

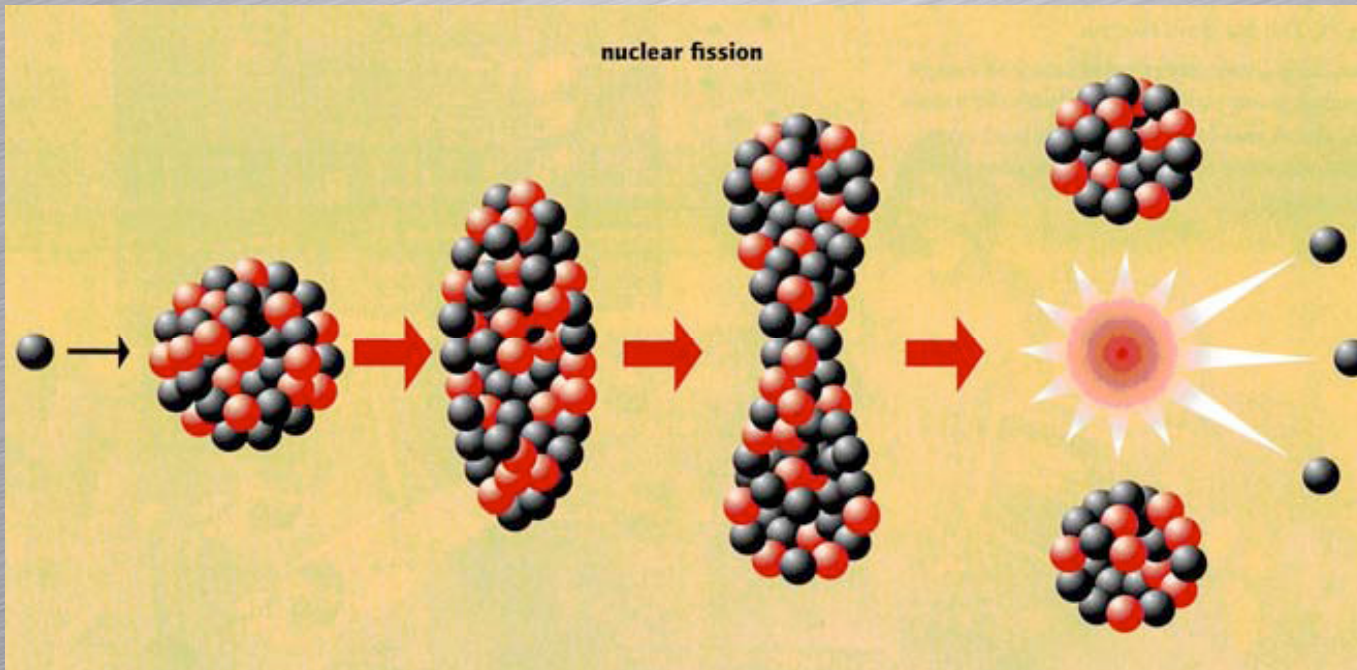
Kurkászó neutronok, avagy hogyan látjuk az atomok mozgását

Faragó Béla
Institut Laue Langevin,
Grenoble

Szucsán András fizikatanárom emlékére 1935 -2013



Hogyan keletkeznek neutronok....



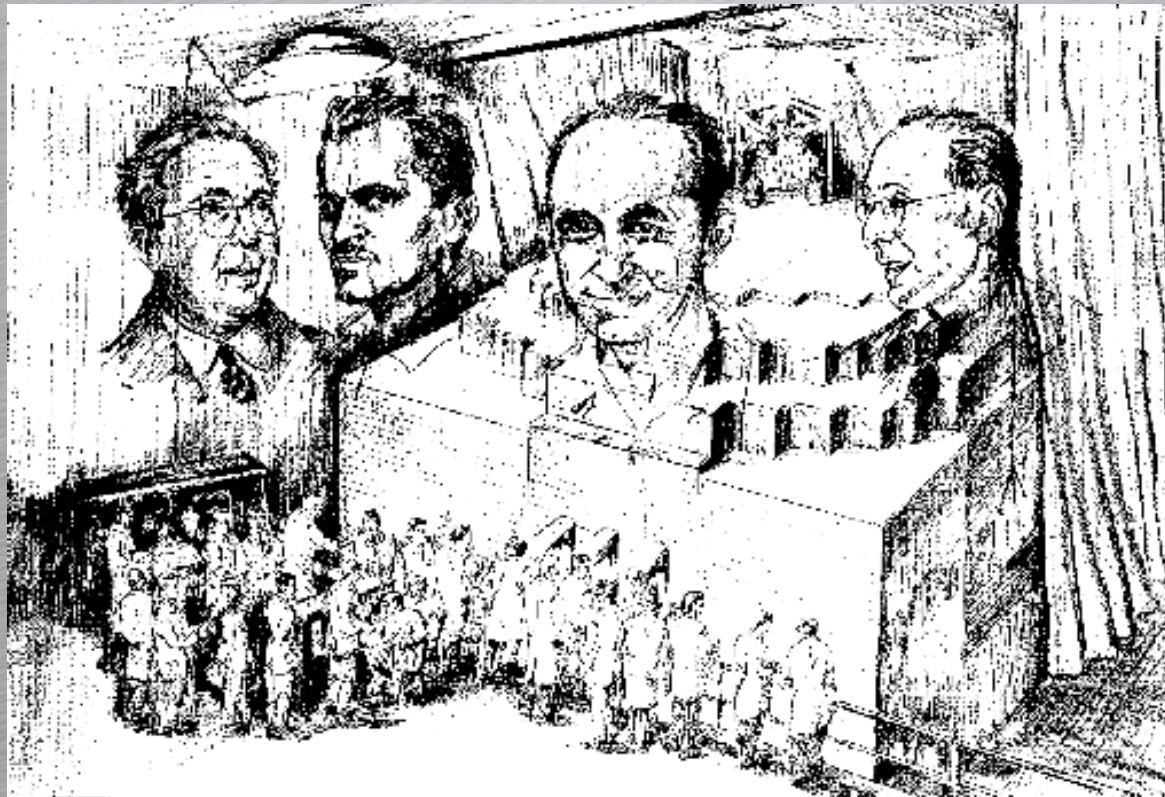
Példa: 60 MW kutató reaktor

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

5×10^{18} neutron/sec generálódik a teljes reaktor-térfogatban

1942 december 2. Az első tartós láncreakció Chicago

Szilárd Compton Fermi Wigner

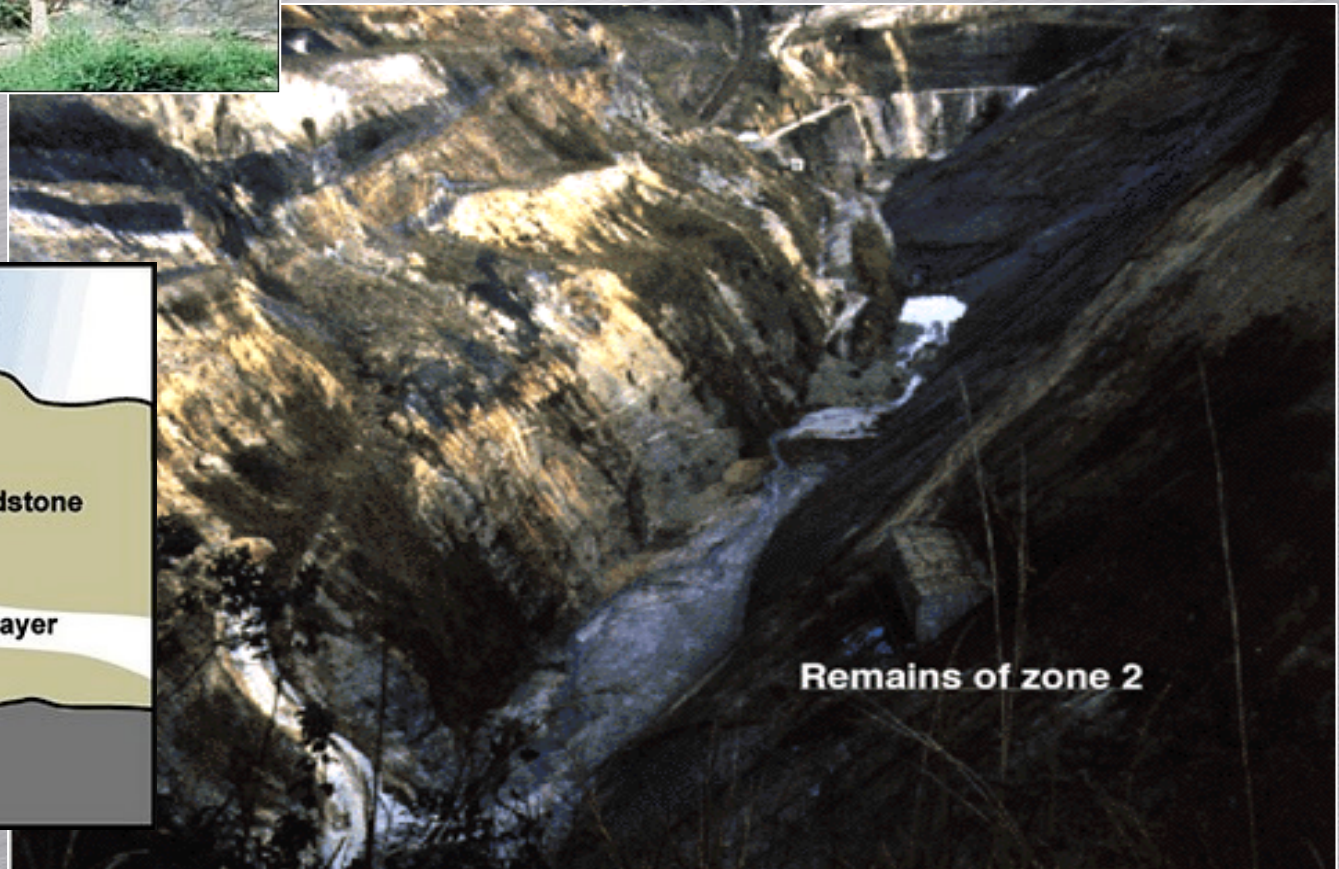
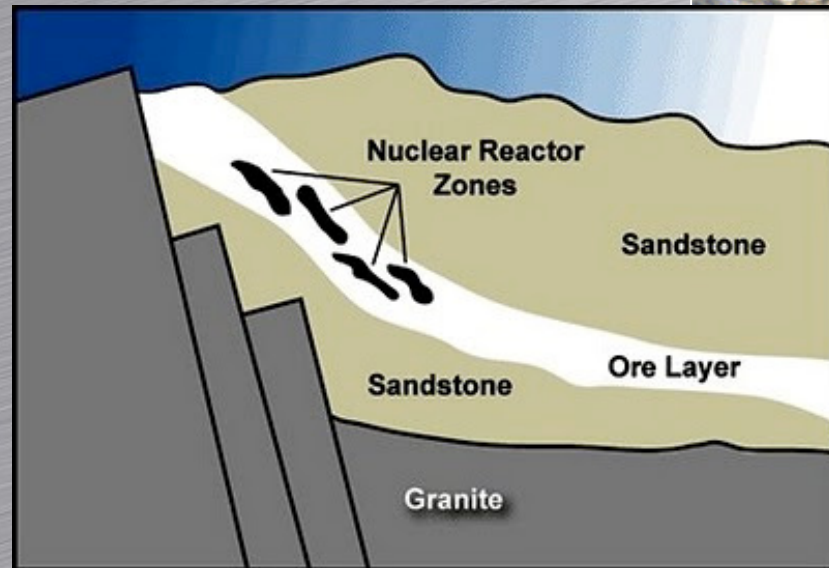
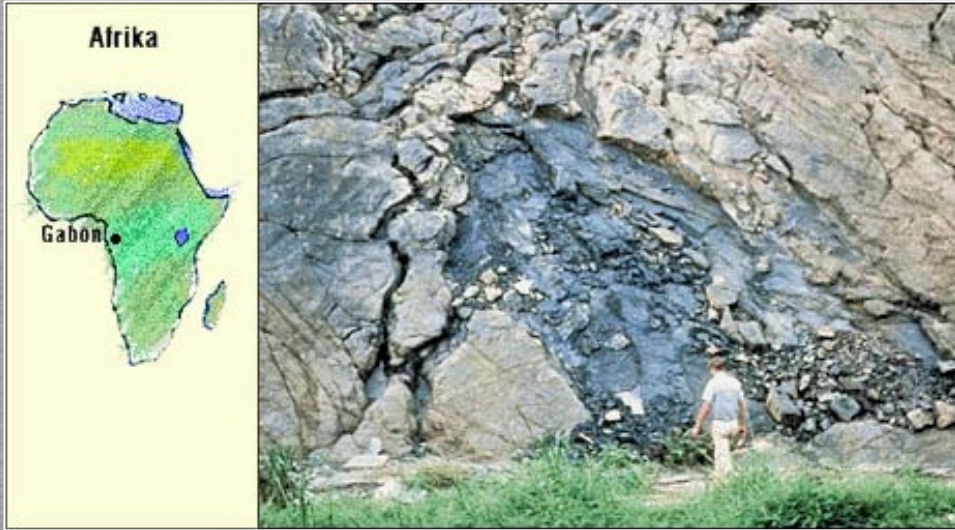


Az Oklo-jelenség (Gabon): természetes atomreaktor

1972-ben nyilvánosságra hozott tények:
helyenként: $1,5 \times 10^{21}$ n/cm² (ILL 10^{15} !)
.... 1800 millió évvel ezelőtt

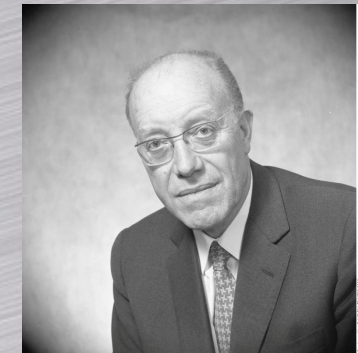
Forrás:

