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# Status of High Current Ion Sources

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# Content

- Overview of available high current sources
- Requirements for underground accelerator
- Why ECR Ion Sources for NUSEL?
- Options for the NUSEL Accelerator
- Beam transport
- Areas for R&D

# High current Ion sources
# Brief Overview

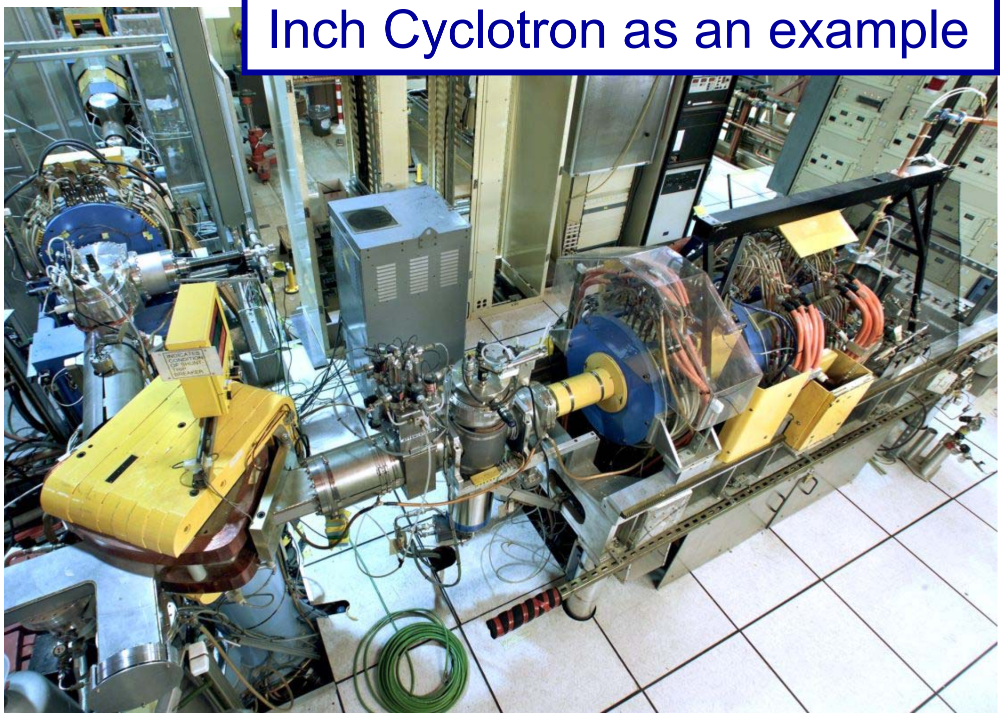
- **MEVVA** (Metal Vapor Vacuum Arc Ion Source) **and Laser Evaporation Ion Sources**
  - Medium charge states
  - High currents >100 mA
  - no gases
  - Pulsed
- **Multicusp ion sources (Filament/ RF) and cathode based ion sources**
  - Single to low charge states
  - High currents >100 mA
  - Limited lifetime
- **Microwave Sources**
  - Singly Charged Ions
  - High currents >100 mA
  - High Reliability
  - Long Lifetime
- **High charge ECR Ion sources** (Electron Cyclotron Resonance)
  - Medium to high charge state ions
  - Medium currents (μA to mA)
  - High Reliability
  - Long Lifetime

# What are the requirements for an underground injector system

- High Reliability
- Low Maintenance
- Easy Operation
- Flexibility
  - change charge state to change energy
  - beams from solid material and gases
- Low Power Consumption
  - high voltage Platform
- High Stability

# Why are ECR Ion Sources the ideal ion source type for NUSEL?

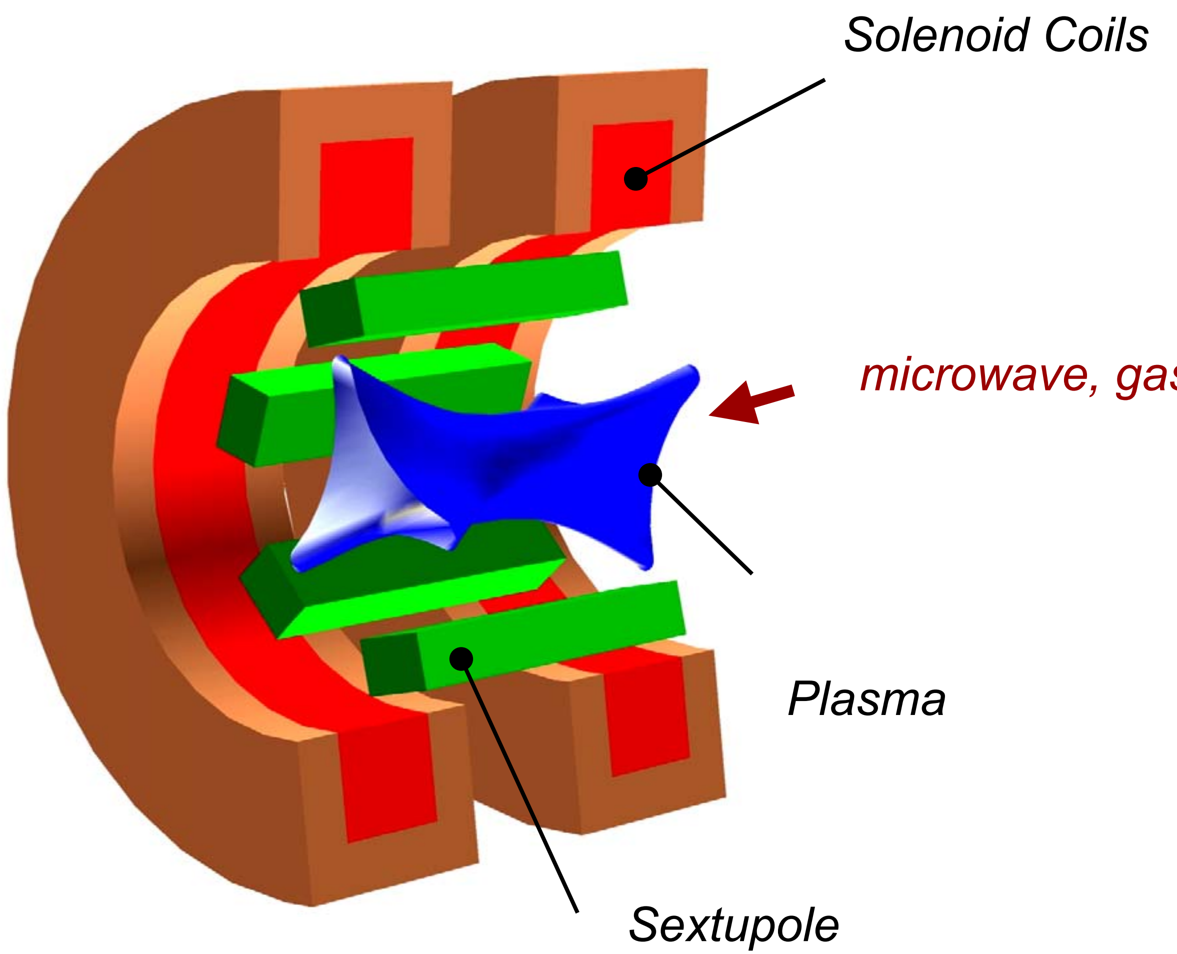
AECR-U Injector at the 88-Inch Cyclotron as an example



