Science & Technology
Facilities Council

Particle Accelerators – Engines of Discovery

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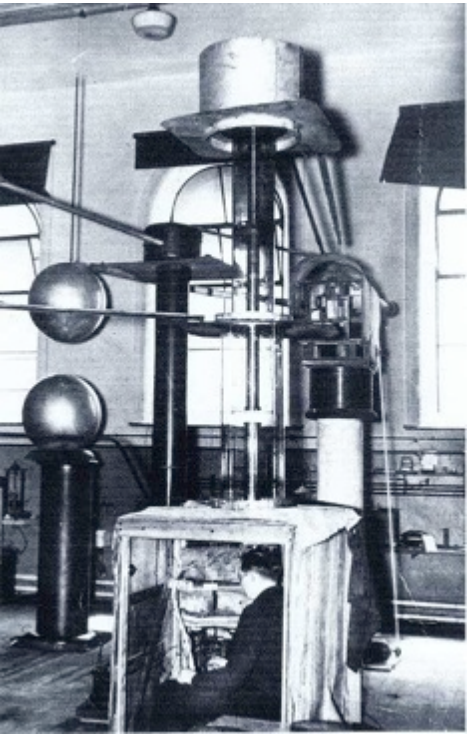
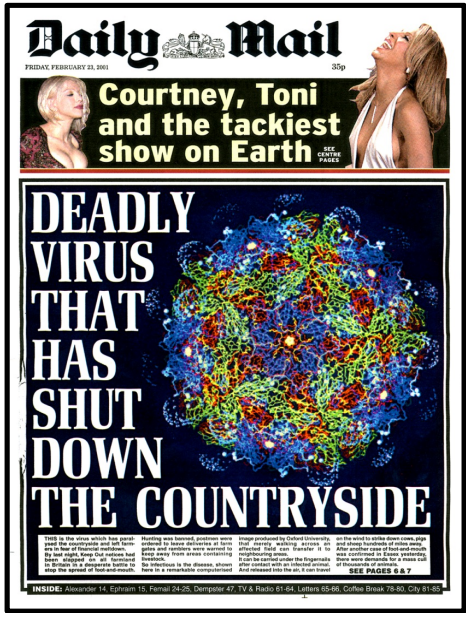
STFC

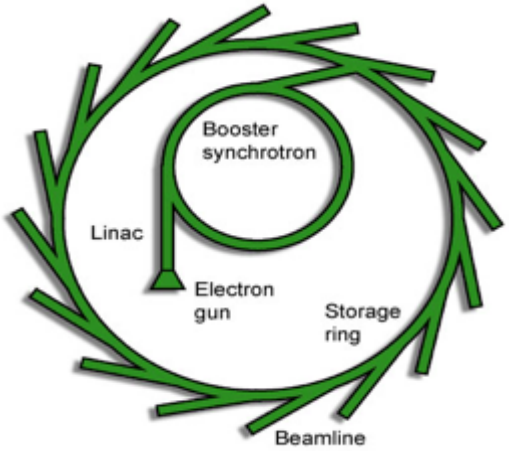
Liverpool
26th June 2015

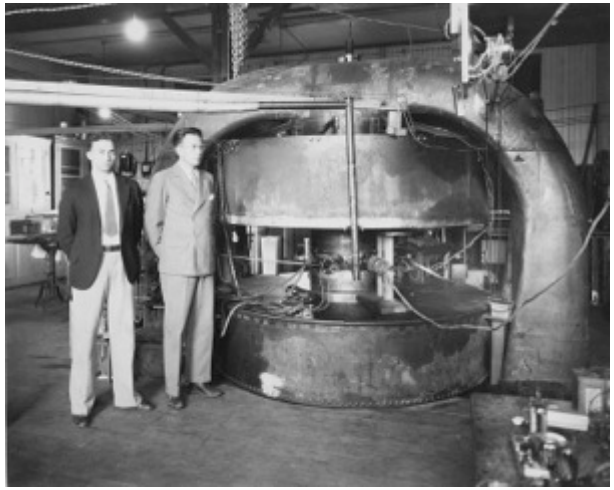


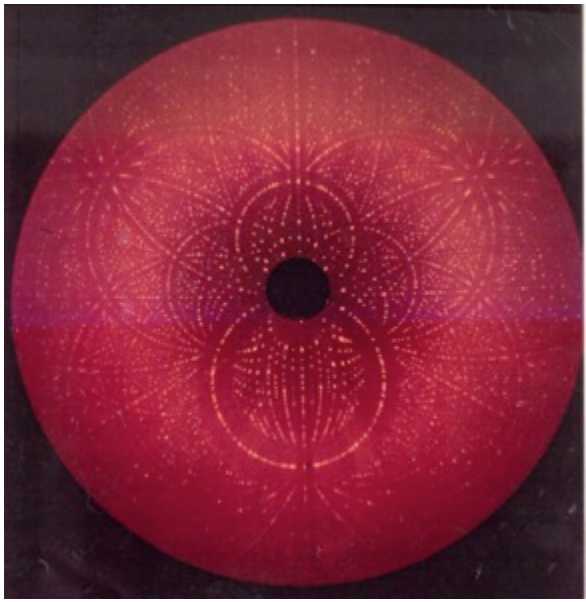
Overview

- Fundamental questions
- Energy Frontier machines
- Science enabling machines
- Wider Applications
- Conclusion



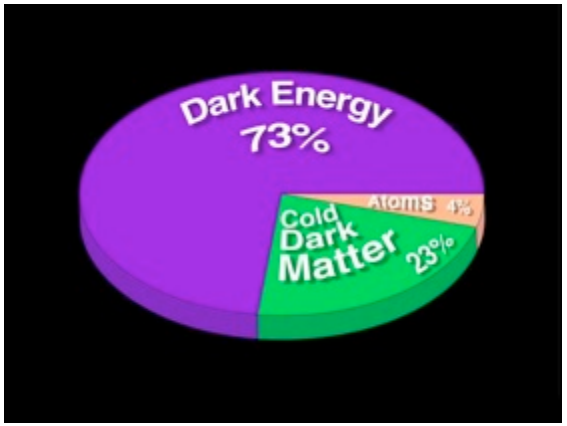






Fundamental Questions

- Role of gravity ?
- Origin of matter ?
- Origin of mass ?

