
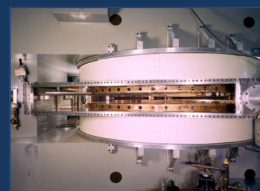

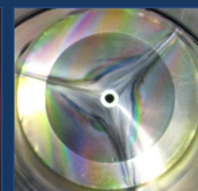
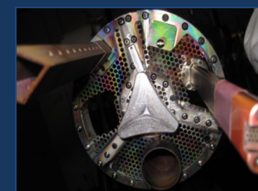
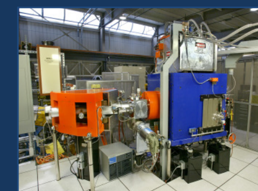

ECR Ion Source Operations

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Lawrence Berkeley National Lab

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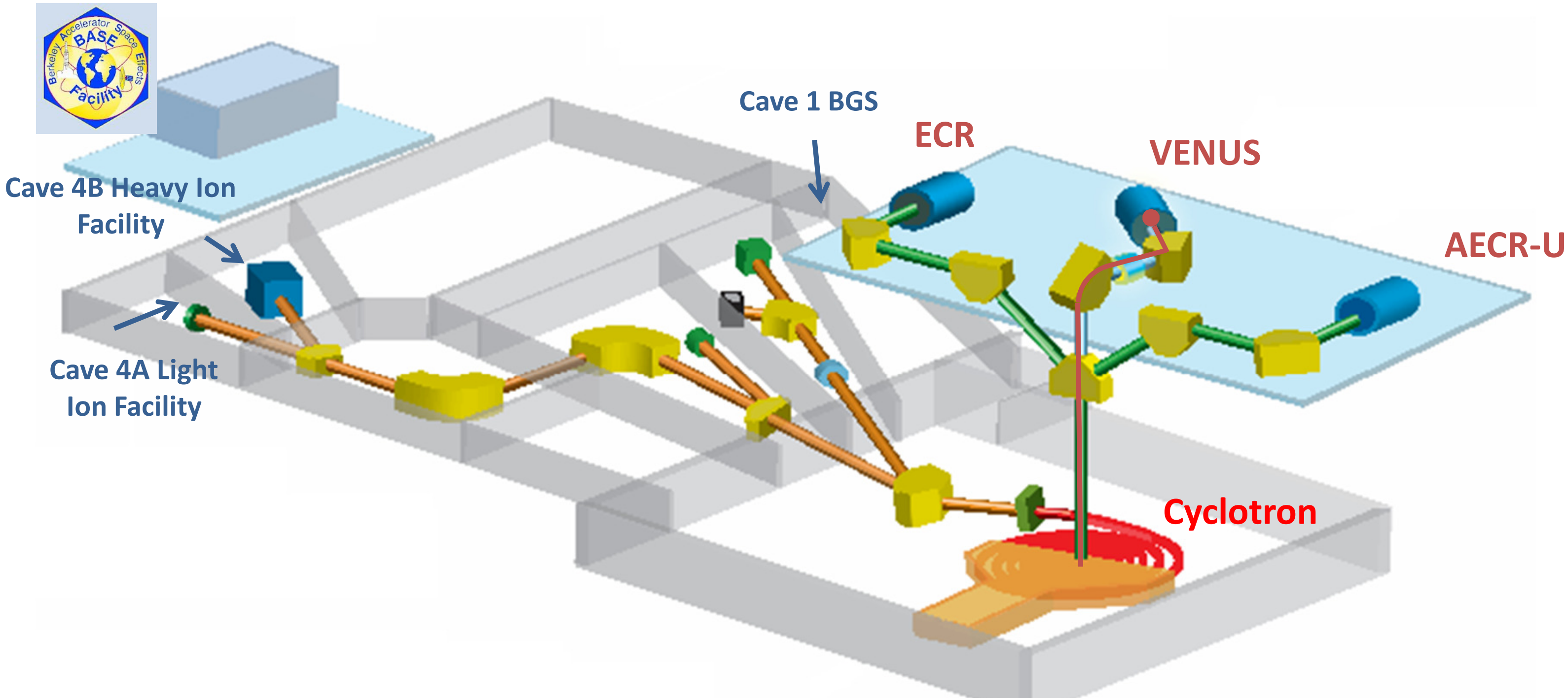
Outline

