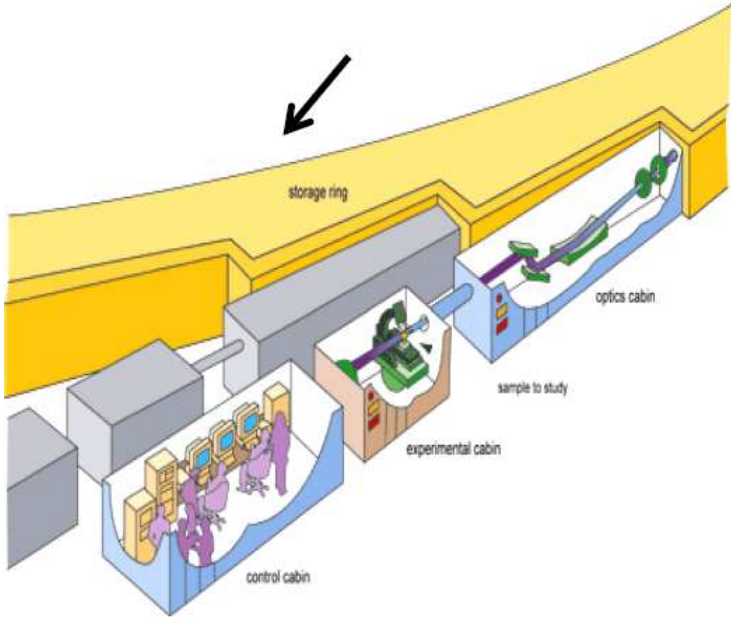
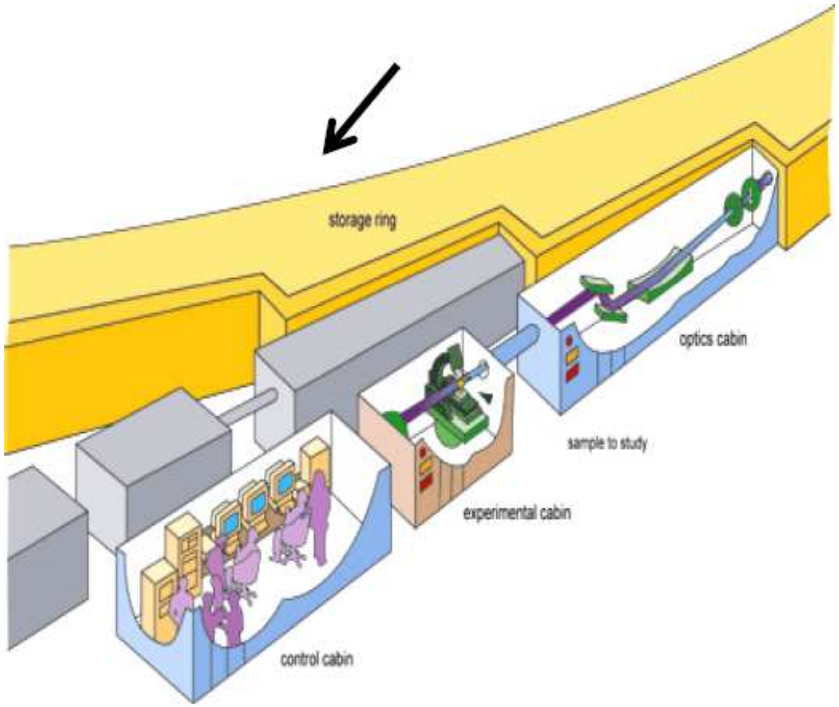
12. Applications outside HEP

What can you do with a Particle Accelerator?



- Applications range
- Radiocarbon
- Medical accelerators
- Light sources
- Neutron sources
- Accelerator driven sub-critical reactors
- Laser-driven plasma accelerators
- Jobs

Where are we?

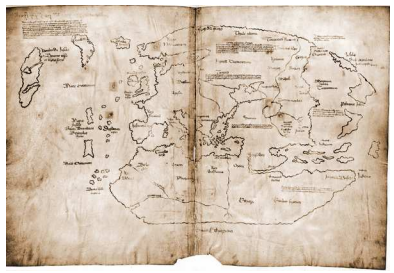


- You now have a good overview of what a particle accelerator is.
- You know what are its main components, what is the beam's dynamic, how to measure the particles' properties and how to commission and operate and accelerator.
- But what can you do with it?
- Can this help you to get a job?

Quiz:
Have these objects been studied or improved by a particle accelerator?

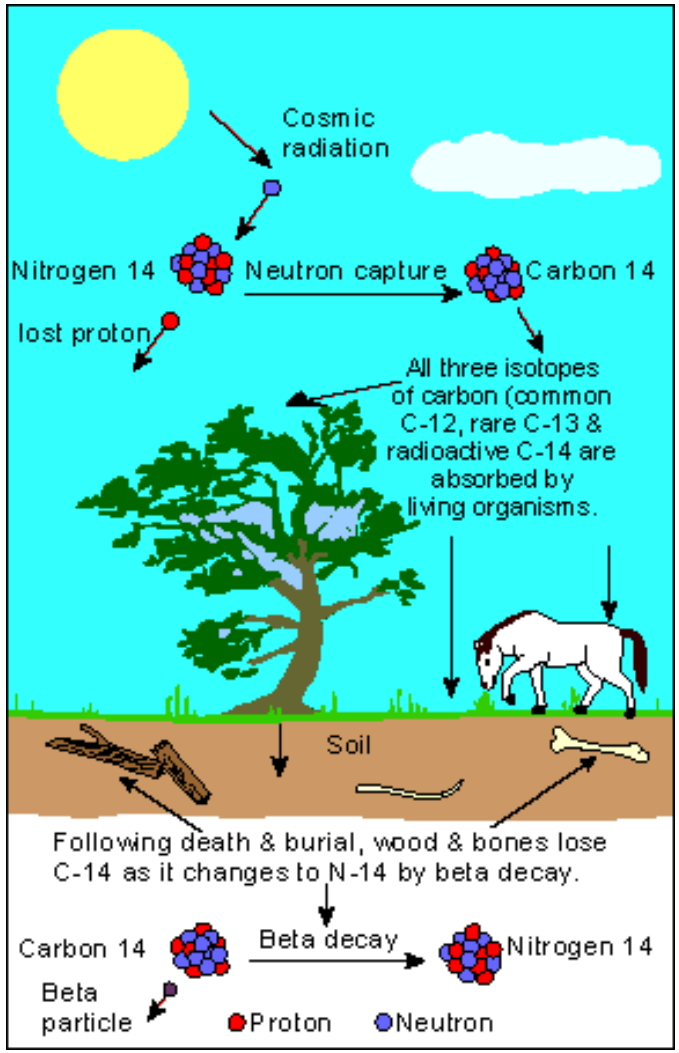
- Early settlement of America
- Cancer treatment
- Pharmaceutical drugs
- An Ipod
- Advanced aircrafts
- Unwanted nuclear material

Answer:
All are connected to accelerators!



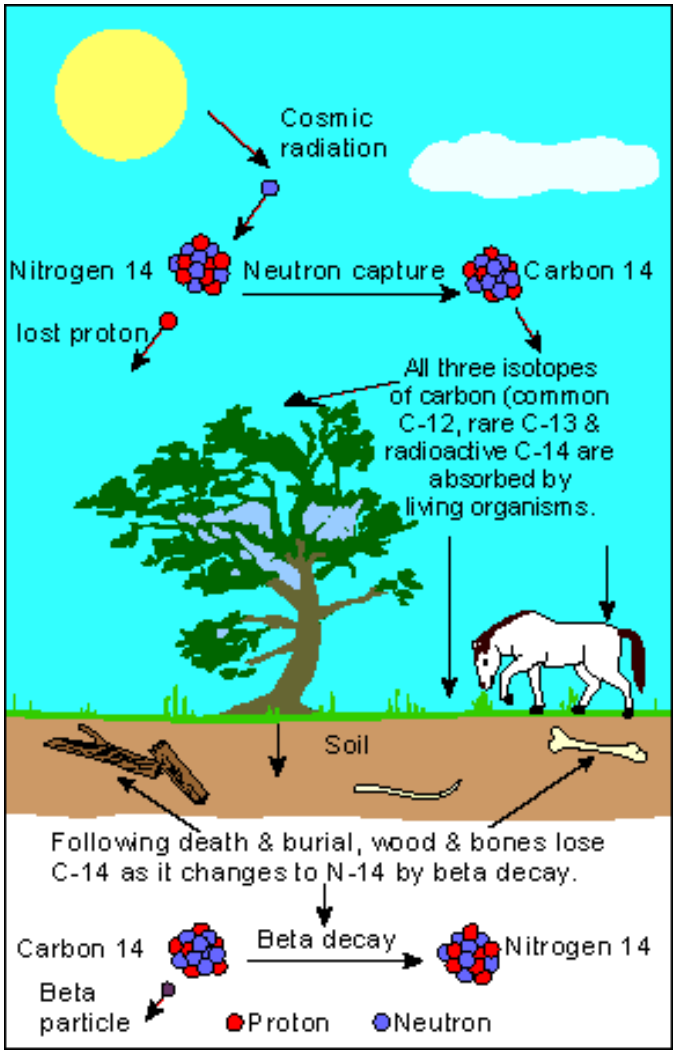
- Several accelerator based methods can be used to date old artefacts.
- Hospitals use accelerators everyday to treat some forms of Cancer.
- The data storage capacity of electronic devices has been improved by studying GMR at accelerators.
- The structure of molecules, including drugs, can be studied with intense sources of X-rays.
- Material hardness can be studied with neutrons
- Intense flux of neutrons can burn unwanted nuclear materials

