KU LEUVEN

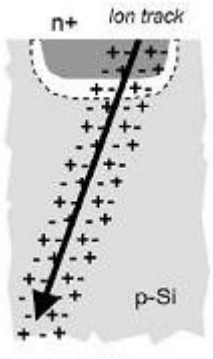
Testing for Radiation Hardness

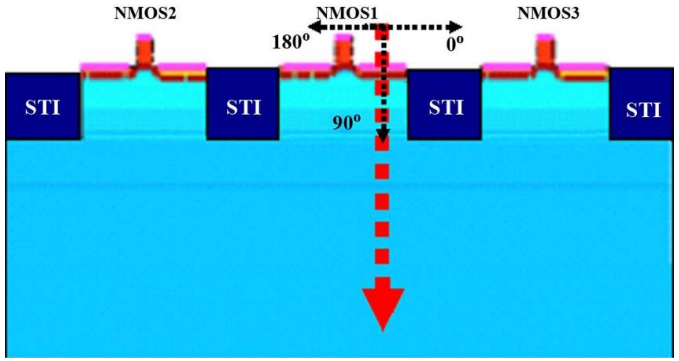
Dr. ing. Jeffrey Prinzie

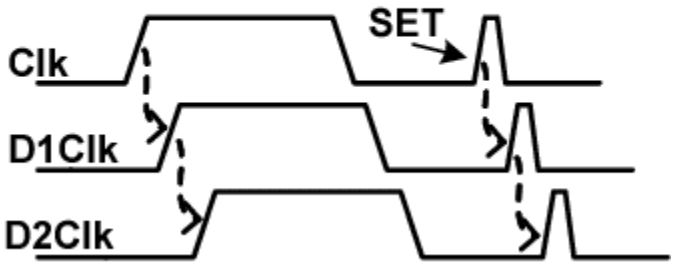
Overview of radiation test

- Simulation:
  - MC particle simulators
  - TCAD – circuit simulation
- TID:
  - X-ray
  - ^{60}Co gamma
- SEE testing
  - Heavy ions
  - Protons
  - Mixed fields
  - Two-Photon Absorption laser testing

Simulation







Particles ionize Si atoms

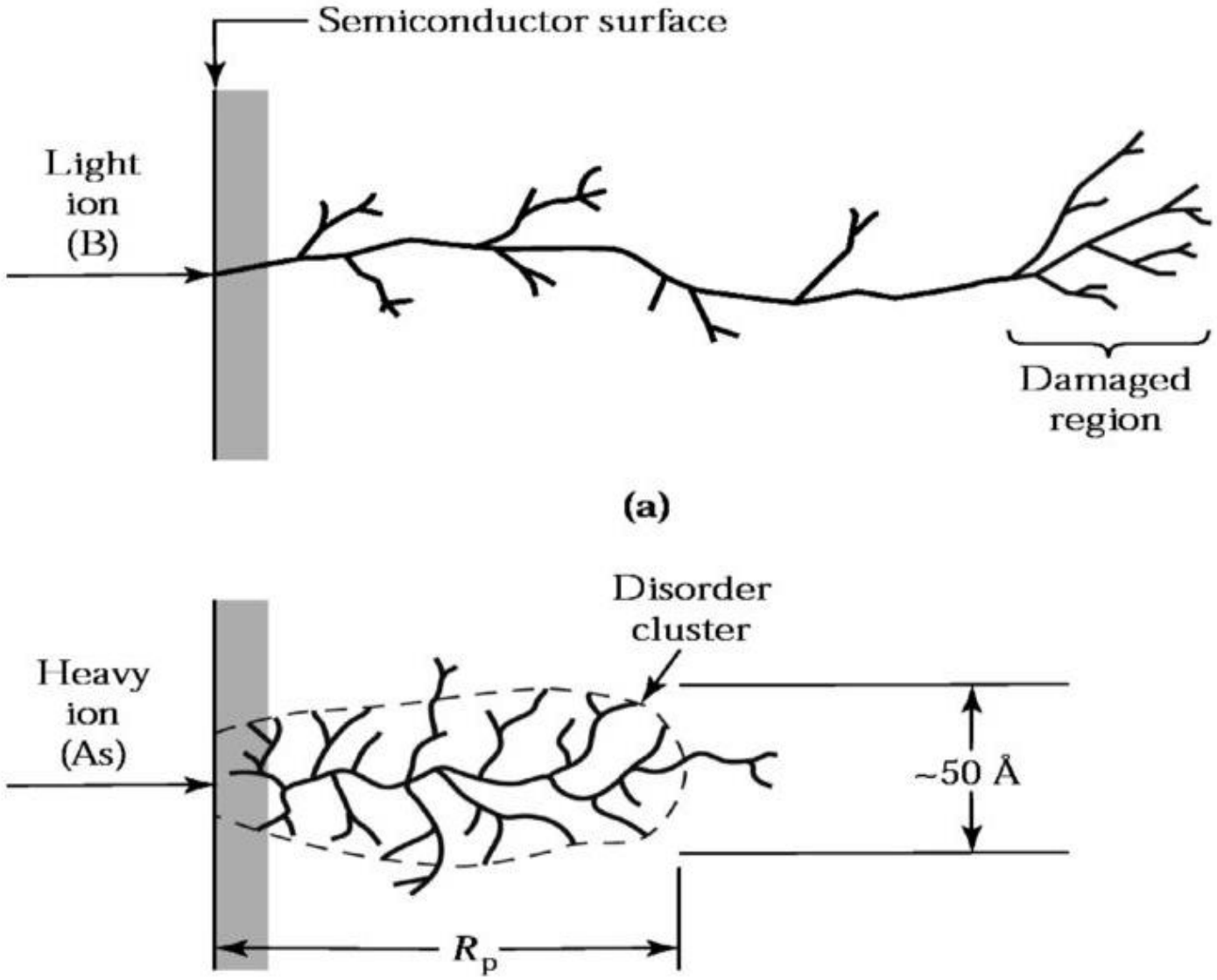
Nuclear physics
- Particles
- Atoms
- Energy

e-h Pairs drift/diffuse and generate currents

Device physics
- Charges
- Doping
- Potential
- Band diagrams

Currents affect circuit (Analog/Digital)

Circuit theory
- Currents
- Voltages
- Transistors
- Circuits
- Systems



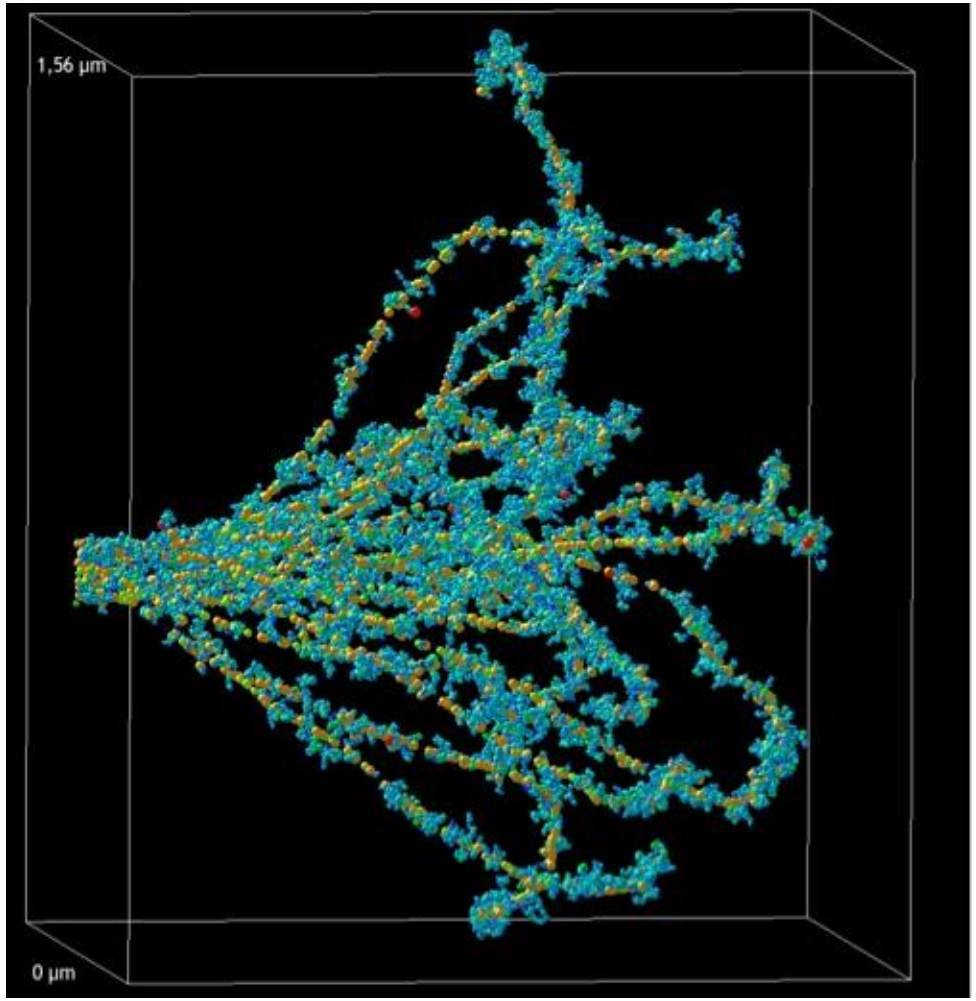
How to simulate this?

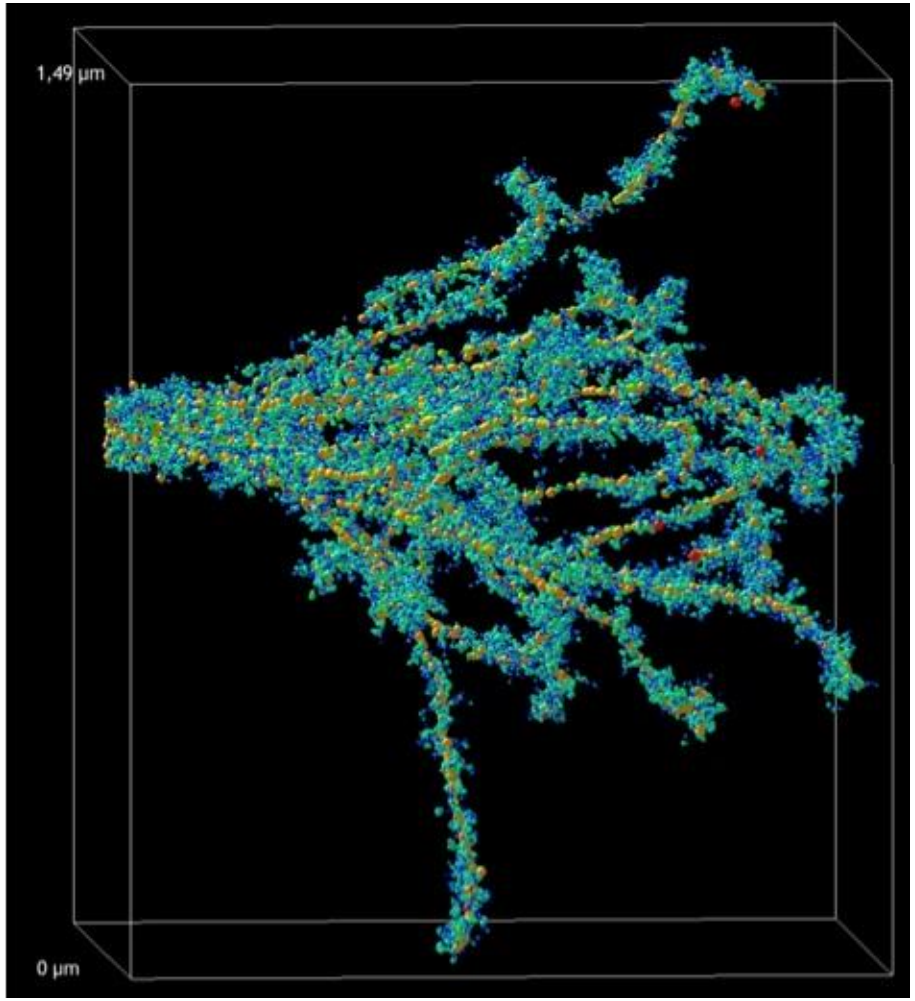
Monte-Carlo nuclear simulation

- Interactions of radiation with matter
- Statistical, chance of certain interactions (ionization, scattering, displacement, nuclear reactions): cross section
- Monte-Carlo simulators:
  - MCNP
  - GEANT4 (Geometry and Tracking 4)
  - FLUKA (Fluktuierende Kaskade)
  - SRIM/TRIM Stopping tables

- **<u>GOAL:</u>** Find ionization energy in the silicon (~LET)

