WP4: RF systems

Update on the 36 GHz and 48 GHz power sources

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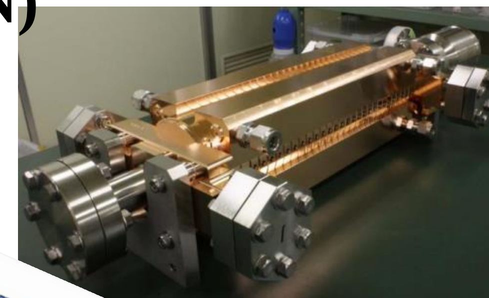
Outline

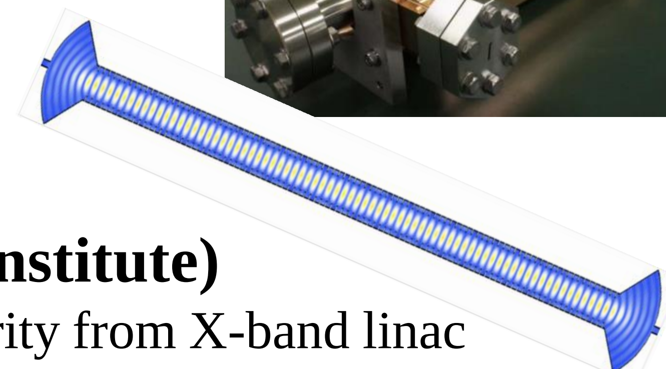
- Research groups (Strathclyde & UESTC)
- Motivation
- Principles of klystron and gyro-klystron
- 36GHz 2 MW gyroklystron simulation results
  - – MIG gun
  - – Cavity simulation
- 36 GHz 3 MW gyroklystron simulation results
- 48 GHz 1.5 MW studies

Motivation

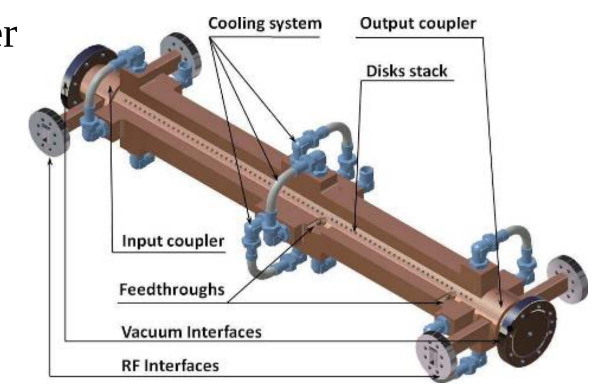
- **Accelerator (High acceleration gradient, CERN)**
  - Higher operating frequency
  - Breakdown limit



- **Microwave undulator (WP5)**
  - Smaller period requires higher frequency
  - High power required

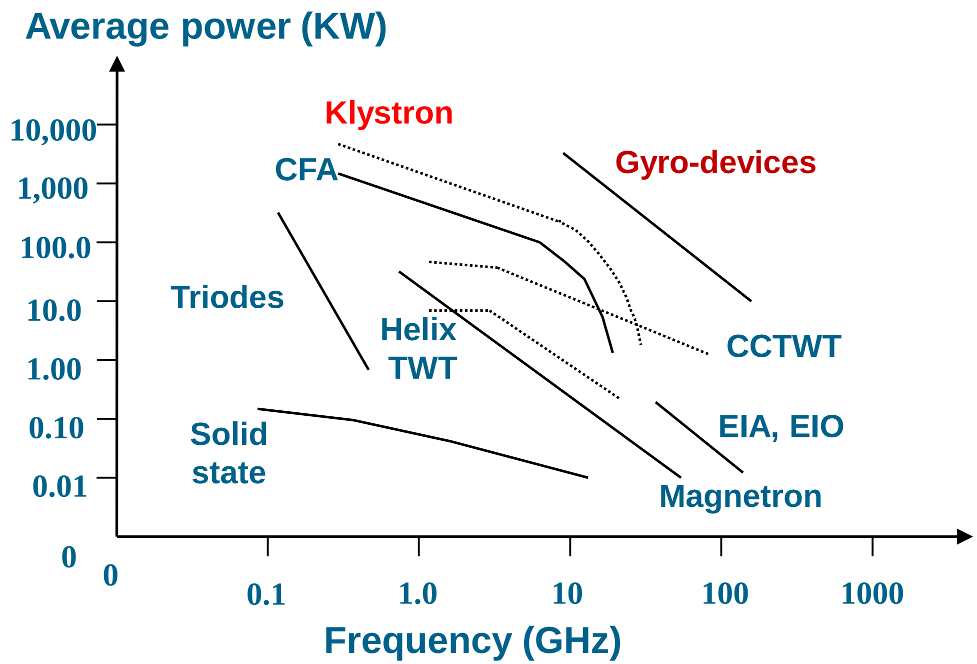


- **Lineariser (CompactLight, Cockcroft Institute)**
  - Correct the longitudinal phase space non-linearity from X-band linac
    - compensate for the curvature imposed on the bunch by the fundamental by adding harmonic
  - 3rd (36GHz) or 4th (48GHz) harmonic of X-band (12GHz) LINAC frequency
    - the higher the harmonic, the less amplitude (and thus RF power) required
    - The higher the frequency and power the shorter the lineariser



- **Design targets**
  - Gyro-klystron (amplifier, narrow bandwidth)
  - 36 GHz, >2MW
    - Design for 48 GHz, 1.5MW output power (Laurence Nix)
  - Pulse duration 2 us, PRF 100 Hz.

