

Spawning Neutrons, Protons, Electrons and Photons from Universities to Society

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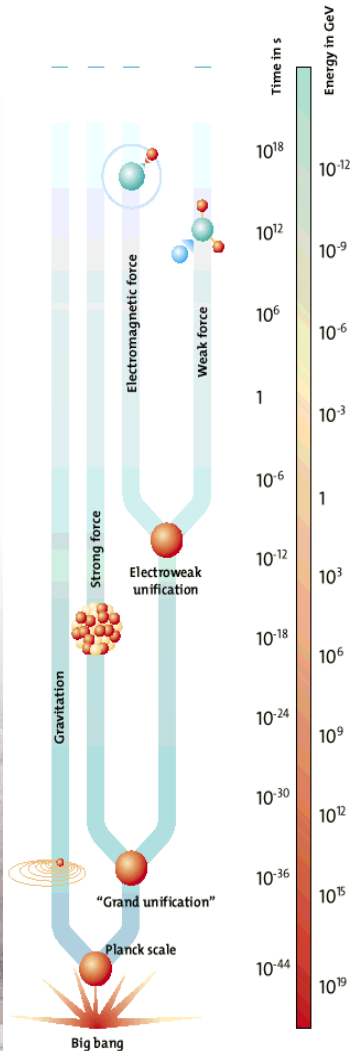
Outline

- What can we do with **N**eutron, **P**roton, **E**lectron and **P**hoton (**NPEP**)?
- What's important for spawning **NPEP** from University to Society?
 - **C**ompact, **R**eliable, **S**table , **S**afe, **U**nique, **C**heap, **F**riendly...
- Low Energy Electron Linacs and Their Applications in Cargo Inspection Systems for Homeland Security.



We need high energy electron and proton, to explore the world.

- While exploring the interior of matter accelerators are used as tools, either as energy transformers or as super microscopes.



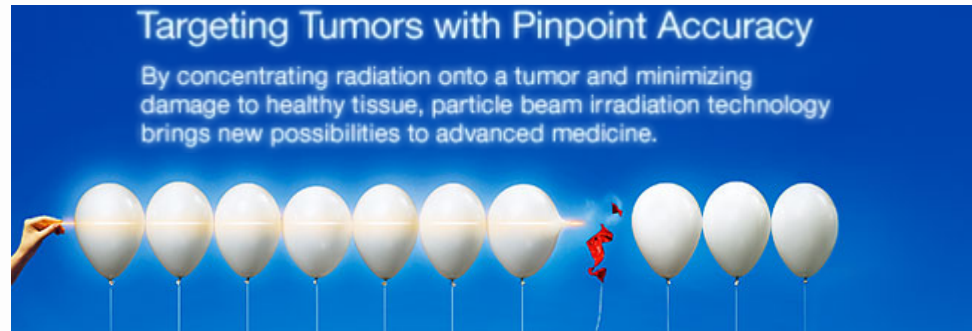
In particle collisions the energy of the colliding particles can be transformed to mass.



The accelerator can be used as a super microscope to "see" quarks

We also need low energy electron and proton, to let us have a better life.

- Proton Therapy:



- Electron Irradiation :

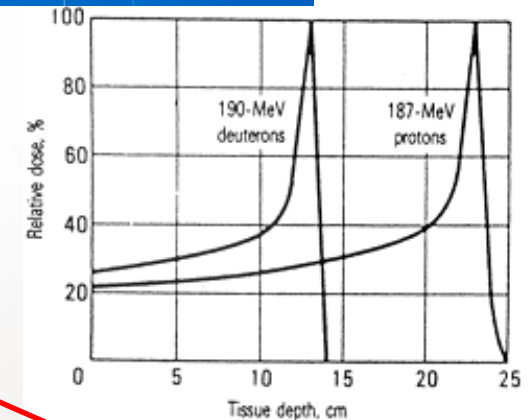
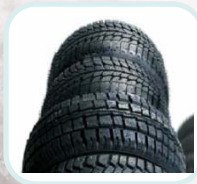
-Food irradiation



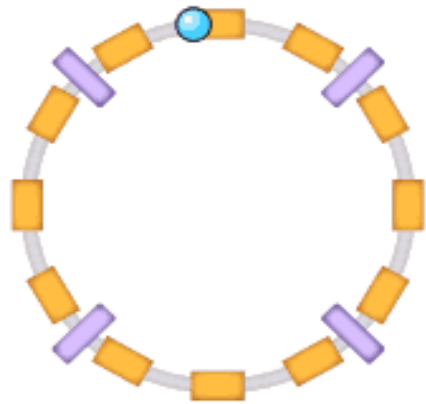
-Sterilization



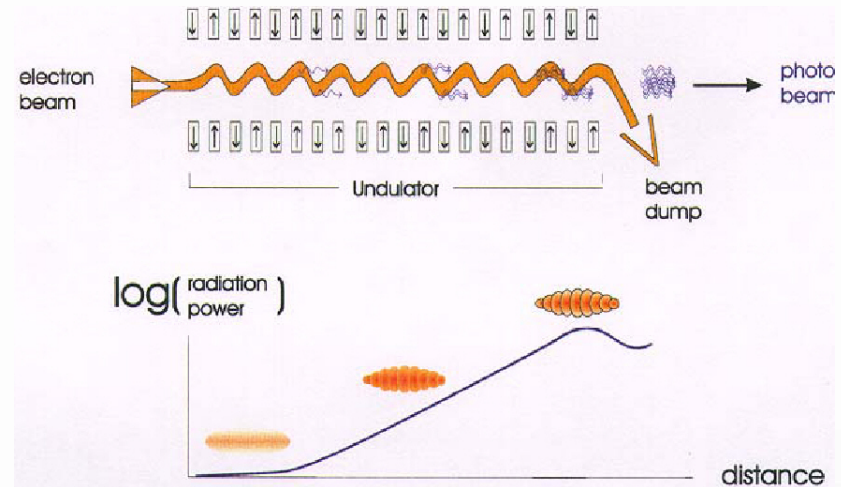
-Industrial irradiation



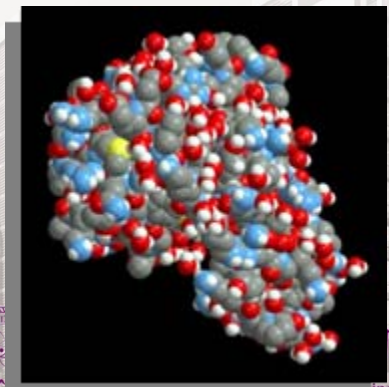
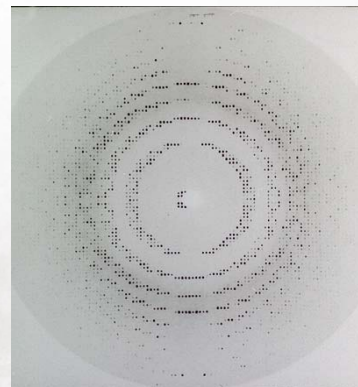
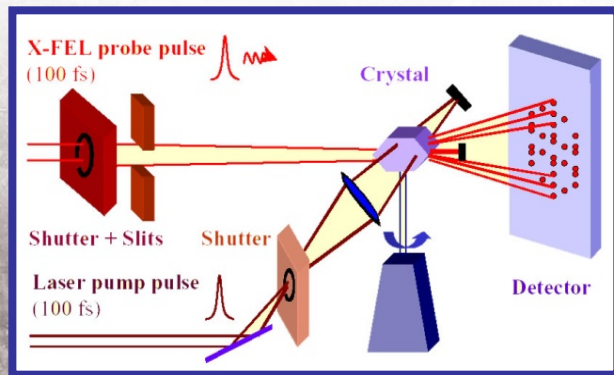
We need large photon and neutron facilities, to serve as tools for other fundamental researches.



Synchrotron Radiation



Free Electron Laser



X-Rays have opened the Ultra-Small World X-FELs open the Ultra-Small and Ultra-Fast Worlds

Ultra-Small

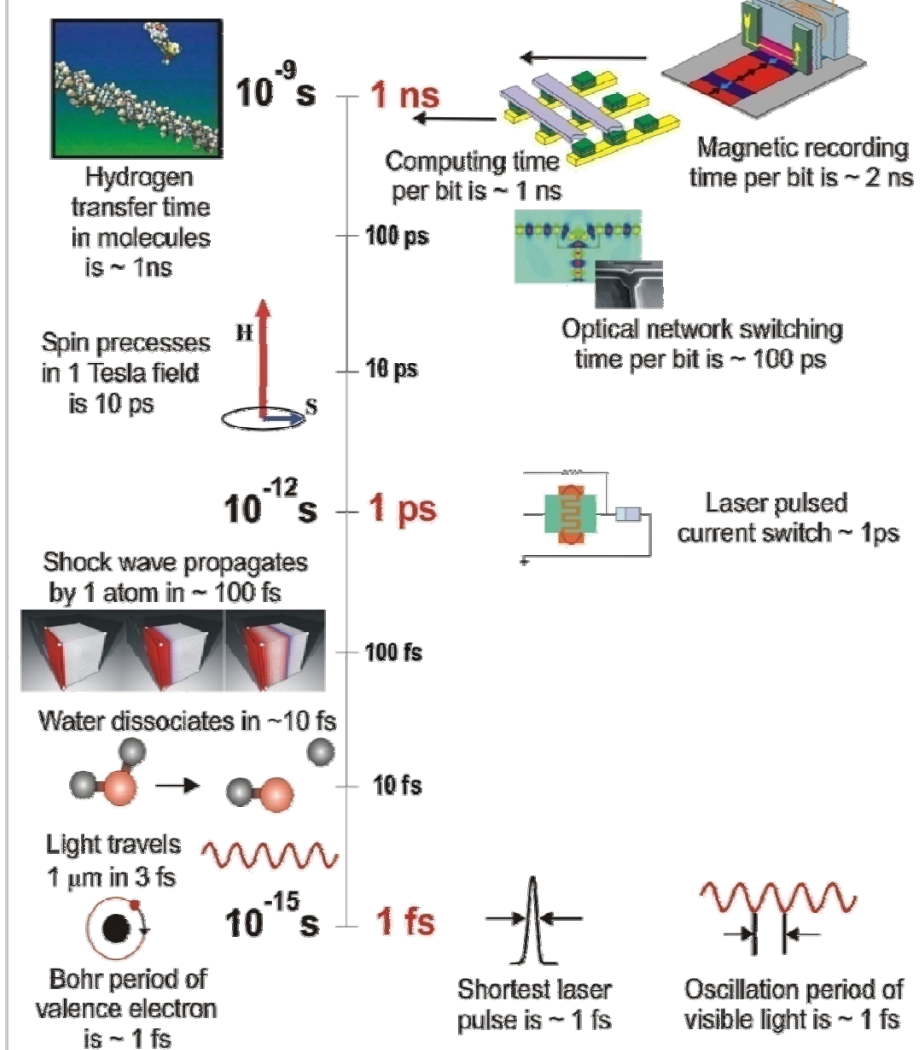
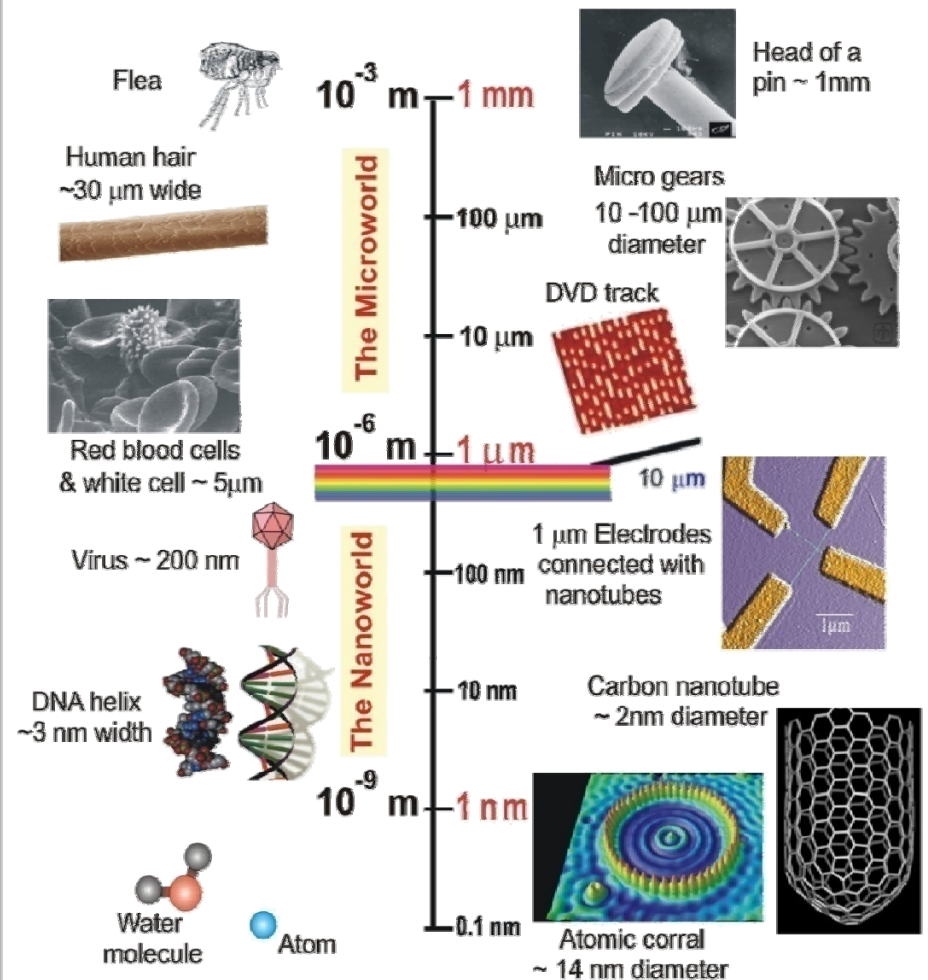
Ultra-Fast

