上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Synchrotron radiation source based on laser wakefield accelerator inside plasma channel

Min Chen[1，2]，Ji Luo[1，2]，Fei-Yu Li[3]，Feng Liu[1，2]，
Zheng-Ming Sheng[1,2,3]，Jie Zhang[1，2]

[1] Laboratory for Laser Plasmas, Department of Physics and Astronomy
[2]IFSACollaborative Innovation Center，
Shanghai Jiao Tong University，Shanghai 200240
[3] SUPA, Department of Physics, University of Strathclyde,
Glasgow G4 0NG, UK

激光等离子体教育部重点实验室
Key Laboratory for Laser Plasmas，SJTU

2nd EAAC, 13-19/09 2015 La Biodola, Isola d'Elba, Italy

Outlines

- A short introduction to our lab
- Introduction to Synchrotron Radiation
- SR based on LWFA guided in Plasma Channels (Plasma undulator; Plasma bending magnet)

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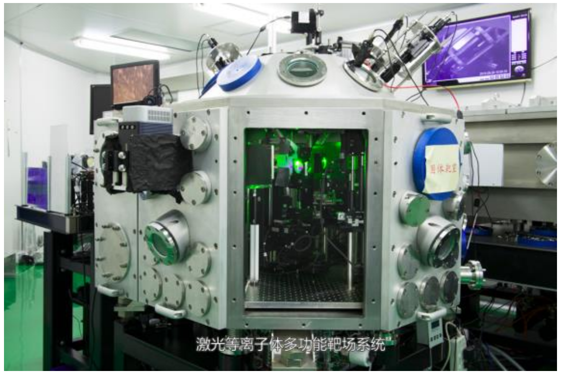
Laboratory for Laser Plasmas at SJTU

Our campus is 25km from downtown shanghai, 44km from Pudong international airport.

Leader: Prof. J. Zhang
Lie-Jia Qian & Zheng-Ming Sheng

200TW laser system 10Hz 5J/25fs; kHz laser system; 400J laser system
Both laser, experiment & theory group.



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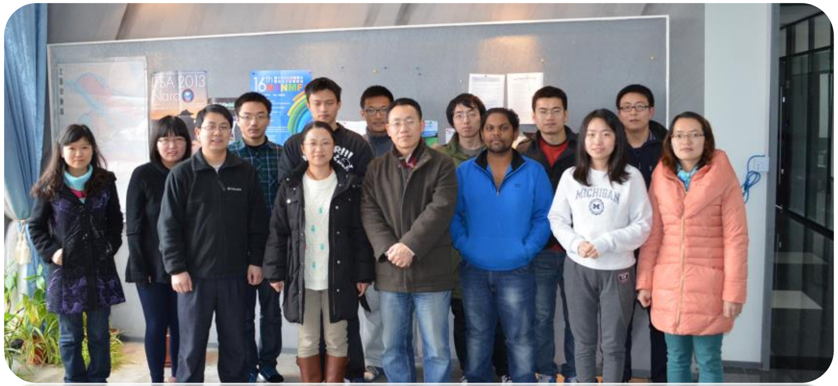
Key Laboratory for Laser Plasmas， SJTU

Laser Wakefield Acceleration Group at LLP, SJTU



Theory:

Z.M. Sheng, M. Chen, L.L. Yu, S.M. Weng

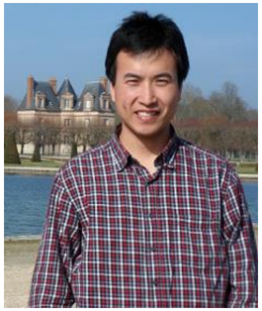
5 Graduated Students

Experiment:

J. Zhang, T. Sokollik, N. Hafz,

F. Liu,X.H. Yuan

X.L. Ge+6 Graduated Students



Main topics:

1. **Electron injection in Wakefields**
2. **Radiation in Wakefields (From THz to γ-ray)**
3. **Experimental studies on electron injection and radiation in LWFA**