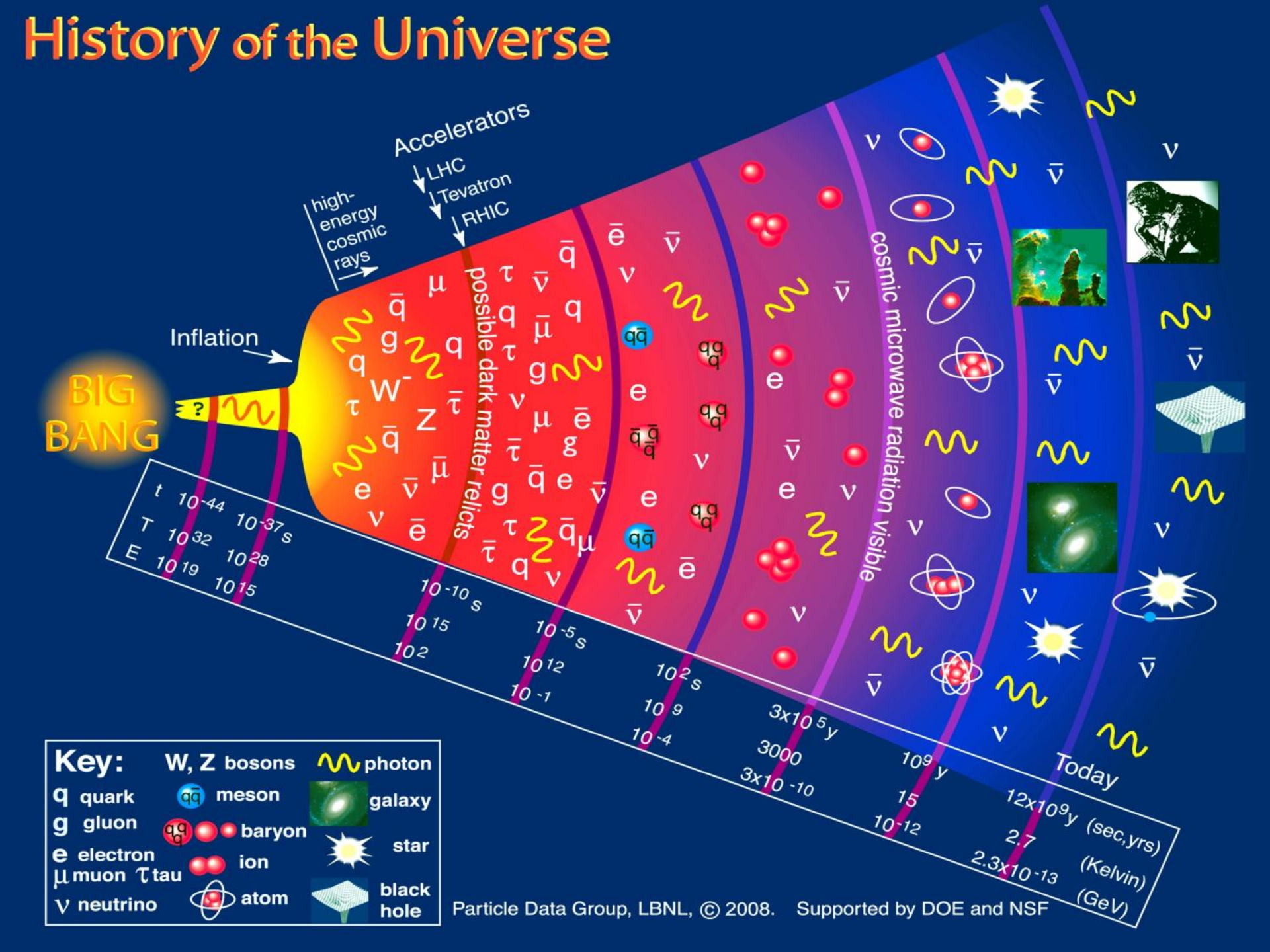


Newton's constant $G_N = 6.674\times10^{-11}\,\mathrm{m^3kg^{-1}s^{-2}}$

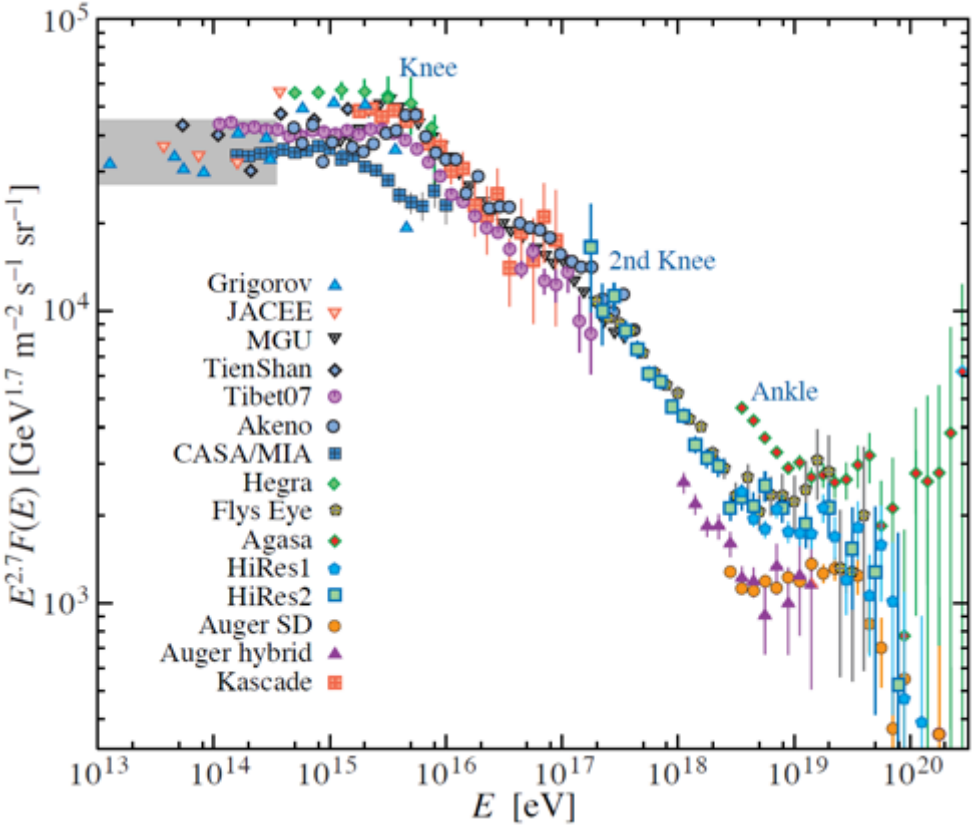
Natural units $G_N = \dfrac{\hbar c}{m_{Pl}^2}\ \mathrm{GeV^{-2}}$

$$\Rightarrow m_{Pl} = 1.22\times10^{19}\ \mathrm{GeV}$$

History of the Universe



Can we access 10^{15} GeV Directly?



