ECR Ion Sources for RIA

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- Driver Linac ECR(s)
  - —High intensity -- 8pμA $^{238}U^{29+}$ (Next Talk Daniela Leitner)
  - —High efficiency-- for rare stable elements ^{36}S, ^{48}Ca, ^{64}Ni
- Post accelerator
  - —High efficiency 0 to n^{+} for volatile elements
  - —Charge multiplier 1^{+} to n^{+}
- Trapping experiments
  - —Laser, MOT etc

Rare Isotope Accelerator
R&D Workshop
August 27, 2003

FY03 RIA R&D priorities*

Electron cyclotron resonance (ECR) ion sources producing high intensity, high-charge- state uranium, and the low energy beam transport (LEBT). The driver linear accelerator requires ECR ion source performance for uranium greater than the current state of the art by a factor of 2 to 8.

Other RIA accelerator and experimental facility components will also require focused effort. These include post-acceleration including radio frequency quadrupoles (RFQs) and very low velocity accelerating structures, charge-multiplying ECRs, radiation hardened magnetic equipment, innovative detector instrumentation, beam diagnostics optimized for a broad range of beam intensities, beam dumps, radio-frequency equipment, and controls.

*partial list from http://www.science.doe.gov/grants/Fr03-23.html

RIA Driver Beams

Table 4

Projected Driver Output Beams

A/Z	I source (pμA)	Q_{inject}	Q_{strip1}	Q_{strip2}	I out (pμA)	Beam Energy (MeV/nucleon) 1st Strip	2nd Strip	Output	Power (kW)
1/1	548	1	1	1	448	51	228	731	400
3/2	218	2	2	2	186	40	173	612	400
2/1	379	1	1	1	333	33	140	528	400
18/8	54	6	8	8	40	26	125	491	400
40/8	29	11	18	18	18	22	125	494	400
86/36	15	17	35*	36	8.8	18	113	460	390
136/54	12	25	50*	53-54*	6.2	17	104	445	206
238/92	3	29	74.5*	87-90*	1.6	12	87	403	152

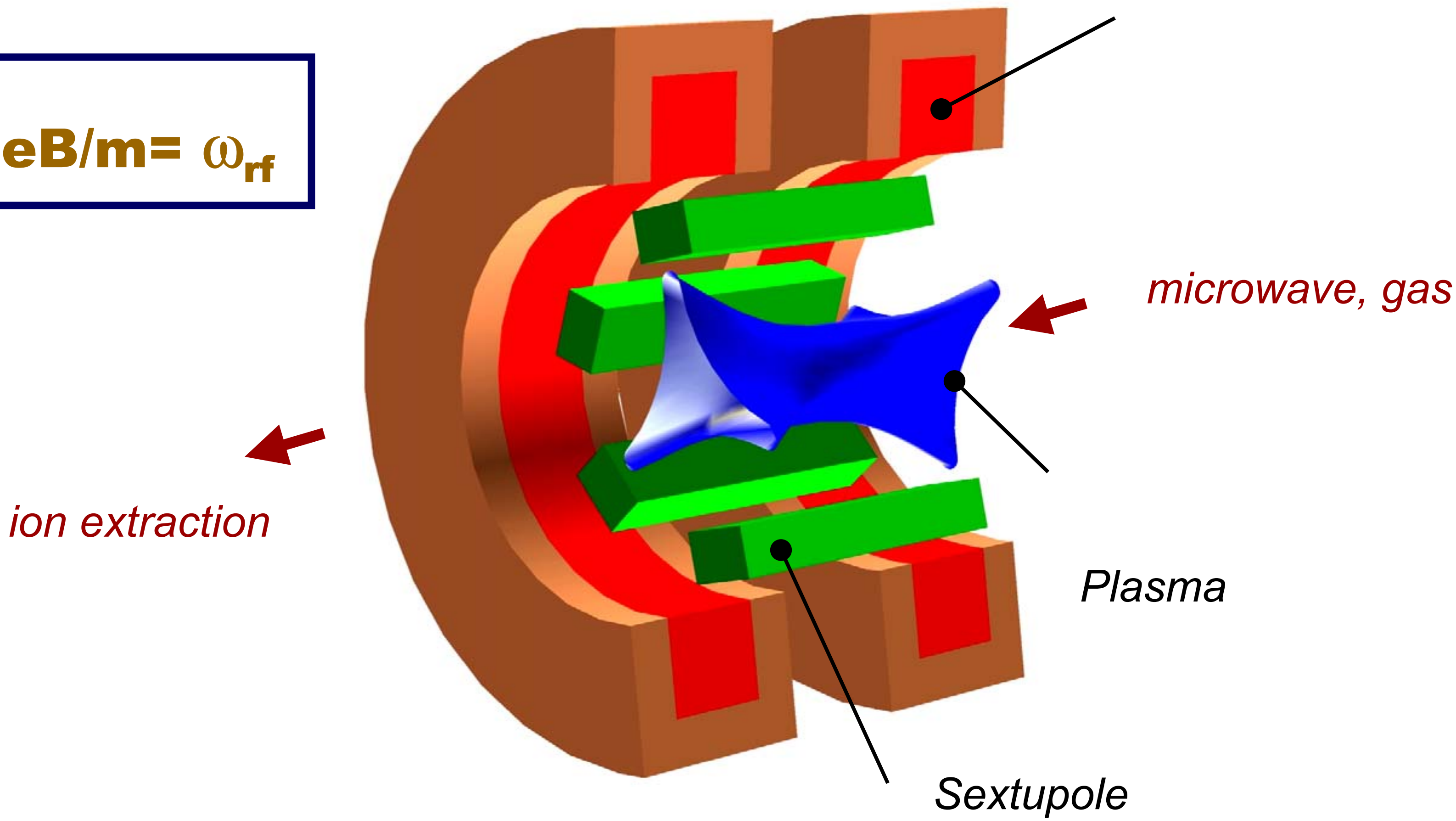
* Indicates multiple charge states.

