
# PART V:

## Industrial Applications

# Defining Industrial Applications of Accelerators?

- Generally, high energy particle beams induce nuclear reactions and activation
- In contrast, in industrial applications, nuclear reactions and activation are undesirable and avoided, but other effects of ionizing radiations are researched
- These desired effects include:
  - Sterilization
  - Cross linking of polymers
  - Curing of composite materials
  - Modification of crystals
  - Improvement of semi conductors
  - Beam aided chemical reactions
  - Thermal or mechanical effects of the particle beam

# Which beams are used?

- The choice of particle beams used in industrial applications is defined, to a large extent, by the desire to avoid nuclear reactions and activation.
- Commonly used beams include:
  - Electron beams below 10MeV.
  - X-Rays from e-beams below 7.5MeV.
  - Intense, low energy proton beams.
  - Heavy ion beams well below the Coulomb barrier.
- Also, for industrial applications, large beam currents/powers are needed to reach industrial scale production rates. Beam powers from 50 kW to 1 MW are common.

# Key E-beam and X-ray Industrial Applications

- **Sterilization**
  - Sterilization of Medical Devices
  - Surface Sterilization
  - Food Pasteurization
- **E-beam induced chemistry**
  - Reticulation of Polymers
  - Curing of composites
  - Environment remediation
- **E-Beam induced crystal defects**
  - Modification of Semiconductors
  - Coloring of Gemstones

# The options for the sterilization of medical devices

- Steam (incompatible with most polymers)
- Ethylene Oxyde
  - Inexpensive
  - EtO is explosive, toxic and harmful to the environment
  - EtO sterilization may leave harmful residues
- Irradiation
  - Cobalt
  - E-beam
  - X-ray



iba Particle Therapy

# The options for sterilization by irradiation (1)

- **Gammas from Co60** ($T_{1/2}$=5.2 y; $\gamma_1$=1.33 MeV; $\gamma_2$=1.17 MeV)
  - Low investment cost, specially for low capacities
  - Simple and reliable, scalable from 100 kCuries to 6 MCuries (about 5 kg of Co-60)
  - Isotropic radiation > inefficiencies in use
  - Pallet irradiation, but low dose rate > slow process
  - Absolutely no activation
  - Cannot be turned OFF > inefficient if not used 24/7
  - Growing security concern: the cobalt from a sterilization plant could be used to make dirty bombs

# The options for sterilization by irradiation (2)

- **Electron beams**
  - Directed radiation > Efficient use
  - Lowest cost of sterilization for large capacities
  - Can be turned OFF > safer
  - Short range (4.5 $g/cm^2$ at 10 MeV) > 2-sided irradiation of boxes
  - More complex dose mapping
  - Minimal, hardly measurable, but non zero activation

# The options for sterilization by irradiation (3)

- **X-Rays from E-beams**
  - Excellent penetration
  - Simple dose mapping
  - Pallet irradiation
  - Directed radiation > Efficient use
  - Loss of a factor 10 in energy when converting e-beams to photons
  - Cost of sterilization higher than electrons
  - Cost of sterilization is generally higher by X-Rays than Cobalt if used 24/7, excepted for very large capacities
  - Can be turned OFF > safer
  - Minimal, hardly measurable, but non zero activation

# Food irradiation applications

## Low Dose Applications (< 1kGy)

- **Phytosanitary** Insect Disinfection for grains, papayas, mangoes, avocados...
- **Sprouting Inhibition** for potatoes, onions, garlic...
- **Delaying of Maturation**, parasite disinfection.

## Medium Dose Applications (1 – 10 kGy)

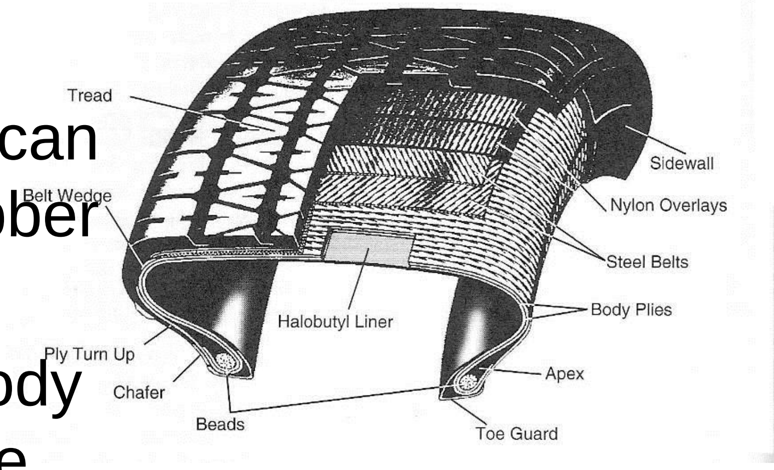
- **Control of Foodborne Pathogens** for beef, eggs, flounder-crab-meat, oysters...
- **Shelf-life Extension** for chicken and pork, low fat fish, strawberries, carrots, mushrooms, papayas...
- **Spice Irradiation**

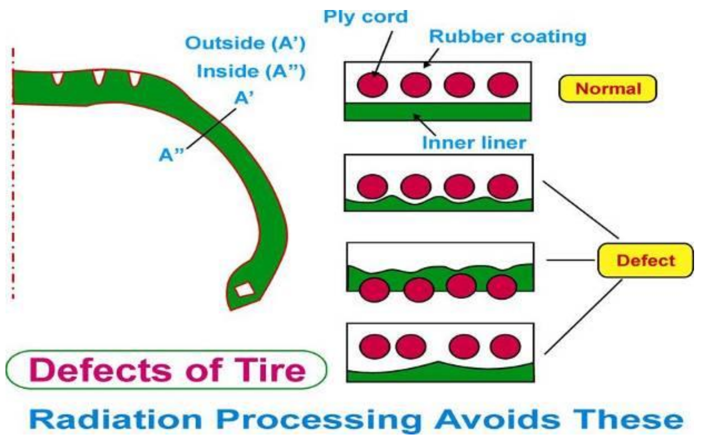
## High Dose Applications (> 10 kGy)

- **Food sterilization** of meat, poultry and some seafood is typically required for hospitalized patients or astronauts.

# E beam treatment of Tires

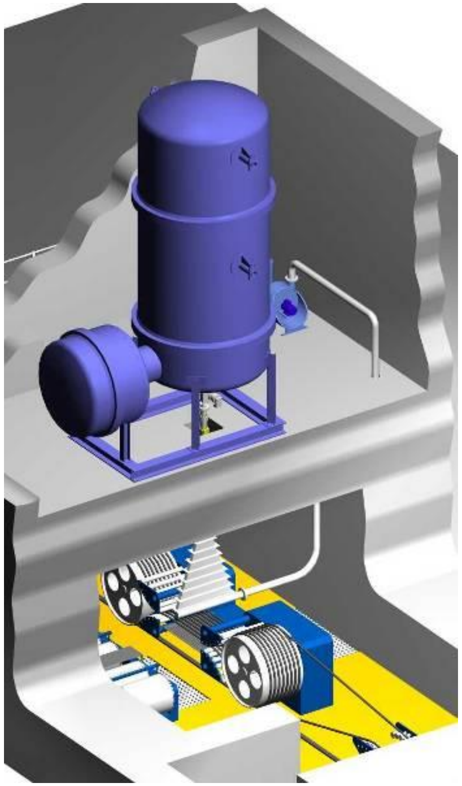
- Reduction in material hence in the weight of the tire
- Relatively low cost synthetic rubber can be used instead of costly natural rubber without a loss in strength
- The radiation pre-vulcanization of body ply is achieved by simply passing the body ply sheet under the scan horn of an electron accelerator to expose the sheet to high-energy electrons
- Higher production rates
- Construction of green tires
- Reduction of production defects



