WP4: RF systems

Progress towards 36GHz and 48GHz high power microwave sources

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Outline

- Research groups (Strathclyde, UESTC, & Shenzhen)
- Motivation
- Principles of gyro-klystron operation
- 36GHz, 3 MW gyro-klystron
  - Simulation results
  - 1kHz pulse repetition frequency design
- 48GHz, 1.5 MW results

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Motivation

- **Accelerator (High acceleration gradient, CERN)**
  - Higher operating frequency, higher breakdown limit
- **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 microwave power) required
    - the higher the frequency and power the shorter the lineariser

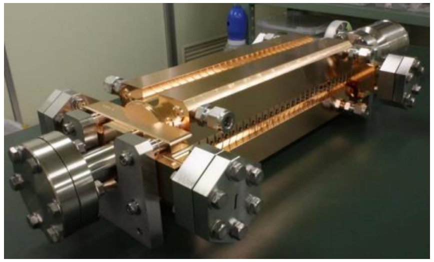

Image courtesy of Walter Wuensch, CERN

- **Progress on**
  - Gyro-klystron (amplifier, narrow bandwidth)
  - 36 GHz, 3MW, pulse duration 1.5 μs
    Pulse Repetition Frequency 1kHz
  - 48 GHz, 1.5MW, pulse duration 1.5 μs

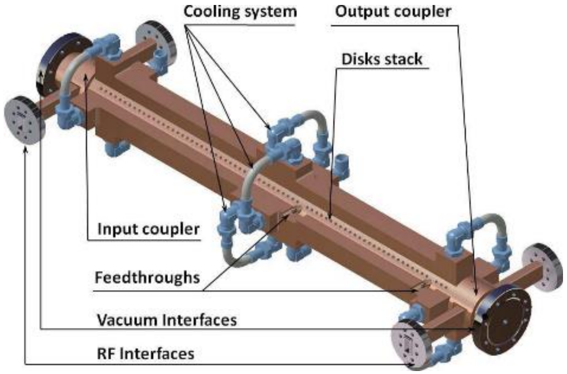

Image courtesy of Louise Cowie, Daresbury Labs

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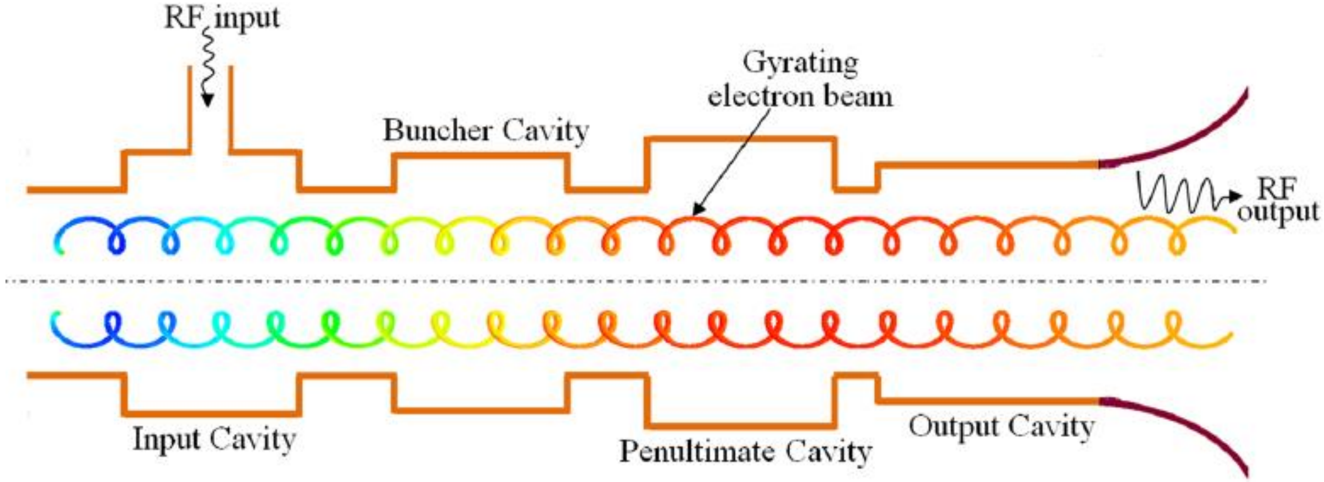
Gyro-klystrons

- Gyro-klystron
  - Azimuthal Bunching, TE modes
  - Lower axial velocity than linear klystron
  - High beam alpha (v_{perp}/v_{para})
  - Operating frequency determined by the external magnetic field
  - Open output cavity, high power capability



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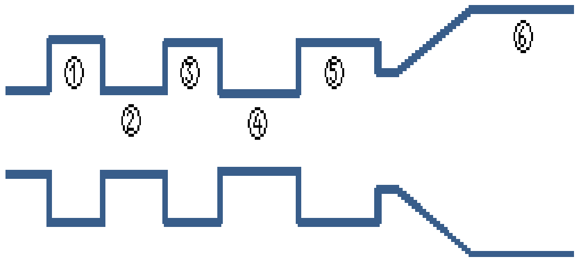
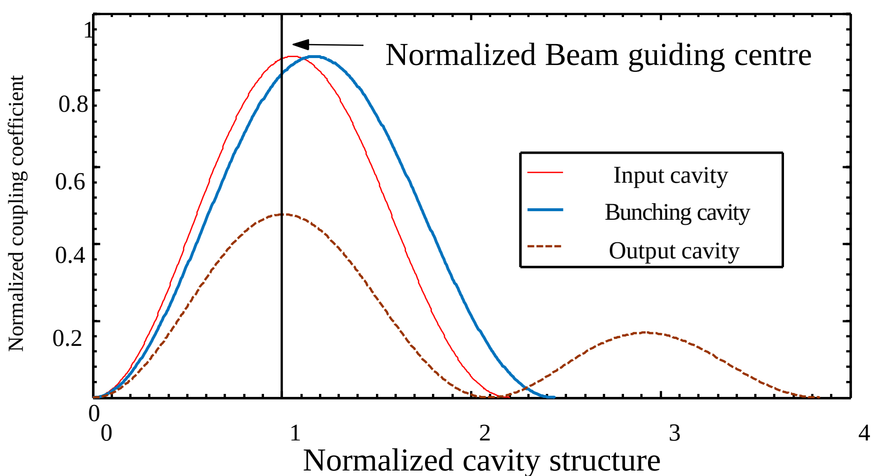
Nonlinear simulation model

