# Generation of 600 MeV carbon ions with composite ultrathin targets

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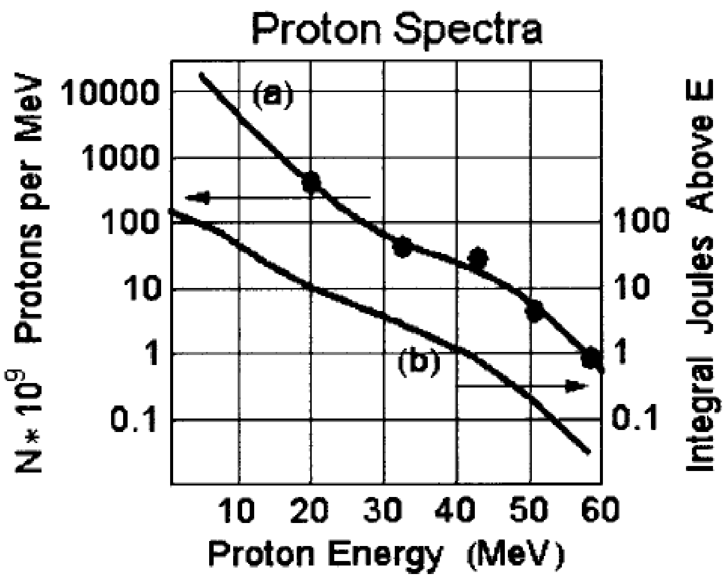
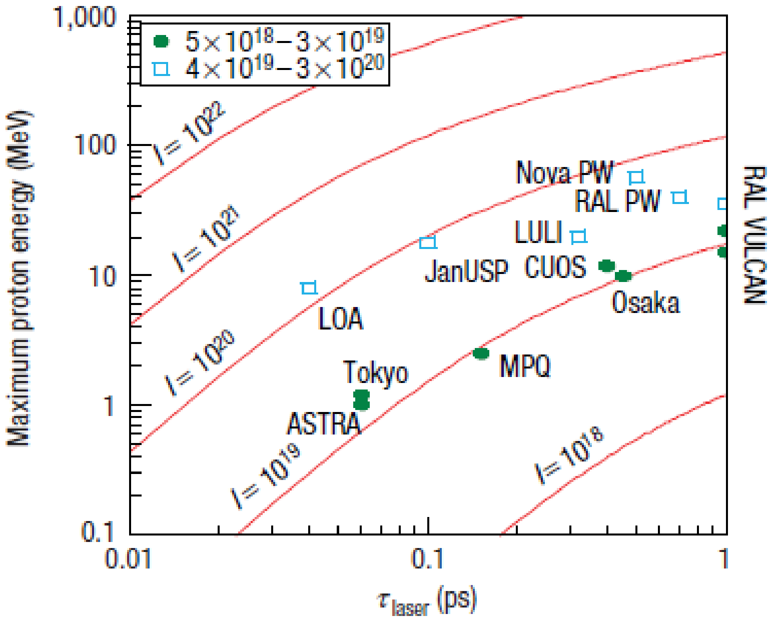
# Laser-driven ion acceleration




1st PW laser-driven ion acceleration: Snavely, PRL (2000)

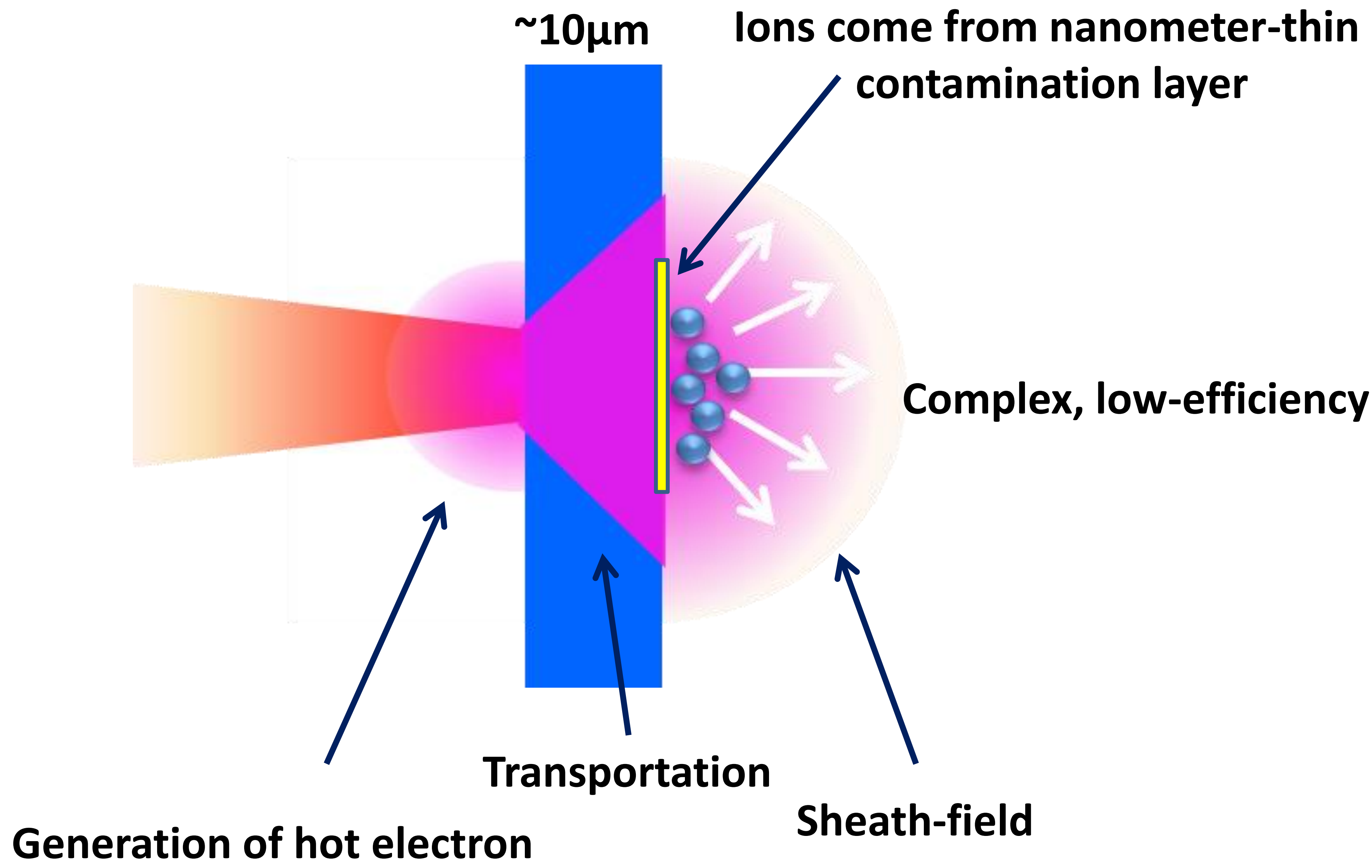



Scaling law: J. Fuchs, Nature Physics(2006)

