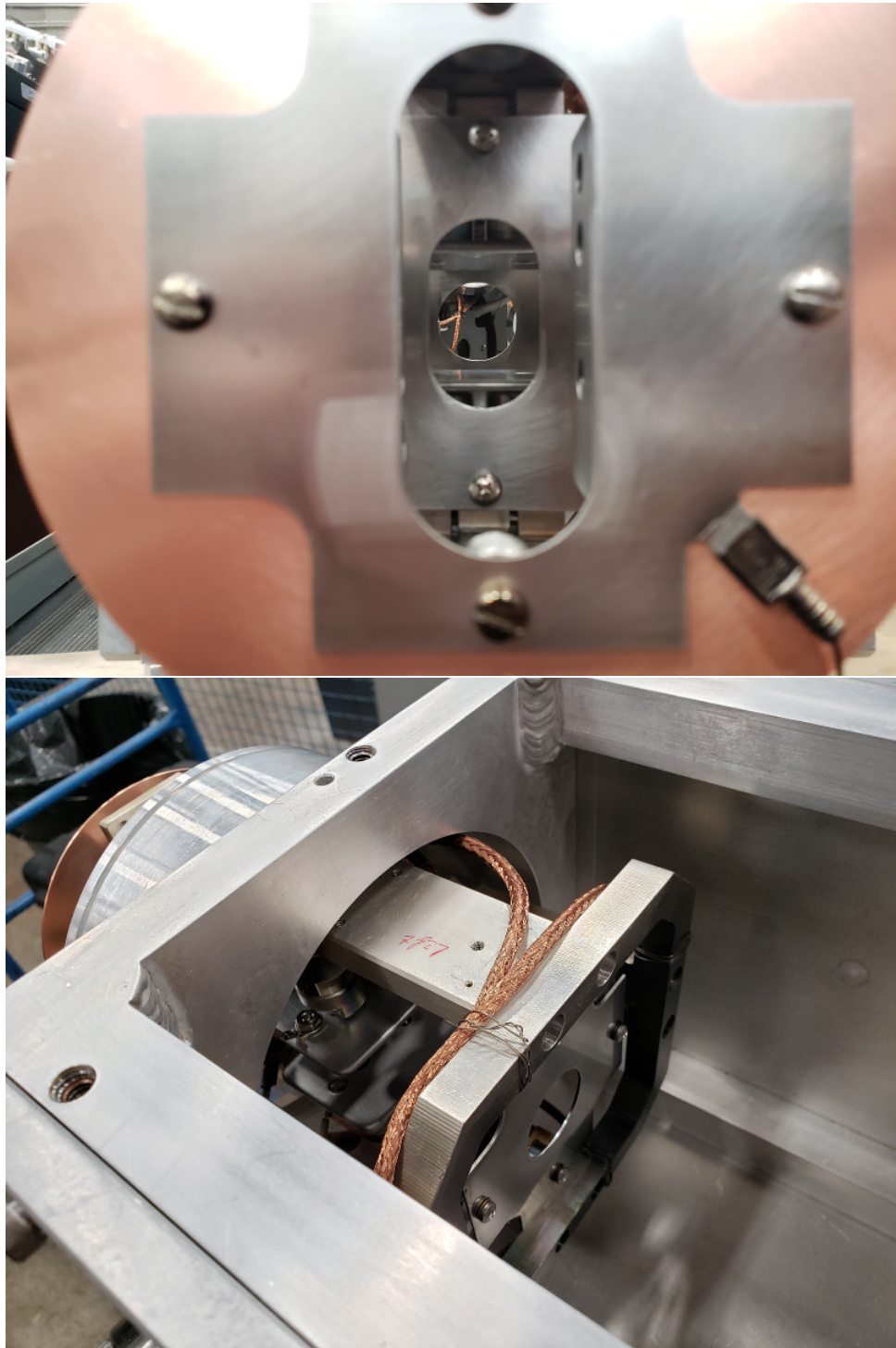


Figure 9: **Top:** On-axis view of the as-found y-correction bender IOS:YCB1 (foreground) and x-deflector IOS:XCB1AW/E (background). Note the foreground skimmer, with a more elongated profile, the central skimmer has an intermediate profile, while the downstream skimmer is circular. **Bottom:** Downstream as-found circular molybdenum skimmer for the 9° x-deflector. **Photos courtesy of M. Marchetto.**

