Can Megawatt Gyrotrons Achieve an Efficiency > 50%?

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on behalf of VLT ECH Research Group:
Comm. Power Industr. (CPI) , General Atomics, MIT, Univ. Maryland, Univ. Wisconsin, Calabazas Creek Research

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Motivation / Goals

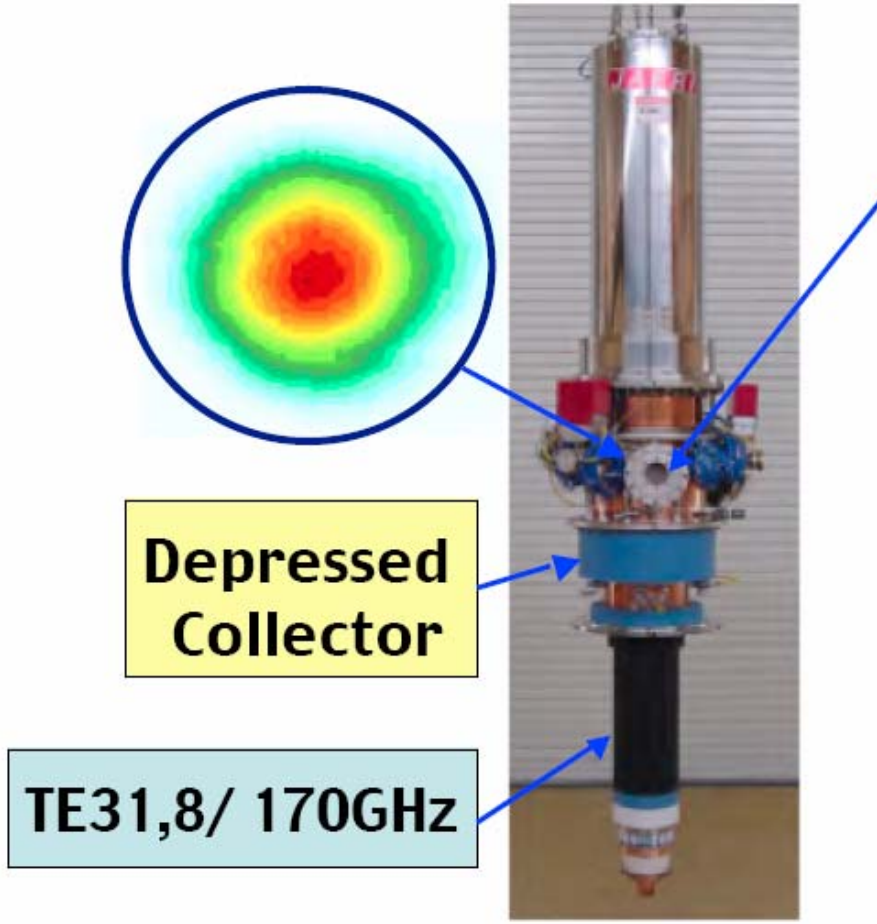
Motivation

- High gyrotron efficiency (> 50 %) is necessary for multi-megawatt gyrotron systems, such as DIII-D, W7-X or ITER.
- Need to understand both physics and engineering issues.

Goals

- Demonstrate high efficiency in a depressed collector gyrotron.
- Design cavity and depressed collector for efficiency enhancement.
- Implement research results in industrial gyrotrons.

ITER Gyrotrons Have Low Efficiency



ITER Gyrotron

170 GHz, 1 MW JAERI GYROTRON

Diamond window

32 % Efficiency at 1 MW

50% needed!