- Runs 24 hours/day, 7 days/ week with minimum intervention
- Minimum maintenance (typically not required for years)
- Excellent Beam Stability
- High Reliability
- High intensities
- High flexibility
- Can produce ion beams from every element
- Good beam quality

# How do ECR ion sources work

$$\omega_e = \frac{B}{q \cdot m} = \omega_{rf}$$




$$I \propto \omega_{rf}^2 M^{-1}$$

$$I \propto \log B^{1.5}$$

# ECR Ion source have been developed mainly for two areas

- **high charge state ECR ion sources**
  - high charge states and low charge states
  - $10^{-7}$ to $10^{-6}$ mbar, total current ≈ 1-5 emA

    $Ar^{8+}$ (2000 eμA)

    $O^{6+}$ (1500 eμA)

    several mA for light ions
  - Beam transport challenging
  - R&D area( RIA)

- **Single Charged ECR ion source (Chalk River)**
  - single charge
  - $10^{-3}$ to $10^{-2}$ mbar total current up to 130 emA*
  - Beam transport challenging but demonstrated (LEDA)
  - R&D area for high quality beams

*J. Sherman, et. al. *RSI*, vol. 69, pp. 1003, 1998

# LEDA has demonstrated > 100 mA $H^+$ transported through CW RFQ

low-energy demonstrator accelerator (LEDA)

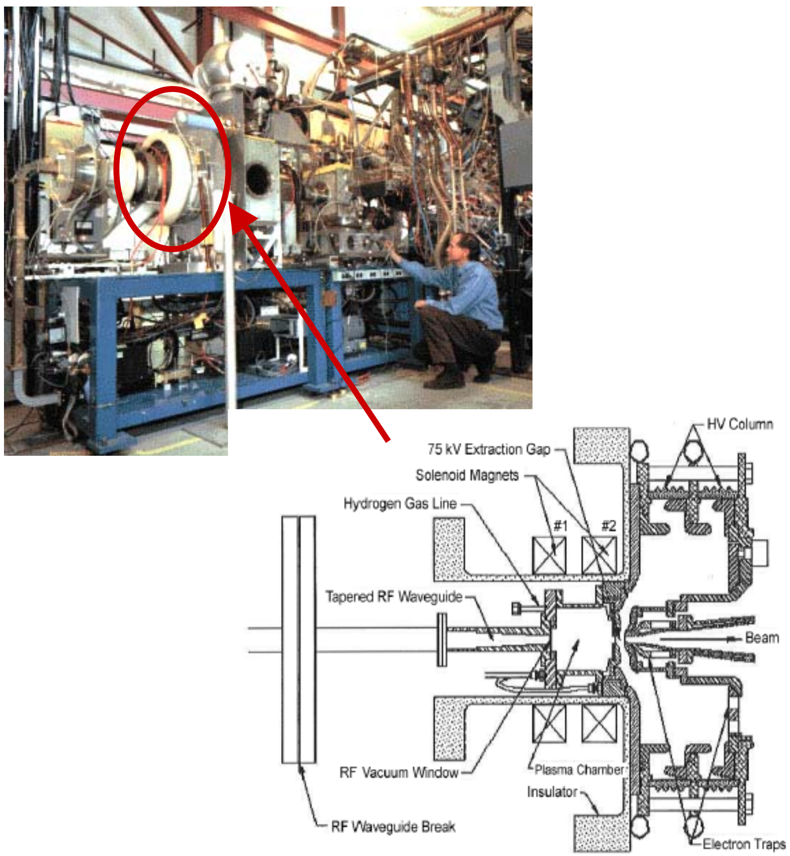



Figure 1. LEDA microwave proton source.

| | |
|---|---|
| Proton beam current (mA) | 117 |
| Proton fraction(%) | 90 |
| Beam energy (keV) | 75 |
| Discharge power (W) 2.45 GHZ | 600 to 800 |
| Beam noise (%) | ±1 |
| Ion source emittance (πmm-mrad) | 0.13 (rms, normalized) |