1. 88-Inch Facility Layout
2. Intro to ECRs
3. Cocktail Beams
4. Availability & Reliability
5. Resources to Support Chip Testing and SHE

AECR-U aluminum
plasma chamber

Cyclotron Facility Layout

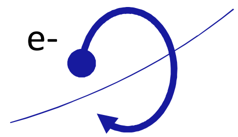
The 88-Inch Cyclotron is fed by three ECR ion sources: ECR, AECR-U, and VENUS.



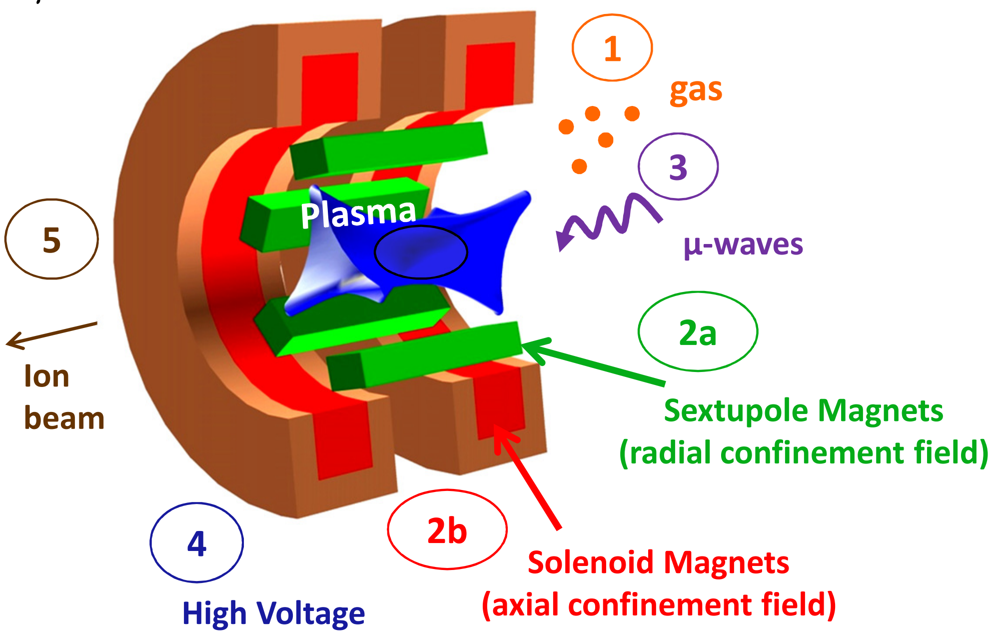
ECR Ion Source Physics

ECR: Electron Cyclotron Resonance

$$\frac{e \cdot B_{ECR}}{m_e} = \omega_{\mu-wave}$$



$$\omega_{\mu-wave} = 28GHz \rightarrow B_{ECR} = 1T$$



Key Ingredients

1 gas
\+
2a radial field
\+
2b axial field
\+
3 µ-waves
\+
4 High Voltage
=
5 Ion beam