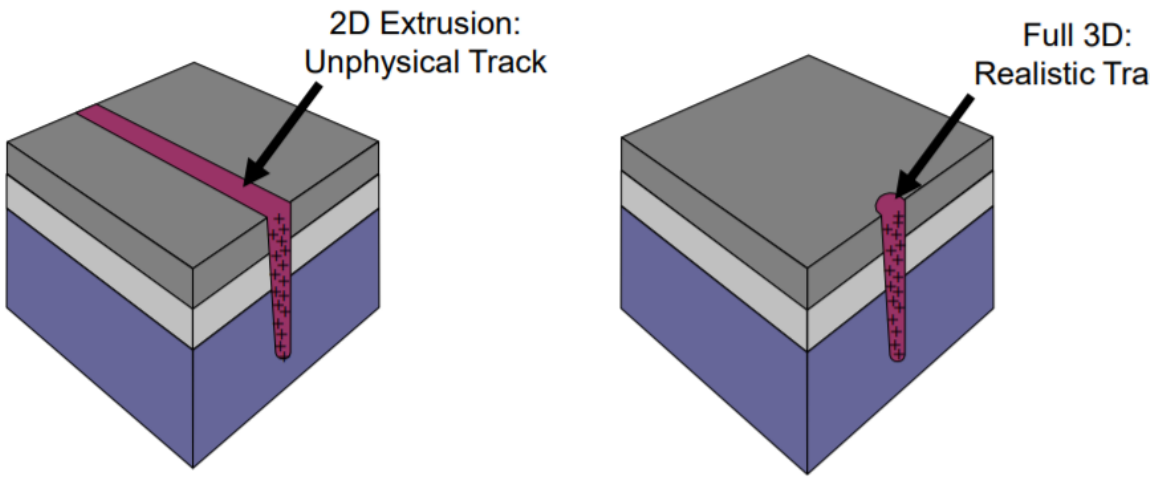
Monte-Carlo nuclear simulation

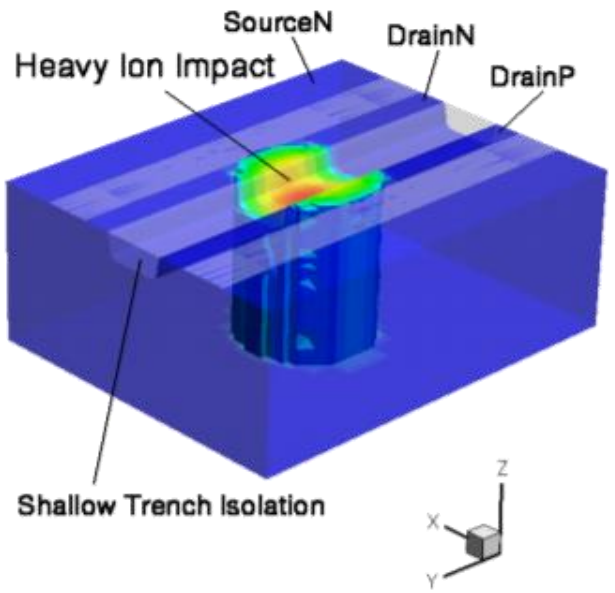




TCAD simulation

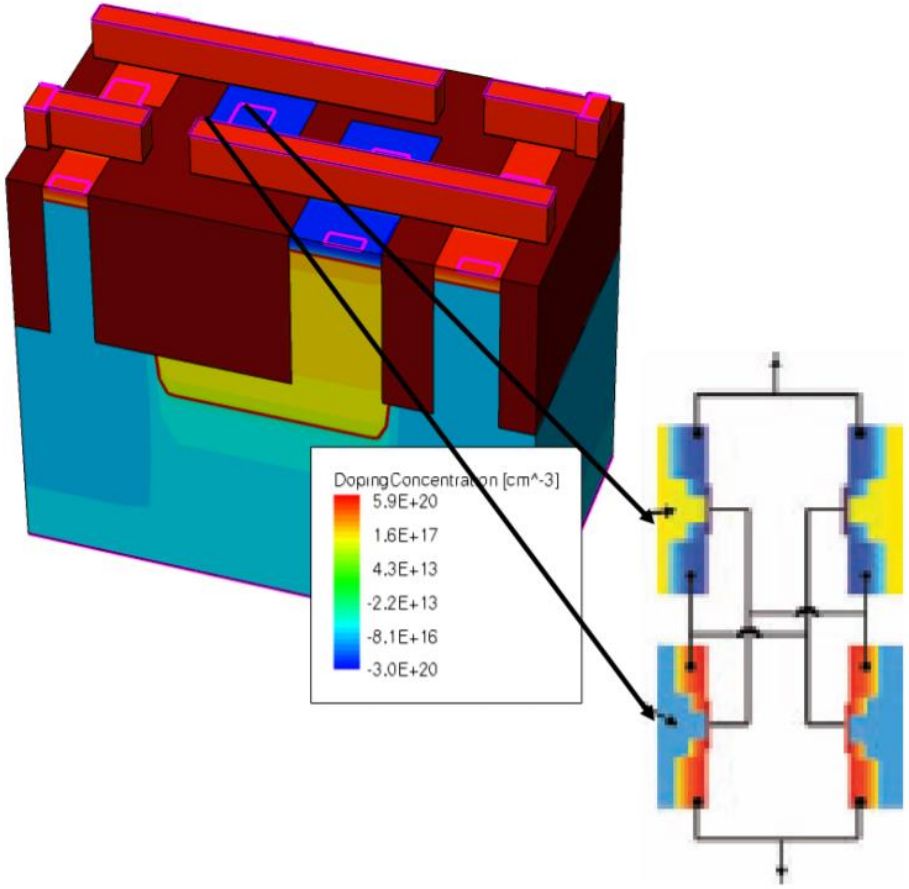
- “Technology Computer Aided Design”
- Simulation of semiconductor devices
- Transient analysis of charges
- Particle e-h pair generation
  = impulse charge
- **<u>GOAL:</u>** Find collection current waveform
- **Time consuming simulation!**
- 2D and 3D
- Vendors: Synopsys TCAD; Robustchip; Silvaco

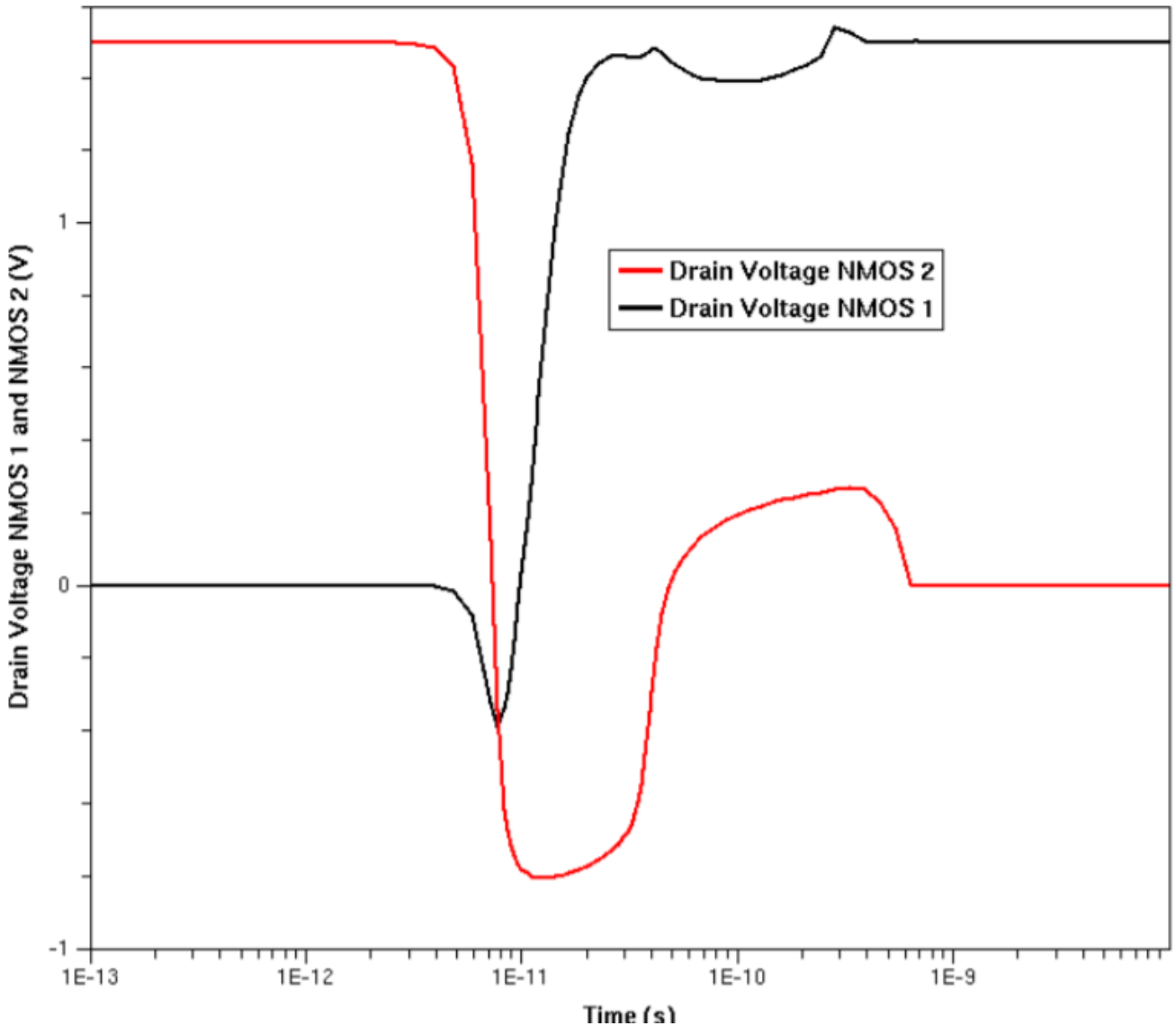




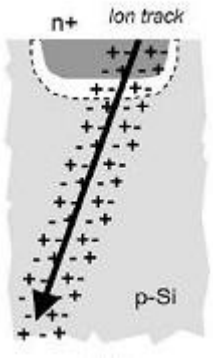
TCAD simulation

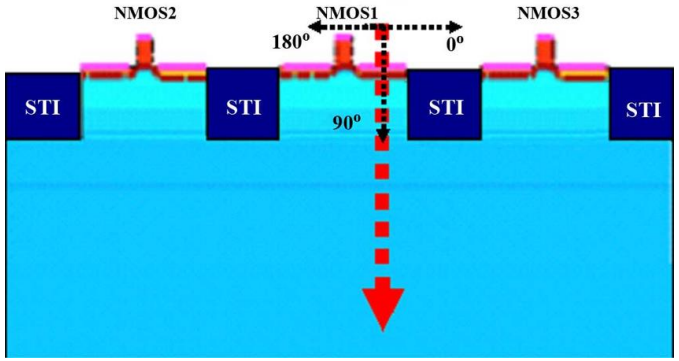
6T SRAM

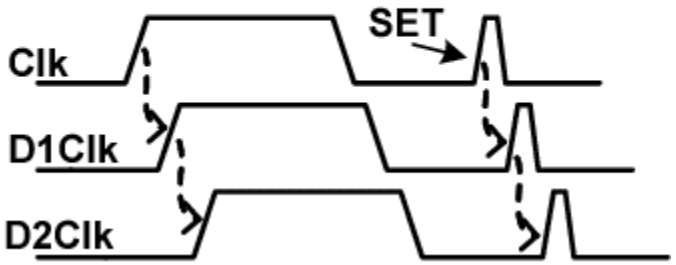




Simulation







Particles ionize Si atoms → **e-h Pairs drift/diffuse and generate currents** → **Currents affect circuit (Analog/Digital)**

Nuclear physics
- Particles
- Atoms
- Energy

→

Device physics
- Charges
- Doping
- Potential
- Band diagrams

→

Circuit theory
- Currents
- Voltages
- Transistors
- Circuits
- Systems

Test Facilities

Overview of radiation test

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  - Heavy ions
  - Protons
  - Mixed fields
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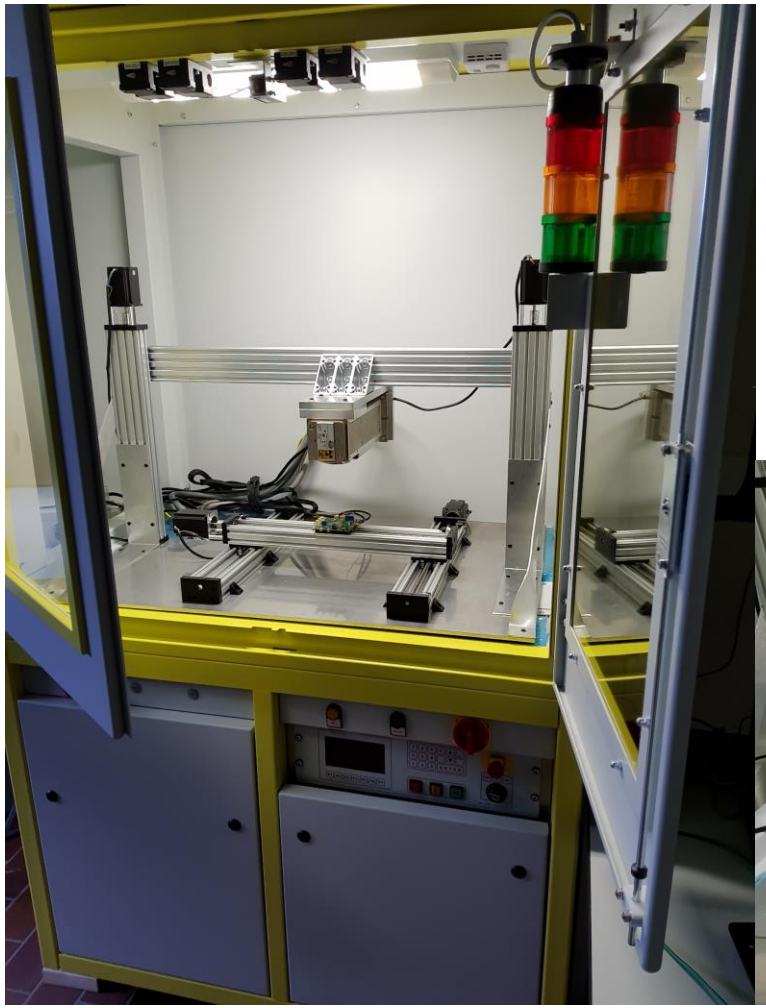
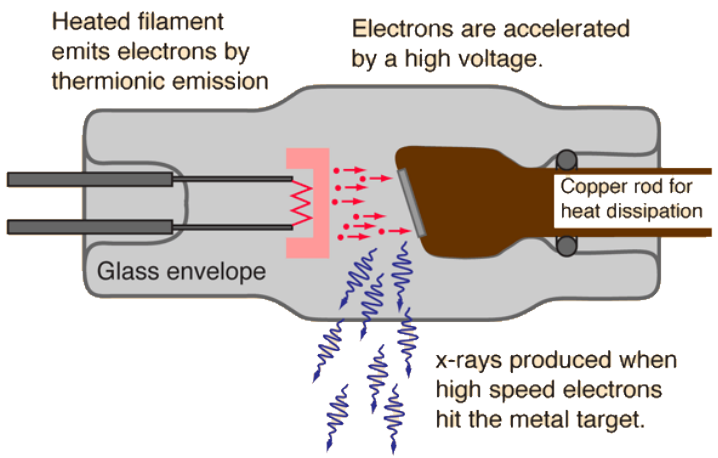
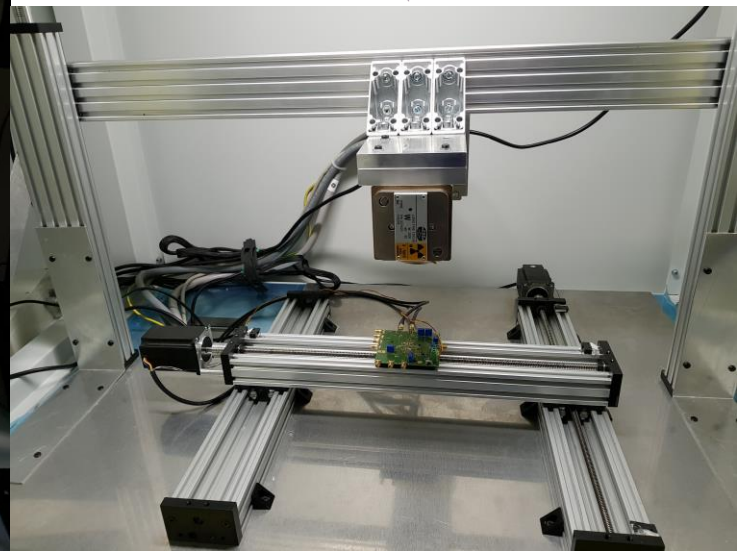
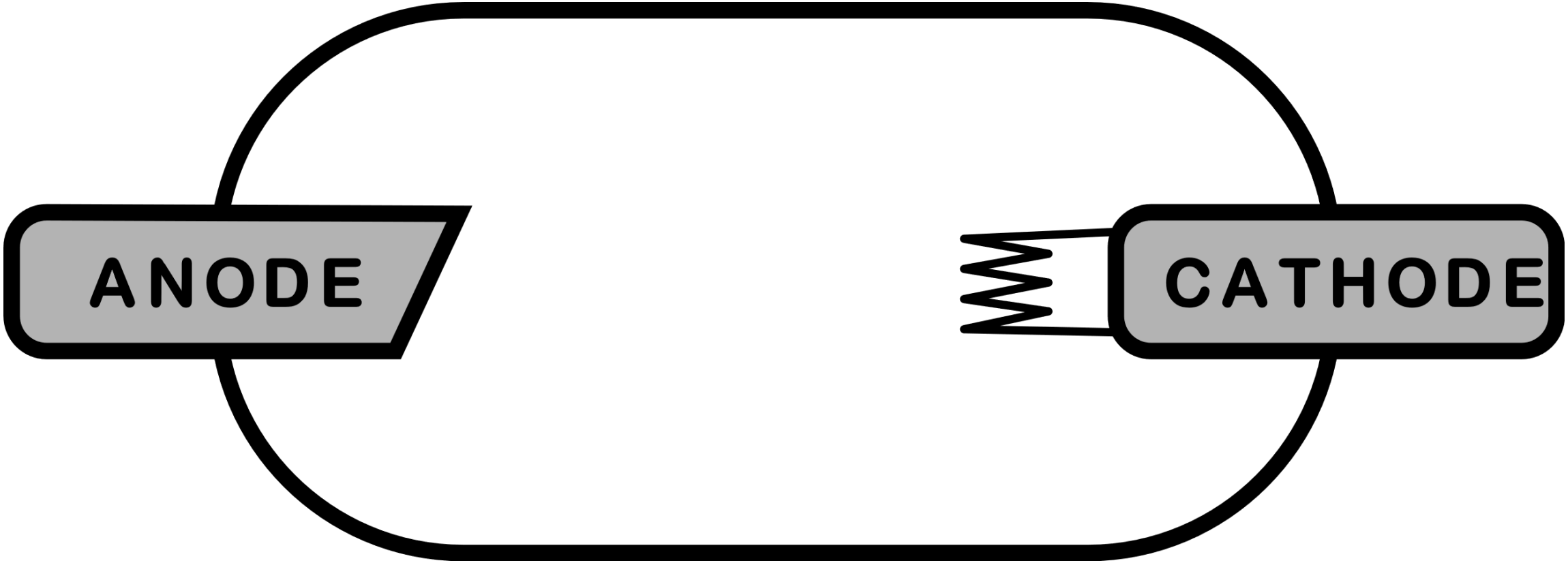
X-ray radiation testing (ADVISE lab)

