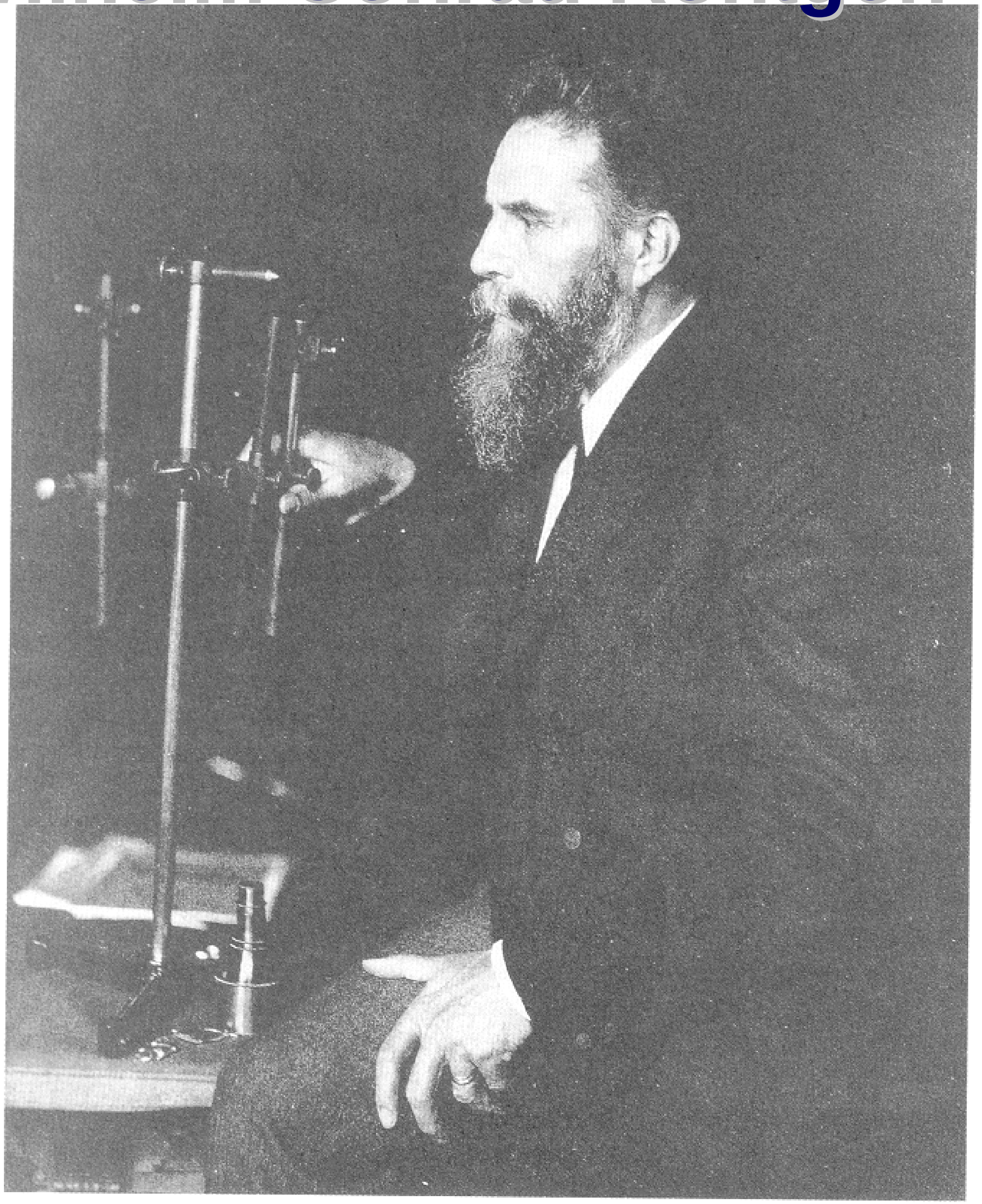
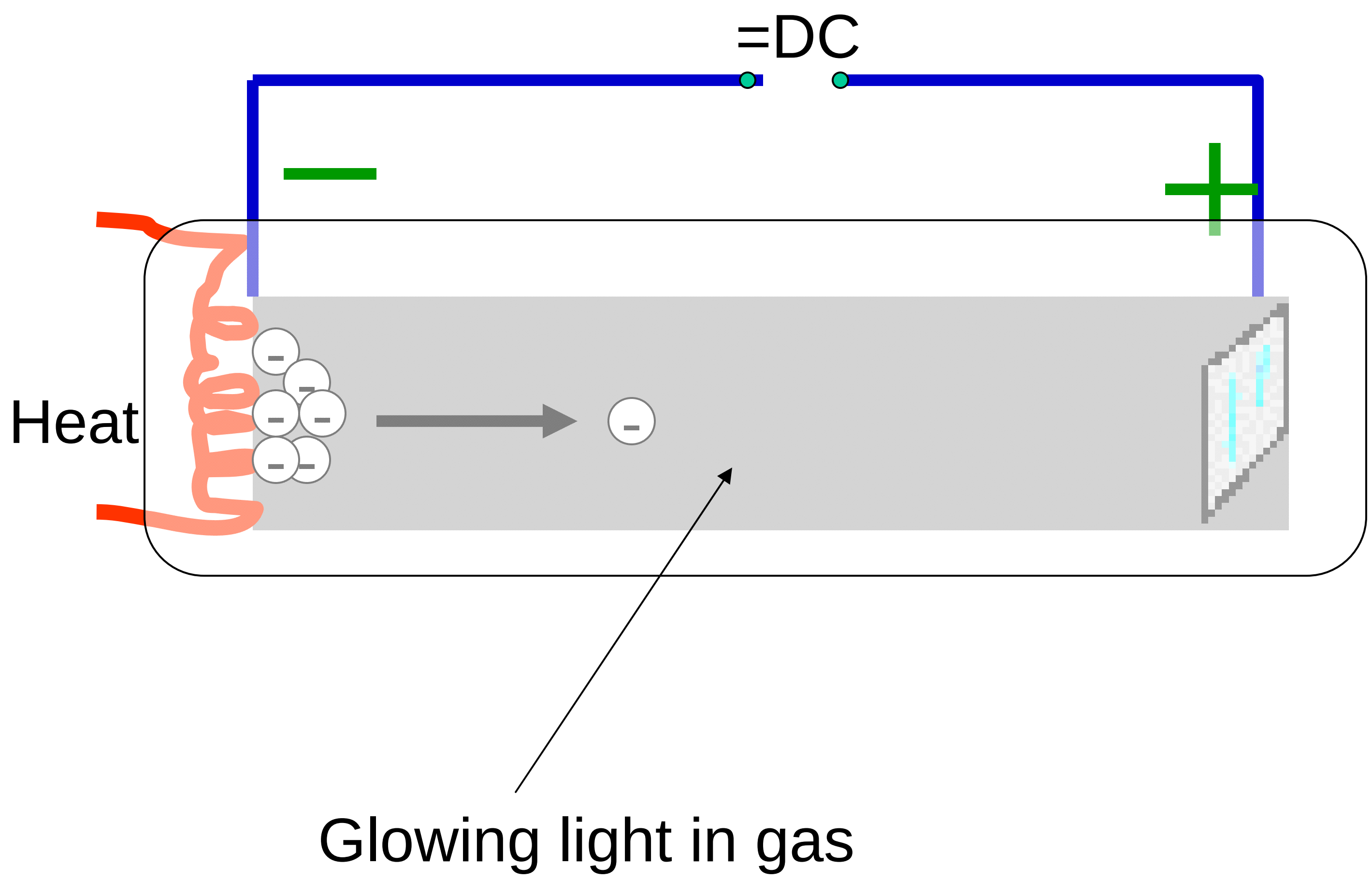
X-ray imaging

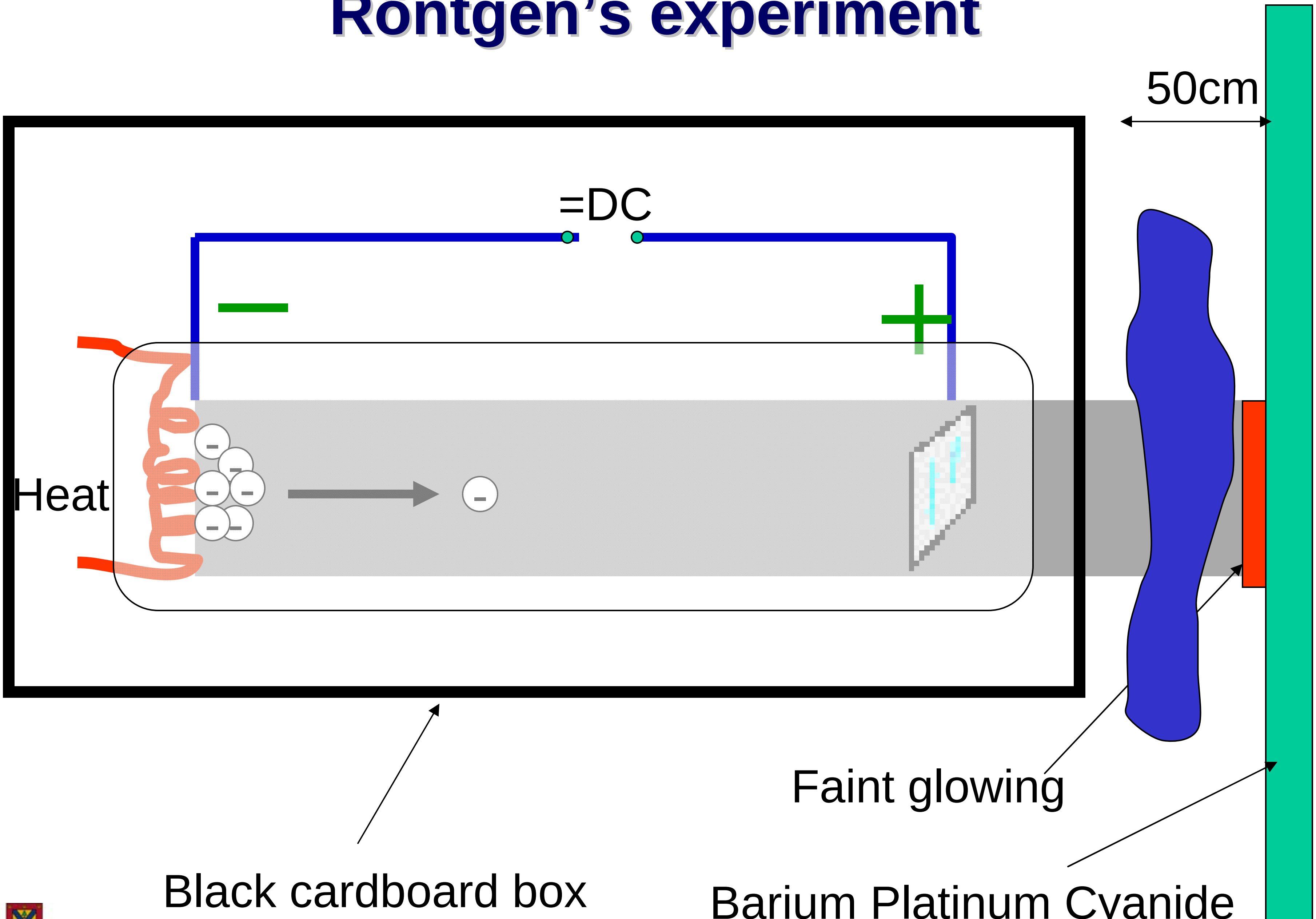
Würzburg, November 8, 1895: Dr. Wilhelm Conrad Röntgen



Fluorescence in glass tube by cathode rays



Röntgen's experiment



What did Röntgen know and did not know?

