Budapest Neutron Centre
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Budapest Research Reactor
Multipurpose Utilisation of a Medium Flux Facility

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May 2012

Nuclear sciences and neutron research have long traditions in Hungary

Great fathers:

- WIGNER Jenő
- SZILÁRD Leó
- HEVESY György
- TELLER Ede

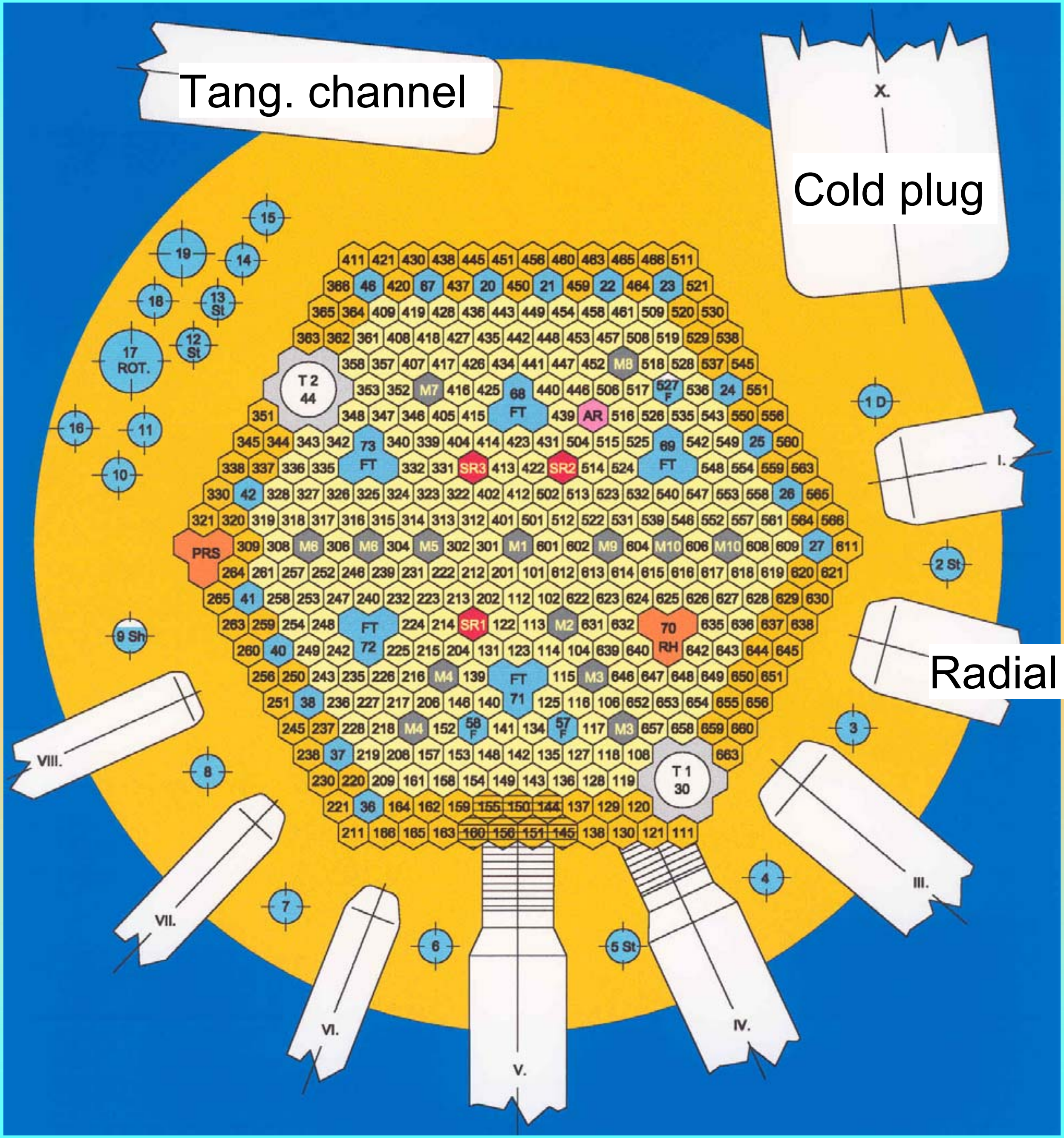
Nuclear Rector Facilities in Hungary

- Paks Nuclear Power Plant (4x500 MW-e)
- Budapest Research Reactor (KFKI, 10 MW)
- Training Reactor at the Budapest TU (0.8 MW)

Research Reactor – Benefit for the society

- Support for the energy sector
- Research and radioisotope supply for healthcare
- Materials research for industry, life-sciences, nanotechnology....
- Basic science, methodical research, technology transfer, products...

KFKI campus



Reactor core

225 fuel elements, 36% of ^{235}U

T ~ 20 K

$\lambda_{maximum\ flux} = 4$Å

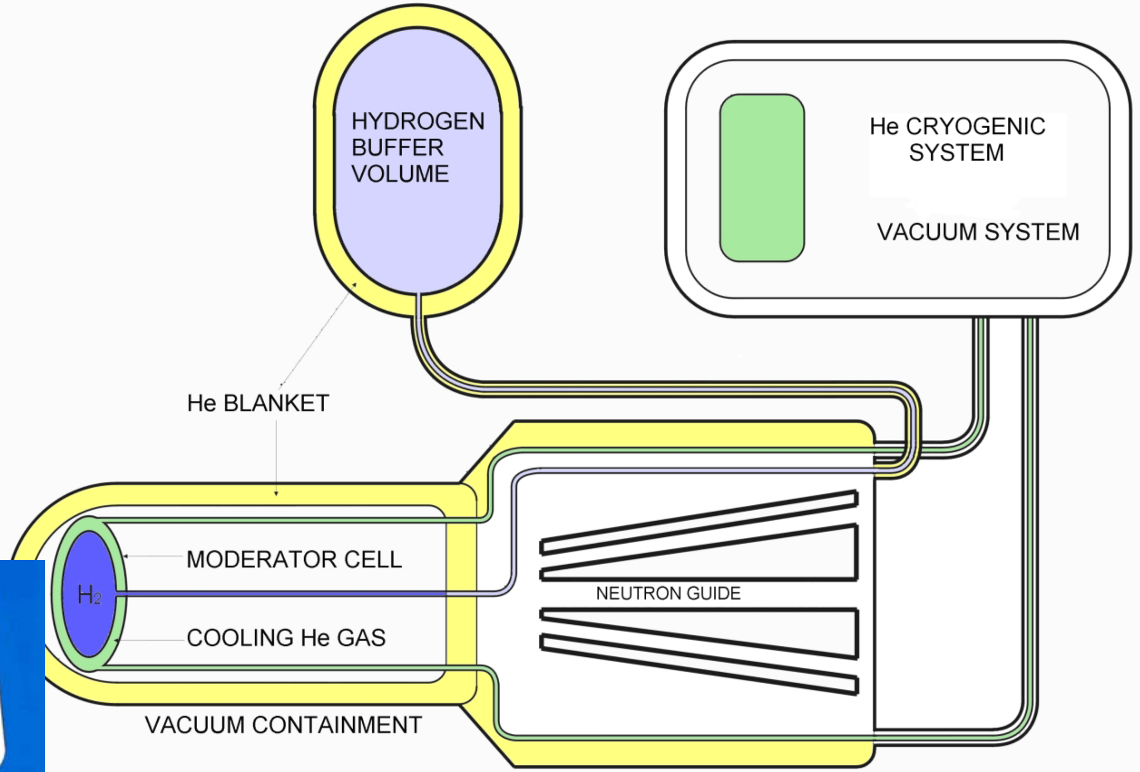
NEW: Bagira loop

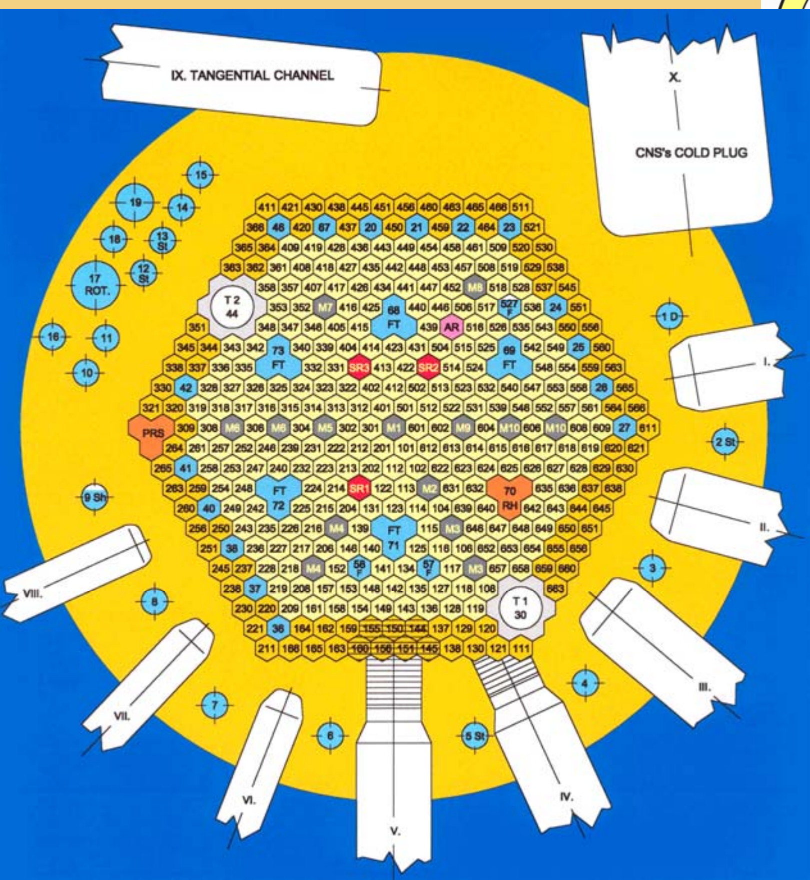
T ~ 320 K

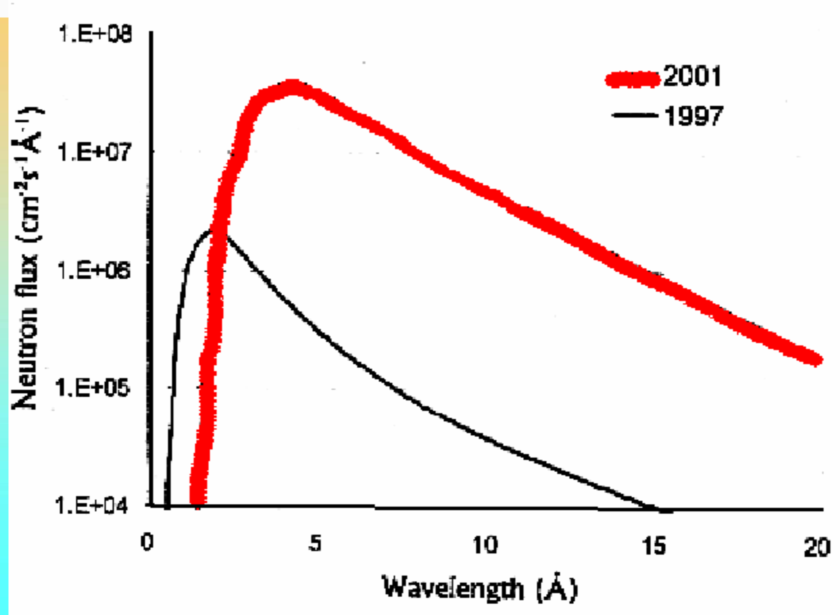
$\lambda_{max\ flux} = 1.2$Å

Transition to 20% enriched fuel (2007-08)

