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THE STUDY OF ABLATION AND IMPLOSION DYNAMICS IN CLOSELY COUPLED NESTED CYLINDRICAL AND STAR WIRE ARRAY Z PINCHES*

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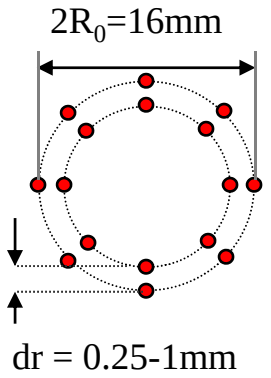
Motivation

Non-precursor implosion is possible in closely coupled (closely spaced) nested wire arrays

Closely spaced nested cylindrical arrays have a small gap between the inner and outer array (1mm or less) of equal wire numbers

Estimates predict dominant “local” fields, outward ablation on inner wires with “non-precursor” regime

In linear arrays, non-precursor implosion reduced X-ray yield by 5-10%*



- ⇨ Determine under what conditions would non-precursor implosion happen
- ⇨ Investigate the effects of precursor presence on X-ray yield
- ⇨ Study the interaction within wire pairs
- ⇨ Some physical mechanisms may be similar to effects in cylindrical arrays with small interwire gap* *

*:Ivanov, V.V. et al., Physics of Plasmas **14** (2007), 032703

:Sanford, T.W.L. et al., PRL **77, 5063 (1996) Coverdale, C.A. et al., PRL **88**, 065001-3 (2002)

In closely spaced nested arrays models predict outward ablation on the inner wires

I×B forces give guidelines for ablation behavior - they determine the direction of ablation, and presence of precursor

If the wires are “closely spaced”, the field from the closest wire dominates – the magnetic field and forces at the inner wire are reversed in direction

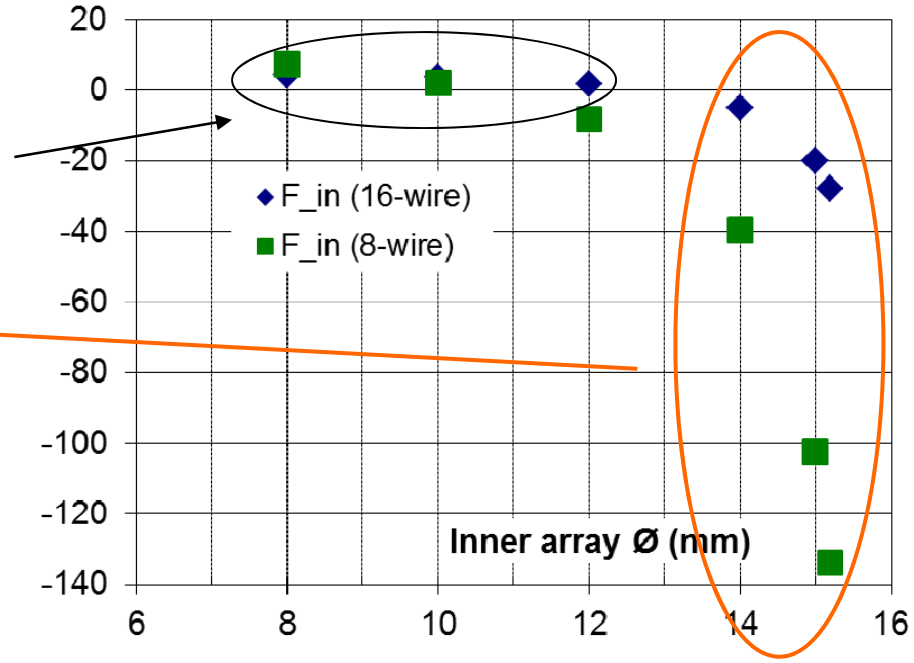
With even current distribution through the wires the criterion can be written as $dr \leq 2 \cdot R_0/(N\text{-}2)$

Using an inductive load model*, 35-45% of the total current flows through the inner wires in investigated 8-16 wire arrays

For star arrays, the calculated direction of I×B forces are in agreement with the presence of precursor