Cosmic Accelerators

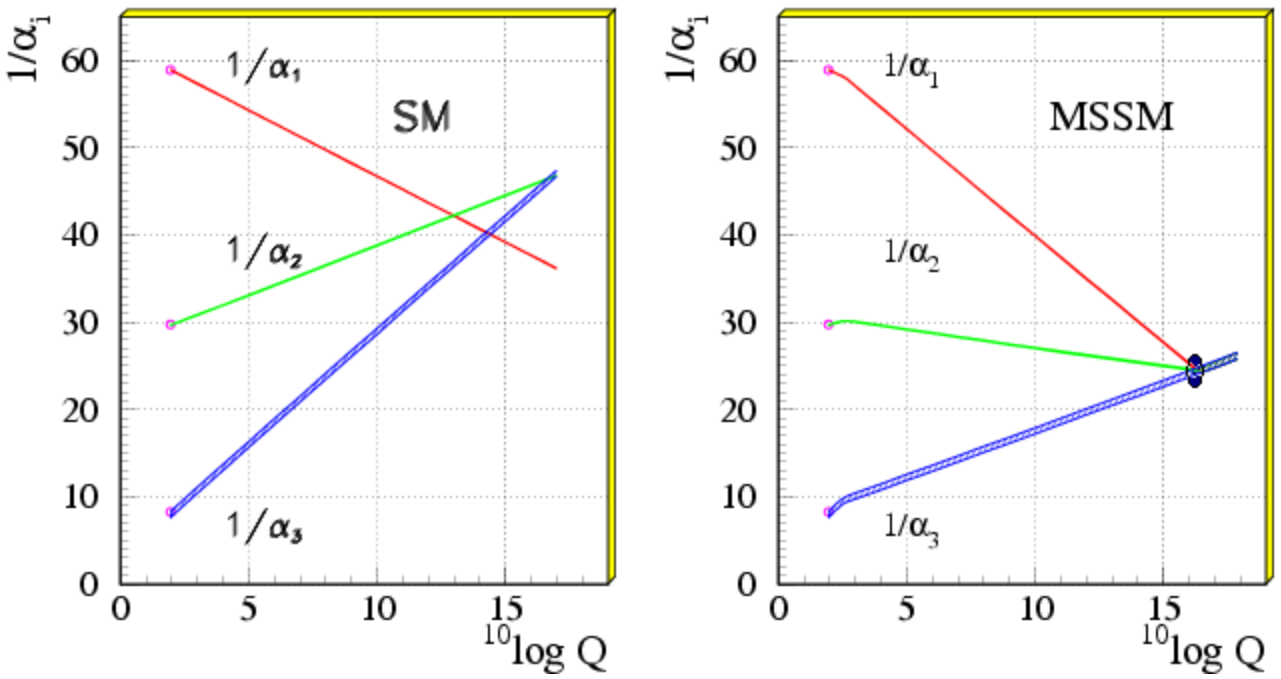
Highest energy cosmic rays are of order 10^{11} GeV.

They are very infrequent.

No precision detector in space.

CMS energy of atmospheric collision = $\sqrt{2m_pE}$ ~ 10^5 GeV.
So a long way off from our desired energy range.

Indirect methods: Extrapolation?



Precision TeV scale measurements are essential to get a better view of GUT-scale physics, via extrapolation.

Need high energy colliders:

LHC for discovery and percent precision

LC or Muon collider for discovery and, for lighter states, per-mille precision?

Fundamental Issue

- Typical "cross sections" $\sigma \simeq \frac{\alpha^2}{E^2}$
- Reaction Rates $\simeq L\sigma$

Where L is the "luminosity" of the accelerator

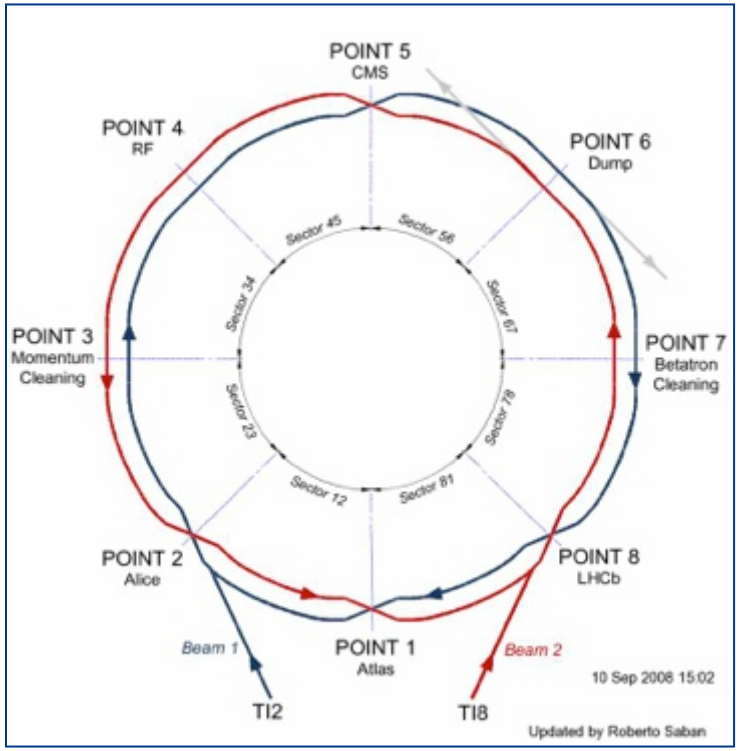
So to explore higher energies you also need high luminosity.

It's not just about "energy" – it's also about "quality"

Beam diagnostics, control, Computing, …

The LHC

LHC Energy per proton	**=**	**7,000,000,000,000 eV**
Cockroft-Walton accelerator (1932)	**=**	**700,000 eV**
Car Battery	**=**	**12 eV**



The LHC is installed in a 27km long tunnel, ~100m underground. It is designed to supply 7 TeV proton on 7 TeV proton collisions to 4 experiments, as well as heavy ion collisions

Courtesy P.Collier

The LHC: Stored Energy

- **Energy stored in the magnets:**

  10 GJ (1100 MJ/octant)

- **In LHC we must dump the magnetic energy in around 40 seconds i.e. stop the aircraft carrier in 40 seconds (in case of a problem)**

- **Energy stored in each beam:**

  362 MJ (in 89ms)

  = 4TW (power)

- **Dumping the beam is therefore like driving a TGV into a wall (withou damaging the wall!)**

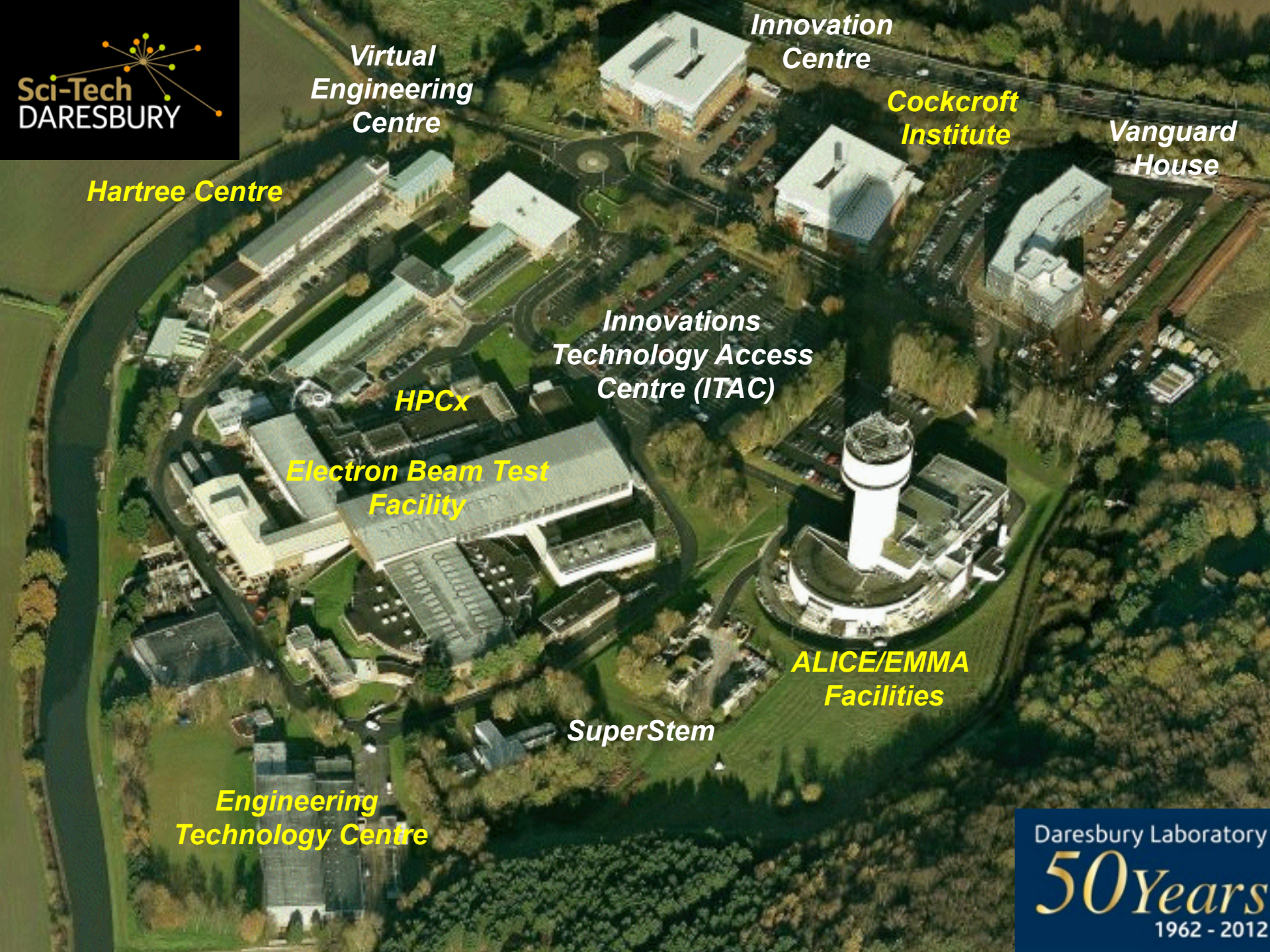
Nimitz class aircraft carrier (90 000 tons) at battle-speed of 30 Knots; Energy = ½ mv^2 ~ 10GJ

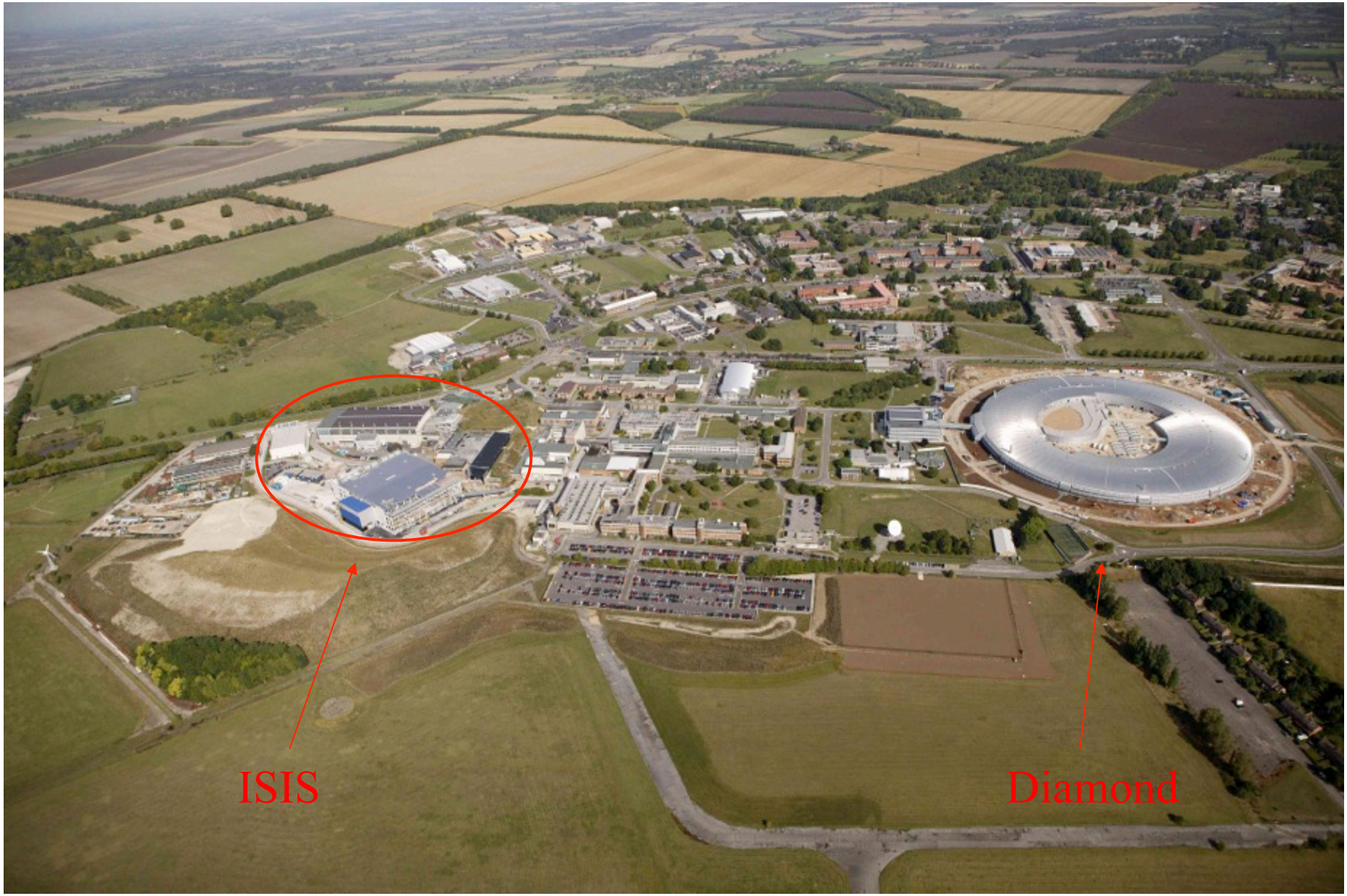
Copper: Melting point 1356 K
Specific heat capacity 386 J
Latent heat of fusion

So to heat and (386+205000) J =0.73MJ
362M half a tonne (500kg) of copper
1 and melt 1.5 tonnes (1500kg) of copper

A very thin long hole

Courtesy P.Collier


Sci-Tech
DARESBURY
Virtual
Engineering
Centre
Innovation
Centre
Cockcroft
Institute
Vanguard
House
Hartree Centre
Innovations
Technology Access
Centre (ITAC)
HPCx
Electron Beam Test
Facility
ALICE/EMMA
Facilities
SuperStem
Engineering
Technology Centre
Daresbury Laboratory
50 Years
1962 - 2012



Rutherford Appleton Laboratory, looking north

ESRF/ILL

Synchrotron Radiation

- A phenomenon called Synchrotron radiation was originally an undesirable energy loss in circular particle physics accelerators.
- It is now a powerful tool for providing brilliant X-ray sources for material science, chemical and biological studies.
- The world's first machine of this kind was in the UK
  – the SRS at Daresbury.

