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Applications of Particle Accelerators

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Outline

- The particle accelerator business
- What is the role of the laboratories represented in ICFA?
- Some personal observations and suggestions

Acknowledgments:

- EUCARD^2 report on Applications of Particle Accelerators in Europe
- R. Hamm and M. Hamm (eds.) “Industrial Accelerators and their applications”
- Presentations at IPAC 2017 by Robert Hamm, Robert Kephart, Angeles Faus-Golfe and Soren Pape Moller

Particle accelerators as a business

- Devices that can accelerate subatomic particles to relativistic velocities
- 30 - 40,000 in use worldwide, vast majority commercially manufactured
- Over 100 companies worldwide
- Over $5B in sales annually
- Involved in the creation of over $500B/year in products



Markets

- Major non-scientific markets
  - Cancer therapy $2.6B
  - Ion implantation in semiconductors and materials $1.6B
  - Electron beams for materials processing $180M
  - Electron beams for irradiation $160M
  - Non-destructive testing and inspection $160M

- Plus equipment for big science facilities

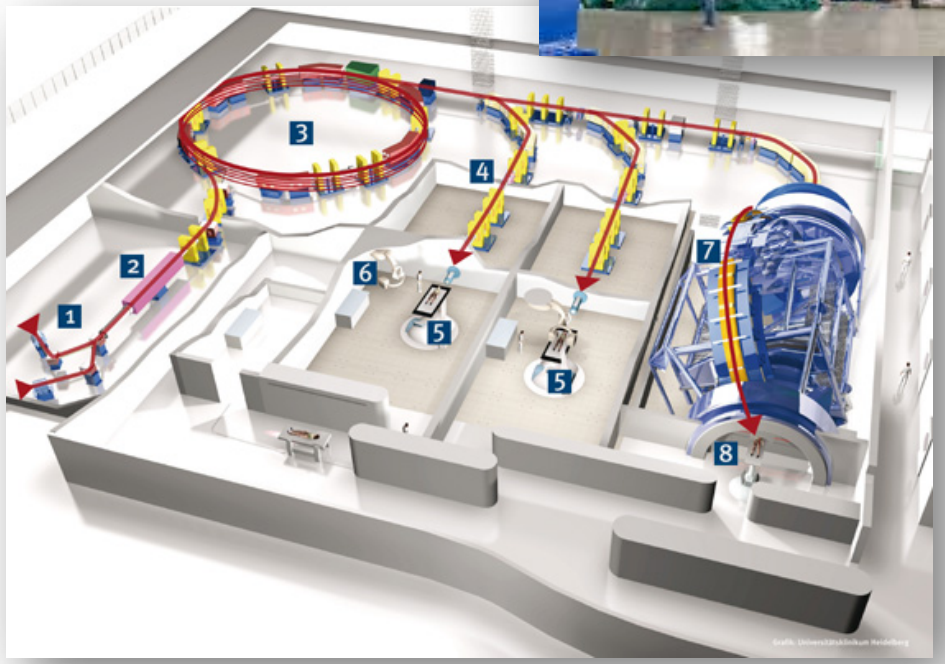
Medical applications

- Over 14,000 electron linacs (4-20MeV) for x-ray production
- 60-70 proton and ion therapy accelerators
- 1600 isotope production accelerators

Challenges

- Cancer rates increasing – especially in LMICs
- Combined imaging and treatment
- Dosimetry
- Lower cost, more compact, higher throughput hadron therapy
- Reducing cost of radioisotope production
  - Yesterday's presentation by Paul Schaffer

Heidelberg Ion Therapy centre



Industrial applications

- Over 11,000 ion implantation machines (< 1 MeV)
- 7500 electron accelerators for materials processing and welding (< 10 MeV)
- 3000 electron accelerators for sterilisation (< 10 MeV)
  - All requiring high current (10-150 mA)

Challenges

- Lower costs, higher efficiency, simpler operation
- Miniaturisation
- Higher beam power (< MW)
- Regulatory barriers in EU to use of ionising radiation in food processing