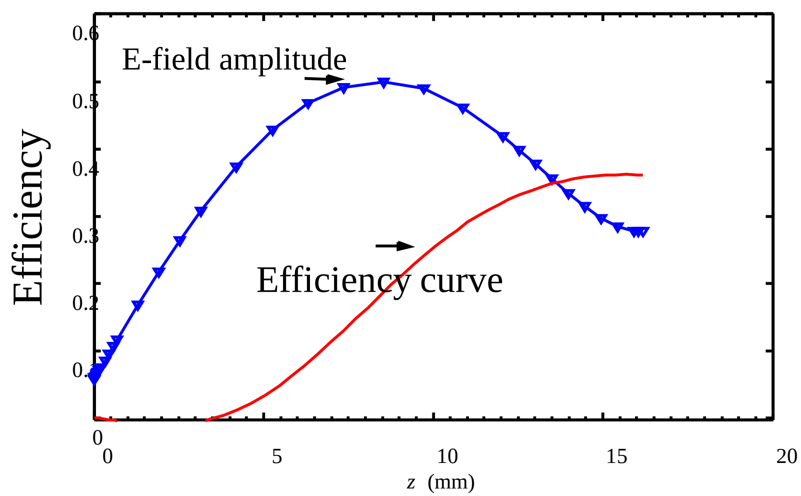
University of Strathclyde



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

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





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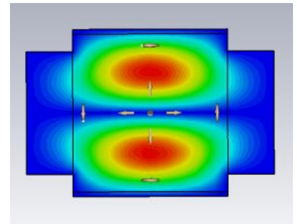
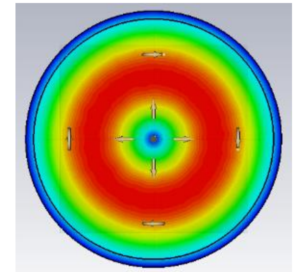
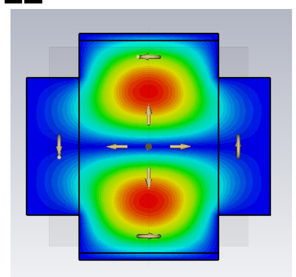
36GHz Cavities

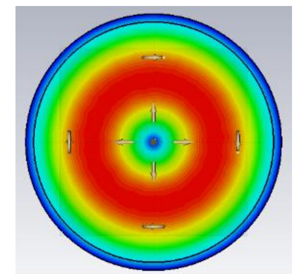
Input cavity, TE_{01}, Loss material, ε=9 σ=12



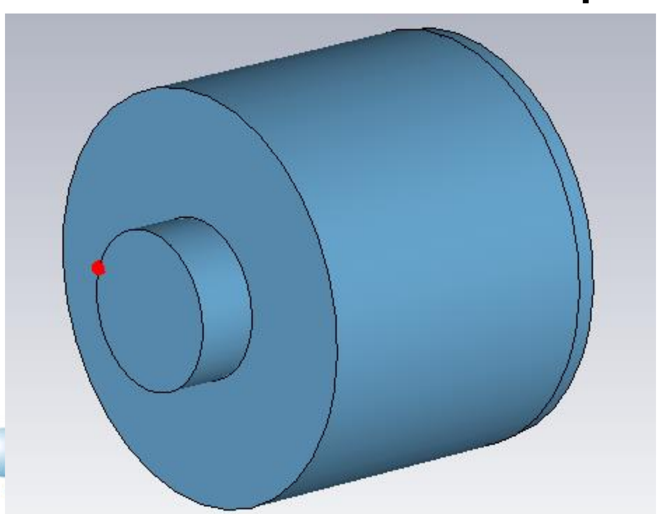


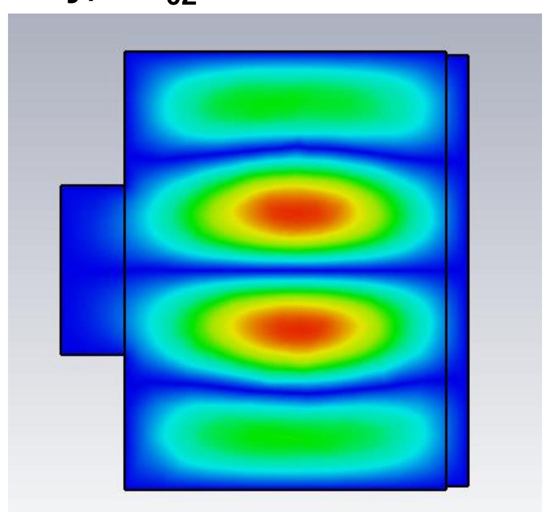
Modulation cavity, TE_{01}, Loss material, ε=9, σ=12

