INHOMOGENEITIES IN BEAMS EXTRACTED FROM ECR ION SOURCES

A semi-opinionated overview

J. Stetson, NSCL/MSU; P. Spädtke, GSI

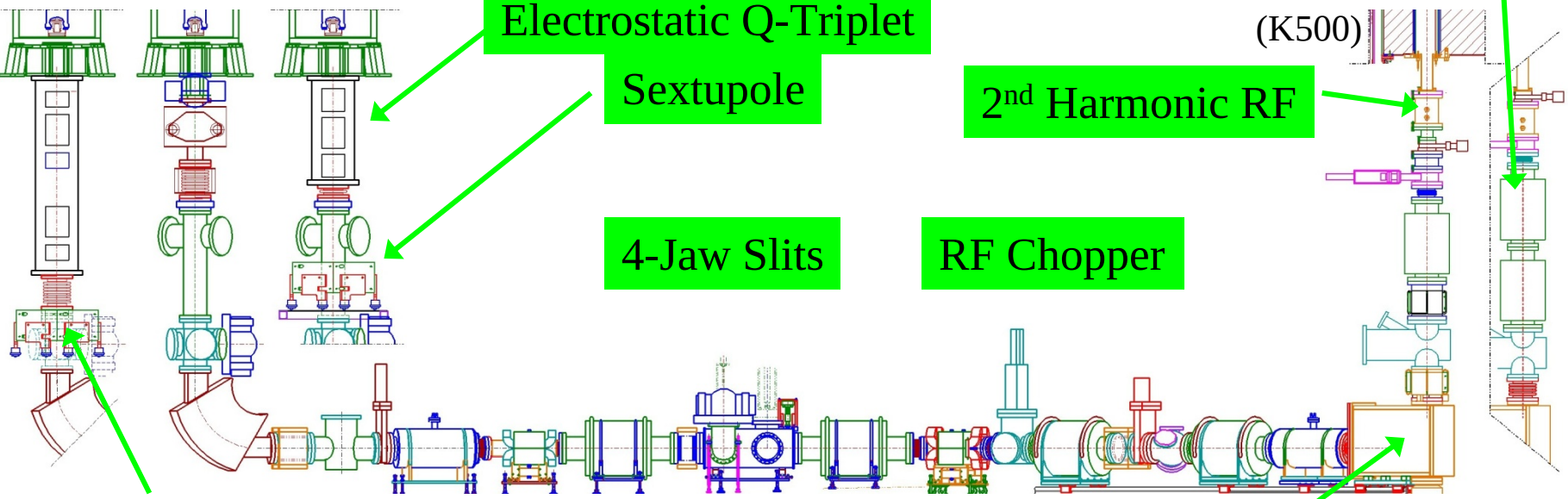
Mount Doom

From PAC07 (talk MXOXKI03)

"The key to high intensity and low beam losses is very careful control of ***injection*** *and extraction."*

Stuart Henderson, ORNL

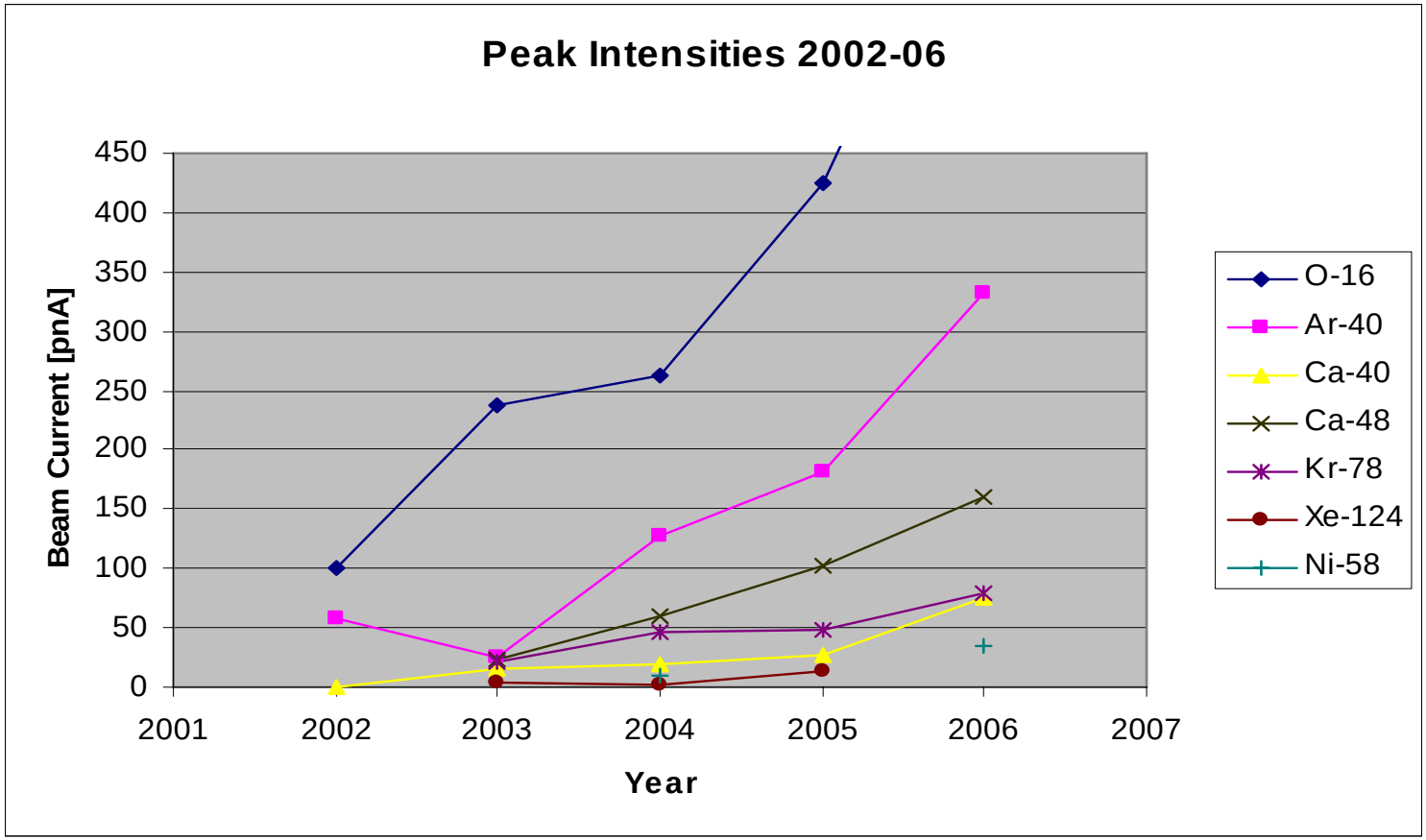
Injection Line + Improvements



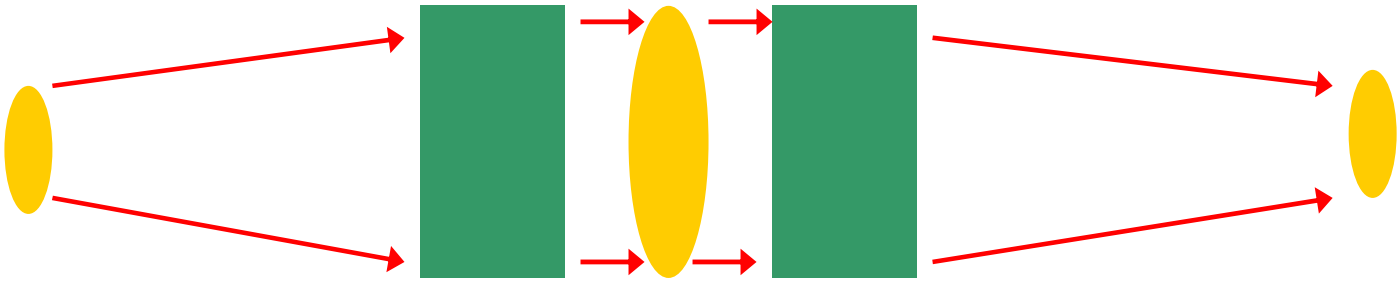
Hardware Changes Affecting Beam Dynamics 2003-2007 (Injection line In Orange)

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 SCECR 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: Moved Plasma Electrode and Puller 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 SCECR; remove S006SX
15-Jan-07: Water-cool K12E1D drive rod
19-Jan-07: reversed polarity of J056SN

