ANAR, 25~29 April, 2017

Recent progress on laser plasma acceleration in China (SIOM & PKU)

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Acknowledgement

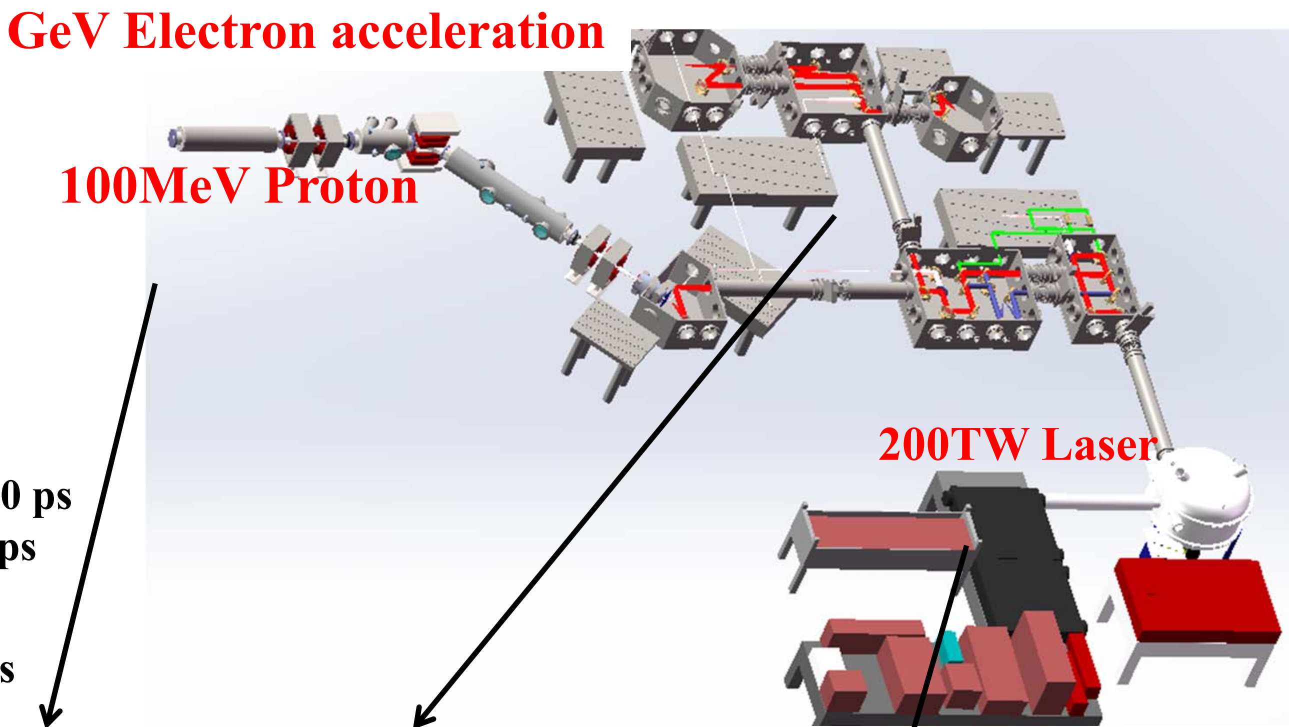
- **C.Zhang, Z.Y.Heng** **IHEP**
- **R.X.Li** **SIOM**
- **H.Y.Lu** **Peking University**

Institute of Heavy Ion Physics @Peking U. China

CLAPA at Peking University

CLAPA Laser

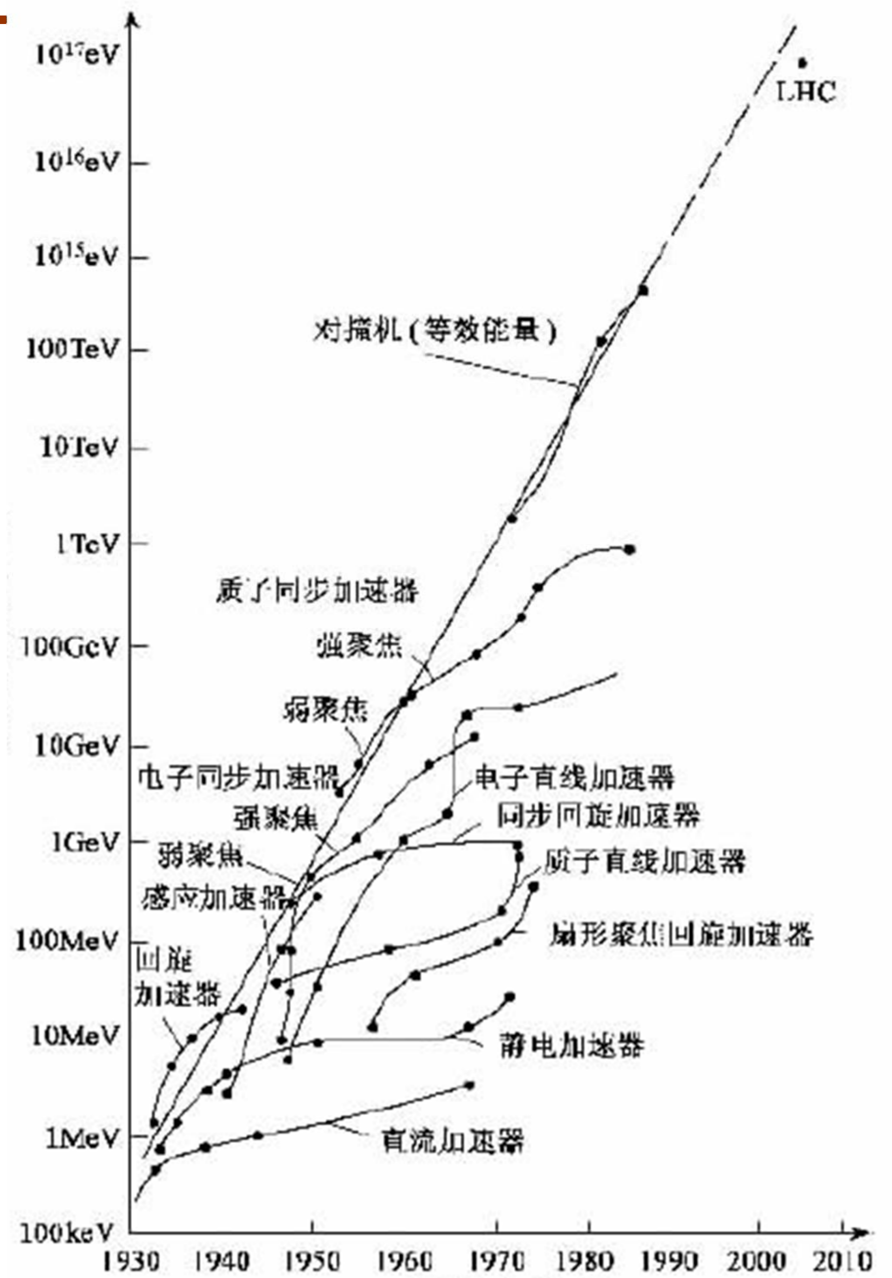
Pulse Energy:	5 J /5Hz
Pulse Duration:	< 25 fs
Wavelength:	800 nm
Contrast Ratio:	10^{10}:1 @ 100 ps 10^{9}:1 @ 20 ps 10^{6}:1 @ 5 ps



Outline

- LPA driven Bright 2-7GeV electron beam for Tao Charm physic
- Progress of Ion acceleration

Moore's Law in HEP accelerators



Effective energy

$$E_{\mathrm{eff}} = E_{\mathrm{C.M.}}{}^2 / 2E_0$$

Energy in CM

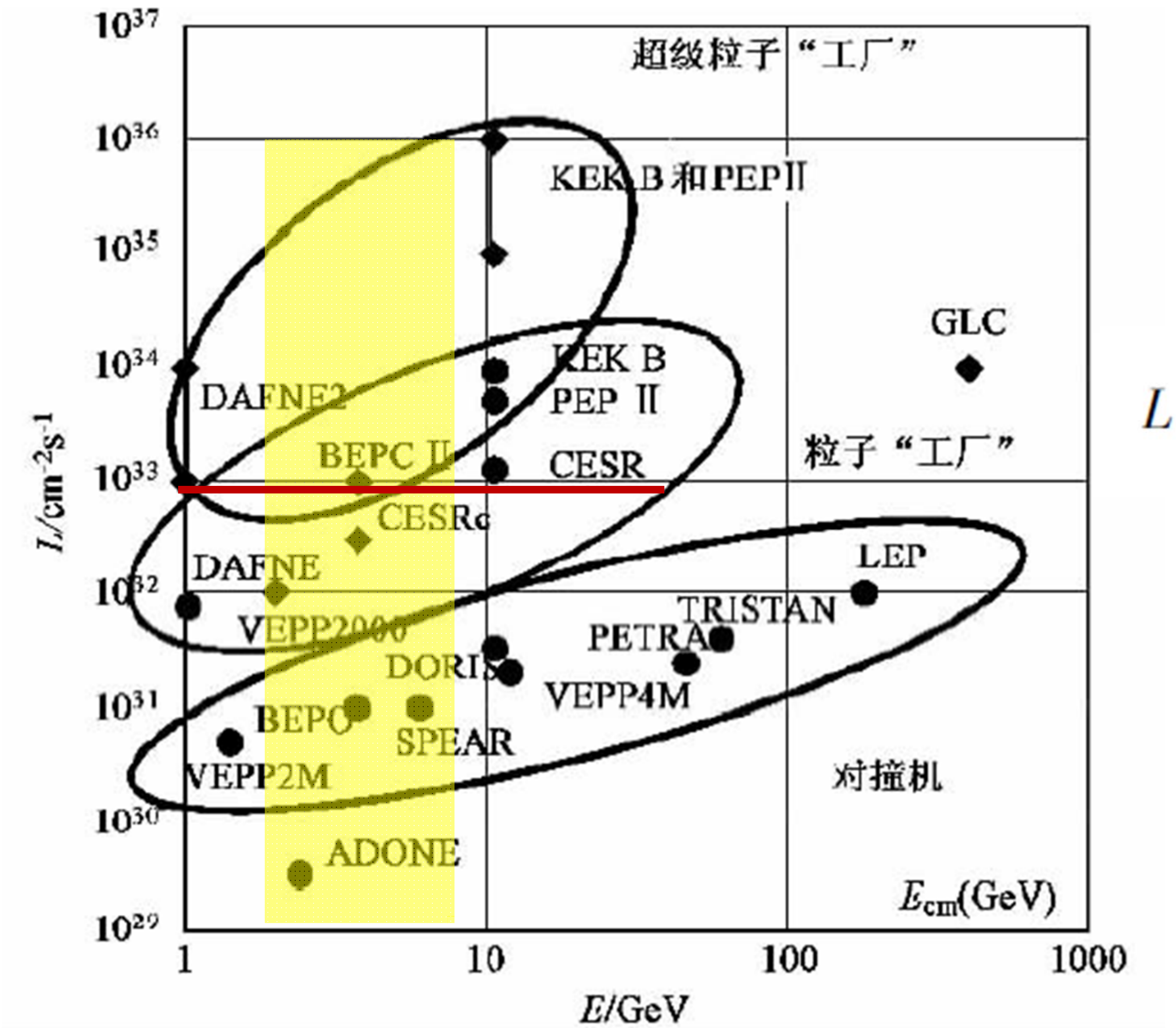
$$E_{\mathrm{C.M.}} \approx \sqrt{2E_0 E}$$

CM Energy for e+e-/LHC

$$E_{\mathrm{C.M.}} = 2E$$

Luminosity of e+e- collider

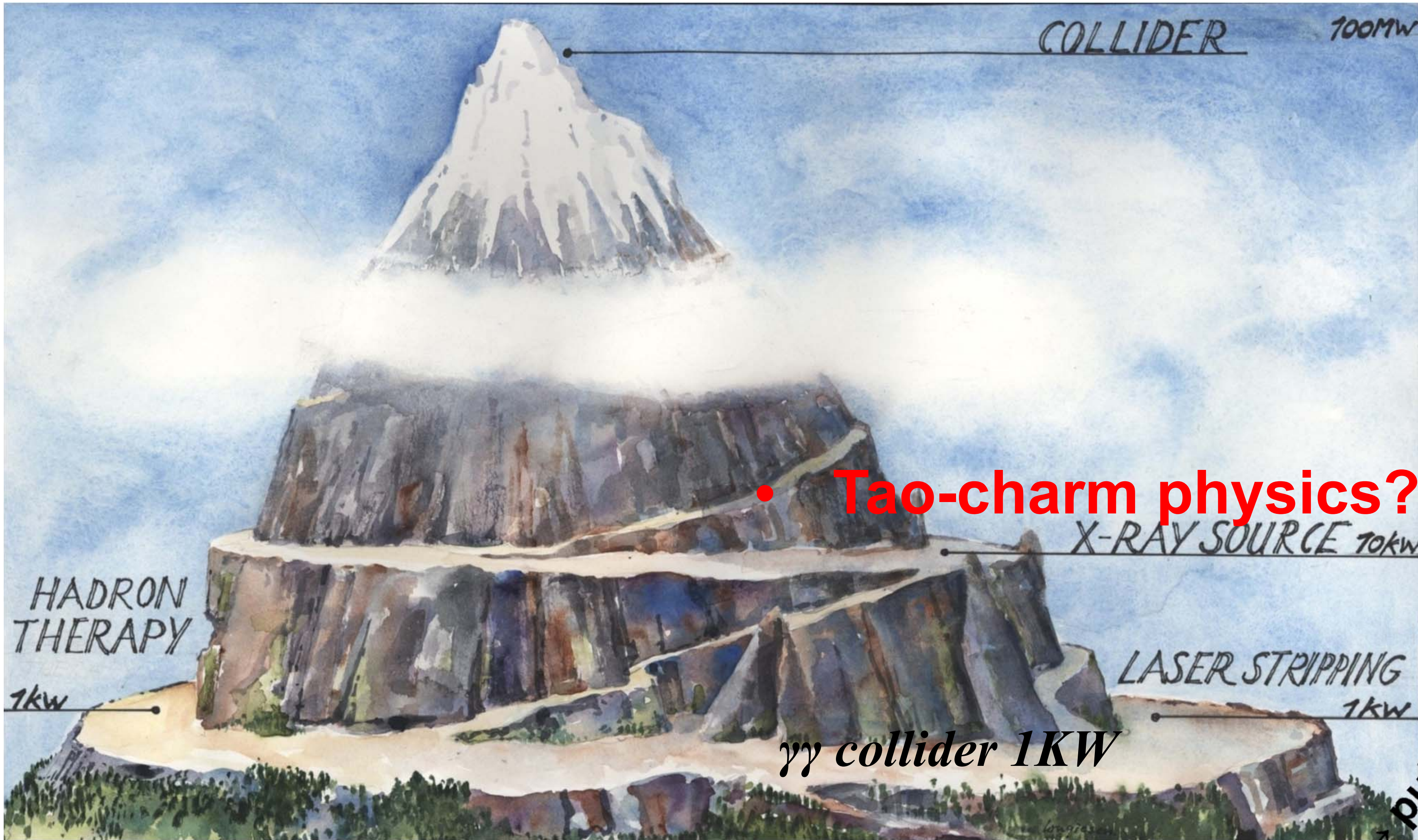
2-7GeV is for tao charm physic



Luminosity

$$L = \frac{fN_1N_2}{4\pi\sigma_x\sigma_y}$$

Mountain of Laser Plasma Accelerator



- Tao-charm physics?

