

Generation of 600 MeV carbon ions with composite ultrathin targets

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Acknowledgement

Joerg Schreiber

Queens University Belfast (UK):

M. Zepf, M. H. Wang, Yeung, B. Dromey, D. Jung



Center for Relativistic Laser Science(IBS), Gwangju, Korea

I. J. Kim, I. L. Choi, C.H. Nam

Rutherford Appleton Lab (UK):

P. Foster, C. Spindloe, R. Pattathil et al.

FSU Jena (Germany):

M. Zepf, H. Wang, M. Kaluza, et al.

Max-Plank Institute of Quantum Optics(MPQ)

B. Liu, J. Meyer-ter-vehn

Los Alamos National Lab (LANL)

S. Palaniyappan

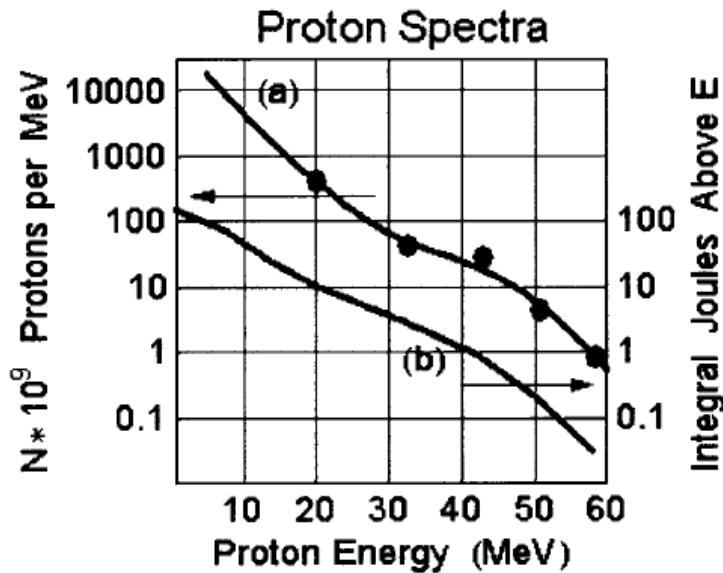
Ludwig-maximilian-University of Munich (LMU)

J. Schreiber, J. Bin, D. Haffa, P. Hilz, C. Kreuzer, D. Kiefer, T. Ostermayr, K. Allinger,

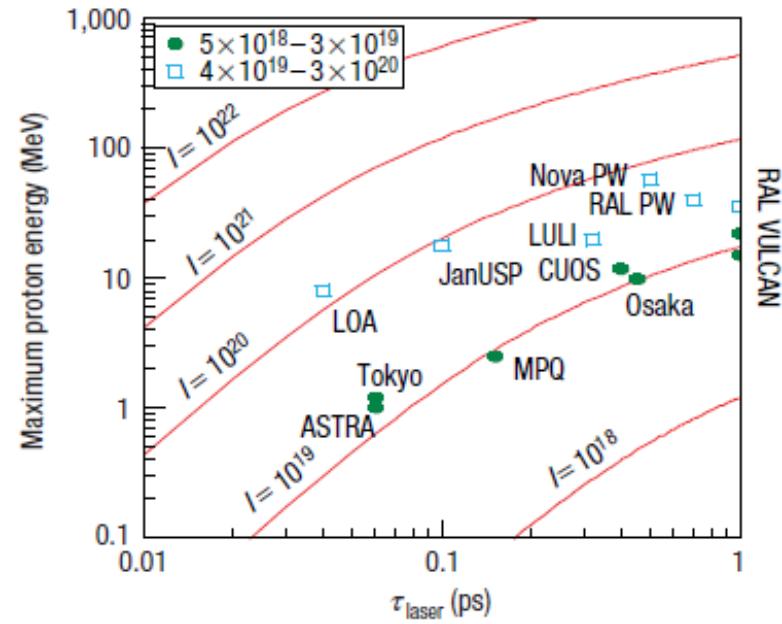


supported by the DFG Cluster of Excellence Munich-Centre for Advanced Photonics (MAP) and the Transregio TR18

Laser-driven ion acceleration



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

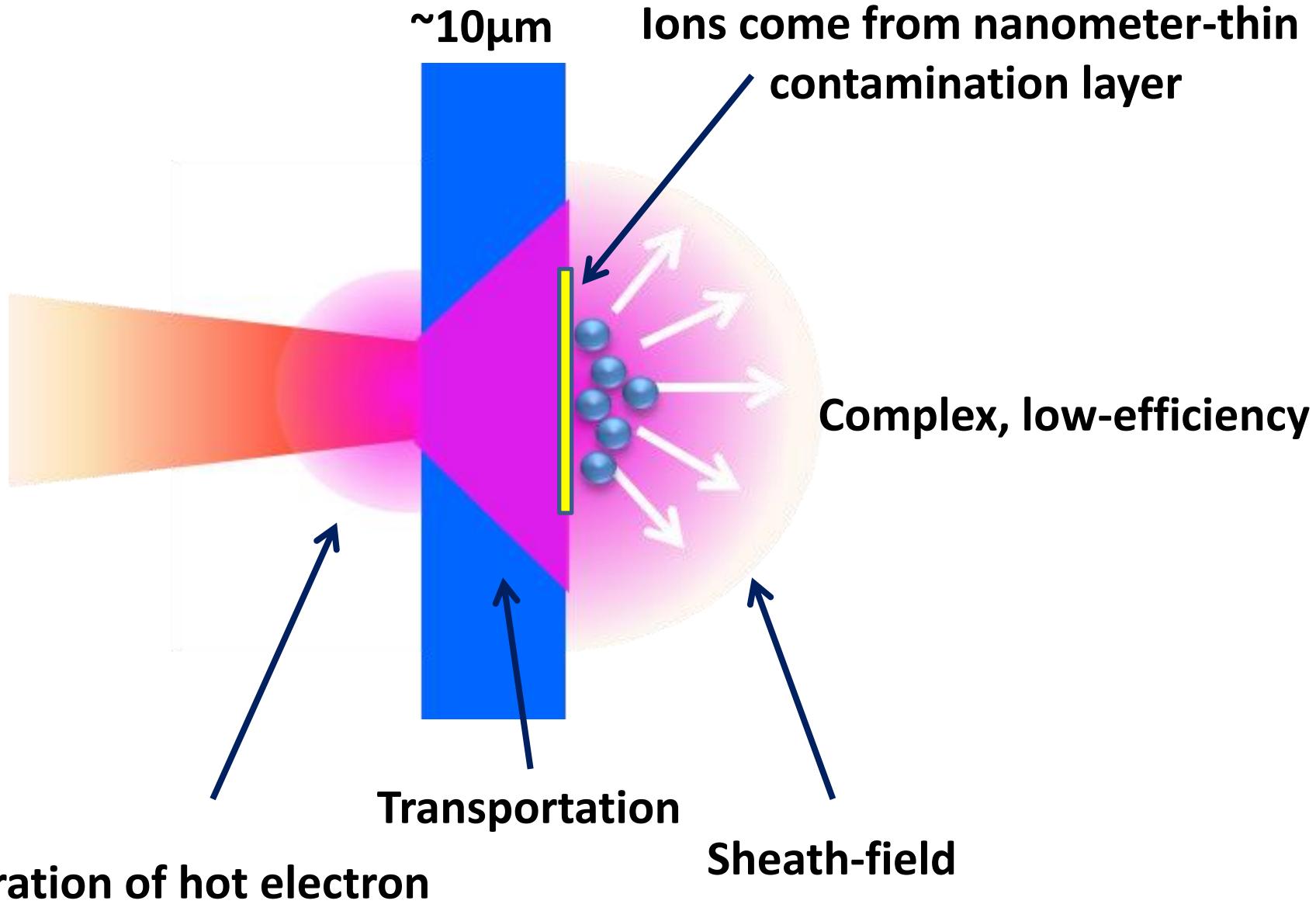


Scaling law: J. Fuchs, Nature Physics(2006)

Cut-off proton **60 MeV**

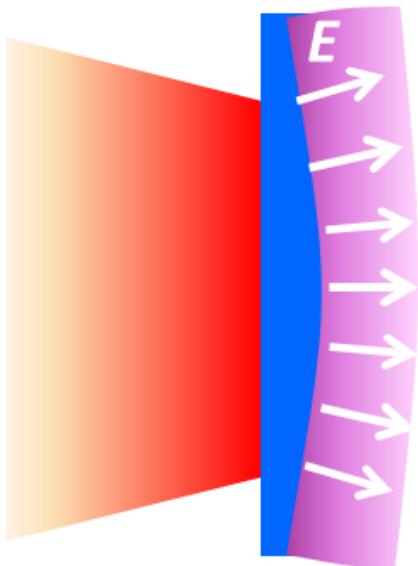
Pulse energy **500 J**

Ultrathin targets, why?