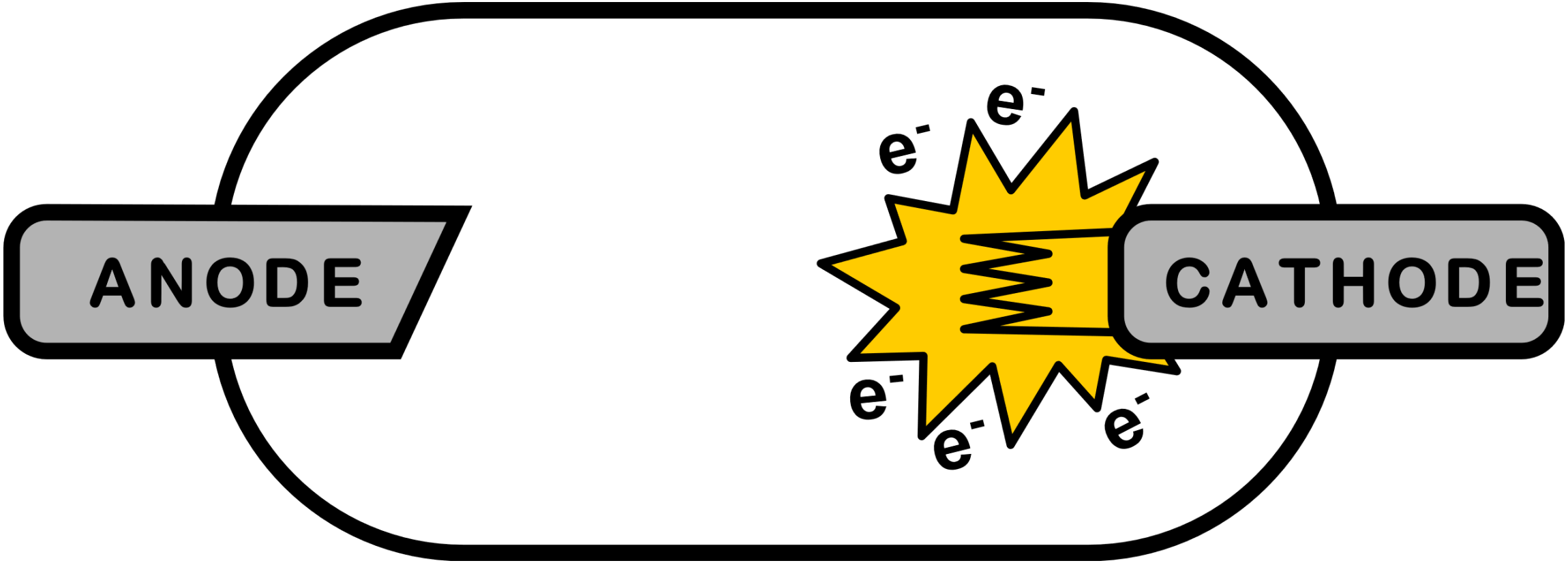
- 3 kW X-ray source
  - Roentgen tube
  - 60 kV electron accelerator
  - 50 mA current
- 0.5 MGy / 12h
- Efficiency ~1%
  - Extensive cooling needed!
- Some have rotating target

