High Current Beam Extraction from the 88-Inch Cyclotron at LBNL

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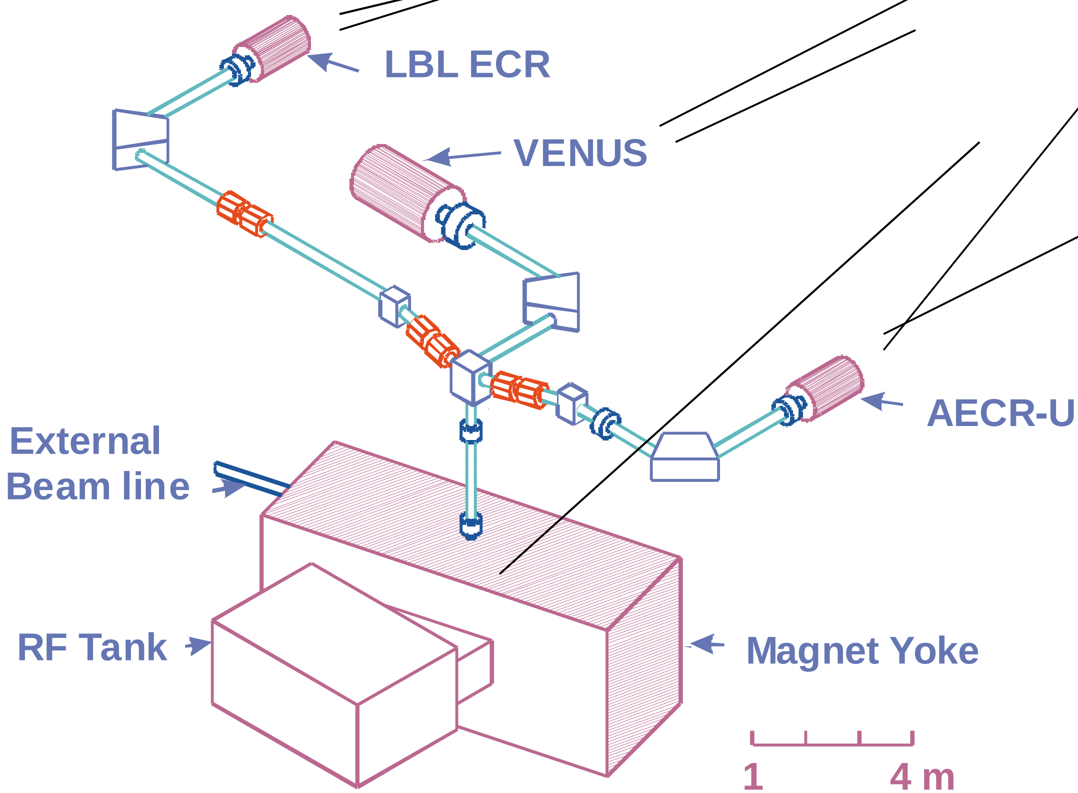
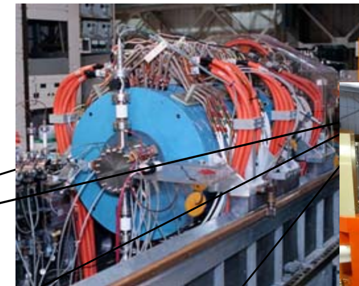
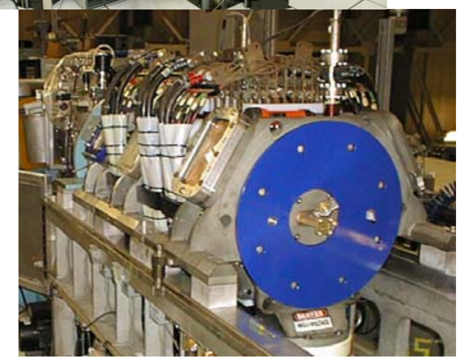
88-Inch Cyclotron at LBNL

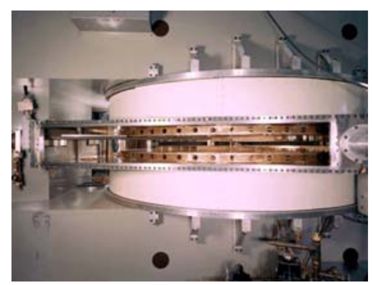
- **Sector-focused Cyclotron**
- **K=140**
- **88 inch, 2.235 m diameter**
- **Species accelerated:**
  protons to uranium