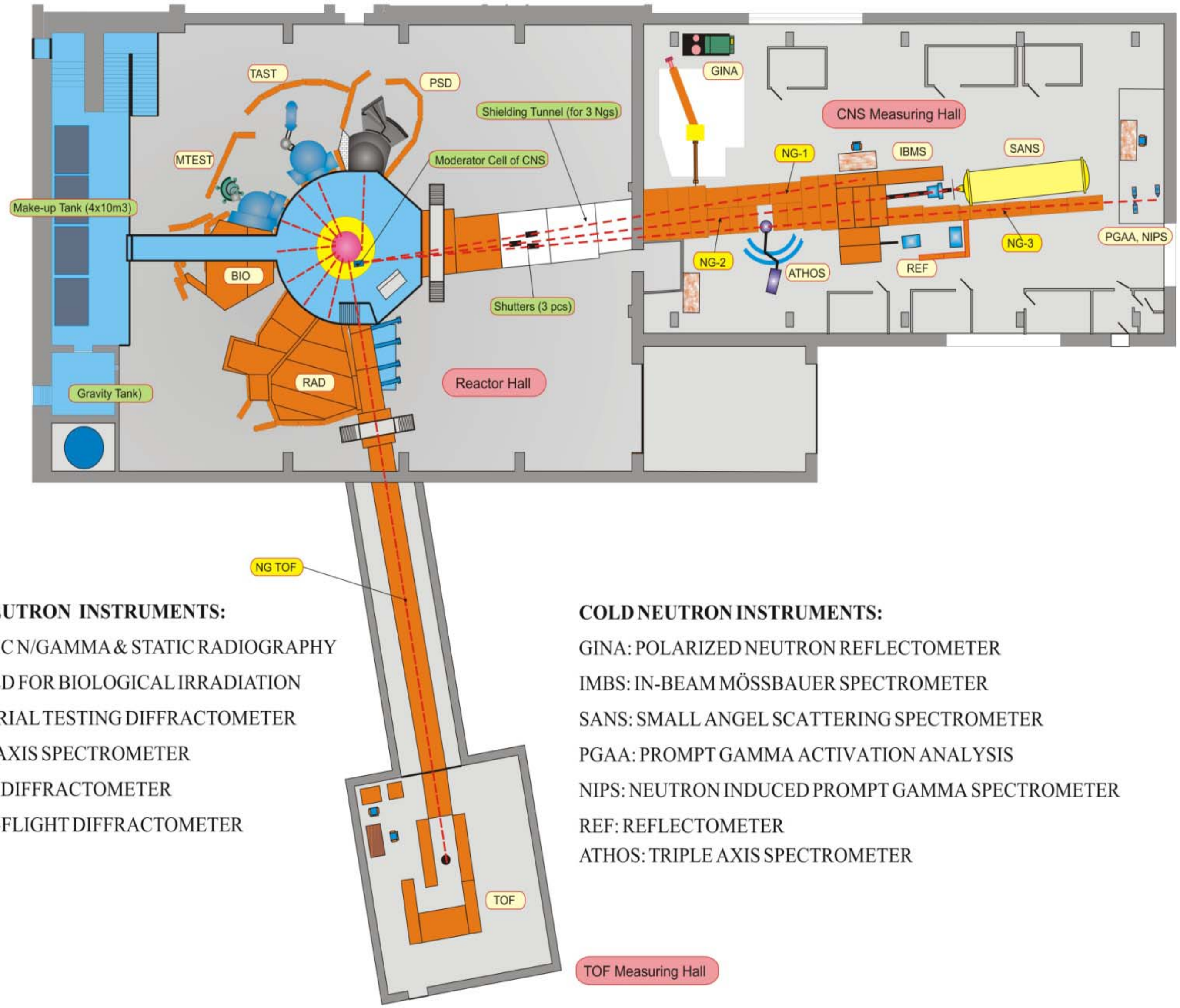
Liquid Hydrogen Cold Moderator







12 operative beam instruments



THERMAL NEUTRON INSTRUMENTS:

RAD: DYNAMIC N/GAMMA & STATIC RADIOGRAPHY

BIO: PORT USED FOR BIOLOGICAL IRRADIATION

MTEST: MATERIAL TESTING DIFFRACTOMETER

TAST: TRIPLE AXIS SPECTROMETER

PSD: POWDER DIFFRACTOMETER

TOF: TIME-OF-FLIGHT DIFFRACTOMETER

COLD NEUTRON INSTRUMENTS:

GINA: POLARIZED NEUTRON REFLECTOMETER

IMBS: IN-BEAM MÖSSBAUER SPECTROMETER

SANS: SMALL ANGEL SCATTERING SPECTROMETER

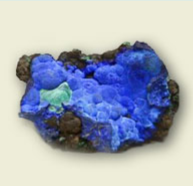
PGAA: PROMPT GAMMA ACTIVATION ANALYSIS

NIPS: NEUTRON INDUCED PROMPT GAMMA SPECTROMETER

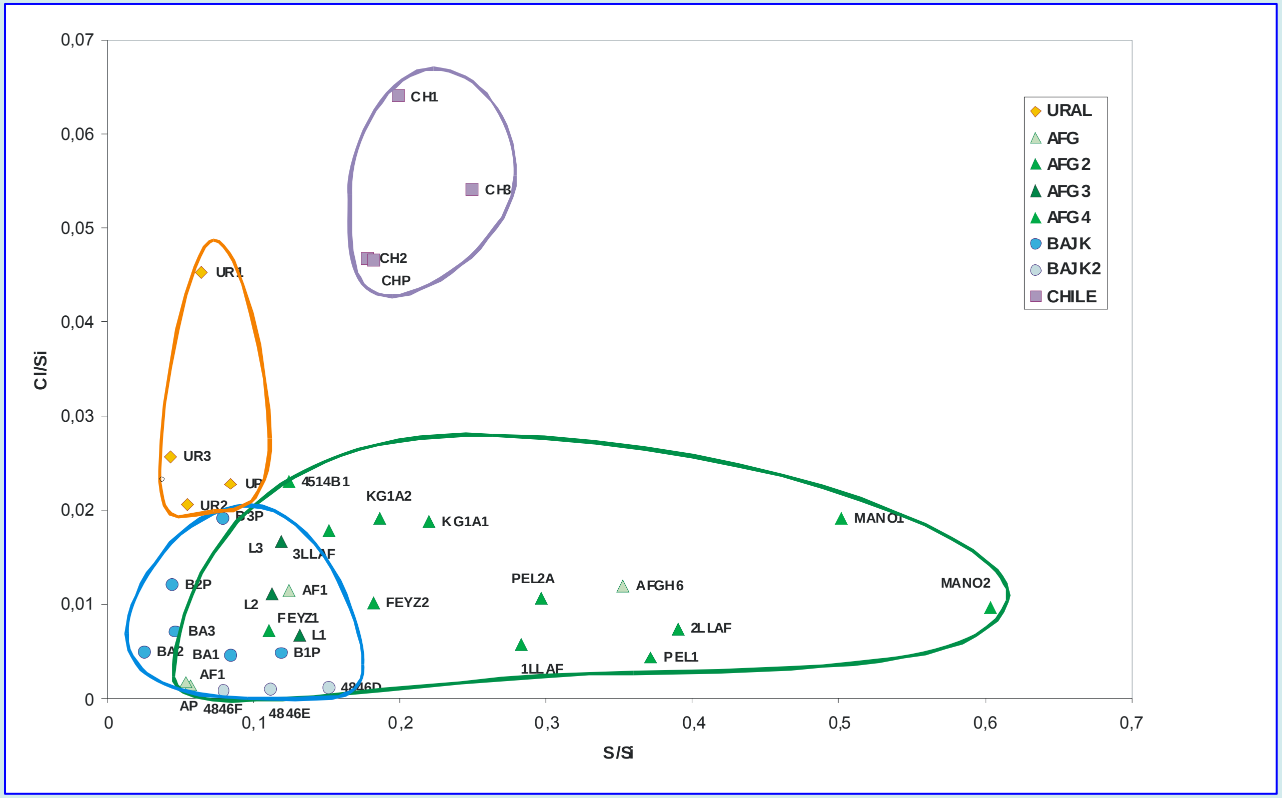
REF: REFLECTOMETER

ATHOS: TRIPLE AXIS SPECTROMETER

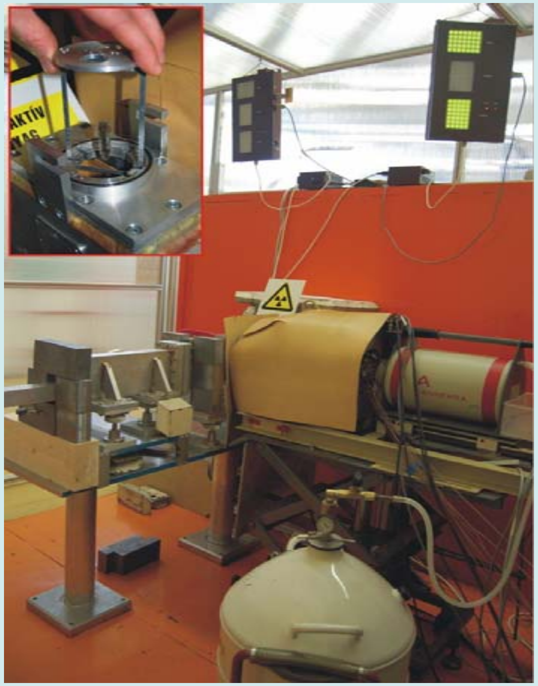
Investigation of objects of cultural heriage PROVENANCE STUDY OF LAPIS LAZULI

