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DTL Dashboard: A Dynamic, Longitudinal Tracking Tool for the ISAC Heavy Ion Linac

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Abstract: Part of the High-Level Application project at TRIUMF, this note details a new browser-based tool for operators and physicists alike, tailored for phasing the ISAC Drift Tube Linac. The former, a separated function, IH-mode, variable energy output heavy ion accelerator which serves as the workhorse of the ISAC facility, accelerating radioisotope beams at energies typically in the $0.153 \leqslant E \leqslant 1.53$ MeV/u. The present note both explains the design and functionality of the application, in addition to serving as a record of its status, and as such may be considered as a user's manual.

The TRIUMF-ISAC Drift Tube Linac

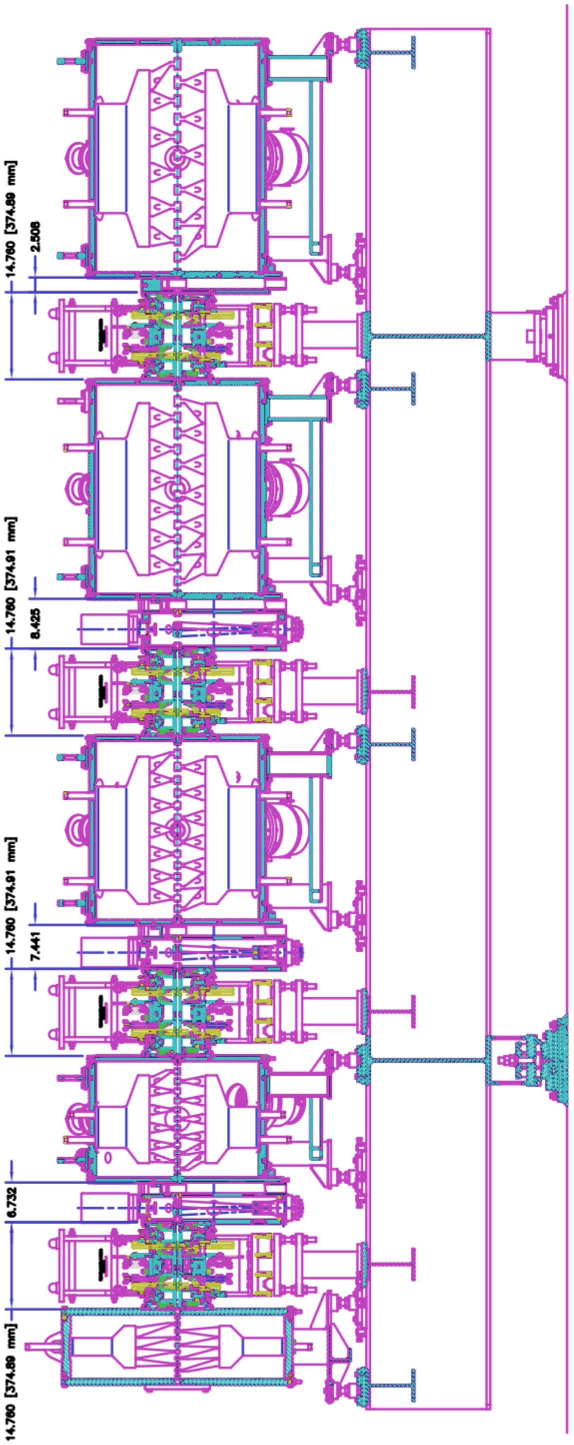

Figure 1: An overview of the ISAC Drift Tube Linac (DTL), taken from TRIUMF Design Office drawing `IRF1002D.dwg`. The four triplet assemblies may be seen with a teal/yellow tint. **Note, the inner details of the tanks, featuring the drift tubes, should be considered for illustrative purposes only, as the drawing is of an older 105MHz design. The tanks were re-designed for 106.08MHz operation.** Beam propagation occurs from bottom to top.