Dating old artefacts



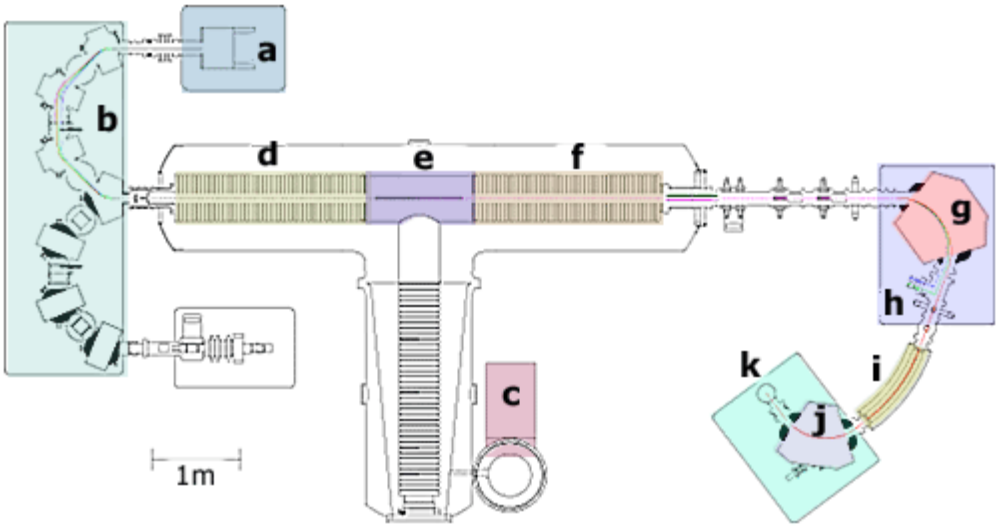
- Radiocarbon dating is allows to measure the age of ancient artefacts.
- The ratio C13 vs C14 can be measured by using an accelerator.
- This technique is called “Accelerator Mass spectroscopy”.

Accelerator Mass Spectroscopy (1)



- In an AMS device the C12, C13 and C14 beams need to be separated to allow an accurate counting.
- An energy of 10-15MV is sufficient.
- Beam stability is very important to ensure good accuracy.
- What type of source would you recommend?
- What type of accelerator?
  RF or electrostatic?
- Does the emittance matter?
- How would you count the charge of the ion beams with a good accuracy?

Accelerator Mass Spectroscopy (2)

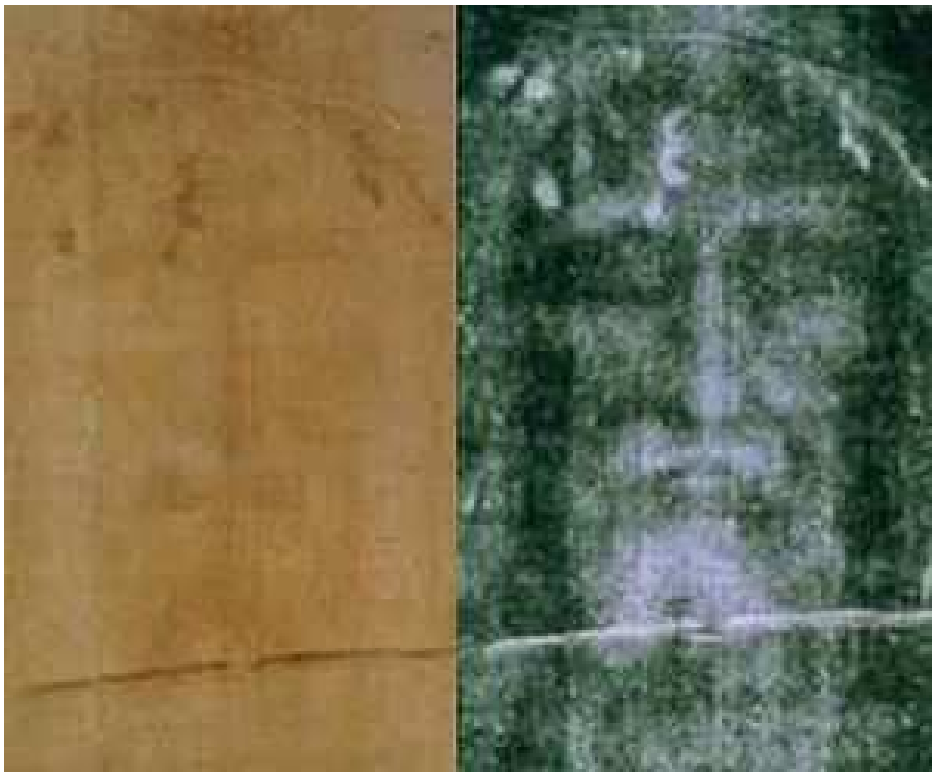


- AMS machines use a sputtering ion source producing C- ions.
- A tandem Van de Graff is then used to accelerate the ions and strip then to C^{3+}.
- A DC accelerator offer a better stability than a RF accelerator.
- A Faraday cup is used to measure the beam charge.
- Oxford has one of the world leading AMS lab.
- The AMS accelerator is on level 3 of the DWB.

Example of AMS application (1) Vinland

- AMS was used to date ashes found in Newfoundland in a European-type settlement. These ashes were dated back to the XIth century.
- A viking map featuring Newfoundland was shown to be older than Columbus' trip to America.
- AMS has contributed to establish that North America was visited by Vikings well before other European nations.

Example of AMS application (2) The Shroud of Turin

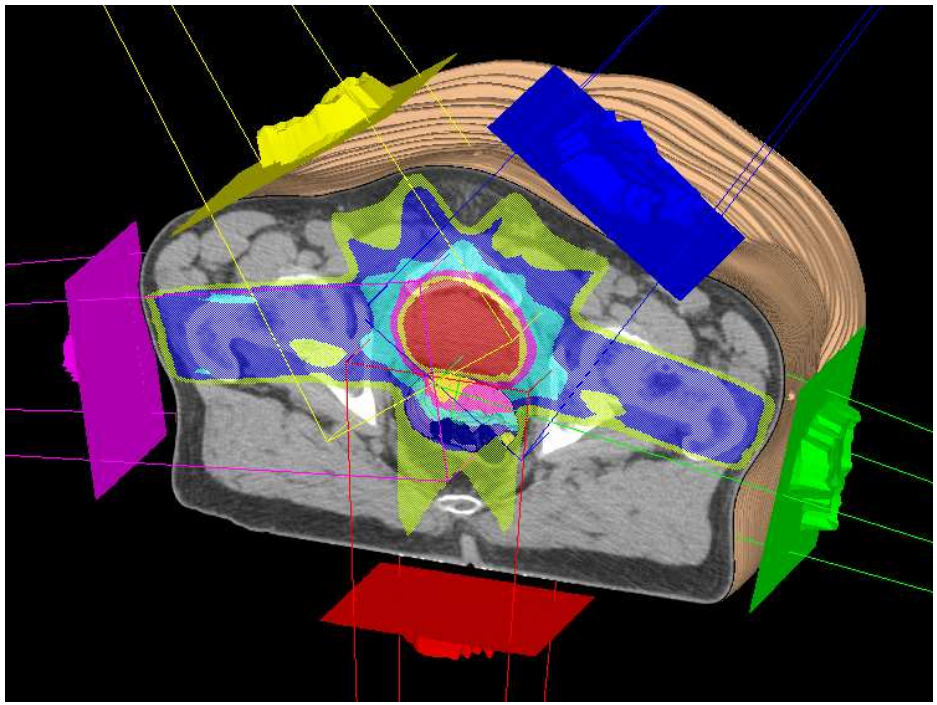


- The shroud of Turin is a piece of cloth which was first mentioned in the middle age.
- On it the face of a man can be seen.
- Some claim that it is the shroud that was used after the Christ's crucifixion.
- In the 1980s 3 AMS laboratory (including Oxford) independently dated the sample they were provided to 1260-1390.

Dating old artefacts...

- There are many other accelerator based dating techniques which I do not have time to cover.
- Proton, Neutron and light sources can all be used to investigate some properties of old artefacts.
- Left:
  Roman Jug dated by ISIS.