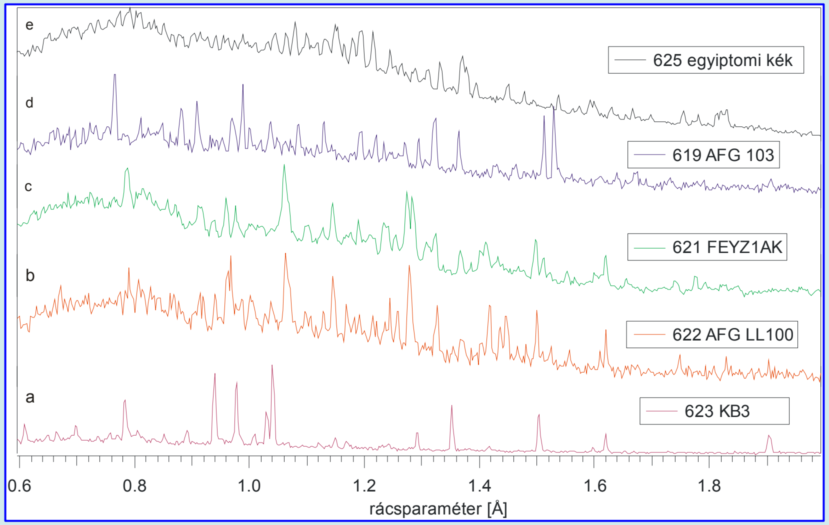


- A few geological occurances in the Wo (Ural, Chile, Afghanistan, Lake Bajkal)
- **Main mineral**: Lazurit / $(Na,Ca)_{7-8}(Al,Si)_{12}O_{24}[(SO_4)Cl_2(OH)_2]$
- **AIM**: Identification of raw materials, provenance of art objects
- **PGAA**: H, Na, Mg, Al, Si, K, Ca, Ti, Mn, Fe, S, Cl

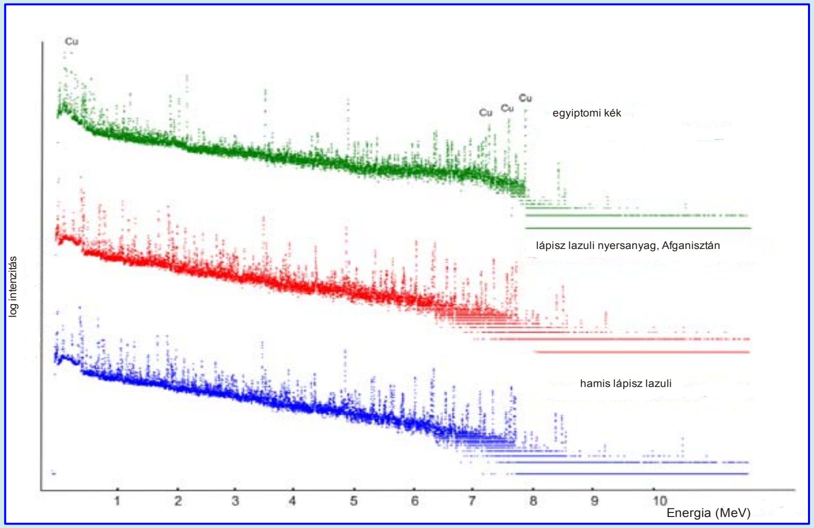


Characterisation of raw materials with





Fake identification with TOF-ND



Fake identification with PGAA

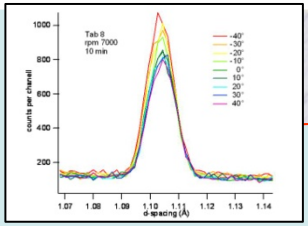
TOF - Time of Flight Neutron Diffraction

No sample preparation
Measurements possibility of large sample
Maximum illuminate surface on sample $2.5*10 cm^2$
Minimum sample volume $3 cm^3$

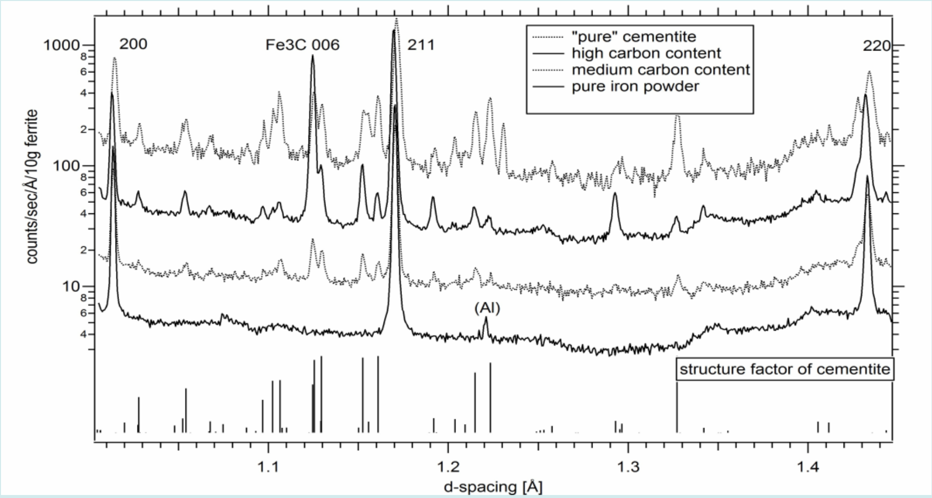
http://www.bnc.hu
contact: György KÁLI
kali@szfki.hu

- ✓Single and polycrystal structure determination
- ✓Strain analysis
- ✓Texture analysis
- ✓Phase analysis

The appearance of precipitated cementite in medium and high carbon steel sword blades. In the high carbon content blade the cementite is also present in highly oriented phases.



Investigated Bronze Age axes

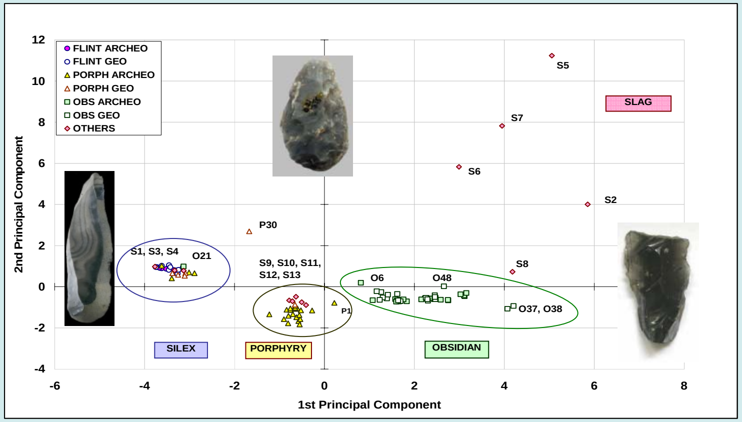


PGAA – Prompt Gamma Activation Analysis

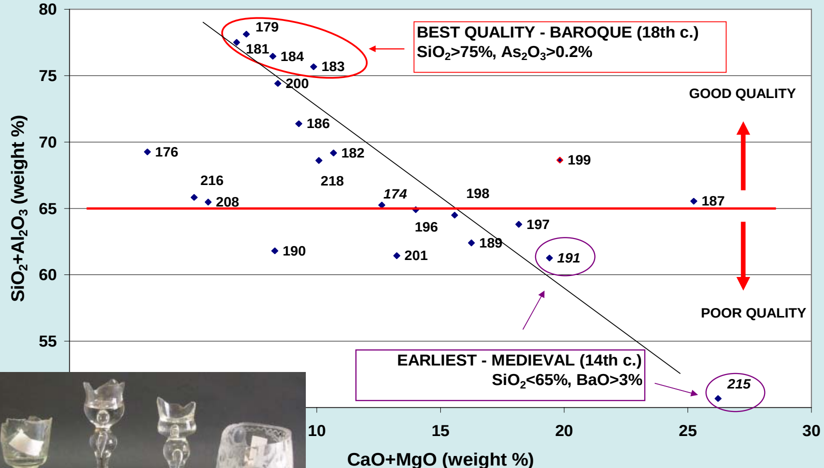
PGAA facility is built on the external cold neutron beam of $10^8 cm^{-2}s^{-1}$
The beam size can vary between $5mm^2$-$400mm^2$

http://www.bnc.hu
contact: Zsolt KASZTOVSZKY
kzsolt@iki.kfki.hu

- ✓Non-destructive nuclear method for determination of bulk elemental composition.
- ✓Elemental identification is based on the (n, γ) reaction
- ✓All chemical elements can be measured, with the LOD of 0.1ppm-1000ppm
- ✓PGAA is extremly sensitive for **H, B, Cl, Cd, Nd, Sm, Eu and Gd.**
- ✓Spectrum analysis is done by HYPERNET-PC software, using our PGAA library



Characterisation of Prehistoric chipped stone objects



Characterisation of Baroque & Medieval glass objects

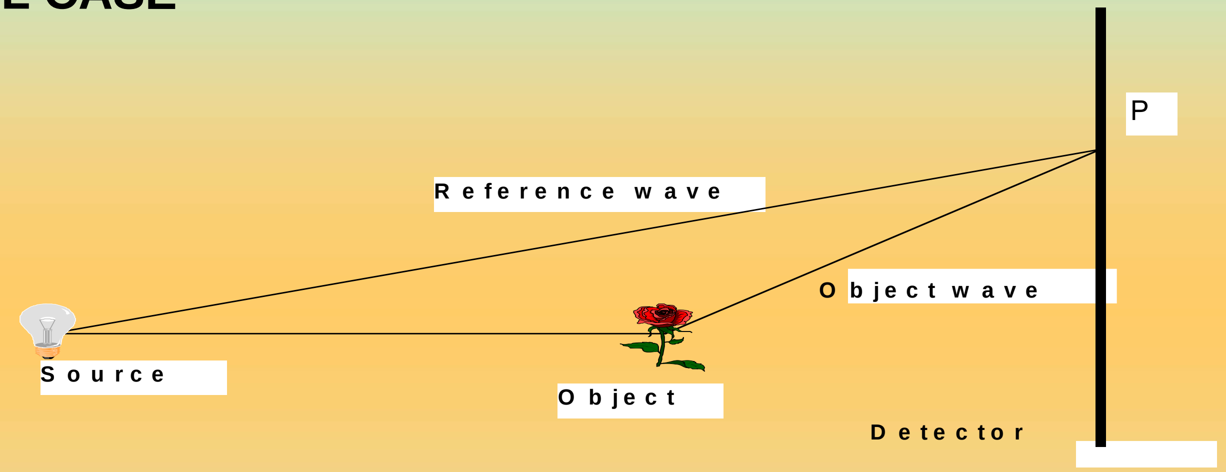
ATOMIC RESOLUTION NEUTRON HOLOGRAPHY

THE PRINCIPLE OF HOLOGRAPHY

Gábor Dénes, 1948, holography:

ολος **(all) and** γραφειν **(write).**

OPTICAL CASE



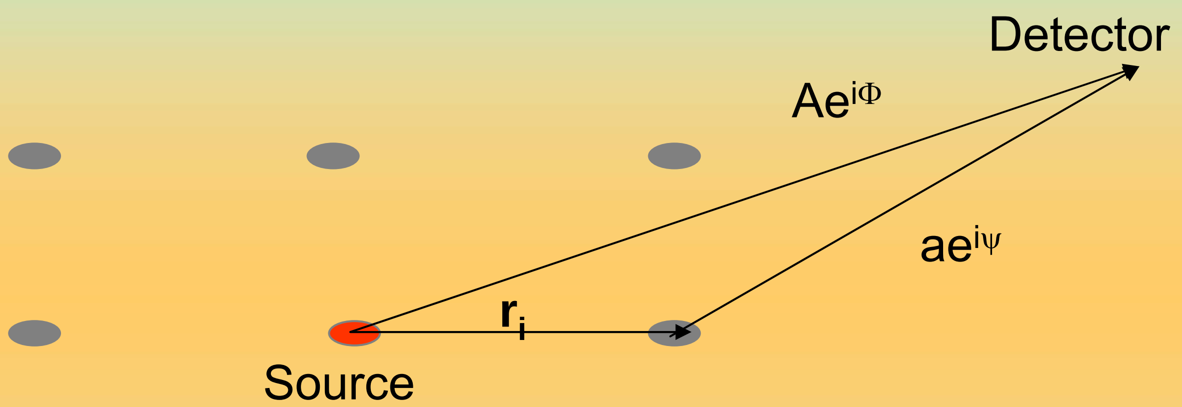
Reference wave: $Ae^{i\Phi}$; Object wave: $ae^{i\Psi}$

$$U(P) = Ae^{i\Phi} + ae^{i\Psi}$$

$$I(P) = |a^2 + A^2 + aA[e^{i(\Psi-\Phi)} + e^{-i(\Phi-\Psi)}]|^2 =$$

$$= a^2 + A^2 + 2aA\cos(\Psi-\Phi)$$

ATOMIC LEVEL HOLOGRAPHY



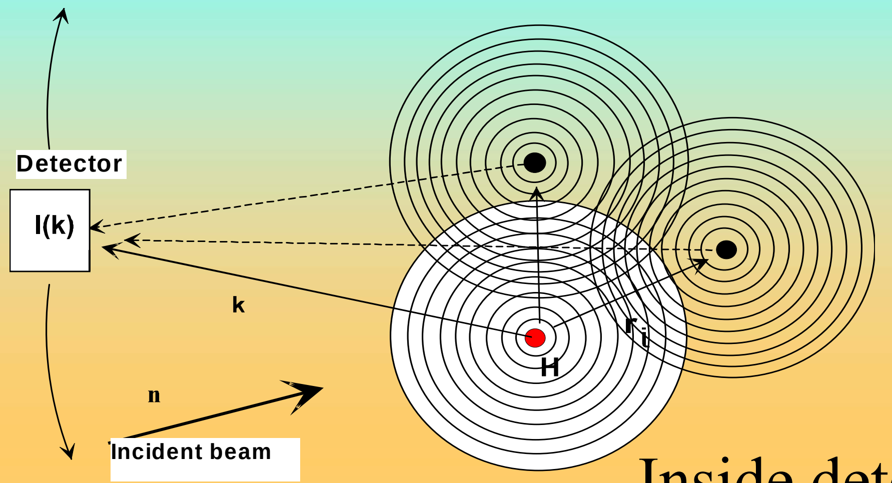
$$I(D) = \frac{I_0}{R^2}\left[1 + \mathrm{Re}(\Sigma a_i) + \left|\Sigma a_i\right|^2\right]$$

$$a_i = \frac{1}{r_i} F(\Theta, \vec{r}_i, \vec{k}) \exp[i(r_i k - \vec{r}_i \vec{k})]$$

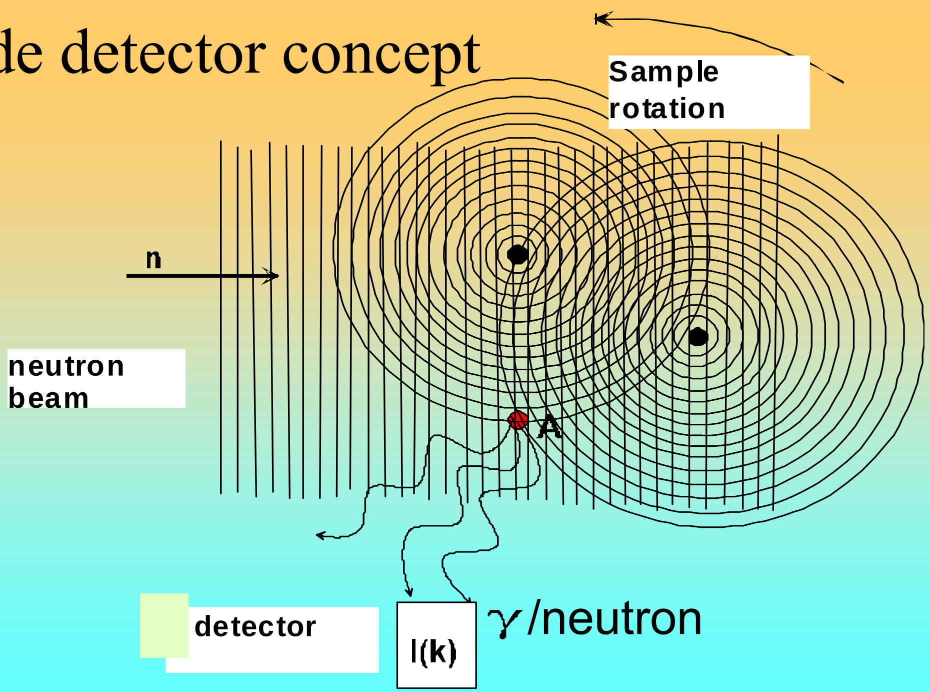
For neutrons $F(\Theta, \vec{r}_i, \vec{k})$ = const.=b_i (scattering length)

$k = 2\pi/\lambda$, conditions: $R = SD >> r_i > \lambda$

Inside source concept



Inside detector concept



MATHEMATICAL DESCRIPTION

$$I(\mathbf{k}) = \frac{I_0}{4\pi R^2}\left|1+\sum_j a_j(\mathbf{k})\right|^2 = \frac{I_0}{4\pi R^2}\left[1+2\Re\left(\sum_j a_j(\mathbf{k})\right)+\left|\sum_j a_j(\mathbf{k})\right|^2\right]$$

Reference beam

Object beam

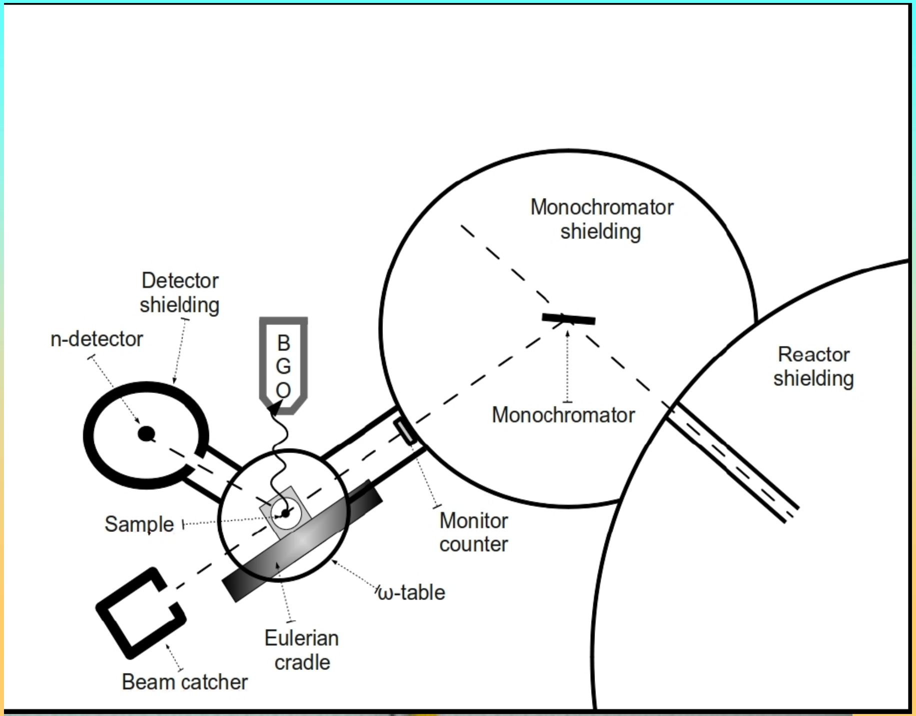
Background

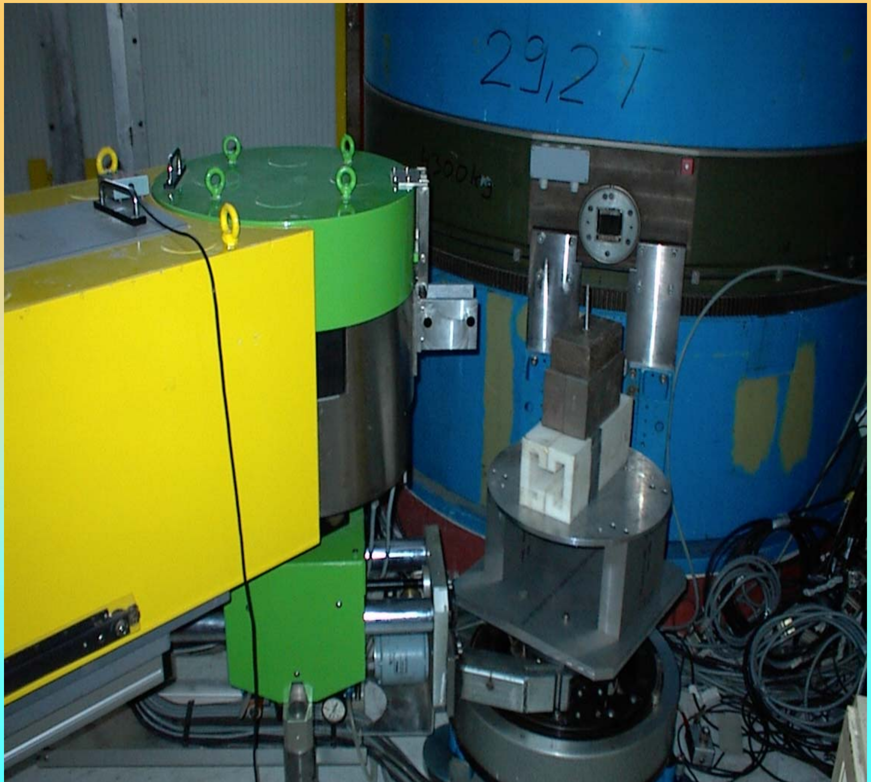
Hologram

negligible

$$I(\mathbf{k}) = \frac{I_0}{4\pi R^2}\left(1+\sum_j \chi_j(\mathbf{k})\right) = \frac{I_0}{4\pi R^2}\left(1+\chi(\mathbf{k})\right)$$

