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Study of the spectrometer after the LIS RFQ

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1. Introduction

In this note we analyze the spectrometer measurement line foreseen after the LIS RFQ with the program PATH, a multiparticle program able to calculate space charge and magnets aberrations. The base design, obtained with TRACE (Richard Scrivens, Nov. '95), is reported in appendix 1 for completeness. It includes: two quadrupoles of the type currently used in the LINAC3 ITM line; a delimiting slit; and a bending magnet with a 345-mm radius of curvature and a 25-mm gap (the originally a50-mm gap , reduced to increase magnetic field).

2. Beam from RFQ (Base case)

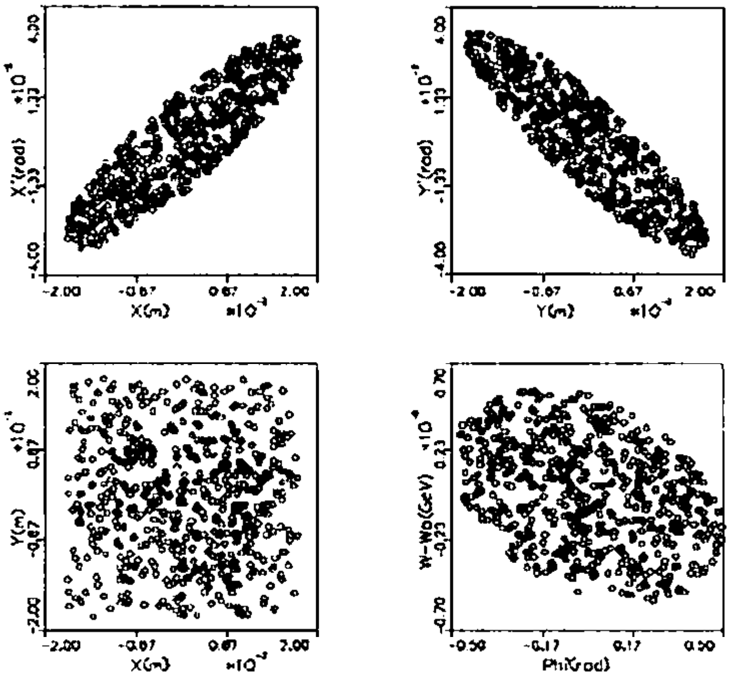
⇘ Beam parameters

$E_{Pb\ 18+}$ = 26.2 MeV (126 keV/u)

⇨	x	y	φ
α	-1.82	1.97	-0.38
β	0.115 mm/mrad	0.118 mm/mrad	55 deg/MeV
ϵ_{total}	27 mm mrad	28 mm mrad	15 deg MeV

The above parameters correspond to beam with a transverse dimension of about 2 mm, divergence 30 mrad, phase extension 30 deg, and 1% energy spread.

⤷ Beam distributions



3. Spectrometer setup

⤷ Transport line elements and parameters

	Length(m)	Gradient/Field	radius(cm)
1. *Drift*	0.2		
2. **Quadrupole**	0.15	**28.4 T/m**	
3. *Drift*	0.06		
4. **Quadrupole**	0.15	**-193 T/m**	
5. *Drift*	0.2		
6. **Slit**			0.05
5. *Drift*	0.3033		
6. **Bending M.**	0.4634	**1.72 T**	2.5
7. *Drift*	0.3033		

⤷ Design & analysis criteria

The spectrometer magnet is a device that transforms the beam energy distribution in a corresponding transverse pattern distribution easily measurable by a profile harp. In order for this device to work, i.e. in order to keep a fix correspondence between particle energies and particle positions at the analysis point, the following criteria have to be met :

1. The transverse dimension of a beam with nominal emittance and zero energy spread at the analysis point should be sufficiently small in order not to spoil the accuracy of the measurement.

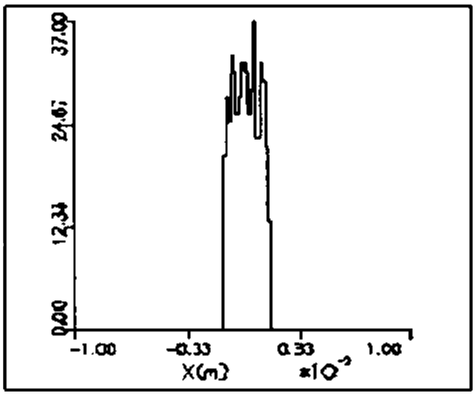
2. The spot generated by a zero-emittance beam with nominal energy spread ("pencil beam") has to be sufficiently big in order to be measured by a profile harp with a finite resolution.

