

# Mágnesség és elektromos vezetés „kétdimenziós” molekulakristályokban

Jánossy András

Budapesti Műszaki és Gazdaságtudományi  
Egyetem Fizikai Intézet, Fizika Tanszék  
Kondenzált Anyagok MTA-BME Kutatócsoport

Ágnes Antal<sup>1</sup>

Titusz Fehér<sup>1</sup>

Erzsébet Tátrai Szekeres<sup>1</sup>

Ferenc Fülöp<sup>1</sup>

Richárd Gaál<sup>2</sup>

Bálint Náfrádi<sup>1,2,4</sup>

László Forró<sup>2</sup>

Cécile Mézière<sup>3</sup>

Patrick Batail<sup>3</sup>

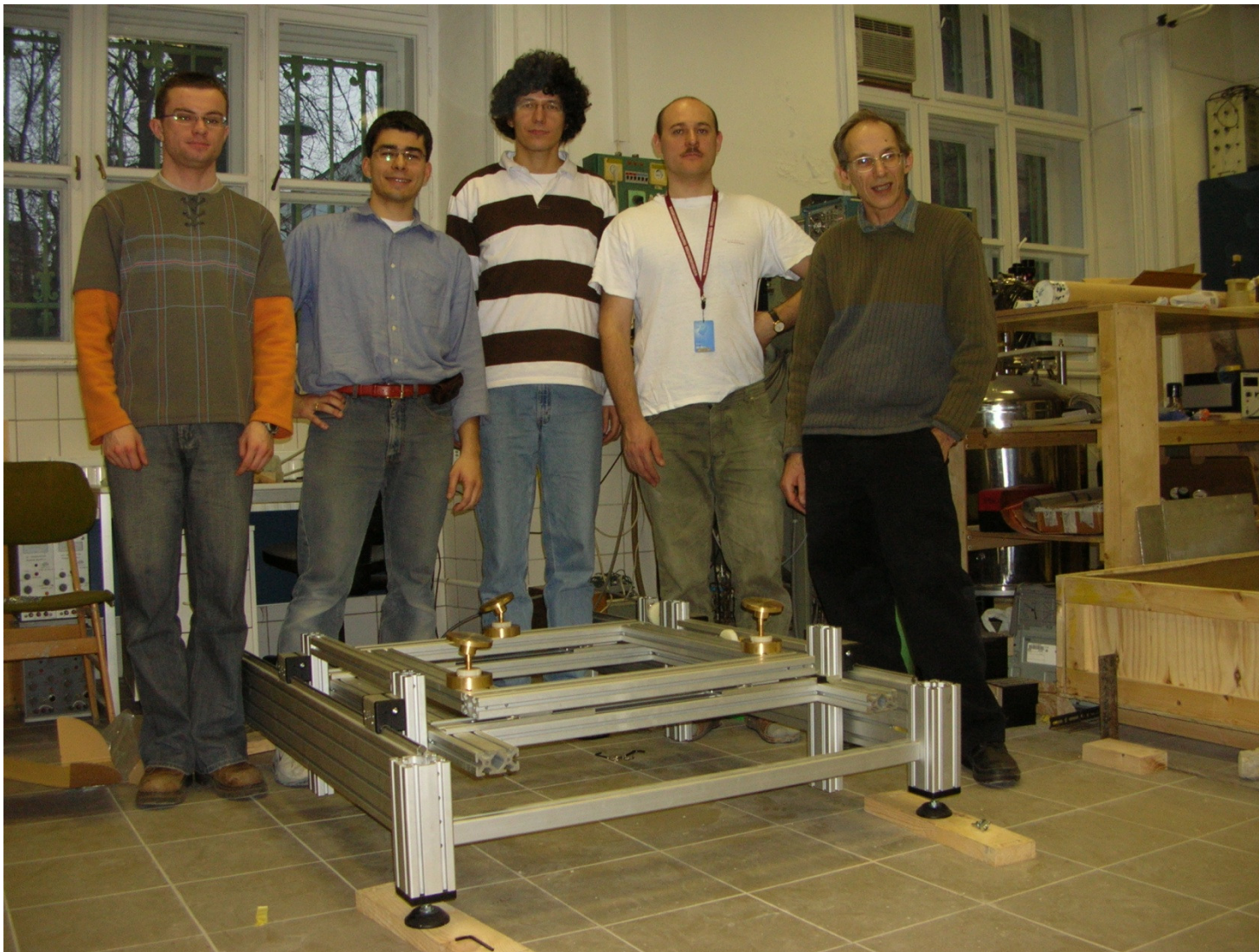
<sup>1</sup>*Budapest University of Technology and Economics, Institute of Physics, Hungary*

<sup>2</sup>*Ecole Polytechnique Federale de Lausanne , Switzerland*

<sup>3</sup>*Laboratoire de Chimie et Ingénierie Moléculaire d'Angers, CNRS Angers, France*

<sup>4</sup>*Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany*

# ESR spectrometer 2007 January



Mihály  
Karaszi

Dario  
Quintavalle

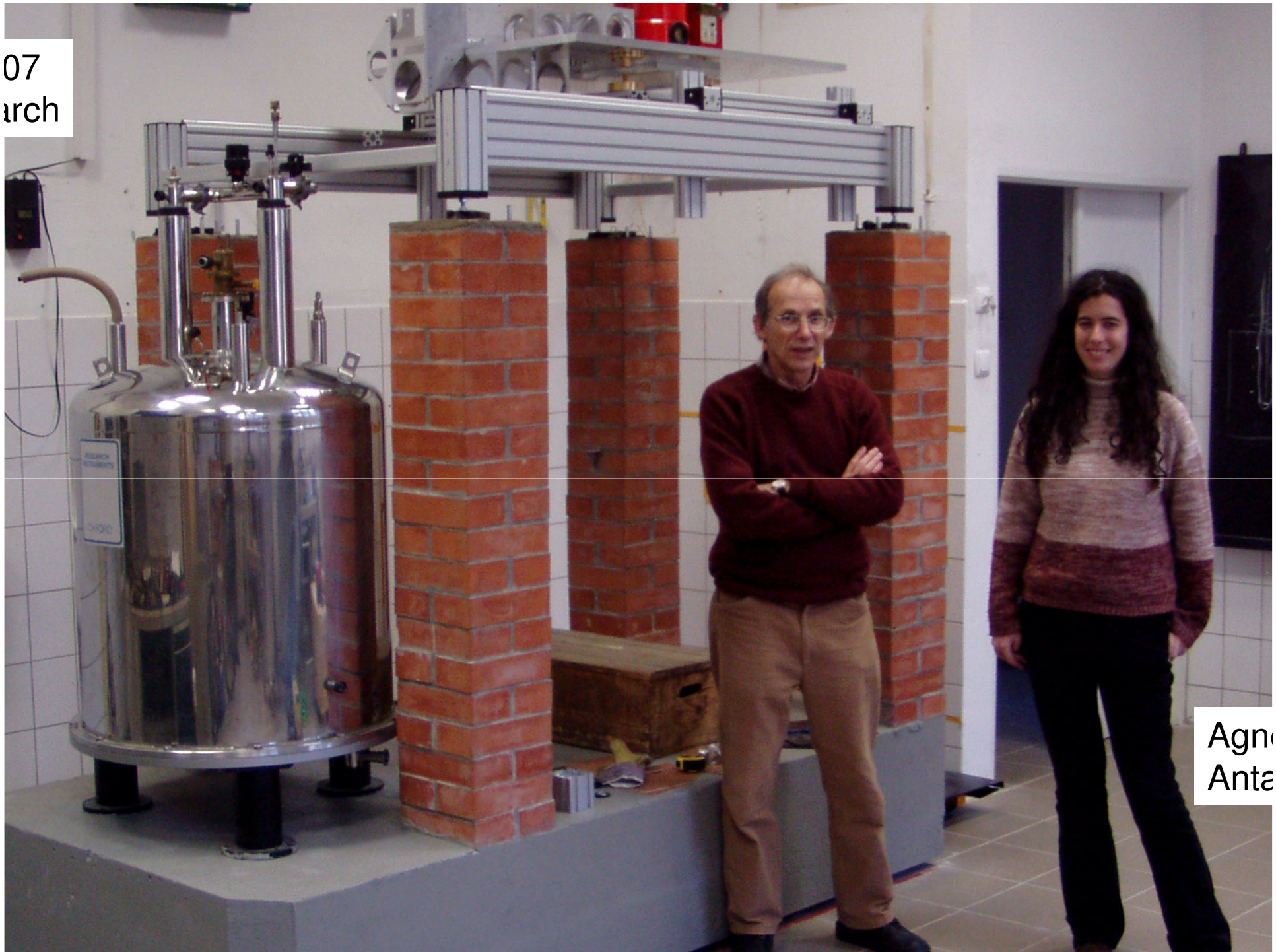
Titusz  
Fehér

Kálmán  
Nagy

András  
Jánossy

BUTE, 2007

07  
arch



Agn  
Anta

egy nem jellemző példa

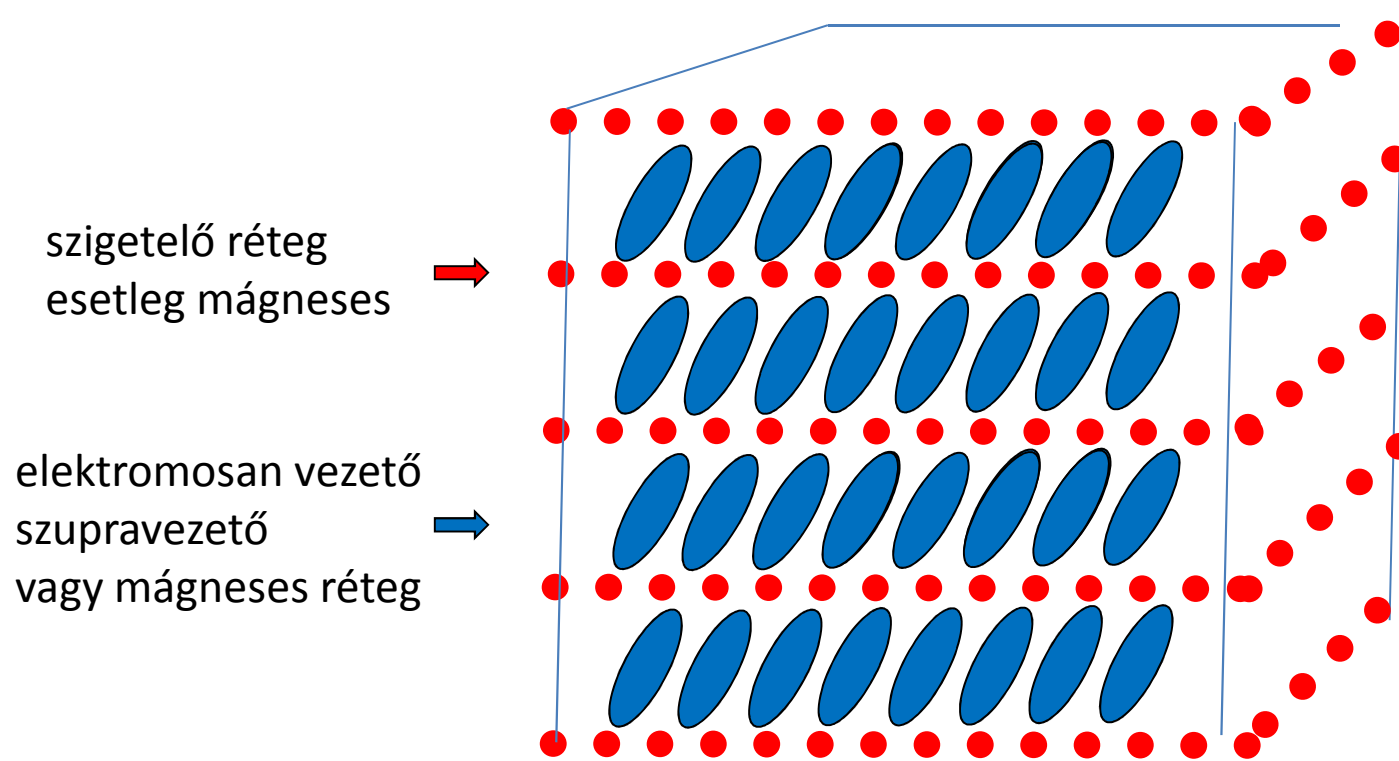
ET-Cl fázis diagram

Mott fém szigetelő átmenet

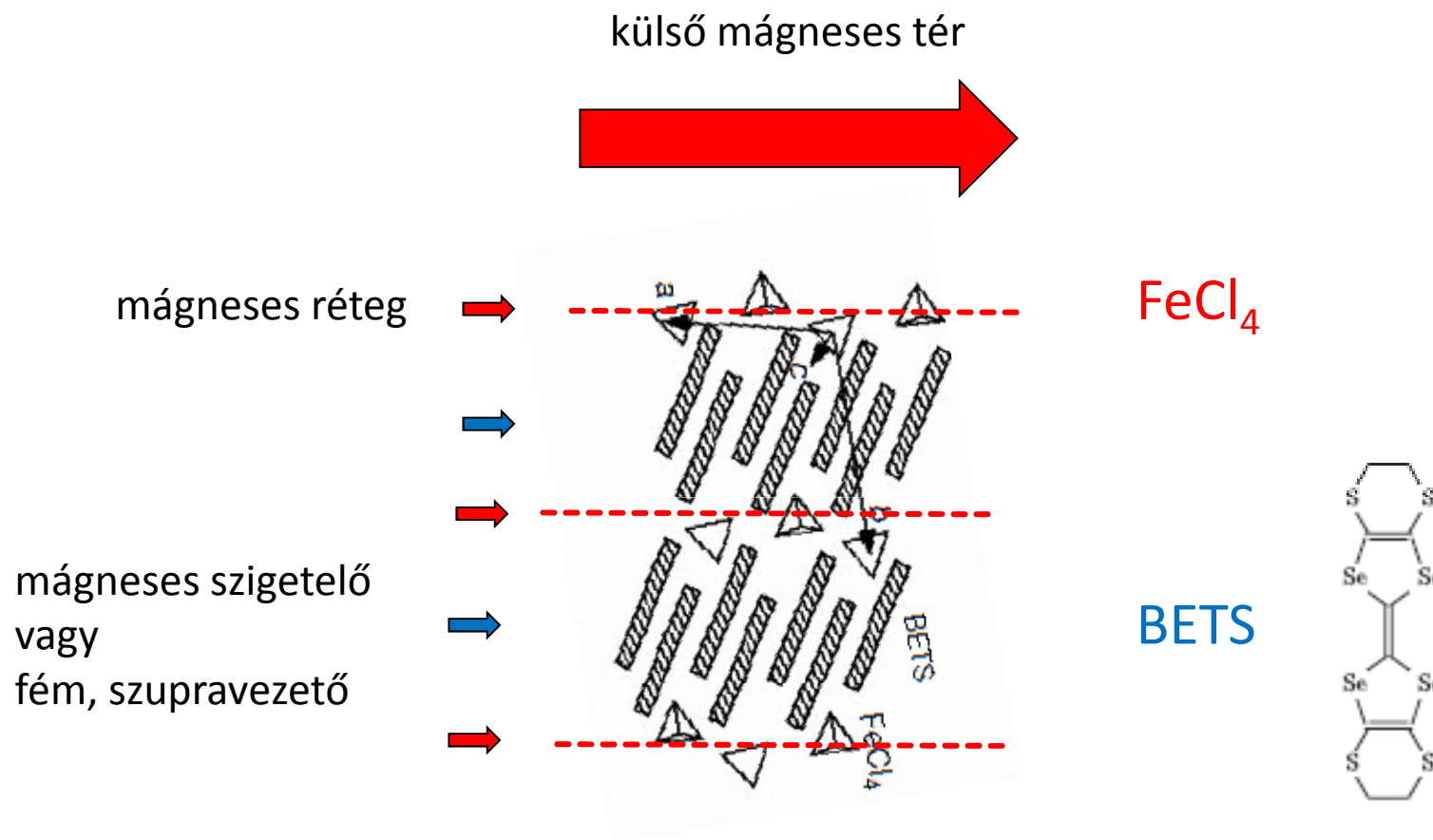
elektron hopping frekvencia mérése  
ESR spektroszkópiával

(Mire jó?)

