Possibility of D-^{3}He Fusion Based on Fast-Ignition Inertial Confinement Scheme

ICENES 2007 (June.3rd~9th , 2007) , Istanbul

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1. Background

- **DT**

  About 80% of output energy is carried by Neutron

- **D^{3}He**

  Most is carried by Charged particles (By Neutron is few)

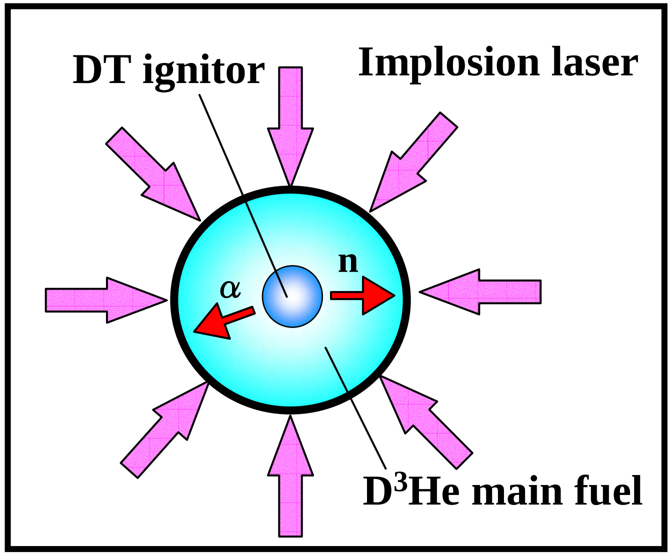
- **High efficient conversion of output energy**
- **Reduction of radioactivation of reactor**

Unrealistic driver energy is required

Need for adopting schemes which relax ignition condition

Scheme for relaxing the ignition requirements

DT / D^3He Pellet model



Placing a small amount of DT as ignitor inside the majority D^3He

DT ignitor reacts at first

α -particles and neutrons generated by DT reaction heat surrounding D^3He fuel

Igniting DT fuel while main D^3He fuel still imploding (Pre-ignition of DT fuel)

H. Nakashima, et al., Laser Part. Beams, 11, 137 (1993).

Can be resolved or mitigated by adopting fast ignition

M. Tabak, et al., Phys. Plasmas, 1, 1626 (1994).

Scheme of fast ignition

Divide laser irradiation into
Compression and ignition phases

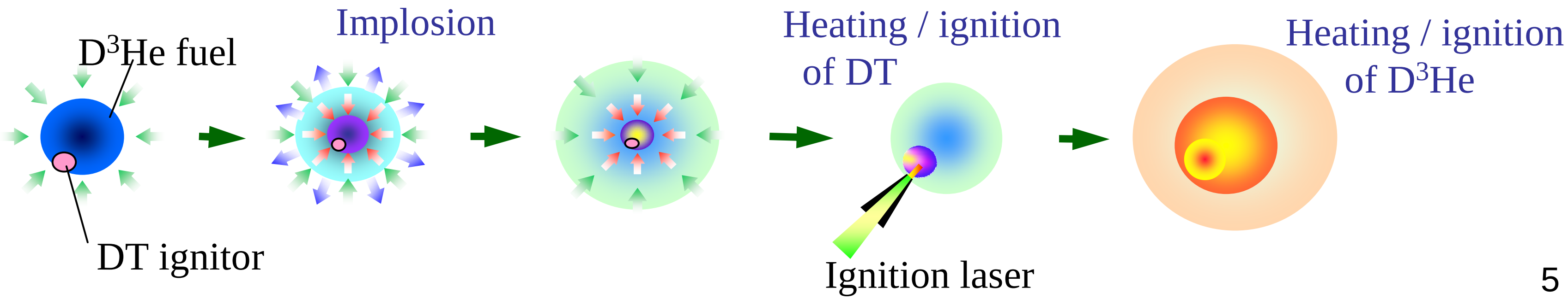
Central ignition
（Laser irradiation is
once）

By optimizing each laser ….

- ✓ **Preventing pre-ignition of DT ignitor**
- ✓ **Reduction of driver energy**

can be expected

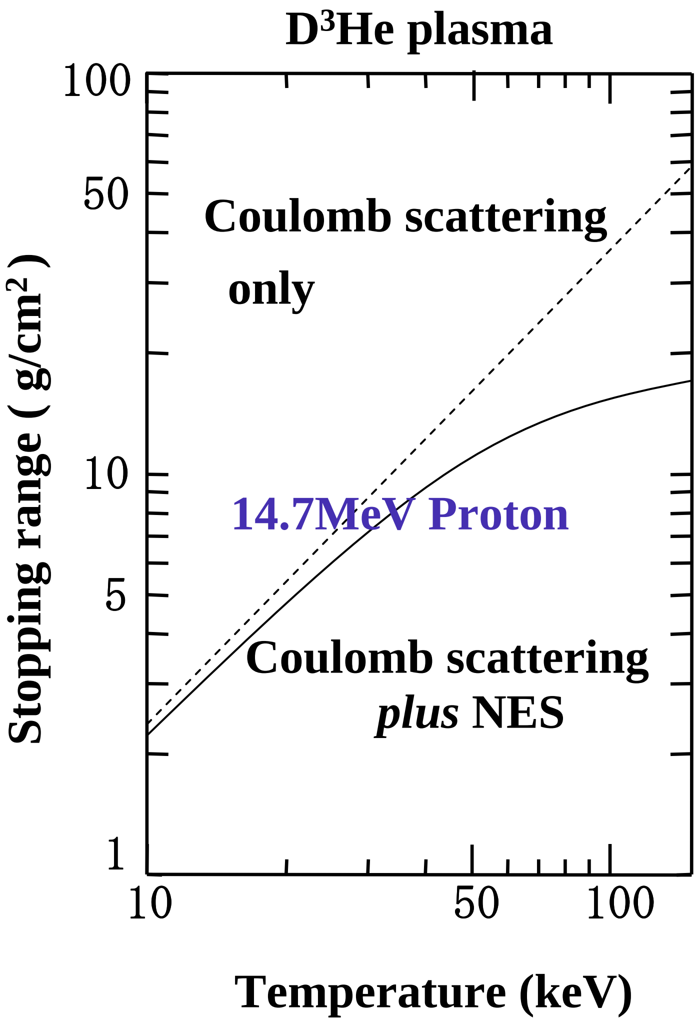
The possibility of obtaining pellet gain more than 50 with driver energy below 10 MJ



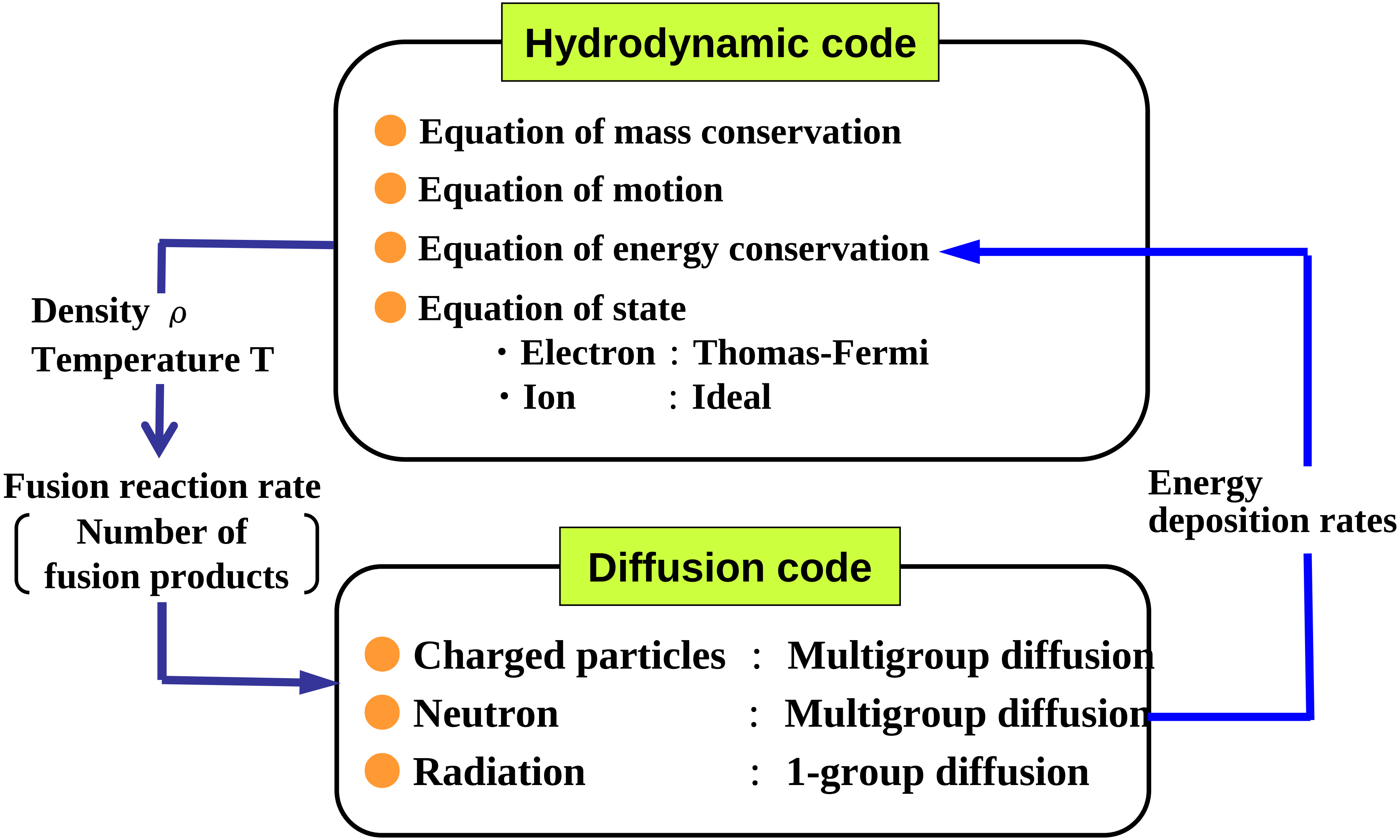
Nuclear reactions and scattering occurring in DT/D^{3}He plasmas