Positive force – inward ablation and precursor

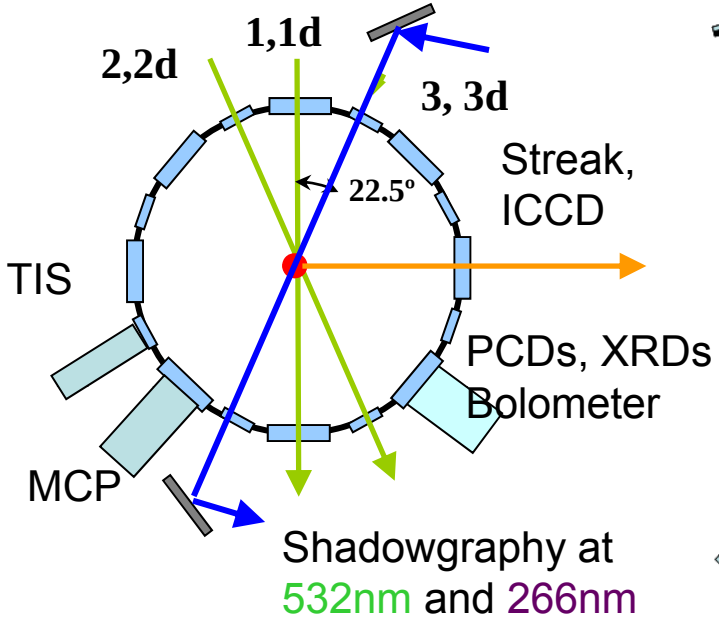
Reverse force – outward ablation, no precursor

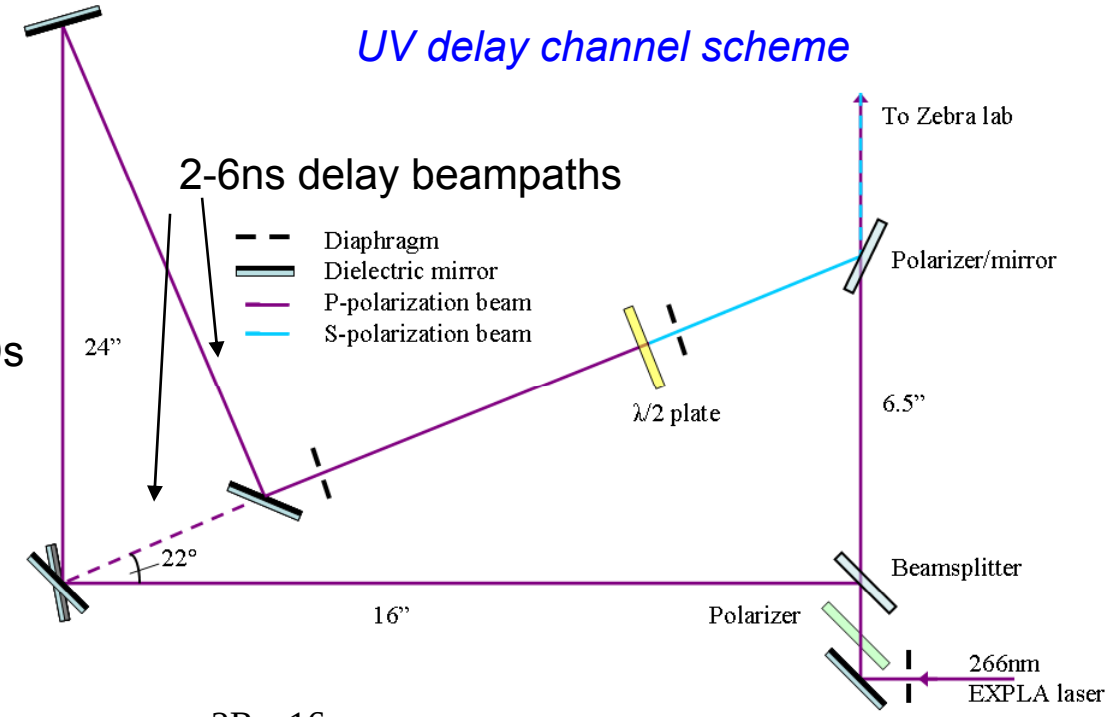


I×B force (AU) on the inner array wires, in nested cylindrical loads with 8 and 16 wires, and Ø16mm outer arrays

*:Davis et al., Appl. Phys. Lett. **70**, 170 (1997)

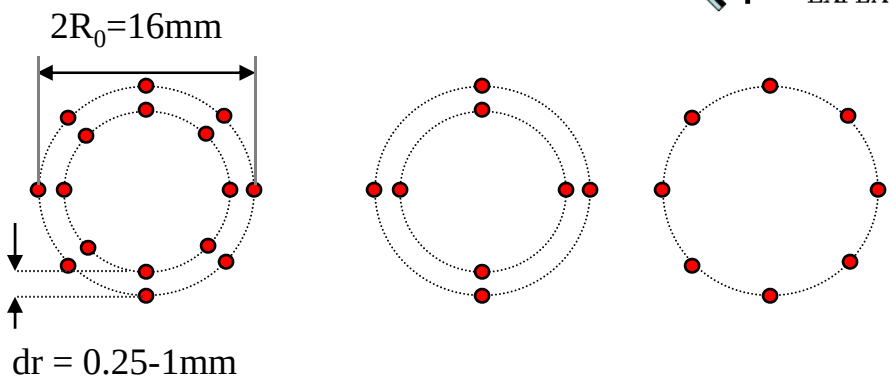
Experiments were conducted at the 1MA 80ns Zebra Generator at UNR Nevada Terawatt Facility