A 'guest star' identified as the **Supernova of 1054** in the pages of the Lidai mingchen zouyi (歷代名臣奏議), which dates to 1414.

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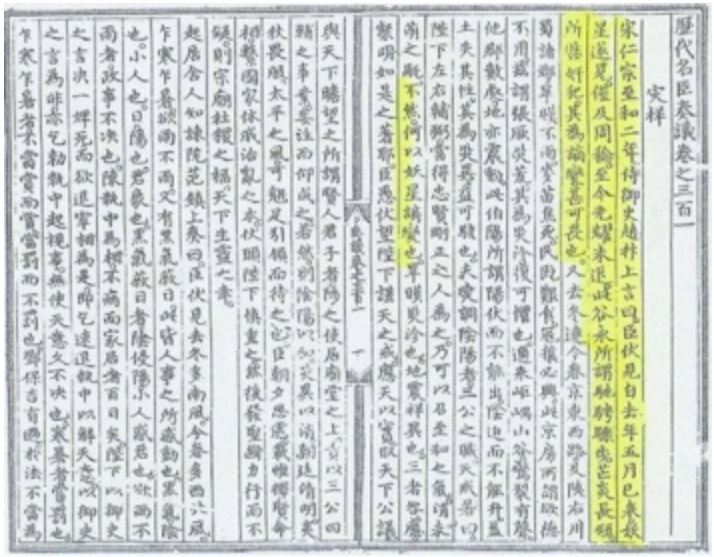
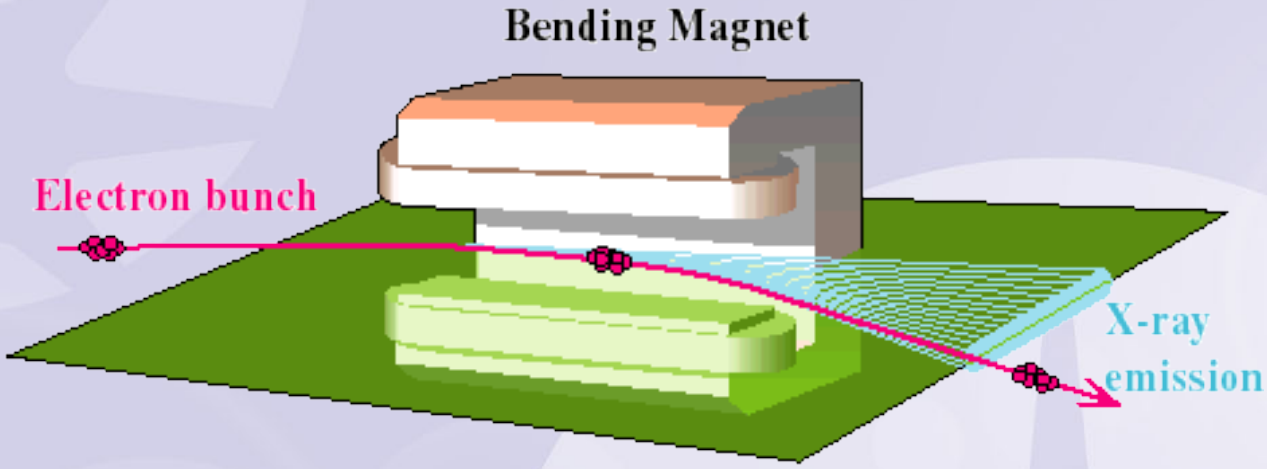
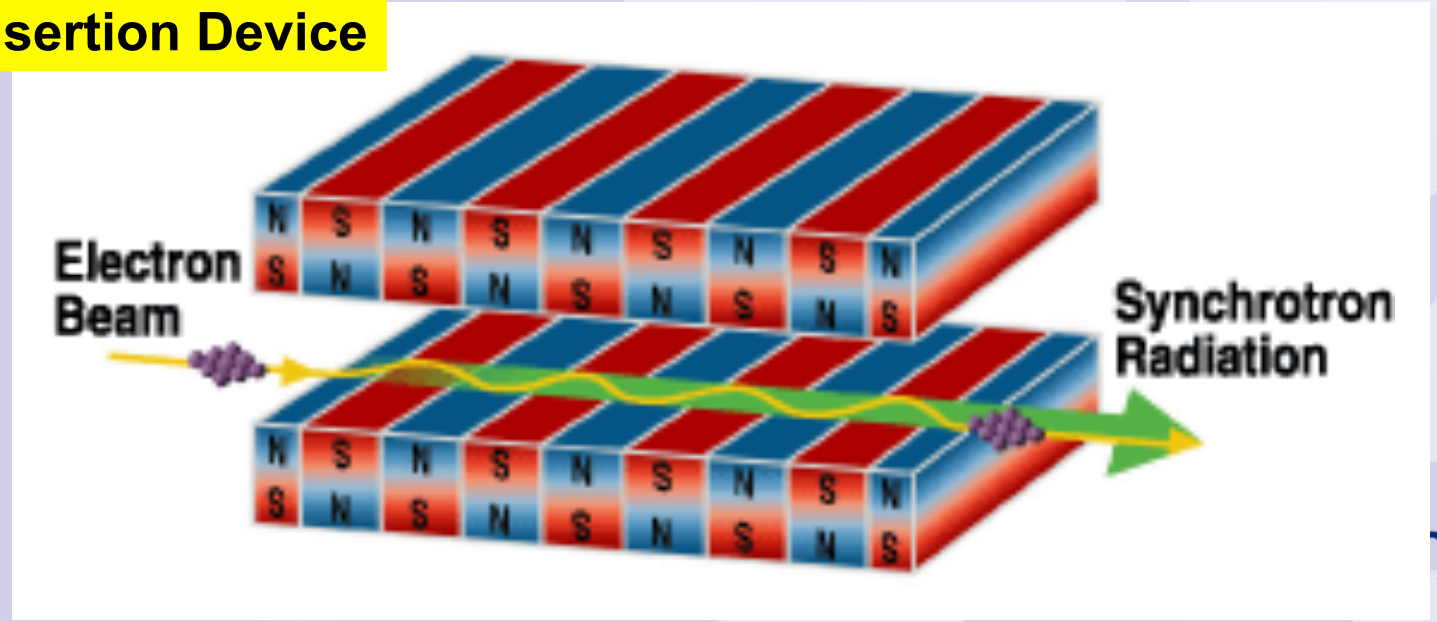

