Effect of the source tuning parameters on the plasma potential of heavy ions and its influence on the longitudinal optics of the High Current Injector

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Outline

Inroduction

Motivation

Why measure plasma potentials ?

- Plasma potentials give an important figure of merit which finally determines the degree of stability of a plasma
- Plasma stability is better when the plasma potential is low in the range of few tens of volts
- This give rise to higher beam intensity of the highly charged ions due to better confinement in ECR ion sources.
- Therefore, an accurate knowledge can provide insights in the plasma

A.G.Drentje et al, Review of Scientific Instruments, Vol 71 (2000)623

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A.G.Drentje et al, Review of Scientific Instruments, Vol 71 (2000)623

Motivation

Additionally....

They are also give information on the energy spread which is extremely important for estimating the longitudinal optics of a transfer line

Energy spread

The energy spread coming from the ion source is dictated mainly

- The source instability
- high voltage platform instability
- Inherent energy spread of the ions
- Thermal energy of the ions are in the range of few eV

Energy spread

Total beam energy, E

- E = q(extraction voltage + plasma potential)

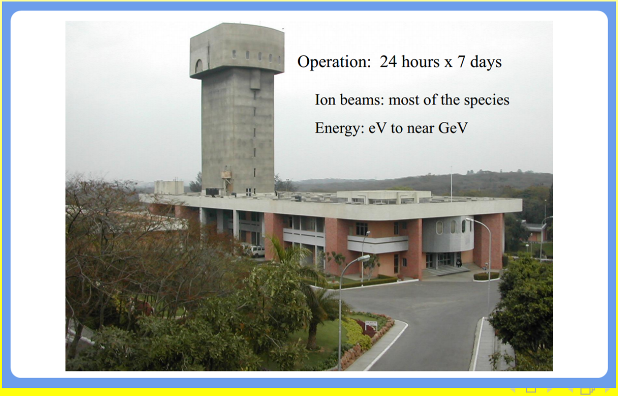
Motivation

The High Current Injector for the Superconducting Linear Accelerator

The High Current Injector will provide a wide range of ion beams than what is current available from the 16UD/15MV Pelletron

Overview of the Accelerator Complex

- 16UD/15MV Pelletron + LINAC ; HCI development



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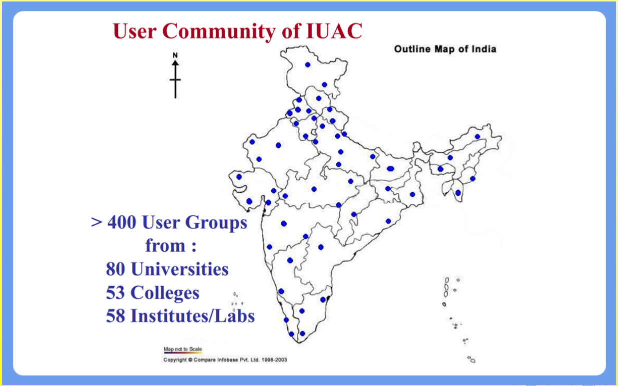

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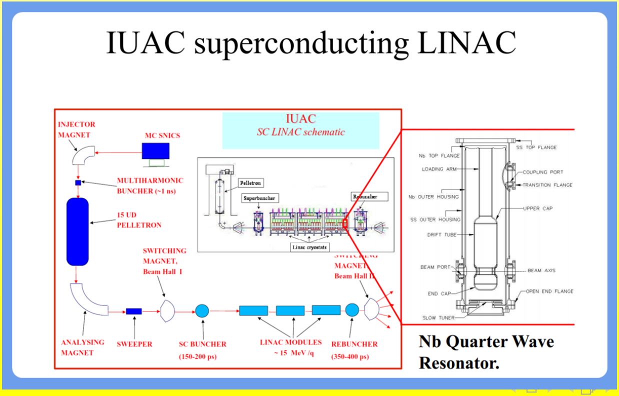

