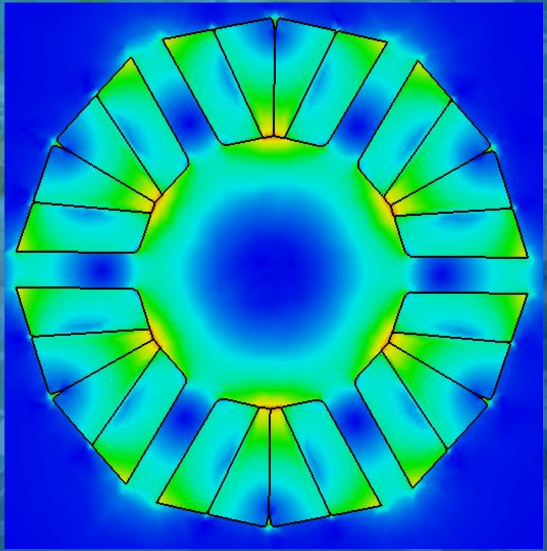
SEPTEMBER 17, 2024

ECR2 PERFORMANCE UPGRADES AT ATLAS



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U.S. DEPARTMENT OF ENERGY
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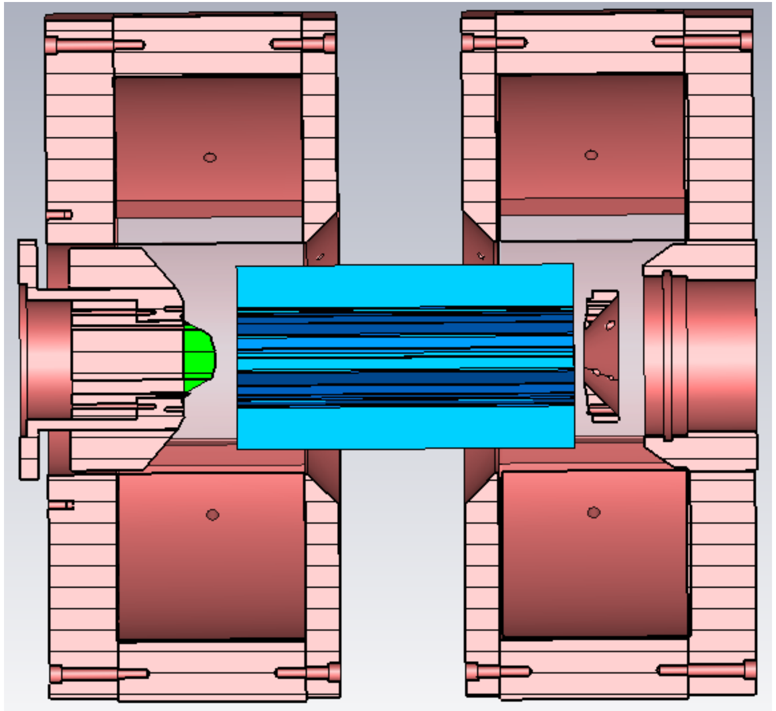
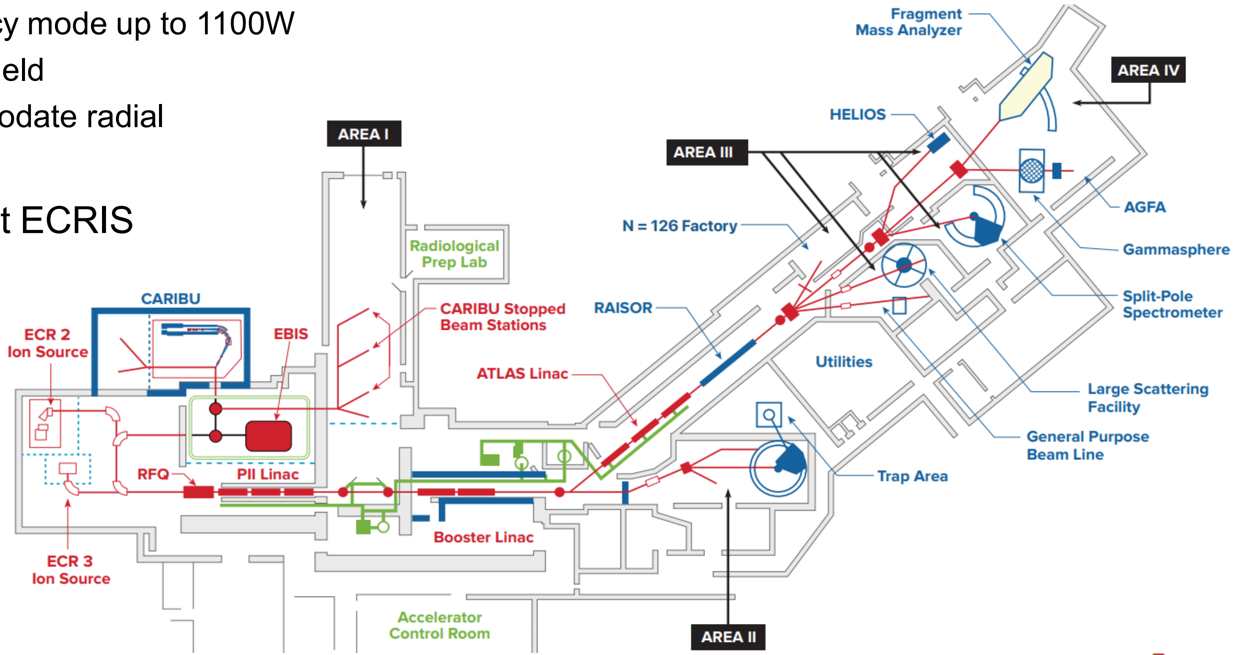
OUTLINE