Potential of nanotargets

~10nm



Pulse energy: 1J

Ions in the targets: 10^{10}

Theoretical up-limit of ion energy

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

Light sail acceleration

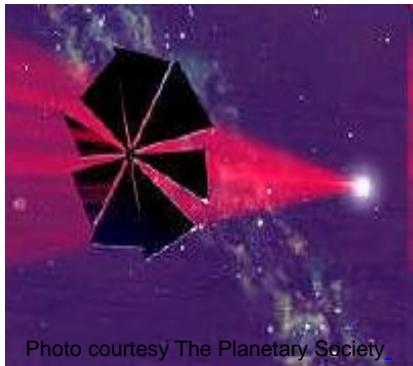
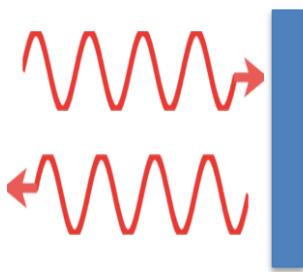


Photo courtesy The Planetary Society

Radiation pressure:

$$P_{rad} = \frac{I}{c} = \frac{3 \times 10^{-7} \text{ N/cm}^2}{1 \text{ W/cm}^2}$$
$$= 3 \times 10^{13} \text{ N/cm}^2 \quad (I = 10^{20} \text{ W/cm}^2)$$



Mass of 10 nm carbon foil $\sim 2 \mu\text{g/cm}^2$, acceleration:

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

$$\approx 1 \text{ MeV/u/fs}$$

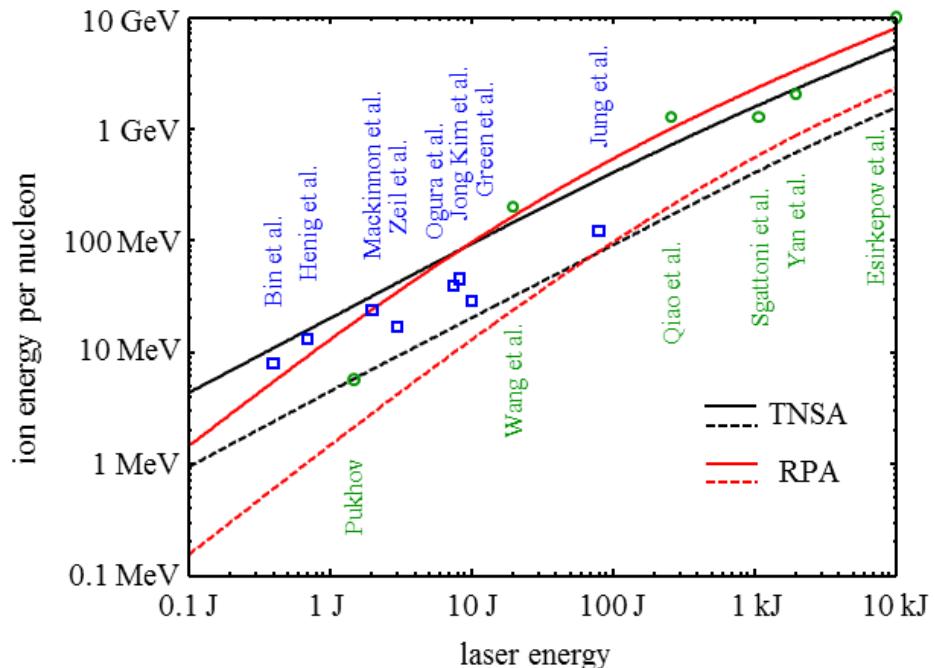
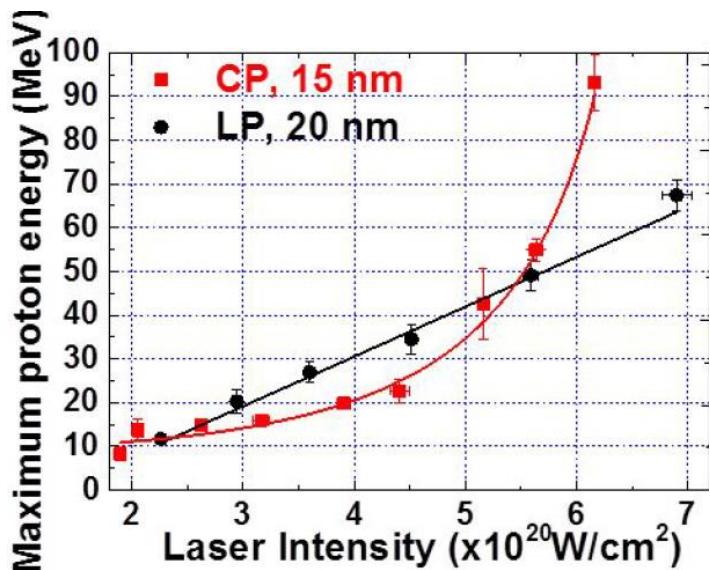
Advantages of light sail scheme

- ✓ 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



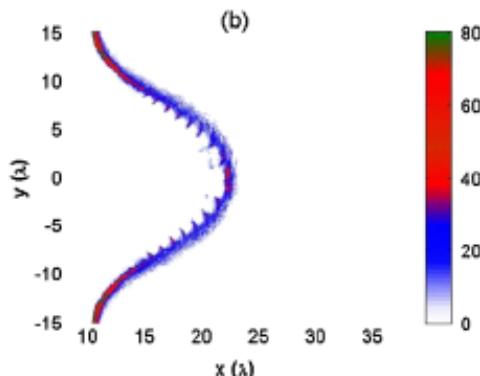
J. Schreiber, *et al.*, High Power Laser Science and Eng. 2, e41 (2014)

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

Problems of light sail scheme

Sail must NOT be broken!