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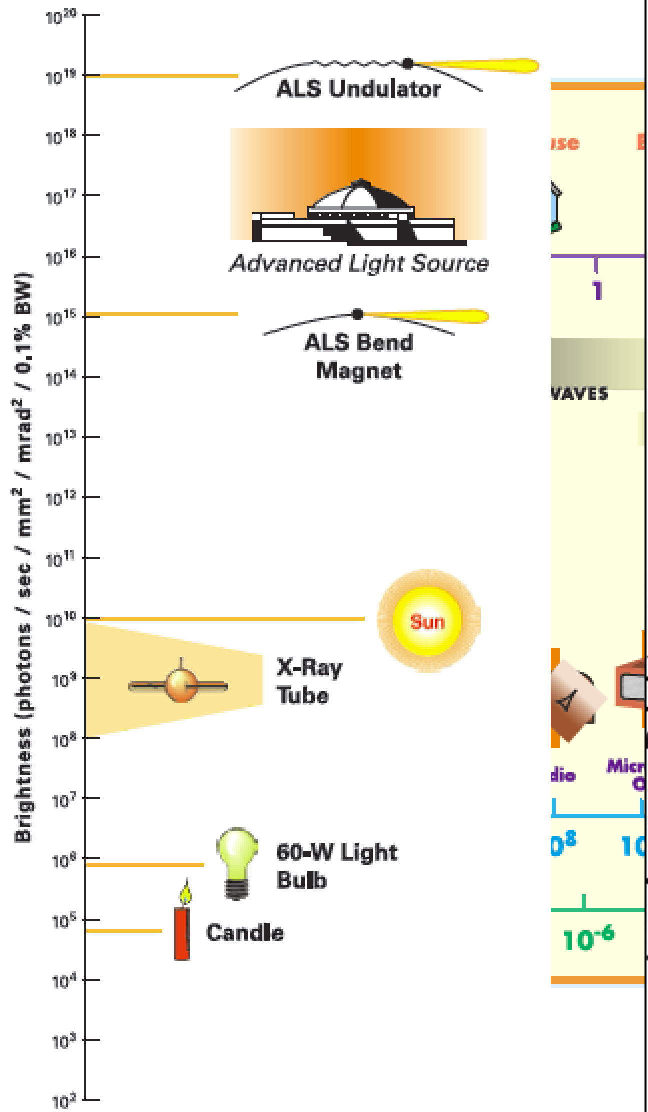