MW amplifiers



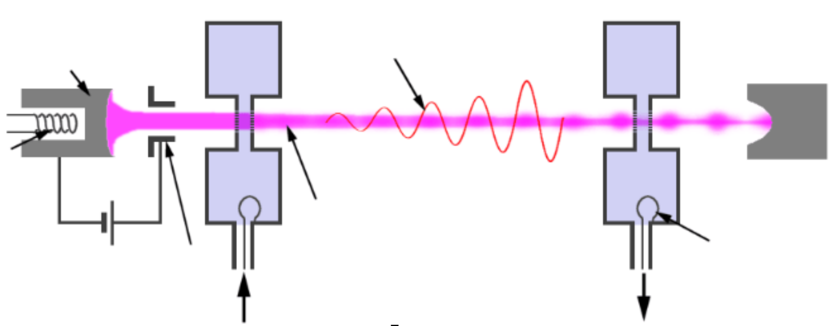
X-band (~12 GHz) klystrons

	SLAC XL4,5	CPI 8311A	Toshiba E3768B
Frequency (GHz)	11.424	11.994	11.424
Beam Voltage (kV)	440	410	500
Beam Current (A)	350	310	270
Peak Power (MW)	50	50	75
Gain (dB)	50	48	60
Efficiency	40%	40%	55%

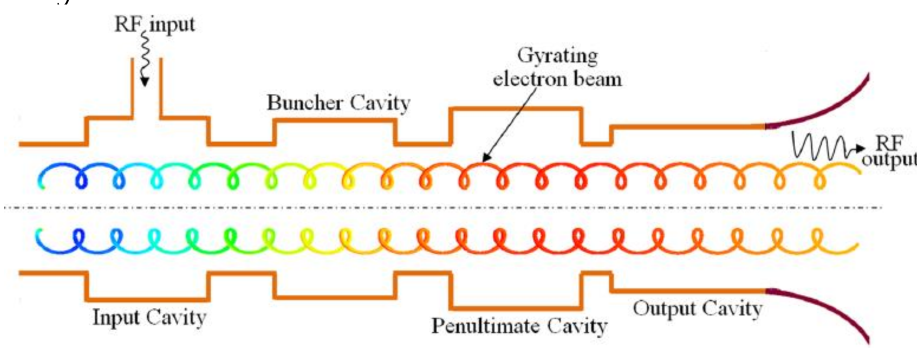
Klystrons: Operating frequency determined by the cavity size, difficult to achieve high power at high frequency

Klystrons & Gyroklystrons

- Conventional klystron
  - Bunching in axial direction, TM modes
  - Operating frequency determined by the cavity size, difficult to achieve high power at high frequency
  - High beam voltage, high frequency leads to small cavity gap
  - To reduce the space charge effect and get higher power (still small dimensions)
  - Multiple-beam klystron
  - Sheet-beam klystron
- Gyro-klystron
  - Bunching in azimuthal direction. TE modes.
  - Lower axial velocity due to the beam alpha results in larger cavity size.
  - Operating frequency determined by the external magnetic field.
  - Open output cavity, high power capability.



Klystron

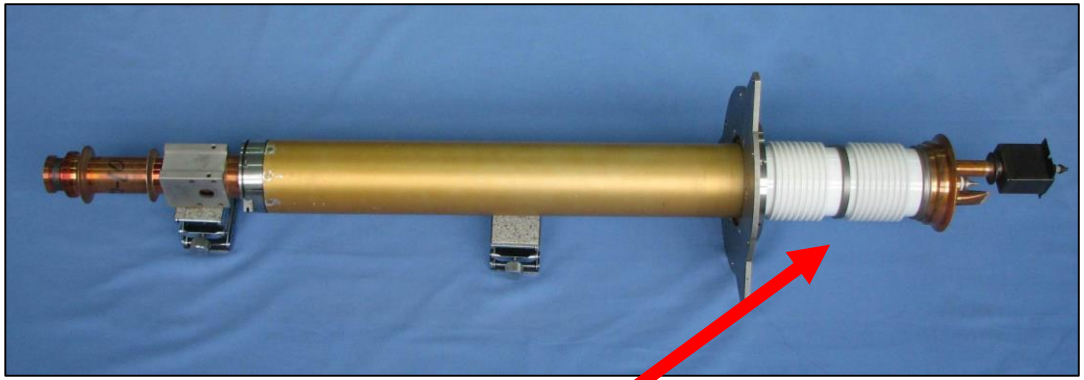


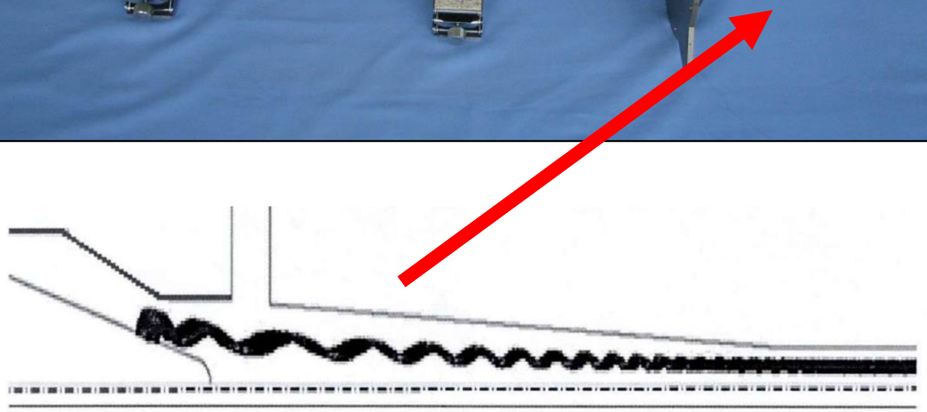
Gyro-klystron

Ka-band gyro-klystron at UESTC

Medium-power demonstration version

Output power (kW)	260
Beam voltage (kV)	68
Beam current (A)	11
Magnetic field (T)	1.32
Output frequency (GHz)	33.98
Drive power (W)	40
Gain (dB)	38.8
Efficiency	40%
Bandwidth (MHz)	280

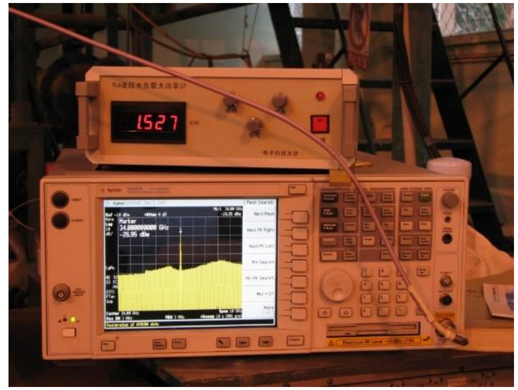




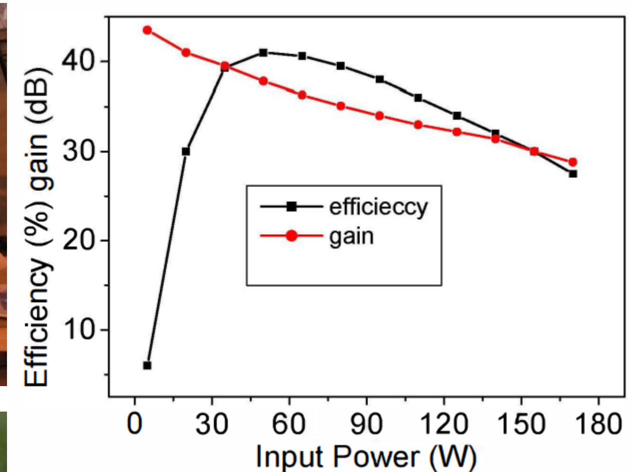
Dual-anode MIG gun.
Beam alpha 1.2
Magnetic field compression ratio 7.8

