

# **FIREX(Fast Ignition Realization Experiment) toward Fusion Burn by Fast Ignition**

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**In collaboration with Rutherford Appleton Lab.  
and Imperial College, UK**

**Snowmass 2002 Fusion Energy Science Study, July 11, 2002**

# Outline

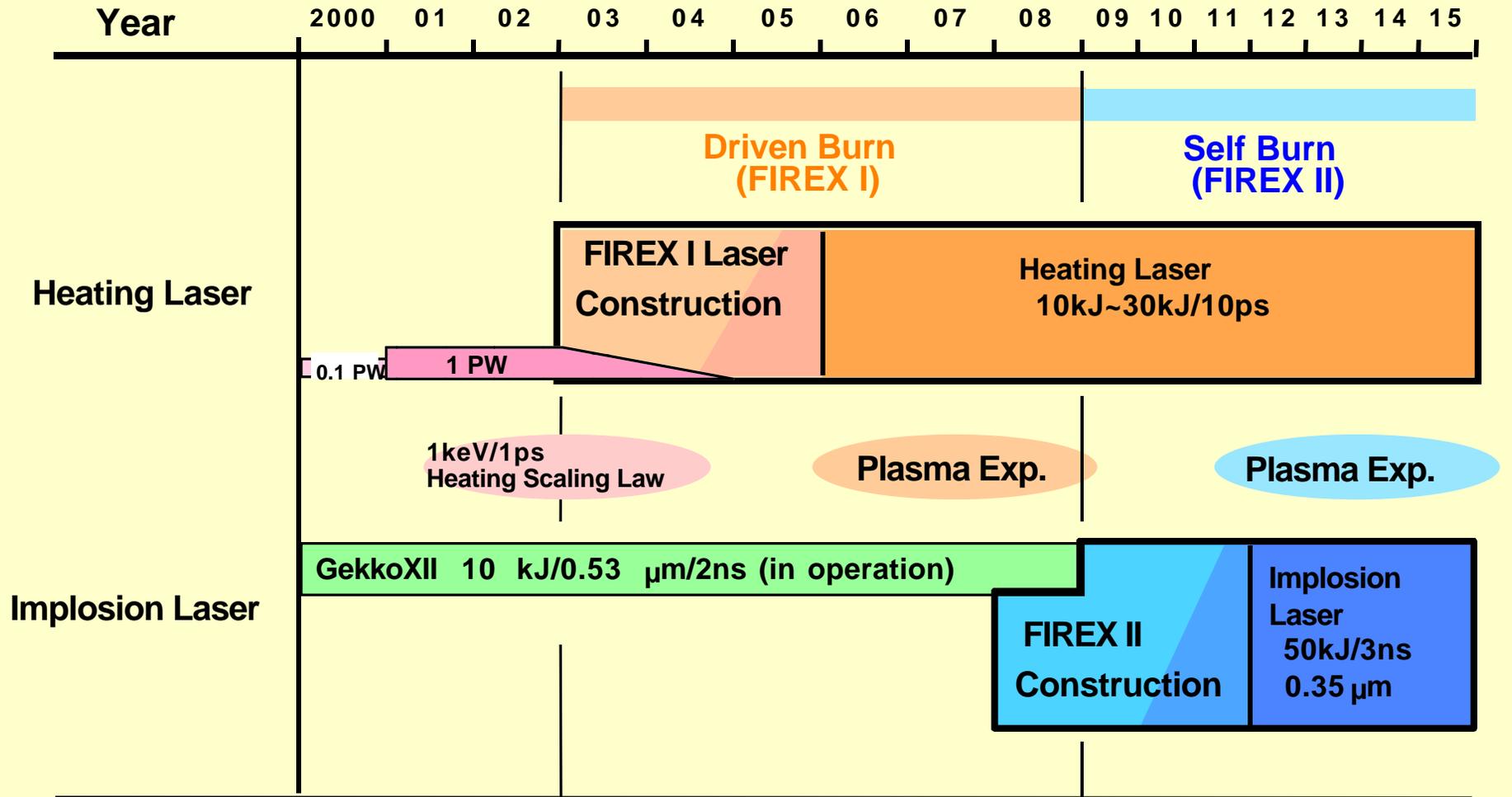
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- **FIREX Objectives and Plan**
- **Integrate Code Development**
- **Cone target laser plasma interactions and micro laser plasma focusing optics**
- **Electron transport and fusion gain**
- **Summary and future prospects**

# Fast Ignition Realization Experiment(FIREX) Project (Aiming at ignition with 30kJ CPA laser)

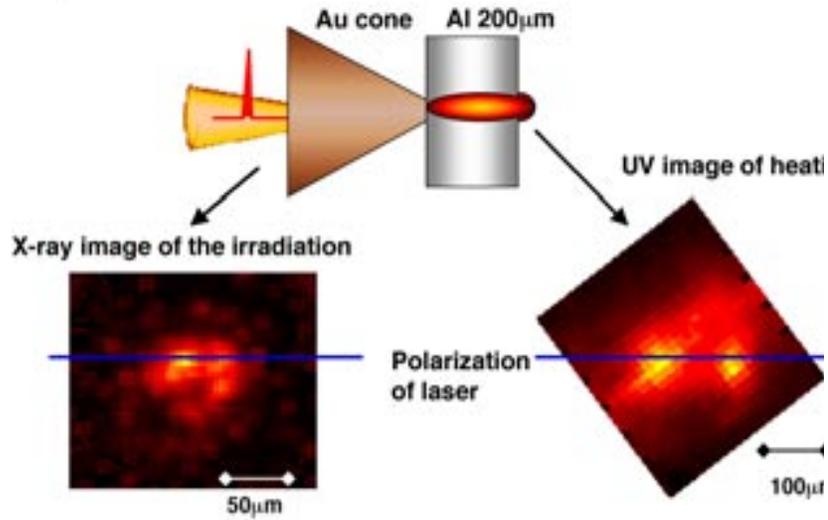


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### Energetic Electron Beam was Created at the Top of the Cone

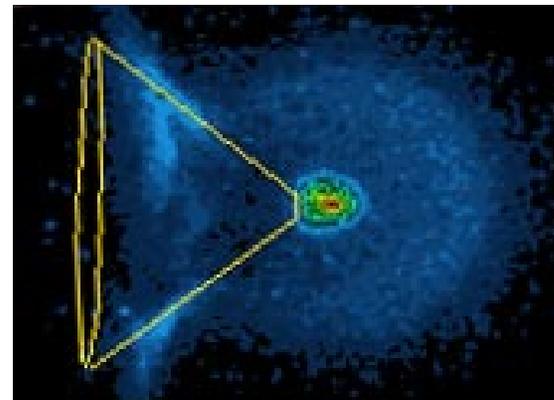
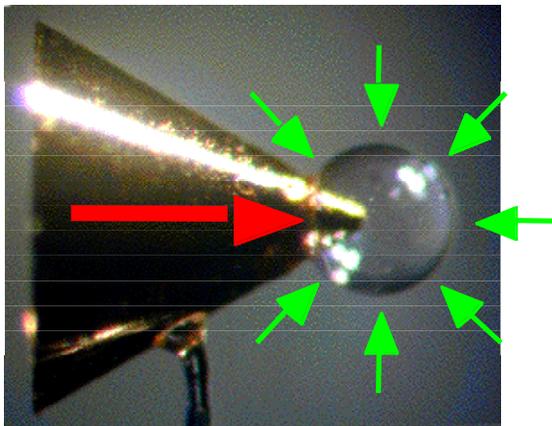
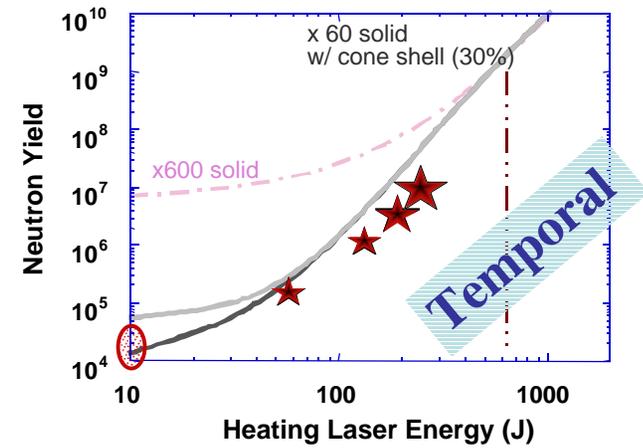
Energetic electrons from the cone heated the solid Al (200 $\mu\text{m}$ ). The heating pattern is consistent with that of the laser absorption, indicating 20-30% divergence beam.