- History and Current Performance
- Upgrade Motivation
- 18GHz ECR2
- Magnetic Improvements
  - Hexapole Upgrade
  - Axial Field Upgrades
- Plasma Chamber Redesign
- Supporting Hardware Redesign
- Extraction Optics
- Expected Performance



ATLAS ECR ION SOURCES

- The Argonne Tandem Linac Accelerator System (ATLAS) has two ECR ion sources, ECR2 and ECR3.
- ECR2 is a room temperature AECR style ECRIS
  - Typically run in a multiple frequency mode up to 1100W
  - 2 solenoid magnets provide axial field
  - Open hexapole design to accommodate radial material introduction and pumping
- ECR3 is an all-permanent magnet ECRIS
  - Formerly the BIE100
  - Used primarily for 14C and gases
- ECR2 is the workhorse ion source at ATLAS



ECR2 HISTORY AND PERFORMANCE

Are we due for an upgrade?

- Currently running well, but not well enough for the facility requirements moving forward
  - N=126 Factory being commissioned
- ECR2 was originally built in 1997
  - Designed for 10GHz & 14GHz 2-frequency operation
- Hexapole and injection iron upgrade in 2003
  - Raised injection B field to 2.0 T from 1.7 T
  - Raised wall B field to 0.98 T from 0.85 T
    - NdFeB magnet material and design improvements
    - Still fell short of the ideal 1.1T B_{rad} for 14GHz operation
  - Roughly a factor of 2 increase in beam intensities

IMPROVING FACILITY CAPABILITIES

Why upgrade a well functioning source?

- Upcoming ATLAS experimental campaigns require increase in intensity capabilities from ECR2
  - Typically, middle to high charge state requirements
  - Table assumes 60% source to target. 40% is typical.
- Upgrade must retain room temperature designs
  - Improve hexapole design
  - Consider different permanent magnet materials
  - Improve injection iron design
- Optimize 14GHz and support 18GHz operation
  - Most other facilities' 18GHz improvement results are sufficient for our intensity goals

Beam Species	Current Performance	Desired Performance
Ca-48	2puA	2puA
Ti-50	0.9puA	1puA
Xe-136	0.7puA	5puA
U-238	<0.1puA	1puA

SCALING LAWS FOR 18 GHZ ECR2

What needs to change?

- Scaling laws for performance have driven design decisions
  - $I_{peak} \propto f_{RF}^2$
  - $\frac{B_{rad}}{B_{ECR}} = 2$
  - $\frac{B_{inj}}{B_{ECR}} = 4$
  - $V_{ext} \propto I_{tot}^{2/3} \propto f_{RF}^{4/3}$

Frequency	∇B_{ECR}	B_{min}/B_{ECR}
14.5 GHz	5.87	0.695
18 GHz	7.45	0.560

- Must preserve appropriate magnetic gradients at the resonant surface to avoid plasma instabilities
  - ∇B_{ECR} greater than 5.8 T/m and a B_{min}/B_{ECR} less than 0.7
    - Fully adjustable solenoid magnets to dial in fields and stability

HEXAPOLE

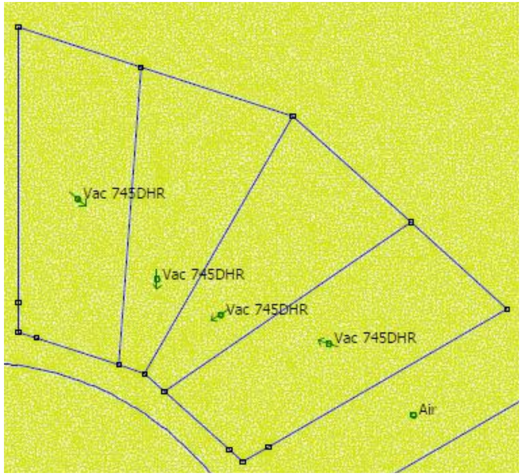
What permanent magnet material?