ECR's at the 88-Inch

ECR
1983

Max B-Field: 0.4T

Frequencies: 6.4GHz

Max Power: 0.6kW

AECR-U
1996

Max B-Field: 1.7T

Frequencies: 10, 14GHz

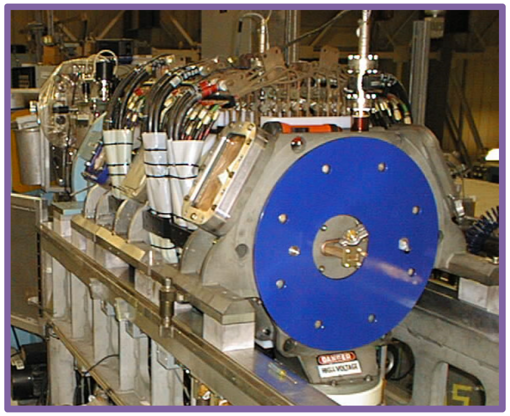
Max Power: 2.6kW

VENUS
2004, 2008 for operations

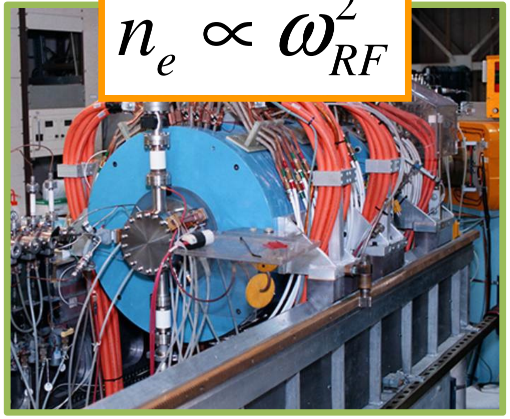
Max B-Field: 4.0T
(superconducting)

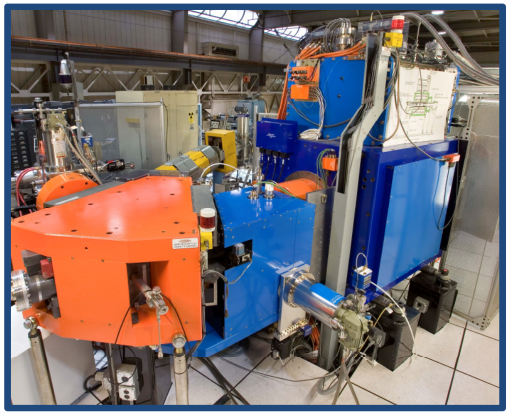
Frequencies: 18, 28GHz

Max Power: 12kW



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





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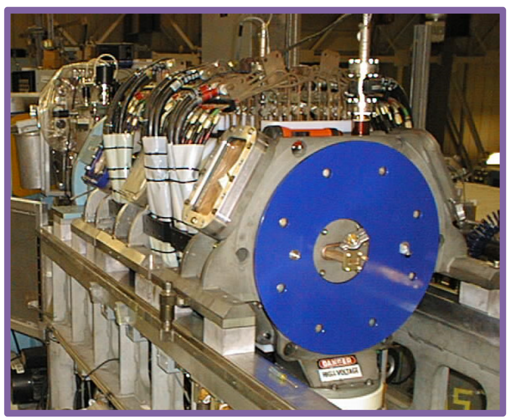
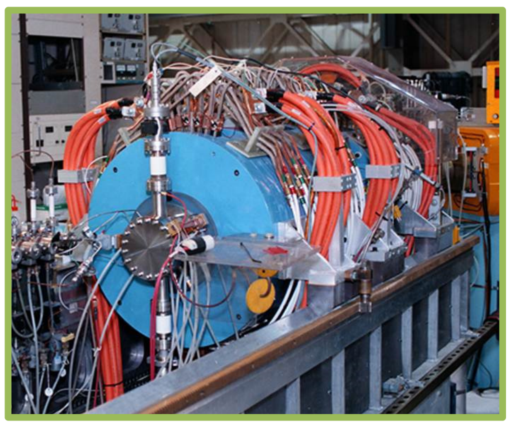
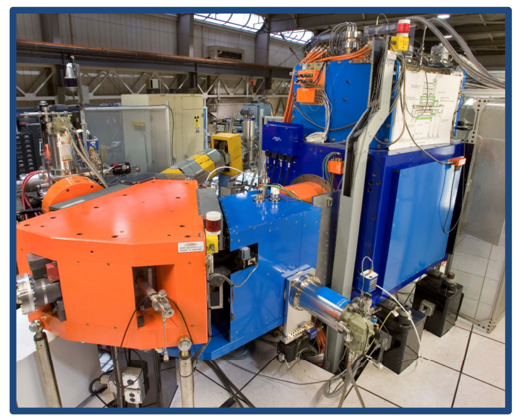
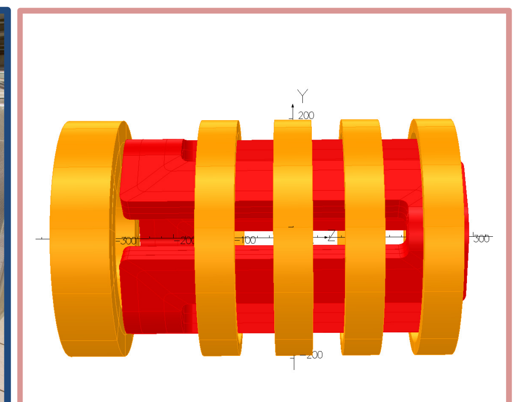
MARS