γγ collider 1KW

↑ average power

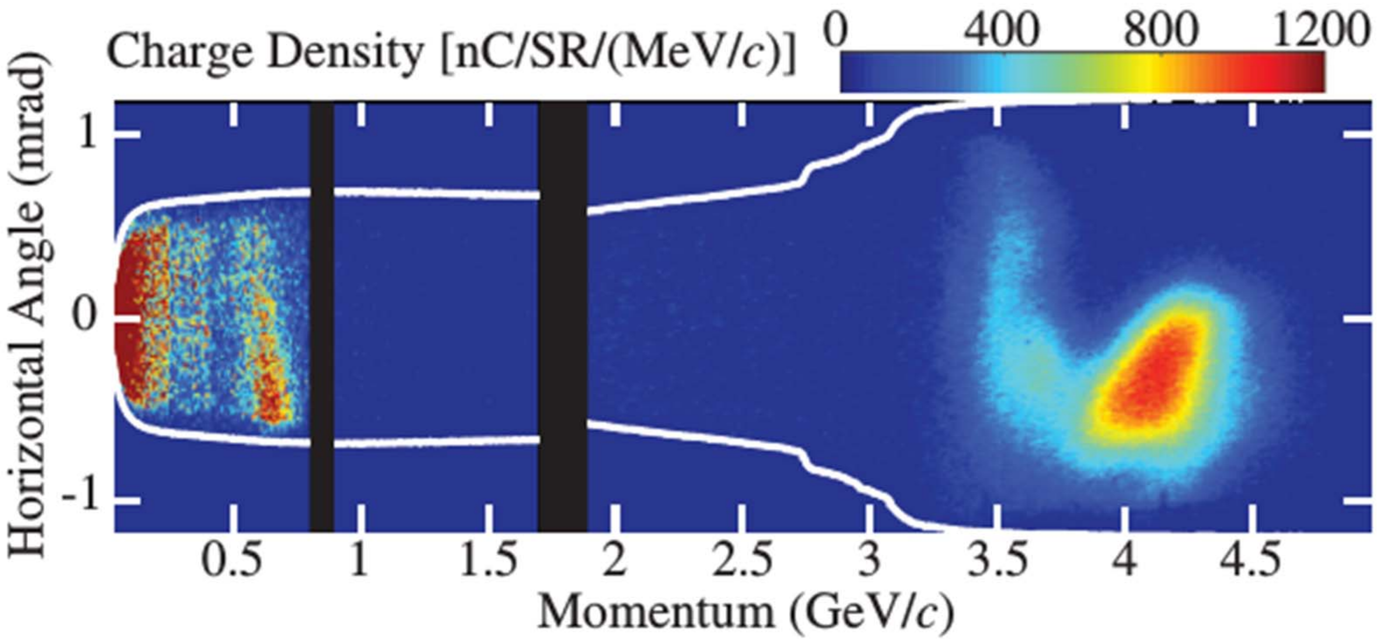
→ rep rate

↗ pulse shortness

(HEP Examples from *ICFA-ICUIL* JTF)
Friday 6pm Rochester: open JTF

Single stage → 10GeV→TeV ?

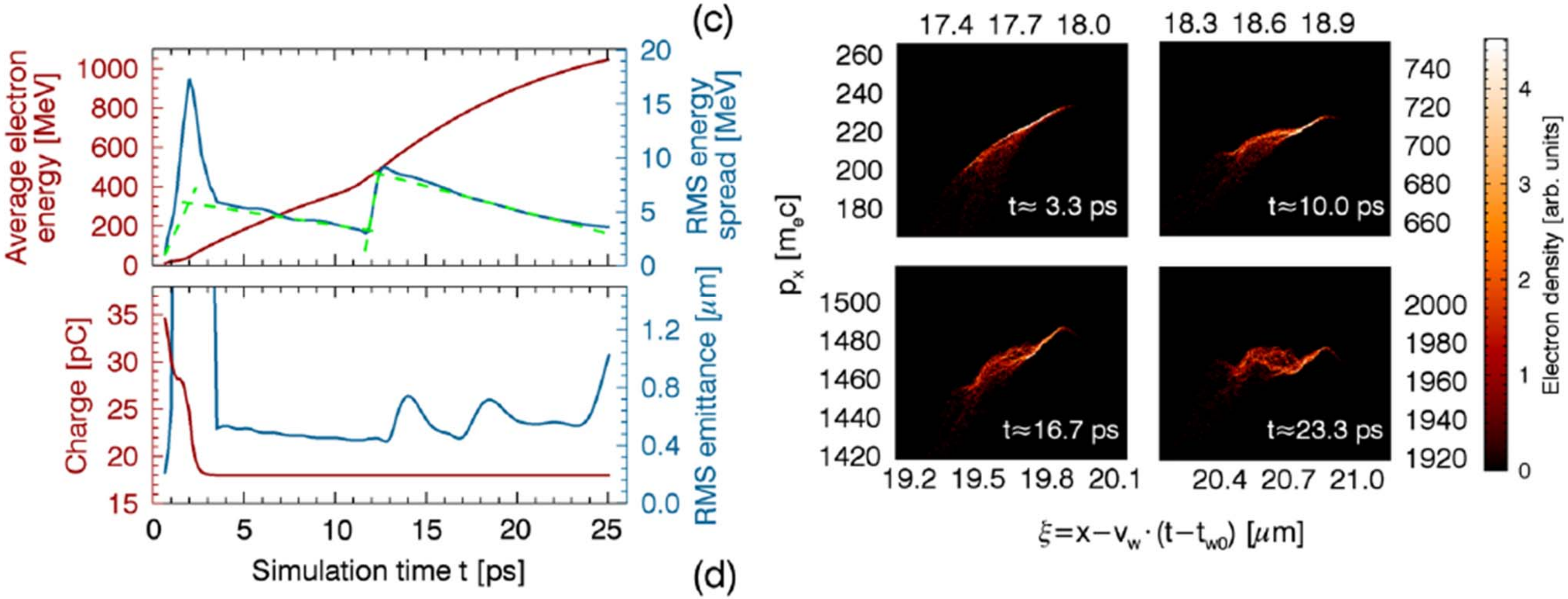
- 2014,LBNL,(~400 TW),(~9 cm),4 GeV electron beam
- **Brightness ? Energy spread/ Emittance/Charge**



Leemans et al, Phys. Rev. Lett., **113**, 245002(2014)

Bean rephasing to increase the brightness

- Energy spread ~0.5%
- Emittance ~0.5 um (RMS)
- Charge ~20pC

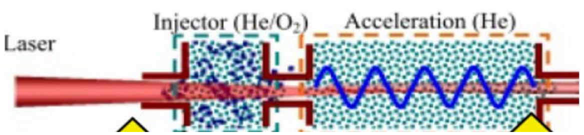


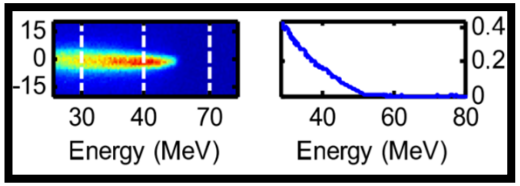
Hu et al, Phys. Rev. Accel. Beams, **19**, 091301(2016)

Progress in generating high-quality electron beams at SIOM

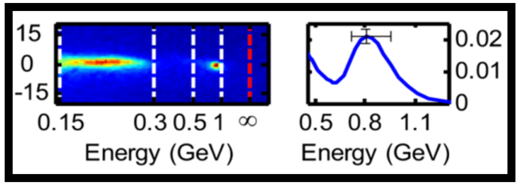
Ionization-induced injection

$5.7 \times 10^{19}\ cm^{-3}$ | $2.5 \times 10^{18}\ cm^{-3}$





Injector: Energy spread 100%

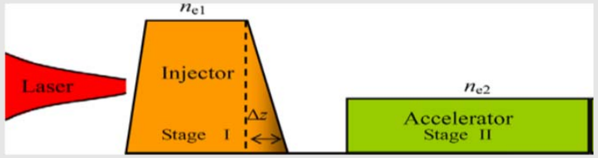


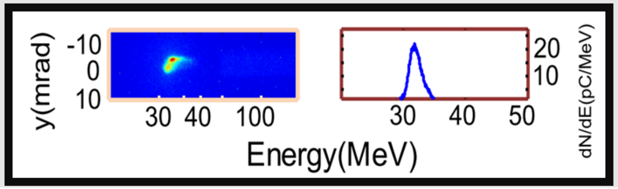
Injector+ Accelerator
Energy spread <25%

Phys. Rev. Lett. 107, 035001 (2011).

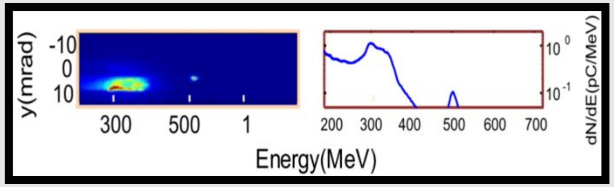
Gradient injection

$7\text{-}9 \times 10^{18}\ cm^{-3}$ | $\sim 3 \times 10^{18}\ cm^{-3}$





Injector: Energy spread 10 %

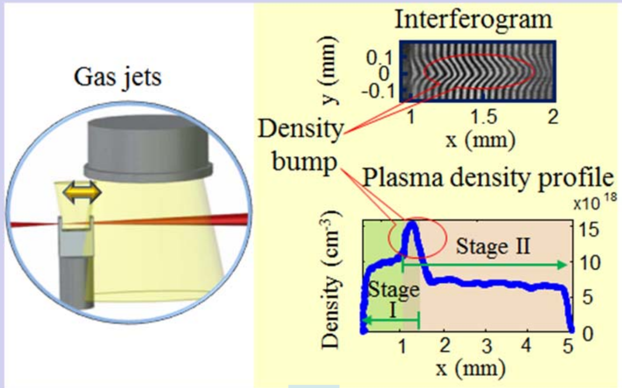


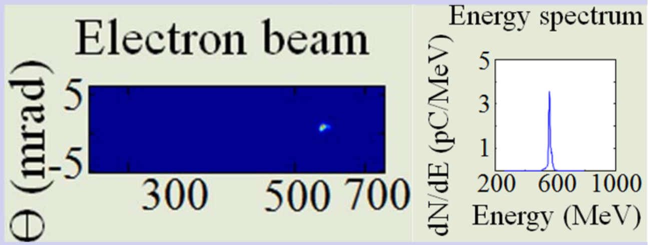
Injector+ Accelerator
Energy spread 3%

Appl. Phys. Lett. 103, 243501(2013).

Energy chirp control

$1.1 \times 10^{19}\ cm^{-3}$ | $6 \times 10^{18}\ cm^{-3}$



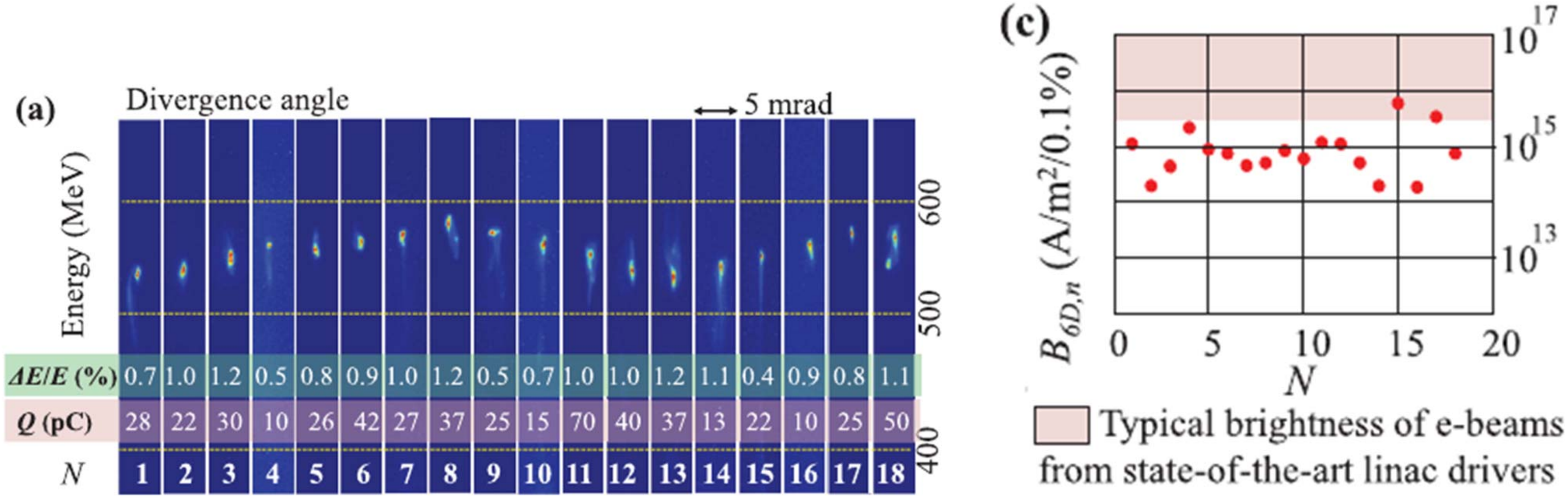


Injector+ Accelerator
Energy spread < 1%

Phys. Rev. Lett. 117, 124801(2016)

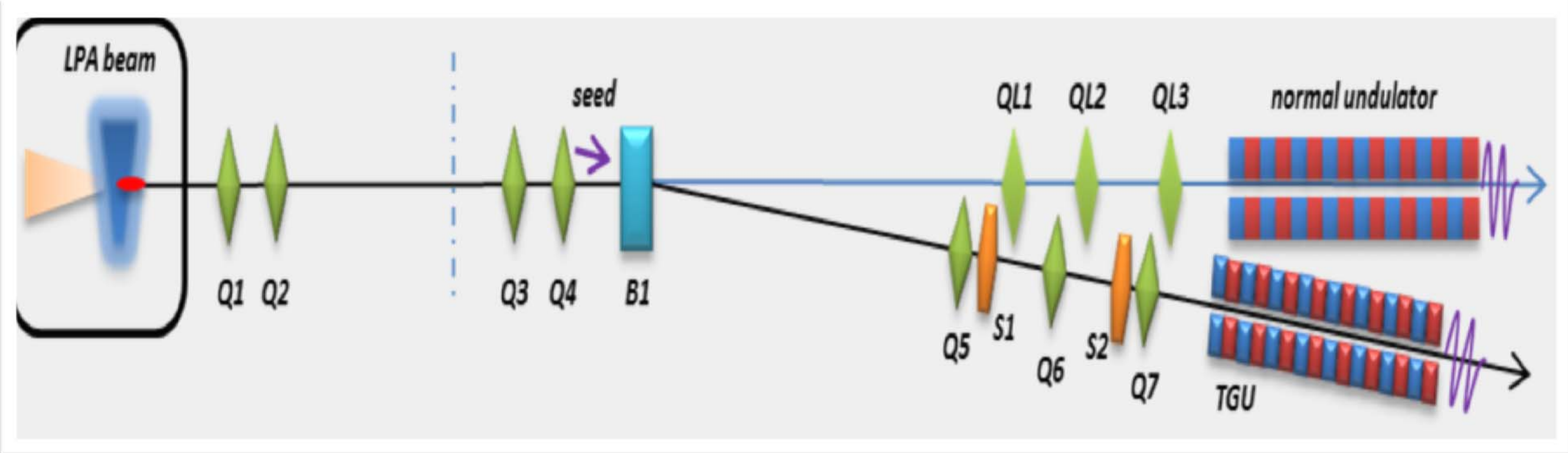
Brightness is close to the LCLS(XFEL)