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



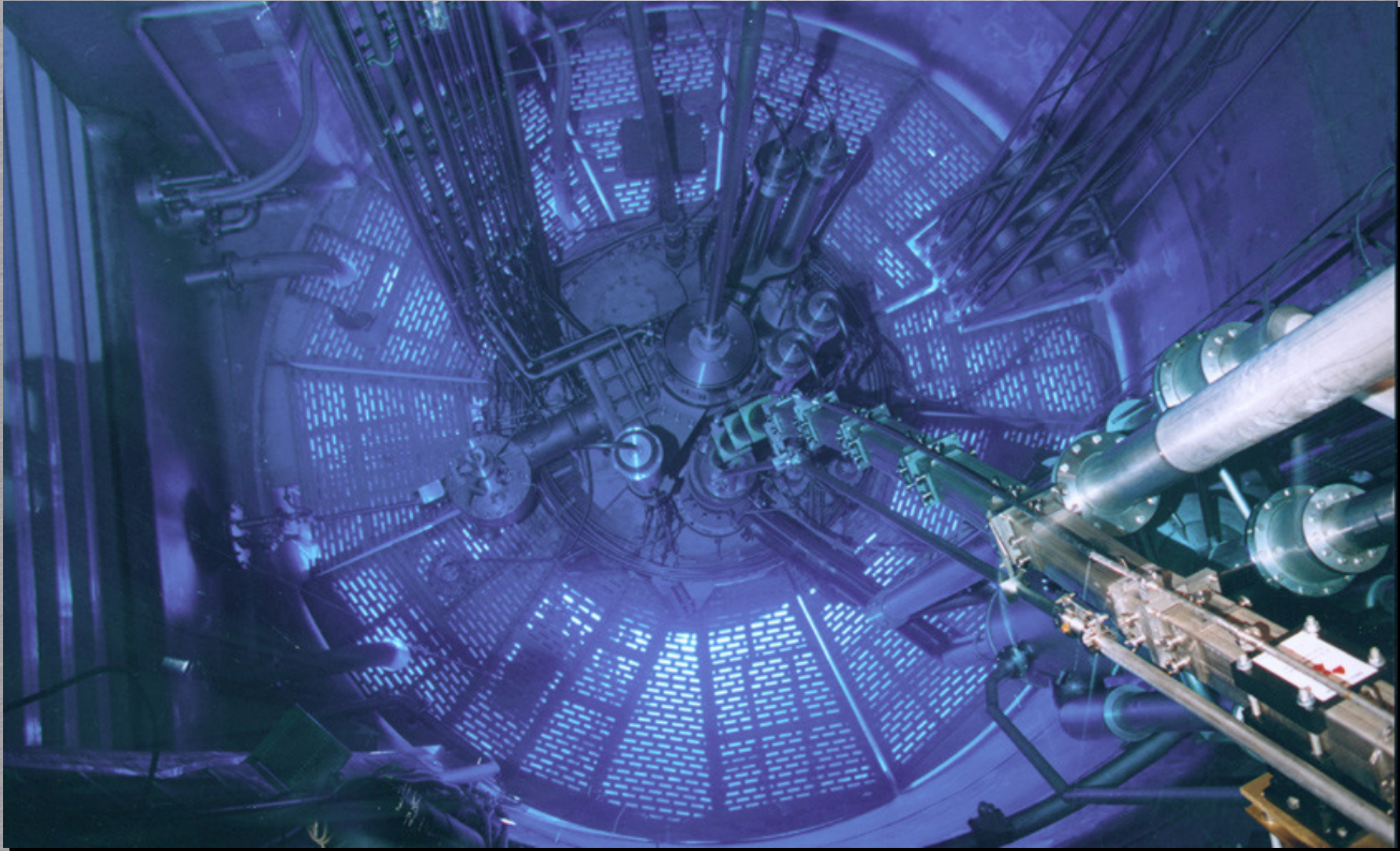
Az ILL alapítása

- **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...

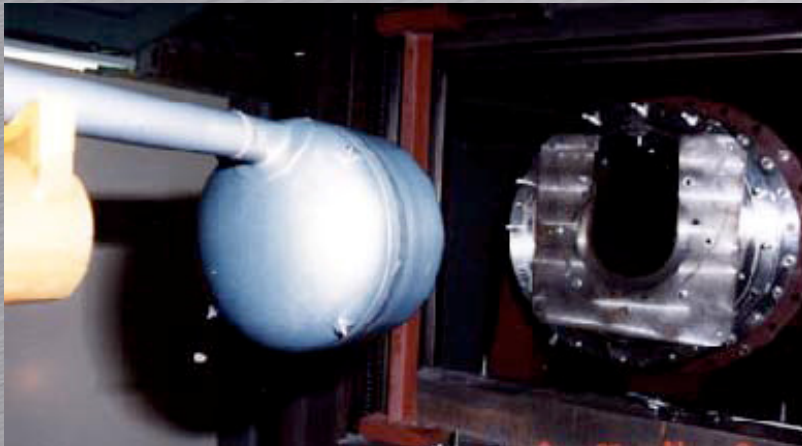
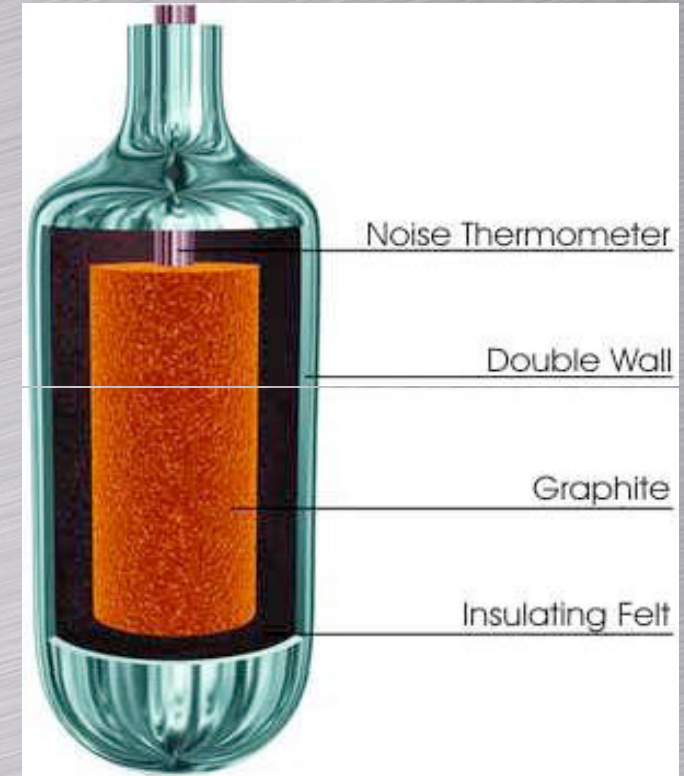
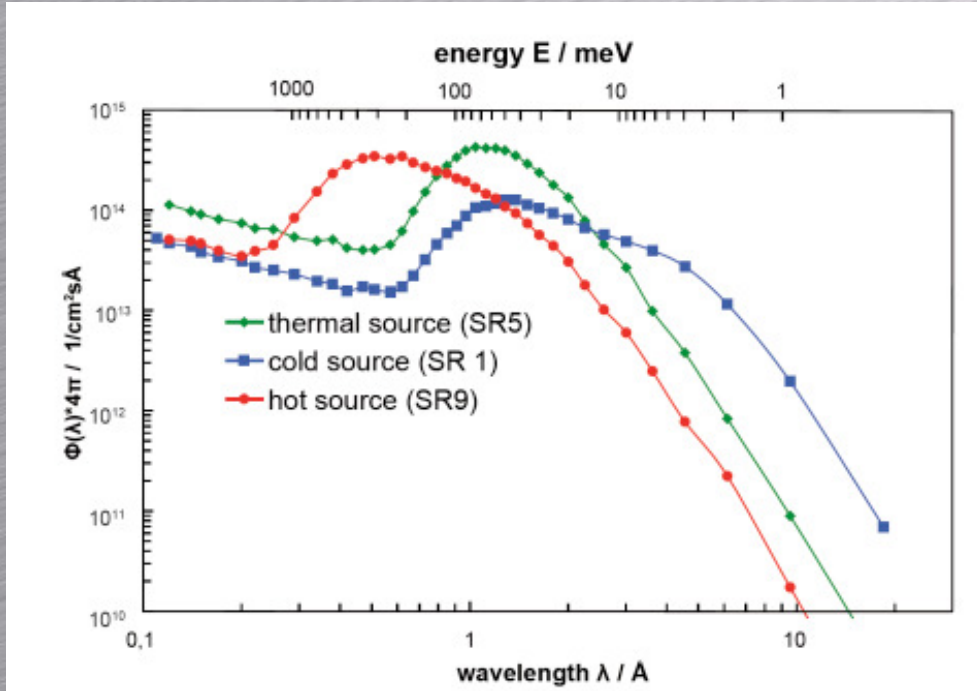


Institut Max von Laue - Paul Langevin





Mért neutron-spektrum (FRM-II München)



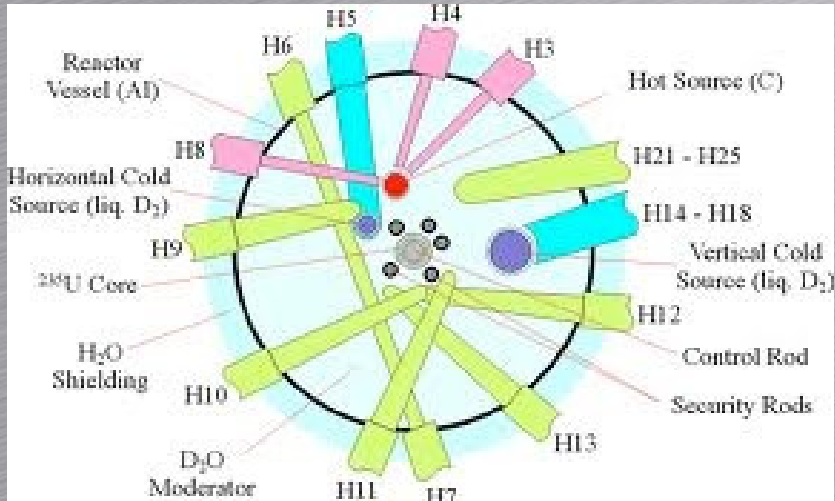
Hideg forrás
20 K (D_2)

Meleg forrás
2000 K (grafit)