(Dan's Talk)







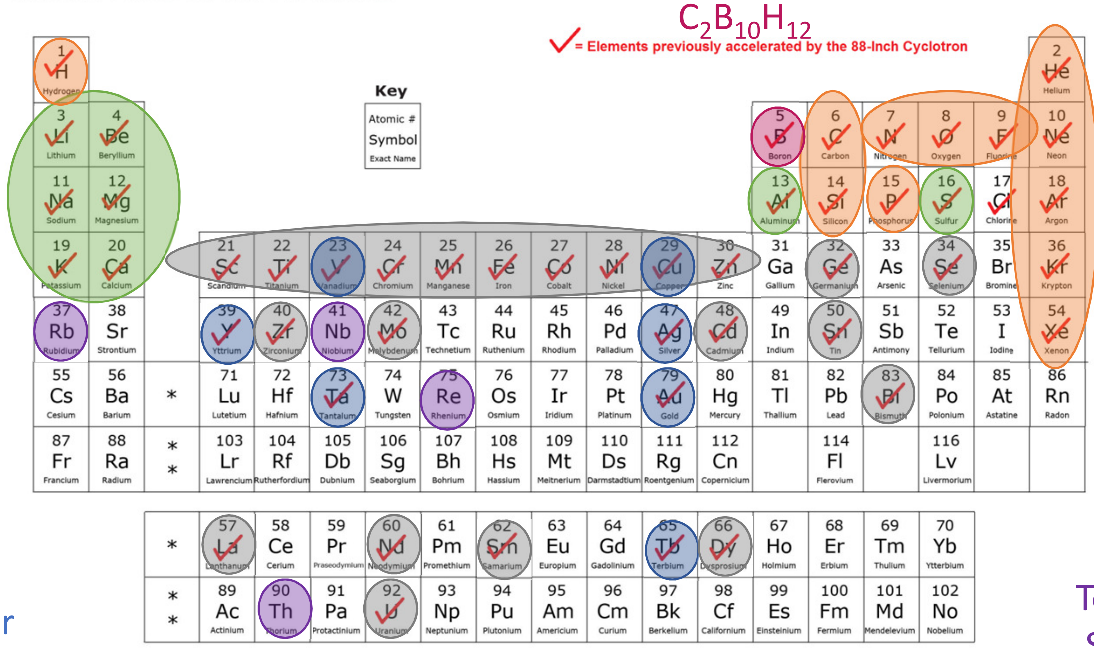


Beams Produced/Accelerated

MIVOC: Metal Ions from Volatile Compounds

$C_2B_{10}H_{12}$

Periodic Table of the Elements



Low Temperature Oven <800°C

High Temperature Oven <2200°C

Sputter Probe

Gas, Gaseous compounds

With the right tool we can produce any beam.

Tested in Ion Source/Not Accelerated

What Makes a Good ECR Source?