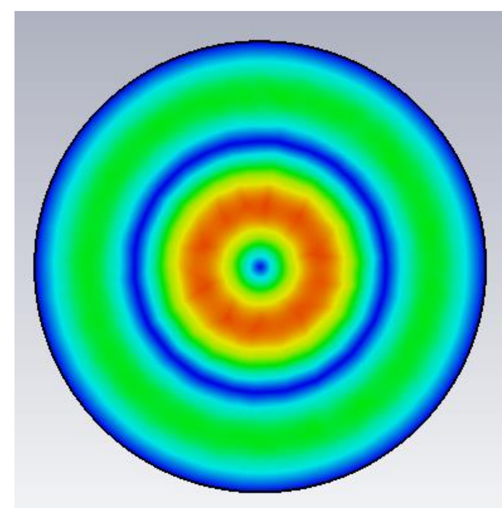




Output cavity, TE_{02}，fo=36.098GHz

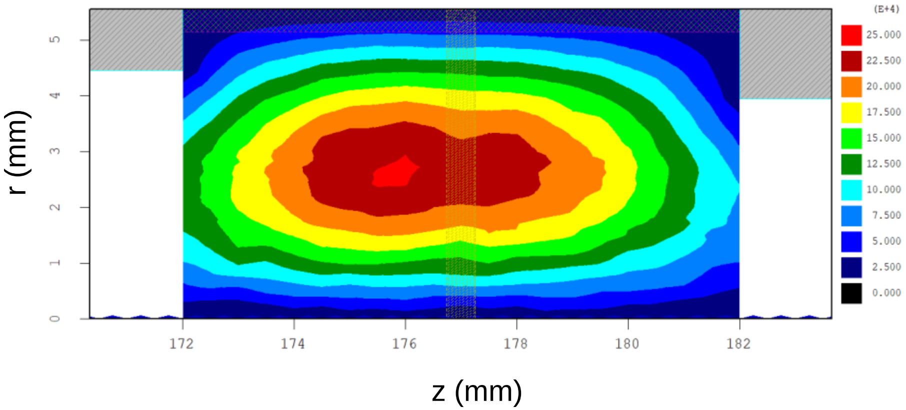




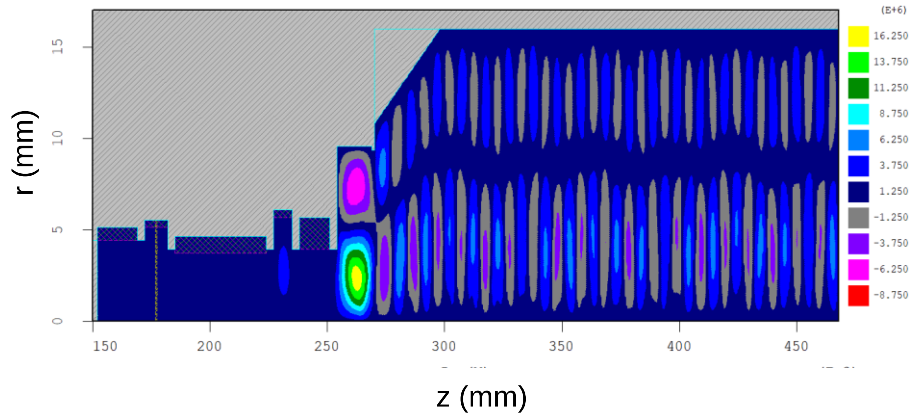


36GHz Gyro-klystron PIC simulations

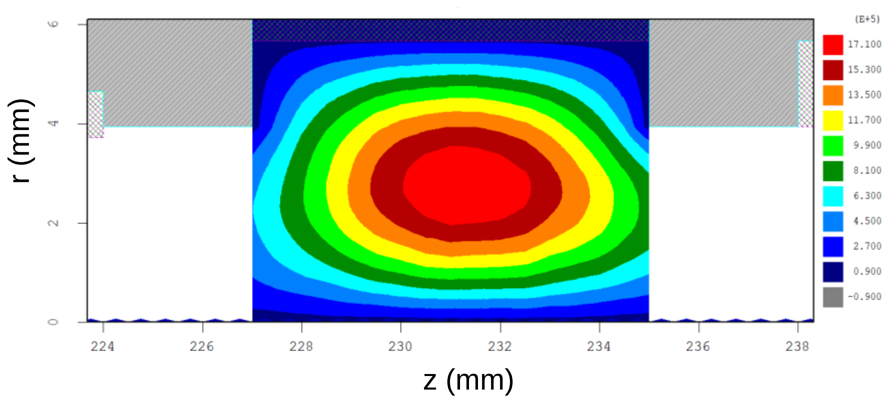
E_{Φ} field pattern in 1st cavity



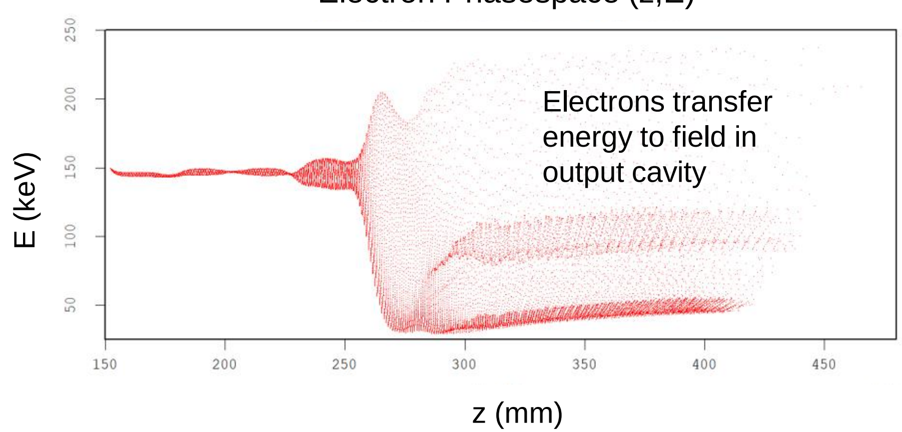
E_{Φ} field pattern in 3rd cavity



E_{Φ} field pattern in 2nd cavity



Electron Phasespace (z,E)