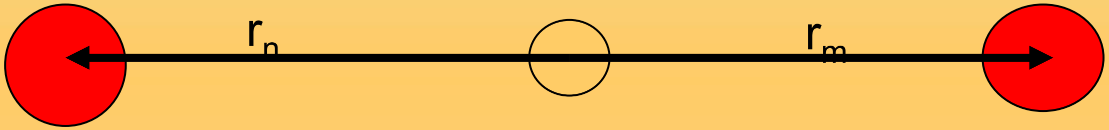
Holographic instrument





$$\chi(\vec{k}) = 2\sum_i \frac{b_i}{r_i}\cos(kr_i - \vec{k}\,\vec{r}_i)$$

$$\chi(\vec{k}) = 2\sum_n \frac{b_n}{r_n}(\cos(kr_n - \vec{k}\,\vec{r}_n) + \cos(kr_n + \vec{k}\,\vec{r}_n))$$

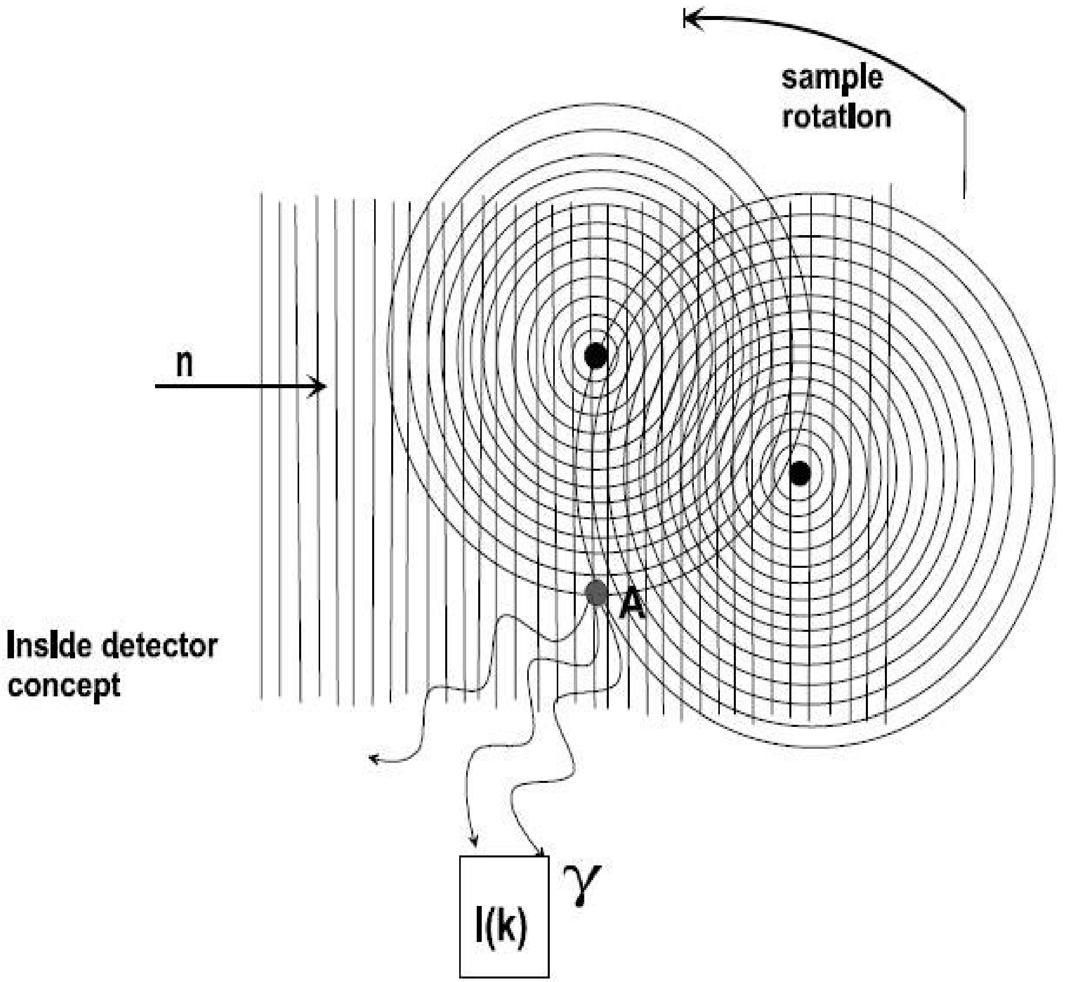


$r_n = -r_m$

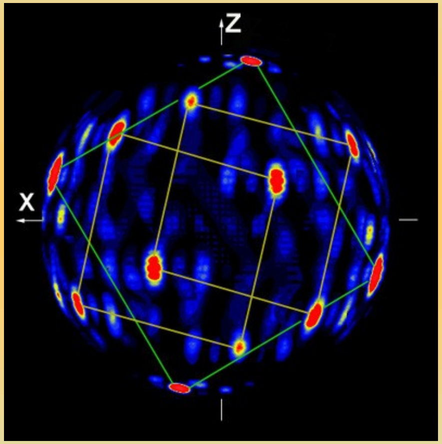
$$\chi(\vec{k}) = 4\sum_n \frac{b_n}{r_n}\cos(kr_n)\cos(\vec{k}\,\vec{r}_n)$$

$$U(\vec{R}) = 4\sum_n \frac{b_n}{r_n}\cos(kr_n)\int_{\sigma_k}\cos(\vec{k}\,\vec{r}_n)\exp(\vec{k}\,\vec{r}_n)\,d\sigma_k$$

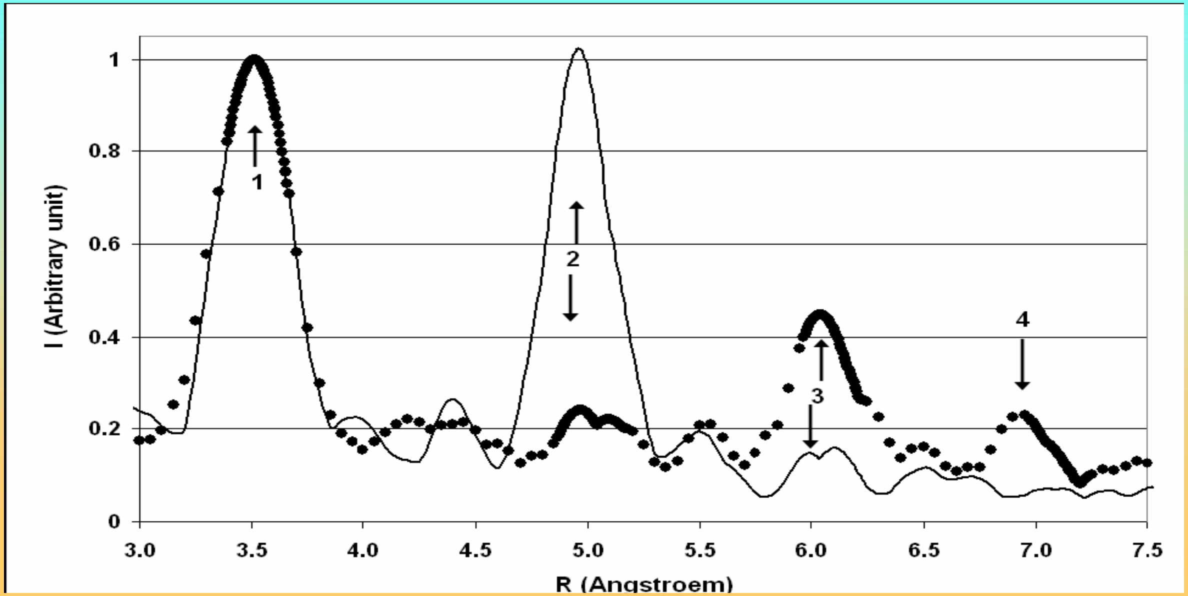
$$I(\vec{R}) = \left|U(\vec{R})\right|^2 \approx \left[\frac{\cos(kr_n)}{r_n}\right]^2$$


sample
rotation
n
A
Inside detector
concept
γ
I(k)

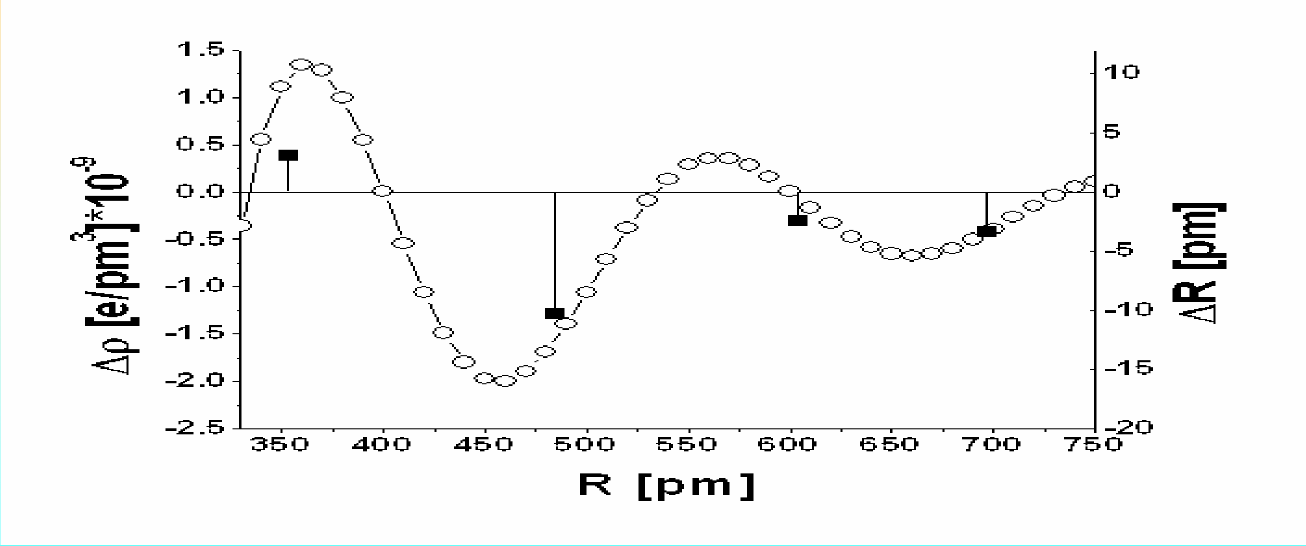
PbCd



Z
X



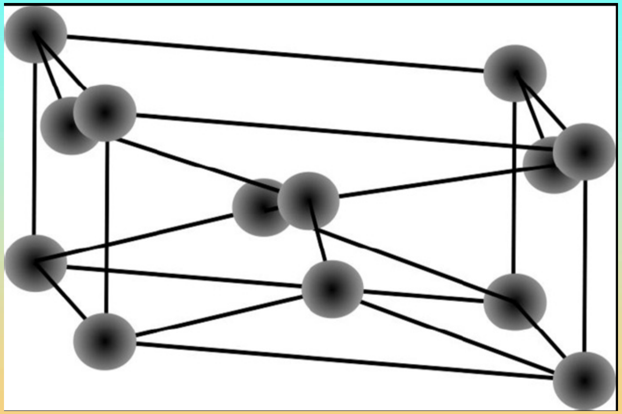
I (Arbitrary unit)
R (Angstroem)
1
2
3
4
0
0.2
0.4
0.6
0.8
1
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5