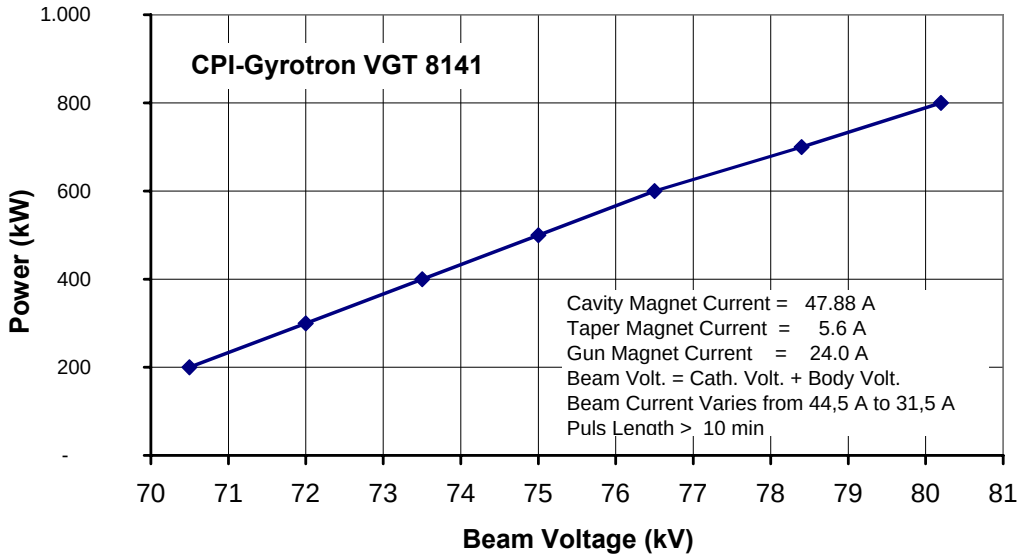
Frequency (GHz)	Power (kW)	Duration (sec)
170	900	9.
	750	17.
	500	100.

