First Commissioning Results of the SuSI ECRIS

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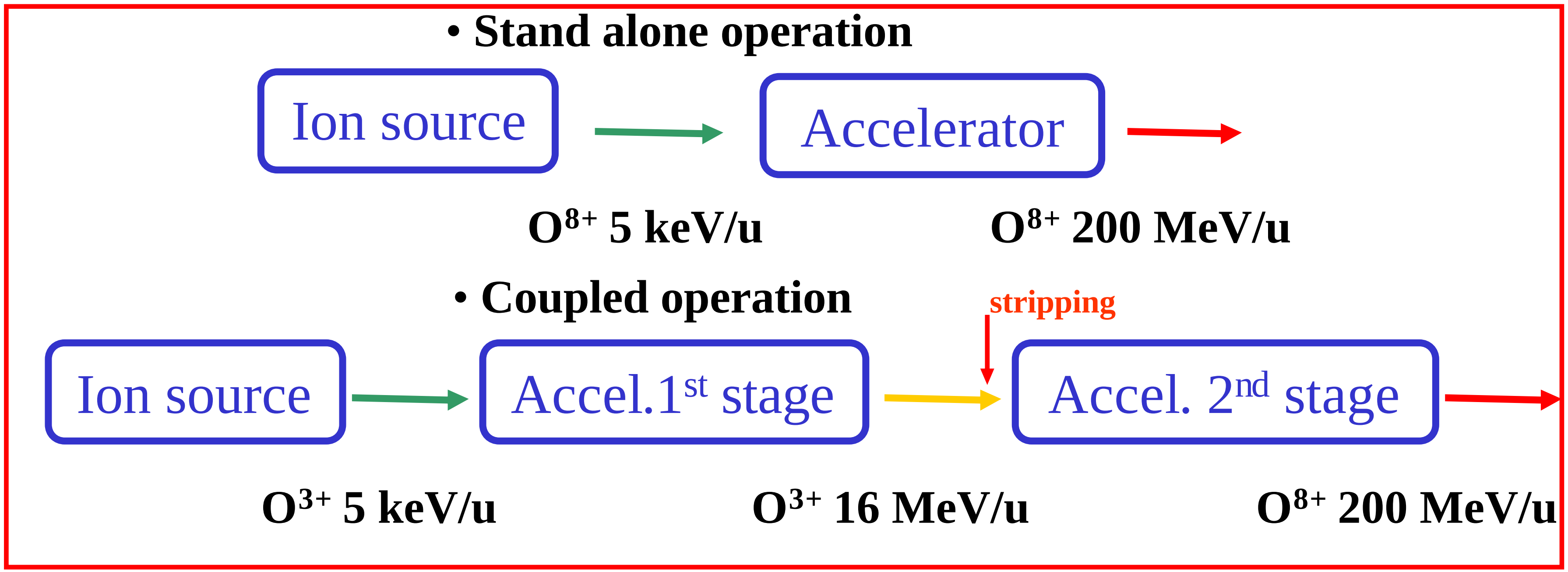
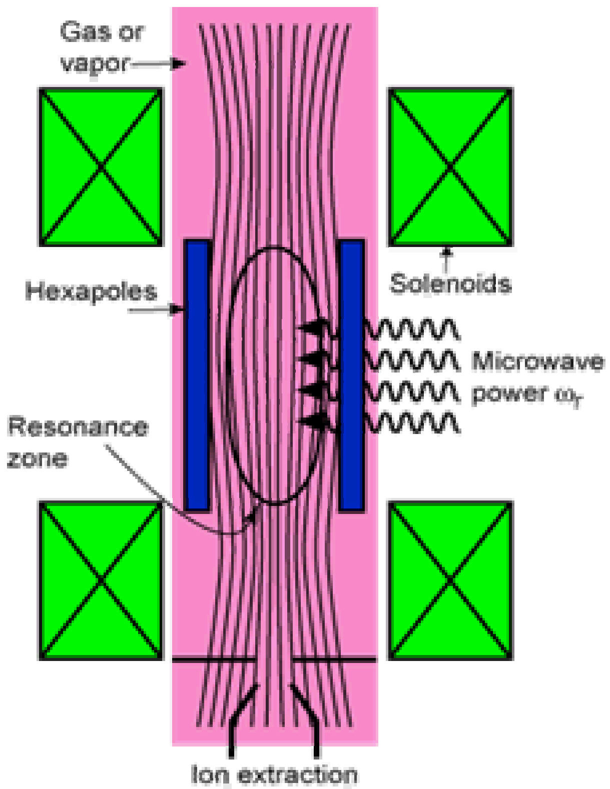
Motivation for Production of Highly Charged Ions

- intense highly charged ions are used in many accelerator applications
- dc beams for RIA/ISF, RIKEN RIB, etc.
- pulsed beams for injection in synchrotrons such as RHIC, LHC, FAIR, hadron therapy
- higher M/Q from an ion source makes the accelerator more compact and less costly
- there is generally a tradeoff between intensity and charge state from an ion source



Key Parameters of an ECRIS



Minimum-B field Confinement

- **Magnetic field configuration:**

B_{inj} » 4 B_{ECR} B_{ext} < B_{rad} » 2 B_{ECR}

B_{min} » 0.8 B_{ECR}

I µ log $B^{1.5}$

- **Microwave frequency:**

$w_e = qB_{ECR}/m = w_{rf}$

I µ $w_{rf}^2 M^{-1} t^{-1}$

- **Extraction voltage:**

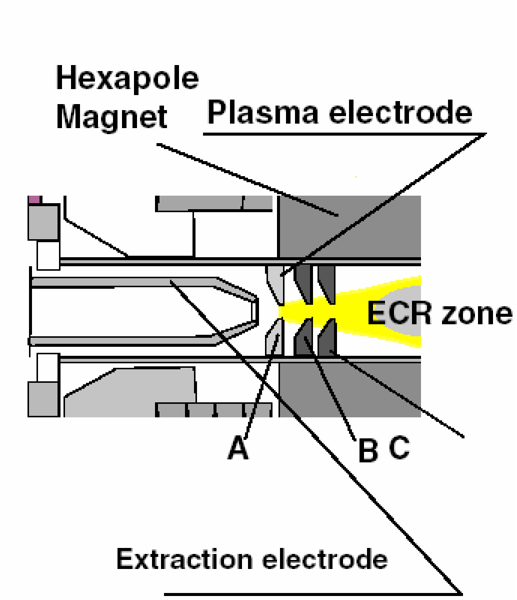
I µ $U_{ext}^{3/2}$

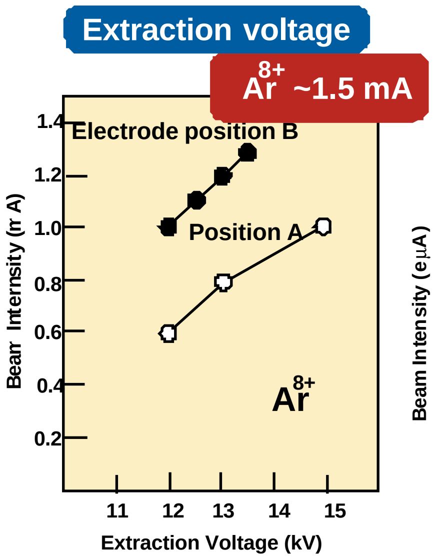
- **Plasma chamber geometry (length, diameter) and wall material**

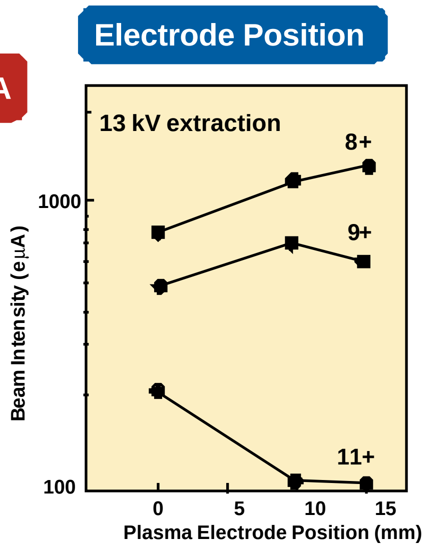
- **Extraction system (gap, voltage, plasma electrode position)**