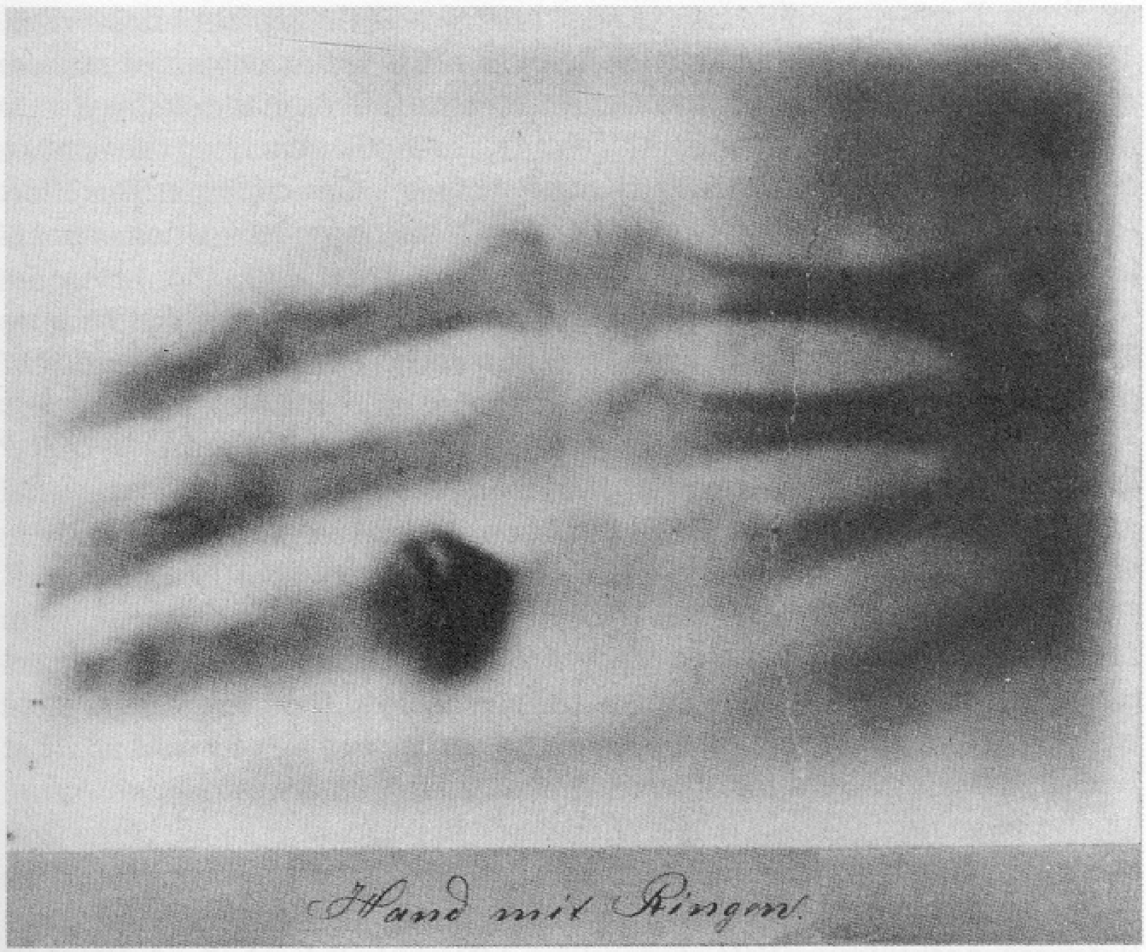
DID KNOW

- Ray-like phenomenon (named it X for “unknown” ray)
- Not charged
- Carries to some distance
- Penetrates through regular materials
- Absorption rate depends on material density
- Absorption depends on material mass
- Carries significant energy
- Energy changes with tube voltage

DID NOT KNOW

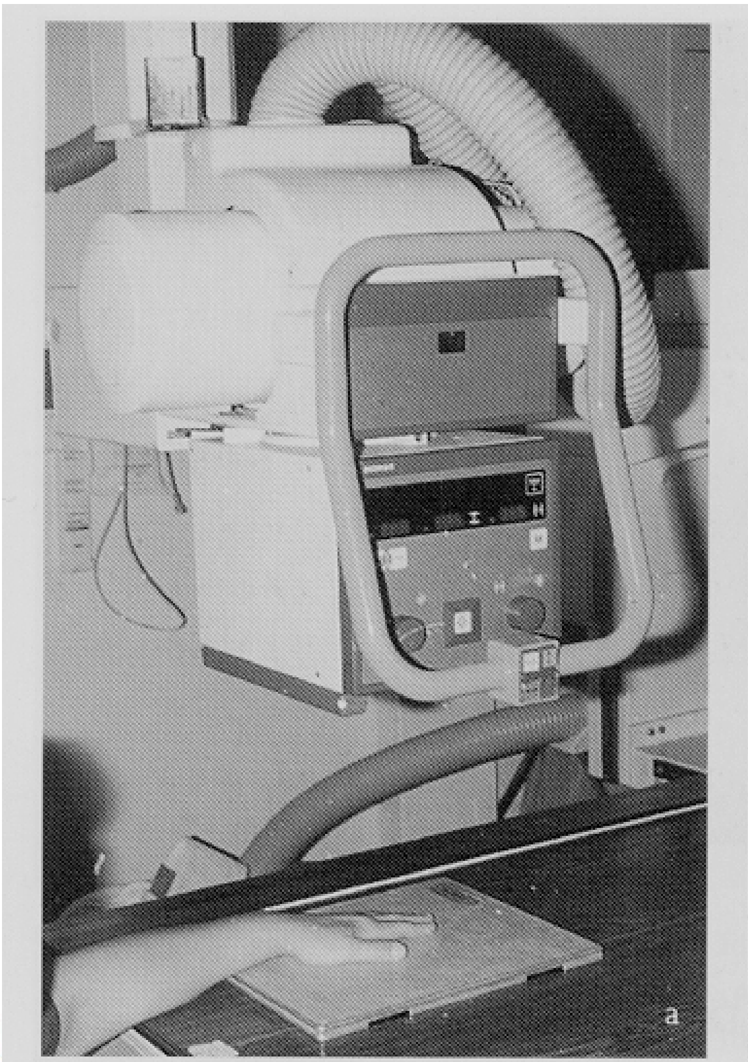
- Electromagnetic wave, just like visible light
- Shorter wavelength ($E=h*\nu$)
- Always harmful, potentially lethal

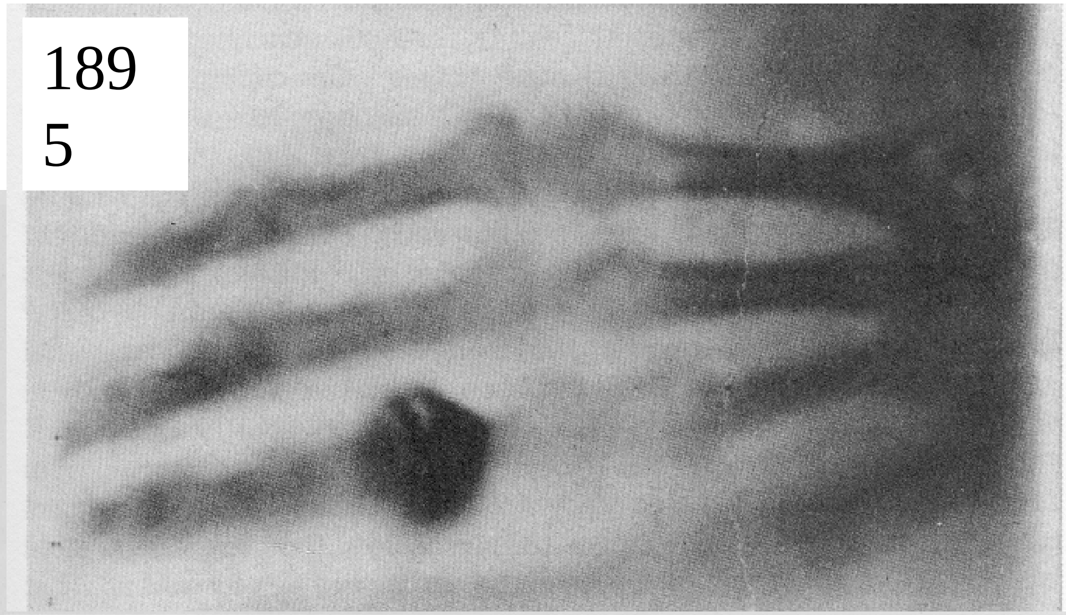
Frau Röntgen's hand, December, 1895

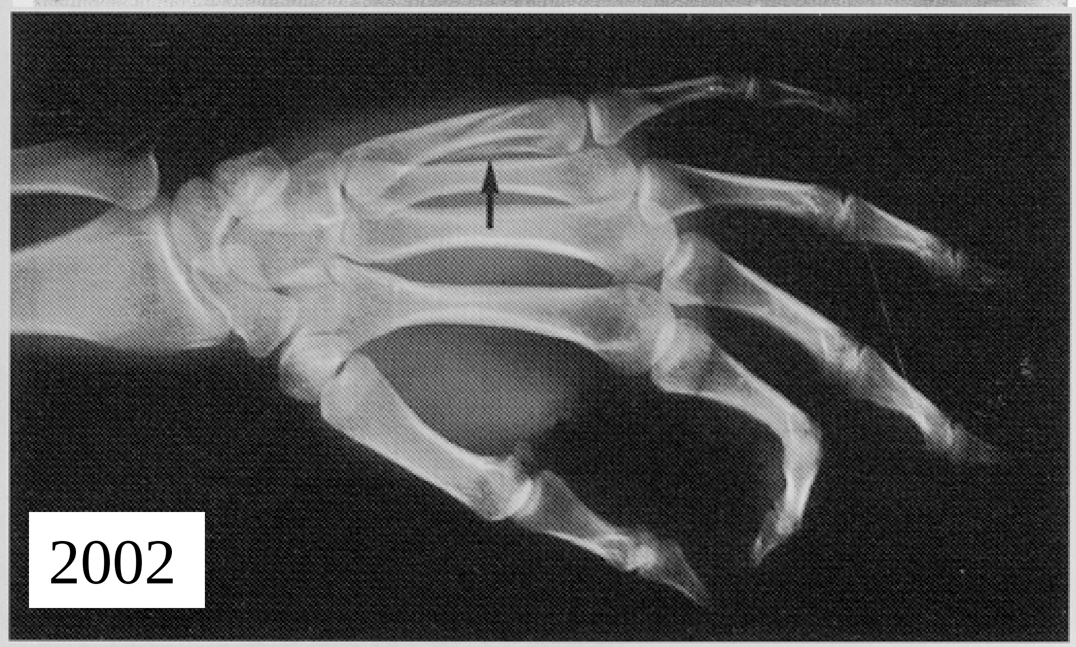


4. Frau Roentgen's hand (1895). Roentgen mailed eight copies of his paper along with this picture, among others, on January 1, 1896.

