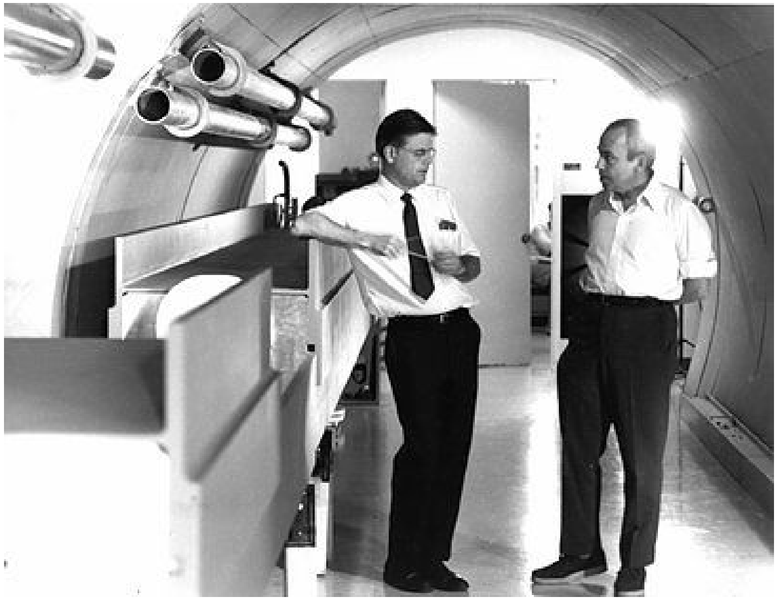
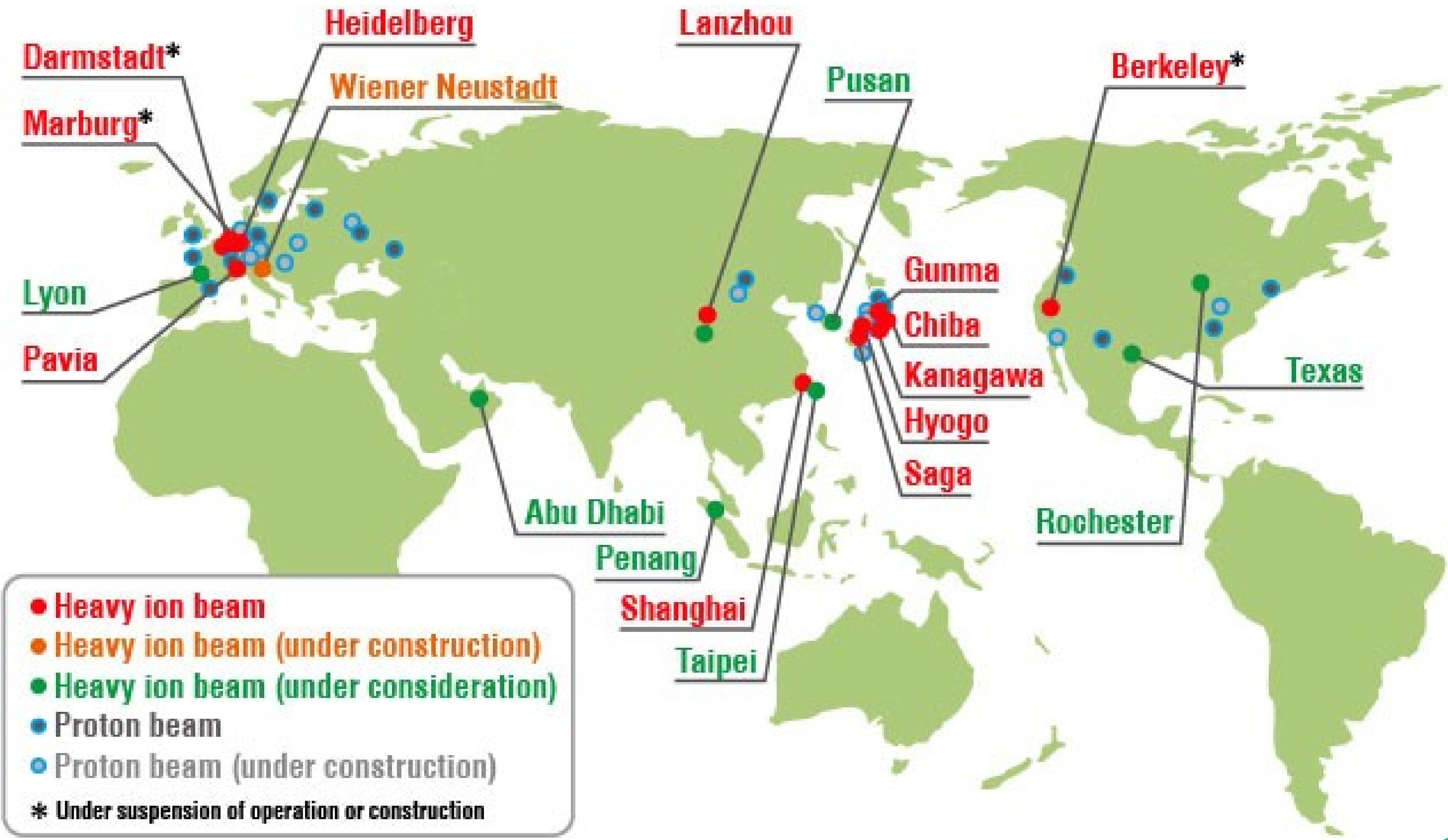
Physics behind Particle Therapy