*J. Sherman, et. al. *RSI*, vol. 69, pp. 1003, 1998

# High Charge state ECR ion source development at LBNL

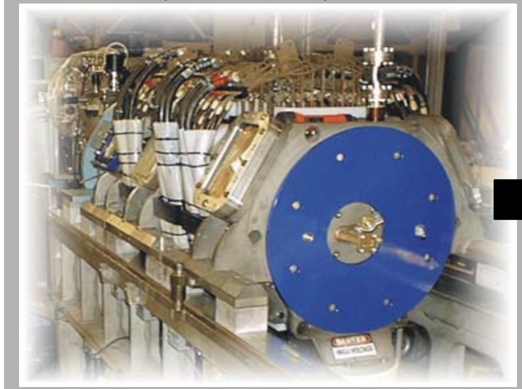
$n_e \propto \omega_{rf}^2$

$\tau_{ion} \propto BL_{mirror}$

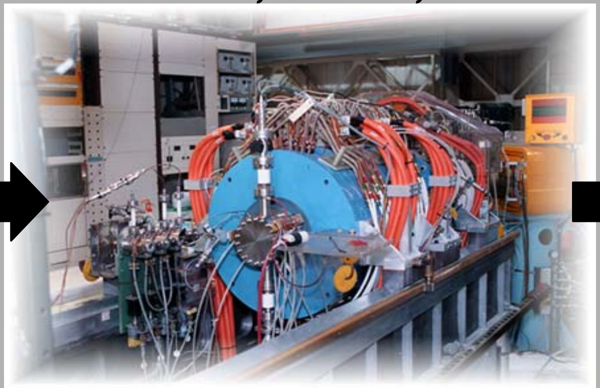
$I \propto \omega_{rf}^2 M^{-1}$

$I \propto P_{rf}^{1/3}$

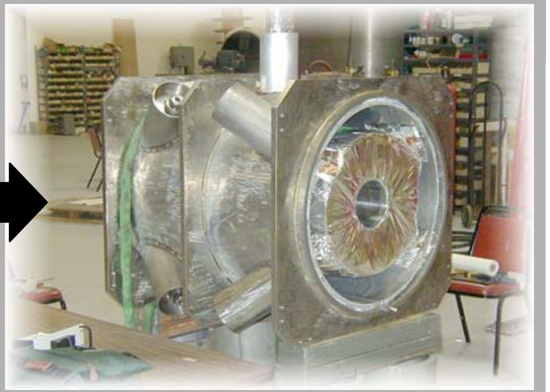
*ECR (1983)*
*0.4 T, 0.6 kW, 6.4 GHz*



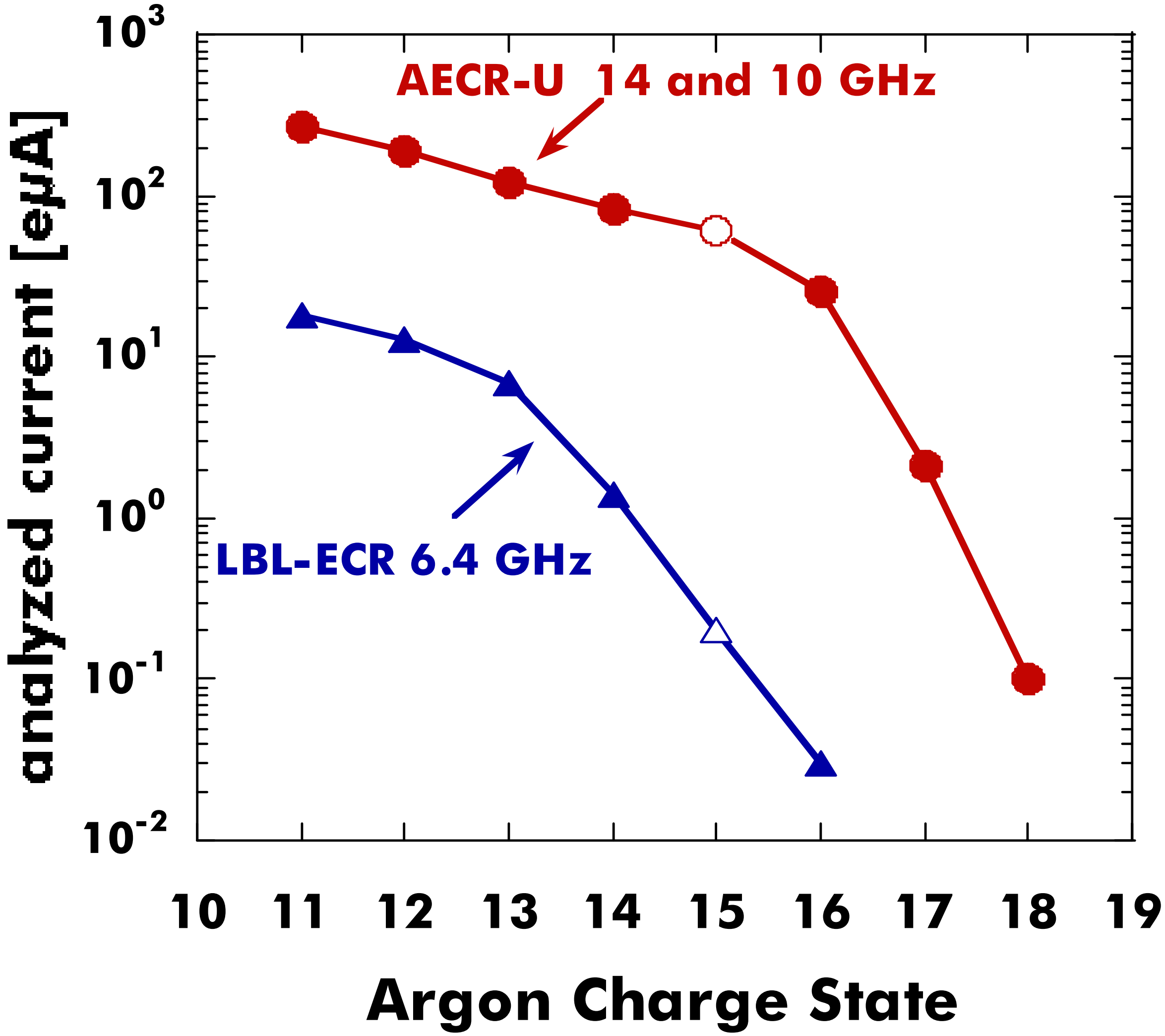
*AECR-U (1996)*
*1.7 T, 2.6 kW, 10 + 14*



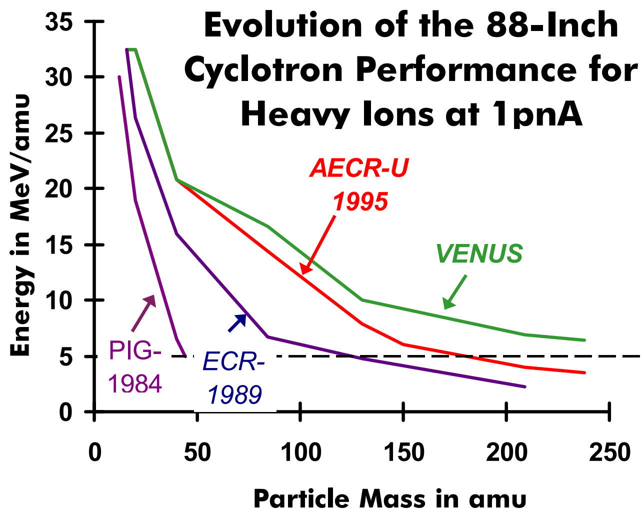
*VENUS (2001)*
*4.0 T, 14 kW, 18 + 28 GHz*

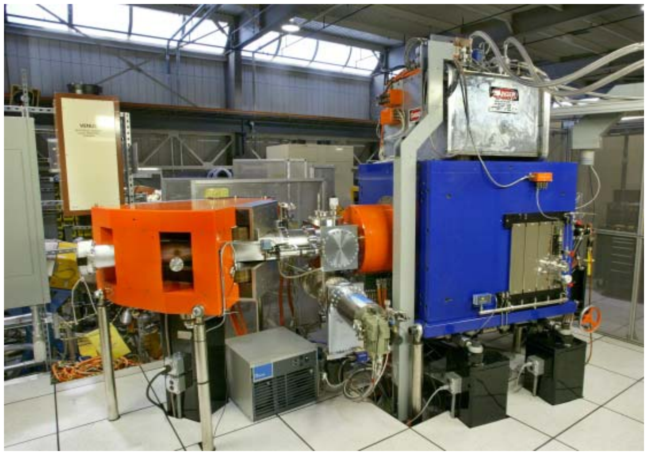


# The frequency scaling for the LBNL ECR ion sources

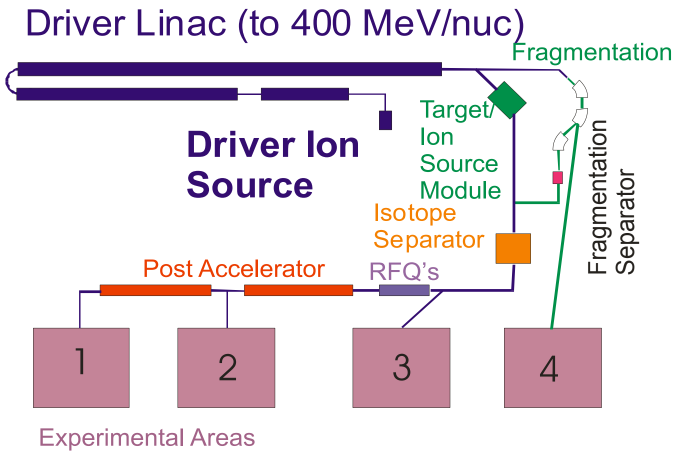


# Most advanced ECR ion source is VENUS at LBNL



*Produce the world most intense high charge state heavy ion-beams for the 88-Inch Cyclotron*



