



Klystron



Possible RF Sources

- Klystron today
Frequency Range: ~350MHz to ~17GHz
Output Power: CW: up to ~1.3MW
Pulsed: up to ~200MW at ~1ms
up to ~10MW at ~1ms
Klystron Gun Voltage: DC: ~100kV
Pulsed: ~600kV at ~1ms
~130kV at ~1ms
- ~~Tetrode, Triode: Frequency up to ~200-300MHz, ~10kW~~
- ~~IOT: Frequency up to ~1.3GHz, Power: ~30kW, HOM IOT maybe 5MW in the future~~
- ~~Gyroklystron: Frequency above ~20GHz, ~10MW~~
- ~~Gyrotron: Frequency typical 100GHz, ~1MW~~
- ~~Magnetron. Oscillator, ~10MW~~
- ~~Travelling Wave Tube, Magnicon, Orbitron, Amplicon etc.~~

Not for ILC

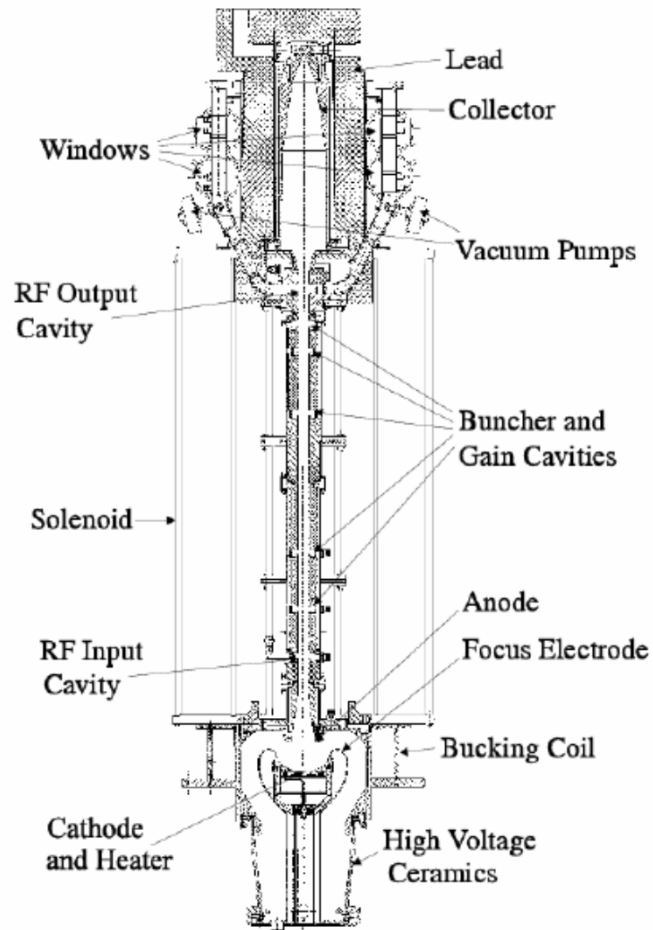


Klystron Theory

- The klystron principle will be explained
- A basic and simplified theory can be found in the appendix
- Today klystrons or subcomponents of klystrons are designed and calculated making use of different computer codes (Egun, FCI, Mafia, Microwave Studio, Ansys, Magic, special codes developed by klystron manufacturers ...)
- PIC codes have been developed recently



Klystron Principle



Example: 150MW,
3GHz S-Band Klystron

- The cathode is heated by the heater to $\sim 1000^{\circ}\text{C}$.
- The cathode is then charged (pulsed or DC) to several 100kV.
- Electrons are accelerated from the cathode towards the anode at ground, which is isolated from the cathode by the high voltage ceramics.
- The electron beam passes the anode hole and drifts in the drift tube to the collector.
- The beam is focussed by a bucking coil and a solenoid.
- By applying RF power to the RF input cavity the beam is velocity modulated.
- On its way to the output cavity the velocity modulation converts to a density modulation. This effect is reinforced by additional buncher and gain cavities.
- The density modulation in the output cavity excites a strong RF oscillation in the output cavity.
- RF power is coupled out via the output waveguides and the windows.
- Vacuum pumps sustain the high vacuum in the klystron envelope.
- The beam is finally dumped in the collector, where it generates X-rays which must be shielded by lead.