Particle therapy

- In 1947, the American Physicist Robert Wilson pointed out that beams of protons could offer a dose distribution that was superior to that of X-rays, because of the differing nature of the energy loss, as protons slow down when passing through matter.



Charged particle therapy facilities around the world

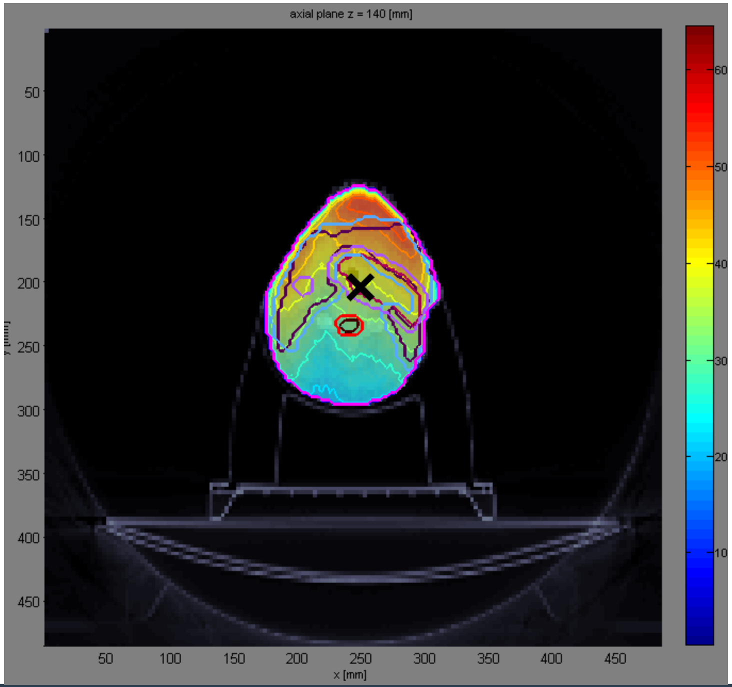


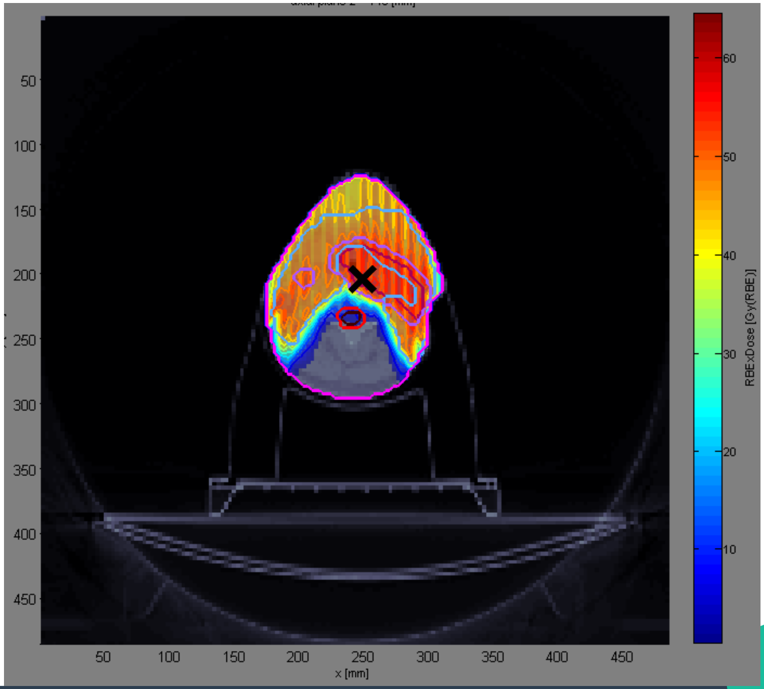
Why are these Centers so rare?