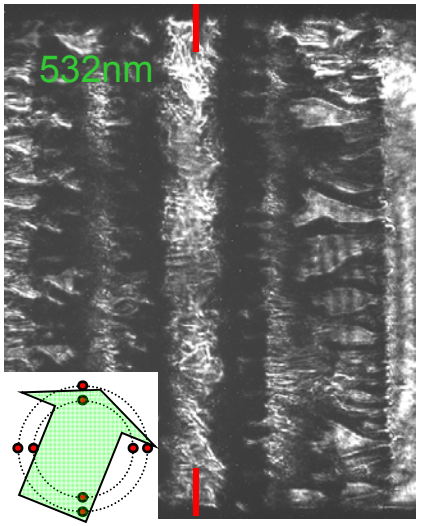
Closely spaced arrays with 6-16 wires, and array mass of 34-53 *μg/cm* were investigated

Gap between paired wires was 0.25-1*mm* (15.5-14*mm* inner array diameter)

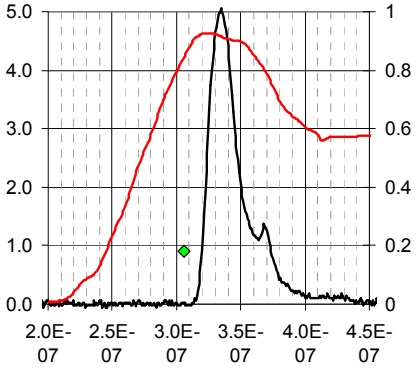


*:Ivanov, V.V. et al., IEEE Trans. Plas. Sci. **38**, 574 (2010)

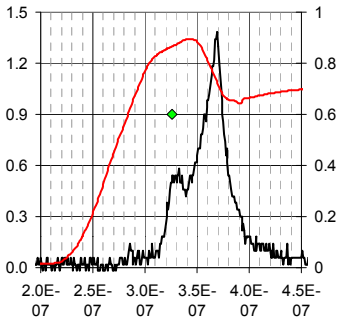
In low (6-8) wire number closely spaced nested arrays, no plasma on axis until late implosion stage