Treating Cancer

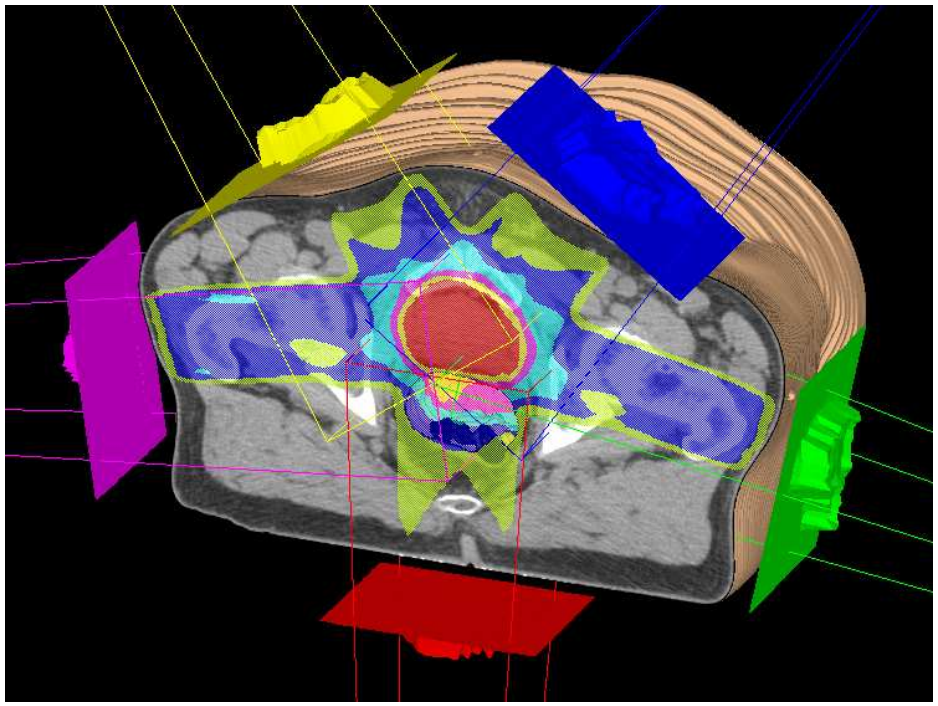


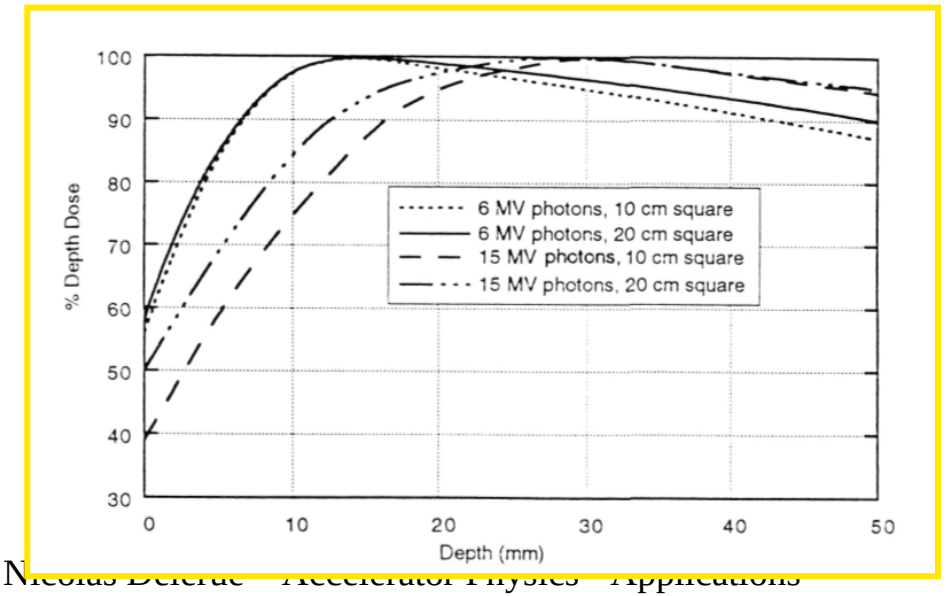
- Some type of cancer tumours are located at places difficult to reach by Surgery.
- X-rays can be used to kill such tumours.
- This is called Radiotherapy.
- Radiotherapy need 10-15 MeV electrons for a few seconds.
- The accelerator needs to be compact so that it fits in an hospital room and fields can be contained.
- What type of cathode do suggest to use? Thermionic or Photocathode?
- What type of accelerators do suggest to use?

Medical linac

- Radiation therapy uses small 15MeV “linacs”.
- It is safer to produce a low current over several pulses rather than a high peak current over a few pulses, hence a thermionic gun is used (such gun are also more reliable and easier to maintain).
- To reach 15 MeV with a large electrostatic accelerator would require a large installation likely to frighten the patients.
- A short RF cavity is used to reach the required energy.

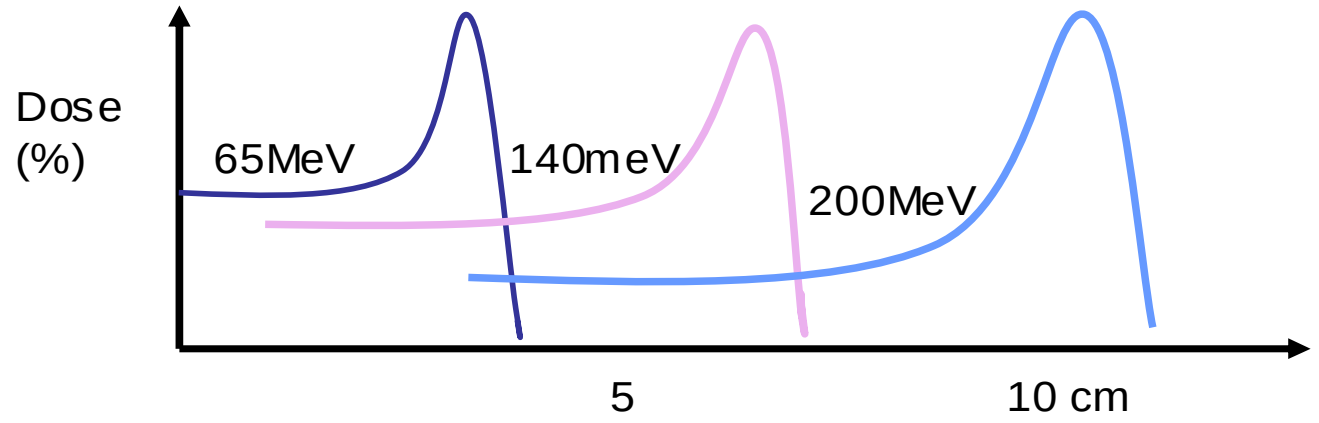
Radiotherapy



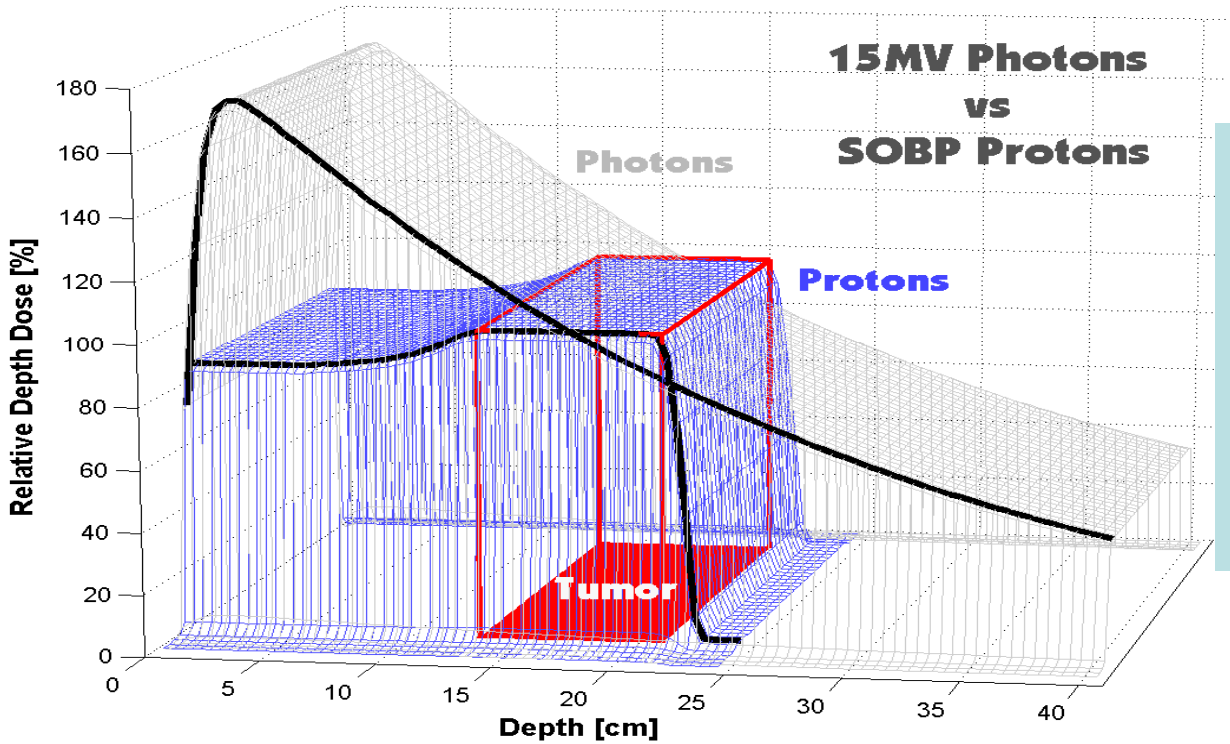


- X-rays are used to kill a tumour.
- To minimize the dose sent on healthy tissues several X-ray beams are sent in turn from different directions.
- However this technique is not ideal due to its impact on healthy tissues.
- In Oxford 6 linacs are used in the Churchill hospital to treat cancers.