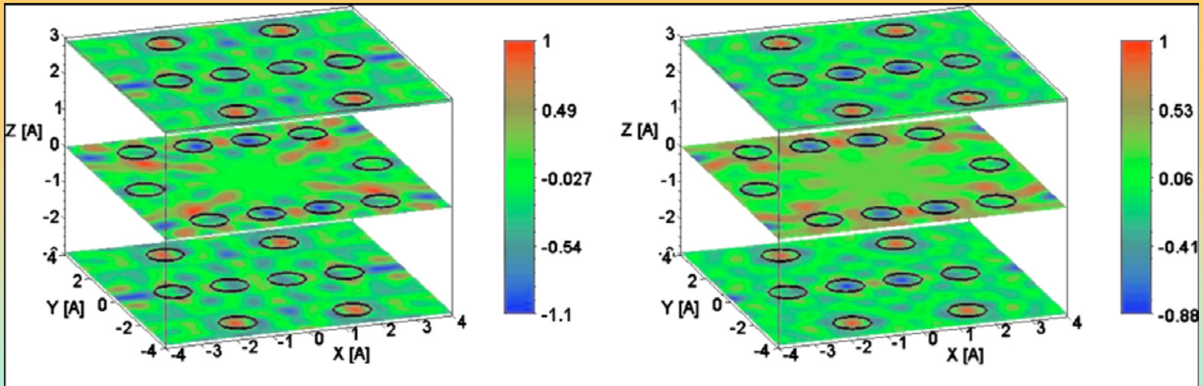


Δρ [e/pm³]*10⁻⁹
ΔR [pm]
R [pm]
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
350
400
450
500
550
600
650
700
750
10
5
0
-5
-10
-15
-20

Inside detector

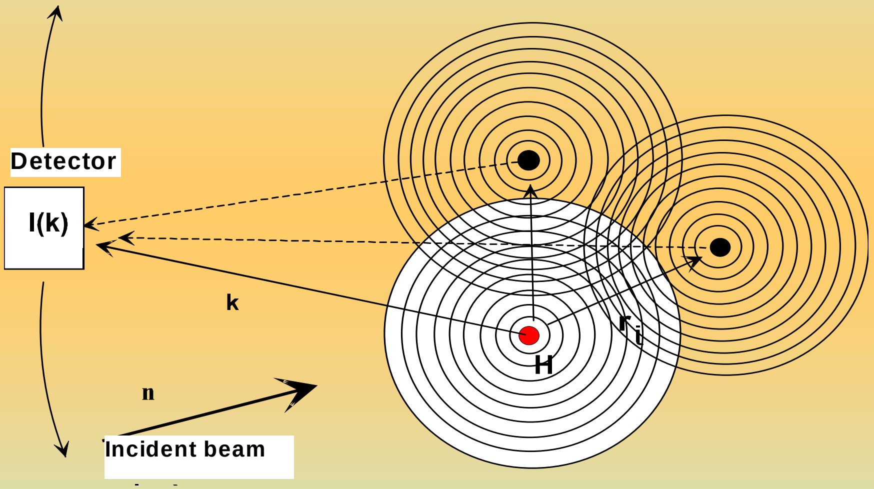
SnCd alloy





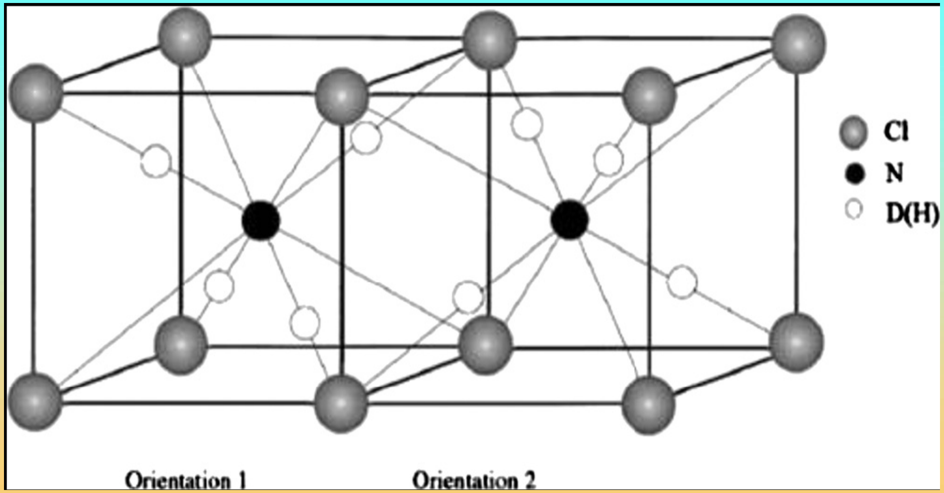
(a) (b)

