Electron Screening in Nickel

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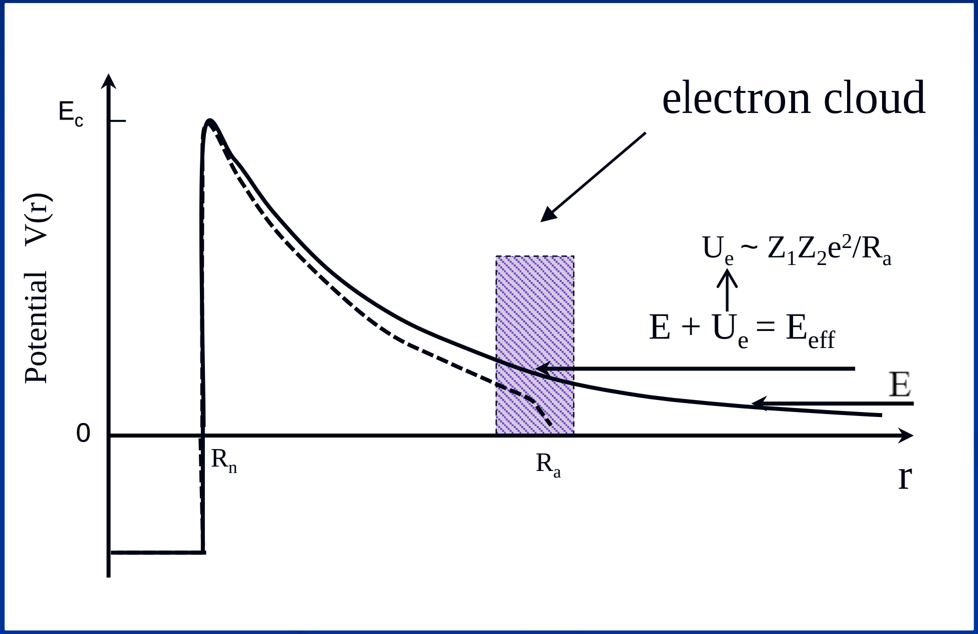
Split, September 2011

Electron Screening

Due to Coulomb repulsion the cross section σ for charged particle induced nuclear reactions drops rapidly with decreasing beam energy.

$$\sigma(E) = \frac{S(E)}{E} e^{-2\pi\eta},$$

where $\eta = Z_1 Z_2 e^2 / 4\pi\varepsilon_0 \hbar \sqrt{(2E/\mu)}$ is the Sommerfeld parameter.



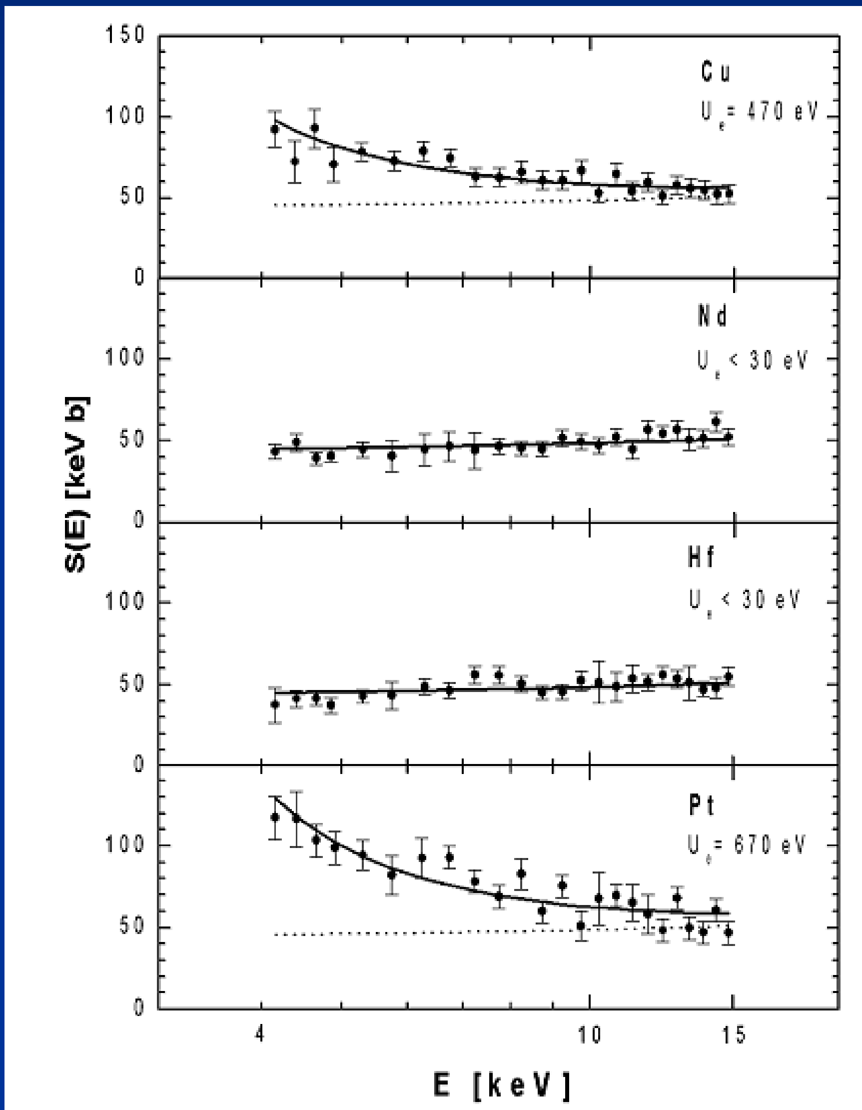
Cross section increases at low energies when the interacting nuclei are not bare.

$$f(E) = \frac{\sigma(E+U_e)}{\sigma(E)},$$

where U_e is the screeening potential.

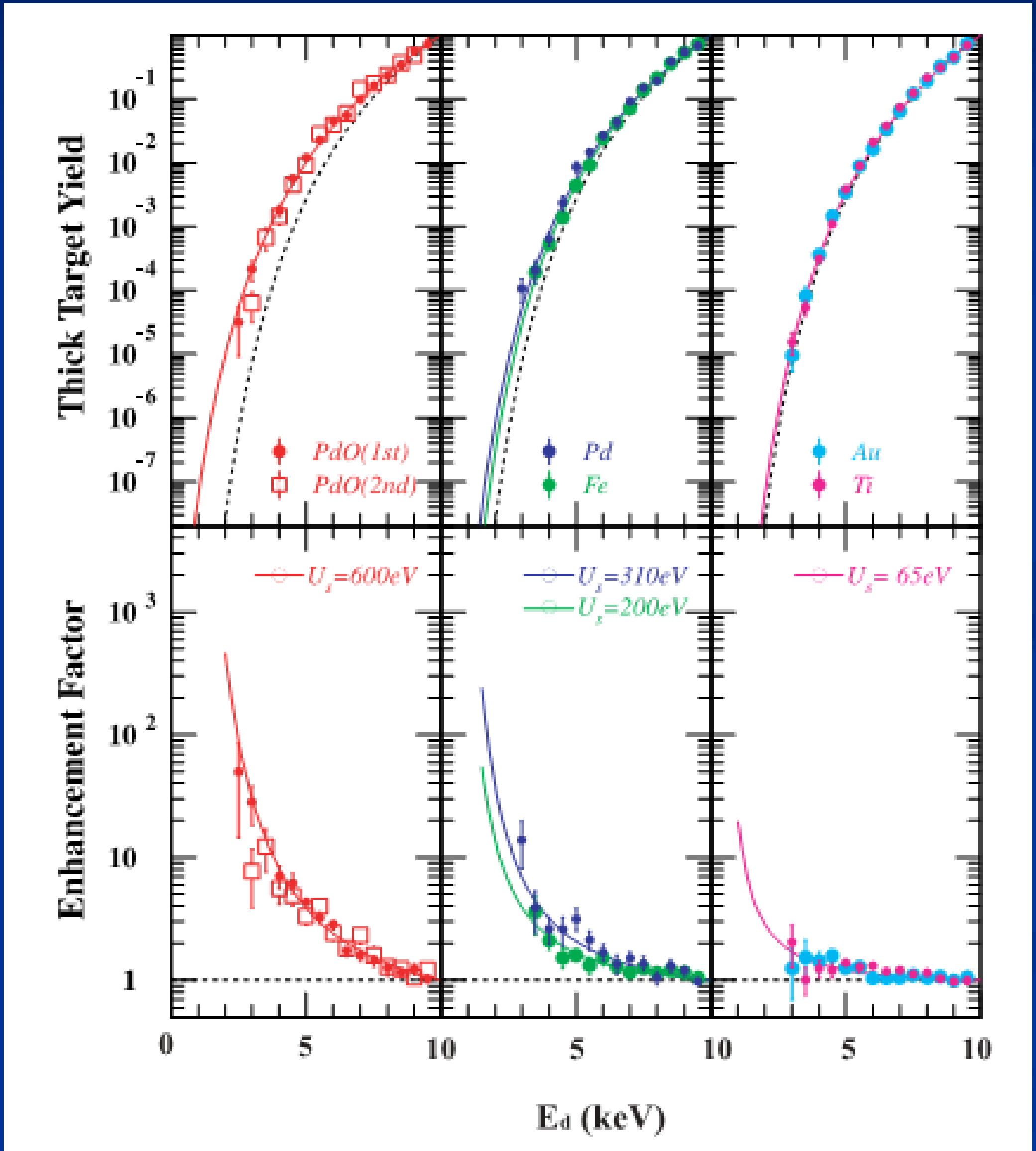
Previous Results 1

for d(d,p)t reaction from F. Raiola et al., Eur. Phys. J. A**19** (2004) 283.