Klystron Perveance

- Perveance $p = I / U^{3/2}$ (I = klystron current, U = Klystron voltage) is a parameter of the klystron gun determined by the gun geometry (Theory see Appendix)
- Example: THALES TH2104C 5MW, 1.3GHz Klystron $U=128\text{kV}$ $I=89\text{A}$
 $p=1.94 \cdot 10^{-6} \text{A/V}^{3/2}$ (mperveance=1.94)





Klystron Output Power

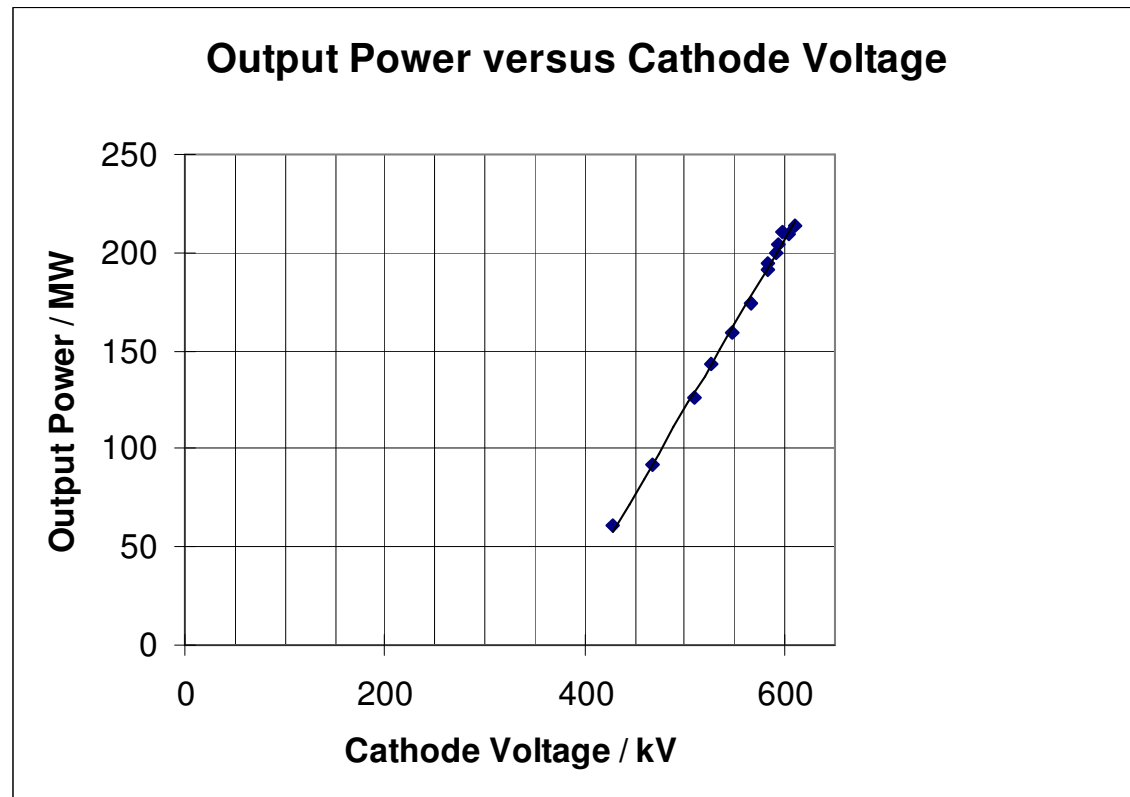
$$P_{RF} = \eta P_{Beam}$$

$$P_{Beam} = UI$$

$$P_{Beam} = pU^{5/2}$$

$$\eta = \eta(U) \propto U^{>0}$$

$$P_{RF} \propto U^{>5/2}$$

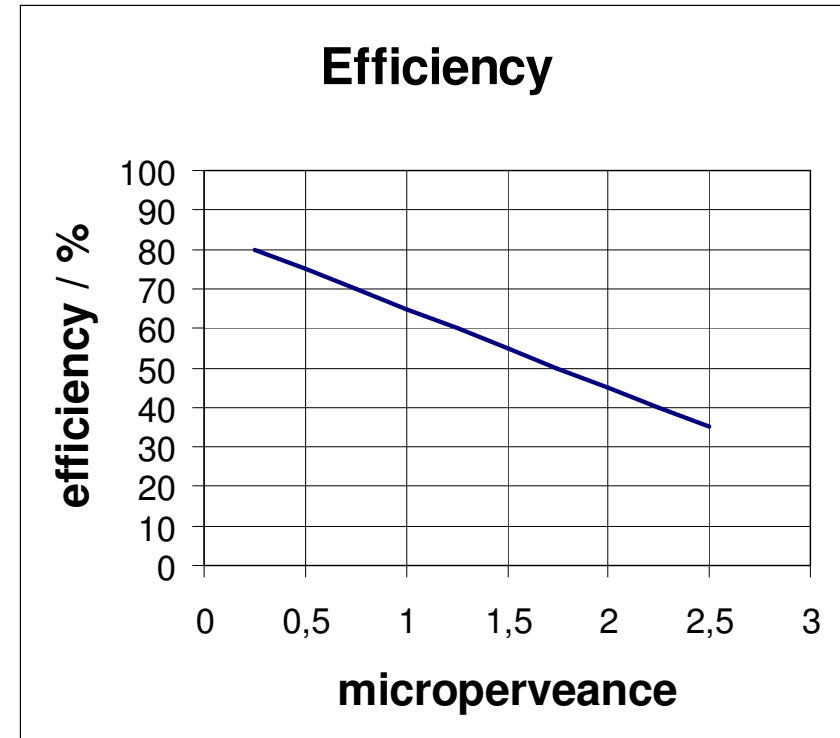


Example: RF output power of a 3GHz (S-band) klystron as function of the voltage



Klystron Efficiency

- Efficiency of a klystron depends on bunching and therefore on space charge forces