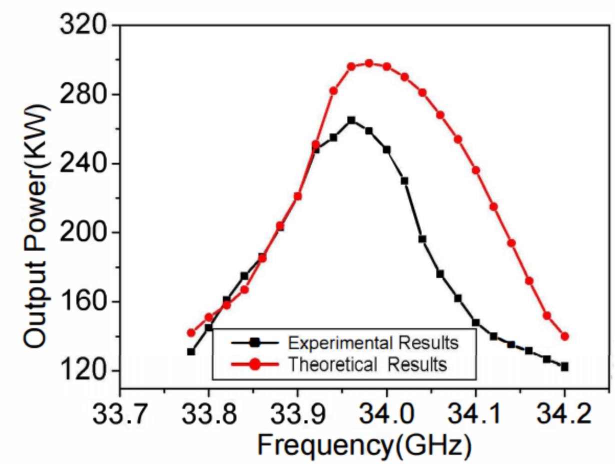
Ka-band gyroklystron at UESTC

Measurement setup
PRF 220 Hz



The TE01 output mode pattern captured on film





Successfully verified the design, further improvements on the electron gun and collector are required.

36 GHz, 2 MW gyro-klystron design

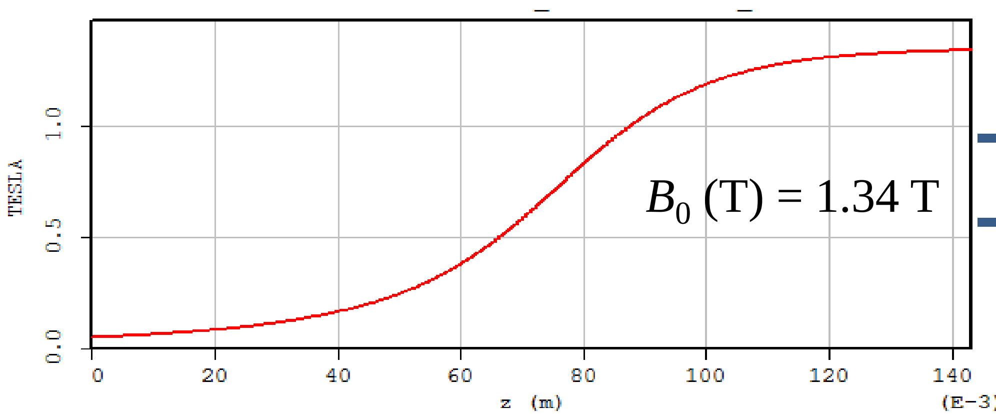
Voltage (kV)	95	Current (A)	45
Velocity ratio	1.3	Drive power (W)	200
Beam guide radius (mm)	2.3	Magnetic field (T)	1.33
Result			
Power (MW)	1.9	Bandwidth	0.3%
Efficiency	44%	Gain (dB)	39 (max 42)

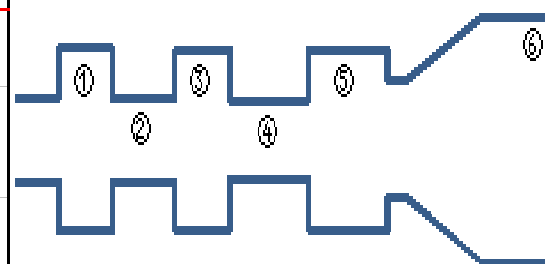
- MIG-type electron gun
- Three-cavity structure
- TE01 mode for input and intermediate cavity
- TE02 for output cavity

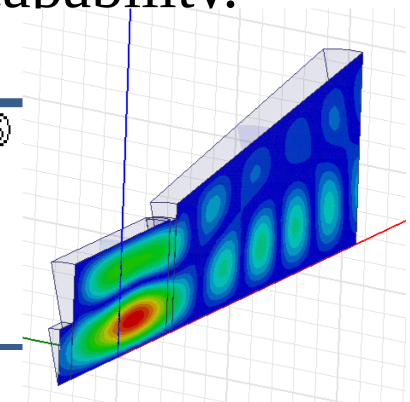
Electron gun and cavity

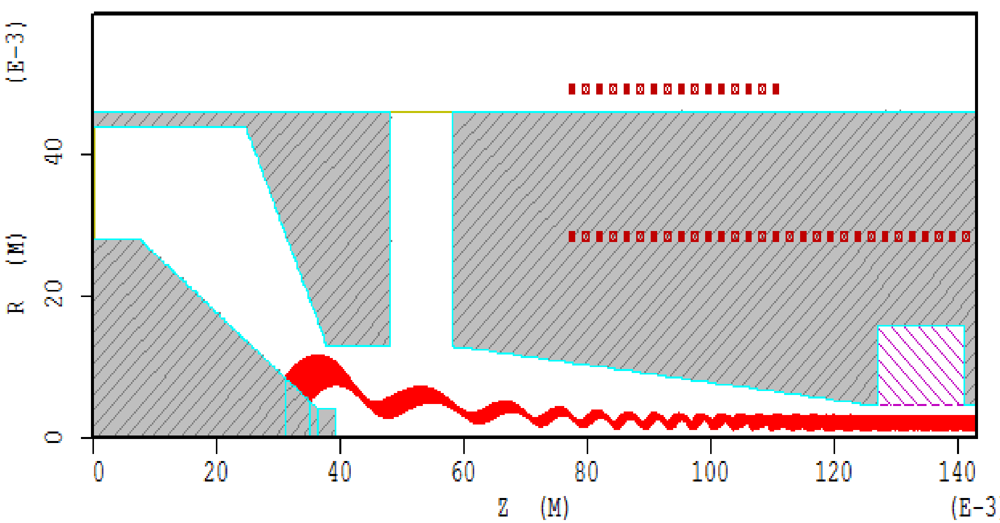
The Cockcroft Institute of Accelerator Science and Technology
University of Strathclyde

- Three-cavity structure
- The operating mode of input and buncher cavity are TE01. The mode of output cavity is TE02, to have larger power capability.