Material	U_e (eV)[b]	Solubility $1/x$ [c]	n_{eff} [b]	n_{eff} (Hall)[d]
		Metals		
Be	180±40	0.08	0.2±0.1	(0.21±0.04)
Mg	440±40	0.11	3.0±0.5	1.8±0.4
Al	520±50	0.26	3.0±0.6	3.1±0.6
V	480±60	0.04	2.1±0.5	(1.1±0.2)
Cr	320±70	0.15	0.8±0.4	(0.20±0.04)
Mn	390±50	0.12	1.2±0.3	(0.8±0.2)
Fe	460±60	0.06	1.7±0.4	(3.0±0.6)
Co	640±70	0.14	3.1±0.7	(1.7±0.3)
Ni	380±40	0.13	1.1±0.2	1.1±0.2
Cu	470±50	0.09	1.8±0.4	1.5±0.3
Zn	480±50	0.13	2.4±0.5	(1.5±0.3)
Sr	210±30	0.27	1.7±0.5	
Nb	470±60	0.13	2.7±0.7	(1.3±0.3)
Mo	420±50	0.12	1.9±0.5	(0.8±0.2)
Ru	215±30	0.18	0.4±0.1	(0.4±0.1)
Rh	230±40	0.09	0.5±0.2	(1.7±0.4)
Pd	800±90	0.03	6.3±1.3	1.1±0.2
Ag	330±40	0.14	1.3±0.3	1.2±0.3
Cd	360±40	0.18	1.9±0.4	(2.5±0.5)
In	520±50	0.02	4.8±0.9	
Sn	130±20	0.08	0.3±0.1	
Sb	720±70	0.13	11±2	
Ba	490±70	0.21	9.9±2.9	
Ta	270±30	0.13	0.9±0.2	(1.1±0.2)
W	250±30	0.29	0.7±0.2	(0.8±0.2)
Re	230±30	0.14	0.5±0.1	(0.3±0.1)
Ir	200±40	0.23	0.4±0.2	(2.2±0.5)
Pt	670±50	0.06	4.6±0.7	3.9±0.8
Au	280±50	0.18	0.9±0.3	1.5±0.3
Tl	550±90	0.01	5.8±1.2	(7.4±1.5)
Pb	480±50	0.04	4.3±0.9	
Bi	540±60	0.12	6.9±1.5	

Previous Results 2



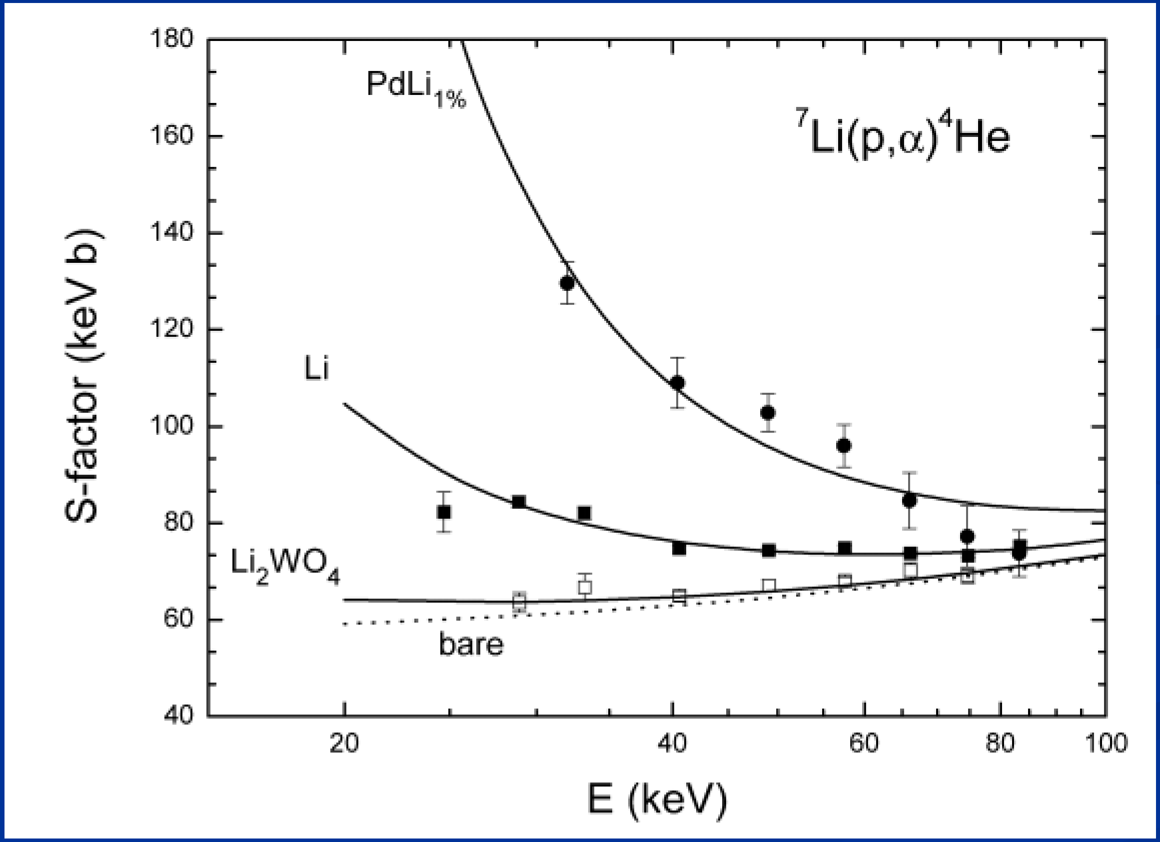
J. Kasagi, Prog. Theo. Phys. Suppl. 154 (2004) 365

for the d(d,p)t reaction
U_e=310±30 eV @ 7% H/Pd

=> concentration dependence

Previous Results 3

J. Cruz et al., Phys. Lett. B 624 (2005) 181.



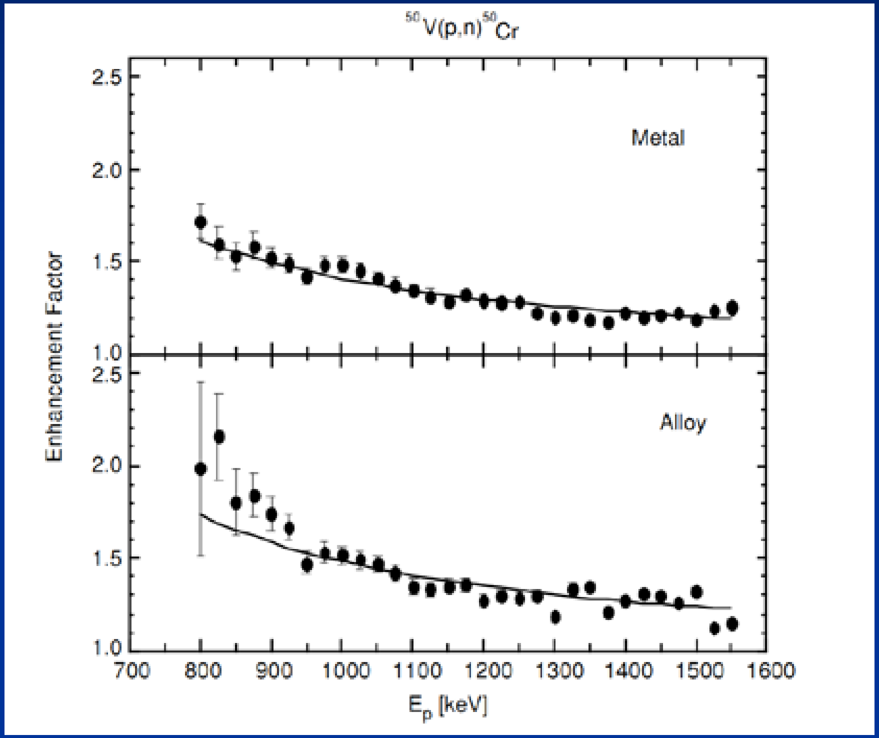
For $PdLi_{1\%}$:

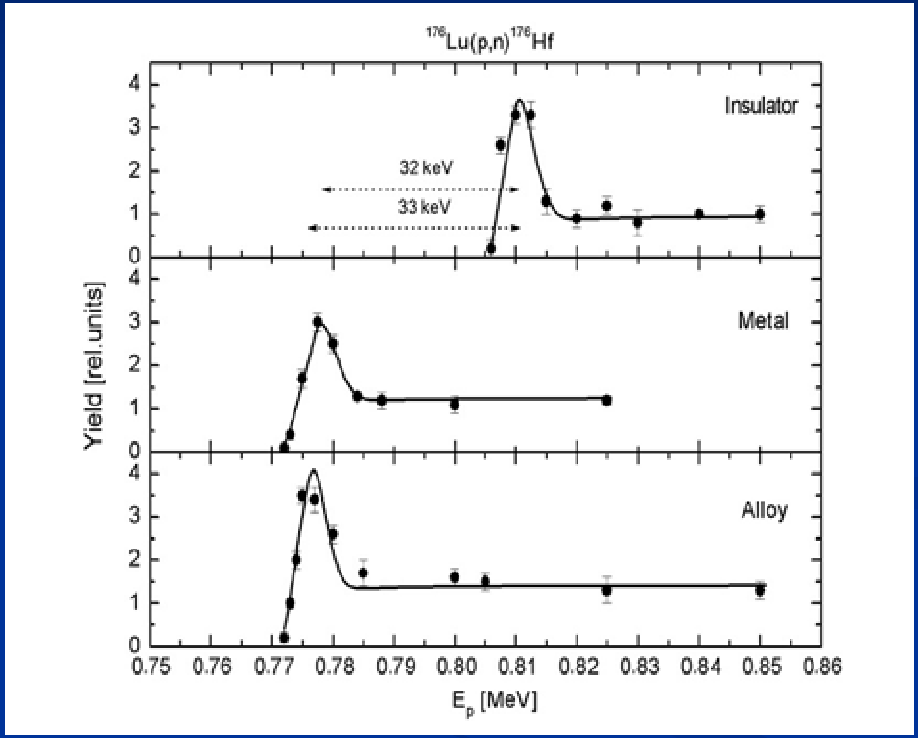
$S(E)=0.055+0.21E-0.31E^2$ [MeV b]

U_e=3.8 keV

Previous Results 4

K. U. Kettner et al., J. Phys. G **32** (2006) 489.





$^{50}V(p,n)^{50}Cr$ reaction in different environments: VO_2 insulator, V metal and $PdV_{10\%}$ alloy. Relative to the insulator, metal and alloy showed a large screening potential of $U_e = 27$ and 34 keV.