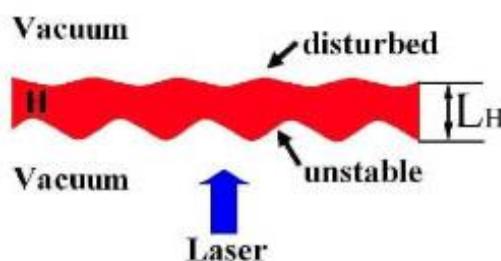
1. Laser heating



2. Instability



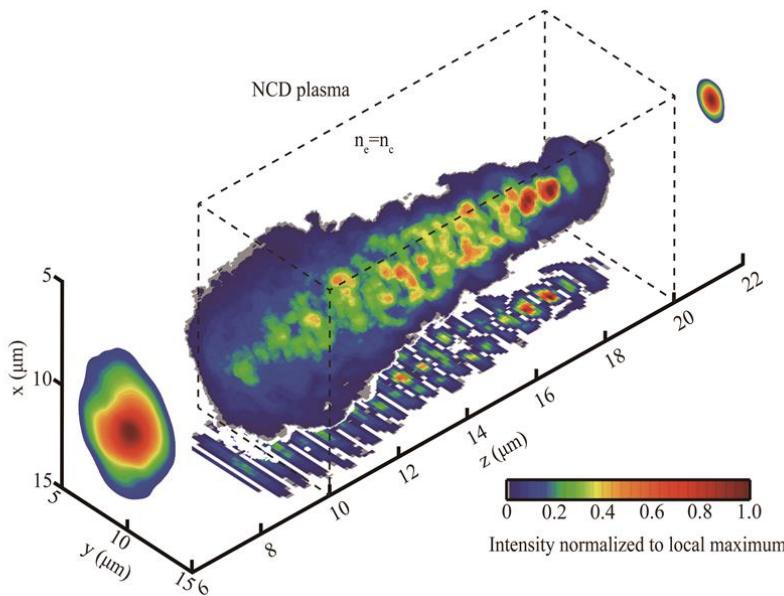
Punch the foil as hard as possible before it breaks



$$I \uparrow, \tau \downarrow$$

Near-critical-density plasma lens

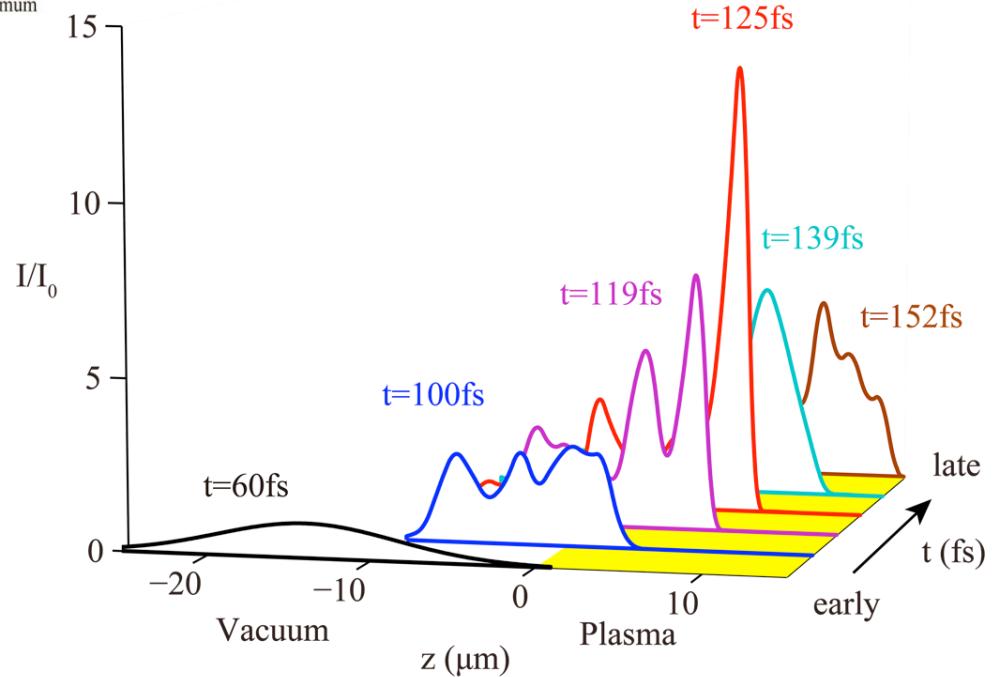
a



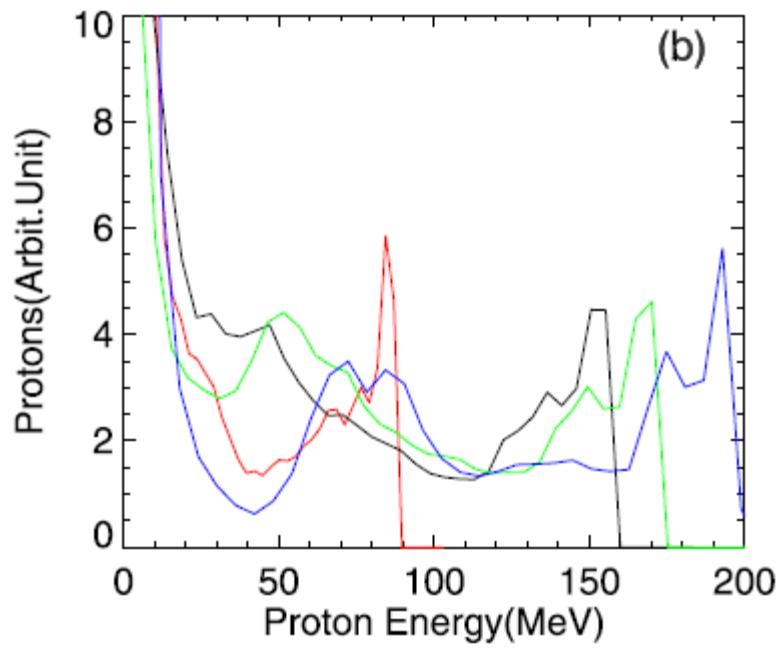
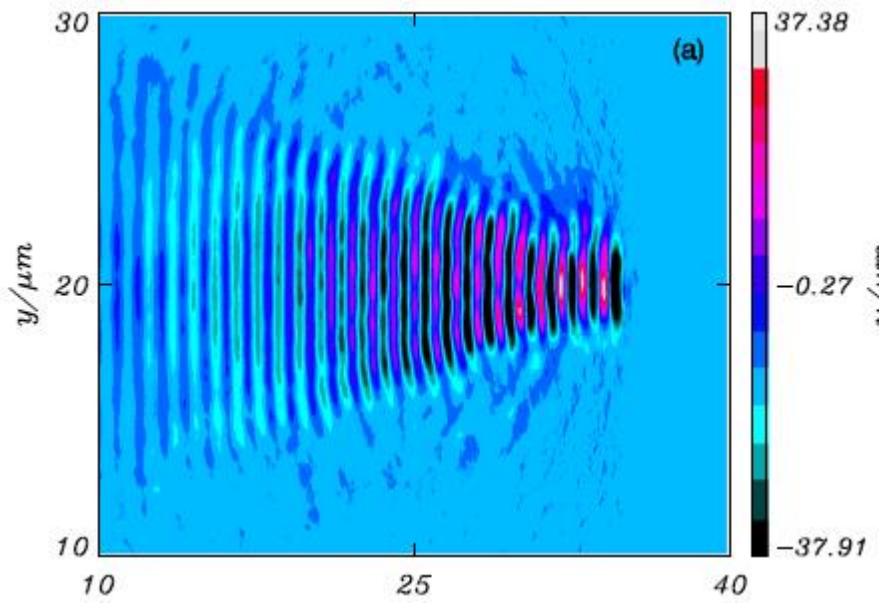
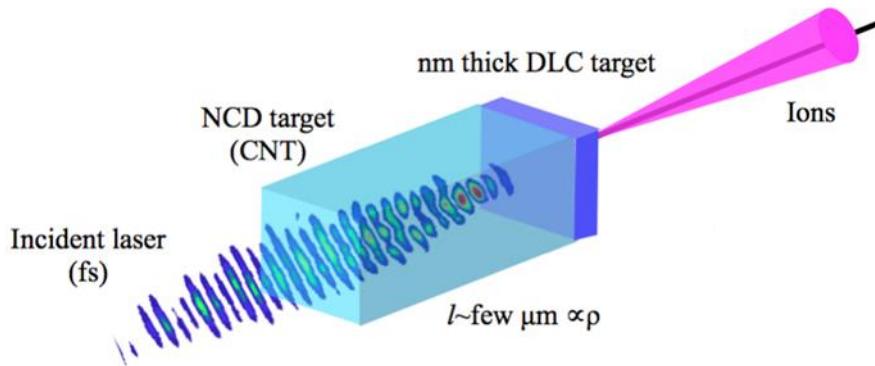
Laser pulse propagating in
 $2n_c$ plasma (3D PIC)

