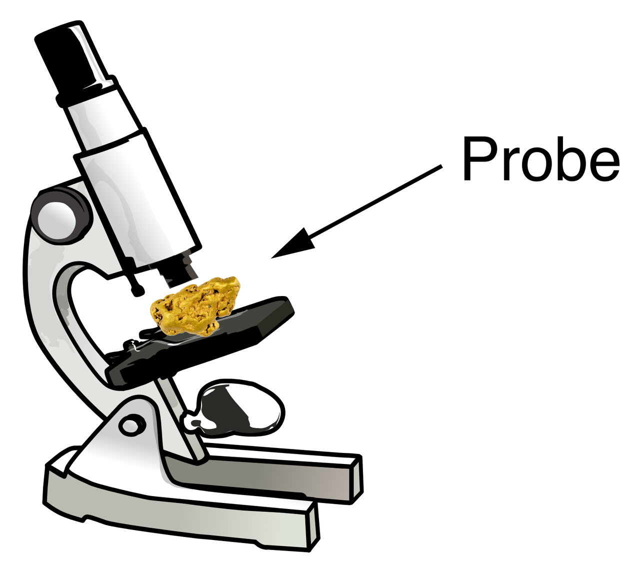
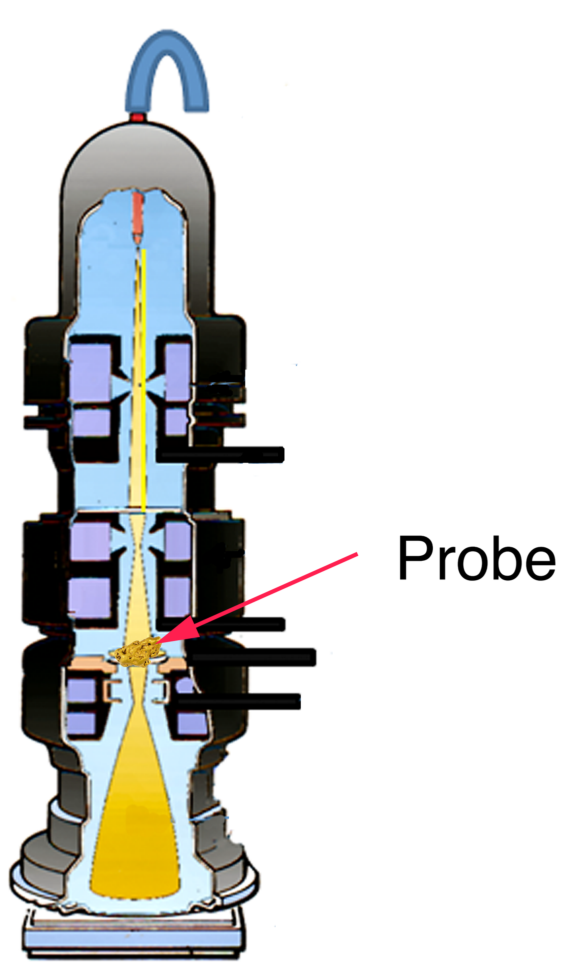
Studying the structure of Matter at less that 10^{-15} meter with high resolution femto-scopes

