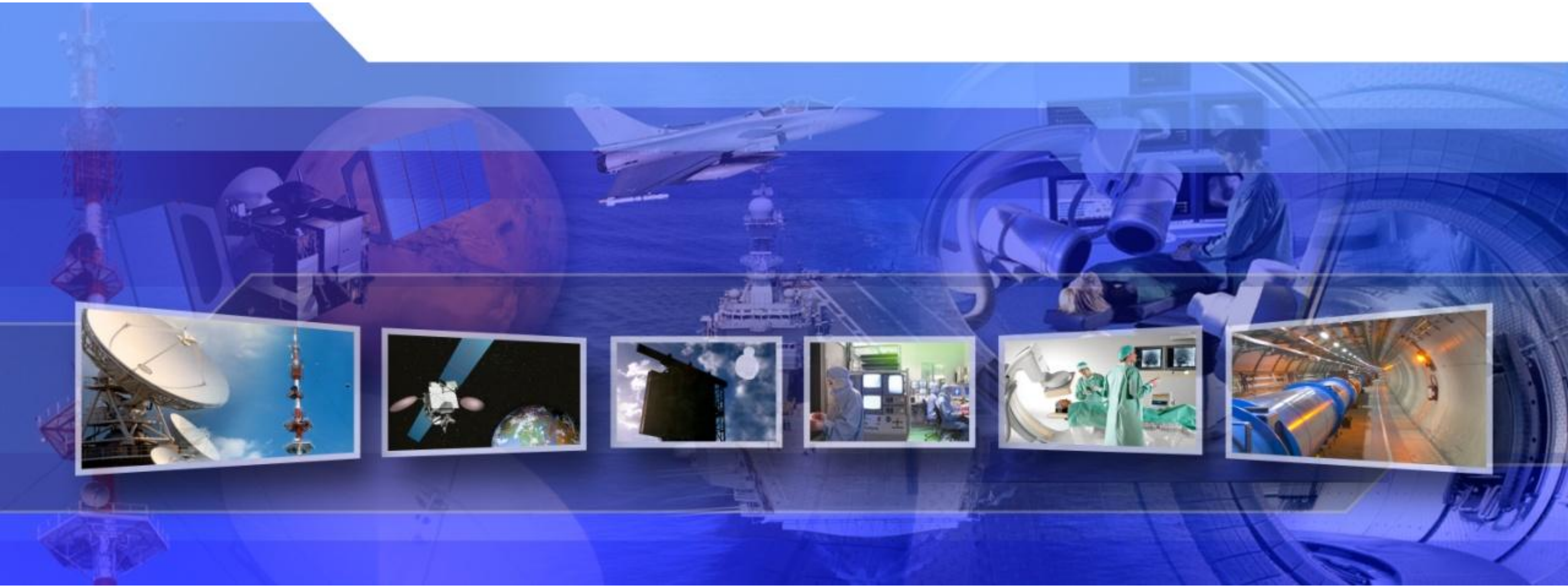
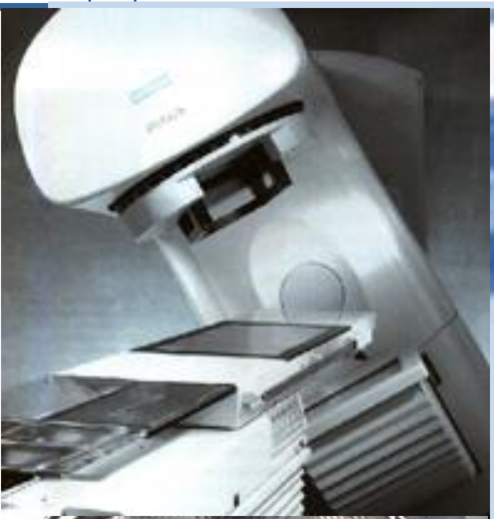


Contribute to success of scientific programs in industrial, physics and medical applications

Industrial, Science and Medical applications (ISM)