The W7-X 140 GHz Gyrotron: CPI

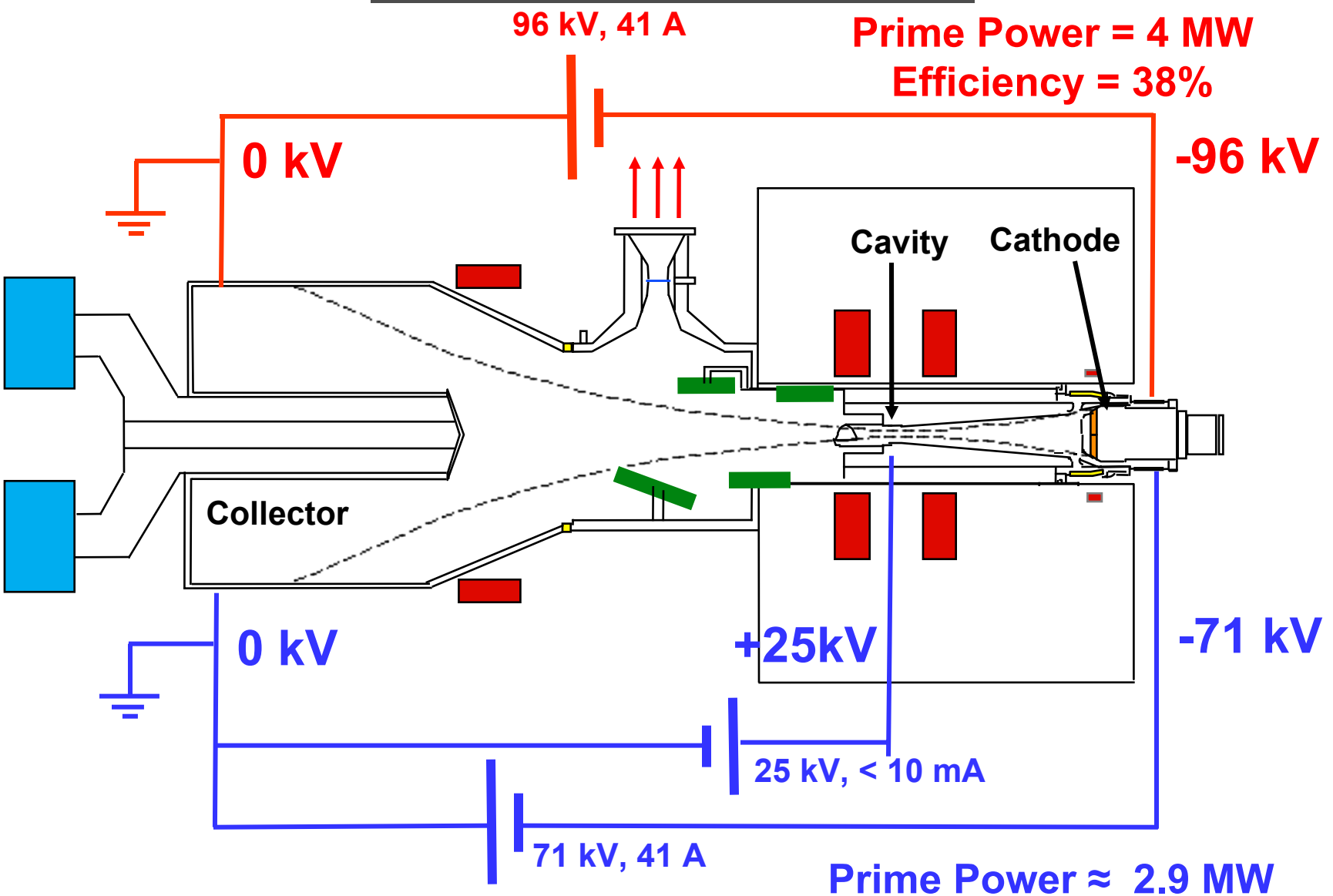
Test results at IPP:
0.9 MW for 30 min

World Record!

Efficiency = 36%



1.5 MW Depressed Collector Gyrotron



VLT Gyrotron Research

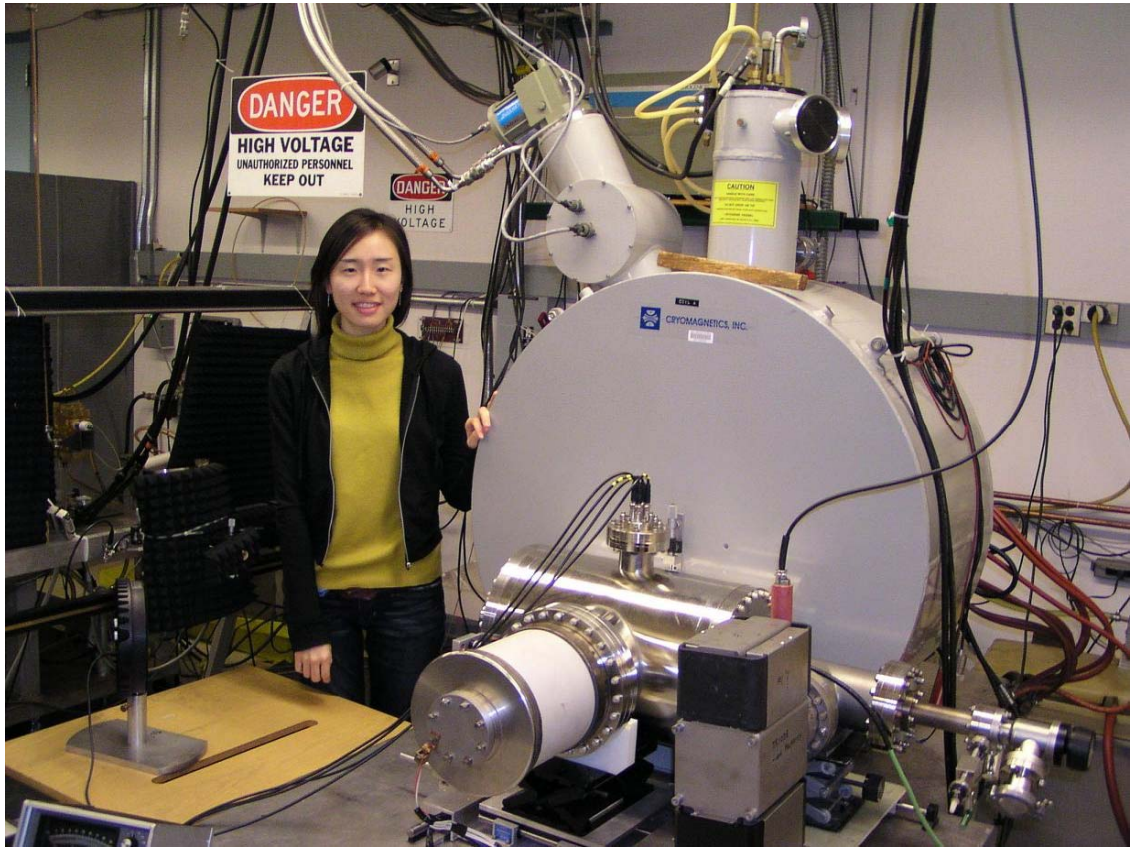
Basic Research Experiments at MIT

- Build and test gyrotrons to investigate output power, single mode operation, internal mode converters, efficiency, tunability, etc.
- Operate in short pulses, 3 microseconds; avoid thermal engineering.
- Provide pioneering results on physics and microwave engineering issues.

