Medical and industrial applications of linear electron accelerators

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Sector Healthcare
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Abstract

Medical and industrial applications of linear electron accelerators

Roland Schmidt, Siemens Healthcare

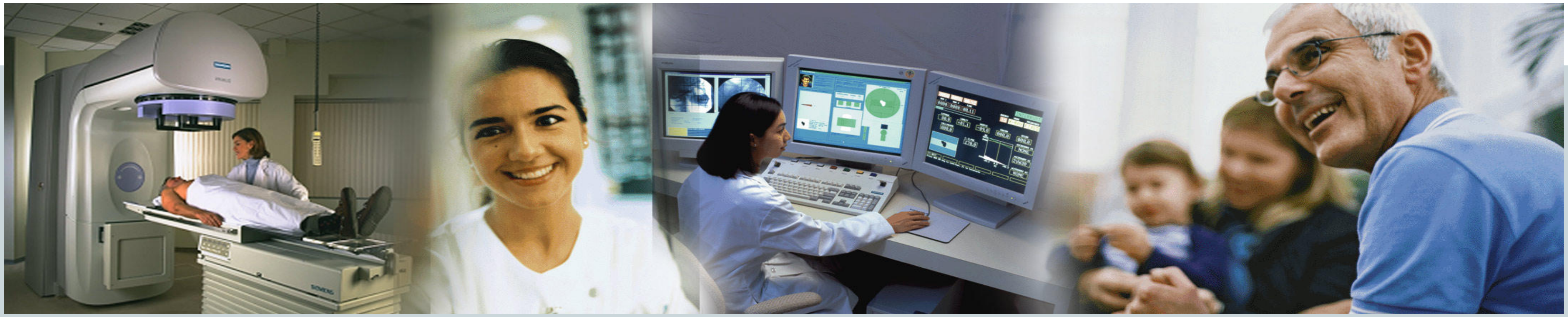
The first industrial applications of linear electron accelerators showed up in the Fifties of the last century. We will give a short overview about the history of this technology, especially about their rise in medical industry for cancer treatment.

In the second chapter, we will talk about the basic physics, the functionality, the main components and limitations of this technology. This will be explained at the model of a typical S-band accelerator, as it is used at Siemens and other competitors for medical applications.

In a side view, we will look at the necessary assemblies, which are used to operate this type of accelerators appropriately, like modulators, injectors or dose chambers. An example of a complete system in a clinical environment will be shown.

The third part of this talk will open a window in the industrial fields like security business (e.g. cargo screening) or NDT (non destructive testing) and point out how worldwide linear electron accelerators might become more and more important.

A brief look at our facility in Rudolstadt, Thuringia, will close this talk.



Introduction

History and basics of Radiation Therapy

Linear Accelerator: Concepts & Technologies

Industrial Applications

Closing remarks and discussion

History of Radiation Oncology

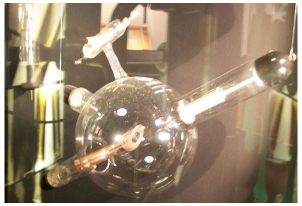
First articles about treatment with X-rays in the early 20th century.
This therapy with standard X-ray tubes was the only choice until the Fifties.

Since late Fifties until end of the last century the use of Co60 (or Cs137) was very popular but lost its attractiveness due to safety and environmetal reasons.

At the same time accelerators for electron had been developed – 3 main types:

a. Van-de-Graaf (1954): minor importance
b. Betatron: circular acceleration in a strong magnetic field: until the late 70ies
c. Linac: Linear accelerator, driven by high frequency: since 1970 until today

Recent technologies are based on high energy accelerators for protons or heavy ions.



Treatment choices

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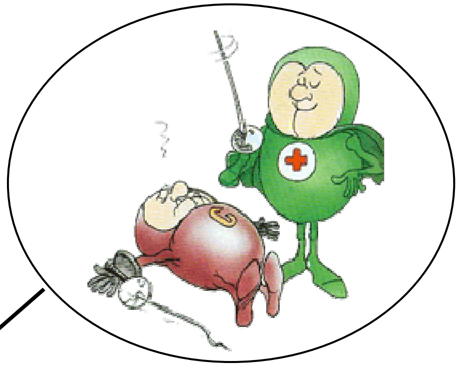
3 different treatment modalities

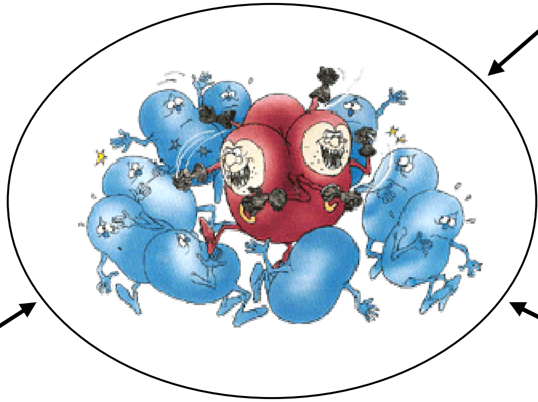


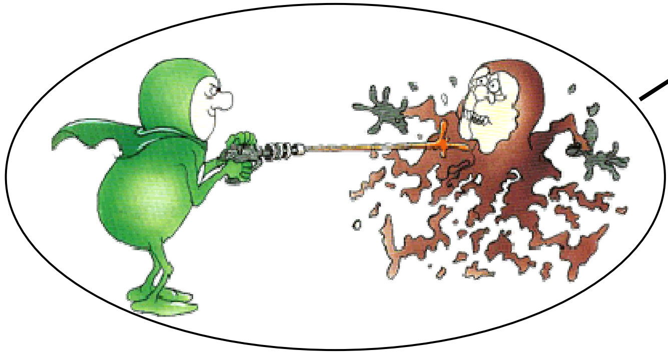
Surgical Oncology

Works best for tumors that are well-contained and accessible; some are neither

Medical Oncology (Chemotherapy)

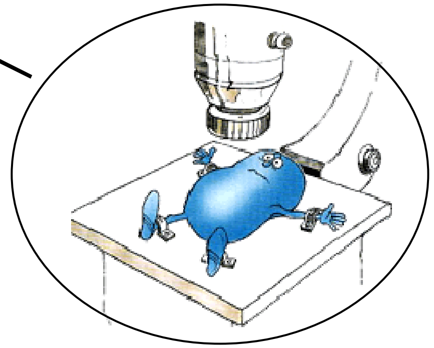
Anti-mitotic Drugs - prevent cell division
Anti-angiogenesis drugs - prevent formation of new blood vessels
Biologic Response Modifiers – enhance normal immune response





Radiation Oncology

Tele-therapy is radiation delivered from a distance
Brachy-therapy is radioactive seeds that are placed inside the body



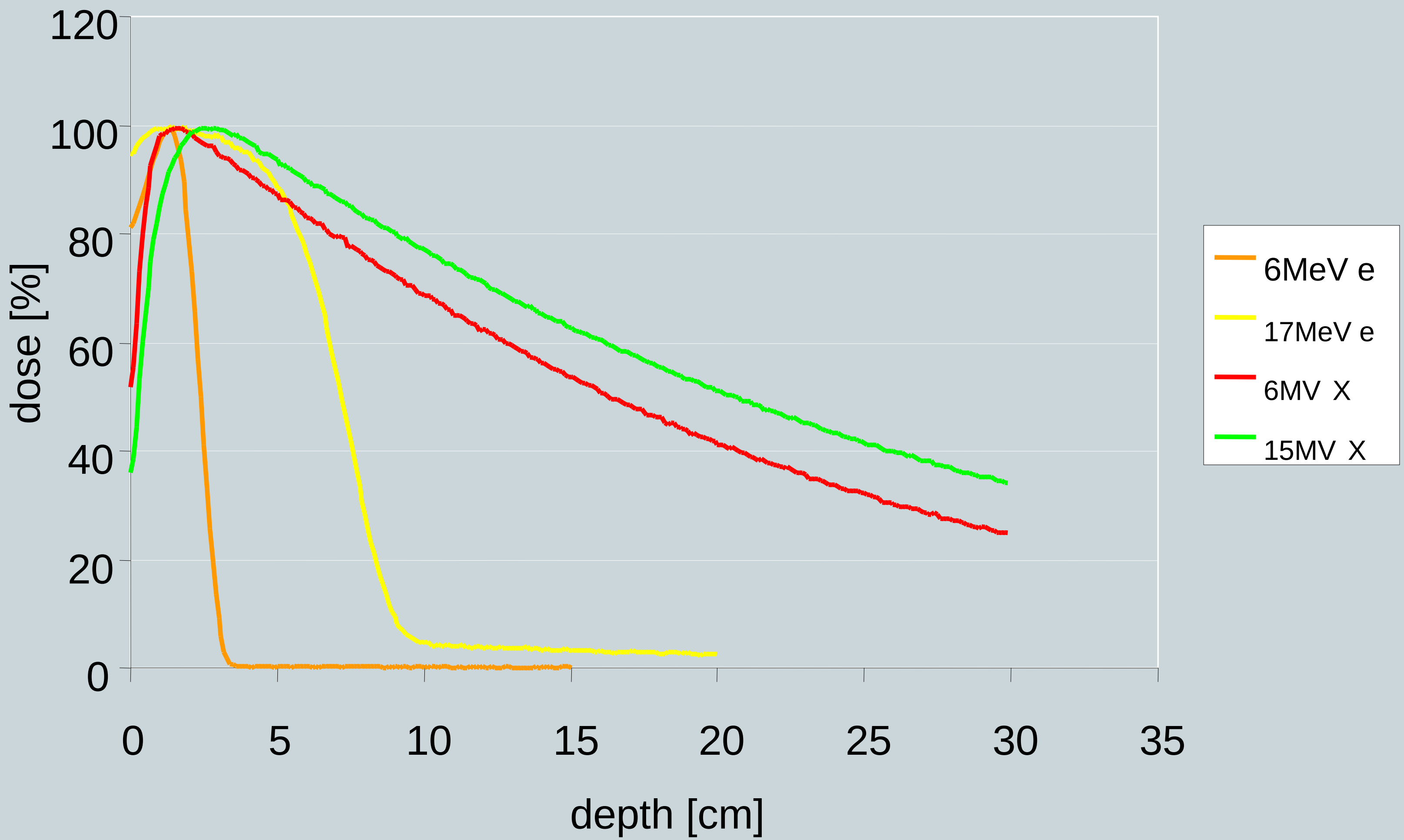
Purpose of Radiation Therapy

Radiation Therapy is used in Cancer treatment to destroy tumor cells, while minimizing damage to normal cells.

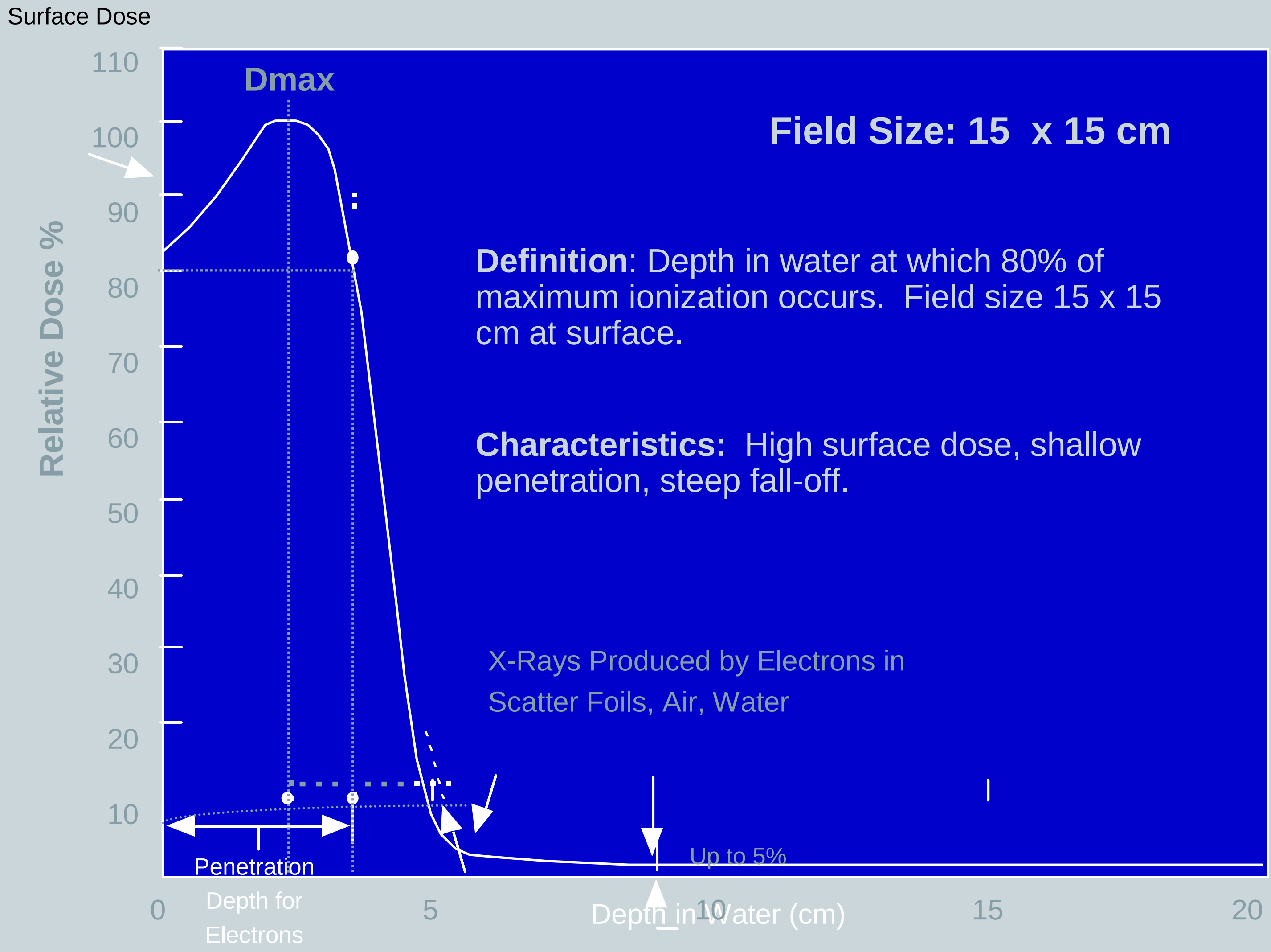
Radiation is not selective, it damages both normal cells and tumor cells !

Fortunately, *healthy cells can repair themselves* more readily than tumor cells, under some conditions.