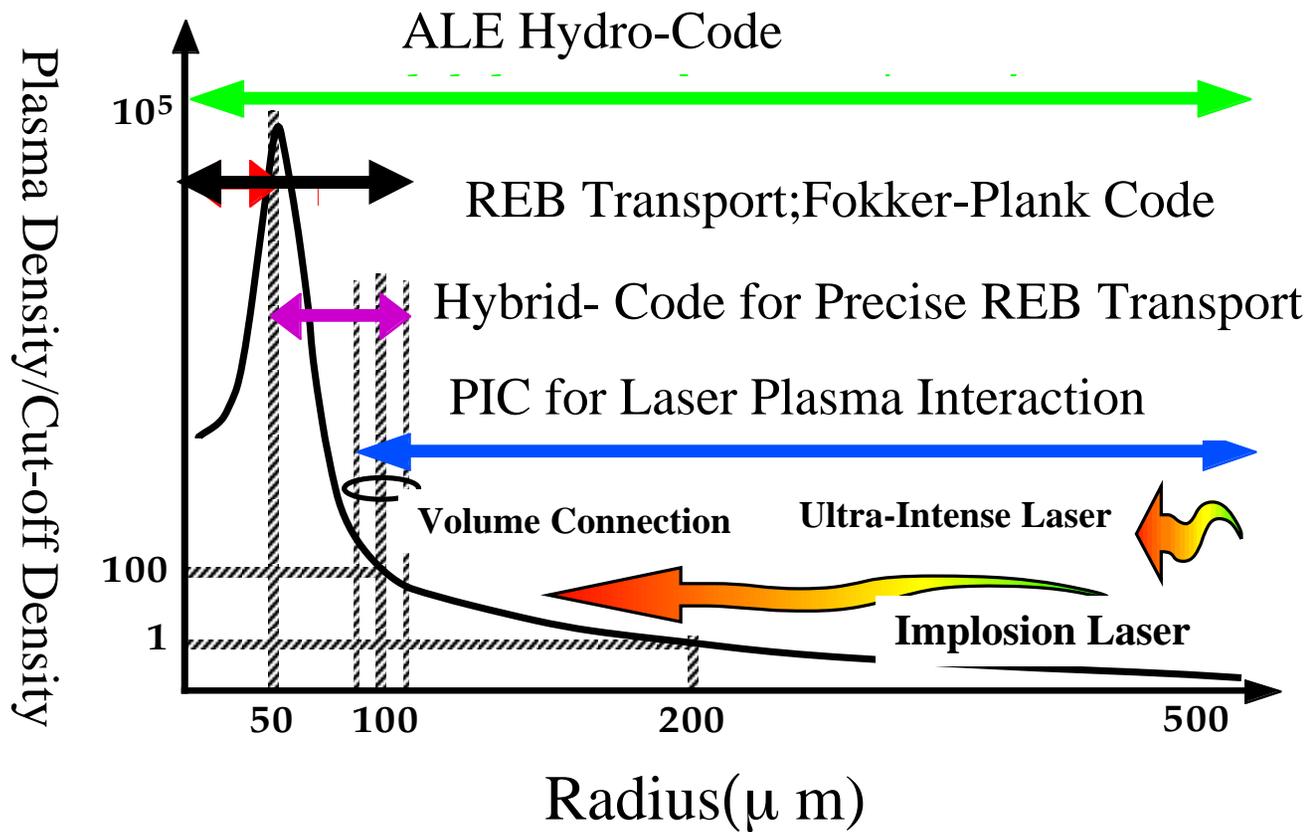
R.Kodama

### Clear Enhancement was Observed in Thermal Neutrons

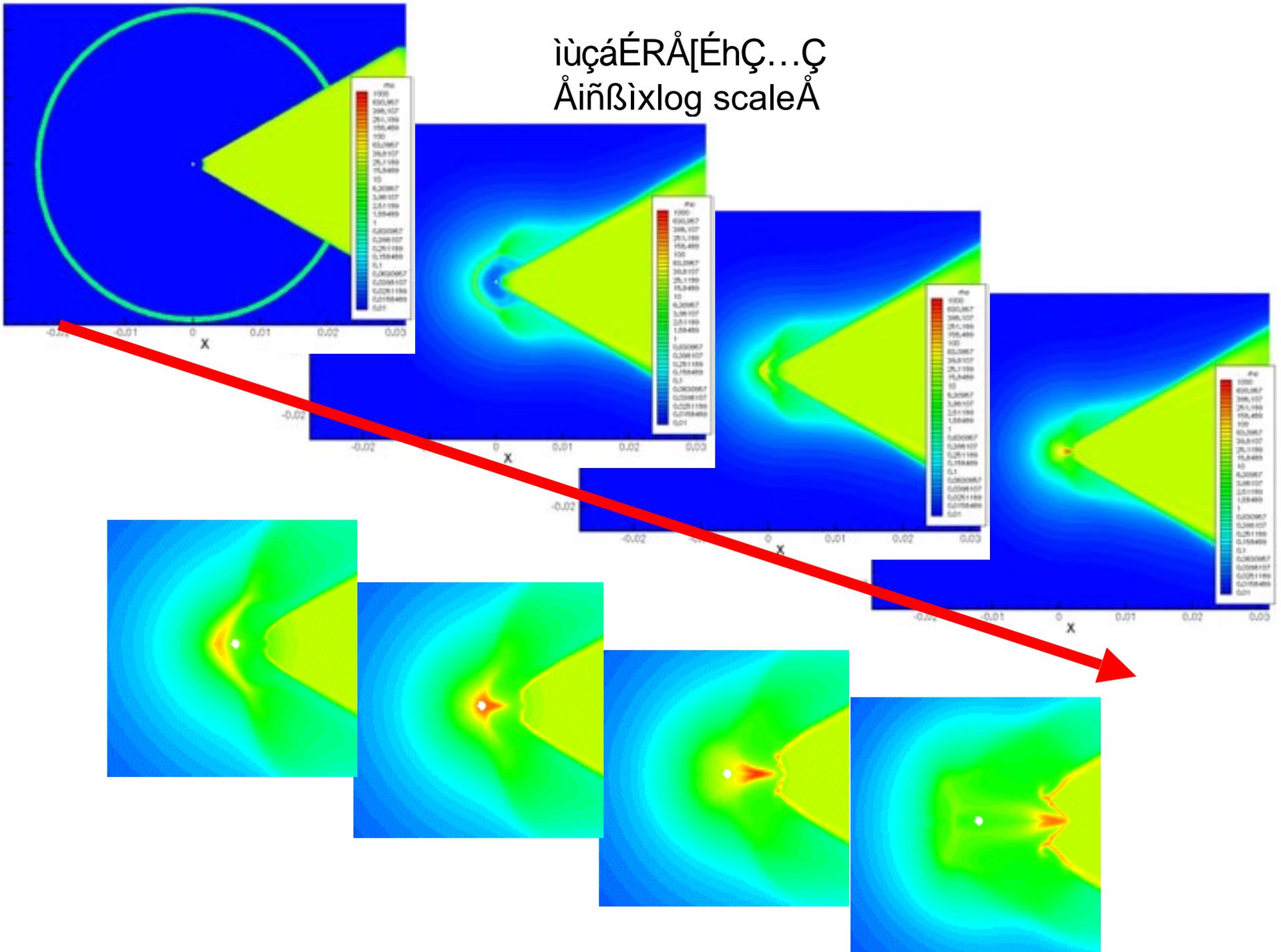
Enforced heating was realized at a heating power close equivalent to the ignition condition.