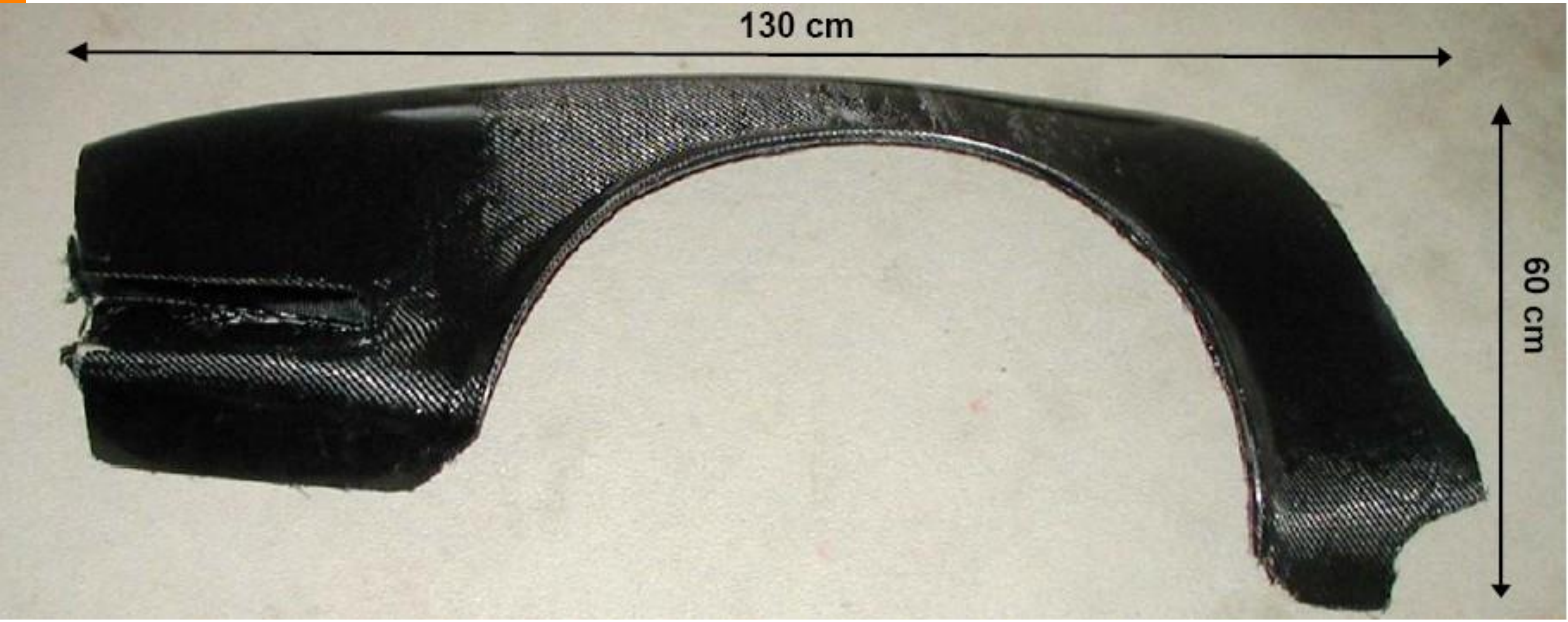
# Polymer Cross-Linking

- **Wires** stand higher temperature after irradiation
- **Pipes** for central heating and plumbing
- **Heatshrink elastomers** are given a memory

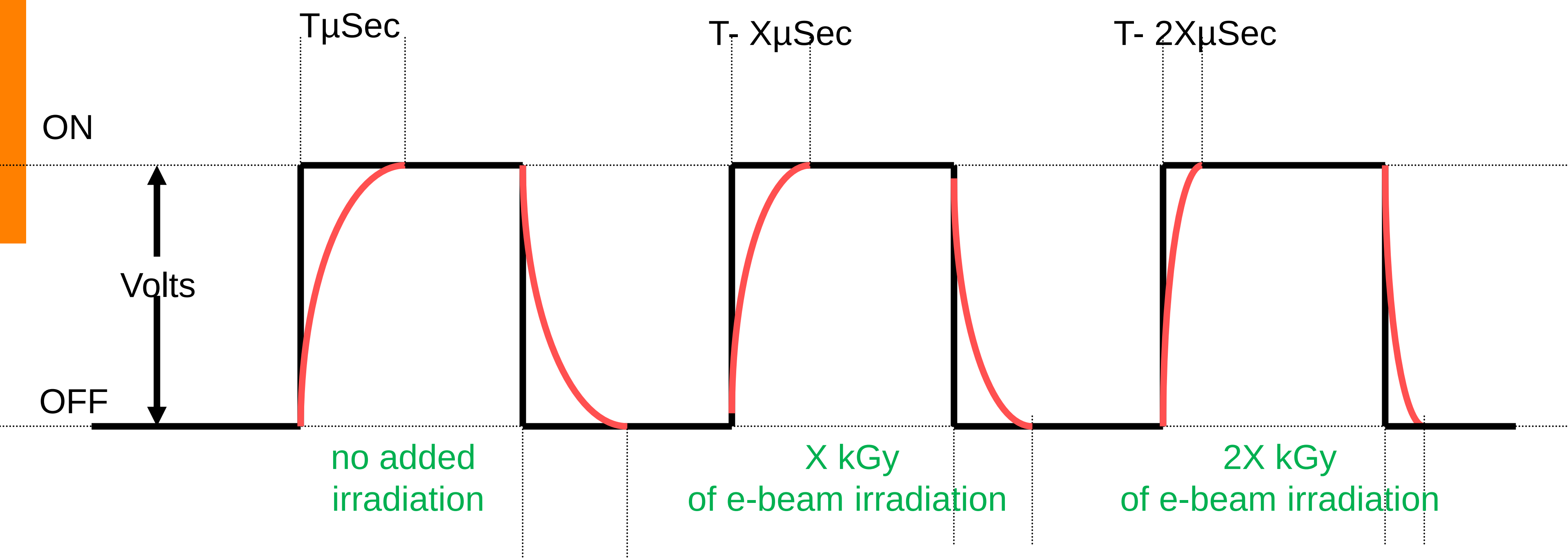


# Composite curing: X-ray Cured Carbon Fiber

- Sports Car Fender made light, restistant and requiring less fuel



# E-beam irradiation improves SC switching speed

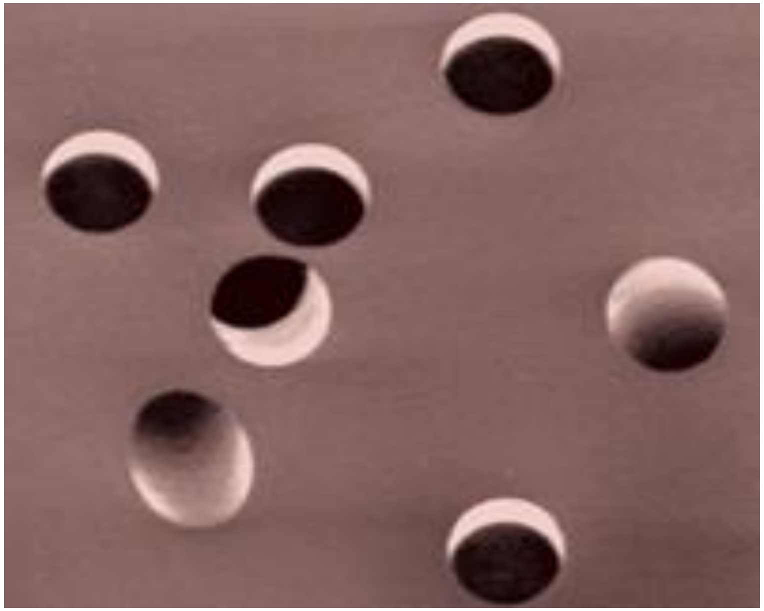


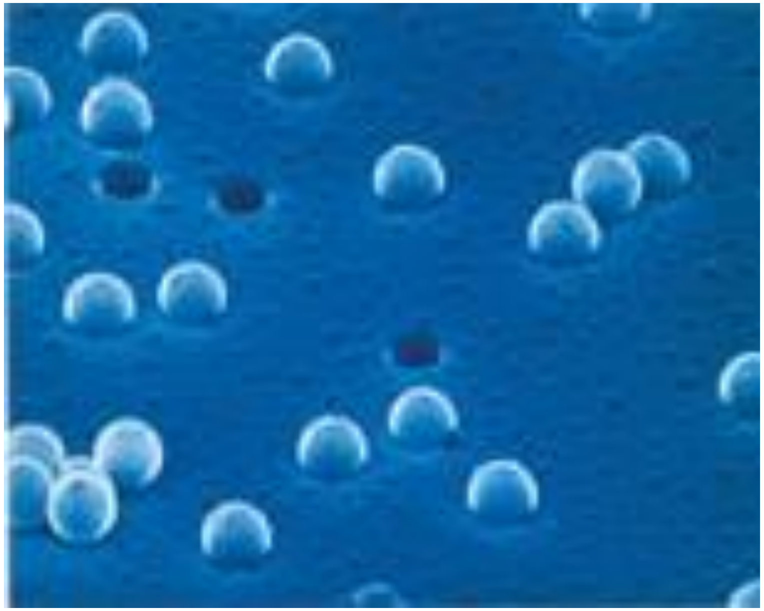

**Typical semicondutors:**

- fast recovery diodes
- power diodes
- Bipolar power transistors
- power MOSFETs
- power rectifiers
- IGBT's
- thyristors
- silicon-controlled rectifiers

