THE CMAF WINDOW

Possible sizeable energy production
from 500/1000 eV deuterons

Main topics covered

- I The physics and maths used in alpha disintegration constants and d/d fusion reaction rates. The Yukawa potential.
- II Determination of the coupling constant of the Yukawa potential (alpha disintegration)
- III Determination of d/d reaction rates
- IV Comparison with experimental data (Huke and SPAWAR).
- V The coupling resonnance and the CMAF window.

I - Physics and Maths The Gamow penetration factor γ

Plays a major role

- In alpha disintegration constants
- In d/d fusion reactions rates

$$\gamma = \frac{2\sqrt{2m}}{\hbar}\int_{R_1}^{R_2}\sqrt{\left(B\left(r\right)-E\right)}dr \quad \left(m = reduced\ \ mass\right)$$

I - Physics and Maths Expression of the barrier

- The barrier equation is:

$$B(r) = +ke^2\left(\frac{1}{r}\right) + \frac{l\left(l+1\right)\hbar^2}{r^2} - k'Cg^2\,\frac{e^{-r/\rho}}{r}$$

Coulomb Centrifugal Yukawa

- With

$$k = 1 \; and \; k' = 4 \; in \; the \; d/d \; case$$
$$k = 2Z' \; and \; k' = 4A' \; in \; the \; \alpha \; case$$

. Calculation of the tunnelling probability P(Ed) using a spreadsheet

I - Physics and Maths Expression of the barrier

- The boson carrying the Yukawa interaction might be a neutral and virtual electron/ positron pair, with mass $2m_e$ (electron mass)

  $2m_e$

  (A. Meulenburg suggestion August 2008)

- Its range would be:

$$\rho = \bar{\lambda} = \frac{\hbar}{2m_e c} = 193\ fm$$

- The coupling constant C can be calculated from known experimental values of the alpha disintegration constants.

II - Alpha disintegration case

- Following relations allow the determination of C (Yukawa coupling constant) by fitting calculated alpha disintegration constants λ with measured ones:

$$\lambda = \nu P$$

$$\nu = \frac{1}{2R_1}\sqrt{\frac{E_\alpha}{2m_\alpha}}$$

$$P = e^{-\gamma}$$

$$C = 3.79*10^{-6} g^2 = 7.53*10^{-3} e^2$$

III - d/d reaction rates case

- $r(cm^{-3}s^{-1}) = \sigma(cm^{2})\varphi(cm^{-2}s^{-1})N_{0}(cm^{-3})$

σ *cross section* $\sigma = \sigma_{geom.} P\left(E_d\right)$ *probability of tunnelling*

N_0 *deuteron concentration in palladium*

φ *incident deuteron flux* $(cm^{-2}s^{-1})$

- The energy produced is:

$$W = r\left(1+3+0.83+2.44\right)1.6*10^{-13} \ \left(W \ cm^{-3}\right)$$

III - d/d reaction rates case

- The d/d reaction rates were calculated (with $P(E_d)$ given by the model) for an incident deuteron flux corresponding to 1 W with energy E_d (varying from 2 to 100,000 eV) on a 1 cm2 target, containing 1 mmole of d (d/Pd = 0.7)

- Calculations were run in 2 cases : no screening and screening + action of the Yukawa potential (with strength C from the alpha case).
- The influence of the Yukawa was found negligible at a few eV (huge impact of the screening) and of the same order of magnitude as the electron screening at a few keV.

III - d/d reaction rates case

- With these hypothesis, the number of incident deuterons is:

$$n = \frac{1}{100E_d}\sqrt{\frac{\mathrm{m_d}}{2\mathrm{E_d}}}\ (\mathrm{cm}^{-3})\ \ \left(E_d\ in\ eV\right)$$

and their flux:

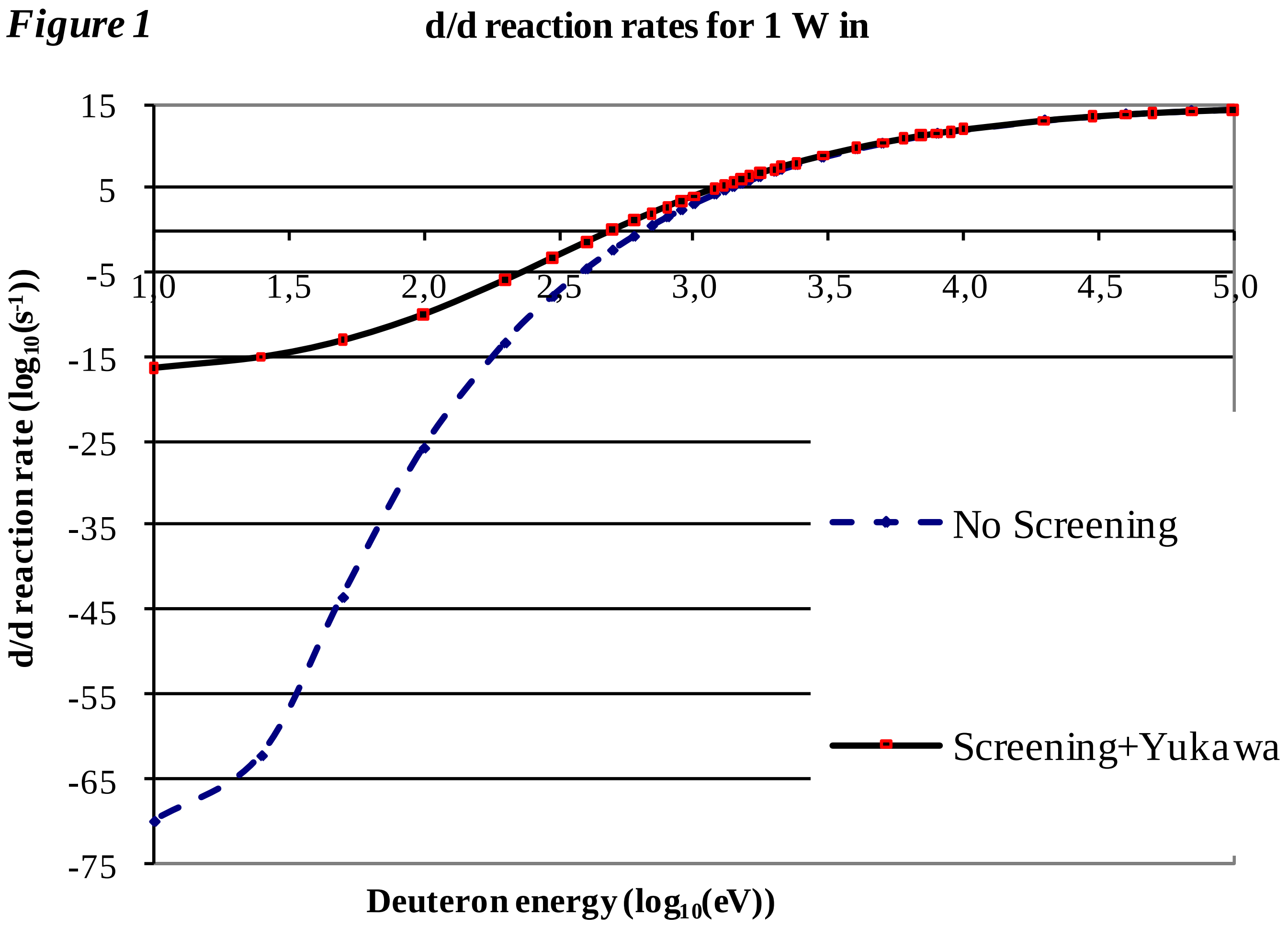
$$\varphi = \frac{1}{\mathrm{E_d}}\ \left(cm^{-2}s^{-1}\right)$$

The palladium target thickness is *126 µm,* containing 1 mmole d (*6*10^{20}* d) corresponding to