- Lower space forces allow for easier bunching and more efficiency
- Decreasing the charge density (current) and increasing the stiffness (voltage) of the beam increase the efficiency
- Higher voltage and lower current, thus lower perveance would lead to higher efficiency



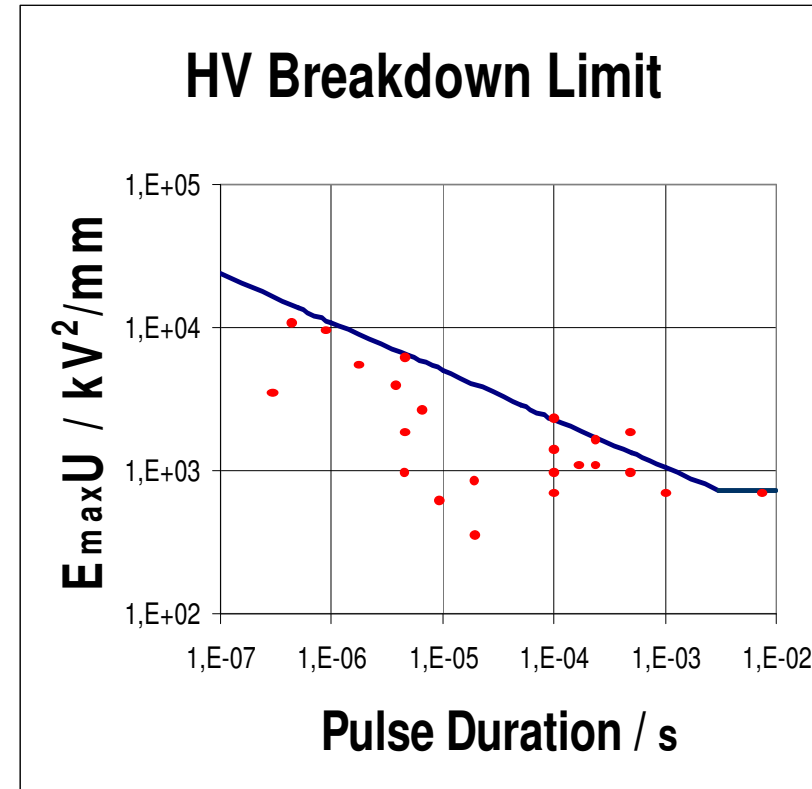
Rule of thumb formula from fit to experimental data

$$\eta = 0.85 - 2 \times 10^5 \times p$$



Klystron Gun Breakdown Limit

- Disadvantage: higher voltage increase the probability of breakdown
- The breakdown limit EU depend on the pulse duration



$$E_{max} \times U = 100 \times \tau^{-0.34} (kV)^2 / mm$$



Multibeam Klystron

Idea

Klystron with low perveance:

=> High efficiency but high voltage

Klystron with low perveance and low high voltage

=> low high voltage but low power

Solution

Klystron with many low perveance beams:

=> low perveance per beam thus high efficiency

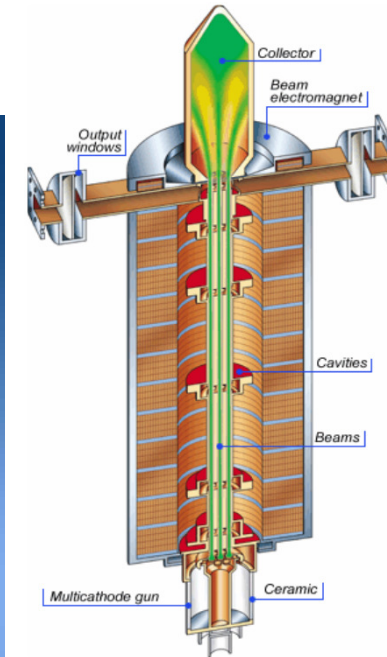
low voltage compared to klystron with single low perveance beam



Multi Beam Klystron THALES TH1801 (1)

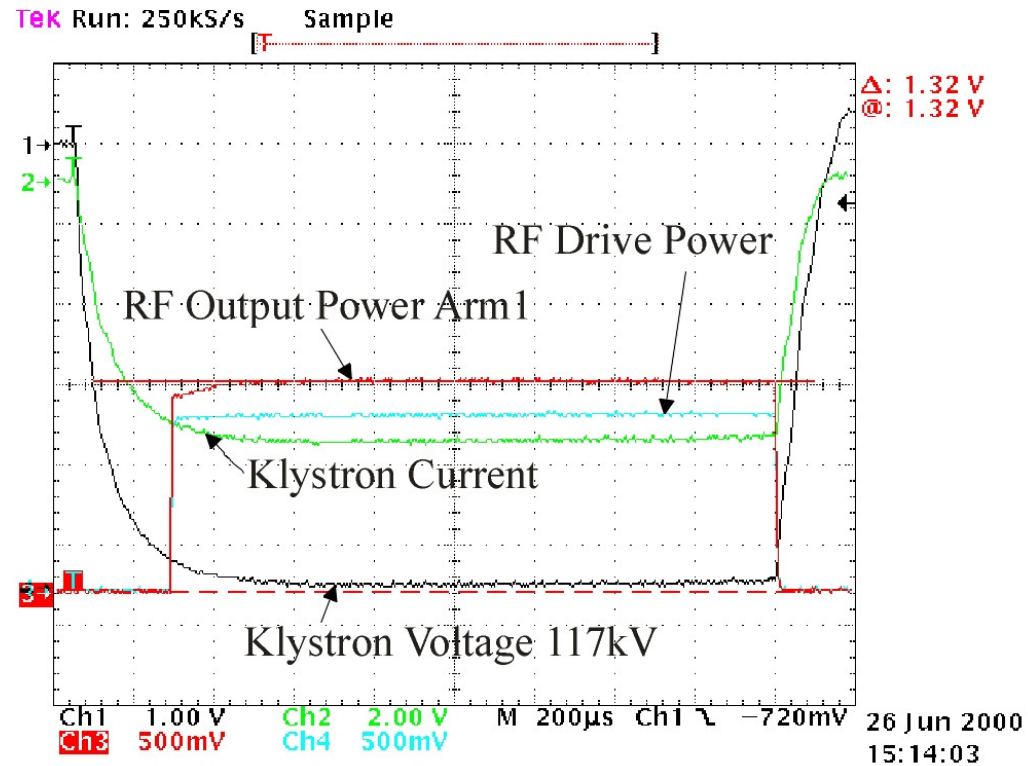
Measured performance

Operation Frequency:	1.3GHz
Cathode Voltage:	117kV
Beam Current:	131A
mperveance:	3.27
Number of Beams:	7
Cathode loading:	5.5A/cm ²
Max. RF Peak Power:	10MW
RF Pulse Duration:	1.5ms
Repetition Rate:	10Hz
RF Average Power:	150kW
Efficiency:	65%
Gain:	48.2dB
Solenoid Power:	6kW
Length:	2.5m
Lifetime (goal):	~40000h