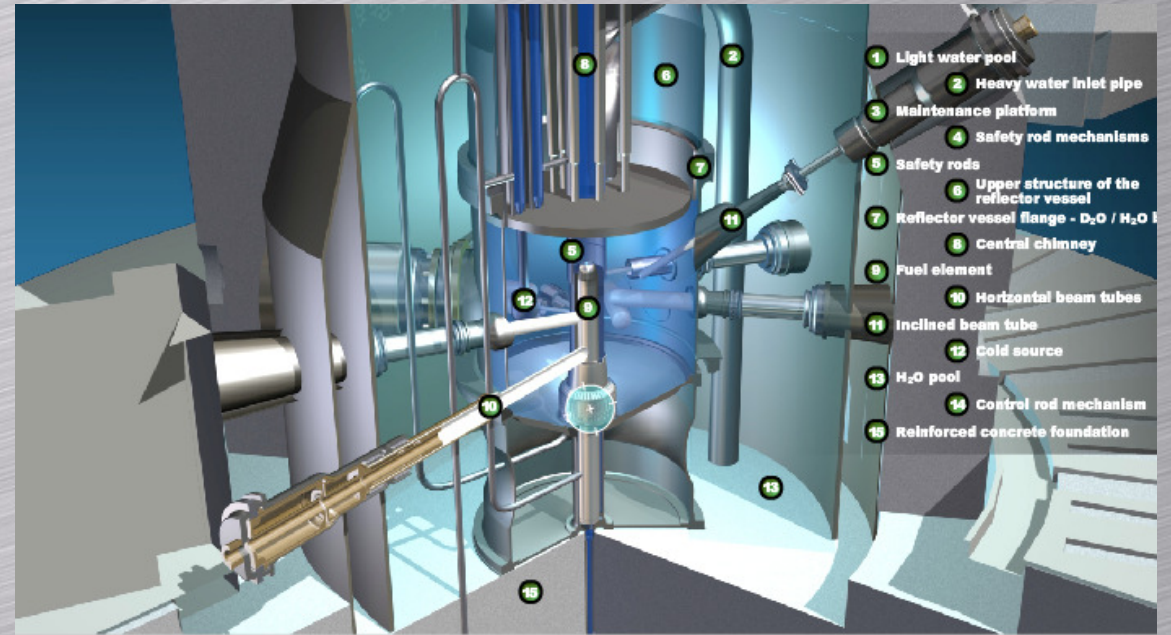
Reaktor dupla héj



neutron-nyalábok

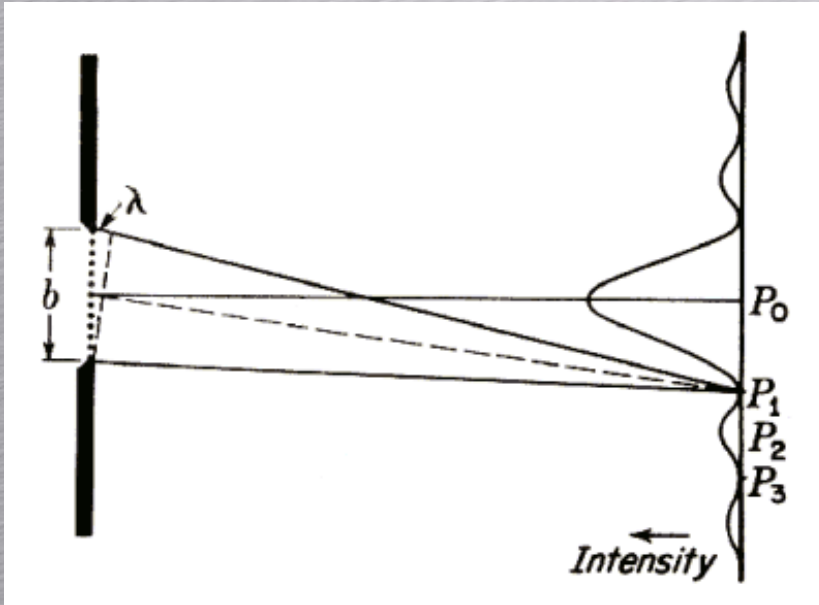


Reaktor aktív zóna



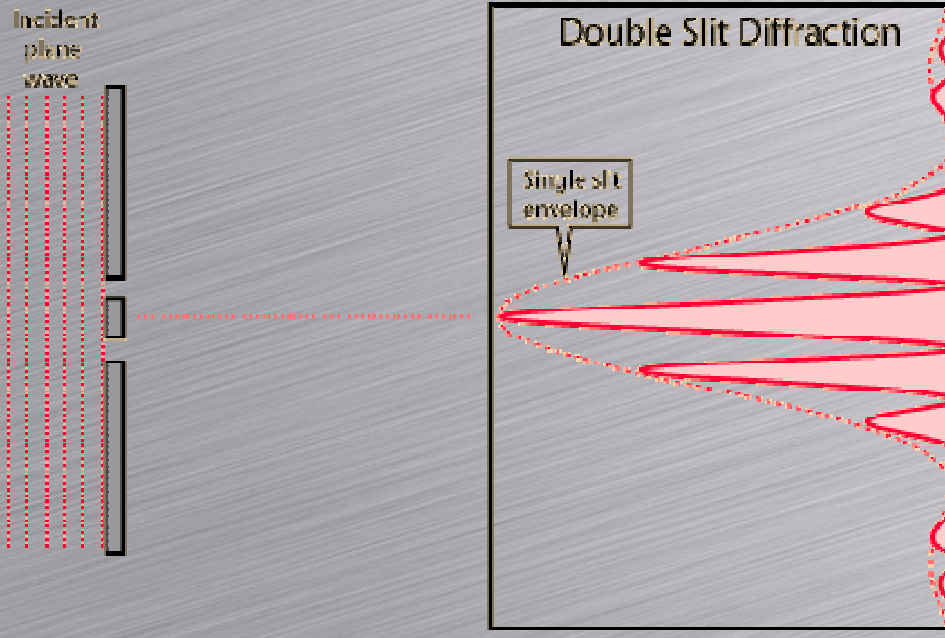
Fűtőelem 8,6 kg U²³⁵





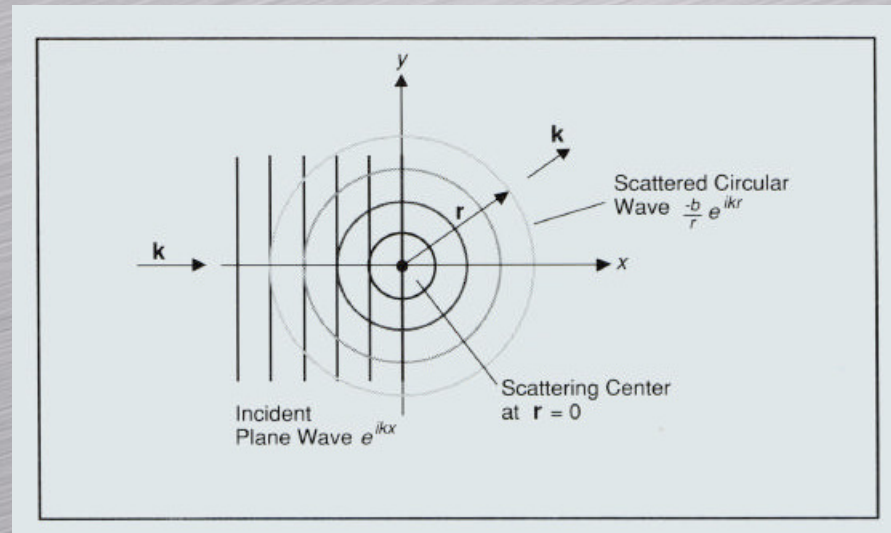
Fényelhajlás

A neutronnak is van hullámtermészete

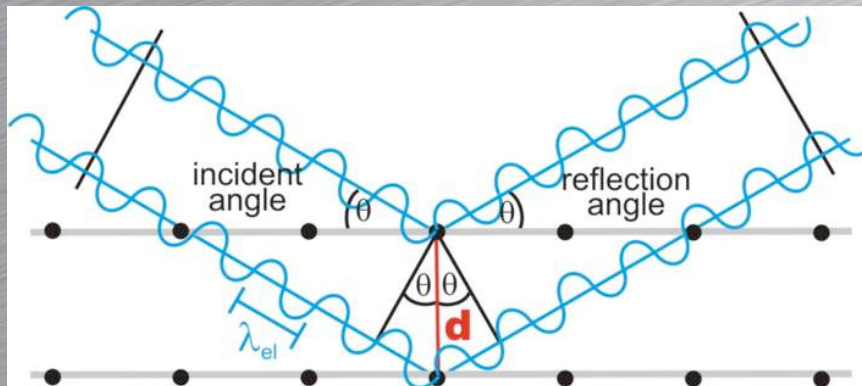


“Csak a kezemet figyeljék, mert csalog”
A Fourier-transzformációt most nem ismertetjük..... vagy mégis?

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



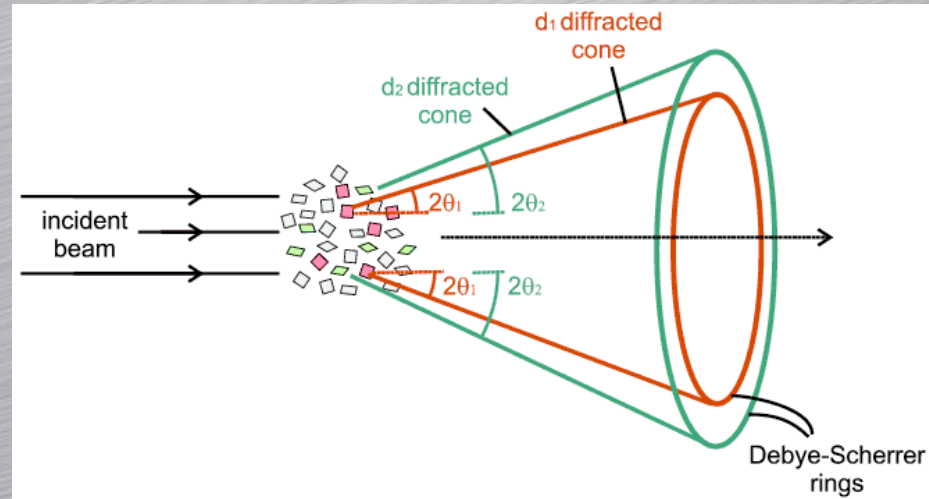
Egy kristályban adott hullámhosszú neutron csak bizonyos irányokba tud szóródni.



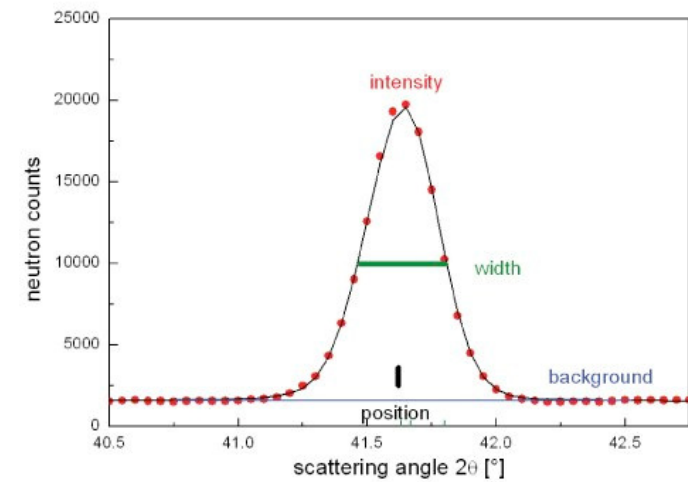
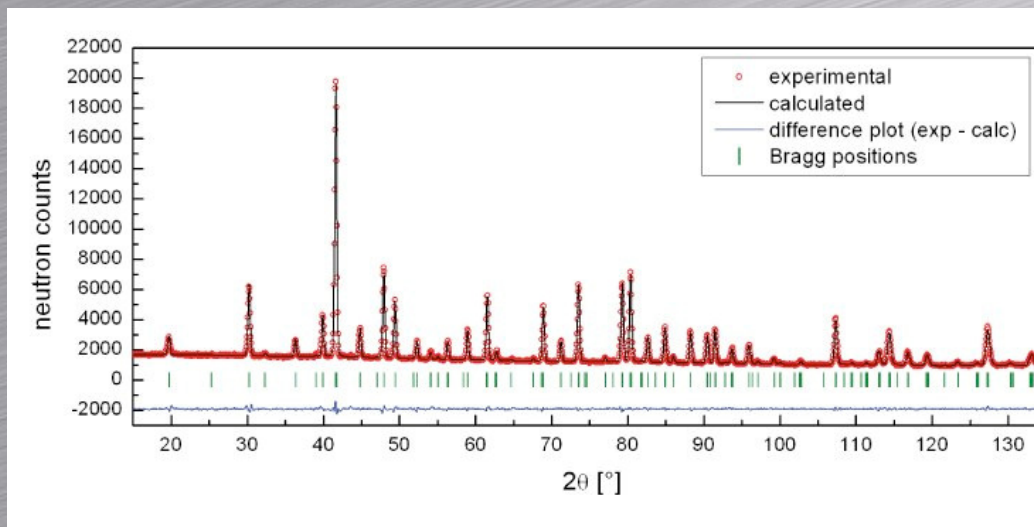
Bragg-törvény
(2014 a krisztallográfia éve!)

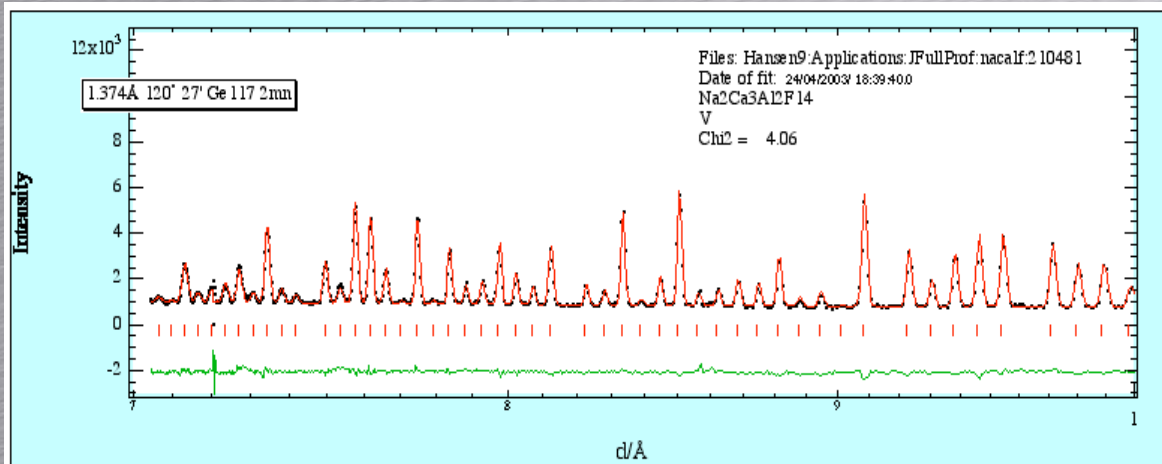
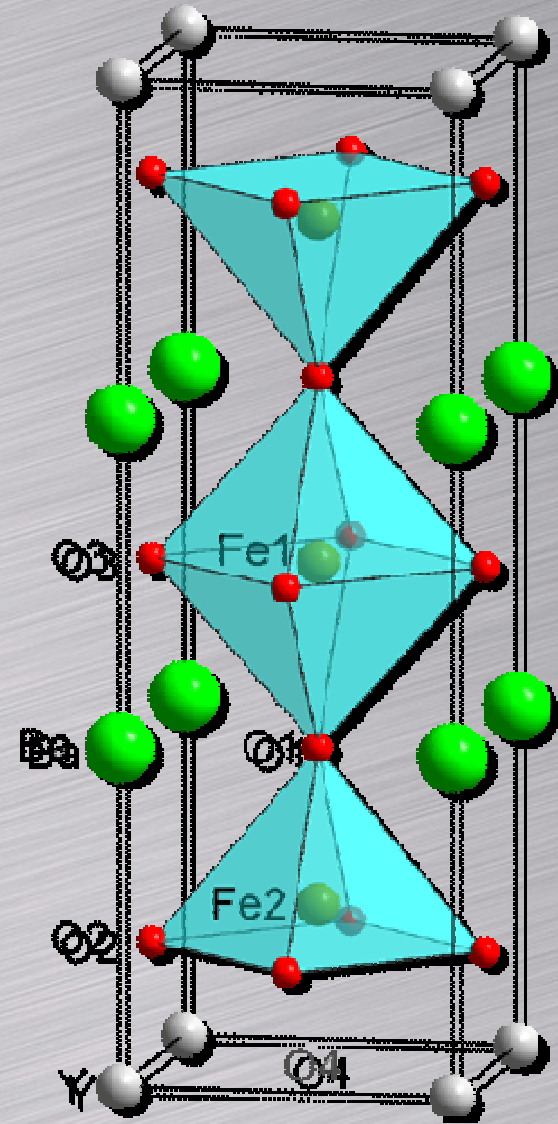
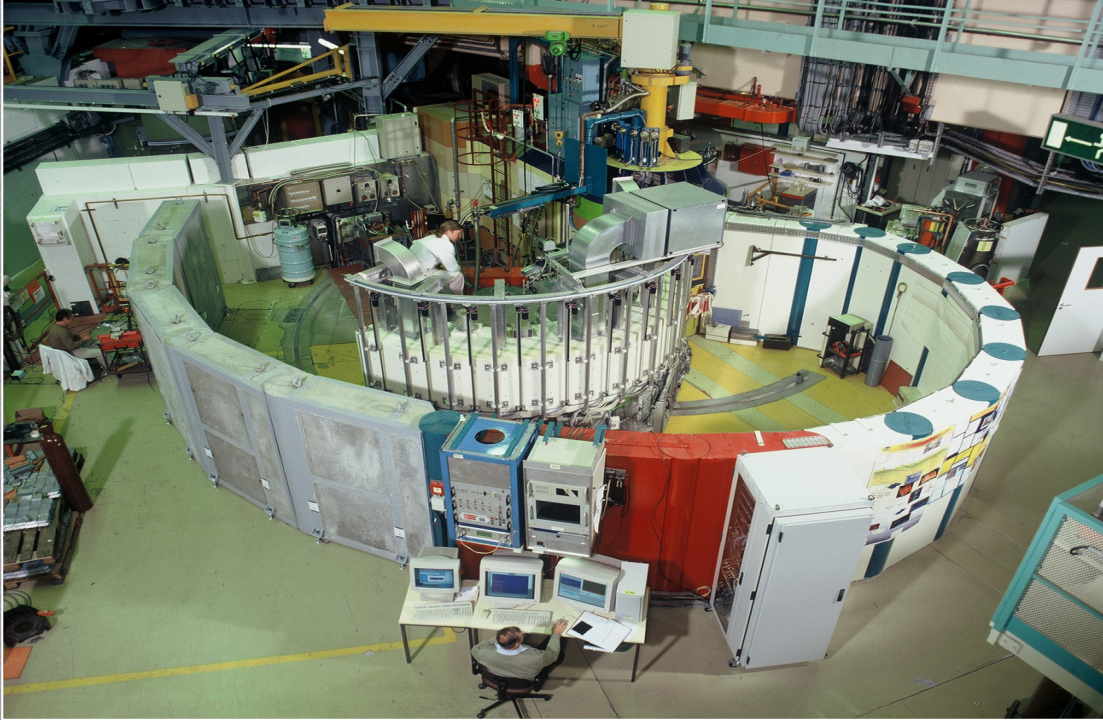
$$2d \sin(\Theta) = n\lambda$$

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 | 10×10 | 10^{11} |
| Rotating Anode | 10^{16} | 3 | 0.5×10 | 5×10^{10} |
| Bending Magnet | 10^{24} | 0.01 | 0.1×5 | 5×10^{17} |
| Wiggler | 10^{26} | 0.01 | 0.1×1 | 10^{19} |
| Undulator (APS) | 10^{33} | 0.01 | 0.01×0.1 | 10^{24} |