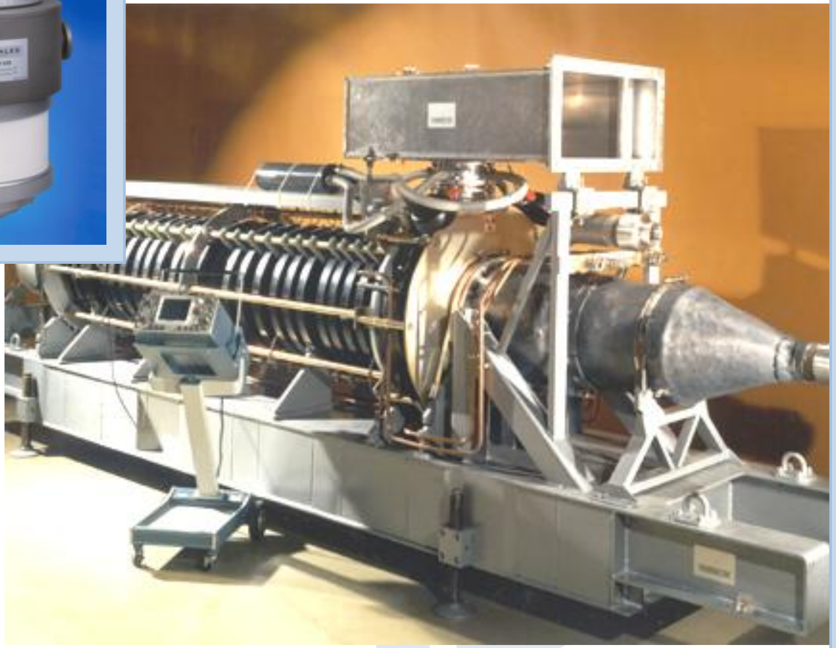
Contribute to success of scientific programs in biology, industry, healthcare, energy sources...

- **World leader in microwave & RF sources and imaging devices for scientific research and for professional applications**
- **Partnership with the most prestigious research centers and universities worldwide.**

A very wide range of electron tubes for research and professional applications

Diacrode

Klystron for oncology



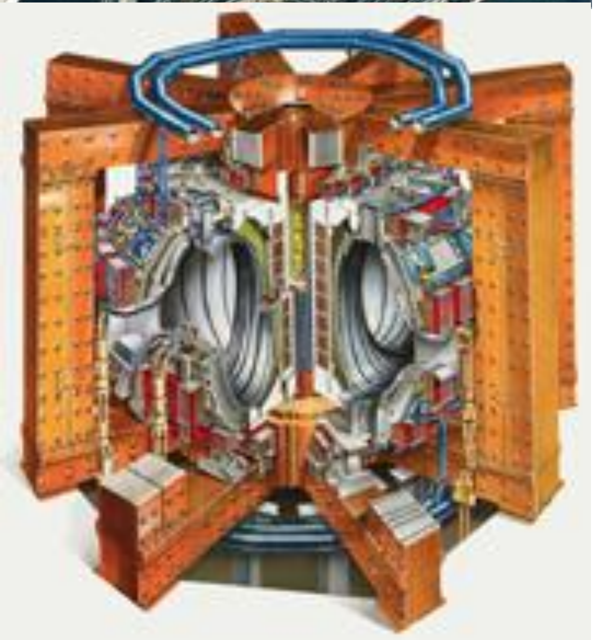
Very high power klystron for particle accelerator

140 GHz Gyrotron for fusion

Microwave tubes performances

The microwave are used to transport the energy. The scientific machines require very large amount of pulsed and CW, RF power.