I boosted by a factor of 9

Pulse duration reduced by
50%, 1 cycle rising edge



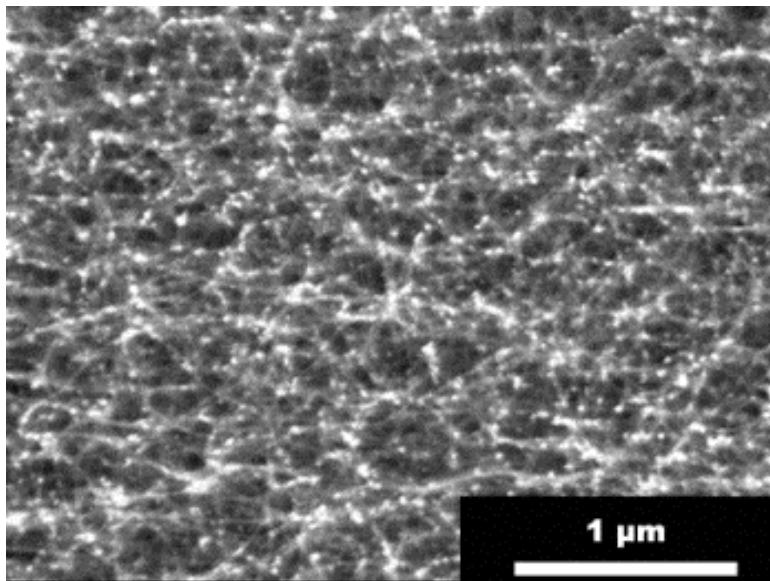
Composite nanotargets:



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

Ultrathin Carbon Nanotube Foam

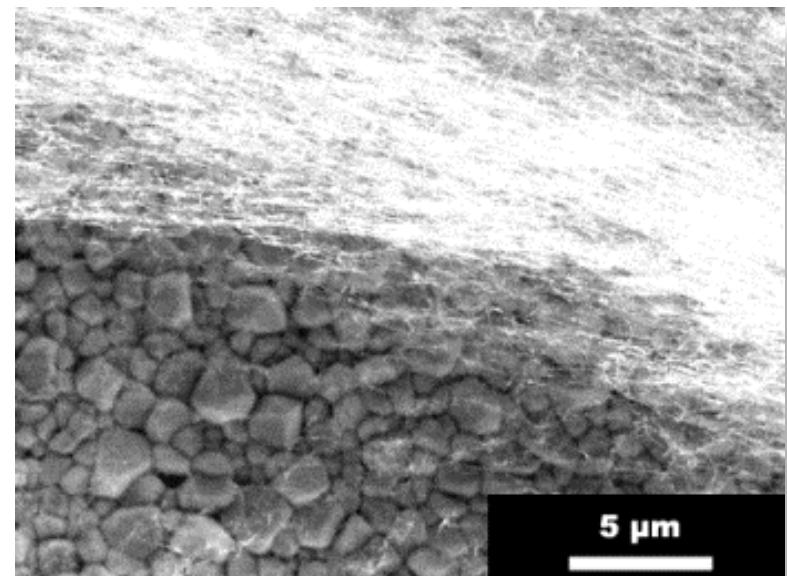
Freestanding UCNF



Density: $\rho = 1.5\text{--}12 \text{ mg/cm}^3$

Thickness: $d = 1\text{--}200 \text{ } \mu\text{m}$

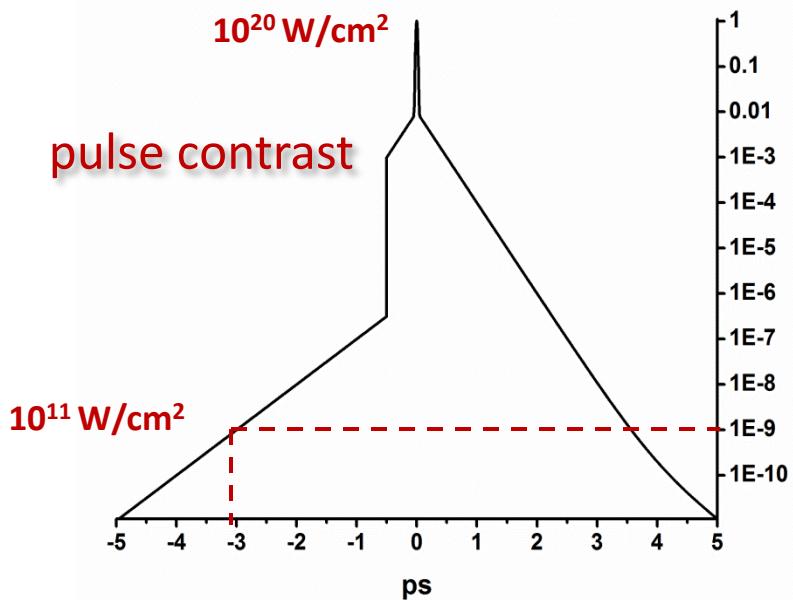
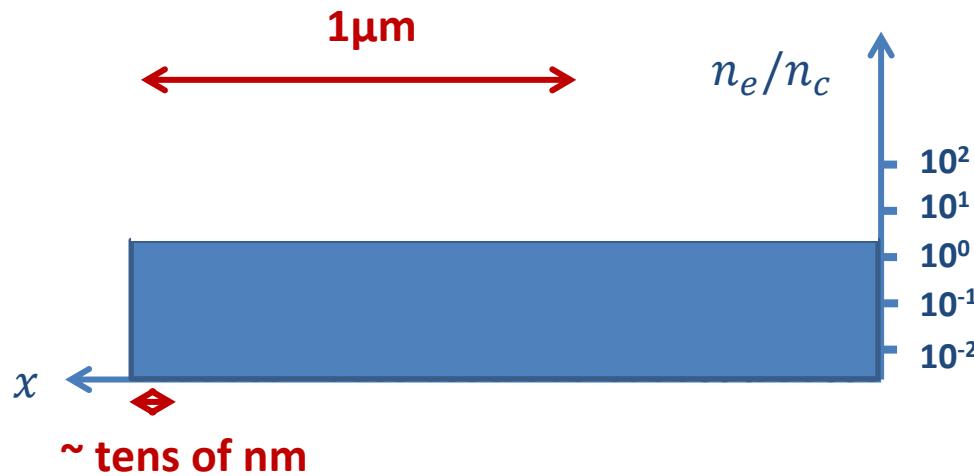
UCNF on DLC Foils