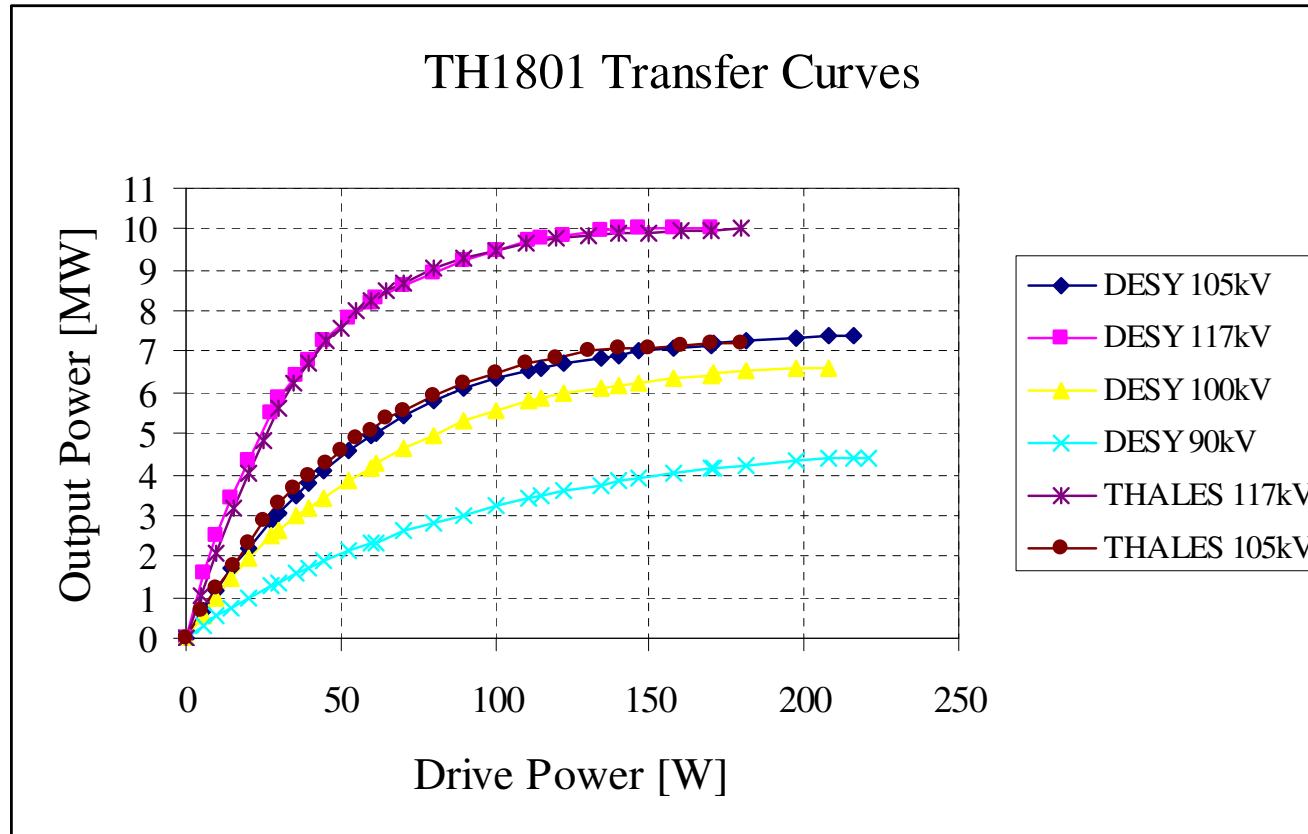
Multi Beam Klystron THALES TH1801 (2)



Pulse Waveforms of a Klystron (Voltage, Current, RF Drive Power, RF Output Power)



Multi Beam Klystron THALES TH1801 (3)