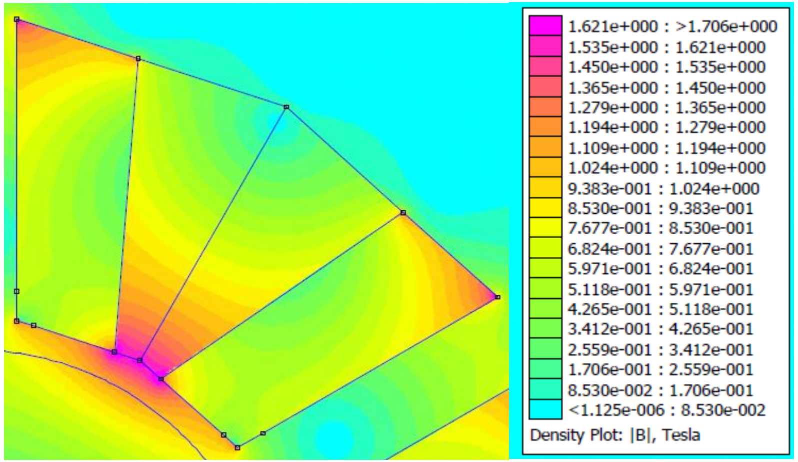
- ECR2 presently uses MCE N5064
- Originally down to two choices
  - Vacodym 745 DHR & MCE N5064
- Main factors for material consideration
  - High H_{cB} (coercivity) for high B field
  - High H_{cJ} (intrinsic coercivity) to resist demagnetization
  - High temperature resistance
- We later found that Vacodym 745 DHR is a surface treatment of Vacodym 745 HR
- How does Vacodym 745 HR perform?
  - Bulk material available
  - Highest coercivity among the materials discussed
  - Consider the DHR treatment if demagnetization is a large concern after simulations

Material	**$H_{cB,min}$ (kA/m)**	**$H_{cJ,min}$ (kA/m)**
Vac 745 DHR (2mm depth)	1046	1631
Vac 745 HR	1065	1115
MCE N5064	1050	1114

MAXIMIZE B_{rad} AND AVOID DEMAGNETIZATION

- Many iterations of magnet shapes and magnetization vectors considered
- Best design utilized 4 segments per magnet bar
- 2D simulations in FEMM resulted in a B_{rad} of 1.22T
- This design was then exported to CST for 3D simulations
  - First without contributions from the solenoid magnets, then with them
  - Finally analyze the demagnetization potential of the magnets

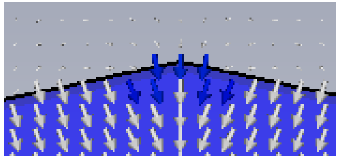


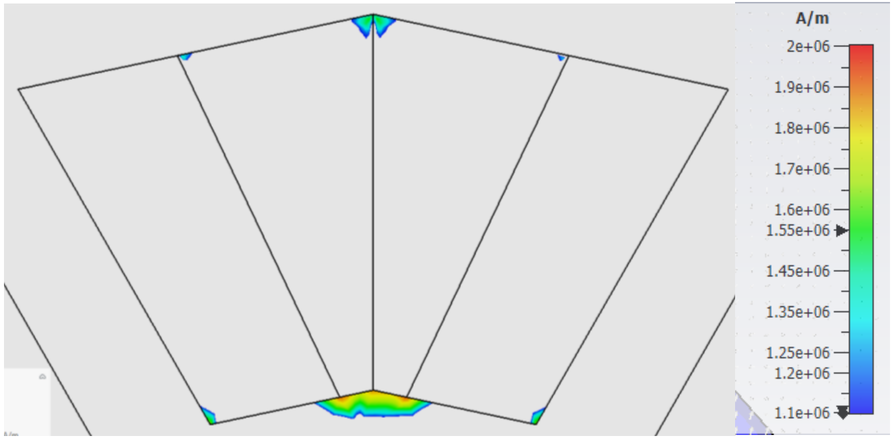


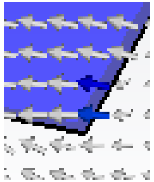
2024 HEXAPOLE

3D *without* solenoid magnet contributions

- B_{rad} = 1.19 T at source midplane
- Running the 3D simulation for the magnet bars without solenoid contributions exposed potential problem areas
  - Color on plot indicates >1100kA/m
  - Arrows show direction of field primarily against magnetization angle
- Next, simulate "effective" geometry with removed demagnetized sections
  - Solenoid H field contributions will only make things worse for demagnetization
    - Cut out expected demagnetized sections of magnet bar
      - Assumed to not contribute to the field