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

$$n_e/n_c = 0.3\text{--}2$$

NCD Plasma from CNUF

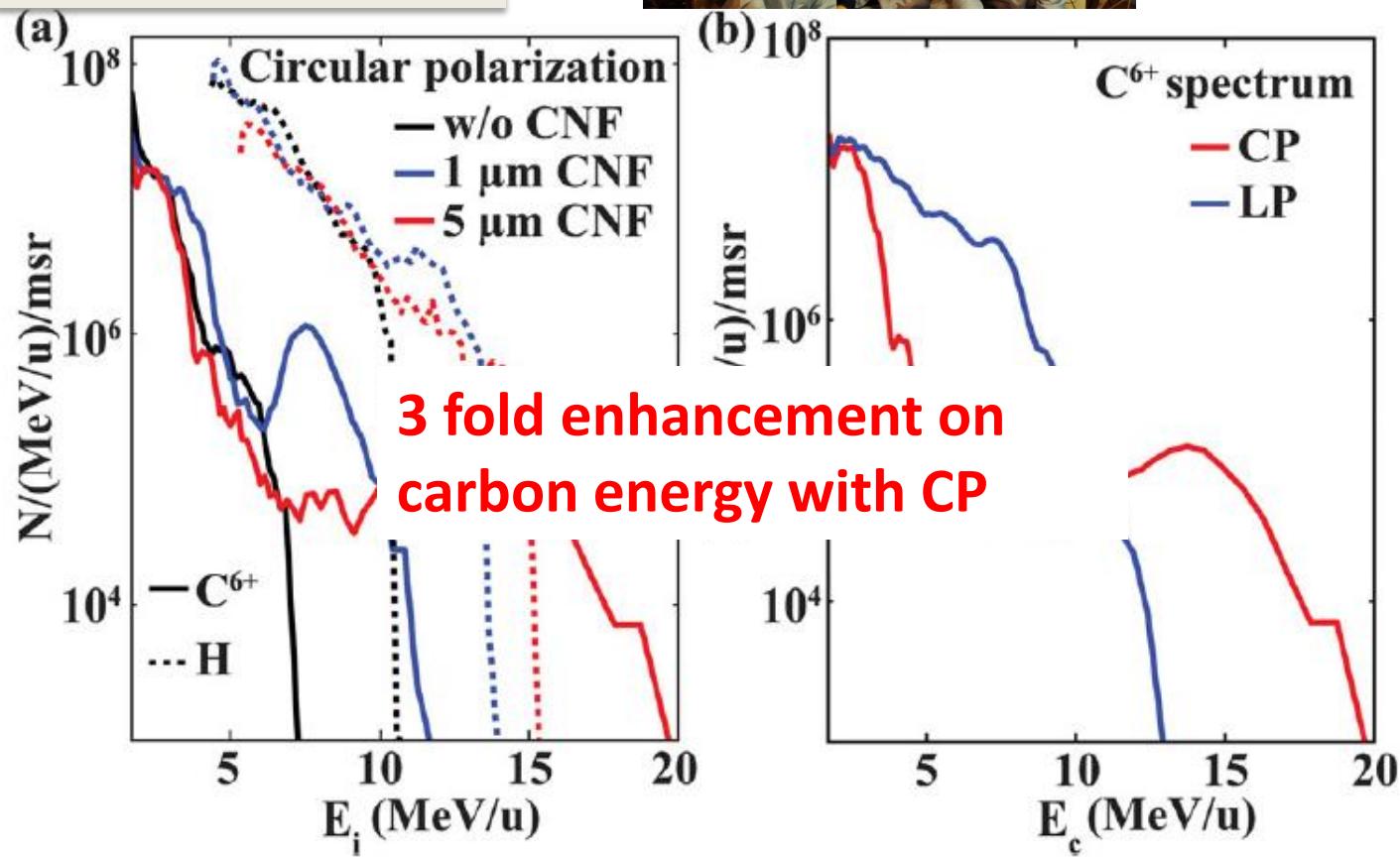
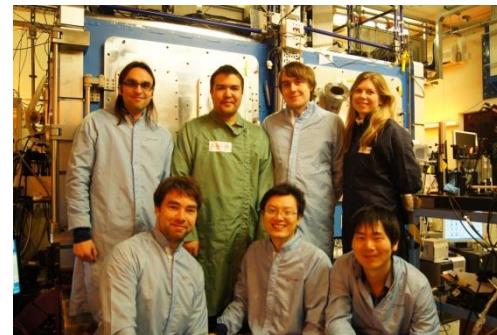


- ✓ Fully ionized
- ✓ Highly uniform
- ✓ Sharp boundary
- ✓ Thickness smaller than deletion length
- ✓ Freestanding or deposited on any substrates

Results from composite nanotargets

Astra Gemini Laser in RAL

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





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

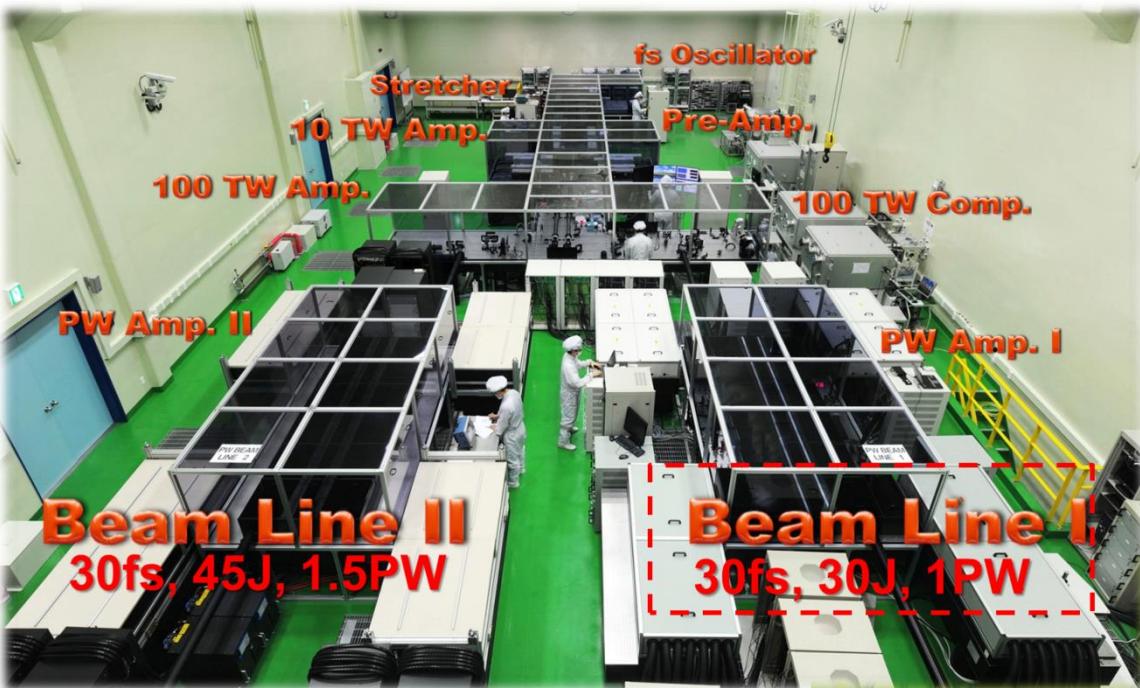
The screenshot shows the APS Physics website. At the top, there are navigation links for Journals, Physics, PhysicsCentral, and APS News. Below that is a purple header bar with the Physics logo, 'ABOUT', 'BROWSE', and 'JOURNALISTS' buttons, and a search bar. The main content area features a title 'Synopsis: Bringing Ions up to Speed' with a date of August 3, 2015. A sub-headline states: 'Laser pulses that have passed through a carbon-nanotube foam are ideally suited to accelerate ions.' To the left is a small image of a red laser beam hitting a white, porous material. To the right is a box containing the full article title and authors, followed by a link to Phys. Rev. Lett. 115, 064801 and the publication date of August 3, 2015. Below the article is an 'Announcement' section about the 2015 International Year of Light.

- IOP physicsworld: Nanotubes energize laser-accelerated ions

The screenshot shows the IOP Physics World website. At the top, it says 'IOP Physics World - the member magazine of the Institute of Physics'. The main banner features the website's name 'physicsworld.com'. Below the banner is a navigation menu with 'Home', 'News' (which is highlighted in red), 'Blog', 'Multimedia', 'In depth', and 'Events'. On the left, there is a 'News archive' sidebar with links to years from 2013 to 2015. The main content area has a title 'Nanotubes energize laser-accelerated ions' with a date of Aug 31, 2015. It includes a large image of a red laser beam hitting a white, porous material.