Introduction & Background

In this brief note I summarize recent work done to produce a DTL tuning application, the `DTL dashboard`, part of the TRIUMF-HLA endeavour [1], which aims to provide operators and physicists with simple and lightweight web-based tools [2] to assist in RIB facility operation. The tool was initially developed circa September 2018, but was shelved for a variety of reasons, including changes to the HLA framework/web server, and has been brought back online as of May 2019.

Phasing of the ISAC DTL is considered a tricky procedure by operations, in no small part due to the large parameter space of the DTL, featuring 5 accelerating tanks, 3 bunchers, in addition to 12 quadrupoles, arranged in triplets, interspersed amongst the structures' RF cavities. RFQ accelerated beam, generally at an energy in the neighbourhood of 0.153 MeV/u, is drifted through the DTL, while all RF is unpowered. The variability of the RFQ output energy (and energy spectrum) may be attributed to factors such as the use of a stripping foil in the MEBT section, which will slightly diminish the energy. Other factors may include variability in any of the MEBT RF settings, which can produce an energy centroid shift.

Once the input energy centroid and spectrum has been verified by operations, the process of DTL phasing may begin. During this process, operators will ramp the accelerating electric field gradient while monitoring the output $(E, \Delta E/E)$ pair on a beam monitor, presently located past HEBT1:MB0, affectionately known as the Prague magnet, denoting its origin. Throughout the process of longitudinal adjustment, during which electric field gradients are increased and cavity phases continually adjusted, operators must periodically shift focus to the transverse tune, which must be adjusted to compensate for the incremented beam energy.

Prior to the present implementation, a suite of spreadsheets has been devised and provided to operators, which allows for the computation of both quadrupole current setpoints in addition to the conversion of the Prague magnet field into an effective beam energy. The former operates by scaling computed element setpoints with respect to a reference tune [3]. Current values are provided to operators via BI fits of the magnetic quadrupoles. While the spreadsheet tool is well known by operators, it does add complexity to an already onerous procedure. As such, it is hoped that the simple tool detailed in the present note, when paired with the full power of the HLA suite, including `tuneX`, `tuneDisplay` and the envelope visualization tool, will contribute to the reduction in procedural load to those who seek to tune the DTL.

The DTL Dashboard

DTL longitudinal bunch analysis at the Prague magnet may now be performed in a web browser environment, accessible at `this link`[1]. At present, the `DTL dashboard` tool is a passive-only display utility, meaning it does not allow for the manipulation of EPICS process variables in any way. Accelerated bunch energy spectra are collected by a HARP detector located immediately downstream of the Prague magnet, in the HEBT1 diagnostic box.

The HARP readback is fed to the dashboard application via the HLA jaya/vijaya pair, which is then plotted as a histogram on the dashboard, with one histogram bar representing one HARP wire. The y-axis shows relative signal intensity, which is controlled by operators via EPICS, by adjusting the HARP scanner gain on EPICS page `/usr1/isac/edl/hebt1mb0cp.edl`. The x-axis shows energy, which is computed from the Prague magnet Hall probe. The dynamic range of the energy axis is derived from the HARP's intrinsic resolution: 0.1% $\Delta E/E$ between adjacent wires, with 15 in total, producing a full HARP energy range of $\sim$ 1.5% DTL output.

Operators are prompted to enter two quantities, on the top left hand side of the dashboard, as shown in Figure 2. This will provide the app with the proper A/q required for the Hall probe to beam energy computation. **Improperly set A and/or q values in these fields will result in an incorrect energy axis for the application, the same way as entering erroneous information in the ISAC spreadsheet will.**

As operators increase the current on the Prague magnet, the energy axis on the `DTL dashboard` is automatically updated, without need for manual intervention. Thus, operators may now tune the DTL without having to constantly update the Prague magnet field on the spreadsheet tool to remain aware of the beam energy. **The design energy of each tank and buncher in the DTL is marked with a vertical red line and label, for operator's reference.** Further, through concurrent use of `tuneX`, optical elements may now be set by updating the output DTL energy and loading updated element setpoints. Finally, a `Design Energies` button brings a popup window, which also displays RF amplitude limits, supplied by the RF group.