X-ray of a hand





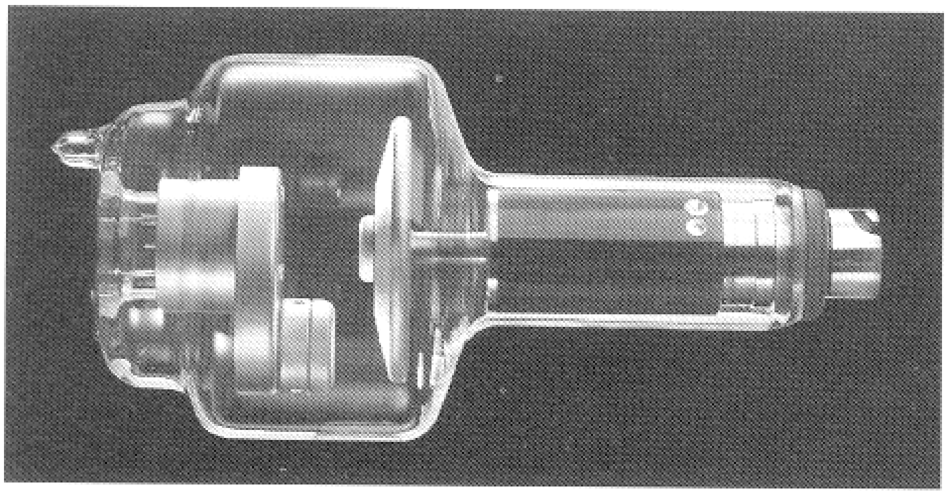


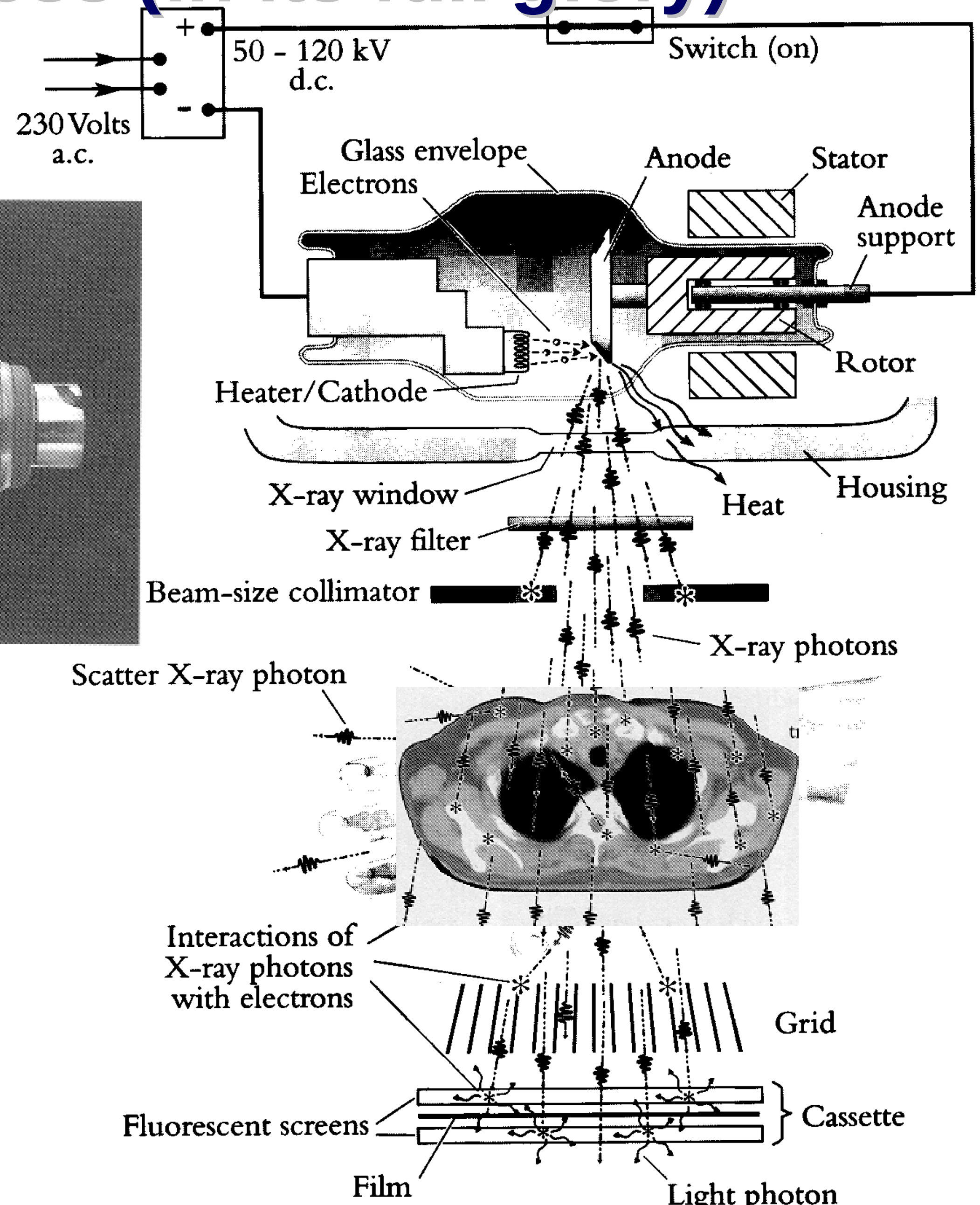
Modern chest X-ray machine

Number of X-rays registered by Medicare in 1993:

207,753,747

X-ray process (in its full glory)





Silver bromide film coating

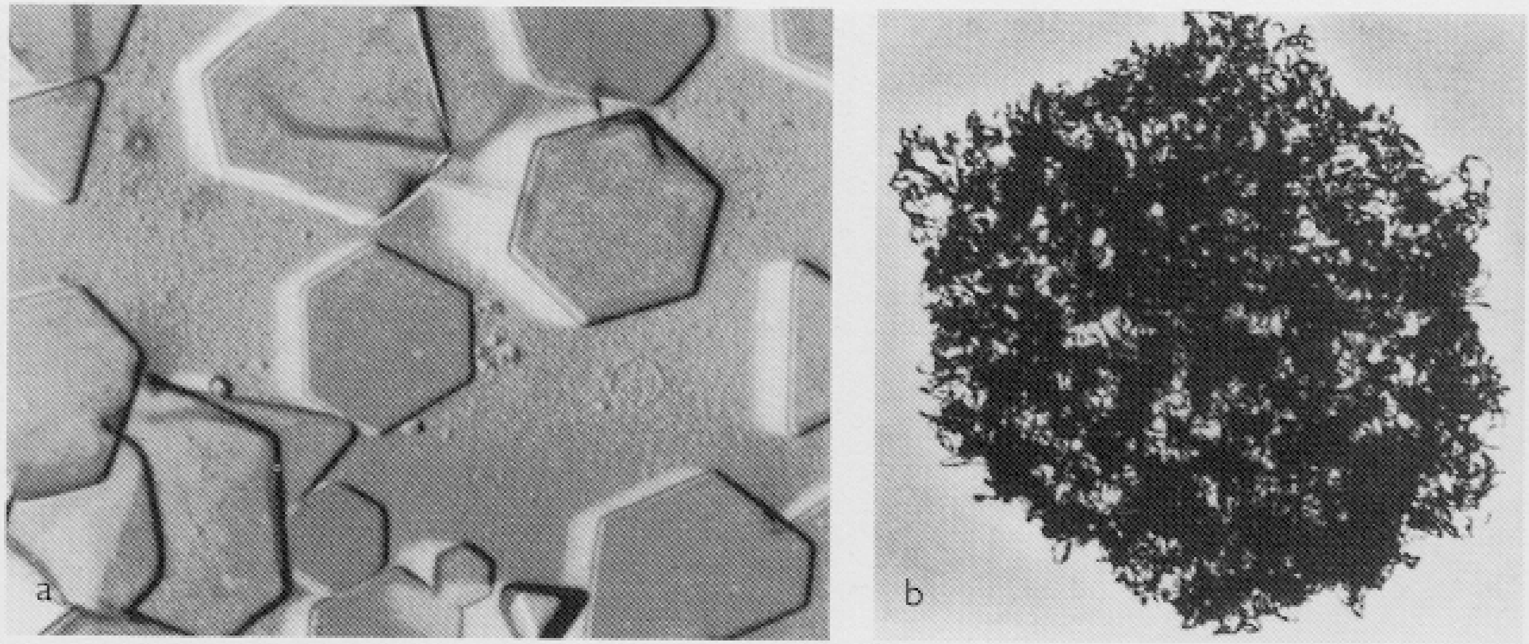
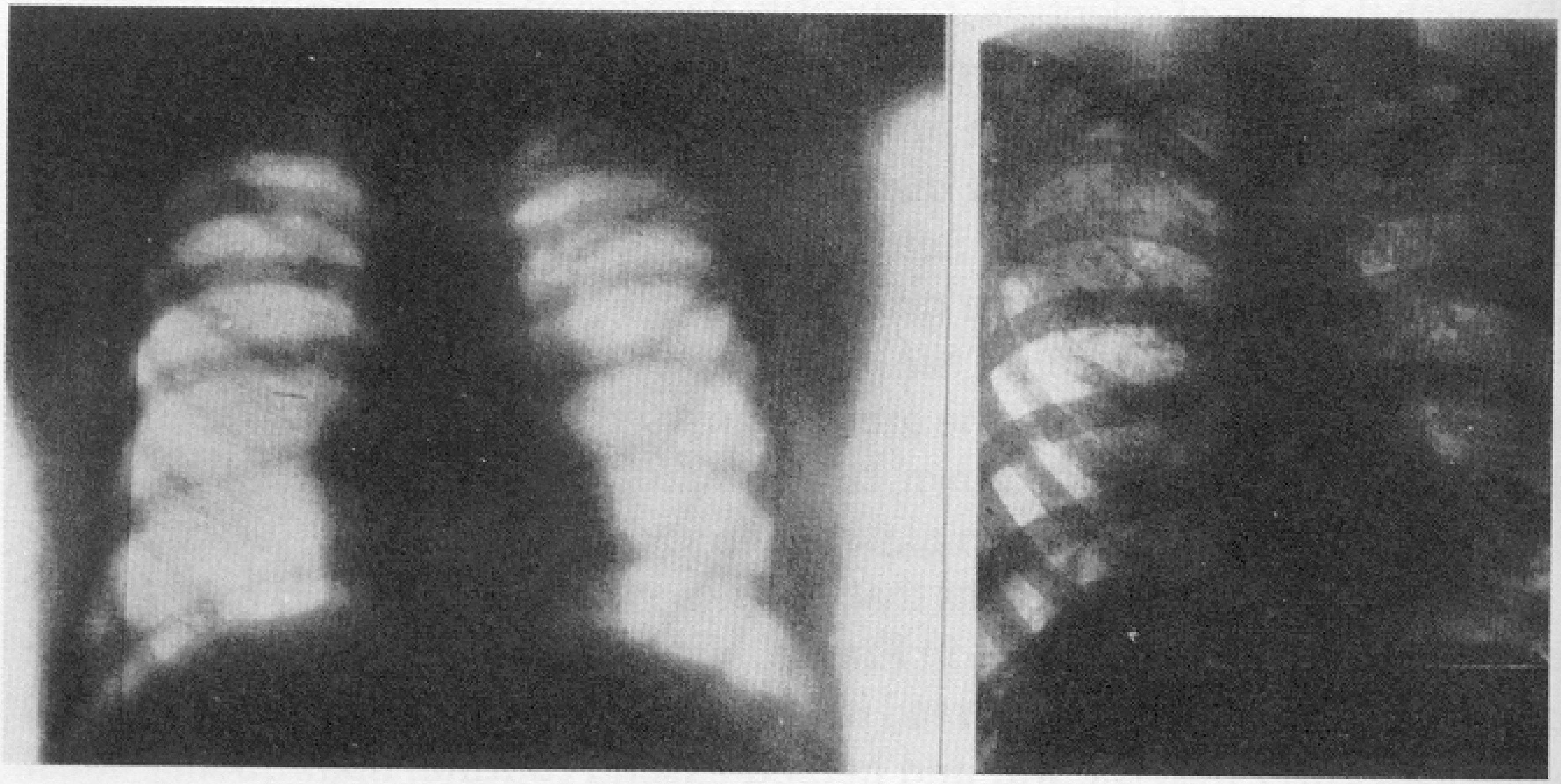


Figure 26. What makes photographic film dark: (a) The active ingredient in film is tiny crystals of (mostly) silver bromide, seen here with the aid of an electron microscope. (b) During the chemical development process, those microcrystals that were sensitized by exposure to X-ray or light photons are transformed into tiny flecks of opaque, pure silver metal, one of which is shown here. The crystals that are not sensitized (and are not subsequently converted to metallic silver) are dissolved and removed from the film during fixation and washing. Courtesy of Arthur Haus, Eastman Kodak Company.

Chest X-ray, 1903

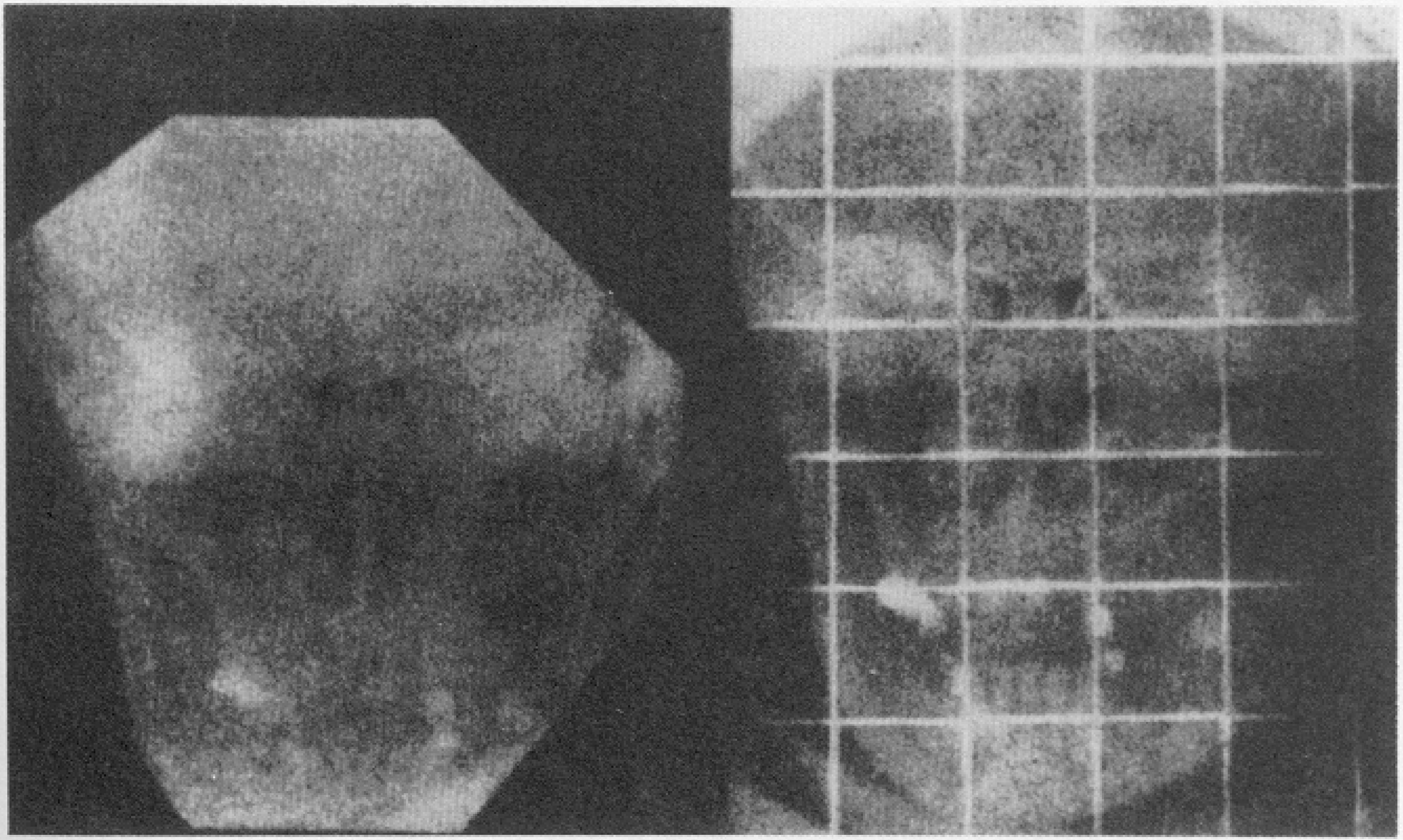


18. Chest X-rays (1902). *Left,* radiograph of normal chest (M. Kassabian, "Instantaneous Skiagraphy of the Thoracic Organs," *Transactions of the ARRS* [1903]: 95–100). *Right,* radiograph of tubercular chest (H. Hulst, "Skiagraphy of the Chest," *Transactions of the ARRS* [1903]: 88–94). Courtesy of the American Roentgen Ray Society.