歷代名臣奏議卷之三百

Synchrotron Light Generation



Insertion Device



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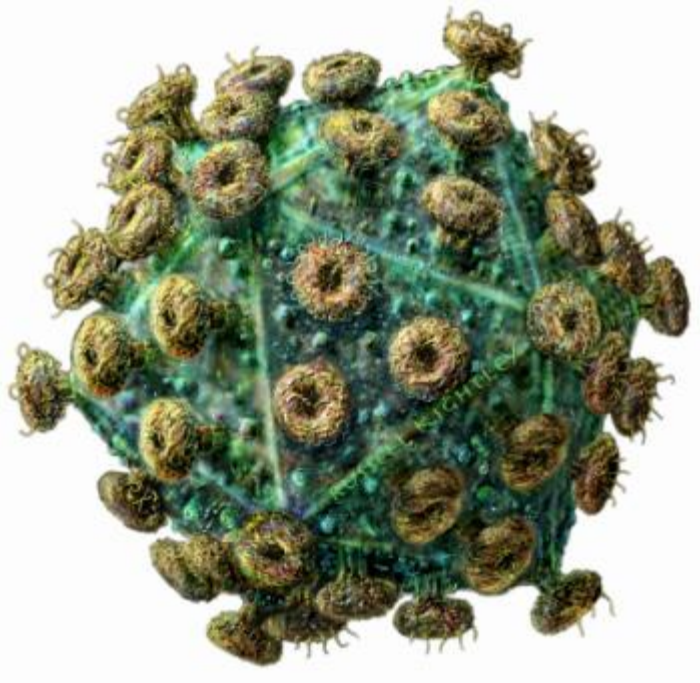
SRS – A UK Case Study

- Direct or short term
  - Helped trained 4,000 PhD students
  - 11,000 users trained in techniques
  - 100 staff working on other synchrotrons
  - 1,200 protein structures solved
- Indirect or medium term
  - 9 spin-outs, 25 patents, 11 licenses
  - 200 industrial proprietary users
  - New applications, eg RF coating in TV transmitter generated £250m sales
- Global, usually long term
  - First 2nd generation multi user synchrotron
  - Pioneered protein crystallography
  - Led the way to 70 further facilities



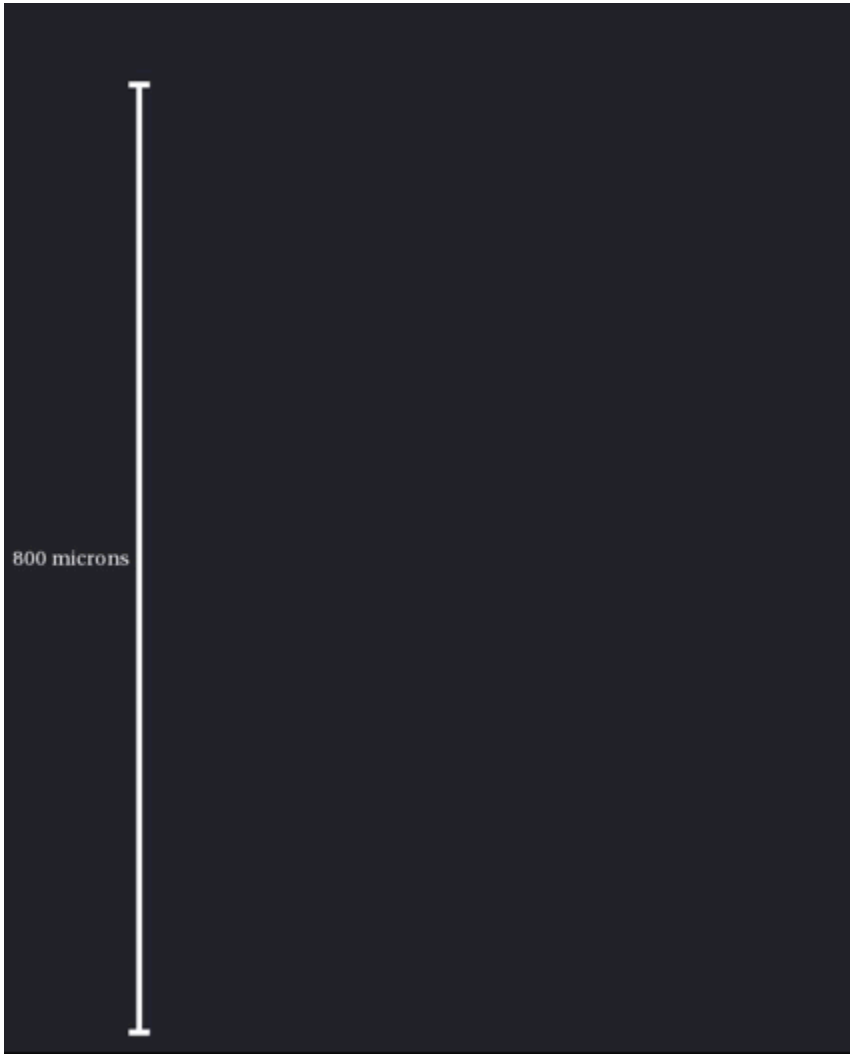
Diamond Light source

Energy	3 GeV
Circumference	561.6 m
No. cells	24
Symmetry	6
Straight sections	6 x 8m, 18 x 5m
Insertion devices	4 x 8m, 18 x 5m
Beam current	300 mA (500 mA)
Emittance (h, v)	2.7, 0.03 nm rad
Lifetime	> 10 h
Min. ID gap	7 mm (5 mm)
Beam size (h, v)	123, 6.4 mm
Beam divergence (h, v) *(at centre of 5 m ID)*	24, 4.2 mrad

