

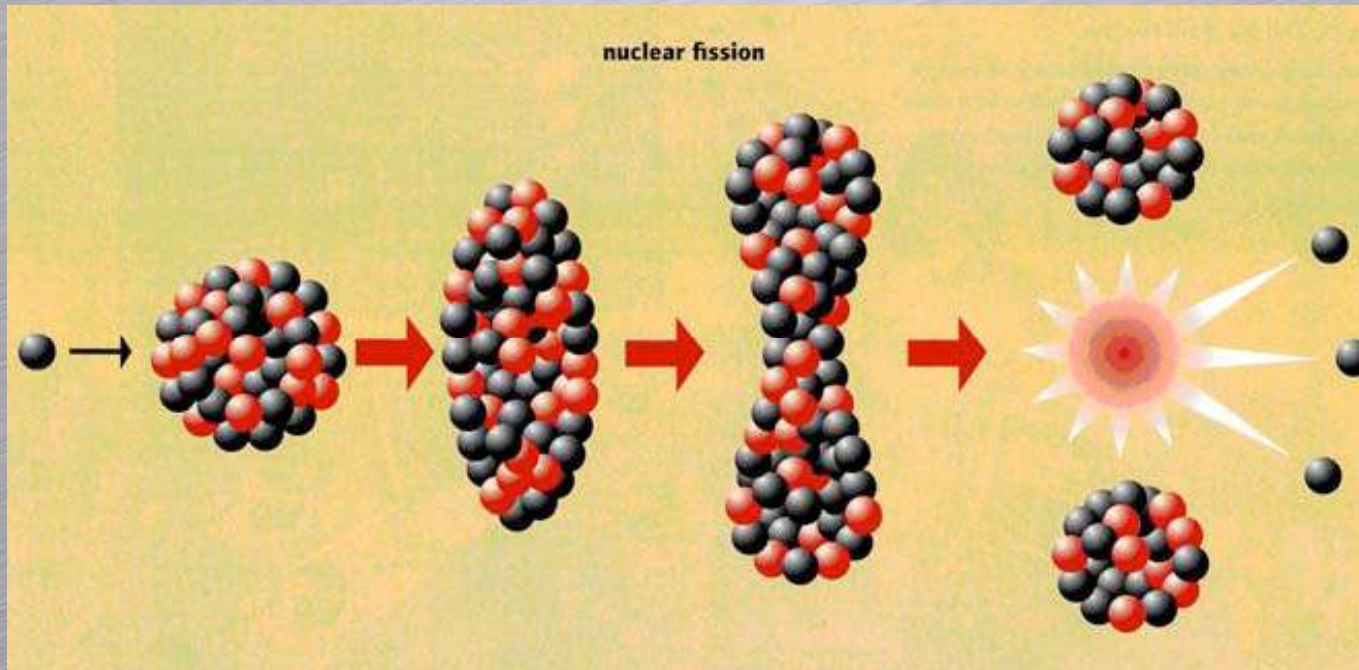
# Kurkászó neutronok, avagy hogyan látjuk az atomok mozgását

Faragó Béla  
Institut Laue Langevin,  
Grenoble

Szucsán András  
fizikatanárom emlékére  
1935 -2013



# Hogyan keletkeznek neutronok....



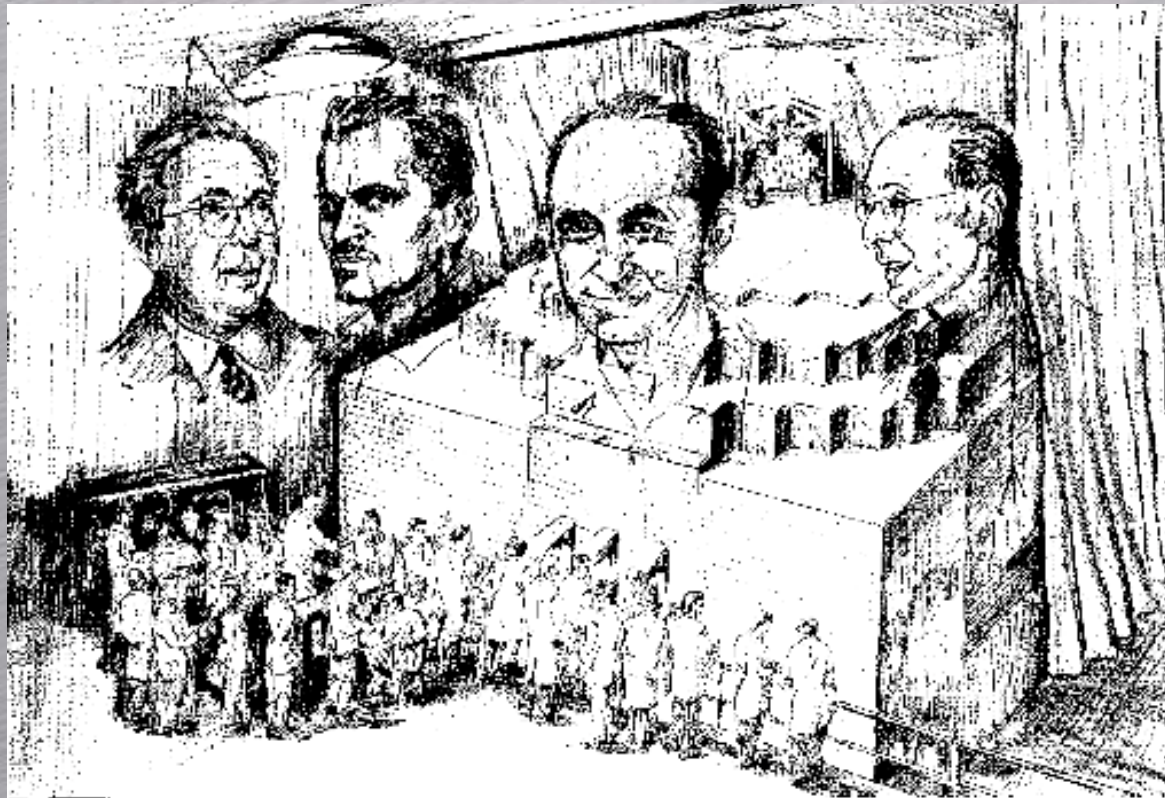
Példa: 60 MW kutató reaktor

$$\frac{60 \times 10^6 \text{ Watt}}{200 \text{ MeV/hasadás}} \dagger = 2 \times 10^{18} \text{ hasadás/másodperc}$$

$5 \times 10^{18}$  neutron/sec generálódik a teljes reaktor-térfogatban

1942 december 2. Az első tartós láncreakció Chicago

Szilárd Compton Fermi Wigner

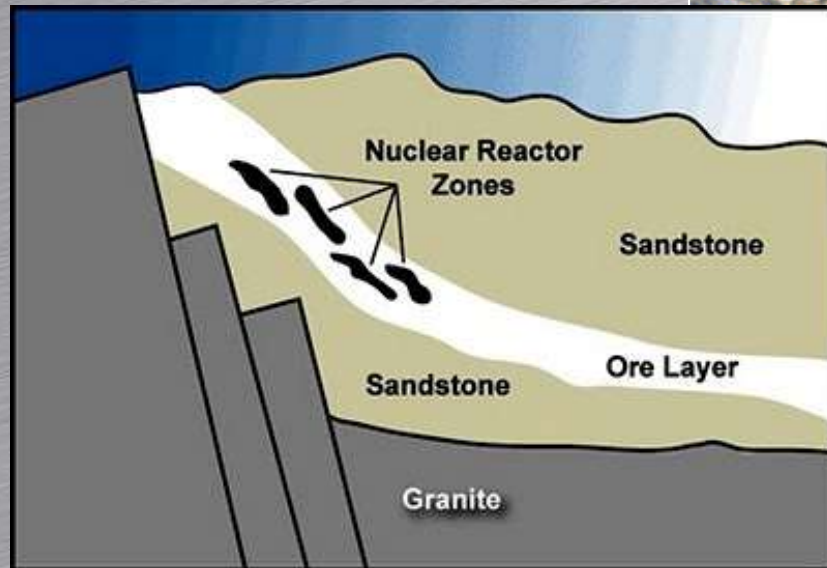
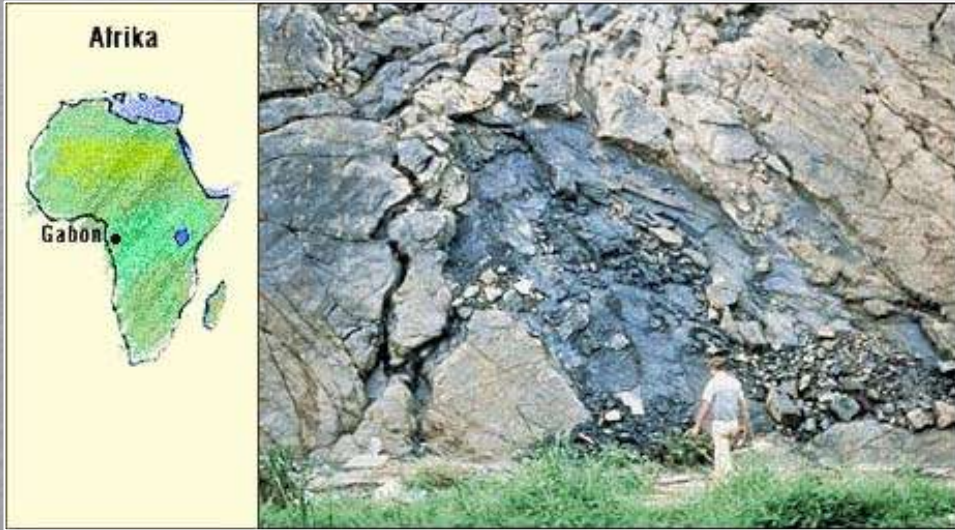


# Az Oklo-jelenség (Gabon): természetes atomreaktor

1972-ben nyilvánosságra hozott tények:  
helyenként:  $1,5 \times 10^{21}$  n/cm<sup>2</sup> (ILL  $10^{15}$  !)  
.... 1800 millió évvel ezelőtt

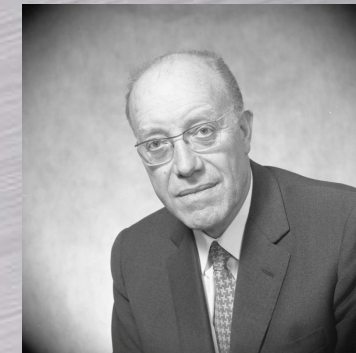
Forrás:

IEAE INTERNATIONAL SYMPOSIUM  
ON THE OKLO PHENOMENON  
LIBREVILLE, GABON, JUNE 1975



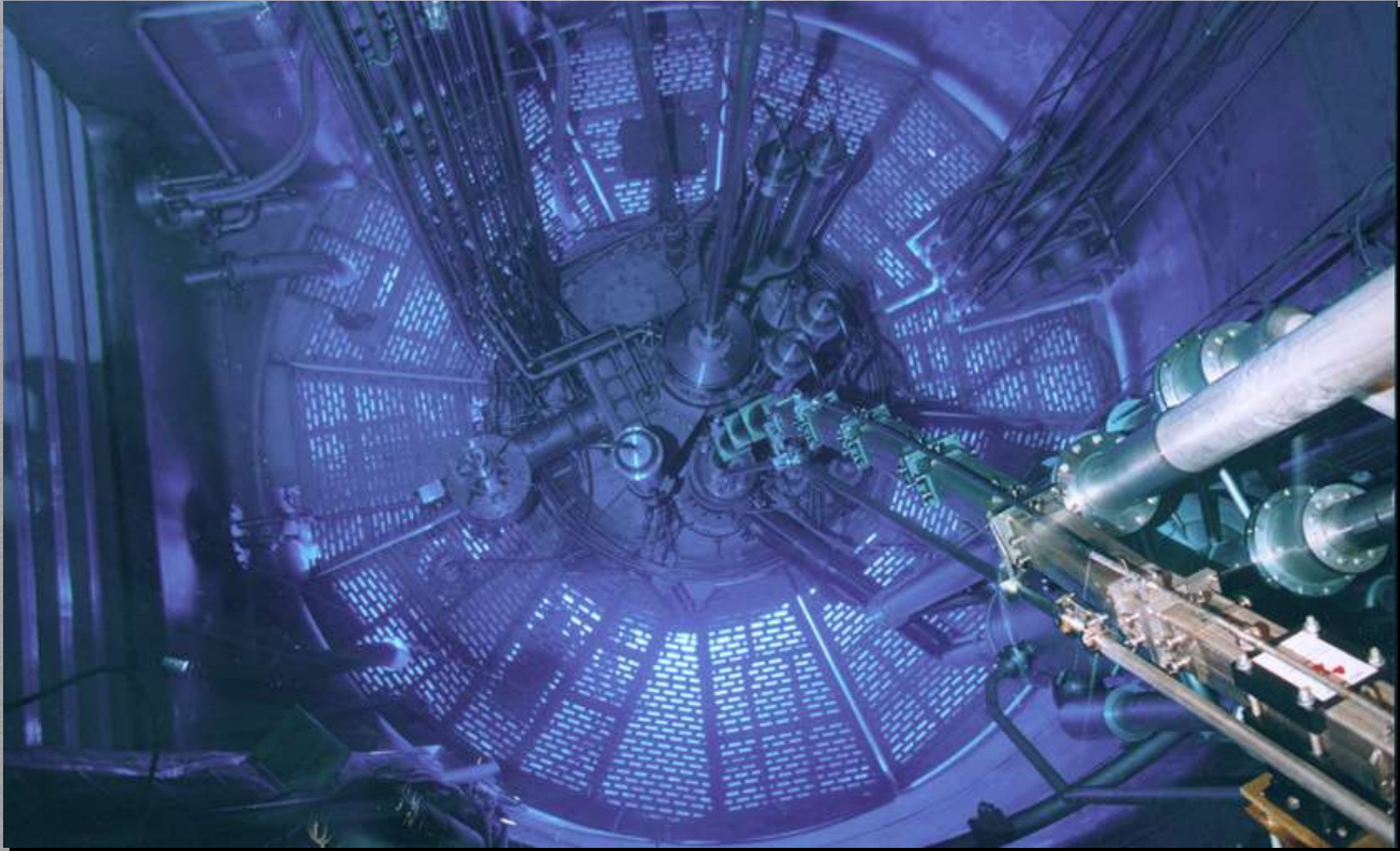
# Az ILL alapítása

- **Az ötlet** 1964-ben lett javasolva
- **A laboratóriumot** 1967 alapították, költségvetési alapból  
**Franciaország és Németország**  
- Luis Néel és Heinz Maier-Leibnitz
- **Reaktor** kritikus 1971-ben  
első kísérletek 1972 - 58 MW
- **"Tulajdonosok"** Németország + Franciaország,  
majd Nagy-Britannia 1973-tól
- **Tudományos partnerek:**
  - Spanyolország 1987**
  - Svájc 1988**
  - Ausztria 1990**
  - Oroszország 1996**
  - Olaszország 1997**
  - Csehország 1999 Svédország 2005 Szlovákia 2005 Magyarország 2006...**