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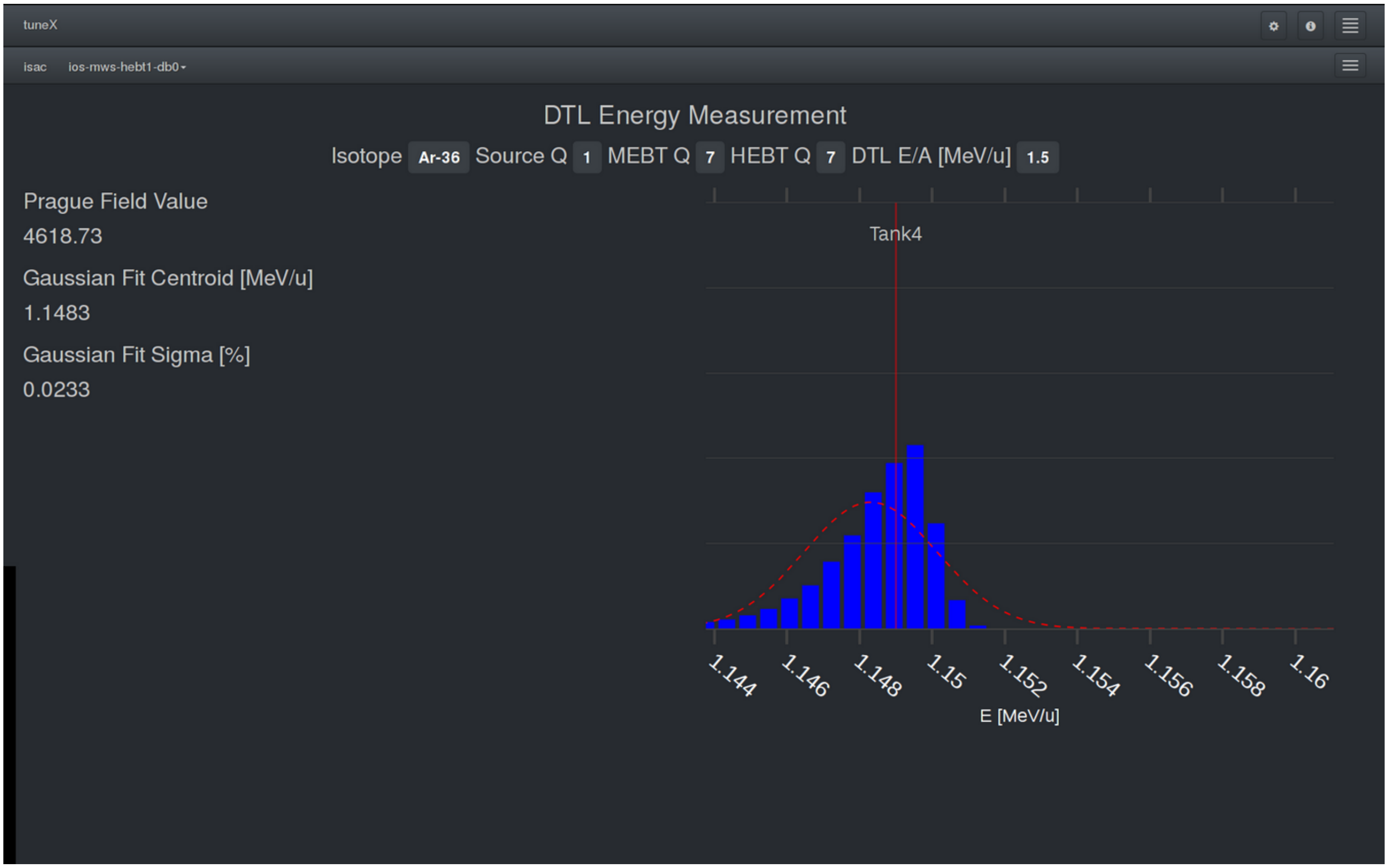
[1] https://beta.hla.triumf.ca/beam/tuneX/isac/dtl



DTL Energy Measurement

Isotope Ar-36 Source Q 1 MEBT Q 7 HEBT Q 7 DTL E/A [MeV/u] 1.5

Prague Field Value
4618.73

Gaussian Fit Centroid [MeV/u]
1.1483

Gaussian Fit Sigma [%]
0.0233

Figure 2: The `DTL Dashboard` page on `link.triumf.ca`, showing the HARP readback display (blue histogram, right hand side) and Prague magnet information (top left hand side).