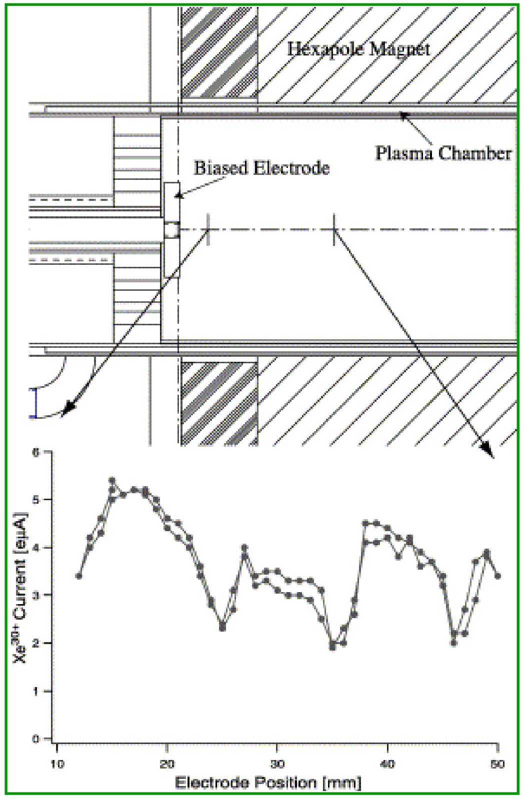
- **Biased disc (voltage, position)**

Plasma Electrode Location and Biased Disc Effect



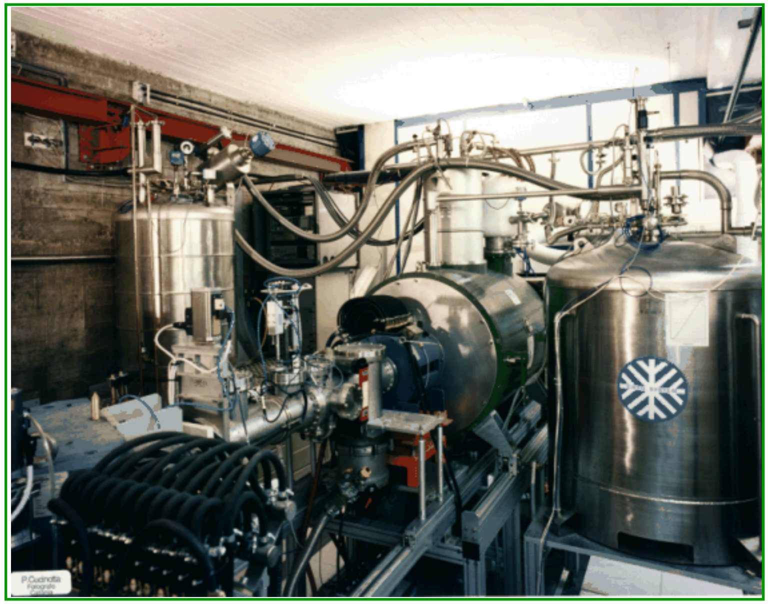




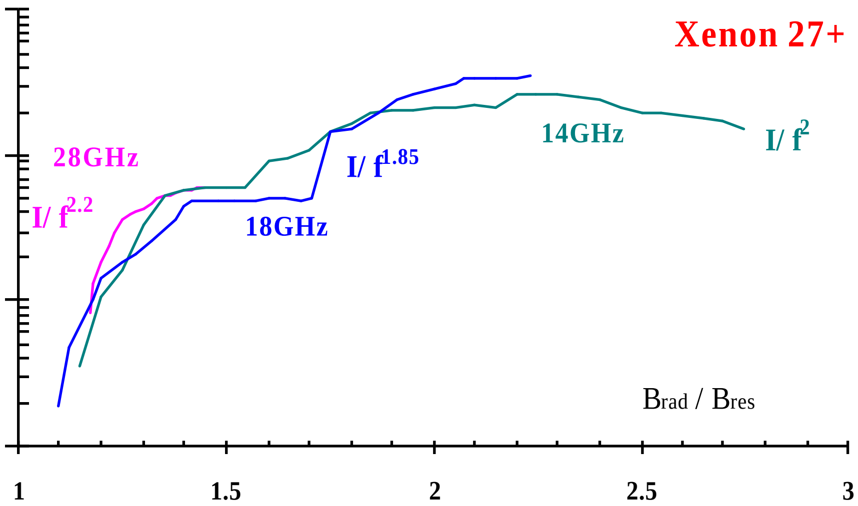


- The beam intensity is strongly dependent on the position of the bias disc
- Desirable to have an adjustable length of the plasma chamber to be able to change the matching conditions between the plasma and the microwaves

SERSE at INFN-LNS Catania, Italy

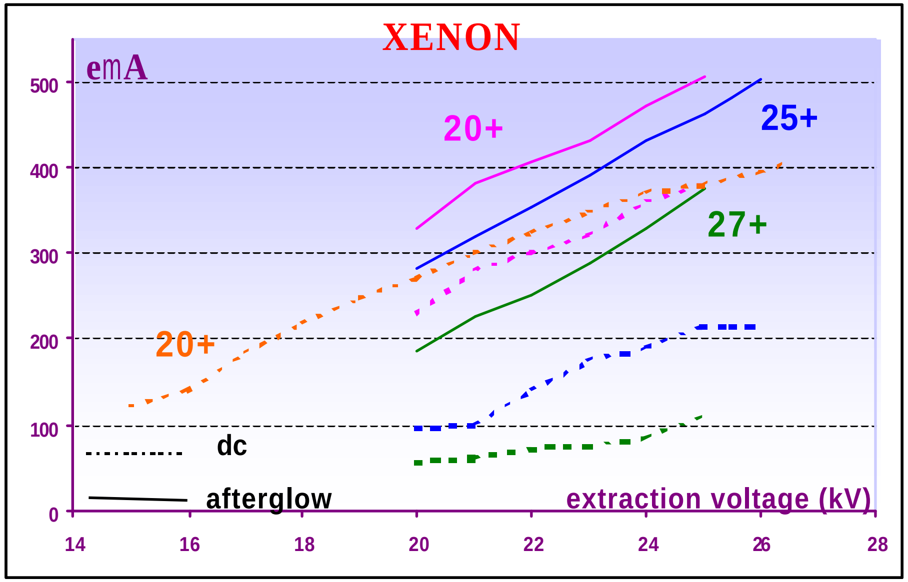


Test of scaling laws at ***14 – 18 – 28 GHz***



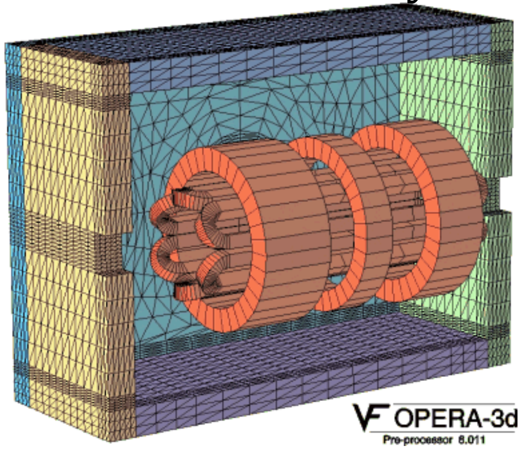
First 28 GHz operation (2000)
Designed for 18 GHz
B_{rad}=1.45 T

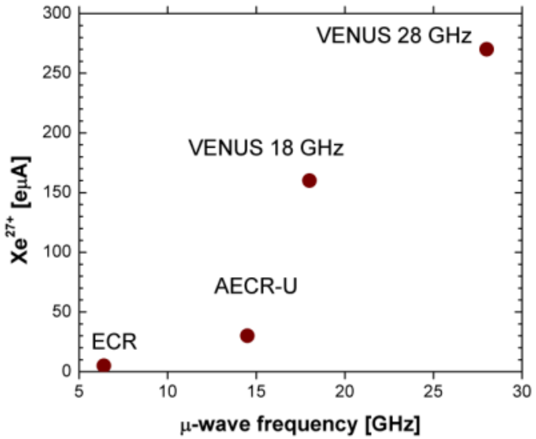
Results of 28 GHz tests
- $I \sim f^2$, verified at 14, 18 and 28 GHz
- P• 3 kW
- Optimum B_{rad} at 28 GHz > 1.45 T



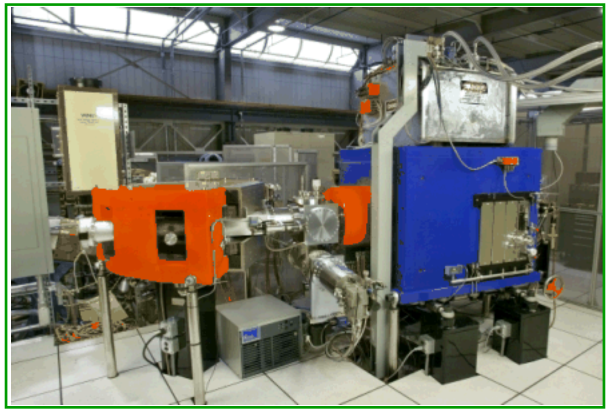
VENUS at LBNL Berkeley, CA

Superconducting Magnets
State of the art cryostat





Beam Transport



New Plasma Chamber

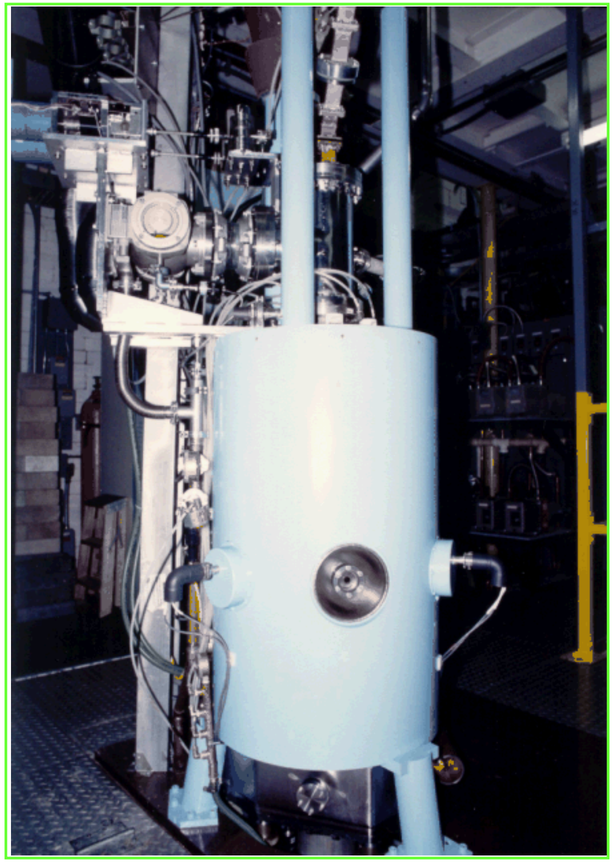
Ta X-ray shielding

Challenges

- Superconducting Magnet
- 28 GHz microwave heating
- X-rays from the Plasma
- Ion Beam Transport