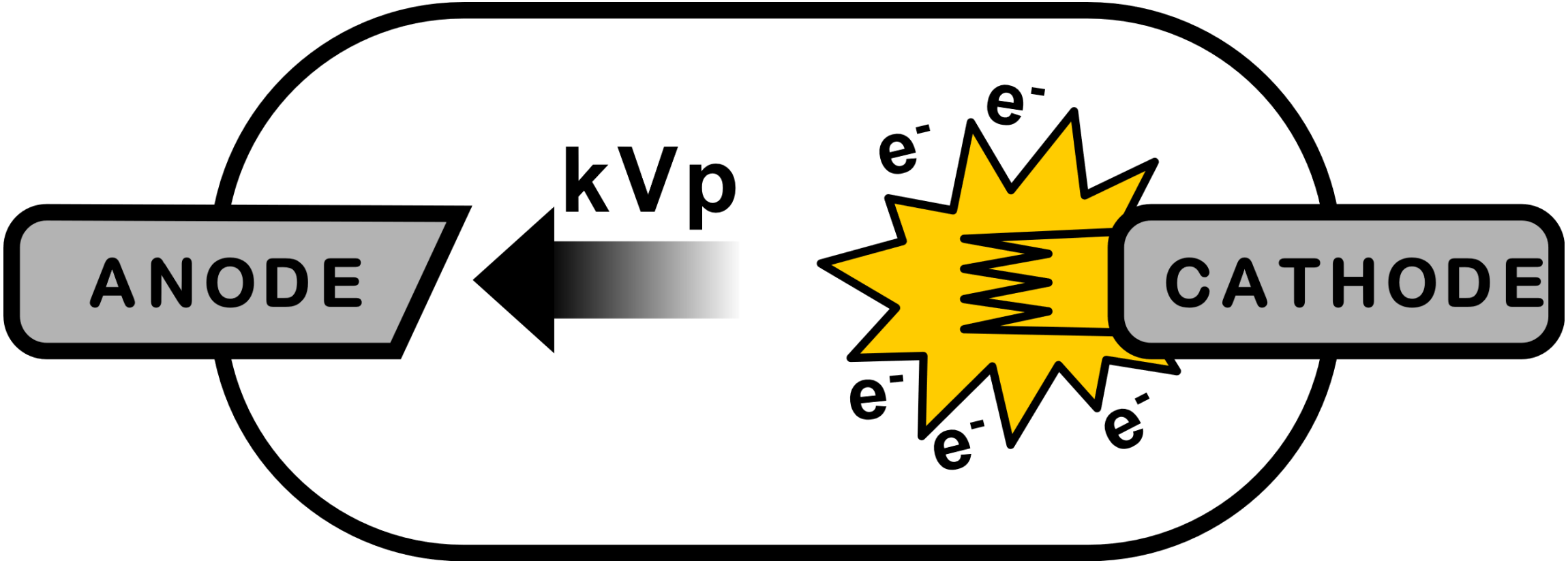


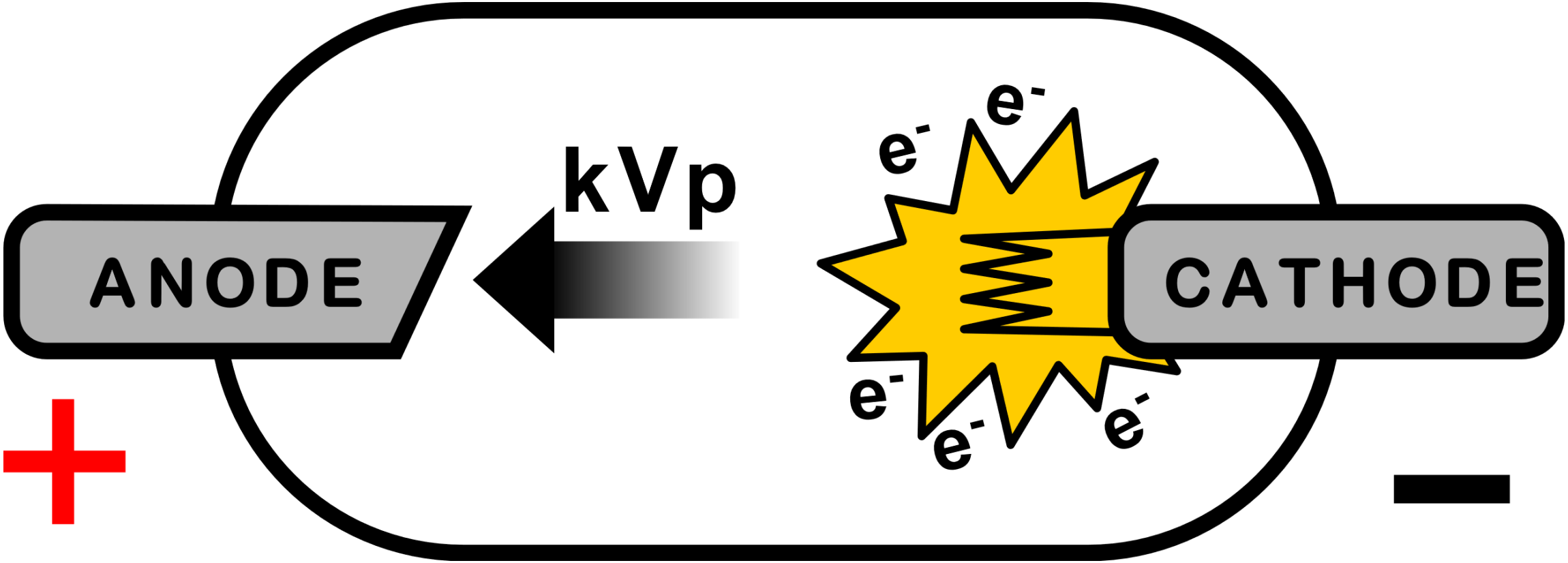


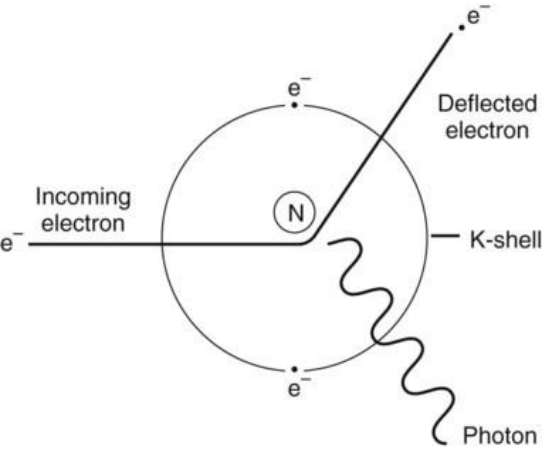


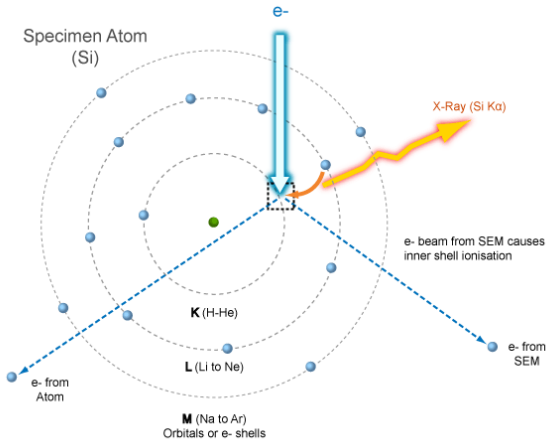

ANODE
CATHODE

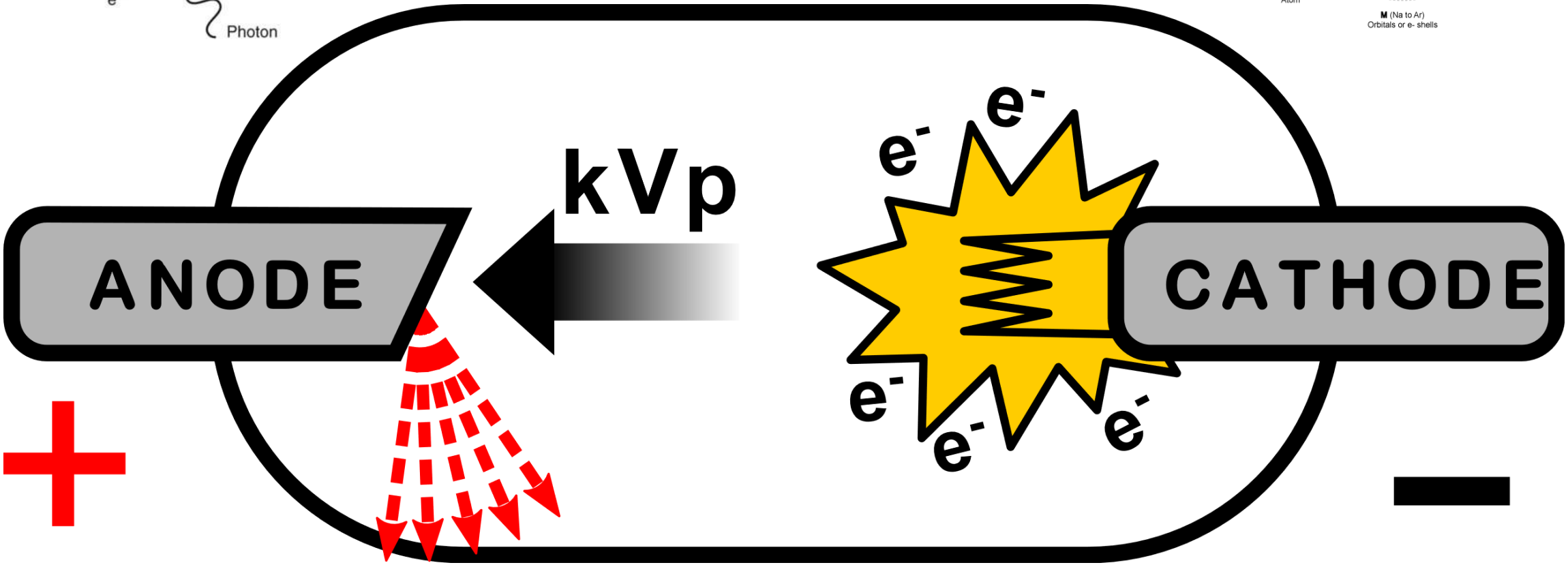

ANODE
CATHODE
e-
e-
e-
e-
e-


ANODE
kVp
e-
e-
e-
e-
e-
e-
CATHODE

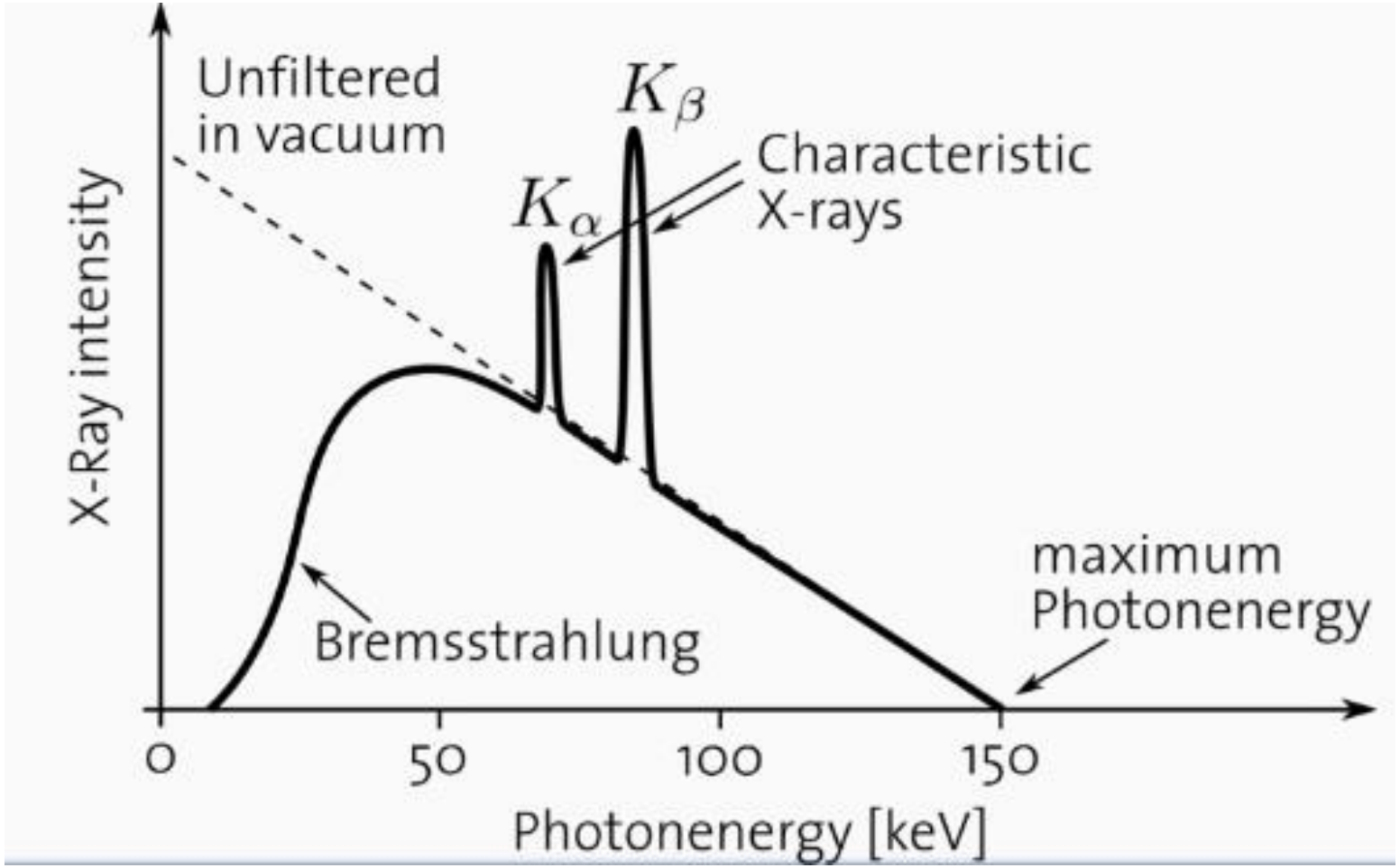

ANODE
kVp
e-
e-
e-
e-
e-
e-
CATHODE
+
–

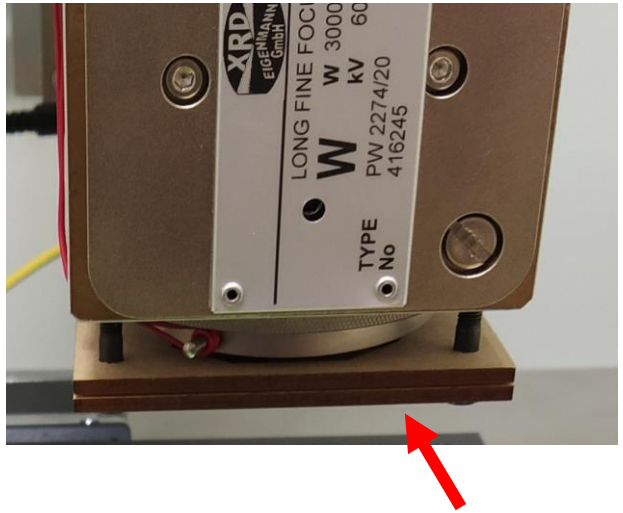

e⁻
Deflected electron
Incoming electron
e⁻
N
K-shell
e⁻
e⁻
Photon


e-
Specimen Atom (Si)
X-Ray (Si Kα)
e- beam from SEM causes inner shell ionisation
K (H-He)
L (Li to Ne)
M (Na to Ar)
Orbitals or e- shells
e- from Atom
e- from SEM