# Institut Max von Laue - Paul Langevin

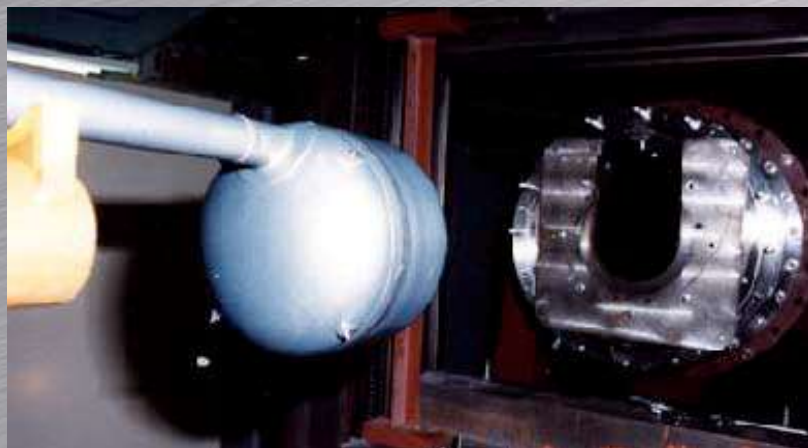
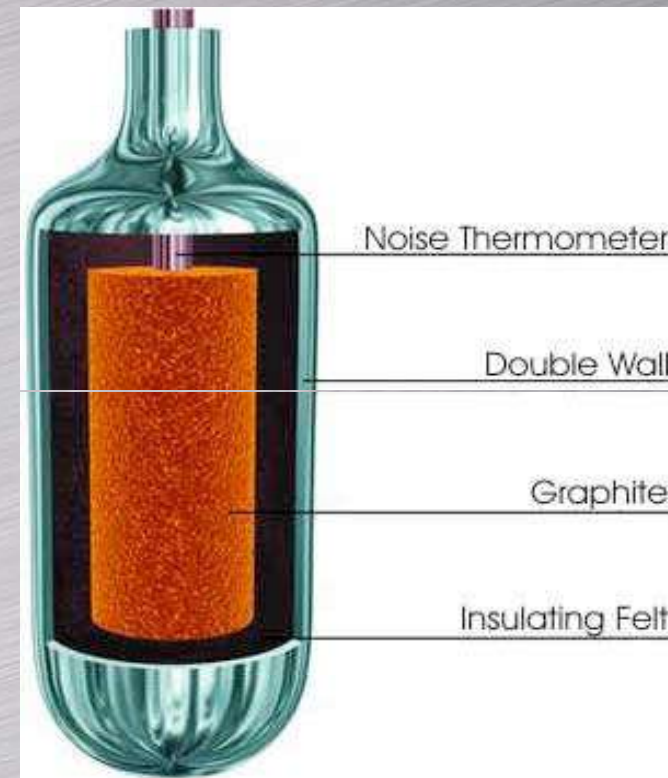
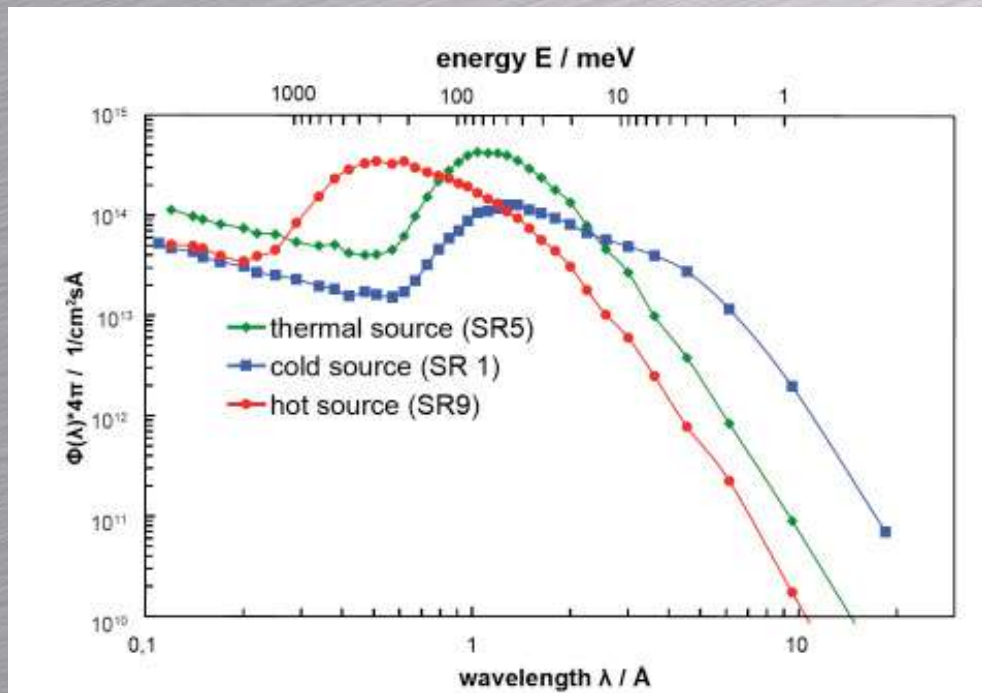








# Mért neutron-spektrum (FRM-II München)



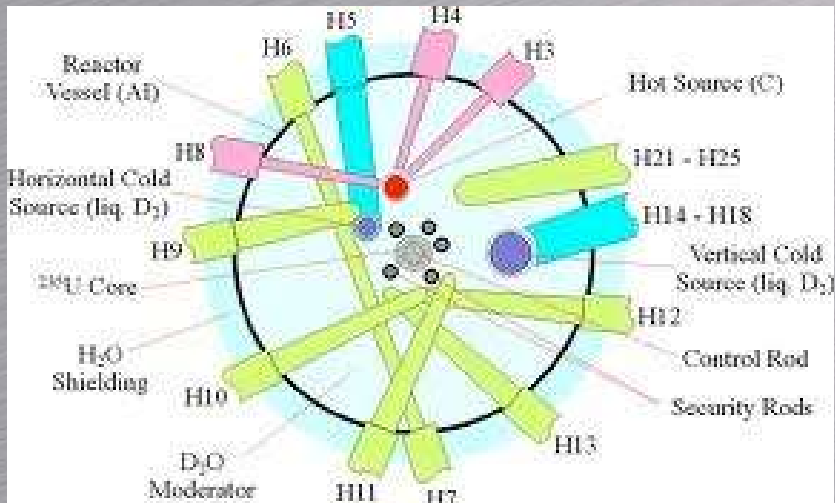
Hideg forrás  
20 K ( $\text{D}_2$ )

Meleg forrás  
2000 K (grafit)

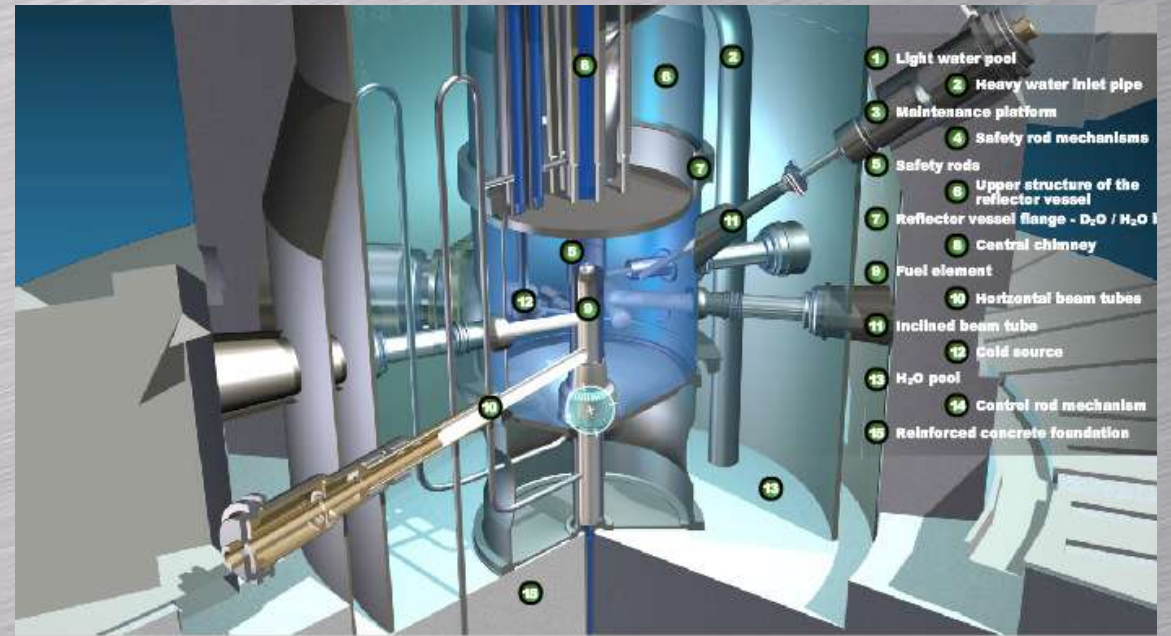
## Reaktor dupla héj



## neutron-nyalábok

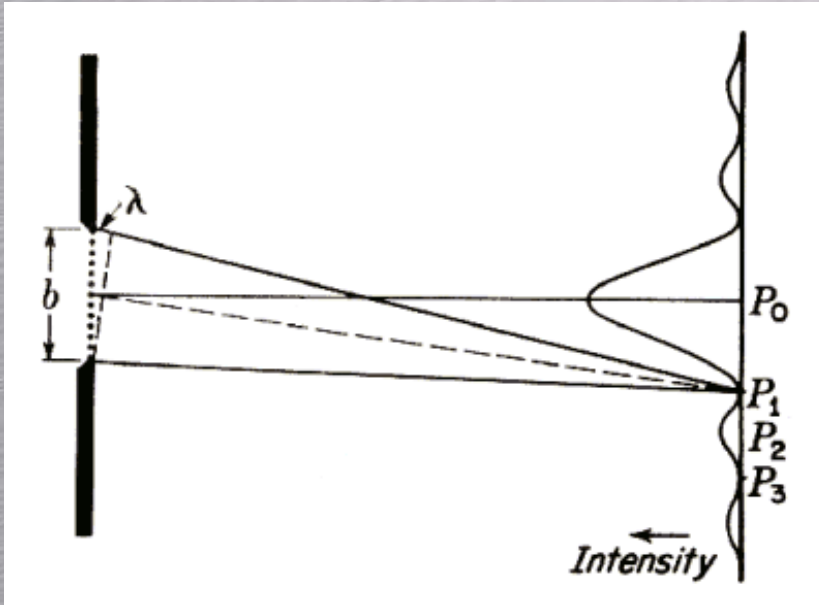


## Reaktor aktív zóna



Fűtőelem 8,6 kg U<sup>235</sup>

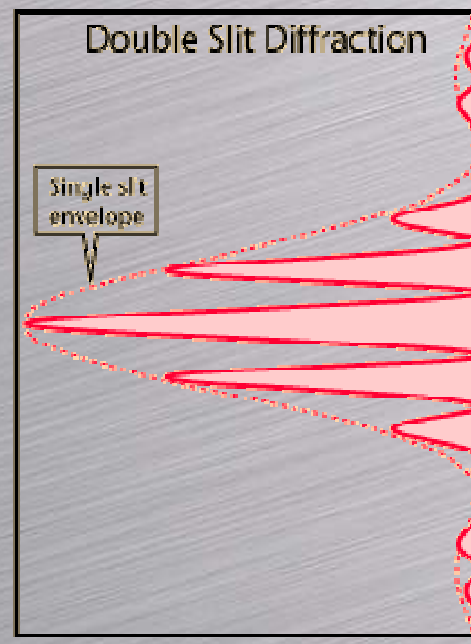
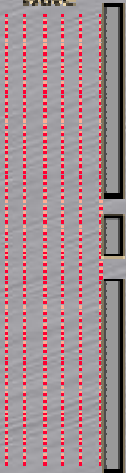




## Fényelhajlás

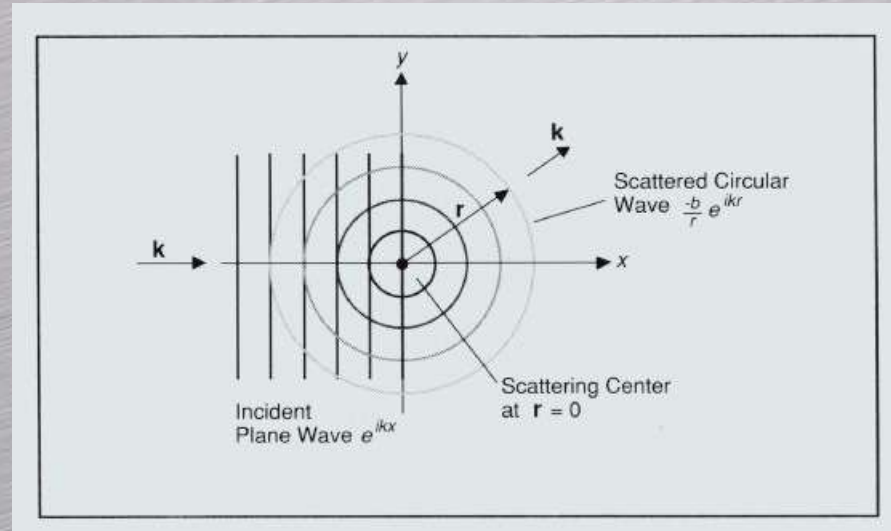
A neutronnak is van hullámtermészete

Incident plane wave

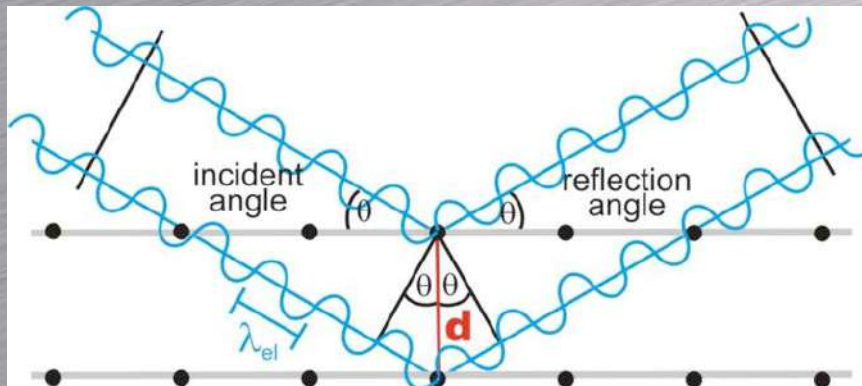


“Csak a kezemet figyeljék, mert csalog”  
A Fourier-transzformációt most nem ismertetjük..... vagy mégis?