# Integrated Code for Fast Ignition

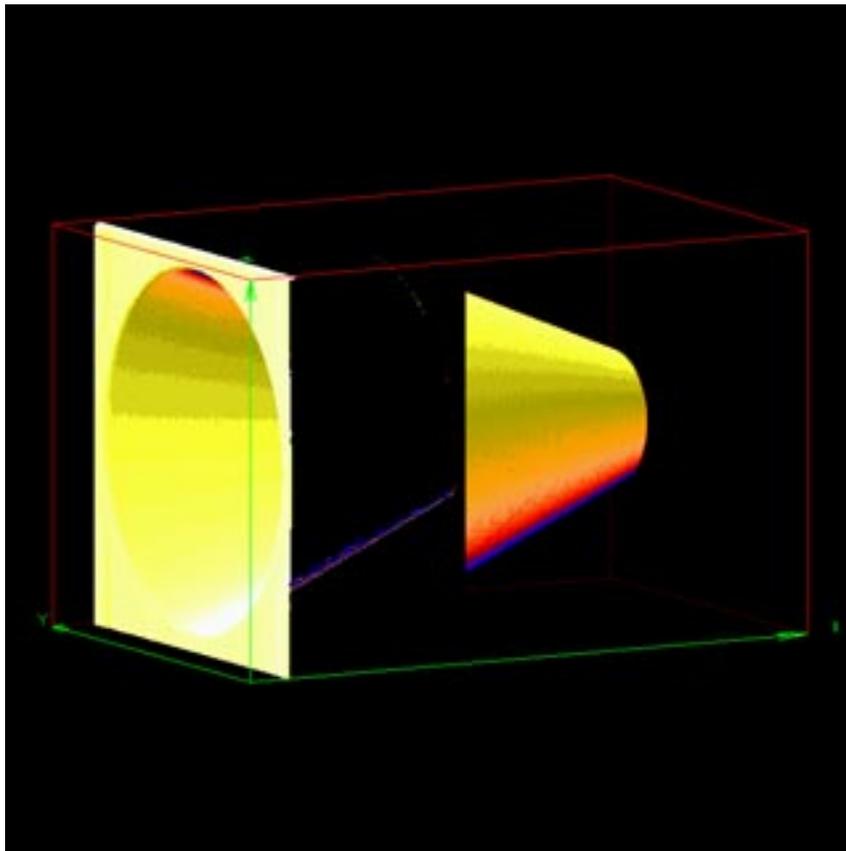


Ψ  
Αιñβixlog scale



# Simulation Parameter

## - 3D PIC -



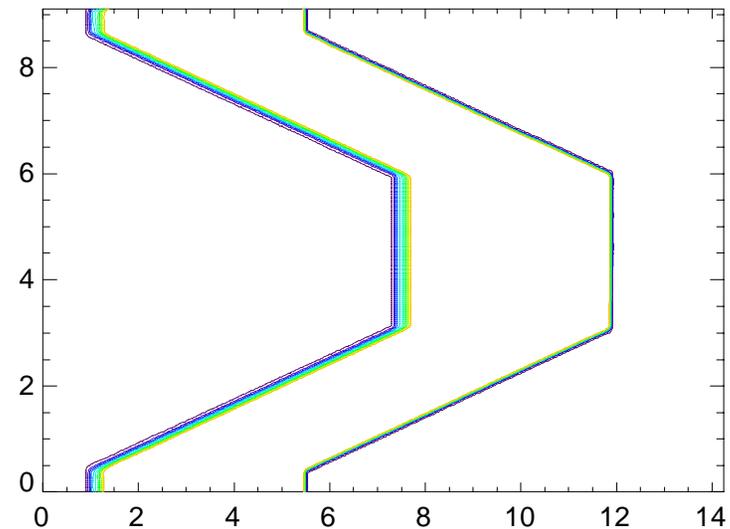
**Laser Amplitude  $a = 1.5$**   
**( $I = 5 \cdot 10^{18} \text{ W/cm}^2$ )**

**Pulse Width  $L_w = 6 \mu\text{m}$**

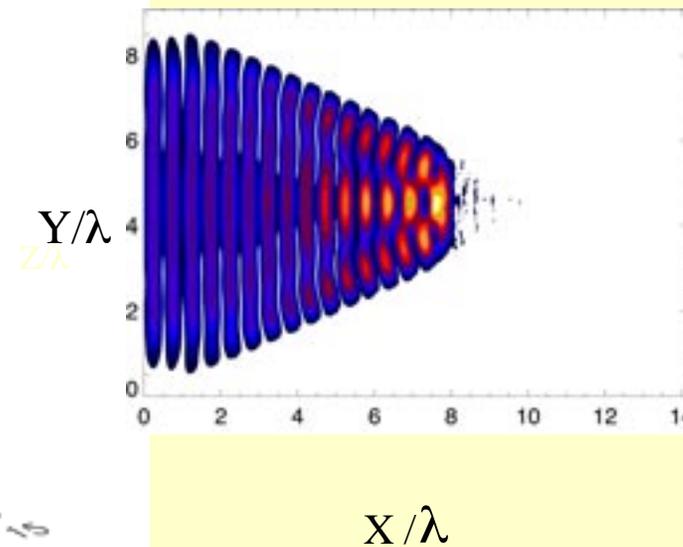
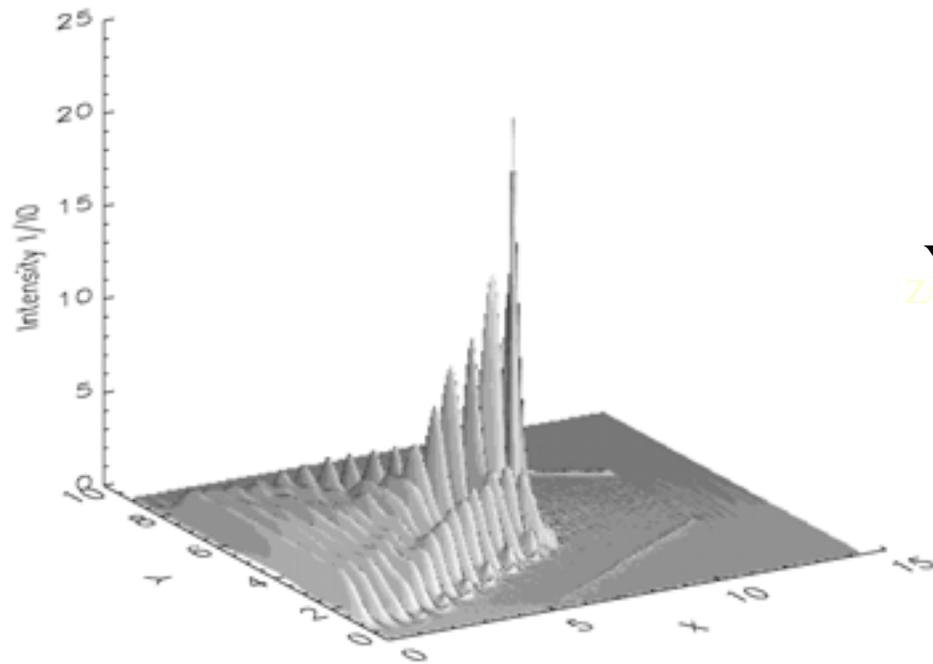
**Cone :  $5 n_c$ ,**

**depth =  $6.5 \mu\text{m}$ , width =  $8 \rightarrow 3 \mu\text{m}$**

**Simulation Box :  $14 \mu\text{m} \times 9 \mu\text{m} \times 9 \mu\text{m}$**

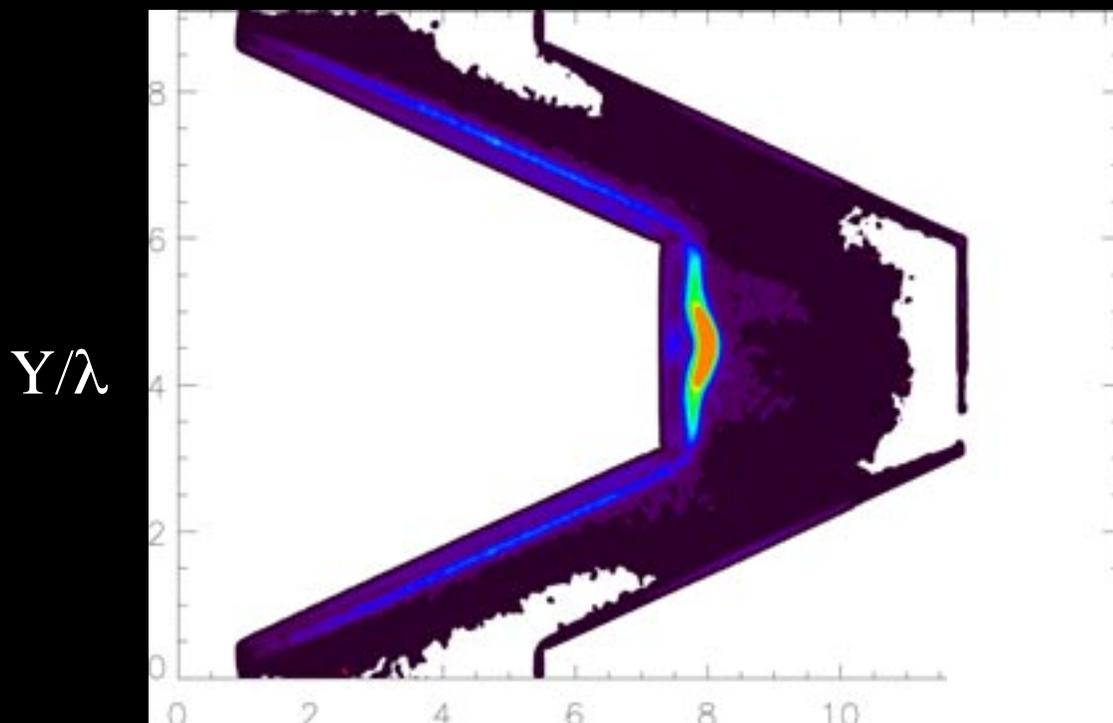


# Laser Intensity Profile in cone target at $t=16\tau$



The focused intensity reaches 20 times larger than  $I_0$

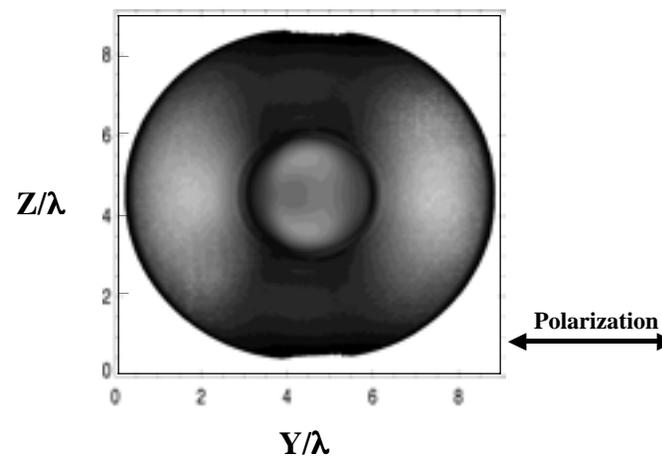
# Electron Energy Density $(\gamma-1)n_e/n_c$ at $t=16\tau$