$$N_0 = 4.74*10^{22}\ (cm^{-3})$$

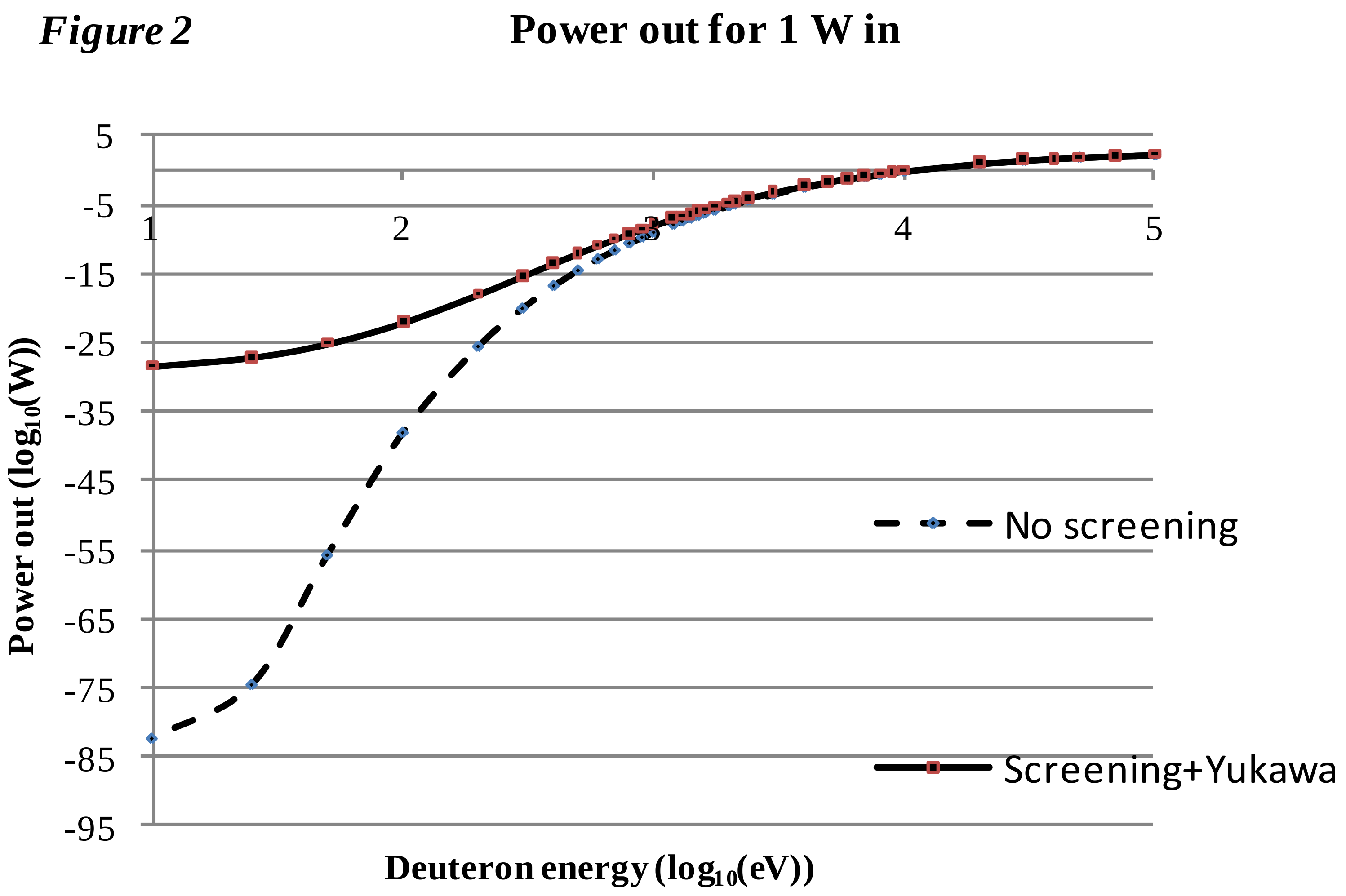
IV - Comparison with experimental data
Calculated d/d reaction rates

Figure 1



IV Comparison with experimental data
Calculated Power out

Figure 2



IV - Comparison with experimental data

- Hucke results (ref.1) show experimental reaction rates r_{ex} higher than calculated ones r_{cal} , with screening and Yukawa (ref.3)

$$r_{ex} = F_c r_{cal}\,, \quad with\ F_c = 1.5\ to\ 2$$

- SPAWAR results (ref.2) show experimental reaction rates r_{ex} very much higher than calculated ones r_{cal} , with screening and Yukawa (the latter negligible)