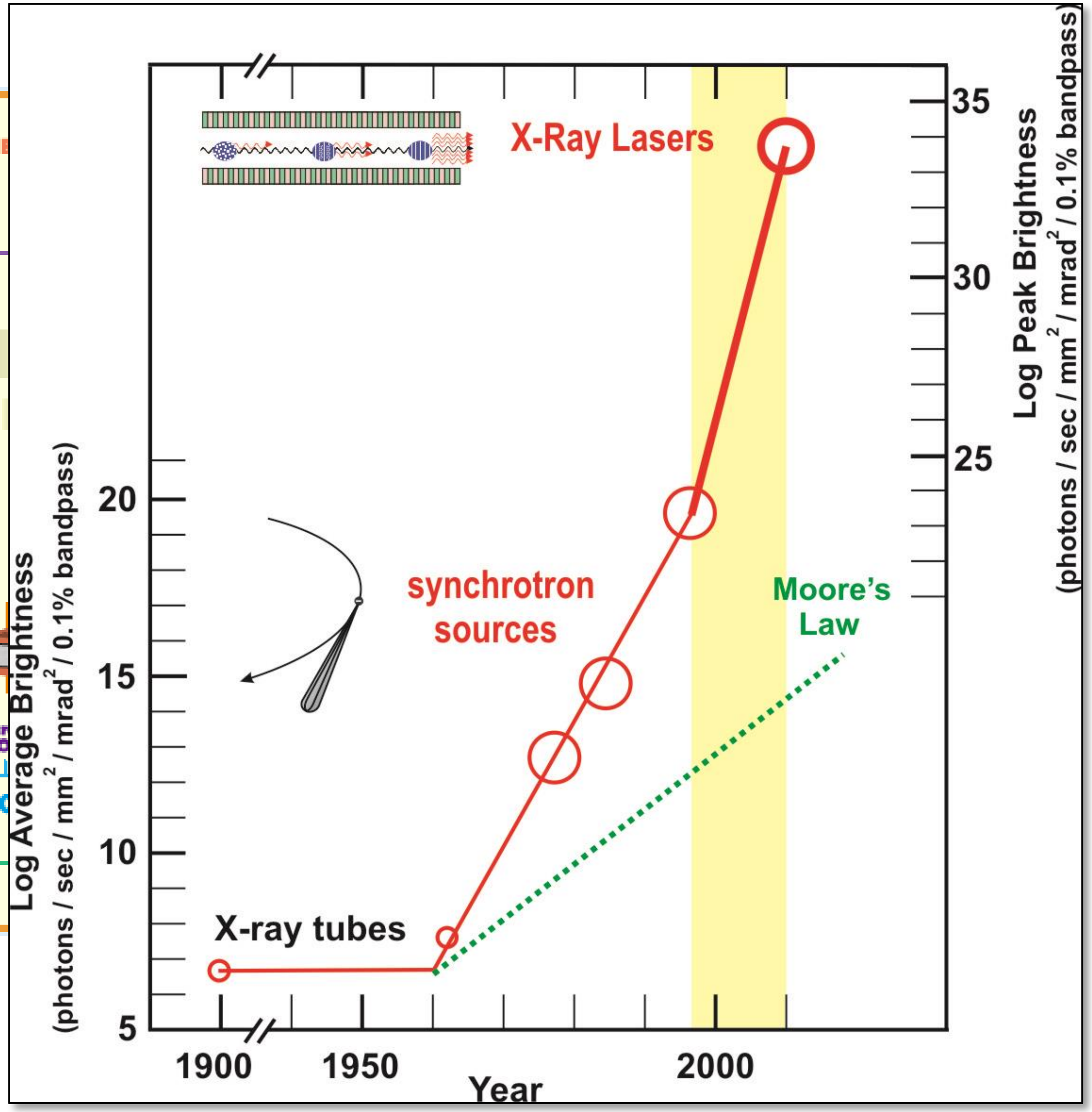
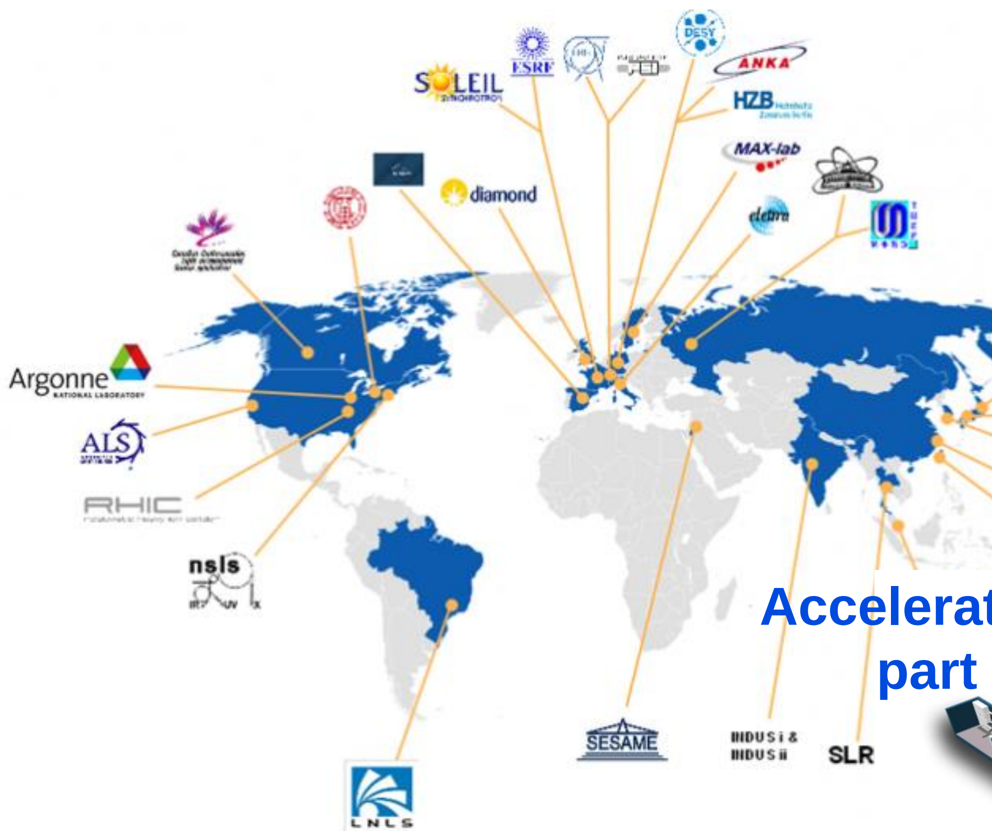
SR light sources around us