6 Post Maintenance 41keV ²⁰Ne⁺ MWS Exploratory Tune

Two initial tuning sessions were scheduled on 2020-02-26 and 2020-02-28, both taking place before the installation of the MWS protect collimator, intended to both confirm proper source and beamline function and explore overall tune behavior. The tuning session on the 26th was done with the MCIS cart removed from the OLIS cage, while it was installed on the 28th. This was intended to explore whether any major observable differences would emerge.

After the optics were re-installed and the beamline pumped down to vacuum, Keerthi prepared a ²⁰Ne⁺ beam at 2.05 keV/u, RFQ injection energy, meaning a 41kV source bias. The theoretical tune as provided to RIB Operations by the Beam Physics group, available on the RIB Ops homepage, was loaded manually into EPICS. The OLIS collimators were manually tuned for transmission, with used values shown in Figure 10.

All common correction benders were set to 300V, so were all steering plates up to IOS:FC6, the end point of the tune. As MWS possesses no source cup prior to IOS:FC3 at this time, it was not possible to measure transmission from the source to that point. As such, with the optics set to theory and all steering neutral, IOS:B1A was varied in 10V increments. Maximum FC3 beam current was found with a -190V offset to the B1A positive electrode. The OLIS overview page is shown in Figure 11. The theory values are shown in Figure 12.

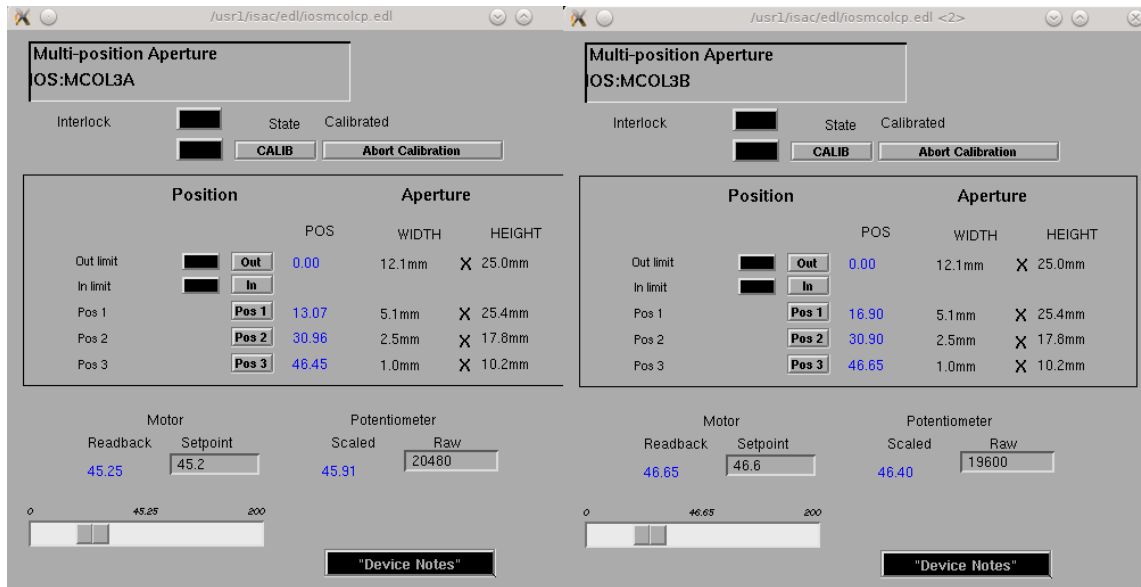


Figure 10: Manually defined 1mm Collimator readback settings as used for tune.

Since the collimators had to be manually defined looking at beam current only, this renders the significance of this -190V offset more uncertain. Maximum FC3 current was recorded as $30 \mu\text{A}$, while IOS:FC6 current was recorded as $6 \mu\text{A}$ using the collimator settings shown in Fig., 10. Verification of the optical centering of the collimators still needs to be performed and there was insufficient time for such a procedure.