Az atommag olyan kicsi, hogy  
a neutron a teljes térszögbe szóródik.



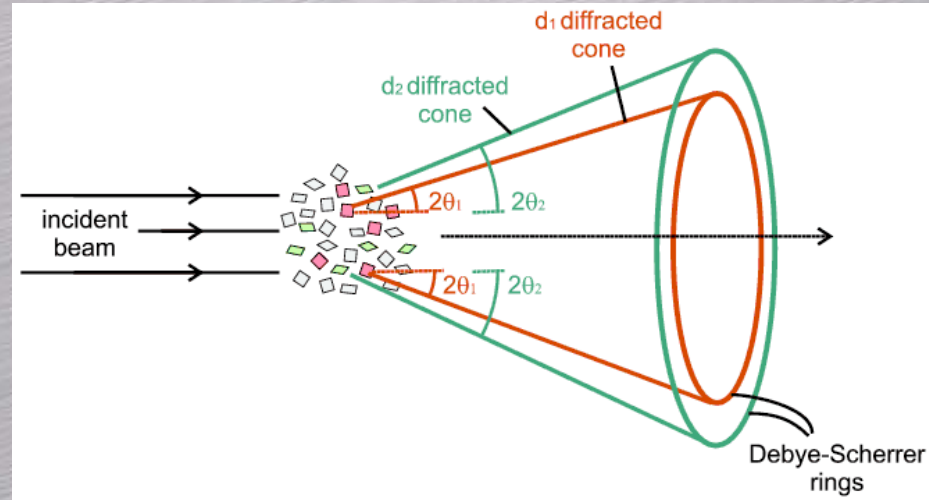
Egy kristályban adott hullámhosszú neutron csak bizonyos irányokba tud szóródni.



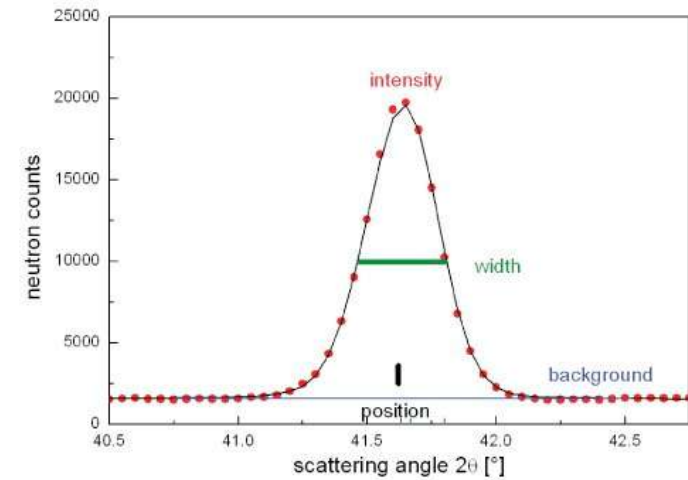
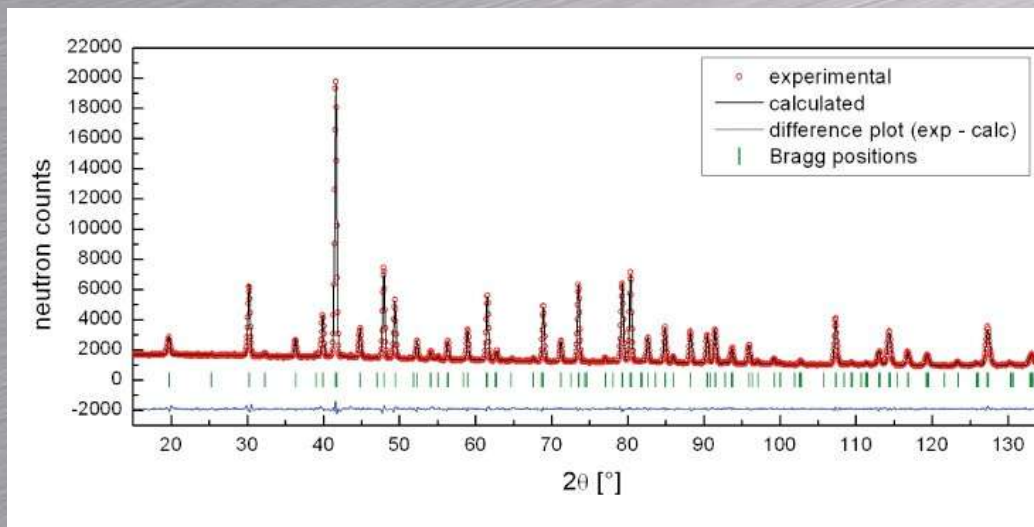
Bragg-törvény  
(2014 a krisztallográfia éve!)

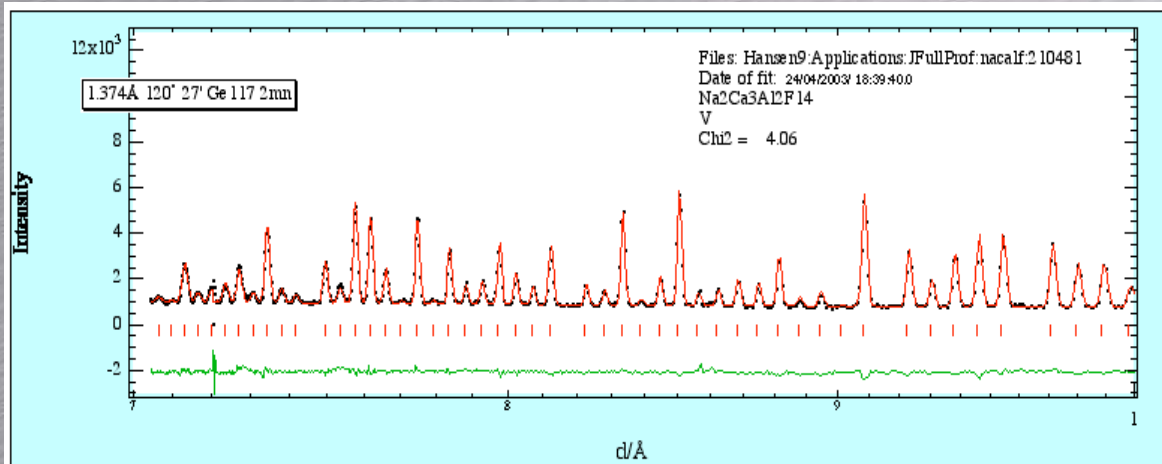
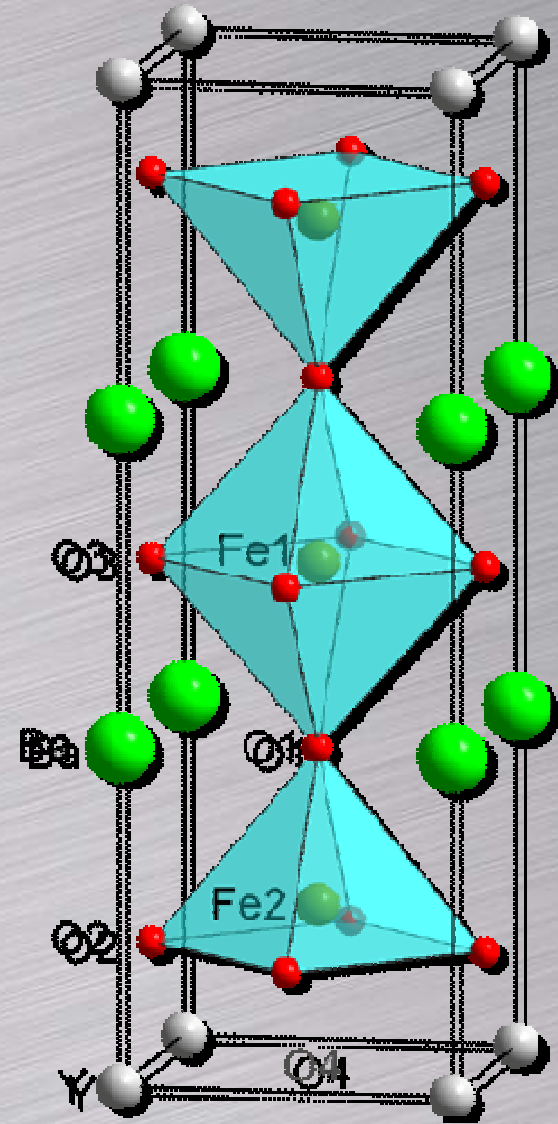
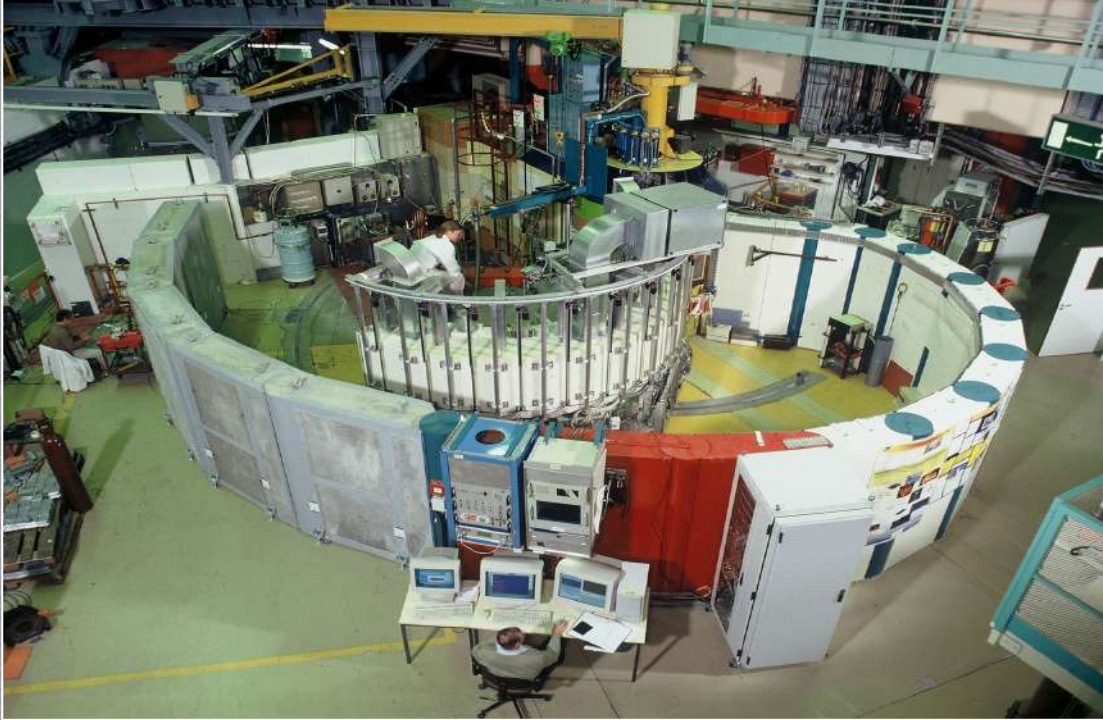
$$2d \sin(\Theta) = n\lambda$$

Por-diffrakció => csak a jól orientált szemcsék szórnak



vagy a szórési szög függvényében





# Na és a röntgen-sugárzás?

## Brightness & Fluxes for Neutron & X-Ray Sources

	<i>Brightness</i> ( $s^{-1} m^{-2} ster^{-1}$ )	<i>dE/E</i> (%)	<i>Divergence</i> ( $mrad^2$ )	<i>Flux</i> ( $s^{-1} m^{-2}$ )
Neutrons	$10^{15}$	2	$10 \times 10$	$10^{11}$
Rotating Anode	$10^{16}$	3	$0.5 \times 10$	$5 \times 10^{10}$
Bending Magnet	$10^{24}$	0.01	$0.1 \times 5$	$5 \times 10^{17}$
Wiggler	$10^{26}$	0.01	$0.1 \times 1$	$10^{19}$
Undulator (APS)	$10^{33}$	0.01	$0.01 \times 0.1$	$10^{24}$