kVp
ANODE
CATHODE
e-
e-
e-
e-
e-
e-
+
−

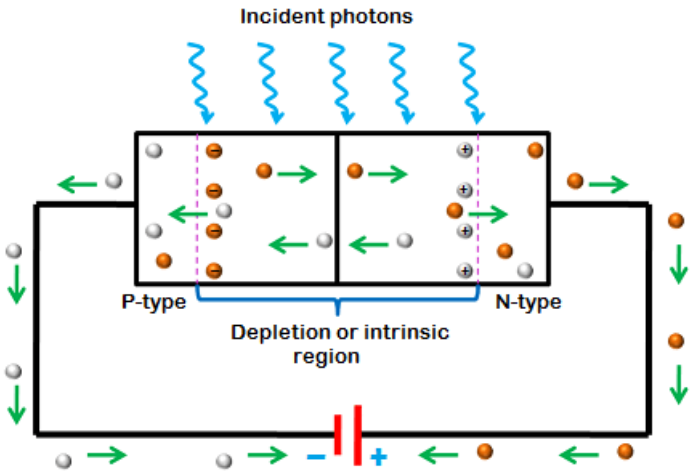
X-ray Filter

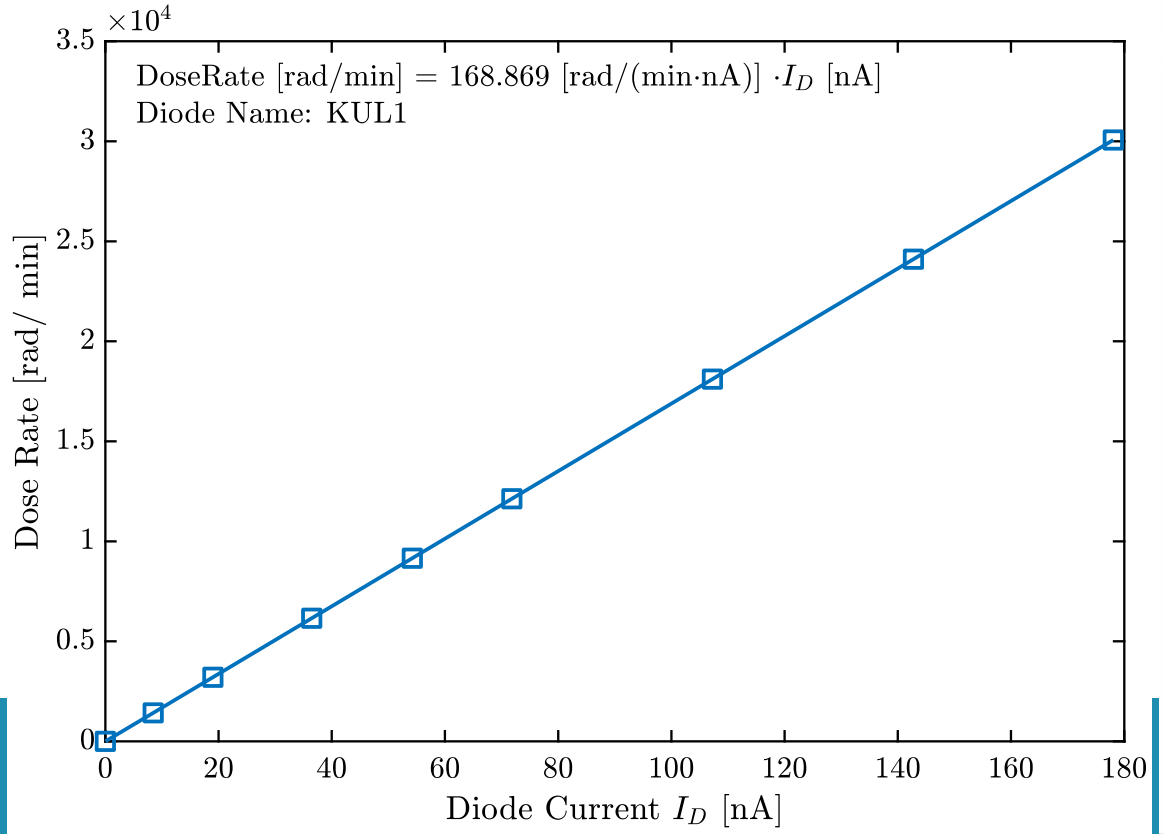


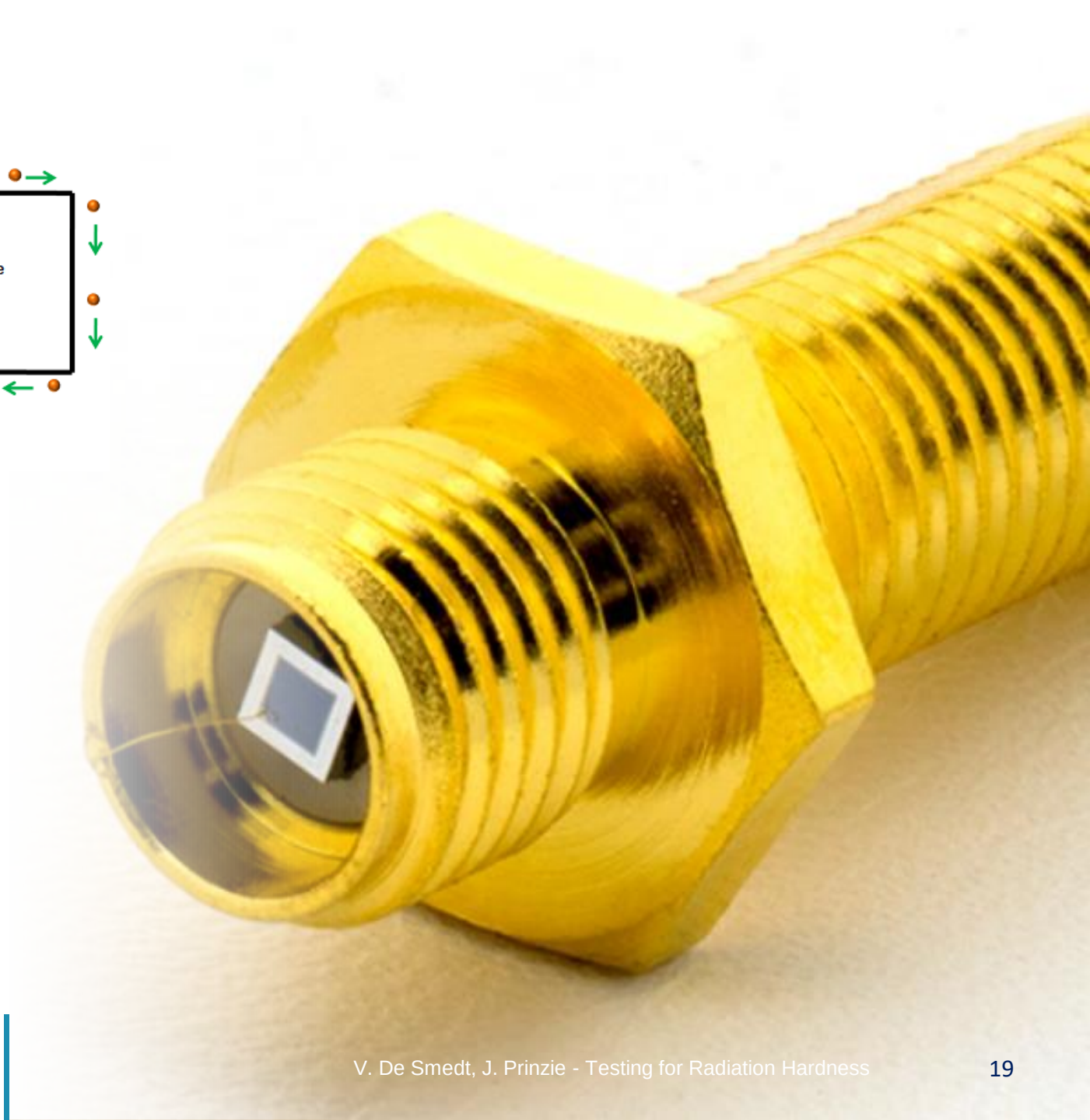


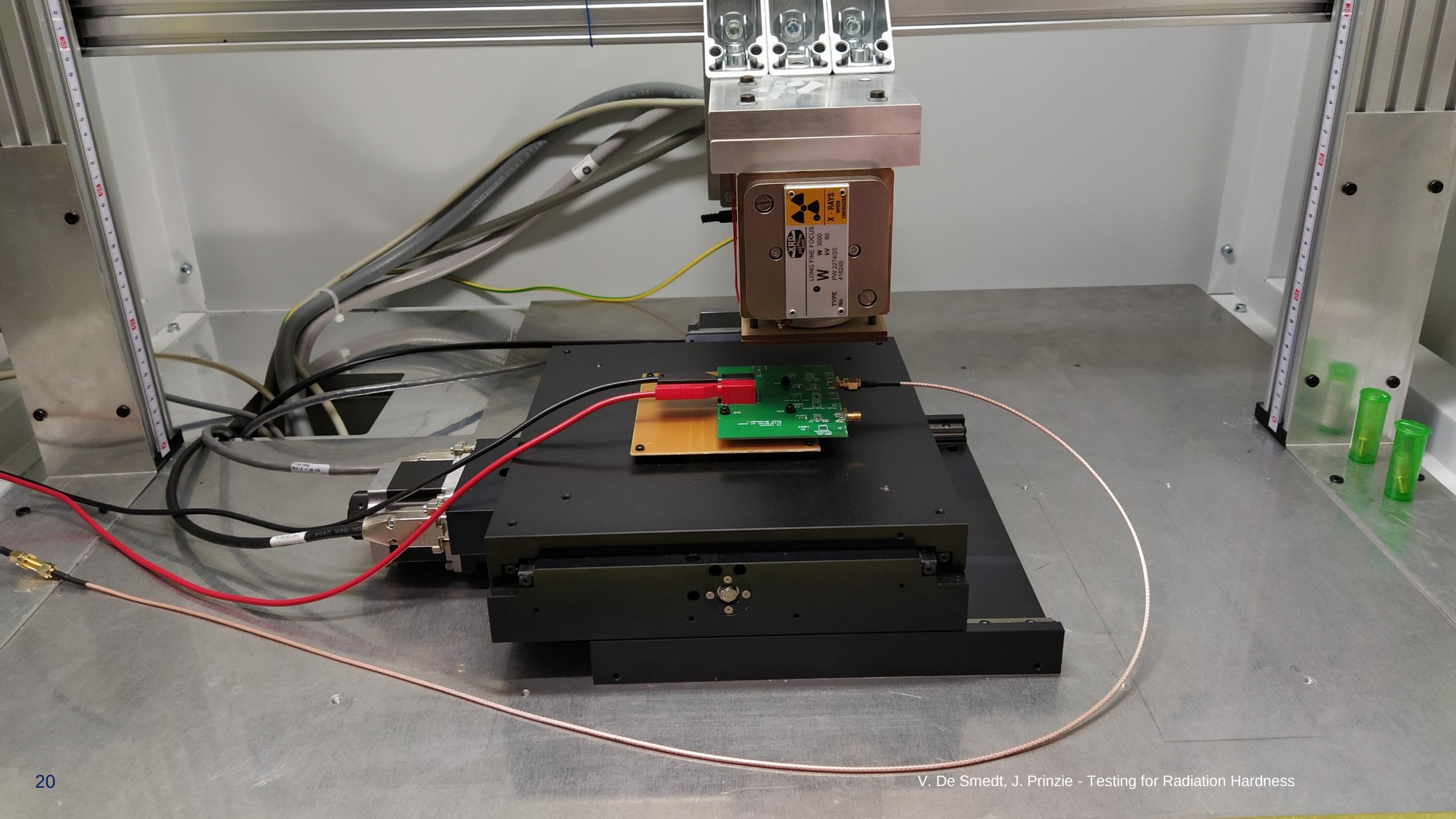
- Aluminum filter
- 150 µm thick
- < 8-10 keV

Dose rate calibration



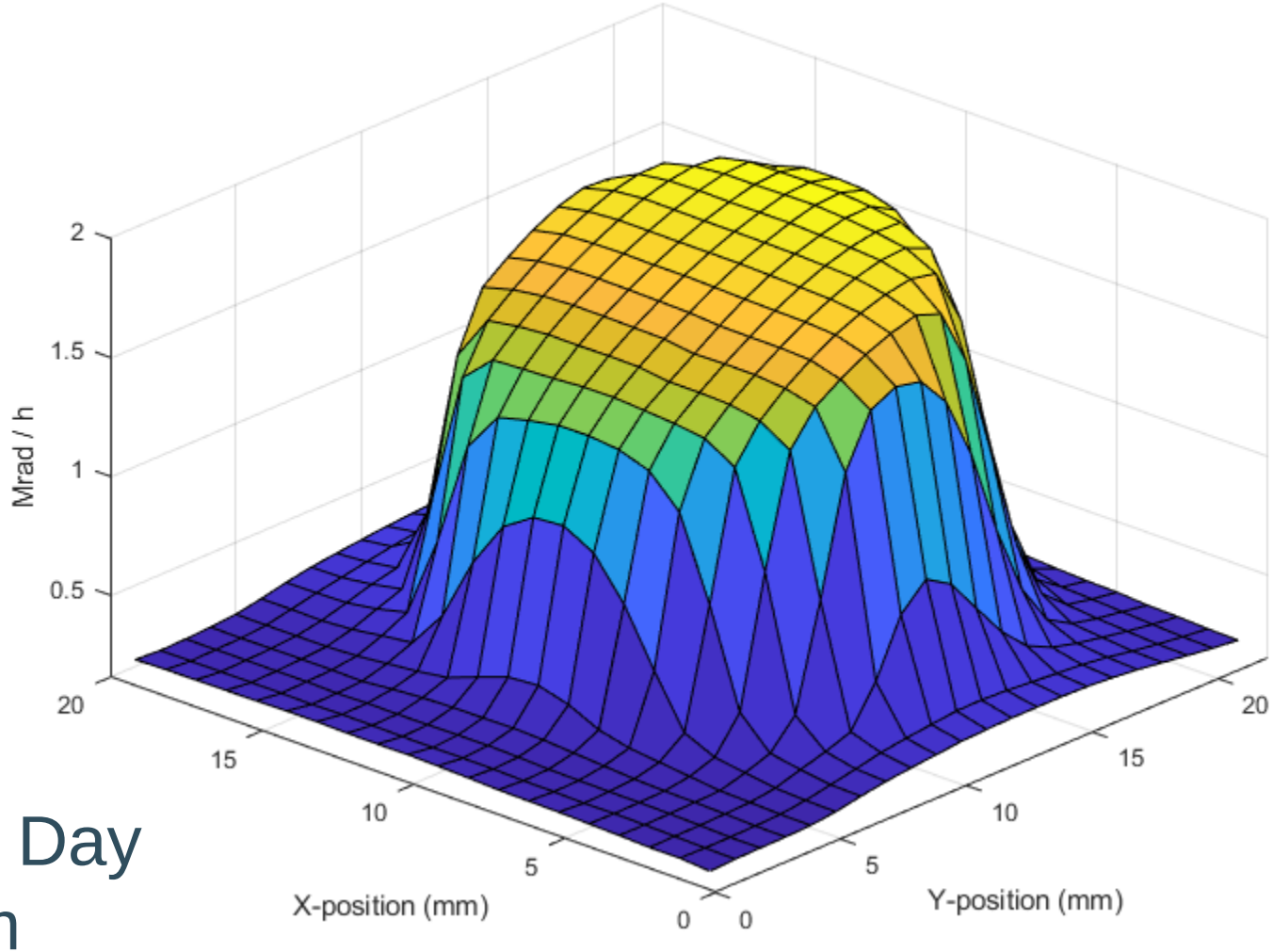




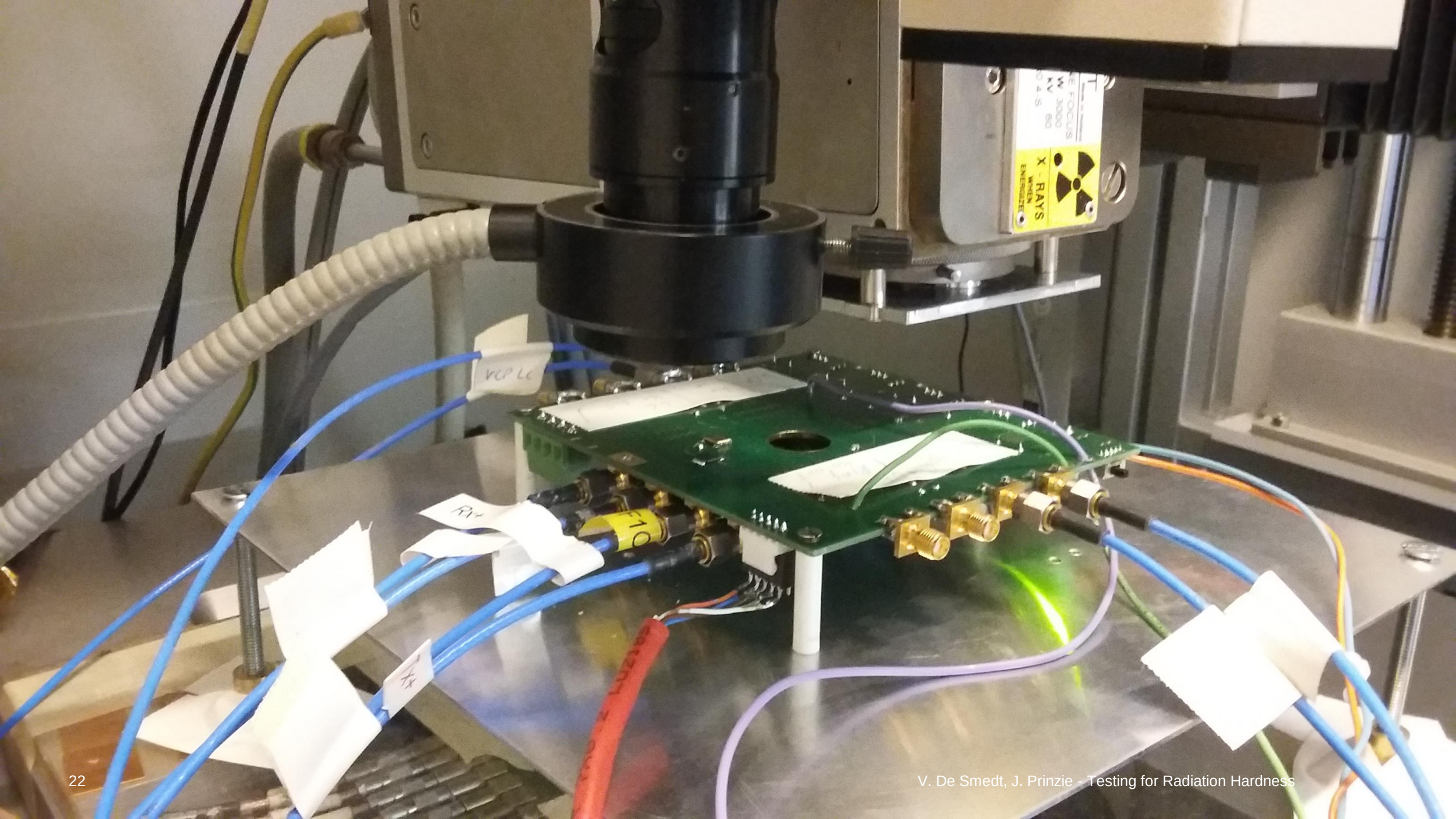

X - RAYS
LONG FINE FOCUS
W
W 3000
kV 60
TYPE
No
P/N 2274/20
416245

X-ray Calibration

- 40 kV
- 60 mA
- @ 3cm

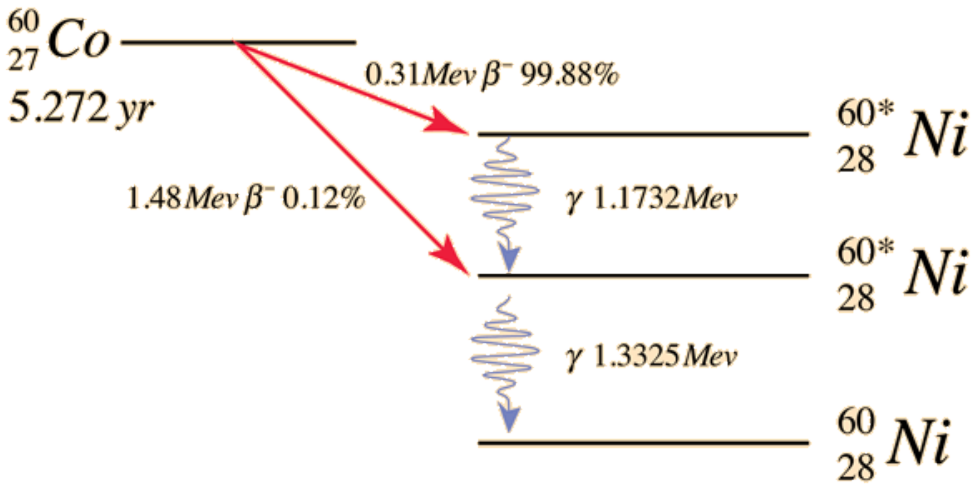


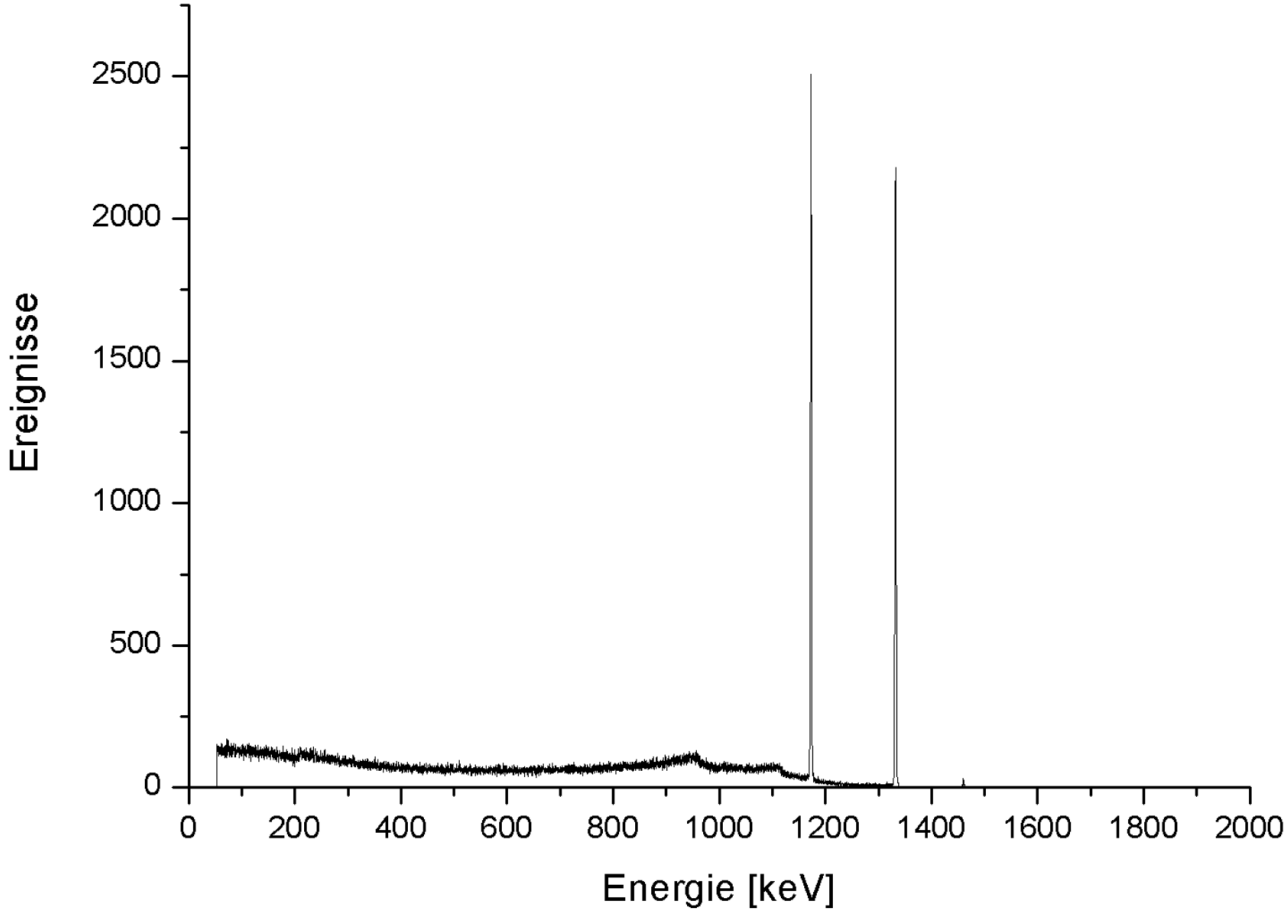
0.45 MGy / Day
14 x 14 mm


X - RAYS
WHEN
ENERGIZED
Rx+
Tx+

Gamma irradiation facilities

- ^{60}Co
  - β-decay (+ antineutrino)
  - half-life of 5.27 years
  - Nuclear excited state of Ni

