TITAN Meeting Minutes
March 25th, 2010

NSERC Funding:

Mass Measurement Program:	>$300,000
Users:	$75,000
Electron Capture:	$100,000
Money from TRIUMF:	$80,000
German Detectors:	$900,000

RFQ – EM
- 27% transmission at 2keV
- Avoiding use of drift tube to measure actual rfq beam properties
- emittance measurements over the weekend

EBIT – AG, MS
- Previous: 200mA – Reconditioned cathode, beam is back
- Priorities & Requirements ** See attached report

CPET – PD
- Fits for field map done
    - Can move the beam pipe to match B-field axis.

MPET – SE
- Vacuum is back
    - (Bake ion pump and vent to argon to avoid contamination?)
    - RGA: ~80% hydrogen in MPET beam pipe
- Reinstall pipe next week when Mel is back
- Daly detector is being built
- Power supplies for new section is being built

TITAN-EBIT

Status and Roadmap

an internal report

25th March 2010

Martin C. Simon

martin.simon@mpi-hd.mpg.de

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Overview

This short report on the TITAN-EBIT covers status, performed test runs and recommendations. The work was conducted during my visit to TRIUMF from 21st of February to 26th of March 2010. Some principle guidelines for handling the TITAN-EBIT at the current stage are included as well.

All digital files used to produce this report (pictures, xls-files, manuals, email correspondence…) as well as a hardcopy of the notebook are available (ask Stephan Ettenauer, Aaron Gallant). A digital version of this report is added to the minutes of the group meeting of 25th of March.

Status

The wiring of the electron gun/collector rack was examined. Main defiance is the incomplete analogue interlock system (q.v. Agenda – Interlock).
Minor points were (fixed):

- a missing interlock-signal (fibre optics) for the Focus power supply
- a negative voltage signal proportional to the electron beam current at the collector (drop over a 10 Ω resistance) couldn't be monitored by the LabView VI

Open tasks in order to allow remote control the whole gun/collector rack (necessary for bias of gun and collector and for additional software interlocks):

- programming cable for cathode power supply (Glassmann, LQ 2 kV 5 A)
- suppressor: current readout (iseg NHQ 2##M)

Recommended improvements for the TITAN-EBIT setup are:

- off-line ion source (plasma source) and ion extraction beamline (Wien filter)
- set up a more flexible multi-parameter data acquisition
- more consistent EBIT control: EPICS vs. LabView (needs to be discussed)

Magnet: warm up, cool down, ramp up

Using a Hall probe, the magnetic fields of the compensation coils (bucking and collector) have been measured. The polarizations are correct to counteract the field of the superconducting magnet.

Due to maintenances on the cooling water system (25th Feb. – 3rd Mar.), the superconducting EBIT Magnet had to be warmed up.

Residual and injected gas, frozen to the magnets and trap construction (i.e. parts on cryogenic temperatures: 4 to 6 K) could evaporate off. During the cool down process (3rd Mar.) the pressures in the collector- (and magnet-) chamber dropped from 3.2 (-8) Torr to 2.7 (-10) Torr.

The procedure of ramping up the superconducting magnet manually was explained to Aaron. An existing LabView Program for this task will be set up at a later date (if necessary at all).
Ramp rates: ~0.08 A/s with load, ~0.15 A/s without load
rule for turning on the heater of the bridge: There must be no current flowing over the bridge.