Army hospital ~1915, waiting for X-ray

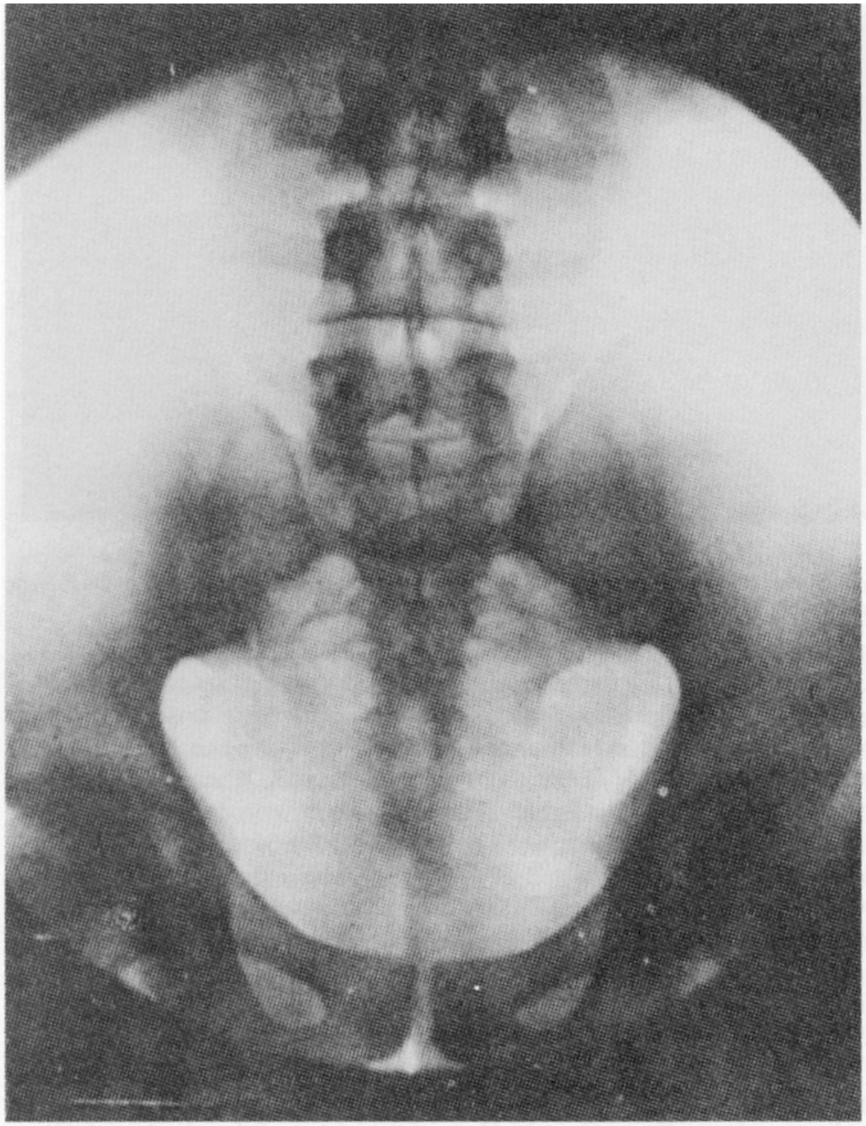
17. En route to the X-ray room. A corridor of a French castle, transformed into an American Army hospital during World War I. Courtesy of the American College of Radiology.

Bucky Grid (1913)



13. Radiograph of the face with and without the Bucky grid/diaphragm (1913). Initial example of the value of Bucky's invention. *Left,* without grid. *Right,* with grid. Courtesy of the *British Journal of Radiology.*

Potter's Grid (1920)



14. Picture of the spine using the Potter improvement on the Bucky grid/diaphragm (1920). (H. E. Potter, "The Bucky Diaphragm Principle Applied to Roentgenography," *American Journal of Roentgenology* 7 [1920]: 292–295.) Courtesy of the American Roentgen Ray Society.

Collimator grid

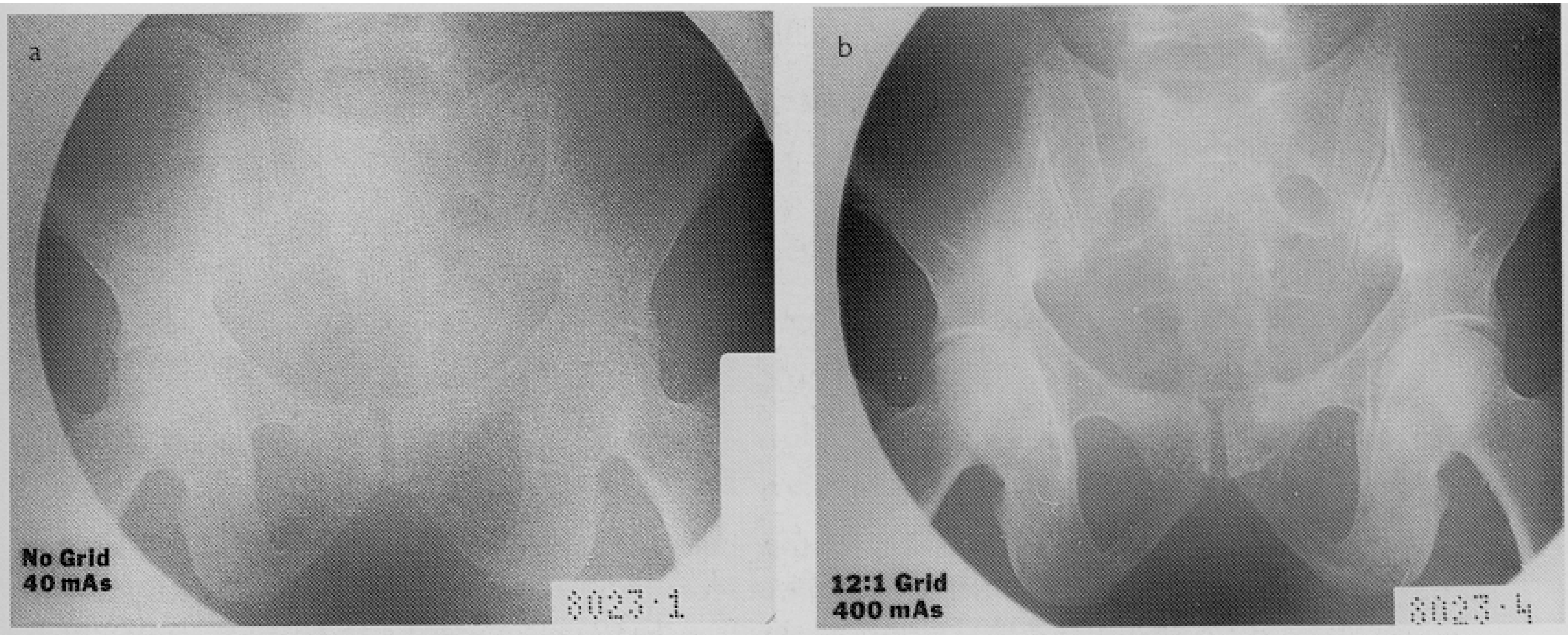


Figure 25. Scattered X rays produced within a patient's body degrade image contrast. (a) Radiograph of a pelvis, taken without a grid. (b) When a grid is used, the contrast is considerably better, but the radiation dose to the patient is higher; to end up with the same average darkening of the film, it is necessary to increase beam output to compensate for what the grid removes. A second trade-off. Courtesy of the American College of Radiology.

X-Ray dermatitis & protective garment

1910

1914

X-ray interaction with matter – ionizing radiation

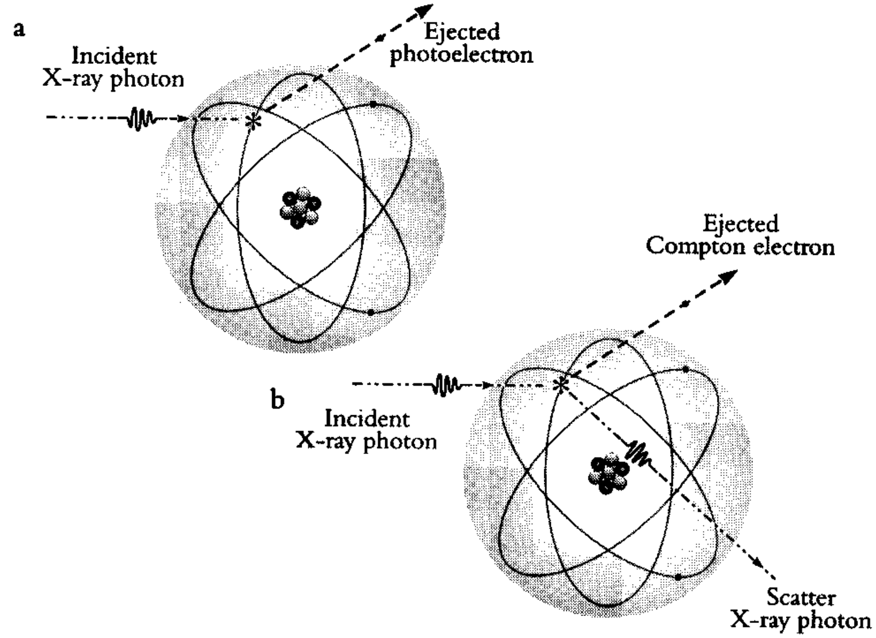


Figure 21. There are two important mechanisms by which diagnostic X-ray photons interact with matter, whether it be tissue within the patient or the fluorescent material of a cassette. (a) In a photoelectric absorption event, the photon imparts all of its energy to an atomic electron. The photon is removed from the beam, the electron is ejected from the atom at high velocity, and the atom is ionized. (b) In a Compton scatter collision, only part of the incoming photon's energy is transferred to an atomic electron; the rest leaves the scene of the interaction in the form of a lower-energy scattered X-ray photon. Either way, X-ray photons are removed from the beam; interactions that take place within the patient's body imprint a shadow image in the X-ray beam. Also, either way, energy is deposited in irradiated materials (patient and cassette); X-ray photons that pass through the patient and strike a fluorescent screen of a cassette produce bursts of light that expose the X-ray film.

