Deuterons-to-^{4}He Channels

Akito Takahashi*[1]

*[1] Osaka University, Osaka, Japan;

akito@sutv.zaq.ne.jp

Presented at ICCF13, June 2007, Russia

Revised, July 2009

Major criteria of theoretically modeling the process of "radiation-less excess heat with ^4He ash" as condensed matter nuclear effects (CMNE) are:

A) How can the mutual Coulombic repulsion between deuterons be overcome, so as to reach at significant level of deuteron-related fusion rates?

B) How can ^4He generation channel be predominant?

C) How can hard radiations be suppressed?

D) What kinds of environments in/on condensed matter are incubating CMNE?

Outline

- Two-Body d + d fusion and Out-Going Channels
- Third Interaction to d + d strong force for Changing Out-Going Channels
- D-Cluster Fusion to Produce ^{4}He

Major Experiments

(green; after 2001)

1) Excess Heat with He-4

Miles, Arata, McKubre, Gozzi, Isobe, de Ninno
Celani, El Boher, and so on

2) Cold Transmutations

Iwamura, Mizuno, Miley, Ohmori, Celani, Karabut
Szpak, and so on

3) Weak Neutron Emission

Jones, Takahashi, Mizuno and so on

4) Anomalous DD Enhancement

Kitamura, Kasagi, Takahashi, Huke and so on

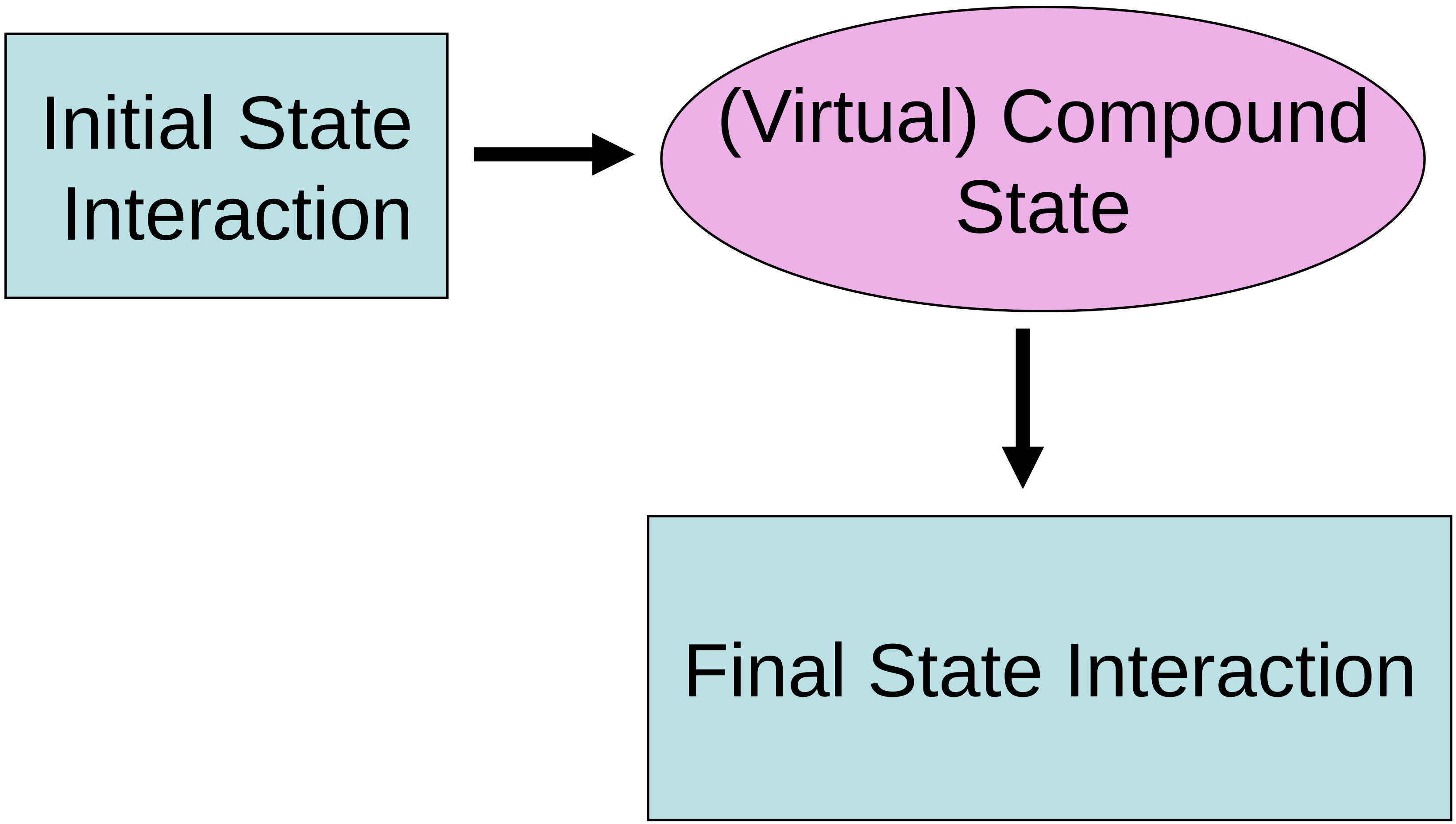
[Essential Conclusions of Recent Studies]:

① Clean Fusion Phenomena producing ^{4}He ash and energy

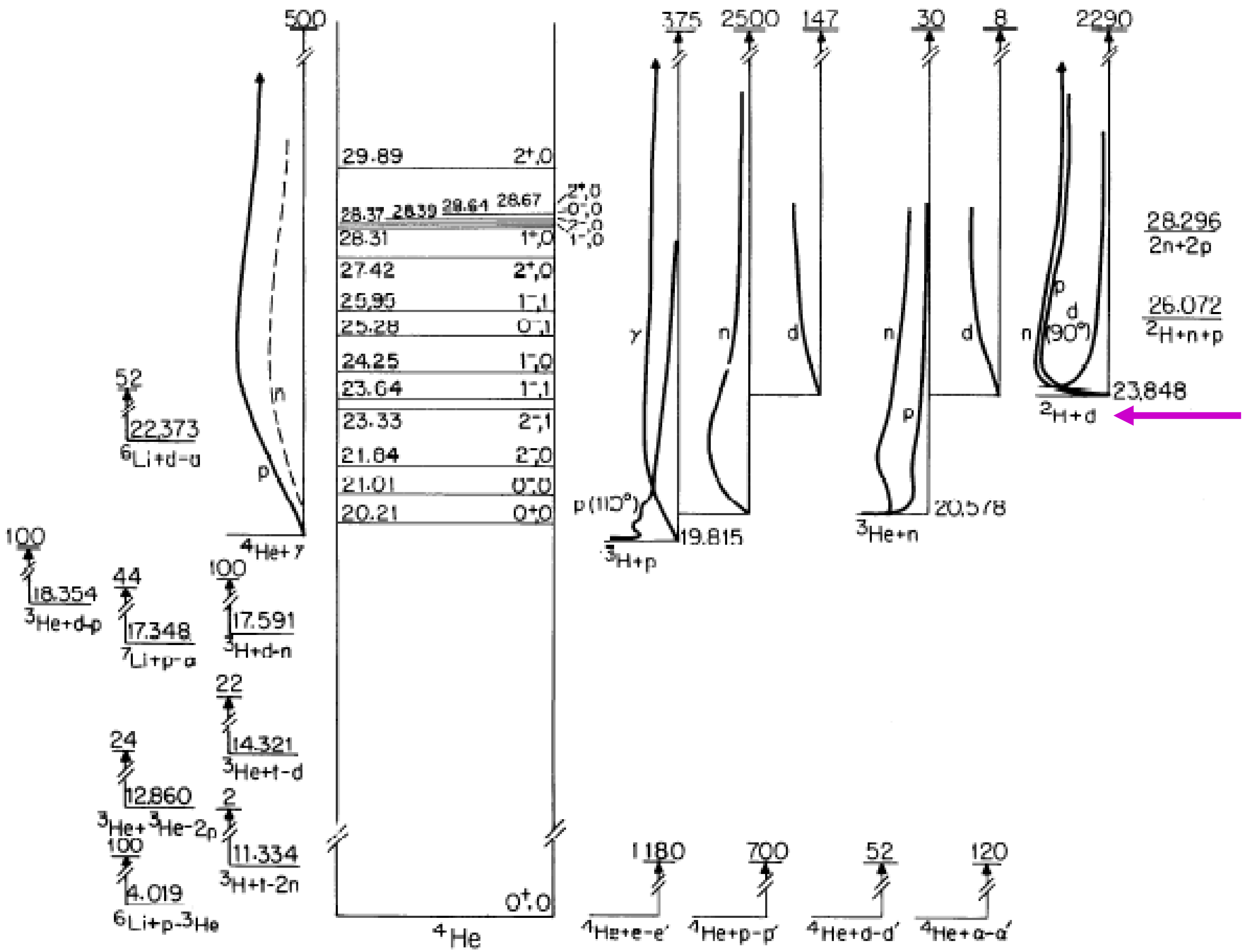
② Occurrence of Cold Transmutation and Fission