28 GHz microwave plasma heating

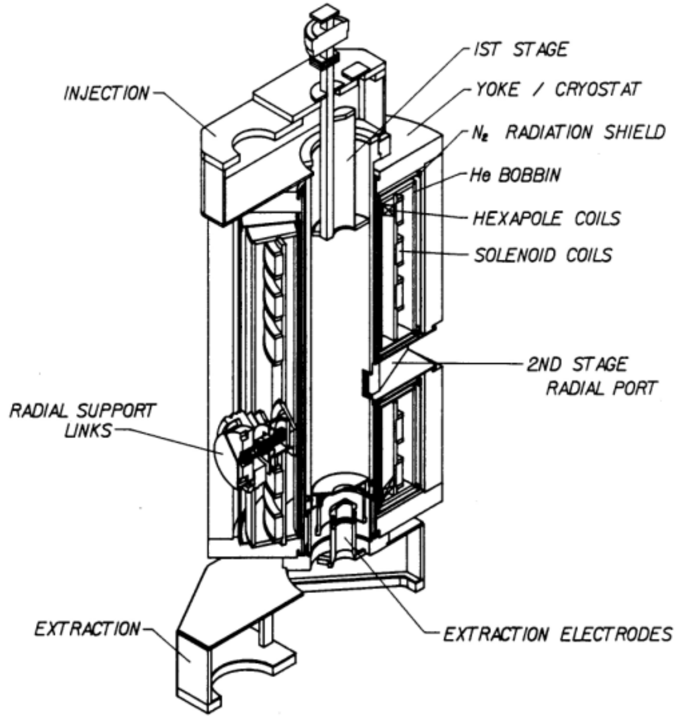
Superconducting ECR Ion Sources at NSCL/MSU I.



SC-ECR (1993)

The first dynamically tunable SC ECRIS using the High-B mode

Designed by T. Antaya (now at MIT)



First Vertical SC ECR

Designed for 6.4 and 14.5 GHz

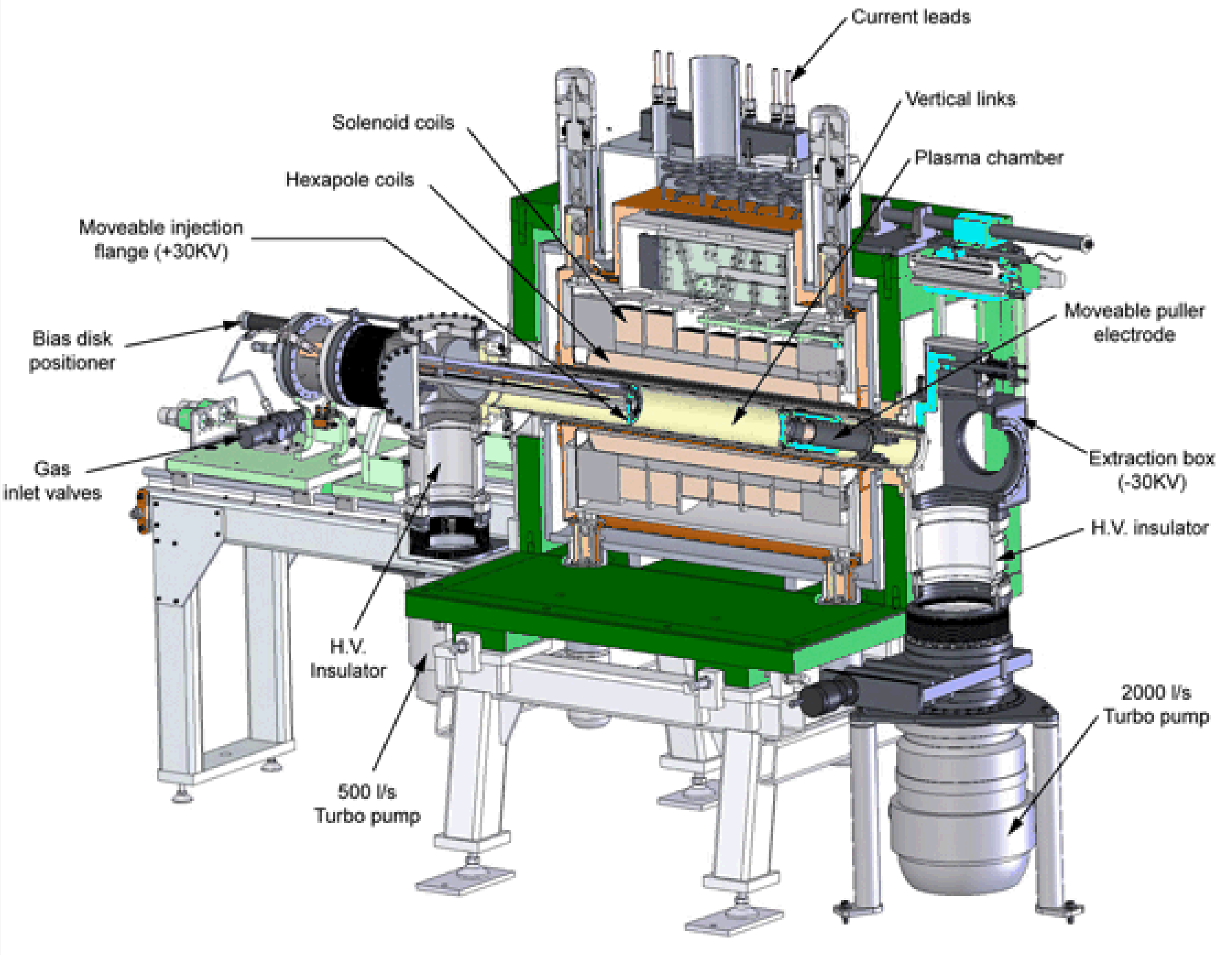
High B-mode demonstration at 6.4 GHz

Sextupole field too low for 14.5 GHz

(Quenching)

Superconducting ECR Ion Sources at NSCL/MSU II.

SuSI – Superconducting Source for Ions



- **maximum magnetic fields:**

Original Design:
- 2.6 T, 1.5 T axial field
- 1.5 T radial field

Tested (February 2006):
- 3.6 T, 2.2 T axial field
- 2 T radial field

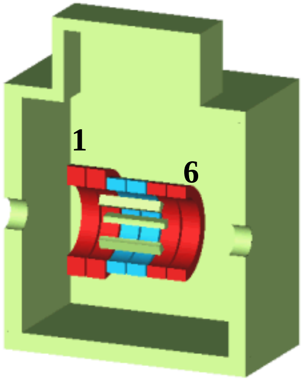
- **plasma chamber diameter:**
  101.6 mm (aluminum)
- **superconducting wire:**
  - **2x1 mm NbTi**
  - **Cu/SC ratio 1.7**
- **operating frequency:**

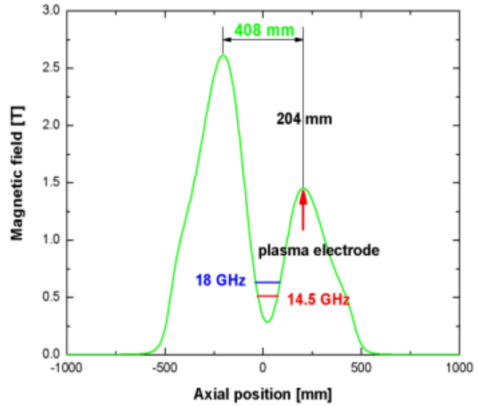
Phase I: 18 + 14.5 GHz
Phase II: 24-28 GHz

- **maximum extraction voltage:**
  60 kV (ion source at +30 kV, beamline at –30 kV)
- **tunable plasma chamber length**
- **tunable bias disc position**

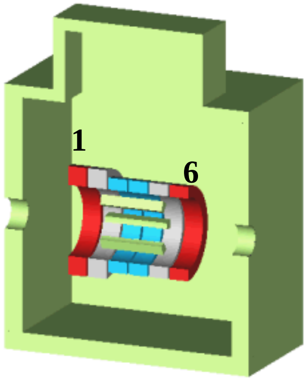
The Flexible Axial Magnetic Field Concept

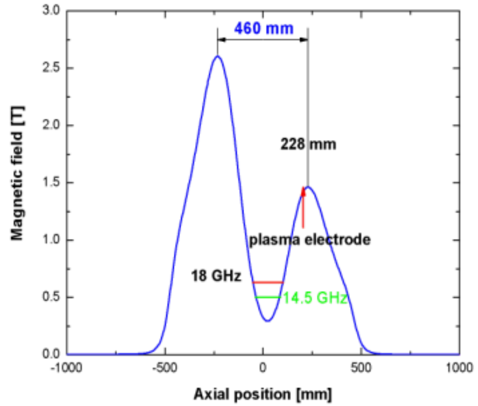
$J_1=J_2=61\ A/mm^2$
$J_3=J_4=-60\ A/mm^2$
$J_5=J_6=74\ A/mm^2$