Simulated by PIC-code MAGIC 2D

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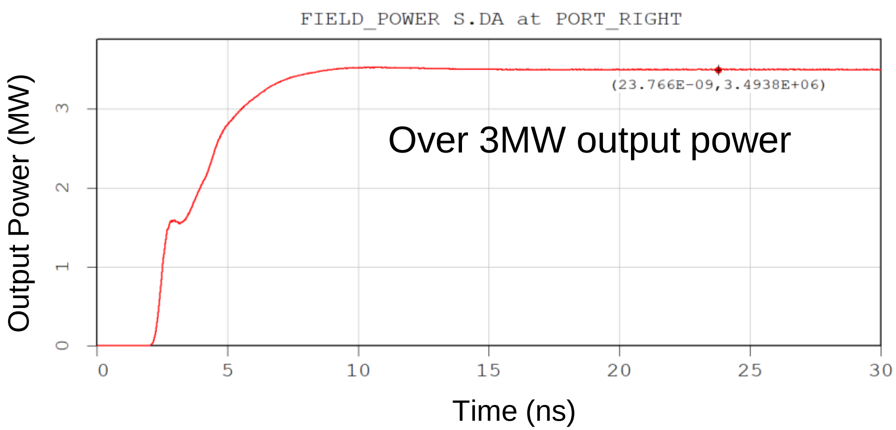
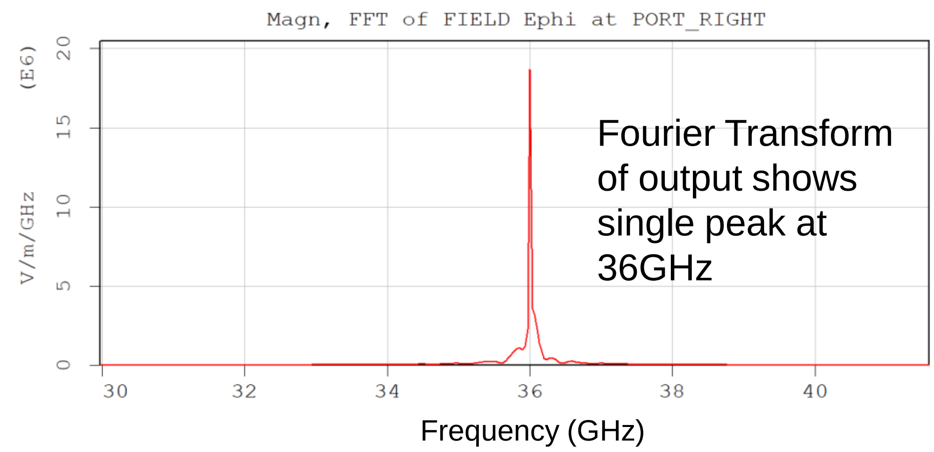
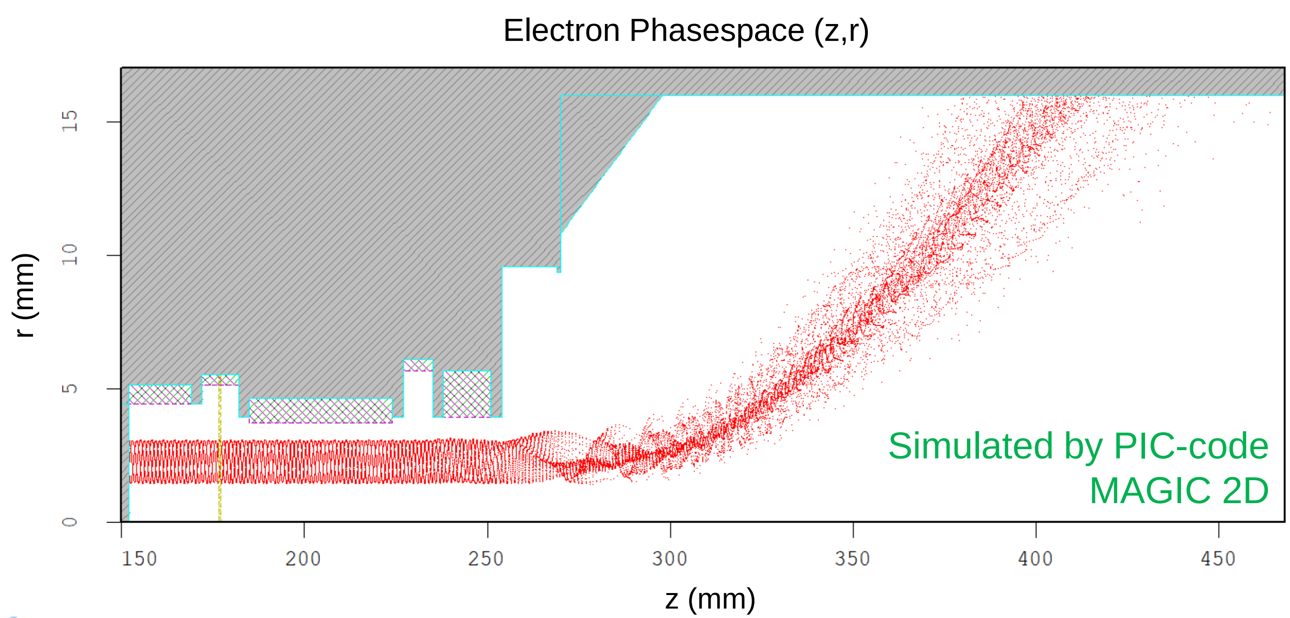
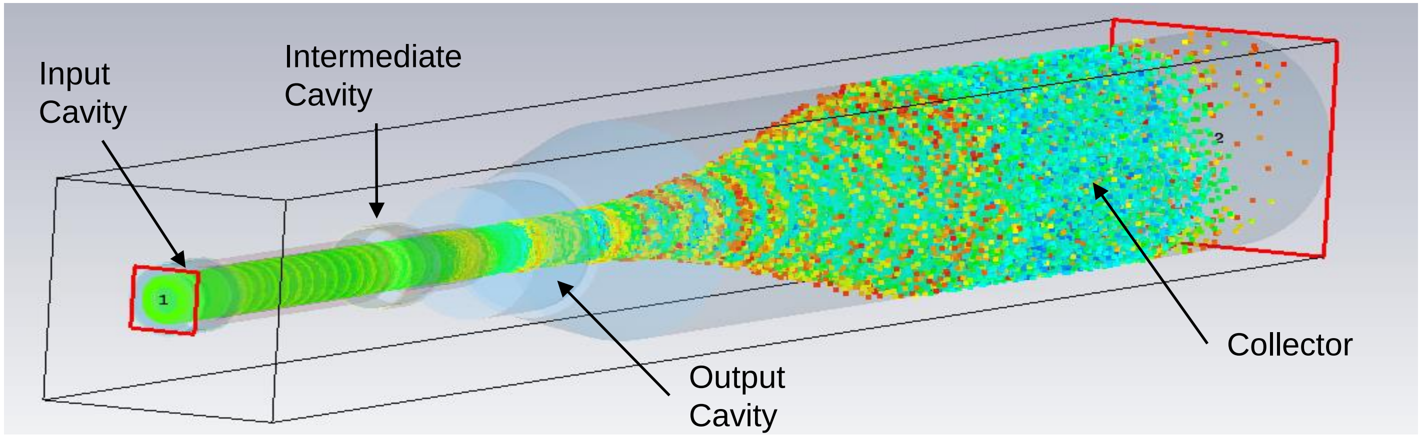
36GHz Gyro-klystron PIC simulations