- **Working frequencies: 50 MHz to 200 MHz**
- **Power range : 1MW CW to 100 MW peak**



Electron tubes are the power devices in:

- **Particule accelerators for**
  - Research, Synchrotrons

    (Fundamental physics reseach research in biology, chimistry, medicine,…)
  - Therapy
  - Industry (food decontamination, sterilization)
  - Security (non detructive control of trucks, containers…)
- **Fusion machines for**

  Energy production experiments

Some programs

- **Commercial :**

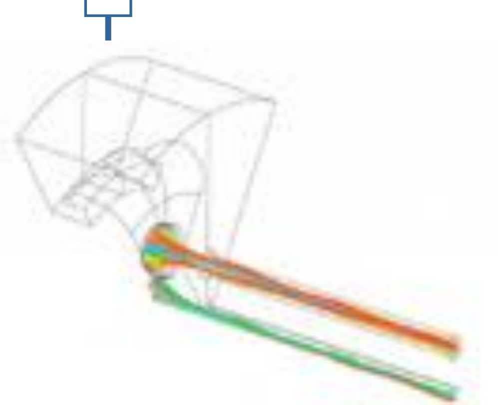
  Advanced Photon Source (Argonne Labs), LEP (CERN), DESY, JET, Tore Supra, FTU, ESRF, IPR

- **Military :**

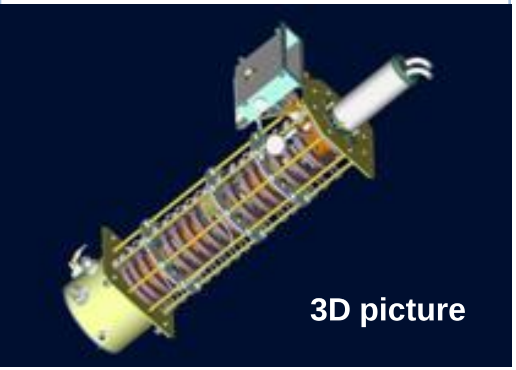
  ELSA, SDI

In contact with the world's physical sciences research community:

ESRF, GANIL, LURE, ANKA, BESSY, COSY, DESY, GSI, LNF, NIKHEF, MIT-Bates, CERN, PSI, Rutherford Appleton, Daresbury, LBNL, BNL, CHESS, Fermi, LANL, ANL, SLAC, KEK, RIKEN, Spring-8, AGS, NSRL, DAFNE, BINP, TRIUMF, SBSL at SUNY, PLS Korea, NSC India



Electron trajectories in MBK



3D picture

In relation with the most awared universities and laboratories

- **Scientific calculs**
- **Developments in collaboration with research laboratories such as : CEA, EPFL, Karlsruhe, los Alamos ...**

Multicathode electron gun

300 kW cw
of RF power klystron

Research applications

- *The microwave tubes are used to accelerate charged particles at very high velocity to perform fundamental research in physics*

  - Linear e accelerator: Orsay (F), SLAC(US)
  - e injectors
  - Large circular colliders: LEP (CERN)
  - Synchrotron radiation sources: ESRF, ELETTRA, BESSY
  - Protons accelerators: LHC (CERN)

  Neutron sources (material physics, transmutation …)

  LEDA > APT & SNS

  IPHI > TRISPAL & CONCERT

  - New e- e+ linear collider: NLC (US), TESLA (D)
  - Specific application: Ionosphere UHF radar

Klystron
for sterilization

Industrial applications

- The microwave tubes are used to accelerate an electron beam at high energy, to obtain an intense X-radiation.

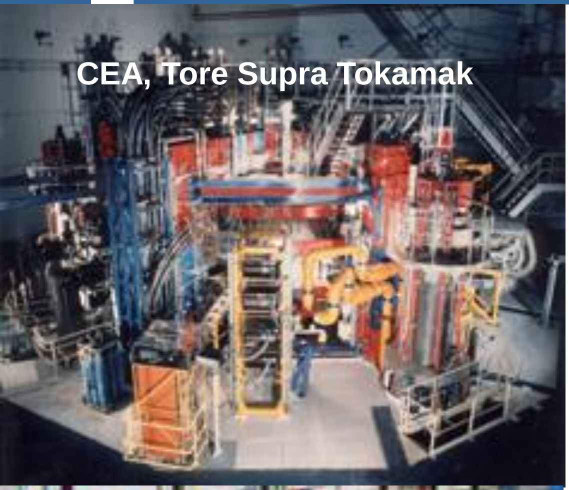
This radiation is used for:

- Food sterilization
- Decontamination
- Non destructive control

High peak power
Klystron for therapy
machine

Therapy applications

- The microwave tube feeds a particule accelerator to accelerate an electron beam, to obtain an X-radiation for cancer therapy



Energy production

Thermonuclear controlled fusion

- **Plasma Heating, current drive, profile control in Tokamaks or Stellarators**

with 0.5 to 2 MW very long pulses and CW

- ION Cyclotron Resonance Heating (ICRH)
Several MHz up to 120 MHZ

- Lower Hybrid Resonance Heating (LHRH)
1 to 8 GHz

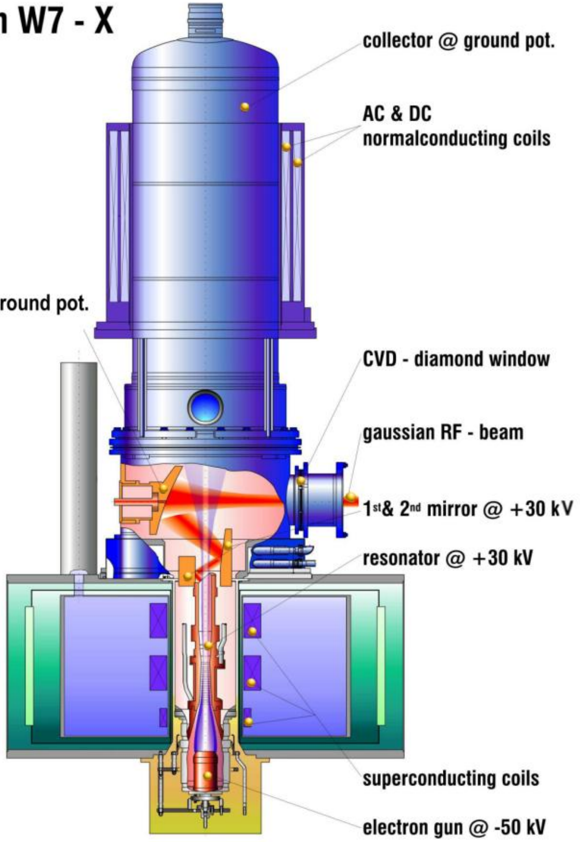
- Electron Cyclotron Resonance Heating (ECRH)
30 to 170 GHz

Examples: Tokamaks ➡ JET, Tore Supra, Frascati, ITER

Stellarators ➡ W-7X project

Design and construction of fusion tube in collaboration

Gyrotron 140 GHz , 1 MW CW for Stellarator **Wendelstein 7-X at IPP Greifswald (Germany)**



Designed and constructed as a join collaboration with FZK-Karlsruhe, CRPP-Lausanne, IPF-Stuttgart, CEA-Cadarache

1 MW power diacrode

Thermonuclear controlled fusion

- Plasma Heating in Tokamaks or Stellarators

Type of plasma resonnance	Frequency domain	type of tube
ION Cyclotron Resonance Heating (ICRH)	10 to 50 MHz	Tetrode or diacrodes
Lower Hybrid Resonance Heating (LHRH)	3 to 10 GHz	Klystrons
Electron Cyclotron Resonance Heating (ECRH)	80 to 200 GHz	Gyrotrons

THALES

Klystrons, TWTs and Gyrotrons

Maximum output power vs frequency

Frequency	P	L	S	C	X	Ku	Ka	F	
Band	350 MHz							118 GHz	140 GHz
Peak output Power (1)	----	30 MW	45 MW	5 MW	----	----	----	----	----
Average output power (1)	----	250 kW	60 kW	10 kW	----	----	----	----	----
Output power (2)	1.3 MW CW	4 MW (10 ms)	650 kW (10 s)	----	1 MW (1 s)	2.5 kW CW	120 W CW	500 kW (210 s)	1 MW CW

1) = Pulsed Tubes

(2) = Long pulse and CW Tubes (pulse length)

