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Preliminary Characterization of the O^{4+} Beam in Linac 3

L. Dumas, D. Küchler, R. Scrivens

Abstract

The new GTS-LHC ECR ion source was installed in 2005. An oxygen 4+ beam was delivered to LEIR both for injection line (June 2005) and for the ring commissioning (September to December 2005). During these runs, studies were made of the beam transport in the Linac and towards LEIR. Some of the most significant results concerning the Linac are presented in this report. From 2006 the ECR source and the Linac3 delivered a lead beam for the LEIR commissioning, leaving some questions open for the oxygen beam transport. This report serves as a summary of the status of the investigations on the oxygen beam.

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Introduction

The new GTS-LHC ECR ion source was installed in 2005. An oxygen 4+ beam was delivered to LEIR both for injection line (June 2005) and for the ring commissioning (September to December 2005).
During these runs, studies were made of the beam transport in the Linac and towards LEIR. Some of the most significant results concerning the Linac are presented in this report. From 2006 the ECR source and the Linac3 delivered a lead beam for the LEIR commissioning, leaving some questions open for the oxygen beam transport. This report serves as a summary of the status of the investigations on the oxygen beam.

Source – ITL

Measurements of the O^{4+} beam after extraction were made on 6 June 2005. The solenoid scan, guillotine and spectrometer method was used (1D method).
The calculation of the emittance relies on the following assumptions:

- No growth of the emittance in the solenoid of the subsequent drift.
- The beam is well centred.
- The beam is symmetric in the horizontal and vertical planes,
- There is no coupling between x & y planes.

The main configuration parameters for the measurement were the following (see Table 1):

Guillotine step:	0.5mm
Current measurements per point:	6*
Number of solenoid settings:	7
Energy:	2.563 keV/u
Bρ (10.25kV O4+):	0.02914 Tm

Table 1: Settings for the solenoid scan (*Typical value)

The ITL.SOL01 was scanned, and the magnet AQN values were converted with the calibration factor of 29.1 Gauss/Ampere. The resulting beam profiles are given in Figure 1.
The beam current in ITL.MFC02 could be maintained at approximately 260μA for all the settings.

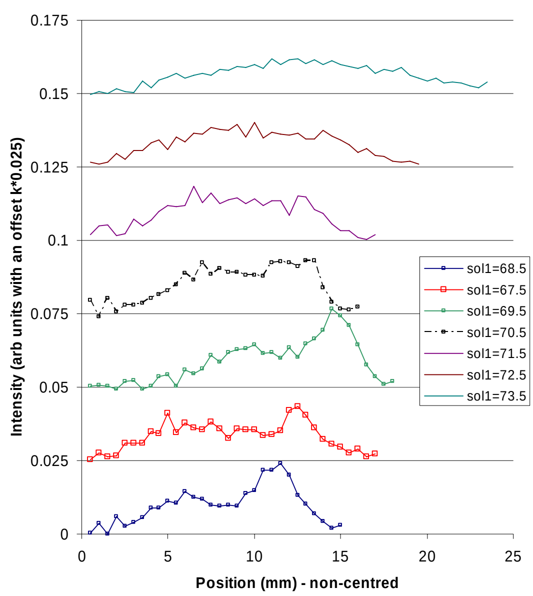

Figure 1. Measurement of the beam width at ITL.SLV01

The Twiss parameter results (see Table 2) are very sensitive to the calibration of the solenoid strength (i.e. the magnet current, calibration factor and the beam energy). However, the emittance does not change by more than 10% for reasonable assumptions about these values.

	X & Y – GTS-LHC O^{4+}	X & Y – ECR4 Pb^{27+}
αx	-1.1	-0.9
βx	0.22	0.04
γx	9.5	45
εx (4rms geom) mm.mrad	200	100
εx (1rms norm) mm.mrad	0.12	0.058
Width 4rms (mm)	13.27	4.0

Table 2. Twiss parameters and emittances calculated 44.5cm upstream of the ITL.SOL01 magnet.

The beam can then be transported through the ITL line, the resulting TRACE output is shown in Figure 2. The beam is transported without losses, and stays well within the vacuum chamber. The large emittance growth in the calculation is caused by the non circular beam at the entrance of the last solenoid.

