

Beeldvorming met fotonen en protonen voor de planning en verificatie van protonentherapie

Emiel van der Graaf



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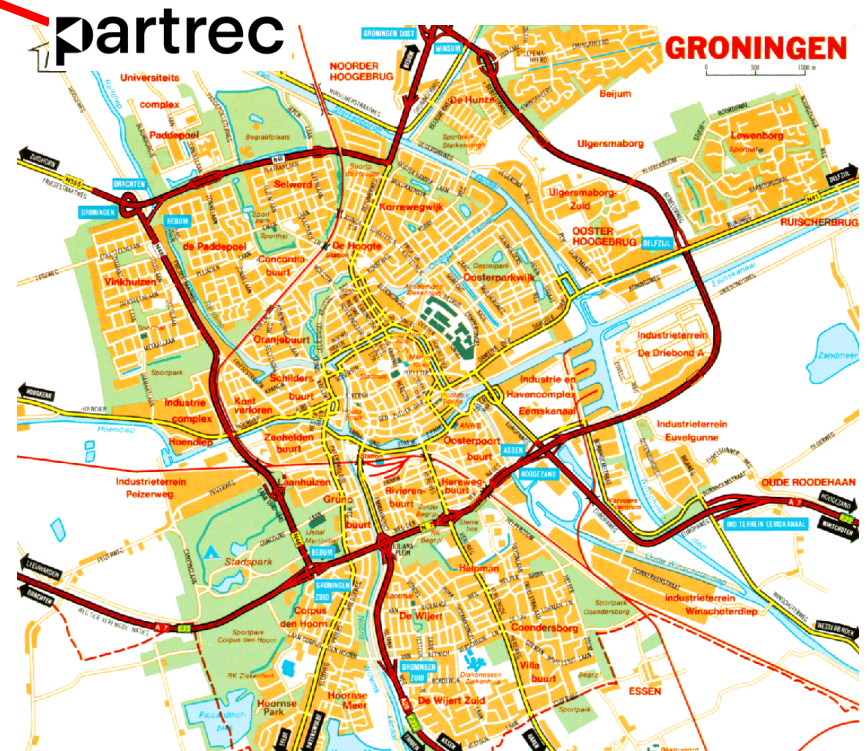


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Wat?

- **PARTREC (PARticle Therapy Research Center)**
- **Protonentherapie**
- **Wisselwerking protonen en fotonen**
- **Beeldvorming met SECT en DECT**
- **Protonradiografie en pCT**
- **Real time imaging met PET**

PARTREC Waar?



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PARTREC Waar?



**Noordzijde Zernikecampus,
Zernikelaan 25**

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Geschiedenis

- 1968 Kernfysisch Versneller Instituut (KVI) begonnen
- 1972 – 1993 Philips cyclotron
- 1985 – 1994 AGOR cyclotron gebouwd IPN Orsay, Frankrijk
(AGOR: Accelérateur Groningen-Orsay)
- 1996 AGOR cyclotron operationeel @ KVI
- 2014-2020 KVI-CART
(CART: Center for Advanced Radiation Technology)
- 2020-nu PARTREC
(PARTREC: PARTicle Therapy REsearch Center)

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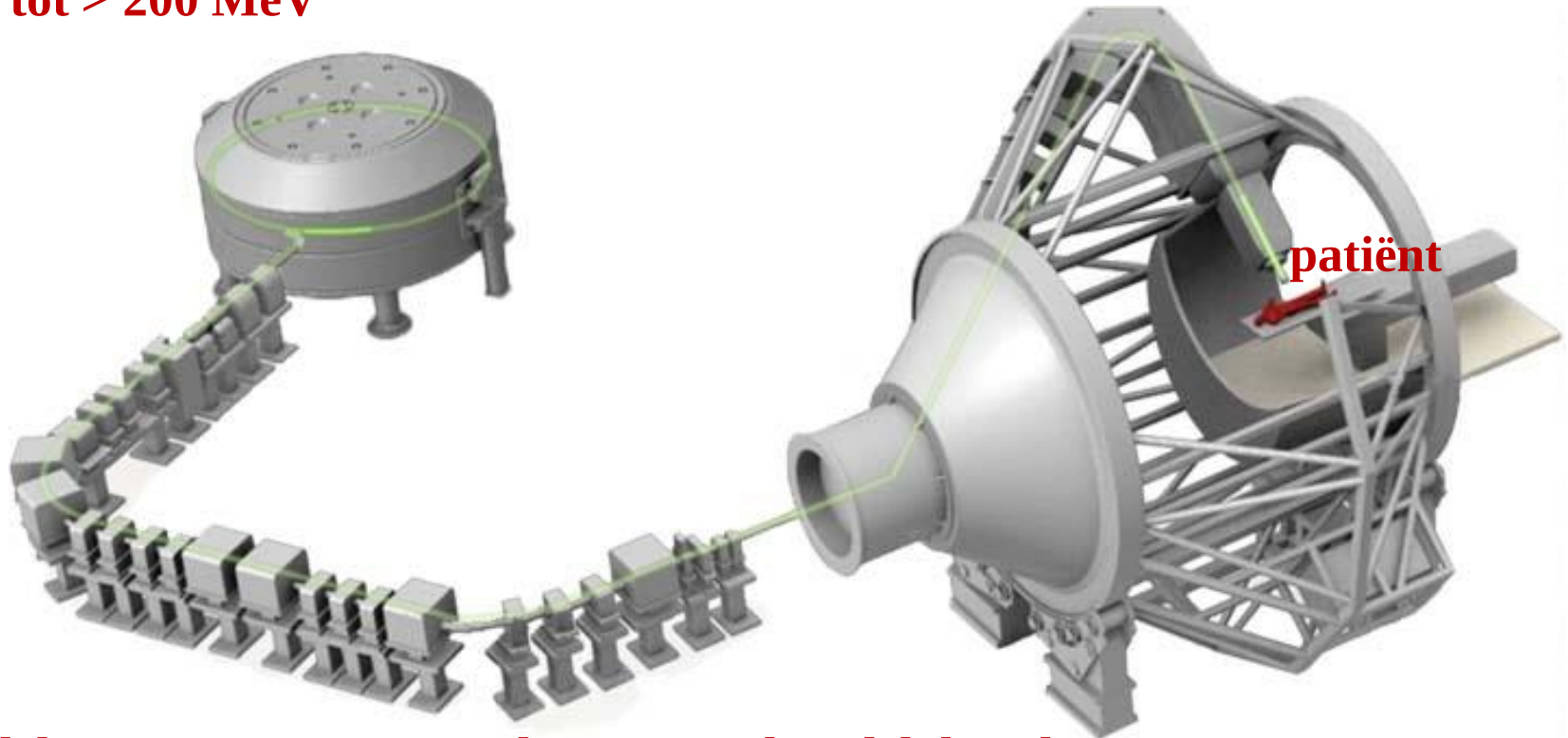


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Protonentherapie

Gantry om de patiënt
van verschillende
kanten te bestralen

cyclotron versnelt protonen
tot $> 200 \text{ MeV}$



elektromagneten sturen de protonenbundel door het vacuüm
van het bundelgeleidingssysteem

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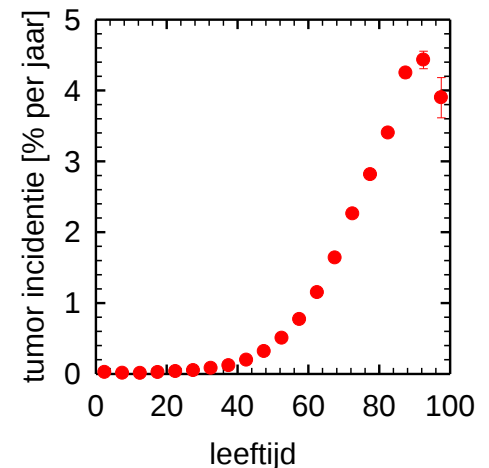
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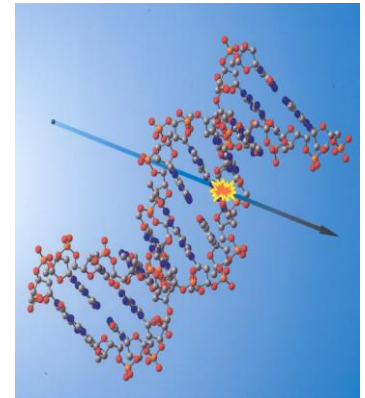
Kanker in Nederland

- **bevolking** ~ 18 miljoen
- **nieuwe tumoren** ~ 120000 per jaar (~ 6 per 1000)
 - totale kans ~ 40 %
 - genezingkans ~ 50-60%
 - kans op herhaling ~ 10 %
- **behandeling**
 - operatief
 - chemotherapie
 - radiotherapie ~ 80.000 per jaar
- **50 % genezen patiënten radiotherapie deel behandeling**



Radiotherapie

- **ioniserende straling veroorzaakt schade/dood cellen**
- **gewenst effect: dood cellen in tumor**
 - hoge stralingsdosis in tumor
- **meebestralen gezond weefsel onvermijdelijk**
 - **bijwerking: schade gezond weefsel**
 - **functieverlies**
 - ademhalingsproblemen
 - speeksel- / slikproblemen
 - onvruchtbaarheid
 - **secundaire tumoren**
 - incubatietijd 10 – 30 jaar dus van belang voor kinderen



courtesy Fresia Alvarado

Radiotherapie

- ~ 85 % bestraling met externe röntgenstralingsbron



- optimalisatie behandelplan
 - maximale dosis tumor: genezing
 - minimale dosis gezond weefsel: complicaties**in veel gevallen beperkende factor**

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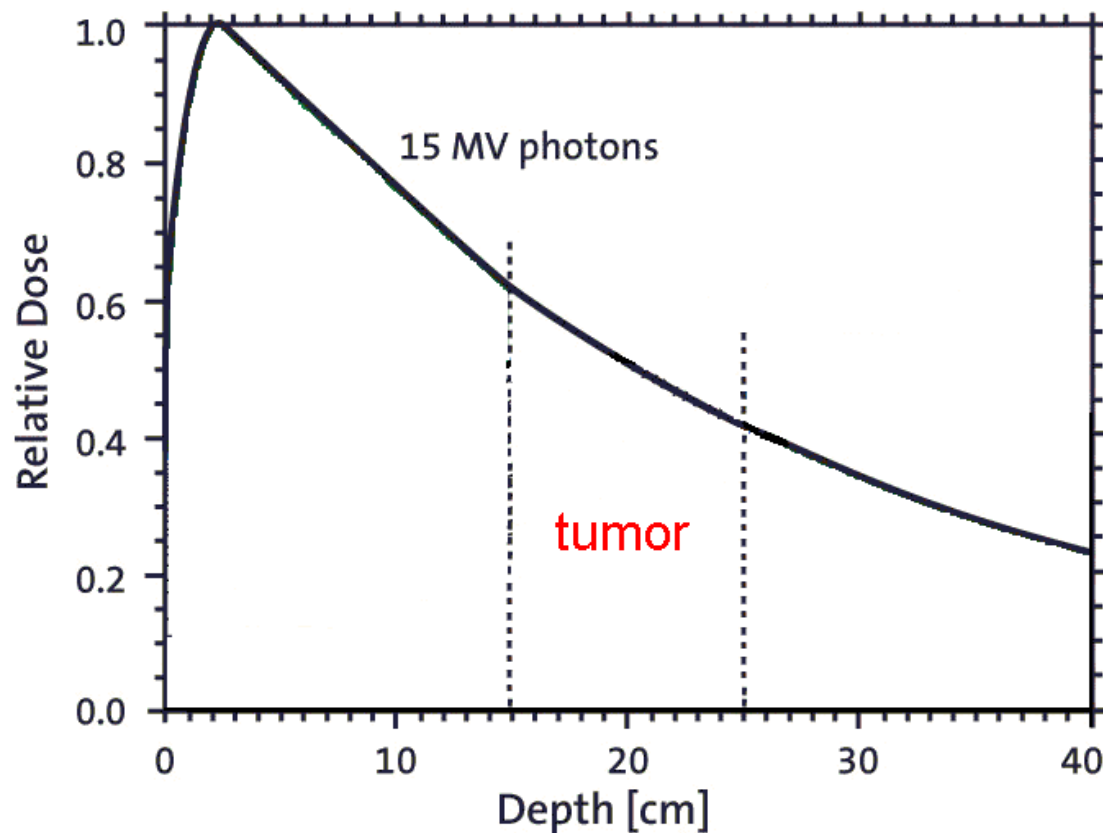
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Motivatie protonentherapie

Dosisafgifte van fotonen



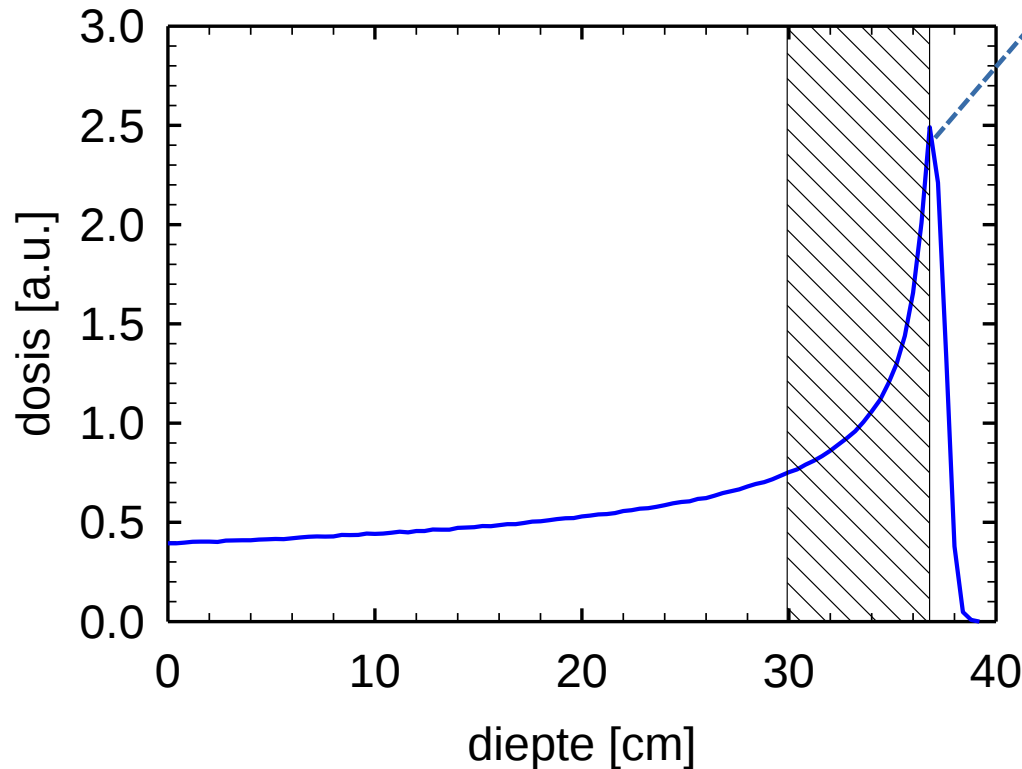
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Dosisafgifte van protonen



Bragg piek

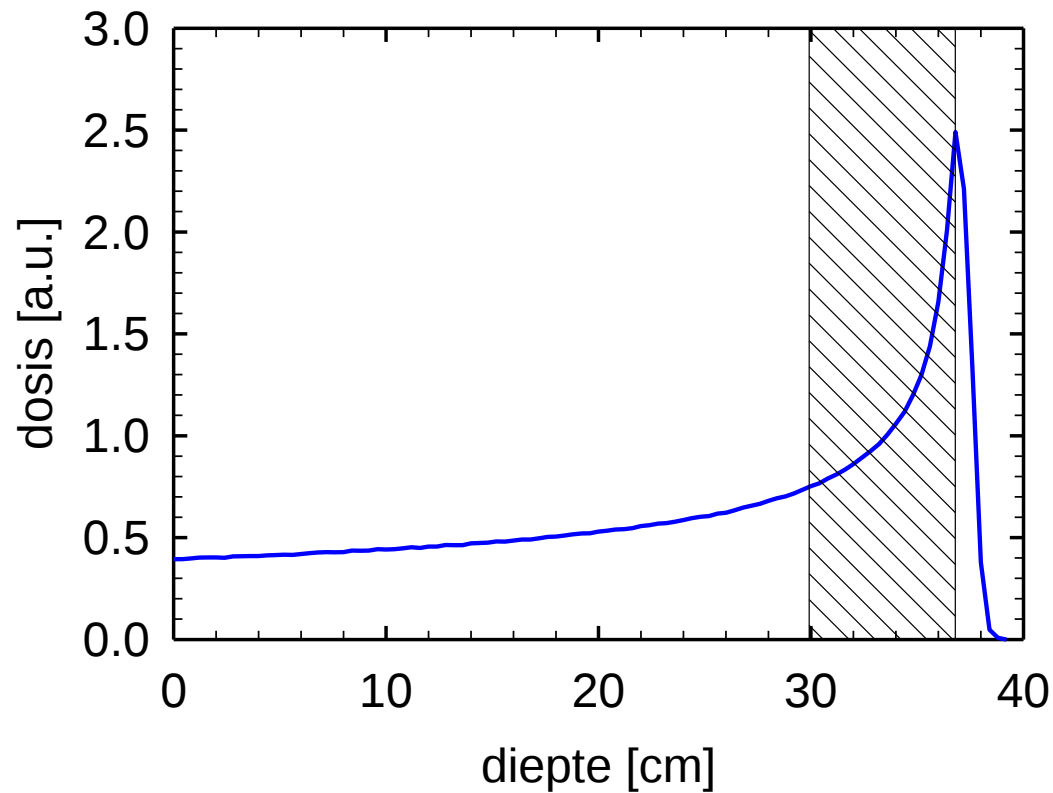
**energie bepaalt
indringdiepte
grootste dosisafgifte
aan het eind
bestralen met
meerdere energieën**