③ Consistent Theoretical Models for Condensed Matter Nuclear Effects

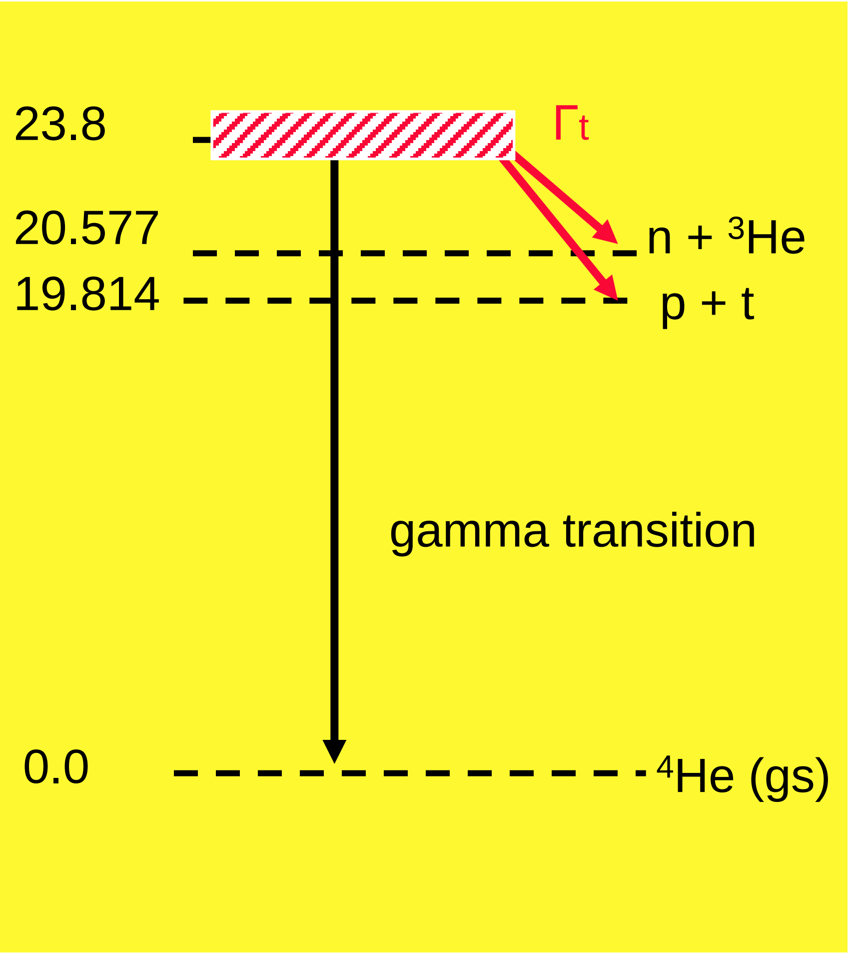
Three Steps in Nuclear Reaction



Level scheme of He-4



$d + d \rightarrow {}^4He^*(23.8MeV) \rightarrow$ Break-up



- Branching Ratio : $S_n(0)/S_p(0)/S_g(0) = \Gamma_n/\Gamma_p/\Gamma_g = 0.5/0.5/0.0000001$
- $\Gamma_n = \Gamma_p = 0.2$ MeV
- $\Gamma_g = 0.04$ eV
- $\Gamma_t = \Gamma_n + \Gamma_p + \Gamma_g$
- $\tau = h/\Gamma_t = 1E-22$ s
- No forces to change BRs have ever been proposed!

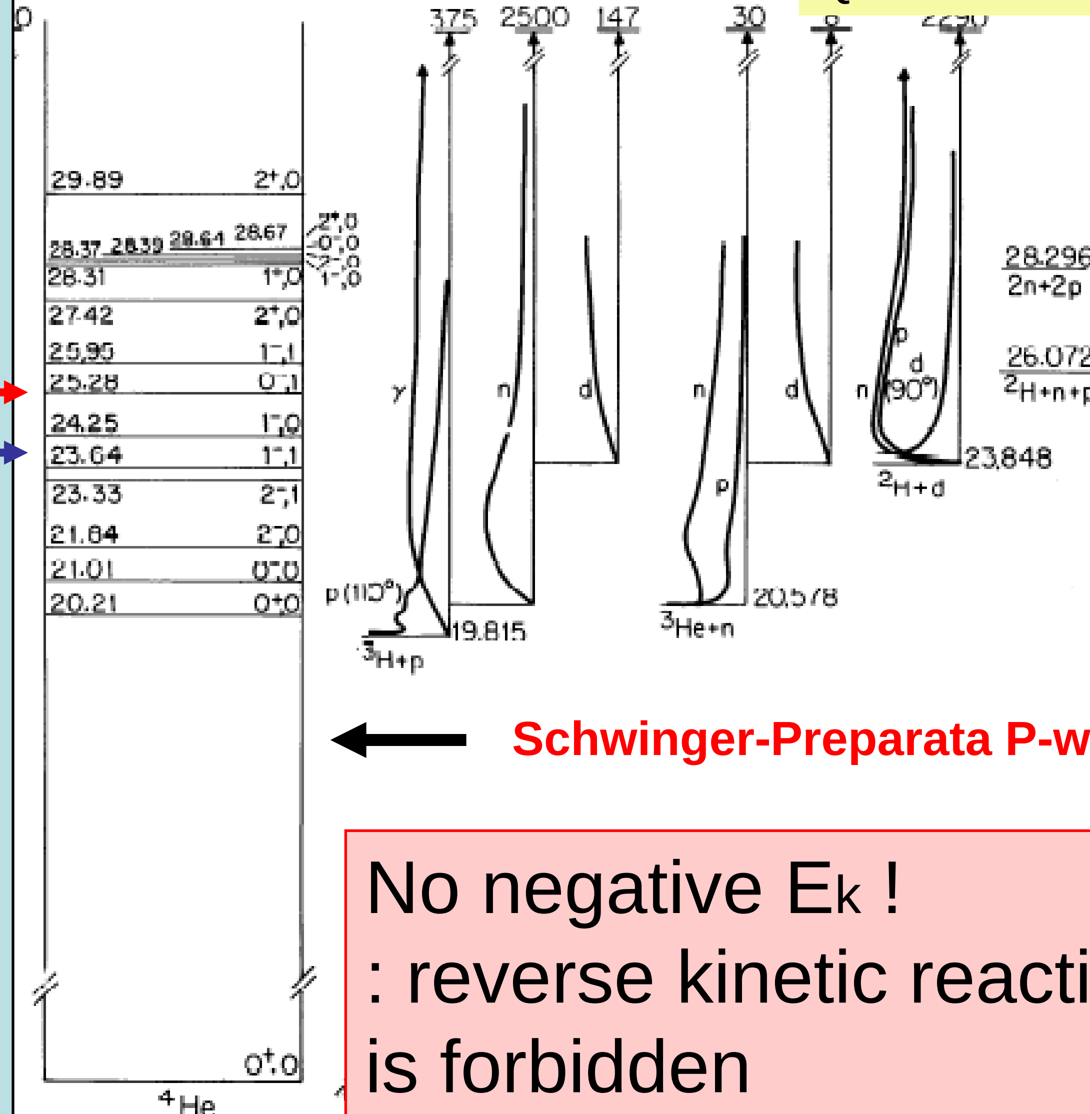
d + d + Ek = ^{4}He*(Ex) = ^{4}He*(Q + Ek)

Q = 23.8 MeV

Broad Resonance

Ex = Q + 1.5MeV

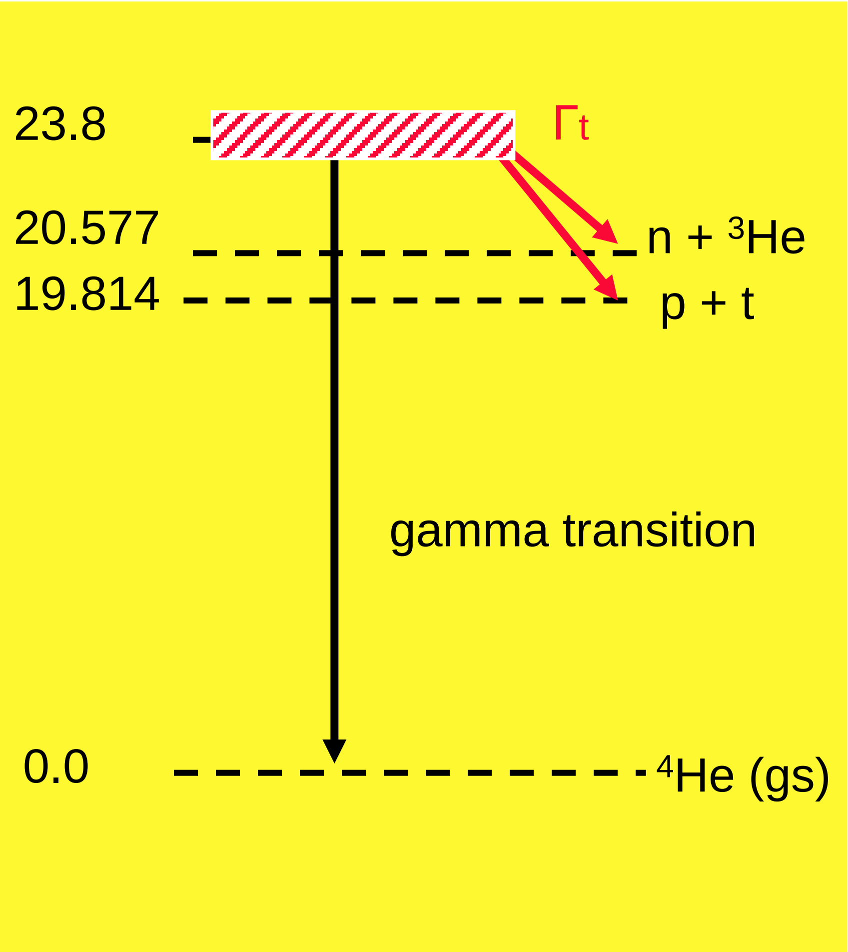
Ex = Q + 0.025eV :   CF?



Schwinger-Preparata P-wave State ?

No negative Ek !
: reverse kinetic reaction is forbidden

d + d → ^{4}He*(23.8MeV) → Break-up



- Branching Ratio : $S_n(0)/S_p(0)/S_g(0) = \Gamma_n/\Gamma_p/\Gamma_g$ = 0.5/0.5/0.0000001 for E_k = 0 to 200 keV
- $\Gamma_n = \Gamma_p$ = 0.2 MeV
- Γ_g = 0.04 eV
- $\Gamma_t = \Gamma_n + \Gamma_p + \Gamma_g$
- $\tau = h/\Gamma_t$ = 1E−22 s
- $\tau_{gamma} = h/\Gamma_g$ = 1E−15 s

Summary of d+d fusion

- Life Time of Virtual Compound State $^4He^*$ is too short, ~10^{-22} s, to change final state interaction (Branching Ratios) by External Field.
- No lower excited state than n- and p-emission channels is possible, due to non-existence of negative kinetic energy.
- [n]/[t]/[γ] = 0.5/0.5/10^{-7} for E_d = 0.025eV to 0.1 MeV; almost constant branching ratios.

Third Interaction to d+d fusion

- To change Final State Interaction of d+d process for producing ^4He, we need some **Third Interaction Field during Initial State Interaction**.
- As External Interaction Fields, we have in principle;

1) Gravity,

2) Weak Interaction,

3) Electro-Magnetic Interaction

4) Strong Interaction

Scaling of PEF (Pion Exchange Force) for Nuclear Fusion

Two Body Interaction: PEF = 1

$n + \pi^{+} \rightarrow p$

(udd) (ud*) (uud)

$p + \pi^{-} \rightarrow n$

(uud) (u*d) (udd)

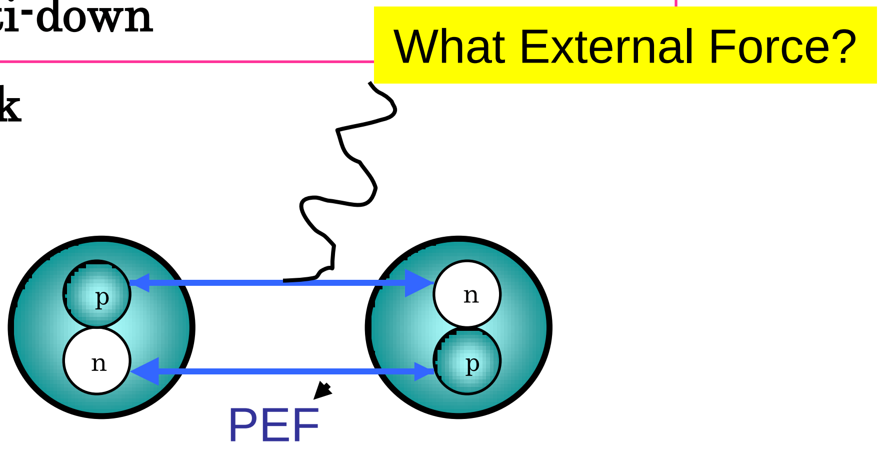
: u ; up quark

: d ; down quark

: u* ; anti-up quark

: d* ; anti-down quark

For D + D Fusion; PEF = 2



We need additional force in the initial state interaction, to change final state Branching Ratio and Products.

Comment by A.T.

Fusion Rate for Collision Process - dynamic or transient process -

- **$T = <\Psi_f | H_{int} | \Psi_i>$**

  = <Initial State Interaction>

  x<Intermediate Compound State>

  x<Final State Interaction>
- **Cross Section ~ T^2** $\rho(E')$
- $\rho(E')$: final state density
- **Reaction-Rate(σv): $(4\pi^2/h)vT^2\ \rho(E')$**
- <Initial> = <El. EM Int><Strong Int>
- <Final>=BRs to Irreversible Decays

Relative Strength of Interactions

Comment by A.T.

- Nuclear Strong Interaction: f^2/hc = **1**
- Electro-magnetic Interact.: e^2/hc =**7.3E-3**
- Weak Nuclear Interaction: $(ghc)^2(mc/h)^4$=

  5E-14
- Gravity : GM^2/hc = **2E-39**

- S_{dd} = 1.1E2 keVb vs. S_{pp} = 1E-22 keVb

  (Strong Interaction) (Weak Interaction)

$\sigma \sim (\text{T-matrix})^2$

Third Interaction by Photon/Phonon

- About 4 MeV from close <d-d> pair should be removed by multiple <d-d>/P/P coupled channels. <d-d>: out of strong force range!
- Photon energy quantum should be less than D displacement energy in lattice (about 40 eV): we need more than 10^5 photon-coupled channels.
- <d-d> Life Time should be greater than 3(nm)x(3x10^{-18} s)x10^5 =9X10^{-13} s ~ 1 ps

Third Interaction by Photon/Phonon

- The many-body interaction process between the d+d pairing and the third field of photon-phonon coupling (more than 10^5 channels) in the lattice of condensed matter may be considered.
- Due to the very short range force of d+d strong interaction and its very short life time of virtual intermediate compound state, no processes have ever been proved to remove the 4 MeV gap energy. (Avoid single photon transition from $^4He^*$ -P-wave!)
- Moreover, the field coupling constant of electro-magnetic interaction looks too weak, on the order of 10^{-2} of that for the strong interaction, to drastically change the state of d+d strong interaction for fusion. Quantitative studies on transition probabilities will be needed.

Deuteron-Cluster Fusion

- Third (plus 4th) Field by Strong Interaction requires D-Cluster Fusion under Ordering Process.