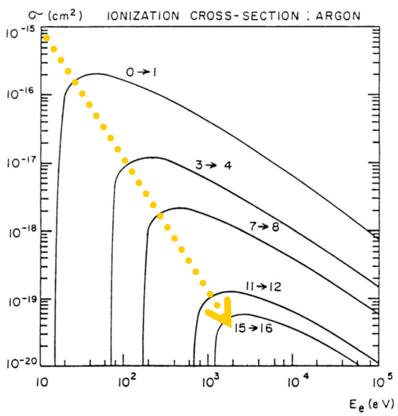
Cocktails and Chip Testing

Require hot electrons to reach high charge states

σ for producing high charge state is orders of magnitude lower

VENUS produces $^{124}Xe^{43+}$ for users!

For Z=54, to reach a Xe^{+43} charge state requires ~$5x10^3$eV electrons!



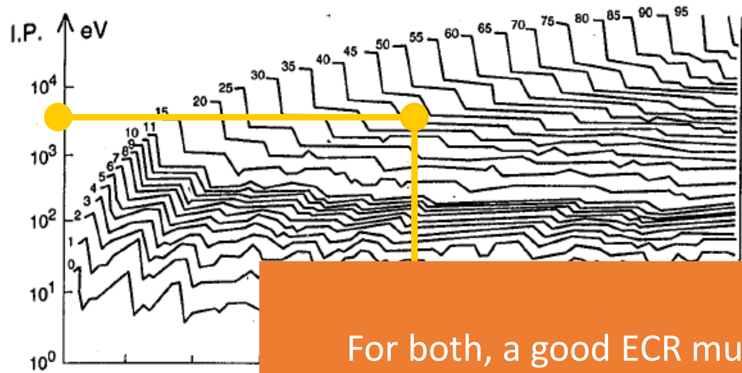


Figure: Carlson

For both, a good ECR must be followed by a good accelerator!

Super Heavy Elements

★ Stable beam production
Good source conditions

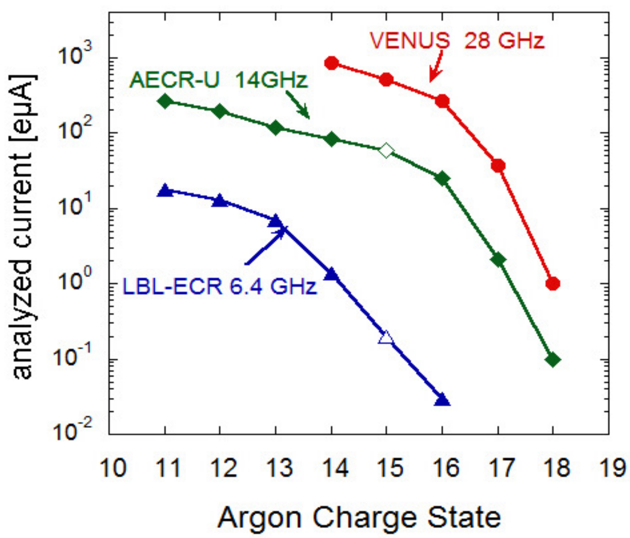
★ Long term beam production
Good oven technology
Low consumption of metals

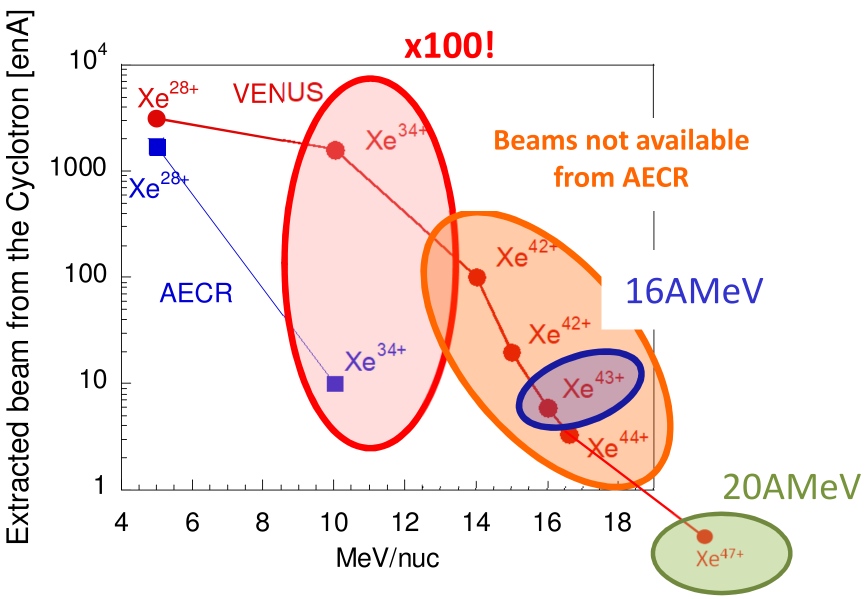
★ High intensity beams
density ∝ heating freqency²