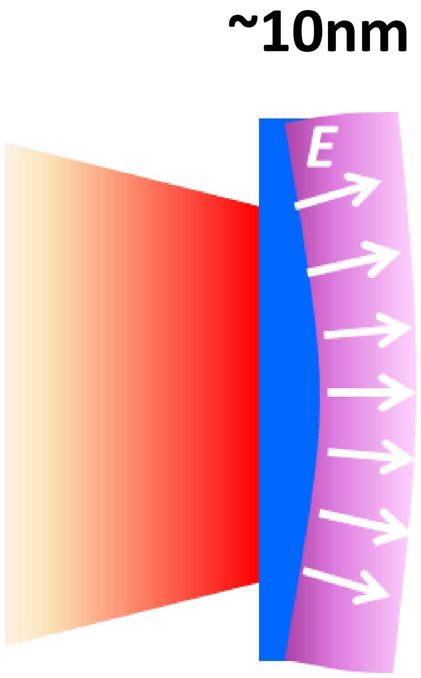
**Cut-off proton** **60 MeV**

**Pulse energy** **500 J**

# Ultrathin targets,why?



# Potential of nanotargets



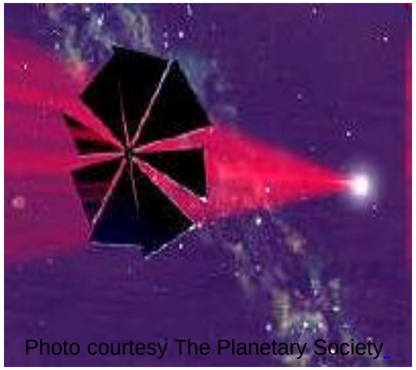

Pulse energy： 1J

Ions in the targets： $10^{10}$

Theoretical up-limit of ion energy

$$\frac{1J}{10^{10}} \approx 1000MeV$$

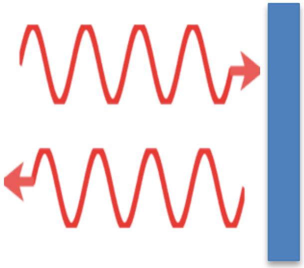
# Light sail acceleration




Radiation pressure:

$$P_{rad} = \frac{I}{c} = \frac{3 \times 10^{-7}\ \mathrm{N}/cm^2}{1W/cm^2}$$

$$= 3 \times 10^{13}\mathrm{N}/cm^2 \quad (I = 10^{20}\, W/cm^2)$$



Mass of 10 nm carbon foil~2 μg/cm$^2$, acceleration:

$$a \approx 10^{22}\, m/s^2 = 0.03\ c/fs$$

$$\approx 1MeV/u/fs$$

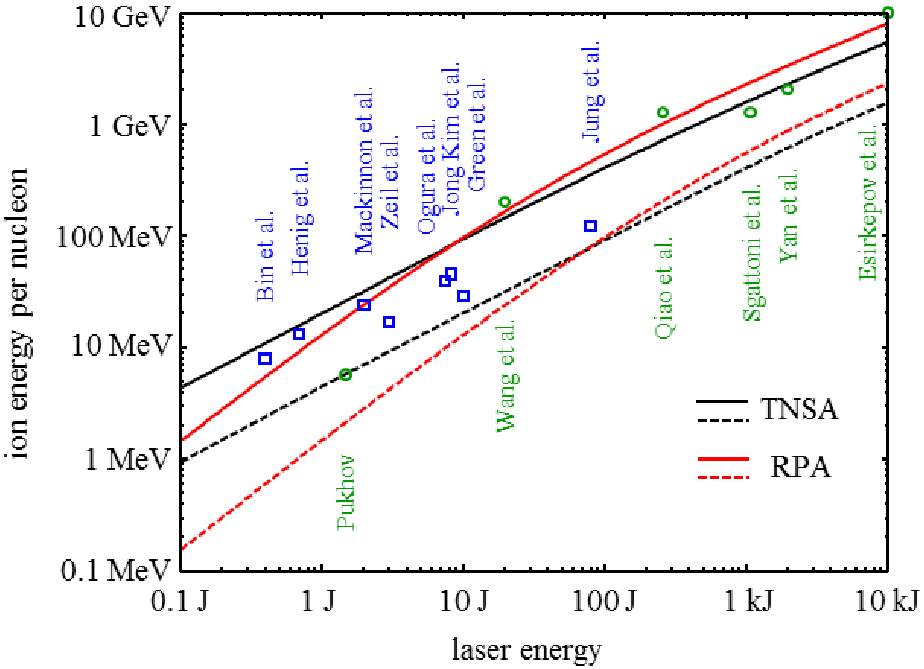
# Advantages of light sail scheme

- ✓ Better scaling law at high intensity

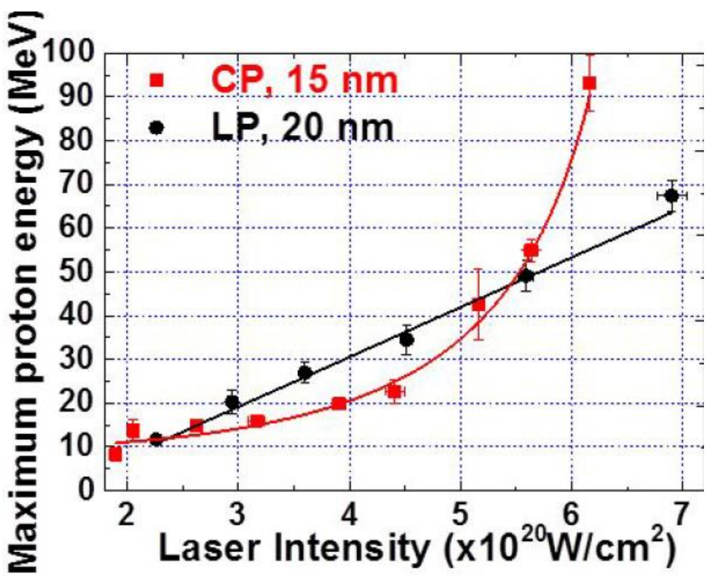
Light sail: $E \propto \begin{cases} I^2 \ (d < \sigma) \\ I \ \ (d \sim \sigma) \end{cases}$

TNSA: $E \propto \sqrt{I}$

- ✓ Possible to get monoenergetic ions




J. Schreiber, *et al.*, High Power Laser Science and Eng. 2, e41 (2014)

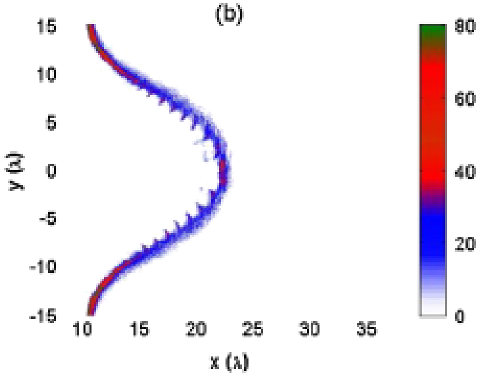



I Jong Kim, et.al., arXiv:1411.5834

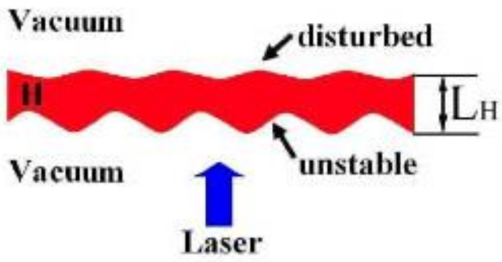
# Problems of light sail scheme

Sail must NOT be broken!