Proton and ion therapy



Effective Range varies with proton Energy



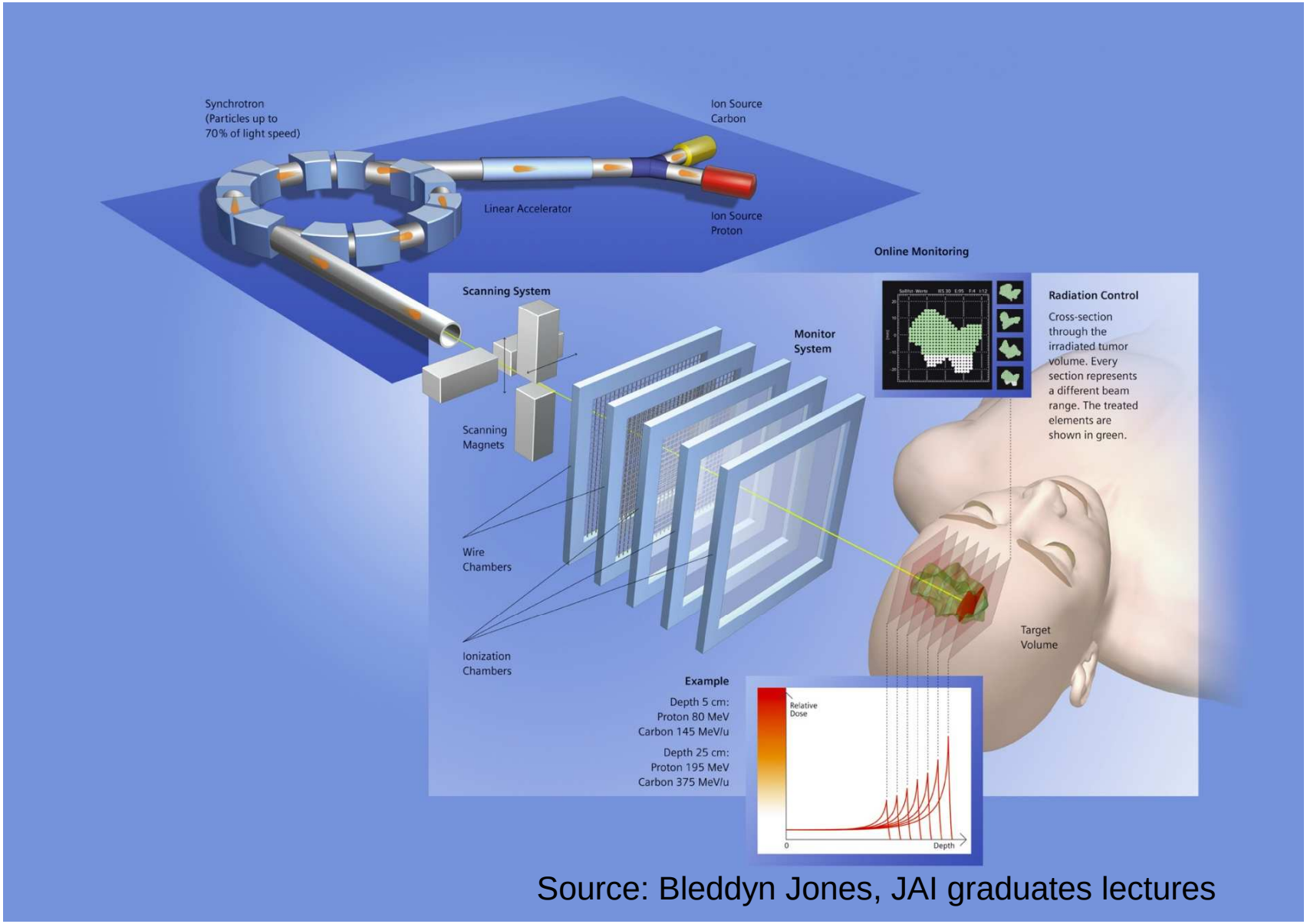
The 'spread-out' Bragg Peak – plateau effect

[SOBP]

Source: Bleddyn Jones, JAI graduates lectures

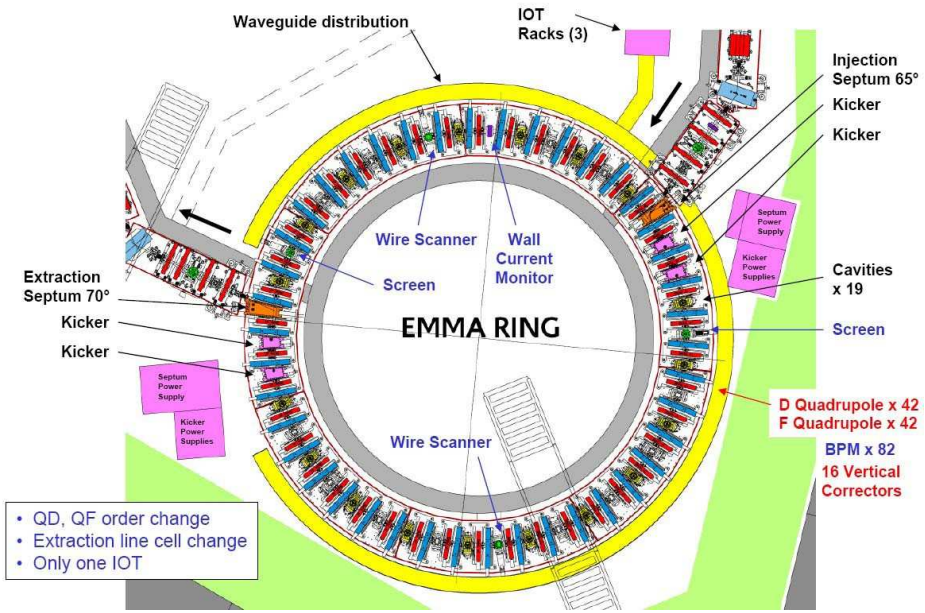
What gun and what machine shall we use for proton and ion therapy?

A possible solution...



Source: Bleddyn Jones, JAI graduates lectures

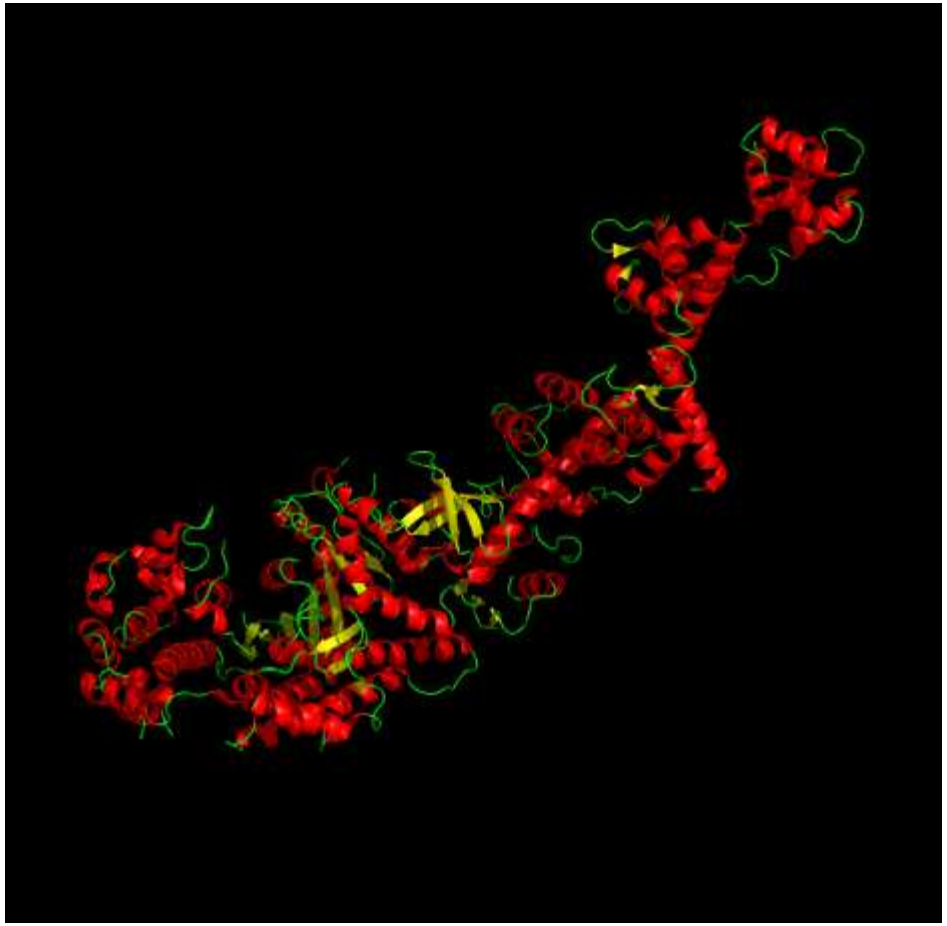
... Another solution



EMMA: an electron demonstrator for PAMELA

- The UK is studying a special type of accelerators called “non-scaling FFAG”.
- A Fixed Field Alternating Gradient is a ring accelerator where the field of the magnets is kept constant during the acceleration (unlike a synchrotron).
- These accelerators would allow very fast acceleration of protons and ions by compact accelerators.
- Significant work on this project called PAMELA is being done in Oxford.

Pharmaceutical drugs

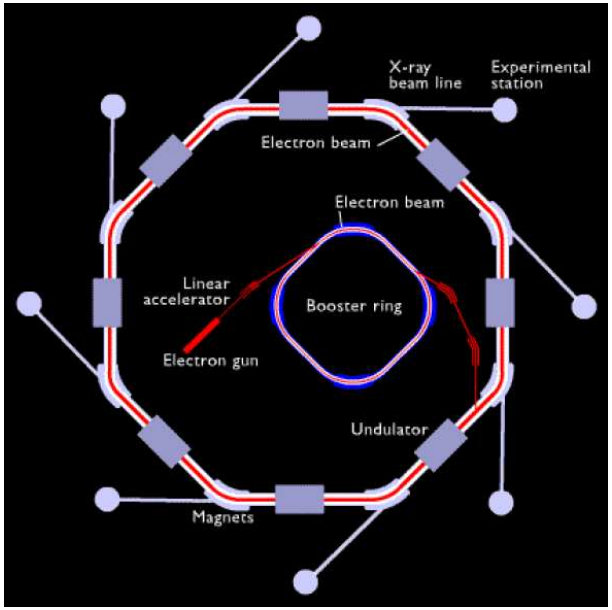


- To be efficient a drug need to target the correct molecule.
- This can only be achieved by studying the diffraction of intense on the molecule.
- What type of machine (gun, accelerator, ...) is best suited to deliver an intense stable beam of X-rays?