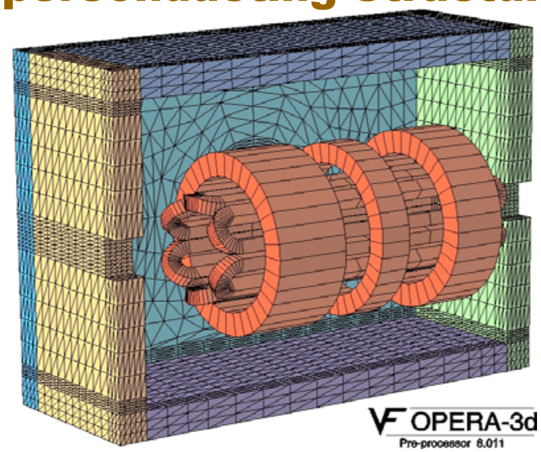

RIA R&D Ion Source

10 pμA $U^{30+}$

*Provide highest current high-charge state beams for the next generation heavy ion accelerators.*

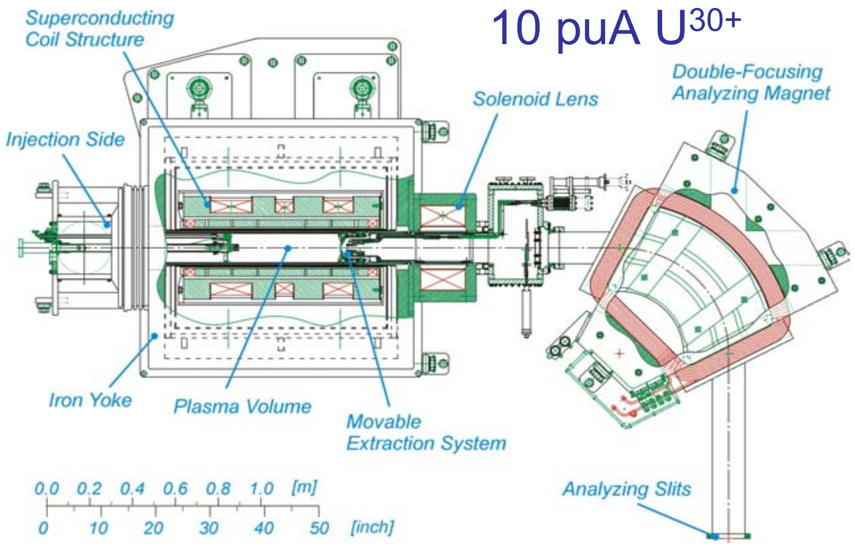
# VENUS Components

## Superconducting Structure

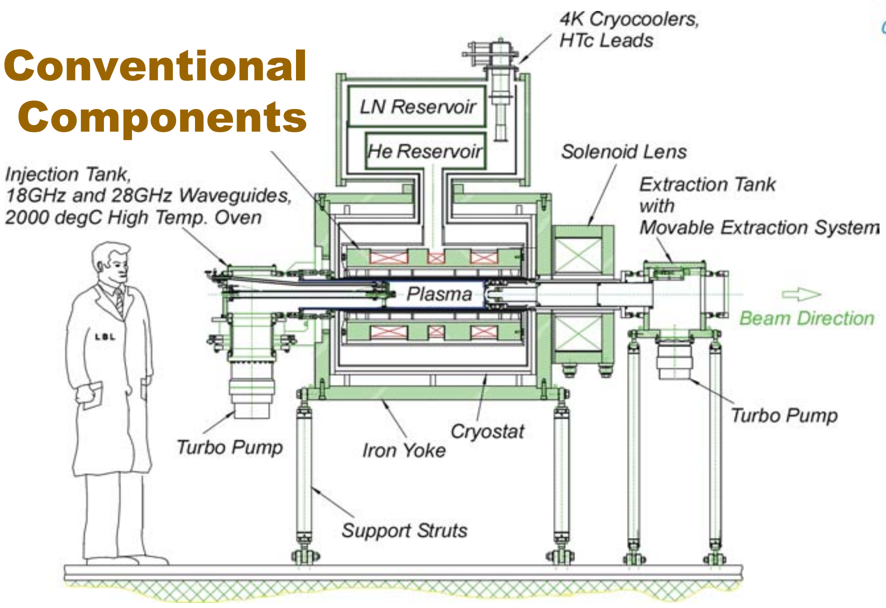



## Beam Transport

RIA R&D Source
10 puA $U^{30+}$

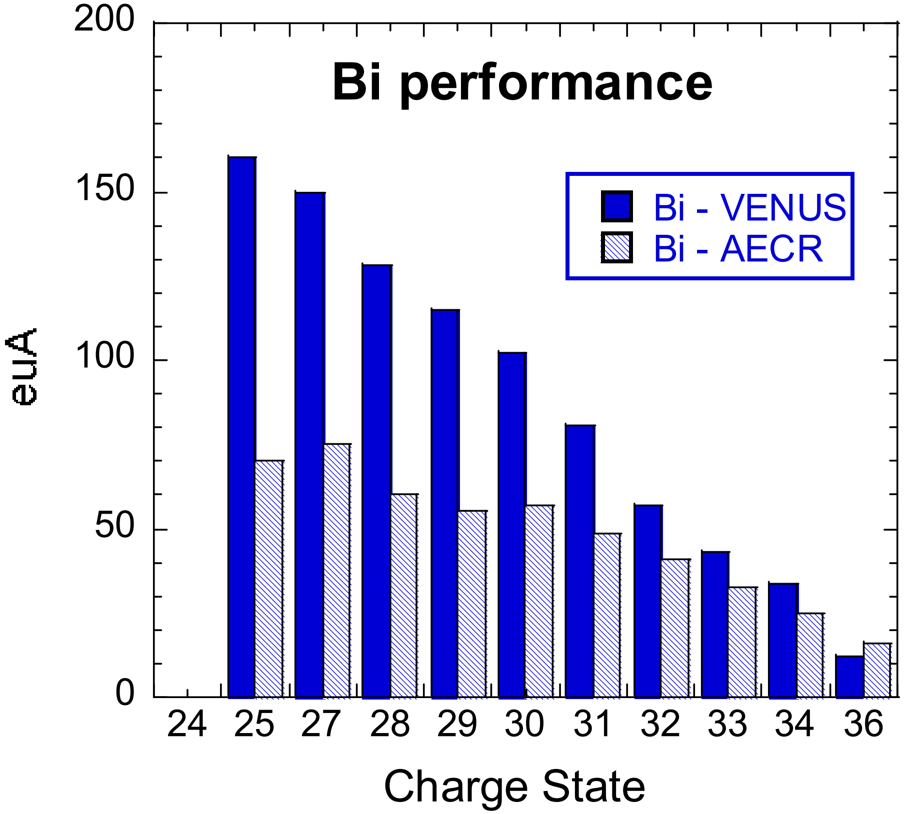


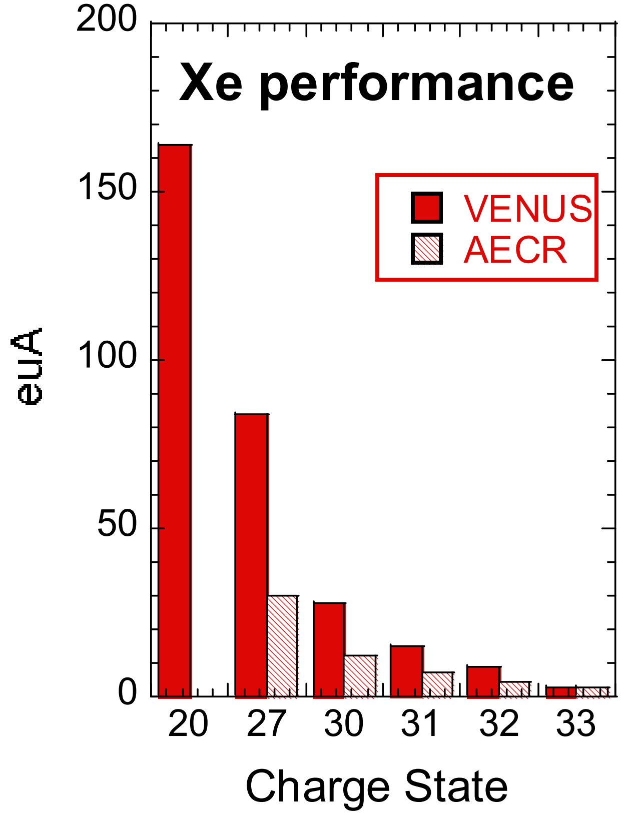

## Conventional Components




1. **Superconducting magnet structure forces a completely new ion source design, not an extension of an existing design.**