1. Laser heating



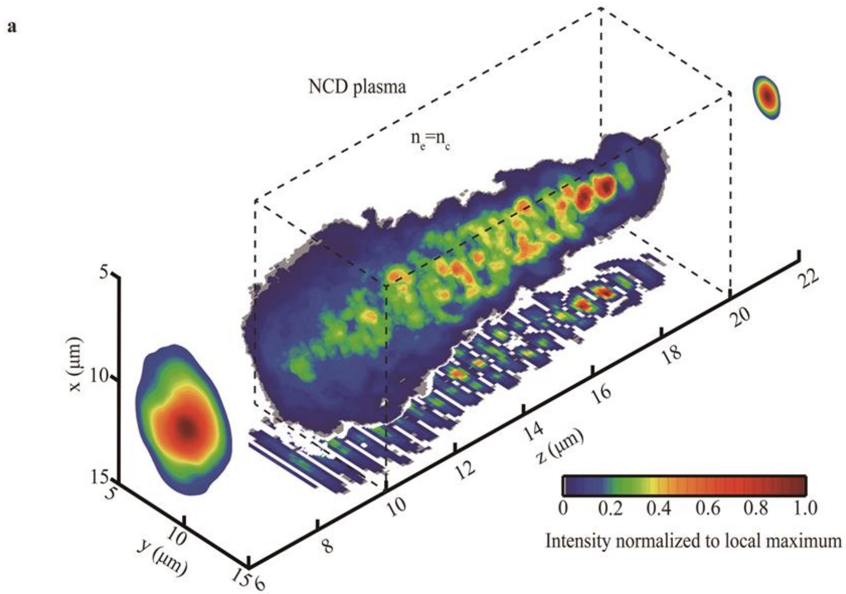

2. Instability




**Punch the foil as hard as possible before it breaks**

$I \uparrow, \tau \downarrow$

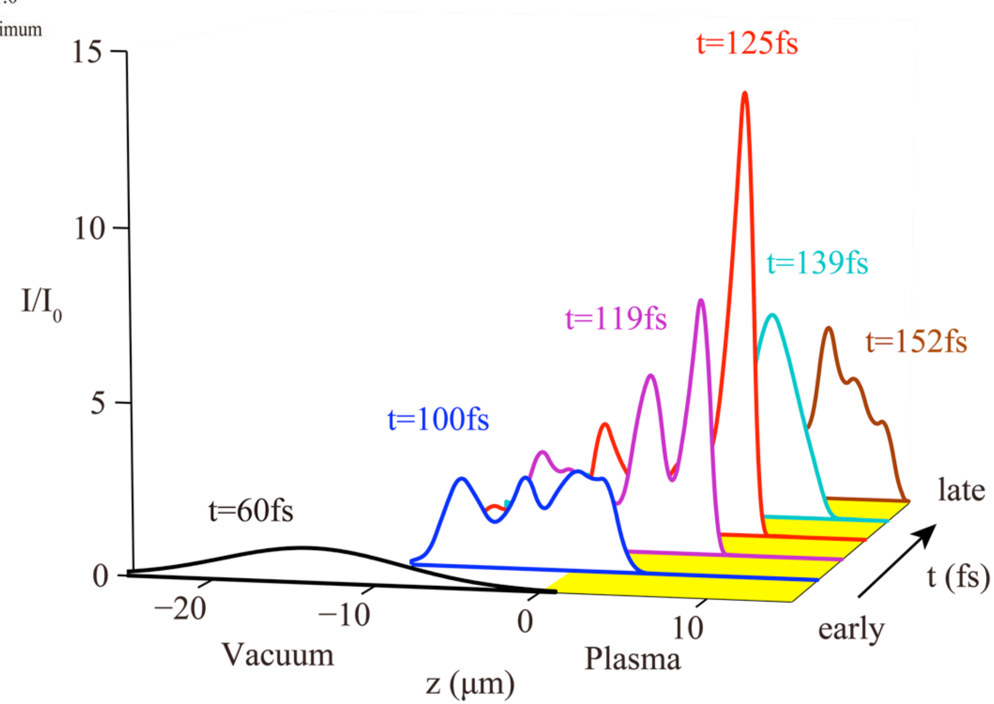
# Near-critical-density plasma lens



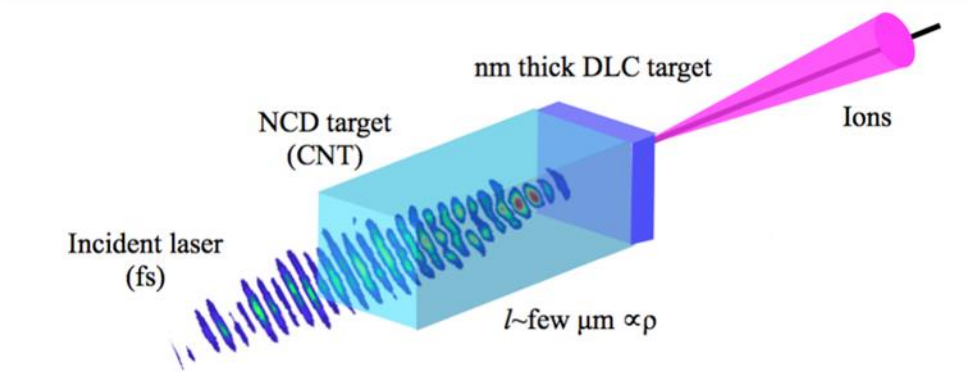

Laser pulse propagating in $2n_c$ plasma (3D PIC)

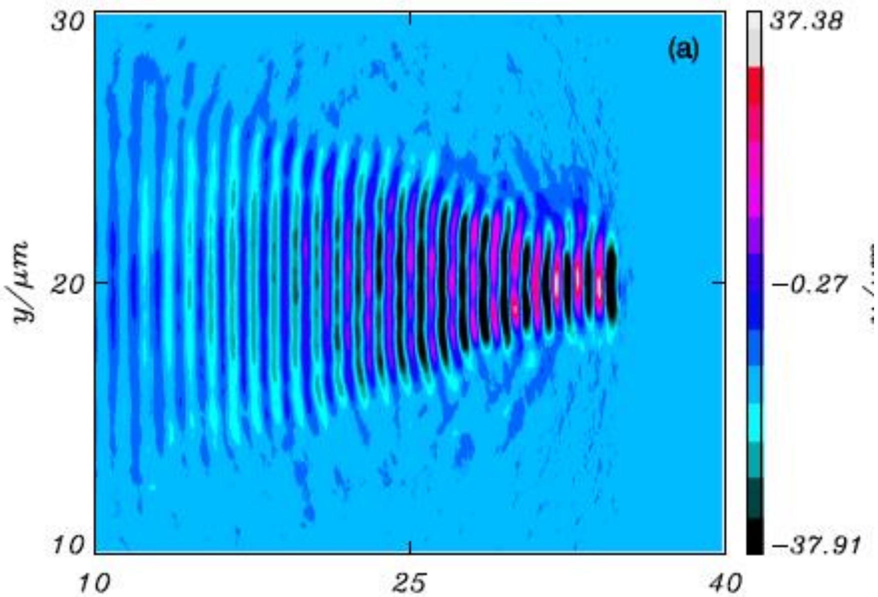
*I* boosted by a factor of 9

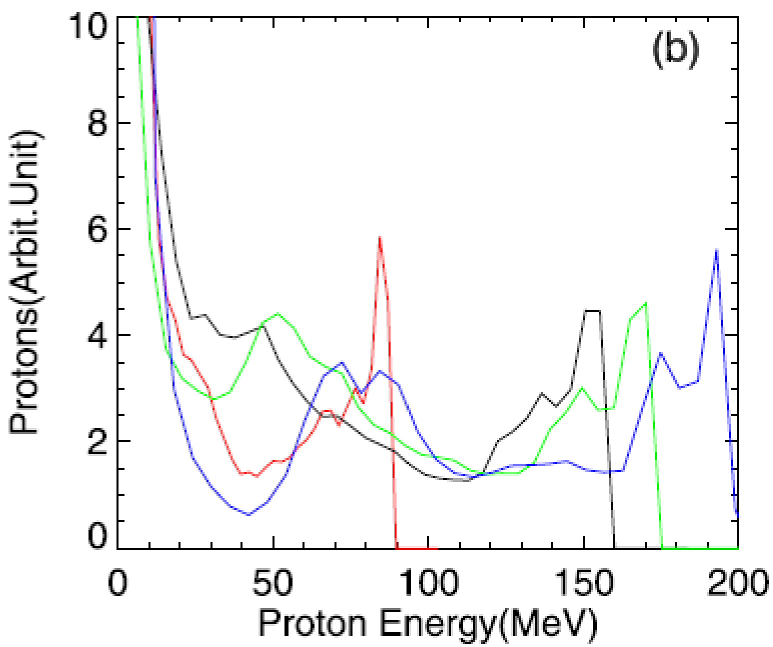
Pulse duration reduced by 50%， 1 cycle rising edge