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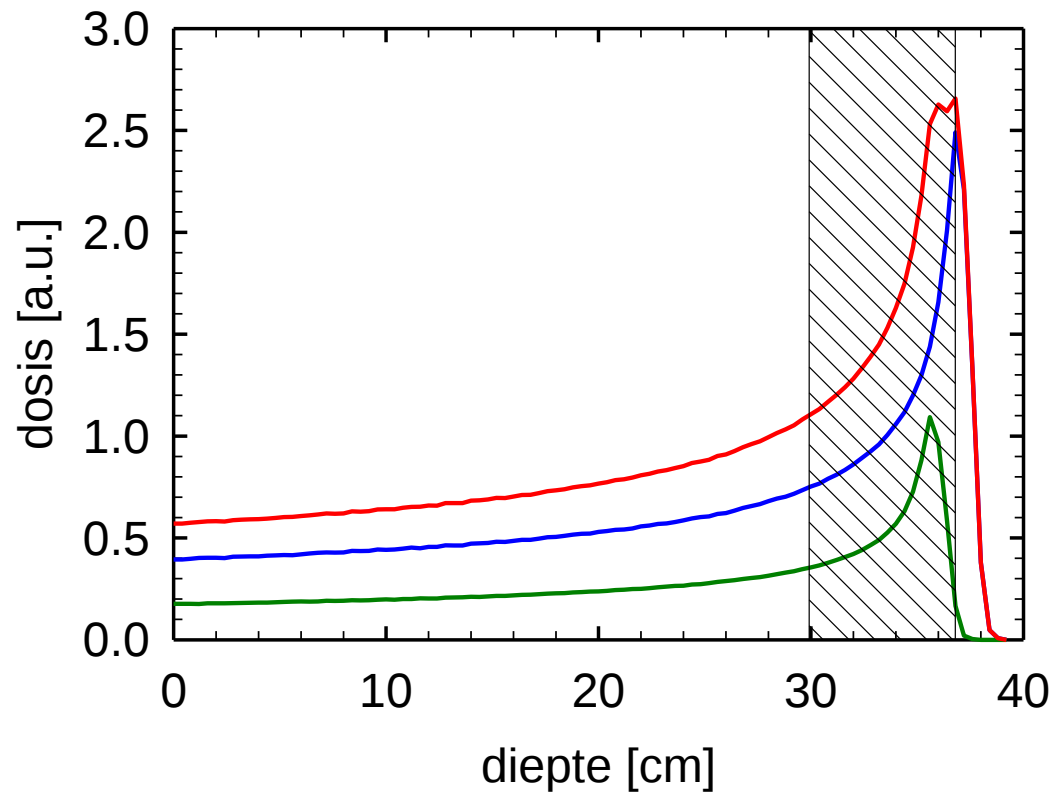


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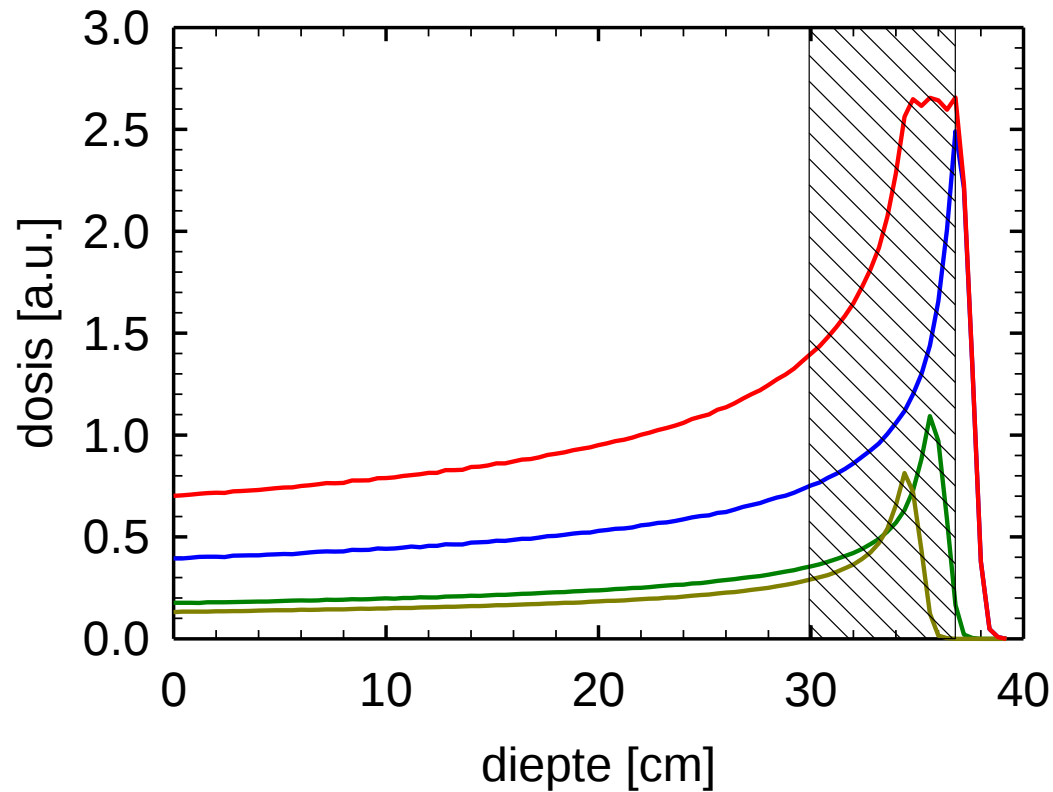


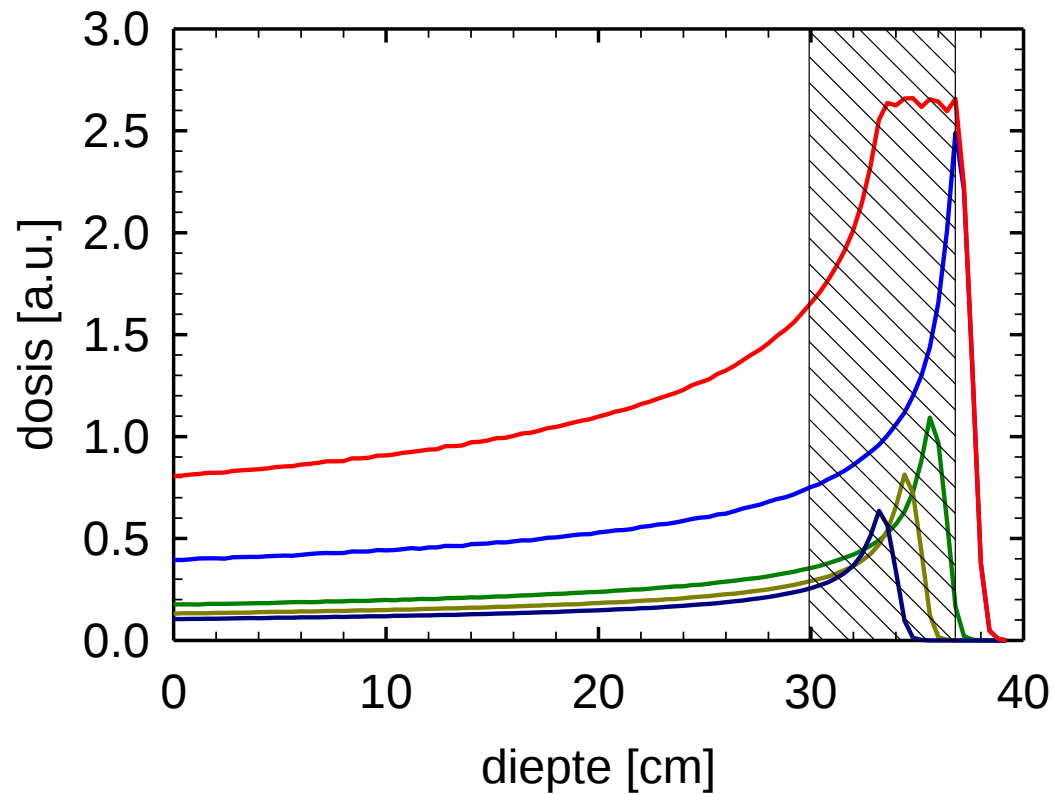
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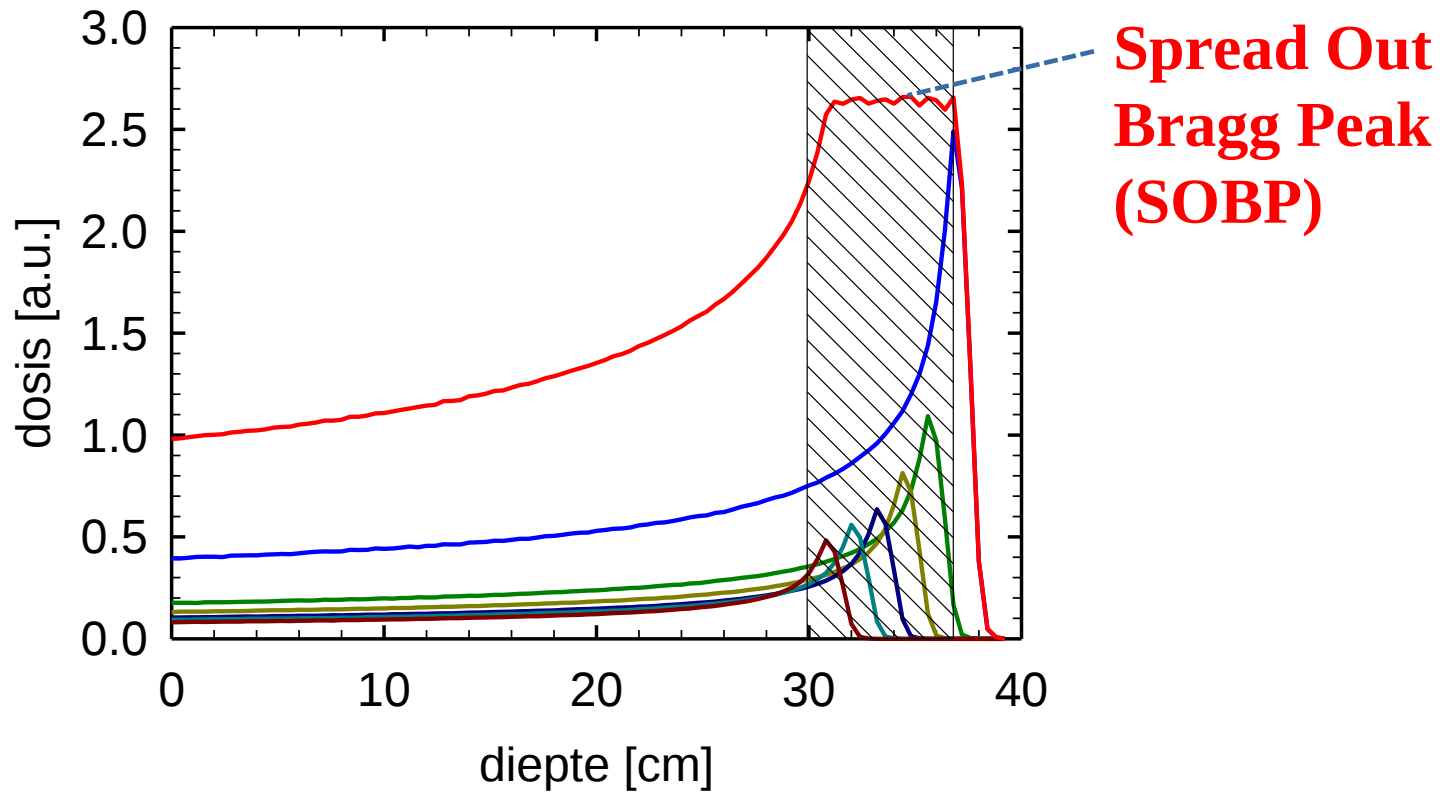


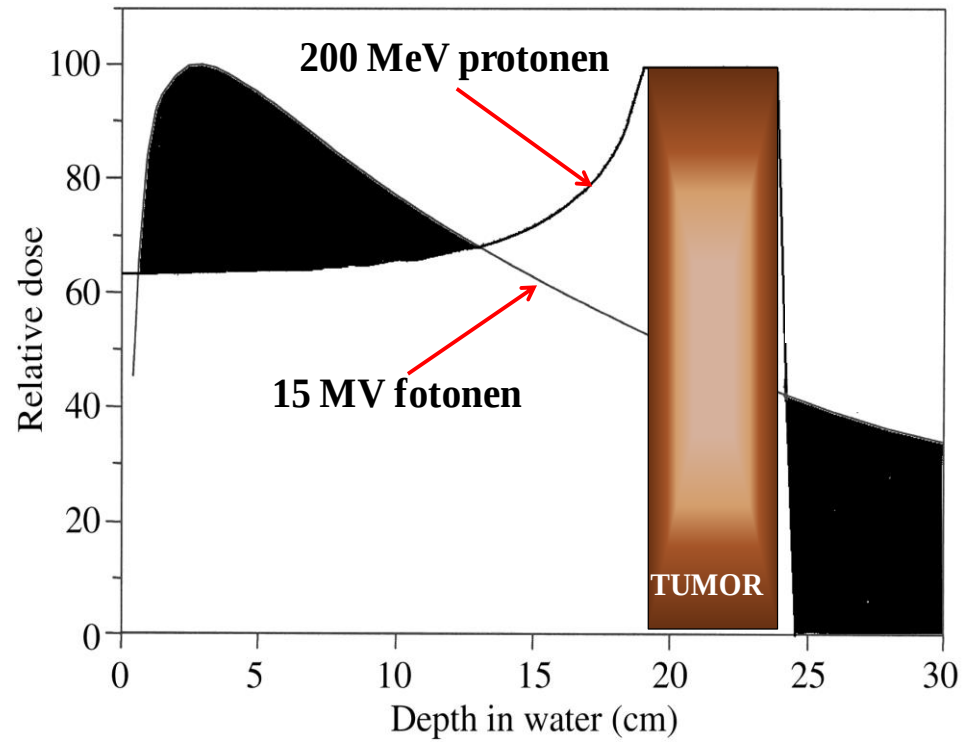
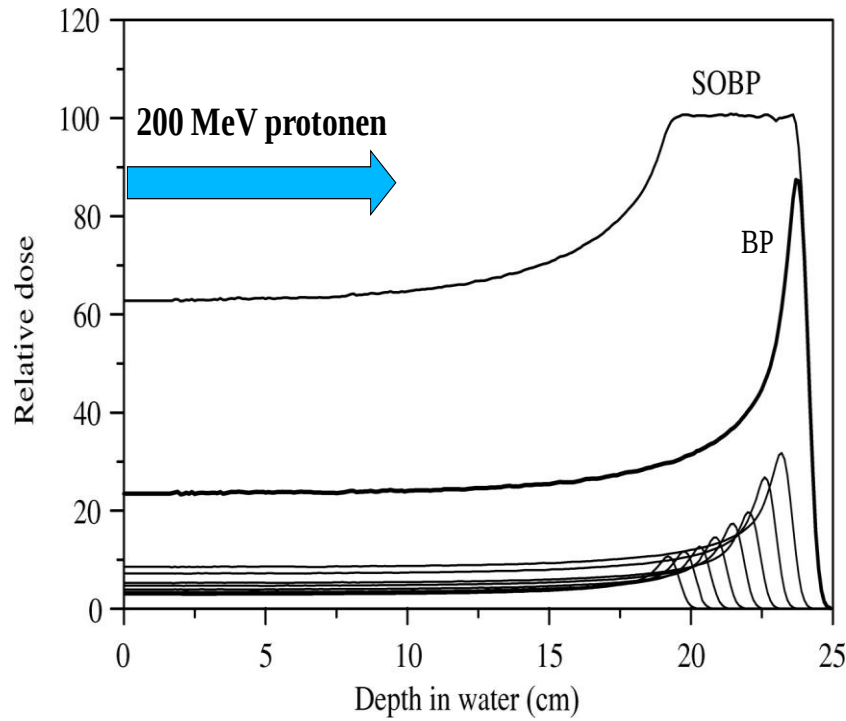
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**Proton geeft zeer lokaal
zijn energie af**