Cyclotron is fed by three Electron Cyclotron Resonance (ECR) Ion Sources









LBL ECR (1983) 1st Generation 6.4 GHz

(1996) 2nd Generation 10+14 GHz

VENUS 3rd Generation 18+28 GHz

Some performance highlights for VENUS

Species	Charge State	Intensity [eμA]
^{4}He	1+	20,000
^{4}He	2+	11,000
^{16}O	6+	3,000
^{40}Ar	11+	860
^{40}Ar	16+	150
^{40}Ca	11+	400
^{40}Ca	12+	400
^{209}Bi	31+	300
^{238}U	33+	450

Species	Charge State	Intensity [eμA]
^{209}Bi	50+	5.3
^{238}U	50+	13

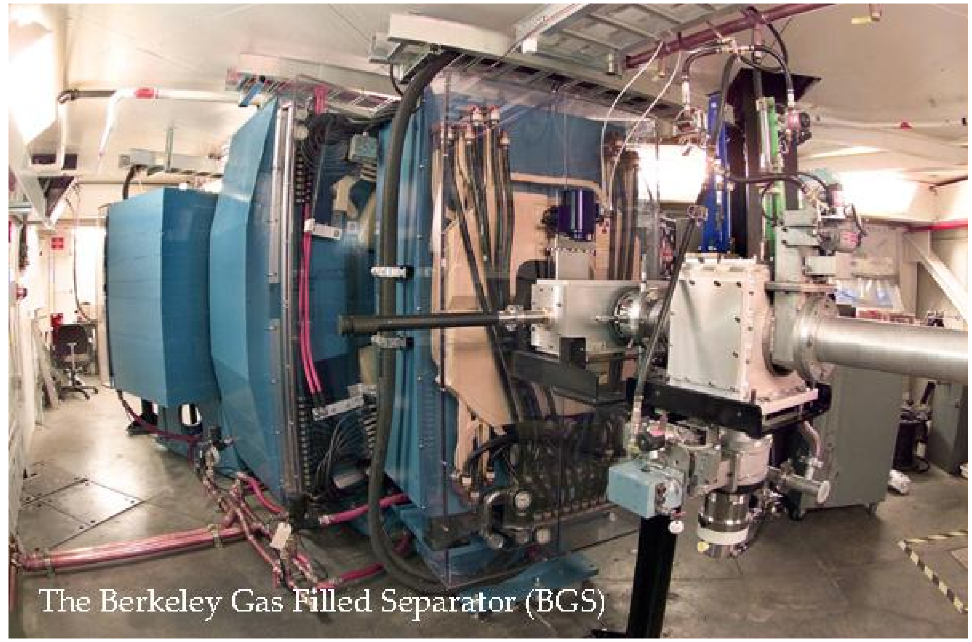
VENUS is a powerful source that can produce both high current beams and highly charged ion beams

Two primary user groups at LBL

Microchip testing for National Security
Space community

Requirements:
- Highly charged ion beams
- Relatively low currents

Examples:
Produced Xe^{43+} and developing Bi^{56+}


The Berkeley Gas Filled Separator (BGS)

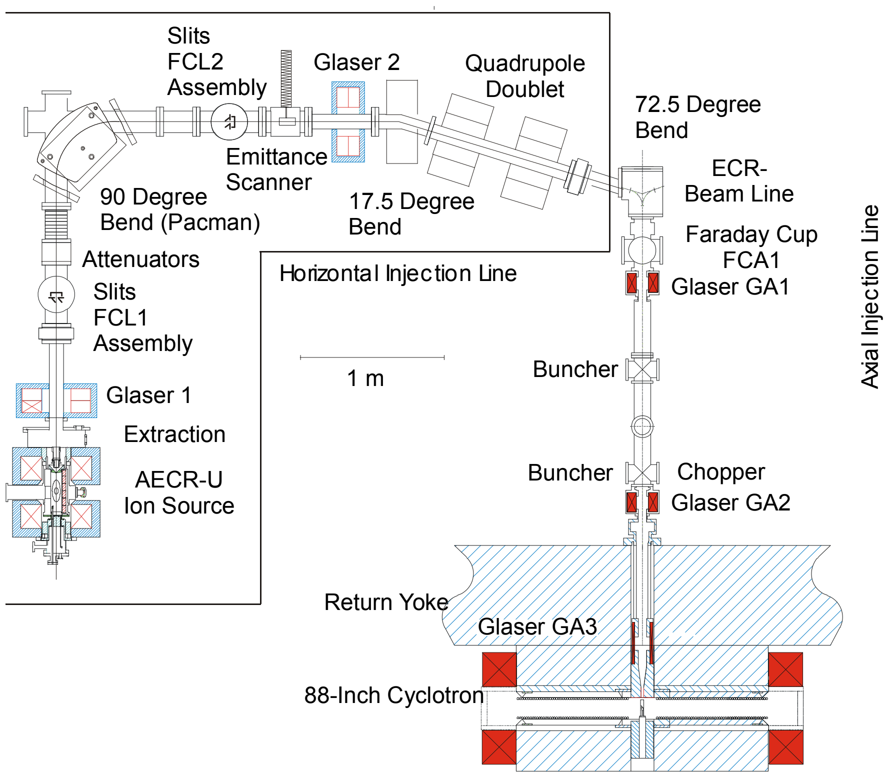
Nuclear Science/Heavy Element Physics community