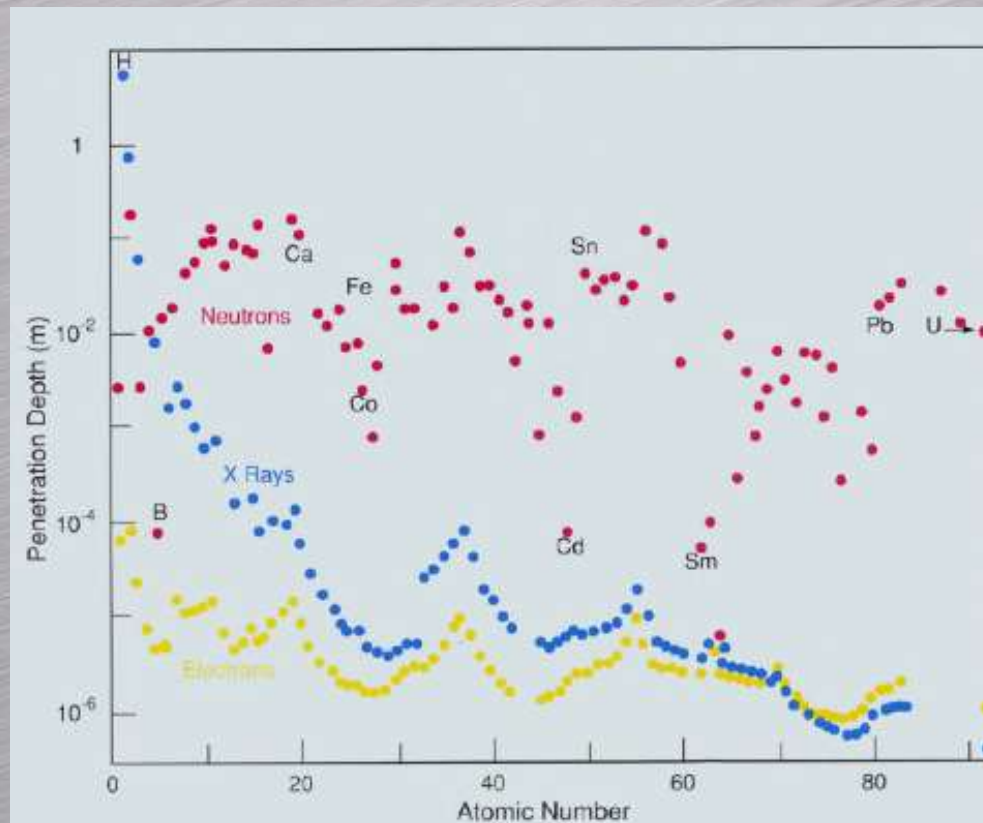
## neutron vs röntgen

Tömeg: neutron:  $1,675 \times 10^{-27}$  kg, foton: 0  
2 Å hullámhosszhoz tartozó energia:  
neutron: **20,6 meV**, foton: **6,25 keV**  
**249 Kelvin vs 75 000 000 Kelvin**

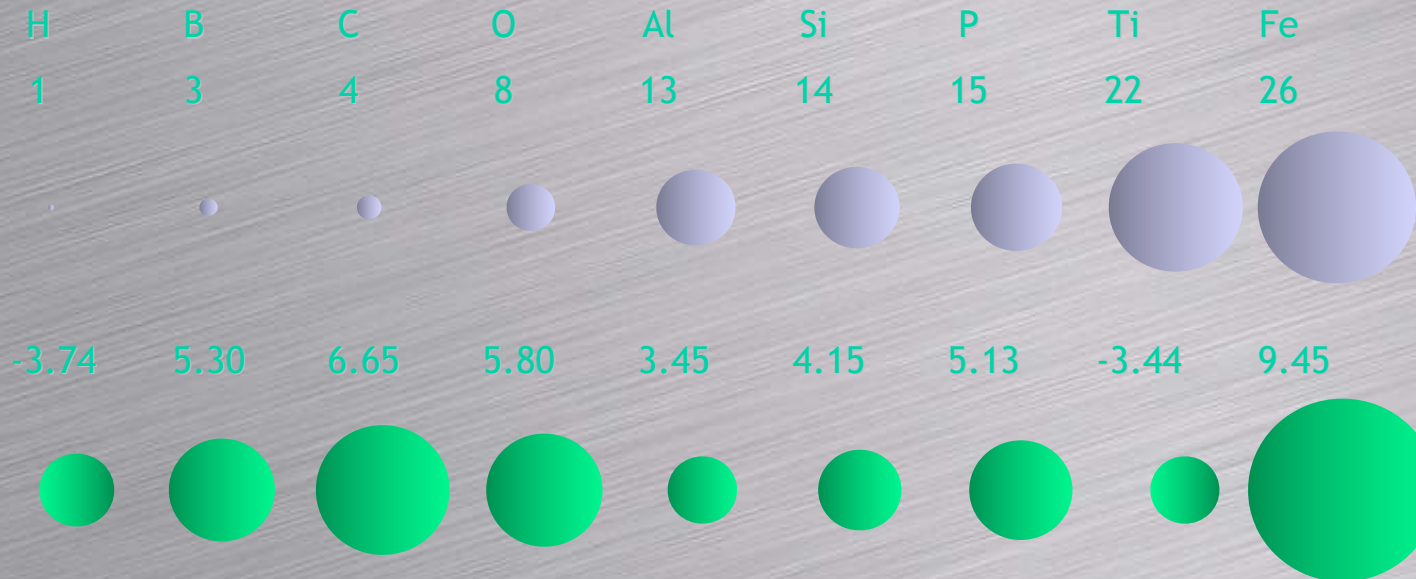
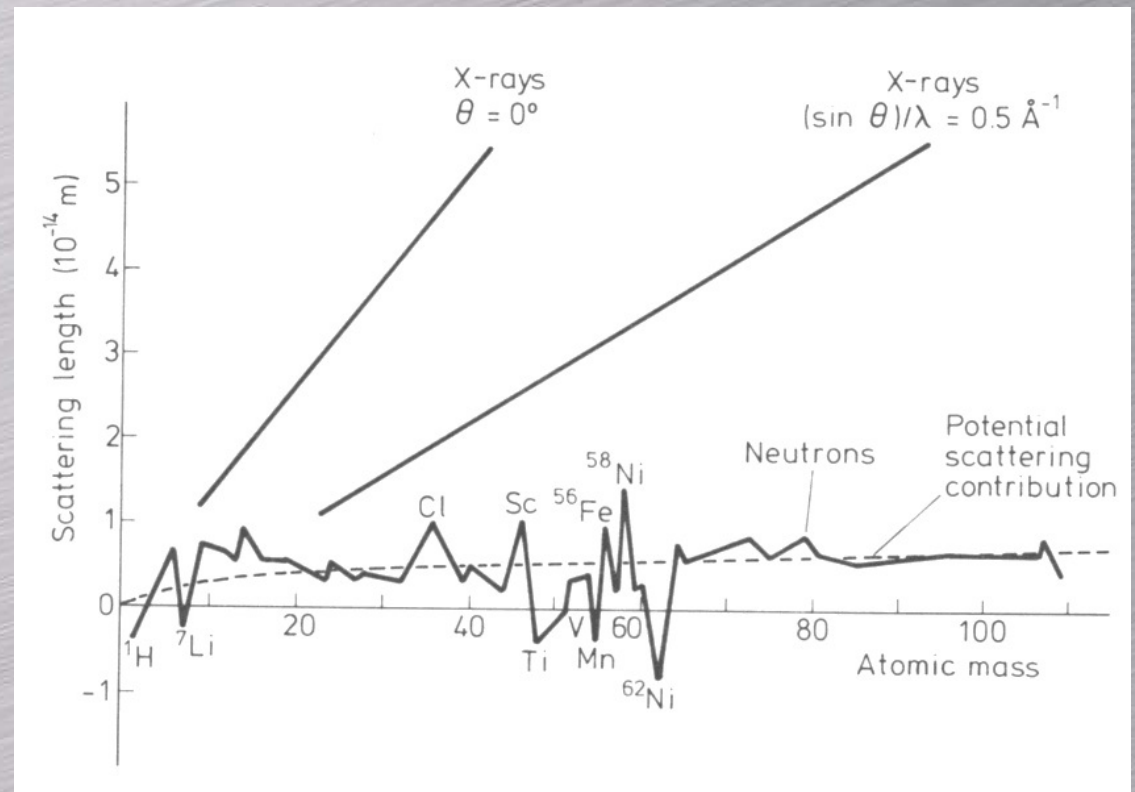
A termikus jelenségeket jobb neutronnal mérni!

Egyéb ?

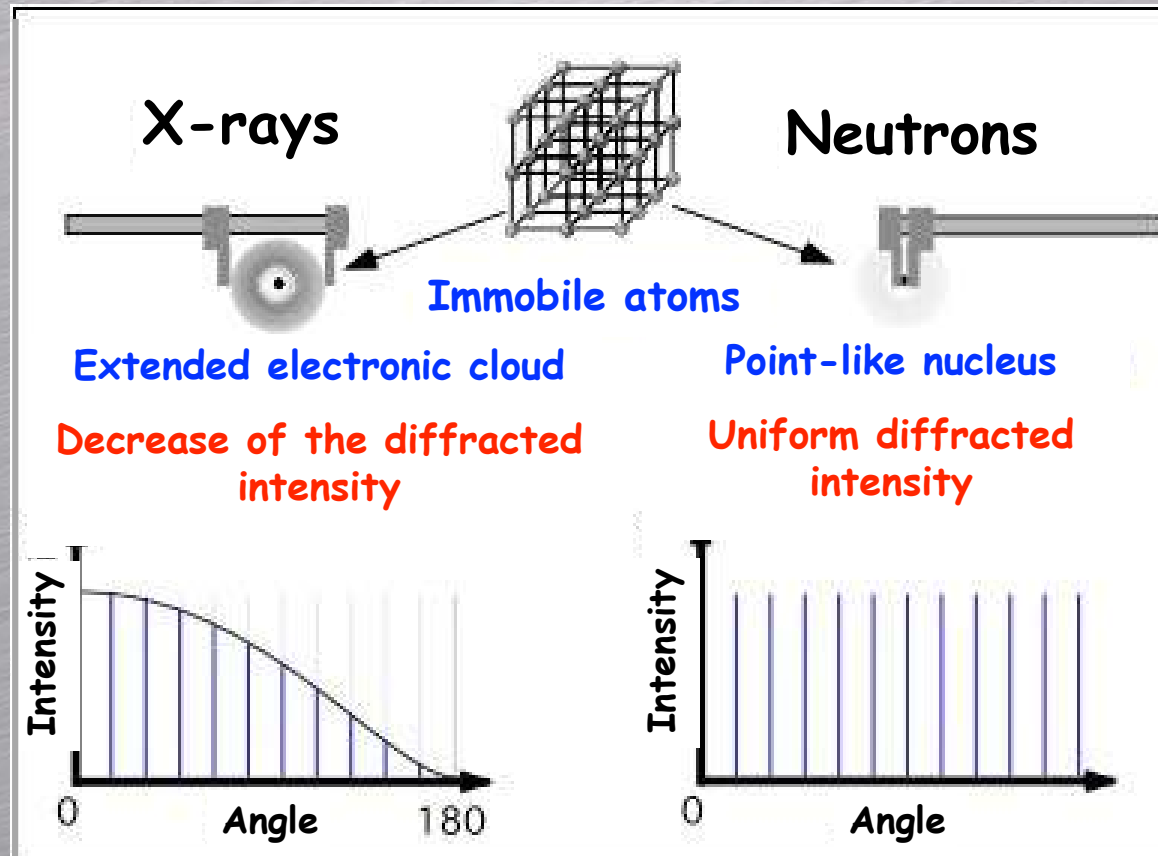
# Behatolási mélység összehasonlítása



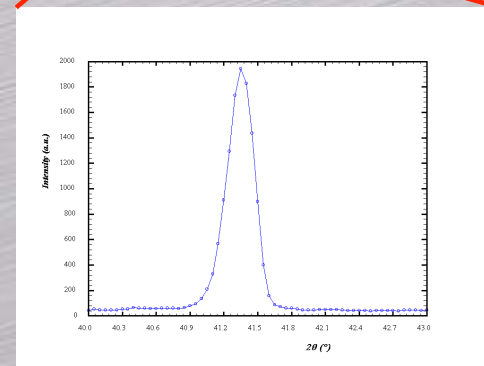
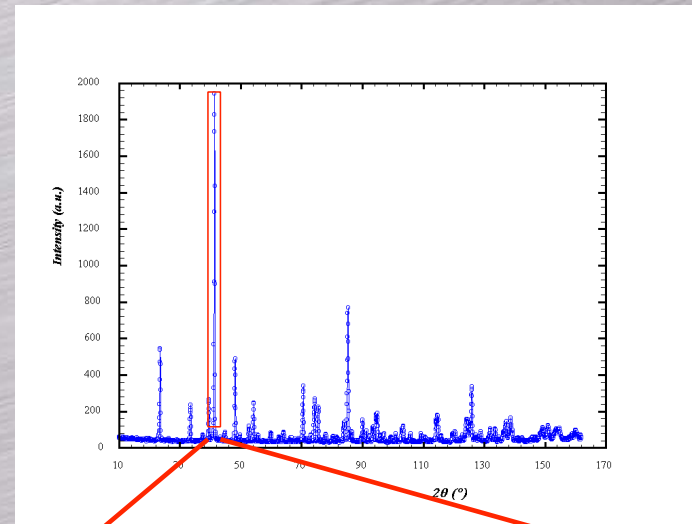
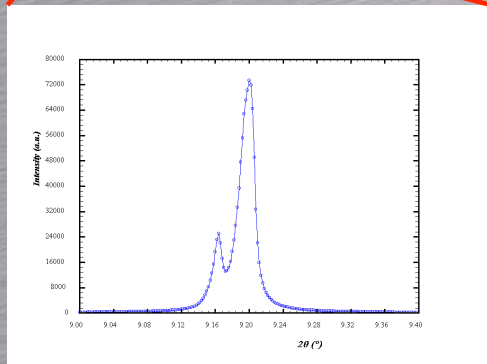
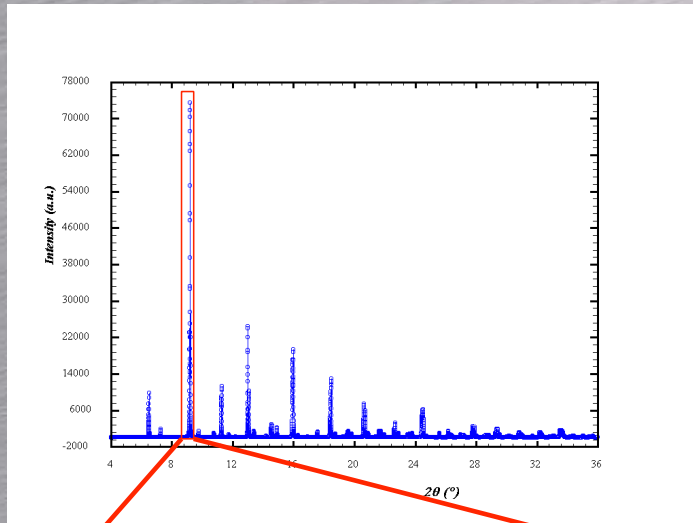
# A szórási hossz összehasonlítása