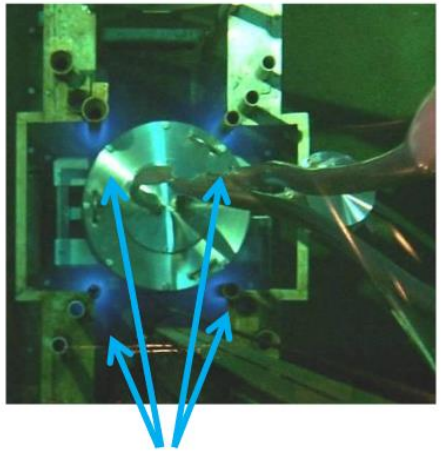




RITA: Co^{60} under-water irradiation facility

Available volume (max):
Ø38 cm, h = 60 cm
(with some conditions Ø43 cm)
Ambient temperature: 26-27°C
Temperatures up to **250 °C** are possible with an oven (smaller volume)

Cylindrical Container for irradiated samples



Container in the irradiation position: Co^{60} sources emit blue light – Cherenkov radiation

Available dose-rates: 50 - 700 Gy/h. The dose-rate is adjusted by changing the position of Co^{60} sources and changing the vertical position of the samples in the chamber, max dose-rate over ~15 cm height (<10% gradient)

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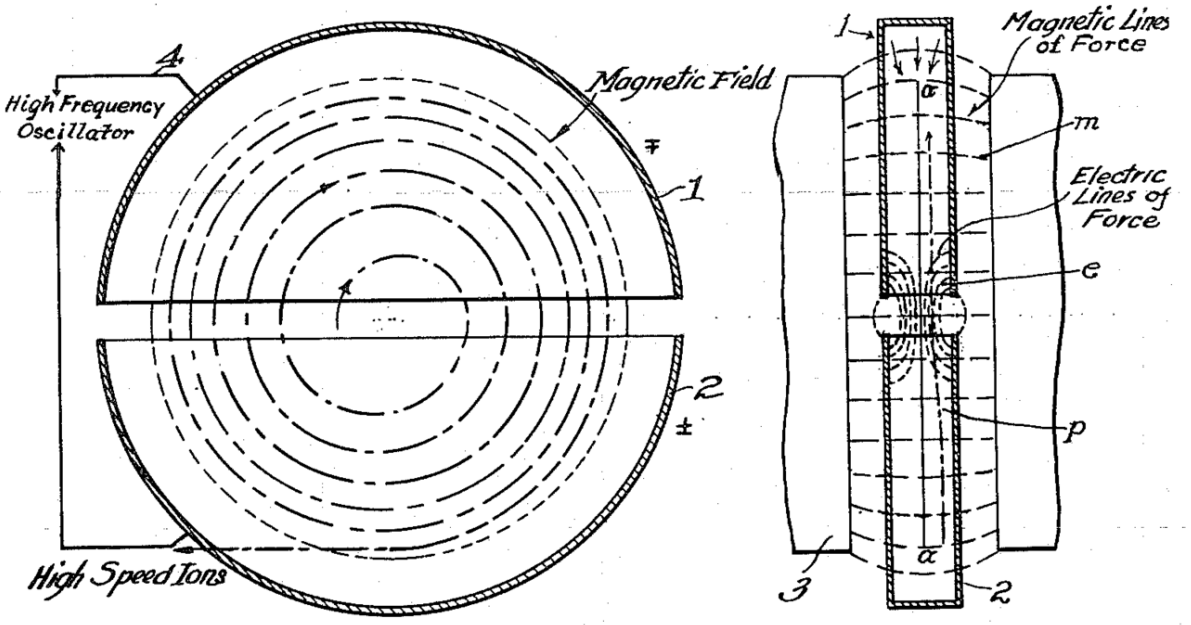
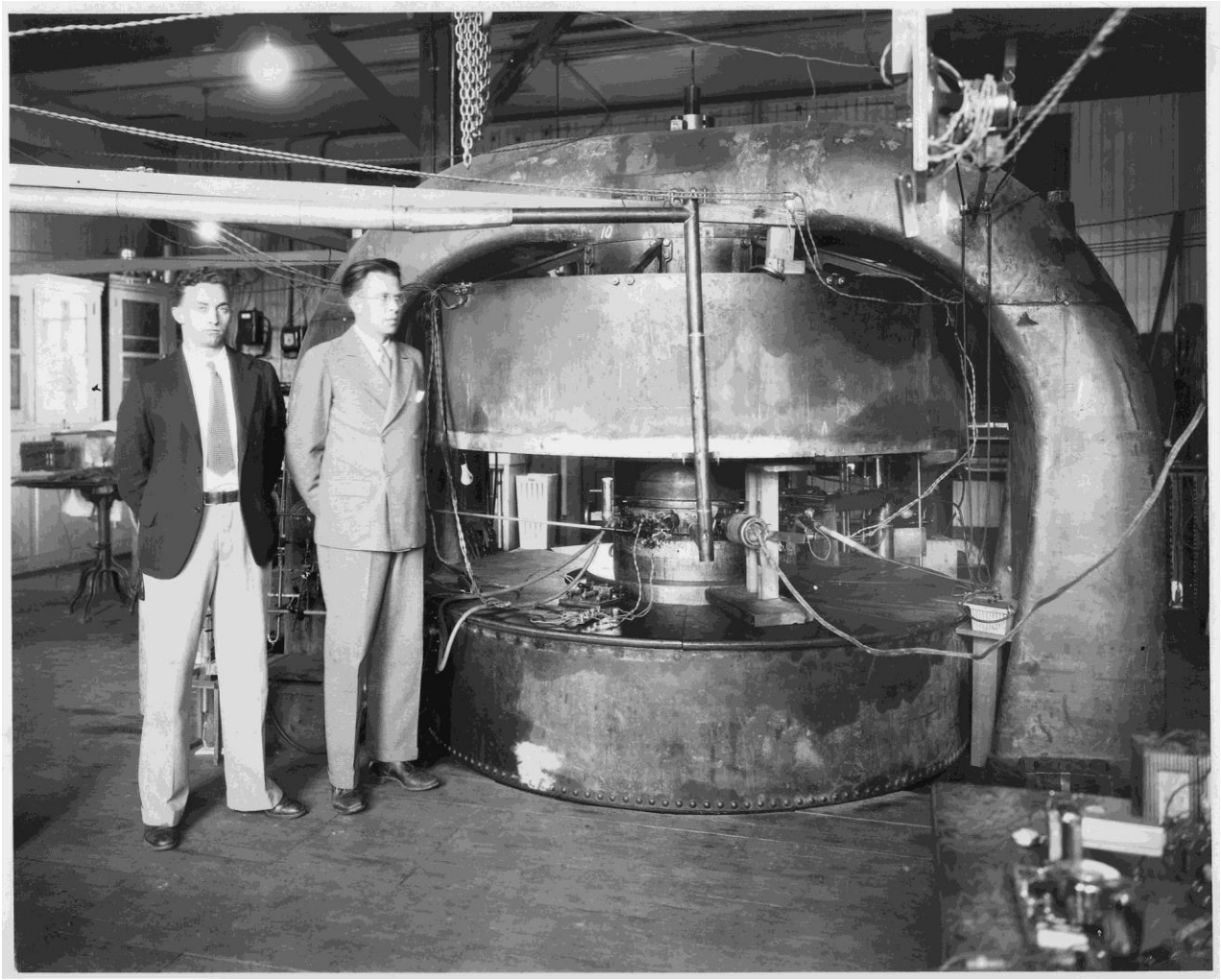
- TID:
  - X-ray
  - ^{60}Co gamma
- **SEE testing**
  - Heavy ions
  - Protons
  - Mixed fields
  - Two-Photon Absorption laser testing

Cyclotron as a Radiation Source

- Invented by Ernest O. Lawrence
  - Berkeley, 1929 (NP Phys. 1939)
- More compact than lin. accelerator