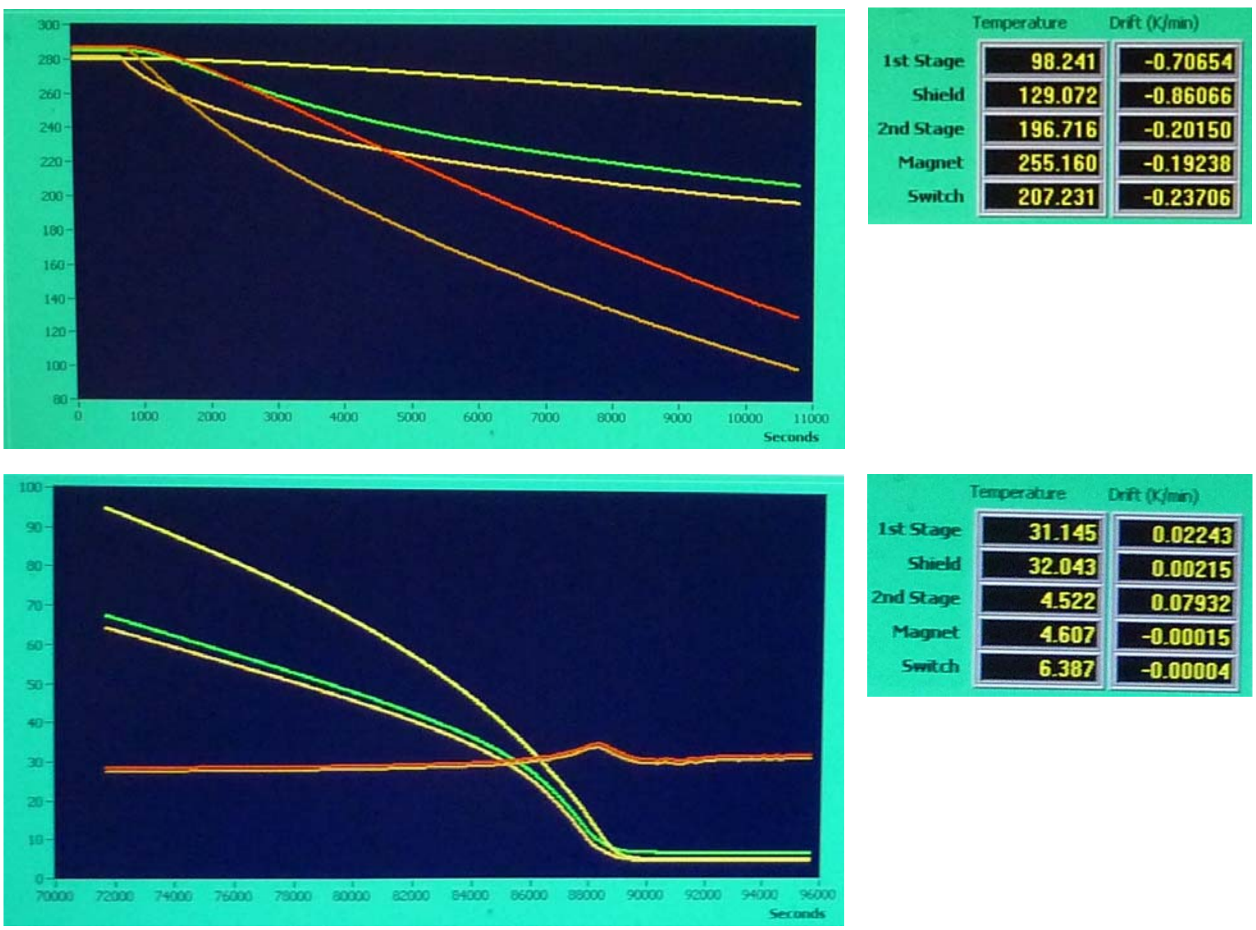

Fig. 1: Screenshots of beginning (3rd March 2:15pm) and end (4th March 3:00pm) of "cool-down" process.

The total "cool-down" process took 24h 45min.

Optimization

After the periods of initial commissioning of the "gun-rack" and cooling water shut down we tried to reconstruct the last working settings, which stem approximately from November 2009.

First electron beam operation could be achieved on 11th of March after consulting Alain Lapierre, who recommended higher powers for the cathode heater (LabView Value 2.4 instead of 2.0).

The subsequent steps of the optimization procedure are summarized in the table 1 and figure 2 (details can be found in the hardcopy of the notebook).

			Main Running Parameters			Main Control Parameters								Pressure		Gun Position		
DATE (DD:MM)	TIME (hh:mm)	Comment	eBeam (mA)	I anode (μA)	I supp (μA)	TrimmCoil (LabView)	CollCoil (LabView)	BuckCoil (LabView)	Anode (LabView)	Focus (LabView)	Heater (LabView)	Cathode (V) neg	Extractor (V) neg	Gun 10^{-10} (Torr)	Coll 10^{-10} (Torr)	X (mm)	Y (mm)	Z (mm)
11.March	09:00	first beam	2.4			0.5	1.5	2.5	0.3	0.3	1.9	500	600					220
			6.6								2.2	600	700					
			11.5						0.7	0.5	2.3							
		steadily inc.	16	20		0.5	0.45	2.8										
	11:50		18.5															
	12:00		24.3	2		0.5	0.4	2.4	0.5	1.1	2.4	700	1000	3.8	3.1	13	16.7	
	13:27		39.6	2.5	75													
			36.6	4	75	0.5	0.4	2.8	0.6	1	2.4	800	1000					
			36.7									900						
	15:00		33.1	5	82													
			35							1.1								
	17:55		35													13.03	15.8	
			37.7	5	6	1.3	0.3	2.8	0.8	1.3								
		overnight	4								1.8							
12.March		-> overnight rec	0						0.4	0.2		200	400					
	10:30		0.8								2.4	200						
	12:30		11.6	8	0.5							I-compliance?						
	14:15		40.3	15	32							400						
	14:20	CathPS was or	60.7			1	0.4	1	1	1.5		1000	1300					
	21:00	reduced for ove	*30*						0	0.5								
14.March			32	3	10													
			131	14	150	1	0.46	1	1	1.7		1000						
			122	14	81	0.5	0.41	1.6	0.5	1.7		1000	1100					
	13:50	overnight:	50	4	13	0.5	0.46	1.1	0	1		500	600	6.1	2.4			
15.March	09:10		60	4.8	6									5.3	2	13.75	13.7	
	09:30		177	17	7	0.5	0.46	0.9	1	2.2		1500	1600	5.4	7.7			
	11:20		185	15	7			0.6	0.5	2.5								
	14:35		186	15	6.8													
	15:10	overnight	68						0	1		1000	1100					
	17:50	stability check for overnight: OK																
16.March	10:10		71	7	0.4									7	2			
	10:20		200	19	7	0.3	0.46	0.8	0.6	2.5		1700	1750					
	11:30	Emittance-Mes	220									2000	2100					
	12:00	CRASH	0															
		Cathode recovery									0..2.4					changed		
23.March	12:50	beam is back	10	0.2	0.2	0.5	0.46	0.3	0.1	0.3	2.4	200	210	7.8		?	?	
	13:10		8.2								2.3							
	13:20		19.5	0.5	0.2			0.6	0.15	0.5		300	320			15.8	11.25	
	13:35		20.3											7.5				
	15:00		41	5				1		0.9		500	520					
	15:15	overnight	12	0	0.2				0.05	0.3		200	300					
24.March	08:45		8.5	2.5														
	08:50		13	0														
	09:30	EPICS reboots: shut down									2.2			7.7				
25.March	11:00		35	6	0.2	0.5	0.45	0.5	0.1	0.6	2.3	400	500	4.2				

Table 1: Optimization procedure (more details in *TITAN-EBIT_operation_March2010.xls*).

For an emittance measurement on 16th of March the cathode bias voltage was raised to the maximal value of -2000 V. Although a stable operation seemed to be achieved, the electron beam hit the anode (~220 mA times 3.2 kV → "crash"). Attempts to restart the EBIT lead to high currents on the anode immediately, without any current reaching the collector. Unfortunately, exact time and duration of this "crash" are unknown, since we were preparing the emittance meter at that moment. Testing the gun electrodes (cathode, focus, anode) for shorts showed a resistance of approximately 5 MΩ between focus-electrode and anode. However, this result could not be reproduced at a later stage. Very likely the cathode has been contaminated with copper ions sputtered off the anode electrode and accelerated towards the cathode (-2000 V). Hence, a cleaning procedure for the cathode was started subsequently based on a slow stepwise heat up (q.v. "Cathode recovery"). After this procedure and several attempts successful electron beam operation at 20 mA could be reached again on 23rd of March.

Hints and rules for the optimization procedure:

- Vary the parameters (as in table 1) to increase the electron beam current, while keeping currents on anode and suppressor as small as possible.
- When looking at the trap content (germanium-detector or extraction) additional optimization parameters come into the play: amount and charge state of ions. Typically higher anode and suppressor currents have to be accepted in order to optimize the ion yield.
- Coil setting are compensating the magnetic field of the superconducting magnet. Hence, only a weak dependence on the electron beam current and energy is expected
- "Metastability" of settings is often observed. Check, that small variations of the parameters do not lead to sudden changes. Don't keep parameters to close to stability boarders.
- Good settings should enable to increase the voltage on the focus electrode continuously from zero to the desired value, without crossing instable regions (while keeping all other control parameters unchanged). This increase of the focus potential should be accompanied by a steady increase of the electron beam current.

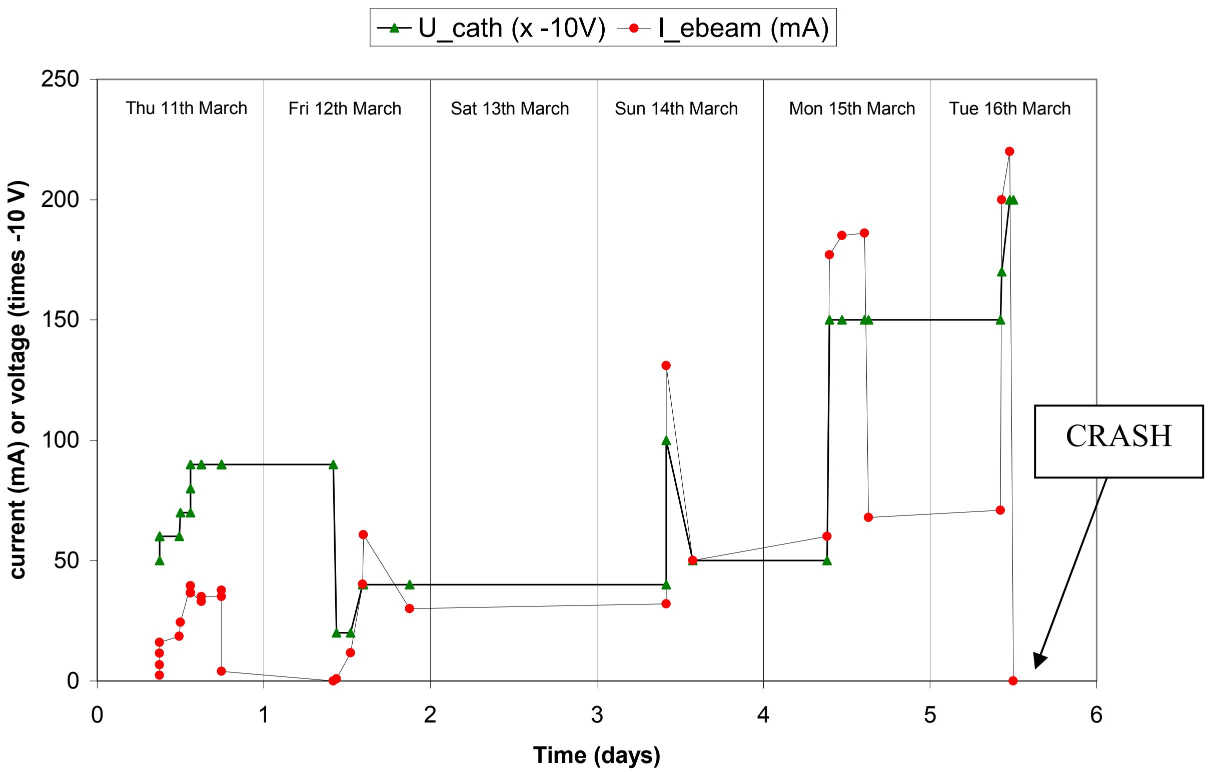

Fig. 2: Development of the electron beam operation.

Cathode recovery

The slow heat up of the cathode in order to clean it after the "crash" was used for an analysis of the temperature dependent resistance [R(T), T(P), P(U) → R(U)] of the cathode heater in order to retrieve more reliable values for the applied heater power in dependence of the adjusted value in the LabView VI.

The total resistance (heater plus wires) is plotted as a function of the power supply voltage in figure 3. Consulting "Heatwave Labs" confirmed the recommended design value for the heater power of 7.5 W. Higher powers are possible but applying more than 10 W is discouraged.
A set of values from the datasheet of the cathode (4.7 V, 1.1 A, 1050°C) was used to correct for the voltage drop in the wires. The corrected heater power as a function of the LabView setting (proportional to power supply voltage) is shown in figure 4.

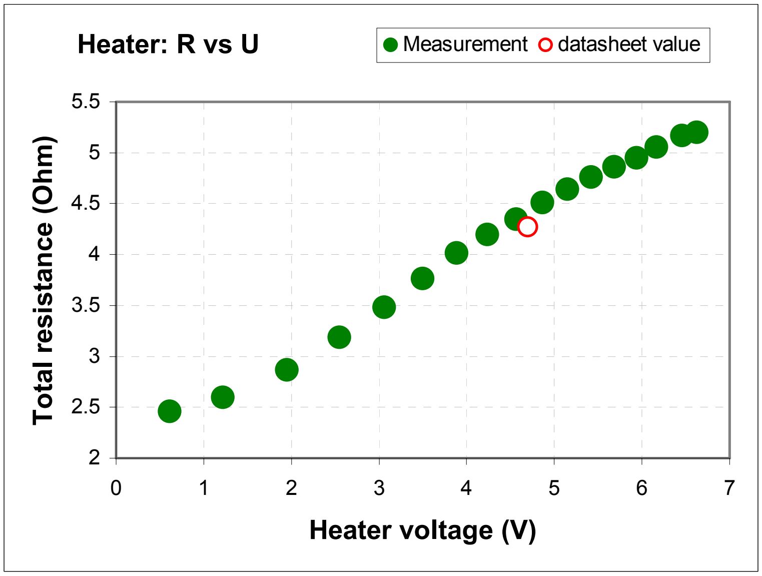

Fig. 3: Total resistance as a function of applied heater voltage.

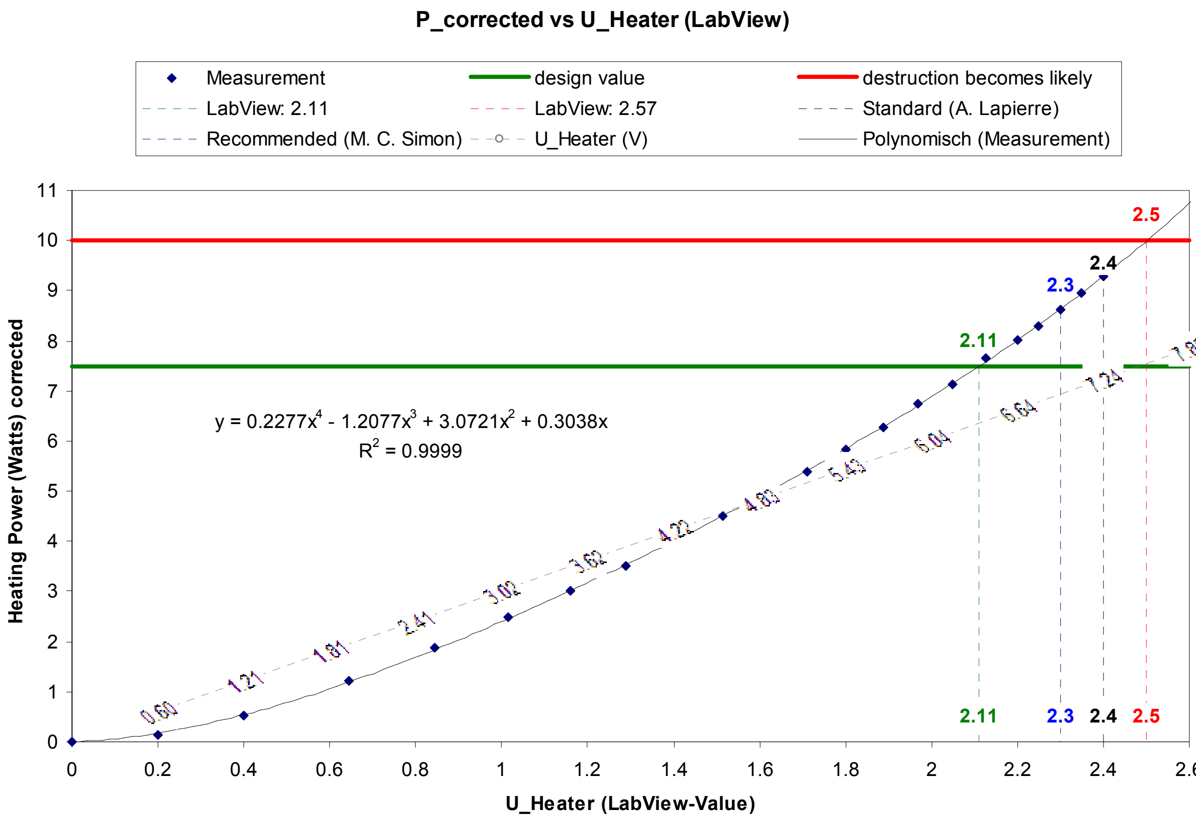

Fig. 4: Corrected cathode heater power vs. LabView setting.

The interplay between LabView value, voltage and power for the compensation coils (trimm, collector, bucking) was analyzed, however in less detail (see figure 5). Corresponding analogue compliance values (for collector and bucking coil) and software thresholds in the existing labview VI have been set.

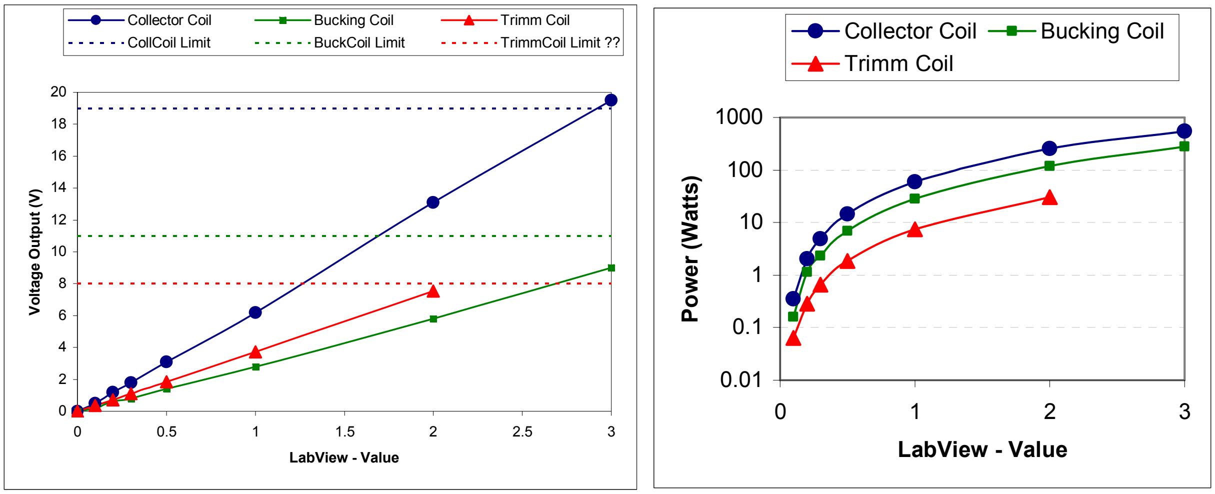

Fig. 5: Correlation of LabView Value and voltage as well as power on the compensation coils (Trimm, Bucking and Collector).

Printouts of these Diagrams have been placed on the gun-rack cage, in order to remind EBIT operators of upper threshold values.

Agenda

In this section considerations for a TITAN-EBIT roadmap are presented. The main improvement to be made to the EBIT is a re-examination and completion of the interlock system. This has been recognized already during the gun rack examination and was highlighted by the "crash" and especially the long recovery period.

The task of this special EBIT is charge breeding of short-lived radionuclei. The existing setup seems sufficient to perform this task, once the optimal procedure has been found. However, for the optimization and characterization some additional extensions and improvements are strongly recommended. Scanning the electron beam energy in order to identify resonances (DR: dielectronic resonances → charge state optimization) is hardly possible at the moment. Detection can rely on photons (germanium detectors) or ion extraction and charge state analysis. Therefore, this aim splits into several demands:

- Improved control possibilities → scanning parameters
- Set up a more flexible multiparameter data acquisition
- Extraction beamline with higher charge over mass resolution compared to the existing time of flight (TOF) measurements
- An independent off-line ion source (plasma ion source) for test runs

The completion of the interlock system should start as soon as possible (priority I).

A combined ion source – ion extraction setup to over the last to listed points is suggested. Layout and construction of these parts should start as soon as possible (priority II).

In cooperation with the data acquisition group the best solution for our demands have to be worked out. The existing DAQ-card (SIS3302 8 Channel 100 MS/s 16-bit ADC) seems appropriate for pulse height analysis and digitized wave form)**.** Together with the unsatisfactory status of the EBIT control system (EPICS and Labview, no scanning possible) this forms priority III.

Interlock

Status as well as suggestions and tasks for a complete interlock system are listed in table 2. Additionally the scheme of the interlock system, that should be installed, is sketched in figure 6.

monitored value	signal origin	failure action	type	status	open tasks & other comments
pressure	gauge	total shut down [1]	analog	EPICS exist: threshold hard to adjust	connect EPICS signal EBITVACOK_2 (or 1) contact: Mike LeRoss
water cooling	flow wheel	shut down [2]	analog	acts only on coil PSs	add shut down of cathode PS
B-field (quench)	probe	shut down [3]	analog	not existing	on/off signal sufficient, however quantitative meas. would allow long-term field decay observation
I_{cath} - I_{coll} current differnece	current in wires	shut down [3]	analog	not existing	GFCI (DC ground fault circuit interrupter) could be appropriate for this task (check with electronics dep.)
I_{anode} , I_{suppr} thresholds	PS monitors	restore procedure (ramping of focus)	softw.	exists in LabView VI, suppressor not connected	connect current monitors of iseg PS (NHQ) to LabView improved LabView VI (if not unified to EPICS)
$U_{extr} > U_{cath}$	PS monitors	increase U_{extr}	softw.	not existing self stab.*	implement in LabView (if not unified to EPICS)

Table 2: Overview on the EBIT interlock system.

In a simple preliminary version the failure of each monitored value could lead to a total shut down → [1]. The more sophisticated version as described here only shuts down the components really necessary for the corresponding type of failure (shut down [2] and [3]).

* a self stabilization effect was observed for the extractor: if set to voltages below the cathode potential, a charge up by the electron beam prevents the voltage to drop further.

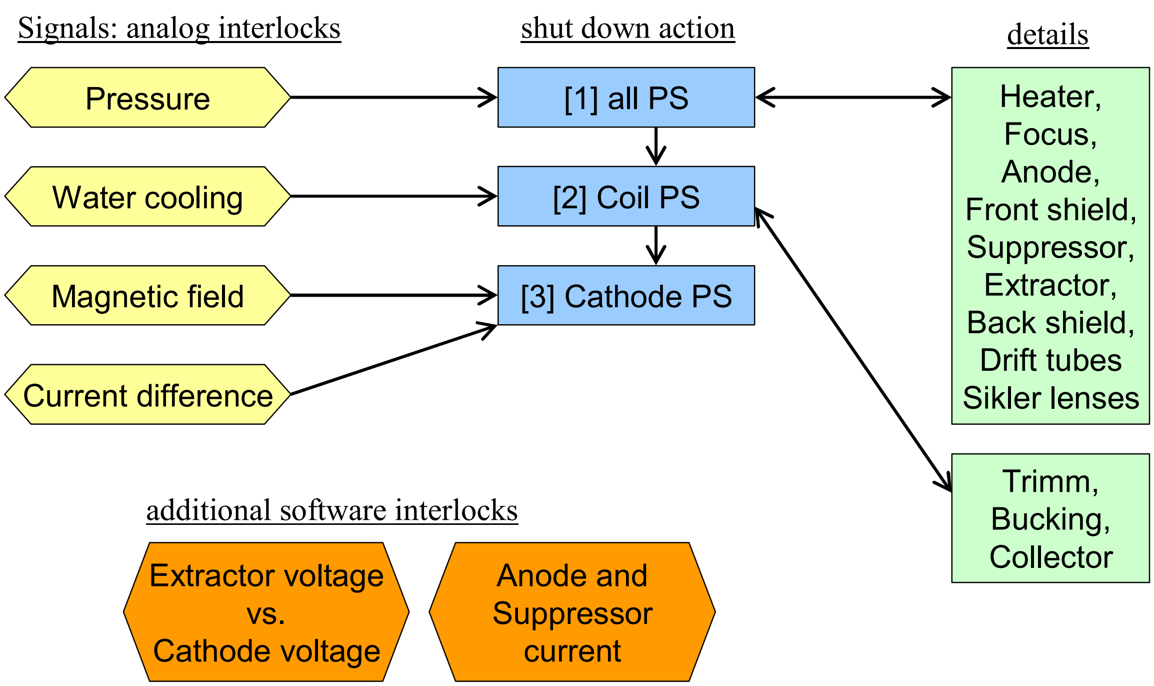

Fig. 6: Scheme of the interlock system.

Ion source and Wien filter

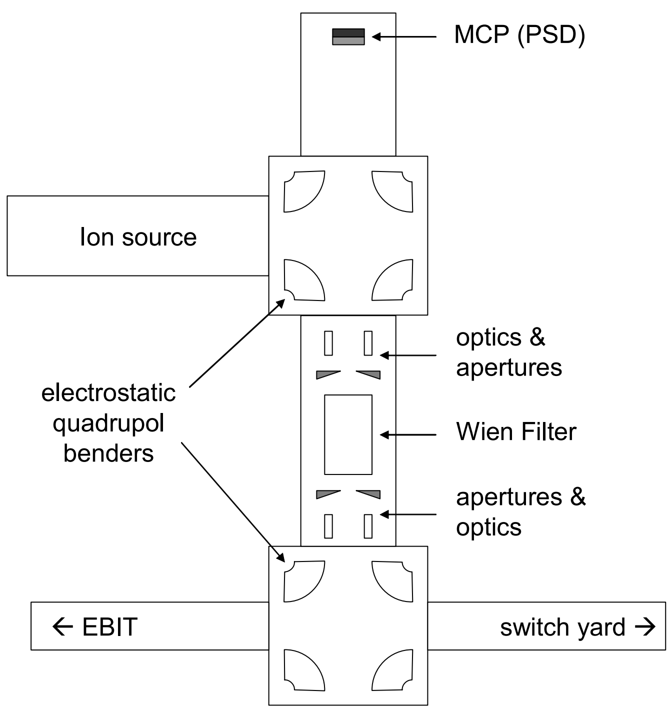

Fig. 7: Scheme of the combined off-line ion source and EBIT extraction beamline.

It is planned to install an off-line ion source (plasma ion source) close to the EBIT for independent operation and optimization from the other TITAN components (MPET, RFQ, surface ion source and CPET at a later stage).

By placing a Wien filter and a retractable position sensitive detector (PSD) between the ion source and the electrostatic quadrupol-bender a versatile setup is formed:

- the Wien filter enables to select pure (single mass component) ion beams from the plasma ion source
- the direction of operation can be inverted easily by switching the electric field of the Wien filter an enables to analyse continuous ion beams from the EBIT on a retractable PSD
- an electrostatic deflection (selecting potential) and a magnetic analysis (selecting charge state) are possible → the dispersive axis of the Wien filter and the quadrupol bender should be orthogonal

Data acquisition

Specifications:

- multiparameter
- combine pulse height analysis and voltage sampling (wave form digitizing)
- set conditions (discriminators)
- online visualisation of measurements
- position sensitive ion detection: pulse height (wedge and stripe anode) or time delay anode (PSD: position sensitive detector)