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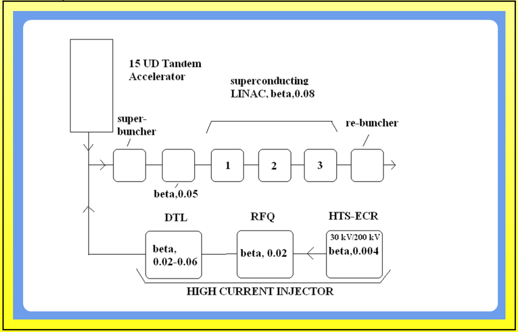
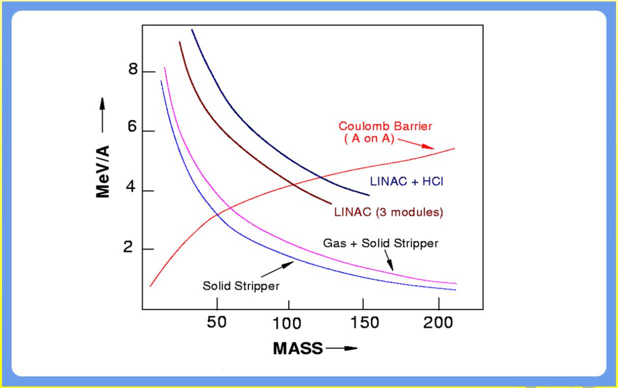


A.Roy, Current Science, 76(1999)149

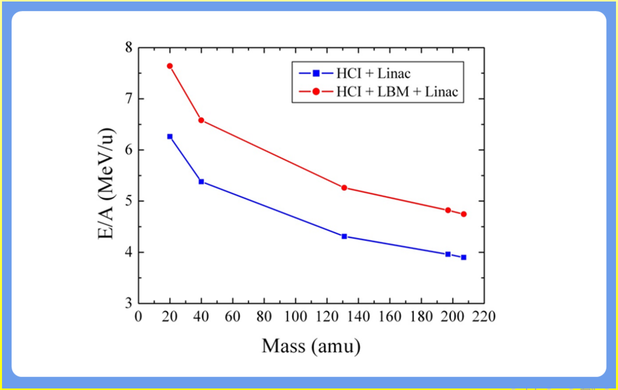
Available beam energies

- Energy per nucleon versus mass number : HCI



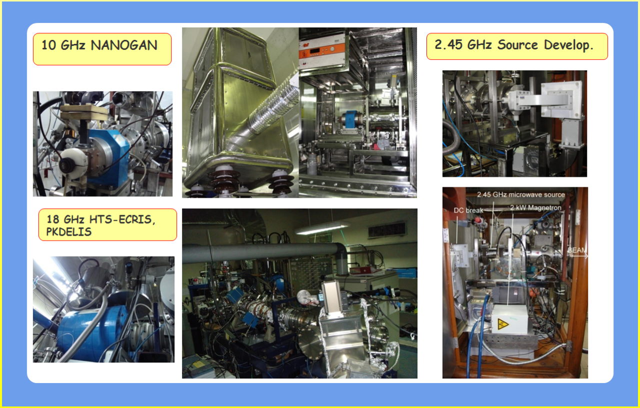
Available beam energies

- Energy per nucleon versus mass number : HCI + low beta module



ECR ion sources at IUAC

- 2.45 GHz , 10 GHz (Materials Sciences) and 18 GHz (for HCI)



Motivation

The High Current Injector for the Superconducting Linear Accelerator

It is important to know the effect of the energy spread on the pulse width of the bunched beam which is crucial for nuclear physics experiments

Various methods to measure the plasma potential

What are they ?