HEBT1:MB0 Hall Probe Field Conversion

The DTL energy is measured, as of 2019, by converting the magnetic field readback of a Hall probe attached to the device, by scaling a known reference measurement, shown in Table 1:

$$E = E_{REF}\left(\frac{A}{q}\right)^{2}\frac{B^{2}}{B^{2}_{REF}}\left(\frac{A}{q}\right)^{2}_{REF} \tag{1}$$

Parameter	Value
A/q (ref)	3.5
Field [G]	2590.0
E_{ref} [keV/u]	781.0

Table 1: Reference Hall probe values used for HEBT1:MB0 (Prague Magnet) energy computation.

The HARP detector HEBT1:HARP0 is located immediately downstream of the Prague magnet, and is used as the energy spectrum analyis device. The HARP, consisting of 30 parallel vertical wires, of which 15 are in use, each recording local beam intensity, has a known range of 1.5% of the incident beam energy. As such, the x-axis visible in the `DTL dashboard` corresponds to 1.5% of the cendroid energy, as computed in Equation 1.

The `python` subroutine `get_prague_harp` computes all of the above-described quantities from the EPICS read raw-data. The former is located in: `$MAIN/beam/tuneX/tuneXlib.py`, where `$MAIN` is the base HLA directory.

Skew-Gaussian Fitting

It is noted that this feature is at present not implemented, however was previously coded and tested for development purposes.

The skew-Gaussian formulation of O'Hagan and Leonard was selected as a fit function for HARP-measured DTL energy profiles. It is noted that fundamentally, this presupposes a Gaussian-like beam distribution in the longitudinal phase space (coordinates 5 & 6). The validity of this assumption remains to be tested or modelled. Nevertheless, it is a fact that qualitatively, output DTL energy profiles as measured on the HARP present a skewed Gaussian profile. As such, the skew-Gaussian is chosen primarily to avoid systematic errors arising from fitting a normal distribution to a skew-normal set, which would result in centroid errors.

The Skew-Gaussian distribution is defined as the product of a Gaussian distribution:

$$g(x) = \frac{1}{\sqrt{2\pi}} \exp(\frac{-x^2}{2}) \tag{2}$$

together with the Gaussian error function:

$$h(x) = \int_{-\infty}^{x} g(\zeta) d\zeta = \frac{1}{2}\left(1 + \mathrm{erf}(\frac{x}{\sqrt{2}})\right) \tag{3}$$

Then, the Skew-Gaussian distribution is defined as:

$$\phi(x) = 2g(x)h(\alpha x) \tag{4}$$

the parameter α controlls the skewness of the Gaussian, with right-skewness for positive α and left-skewness for negative. The extraction of centroid and standard deviation is accomplished by fitting the HARP energy profile readback with Equation 4, having substituted:

$$x \rightarrow \frac{x - \mu}{\sigma} \tag{5}$$

The parameter α at present only serves as a dimensionless parameter enabling skewness, from which a centroid better representing the center of mass of the distribution is extracted.

Acknowledgements

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References

[1] Barquest C. *A Brief History of High Level Applications at TRIUMF*. Technical Report TRI-BN-19-01, TRIUMF, 2019.

[2] Barquest C. *Web-Based Control Room Applications at TRIUMF*. In *Proceedings of the 9th International Particle Accelerator Conference*, pages 4832–35, 2018.

[3] Laxdal RE. *Concept Design for Quadrupole Triplets for the ISAC Separated Function Drift Tube Linac*. Technical Report TRI-DN-99-05, TRIUMF, 1999.