$X/\lambda$

Contour Level: 0-25

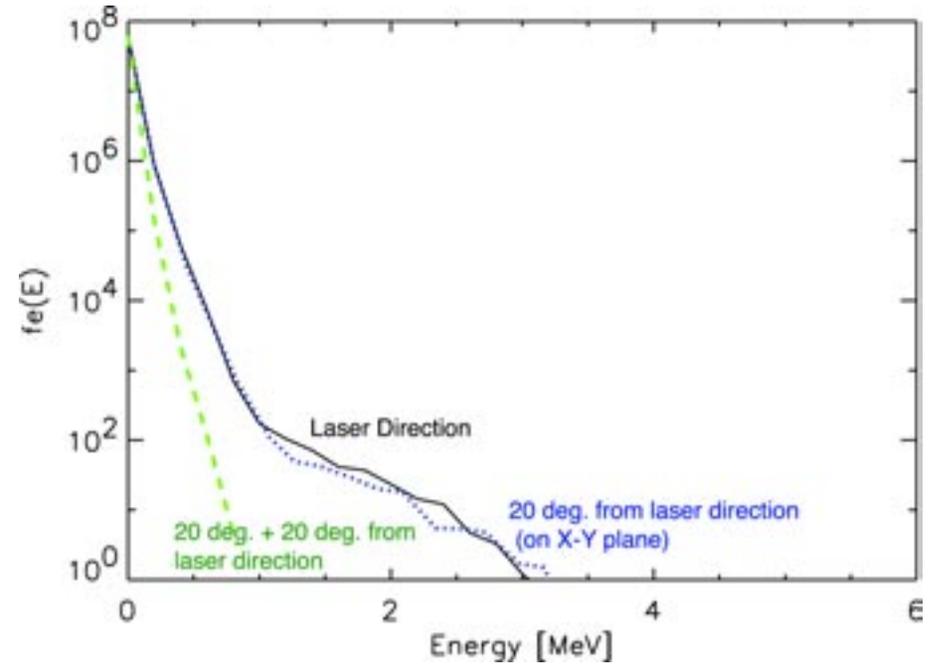
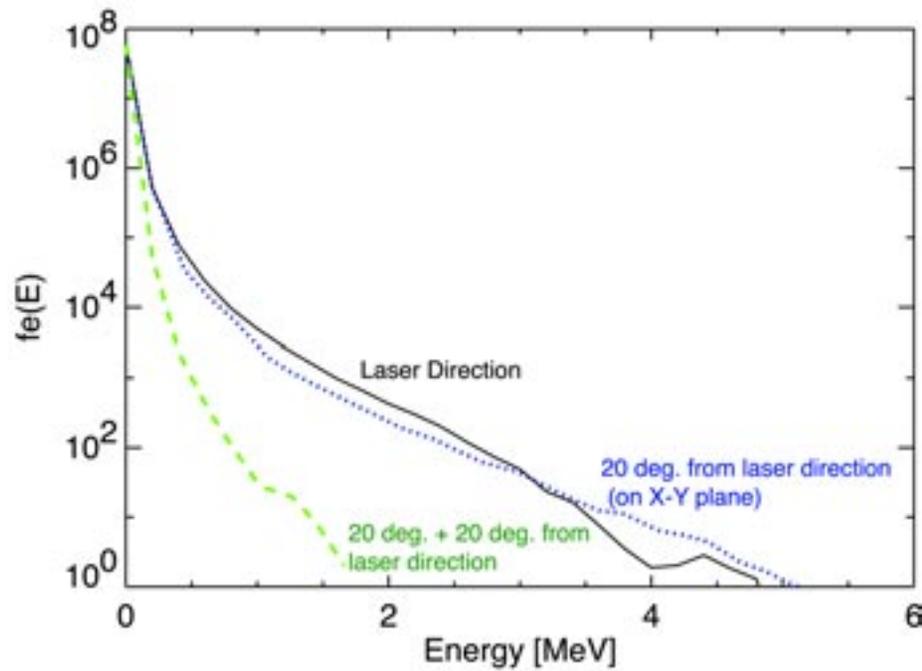
## Electron Energy Density $(\gamma-1)n_e/n_c$ at $t=16\tau$



Cone target heating, corresponded to Backside X-ray Image (Integrated in X-direction)

at  $t=16\tau$

# Electron Energy Distribution in 3 directions



# Fokker Plank Simulation for Dense Plasma Heating

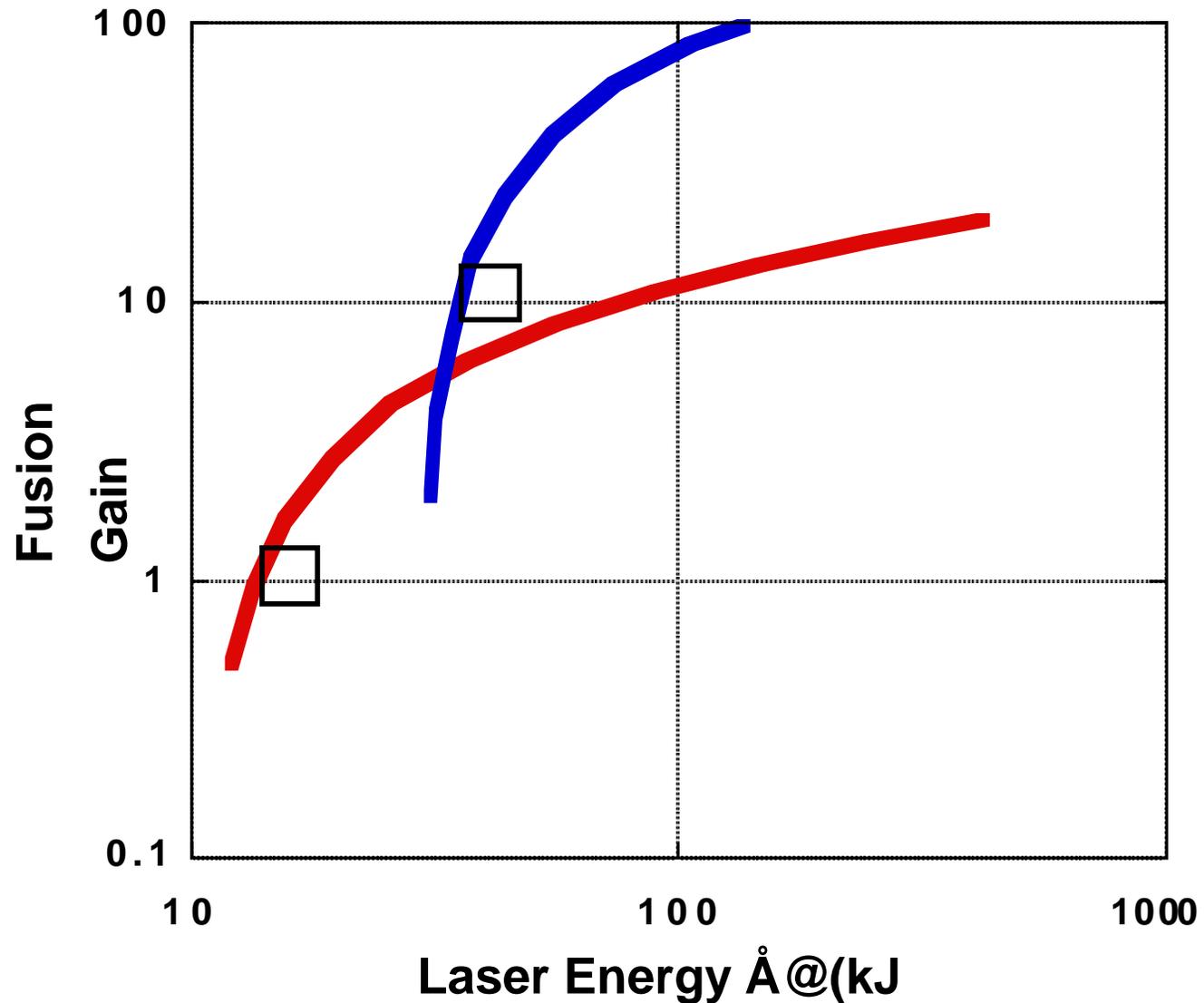
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**The F.P. Simulation with PIC electron spectrum indicates Significant fusion reaction with 10kJ FIREX laser.**