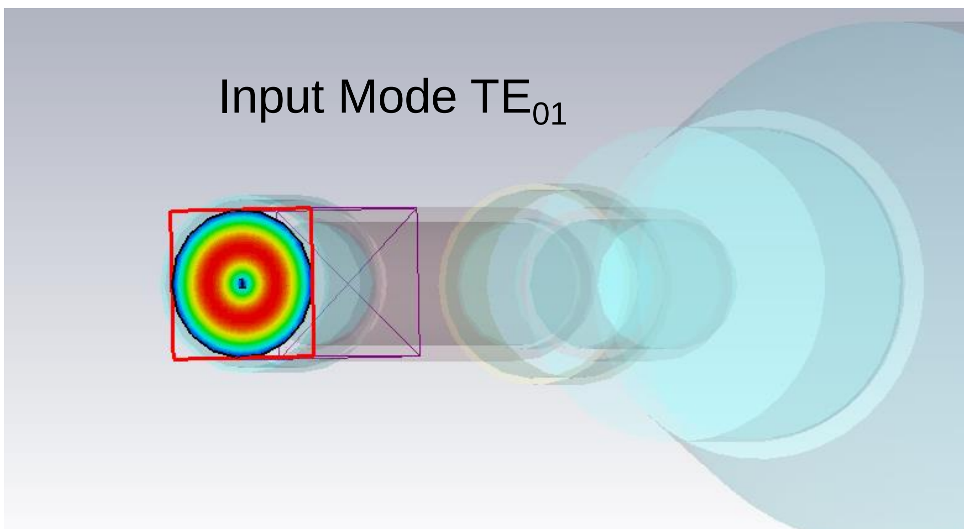


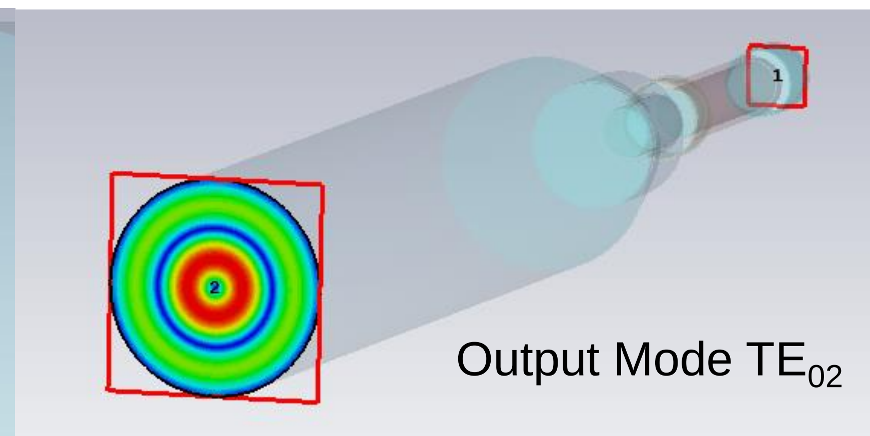




36GHz Gyro-klystron Verification







Verified by 3D PIC-code CST-PS

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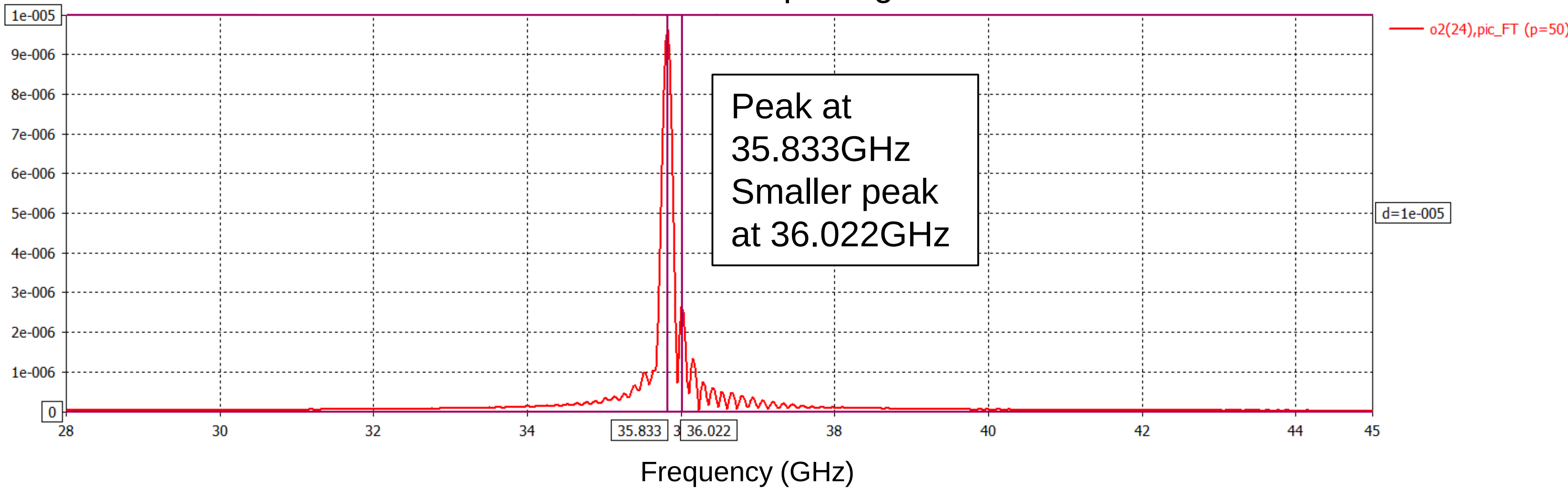
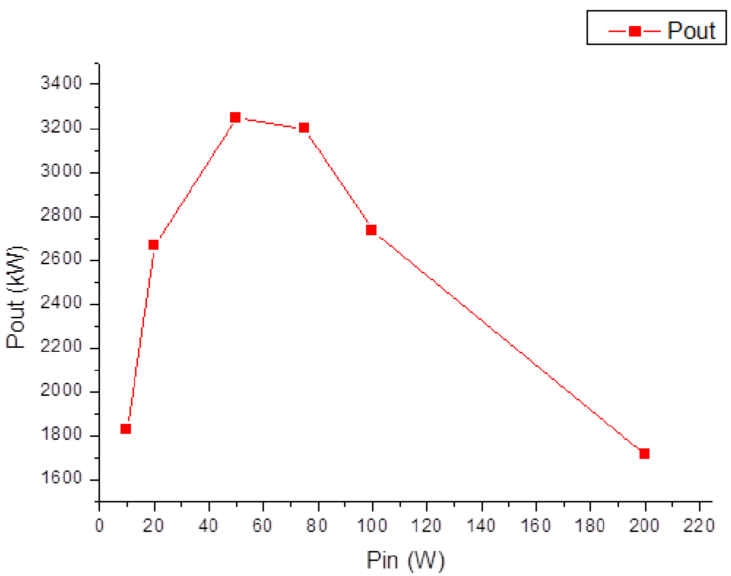
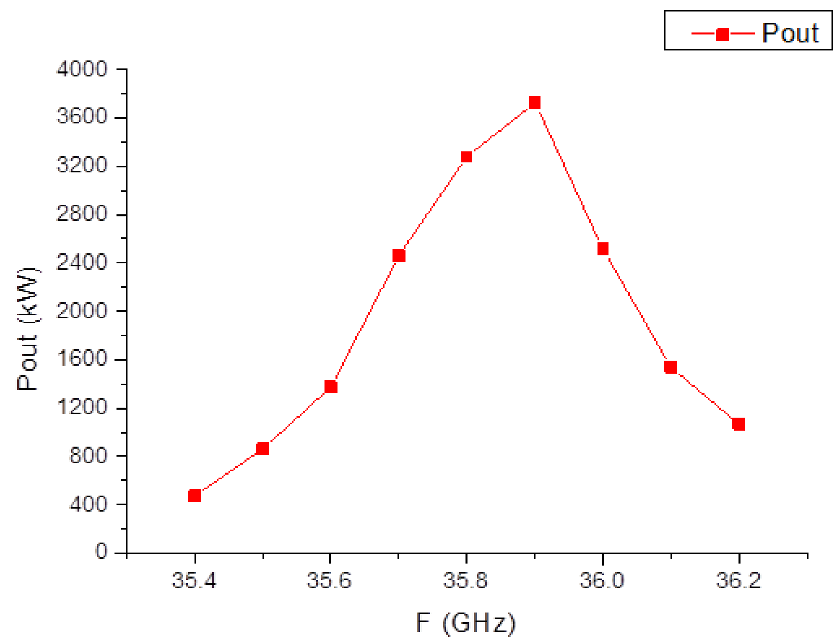
36GHz Frequency, Input & Output Power