# Microfiltration membranes by heavy ions

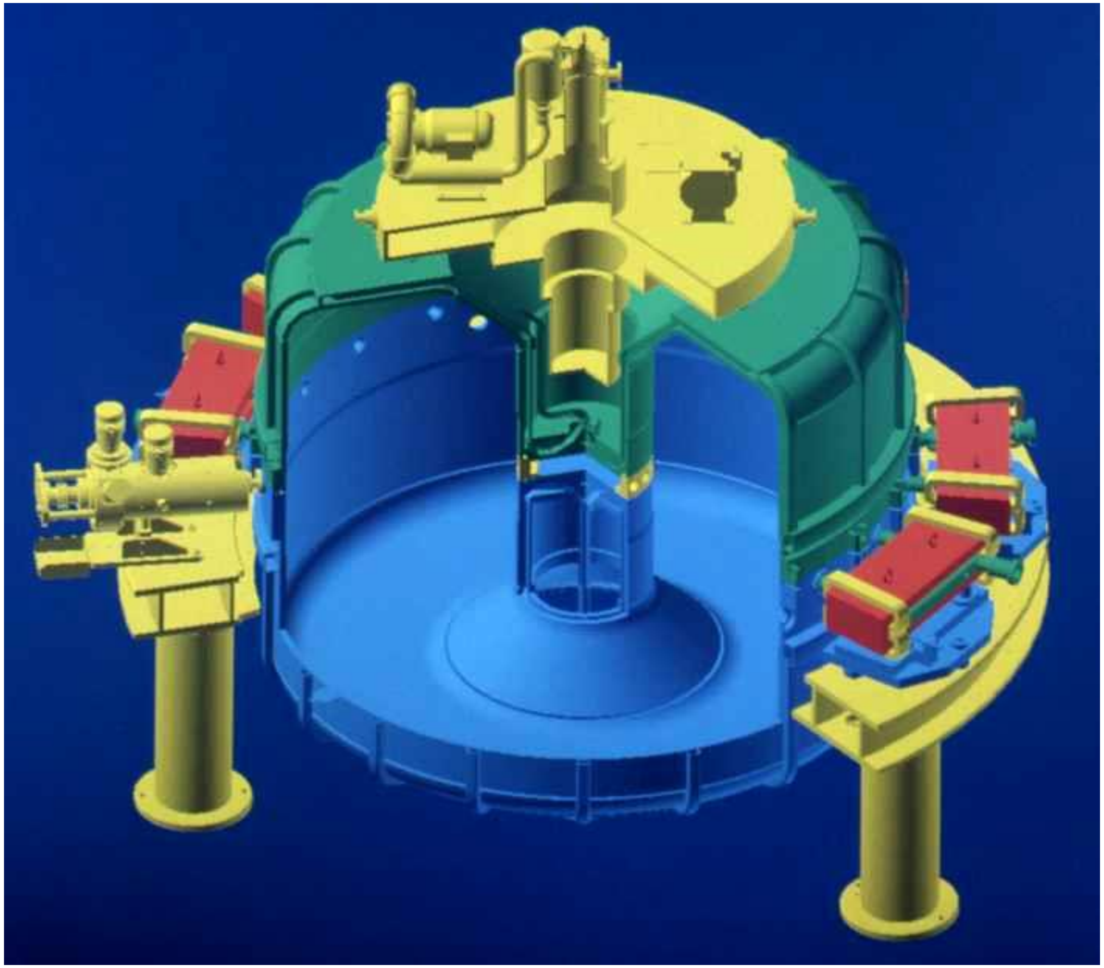
- Heavy ion beams are used to produce track-etched microfiltration membranes, commercialized i.a. under the brand name “Cyclopore”
- In these membranes, tracks of slow, heavy ions crossing a sheet of polymer are chemically etched, giving cylindrical pores of very accurate diameter





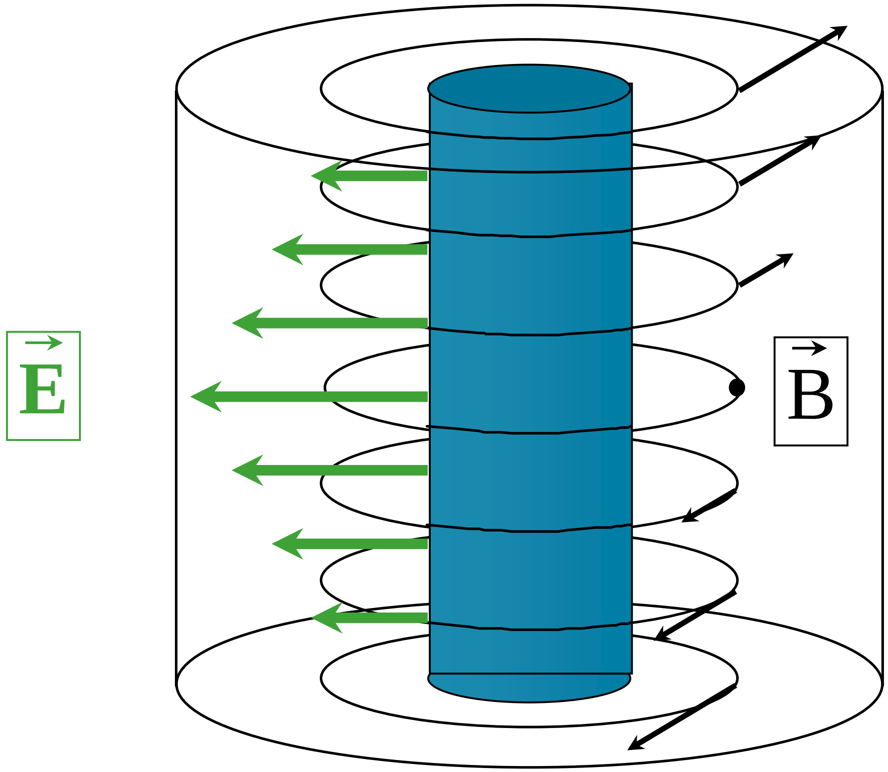
# High power E-beam accelerators: 1) the Rhodotron

- **Typical applications of the Rhodotron:**



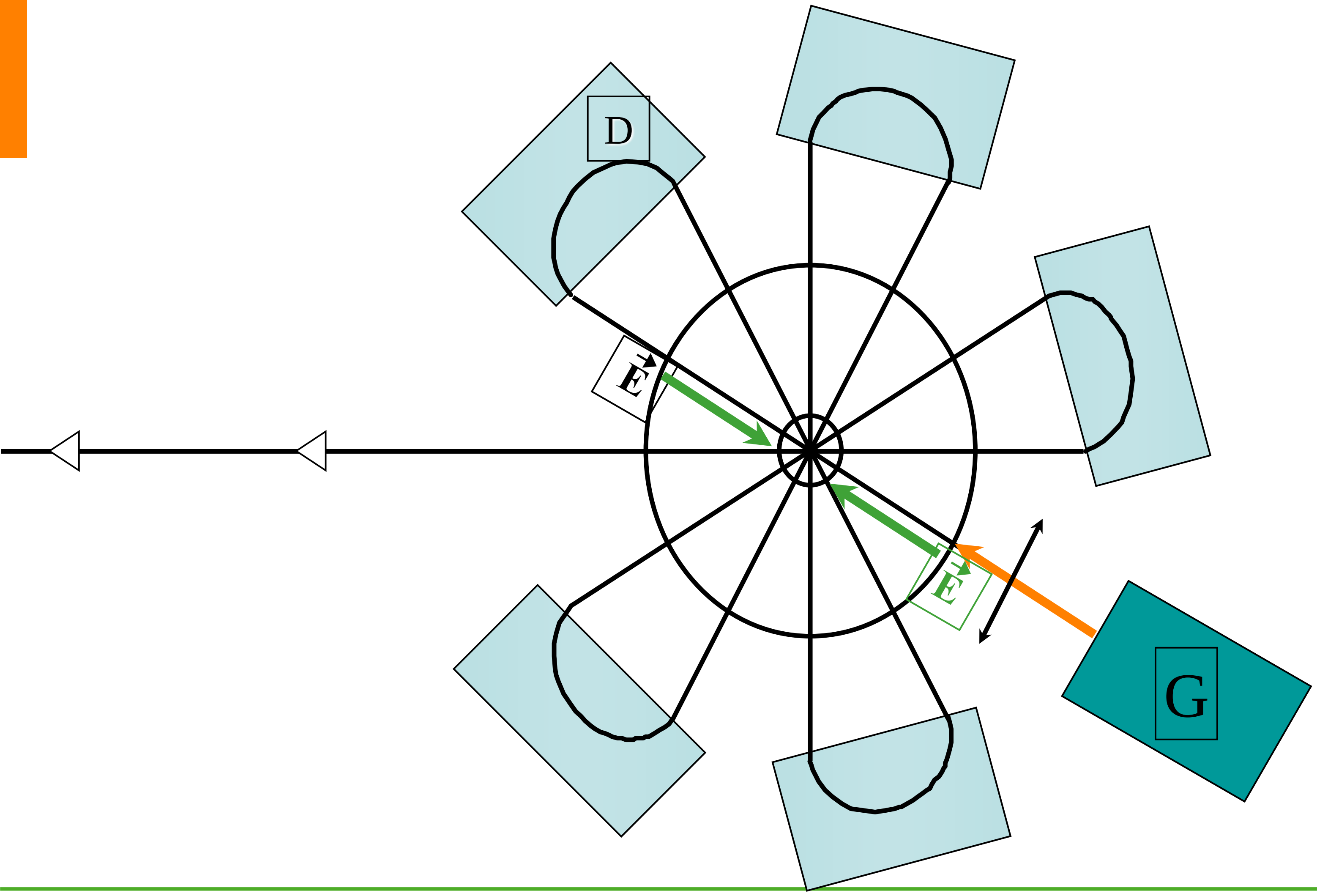
- Modification of polymers
- Sterilization of medical devices
- Preservation of foods
- Treatment of waste materials
- Gemstones and semiconductors