A source of intense X-rays

- Synchrotrons are best suited to deliver intense beams of X-rays.
- Although synchrotrons operate at ultra low emittance the gun can be thermionic as radiation damping reduces the transverse emittance.
- A RF accelerator is then used to accelerate the particles up to the ring energy. A booster ring is used to reduce the length of the linac.

Source: Diamond

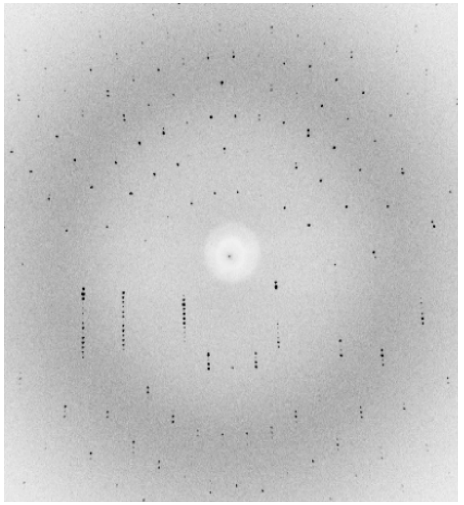


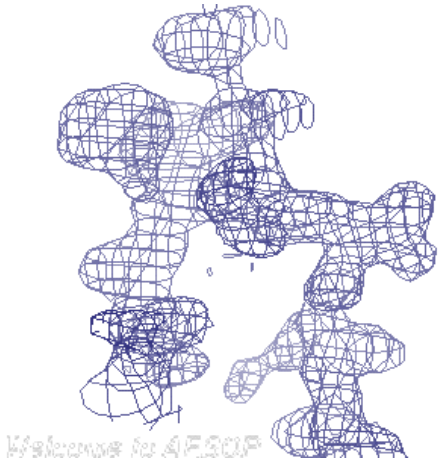
Applications of synchrotrons

- Light sources have a wide range of applications.
- The SRS at Daresbury has been used to improve the quality of chocolate!
- Diamond is being used to study old manuscripts too precious to be opened!
- Protein imaging, drugs, material studies,...
- GMR (the phenomena that allows dense magnetic storage in your ipod) has been studied with light sources.

Crystallography at a light source

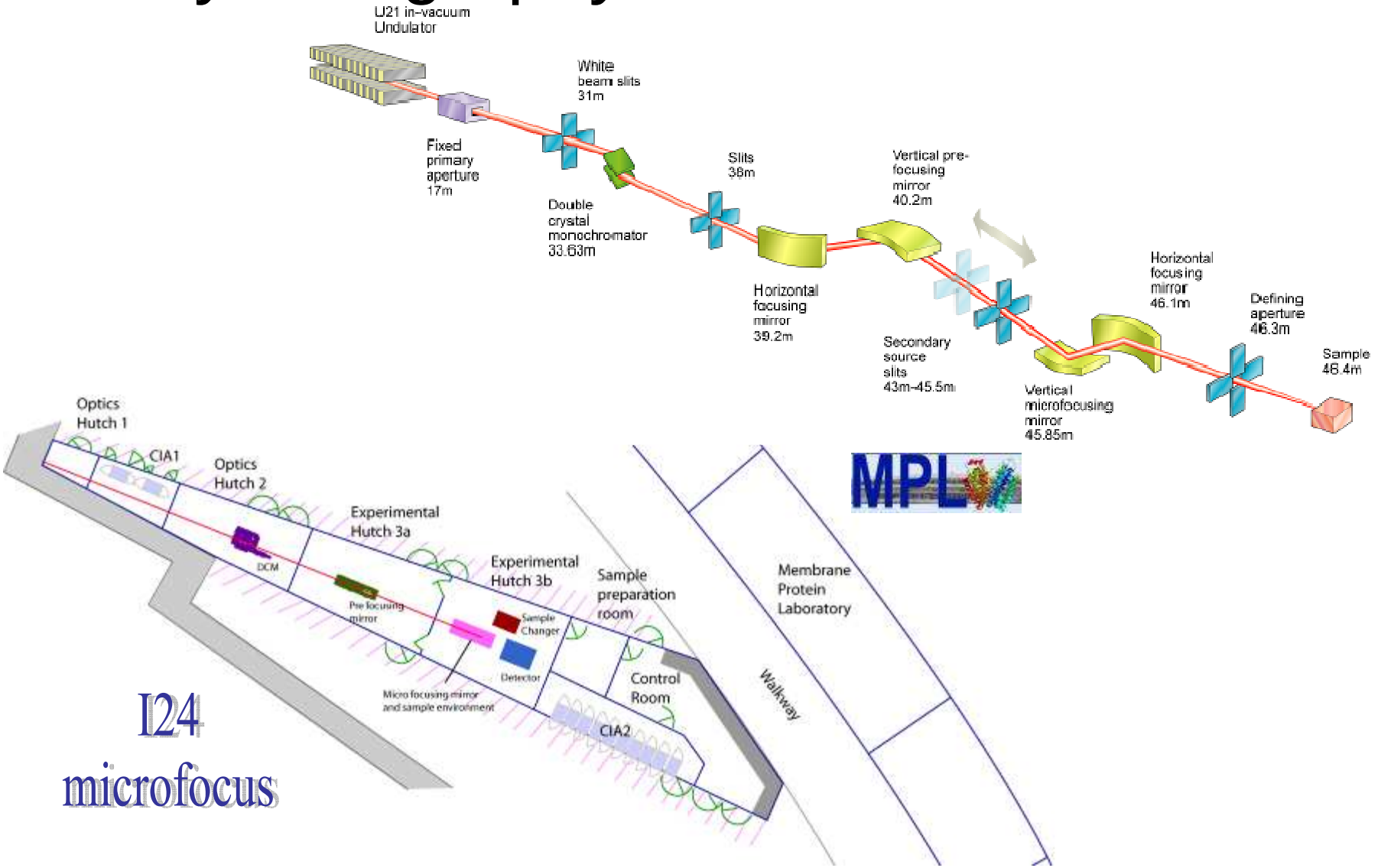
- A crystal is exposed to an intense X-ray beam and rotated.
- For each position the diffraction pattern is recorded.
- Once enough data have been collected it is possible to reconstruct the shape of the molecule.





Source: G. Evans, JAI Graduate lectures

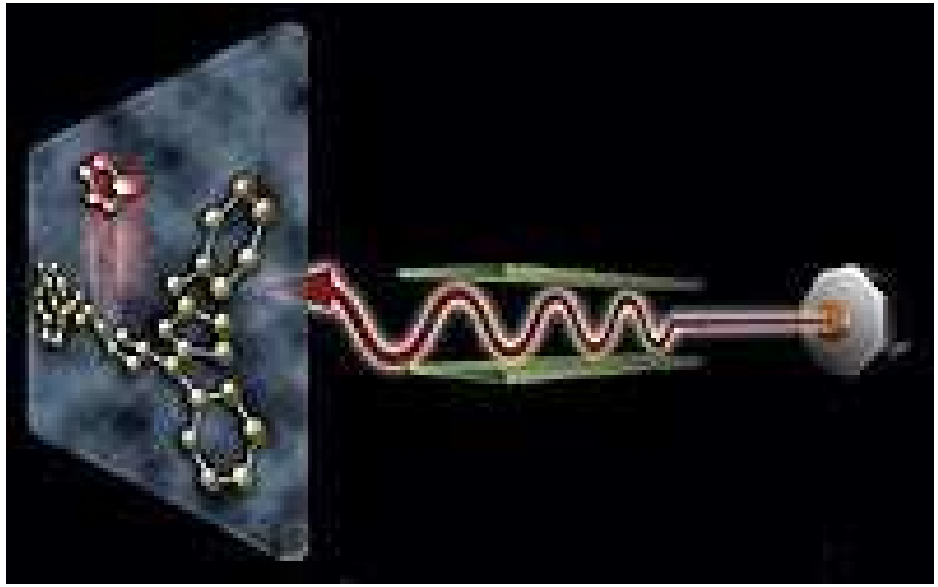
Microfocus macromolecular crystallography beamline at Diamond



Source: G. Evans, JAI Graduate lectures

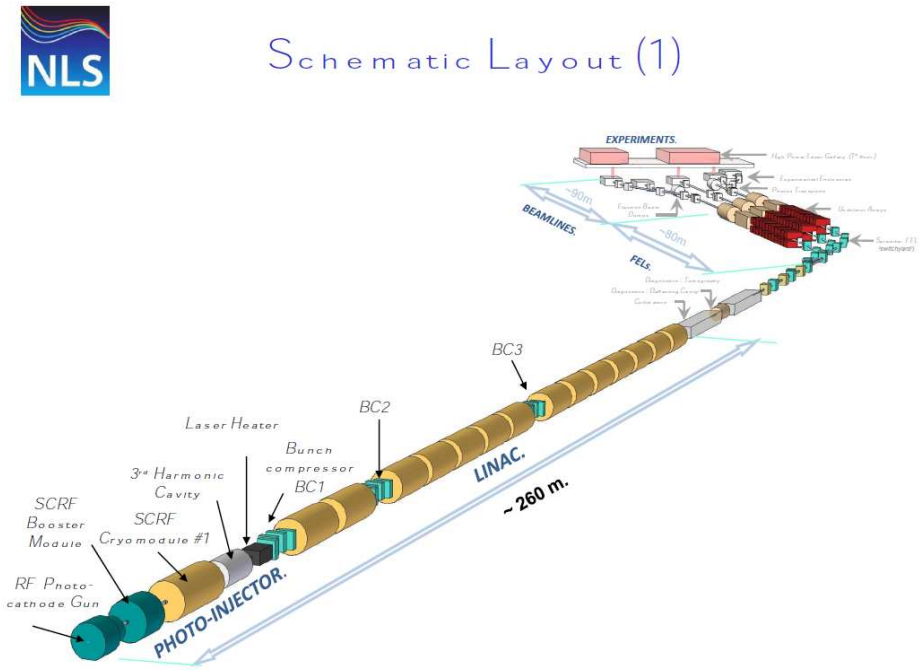
The next generation of light sources

- The drawback of using radiation damping to reach ultra-low emittance is that the beam is stretched longitudinally.
- This means that the X-ray pulse have a long (ps) duration.
- Some applications require fs long high brightness X-ray pulses...
- How can this be achieved?