# Composite nanotargets:



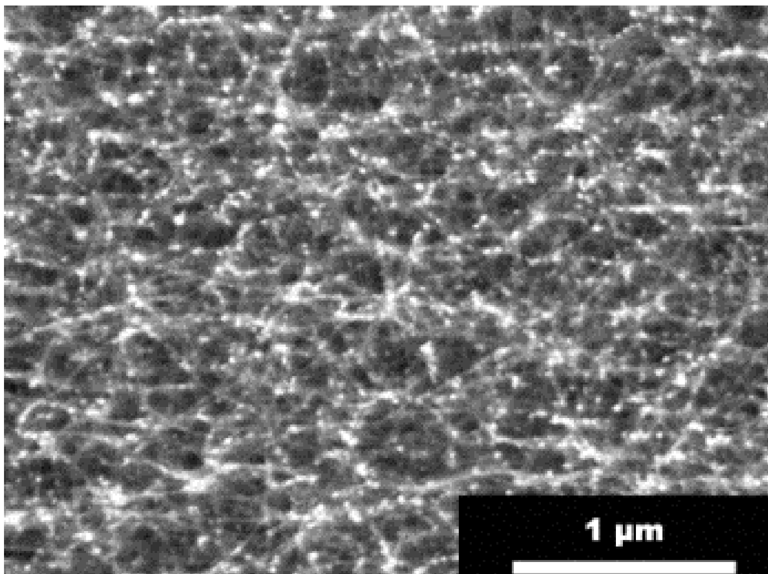



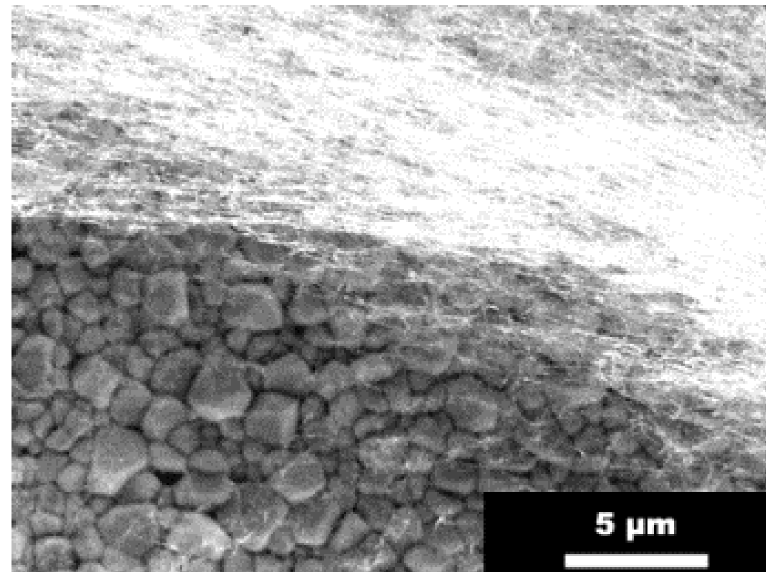

H. Wang,… W. Ma*, et.al. Physics of Plasmas **20**:13101(2013).

# Ultrathin Carbon Nanotube Foam

Freestanding UCNF




UCNF on DLC Foils



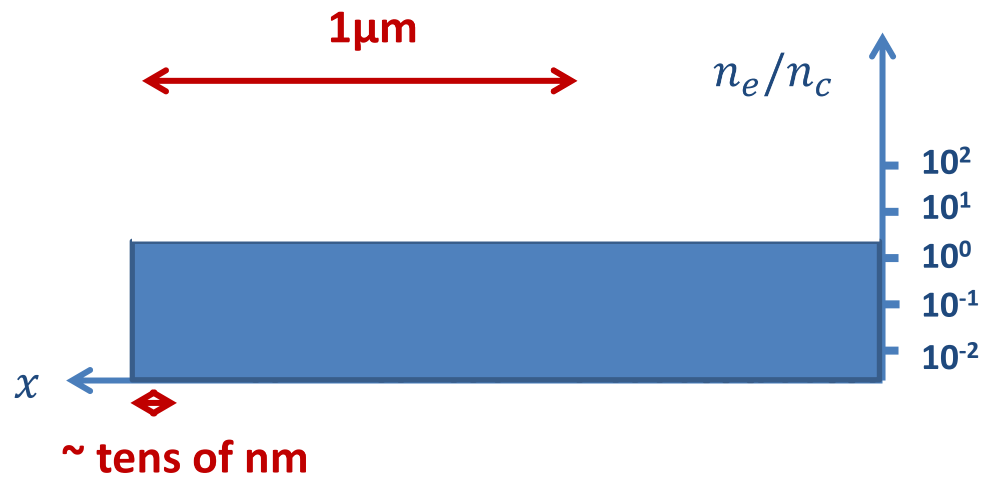

Ma, W. J, Song, L., et al. *Nano Letters* 7(8): 2307-2311.