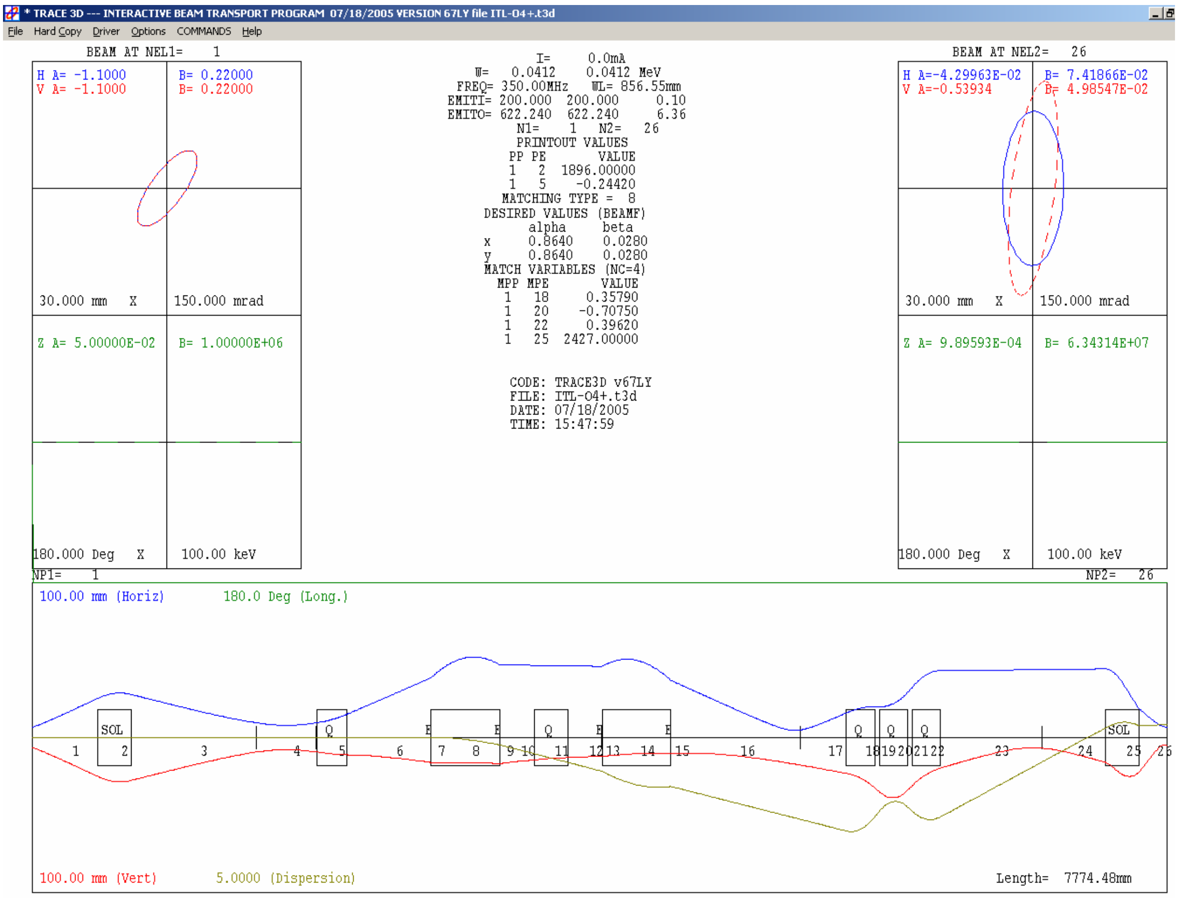

Figure 2. Beam transport through the ITL line to the RFQ, based on the input conditions calculated with a solenoid scan

However, beam measurements further downstream do not confirm these results.
Measurements of the beam emittance using the quadrupole scan technique in the ITL line after the spectrometer, have not been successful. Due to the very large beam, it is not possible to scan quadrupoles without large beam losses. In this case stable emittance values cannot be calculated.

Possible errors in the understanding of the line optics could not be investigated with oxygen due to lack of time.
Further measurements have been completed with a lead beam [2].