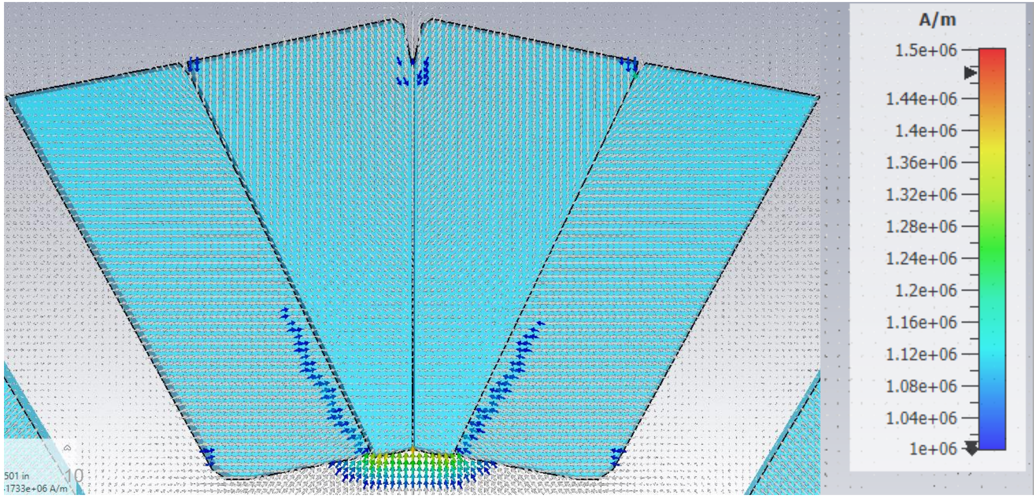




2024 HEXAPOLE

3D *without* solenoid magnet contributions

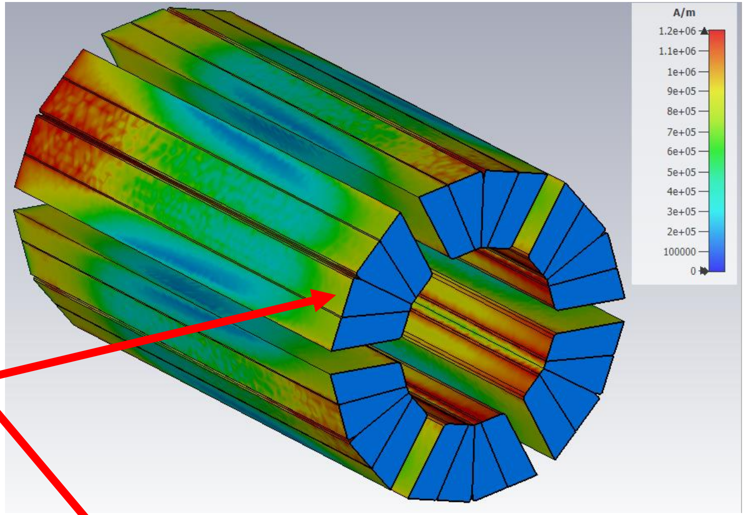
- Second iteration
  - No demagnetization field with chamfers added throughout the problem areas of magnet
- B_{rad} = 1.17 T at source midplane
- Maximum H field less than 1.1E6 A/m
- No need to do additional cut outs
  - Onto the 3D model with solenoid contribution
  - Will confirm with additional simulation that demagnetizing field does not exceed 1.1E6 A/m

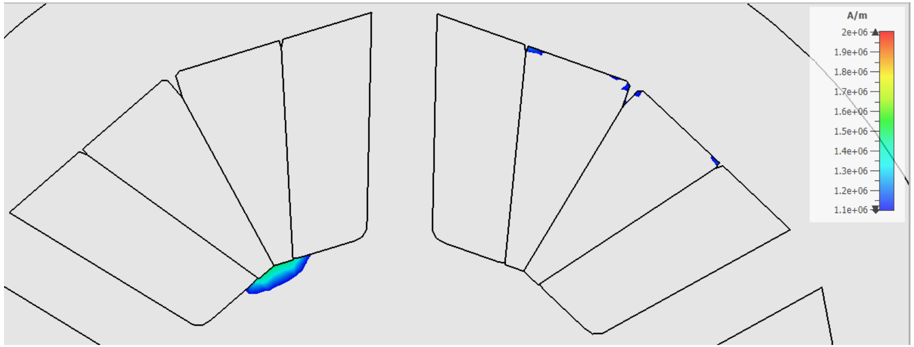


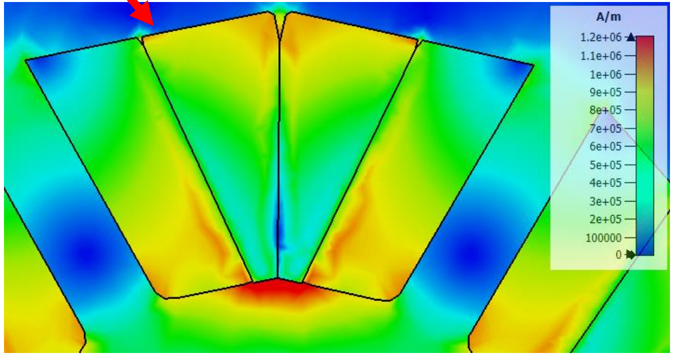
2024 HEXAPOLE

3D with solenoid magnet contributions

- Simulated new hexapole with injection and extraction solenoids at 525A
  - B_{rad} = 1.18T at source midplane
- Took H field slice at max H field axial position
  - Portions of magnet are over 1.1E6 A/m
  - Must look at demagnetization field against magnetization angle