- Magnetic rigidity analysis
- Retarding field energy analysers
- Langmuir probe

Magnetic rigidity analysis

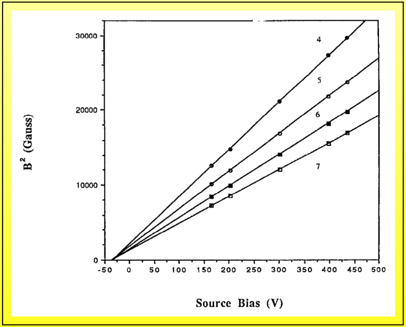
Magnetic rigidity analysis

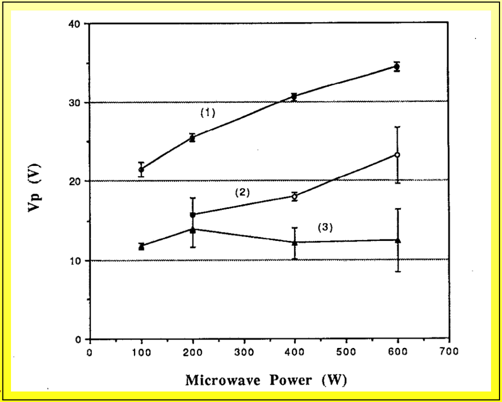
- PP determined by measuring the magnetic rigidity of the beams with a bending magnet
- Rigidity formula does not take into account ion optical effects...
- For accurate results, several measurements with different source voltages are required
- Special attention for fine collimation of the beam is required to measure the magnetic field accurately

Z.Q.Xie and C.M.Lyneis, Review of Scientific Instruments, Vol 65 (1994)2947

Magnetic rigidity analysis

Magnetic rigidity analysis





Z.Q.Xie,C.M.Lyneis, RSI,Vol.65(1994)2947

Retarding field energy analysers

Traditional parallel plate retarding energy analyser

- Consists of two parallel plates, first plate is grounded and the second is biased to a high voltage to retard the beam
- Only those particles whose longitudinal kinetic energy is higher than the retarding potential can pass this second electrode and reach the collector forming a current signal
- Resolutions are in the range of 10-2 to 10-3 (dE/E)
- Structure has good resolution for beam trajectories parallel to the axis of the energy analyser

J.A.Simpson, Review of Scientific Instruments, Vol 32 (1961)1283

Langmuir probe

In-situ Langmuir probe measurements

What are they ?

- Standard technique to measure the plasma potentials
- They are used generally at the edge of the ECR plasma
- Disturbs the ion source plasma ,Probe lifetimes are limited

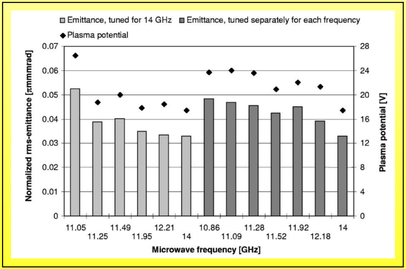
Present scenario

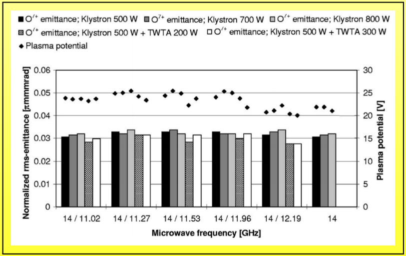
ECR group at Jyvaskyla, Finland

- Tarvainen et al found that the PP increase with RF power and gas pressure
- Values changed when the negative DC bias was varied
- They measured the effect of gas mixing on PP,energy spread and emittance
- Energy spread can influence the emittance to several tens of percent in bending plane of the dipole magnet
- They compared the measured values of emittance and PP using single and double frequency heating modes

O.Tarvainen et al., RSI, Vol 75 (2004)3138, RSI, Vol 76 (2005)093304,RSI, Vol 77 (2006)03A309

ECR group at Jyvaskyla, Finland





O.Tarvainen et al., Review of Scientific Instruments, Vol 77 (2006)03A309

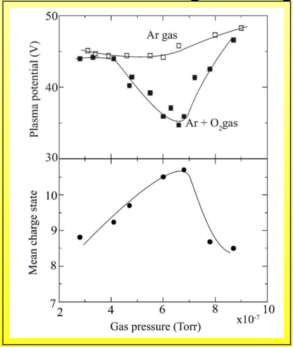
ECR group at RIKEN, Japan

- General trend of increase of PP for lower charge states in comparison to higher ones,reported by Higashijima et al
- Higashijima et al measured the PP and it was observed to be constant above 5+ for Argon
- An additional effect of the gas mixing was observed...
- For Ar+O2 feed, the plasma potential decreases with increasing gas pressure