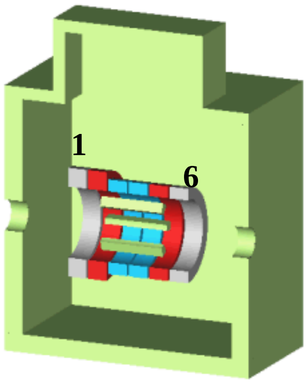


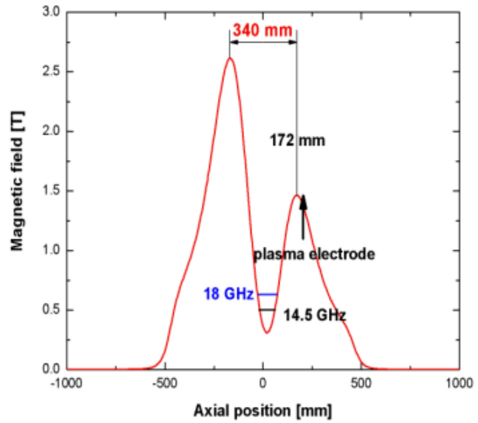
$J_1=120\ A/mm^2$
$J_2=J_5=0$
$J_3=J_4=-27\ A/mm^2$
$J_6=96 A/mm^2$





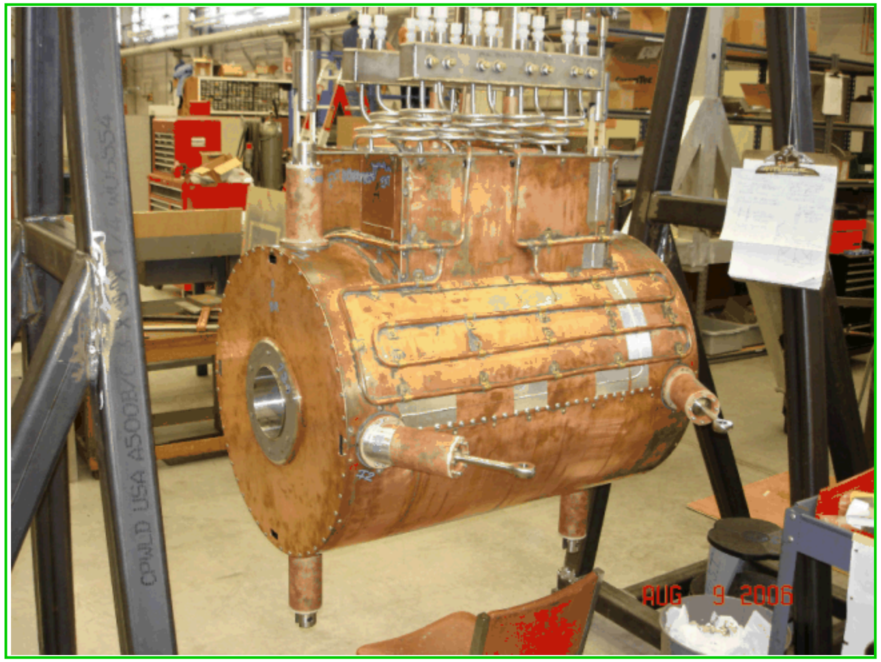
$J_1=J_6=0\ A/mm^2$
$J_2=170\ A/mm^2$
$J_3=J_4=-100\ A/mm^2$
$J_6=150 A/mm^2$



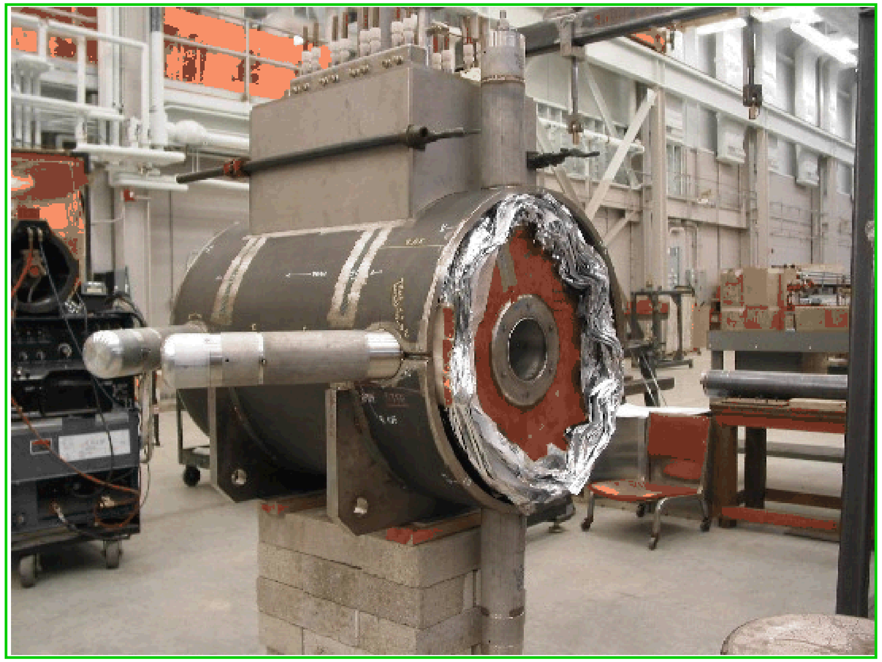


- the relative distance between the resonant zone and plasma electrode can be varied
- the distance between the two magnetic maxima can be varied
- the “depth” of the magnetic minimum can be varied
- the position of the magnetic profile can be shifted

SuSI Magnet Construction I.



The assembly of the SuSI magnet liquid nitrogen thermal shield.



The SuSI magnet cryostat before the super insulation is applied to the front and back end of the liquid nitrogen thermal shield.

SuSI Magnet Construction II.

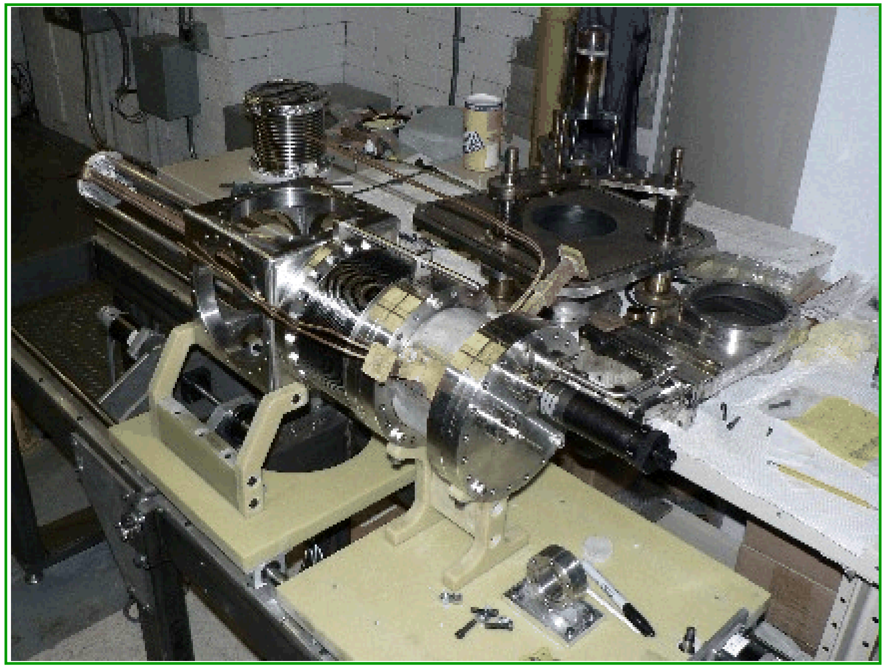
The SuSI magnet yoke with the injection and extraction hardware and plasma chamber with electrical isolation ready for tests.

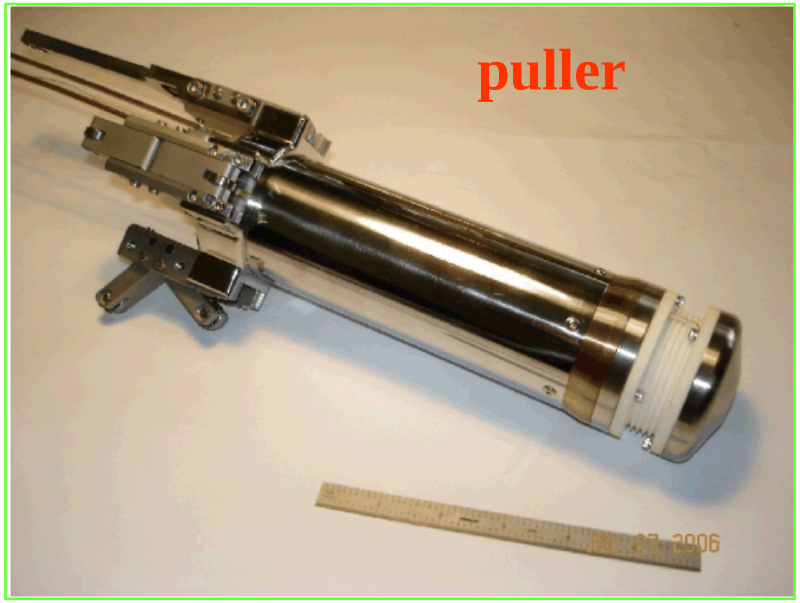
- Magnet tested in a vertical test dewar Febr. 2006.
- Cryostat was finished in Sept. 2006.
- Vacuum vessel installation was completed in Dec. 2006.