Sterilisation

Security applications

- Maybe 100 electron accelerators for x-ray border screening of cargo

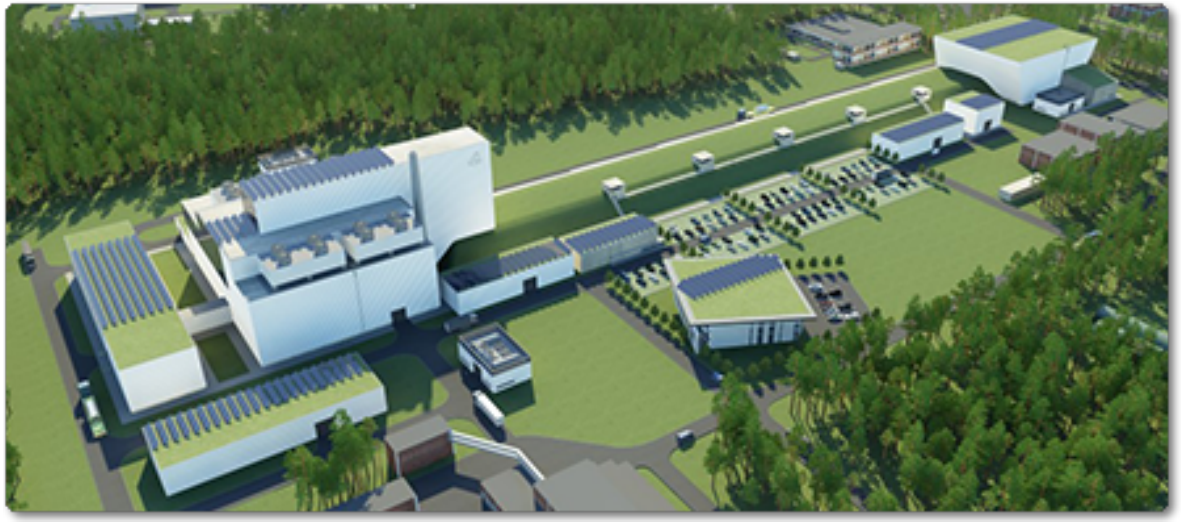
Challenges

  - Low cost, simple to use, portable systems
  - 3D imaging by CT
  - Smarter (AI?) image processing
  - Lower dose rates (to avoid hazard to any people being smuggled in cargo)

- High energy x-ray (or FEL) machines for nuclear weapons stewardship
  - imaging and hydrodynamics e.g. MARIE at Los Alamos

Dreams of new applications

- Radioactive waste transmutation
- Accelerator-driven systems (including thorium) for energy production
- Bio-fuel production
- Fusion and fusion materials
  - e.g. IFMIF
- Compact (university scale) neutron sources



MYRRHA at SCK-CEN

… and mustn't forget accelerator technologies (like very high field magnets) with applications in other areas

Commercial accelerators need to be

- **Cheap**
- **Reliable**
- **Proven**

- New technology
  - only needed if
    - it reduces cost or increases reliability
    - if it can open new markets
  - will likely take many years to gain acceptance

Where could recent R&D in our laboratories lead?

- Major R&D investment in superconducting RF acceleration over past decade
- Now many applications in big science facilities
  - LCLS II, European XFEL, ESS…

Where could this technology find a commercial market?