Ion source requirement for 400 kW beam 8 pμa of U^{29+}

Assumes (~50% transmission end to end)
and multiple charge state acceleration

ECR ion sources

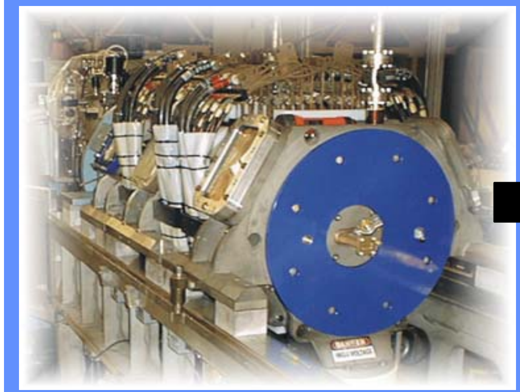
$$\omega_e = eB/m = \omega_{rf}$$



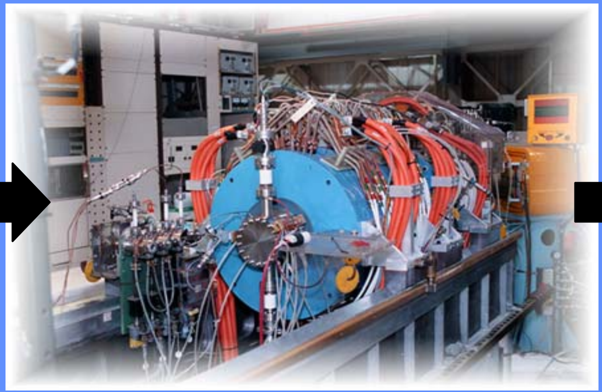
Development of VENUS at Berkeley

(Versatile ECR for NUclear Science)