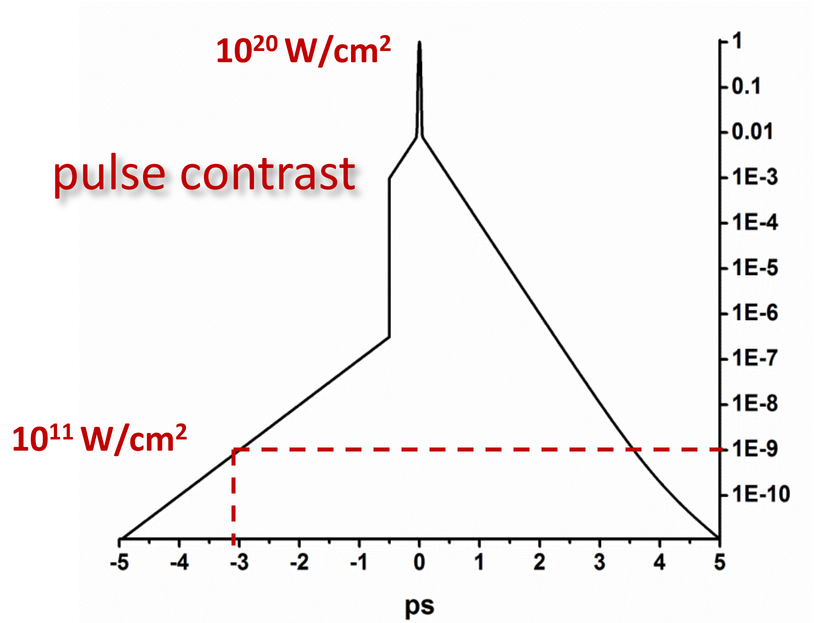
Density: $\rho = 1.5\sim12 mg/cm^3$

Thickness: $d = 1\sim200\ \mu m$

$n_e/n_c = 0.3\sim2$

# NCD Plasma from CNUF



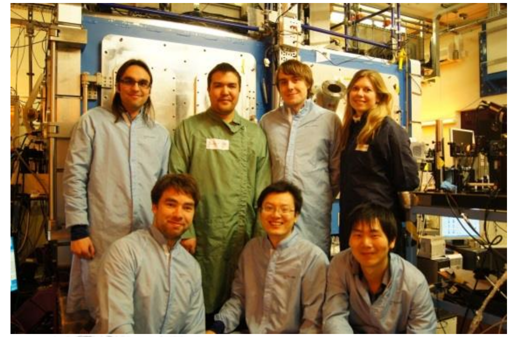



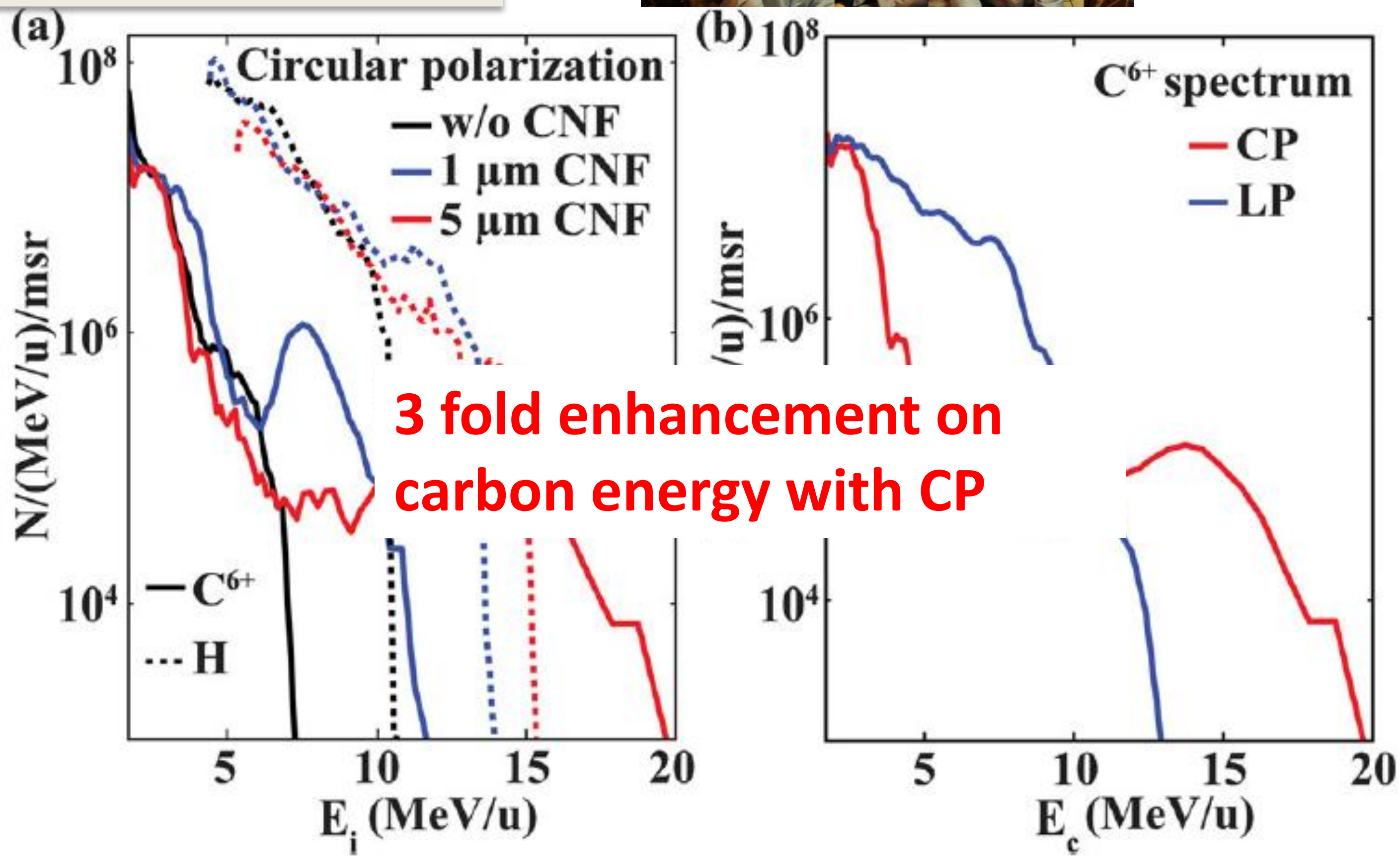

- ✓ Fully ionized
- ✓ Highly uniform
- ✓ Sharp boundary
- ✓ Thickness smaller than deletion length
- ✓ Freestanding or deposited on any substrates

# Results from composite nanotargets

**Astra Gemini Laser in RAL**

**50 fs,4~5 J on targets**
**I=2*$10^{20}$ W/cm$^2$**






**3 fold enhancement on carbon energy with CP**

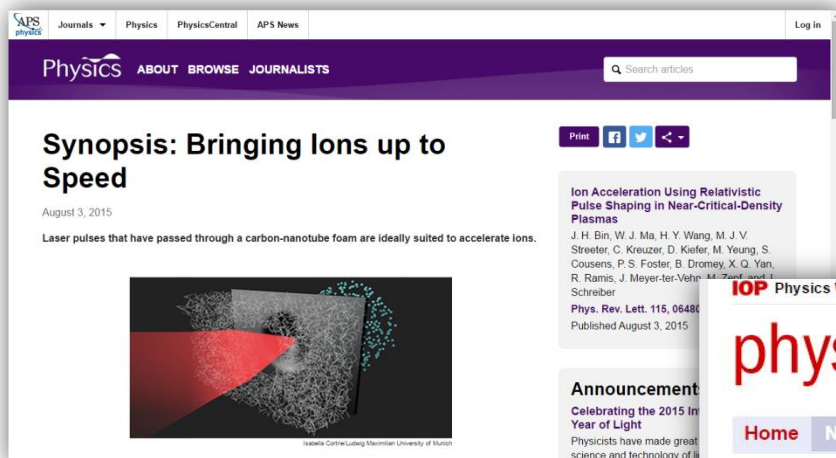
J.H.Bin, W.J. Ma, et.al. *PRL 115, 064801 (2015),* in collaboration with QUB (M. Zepf), RAL

PRL 115, 064801 (2015) PHYSICAL REVIEW LETTERS week ending 7 AUGUST 2015

# Ion Acceleration Using Relativistic Pulse Shaping in Near-Critical-Density Plasmas

J. H. Bin,[1,2,*] W. J. Ma,[1,3,†] H. Y. Wang,[1–3] M. J. V. Streeter,[4] C. Kreuzer,[1] D. Kiefer,[1] M. Yeung,[5] S. Cousens,[5] P. S. Foster,[5,6] B. Dromey,[5] X. Q. Yan,[3] R. Ramis,[7] J. Meyer-ter-Vehn,[2] M. Zepf,[5,8,‡] and J. Schreiber[1,2,§]

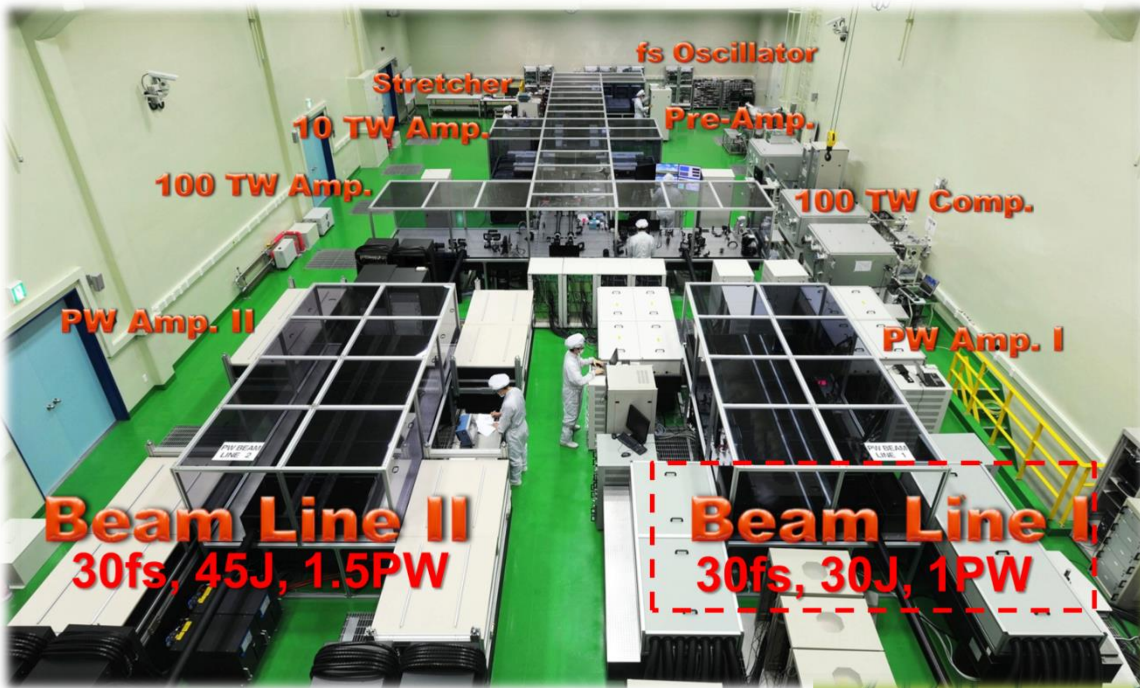
- PRL editor selected
- APS news: Synopsis : bringing ions up to speed




- IOP physicsword: Nanotubes energize laser-accelerated ions

# New step: higher intensity

PW Ti:Sapphire Laser (PULSER)



