

Transmission imaging 3

HLI 202

m colarieti tosti, mct@kth.se

1. Object contrast vs image contrast

2. 3D imaging: computed tomography

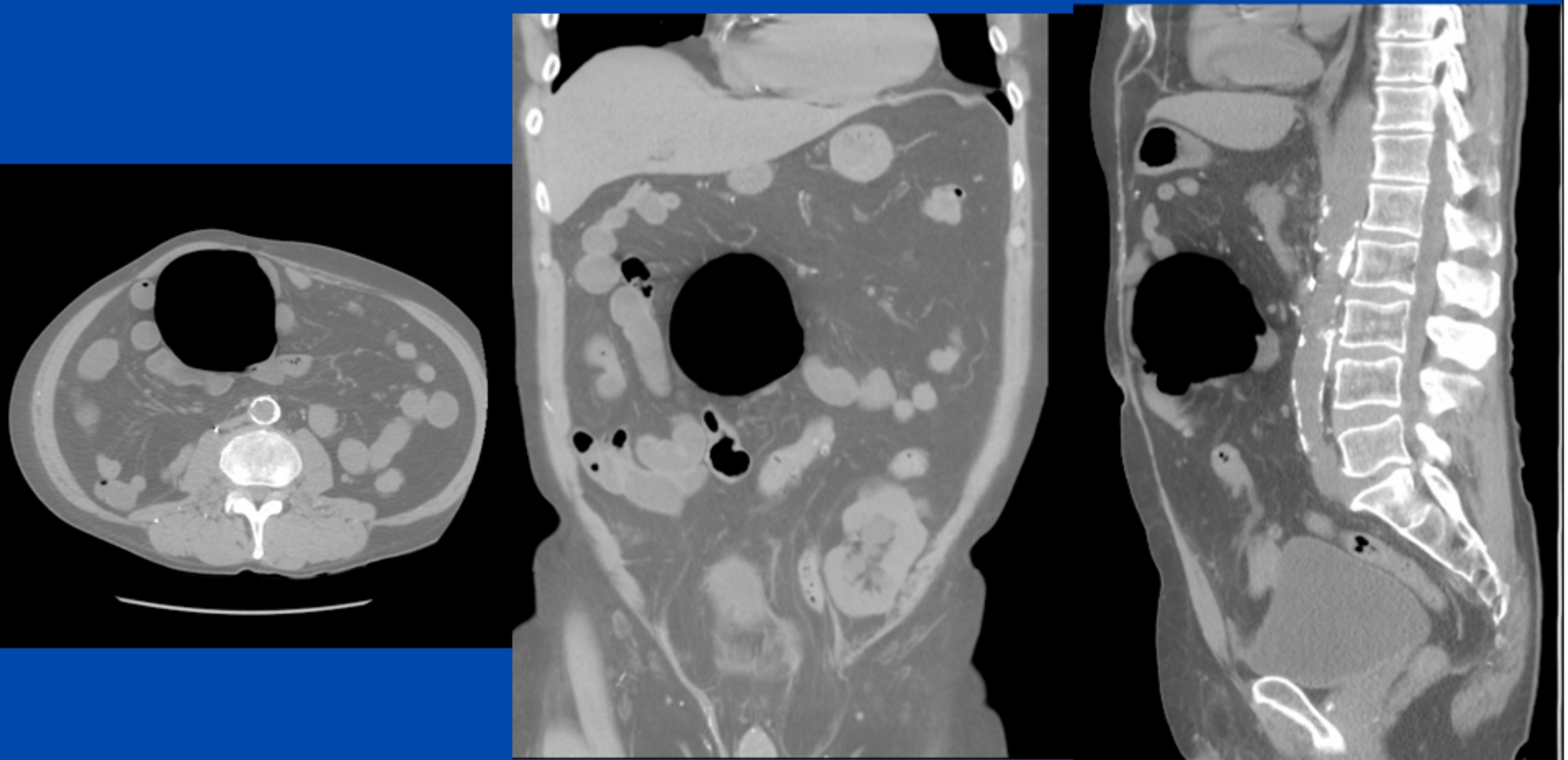
3. Dose

3D imaging: computed
tomography

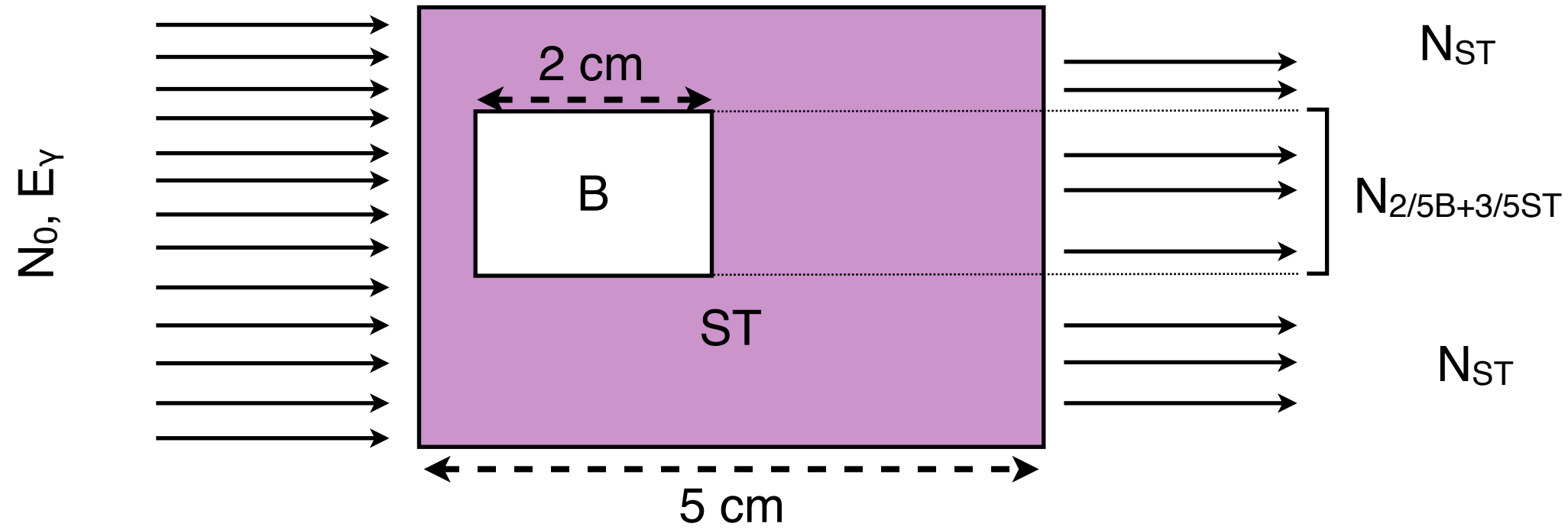
Modern datortomograf

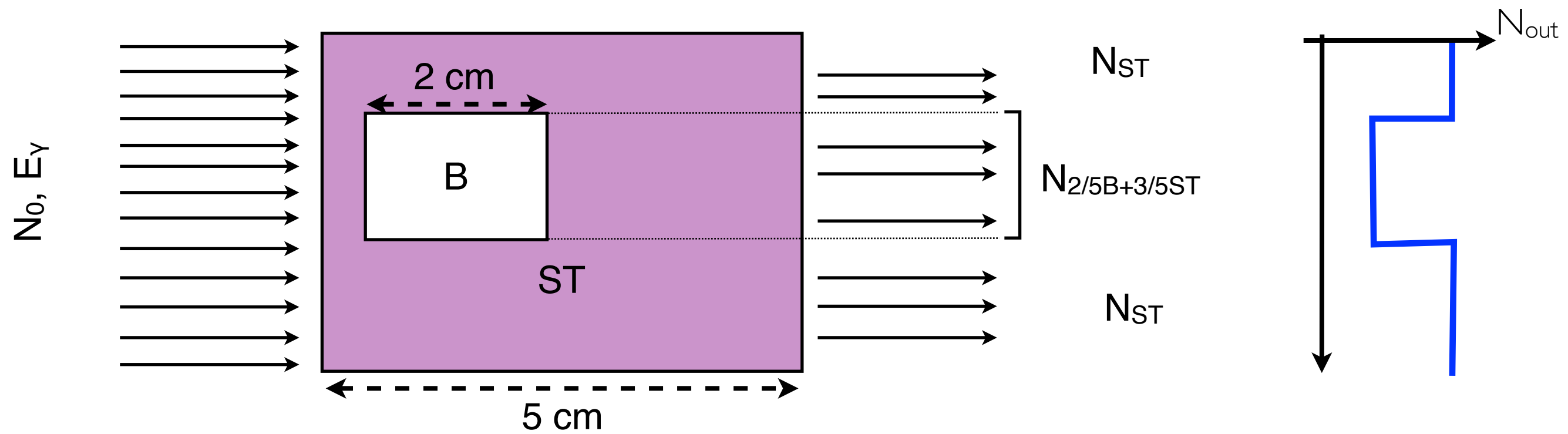


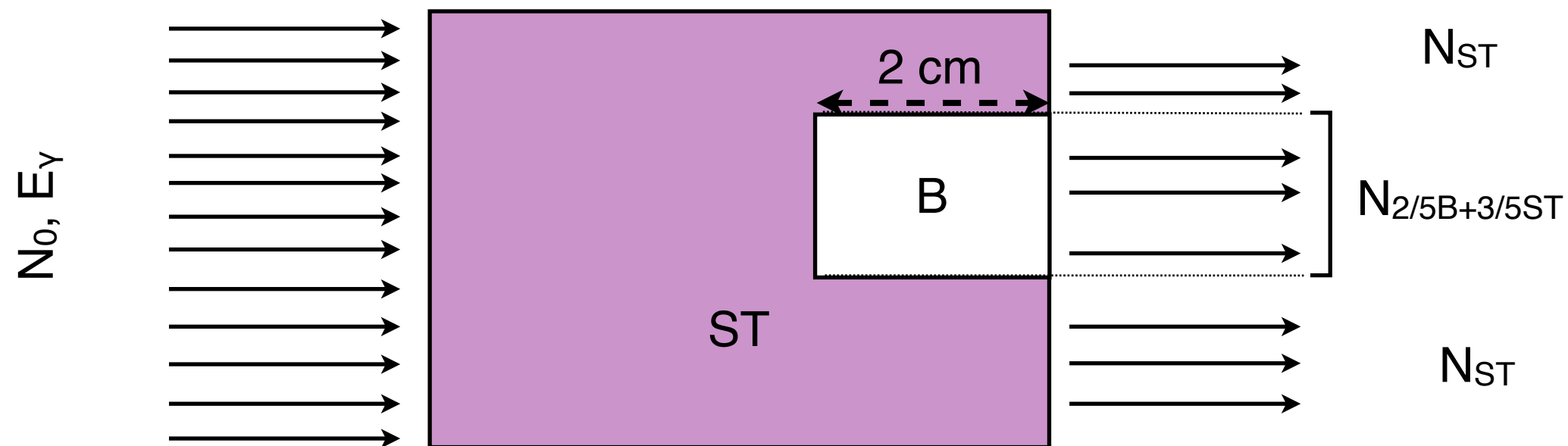
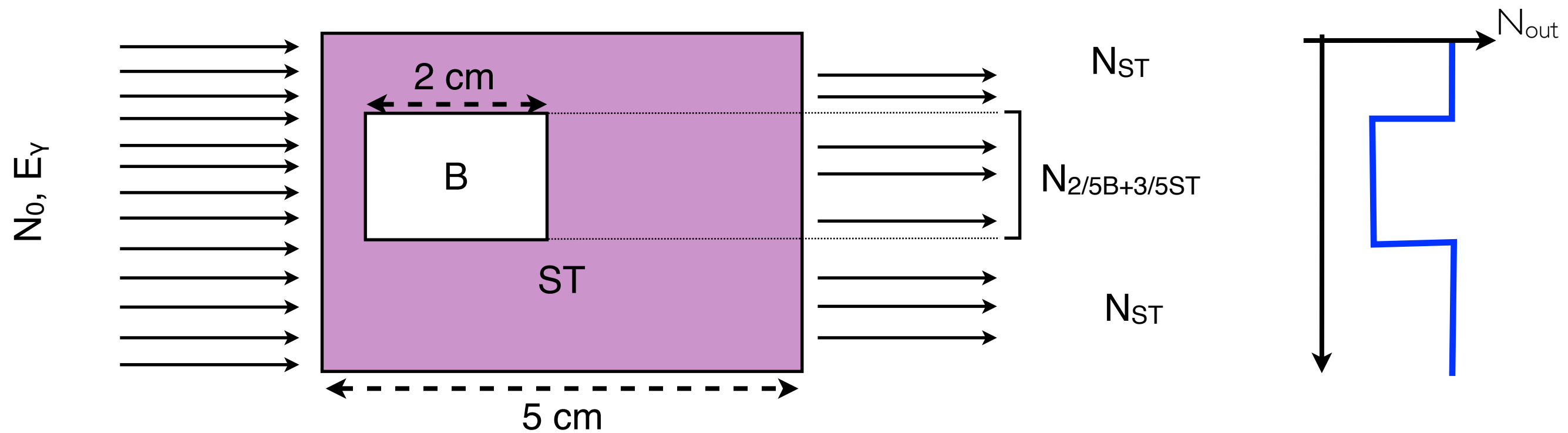
CT bilder från Danderyds Sjukhus

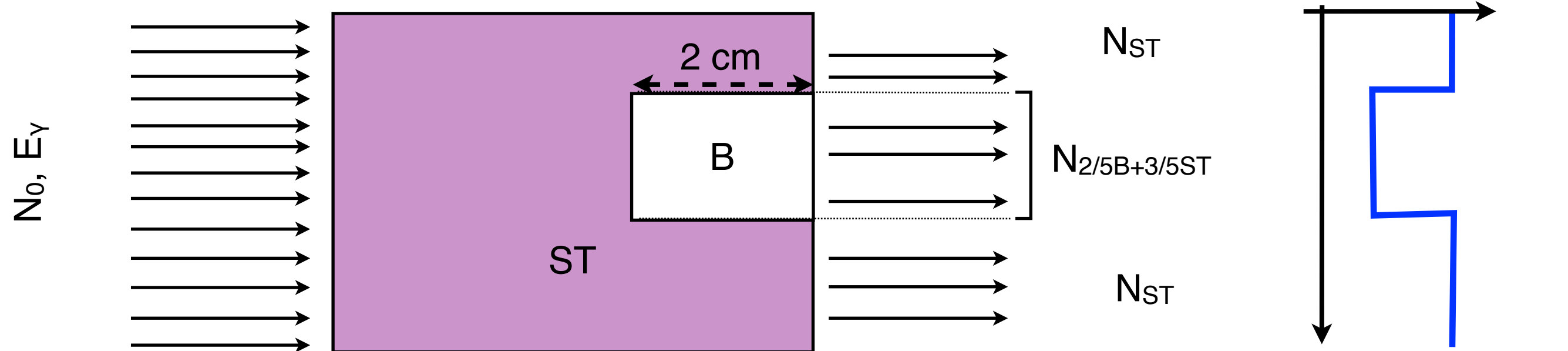
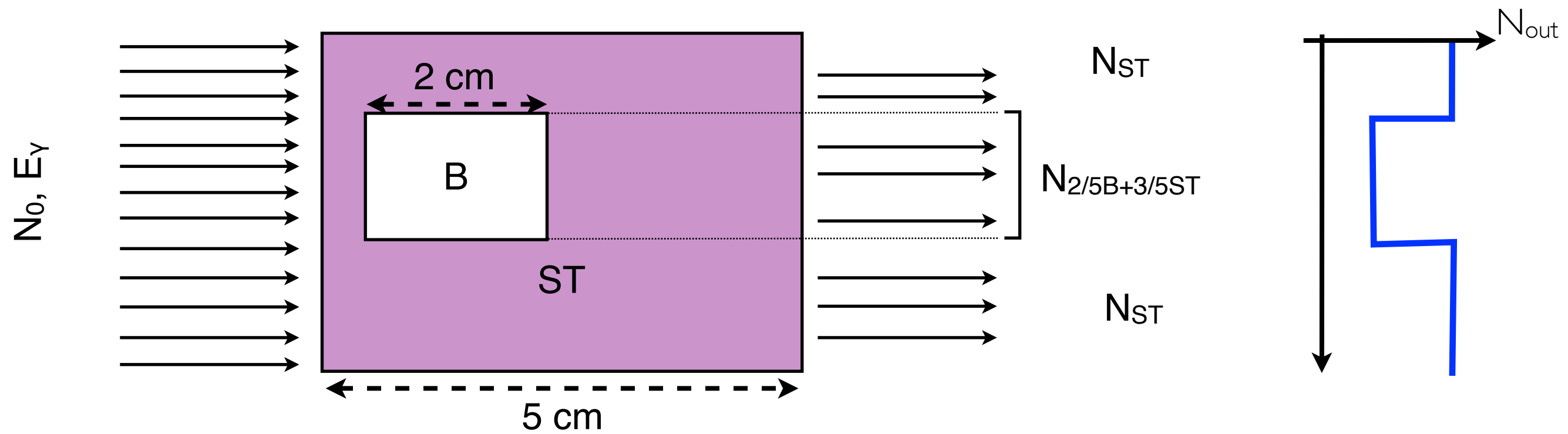


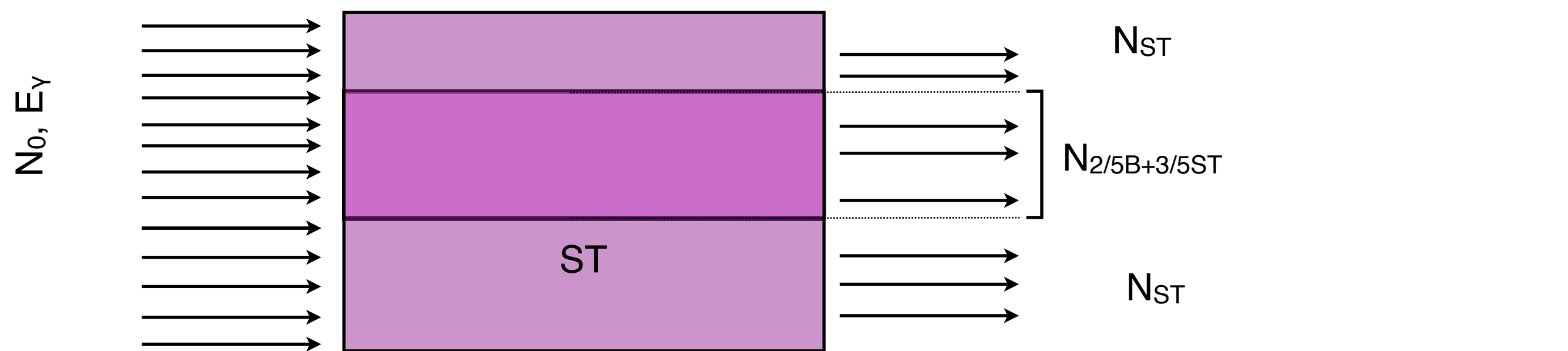
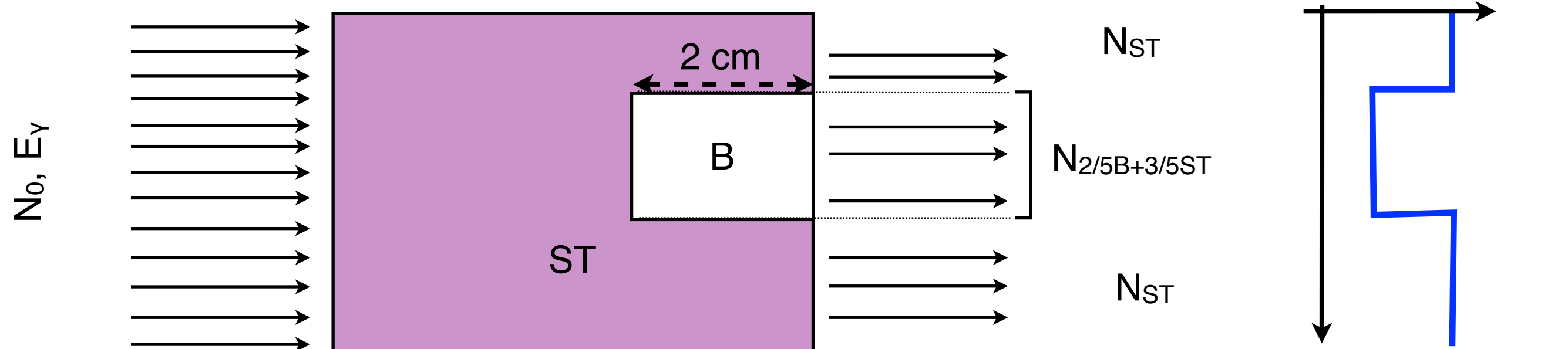
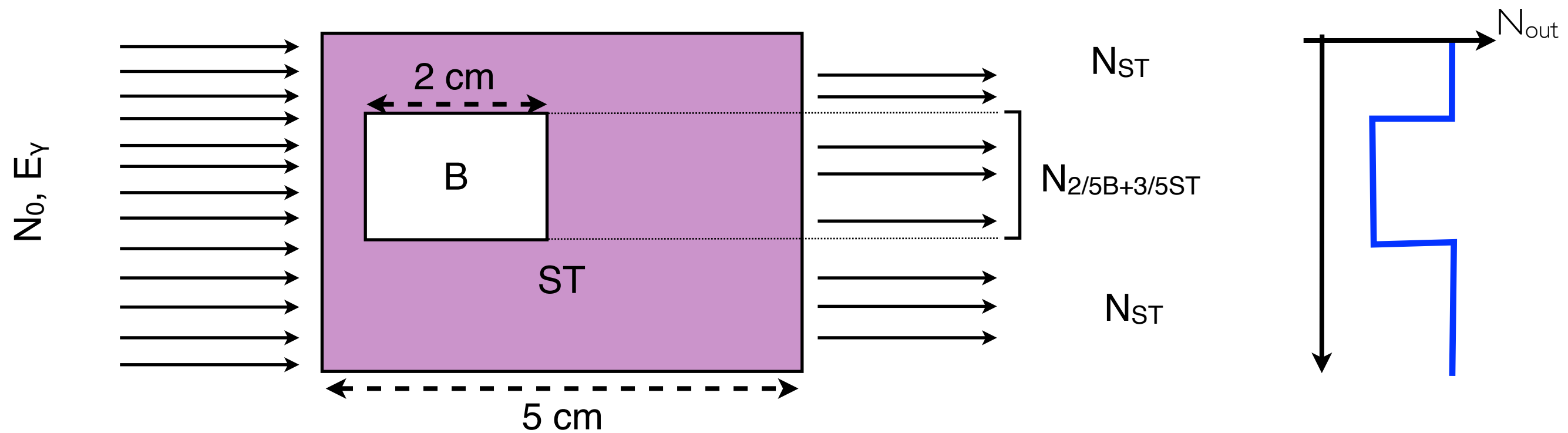
64 slice CT - samma undersökning av buken, rekonstruerad i tre plan

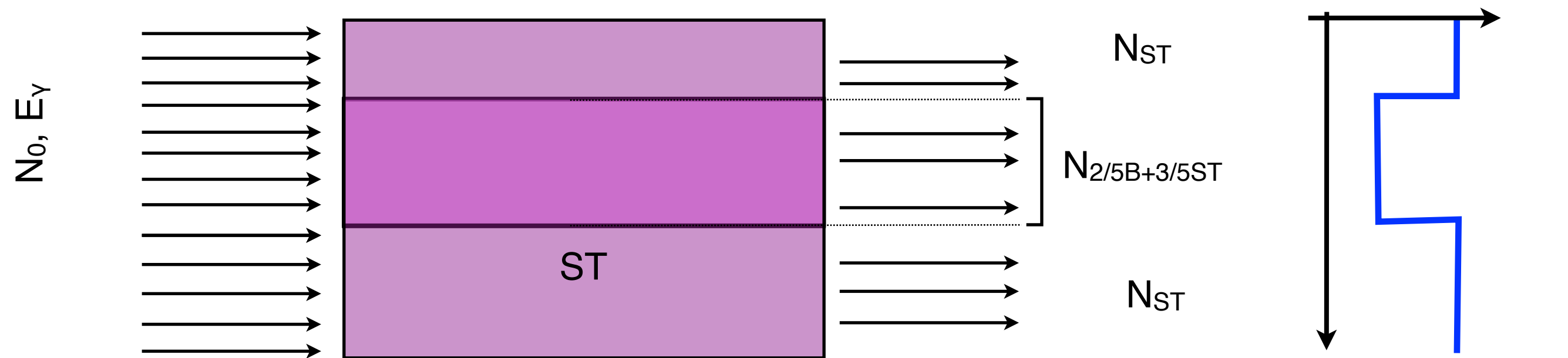
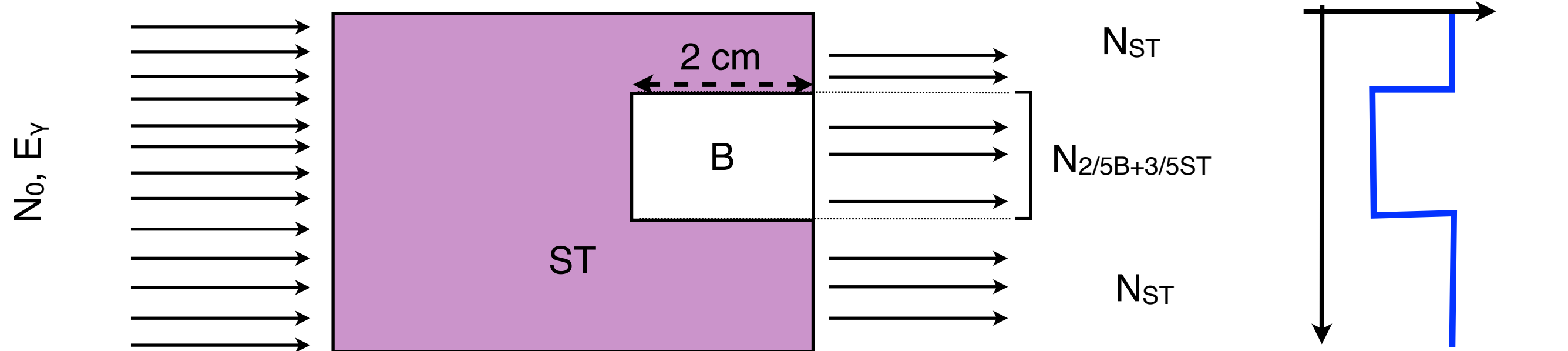
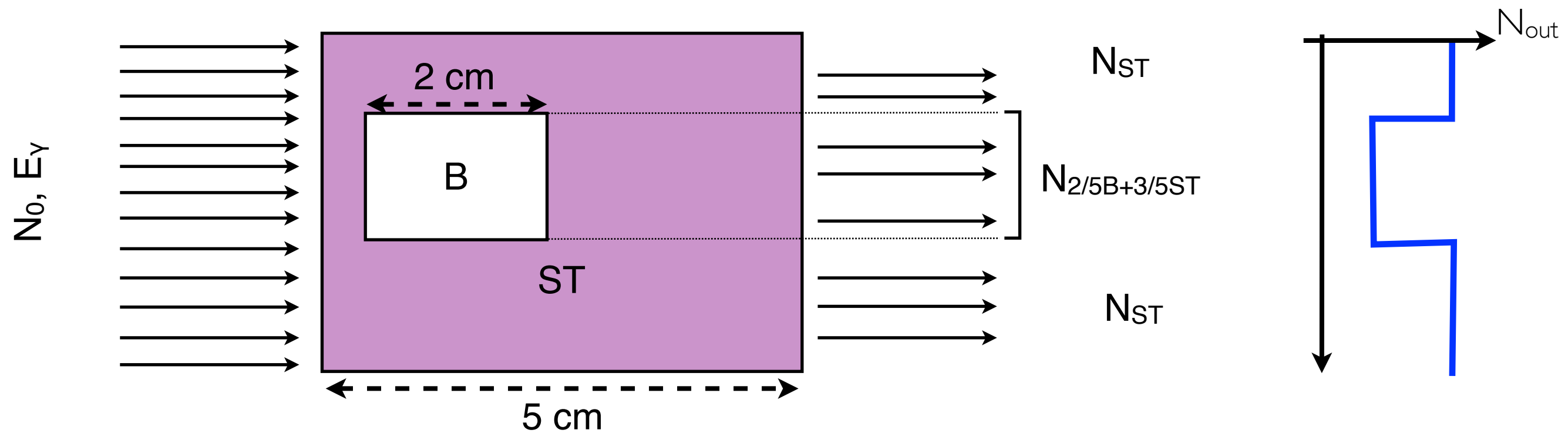


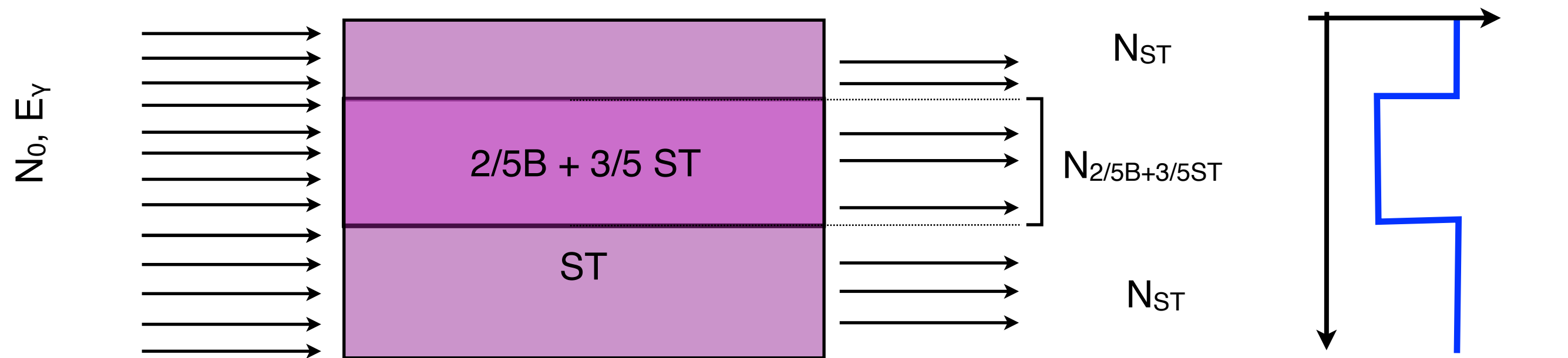
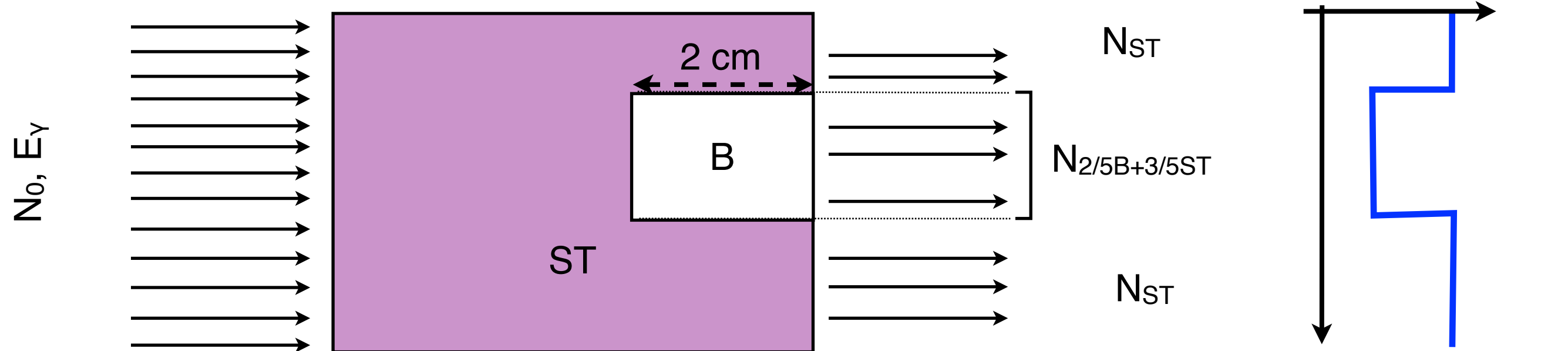
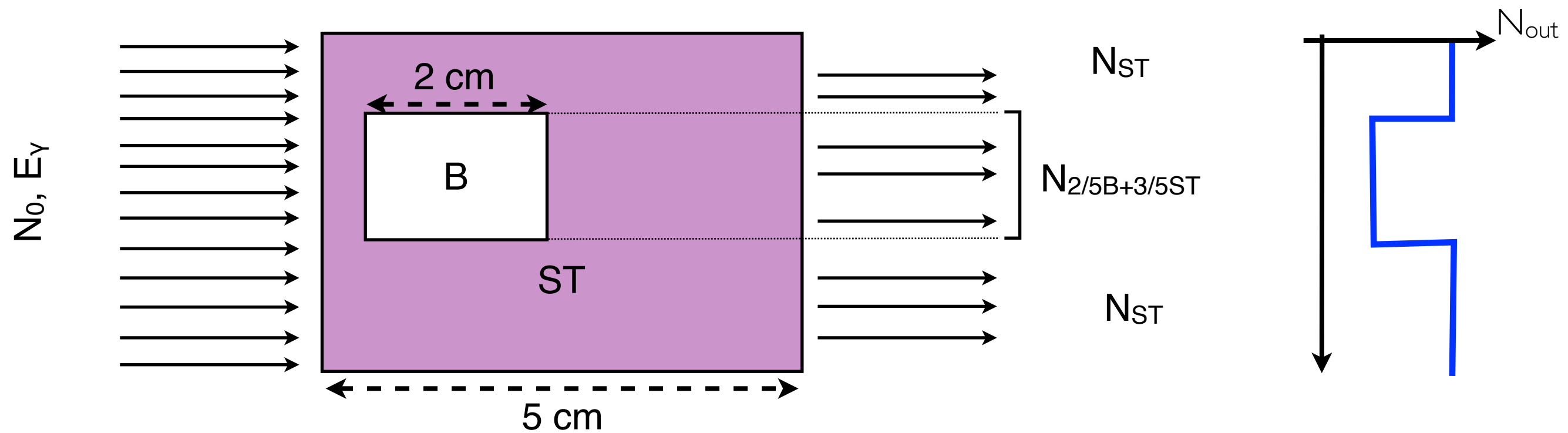


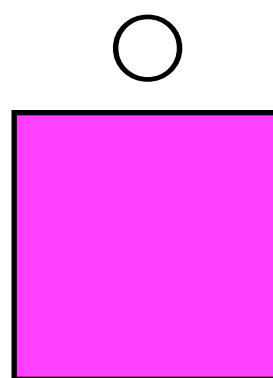


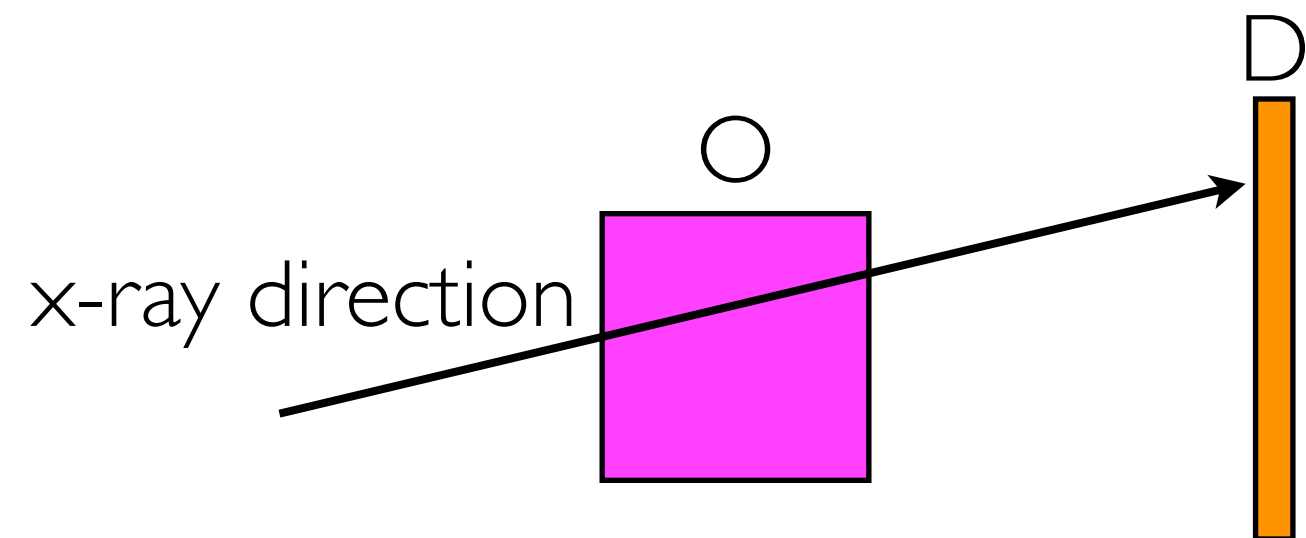


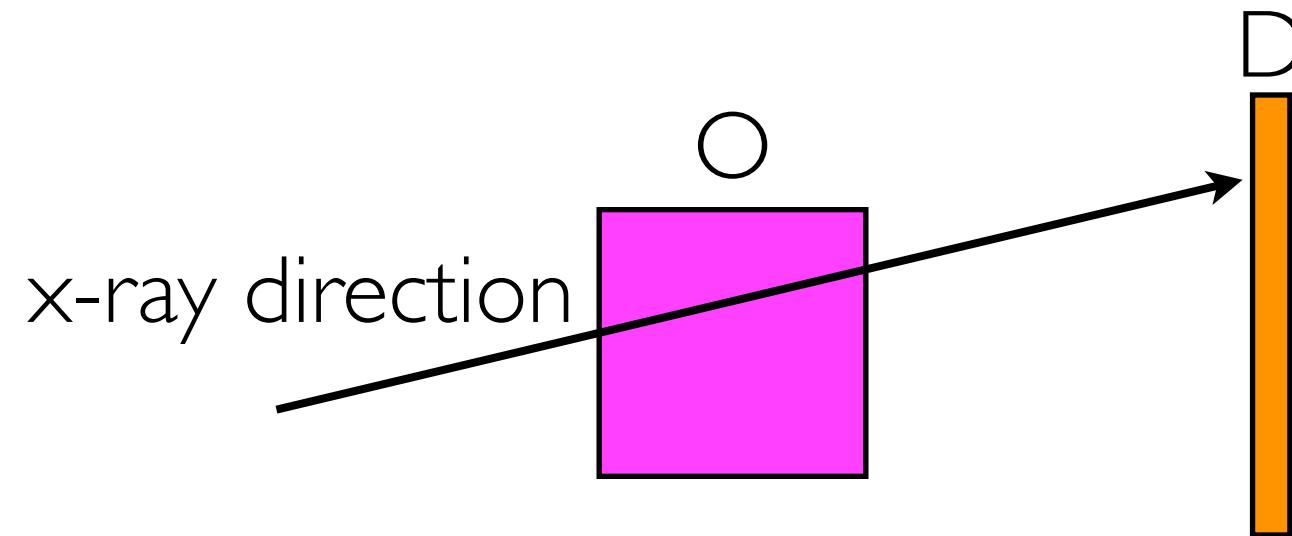






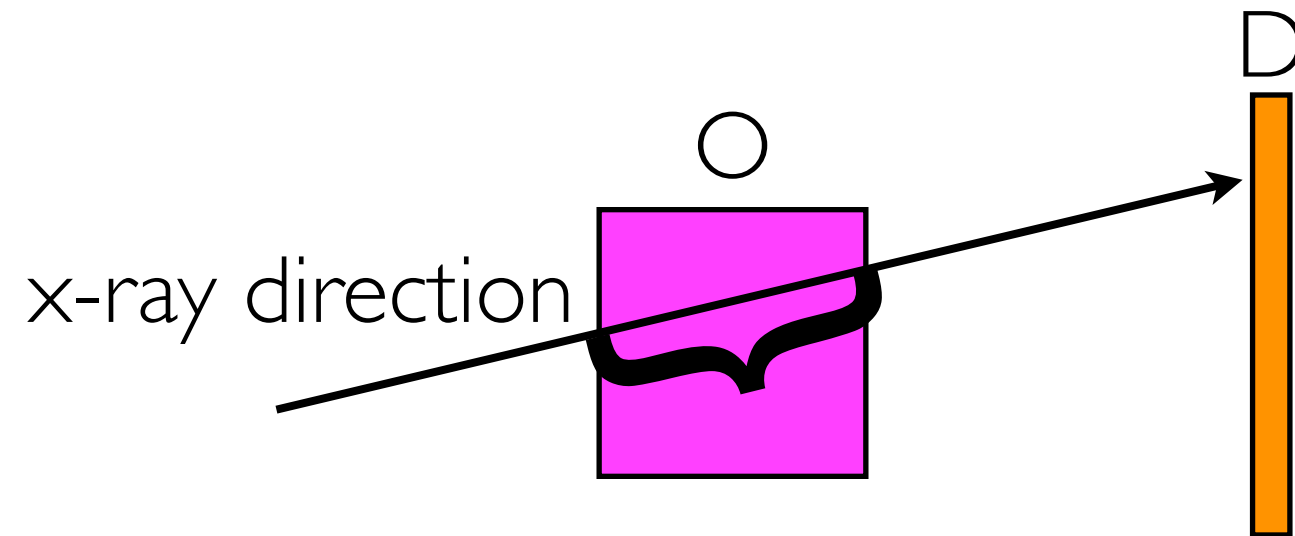




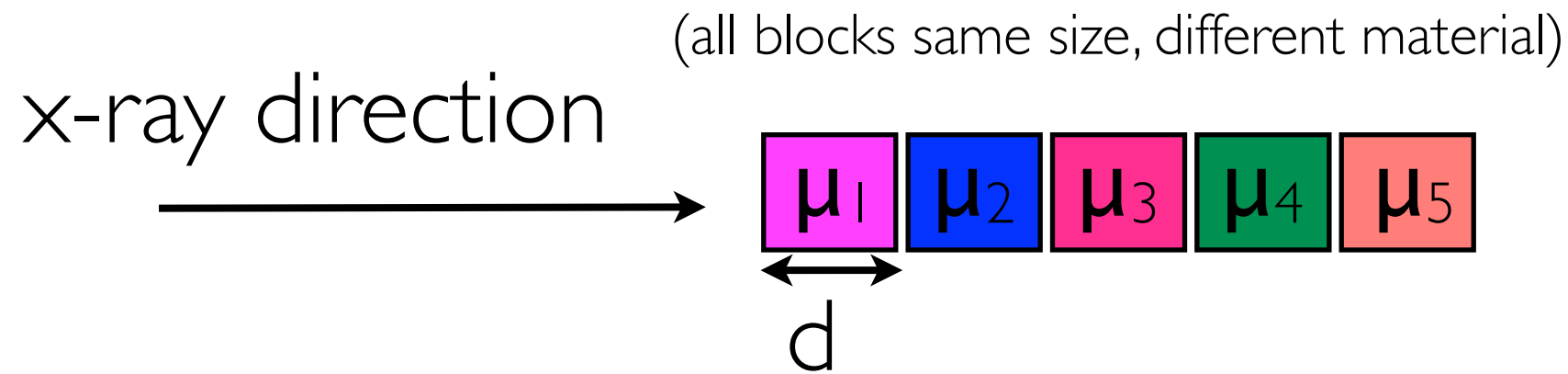


I transmission mäter man summan av attenuering
längs röntgensstrålarnas väg genom objekt

The truth about transmission!



I transmission mäter man summan av attenuering
längs röntgenstrålarnas väg genom objekt

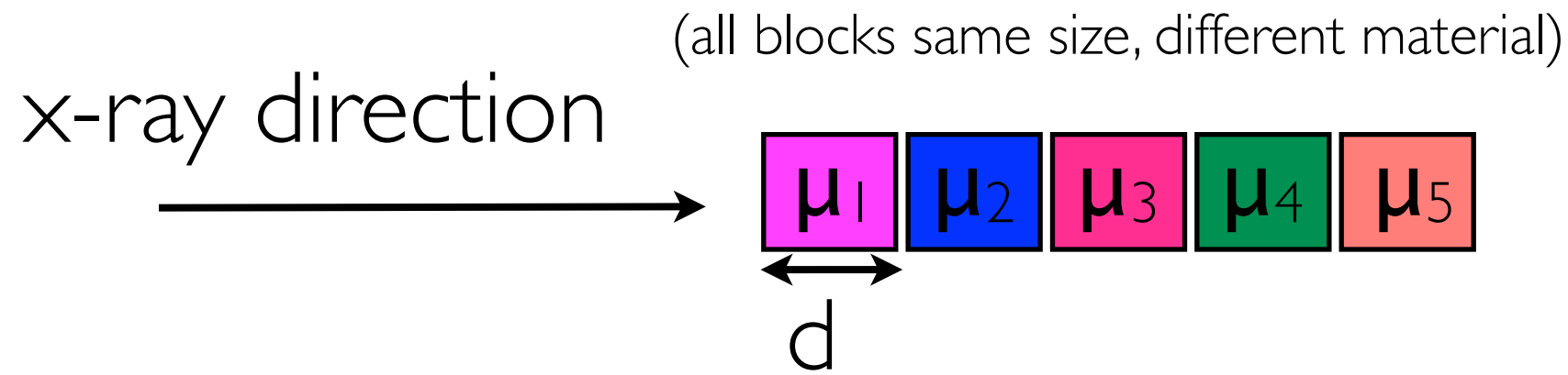


The attenuation factor through the entire row is:

1. $e^{-\mu_1 d} + e^{-\mu_2 d} + e^{-\mu_3 d} + e^{-\mu_4 d} + e^{-\mu_5 d}$

2. $e^{-(\mu_1 + \mu_2 + \mu_3 + \mu_4 + \mu_5) d}$

3. $e^{-\frac{(\mu_1 + \mu_2 + \mu_3 + \mu_4 + \mu_5)}{5} d}$

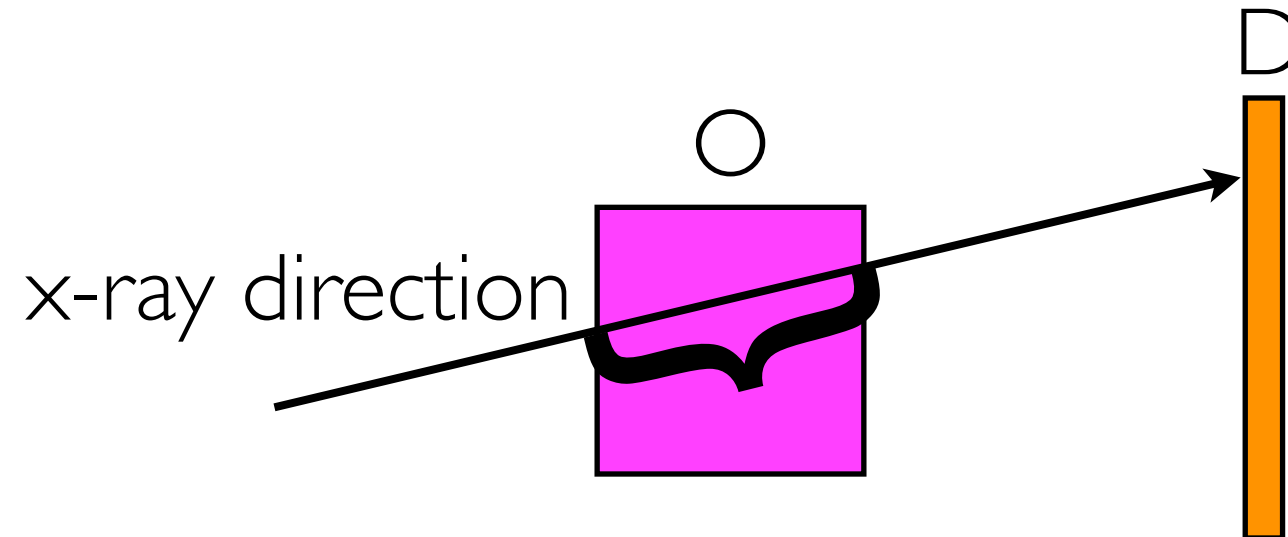


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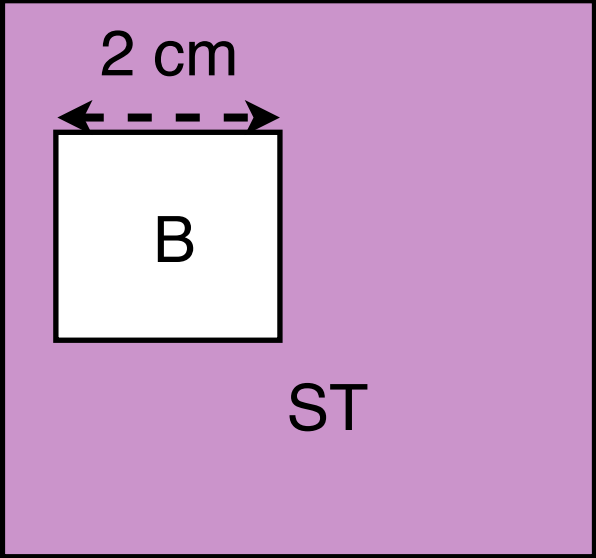
3. $e^{-\frac{(\mu_1 + \mu_2 + \mu_3 + \mu_4 + \mu_5)}{5} d}$



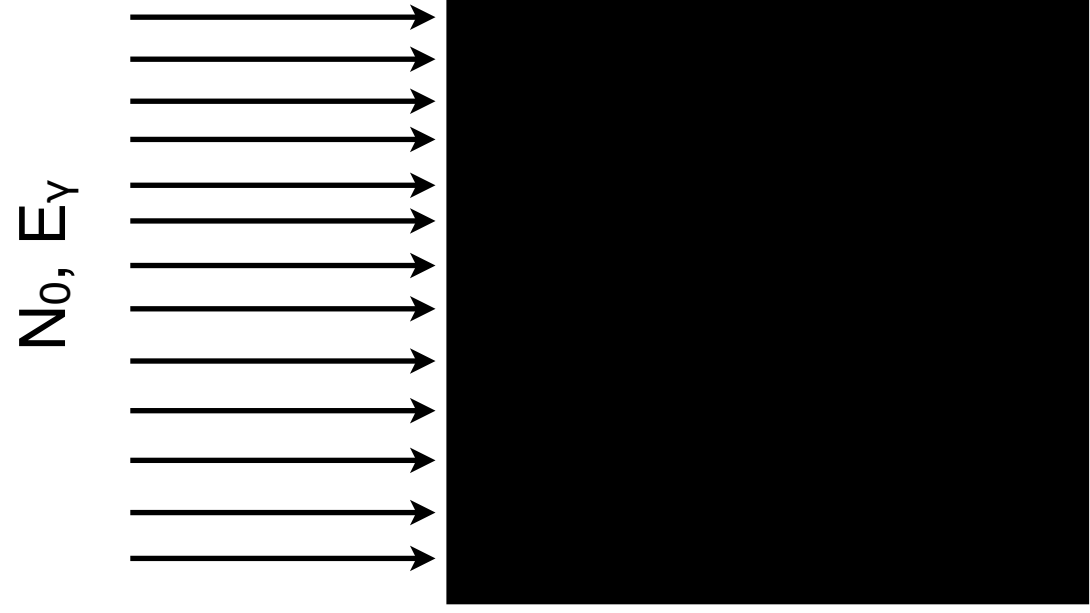
I transmission mäter man summan av attenuering längs röntgenstrålarnas väg genom objekt