# „Kétdimenziós” molekula kristály



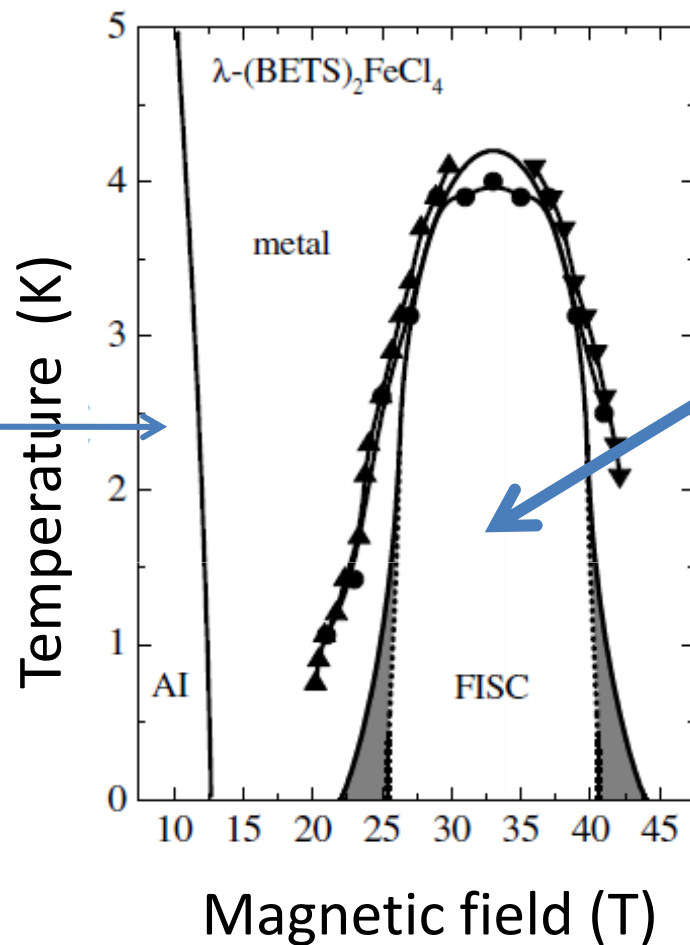
Egy nem tipikus példa:  
 $\lambda$ -(BETS)<sub>2</sub> FeCl<sub>4</sub>



Egy nem tipikus példa:  
 $\lambda$ -(BETS)<sub>2</sub>FeCl<sub>4</sub>

Mágneses tér indukált  
szupravezetés

insulating  
antiferromagnet



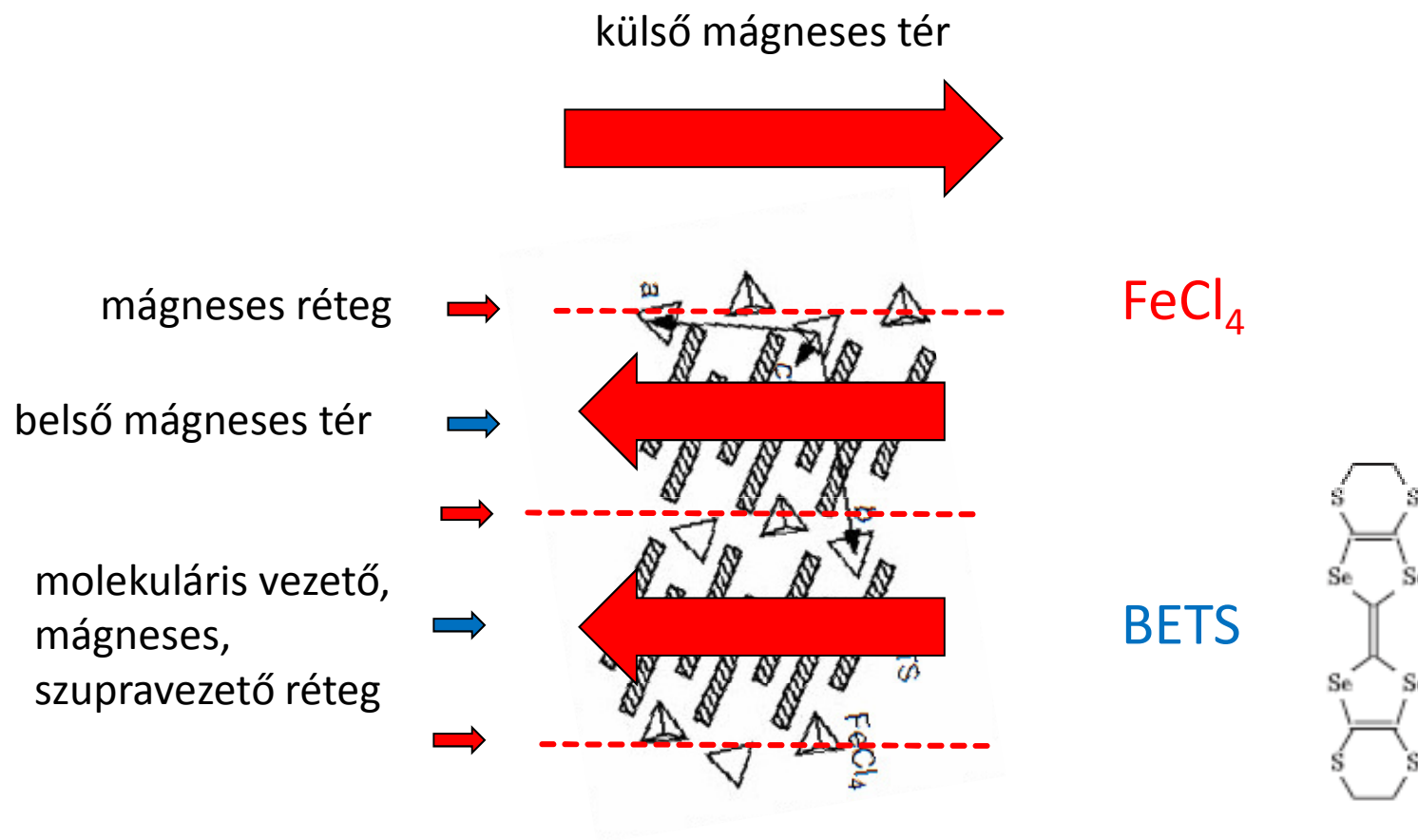
NHMFL, Tallahassee

S. Uji *et al.*, Nature (London) **410**, 908 (2001)

Balicas et al PRL 87 067002 2001



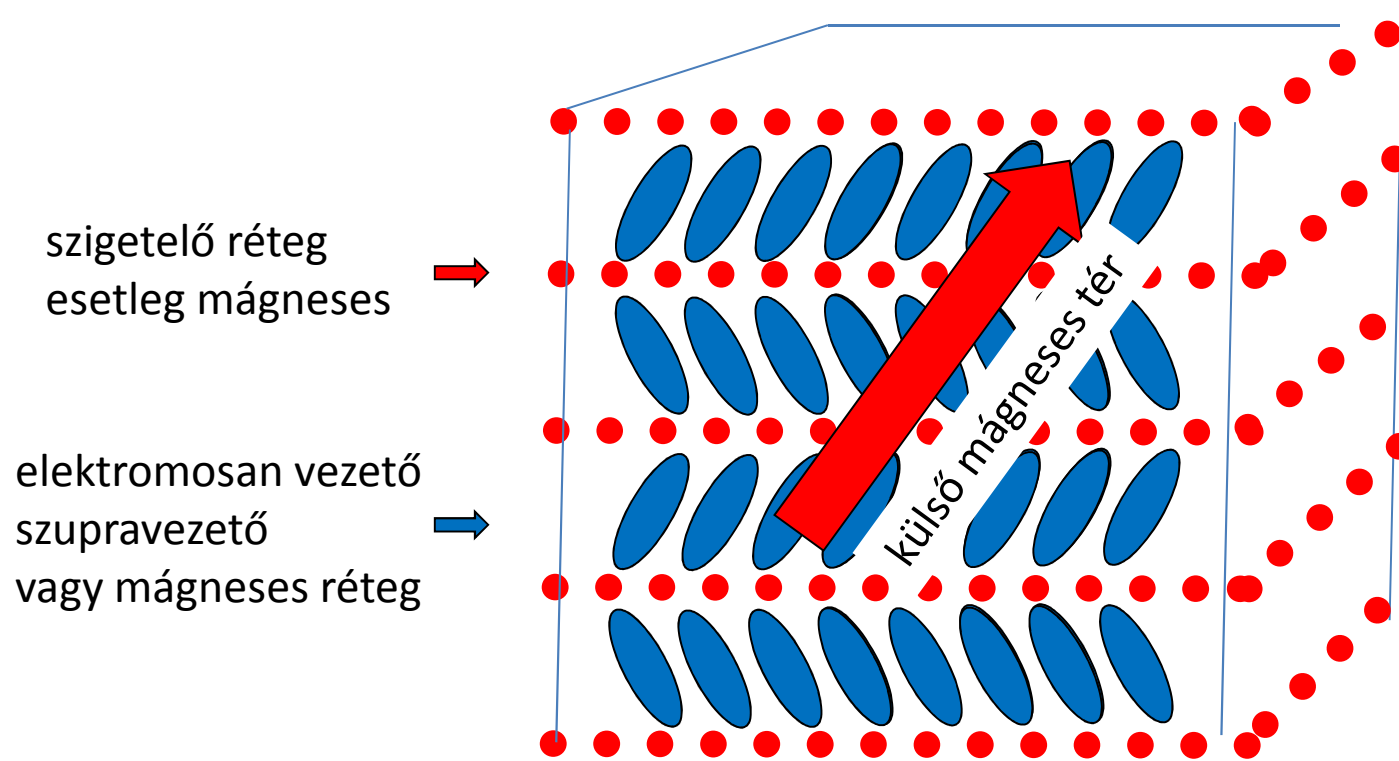
Egy nem tipikus példa:  
 $\lambda$ -(BETS)<sub>2</sub> FeCl<sub>4</sub>



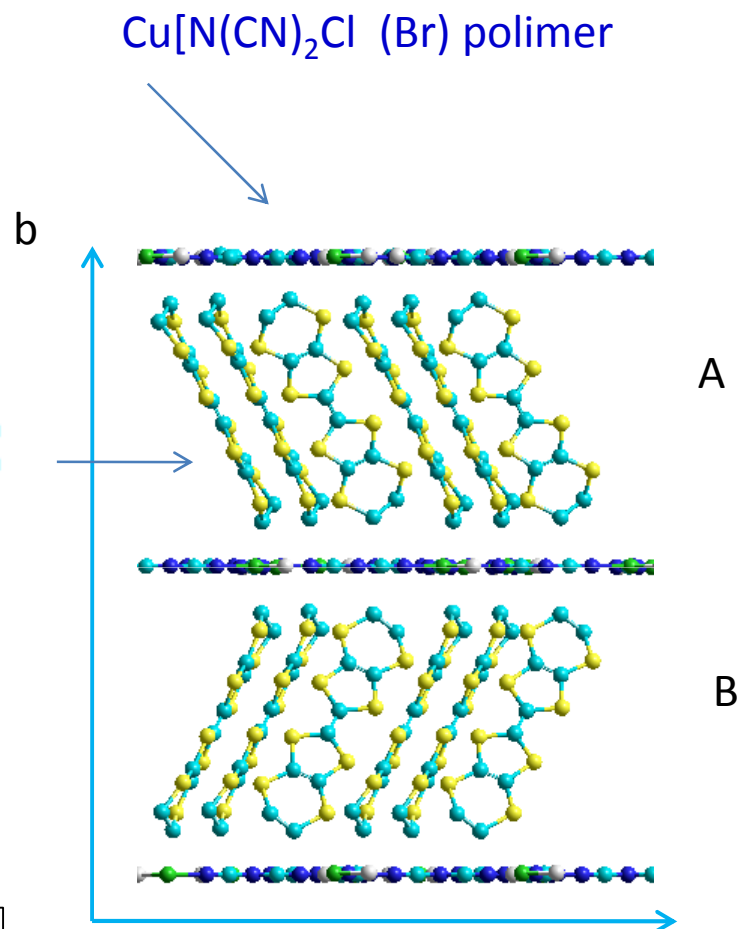
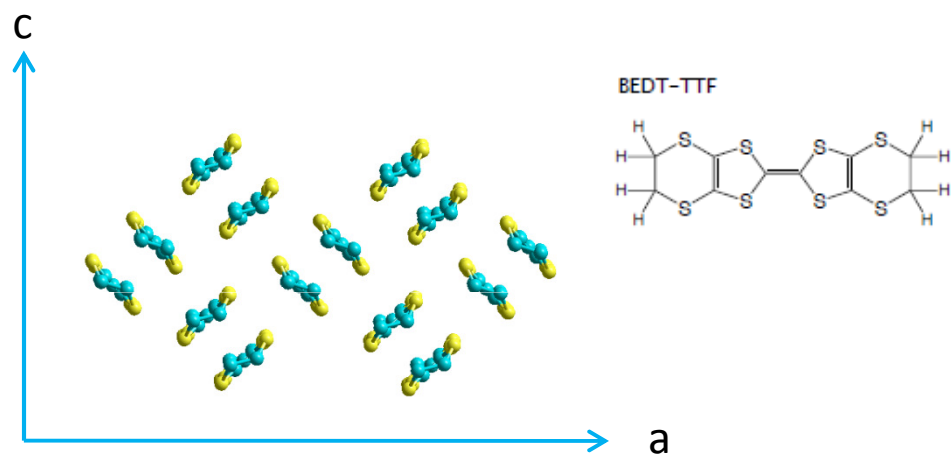
Ezen előadás:

Mekkora a kölcsönhatás a rétegek között?