Fourier Transform of Output Signal







36GHz Collector Simulations

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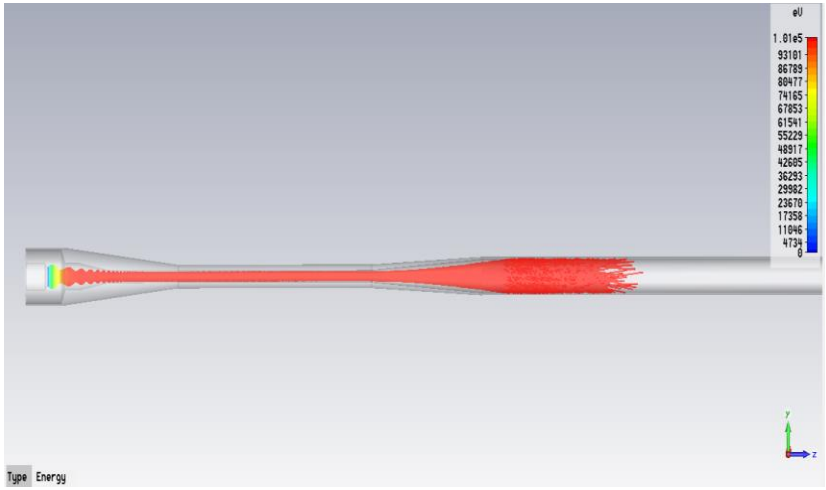
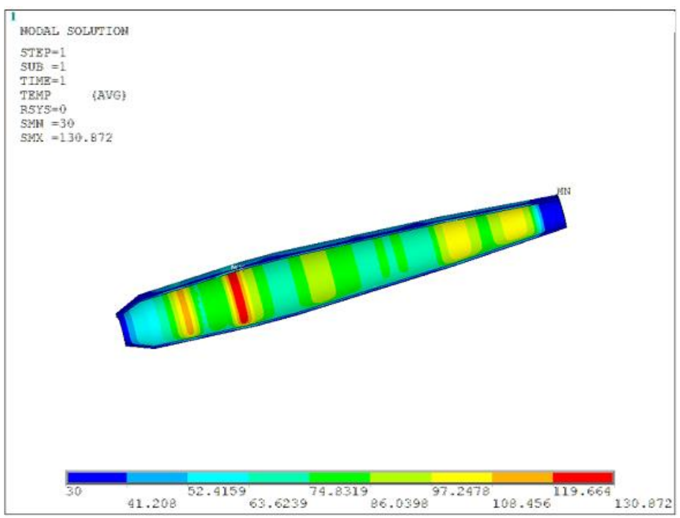
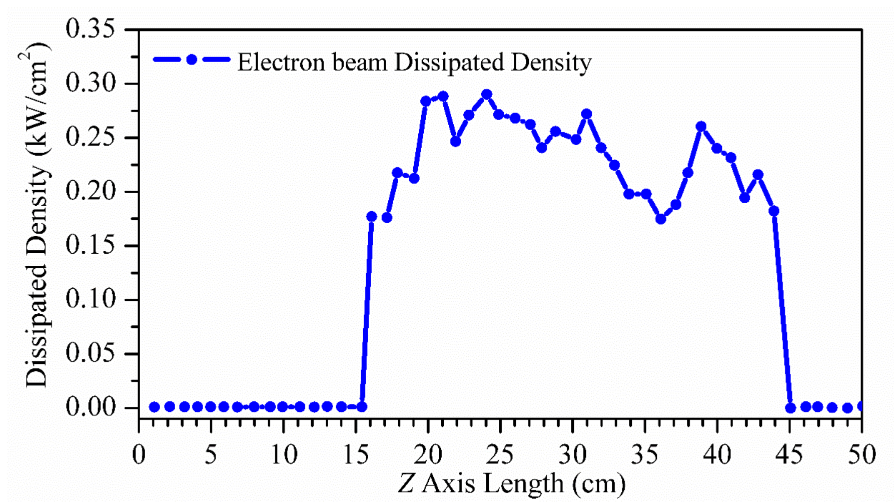


τ=1.5μs， f=1000Hz； V=150kV； I=50A， η=40%；
Electron beam power 7.5MW;
Output microwave power 3MW;
We ignore the loss power (for it is small)
Power in the spent beam 4.5MW;
Average spent beam power is 6.75kW；
Structure optimized for higher average power capability with fins added to lower the temperature on the collector
85W/cm^2 power loading at 1000Hz rep. rate.





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Voltage (kV)	150	Current (A)	50
Velocity ratio	1.4	Drive power (W)	400
Beam guide radius (mm)	2.3	Magnetic field (T)	1.46
36GHz Gyro-Klystron can operate a PRF of 1kHz			
Power (MW)	3.0	Bandwidth	0.3%
Efficiency	40%	Gain (dB)	39 (max 42)

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48 GHz, 1.5 MW Gyro-klystron

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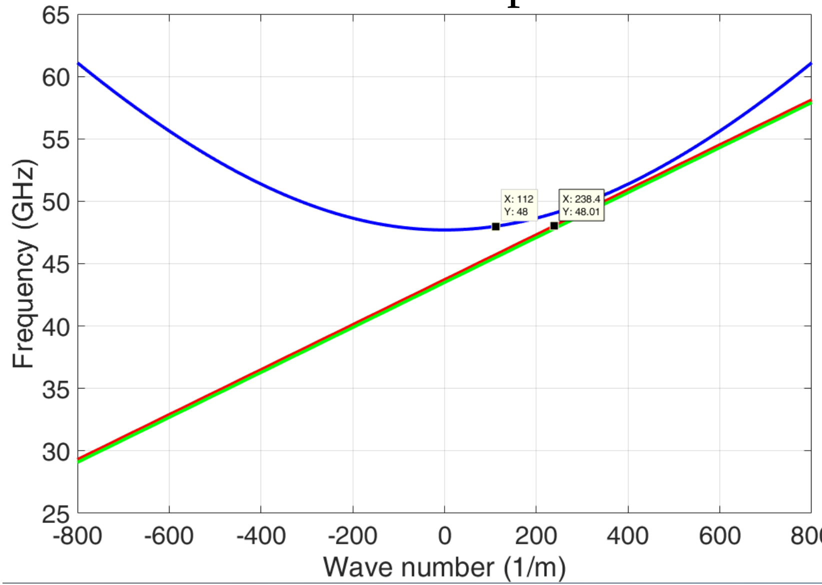
Beam parameters		Frequency (GHz)	
Beam voltage	150kV	Input cavity (TE01)	47.86
Beam current	30 A	Intermediate cavity (TE01)	47.22
Beam alpha	1.35	Output cavity (TE02)	47.7
Cavity number	3		
Magnetic field (T)	2.02 T		
Larmor radius	0.53 mm		