The power grid tubes comprise a wide range of tetrodes, triodes, IOTs and diacrodes


Tetrode TH 781


IOT 80KW

TETRODES :

Current RF Modulation in KG_1

DC Acceleration in G_2 A and, at the same time, slowing down of the e^- bunches

Gains ⇗ 14 dB ; Efficiencies ⇗ 65 % (depending of the USWR)

Limitations : overheating of the Anode (e^- bombardement)

overheating of the screen grid G_2 (reactive current losses)

Results : 1,25 MW CW at 60 MHz and 300 KW CW at 200 MHz

DIACRODES :

Double ended tetrode, Important increase of the product "Pout x Freq."

At 70-80 MHz : 2 MW CW and at 200 MHz : 1 MW CW or 3 MW/2ms/650kW

IOT :

RF modulated gridded Pierce' s gun + a klystron output cavity

TV applications (80 kW peak of sync) ; but 250/300 kW feasible.

1.3 GHz, 15 kW IOT for new generation accelerators

High power klystrons

5 MW/ 100 kW long
pulses at 1.3 GHz

- **Klystrons**

are linear beam tubes, where the electron beam(s) travel(s) through resonant cavities separated by narrow drift tubes.

The diameter of these tubes is much less than one wavelength, so there is no inter-cavity coupling.

The input cavity is connected to the signal to be amplified and the output cavity to the utilization.

Multibeam klystron

Separated functions : e^- gun, e^- beam, cavities, drift tubes, window (s), collector, (electro- magnet…)

No more cathode emission modulation, but velocities modulation converted into a density modulation (or e^- bunching) thanks to the cavities and to the drift tubes.

Electron bunches slowing down in the last cavity, where the e^- kinetic energy is transformed into electromagnetic energy.

Gains ☞ 50 dB ; Efficiencies 50 to 65 % (microperveance 1,5 to .5 µperv)

<u>Limitations</u> : overheating of the collector, the output cavity

Breakdown in the gun (DC), in the last cavity (RF) Windows

<u>Results</u> : 1,3 MW at 3 to 500 MHz (➔ = 65 %)

500 to 750 kW at 3,7 GHz (➔ = 45 %)

45-60 MW peak (up to 150 MW), S band, 1-4 µs, 325 kV

MBK (Multi Beam Klystrons)

- **Gyrotrons**

are fast-wave tubes, characterized by an electromagnetic wave whose phase velocity is greater than the speed of the light.

The interaction is located in a single cavity crossed by a strongly spiraling electron beam.

Principle of operation

Overmoded interaction cavity (ex : $TE_{5,1}$ or $TE_{28,8}$…) : large dimensions despite the small millimeter operating wavelengths.

Hollow beam (MIG e^- gun) where the individual electrons spiral at $\Omega = eB/m$ with Ω is just slightly smaller than the operating frequency w (F = 140 GHz, B # 4.5 T)

Azimuthal bunching thanks to the relativistic variation of the e^- mass ($\gamma\, m_o$)

Characteristics

Oscillators

High frequencies

Efficiencies ☞ 30 % up to 45 % with depressed collector

Limitations

Very high magnetic field (supraconductor electromagnet)

Output circuit and modes conversion

Heat dissipation (cavity, collector)

Window

Results

8 GHz	1 MW/ 2 sec.
118 GHz	350 kW/ 200 sec.
140 GHz	900 kW/ 8 sec. and 500 kW/ 3 minutes

Continuous 1 MW CW : horizontal line up to # 200 MHz

The pulsed tubes are concentrated between 1 and 10 GHz : 100 MW/µs or 10 MW/ms

Comments :