„Kétdimenziós” molekula kristály  
kémiaailag azonos, alternáló rétegekkel



Réteges szerves kristály  
 $\kappa$ -(BEDT-TTF)<sub>2</sub> Cu[N(CN)<sub>2</sub>Cl]  
( $\kappa$ -(ET)<sub>2</sub>Cl)

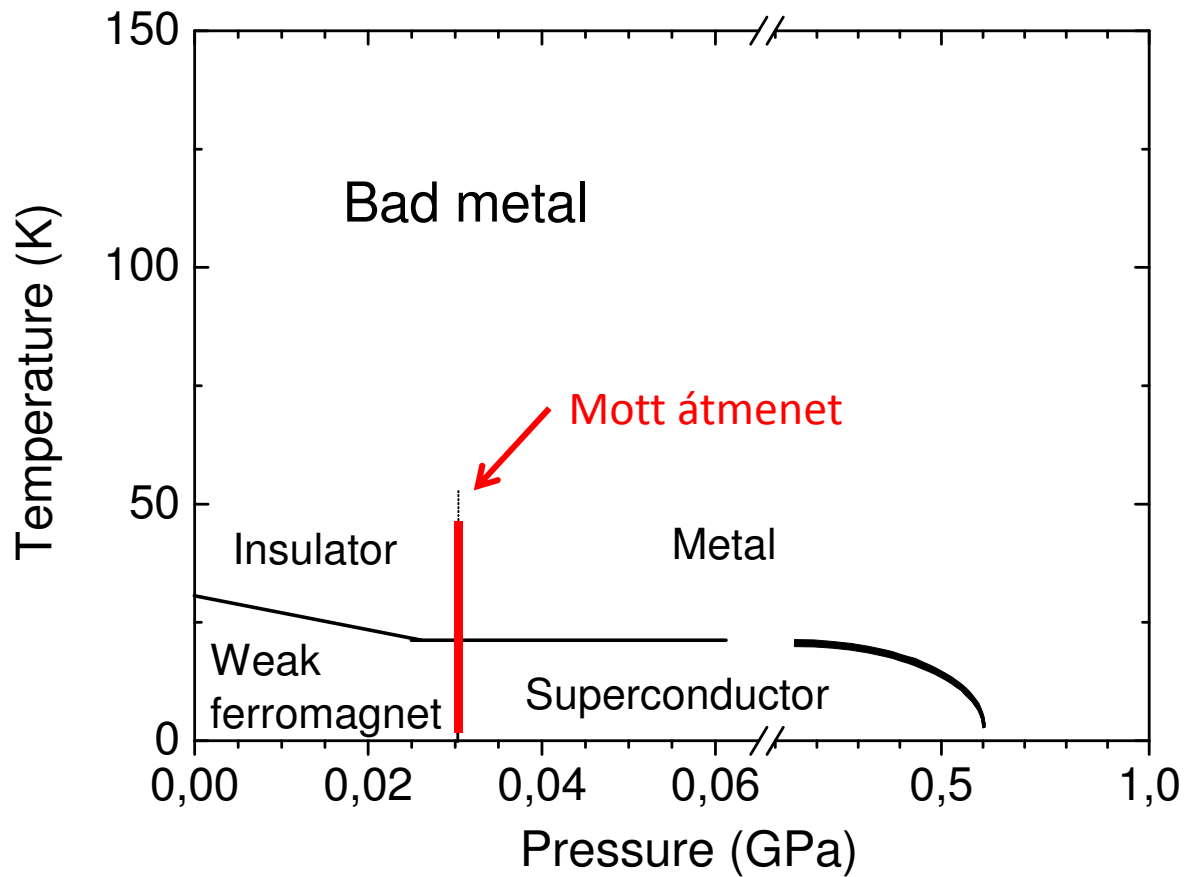
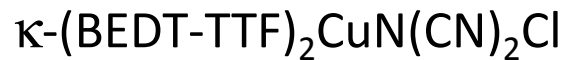


Fém-szigetelő „Mott” átmenet

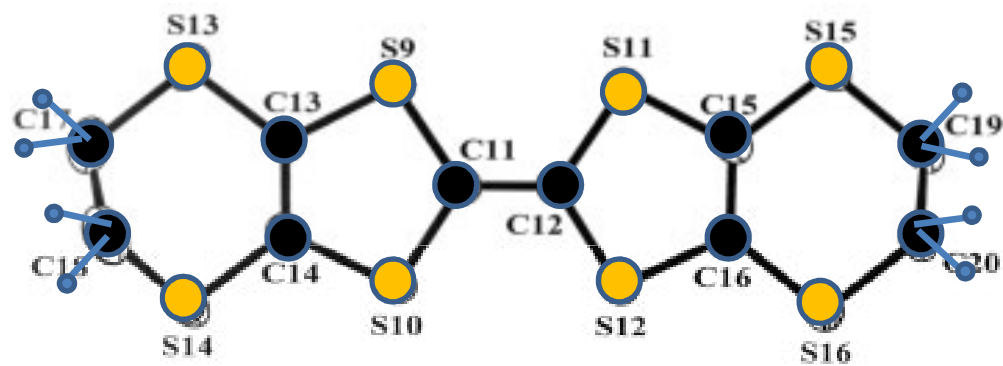
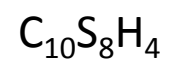
Jellemzően **nyomás (kémiai nyomás)** hatására

**mágneses szigetelőből → fém**

# Nyomás-hőmérséklet fázis diagram

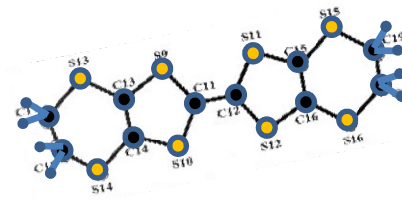
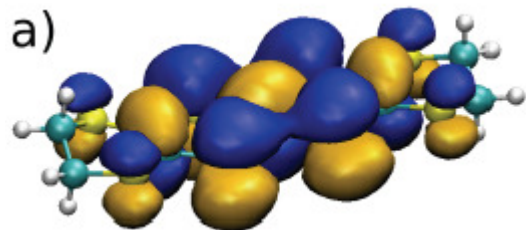


BEDT-TTF molekula

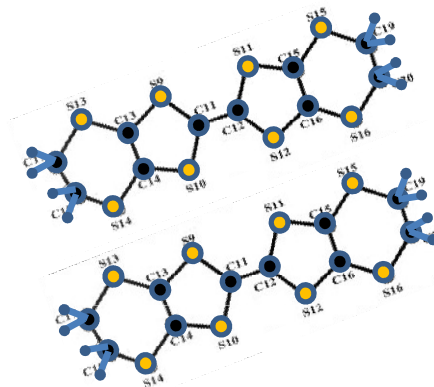
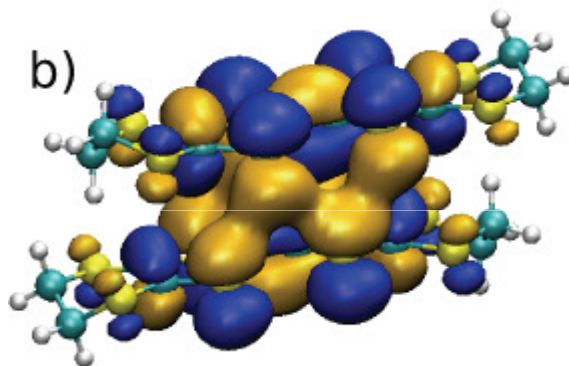


# Izolált molekulák elektronszerkezete

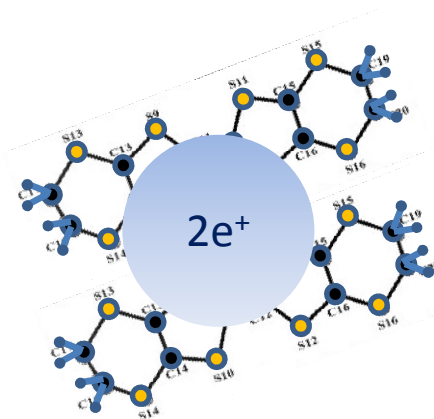
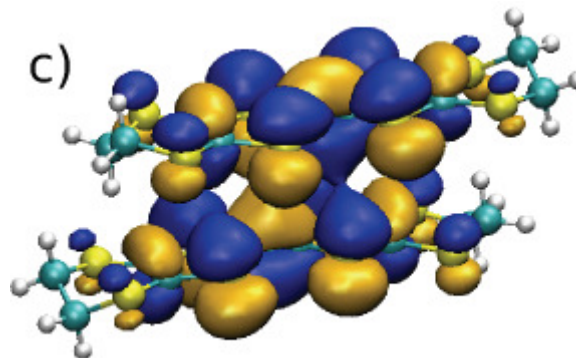
BEDT-TTF