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

VENUS ECR Ion Source

- Currently one of the most powerful ECR ion sources in the world
- Exploring limits of ECR ion sources through **R&D**





Cocktail Beams Development

Development of new cocktail ions using VENUS to increase LET and range underway

$^{124}Xe^{43+}$ in 16MeV cocktail: extends LET from 25 to 50MeV/(mg/cm^2)→ now regularly used

$^{197}Au^{52+}$ in 10MeV cocktail: extends LET from 59 to 86MeV/(mg/cm^2)→ now regularly used

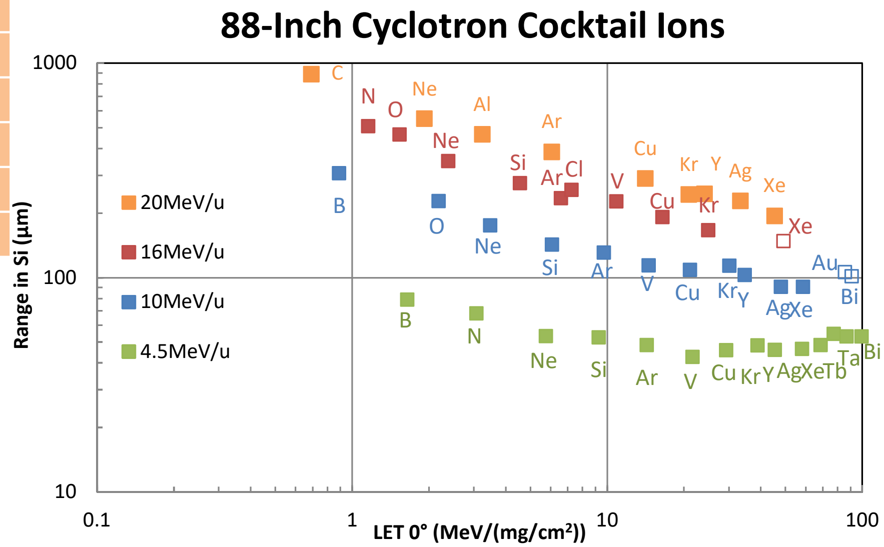
$^{124}Xe^{47+}$ in 20MeV cocktail: also now regularly used!

20MeV/u	M/Q	Production Method	LET (MeV/(mg/cm^2))	RANGE (µm)
$^{20}Ne^{8+}$ ✓	2.50	GAS	1.92	548.5
$^{27}Al^{11+}$ ✓	2.45	GAS	3.25	463.9
$^{78}Kr^{32+}$ ✓	2.44	GAS	20.9	243.3
$^{89}Y^{36+}$	2.47	Sputter Probe	24.2	244.9
$^{109}Ag^{44+}$	2.48	Sputter Probe	33.3	226.8
$^{124}Xe^{47+}$ ✓	2.64	GAS	45.4	193.8

Why the need for 20MeV/u cocktail?