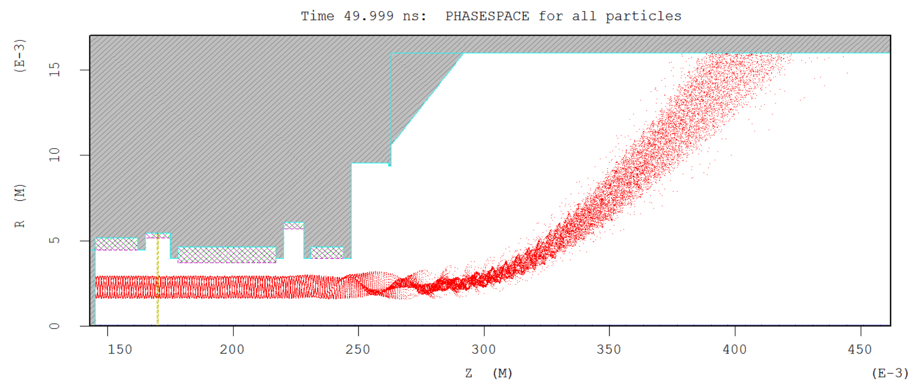


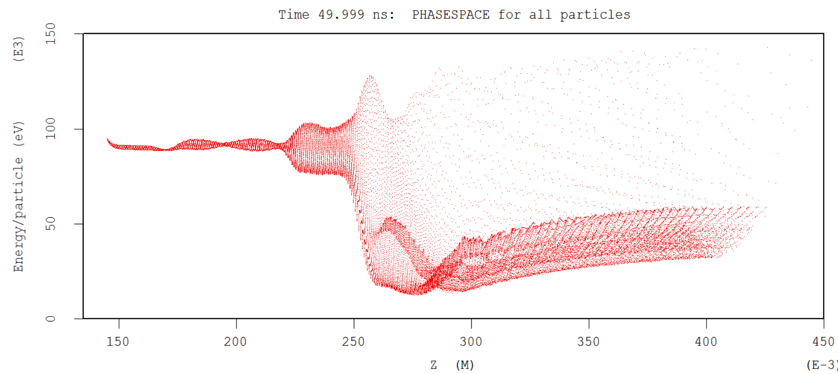


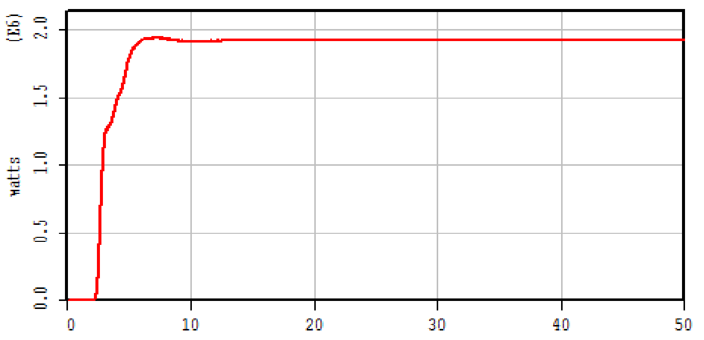
① is the input cavity, ② is the 1st drift tunnel, ③ is the bunching cavity, ④ is the 2nd drift tunnel, ⑤ is the output cavity and ⑥ is the collector.

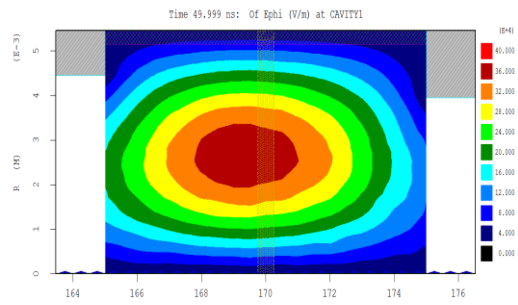
Structure	F	Q
Cavity 1	35.25	52.6
Cavity 2	34.58	23.5
Cavity 3	35.79	78.6