Beam-wave dispersion



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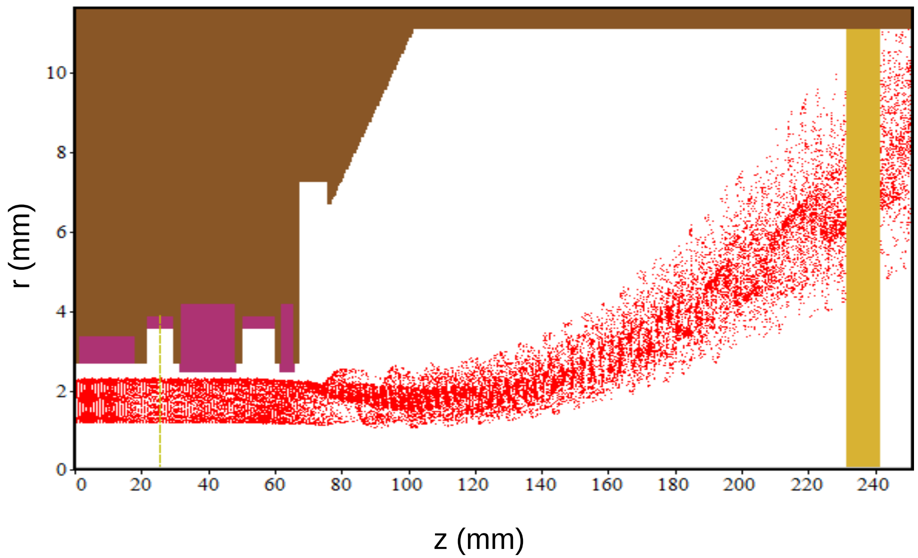
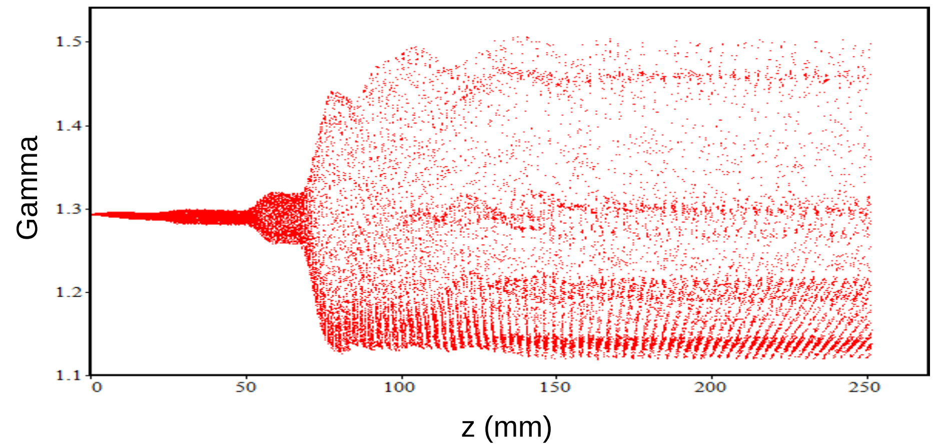
48 GHz Gyro-Klystron Magic Simulations

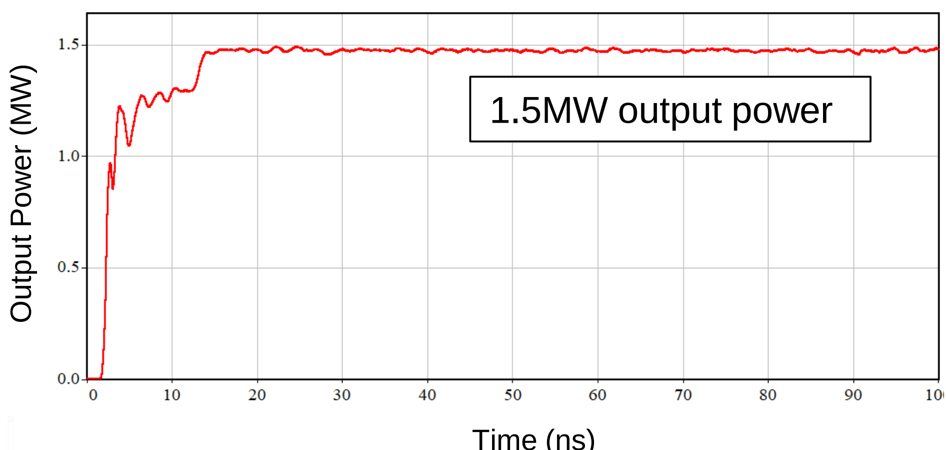
Electron Phasespace (z,r)



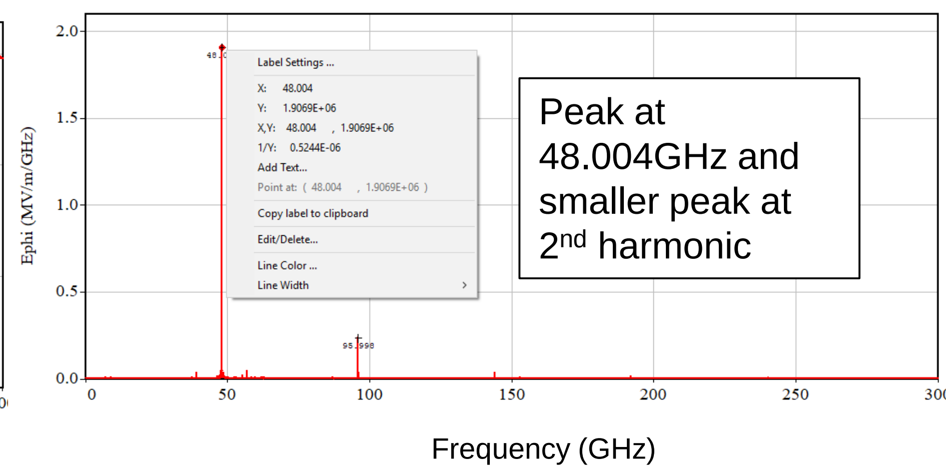
Electron Phasespace (z,γ)