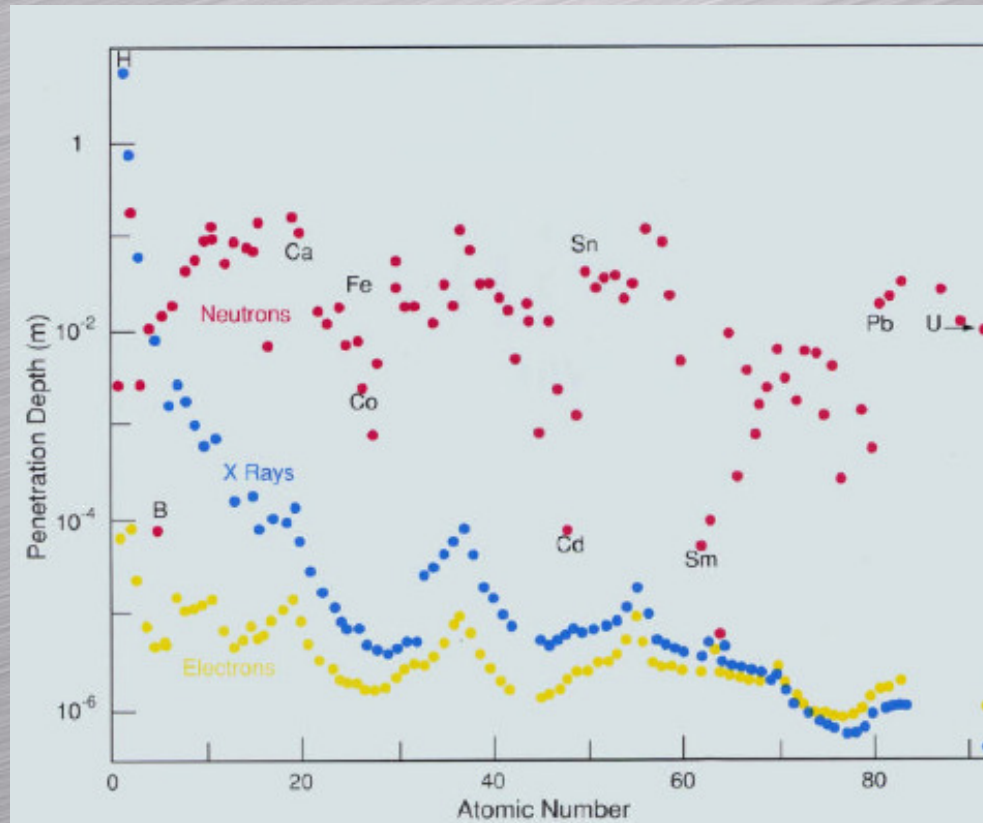
neutron vs röntgen

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

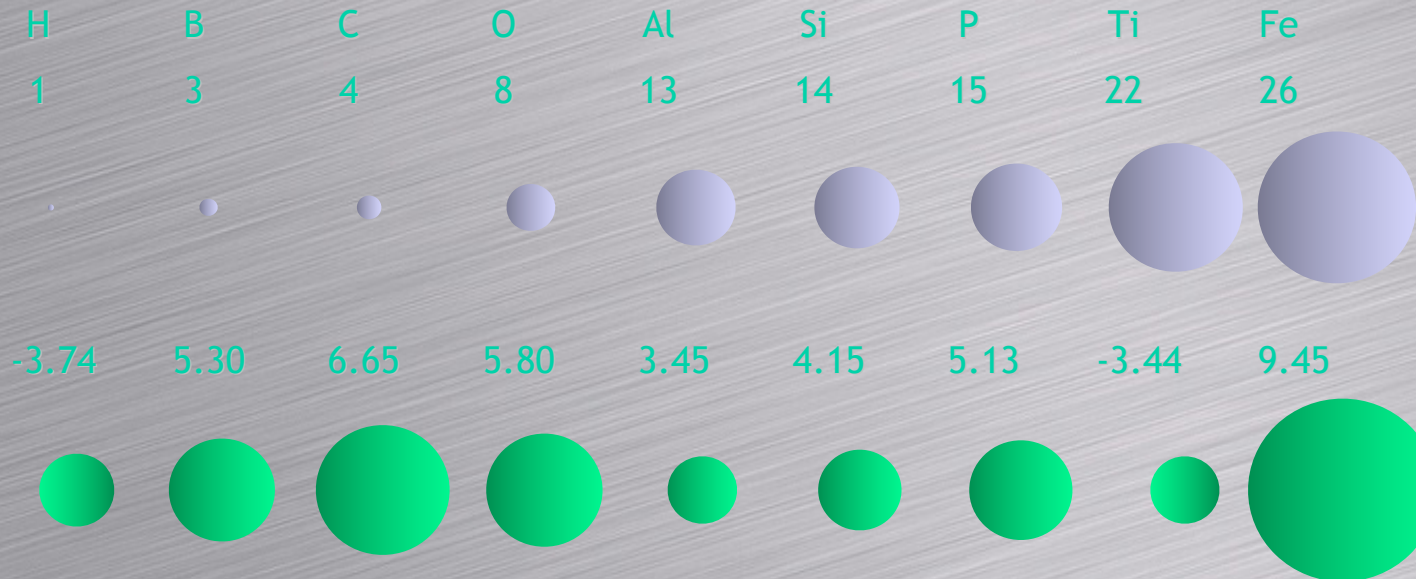
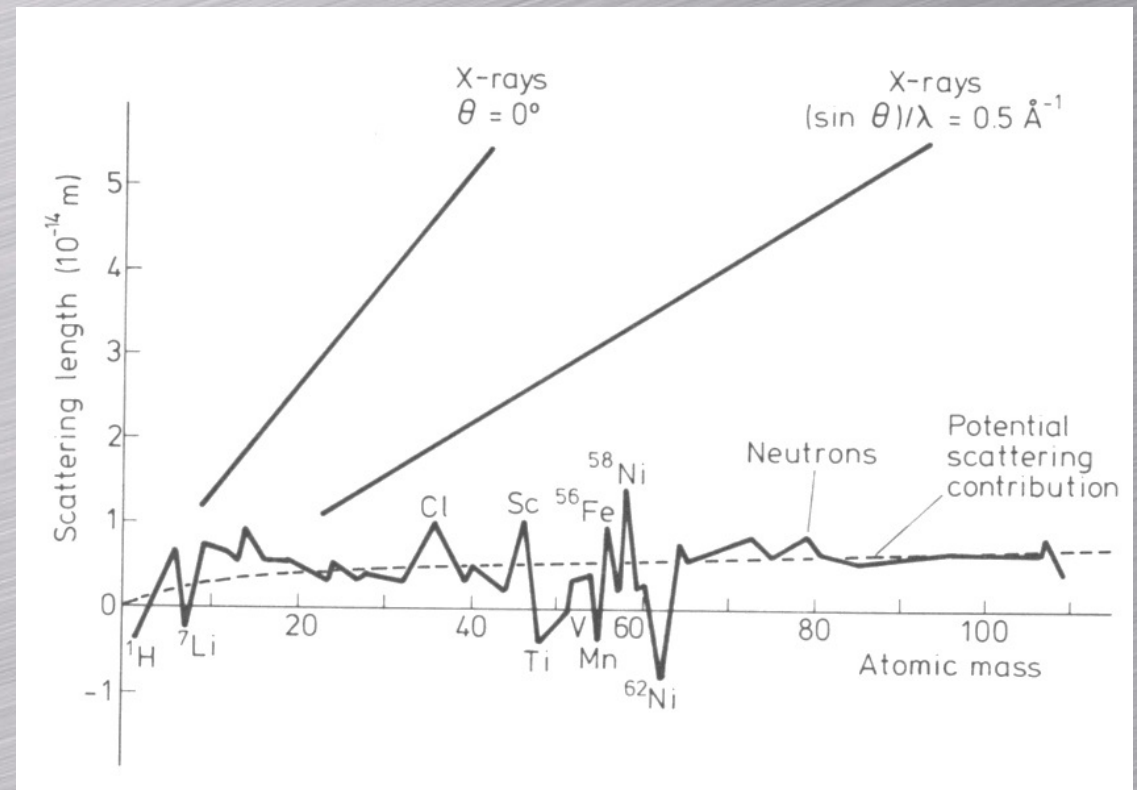
A termikus jelenségeket jobb neutronnal mérni!

Egyéb ?

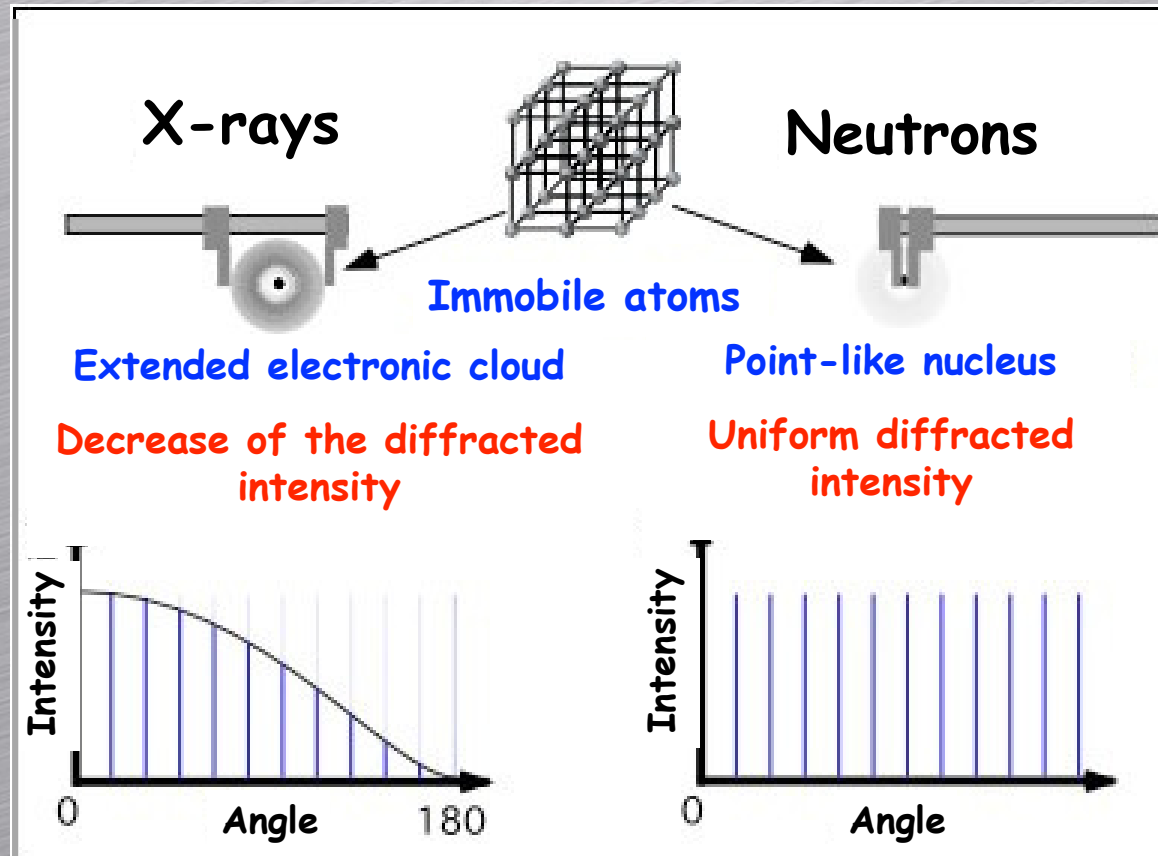
Behatolási mélység összehasonlítása



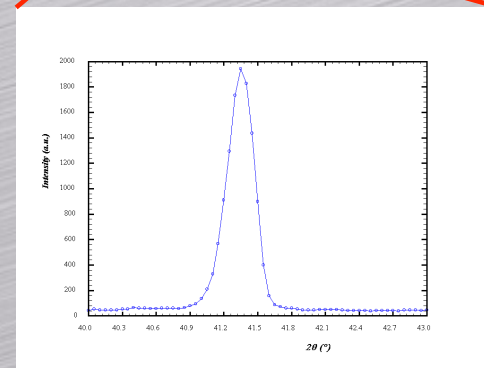
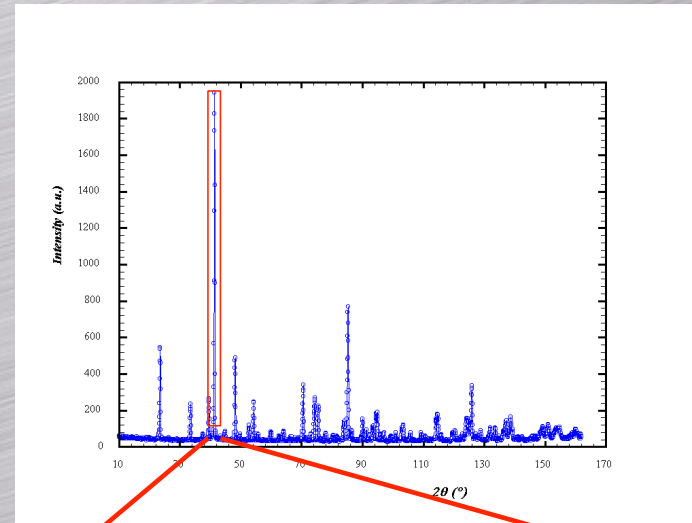
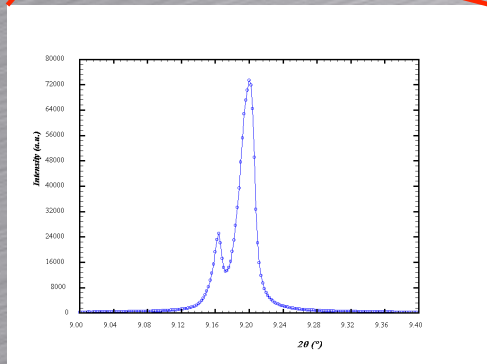
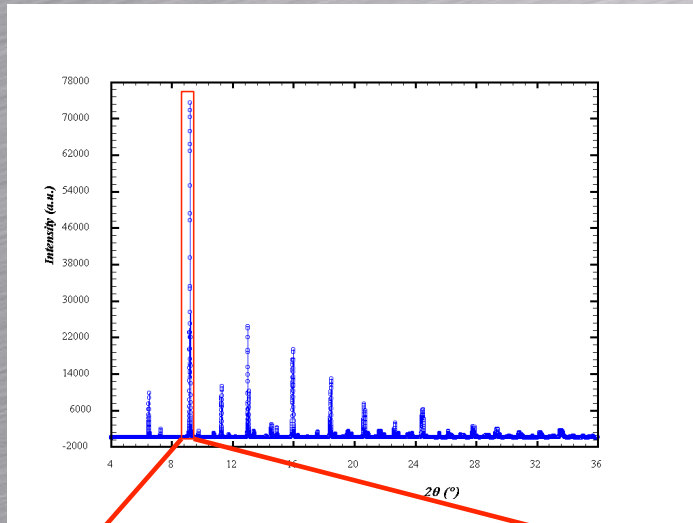
A szórási hossz összehasonlítása