2. **VENUS serves as test bed to understand the transport of high current heavy ion beams**

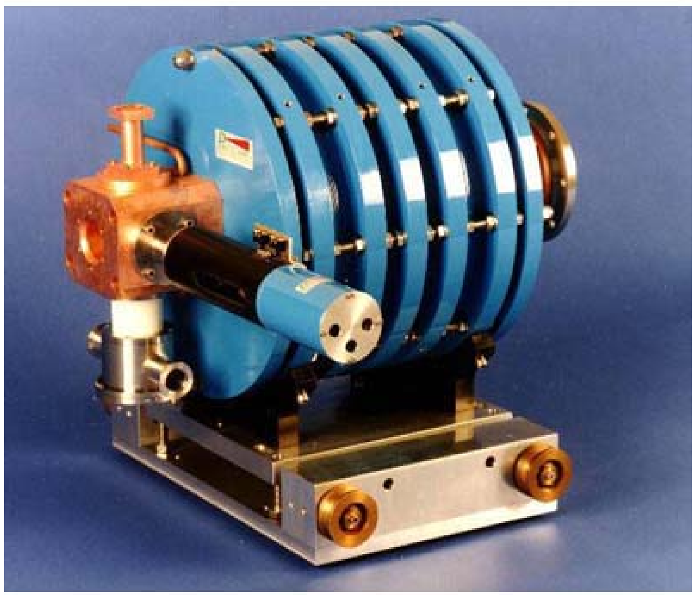
# Venus at 18 GHz out performances AECR-U especially for heavy ions



# High performance fully permanent magnet ECR ion source (commercially available)

SUPERNANOGAN



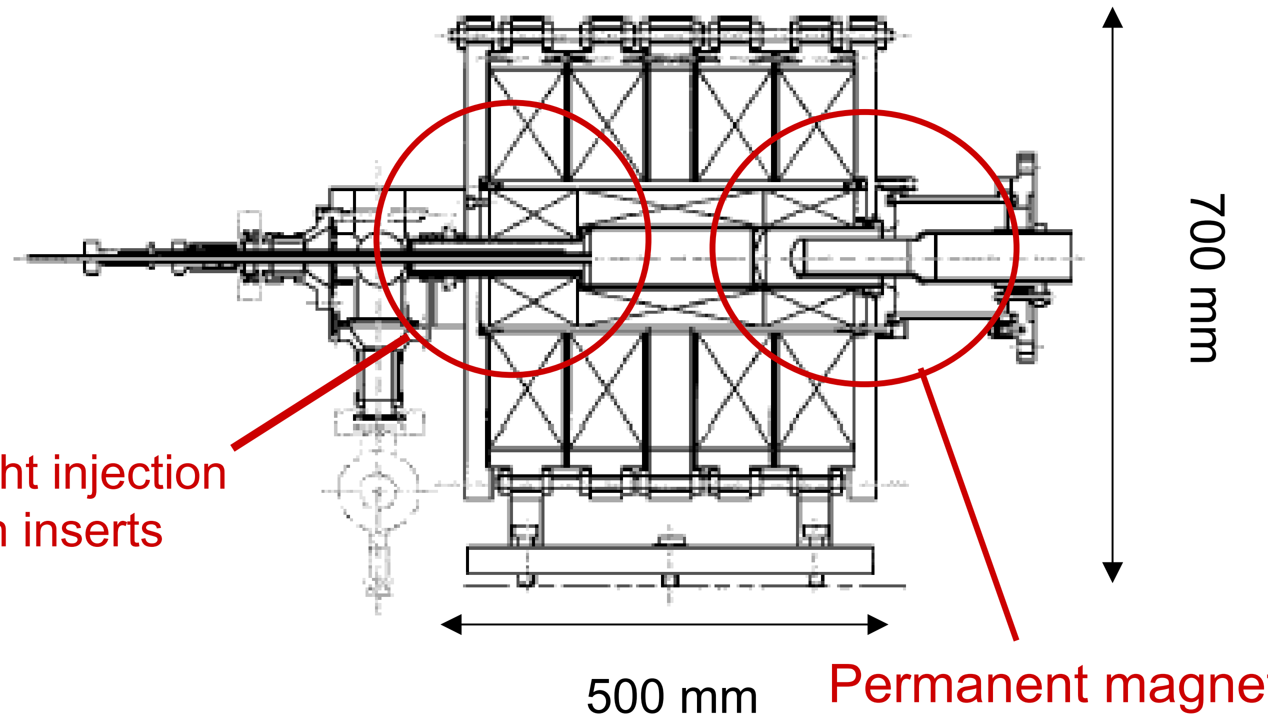
- High Frequency 14.5 GHz
- Fully permanent magnet
- Compact, but
  - Performance limited
  - Ovens difficult
  - Beam transport difficult
- Compact RF system (Traveling Wave Tube) Power limited (400 W)
- Especially suitable for high voltage platforms