a röntgen az elektron-szerkezetet látja

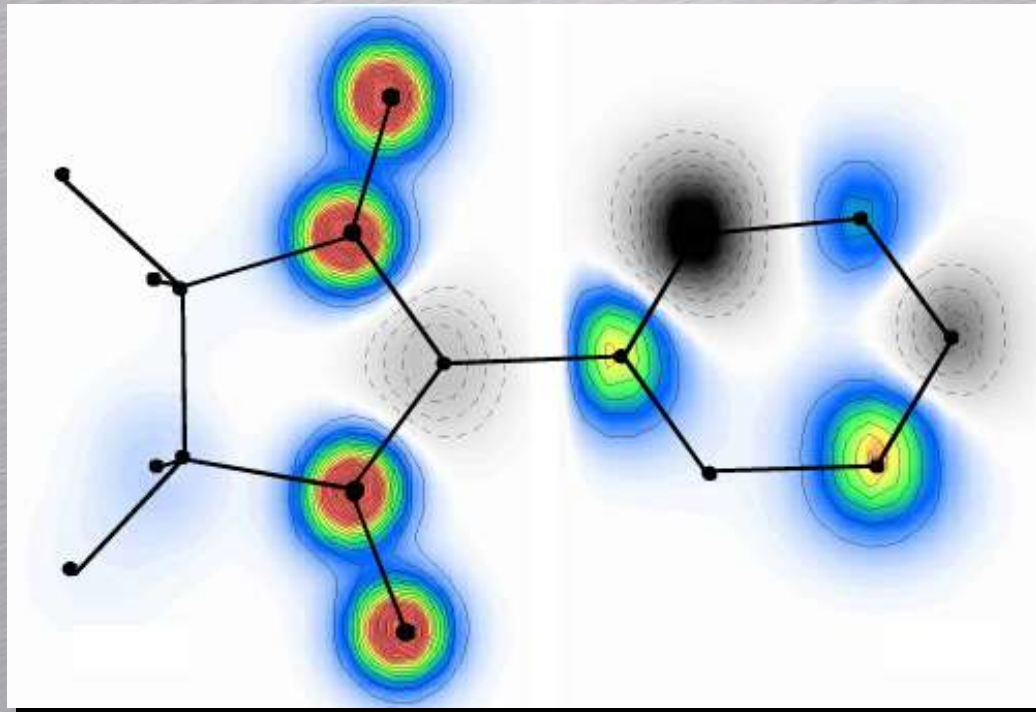


# de a felbontás sokkal jobb



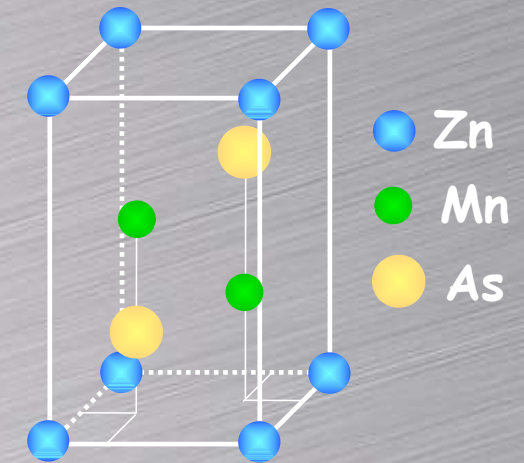
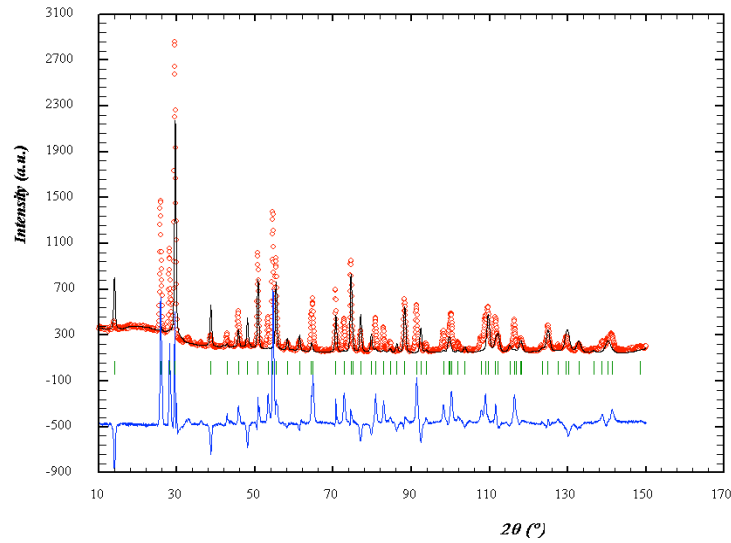
## További nagyon fontos előnyök:

- a mágneses szórás hasonlóan erős, mint a nukleáris!
- a szórási hossz izotóp-függése, pl: H/D !!



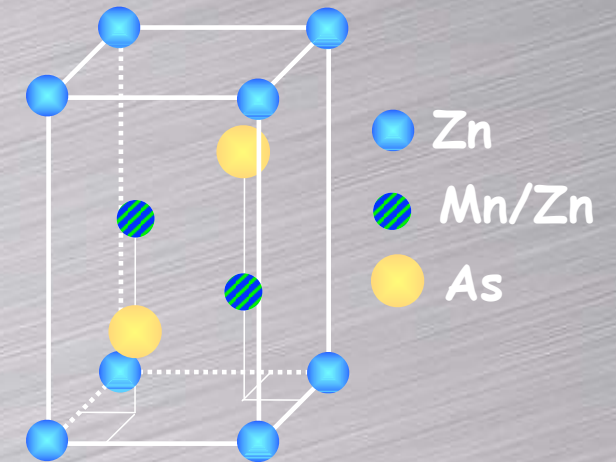
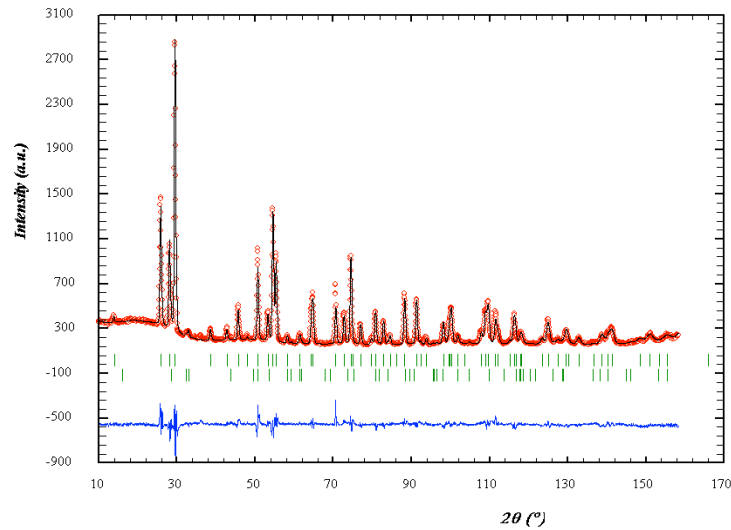
Mágnesezettségi térképek

# ZnMn<sub>2</sub>As<sub>2</sub>



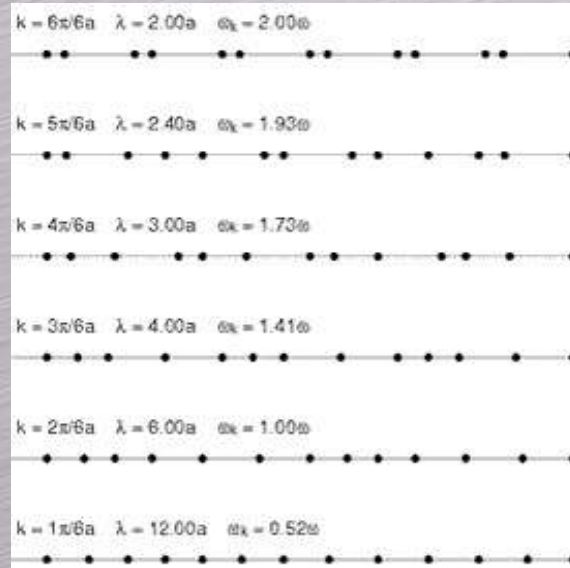
$$b_{\text{Mn}} = -0,373 \times 10^{-12} \text{ cm}$$

$$b_{\text{Zn}} = 0,568 \times 10^{-12} \text{ cm}$$



# Na és a mozgás?

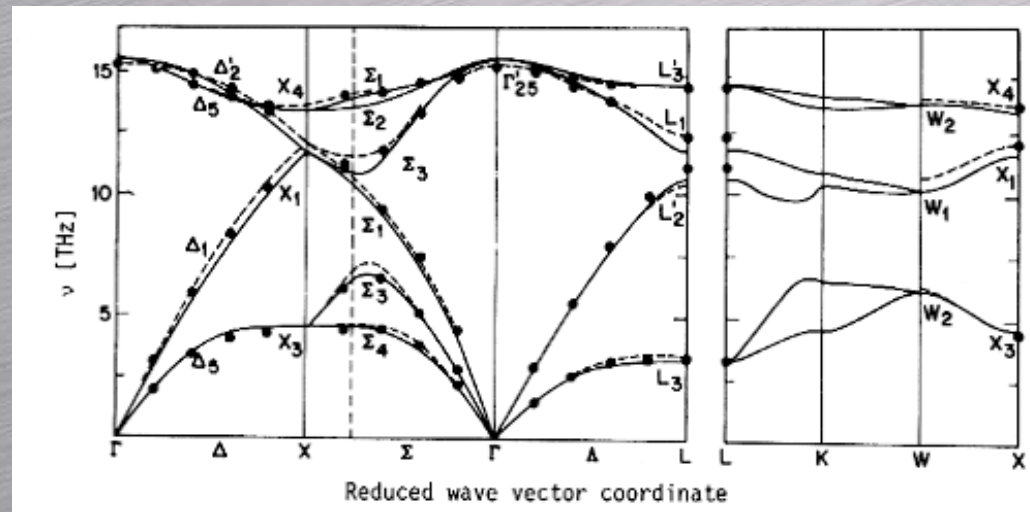
1994 Brokhause, Shull



A neutron a mozgó atomokról energiaveszteséggel (vagy nyereséggel) szóródik.

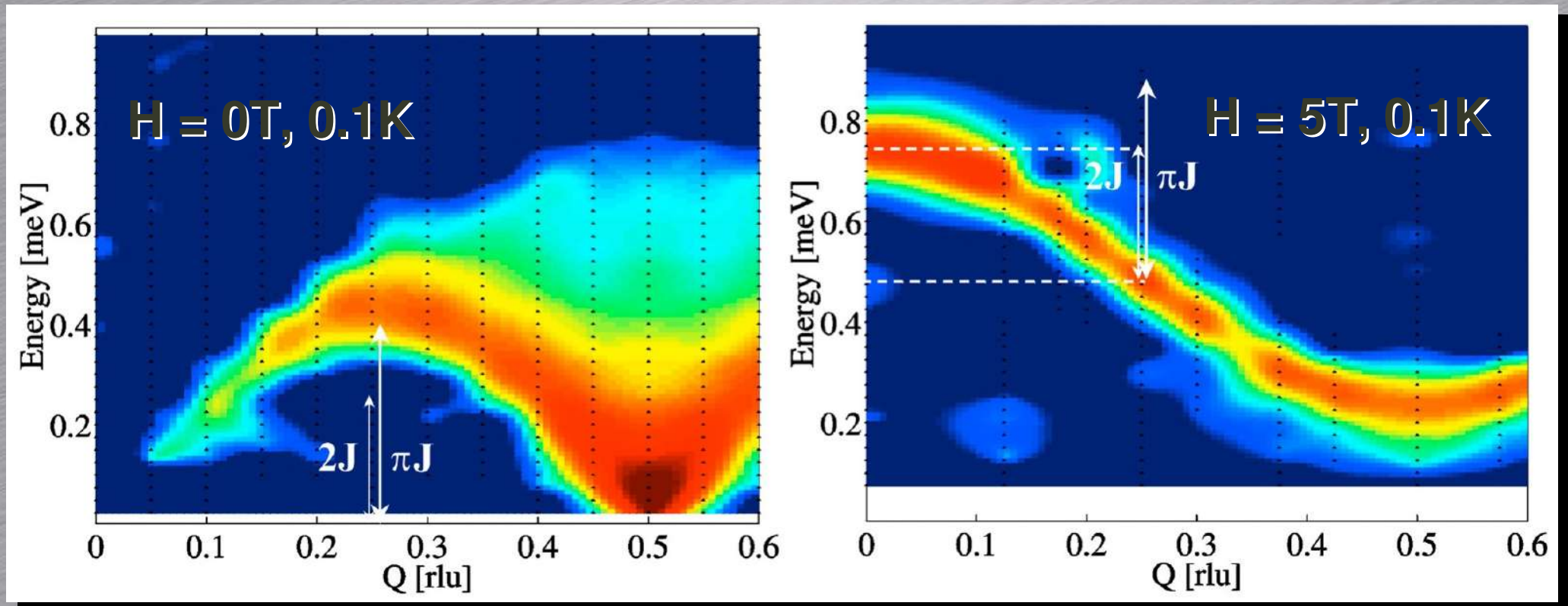
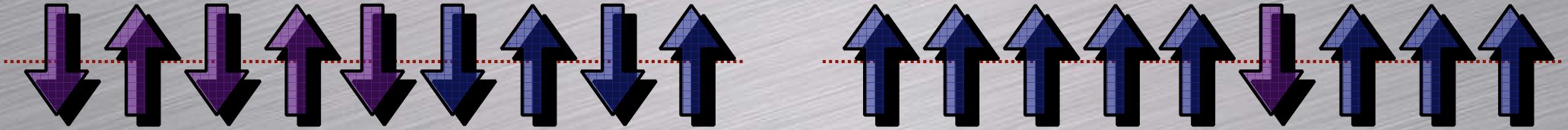
DE csak ha az **energia-** ÉS az **impulzus-**megmaradás is teljesül!