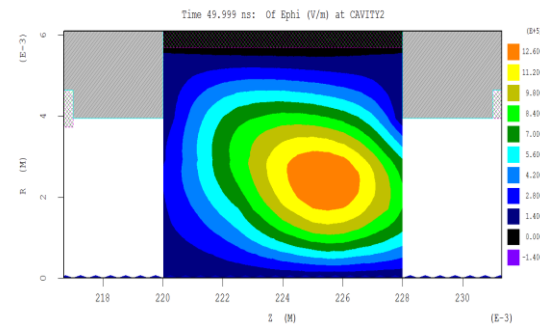
PIC simulations results

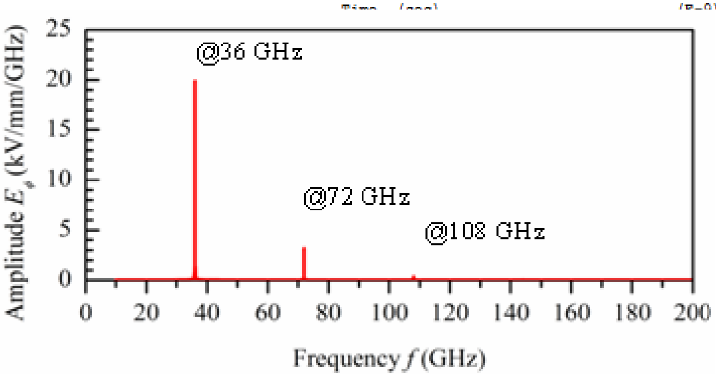


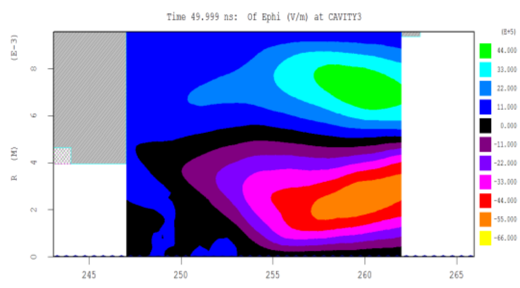




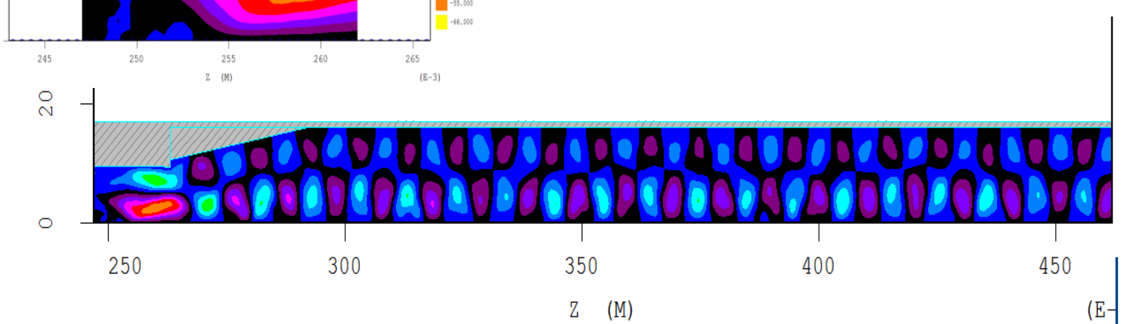




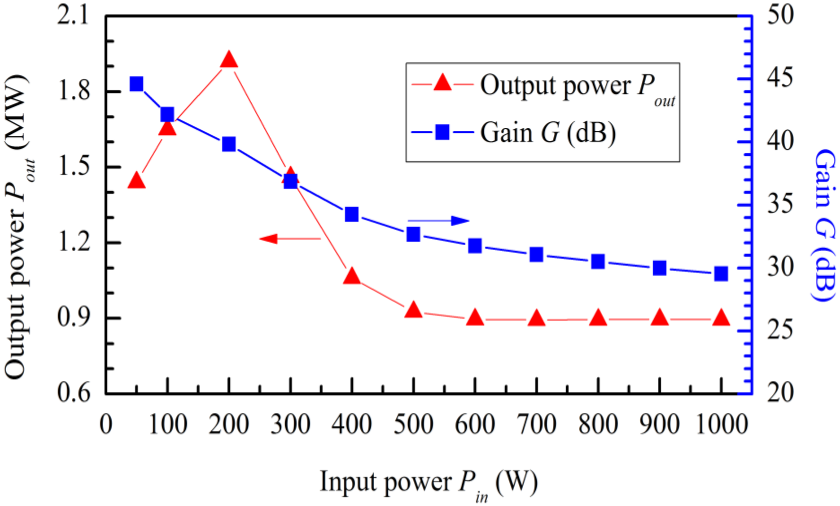


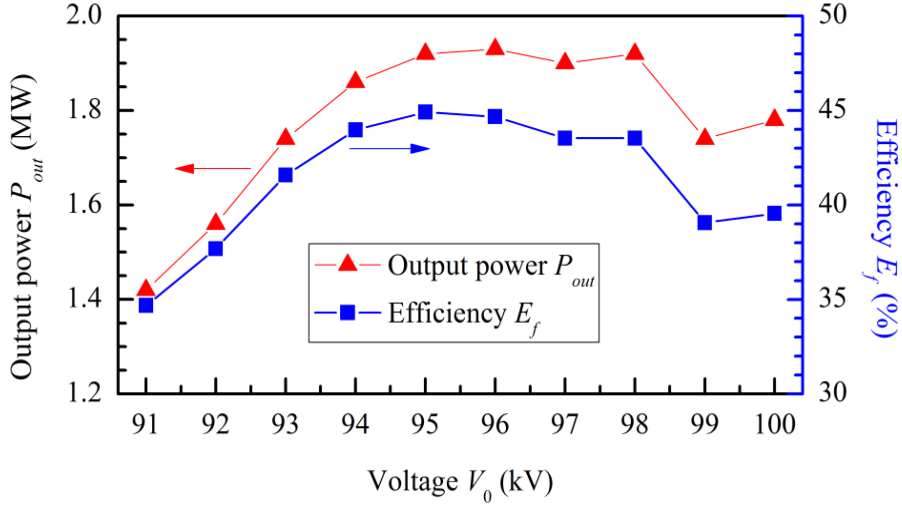


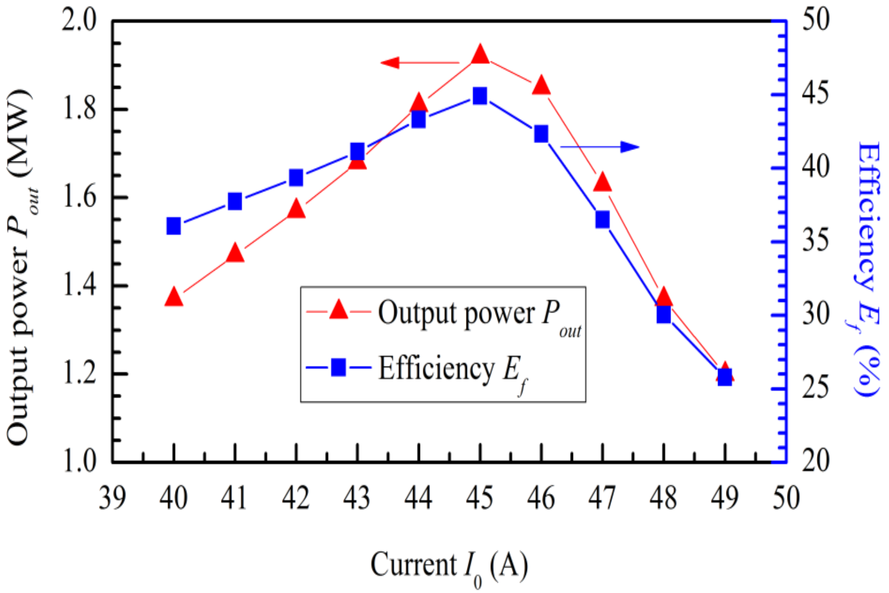
Output cavity

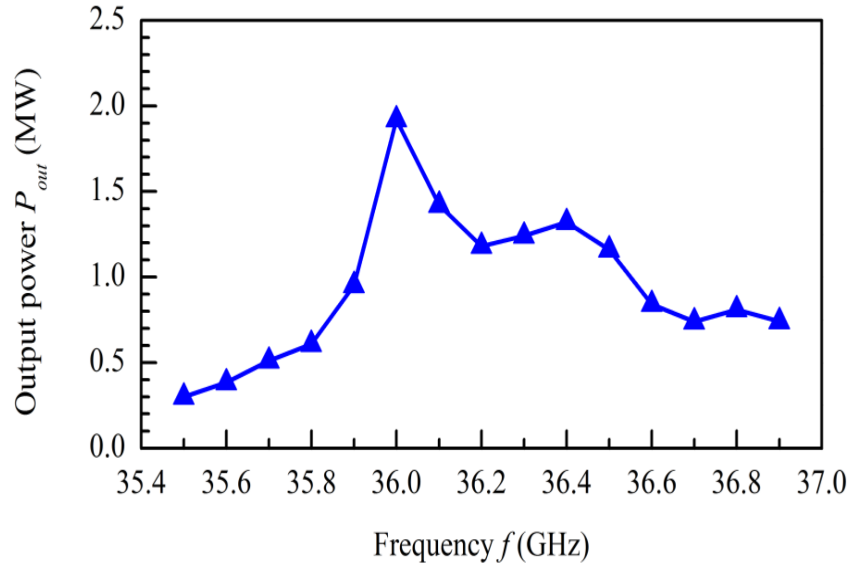


Gain curves in simulations









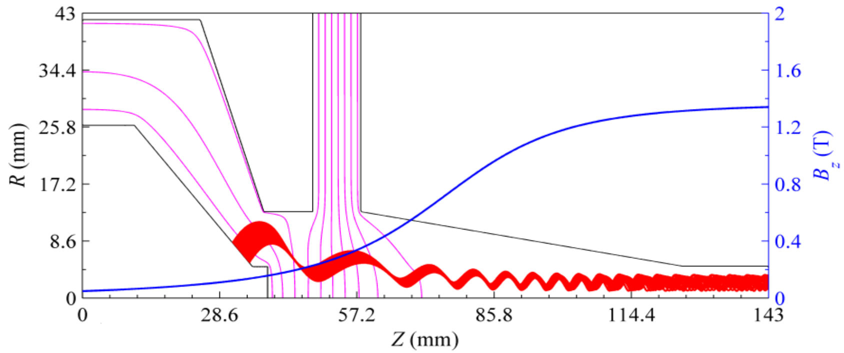
Output power and gain