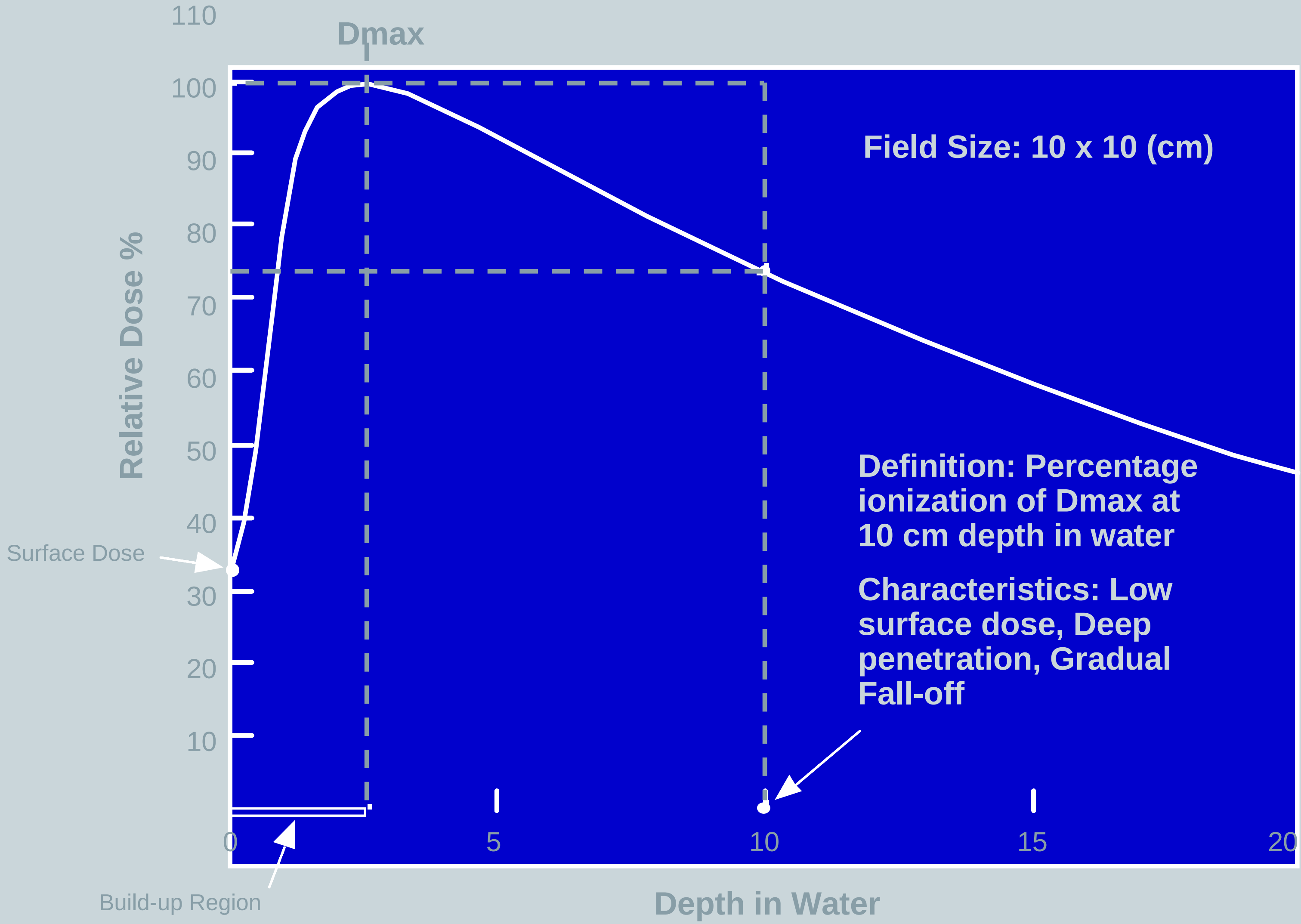
Depth Dose in Water



10 MeV Electron Beam

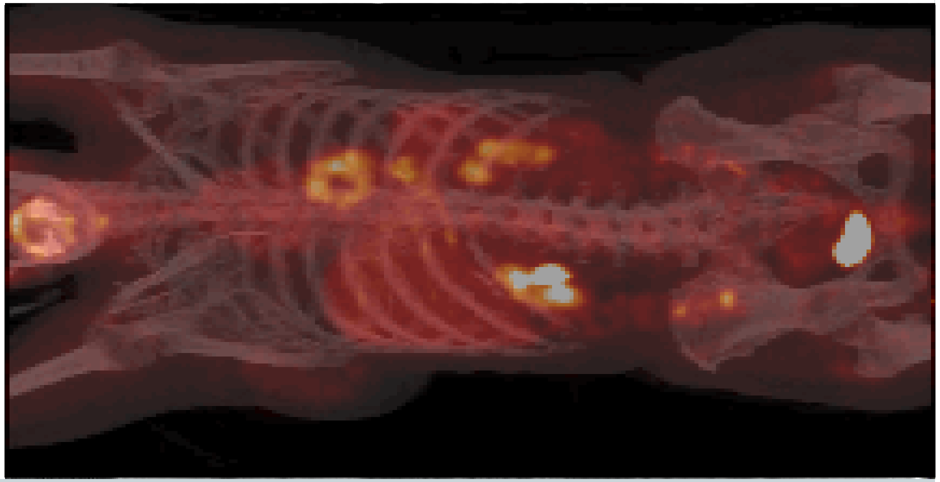


10 MV Photon Beam



Radiation Therapy
Workflow

DIAGNOSE



Cancer diagnosis

- Diagnostic imaging from MR, CT, PET/CT
- Patient is diagnosed with cancer

Workflow

DIAGNOSE → PRESCRIBE

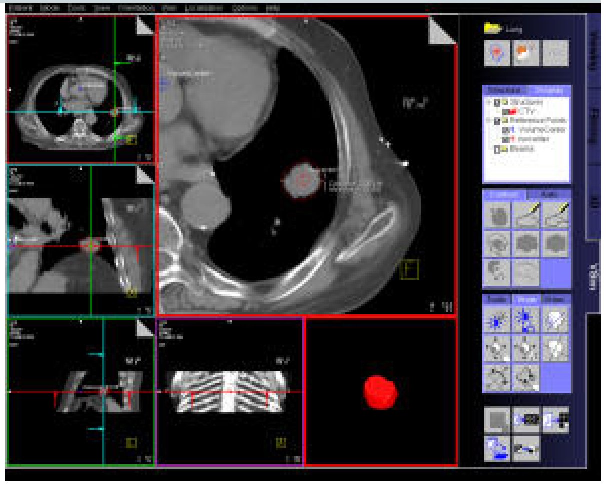
Treatment decision

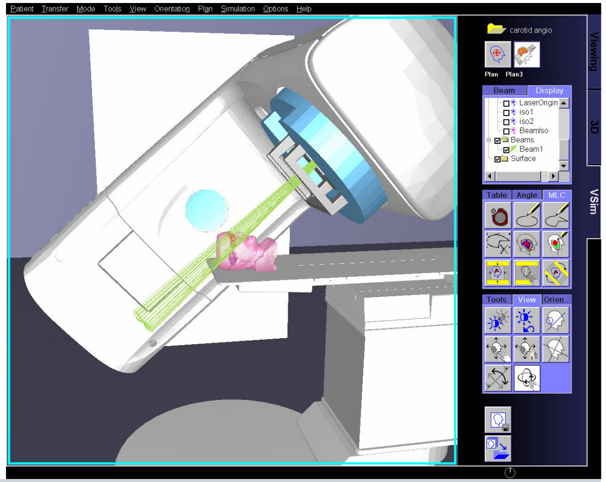
- Surgery, Chemotherapy, Radiation Therapy??
- Depends on tumor type, tumor progression, location
- Ideally, decision is agreed upon

Radiation Therapy

Workflow

DIAGNOSE → PRESCRIBE → PLAN & SIMULATE





Preparation of treatment plan

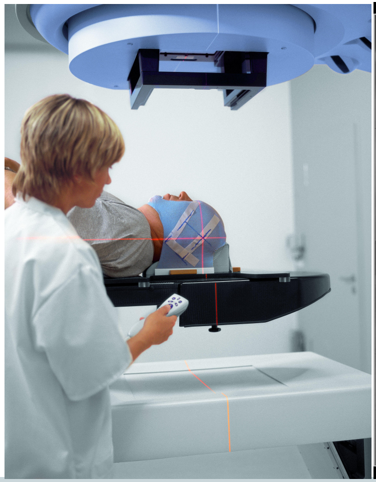
- Cancer outlining, definition of critical structures
- Calculation of required dose & placement of beam angles
- Virtual simulation of treatment plan & fitting of immobilization

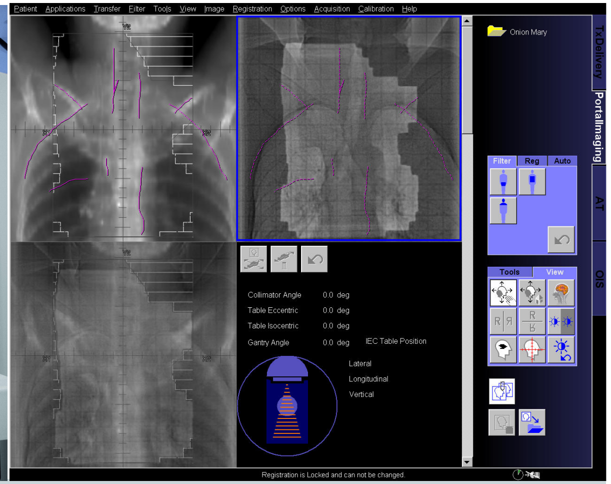
Radiation Therapy
Workflow

DIAGNOSE → PRESCRIBE → PLAN & SIMULATE → **POSITION**

Radiation therapy starts

- Patient set-up
- Portal imaging
- Radiation treatment





Workflow

DIAGNOSE → PRESCRIBE → PLAN & SIMULATE → POSITION → **TREAT**

Treatment delivery

- Automatic gantry movement to planned gantry angles
- Automatic positioning of MLC leaves to conform to tumor PTV

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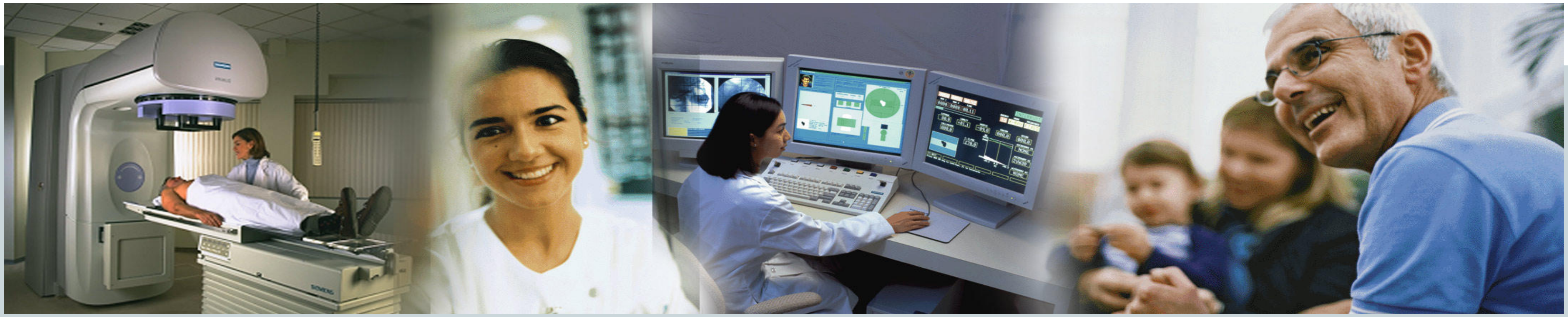

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LINAC Key Components

- Gantry
- RF Sources
- Waveguide
- Beam
- Collimation
- Treatment Table
- Imaging Device

Schematic view of a Magnetron Linac

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RF Sources

Magnetron

- e.g. Model 6250 (E2V)
- Nominal peak power 2.6 MW
- Covers up to medium energies
- Self oscillating/Amplifier
- 4-15MV photon (x-ray) energies
- 5-14 MeV electron energies

Klystron

- e.g. Model 2157 (Thales)
- Nominal peak power 7.5 MW
- Delivers up to high energies
- Only amplifies, needs RF Driver
- 4-25MV photon energies
- 5-21 MeV electron energies

Types of linear accelerators (waveguides)

A. TRAVELLING WAVE

- RF power input near head (or gun) of the waveguide
- Particle “rides” the wave down the waveguide
- Unused RF power recycled at the end of waveguide

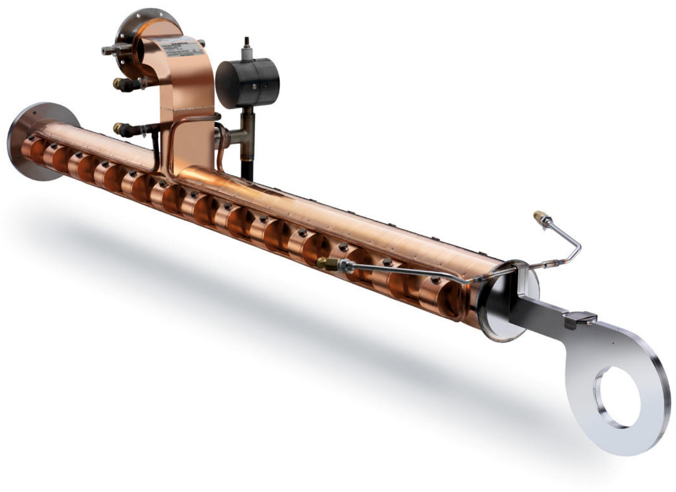
+ Low RF power required
- Beam time formation, beam stability

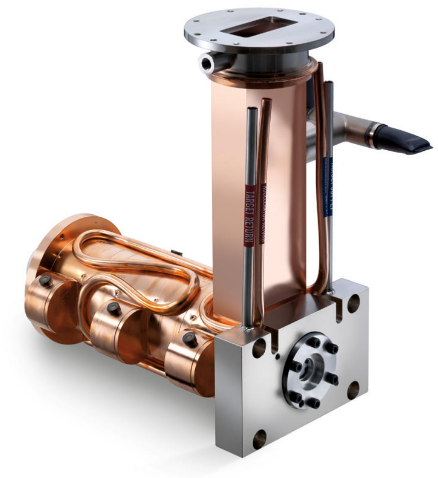
B. STANDING WAVE

- RF power input near center of waveguide (or any other position)
- RF standing waves set up in cavities

+ Fast operation and mode changes; high stability
- High RF power required

Electron Accelerators (standing wave)





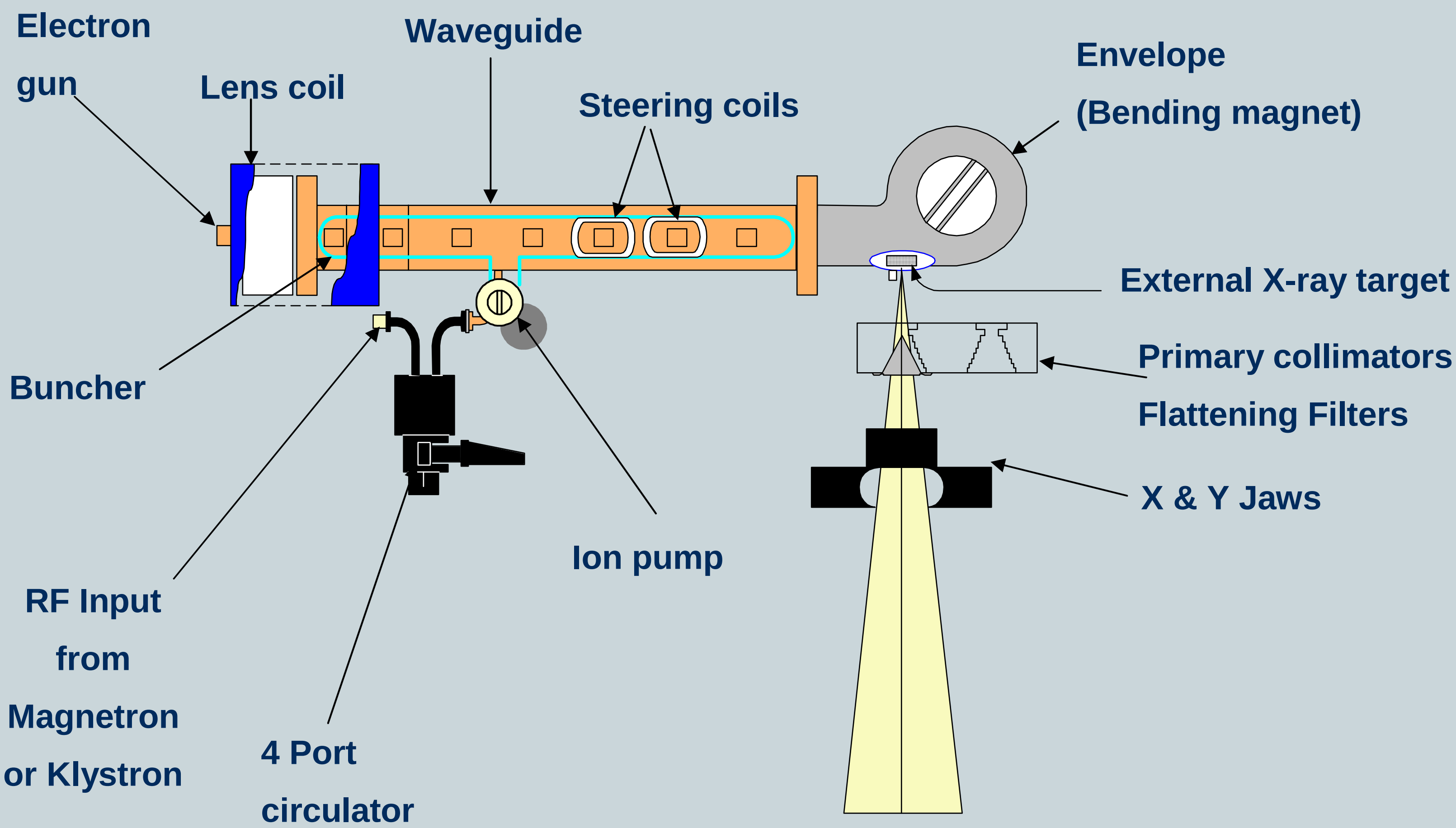
Photon and Electron modes
with one single accelerator