H.Higashijima et al, Review of Scientific Instruments, Vol 79 (2008)02B505

ECR group at RIKEN, Japan

- Additional effect of gas mixing



H.Higashijima et al, Review of Scientific Instruments, Vol 79 (2008)02B505

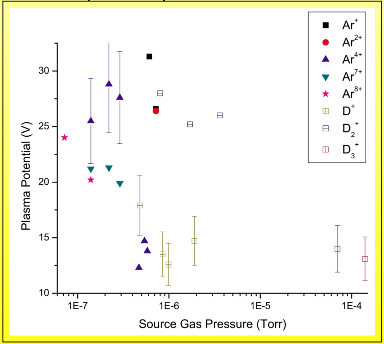
ECR group at ORNL, USA

- General trend of increase of PP for lower charge states in comparison to higher ones,reported by Harris et al
- Decelerated beam measurements are compared to in-situ probe results and external beam results based on magnetic analysis

P.R.Harris et al, Review of Scientific Instruments, Vol 81 (2010)02A310

ECR group at ORNL, USA

- Deduced plasma potential values as a function of source pressure



P.R.Harris et al, Review of Scientific Instruments, Vol 81 (2010)02A310

Principle of the method

Deceleration Technique

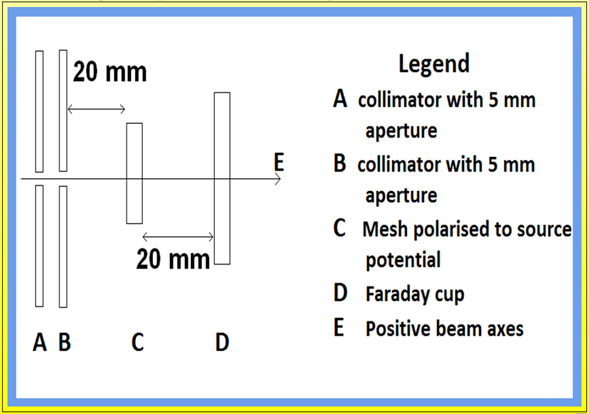
Technique derived from Jyvaskyla's group

Using a single electrode (mesh) biased to the source potential, the beam is decelerated close to the location of the mesh ;

O.Tarvainen et al., Review of Scientific Instruments, Vol 75 (2004)3138

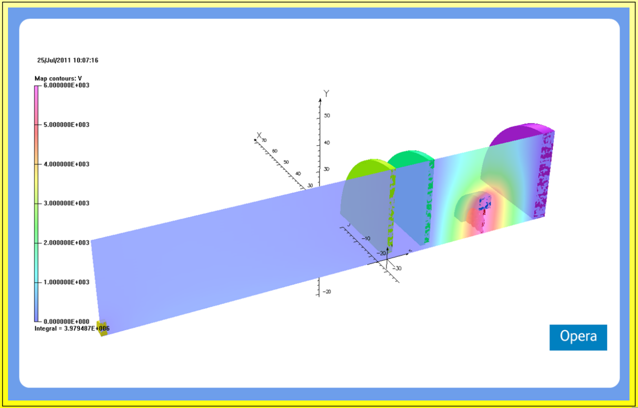
Schematic of the deceleration system

- View of the geometry of the deceleration system



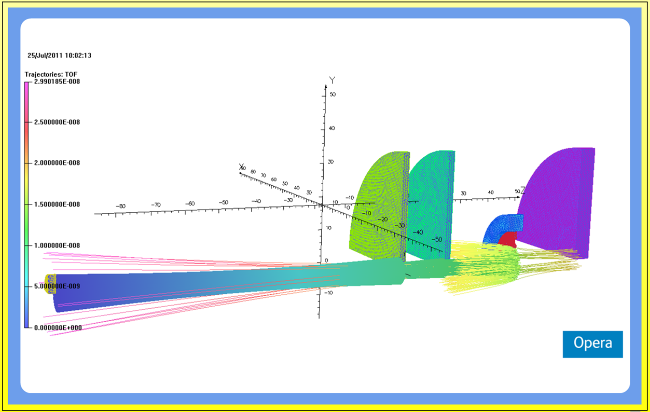
Simulation using TOSCA

- View of the equipotentials (mesh polarised to 6 kV)