> 2 mA of H+

150 eμA $O^{6+}$

350 eμA of $Ar^{8+}$

# High performance fully permanent magnet ECR ion source (continue)



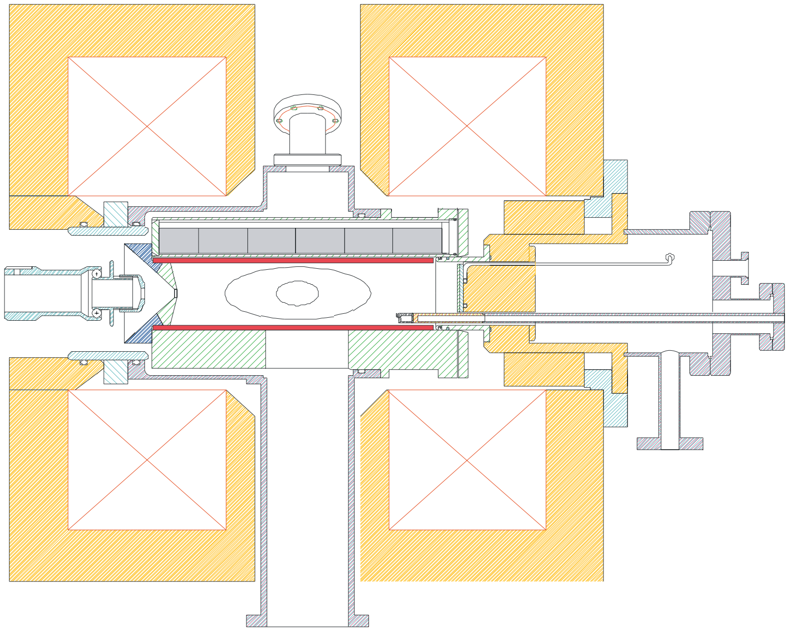

Very tight injection for oven inserts

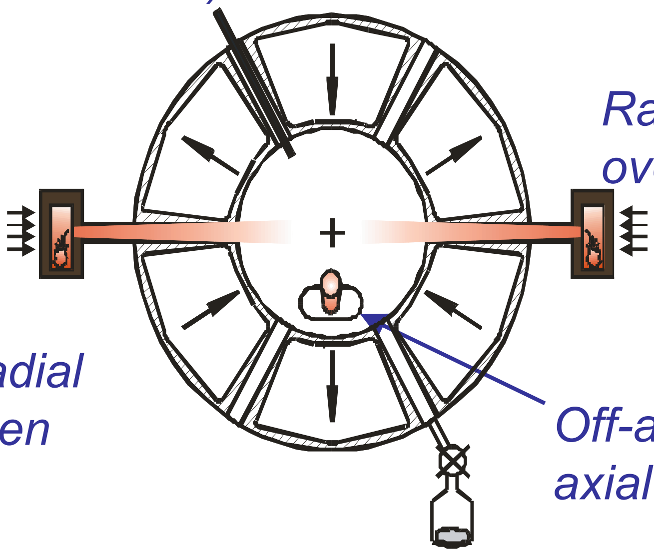
Permanent magnets imply very narrow extraction (beam blow up due to space charge)

Ref.: C. Bieth, J. L. Bouly, J. C. Curdy, S. Kantas, **P. Sortais**, P. Sole, and J. L. Vieux-Rochaz Rev. Sci. Instrum. **71**, 899 (2000)

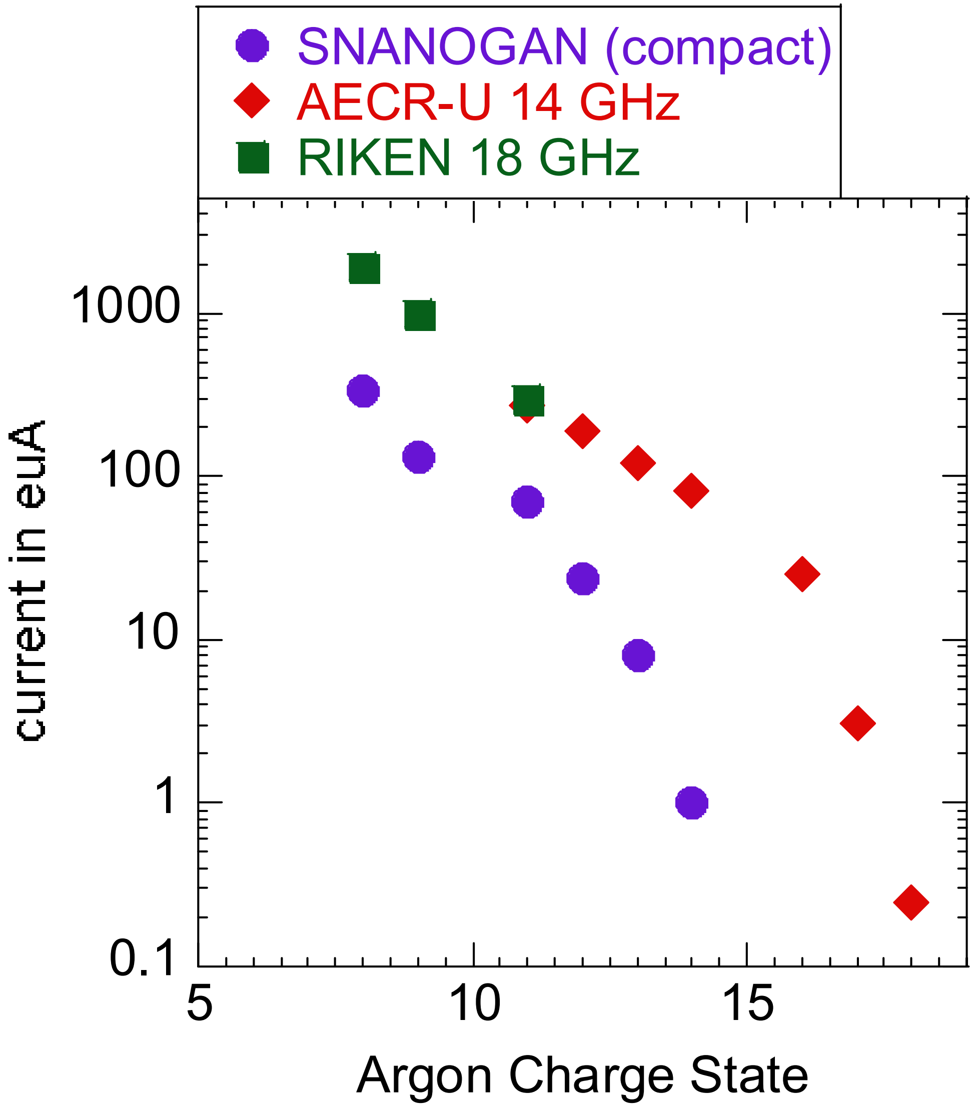
# A conventional ECR Ion source offers more operational flexibility and higher intensities than fully permanent sources