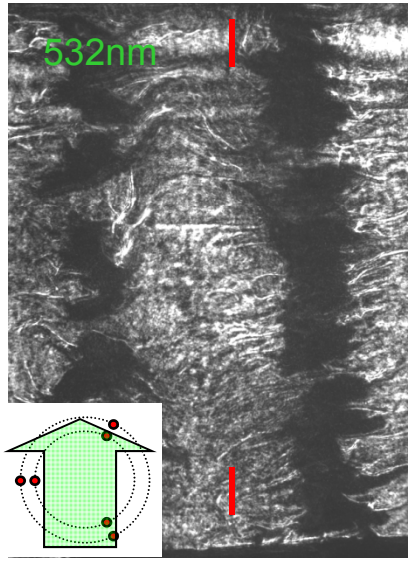


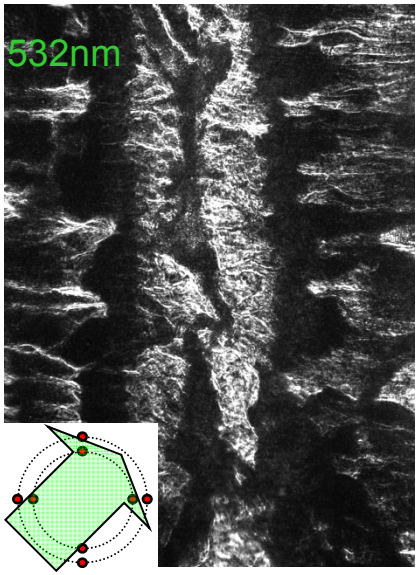
#978, 8x15*μm*, 14/16*mm* load

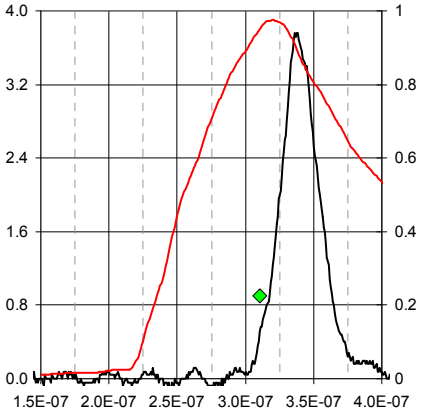


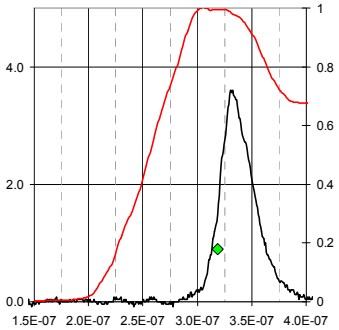
#1344, 6x15*μm*, 14/16*mm* load



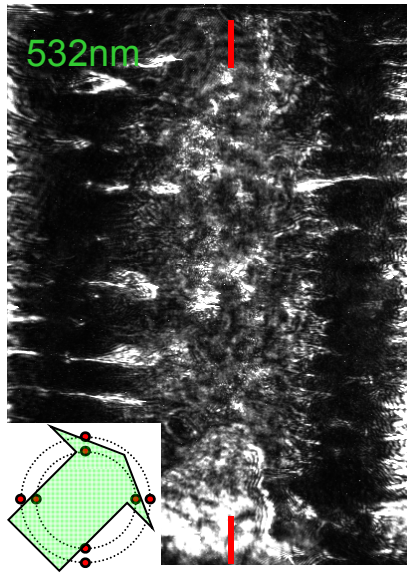








#2396, 8x17.8*μm* 15/16*mm* load

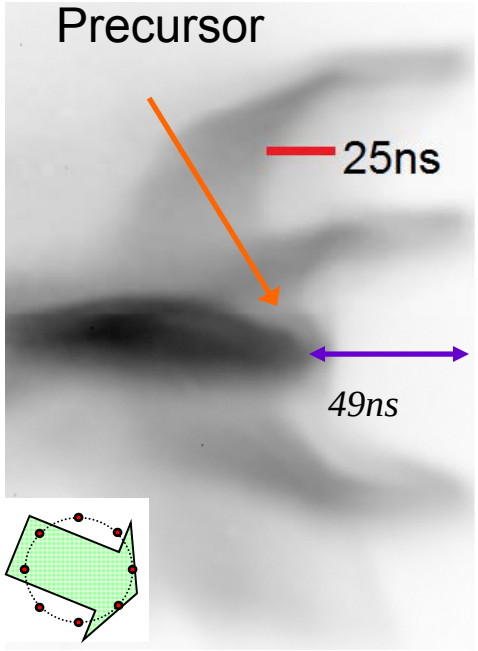


#2400, 8x17.8*μm* 14/16mm load at 130*ns* (left)

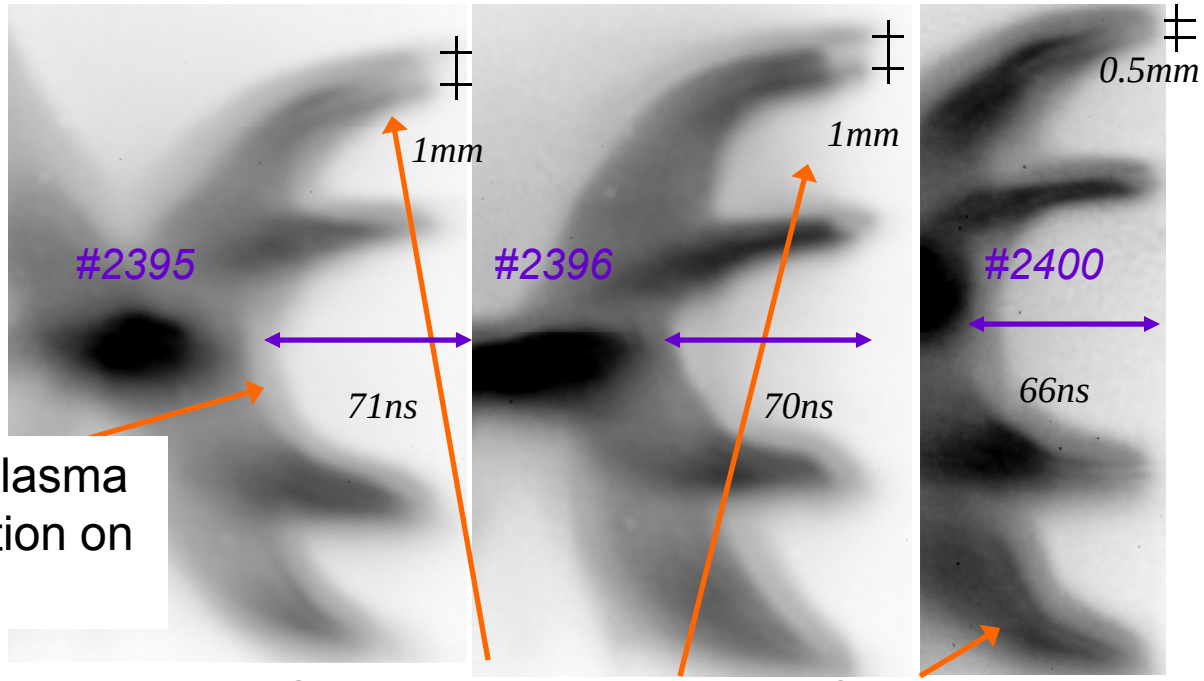
Plasma accumulates on axis just before implosion