$^{176}Lu(p,n)^{176}Hf$ reaction in Lu_2O_3 insulator, Lu metal and $PdLu_{10\%}$ alloy; there is a narrow resonance and a shift in proton resonance energy of $U_e = 32$ and 33 keV for the metal and alloy, respectively, relative to the insulator.

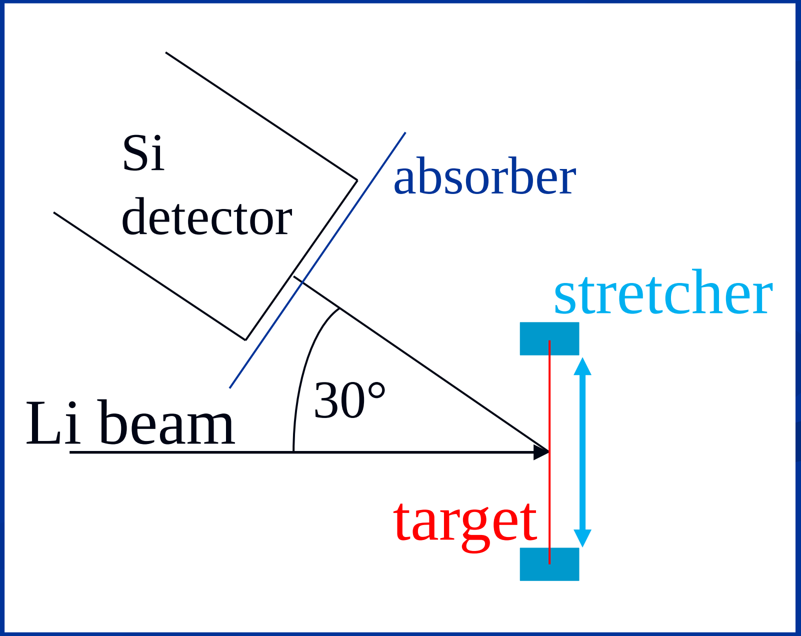
$$\Rightarrow U_e \propto Z$$

Measurements @ JSI

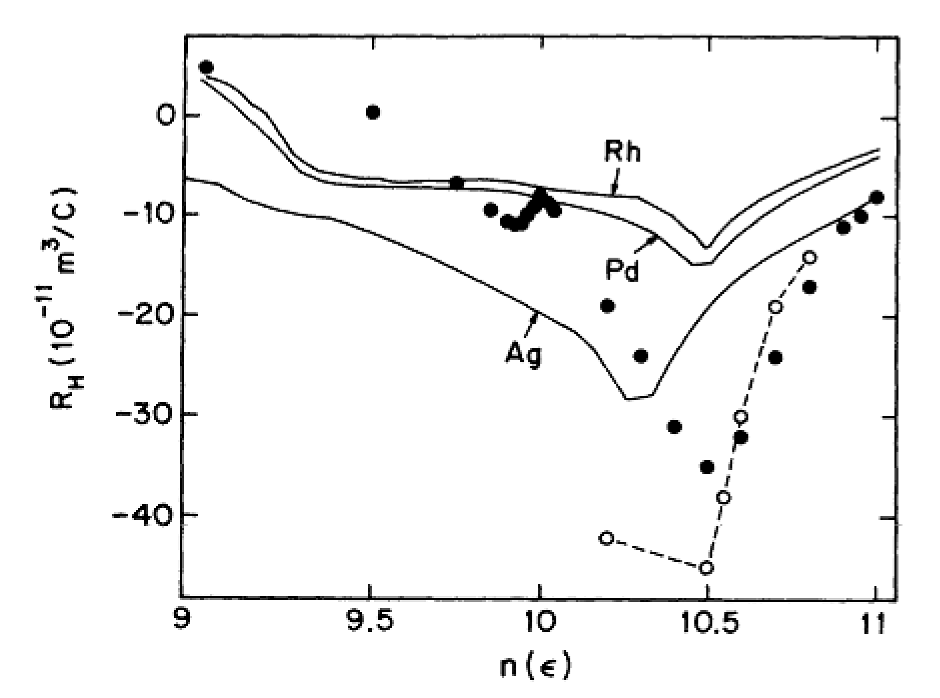
2 MV Tandem van de Graaf accelerator

Reaction: $^{1}H(^{7}Li,\alpha)^{4}He$

targets:
Kapton (insulator),
Pd, $Pd_{77}Ag_{23}$ (metals)



Hall Coefficient in PdAg Alloys



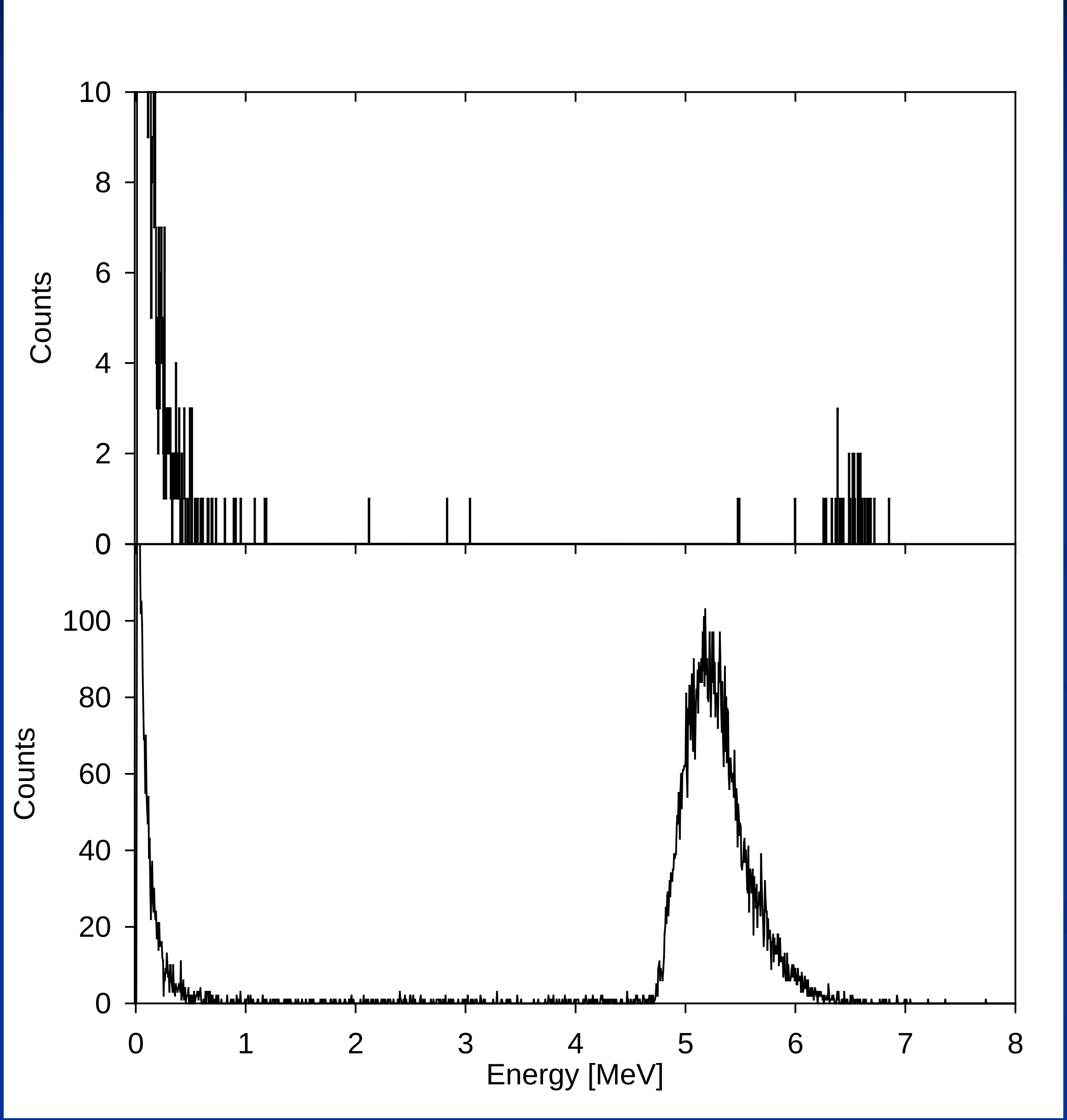
$R_H(Pd) = -7 \cdot 10^{-11} m^3/As$

$R_H(Pd_{50}Ag_{50}) = -35 \cdot 10^{-11} m^3/As$

$$|R_H| \mu \frac{1}{n_{eff}}$$

Phys. Rev. B 45 (1992) 10886.