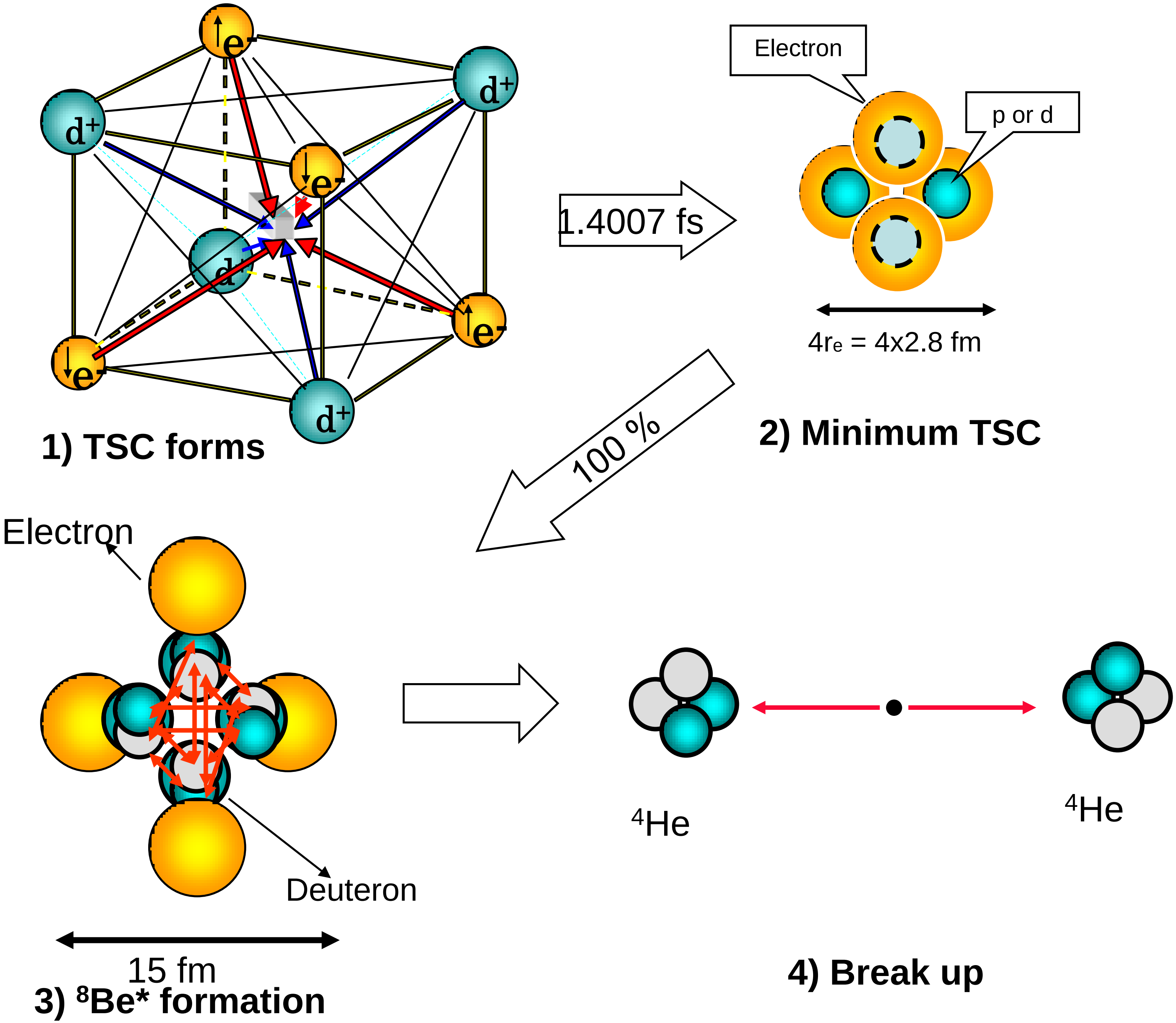
- **4D Fusion by TSC** (Tetrahedral Symmetric Condensate) is proposed by Takahashi.

Basic Mechanism (Takahashi Model)

- **Tetrahedral Symmetric Condensate (TSC)**:

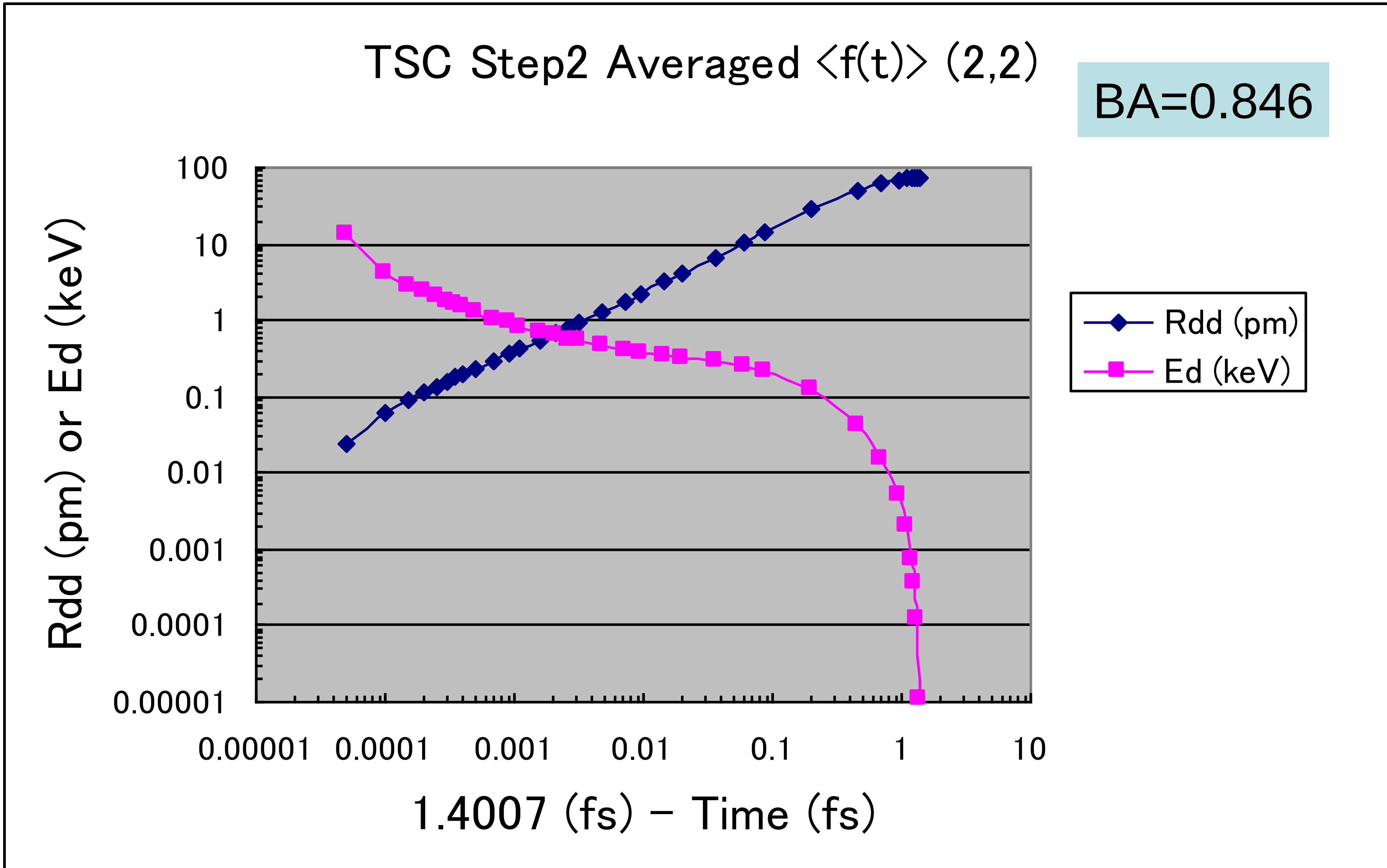
  4d+4e can squeeze to Transient Bose Condensation (TBC),

  under 3-Demensional Symmetric Constraint at some site in CM, to form a very small Charge-Neutral Pseudo-Particle



e^-
d^+
1) TSC forms
1.4007 fs
Electron
p or d
$4r_e$ = 4x2.8 fm
2) Minimum TSC
100 %
Electron
Deuteron
15 fm
3) ^{8}Be* formation
^{4}He
^{4}He
4) Break up

TSC Condensation Motion calculated by TSC-Langevin Code



E_d = 13.68 keV at R_{dd} = 24.97 fm, with Vtrap = -130.4 keV

Fusion Rates of Steady State dde* Molecules:

$$\lambda_{nd} = \frac{2}{\hbar}\langle W \rangle P_{nd}(r_0) = 3.04 \times 10^{21} P_{nd}(r_0)\langle W \rangle$$

Regarding b_0 as R_{gs}, we get $P_{nd}(r_0)$ values.

Molecule	$R_{dd}=R_{gs}$ (pm)	$P_{nd}(r_0)$; Barrier-Factor	<W> (MeV)	λ_{2d} (f/s)	λ_{4d} (f/s)
D_2	74.1	1.0E-85	0.008	2.4E-66	
dde*(2,2)	21.8	1.3E-46	0.008	3.2E-27	
μdd	0.805	1.0E-9	0.008	2.4E+10	
4D/TSC-min	0.021	1.9E-3	62		3.7E+20

4D/TSC-min exists within $\Delta t=2\times10^{-20}$ s at final stage of condensation:
Decay of TSC: $\exp(-\lambda_{4d}\Delta t)=\exp(-7.6)=0.0006\rightarrow$ **4D fusion by 100% per TSC Gen.**

4D Fusion and ^{4}He Production Rate by TSC

- t_c : Condensation Time of TSC (1.4007 fs)
- **η_{4d}**: 4D Fusion Yield per TSC

$$\eta_{4d} = 1 - \exp\left(-\int_0^{t_c} \lambda_{4d}(t)dt\right)$$

$$\lambda_{4d}(t) = 3.04 \times 10^{21} \langle W \rangle P_{4d}(r_0; R_{dd}(t)) = 1.88 \times 10^{23} P_{4d}(r_0; R_{dd}(t))$$

$$\int_0^{t_c} \lambda_{4d}(t)dt = 1.88 \times 10^{23} \int_0^{t_c} P_{4d}(r_0; R_{dd}(t))dt$$

$$\int_0^{t_c} P_{4d}(r_0 : R_{dd}(t)dt = 2.31 \times 10^{-22}$$

$$Y_{4d} = Q_{tsc}\eta_{4d}$$

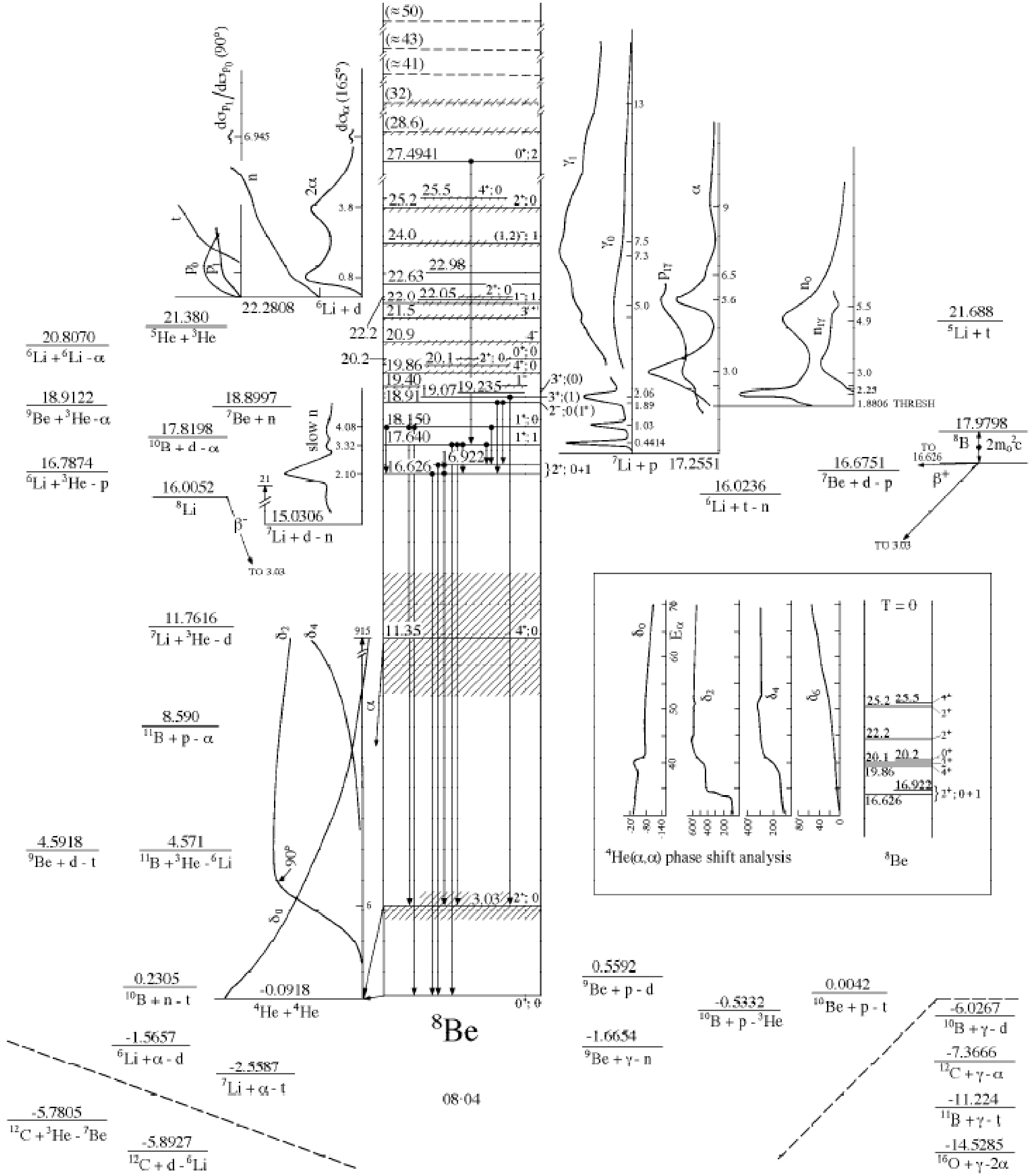
Macroscopic 4D Fusion Production Rate

$$\eta_{4d} \cong 1.0$$

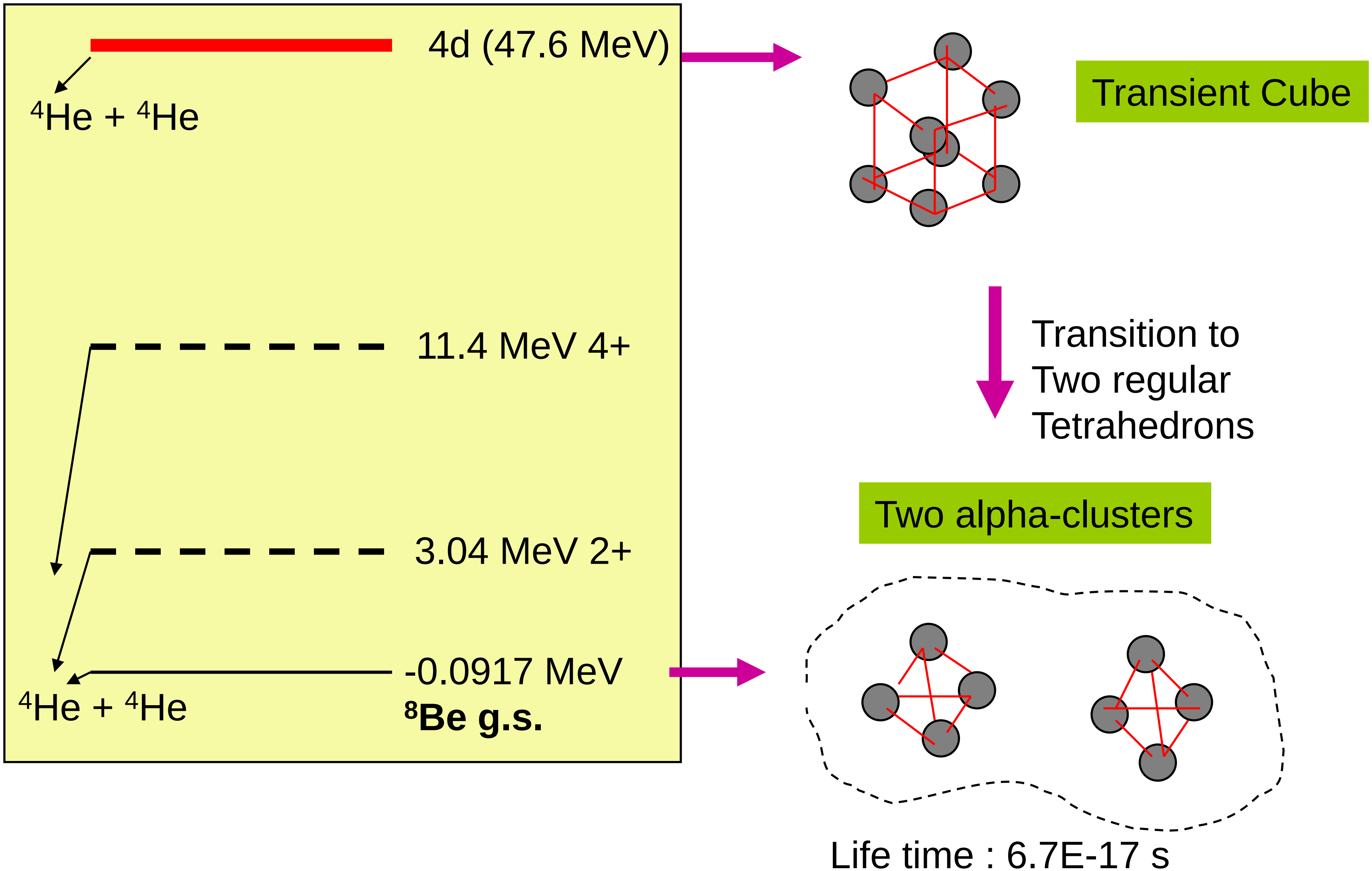
$$Y_{4d} \approx Q_{tsc}$$

Q_{tsc} : TSC Generation Rate

Energy Level Scheme of Be-8



4D → ^4He + ^4He + 47.6MeV (Final State Interaction)



Decay-Channel of ^{8}Be

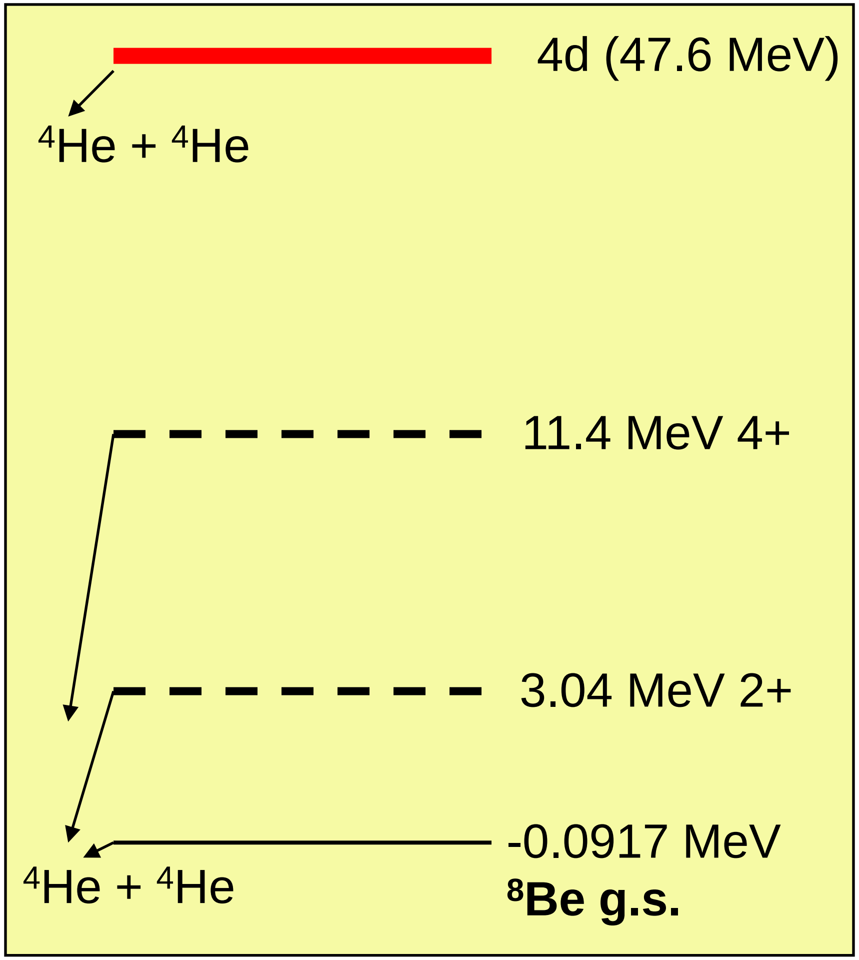
$4D \longrightarrow {}^{8}Be + 47.6$ MeV :

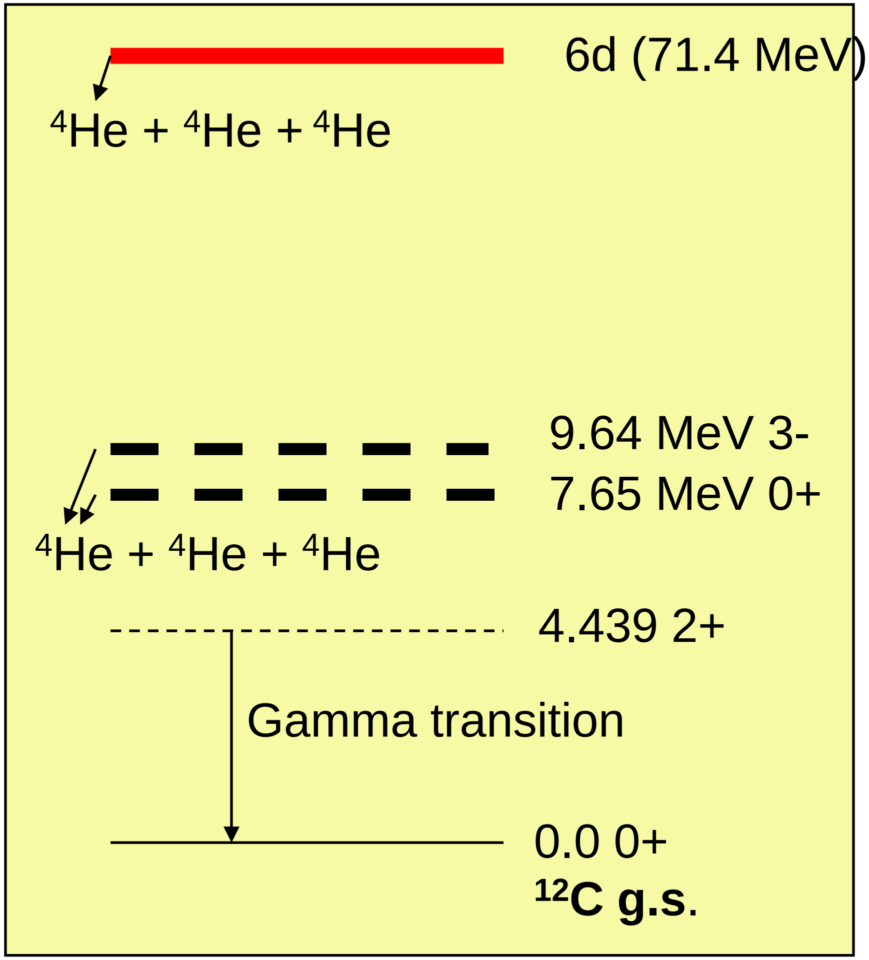
$^{8}Be \longrightarrow {}^{4}He + {}^{4}He + 91.86$ keV: Major Ch.

- $\longrightarrow {}^{3}He + {}^{5}He(n+{}^{4}He)$ – 11.13 MeV
- $\longrightarrow t + {}^{5}Li(p+{}^{4}He)$ - 21.68MeV
- $\longrightarrow d + {}^{6}Li$ - 22.28 MeV
- $\longrightarrow p + {}^{7}Li$ - 17.26 MeV
- $\longrightarrow n + {}^{7}Be$ – 18.90 MeV

^{8}Be Excited State may open to threshold reactions

Branching Ratio
(Final State Interaction)





Channels for CP Generation by 4D

I. Symmetric Fragmentation

1) 4D → $^8Be^*(47.6MeV;0^+,0)$ →
$^4He^*(Ex)$ + $^4He^*(Ex)$ + 47.6MeV-2Ex

- 1-1) Ex=0;

  $^4He^*(gs;0^+,0)$: 4D→α+α+47.6MeV; **Eα=23.8MeV**

- 1-2) Ex=20.21MeV (1st excited state of ^4He);

  $^4He^*(20.21MeV;0^+,0)$→p(0.6-2.2MeV)+**t(1.8-3.4MeV)**

  \+ (Ex-19.815=0.4MeV) + (3.6MeV; moving $^4He^*$)

  ; this **triton** makes secondary d+t reaction to **emit 10-17MeV neutrons**

1) 4D → $^{8}Be^{*}(47.6MeV; 0^{+}, 0)$ → $^{4}He^{*}(Ex)$ + $^{4}He^{*}(Ex)$ + 47.6MeV-2Ex
- continued -

- Ex=21.01MeV(0^{-},0), 21.84MeV(2^{-},0), 22.33MeV(2^{-},1), 23.04MeV(1^{-},1) **are forbidden by odd parity**