Max Recorded Beam Intensities 2002-2006



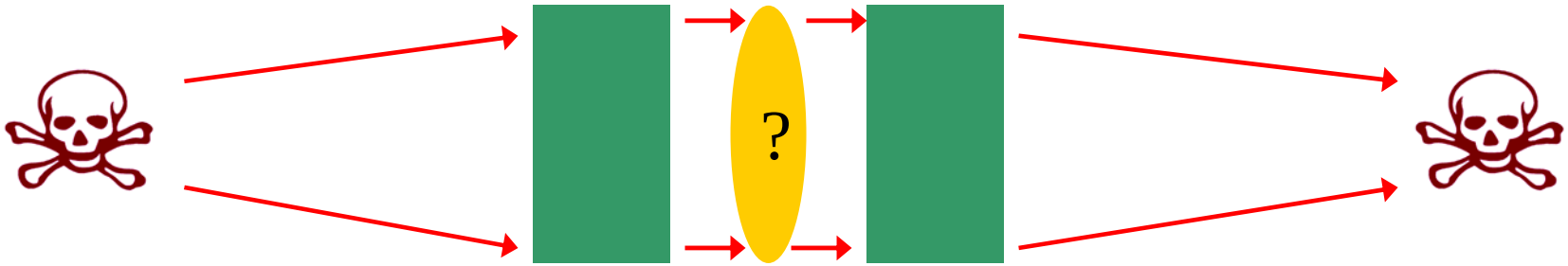
Ideal Case for Perfect Injection



Lens 1 Lens 2

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

Our Less-than-Ideal Situation



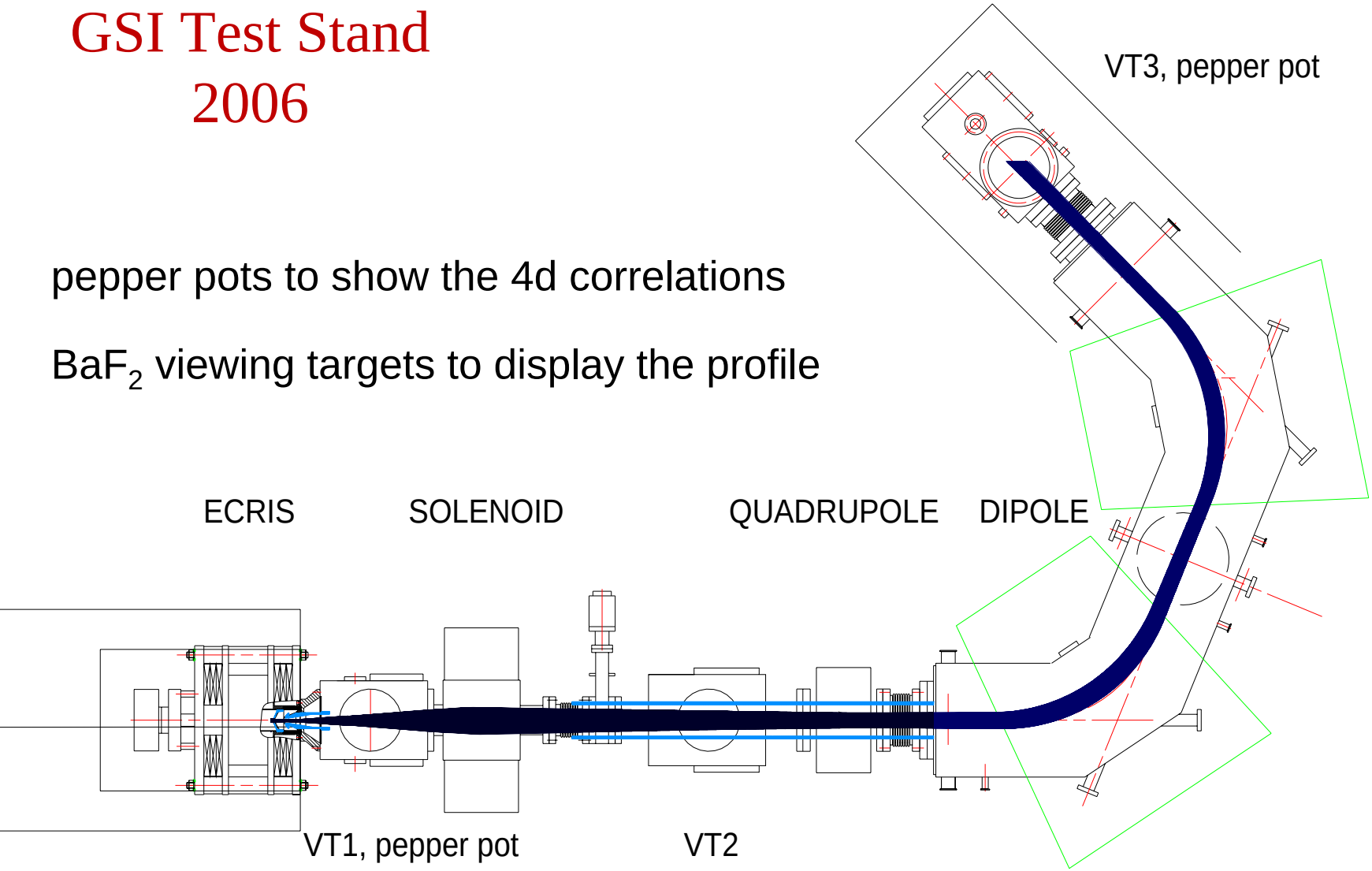
What kind of Object gives ***Strange Stuff*** as an Image?

Strange Stuff

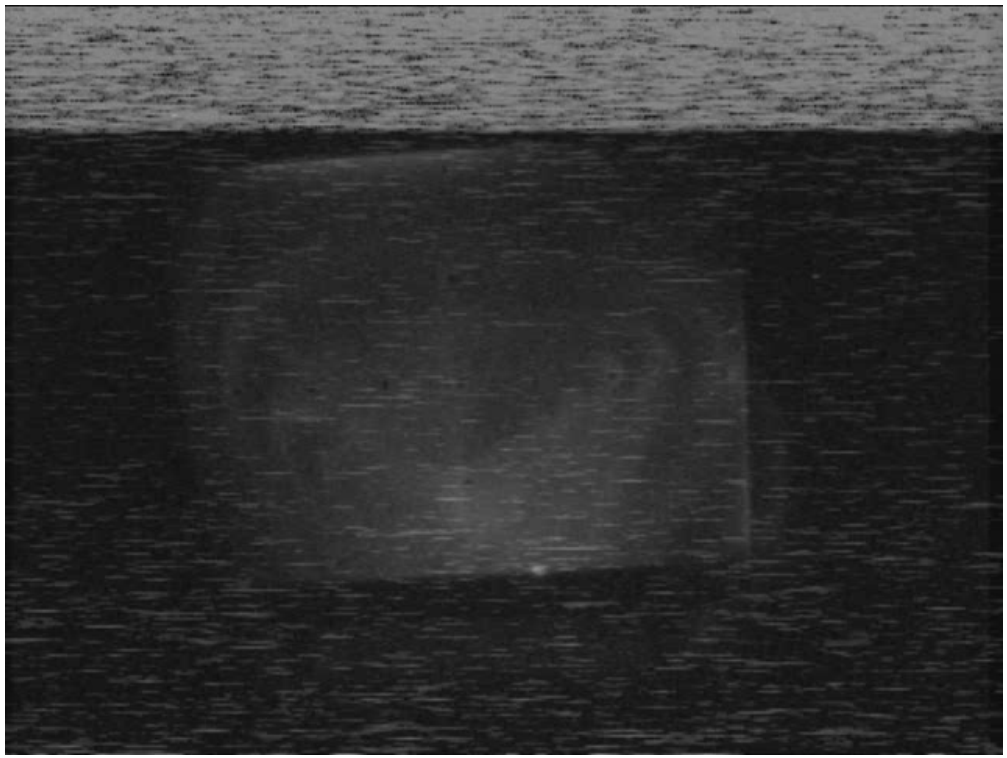
GSI Test Stand 2006

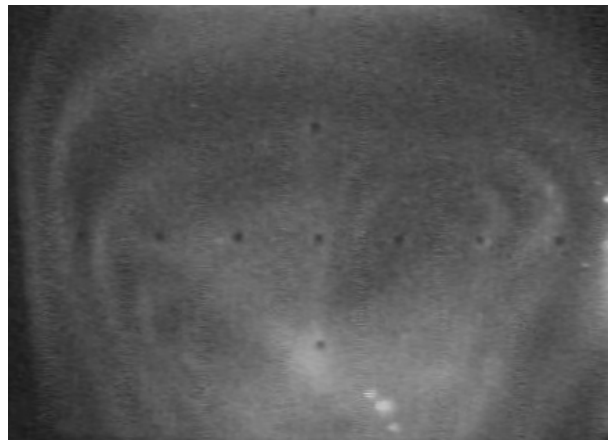
pepper pots to show the 4d correlations

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"

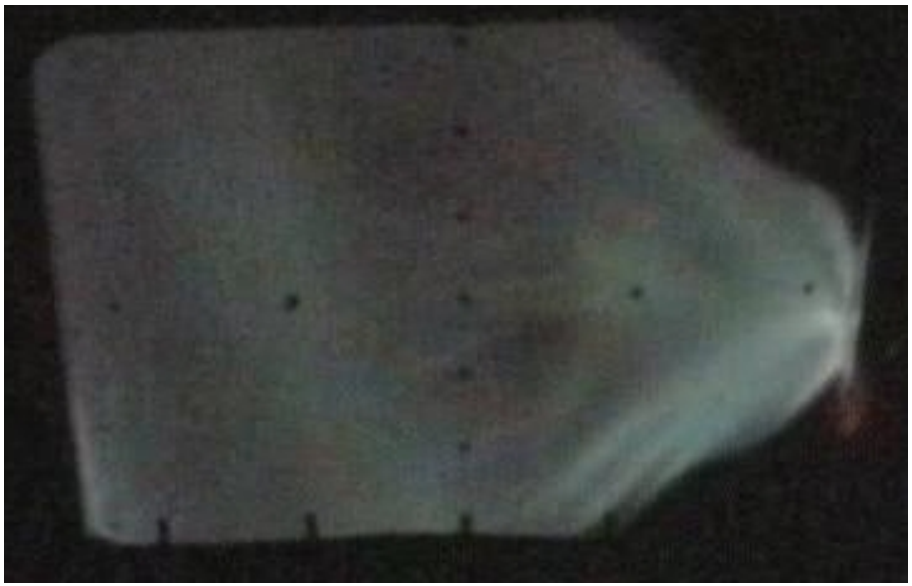
ECRIS Beam has a Special “Tag”

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

Simulations:

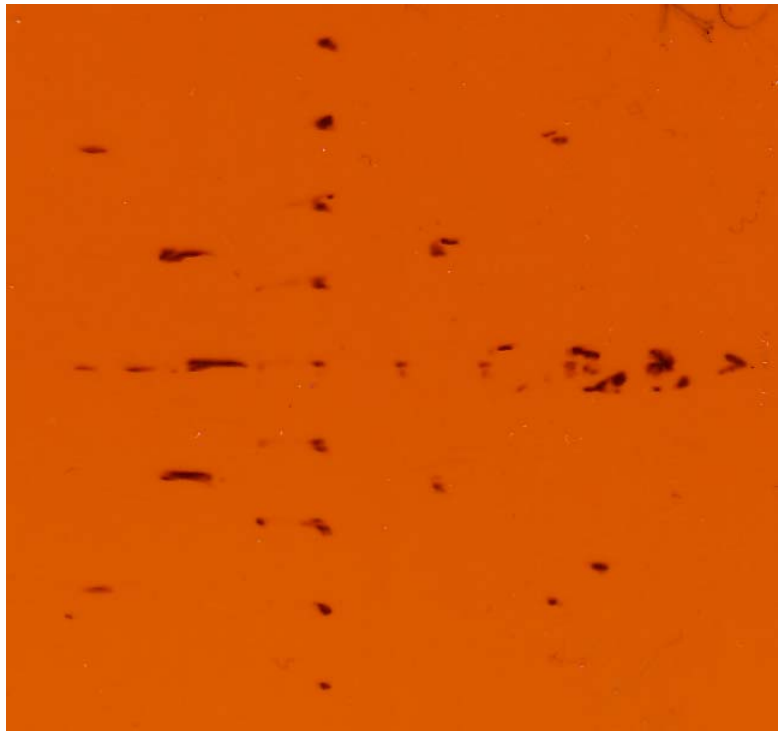
This is not explained by 2nd Order Alone

$40Ar^{7+}$ VT3 After Dipole (GSI)



Side View of source plasma?

