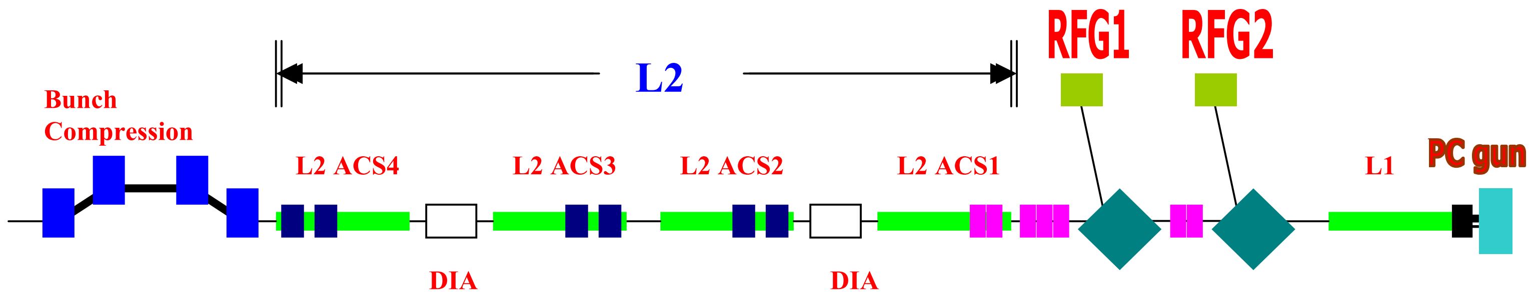
Microwave for Linear Accelerators

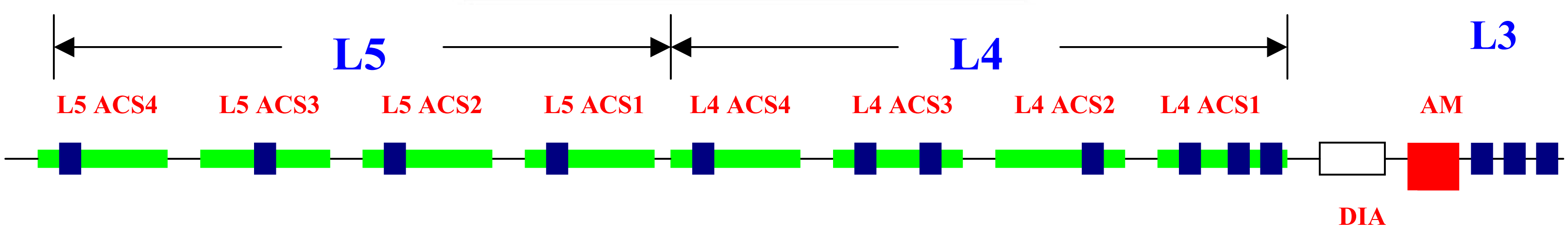
Lecture 4 – October 24, 2002

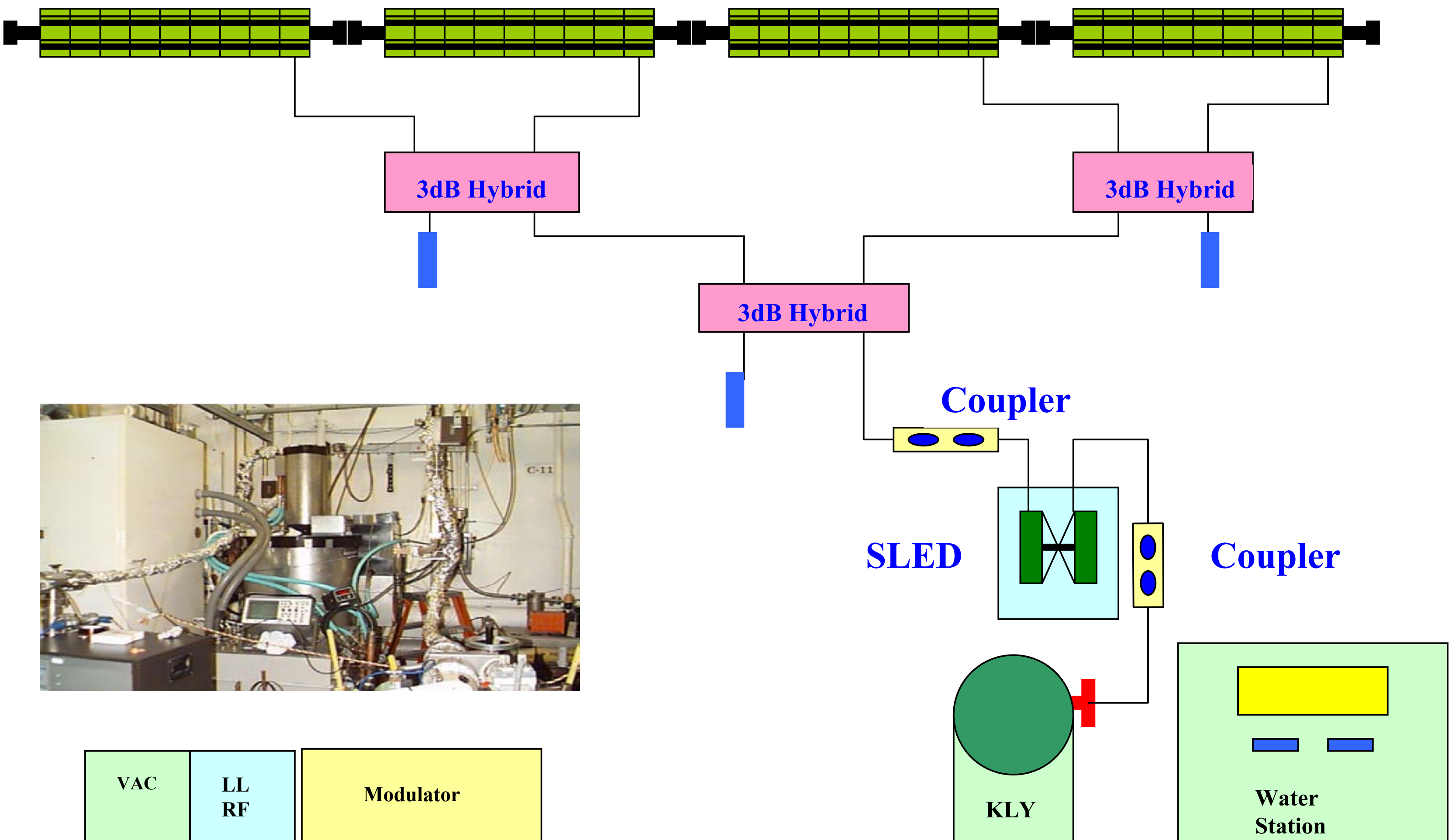
Outline

- Linac Layout
- Power system
- Klystron Operation
- RF Breakdown and RF Conditioning