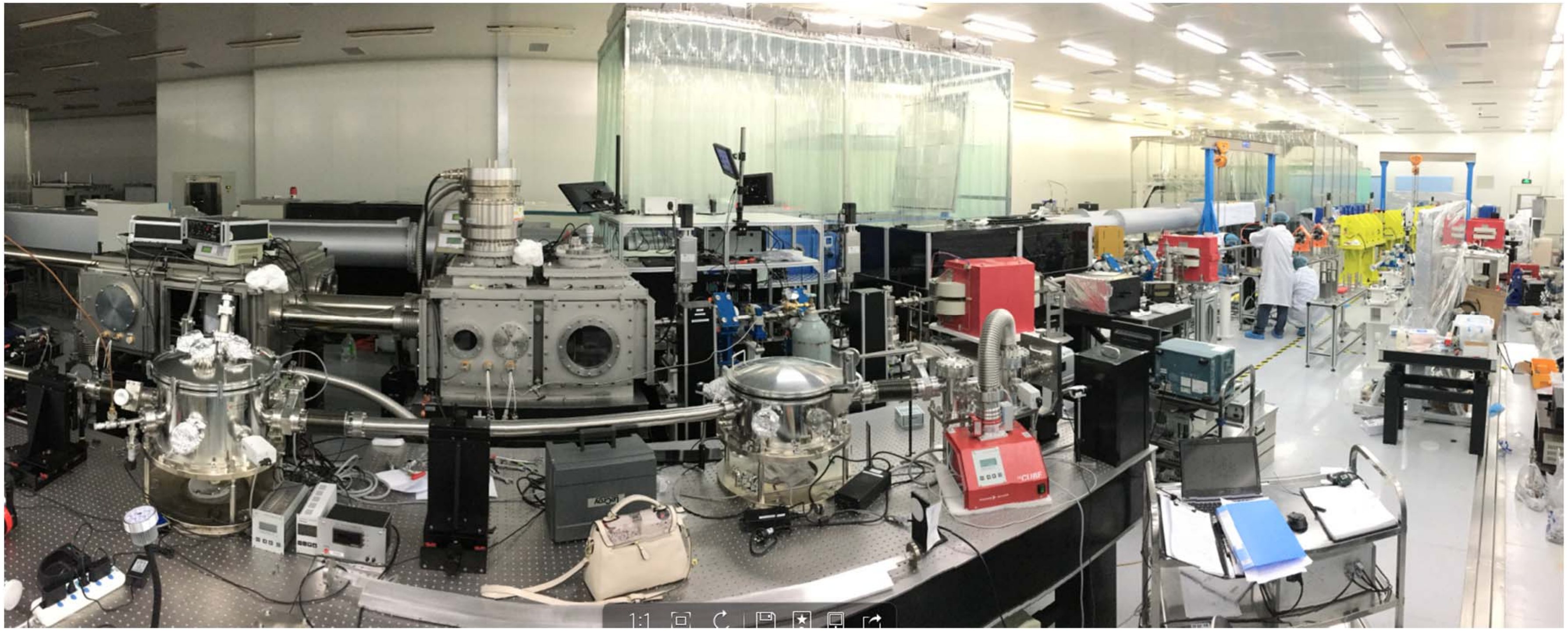
- 2016,500 MeV, 10^{16} A/m^2/0.1%



Wang et al, Phys. Rev. Lett., **117**, 124801(2016)

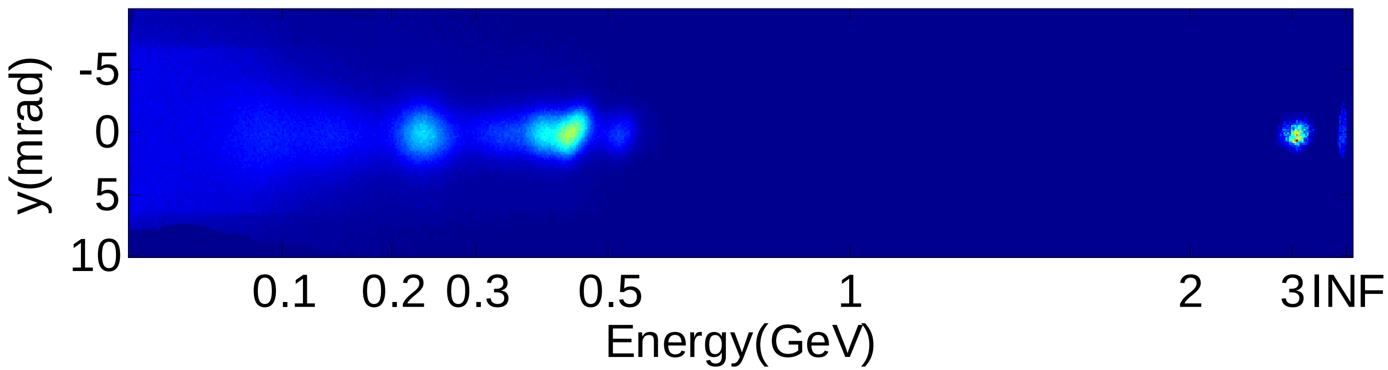
A XFEL platform based on a LWFA has been assembled at SIOM

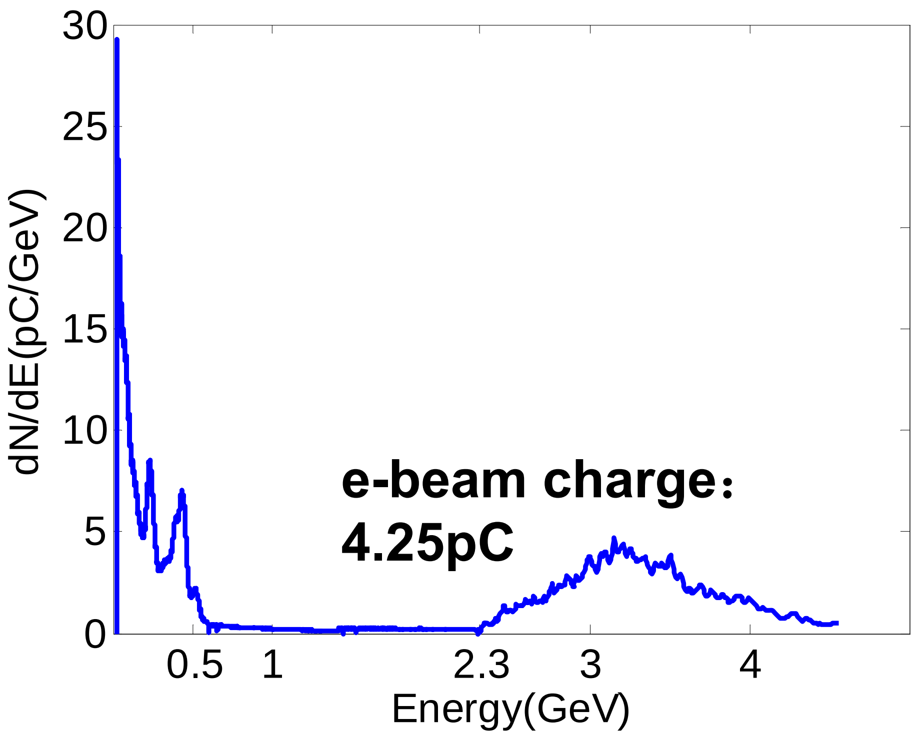




10 GeV-class e-beam generation from a cascaded LWFA using an capillary discharge waveguide powered by a 1-PW laser pulse

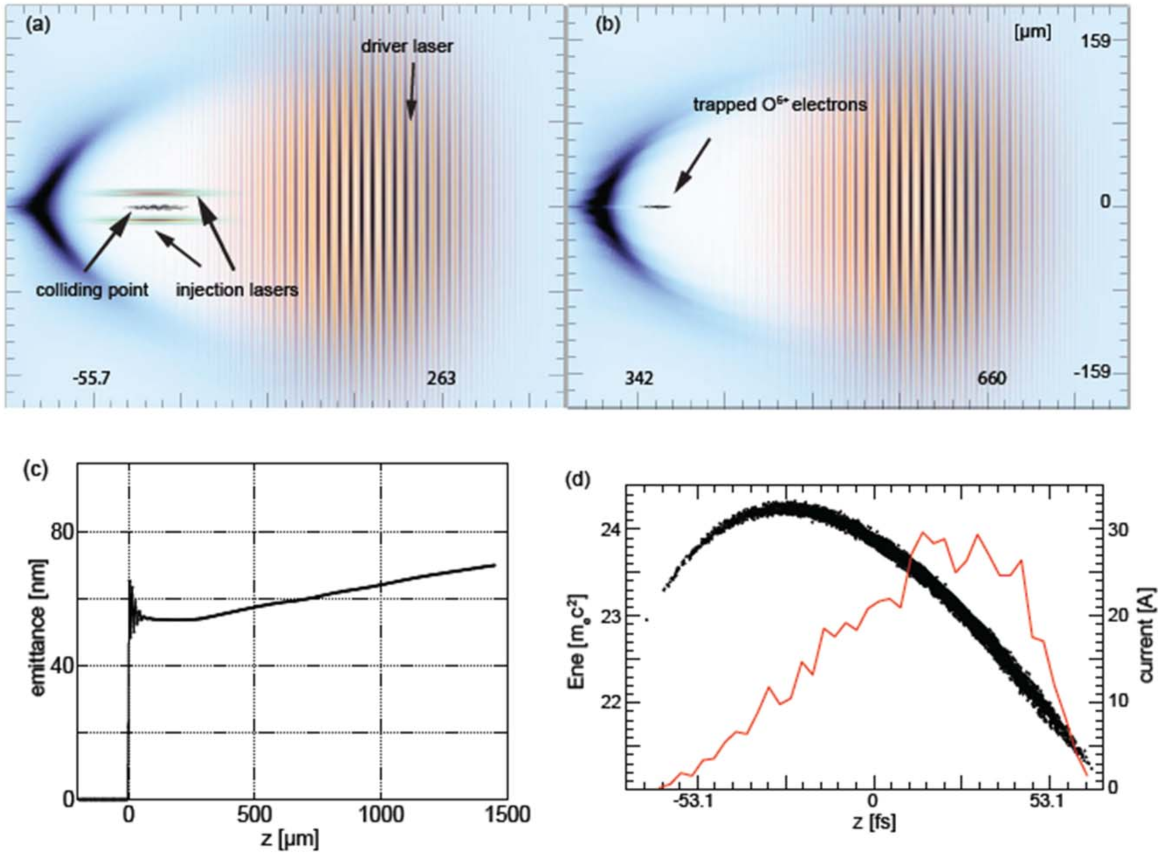
2015121704





Two color scheme to reduce the emittance to <80nm

- **Injection by Short wave laser, to separate the injection process from the wakefield excitation process.**



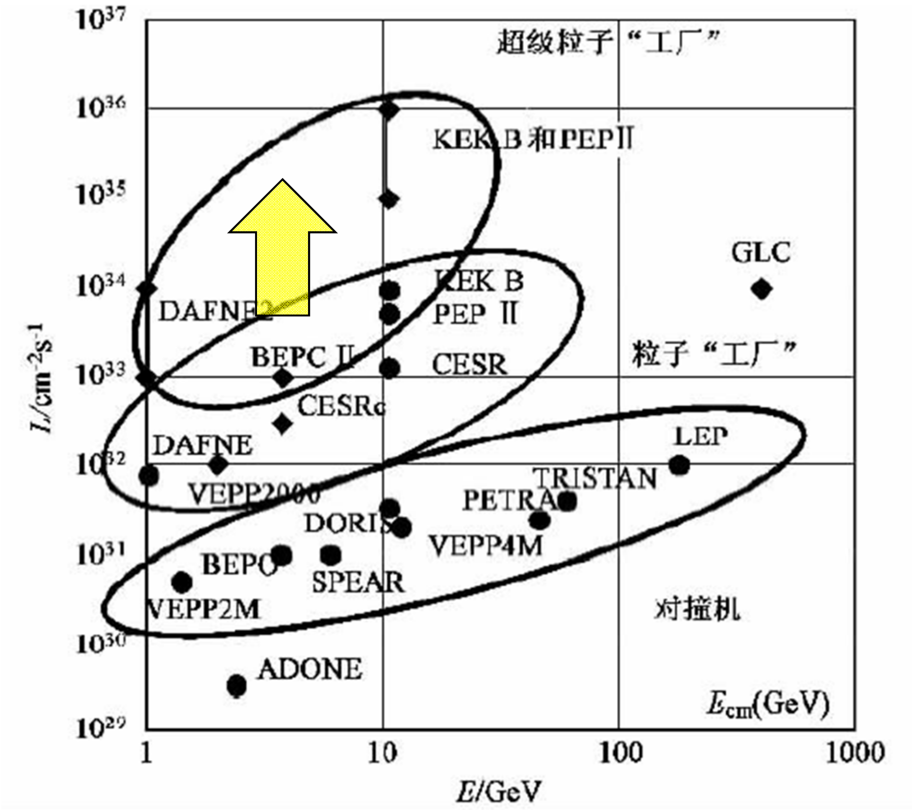
L.-L. Yu et al., in SPIE Optics+ Optoelectronics (International Society for Optics and Photonics, 2013) ;Xu et al, Phys. Rev. ST Accel. Beams, **17**, 061301(2014)

Luminosity of LPA for tao-charm physics

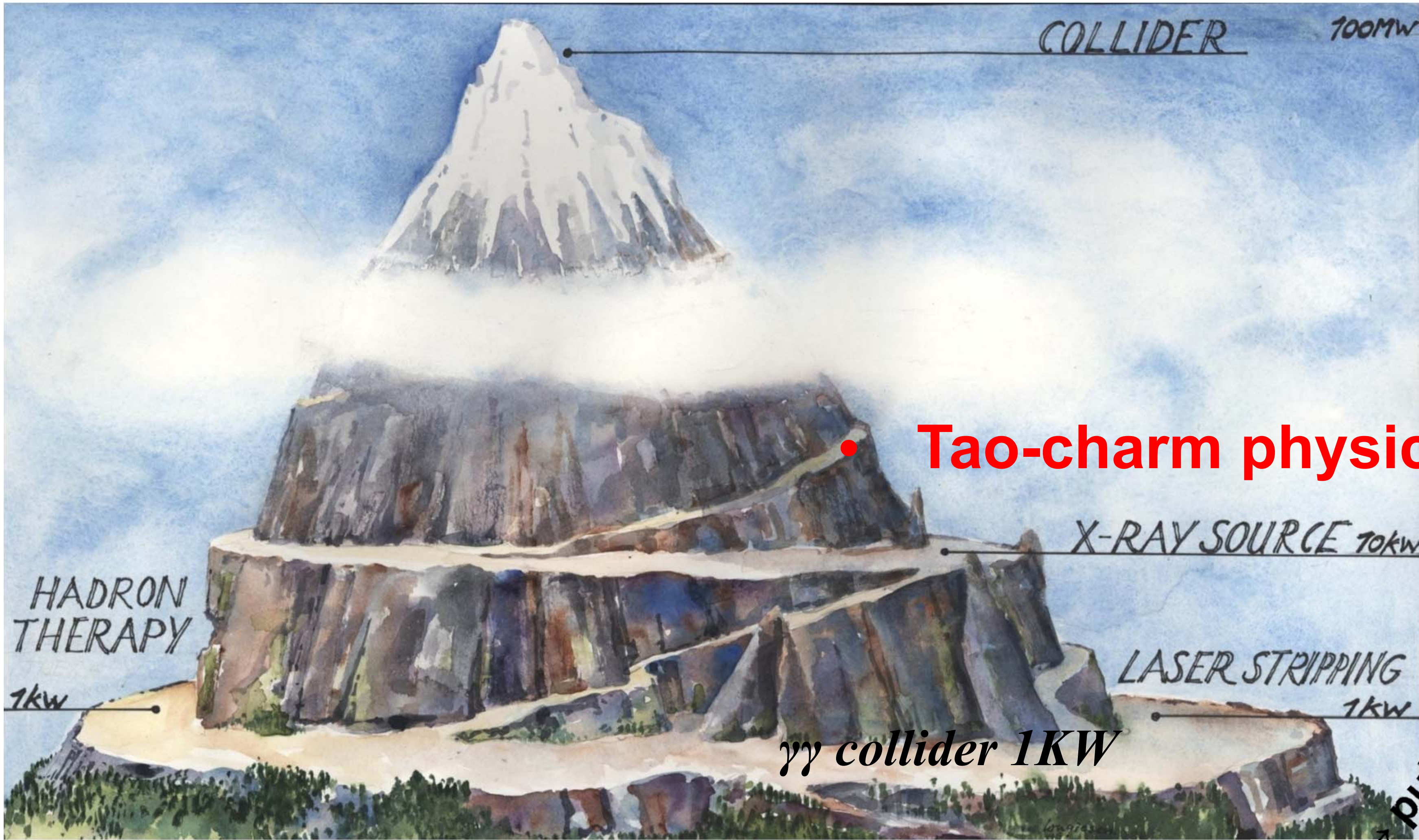
- **1KzHz PW laser**

$$L = \frac{f N_1 N_2}{4\pi\sigma_x\sigma_y}$$

L=1KHz*10^9*10^9/(4 Pi*1nm*1nm) ~10^33-34 $cm^{-2}s^{-1}$



Bright ~GeV electron beam for Tao-charm physics



• **Tao-charm physics**

γγ collider 1KW

← average power

→ pulse shortness

→ rep rate

(HEP Examples from *ICFA-ICUIL* JTF)
Friday 6pm Rochester: open JTF

Outline

- LPA driven Bright 2-7GeV electron beam for Tao Charm physic
- Compact Laser proton accelerator (CLAPA) at PKU