Multi energy operation:
- Photon mode from 4 to 23 MV
- Electron mode from 5 to 21 MeV

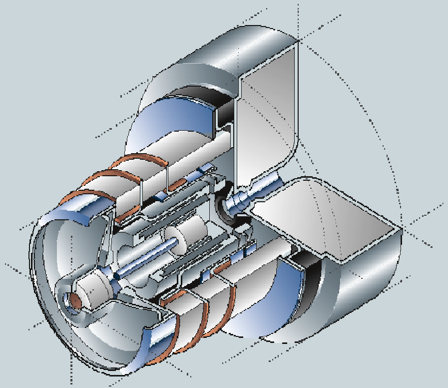
Photon mode operation only

Fixed tungsten target
Energies up to 6 MeV

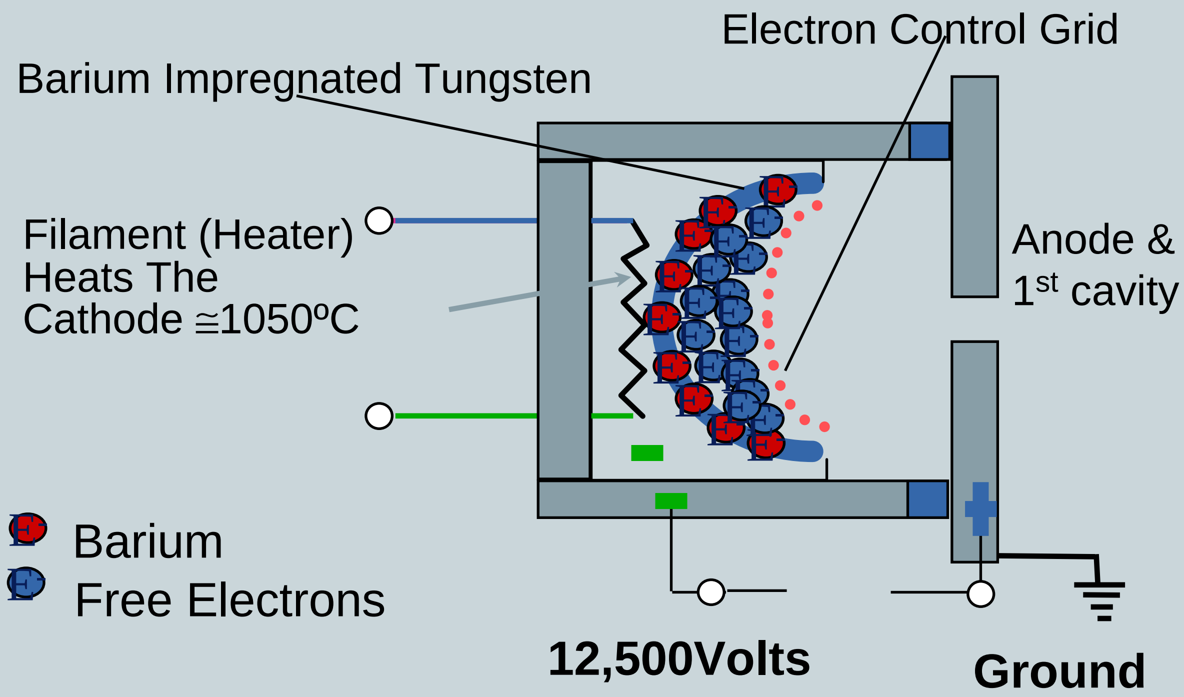
Parts of an accelerating waveguide



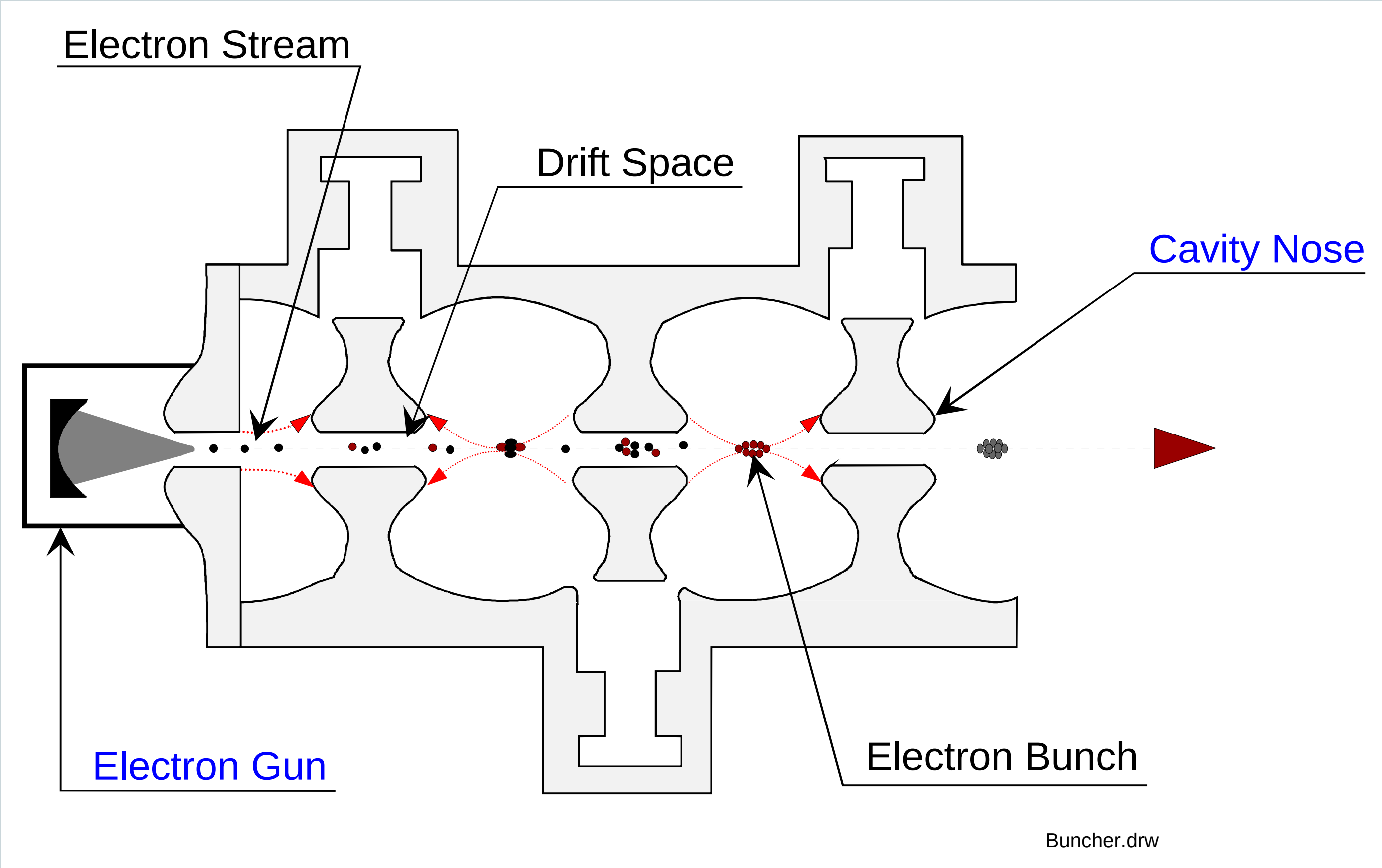
Source: Electron Gun



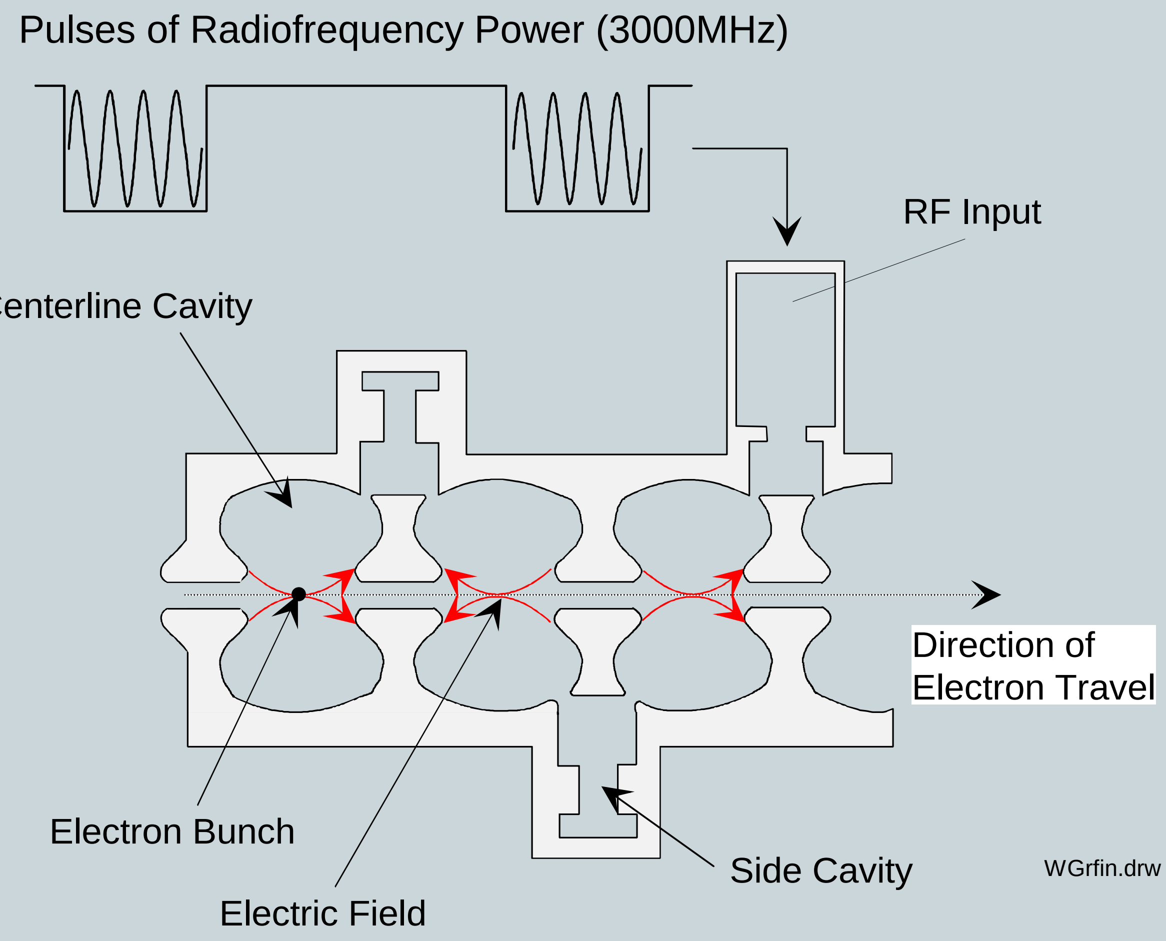
Electron gun



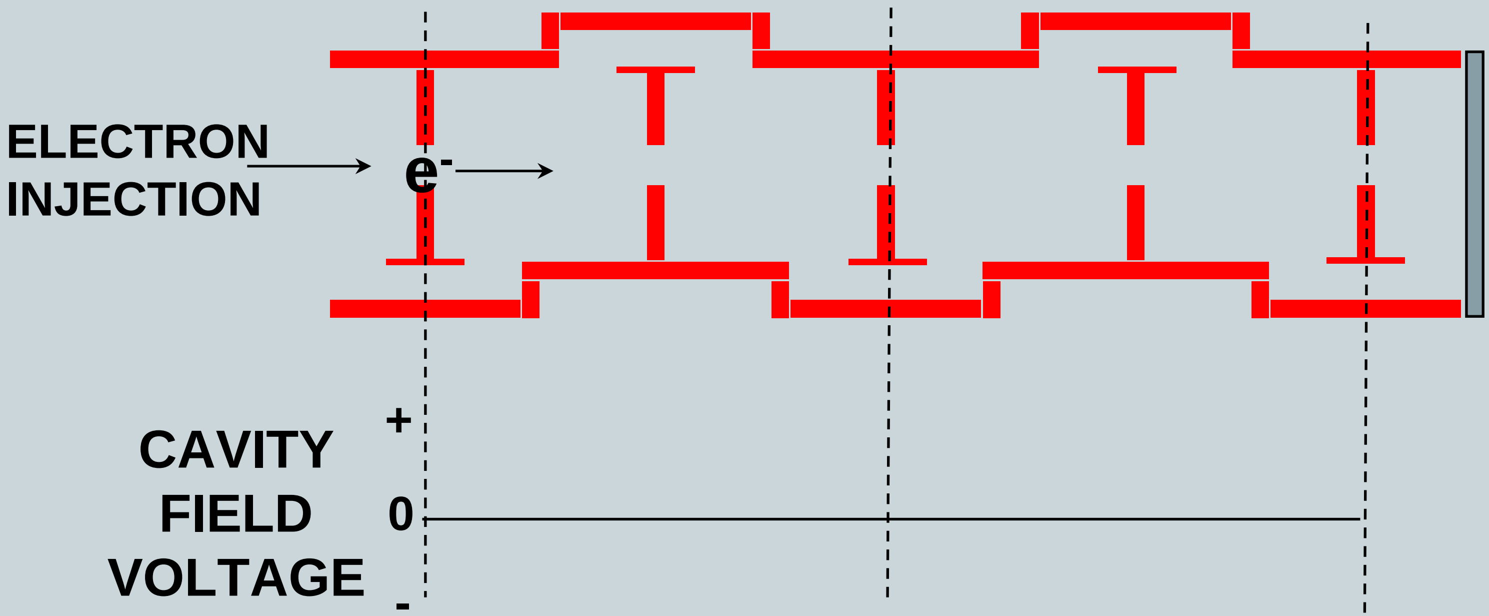
Design of the waveguide



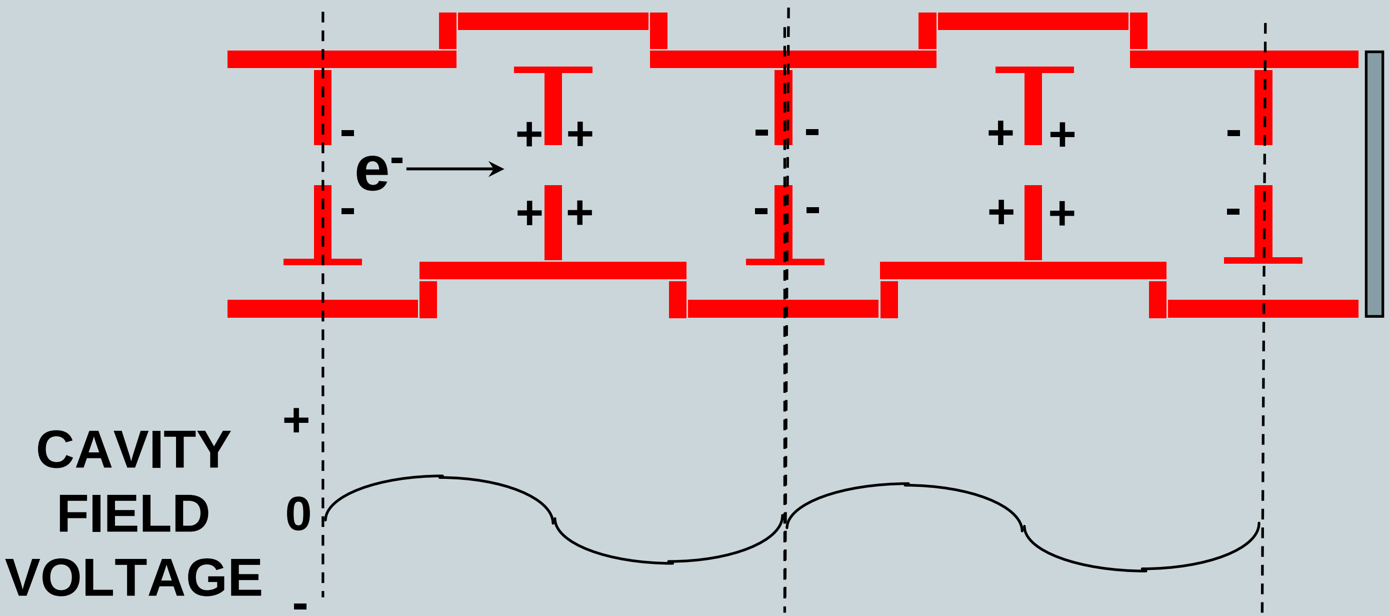
Accelerating the electrons



Standing wave acceleration