**Betere mogelijkheden om
dosis in tumor te krijgen en
gezond weefsel te sparen**

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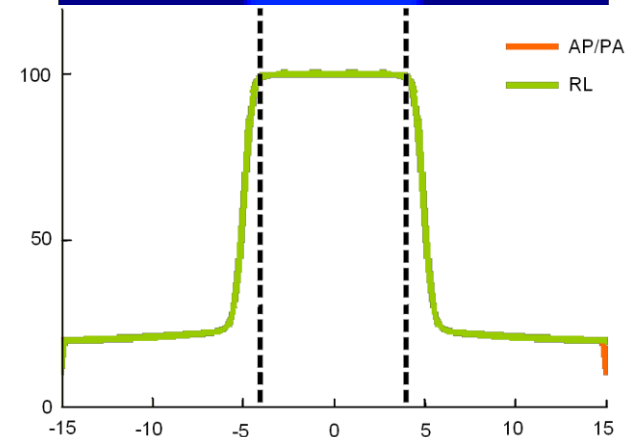
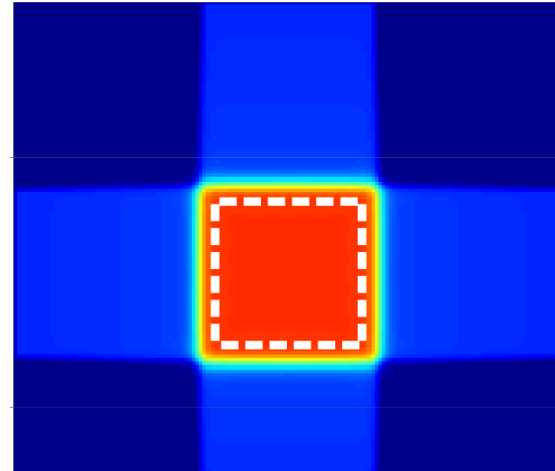
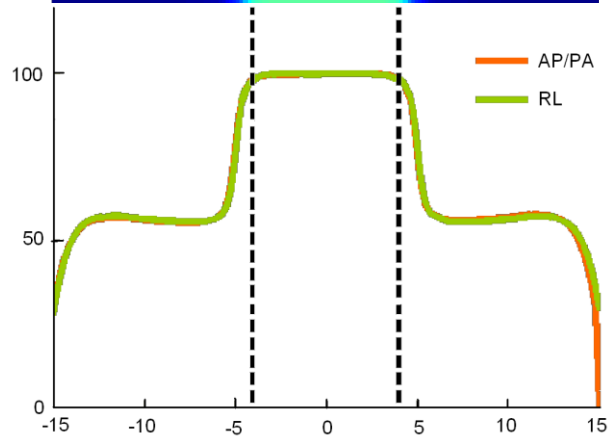
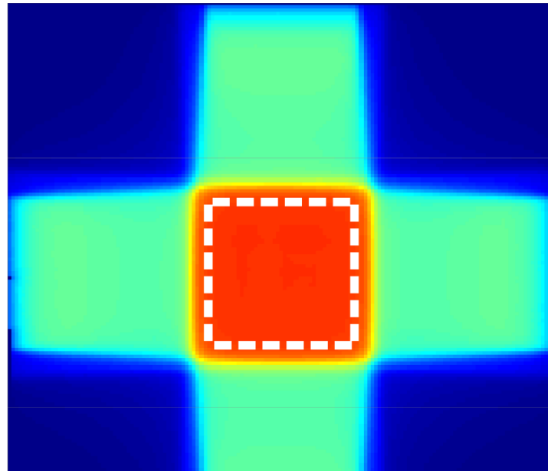
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Fotonen versus protonen

courtesy R. Slopsema, FPTI

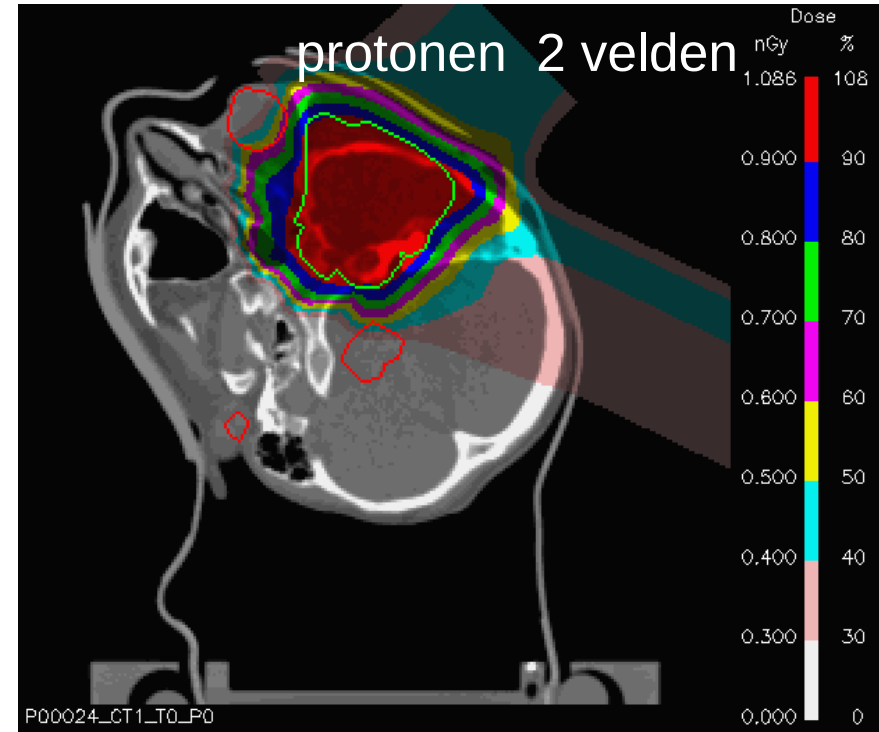
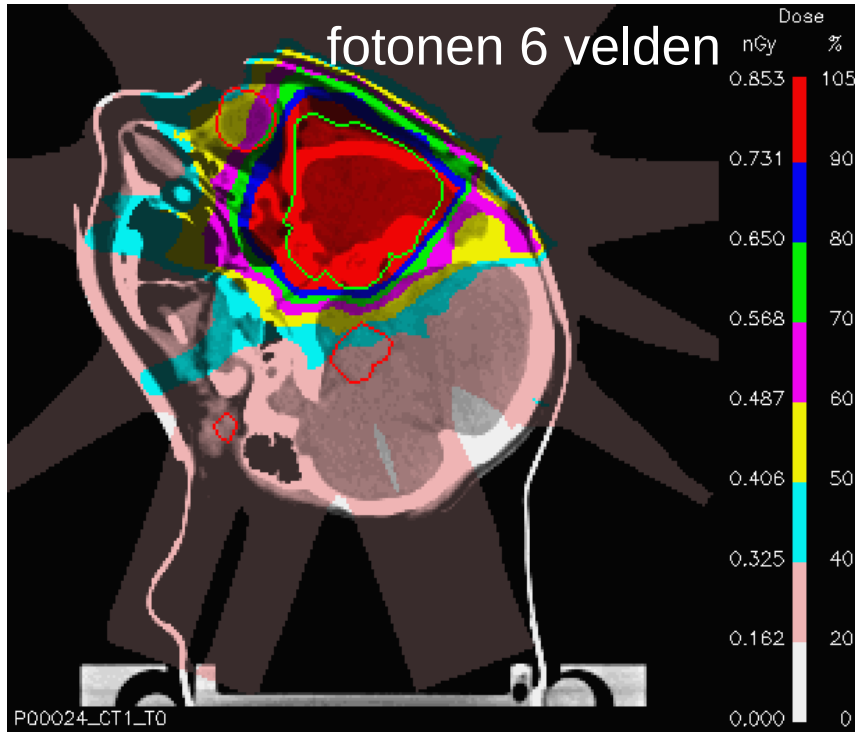


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Protonen: dosis gezond weefsel factor 2 - 3 lager
aanzienlijk verminderde kans op complicaties

Protonentherapie in Nederland

- **Groningen GPTC**
UMCG,
regionale instellingen
- **Holland PTC**
TU Delft, Erasmus
MC,
Leiden UMC
- **Maastricht/Aachen**
MUMC+, MaastRO,
UKA, RWTH



vergund: 600+600+400
patienten per jaar

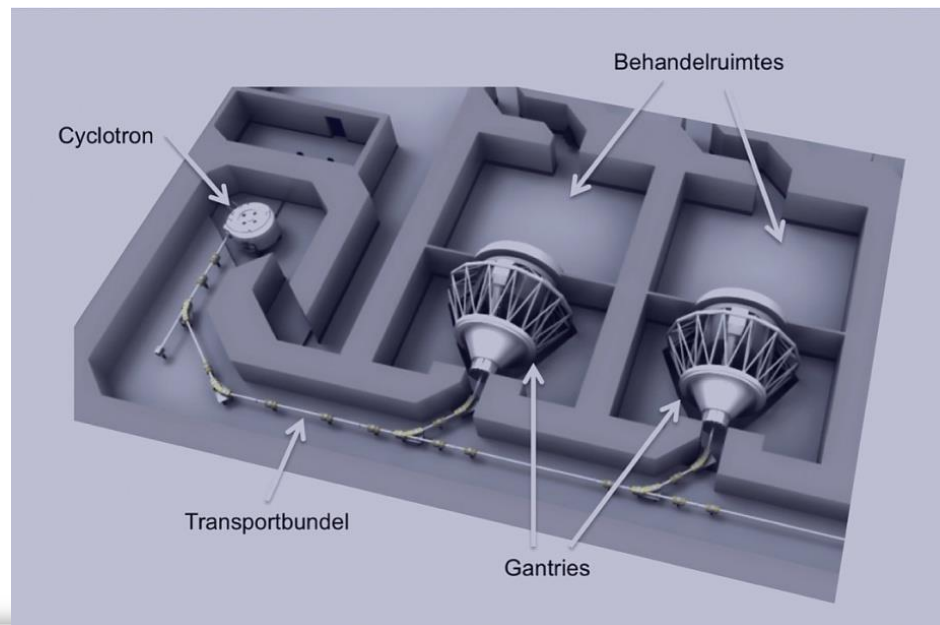
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Groningen Proton Therapy Center



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Particle Therapy Research Center



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PARTREC is a dedicated research facility functioning in synergy with the UMCG Groningen Proton Therapy Center (GPTC).

We uniquely combine technological development, preclinical and patient studies with an R&D program **to continuously improve proton therapy technology and the treatment itself, while assessing the feasibility of other particles for high precision radiotherapy.**

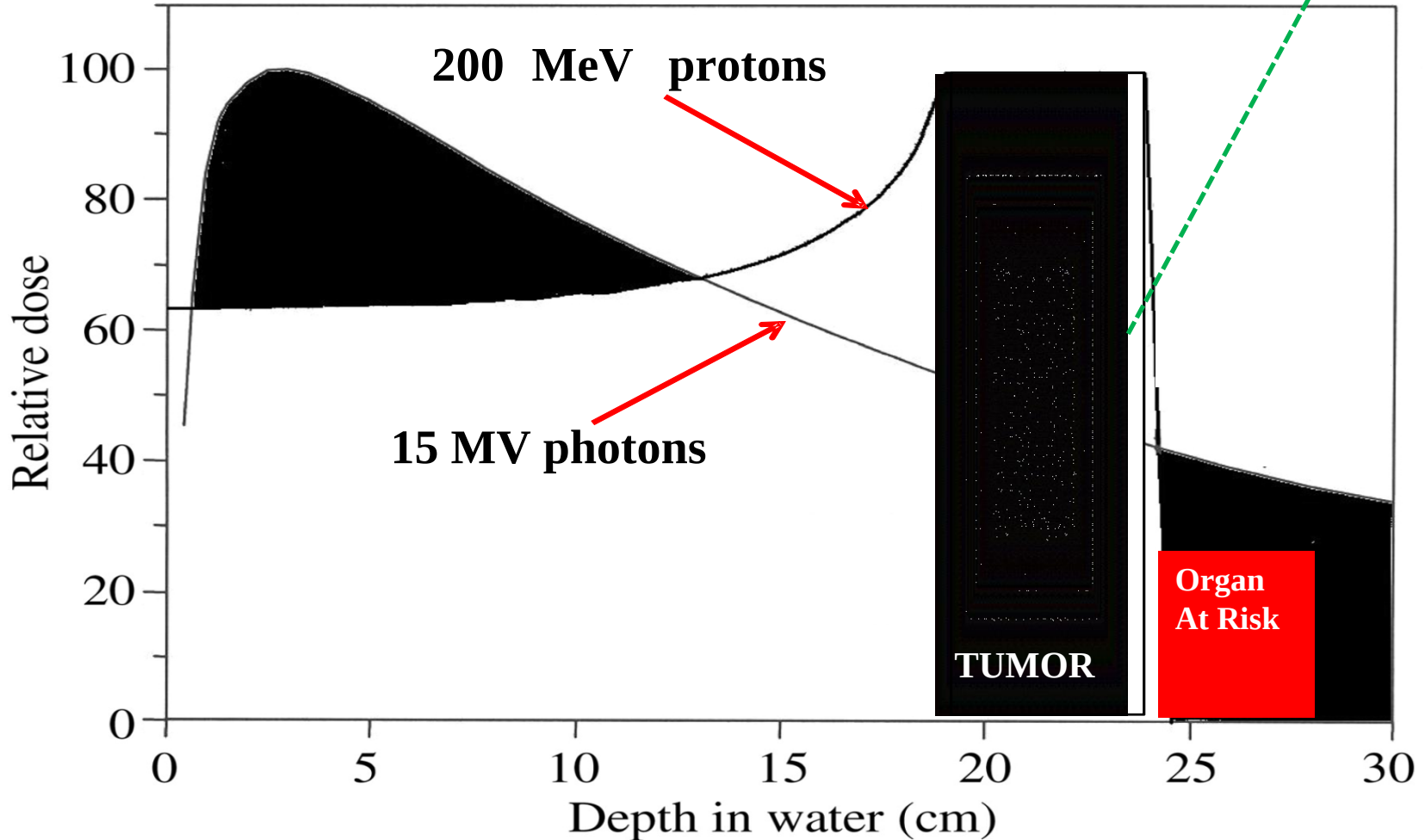
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Precisie is belangrijk! Hoge dosis in gezond weefsel



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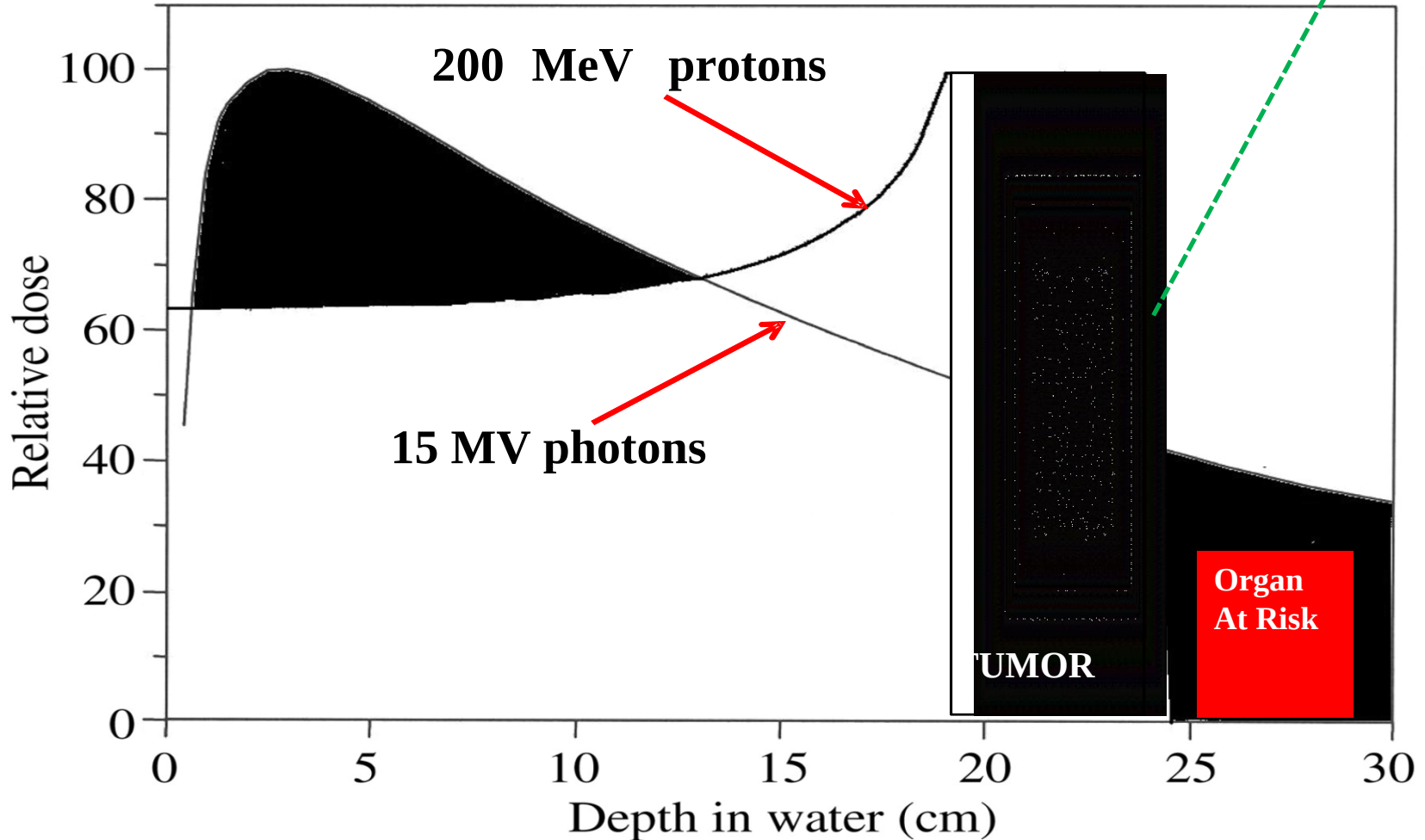
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Precisie is belangrijk!