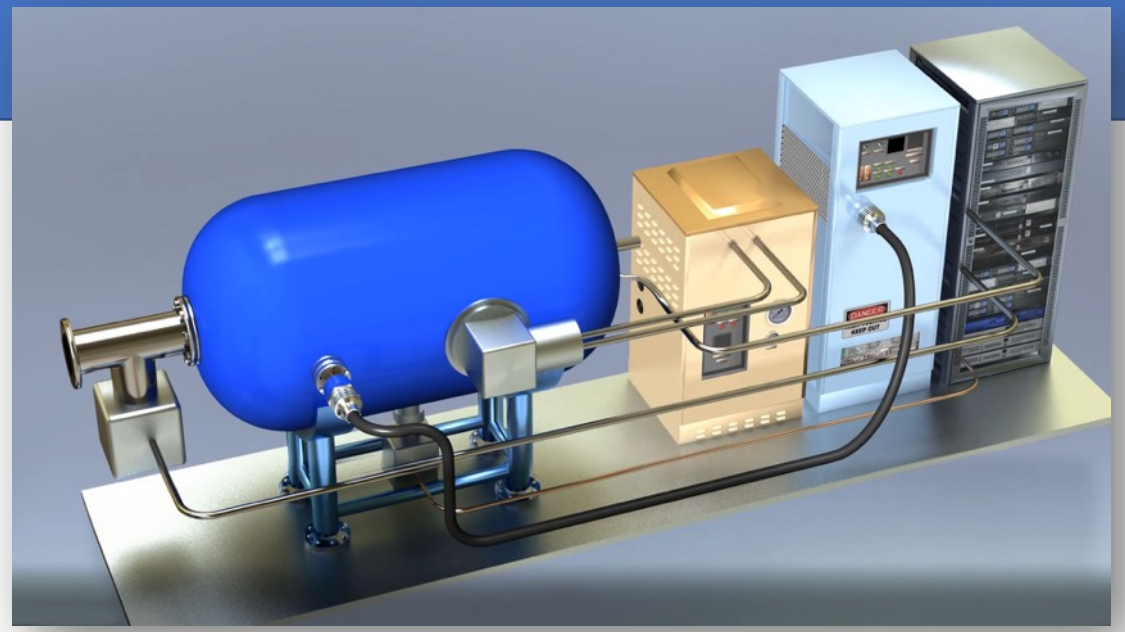
Potential applications of SC RF

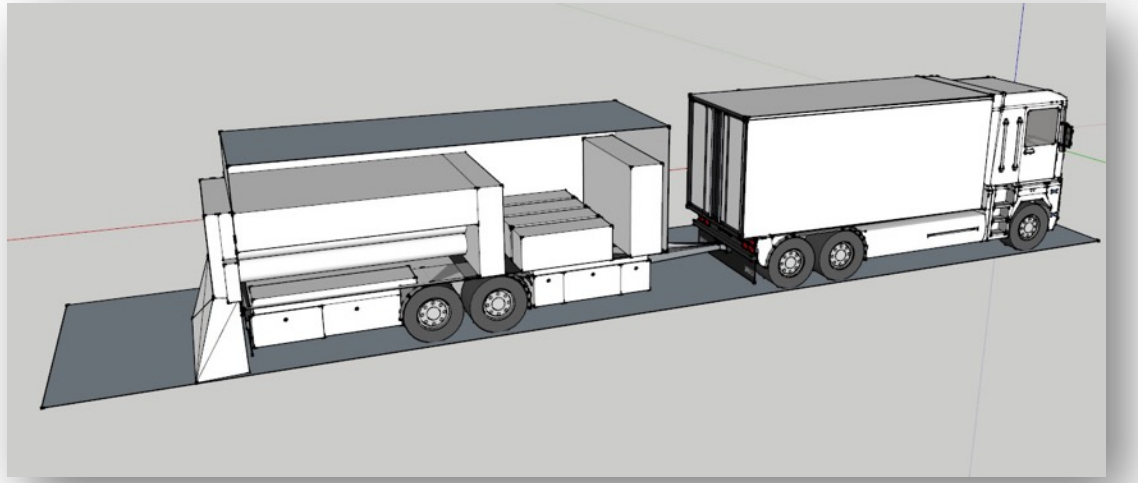
- Environmental remediation, wastewater and flue-gas treatment
- Electron-beam melting for additive manufacturing
- Replacement of ^{60}Co in sterilization of medical devices
- Chemical catalysis, polymerisation
- Security scanning

Prototype flue gas treatment in Poland

Concept for a high power (MW), MeV energy, cheap, compact, mobile electron accelerator based on superconducting RF