Si



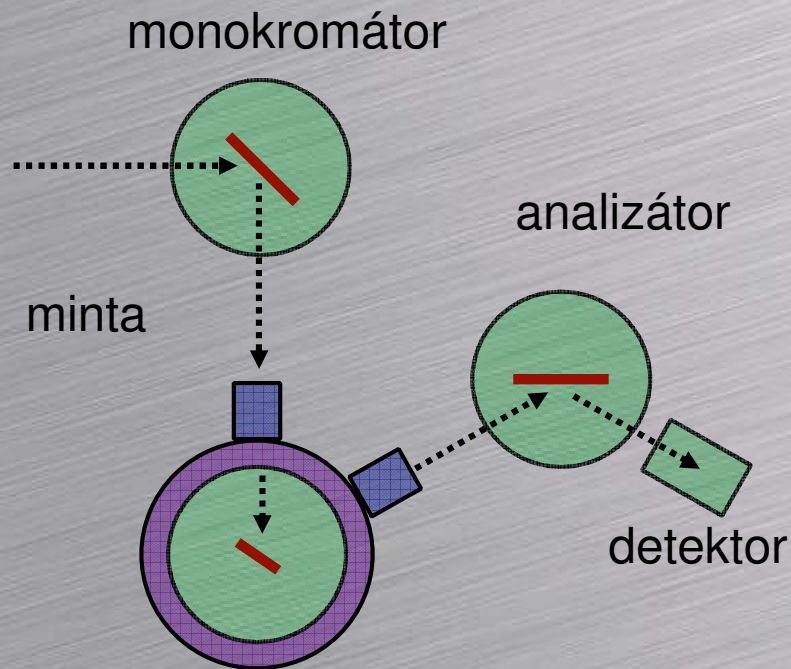


# mágneses gerjesztések $\text{CuSO}_4 \cdot 5 \text{D}_2\text{O}$ -ban (IN14)

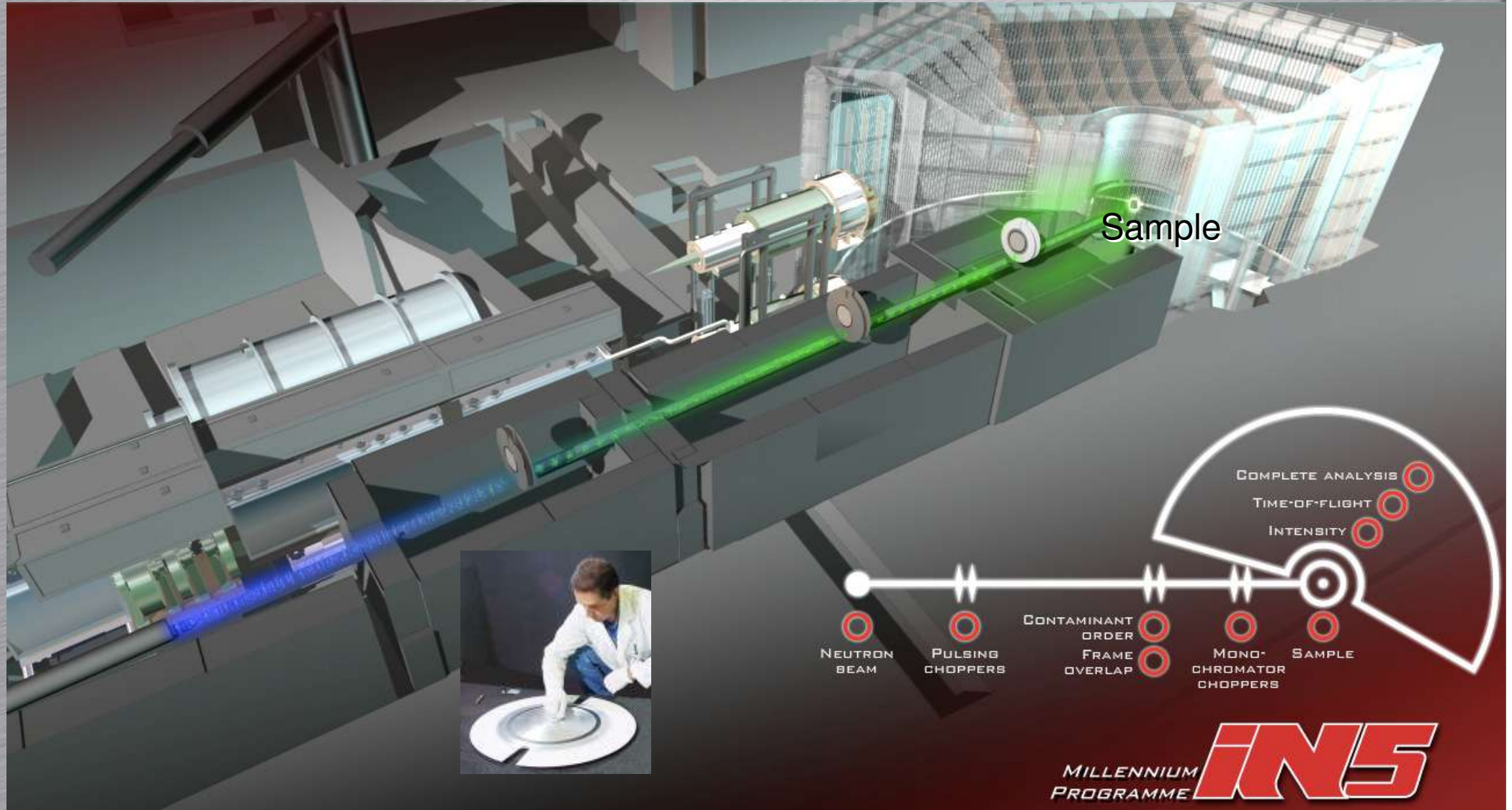


# 3 tengelyű spektrométer

egyszerre csak egy impulzus-energia pontot mér



# Repülési idő spektrométer (IN5 )

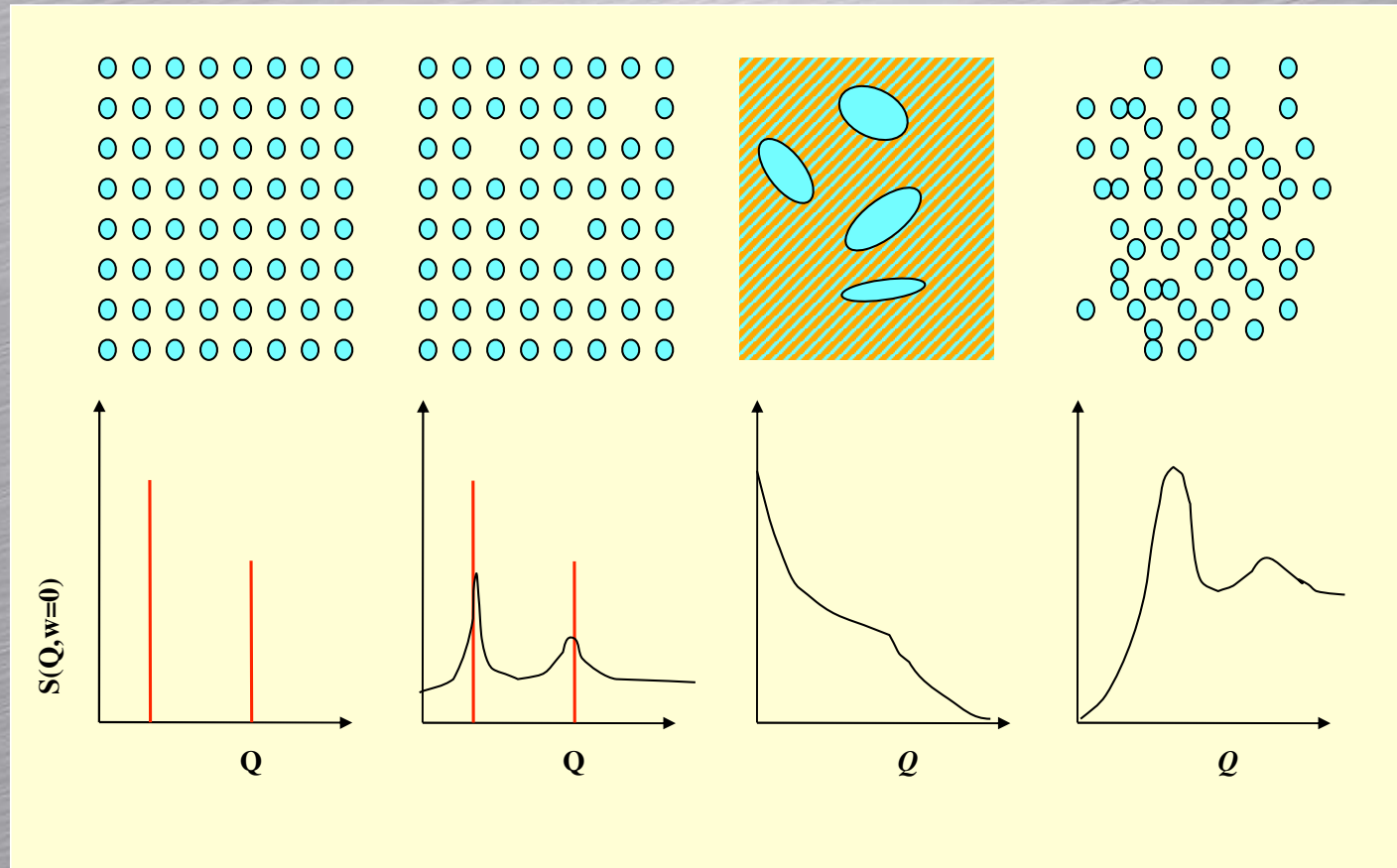


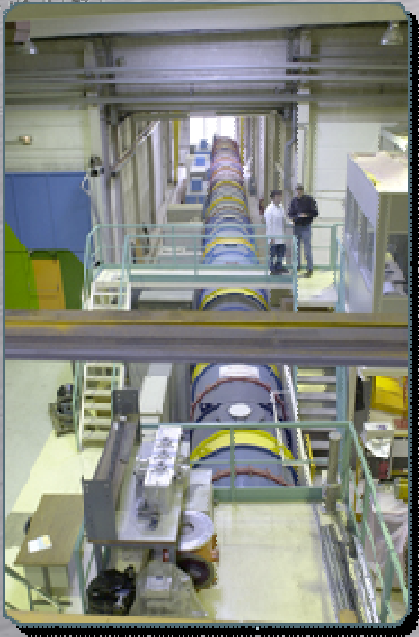
# Helyzetérzékelő detektorok



3 m magas

amikor nem annyira rendezett....

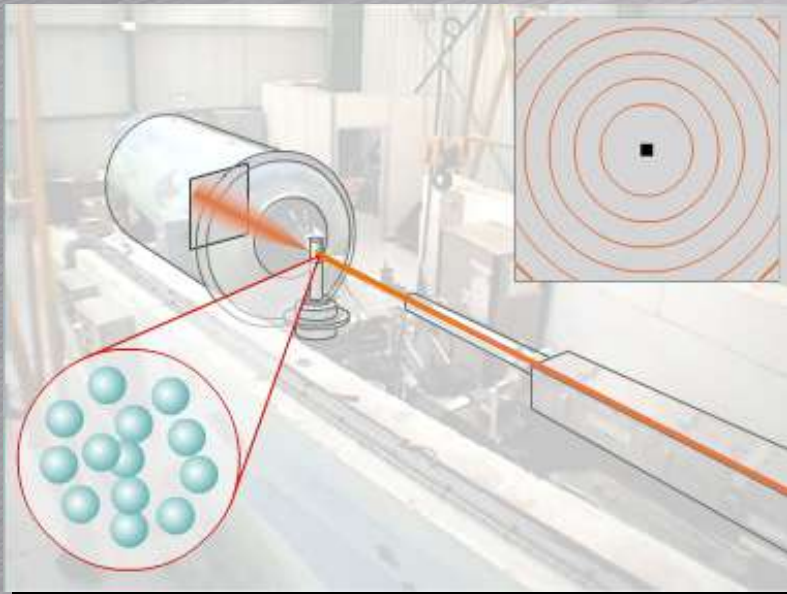




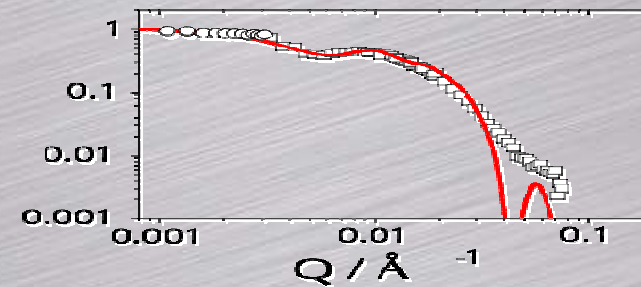
Polimerek, aggregátumok, mikroemulziók  
karakterisztikus méret: 10 – 1000 Å

(Fourier-transzformáció)

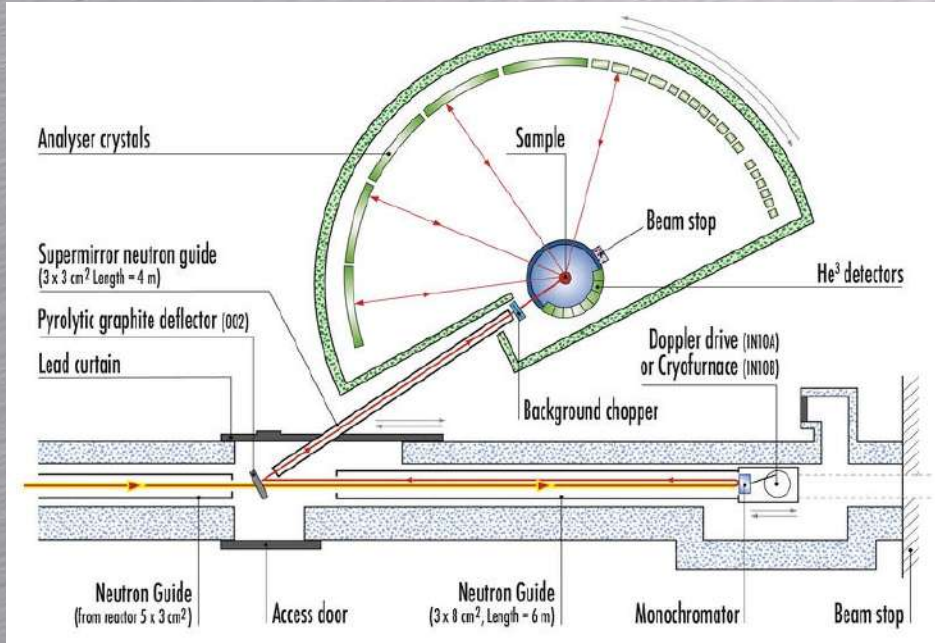
nagy méret  $\Rightarrow 4\pi/\lambda \sin(\Theta/2) \Rightarrow$   
 $\Rightarrow$  kicsi szórási szög