$(\text{BEDT-TTF})_2$



$[(\text{BEDT-TTF})_2]^{2+}$

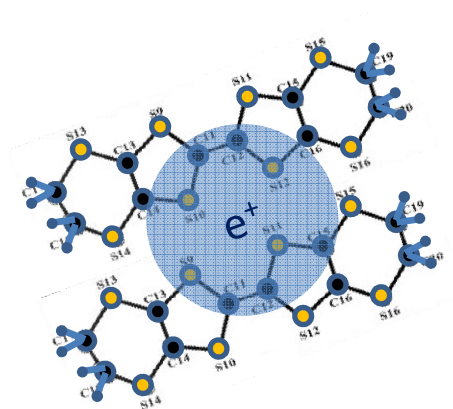


Egyszeresen töltött BEDT-TTF dimer ion



elektromosan töltött:  $e^+$

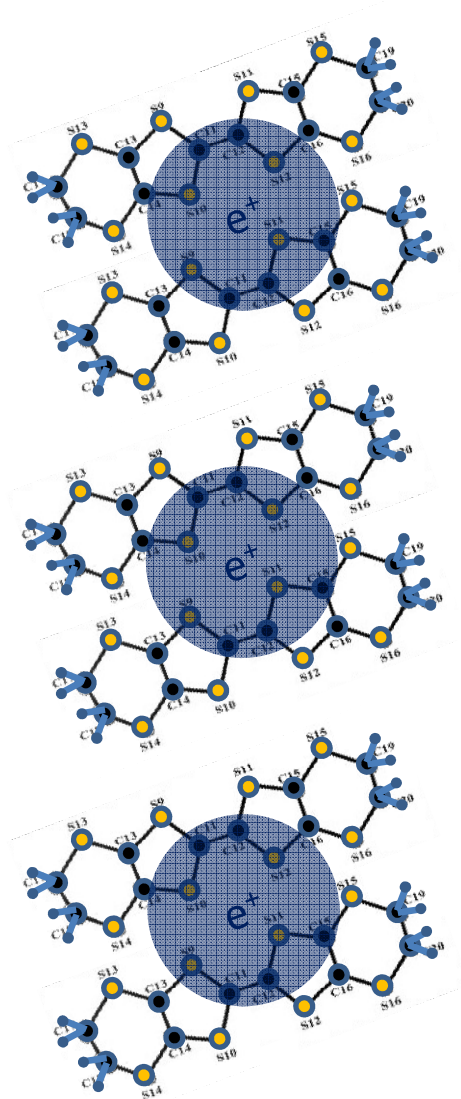
mágneses:  $S=1/2$



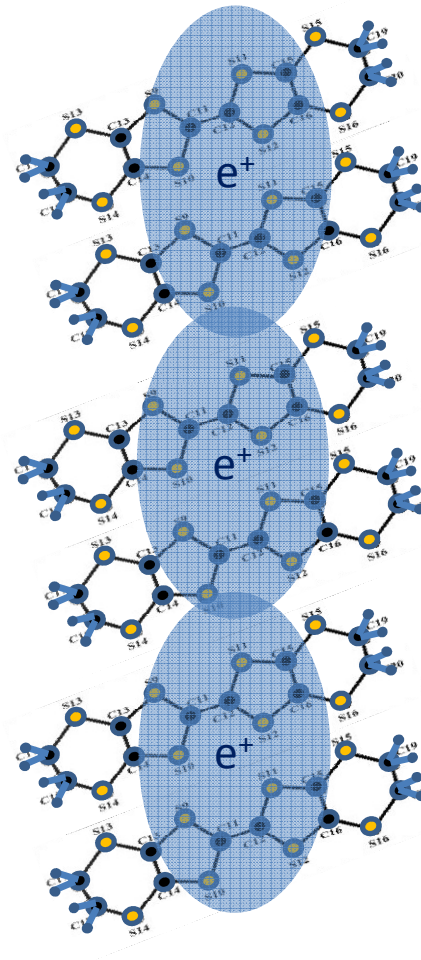


# Mott átmenet

Kis nyomás  
Szigetelő paramágnes,  
ferro- v. antiferromágnes



Nagy nyomás  
Fém



Mott átmenet

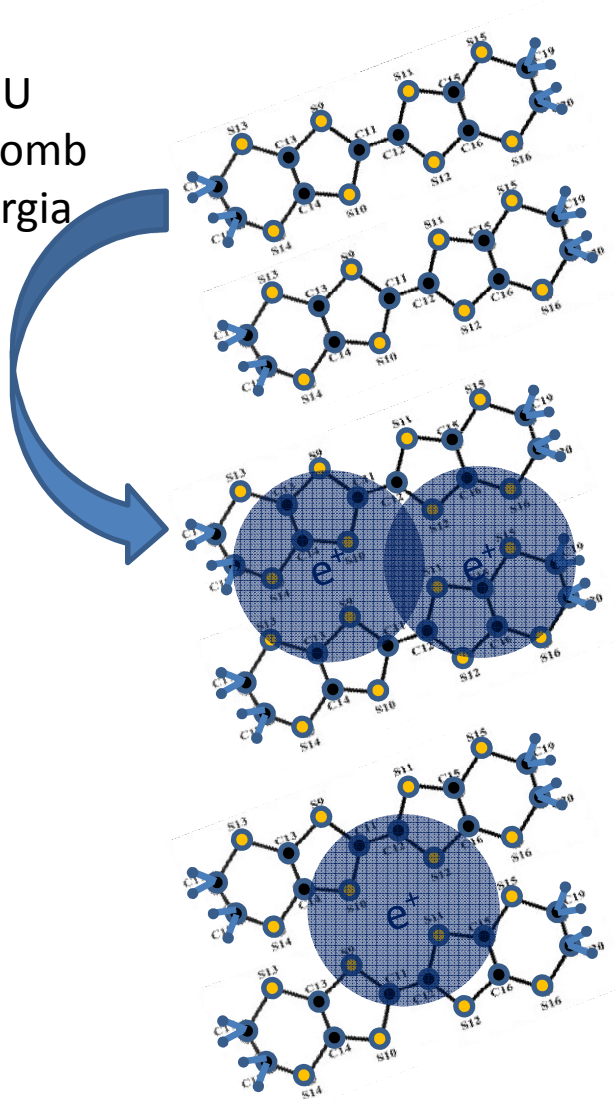
Szigetelő  
paramágnes

Fém

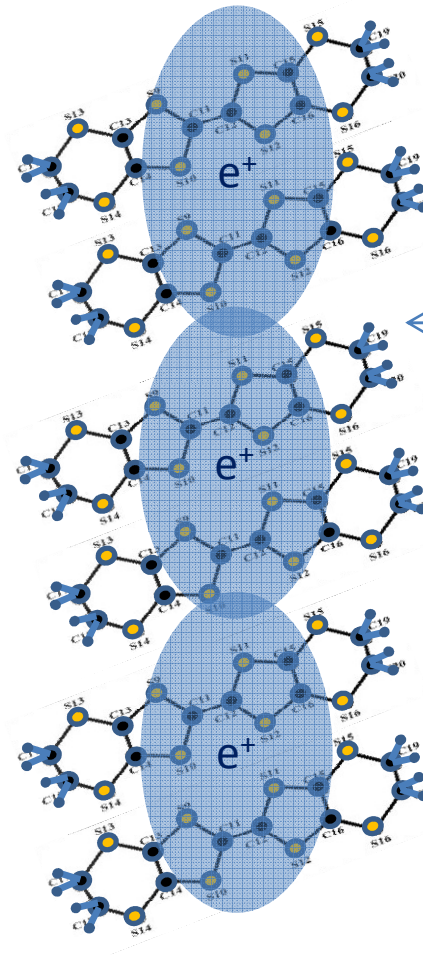
U nagy

W nagy

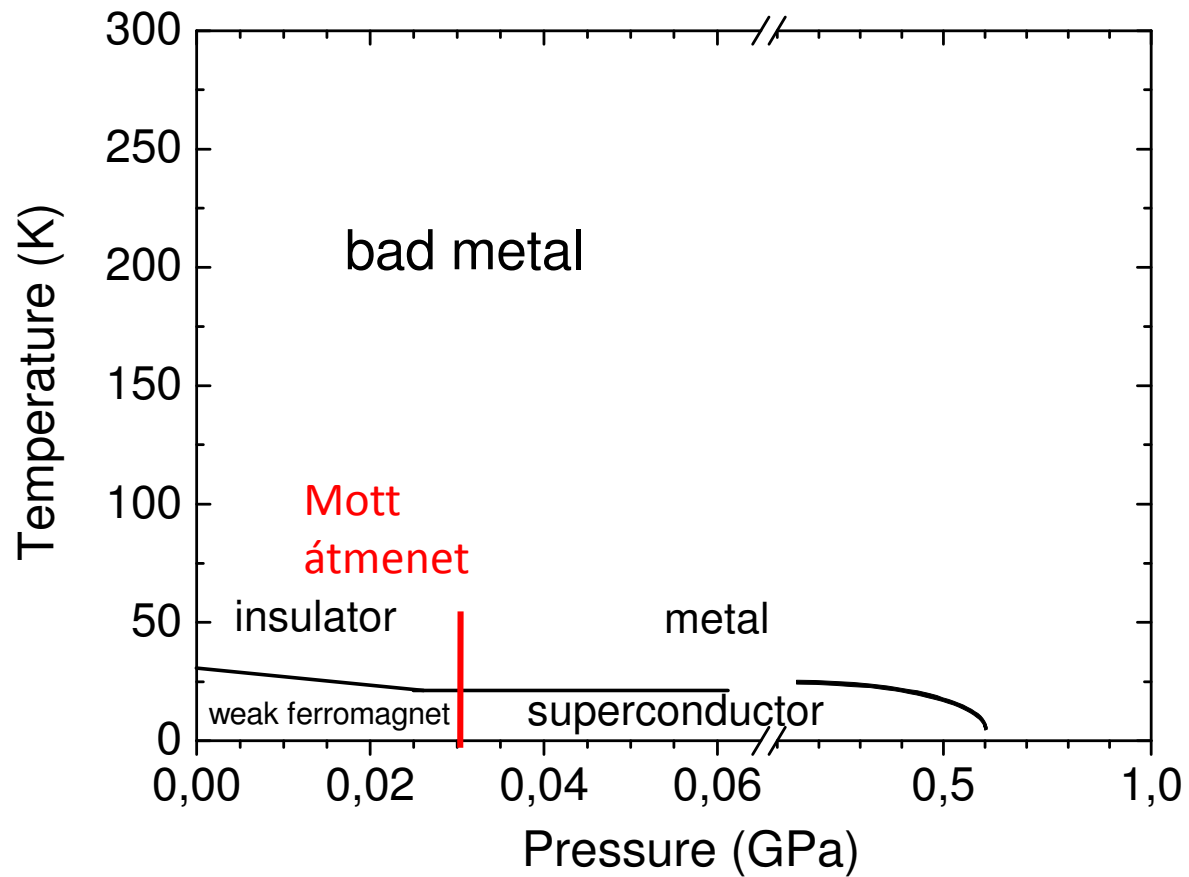
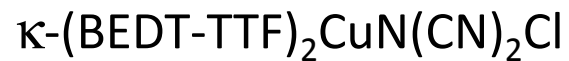
+U  
Coulomb  
energia



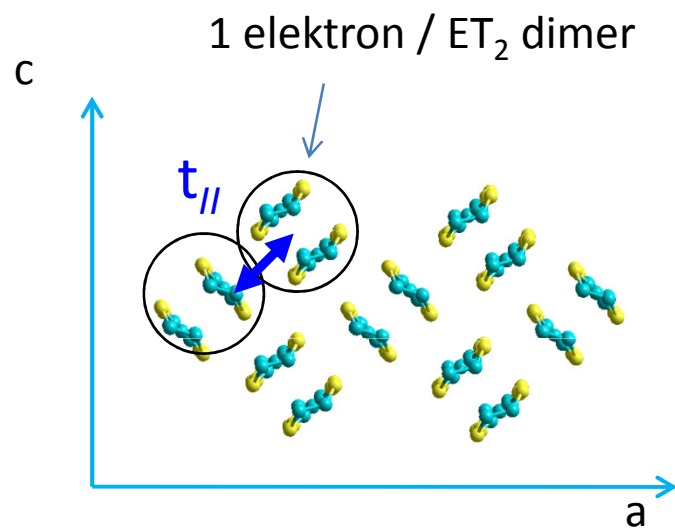
W  
átfedési  
energia



# Nyomás-hőmérséklet fázis diagram

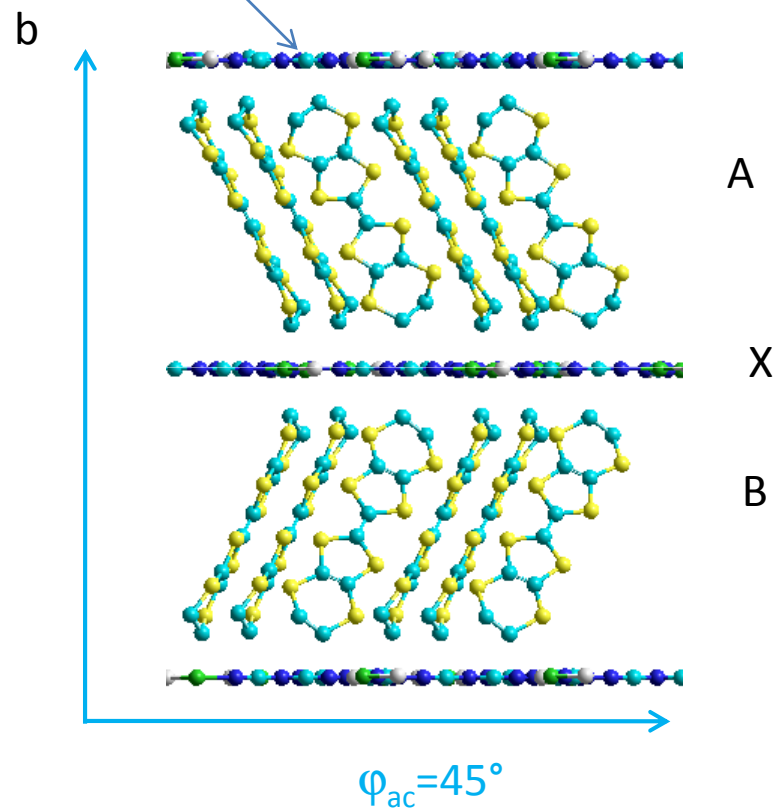


Réteges szerves kristály  
 $\kappa$ -(BEDT-TTF)<sub>2</sub> Cu[N(CN)<sub>2</sub>Cl]  
( $\kappa$ -(ET)<sub>2</sub>Cl)



$t_{//} \approx 100 \text{ meV}$

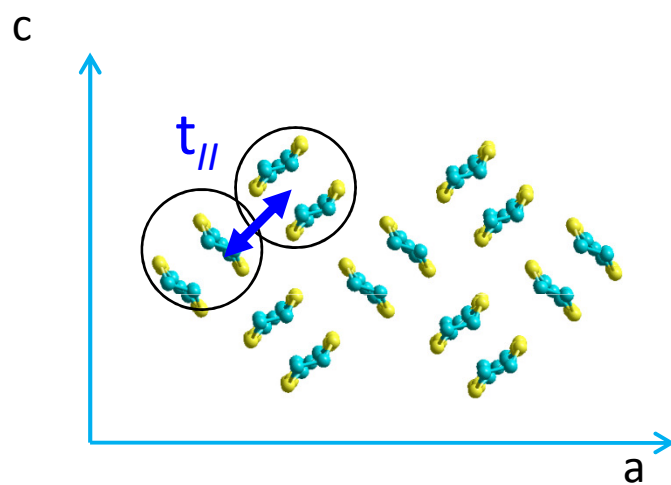
Cu[N(CN)<sub>2</sub>Cl polimer



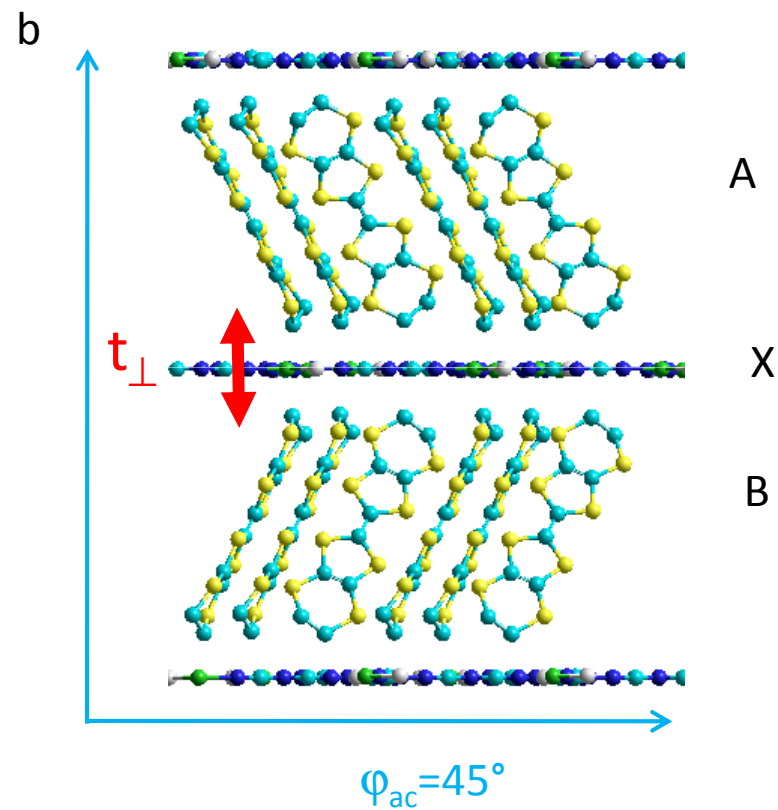
# Réteges szerves kristály átfedési integrálok

$\kappa$ -(BEDT-TTF)<sub>2</sub> Cu[N(CN)<sub>2</sub>Cl

( $\kappa$ -(ET)<sub>2</sub>Cl)