α-particle spectra

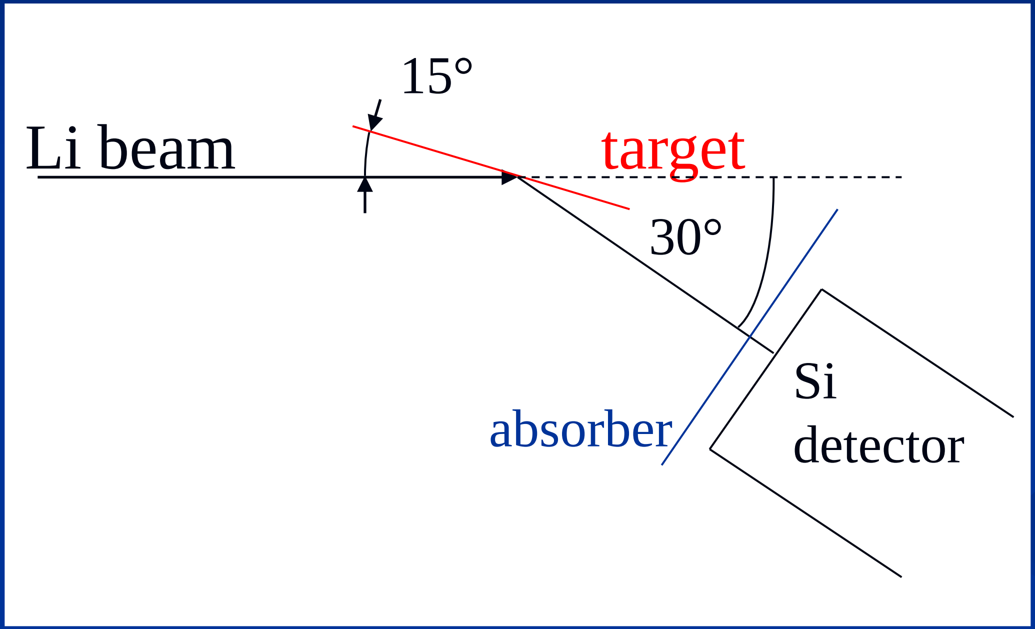


on Kapton @ 340 keV
Li beam energy

on Pd with 43% H
@ 1.05 MeV
Li beam energy

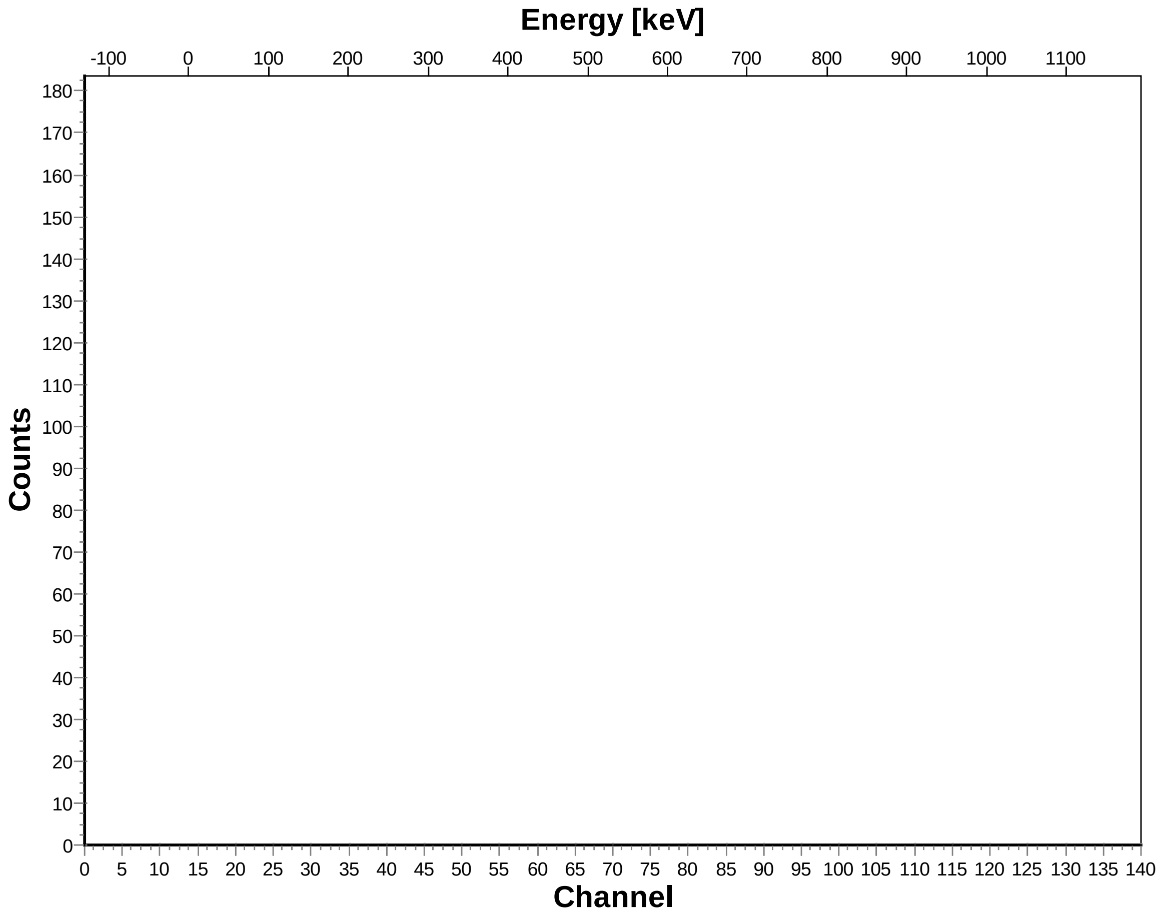
Hydrogen Concentration

Elastic Recoil Detection Analysis (ERDA) @ 4.3 MeV Li-7 beam



Elastically scattered protons

Kapton ERDA

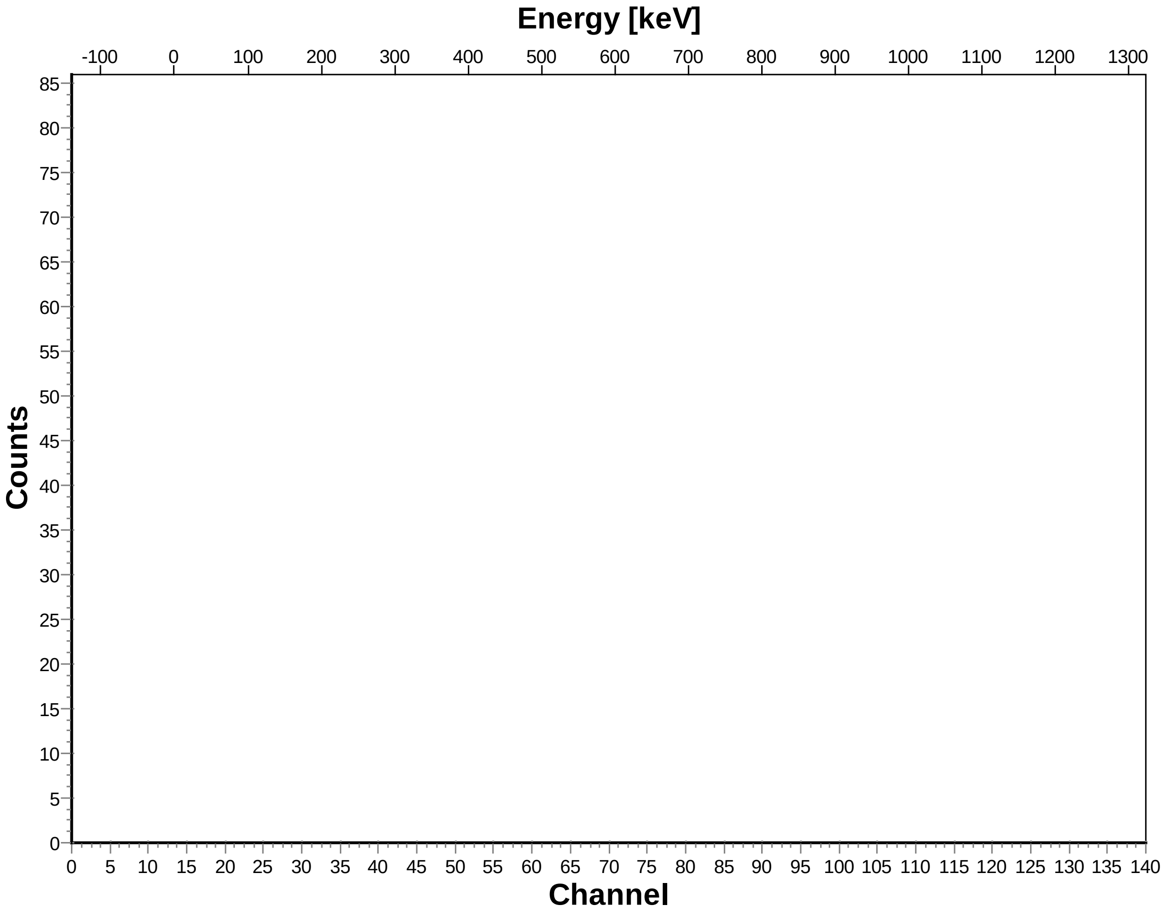


Proton spectrum @ Li beam energy of 4.3 MeV

Kapton ($C_{22}H_{10}N_2O_5$) used for calibration

Simulated using SIMNRA, M. Mayer, Nucl. Instr. Meth. Phys. Res., **B194**, 177 (2002)
Cross sections from Z. Siketic et al., Nucl. Instr. Meth. Phys. Res., **B229**, 180 (2005)