Commissioned in 2006 and open for users in January 2007

Currently operating 13 beamlines with 10 in-vacuum insertion devices

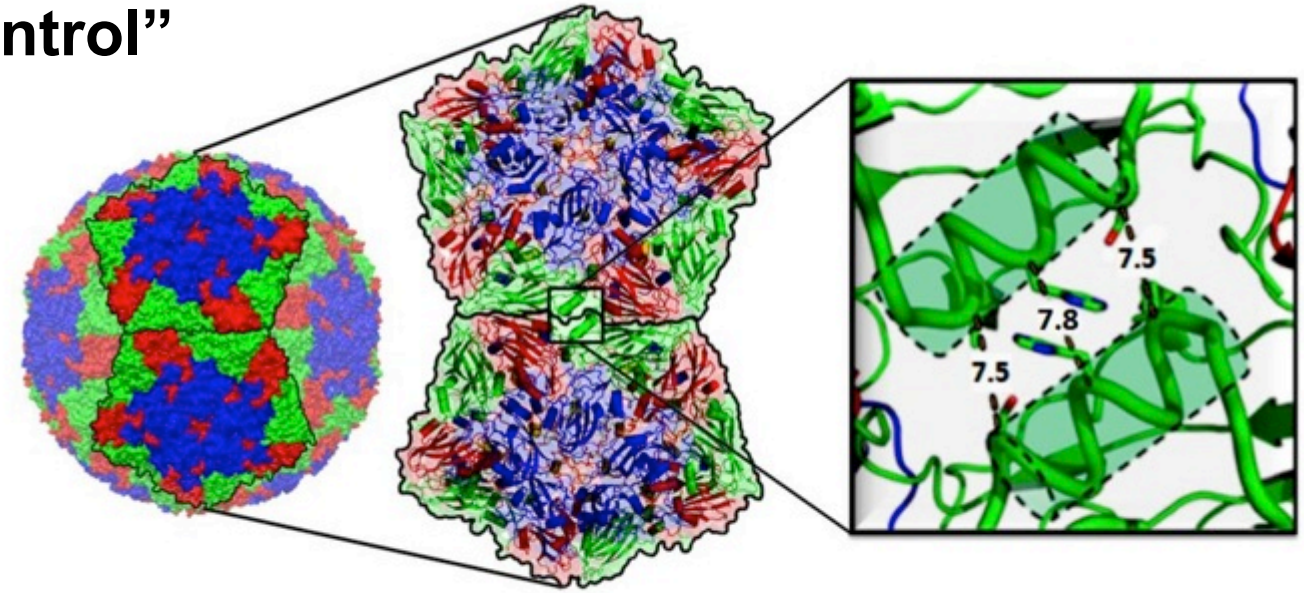

Hand mit Ringen 5. 2. 96.
Eigenthum von Prof. Zehnder
Freiburg i/B
PHYSIK. INSTITUT
DER UNIVERSITÄT


800 microns


CASING SHIELD
KEVLAR
FAN BLADE
Rolls-Royce Trent 800
Normal Conformer
Rogue Conformer (speculative)

Important Result from Diamond
March 2013

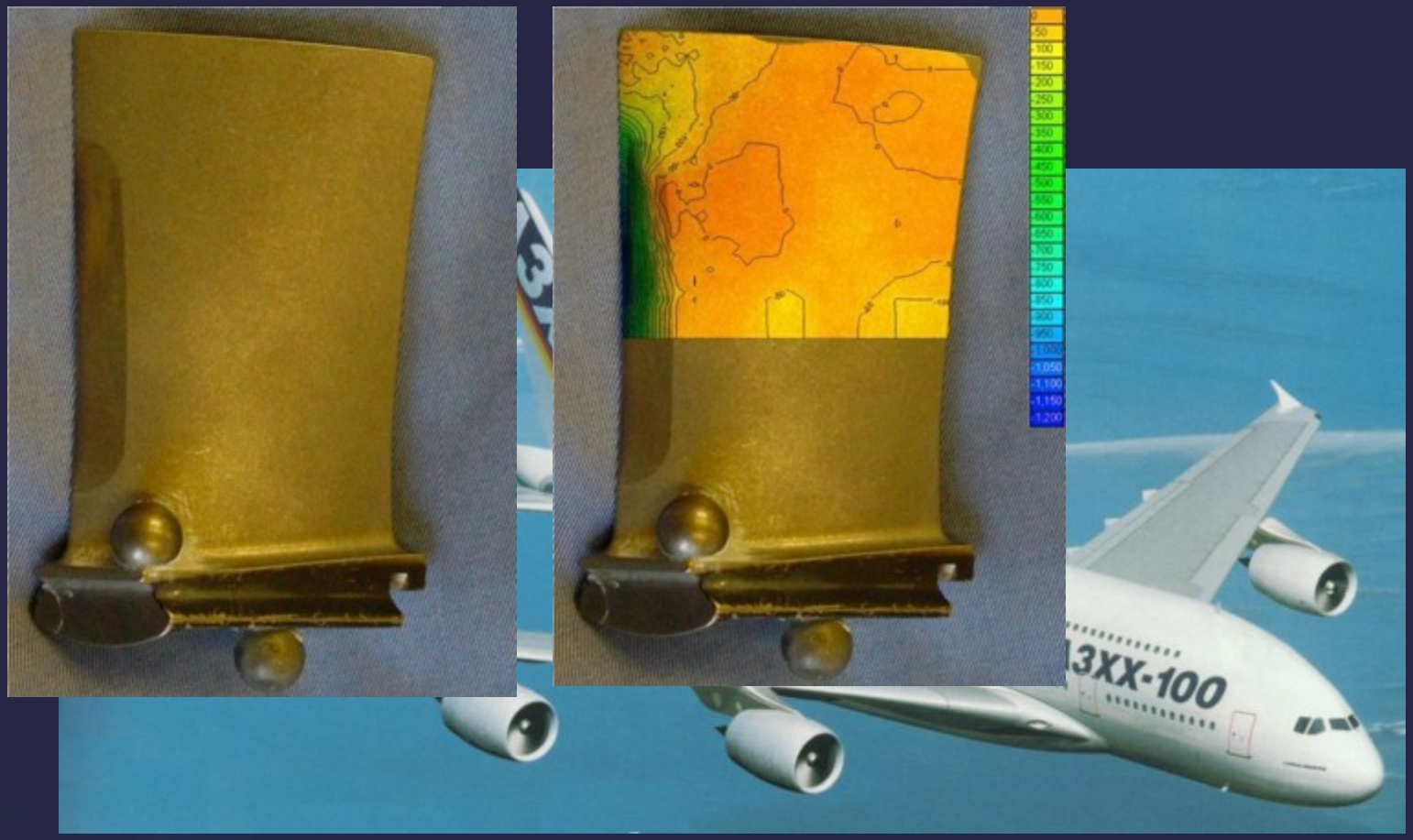
“New foot-and-mouth vaccine signals huge advance in global disease control”



Scientists have developed a new methodology to produce a vaccine for foot-and-mouth disease virus. Because the vaccine is all synthetic, made up of tiny protein shells designed to trigger optimum immune response, it doesn’t rely on growing live infectious virus and is therefore much safer to produce.

The University of Manchester

Strain mapping



diamond

In collaboration with Rolls Royce

ISIS is a high power accelerator that fires high energy protons into two targets to release neutrons for experiments.

The ISIS synchrotron accelerates protons to 84% of the speed of light then fires them into two tungsten targets.

Target Station 1

Neutrons are released from both targets via spallation. Using neutrons, scientists can study the atomic structure of materials and can even measure the forces between atoms.

Target Station 2

The second target station is optimised for low energy neutrons providing greater capacity at ISIS and opening up new areas of research.