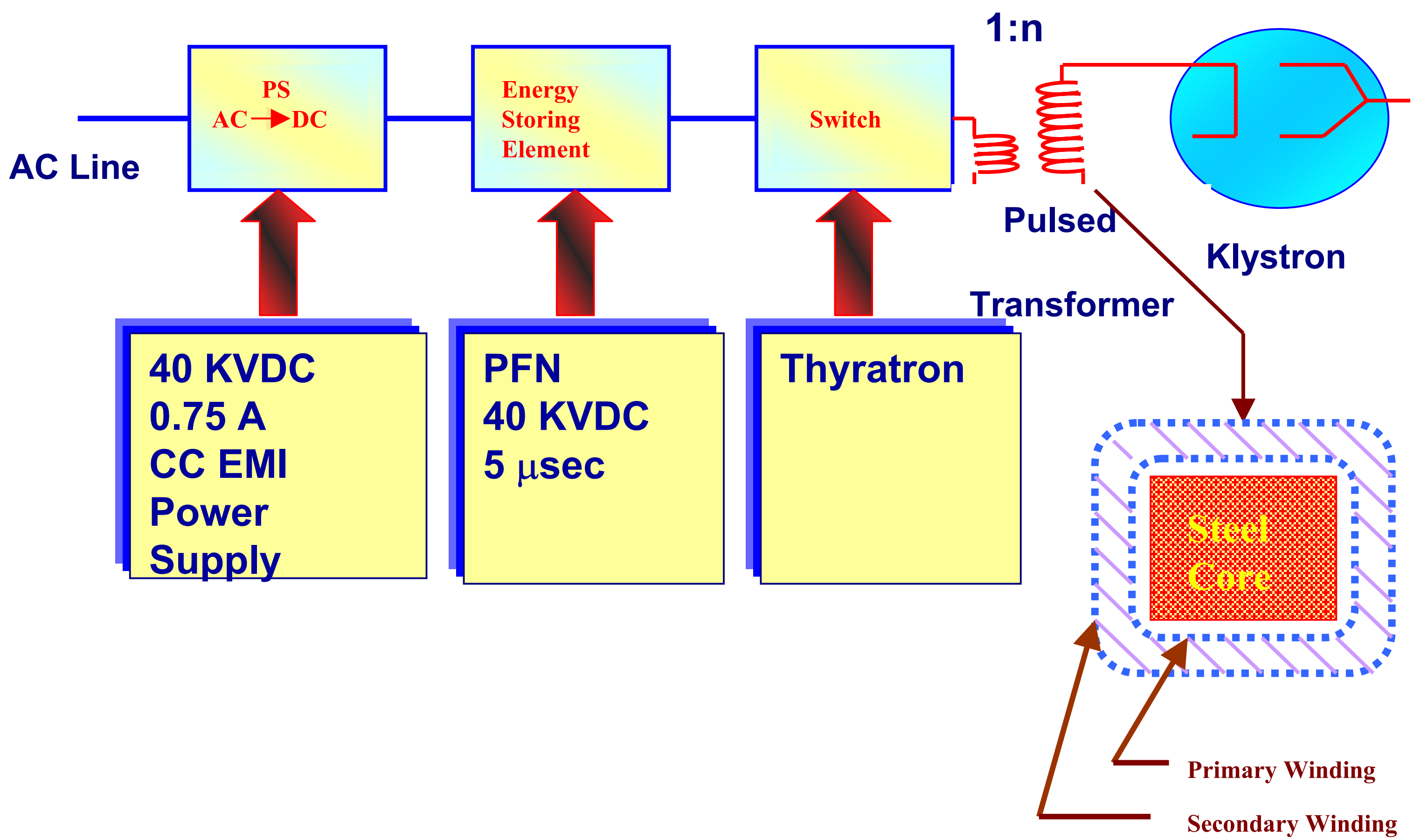
Linac RF Layout

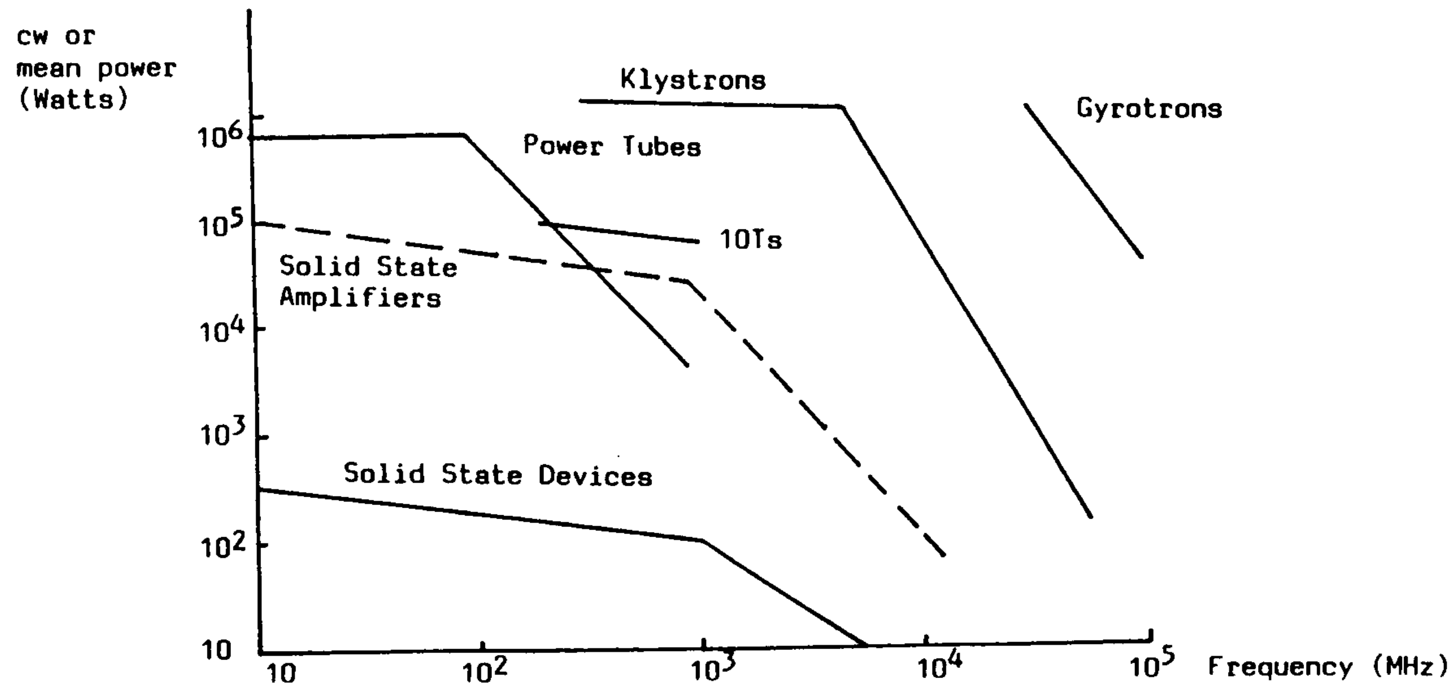




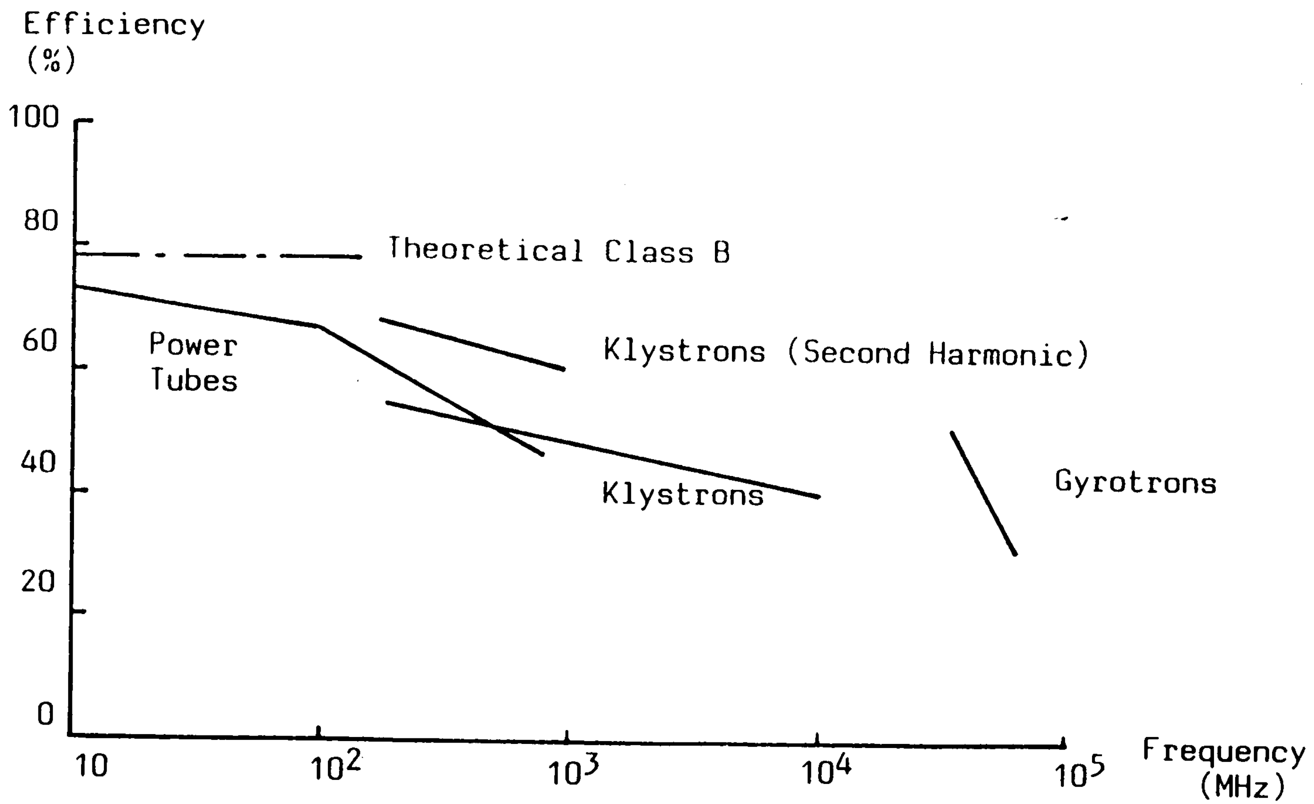

3dB Hybrid
3dB Hybrid
3dB Hybrid
Coupler
SLED
Coupler
KLY
Water Station
VAC
LL RF
Modulator

Linac Modulator System





State of the art of RF power sources

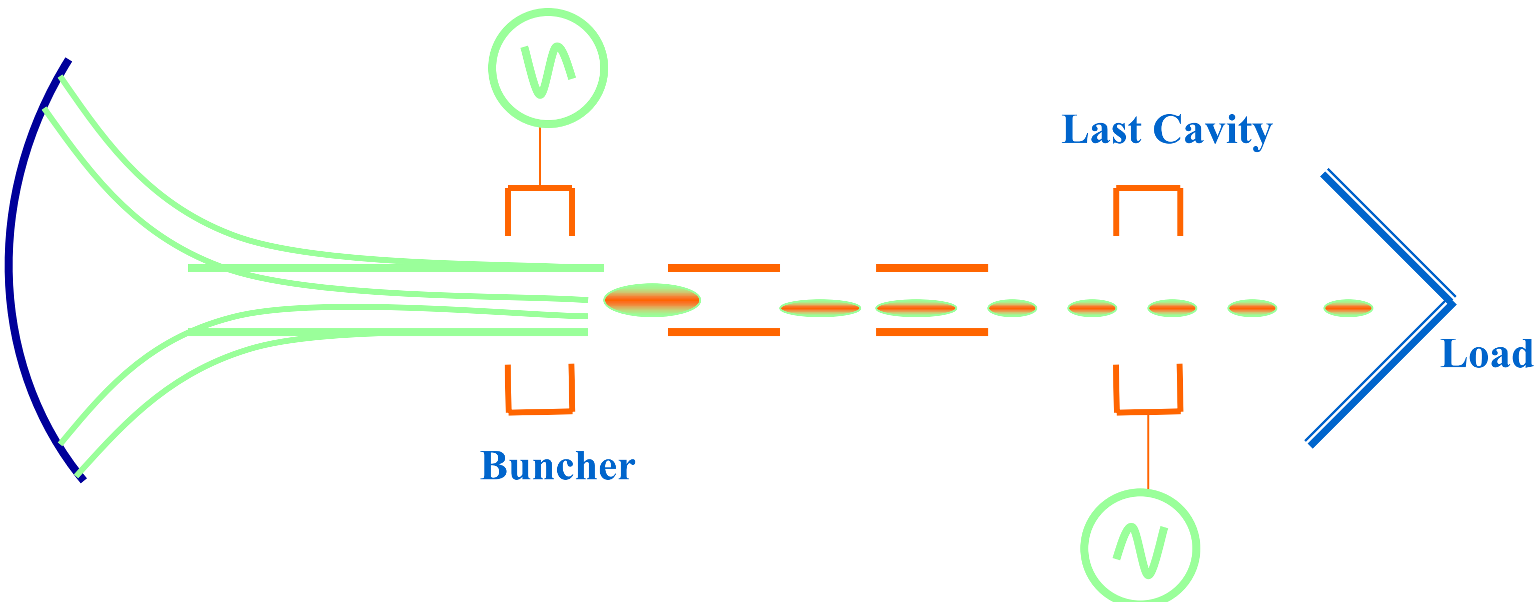

Efficiency
(%)
100
80
60
40
20
0
Theoretical Class B
Power
Tubes
Klystrons (Second Harmonic)
Klystrons
Gyrotrons
10
10^2
10^3
10^4
10^5
Frequency
(MHz)

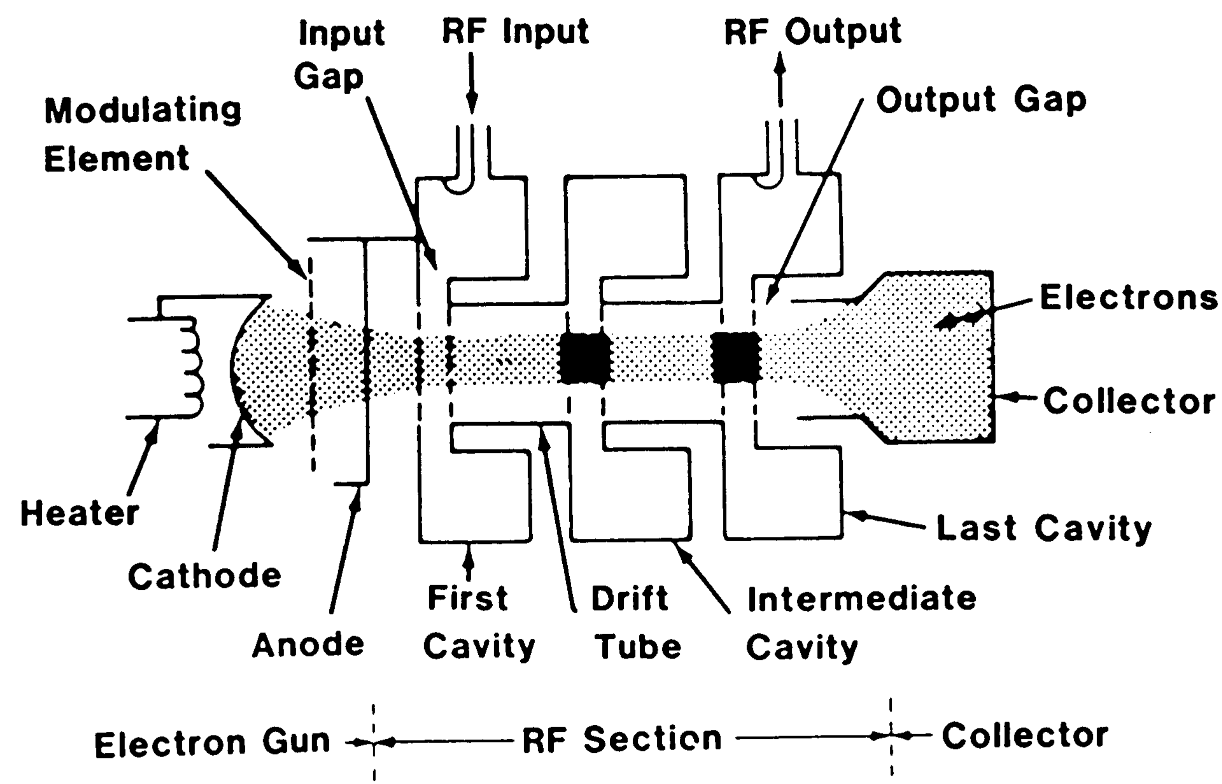
Klystrons

- Klystron was invented at Stanford in 1937. The klystron severed as an oscillator in radar receivers during WWII. After the war, however, very high-power klystrons were built at Stanford for use in the first linear accelerators. This opened the way for the use of klystron not only in accelerators and radar, but also in UHF-TV, satellite communications, and industrial heating.