Next generation: Linac based Free electron lasers

- Only linac based accelerators can deliver ultra-short pulses.
- Hence the emittance must be ultra-low from the start.
- This requires a photo-cathode RF gun.
- With an ultra-low emittance it is possible to achieve lasing in the undulators (and thus an even higher light output).
- Several FEL arte being built (or operated) around the world.



Neutron crystallography

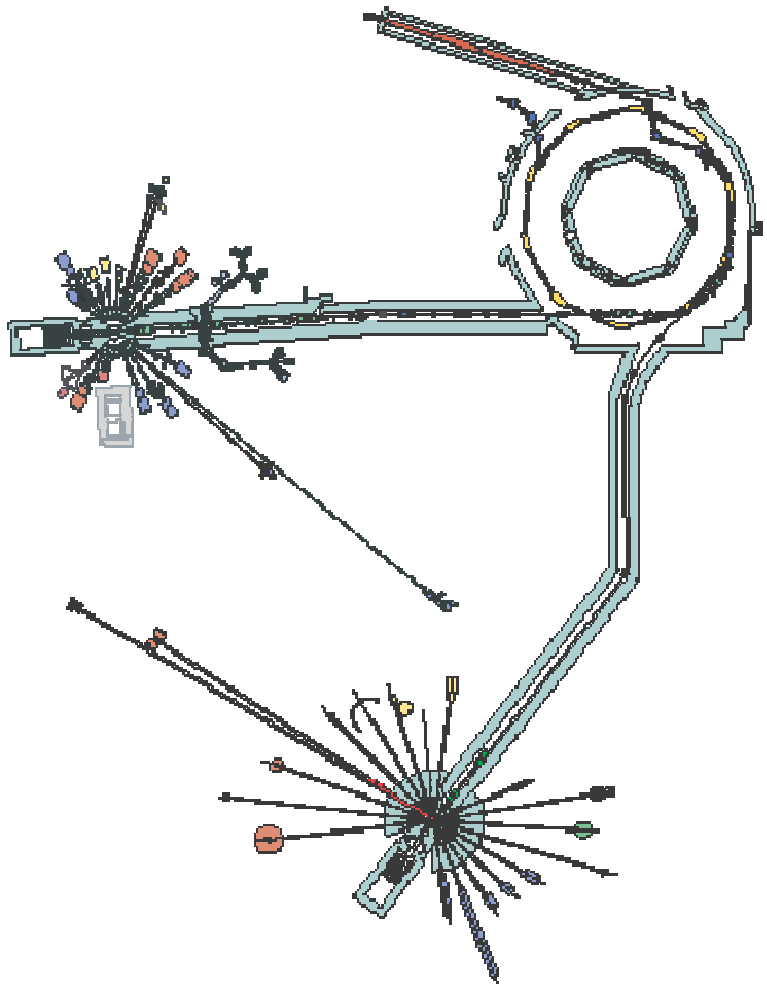
- X-ray crystallography can only be used on matter that is rather transparent to X-rays.
- Other objects such as this Roman vase or the materials used to build an aircraft need a probe that penetrate deeper in the material: Neutrons.
- How can we produce neutrons?

Neutrons sources

- It is not possible to directly accelerate neutrons.
- However neutrons are produced when a target is bombarded with protons.
- The ISIS neutron source requires 800 MeV protons.
- How to build this?

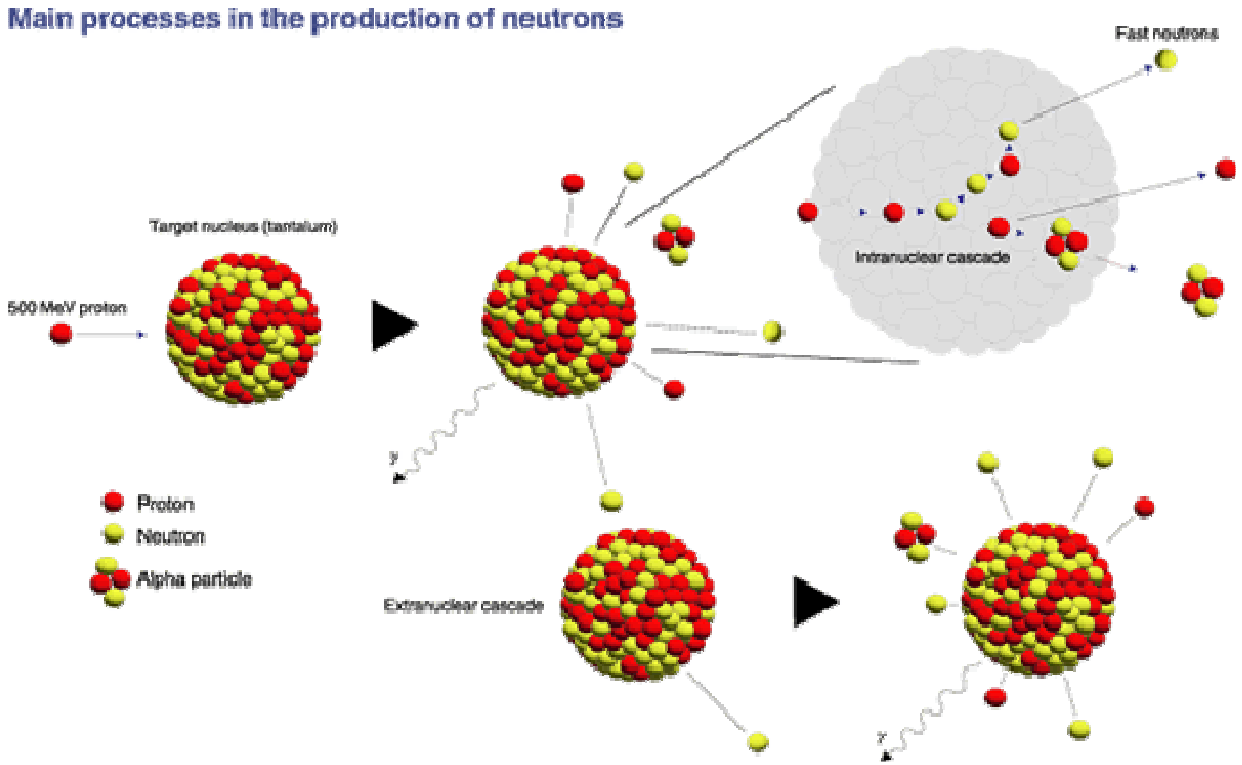
A neutron source: ISIS

- A proton synchrotron can be used to bring the protons to the right energy.
- Emittance is not a challenge at the target location but a low emittance beam helps minimizing the losses in the accelerator (and hence the activation).
- For beam dynamics reason it is preferable to accelerate H- in the firststage of the accelerator rather than H+.