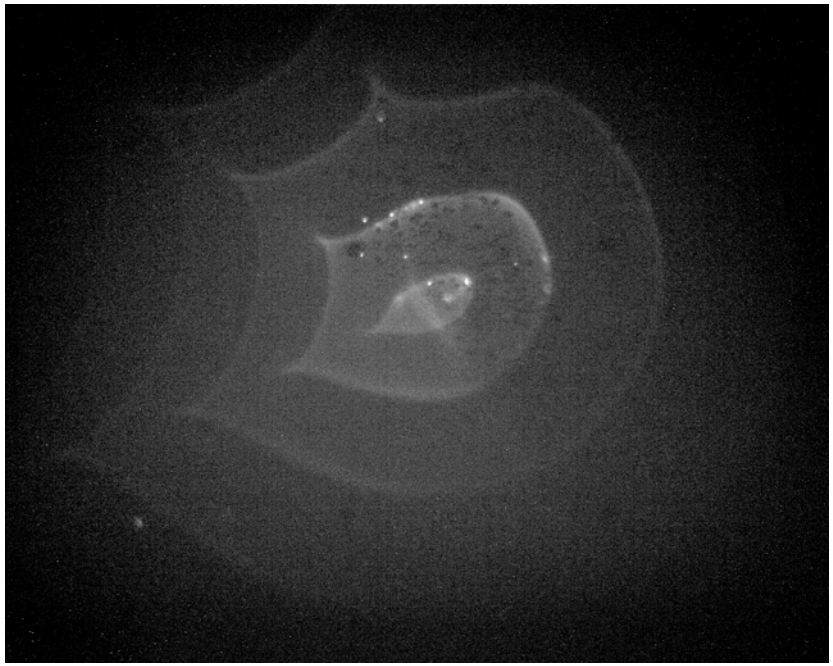
Beam line = Angle Spectrometer?



Pepper Pot at VT3

NSCL ^{40}Ar Rings (before dipole)

(ECRIS →Solenoid →Viewer)



(Distortions to Rings Caused by Current Leads on the Solenoid Ends)

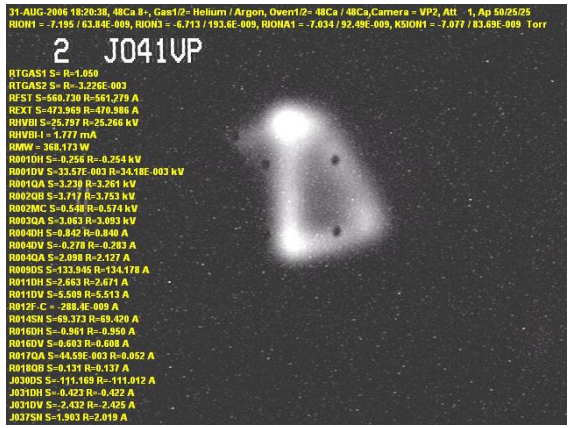
Rings of ^{58}Ni Charge States

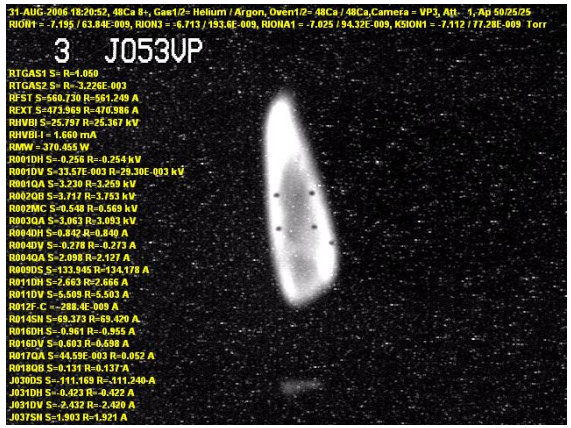
(ECRIS →Solenoid →Dipole →Viewer)

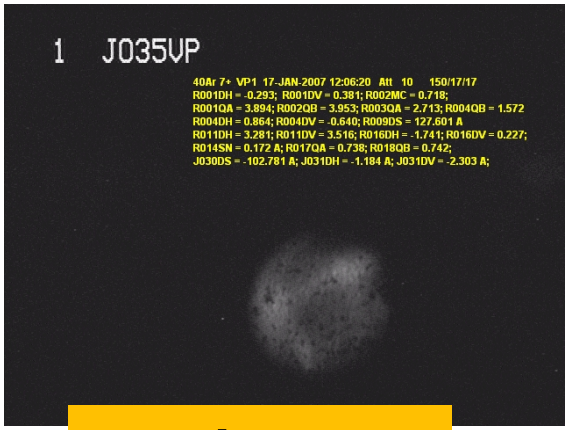
Ring to Star using Beam Line Solenoid

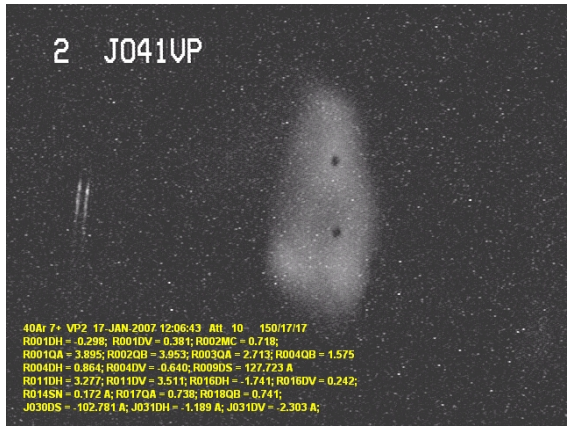
(ECRIS →Solenoid →Dipole →Solenoid →Viewer)

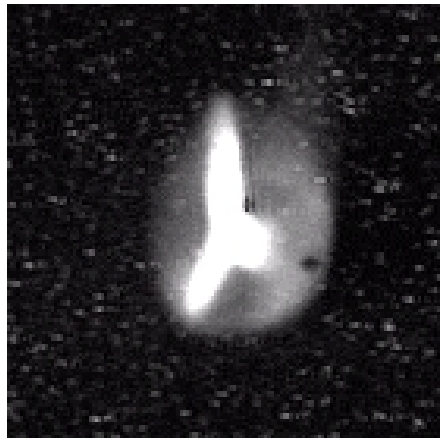
Image Propagation thru Injection Line





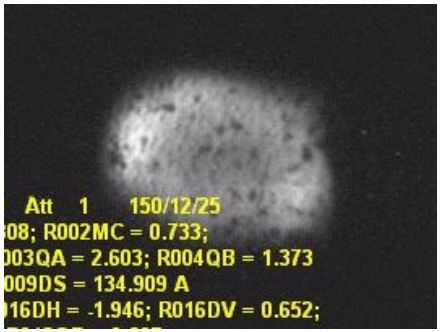




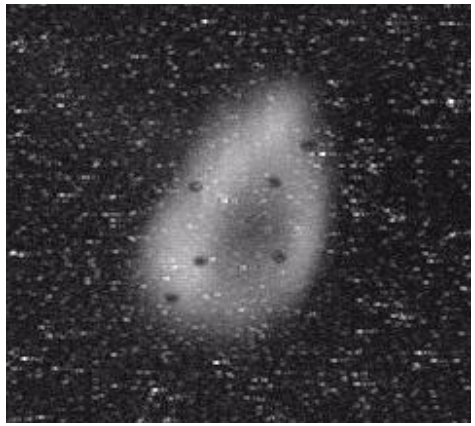


Round Aperture

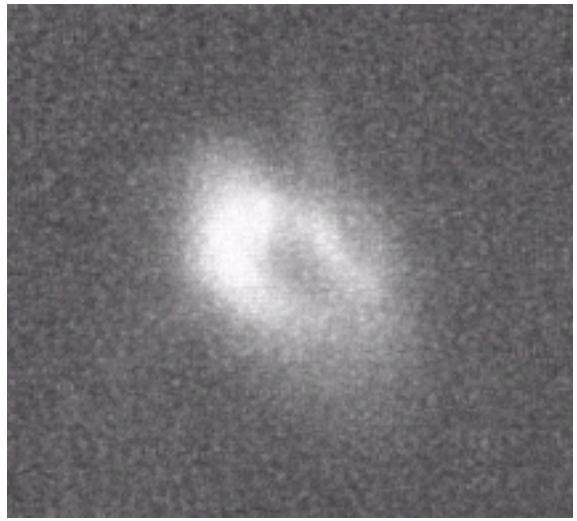
^{48}Ca Rings: Here, There, Everywhere?