- Klystrons are high-vacuum devices based on the interaction of well-focused pencil-like electron beam with a number of microwave cavities that it traverses, which are tuned at or near the operating frequency of the tube. The principle is conversion of the kinetic energy in the beam, imparted by high accelerating voltage, to microwave energy. Conversion takes place as a result of the amplified RF input signal, casing the beam to form “bunches.” These bunches give up their energy to the high level induced RF fields at the output cavity. The amplified signal id extracted from the output cavity through a vacuum window.

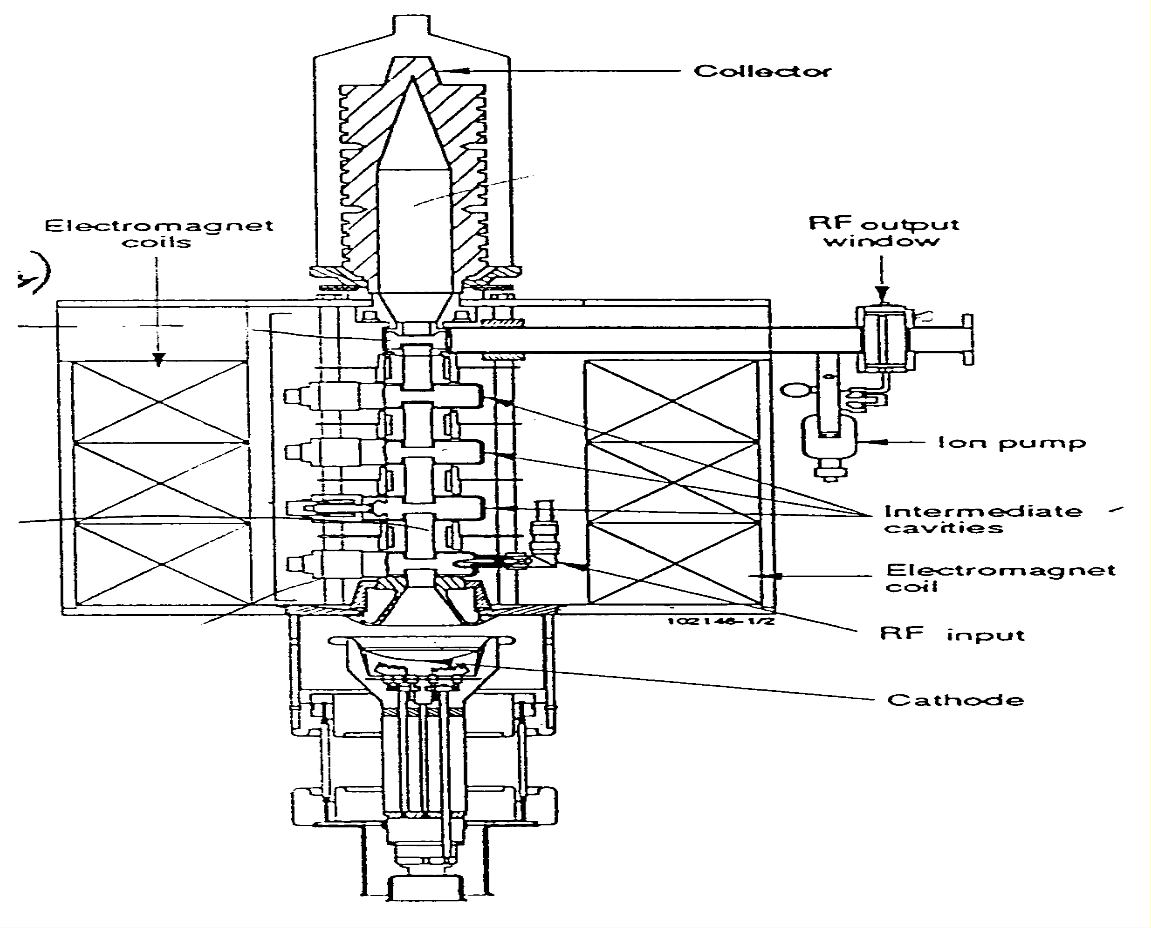
Klystrons




Input
Gap
RF Input
RF Output
Output Gap
Modulating
Element
Electrons
Collector
Heater
Cathode
Anode
First
Cavity
Drift
Tube
Intermediate
Cavity
Last Cavity
Electron Gun
RF Section
Collector

S-Band 35 MW Klystron (TH2128)

General Description of Thomson Klystron TH2128:

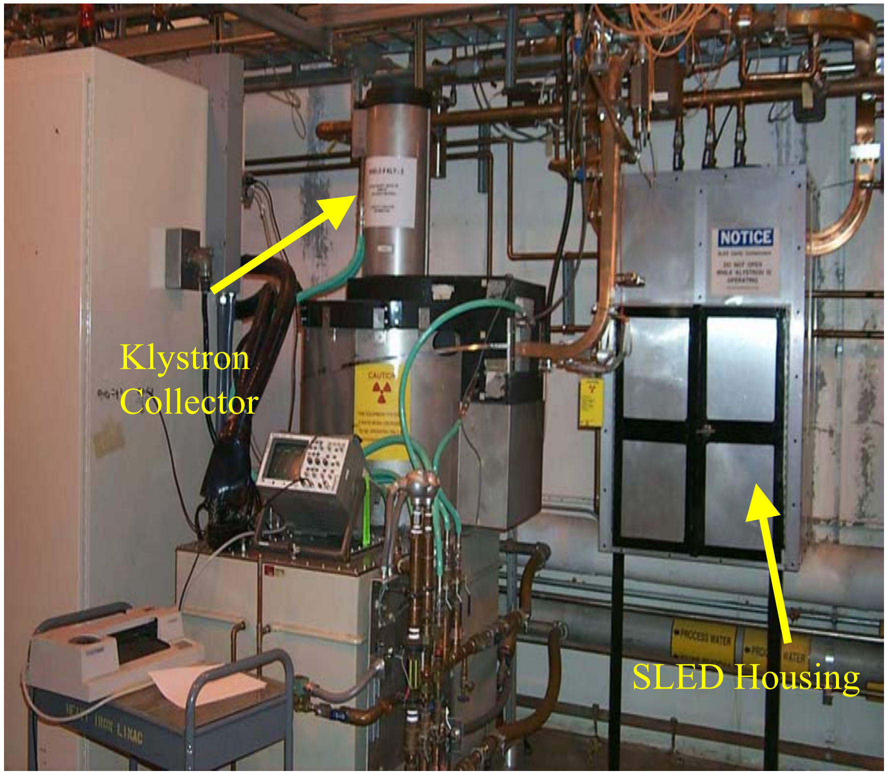


Main Parameters of TH2128 Klystron:

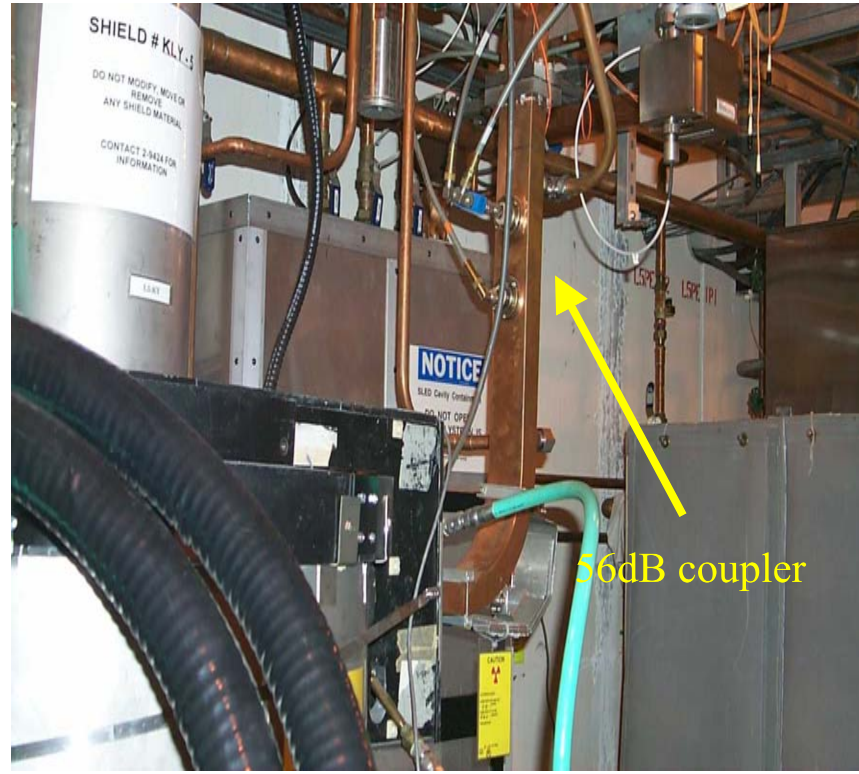
Frequency	2856 MHz
Peak Output Power	35 MW
Average Power	11kW
RF Pulse Duration	5μsec
Peak Beam Voltage,Max	300 kV
Peak beam Current,Max	300 A
Peak RF Drive Power, Max	200 W
Efficiency	42%
Perveance	1.9 to 2.15 $\mu A \cdot V^{-3/2}$
Filament Voltage	20 to 30 V
Hot Filament Resistance	1.1 Ω
Cold Filament Resistance	0.1 Ω

Typical Operation:

Frequency	2856 MHz
VSWR, Max.	1.1:1
Peak Beam Voltage	280 kV
Peak Beam Current	297 A
Peak RF Power	35 MW
Average Output Power	10.5 KW
RF Pulse (at -3 dB)	5 μsec
Power Dissipated on the Body	800 W