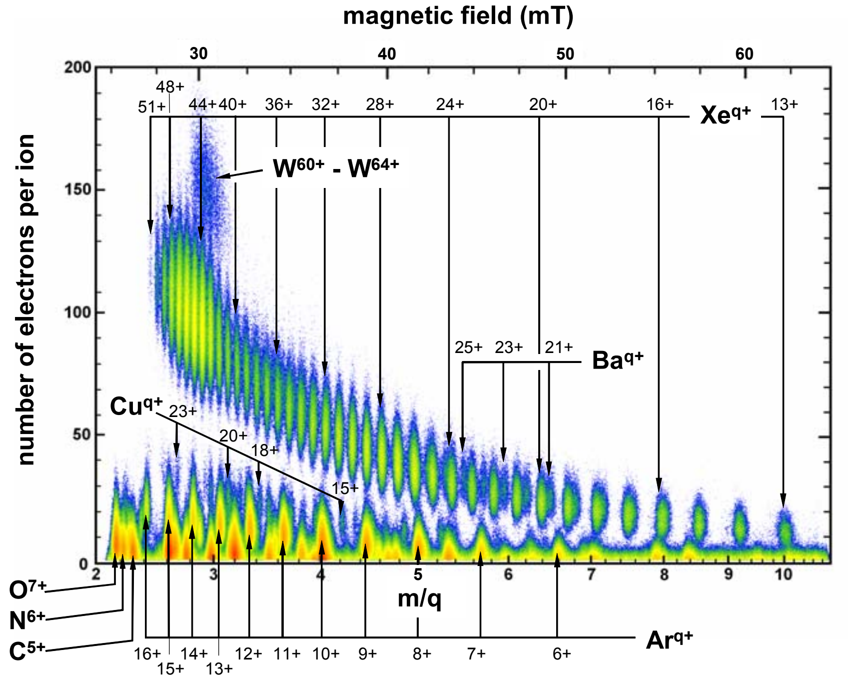

Fig. 8: Multiparameter DAQ example: Number of electrons produced upon impact of highly charged ions Z^{q+} on a well defined surface vs. charge over mass ratio.

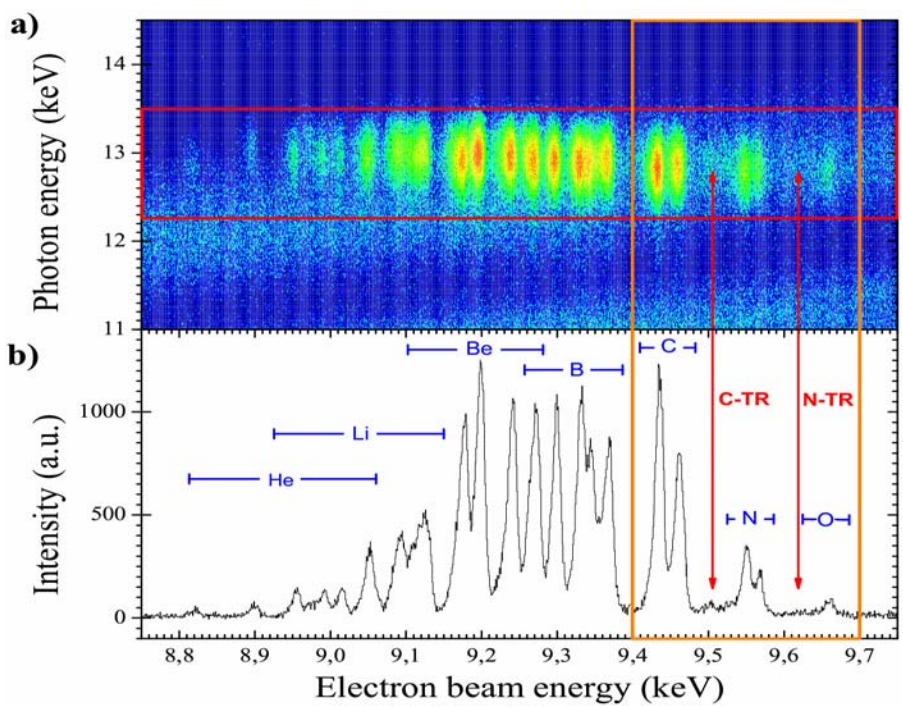

Fig. 9: Multiparameter DAQ example: Scan for dielectronic resonances (Kr) by plotting the photon energy (germanium detector) vs. electron beam energy.

Minor issues

Focus-cathode behaviour: The focus PS (positive voltages: U_{foc}) is floating on the cathode potential (negative voltages U_{cath}). The voltages on the SHV-cables connecting the cathode and the focus respectively have been tested before starting the EBIT and showed following behaviour for the focus voltage:

- if the sum of U_{foc} and U_{cath} is positive ($|U_{foc}| > |U_{cath}|$) the output is the direct sum, as expected
- if the sum of U_{foc} and U_{cath} is negative ($|U_{foc}| < |U_{cath}|$) the output is always $U_{cath}/20$, independent of the actual value of U_{foc}

The cathode output behaves normal. When the EBIT is running everything seems to behave normal. A possible explanation is, that the focus PS cannot deliver electrons by its self and cannot reach the negative potentials supplied by the cathode PS. When the EBIT is running the electrons bring the focus electrode to negative voltages, when necessary.

Furthermore, the current and voltage monitor for the focus PS, which have to be transformed from cathode to ground potential, are not working. If this "cage" (containing the floating focus and heater PSs) is examined, the extractor could be biased as well to the same floating potential, which would replace the planned software interlock by an preferable analogue interlock.

Sikler Lenses: The four central electrodes of this "steering lenses" can be controlled individually in EPICS or via more descriptive control parameters: namely total focus, horizontal and vertical steering. A fourth possible parameter is cannot be varied at the moment: astigmatism. Full control of the four degrees of freedom is only achieved with four parameters.

Additional remark: The Sikler lenses are mounted such, that the astigmatic elongation appears in a 45° plane, therefore it is probably not straight forward to use these lenses for astigmatic corrections.

Gun position: The scale of the X-drive of the electron gun manipulator is loose.

He-Level in compressor: He-pressure: static 1.6 MPa / dynamic 2.5 MPa) The static pressure is too low, although the dynamic pressure is appropriate.

Possible measurements

For the moment the TITAN-EBIT can be operated without interlock system by using “save settings” (low voltages, especially between cathode and anode). Some measurements can be performed within the next weeks:

- emittance measurement
- time of flight (TOF) for charge state analysis with pulsed extraction
- X-ray spectra (with the low energy germanium detector)

Test measurements using the full power of the TITAN EBIT should await the completion of the interlock system. Setting up a multi-parameter data acquisition and improved control programs will allow characterization measurements similar to the ones shown in figure 8: Dielectronic recombination measured with the germanium detectors or with extracted ions via TOF (pulsed).