Några (andra) problem med planröntgen:

- 3D anatomin är reducerad till en 2D bild
- Organen (bildens 3D komponenter) ligger ovanpå varandra i 2D bild
- Bilden är förvrängd pga avståndseffekt
- Svårighet att avbilda mjuka organ innanför ben (hjärna, ryggmärg)
- (Film-screen – har begränsad dynamiskt område. Lätt att under eller överexponera)

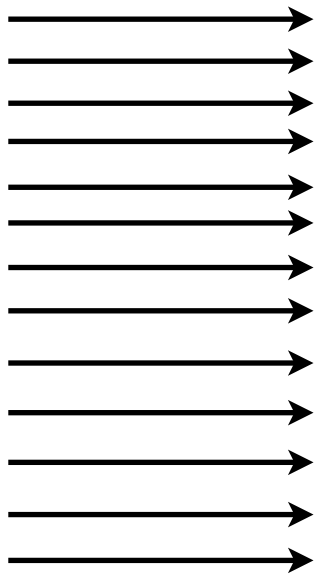


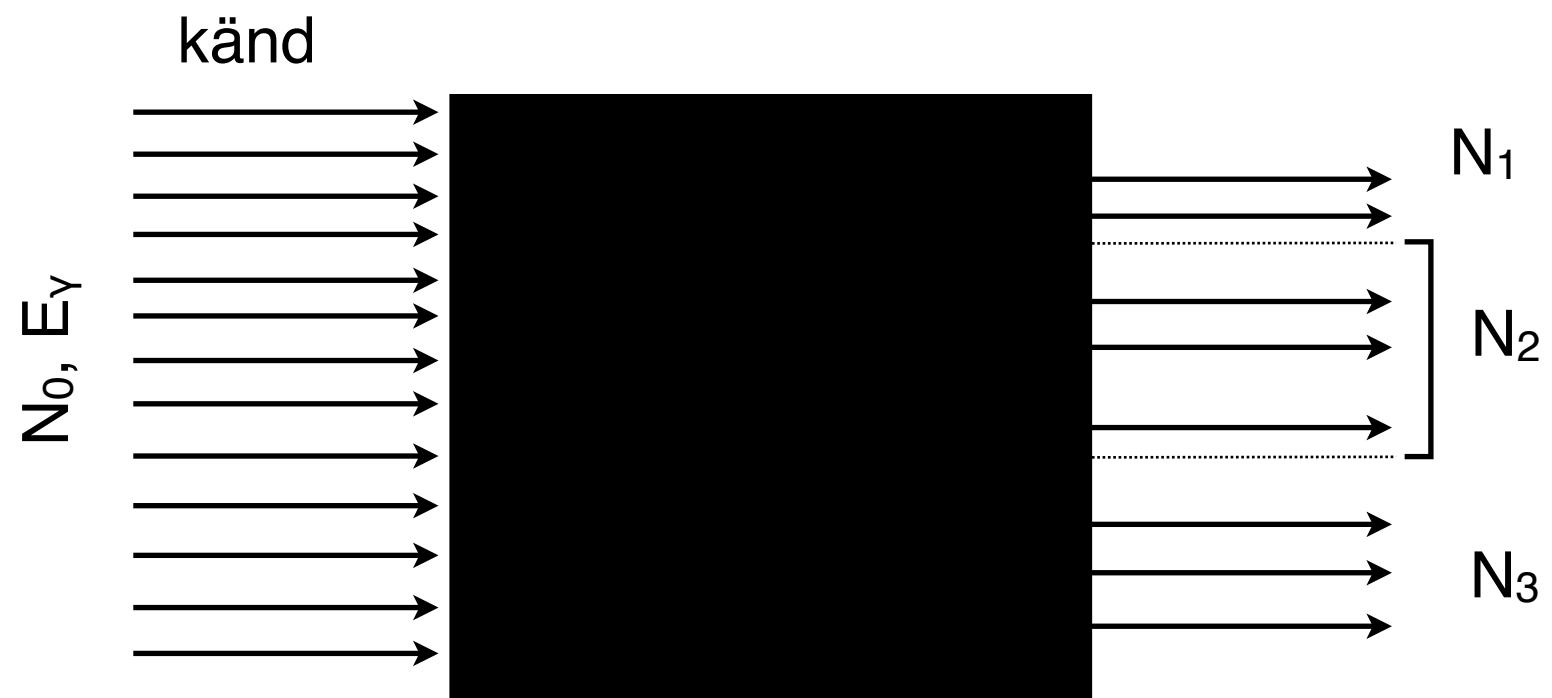


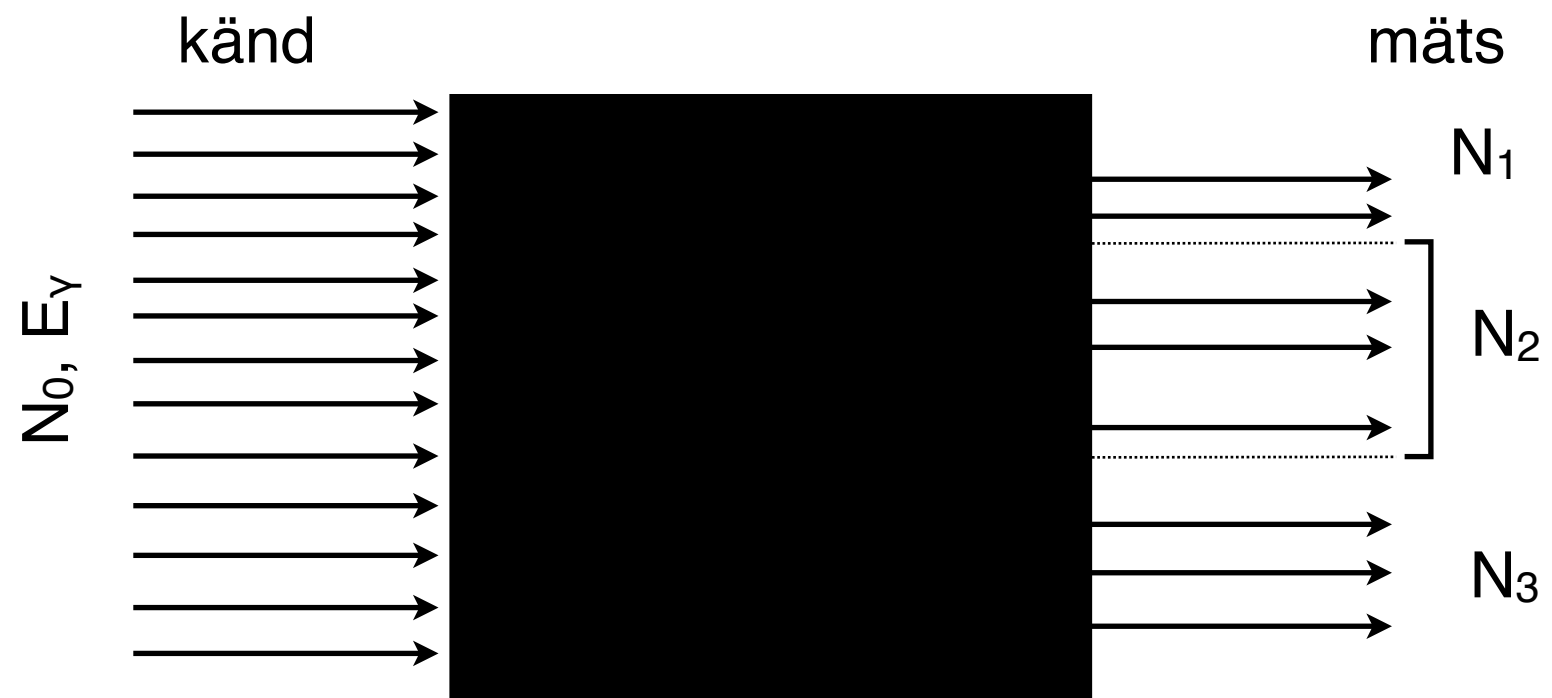


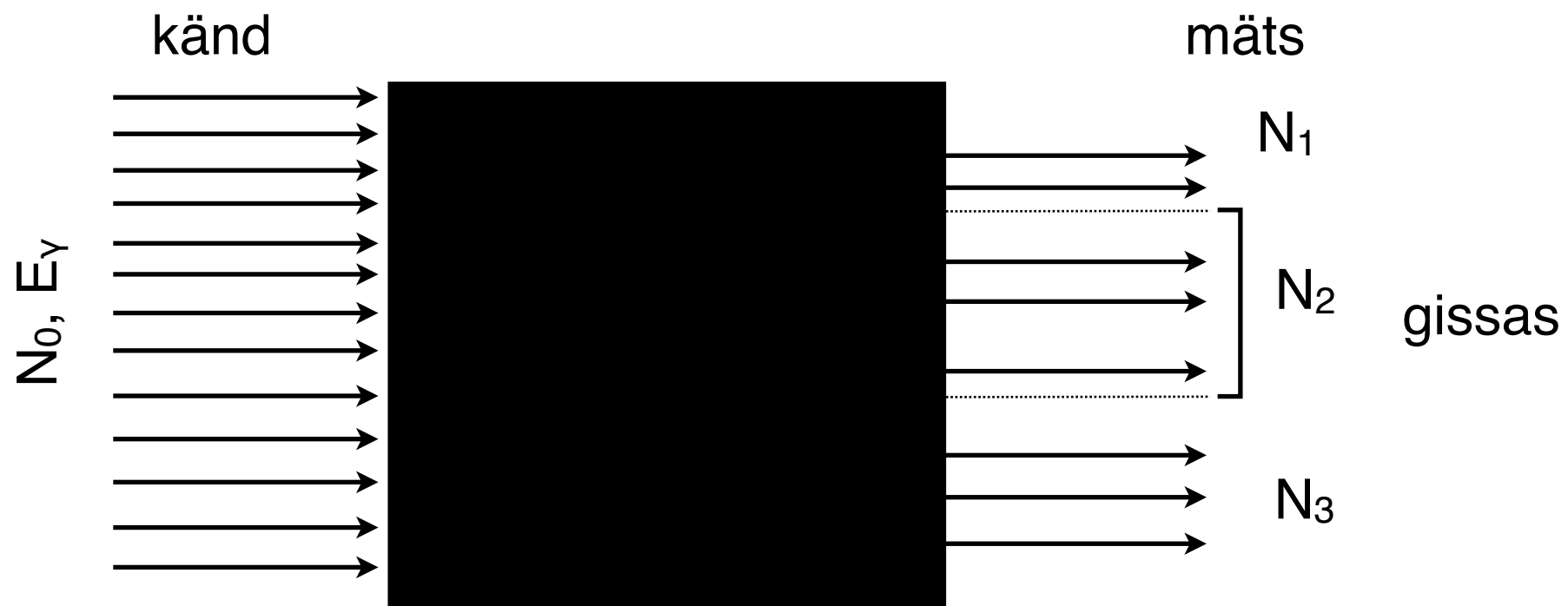
N_0, E_y

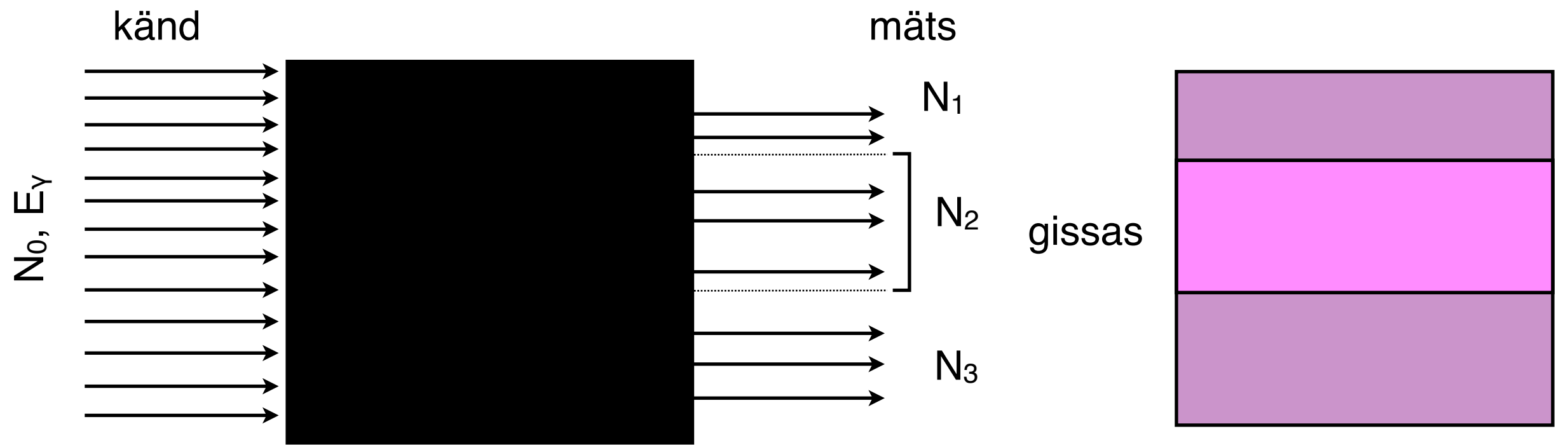
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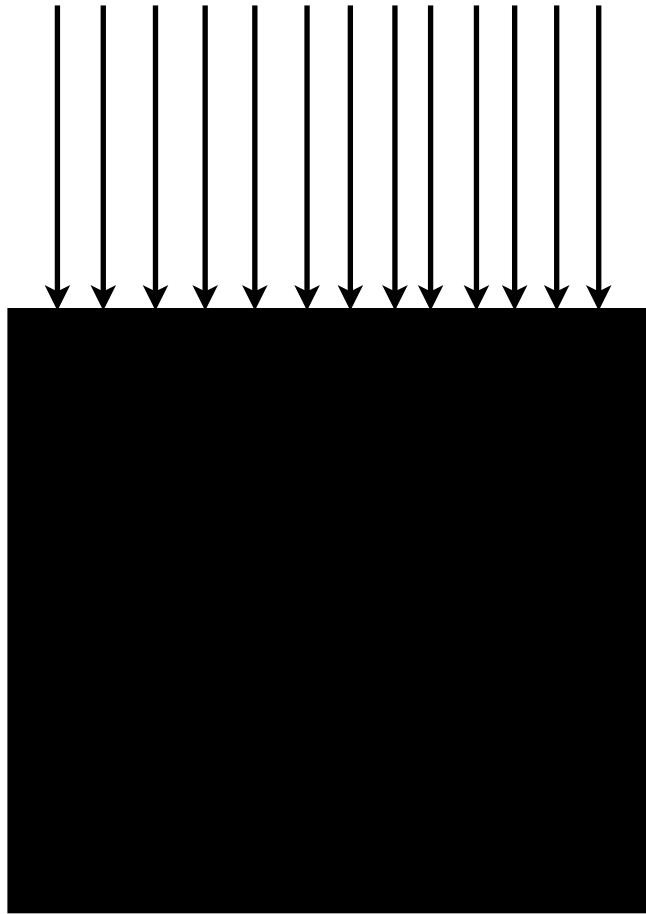


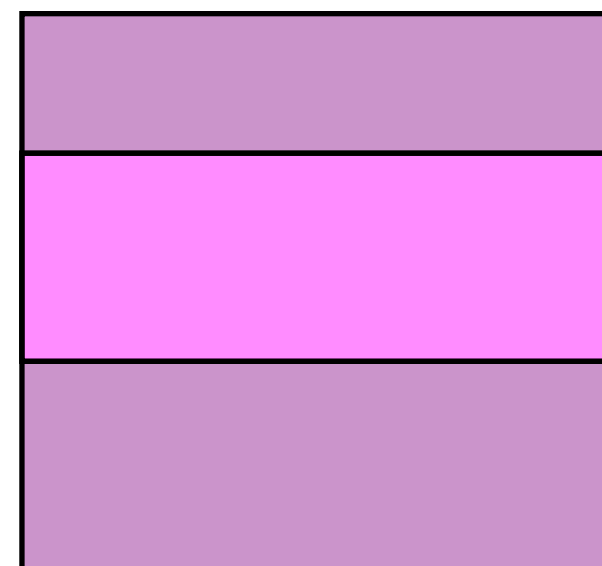
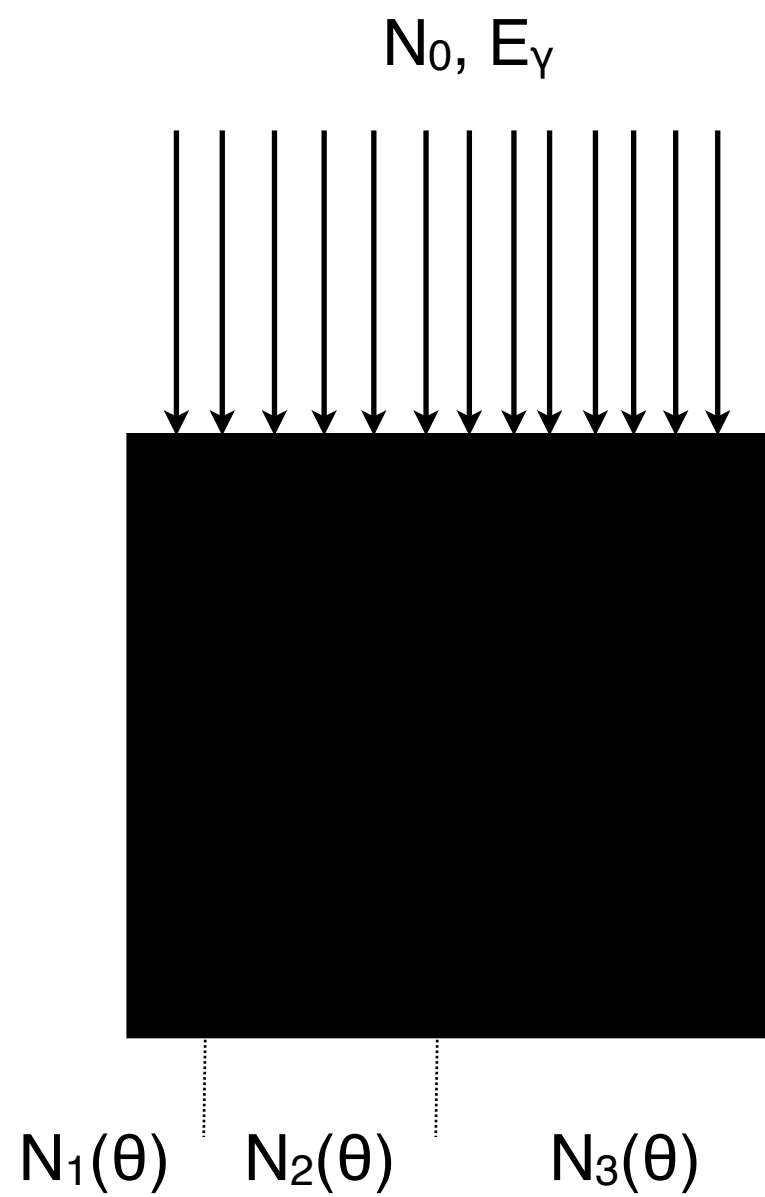




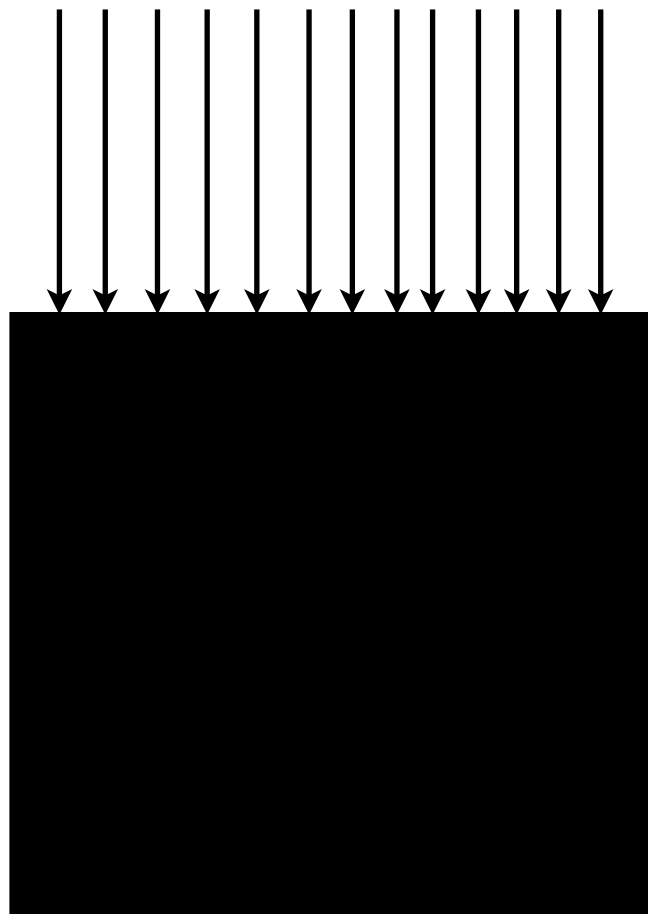


N_0, E_γ





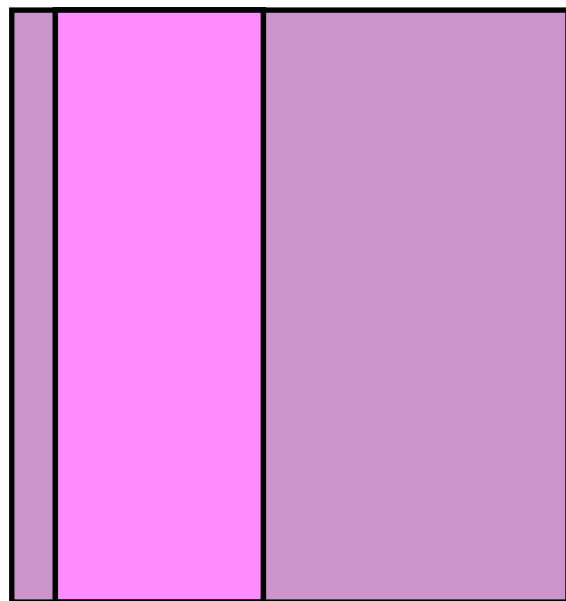
N_0, E_γ

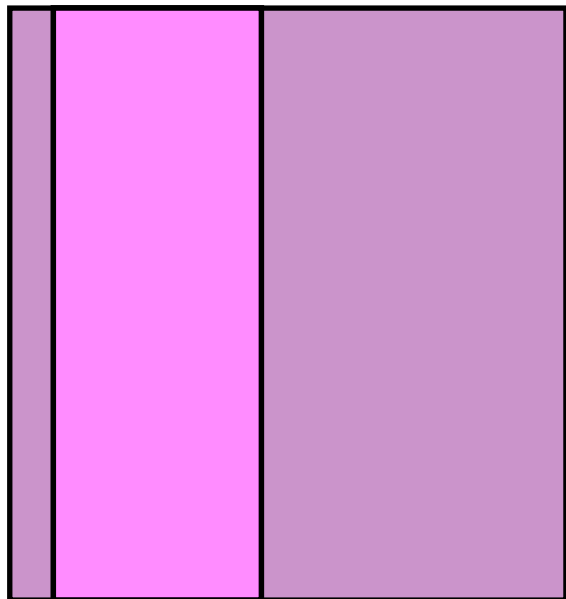
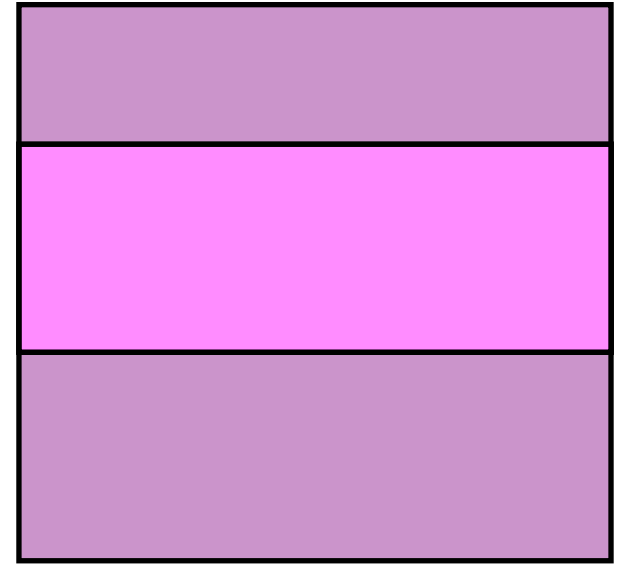


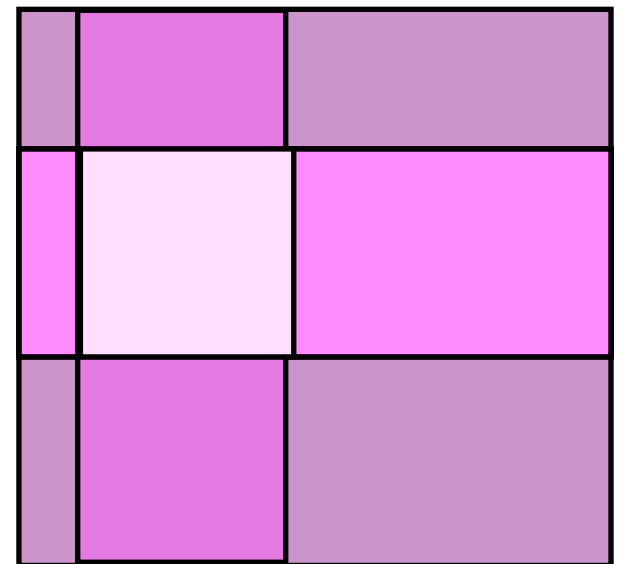
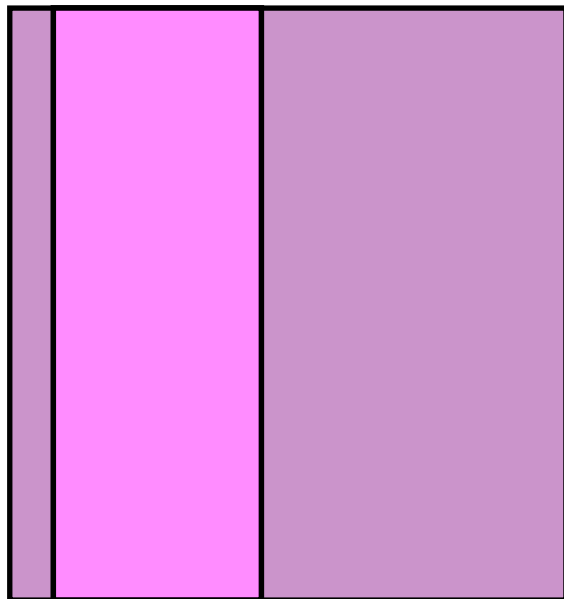
$N_1(\theta)$

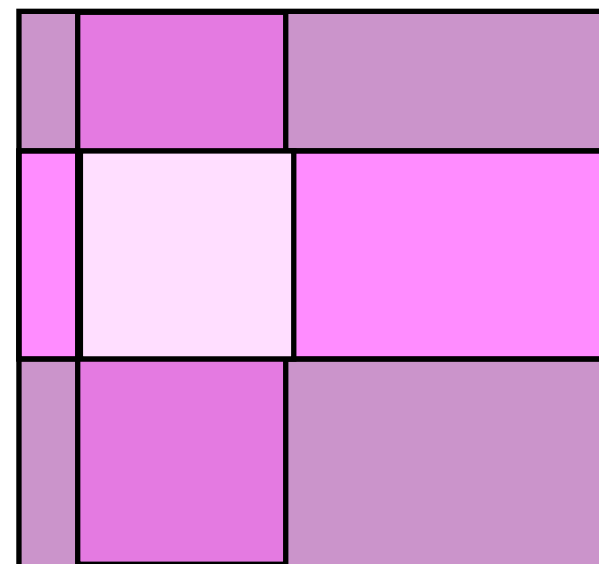
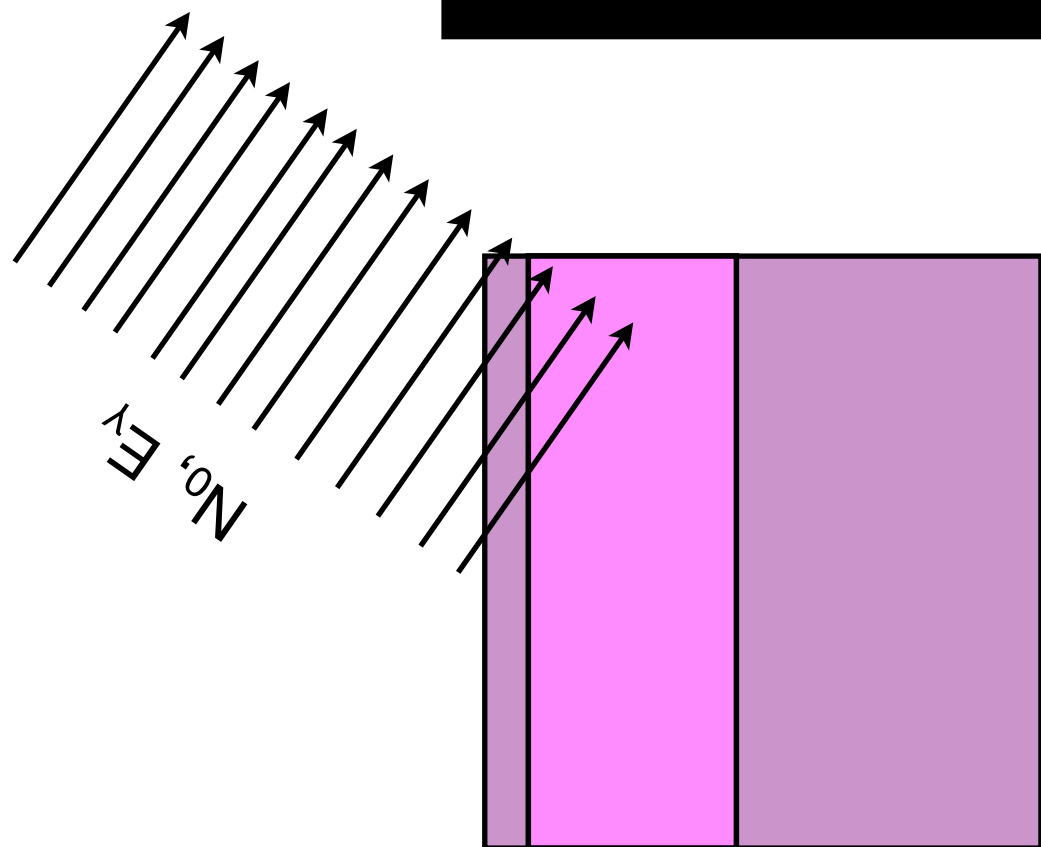
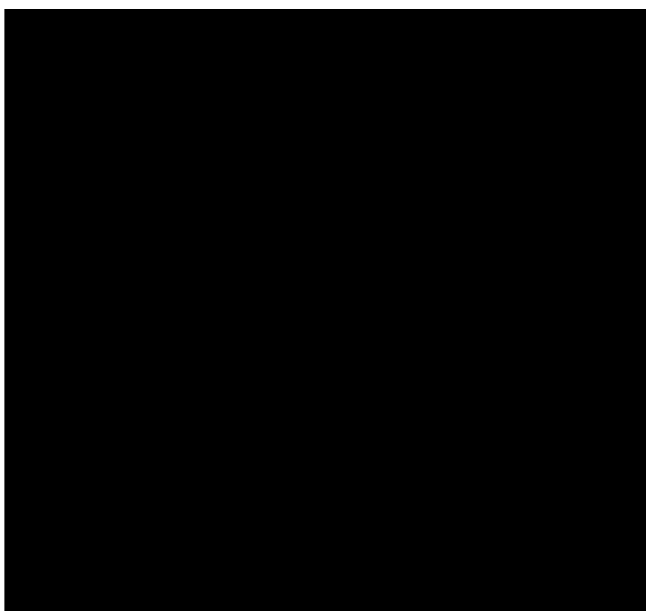
$N_2(\theta)$

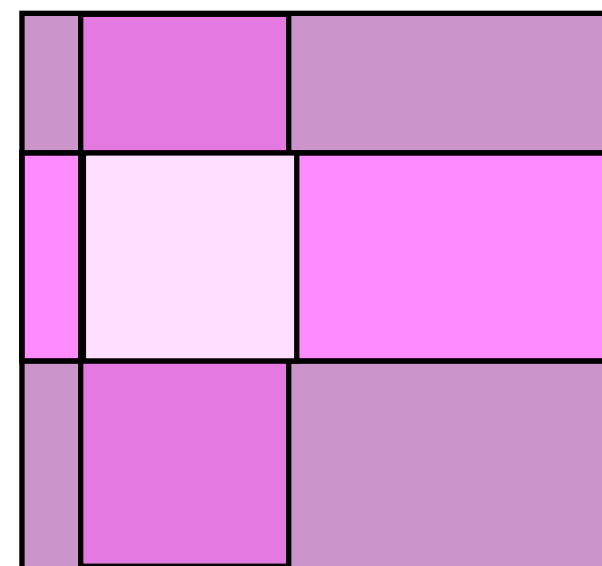
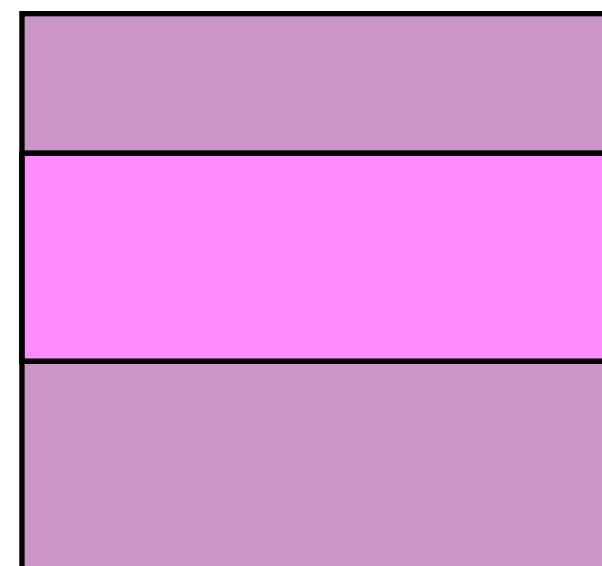
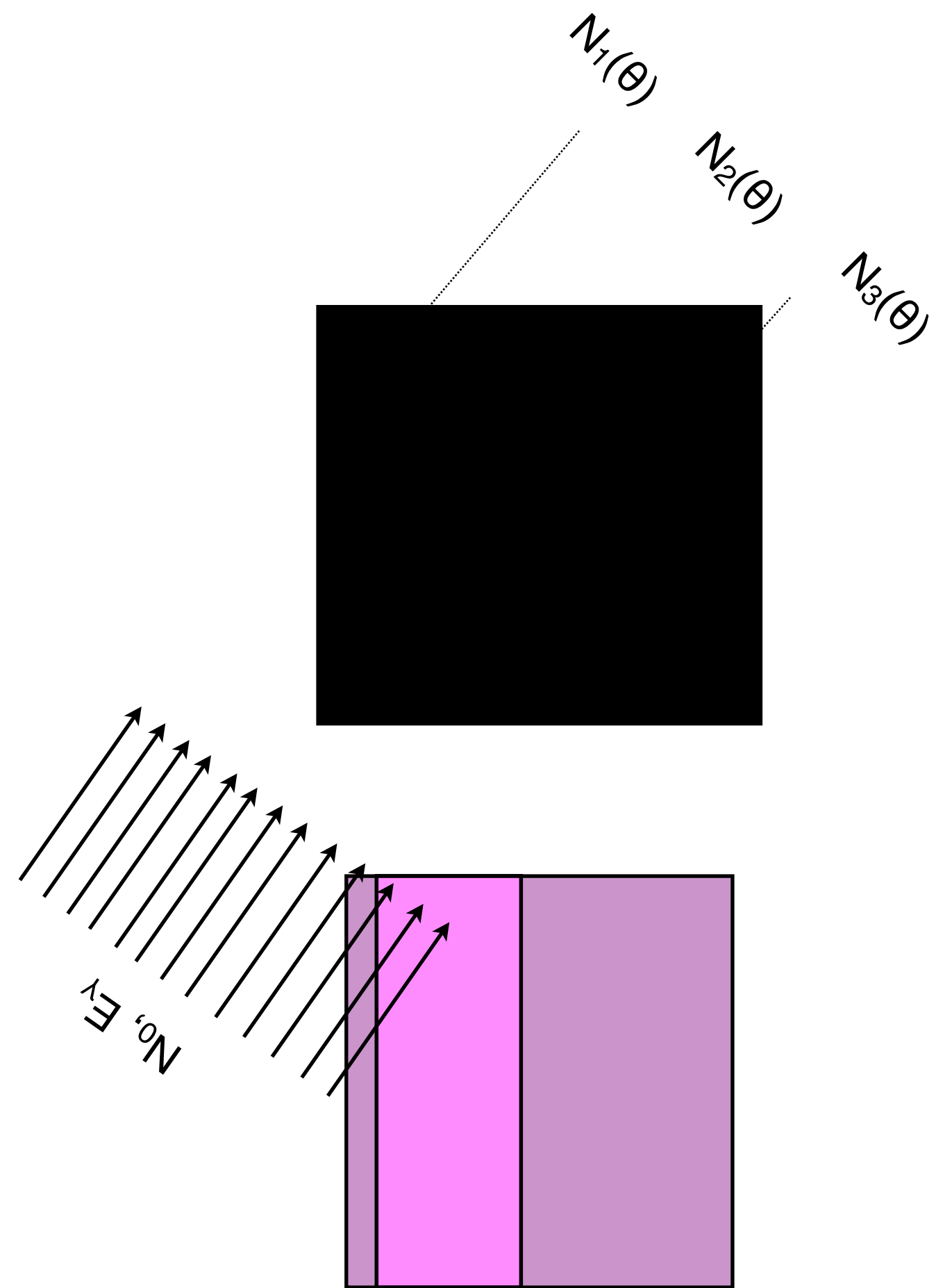
$N_3(\theta)$

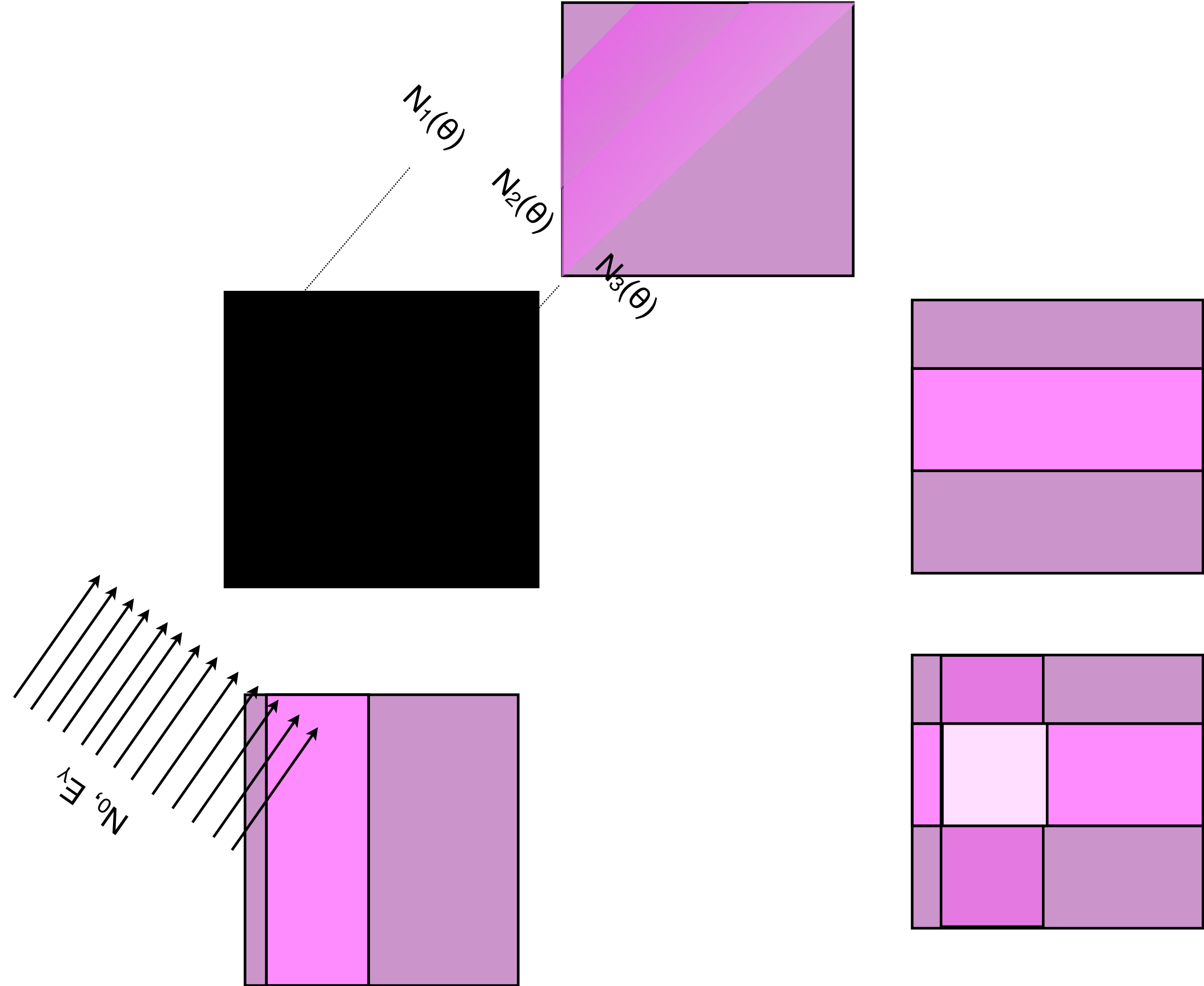


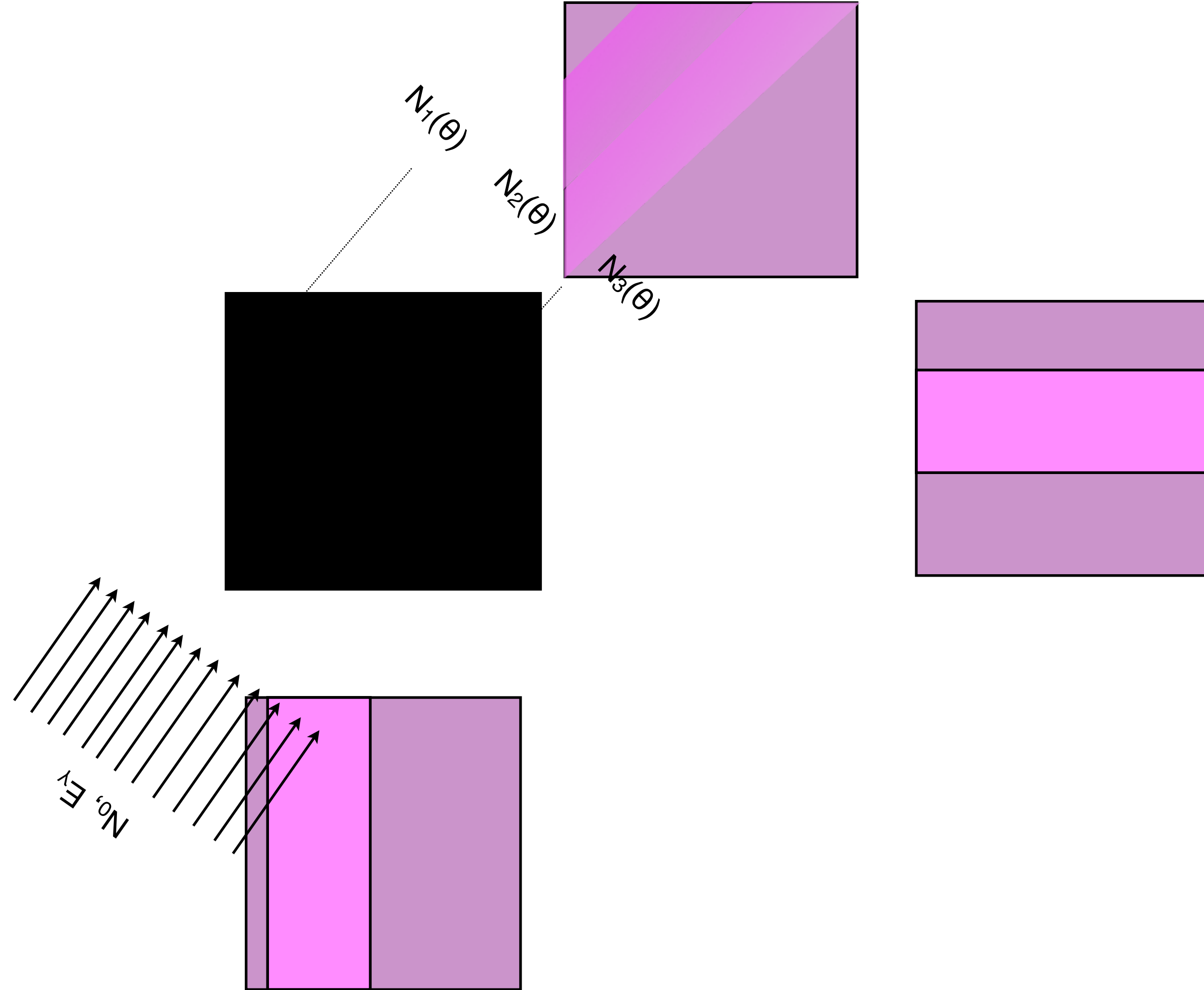


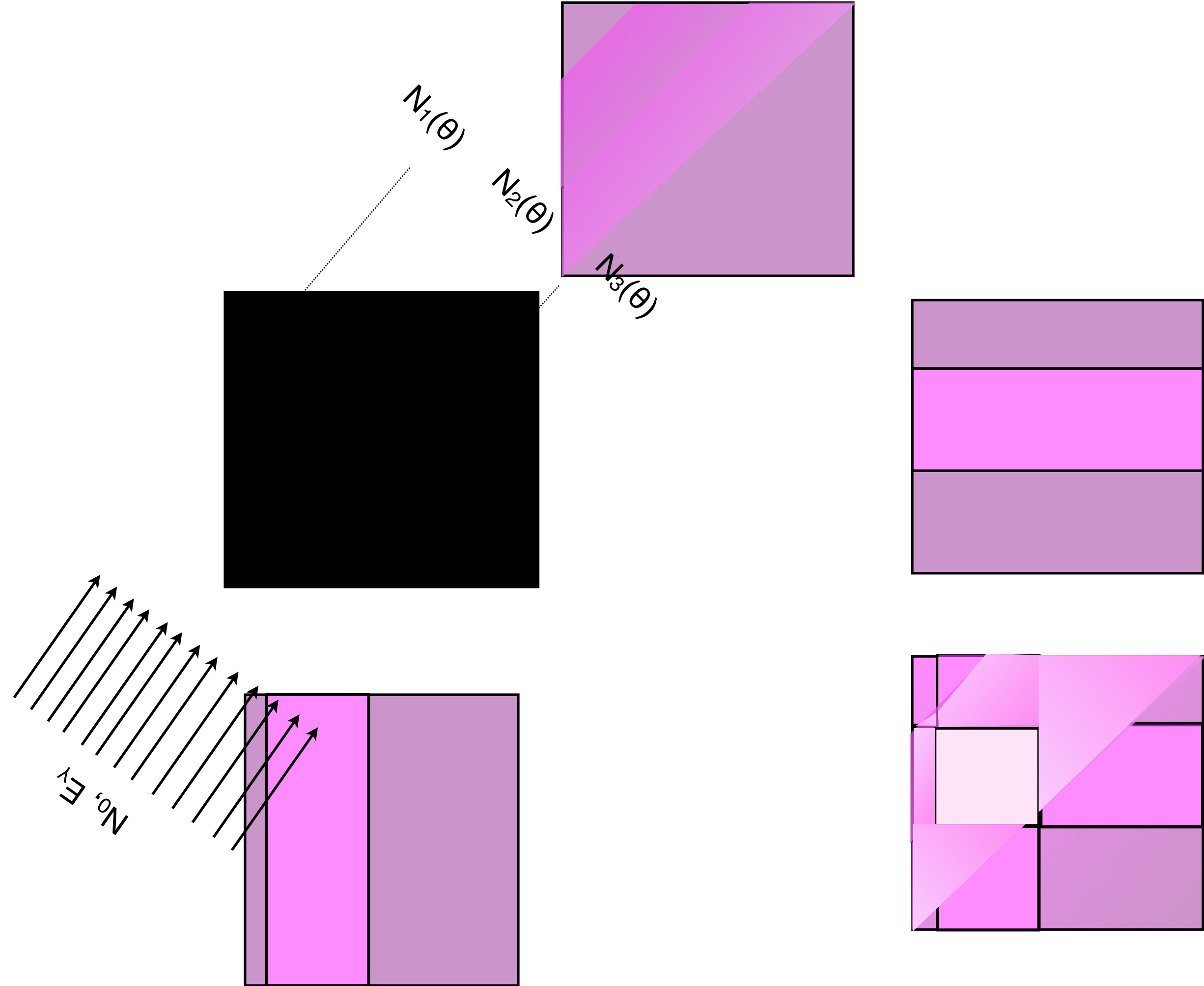


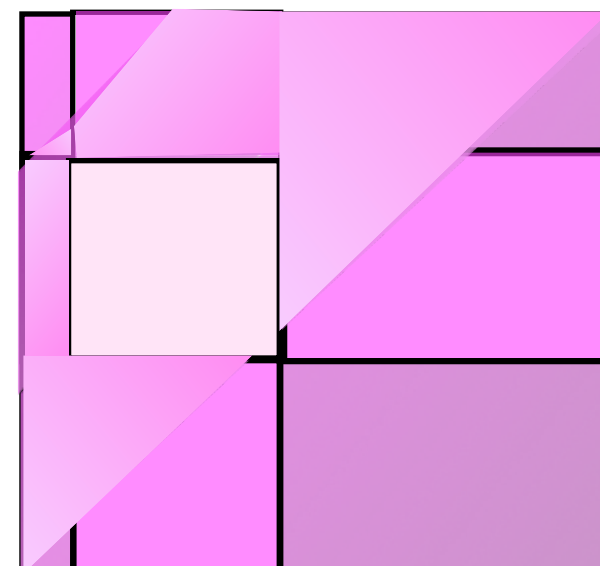
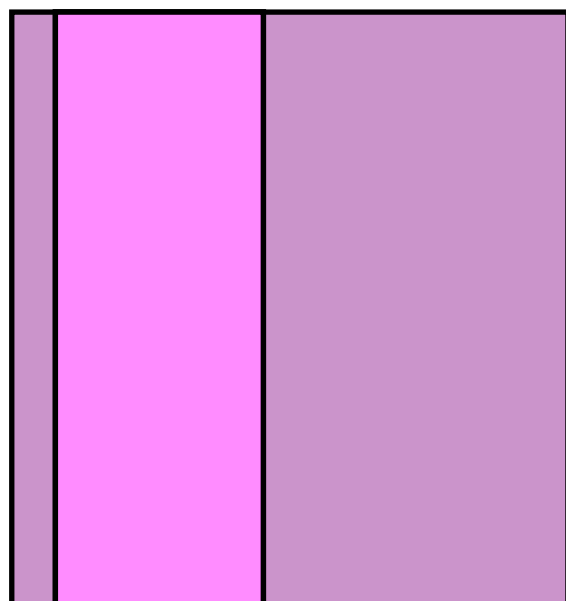
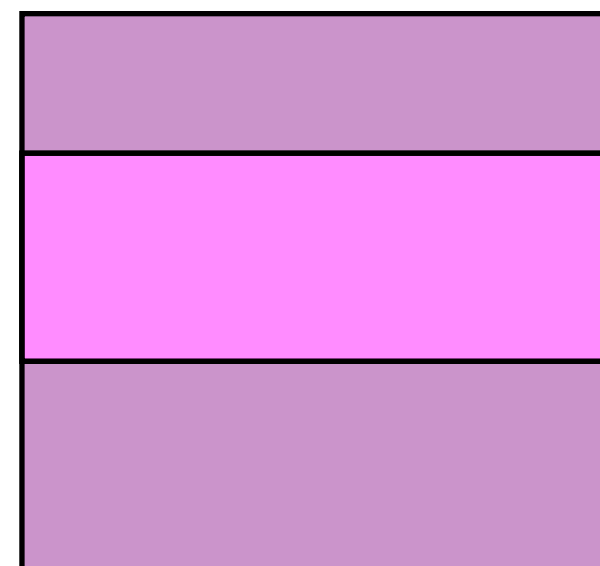
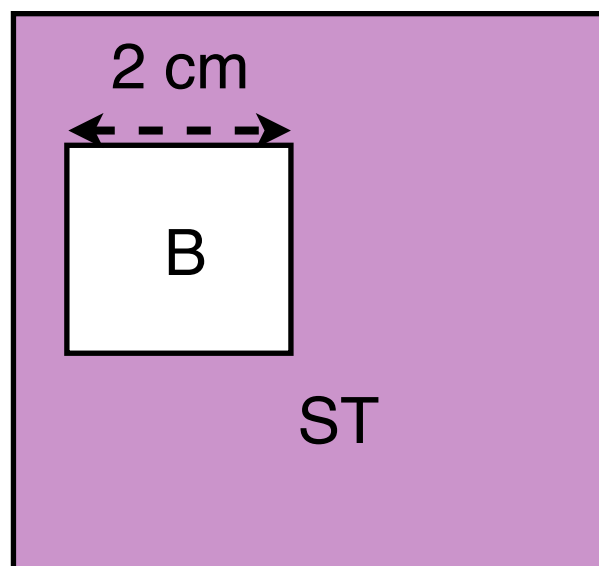
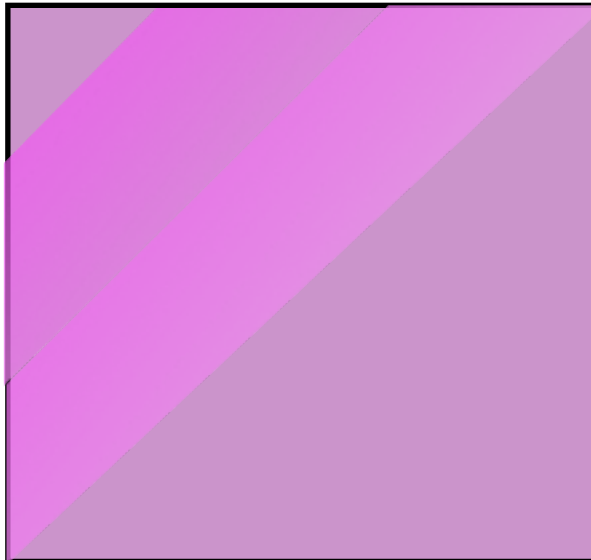