ITF

Measurements on the O4+ beam in the ITF line were performed on 2 June 2005. A quadrupole scan from ITF.QDN02 to ITF.MSG02 was performed in both horizontal and vertical planes. The beam parameters at the IH structure exit are given in Table 3.

	X	Y
αx	-2.5	-0.09
βx m/rad	2.5	1.75
γx rad/m	2.9	0.403
εx (4rms geom.) mm.mrad	5.2	8.0
εx (1rms norm.) mm.mrad	0.12	0.19

Table 3. Beam parameters at the exit of the IH structure, beginning of the ITF line.

ITH

❖ *Measurements ramping cavity OFF (06/07/2005)*

The emittance was measured at the input of the ITH line, using the quadrupole and SEMGrid scan technique. Table 4 shows the results of the scan done on 6 July 2005 with the first quadrupoles of ITH line and ITH.MSG11, and Table 5 gives the parameters at the entrance of the ITH line.

	X	Y
αx	0	-2.9
βx m/rad	9.0	46
γx rad/m	0.11	0.205
εx (4rms geom) mm.mrad	6.4	7.2
εx (1rms norm) mm.mrad	0.15	0.17

Table 4. Emittance and Twiss values at the entrance of ITH.QDN08.

	X	Y
αx	0.543	-1.9
βx m/rad	11.65	22.5
γx rad/m	0.111	0.205
εx (4rms geom) mm.mrad	6.4	7.2
εx (1rms norm) mm.mrad	0.15	0.17

Table 5. Emittance and Twiss values at the entrance of ITH (0.0646 m upstream of the wall), back calculated from ITH.QDN08.

Measurements of the dispersion in the ITF and ITH lines[3] are compared with the model in Figure 3. Two data sets of measurements are shown to suggest the continued ambiguity of the polarity of the profile monitors. There is a reasonable agreement, except between the third and forth bending magnets (B3 and B4), where the wrong sign of the dispersion is found. However, an inversion of the polarity of the profile monitor is not confirmed by other beam measurements. The difference may be explained by additional focussing from the bending magnets, and more measurements will be required with the Pb beam.

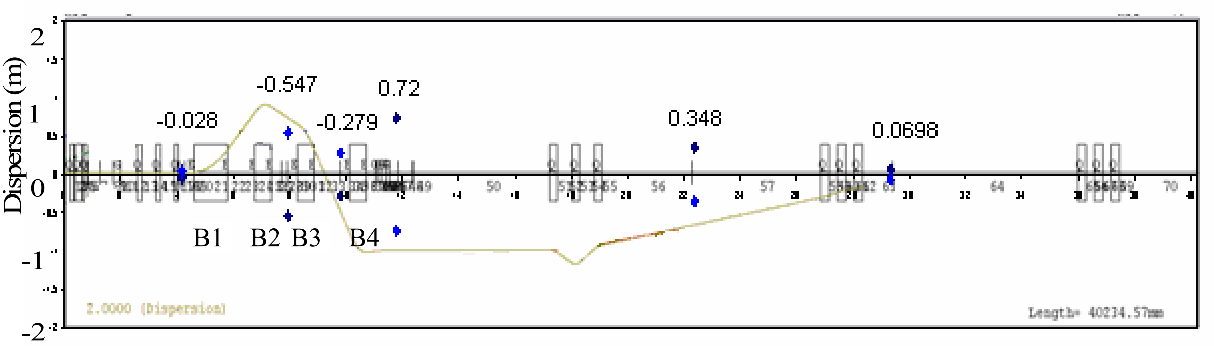

Figure 3: Evolution of the dispersion along the ITF-ITH lines. The green curve is calculated from TRACE3D and the points come from LEIR team's dispersion measurements. Those values were measured on July 8th 2005 after re-steering the beam in the filter line.

❖ *Measurement ramping cavity fixed phase (21/09/2005)*

In September, the Linac returned to the O^{4+} beam after a test with lead. In this case the source operation mode was pulsed with an afterglow and a pulsed biased disk, and the low energy line settings had been re-optimized. In addition, the ramping cavity was working at a fixed phase.
Measurements with two different quadrupole scans in the ITH line yield the following results (Table 6). All elements after the RFQ had the same setting as used for the previous section, and listed in Table 4. There is good agreement in the horizontal and vertical planes with measurements.
Otherwise scans use standard LEIR settings. At the time of the measurements ITM.MFC03= 110 µA, ITF.TRA15=50µA, ITF.TRA25=50µA, ITH.TRA41~46µA, indicating good transmission in this region.