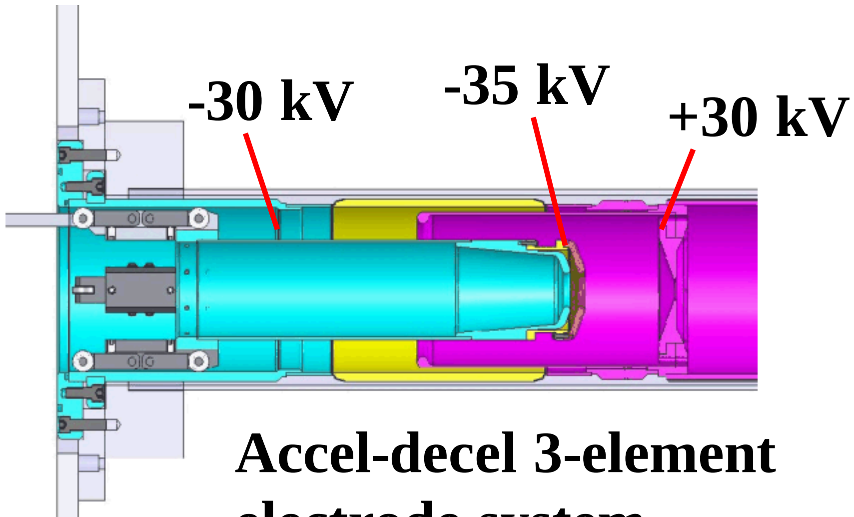
SuSI installation and commissioning started in January 2007

SuSI Injection and Extraction

Movable injection hardware with two microwave waveguides

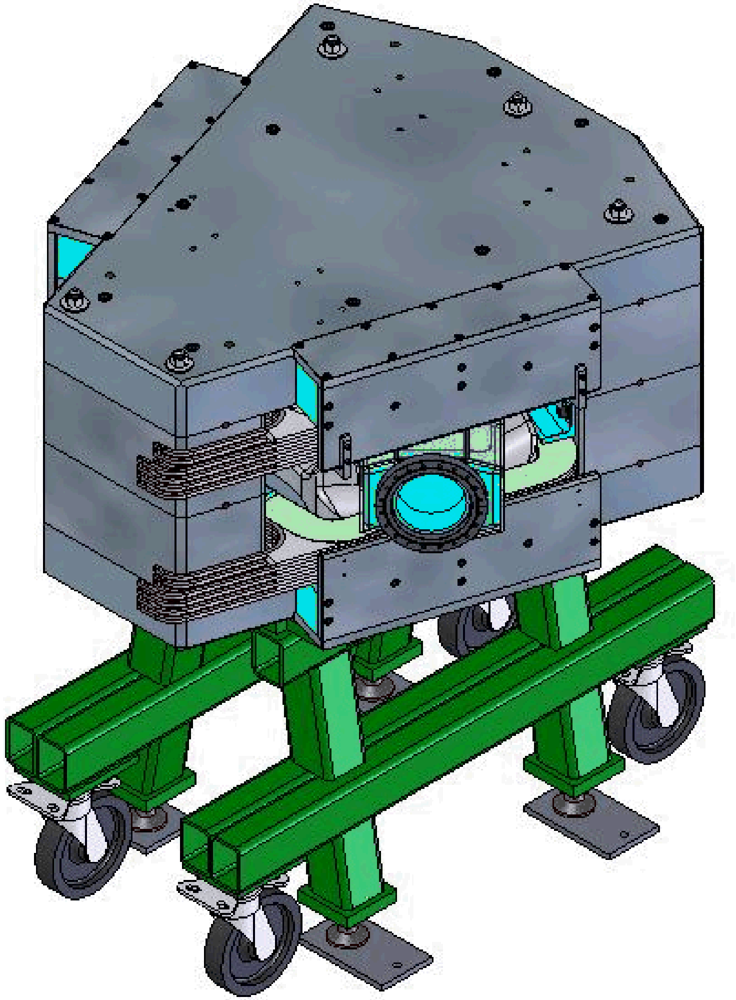


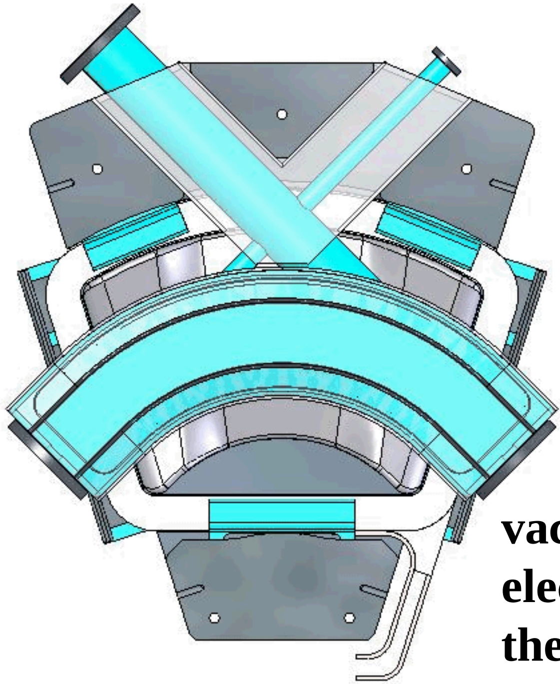




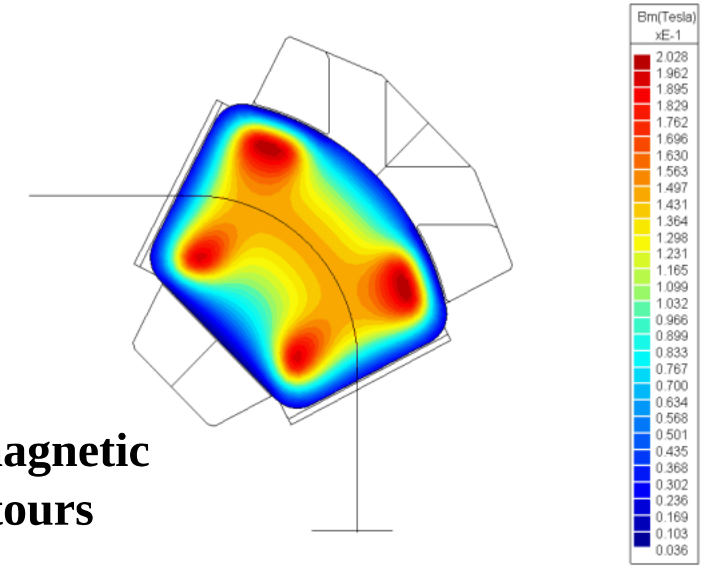
Accel-decel 3-element electrode system

90º Analyzing Magnet





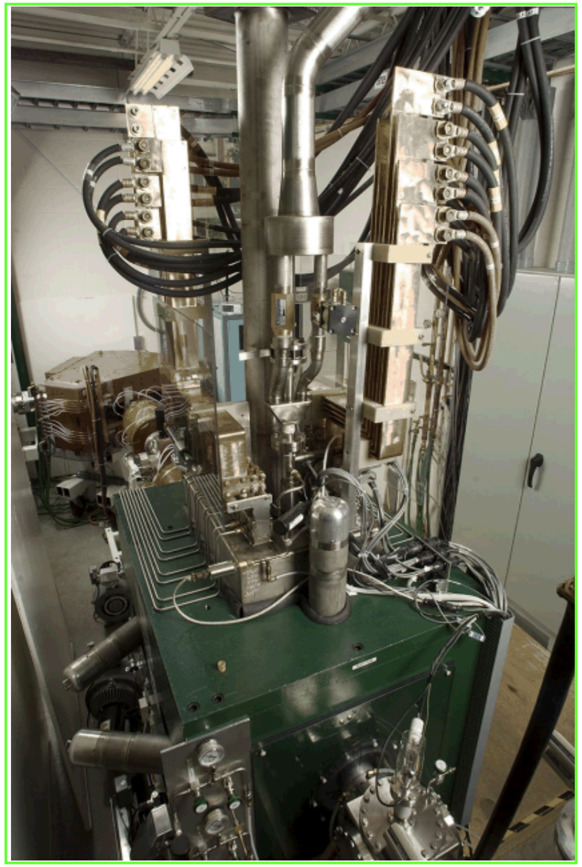
vacuum chamber is electrically isolated from the rest of the magnet