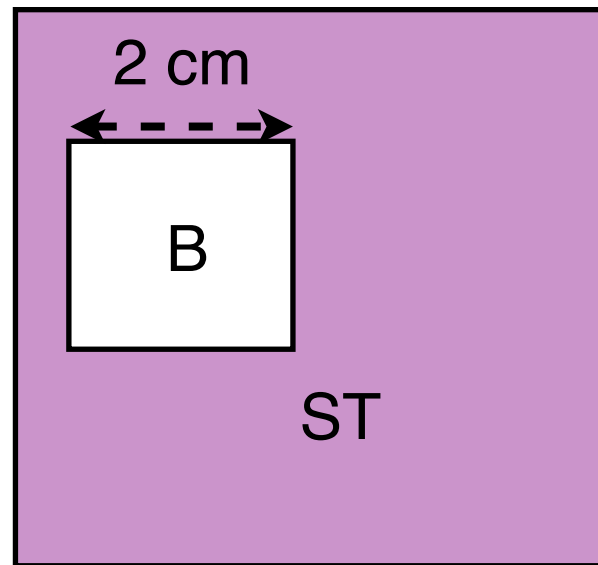
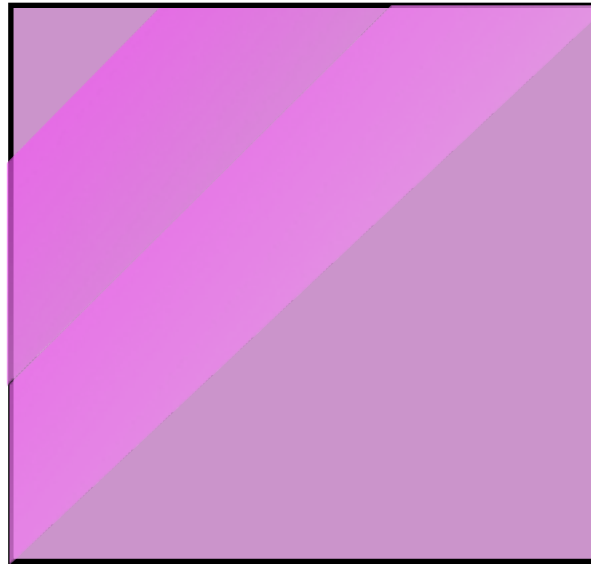




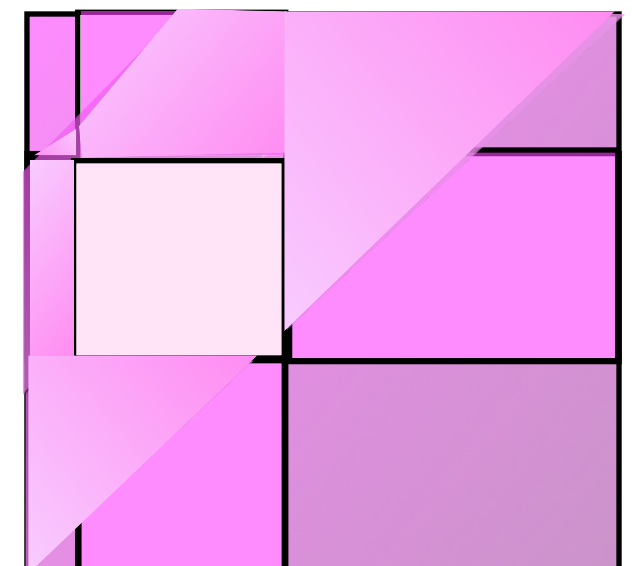
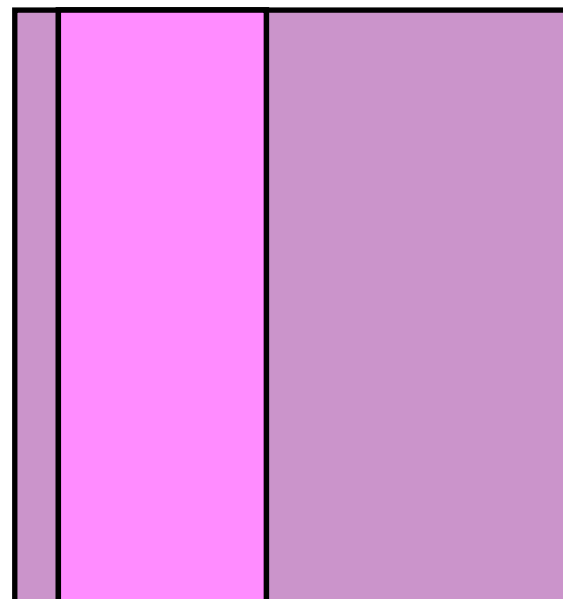








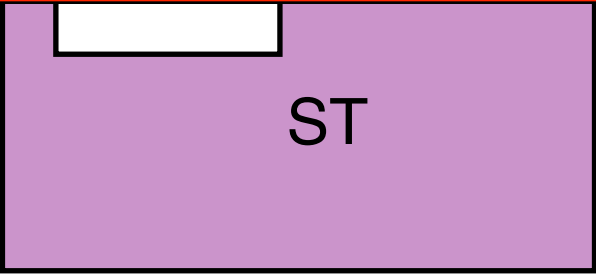
ska man
verkligen få
Nobelpris för
det?





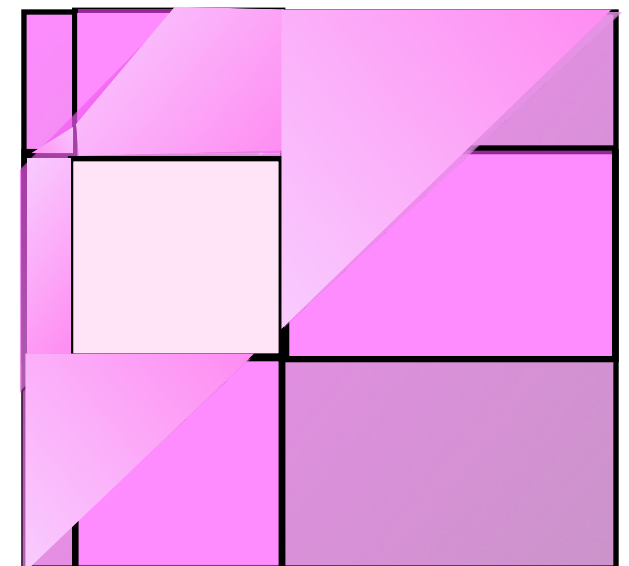
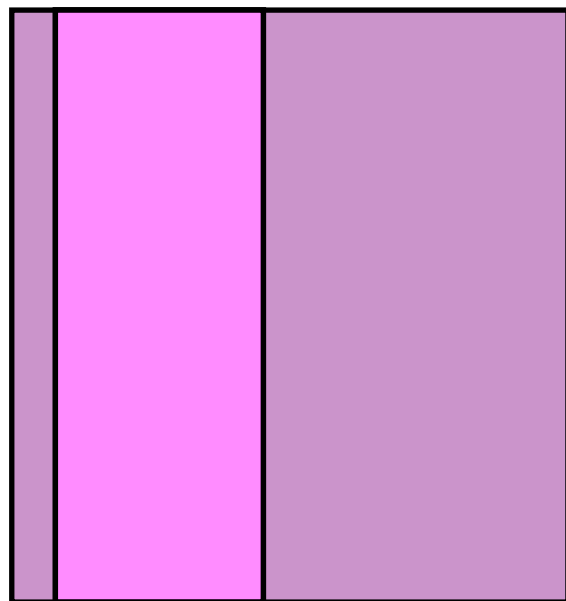
Johann Radon redan 1917:

... an image of an unknown object could be produced if one had an infinite number of projections through the object.

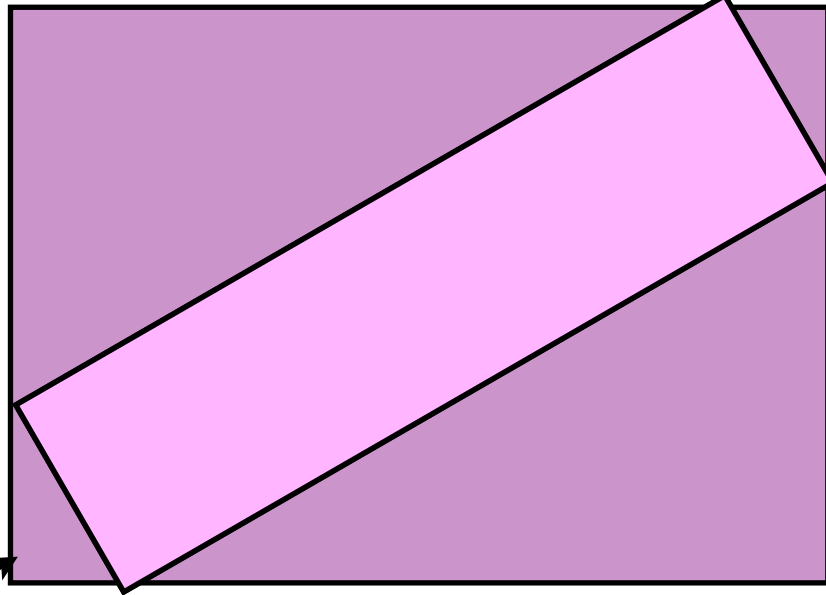
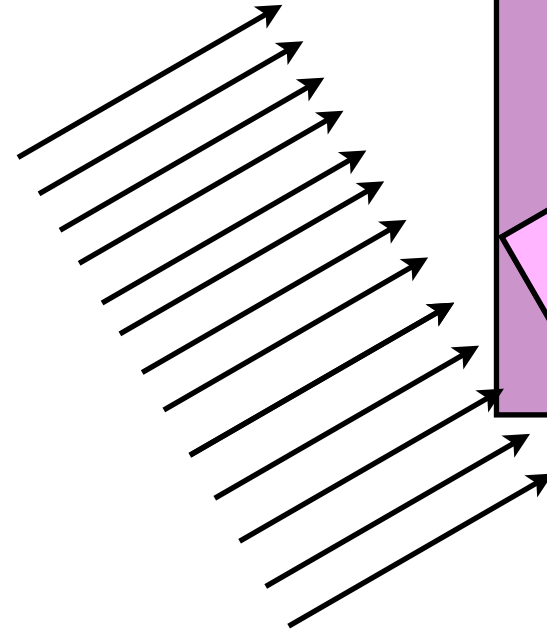


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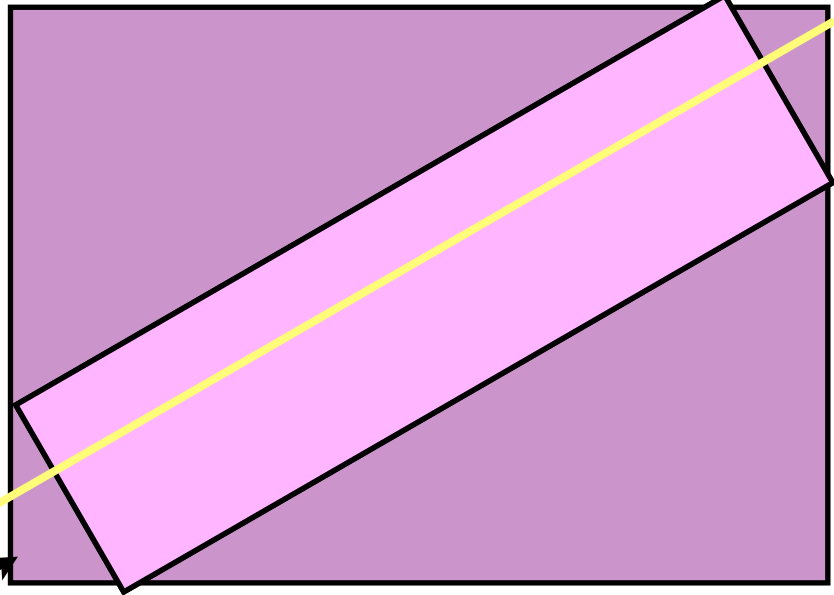
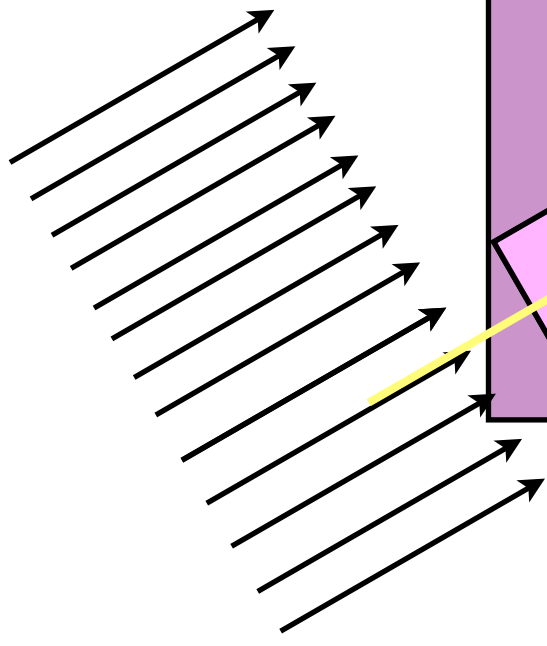
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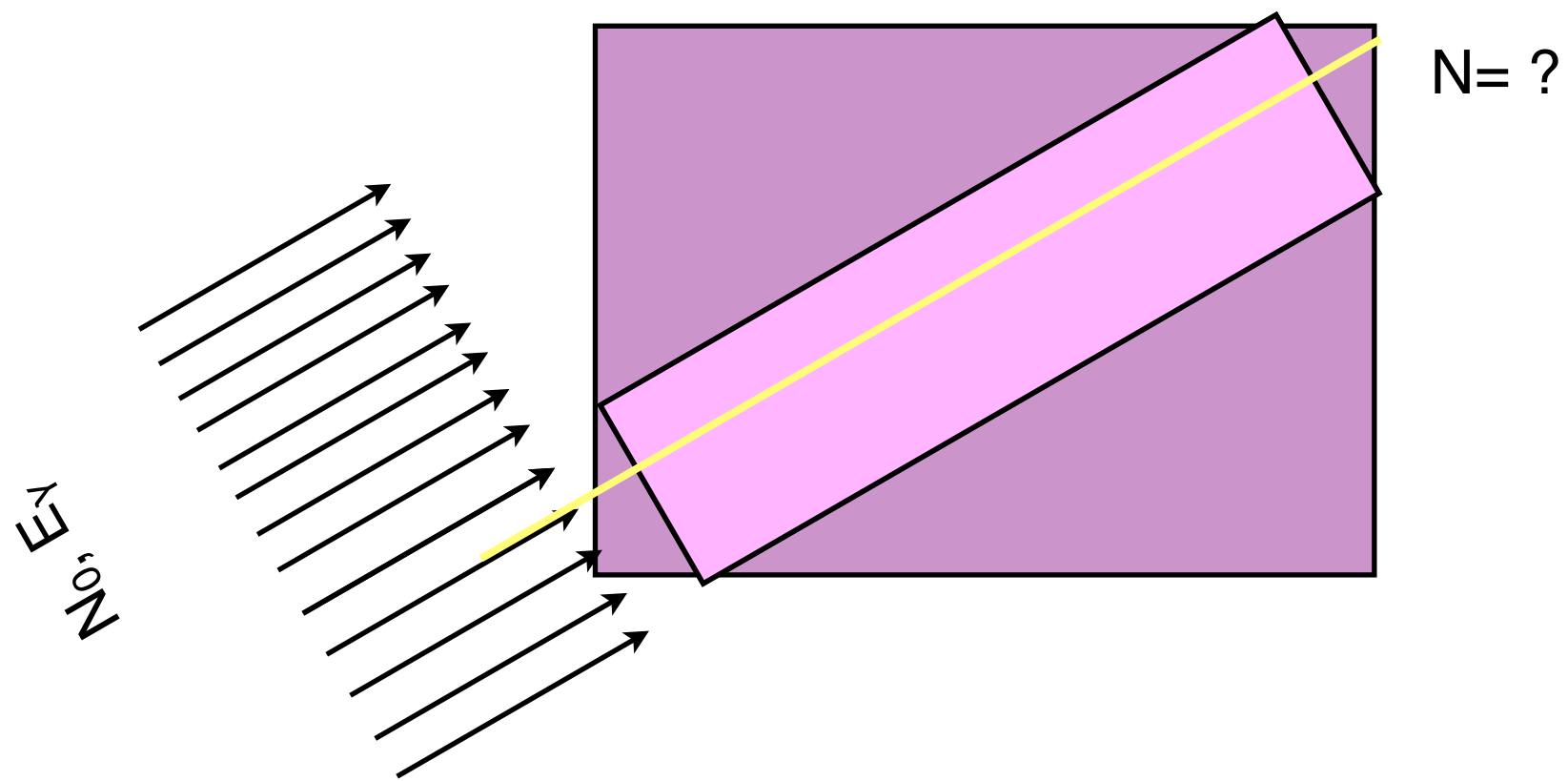
E_0



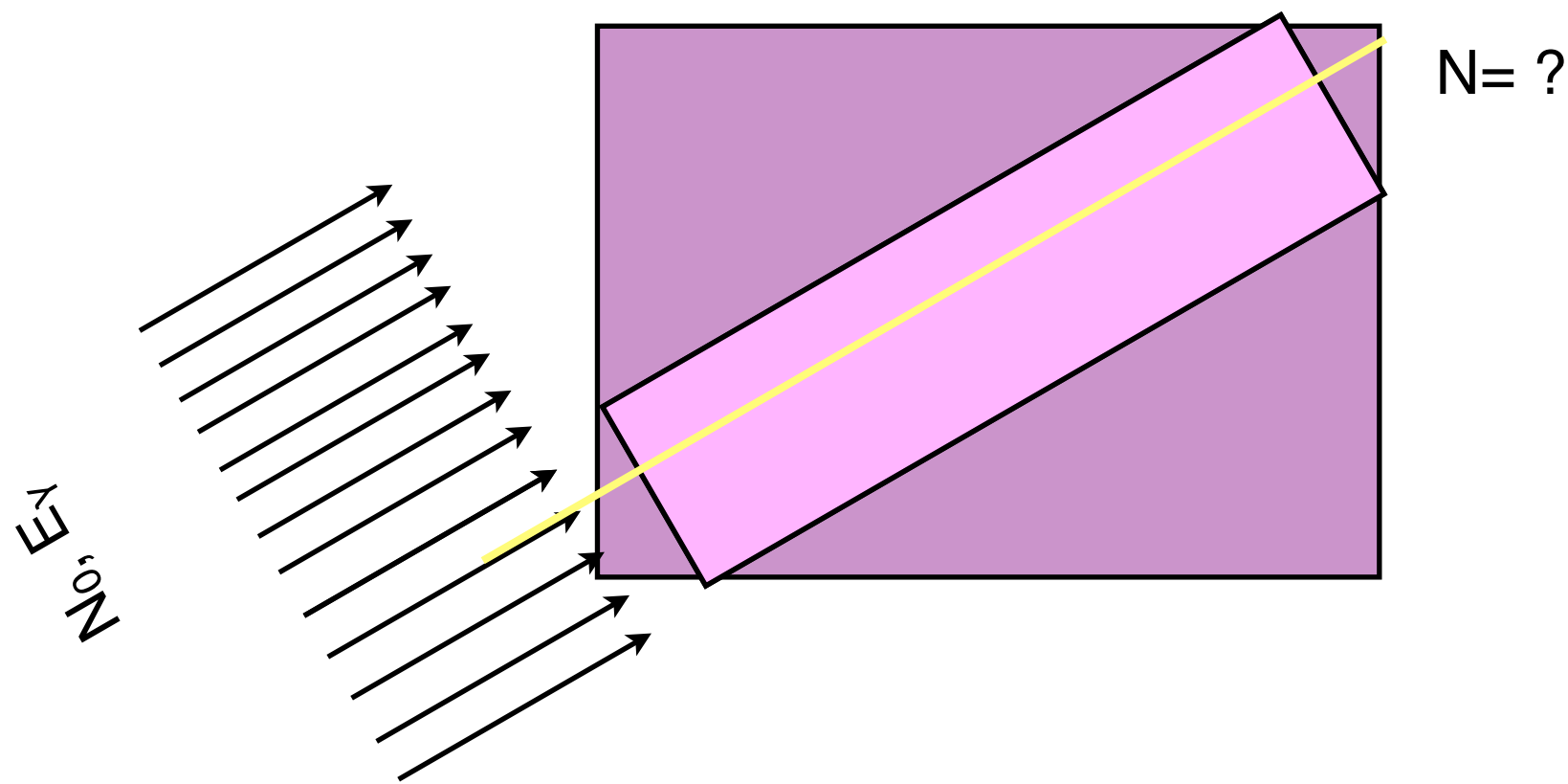
E_1
 N_0



$N = ?$

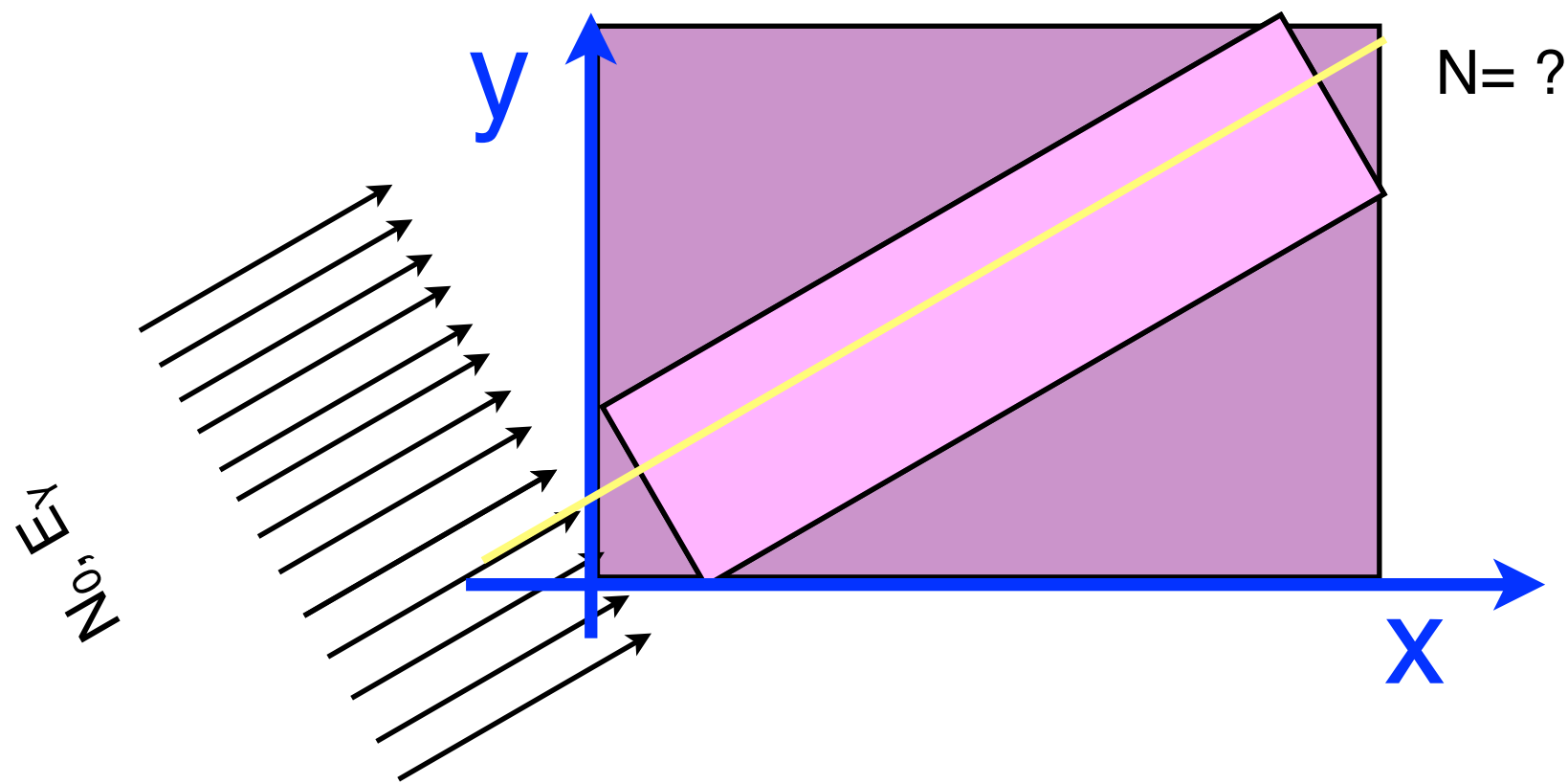


Om man vill vara cool som Radon så skriver man:



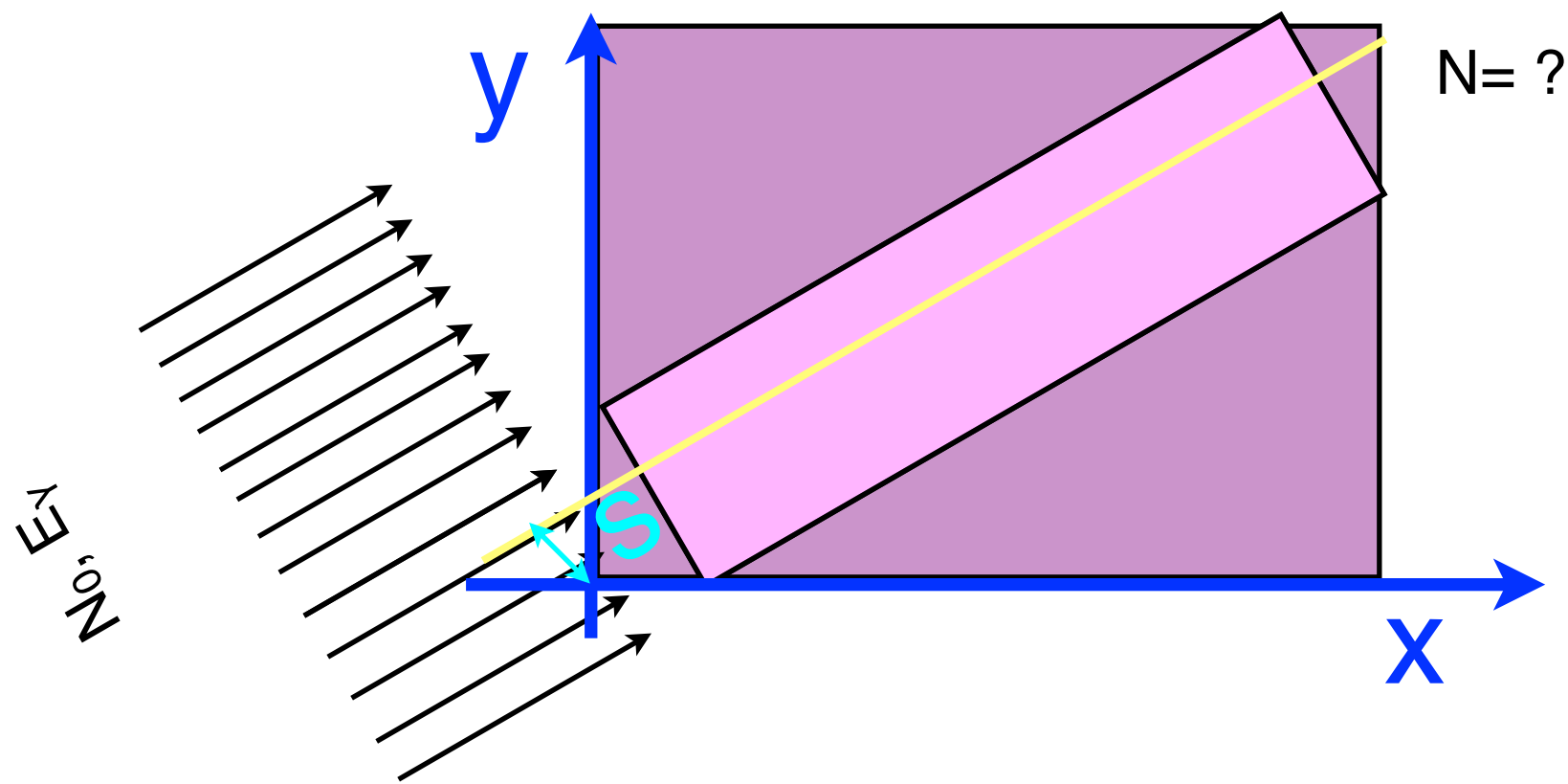
Om man vill vara cool som Radon så skriver man:

$$N(\theta, s) = N_0 e^{-\int \int \mu(x, y, E) \delta(x \cos \theta - y \sin \theta - s) dx dy}$$



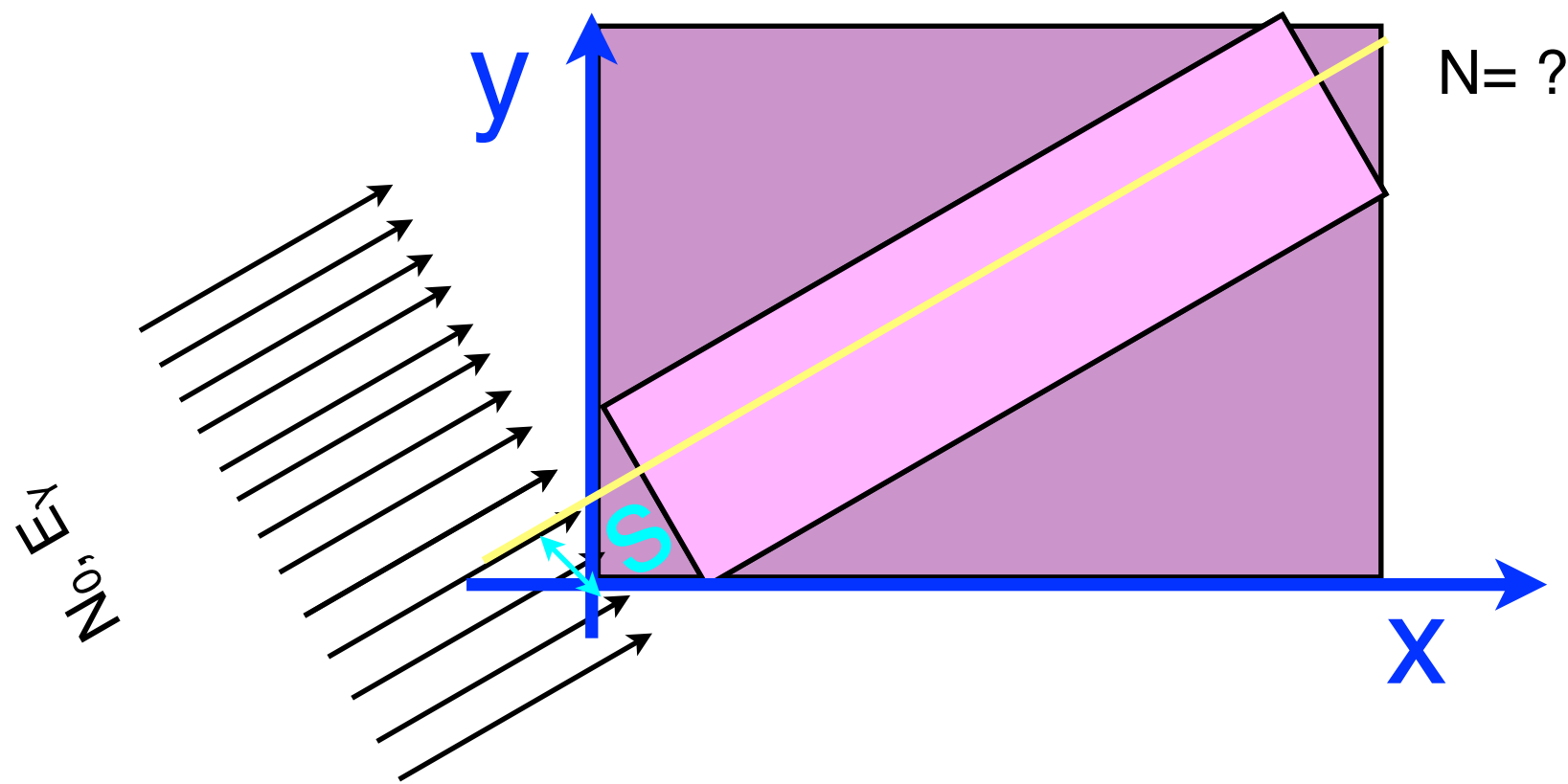
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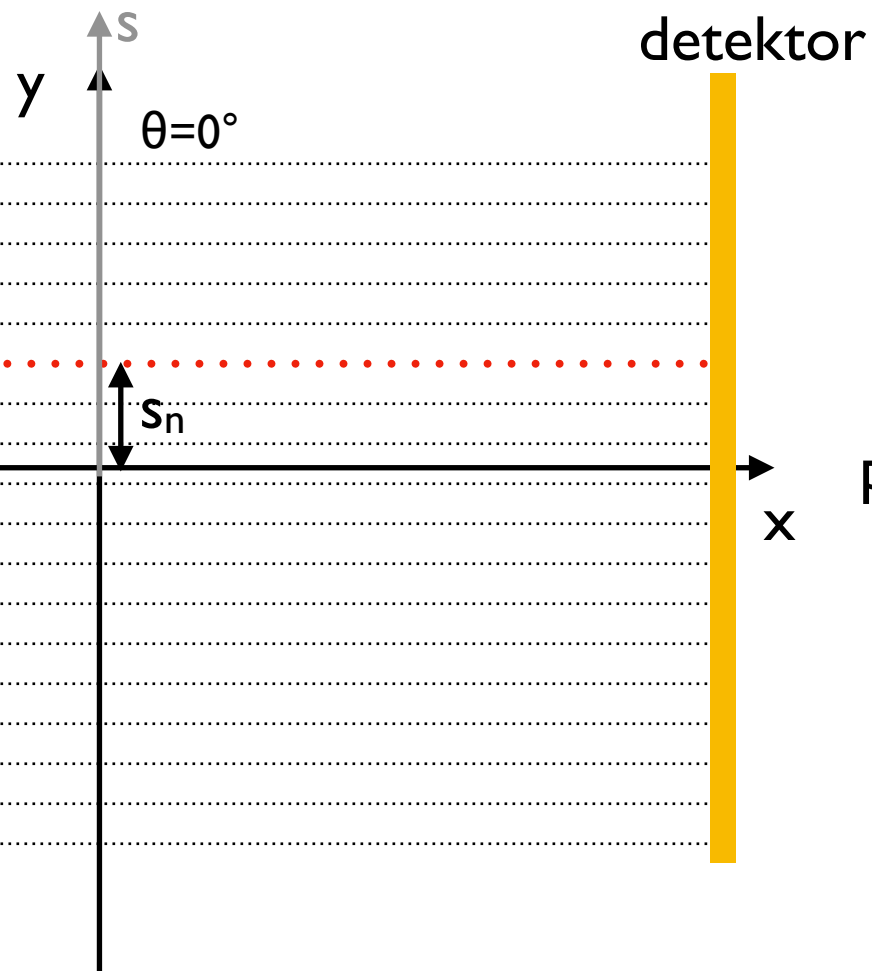


$$N(\theta, s) = N_0 e^{-\int \int \mu(x, y, E) \delta(x \cos \theta - y \sin \theta - s) dx dy}$$

The double integral on the exponent represents:

1. the sum of all $\mu(x, y)$ along the line of x-ray propagation
2. all the parallel lines with given angle θ
3. all the points with coordinates x, y that are at distance s from origo
4. Radon exponent

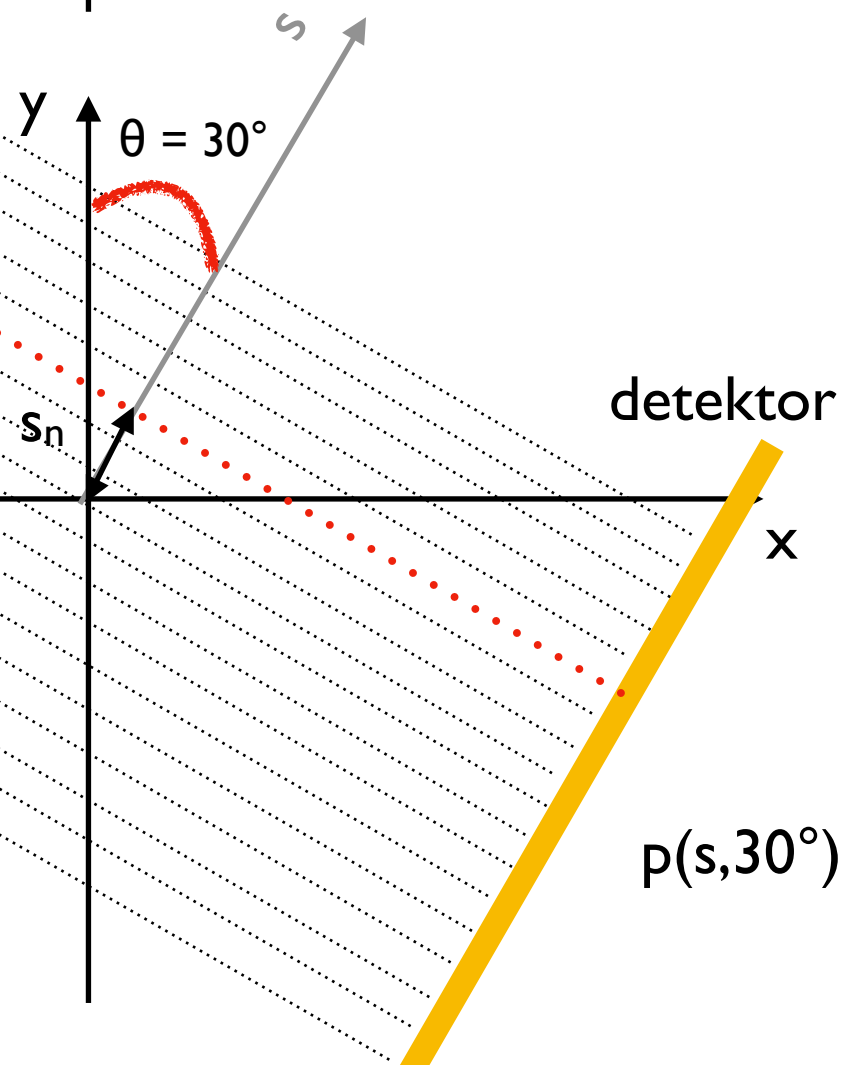
röntgenstrålen



$p(s, 0^\circ)$

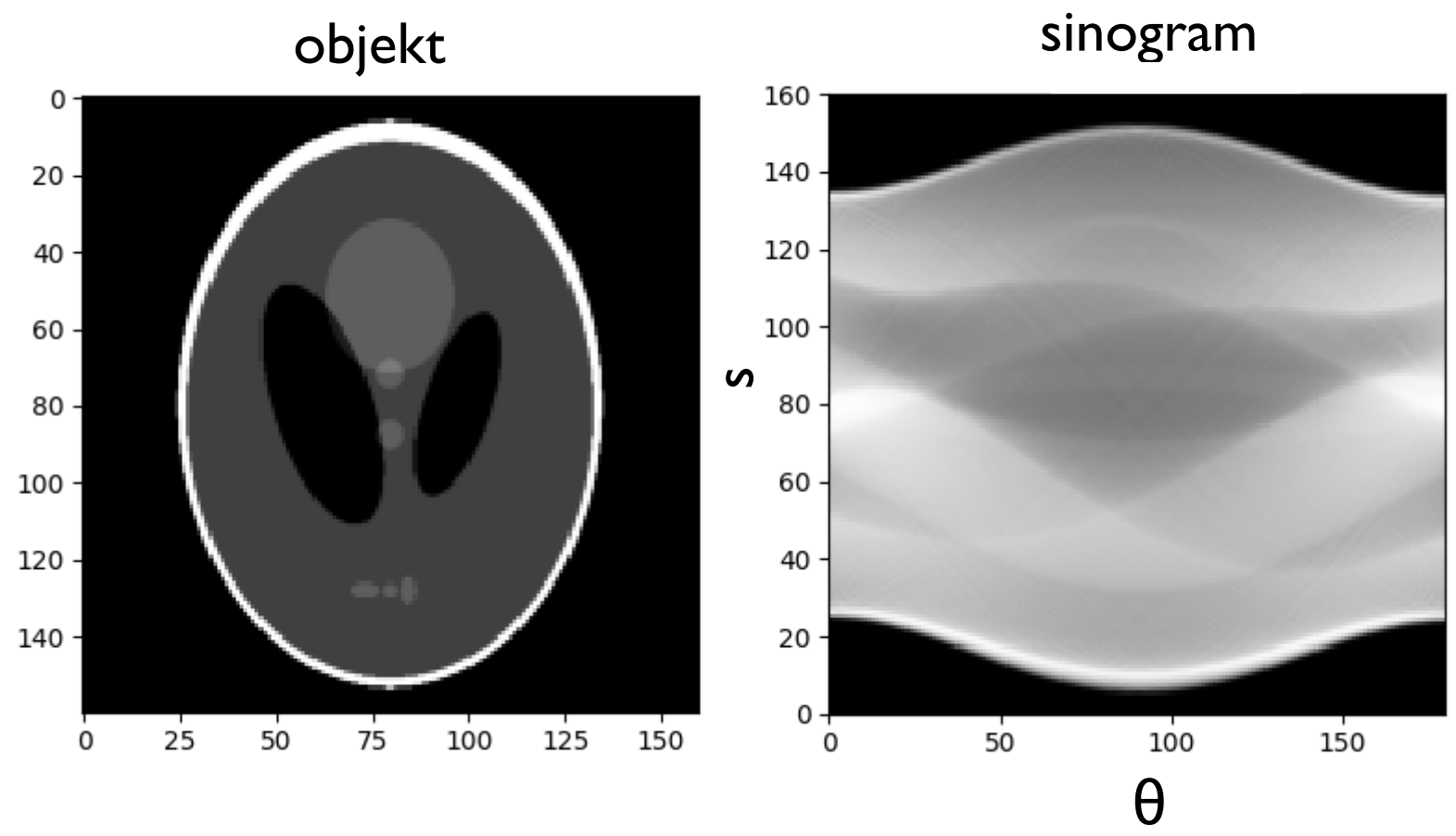
- samtliga linjer i xy -plan kan beskrivas med hjälp av parametrar s och θ
- om θ behövs konstant, så får man alla parallella linjer när s varieras
- om s behövs konstant så får man alla linjer som tangerar en cirkel när θ varieras
- $p(s_n, \theta_n)$ betecknar integralen av objektet längs linjen som bestäms av s_n samt θ_n (den röda i figuren)
- $p(s, 0^\circ)$ betecknar projektionen vid $\theta = 0^\circ$, $p(s, 30^\circ)$ projektionen vid 30° (det är det som detektor mäter vid 0° respektive 30°)

röntgenstrålen

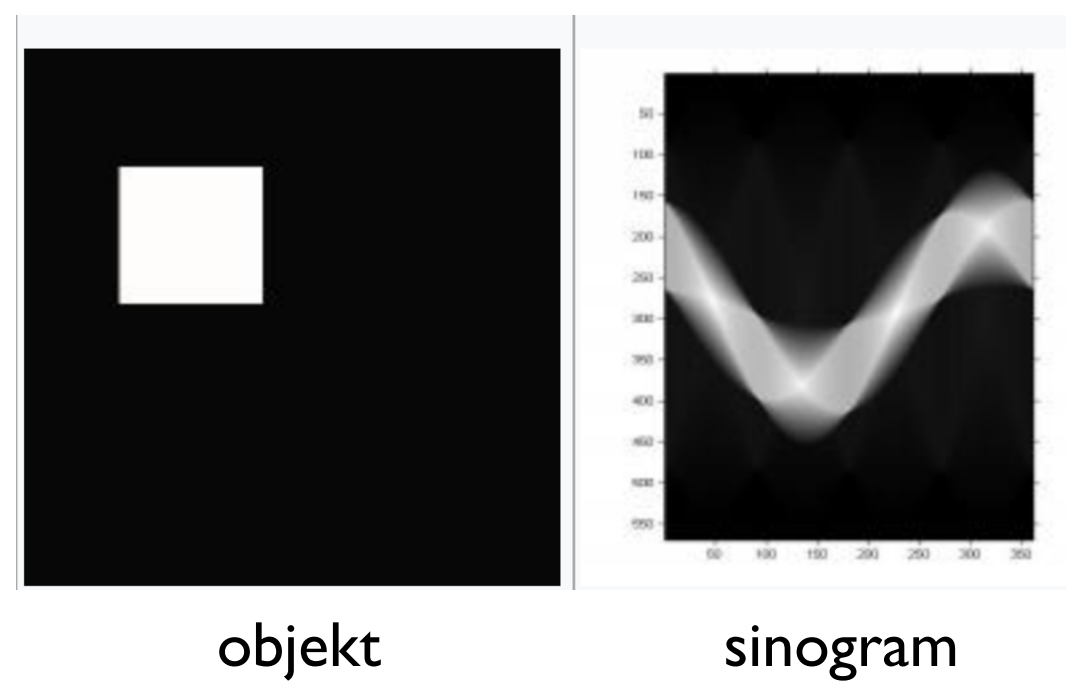
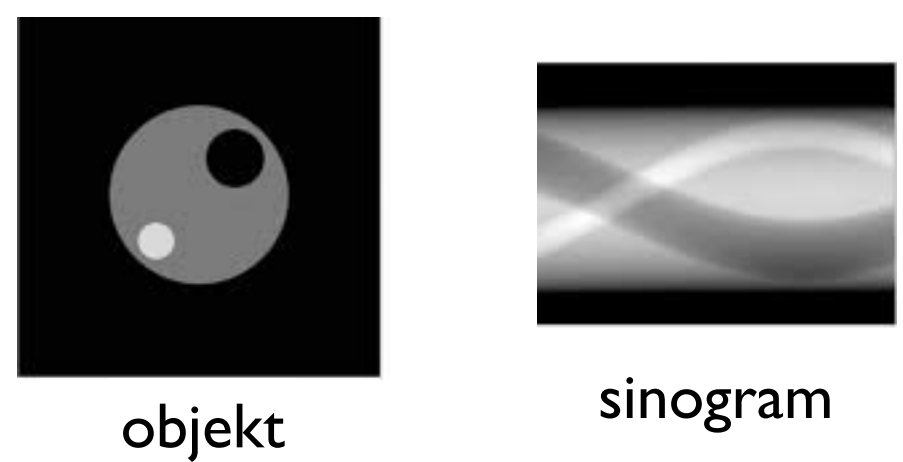


$p(s, 30^\circ)$

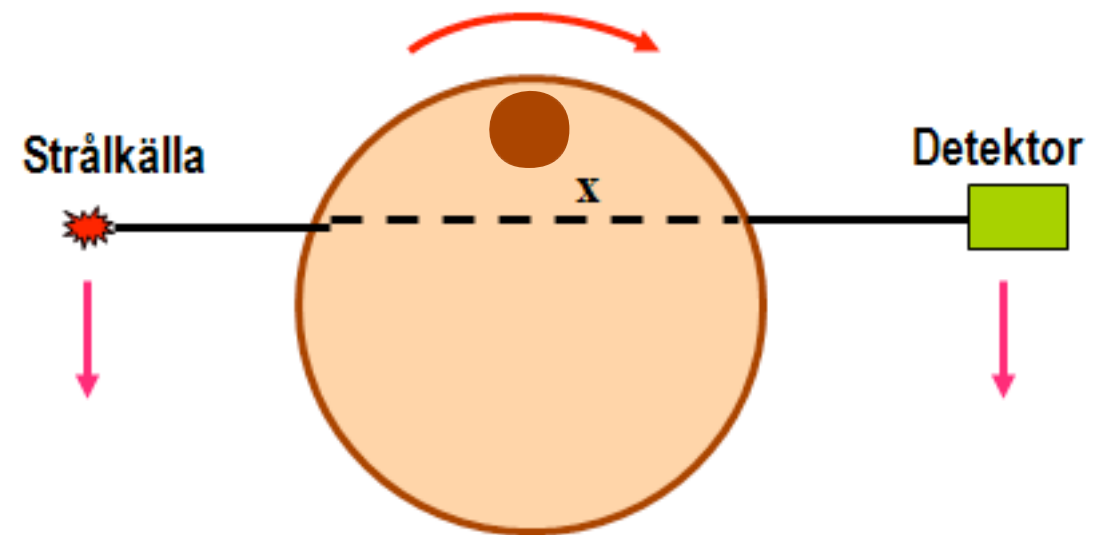
$p(s, \theta)$, dvs samtliga projektioner vid alla vinklar, kallas sinogram. Ett exempel visas nedan:



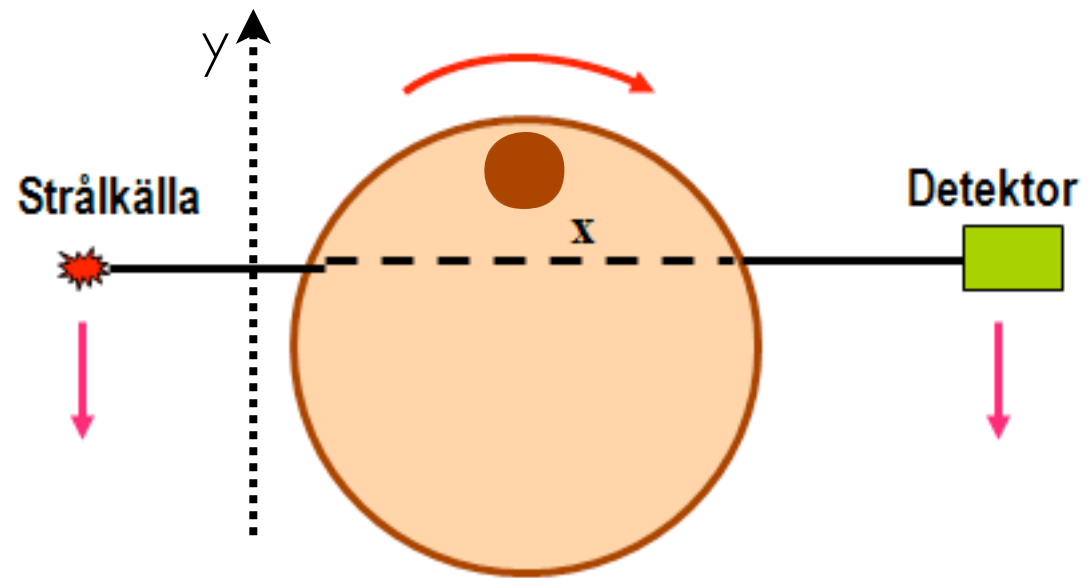
Här visas exempel av sinogram för enkla objekt:



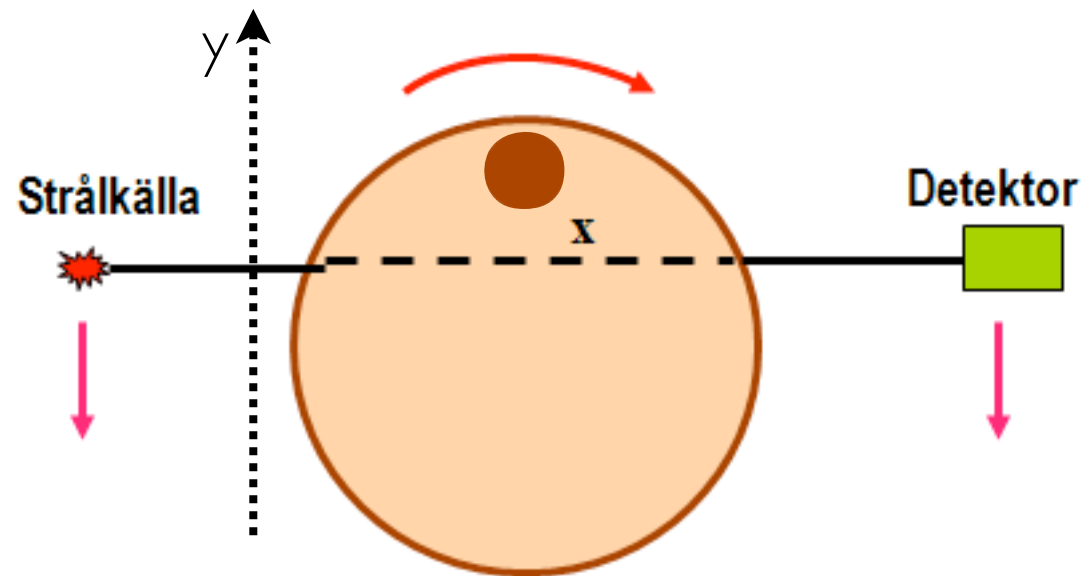
Sinogram



Sinogram

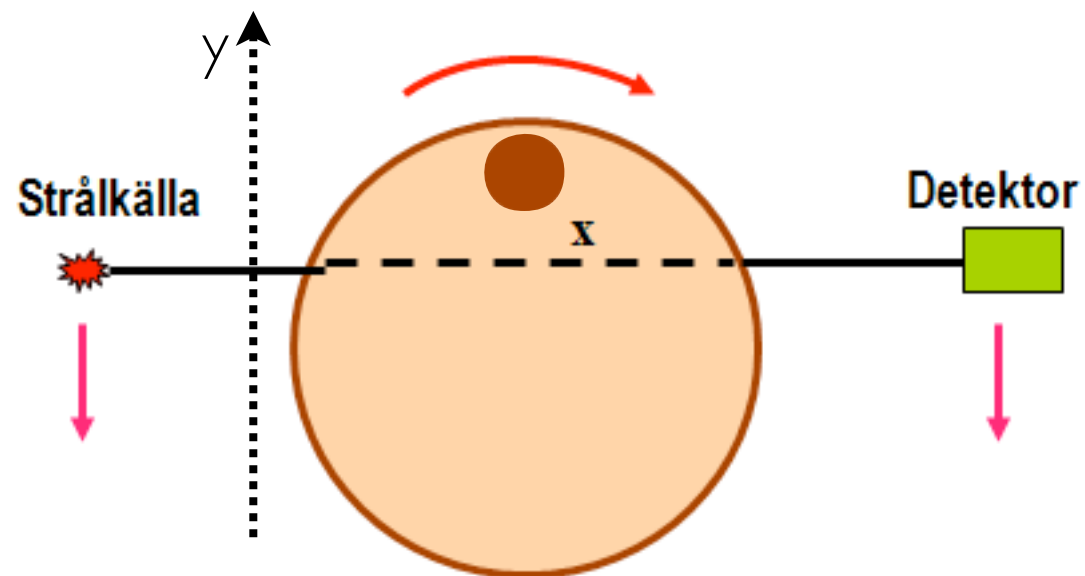


Sinogram

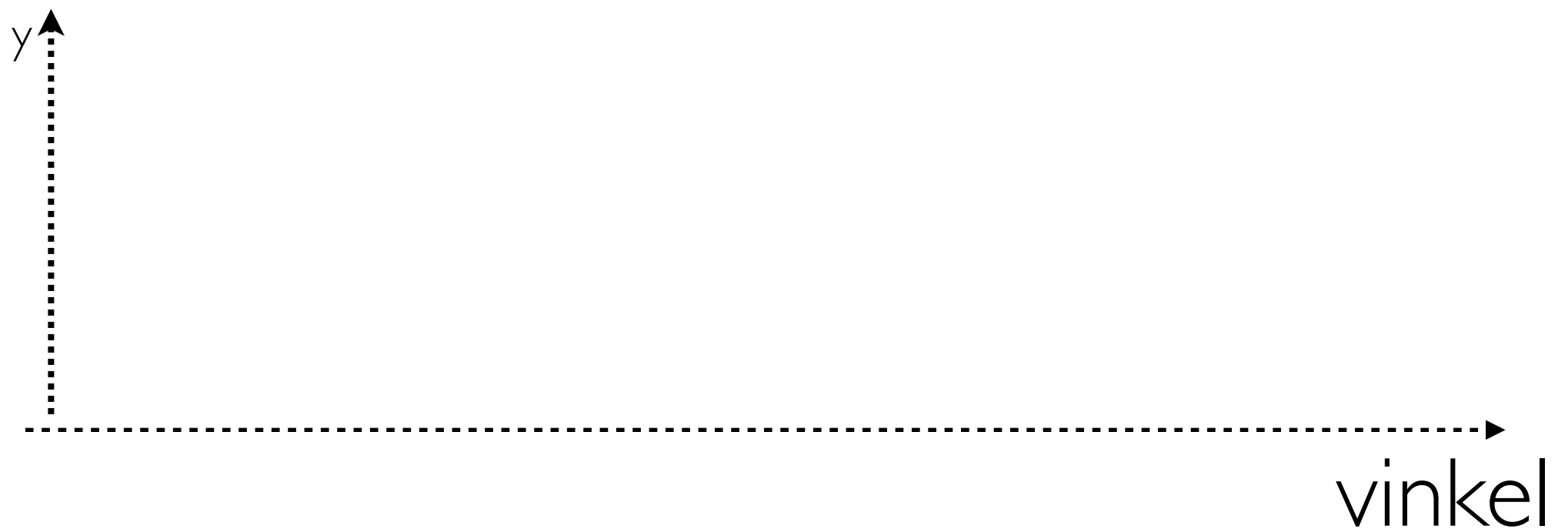


kalla detta 0° hur ser projection ut?

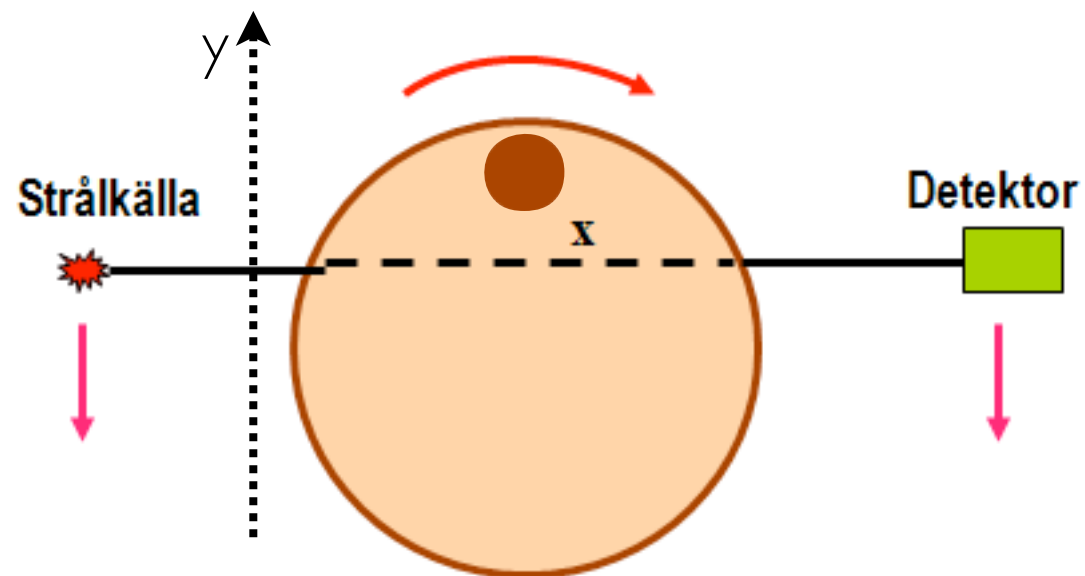
Sinogram



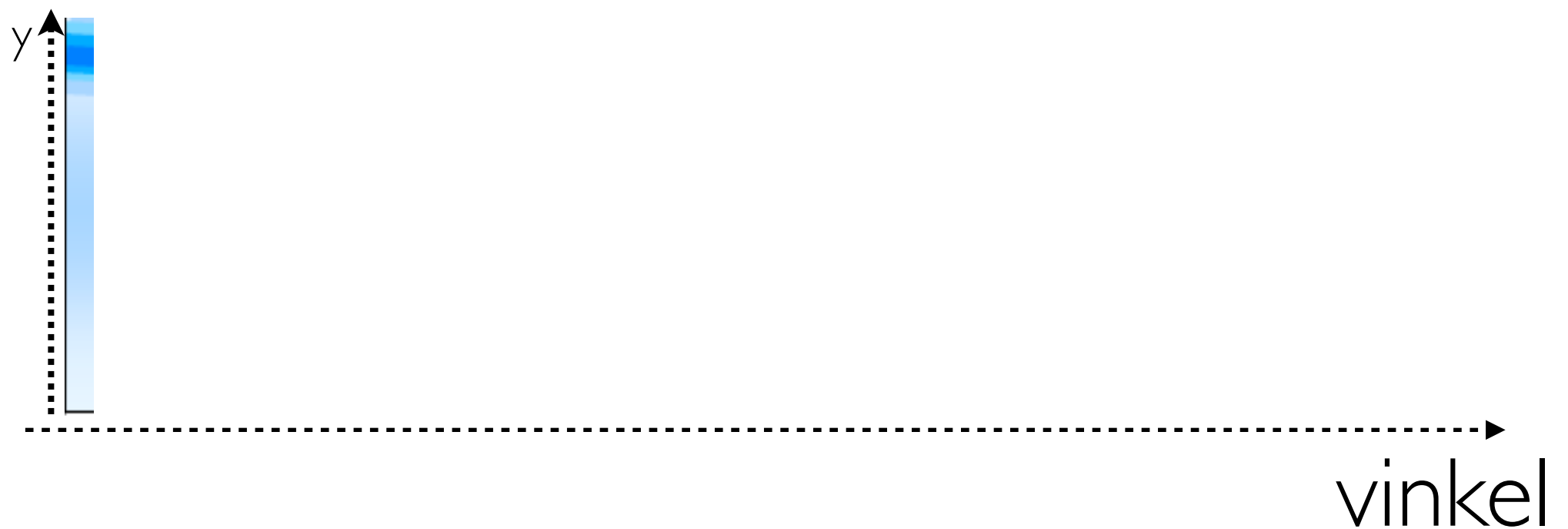
kalla detta 0° hur ser projection ut?



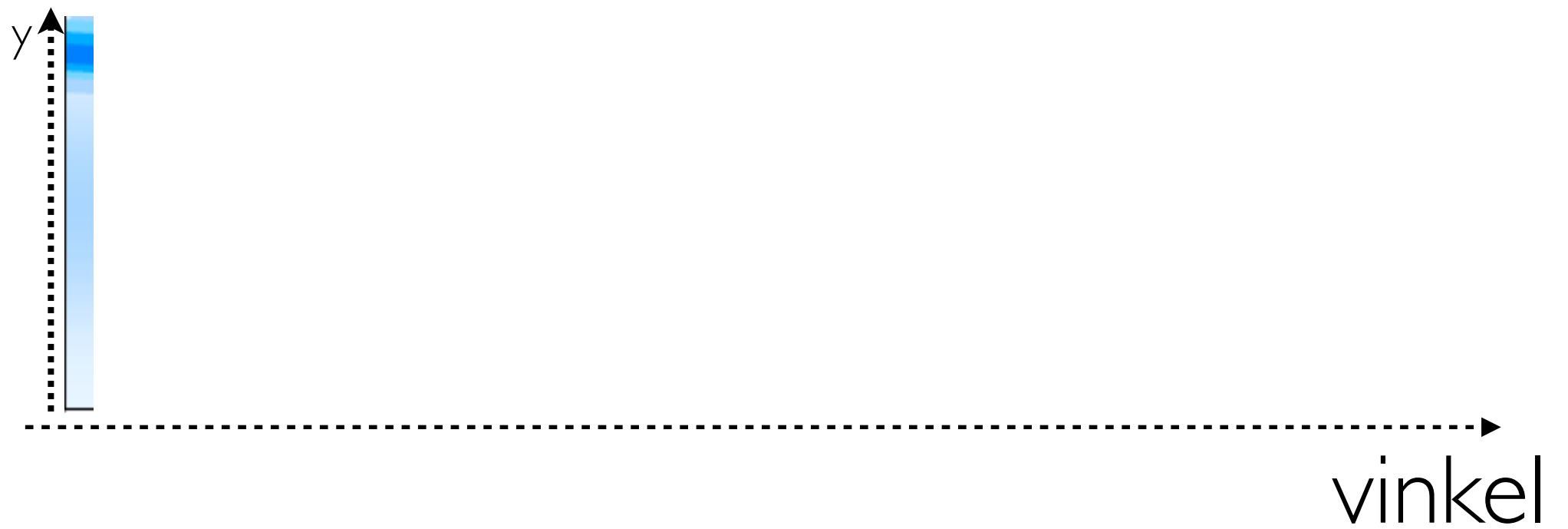
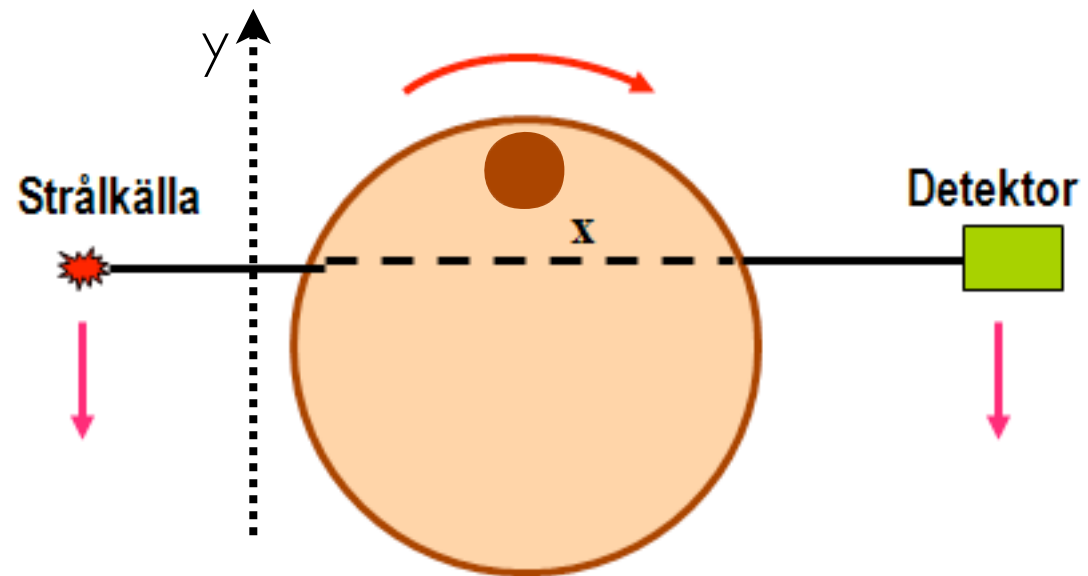
Sinogram



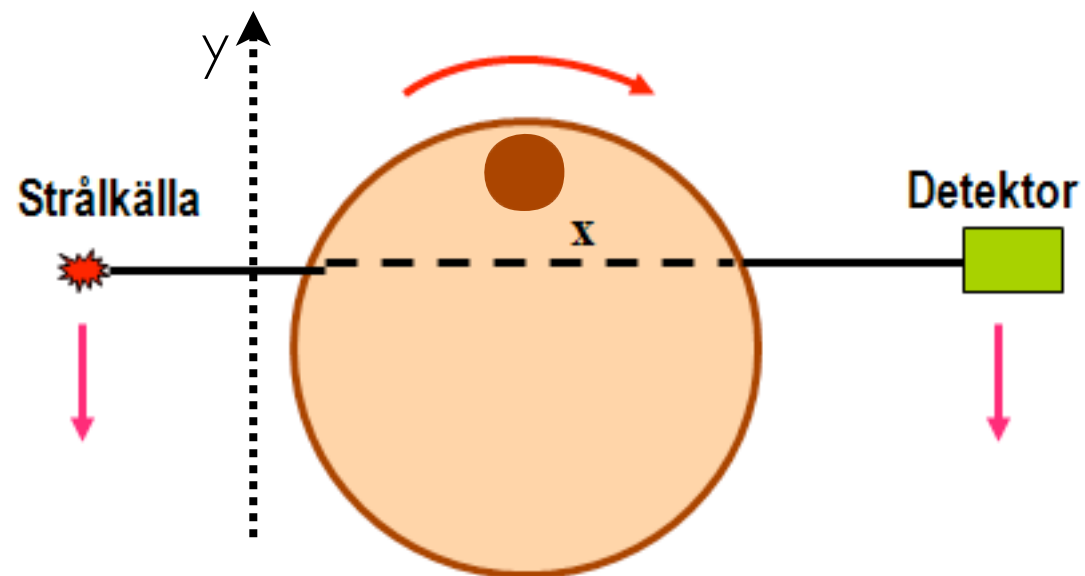
kalla detta 0° hur ser projection ut?



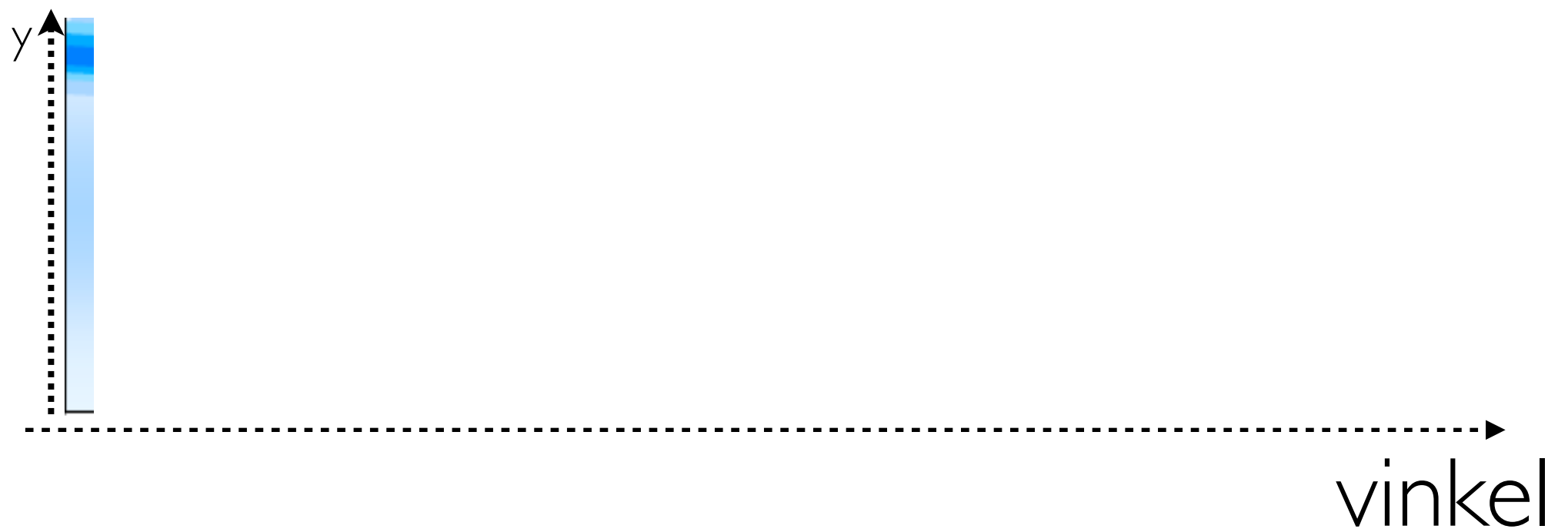
Sinogram



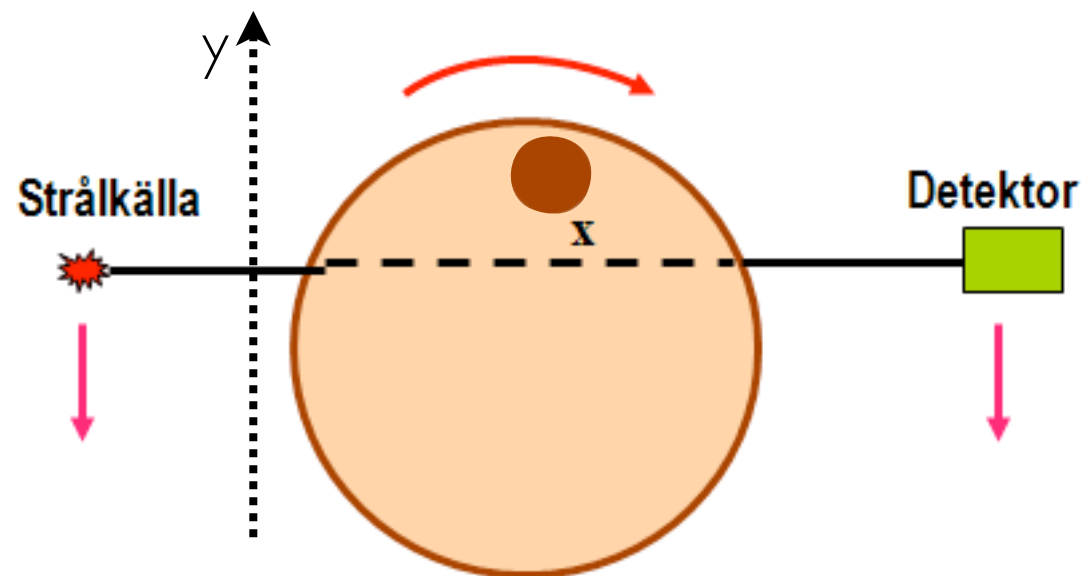
Sinogram



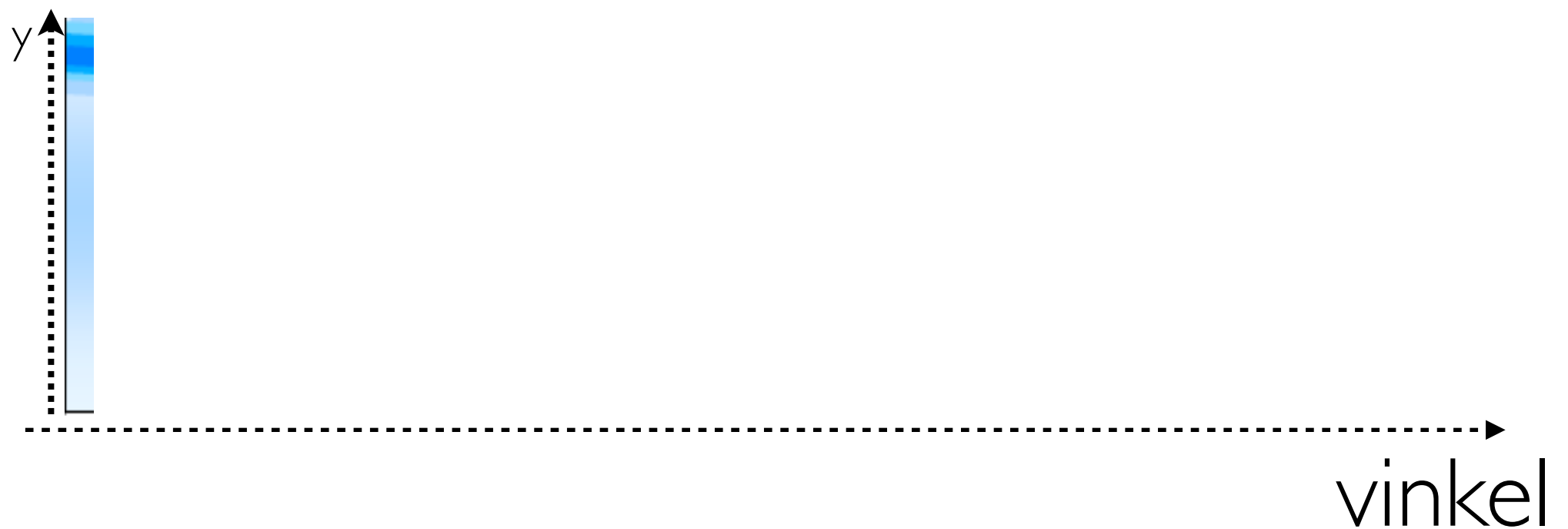
obj roteras 10° hur ser projection ut?



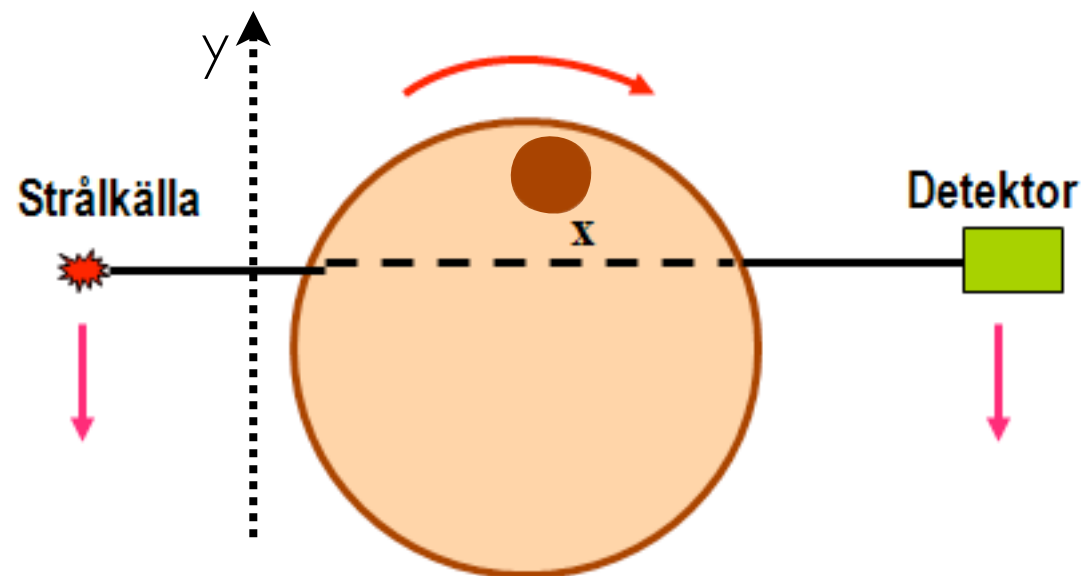
Sinogram



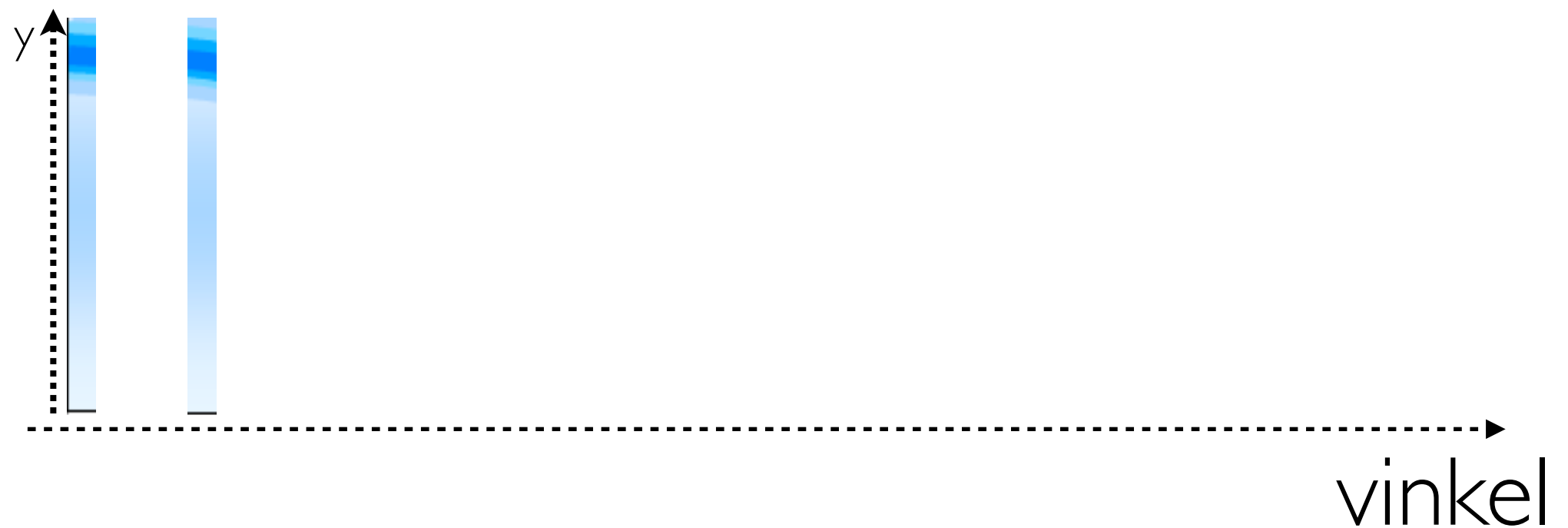
obj roteras 10° hur ser projection ut?



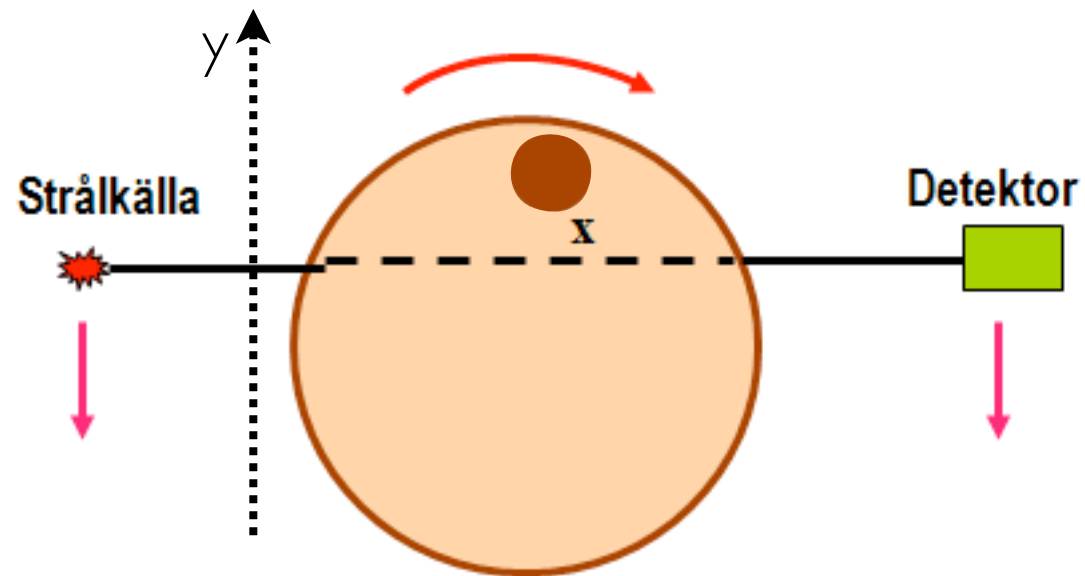
Sinogram



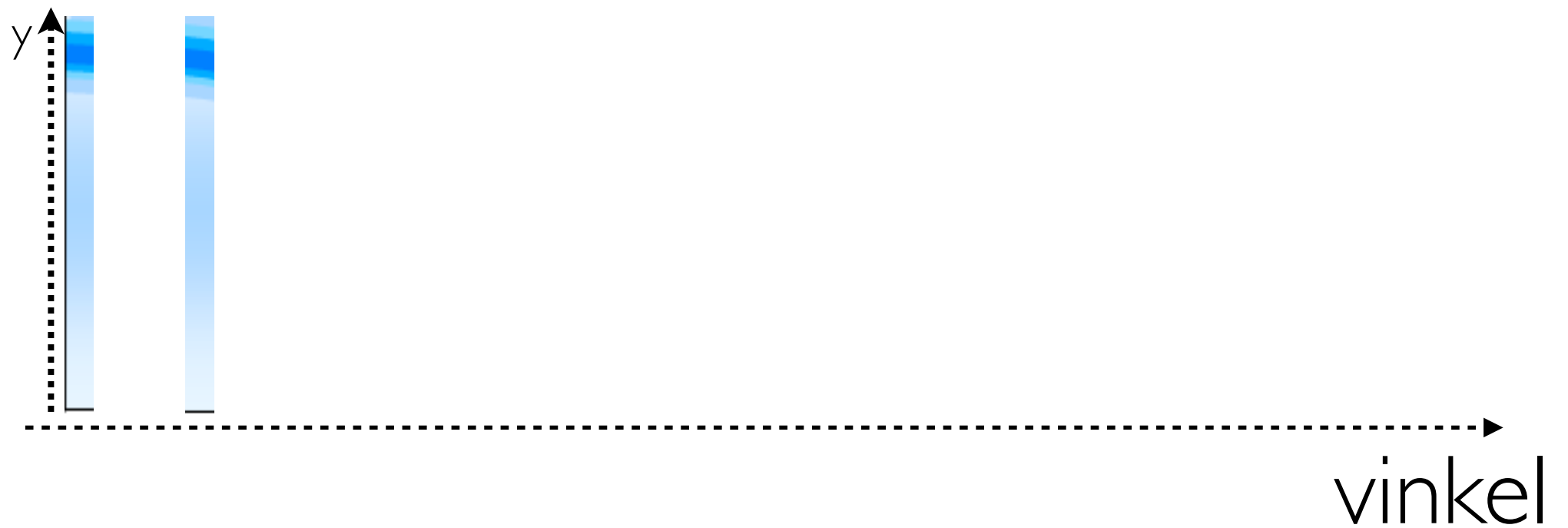
obj roteras 10° hur ser projection ut?



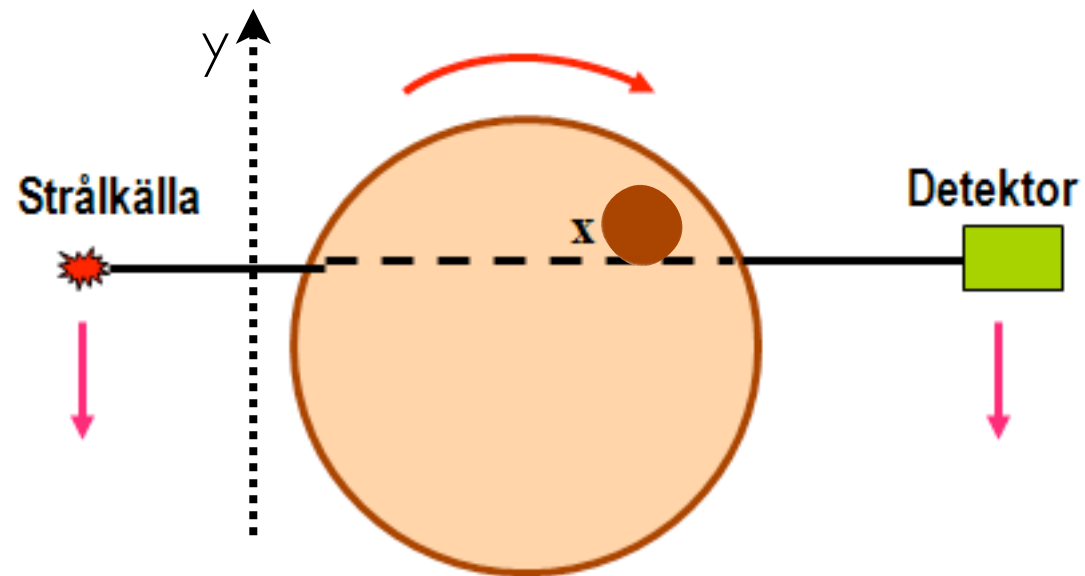
Sinogram



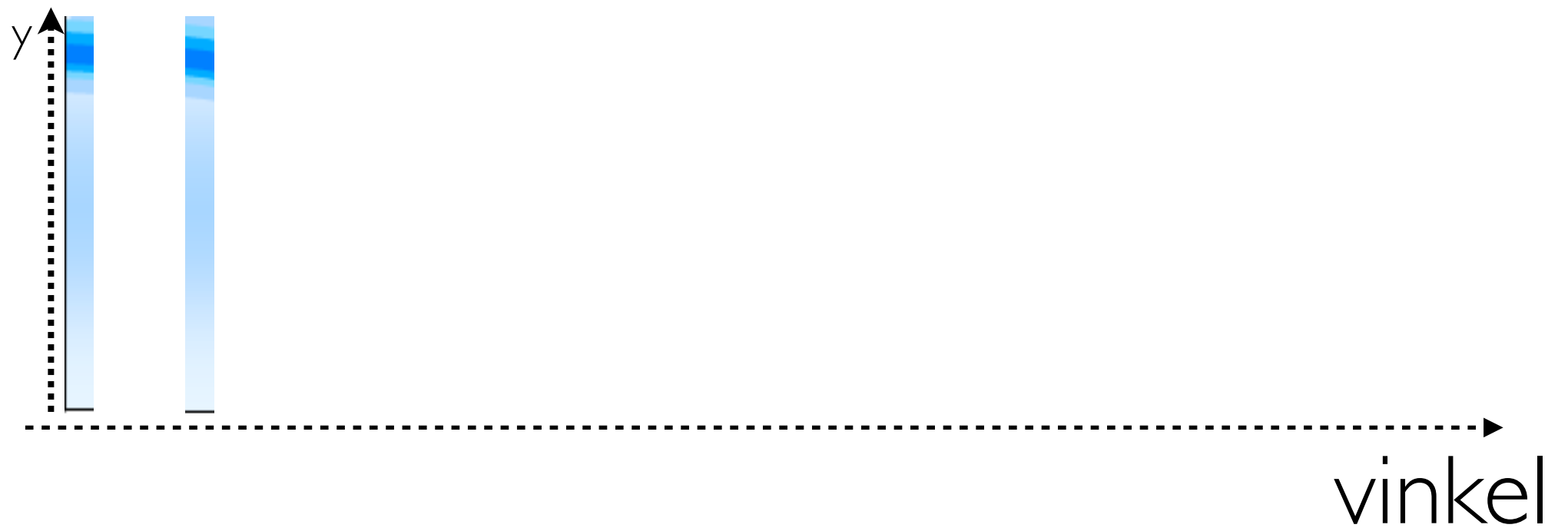
50° då?



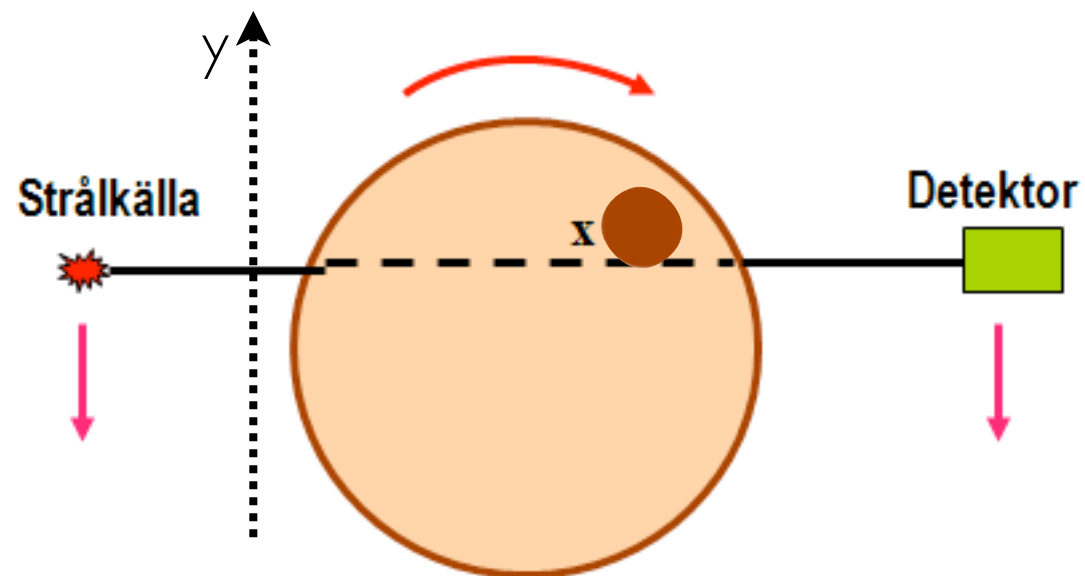
Sinogram



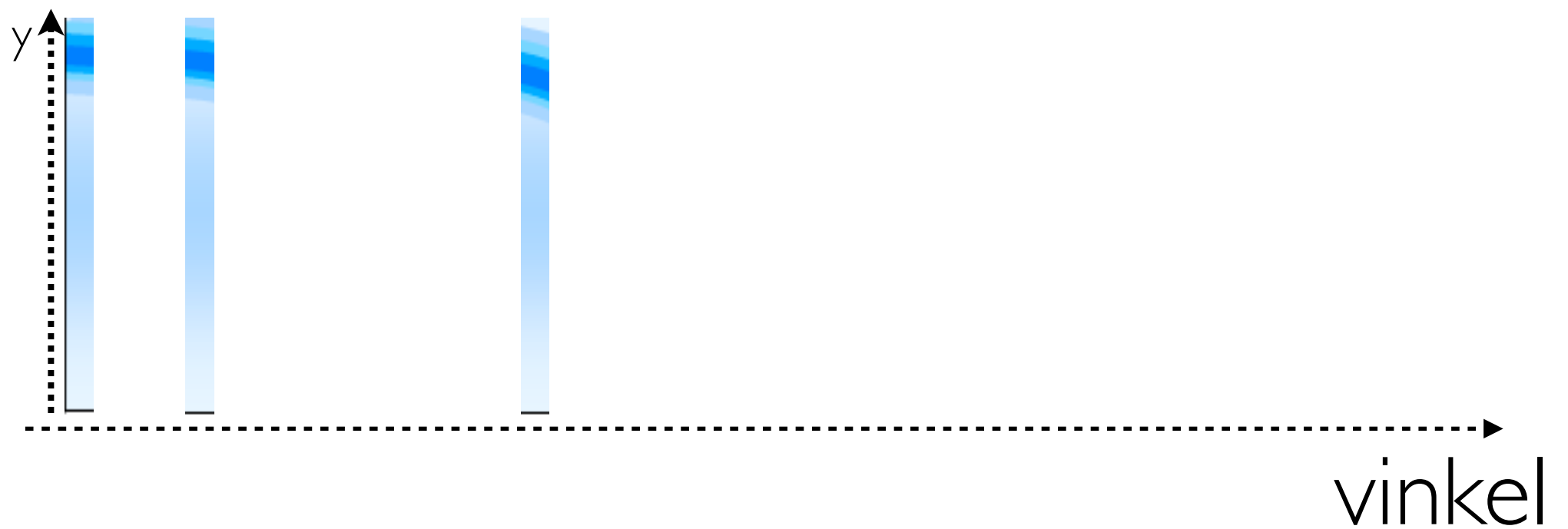
50° då?



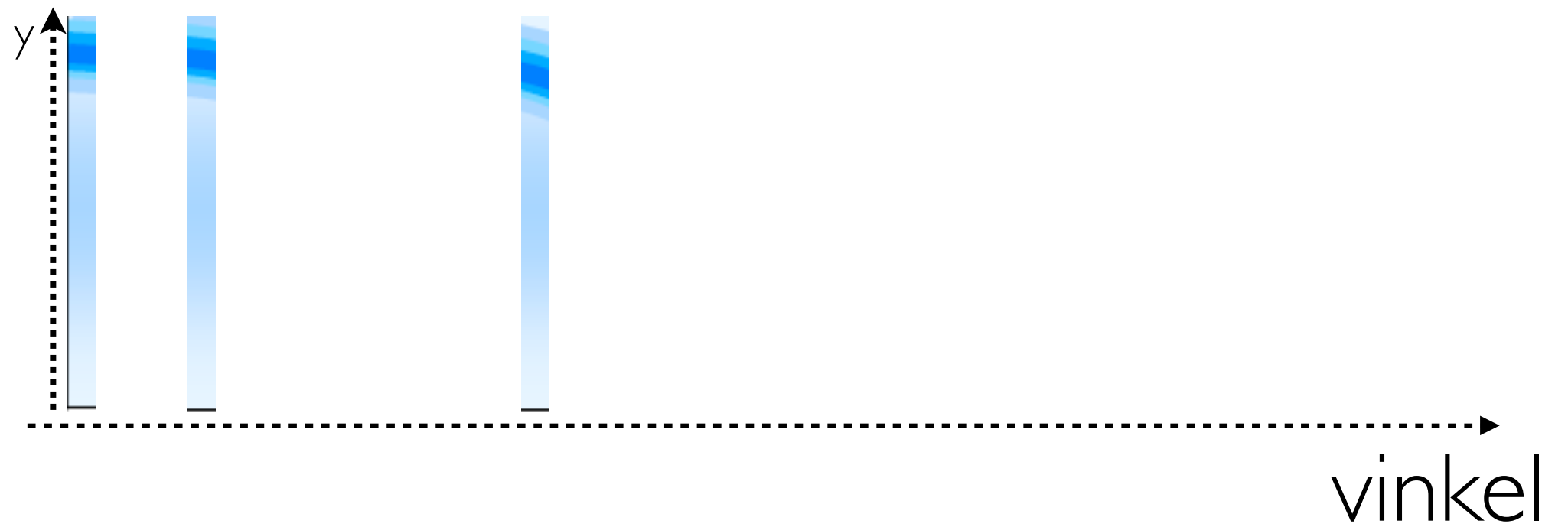
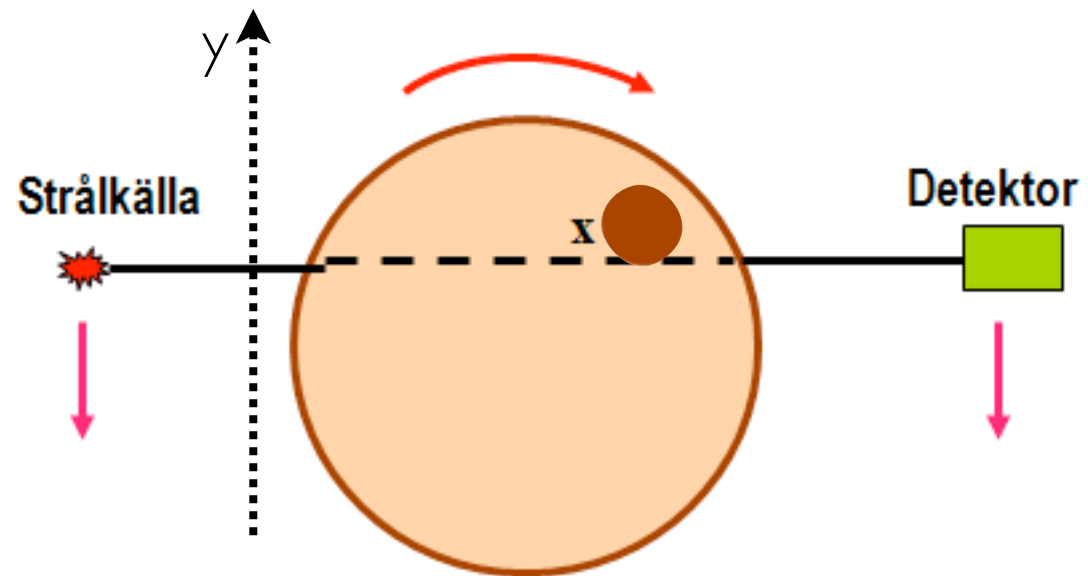
Sinogram



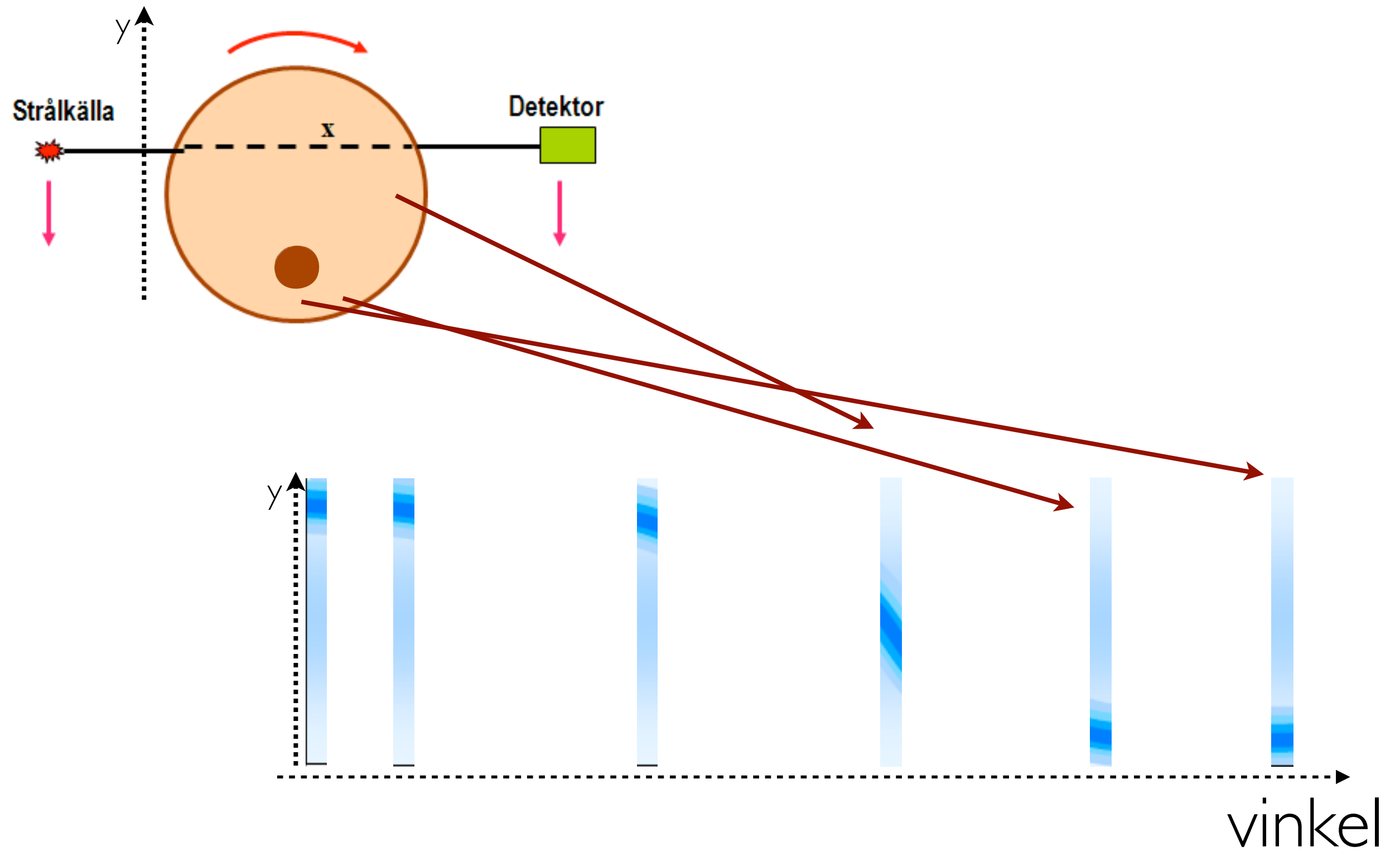
50° då?