Notable is that all OLIS optics are at theory and produce high beam current at both source cups, with very little steering. Typical operational OLIS tunes frequently involved both considerable steering and off-theory quadrupoles, both of which are manually tuned to maximize current on the source cups. It was observed that tuning the quadrupoles off-theory did not produce more current on either. The OLIS dipole was set by entering the desired field in the PID control parameter, which also produced high current to FC6. Beam could only be partially sent down the ILT line toward the RFQ due to shutdown related maintenance, though it was possible to extend the tune up to ILT:RPM33 for transport matching verification. Beam profiles measured at IOS:RPM8, RPM11 and ILT:RPM33 are shown in Figures 13 and 14.

It is important to note that only during the 2020-02-28 tune was it possible to image beam on the RPM's, thus it was not possible to comparatively investigate MCIS effects upon the beam profile. **This should be carried out, as there remains great uncertainty about the potential effect of MCIS' fringe field upon MWS extracted beams.** Leakage currents on much of the optics up to IOS:FC3 were noted to be higher than usual. A sample of the EPICS recorded leakage currents are shown in Table 1. For this reason, it was determined, following discussions between Stable Sources & Beam Physics groups, that additional collimation should be installed prior to IOS:B1A. This led to the installation of the protect collimator which was shown in Figure 5.

Device	Leakage Current [μA]
IOS:XCB1	3.18
IOS:YCB1	7.55
IOS:B1A I+	532.16
IOS:B1A I-	552.30
IOS:YCB1A	26.51
IOS:XCB1AW	142.33
IOS:Q1 I+	27.08
IOS:Q1 I-	4.38
IOS:Q2 I+	25.29
IOS:Q2 I-	4.55
IOS:Q3 I+	99.34
IOS:Q3 I-	1.14

Table 1: Recorded EPICS leakage currents during 2020-02-28 MWS tune with MCIS cart installed. Beam is 41keV, $^{20}\text{Ne}^+$ from OLIS MWS, using Baartman's design OLIS to RFQ transport tune.