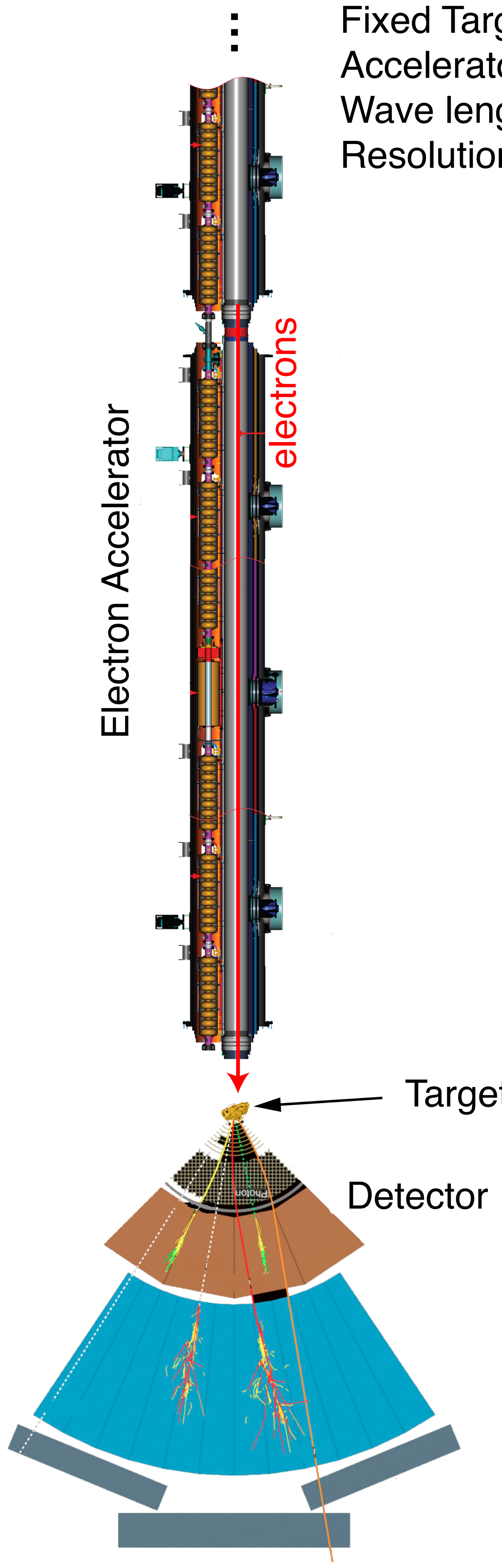
Light Microscope
Wave length: 380-740 nm
Resolution: > 200 nm