J035



J053
(into K500)



N053
(into K1200)

N053 Star (just before K1200 injection)

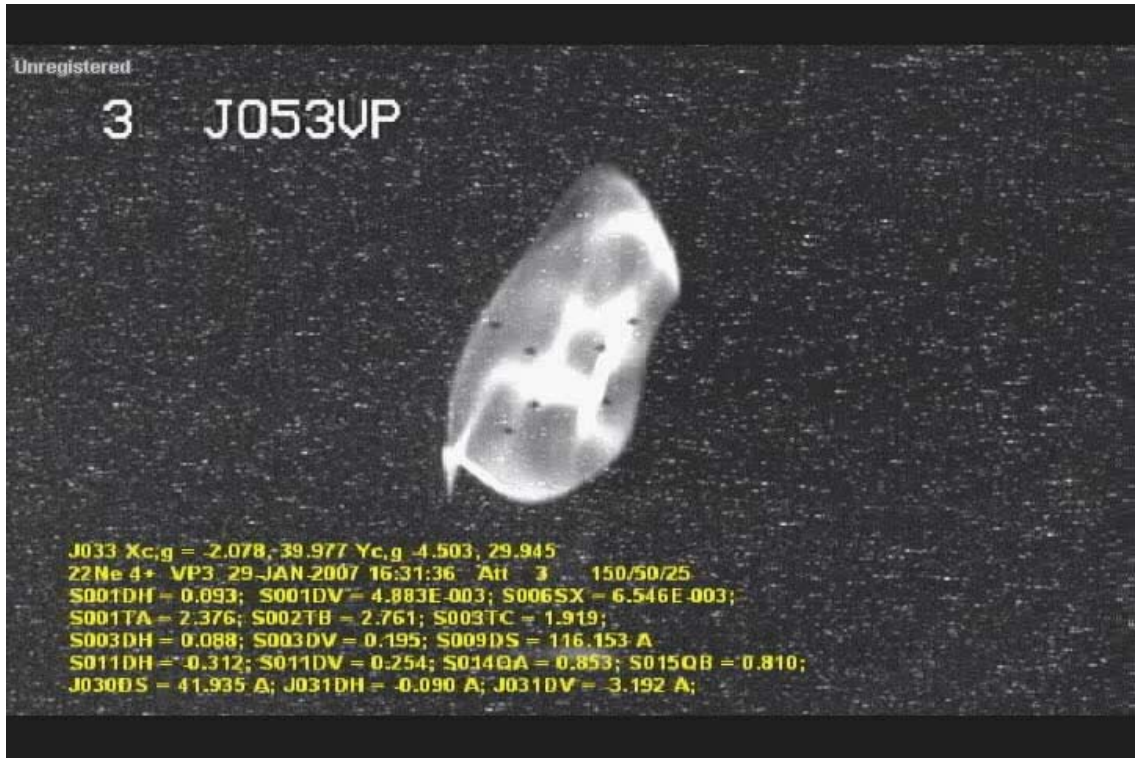
Ring-to-Star “Tag” survives Acceleration in Cyclotron!

(Tail too Dim to see without blocking main part of the beam)

Hz Slit Scan J033XGap = 2 mm

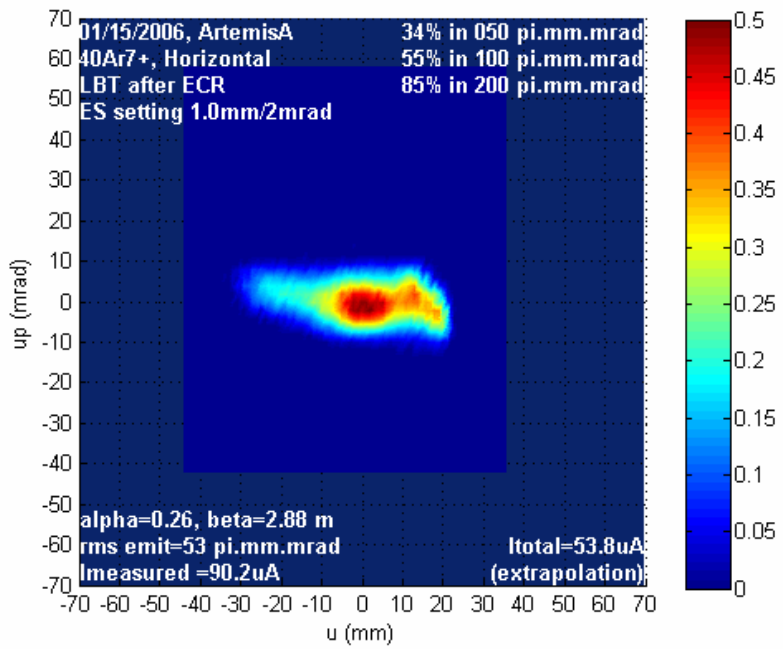
Slit half-way thru Injection Line, Viewer Just Before K500

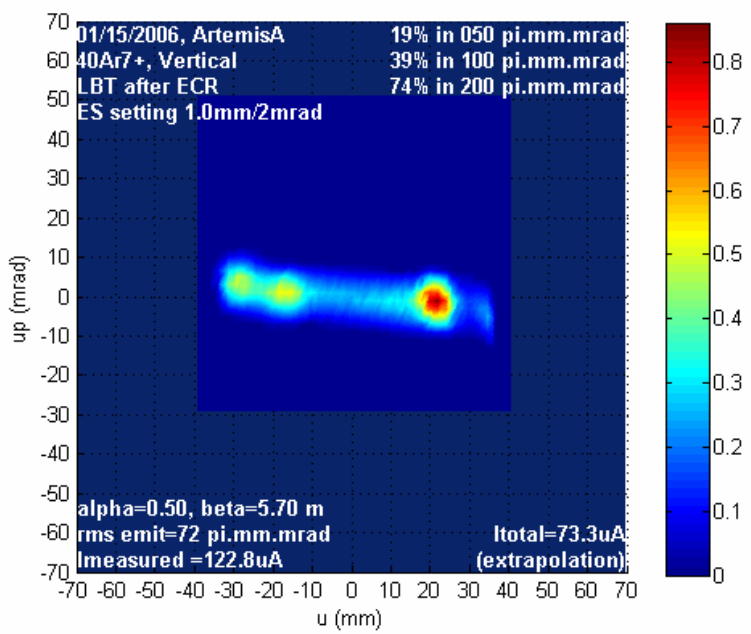
Cut 90% of Intensity with J033 Slits centered on Beam



Slit half-way thru Injection Line, Viewer Just Before K500

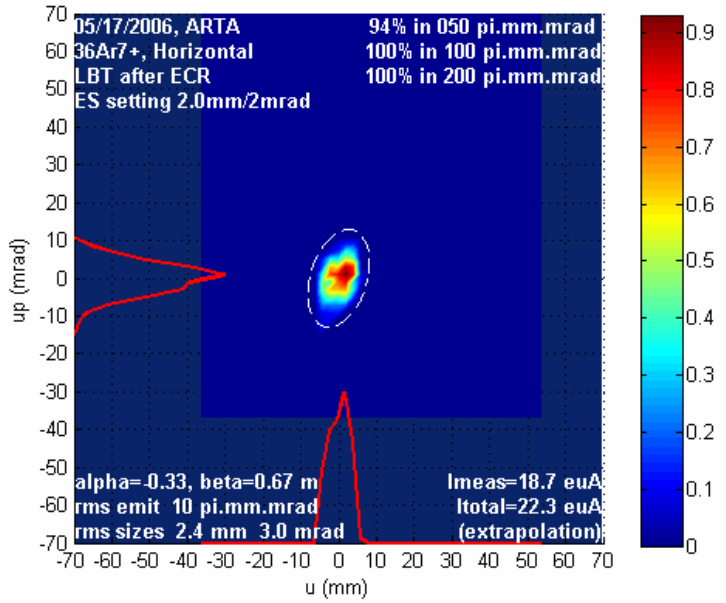
Possible Results of “Blind” Tuning

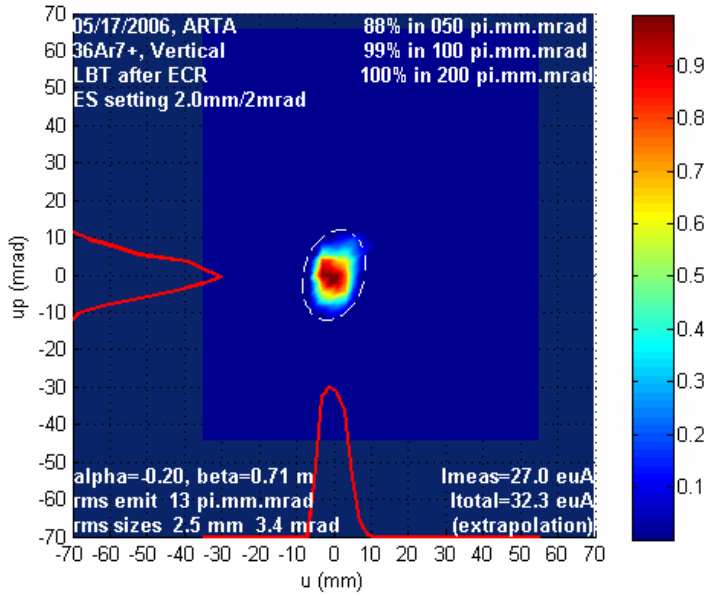




< 50 pi*mm*mrad: 34% Hz, 19% Vt

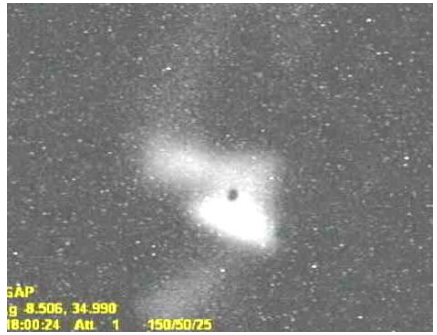
Tuned for good measured 2d Emittance



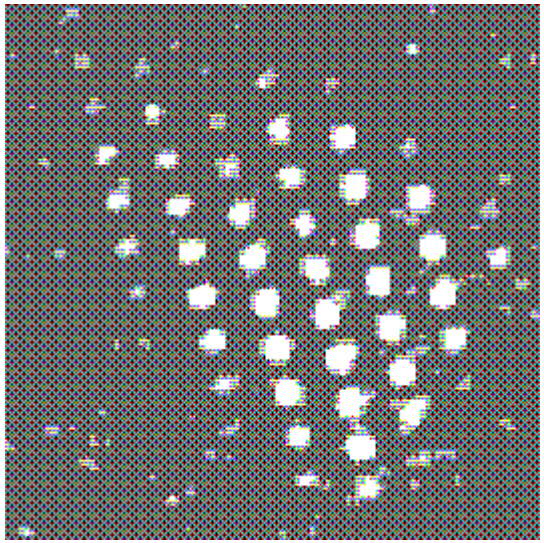


< 50 pi*mm*mrad: 94% Hz, 88% Vt

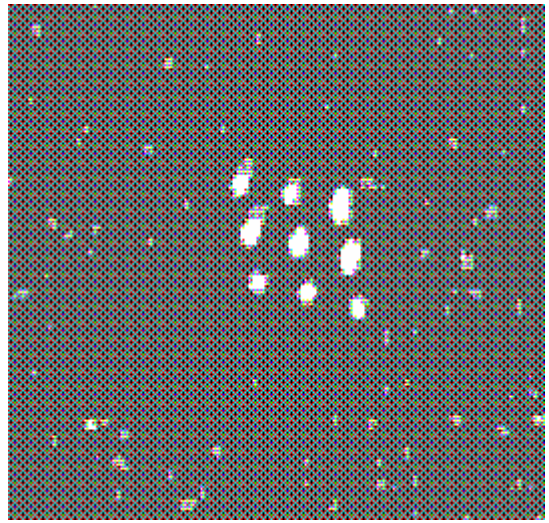
An Effective Slit Cut (Grid at Slit Location)