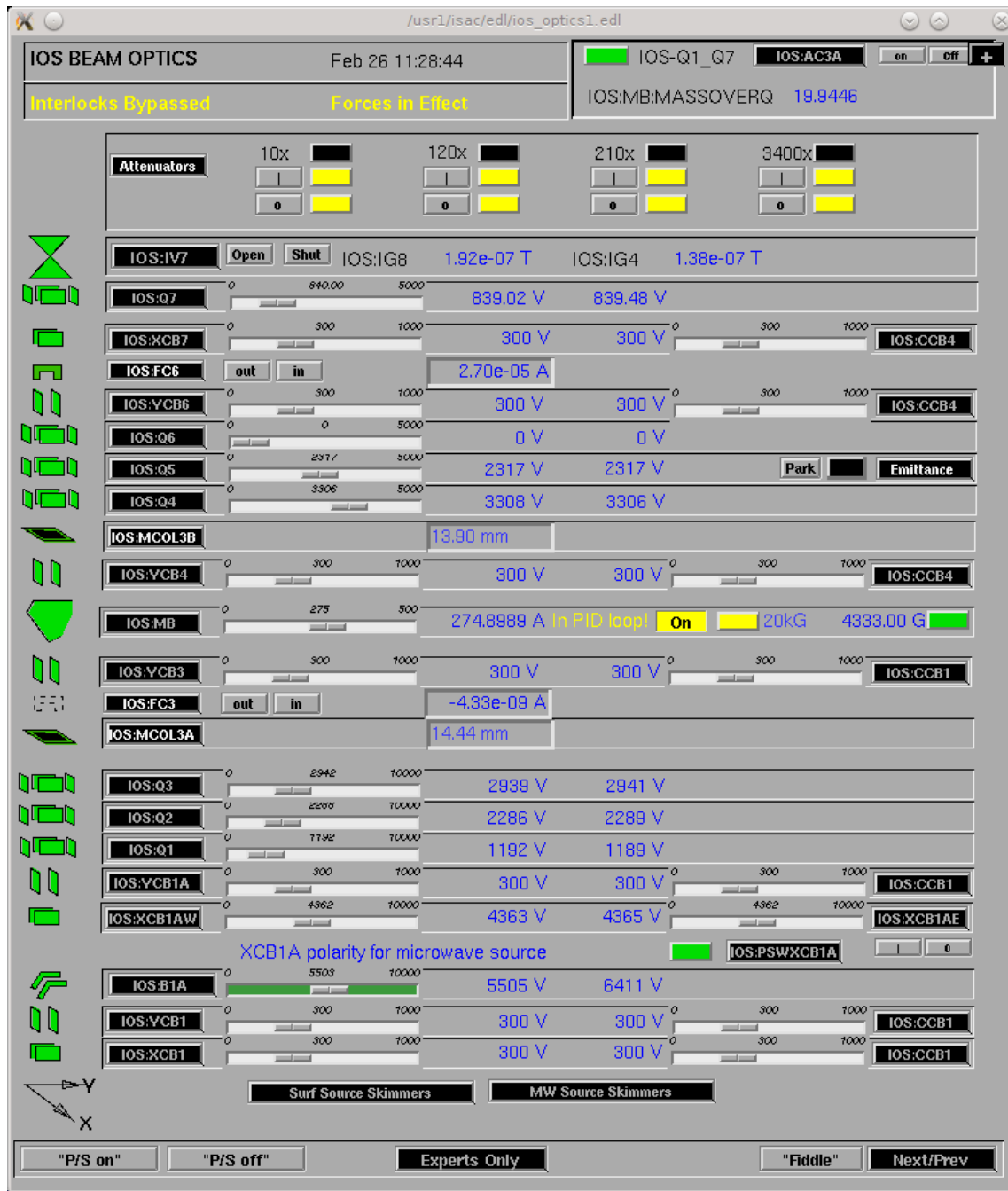


Figure 11: 2020-02-26 EPICS OLIS optics page, showing a 41keV $^{20}\text{Ne}^+$ tune from MWS up to IOS:FC6 with all quadrupoles to theory, all steering neutral. The 36° spherical bend is detuned by -190V.

TuneOLIS - Chromium

web.accel.triumf.ca/~baartman/Tunes/TuneOLIS.html

Tune for Microwave or Surface Offline Ion Source

Charge =

Mass = amu

Beam Extraction voltage = kV

Name	Value
IOS:BIAS	<input type="text" value="40.800"/> kV
IOS:EE	<input type="text" value="3.064"/> kV
IOS:B1A	<input type="text" value="5.693"/> kV
IOS:XCB1AW	<input type="text" value="4.362"/> kV
IOS:XCB1AE	<input type="text" value="4.362"/> kV
IOS:Q1	<input type="text" value="1.192"/> kV
IOS:Q2	<input type="text" value="2.288"/> kV
IOS:Q3	<input type="text" value="2.942"/> kV
IOS:MB	<input type="text" value="4333"/> Gauss
IOS:Q4	<input type="text" value="3.306"/> kV
IOS:Q5	<input type="text" value="2.317"/> kV
IOS:Q6	<input type="text" value=".000"/> kV
IOS:Q7	<input type="text" value=".840"/> kV
IOS:Q8	<input type="text" value="1.443"/> kV

[Rick Baartman](#)
 Last modified: Mon Oct 21 15:58:39 PDT 2019

Figure 12: 2020-02-26 as recorded OLIS Beam Dynamics theory tune page, showing values for 41keV $^{20}\text{Ne}^+$.