Nature

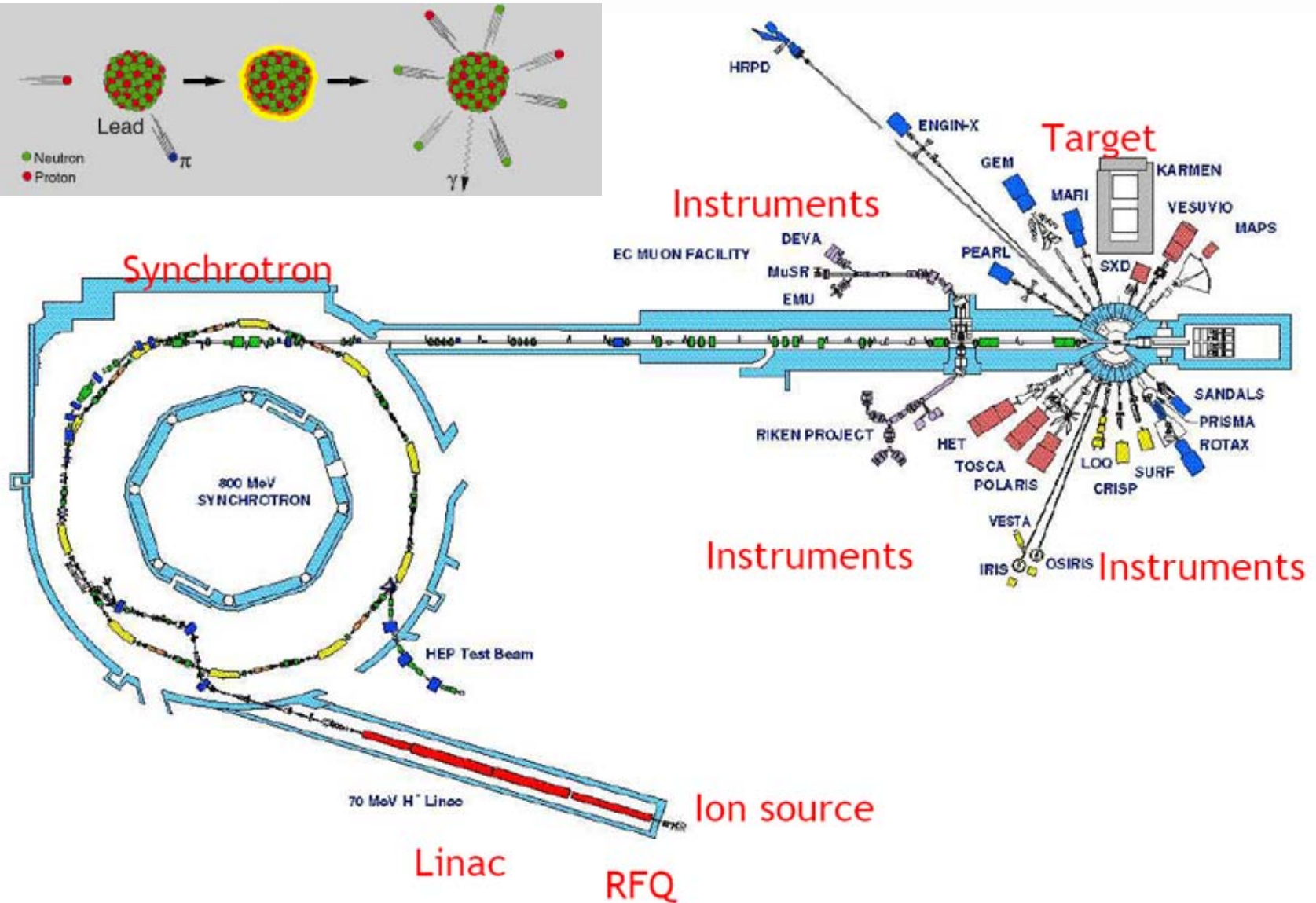
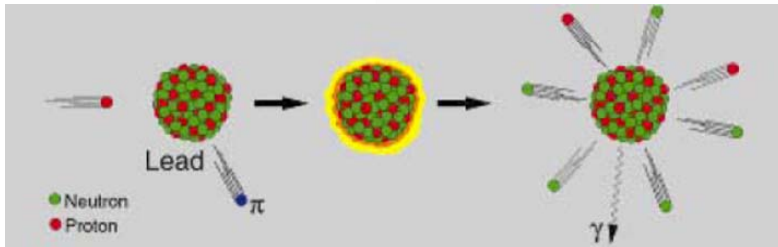
Technology

Nature

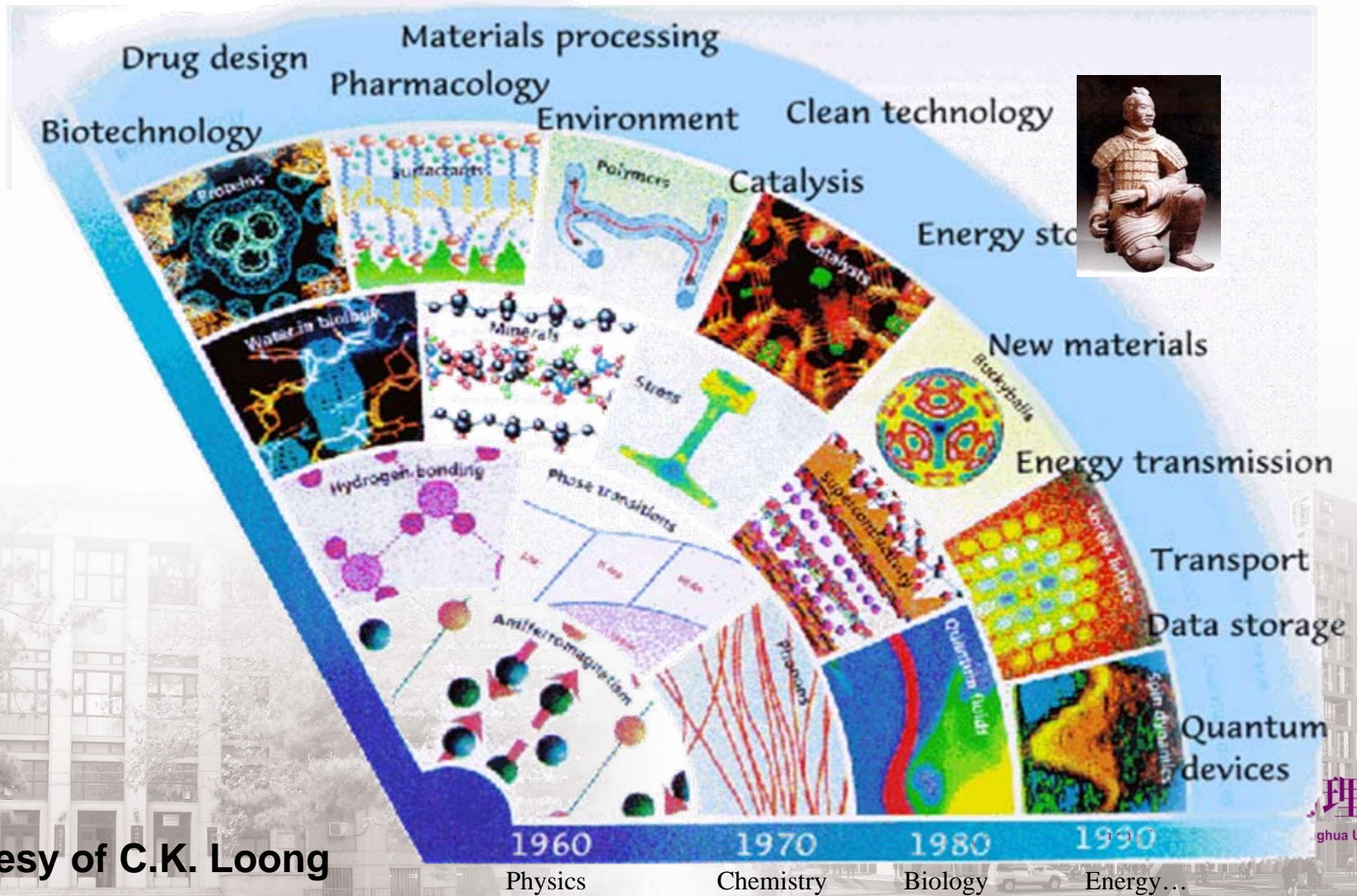
Technology



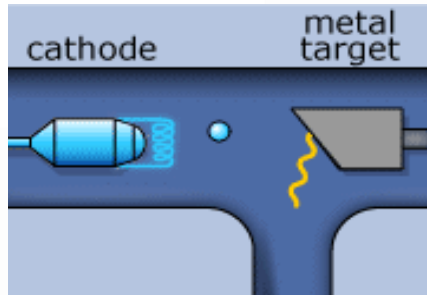
Neutron Sources based on Accelerators



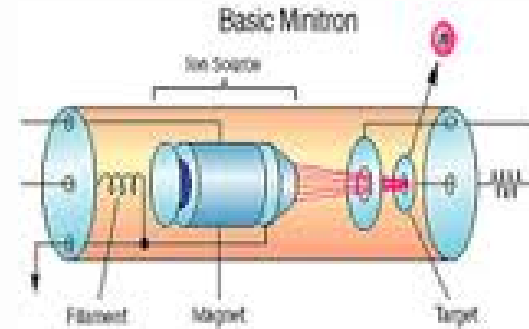
Applications of Neutron Scattering



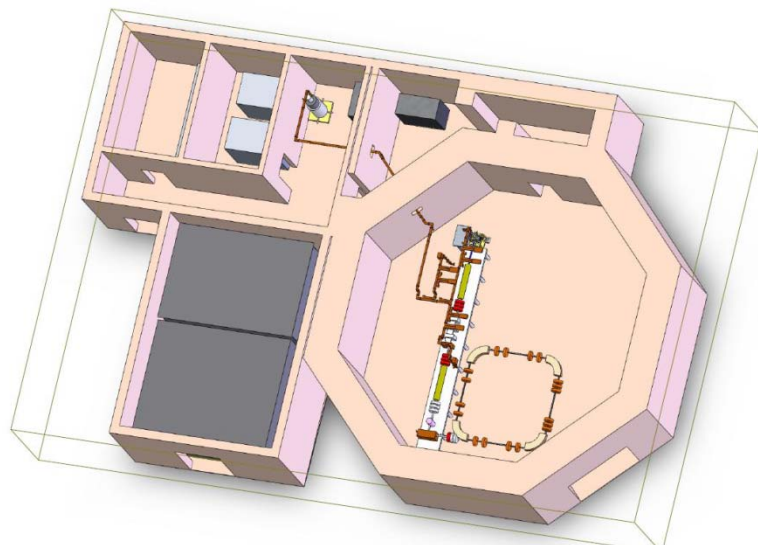
We also need compact neutron and photon sources, which can be more widely used.



X-ray Tube



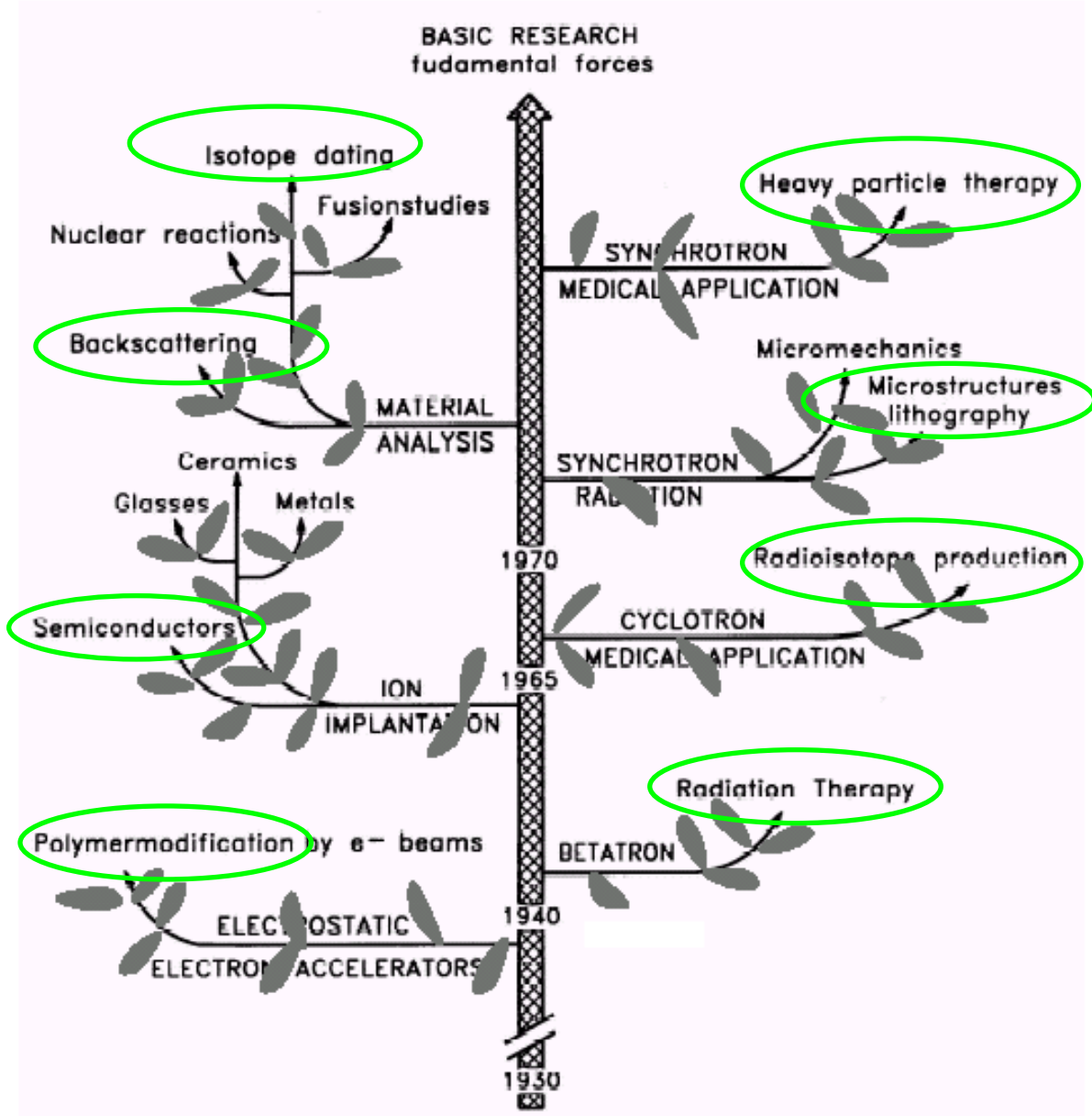
Neutron Tube



Thomson Scattering X-ray Source



Accelerator Driven Compact Neutron Source



static fields - Accelerators - alternating fields

K. Betghe plot, modified by U. Amaldi



Spawning **NPEP** from University to Society

- Orientation:
 - Product or Science?
- Mechanism:
 - How the technology is transferred from University to Company?
- Product oriented research:
 - **C**ompact : Can be used in different situation.
 - **R**eliable: Needn't professional person to take care.
 - **S**table : The performance is stable.
 - **S**afe: No harm to public.
 - **U**nique: There is hardly any other technology can fulfill the same purpose.
 - **C**heap: Can be affordable to the user.
 - **F**riendly: Easy to be operated.
 - ...