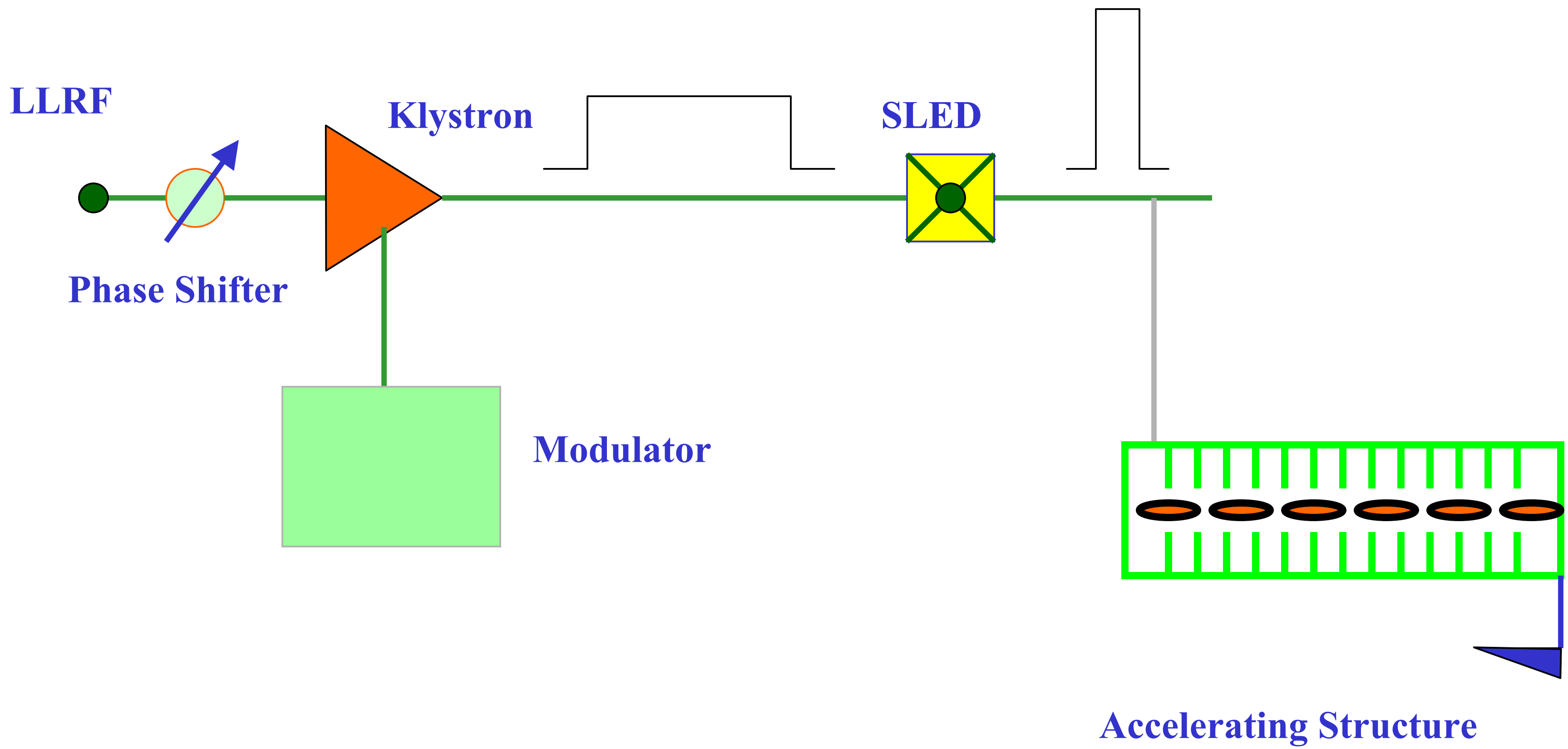


Klystron/SLED Unit

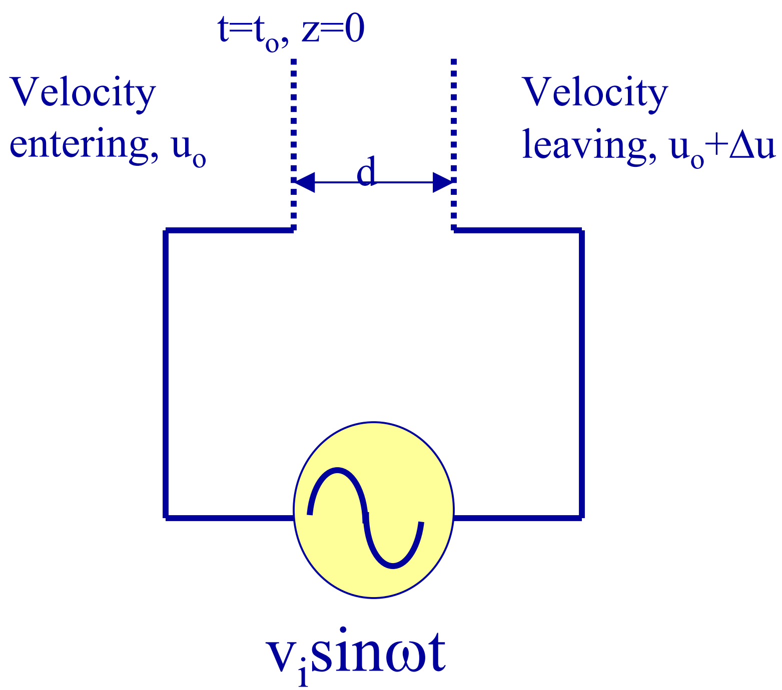


WG Coupler at the output of the klystron

RF Power Distribution to the Accelerating Structure



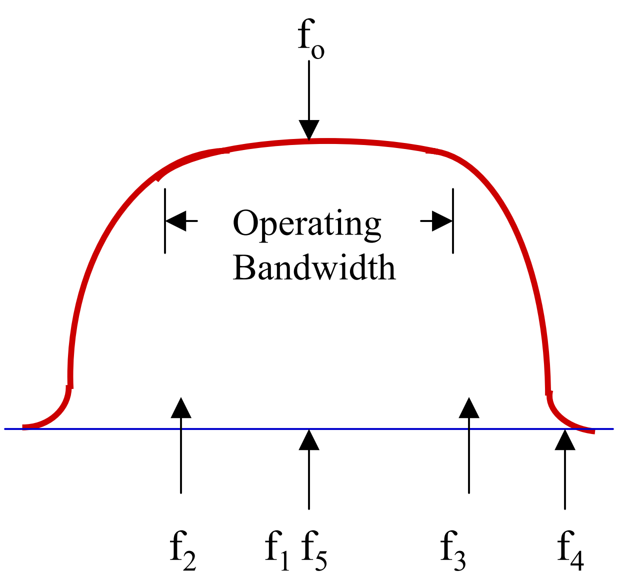
Velocity Modulation



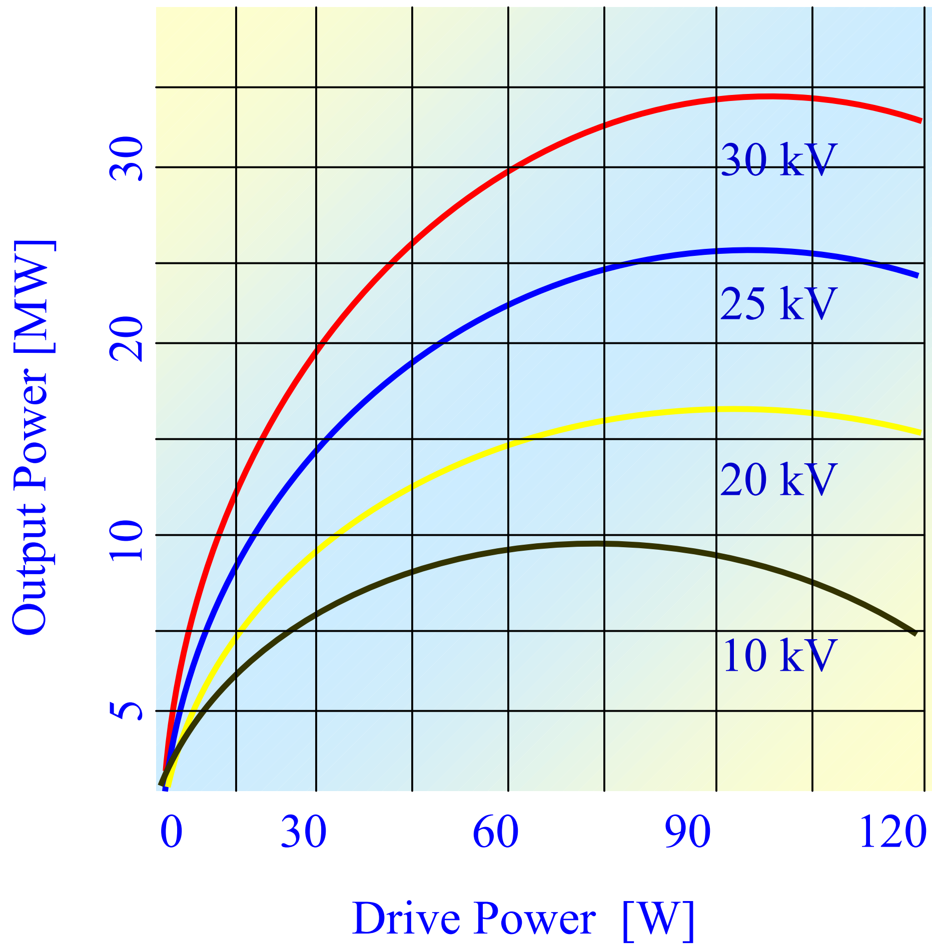
When electrons are passed through the modulating field, some electrons have their velocities increased and some will have their velocities decreases when the voltage is reversed.

As the electrons leave the gap, those with increased velocities overtake the slower electrons, as a result electron bunching (density modulation) occurs.

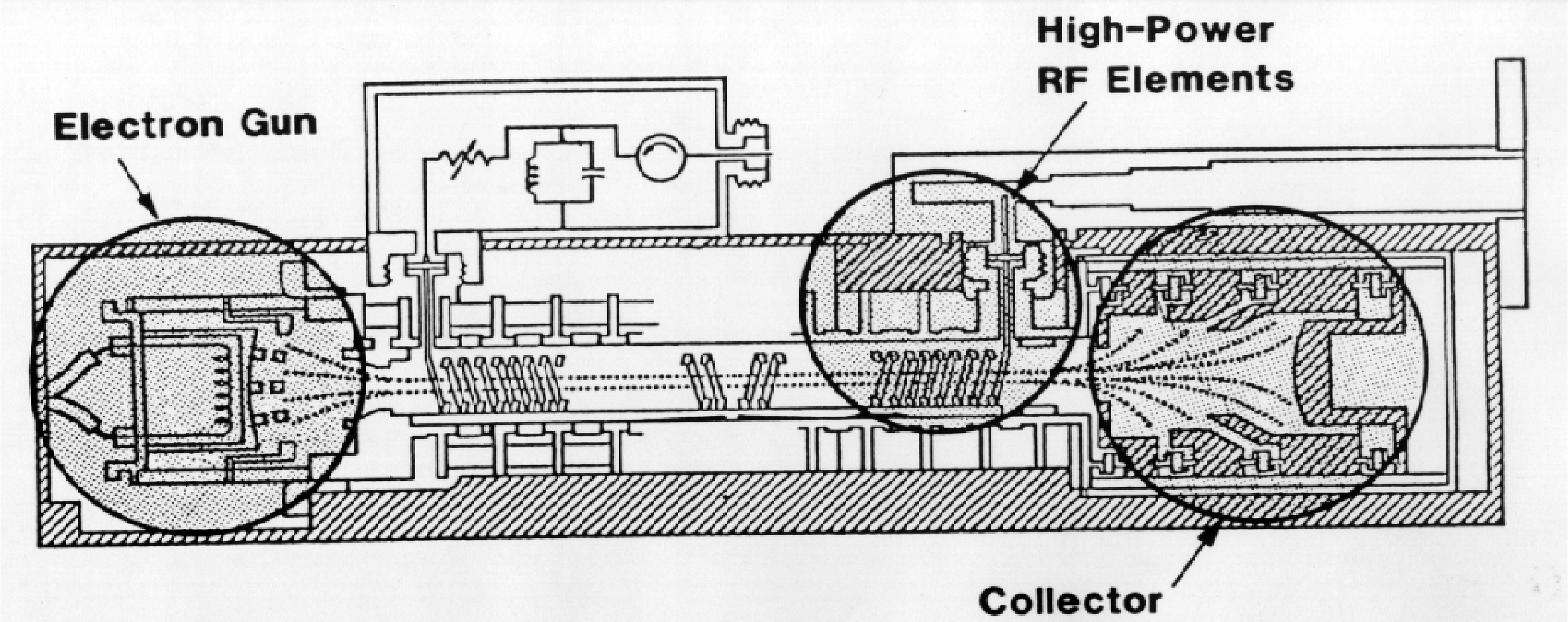
Cavity Bandwidth



Typical Klystron Saturation Curves



Breakdown and Protection



- In the gun (between electrodes,between leads or from electrodes or leads to ground)
- In the collector
- In high-power portion of the RF structure