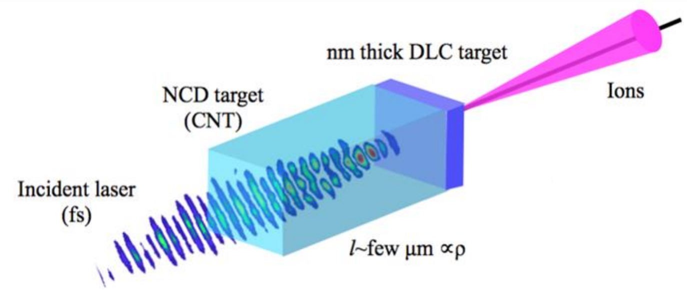

**1.5 PW laser (PULSE) in Center for Relativistic Laser Science(IBS), Korea**

**25fs-30fs,**
**Double plasma mirror,**
**9.2J on targets for LP,**

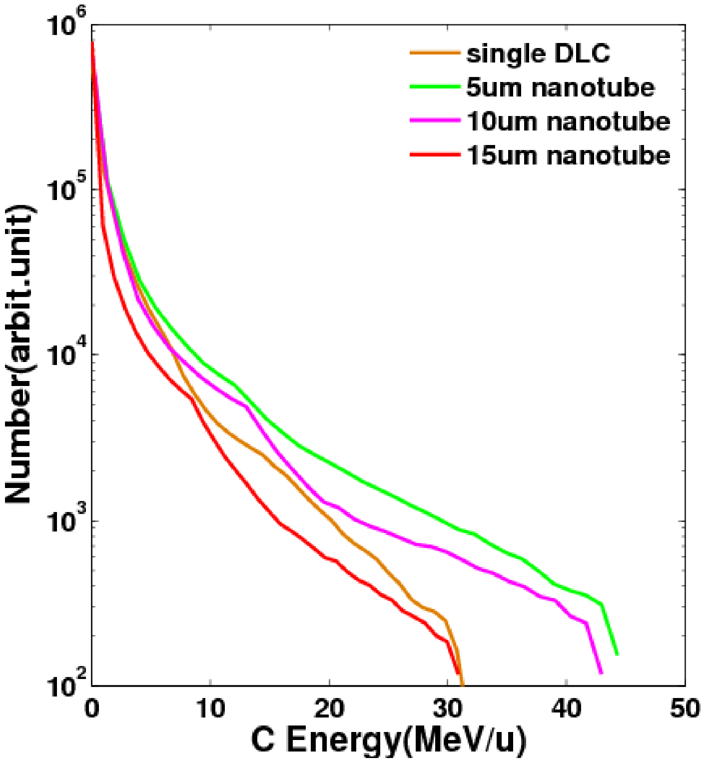
**$I = 5.45 \times 10^{20}$ W/cm$^2$**

2015.03

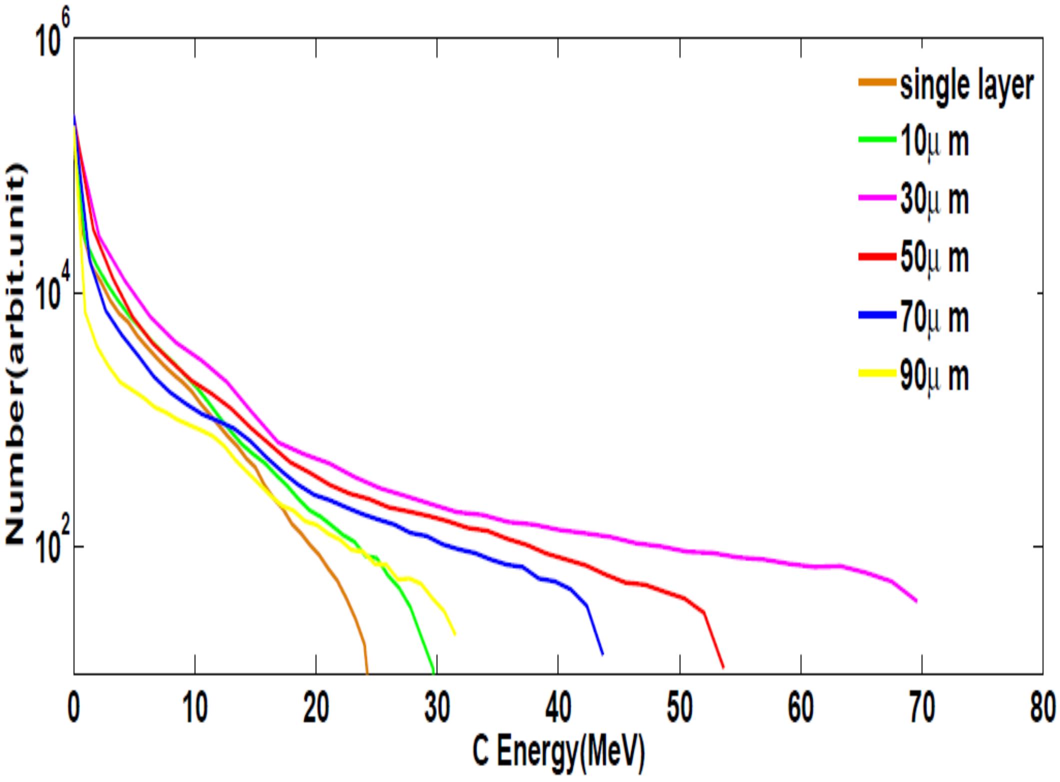
# Hints from simulation: reduce the density of the foam