Simulation using TOSCA

- View of the beam deceleration

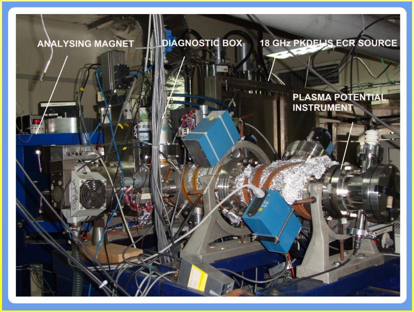


The deceleration system

- View of the deceleration system

View of the experimental set-up

- HTS-ECR Ion Source, PKDELIS and Low Energy Beam Transport



D.Kanjilal et al, Review of Scientific Instruments, Vol 77 (2006)03A317
G.Rodrigues et al, Review of Scientific Instruments, Vol 83 (2012)033301

Errors and repeatibility

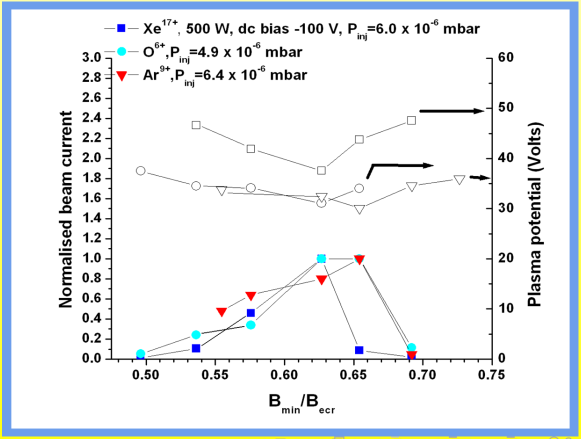
- The errors in the measurements was measured to +/- 2 V
- The repeatability in the measurements was found to be +/- 0.8 V

RF power, DC bias,gas pressure fixed

RF power, DC bias,gas pressure fixed

- Unstable beyond Bmin/Becr= 0.73
- Earlier measurements, similar
- intensities maximised at 0.65

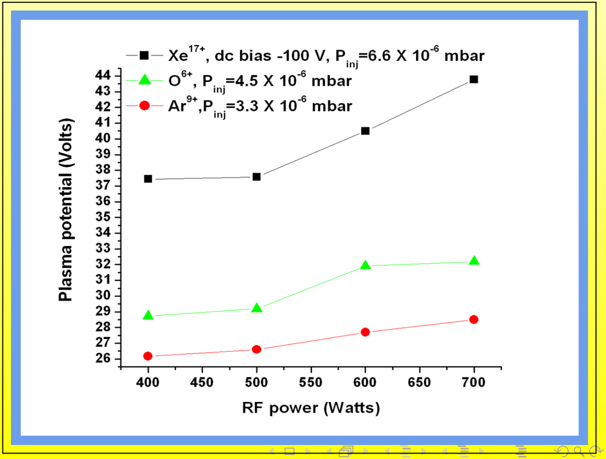
G.Rodrigues et al, RSI, Vol 81 (2010)02A323



gas pressure, DC bias and magnetic field fixed

gas pressure, DC bias and magnetic field fixed

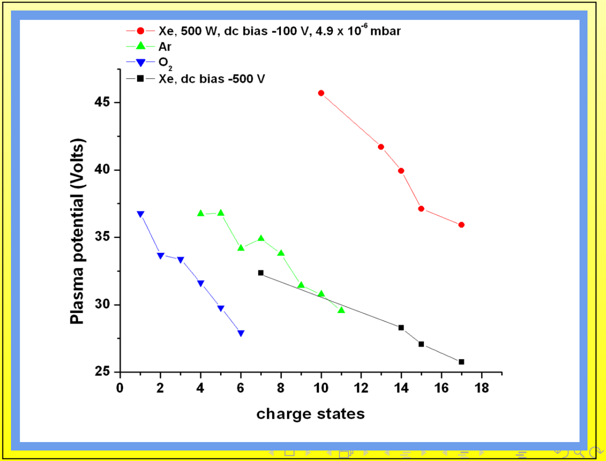
- PP strongly dependant on the gas pressure variation