# Acceleration principles



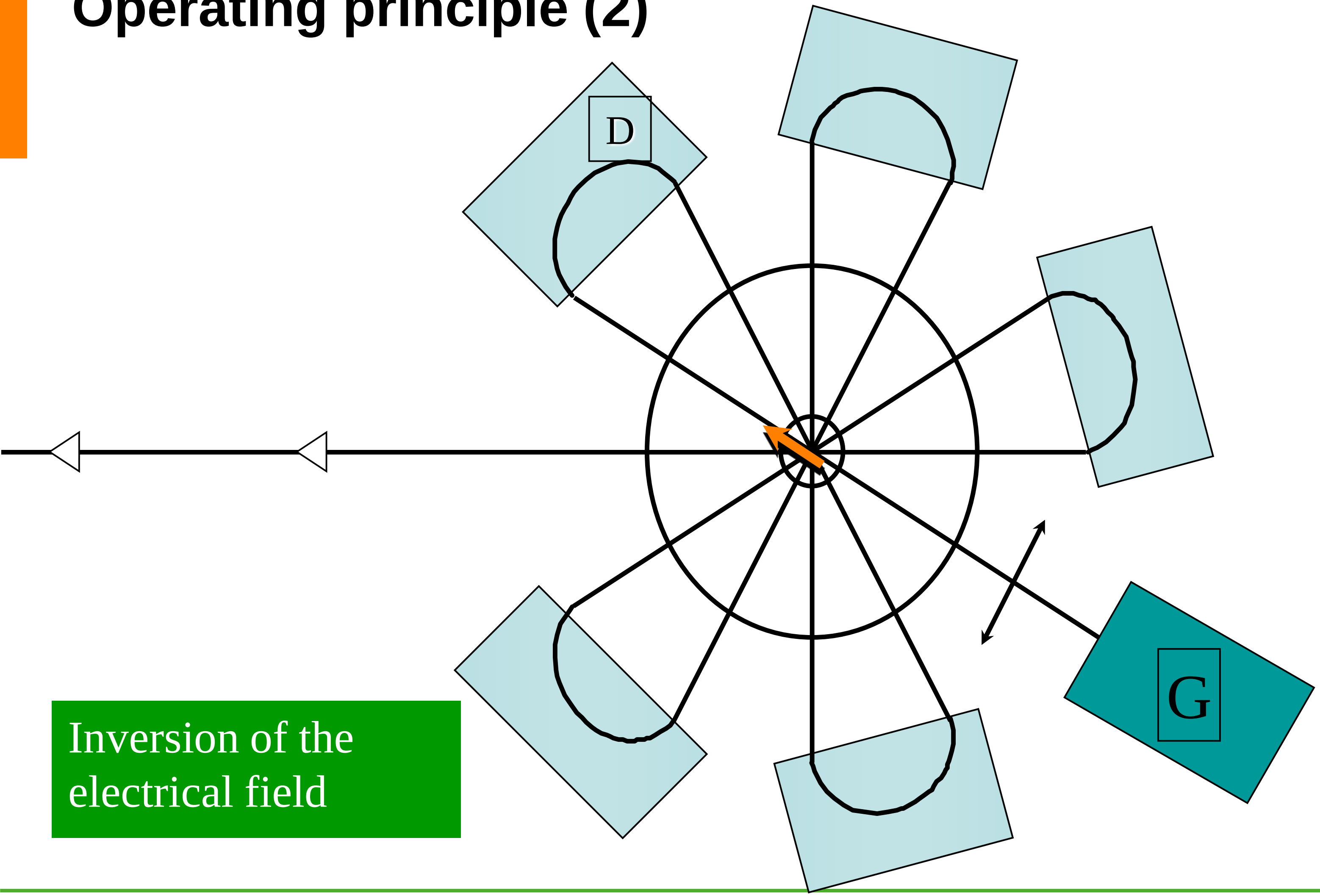

Electric ($\vec{E}$) and magnetic ($\vec{B}$) fields
in Rhodotron coaxial cavity

# Acceleration principles



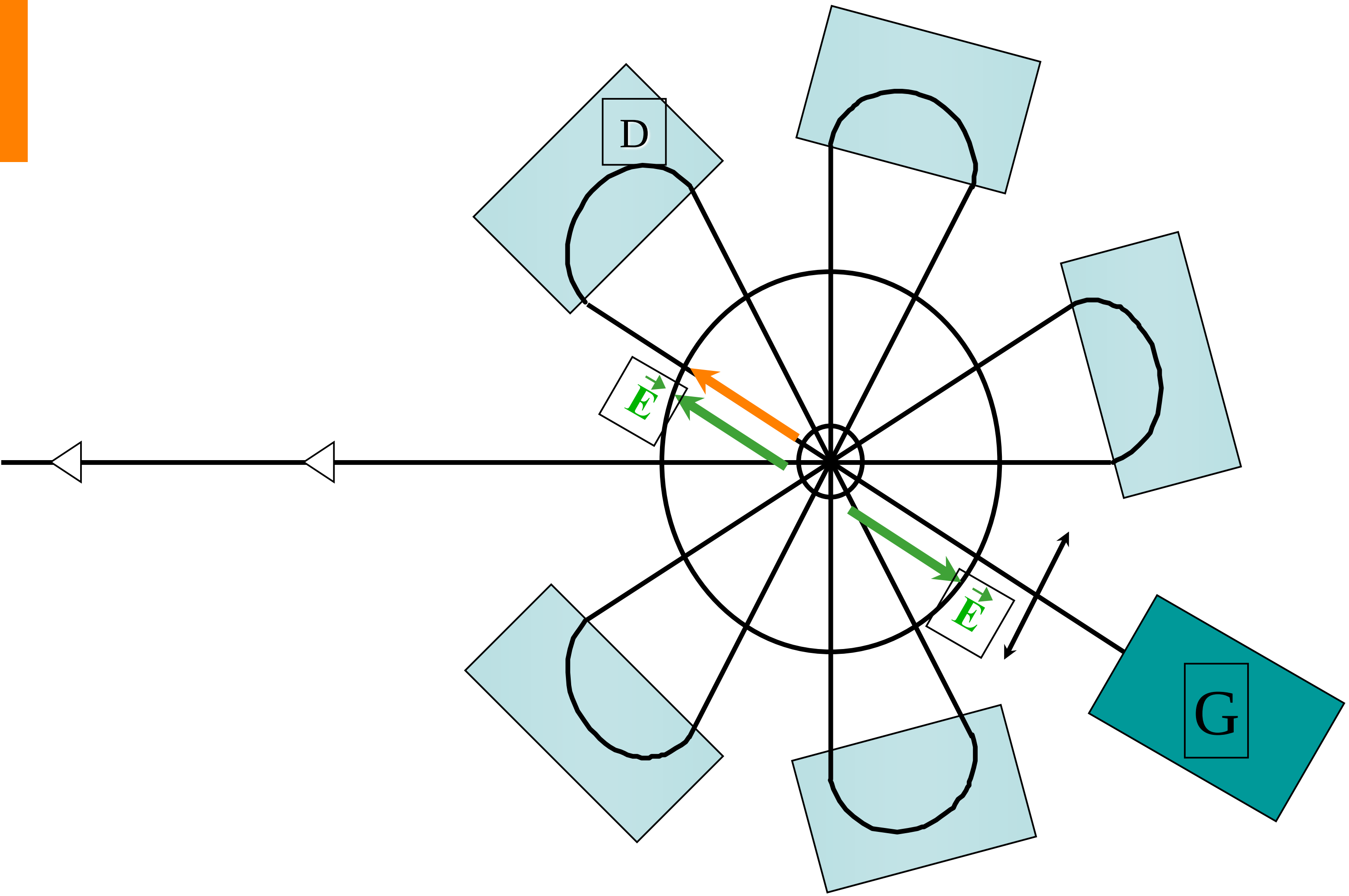
# Acceleration principles

## Operating principle (2)

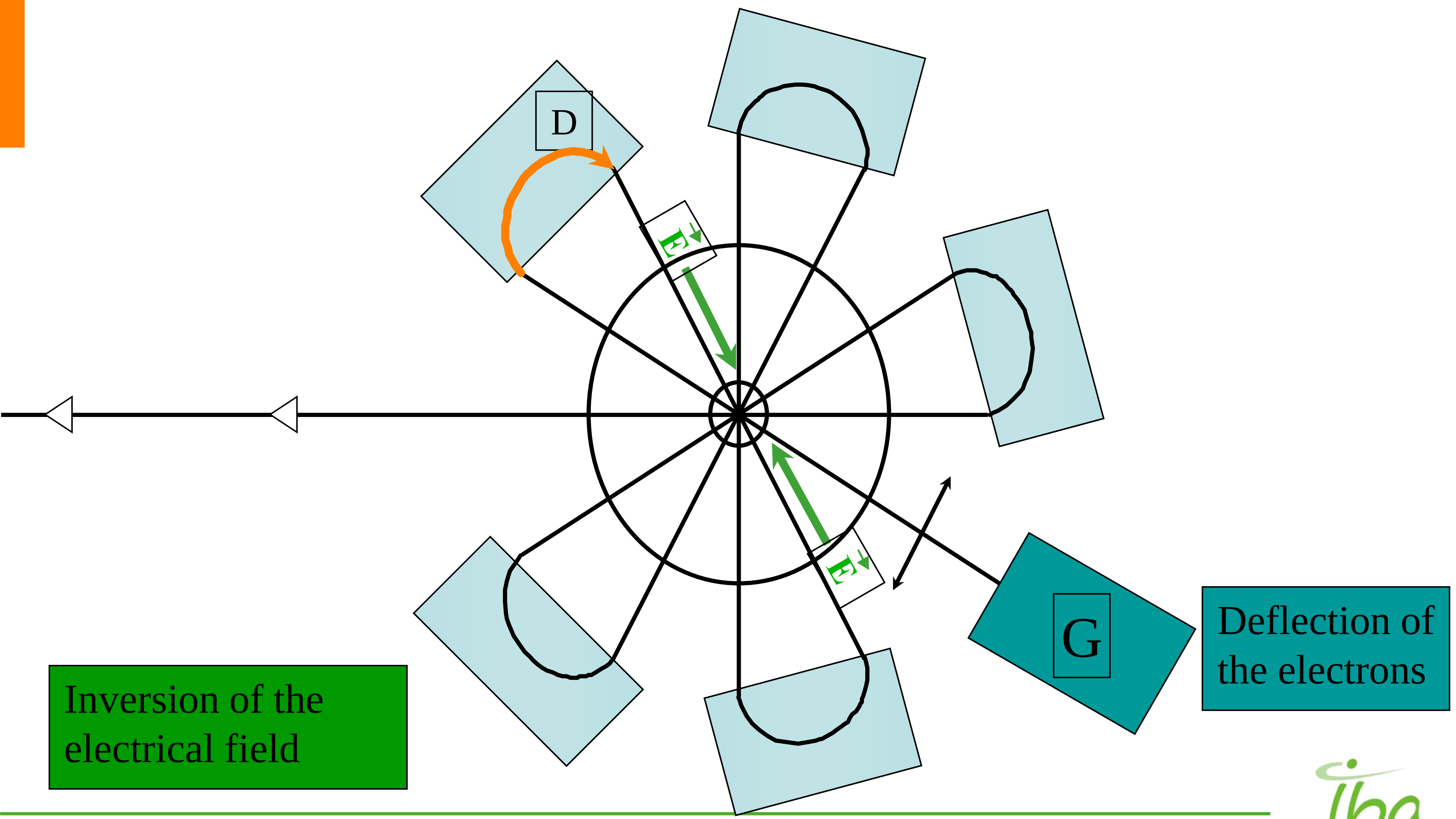



Inversion of the electrical field

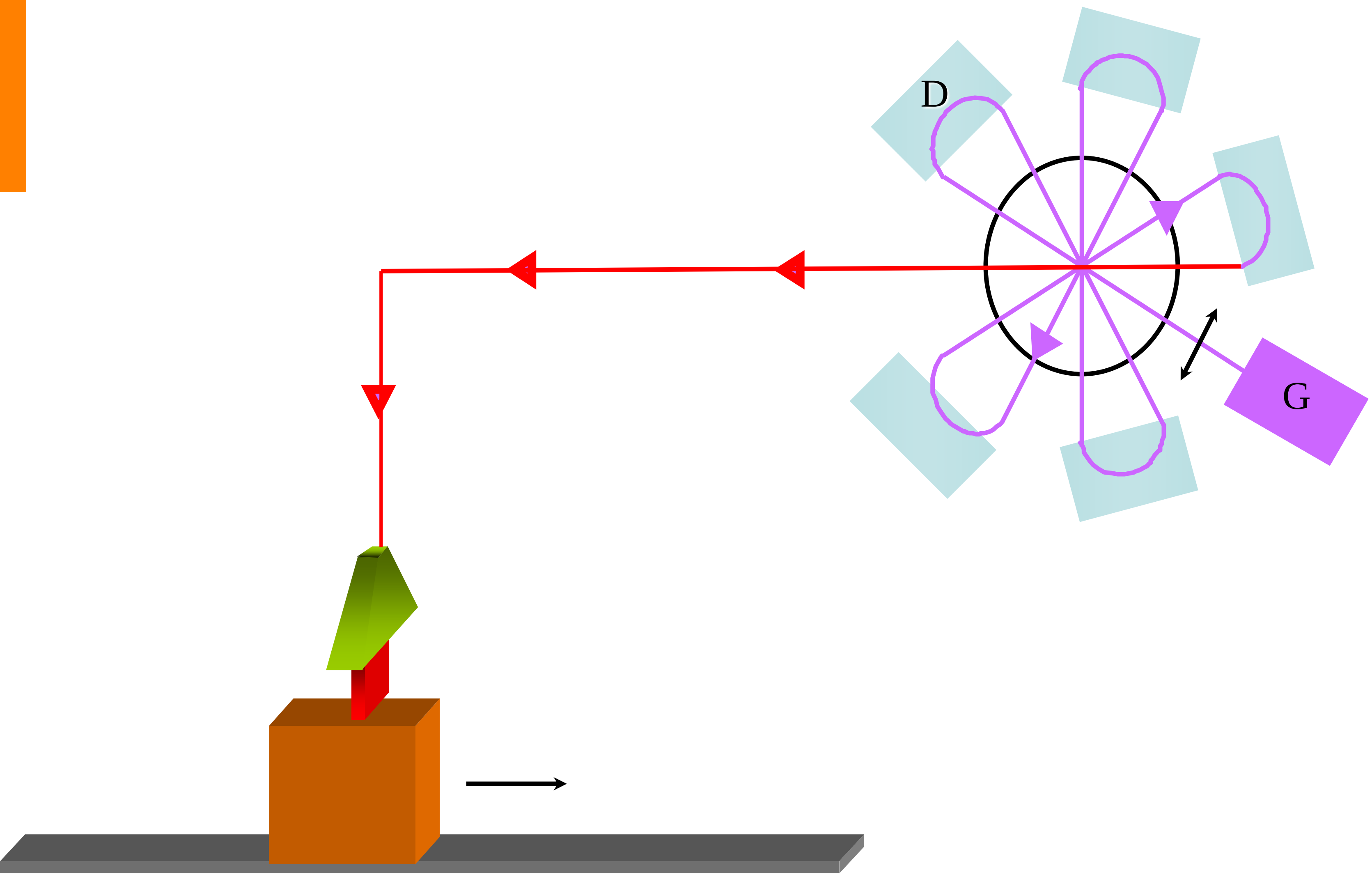