Streak camera shows late plasma accumulation on the axis in 8-wire closely spaced arrays

8-wire cylindrical array # 2394



8-wire closely nested arrays



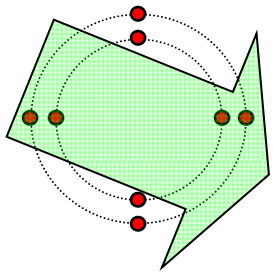
Late plasma formation on axis

Simultaneous implosion of wires

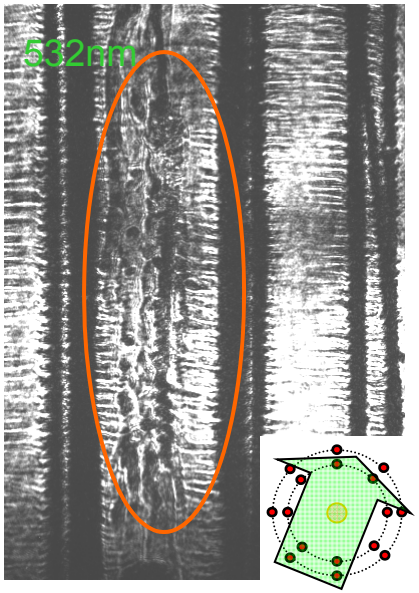
Plasma formation on axis is minimally ahead of the main pinch

Two-wire structure appears to be preserved during implosion

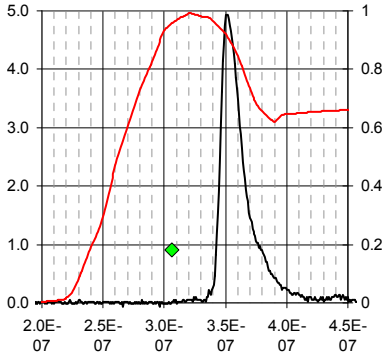
Inner wires do not move outward and merge early



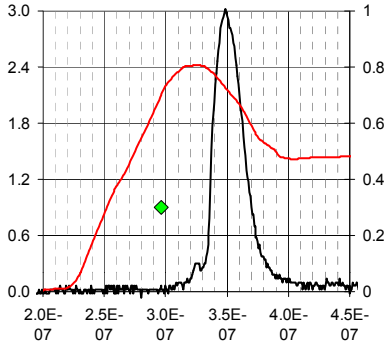
Surprisingly, precursor is found in 12-16 wire closely spaced nested arrays, despite outward I×B forces