New step: higher intensity

PW Ti:Sapphire Laser (PULSER)



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

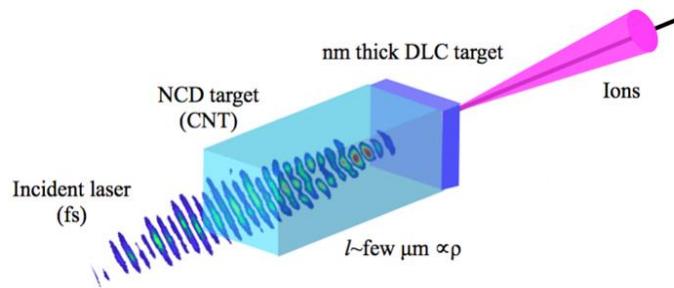
$$I = 5.45 \times 10^{20} \text{ W/cm}^2$$

2015.03

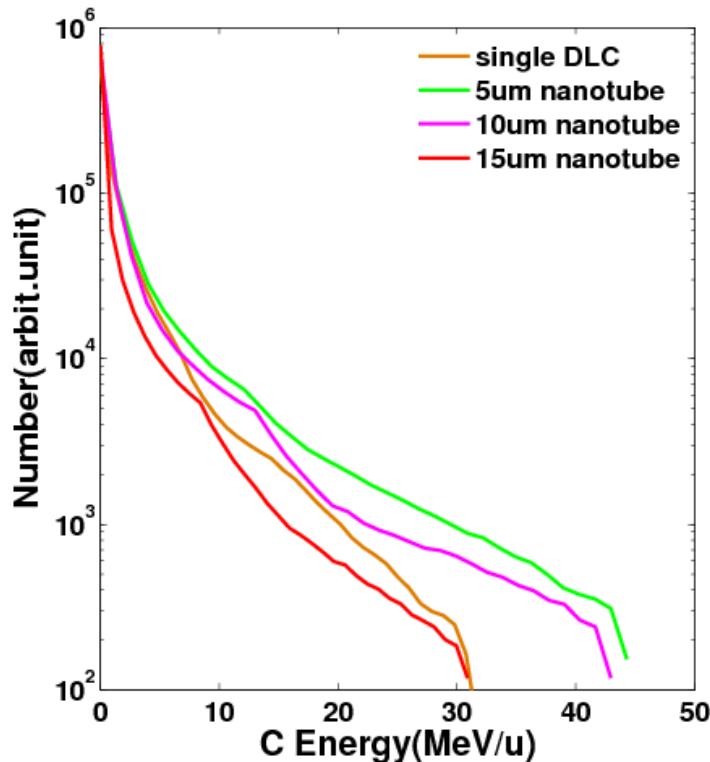
1.5 PW laser (PULSE) in
Center for Relativistic Laser
Science(IBS), Korea



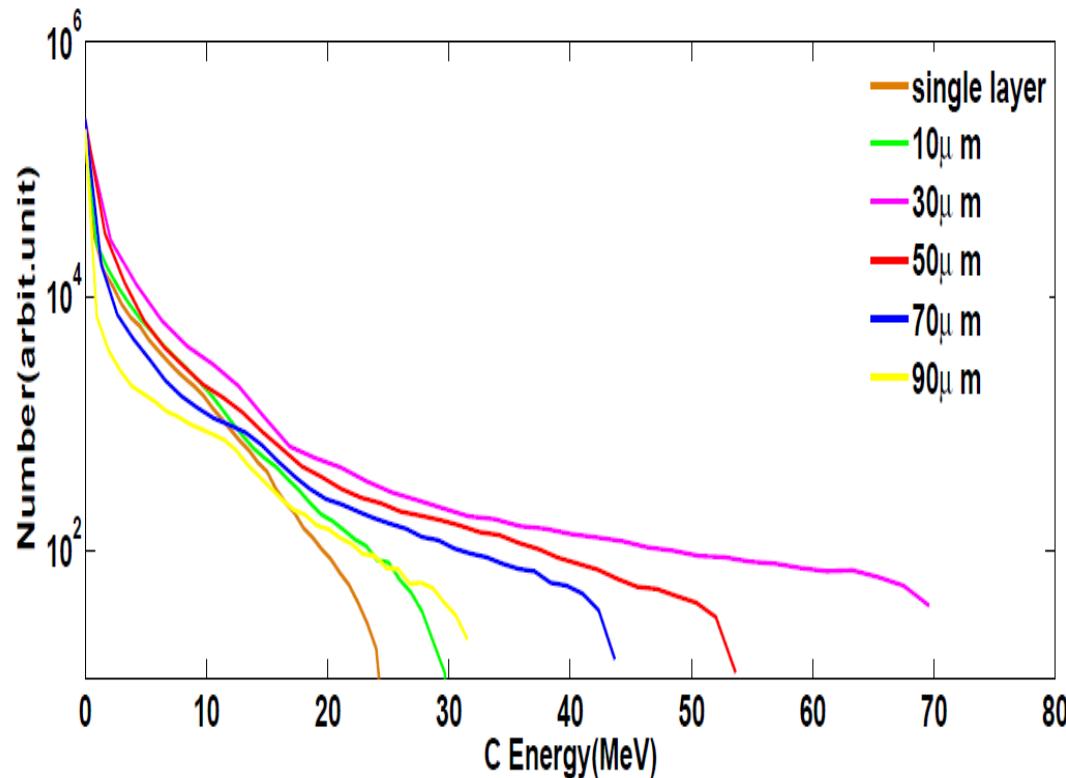
Hints from simulation: reduce the density of the foam