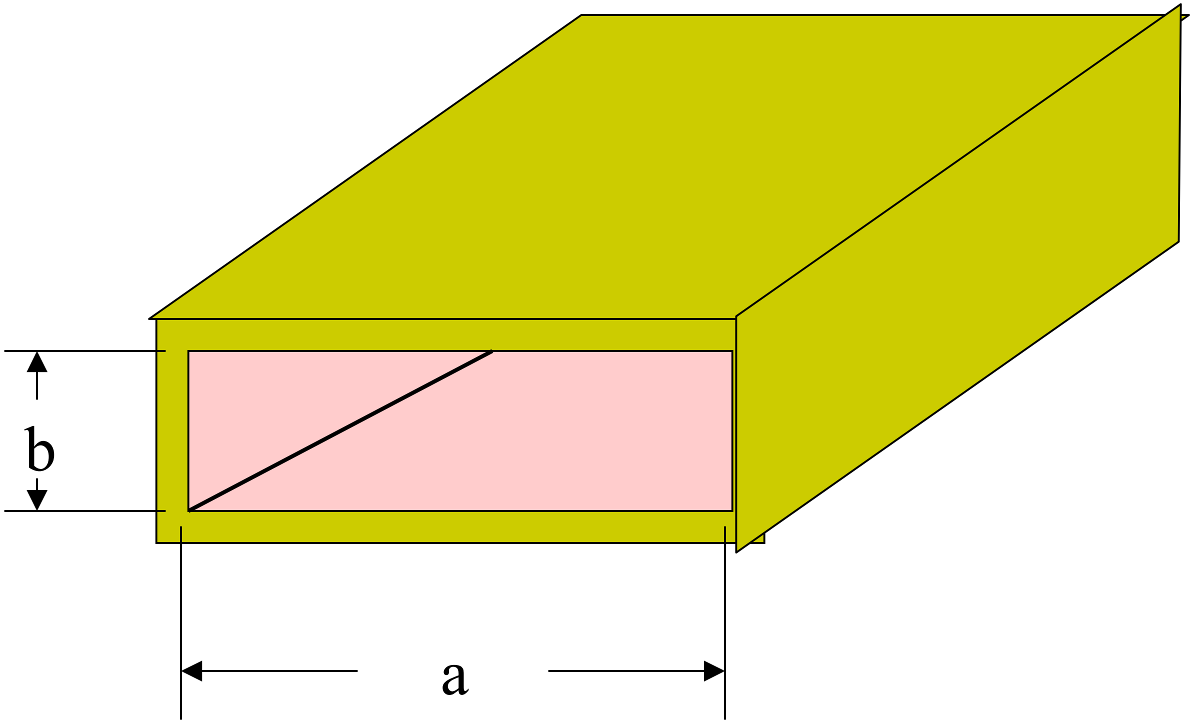
RF Components:

- Driver amplifier to power klystron
- Klystron is used to generate high peak power (A small accelerator)
- Need to transport power to the accelerating structure
- Waveguide is used (under vacuum) to propagate and guide electromagnetic fields
- Windows (dielectric material, low loss ceramic) are used to isolate sections of the waveguide
- Termination loads (water loads) are used to provide proper rf match and to absorb wasted power
- Power splitters are used to divide power in different branches of the waveguide run

Rectangular Waveguide

Cut-off frequency:

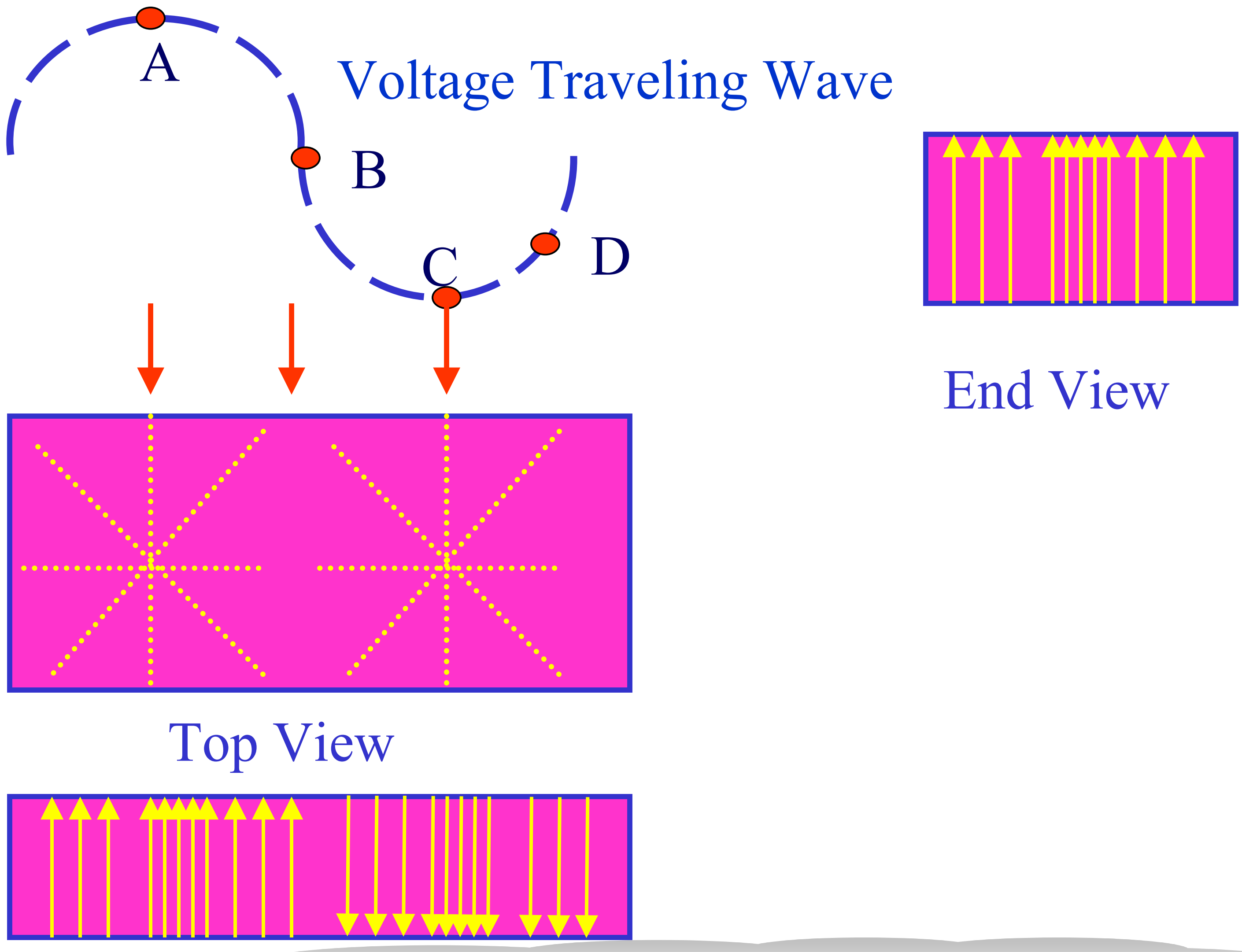
$$f_c = \frac{c}{2a}$$



For S-band:

$$a = 8\ cm$$

$$f_c = \frac{3\times 10^{10}\ cm/\sec}{16\ cm} = 1.875\ GHz$$



Side View

Guide Wavelength:

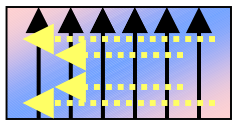
$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

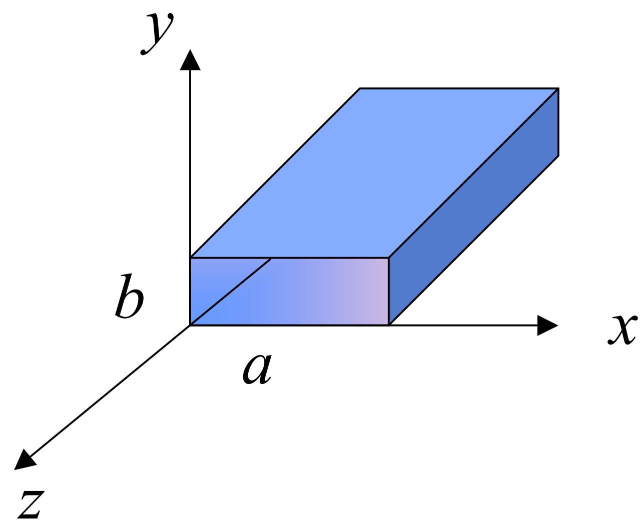
Using $f_c = 1.875\ GHz$,

$$\lambda_g = \frac{10.5\ cm}{\sqrt{1-\left(\frac{1.875\ GHz}{2.856\ GHz}\right)^2}} = 18.5\ cm$$

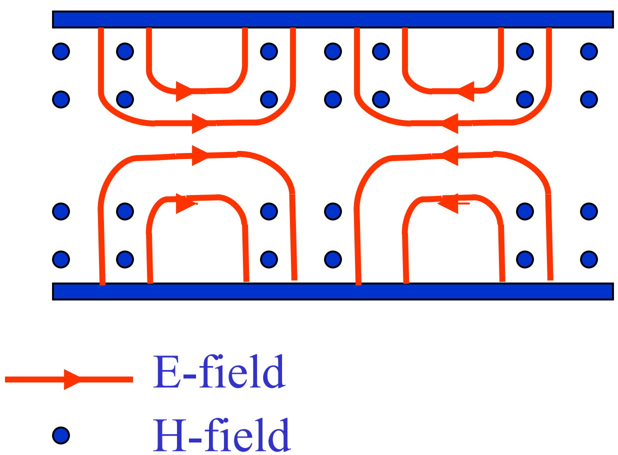
Waveguide Propagation Modes

TE - Transverse Electric Field





TM - Transverse Magnetic Field



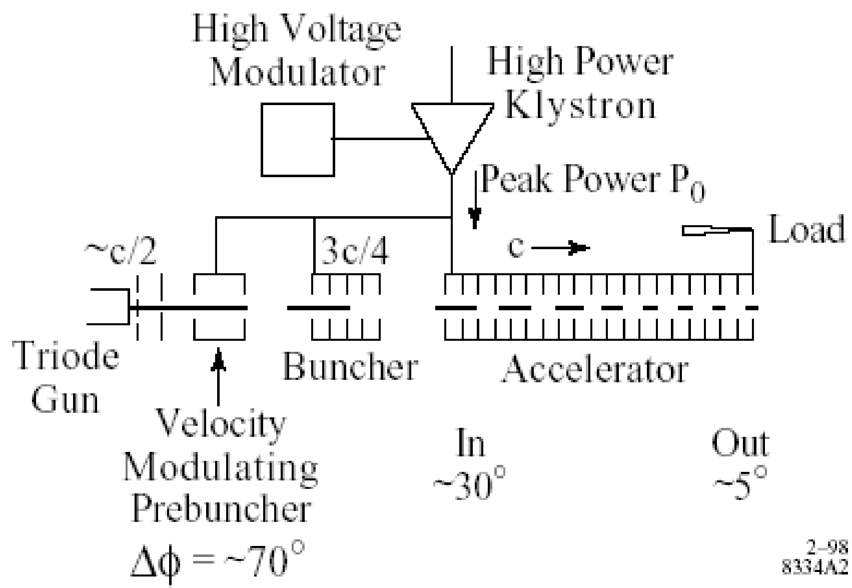
$$\kappa = \frac{\omega}{v} = 2\pi \frac{f}{v} = \frac{2\pi}{\lambda}$$