	H-Q09-MSG11 (103,scan,off)*	H-Q10-MSG15 (103,184,scan,off,off)*	V-Q08-MSG15 (scan, off,off,off,off)*	V-Q10-MSG15 (103,184,scan,off,off)*
$\alpha_{x,y}$	0.5	0.7	-4.7	-5.5
$\beta_{x,y}$ m/rad	7.0	6.0	60	75
$\gamma_{x,y}$ rad/m	0.18	0.25	0.39	0.417
$\varepsilon_{x,y}$ (4rms geom) mm.mrad	3.1	2.8	6.4	8.0
$\varepsilon_{x,y}$ (1rms norm) mm.mrad	0.08	0.07	0.16	0.2

Table 6. Results of quadrupole scan emittance measurements in the ITH line on 21/09/2005, with O^{4+} beam. All values are given at the entrance of ITH.QDN08.
*** Currents (Amps) in quadrupoles ITH.Q08, Q09, Q10, Q11S, Q12**

❖ *Measurements ramping cavity active (15/12/2005)*

Measurements were performed with O^{4+} beam and dynamic momentum ramping (Phase ramp: 214° to 41°, Amplitude: 6030). Integration time of the SEMGrids = 400µs, hence the measurement includes the whole ramped beam pulse.

	H-Q9-MSG11 (56,scan,off)	V-Q08-MSG15 (scan,off,off,off,off)	Scan Q10 Vert – SEM 15 (103,184,scan,off,off)
α	0.6	-7.8	-8.1
β m/rad	9	104	100
$\gamma_{x,y}$ rad/m	0.151	0.595	0.666
$\varepsilon_{x,y}$ (4rms geom) mm.mrad	8.4	5.2	5.2

Table 7: Twiss parameters just before ITH.QDN08 from quad scans done 15/12/05

The ramping effect might explain such an emittance growth. That could modify the beam position or its Twiss parameters. In these scans, the dispersion was not taken in account.

LBS Spectrometer – beam energy

To centre the beam in the LBS line, it requires ~229Amps on the magnet LBS.BVT10 (Figure 4), compared to 222Amps for Pb^{53+}.

However, comparison of the required B Field on the magnet gives the following:
Pb^{53+} I=222A B=0.9399 T
O^{4+} I=229A B=0.9684 T

$B_{O4+} / B_{Pb53+} = 1.0303$ but: $(A/q)_{O4+} / (A/q)_{Pb53+} = 1.0191$

Hence the magnetic field reading suggests the velocity of O^{4+} is 1.1% higher than Pb^{53+}.
The momentum loss in the stripper foil for lead ions is ~0.66% (which is not the case for O^{4+} ions). A calibration of the NMR probe showed no drift, measured with an accuracy of 10^{-6}. Comparing high LBS.BVT10 magnet currents of 2002 to 2005, shows a variation in the magnetic field reading against magnet current of between 0.2% and 0.5% higher in 2005 than 2002 (see Figure 5). Some of this difference may also be explained by a drift in the power supply control and acquisition circuits, however, the Linac 2 proton beam is "centred" in the LBS measurement for the same BVT10 current (196.5A) in April 2002 and July 2005. The remaining difference should be explained by the RF tank setting which can change the energy of 1%.

From Figure 4 the beam momentum spread is 0.72‰.

The magnet LBS.BVT10 cannot be continuously run at 230Amps.

1. The power converter provides 230A at 105V (cold) giving 24.2kW.
2. The power converter trips when the voltage reaches 120V, a 14% increase. The resistivity coefficient for copper is 4.27×10^{-3}, suggesting a 33°C temperature rise.
3. Water cooling with a temperature rise of 33°C can extract 2.3kW (liter/minute)$^{-1}$. So 10.5l/min cooling rate is the minimum required. (This is only to keep the power supply below the voltage limit because that resistance follows the temperature increase).