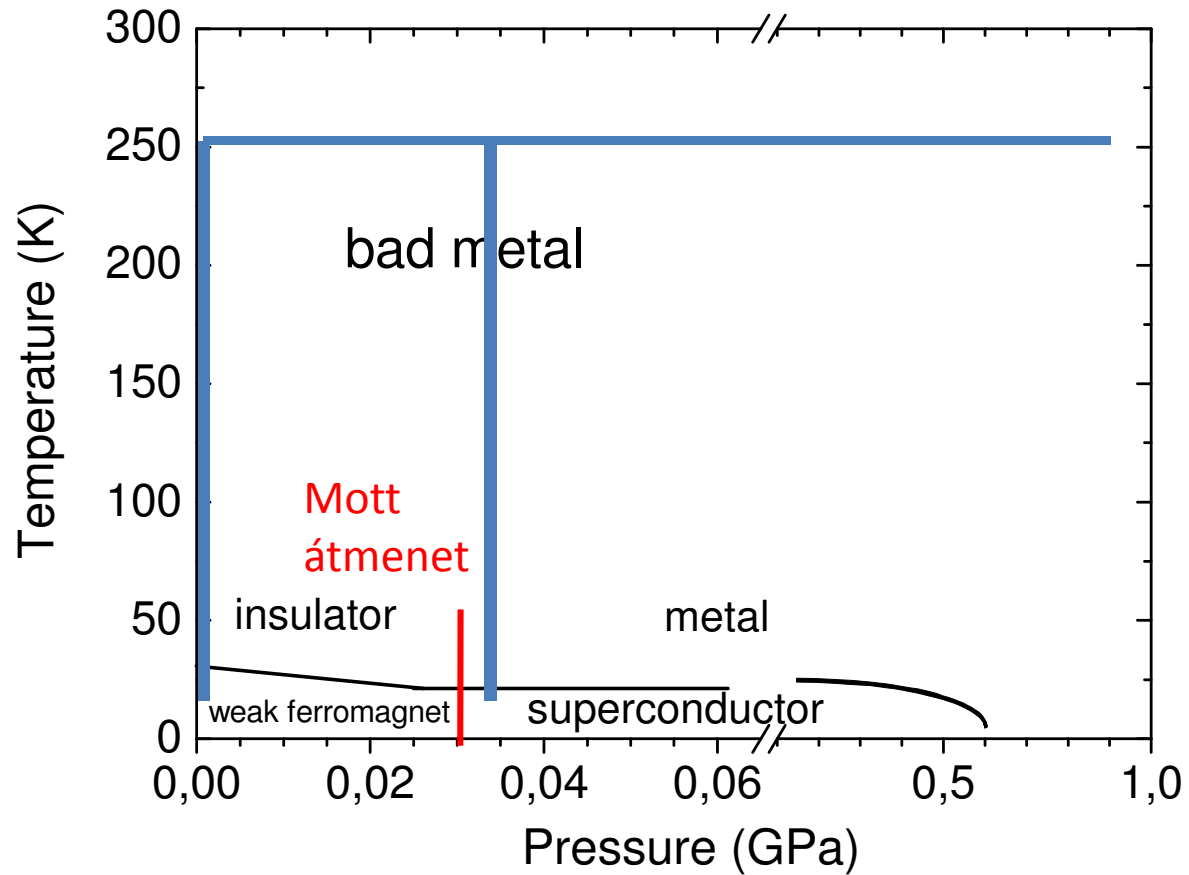
$$t_{//} \approx 100 \text{ meV}$$



$$t_{\perp} \approx 0.1 \text{ meV}$$

# Merőleges elektron hopping mérések

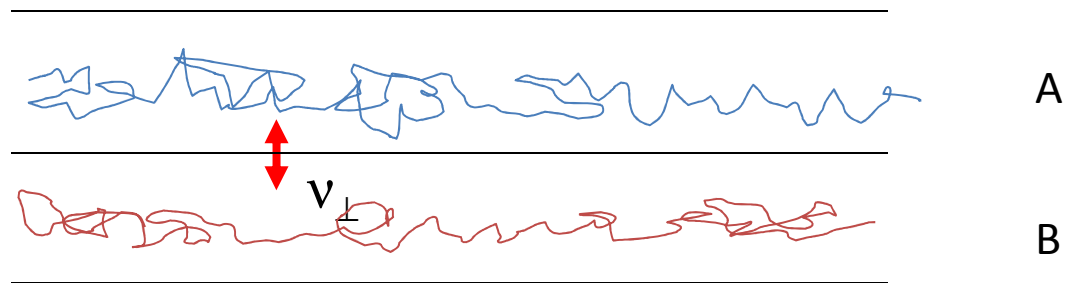
$\kappa$ -(BEDT-TTF)<sub>2</sub>CuN(CN)<sub>2</sub>Cl



## Rétegek közötti hopping mérés

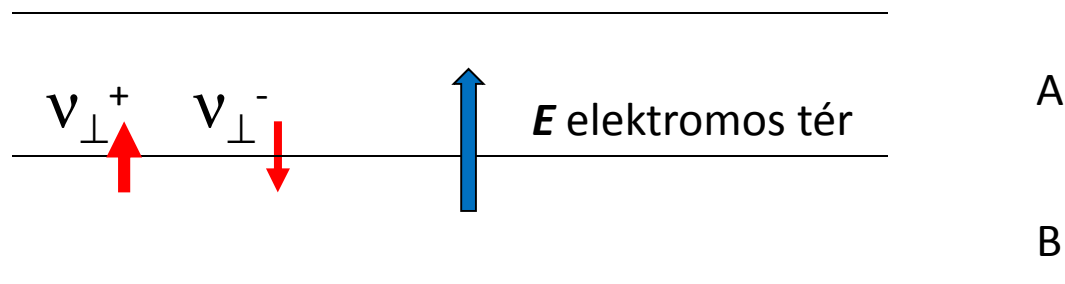
1. elektron spin diffúzió (ESR)
2. elektromos vezetőképesség

## spin diffúzió (ESR):



$v_{\perp}$  : rétegek közötti hopping frekvencia

## merőleges elektromos vezetés:

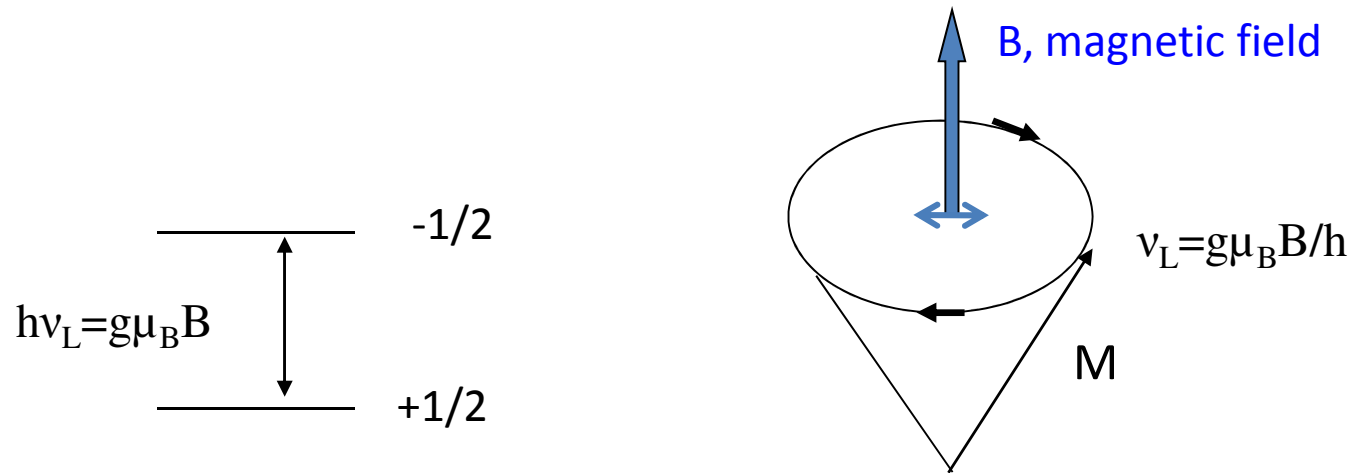
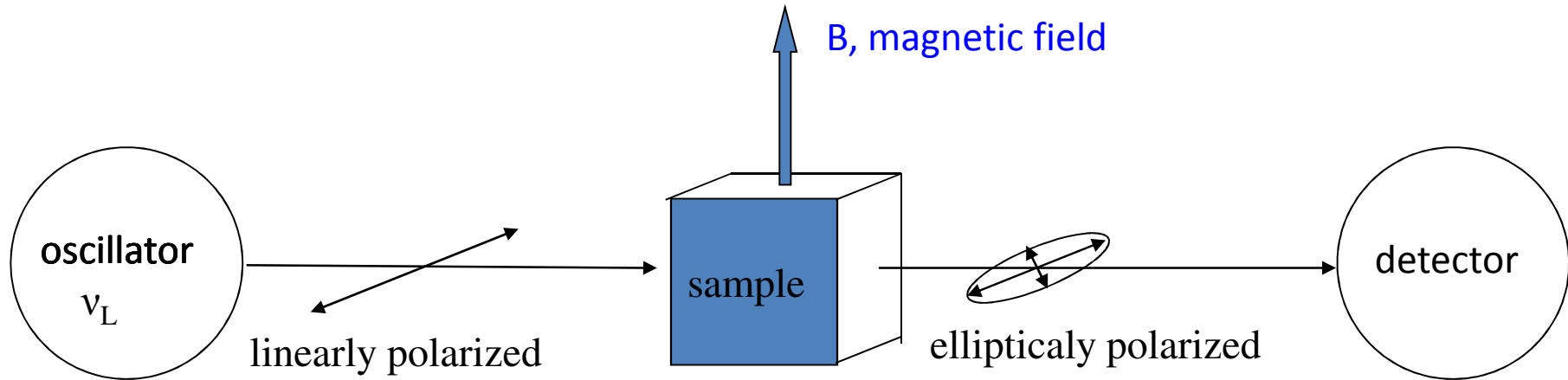


$j \sim v_{\perp} n(E_F) E$  elektromos áram  
 $n(E_F)$  állapotsűrűség

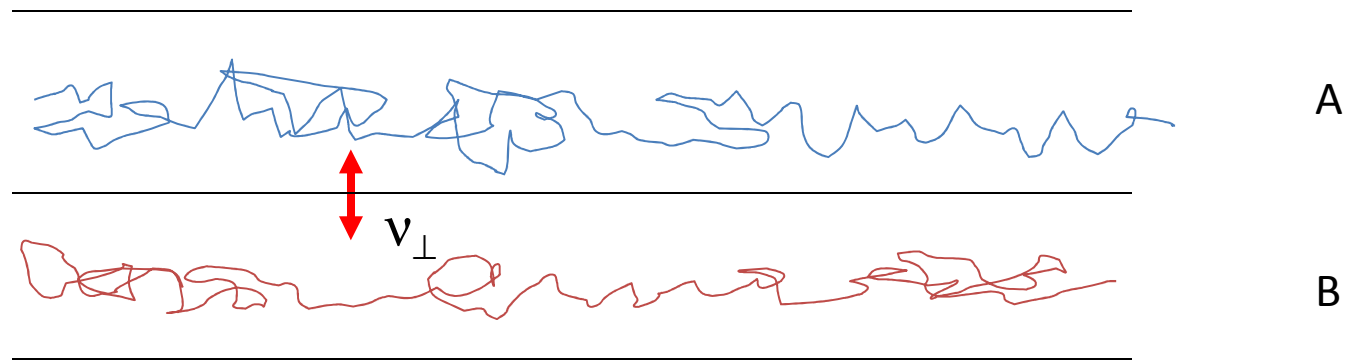


# ESR spektrometer

$\nu_L = 100\text{-}420 \text{ GHz}$  (Budapest, Lausanne)