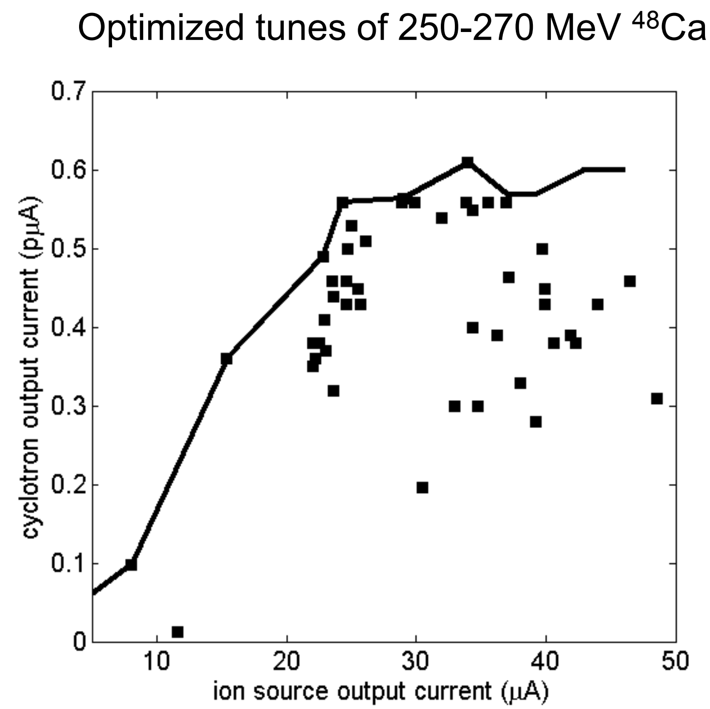
Requirements:
- Medium charged ions (usually)
- High beam currents

Example: 2 pμA, 260 MeV ^{48}Ca

Upgrade of cyclotron concentrated on high current beams for nuclear science; in particular ^{48}Ca

Previous history with ^{48}Ca





- Using AECR-U as source, cyclotron can only deliver about 0.6 pμA
- Increasing source output current doesn't help performance
- Overwhelming majority of losses occur by 13 cm radius in cyclotron