“Mess”

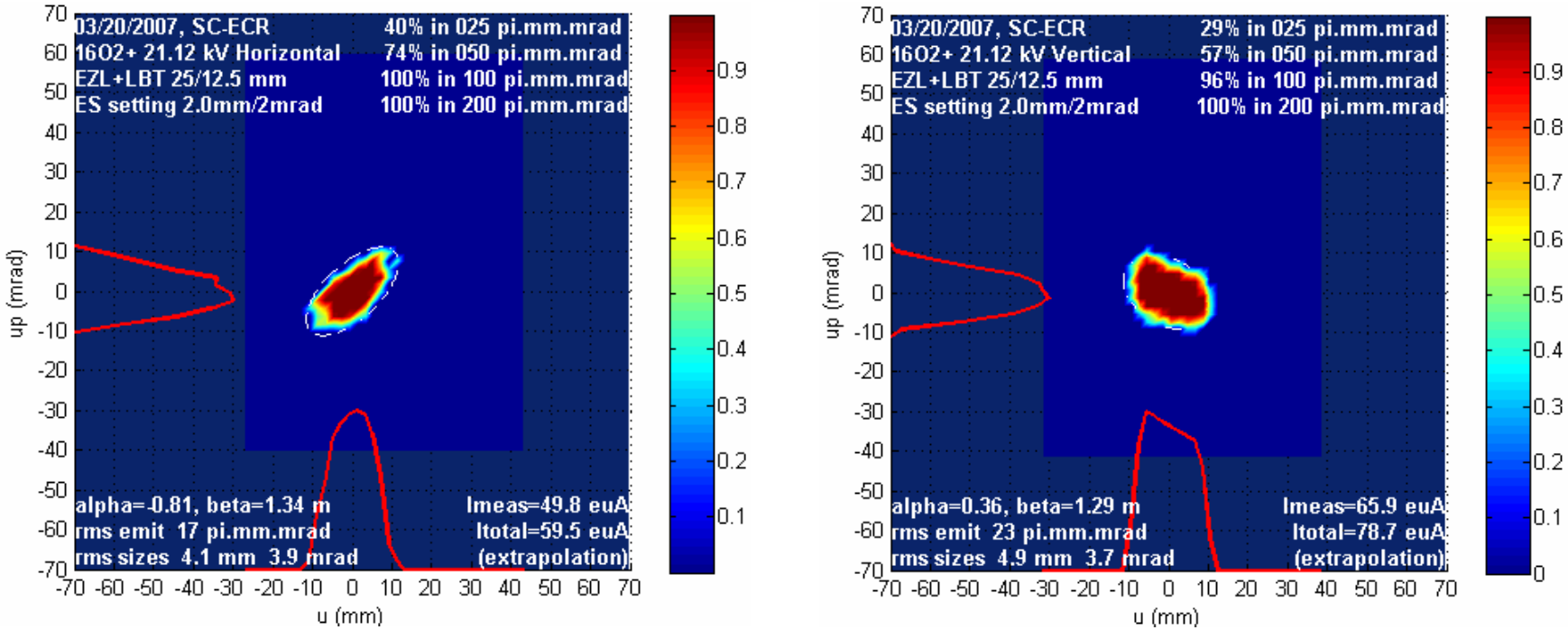


“Organized” Beam
Slits Open



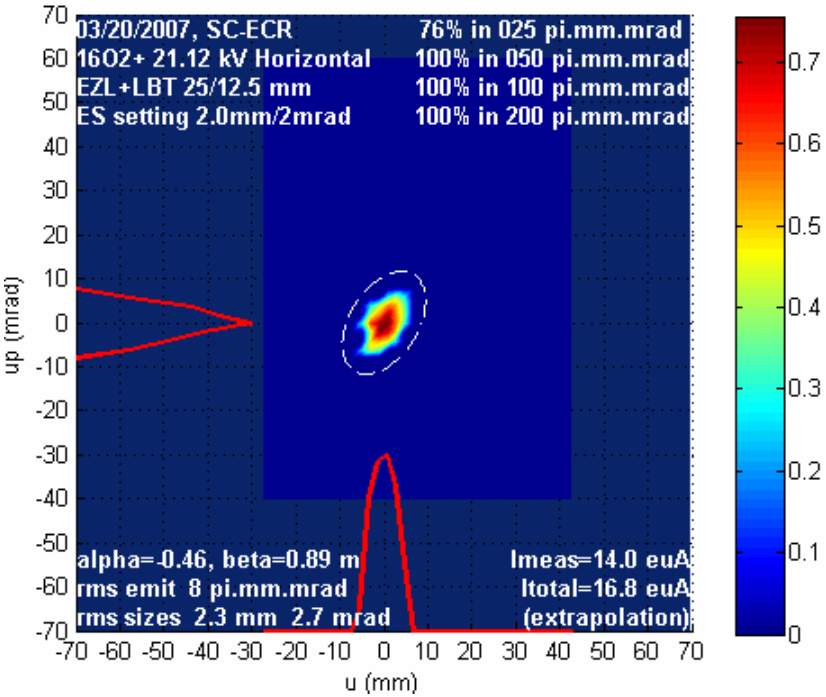
“Organized” Beam
Slits Closed

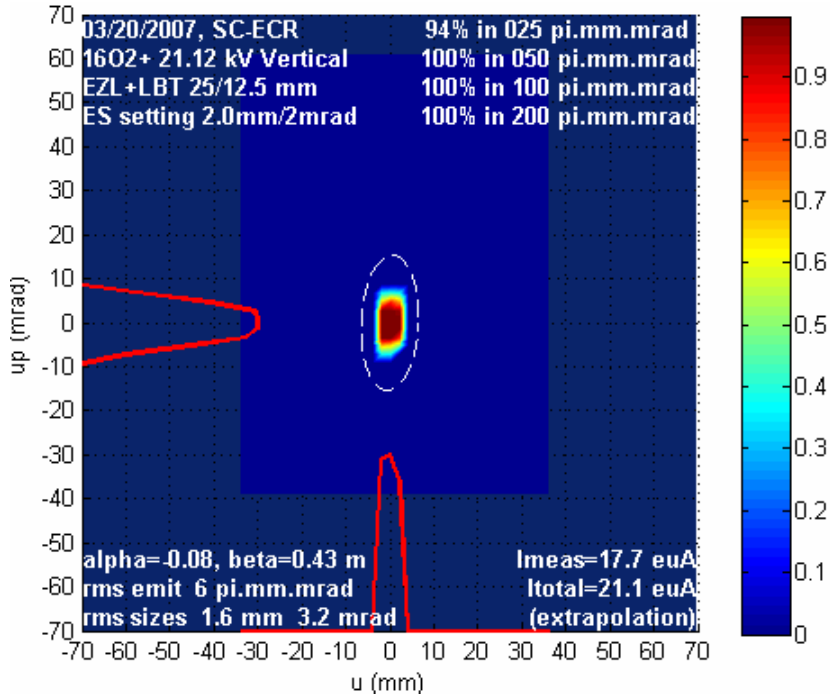
Orderly Beam: Slits Out (60mm x 60mm)



< 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

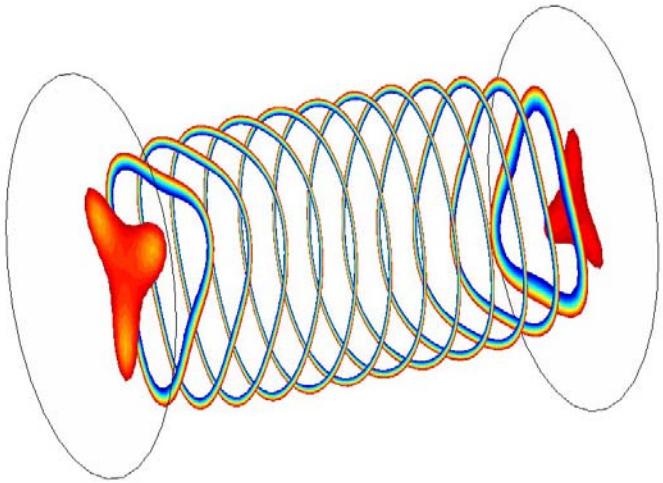
ECRIS Beam Characteristics

1) **Transverse Structure (Hollow)**
2) **Large 2nd Order Aberrations (Triangle)**
3) **Strong Phase space cross-coupling (beam is "correlated")**
4) **Focusing morphs Ring into Star (not explained by 2nd order)**
5) **Under some conditions, a fractal nature (round cut can redevelop into a triangle)**

Model Assumptions/Opinions

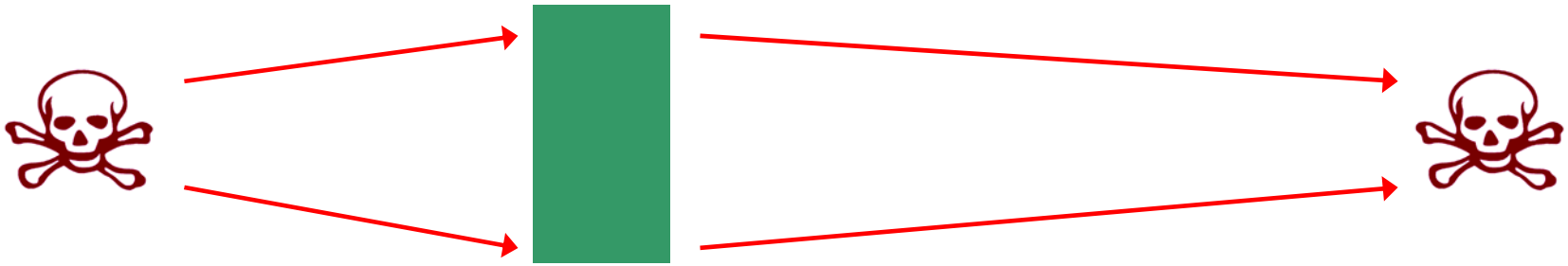
1) **“Miniscus” emission is not adequate. The object of the following optical system is within the plasma chamber.**
2) **Extracted Ions travel on a largely undistubed path from their creation.**
3) **The ions are emitted from a volume, not a disc.**
4) **….**