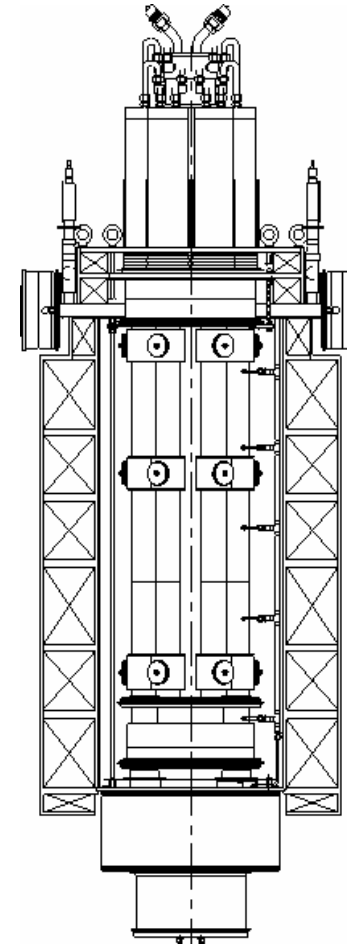
Transfer Curves: RF output as function of RF drive power with klystron voltage as parameter



Multi Beam Klystron CPI VKL-8301(1)

Design Features:

- 6 beams
- HOM input and output cavity
- Individual intermediate FM cavities
- Cathode loading: $<2.5\text{A}/\text{cm}^2$ lifetime prediction: $>100000\text{h}$



Drawing of the Klystron



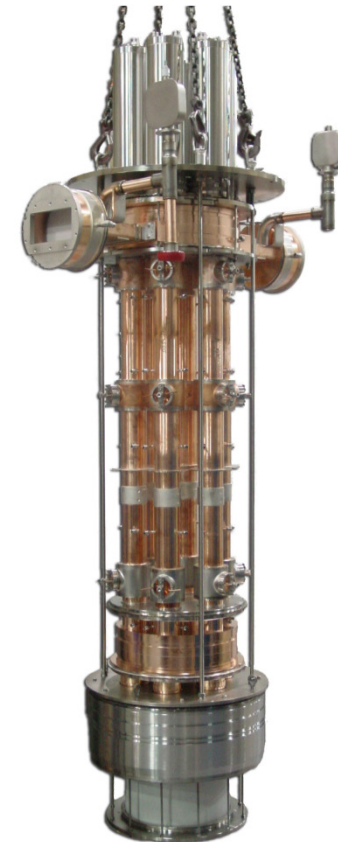
Multi Beam Klystron CPI VKL-8301 (2)

Specified Operating Parameters

Peak Power Output	10	MW (min)
Ave. Power Output	150	kW (min)
Beam Voltage	114	kV (nom)
Beam Current	131	A (nom)
mperveance	3.40	
Frequency	1300	MHz
Gain	47	dB (min)
Efficiency	67	% (nom)
Cathode Loading	2.0	A/cm ²
Dimensions	H,Ø:	2.3 by 1.0 meters
Weight	2000	lbs

Electromagnet

Solenoid Power	4	kW (max)
Coil Voltage	200	V (max)
Weight	2800	lbs



Klystron during construction



Multi Beam Klystron CPI VKL-8301 (3)

Measured Operating Parameters at CPI at 500ms pulsewidth

Peak Power Output	10	MW
Ave. Power Output	150	kW
Beam Voltage	120	kV
Beam Current	139	A
mperveance	3.34	
Frequency	1300	MHz
Gain (saturated)	49	dB
Efficiency	60	%