Bragg peak

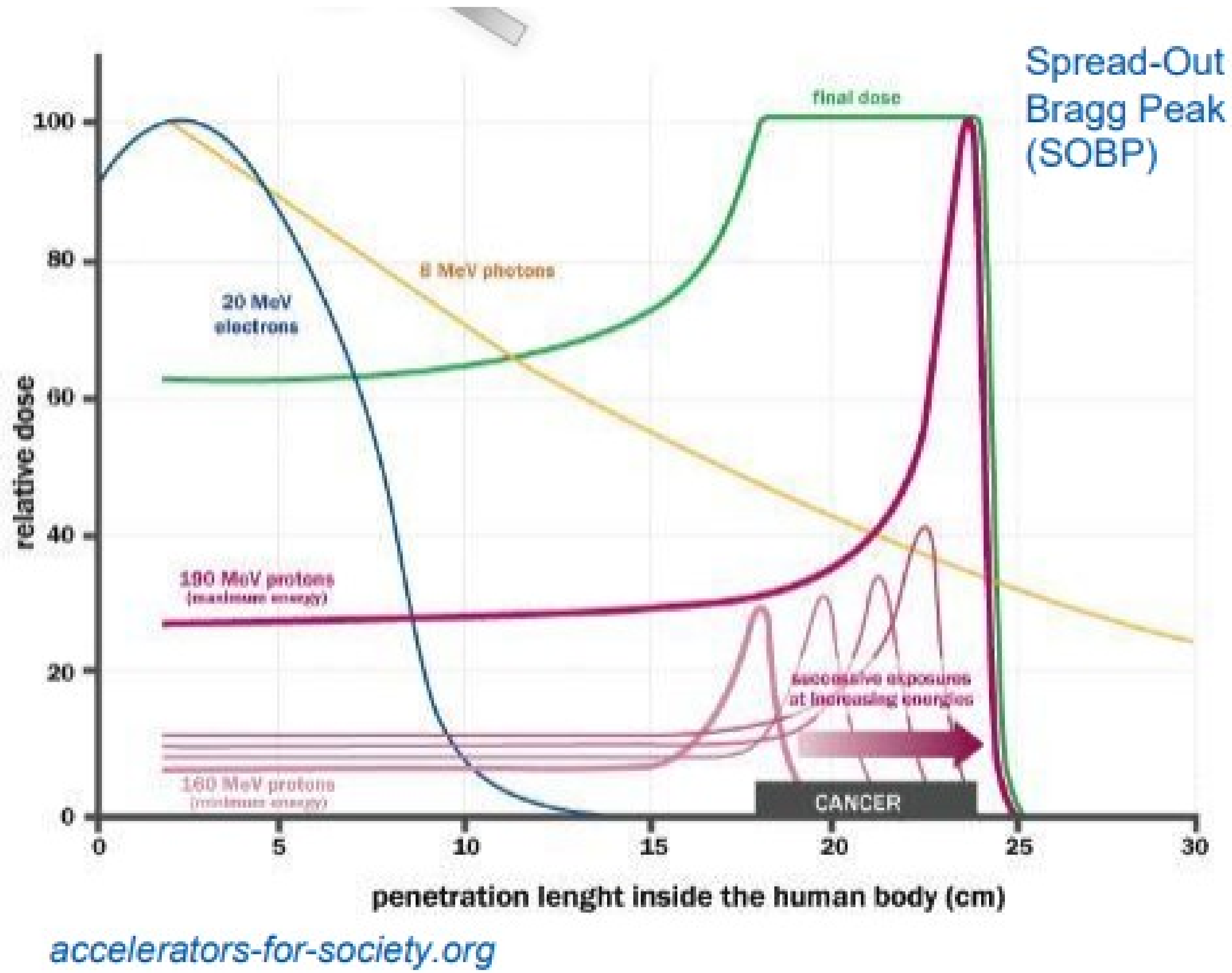
The main advantage of proton treatments is that the dose reaching critical biological structures - particularly downstream of the treatment volume - is drastically reduced.

photons vs protons





Bragg peak


Spread-Out
Bragg Peak
(SOBP)
final dose
8 MeV photons
20 MeV
electrons
190 MeV protons
successive exposures
at increasing energies
160 MeV protons
CANCER
relative dose
100
80
60
40
20
0
0
5
10
15
20
25
30
penetration lenght inside the human body (cm)
accelerators-for-society.org