Industrial Research Program at CPI / GA

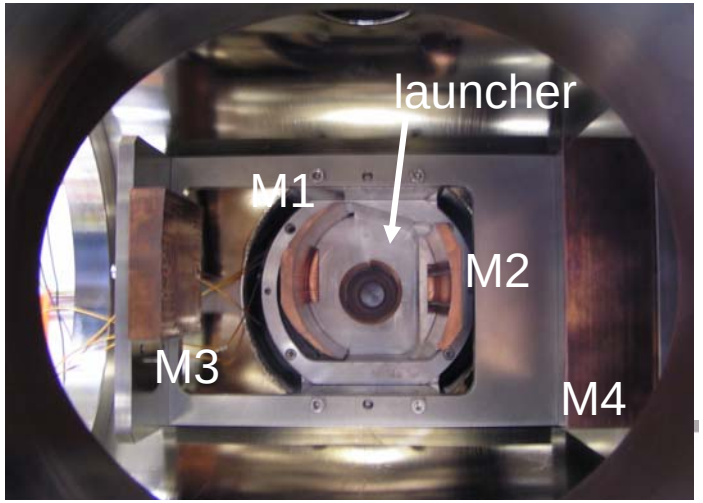
- Build gyrotrons at CPI for long pulse and CW operation.
- Test gyrotrons at CPI in 10 s pulses to limit of CPI supply, <500 kW.
- Ship gyrotrons to GA for testing to full power and use for ECH.