**The break even could be achieved if the coupling efficiency is higher than 30% .**

# FIREX Fusion Gain vs laser Energy

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# Summary and Future Prospects

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1. We demonstrated that high density implosion plasmas can be heated by 0.1 and 1.0PW laser both for cone and coneless target in **collaboration with the Imperial college and RAL group**.
2. 3D simulation shows that local laser heating generates a strong global magnetic field and confines heat flux carried by relativistic electrons .
3. In the cone target, laser beam and relativistic electrons are guided to the top of the cone along the cone surface . This energy focusing optics can be applied to **efficient ion acceleration** and point X ray source as well as laser fusion.
4. The recent research results on fast ignition indicate that the **FIREX project** will achieve breakeven and ignition.

# Laser Fusion Facilities at Osaka University



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ÅGEKKO XII Åwavelength:1053nm, power max20kJ/nsÅ  
Åwave length:530nm, power max10kJ/nsÅ

ÅPeta watt laser Å max1kJ, 1PWÅ

## Peta watt laser system

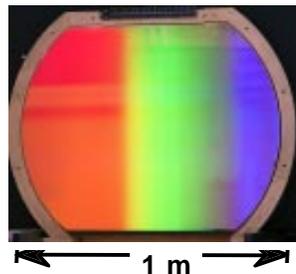
Amplifier



pulse compressor



grating



## GEKKO XII

Amplifier



Focusing System

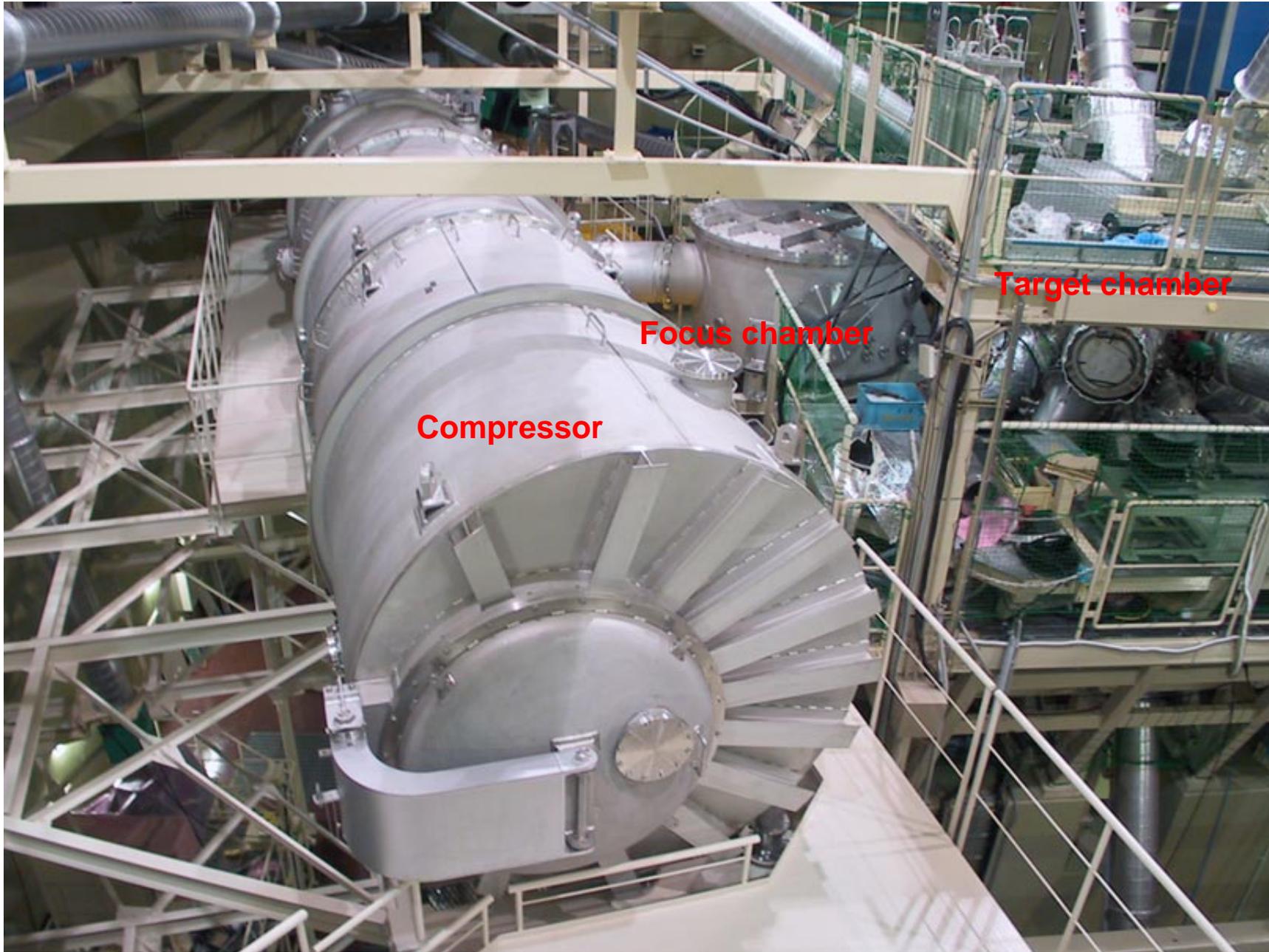


spherical symmetry irradiation



one side irradiation system (HIPERÅ)