Neutron Spallation

Research by EDF Energy at ISIS enabled five-year life extensions to be made to two nuclear power stations

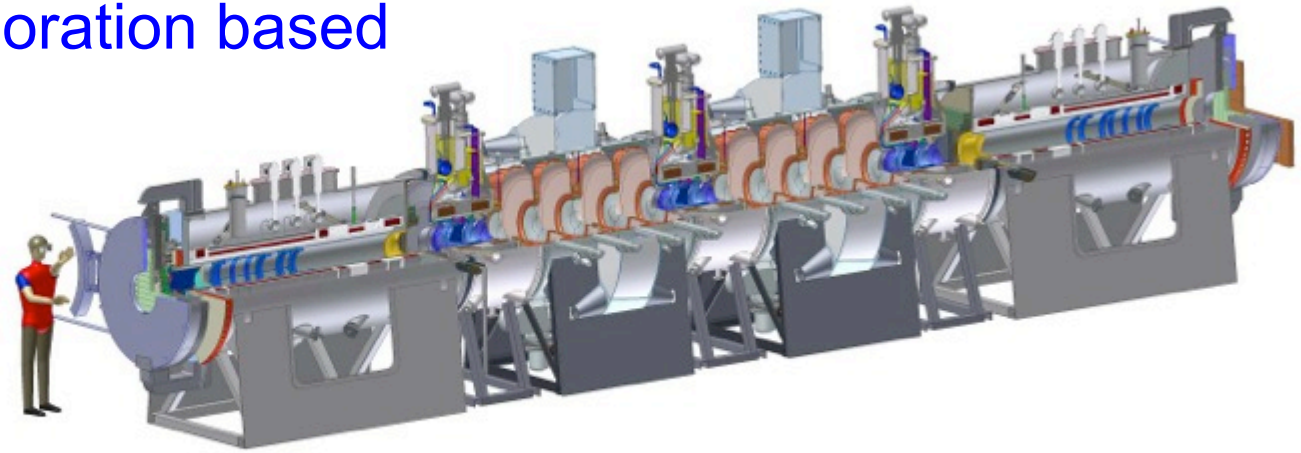
- Uninterrupted electricity generation
- Deferment of **£3 billion** in decommissioning and replacement costs

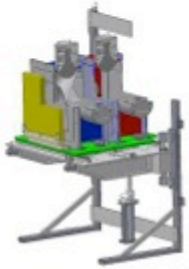
Zero-emission vehicles

- Scientists at the ISIS neutron source are developing new materials to provide a safer, cheaper and more efficient method of hydrogen storage
- Looking at the atomic and molecular structure of new materials to see how they absorb and release hydrogen gas
- New materials that can safely release hydrogen at the right temperature
- This avoids the safety fears associated with compressed gas

Muon ionisation cooling experiment

International collaboration based at RAL, Harwell





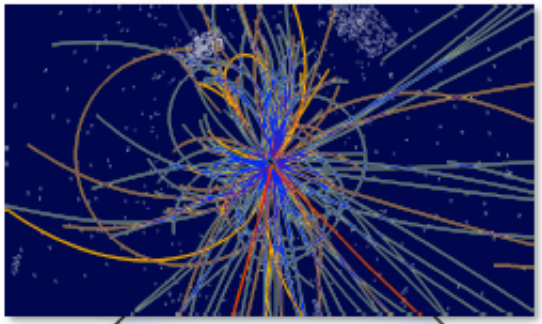
- MICE:
  - Design, build, commission and operate a realistic section of cooling channel
  - Measure its performance in a variety of modes of operation and beam conditions.
  - Data taking starting now.
  - Results will be important for a future muon collider or neutrino factory.

Applications

The first capacitive touchscreens were also developed at CERN in 1973, to simplify their particle accelerator control system.

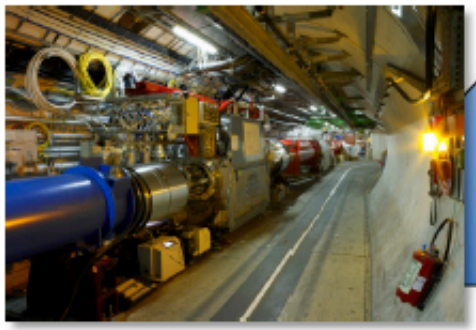
CERN Technologies and innovation

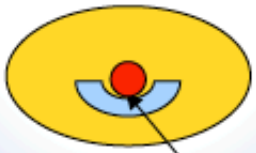
Combining accelerators, detectors and IT to fight cancer



Detecting particles

Accelerating particle beams





CANCER

Large-scale computing (Grid)

Accelerators Have Wide Application

Accelerators are also used to provide practical nuclear data for fission reactors and fusion devices.

Electron linacs are used to inspect steel vessels by radiography, for non-destructive testing, as thickness gauges, inspection devices and for sterilization.

Are used in oil and gas surveys – they are lowered into wells where their particles probe the surrounding material.

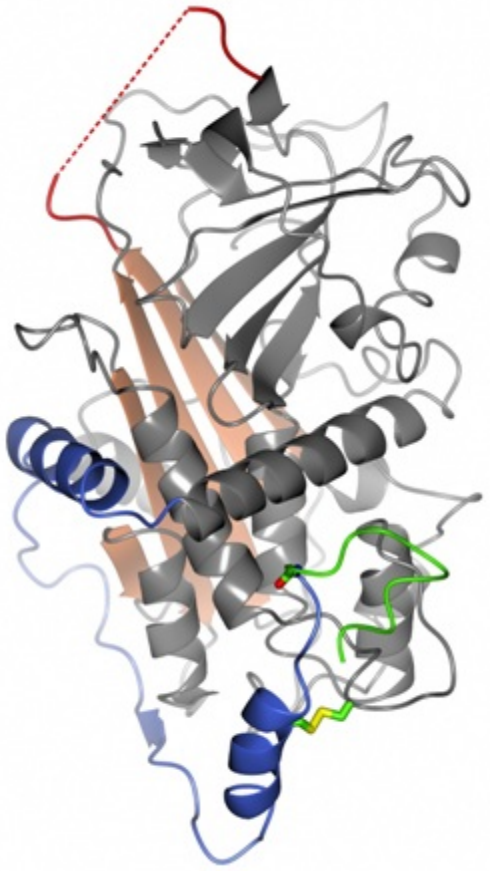
Ion implantation in semiconductors; this has given rise to a huge industry.

Higgs Discovery in the media

- Reached 12 million on UK TV
- 14 million on UK radio
- 1200 stories in UK broadcast media over 24 hours
- Mentioned every 1.1 seconds on Twitter at the peak of the excitement
  - 8 of 10 'trending' topics were Higgs-related
- Almost 4,500 articles printed globally


The UK is playing a leading role in the world's biggest scientific experiment, the Large Hadron Collider at CERN in Geneva - recreating the conditions that existed a trillionth of

Summary



- Role of gravity ?
- Origin of matter ?
- Origin of mass ?
- New materials and molecules?

- Accelerator science will underpin the way - new technology advances in other fields.
- Not only energy is key; luminosity, stability, quality…
- Accelerators and accelerator-based science are inspirational to future generations of scientists and engineers.
- Accelerators are engines of discovery across all fields of science.