Standing wave acceleration



Standing wave acceleration

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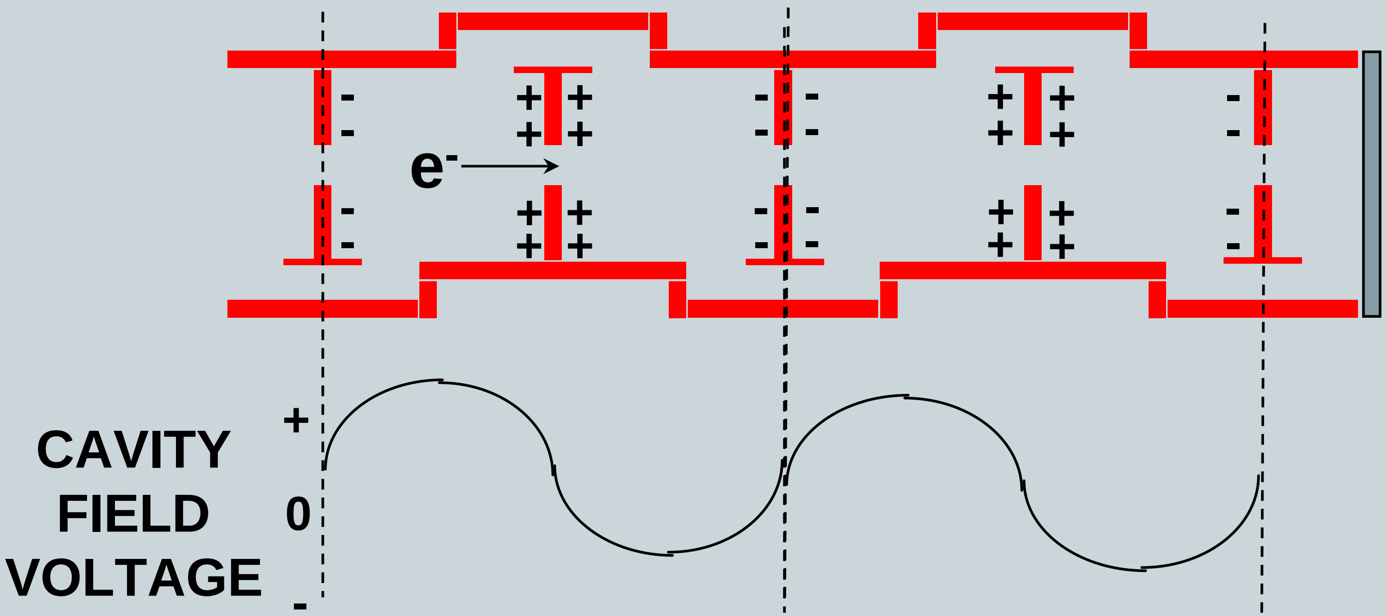
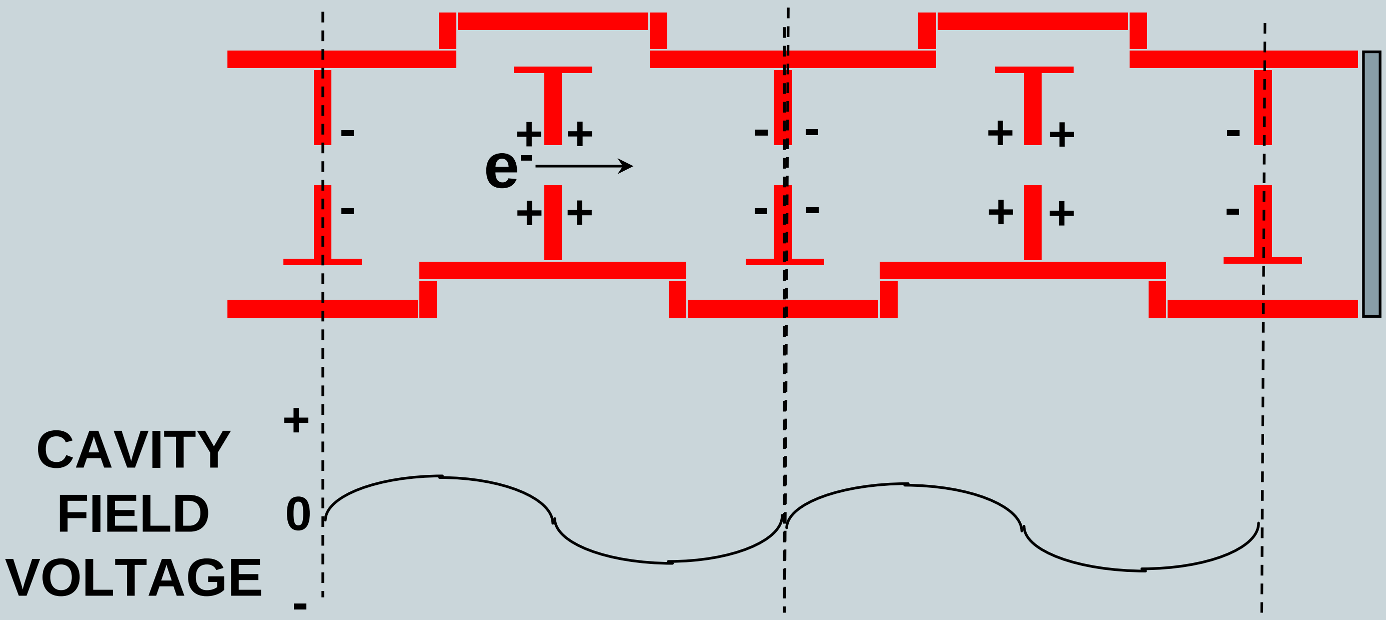
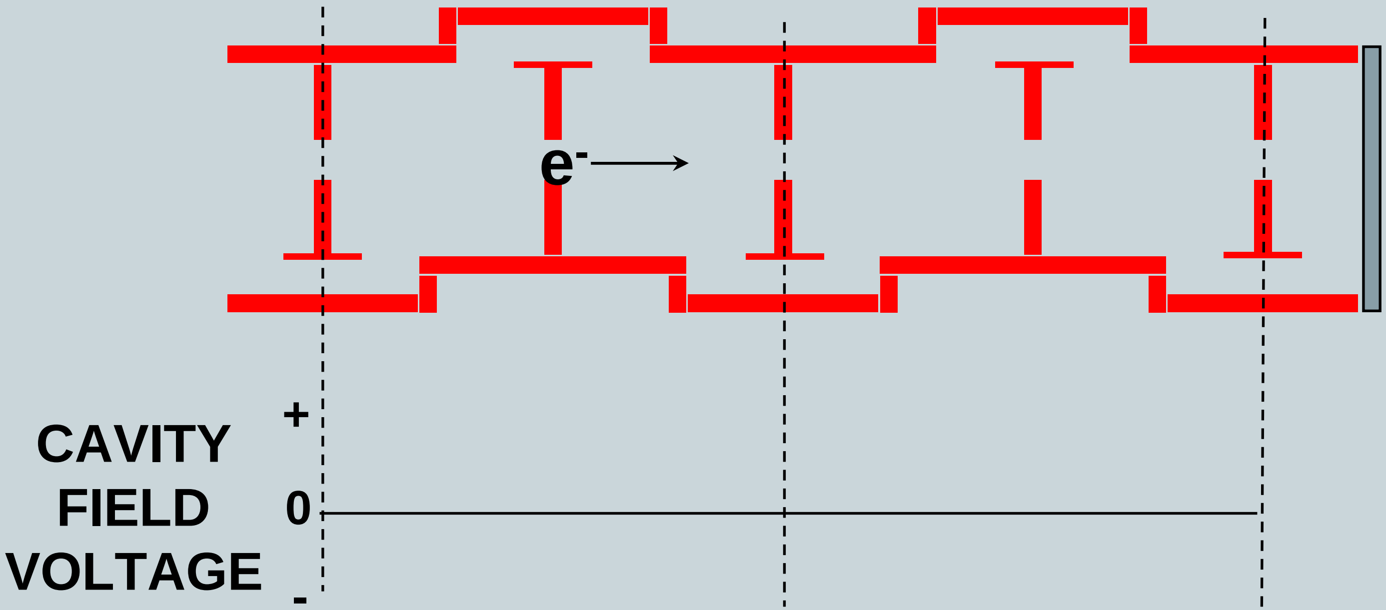


Standing wave acceleration



Standing wave acceleration



Standing wave acceleration

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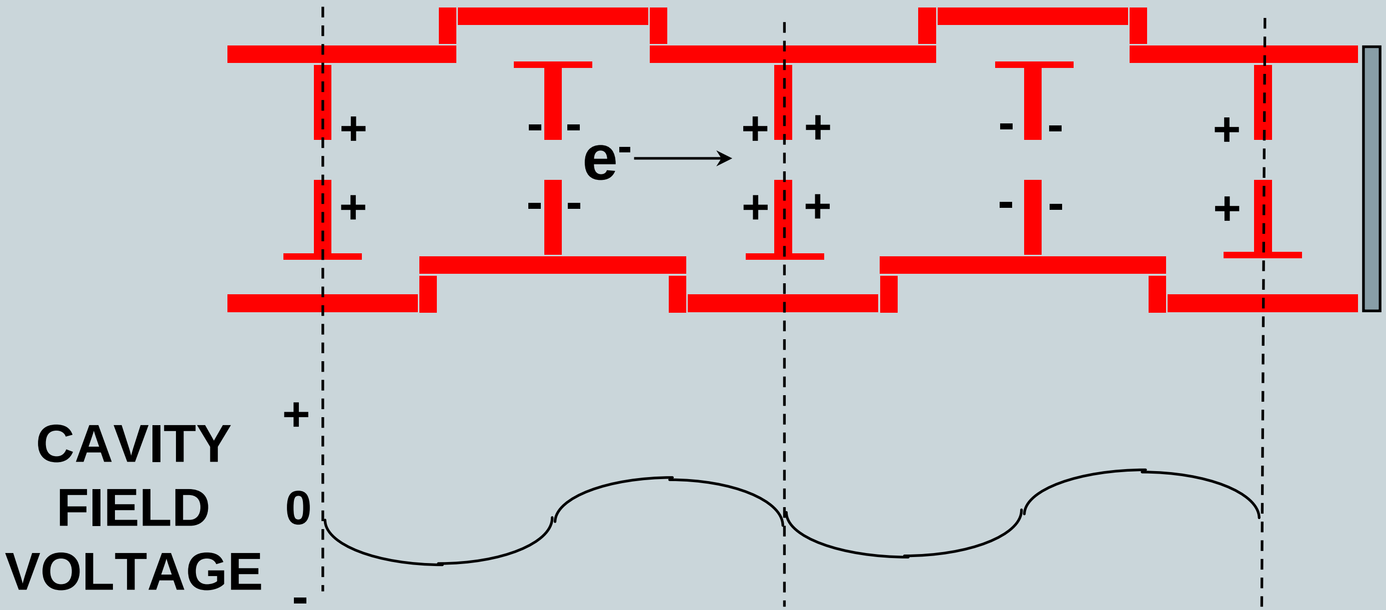

Standing wave acceleration

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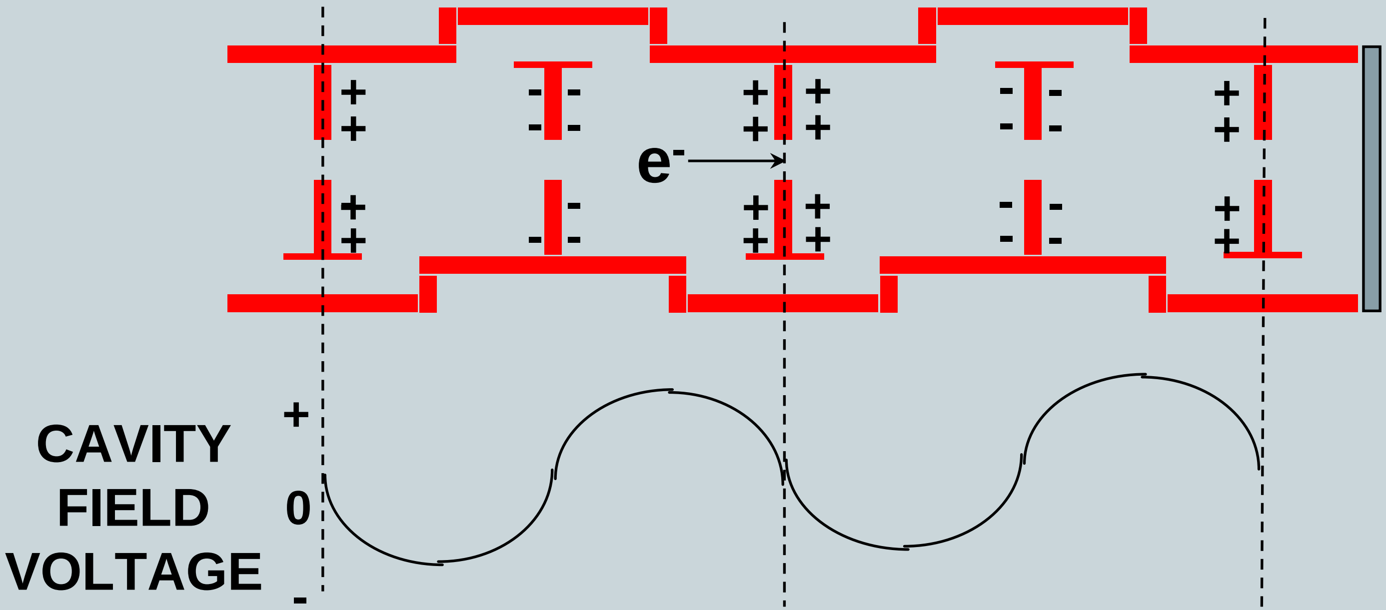