Compact Laser proton accelerator (CLAPA)

laser	200TW/5Hz
proton	>15-60 MeV
carbon	>10MeV/u
electorn	400 MeV-2GeV
photon	>1keV-30MeV

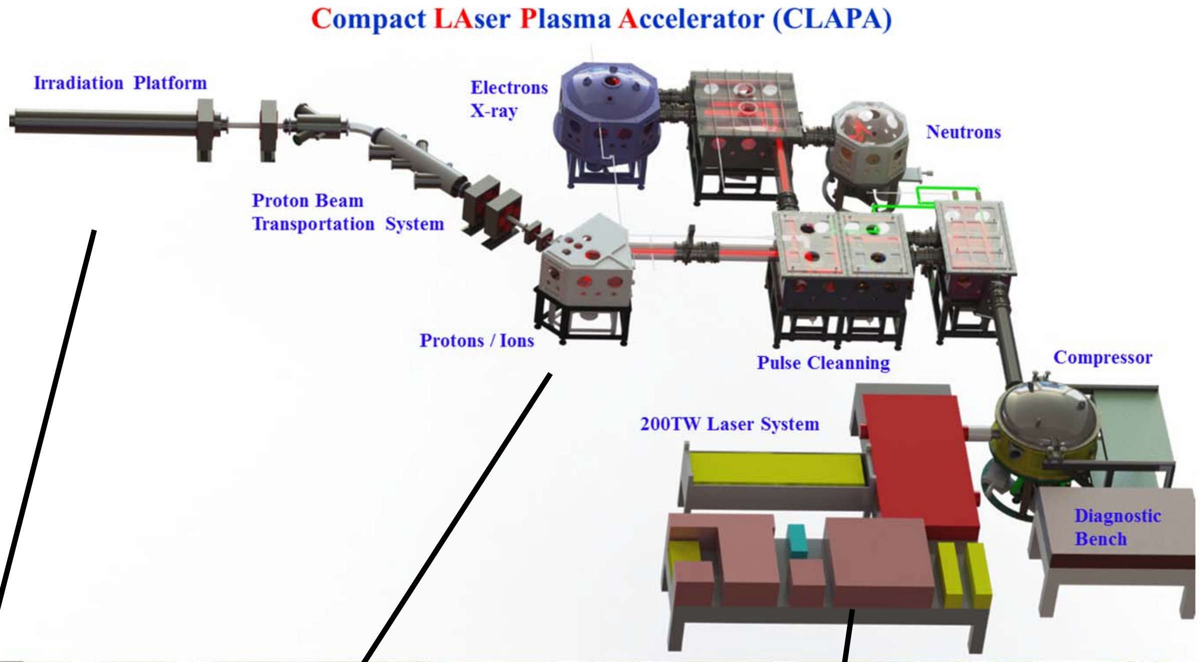
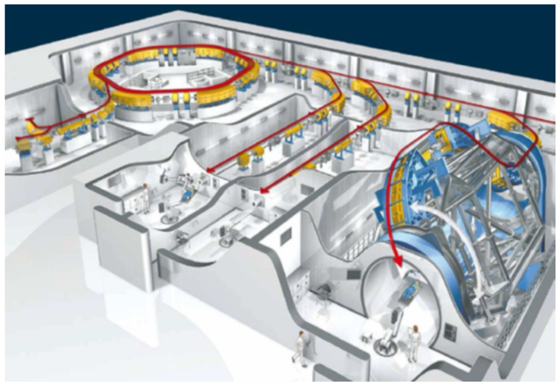


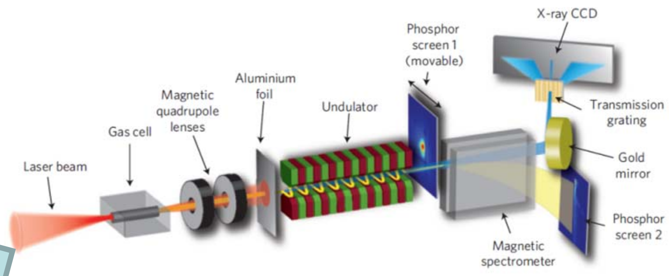
Table top proton therapy system

Shanghai light source

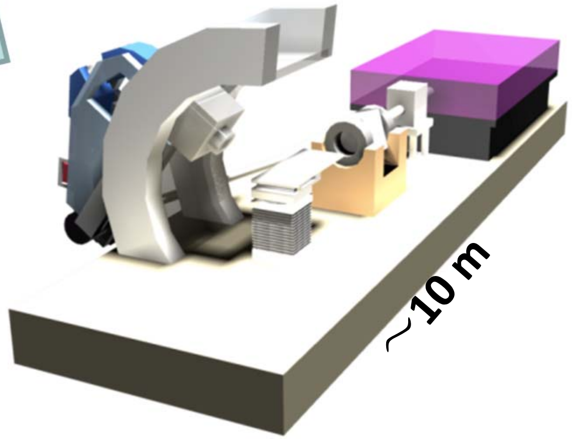
HIT



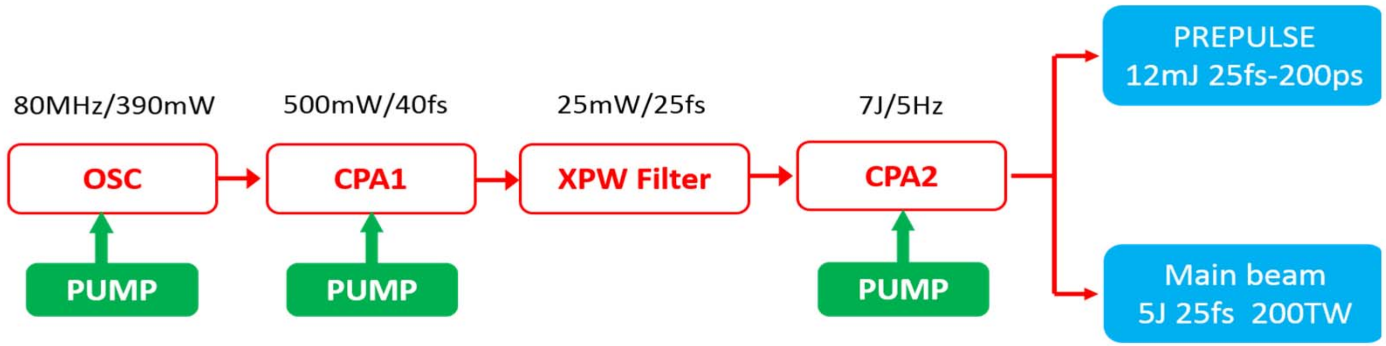
100m

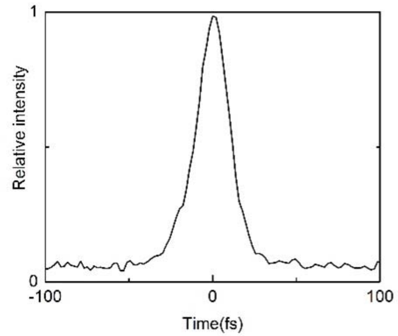


～10 m



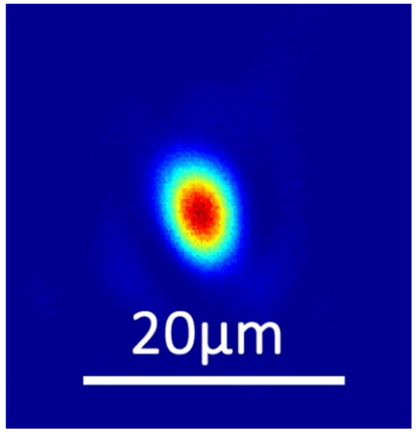
CLAPA 200TW





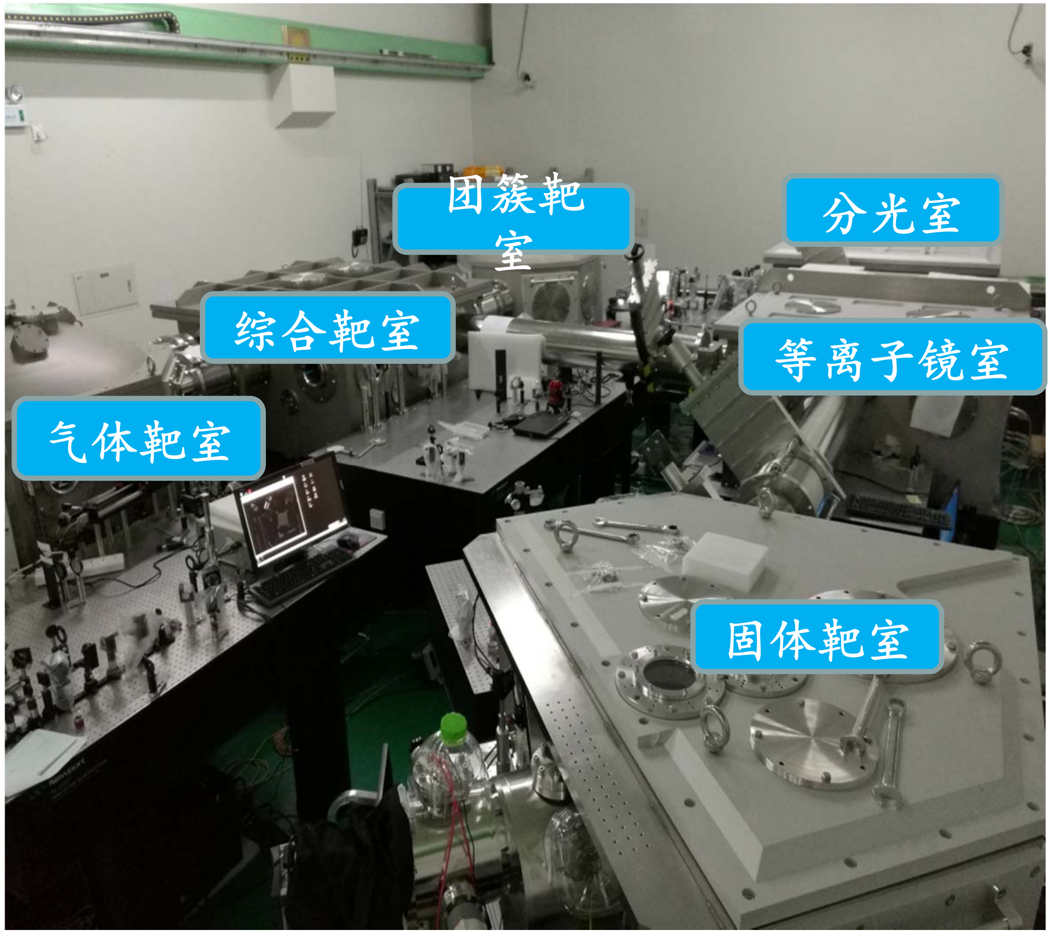
脉冲宽度=25fs

输出光斑：80mm
输出能量：5.1J
激光脉宽：25fs
指向稳定性：<3urad
中心波长：800nm
斯特列尔比：94%
对比度：10^{-10}@ 100ps/10^{-9}@ 20ps /10^{-6}@ 5ps/10^{-3}@ 1ps



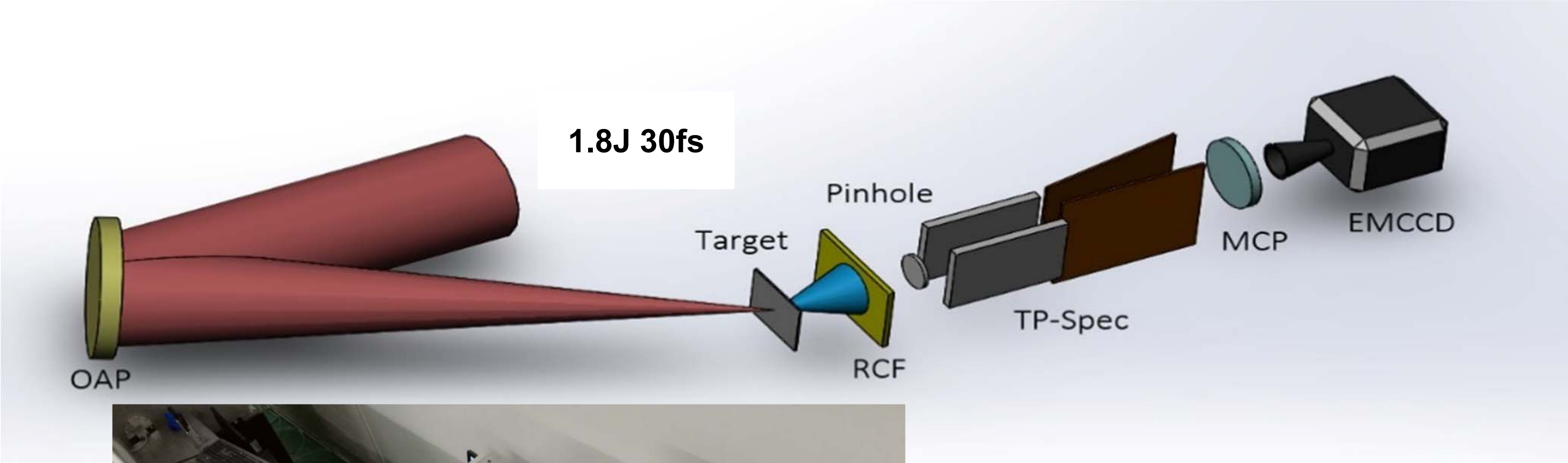
激光焦斑
4.5μm*5.3μm

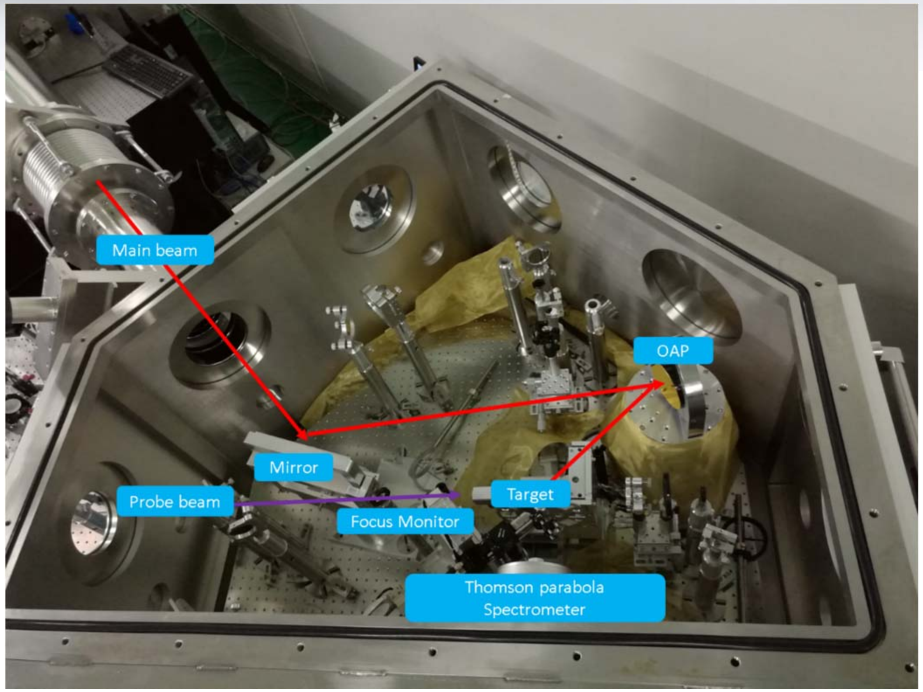
CLAPA target area



分光室：模拟光与主光路切换；
等离子体镜室：等离子体镜搭建；
固体靶室：强激光与固体相互作用实验；
综合靶室：团簇-气体靶室光路切换；
气体靶室：强激光与气体相互作用实验；
团簇靶室：强激光与超薄固体靶相互作用实验；