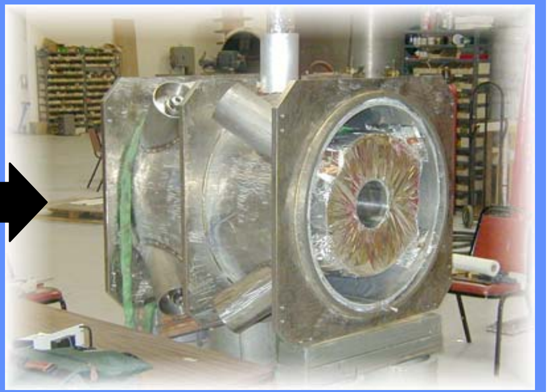
LBL ECR (1984)
0.4 T, 0.6 kW, 6.4 GHz

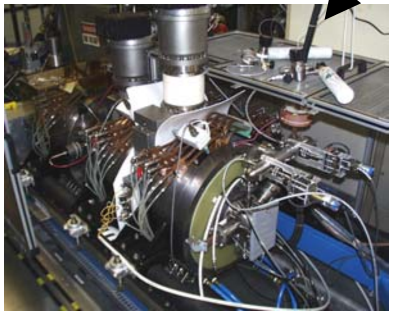


AECR-U (1996)
1.7 T, 2.6 kW, 10 + 14 GHz



VENUS (2001)
4.0 T, 14 kW, 18 + 28 GHz



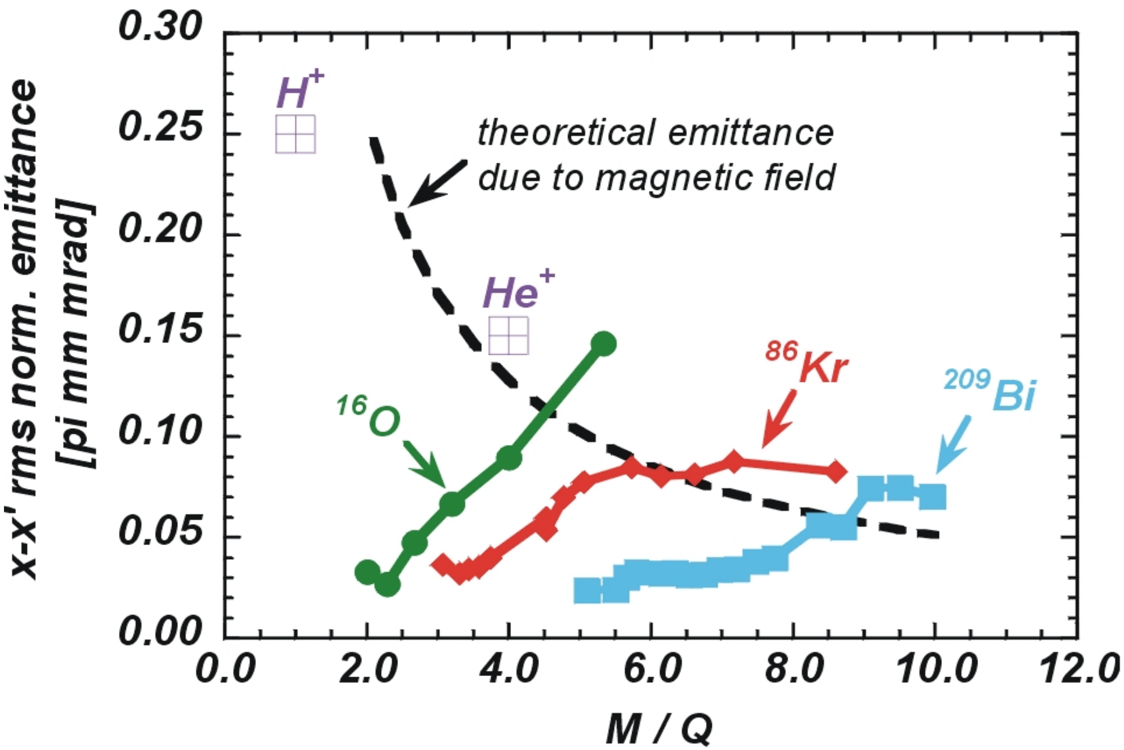


ANL
ECR 2

MSU-NSCL
ARTEMIS

Future
Superconducting Sources
GSI
CERN- GyroSerse
Lanzhou
RIKEN

Experimental Emittance with the AECR-U



- **Emittance decreases for higher charge states.**
- **Measurements indicate a strong mass dependence.**
- **This behavior cannot be explained with ion optical considerations.**
- **The highly charged heavier ions appear to be more concentrated on the ion source axis.**

- *Total extracted current approx. equal for all masses (1.5 mA ≈ 1/4 of the expected VENUS currents)*
- *The axial peak magnetic field at extraction was ~0.9 Tesla*
- *The plasma outlet hole radius is 4 mm*

RIA Driver will need ^{36}S, ^{48}Ca, ^{64}Ni ….