RF power, gas pressure and magnetic field fixed

gas pressure, DC bias and magnetic field fixed

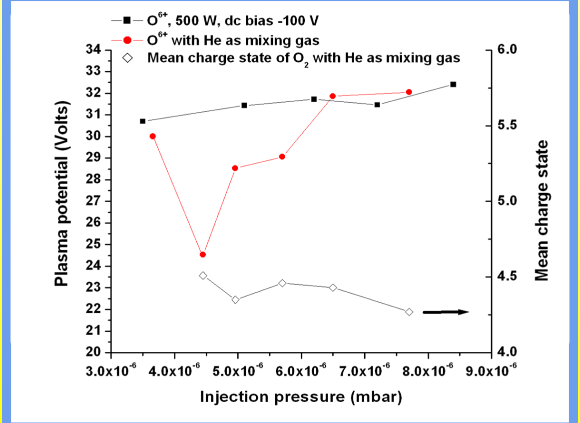
- Bmin/Becr = 0.63



Plasma potential variation of O6+

Plasma potential variation of O6+

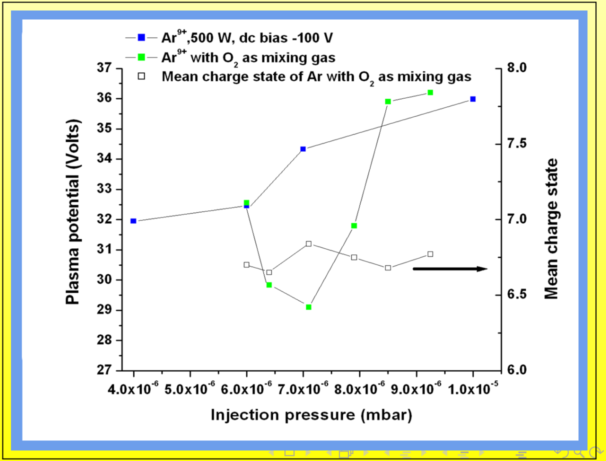
- oxygen gas pressure fixed at 3.5 x10-6 mbar



Plasma potential variation of Ar9+

Plasma potential variation of Ar9+

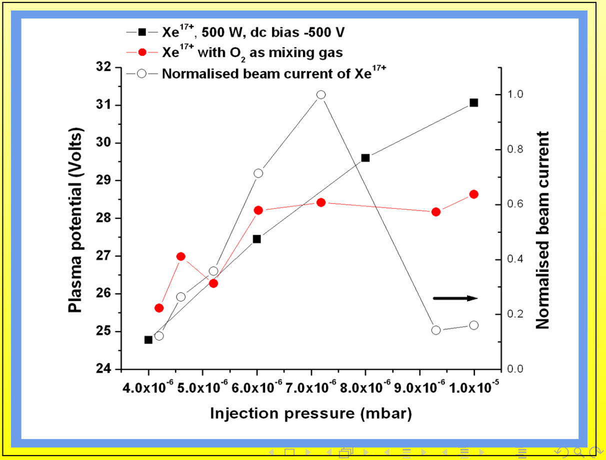
- argon gas pressure fixed at 4.0 x 10-6 mbar



Plasma potential variation of Xe17+

Plasma potential variation of Xe17+

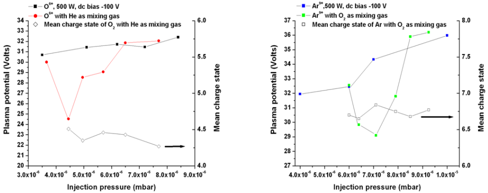
- Xe gas pressure fixed at 4.0 x 10-6 mbar



Comparison with theoretical model

Comparison with theoretical model

- Cold electron temp. in the range of few tens of eV
- Maxwellian electron distribution function



$$U_{pl} = \left(\frac{kT_e}{2e}\right)\left(5.67 - \ln\left\langle\frac{q}{M}\right\rangle\right)$$

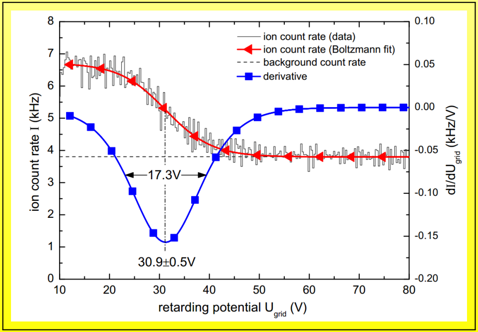
U_{pl} the plasma potential
k the Boltzmann constant
T_e cold electron temperature
$\langle q \rangle$ the mean charge state

N.K.Bibinov et al., Plasma Sources Sci.Technol. 14 (2005)109

Energy spread

How to estimate the energy spread ?