AECR-U Ions Source



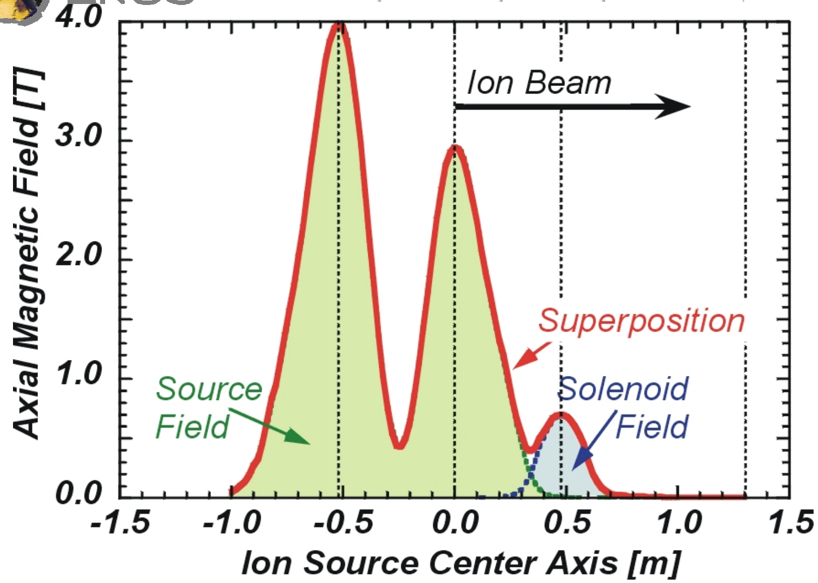


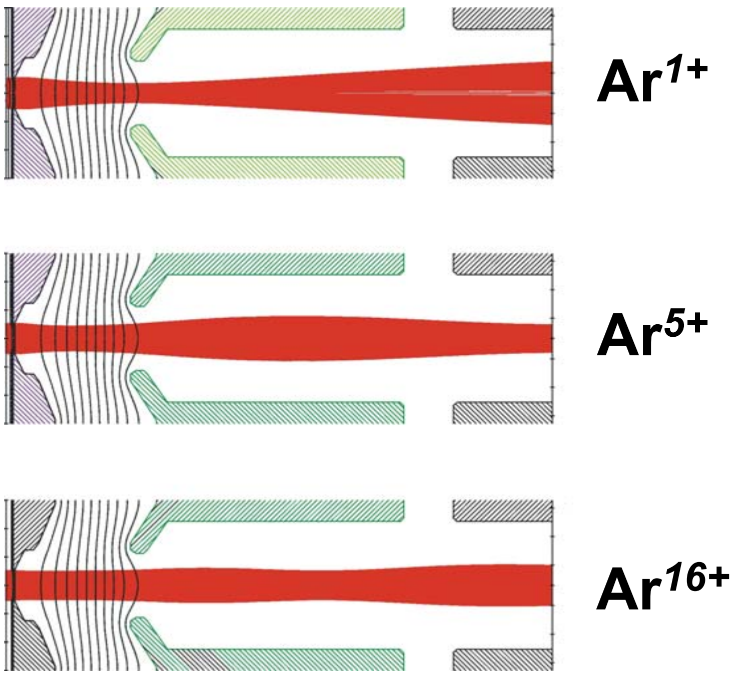
# Comparison of highest performance conventional and fully permanent ECR ion sources



# Beam Transport

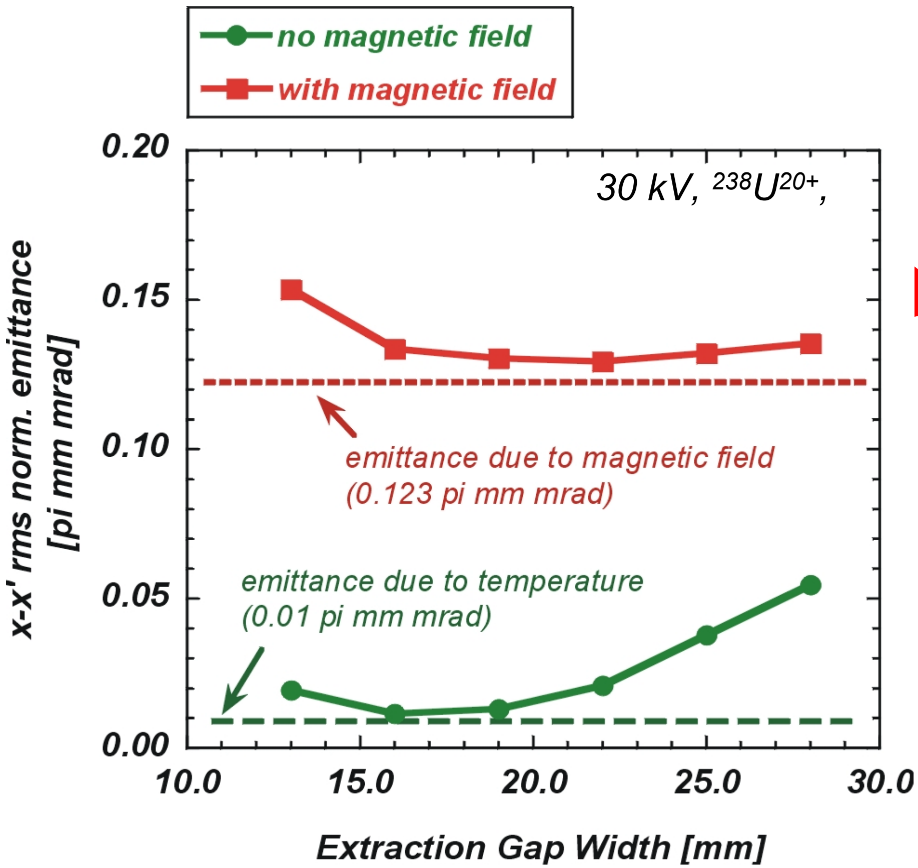
# Multi Charged ECR Ion Beam Transport




- Space charge dominated beams
- Charge state distribution for each species present at extraction (each contribution must be taken into account correctly)
- Different focusing properties for each M/Q
- Emittance contribution due to the high solenoid field at the extraction

# The ECR Ion Source Emittance dominated by the magnetic field at extraction




$$\varepsilon_{MAG}^{xx'-rms-norm} = 0.032 \cdot r^2 \cdot B_0 \cdot \frac{1}{M/Q}$$

**Magnetic Field Dominates Emittance for given M/Q above**

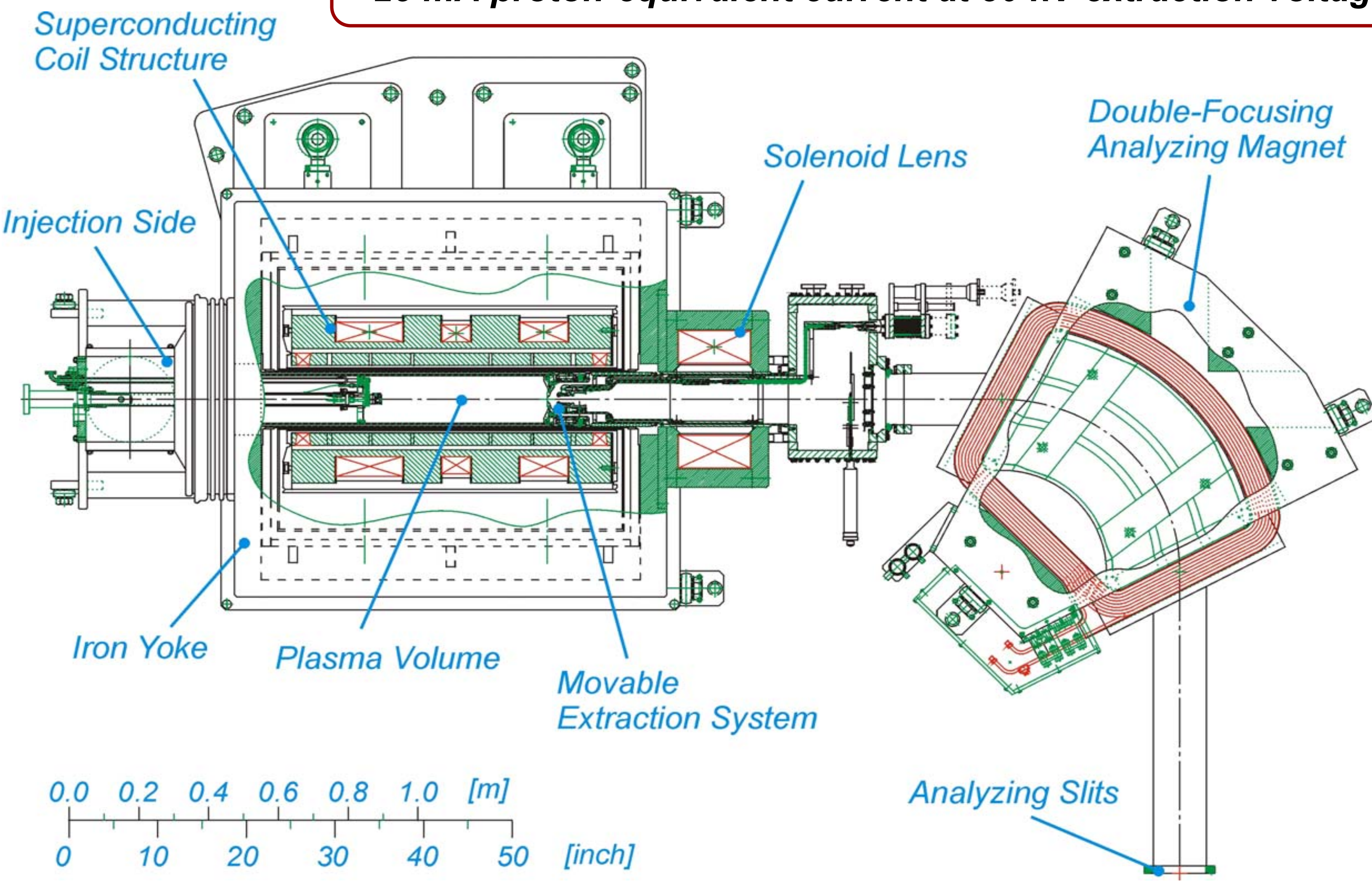
***M/Q=1 $B_0$ > 0.07 T***
***M/Q=5 $B_0$ > 0.15 T***
***M/Q=30 $B_0$ > 0.38 T***