Evaluating the flow rate required to keep the converter voltage below 120V gives: Pb^{54+} - 218Amps - 8l/min.

Measurements on 4 October 2005 measured a water flow of 9 l/min with the return pressure removed, resulting in 7.5 l/min for the normal operation (entrance 14.5 bar to 2.5 bar at output).

The LBS.BVT10 supply can (at the end of 2005) provide the 230A current for up to 10 minutes (on the first switch on). Operation for longer periods will therefore be possible for Pb^{54+}.

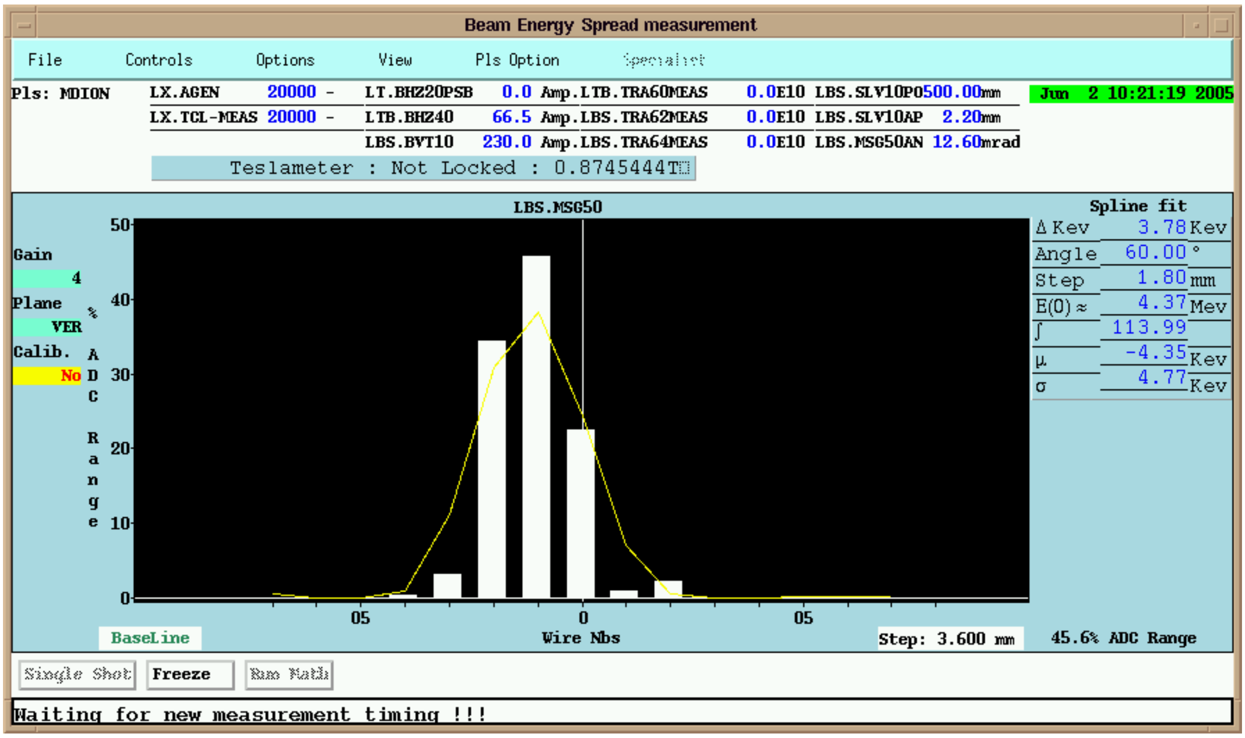

Figure 4. Beam energy measurement in the LBS line. With debuncher on and ramping cavity off.