Thermonuclear fusion reactions	**Q (MeV)**
T (d, n) ^{4}He	17.59
D (d, p) T	3.27
D (d, n) ^{3}He	4.03
^{3}He (d, p) ^{4}He	18.35
Neutron interactions	
Elastic scattering	----
D (n, 2n) p	2.23
^{3}He (n, p) T	0.76
Charged-particle scattering	
Coulomb collision	----
NES*	----

*Nuclear Elastic Scattering



Structure of simulation code FIBMET



Hydrodynamic code

- Equation of mass conservation
- Equation of motion
- Equation of energy conservation
- Equation of state
  - Electron : Thomas-Fermi
  - Ion : Ideal

Density ρ

Temperature T

Fusion reaction rate

(Number of fusion products)

Diffusion code

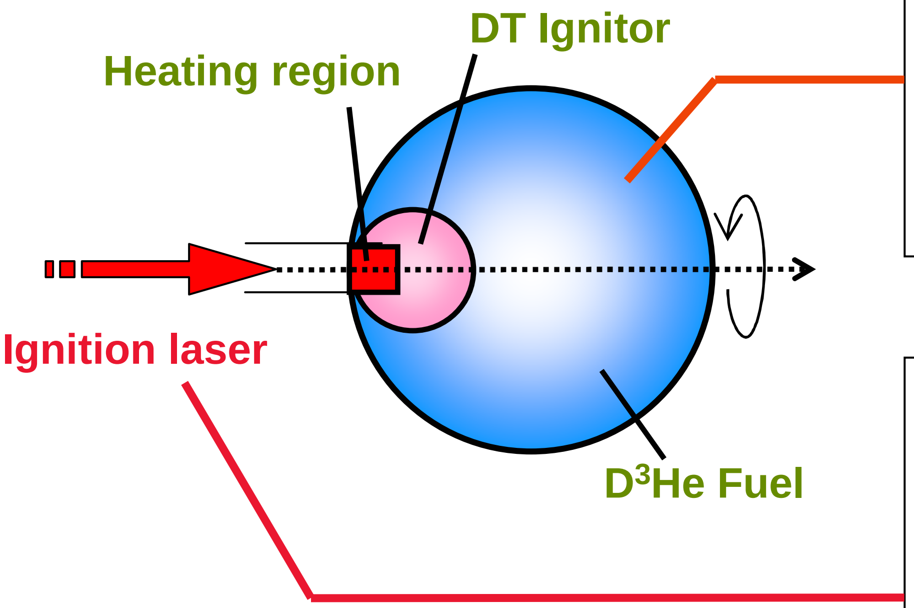
- Charged particles : Multigroup diffusion
- Neutron : Multigroup diffusion
- Radiation : 1-group diffusion

Energy deposition rates

Initial pellet condition and assumptions

- ✓ Simulation starts with the state after implosion
- ✓ Vary the ρR value of whole pellet ($\rho R_{total} = 8 \sim 12$ g/cm^2) and that of DT ignitor ($\rho R_{DT} = 2\sim5.5$ g/cm^2) respectively

Examine the possibility of obtaining pellet gains G > 50 with driver energy $E_d < 10$ MJ



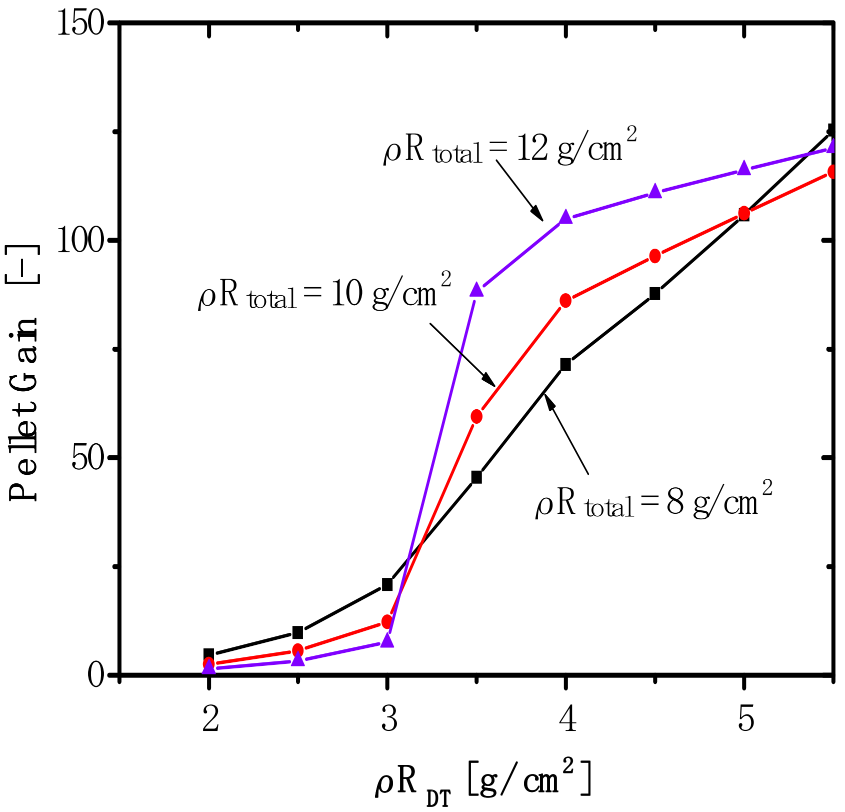
Initial Plasma State （ $\eta_{imp} = 10\%$ ）

Ion temperature	0.2 keV
Electron temperature	0.2 keV
Density of D^3He fuel	640 g/cm^3 ($\rho = 4000\,\rho_L$)
Density of DT igniter	640 g/cm^3 ($\rho = 4000\,\rho_L$)

Core Heating （ $\eta_c = 30\%$ ）

Duration time	30 ps
Spot diameter	30 μm
Optical depth	1.0 g/cm^2
Laser intensity	3.33×10^{20} W/cm^2
REB heating power	70.6 kJ

3. Results



Pellet gains of various-sized pellet as a function of igniter areal density *ρR*

Burn characteristics of a typical DT / D^{3}He fuel pellet

Initial fuel energy [MJ]	**0.67**	
Driver energy [MJ]	**6.9**	
Fusion energy production [MJ]	**412**	**(160)**
Contribution from		
T(d,n)^{4}He [%]	**23.3**	**(54.5)**
D(d,n)^{3}He [%]	**6.0**	**(6.3)**
D(d,p)T [%]	**6.7**	**(7.1)**
^{3}He(d,p)^{4}He [%]	**64.0**	**(32.1)**
Output energy carried by		
Plasma particles [%]	**59.8**	**(33.8)**
Radiation [%]	**21.3**	**(22.8)**
Neutrons [%]	**18.9**	**(43.4)**
Pellet gain	**59.4**	**(23.0)**

$\rho = 4000\,\rho_L$, $\rho R_{total} = 10$ g/cm^2, $\rho R_{DT} = 3.5$ g/cm^2

Internal energy = 0.67 MJ

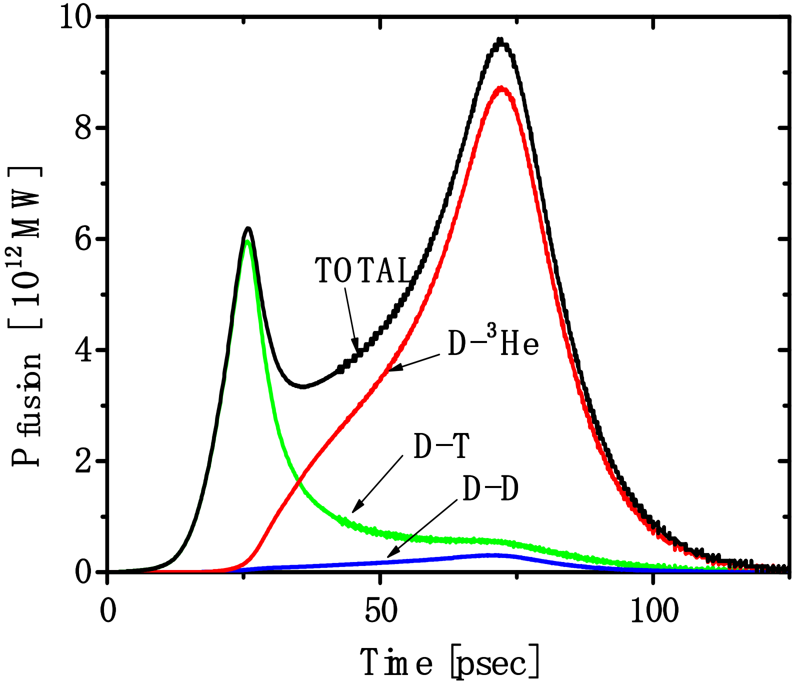
The values in parentheses are result from neglecting NES of 14.7MeV protons

Time evolution of fusion power generation

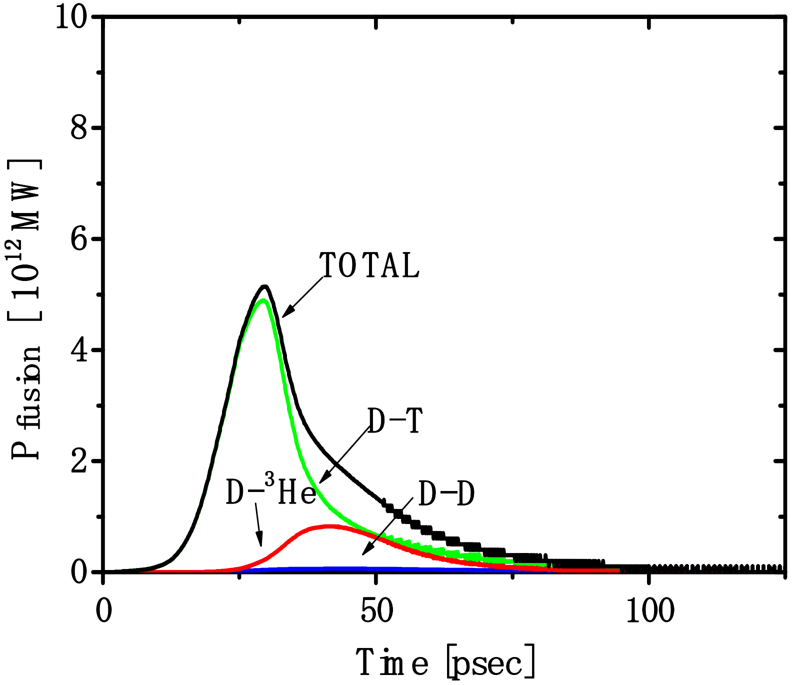
$\rho_{D^3He} = \rho_{DT} = 640$ g/cm^3 $\rho R_{tot} = 10.0$ g/cm^2

$T_i = T_e = 0.2$ keV $\rho R_{DT} = 3.5$

g/cm^2



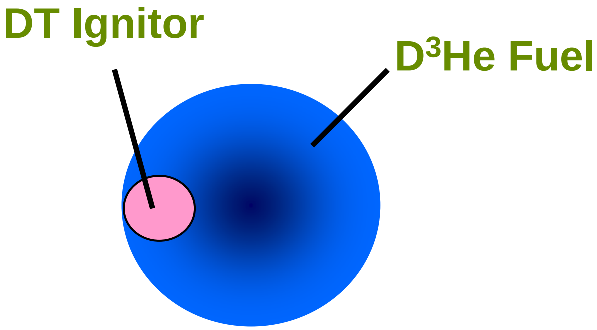
With neutron heating



Without neutron heating

Comparison with previous calculation

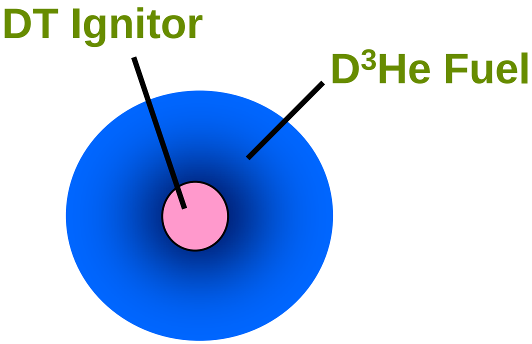
Present calculation
(Fast ignition)



$\rho R_{DT} = 3.5\ \mathrm{g/cm^2}$, $\rho R_{tot} = 10\ \mathrm{g/cm^2}$

Driver energy	~7 [MJ]
Pellet gain	~60
N fraction	~19 [%]

Previous calculation
(Central ignition)



$\rho R_{DT} = 3.0\ \mathrm{g/cm^2}$, $\rho R_{tot} = 14\ \mathrm{g/cm^2}$

Driver energy	~30 [MJ]
Pellet gain	~50
N fraction	~4 [%]

Summary

We have examined the burn characteristics of DT/D^{3}He pellet models in the fast-ignition scheme, assuming initial states to be compressed to 4000 times the liquid density.

- **It is possible to achieve sufficient pellet gains (>50) with reasonable driver energy below 10MJ.**
- **The fraction of fusion output energy carried by neutrons is increased compared to the case of central ignition.**
- **The neutron energy fraction may be further reduced by considering the optical shape of the DT ignitor.**
  ex. cylindrical ignitor etc

Fusion reactions occurring in DT/D^{3}He plasma

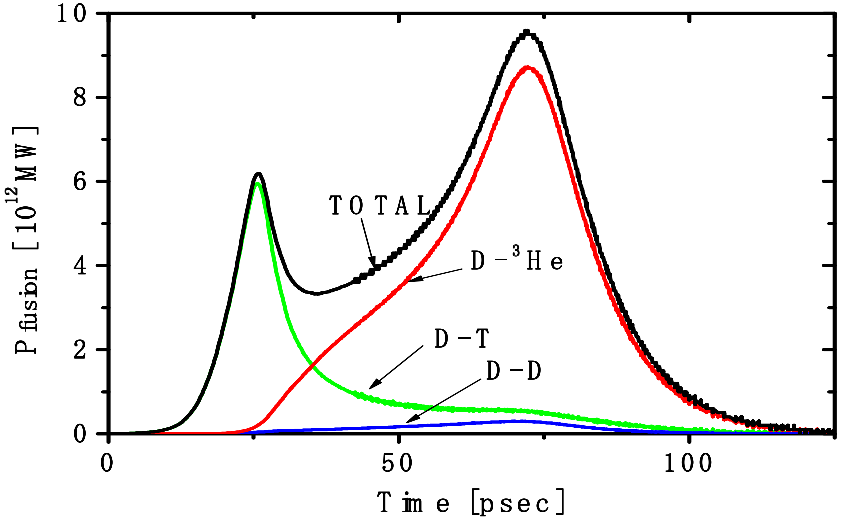
$D+{}^3He \rightarrow {}^4He(3.67MeV)+p(14.67MeV)$ (Main fuel)

$D+T \rightarrow {}^4He(3.52MeV)+n(14.06MeV)$ (Ignitor)

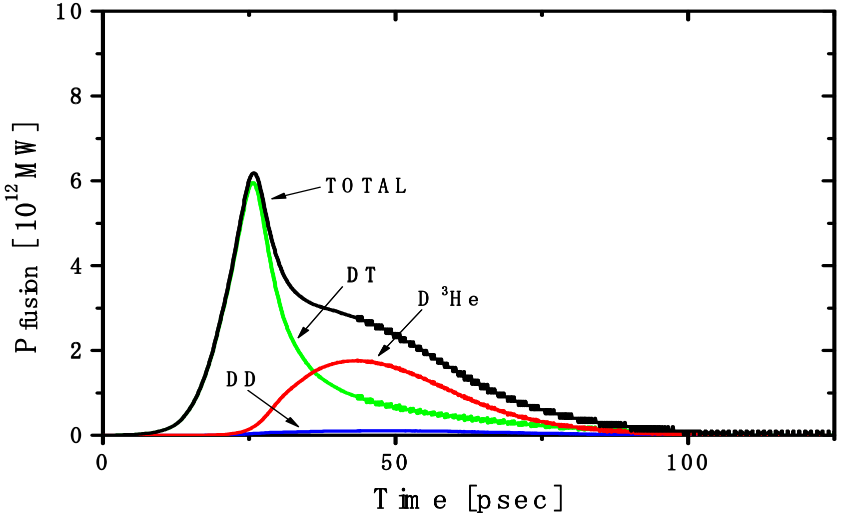
$D+D \rightarrow {}^3He(0.82MeV)+n(2.45MeV)$

$D+D \rightarrow T(1.01MeV)+p(3.03MeV)$

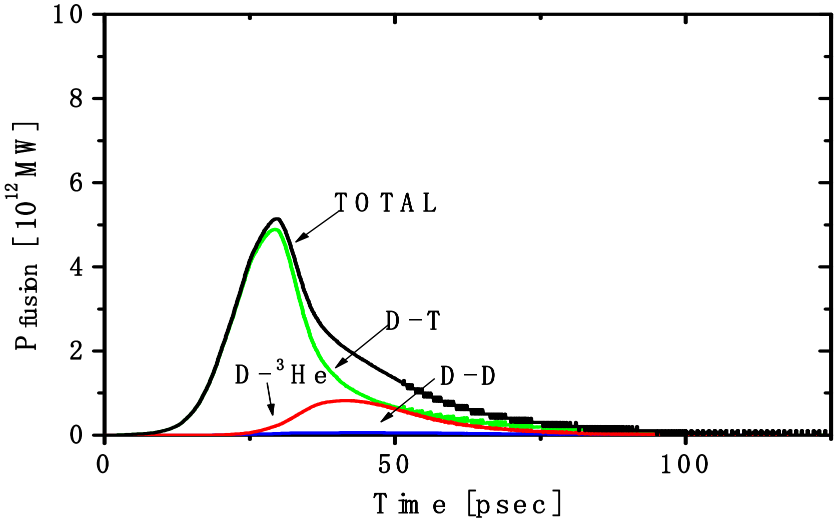
Time evolution of fusion power generation



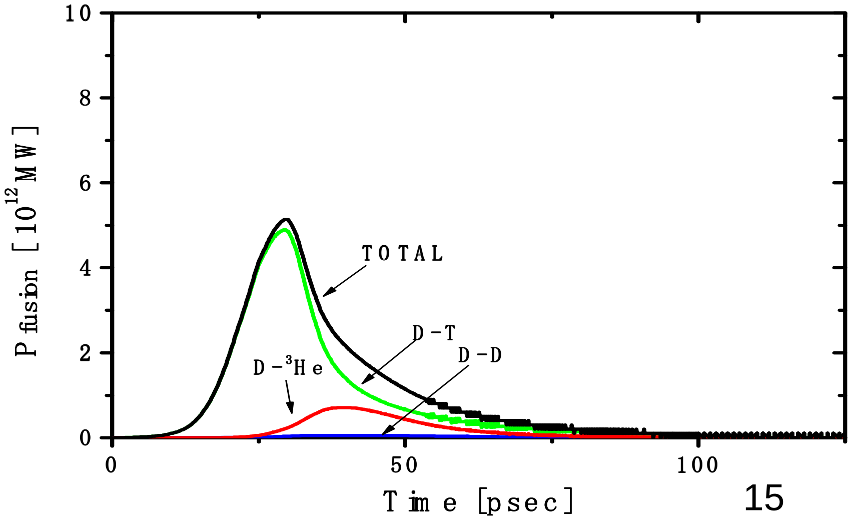
Coulomb + NES + Neutron heating



Coulomb + Neutron heating



Coulomb + NES



Coulomb only