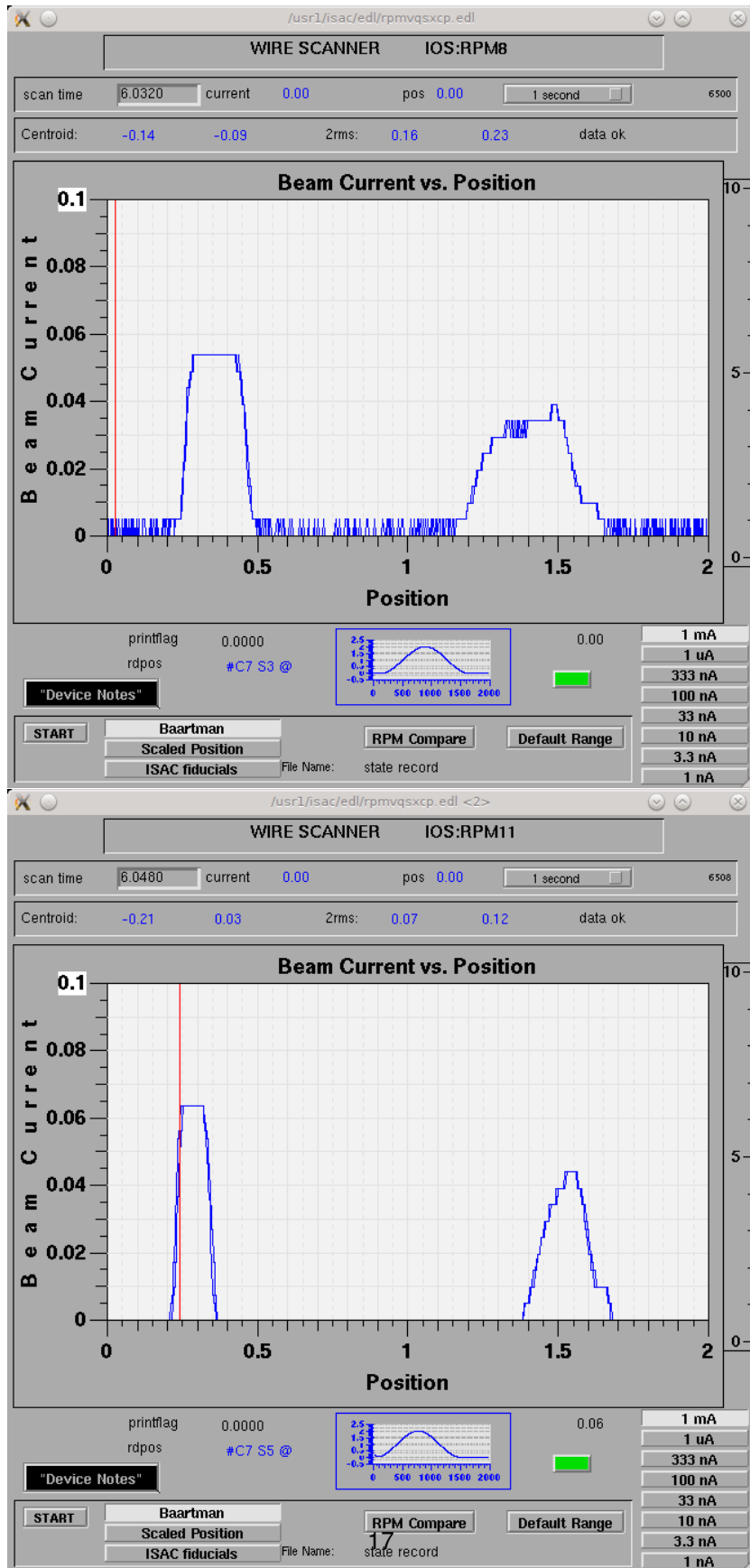


Figure 13: OLIS rotary position monitor (RPM) readbacks for RPM8 (Top) and RPM11 (Bottom). Beam is 41keV, $^{20}\text{Ne}^+$ from OLIS MWS, using Baartman's design OLIS to RFQ transport tune.