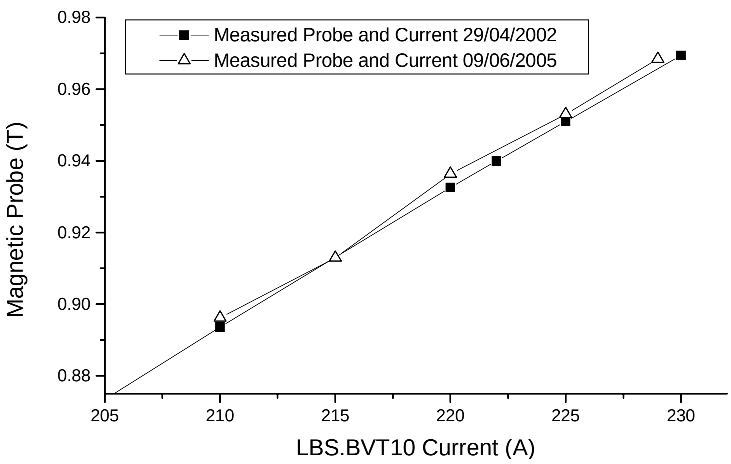

Figure 5. Comparison of the magnetic field measurement verses magnet current in April 2002 and June 2005.

LBE Emittance measurement

Measurements of the emittance in the LBE line have been made with all the ITH and LTB settings scaled to O^{4+} (see Figure 6).

The parameters of the LBE line were not scaled for O^{4+}, and hence there is some influence on the value of the emittance, which is probably less that 5% of the recorded values.

The emittance values are significantly larger than the values measured in the ITF line, and the Twiss parameters are very different from the indium beam measured in 2003.
The beam length was only 40µs, which is sufficient for measurements.