$$\kappa_0 = \frac{2\pi}{\lambda_0}, \quad \kappa_c = \frac{2\pi}{\lambda_c}$$

$$\beta = \left(\kappa_0{}^2 - \kappa_c{}^2\right)^{1/2}$$

$$\beta \equiv real \Rightarrow propagating \ \text{mode}$$

$$\beta \equiv imaginary \Rightarrow evanescent \ \text{mode}$$



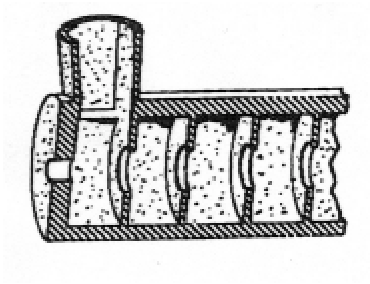
RF Control System

Vacuum System

Water Cooling System

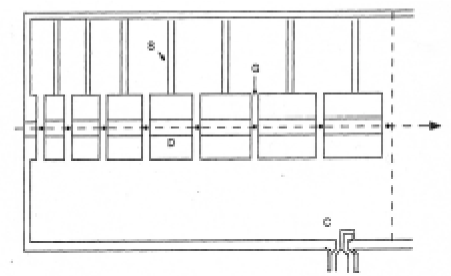
Electric Power System

- 1947 W. Hansen (Stanford) Disk-loaded waveguide linac



DLWG

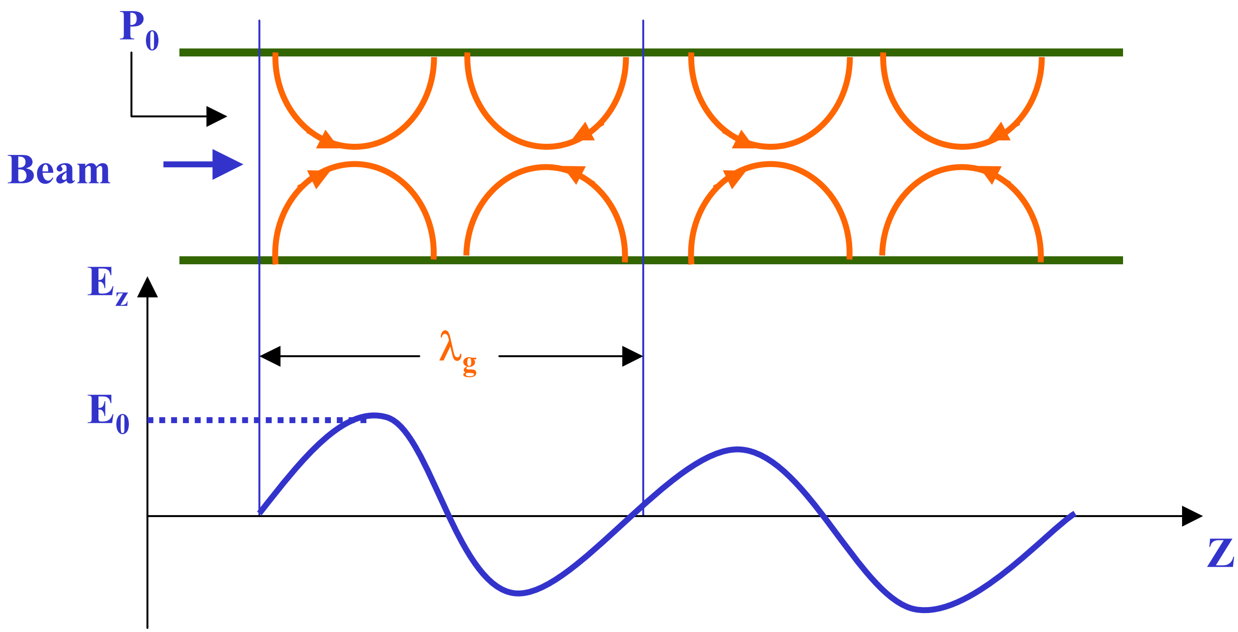
- 1955 Luis Alvarez (UC Berkeley, DTL)



Alvarez 200MHz, 32MeV

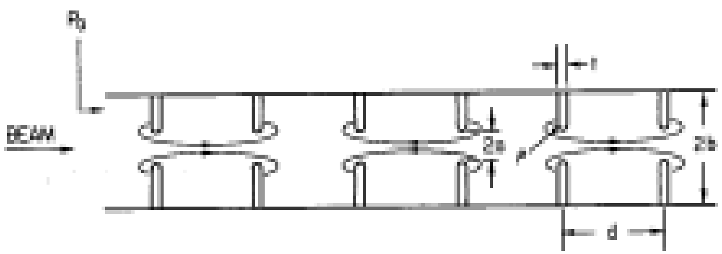
- 1970 Radio Frequency Quadruple (RFQ)

RFQ 6 - 400 MHz 0.01-0.06C



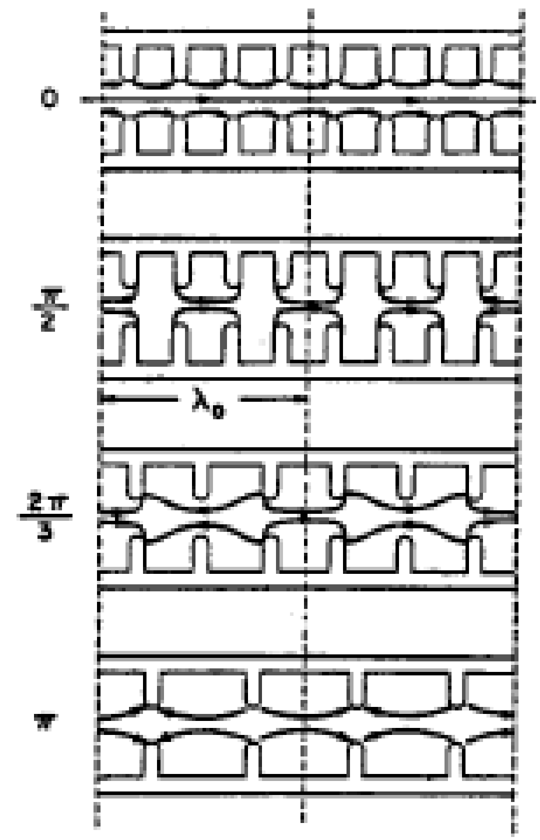
TM$_{01}$mode-pattern and traveling wave axial electric field amplitude in a uniform cylindrical waveguide.

Snapshots of e-field configuration for DL structures with various phase shift per period.

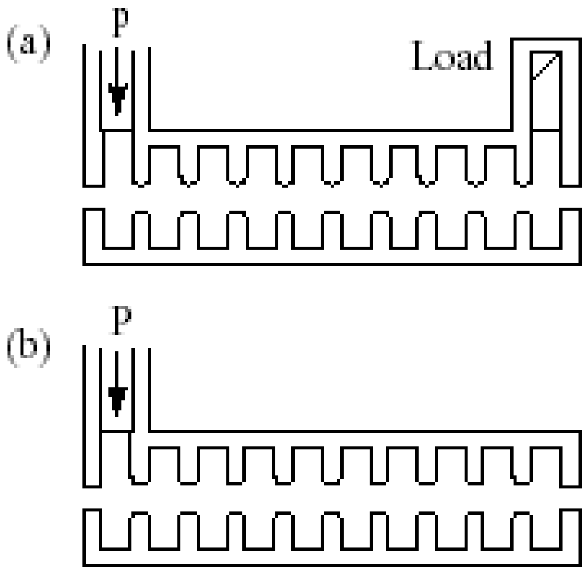


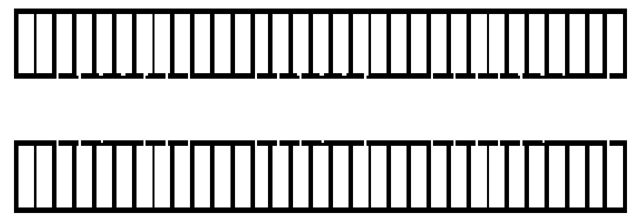
$\pi/2$ mode

Electric field amplitude along z-axis for $\pi/2$ mode



Structure Types

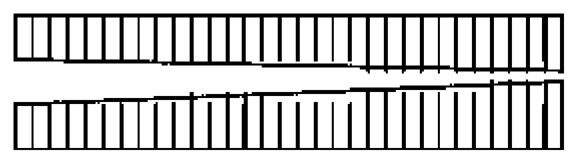




Constant Impedance Structure (CI)

(a) Traveling Wave (TW) Structure

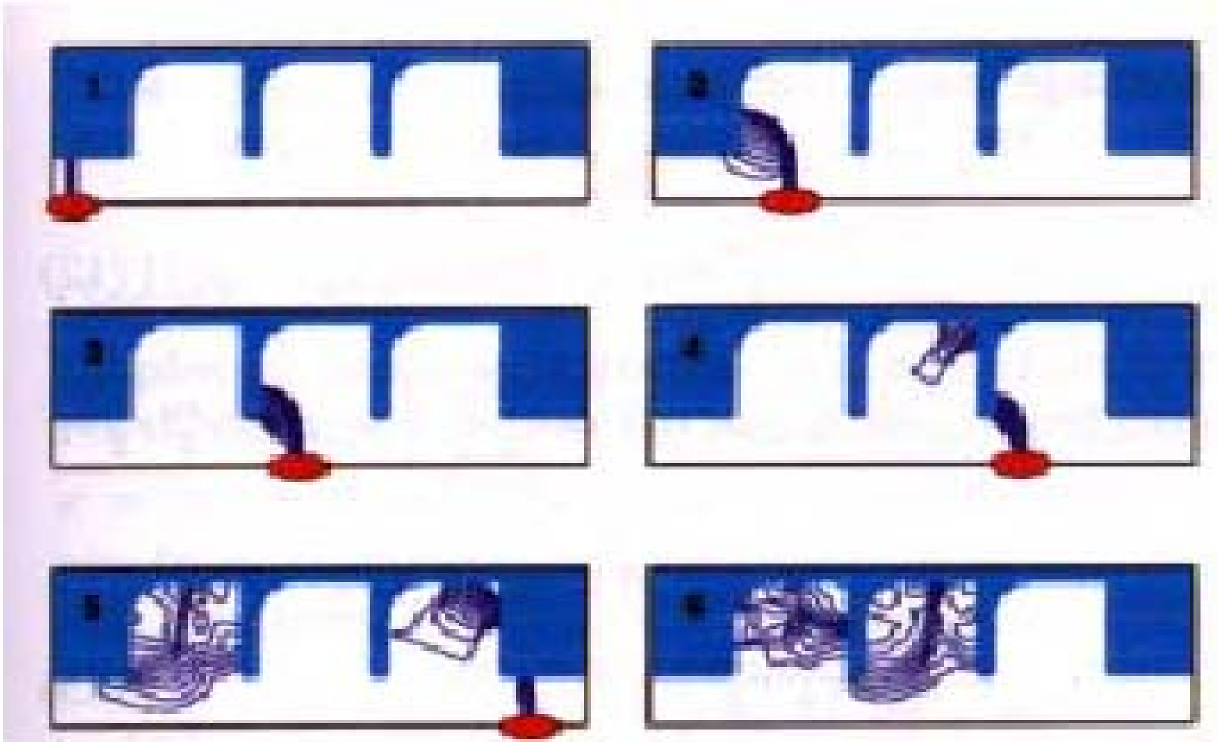
(b) Standing Wave (SW) Structure



Constant Gradient Structure (CG)