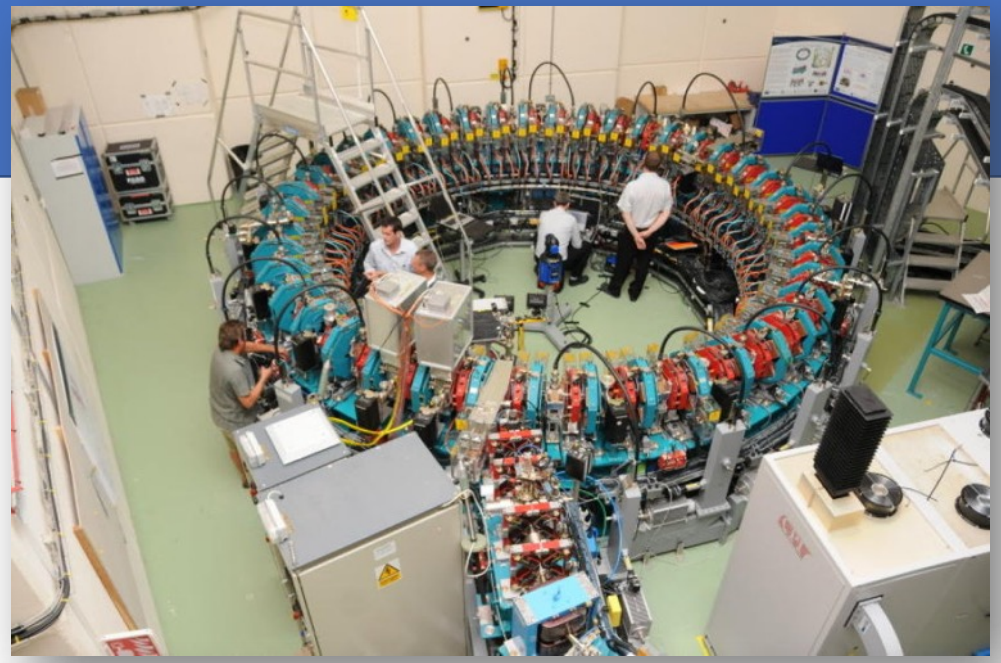
Fermilab with funding from US DOD





Other new technologies

- New accelerator configurations
  - FFAG rings
  - new electrostatic configurations
- Laser plasma acceleration
  - A better test bed than particle physics?
  - Plenty of applications need compactness without stringent beam quality



Accelerators for Big Science

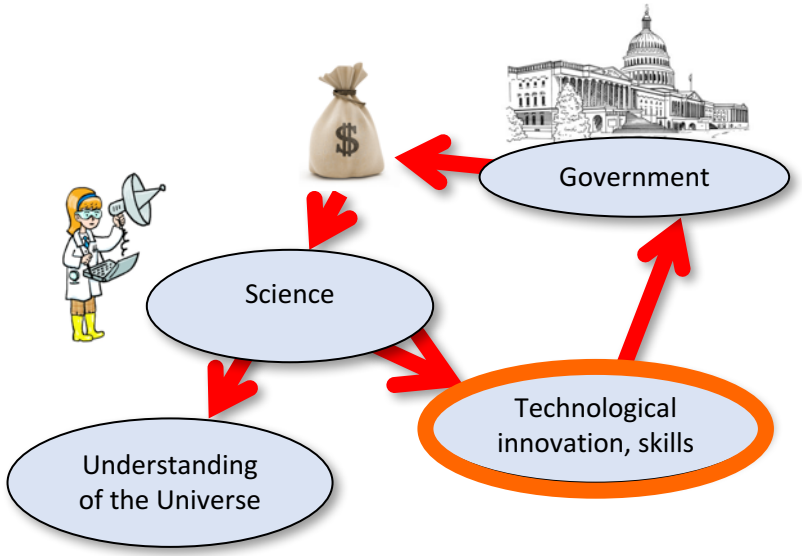
- CERN (LHC) and Fermilab (neutrino programme) $2B
- Nuclear physics $4B
- Synchrotron Light Sources $1-2B
  - Many planned upgrades to low emittance MBA design
- X-ray Free electron lasers $1B
- Neutron sources $2B
- IFMIF (?) $0.5B

Total roughly $1B /year if spread over ten years


EUROPEAN
SPALLATION
SOURCE
5 MW SC proton linac
October 2017

What is the role of the laboratories in ICFA?