Model Assumptions/Opinions



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

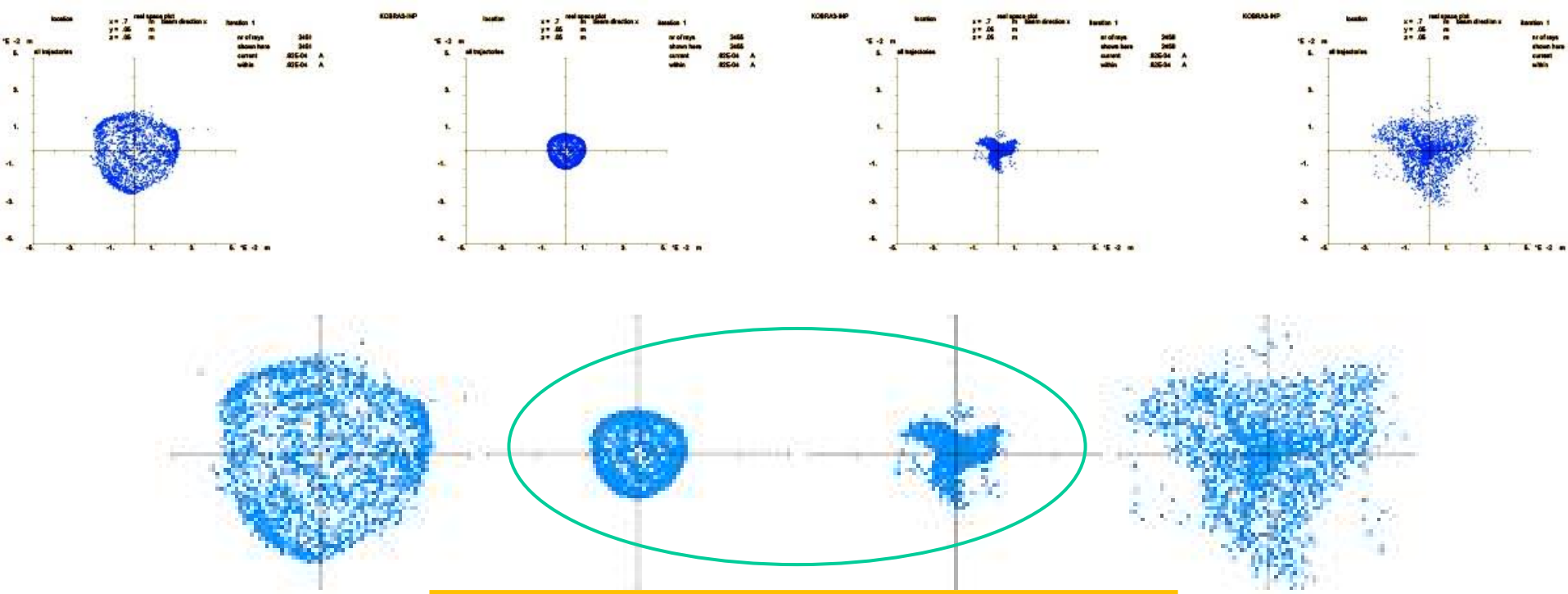


Solenoid

Ions Start In Plasma Chamber

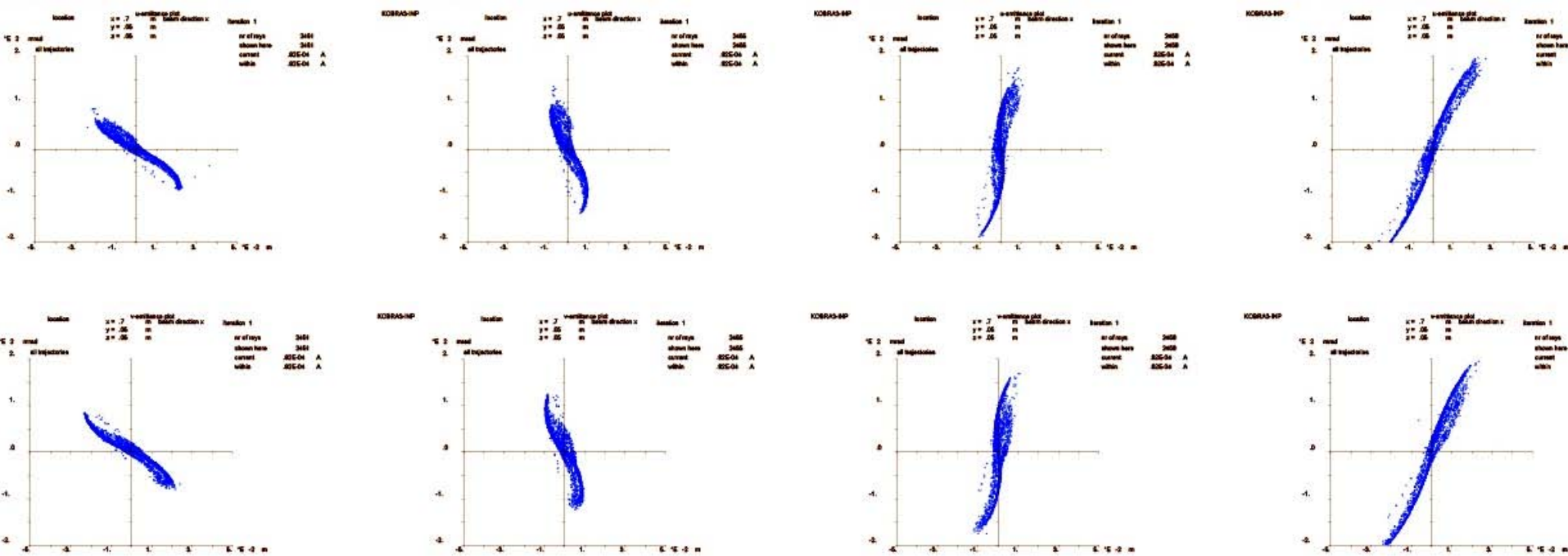
Rings and Stars On VT2?

Beam on VT2 (X-Y) Space with Increasing ***Beam Line*** Solenoid Strength



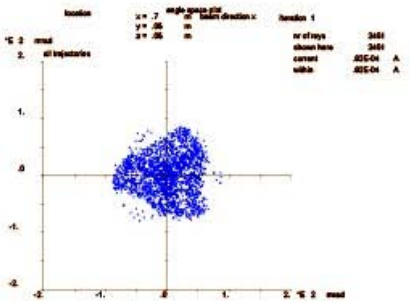
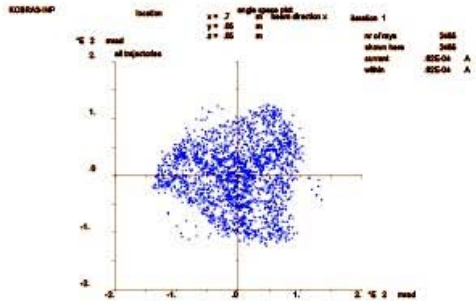
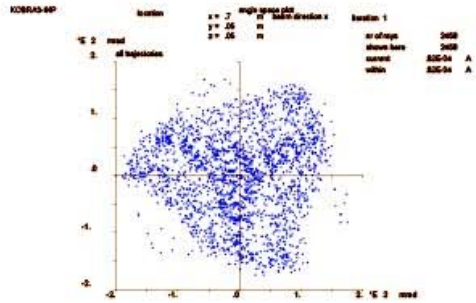
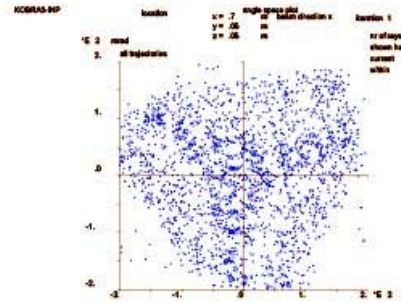
Shows the Ring-to-Star "Tag"

Beam on VT2 (X-X') and (Y,Y') Space with Increasing ***Beam Line*** Solenoid Strength