Effect of tube voltage

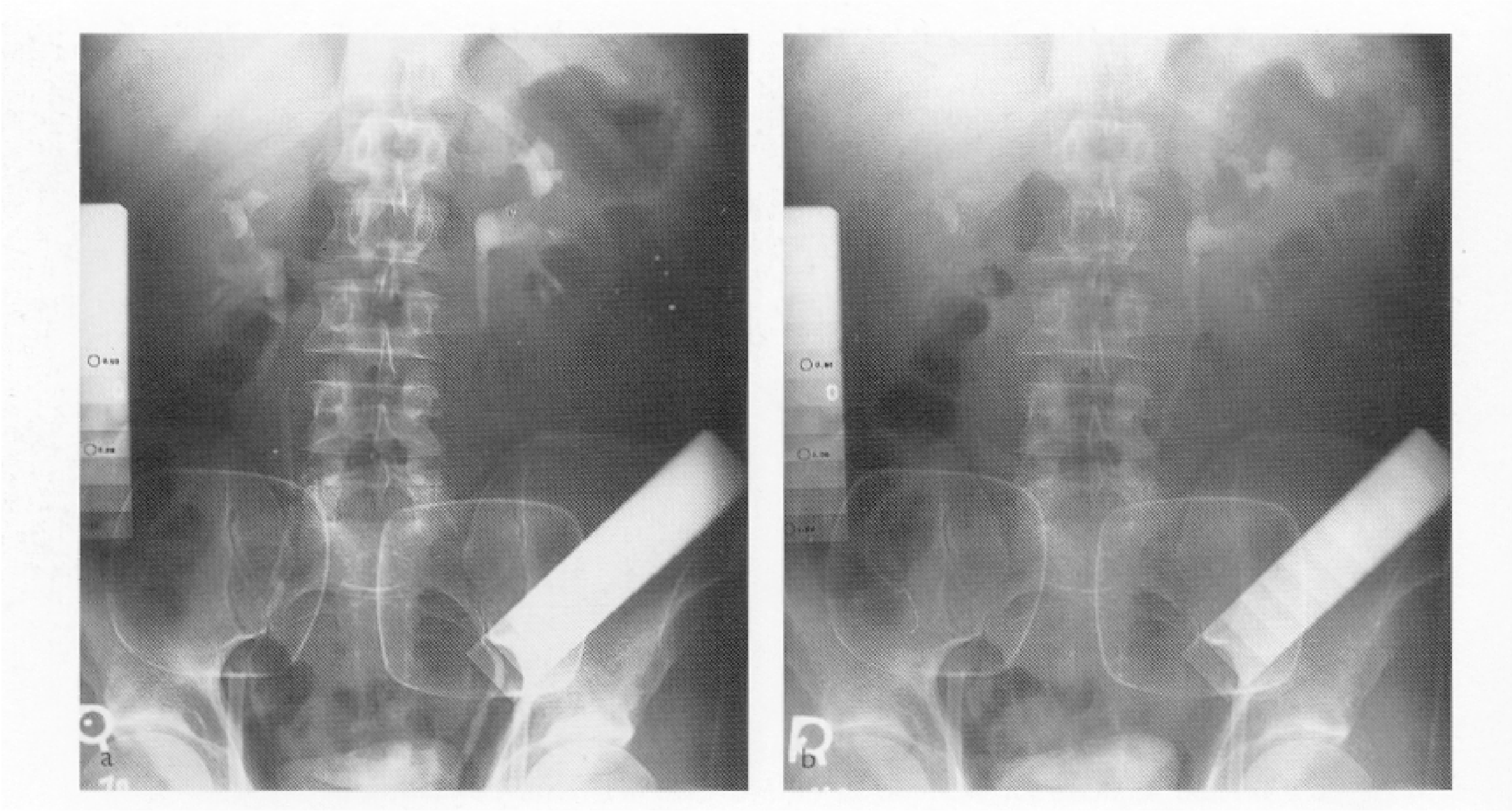


Figure 24. An important, and adjustable, determinant of image quality in radiography is the voltage applied across the X-ray tube by the generator. The image to the left, (a), was made at a lower voltage (70,000 V) than (b), the one on the right (110,000V). As a result, (a) more clearly shows the two ureters, which are carrying urine (and iodine-based contrast agent) from the kidneys to the bladder. The lower the voltage, the better the contrast, but the greater the amount of radiation dose that is delivered to the patient-one of many trade-offs to be considered in imaging. Courtesy of the American College of Radiology.

Exponential decay of intensity in matter

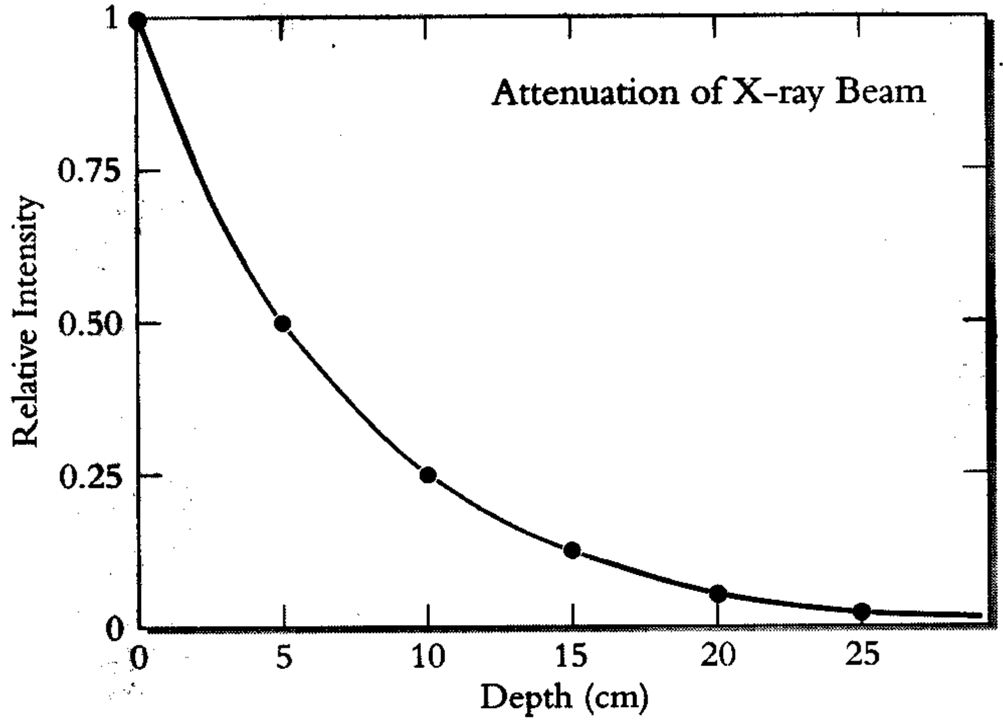
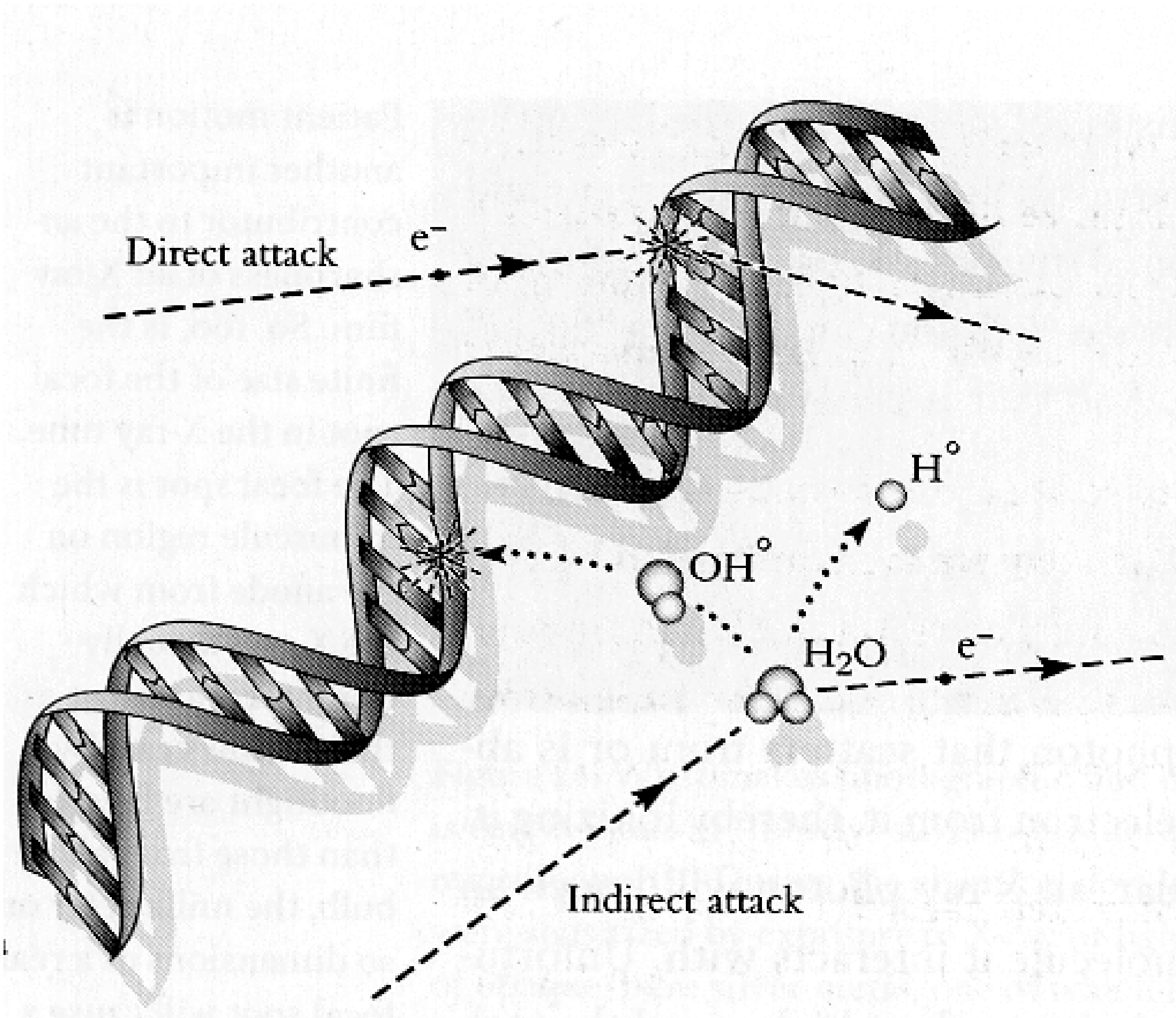


Figure 22. Attenuation of an X-ray beam passing through soft tissue. As ionizing radiation traverses a block of material, roughly the same fraction of what remains is absorbed or scattered in each centimeter. Suppose, for example, that the intensity of an X-ray beam entering the material from the left is 1, and that it falls to ½ in traversing 5 centimeters. At a depth of ten centimeters, only about half of that remains, or ¼ of the original beam strength. Likewise, 15, 20, 25, . . . centimeters into tissue, the intensity will be about ⅛, 1/16, 1/32, . . . The beam is said to be undergoing exponential attenuation.

X-ray interaction with DNA



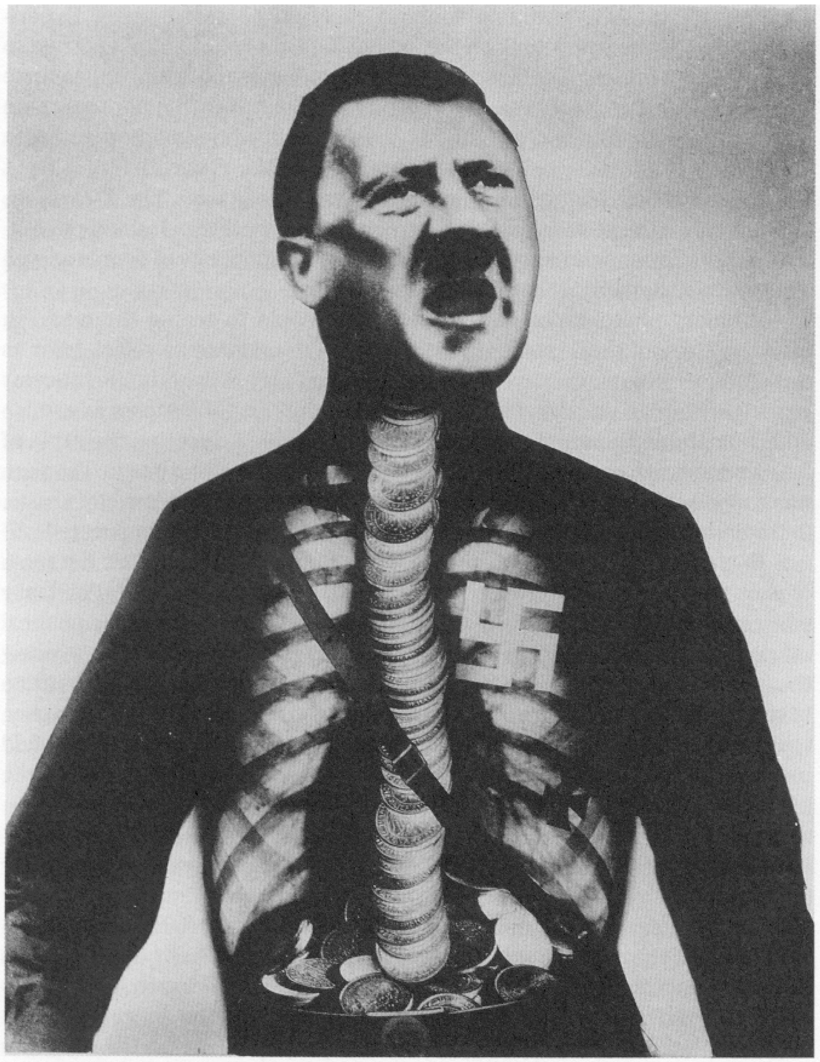
Radiation risk assessment

- Risk = possibility that something bad may happen
- Public's feeling depends on source of risk
  - Human made hazards are less acceptable
  - Risk feels greater if comes without consent or consultation
  - Accidents increase the feel of risk
- In radiology: possibility that ionizing radiation used in medical procedures might give rise to cancer
- It has been documented to happen
- Risk = Dose * Riskprobability
- Riskprobability depends on the type of cancer & organ
- Dose is what we can control…
- Yardstick: whole-body background 300 mrem /year
- Chest X-ray: 20 mrem at skin, 1-2 mrem at exit
- **Equivalent cancer risk:**
  - **Skin : cosmic backgr = 15 shots /year**
  - **Internal organs: cosmic backgr = 100-150 shots /year**