Therefore, focus upgrade on LEBT and cyclotron center region

Improve low energy beam transport

1. AECR-U: careful alignment of extraction system and lens elements

2. Reduce emittance growth due to space charge along beam line by extracting beams from sources at higher voltages

    - VENUS already designed to extract using to 30 kV

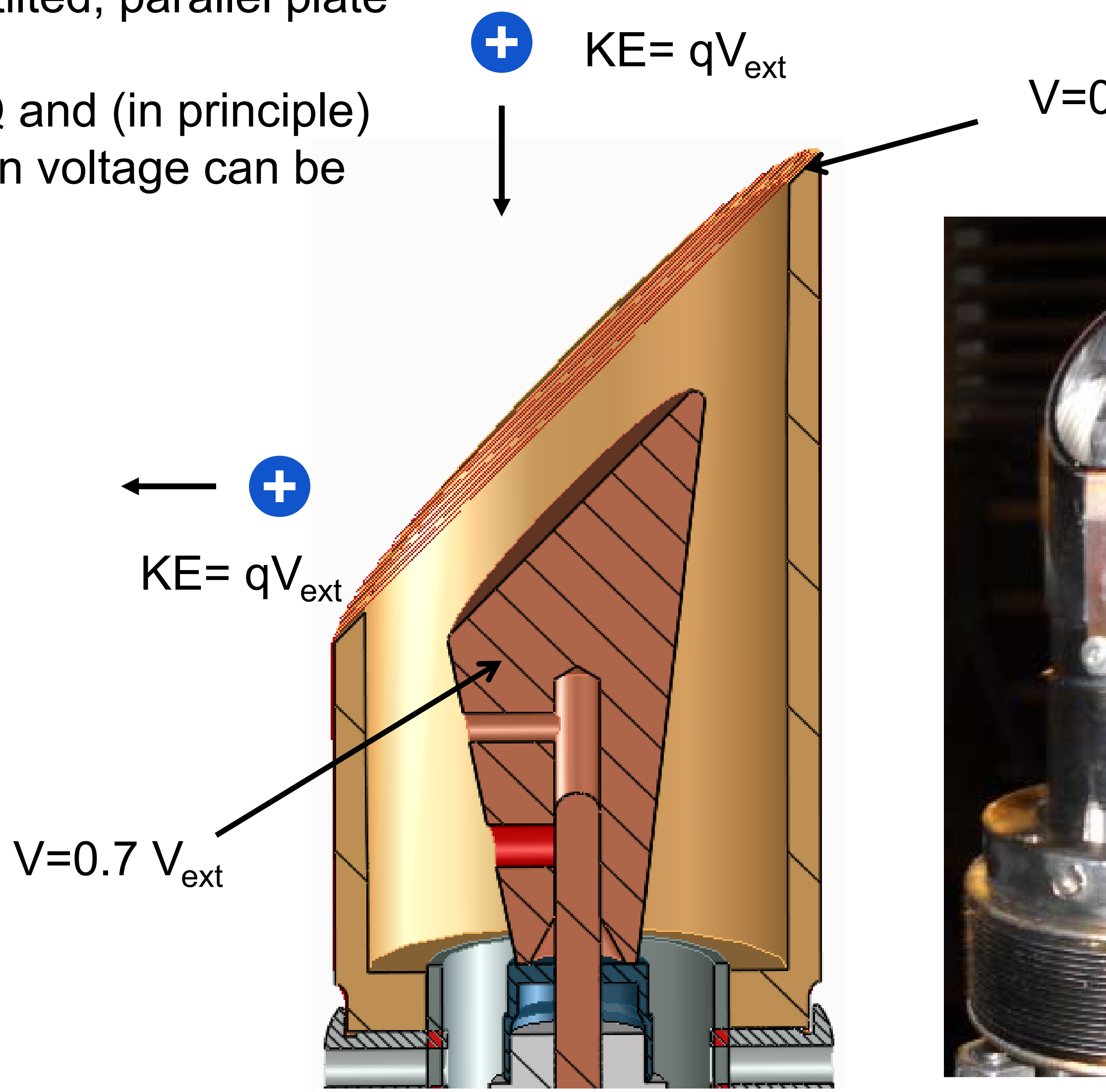
    - Increase insulation on AECR-U to allow for > 25 kV extraction voltages

Improve injection into cyclotron

- Mirror inflector used for injection
- Mirror is basically a tilted, parallel plate capacitor
- Advantage: any M/Q and (in principle) any source extraction voltage can be used