MIT Experimental Setup



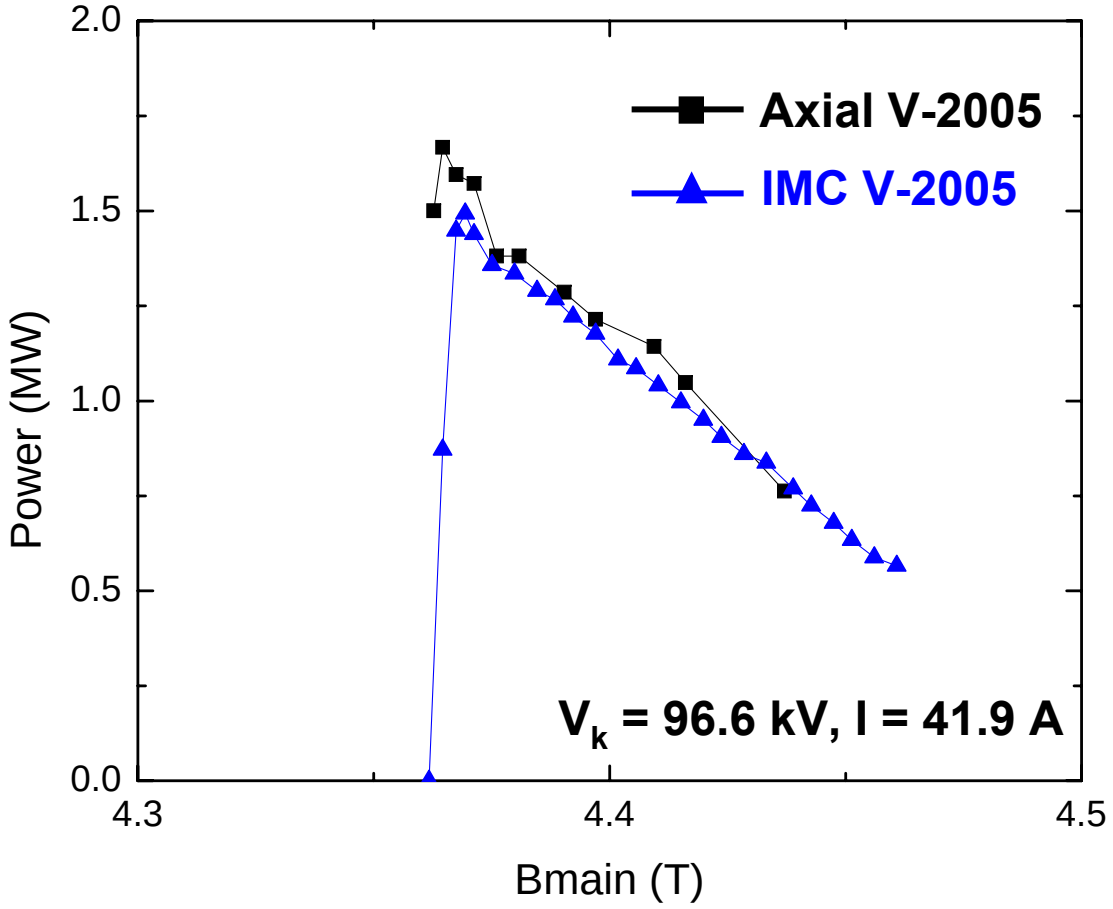
Design parameters

Frequency	110 GHz
Power	1.5 MW
Voltage	96 kV
Current	40 A
Mode	$TE_{22,6}$
Pulse length	3 μs
Magnetic field	4.3 T



Power vs. B

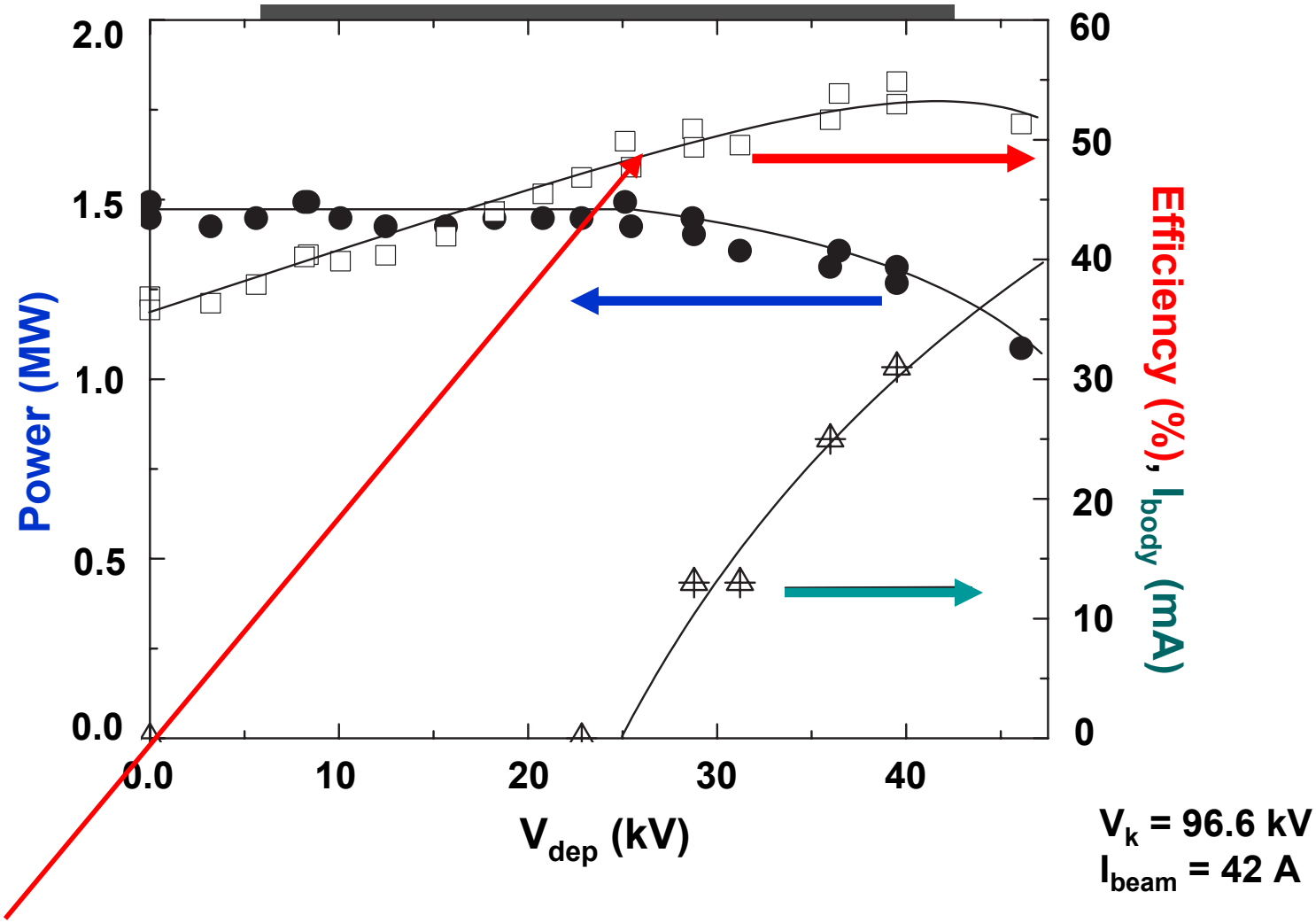
Internal Mode Converter (IMC) vs. Axial Configuration