$Pd_{75}Ag_{25}$ ERDA

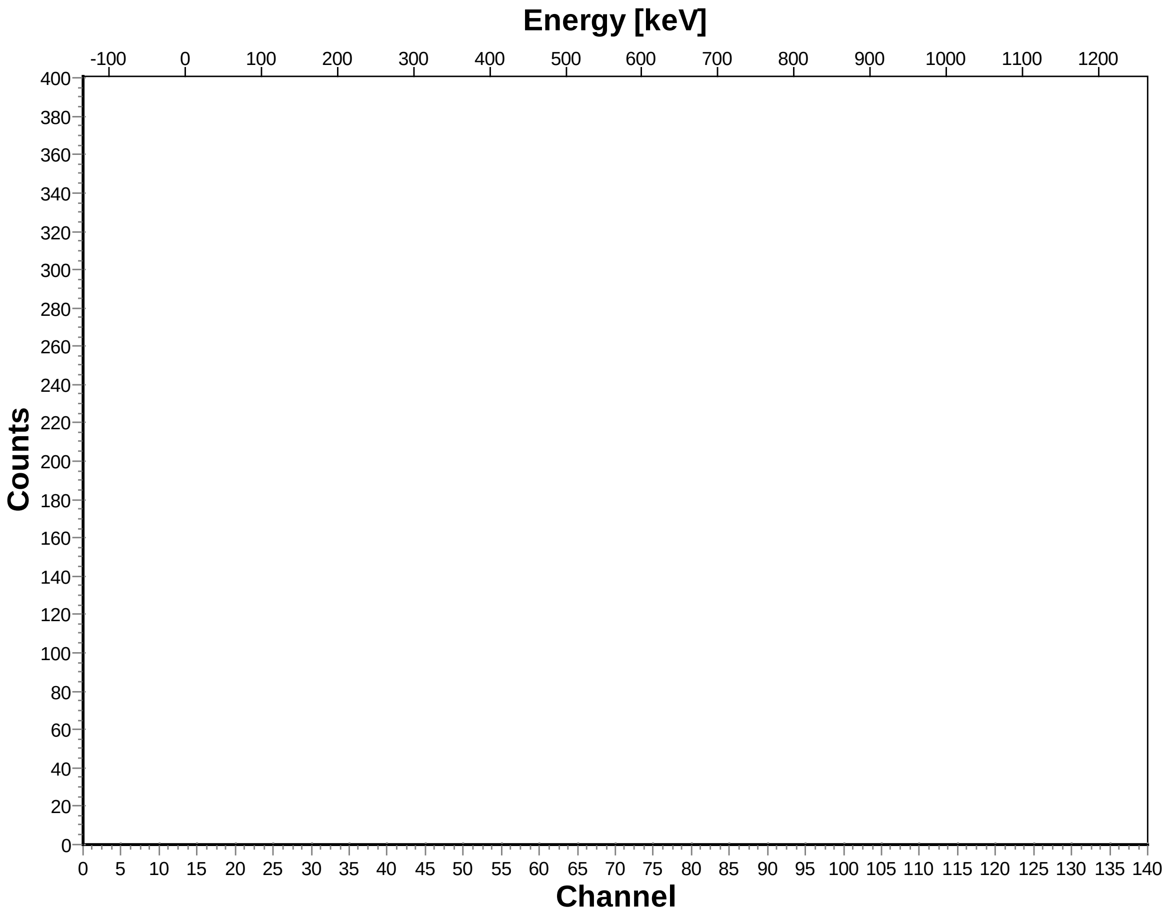


Proton spectrum @ Li beam energy of 4.3 MeV

SIMNRA gives H/Pd ratio of 0.45% and $4 \cdot 10^{16}$ cm^{-2} H atoms on the surface

Surface peak due to hydrogen dynamics

Pd ERDA



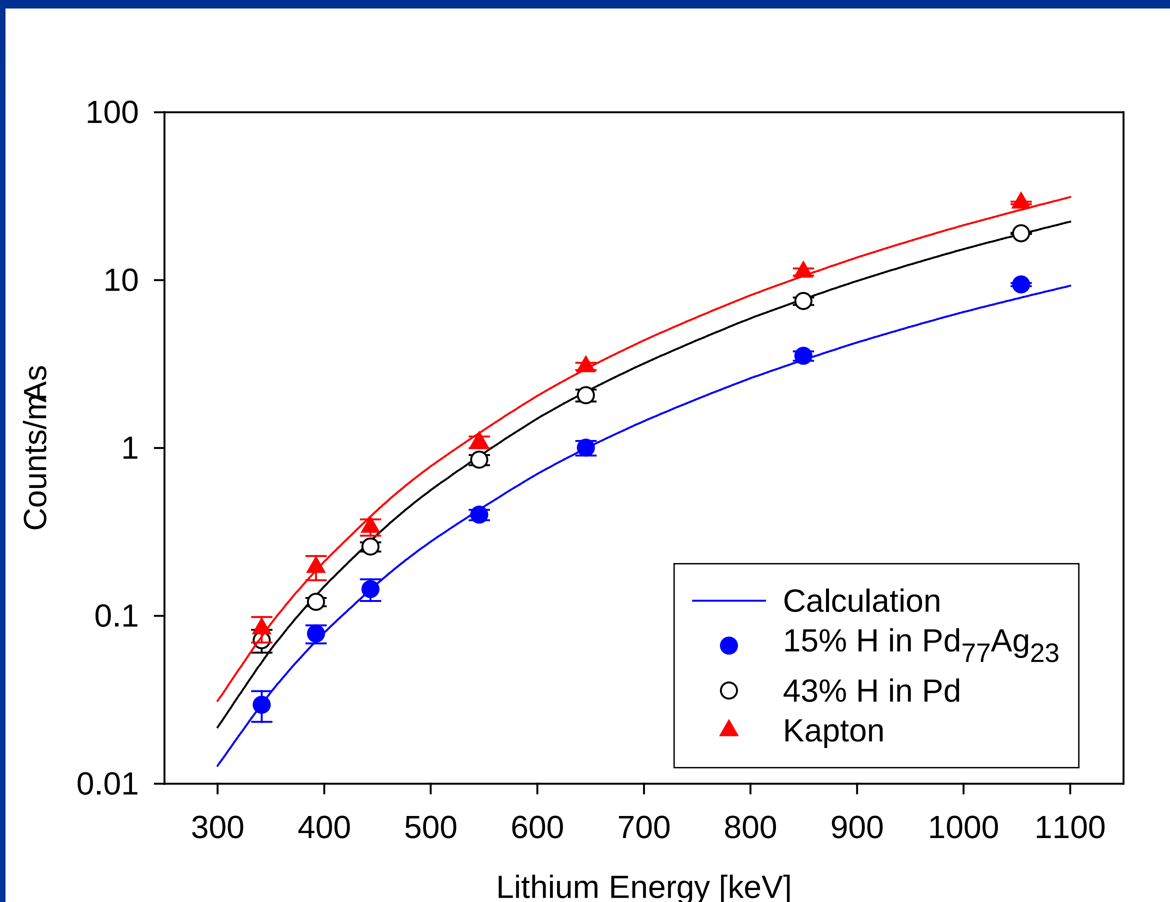
Proton spectrum @ Li beam energy of 4.3 MeV

SIMNRA gives H/Pd ratio of 43 at.% and a constant depth profile

After heating at 900ºC for 15 minutes in vacuum and soaking in H_2 at 1 bar for 2 hours at room temperature

Thick Target Yields

α-particle yield calculation: $N_\alpha = 2N_{Li}\frac{\rho N_A}{M}\int_{E_0}^{0}\Omega W \frac{\sigma(E)}{dE_{Li}/dx}dE_{Li}$