With the off-line ion source and an improved ion extraction (Wien filter) analysis under continuous conditions and independent simulation of complete measurement cycles will become possible.

Hints for EBIT use:

- Avoid high voltages between cathode and anode, as long as analogue interlock system is missing
- Avoid higher LabView values than 2.30 for the cathode heater (corresponding to 6.93 V and 1.33 A on the heater power supply and a corrected power of 8.6 W)

Extraction schemes

As can be seen in figure 9, EBITs accumulate significant amounts of residual gas. A separation based on TOF won’t be easy due to limited resolving power. For higher charge states the situation becomes more difficult. As the most problematic background is presented by ions with similar charge to mass ratios RF cleaning probably cannot circumvent the background problem, however the primary accumulation of residual gas could be reduced. In figure 8 and 9 two extraction schemes are suggested, which could allow electrostatic separation of the ions of interest. Scheme I is a fast “single bounce” procedure, where only moderate charge states will be reached. Scheme II includes a breeding time and a subsequent resonant decrease in charge state upon extraction. This effectively increases the corresponding acceleration potential ΔU_{eff} (equation 1) and allows the ions of interest to overcome a second electrostatic barrier.

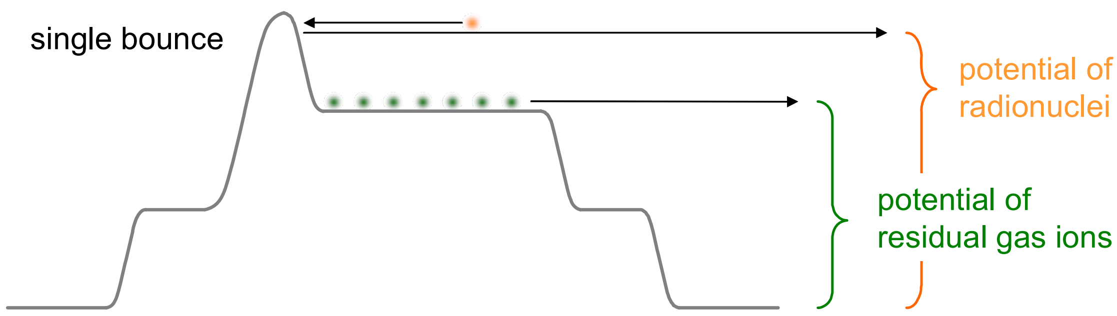

Fig. 10: Scheme I for electrostatic separation of radionuclei – in a fast single bounce a moderate increase of the charge states should be achievable.

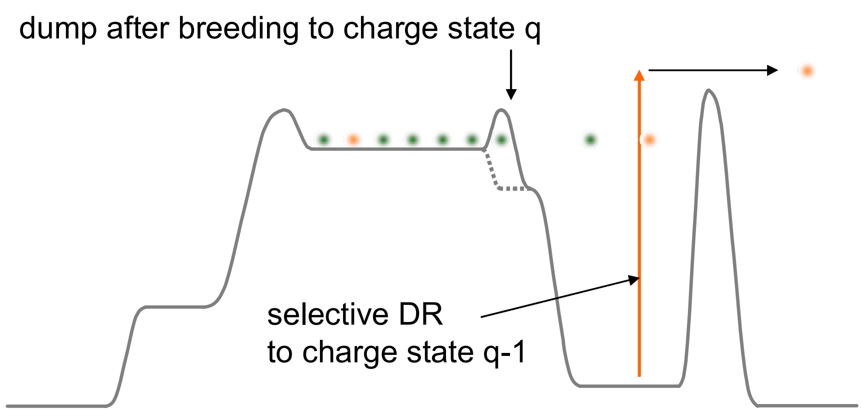

Fig. 11: Scheme II for electrostatic separation of radionuclei – after breeding to higher charge states, selective (resonant) dielectronic recombination decrements the charge states of the radionuclei, thus they are able to overcome a barrier.

$$E_{kin} = q \cdot \Delta U = (q-1)\, \Delta U_{eff} \rightarrow \Delta U_{eff} = {}^{q}/_{(q-1)}\, \Delta U > \Delta U \qquad (1)$$

Summary

Specifications

a) Safe operation

b) Means for independent test runs

c) Improved analysis methods

Requirements

1) Interlock system (a)

2) Improved control programs (c,a,b): details to be discussed with EPICS group (Jane Richards)

3) Improved data acquisition (c,b)

4) Ion source (b)

5) Wien filter (c,b)

6) MCP (if 5, c)

Priorities

In table 3 priorities are determined for the requirements by distributing 100 pts to the three specifications and subsequent distribution of those pts within the corresponding tasks (requirements to fulfil one specification). An estimate for the effort connected to each task (again 100 pts total) leads to a second evaluation criteria: (priority / effort). These numbers are merely preliminary values and rather a basis for discussions. Costs have not been considered.

Requirements (tasks and improvements)	**Specifications**			**Priority (weight)**	effort (responsibility)
	Safe operation (40)	Independent runs (30)	Analysis (30)		
Interlock	30			**30 (1.5)**	20 (AG)
Control prog.	10	5	10	**25 (1.7)**	15 (MS)
DAQ		5	10	**15 (1.0)**	15 (AG,MS)
Ion source		15		**15 (0.7)**	25 (MG,AG,MS)
Wien filter		5	5	**10 (0.5)**	20 (MG,AG,MS)
MCP			5	**5 (1.0)**	5 (AG,MS)

Table 3: Evaluated open tasks listed according to specifications and corresponding requirements.