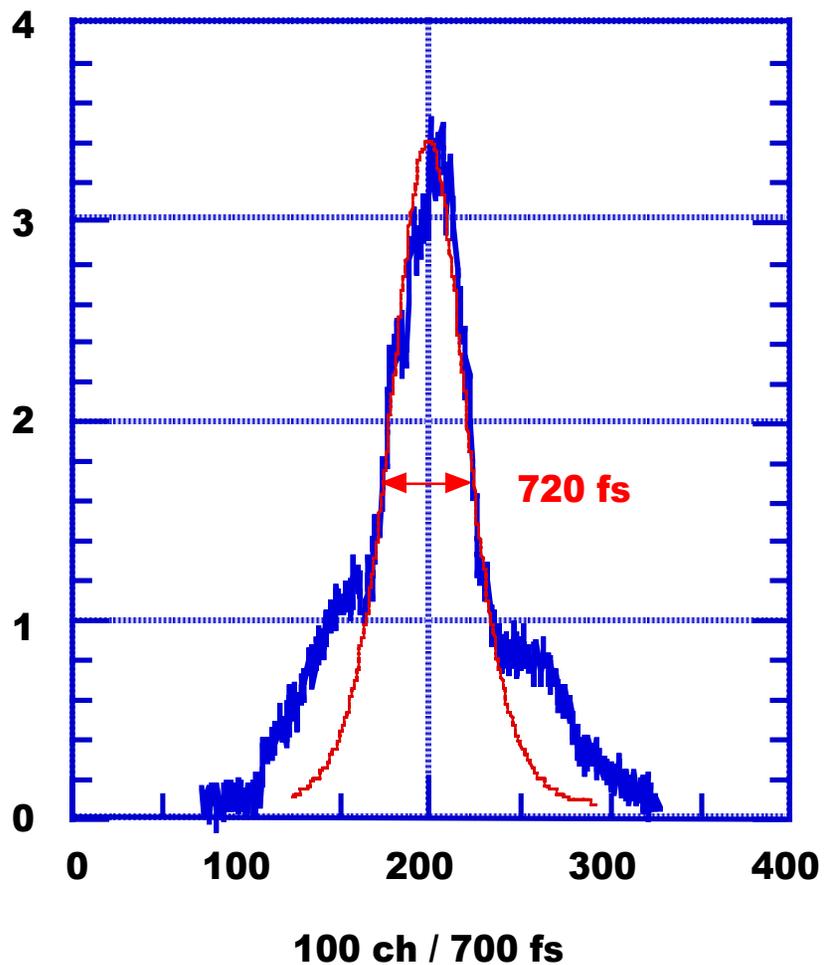


**Compressor**

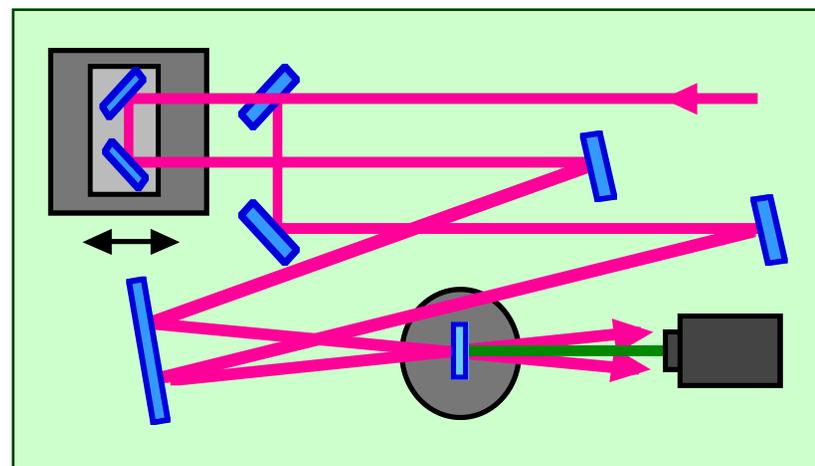
**Focus chamber**

**Target chamber**

# Typical 2nd-order Autocorrelation result



## 2-nd Order Autocorrelator

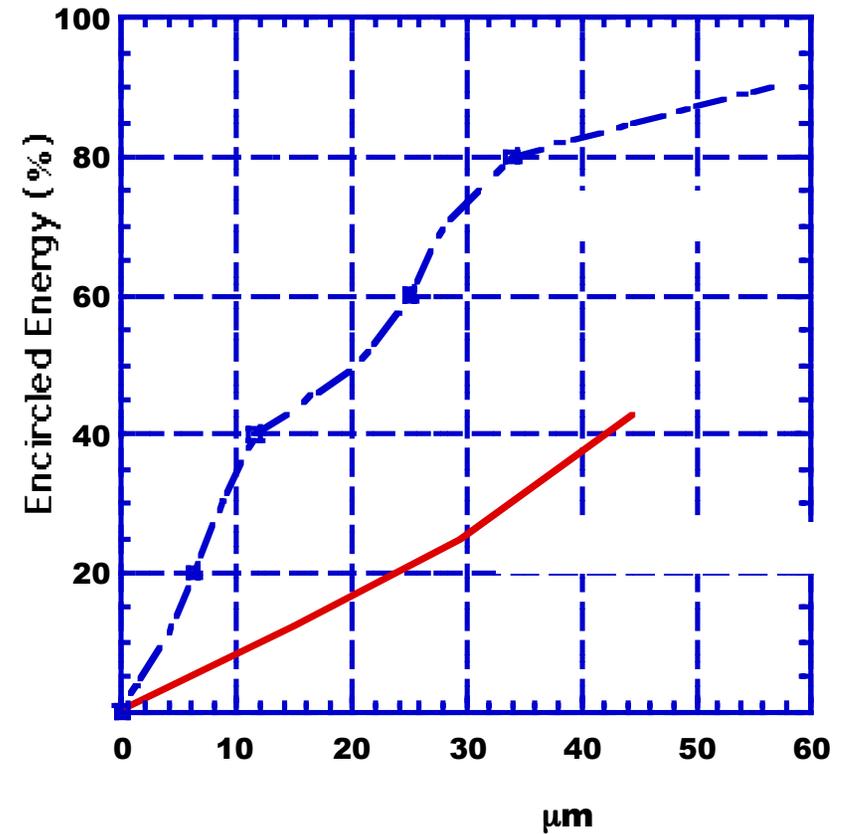
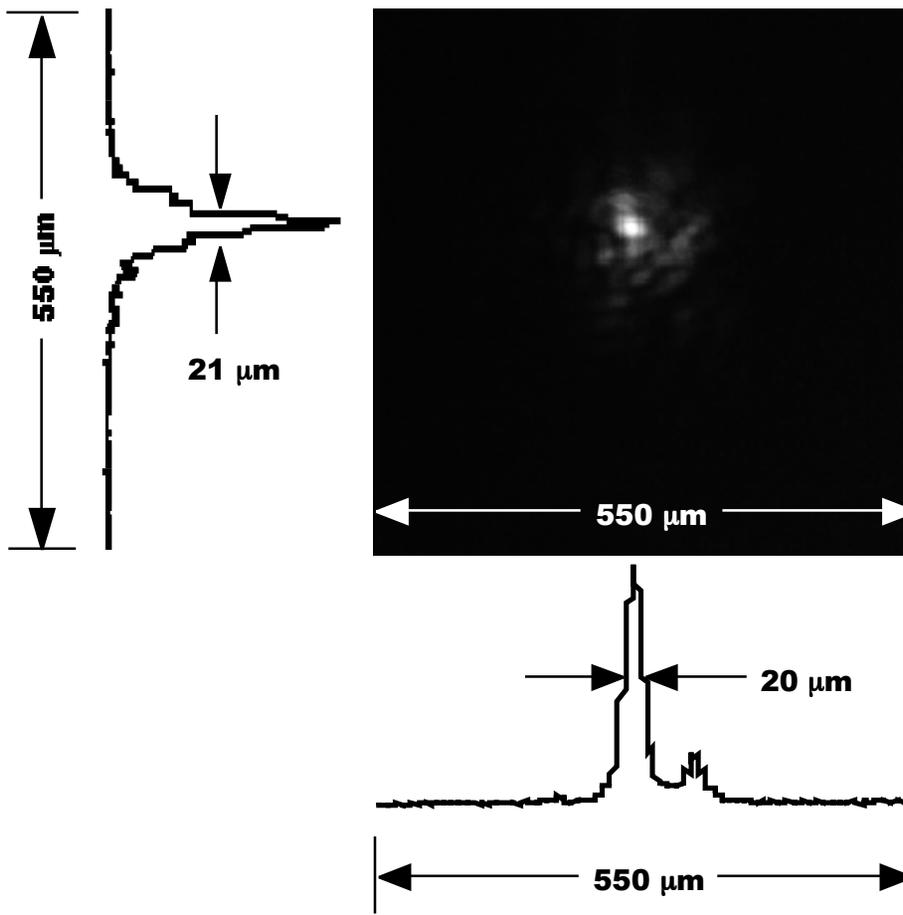


**Sech-square shape fitting yields pulse width of 720 fs.**

# Far Field Pattern & Encircled Energy



FFP (Far Field Pattern)



# Comparison between PWM &PW

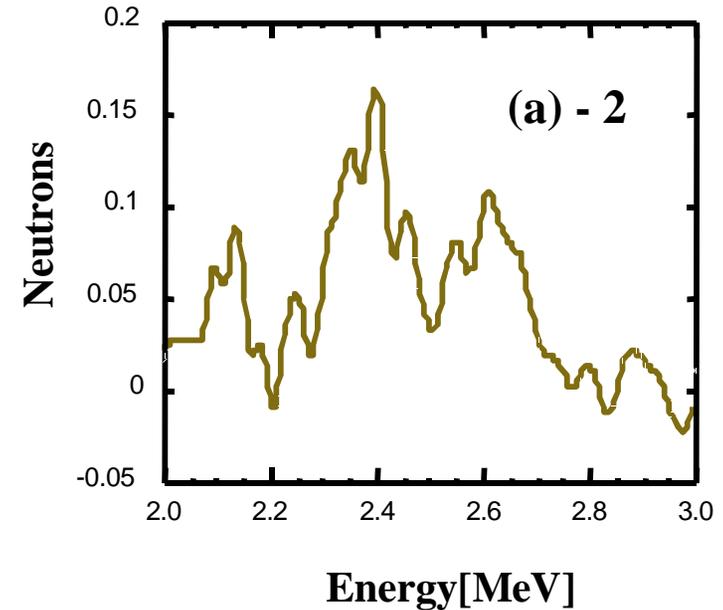
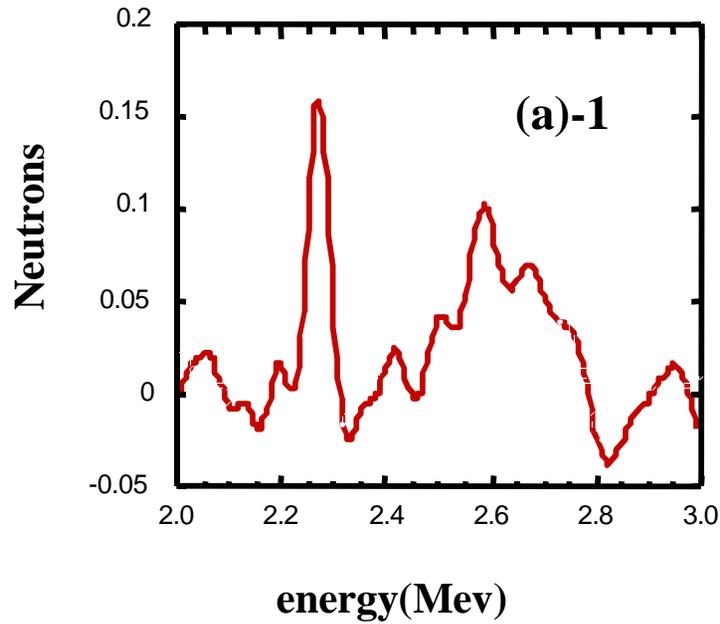


	PWM	PW	Remarks
CPA Specification		3.0	$\mu$
		100	
		2.0	
Pulse Length		500	
Energy / Dimensions		500	
		70	
		0.42	

# Neutron Energy Spectra from Imploded Plasmas

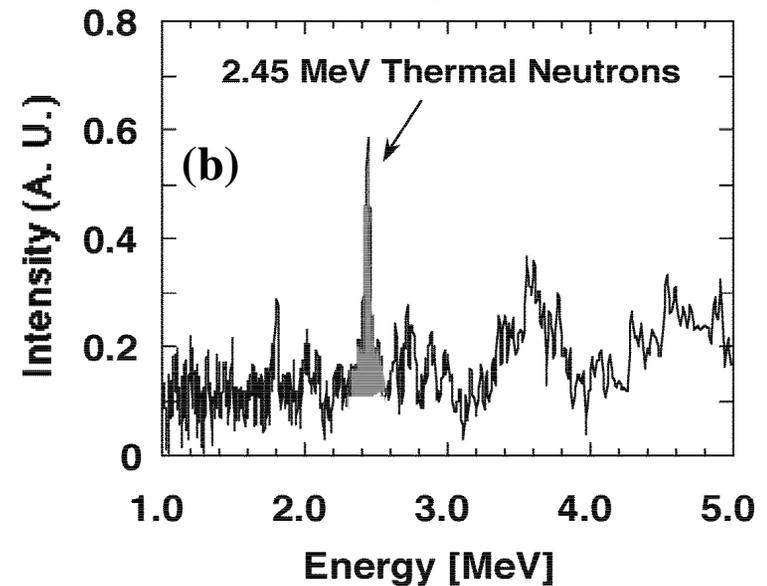


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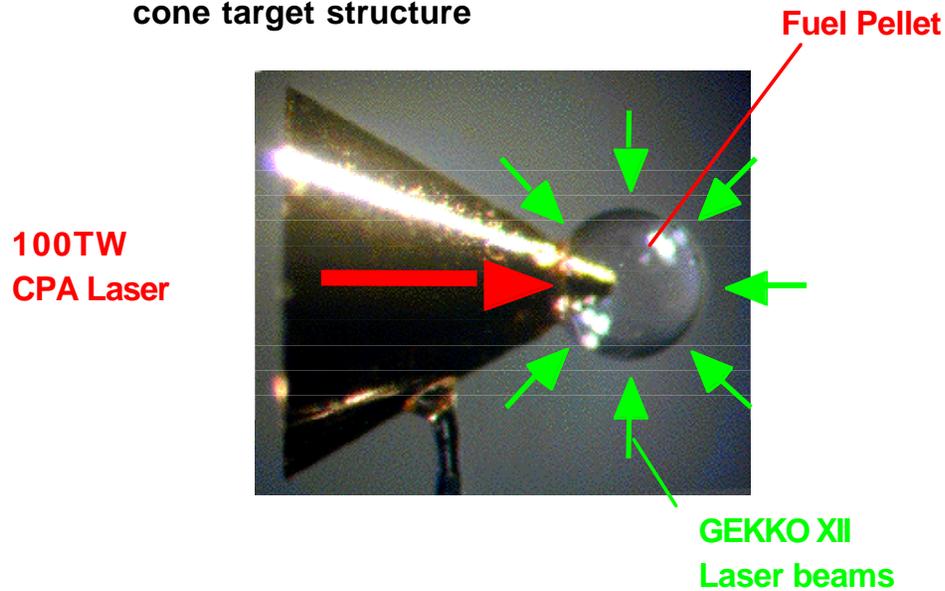
**(a)-1 and -2 ; the neutron spectra from coneless targets**

**(b) ; the neutron spectrum from cone guide targets**



# Cone Guided Target Implosion and Heating by CPA Laser

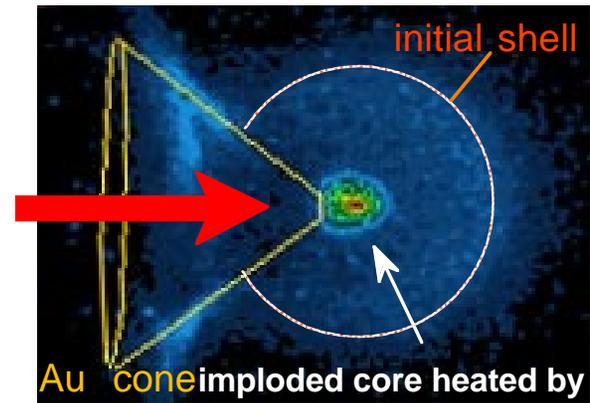
cone target structure



with heating

$$N_y : (1-3) \times 10^5$$

Xray pinhole camera



without heating

$$N_y : (0.8-1) \times 10^4$$

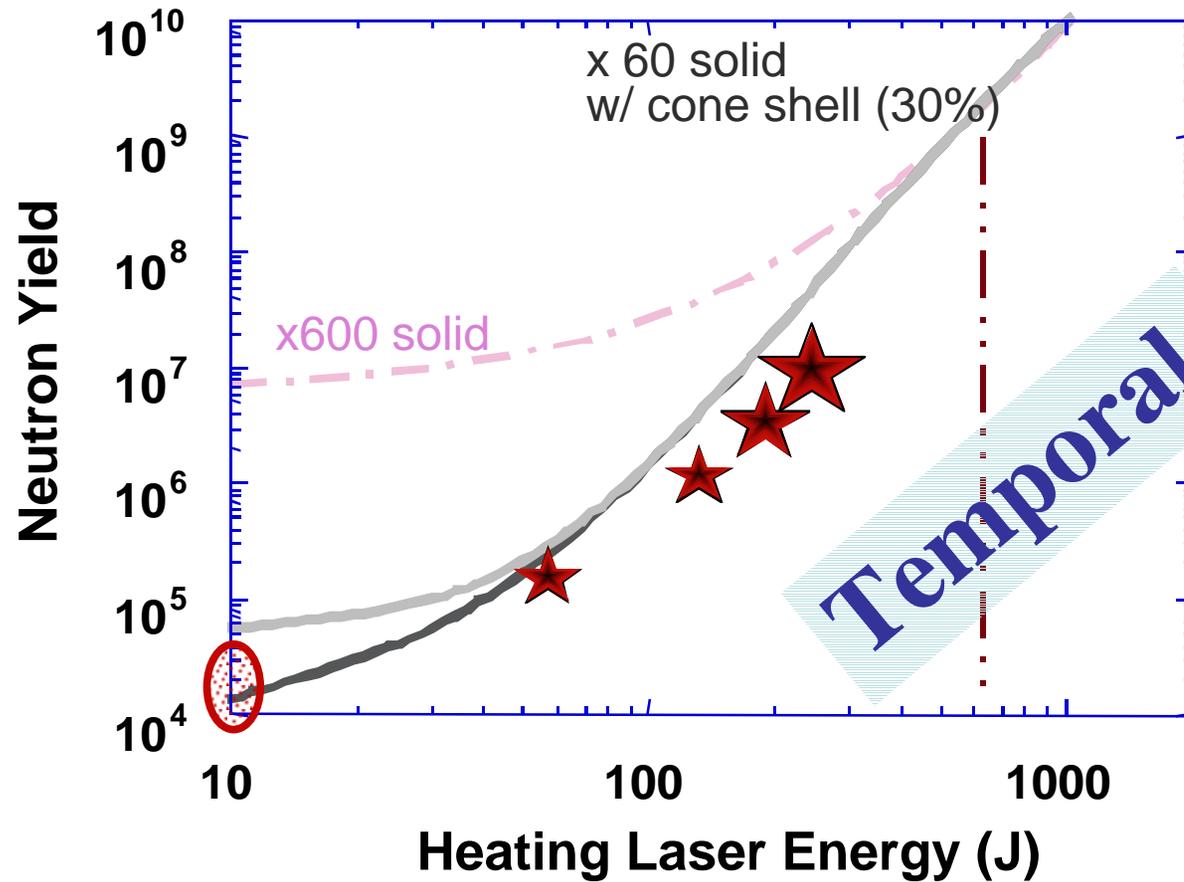
The temperature increased by 130<sup>8</sup>eV. This is 20J/80J coupling

# Clear Enhancement was Observed in Thermal Neutrons



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Enforced heating was realized at a heating power close equivalent to the ignition condition.