Geen dosis in de tumor



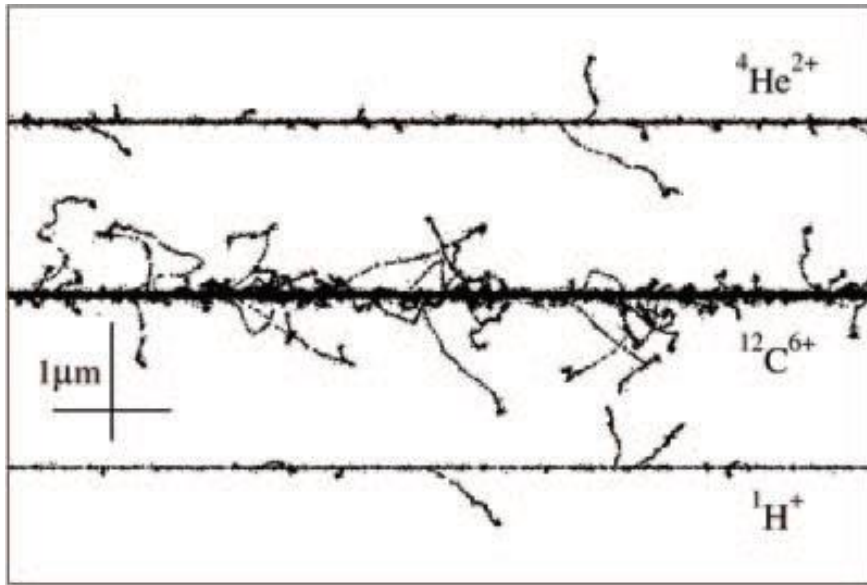
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Wisselwerking protonen en materie



electronen
dichtheid ρ_e

excitatie-energie
 I , functie van
effectieve atoom
nummer van de
materie Z'

Stopping power (energieverlies)

$$S = -\frac{dE}{dx} = \left(\frac{e}{4\pi\epsilon_0}\right)^2 \left(\frac{4\pi e^2 \rho_e}{mc^2 \beta^2}\right) \left[\ln \left(\frac{2mc^2 \beta^2}{I(Z)(1 - \beta^2)} \right) - \beta^2 \right]$$

Bethe Bloch relatie

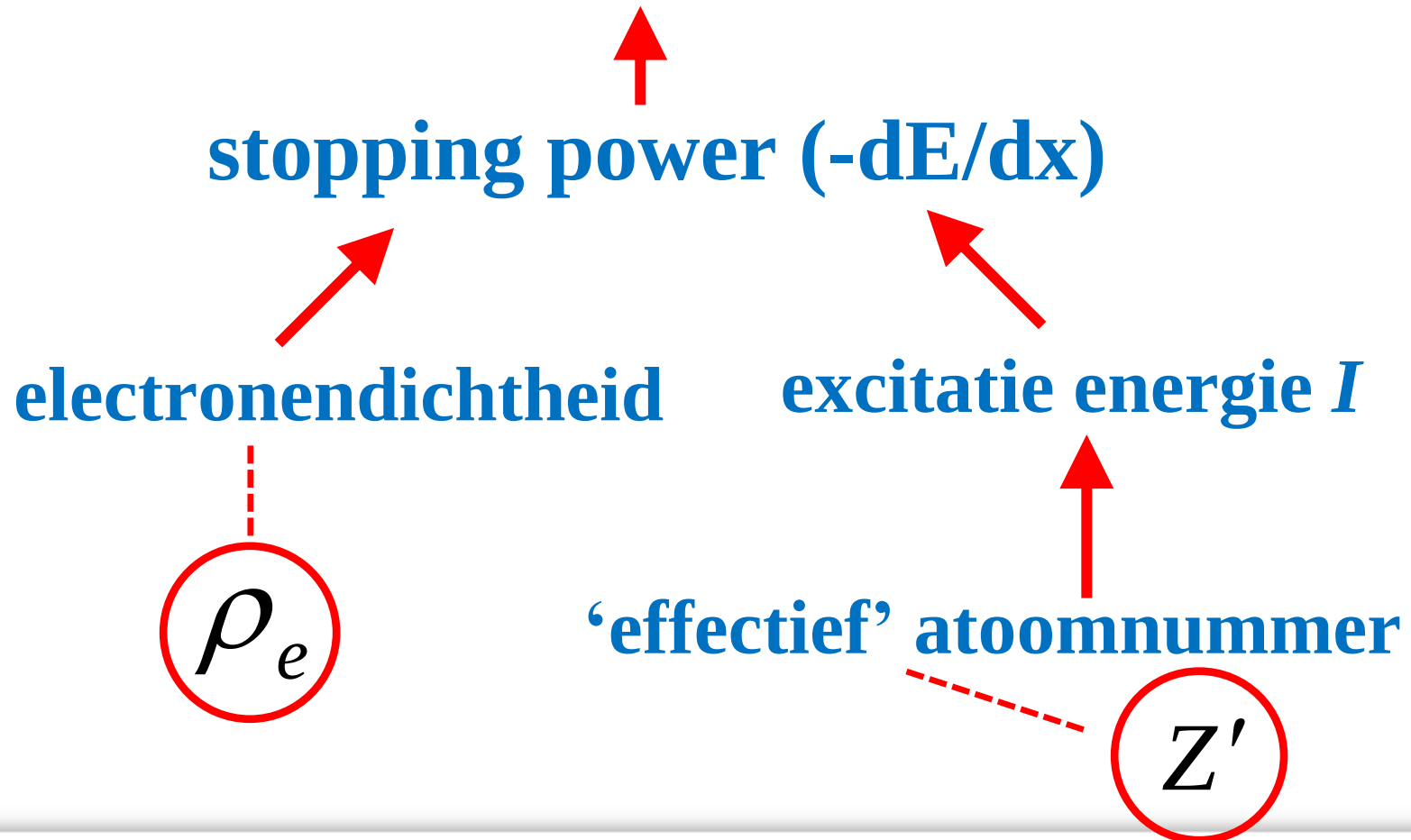
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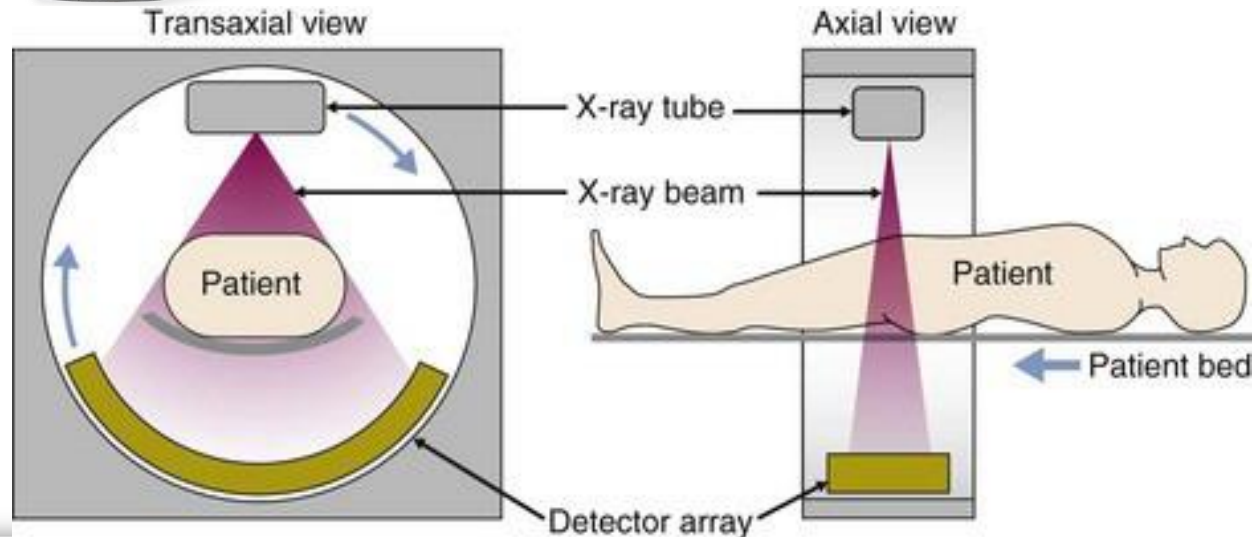
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Informatie die we nodig hebben dracht van proton



Informatie die we hebben is via fotonen

Computed Tomography (CT) met röntgenstraling



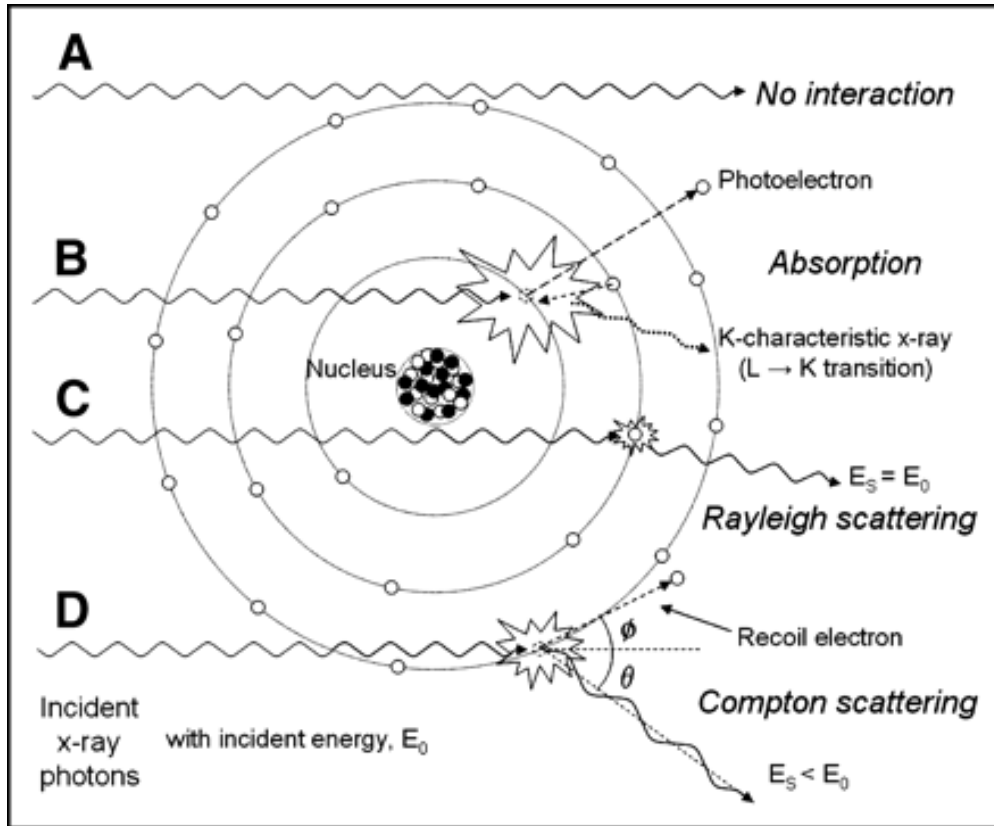
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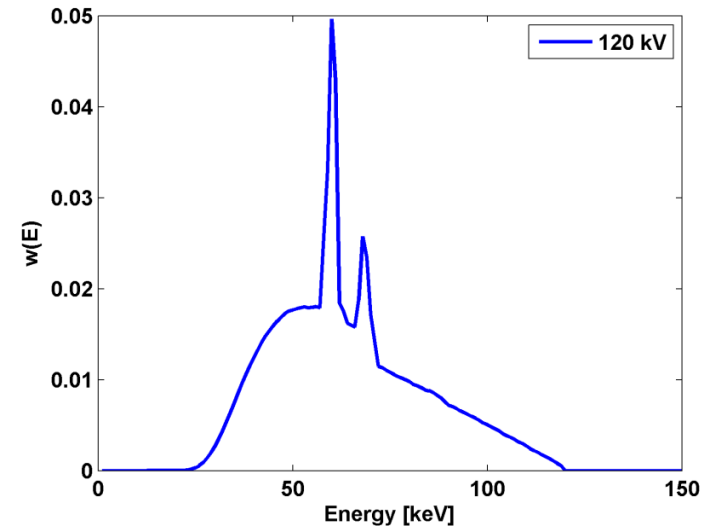


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Wisselwerking fotonen en materie



röntgenspectrum CT



- fotoelectrisch effect
- compton verstrooing
- coherente verstrooing

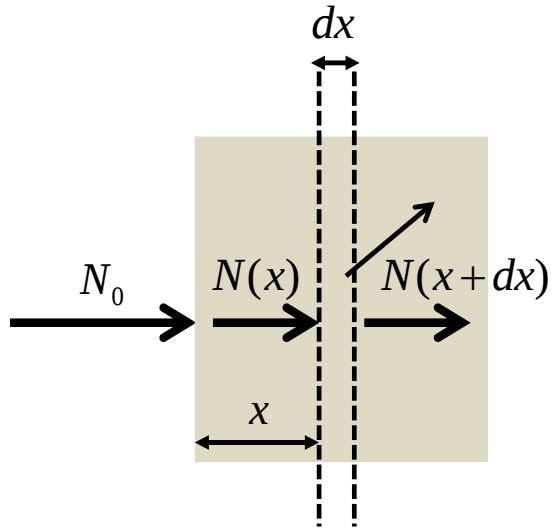
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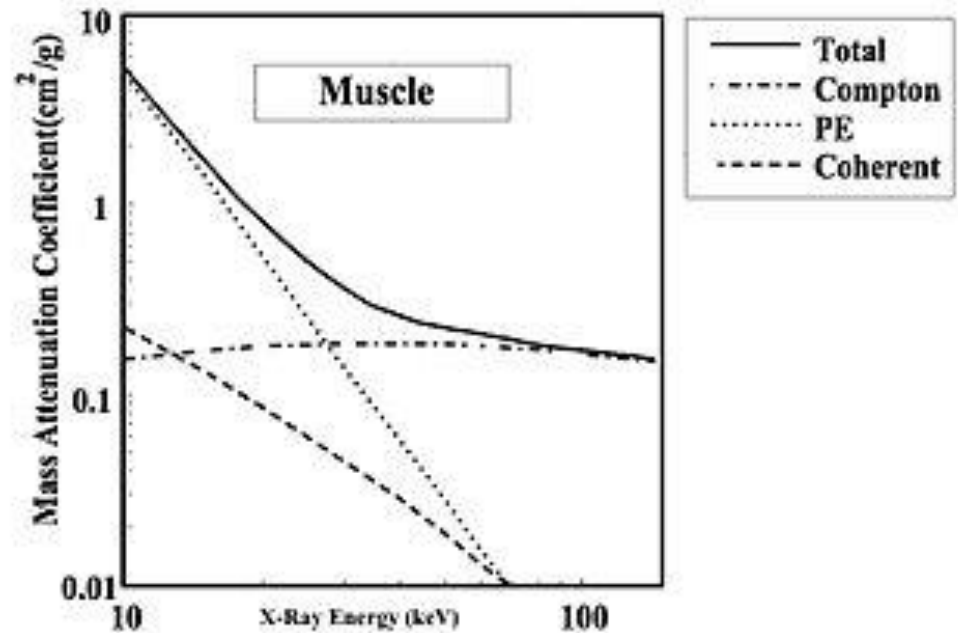
Wisselwerking fotonen en materie



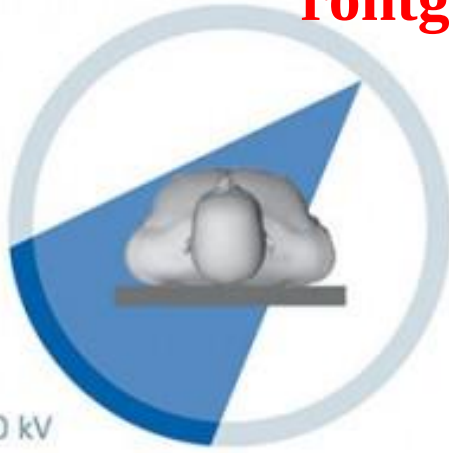
$$N(x) = N_0 e^{-\mu x}$$

verzwakkingscoëfficiënt

$$\mu(E) = \rho_e \sigma_e(E, Z)$$



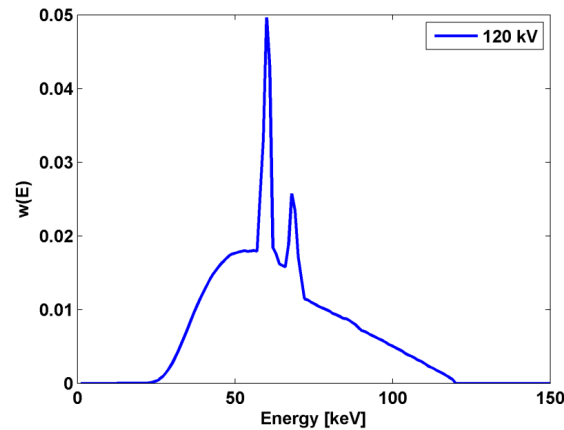
<http://www.dsct.com/>



röntgenbuis

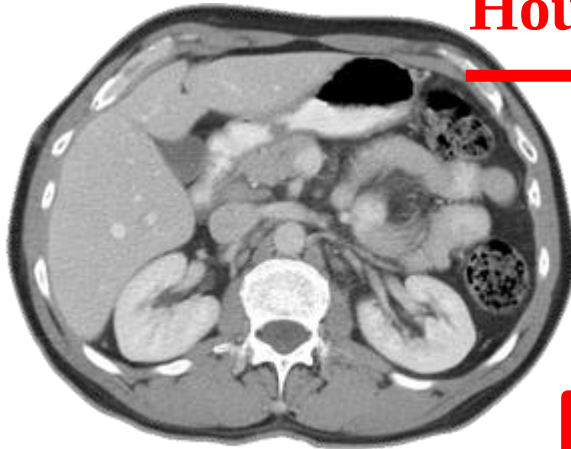
120 kV

detectoren



Single Energy CT (SECT)

<http://www.fda.gov/>



Hounsfield Units

$$HU = \frac{\mu - \mu_{H_2O}}{\mu_{H_2O}} \cdot 1000$$

$$\mu(E) = \rho_e \sigma_e(E, Z)$$

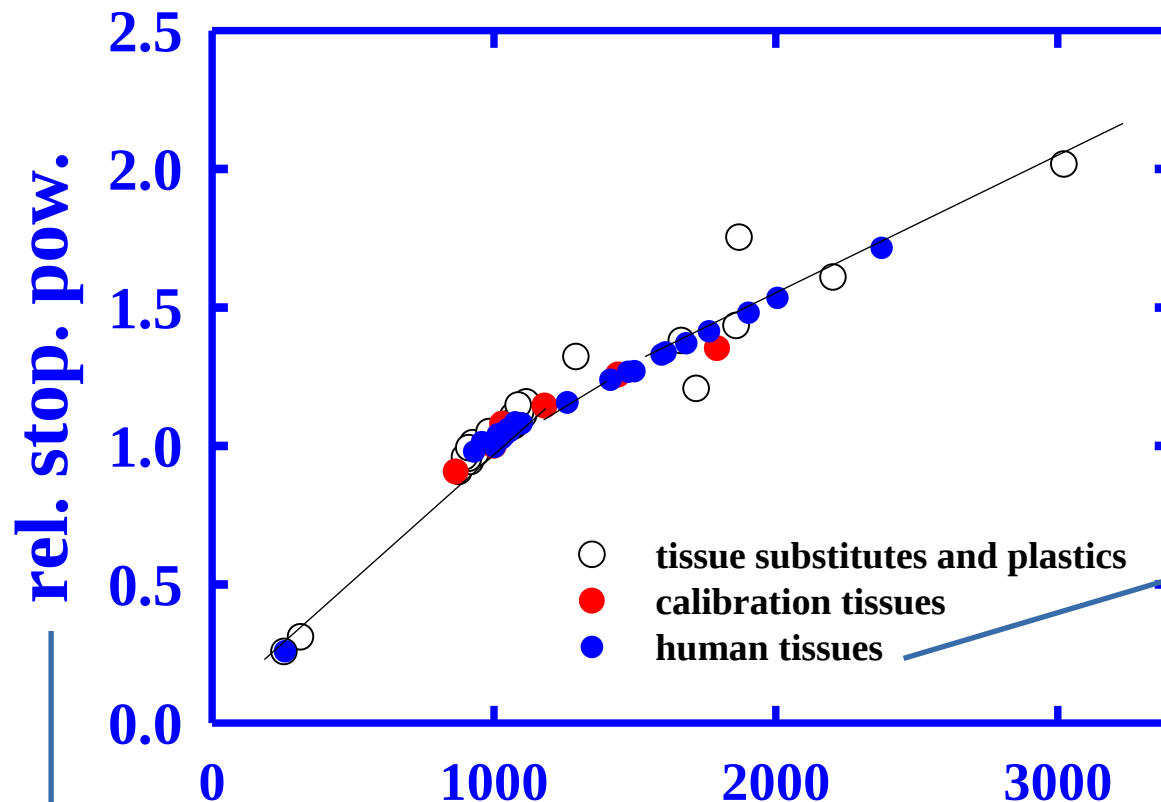
1 vergelijking; 2 onbekenden!