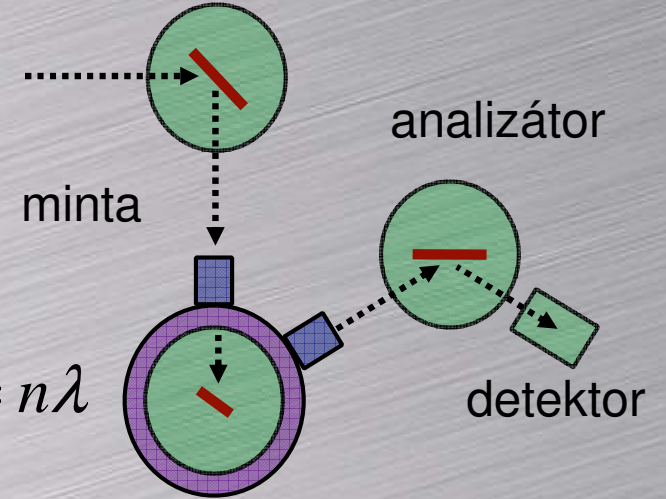
... és lassan mozog



jobb energia-felbontás kell: “hátraszórási” spektrométer

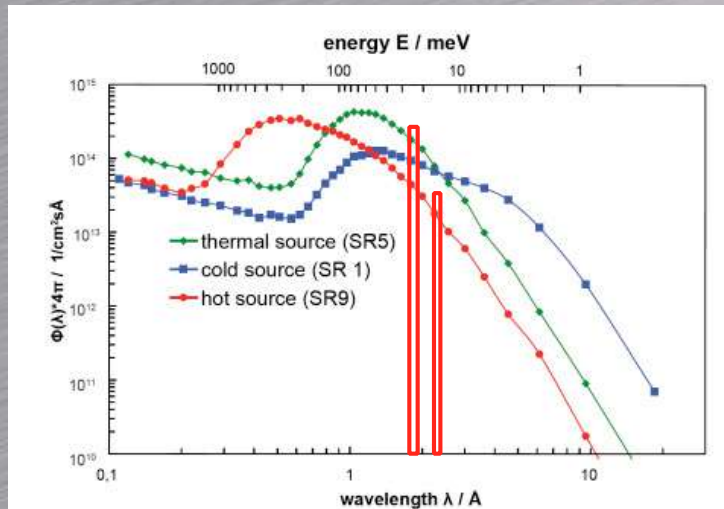


monokromátor



$$2d \sin(\Theta) = n\lambda$$

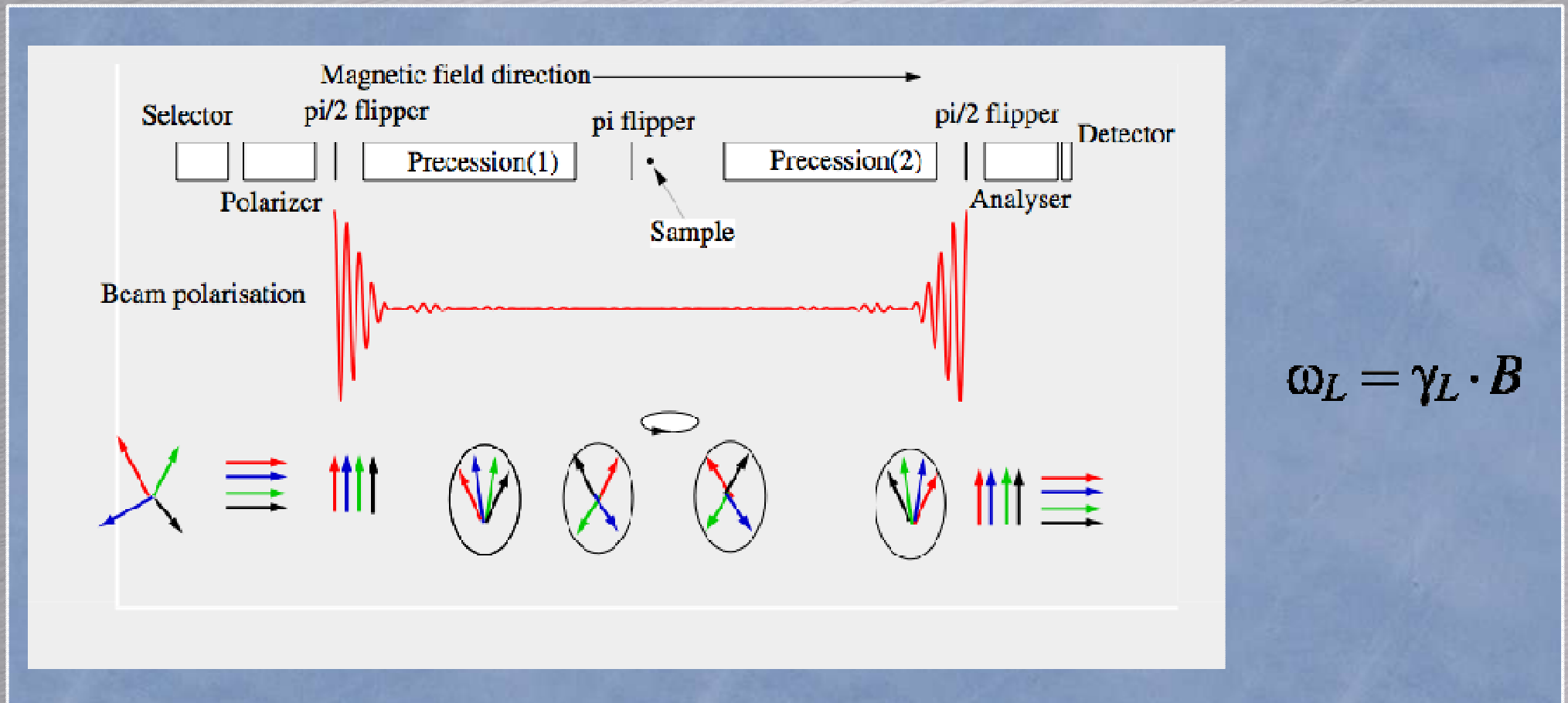
Elfogy az intenzitás!!!



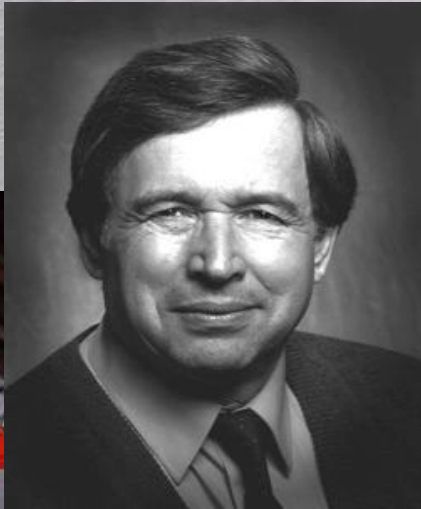
Lehetne ezt jobban is csinálni?

Klasszikus módszer:  
energiacsere = (energia szórás előtt) - (energia szórás után)

Mérjük CSAK az energiacserét!!!





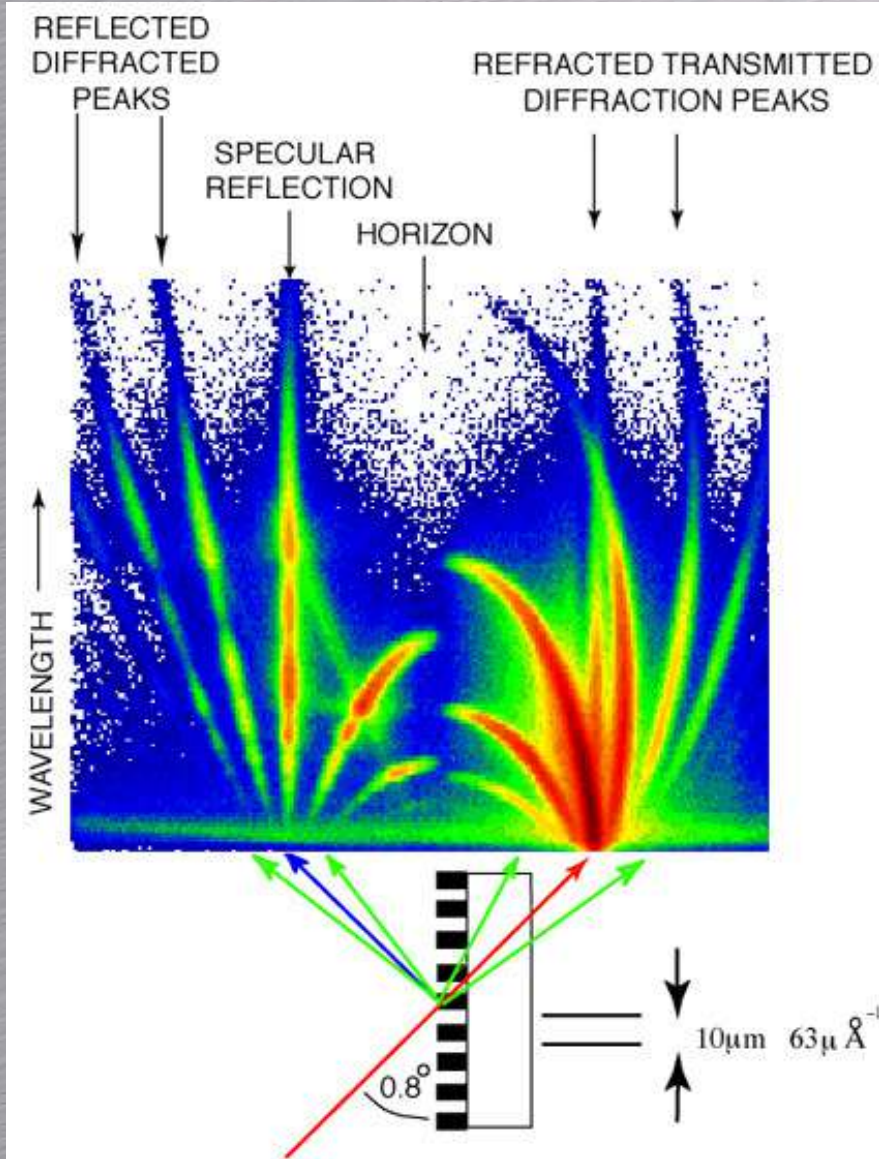


# Neutron Spin Echo

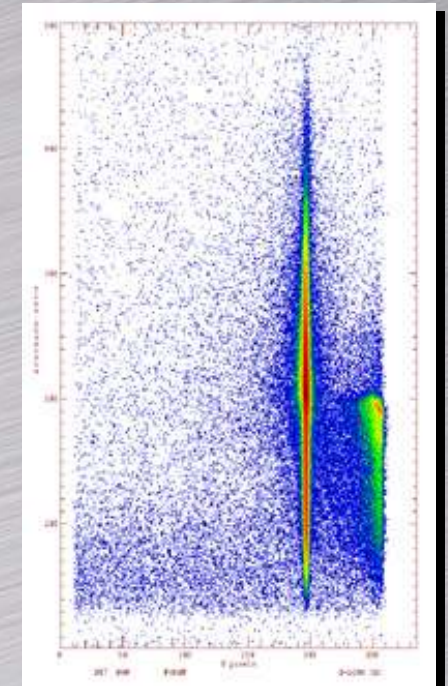
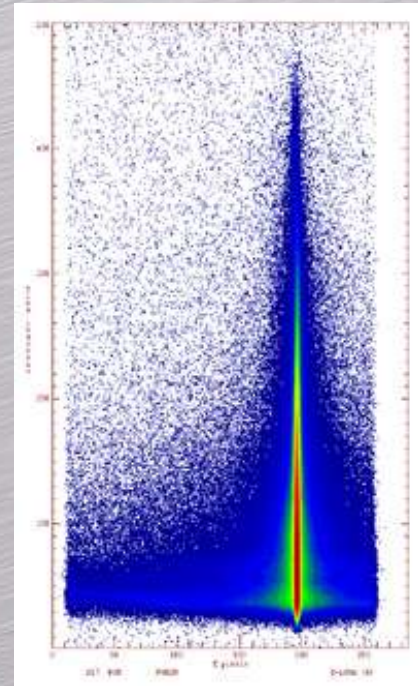
Mezei Ferenc 1972-ben gondolta ki (és csinálta meg)



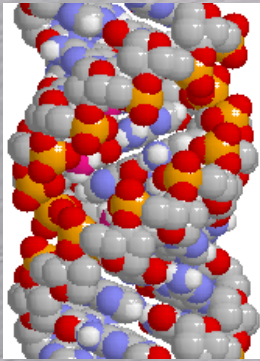
# Demo klasszikus és kvantum módon....