a röntgen az elektron-szerkezetet látja

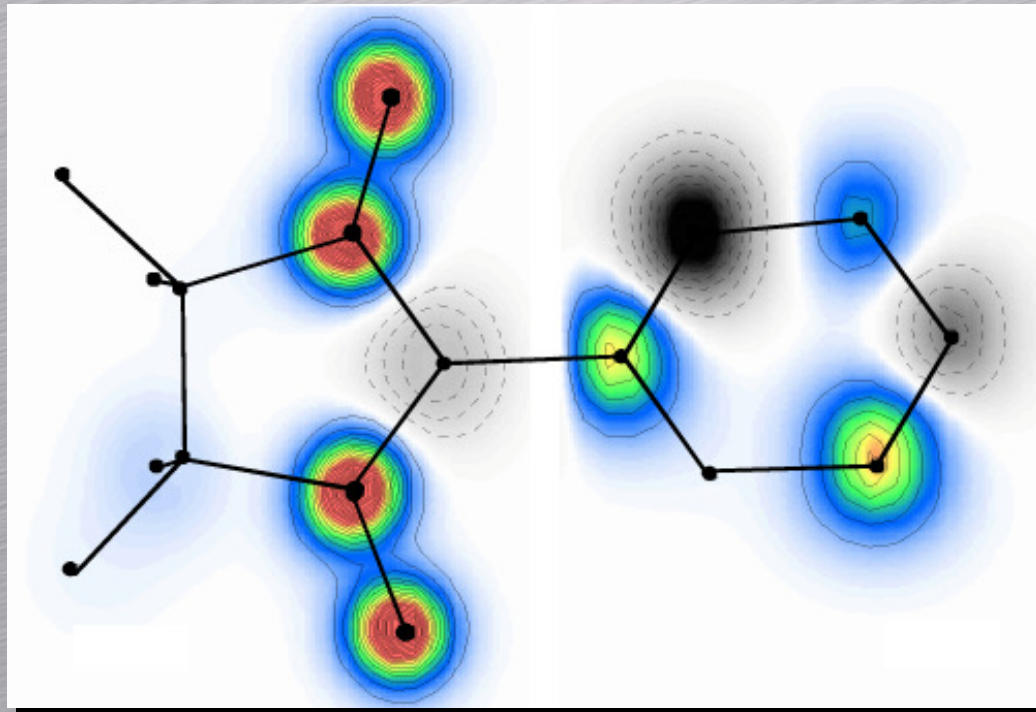


de a felbontás sokkal jobb



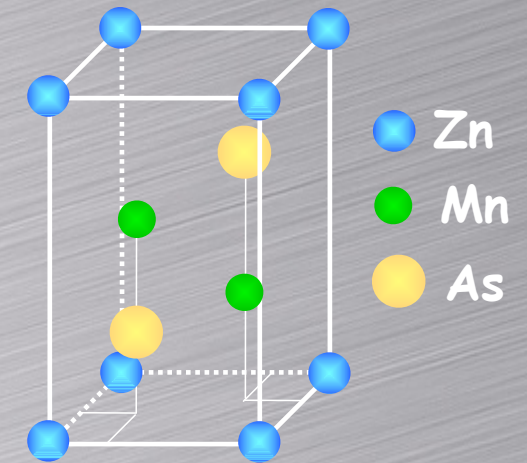
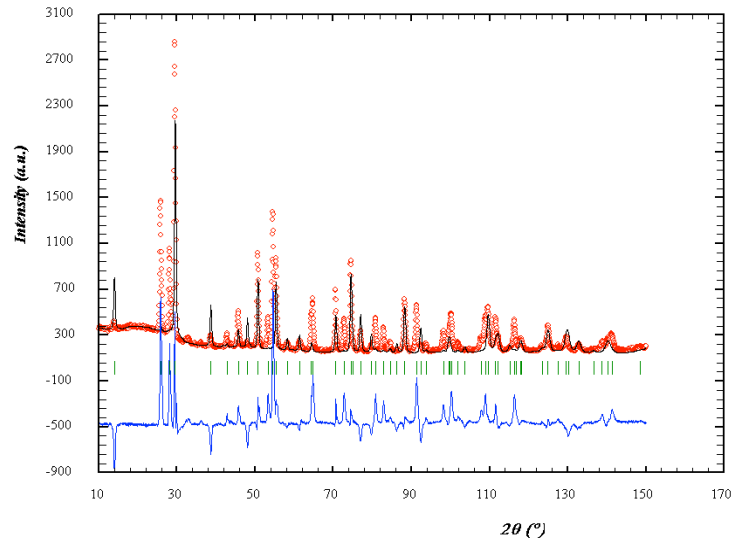
További nagyon fontos előnyök:

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



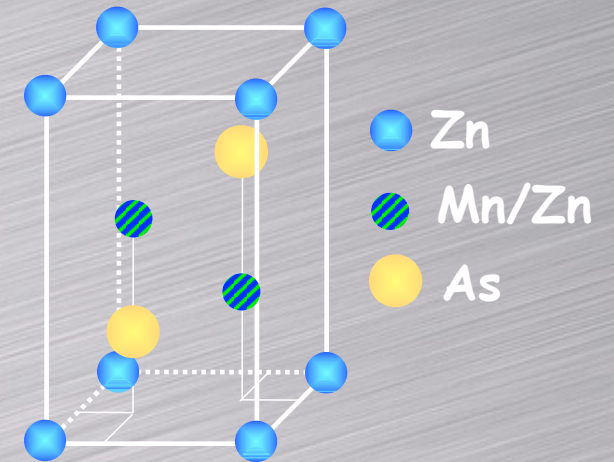
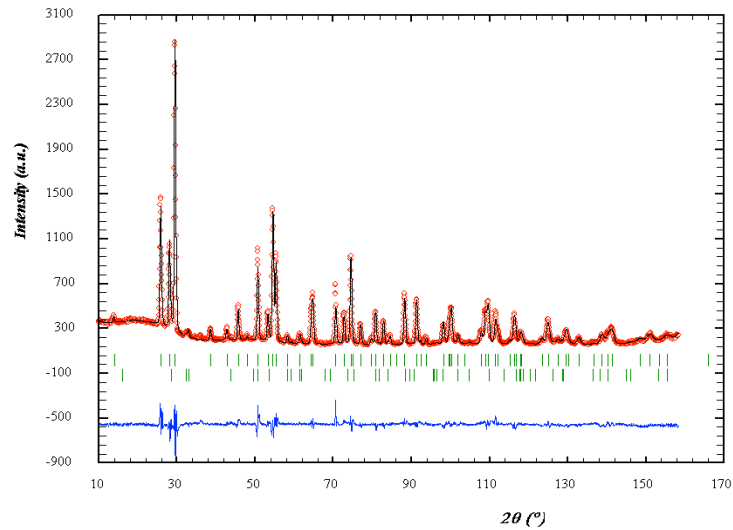
Mágnesezettségi térképek

ZnMn₂As₂



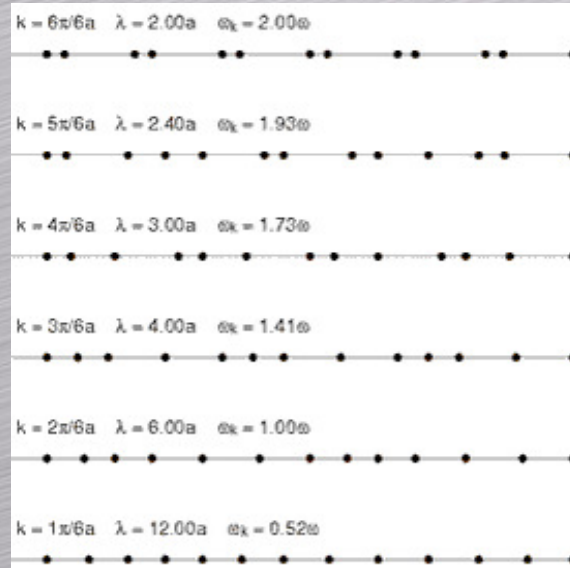
$$b_{\text{Mn}} = -0,373 \times 10^{-12} \text{ cm}$$

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



Na és a mozgás?

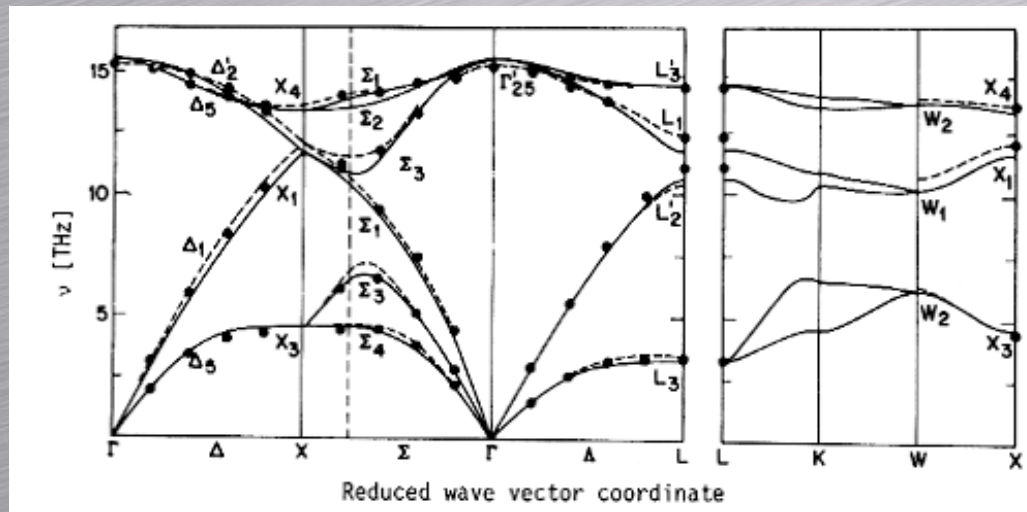
1994 Brokhause, Shull



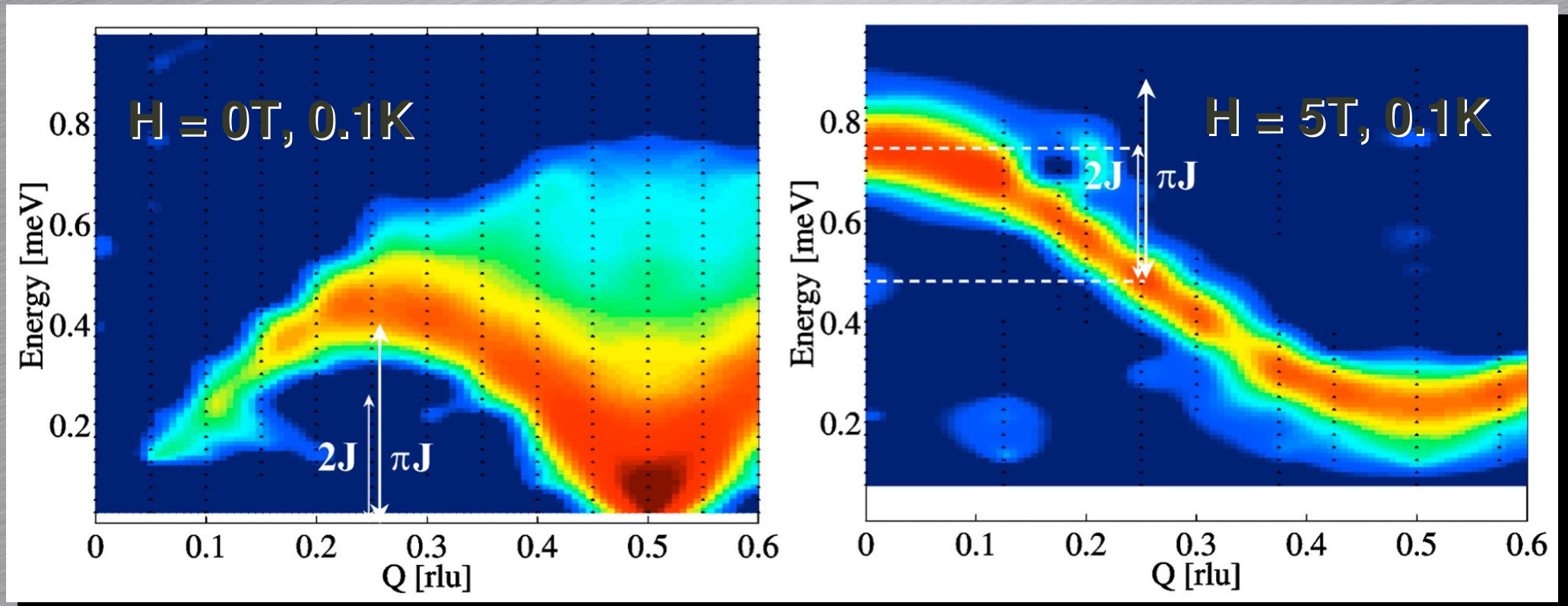
A neutron a mozgó atomokról energiaveszteséggel (vagy nyereséggel) szóródik.