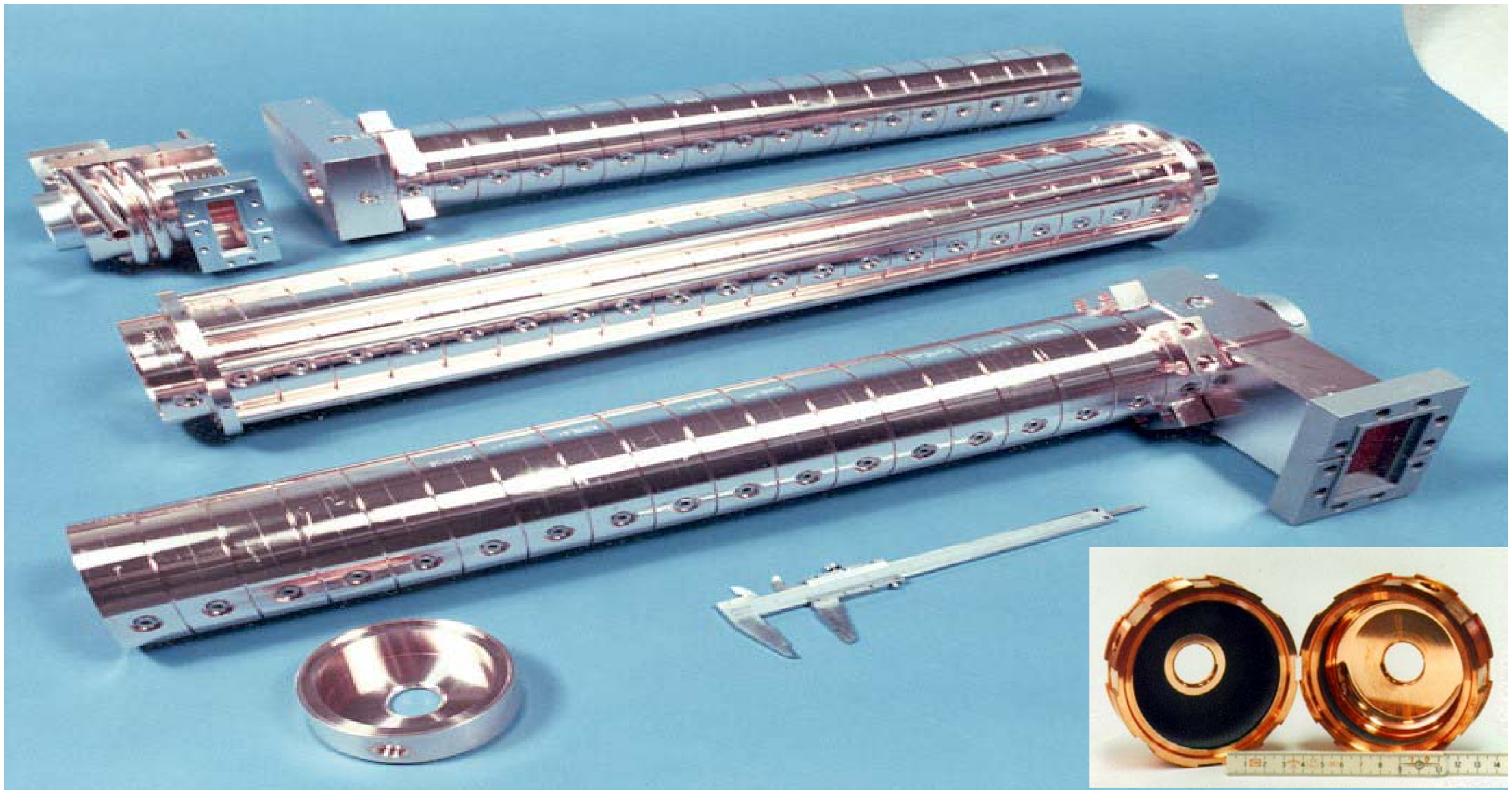
Wakefields

The wakefield is the scattered electromagnetic radiation created by relativistic moving charged particles in RF cavities, vacuum bellows, and othe bem line components.

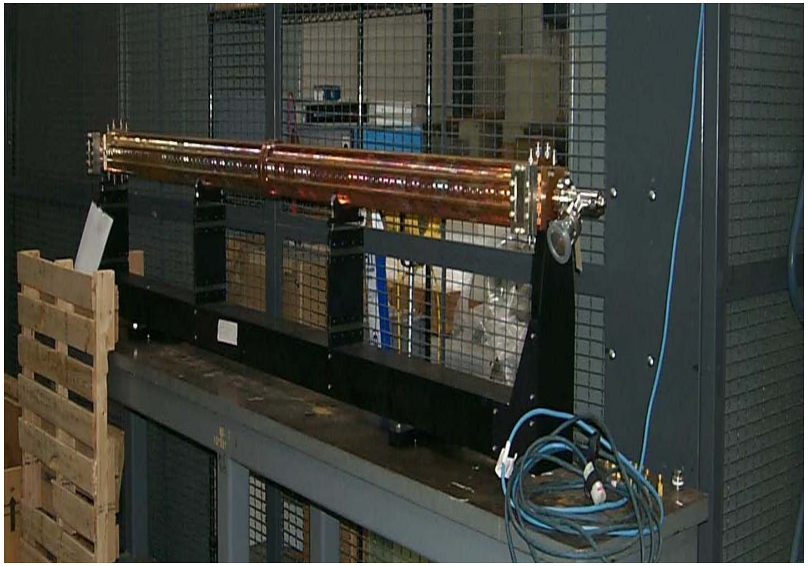


Electric field lines of a bunch traversing through a three-cell disk-loaded structure

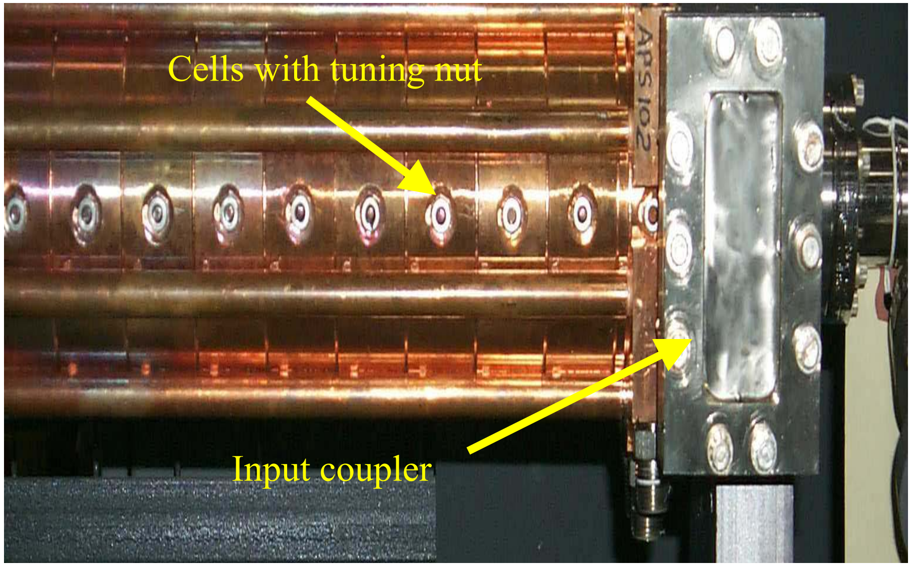
J. Wang, SLAC



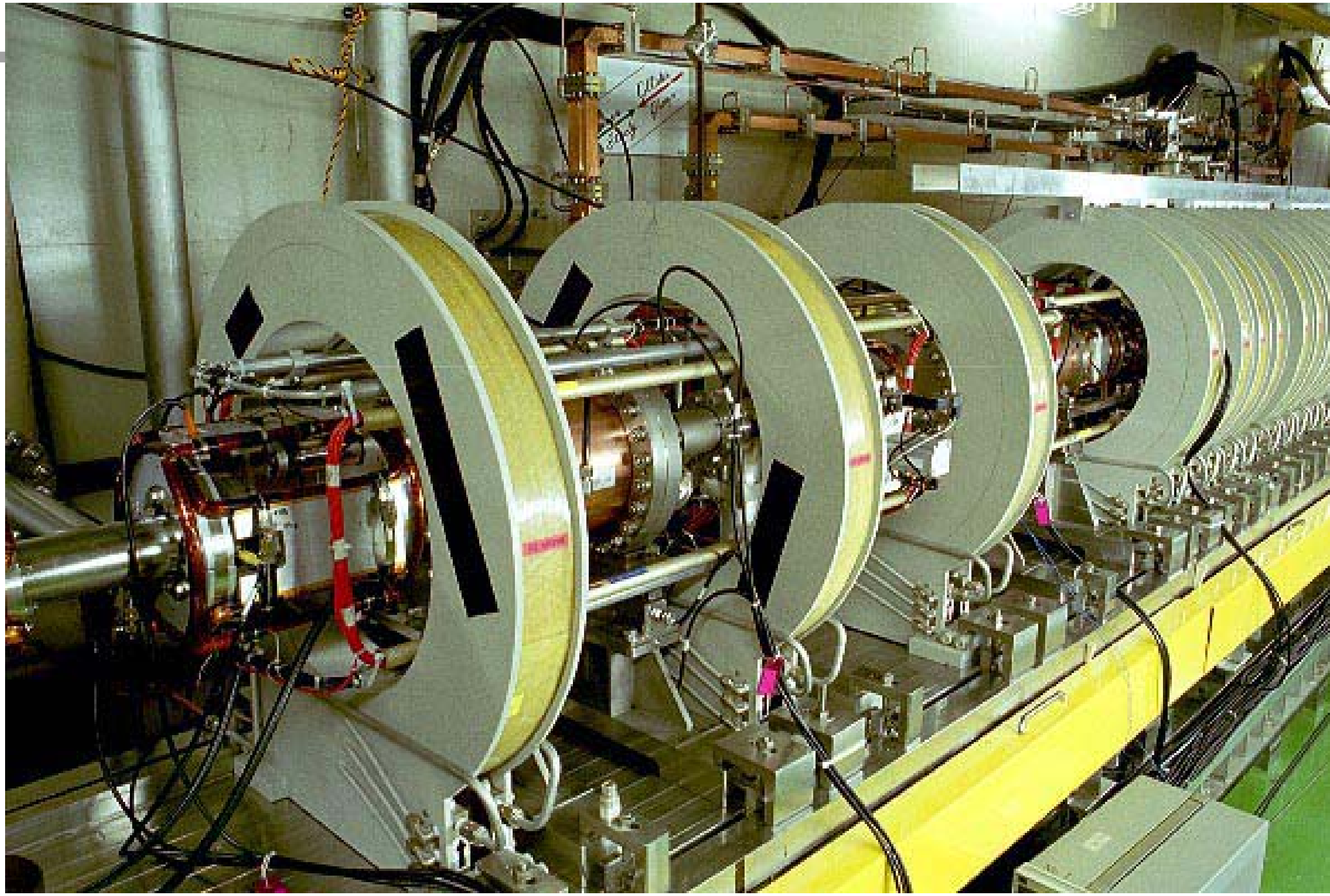
Disk-Loaded Constant Gradient S-Band Structure