3. The nominal beam spot should be as close as possible to the pencil beam case.

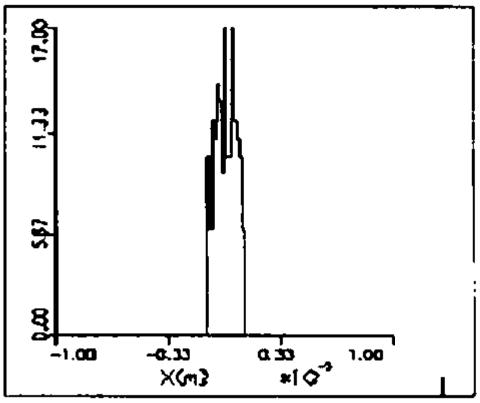
The beam transverse distributions for the proposed design, in the three abovementioned conditions, are the following :

1) Beam at the spectrometer analysis plane if $\Delta E_{in} = 0$.
(Nominal input transverse parameters and zero energy spread.)

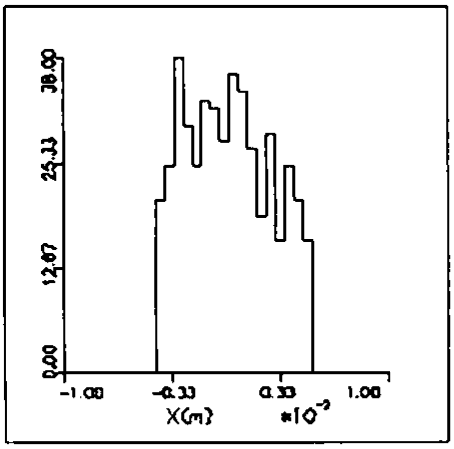
without slit:



with 1 mm slit:

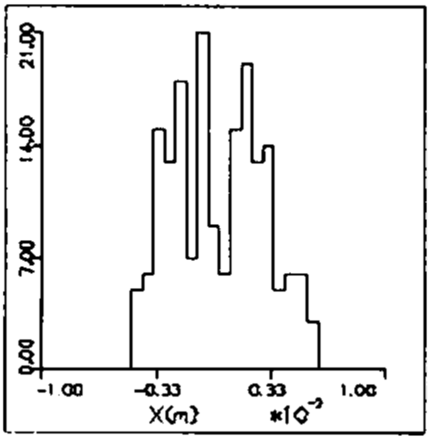


2) Beam at the spectrometer analysis plane if $\epsilon_x = \epsilon_y = 0$
(Pencil input beam with nominal energy spread.)



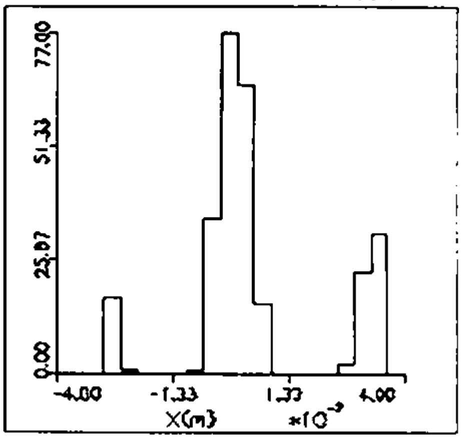
3) Beam at the spectrometer analysis plane for the nominal beam.
/Nominal input transverse parameters and nominal energy spread./

with 1mm slit:



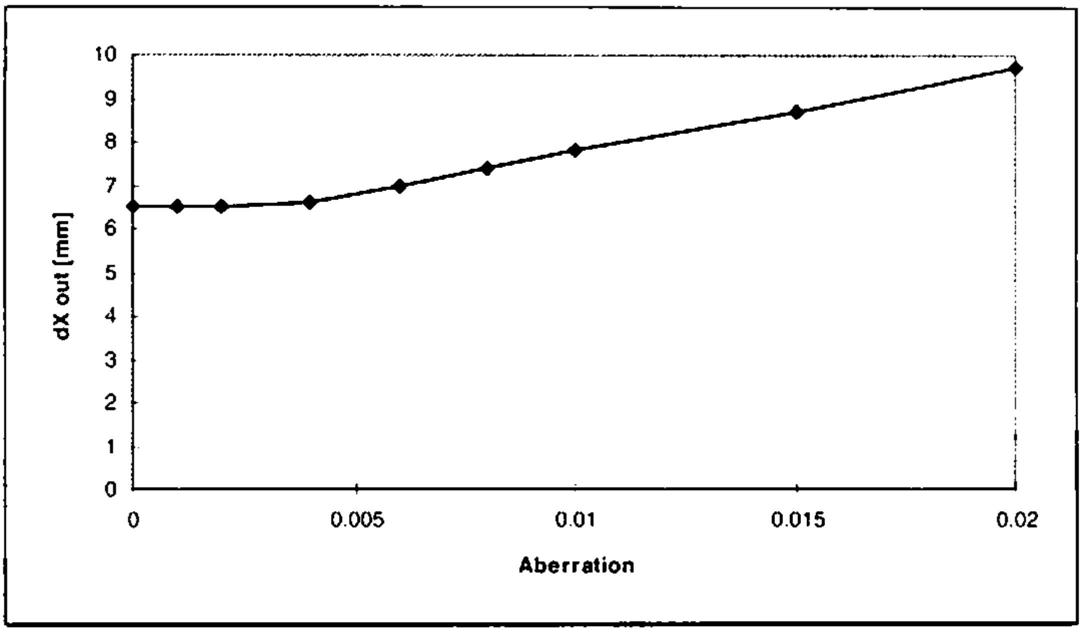
including adjacent charge states:

17+ 18+ 19+



⧅ Bending magnet aberration effects

The following graph shows the effect of magnet aberrations (defined as the ratio between the 1-cm off-axis field and the on-axis field) on the transverse size of the beam at the analysis point for the nominal beam and spectrometer parameters. From the graph we can estimate that in order to meet criteria number 3, the maximum tolerable aberration coefficient is 0.005.



4. Rescaling to other configurations

As mentioned in the joint proposal by W. Pirkl & R. Sherwood, 1994, the first step for the LIS RFQ project assumes a machine of a set length (253 cm). For lead 18+, the energy attainable in that length together with acceptable output beam quality is 126 keV/u. This is what, up to now, we call the base case. Nonetheless, we are also considering a reduced output-energy design, which would bring the 18+ lead beam to a final energy of 100 keV/u.
A second set of vanes in the 253 cm length will be dedicated to lead 25+. The energy attainable in the present design is 190 keV/u.
The second step will involve to bring the lead 25+ beam to the final energy of 250 keV/u.

Beam rigidities and required bending magnet field for the different cases are compared in the following table :

	rigidity(Tm)	field required in the existing magnet(T)
100 keV/u lead 18+	0.528	1.53
126 keV/u lead 18+ (step 1)	0.593	1.72
190 keV/u lead 25+ (step 1.2)	0.524	1.52
250 keV/u lead 25+ (step 2)	0.601	1.74

A magnetic field of 1.7 Tesla is required for the base design case and for the final target energy. However, a magnetic field of about 1.5 Tesla would suffice for the reduced-output-energy 18+ case as well as for the first part of the work with 25+. As a side comment, the set-up can be easily rescaled to the equivalent proton test beam (test in the south hall) due to the much favorable ratio mass/charge.

5. Conclusions

This preliminary work on the proposed LIS spectrometer line sets the tolerances for the magnets aberration to a maximum value of 0.005 (ratio between 1-cm off-axis field and on-axis field). On the other hand, it is shown that the proposed set up can be easily re-scaled to the other RFQ configurations contemplated.

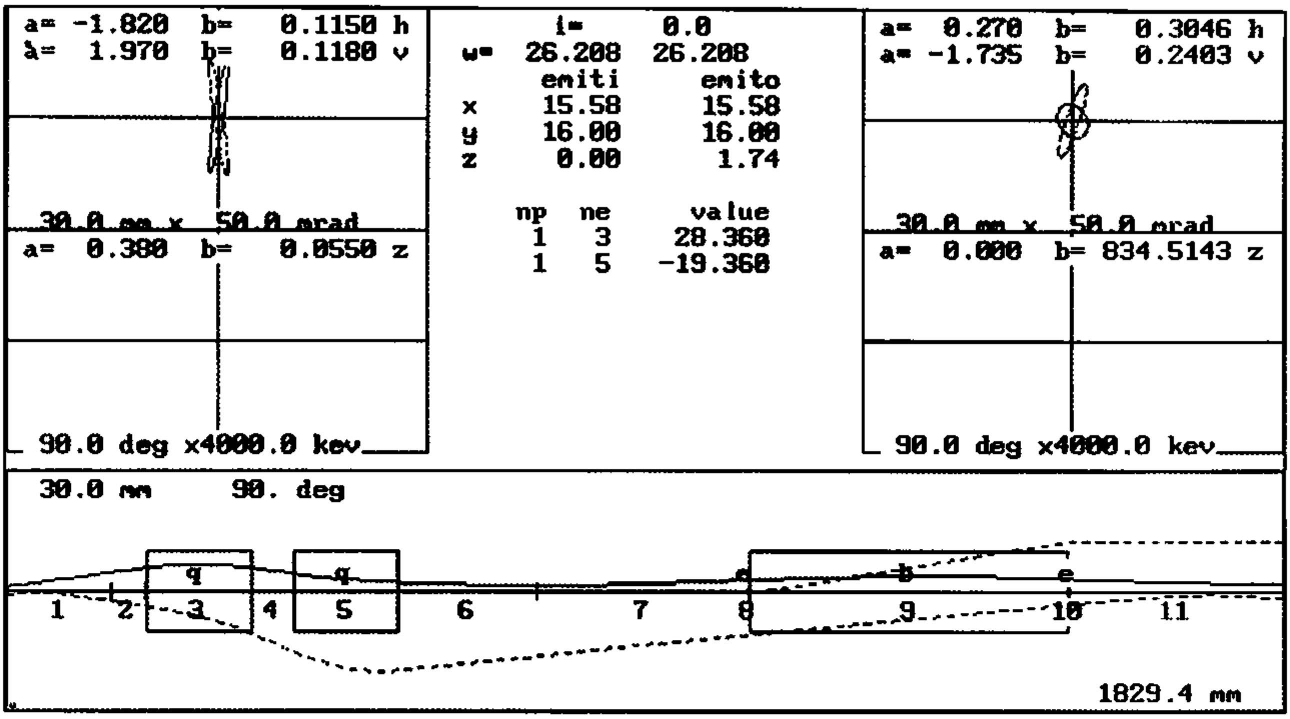
Before installation at the laser ion source, the LIS RFQ will be tested with an equivalent proton beam in the south hall. The measurement apparatus will be the one used for RFQ2; the setup is presented in Appendix 2 for a 100 KeV/u proton beam.