Low Energy Electron Linear Accelerators

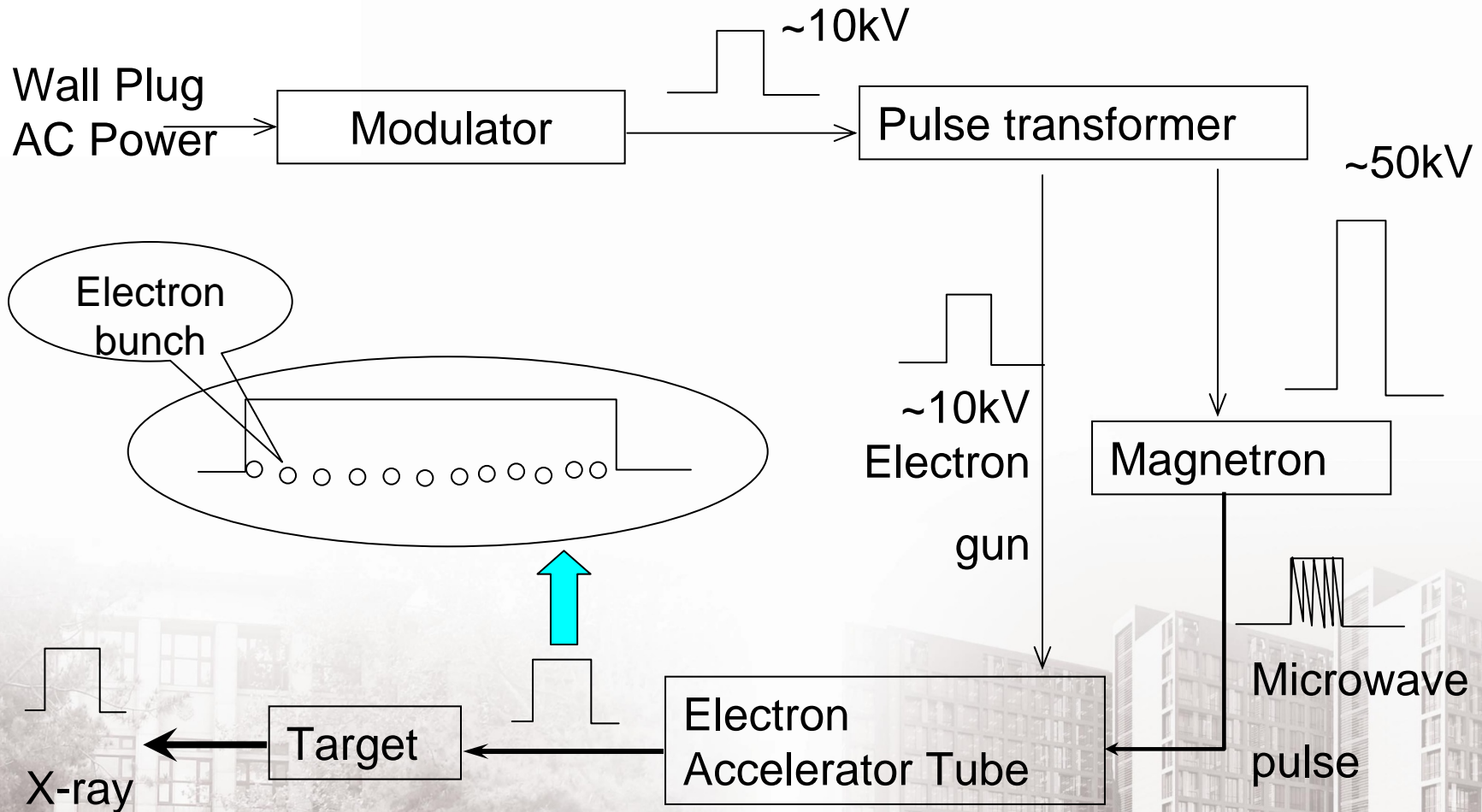
- **Electron Energy** : From 1MeV to ~30MeV
- **Accelerating Structure**: SW or TW
- **Electron Source**: Diode or triode gun
- **RF Frequency**:
 - S-band (2856MHz, 2998MHz), X-band (9300MHz), C-band (5712MHz), L-band (1300MHz)
- **RF Power Source**:
 - Magnetron or Klystron
- **Applications**:
 - X-ray or electron Radiotherapy
 - Irradiation
 - Non-destructive test / x-ray imaging/ Cargo Inspection System

What's important for developing a linac of industrial applications?

- Reliability and Stability
 - Modulator
 - Cooling System
- Performance meeting the requirement
- Simpler better
- Easy for operating and maintenance



A low energy linac system with magnetron as its rf power source

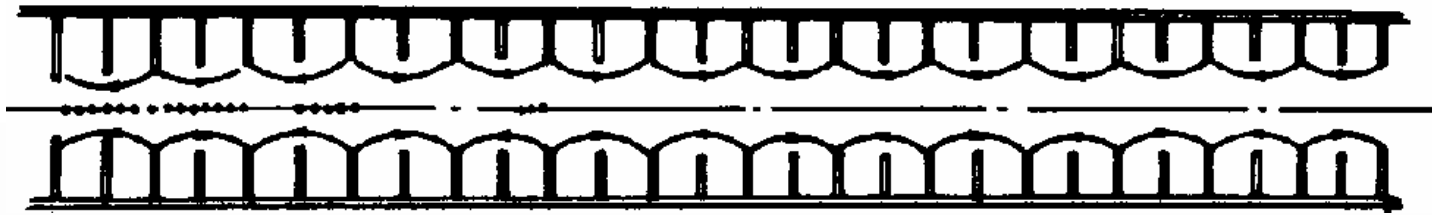


SW or TW?

	SW	TW
Gradient:	~10MeV/m	~5MeV/m
Efficiency:	30~60%	20~50%
Capture:	20~30%	~80%
Gun voltage:	5~20kV	~40kV
Band:	~200kHz	~2MHz
AFC:	Required	not required
Size:	small and simple	large
Stability:	good	can be good



Traveling Wave Accelerating Structures



Bunching section

Main accelerating section

- Constant impedance

A 9 MeV traveling -wave linac developed for cargo inspection systems

Length: 2.4 m

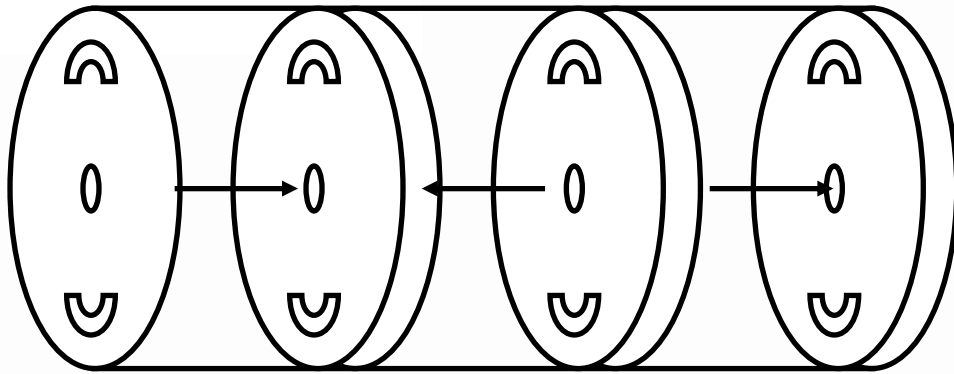
RF source: 5MW klystron

Electron Energy: 9MeV

Dose Rate: 30 Gy/min-m

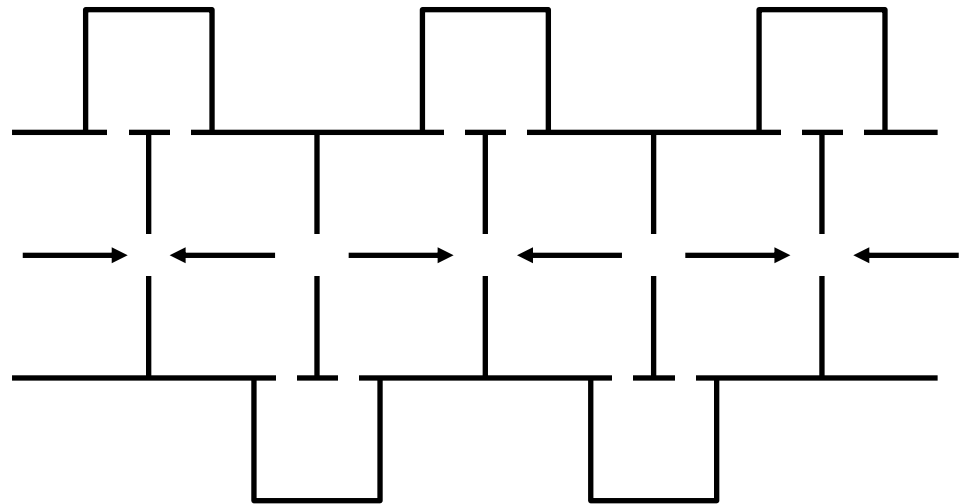


Standing Wave Accelerating Structures

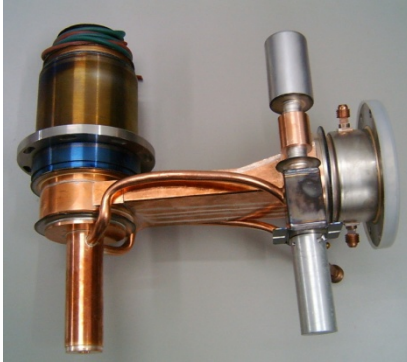


On-axis magnetic coupled bi-period structures

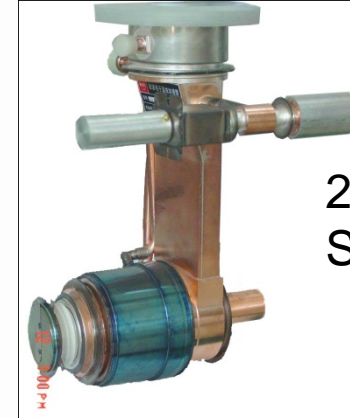
Side coupled structures



S-band Linacs for X-ray Imaging



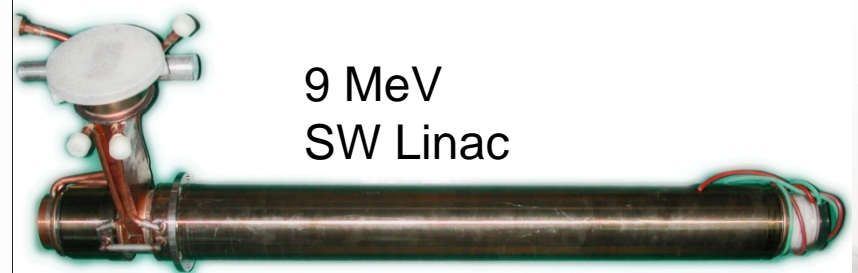
1.5 MeV
SW Linac



2 MeV
SW Linac

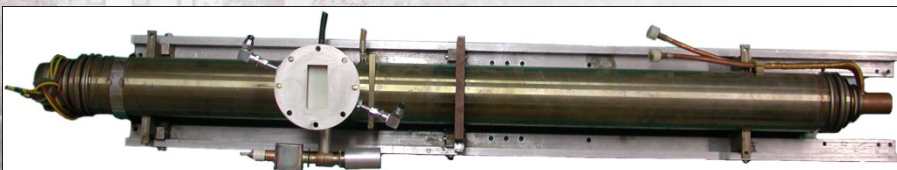


4 MeV
SW Linac



9 MeV
SW Linac

15 MeV
SW Linac

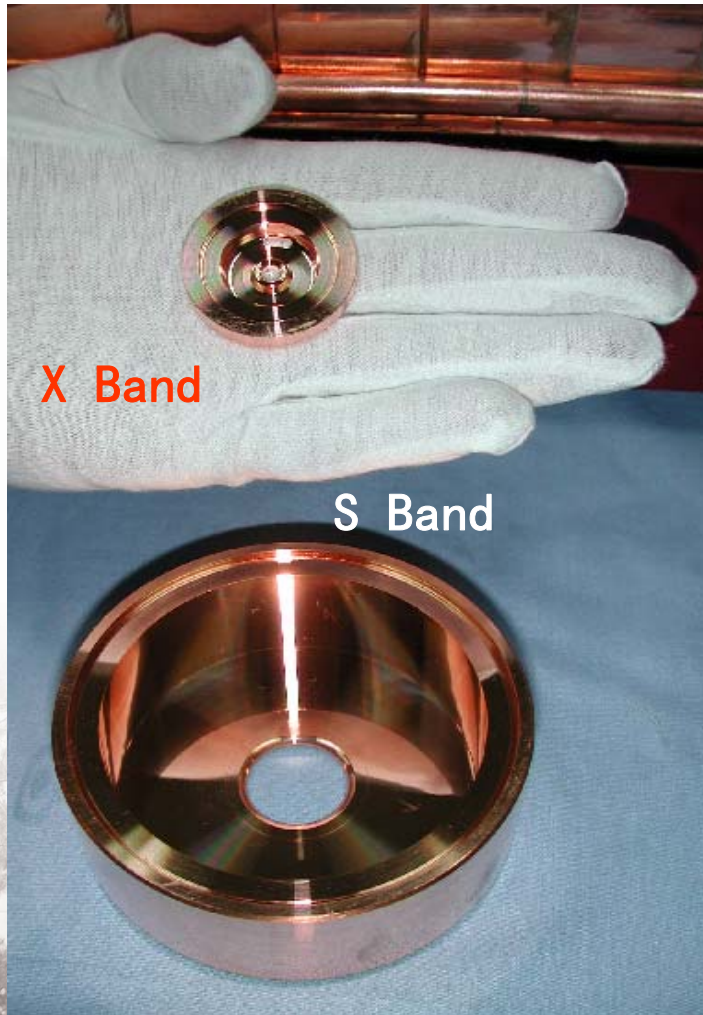


6 MeV
SW Linac

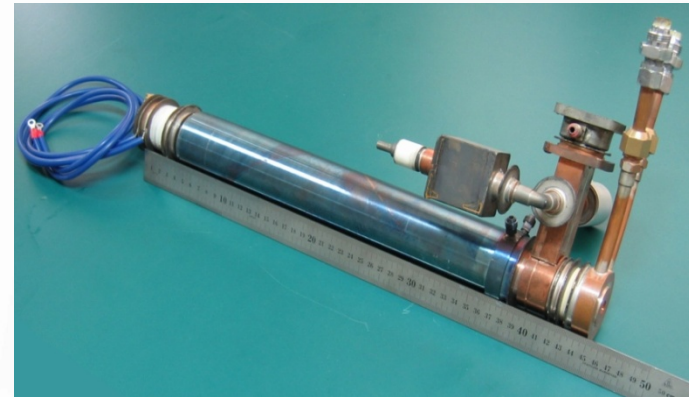
X-band, C-band , S-band or L-band?

- **Mainly depends on:**
 - Requirement of different applications
 - Commercial microwave power source available
 - The knowledge and technology
- **Most of the low energy linacs are s-band**
 - The microwave power source are common and cheaper
 - Size and weight are medium
 - Technologies are easy now
 - Electron parameters are enough for most applications
- **X-band is used for mini-systems or portable systems**
 - Cybernife and Mobitron for radiotherapy
 - Mobile cargo inspections
- **L-band is more suitable for high average power linacs**
 - For L-band power source can deliver more than 1MW average power
- **C-band is becoming more and more attractive**
 - C-band less of commercial power source

X Band Accelerating Structure



X-band 2.5MeV Accelerating tube



X-band 6MeV Accelerating tube



RF Power Source: Klystron or Magnetron?

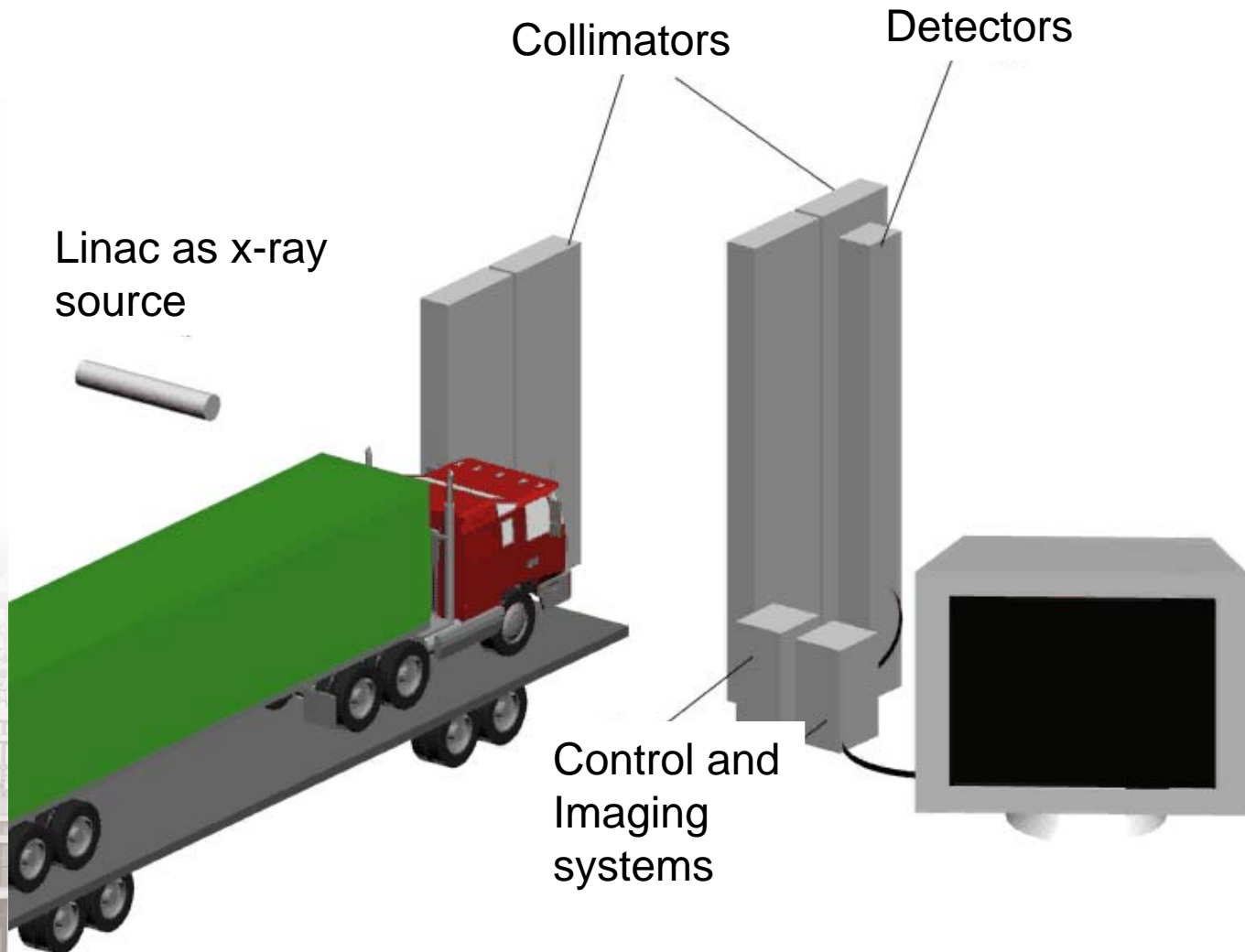
Klystron

Magnetron

Type:	Amplifier	Oscillator
Peak Power:	10s MW or more	normally less 5MW
Price:	expensive	cheap
Size:	large	compact
Stability:	good	need more efforts to control



Linacs Used as the X-ray Source in a Cargo Inspection System



Cargo Inspection Systems and Their Linacs

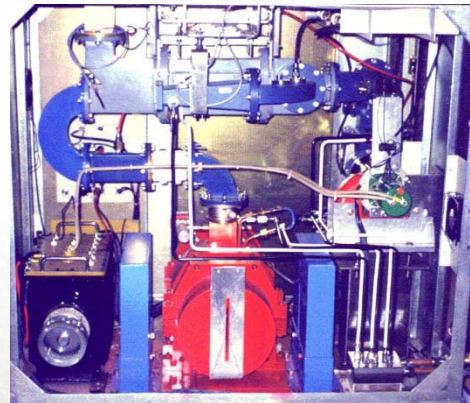
Fixed



Relocatable



mobile



RF source: 5MW klystron

Electron Energy: 9MeV

Dose Rate: 30 Gy/min-m

Electron energy 6MeV

Dose rate ~12cGy/min

RF Source: 2.6MW

Magnetron

X-band 2.5MeV
SW Tube

Powered by a
1MW 9300MHz
magnetron

S-band 2.5MeV
SW Tube

Powered by a
MG5125
magnetron

Smuggling Cars



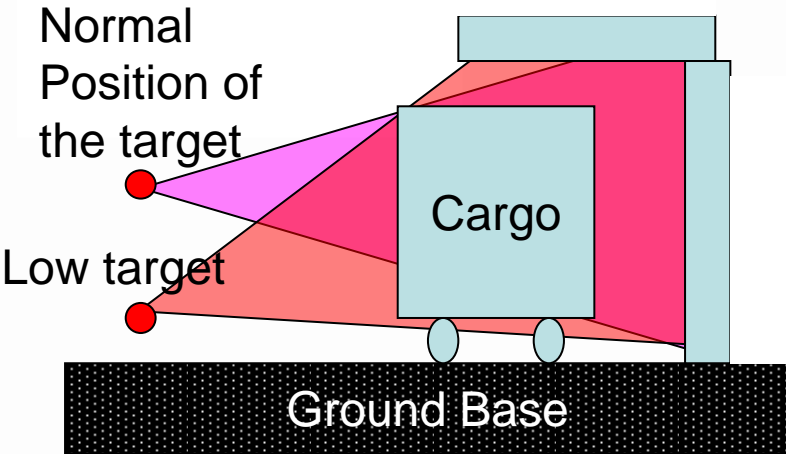
3 sets of smuggling car

Declaration Goods: Carpets



Low Target Mobile System-III

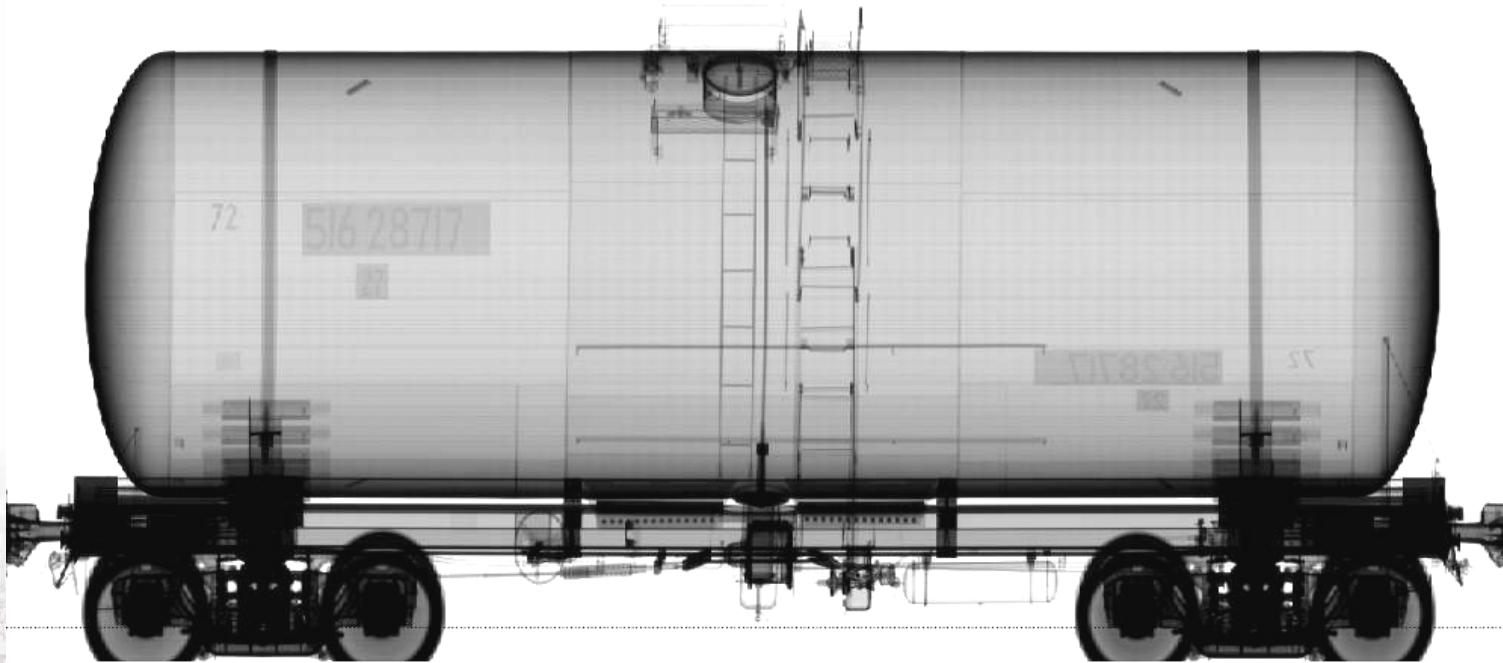
with An S-band 2.5 MeV electron linac as x-ray source



Railcar Inspection Systems



Railcar Inspection with speed of 40km/h

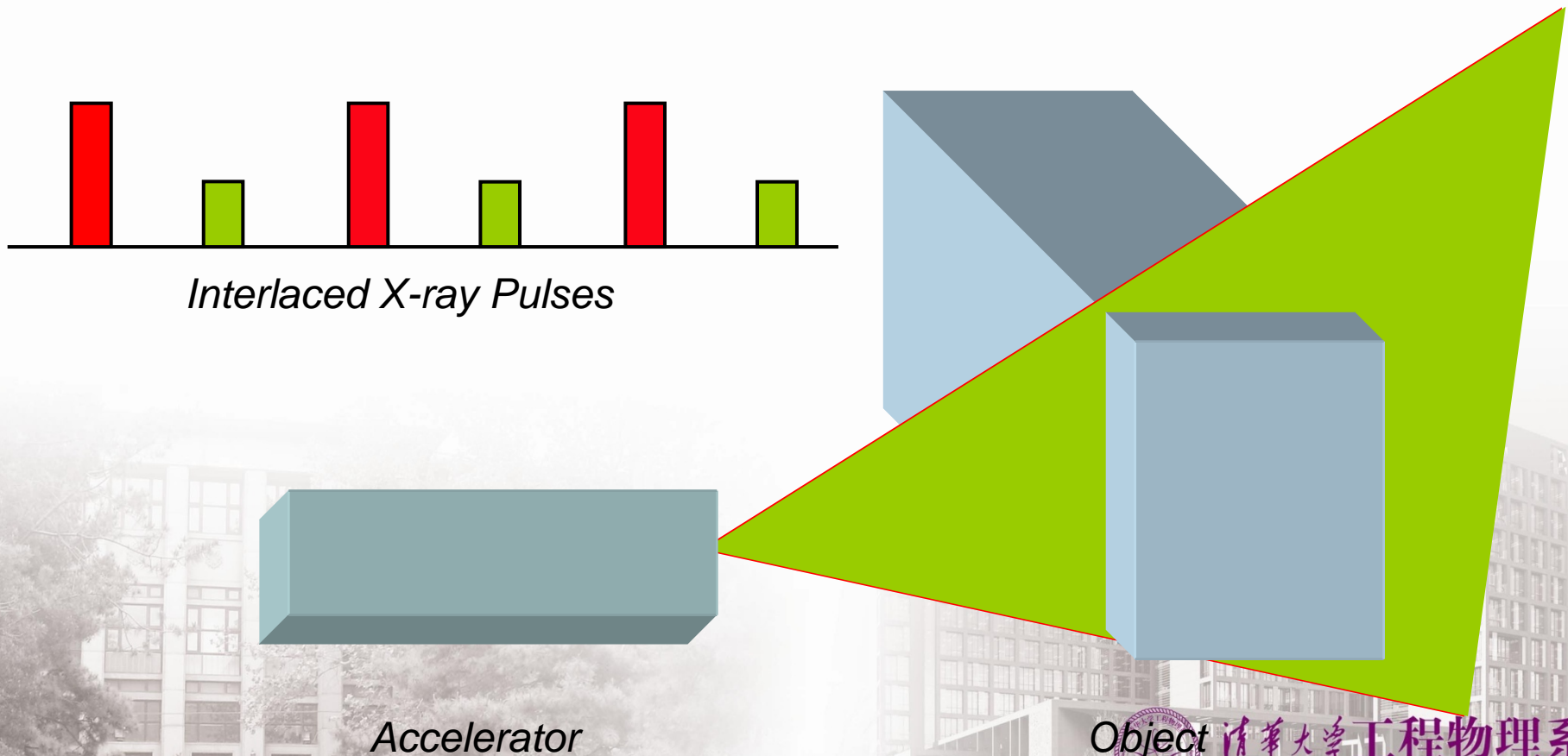


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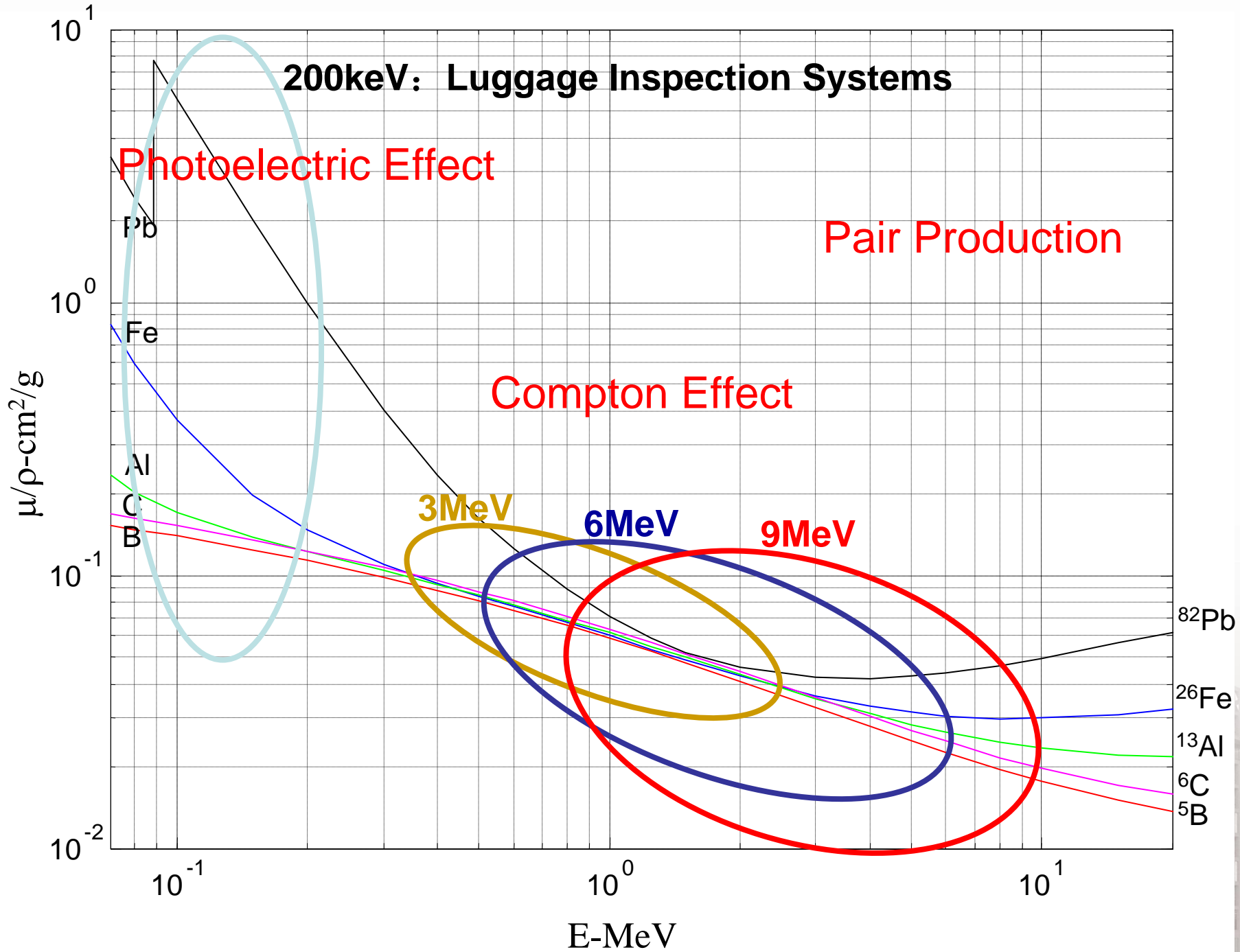
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New Challenges to Linacs for Material Identification Cargo Inspection Systems

- Interlaced dual energy pulses with similar x-ray dose
- Electron energy and pulse dose stability

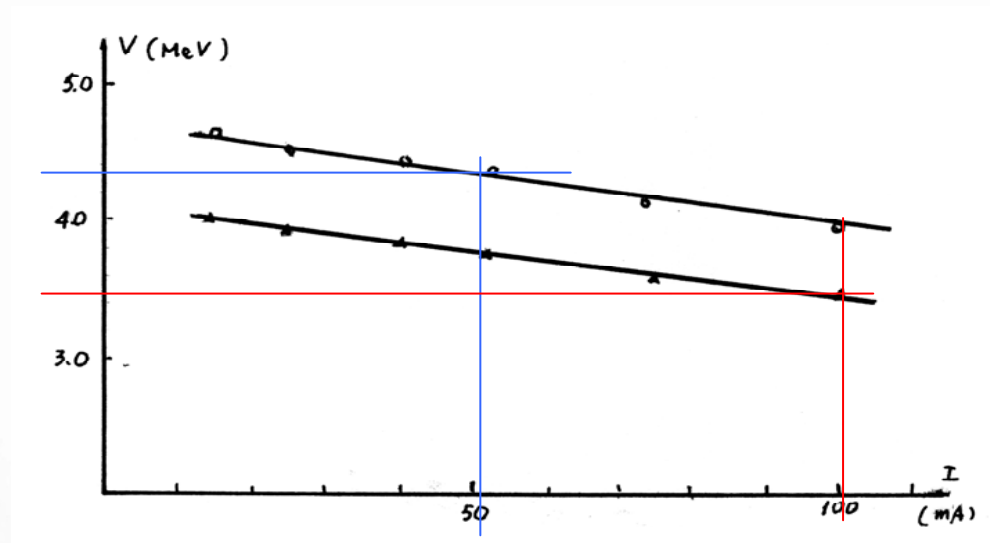
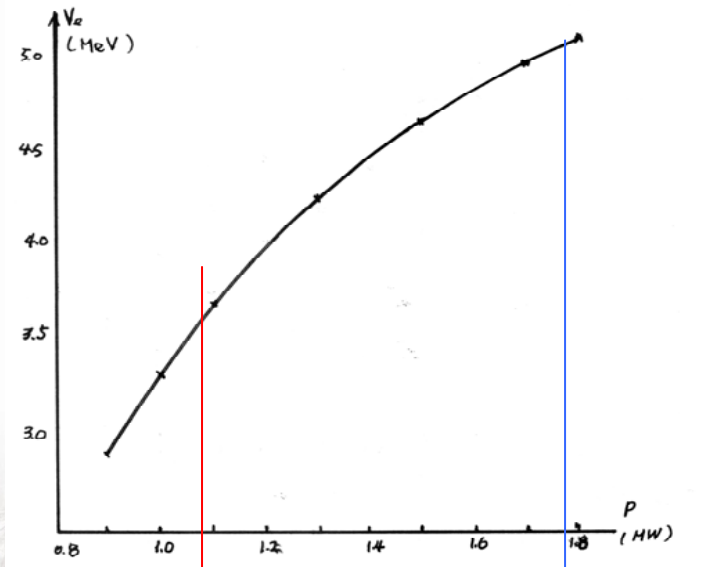


Accelerator



X-ray Source-The Dual Energy Linac

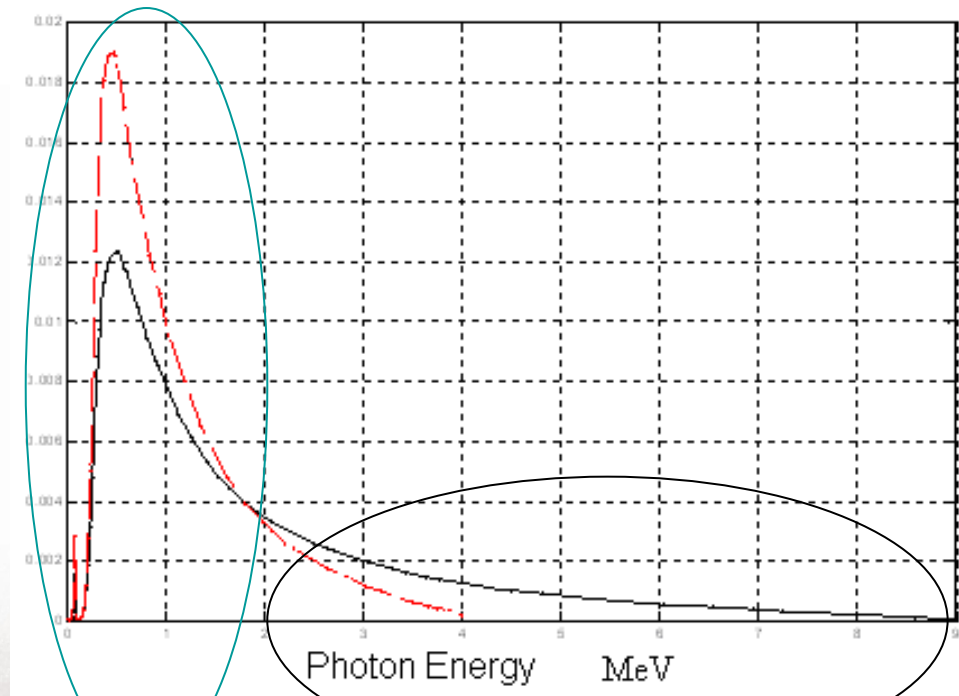
- Interlaced Dual Energy



$$V = a \cdot \sqrt{P} - b \cdot I$$



Dual Energy X-ray Spectra

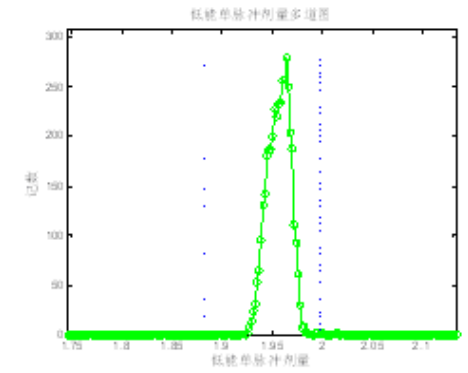
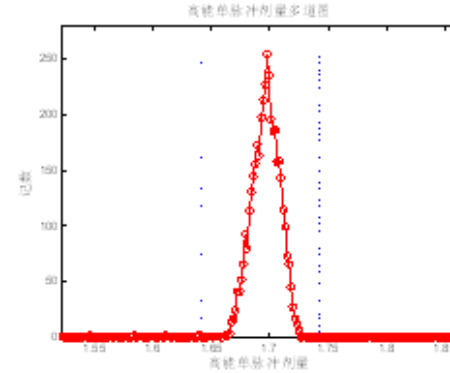
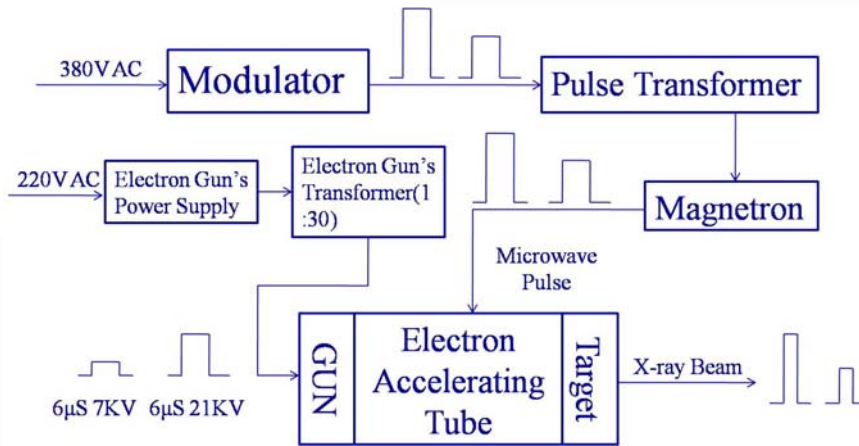


Low Energy X-ray

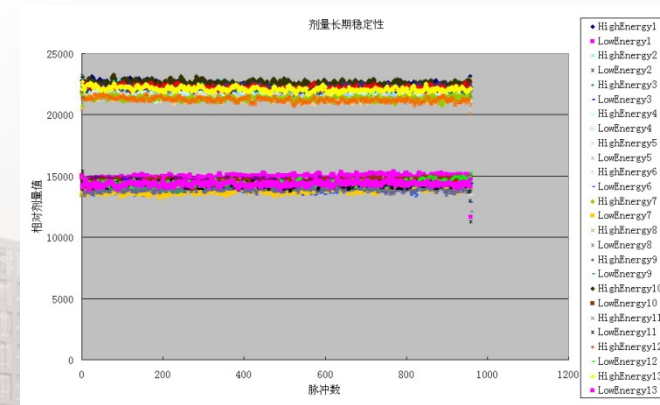
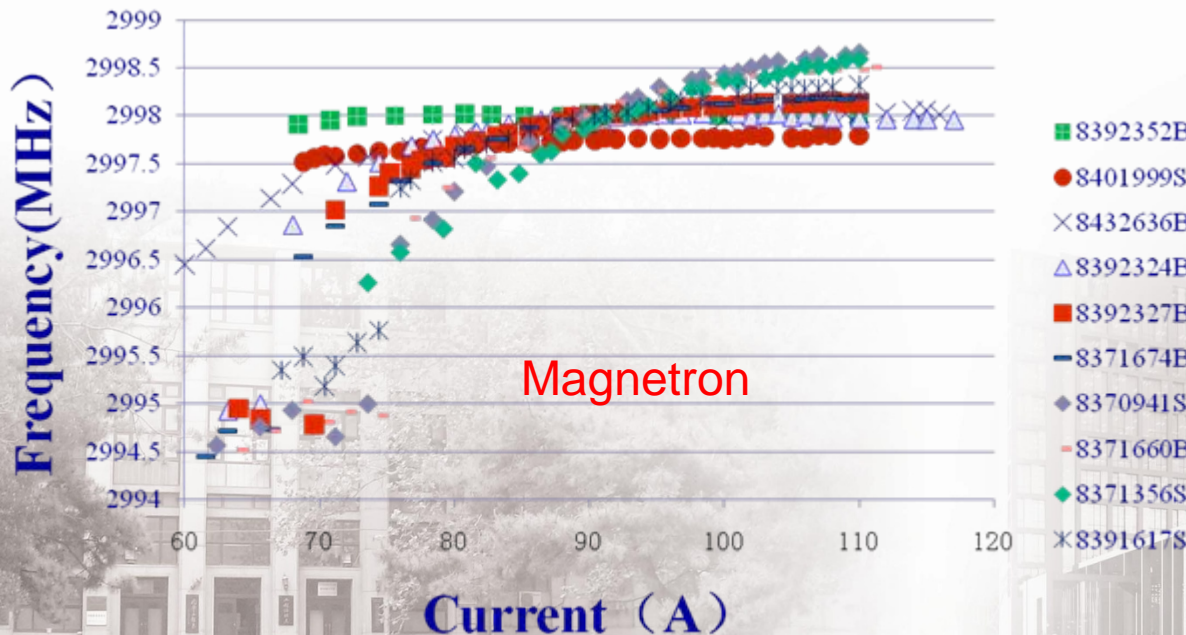
High Energy X-ray



The Dual Energy Linac using a Magnetron



By improving the modulator to stabilize the dose rate fluctuation from pulse to pulse



By improving the AFC, to control the long time dose rate fluctuation

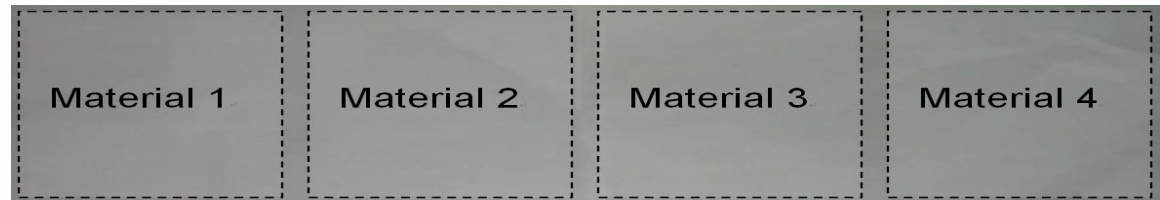
The Dual Energy Linac

- Magnetron MG5193: 2.6MW, 2998MHz, 4~5ms, 300pps
- Low-energy: 6-7MV and High-energy:9-10MV
- Maximum doserate(un-filter):
 - 6MV non-interlaced: 1000cGy/min@1m
 - 9MV non-interlaced: 3000cGy/min@1m
 - 6/9MV interlaced: 1500cGy/min@1m(500 of 6MV & 1000 of 9MV)
- 300pps in non-interlaced mode, and 150pps+150pps in interlaced mode
- X-ray focal spot size: smaller than 2 mm diameter at FWHM

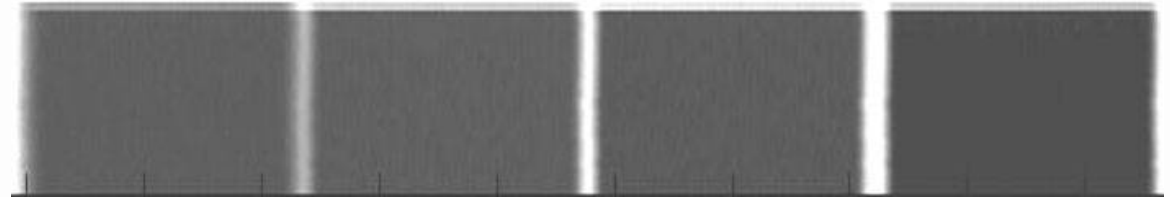


Material Identification by Dual Energy Linac

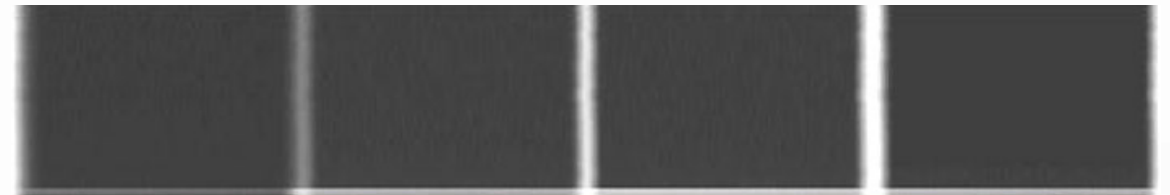
- Unknown material



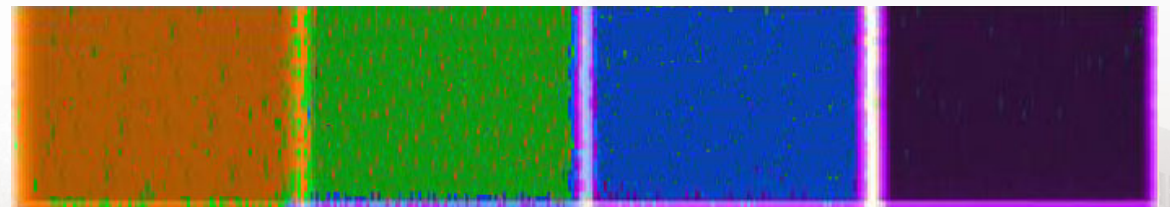
- High-energy image



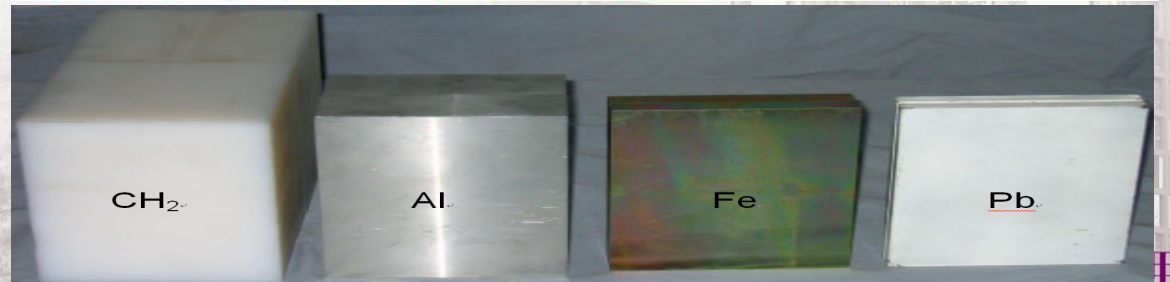
- Low-energy image



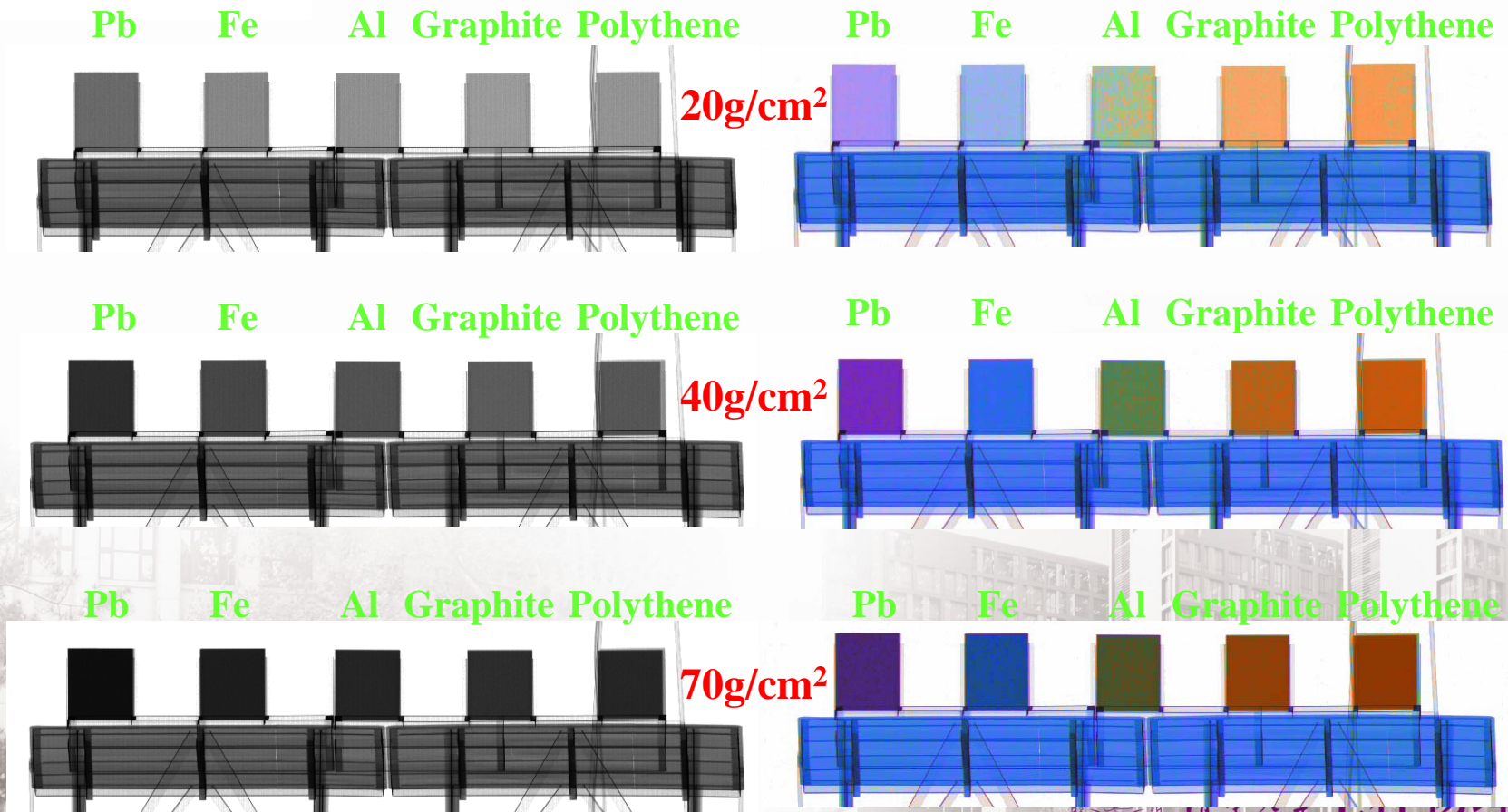
- Dual-energy image



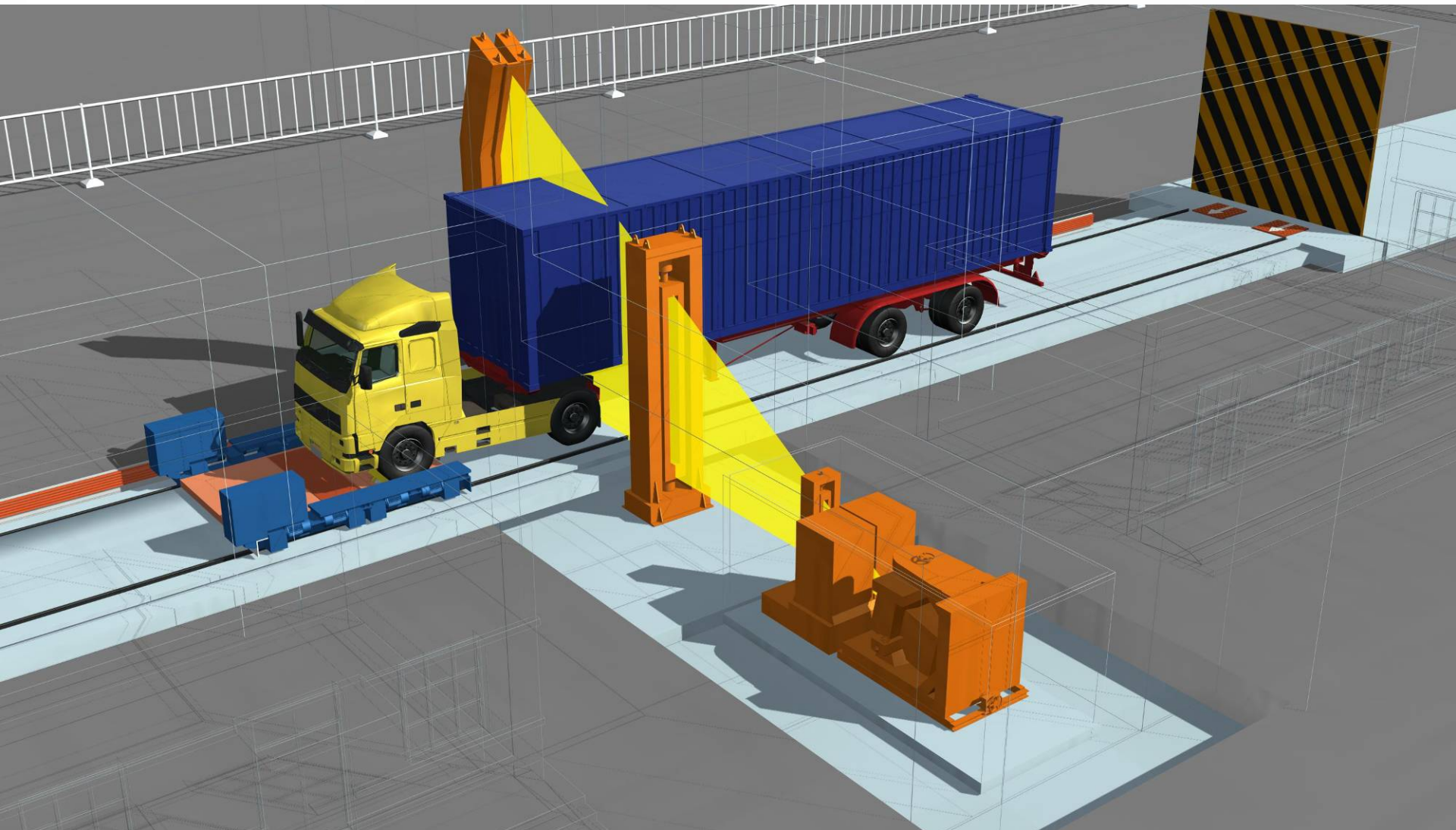
- Unveil the scanned object



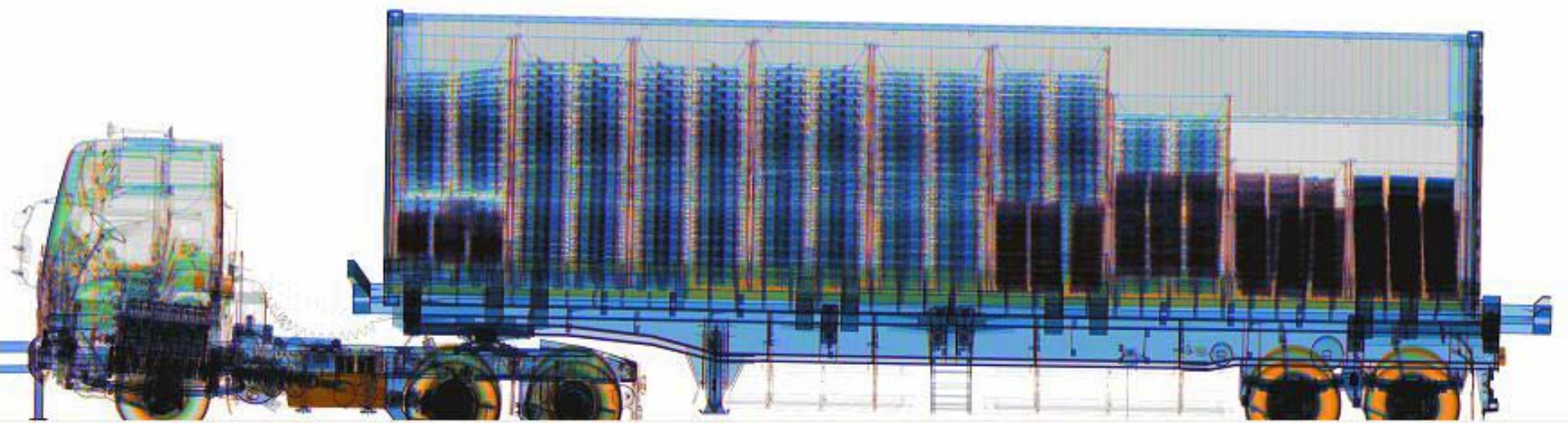
Material Discrimination with different mass-thickness



NUCTECH FG9000DE



NUCTECH FG9000DE



NUCTECH MT1213DE

Dual-energy technology

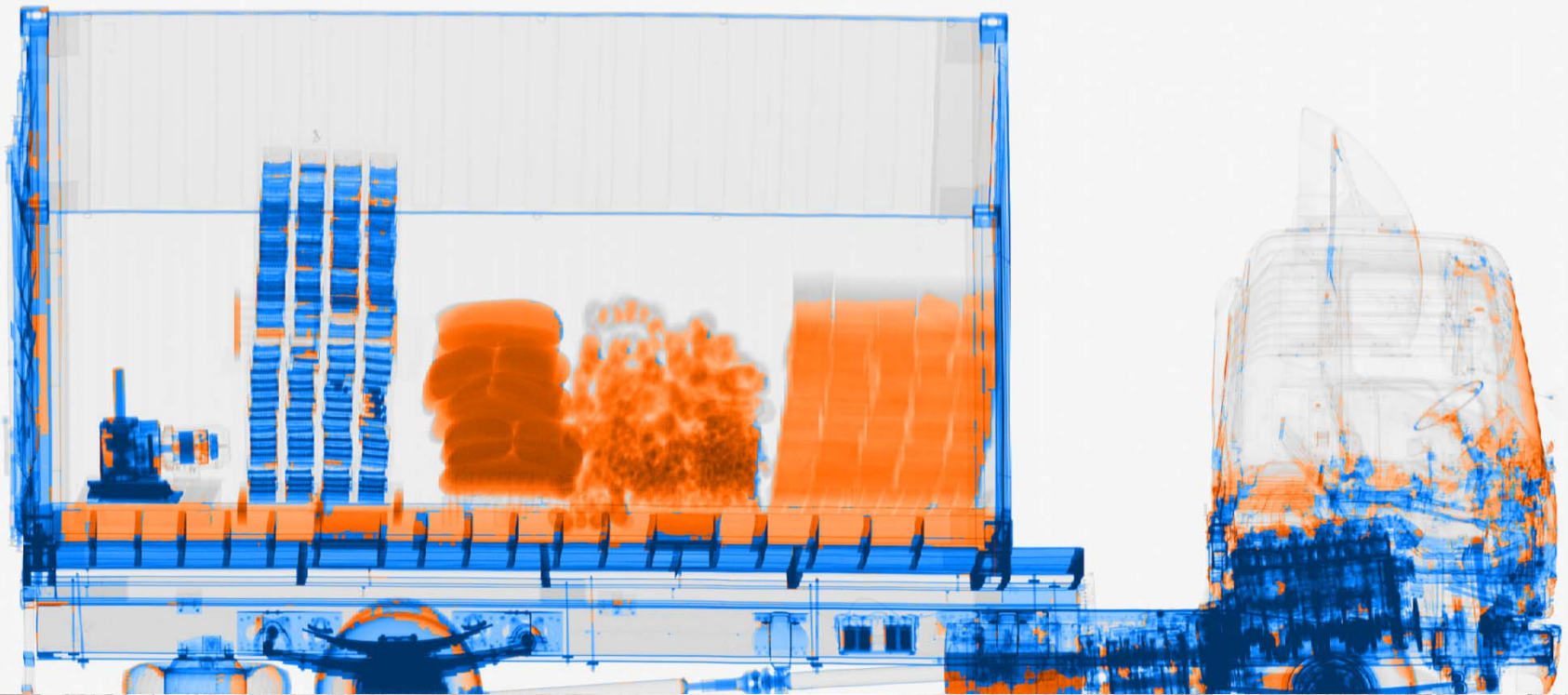
- Mobile system
- For ports, border

Features

- **Material discrimination**
- A 6MeV/3MeV accelerator
- Excellent flexibility
- Excellent image quality and high penetration ($\geq 300\text{mm}$)
- Optional Integrated radioactivity monitor



Scanning image



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NUCTECH MB1215DE

Dual-energy

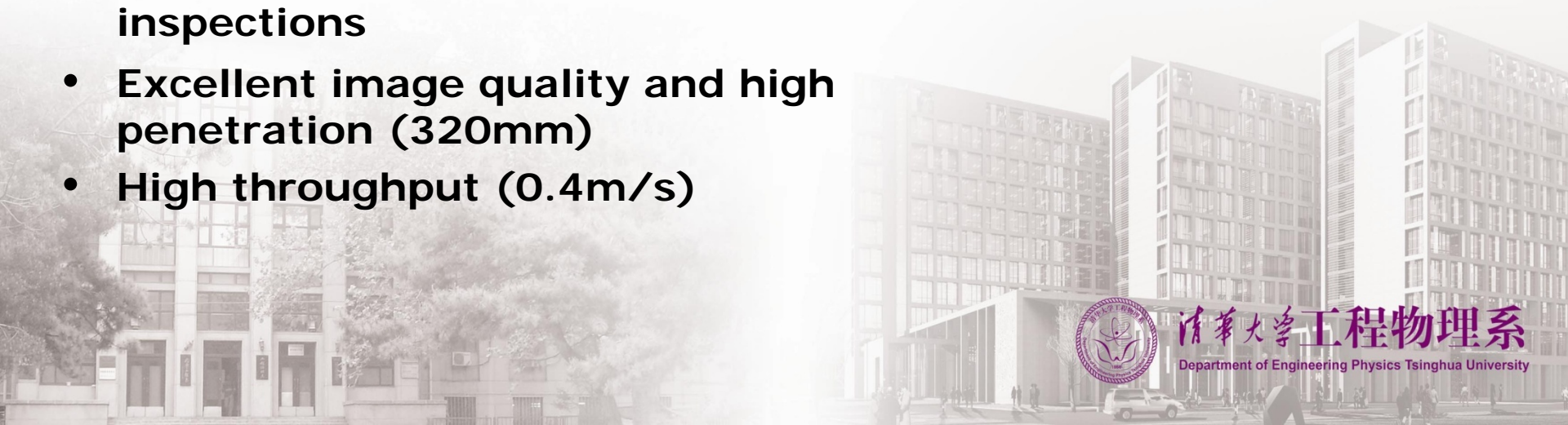
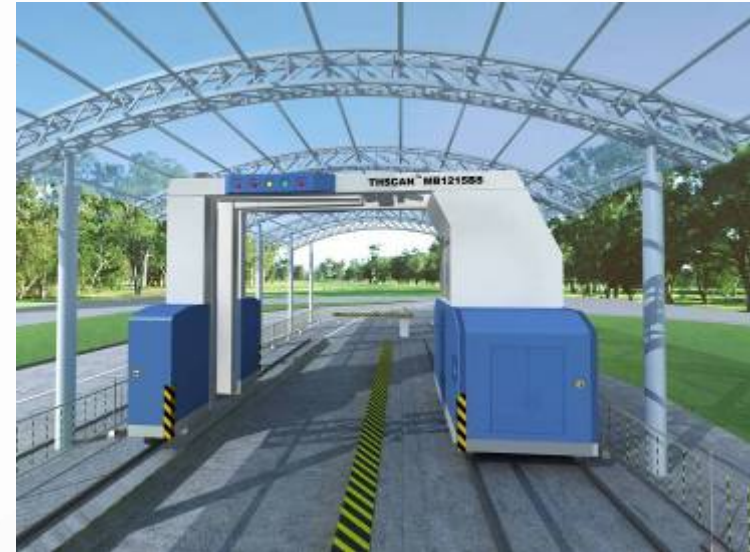
- Relocatable system
- For ports, border