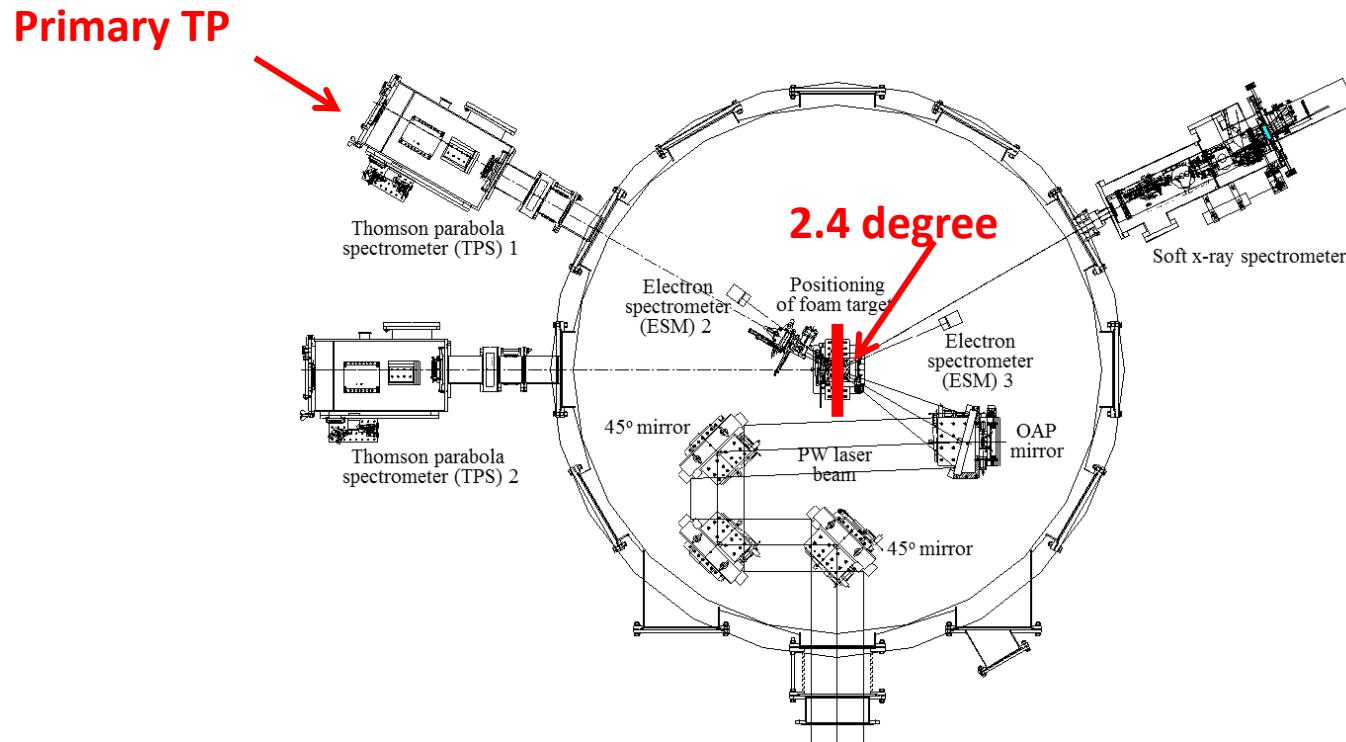


$2n_c$:optimal thickness=5 um



$0.4n_c$:optimal thickness=30 um

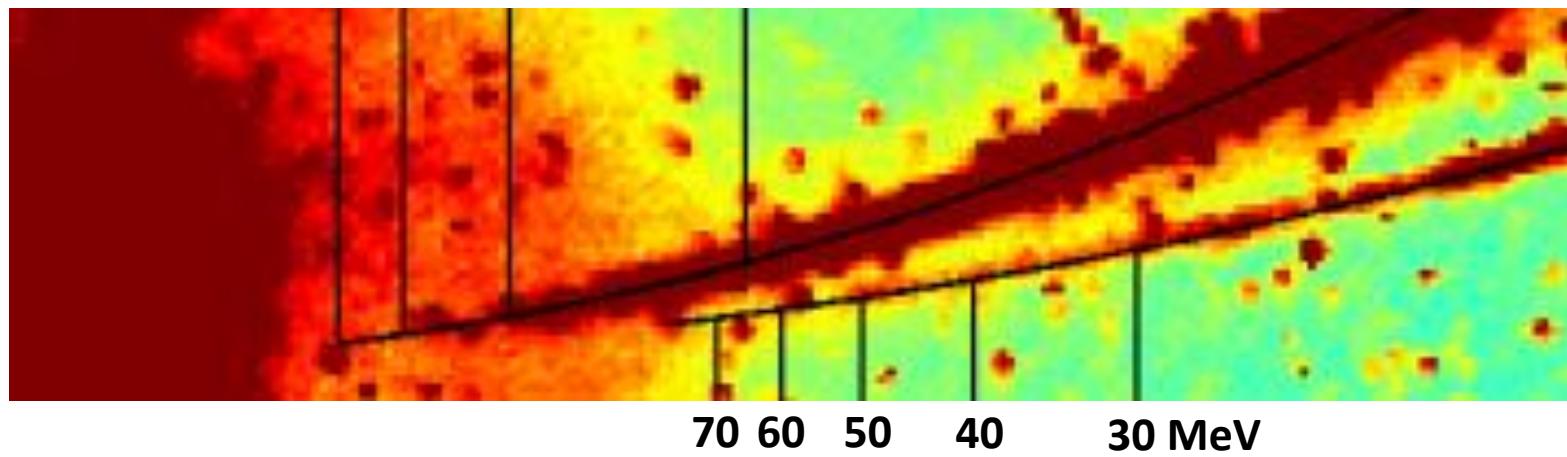




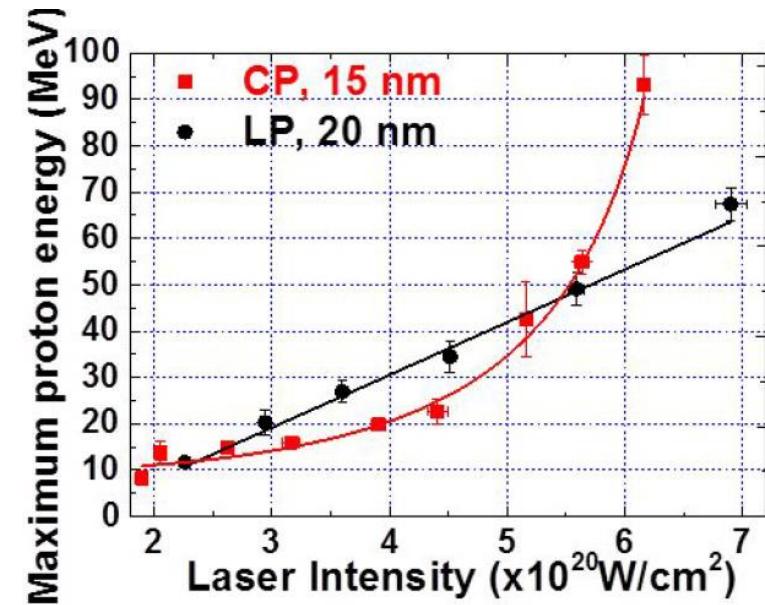
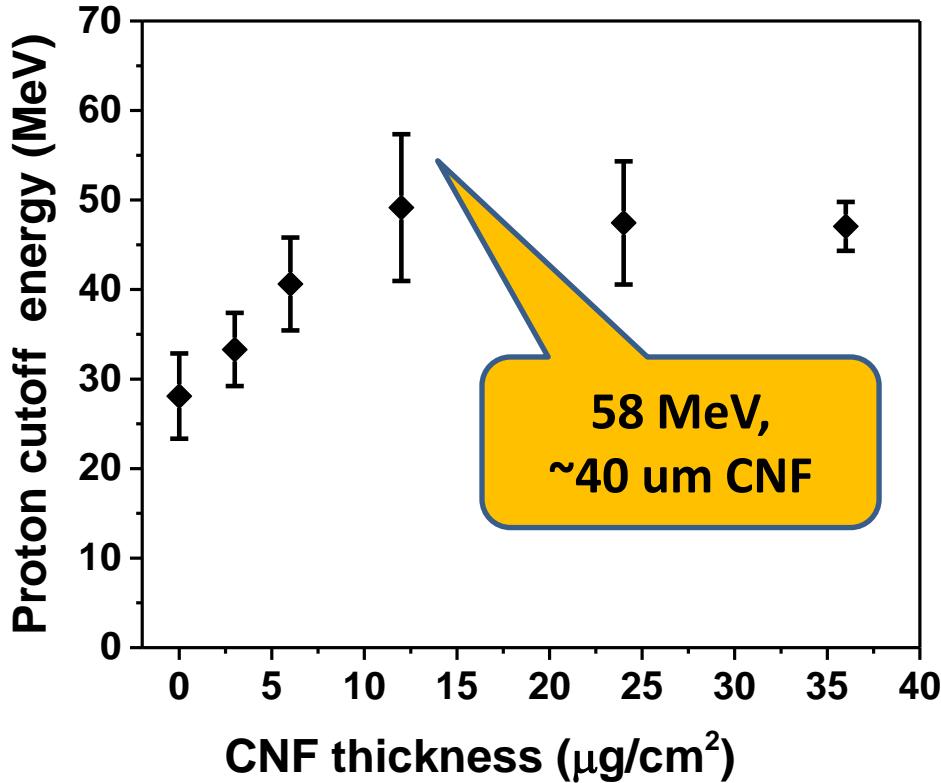
Raw data shot 344: : LP, Proton cutoff=54.3 MeV Carbon cutoff= 597 MeV