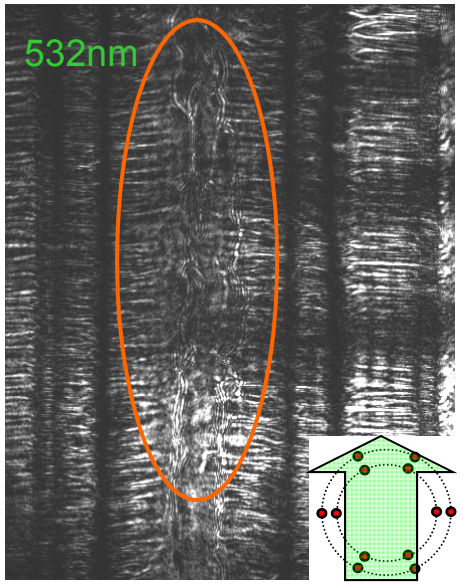


#966, 16x10μm, 14/16mm

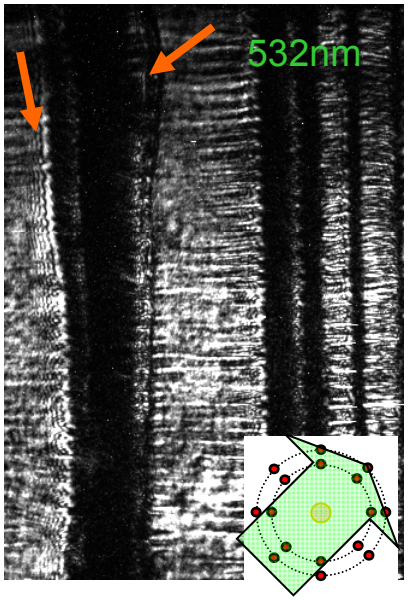


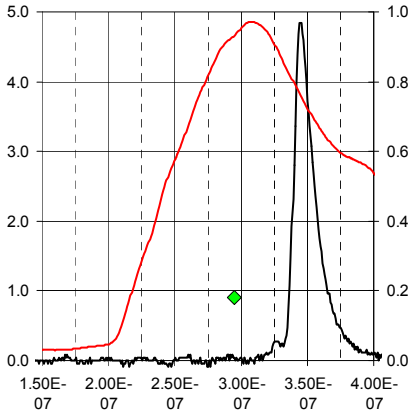
#1352, 12x10μm, 15/16mm



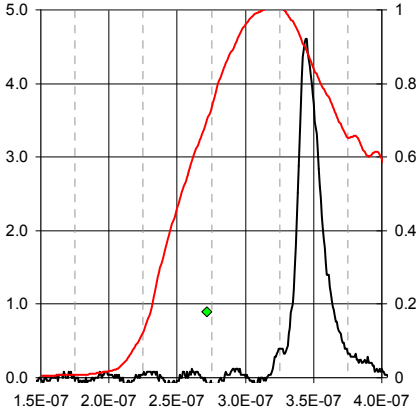


532nm probing cannot resolve ablation features of closely located wires

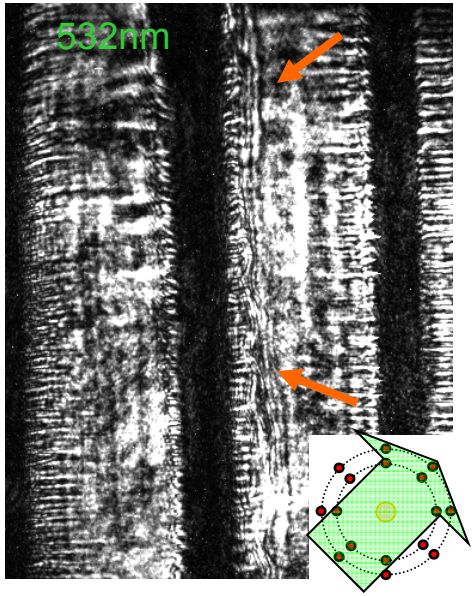




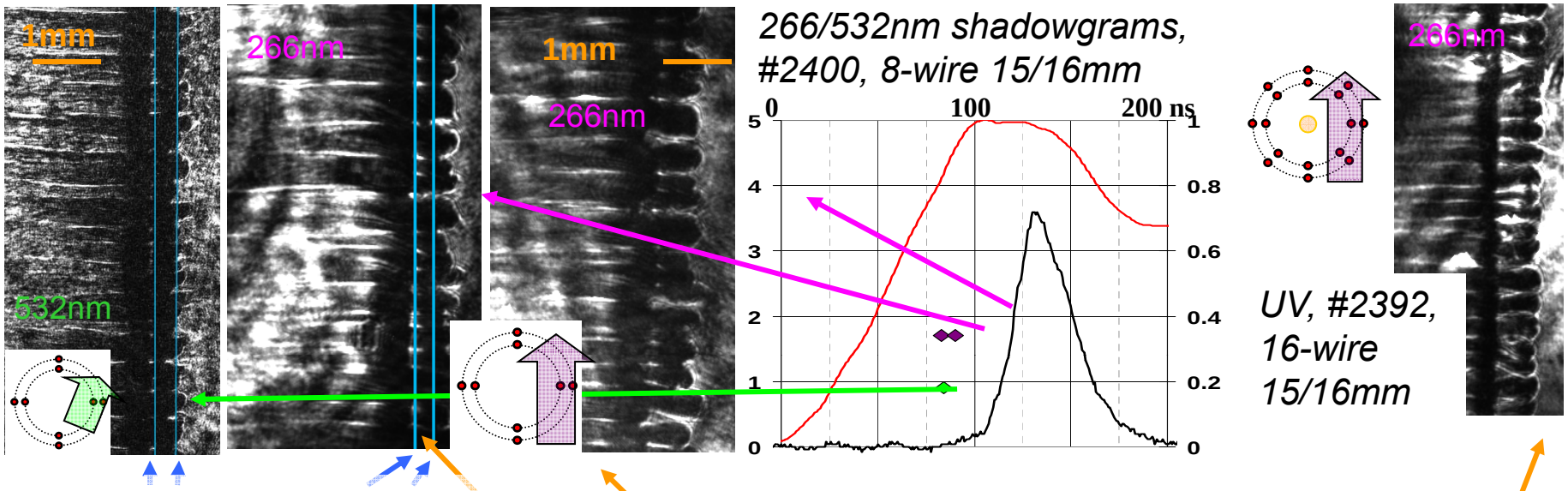
#2393, 16x12.7μm, 14/16mm



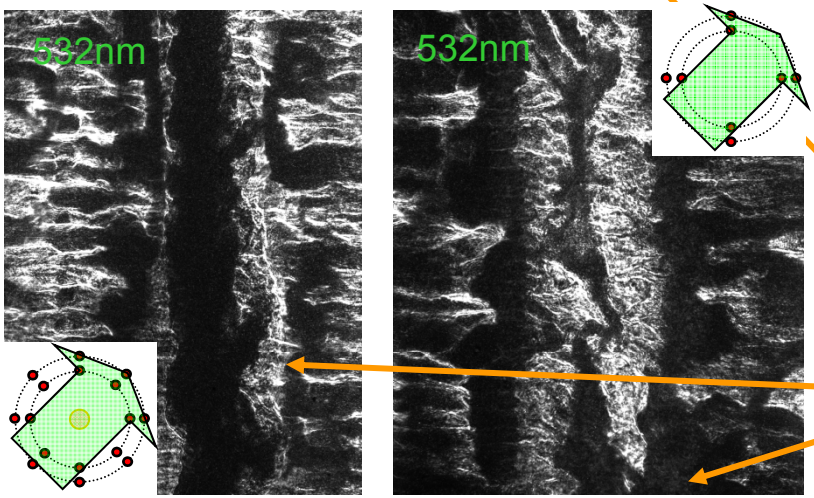
#2391, 16x12.7μm, 15/16mm



Cascading implosion, similar to star arrays, is observed on shadowgrams



Original wire positions