# Acceleration principles



# Acceleration principles

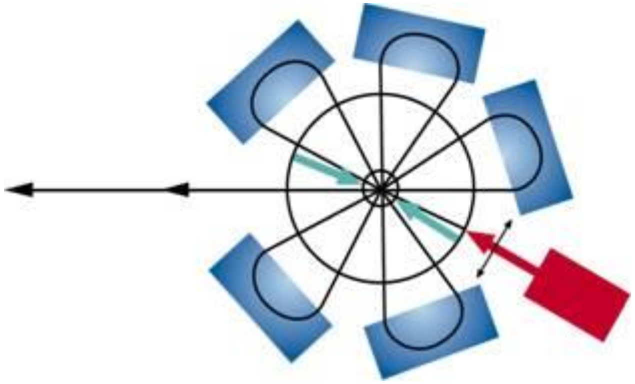


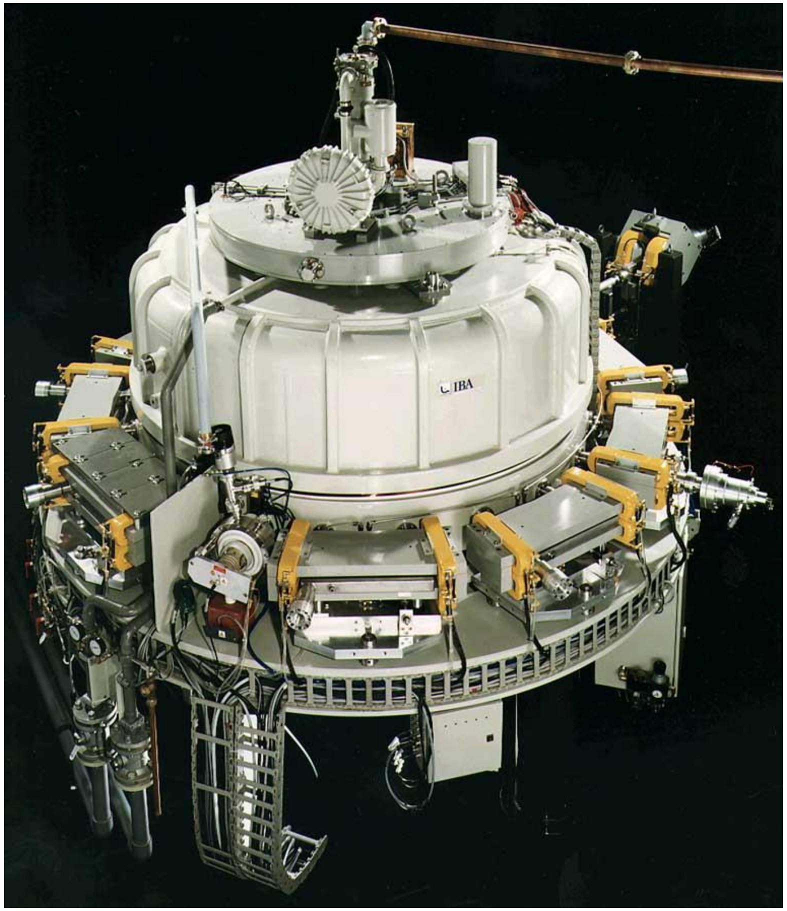
# Acceleration principles



# Rhodotron

- TT200 – TT300





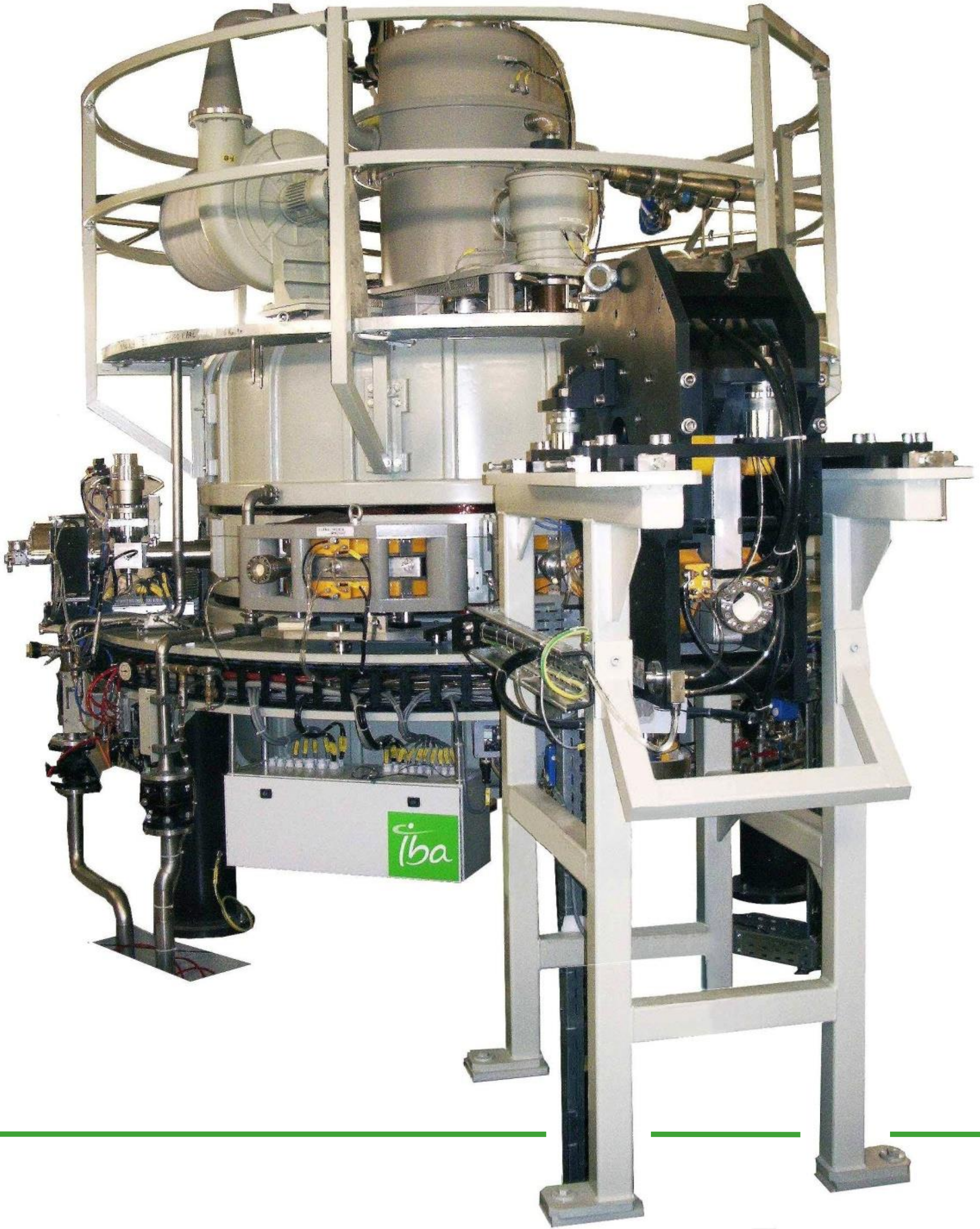




Iba Particle Therapy

# Rhodotron

- TT1000





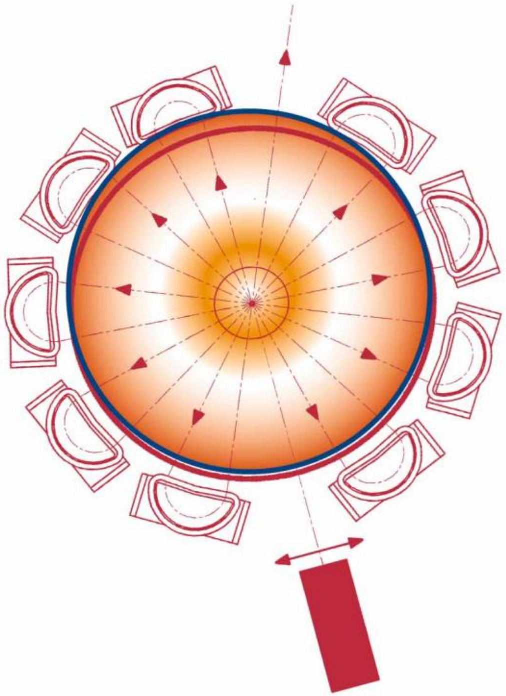
Particle Therapy

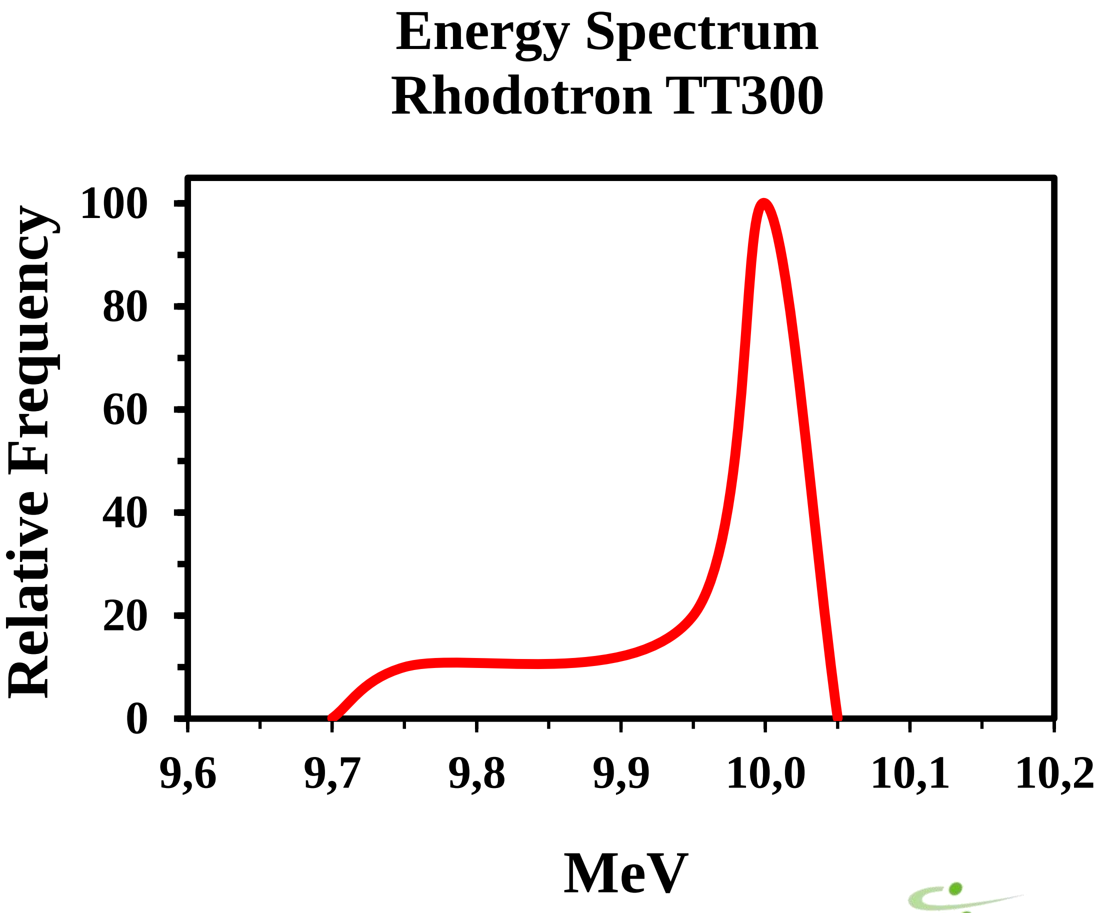
# Rhodotron

| | TT100 | TT200 | TT300 | TT1000 |
|---|---|---|---|---|
| Beam energy (MeV) | 3~10 | 3~10 | 3~10 | 2.4~7 |
| Maximum beam power (kW) | 35 | 80 | 190 | 700 |
| Design value (kW) | 45 | 100 | 200 | 1000 |
| Cavity diameter (m) | 1.60 | 3.00 | 3.00 | 3.00 |
| Cavity height (m) | 1.75 | 2.40 | 2.40 | 2.40 |
| Weight (T) | 2.5 | 11 | 11 | 12 |
| MeV/pass | 0.833 | 1.0 | 1.0 | 1.167 |
| Number of passes | 12 | 10 | 10 | 6 |
| Electrical power at full beam | <210 | <260 | <440 | <1300 |