- Depend upon particle accelerators to maintain cutting edge science capability
- Substantial investment in R&D necessary
- ‘Stewardship’ role (whether formalised or not) of high energy physics in developing accelerator technology capabilities



- Increasingly a requirement to explain how this investment contributes to broader societal and national goals
- And increasingly a requirement (whether formalised or not) to promote more such impact

STFC CERN Business Incubation Centre at Daresbury

- Offers tenant companies access to CERN IP, free access to STFC expertise, cash incentive, business and marketing support
  - 100% the right thing to do
  - 100% harder than we expected

- Needed to broaden scope from accelerators to include detectors, cryogenics, computing and other technology

- Analogy: ESA BIC is for applications of space not rockets…

Illinois Accelerator Research Center (IARC) at Fermilab

- Again, it's been a long, slow journey

Observations - 1

- Accelerator technology transfer is hard!
  - Which doesn't mean it's the wrong thing to do
  - Industry has no duty to employ anything that we have developed

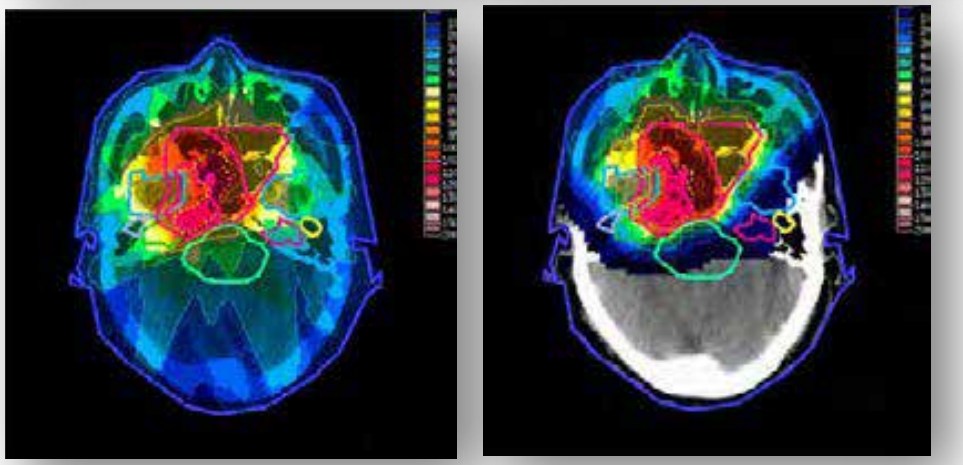
- Accelerators are a tough business
  - Capital and R&D intensive
  - Slow
  - May not be for startups or SME's
  - We've seen very big companies (Siemens) pull out

Observations - 2

Technology push plus physicist arrogance can lead to problems…

Just because we have a beautiful technical solution doesn't mean it solves a real world problem in a cost effective way

- often we seem to propose a Concorde when the application needs a 747
- e.g. ion therapy, radioactive waste transmutation, cargo scanning…



My advice to the accelerator laboratories in ICFA

- Every large accelerator laboratory should have a business/industry engagement programme
- One goal should be to facilitate the broader application of new technologies we have developed for our own needs
- Accelerator technology should be part of this programme
  - While acknowledging that it's a challenging technology that may not be suitable for all
  - Part of a package along with detectors, data handling, etc.
- Be realistic – better to under-promise and over-deliver than the reverse…

Conclusions

- Particle accelerators are a significant business sector with applications from medicine to industry and several billion in annual sales, mostly based on mature technologies
- There is a wide range of new application areas
- There are new technologies ripe for application
- We should help
- But we mustn’t underestimate the real-world challenges