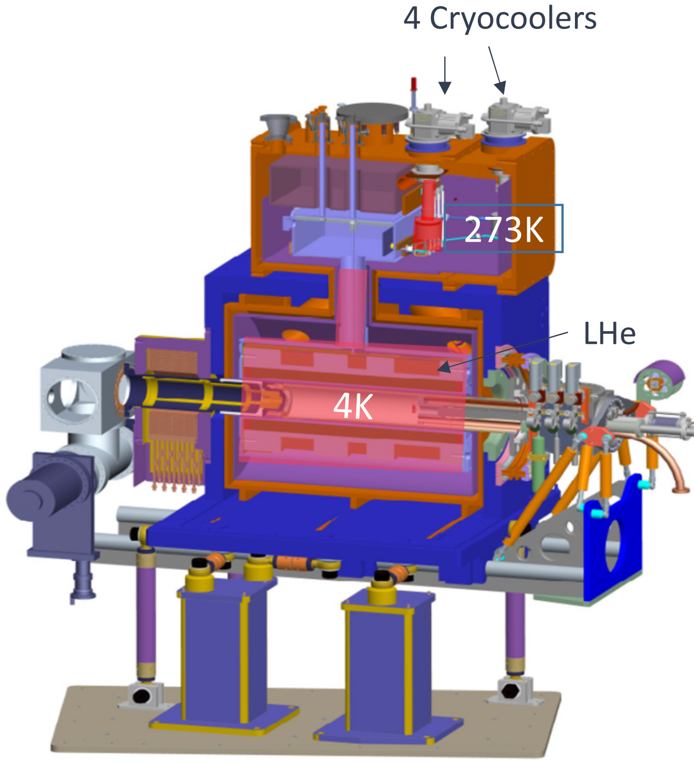
- increasing beam energy allows for deeper penetration into parts
- Layers on chips are increasing in thickness

Development for higher energy beams to use for testing in air if this is requested…ex: 25MeV/u $^{78}Kr^{34+}$



ECR Ion Source Reliability & Availability

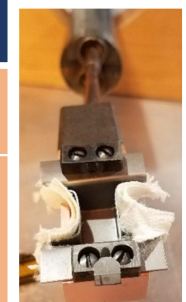
Reliability	Fail time due to ECRs since 2/2/2017 is 13.5 hrs! However, this doesn't mean all ions were always available! AECR-U & VENUS not one-to-one replacements for each other.
Availability	VENUS availability for beam delivery increased: Cryostat Modification Implemented in 2017 and tested successfully in 2019. Additional heaters reduced cryocooler maintenance from ~8 weeks to 1 week! However, beam development time decreased! Shutdown development time is hampered by LCW outages No cyclotron available during shutdowns

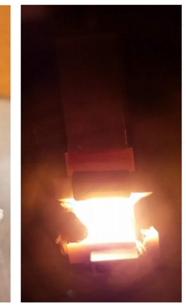


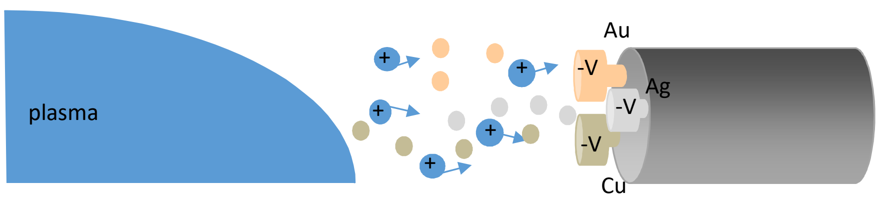
Mitigating Risks

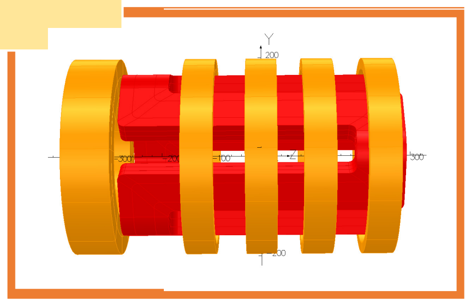
Increase reliability for cocktails	
Failure & Consequence	**Solution**
AECR Failure: No sputter probe metals (Ag, Y, Ta, Cu, Tb, Si, V)	Sputter probe with multiple metals at VENUS
VENUS Failure: No high charge state Au, Xe, Kr	Backup to VENUS: 3rd/4th generation ion source
VENUS high intensity runs: Difficult to run high charge state cocktails after	Backup to VENUS: 3rd/4th generation ion source