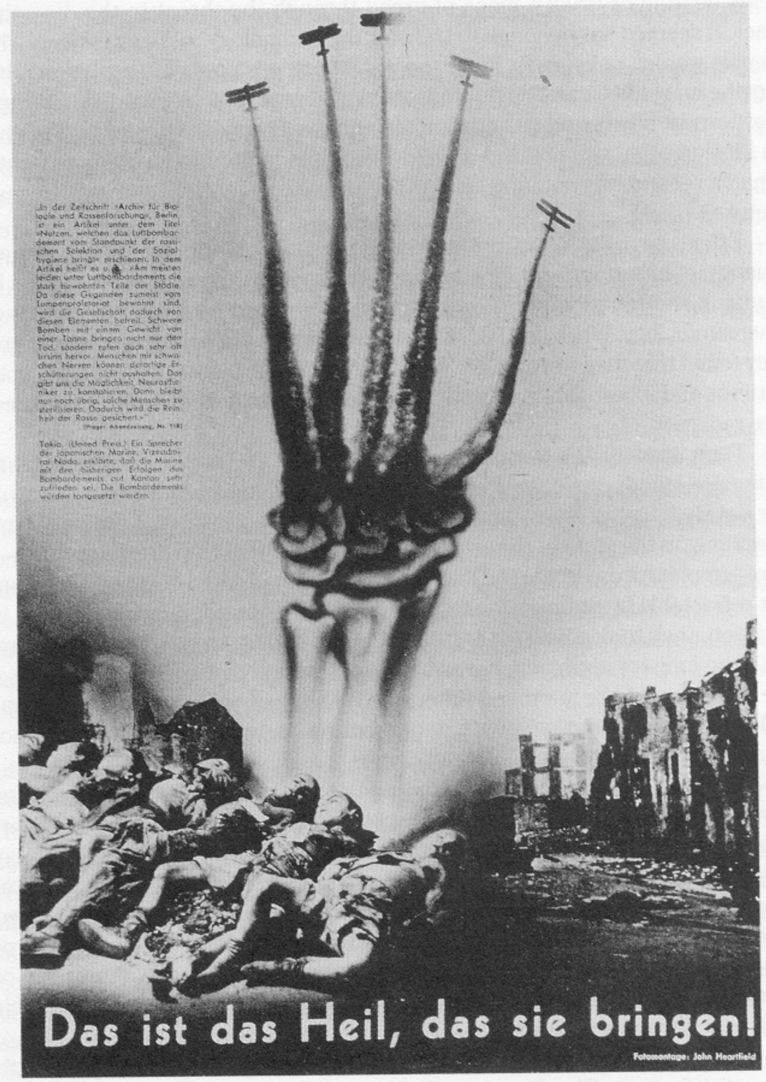
Dose escalation (accumulation) models

- Under debate
- It has been linear accumulation model = the body never forgets radiation
- But the body does forget radiation, we just do not know how.
- How does genetic distortion caused by ionizing radiation fades out? – we do not know
- New: “annual limits” for medical staff
- Dose tolerance levels are set for organs
- Sensory organs are very sensitive
- Brain, lymph nodes, bone marrow are generally sensitive
- Large differences in tolerance, even inside brain

X-ray = terror and X-ray = horror



26. John Heartfield, *Hitler Swallows Gold and Spouts Junk.* Copyright © 1997 Artists Rights Society (ARS), New York/VG Bild-Kunst, Bonn.

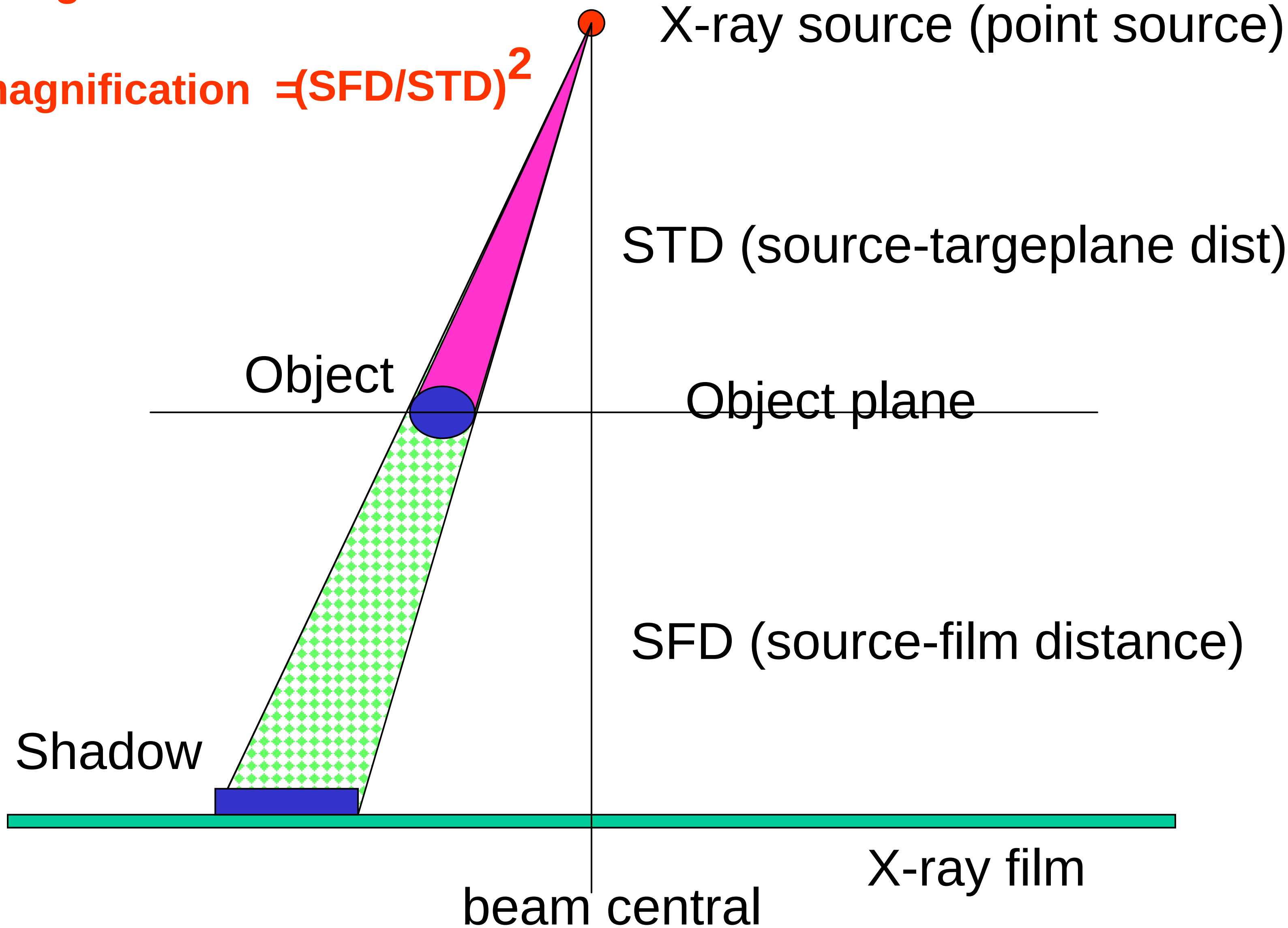


27. John Heartfield, *Das ist das Heil, das sie bringen!* Copyright © 1997 Artists Rights Society (ARS), New York/VG Bild-Kunst, Bonn.