Standing wave acceleration

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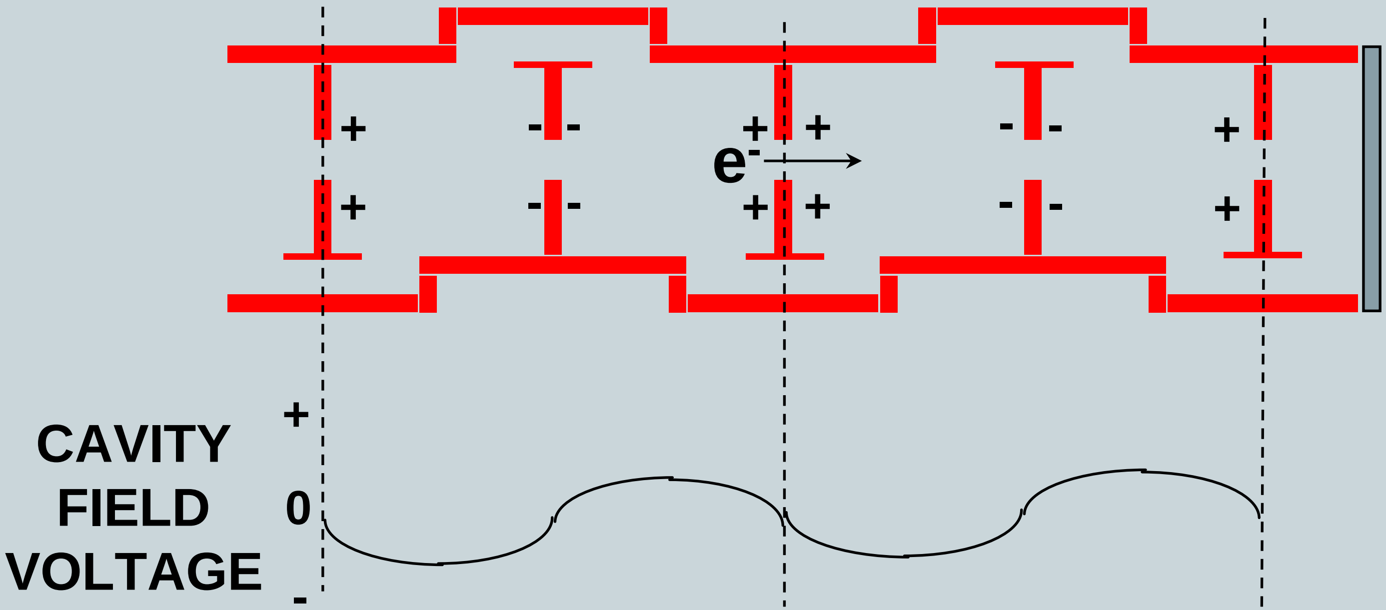

Standing wave acceleration

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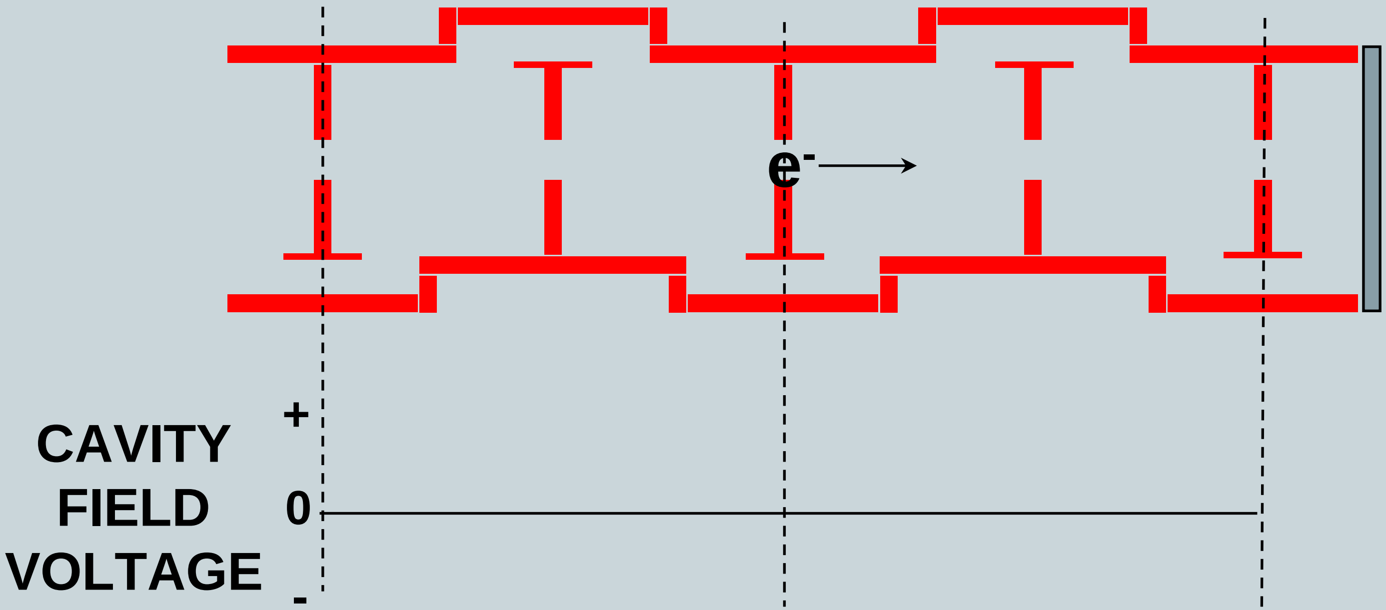

Standing wave acceleration

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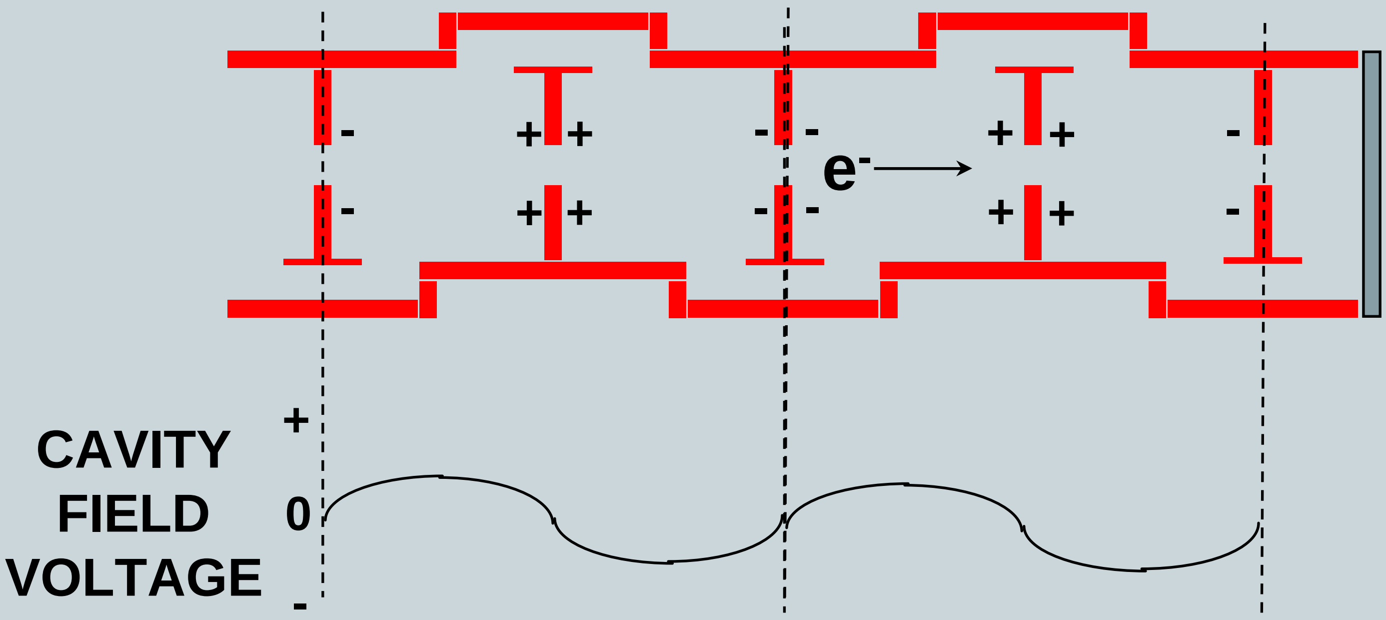
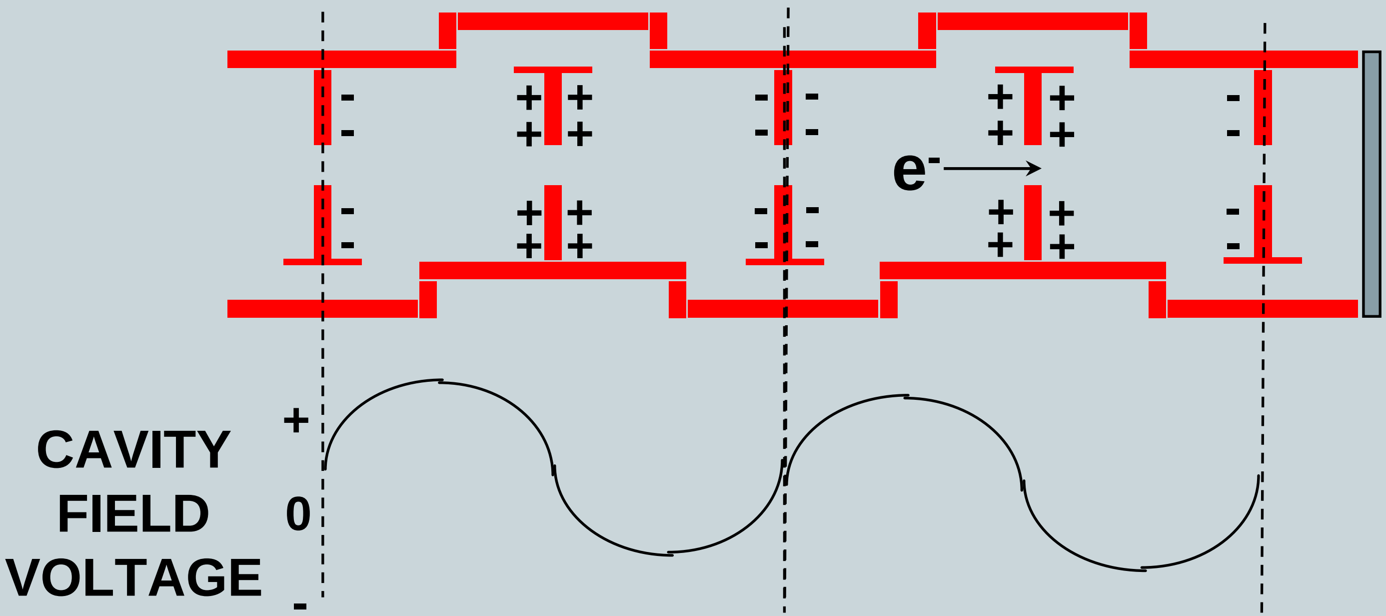


Standing wave acceleration



Standing wave acceleration

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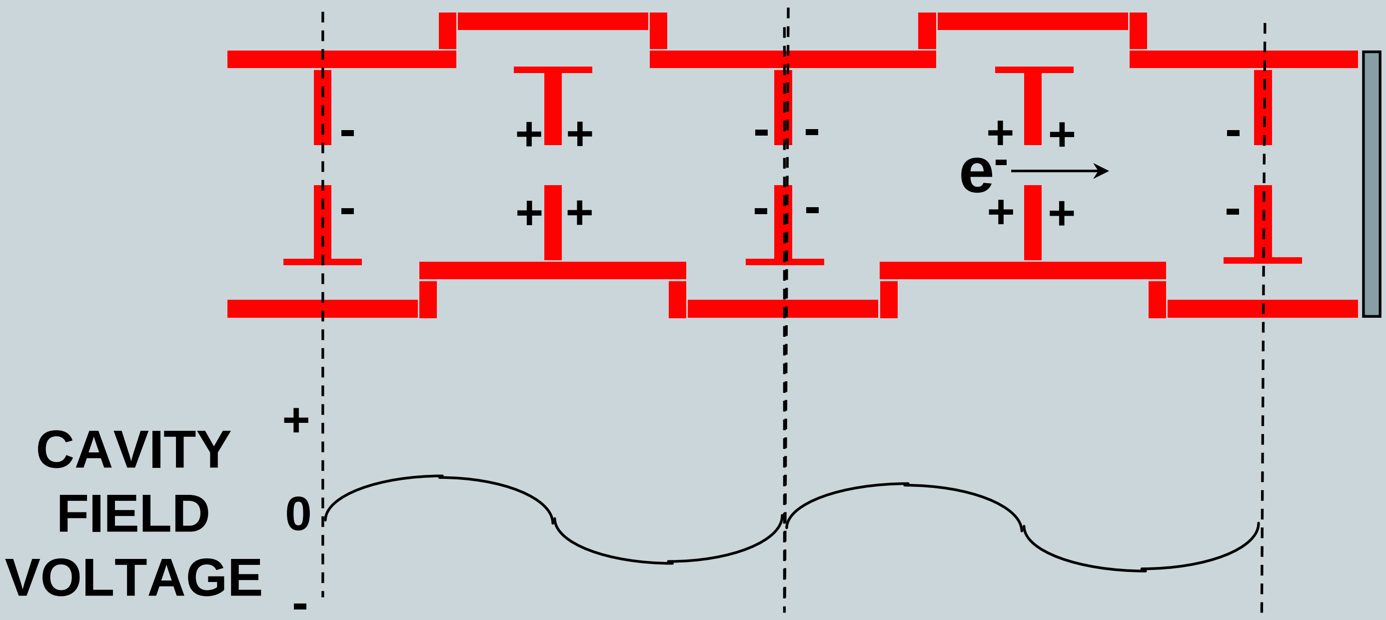