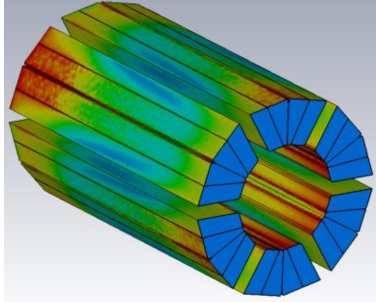




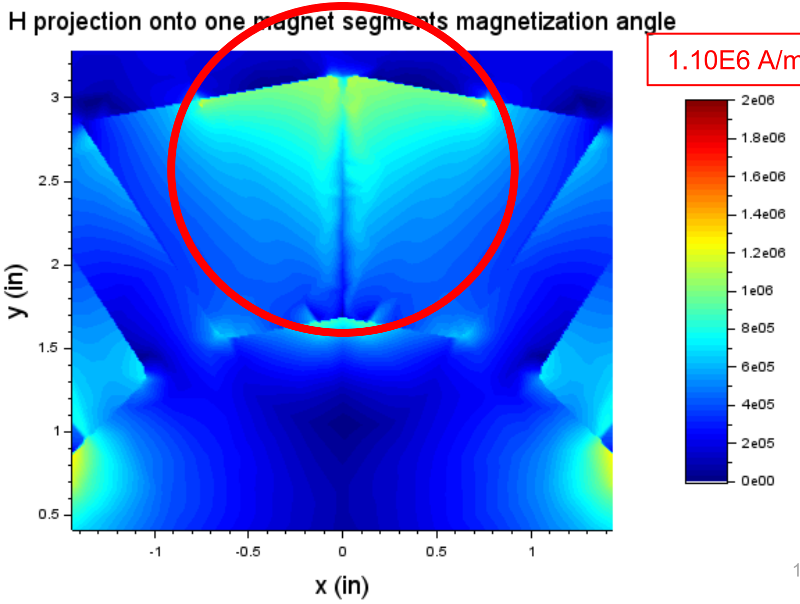


2024 HEXAPOLE

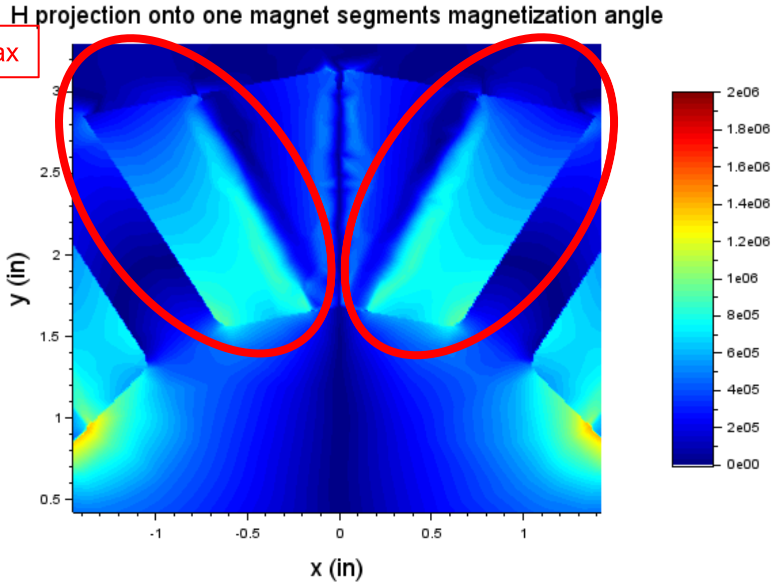
3D with solenoid magnet contributions



- Maximum H field along the demagnetization vector is 1.10E6 A/m
  - — $H_{cJ,min}$ is 1.15E6 A/m
  - — This is under, but barely under, where demagnetization occurs at room temperature
  - — Will carry out the diffusion treatment to give us the temperature and demagnetization capabilities of the 745 DHR in the concerning areas near the surface of the magnet bar