Appendix 1

input file:

```
&data er=193752.000, q=18., w=    26.208, xi=     0.000,
emiti(1)=      15.58,      16.00,        0.0001 norm=  0
beami(1)=   -1.8200,    0.1150,    1.9700,    0.1180,    0.3800,    0.0550
freq=   101.280, pqext=  2.50, ichrom= 1,
xm= 30.00, xpm=  50.0, ym=  30.0, dpm=  90.0, dwm=4000.0, dpp=  90.0,
n1=  1, n2= 11, smax=  10.0, pqsmax=   2.0
nprin= 2, ijprin(1,1)=1, 3,1, 5
nt(  1)=  1, a(1,  1)= 150.0
nt(  2)=  1, a(1,  2)= 50.00
nt(  3)=  3, a(1,  3)= 28.36      ,149.9     , 0.0000     , 0.0000     , 0.0000
nt(  4)=  1, a(1,  4)= 60.00
nt(  5)=  3, a(1,  5)=-19.36      ,149.9    , 0.0000     , 0.0000     , 0.0000
nt(  6)=  1, a(1,  6)= 200.0
nt(  7)=  1, a(1,  7)= 303.0
nt(  8)=  9, a(1,  8)= 0.0000   ,-345.0     , 25.00     , 0.4500     , 2.800
nt(  9)=  8, a(1,  9) -77.00    , 345.0     , 0.0000
nt( 10)=  9, a(1, 10)= 0.0000   ,-345.0     , 25.00     , 0.4500     , 2.800
nt( 11)=  1, a(1, 11)= 303.0
&end
```

beam envelope:



Appendix 2

(South Hall setup)

inputfile:

```
&data er=   938.260, q= 1., w=     0.100, xi=     0.000,
emiti(1)=     24.40,      22.80,       0.0001
beami(1)=   1.5400,   0.1170,  -1.5400,   0.1080,   0.0700,   0.0300
beamf= 1.079,0.1310,1.52,7.5
mt=8,mp=1,3,1,5
freq=   101.280, pqext=  2.50, ichrom= 1,
xm= 30.00, xpm= 100.0, ym=  30.0, dpm=  60.0, dwm=  50.0, dpp=  60.0,
n1=  1, n2= 14, smax=  10.0, pqsmax=   2.0
nt(  1)=  1, a(1,  1)= 110.0
nt(  2)=  1, a(1,  2)= 100.0
nt(  3)=  3, a(1,  3)=-6.065    , 55.00    ,0.0000    ,0.0000    ,0.0000
nt(  4)=  1, a(1,  4)= 45.00
nt(  5)=  3, a(1,  5)= 4.575    , 55.00    ,0.0000    ,0.0000    ,0.0000
nt(  6)=  1, a(1,  6)= 185.0
nt(  7)=  1, a(1,  7)= 800.0
nt(  8)=  9, a(1,  8)=0.0000    , 310.0    , 20.00    ,0.4500    , 2.800
nt(  9)=  8, a(1,  9)= 51.00    , 310.0    ,0.0000
nt( 10)=  9, a(1, 10)=0.0000    , 310.0    , 20.00    ,0.4500    , 2.800
nt( 11)=  1, a(1, 11)= 295.0
&end
```

beam envelope: