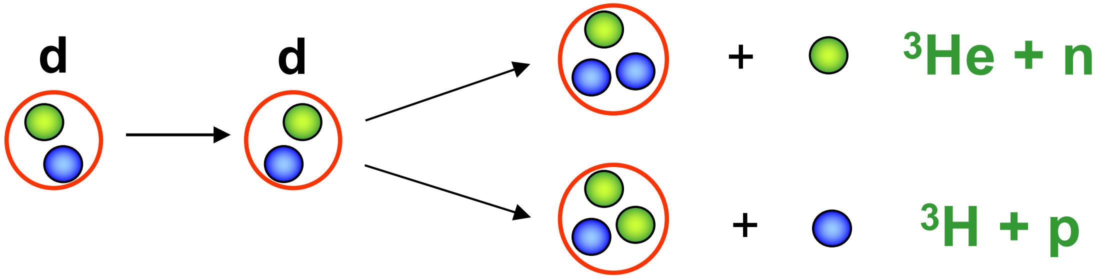
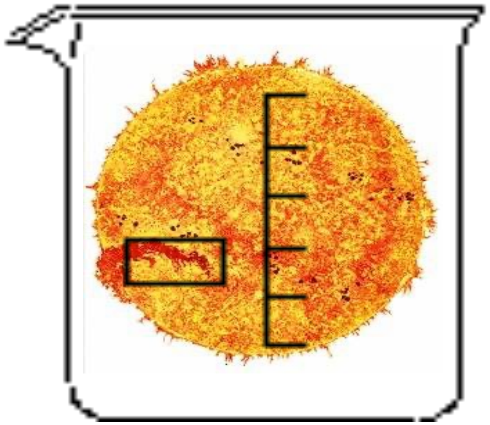
Reakcje deuteron-deuteron przy ekstremalnie niskich energiach –

zimna fuzja w eksperymentach akceleratorowych





Zakład Fizyki Jądrowej, Uniwersytet Warszawski
9.05.2024

Konrad Czerski

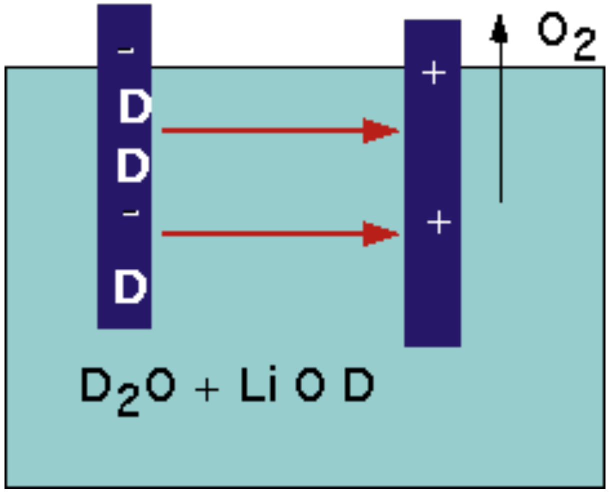
Cold Fusion: Heavy Water Electrolysis

Stanley **Pons** & Martin **Fleischmann**

1989

Press conference at the University of Utah:

We have solved the energy problem of the world!



Cold Fusion: Gas-Loading Experiments

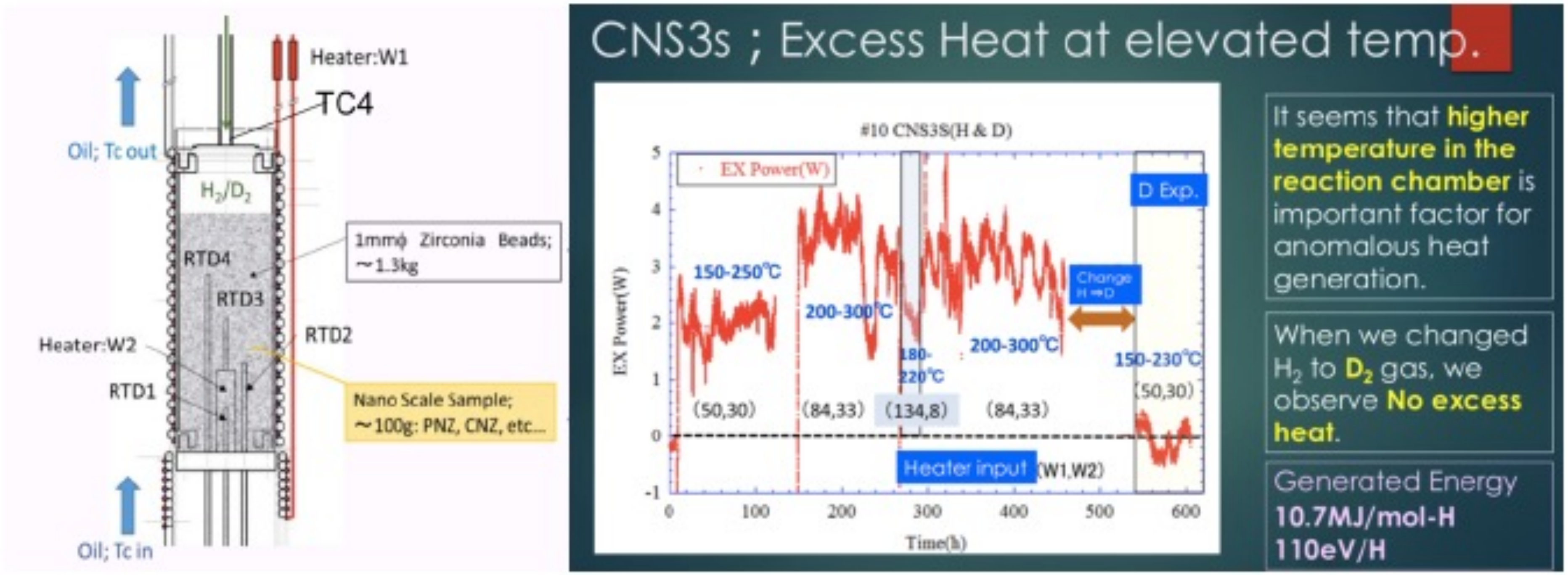


Fig.1.1: *Sketch of one of the reactors used by the NEDO Project and typical result. Note that excess heat was produced when the Ni-Cu powder supported on meso-porous silica was exposed to hydrogen. The time scale is in hundreds of hours [1].*

A. Kitamura et al., Int. J. of Hydrogen Energy 43 (2018) 16187-16200
Y. Iwamura et.al, J. Condensed Matter Nucl. Sci. 33(2020) 1–13

Cold Fusion: Gas Loading Experiments

Research programs

Japan , since 2016, NEDO, Nissan, Toyota, Tokyo U, Tohuku U

USA, Google, 2016-2020

EU, CleanHME, 2020-2025

USA, ARPA-E, 2023-2025, Stanford U, Berkley U, MIT

CF Puzzle (need for a theoretical explanation)

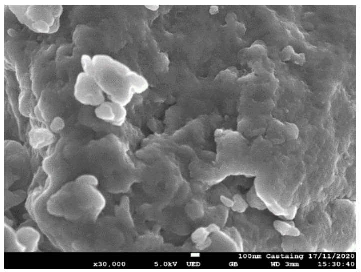
Coulomb barrier penetration (electron screening)

branching ratio $^{4}He/^{3}He \approx 10^{6}$, no gammas (threshold resonance)

poor reproducibility (strongly improved, chemical reactions)

Looking for a proper material and nuclear origin

100W per 100g



<u>Overview:</u> C.P. Berlinguette et al., Nature 570 (2019) 45-51

Clean Power from Hydrogen-Metal Systems

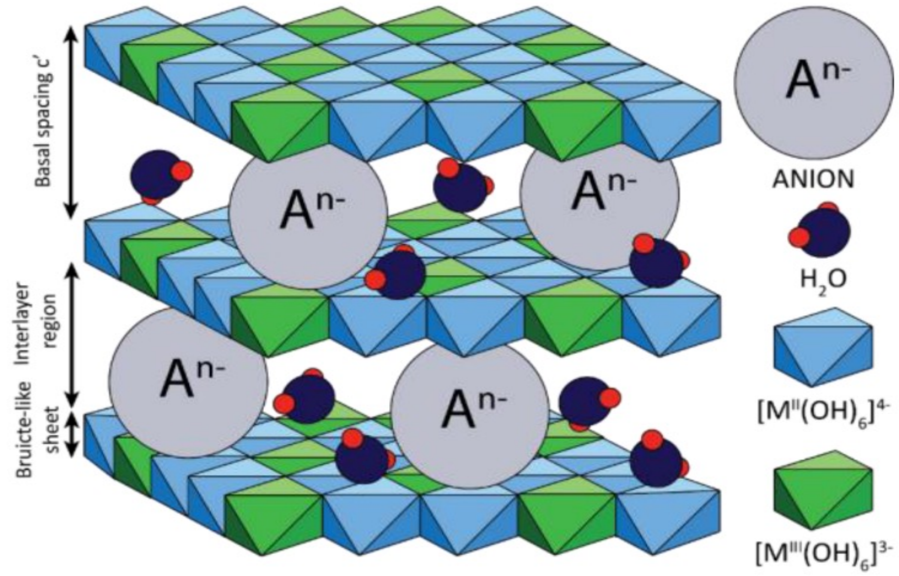
– CleanHME –

Participant No.	Participant organization name	Participant shor name
1 (Coordinator)	University of Szczecin	USZ
2	Institute for Solid-State Nuclear Physics	IFK
3	Institut Josef Stefan	JSI
4	Maritime University of Szczecin	AM
5	FUTUREON	FUT
6	Uppsala Universitet	UU
7	BroadBit Energy Technologies	BET
8	Istituto Nazionale di Fisica Nucleare	INFN
9	Politecnico di Torino	POLITO
10	Universita Degli Studi di Siena	UNISI
11	VEGATEC	VEGA
12	Centre National de la Recherche Scientifique	CNRS
13	SART von Rohr	SART
14	LIFCO Industrie	LIFCO
15	LAKOCO	LAKOCO
16	Massachusetts Institute of Technology	MIT
17	Lakehead University	LU

Achievements: Materials I

CNRS, LIFCO, BET

Example: the case of hydrotalcite (HDL):



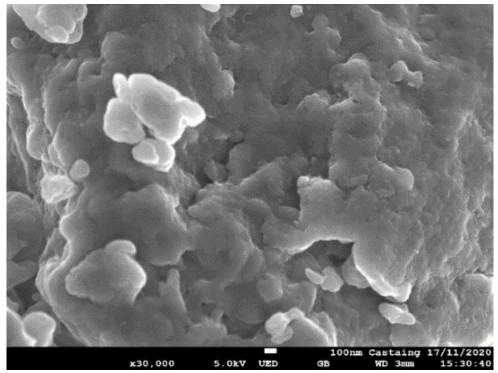
In our case A^{n-} = carbonate

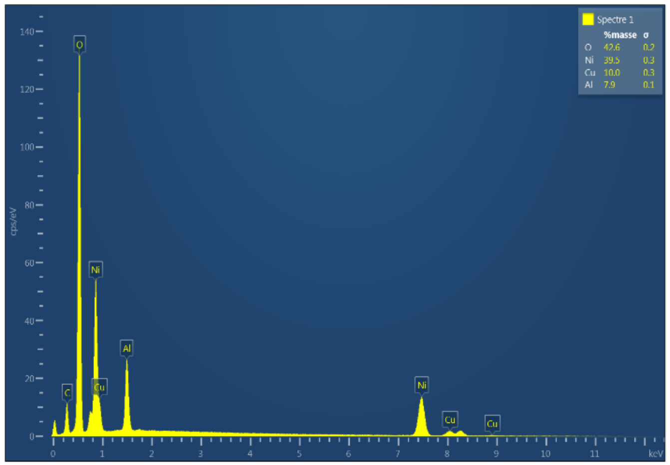
M^{II} = Ni, Cu, Fe, Ca, Zn, …

M^{III} = Al, Fe, Y, …

Low cost synthesis
Precise fine tuning of the composition

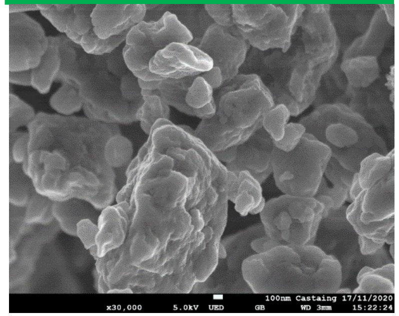
Ex: $Ni_{5.25}Cu_{0.75}Al_2CO_3(OH)_{16} – 4\ H_2O$





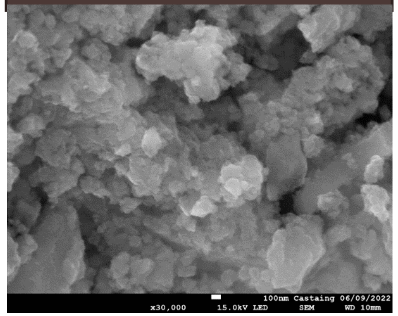
Achievements: Materials II

Green powder
non magnetic (Ni^{2+})



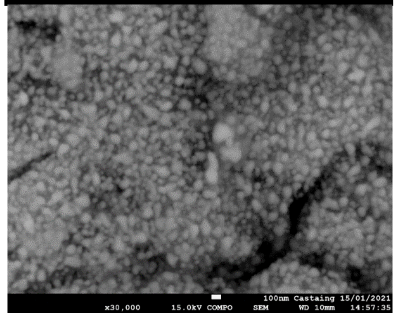
450°C → under air

Brown powder
non magnetic (Ni^{2+})



500°C → under H2

Black powder
magnetic (Ni^{0})



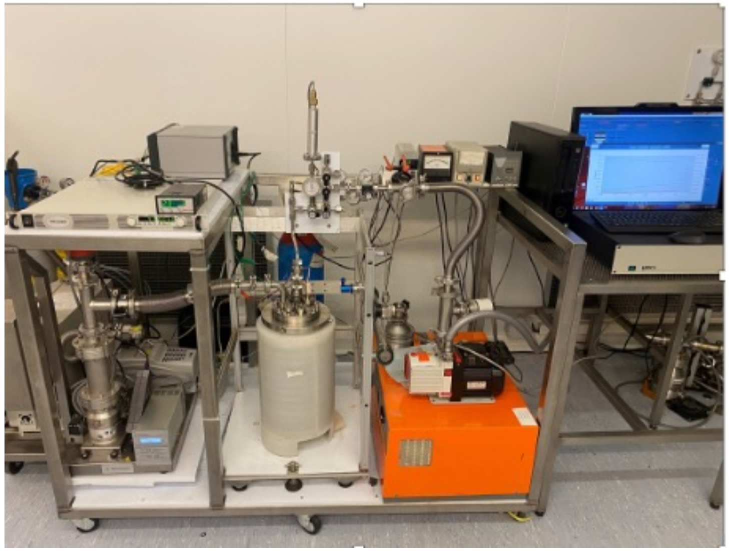
Very simple synthesis for active materials for LENR

Ni/Cu, Ni/Fe, Ni/Bi, ZrO_2, Ni/Cu+ThO_2

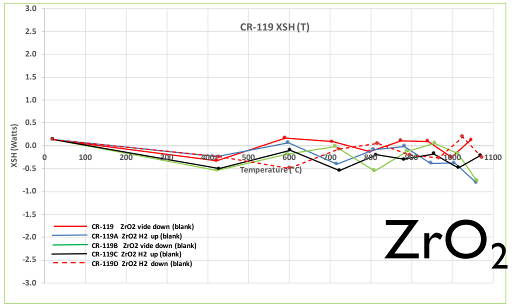
Achievements: Calorimetry

VEGATEC sart von Rohr

France

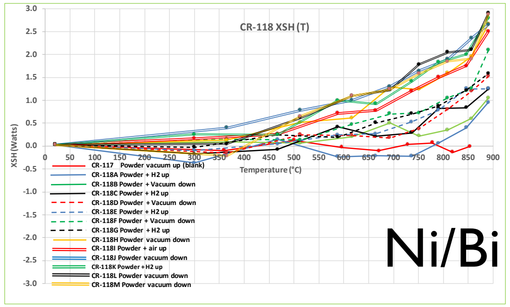


Large Quartz cell able to contain up to 1kg of powder



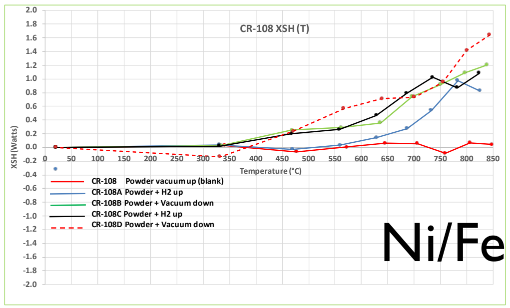
62g

0.0±0.5 W



12g

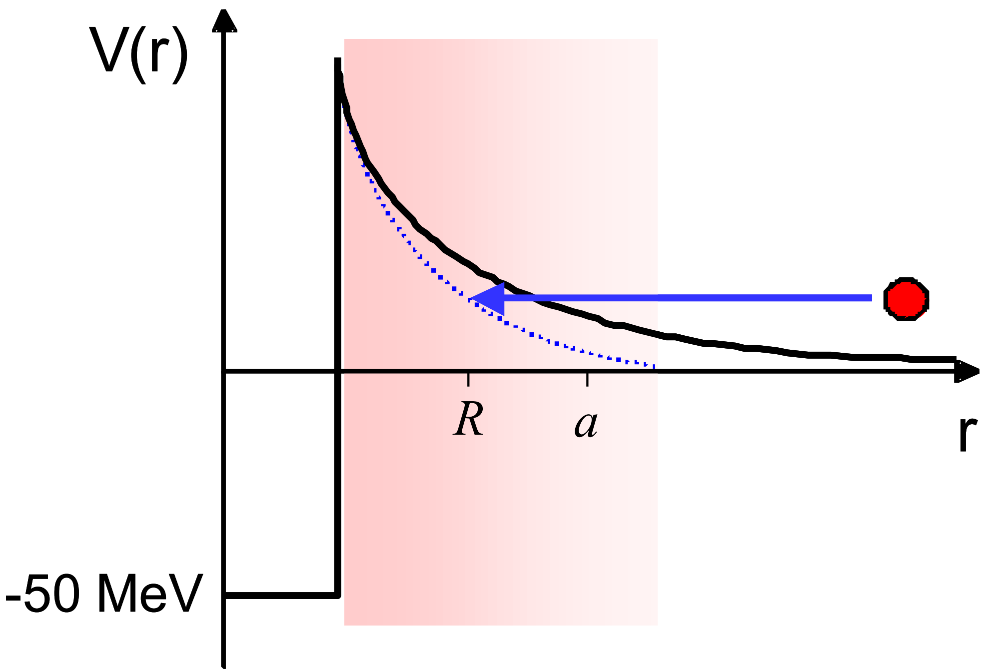
24W / 100g



10.6g

15W / 100g

Nuclear Effects: Electron Screening



$$V(r) = \frac{Z_1 Z_2 e^2}{r} \exp(- r/a)$$

$$\approx \frac{Z_1 Z_2 e^2}{r} - U_e$$

$$U_e = \frac{Z_1 Z_2 e^2}{a}$$

screening energy

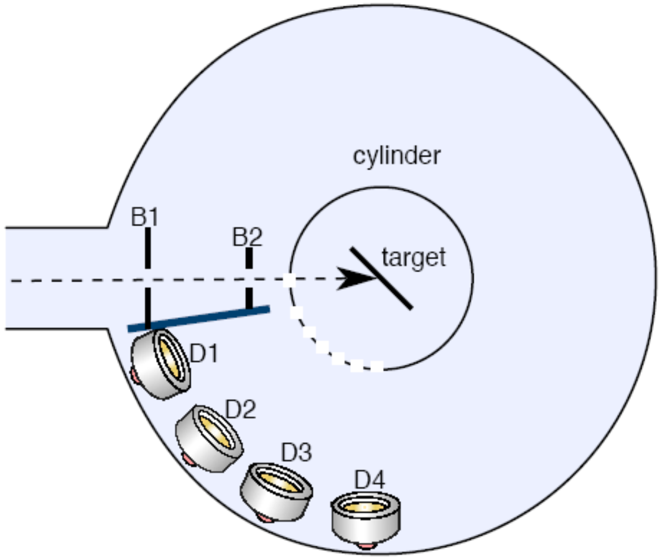
$$P(E) = \sqrt{\frac{E_G}{E}} \exp\left(-\sqrt{\frac{E_G}{E}}\right)$$

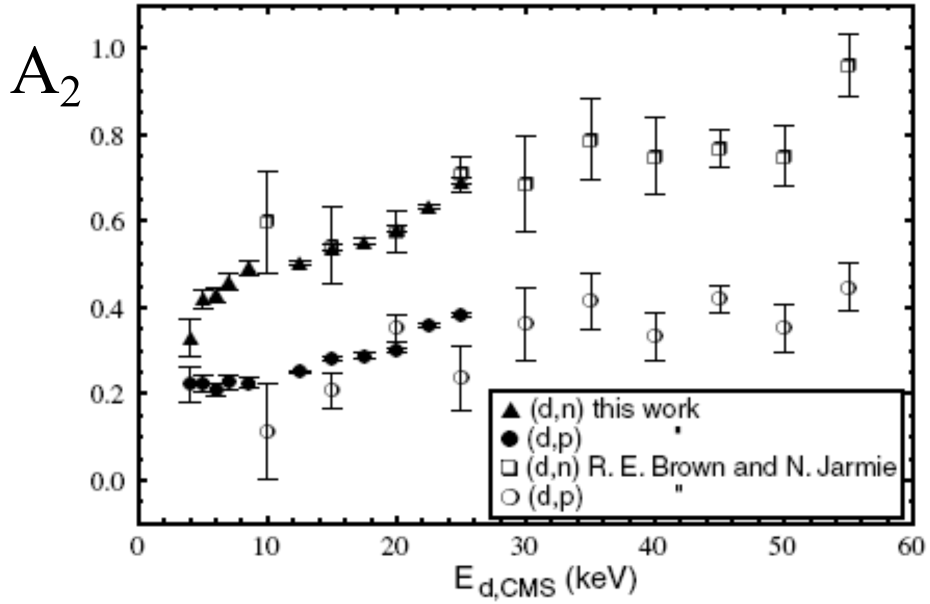
s-wave penetration factor

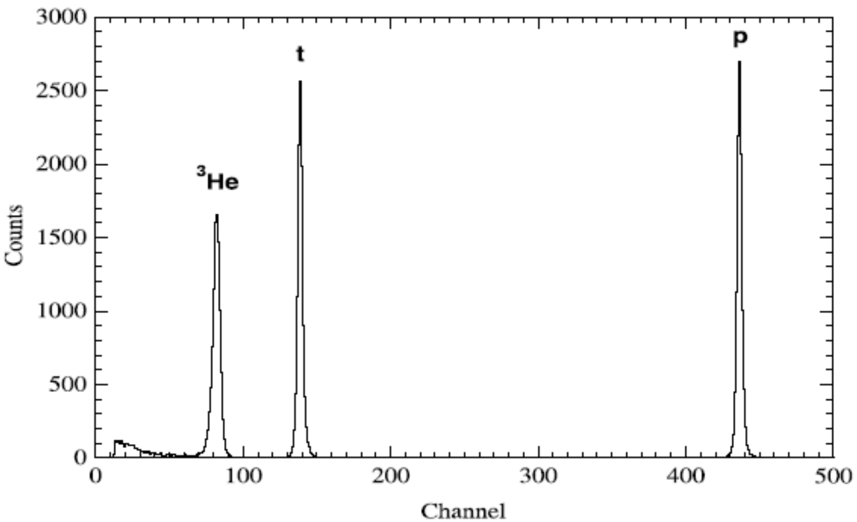
$$P(E) \longrightarrow P(E+U_e)$$

model independent approach

Accelerator Experiments (HV) I





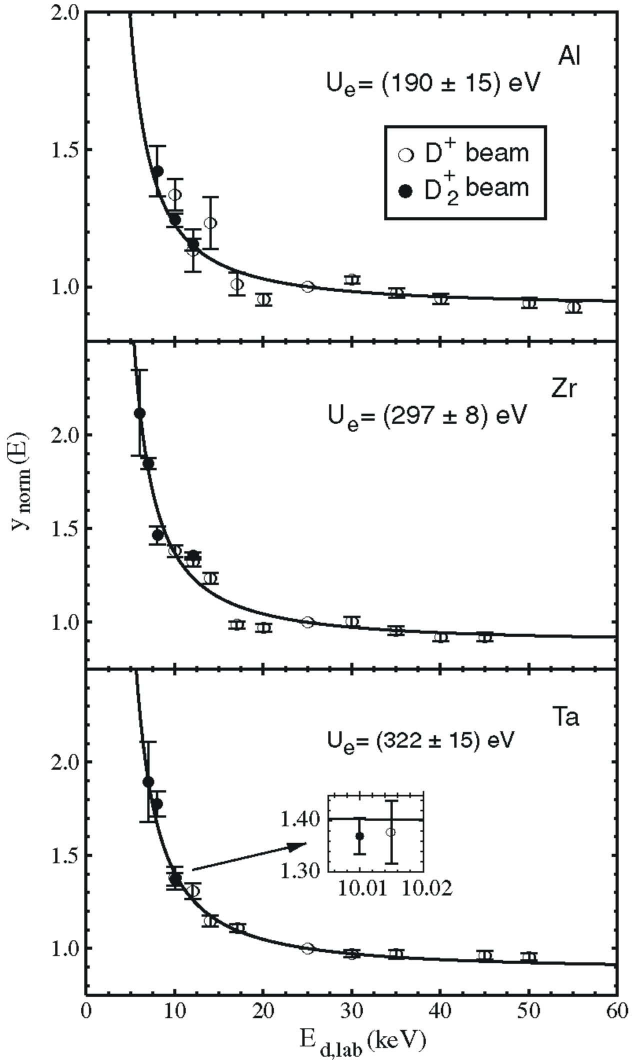


angular distribution

$$\frac{d\sigma}{d\Omega} = \sigma_{tot}\left(1 + A_2 P_2(\cos\varphi)\right)$$

EPL 2001

Accelerator Experiments (HV) II



$$d + d \longrightarrow {}^3He + n$$

$$d + d \longrightarrow {}^3H + p$$

metal target

Europhys. Lett. 54 (2001) 449

J. Kasagi et al., J.Phys.Soc.Jap. 71 (2002) 2281

F. Raiola et al., Eur.Phys.J. A13 (2002) 337

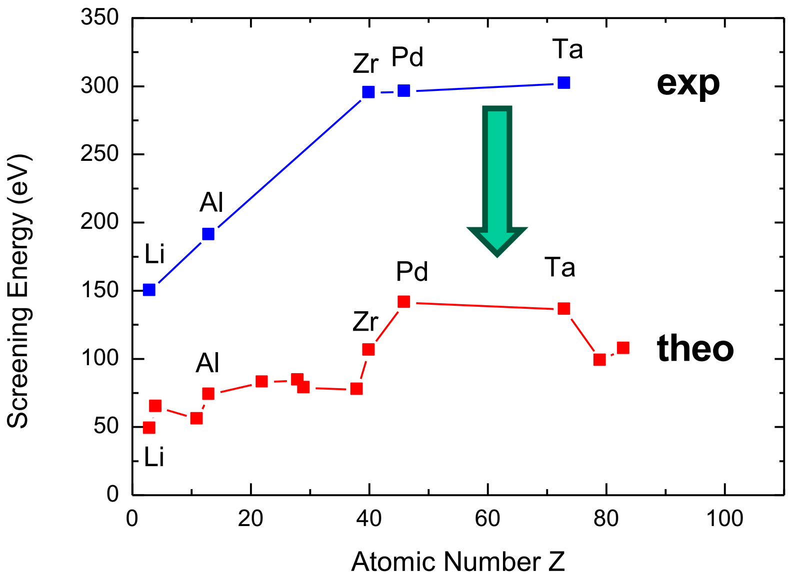
F. Raiola et al., Eur.Phys.J. A19 (2004) 283

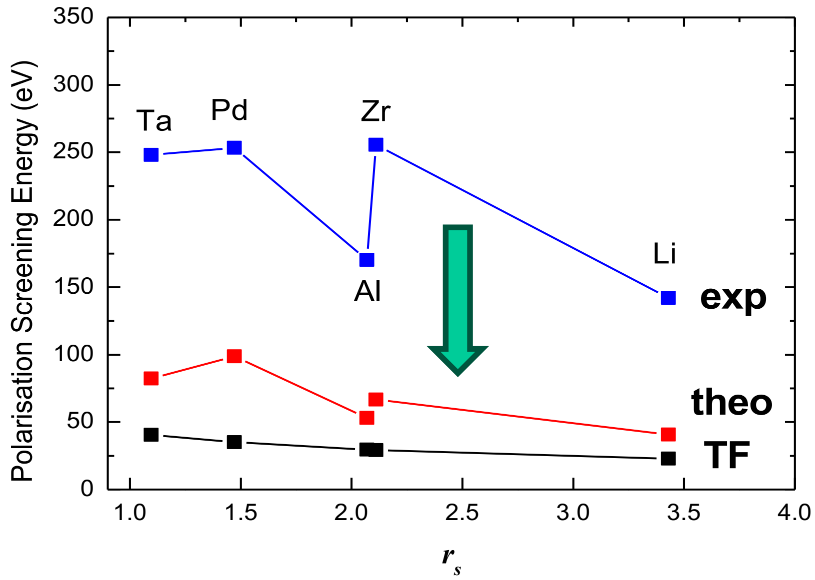
gas target

$U_e = 25 \pm 5$ eV

U.Greife et al., Z.Phys. A351 (1995) 107

Experimental (HV) and Theoretical Results





dielectric function theory:

free and bound electron polarization

cohesion screening

electron-gas parameter r_s

$$r_s = \left(\frac{3}{4\pi\, n}\right)^{1/3} \frac{1}{a_0}$$

Europhys. Lett. 2004, Phys. Rev. C 2008

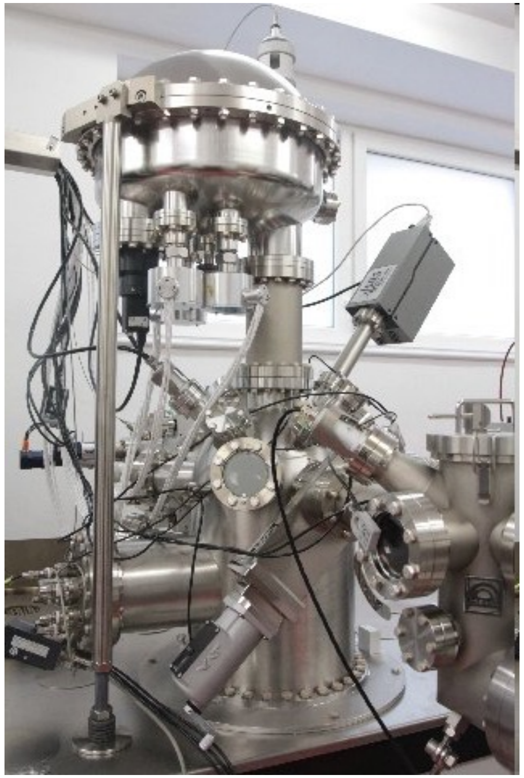
Materials 2023

Laboratory of Nuclear and Medical Physics

accelerator with ultra high vacuum

prototype ECR ion source
low emittance , high current,
light ions – a few mA

Dreebit, Dresden, Germany



Target Chamber:

Electron Auger Spectroscopy

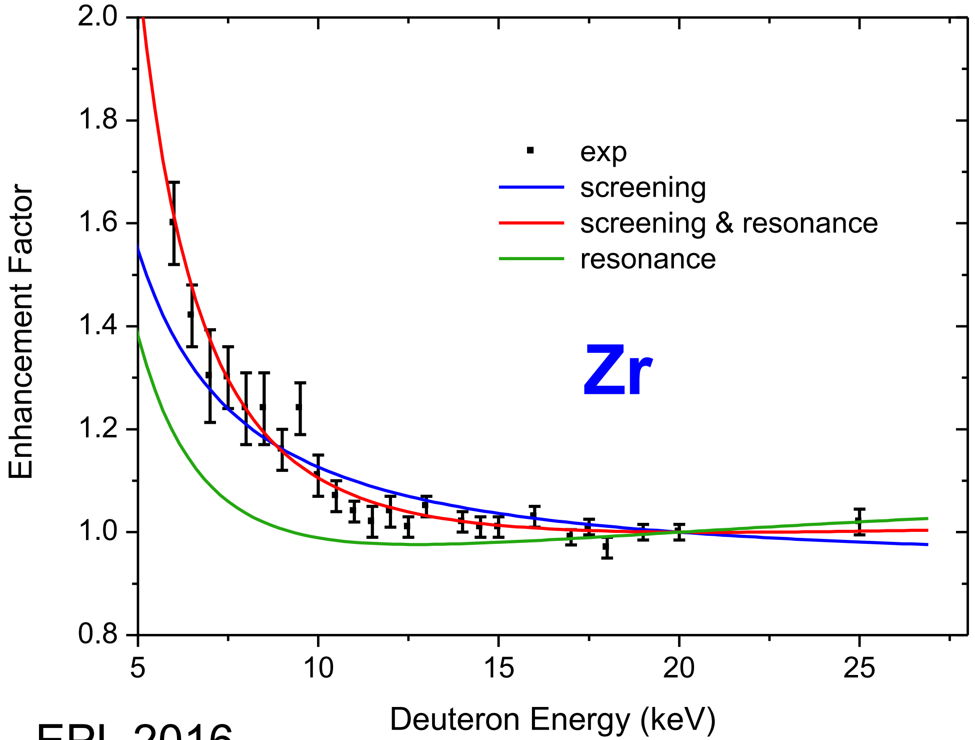
mass spectroscopy

μ-metal

$p = 10^{-11}$ mbar

PREVAC, Poland

UHV Electron Screening – Resonance Contribution



EPL 2016

$U_e = 105 \pm 15$ eV $\Gamma_p = 40 \pm 10$ meV
$\varphi = 110$ deg

flat contribution

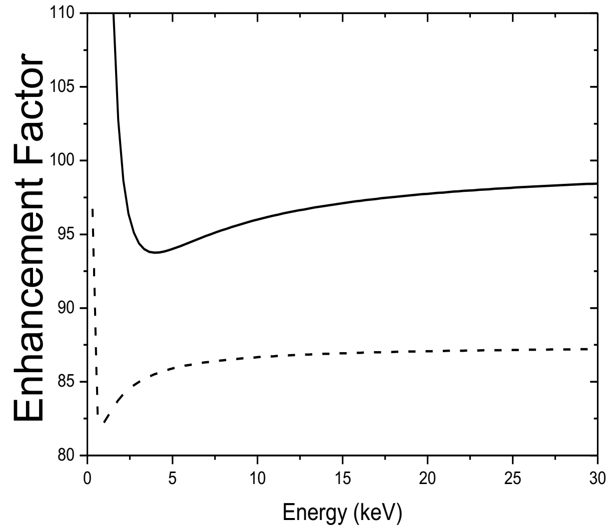
16 transition matrix elements

s.p. resonance contribution

$$\sigma_R = \frac{\pi}{k^2} \frac{\Gamma_d \Gamma_p}{(E - E_R)^2 + \frac{\Gamma^2}{4}}$$

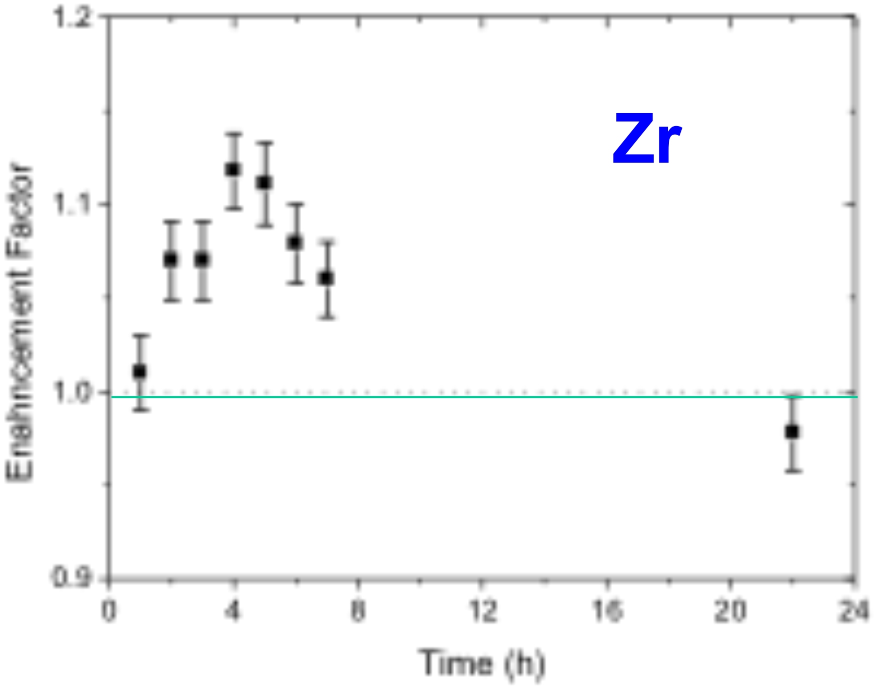
interference effect

$$\sigma = \left| \sqrt{\sigma_F} + \sqrt{\sigma_R} \right|^2 = \sigma_F + \sigma_R + 2\sigma_F \sigma_R \cos\varphi$$



EPL 2016

Effective Electron Mass



long time measuremnts

deuteron energy 15 keV

U_e=100 – 300 eV

impurities

crystal lattice deffects

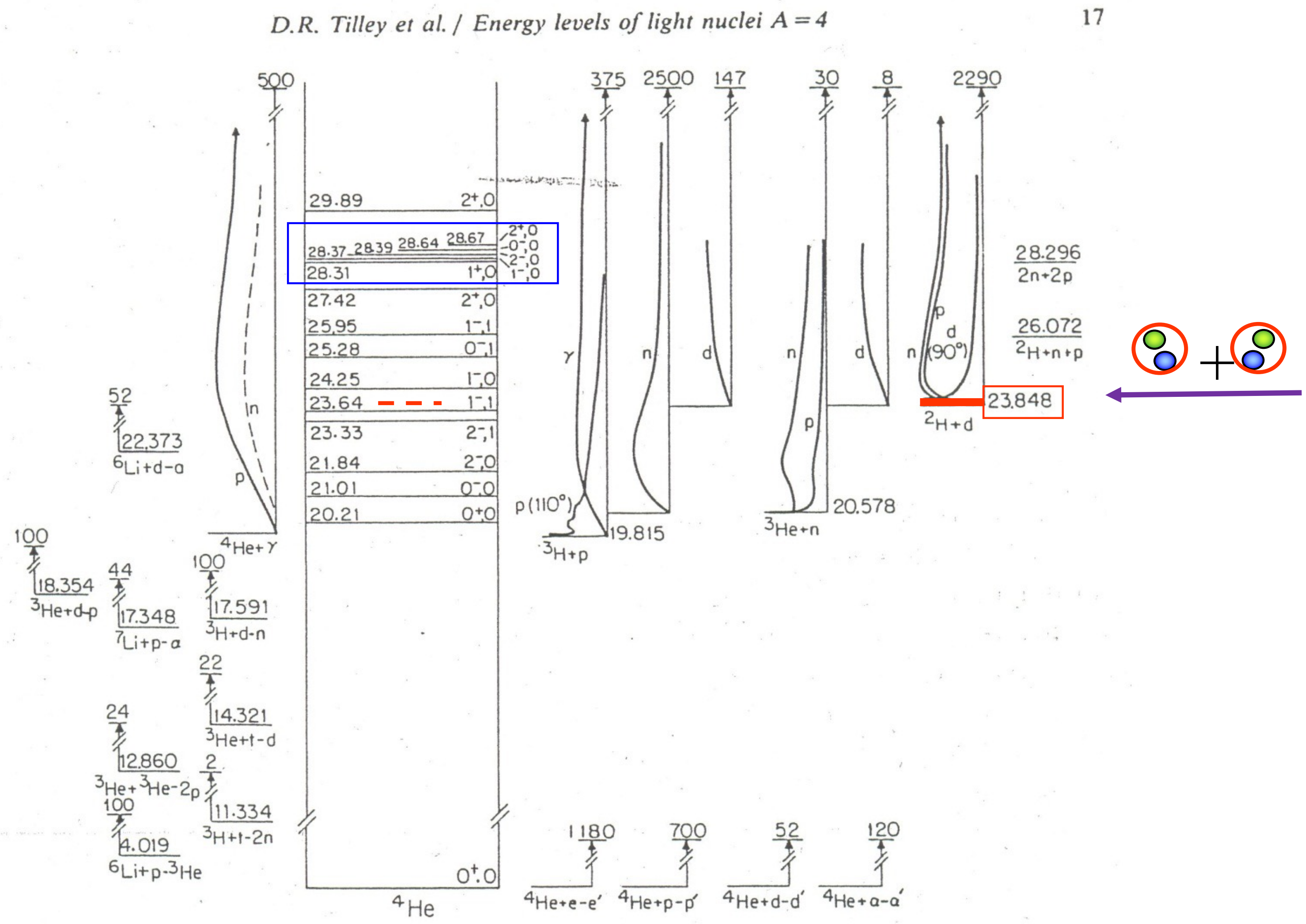
effective electron mass

U_e ↗

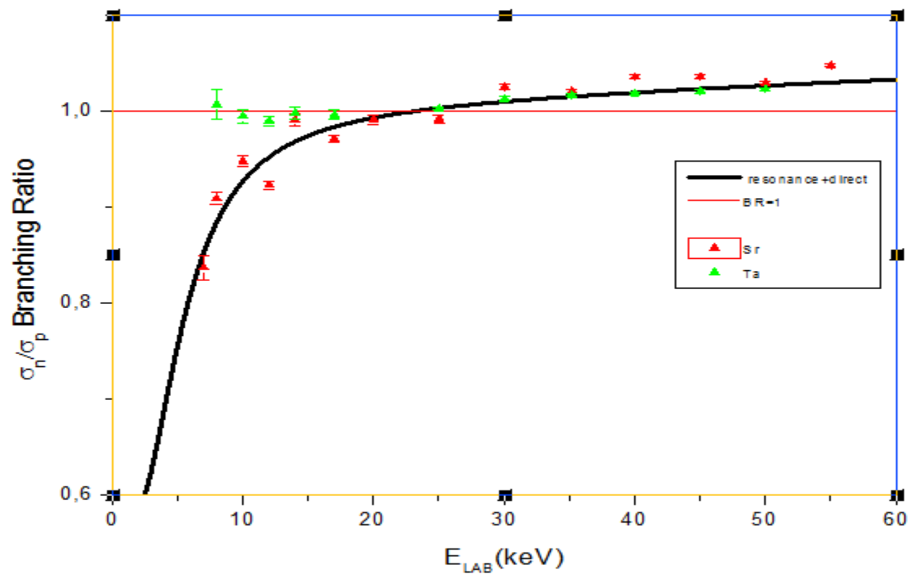
target surface contamination

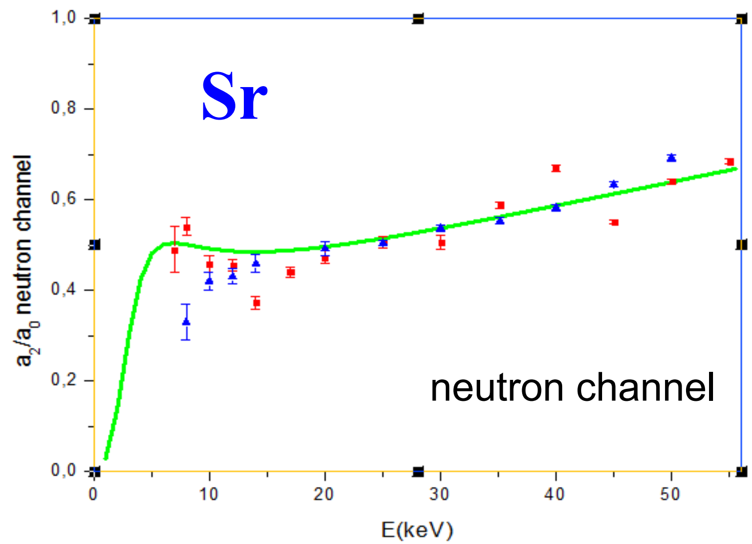
U_e ↘

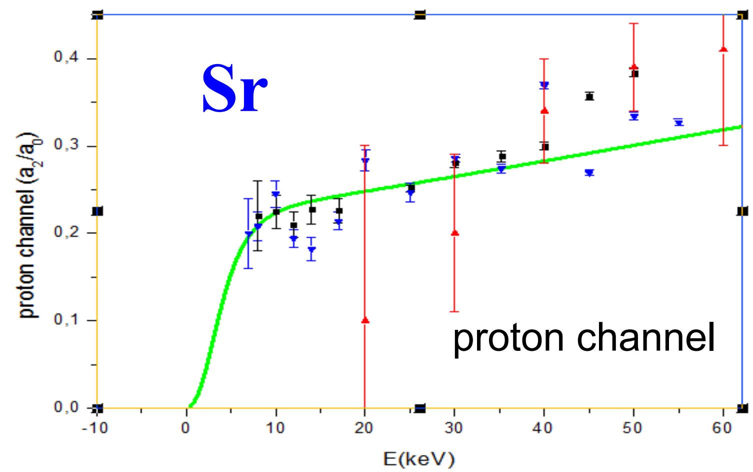
Compund Nucleus ^{4}He



n/p Branching Ratio & Angular Distribution



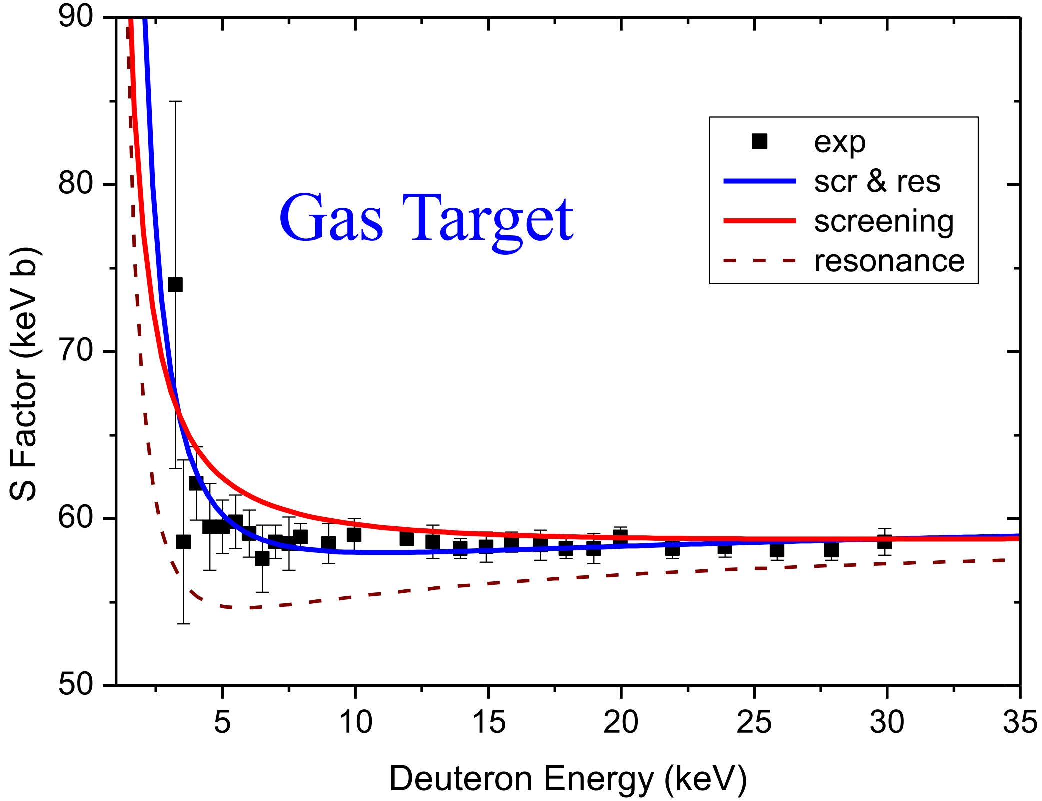




Sr: Γ_n=10 meV, Γ_p= 40 meV

Ta: Γ_n=2 meV, Γ_p=6 meV

Gas Traget Measurements



$U_e = 20$ eV

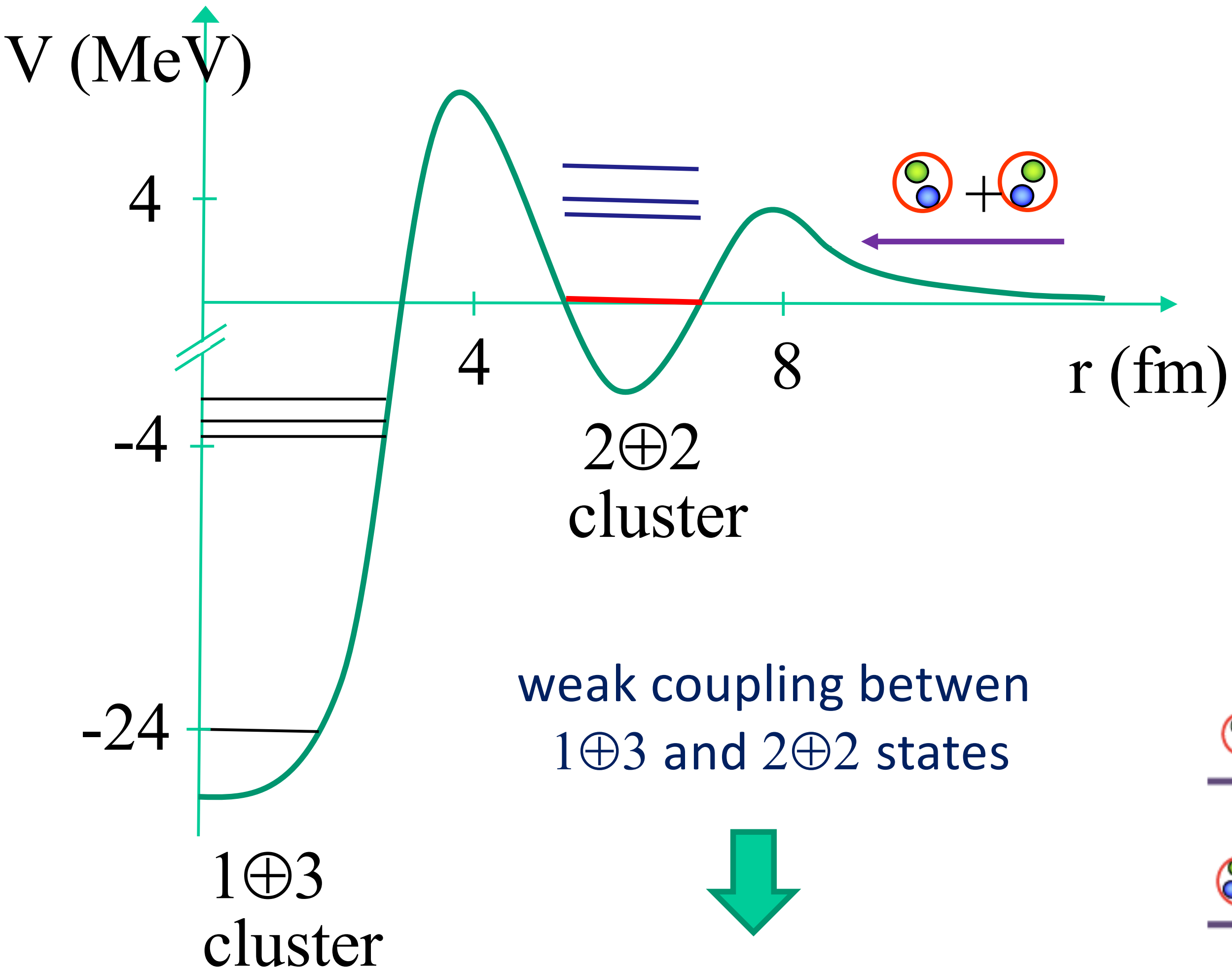
Data:
U. Greife et al.
Z. Phys. 1995

Phys. Rev. C Lett. 2022

$\Gamma_p = 8 \pm 2$ meV , $\varphi = 105 \pm 5$ deg

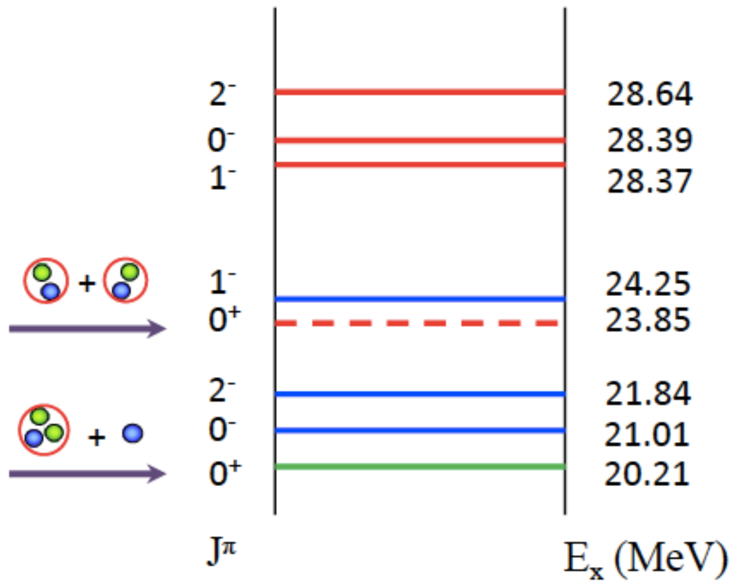
interference effect

Shape Coexistence in ^{4}He



weak coupling betwen
1⊕3 and 2⊕2 states

double Coulomb barrier
in anology to isomeric states



Phys. Rev. C Lett. 2022

D + D Reactions: Room Temperature

Resonance cross section:

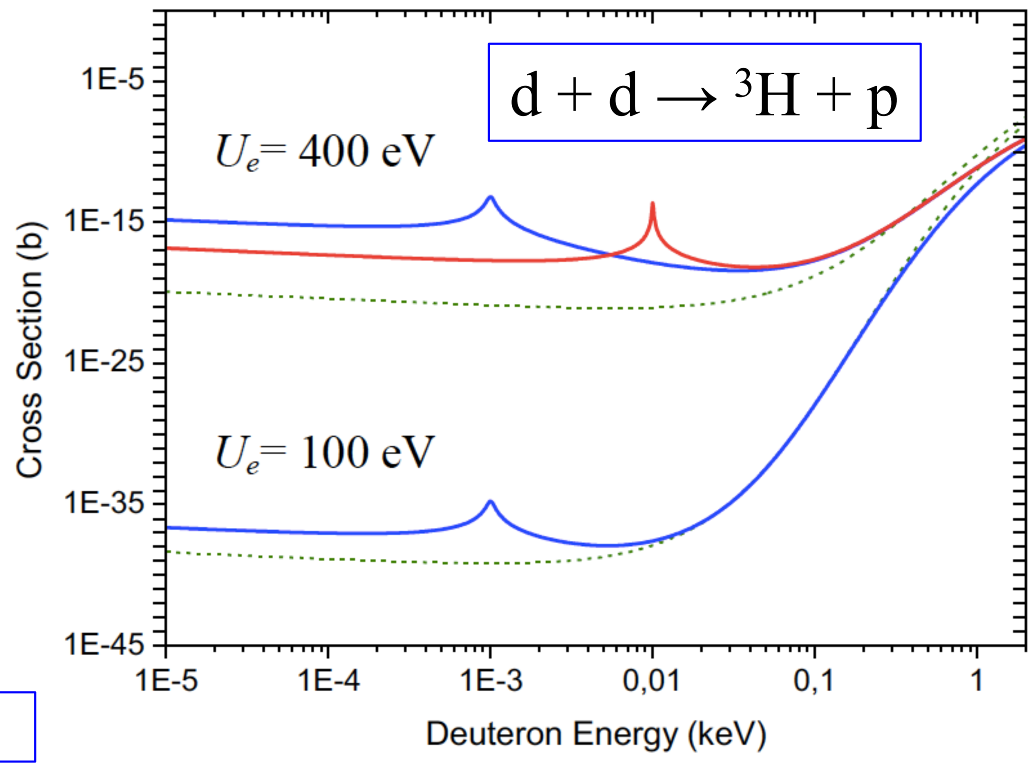
$$\sigma(E) = \frac{\pi}{k^2} \frac{\Gamma_d(E)\,\Gamma_p}{(E - E_R)^2 + \frac{1}{4}\Gamma_\alpha^2}$$

Resonance contribution also depends on the screening energy:

$$\Gamma_d(E) = 2kP(E + U_e)\,|\gamma|^2$$

$$\Gamma_\alpha = 0.1\ eV$$

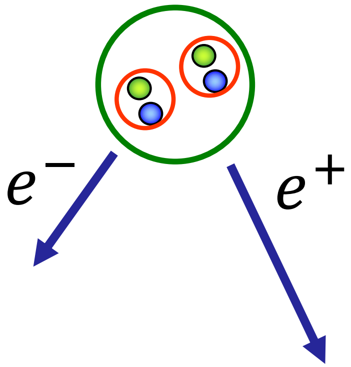
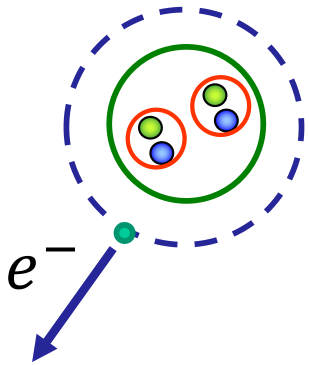
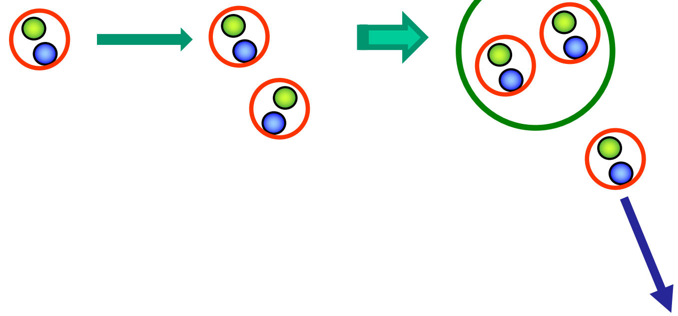
100g ⇨ 10kW



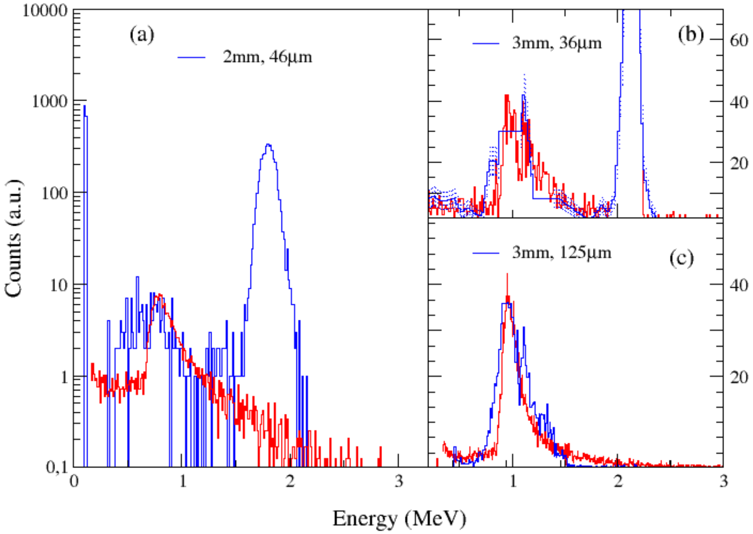
$$\Gamma_\alpha = \Gamma_d + \Gamma_p + \Gamma_n + \Gamma_{pc}$$

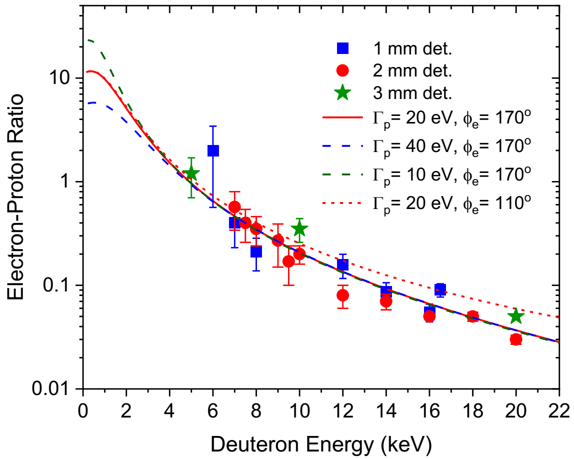
Phys. Rev. C Letters 2022

Decay Channels of the 0^+ Resonance

Internal Pair Production	Internal Electron Conversion	Internal Deuteron Conversion
		
$E_{e-} + E_{e+} = 23$ MeV $E_\gamma = 0.511$ MeV	$E_{e-} = 24$ MeV	$E_d = 16$ MeV , $E_\alpha = 8$ MeV
electron cont. spectrum E0 sum rule	single energy line	two energy lines
$\Gamma_{e-e+} \geq 100$ meV	$\Gamma_{e-} < 1$ meV	$\Gamma_{d\alpha} = ?$ meV

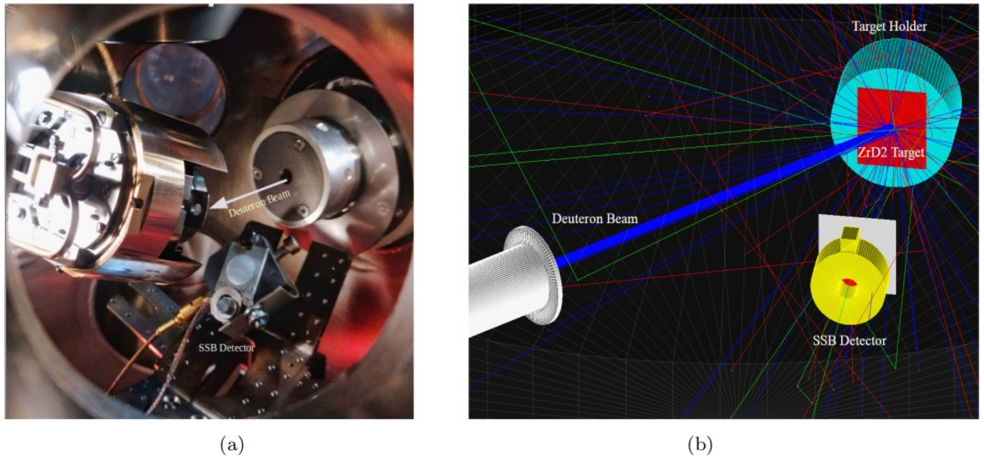
Observation of e+e- Emission

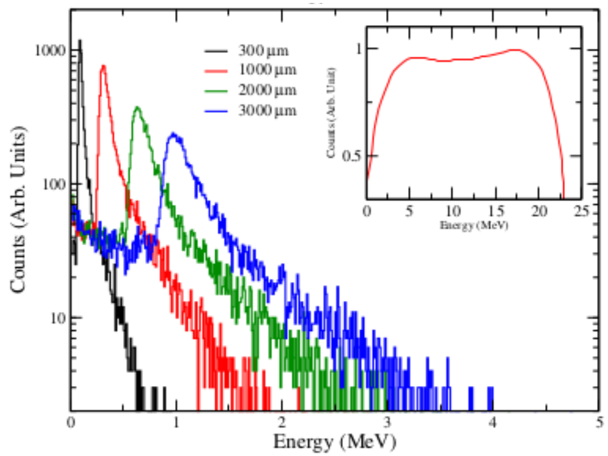




Phys. Rev. C Lett. 2024

Geant 4 simulations





Measurement 2024

Conclusions

1. Electron screening

electron screening locally enhanced by impurities and crystal defects

nuclear reaction rates at room temperature can change dramatically, 40 orders of magnitude

2. 0^+ threshold resonance in ^4He

balance between the resonance and electron screening

explains ^4He production and increases reaction rates at room temperature up to 7 orders of magnitude, changes the branching ratio, electromagnetic transitions dominate, the resonance energy depends on the electron screening

3. Demonstration of the cold fusion in accelerator experiments

People

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U Szczecin

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M. Valat
R. Dubey
K. Czerski

CleanHME @ European Parliament

- Thursday, September 5, 2024
- 9:00 AM 4:00 PM
- European Parliament - Strasbourg