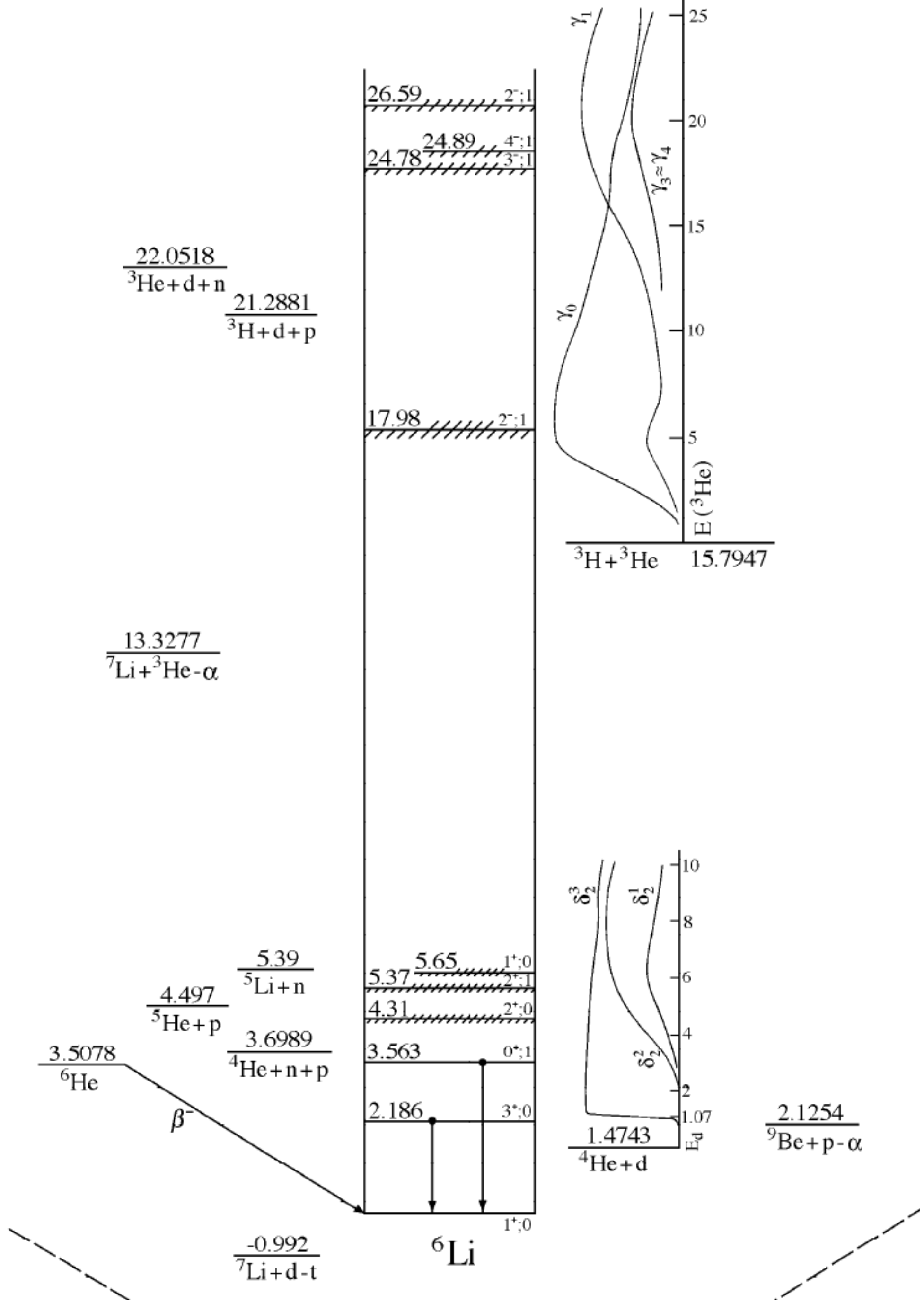
Therefore, no neutron emission channels are allowed!

II. Asymmetric Fragmentation 1-3)

- $4D \rightarrow {}^{4}He^{*}(20.21MeV;0+,0) + {}^{4}He(g.s.;0+,0)$
  $+ 27.39MeV$ **(E_{α}=13.69MeV)**

- ${}^{4}He^{*}$(20.21MeV):KE=13.69MeV:
  → **t(10.2-10.6MeV) + p(3.5-3.9MeV)**

This channel would be the second source of tritium generation.



26.59 2⁻;1
24.89 4⁻;1
24.78 3⁻;1
17.98 2⁻;1
5.65 1⁺;0
5.37 2⁺;1
4.31 2⁺;0
3.563 0⁺;1
2.186 3⁺;0
1⁺;0
6Li
22.0518
3He+d+n
21.2881
3H+d+p
13.3277
7Li+3He-α
5.39
5Li+n
4.497
5He+p
3.6989
4He+n+p
3.5078
6He
β⁻
-0.992
7Li+d-t
γ1
γ3≈γ4
γ0
E(3He)
3H+3He
15.7947
25
20
15
10
5
δ23
δ21
δ22
10
8
6
4
2
1.07
Ed
1.4743
4He+d
2.1254
9Be+p-α

2) 4D $\rightarrow {}^{8}Be^{*} \rightarrow {}^{6}Li(E_x)$+d+(25.3MeV-$E_x$)

- Even parity states: Ex= 2.186MeV(3+,0), 3.563MeV(0+,1), 4.31MeV(2+,0), 5.31MeV(2+,1), 5.65MeV(1+,0), 15.8MeV(3+,0)

- 2-1) 4D$\rightarrow {}^{6}Li$(2.186)+d+23.11MeV

KE=5.77 KE=17.3

${}^{6}Li$(2.186MeV):KE=5.77MeV:

$\rightarrow {}^{4}He$(3.6-4.1MeV) + d(1.6-2.4MeV)

2-1) to 2-6)

E_x (MeV)	K.E. of ^4He (MeV)	K.E. of d (MeV)
2.186	3.6-4.1	1.6-2.4
3.563	2.9-4.3	0.2-2.6
4.31	2.6-4.5	1.9-3.6
5.31	2.1-4.6	0.9-4.2
5.65	1.9-4.7	1.1-4.4
15.8	4.0-5.6	8.0-11.1

2) 4D → $^{8}Be^{*}$(47.6MeV;0+,0) → $^{6}Li^{*}$(Ex)+d+(25.3MeV-Ex)

- 2-7) $^{6}Li^{*}$(25.3MeV)→**α(7.9MeV)**+d(15.9MeV)

- 2-8) $^{6}Li^{*}$(25.3MeV)→$^{4}He^{*}$(20.21MeV;0^{+},0)+d +3.6MeV; this may be path to Ex=20.21MeV

  $^{4}He^{*}$(20.21MeV;0^{+},0) → p+t+0.4MeV

Triton from moving $^{4}He^{*}$ makes secondary d+t reaction to **emit 10-17MeV neutrons**

3) 4D→^{8}Be*(47.6MeV;0+,0) →^{4}He*(Ex) + (d+d) +(23.8MeV-Ex)

- 3-1) Ex=0;

  E_α=11.9MeV, E_d=5.95MeV

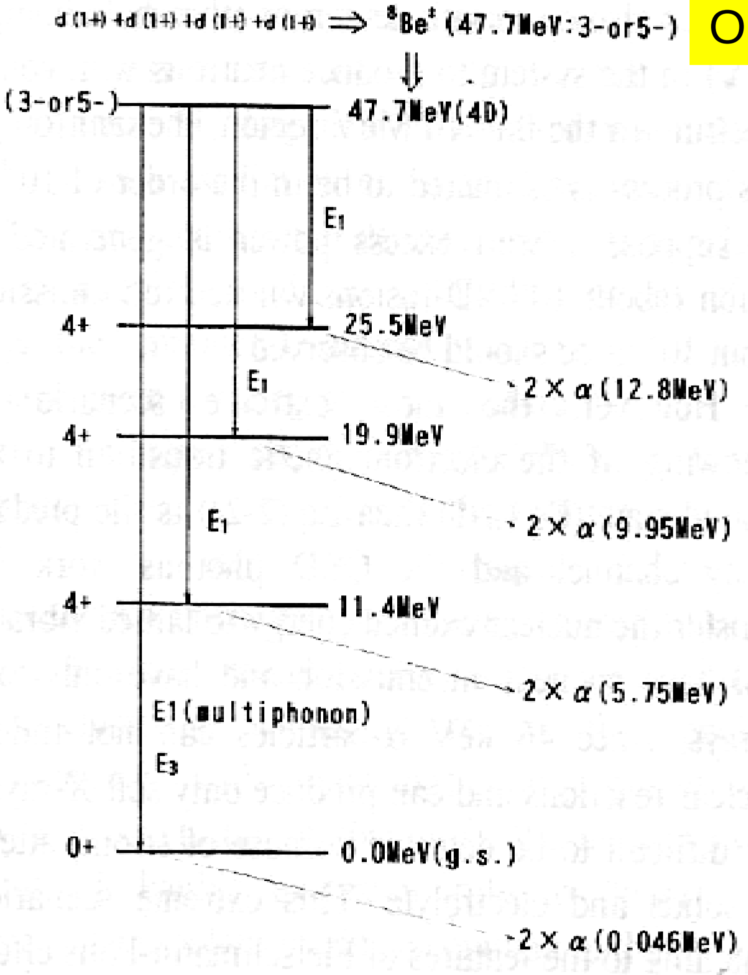
- 3-2) Ex=20.21MeV(0^+,0);

  ^{4}He*(20.21MeV;0+,0): moving with 1.8MeV:→t(1.2MeV)+p(0.7MeV)

  E_d=0.9MeV

After A. Takahashi, Trans. Fusion Technology 1994

Odd Spin-Parity



.1: Typical decay channels of 4D fusion; E_1 transition may be induced with electromagnetic energy transfer via QED photons to lattice plasma oscillation. Major nuclear products are ^{4}He with specified kinetic energies.