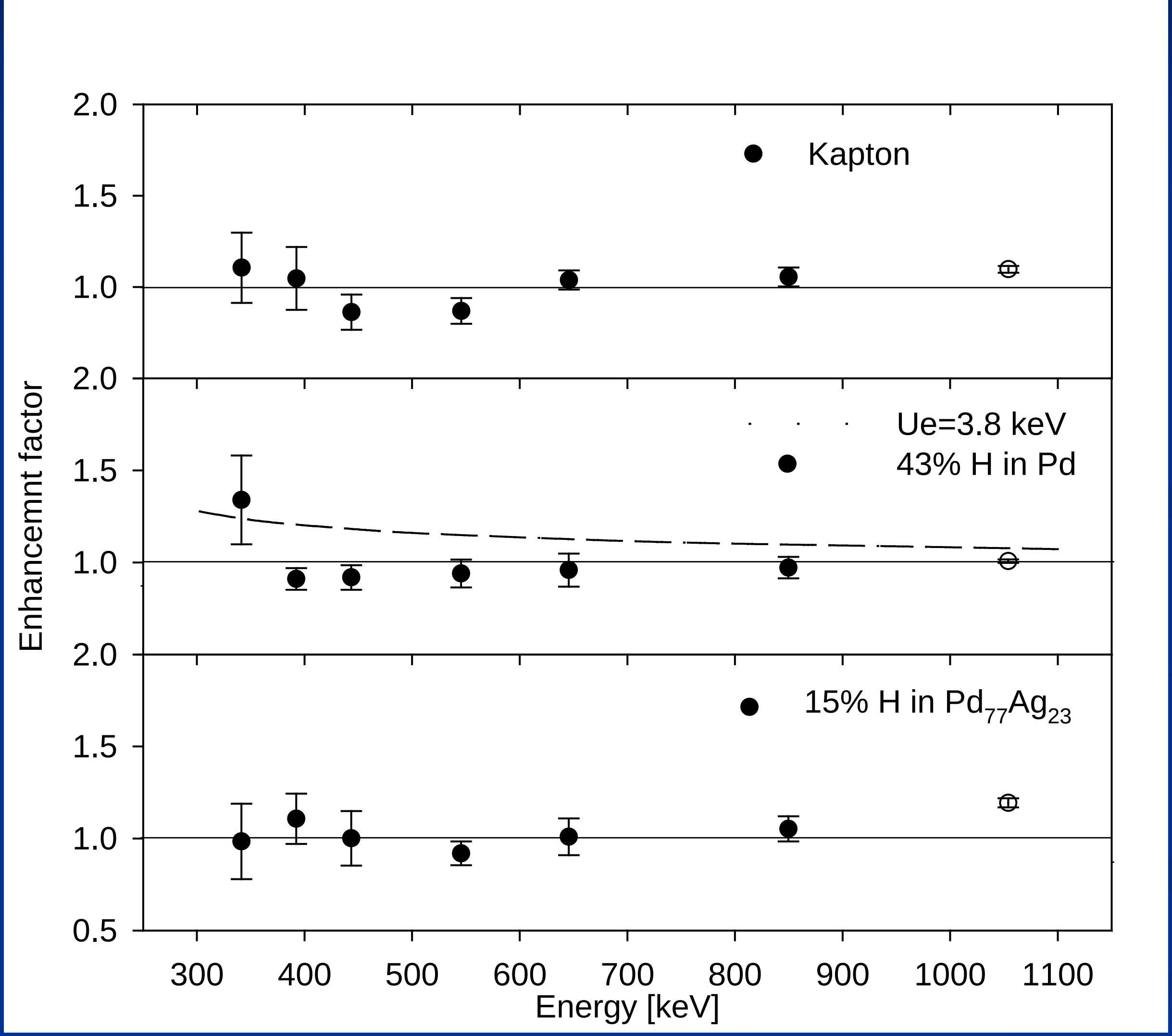
dE_{Li}/dx stopping power
Ω efficiency
W ang. distribution

Reaction: $^{1}H(^{7}Li,\alpha)^{4}He$

Enhancement Factors

$f = N_\alpha(\text{measured})/N_\alpha(U_e=0)$

Screening: $\sigma(E) \rightarrow \sigma(E+U_e)$

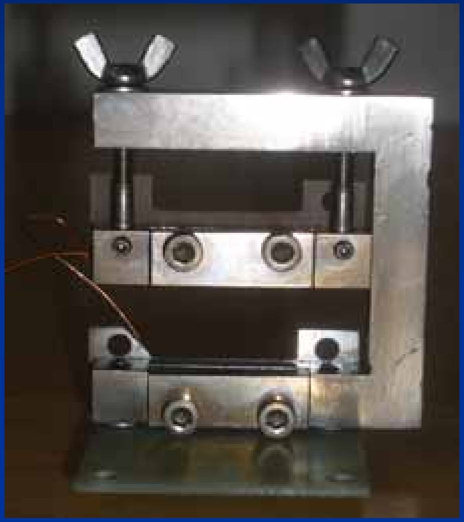


Kapton:
U_e<0.6 keV

Pd:
U_e<0.4 keV

$Pd_{77}Ag_{23}$:
U_e<0.7 keV

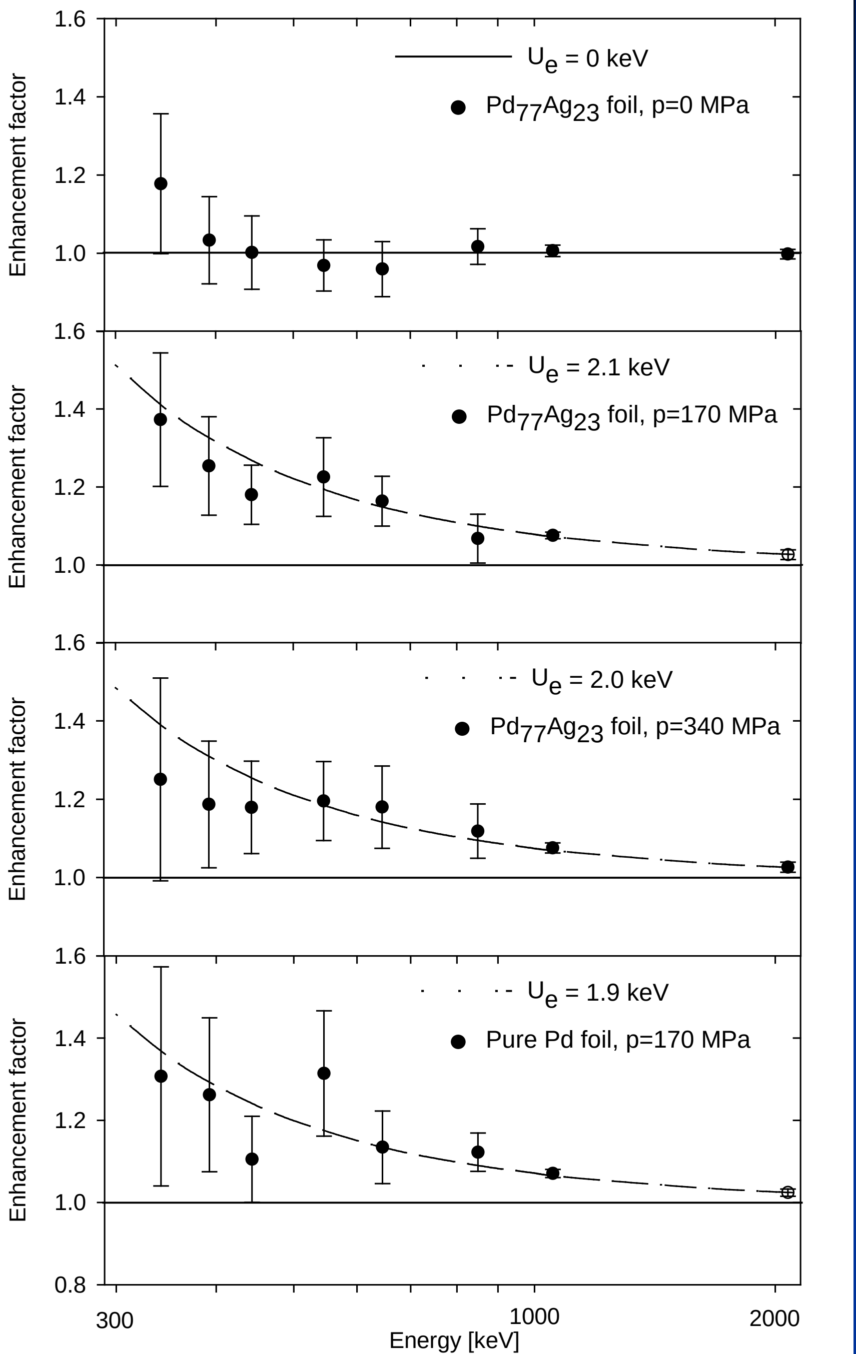
Results with stretching



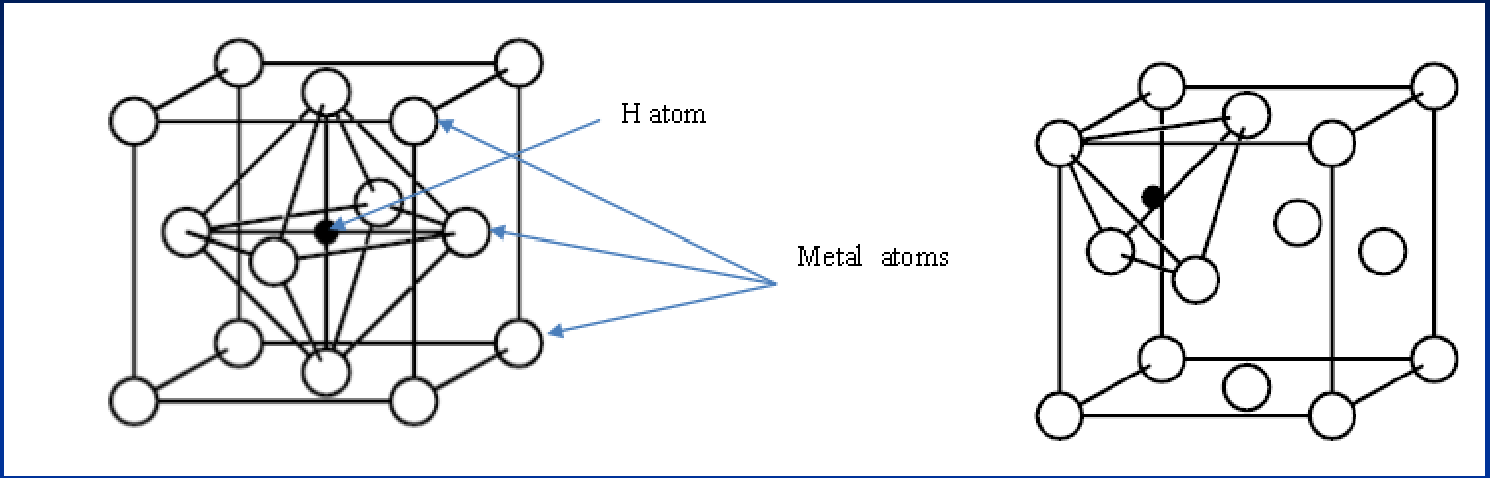
Targets, thicknesses, pressures and screening potentials