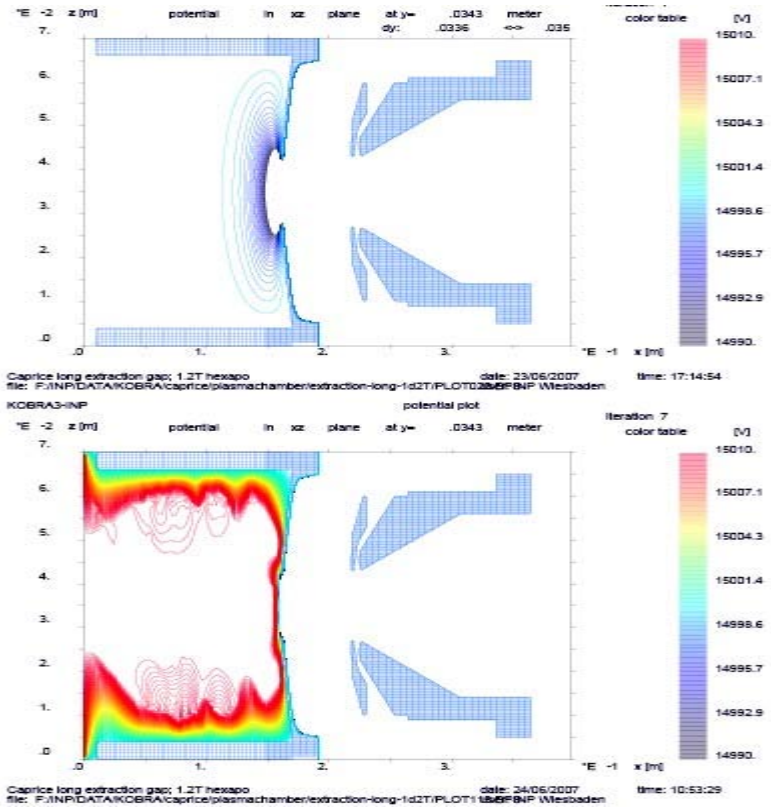
Focus at Case 3

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

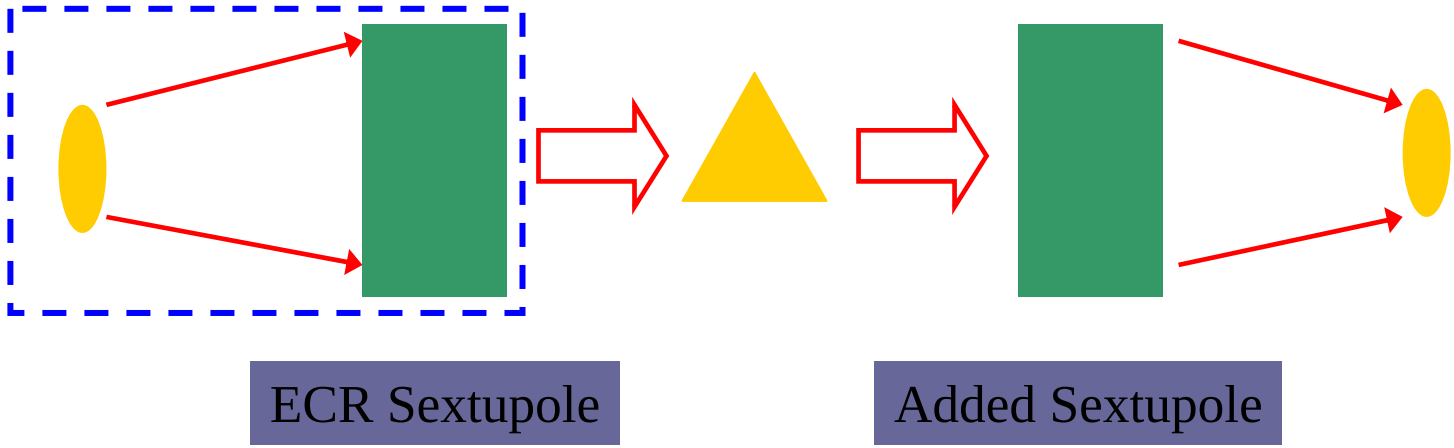


Gives Poor Results

Sensitive to Starting Conditions

Gives Good Results

Test of Concept - Experiment

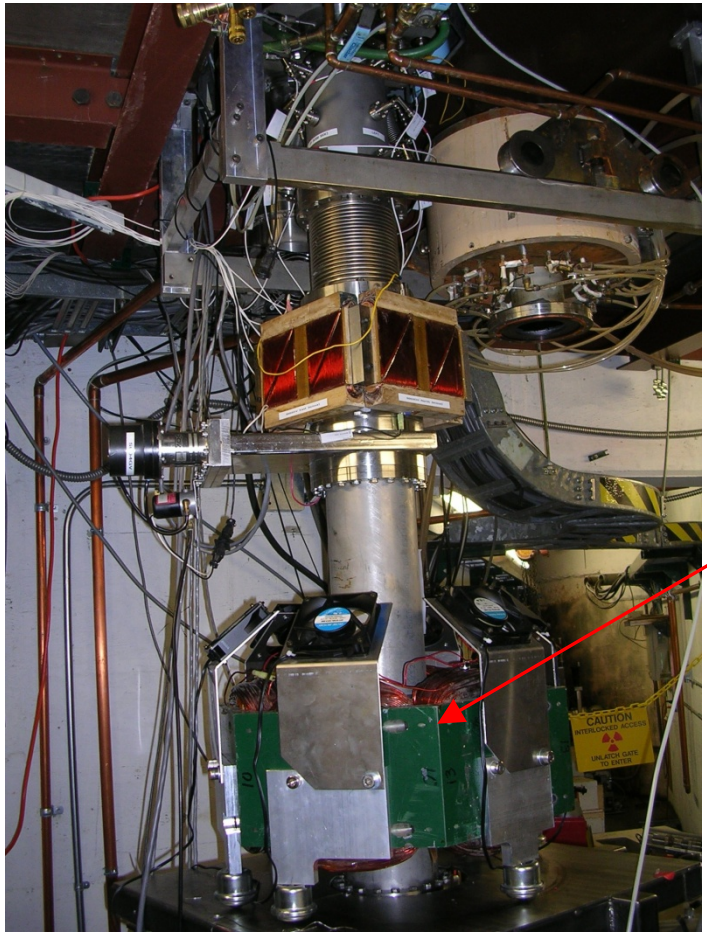


Uncorrelated Round Beam (Object)

Correlated Triangle Beam (Observed)

Uncorrelated Round Beam (Desired)

Add Sextupole to Beam Line



Magnetic Sextupole

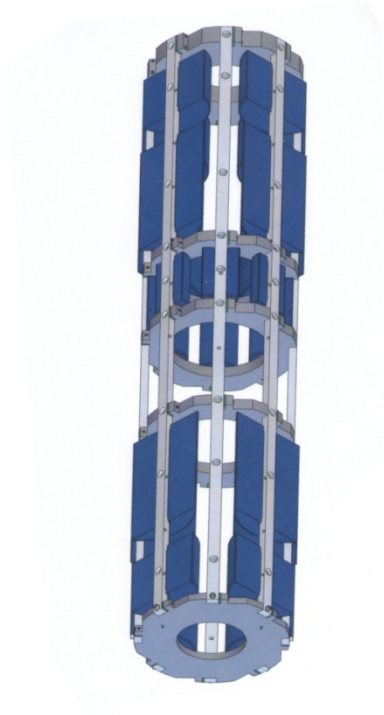
Partial Correction of 2nd Order with External Sextupole (protons)

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

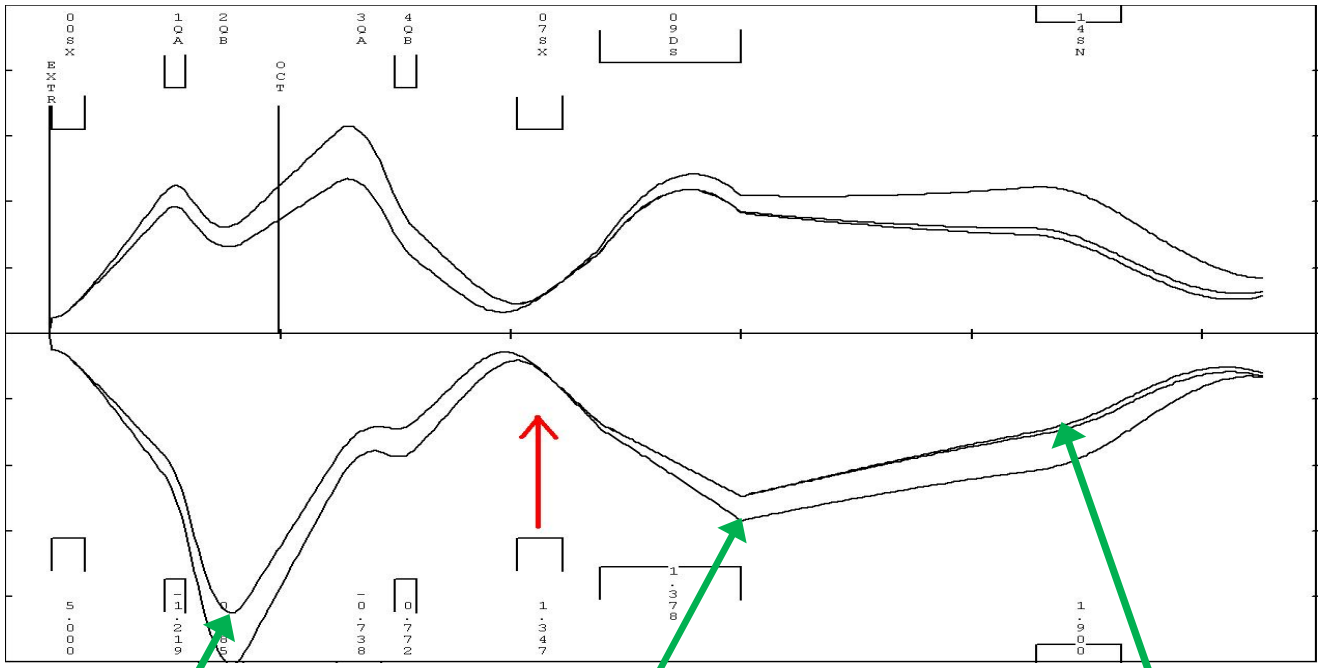


Quadrupole Doublet

Octupole Singlet

Quadrupole Doublet

2nd Order Correction Scheme: ~Pi Phase Advance to Corrector Sextupole



Y

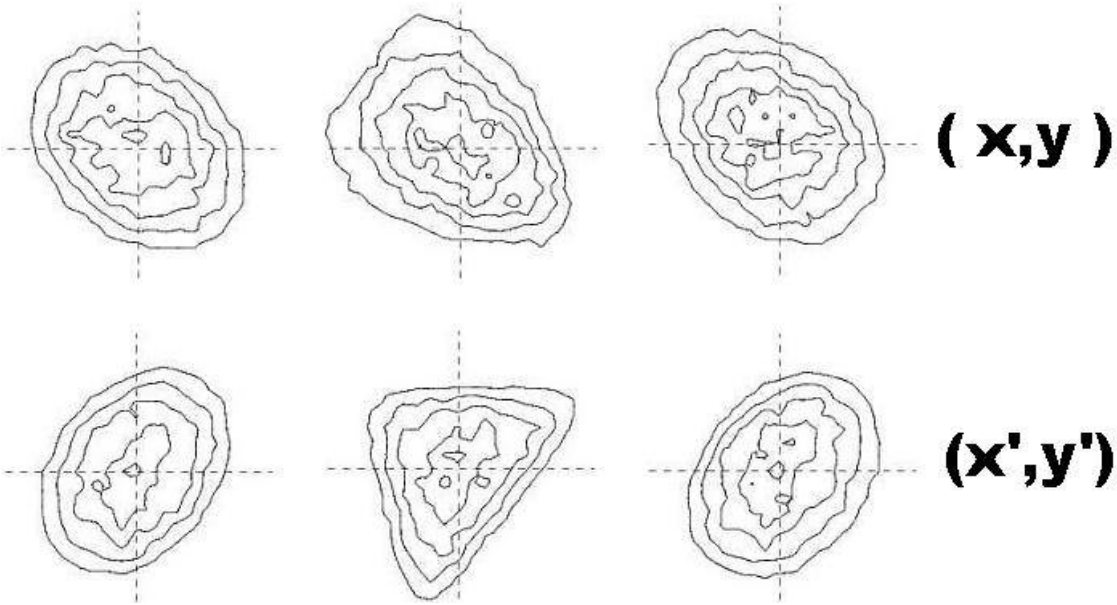
X

1st Order

2nd Order Un-corrected

2nd Order Corrected

2nd Order Correction Scheme: ~Pi Phase Advance



1st Order

2nd Order Un-corrected

2nd Order Corrected

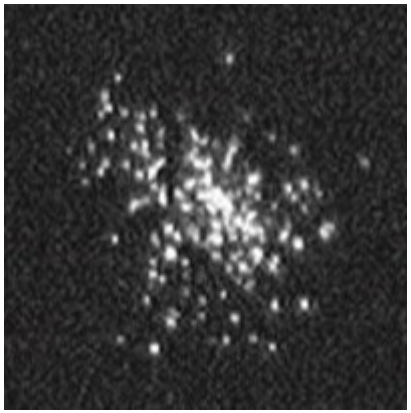
Real Test of 2nd Order Correction Scheme

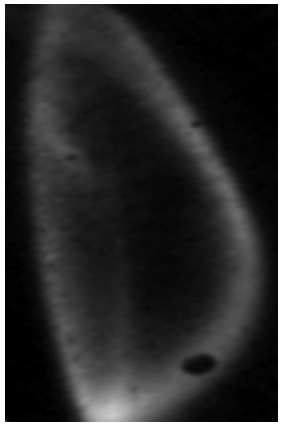
At NSCL (Fall 2007?)

