INHOMOGENEITIES IN BEAMS EXTRACTED FROM ECR ION SOURCES

A semi-opinionated overview

J. Stetson, NSCL/MSU; P. Spädtke, GSI

Mount Doom
“The key to high intensity and low beam losses is very careful control of injection and extraction.”

Stuart Henderson, ORNL
Injection Line + Improvements

Original Configuration (Solenoid)

Electrostatic Q-Triplet

Sextupole

Doublet-Octupole-Doublet + Stronger Sextupole (2007?)

Emittance Scanner

Spherical Bender (2007?)

2nd Harmonic RF

4-Jaw Slits

RF Chopper

Solenoid Doublet

(K500)
Hardware Changes Affecting Beam Dynamics 2003-2007 (Injection line In Orange)

May 2003: Revised ARTEMIS-A Extraction Region
July 2004: Problem with ARTEMIS-A Hex field
05-Sept-04: Install Small Bore Triplet (SBT) on SC-ECR
17-Nov-04: Install S006SX, Remove Aperture 1
7-Dec-04: Repair K12 injection & K12C3,4
Jan-05: ARTEMIS-A Permanent Magnet Sextupole Bars Replaced
Jan-05: SBT on SC-ECR moved up 5"
Jan-05: Buncher moved up 12"
Jan-05: K8C4 Beam Scraper (0.42") Installed
16-Feb-05: remove S007AP
10-Dec-05: Double Solenoid under K500; Buncher moved down 4"
10-Jan-06 Large Bore Triplet (LBT) installed on ARTEMIS-A
10-Jan-06: remove R007Aperture
10-Jan-06: Installed 0.3" Vt Collimation at Full Radius on K500 K5MPSC
7-Apr-06: Add K500 Phase Slits
7-Apr-06: Add J033 4-Jaw Slits
7-Apr-06: K5MPSC Gap reduced to 0.25"
11-May-06: Reverse J046SN Polarity
12-Jun-06: Install Double Doublet System (DDS) on ARTEMIS-A
12-June-06: Replace Buncher grids with 1 cm dia washers
12-Jun-06: Swap R013QA/14QB with J042SN
15-Jan-07 Inflector Collimator 4.2 → 2 mm (failed, returned to 4.2 mm)
15-Jan-07: K5MPSC Gap reduced to 0.19"
15-Jan-07: Einzel Lens + LBT installed on SC-ECR; remove S006SX
15-Jan-07: Water-cool K12E1D drive rod
19-Jan-07: reversed polarity of J056SN
Max Recorded Beam Intensities 2002-2006

![Graph showing peak intensities of various isotopes from 2002 to 2006. The x-axis represents the years (2001-2007), and the y-axis represents the beam current in pA. The graph includes lines for O-16, Ar-40, Ca-40, Ca-48, Kr-78, Xe-124, and Ni-58. Each line shows the trend of the peak intensity over the years.]
Ideal Case for Perfect Injection

Uncorrelated Round Beam (Object) → "Round" Beam → Uncorrelated Round Beam (Image)

Lens 1 → Lens 2
Our Less-than-Ideal Situation

What kind of Object gives *Strange Stuff* as an Image?
GSI Test Stand
2006

pepper pots to show the 4d correlations

BaF$_2$ viewing targets to display the profile
$^{40}$Ar Rings: VT1 view 40cm from extraction (GSI)

Higher Charge States Are Closer to Center
VT2 view after first Beam Line Solenoid (GSI)

“Stars” are over-focused “Rings”
ECRIS Beam has a Special “Tag”

“Rings” morph into “Stars” by varying the focusing strength of lenses.

Simulations:
This is not explained by 2\textsuperscript{nd} Order Alone
40Ar$^7+$ VT3 After Dipole (GSI)

Side View of source plasma?
Beam line = Angle Spectrometer?

Pepper Pot at VT3
NSCL $^{40}$Ar Rings (before dipole)
(ECRIS $\rightarrow$ Solenoid $\rightarrow$ Viewer)

(Distortions to Rings Caused by Current Leads on the Solenoid Ends)
Rings of $^{58}$Ni Charge States

(ECRIS $\rightarrow$ Solenoid $\rightarrow$ Dipole $\rightarrow$ Viewer)
Ring to Star using Beam Line Solenoid

(ECRIS → Solenoid → Dipole → Solenoid → Viewer)
Image Propagation thru Injection Line

Round Aperture

29-Jun-07
FROABA02: J. Stetson, NSCL/MSU
P. Spädtke, GSI
$^{48}$Ca Rings: Here, There, Everywhere?

J035

J053
(into K500)

N053
(into K1200)
N053 Star (just before K1200 injection)

Ring-to-Star “Tag” survives Acceleration in Cyclotron!