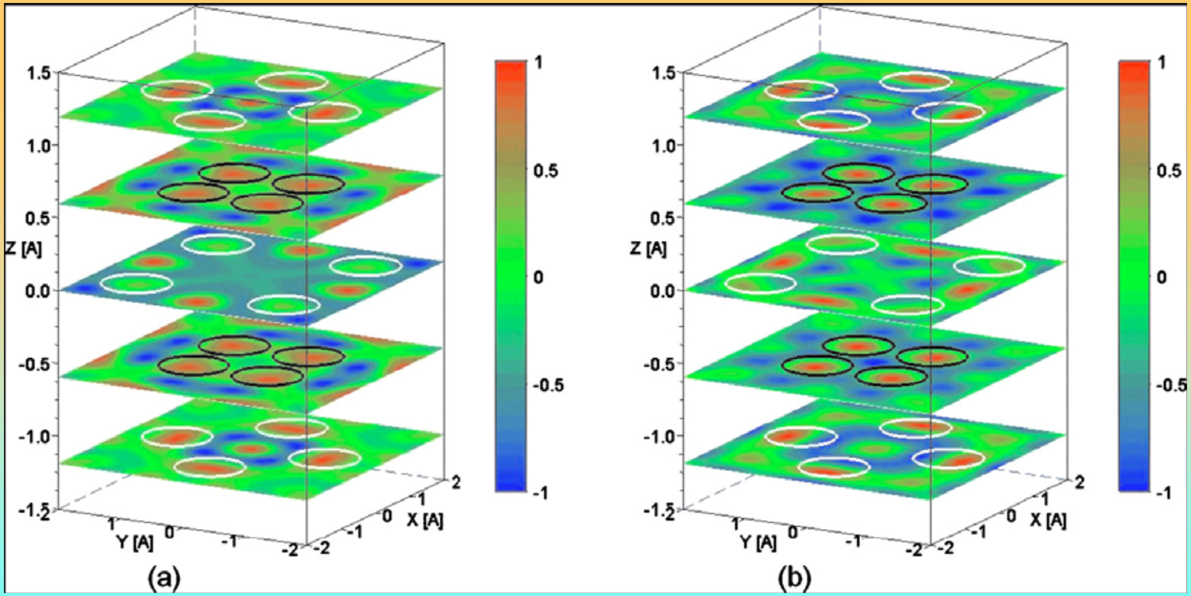
- Inside source concept

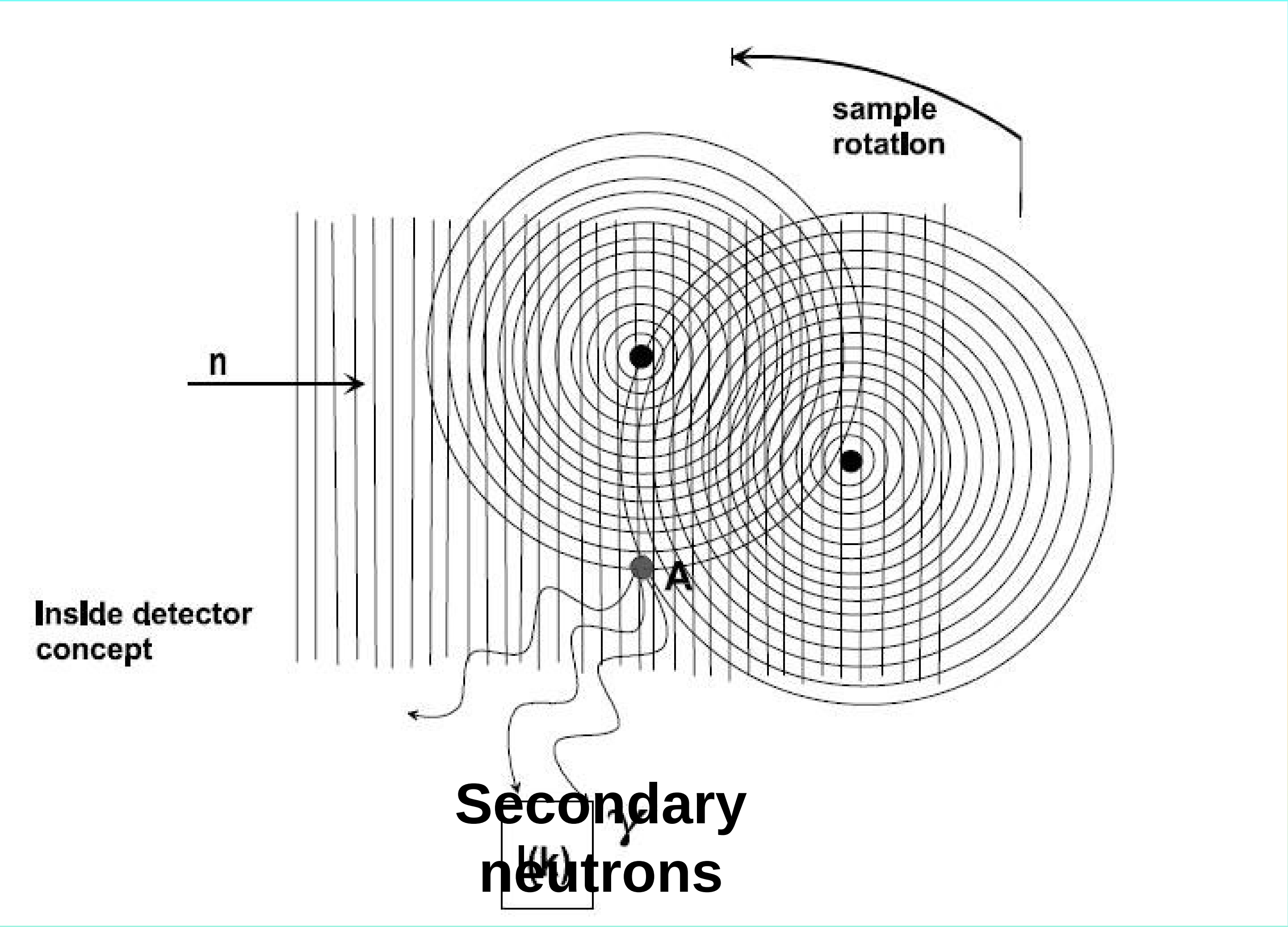


Inside source

NH_4Cl

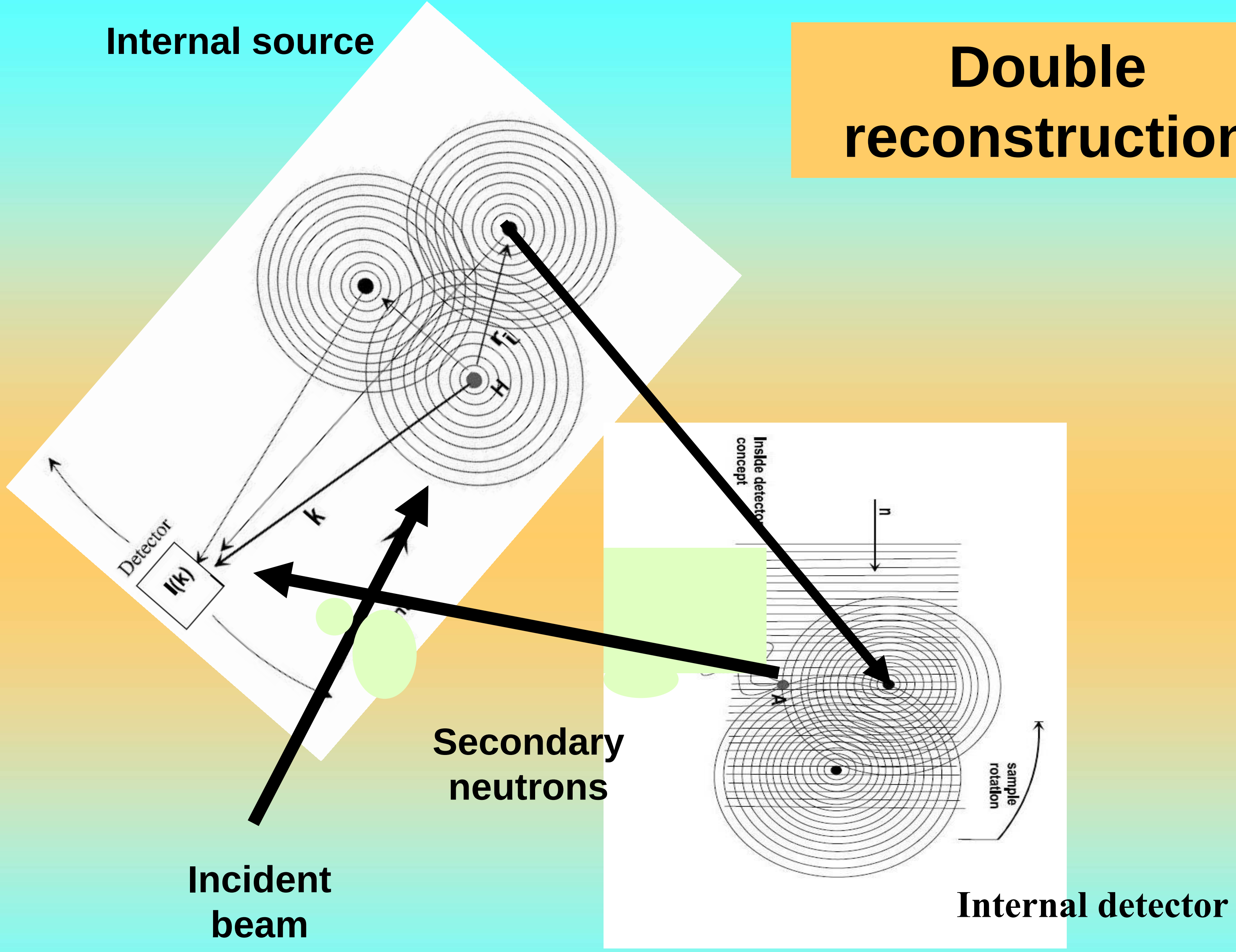




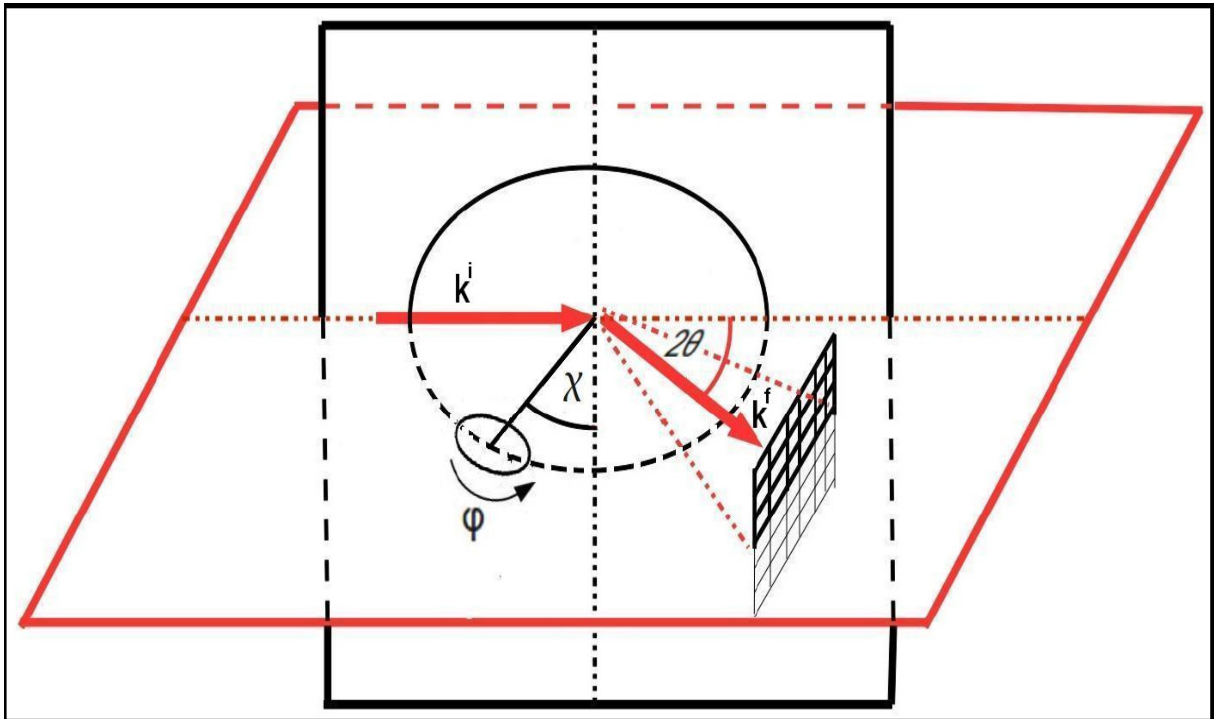


Secondary neutrons

Double reconstruction



Scattering scheme



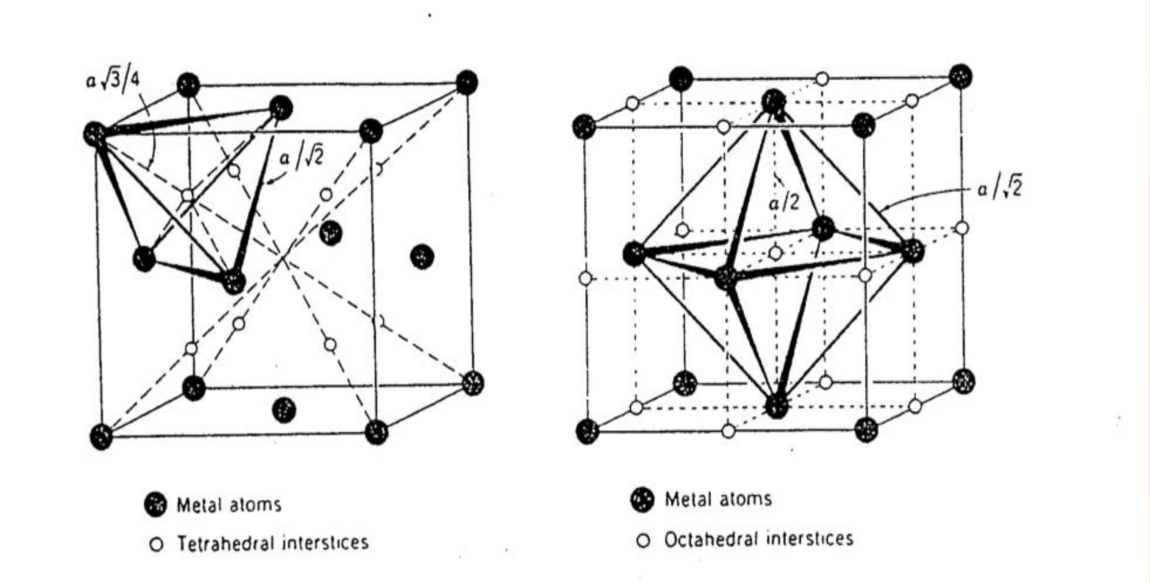
$$I_f\left(\bar{k}^i,\bar{k}^f,\bar{r}_d\right)=\frac{s^2(\phi_0^i)}{r_d^2}\left|\left(1+\sum_{l=2}^{N}\frac{-b_i\exp i\left(\left(\bar{k}^i\bar{r}_n+k^i r_i\right)\right)}{r_i}\right)\left(1+\sum_{l=2}^{N}\frac{-b_i\exp i\left(\left(\bar{k}^i\bar{r}_n-k^i r_i\right)\right)}{r_i}\right)\right|^2$$

$$I_f\left(\bar{k}^i,\bar{k}^f,\bar{r}_d\right)=\frac{s^2(\phi_0^i)}{r_d^2}\left|\left(1+\chi^i\left(\bar{k}^i\right)\right)\left(1+\chi^f\left(\bar{k}^f\right)\right)\right|^2$$

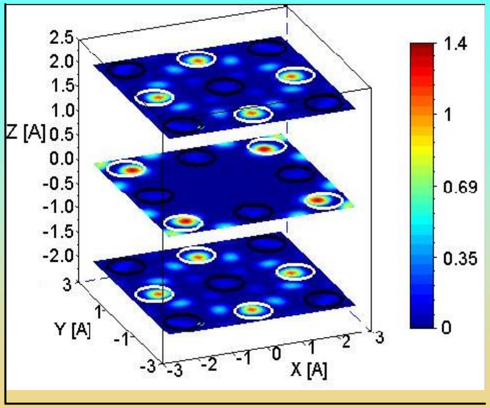
Signal – to - noise ratio increases by a factor of two.