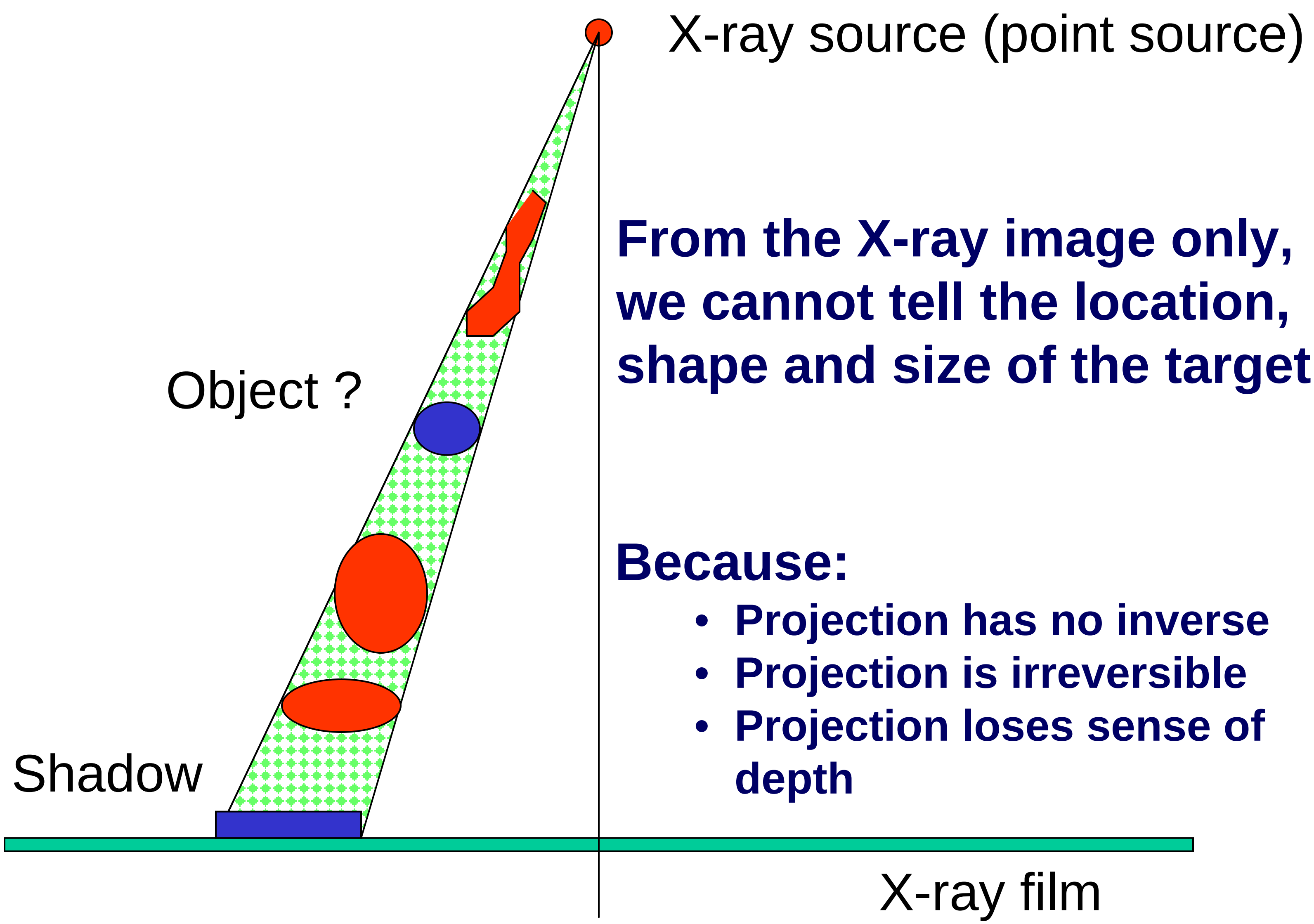
The geometry of X-ray

Linear magnification=SFD/STD

Areal magnification $=(SFD/STD)^2$



The fundamental problem of X-ray

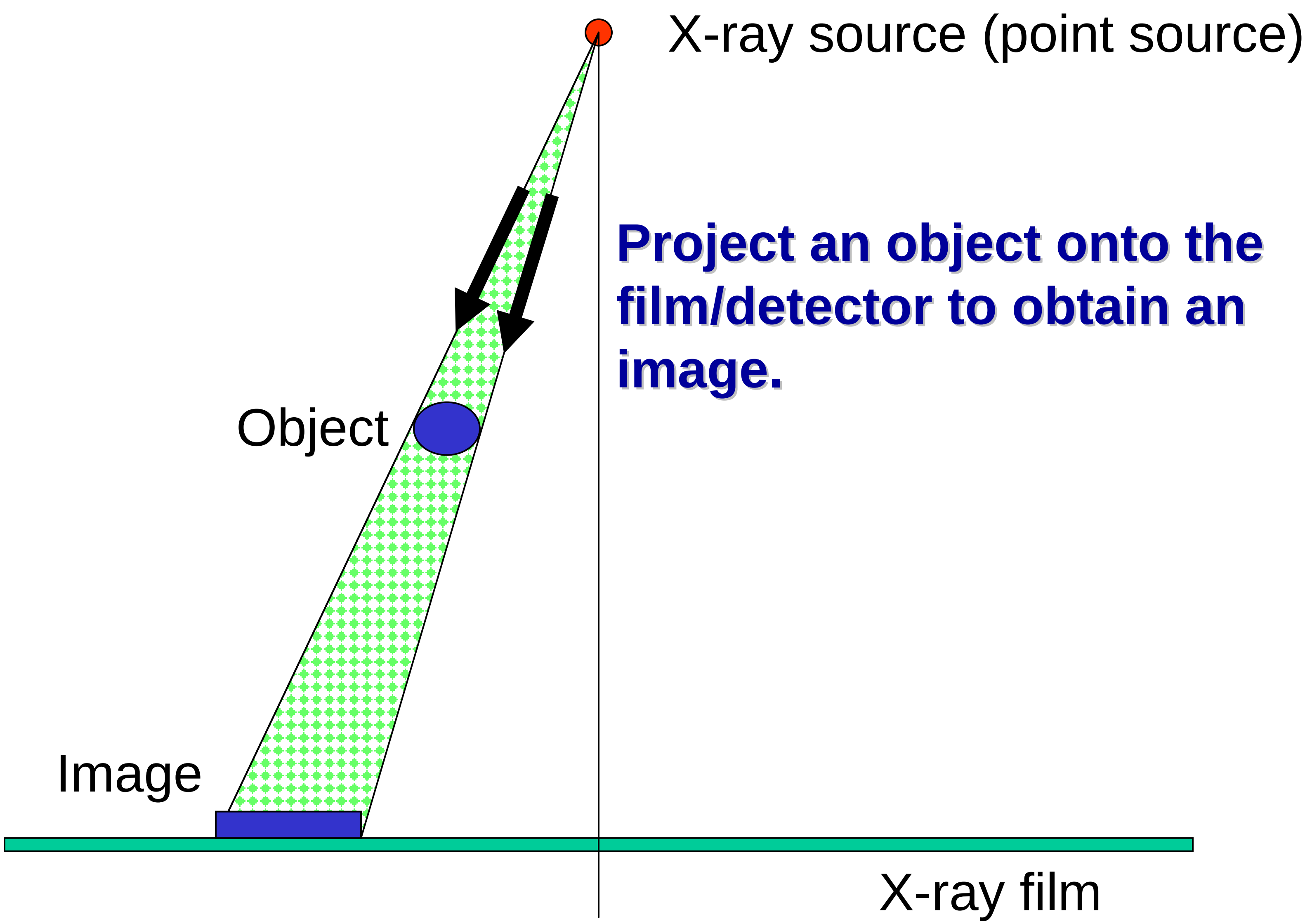


From the X-ray image only, we cannot tell the location, shape and size of the target

Because:

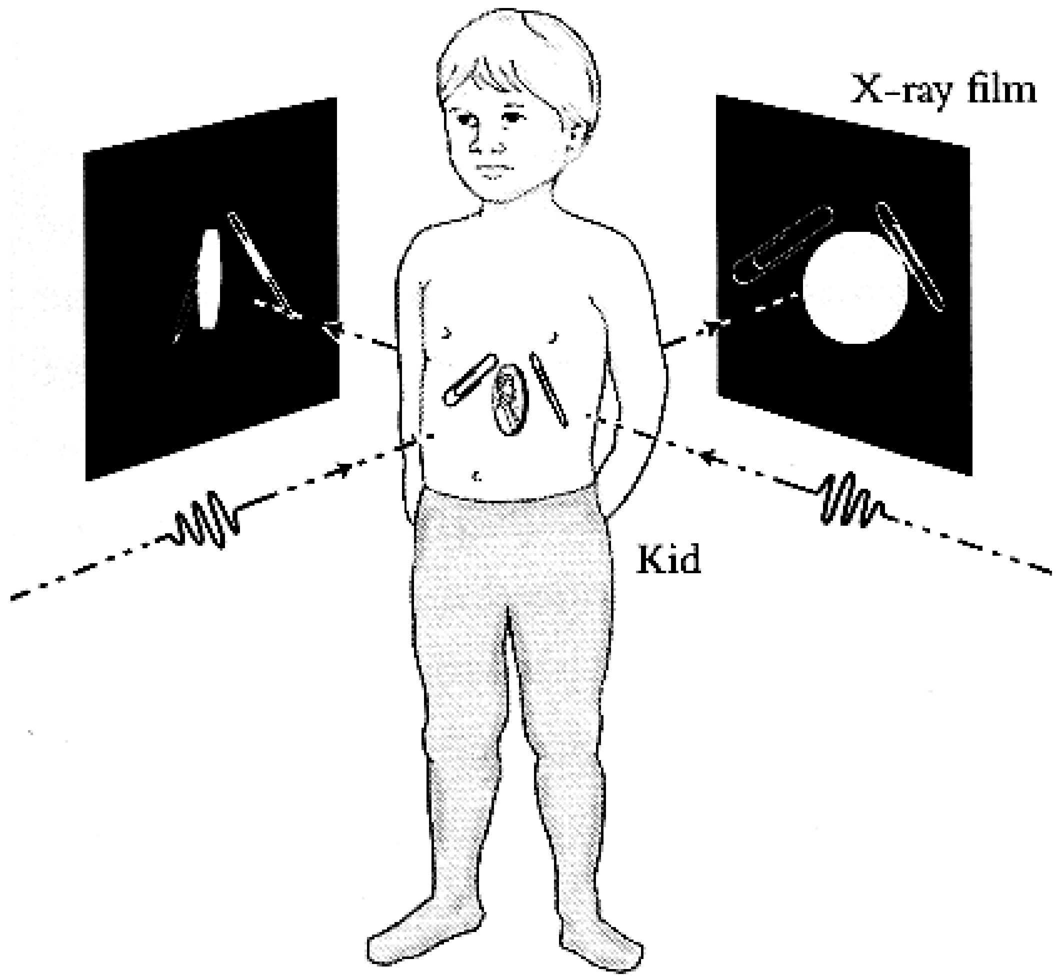
- **Projection has no inverse**
- **Projection is irreversible**
- **Projection loses sense of depth**

Forward projection

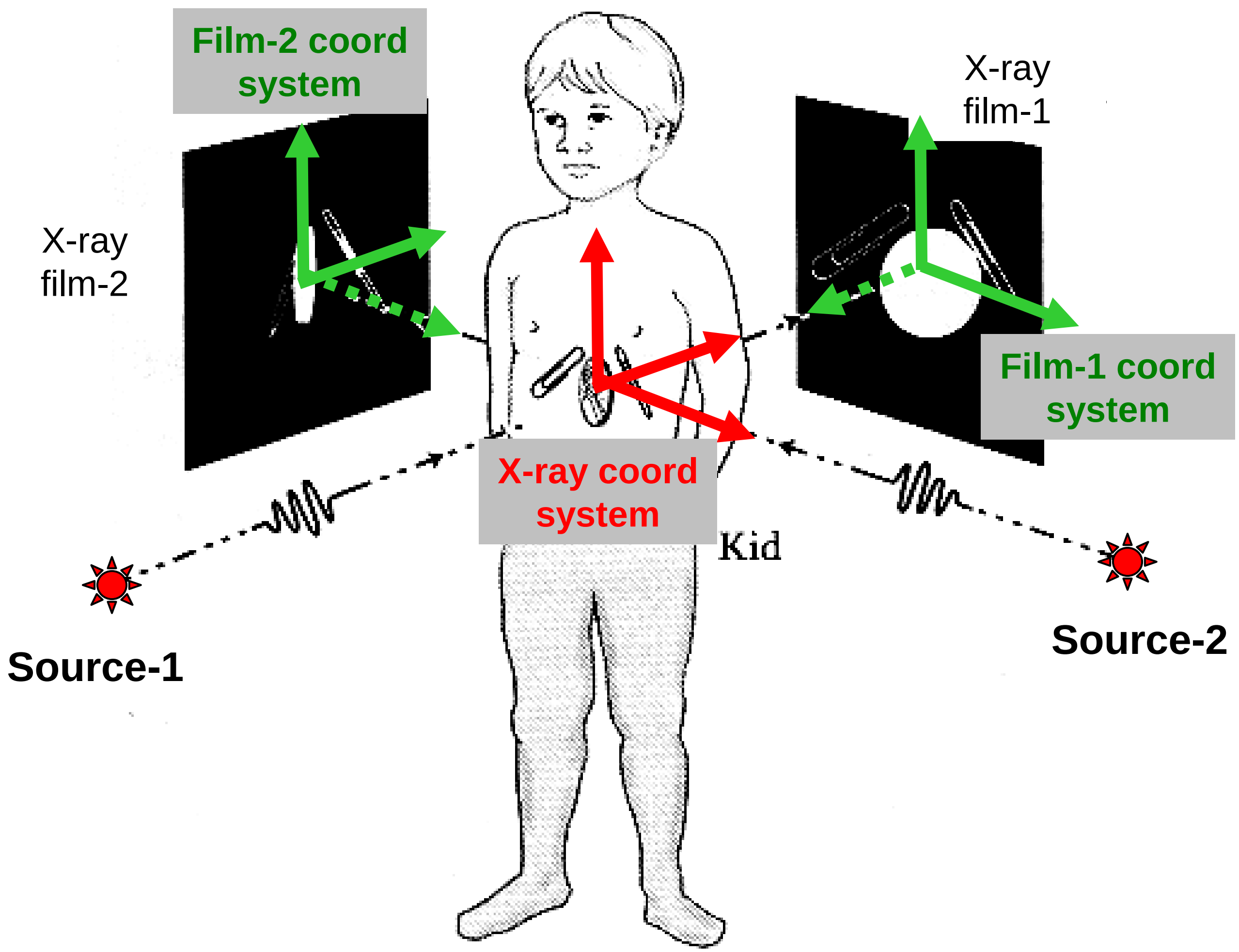


Project an object onto the film/detector to obtain an image.

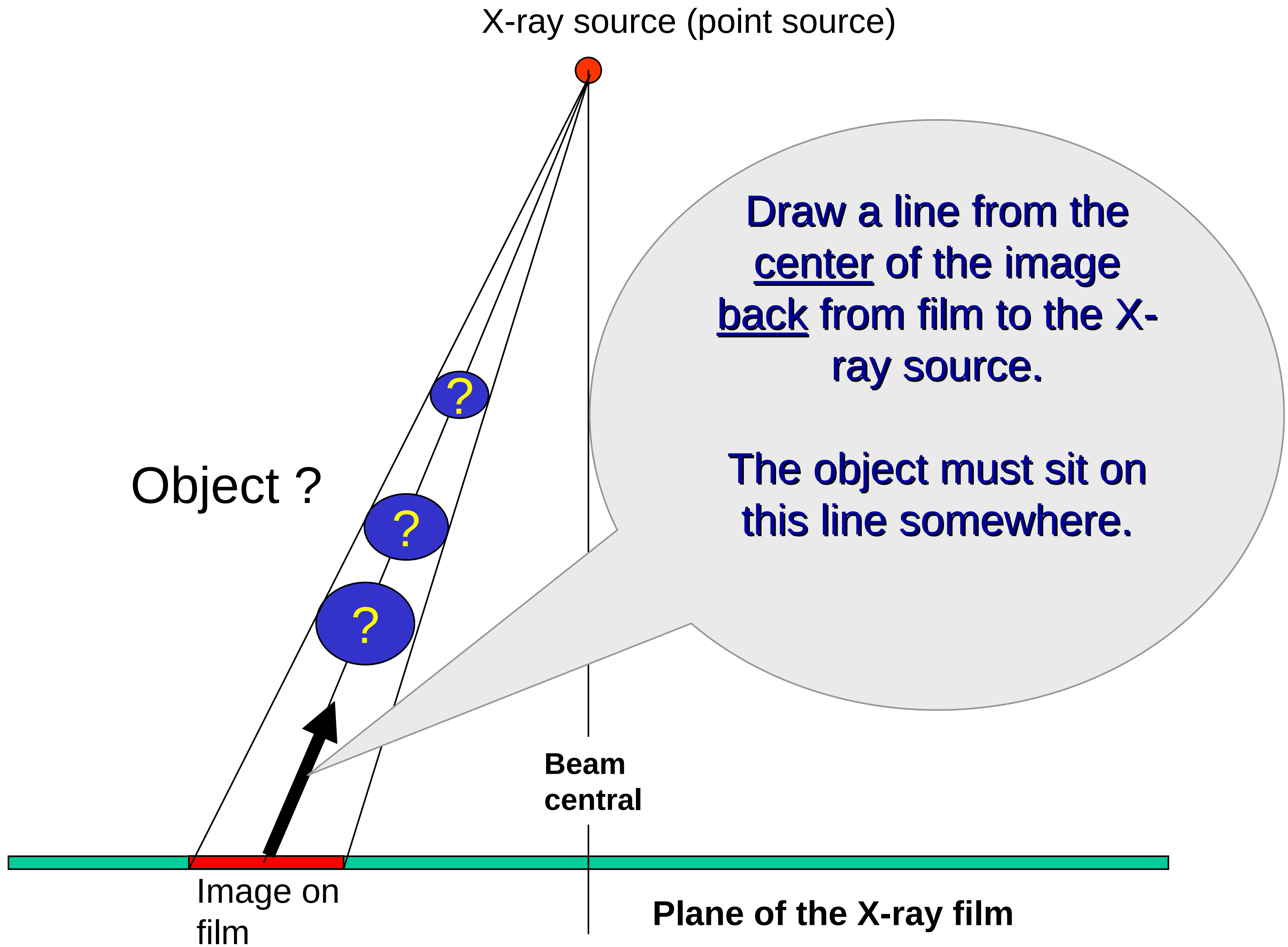
Are depth, 3D shape and volume lost forever?