(Tail too Dim to see without blocking main part of the beam)
Hz Slit Scan J033XGap = 2 mm

Slit half-way thru Injection Line, Viewer Just Before K500
Cut 90% of Intensity with J033 Slits centered on Beam

Slit half-way thru Injection Line, Viewer Just Before K500
Possible Results of “Blind” Tuning

< 50 \text{pi*mm*mrad}: 34\% \text{ Hz}, 19\% \text{ Vt}
Tuned for good measured 2d Emittance

< 50 \text{pi*mm*mrad}: 94\% \text{ Hz}, 88\% \text{ Vt}
An Effective Slit Cut (Grid at Slit Location)

“Organized” Beam Slits Open

“Mess”

“Organized” Beam Slits Closed
Orderly Beam: Slits Out (60mm x 60mm)

< 50 pi*mm*mrad: 74% Hz, 57% Vt
Orderly Beam: Slits In (8mm x 8mm)

< 50 pi*mm*mrad: 100% Hz, 94% Vt
< 25 pi*mm*mrad: 76% Hz, 94% Vt
ECRIS Beam Characteristics

1) Transverse Structure (Hollow)
2) Large 2\textsuperscript{nd} Order Aberrations (Triangle)
3) Strong Phase space cross-coupling (beam is “correlated”)
4) Focusing morphs Ring into Star (not explained by 2\textsuperscript{nd} order)
5) Under some conditions, a fractal nature (round cut can redevelop into a triangle)
Model Assumptions/Opinions

1) “Miniscus” emission is not adequate. The object of the following optical system is within the plasma chamber.

2) Extracted Ions travel on a largely undisturbed path from their creation.

3) The ions are emitted from a volume, not a disc.

4) ....
4) In lieu of a full understanding, the emission volume is taken to be a shell defined by the magnitude of the B field corresponding to the ECRIS resonant condition.
KOBRA3-INP Simulation (27-June-07)
CAPRIS ECRIS – GSI Test Stand

Ions Start In Plasma Chamber

Solenoid

Rings and Stars On VT2?
Beam on VT2 (X-Y) Space with Increasing **Beam Line** Solenoid Strength

Shows the Ring-to-Star “Tag”
Beam on VT2 (X-X’) and (Y,Y’) Space with Increasing Beam Line Solenoid Strength

Focus at Case 3
Beam on VT2 (X’,Y’) Space with Increasing Beam Line Solenoid Strength

(X’,Y’) Space shows Signature of 2nd order aberration
Plasma Boundary Side Views

Gives Poor Results

Sensitive to Starting Conditions

Gives Good Results
Test of Concept - Experiment

ECR Sextupole

Added Sextupole

Uncorrelated Round Beam (Object) → Correlated Triangle Beam (Observed) → Uncorrelated Round Beam (Desired)
Add Sextupole to Beam Line

Magnetic Sextupole
Partial Correction of 2nd Order with External Sextupole (protons)

Problems: 1) Need stronger sextupole. 2) Corrects only at one location; The structure re-forms after a drift. 3) Poor Dipole confuses results.
Magic Electrostatic Lens System:
Gives 90 Deg Phase Advance from
ECRIS Sextupole to an External Sextupole

- Quadrupole Doublet
- Octupole Singlet
- Quadrupole Doublet
2nd Order Correction Scheme: ~Pi Phase
Advance to Corrector Sextupole

1st Order
Un-corrected

2nd Order
Corrected

X

Y
2nd Order Correction Scheme:
~Pi Phase Advance

1st Order

2nd Order Un-corrected

2nd Order Corrected

(x,y)

(x',y')
Real Test of 2\textsuperscript{nd} Order Correction Scheme

At NSCL (Fall 2007?)
Install New Analysis Dipole (under construction)
Install New Sextupole
“Perfection” vs. “Reality”

Design Real Beam Lines for Real Objects (when possible)
The Cast

**BEAM PHYSICS**
- Felix Marti
- Marc Doleans
- Xiaoyu Wu
- Q. Zhao

**ION SOURCE**
- Peter Zavodszky
- G. Machicoane
- Dallas Cole
- Larry Tobos

**GSI**
- R. Lang
- J. Mäder
- J. Roßbach
- K. Tinschert
A Complete Model Must Include:
## Improvements at Similar Source Output

<table>
<thead>
<tr>
<th></th>
<th>~2003 Source out $\rightarrow$ K1200 out (pnA)</th>
<th>~2006 Source out $\rightarrow$ K1200 out (pnA)</th>
<th>Gain (normalized to source output)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{40}$Ar</td>
<td>2280 $\rightarrow$ 58</td>
<td>1920 $\rightarrow$ 222</td>
<td>4.5</td>
</tr>
<tr>
<td>$^{48}$Ca</td>
<td>1275 $\rightarrow$ 32</td>
<td>1400 $\rightarrow$ 160</td>
<td>4.6</td>
</tr>
<tr>
<td>$^{76}$Ge</td>
<td>692 $\rightarrow$ 17</td>
<td>725 $\rightarrow$ 63</td>
<td>3.5</td>
</tr>
<tr>
<td>$^{78}$Kr</td>
<td>2640 $\rightarrow$ 22</td>
<td>2760 $\rightarrow$ 79</td>
<td>3.4</td>
</tr>
<tr>
<td>$^{136}$Xe</td>
<td>700 $\rightarrow$ 2.86</td>
<td>371 $\rightarrow$ 8.16</td>
<td>6.5</td>
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Maximize the Good at the Expense of the Bad

Region of Interest

Not Injectable Beam