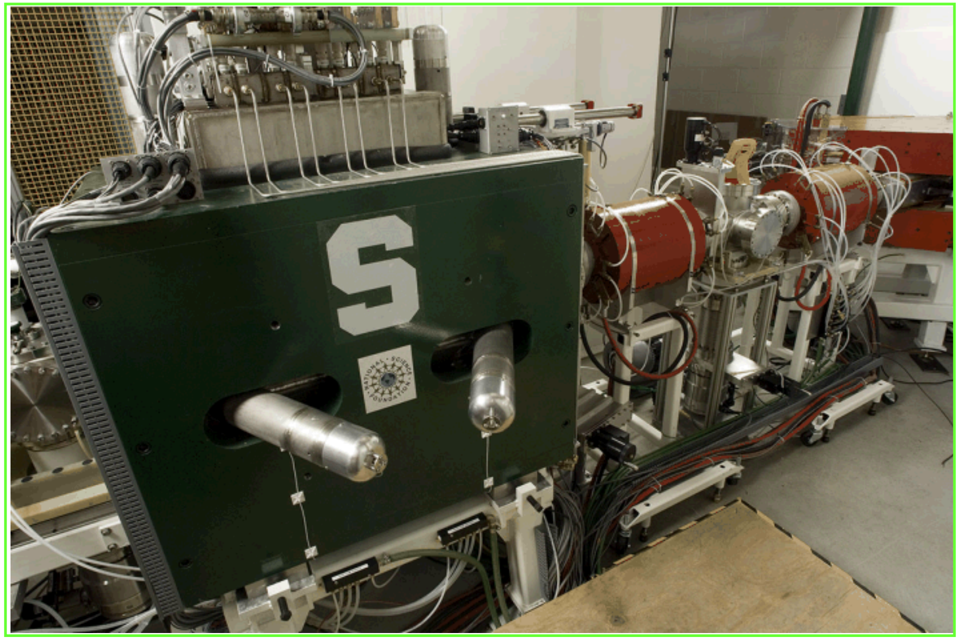


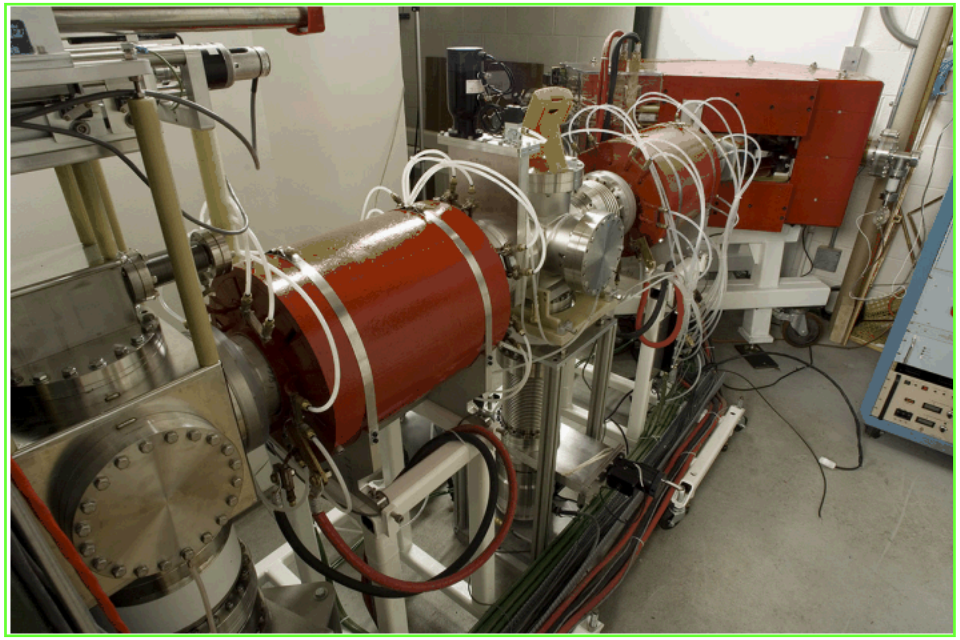
Midplane magnetic field contours

Based on the LBL VENUS analyzing magnet design (M. Leitner)

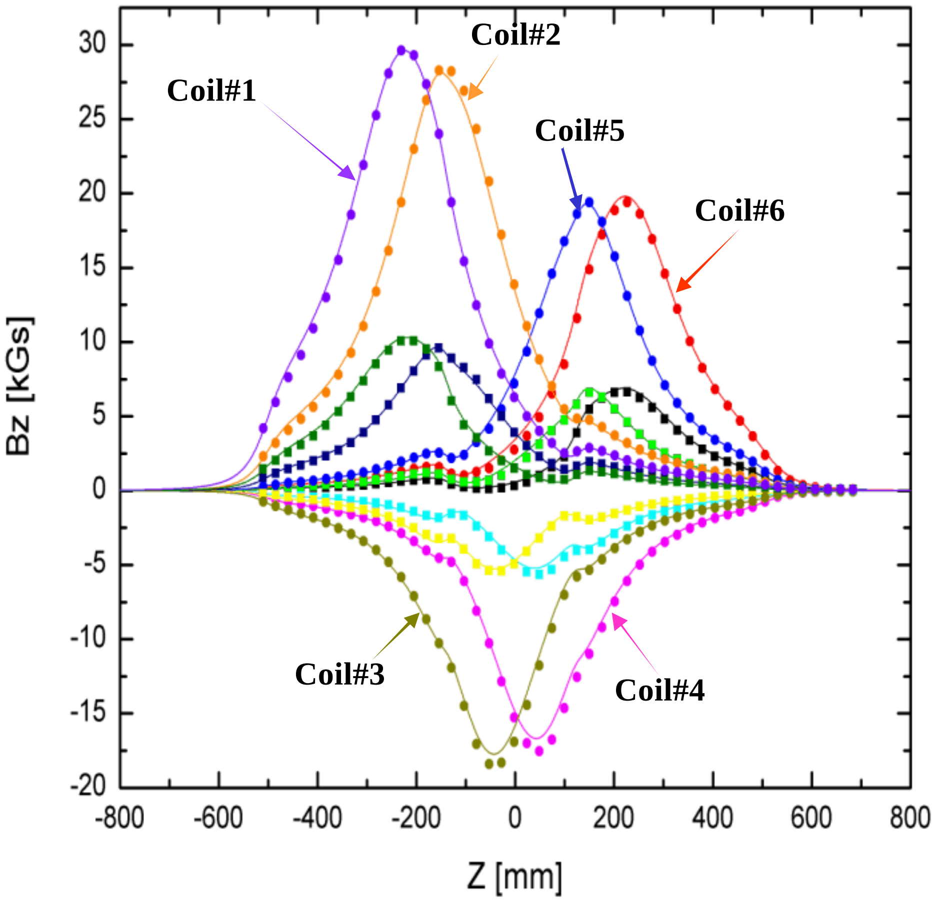
SuSI Photos





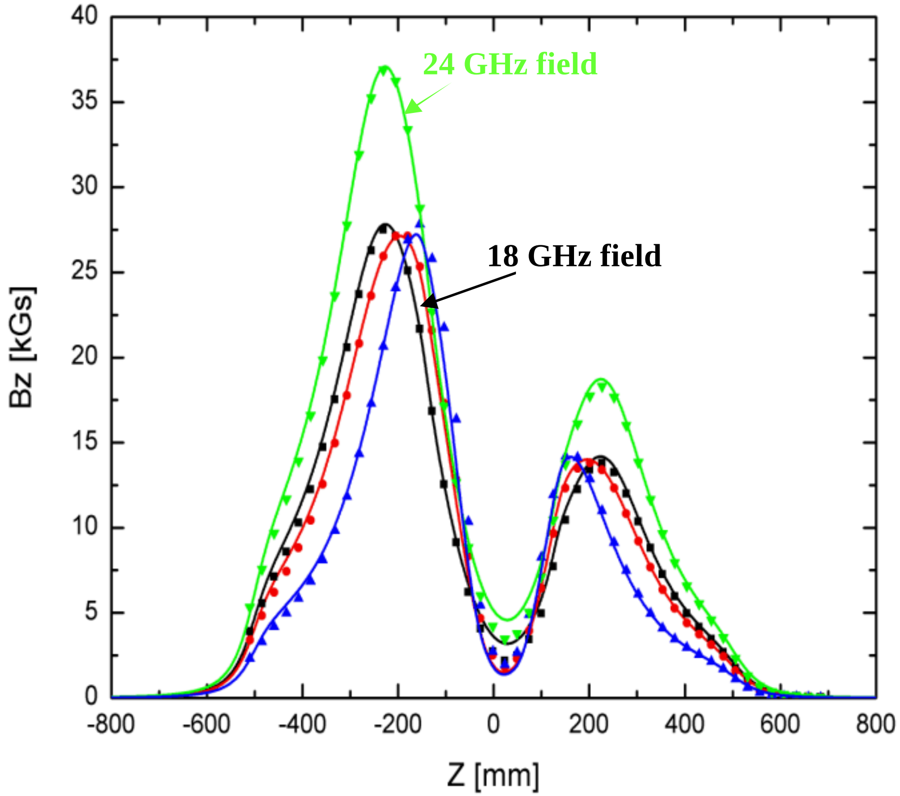


Mapping the Magnet I. (solenoids)