Standing wave acceleration

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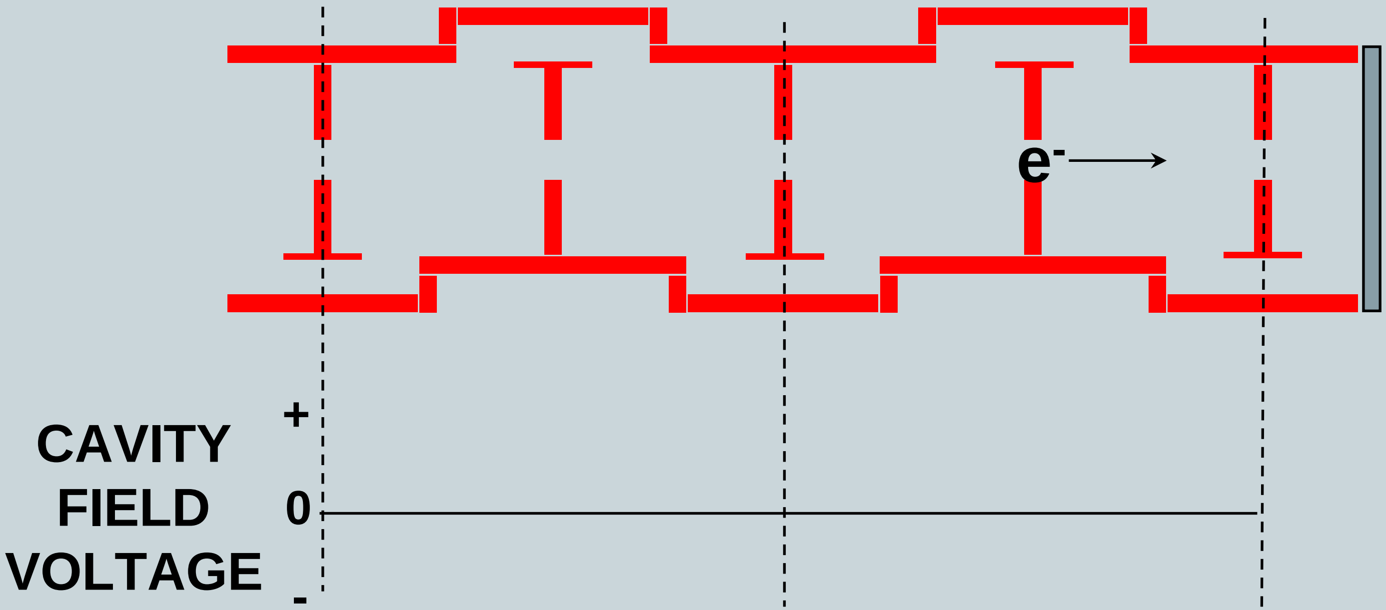
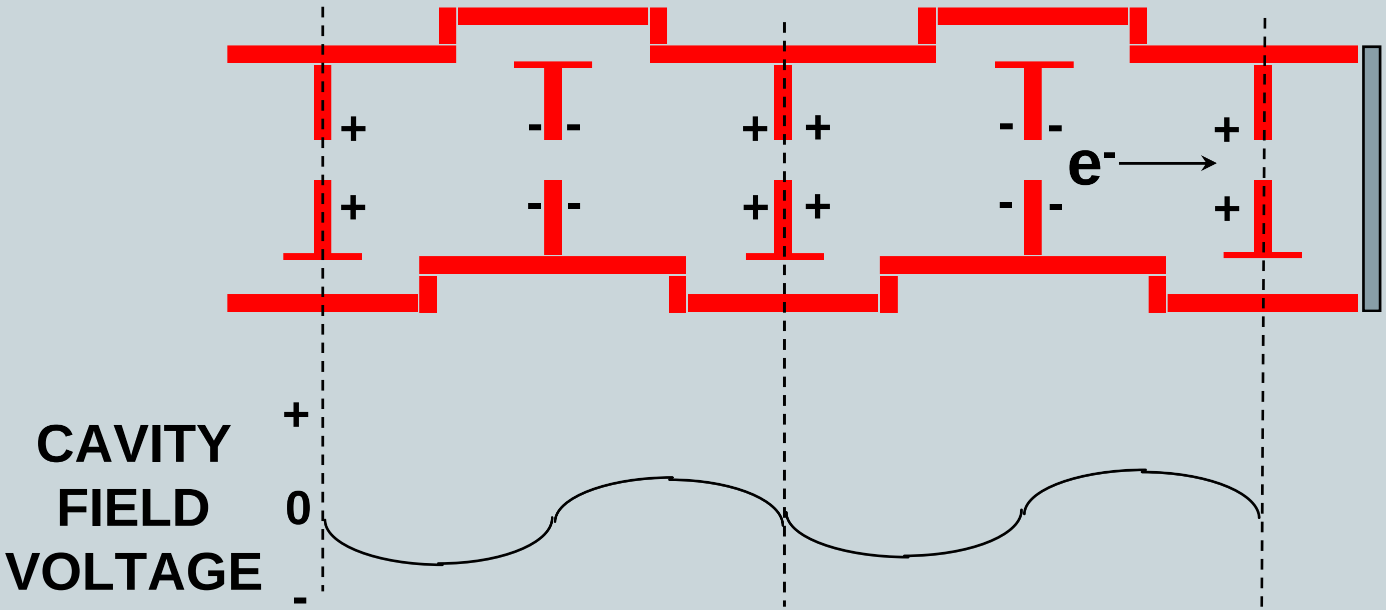
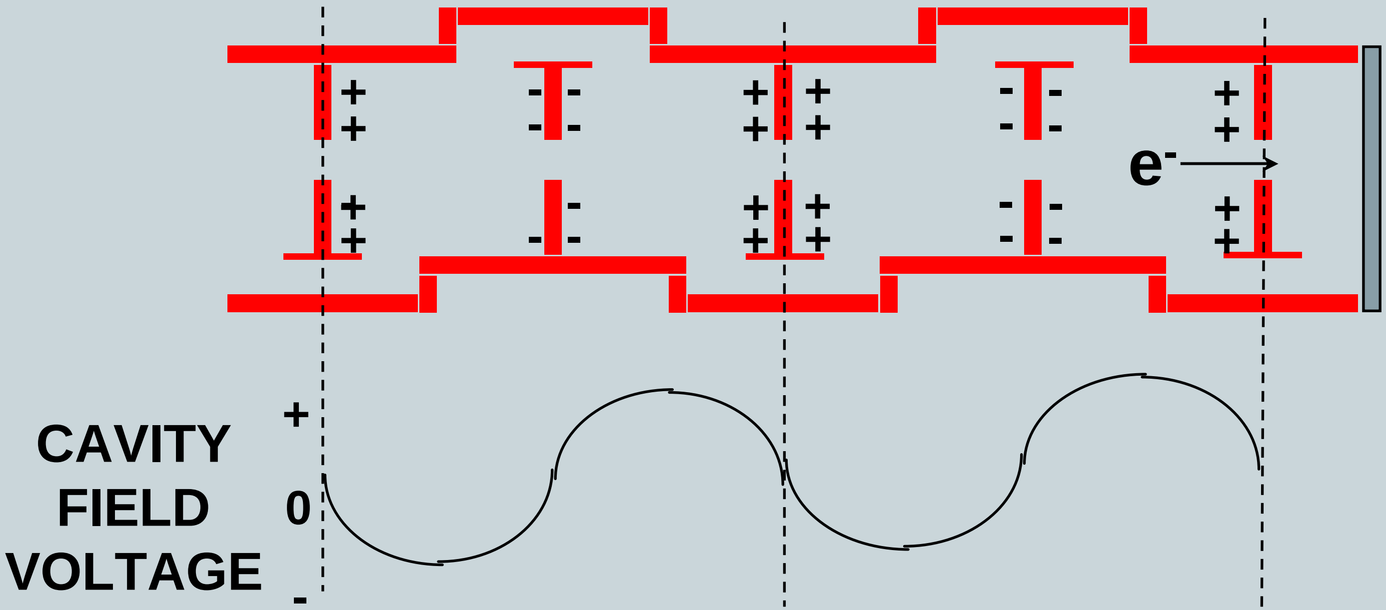


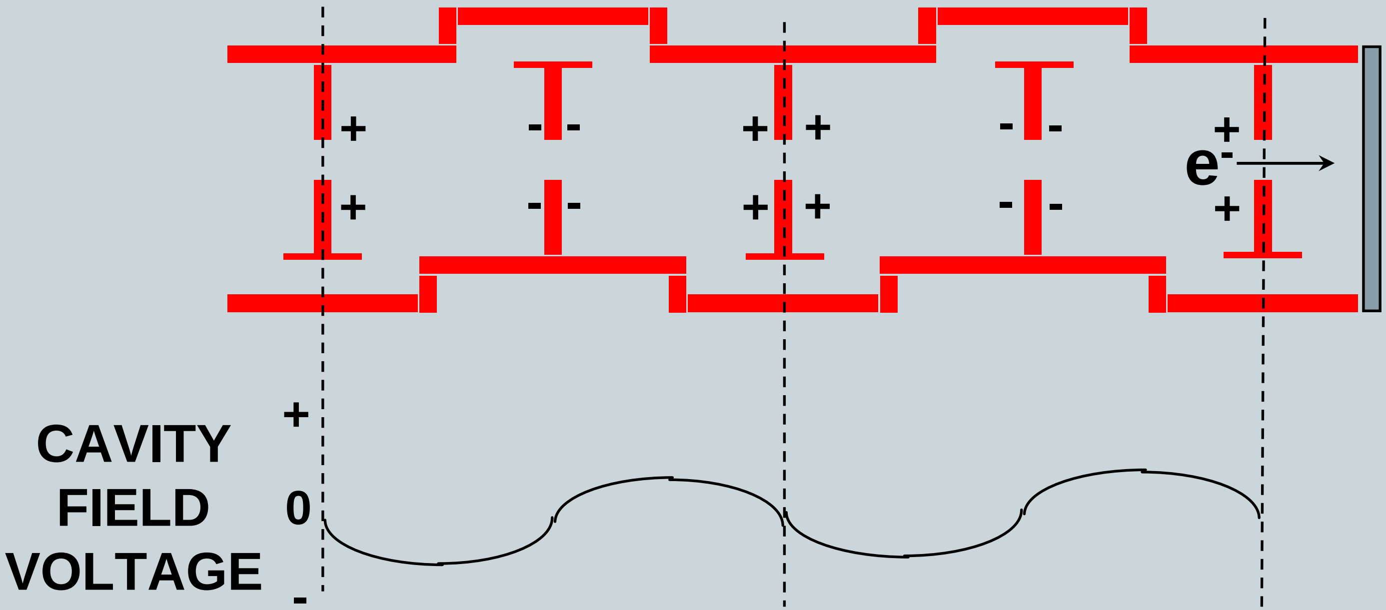
Standing wave acceleration



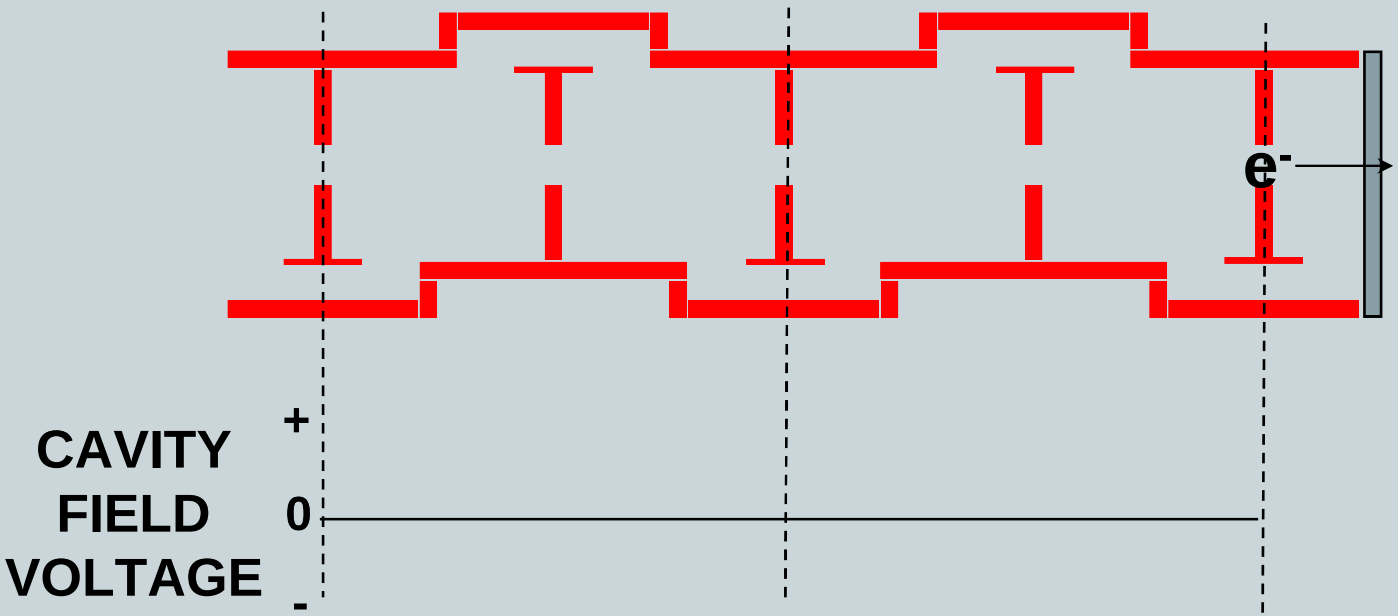
Standing wave acceleration



Standing wave acceleration



Standing wave acceleration



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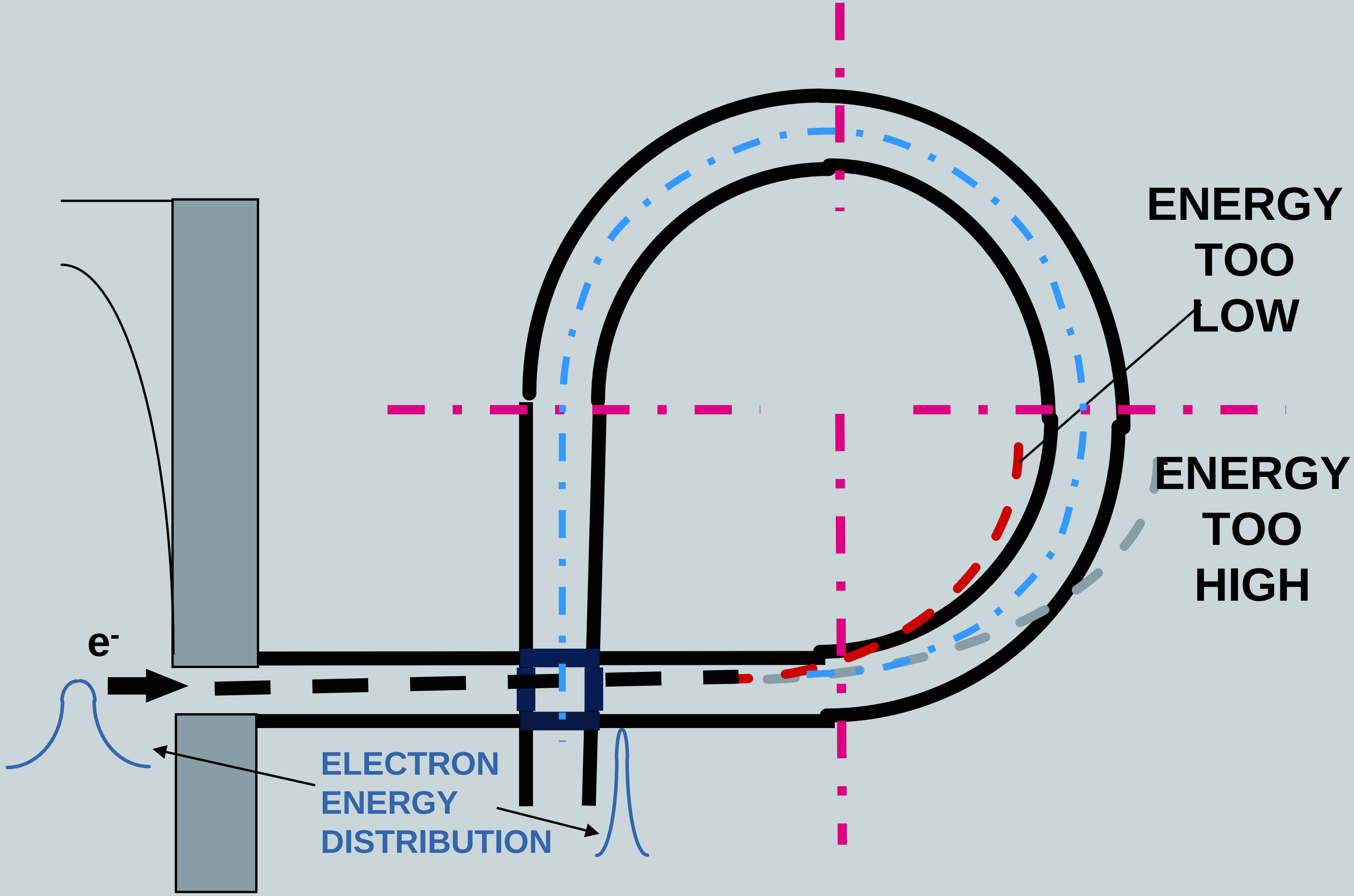
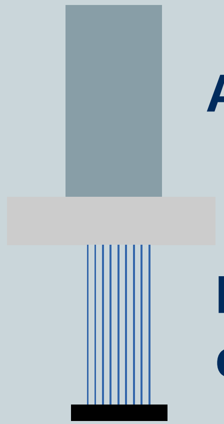
Bending magnet and envelope