Results:

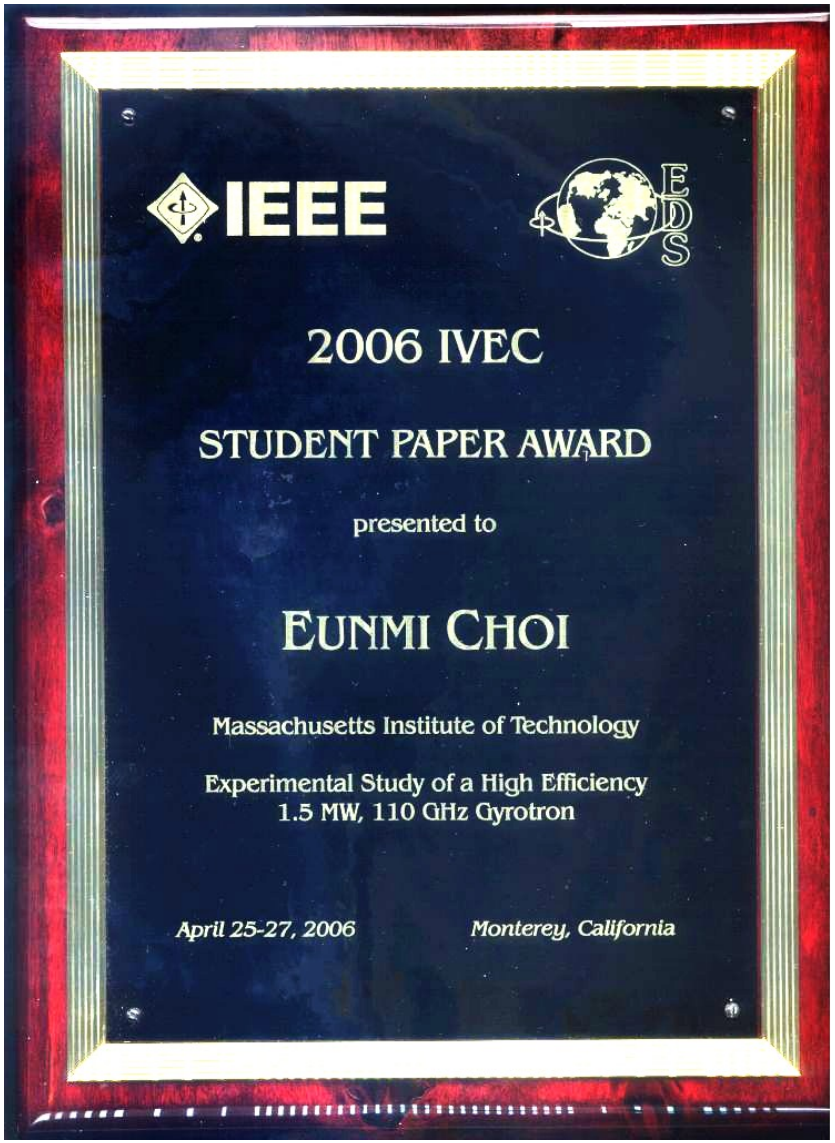
- **P = 1.5 MW**
- **Efficiency = 37 % w/o depr. collector**
- **Results labeled Axial show higher power; IMC is only 90% efficient.**

Experimental results with Dep. Coll.