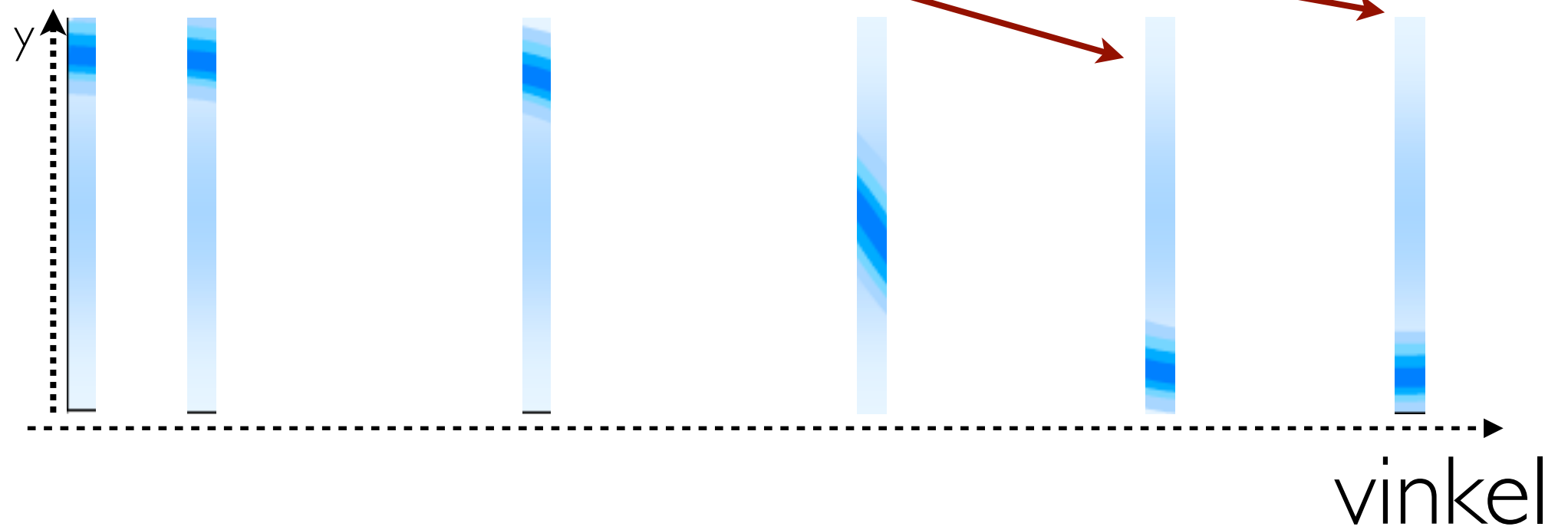
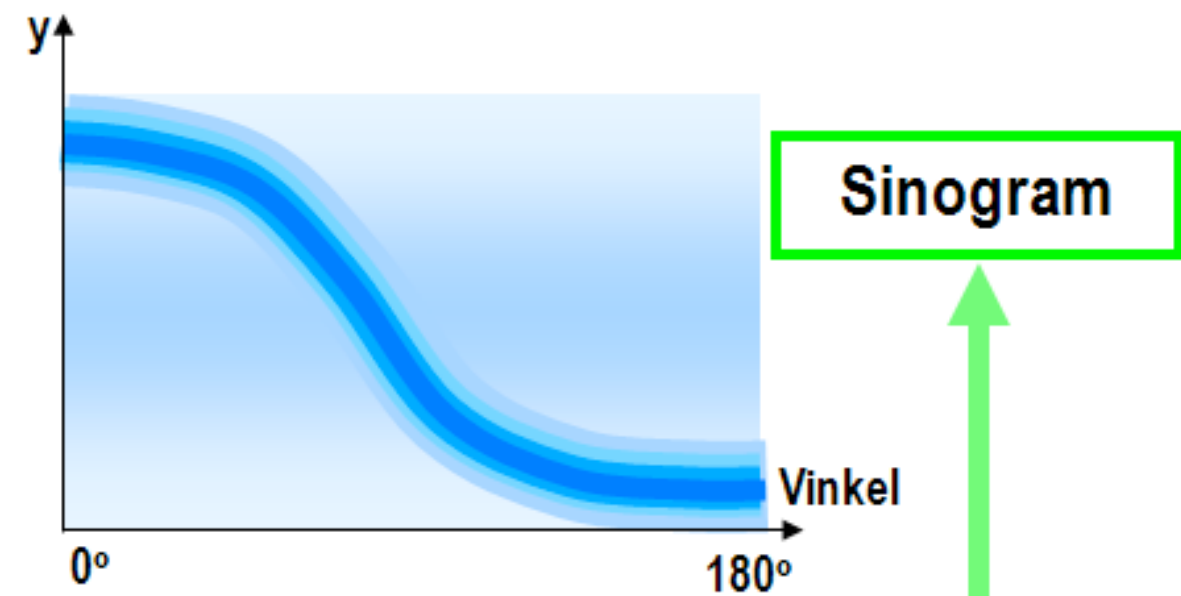
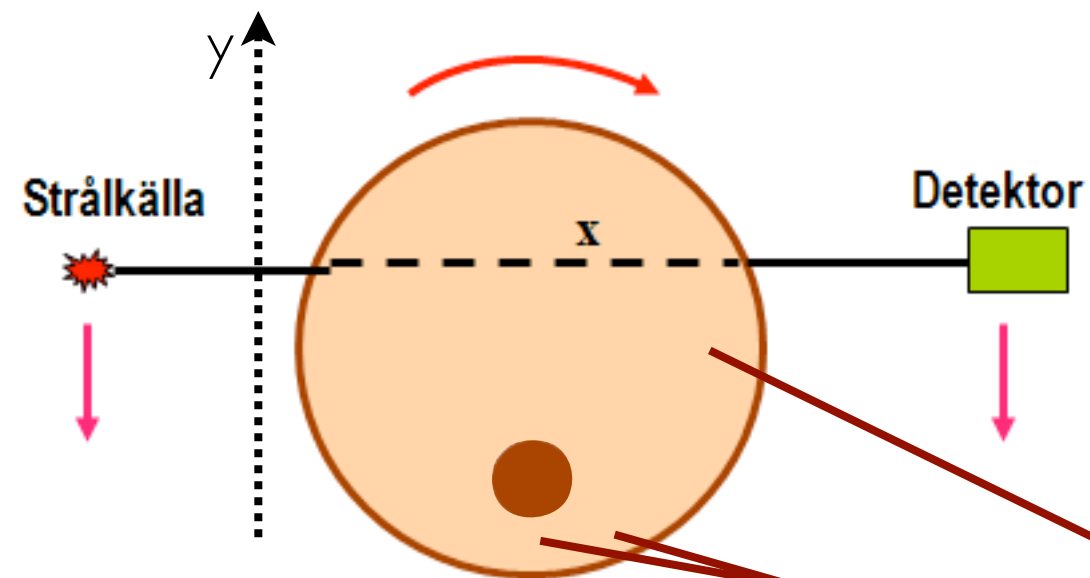
Sinogram



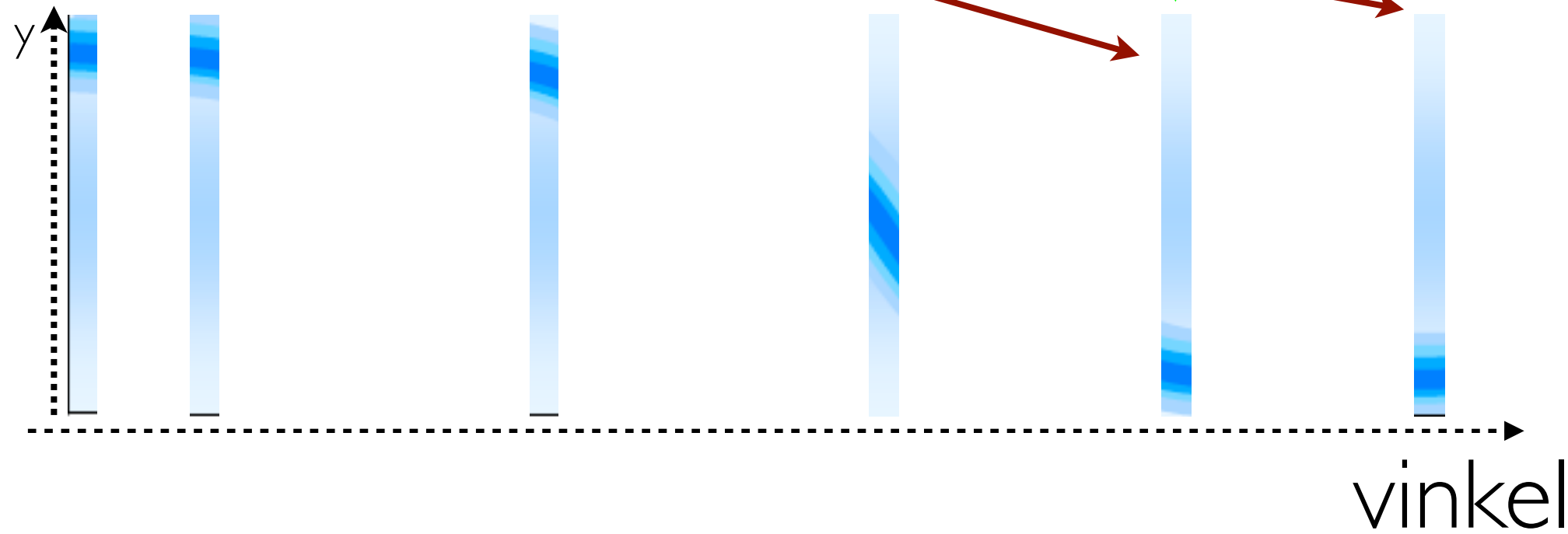
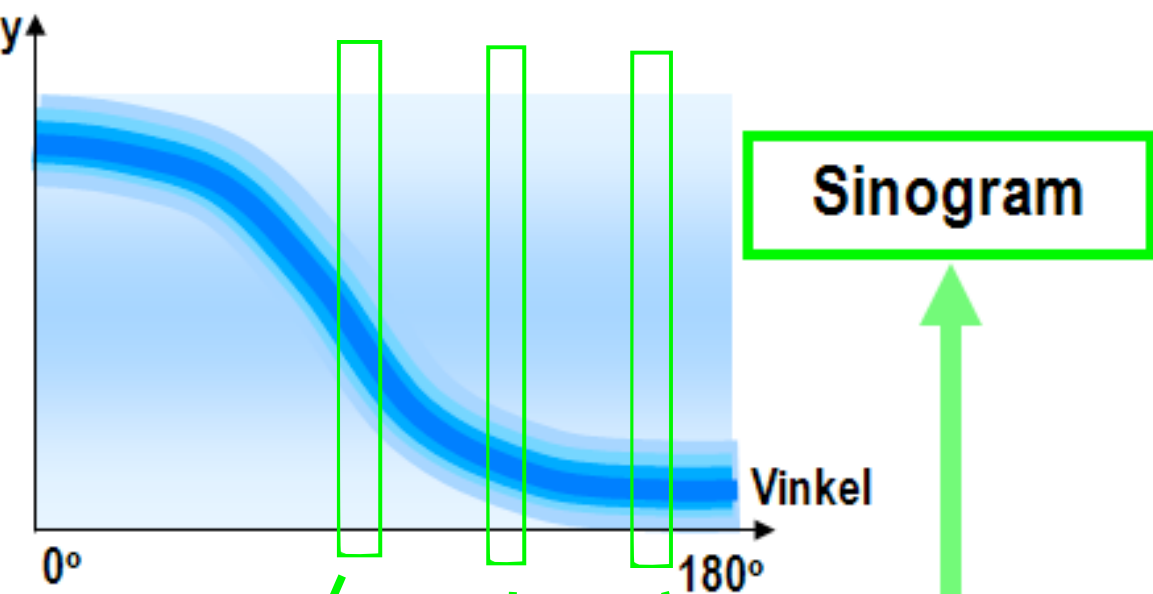
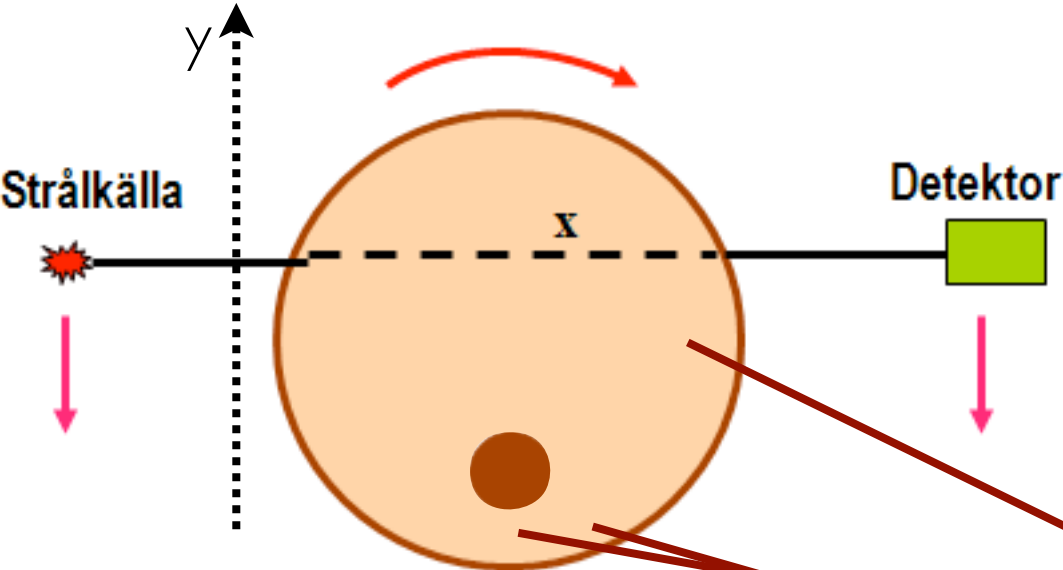
Sinogram



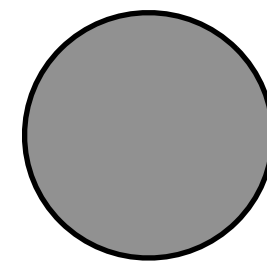
Sinogram



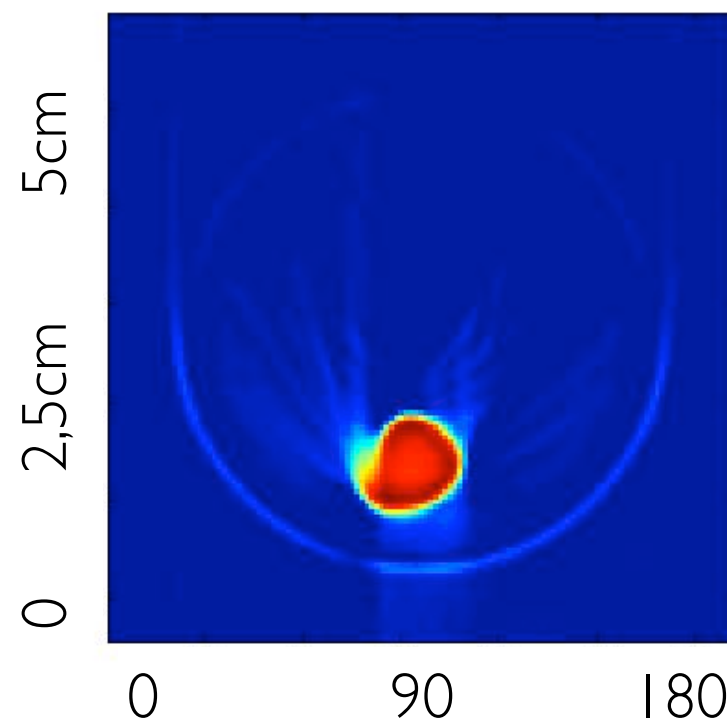
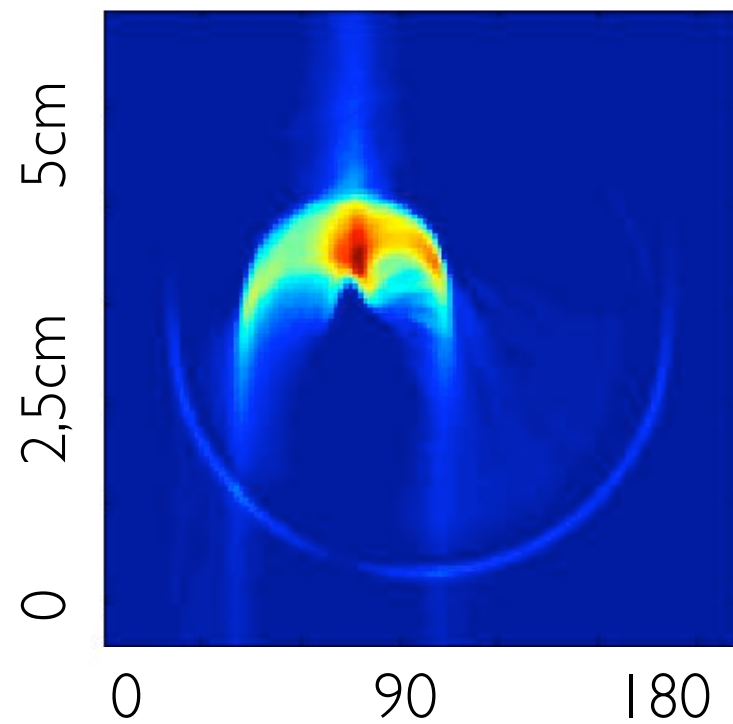
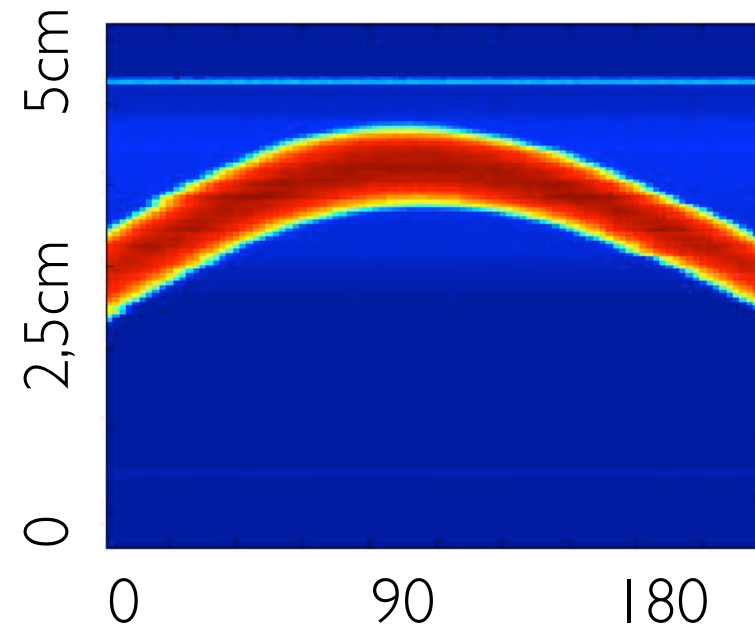
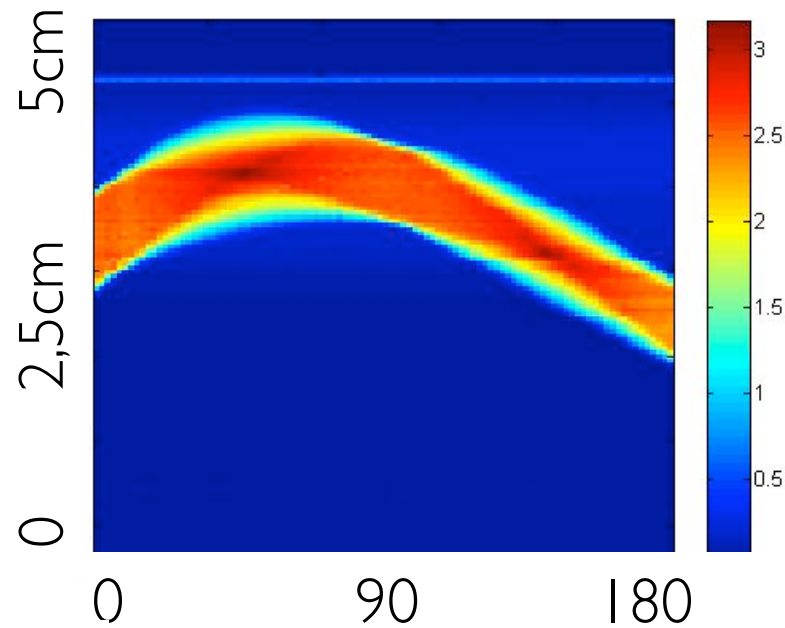
Sinogram



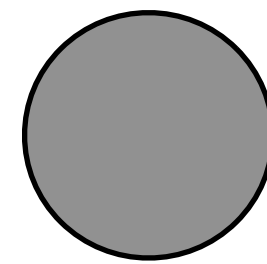
Which of the following is the sinogram of a disk?



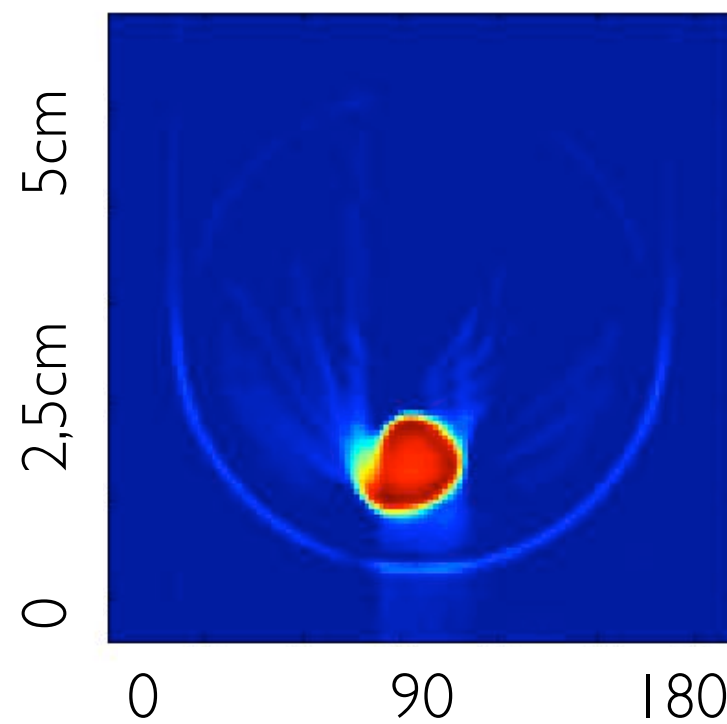
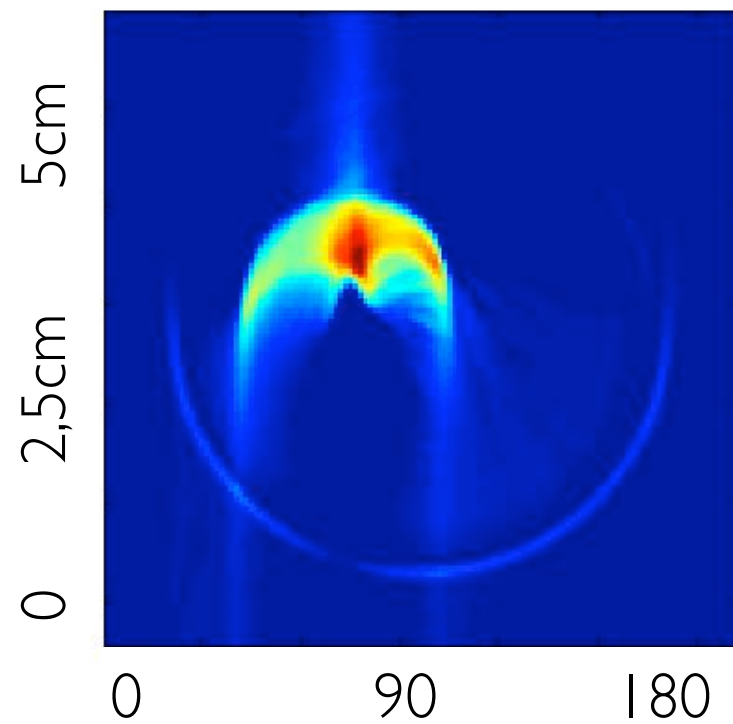
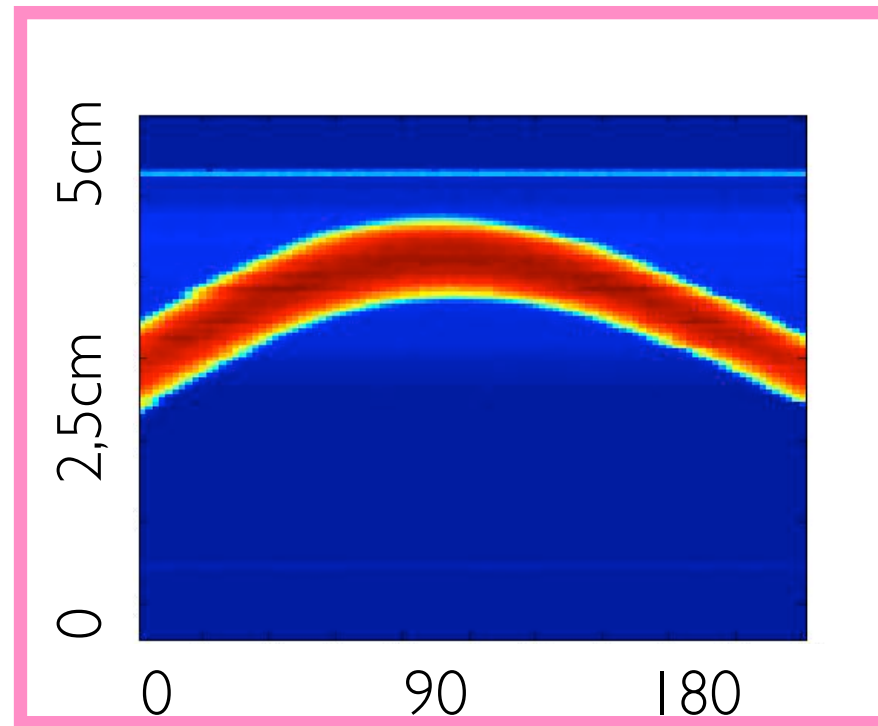
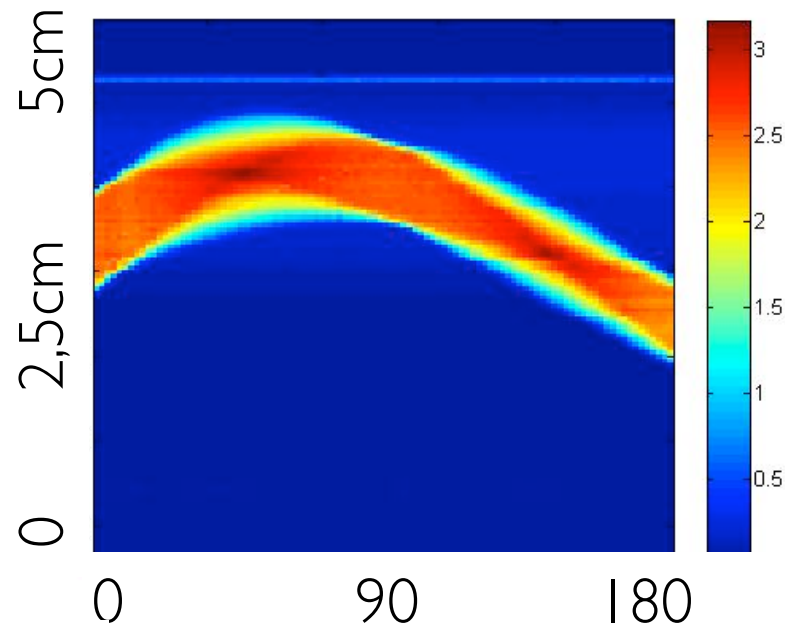
this is a disk!



Which of the following is the sinogram of a disk?

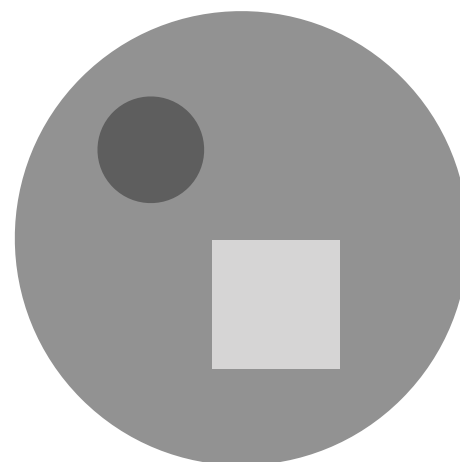


this is a disk!

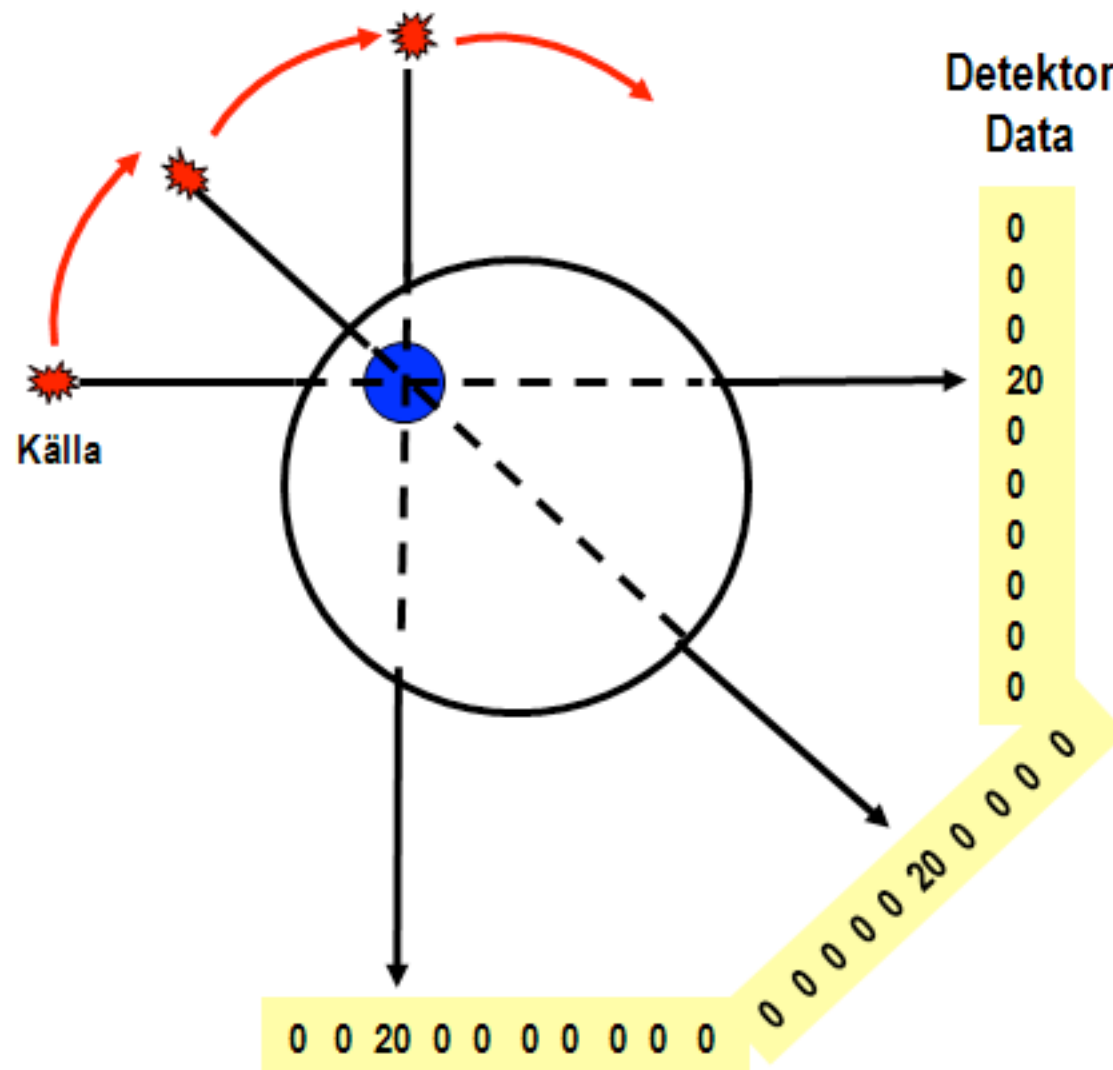


Övningar:

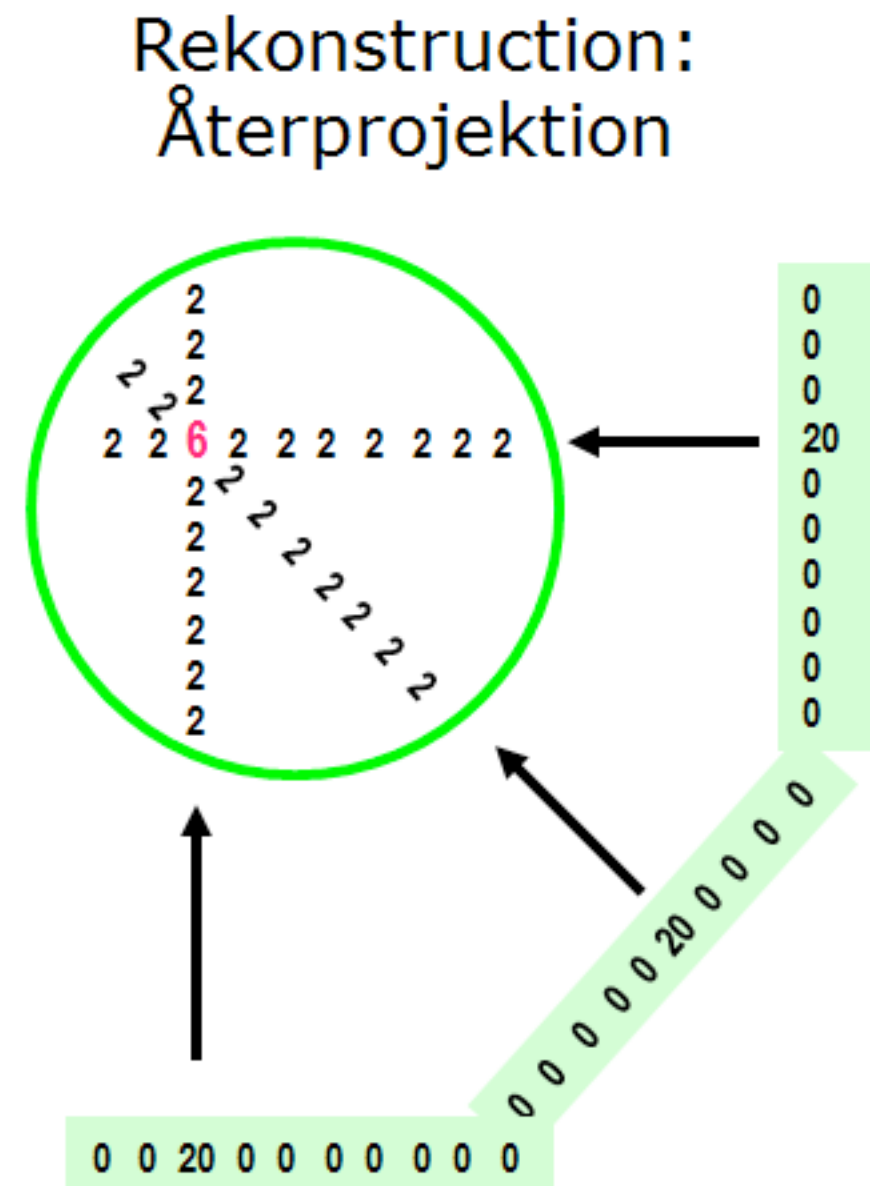
1. Vad har de föregående slides att göra med CT?
2. Tänk att du har ett objekt som är en liten kula som attenuerar mycket och som befinner sig i rotationscenter av en CT-skanner.
 1. Rita en figur av situationen (dvs strålen, detektor samt objekt) när skanner befinner sig vid vinkel 0° respektive 30°
 2. Rita projektionen (dvs det som kommer att mätas i detektorn) när skanner befinner sig vid vinkel 0° respektive 30°
 3. Flytta nu objektet i en annan position, bort från rotationscenter, och repetera 2.1 och 2.2 i den nya situationen
3. Om du lägger en liten disk i rotationscenter av en CT skanner, hur kommer den resulterande sinogram att se ut? Rita det!
4. Om du lägger en liten disk vid avstånd a (valfri riktning) från rotationscenter av en CT skanner, hur kommer den resulterande sinogram att se ut? Rita det!
5. Rita sinogram för följande objekt (ljusare = högre attenuering)



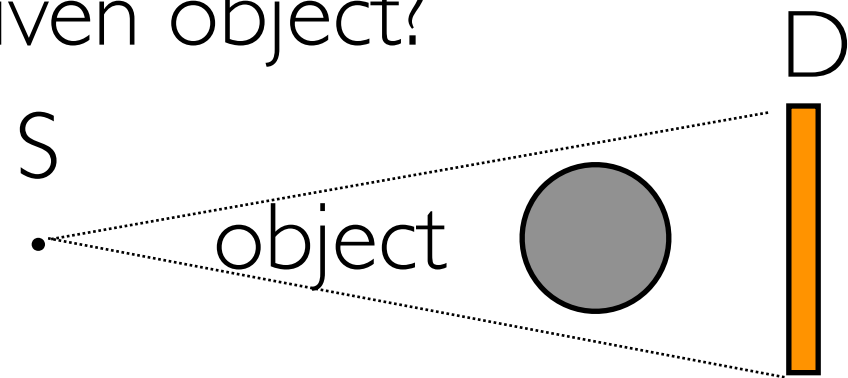
Datasamling - bildrekonstruktion



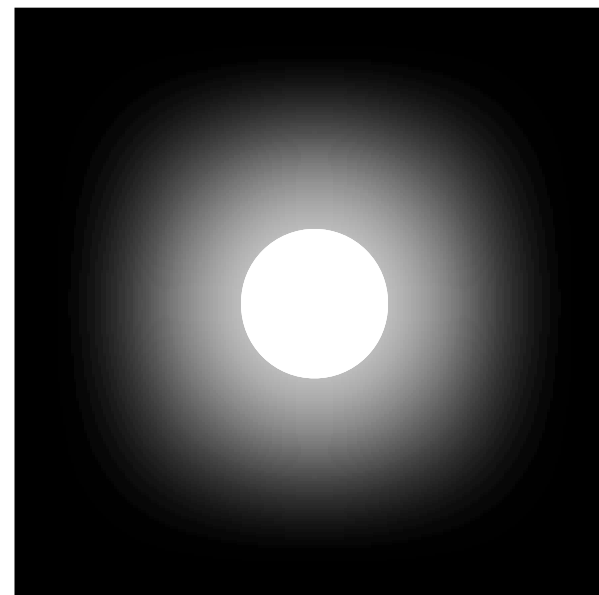
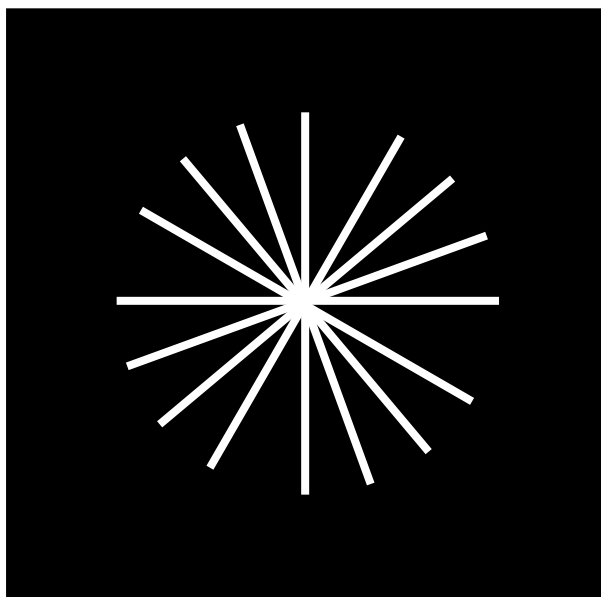
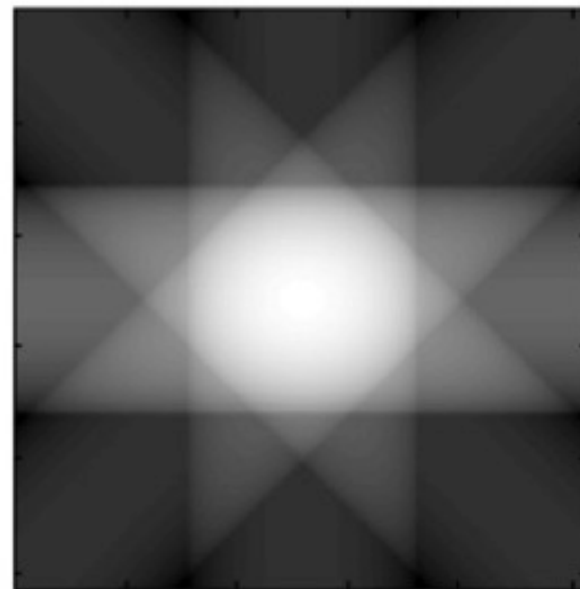
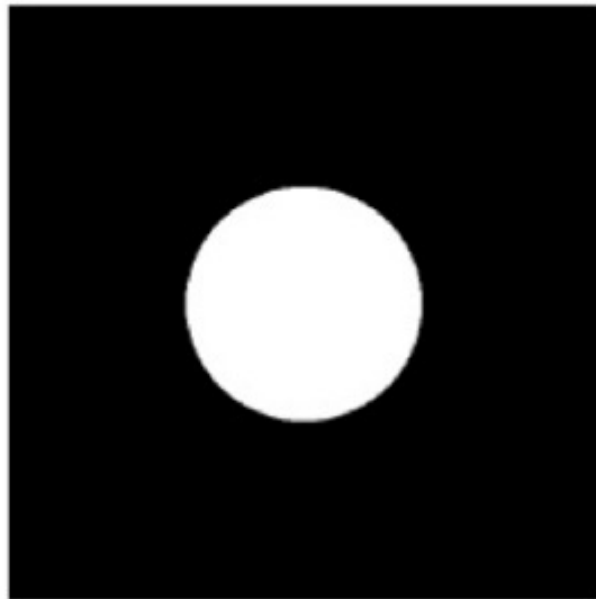
Datasamling



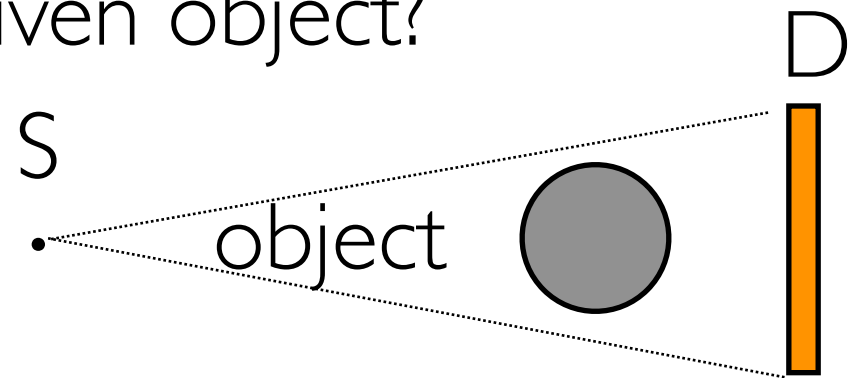
Imagine using back-projection in the way that has been explained before. Which of the following images will represent the given object?



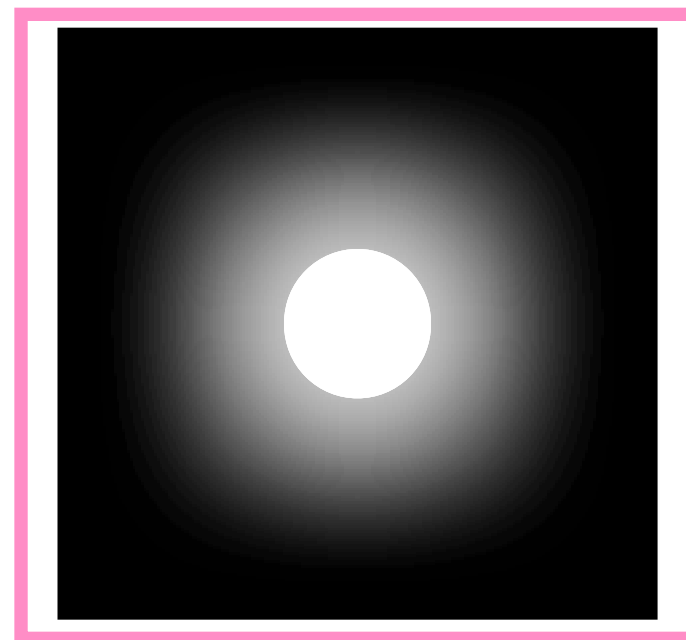
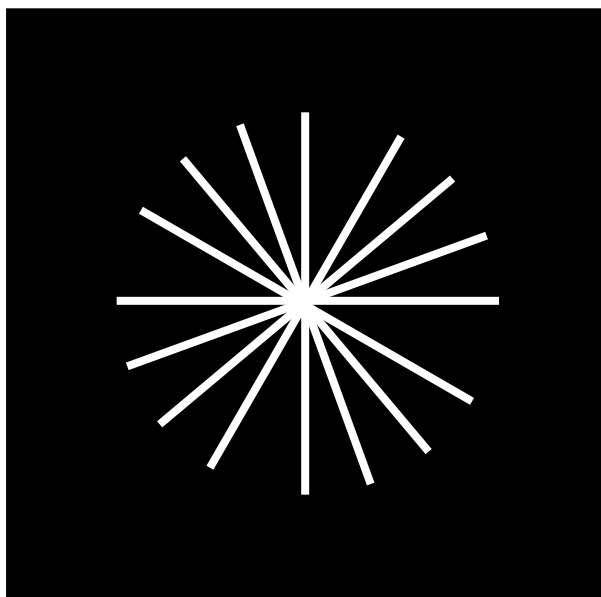
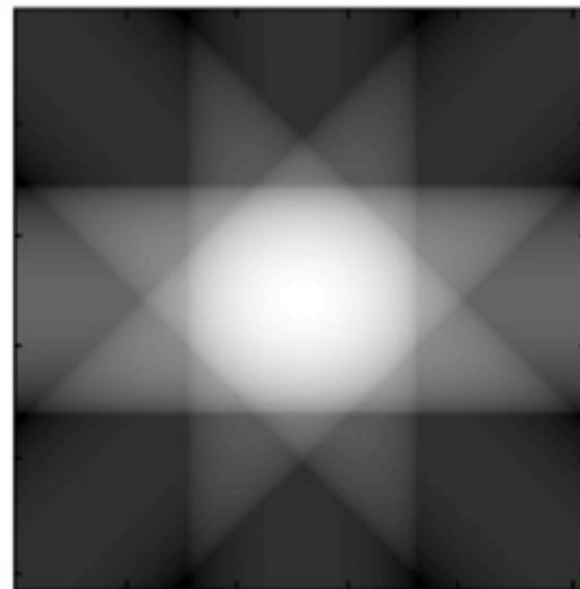
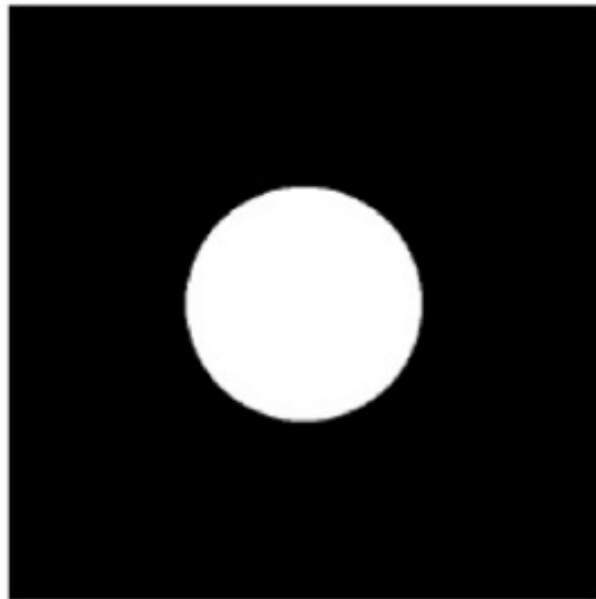
images



Imagine using back-projection in the way that has been explained before. Which of the following images will represent the given object?