setup





Laser

energy : 1.8J

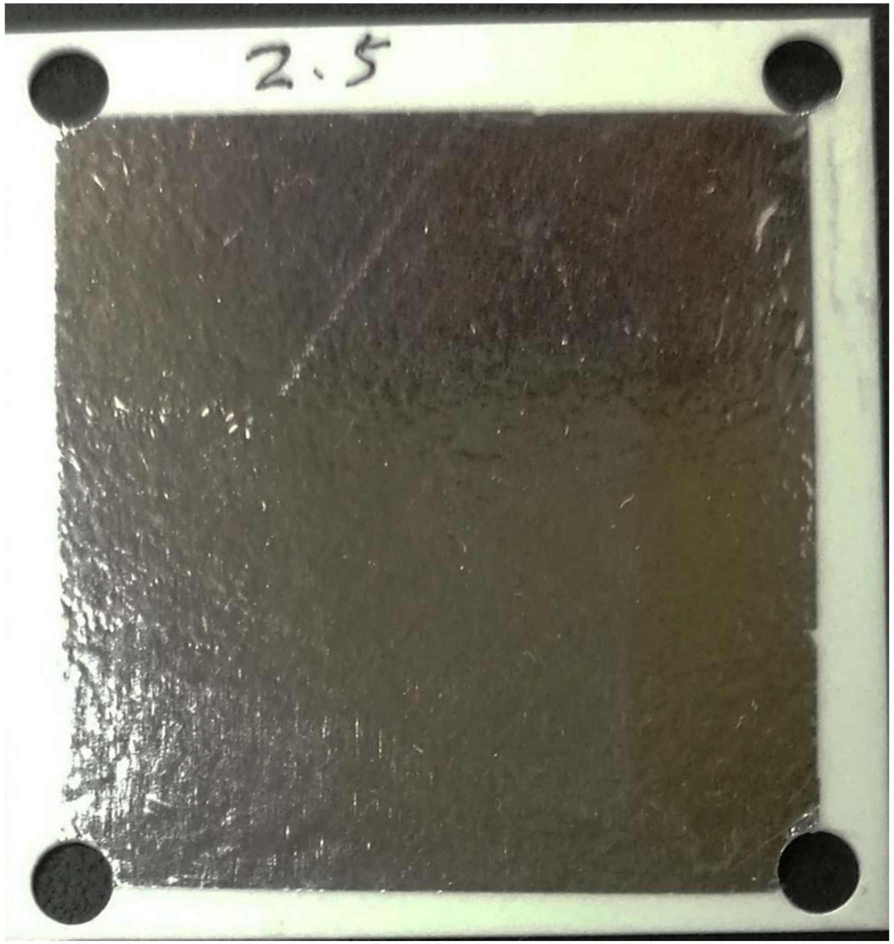
duration : 30fs

Intensity : $8.3 \times 10^{19} W/cm^2$

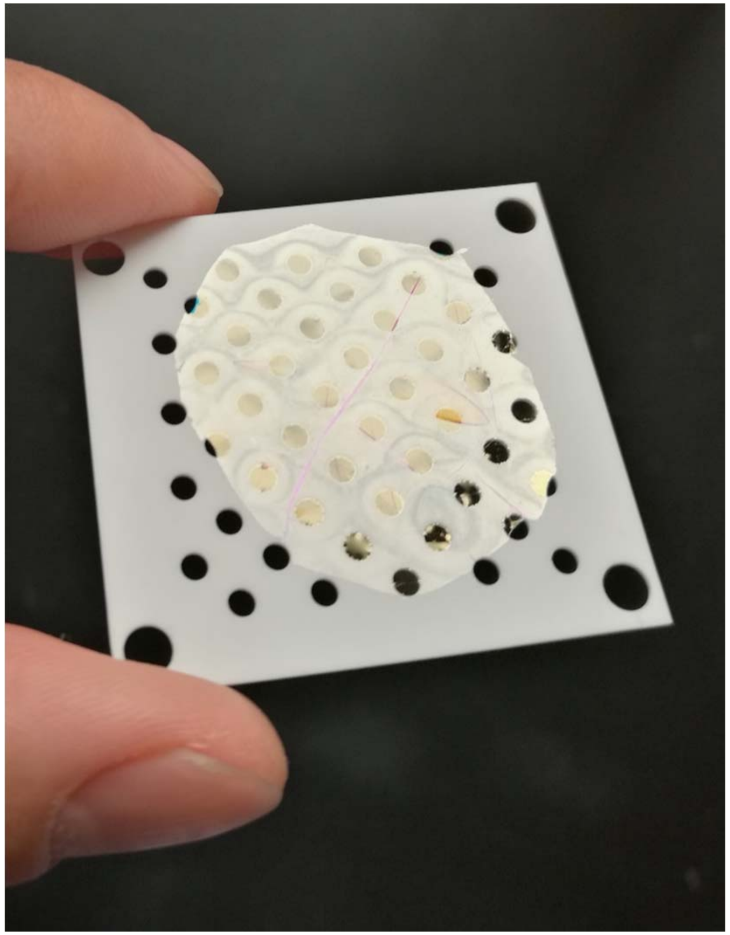
Incident angle : 30

spot : 4.5μm×5.3μm

targets

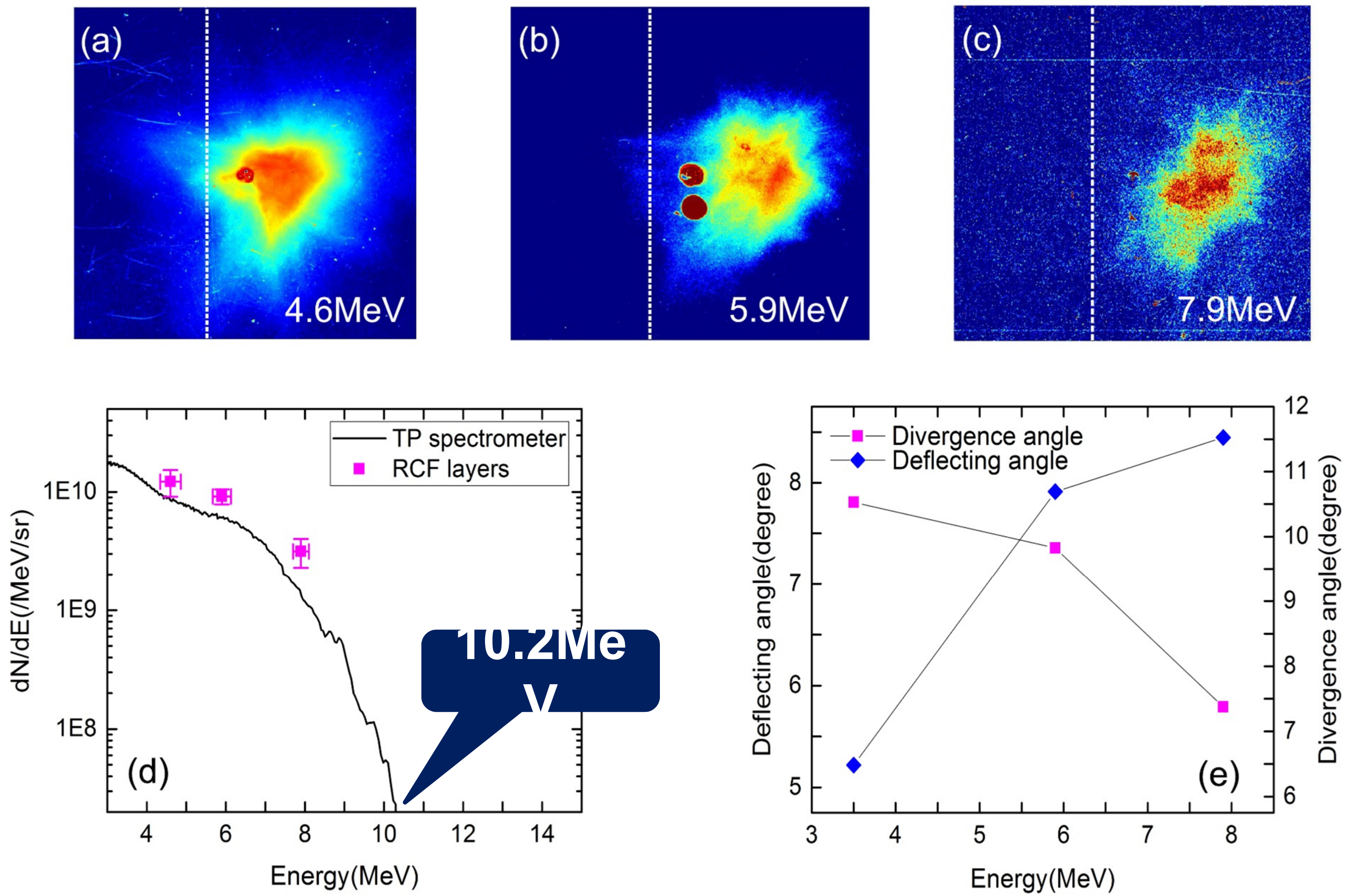


0.8μm-6μm Al

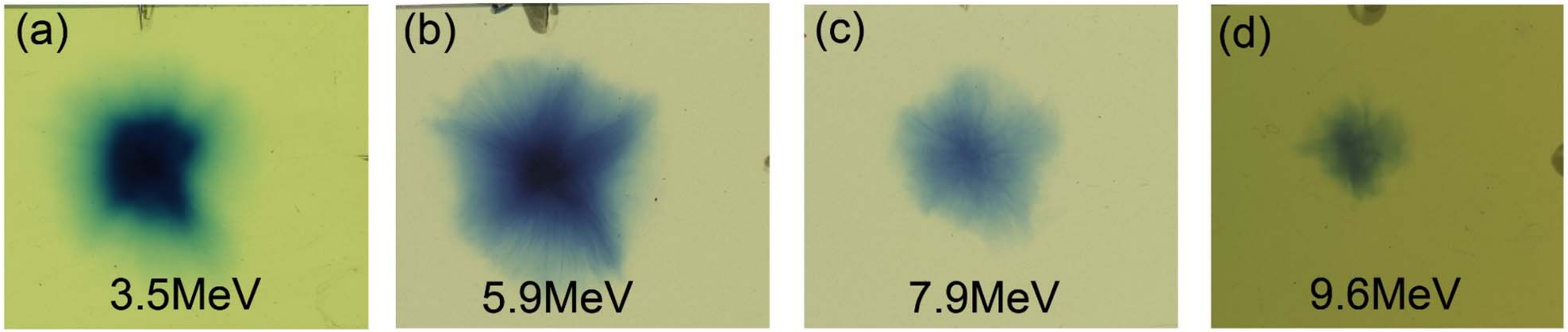


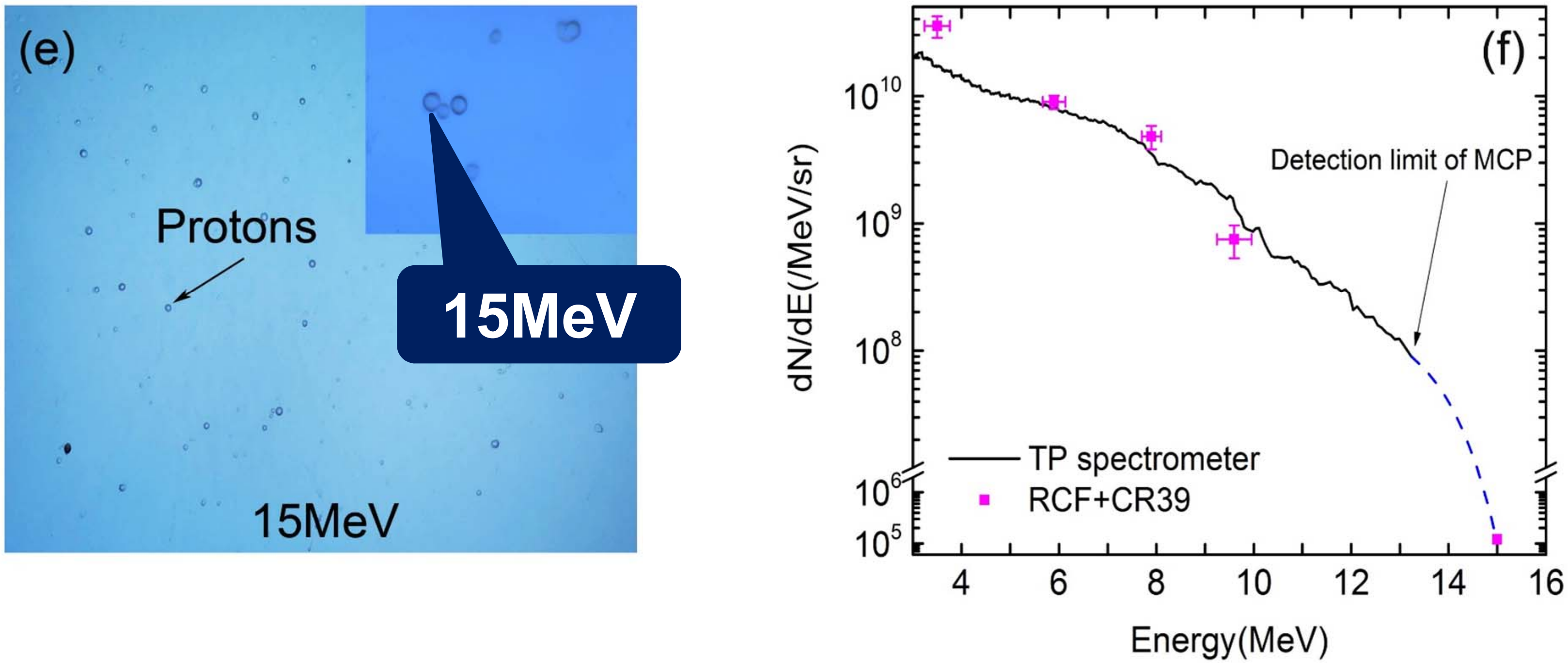
0.02μm-8μm CnHm

Proton spectrum and angular profile @2um Al



Proton spectrum and angular profile @1.2um polymer





Proton divergence angle

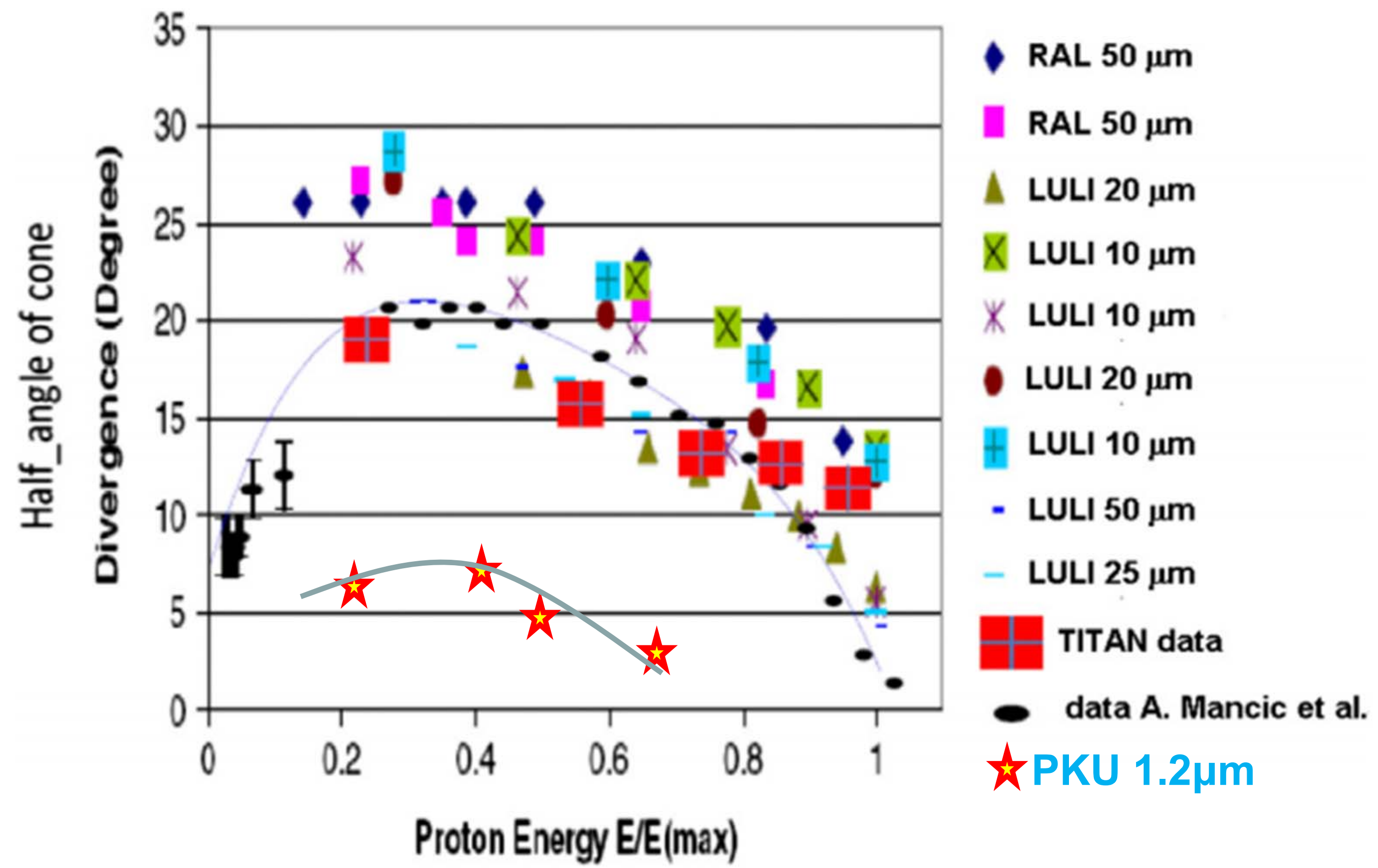
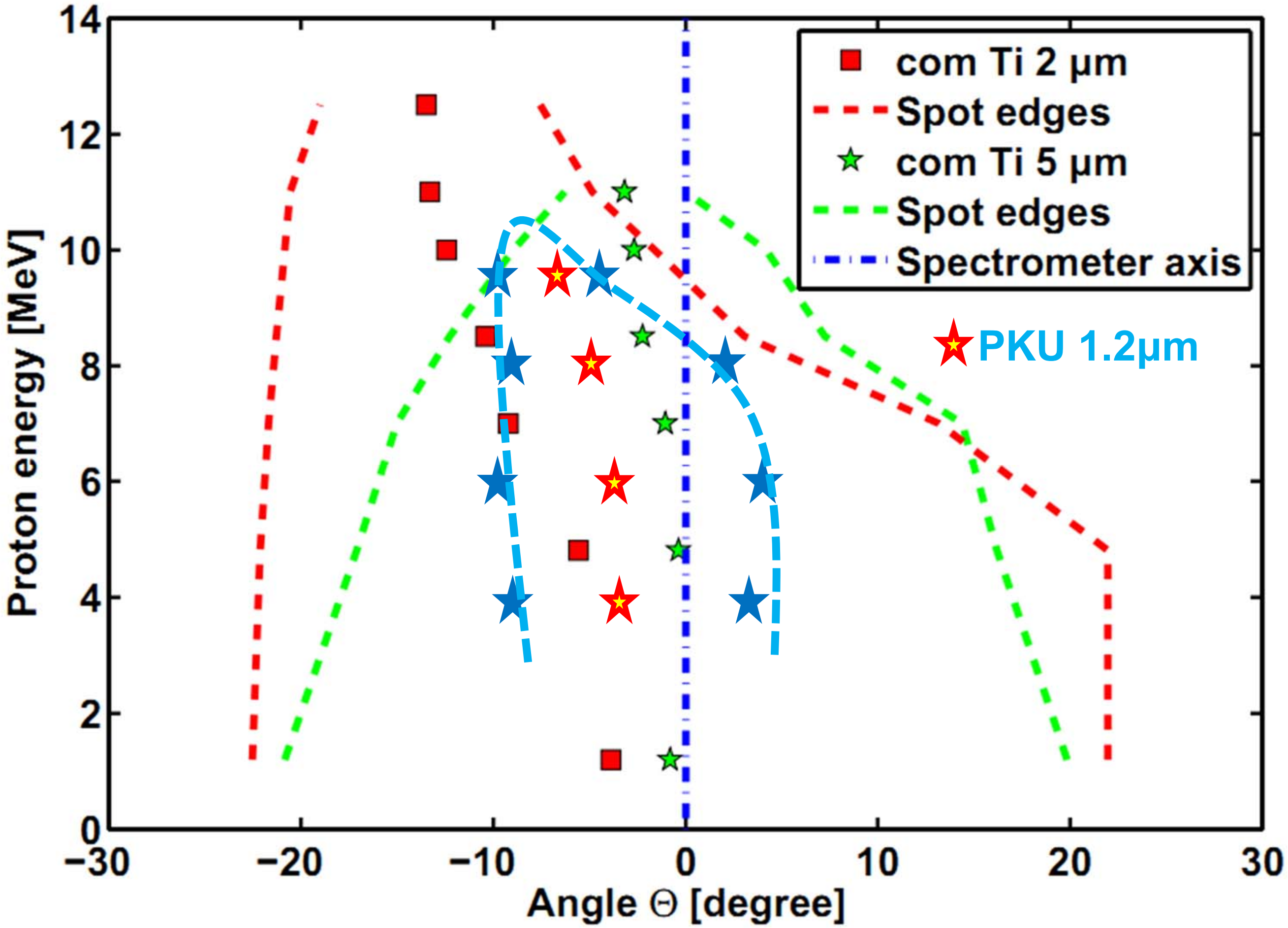