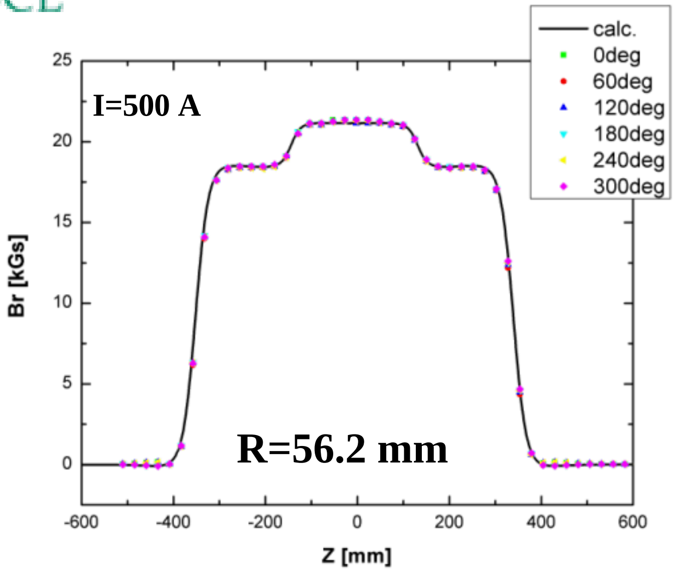


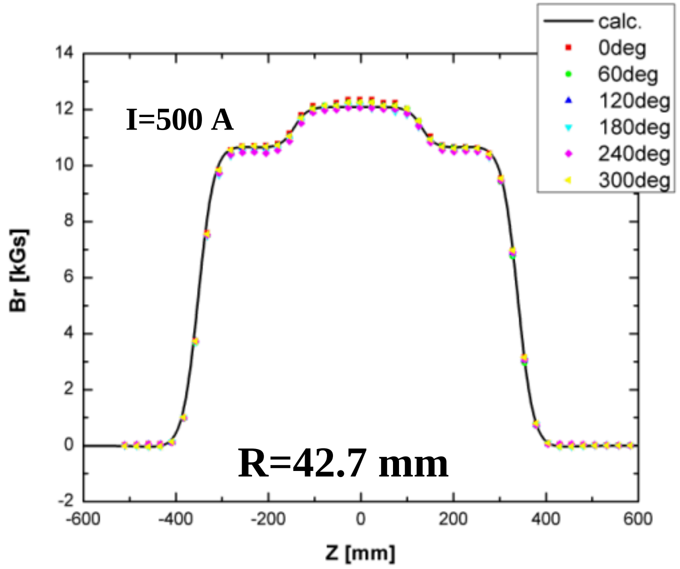
Magnetic field maps of the individual solenoid
Lines – calculated values with AMPERE
Dots – measured values
Each coil was mapped at 100 and 300 Amp

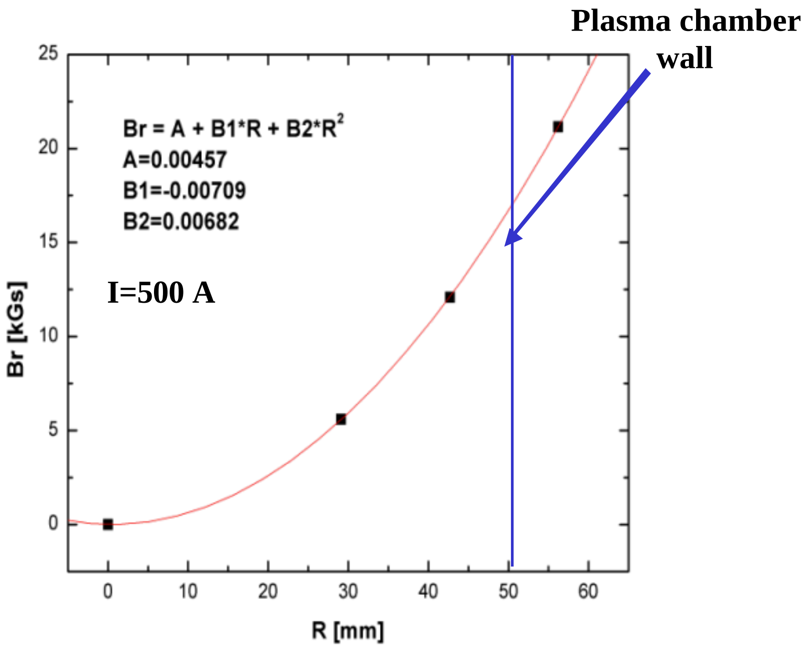
Magnetic field maps of all solenoids
Lines – calculated values with AMPERE
Dots – measured values
Black: 290, 0, -50, -50, 0, 210 Amp
Red: 175, 175, -130, -130, 135, 135 Amp
Blue: 0, 390, -220, -220, 320, 0 Amp
Green: 390, 0, -66, -66, 0, 280 Amp

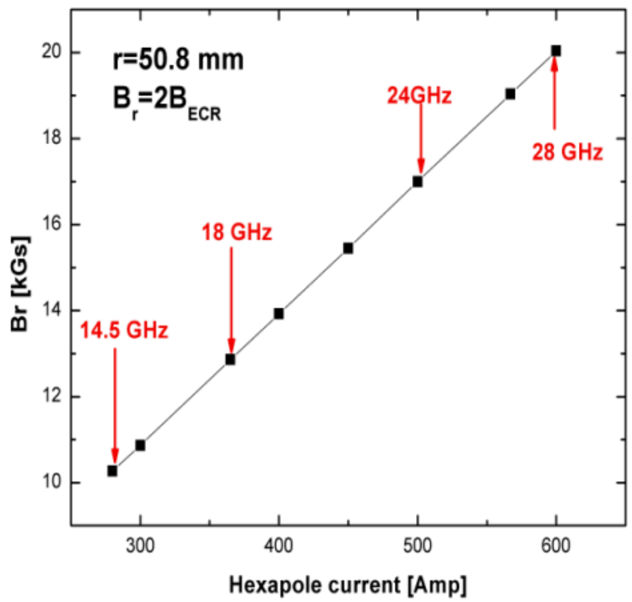


Mapping the Magnet II. (hexapole)

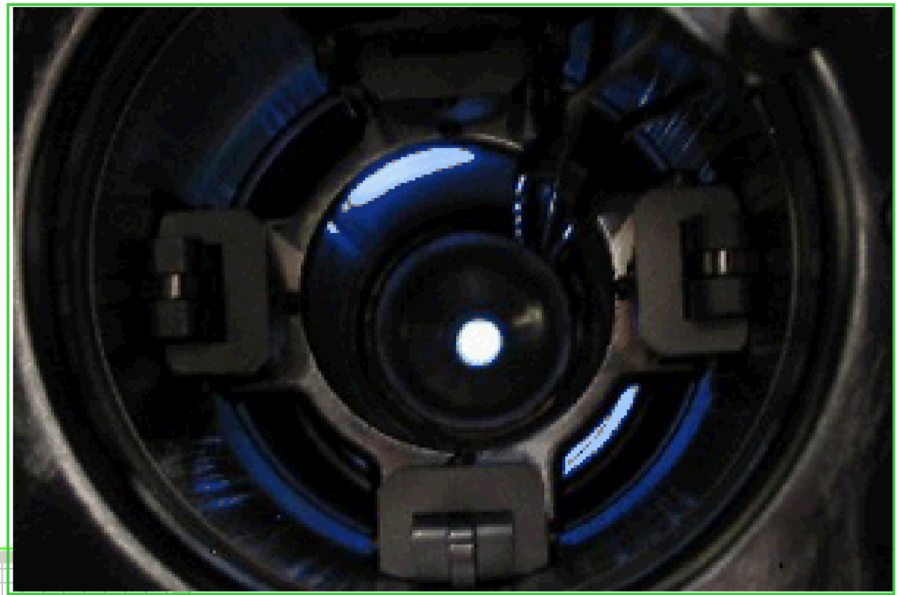


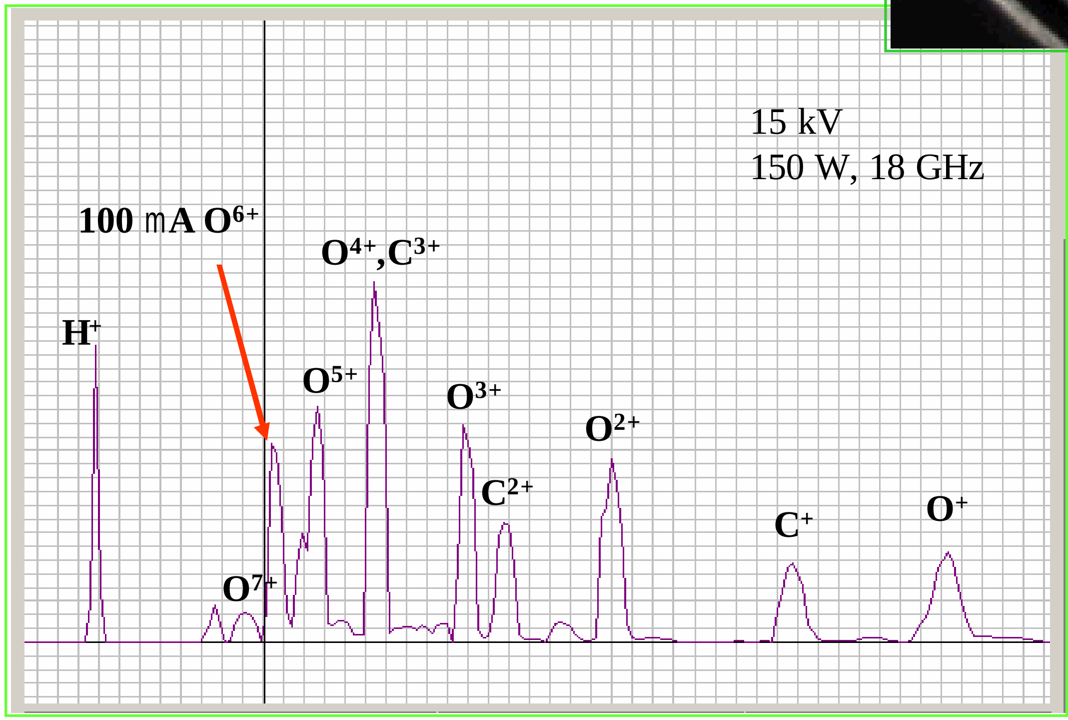






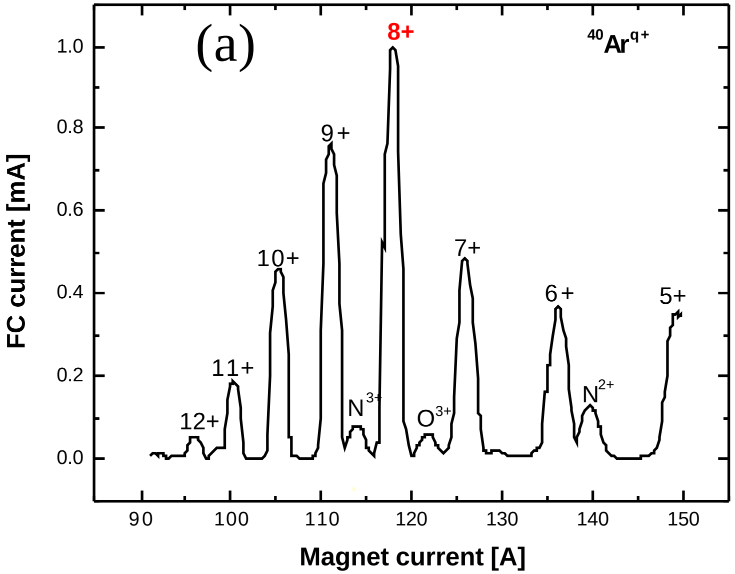
SuSI First plasma ignited on March 29, 2007

