Physics is the experimental science
Richard Feynman

E.N. Tsyganov

Cold Fusion Power, International

Crystal Based Fusion Processes

The 8th International Conference "Charged & Neutral Particles Channeling Phenomena", September 23-28 2018, Ischia (NA), Italy

Outline

1. Introduction
2. Muon catalysis lessons
3. Experiments with deuterium implanted in conducting crystals
4. Brillouin Energy Corporation
5. Possible interpretation of Brillouin EC results
6. Discussion and conclusion

1. Introduction

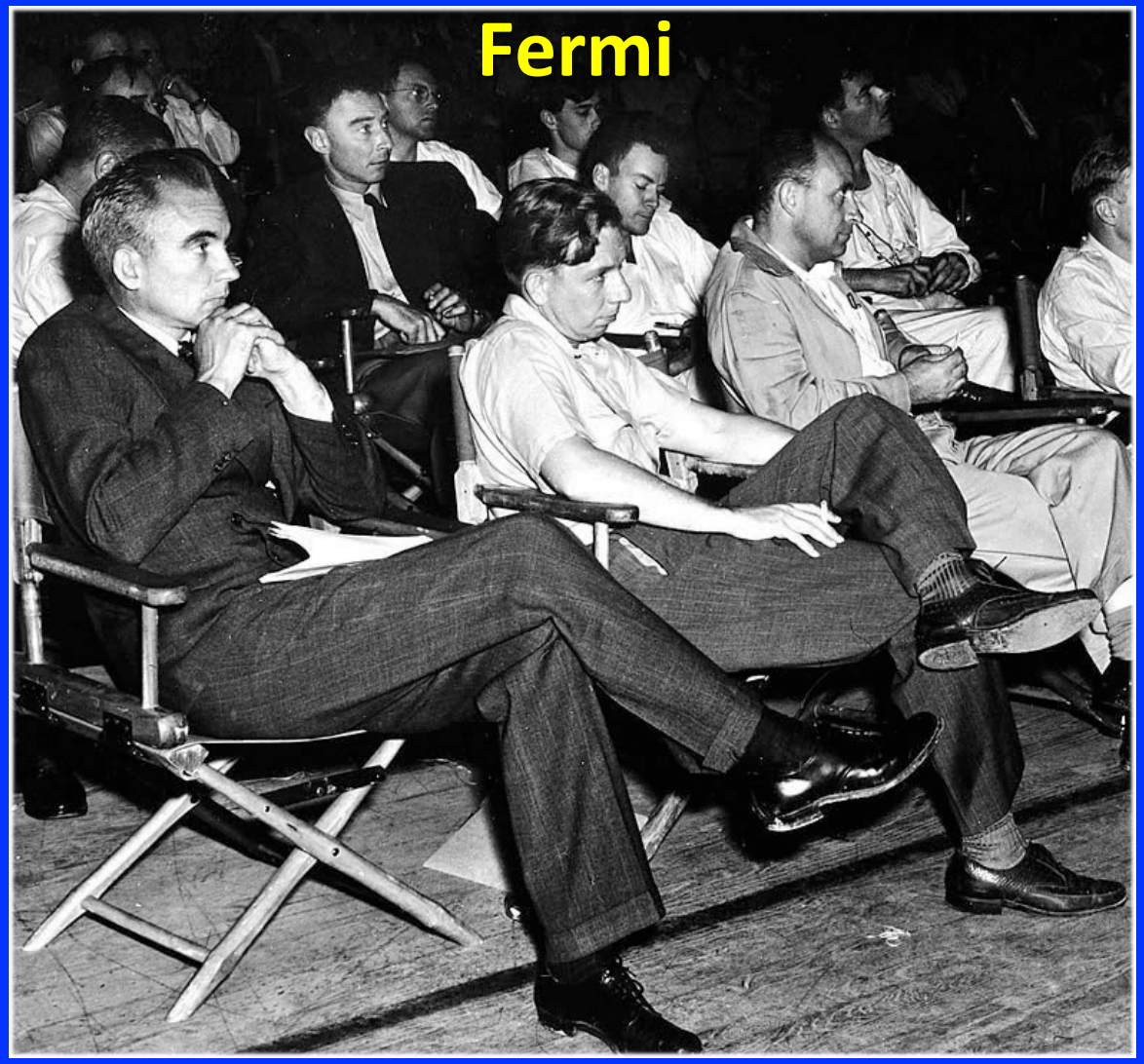
At the present, mankind has come to a stage of development when the struggle for energy resources has become particularly severe. In the next 25–50 years oil and natural gas resources will be close to exhaustion. This imposes severe negative constraints on our future development.

The problem is expanded by the fact that the oil and natural gas resources is bound by the so-called greenhouse effect, i.e. the excess of carbon dioxide in the atmosphere. The coal resources could last somewhat longer, probably up to about 500 years, but the corresponding severe greenhouse effect anyway prevents us to go in this direction.

Already for about 75 years there had been talk on transitioning to a process of controlled thermonuclear fusion. Initial expectations, that this problem would be solved rather soon, did not materialize. Technical difficulties maintaining superhot plasma (10^7-10^9 ^oC) and the destructive effect of enormous neutron outbreak from thermonuclear fusion reactions are pushing the solution of this problem to a more distant and uncertain future.

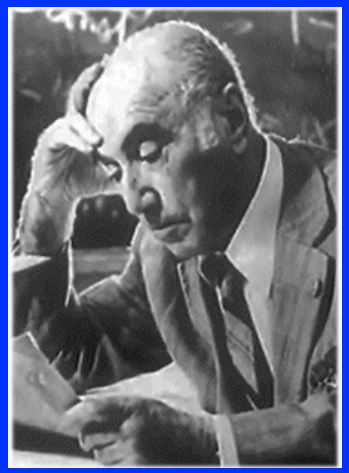
Some time ago the hope, or even assurance that the problem of nuclear fusion can be solved differently, has been established. The Low Energy Nuclear Reaction process *(LENR),* also called "cold nuclear fusion", in our opinion, now is the real possibility.

Los Alamos, 1946.
Robert Oppenheimer, Richard Feynman, Enrico Fermi



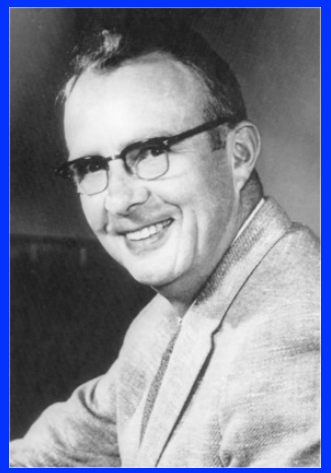
ARCHITECTS OF COLD NUCLEAR FUSION

Richard Feynman



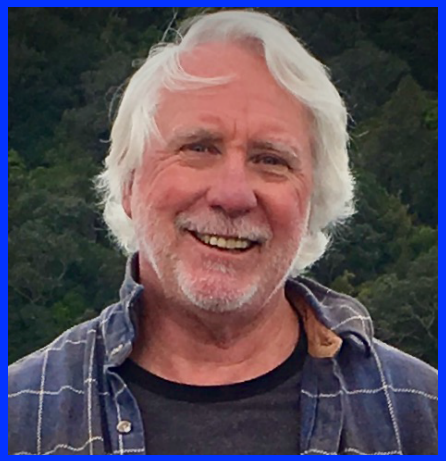
Ya.B. Zeldovich

Julian Schwinger



Luis Alvarez

Martin Fleischmann



Michael McKubre

Peter Hagelstein

Yoshiaki Arata

2. Muon catalysis lessons

The phenomenon of so-called *m*-catalysis was described in detail by Ya.B. Zeldovich in 1954 [1]. In the ionized *DH* molecule prompt convergence occurs between the deuterium and hydrogen nuclei after replacing the only remaining electron by *m*-meson. This process is leading to *DH* fusion. The theory quite accurately describes the reaction of *d-m-p* synthesis.

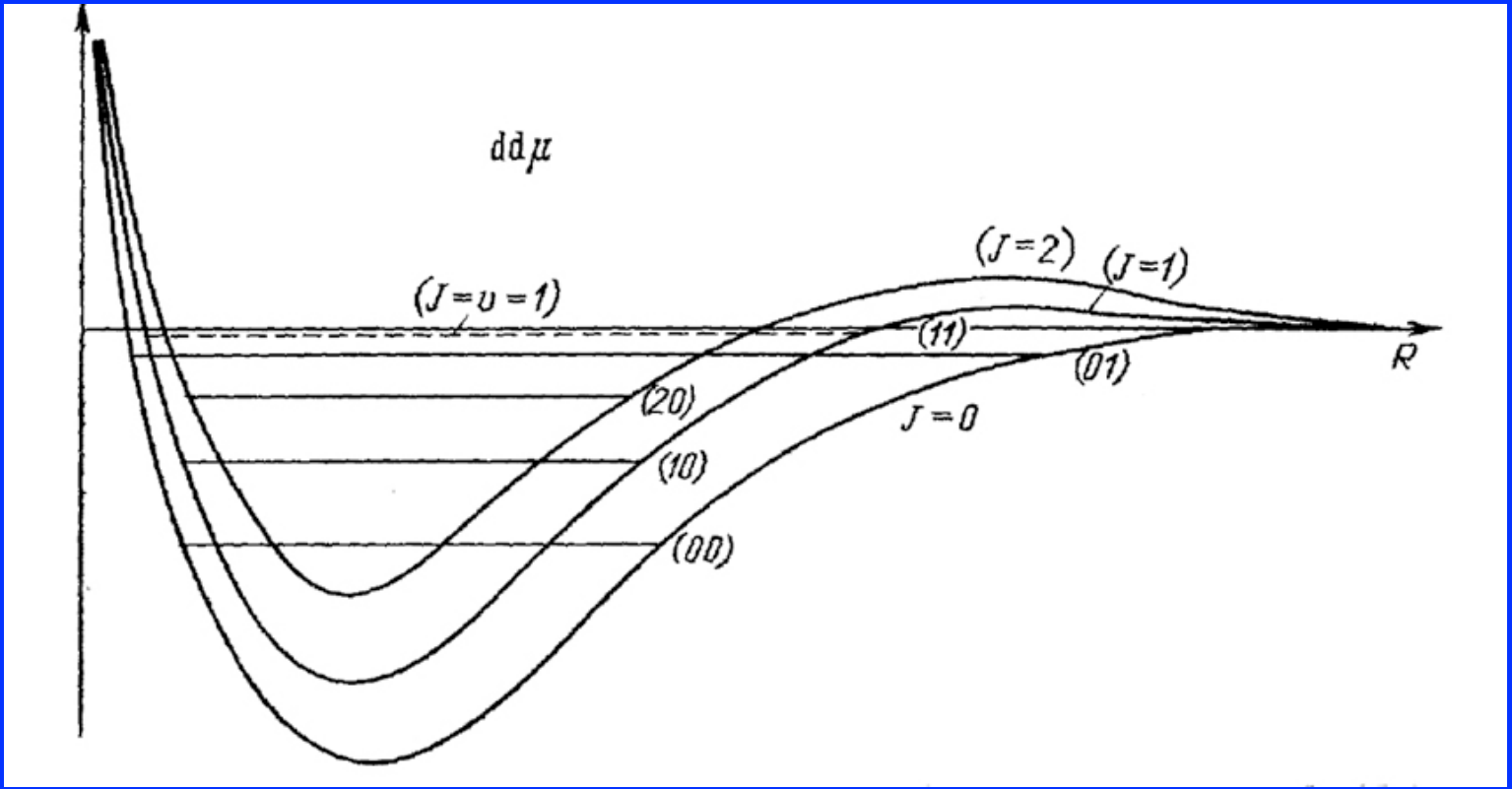
The first events of the process *DH*-fusion were observed in 1957 in L. Alvarez hydrogen bubble chamber [2].

The energy level scheme of rotational-vibrational states (J, v) in meso-molecule *ddm* is presented on the next slide [3]. There $m_p = 139.6$ MeV, $p \rightarrow \mu + \nu_\mu$, $\tau_m = 2.2 \times 10^{-6}$ s, $m_m = 105.7$ *MeV*, $m_e = 0.511$ *MeV*, $m_m / m_e \approx 207$.

The phenomenon of muon catalysis was regarded for a while as a process applicable for use as an energy source, but the short lifetime of *m*-meson did not allow this.

The energy level scheme of rotational-vibrational states (J,ν) in meso-molecule *ddm*

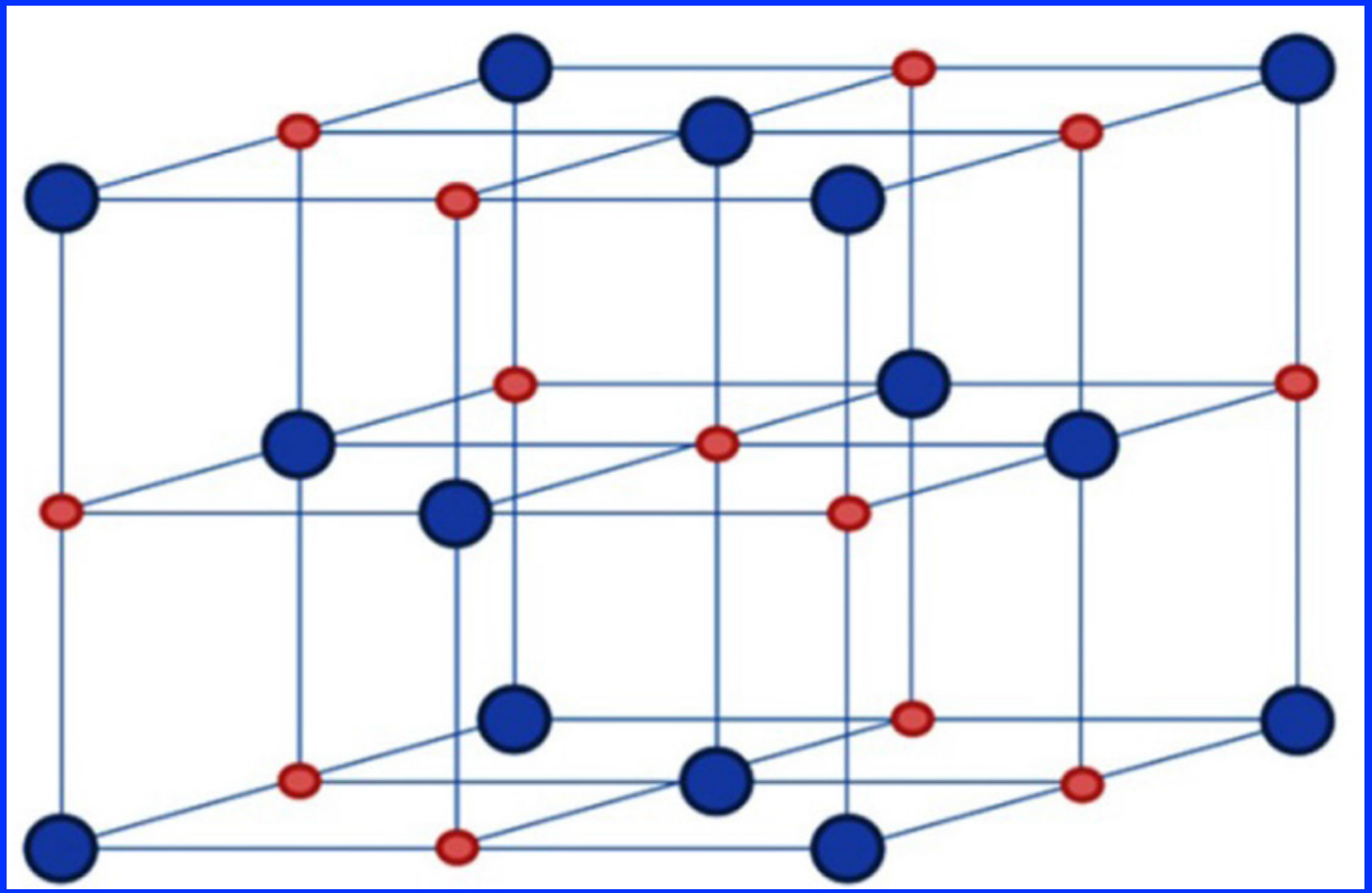
$m_p = 139{,}6$ *MeV*
$p \longrightarrow \mu + \nu_\mu$
$\tau_m = 2{,}2 \times 10^{-6}$ s
$m_m = 105{,}7$ *MeV*
$m_e = 0{,}511$ *MeV*
$m_m/m_e \approx 207$



3. The experiments with deuterium implanted in conducting crystals

A new method of nuclear fusion, the so-called "cold nuclear fusion" was discovered on 1989 by Martin Fleischmann and Stanley Pons [4]. The phenomenon of cold nuclear fusion in metal crystals today has been confirmed by the vast numbers of experiments. A good review of the early cold fusion studies is presented in [5]. There is a detailed description of the process of cold nuclear *DD*-fusion by us in [6, 7]. The crystal structure of *fcc* – palladium, platinum – is presented on the next slide.

The crystal structure of *fcc* – palladium, platinum. Red circles denote the deepest potential niches.



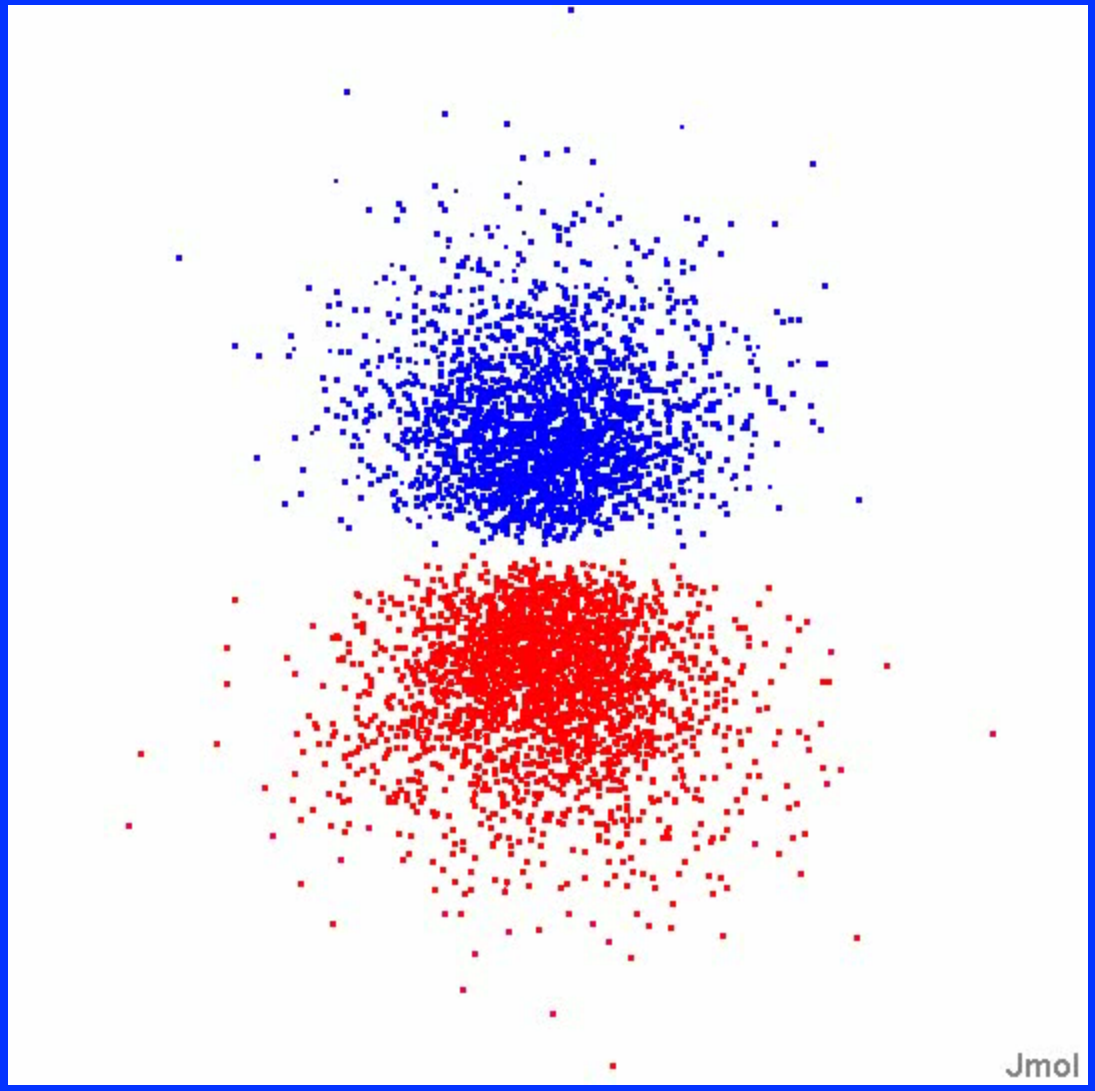
In the explanation of cold fusion of deuterium in the crystals, it should be taken into account that all the Bohr atoms (*1s*) are not able to stay in the center of conductive crystal cell, because it place is reserved for the free conduction electrons. The energy threshold for this ban is about 10 *eV*.

In the process of implanting the hydrogen atom in a metallic crystal the hydrogen atoms are excited from the state *1s* to the states *2p*, *3p* or above by the value of 10 – 14 *eV*.

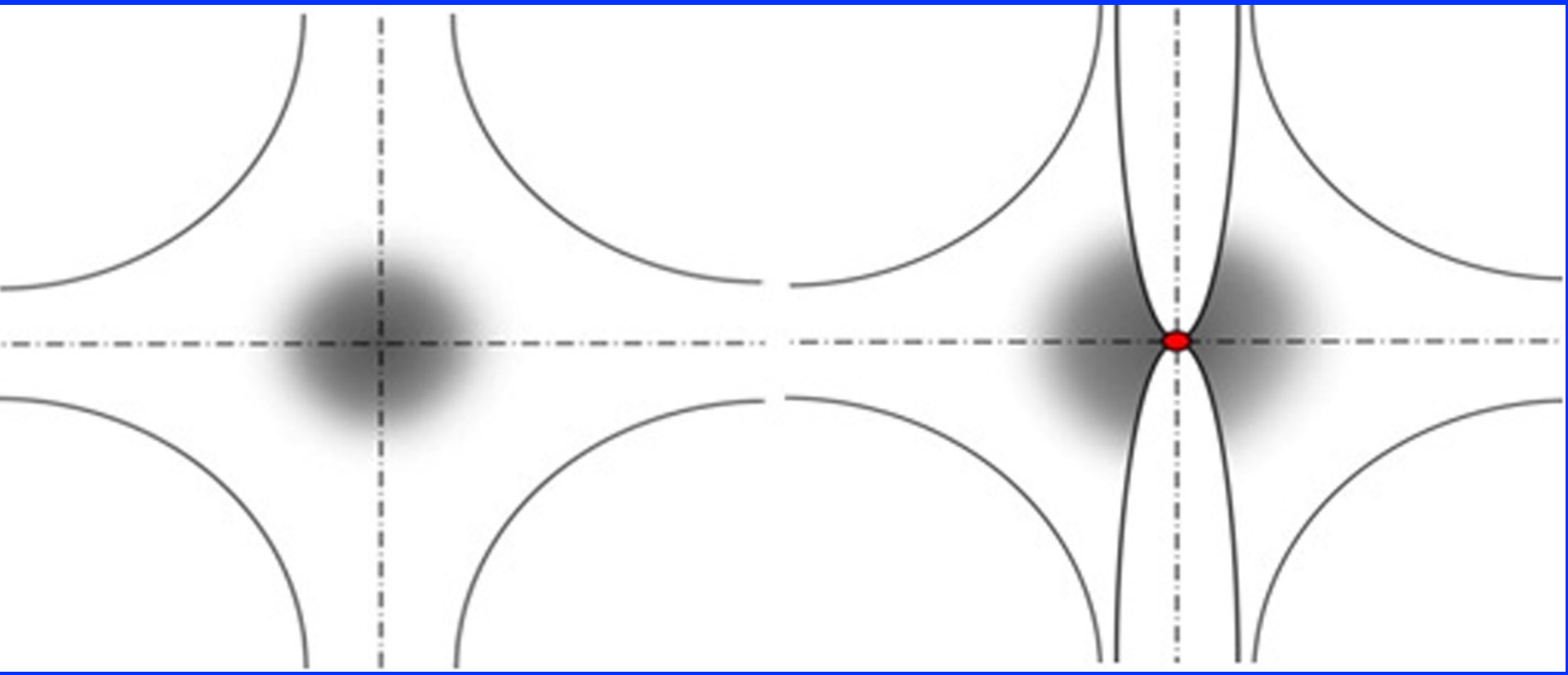
Normally, excited hydrogen atoms quickly return to their ground state. However, in a metal environment hydrogen atoms are prohibited to be in *1s*-state because conduction electrons already assigned to this same area. However, the states *2p*, *3p* and higher can easily survive with this inconvenience, due to their specific shape. The orbitals of the hydrogen atom *1s* and *2p* were presented in our publications [8]. Numerical solutions of the Schrödinger equation for the hydrogen according to the calculations of M. Winter [9] (the University of Sheffield, England) for *2p* state is shown below.

2p orbital of hydrogen atom

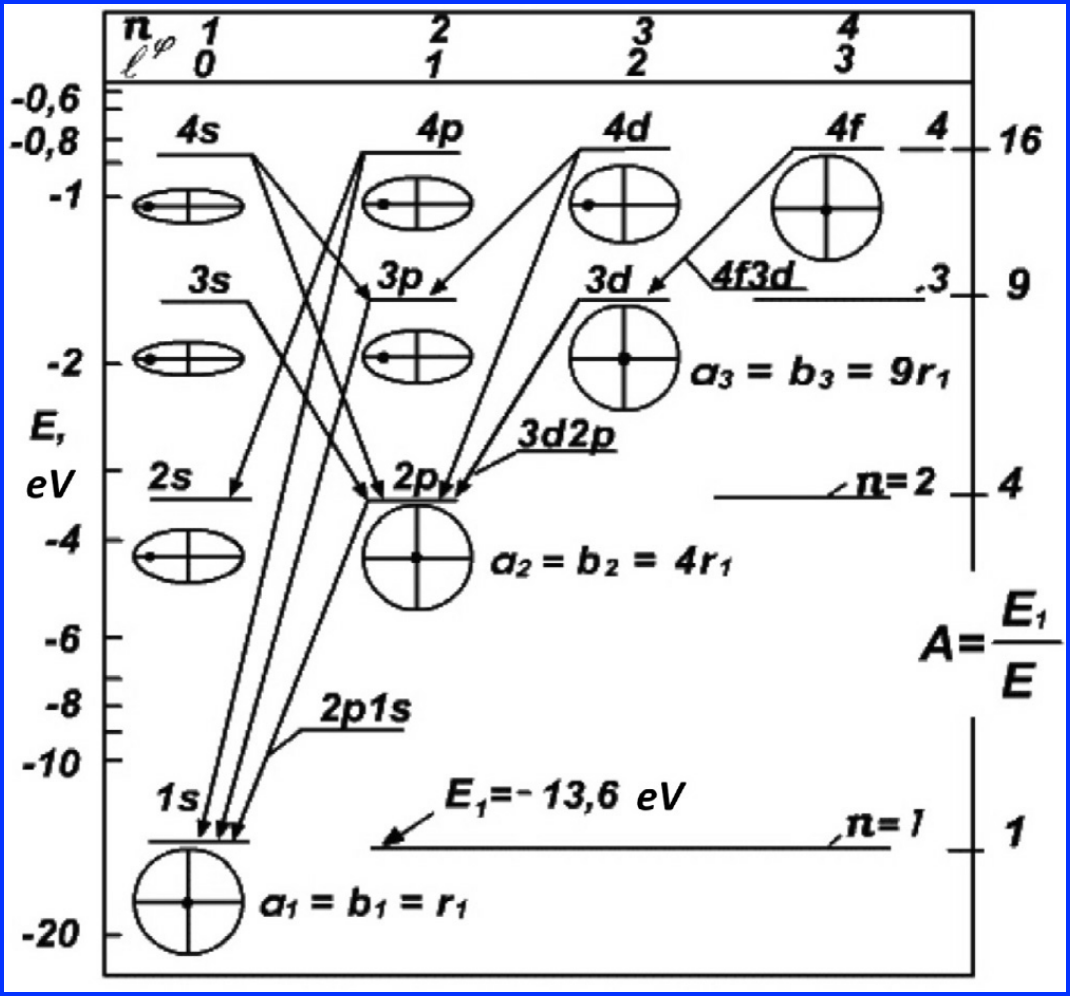
Dot-density plot of the *2p* electron density function ψ_{2p}^2. Blue represents negative values for the wave functions and red represents positive values. http://winter.group.shef.ac.uk/orbitron/AOs/2p/wave-fn.html



Schematic illustration of the influence of the free electrons of conductive crystal for the implantation of foreign hydrogen atoms.

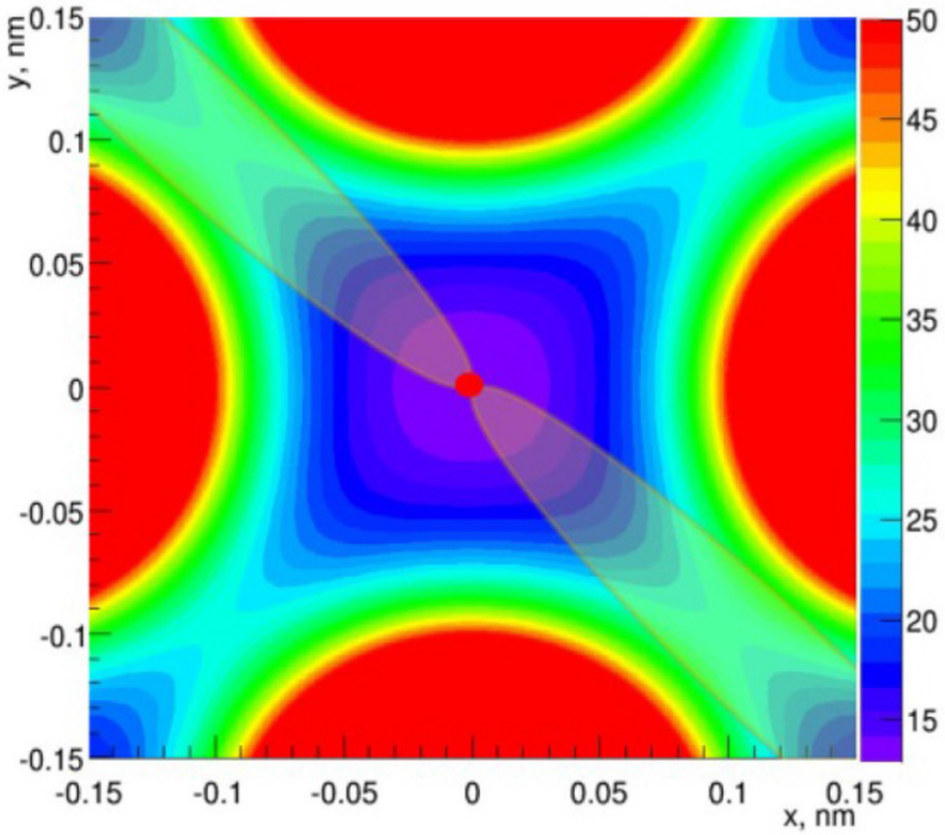


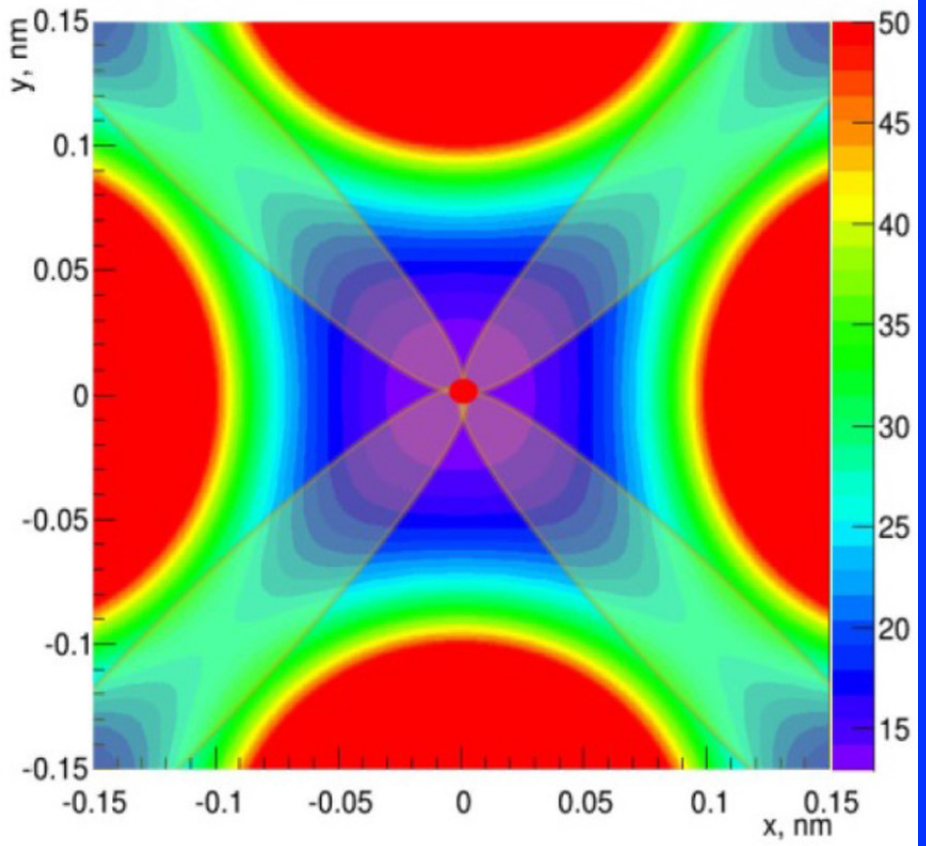
The Rydberg energy levels of the hydrogen atom, 1885. Quantum numbers: *n* – energy, l – the angular momentum.



When all the deepest potential niches in the conducting crystal are already filled by the deuterium atoms in the states *2p* or higher, filling them further leads to the doubling of these implants. In this *2p* or *3p* states, due to their non-sphericity, the crystal niche is not occupied arbitrarily, it forms a certain "crisscross" spatial orientation in order to minimize the potential energy of the double implant cluster in the conducting crystal.

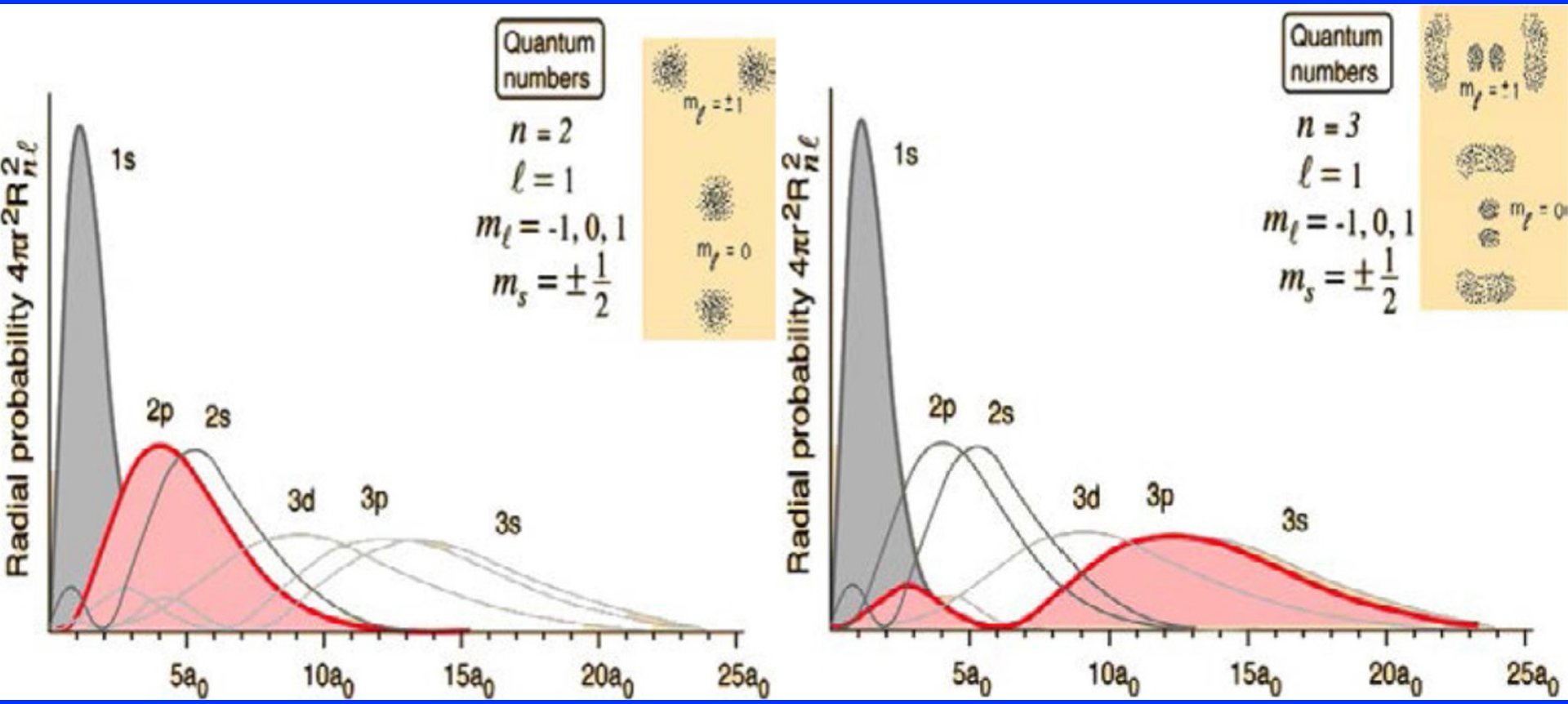
On the next slide: hydrogen atoms in the state *2p* in octahedral niche of platinum crystal in the *XY* horizontal plane, on the left: a single atom; on the right: two atoms in the "crisscross" orientation at *Z*=0. The lower figure shows two implanted hydrogen atoms vertically, i.e. on the axis *Z*. The color scale: the electric potential of the crystal in volts.


y, nm
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
x, nm
50
45
40
35
30
25
20
15


y, nm
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
x, nm
50
45
40
35
30
25
20
15

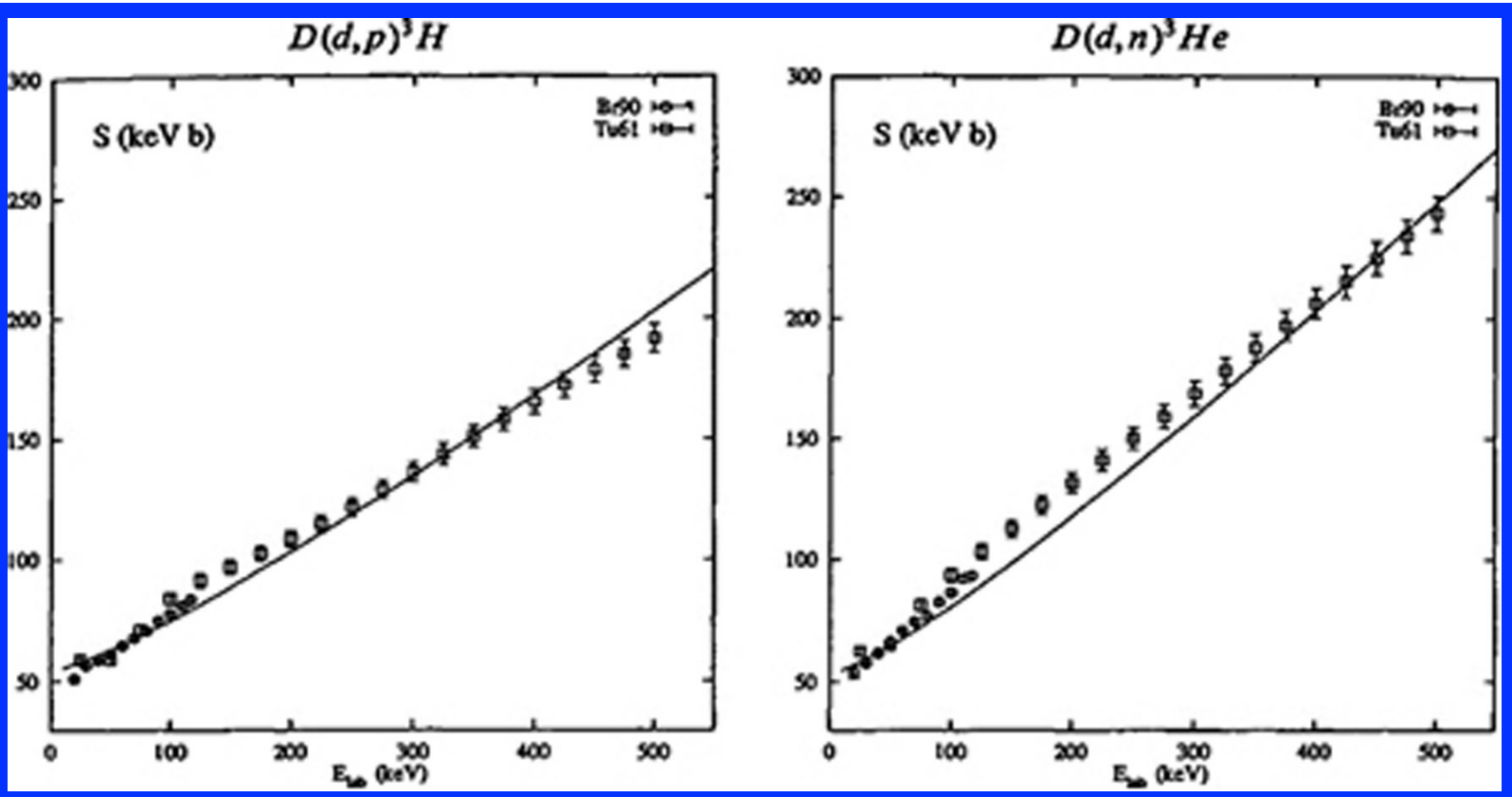

Z

Dependence of the probability of finding the electron in hydrogen atom *vs* radius. Here a_o – Bohr radius = 52.9 *pm*.



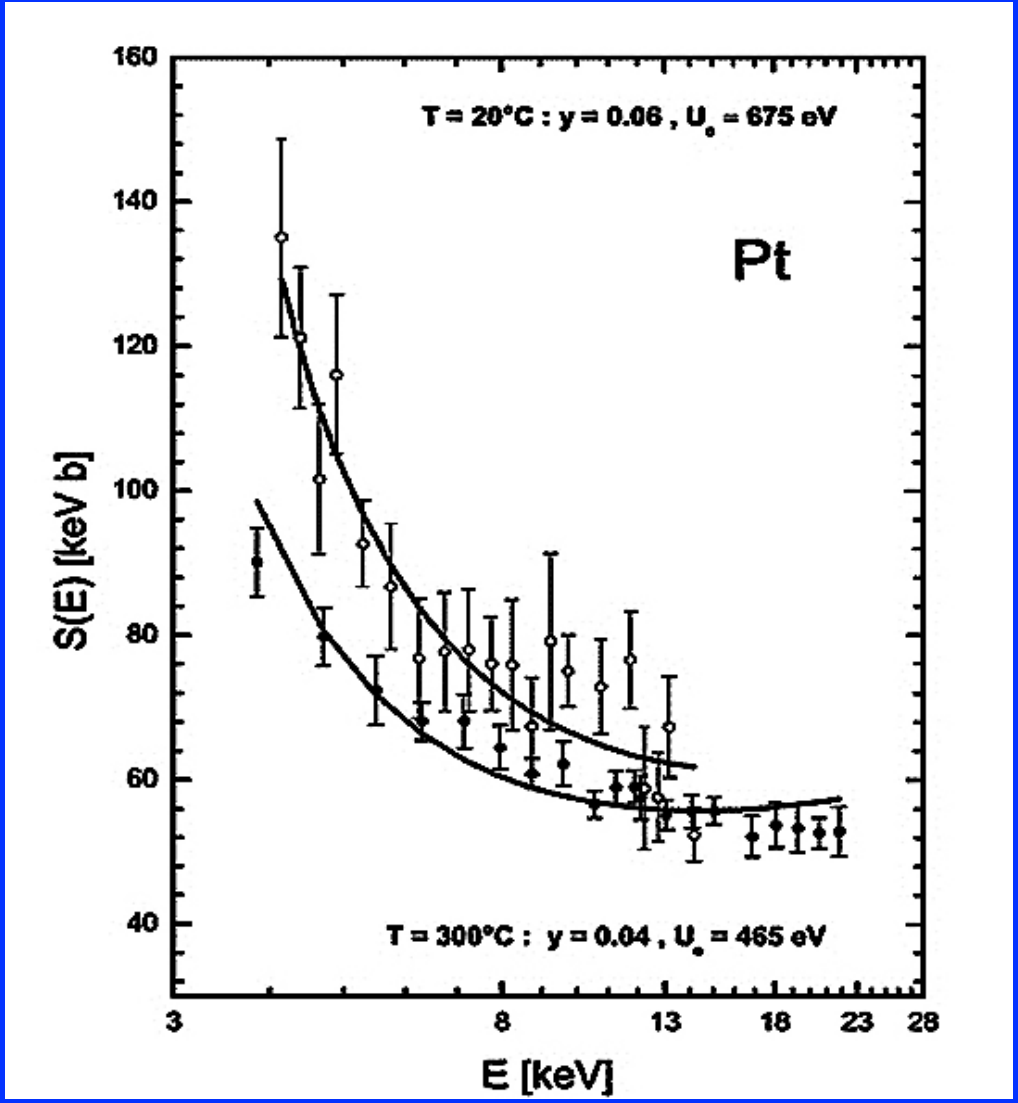
S(E) – astrophysical factor for the reaction *D(d,p)³H* and *D(d, n)³He* from the work of S. Lemaitre et al. [10].

$$S(E) = E\sigma \cdot \exp\left(\pi \frac{e^2}{\hbar c}\sqrt{\frac{M_{\mathbf{d}}c^2}{E}}\right) = E\sigma \cdot \exp(31.41/\sqrt{E})$$



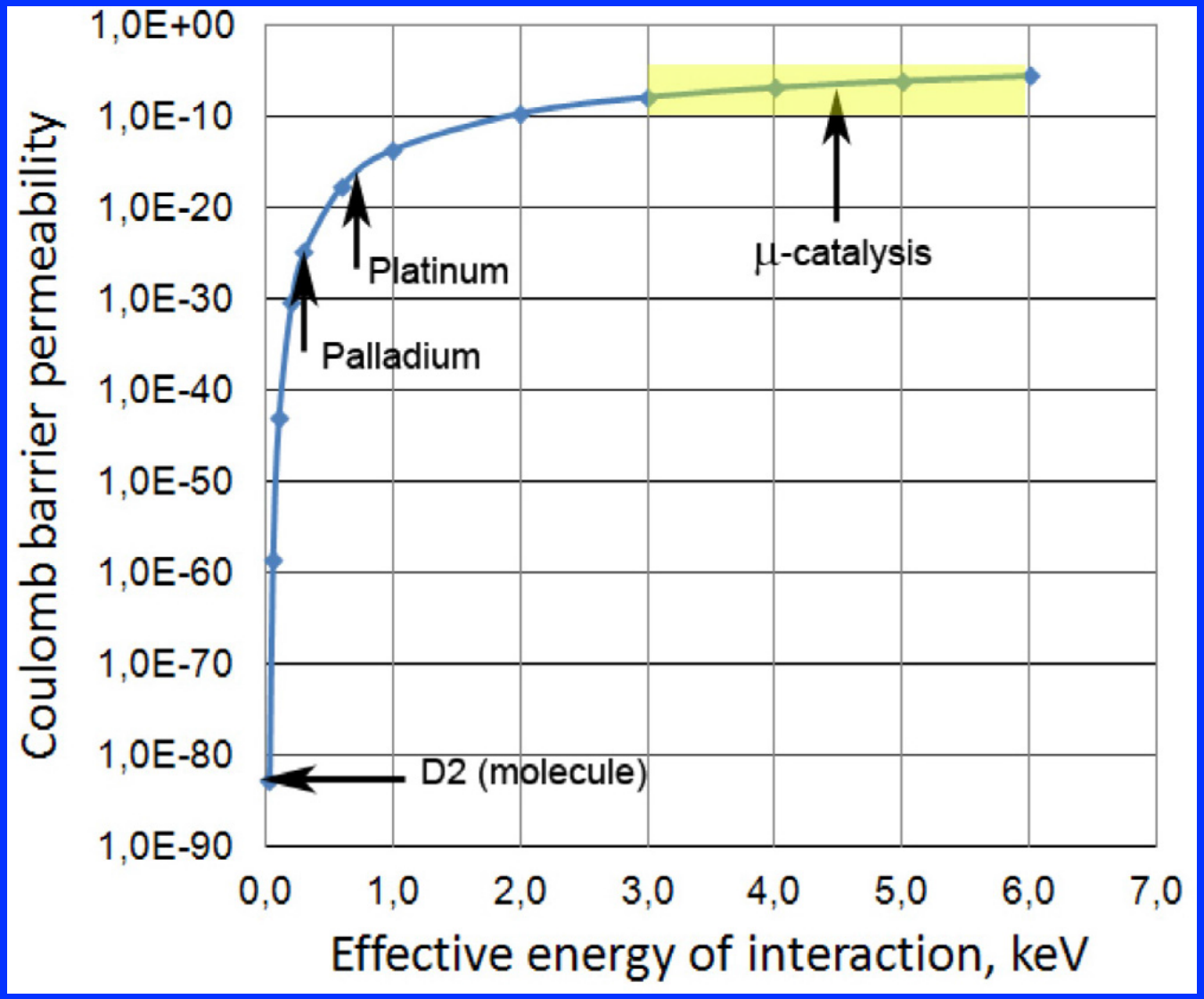
Astrophysical factor *S(E)* for *DD* reaction in Platinum

F. Raiola et al., [11]



Next slide shows that the Coulomb barrier transparency increases by about 65 orders of magnitude with an increase in the so-called screening potential from 27 *eV* (deuterium molecule) to 300–700 *eV* for a cluster of two deuterium atoms in the platinum crystal in the *2p* state or above in the "crisscross" position.

Permeability of Coulomb barrier for *DD* fusion



$$P = e^{-2ph}\ (2ph = 31{,}41/E_{eff}^{1/2},\ E_{eff}\ in\ \kappa eV)$$

The Table 1 on the next slide is collected in this approximation and gives an estimate of the rate of the $D+D \rightarrow {}^4He^*$ fusion reaction for palladium and platinum. As follows from this table, the average waiting time for the fusion of $D+D \rightarrow {}^4He^*$ in the cell of the platinum crystal is a fraction of a second. The *frequency of quantum vibrations* is n ? $E/\hbar$ ($\hbar = 6.5 \times 10^{34}$ *Js*, 1 *eV* $= 1.6 \times 10^{-19}$ *J*).

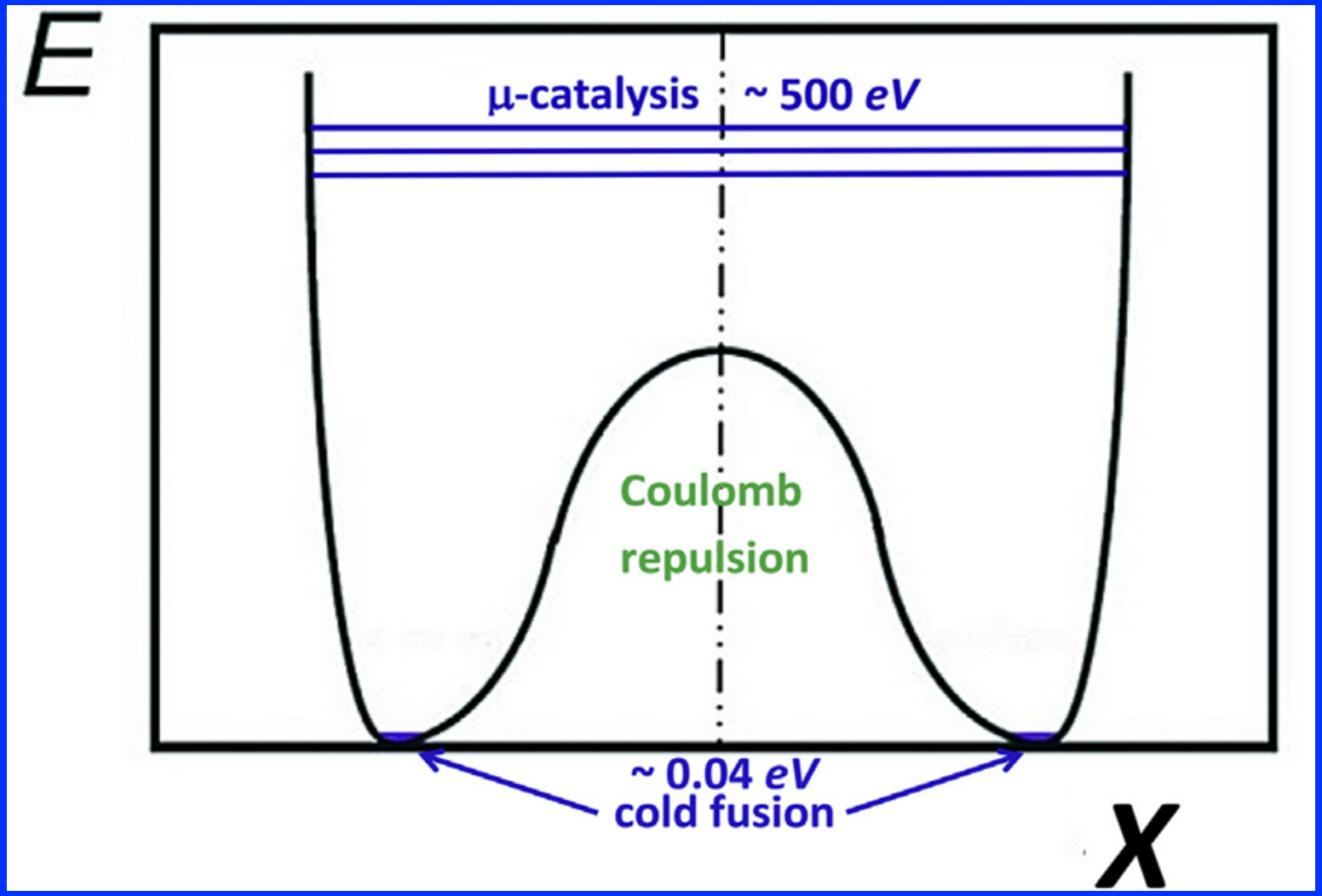
Rate of *DD*-fusion in a crystalline cell [12]

Crystal type	Screening potential, eV	Quantum vibration frequency ν, s^{-1}	Barrier permeability $e^{-2\pi\eta}$	Rate of *DD* fusion λ, s^{-1}
Palladium	300	$0{,}74\times10^{17}$	$1{,}29\times10^{-25}$	$0{,}95\times10^{-8}$
Platinum	675	$1{,}67\times10^{17}$	$2{,}52\times10^{-17}$	4,2

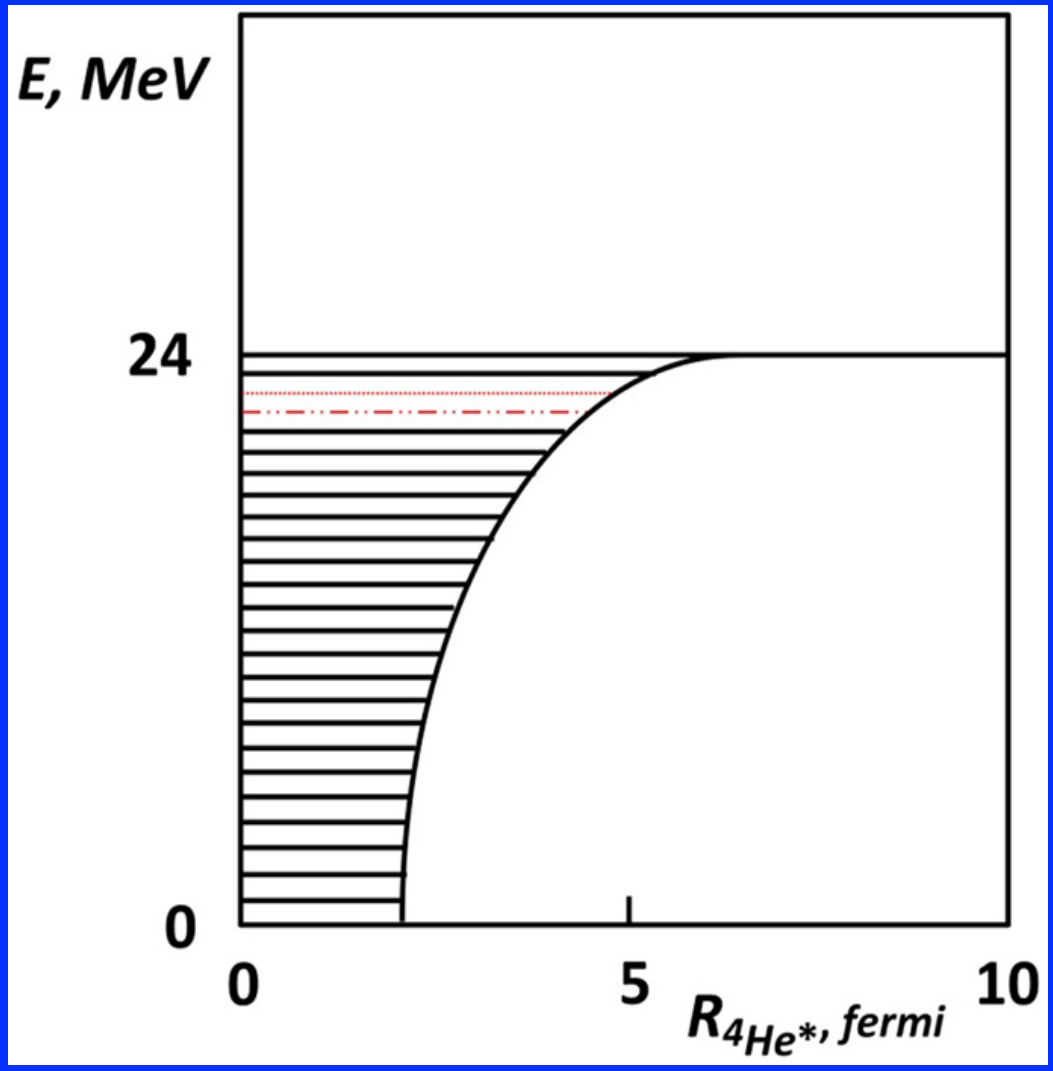
The observed reduction of the decay rate of the created intermediate nucleus after the fusion reaction through the direct channels of nuclear decay ($^4He^*$) in cold fusion experiments can be explained by a *residual Coulomb barrier* (about 100–200 *eV*) already in the potential well of the strong interactions.

Thermal deuterons, penetrated into the potential well of the strong interactions at low excitation energies, still separated by the relic of the *Coulomb repulsion*, and are located on the opposite sides of this potential barrier. In this case, the energy discharge of the $^4He^*$ system having a projection of the orbital angular momentum $l = 0$ goes through the emission of the *virtual photons with their spin directed along the time axis (Richard Feynman condition).*

Potential well for two deuterons fused as $^4He^*$. X-direction is selected along the dipole momentum of $^4He^*$



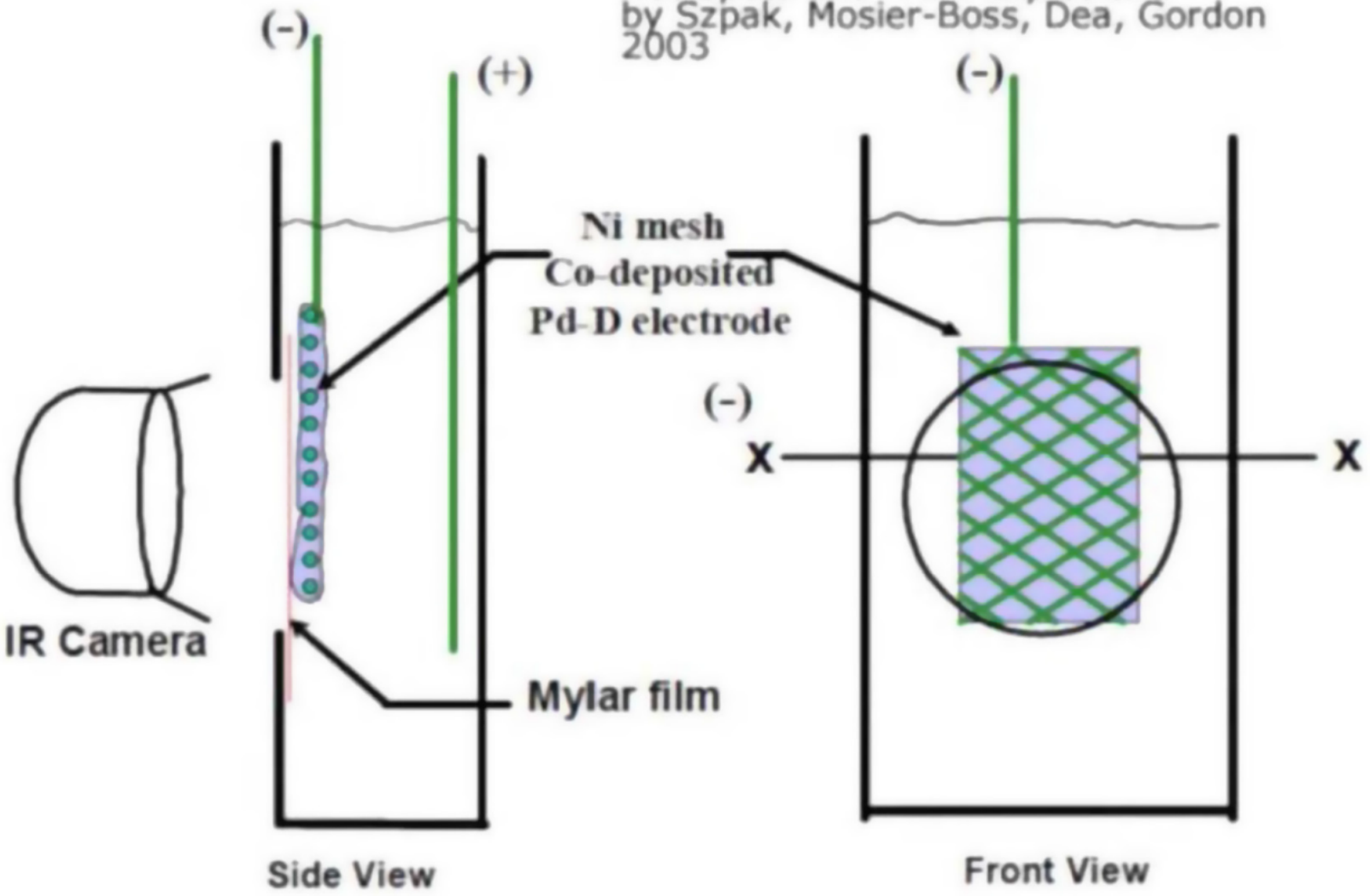
Possible evolution of the intermediate metastable nucleus $^4He^*$



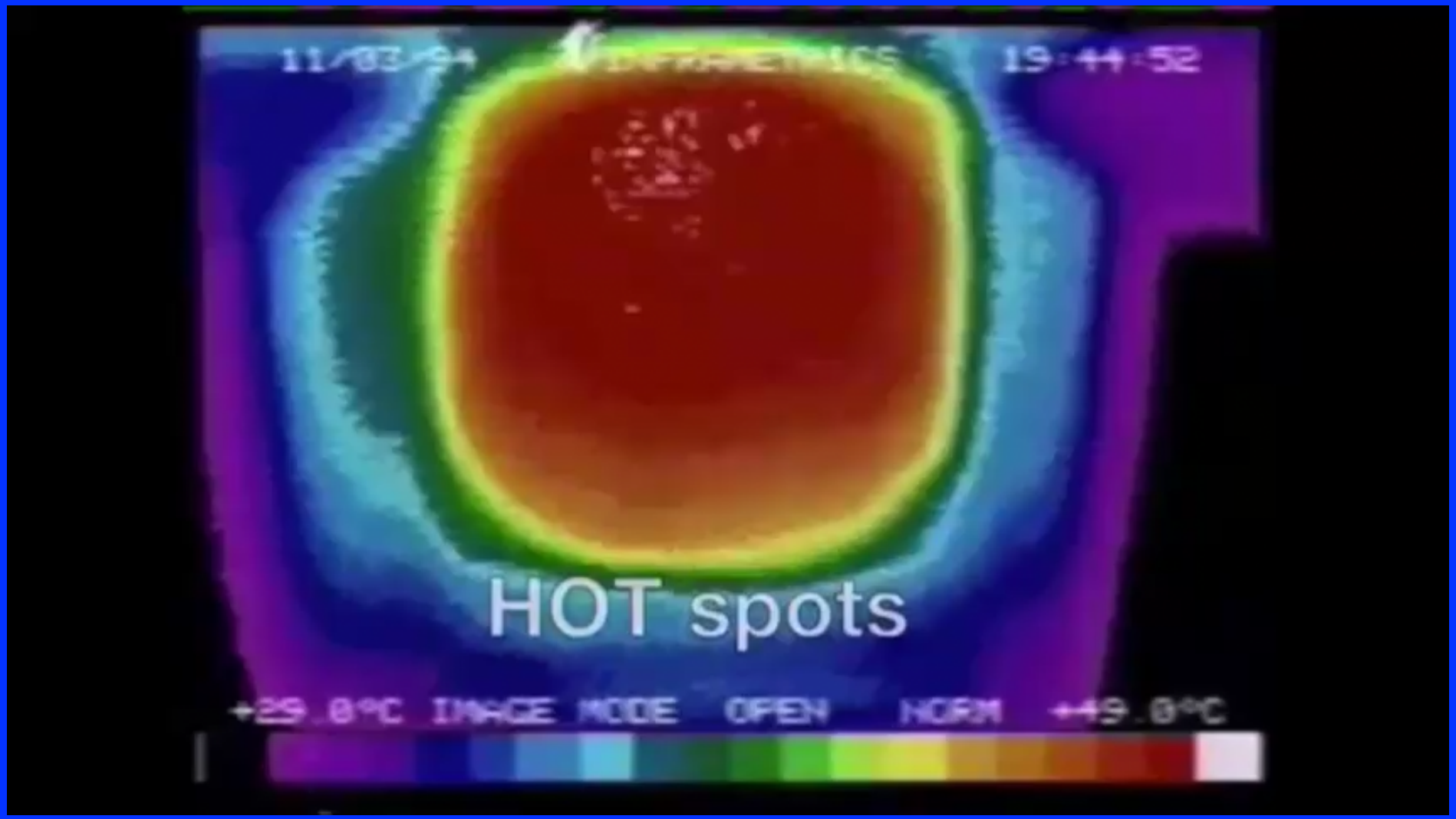
It should be noted that the researchers of cold *DD* fusion, even in 1994, were very close to finding the key to this process. Slides below present a diagram of Stanislaw Shpak [13] and his colleagues' experiment and one of their impressive results. Experiments with continuous deposition of deuterium in forming palladium crystal have observed the well localized bright light flashes.

IR Experimental Set-up

Polarized D+/Pd-D2O System:
Hot Spots and "Mini Explosions"
by Szpak, Mosier-Boss, Dea, Gordon
2003



Hot spots



In conclusion, let us again deliberate the process of cold nuclear fusion of two deuterium atoms in a helium atom ^4He in a metallic crystal. Two stages of this process are:

1. Two deuterium atoms in the *S*-state can not be located in the same cell of the conducting crystal because of the presence of conduction electrons there. Even one deuterium atom in the *S*-state would occupy practically the whole cell of the conducting crystal. When the deuterium atoms are in the *P*-states (*2P*, *3P*, and so on) this strict prohibition does not work.

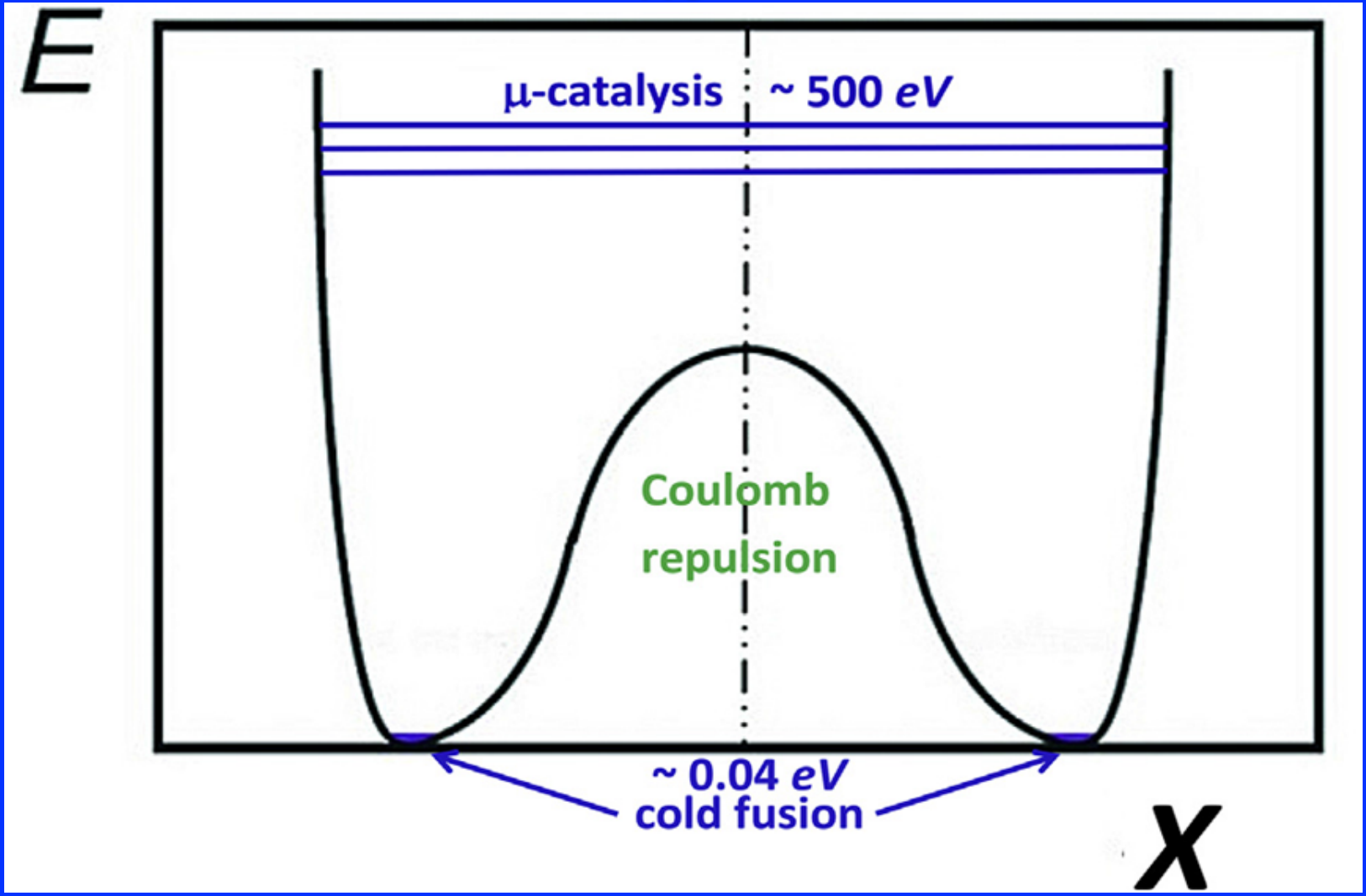
The nuclei of two deuterium atoms in *P*-state in the center of the conducting crystal cell in the "crisscross" configuration may approach each other to distances of 1/10 or even 1/20 of the dimensions of unexcited deuterium atoms. In this approach, the frequency of *quantum vibration* of deuterium nuclei sharply increases. As a first approximation, we accepted an estimate of the *frequency of the quantum vibration* $\nu \sim E/\hbar$, where *E* is the experimentally measured effective screening potential.

Table 1 on slide 24 was collected in this approximation and gives an estimate of the $D+D \rightarrow {}^4He^*$ fusion reaction rate for palladium and platinum. As follows from this table, the average waiting time for the fusion of $D+D \rightarrow {}^4He^*$ in the cell of the platinum crystal is a fraction of a second. The *frequency of quantum vibrations* is $n \boxed{?} E/\hbar$ ($\hbar = 6.5\times10^{34}$ *Js*, 1 *eV* = 1.6×10^{-19} *J*). The dependence of the permeability of Coulomb barrier on the effective energy of deuterons in the *DD* reaction in a conducting crystal was given on slide 24.

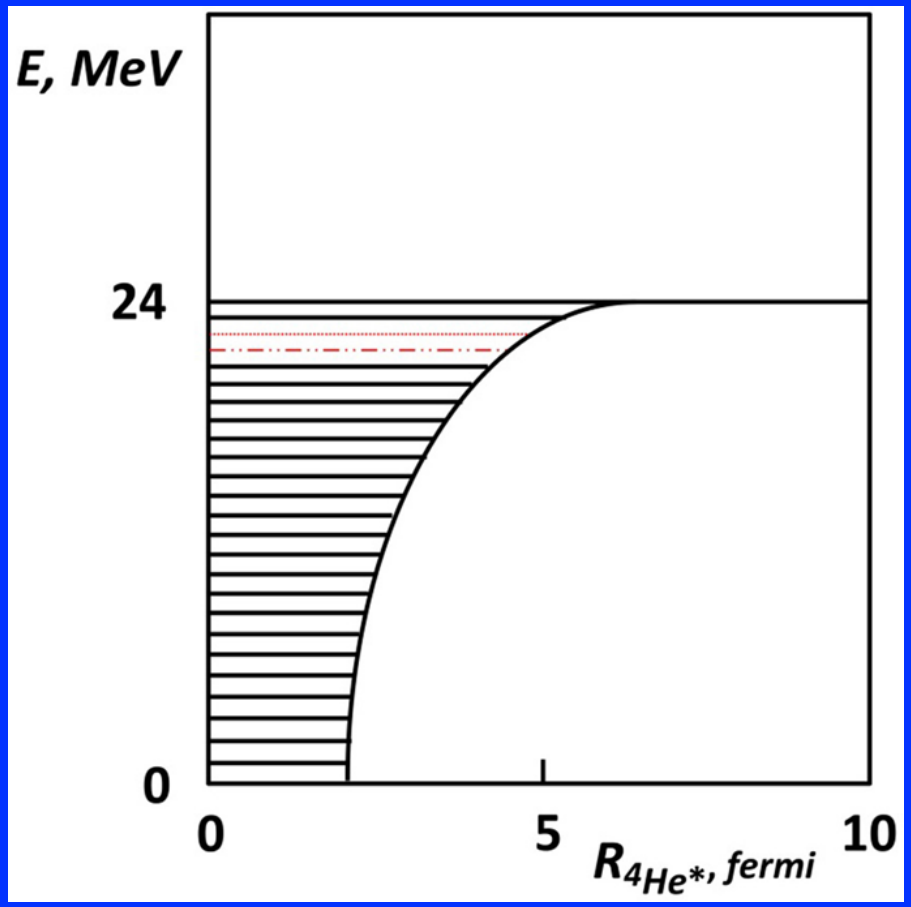
2. When the nuclear fusion process $D+D \rightarrow {}^4He^*$ is completed, the nucleus of the formed helium atom turns out to be excited at 24 *MeV* from the ${}^4He$ ground state. The electron orbits of the formed helium-4 atom, as it was also in the case of deuterium atoms prior to the fusion, are modified to allow functioning for the conduction electrons at the center of the crystal cell.

Below a schematic view of the strong interactions potential well of ${}^4He^*$ is presented. The energy levels of *m*-catalysis are about ~500 *eV*, the level of atomic thermal oscillations ~ 0.04 *eV*, and the *Coulomb repulsion* potential occurs between clusters of former deuterons with a maximum of about 200 *eV*.

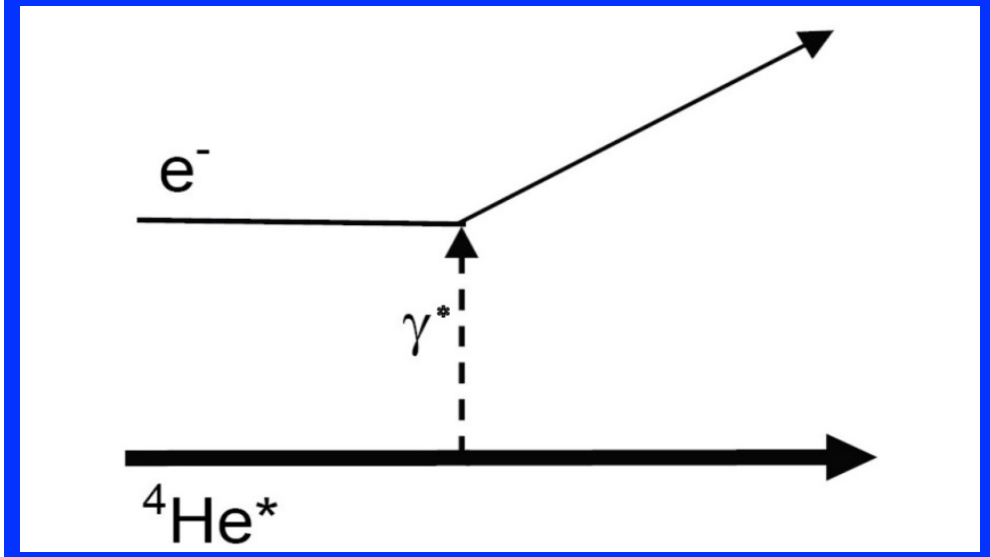
Potential well for two deuterons fused as $^4He^*$. X-direction is selected along the dipole momentum of $^4He^*$



On the next slide, left, the evolution of the size of intermediate metastable nucleus $^4He^*$ in the fusion reaction in the process of the release of the bounding energy is presented. There is a modification of the excitation levels of the intermediate nucleus as the energy of this nucleus $^4He^*$ depletes to the level of the unexcited ^4He nucleus. Right, a figure demonstrates escape of *virtual photon* from the excited nucleus $^4He^*$ and its subsequent absorption with the nearest electron.



Possible evolution of the size of intermediate metastable nucleus $^4He^*$

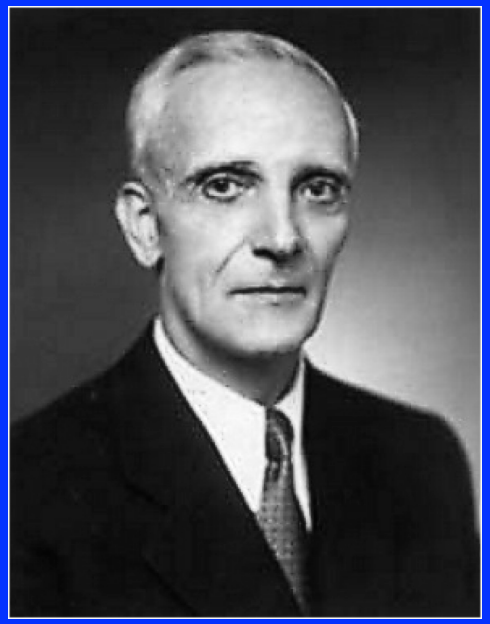


Escape of the *virtual photon* from the excited nucleus $^4He^*$

The process is following uncertainty relation $\Delta E \times \Delta t \geq \hbar$, where Δt is defined by the distance of $^4He^*$ to the nearest electron. ***According to Richard Feynman hypothesis, virtual photons can be considered to have their spin directed along the time axis*** **[14].**

After release of the energy of the system $^4He^*$ due to this mechanism by 3–4 *MeV* and approaching the levels of reaction ^3He+n and ^3H+p, the rate of these reactions decreases sharply, because ***the phase space of these processes becomes very small.***

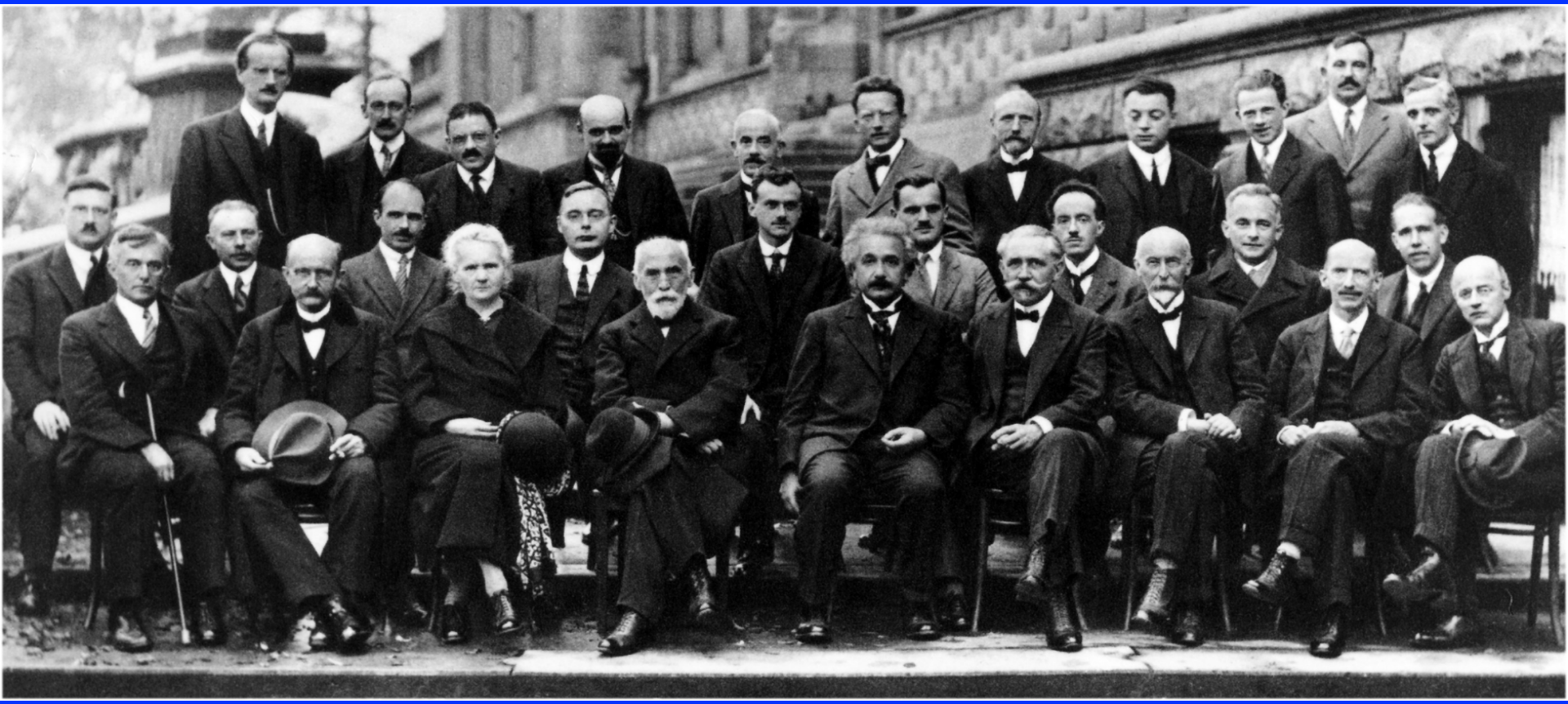
4. Brillouin Energy Corporation



Leon Brillouin
1889 – 1969

Robert Godes

Solvay Conference 1927

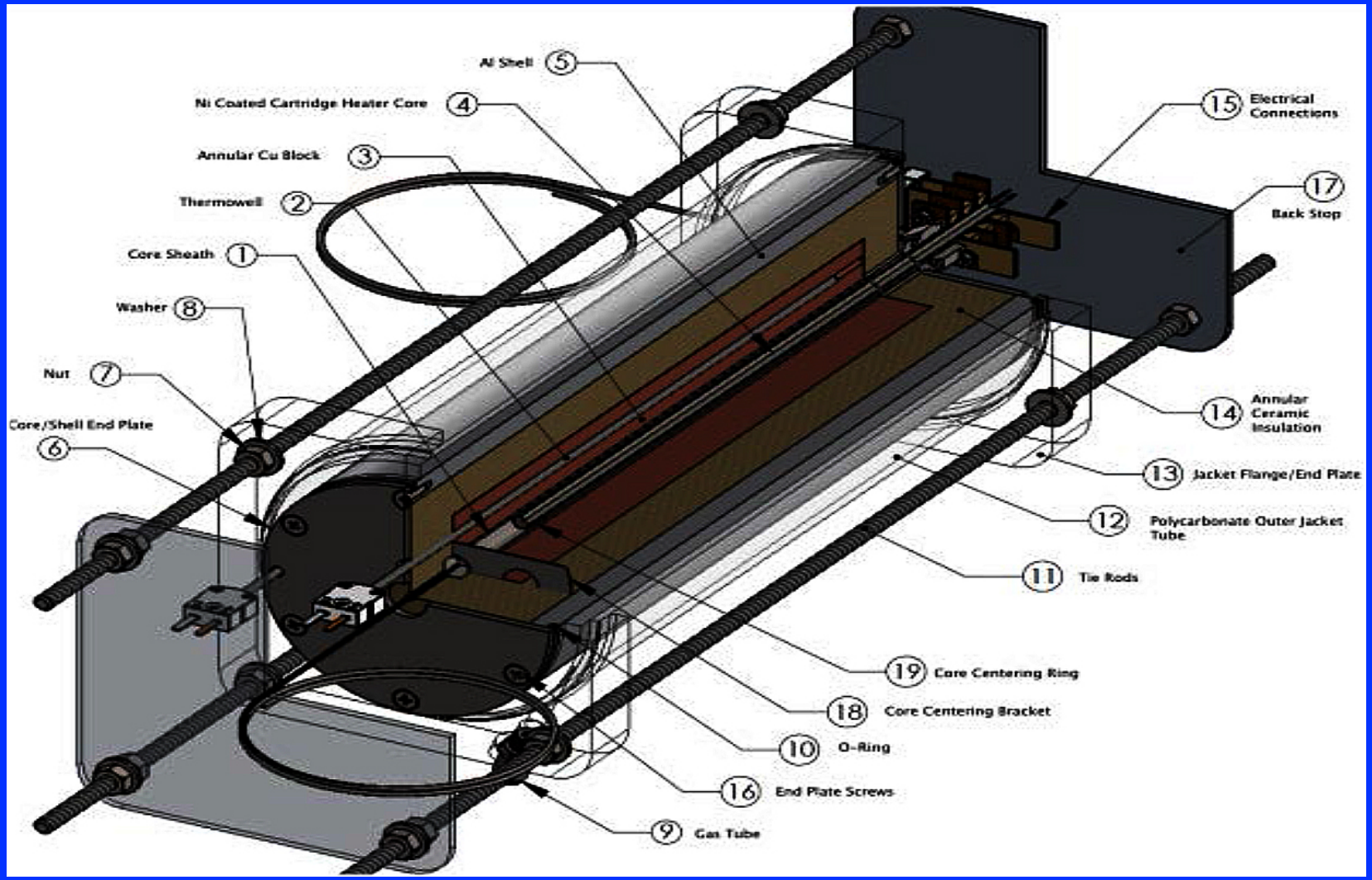


On November 18, 2015, the Brillouin Energy Corporation [15], a developer of technologies based on thermal energy of low-energy nuclear reactions (*LENR*), announced that its research has been presented to U.S. Congress. According to the key participant of this research Dr. M. McKubre, a gain in power by about factor of four was achieved at the impressive industrial operating temperature of about 640^{o} C.

"Now, as of 2014, it is referred to as Controlled Electron Capture Reaction (CECR) or just Electron Capture Reaction (ECR). Robert Godes realized that the reaction must involve electron capture as a natural energy reduction mechanism of the lattice. This endothermic reaction results in the formation of ultra-cold neutrons, probably $<10^{-12}$ eV. The low energy neutrons accumulate onto other hydrogen nuclei, leading to β^- decay".

"In the process of cold fusion, or the expected to be useful Quantum Reaction, low energy neutrons accumulate, ending in a β^- decay".

Brillouin IPB HHT reactor, Stanford Research Institute, Francis Tanzella



Results

Temperature/°C	$Q_{REACTION}$/Watts	COP
300	3.62	1.56
340	2.71	1.37
300	3.59	1.55
340	3.22	1.43
300	3.90	1.62
340	3.58	1.44
300	4.91	1.56
340	5.29	1.52
300	4.99	1.58
340	5.35	1.53
300	4.85	1.58

5. Possible interpretation of Brillouin results

In our consideration, the following mechanism may be assumed as a possible interpretation of the Brillouin group' results.

Earlier, it was observed that the electron capture *(weak interaction)* for a light element, $^{7}Be+e^{-} \longrightarrow {}^{7}Li+n_e$, runs for a lifetime of about 53 days. Experiments have shown that the electron capture rate depends on the electron proximity to the nucleus.

This reaction rate in the case when this process occurs in a metal happens to be higher than in the case when this process occurs in the insulator, see the work of B. Wang et al. [16].

It can be assumed that a similar reaction, $^{1}H + {}^{1}H \rightarrow {}^{2}He^{*} \rightarrow {}^{2}He^{*} + e^{-} \rightarrow {}^{2}H + n_e$ (*weak interaction*) in the case of hydrogen implantation in metals in a "crisscross" configuration, without any apparent energy release, presumably, can run rapidly.

The energy balance below:
Proton mass m_p = 938.272 *MeV*.
Electron mass m_e = 0.511 *MeV*.
Mass of deuteron m_D = 1875.613 *MeV*.
Mass of two protons 938.272 × 2 = 1876.514 *MeV*.
Released energy *E* = 1876.514 − 1875.613 = 0.931 *MeV*.

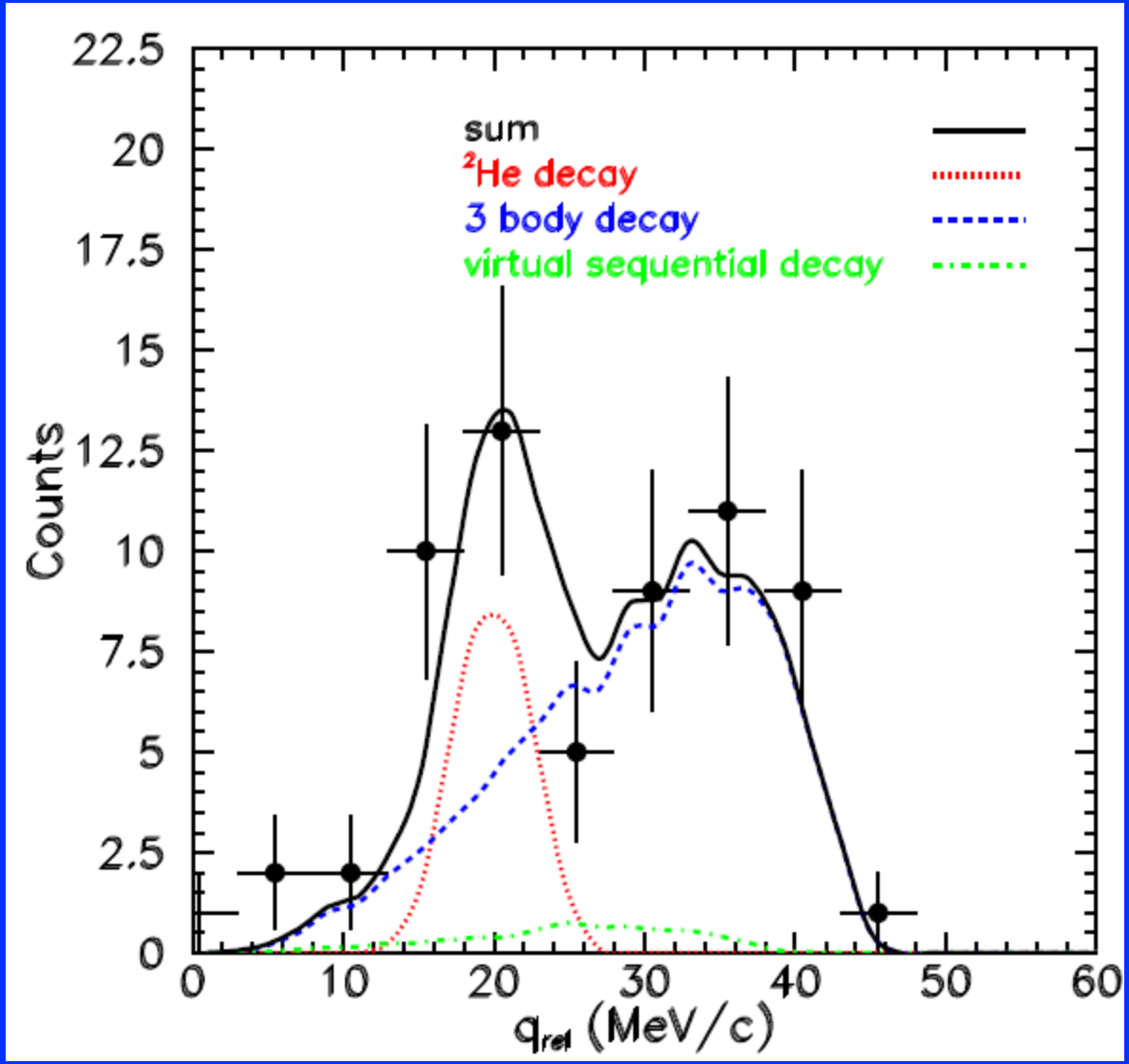
Virtually all of this energy 0.931 *MeV* (based on the law of momentum conservation) carried away by the neutrino, since the deuteron is a fairly heavy particle. Upon further saturation of this conducting crystal cell with hydrogen $^{1}H_{1}$ as a result of cold nuclear fusion $^{2}He_{3}$ is formed, then $^{2}He_{4}$, etc.

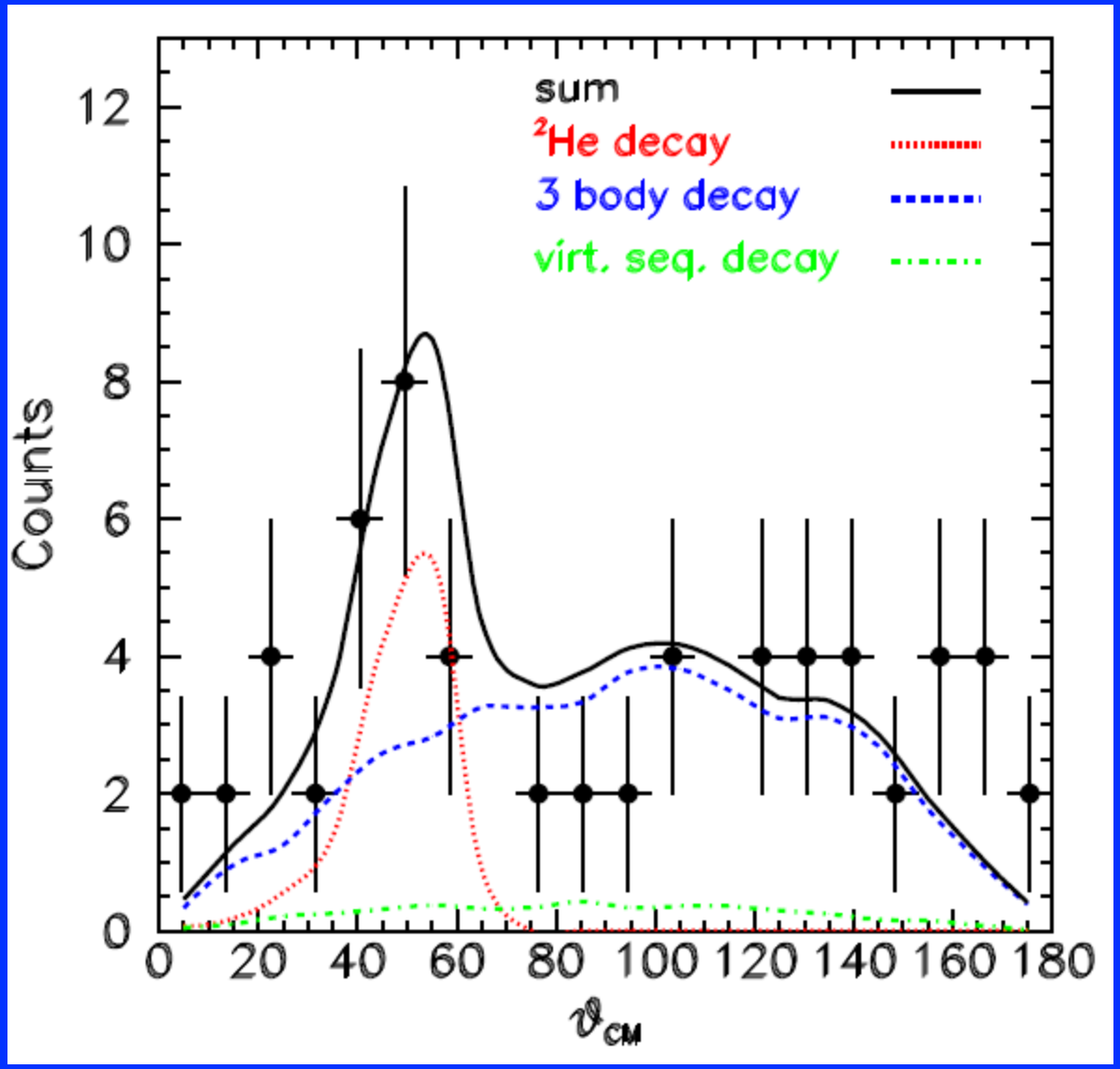
As we see, the first step in the reaction of fusion of two atoms of ordinary hydrogen $^{1}H_{1}$ in the reaction by electron capture in conducting crystals does not cause a recorded release of energy, since all this energy is carried away by the neutrino. It was this circumstance that served as a basis for the assertion of McCubre and other researchers [5] that the reaction of $^{1}H_{1} + {}^{1}H_{1}$ fusion in their experiments does not take place. Further reactions of cold fusion of *HD* and *DD* occur without emission of neutrino.

First experimental evidence of ^{2}He nuclei is presented in G. Raciti et al. [17]. The analysis of the relative momentum and angle of the two protons in excitation energy window $5.9<E^{*}<6.5$ MeV indicates the presence of 31% diproton ^{2}He.

Two-proton decay from ^{18}Ne excited states has been studied by complete kinematical detection of the decay products. The ^{18}Ne nucleus has been produced as a radioactive beam by ^{20}Ne projectile fragmentation at 45 AMeV on a ^{9}Be target.

The ^{18}Ne at 33 AMeV incident energy has been excited via Coulomb excitation on a Pb target. The correlated *2p* emission has been disentangled from the uncorrelated *2p* emission using a high granularity particle detector setup allowing the reconstruction of momentum and angle correlations of the two emitted protons. The obtained results unambiguously show that the 6.15 MeV ^{18}Ne state two-proton decay proceeds through ^{2}He emission (31%) and virtual sequential decay (69%).


sum
^{2}He decay
3 body decay
virtual sequential decay
Counts
q_{rel} (MeV/c)
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
0
10
20
30
40
50
60


sum
^{2}He decay
3 body decay
virt. seq. decay
Counts
0
2
4
6
8
10
12
0 20 40 60 80 100 120 140 160 180
ϑ_{CM}

The analysis of the relative momentum and angle of the two protons in excitation energy window $5.9 < E^* < 6.5$ *MeV* indicates the 31% presence of diproton ^2He.

6. Discussion and conclusion

The scientific community's adaptation to new knowledge was never easy. The current paradigm of physics does not support effects such as cold nuclear fusion. The situation is complicated by the fact that the ambitious and expensive attempts to find a solution to the problems of controlled thermonuclear fusion, which have lasted for more than half a century, have gone too far for a quiet termination.

The most famous attempt for thermonuclear fusion is the International Project *ITER*. Currently, the Project is huge in size and extremely expensive.

Realists have estimated that construction of the *ITER* reactor and the possibility of its launch will be completed no earlier than 35–50 years.

The *ITER* project is seen as a purely scientific investigation, and if it can work, then it would only be in a cyclic mode. After its launch, there are plans to build an even more enormous structure — an industrial tokamak *DEMO*. In this case, the huge financial and material costs will continue for another half century. Global fuel and oil and gas industries welcome this development. This situation, however, can lead to a climate change, a reduction of the population of the planet, and other painful social cataclysms.

Cold nuclear fusion is a real alternative to this tragic scenario. We are confident that the public recognition of the process of cold nuclear fusion will happen in the coming years. There is the real scientific basis for it.

Conclusion

Power plants using the principles of cold nuclear fusion potentially have quite unique advantages over the still hypothetical thermonuclear fusion. Compact cold fusion devises will be successfully used on ships, in aircrafts, and in near and outer space travels. That, in principle, is inaccessible for the giant thermonuclear installations.

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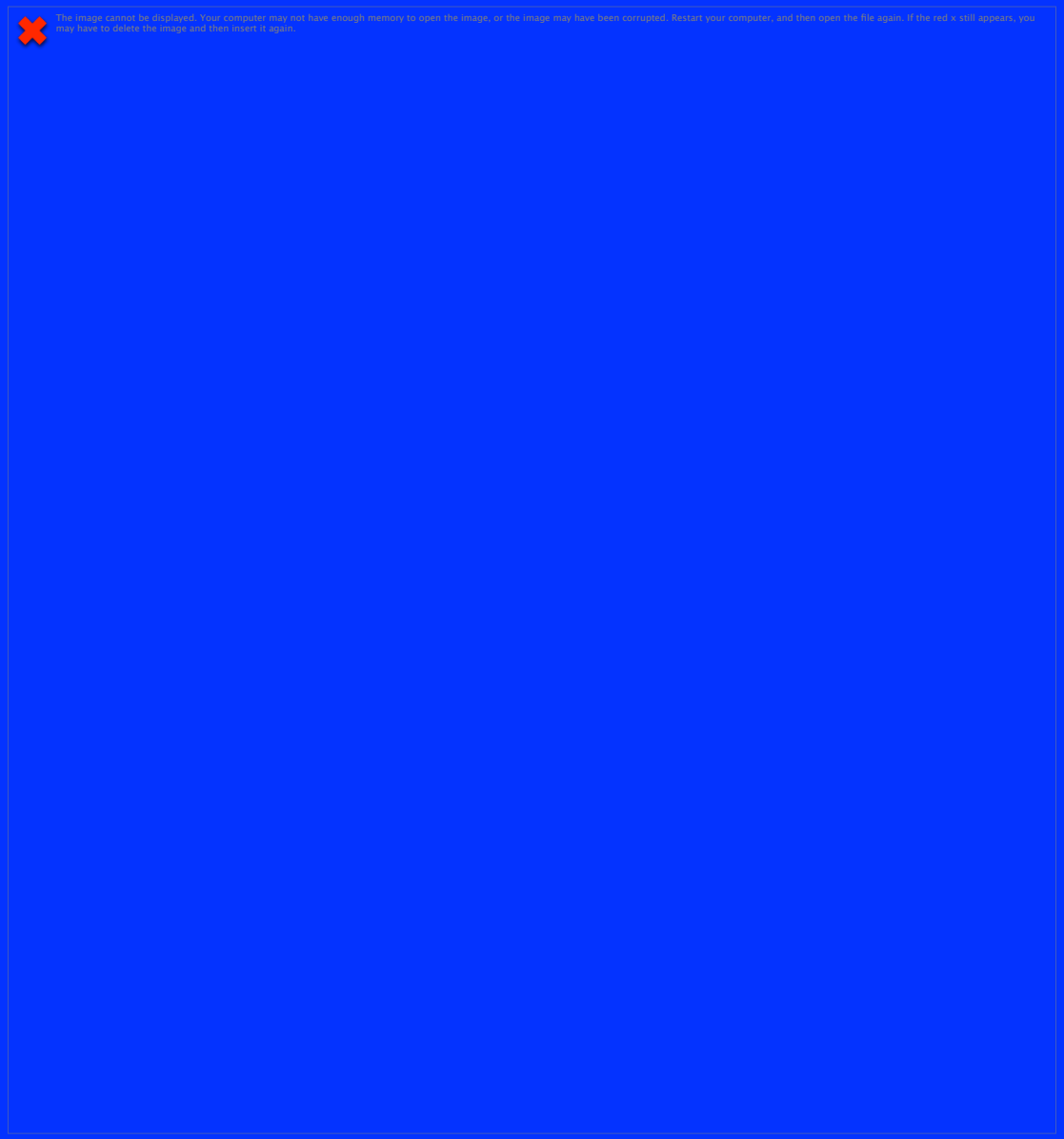
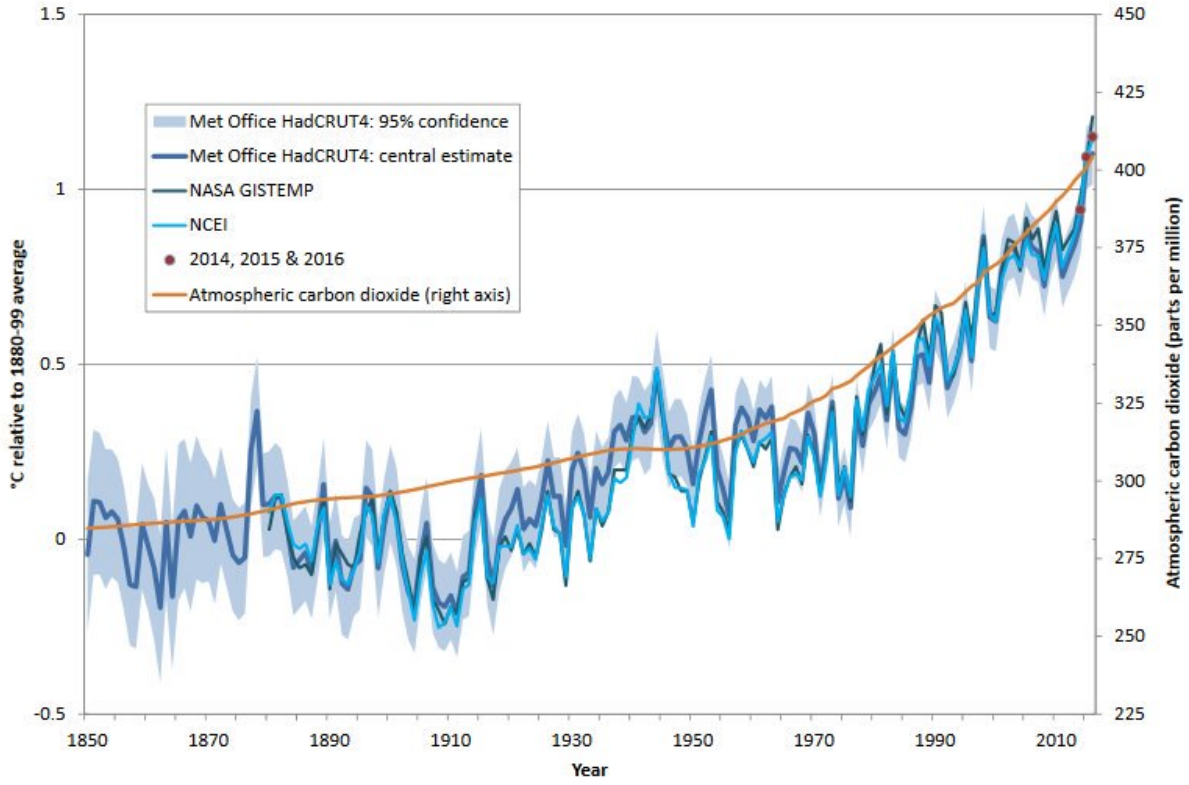


Correlation between the Earth temperature and CO_2 concentration.

Figure 1.2. Atmospheric carbon dioxide and global average surface temperature



Source: Data from Met Office, NASA and the US National Centres for Environmental Information (NCEI).
Notes: The 1880-1899 period is used as a common 'pre-industrial' baseline to allow the three datasets to be compared. Circles showing the temperatures for 2014, 2015 and 2016 are the average of the three datasets. Atmospheric carbon dioxide before 1958 is from ice core data (Law Dome, East Antarctica), and from 1959 as measured by the National Oceanic and Atmospheric Administration (NOAA) at Mauna Loa, Hawaii.

Thank you for your attention
Grazie per la vostra attenzione