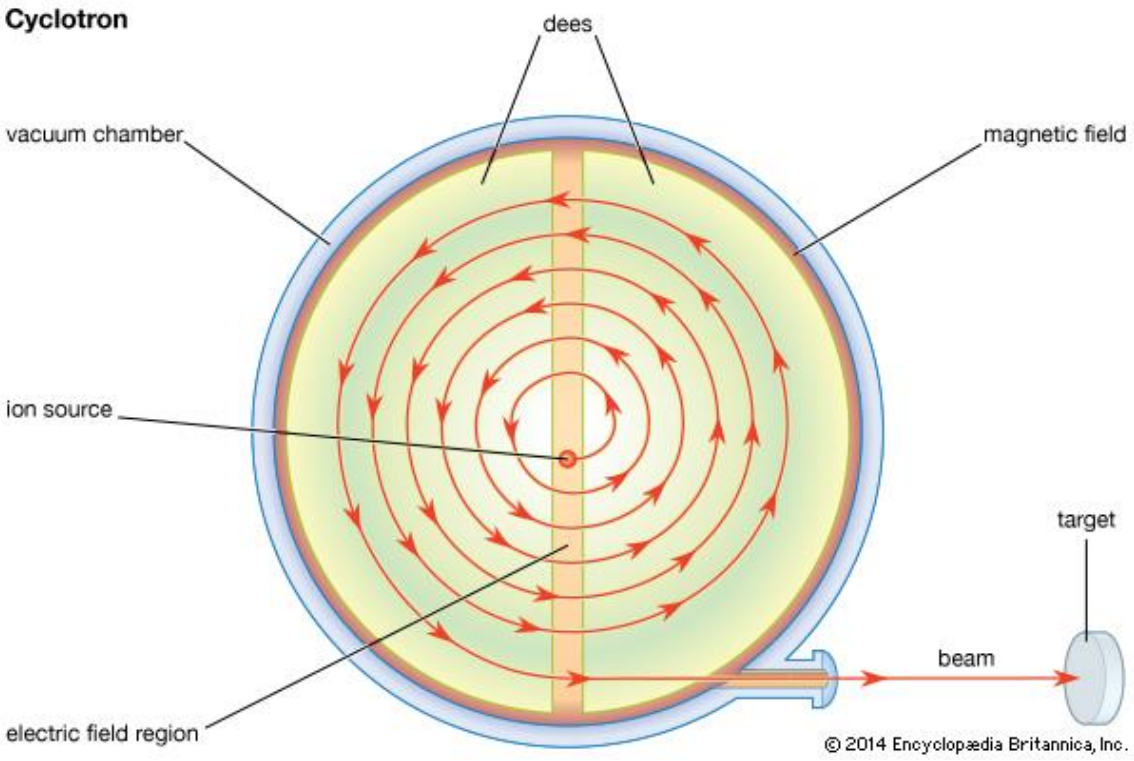




Cyclotron @ UCL

$$f = \frac{qB}{2\pi m}$$

$$E = \frac{1}{2}mv^2 = \frac{q^2 B^2 R^2}{2m}$$



Cyclotron @ UCL

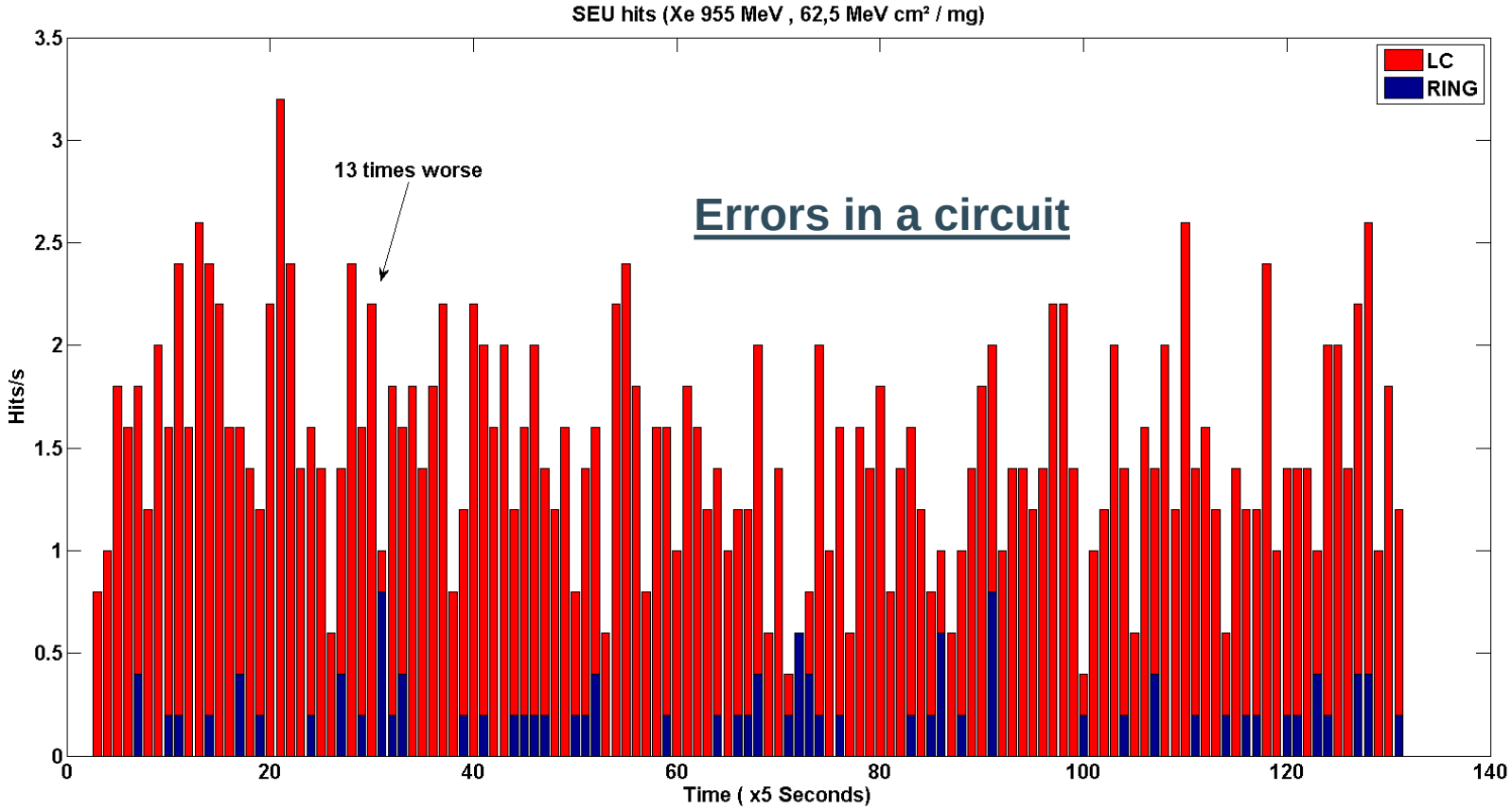
- CYCLONE110 (CYClotron de LOuvain-la-NEuve)
- A multiparticle, variable energy cyclotron accelerator: M/Q ~ 3.3
  - Protons up to 65 MeV,
  - Deuterons up to 50 MeV
  - Alpha particles up to 110 MeV
  - **Heavy ions** up to an energy of 110 Q^2/M MeV (where Q is the charge and M the mass of the ion).
- Flux up to 10^4 particles/s.cm^2
- 25 mm diameter
- Experimental tube is vacuum! Power dissipation is often an issue

Cyclotron @ UCL

~ C/µm in Silicon

M/Q	Ion	DUT energy [MeV]	Range [µm Si]	LET [MeV/mg/cm²]
3.25	$^{13}C^{4+}$	131	269.3	1.3
3.14	$^{22}Ne^{7+}$	238	202.0	3.3
3.37	$^{27}Al^{8+}$	250	131.2	5.7
3.33	$^{40}Ar^{12+}$	379	120.5	10.0
3.31	$^{53}Cr^{16+}$	513	107.6	16.0
3.218	$^{58}Ni^{18+}$	582	100.5	20.4
3.35	$^{84}Kr^{25+}$	769	94.2	32.4
3.54	$^{124}Xe^{35+}$	995	73.1	62.5

Errors in a circuit



Synchrotron

- Particles accelerated in cavities
  - Particles move in circular shape (no spiral)
- Magnets bend particles

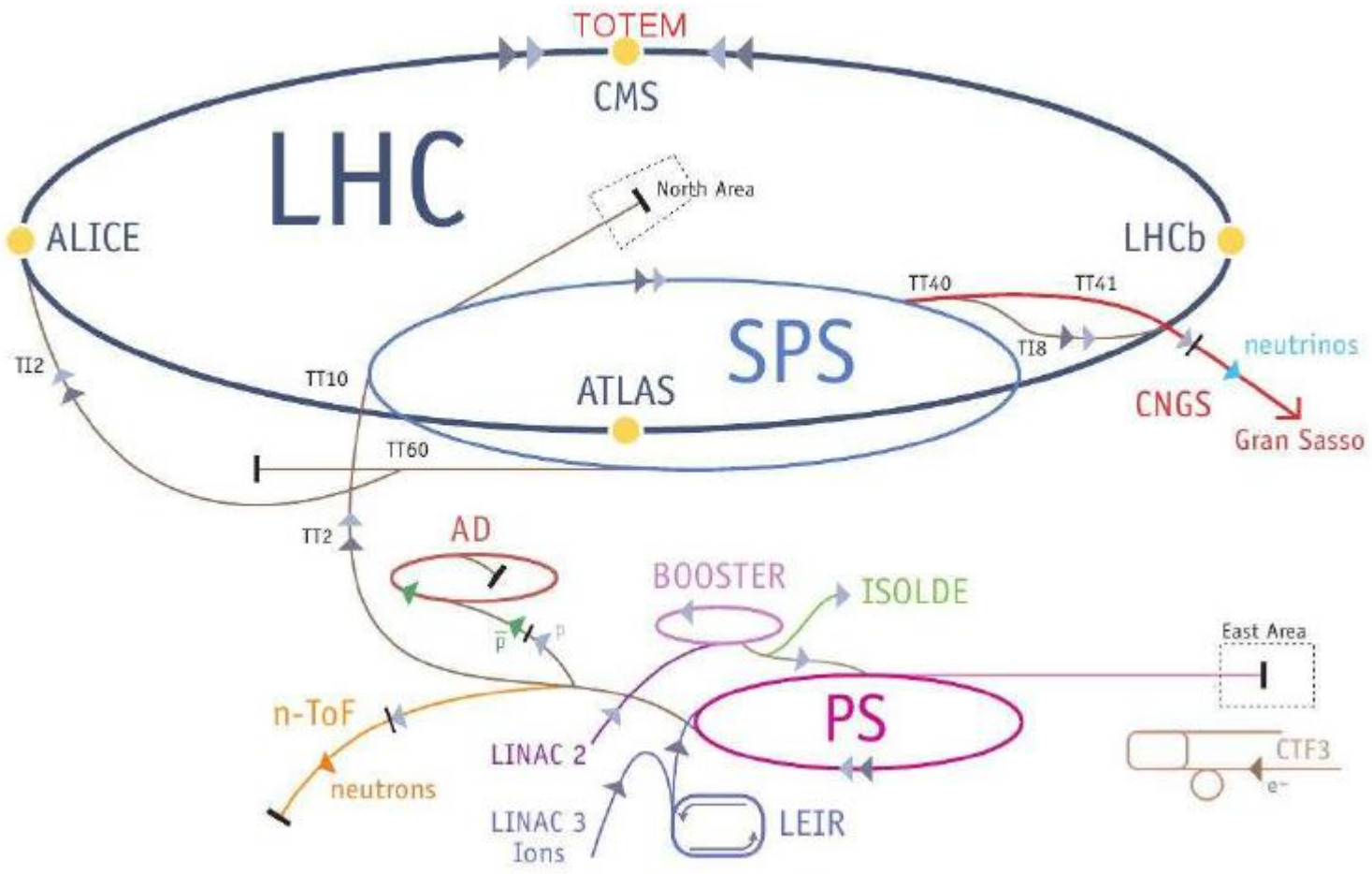
- Experiments are organized around accelerator

- Accelerators have “limited” energy range

  → magnets need to be tuned to keep beam inside

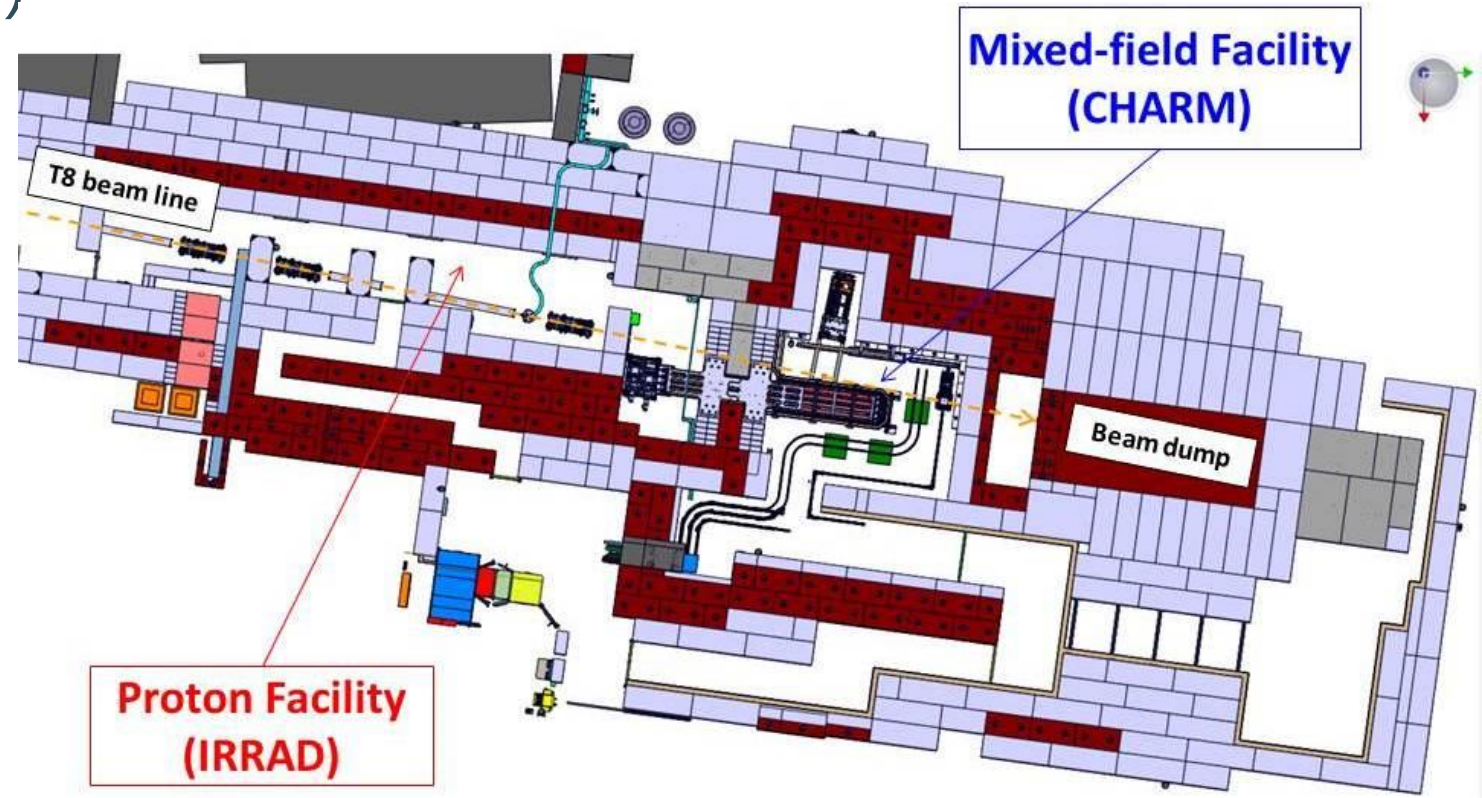
- Usually large accelerator complex

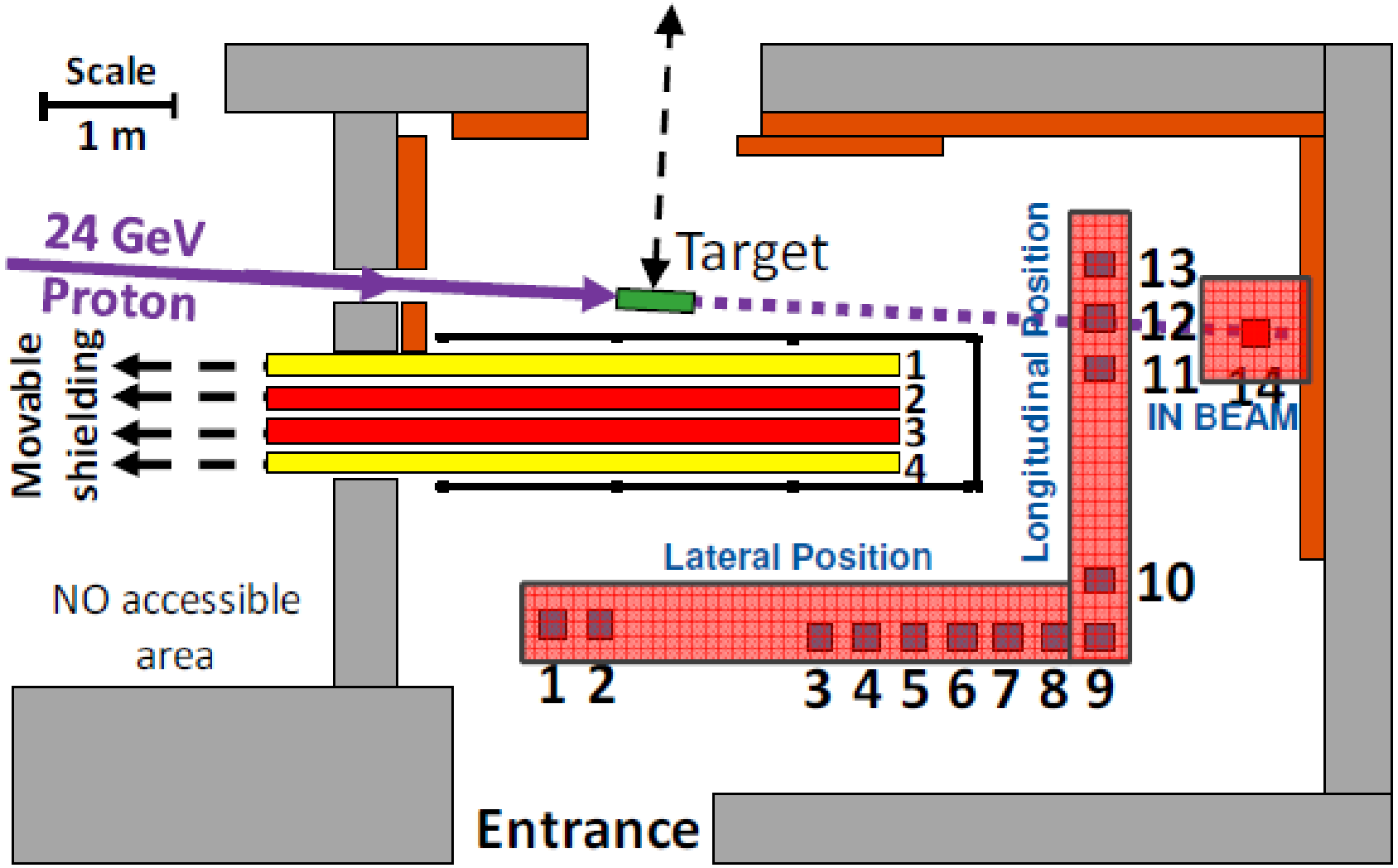
Synchrotron



Charm Facility

- Cern High Energy AcceleRator Mixed Field/Facility
- Proton synchrotron (24 GeV)
- Target to create secondary particles
- Large targets possible
  - Entire satellites
  - Large systems
  - …
- Automatic loading
- Movable shielding

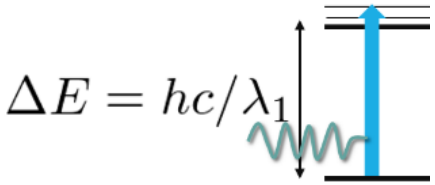



Scale
1 m
24 GeV
Proton
Target
Movable
shielding
1
2
3
4
Longitudinal Position
13
12
11
14
IN BEAM
Lateral Position
10
NO accessible
area
1 2
3 4 5 6 7 8 9
Entrance

Laser SEE testing

- Particle accelerators → €€€
- Measurements are stochastic → difficult to debug.