Figure 12. Compiled measurement of proton beam divergence obtained from several laser facilities (see text for references).

Bolton, P.R., et al., Instrumentation for diagnostics and control of laser-accelerated proton (ion) beams. PHYSICA MEDICA-EUROPEAN JOURNAL OF MEDICAL PHYSICS, 2014. 30(3): p. 255-270.

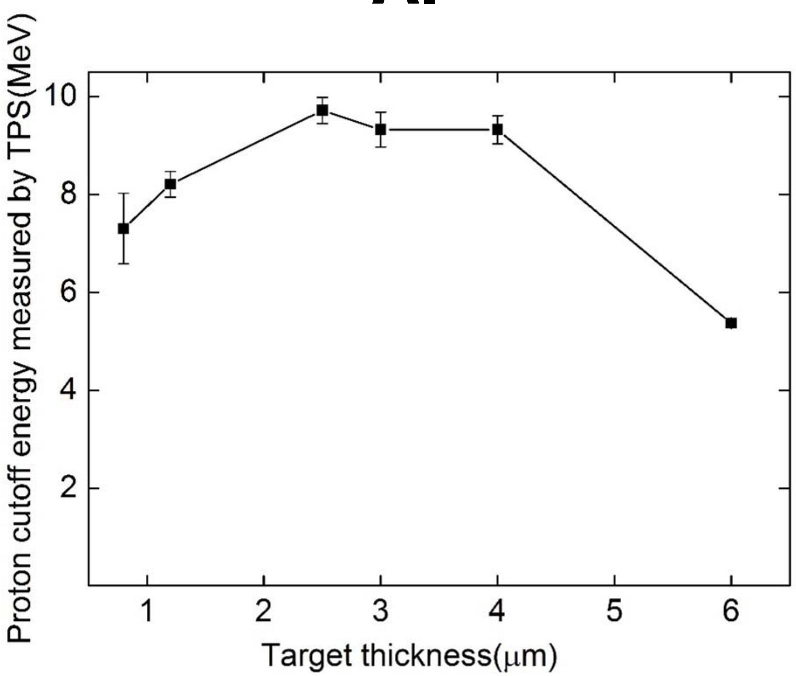
Proton divergence angle



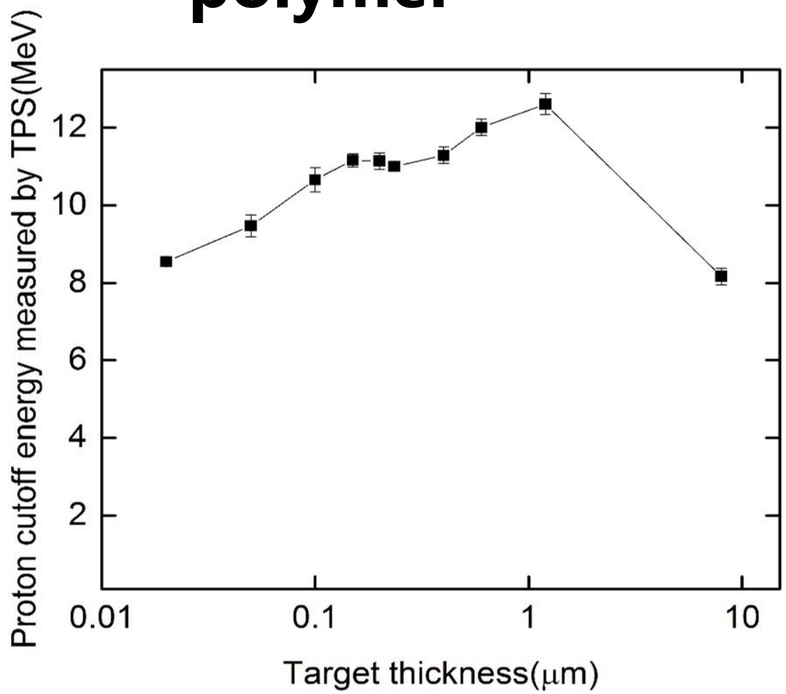
Zeil, K., et al., The scaling of proton energies in ultrashort pulse laser plasma acceleration. NEW JOURNAL OF PHYSICS, 2010. 12(045015).