Beam spot measurement 6MeV Linac

Measurement setup
spot size measure

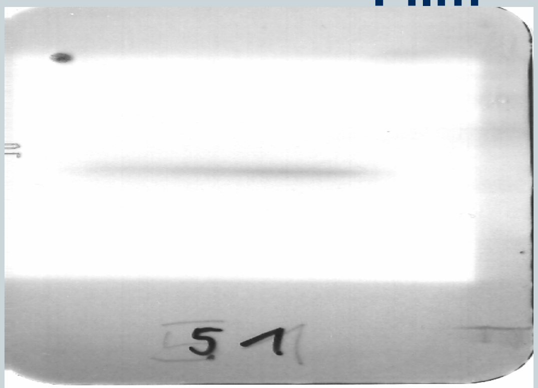


Accelerator

Slit Collimator

Pb film layer collimator

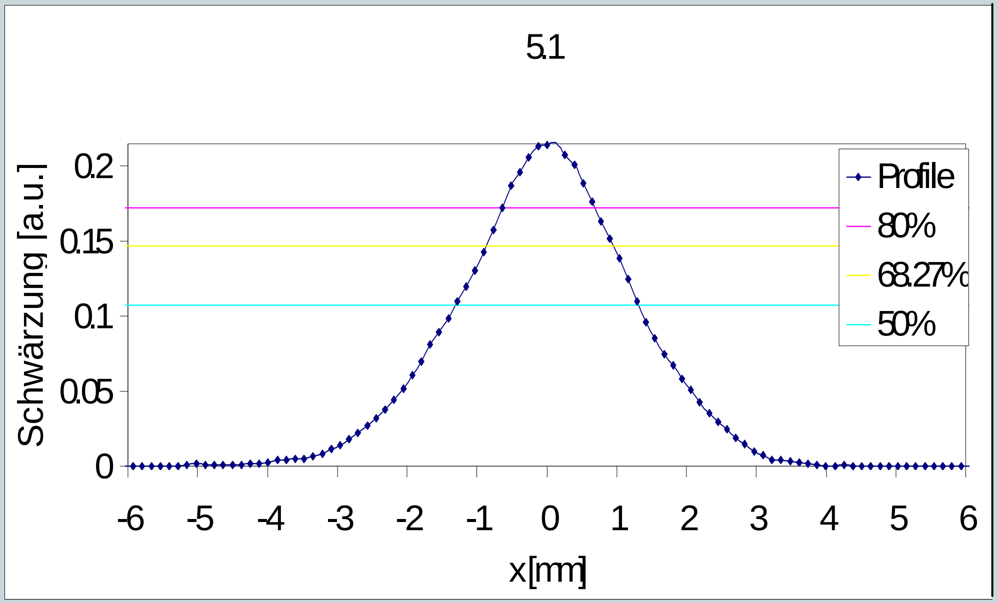
Film



Photon mode operation

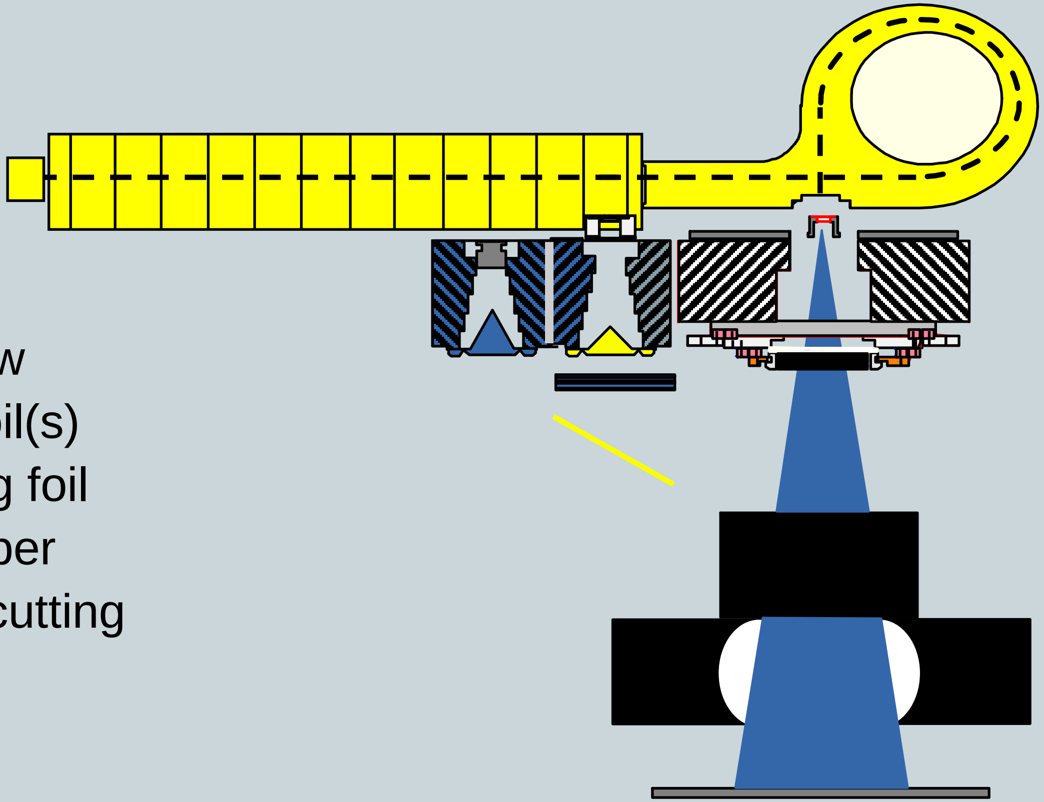
Integrated tungsten target

Energies up to 6 MeV



Beam Formation for Electrons

Electrons exit window
Primary scattering foil(s)
Secondary scattering foil
Electron dose chamber
Primary jaws beam cutting
Electron applicator



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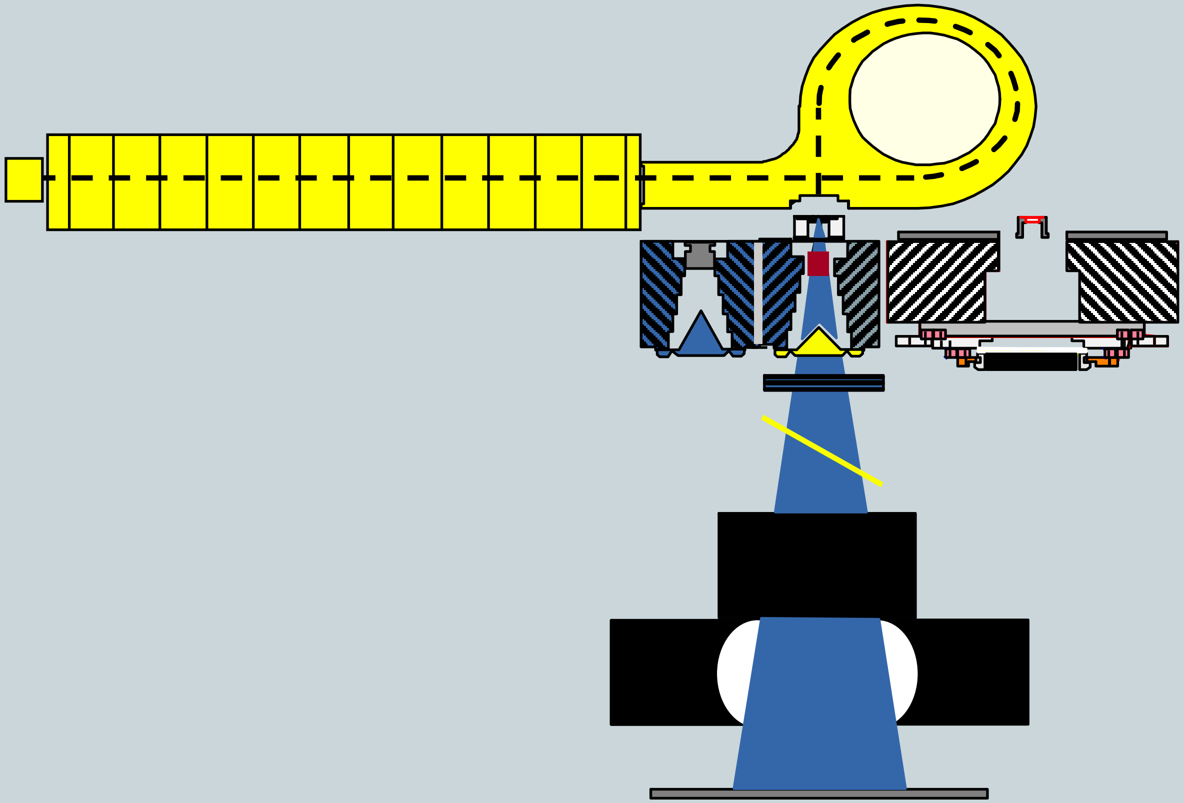
Beam Formation for Photons

Electrons exit window
Strike external W Target
Photons generated
Carbon electron absorber
Primary collimation
Flattening filter
Photon dose chamber
Field light mirror
Primary jaw (s) beam cutting

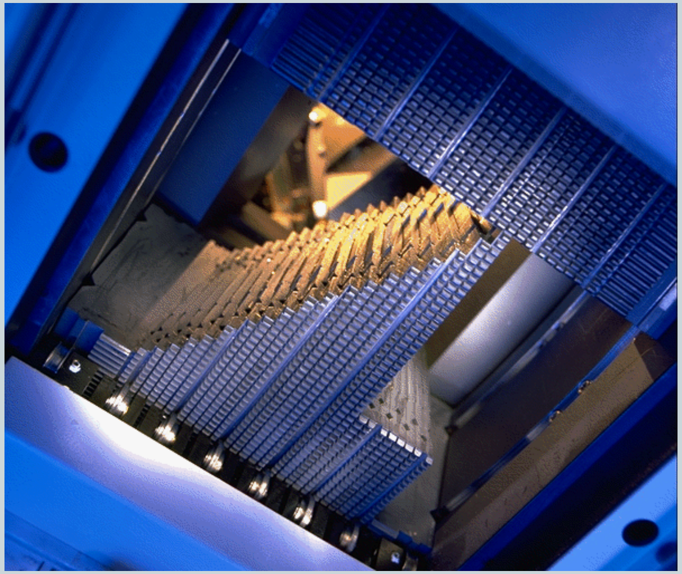


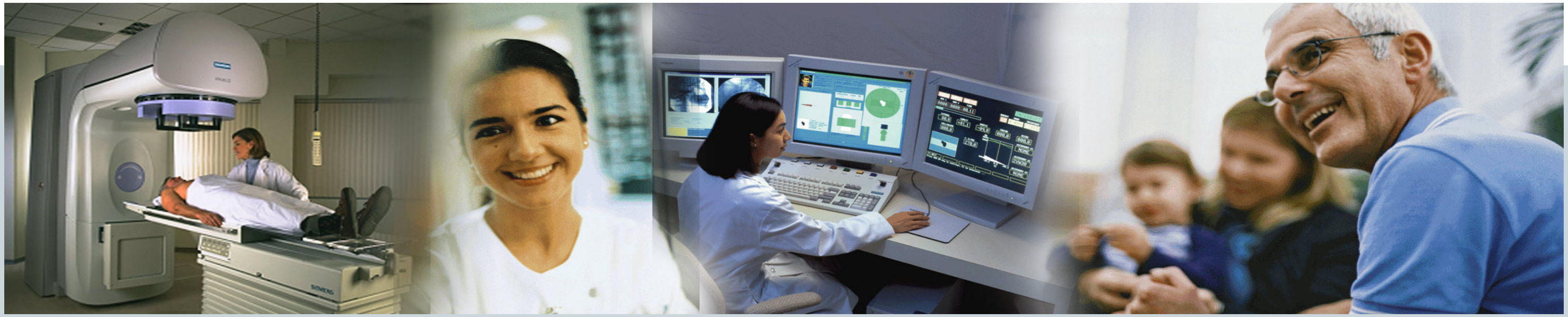
Multileaf Collimator (MLC)

Multi-element collimation device located inside the gantry head to shape the aperture of a treatment field.

Can substitute for a patient-specific, custom-built block used in 3-D conformal radiation therapy. This was the original intent of MLC.

Can also be used as a fluence modulator by varying the aperture across the target volume as a function of dose delivered. Such usage is called Intensity Modulated Radiation Therapy (IMRT). This is today’s most important use of MLC.