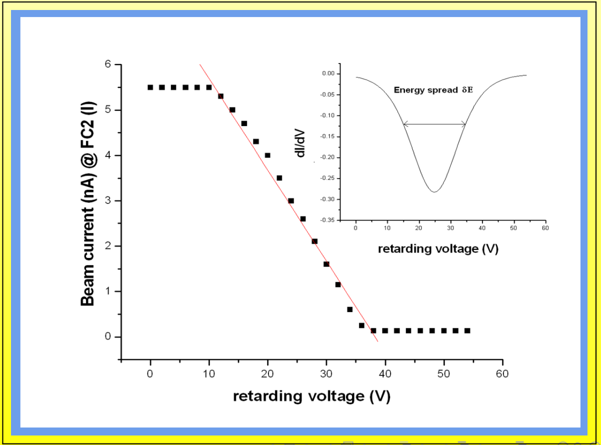
It is calculated from the derivative of the current voltage distribution curve



Retardation curve showing linear fit and it's derivative

Retardation curve showing linear fit and it's derivative

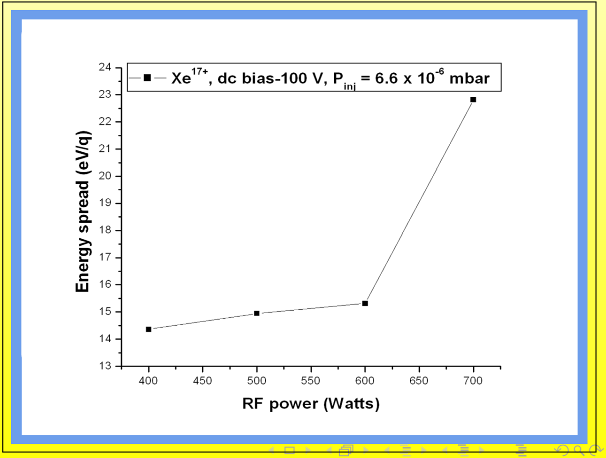
- Measured at 500 W
- Energy spread 14.946 q eV for Xe17+



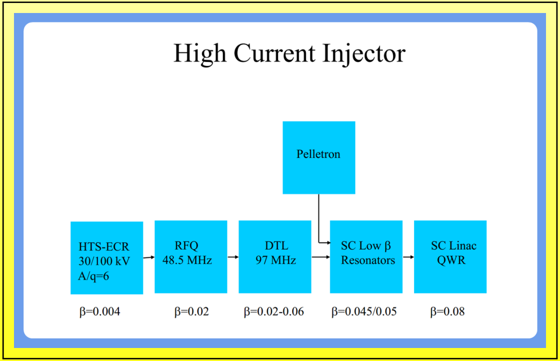
Energy spread as a function of RF power for Xe17+

Energy spread as a function of RF power for Xe17+

dT=(DdE)/(2vEo)
where dT, time spread
dE, energy spread
D, distance
v, particle velocity



Overview



G.Rodrigues et al., Review of Scientific Instruments, Vol 81 (2010)02B713

HCI designed for A/q=6

Reducing the longitudinal emittance

- In order to improve the longitudinal emittance of the RFQ, the adiabatic buncher is replaced with external discrete bunchers.
- The transmission of the RFQ is equal to that of a conventional RFQ with adiabatic bunching, thereby reducing the RFQ length
- Finally the cost you pay for is ...
- Stability requirement of the pre-injector voltage increases by an order of magnitude
- rf defocussing in the buncher may be significant
- May require gridded cavities or small beam size in the buncher

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Pre-acceleration from the Ion Source

- The DC beam will be accelerated to 8 keV/u using the H.V platform (beta=0.004)
- Bunched using a 12.125 MHz multi-harmonic buncher (MHB)with harmonics n=4
- Further accelerated by RFQ to 180 keV/u (beta=0.02)
- Finally accelerated by DTL to 1.8 MeV/u into the SC-LINAC (beta=0.08)