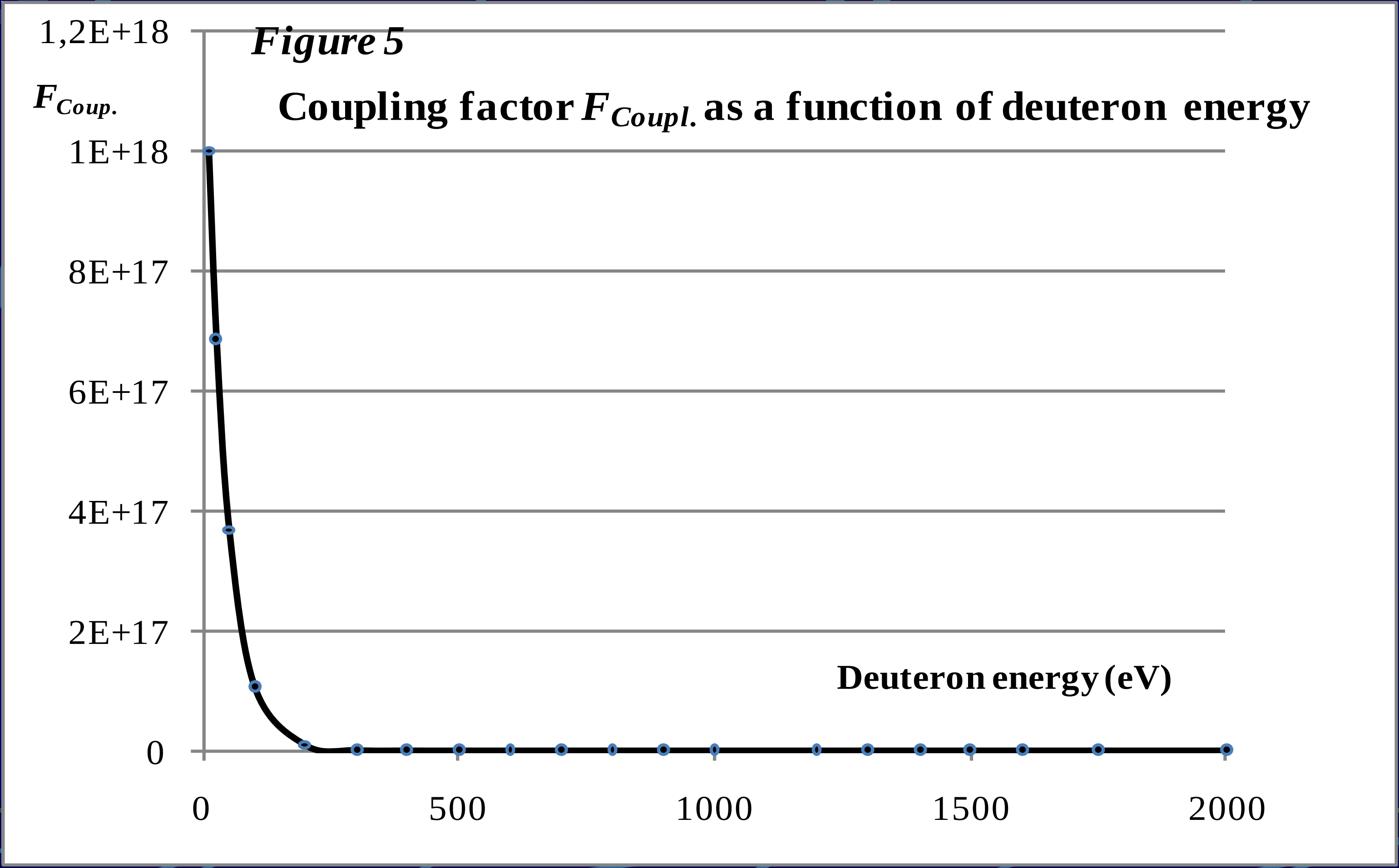
$$r_{ex} = F_c r_{cal}\,, \quad with\ F_c \cong 10^{18}$$

IV - Comparison experimental data versus calculated reaction rates

- Typical energies for Hucke experiments are 2000 to 10000 eV. For SPAWAR experiments they are round 2 eV
- The huge variation of F_c with E_d (energy of the deuteron) suggest a resonnant coupling between the impidging deuteron flux and the deuterons already present in the target (inducing fusion reactions between them).