High Intensity ^{48}Ca Beam with High Ionization Efficiency

Motivation

1pμA ^{48}Ca on target

(6 to 10 pμA out of the source)

1g $\approx$ 200 - 250 k$

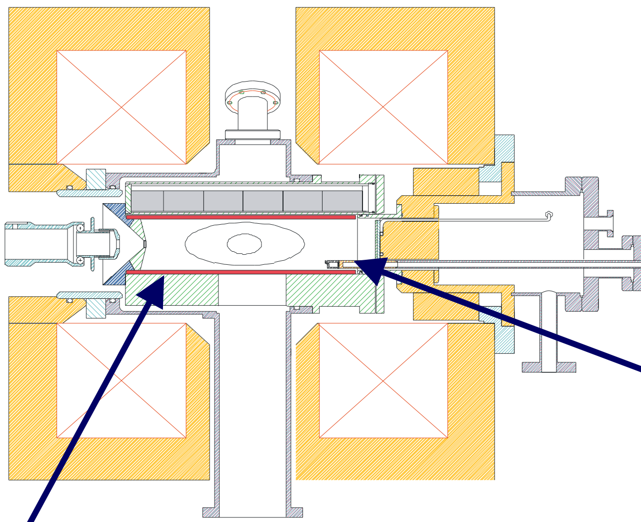
Results

2 high intensity Ca 48 runs

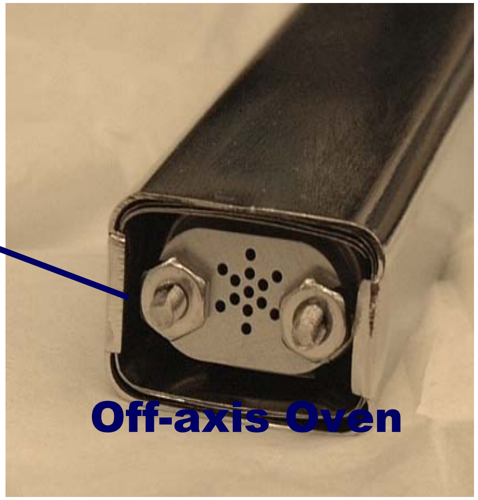
up to 1pμA (average 0.7pμA) on Target at

.25 mg/hour consumption

(Dubna: up to 1pμA on target at 0.7 mg/hour)



Hot Tantalum Liner



Axial Oven and Liner has improved the efficiency for running 48Ca by a factor of 10.

Material cost from 100 k$ to 10 k$!

ECR Ion Sources for the Post Accelerator

- High charge state ECR ion sources must be shielded from the radiation coming from the target.

- For volatile materials this can be done. At Berkeley we have ionized radioactive ^{11}C, ^{14}O and ^{76}Kr with ~10% efficiency into a single charge state

  —BEARS, IRIS, and Recyclotron developments utilize 0 to n+ method.