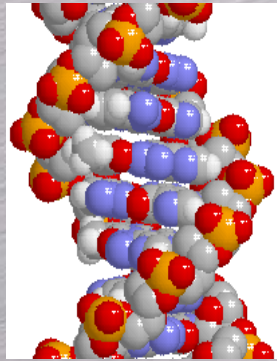
A felületről tükröződött, szórt neutronok hasonlóan sok információt hordoznak



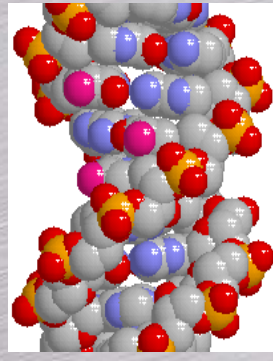
# DNS polimer szerkezetek Trevor Forsyth



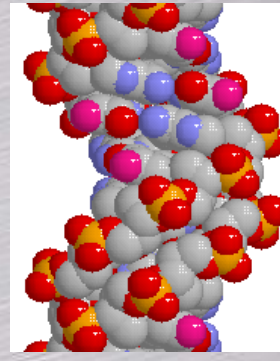
A-DNS  
RH  
11 bp/turn  
pitch=28.2Å



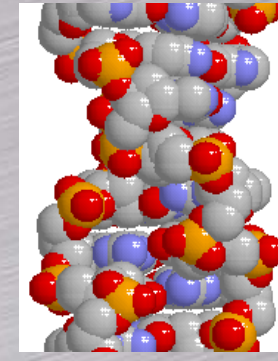
B-DNS  
RH  
10 bp/turn  
pitch=34Å



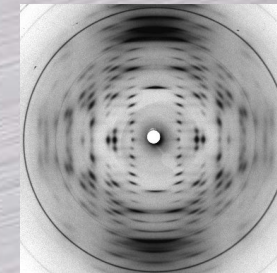
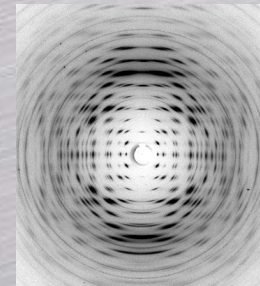
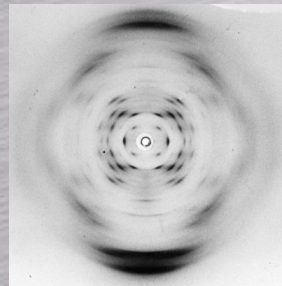
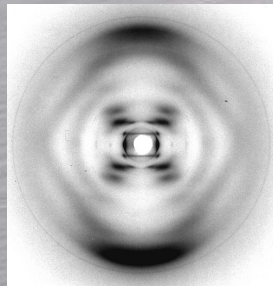
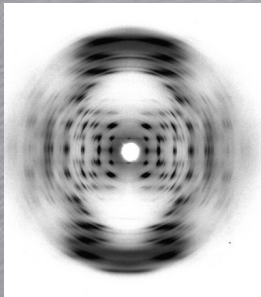
C-DNS  
RH  
9.33 bp/turn  
pitch=31Å



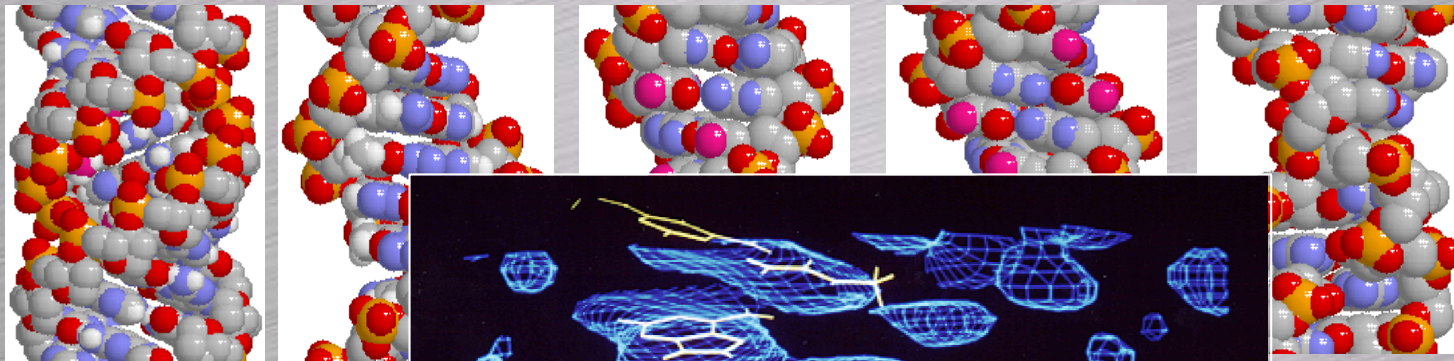
D-DNS  
RH  
8 bp/turn  
pitch=24.2Å



Z-DNS  
LH  
12 bp/turn  
pitch=43Å



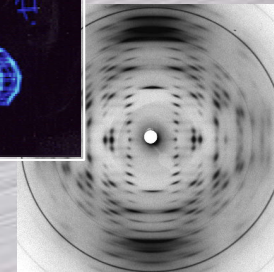
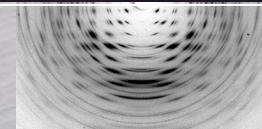
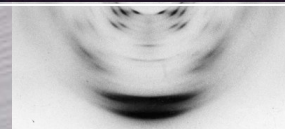
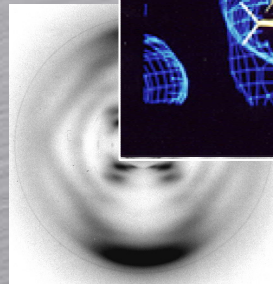
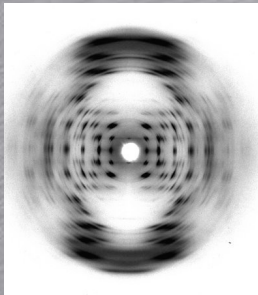
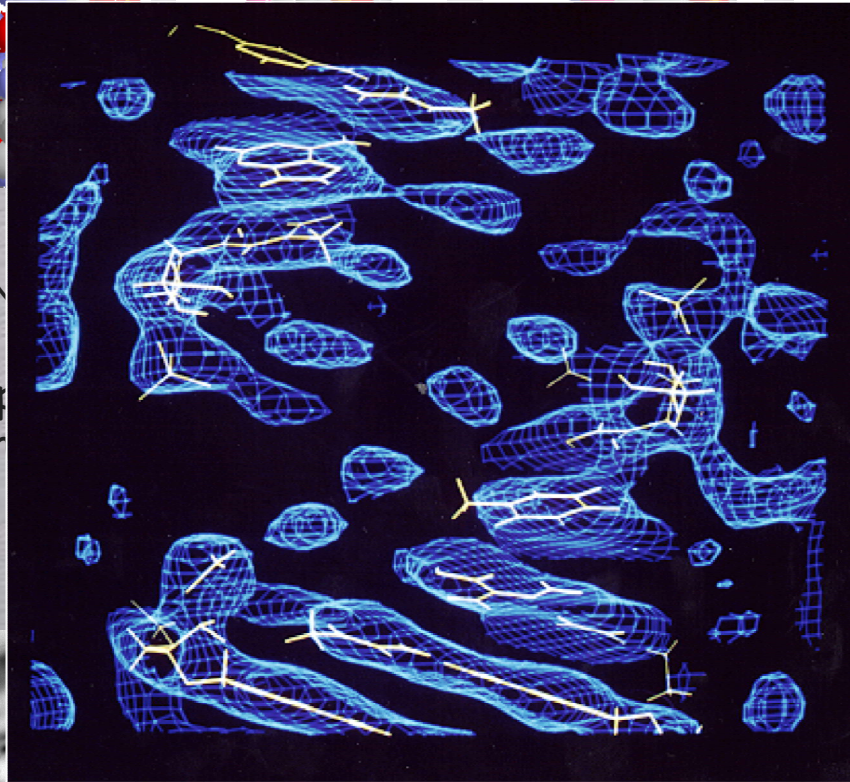
# DNS polimer szerkezetek Trevor Forsyth



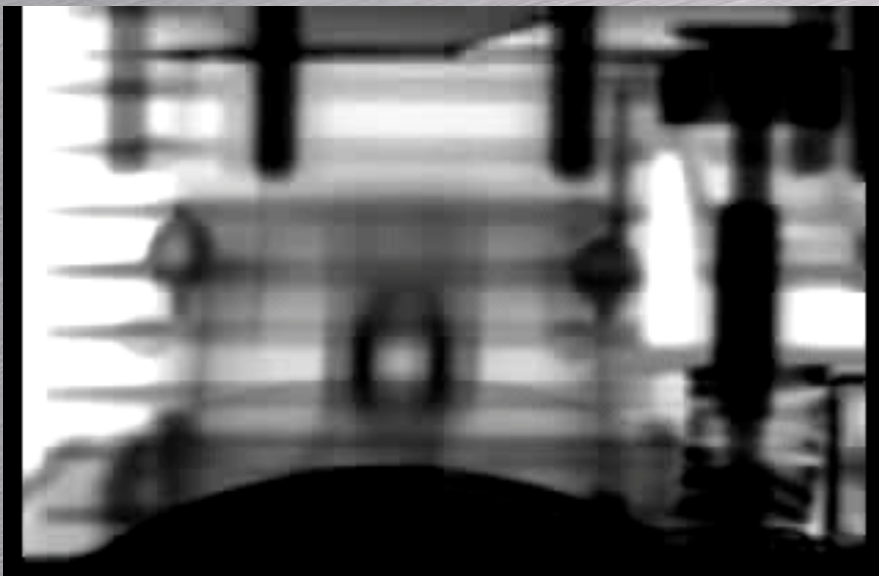
A-DNA  
RH  
11 bp/turn  
pitch=28.2Å

B-DNA  
RH  
10 bp/turn  
pitch=34.4Å

C-DNA  
RH  
11 bp/turn  
pitch=43Å



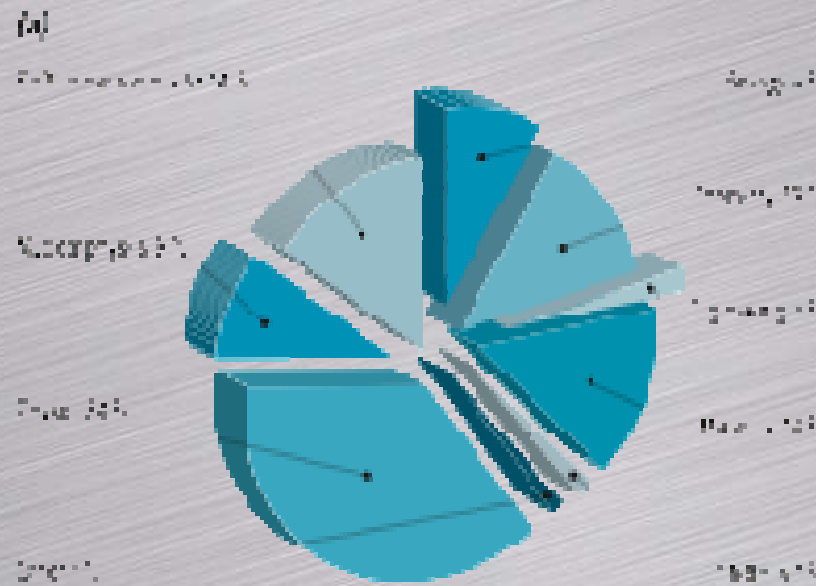
## Neutron-radiográfia



## Neutron-tomográfia

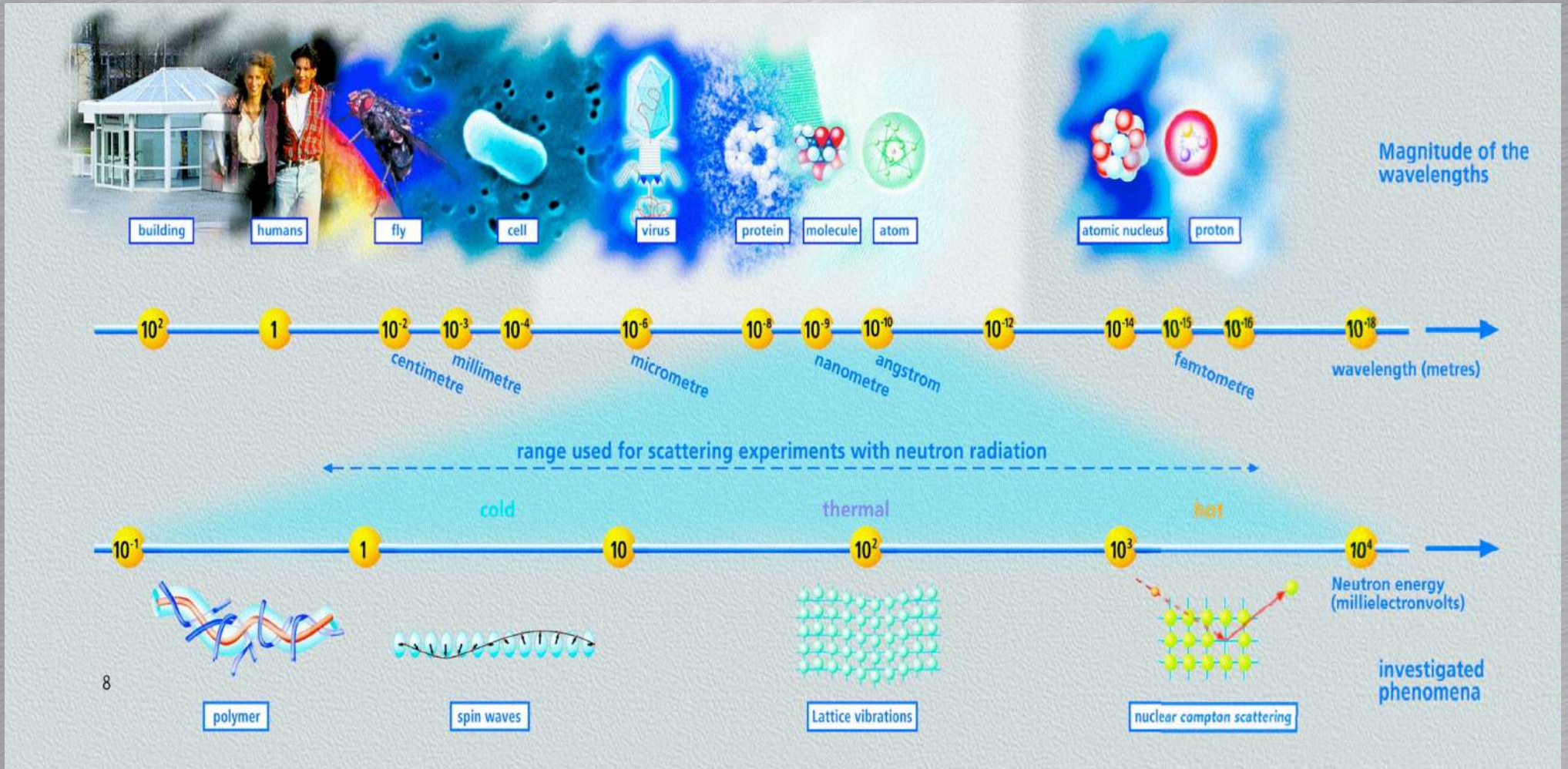
### Neutron tomography of a camera lense.

Dr. B.Schillinger, TU Munich  
Peter Vontobel, PSI  
Eberhard Lehmann, PSI



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