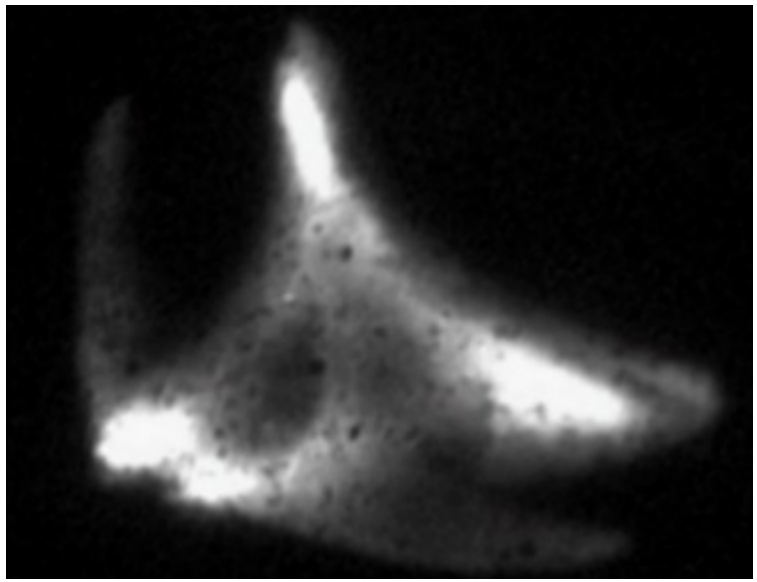
Install New Analysis Dipole (under construction)

Install New Sextupole

“Perfection” vs. “Reality”







Design Real Beam Lines for Real Objects (when possible)

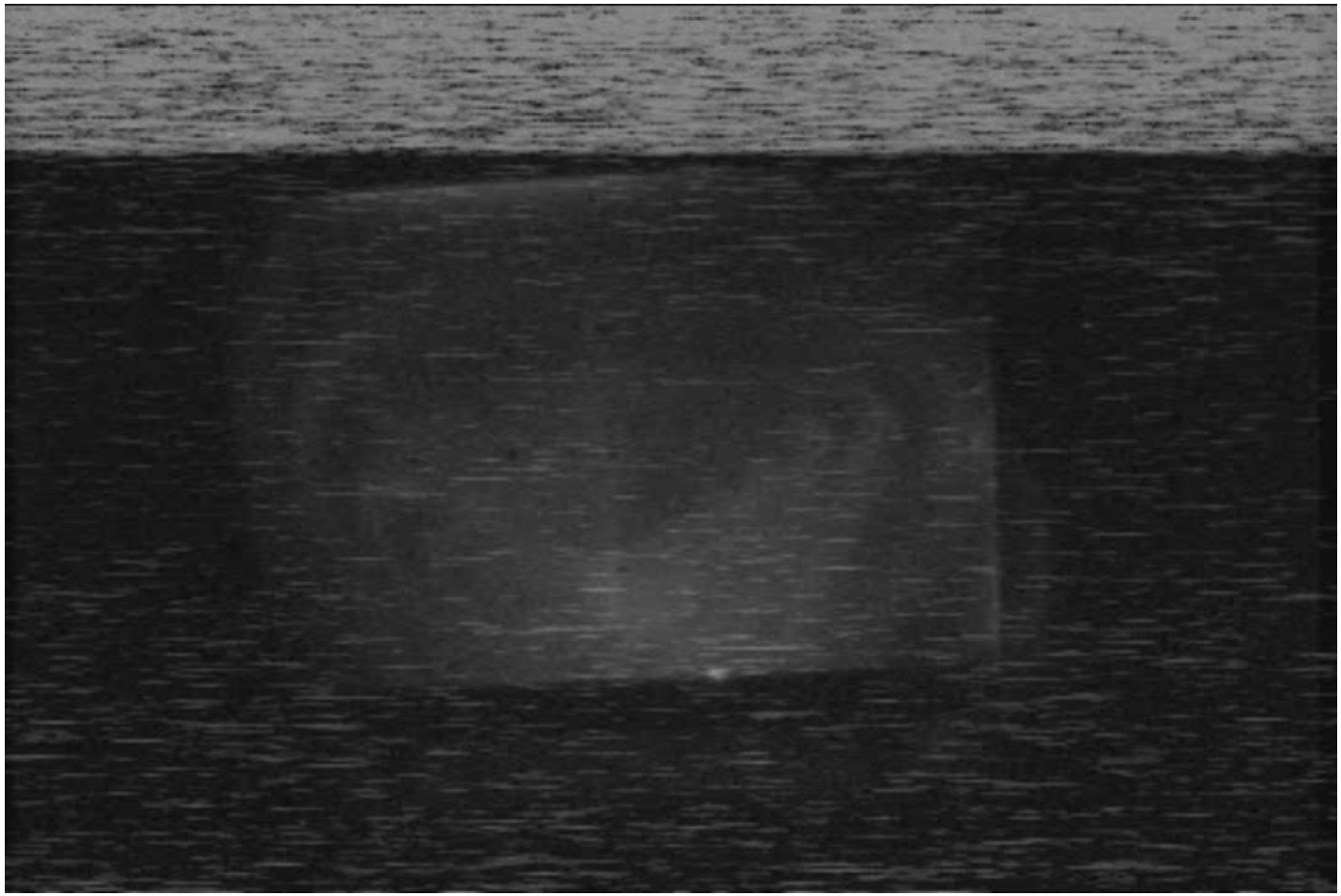
The Cast

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

GSI
- R. Lang
- J. Mäder
- J. Roßbach
- K. Tinschert

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

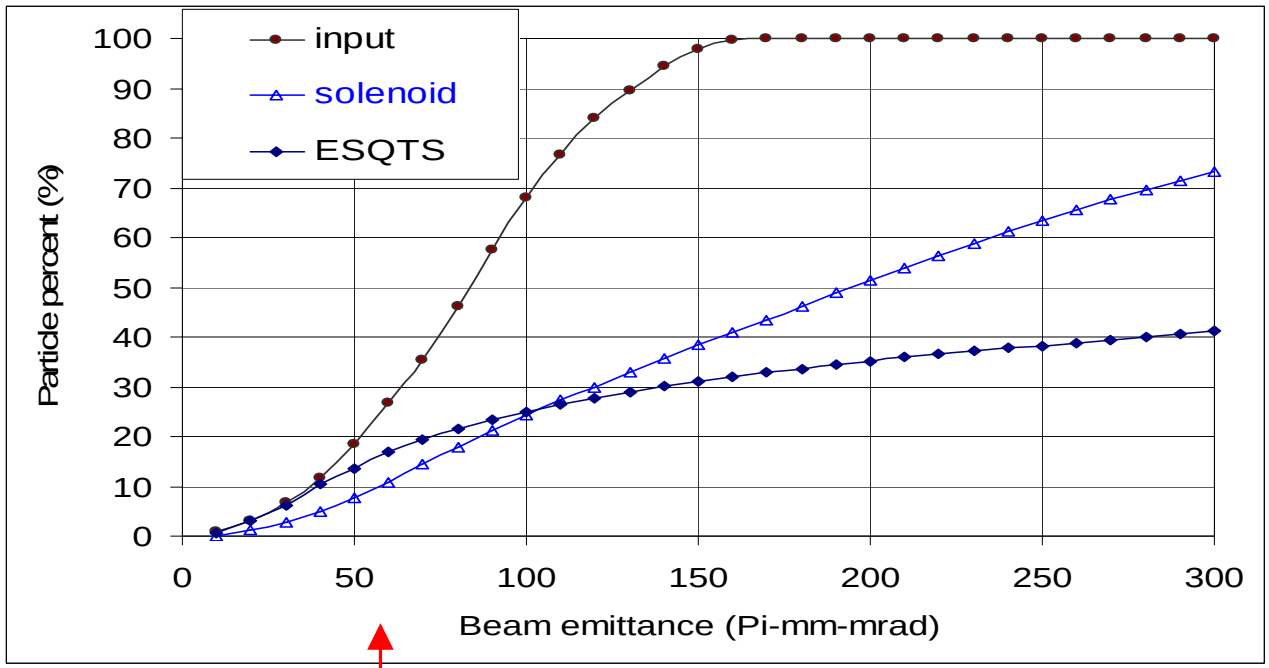
A Complete Model Must Include:



Improvements at Similar Source Output

	~2003 Source out → K1200 out (pnA)	~2006 Source out → K1200 out (pnA)	Gain (normalized to source output)
^{40}Ar	2280 → 58	1920 → 222	4.5
^{48}Ca	1275 → 32	1400 → 160	4.6
^{76}Ge	692 → 17	725 → 63	3.5
^{78}Kr	2640 → 22	2760 → 79	3.4
^{136}Xe	700 → 2.86	371 → 8.16	6.5

Maximize the Good at the Expense of the Bad



Region of Interest

Not Injectable Beam