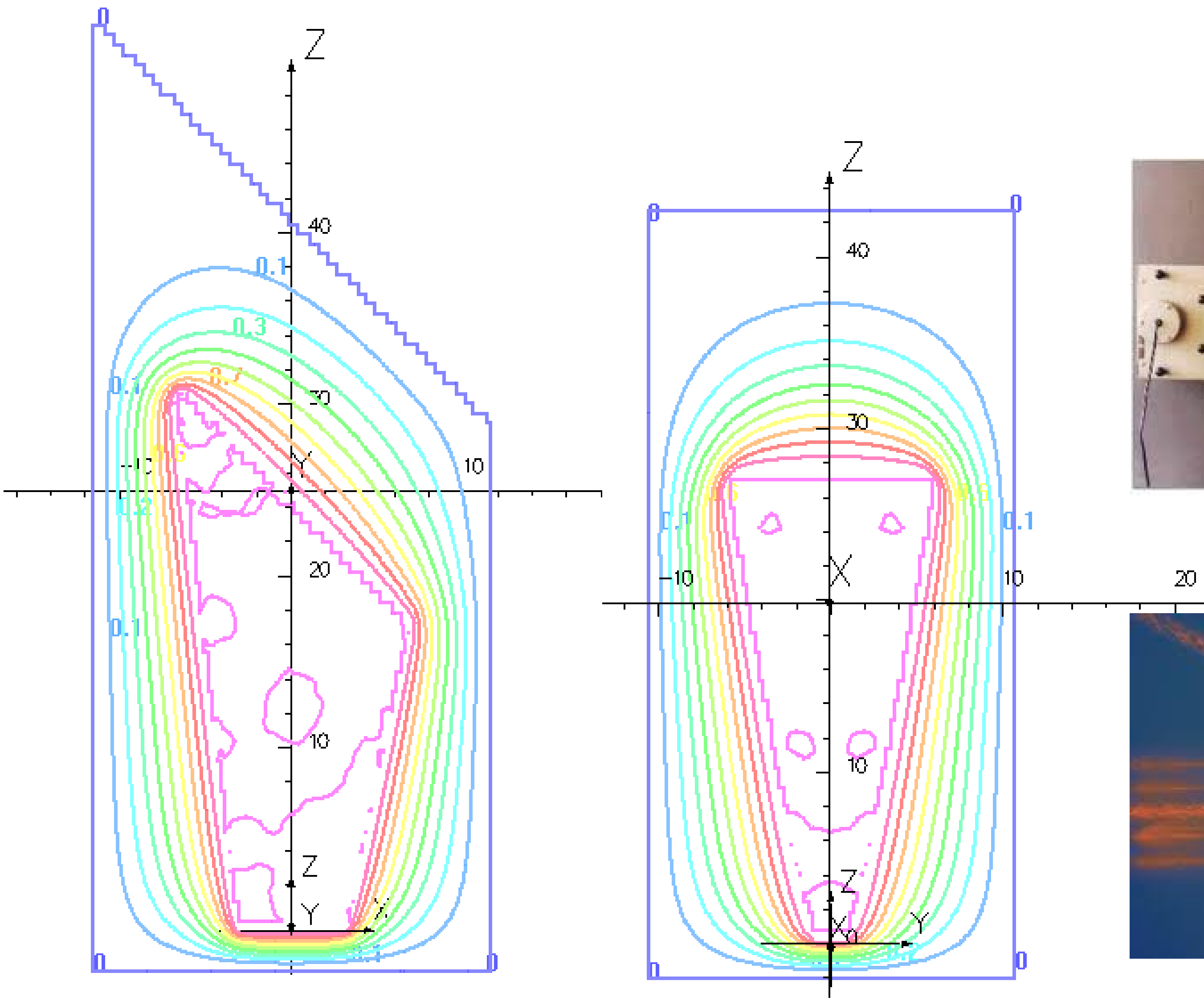
Troubles:

- Breakdowns with high extraction voltages
- Slowing -> space charge effects
- Wires reduce beam current
- Wire failure leads to down time. High current runs require changes up to once a day.