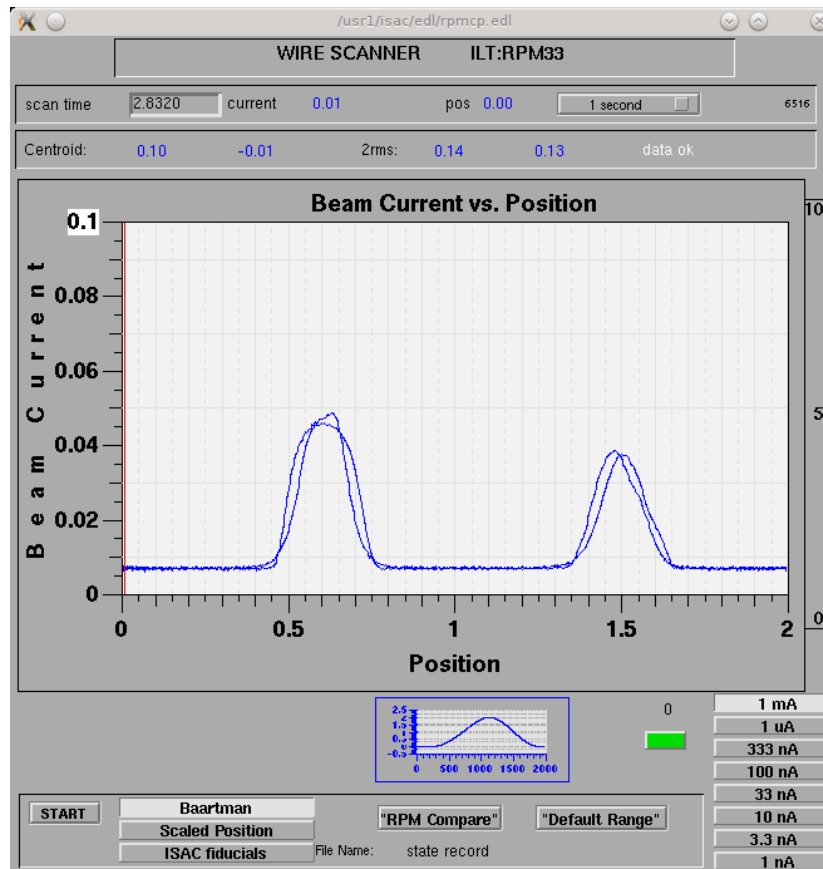


Figure 14: ISAC low energy transport rotary position monitor (RPM) readback for ILT:RPM33. Beam is 41keV, $^{20}\text{Ne}^+$ from OLIS MWS, using Baartman's design OLIS to RFQ transport tune.

7 Post MWS Collimator 41keV $^{20}\text{Ne}^+$ MWS Exploratory Tune

Once the collimator was installed by Stable Sources, vacuum was re-established in the OLIS line and another round of exploratory tuning was done on 2020-03-09, using the same $^{20}\text{Ne}^+$ beam from MWS. The MCIS cart remained installed in the cage during this time and for tuning. Interestingly, with the collimator installed, it was necessary to introduce steering at both IOS XCB1 and YCB1, prior to the 36° bend. For a 41keV beam energy, IOS:XCB1 was neutral at 500V and YCB1 was tuned to 60V, giving 440V of vertical steering immediately after MWS, before the spherical bender. IOS:CCB1 was set to 500V, while IOS:CCB4 after the dipole remained at 300V. IOS:B1A was set -270V from its theoretical setpoint, while IOS:YCB1A was neutral at 500V. Quoting my tuning notes from that day:

We find a higher current at FC3 by moving steerers just ahead of MWS. Keeping all other optics after B1A at theory, we find that the skimmer currents can be lowered this way. Asked Tiff to optimize on FC3, using steering only.

Up to $7.95e-5$ A on FC3 w/ steering only. If we go around the dipole we'll be in good shape!

[...]

Periodically retouch MCOL3A, no easy gains.

We got $\sim 2e-5$ A on FC6.

It may be necessary to alter the procedural setup of MWS given this new collimator installation. In particular, as it is desired to operate OLIS in concordance with model simulations, the practice of tuning quadrupoles to reduce leakage currents should be discontinued. Instead, persistent observation of high leakage or skimmer readback currents should lead to both investigations of additional shielding inside the beamline, but most importantly simulations of the microwave source extraction. Such simulations, for example in the code IGun, based on a custom built model of the MWS, would provide more realistic starting parameters for TRANSOPTR tune computations, and may help improve overall transmission.