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**SECT
stopping
powers**

**data van
menselijke
weefsels**

ten opzichte van water

H

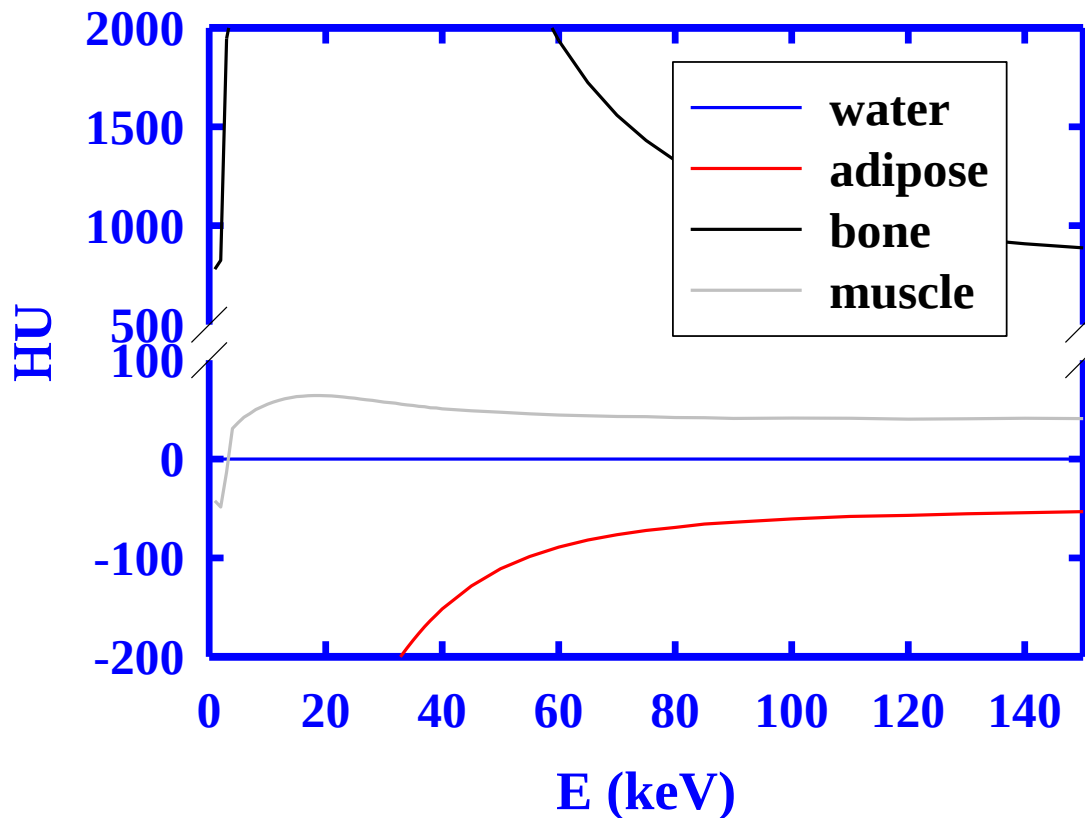
$$H = HU + 1000$$

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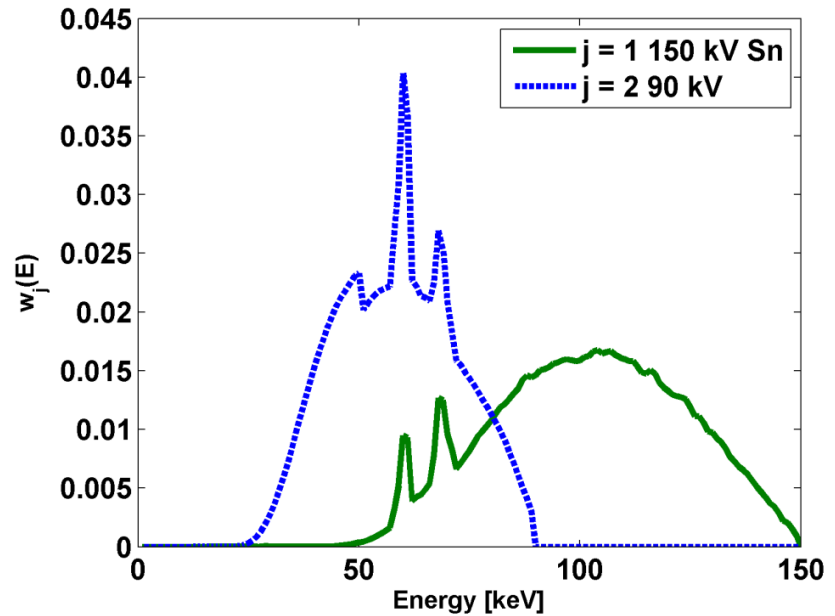


HU's zijn energieafhankelijk dit kunnen we gebruiken voor extra informatie

Dual Energy CT (DECT)



www.healthcare.siemens.com



$$HU(90\text{kV}) \Rightarrow \mu(90\text{kV})$$

$$HU(150\text{kV Sn}) \Rightarrow \mu(150\text{kV Sn})$$

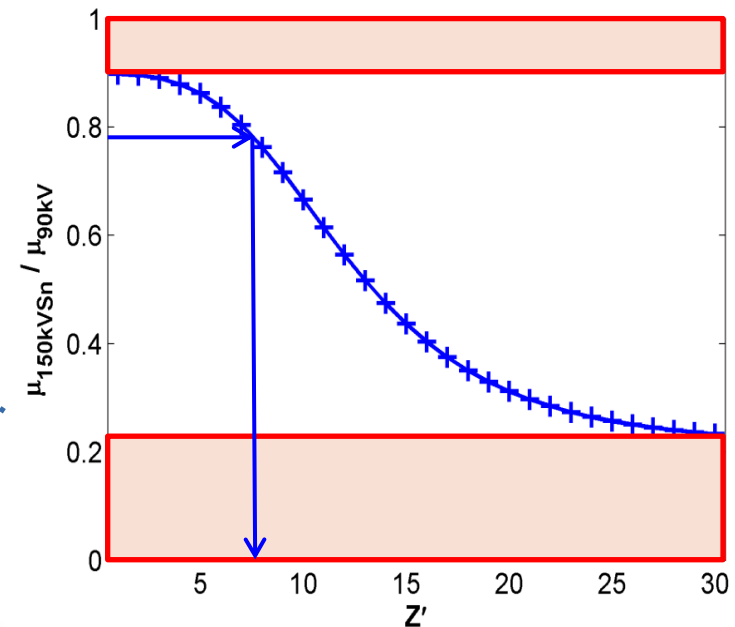
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$$\frac{\mu(90)}{\mu(150)} = \frac{\cancel{\rho_e} \sigma_e(90, Z')}{\cancel{\rho_e} \sigma_e(150, Z')} \Bigg\} Z' \longrightarrow \rho_e$$



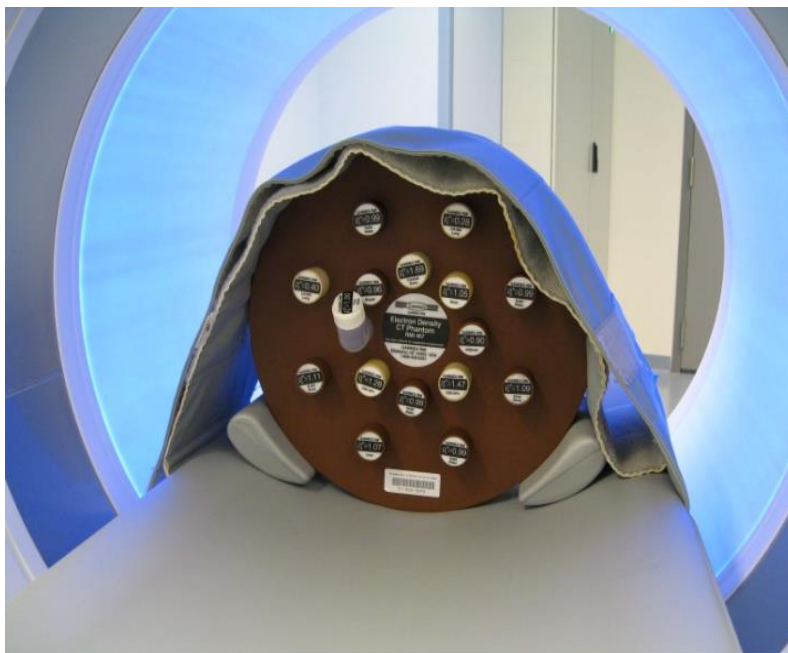
Van Abbema, J.K. et al (2015), Phys. Med. Biol. 60, 3825

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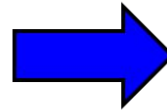
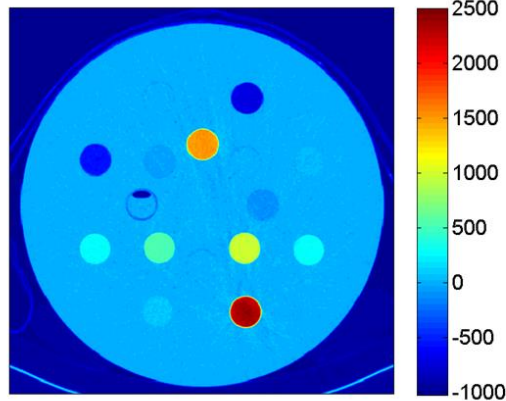
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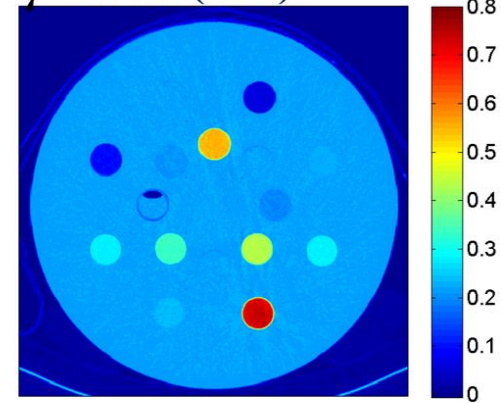


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HU 90 kV

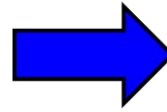
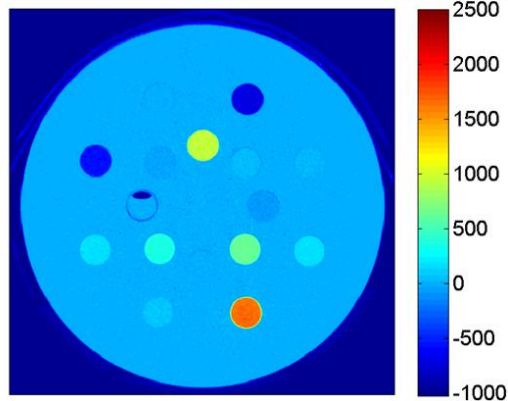


μ 90 kV (cm⁻¹)

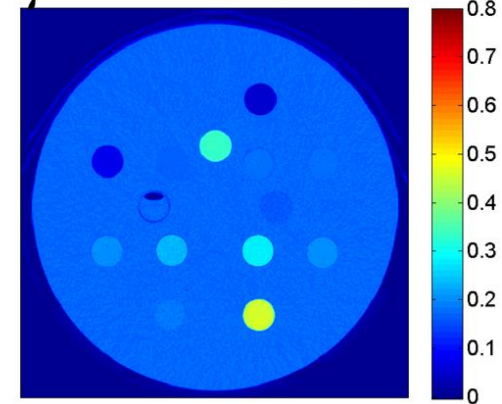


$$HU = \frac{\mu_m - \mu_{H_2O}}{\mu_{H_2O}} \cdot 1000$$

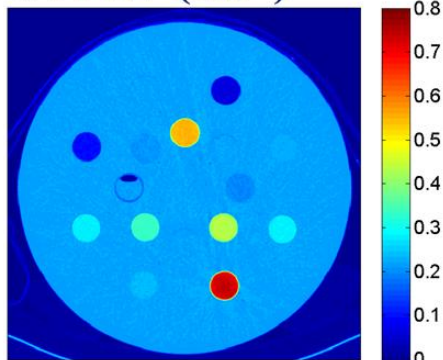
HU 150 kV Sn



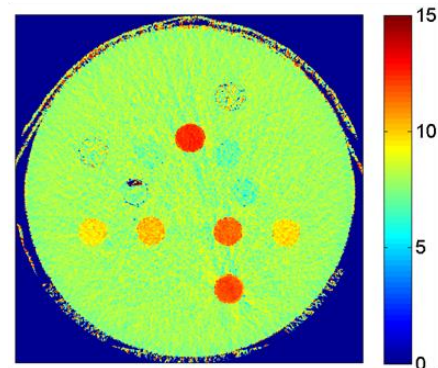
μ 150 kV Sn (cm⁻¹)



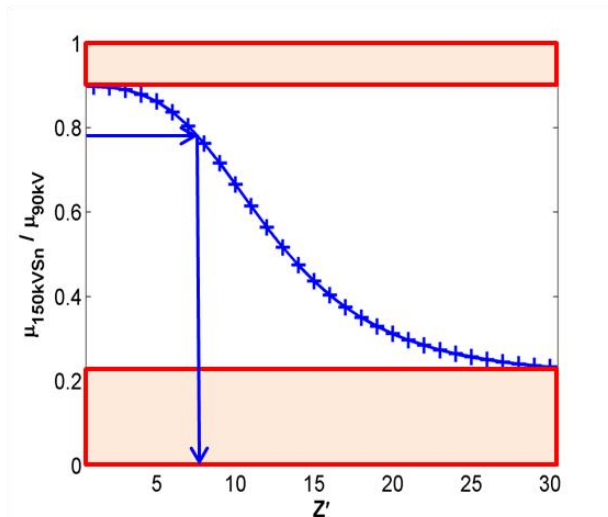
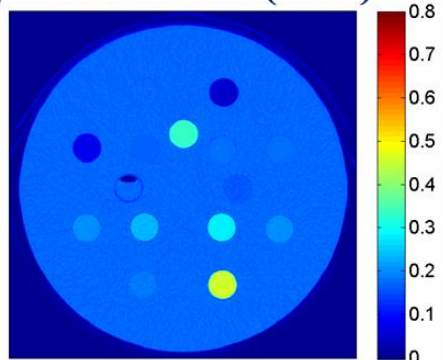
μ 90 kV (cm⁻¹)



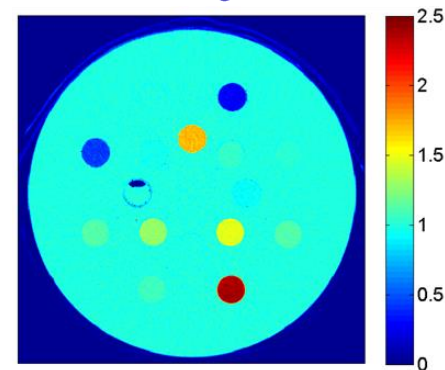
Z'



μ 150 kV Sn (cm⁻¹)