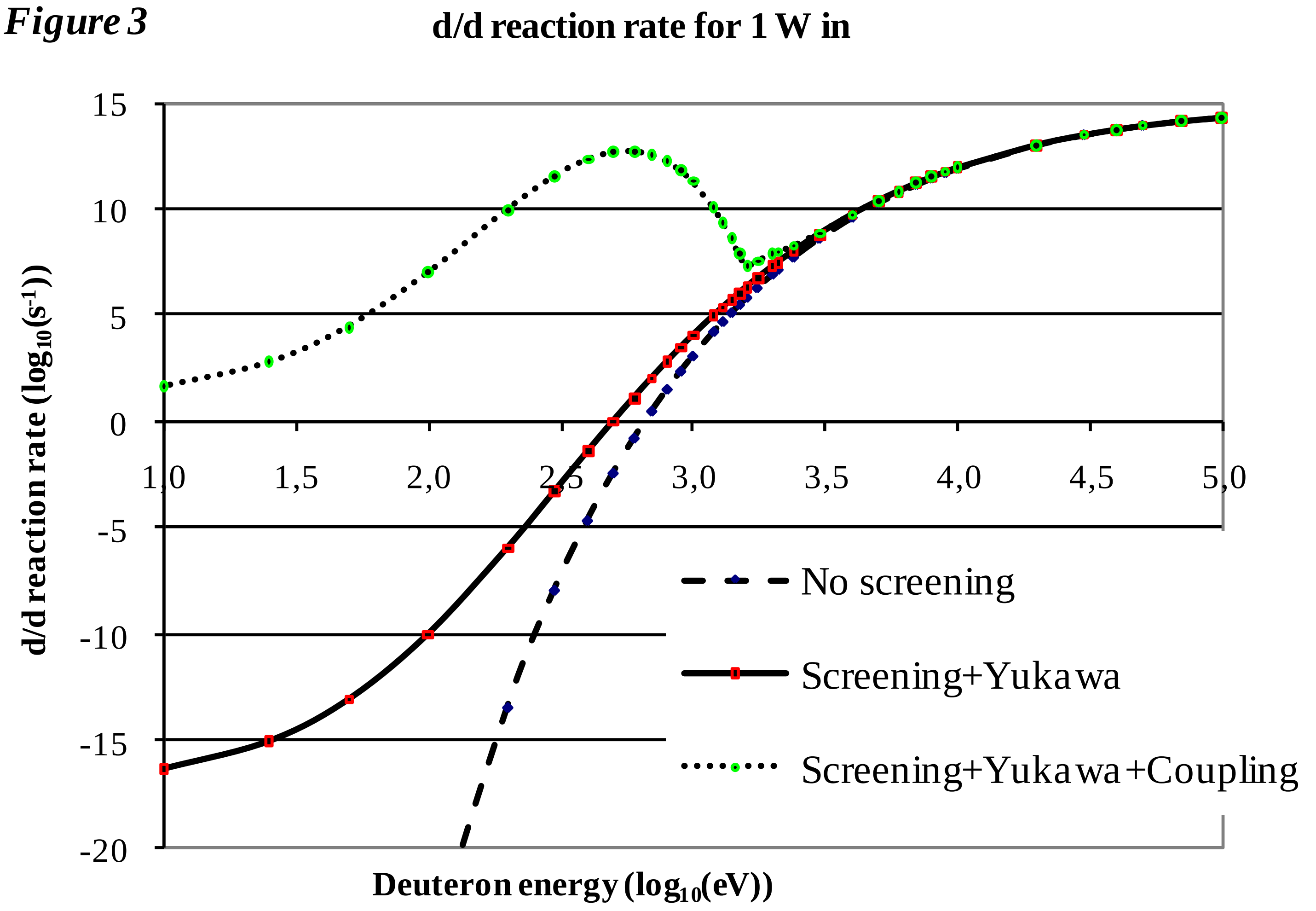
$$F_{coupl.}(E_d) = F_{coupl.}(E_f)e^{-\Delta(F(E_f))\frac{E_d - E_f}{E_f}} \quad \text{with } E_f \ \textit{fermi energy}$$