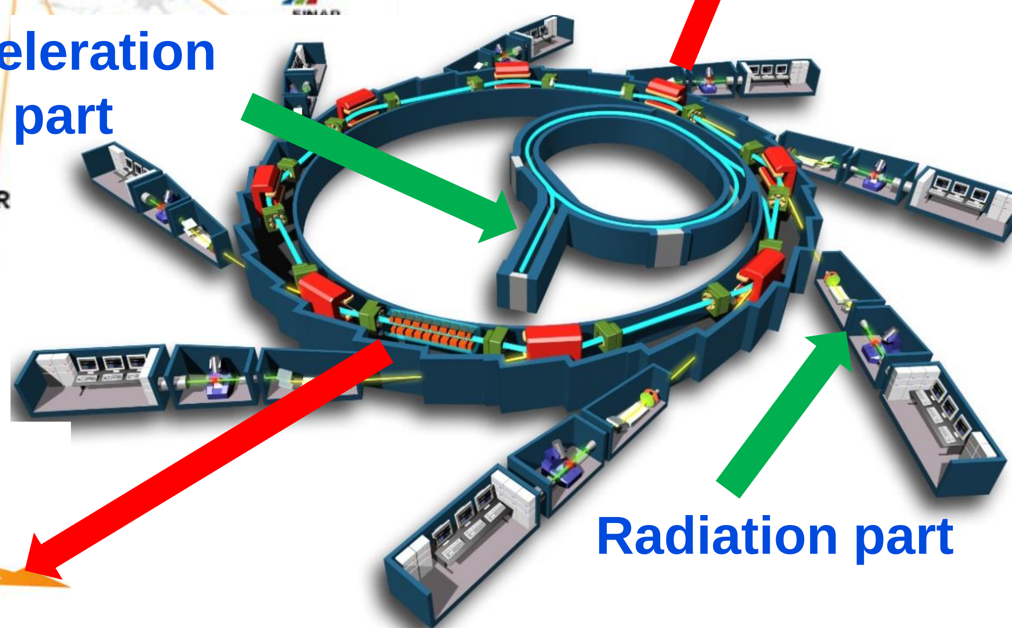


Synchrotron Radiation Source

Deflection magnet radiation

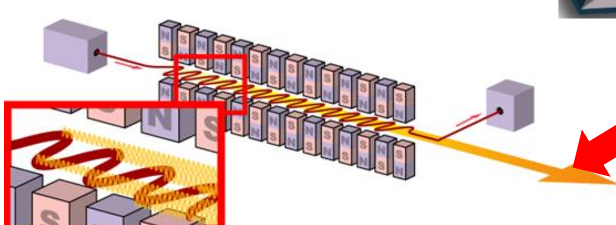


Acceleration part



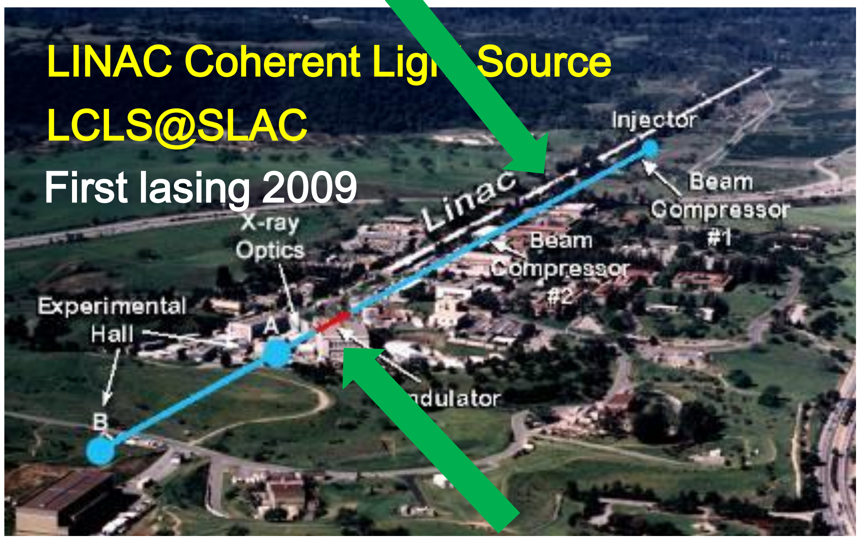
Radiation part

Undulator radiation



Planned X-ray FEL (world wide)

Acceleration Part



Radiation Part

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A new Technology for Accelerator and Radiation Source

Laser Wakefield—Acceleration cavity in plasma

LWFA in Plasma Channel—Plasma undulator and deflection magnet

Revolution of Accelerator

New world record

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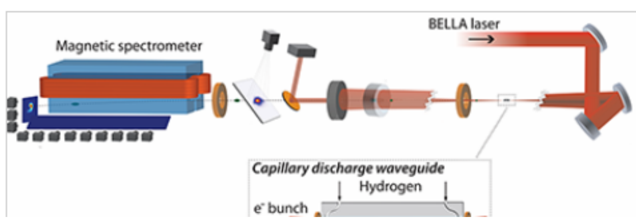
Viewpoint: Power to the Electrons

PDF Version | Print

Georg Korn, ELI Beamlines, Institute of Physics of the Academy of Science, Czech Republic, 182 21 Prague 8, Czech Republic

December 8, 2014 • *Physics* 7, 125

A laser-driven particle accelerator, delivering a beam of electrons with a record-breaking energy of 4.2 giga-electron-volts, could lead to compact x-ray lasers or high-energy colliders.



Multi-GeV Electron Beams from Capillary-Discharge-Guided Subpetawatt Laser Pulses in the Self-Trapping Regime

W. P. Leemans, A. J. Gonsalves, H.-S. Mao, K. Nakamura, C. Benedetti, C. B. Schroeder, Cs. Tóth, J. Daniels, D. E. Mittelberger, S. S. Bulanov, J.-L. Vay, C. G. R. Geddes, and E. Esarey

Phys. Rev. Lett. 113, 245002 (2014)

Published December 8, 2014

Read PDF

4.2 GeV 9cm, 310TW, 15J, 43fs, 6X10^{17}/cm^{3}

BELLA, LBNL, Wim Leemans, Phys. Rev. Lett. 113, 245002 (2014)

This morning, plenary talk by Wim Leemans

Current Main Challenges of LWFA

Direction 1 : High Energy

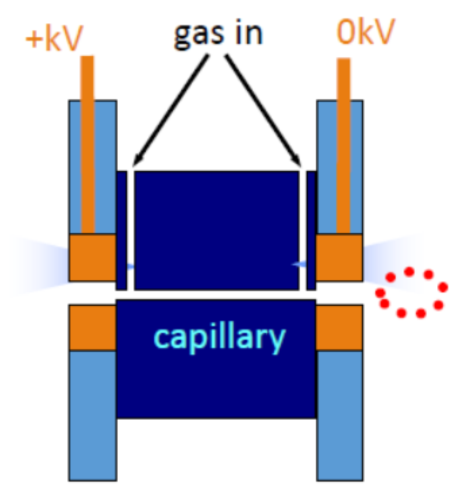
1. Laser Guiding– Diffraction
2. Velocity matching-Dephasing
3. Staging– Depletion

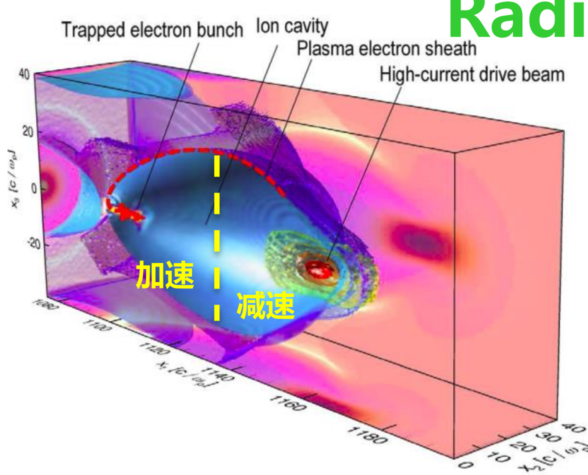
Direction 2: High Quality

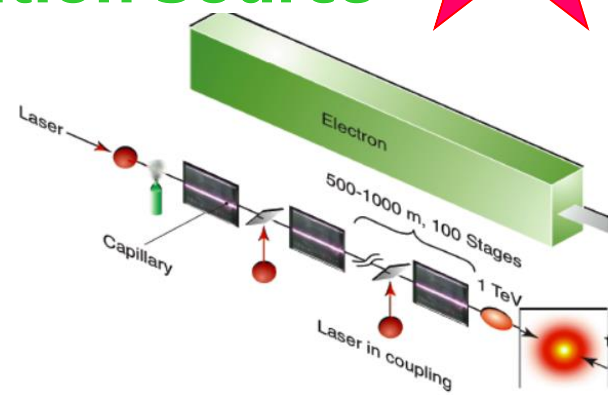
1. Electron injection
2. Transverse acceleration structure control
3. Longitudinal control

New generation of collider

New generation of Radiation Source







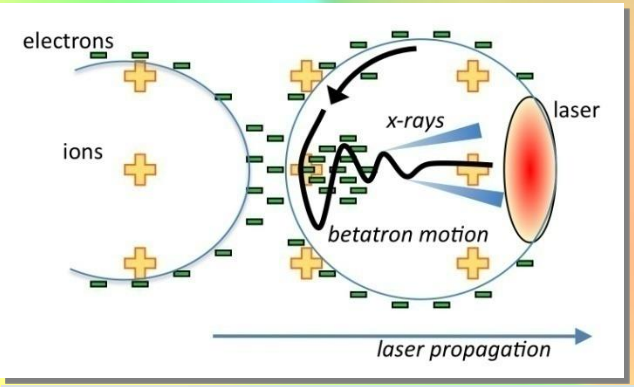
LWFA based radiation sources

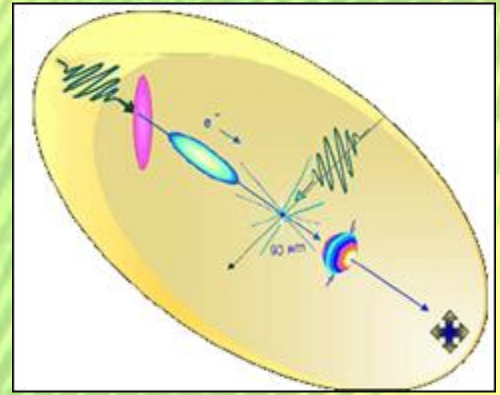
LWFA based radiation mechanisms：

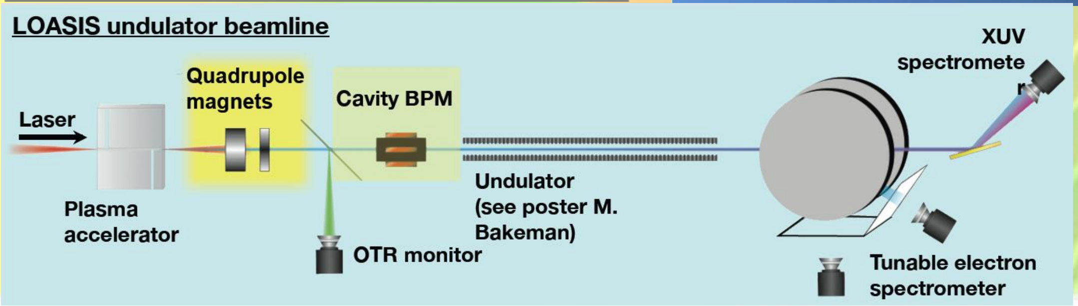
1. Betatron Radiation due to transverse oscillation (X ray)
2. Transition radiation (From plasma to vacuum, THz ray)
3. Laser electron Thomson scattering (X~γ ray)

Using external magnets:

Wiggler or undulator，Thomson,Compton scattering sources





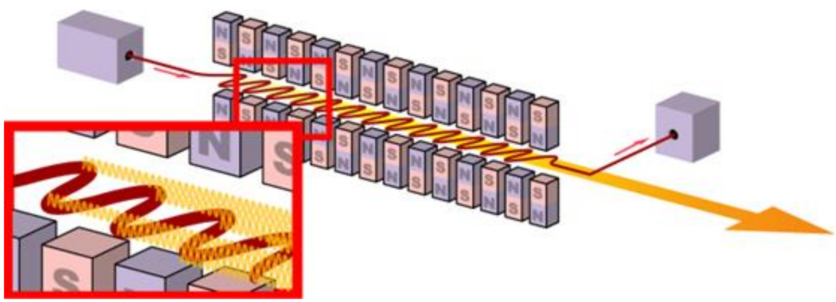


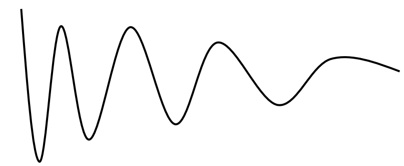
Usually e^- are accelerated straightly inside LWFA

How to make the electrons experience similar trajectories as those in synchrotron?

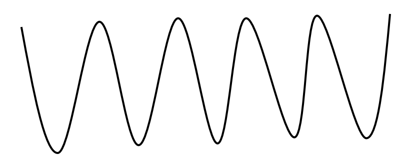
Not the normal betatron motion in wakefield

Periodic oscillation trajectory

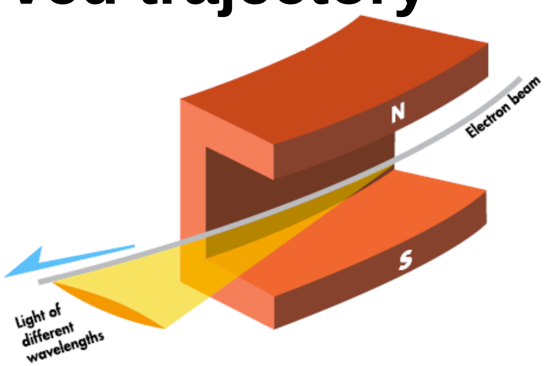




Undulator radiation



Curved trajectory



Deflection magnet radiation

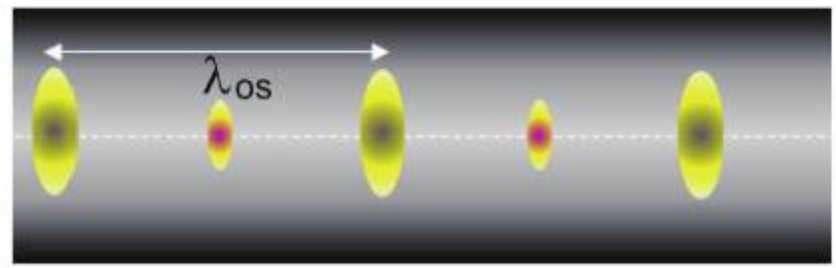
Using plasma channel to control laser propagation

$$|a|^2 = (a_0 r_0/g_s)^2 \exp(-2r^2/r_s^2)$$

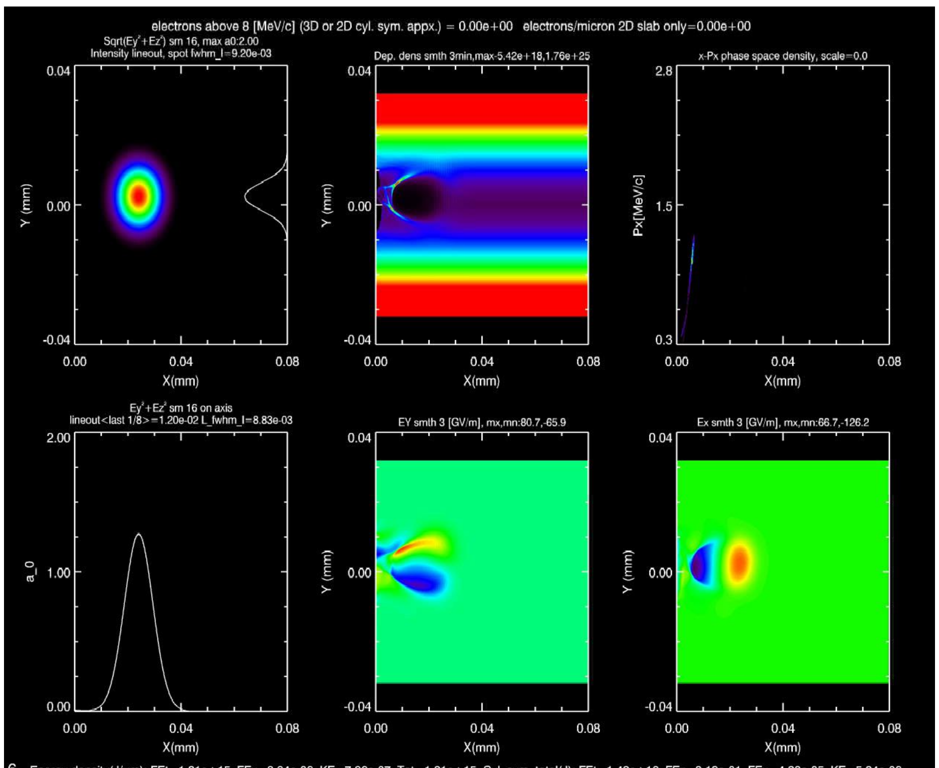
$$\frac{d^2R}{dz^2} = \frac{1}{Z_M^2 R^3}\left(1 - \frac{\Delta n}{\Delta n_c} R^4\right)$$