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

Si

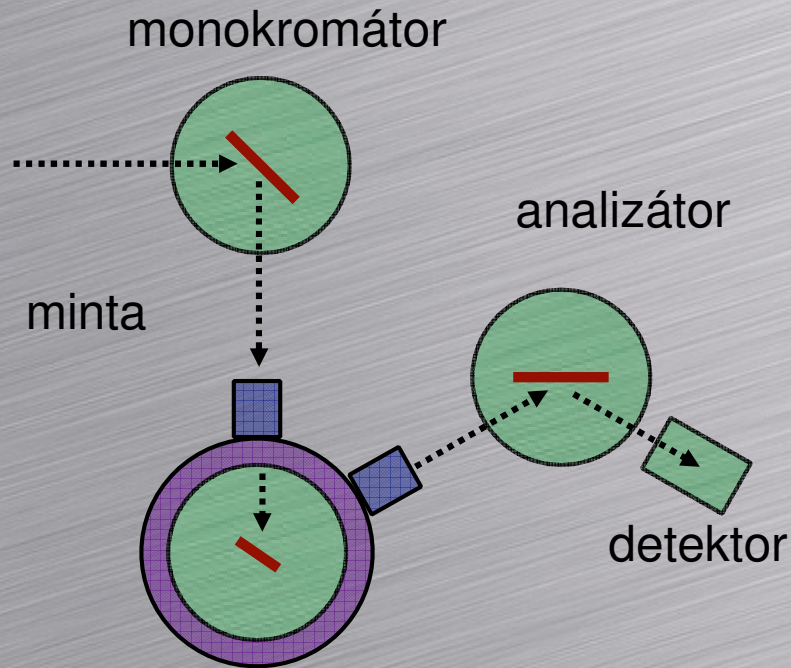


mágneses gerjesztések $\text{CuSO}_4 \cdot 5 \text{D}_2\text{O}$ -ban (IN14)

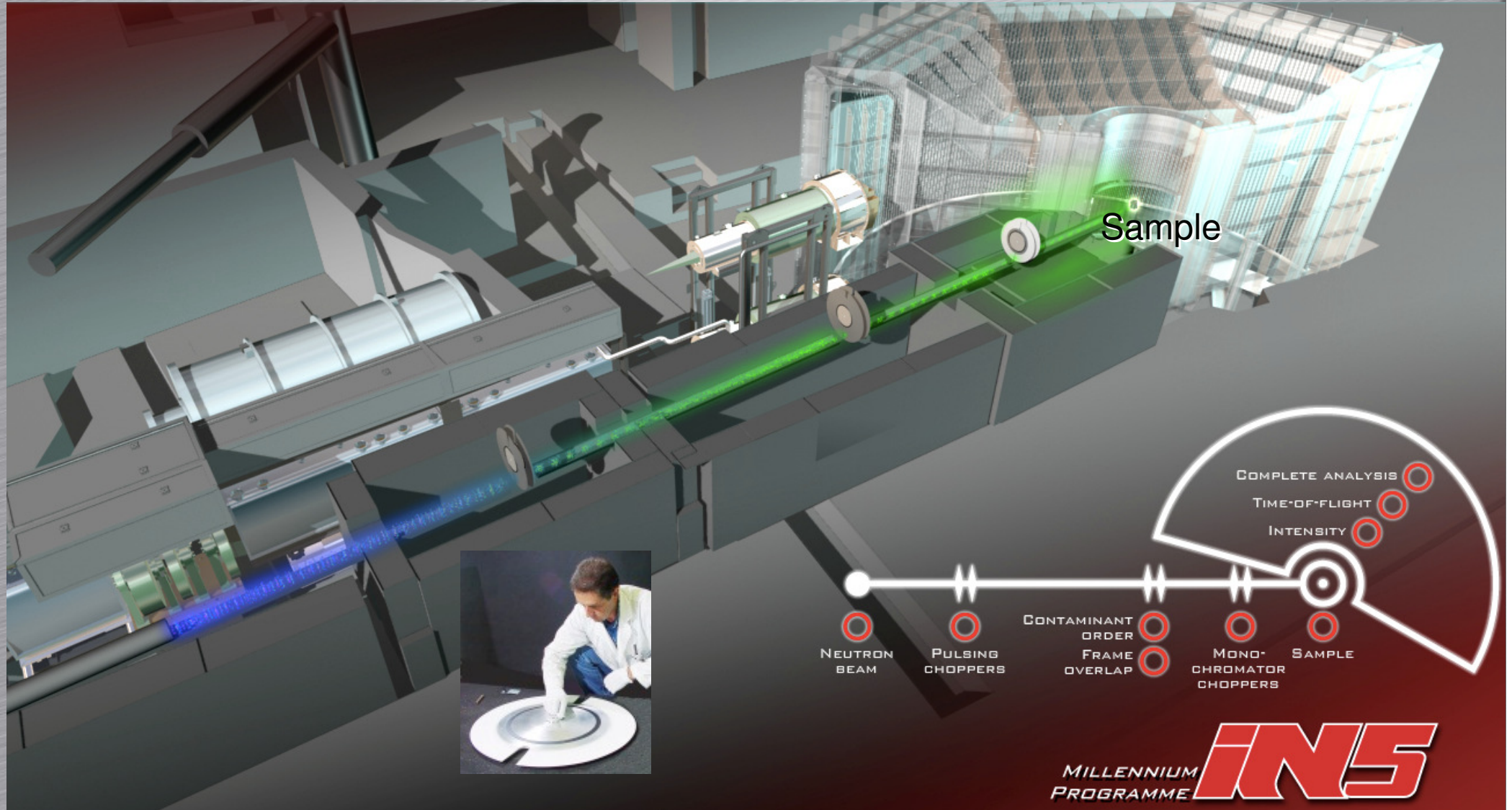


3 tengelyű spektrométer

egyszerre csak egy impulzus-energia pontot mér



Repülési idő spektrométer (IN5)

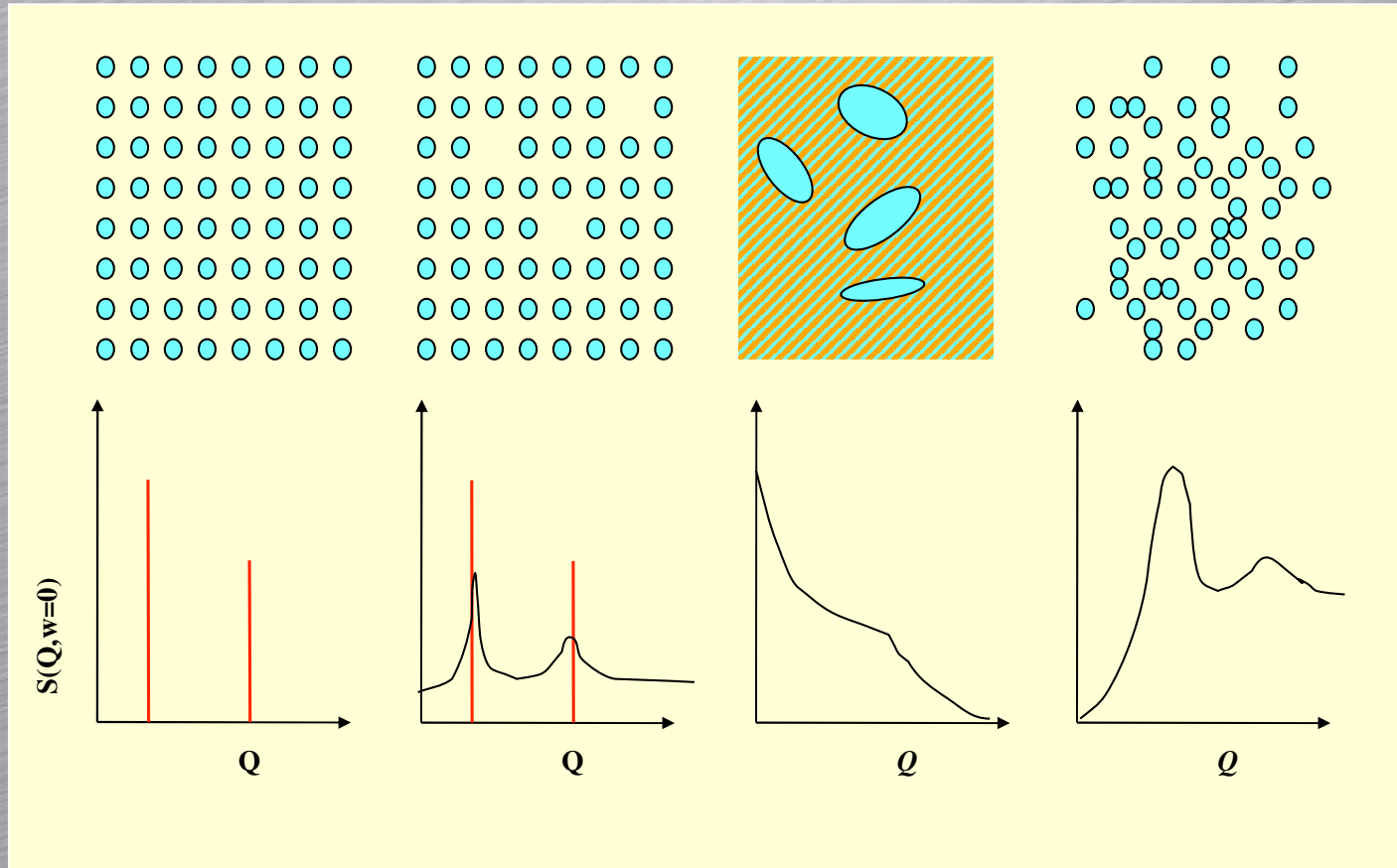


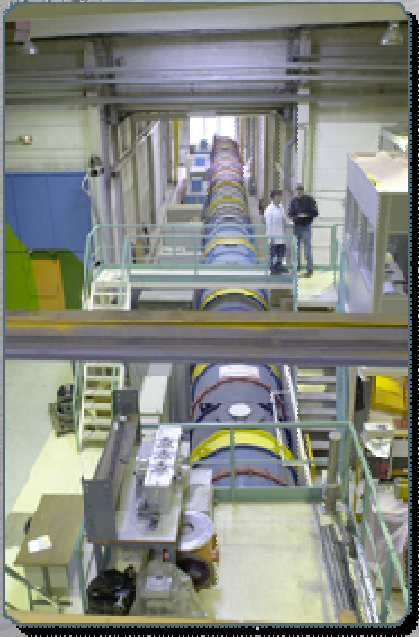
Helyzetérzékelő detektorok



3 m magas

amikor nem annyira rendezett....

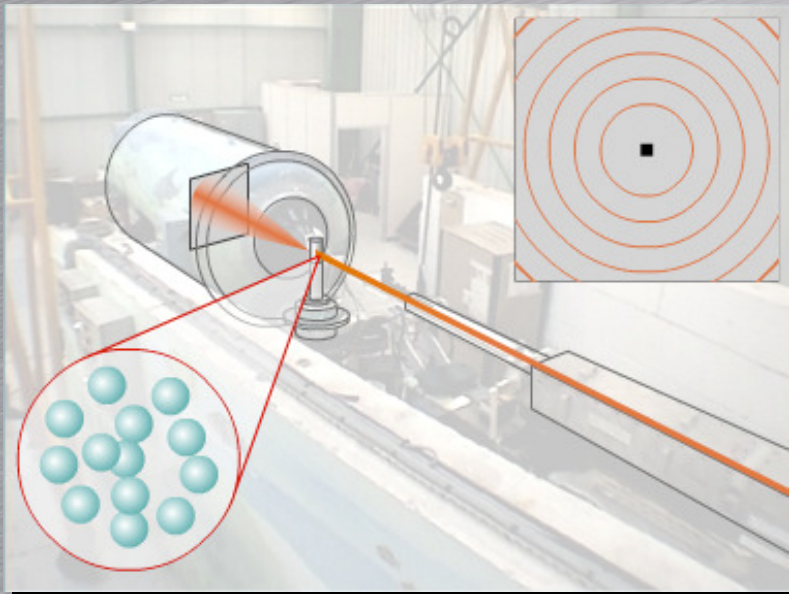




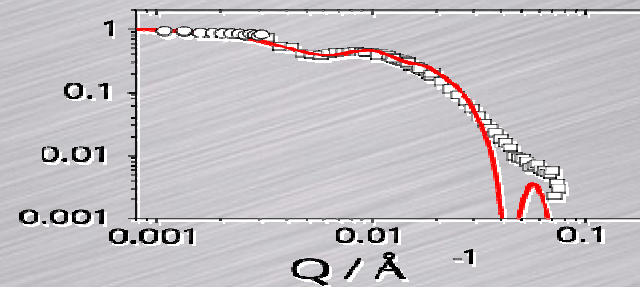
Polimerek, aggregátumok, mikroemulziók karakterisztikus méret: 10 – 1000 Å

(Fourier-transzformáció)

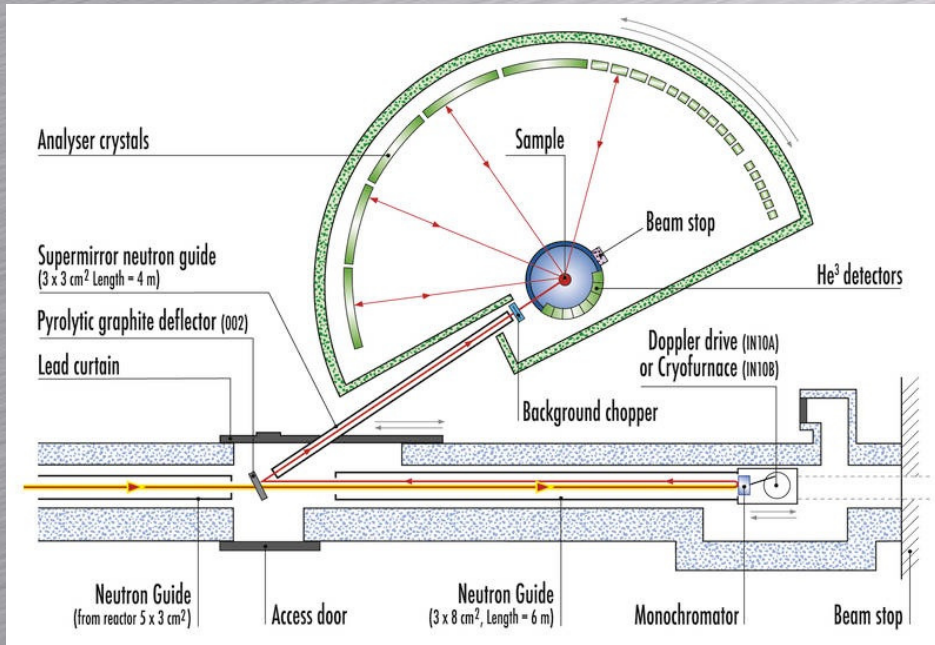
nagy méret $\Rightarrow 4\pi/\lambda \sin(\Theta/2) \Rightarrow$
 \Rightarrow kicsi szórási szög