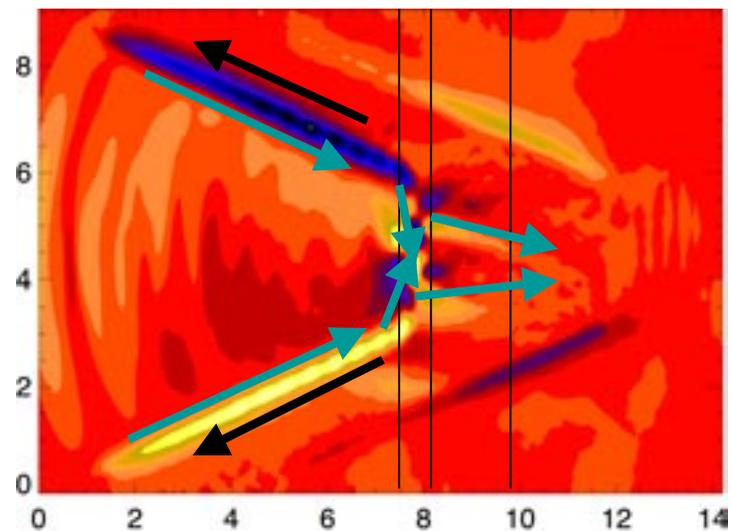


$t=16\tau$

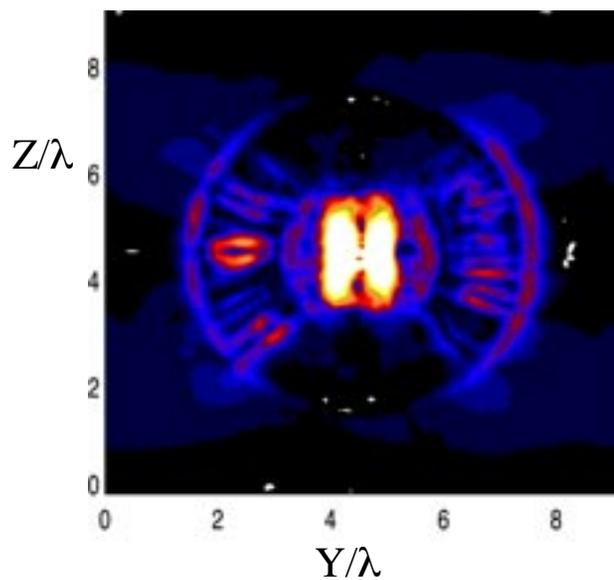
# Quasi-static Magnetic Fields |B|

Contour Level : 0.0 ~ 0.18  $B_0$

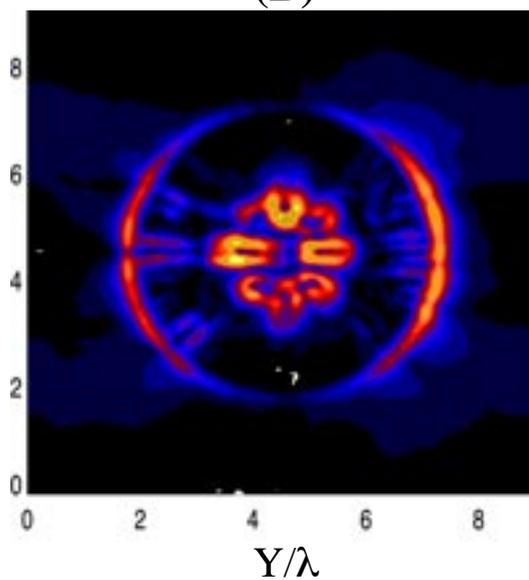
(A)(B) (C)



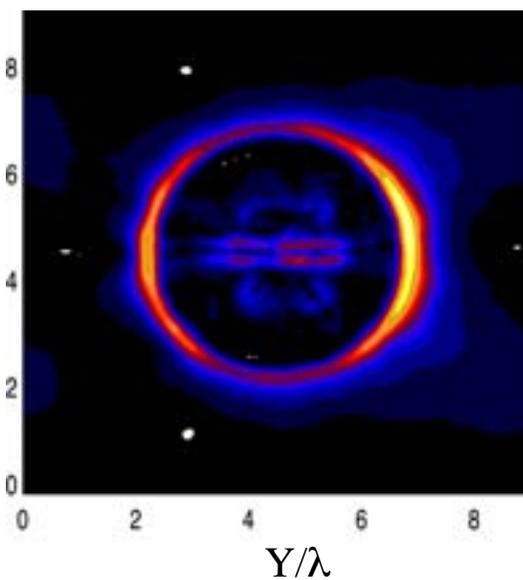
(A)



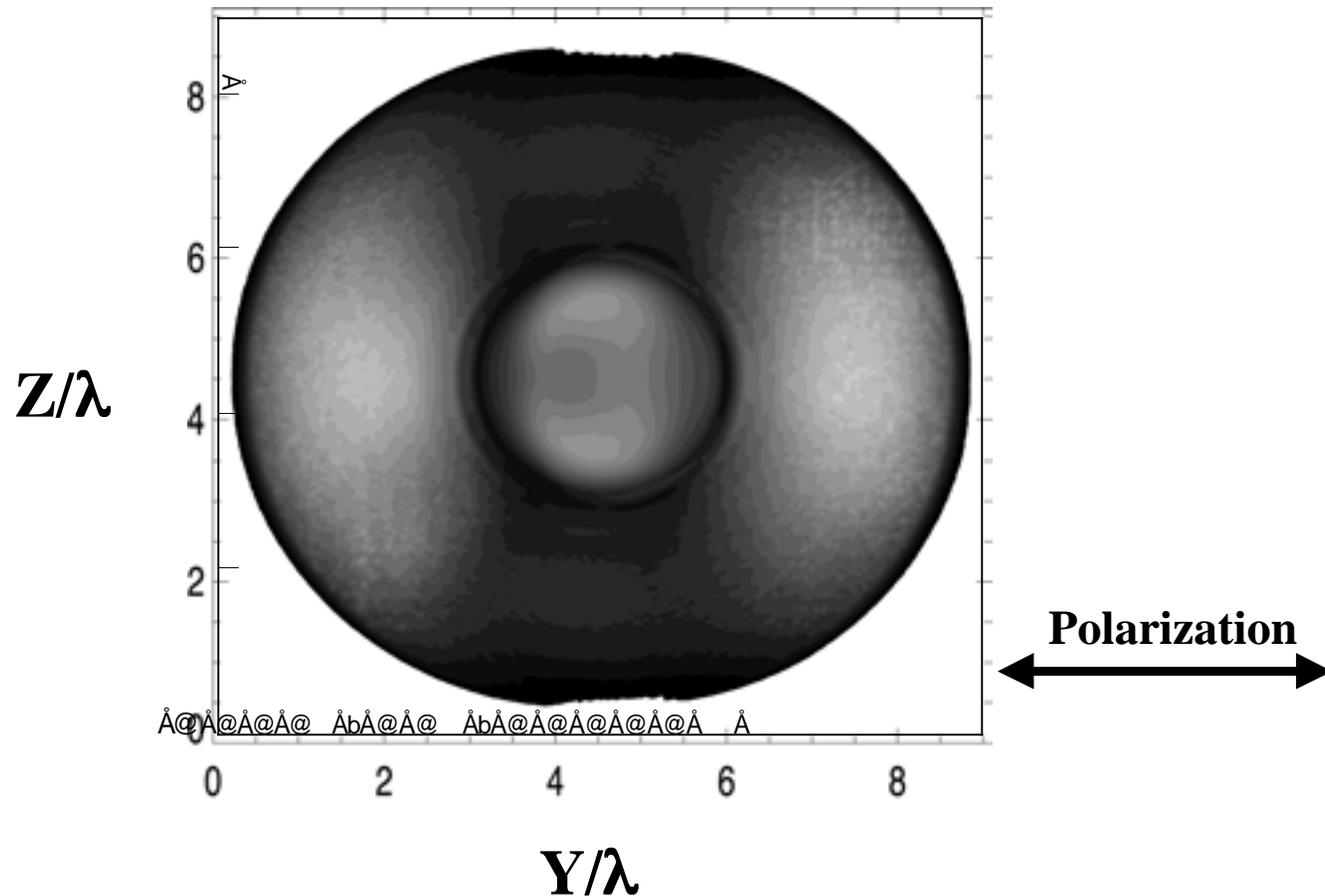
(B)



(C)



# Electron Energy Density $(\gamma - 1)n_e/n_c$ at $t=16\tau$



**Cone target heating, corresponded to Backside X-ray Image (Integrated in X-direction)**