Target	d[μm]	H/M	p[MPa]	U_e[keV]
$Pd_{77}Ag_{23}$	125	0.562(5)	340	2.0±0.3
$Pd_{77}Ag_{23}$	250	0.559(5)	170	2.1±0.2
$Pd_{77}Ag_{23}$	250	0.599(5)	0	<0.4
Pd	250	0.532(5)	170	1.9±0.2

M. Lipoglavsek et al., Eur. Phys. J. A44, 71 (2010).



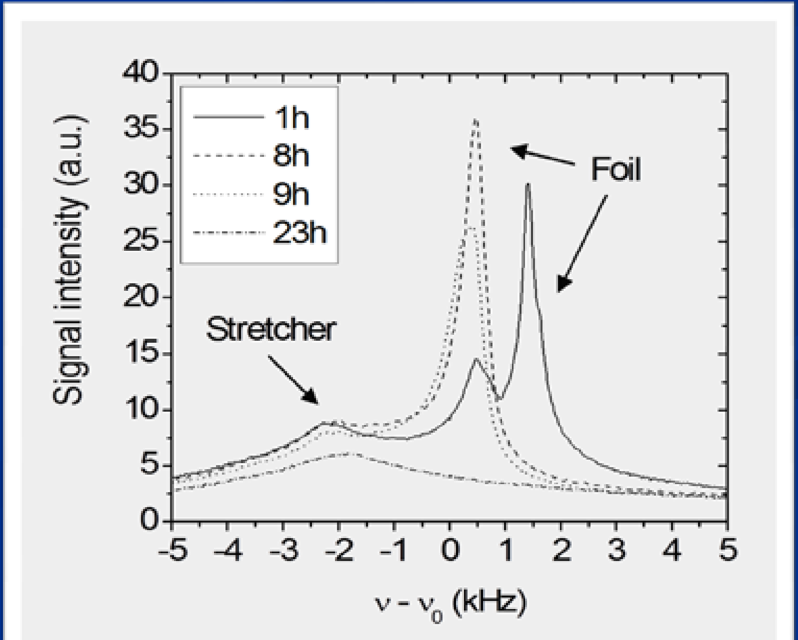
Possible explanation



face centered cubic lattice

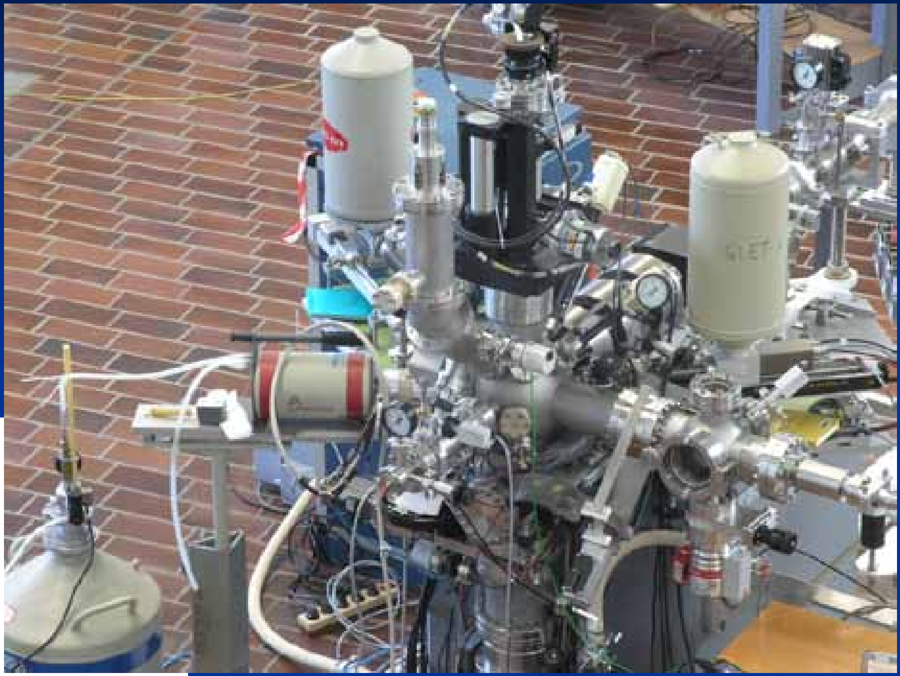
Octahedral position — stretching → Tetrahedral position

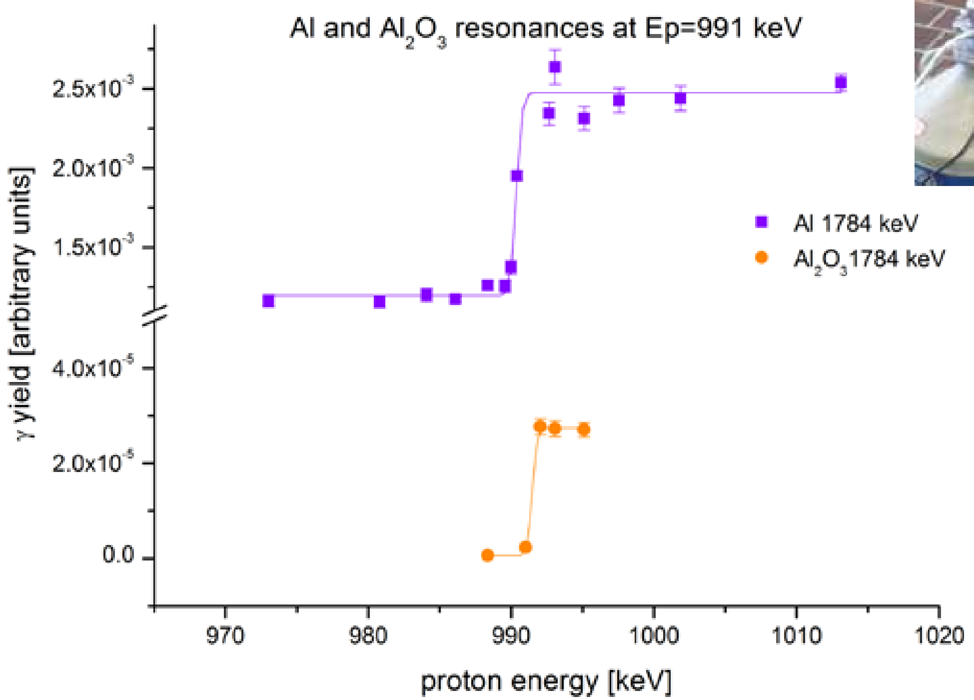
^{1}H NMR lineshapes measured by Hahn echo at υ_0 = 100 MHz of a 250 μm thick Pd foil.



Electron screening in aluminum

(p,γ), (p,p´γ) and (p,nγ) reactions were studied on natural Ni and Al in metals, $Pd_{90}Ni_{10}$ alloy and NiO and Al_2O_3 insulators.