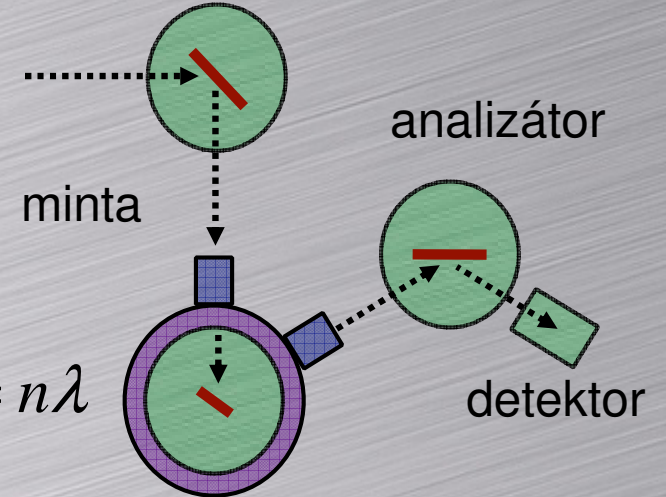
... és lassan mozog



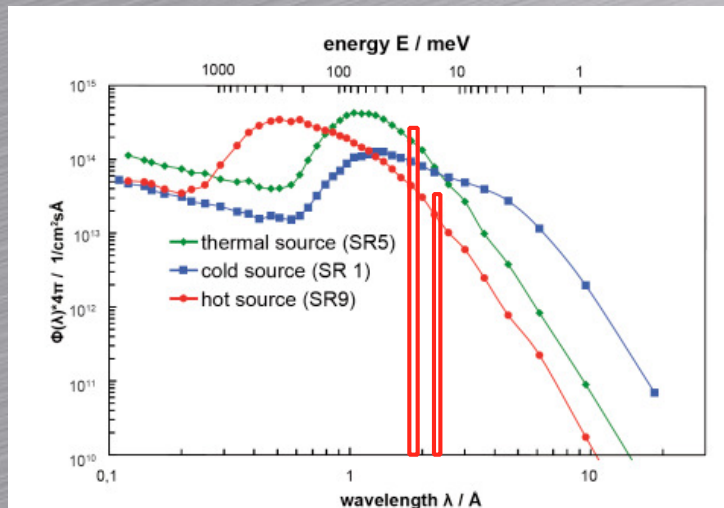
jobb energia-felbontás kell: “hátraszórási” spektrométer



monokromátor



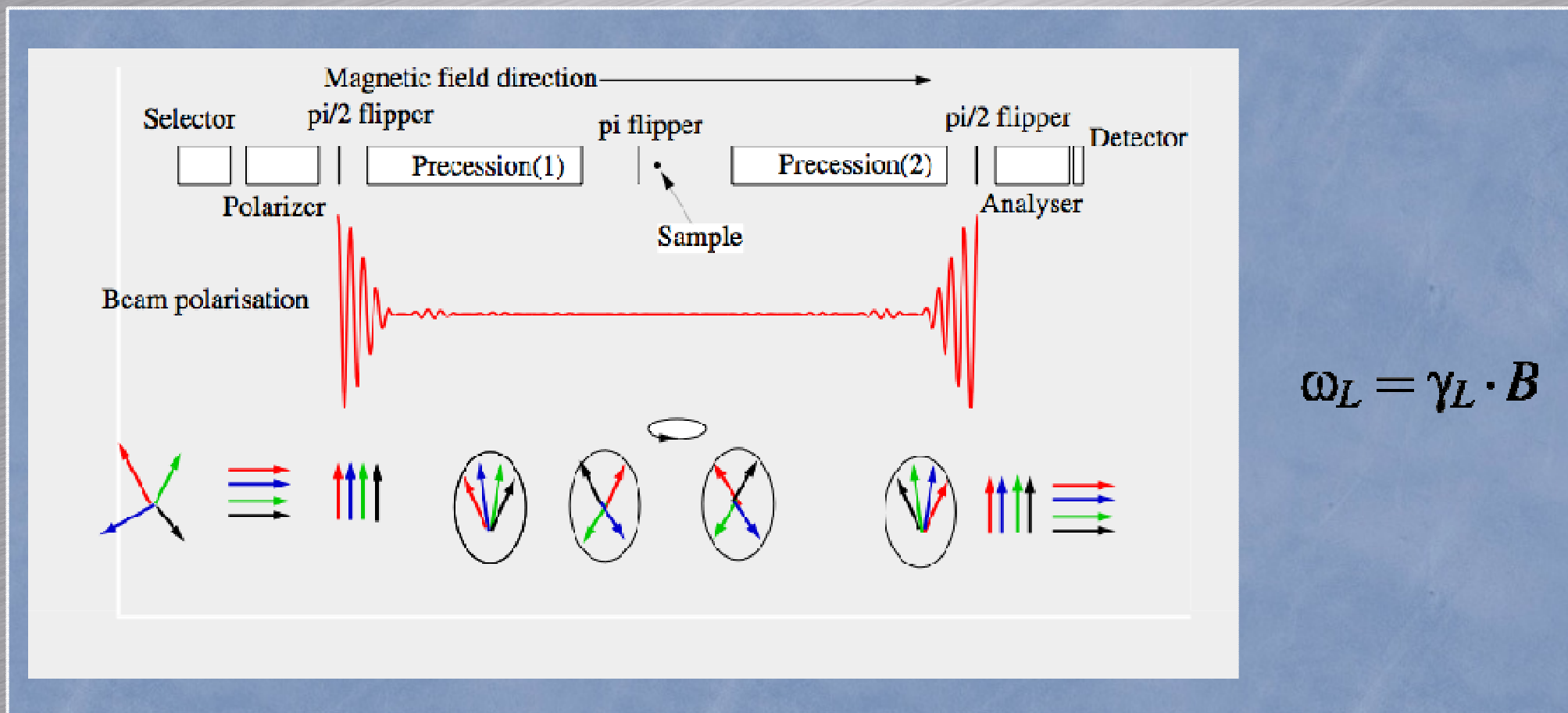
Elfogy az intenzitás!!!



Lehetne ezt jobban is csinálni?

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

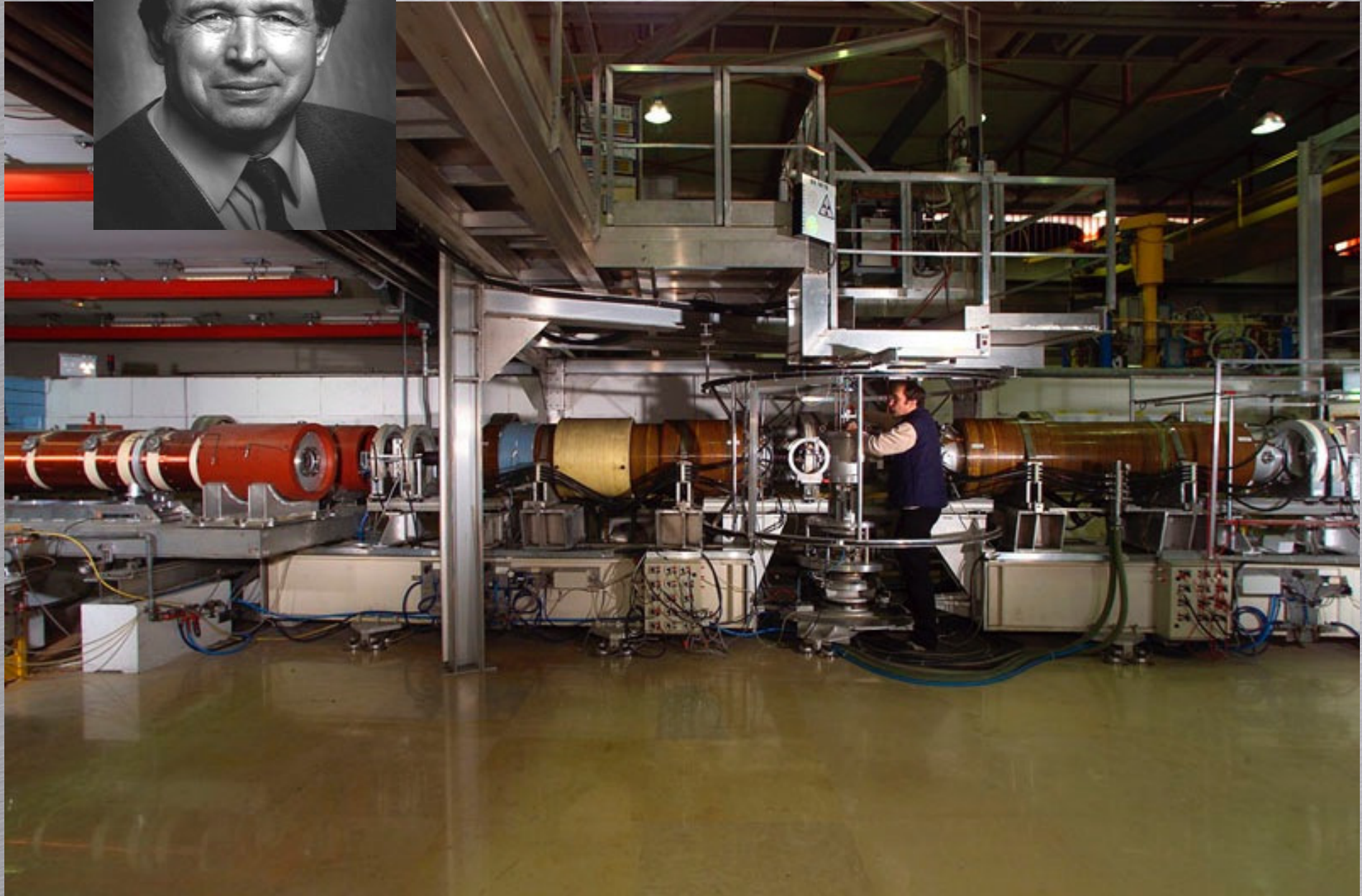
Mérjük CSAK az energiacserét!!!



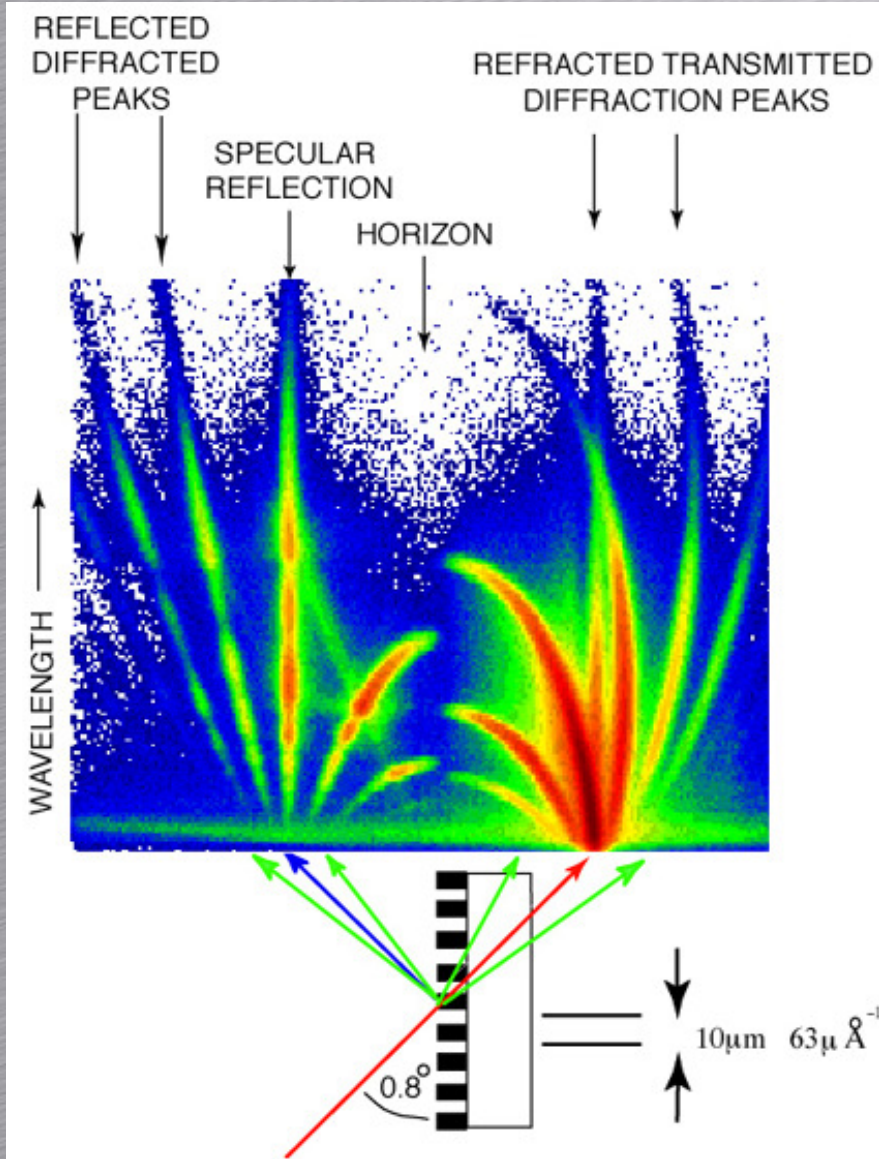
$$\omega_L = \gamma_L \cdot B$$

Neutron Spin Echo

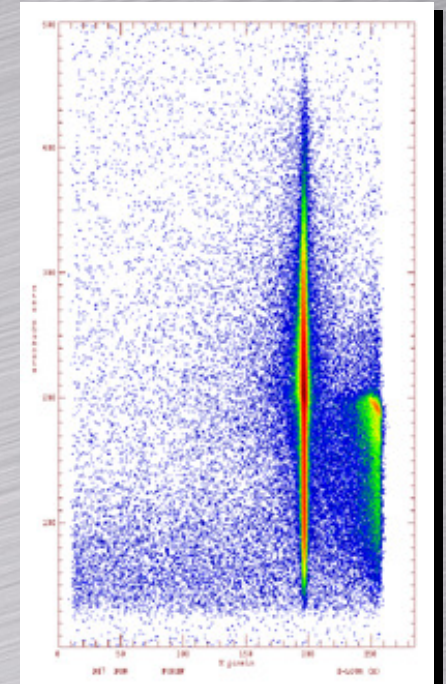
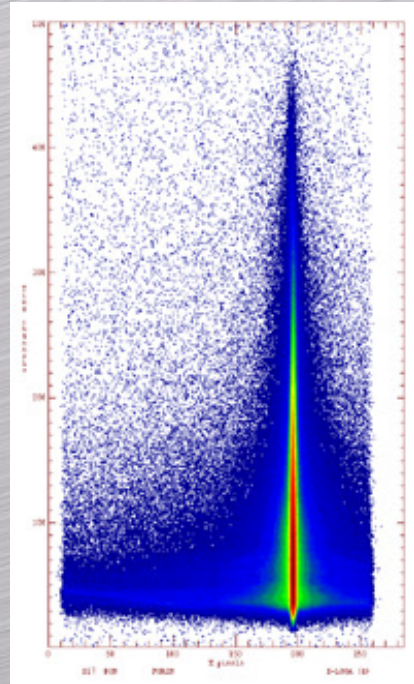
Mezei Ferenc 1972-ben gondolta ki (és csinálta meg)



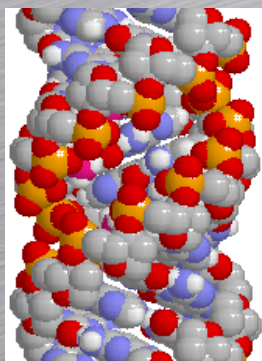
Demo klasszikus és kvantum módon....