Beam Transmission

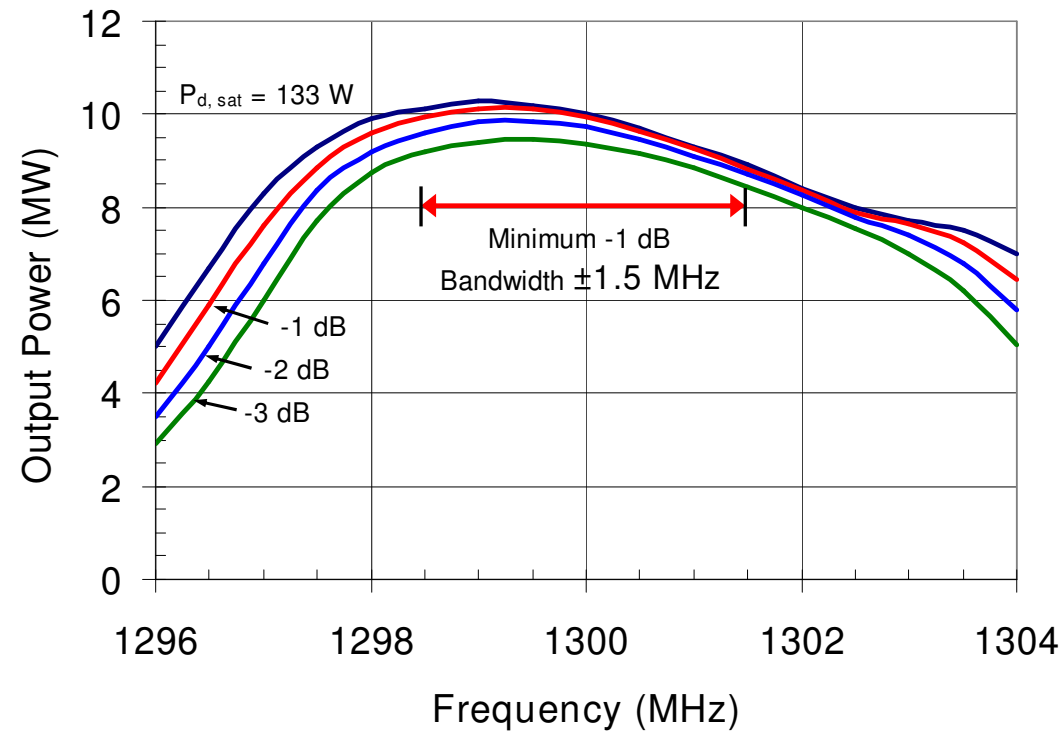
DC, no RF	99.5	%
at Saturation	98.5	%



Klystron ready for shipment



Klystron CPI



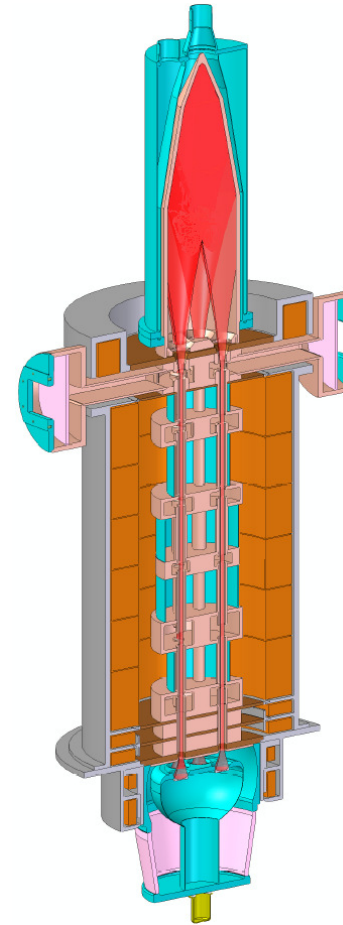
Output power as function of frequency



The TOSHIBA E3736 MBK (1)

Design Features:

- 6 beams
- Ring shaped cavities
- Cathode loading: $<2.1 \text{ A/cm}^2$



Design Layout



The TOSHIBA E3736 MBK (2)

