Laser-Driven High Energy Alpha Beam Interaction with Solid $p^{11}B$ to Achieve Fusion Ignition by Alpha Heating

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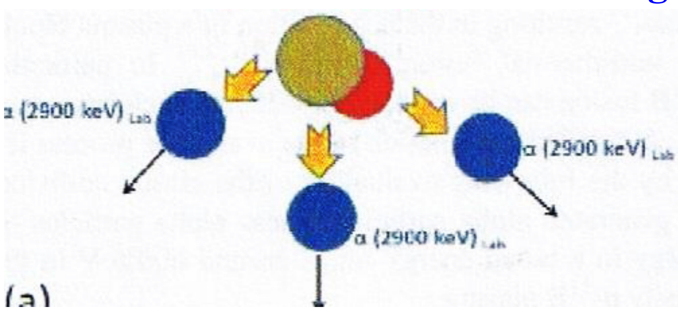
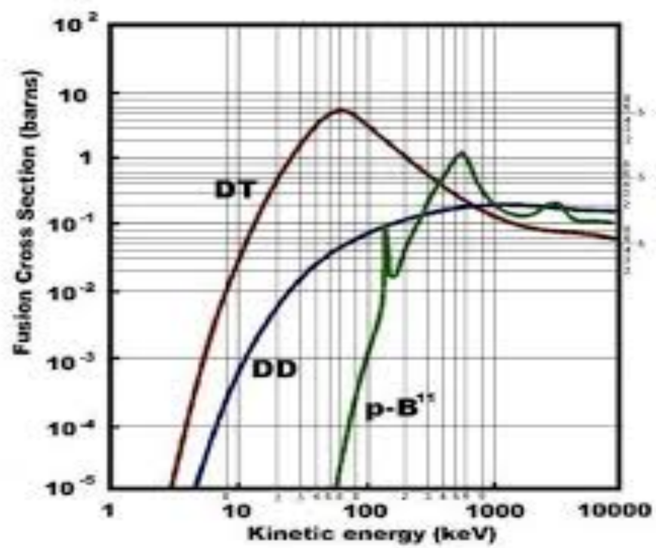
Investigate the effect and the importance of alpha particles for the H [11] B fusion reaction

- The $H^{11}B$ nuclear fusion reaction is attractive not only because is an aneutronic reaction but because have the advantages to produce three alphas with total energy of 8.7 MeV.



A physical process, termed as <u>alpha avalanche effect</u>

→ Fast plasma heating
Increase the plasma Temperature
Improve the reaction rate



The alpha heating effect due to the Avalanche effect

→ Allow to ignite fusion process in relatively low plasma temperatures T<< 300 keV

<u>**Experimental results [1-3]**</u>

- **Relevant experimental results on alpha production, by laser-driven proton beam interaction with ^{11}B plasma, justify extensive numerical investigations on fusion burning feasibility of $H^{11}B$ fuel by High energy particle beam (He) using a multi-fluid code**

[1]_ Labaune, C., S. Deprieraux, S. Goyon, C. Loisel, G. Yahia & J. Rafelski *Nature Communications* **4**, 2506 (2013).
[2]_ G. Korn, D. Margarone, A. Picciotto, Lecture at the IZEST conference, Paris, Romanian Embassy, 19 September 2014.
[3]_A. Picciotto et al. *Physical Review X* **4**, 031030 (2014).

Laser - Driven proton acceleration

Data 2009 - Present day

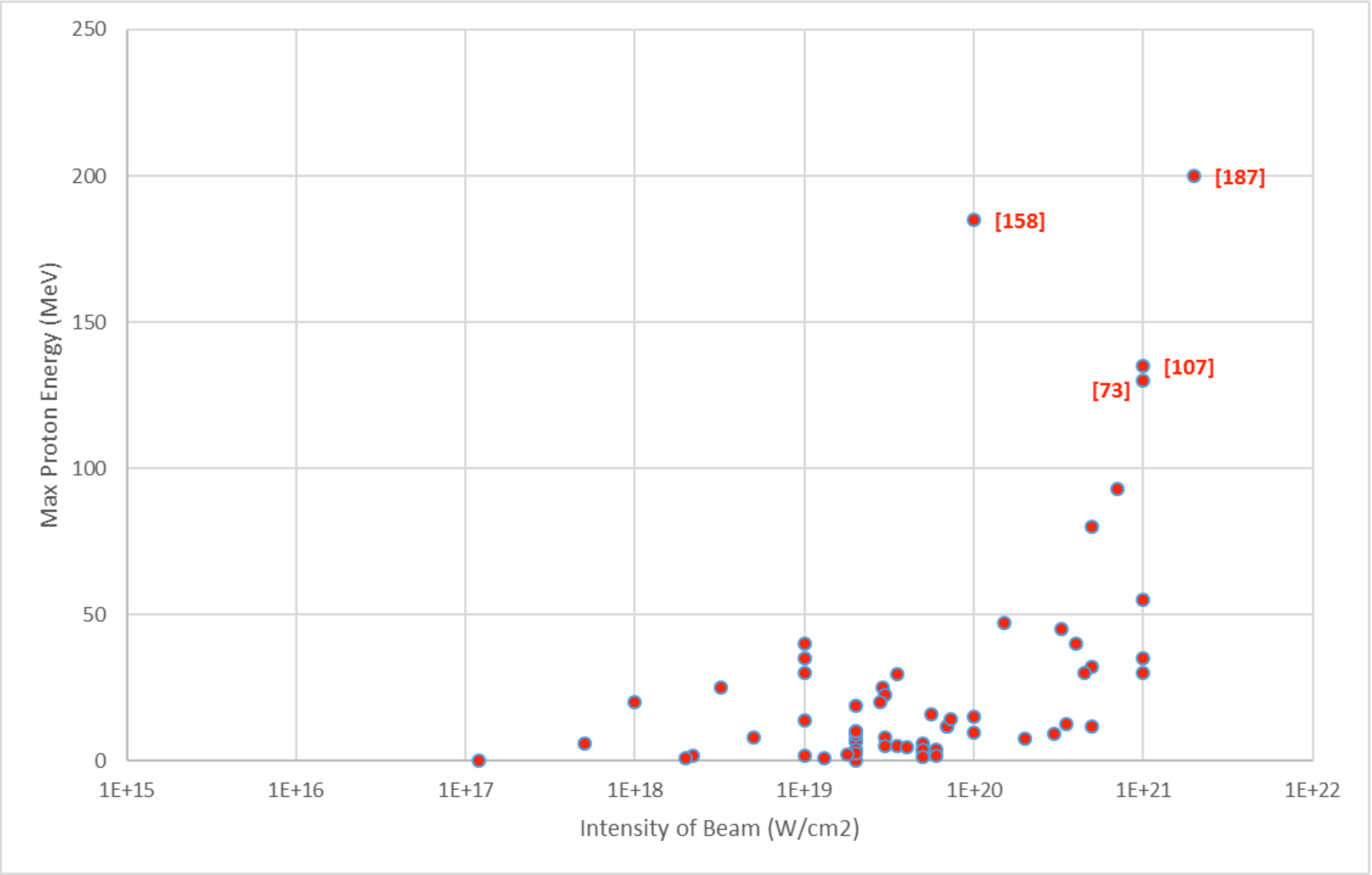


Fig. A

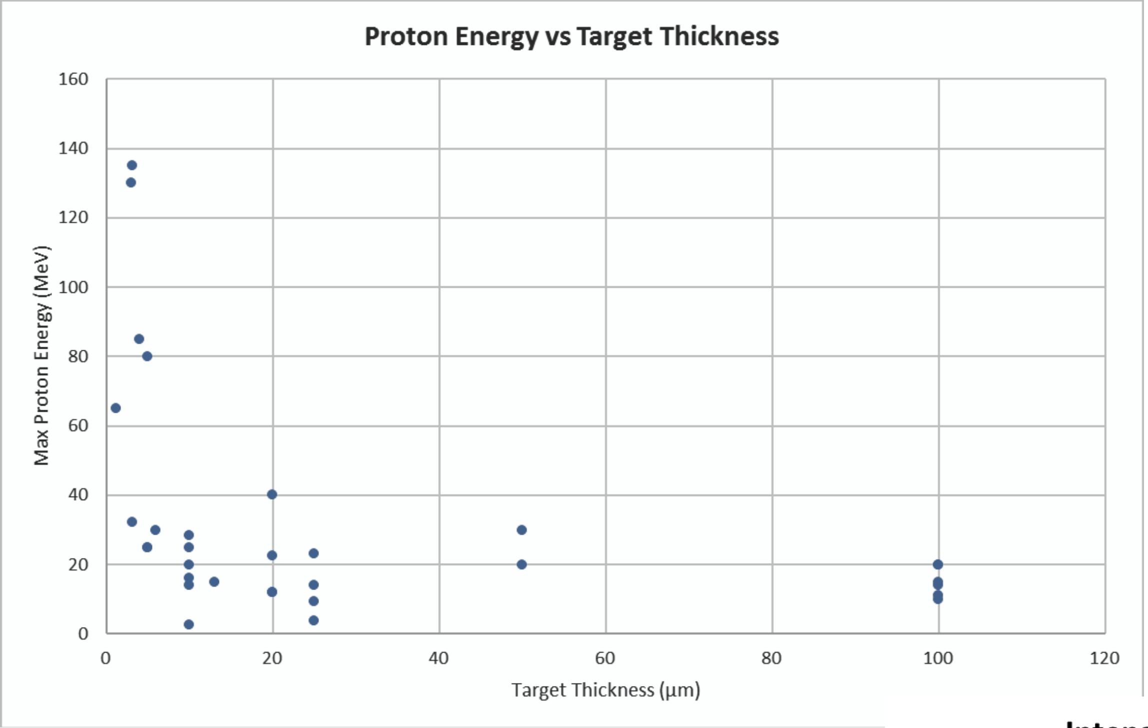
Fig. A Presents Proton energy as a function of laser beam intensity.
The contrast ratio is in the range 10^{-4} to 10^{-12} .
The numbers in fig. A referred to data from the following papers

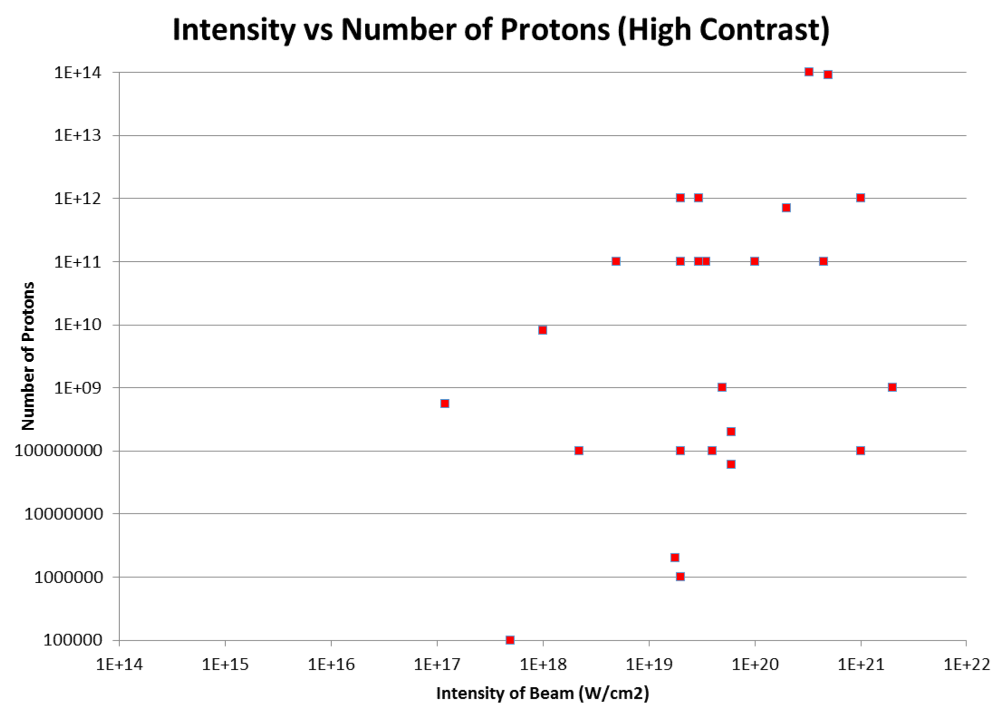
[73] M. Roth, S. Bedacht, S. Busold, O. Deppert, G. Schaumann, F. Wagner, A. Tebartz, D. Jung, D. Schumacher, A. Blažević, V. Bagnoud, F. Kroll, T.E. Cowan, C. Brabetz, K. Falk, A. Favalli, J. Fernandez, C. Gautier, C. Hamilton, R.P. Johnson, K. Schoenberg, T. Shimada, G. Wurden, M. Geißel, M. Schollmeier. ***BREAKING THE 70 MeV PROTON ENERGY THRESHOLD IN LASER PROTON ACCELERATION AND GUIDING BEAMS TO APPLICATIONS***. Proceedings of IPAC2014 1886-1889 (2014)

[107] M. Roth, D. Jung, K. Falk, N. Guler, O. Deppert, M. Devlin, A. Favalli, J. Fernandez, D. C. Gautier, M. Geissel, R. Haight, C. E. Hamilton, B. M. Hegelich, R. P. Johnson, A. Kleinschmidt, F. Merrill, G. Schaumann, K. Schoenberg, M. Schollmeier, T. Shimada, T. Taddeucci, J. L. Tybo, F. Wagner, S. A. Wender, C. H. Wilde, G. A. Wurden. **A bright neutron source driven by relativistic transparency of solids**. Journal of Physics: Conference Series 688 012094 (2016)

[158] Ingo Hofmann, Jürgen Meyer-ter-Vehn, Xueqing Yan, Husam Al-Omari. **Chromatic energy filter and characterization of laser-accelerated proton beams for particle therapy**. Nuclear Instruments and Methods in Physics Research A 681 44–54 (2012)

[187] B. M. Hegelich, D. Jung, B. J. Albright, M. Cheung, B. Dromey, D. C. Gautier, C. Hamilton, S. Letzring, R. Munchhausen, S. Palaniyappan, R. Shah, H.-C. Wu, L. Yin, and J. C. Fernández. **160 MeV laser-accelerated protons from CH_2 nano-targets for proton cancer therapy**. Plasma Physics (2013)



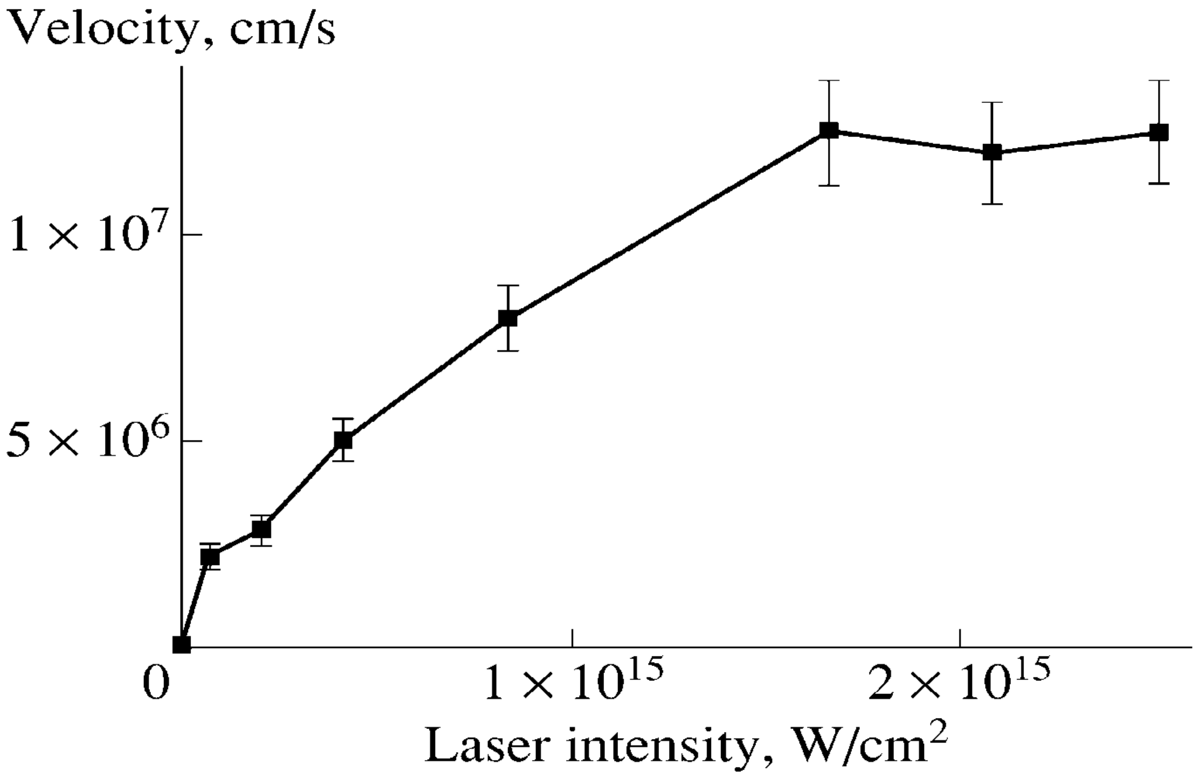


Critical Parameter

Number of Produced Ions

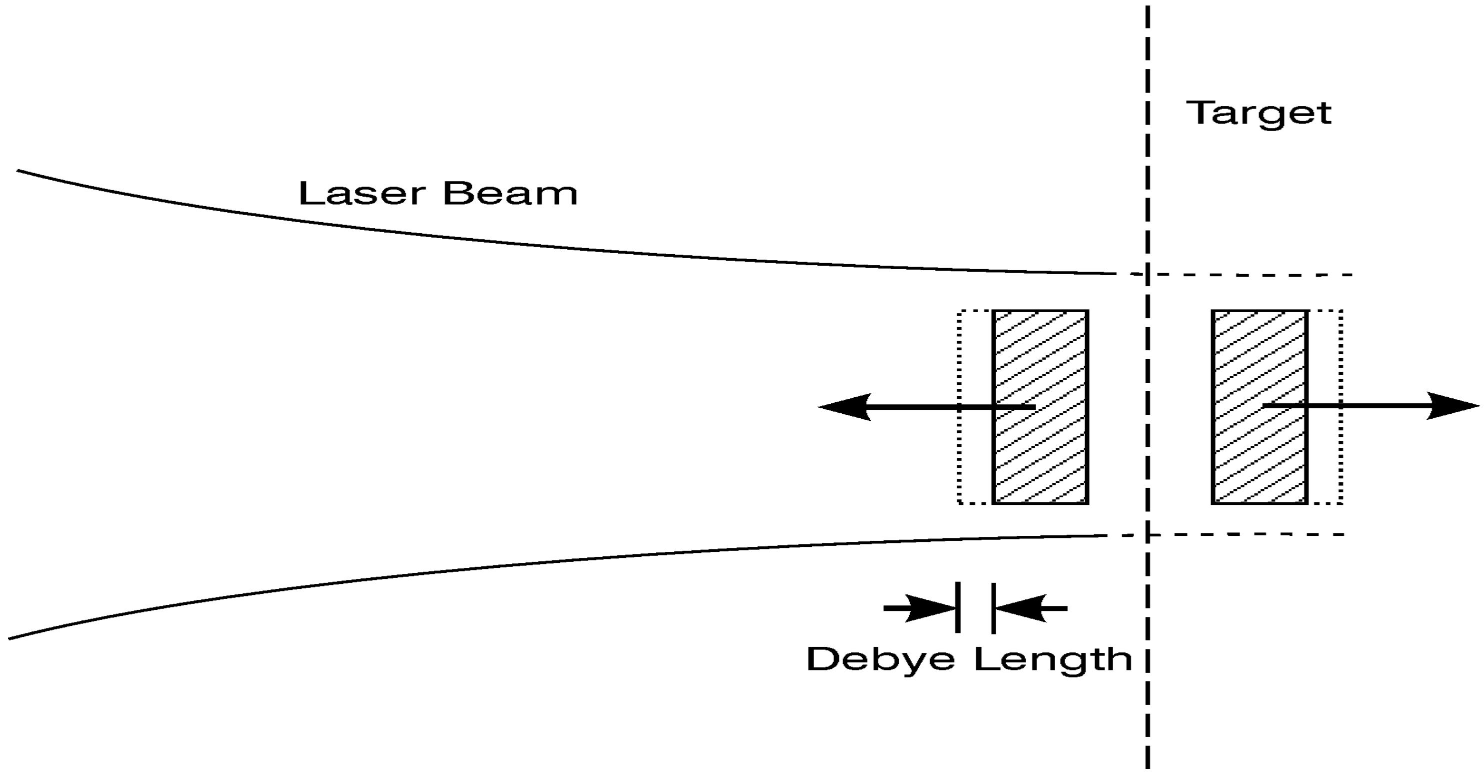
High Contrast Laser Beam Interaction with Solid Target

Plasma Block Acceleration of solid targets



*Intensity dependence of the velocity of the plasma front from the Doppler shift of the reflected 700fs KrF laser pulses from Aluminium target (**Földes,** Szatmari et al., 2000).*

Ultrahigh acceleration $2x10^{19}$ cm/s^2



Generation of directed **plasma blocks**, space charge neutral with ion current density

$$j > 10^{13}\ \text{Amps/cm}^2$$

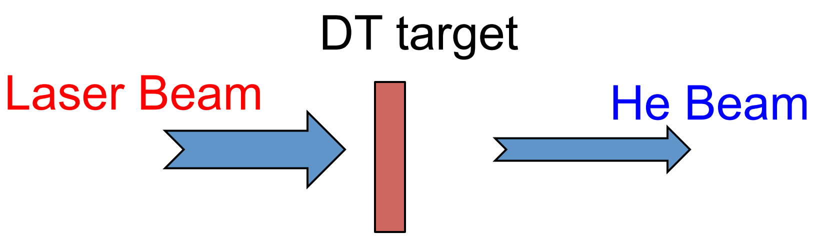
H. Hora, J. Badziak et al. Phys. Plasmas 14, 072701 (2007); H. Hora Laser and Particle Beams 27, 207 (2009)

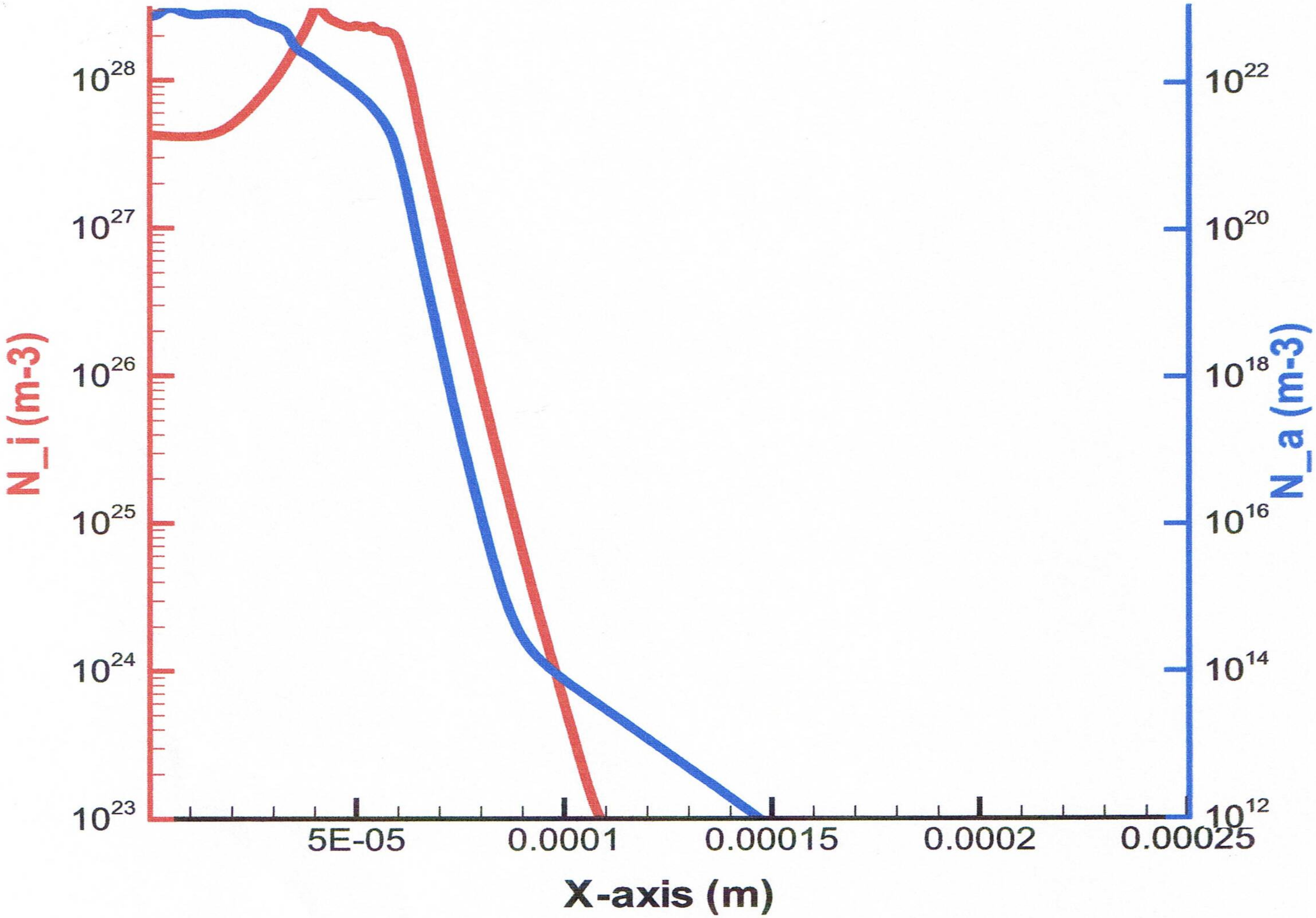
PLASMA BLOCK ACCELERATION

Thin film interaction: 0.5 ps 10^{21} W/cm^2 pulse of 5μm thick block to interact with 10μm solid DD (Gabor stopping).

Distribution of ion velocity u_i after 1.4 ps along the depth x of the generated expanding plasma:
D energy up to 75 MeV.

Alpha particle energy is higher (>150MeV)





Particle Density of D and He ions in the beam

.R. BANATI, H. HORA, P. LALOUSIS, S. MOUSTAIZIS,
"Ultrahigh laser acceleration of plasma blocks with ultrahigh ion density for fusion and hadron therapy",
Journal of Intense Pulsed Lasers and Applications in Advanced Physics, Vol. 4, No 1, p. 11-16, 2014.

COMMENTS

Numerical Investigations on the alpha heating effect induced in high density $H^{11}B$ fusion plasma by the injection of high energy alpha beam

Figures in the next transparencies show the temporal evolution of the fusion process in a high density $H^{11}B$ fusion plasma

Fig. 1 and fig. 4 present the temporal evolution of $H^{11}B$ plasma with different initial temperatures (30 keV and 40 keV)

Fig. 2 and fig. 3 show the effect of the interaction of the initial $H^{11}B$ plasma with an external injected high energy alpha beam

The alpha heating effect due to the interaction of the initial $H^{11}B$ plasma with the alpha beam. allow to improve the fusion process in the plasma.

The important result is that the time necessary for the reaction rate to achieve the maximum value (and consequently the temperature) is shorter than in the case without alpha beam, see the comparisons in fig. 2 and fig.3.

The Initial density of $H^{11}B$ plasma, for all plots, is 8 times the solid state density.

Initial density of $H^{11}B$, for all plots, 8 times solid state density.

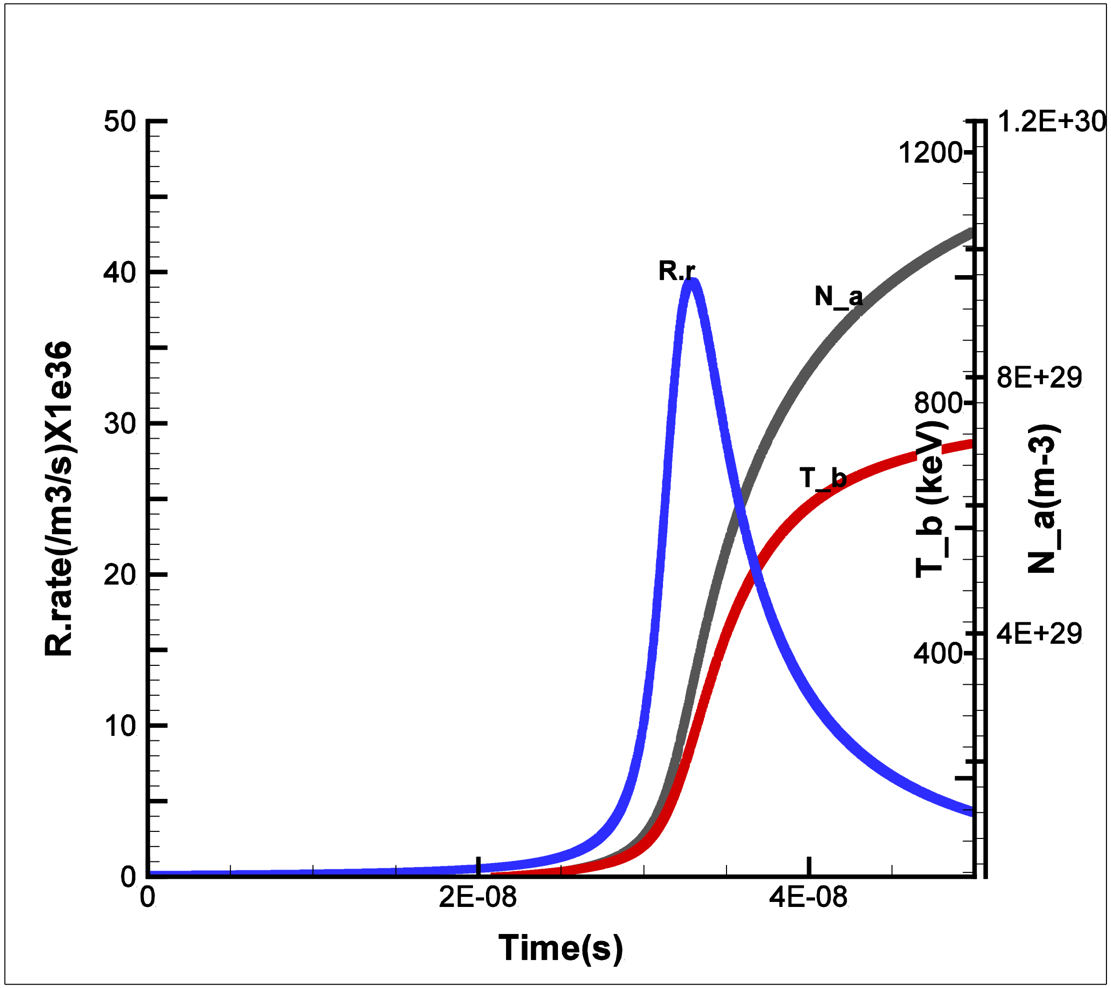


Fig. 1

Initial $H^{11}B$ temperature is 30keV.

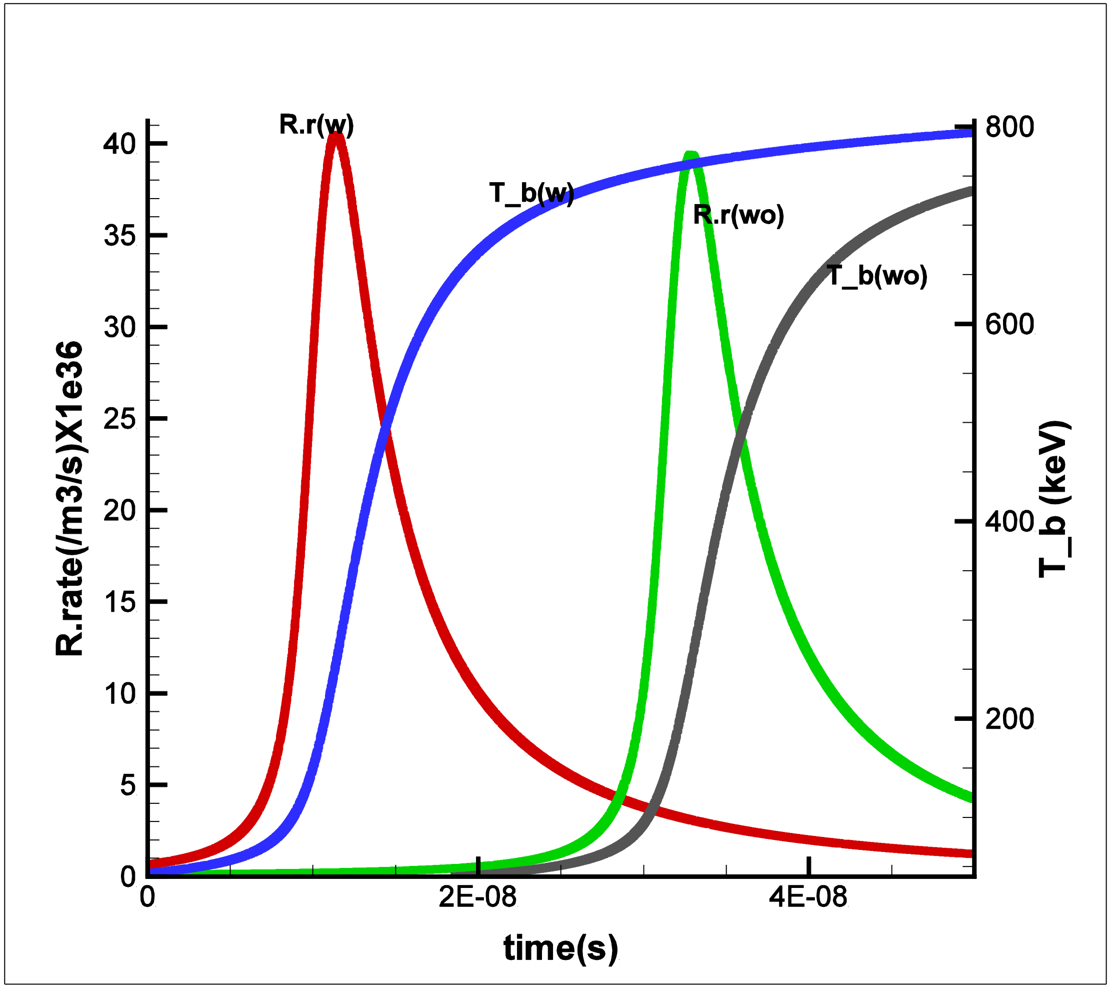
The maximum of reaction rate is at **32 ns**.

without initial alpha beam

Temporal evolution of plasma parameters

Blue line: Reaction rate, Red line: B11 Ion Temperature and Black line Density of alpha particles

Initial density of $H^{11}B$, for all plots, 8 times solid state density.



With alpha beam injection
the maximum of reaction rate
is at **11 ns**

Without alpha beam
The maximum of reaction rate
is at **32 ns**.

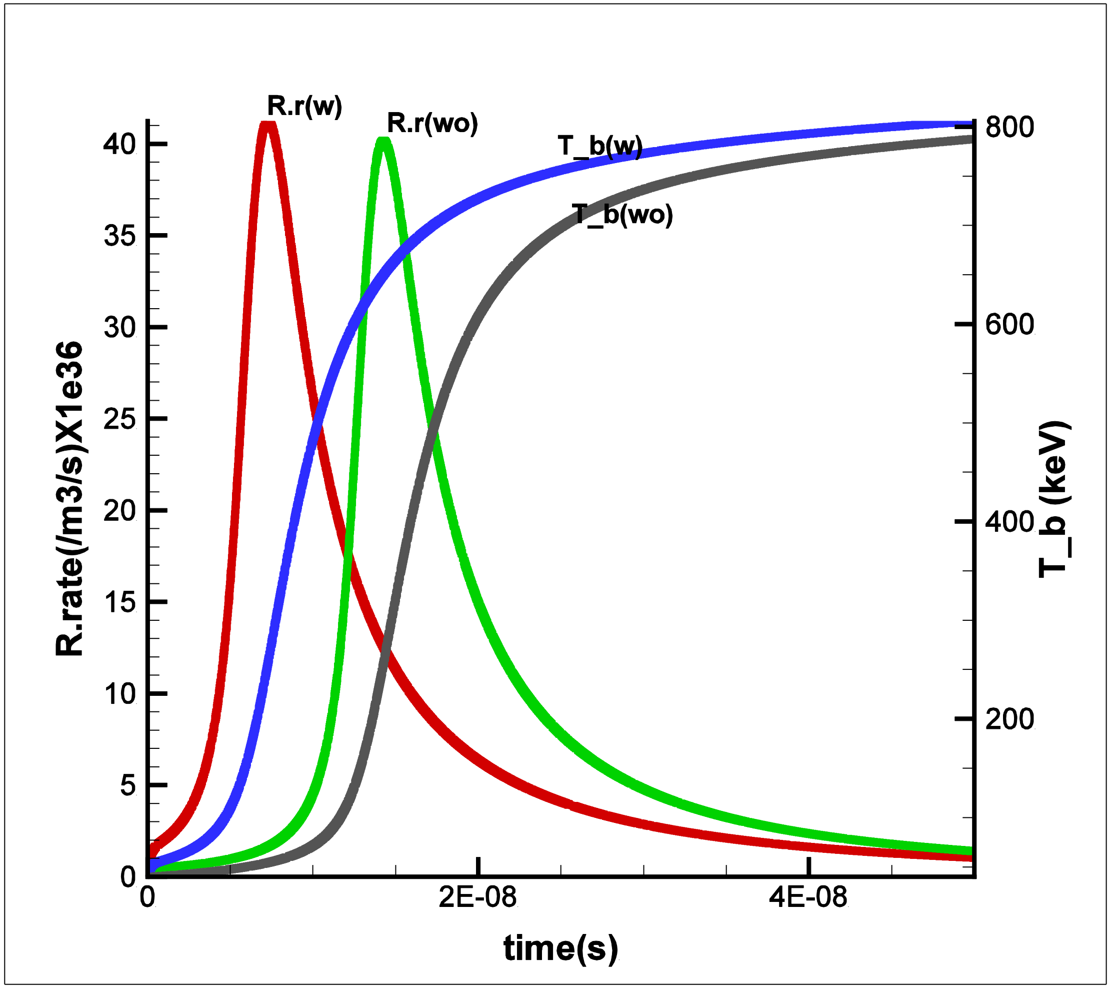
Fig. 2

Initial $H^{11}B$ temperature is **30 keV**

Temporal evolution of plasma parameters

Red line and Blue line present the temporal evolution of reaction rate and the B11 Ion temperature respectively
With (w) initial 1.0e27 m^{-3} alpha beam at **50 MeV Energy**.

Green line and Black line present the temporal evolution of reaction rate andB11 Ion temperature respectively
Without (wo) initial alpha beam



With alpha beam injection
the maximum of reaction rate
is at **7 ns**

Without alpha beam
The maximum of reaction rate
is at **12 ns**.

Fig. 3

Initial **H**^{11}B temperature is **40 keV**

Temporal evolution of plasma parameters

Red line and Blue line present the temporal evolution of reaction rate and the B11 Ion temperature respectively
With (w) initial 1.0e27 m^{-3} alpha beam at **50 MeV Energy**.

Green line and Black line present the temporal evolution of reaction rate and iB11 Ion temperature respectively
Without (wo) initial alpha beam

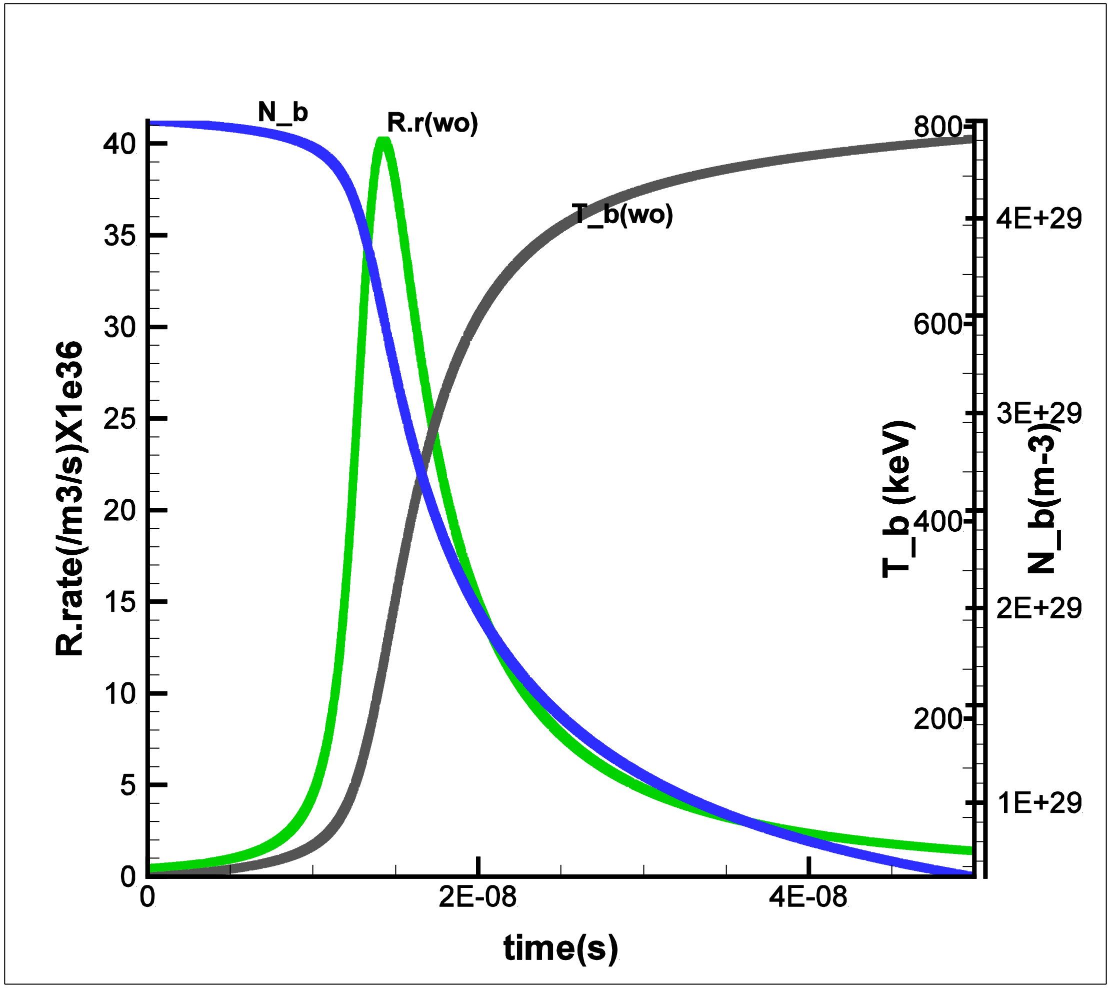


Fig. 4

Initial $H^{11}B$ temperature is 40 keV

without (wo) initial alpha beam

Temporal evolution of $H^{11}B$ plasma parameters

Green line: Reaction rate, Black line: B11 Ion Temperature and Blue line: Density of alpha particles

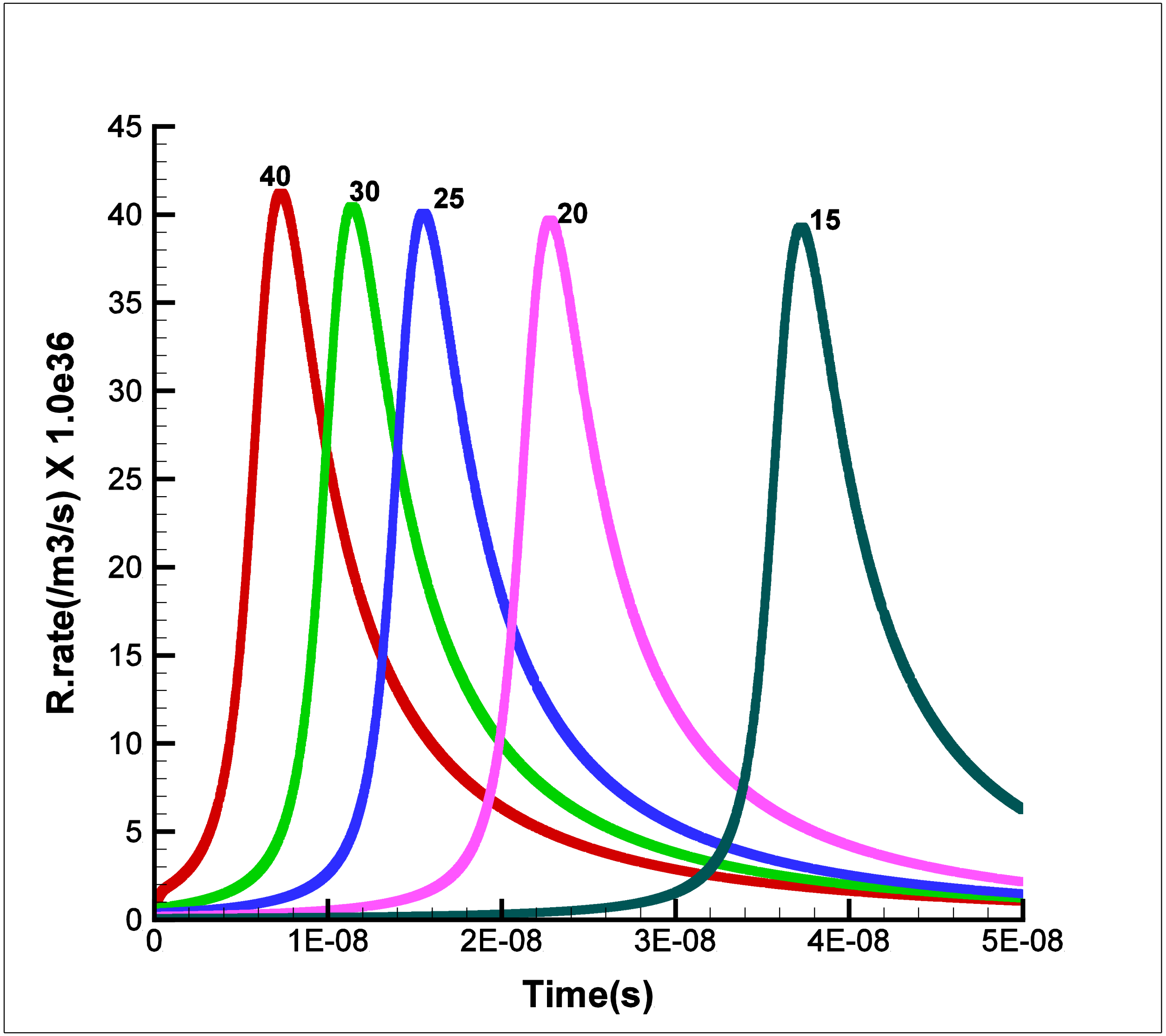


Fig. 5

Plots of reaction rates, for initial temperatures of $H^{11}B$ 40,30,25,20, &15 keV.

With initial 1.0e27 m^{-3} alpha beam at 50 MeV Energy.

Fusion Reactions in Magnetized Plasma

Development and operation of a Laser Based Compact Magnetic Device in open magnetic topology for study burning process and fusion ignition conditions

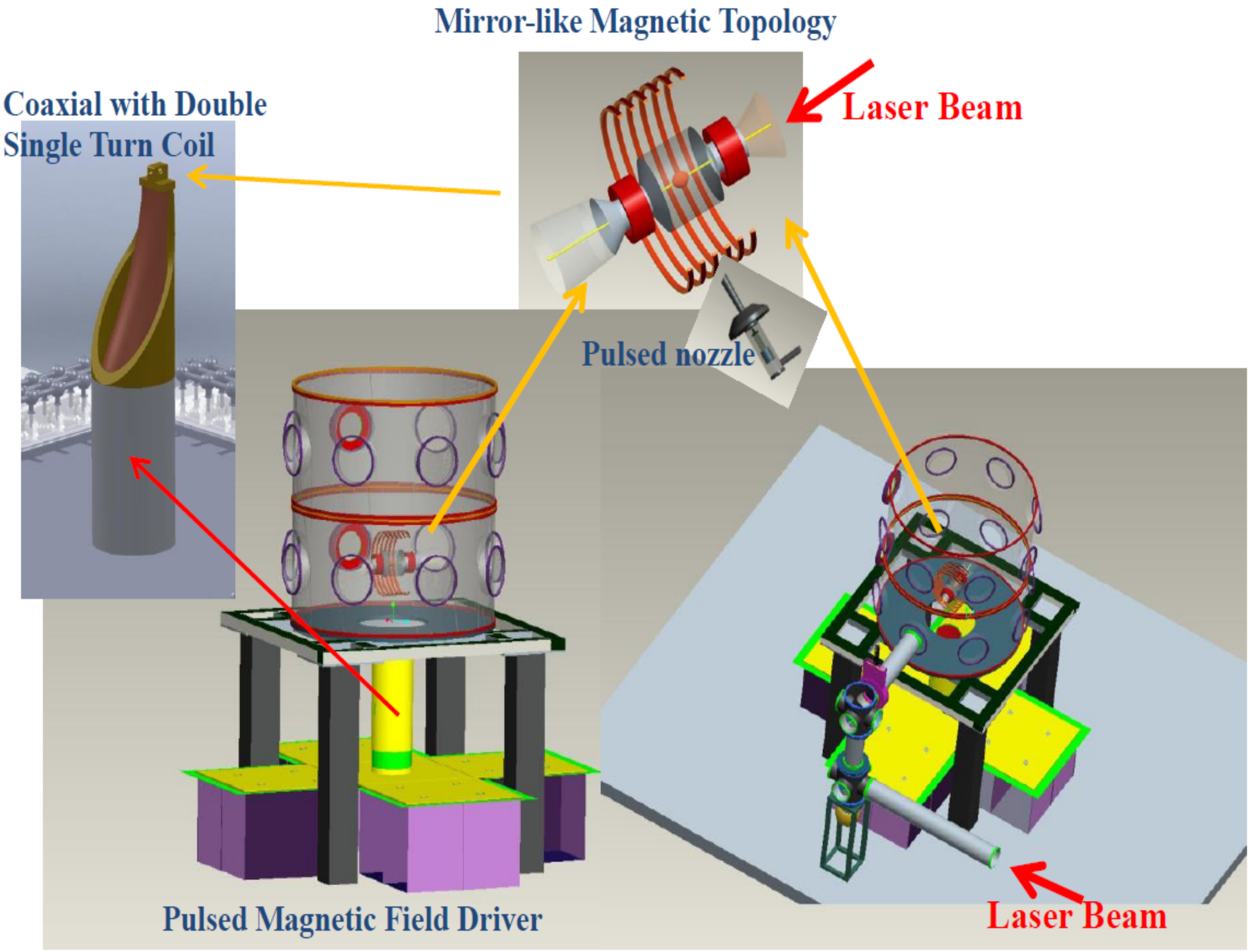
Use of a multi-fluid code allow to simulate:the spatio-temporal evolution of the plasma in different external applied magnetic field topologies

Laser-Driven high energy He beam

The interaction of He beam with high density $H^{11}B$ plasma (8 times or higher of solid density) improves the reaction rate and accelerates the fusion process

Numerical Investigations on the reaction rates and the alpha heating effect.

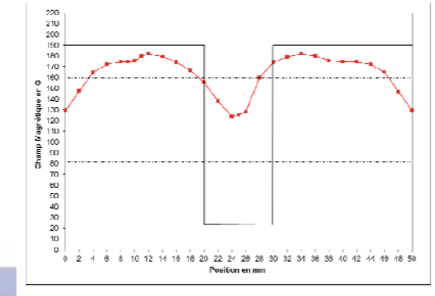
Ignite the fusion with low temperature plasma due to alpha heating effect

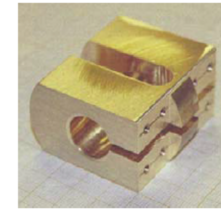


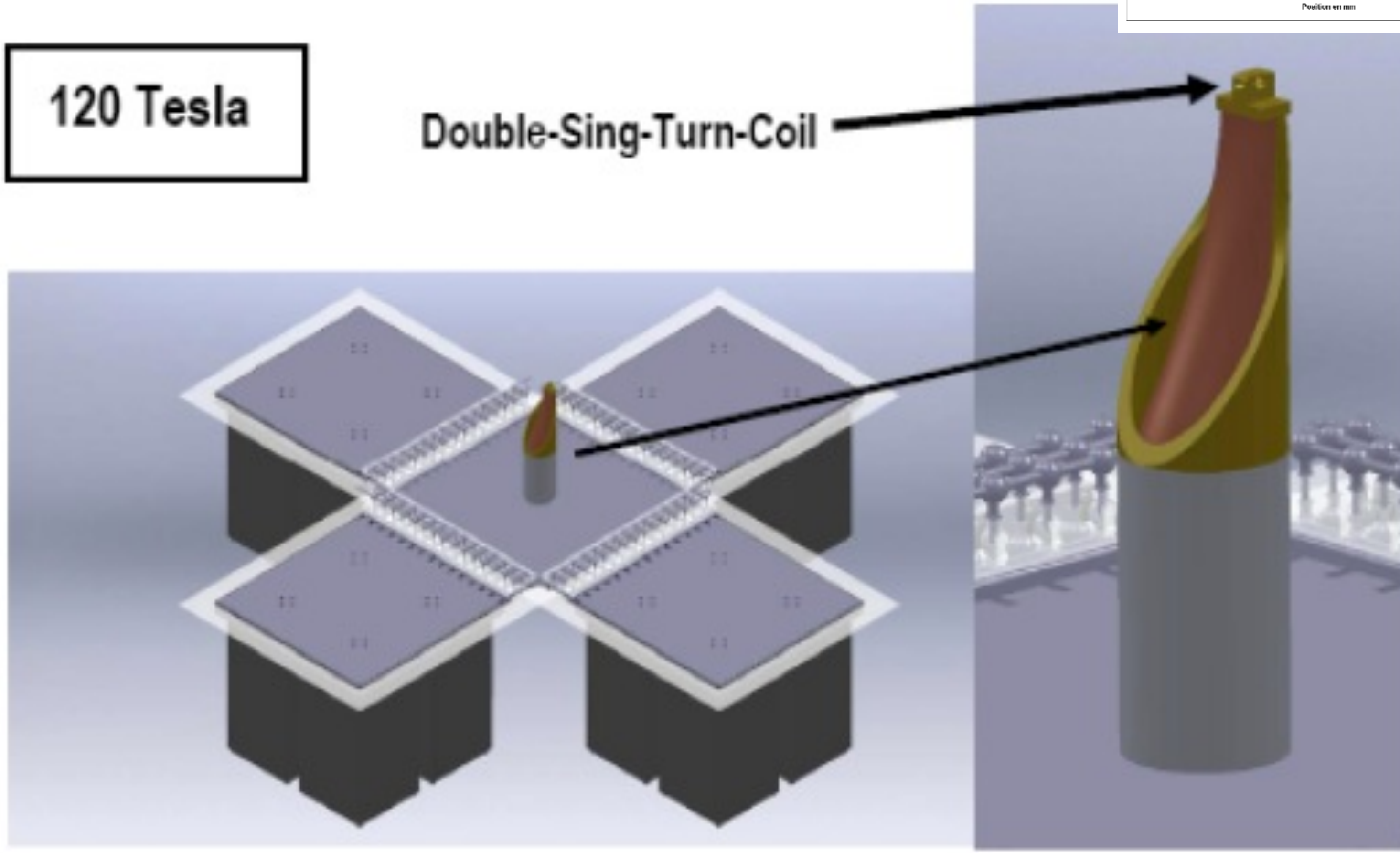
These activities are proposed within the ELI-NP Romanian Pillar (*)

(*)_F. NEGOITA, M. ROTH, P.G. THIROLF, S. TUDISCO, F. HANNACHI, S. MOUSTAIZIS, I. POMERANTZ , P. MCKENNA, J. FUCHS, K. SPHOR, G. ACBAS, A. ANZALONE, P. AUDEBERT, ... B. TATULEA, I.C.E. TURCU, M. VERSTEEGEN, D. URSESCU, S. GALES, N.V. ZAMFIR,
"Laser Driven Nuclear Physics at ELI-NP", **Romanian Reports in Physics, Vol. 68, Supplement, P.S37–S144, 2016**

Capacitor Bank : 4 Modules of 4 Capacitors



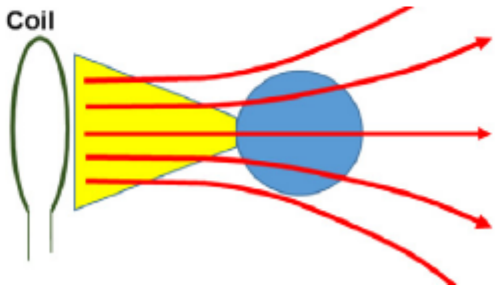




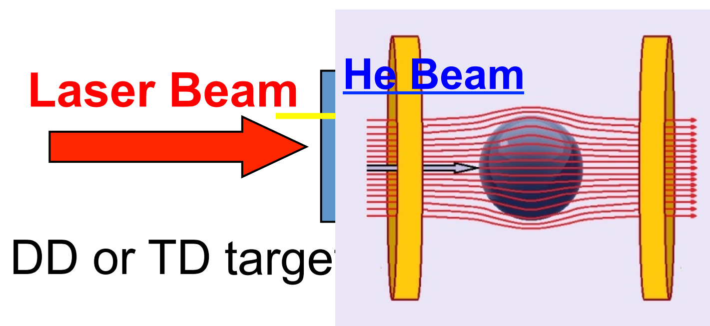
Collaboration P. Auvray andJ. Laroor from LPP Ecole Politechnique, Paris

We work on the development of a Multi-fluid code (with External Applied High Magnetic Field) and alpha heating efffect

Proposed Experiments

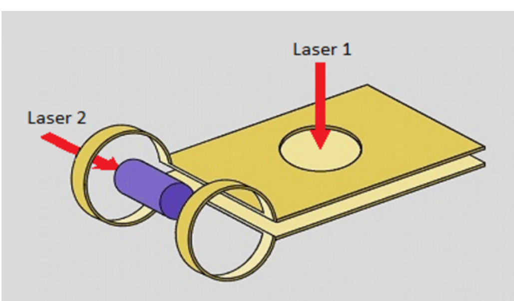


Computational study of magnetic field compression by laser-driven implosion
H. Nagatomo et al. Nucl. Fusion **55 (2015) 093028,** doi:10.1088/0029-5515/55/9/093028



Pulsed Power Technology

High Magnetic Field Driver



Laser Induced high magnetic Field

THANK YOU