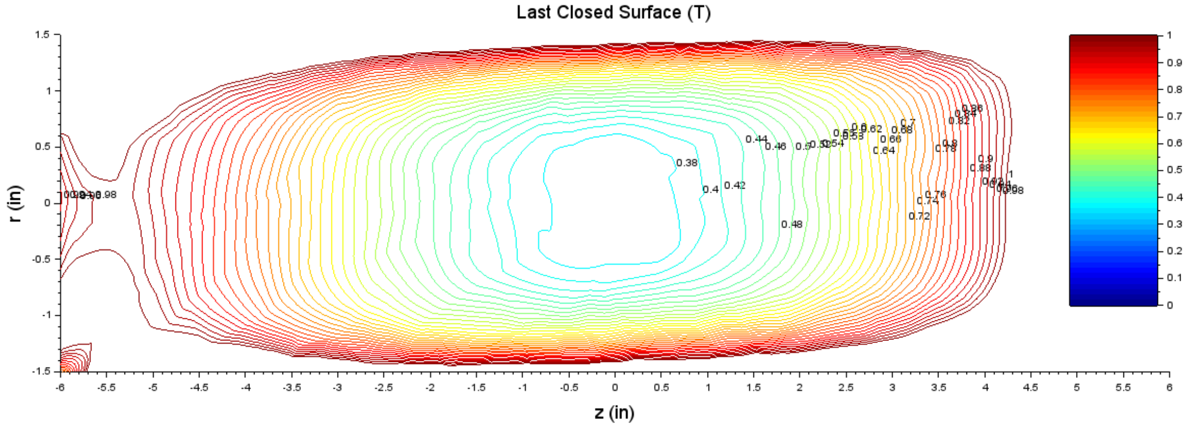
1.10E6 A/m max

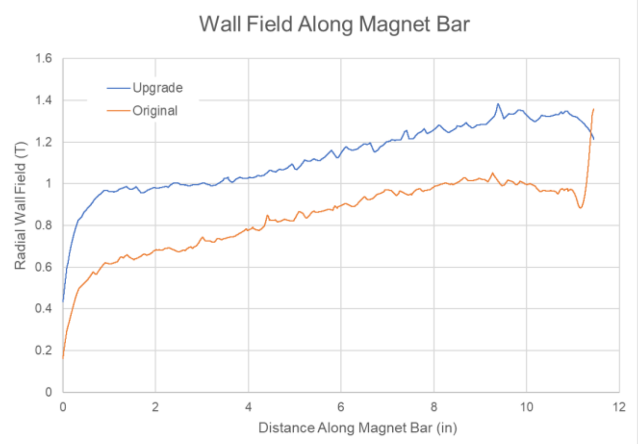


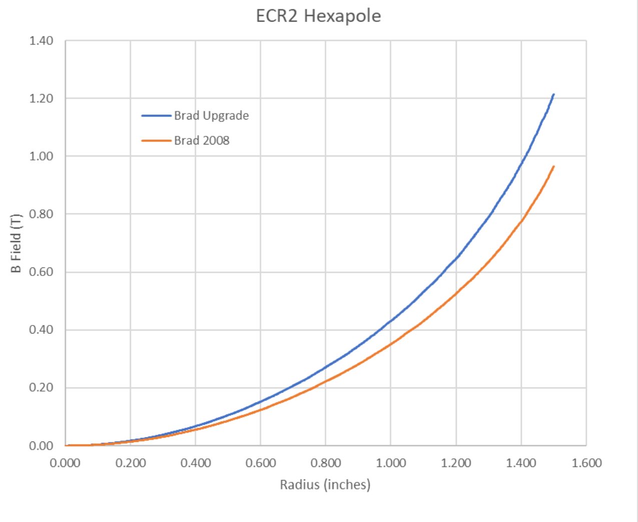
2024 HEXAPOLE

3D with solenoid magnet contributions

- Last closed surface ~1.0T
  - Was 0.85T before upgrade
- Large improvement over current hexapole
- Added bonuses of temperature resistance and demagnetizing field resistance