^{76}Kr – Recyclotron : 1enA extracted from the cyclotron

Cryo-Trap

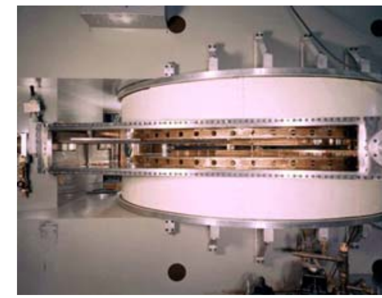
He-jet

Kr/Br

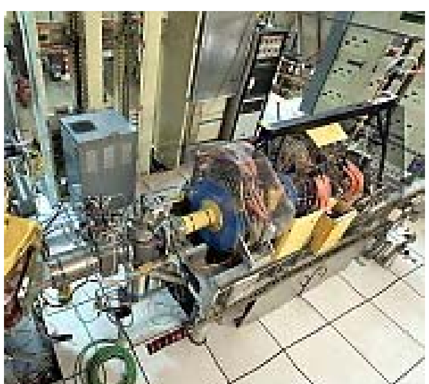
Se Production Target

54 MeV $^{4}He^{2+}$

88 Inch Cyclotron

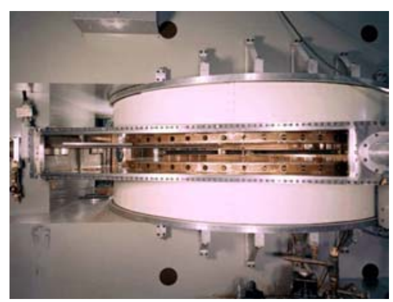


Injection



AECR-U

Ionization



Acceleration

First experiment test run with up to 1enA $^{76}Kr^{15+}$ @ 320 MeV

Opportunities in ECR ion source /RIA R&D Charge Breeding

ECR ion source
for charge multiplication

Developed in Grenoble, France-Geller et al.

Unlike EBIT or EBIS, space charge does not limit number of particles in a the trap.

Plasma densities in ECR ion sources are > 10^{11}e/cm^3

This could be coupled to the gas stopping system

$1^+ \rightarrow n^+$

4.4 x 3.5 in

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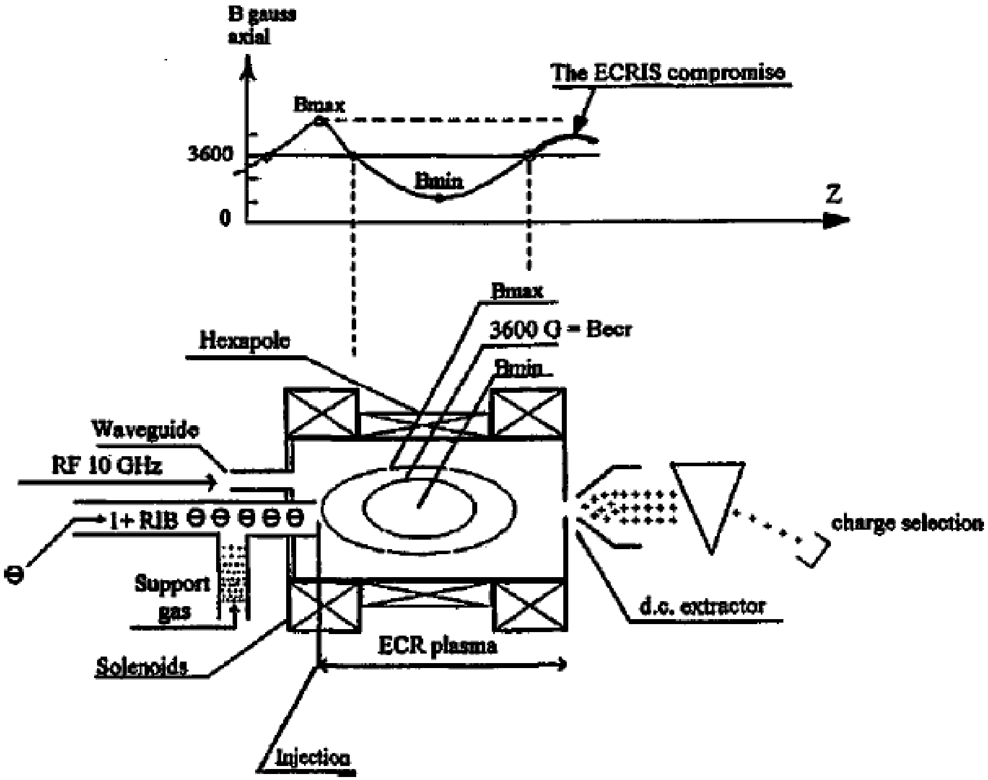

RIA R&D Priorities for FY04

- There are several opportunities to advance the capabilities of RIA with ECR ion sources
  - —VENUS (described in the next talk)
    - Highest priority for the Berkeley ECR development
  - —High efficiency for rare stable isotopes
  - —Charge Breeder for the post accelerator
    - Opportunity as an extension of the RIB work at Berkeley