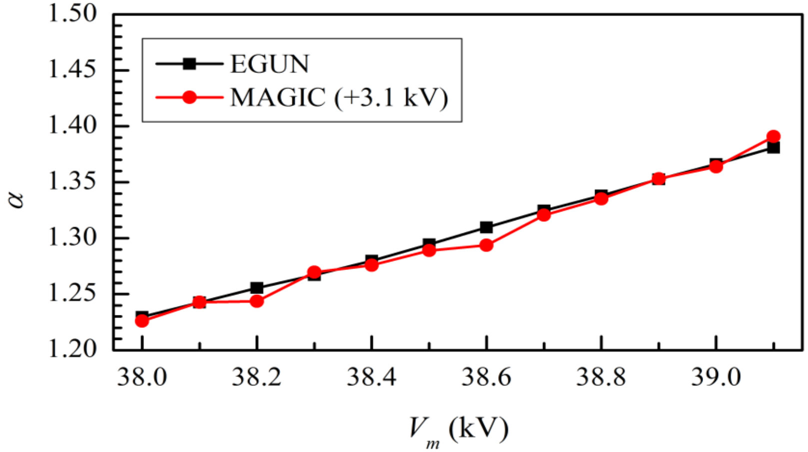
36 GHz 3 MW gyroklystron design

Voltage (kV)	150	Current (A)	45
Velocity ratio	1.4	Drive power (W)	400
Beam guide radius (mm)	2.3	Magnetic field (T)	1.46
result			
Power (MW)	3.0	Bandwidth	0.3%
Efficiency	44%	Gain (dB)	39 (max 42)

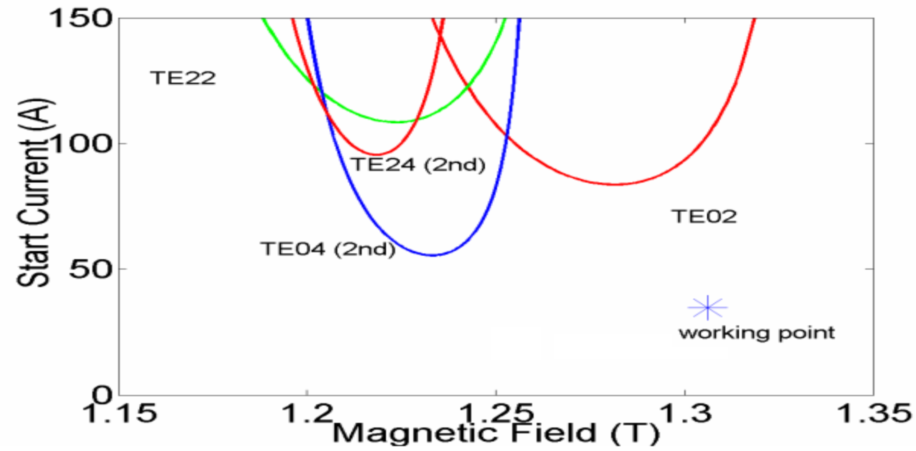
- Similar configuration but with a higher operating voltage
  - it is challenging to Increase the current using an MIG, it will reduce the beam quality, reducing the interaction efficiency