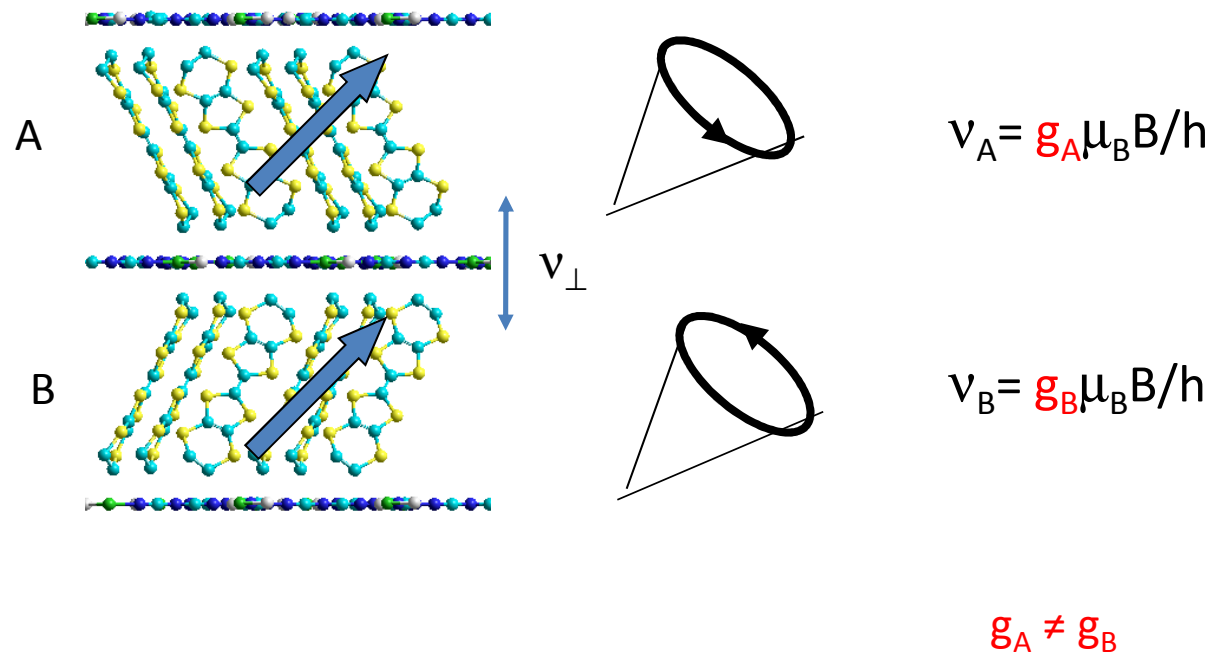
## Elektron spin diffúzió



kis spin hopping frekvencia,  $v_{\perp}$  -> független rétegek

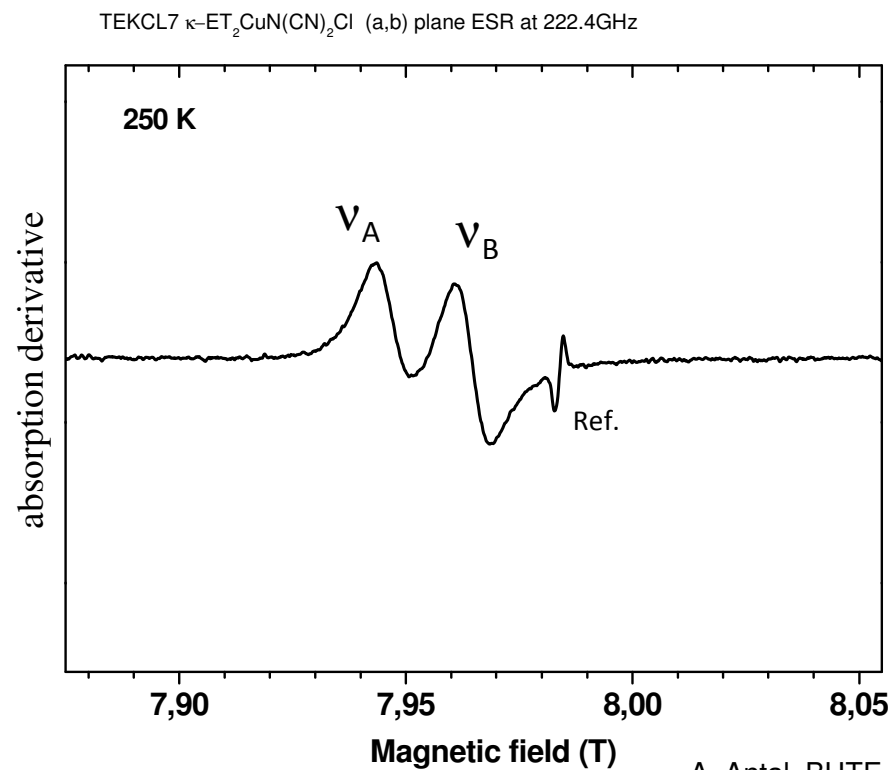
# Measurement of interlayer hopping

## ESR of 2 coupled spins

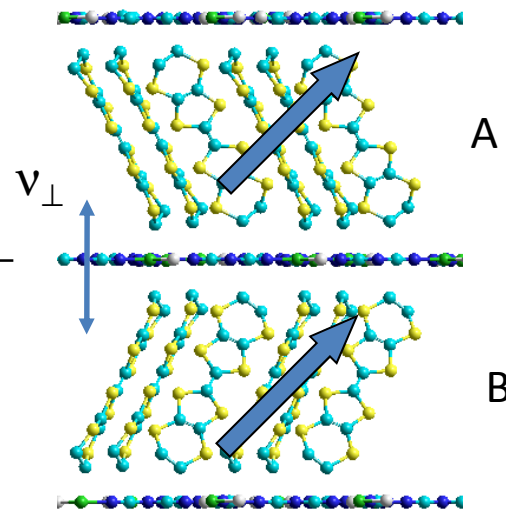


# 2 resolved ESR lines

P=0, T=45-300 K



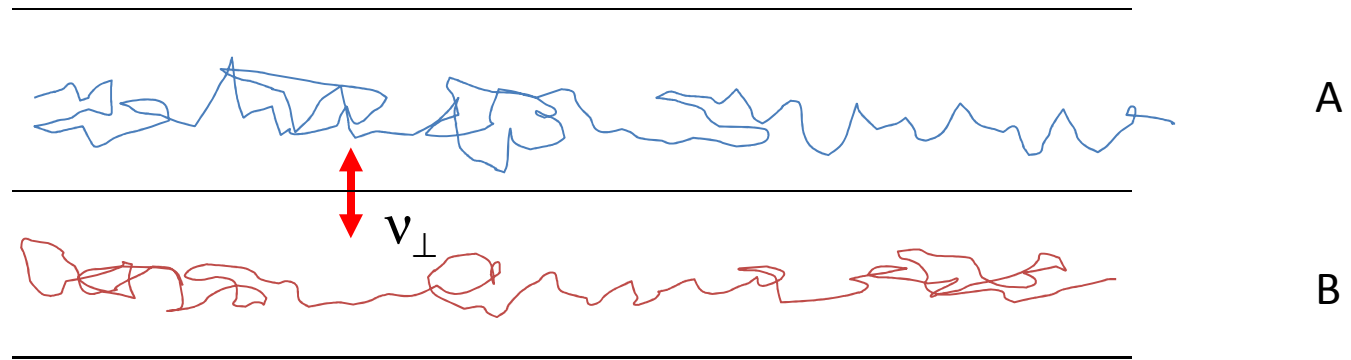
A. Antal, BUTE, April 2008



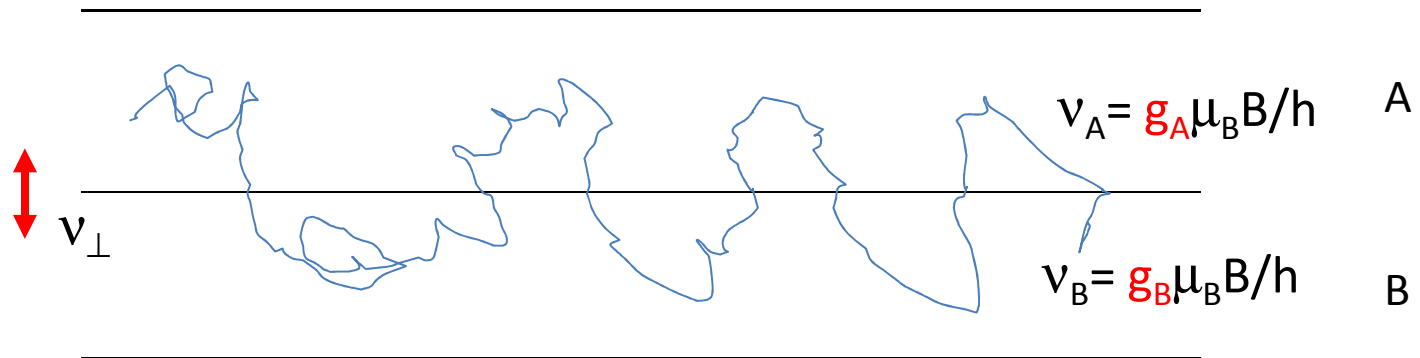
$$v_{\perp} < |v_A - v_B|$$

$$v_{\perp} < 3 \times 10^8 \text{ Hz}$$

# Elektron spin diffúzió



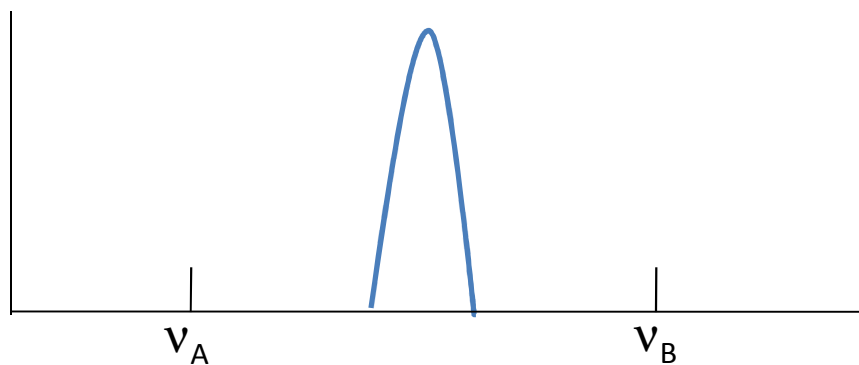
kis spin hopping frekvencia,  $v_{\perp}$  -> független rétegek



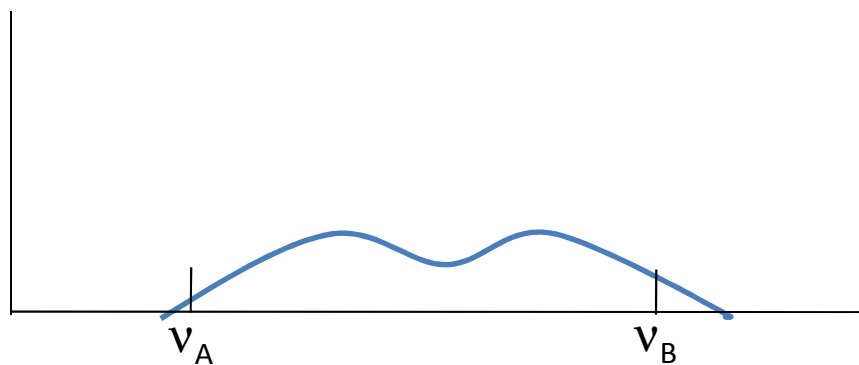
$v_{\perp}$  gyors:  $v_A$  és  $v_B$  átlagát mérjük