Therefore the ion source emittance for every ECR ions is dominated by the magnetic field at extraction

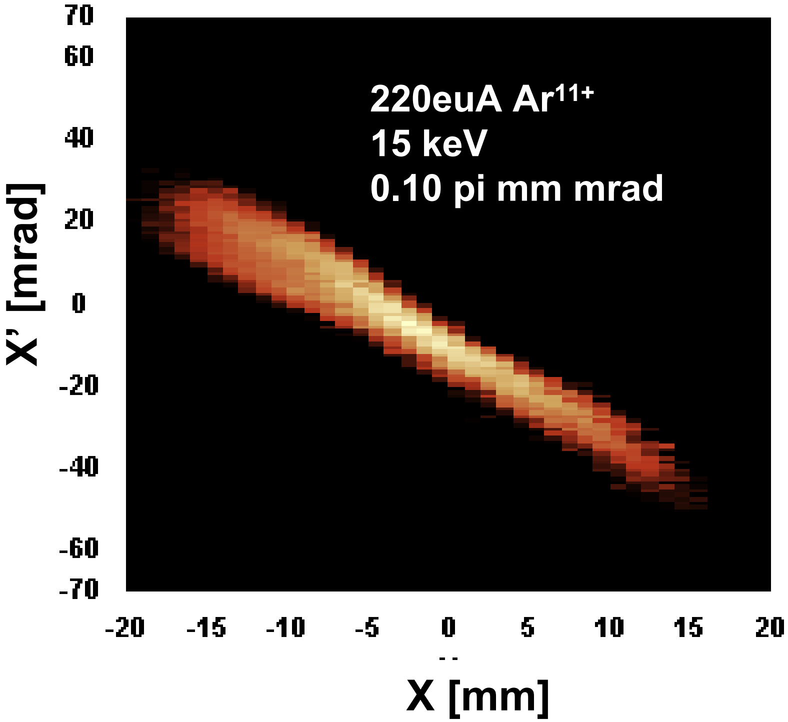
M. Leitner *et al*: "*Design of the Extraction System and Beamline of the Superconducting ECR Ion Source VENUS*",Proc. of the 2001 Particle Accelerator Conference (PAC 2001), Chicago, Illinois, June 2001

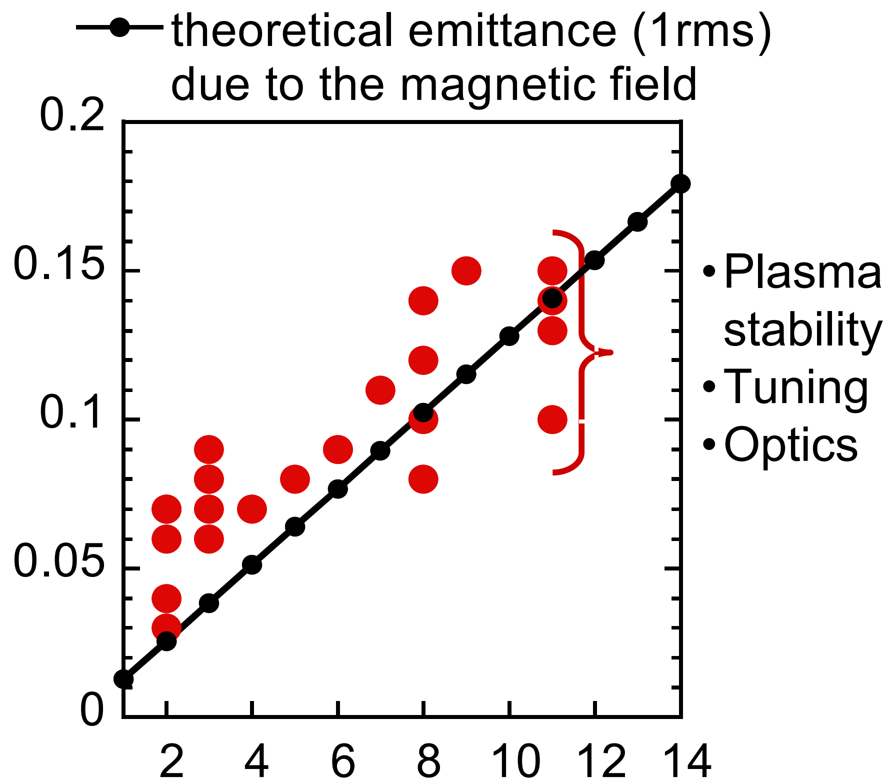
# VENUS Low Energy Beam Transport

***LEBT-Design***
***25 mA proton-equivalent current at 30 kV extraction voltage***



# Emittance Measurements combined with Ion Beam simulations are essential for understanding the ion beam transport for ECR ion source




- Essential for providing very high quality beams as required for precision measurements
- RIA R&D will provide an essential data base for the beam transport

# Experimental requirements are needed for the optimum design of the injector

- Injector system type
  (Power and Space available )
- Intensity needed
- Energy range
- Ion species
- Purity of Ions
- CW or pulsed
- Timing (chopping)
- Beam quality
  - Beam Noise
  - Stability
  - Spot size

?

→

**High Intensity single charge Ion Source**

Maybe required for some low cross section experiments

**High charge state ECR**

Conventional/permanent magnet

Charge state can vary to change energy

Charge state selection

**Beam transport**

# Conclusion and areas for R&D

- **ECR sources are ideal sources for an underground accelerator**
  - Demonstrated performance record on accelerator
  - High Reliability and Flexibility
  - Have to decide which kind of ECR is best suited (depends mainly on intensity required)
- **R&D (simulations and experiments) for the ECR ion beam transport would be beneficial**
  - To assure very high quality beams
  - Build injector system to measure beam parameter
  - overlap with RIA R&D