UV probing resolves the details in the wire plasma

Outer wires break up while inner wires still ablate to the center

Then implode into the inner wires

No outward ablation or movement on inner wires

A smoothened implosion front is formed

Green shadowgrams for 16-wire (#2388, left) and 8-wire (#2400, right) 14/16mm loads

Hard X-ray yield is improved in closely coupled nested arrays

All loads had similar soft X-ray energies

16-wire closely spaced vs. cylindrical:

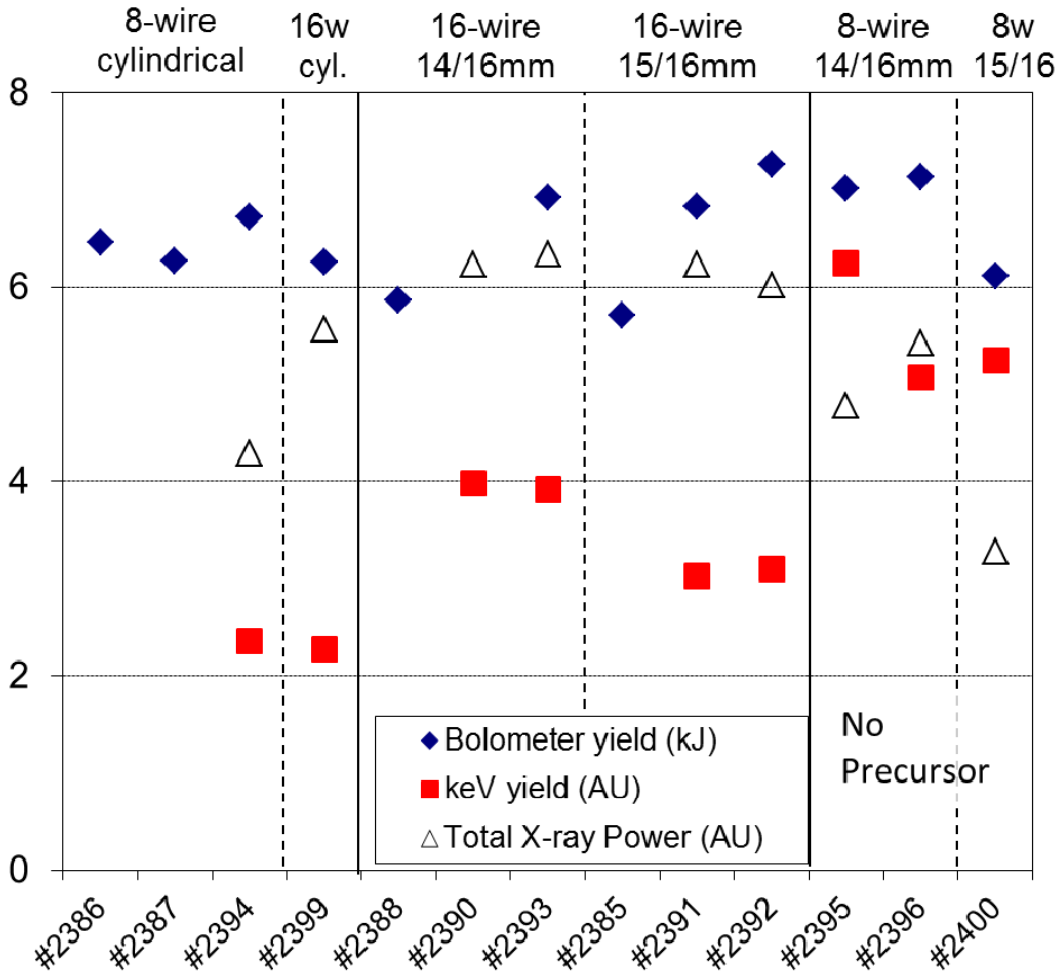
- 40% higher max soft X-ray power
- 50% higher hard (keV) X-ray energy