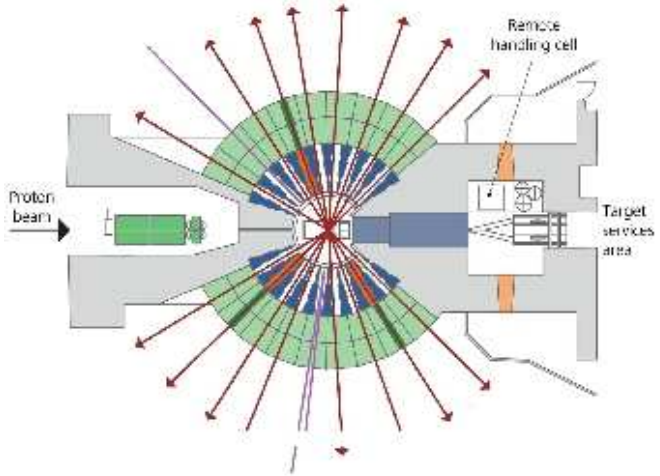


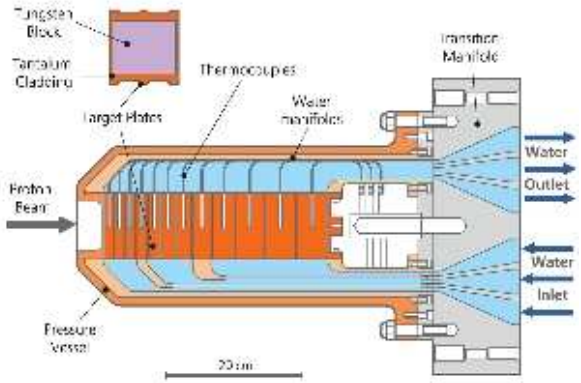
Spallation

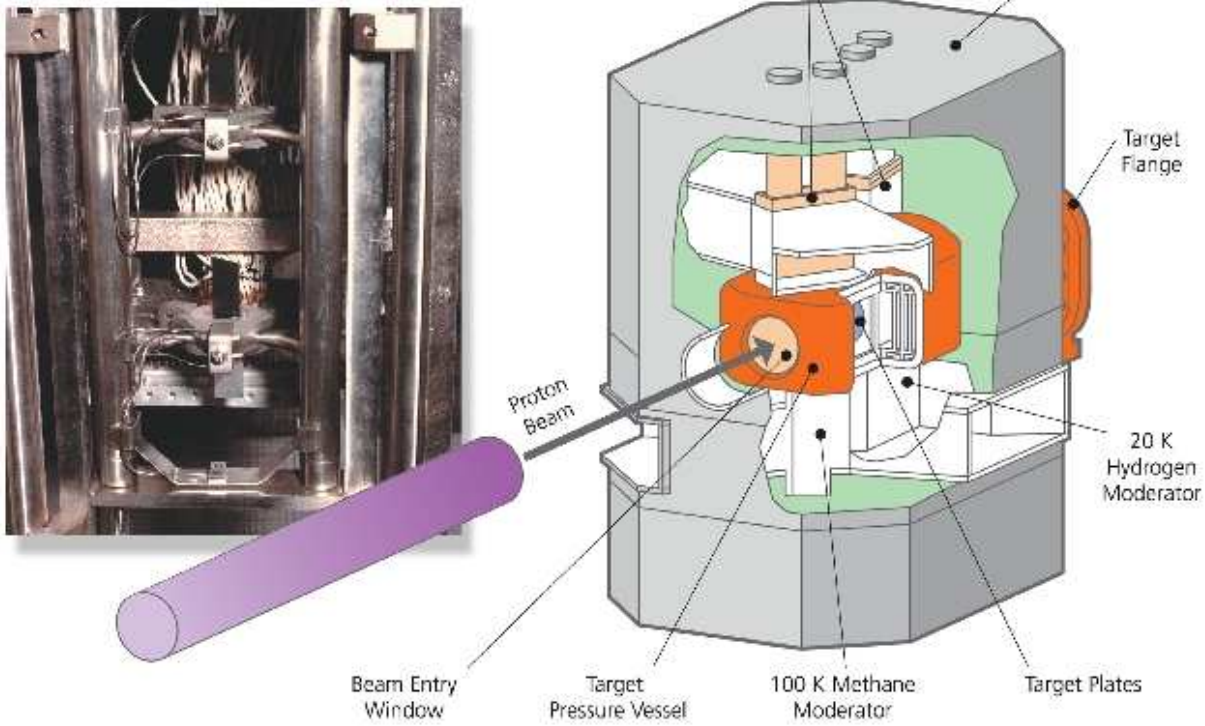
- Spallation is a process in which fragments (protons, neutrons,...) are ejected from a target atom hit by a high energy proton.
- Such target is very challenging as most of the proton power is deposited in the target.