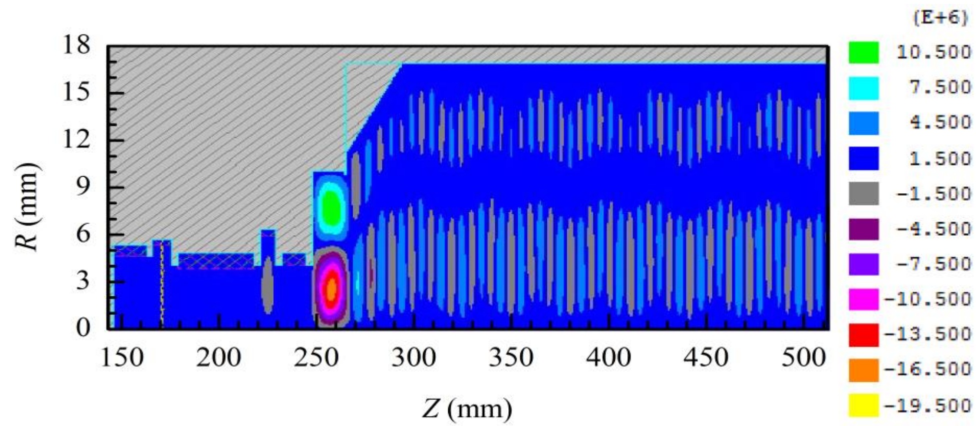
36GHz simulation results

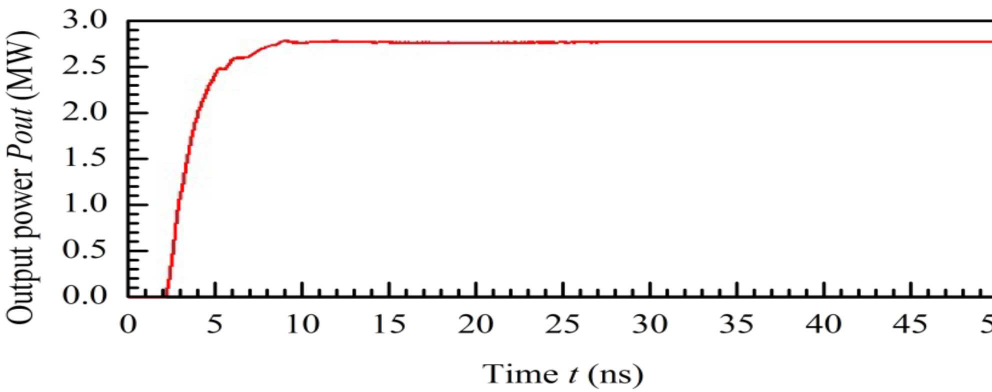




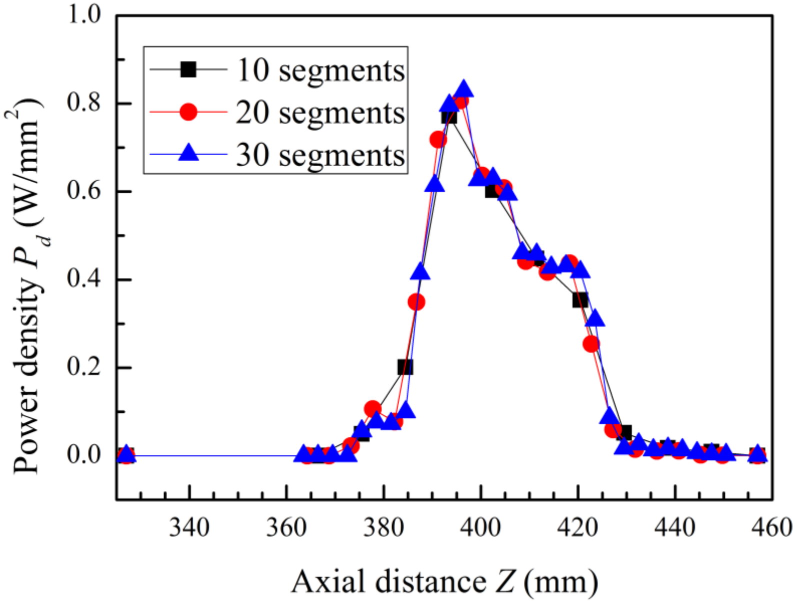
Current I_0 (A)	**45**
Anode voltage V_0 (kV)	**150**
Modulating anode voltage V_m (kV)	**38.5**
Magnetic field @ gun exit B_0 (T)	**1.34**
Magnetic compression ratio f_m	**10.5**
Velocity ratio α	**1.32**
Axial velocity spread $\Delta\beta_z$ (%)	**2.25**
Mean guiding center r_{g0} (mm)	**2.5**