# Rhodotron

- **Multiple checks on beam energy**
  - Each magnet is a energy filter

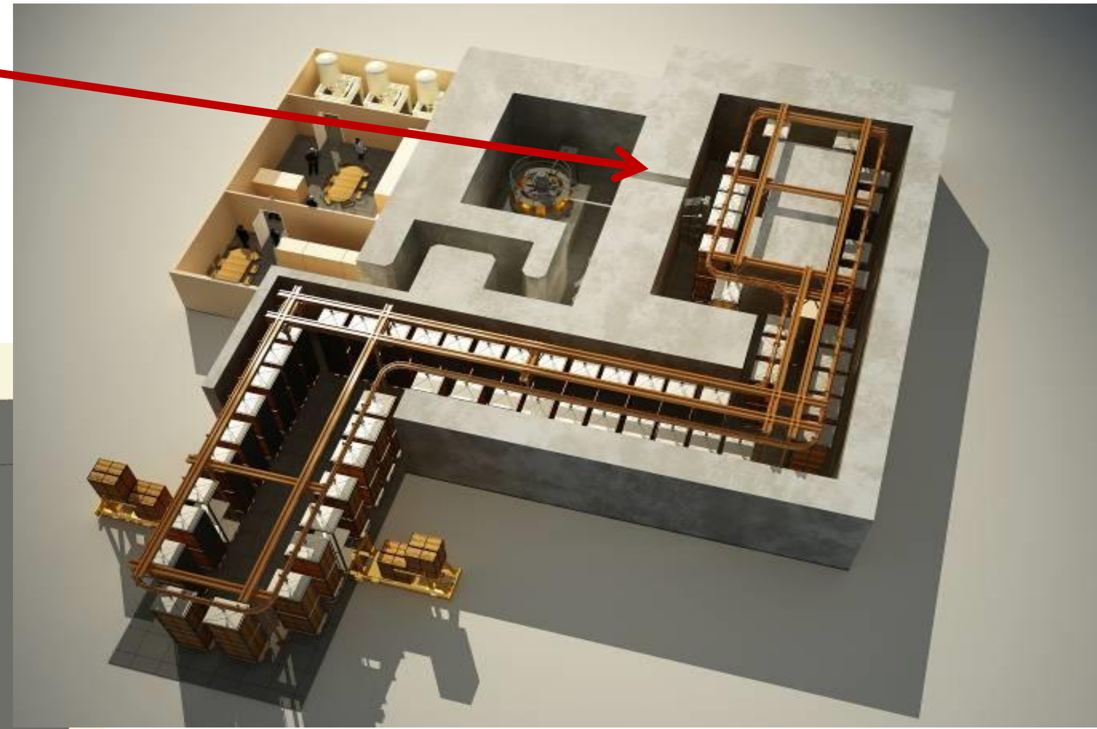


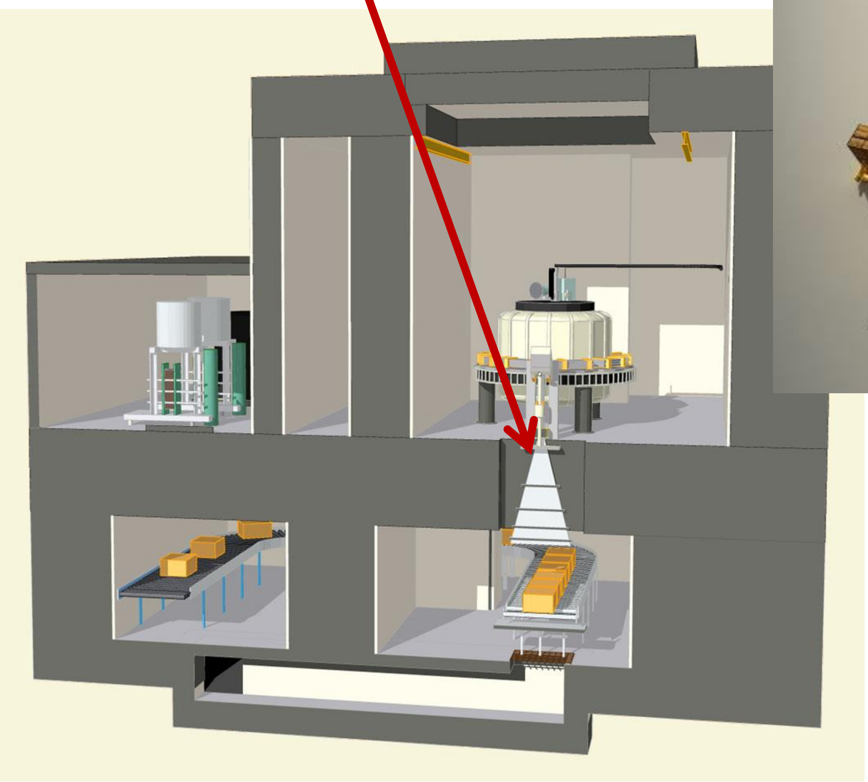


# Rhodotron: typical layouts of irradiation centers

Irradiation from the side

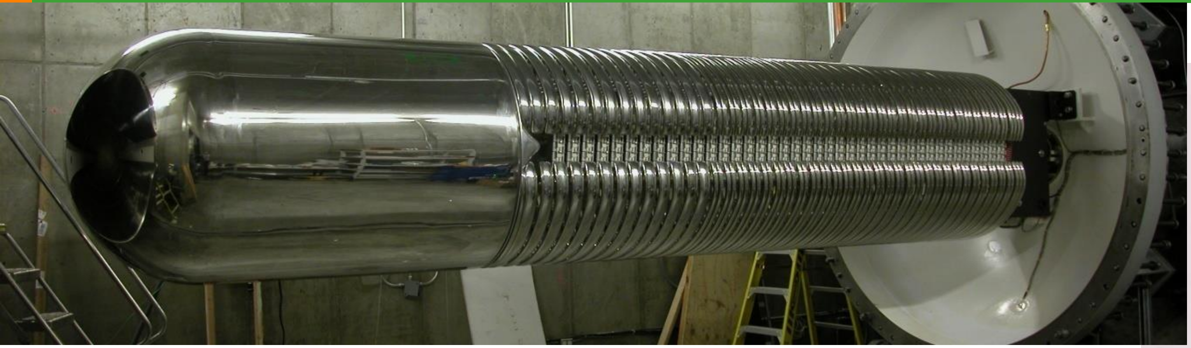
Irradiation from above

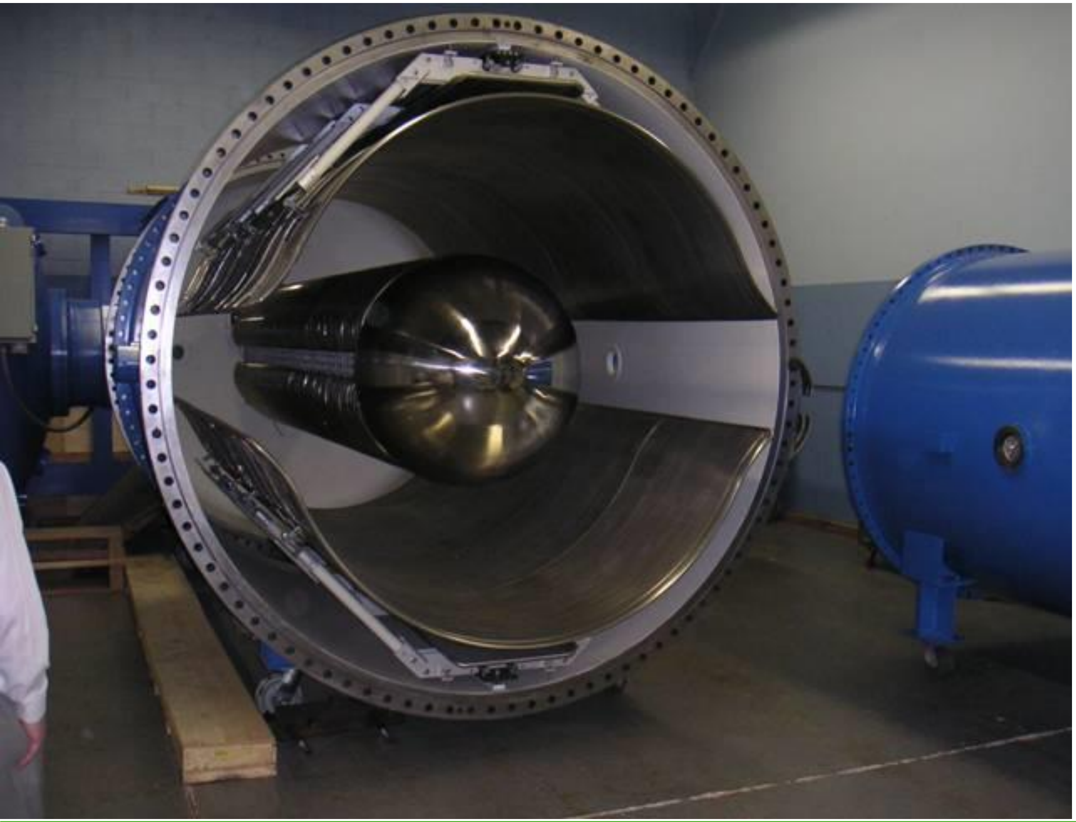


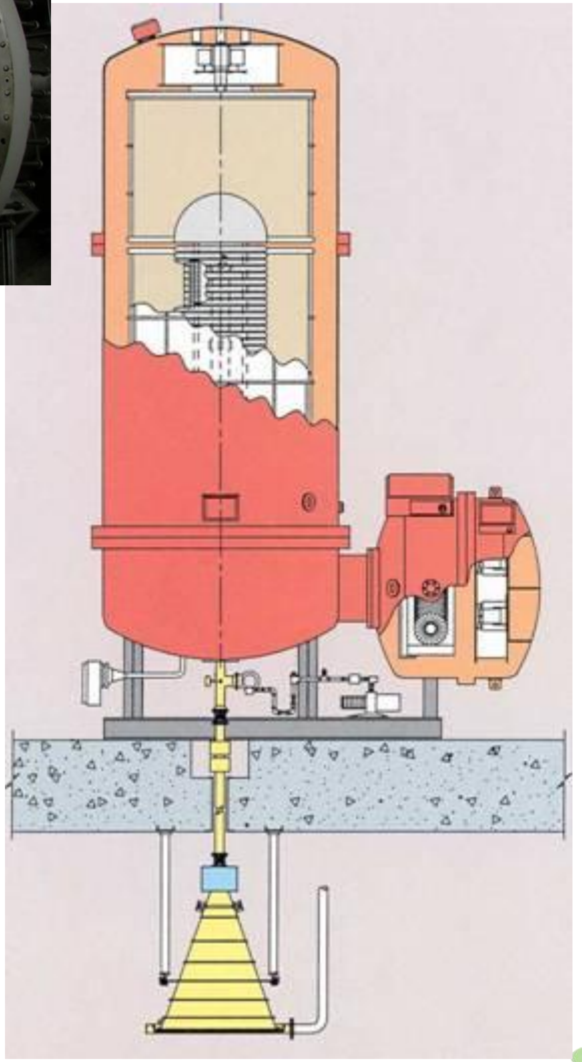


Spreading of the beam by a magnetic scanning system