ρ_e

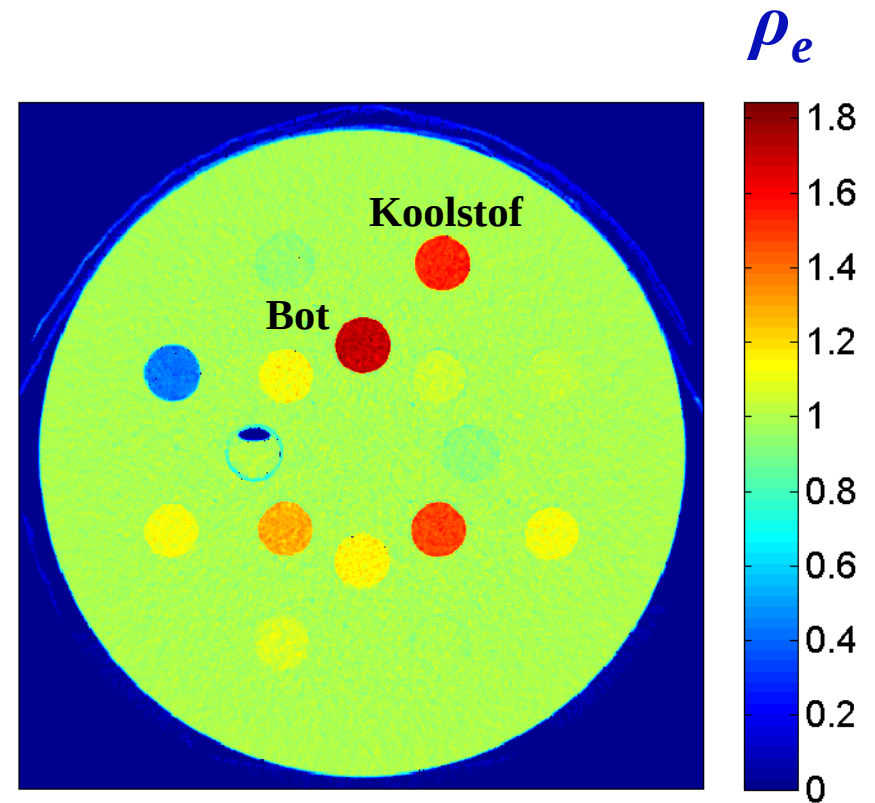
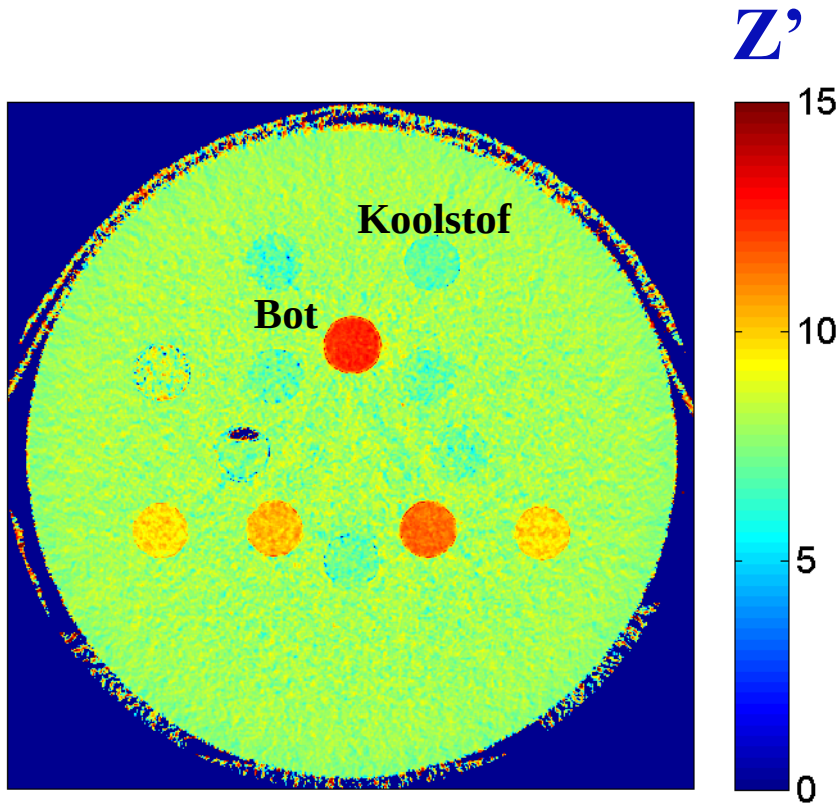


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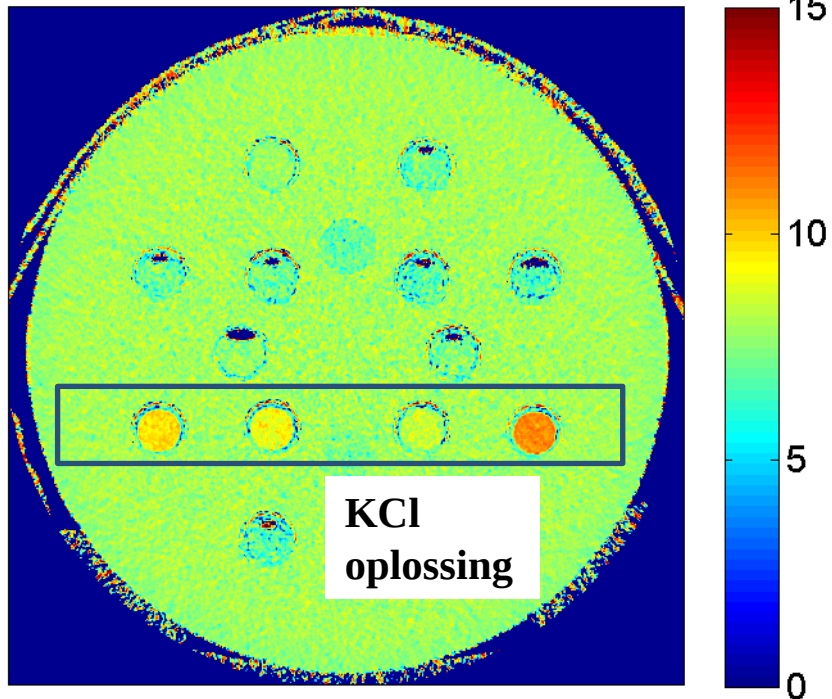


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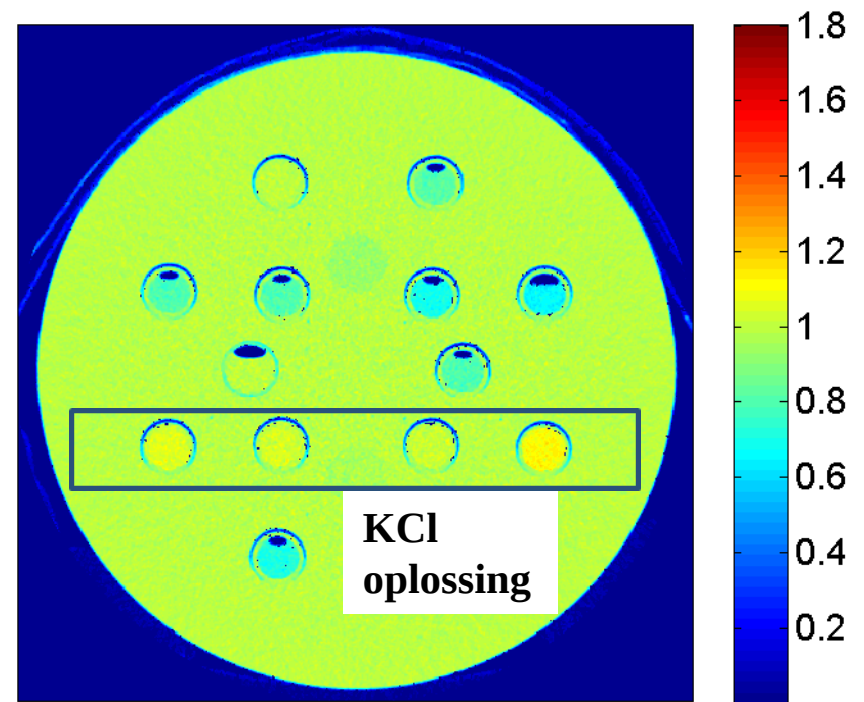
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Z' 

11.1 7.7 4.0 20.0 %

 ρ_e 

11.1 7.7 4.0 20.0 %

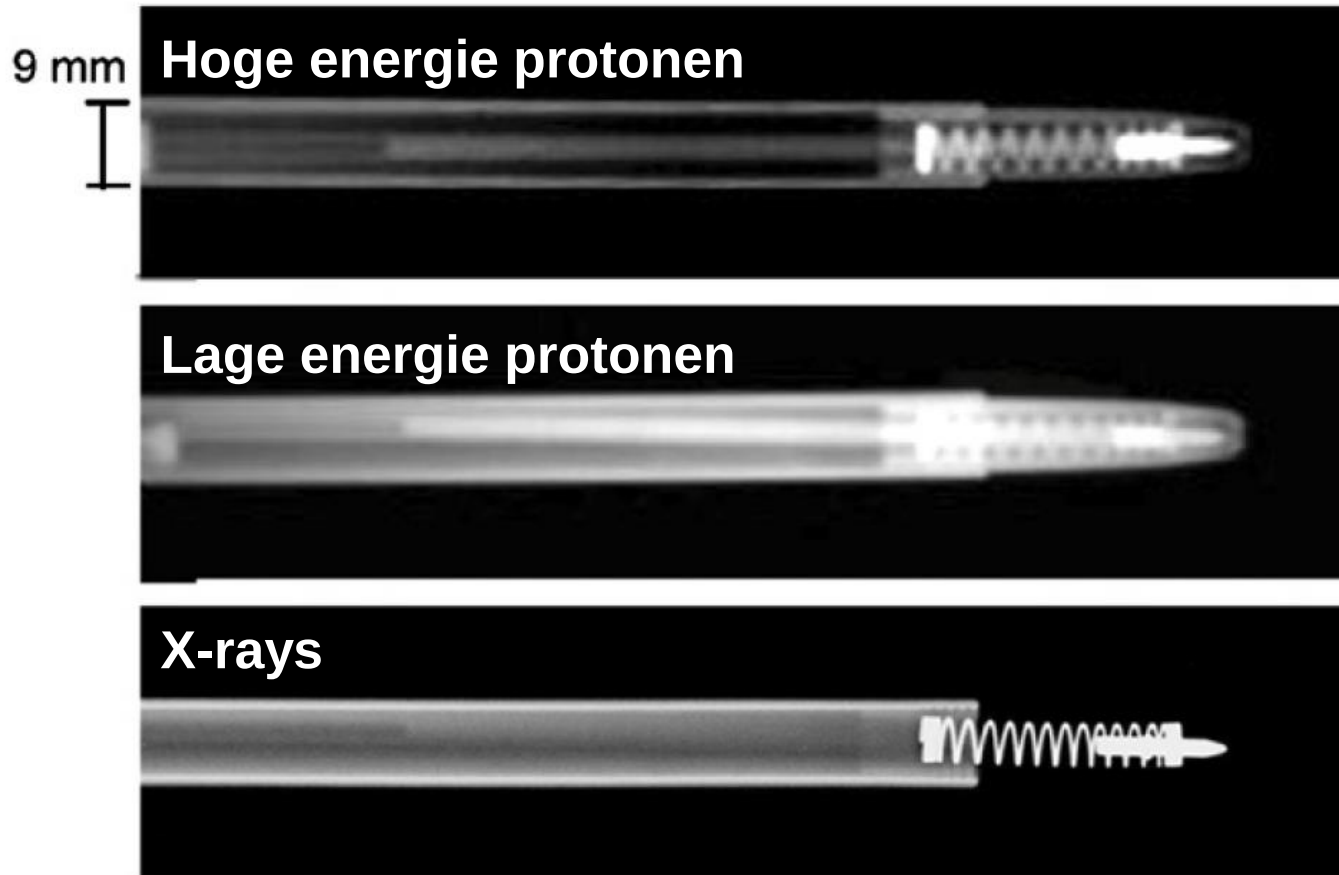
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Beeldvorming met protonen



Ruy et al, PMB53(2008)5461

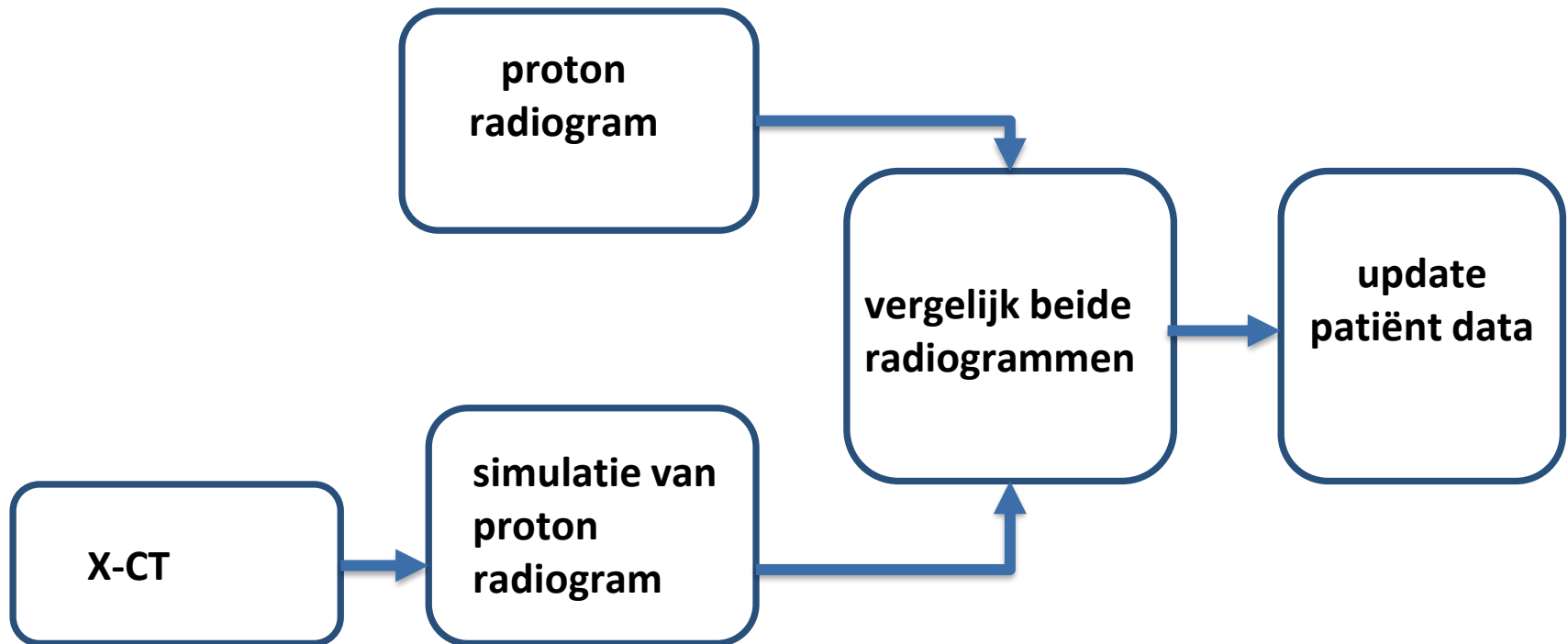
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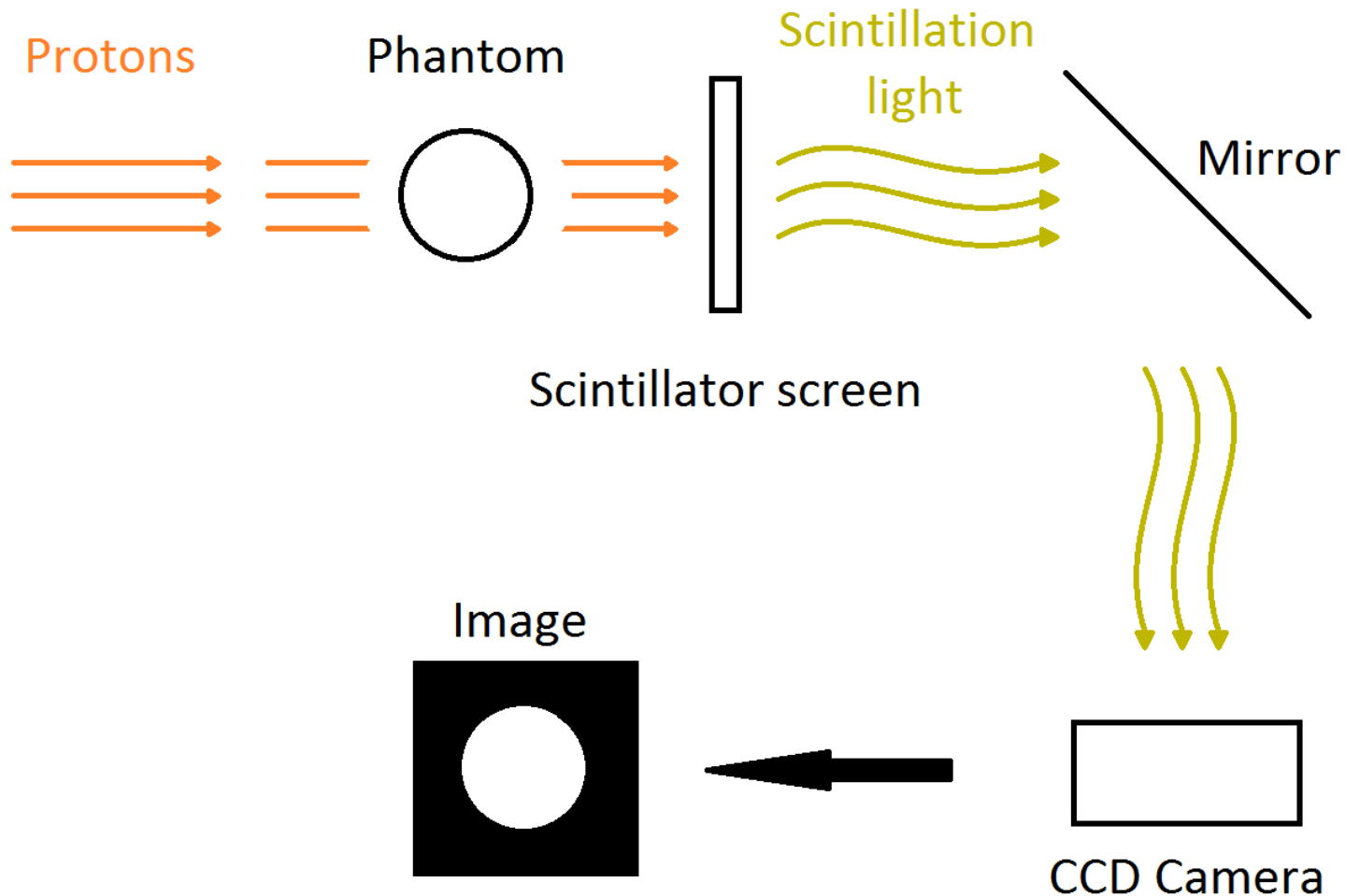


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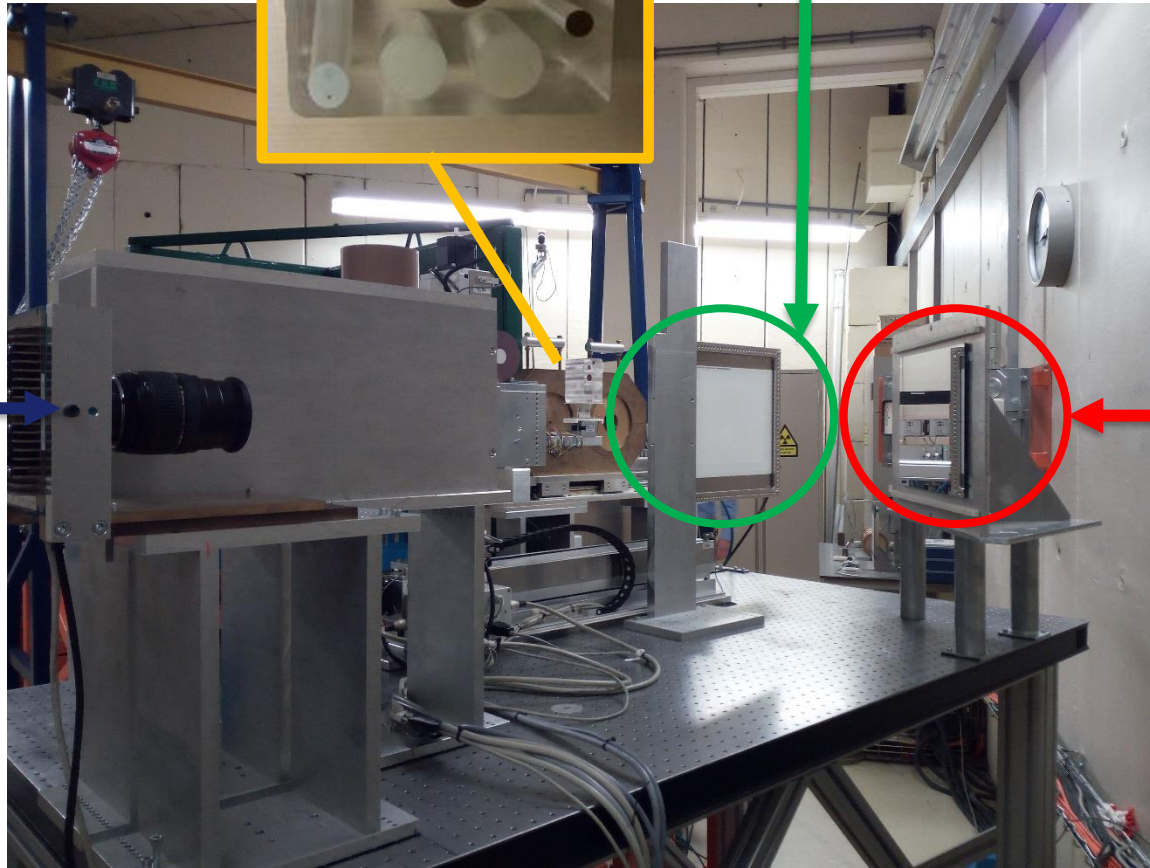
Bestralingsplan-validatie met protonradiografie



Protonradiografie



CCD
Camera



Scintillator screen

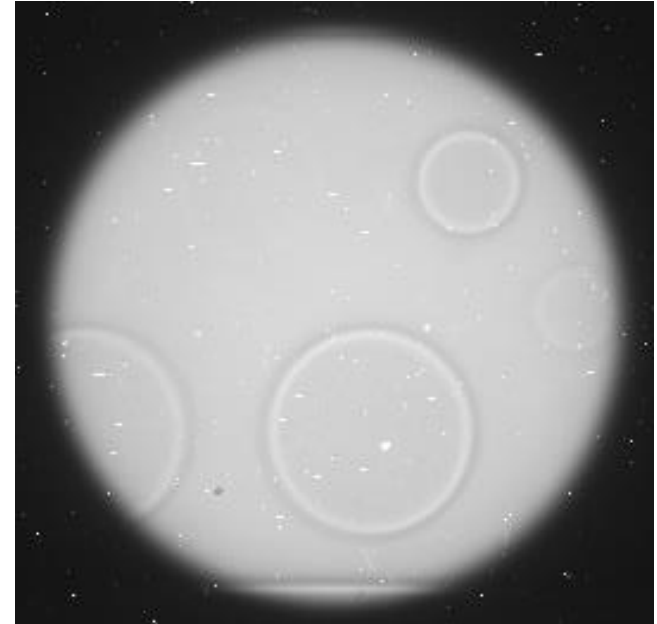
Mirror

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PMMA blok met verschillende materialen

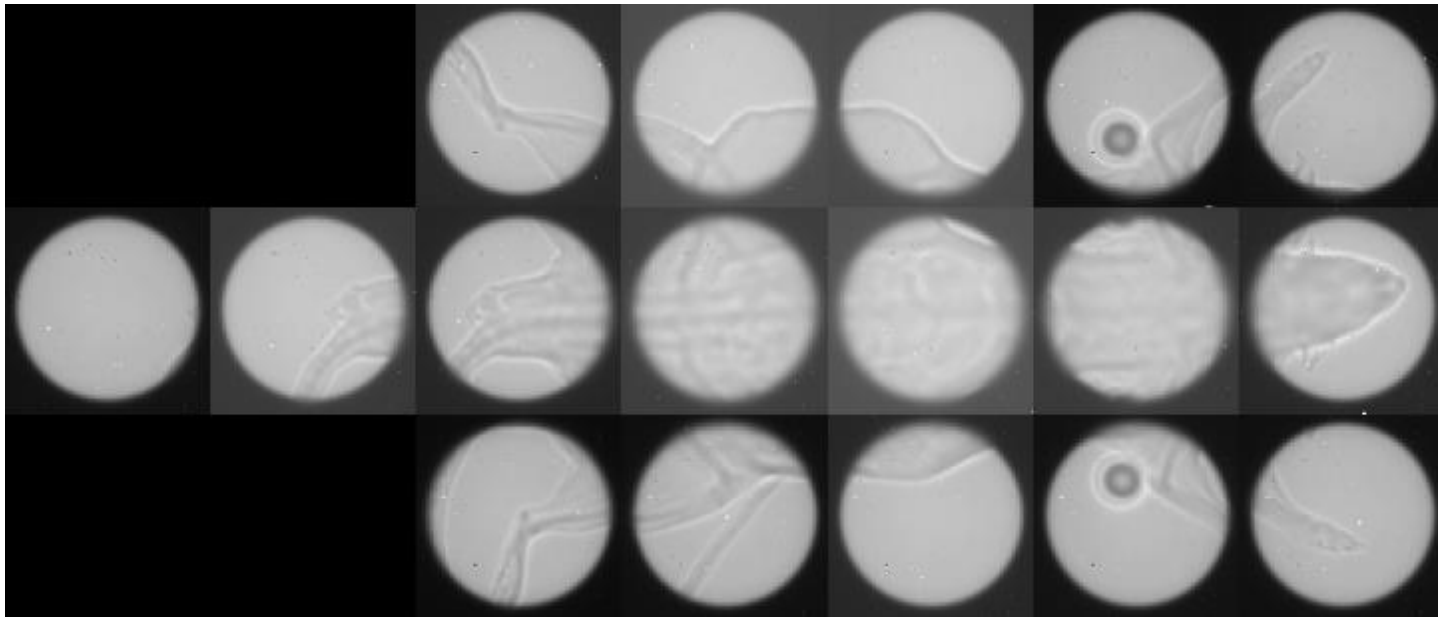
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geplastificeerde muis

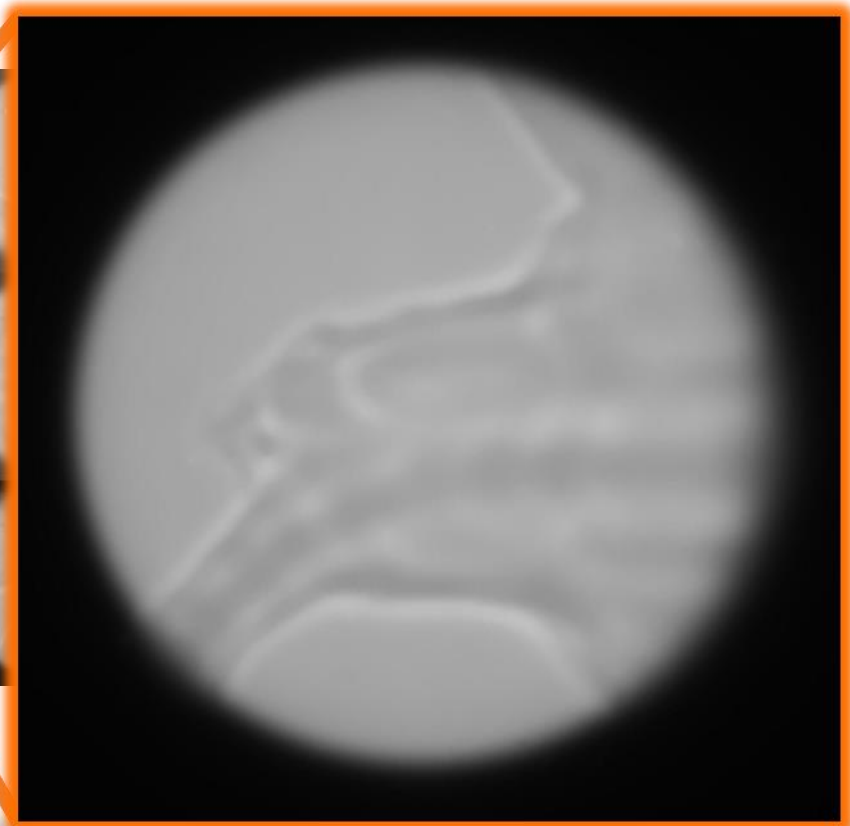
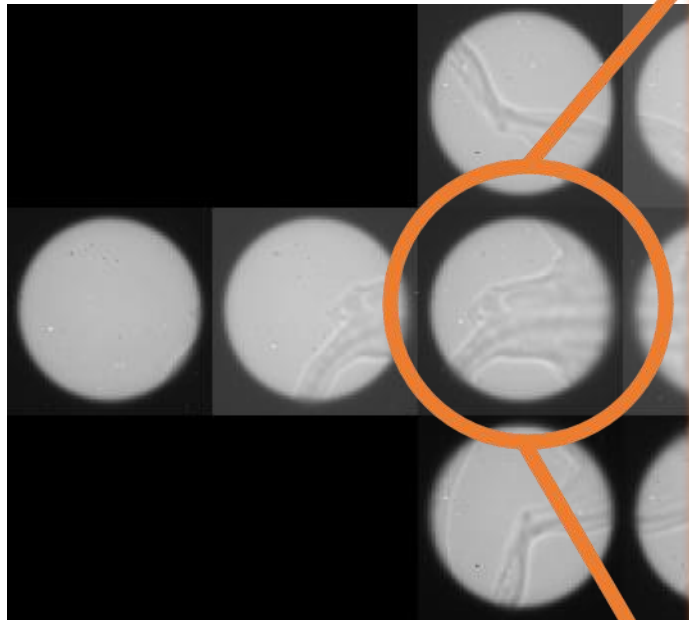


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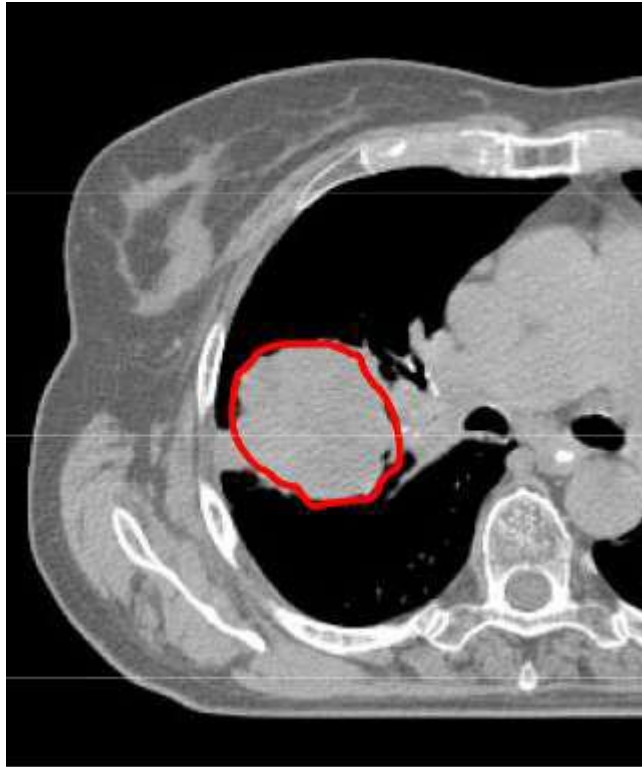
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In vivo dosisafgifte verificatie

source: S. Mori en G.T.Y Chen, MGH



voor bestraling



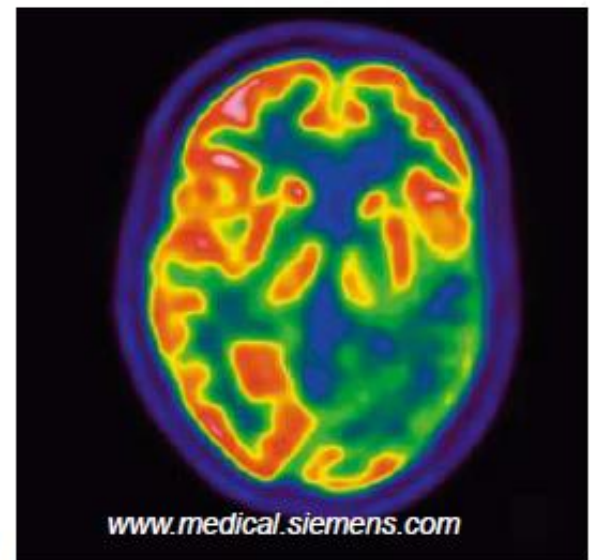
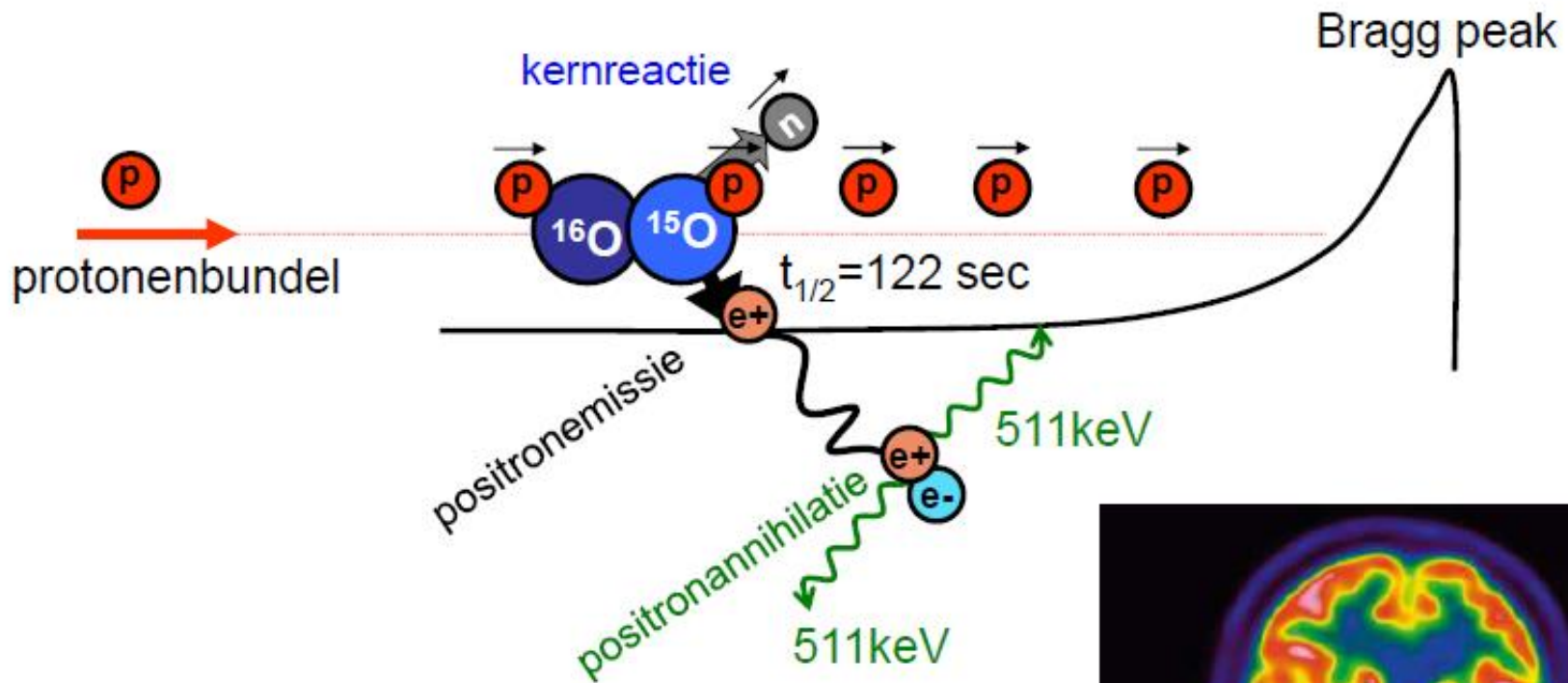
na 5 weken

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PET (positronemissie-tomografie) is een volwassen techniek in de nucleaire geneeskunde

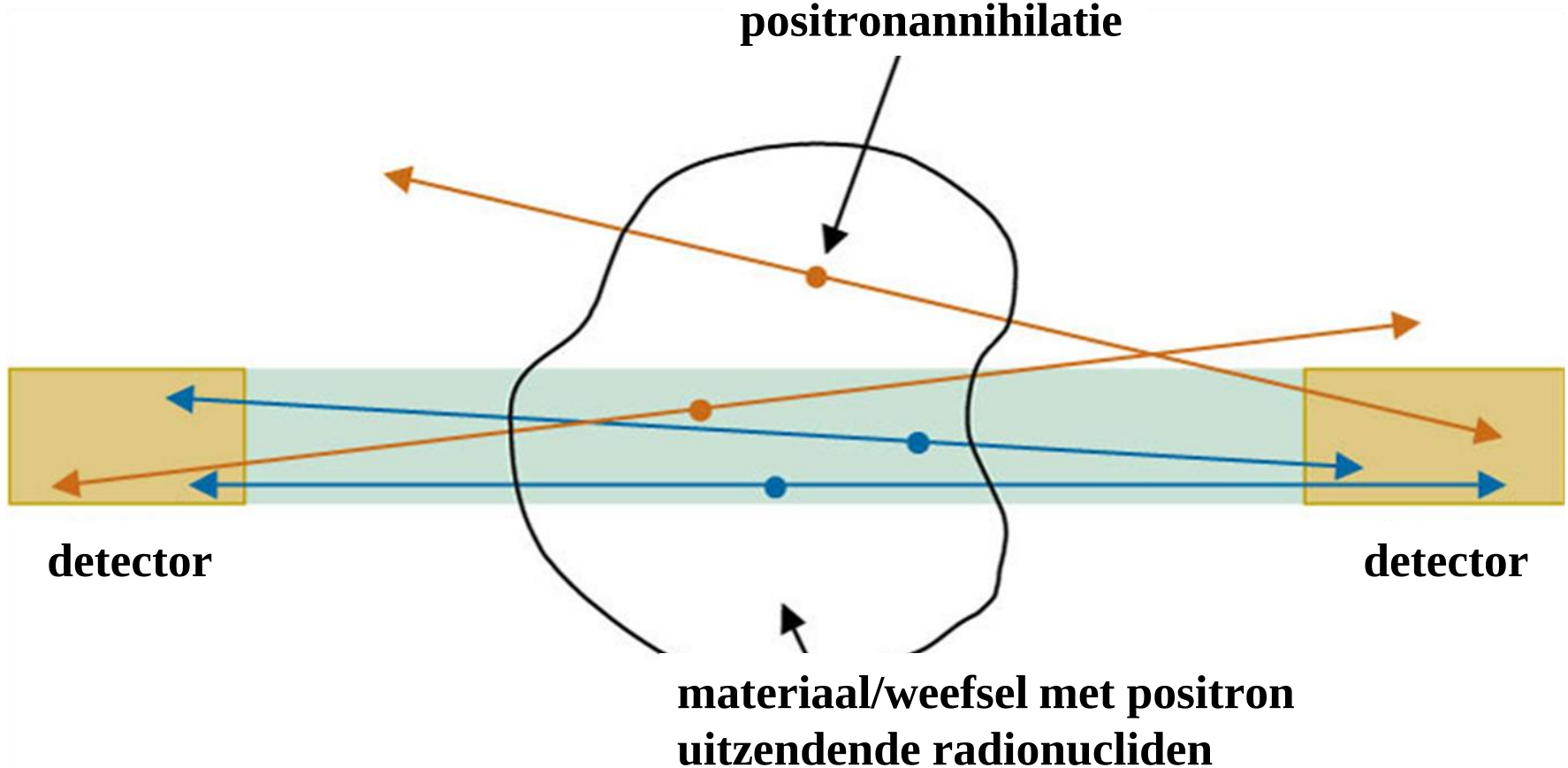
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Positron Emissie Tomografie (PET)



- gelijktijdige detectie van 2 fotonen: geaccepteerd signaal
- detectie van 1 foton: signaal niet geaccepteerd

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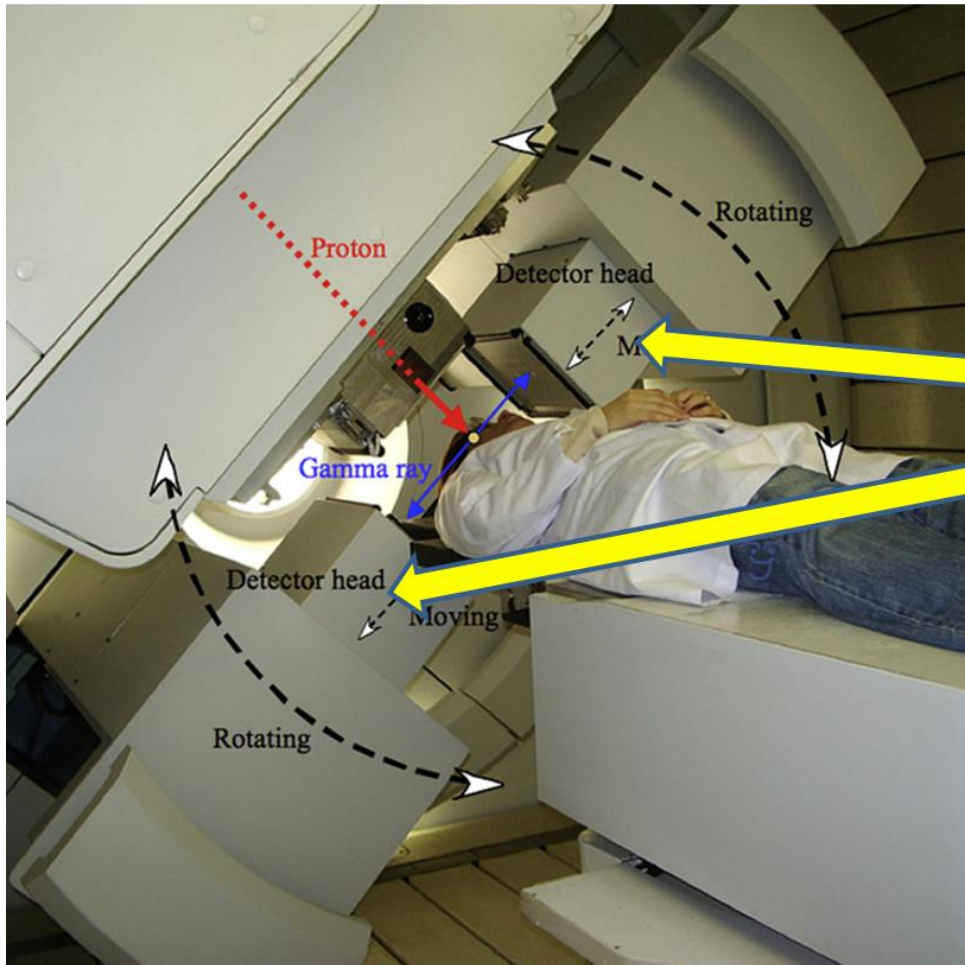
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proton therapy @ NCC, Kashiwa, Japan



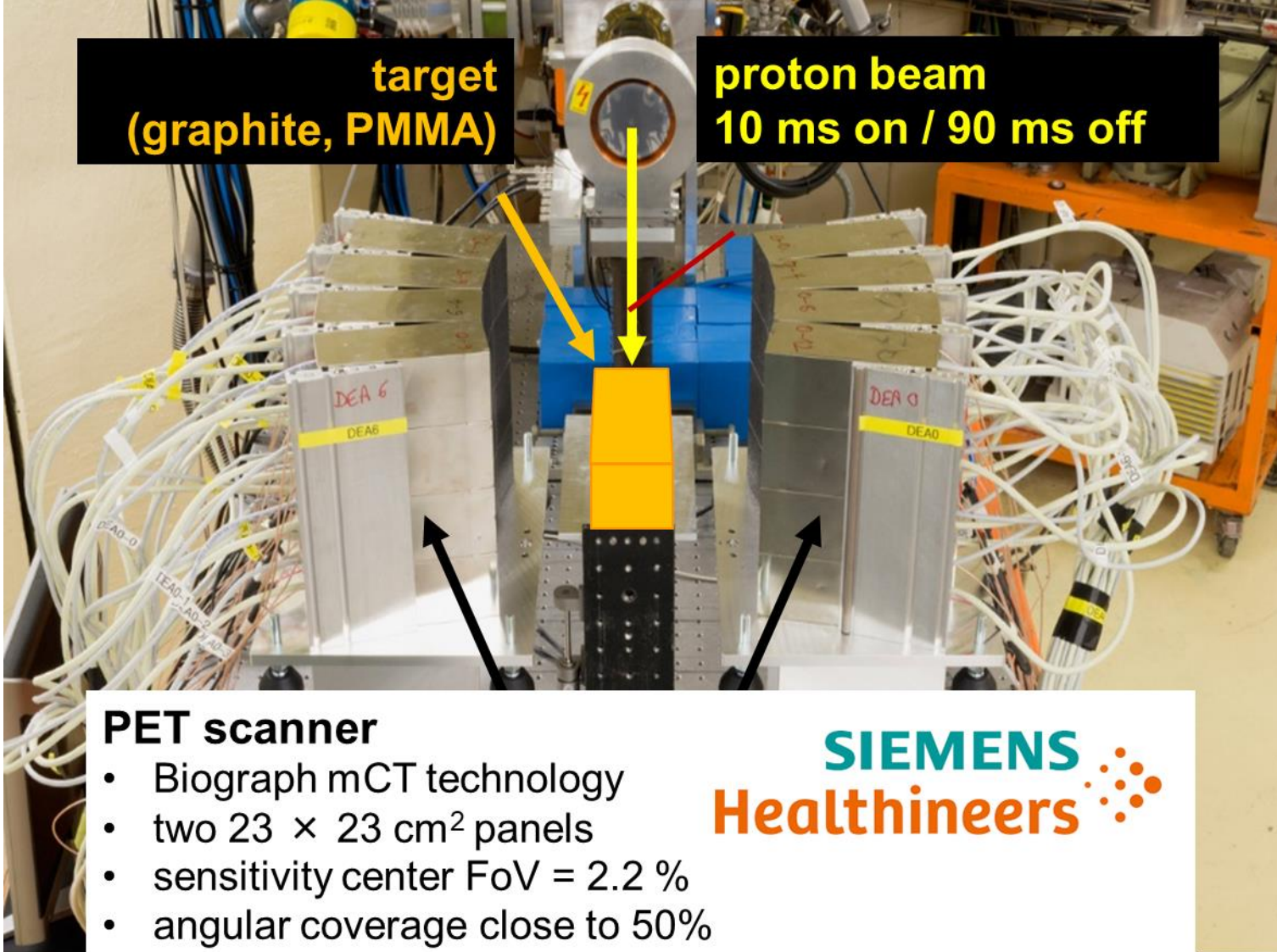
**dual head
scanner**

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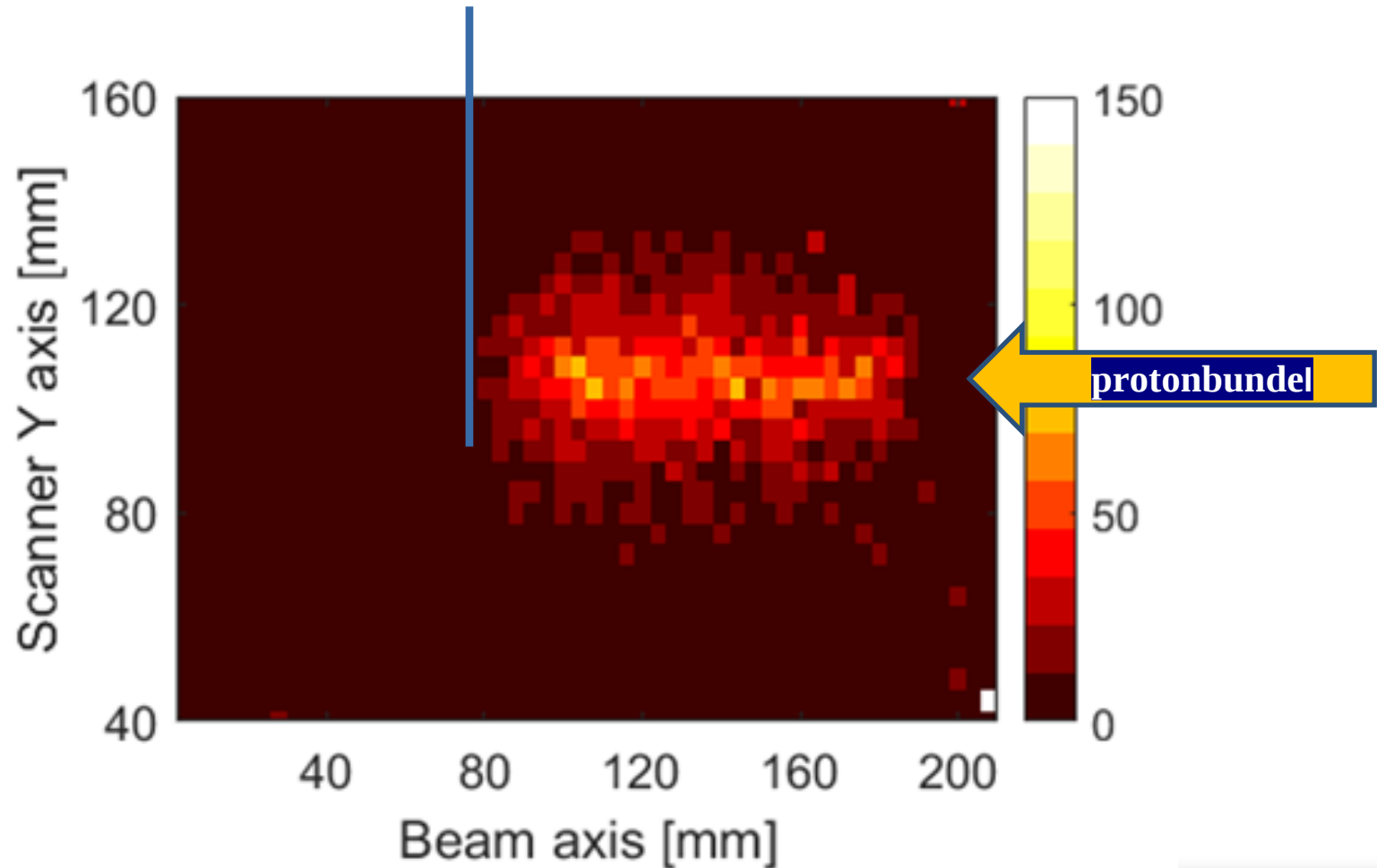
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protonbundel stopt hier



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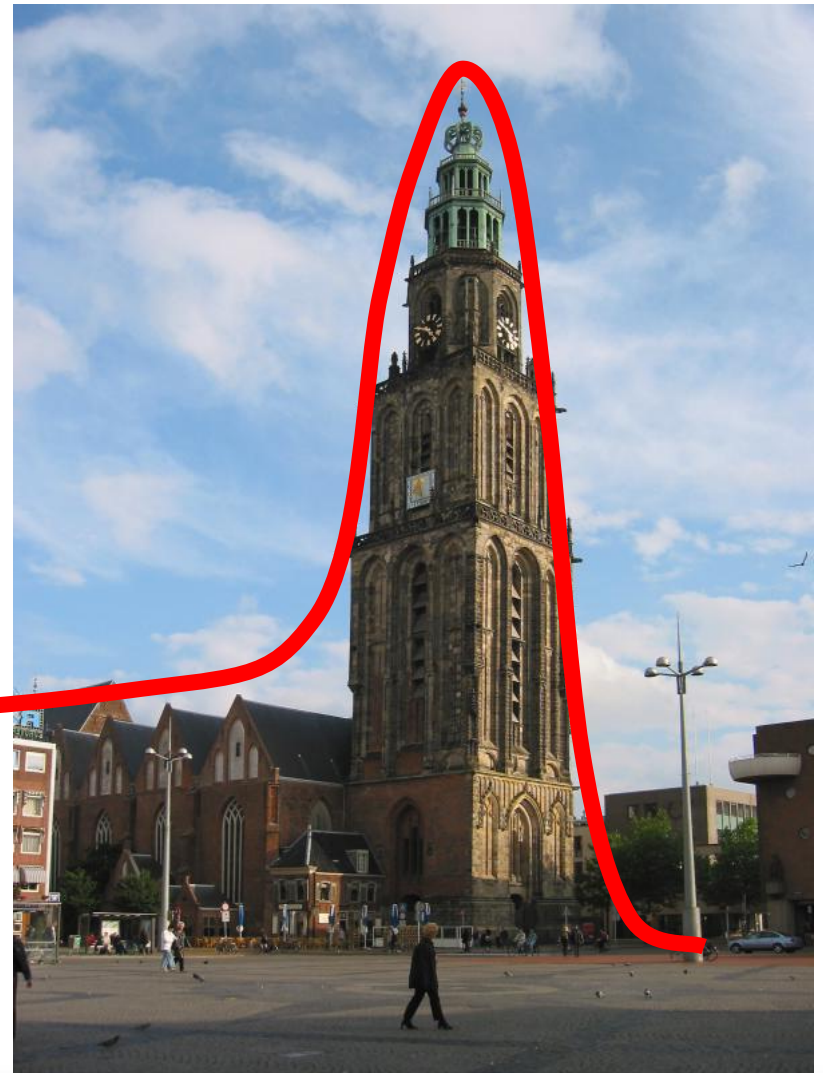
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Dank U voor de aandacht.

Vragen zijn welkom!



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