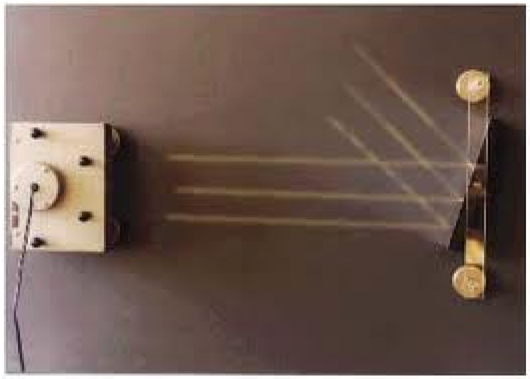


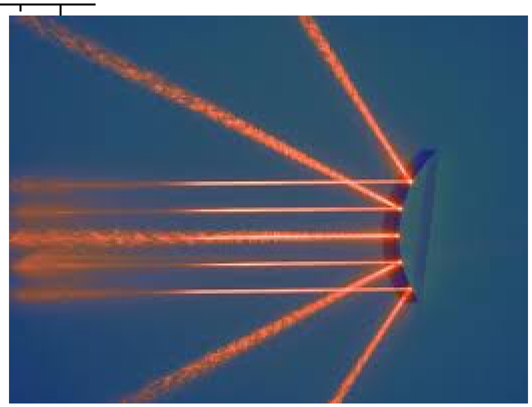
Further trouble with mirror inflector

Mirror inflector does NOT work like a tilted parallel plate capacitor



Potential contours of mirror inflector’s central slices





Spiral inflector

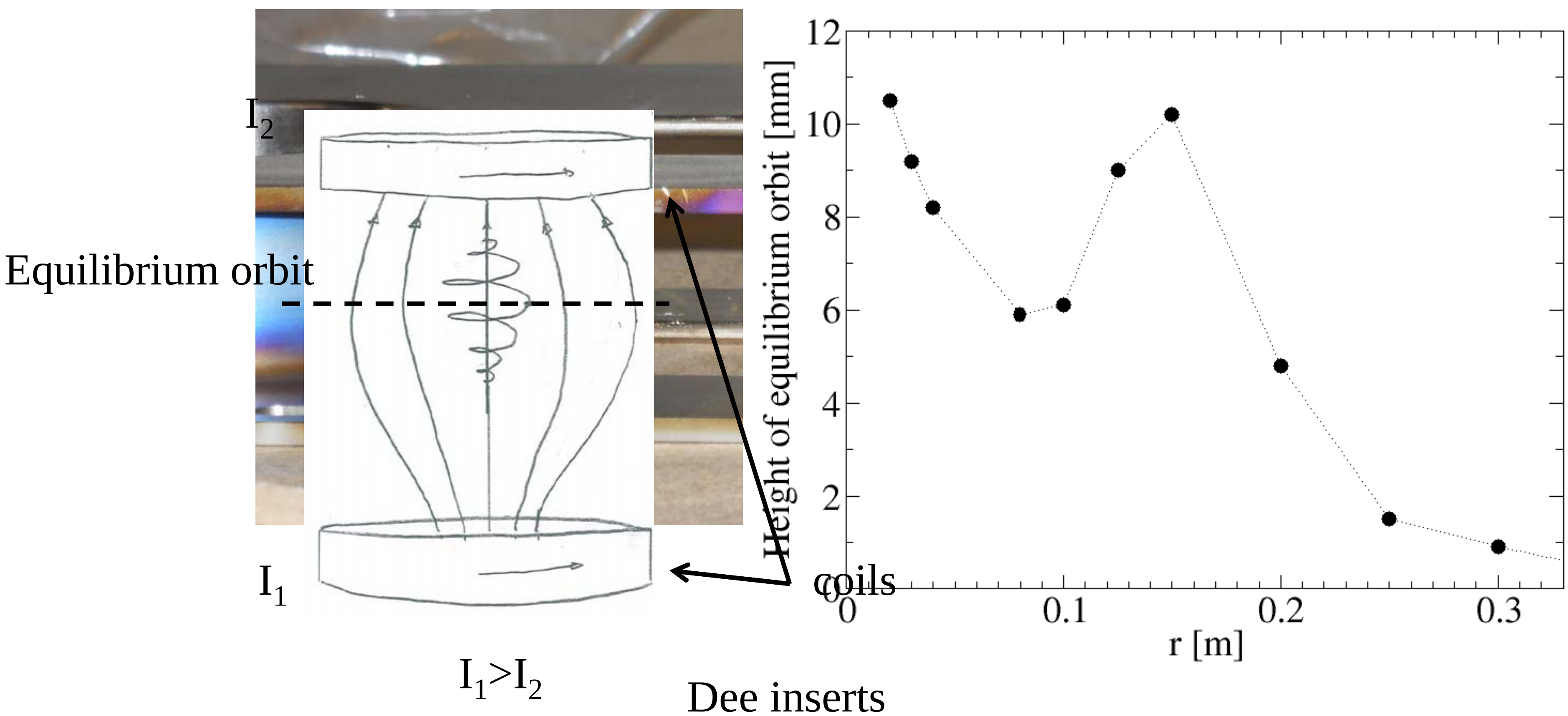
- Advantages: no grids, no slowing, lower required voltages
- Disadvantages: narrow range of energies and M/Q.
  OK, though—typically used for long runs and can be switched with mirror in hours

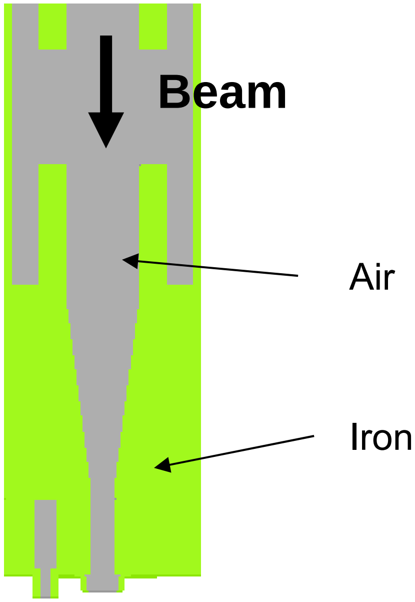
Height (A)	25 mm
Magnetic radius (R_m)	32 mm
Tilt (k')	0
Electrode gap	10 mm
Electric field	2.0 kV/mm