Thickness scan

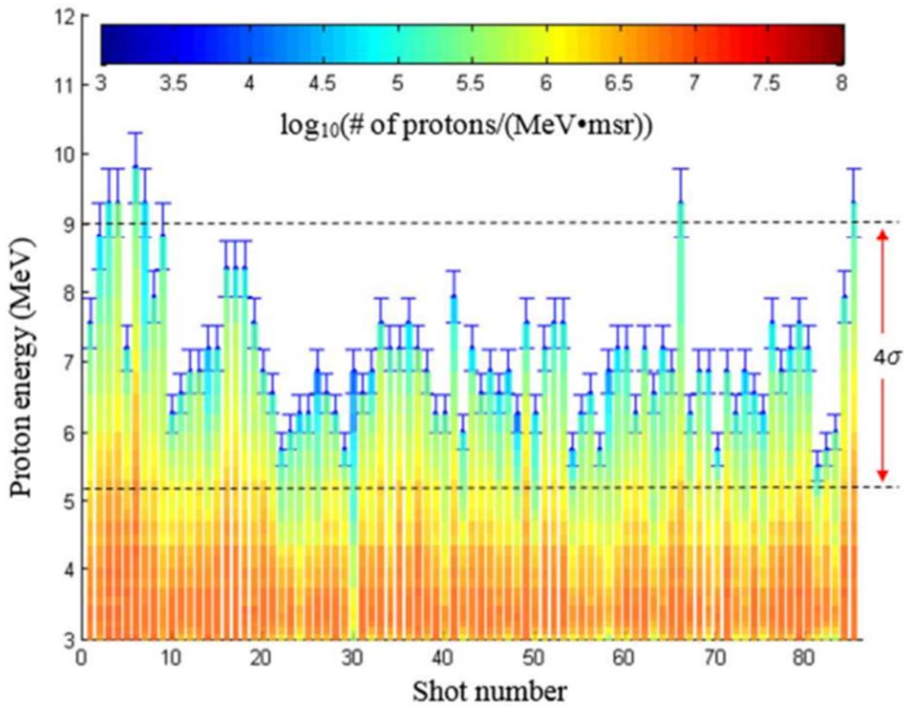
Al

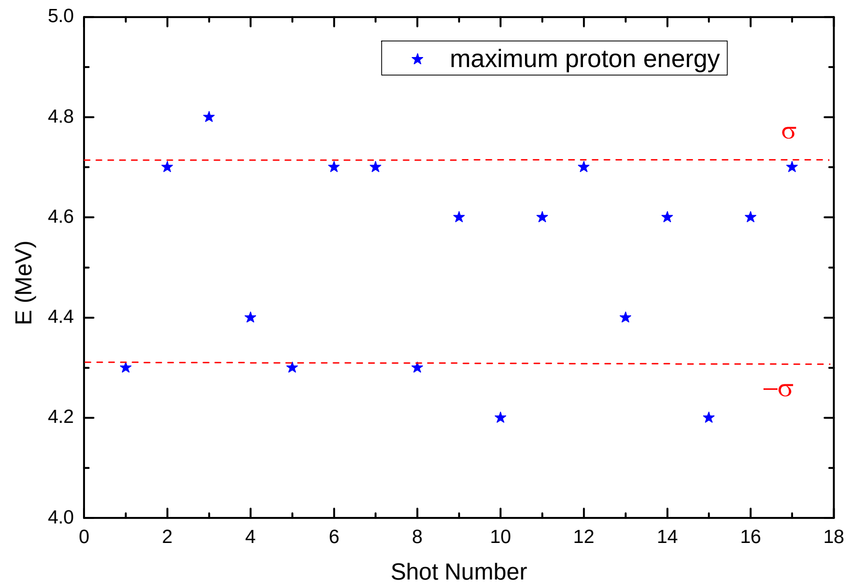


polymer



Repeatability and reliability





Y. Gao et al., An automated, 1 Hz nano-target positioning system for intense laser plasma experiments. Under review.

Laser: 40TW, 25fs

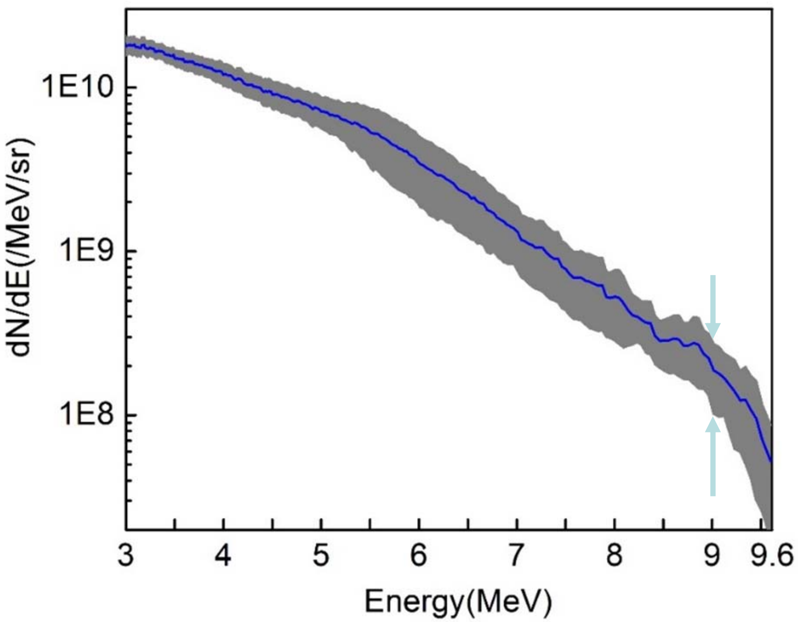
Target: 0.8μm Al

E_ave = 4.52MeV

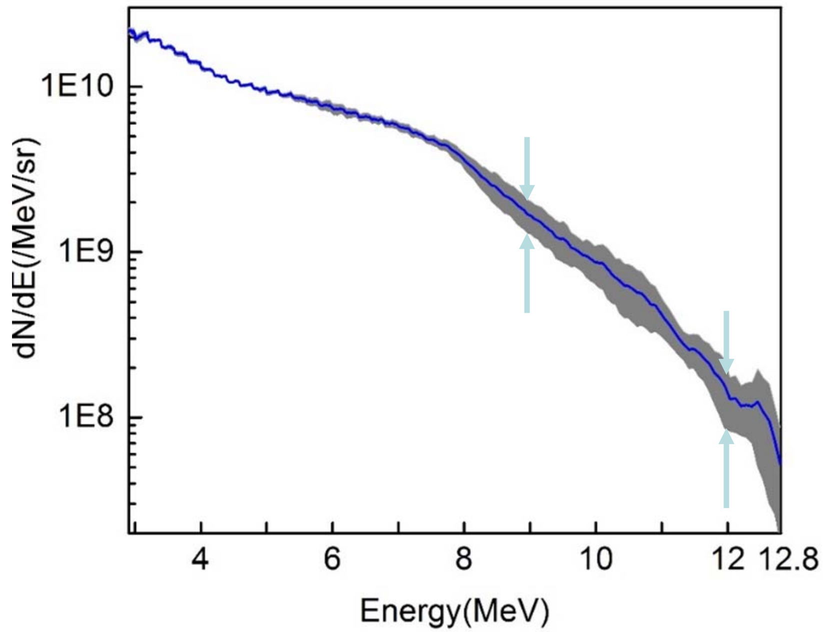
σ = 0.2MeV

Proton spectrum using Al & polymer targets

2.5μm Al/10 shots

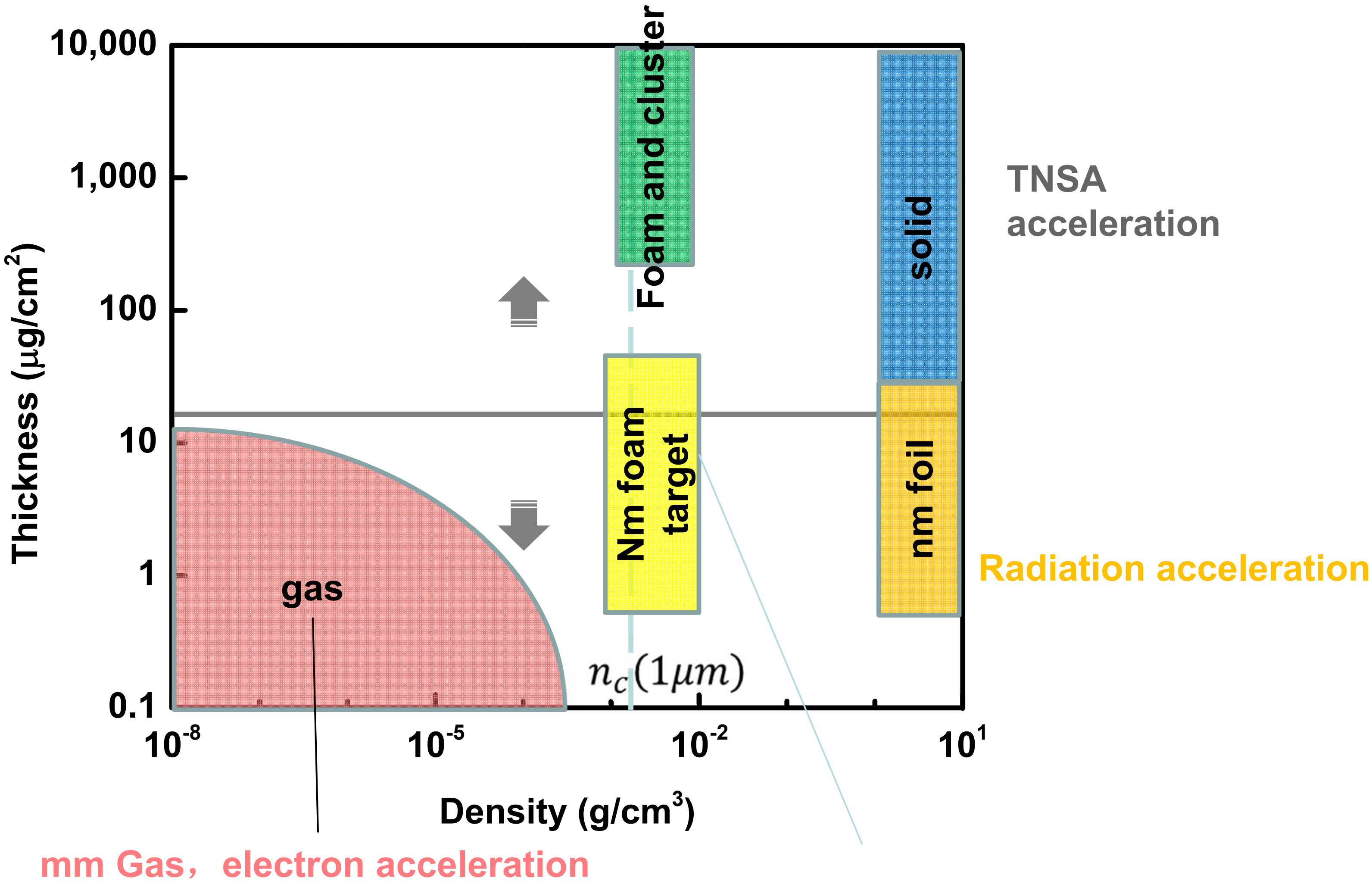


1.2μm polymer/ 10shots



max energy variation $< 3\%$

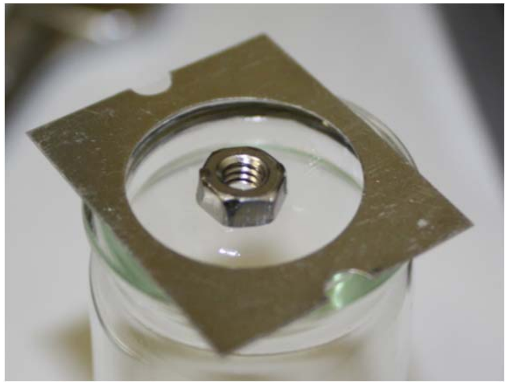
Advanced nanometer targets at Peking Uni.



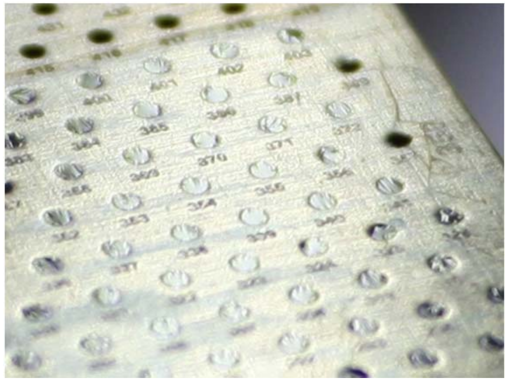
Self standing targets

- Metal foils
  - Al, Cu, Au, Ti…
  - 50nm-10μm

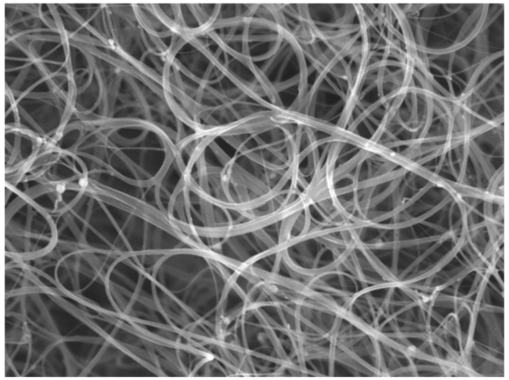
- polymer
  - Size >1cm
  - Thickness 10nm-3μm



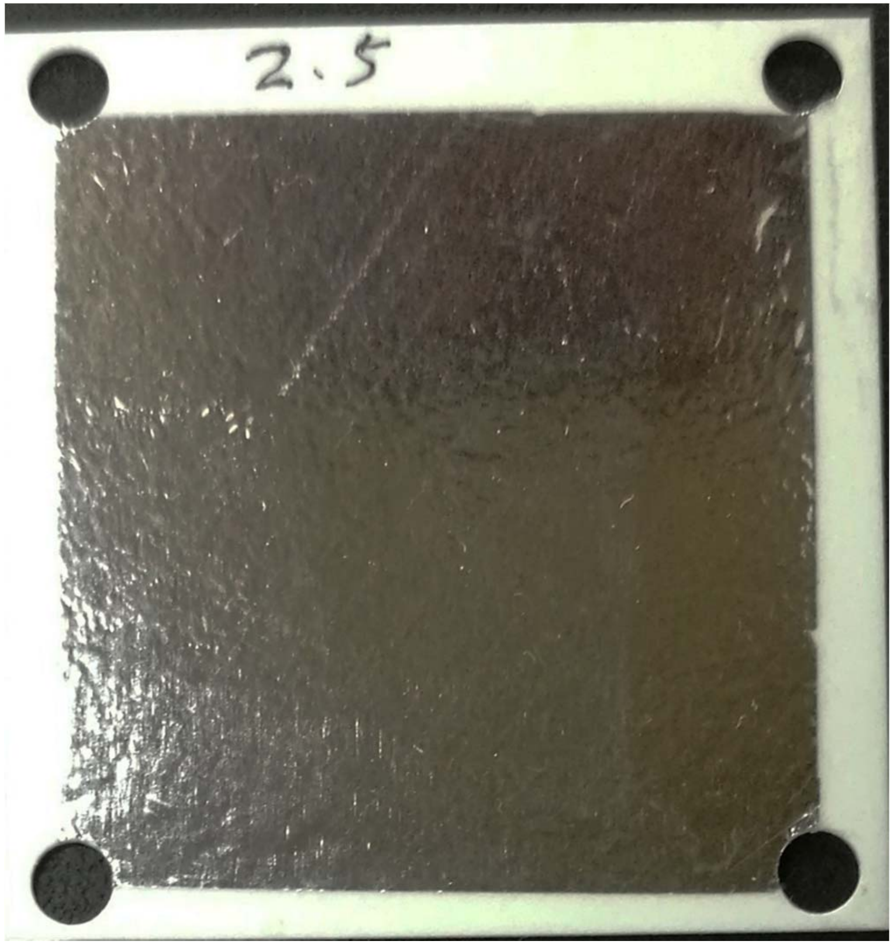
- DLC
  - Pure carbon
  - 5nm-40nm

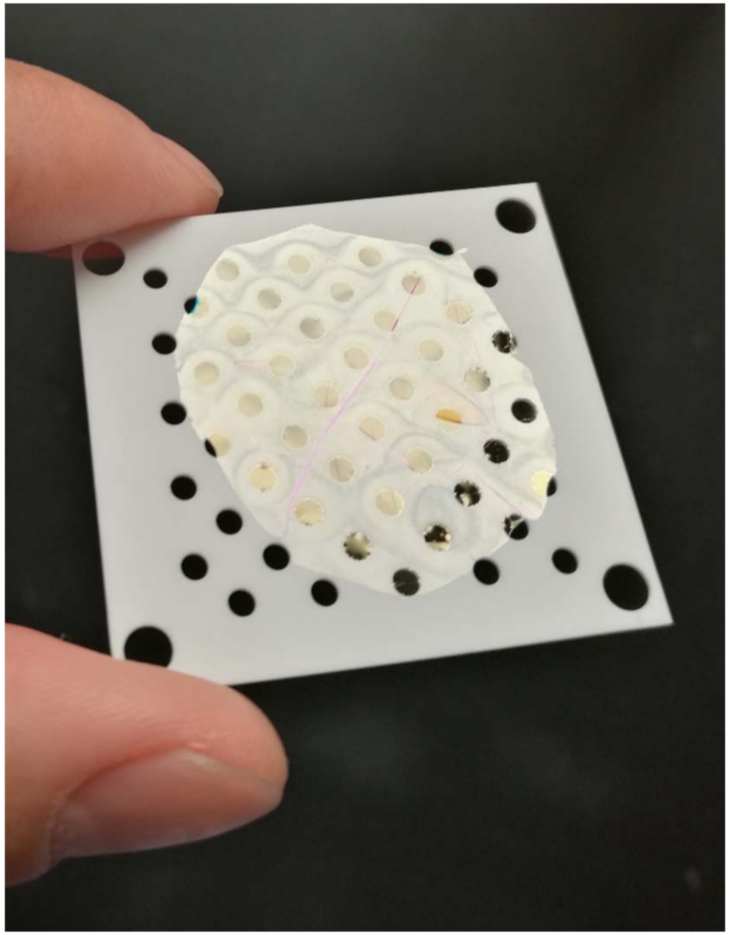


- Carbon nanotube foam target
  - Ne=0.4n_c-3 n_c (800nm)
  - Thickness 2um-120um