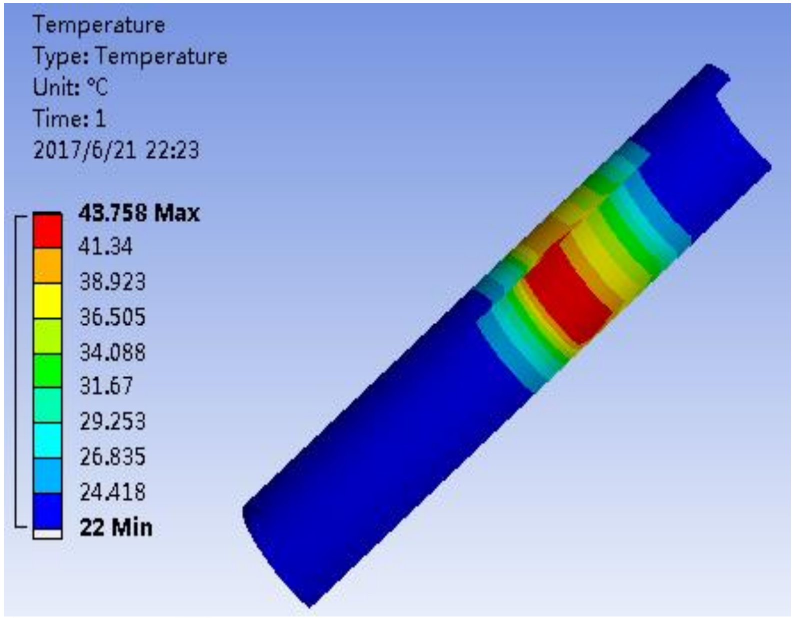


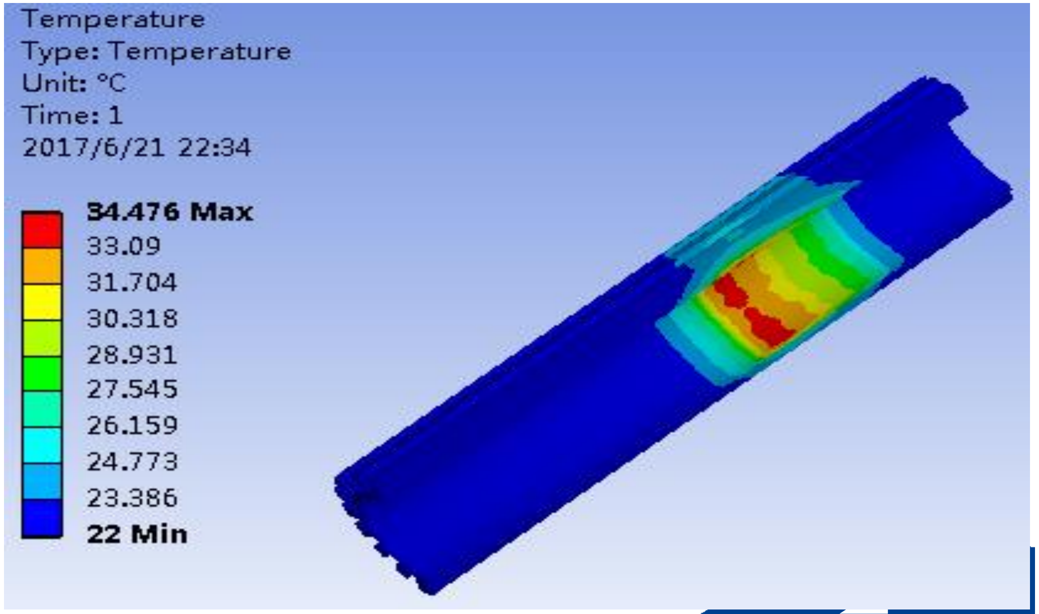


Collector design



Electron beam power 6.75 MW;
Output microwave power 2.77 MW;
Power loss 100 kW;
Power in the spent beam 3.88 MW;
The designed collector power density is 85W/cm^2.



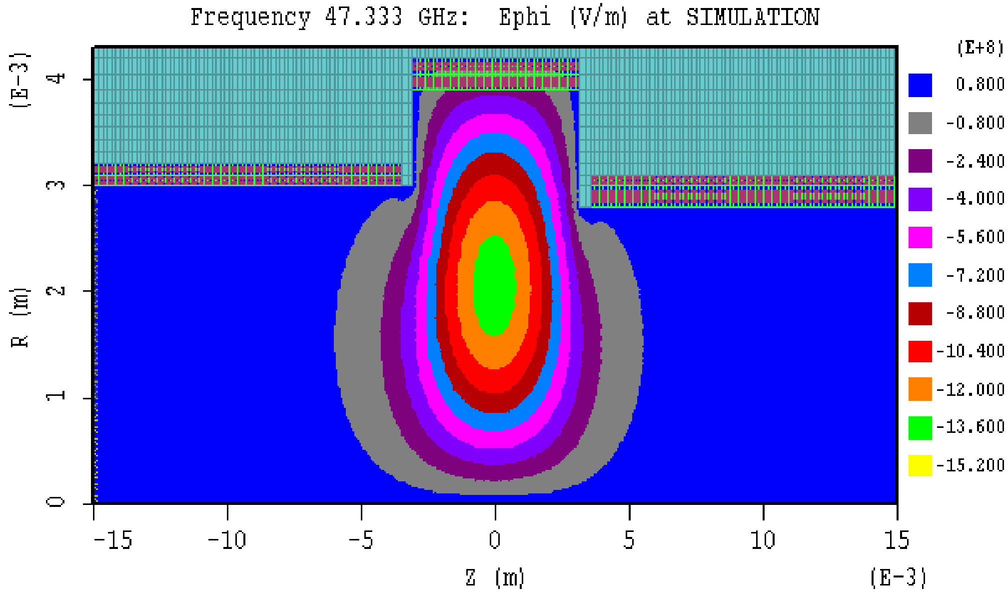


48 GHz 1.5 MW Gyroklystron

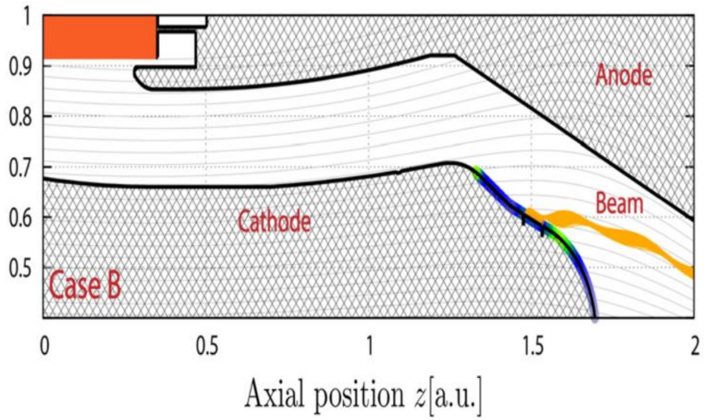
PhD student: Laurence Nix

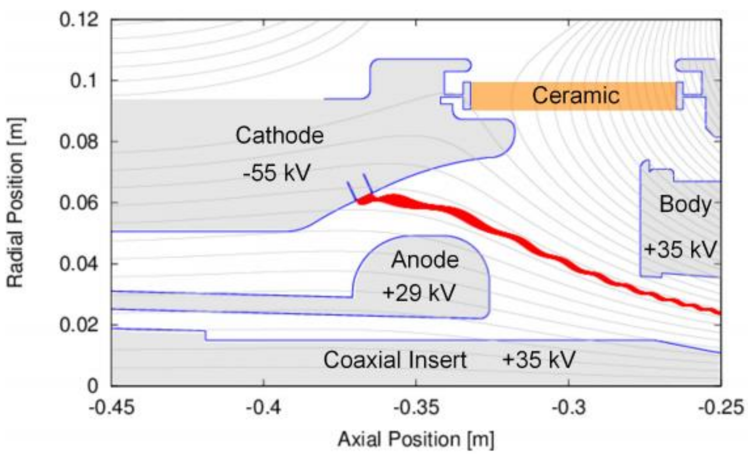
- Higher frequency, smaller dimensions has limit in the beam current due to the space charge effect
- Higher operating voltage up to 300 kV is being investigated
- Higher operating mode than the TE_{02} is being studied.
- Improved inverse-MIG gun for the gyroklystron

Preliminary results



- TE01 mode in an example gyro-klystron cavity ready for further design work to determine optimal frequency and properties





Configuration of MIG and IMIG. An example from KIT for 2MW coaxial-cavity gyrotron. Inverted MIG allows a larger emitter ring to have larger beam current and is able to produce a high quality beam

Acknowledgement

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Thank you for your attention!