Measured performance

Voltage: 115kV

Current: 135A

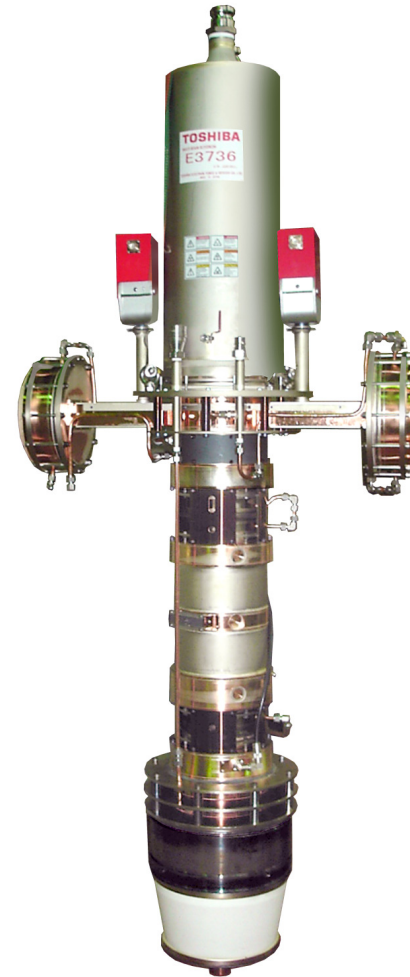
Impedance: 3.46

Output Power: 10.4MW

Efficiency: 67%

Pulse duration: 1.5ms

Rep. Rate: 10Hz



Klystron ready for shipment



Horizontal Klystron

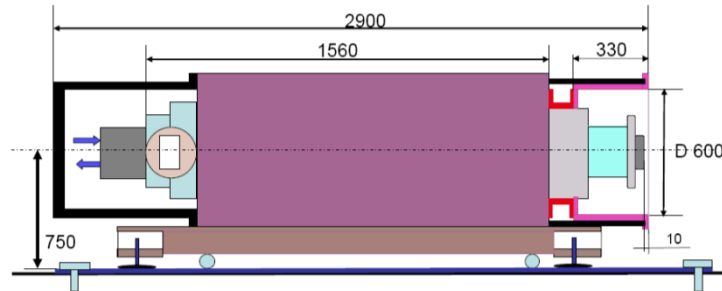
- Horizontal klystrons are already in use e.g. the LEP klystrons at CERN or the B-factory klystrons at SLAC

Aspects

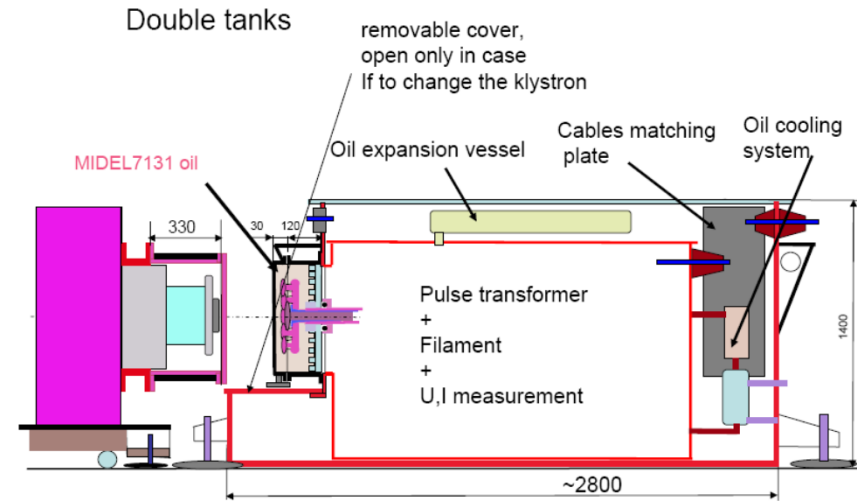
- Space in tunnel
- Transportation of klystron and pulse transformer in the tunnel
- Exchange of the klystrons
- Ease of interchange of different types of klystrons to pulse transformer tank and to waveguide distribution system
- X-ray shielding
- Oil leakage



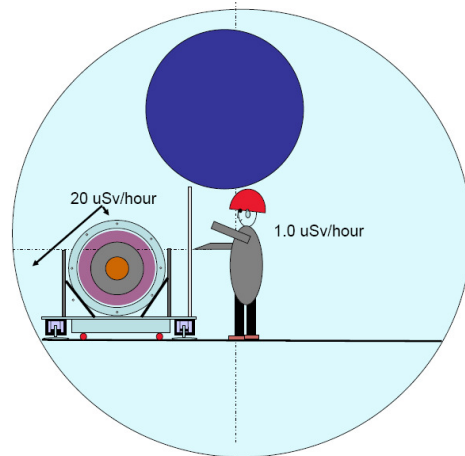
Horizontal MBK



Horizontal MBK



MBK gun and pulse transformer



X-Ray shielding



Klystron Replacement for the TESLA Linear Collider

- The klystron lifetime will be determined most likely by the cathode lifetime since other klystron components are operated at a moderate level
- With a klystron lifetime of 40000h and an operation time of 5000h per year 8 klystrons must be replaced during a monthly access day
- An overhead of 12 klystrons will be installed, therefore no degradation of accelerator performance is expected between two access days
- Teams of 3-4 people will exchange a klystron within a few hours; klystrons will be equipped with connectors (HV, controls, cooling, waveguides) which allow fast exchange of a klystron in the tunnel