Targets in frame

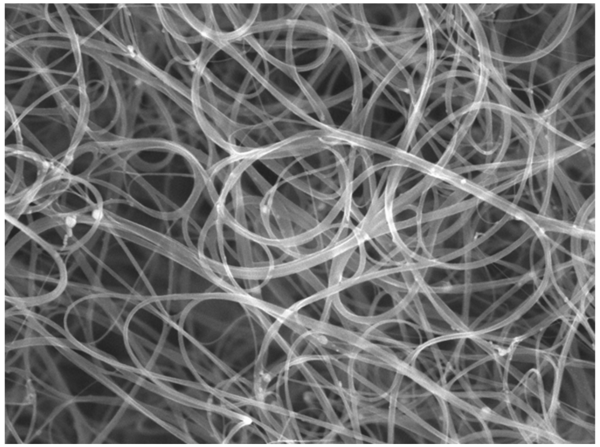




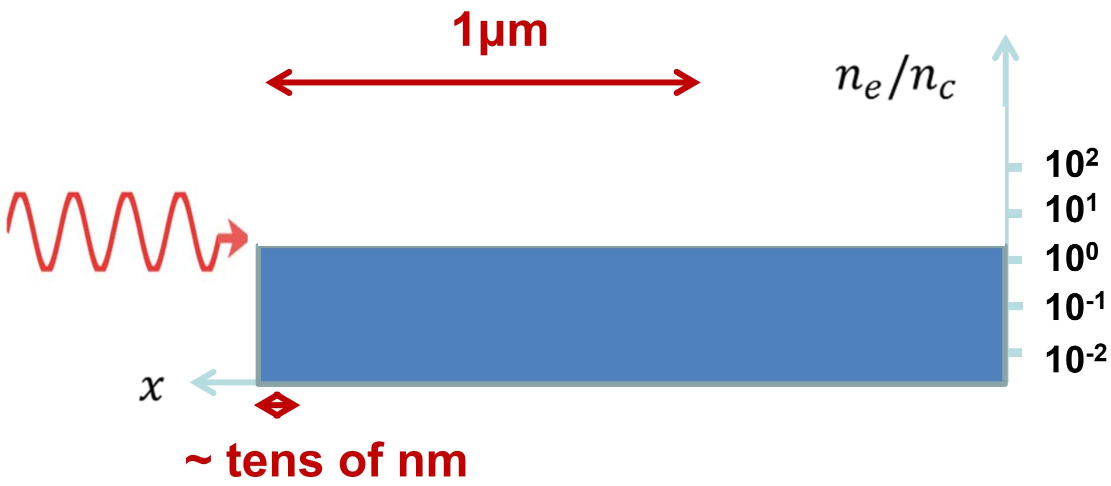
0.8μm-6μm Al

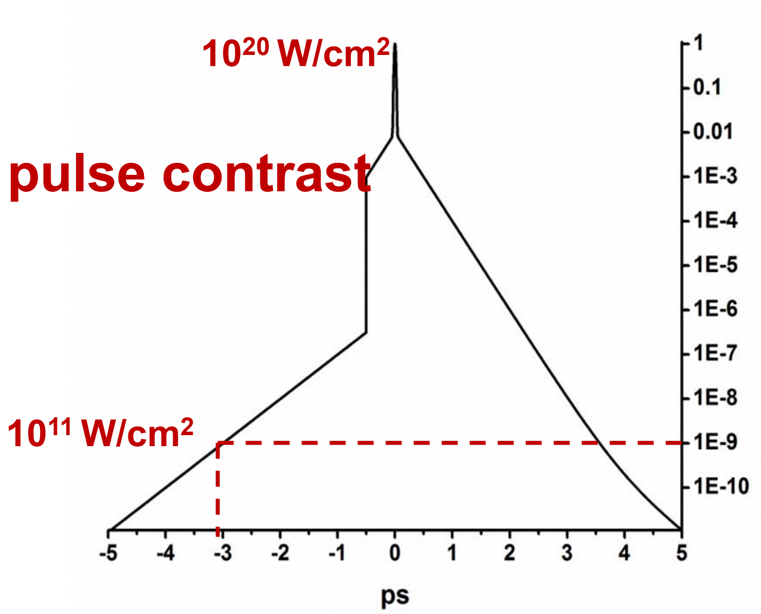
0.02μm-8μm CH

Carbon nanotube foam

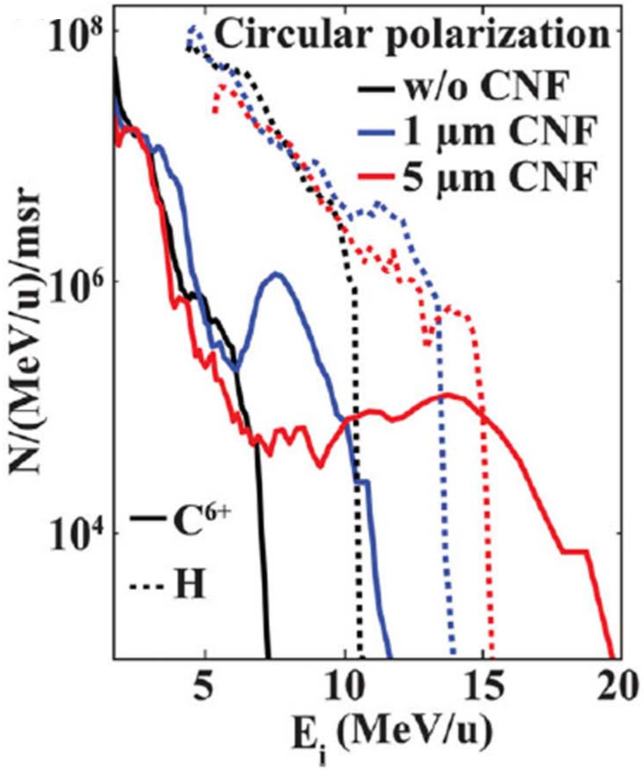


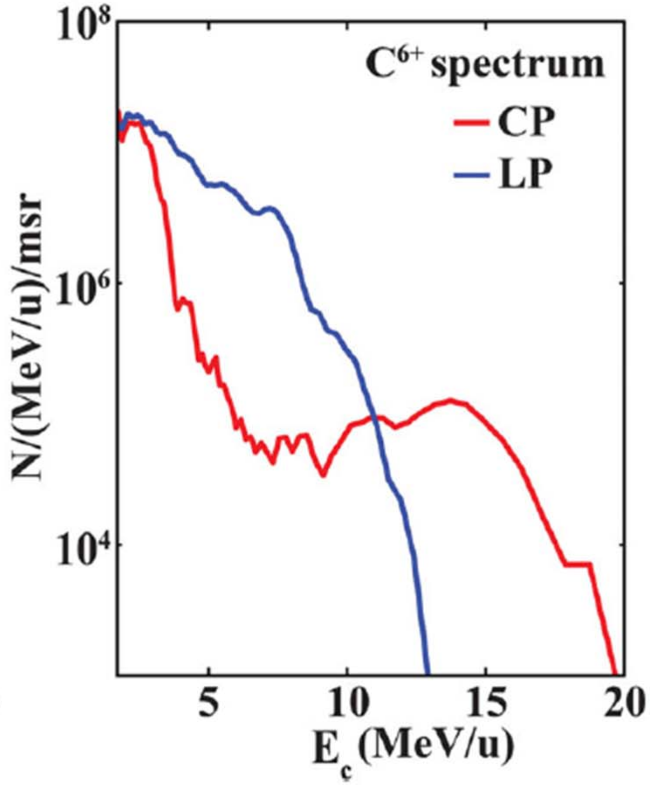
Carbon nanotube foam
~1% of solid density





Ion energy enhancement by a factor 3-4





J.H.Bin*, W.J.Ma*, et al., *Physical Review Letters 115, 064801 (2015).*

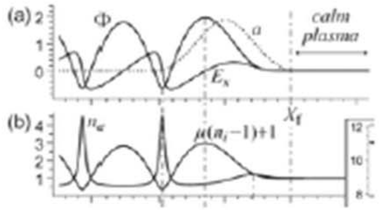
LPA for ion acceleration?

Related works

Similar ideas in electron bubble regime

[9] T. Esirkepov, S. V. Bulanov, M. Yamagiwa, and T. Tajima, Phys. Rev. Lett. **96,** 014803 (2006).
[10] O. Shorokhov and A. Pukhov, Laser Part. Beams (2004).
[11] B. Shen, Y. Li, M. Y. Yu, and J. Cary, Phys. Rev. E **76**, 055402 (2007).

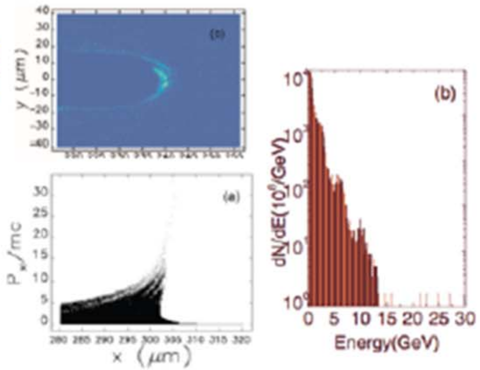
Linear ion wave in electron bubble [9]



A small fraction of light ions mixed into a plasma with heavy ions [10]

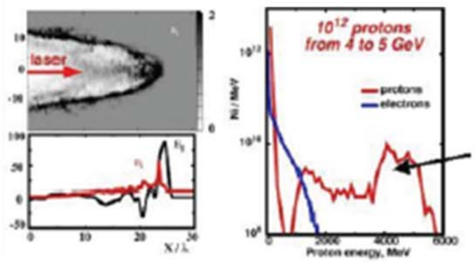
Bubble is almost unperturbed for light ion injection.

Full injection, filled phase space, no spectrum peak [11]



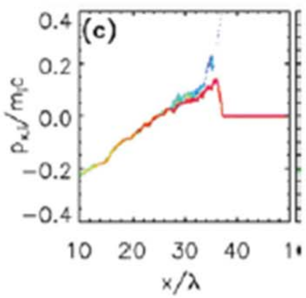
Similar simulation results have been observed before

[12] D. Habs, G. Pretzler, A. Pukhov, and J. Meyer-ter-Vehn, Progress in Particle and Nuclear Physics **46**, 375 (2001).



At almost the same time that they found the electron bubble regime

[13] S. M. Weng, M. Murakami, P. Mulser, and Z. M. Sheng, New J. Phys. **14**, 063026 (2012).



"… In the RT regime, the electrons behind the laser front are highly heated due to their strong coupling with the laser, **but only a small number of fast ions are generated in this regime.** …"

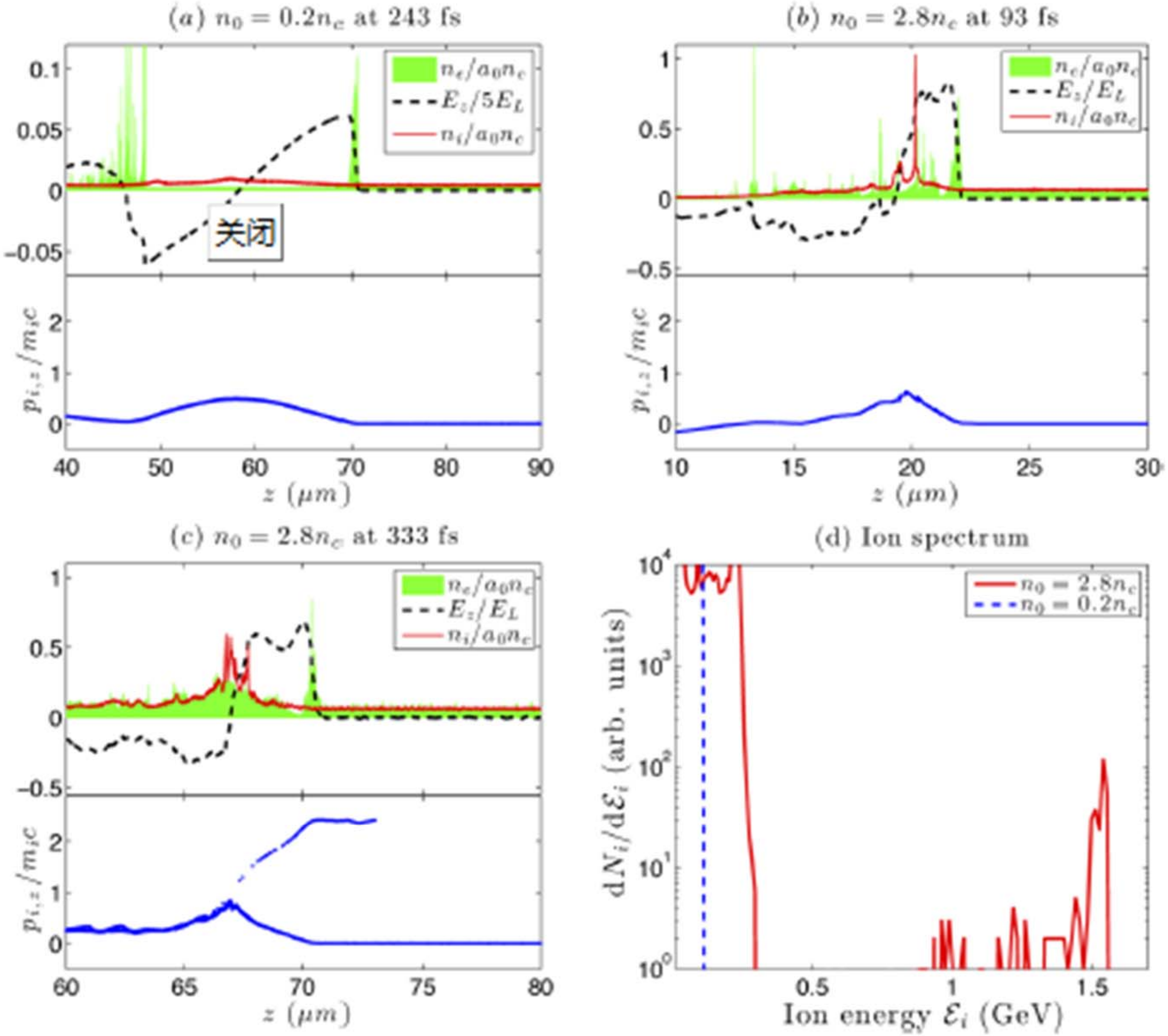


FIG. 1. Results of 1D-PIC simulations. A laser pulse of amplitude $a_0 = 44$ (not shown) is incident from the left, driving a wakefield. Electron and ion densities as well as electric field are plotted for two different initial plasma densities: (a) $0.2n_c$, (b) and (c) $2.8n_c$; lower parts show ion phase space in blue. Results in (b) refer to an early time (93 fs), when the ion wave is just before breaking, while those in (c) refer to a later time (333 fs), when the ion wave is broken and accelerated ions have overtaken the electron layer at the laser front; (a) corresponds to a linear ion wave developing at low plasma density; (d) ion energy spectra corresponding to (c) and (a).

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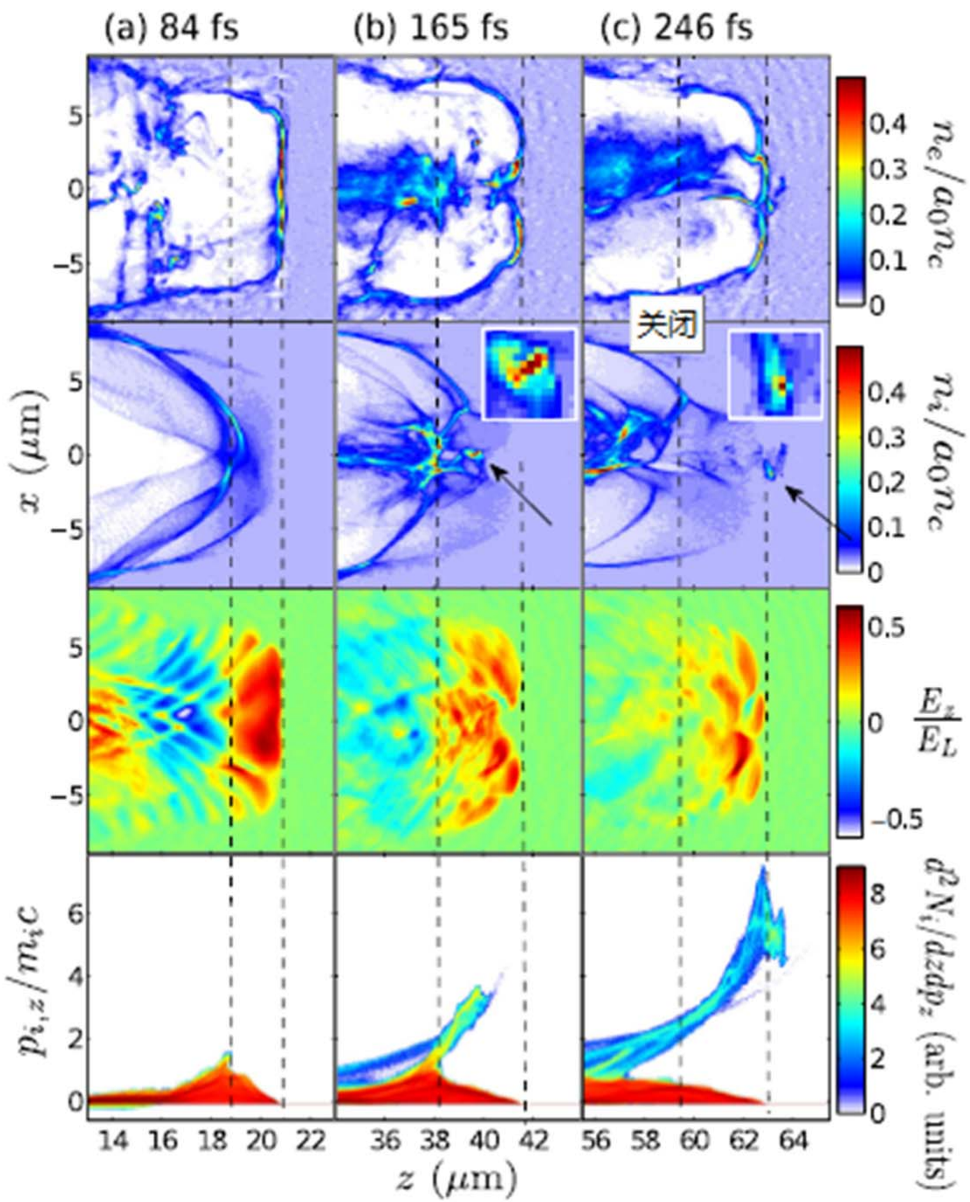

FIG. 4. Results of a 3D-PIC simulation with initial plasma density $n_0 = 3n_c$ and laser amplitude $a_0 = 155$; results are

Thanks for your attention!

感谢支持
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