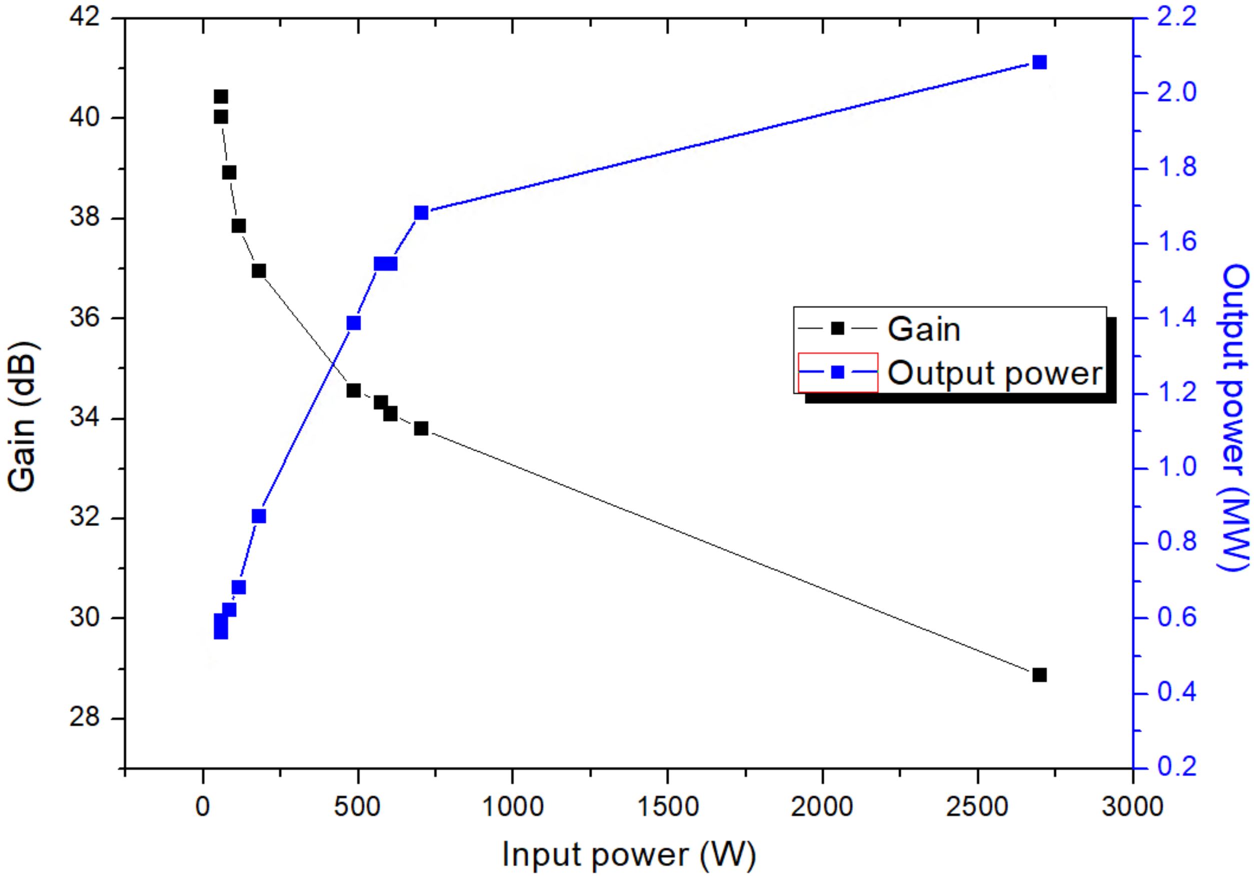
Output Power



Fourier Transform of Output



48 GHz Gyro-Klystron Magic Simulations



More parameter sweeps are in progress to build up a detailed analysis of performance, and to optimise the design toward higher gain and efficiency

Conclusion

- 36GHz, Gyro-klystron (Strath, UESTC, Schenzhen)
  - 36GHz, 3 MW, 1kHz pulse repetition
  - SLED II compressor, ~10MW at 36GHz
- 48GHz Gyro-klystron (Strathclyde)
  - 48GHz, 1.5MW
  - SLED II compressor, ~5MW at 48GHz
- Ka-band Gyro-klystrons have been developed and operated for many years in radar systems
  - CPI, USA
  - Gycom, Russia

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Acknowledgement

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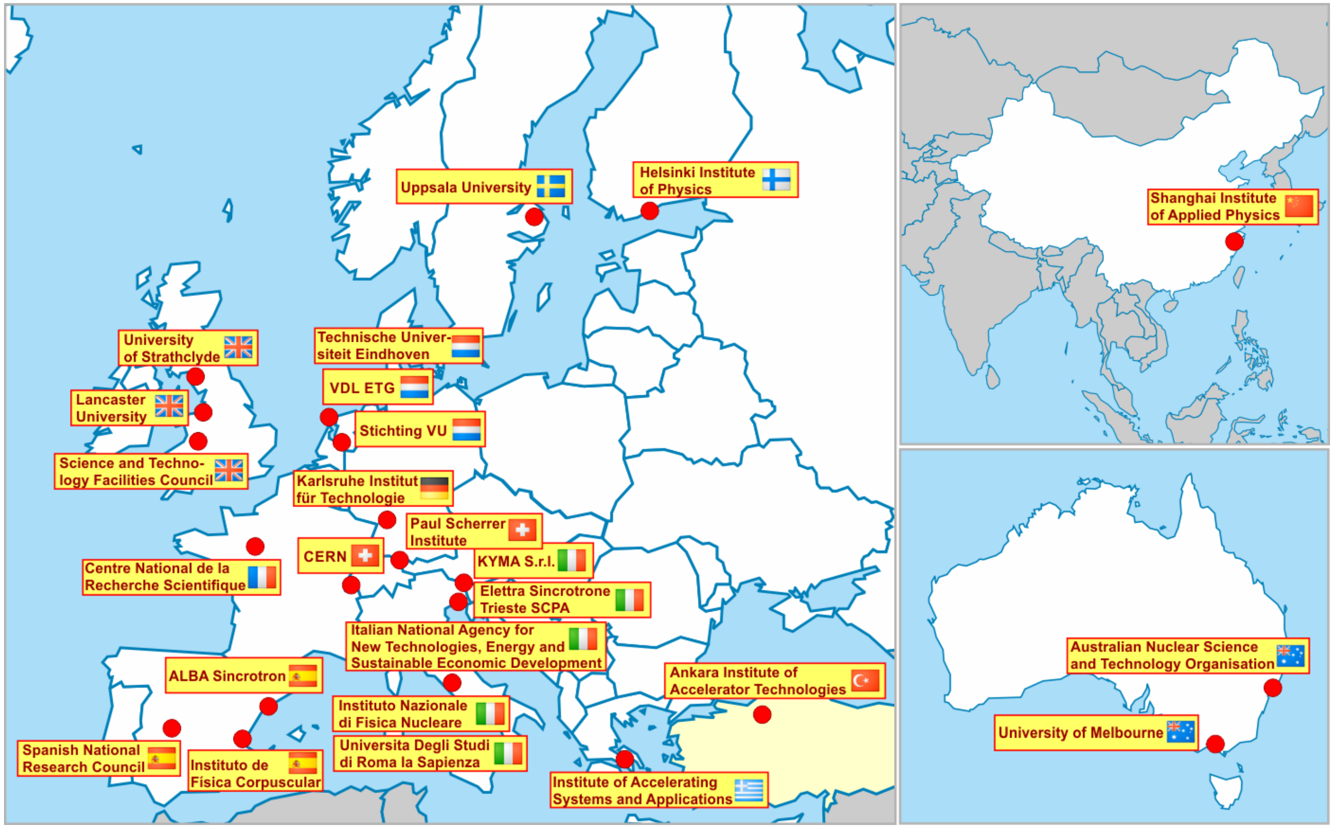

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