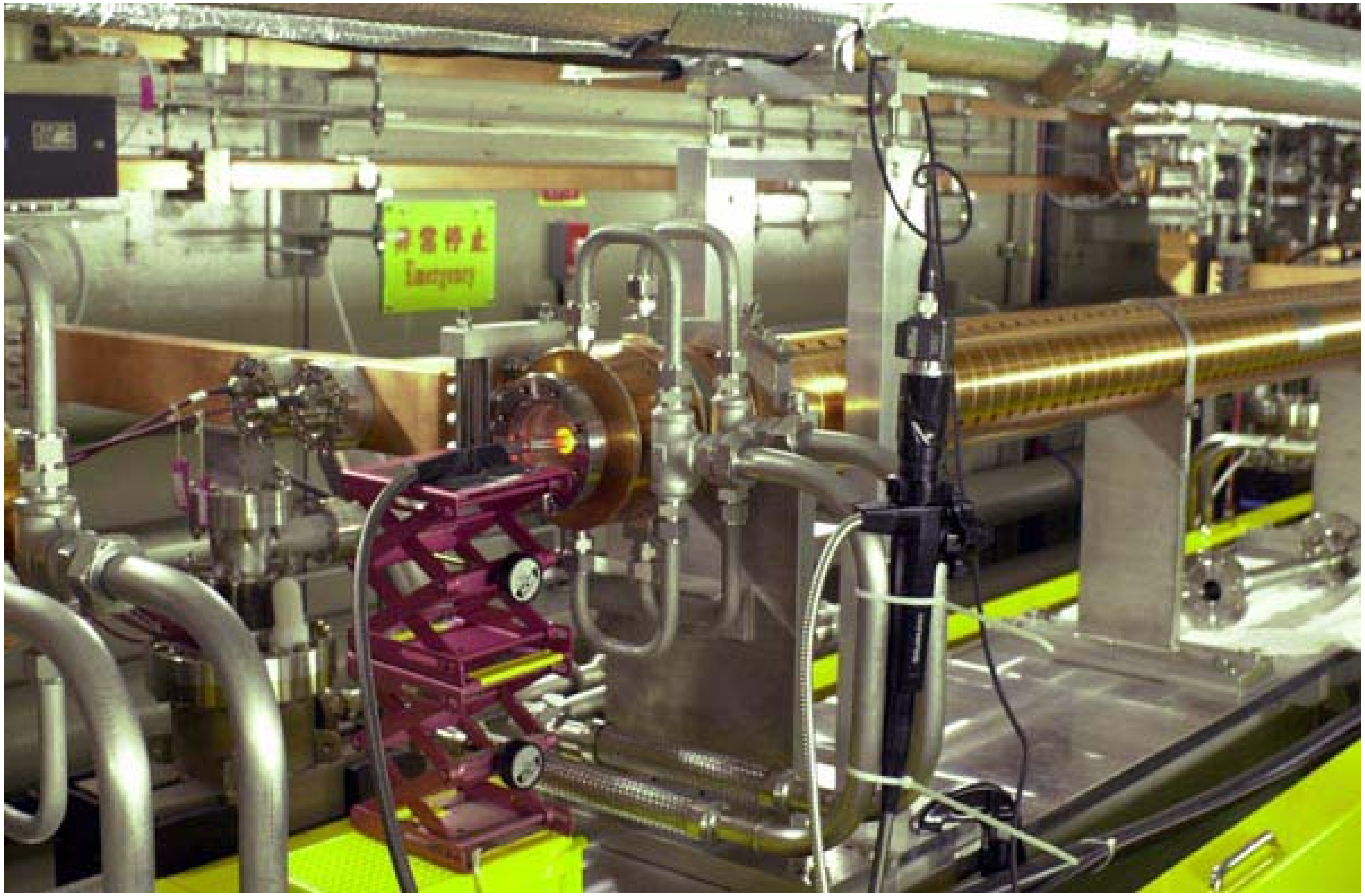


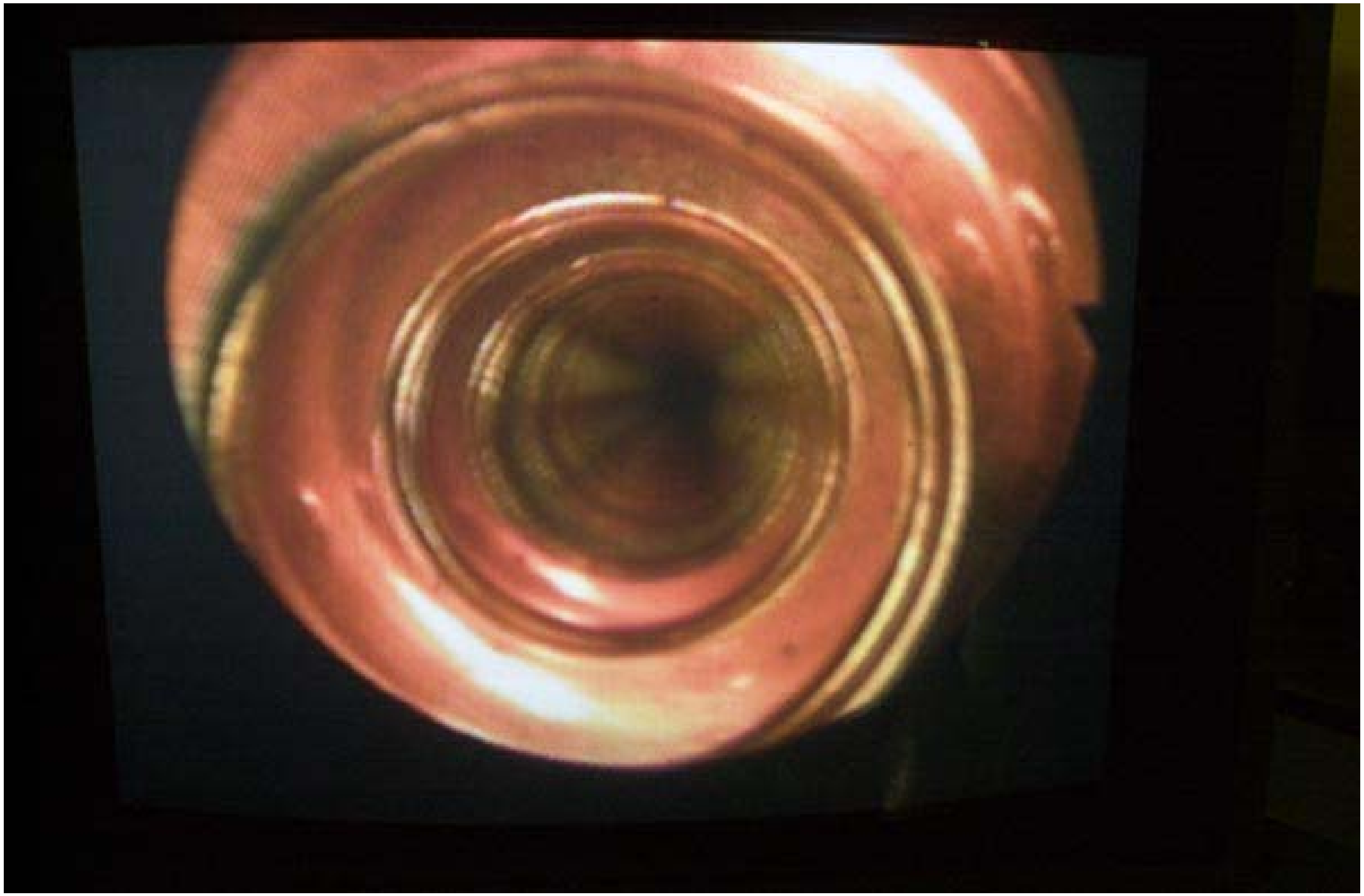
3-meters S-band Structure

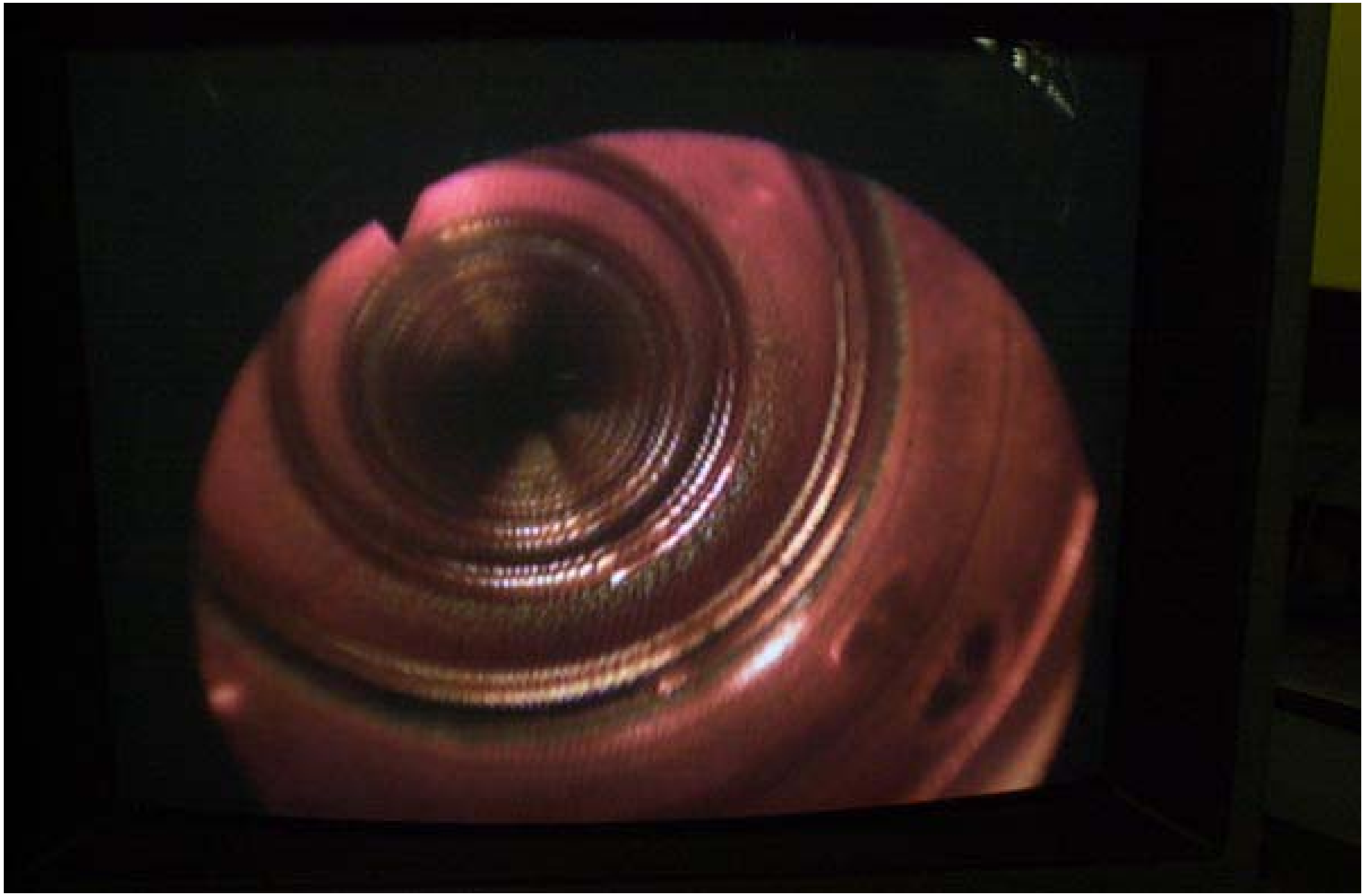


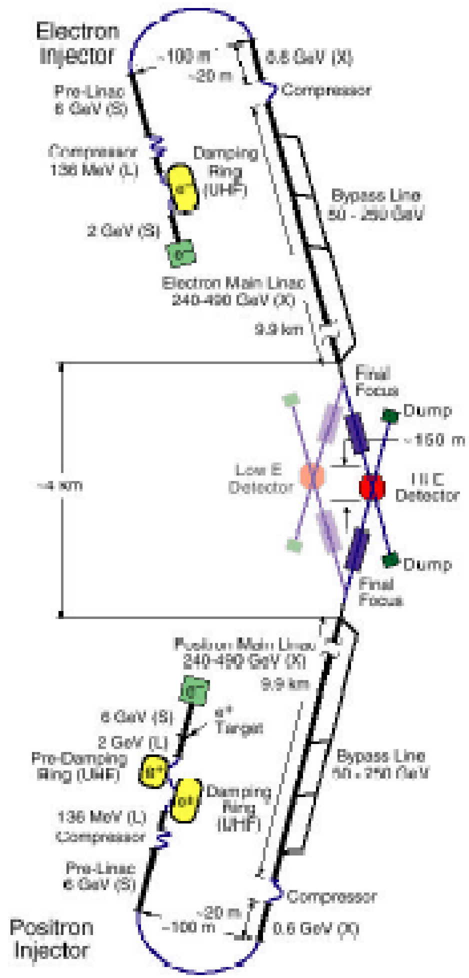
Input coupling cell

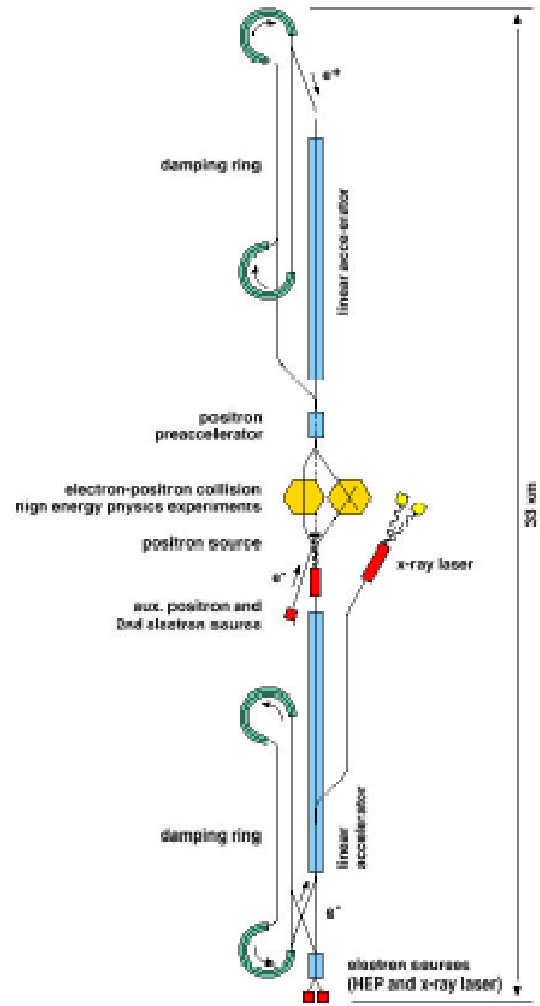












Examples of Very Long Linear Accelerators (Linear Colliders)