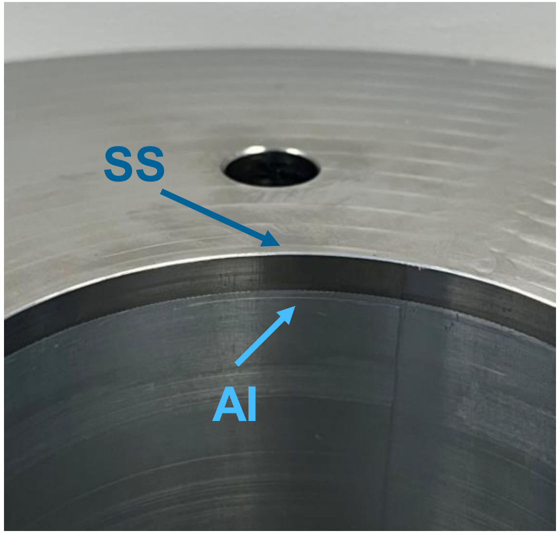




NEW PLASMA CHAMBER

Some old, some new designs incorporated

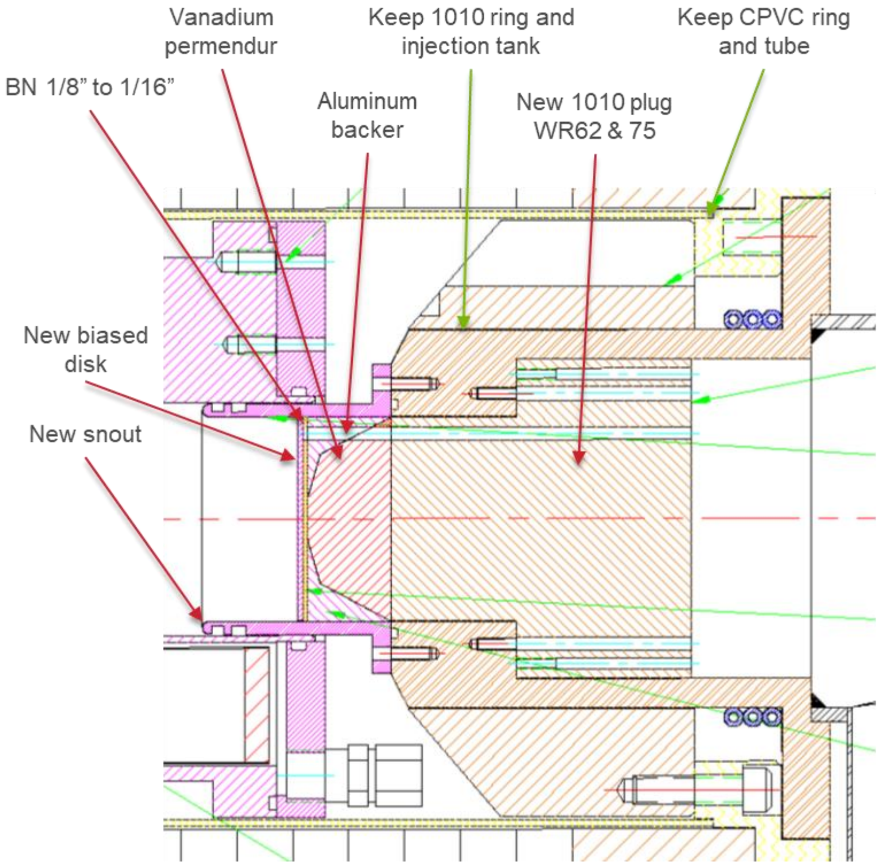
- Expand OD to accommodate new design
  - 0.5-inch increase for larger magnets
- Aluminum and SS bulk material
  - Explosion bonded/welded together
  - Al portion where plasma and heat load are located
  - SS portion where multiple welds are needed
    - SS on extraction side
    - Issue with consistent weld quality when using only aluminum (leaks)
- Cover plate
  - maintain current OD
  - Remove some previously used o-rings and replace them with screws that have integrated o-rings



NEW INJECTION IRON DESIGN

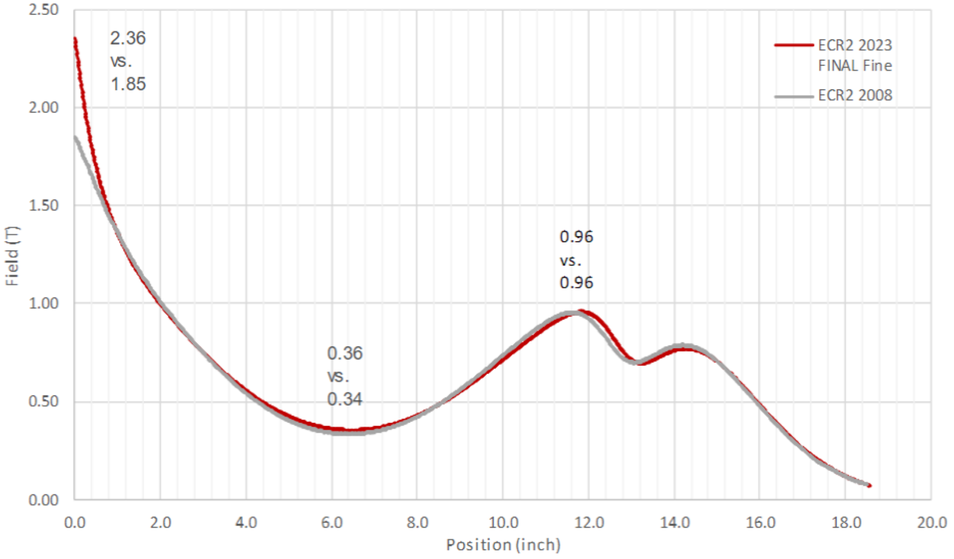
Novel materials help

- Addition of Vanadium Permendur on injection iron
  - Cobalt-iron alloy with small % vanadium
  - High saturation
  - High permeability
- Rework the injection iron for WR62 and WR75 only
- Leaves room for a thinner but still adequate BN insulator between the biased disk and injection iron
- This greatly improves the injection field