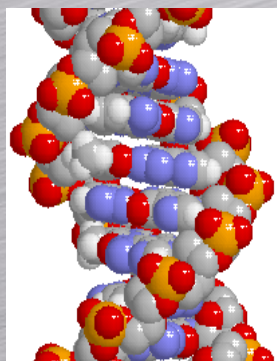
A felületről tükröződött, szórt neutronok hasonlóan sok információt hordoznak



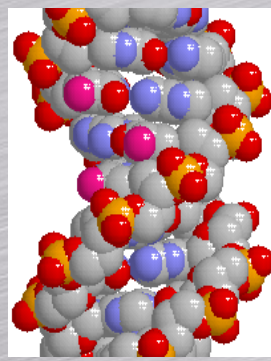
DNS polimer szerkezetek Trevor Forsyth



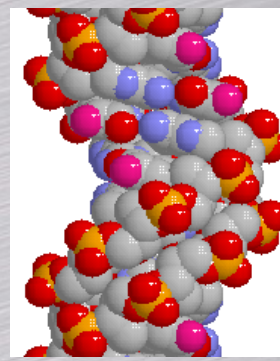
A-DNS
RH
11 bp/turn
pitch=28.2Å



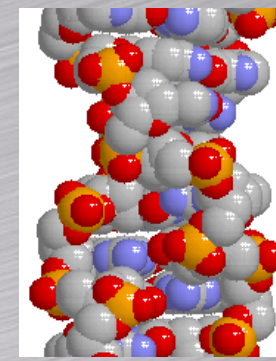
B-DNS
RH
10 bp/turn
pitch=34Å



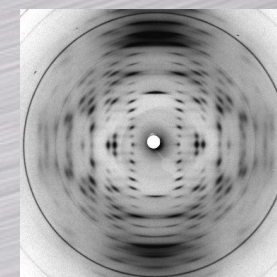
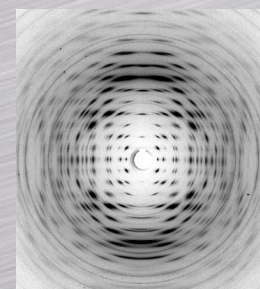
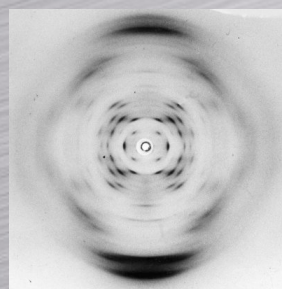
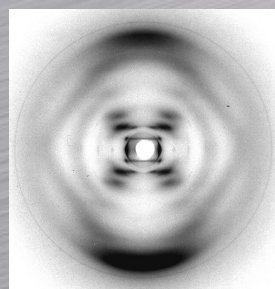
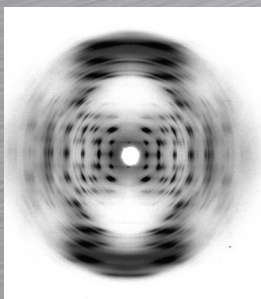
C-DNS
RH
9.33 bp/turn
pitch=31Å



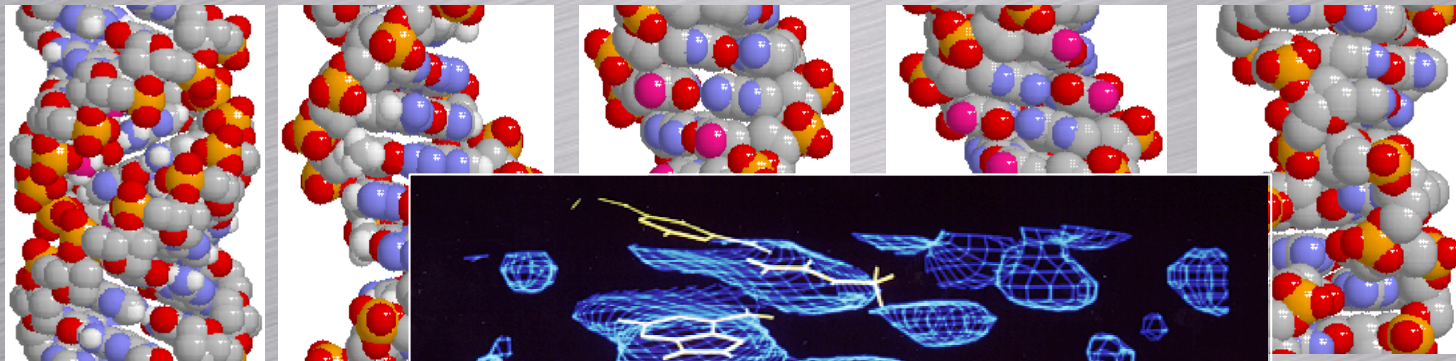
D-DNS
RH
8 bp/turn
pitch=24.2Å



Z-DNS
LH
12 bp/turn
pitch=43Å



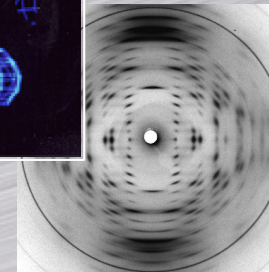
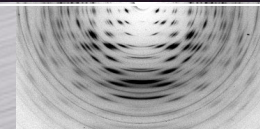
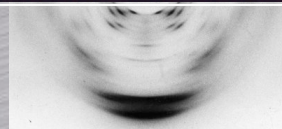
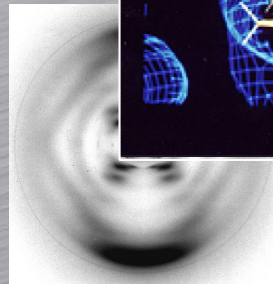
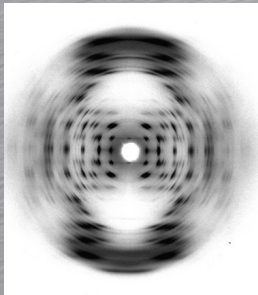
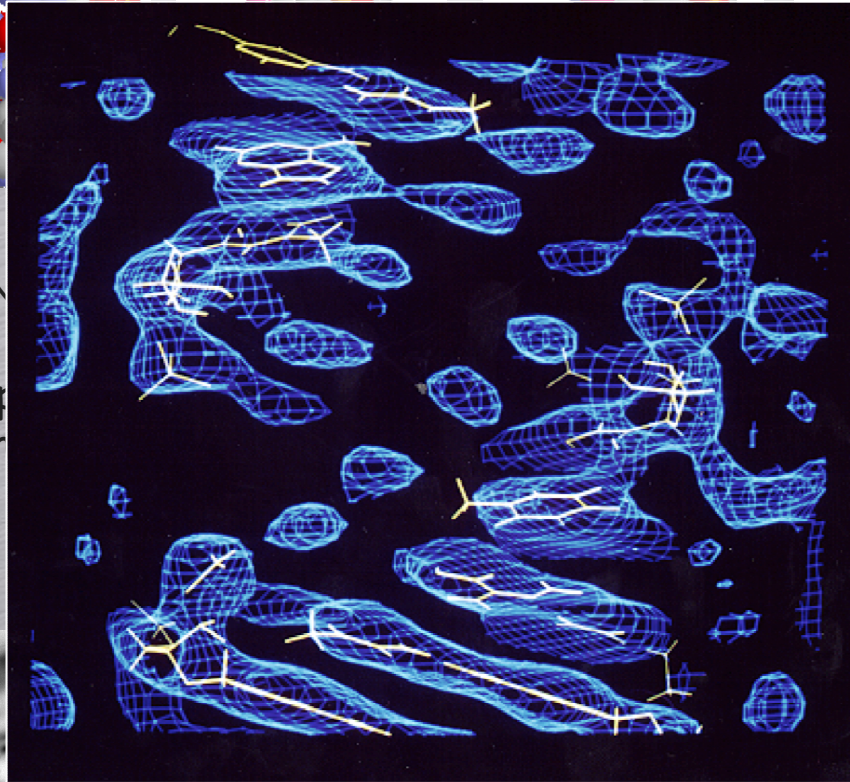
DNS polimer szerkezetek Trevor Forsyth



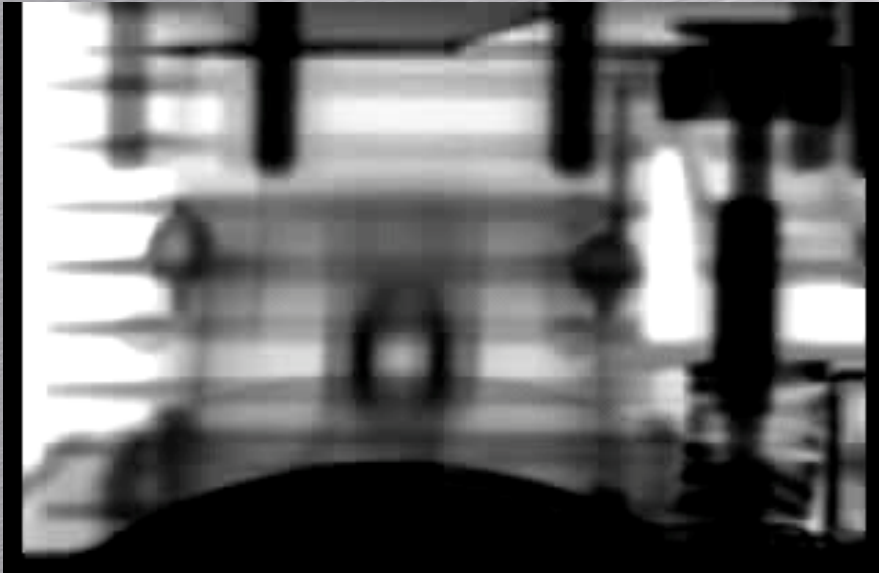
A-DNA
RH
11 bp/turn
pitch=28.2Å

B-DNA
RH
10 bp/turn
pitch=34.4Å

C-DNA
RH
11 bp/turn
pitch=43Å



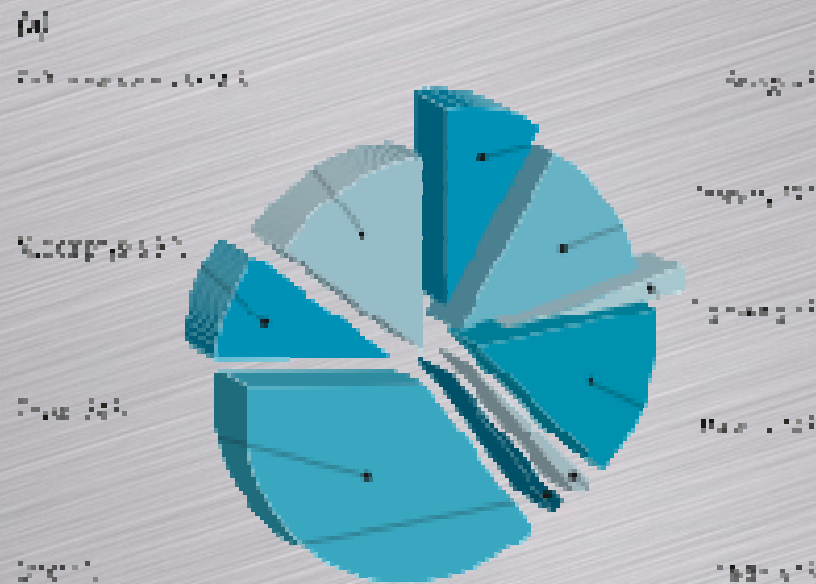
Neutron-radiográfia



Neutron-tomográfia

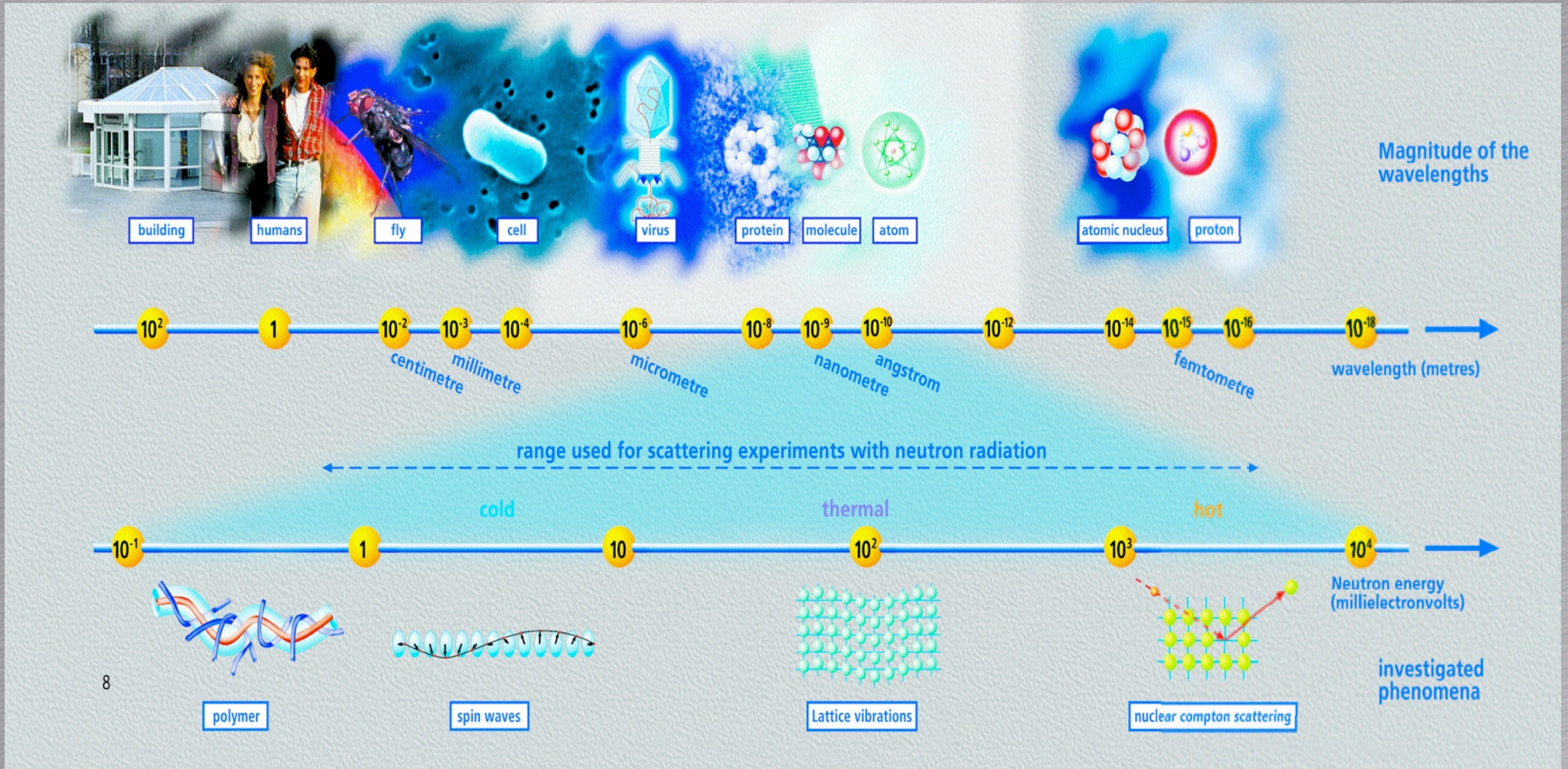
Neutron tomography of a camera lense.

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



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