<u>Laser testing:</u>

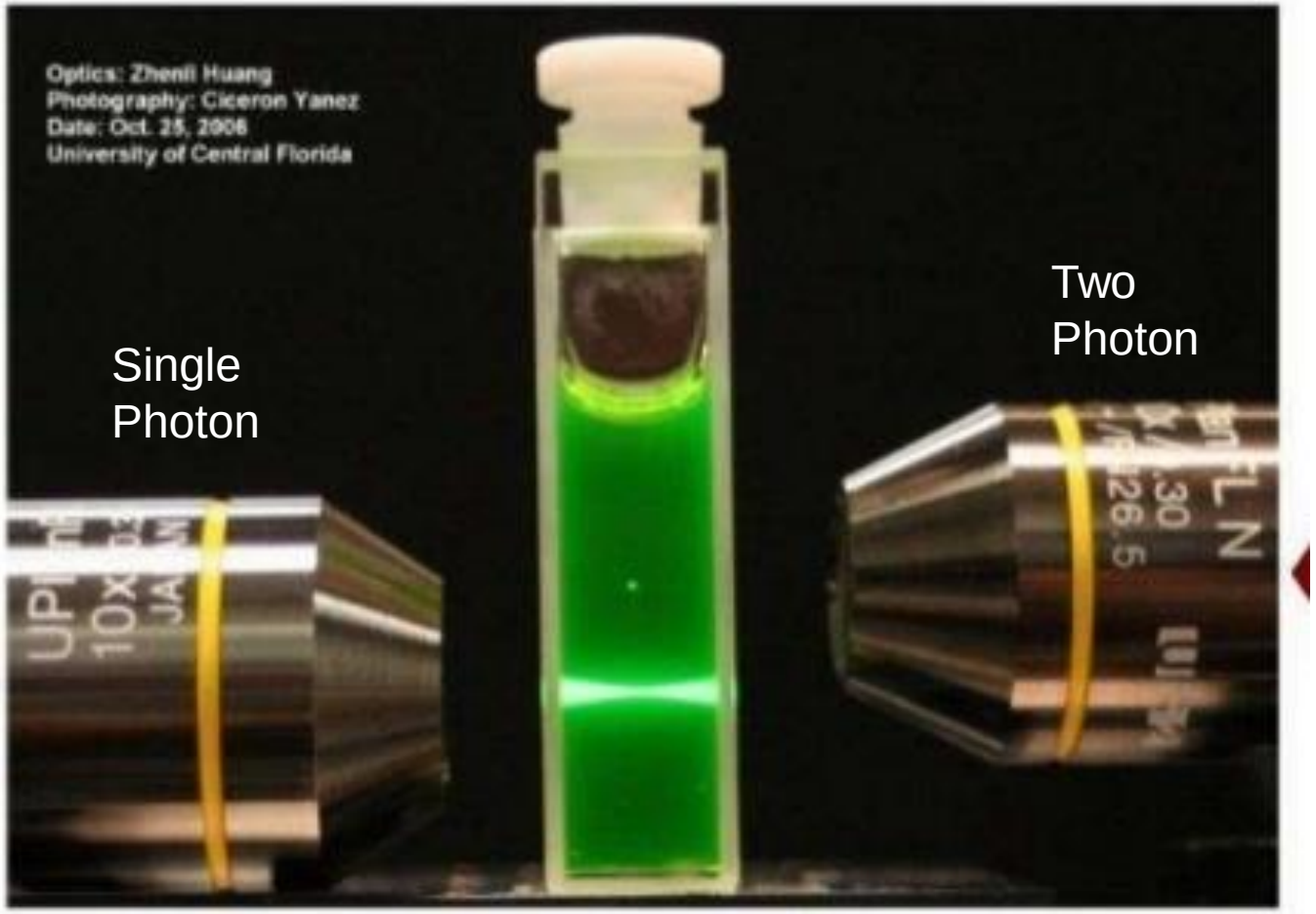


- Generate electrons in the Silicon (photon requires ~3.6 eV)
- <u>Alternative</u> to heavy-ion testing
- Single-photon absorption (SPA) and two-photon absorption (TPA)
- Locate sensitive regions in the chip (2D and 3D for TPA)
- **No ionizing radiation needed**

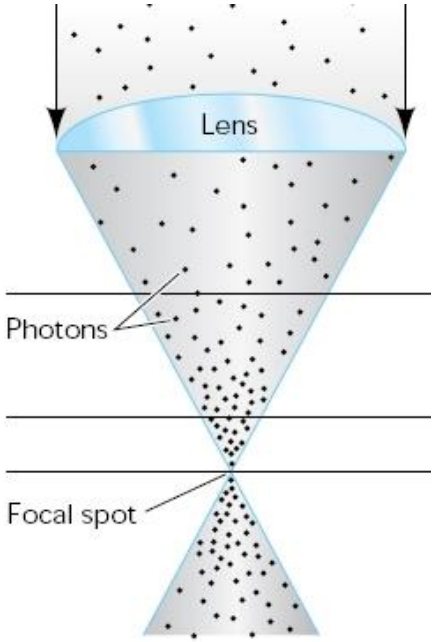
Single vs. two photon absorption

Two-Photon Laser experiments

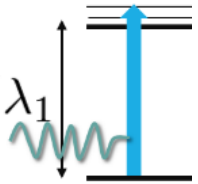
[Z. Huang]



$$-\frac{dI}{dz} = \alpha I + \beta I^2$$

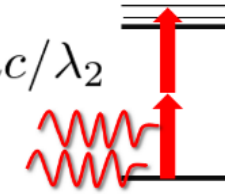


$$\Delta E = hc/\lambda_1$$

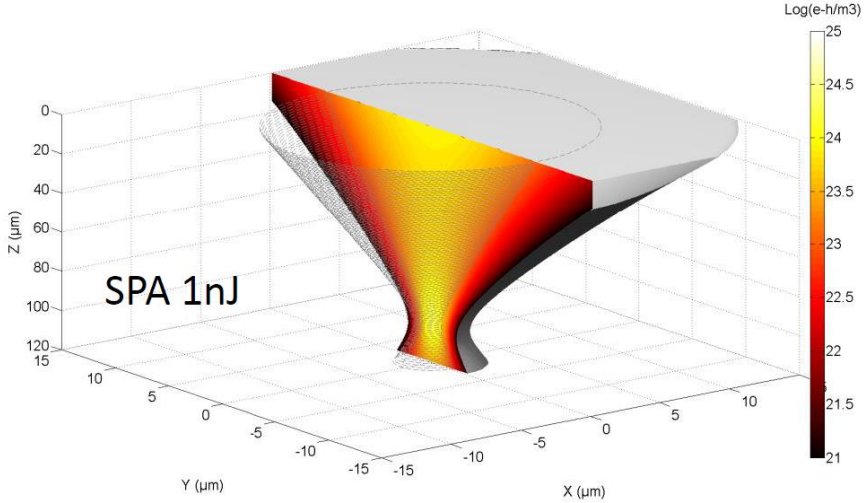


$$\Delta E = 2 \times hc/\lambda_2$$

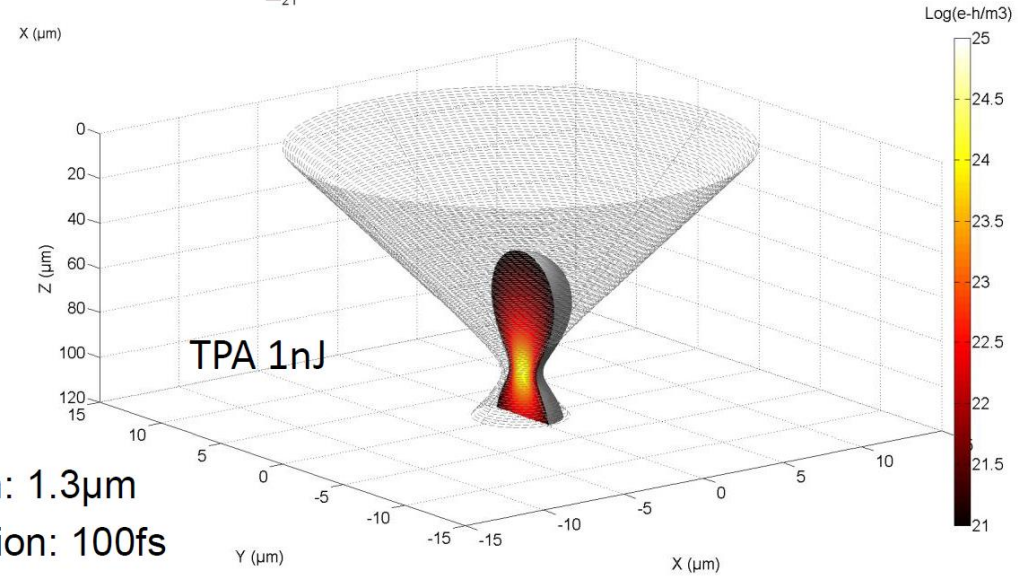
$$\lambda_2 = 2\lambda_1$$



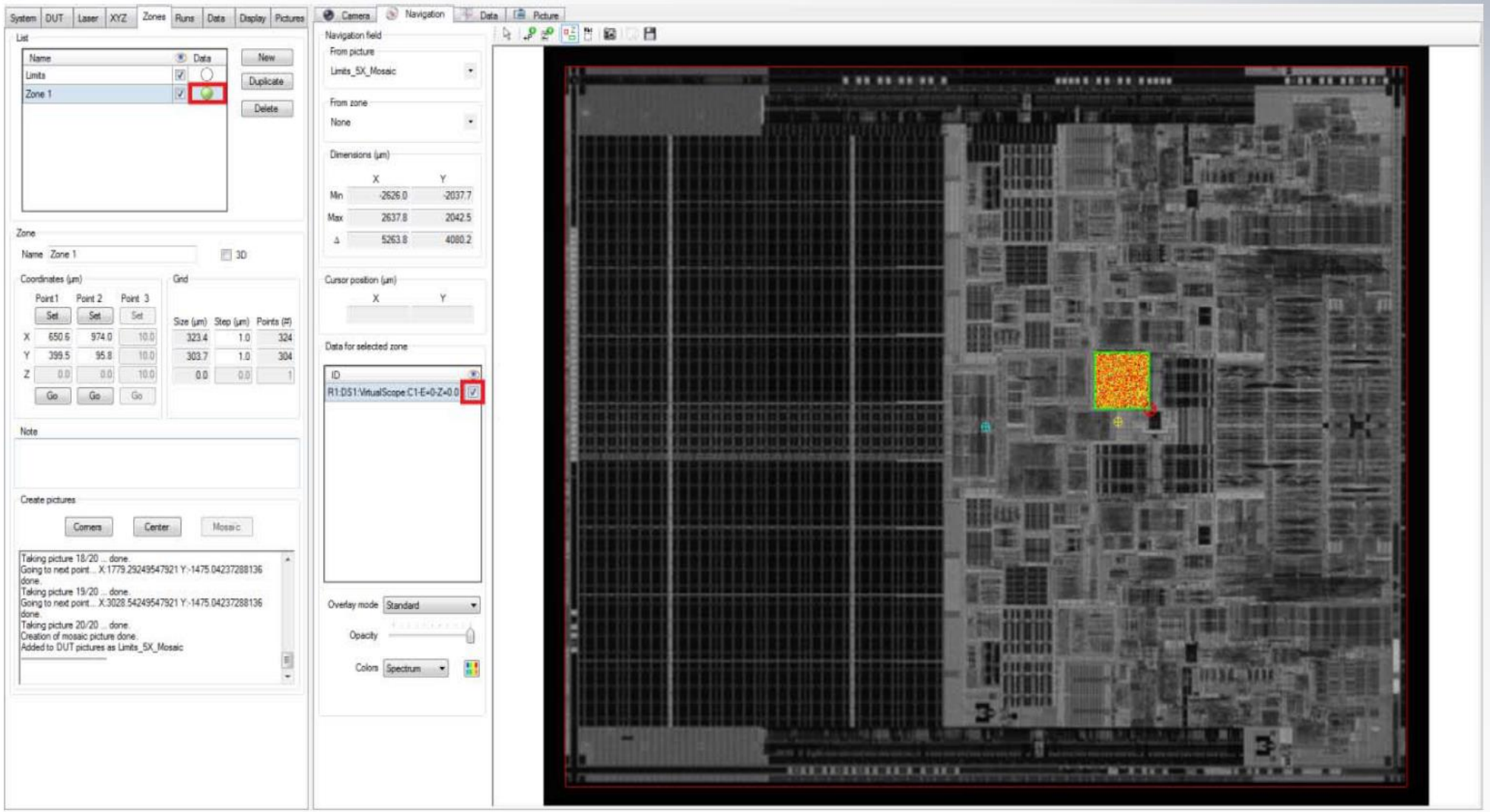
Single vs. two photon absorption



- Wavelength: 1.064µm
- Pulse duration: 30ps



- Wavelength: 1.3µm
- Pulse duration: 100fs


System
DUT
Laser
XYZ
Zones
Runs
Data
Display
Pictures
List
Name
Data
Limits
Zone 1
New
Duplicate
Delete
Zone
Name Zone 1
3D
Coordinates (µm)
Point 1
Point 2
Point 3
Set
Go
Grid
Size (µm)
Step (µm)
Points (#)
Note
Create pictures
Corners
Center
Mosaic
Taking picture 18/20 ... done.
Going to next point... X:1779.29249547921 Y:-1475.04237288136
done.
Taking picture 19/20 ... done.
Going to next point... X:3028.54249547921 Y:-1475.04237288136
done.
Taking picture 20/20 ... done.
Creation of mosaic picture done.
Added to DUT pictures as Limits_5X_Mosaic
Camera
Navigation
Data
Picture
Navigation field
From picture
Limits_5X_Mosaic
From zone
None
Dimensions (µm)
X
Y
Min
Max
Cursor position (µm)
Data for selected zone
ID
Overlay mode
Standard
Opacity
Colors
Spectrum

Thank you!