# Rétegek közti spin hopping frekvencia mérése

ESR



$$\nu_{\perp} > |\nu_A - \nu_B|$$



$$\nu_{\perp} \approx |\nu_A - \nu_B|$$

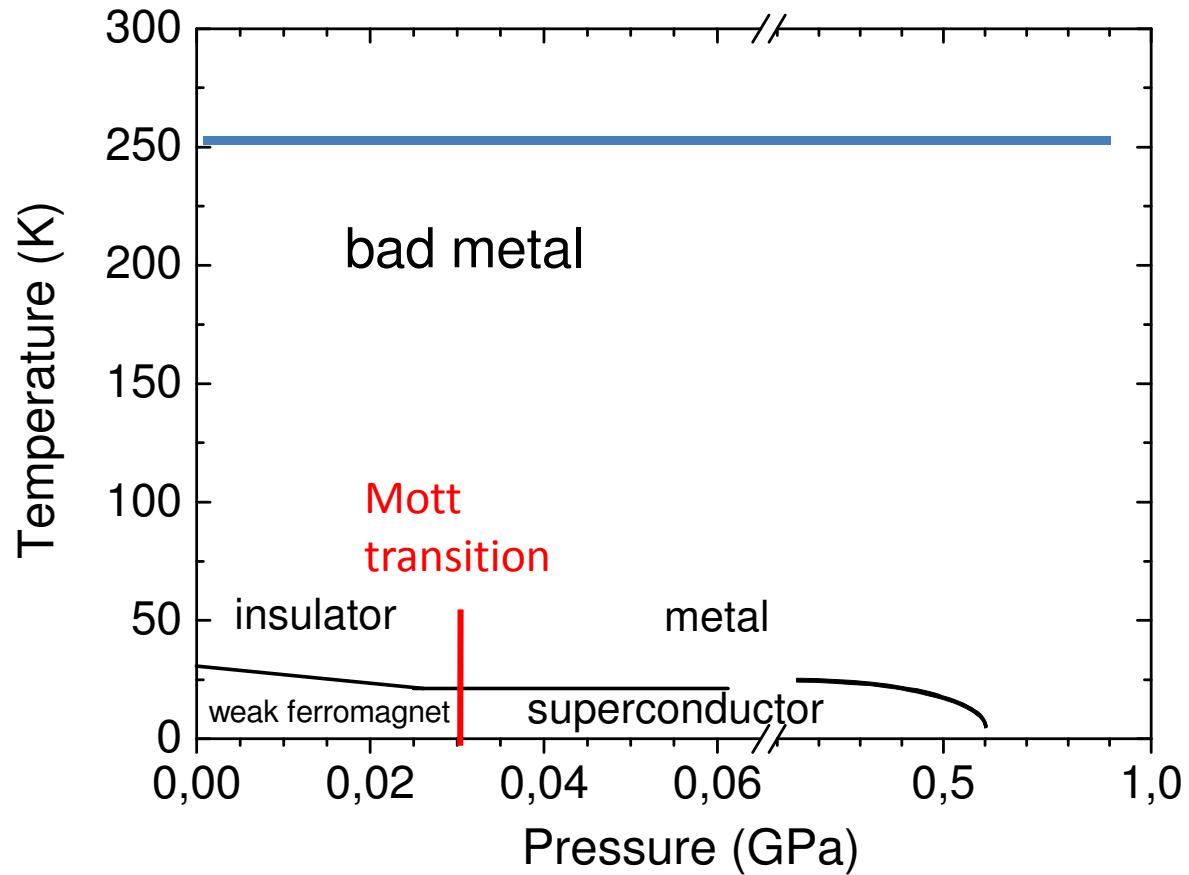


$$\nu_{\perp} < |\nu_A - \nu_B|$$

Réteg-közti spin hopping frekvencia

# Merőleges elektron hopping mérések

$\kappa$ -(BEDT-TTF)<sub>2</sub>CuN(CN)<sub>2</sub>Cl

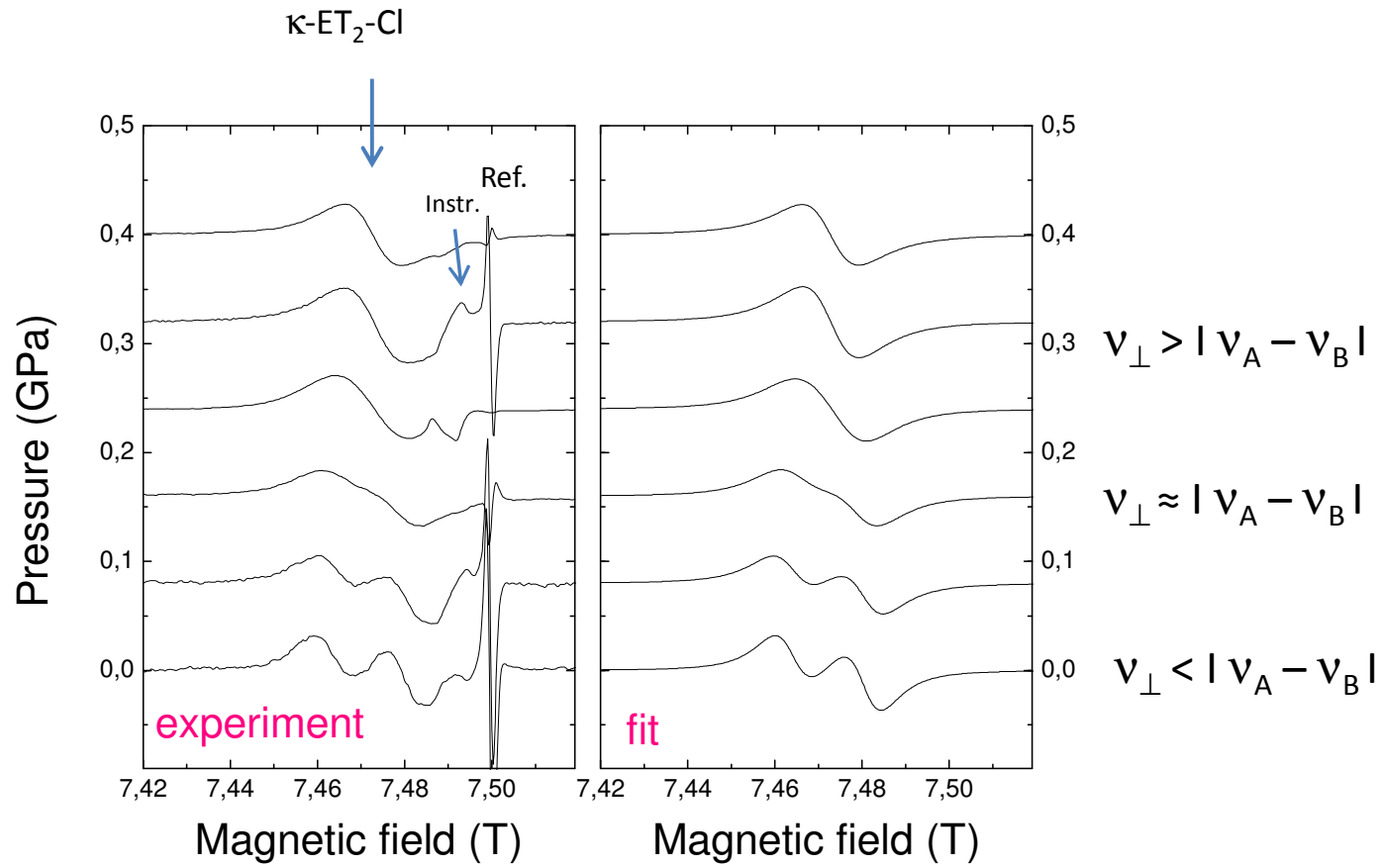


# Measurement of interlayer hopping

Motional narrowing  
under pressure

210 GHz

T=250 K,  
B in (a,b) plane



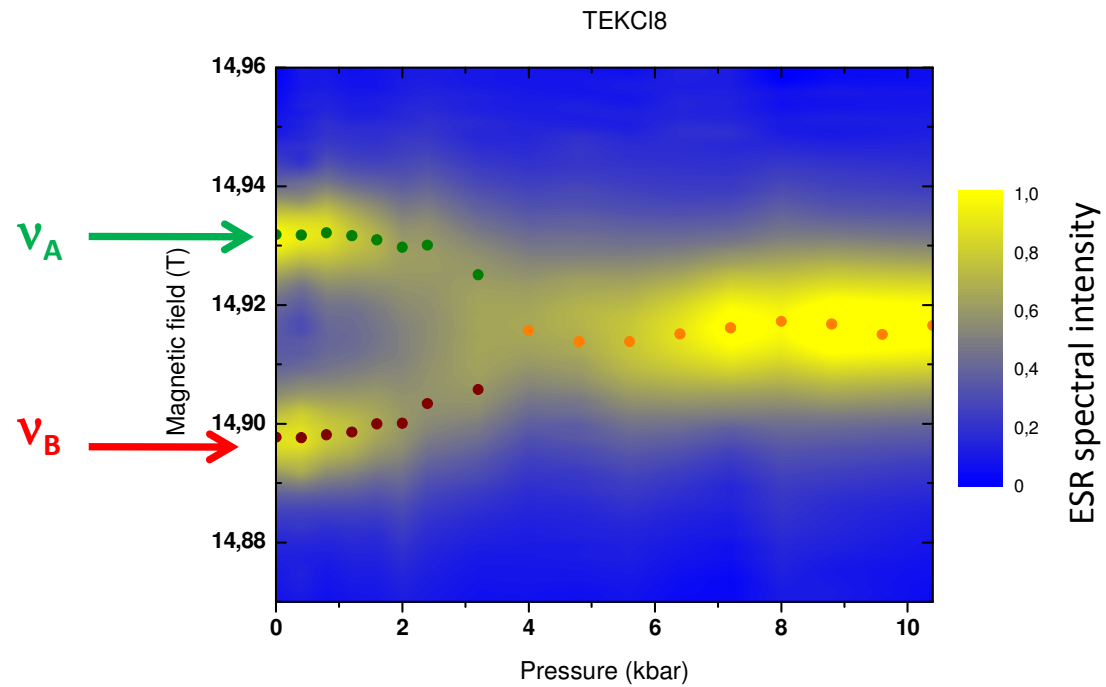


# Measurement of interlayer hopping

Motional narrowing  
under pressure

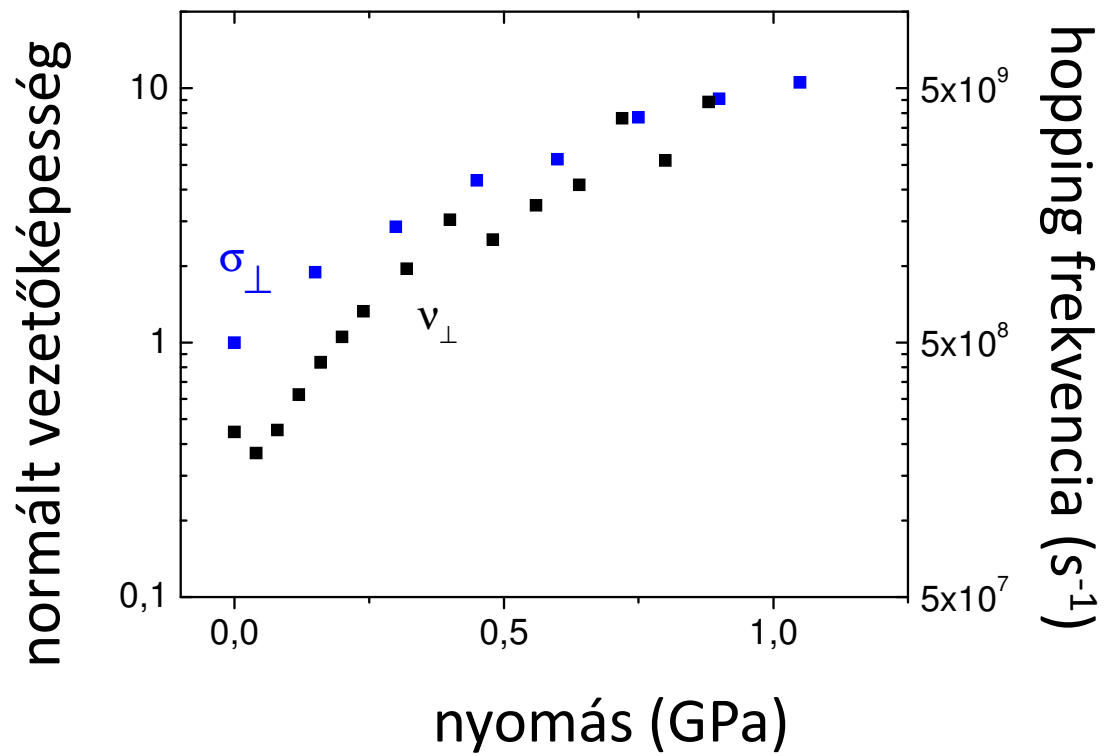
420 GHz

T=250 K,



↑

$$v_{\perp} = |v_A - v_B| = 1.0 \times 10^9 \text{ s}^{-1}$$

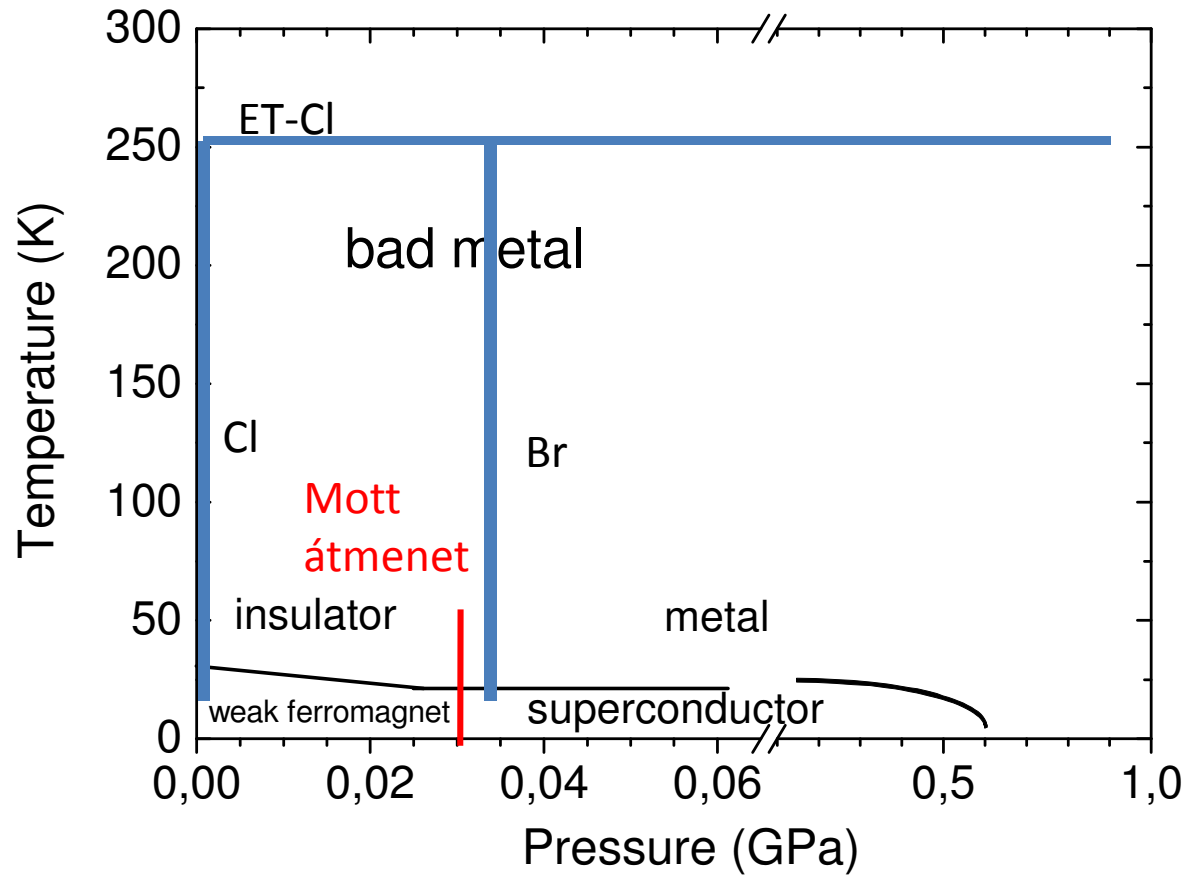


$$\sigma \sim v_{\perp} n(E_F)$$

$n(E_F)$  : állapotsűrűség

# Merőleges elektron hopping mérések

$\kappa$ -(BEDT-TTF)<sub>2</sub>CuN(CN)<sub>2</sub>Cl, Br

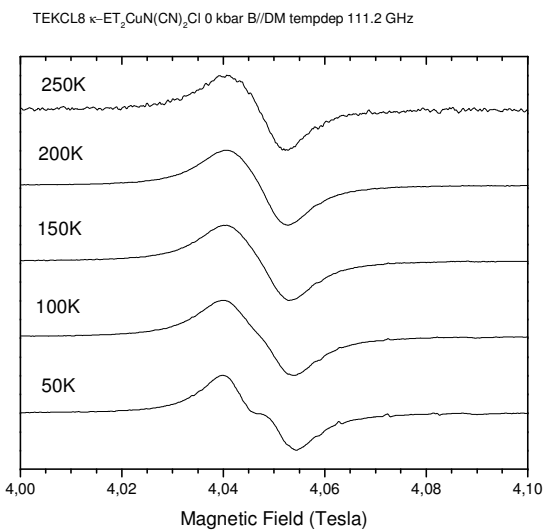