8 20keV $^{87}\text{Rb}^+$ SIS Exploratory Tune

The final post-maintenance verification presented in this report took place on 2020-03-10 and involved use of the surface ionization source (SIS), again with the MCIS cart installed inside the OLIS cage. Unlike MWS, SIS possesses its own dedicated source cup, prior to the spherical bend. This allowed for a source-to-FC3 transmission reading. For all optics set to theory, the transmission was found to be poor. SIS produced 1.22 nA at IOS:FCSS and 0.34 nA at IOS:FC3 with quadrupoles set to theory, roughly 30%. From my notes:

1.16e-9A on FCSS, IOS:IVS open; current appears stable on source cup.

MCOL3A 14496 as-found (~ 2.5 mm position)

MCOL3B 14528 as-found, both moved to 5mm position

8:10AM raw & readback [collimator positions] diverged significantly.
Could be due to IOC reboot?

Tiff checked against 2019-10-31 elog entries

previous e-logs have ~50% from IOS:FCSS -> IOS:FC3, we have ~1/3 Tx.

8:31 ~4e-10A on IOS:FC6, tiff looking at alignment [overall steering]

It was observed that tuning the surface source extraction electrode (IOS:EESS) away from the theoretical number produced large increases in transmission downstream. The extraction electrode was scanned and the corresponding IOS:FC3 and FC6 currents were recorded. It was found that increasing EESS from 1503 V (theory) to roughly 2500V produced an appreciable increase in current at FC3. Such a scan is shown in Figure 15. From my notes:

EESS was set at ~2500 [volts] initially for beam up to FC6. Tiff set it back to theory (1503V). Knobbed on Q1, Q2, Q3, no gains!

B1A 2501 (theory 2791) for initial tune, up to FC3/FC6.

[...]

EESS can double beam when given one more kilovolt.

Despite running EESS off-theory, all quadrupoles in OLIS were kept at theory. Considerable steering throughout OLIS was required to get maximum observable beam current on IOS:FC6. It is unclear if the EESS introduces steering at the source. Given the good performance of the MWS tune, this suggests that SIS extraction may not conform to the tune assumption.

It was confirmed in subsequent discussions between Beam Physics and Stable Sources groups that EESS voltages in the tunes were not expected to be accurate, given the lack of SIS simulations. Given the lack of RPM's prior to FC3, it is difficult to measure the effect of EESS on the beam prior to the first collimator. This implies further SIS development work and investigations are needed, to better understand extracted beam parameters for downstream tune computation.

9 Conclusion

- SAS-0746 work was completed by February 2020.
- IOS:Q2 was found 0.54" away from its intended design position. This has been corrected.
- The ground electrodes for the spherical bender had been closed from 1" to 0.5", to act as collimators.
- The above change likely altered the optical properties of the bender and may explain why it was consistently set off theory.
- The spherical bender's electrodes have been re-adjusted to 1" opening, as designed.
- The skimmers for the 9° x-deflector IOS:XCB1AW/E were found to be of the incorrect design and orientation.
- New skimmers for the x-deflector were produced, identical to the upstream IOS:YCB1 skimmer. These were installed, with a 90° rotation with respect to the upstream YCB1 skimmer.
- The Hall probe mount was replaced with a new design which holds the probe equidistant to both IOS:MB pole faces.
- Initial tuning of MWS lead to the installation of an additional tantalum collimator facing MWS, intended to protect the spherical bender's electrodes and minimize optical device leakage currents downstream.
- Initial IOS:MWS tuning with 41keV, $^{20}\text{Ne}^+$ managed to send beam to IOS:FC6 with all OLIS optics at theory with an FC3 to FC6 transmission similar to previous tunes.
- It was identified that the EESS TRANSOPTR-theory values for SIS operation should not be strictly relied upon. Tuning EESS voltage by +1kV doubled beam observable on FC3.
- Poor transmission was identified from IOS:FCSS to IOS:FC3, about 30%, compared to the more typical 50%. The relationship between this observation and EESS detuning is still unknown.
- The MCIS fringe field should be studied and better understood.
- Simulations of both the microwave and surface sources, based on as-built design drawings, should be pursued. These would provide more realistic starting parameters for TRANSOPTR tune computations and may help shed insight into suspected MCIS fringe field effects upon the beam at MWS extraction. This could also help reduce unwanted beam losses and inform collimator and beamline protection designs and locations.