Ken Yoshiki Franzen: TUPPT015

Cyclotron Center Region

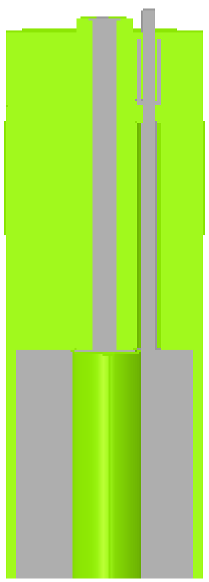
- Beam marks on dee inserts indicate that beams are high in center region
- Scintillator probe confirms this (Markus Strohmeier TU3PB02)
- Particle tracking through field model also shows high beams

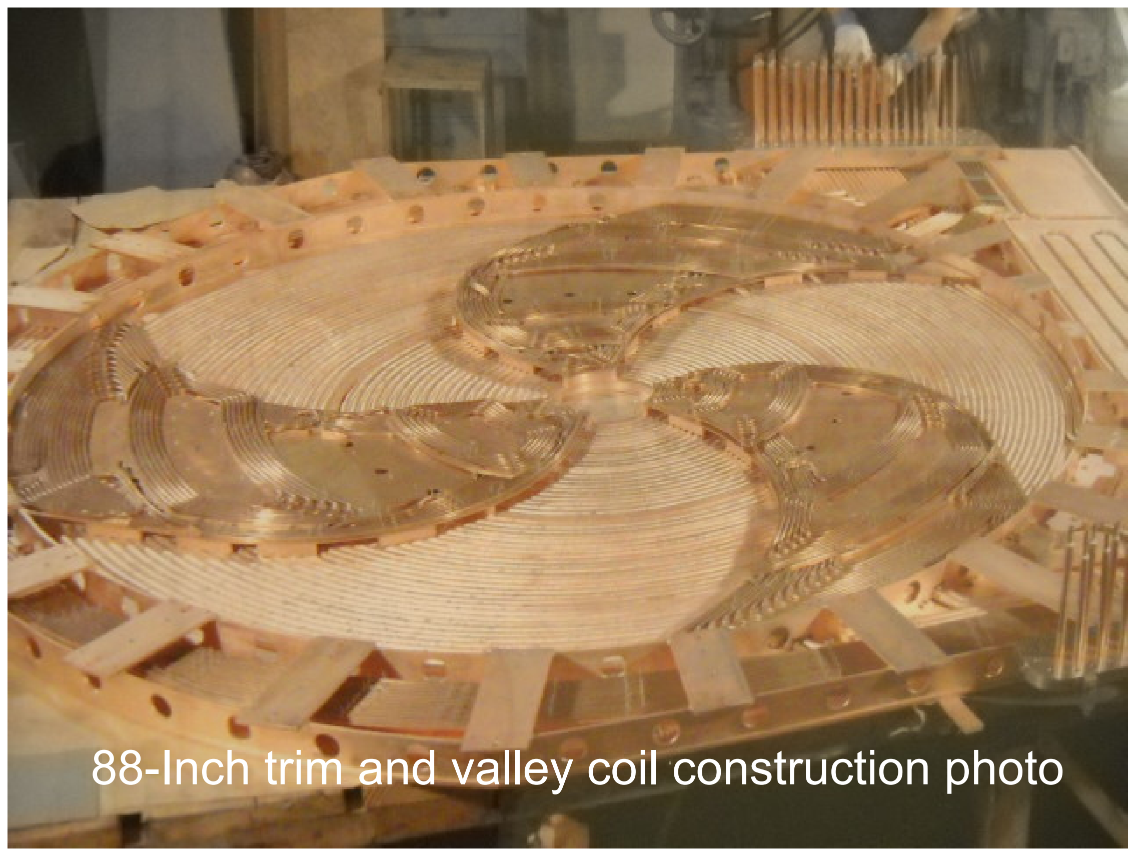




Iron asymmetry leads to higher beams

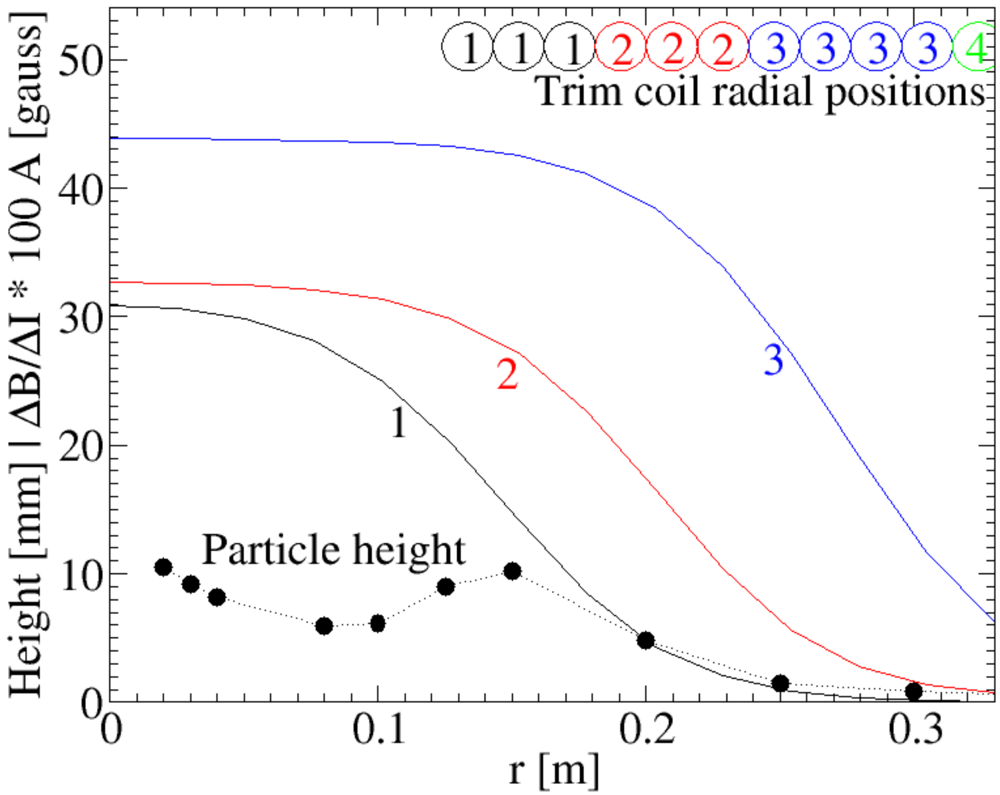
- Magnetic model made it obvious why beams are high; more iron in lower plug
- Best solution: make symmetric plugs
- Next best: reduce field near lower plug via asymmetric trim coils



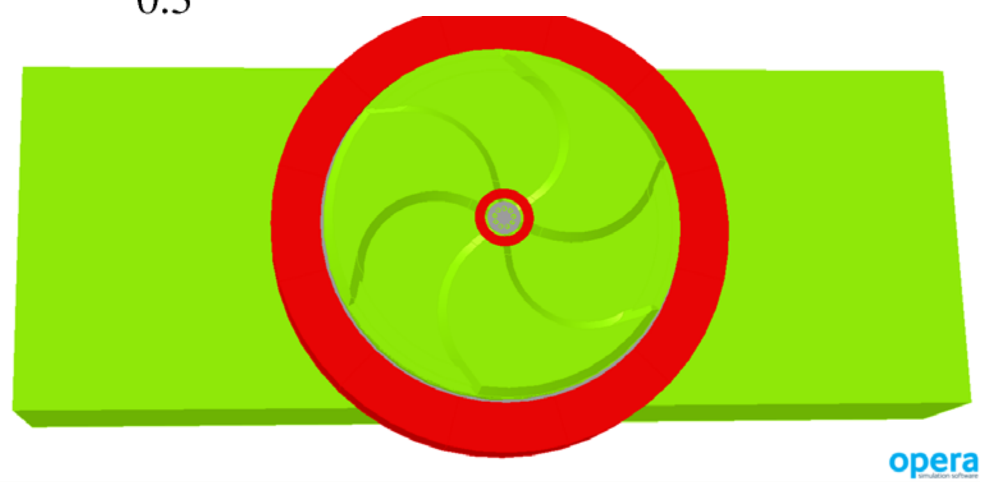


88-Inch trim and valley coil construction photo

Asymmetric trim coil operation



- Trim coil 1 used asymmetrically
- Shunt part of current away to reduce field near lower pole (TUPSH016)
- Increases in beam current of up to 50% through the adjustment of one knob!



Results of 88-Inch Cyclotron Upgrade

- 2 pμA, 260 MeV $^{48}Ca^{11+}$ on target!

- Delivered very stable 1.0-1.4 pμA $^{48}Ca^{11+}$ on target for 60-day run
- 2.1 mg delivered on target during experiment

- Efficiency of 15-20% from source extraction to target

- Average ^{48}Ca consumption rate: 0.27 mg/hr (>200 k$/gram)
- Average percentage of used ^{48}Ca converted into extracted beam: 16%
- Average percentage of used ^{48}Ca converted into 11+: 5%