ET-Cl

fém



$v_{\perp}$



gyenge  
ferromágnes

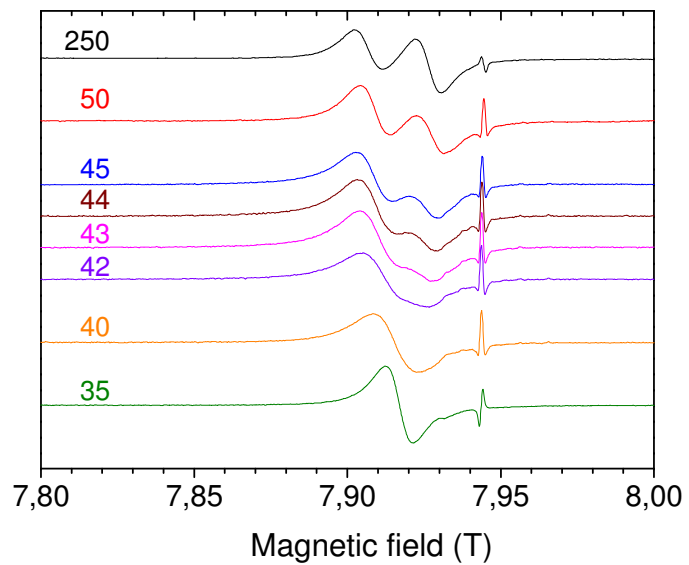
ET-Br

fém



$v_{\perp}$

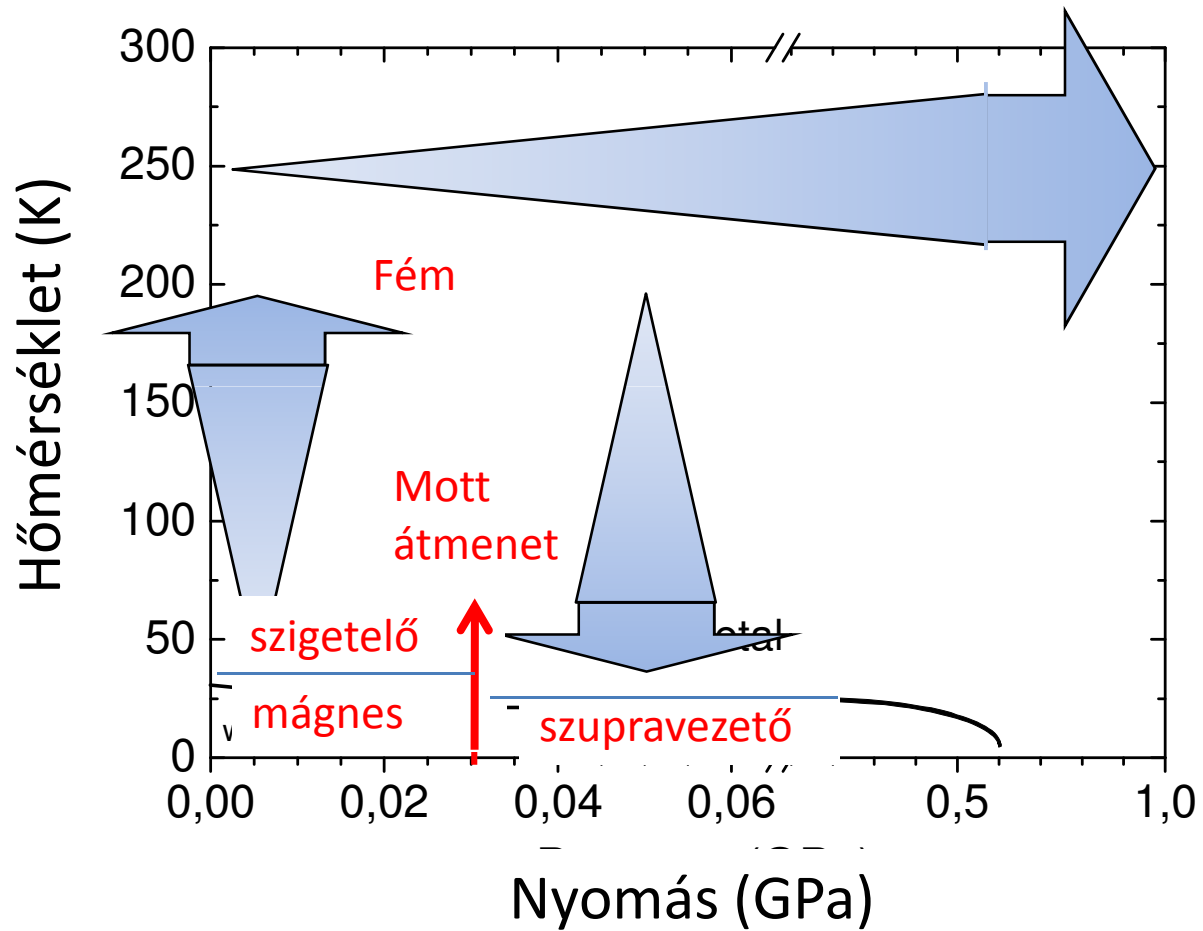
T



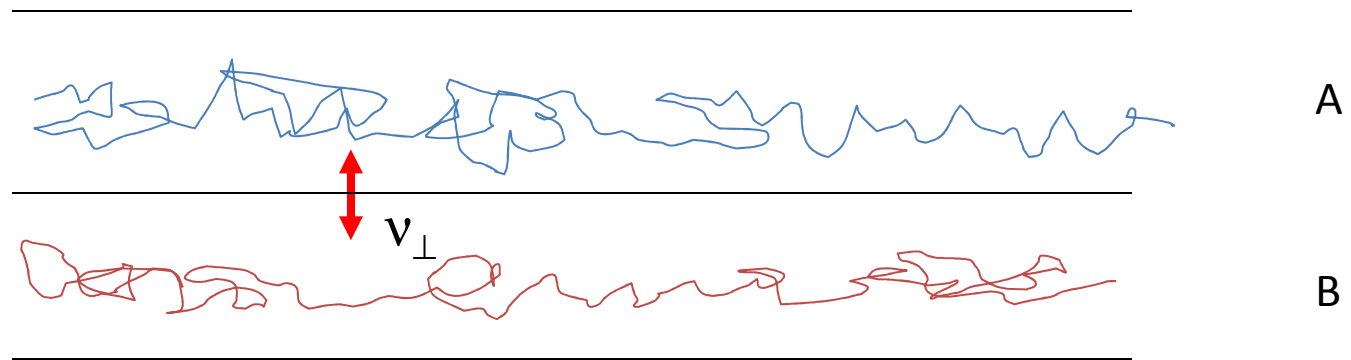
szupravezető

# Merőleges elektron hopping frekvencia

$\kappa$ -(BEDT-TTF)<sub>2</sub>CuN(CN)<sub>2</sub>Cl, Br



## 2D elektron spin diffúzió

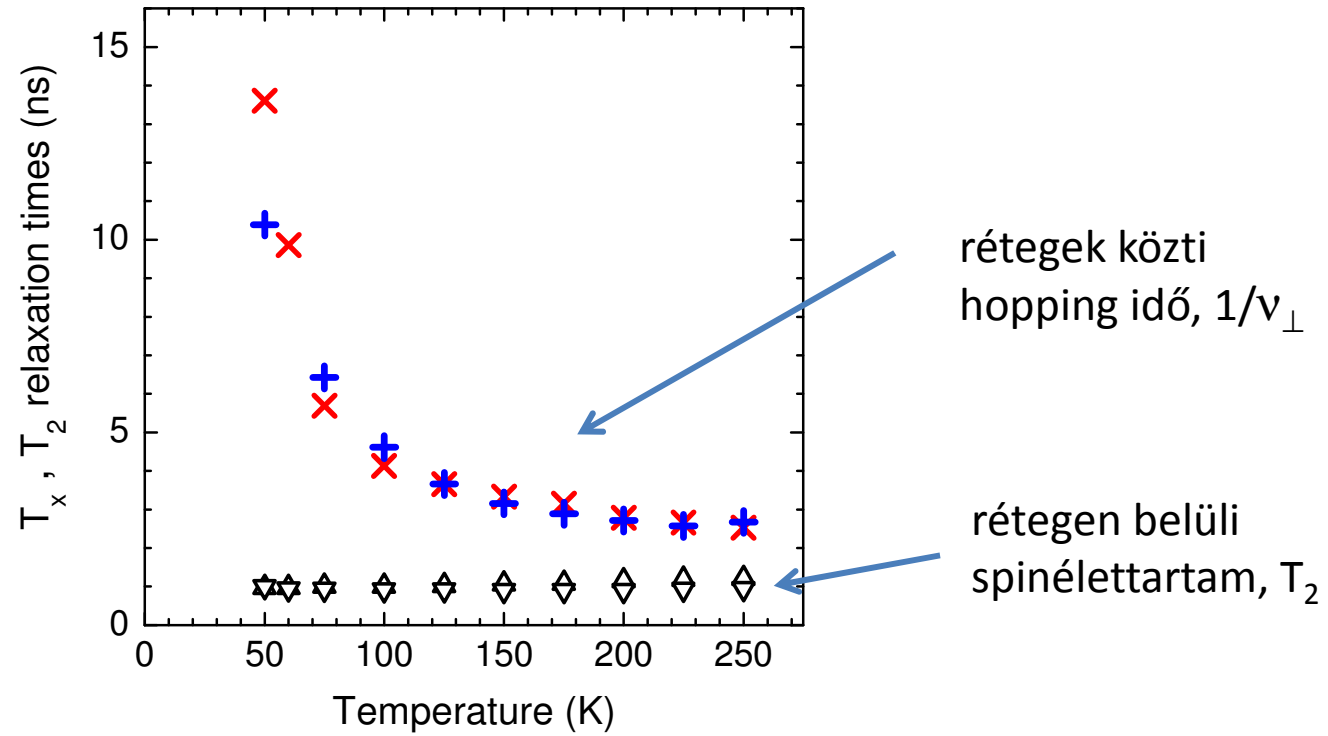


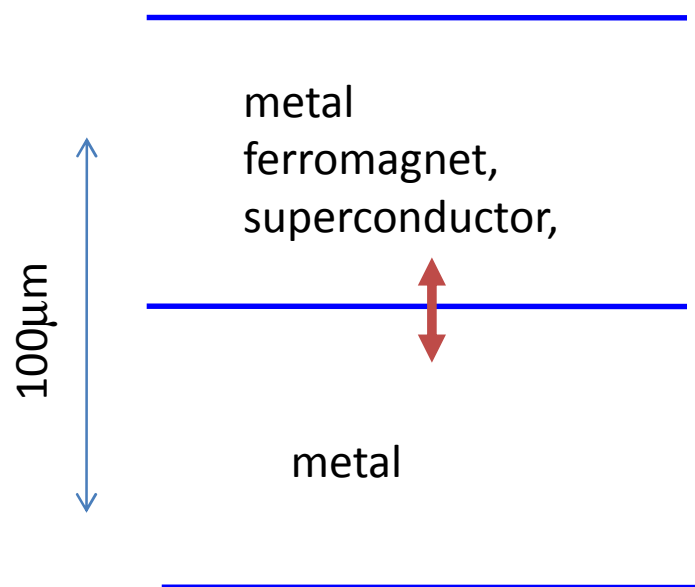
$v_{\perp}$  rétegek közötti spin hopping  
frekvencia

$T_1$  spin élettartam

$v_{\perp} < 1/T_1$  2D spin diffúzió

2D spindiffúzió  
ET-Cl  
P=0

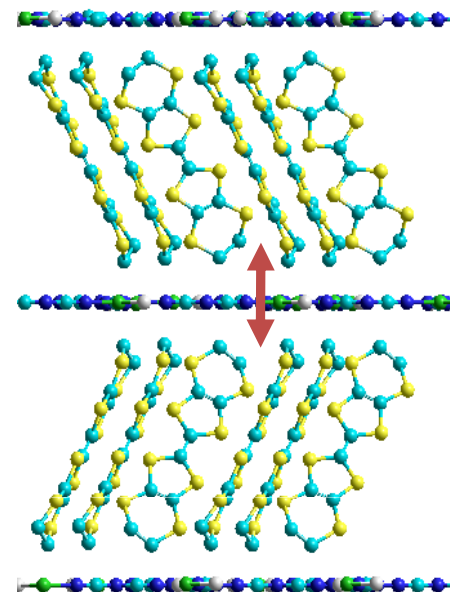




1970-1980

A layer

B layer

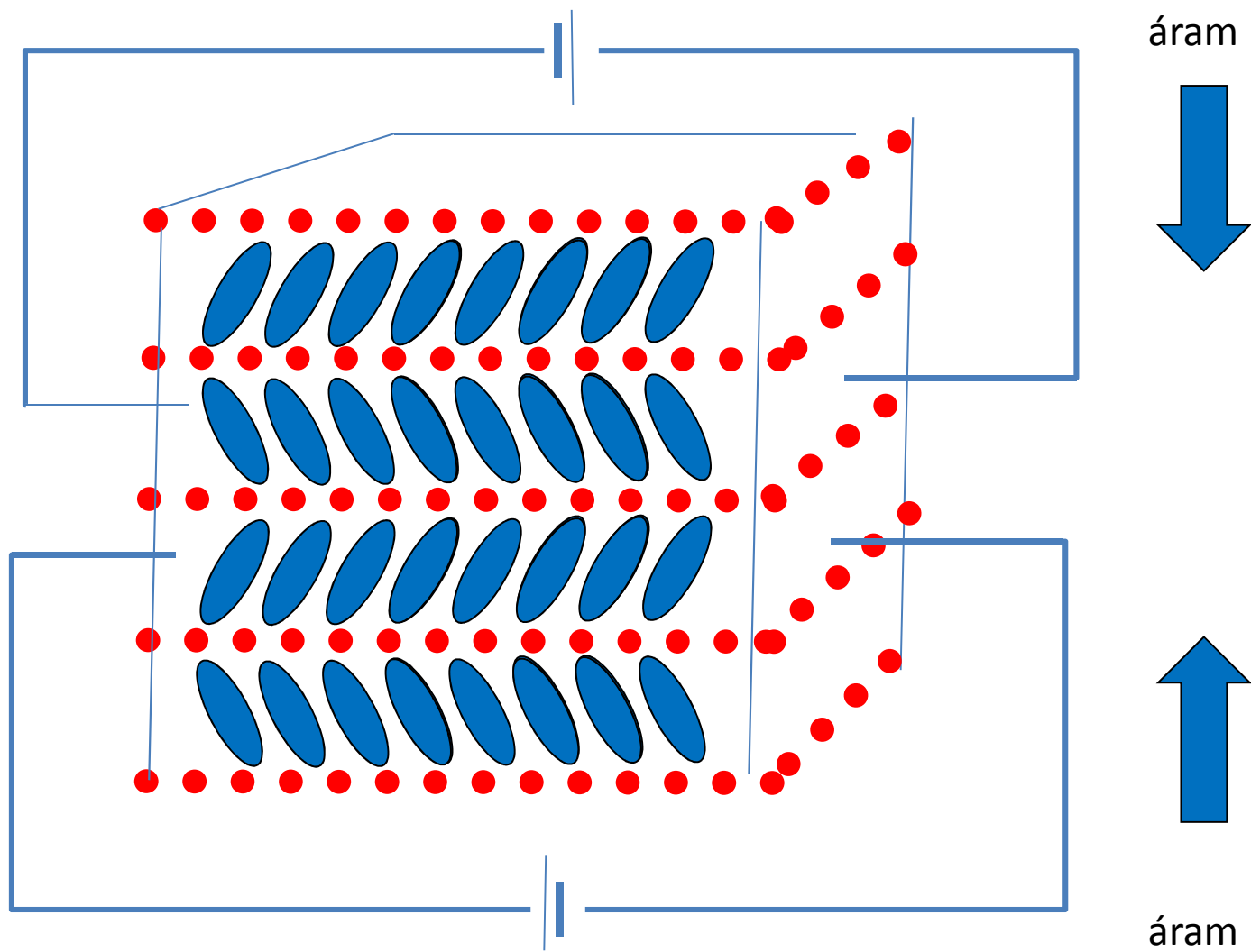


2009

1nm

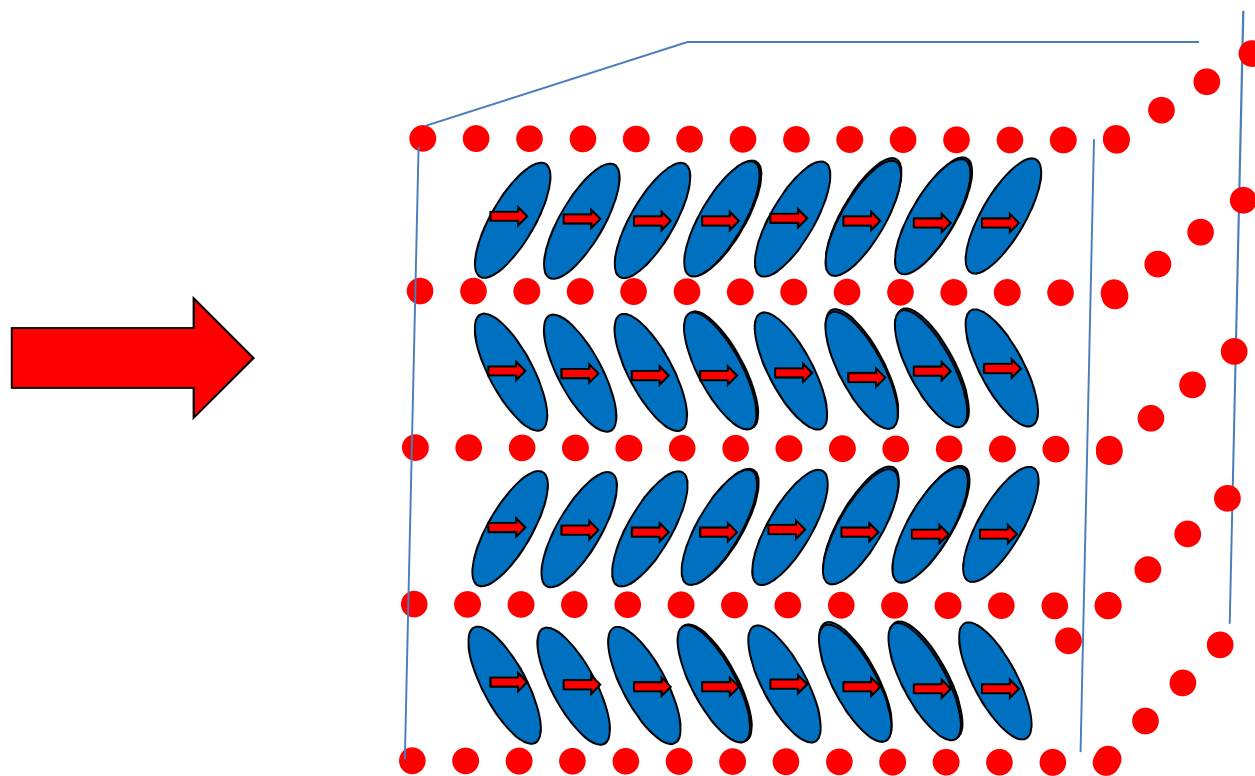


„Kétdimenziós” molekula kristály  
Mennyire kétdimenziós vezető?



# „Kétdimenziós” molekula kristály

Mennyire kétdimenziós mágnes?



# „Kétdimenziós” molekula kristály

Mennyire kétdimenziós mágnes?