SUPPORTING UPGRADES

- Need to revise high voltage insulation throughout
  - Last slide showed injection adjustments
- Requires new extraction electrode
- Requires revision to 1010 steel in extraction region
- Requires higher voltage extraction to support increased intensity
- Requires magnet cooling upgrade
  - New DI water skid
- Must look at ion optics of the immediately downstream low energy beam transport line



ION OPTICS

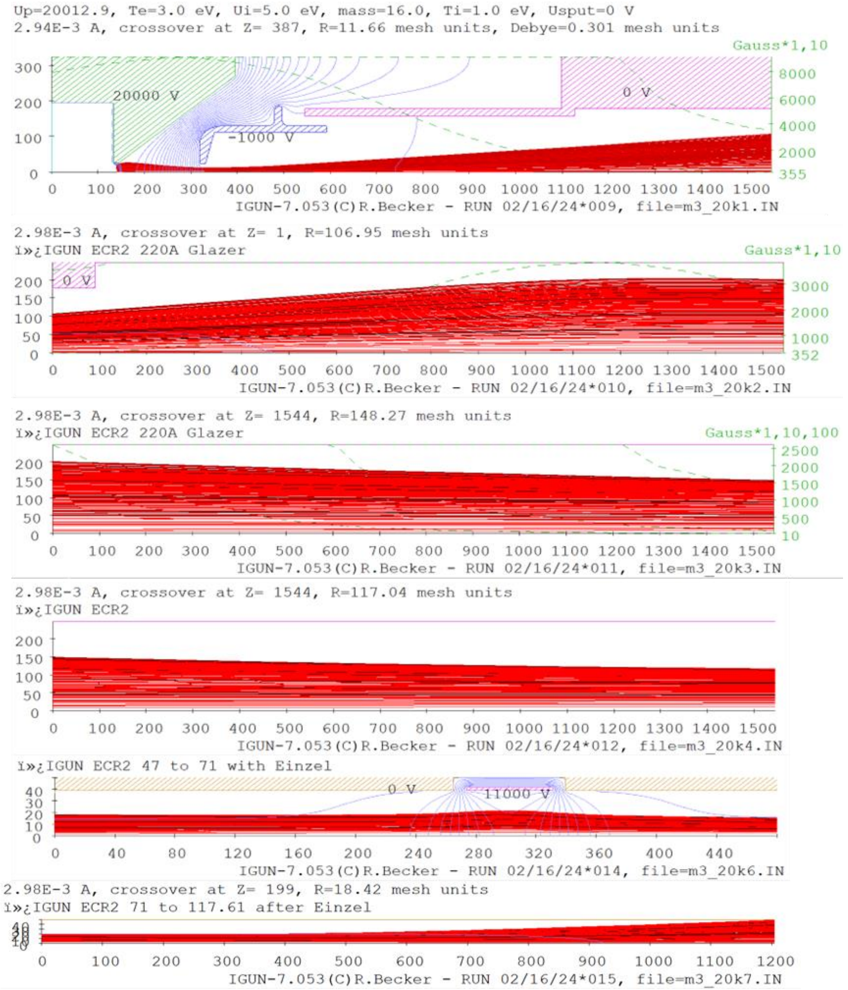
Pre-upgrade conditions

- 14kV Extraction
- 100uA 16/4+
- -1kV Puller
- Solenoids and Glaser contributions
- 100% transmission to faraday cup downstream of analyzing magnet
- This configuration is not sufficient the for increased intensities of the upgrade

ION OPTICS

2024 Upgrade

- 14kV Extraction, 1mA 16/4+
- -1kV Puller
- 525A Solenoids and Glaser contributions
- Added in new einzel lens
  - 81% transmission without einzel lens
- Beam lost after dipole magnet in drift region (space charge effects)
- 100% transmission to FCF101 with new einzel lens before dipole magnet
- Successfully simulated up to 20kV extraction and 3mA at 100% transmission to FCF101



2024 ECR2 SUMMARY & EXPECTATIONS

- ECR2 at ATLAS is due for an upgrade and beam intensity requests are increasing
- An upgrade plan to support 18GHz operation has been established and approved
- A new hexapole was designed and simulated for performance and demagnetization
- A new plasma chamber was designed for the new hexapole magnet bars
- Iron and vanadium permendur components were designed to maximize axial B field
- Ion optics simulations were completed, demonstrating the need of an einzel lens for high intensities

Parameter	Current	Upgrade
B_{inj}	1.85 T	2.44 T
B_{min}	0.34 T	0.36 T
B_{ext}	0.96 T	1.00 T
B_{last}	0.85 T	1.00 T
Coil currents	500 / 500 A	525 / 525 A
B_{rad}	0.96 T	1.18 T
Plasma chamber radius	38.1 mm	38.1 mm
Plasma chamber length	297 mm	297 mm
Hexapole inner radius	42.4 mm	42.4 mm
Hexapole outer radius	74.7 mm	79.7 mm