- 50% efficiency was achieved at V_{dep} = 25 kV.

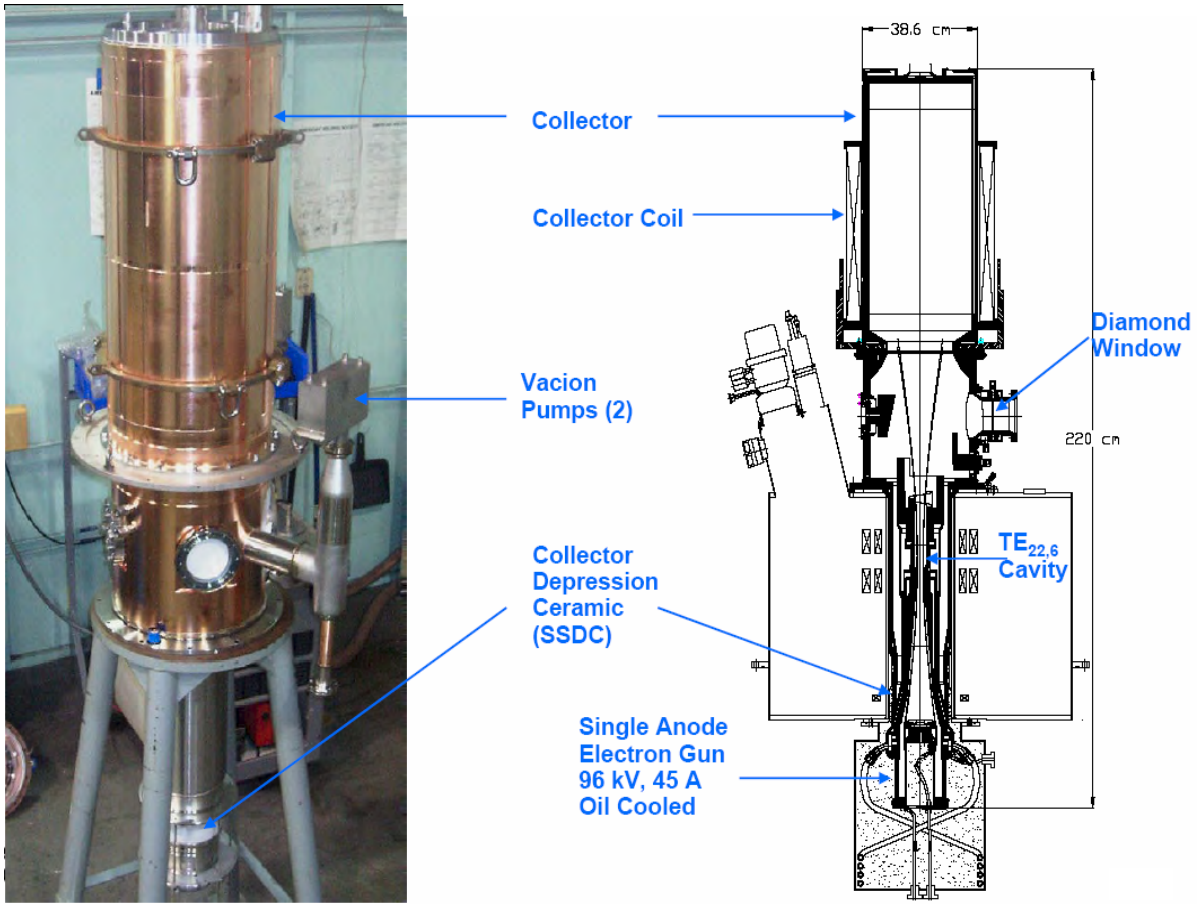
IEEE Award to Ms. Choi



- Ms. Choi won the Student Paper Award at the IEEE Intl. Vacuum Electronics Conf. (IVEC) in April, 2006

- Her paper was on "Experimental Study of a High Efficiency 1.5 MW, 110 GHz Gyrotron."