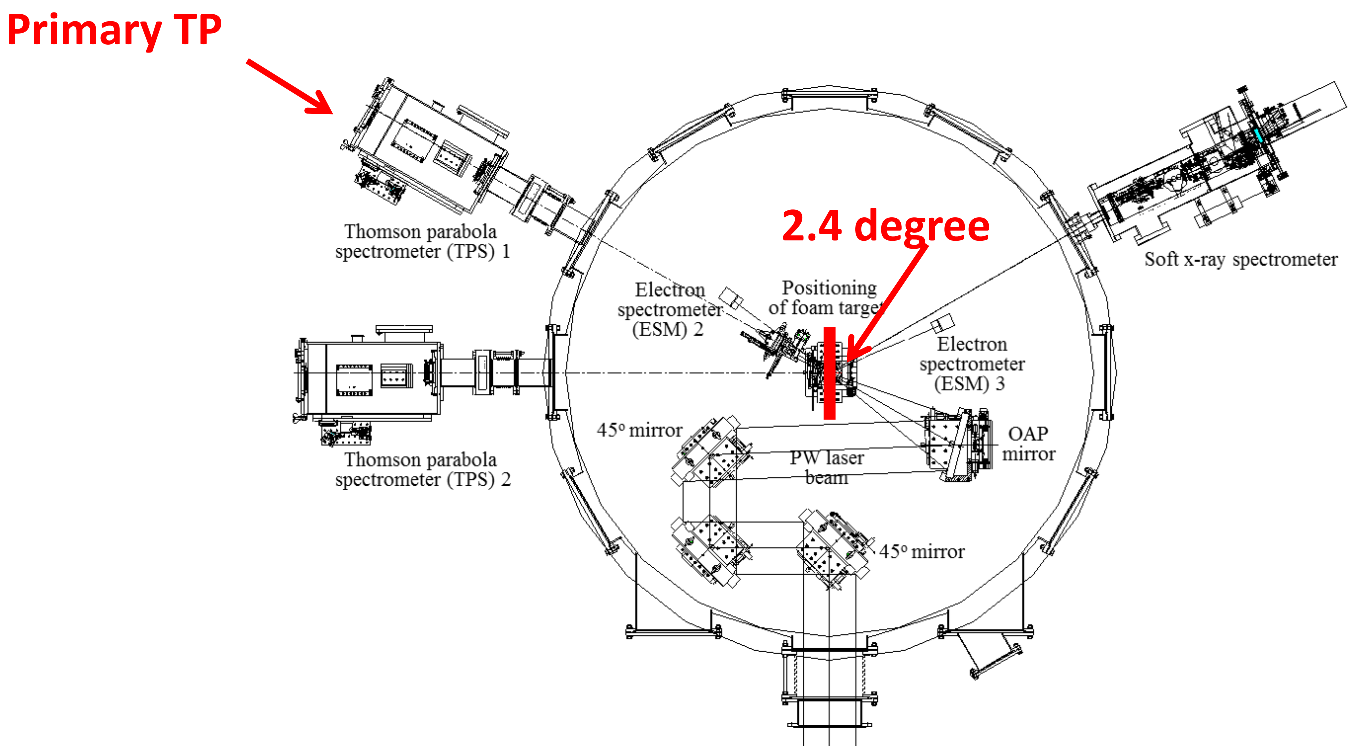

**$2n_c$:optimal thickness=5 um**



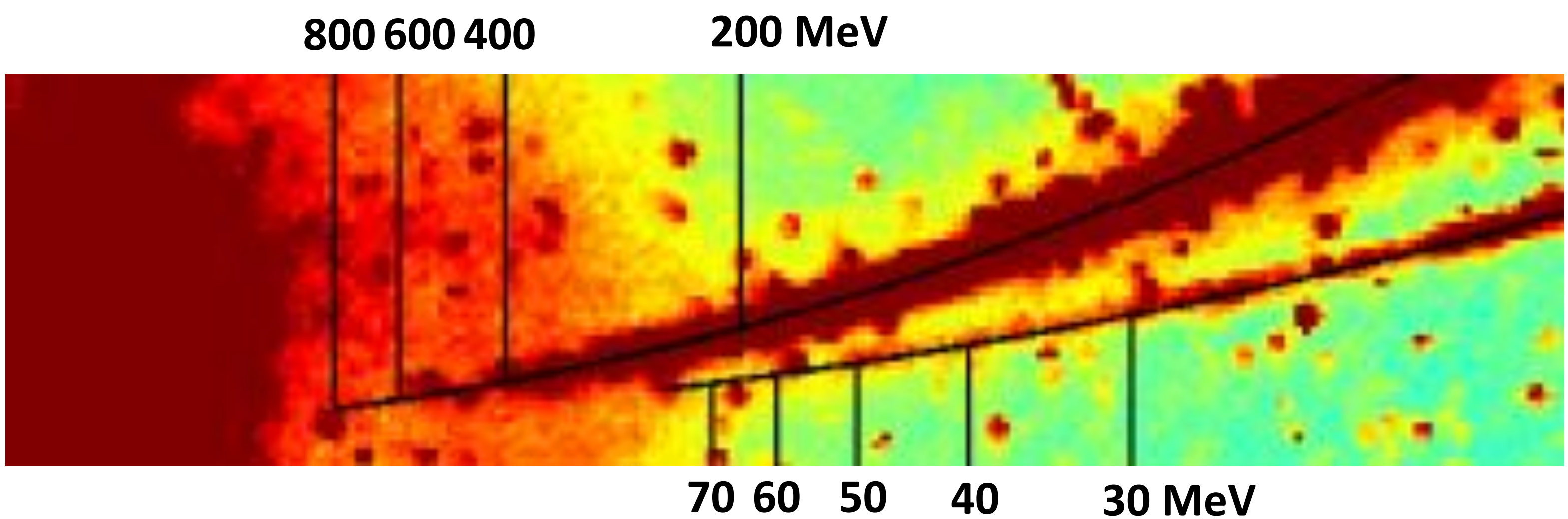

**$0.4n_c$:optimal thickness=30 um**



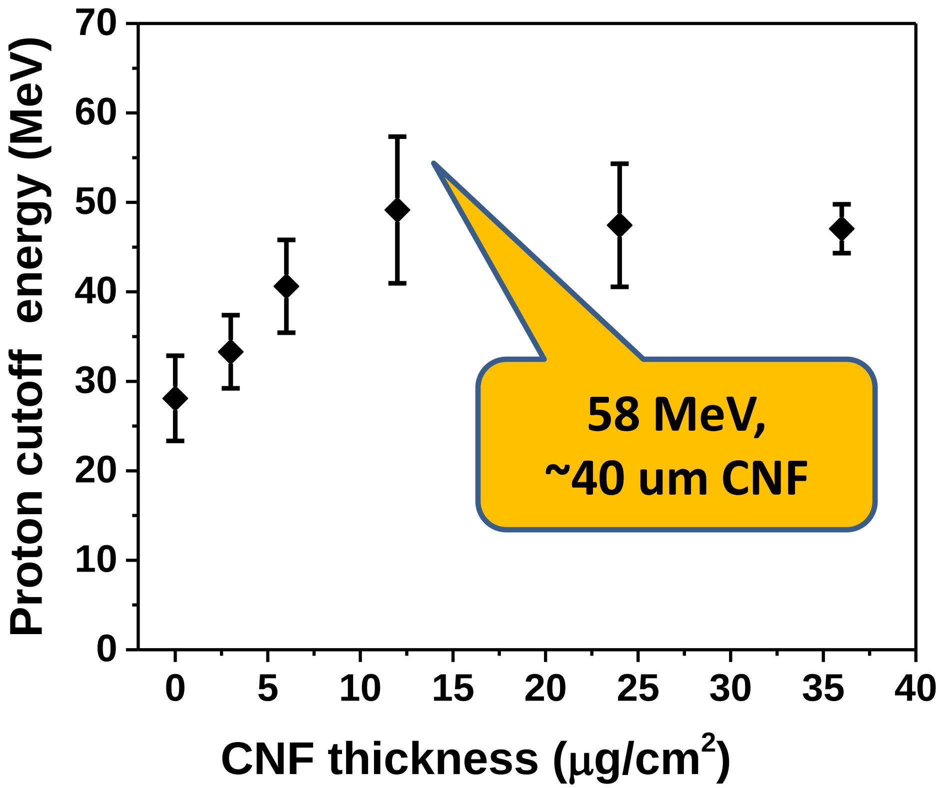

From H.Y. Wang (FSU Jena)