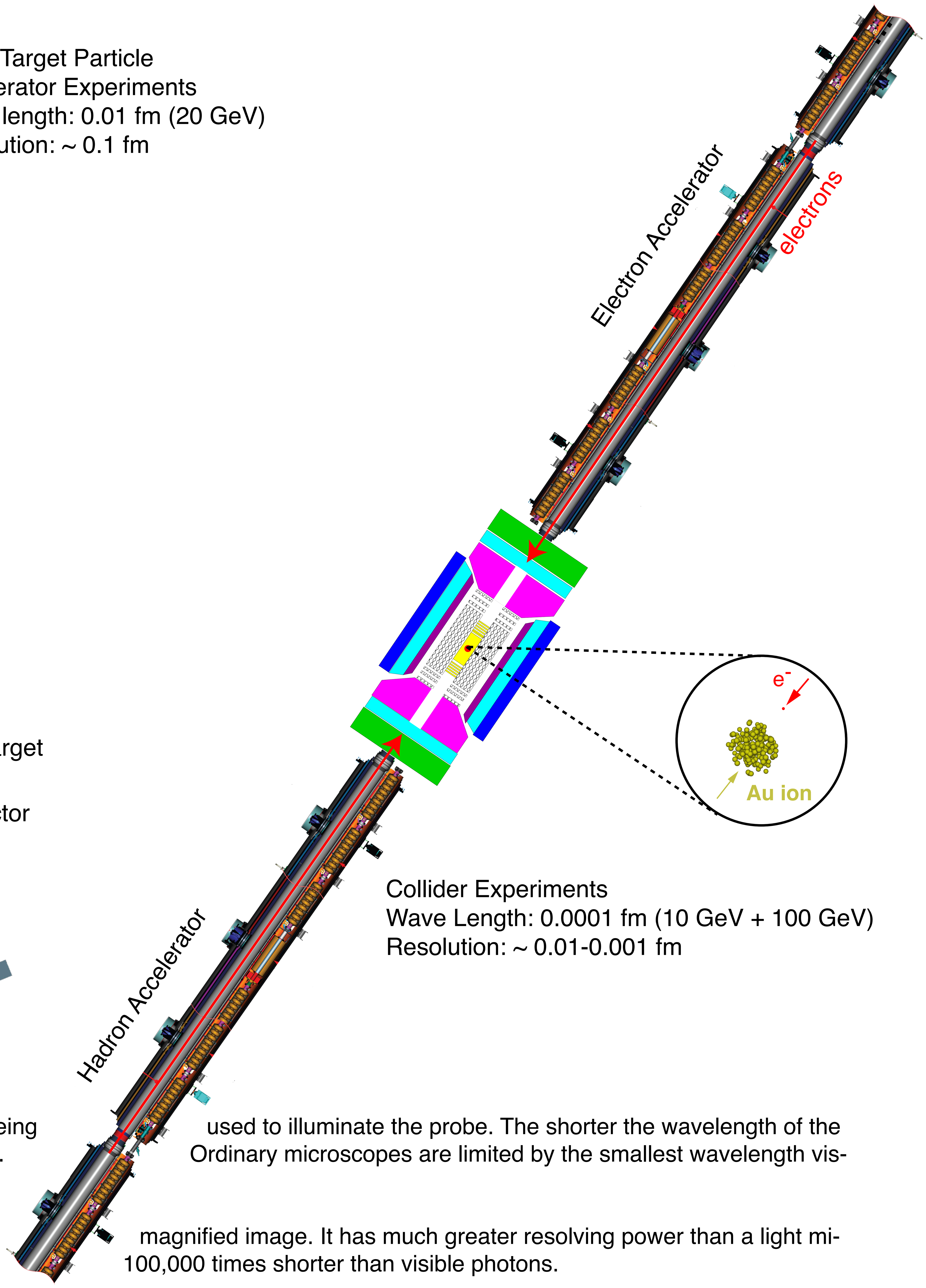


Electron Microscope
Wave length: 0.002 nm (100 keV)
Resolution: > 0.2 nm



Fixed Target Particle
Accelerator Experiments
Wave length: 0.01 fm (20 GeV)
Resolution: ~ 0.1 fm





Collider Experiments
Wave Length: 0.0001 fm (10 GeV + 100 GeV)
Resolution: ~ 0.01-0.001 fm

Microscope resolution is determined by the wavelength of light being used to illuminate the probe. The shorter the wavelength of the light, the higher the resolution, and the finer the structure studied. Ordinary microscopes are limited by the smallest wavelength visible to the human eye.

An electron microscope uses an electron beam to produce a magnified image. It has much greater resolving power than a light microscope because electrons have wavelengths about 100,000 times shorter than visible photons.

Electron microscope resolutions are limited by their electron energy, roughly to energies corresponding to about 1/5 of the electron mass. Large and complex particle accelerators overcome this limit by producing electron beams with energies of up to about 10,000 times the electron mass.) The earliest experiments with such energetic electrons probed matter in a stationary target. Pioneering experiments at the Stanford Linear Collider (SLAC) achieved resolutions of order 0.1 Fermi (1 Fermi = 10^{-15} meters, roughly the size of the proton.) These experiments succeeded in discovering point-like, fractionally charged objects within protons and neutrons, interpreted as quarks.

Much higher resolutions in stationary target experiments require prohibitively large and expensive accelerators. The way out is to also accelerate the target, colliding electron and target together at high energies. A prominent example of this type of sub-Fermi probe, or “femto-scope”, was the HERA collider at DESY, Germany. This machine was the first electron-proton collider and pointed to the unexpected prominent role gluons play deep inside the proton. A future electron-ion collider (EIC) machine will allow collisions of electrons with spin-polarized protons, as well as light and heavy atomic nuclei. Both such experiments will be firsts for collider experiments, with intensities a 1000 fold compared to HERA. The EIC will provide the resolution and intensity to map out in detail the three-dimensional structures in protons and atomic nuclei. This will resolve outstanding puzzles of the sub-atomic universe at distances well below a millionth of a billionth of a meter.