110 GHz, 1.5 MW CPI Gyrotron



- 110 GHz
- 96 kV, 40 A
- 25 kV Collector Depression
- Uses older cavity design, not as efficient as MIT cavity

- 500 kW for 10 sec at CPI (power supply limited)
- 1.3 MW in short pulses at 42%; Efficiency is low!
- Now at GA for long pulse testing

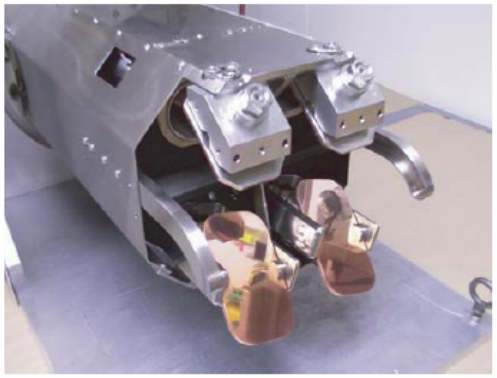
The DIII–D EC System will Provide Enhanced Off-axis Current Profile Control and Important Physics Capability

First replacement gyrotron installed in refurbished "socket" and started up

Refurbished "socket" for second replacement gyrotron in background

Developmental depressed collector gyrotron installed in new "socket"

Steerable Launcher (PPPL)



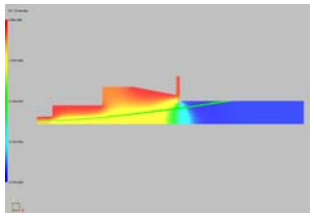
- **Physics Enabled**
  - Current drive
  - Current profile control
  - MHD stabilization
  - Electron heating
  - Transport science
  - Transport barriers

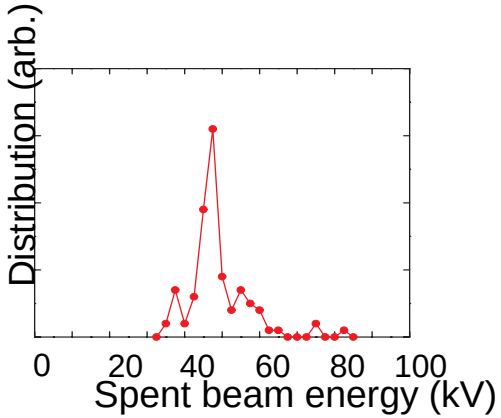
Conclusions

- An internal mode converter experiment has been done successfully at MIT on a 110 GHz gyrotron.
  - 1.5 MW of output power was achieved.
  - Efficiency > 50% achieved with depressed collector.
- Industrial 1.5 MW tube built by CPI will be tested for long pulse operation soon at GA.
  - Achieved 500 kW for 10 seconds at CPI.
  - Short pulse operation only reached 1.3 MW and 42 % efficiency.
- Gyrotron development at CPI needed to finish optimized designs and demonstrate full 1.5 MW for use at DIII-D.

Future plans

- ***Dep. Coll. experiment analysis using MICHELLE 3D***

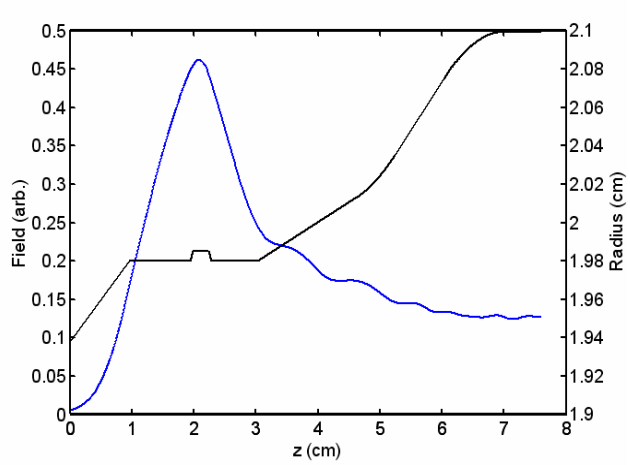




- ***Improved internal mode converter***

- ***Studies of low frequency (100 MHz) oscillations in gyrotrons.***

- ***An improved cavity design***



- ***Improved 110 GHz industrial tube to demonstrate full 1.5 MW output power and efficiency > 50%.***
  - ***Deliver to GA for final testing and use in heating DIII-D.***