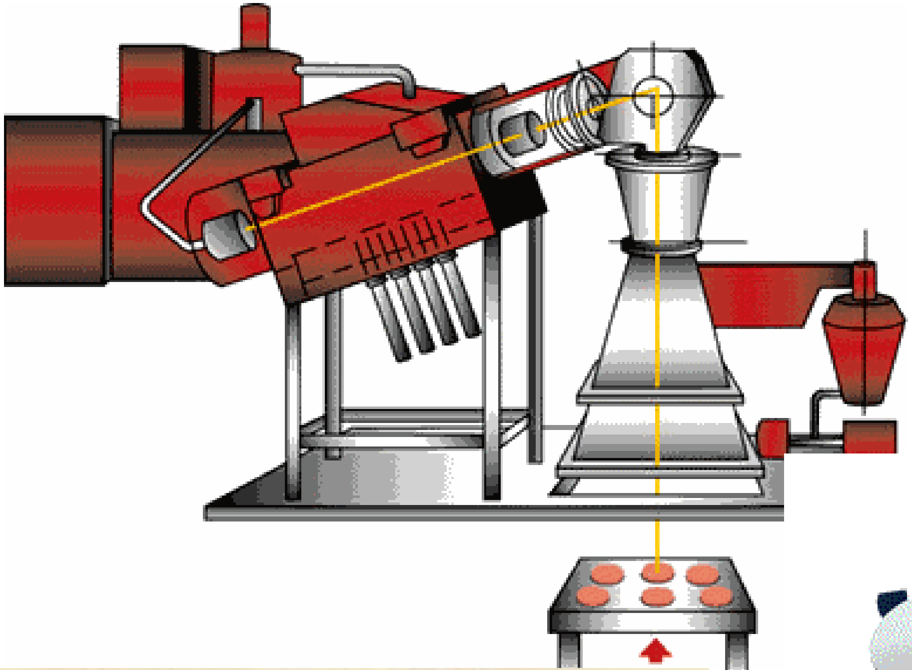
# High power E-beam accelerators: 2) the Dynamitron

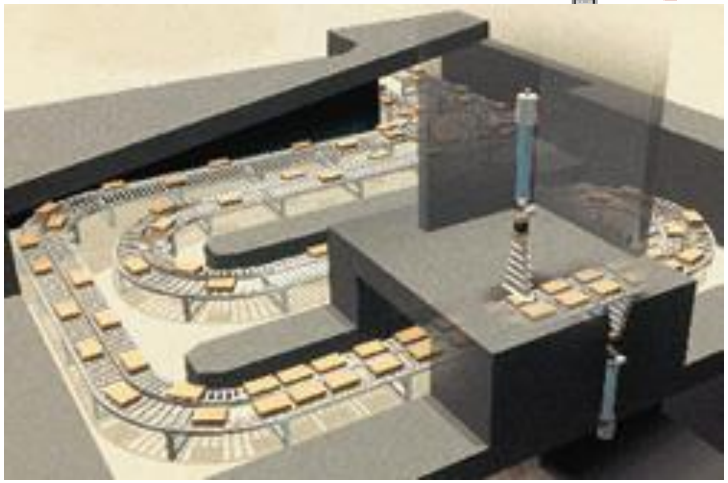


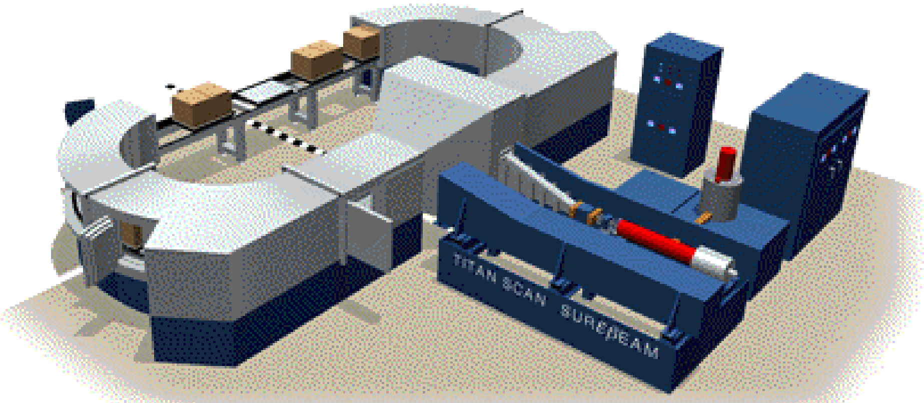




# High power E-beam accelerators: 3) the Linacs








On-Site is a complete turn key operating system validated to ISO 11137 and delivered with all required training, documentation, dosimetry system and process certification.

# Thank you !

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