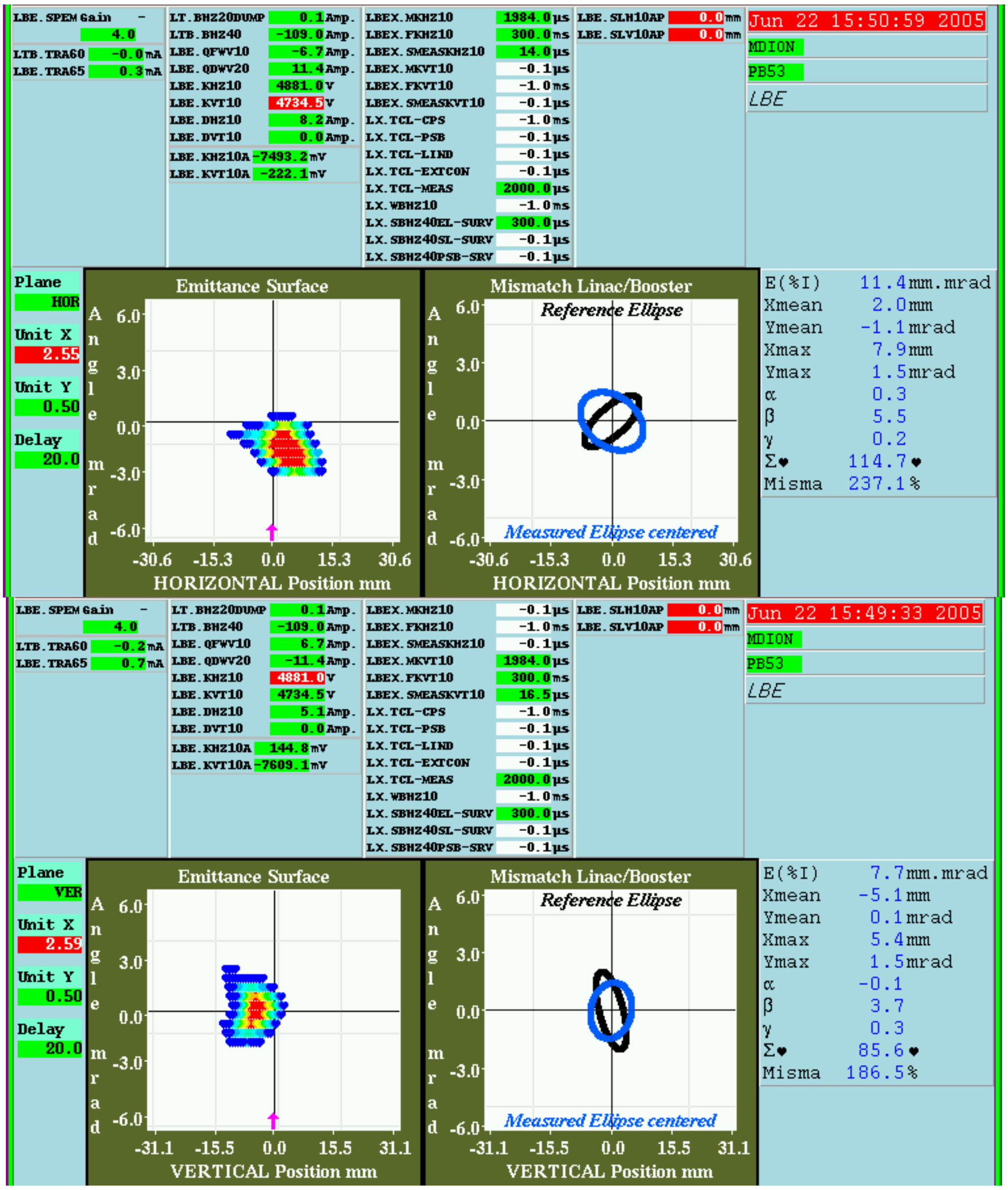

Figure 6. Emittance measurements in the LBE line. Scaled PSB transport settings were used on the ITH and LTB lines (not LEIR transport settings).

The emittance measurements do show signs of saturation in the profile (in particular in the horizontal plane) which will increase the measured emittance. It should not be forgotten that the 63% emittance quoted corresponds to √2σ.
A summary of the mean results (and the width of the measurement distribution) is given in Table 8.
So far it has not been possible to make a reliable measurement of the beam with the LEIR settings of ITH.Q08 to ITH.Q13. This is still under investigation.

	εx	αx	βx	εy	αy	βy
Mean	11.2	0.4	8.2	8.0	0.0	4.5

St. Dev.	0.7	0.3	1.9	0.2	0.1	0.6

Table 8. Mean and measurement distribution widths of the measurements of the beam emittance and Twiss parameters in the LBE line (using the original PSB transport settings, not those for LEIR). β in mm/mrad, ε 2RMS in mm.mrad (calculated with threshold).

Transmissions

Table 1Table 9 gives the transmissions found through the Linac for the 3 beam types delivered from Linac 3 either to the PSB or LEIR. Similar poor transmission was found for He^{+} beams from the ECR4 source[1]. Table 10 gives snap shot measurements of the O^{4+} beam intensity in the Linac.

	O4+	O4+	Pb27+	Pb27+	In21+	In21+	He1+	He1+
	μA		μA		μA		μA	
ITL.MFC02	300		100				500	
ITM.MFC01	120	40%	80	80%	80	-	270	54%
ITF.TRA15	70	58%	140	89% ‡	115	82% ‡	160	59%
ITF.TRA25	70	100%	25	18%	20	17%		
ITH.TRA41	70	100%	25	100%				

Table 9: Transmissions of 3 different elements.
‡ Change in charge state – transmission given for particle numbers
O4+ for GTS-LHC in June 2005; others for ECR4 source

	FC2	TRA05	FC3	TRA15	TRA25	TRA41
01/06/2005	200		95	59	46	
02/06/2005	180		103	55	43	
06/06/2005			115	65	50	
07/06/2005	260		105	60	63	
18/09/2005		180	106	61	54	
22/09/2005		170		59	54	48
18/09/2005	223	180	111	55	44	40
27/10/2005		190		62	60	50
03/11/2005				81	74	62

Table 10: Examples of transmission of the O^{4+} beam FC2: After ITL spectrometer; TRA05: In front of RFQ; FC3 After RFQ; TRA15: After ramping cavity in ITF; TRA25: In selection spectrometer; TRA41: In ITH line. The last 5 measurements correspond to ion production with pulsed microwave power.

References

[1] CE Hill, D Kuchler, R Scrivens, F Wenander, "Studies on ECR4 for the CERN Ion Programme", Rev. Sci. Instrum. 73 (2), 564 (2002).
[2] L. Dumas, R. Scrivens, "Characterization of the Lead beam of Linac3" EDMS: 704788
[3] LEIR Injection Line Studies, F.Roncarolo, G. Arduini, C.Carli, I-LHC meeting, 19 July 2005, http://cern.ch/project-i-lhc/ILHCandLEIR/Meeting_05_07_19/roncarolo_ILHC.pdf