Features

- **Material discrimination**
- Large scanning tunnel as 5.4m(W) × 5.1m(H) for multi-purpose

inspections

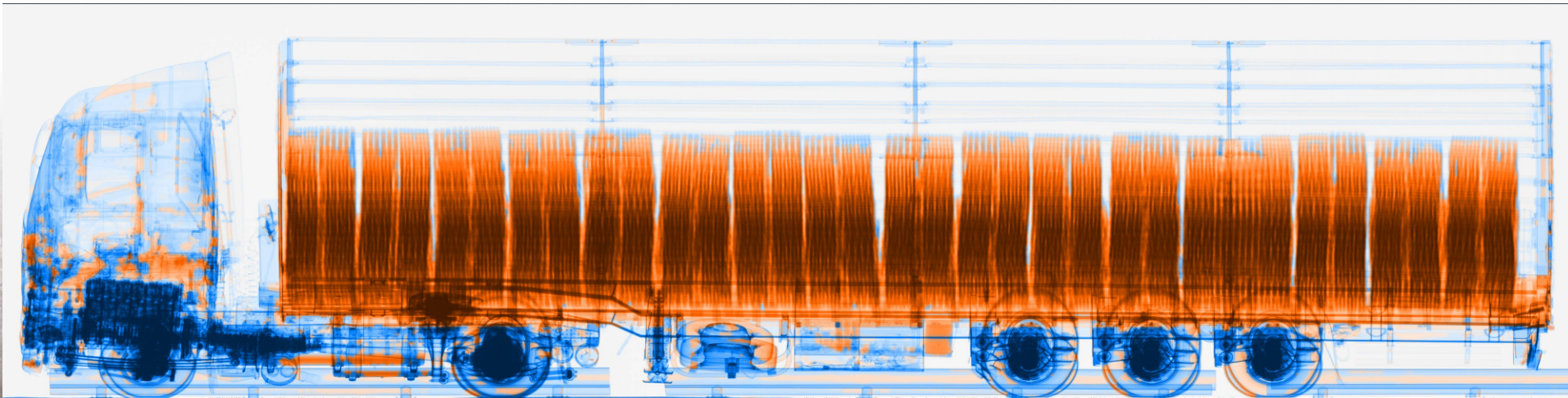
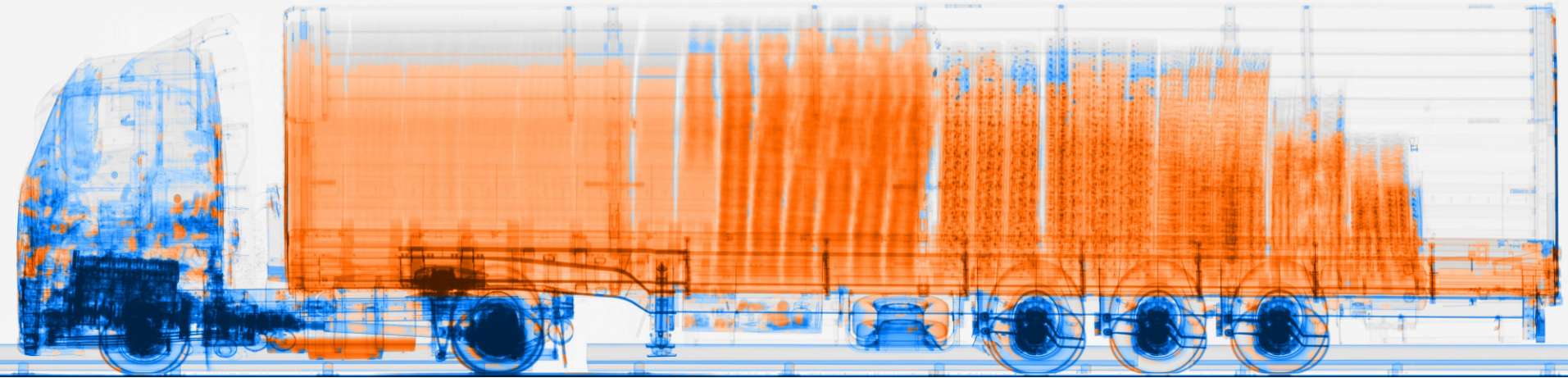
- Excellent image quality and high penetration (320mm)
- High throughput (0.4m/s)



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Scanning image

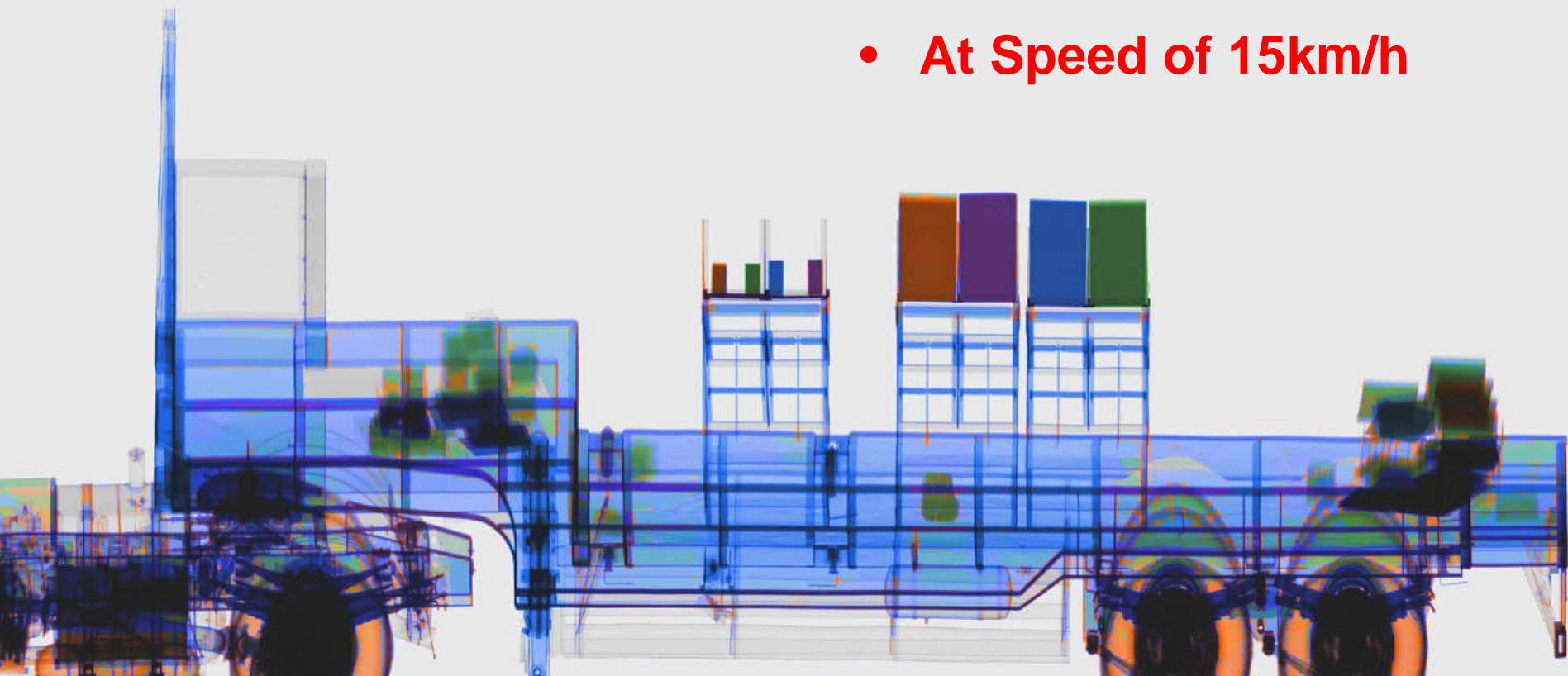


NUCTECH PB6000



Combined Fast Scan with Dual Energy

- At Speed of 15km/h



Achievement of NUCTECH



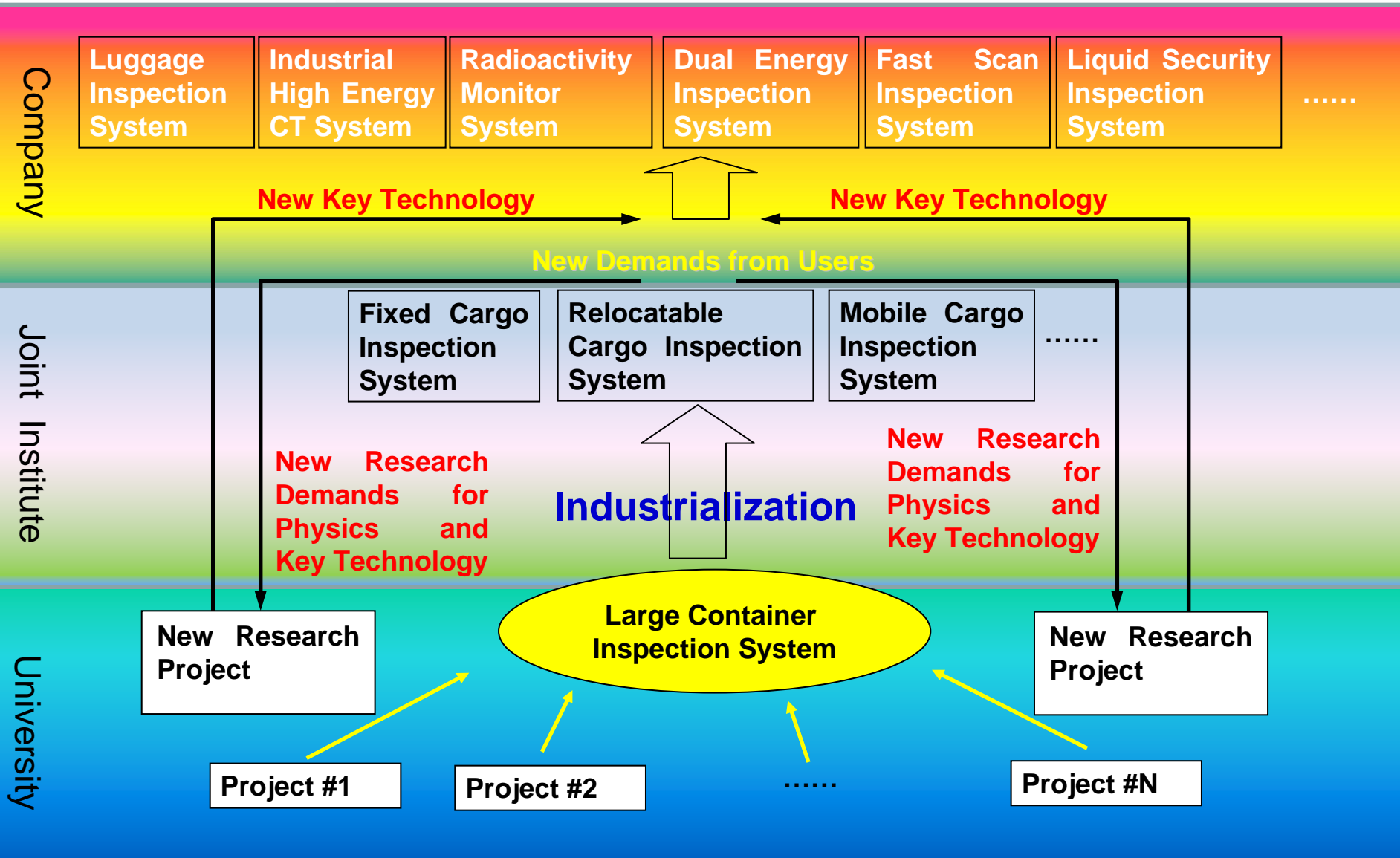
THSCAN™ High-Energy Systems in the World

Update to May 2008

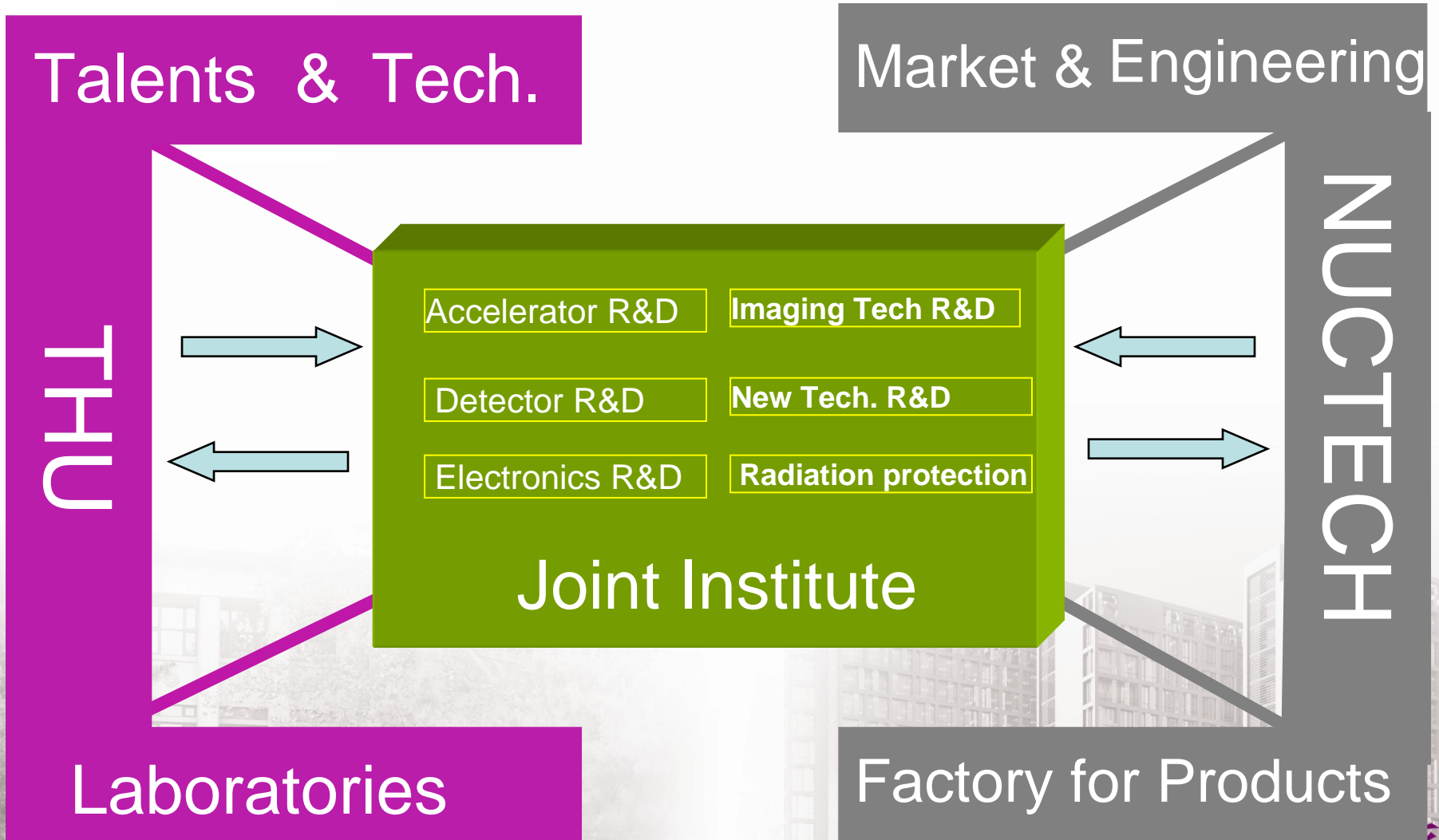


Up to May 2008, more than 310 systems have been exported to over 84 countries

Collaboration between University and Industry



The Joint Institute of THU & NUCTECH



Summary

- **N**eutron, **P**roton, **E**lectron and **P**hoton are important particles for fundamental science, such as nuclear physics , high energy physics, material and life science, biology and so on. And They can be more widely used in society, only if their sources are more compact and safer.
- Besides proton and electron beams can be accelerated to the energy we need directly from accelerators, there are special facilities to generate high quality neutron and photon beams, such as SNS,SR and FEL. But compact sources with good enough parameters for some special demands (such as x-ray tube) are most important for **NPEP** used in society.



Thanks for Your Attention!