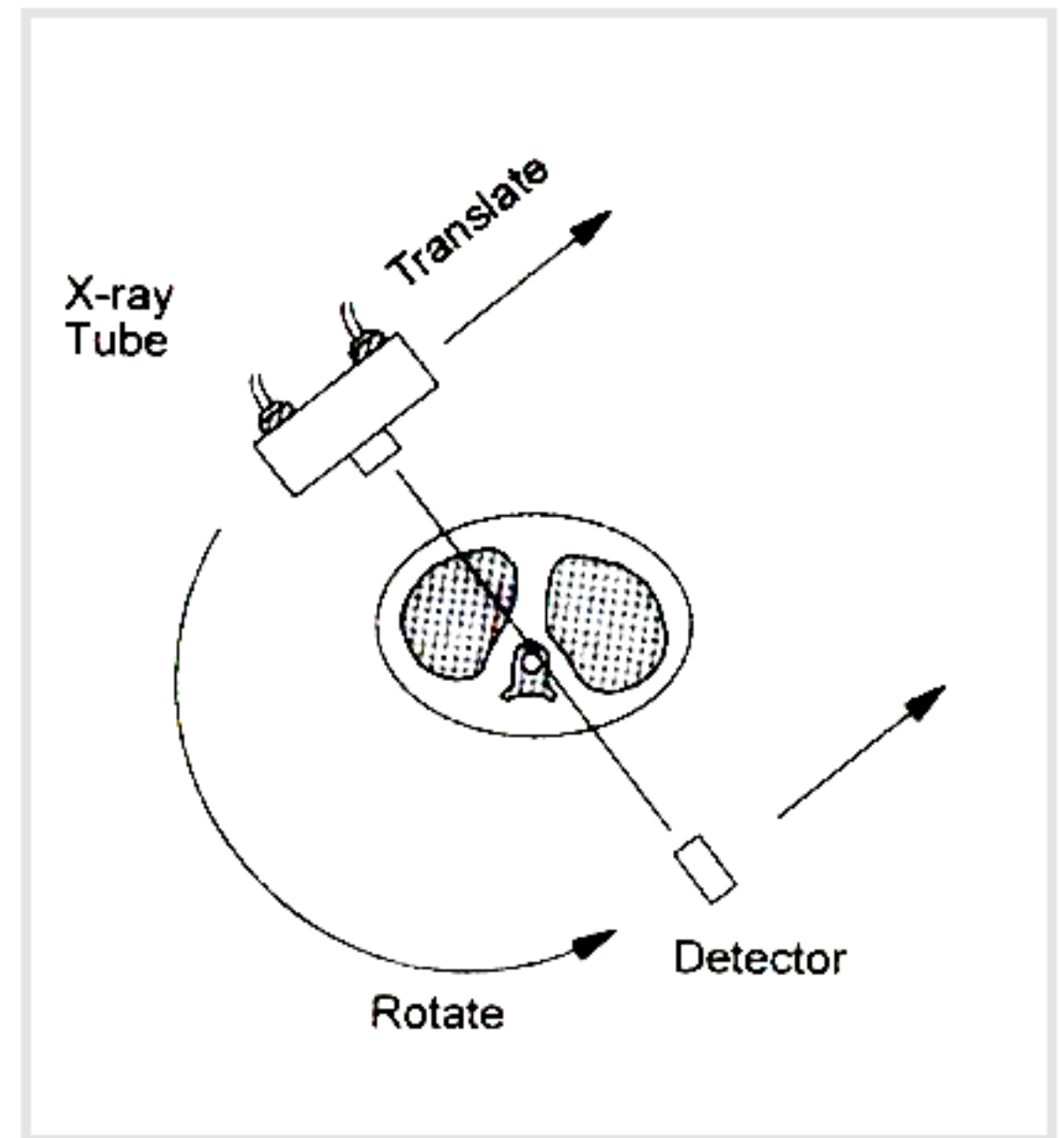
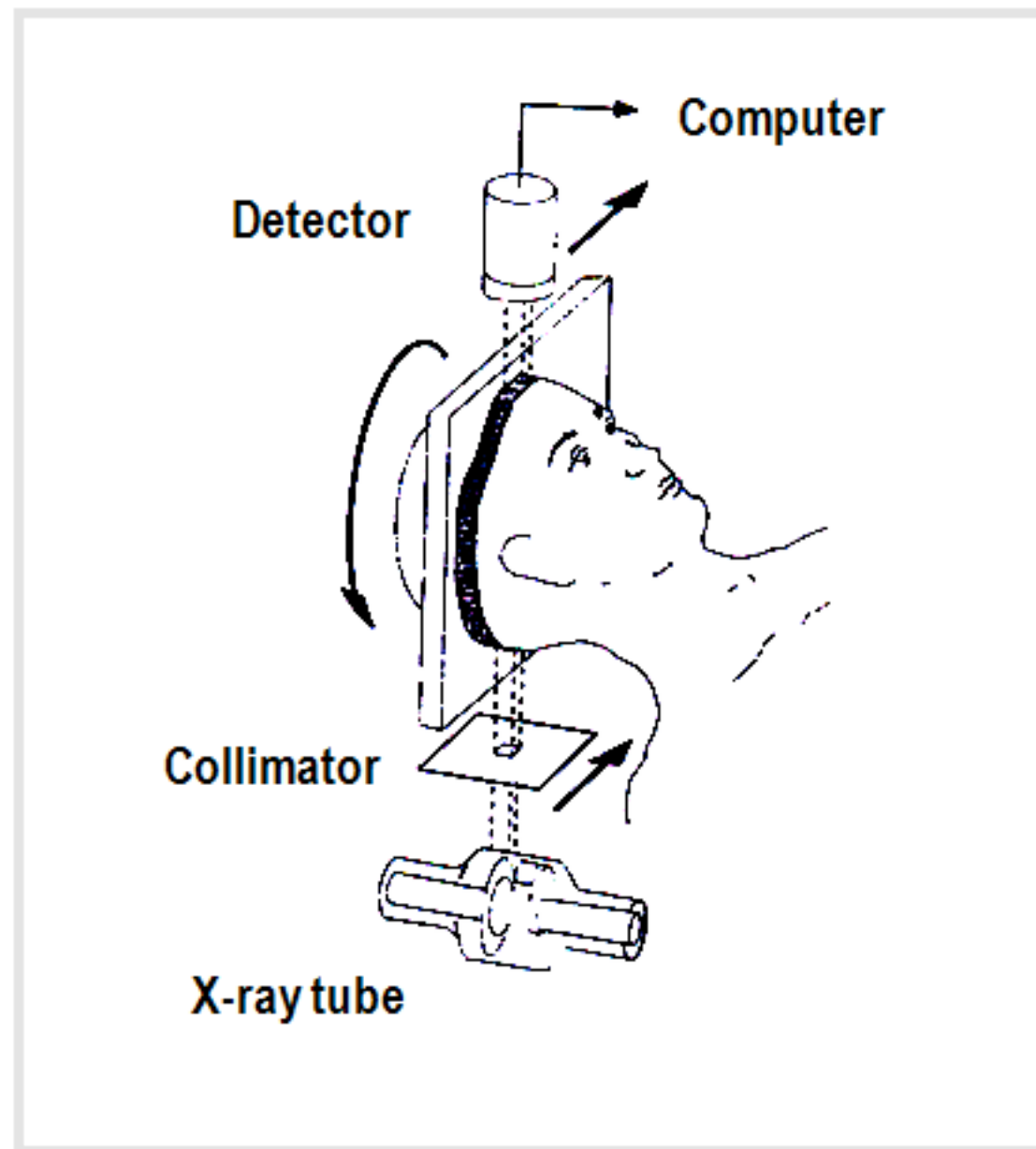


images



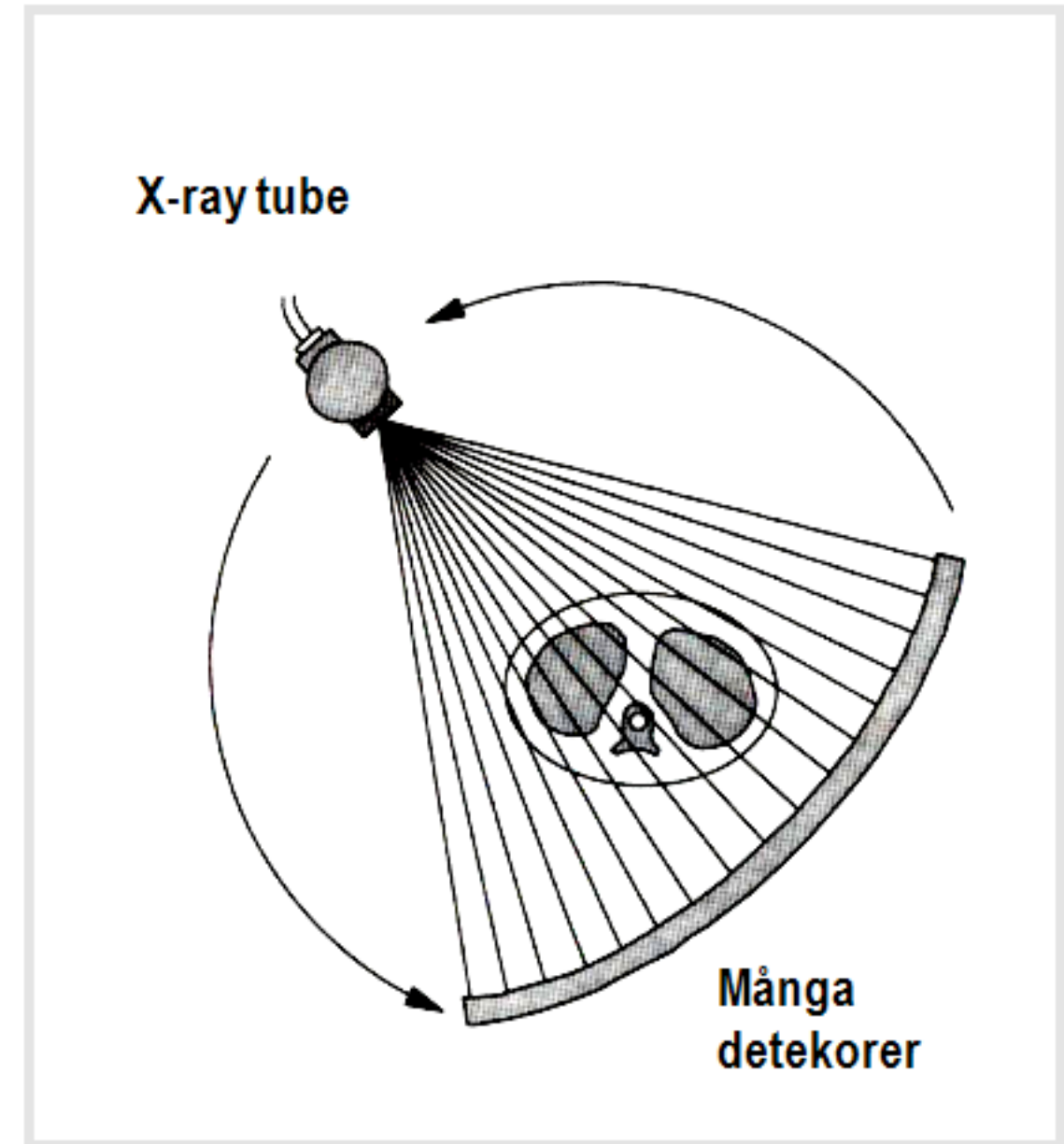
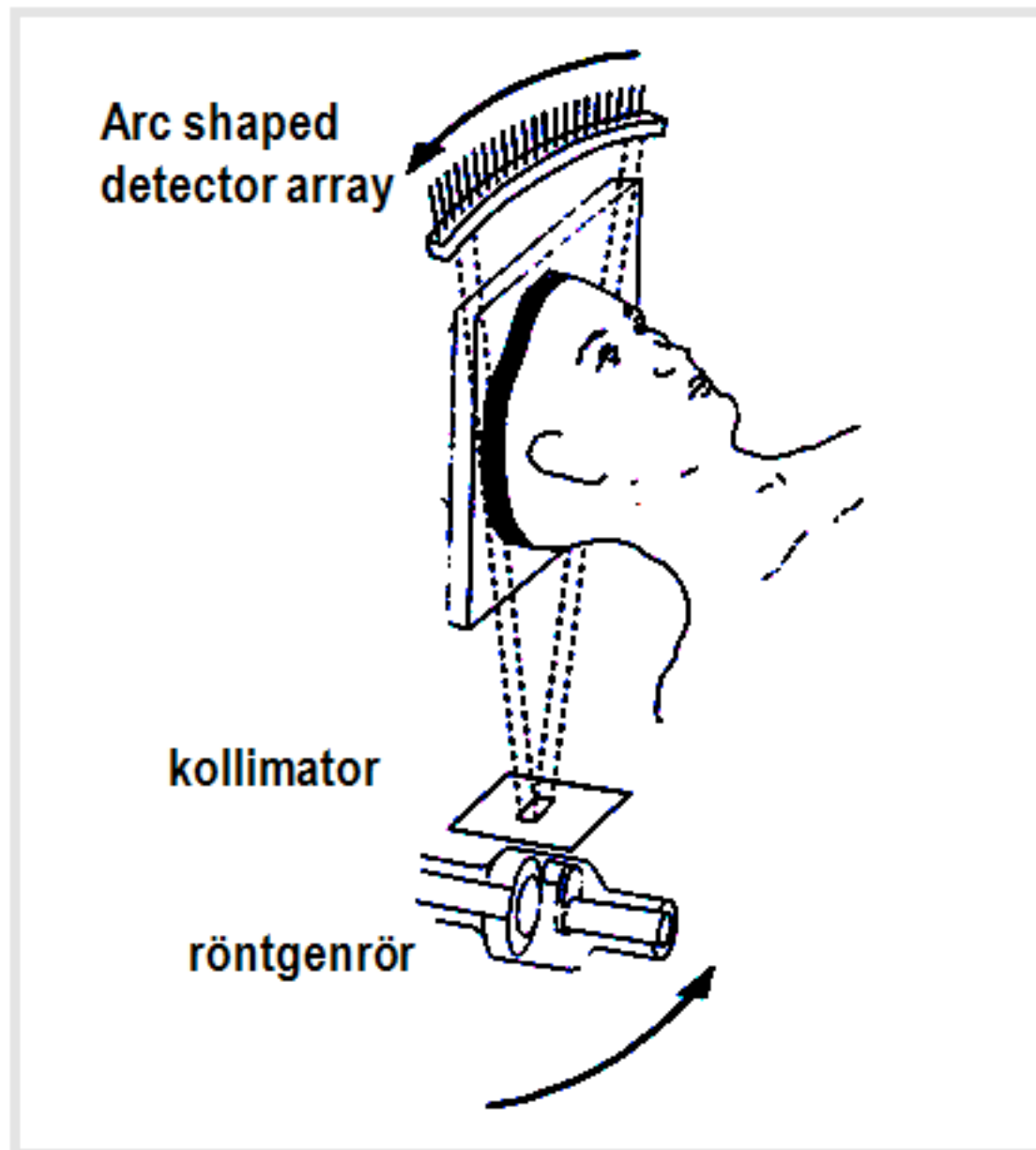
Datortomografi – första generation

- Translation – Rotation, Smal stråle (Pencil beam)



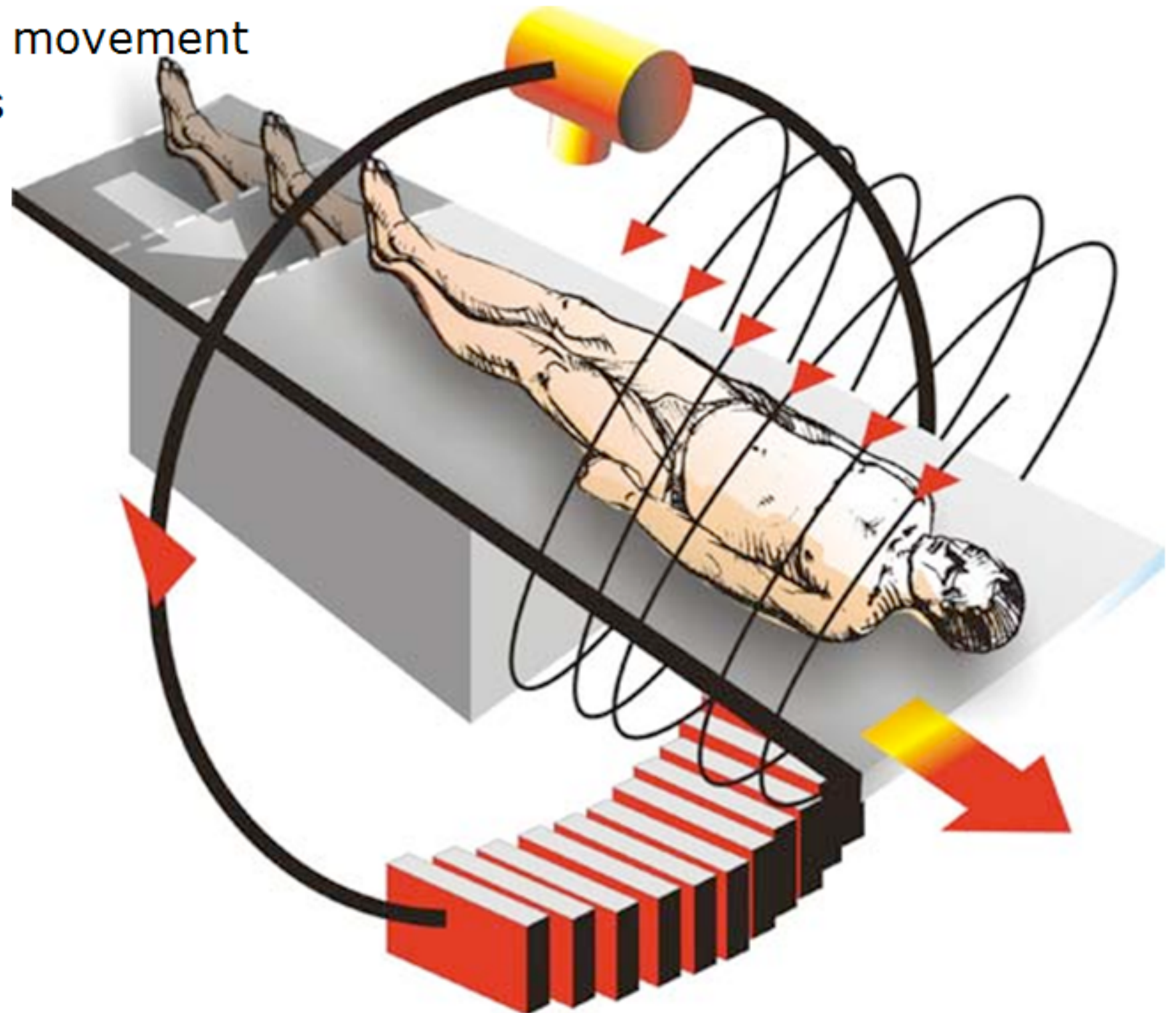
Tredje generationens CT

- Rotation -Rotation, Solfjäderformad stråle
- Samma princip som tidigare men mer komplex datatagnings och rekonstruktionsalgoritmer



Computed Tomography, Helix

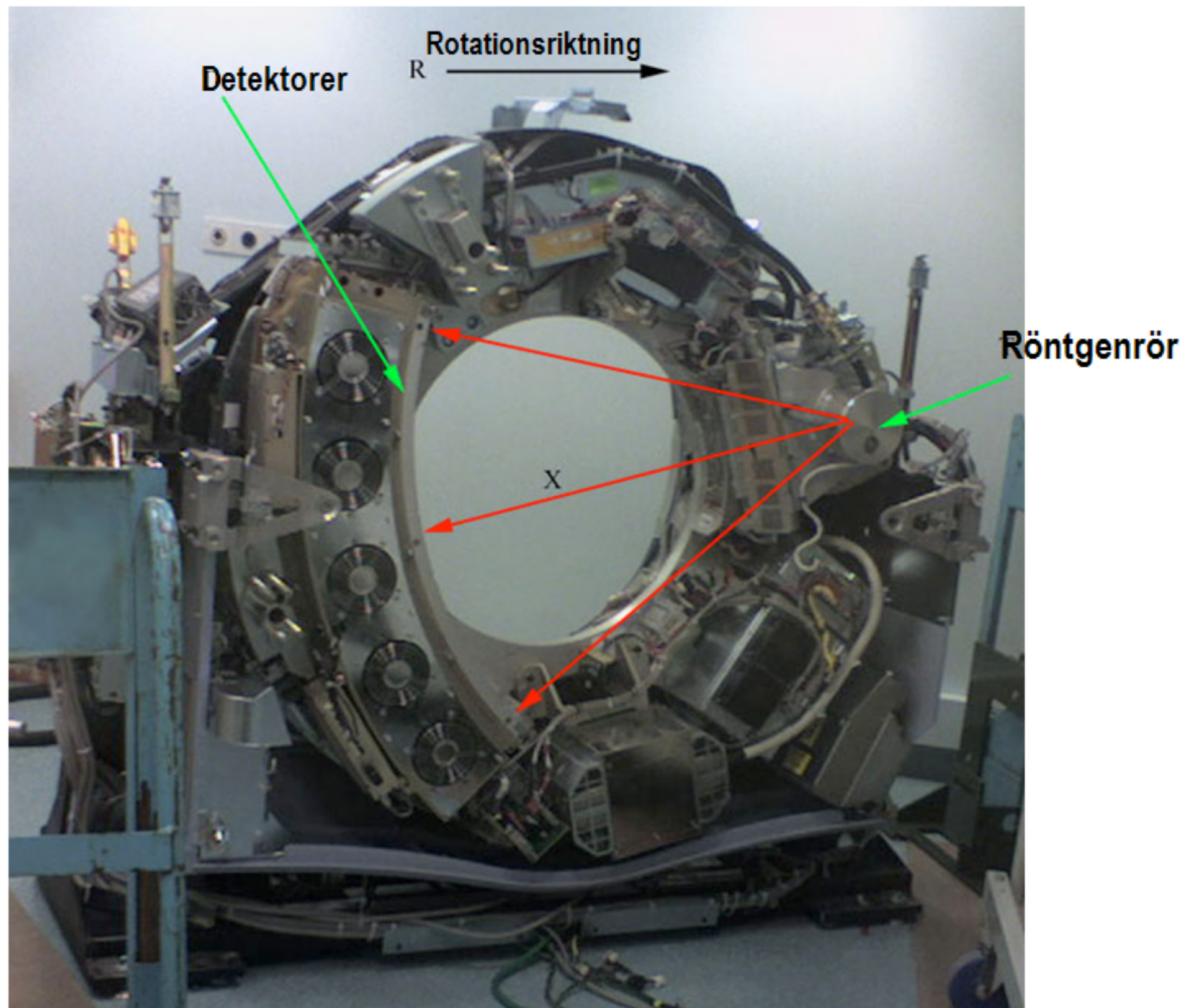
- Volume scanning –
 - Spiral, helical movement
 - Multiple slices



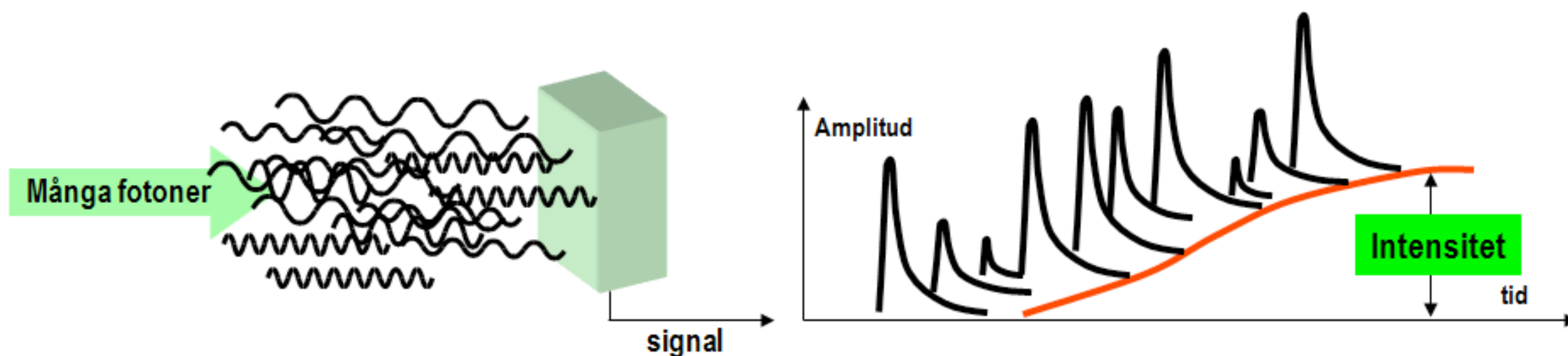
Modern datortomograf



Datortomograf



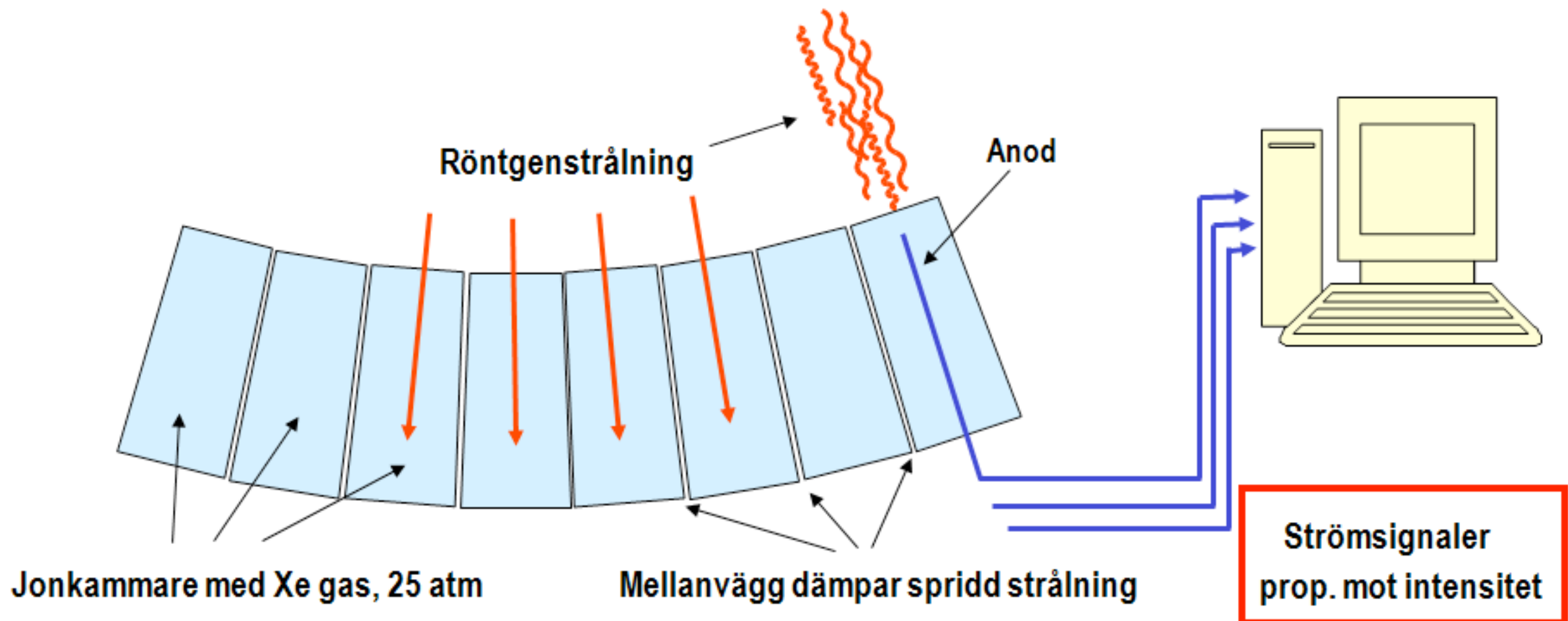
CT Detektorer



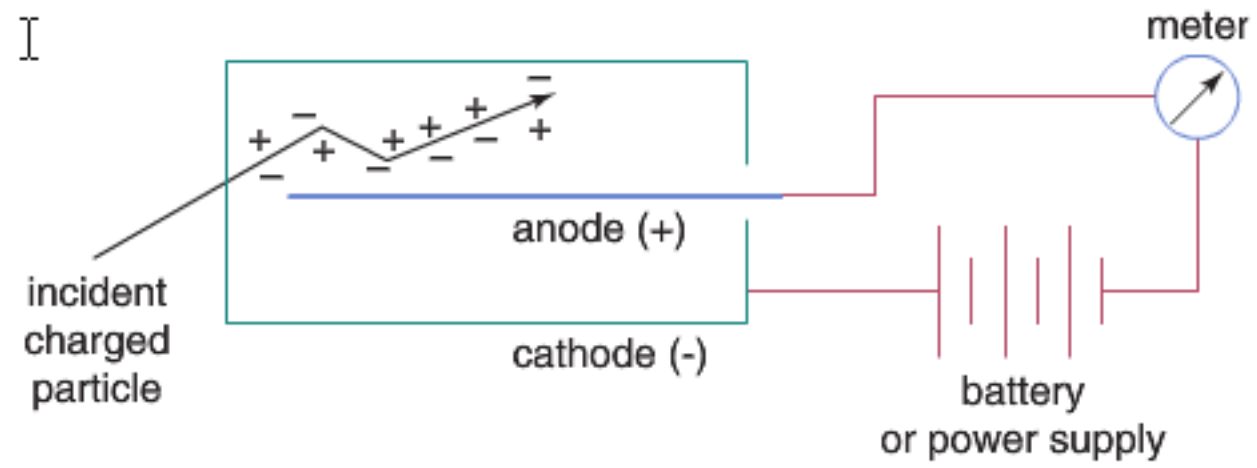
- Hög intensitet – strömmätning
 - Alla fotoner bidrar till strömsignalen
 - Transmissionsavbildning - Röntgen**

CT Detektorer - jonisationskammare

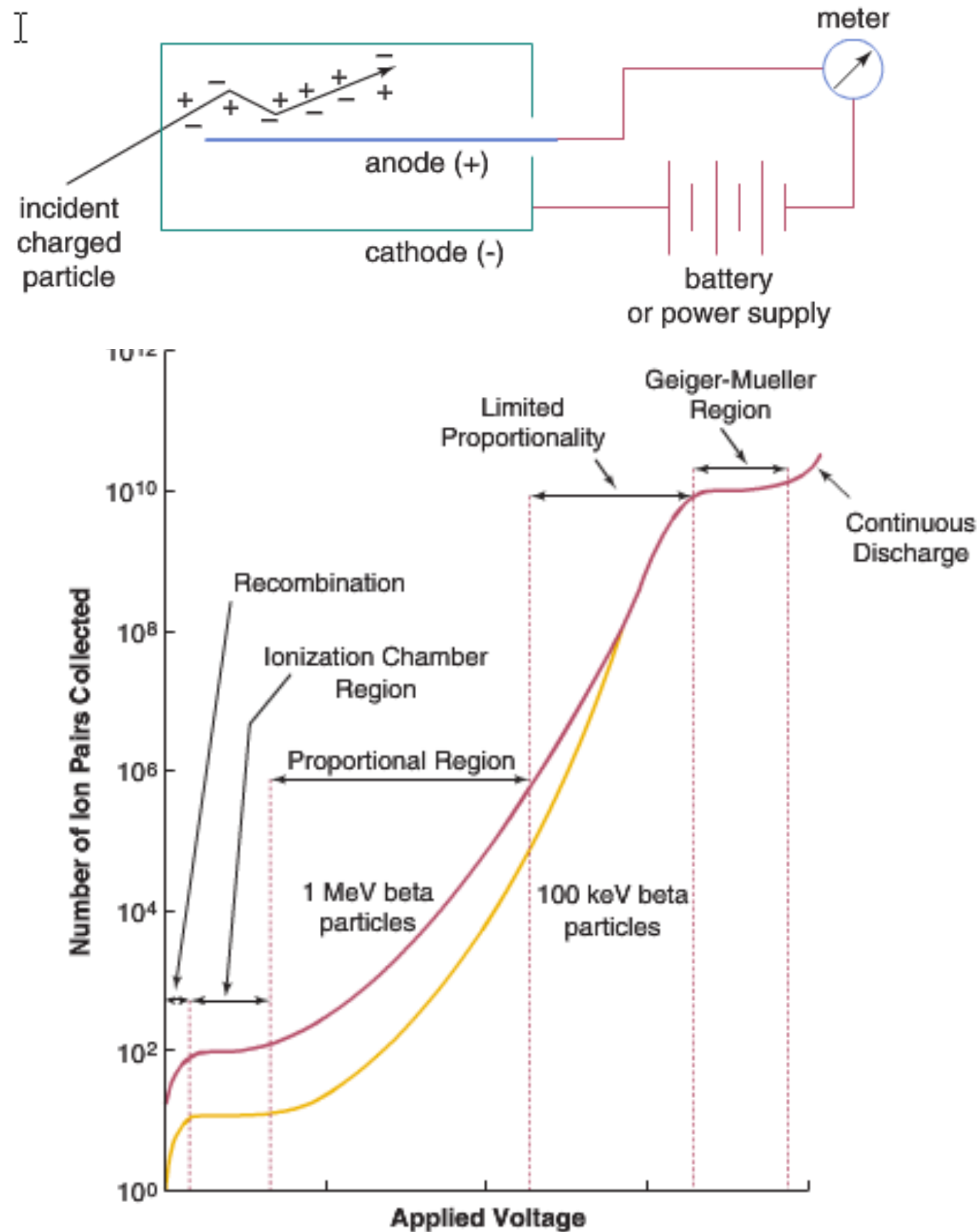
- Intensitetsmätning
- Många detektorelement (~ 1000) – array
- Roterar kring patienten – signalöverföring
- Jonisationskammare - gasdetektor



jonisationskammare

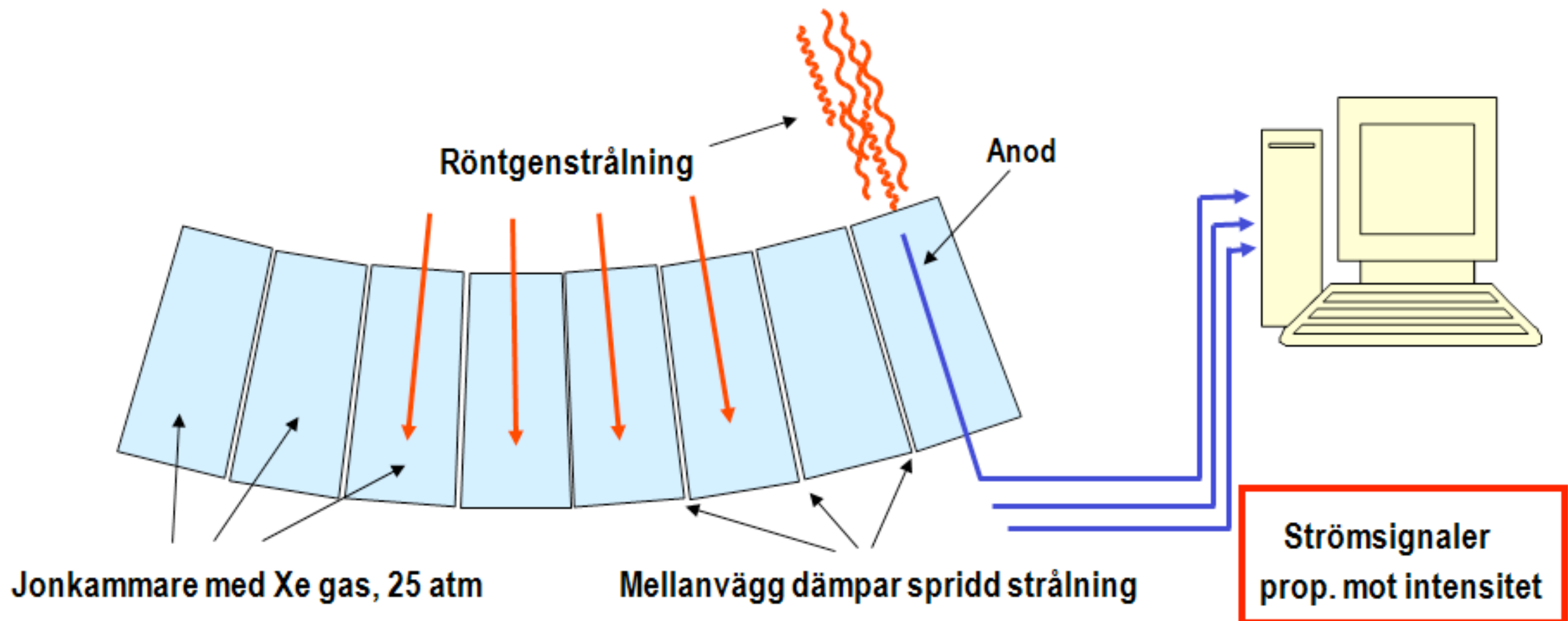


jonisationskammare



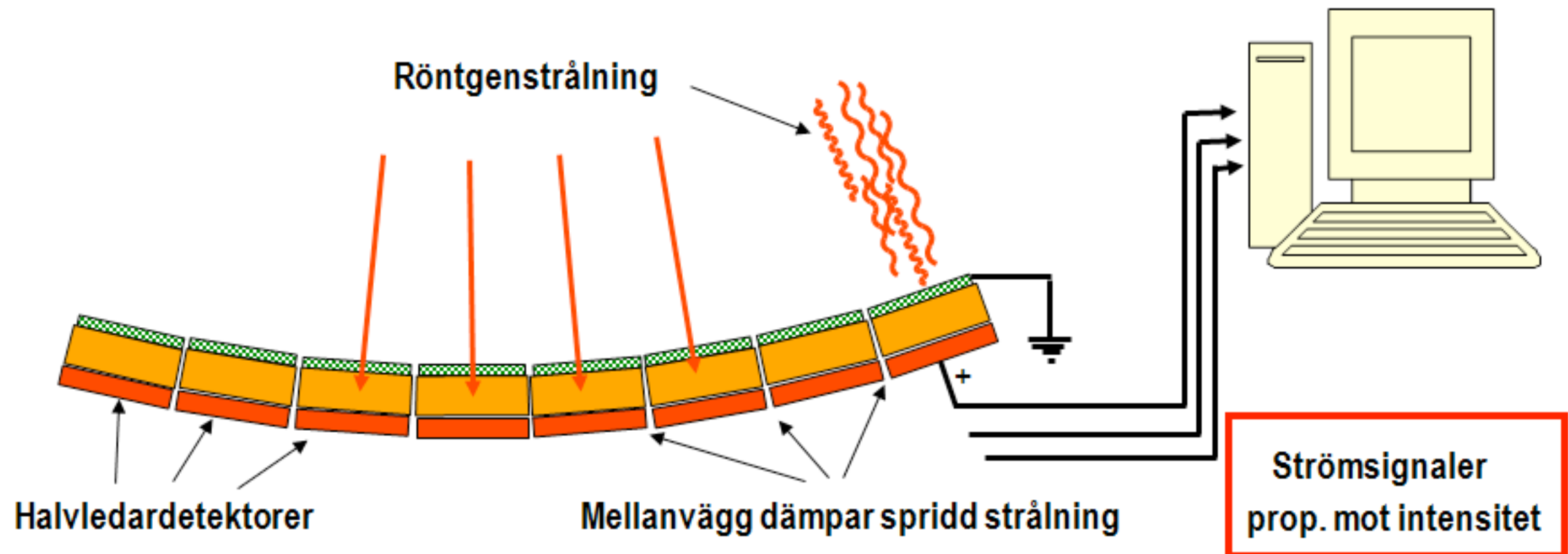
CT Detektorer - jonisationskammare

- Intensitetsmätning
- Många detektorelement (~ 1000) – array
- Roterar kring patienten – signalöverföring
- Jonisationskammare - gasdetektor

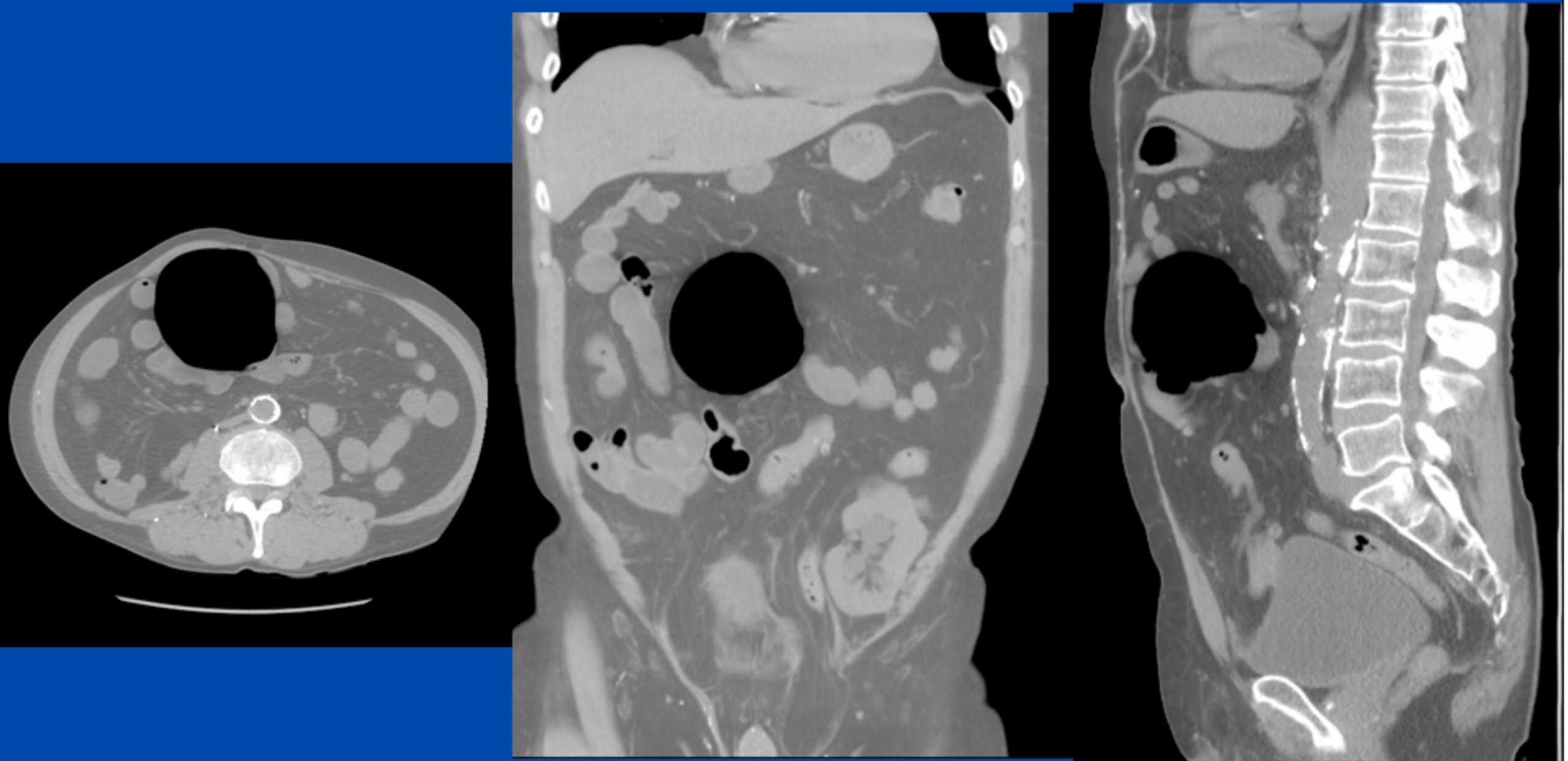


CT Detektorer - halvledardetektor

- Intensitetsmätning
- Många detektorelement (~ 1000) – array
- Roterar kring patienten – signalöverföring
- Halvledardetektor – tunn kiseldetektor



CT bilder från Danderyds Sjukhus

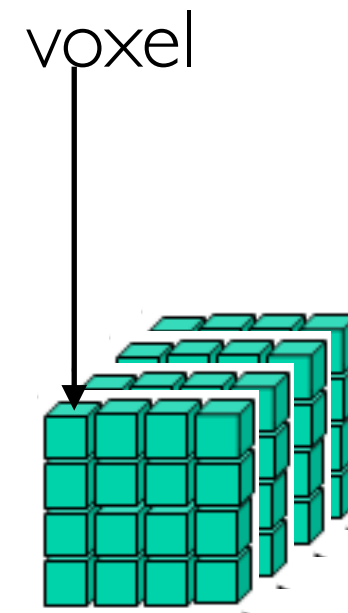


64 slice CT - samma undersökning av buken, rekonstruerad i tre plan

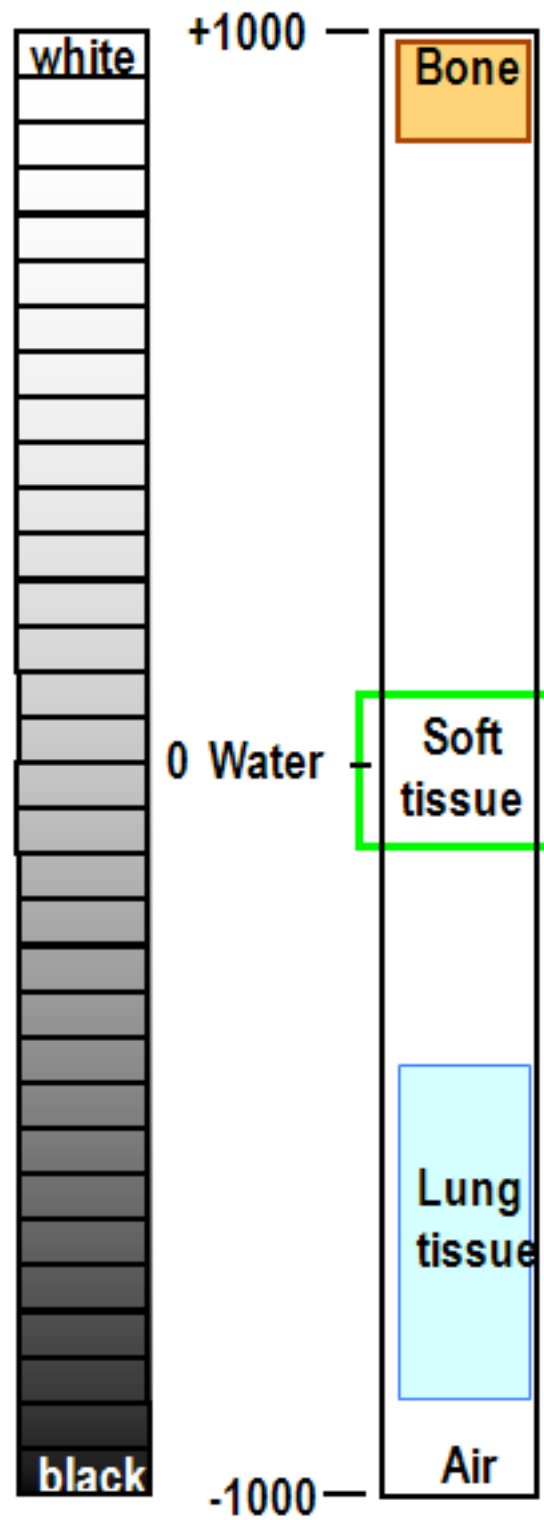
Övning:

What is a CT image, actually?

1. a 3D-matrix with linear attenuation coefficients (or something related to it) for each voxel of the object
2. a binary file that gives grey levels associated with each voxel of the object
3. a file with coordinates of each voxel so that with the help of a computer the object can be visualised
4. it depends on the manufacturer of the CT-scanner



In CT images we use Hounsfield Units (HU) or CT-numbers, which are proportional to the relative attenuation of the tissue compared to water.



- CT number =
$$= 1000(\mu_{\text{tissue}} - \mu_{\text{water}}) / \mu_{\text{water}}$$

The CT-number (HU) of something that attenuates x-rays less than water is:

1. between 0 and 1
2. greater than zero
3. lower than zero
4. exactly 1000
5. exactly -1000

The CT-number (HU) of something that attenuates x-rays less than water is:

1. between 0 and 1
2. greater than zero
3. lower than zero
4. exactly 1000
5. exactly -1000

Övningar:

$$\bullet \quad \text{CT number} = \\ = 1000(\mu_{\text{tissue}} - \mu_{\text{water}}) / \mu_{\text{water}}$$

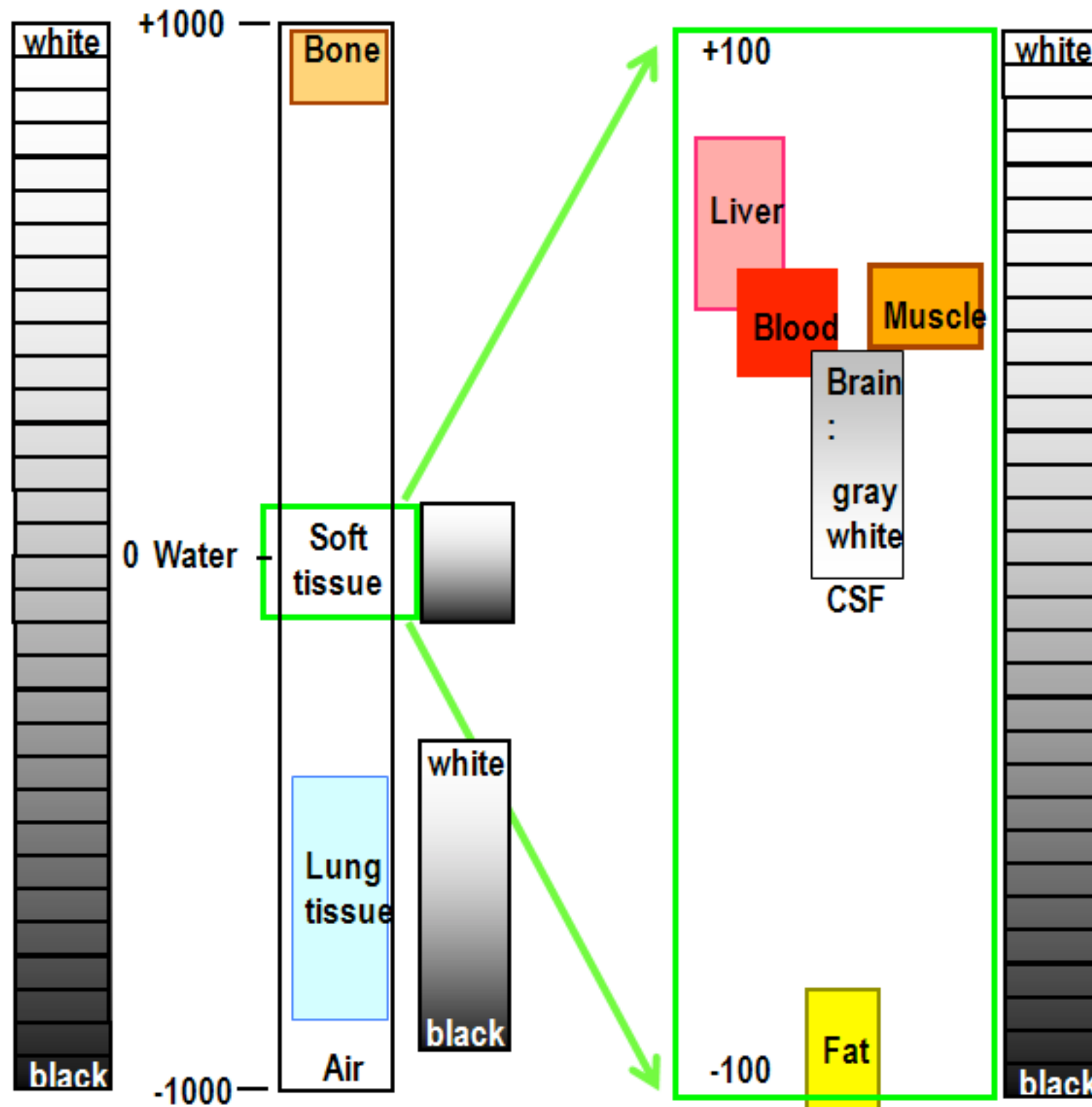
1. The CT-number (HU) depends on the tube voltage:

1. Less than the linear attenuation coefficient
2. As much as the linear attenuation coefficient
3. Much more than the linear attenuation coefficient

Motivate your answer using equations and/or graphs together with text.