Difficulties with Particle therapy

- ➢ Cost: a commercial single-room proton therapy system has a price starting from 30M€, to be compared with 2-3 M€ of a X-ray radiotherapy system. A proton and iontherapy centre has a cost of 150-200 M€. Running costs are also high, mainly because of the needs in personnel to run the facilities.
- ➢ Range uncertainties: X-ray therapy has reached a high level of precision and can be coupled to on-line diagnostics. Particle therapy is difficult to calibrate (energy loss depends on tissues), dosimetry is less precise, and on-line scanning is not possible.
- ➢ Assessing performance: advantage of particle therapy in reducing dose to tissues surrounding the tumour, with less risk of secondary cancer and less damage to critical organs. There is no or little impact on survival rate, the main result is in improving quality of life after treatment. While survival rates are easy to measure and compare, quality of life is not an easily measureable parameter; only recently studies are starting to take this parameter into account.
- ➢ Centralisation of medicine: the high cost of particle treatment calls for large centralised units that have difficulties in attracting patients from hospitals located in a large region.

Physics behind Bragg peak

Using relativistic quantum mechanics, Bethe derived following expression for the stopping power of a uniform medium for a charged particle:

$$-\frac{\mathrm{d}E}{\mathrm{d}x} = \frac{4\pi Z^2 e^4 n}{(4\pi\varepsilon_0)^2 m_e c^2 \beta^2}\left(\ln\frac{2m_e c^2\beta^2}{I(1-\beta^2)} - \beta^2\right), \tag{1}$$

In this formula,

Z - atomic number of heavy particle,

e - magnitude of electric charge,

n - number of electrons per unit volume in the medium,

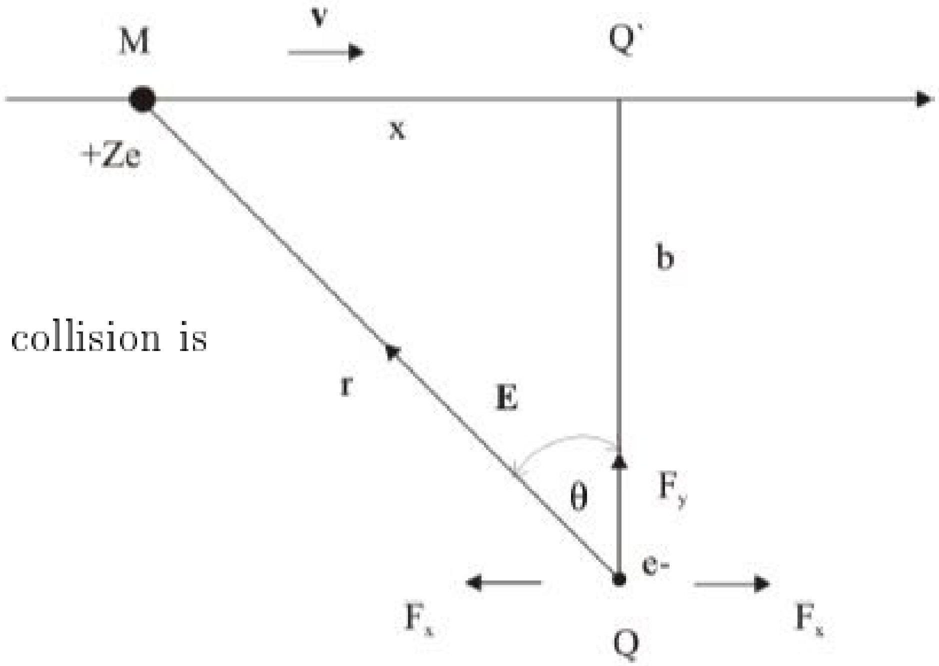
m_e - electron rest mass,

c - speed of light in vacuum,

$\beta = v/c$ - speed of the particle relative to c,

I - mean excitation energy of the medium.

Classical derivation



the Coulomb force

$$F = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2}$$

The total momentum imparted to the electron in the collision is

$$\Delta p = \int_{-\infty}^{\infty} F_y dt.$$

Component F_y of Coulomb force is

$$F_y = F\cos\theta = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2}\cos\theta = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2 b}{(x^2+b^2)^{3/2}}$$

Kinetic energy of the heavy particle is

$$E = \frac{Mv^2}{2}$$

Classical derivation

Energy which electron gets is

$$\Delta E = \frac{Z^2 e^4}{(4\pi\varepsilon_0)^2 b^2 m_e} \frac{M}{E}$$

Most important conclusion from this is that ΔE is inversely proportional to E. Particle with higher energy deposits less energy than particle with smaller energy. So, it deposits most of it's energy on the end of the path - Bragg peak.

Thank you :)