The „parasitic” components appears in second order

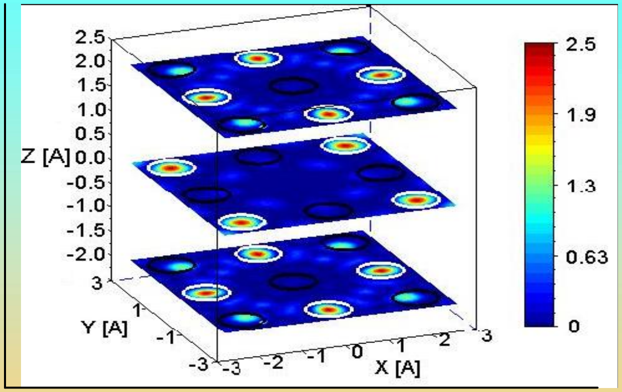
PdH



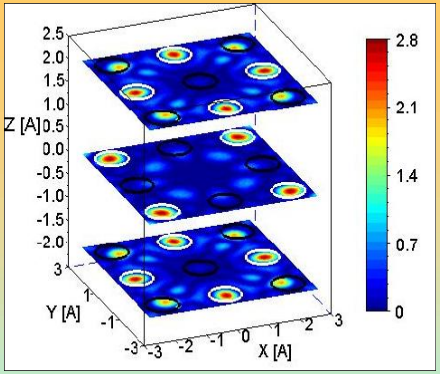
a √3/4
a/√2
Metal atoms
Tetrahedral interstices
a/2
a/√2
Metal atoms
Octahedral interstices


Z [A]
Y [A]
X [A]
1.4
1
0.69
0.35
0

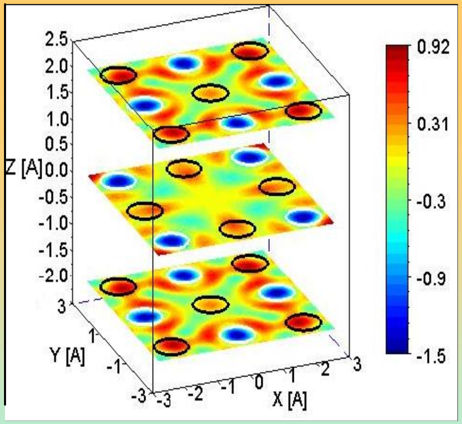
a


Z [A]
Y [A]
X [A]
2.5
1.9
1.3
0.63
0

c


Z [A]
Y [A]
X [A]
2.8
2.1
1.4
0.7
0

b

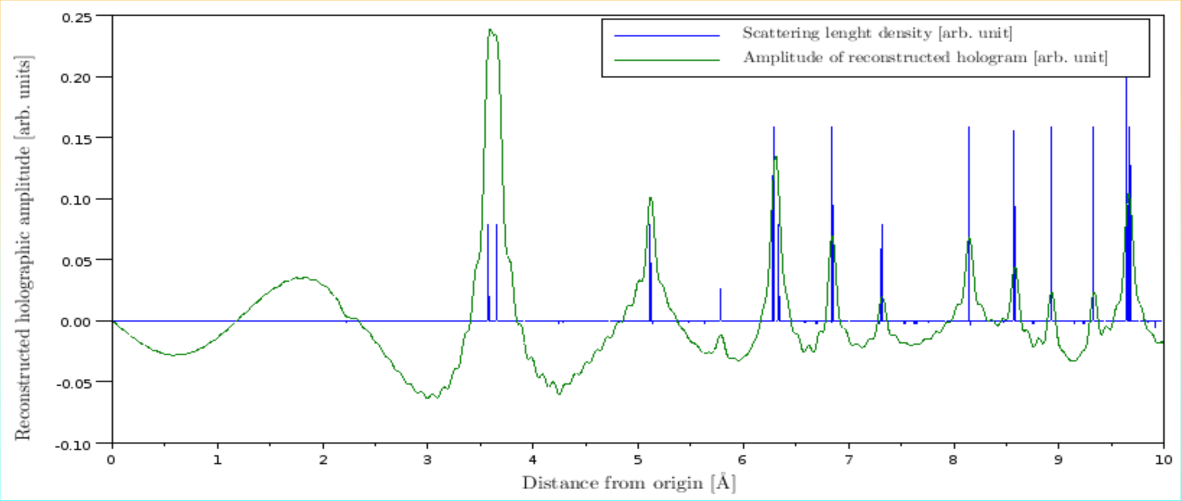

Z [A]
Y [A]
X [A]
0.92
0.31
-0.3
-0.9
-1.5

d

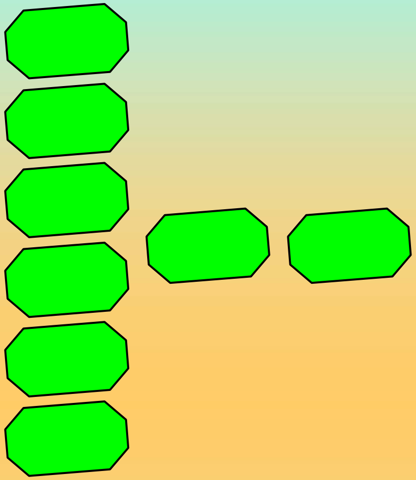
Polycrystalline sample

$$I(\bar{k}) = \frac{I_o}{R^2}\left(1 + \sum_{j=1}^{n} \frac{-2b_j}{r_j}\cos\left(kr_j - \bar{k}\bar{r}_j\right) + \left|\sum_{j=1}^{n} \frac{-b_j}{r_j}\exp i\left(kr_j - \bar{k}\bar{r}_j\right)\right|^2\right) = \frac{I_o}{R^2}\left(1 + \chi(\bar{k}) + \left|O(\bar{k})\right|^2\right)$$

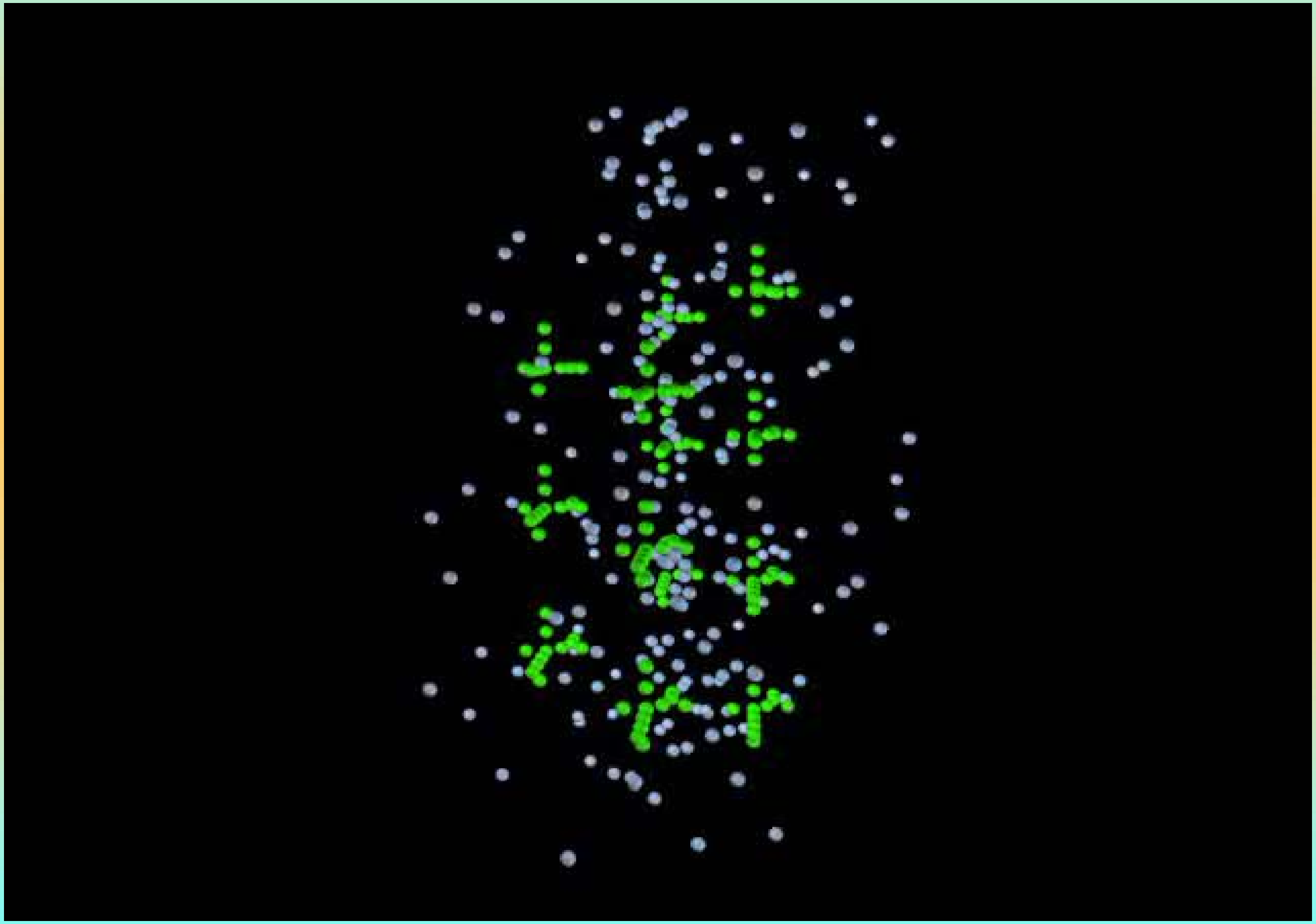
$$I_{poly}(\bar{k}) = \sum_{j} \frac{-2b}{r_j}\frac{1}{4\pi r_j^2}\oint_{|r_j| = r_j}^{I} \cos\left(kr_j - \bar{k}\bar{r}_j\right)dA = \sum_{r_j} \frac{N_{r_j} b}{kr_j^2}\sin\left(2kr_j\right)$$



Pattern Recognition
Biology!!!



Basic pattern



Complex body

PUZZLE

sample	<b> / fermi	$b_{observed}$ fermi	interatomic distance	amplification	wavelength (Å)	cos(kr)/r
Palladium(PdH)	5.91	41	H-Pd: 3.37 Å	7	1.18 Å	0.18
Hydrogen(PdH)	-3.74	- 37	H-H: 2.75 Å	10	1.18 Å	-0.17
H (NH_4Cl)	-3.71	- 37	H-H :1,68 Å	10	1 Å	-0,26
N(NH_4Cl)	9.36	37	H-N :1,03 Å	4	1 Å	0.95
SnCd	6.225	19	Sn-Cd :3.02 Å	3	1 Å	0.33

Thank you for your attention!

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