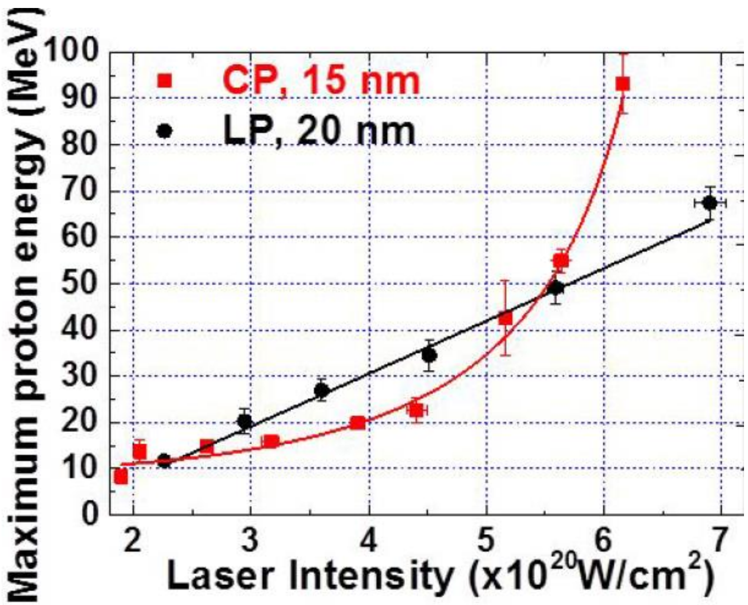



Raw data shot 344: : LP, Proton cutoff=54.3 MeV  Carbon cutoff=  597 MeV



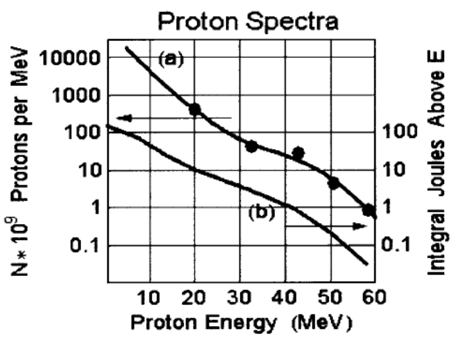
# Proton cutoff energy




I Jong Kim, et.al., arXiv:1411.5834

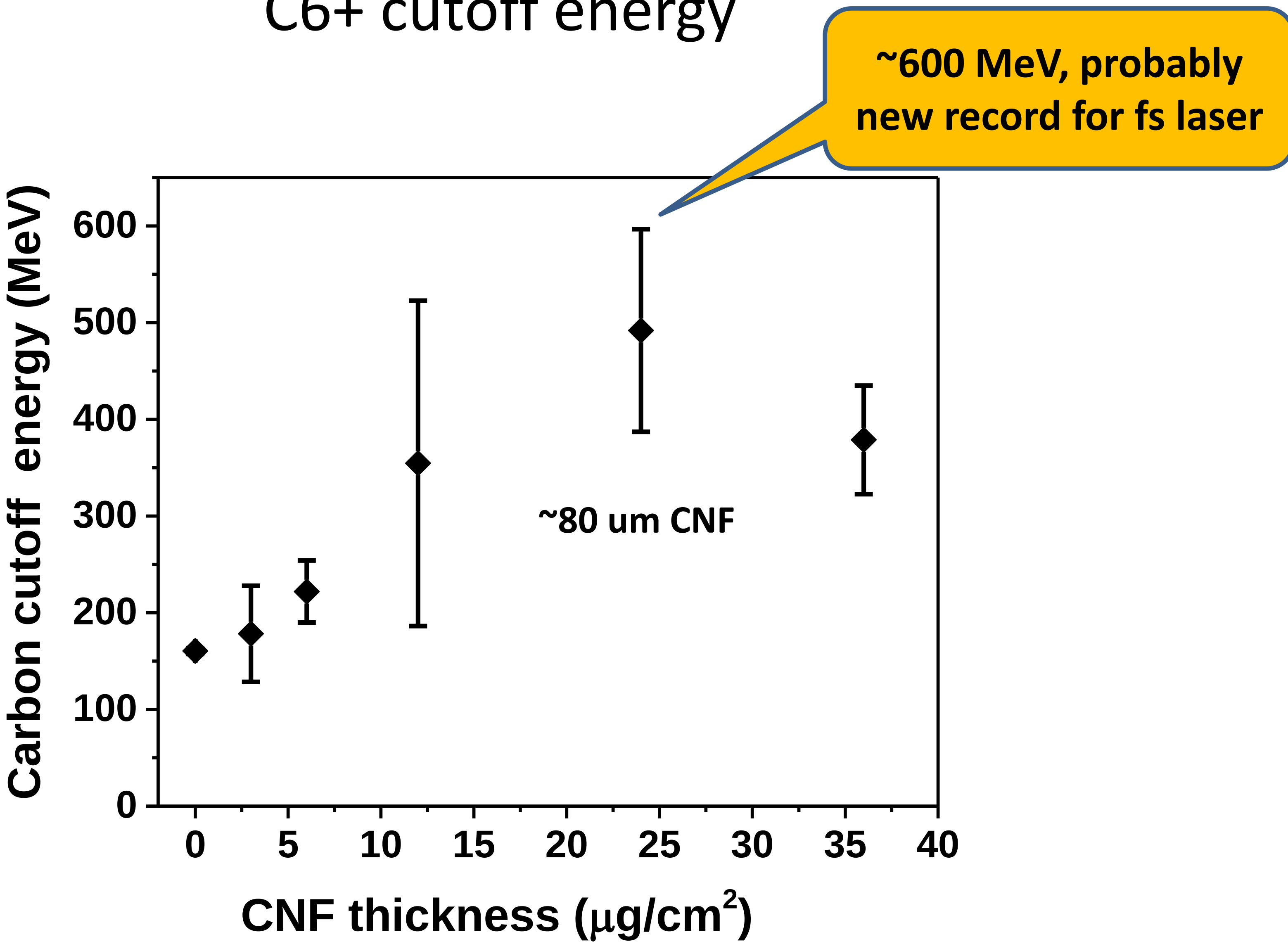
1st PW-laser: Snavely, PRL (2000)



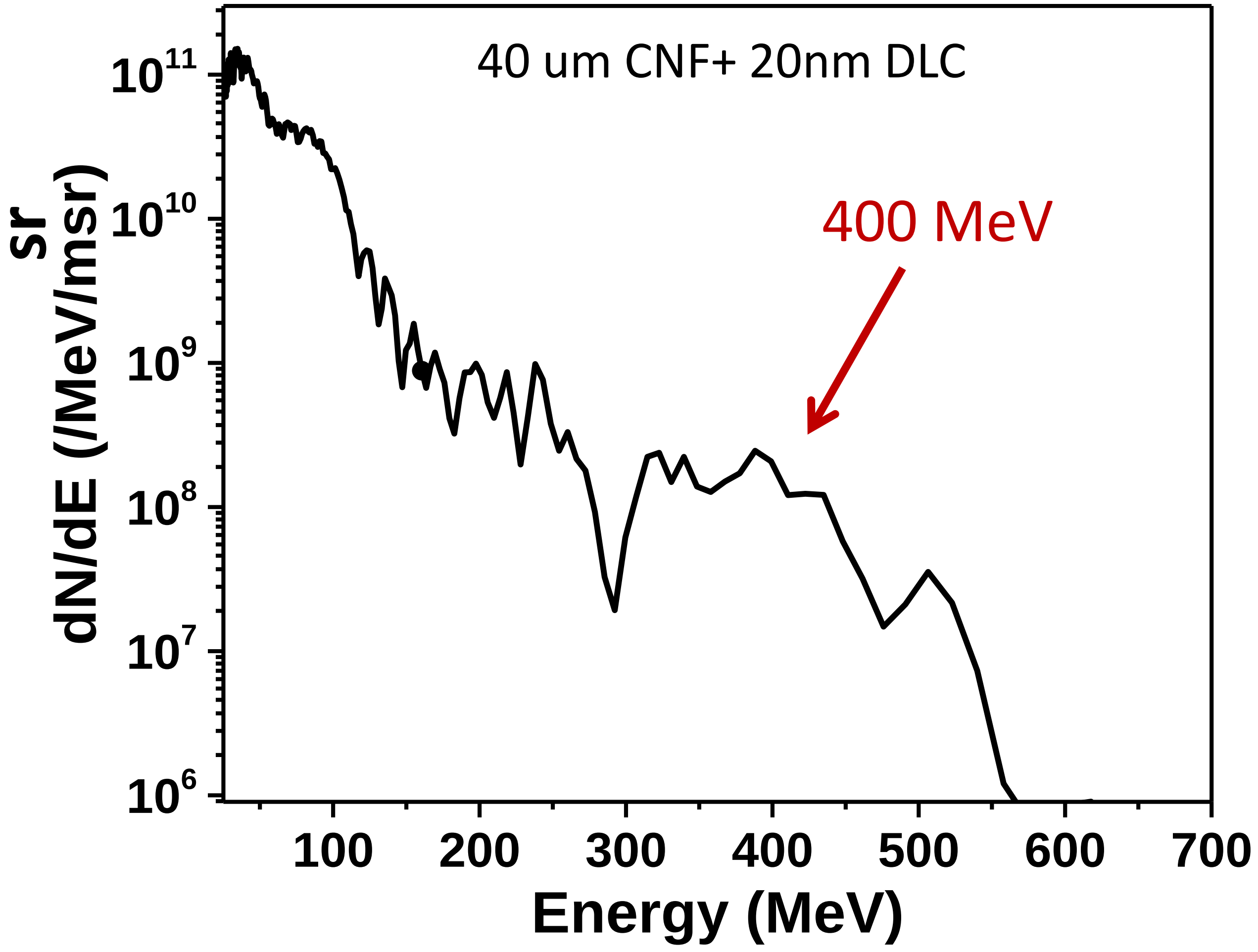

## thick foils vs composite nanotargets

| | | |
|---|---|---|
| **Proton cutoff** | 60 MeV | 58 MeV |
| **Pulse energy** | 500 J | 9.2 J |

# C6+ cutoff energy



# C6+ spectra



40 um CNF+ 20nm DLC
400 MeV
dN/dE (/MeV/msr)
sr
10^11
10^10
10^9
10^8
10^7
10^6
100
200
300
400
500
600
700
Energy (MeV)

# My new position in Peking University, China

## Compact LAser Plasma Accelerator (CLAPA )

200 TW, 25 fs laser, 1400 $m^2$ lab

# Thank you