Increase reliability for SHE	
Failure & Consequence	**Solution**
VENUS HiT Oven Failure: unreliable, no spare shaft	Build a spare HiT Oven shaft
VENUS Failure: Low temperature oven run at AECR with liner, lower intensity and higher consumption	Backup to VENUS: 3rd/4th generation ion source





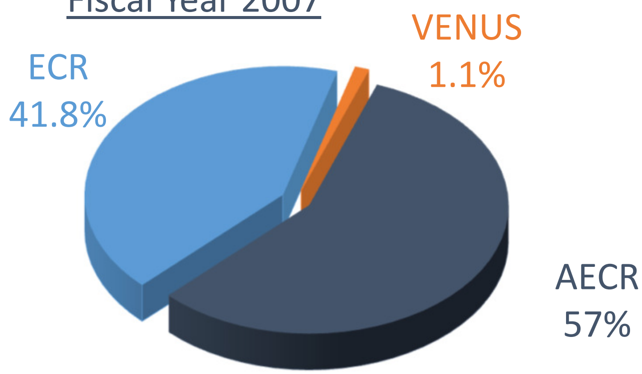




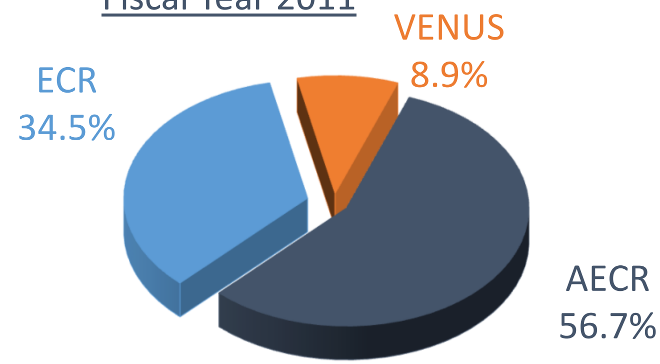
Source Use

Trend is increased need for VENUS beams

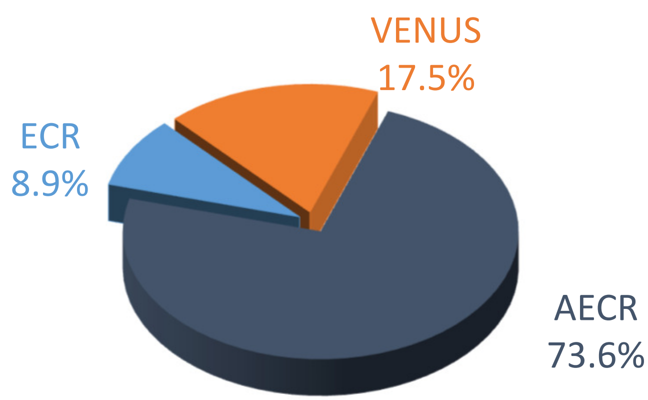
Fiscal Year 2007



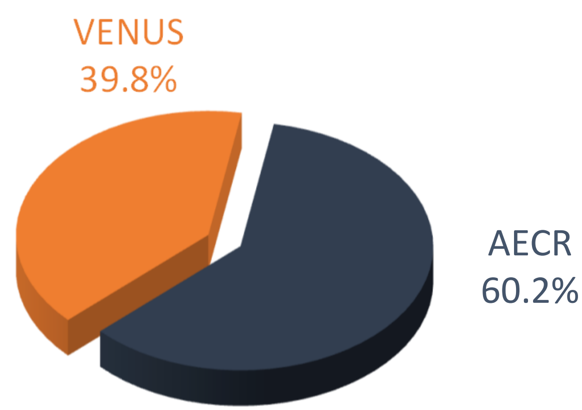
Fiscal Year 2011



Fiscal Year 2012



Fiscal Year 2016



Conclusions

- To fulfill the needs of the chip testing and research communities, development of VENUS continues
- With the regular use of VENUS for beam production we have less time for R&D
- R&D is not only needed to develop 4^{th} generation ECRs but also to develop beams for chip testing and intense beams