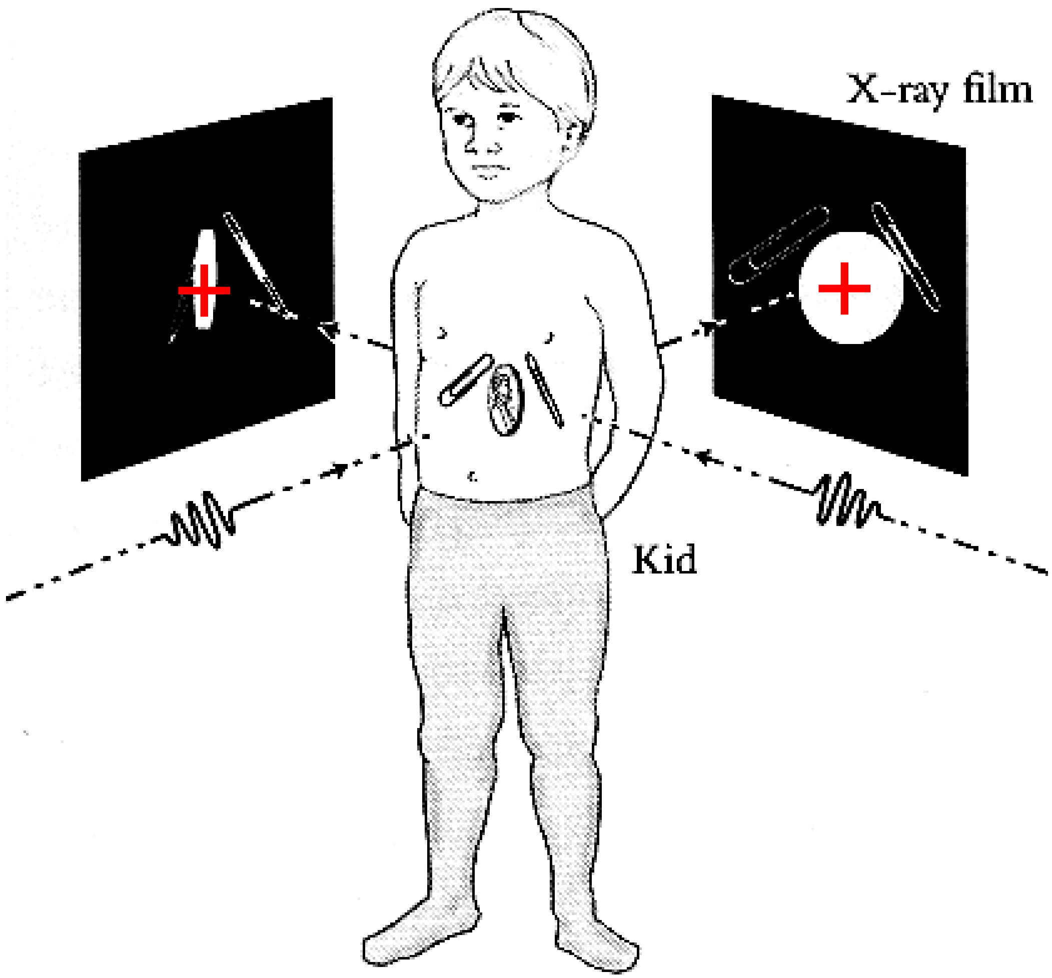
3D coordinate space



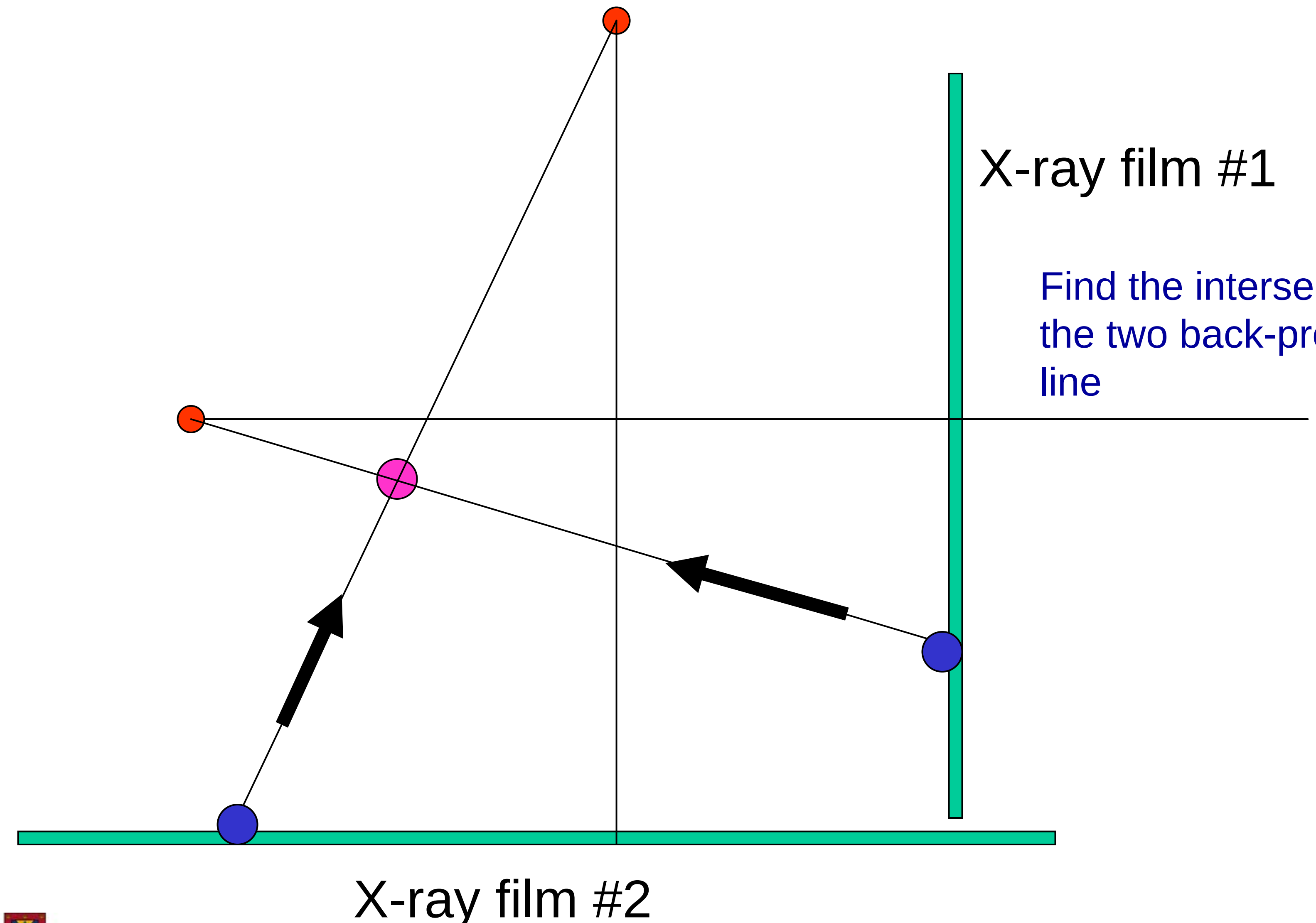
Back projection



Can we find (segment) the center accurately?



Reconstruction from 2 films

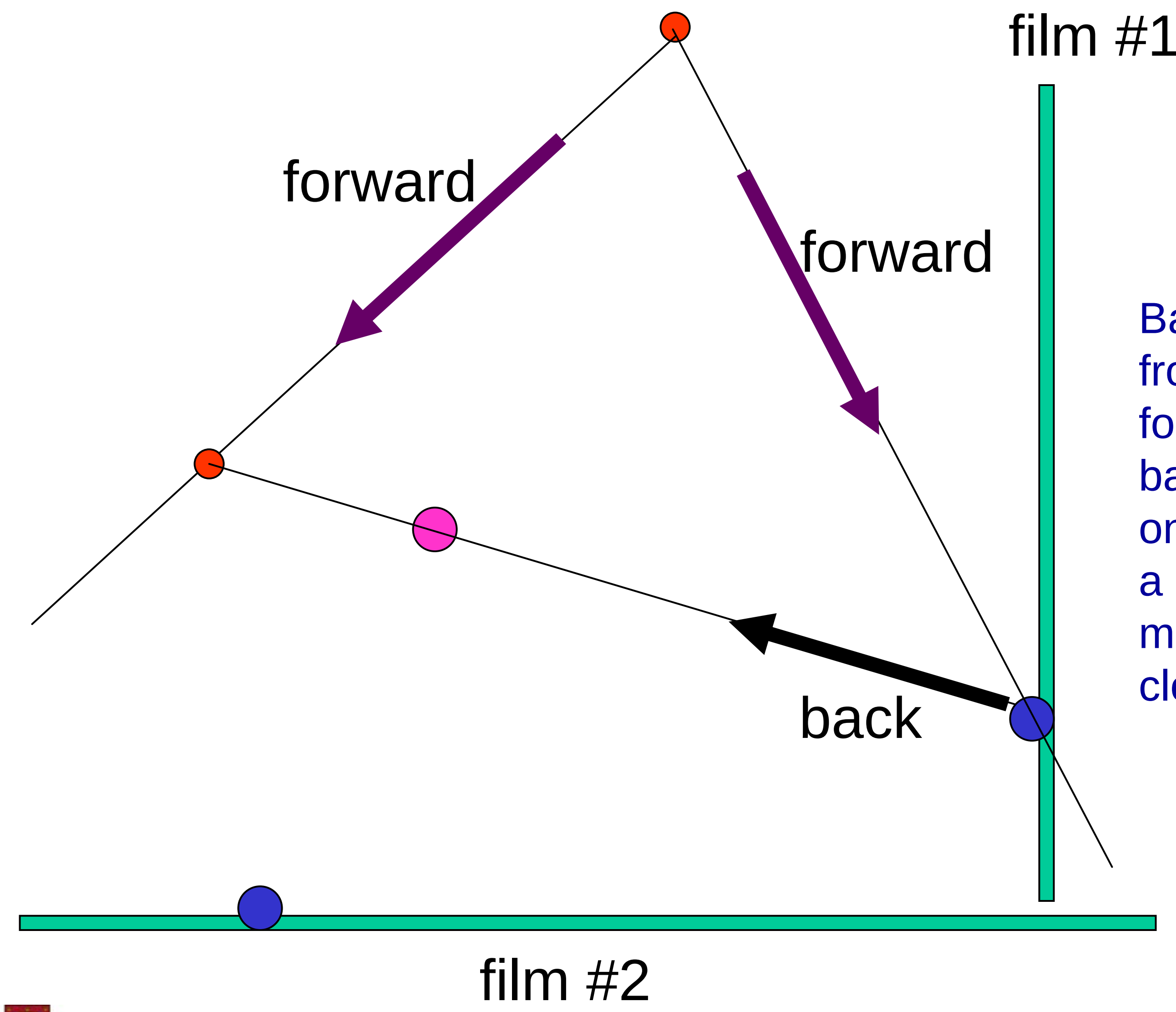


Find the intersection of the two back-projection line

Solve for the intersection of back-projection lines

- We look for the intersection of lines in 3D space
- Mathematical trouble – the intersection generally does not exist
- The two back projection lines avoid each other
- Why?
  - Image processing errors
  - Measurement errors
  - Calibration errors
  - Mechanical imperfections

Epipolar constraint



Back-project image from film1. Then forward project this back-projection line onto film2. The result is a line on film2. Image2 must lay on this line (or close to this line).

Pros and cons of plain X-ray

- Pros:
  - Simple
  - Inexpensive
  - Excellent bone contrast
- Cons:
  - Harmful dose to patient
  - Loss of shape and depth of objects
  - Poor soft tissue contrast
  - **Delay between shots and seeing films**