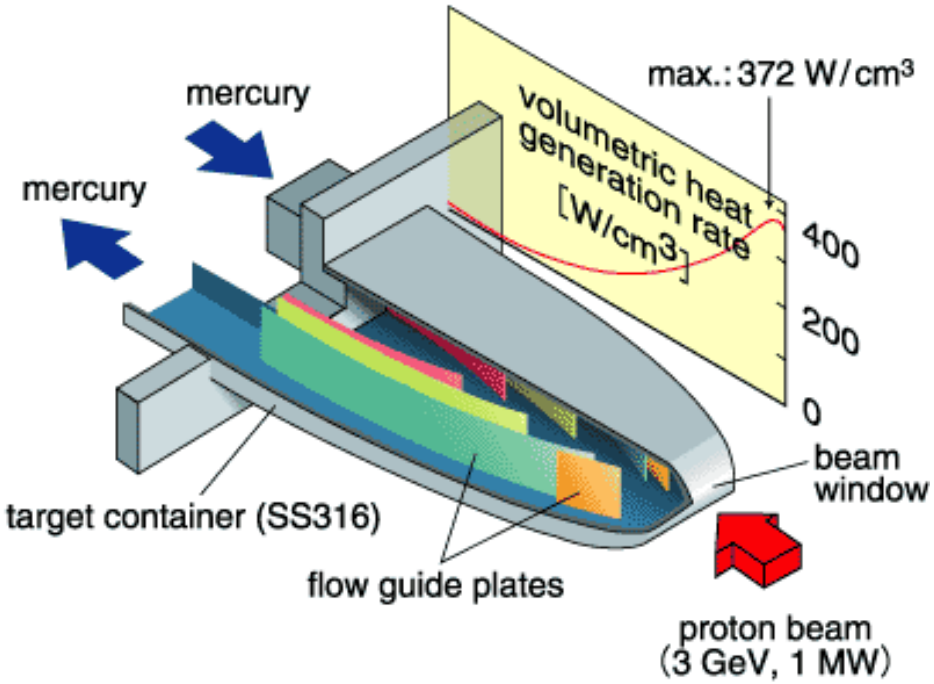
Spallation target

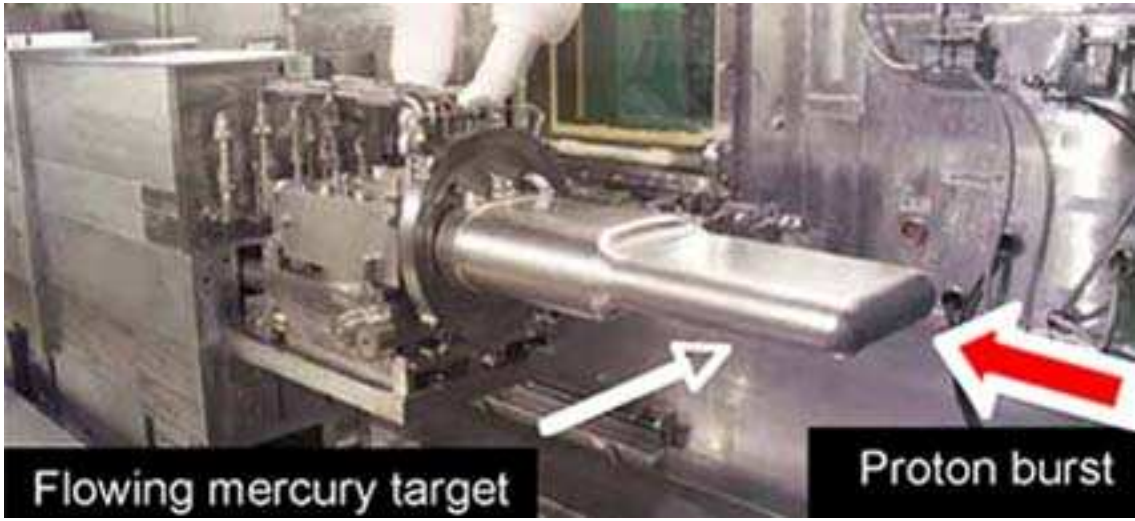






High power target challenge

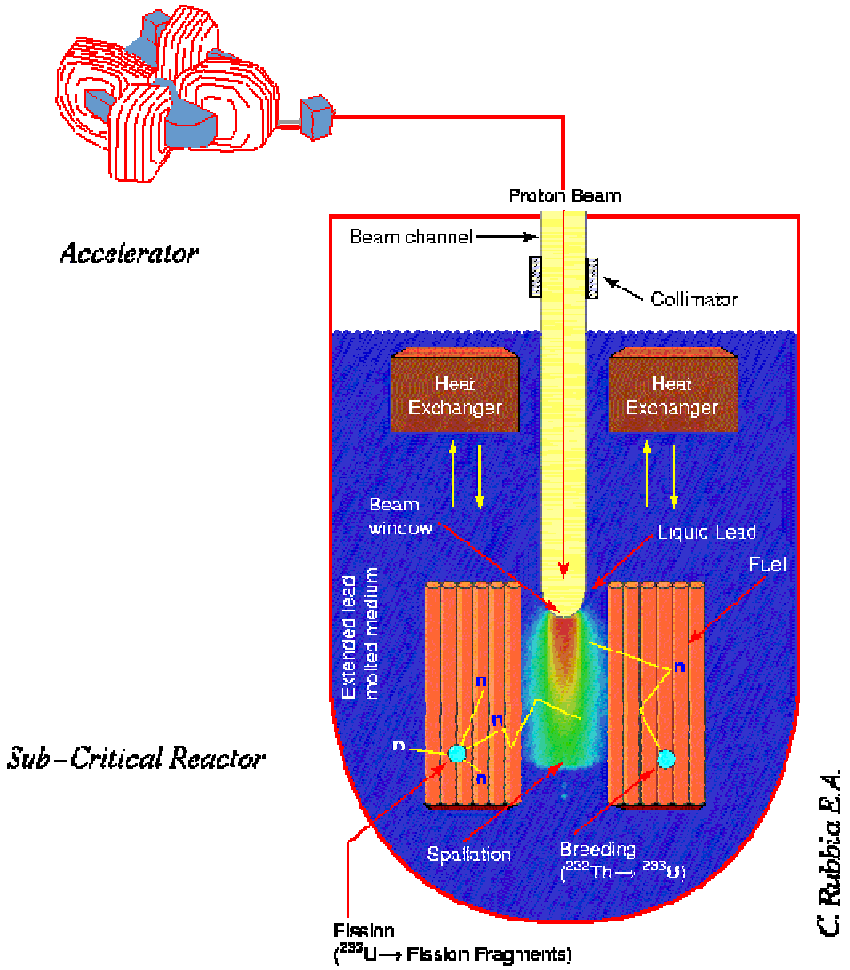




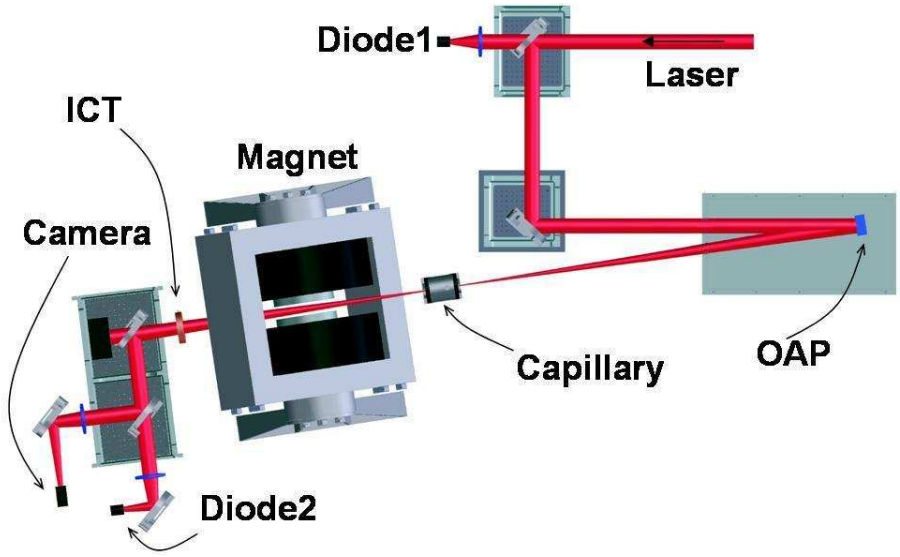
- The target is the main limitation of the power that can be delivered by neutron sources.
- What can be done with a high flux of slow neutrons?

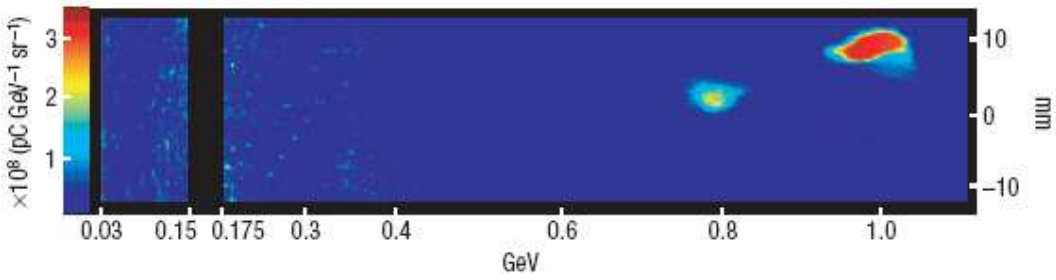
Accelerator Driven sub-critical reactor (ADSR)

- An intense source of protons (see NS-FFAG above) could be used to produce an intense flux of neutrons.
- After moderation these neutrons would trigger nuclear reactions in some nuclear material.
- Advantage the reactor can operate in sub-critical mode (if the accelerator stops the nuclear reactions die automatically).
- The nuclear fuel could be made of isotopes that can not sustain a chain reaction (such as Thorium).
  => no risk of proliferation.



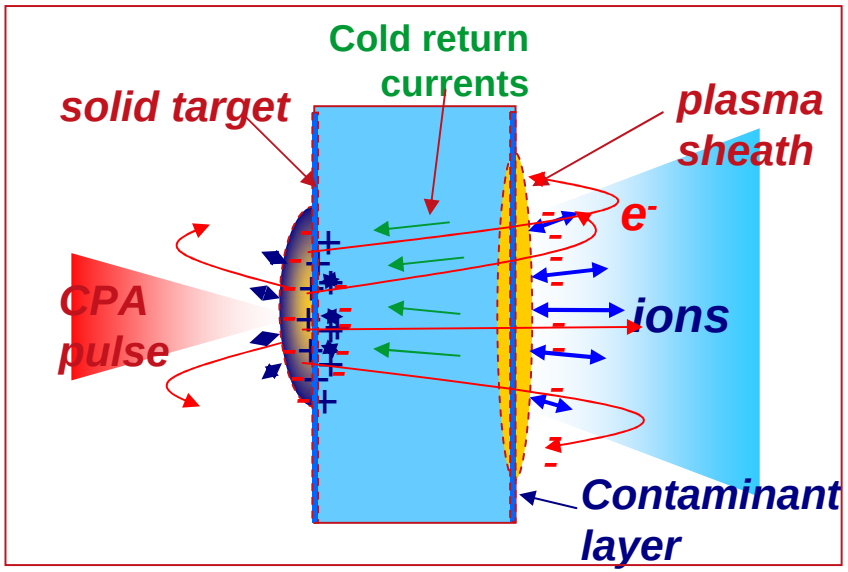
Ultra compact sources: Laser-driven plasma acceleration (1)





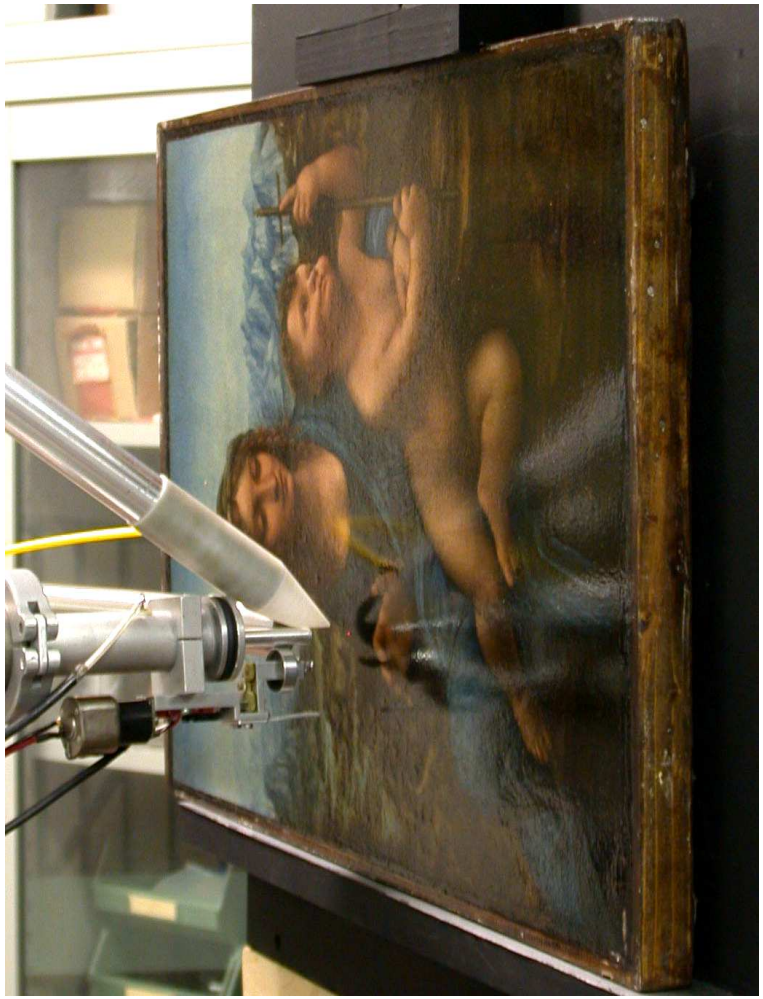
- An intense laser pulse shot in a plasma can accelerate electrons to very high energy: 1GeV over 33mm
- Such electron source could produce high energy low emittance electron beam over very short distances.
- This could be used to drive a compact FEL.
- A group in Oxford is working on this.

Ultra compact sources: Laser-driven plasma acceleration (2)



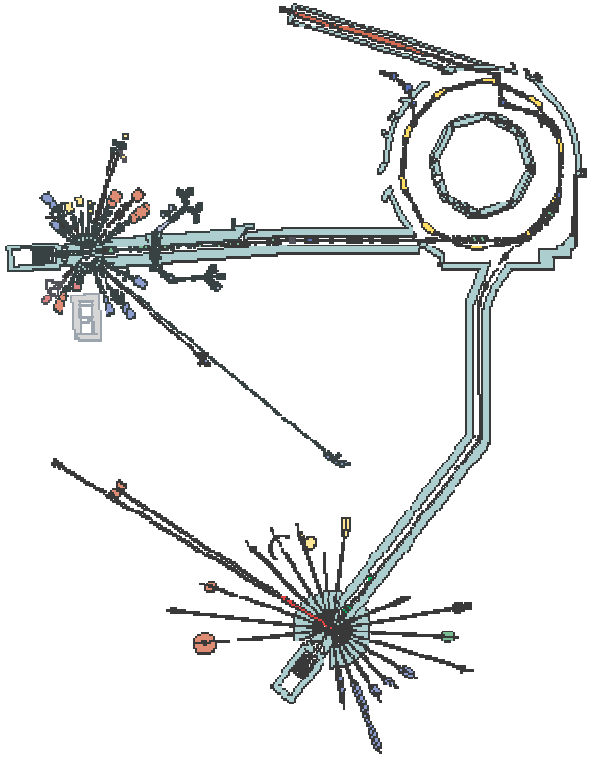
- If a similar laser is shot onto a target, medium energy ions can be produced.
- This could be used for ion therapy.

... and much more



- There are many more applications to accelerators.
- As new generations are built, new potentials and new possibilities are discovered.
- There are more than 150 accelerators in the UK!

Costs



- Large accelerators need to be built as part of international collaborations.
- Access to ISIS or Diamond is free (but peer reviewed).

Jobs and graduate studies

- Accelerators do not operate on their own.
- A team is needed to manage the accelerator operations.
- All accelerators facilities have a wide-range of staff at all levels.
- There are also many jobs connected to the usage of accelerators.
- New machines bring new challenges and there are many opportunities for graduate studies in Accelerator science.