800 600 400

200 MeV

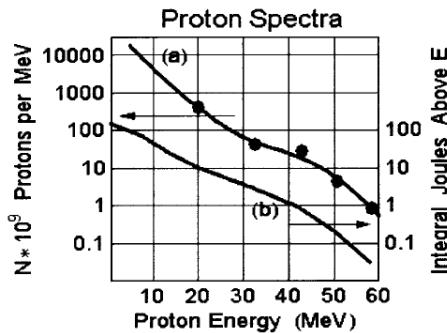


Proton cutoff energy



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

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



thick foils vs composite nanotargets

Proton cutoff

60 MeV

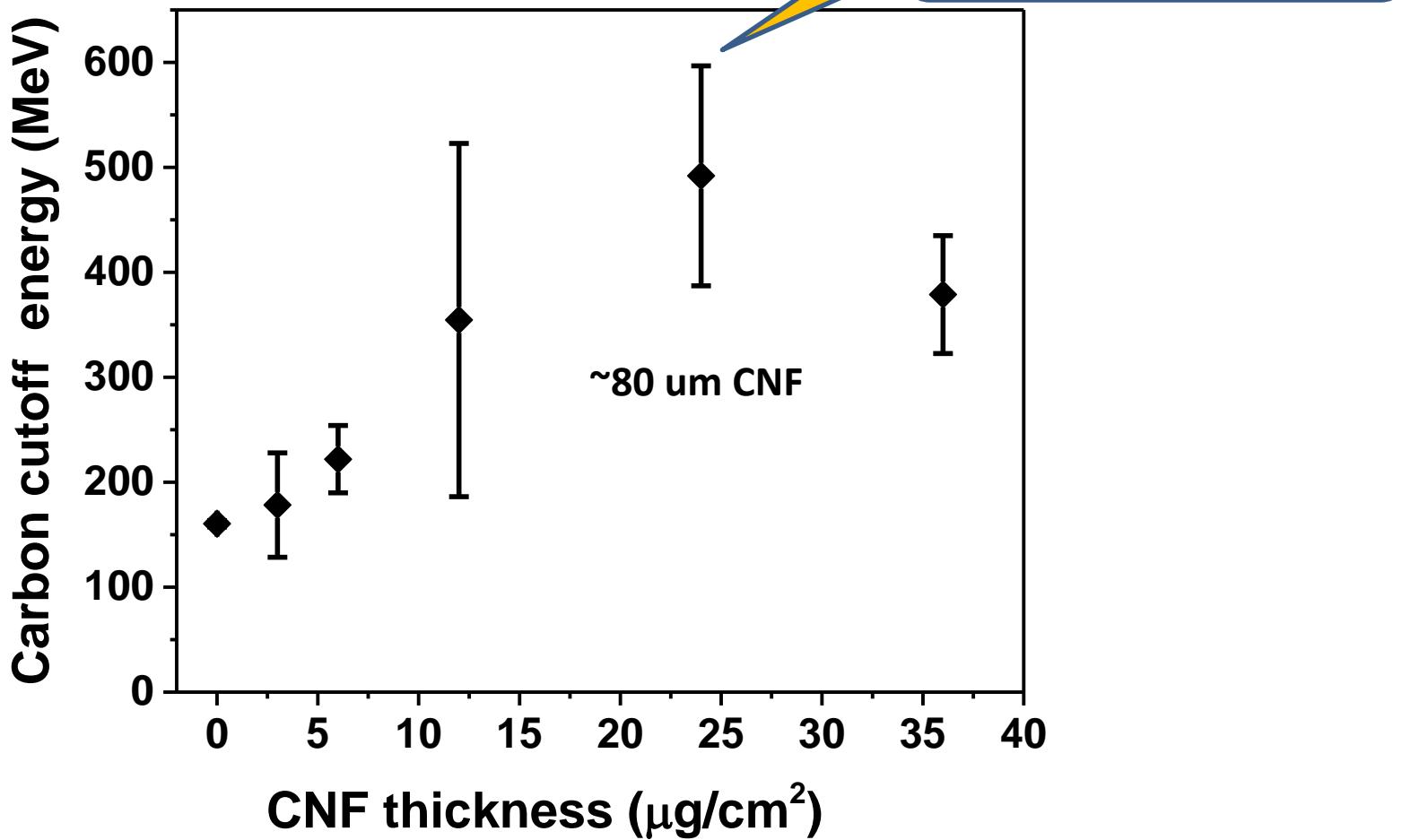
58 MeV

Pulse energy

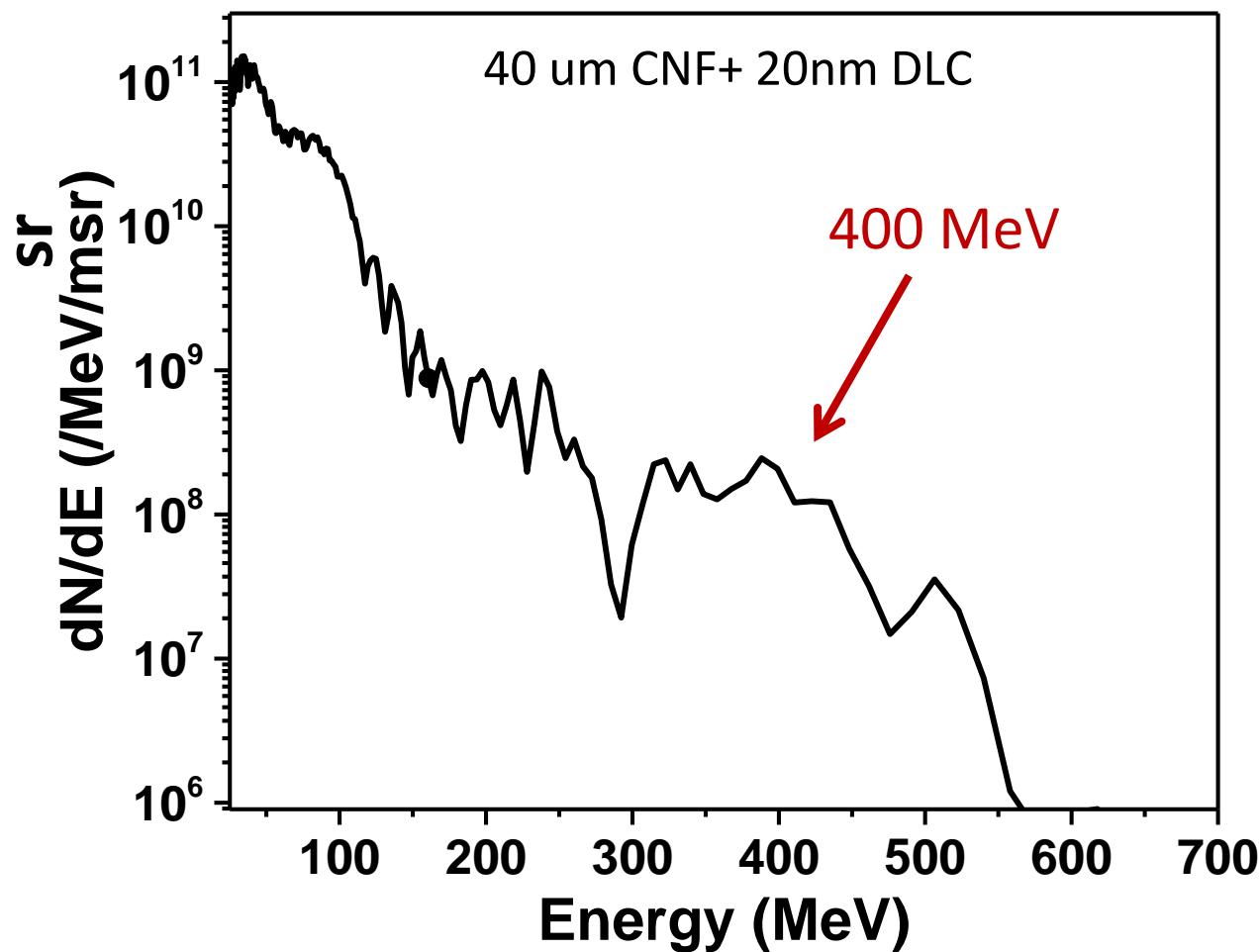
500 J

9.2 J

C6+ cutoff energy



C₆⁺ spectra



My new position in Peking University, China

Compact LAser Plasma Accelerator (CLAPA)



200 TW, 25 fs laser, 1400 m² lab

Thank you