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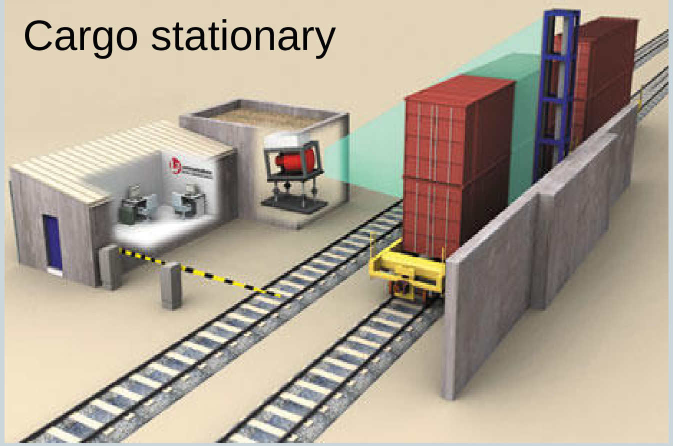
Industrial applications

Linear Electron Accelerators are used in industrial applications too:

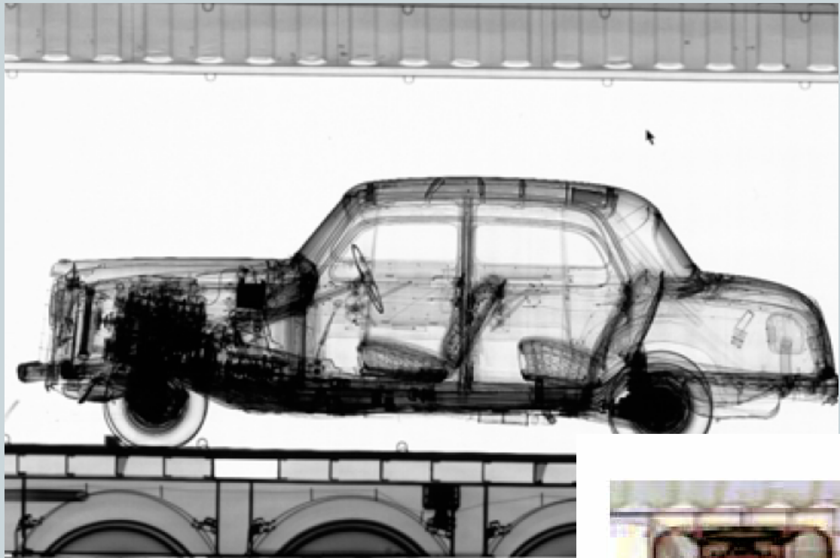
- NDT (non destructive testing)
- CARGO INSPECTION
- FOOD IRRADIATION
- STERILISATION
- PROCESSING SEWAGE WATERS OR INFECTED WASTES BEFORE DISPOSAL
- IRRADIATION OF CABLES, PIPES, PRODUCTS OF COMPLEX SHAPE, etc.
- RESEARCH

Industrial applications

Some examples:



Examples: Cargo Scanner at Customs (Hamburg) (Source: Ph.D. Thesis from Peter Carsten Lotz)



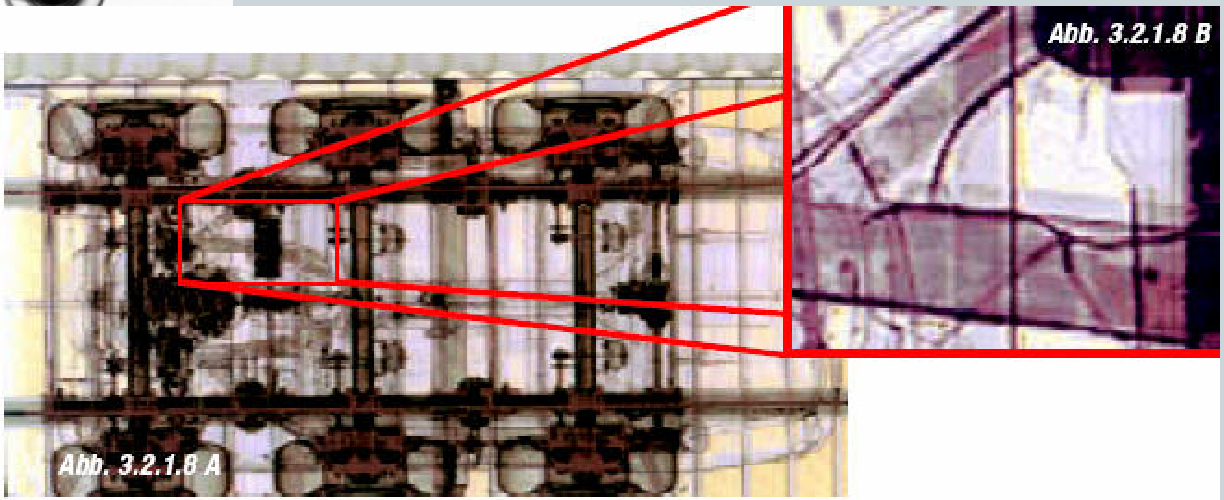


Abb. 3.2.1.8: Nachweis von 19 kg Kokain (Wert ca. 3 Millionen €) in der Karosserie des Oldtimers von Abb. 3.2.1.7. In der vertikalen Sicht (A) und durch Detailvergrößerung (B) zeigen sich die Drogenpäckchen. Containerprüfanlage Hamburger Hafen (1997).

Examples: Cargo Scanner at Customs (Hamburg) (Source: Ph.D. Thesis from Peter Carsten Lotz)

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Abb. 3.2.2.1 B: Waffenkoffer im horizontalen Strahlengang mit einem auf dem Lauf stehendem Gewehr und Munition (rotes Rechteck). Ausschnittsvergrößerung. Containerprüfanlage im Hamburger Hafen

Abb. 3.3.4: Hinter einer Tarnladung Schrott verbergen sich 4,5 t Marihuana. Containerprüfanlage CargoSearch der Firma American Science and Engineering (AS&E, 2001).URL: http://www.as-e.com/technology/imagebank/images/ase_01b.jpg, gesehen 22.07.02.

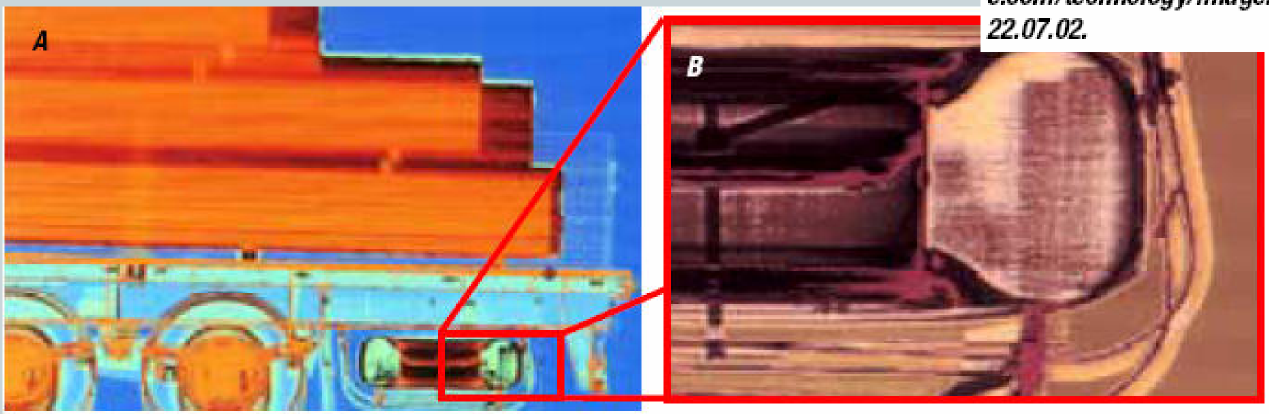
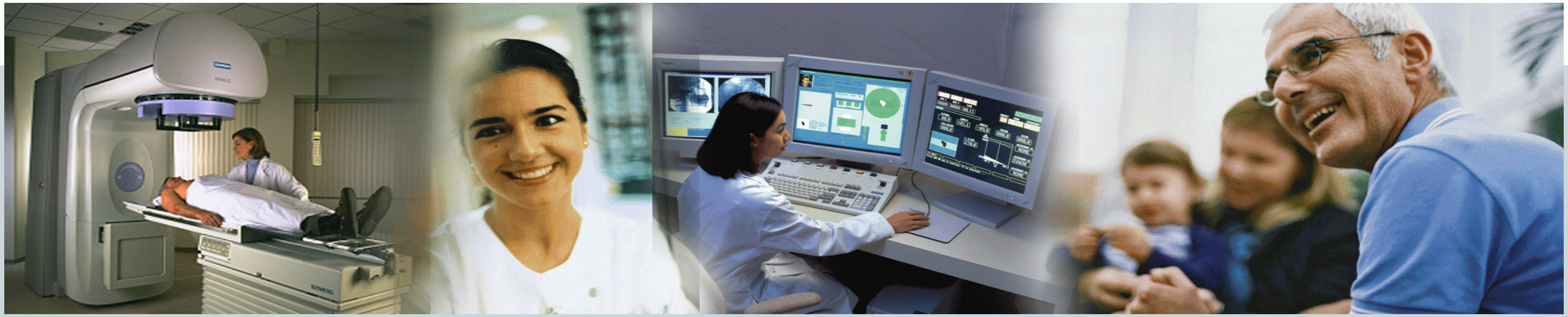


Abb. 3.2.3.1: Zigarettenstangen im Reserverad. Horizontaler Strahlengang (A) und Detailvergrößerung (B). Vorteilhaft für die Schmuggler ist bei dem Reserverad die schnellen Montagen und Demontagen vor bzw. nach dem Grenzübertritt (1998). Containerprüfanlage Hamburger Hafen (1998).



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Welcome to Rudolstadt, Thuringia

Employees 220

Apprentices 35

Surface Area 23 tsqm

Founded 1919

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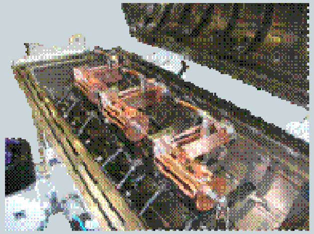
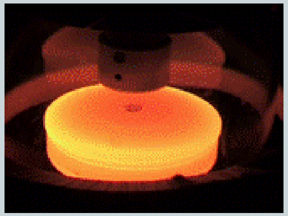
Key Technologies @ H IM CVG

Therapy components

Cleanroom high precision assembly → Vacuum processes → High energy final test



Vacuum components



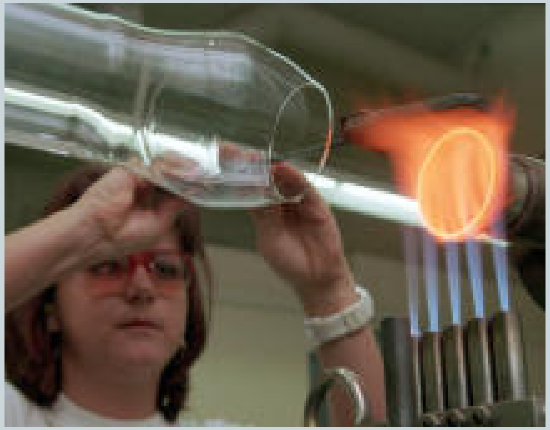
High temperature annealing and brazing ← Cleaning and coating of vacuum components ← Precision machining of special alloys

X-ray Products

Cleanroom high precision assembly → Vacuum processes → High voltage final test

Vacuum components

Mechanical components



Glass treatment

Galvanik processes

High temperature processes

Manufacturing of X-Ray Tubes

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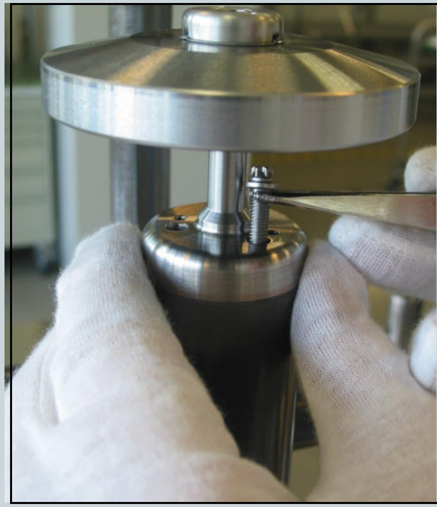
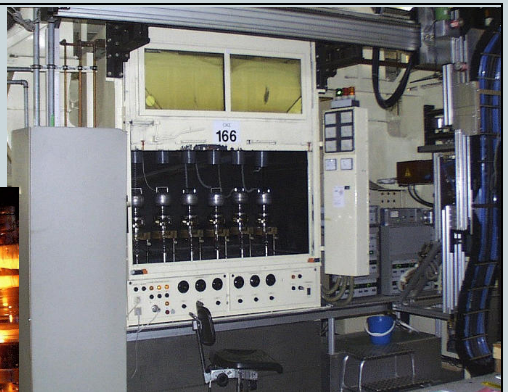
Brazing



Assembly



Degassing

Final Test

Manufacturing of cavities

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Therapy Components / Waveguides

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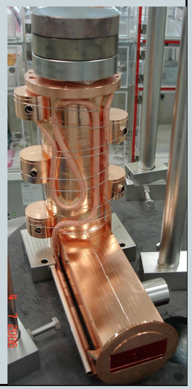
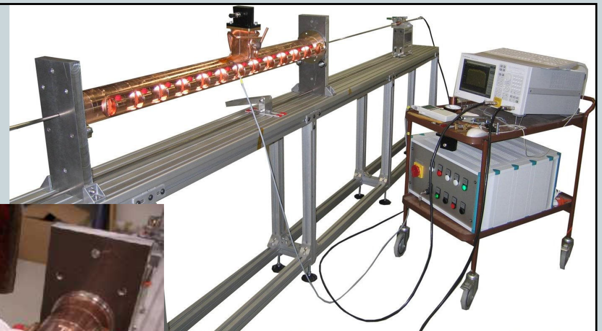
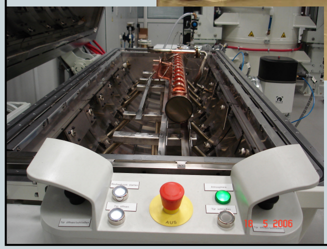


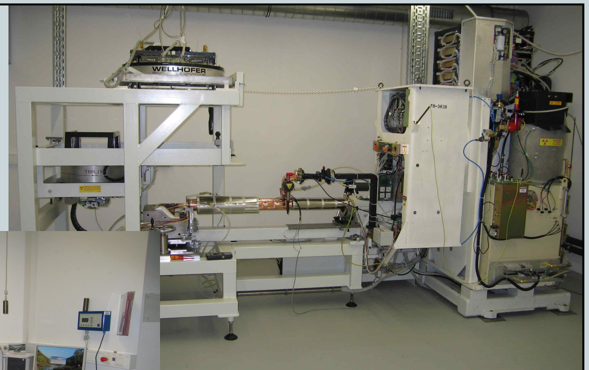
Stacking Brazing




Tuning

Bakeout




Beamtest

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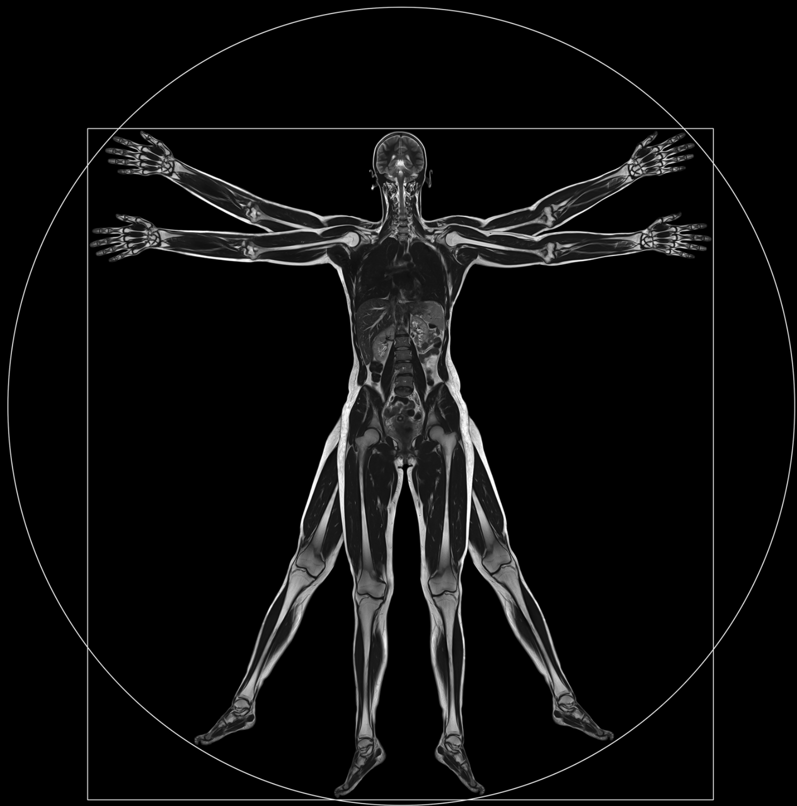
Thank you for attention



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Solutions that help