2. Think about the “progression” from simple examples with pencil-beam, monochromatic sources and thin targets to the clinical set up with an x-ray tube and a patient and list all the reasons you can come up with for using HU instead for linear attenuation coefficient in x-ray CT images.

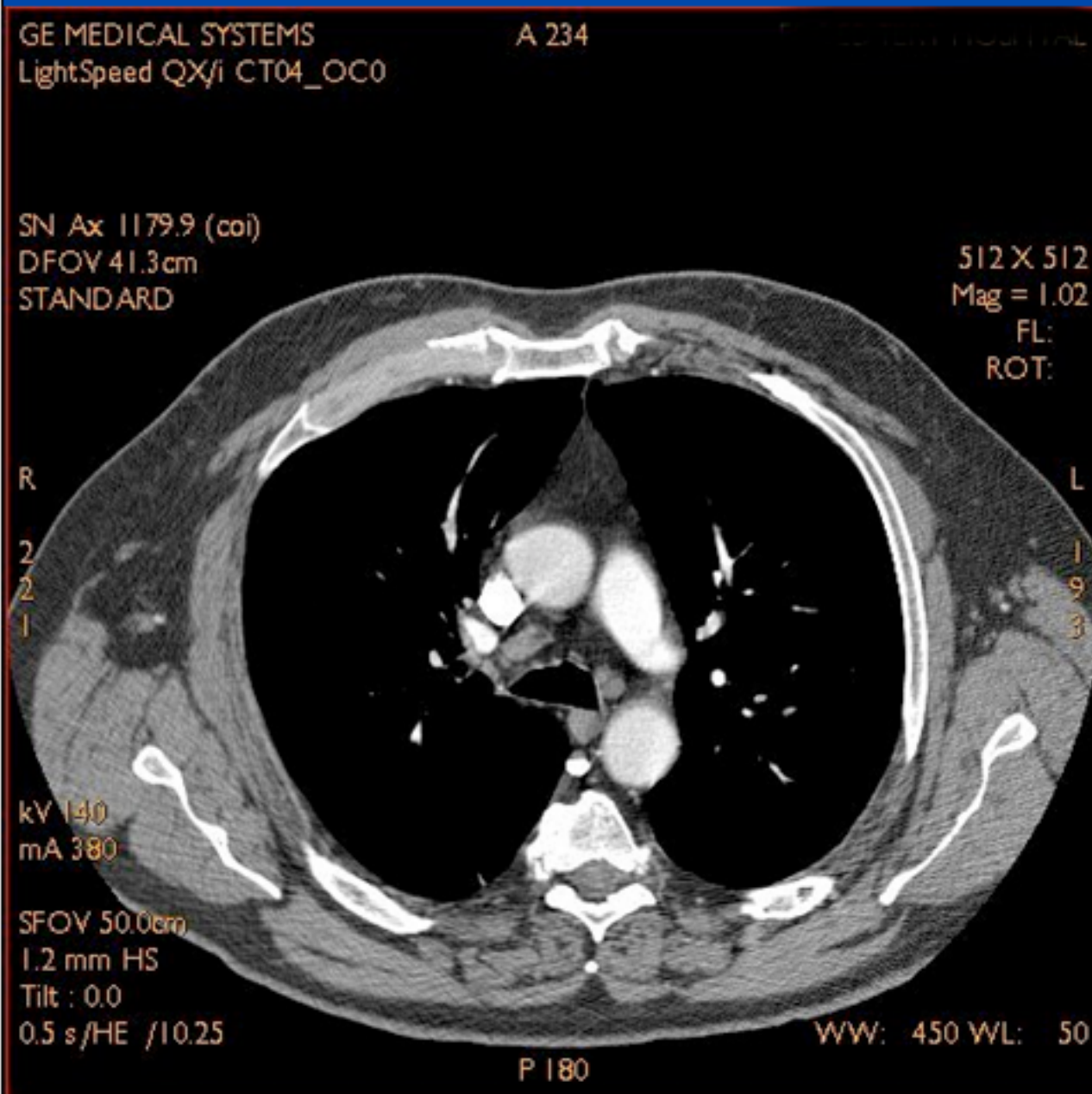
Hounsfield (CT) units and windowing



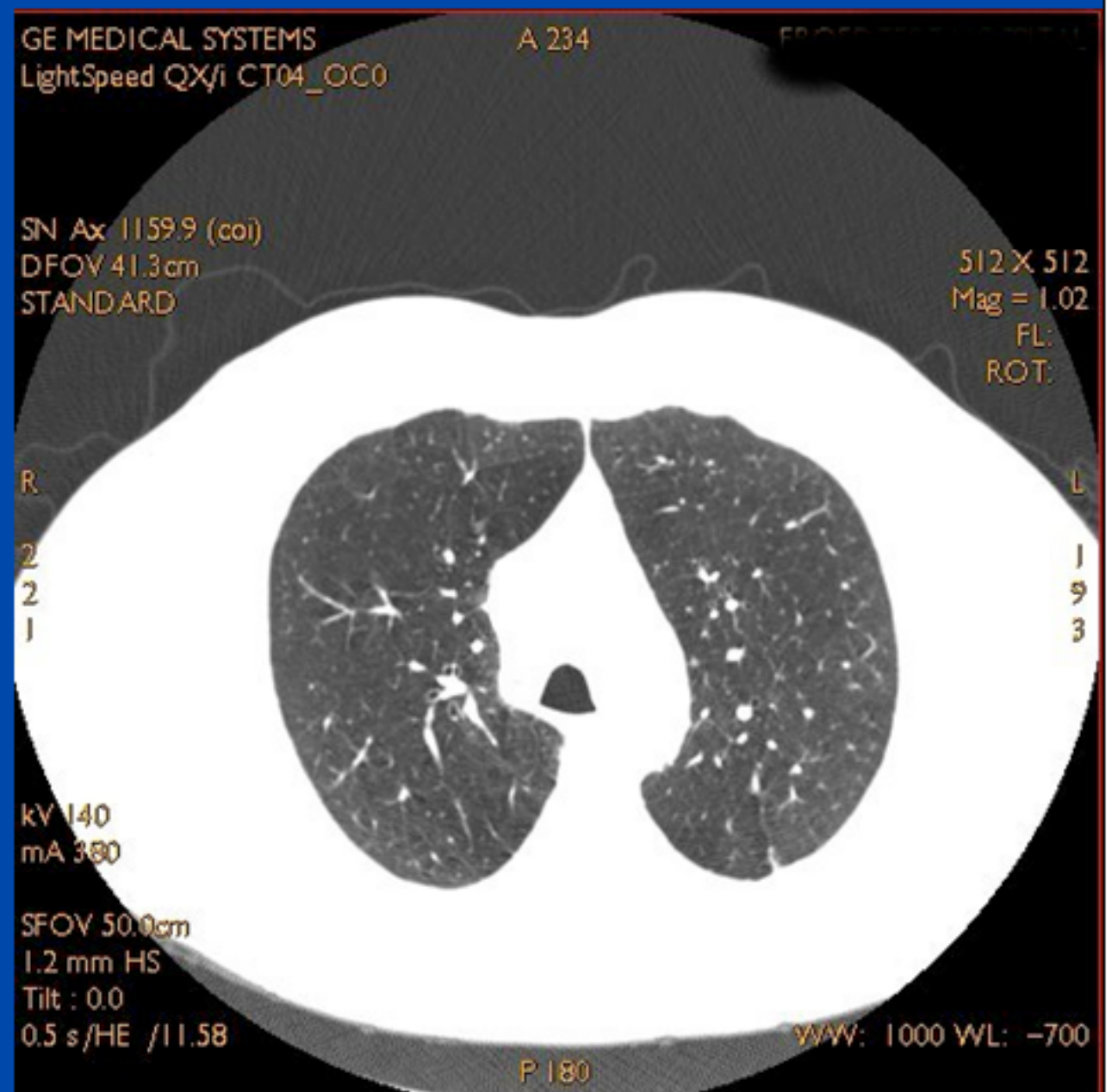
$$\text{CT number} = \frac{1000(\mu_{\text{tissue}} - \mu_{\text{water}})}{\mu_{\text{water}}}$$

- The human eye is able to distinguish between white and black approx 30 shades (=5 bits)
- The contrast for each pixel of the CT image data is stored with 10-11 bits precision
- Windowing is applied for detailed studies and to enhance the image quality after data acquisition

Fönstersättning: 2 snitt genom Thorax



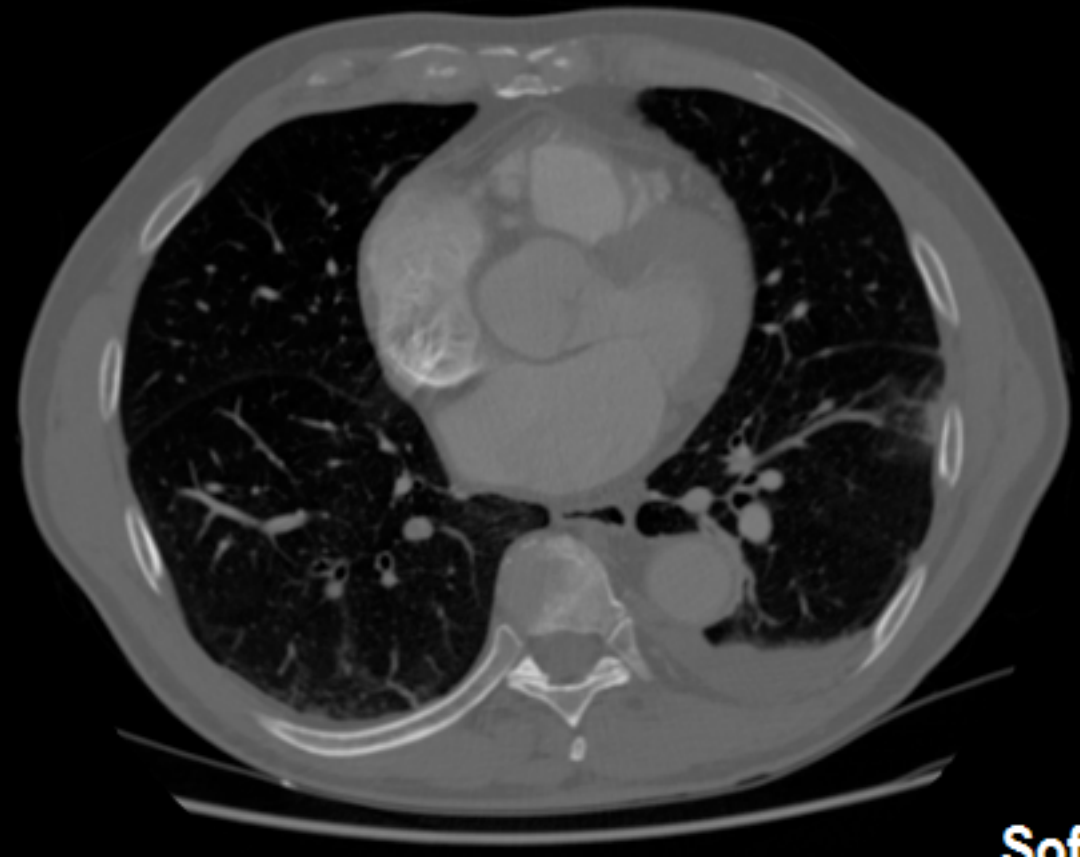
Window Width = 450
Window Level = 50



Window Width = 1000
Window Level = -700



Bone



Soft



Lung

CT bilder från Danderyds Sjukhus

Thorax - Datatomografi med
intravenös kontrast med olika
fönstersättning (mjukdelar,
lungor, ben)

dose

Dose - joniserande strålning

Fysik, enkel!

$$\text{absorberad dos} \stackrel{\text{Def}}{=} \frac{\text{absorberad } E}{\text{mass}} \quad [\text{Gy} = \text{J/kg}]$$

(old rad = 10 mGy)

Dose - joniserande strålning

Fysik, enkel!

absorberad dos $\stackrel{\text{Def}}{=} \frac{\text{absorberad } E}{\text{mass}}$ [Gy = J/kg]
(old rad = 10 mGy)

samma för:



Dose - joniserande strålning

Fysik, enkel!

absorberad dos $\stackrel{\text{Def}}{=} \frac{\text{absorberad } E}{\text{mass}}$ [Gy = J/kg]
(old rad = 10 mGy)

samma för:



och för: α , β , γ , heavy ions, π - och μ -mesons, ...

1 kg of prosciutto di parma is exposed to ionising radiation. The energy deposited by radiation is 1 Joule.

The absorbed dose is then:

1. 1 rad

4. 1 mGy

2. 1 mrad

5. 1 Ci

3. 1 Gy

6. 1 mCi

1 kg of prosciutto di parma is exposed to ionising radiation. The energy deposited by radiation is 1 Joule.

The absorbed dose is then:

1. 1 rad

4. 1 mGy

2. 1 mrad

5. 1 Ci

3. 1 Gy

6. 1 mCi

1 g of prosciutto di parma is exposed to ionising radiation. The energy deposited by radiation is 1 Joule.

The absorbed dose is then:

1. 1 mGy

2. 1 Gy

3. 1 kGy

1 g of prosciutto di parma is exposed to ionising radiation. The energy deposited by radiation is 1 Joule.

The absorbed dose is then:

1. 1 mGy

2. 1 Gy

3. 1 kGy

Vad är farlig?

deponerad E i sig?

Vad är farlig?

deponerad E i sig?

10 Gy medför en T ökning på $0,0024^\circ$

Vad är farlig?

deponerad E i sig?

knappast!

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10 Gy medför en T ökning på $0,0024^\circ$

... men man dör direkt. (100% säkert!)

Vad är farlig?

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knappast!

10 Gy medför en T ökning på $0,0024^\circ$

... men man dör direkt. (100% säkert!)

➡ Fysik makroskopisk nivå: alldeles för enkel modell

Nytt storhet: dose equivalent

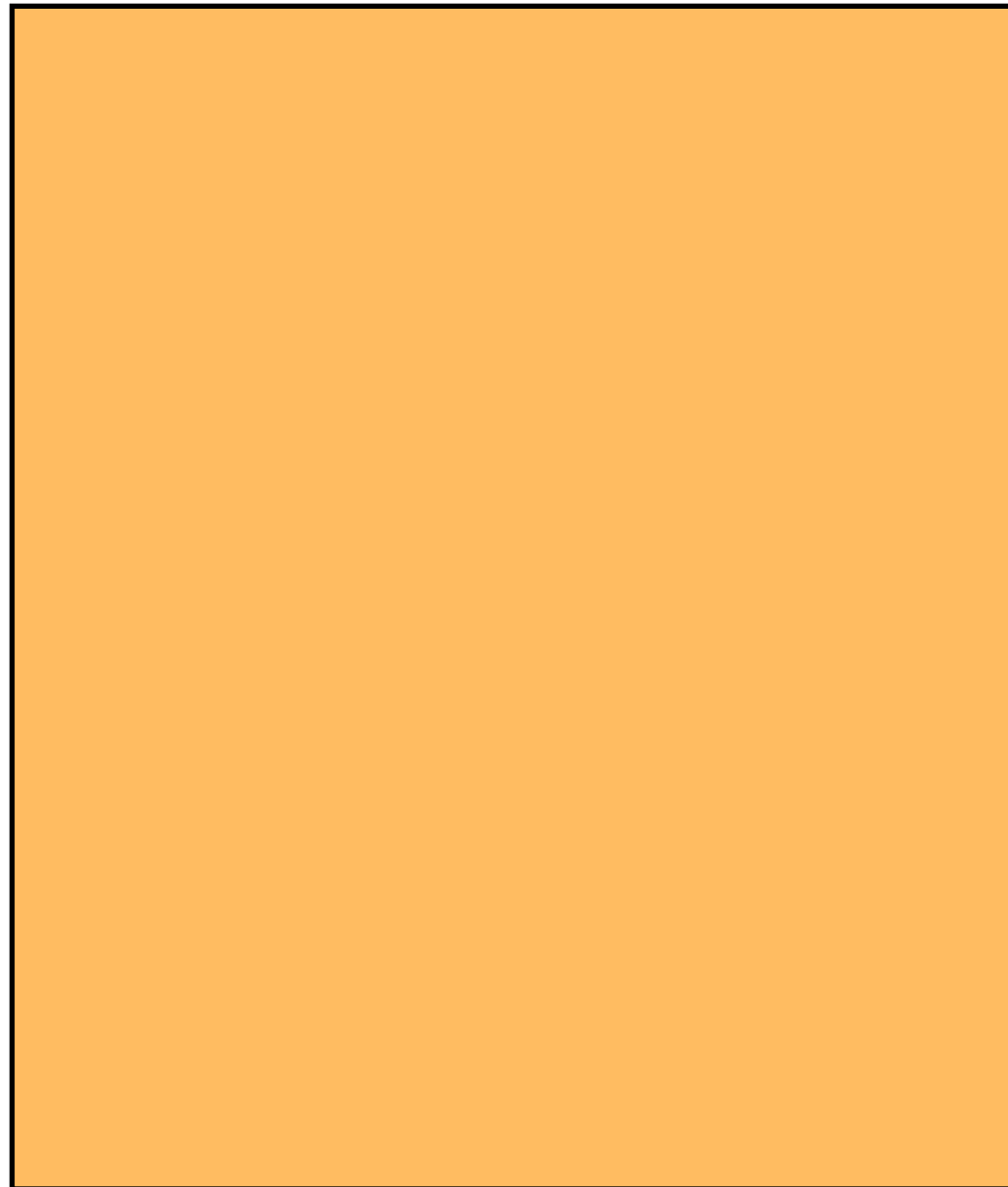
90% Fysik (mikroskopisk nivå)- 10% Biologi

Fysik:

Nytt storhet: dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

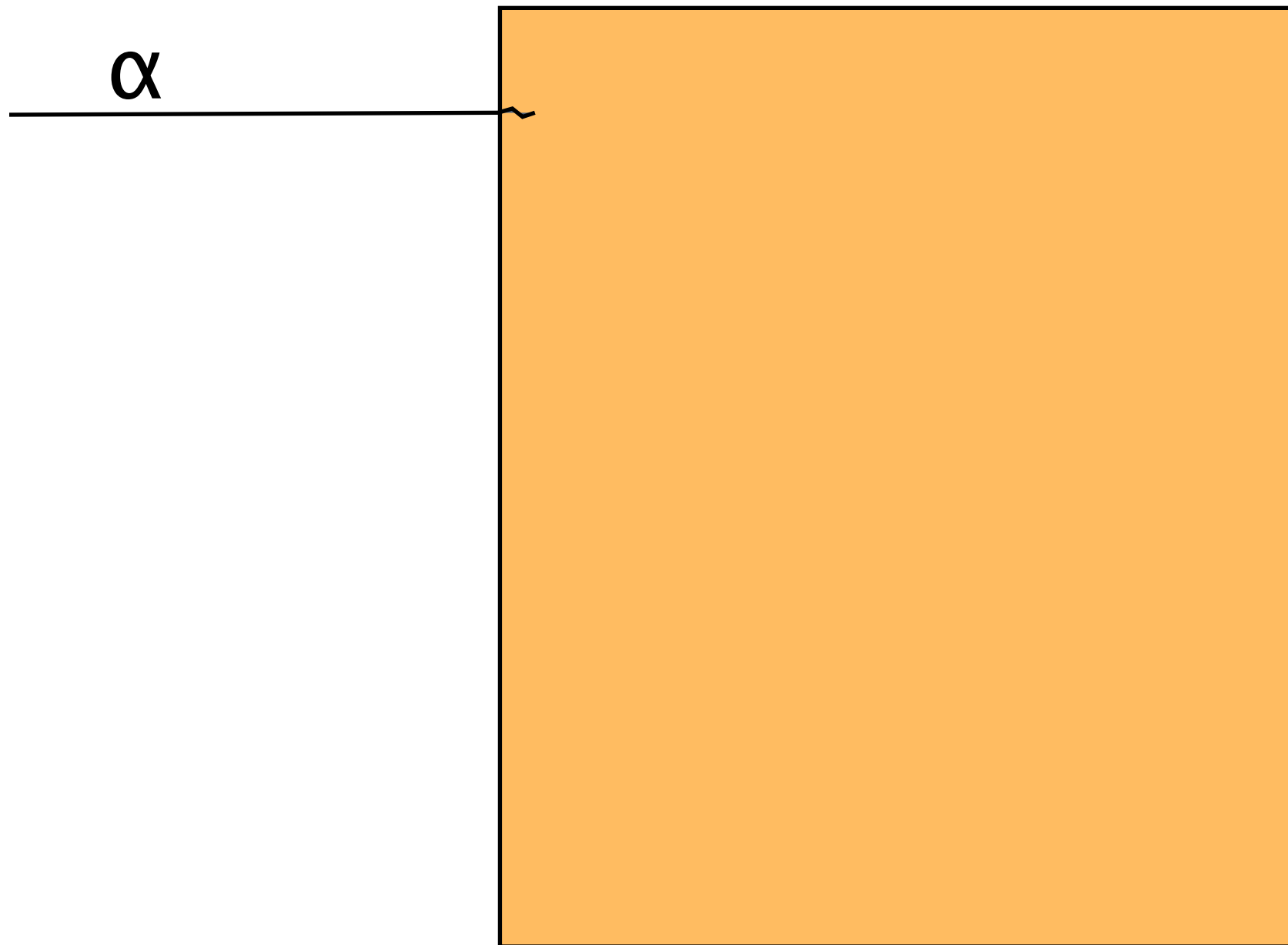
Fysik:



Nytt storhet: dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

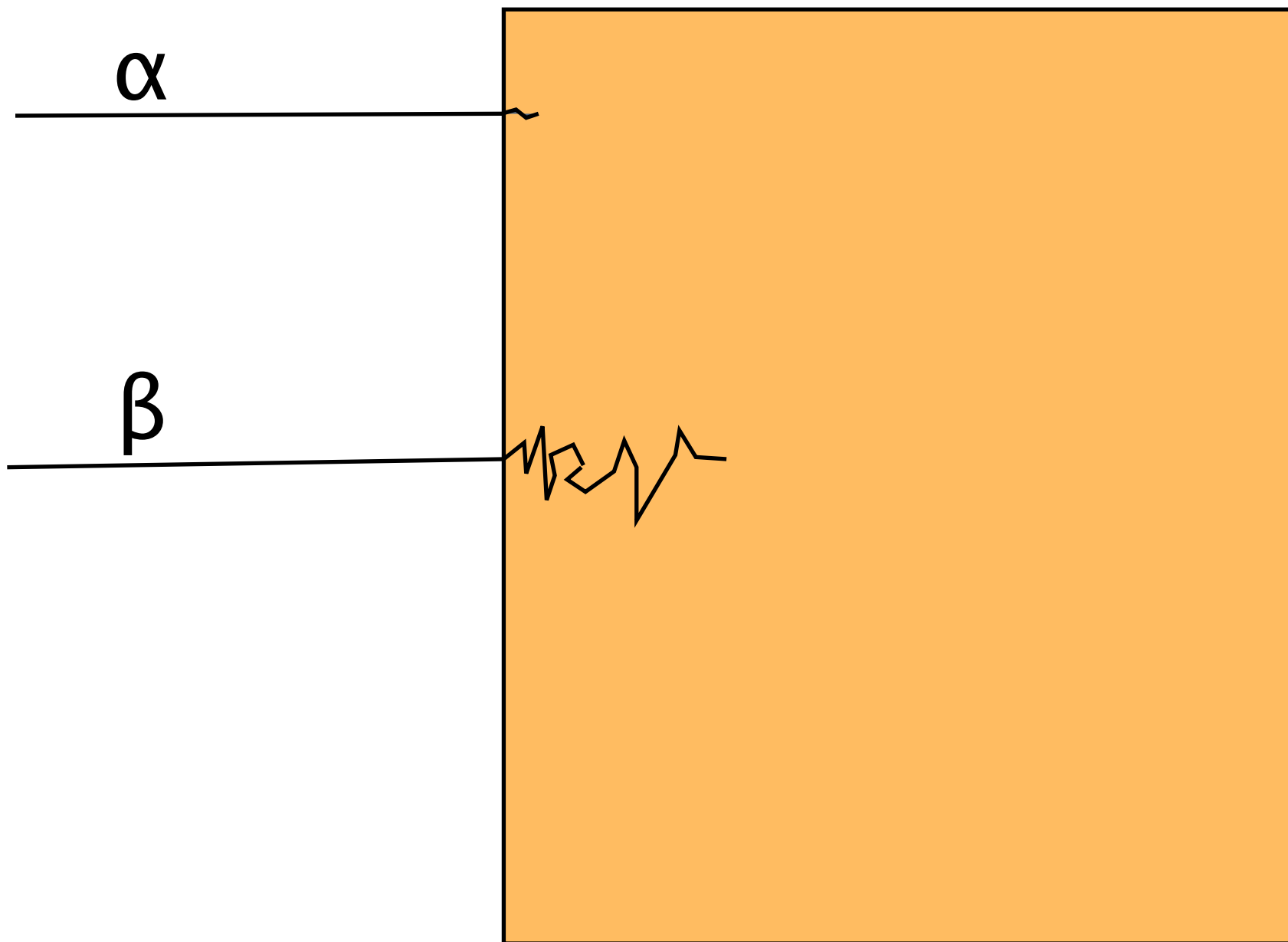
Fysik:



Nytt storhet: dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

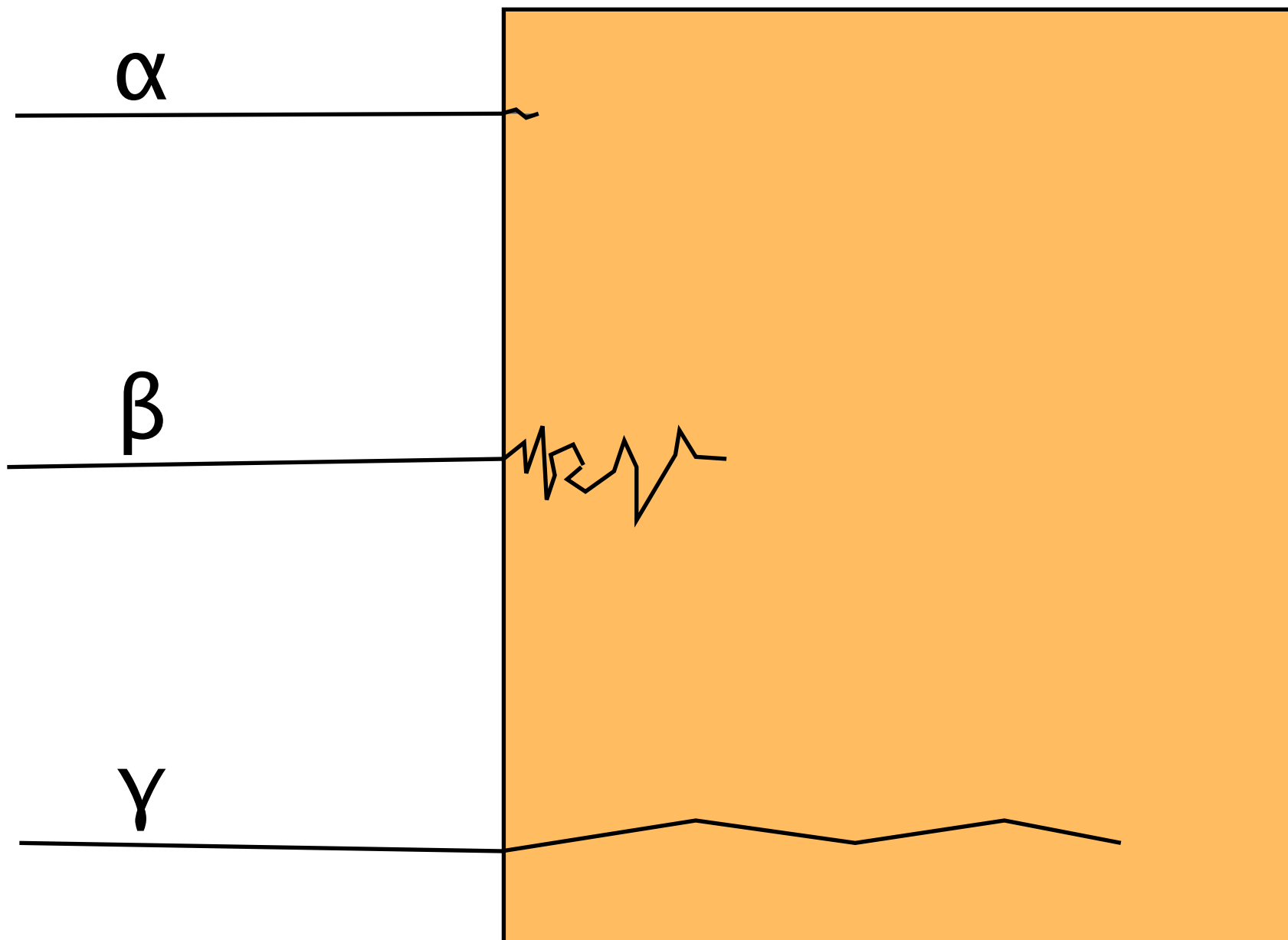
Fysik:



Nytt storhet: dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

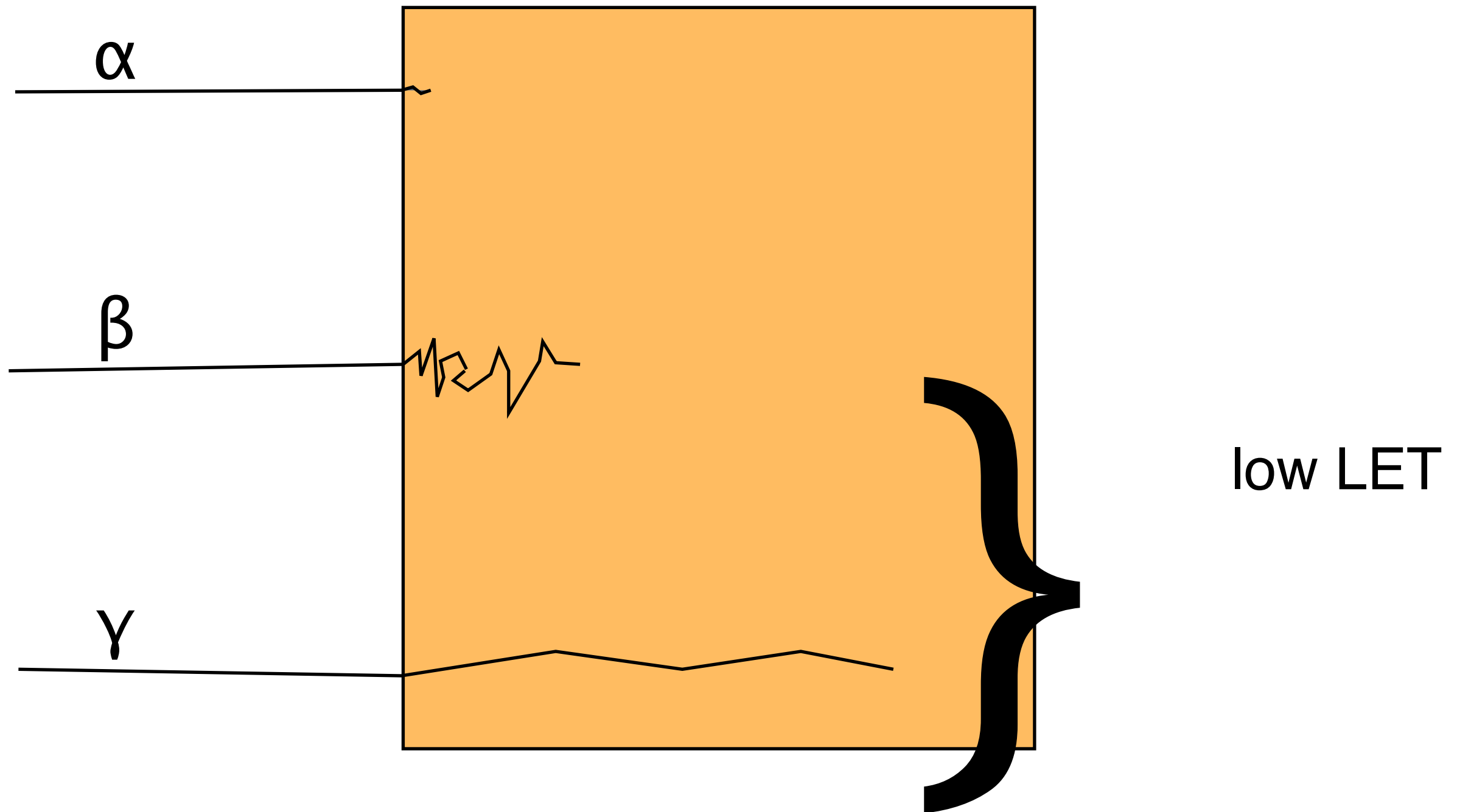
Fysik:



Nytt storhet: dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

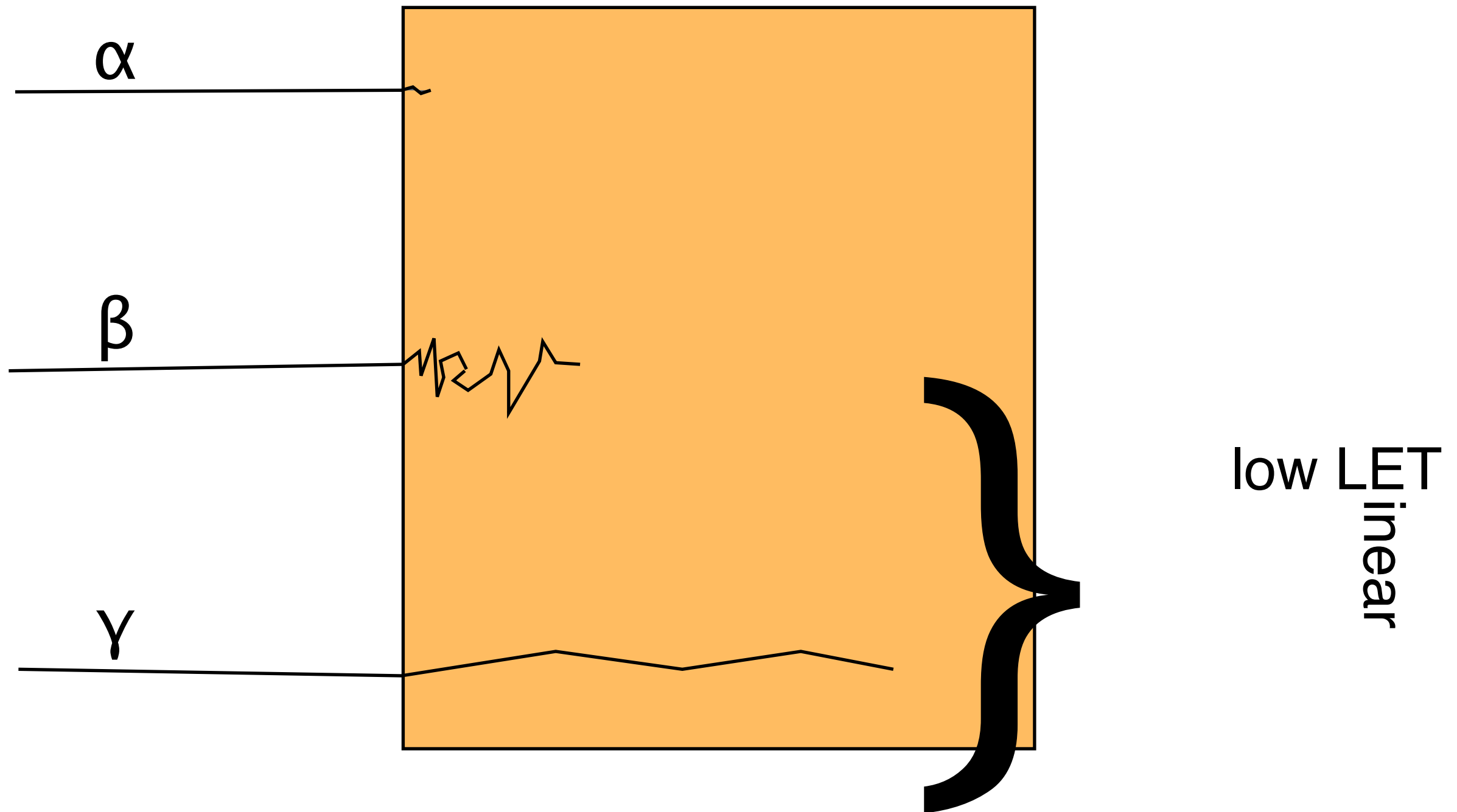
Fysik:



Nytt storhet: dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

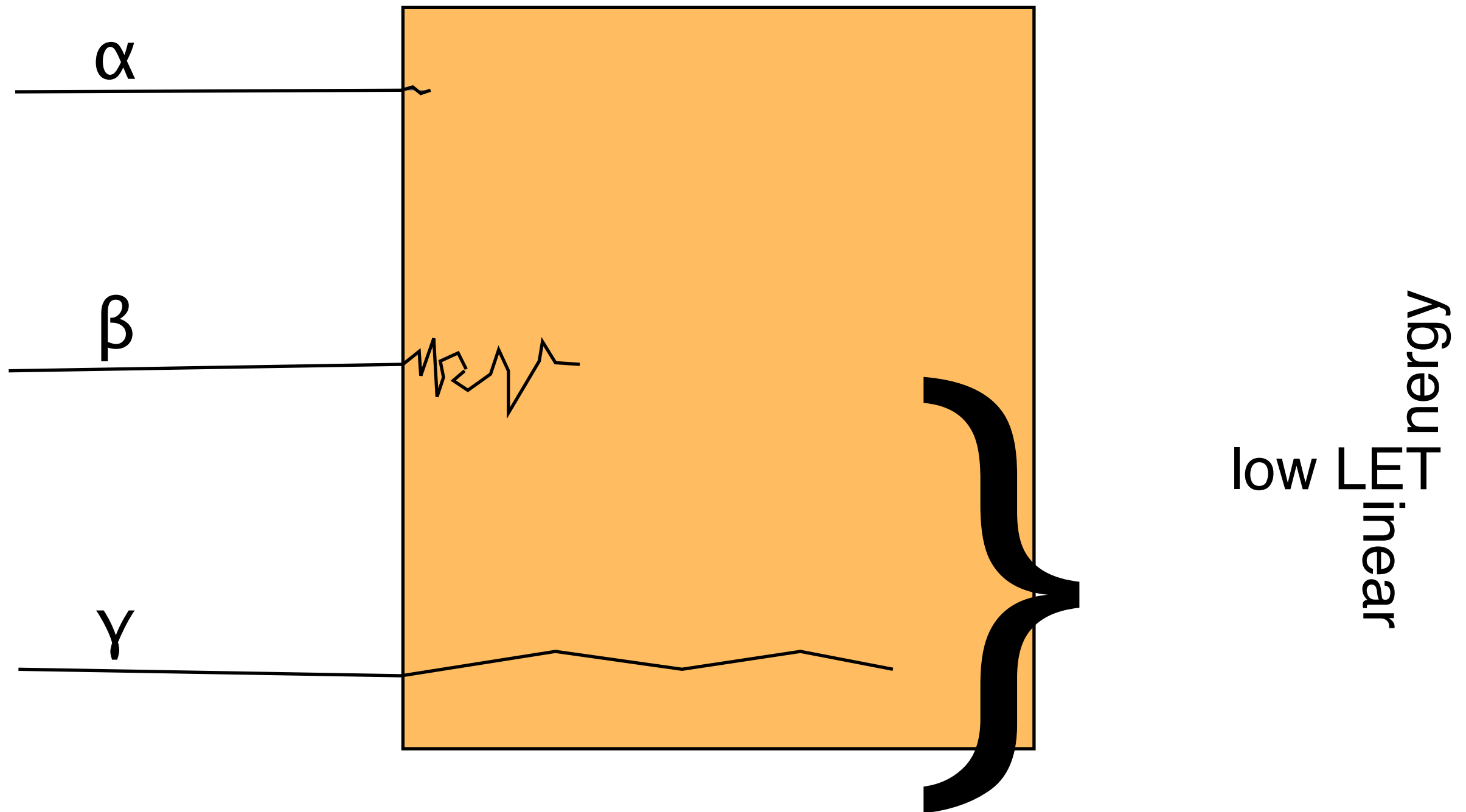
Fysik:



Nytt storhet: dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

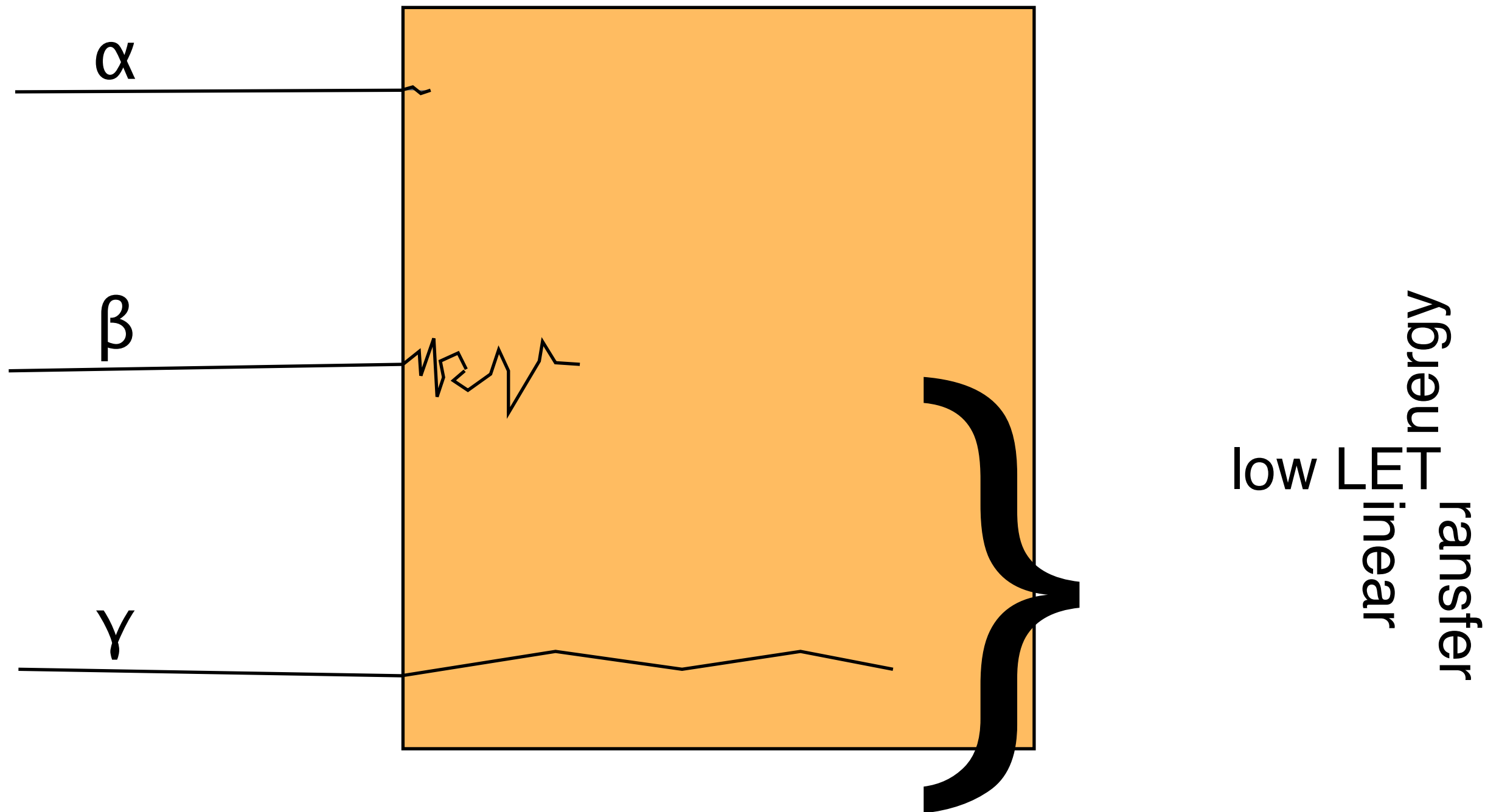
Fysik:



Nytt storhet: dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

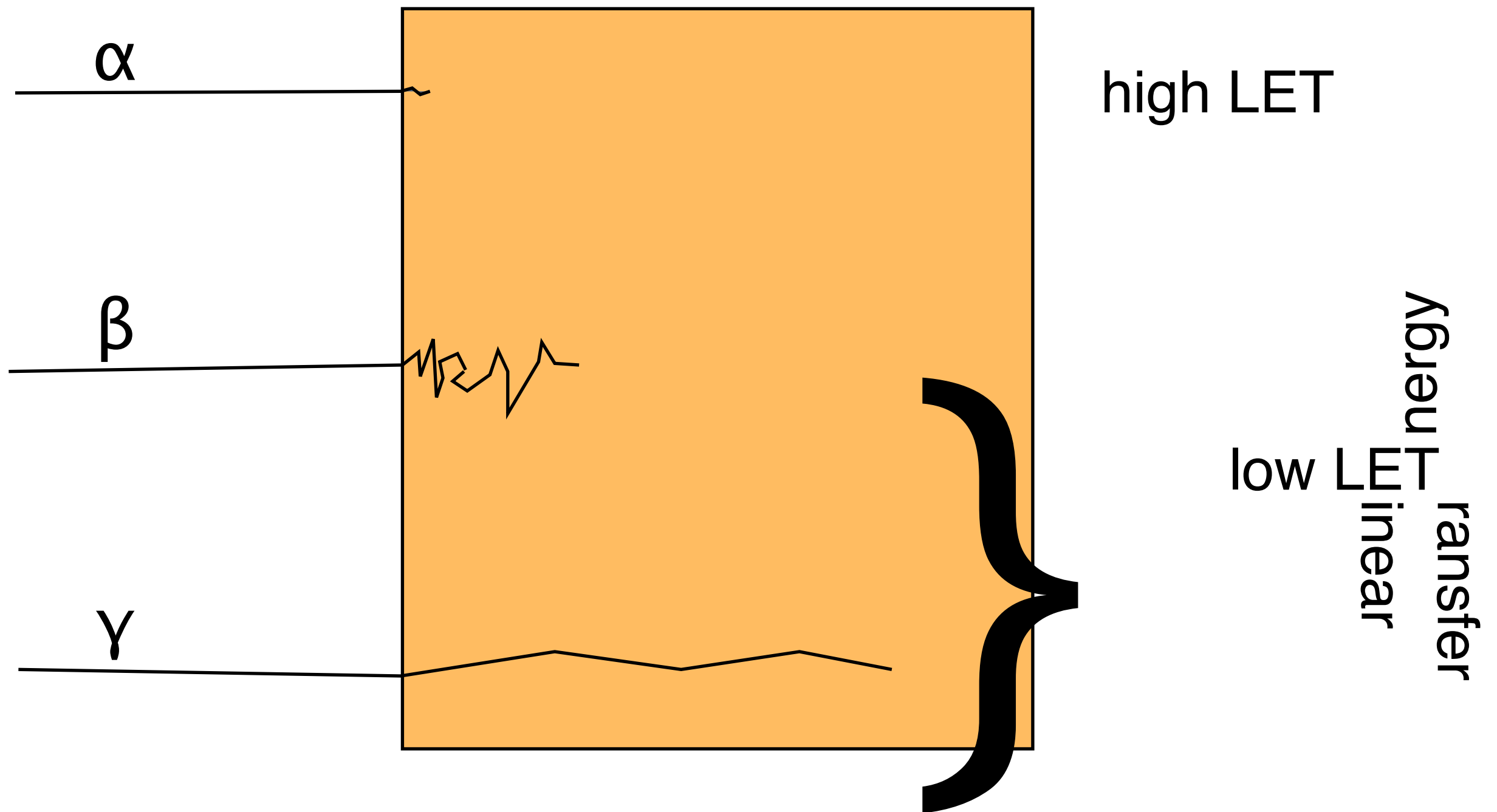
Fysik:



Nytt storhet: dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

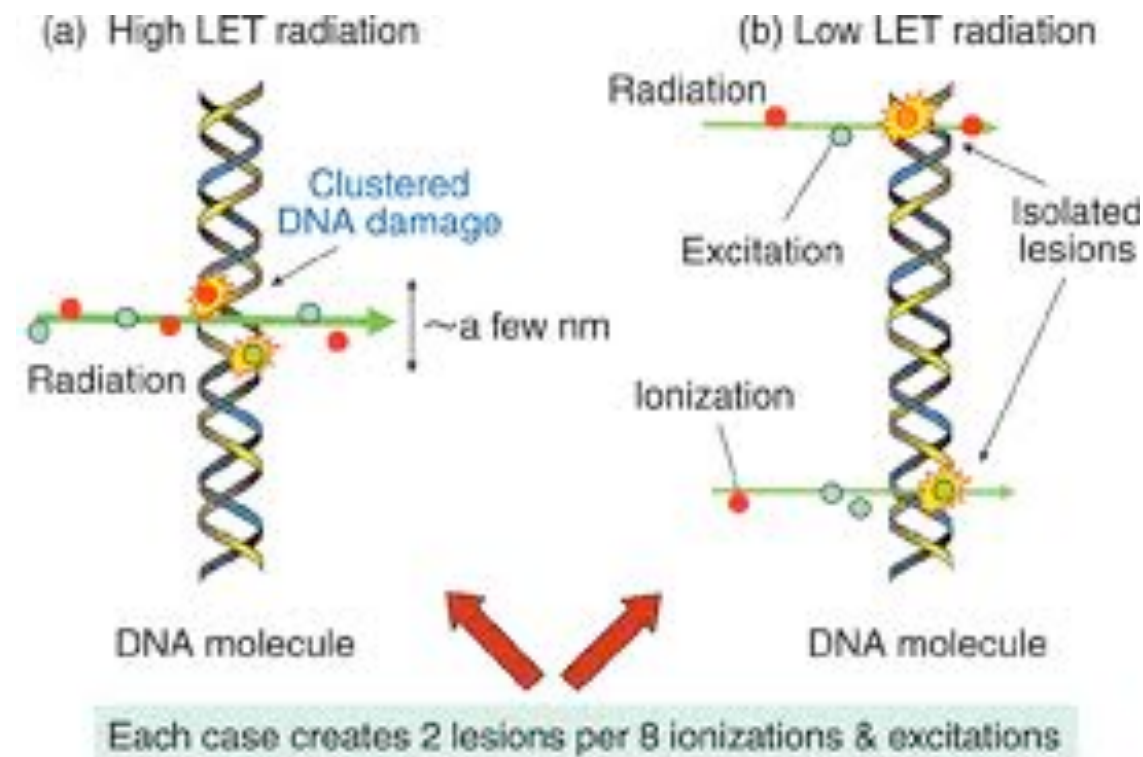
Fysik:



Dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

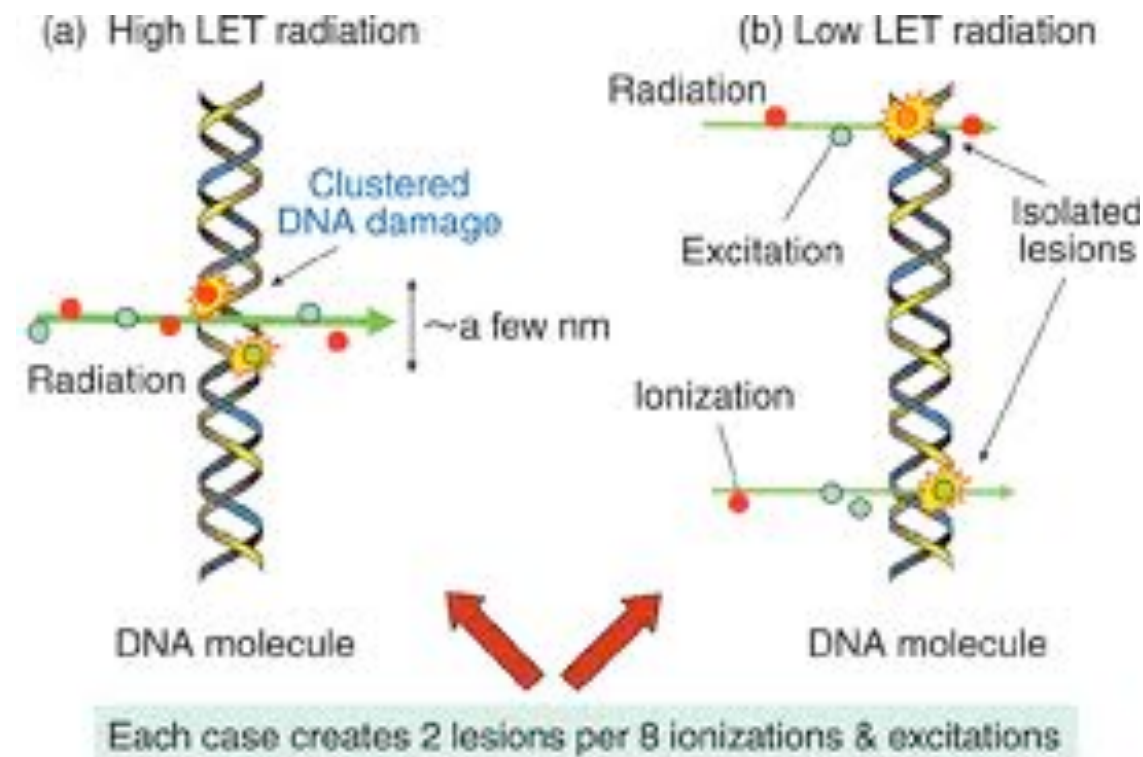
Biologi:



Dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

Biologi:

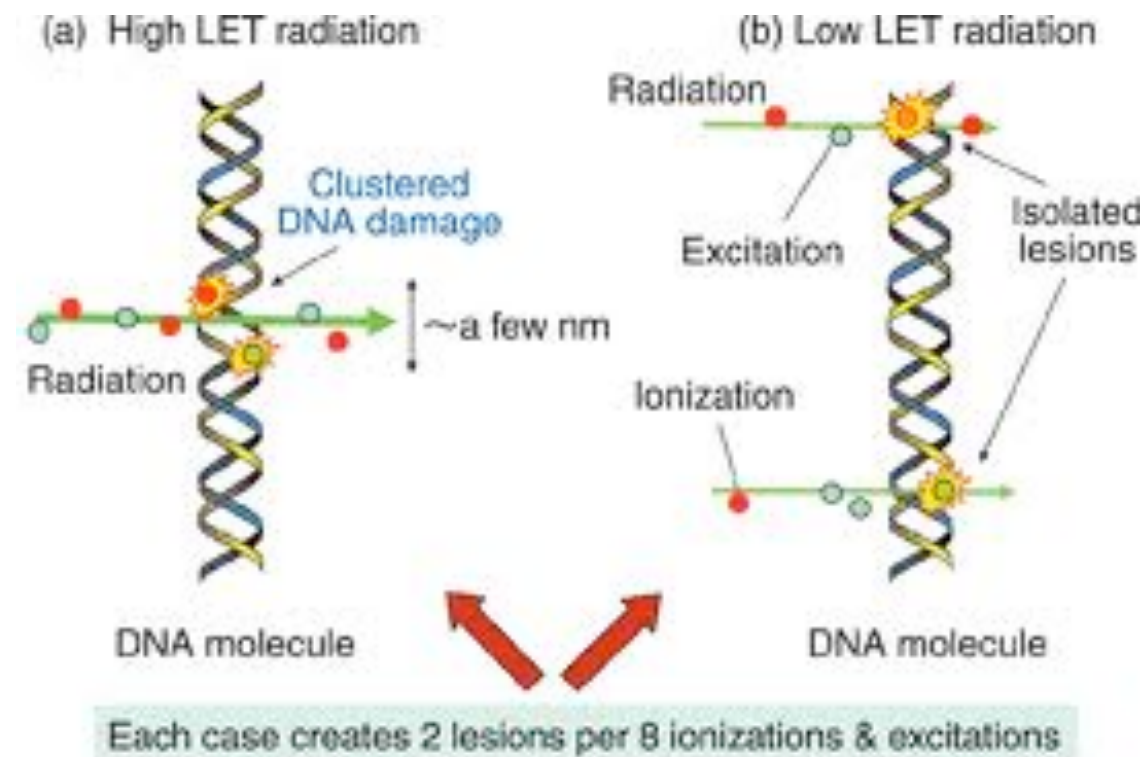


0,9 Fysik + 0,1 Bio $\rightarrow$ quality factor W_R

Dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

Biologi:



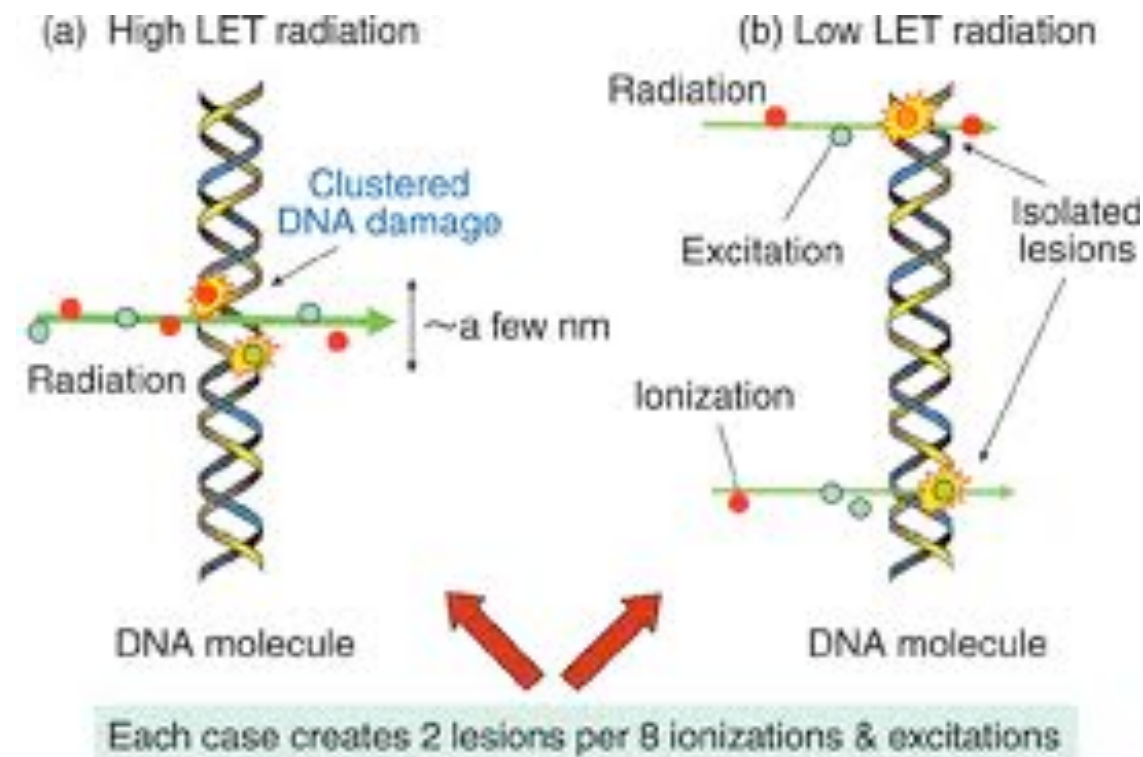
0,9 Fysik + 0,1 Bio $\rightarrow$ quality factor W_R

$$\beta, \gamma: W_R = 1$$

Dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

Biologi:



0,9 Fysik + 0,1 Bio $\rightarrow$ quality factor W_R

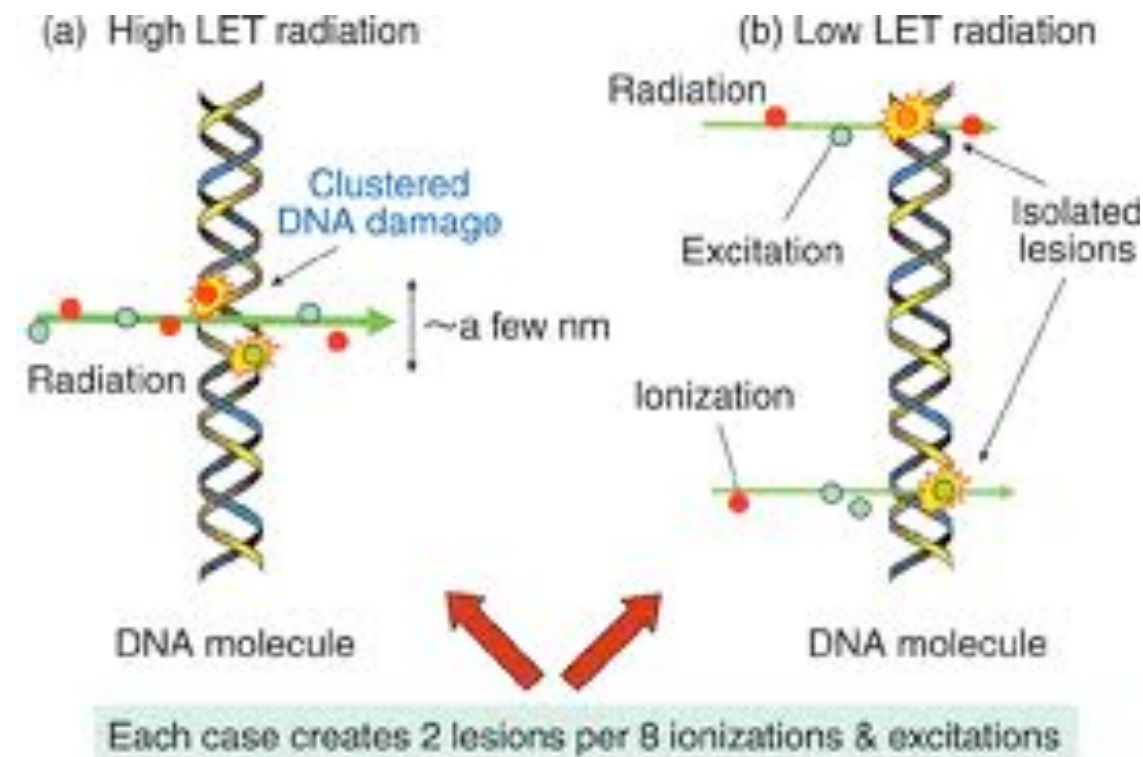
$\beta, \gamma: W_R = 1$

$\alpha: W_R = 20$

Dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

Biologi:



0,9 Fysik + 0,1 Bio $\rightarrow$ quality factor W_R

$\beta, \gamma: W_R = 1$

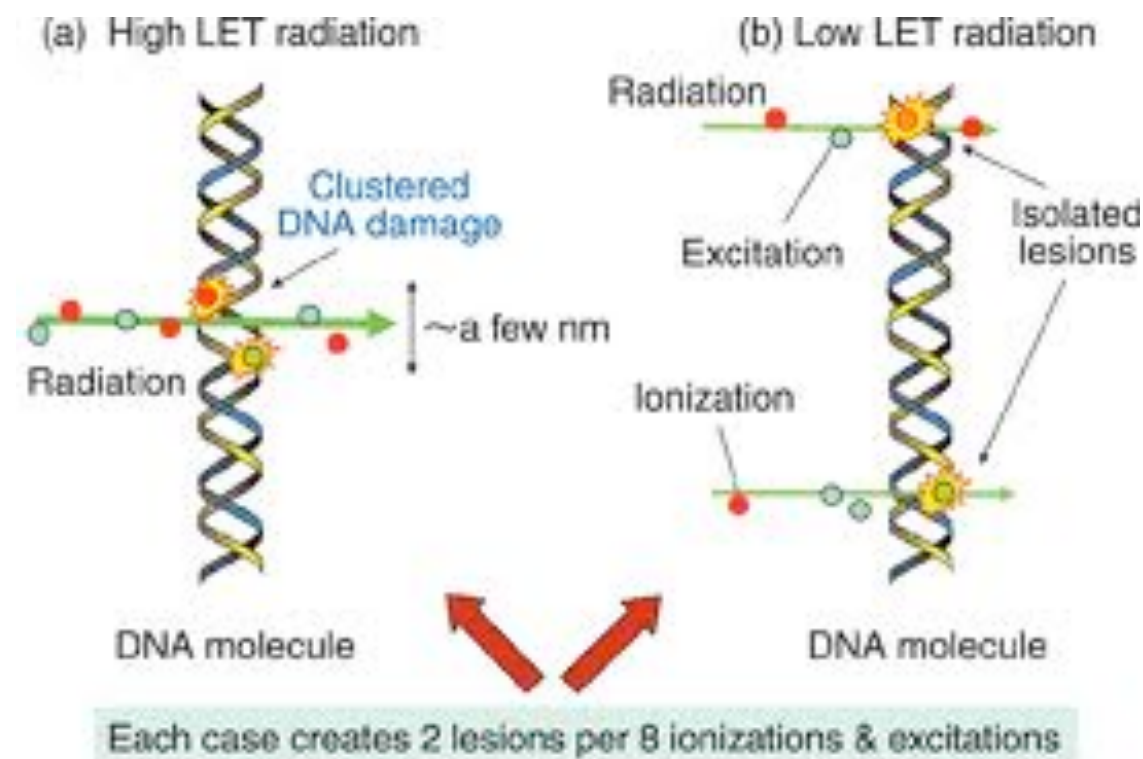
$\alpha: W_R = 20$

Def: dose equivalent = $W_R \cdot \text{abs dose}$

Dose equivalent

90% Fysik (mikroskopisk nivå)- 10% Biologi

Biologi:



0,9 Fysik + 0,1 Bio $\rightarrow$ quality factor W_R

$\beta, \gamma: W_R = 1$

$\alpha: W_R = 20$

Def: dose equivalent = $W_R \cdot \text{abs dose}$

[Sv]

The dose equivalent:

1. Is the same as the absorbed dose, but biologists use different units

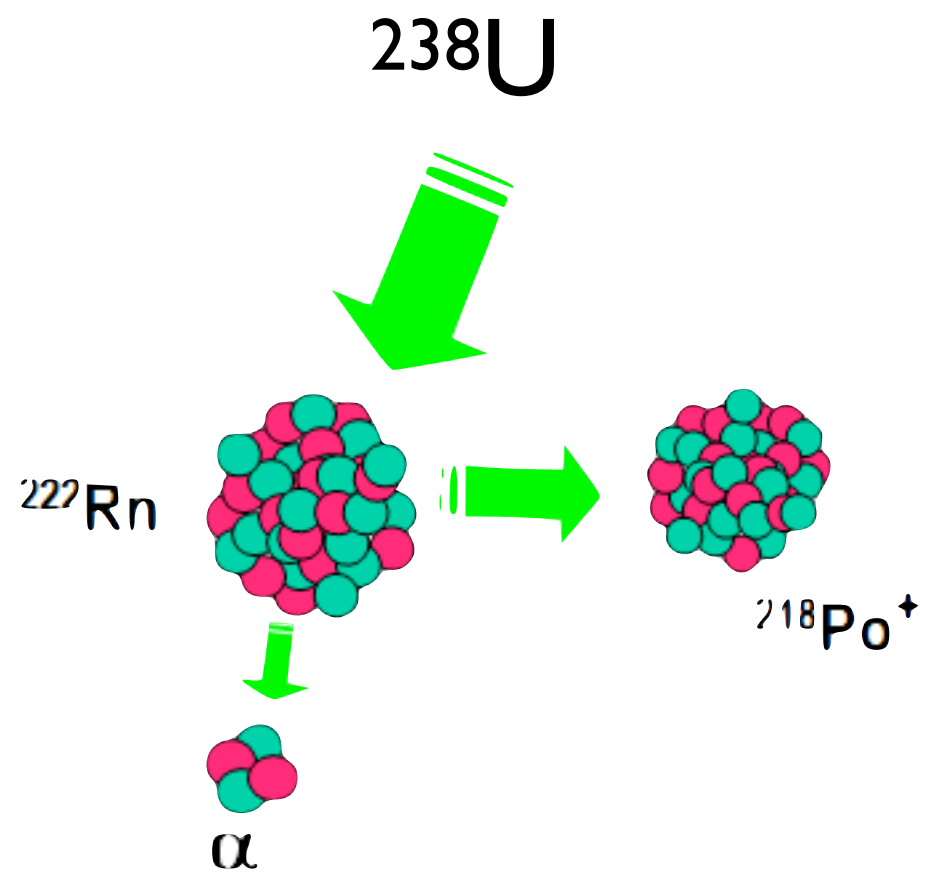
2. It's used to determine if someone has been irradiated by alpha-particles or by other type of radiation

3. It's a way of taking into account the different effect that different kind of radiation have on living tissues

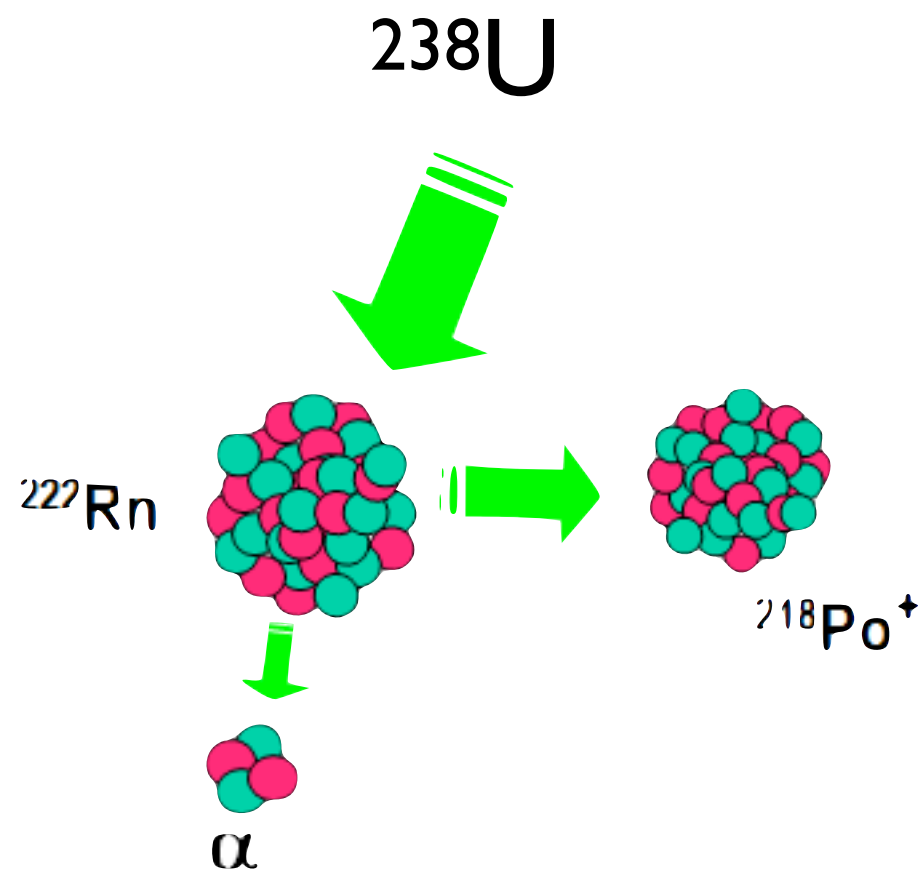
4. It's a way of standardising dose measurements

... men det räcker ändå inte

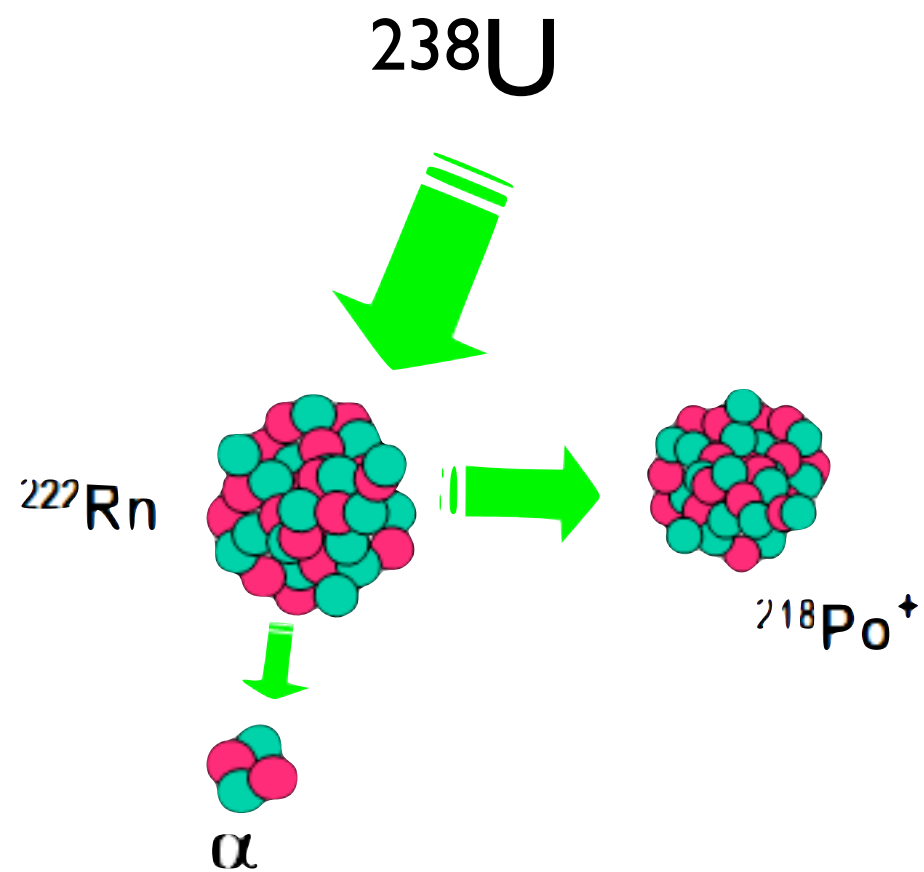
... men det räcker ändå inte



... men det räcker ändå inte

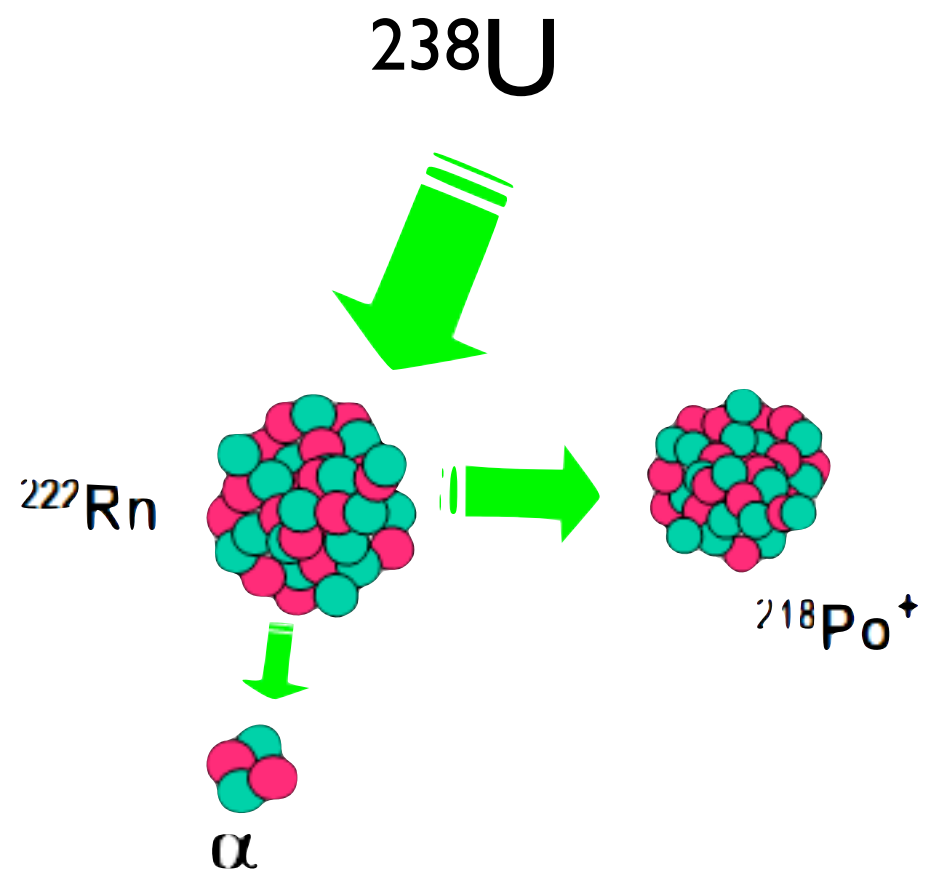


... men det räcker ändå inte

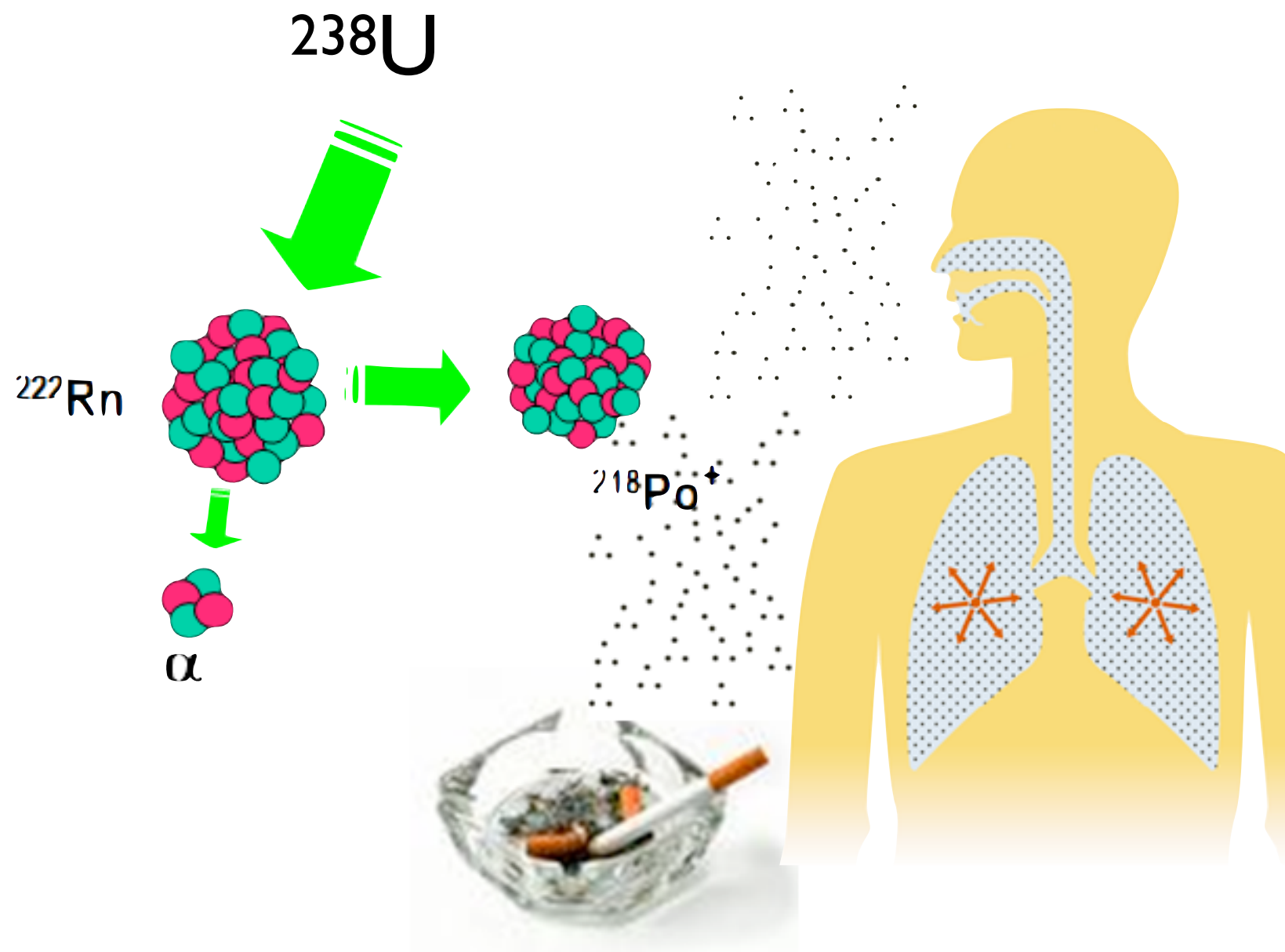


relativt ofarlig

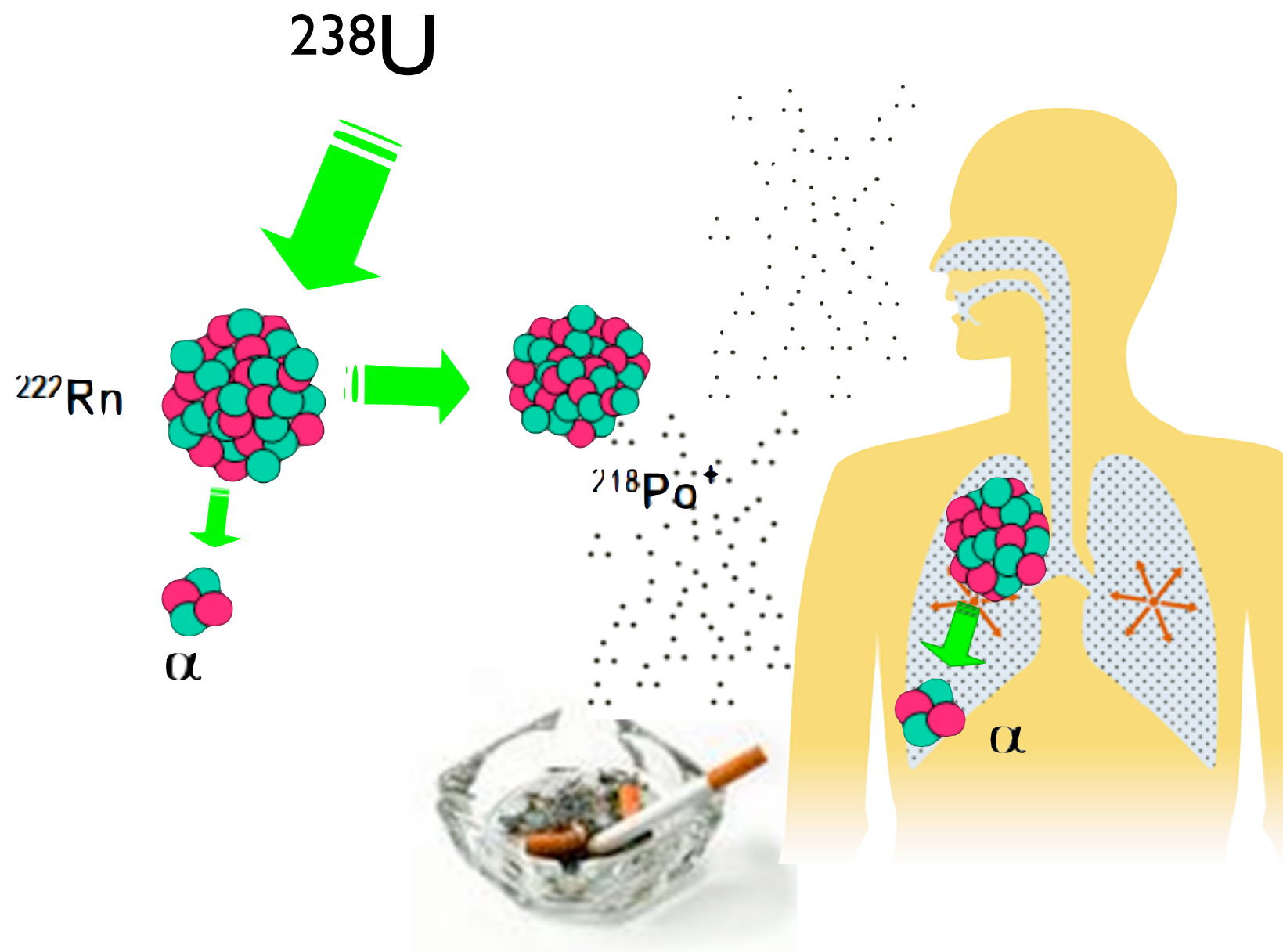
... men det räcker ändå inte



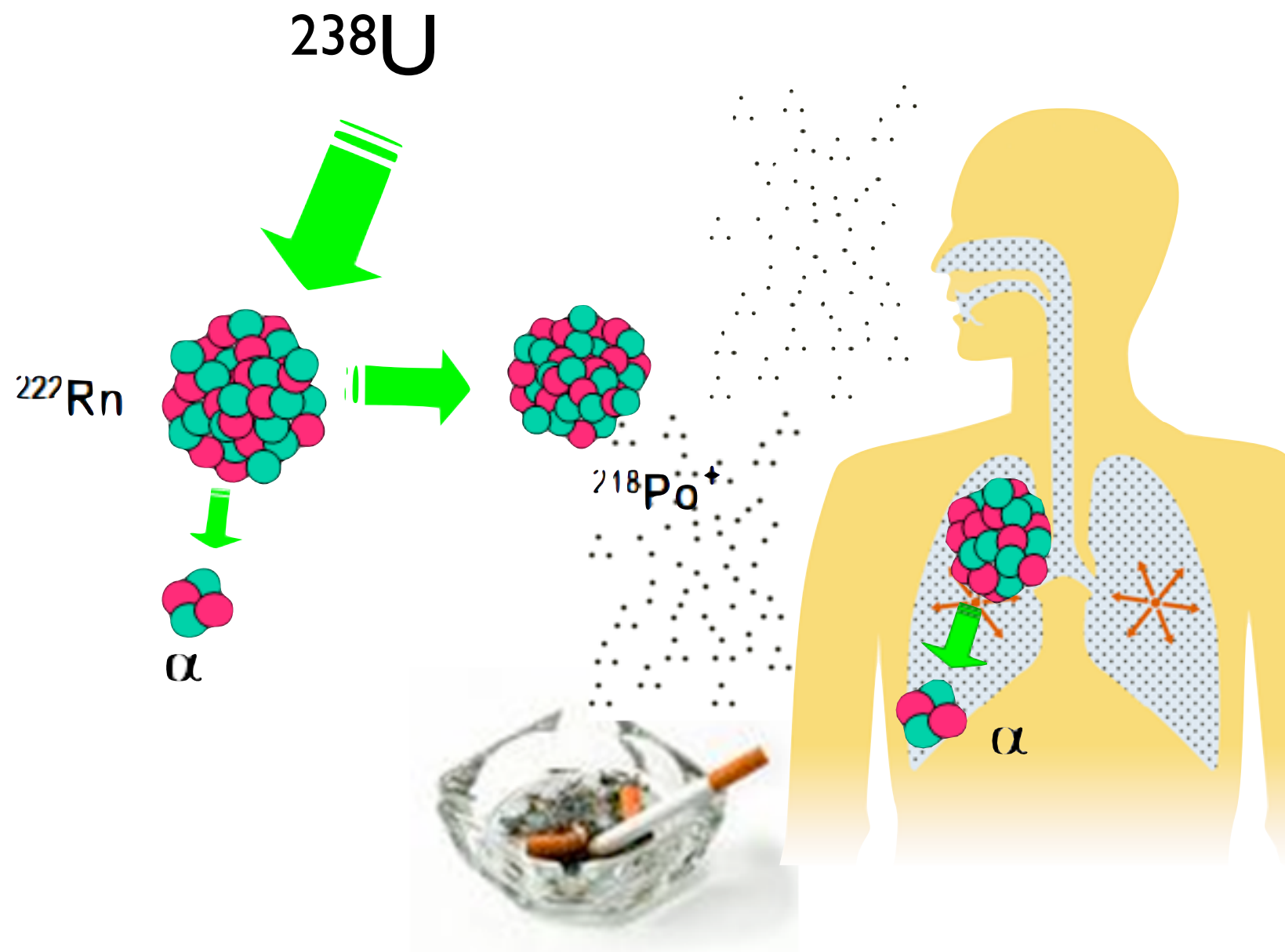
... men det räcker ändå inte



... men det räcker ändå inte



... men det räcker ändå inte



rökare 7 ggr högre sannolikhet lungkancer

Effective dose equivalent:

dose equivalent “viktas” med organfaktor: W_T

From the International Commission on Radiological Protection, ICRP

Organ eller vävnad	W_T
Könskörtlar	0.20
Tjocktarm	0.12
Mage	0.12
Lungor (varav <i>bronchial epithelium</i>)	0.12 (0.08)
Röd benmärg	0.12
Bröst	0.05

Matstrupe	0.05
Urinblåsa	0.05
Lever	0.05
Sköldkörtel	0.05
Benvävnad (yta)	0.01
Hud	0.01
Övrigt	0.05
Summa	1.00

Effective dose equivalent:

dose equivalent “viktas” med organfaktor: W_T

Def: eff. dose equivalent = $W_T * W_R * \text{abs dose}$

From the International Commission on Radiological Protection, ICRP

Organ eller vävnad	W_T
Könskörtlar	0.20
Tjocktarm	0.12
Mage	0.12
Lungor (varav <i>bronchial epithelium</i>)	0.12 (0.08)
Röd benmärg	0.12
Bröst	0.05

Matstrupe	0.05
Urinblåsa	0.05
Lever	0.05
Sköldkörtel	0.05
Benvävnad (yta)	0.01
Hud	0.01
Övrigt	0.05
Summa	1.00

The effective dose equivalent is introduced because:

1. Not all organs react to radiation in the same way

2. Not all countries agreed on using equivalent dose as a standard

3. real measurements of dose are more reliable than estimation based on calculations

4. It's a way of standardising dose measurements

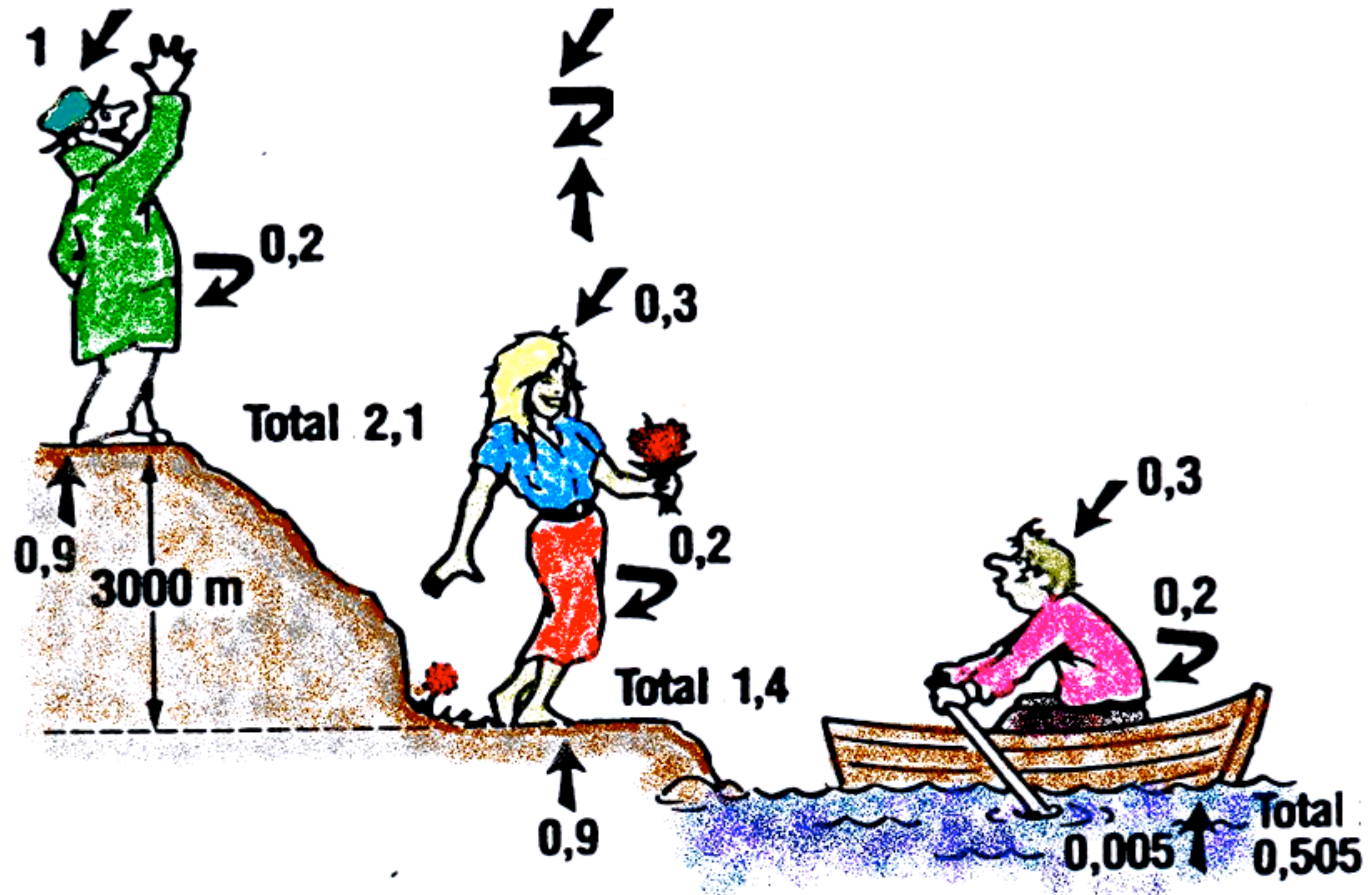
Dosbidrag

- Bakgrundsstrålning
- Medicinska undersökningar
- Yrkesmässig exponering

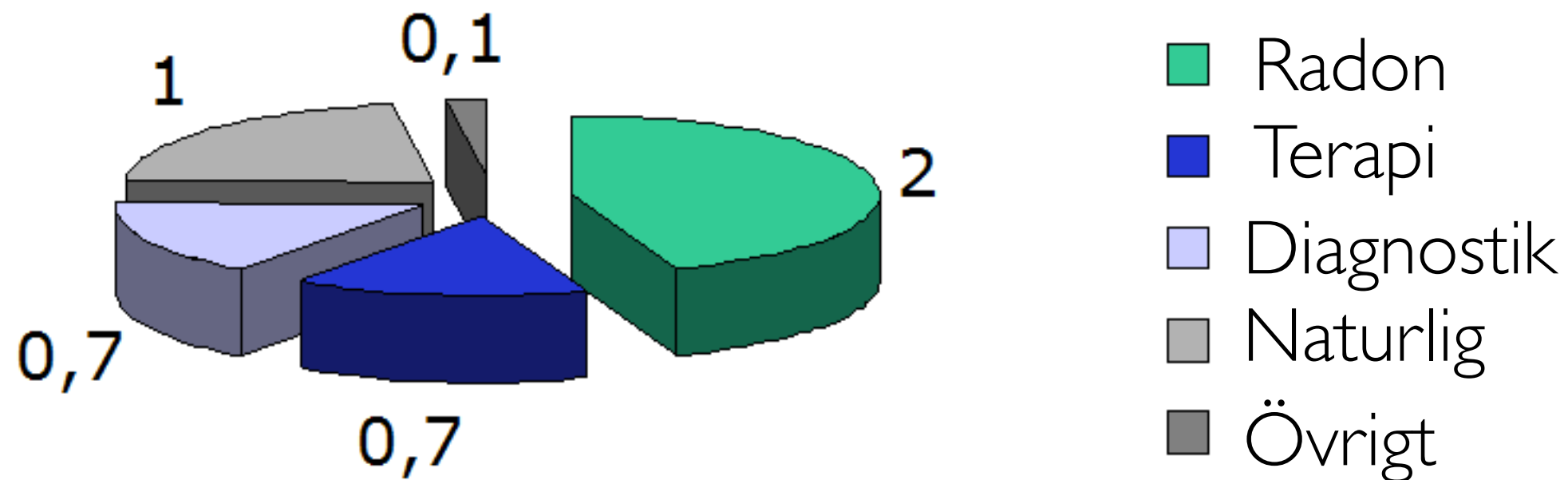
Strålningens biologiska effekt

- Sjukdom
 - Deterministisk
 - Slumpmässig
- Genetisk effekt

Naturliga strålkällor: mSv/år



Genomsnittlig stråldos i Sverige: mSv/år



The largest contribution to average annual dose to the public in Sweden is due to:

1. Imaging with ionising radiation
2. Radon
3. Radiation therapy
4. Oversea flights

Diagnostik

	Undersökning	Effektive dos
Röntgenundersökning	Lungröntgen	0.2 mSv
	Urografi	5 mSv
	Barium kontraströntgen	5 mSv
	Datortomografi huvud	2 mSv
	Datortomografi bröstorg	8 mSv
Fluoroscopi	Huddos	20 mGy/min
	Effektiv dos	1 mSv/min
Nuklearmedicin	Abscess imaging (^{67}Ga 150 MBq)	18 mSv
	Lungventilation ($^{81\text{m}}\text{Kr}$ 6 GBq)	0.1 mSv
	Hjärt- och kärl avbildning ($^{99\text{m}}\text{Tc}$ 800 MBq)	6 mSv
	Njurundersökning (^{123}I 20 MBq)	0.3 mSv

Årsdos för olika yrkeskategorier

Yrke	Effektiv medeldos
Sjukvårdspersonal (röntgen och nuklearmedicin)	1.0 mSv/år
Strålterapi (huvudsak brachyterapi)	2.6 mSv/år
Cardiologer (Angiografi, hjärtkateter)*	16 mSv/år
Flygpersonal	1.7 mSv/år
Kärnkraftspersonal	5.5 mSv/år
Gruvarbetare urangruvor	23 <u>mSv/år</u>

*Personal använder 0.25 mmPb blyförkläde som dämpar >90% av spridd strålning.
Strålning i huvudsak till extremiteter samt huvud och hals

**Maximal årlig stråldos för övervakade yrkesgrupper :
50 mSv**

Biologiska effekter:

Deterministik

Tröskelvärde

- Då tröskelvärdet överskrids ökar den biologiska effekten med dosen
- Inga känd effekt under 50 mSv.
- Cataracts, ögats lins förstörs vid doser över 5 Sv
- Hudrodnad, förlust av benmärgsceller, ...

Statistisk effekt

Inga tröskelvärden

- Inom diagnostisk sjukvård är dosen till patienten liten. Trots detta är det viktigt att minimera användningen av joniserande strålning då mycket stora grupper exponeras.

Risken att drabbas av olika typer av cancer på grund av strålning:

Stochastic biological effects of ionising radiation

Organ	Mortality effect	Death per 1 mSv per million
Thyroid	Cancer	0.8
Red bone marrow	Leukaemia	5
Skin	Cancer	0.2
Bone	Cancer	0.5
Lung	Cancer	8.5
Breast	Cancer	1.5
Esophagus	Cancer	3
Colon	Cancer	8.5
Liver	Cancer	1.5
Stomach	Cancer	11
Bladder	Cancer	3
Ovaries	Cancer	1
Remainder	Cancer	5

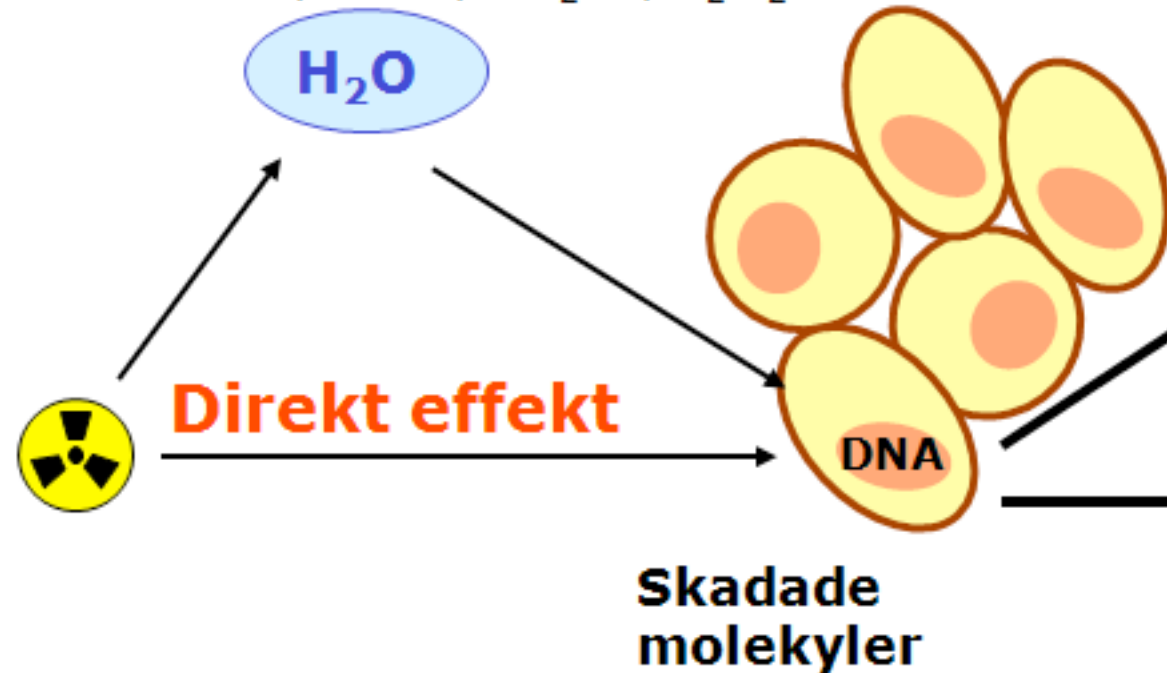
Totalt 50

Strålnings växelverkan med biologisk vävnad

Indirekt effekt

Ionisation och excitation →

Fria radikaler och Hydrogen peroxide $H\bullet$; $OH\bullet$; $HO_2\bullet$; H_2O_2



Fysikaliska konsekvenser ($< \mu s$)

Biologiska konsekvenser (sekunder till årtionden)

Reparation



Mutation



Sjukt organ

Genetisk förändring

Organet slås ut

In order to keep under the max allowed annual dose for the public, which is 6 mSv/year, what should be the dose rate in a room with full occupancy (that is 8h/day 5 days/week)?:

1. 2 mSv/hour
2. 20 μ Sv/hour
3. 2 μ Sv/hour
4. 20 nSv/hour
5. 0