-**No only new concepts but also technology improvements**

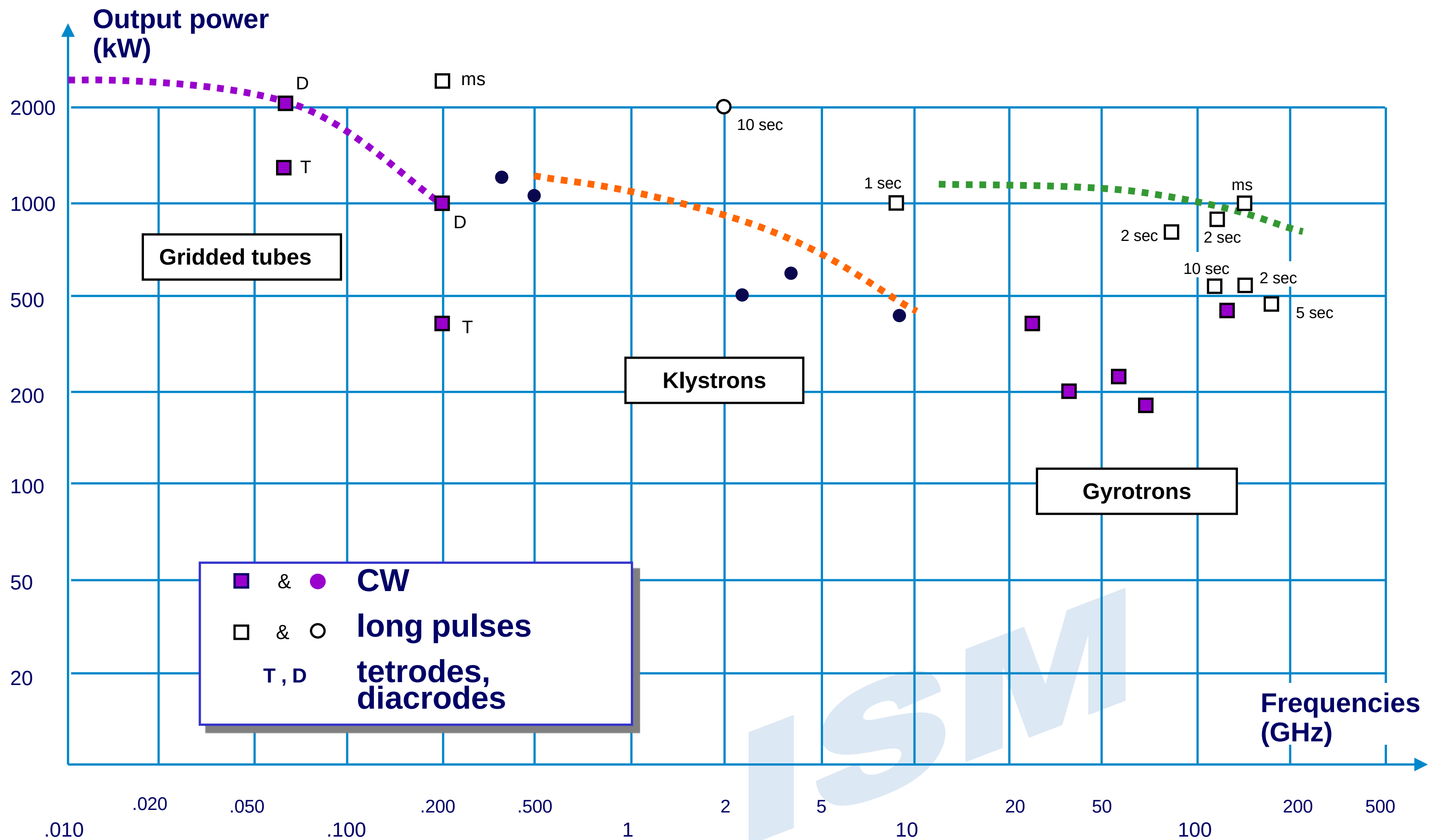
-**Strong efforts to decrease the costs and to increase the reliability**

-**Close collaborations between laboratories and industries (design, technology, tests…)**

-**A lot of development are still requested toward :**

- **Better performances (efficiencies, larger pulses, very high peak powers…)**
- **Easiness of the operations and of the use**
- **Lower Cost of the whole RF generator, including the supplies and the cooling system)**

Output power / frequencies



Thanks you for your attention

Contribute to success of scientific programs in biology, industry, healthcare, energy...