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Purpose of the multi-harmonic buncher

- Most of the DC beam gets bunched close to the entrance of the RFQ
- Improves the capture efficiency
- Growth of the longitudinal emittance at the exit of the RFQ is minimised

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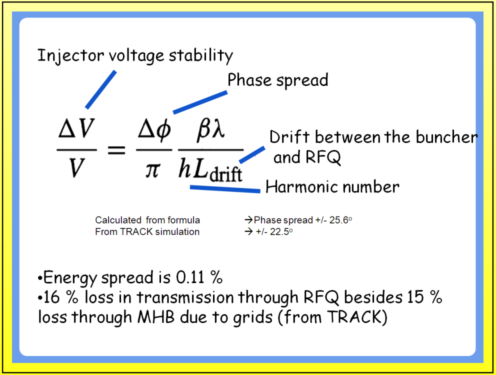
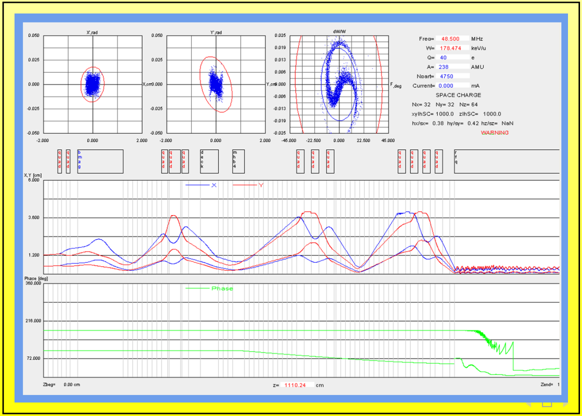
Injector voltage stability



John Staples, Particle Accelerators, Vol.47 (1994)191

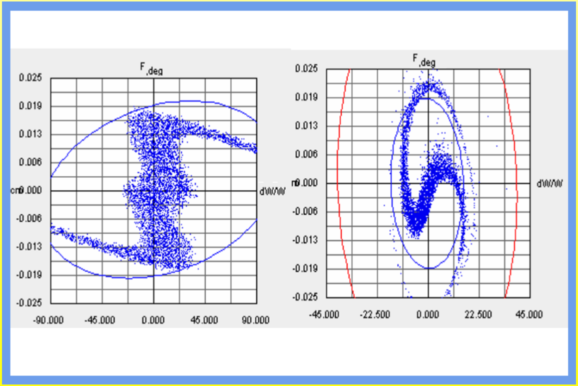
(ECR + HV Platform) + M.H.Buncher + RFQ

- Simulation using TRACK, Beam 238U40+, 10000 particles



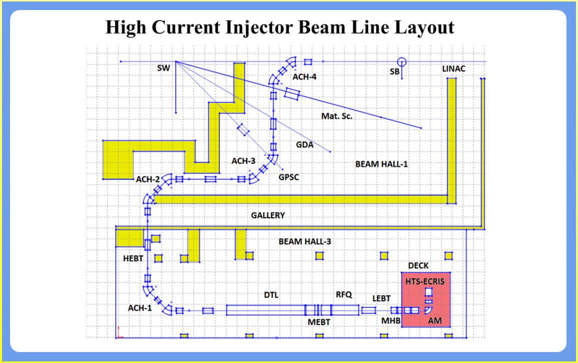
RFQ located at 4.0 m downstream of buncher

- Longitudinal phase space plots at entrance and exit of RFQ



Layout of the facility

- Beam hall III coupled to beam hall I



Summary

- The variation of the plasma potential in an ECR plasma has been studied as a function of different source parameters and for several ion beams
- Shows a mass effect
- The plasma potentials increase with gas pressure and RF power
- In the case of gas mixing, the plasma potential reaches a minimum at an optimum value of the pressure of the mixing gas and the mean charge state maximises at this value
- DC bias and gas mixing reduces the plasma potential

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Conclusions

- The energy spread arising from the plasma potential measurements influences the longitudinal optics of the High Current Injector in terms of increased phase spread that deteriorates the transmission through the RFQ
- The energy spread of the ions is a determining factor for the resultant time width of the beam bunches that would accelerated further by the High Current Injector

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- Thank you for your Kind Attention