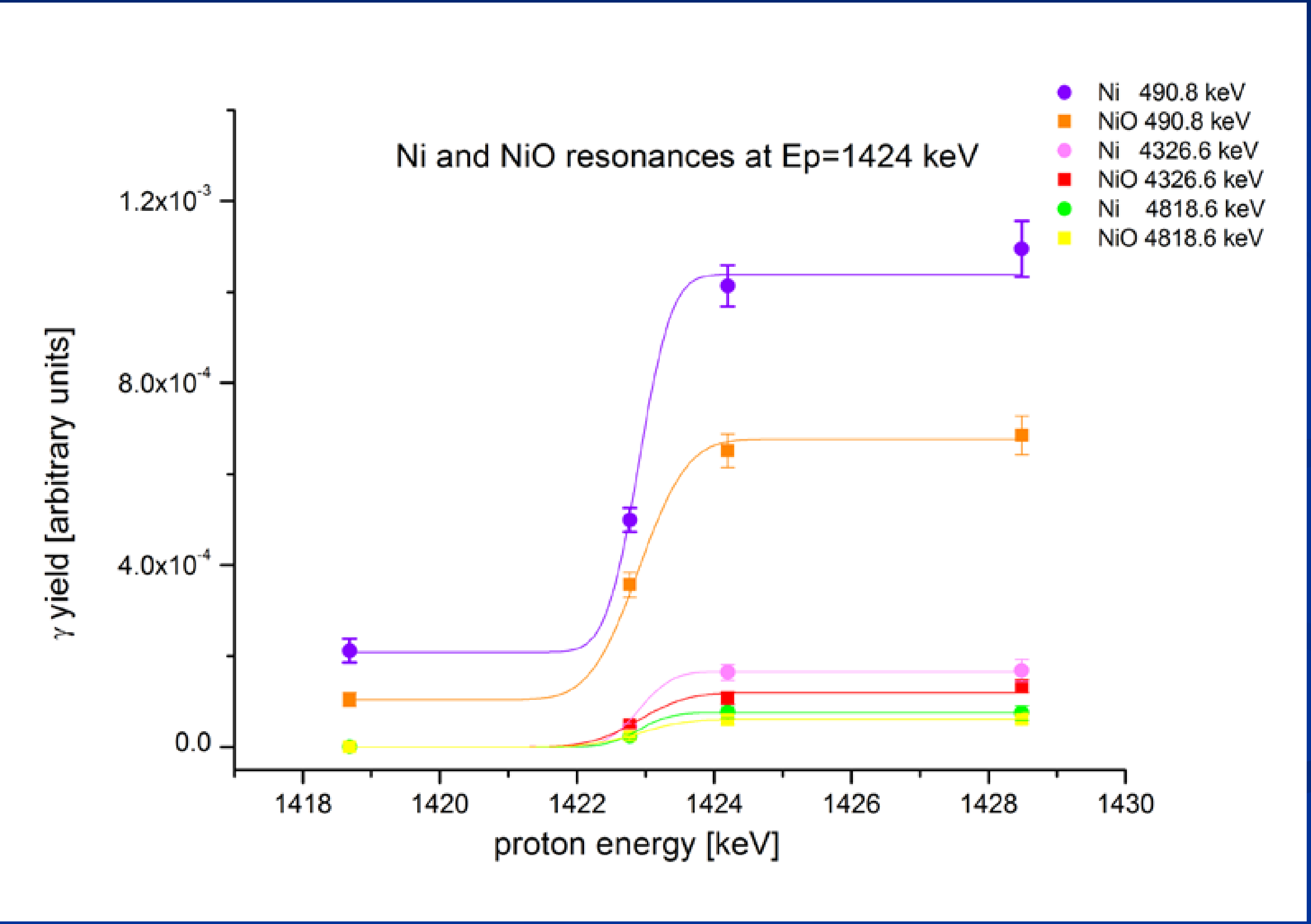




Characteristic γ rays were measured by a Ge detector: 1784 keV γ ray from $^{27}Al(p,\gamma)^{28}Si$ reaction

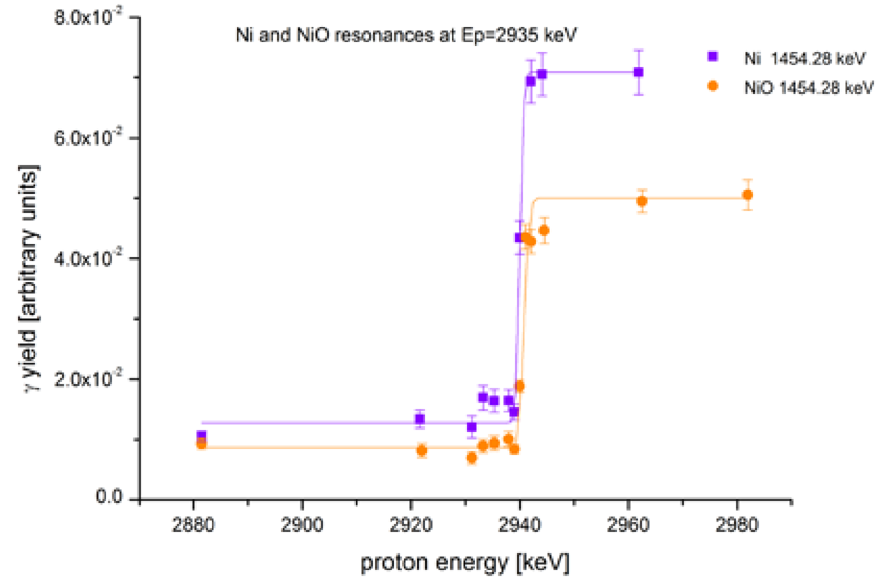
Nickel

3 γ rays from $^{58}Ni(p,\gamma)^{59}Cu$ reaction

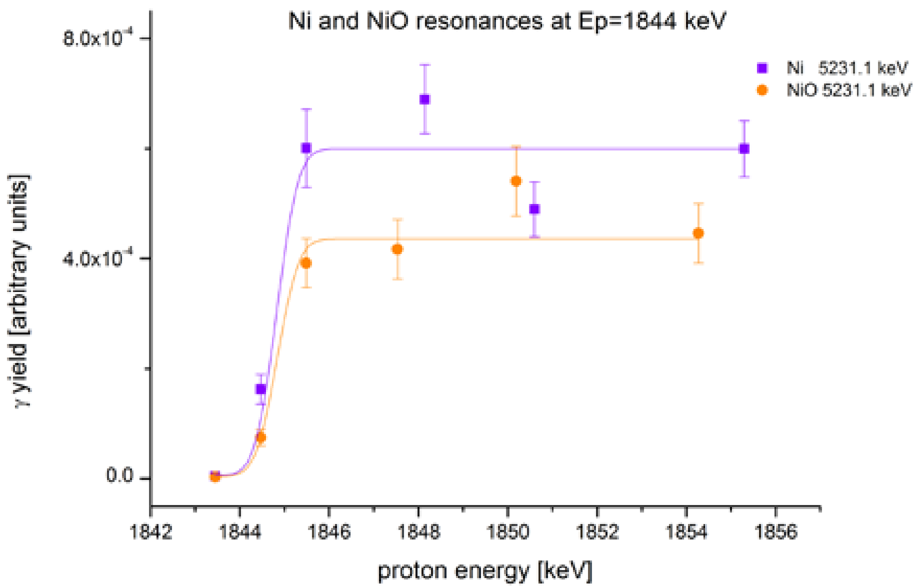


Nickel

1454 keV γ ray from $^{58}Ni(p,p'\gamma)^{58}Ni$ reaction



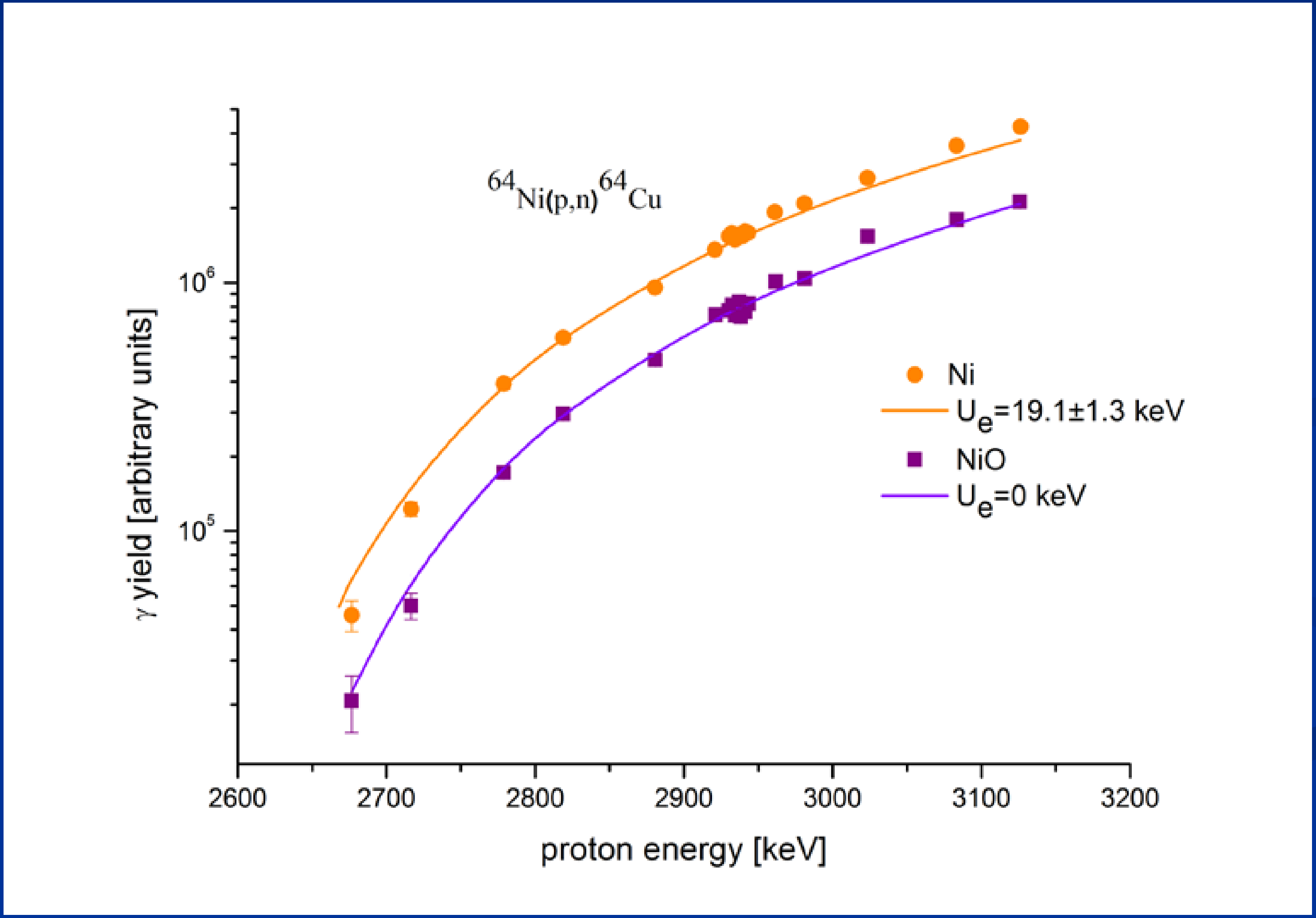
5231 keV γ ray from $^{58}Ni(p,\gamma)^{59}Cu$ reaction



- No shift in resonance energy
- No difference in resonance strength

$^{64}Ni(p,n)^{64}Cu$ reaction

Eγ=159 keV, very preliminary results



Conclusions

- Electron screening in metals depends on H placement in the crystal
- No large screening in slow compound nucleus reactions, (p,γ) and (p,p´γ) resonances
- At high Z only (p,n) reactions possibly show a large electron screening effect (to be confirmed) $\rightarrow$ time scale of screening
- Possible differences in β decay of copper isotopes