8-wire vs. 16-wire closely coupled:

- 30% less maximum power – lack of precursor or lower symmetry
- 50% higher hard X-ray energy

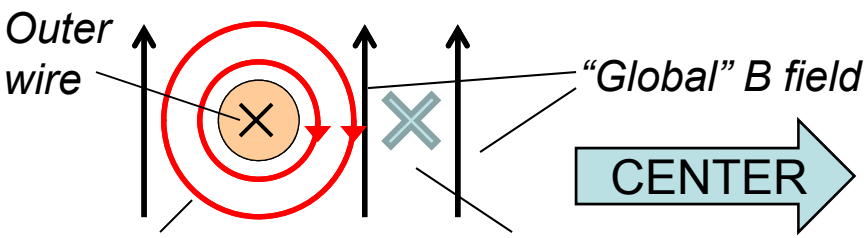
The improvement in implosion quality can be credited to cascading

Reducing wire spacing from 1mm to 0.5mm might decrease *keV* X-ray yield



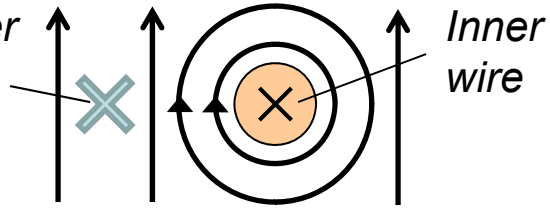
All loads had a mass of 53µg/cm

Ablation is stronger on the outer wires



Position of inner wire
B_{global}= 3.7*T*
B_{local}= -6.2*T*
B_{total}= -2.5*T*

Position of outer wire
B_{global}= 4.2*T*
B_{local}= 6.2*T*
B_{total}= 10.4*T*



Magnetic field values are calculated for a 16-wire Ø14/16*mm* array at 0.5*MA* current

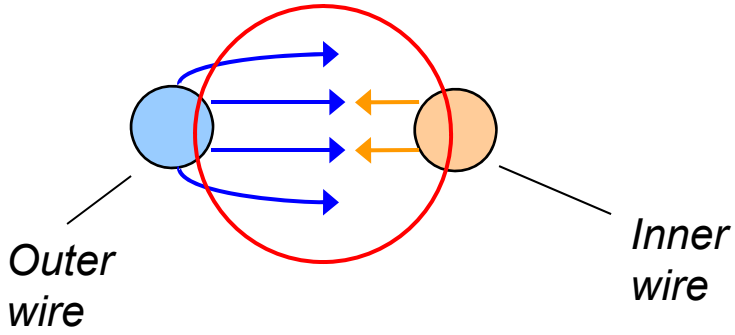
The outside wires ablate stronger and earlier (20-80% higher current)

The behavior might be explained by the interaction of the ablating plasma streams and the inner wire

Some redistribution of current between the wire cores and ablated plasma is possible

For satisfactory description, detailed MHD calculations are necessary

Future experiments are planned for investigating the early ablation stage in closely spaced arrays



Conclusions

1. Implosion of closely spaced nested arrays was studied and ablation details were resolved by two-frame UV shadowgraphy.
2. No outward ablation was observed in low wire number nested cylindrical and star wire arrays which implode without a precursor. In these arrays delayed axial plasma accumulation was observed.
3. 12-16 wire closely spaced arrays imploded with precursor. The implosion quality in closely spaced arrays is better than in regular cylindrical arrays.
4. MHD modeling is necessary to describe the ablation of closely spaced nested arrays.

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