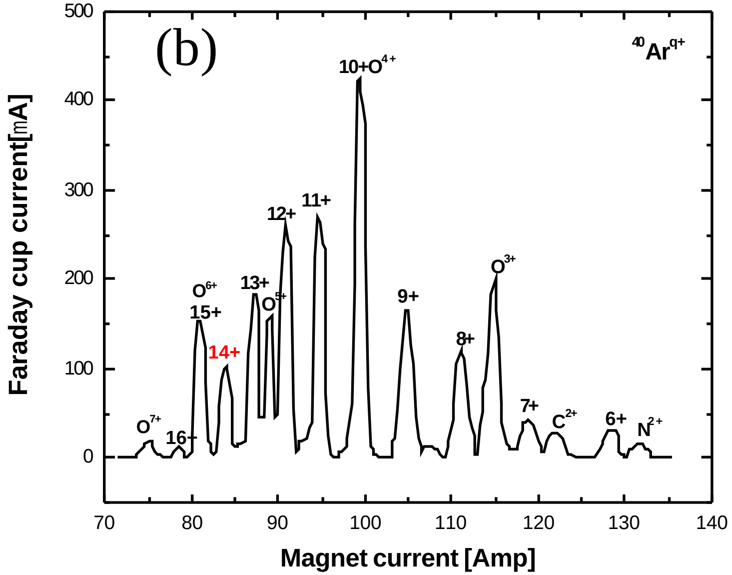


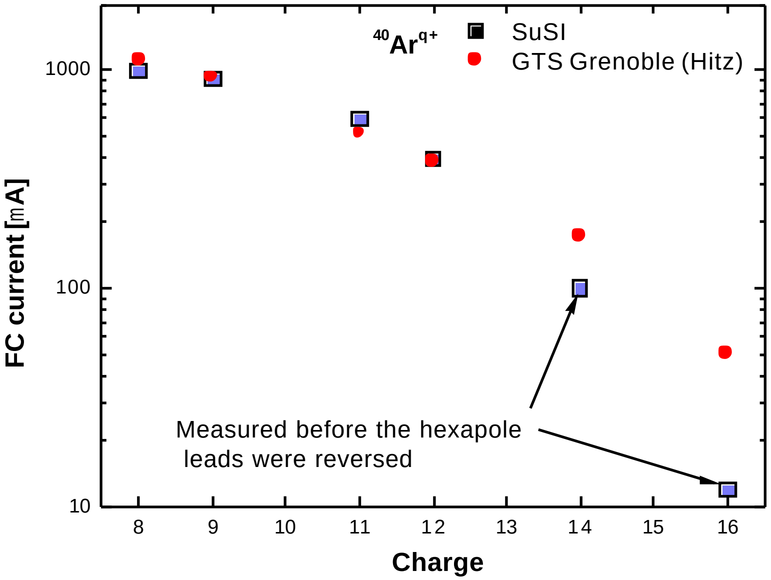


SuSI First charge state distribution obtained on June 8, 2007

Preliminary Results with $^{40}Ar^{q+}$



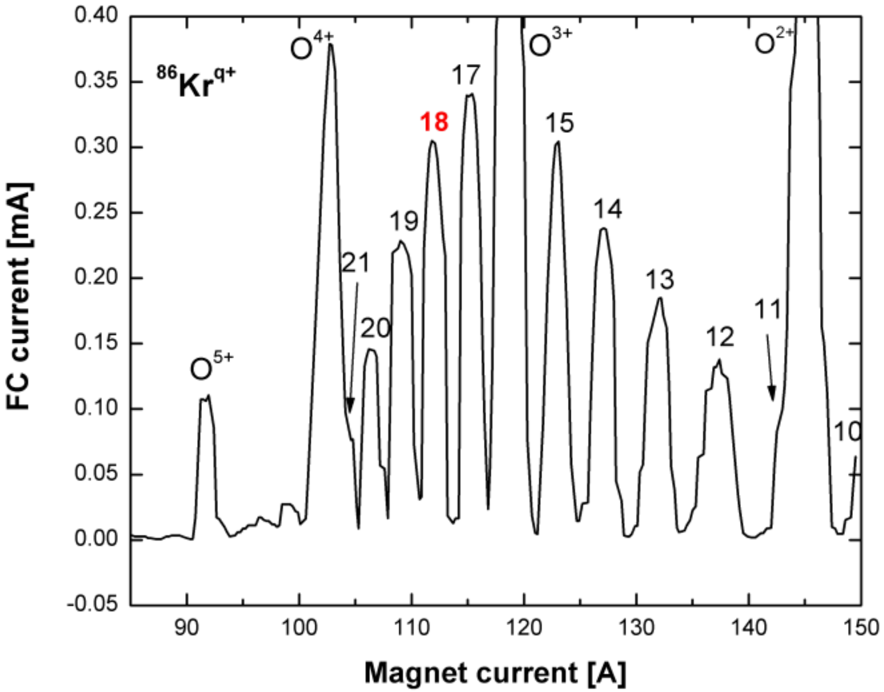


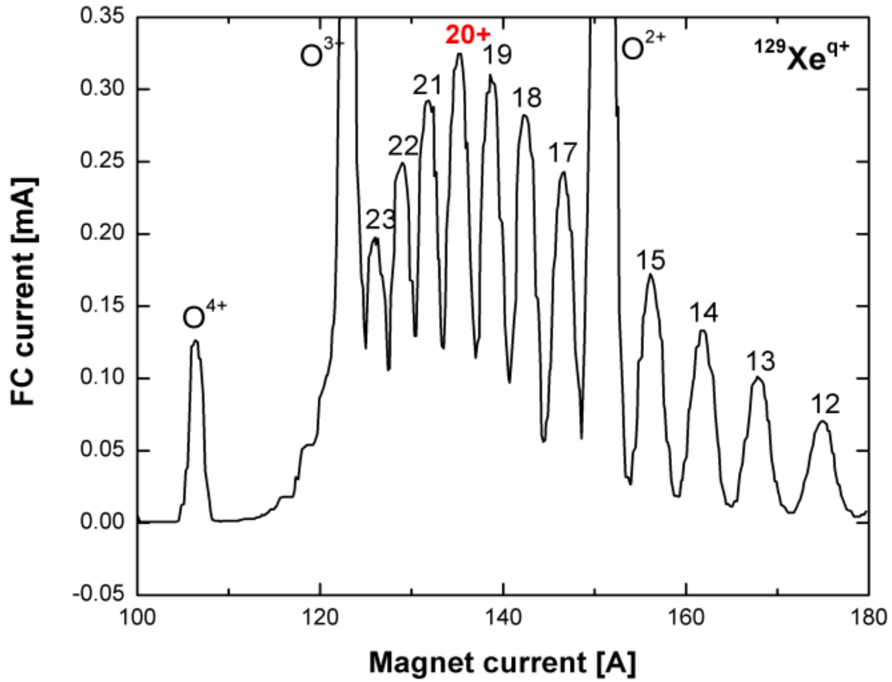


(a) – tuned for 8+ (1.0 emA) (I_{drain}=5 mA)
650 W 18 GHz + 300 W 14.5 GHz
no mixing gas; 27 kV extraction

(b) – tuned for 14+ (100 eμA) (I_{drain}=3.4 mA)
1370 W 18 GHz + 350 W 14.5 GHz
$^{16}O_2$ as mixing gas; 23.5 kV
Floating bias disk

Preliminary Results with $^{86}Kr^{q+}$ and $^{129}Xe^{q+}$





tuned for 18+ (302 eμA)
(I_{drain}=7.0 mA)
900 W 18 GHz + 700 W 14.5 GHz
O_2 mixing gas; 25 kV extraction
B.D. = -90 V

tuned for 20+ (325 eμA)
(I_{drain}=7.0 mA)
780 W 18 GHz + 310 W 14.5 GHz
O_2 mixing gas; 27 kV extraction
B.D. = -100 V

NSCL People Involved in the SuSI Design

Ion Source Physicists:

Dallas Cole
Guillaume Machicoane
Peter Zavodszky

Accelerator Physicists:

Felix Marti
Peter Miller
Xiaoyu Wu

SC Magnet Technology:

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Al Zeller

Mechanical Engineers:

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Patrick Glennon
Jim Moskalik
Jack Ottarson

Electronic and RF Engineers:

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Bill Nurnberger
John Vincent

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