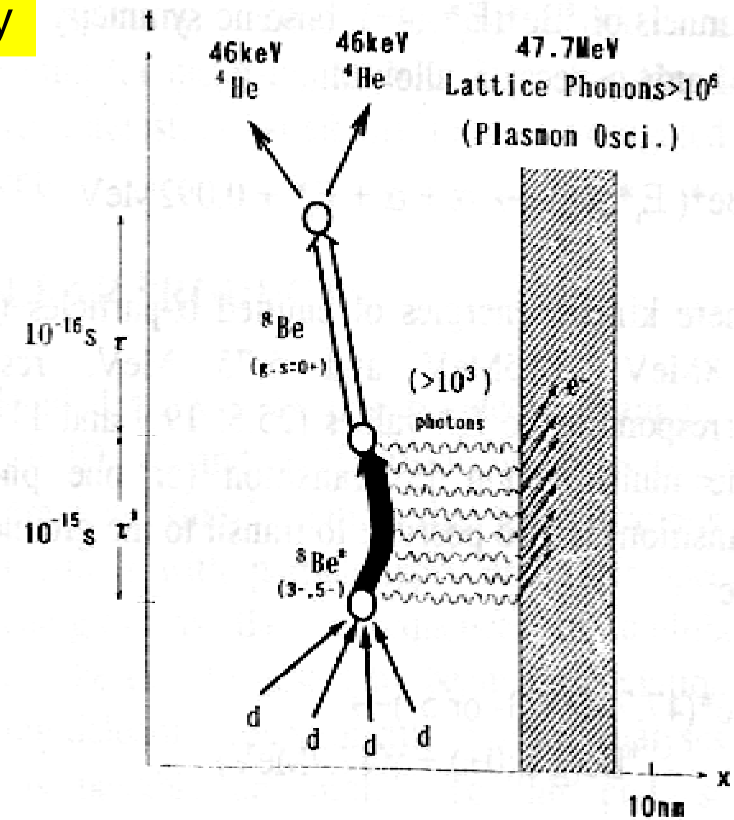


Fig.2: Illustration of extreme scenario of decay channel for 4D fusion; final nuclear products are 46 keV α-particles and most energy (47.7MeV) is transferred to lattice vibration via QED photons.

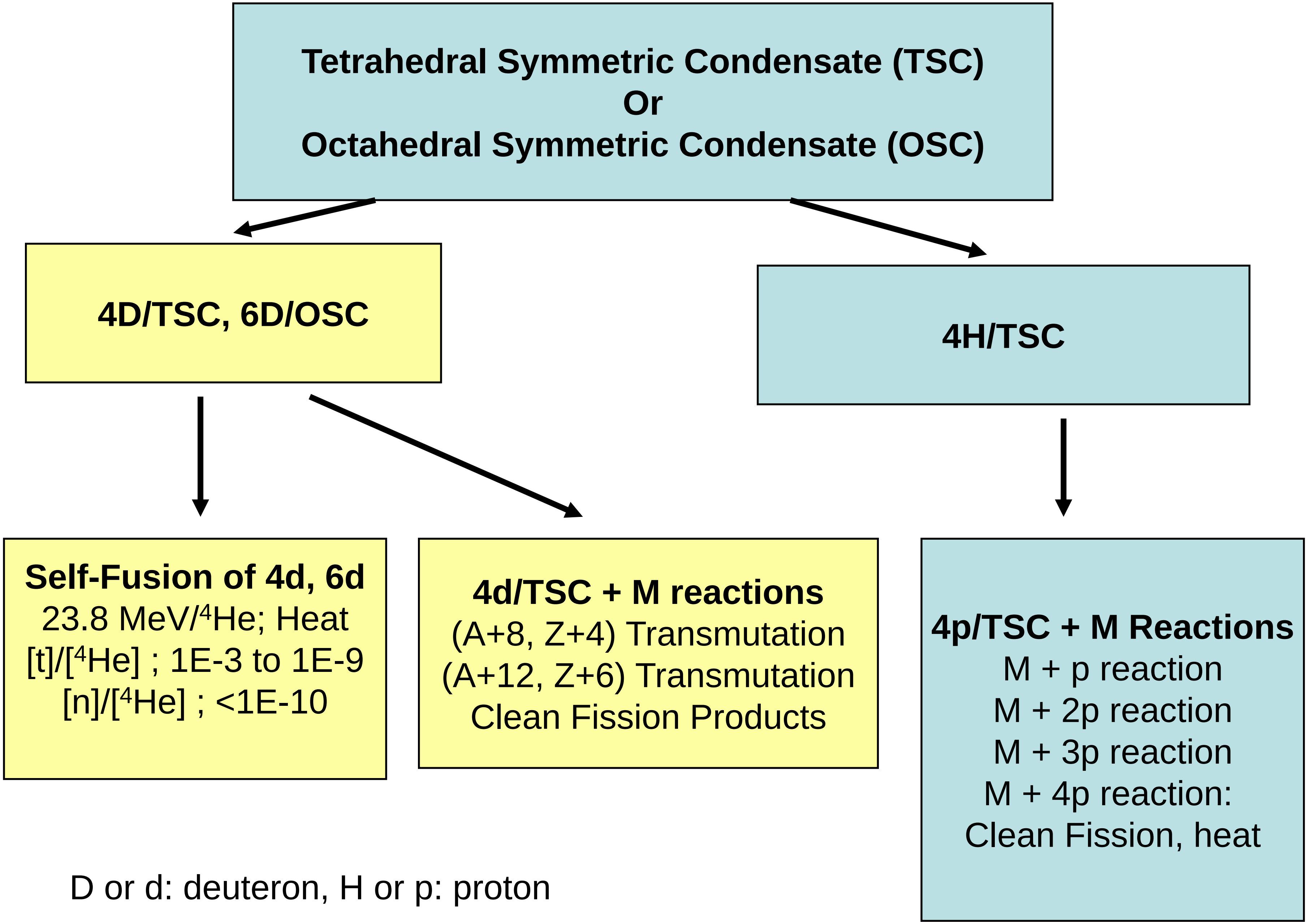
CP Spectra by 4D/TSC; Predicted

- ^{4}**He**: **0.046**, 1.52, **3.6-4.1, 2.9-4.3, 2.6-4.5, 2.1-4.6, 1.9-4.7, 4.0-5.6**, 5.75, **7.9**, 9.95, **11.9**, 12.8, **13.69, 23.8** (MeV)
- **Triton**: **1.8-3.4, 10.2-10.6** (MeV)
- **Deuteron**: **0.9, 1.6-2.4, 0.2-2.6, 1.9-3.6, 0.9-4.2, 1.1-4.4, 5.95, 8.0-11.1,15.9** (MeV)
- **Proton**: **0.6-2.2, 3.5-3.9** (MeV)

Purple values are by odd spin-parity of

^{8}Be*(Ex=47.6MeV)

Others are S-wave Transitions



D or d: deuteron, H or p: proton

Conclusion-1

- The lowest excited energy of $^4He^*$, intermediate compound nucleus, by two-body d+d fusion reaction is 23.8 MeV. Lower excited energy than 23.8 MeV is forbidden by kinematics. As a result, [n]/[t]/[^{4}He] branching ratio becomes almost constant values as 0.5/0.5/10^{-7} for E_k = 0eV to 100keV (relative kinetic energy of reaction)

Conclusion-2

- If there happens the $^{4}He^{*}$ (Ex) state with Ex < 19.8 MeV, the final product becomes ^{4}He with ground state, after electromagnetic transition. To realize this process by d+d reaction, there should exist the third coupling field which must take more than the 4 MeV difference energy (23.8 – 19.8) of the d-d system in the initial state interaction.

Conclusion-3

- The many-body interaction process between the d+d pairing and the third field of photon-phonon coupling in the lattice of condensed matter may be considered. Due to the very short range force of d+d strong interaction and its very short life time of virtual intermediate compound state, no processes have ever been proved to remove the 4 MeV gap energy. Moreover, the field coupling constant of electro-magnetic interaction looks too weak, on the order of 10^{-2} of that for the strong interaction, to drastically change the state of d+d strong interaction for fusion. Quantitative studies on transition probabilities will be needed.

Conclusion-4

- Deuteron-cluster fusion, i.e. 4D fusion, may produce ^{4}He final product as major ash of reaction, and triton, p, d as minor products. To realize the conditions of 4D fusion, the microscopic ordering/constraint process for the dynamic Platonic symmetry should be satisfied. The EQPET/TSC model is one of theoretical models, although we need further investigations to establish.