V - The coupling resonnance and the CMAF window - The resonnance curve



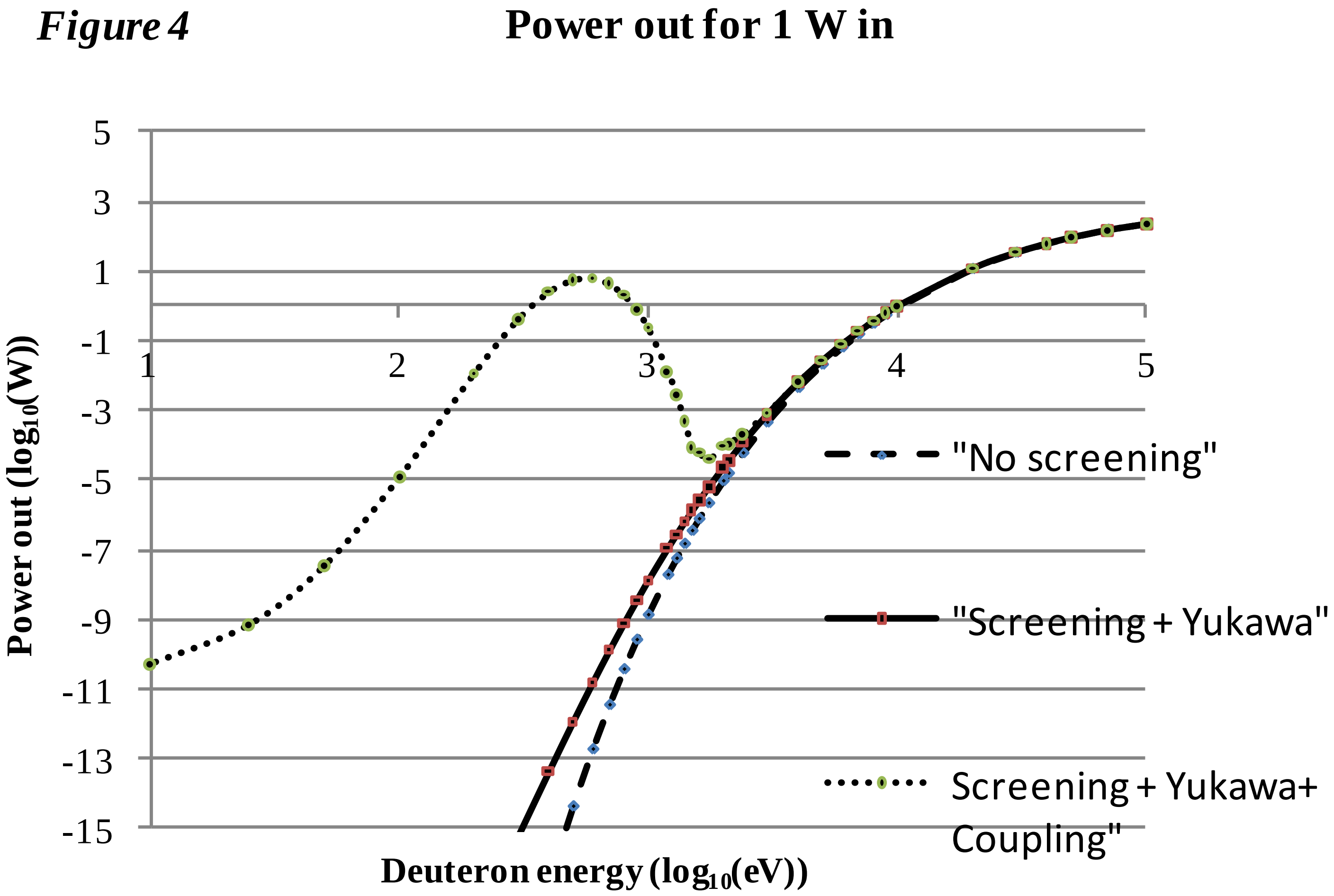
V - The coupling resonnance and the CMAF window - d/d reaction rates

Figure 3



V - The coupling resonnance and the CMAF window - Energy out for 1 W in

Figure 4



V - The coupling resonnance and the CMAF window - Energy out for 1 W in

- At low energy of the deuteron, the reaction rates are in line with SPAWAR results for a huge value of the coupling (#10^{18}) The Yukawa potential has a negligible role.The energy production is very small (10^{-10} *W*). At a few keV, the Yukawa potential has an influence comparable to that of the electrons screening and with a coupling factor of 1.5 to 2, the results are in line with Huke measurements.

- At high energy of the deuteron, the reaction rates are in line with hot fusion.

- At energy of the deuteron between 500 and 1000 eV, sizeable energy production levels are expected. CMAF window (Condensed Matter Assisted Fusion)

V - The coupling resonnance and the CMAF window - Production of deuterons beam in the CMAF window and target optimization

- Prototype for screening studies
- Ion guns for industrial applications
- Importance of Fc, depending upon physical and chemical characteristics of the target (optimization required).