$r_s = r_i$ and $r_s = (\Delta n/\Delta n_c)^{1/2} r_0^2/r_i$

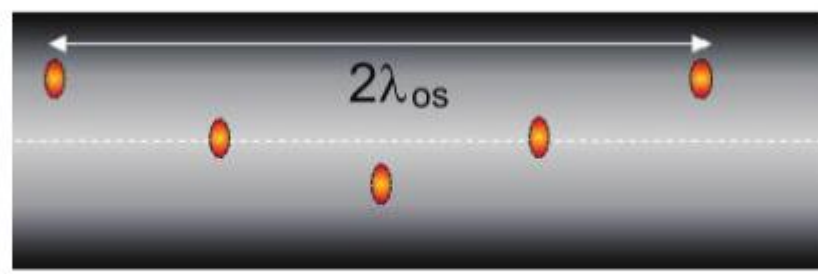
Laser self-focusing in plasma



$$\lambda_{os} = \pi Z_M (\Delta n/\Delta n_c)^{1/2}$$

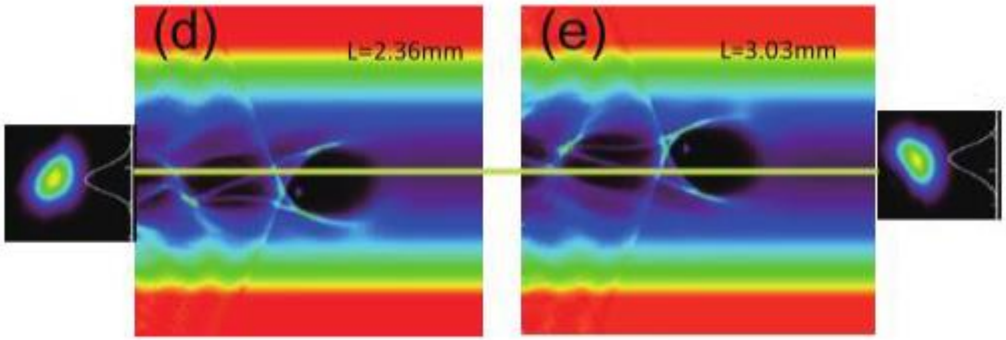


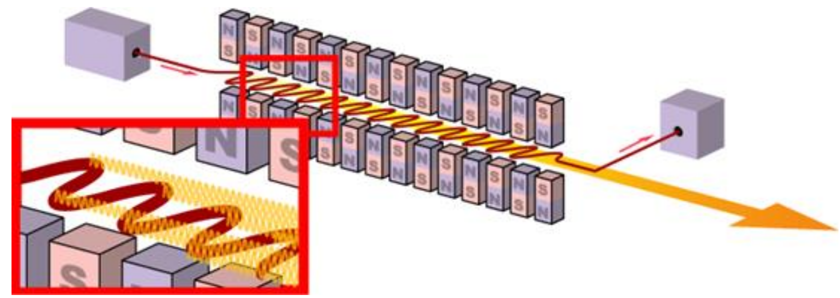
Whole laser oscillation in plasma

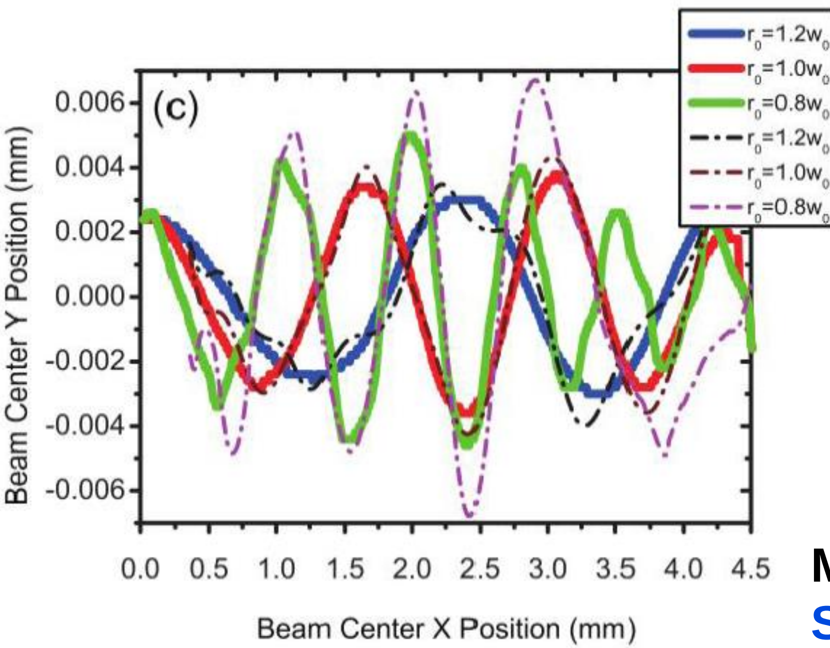


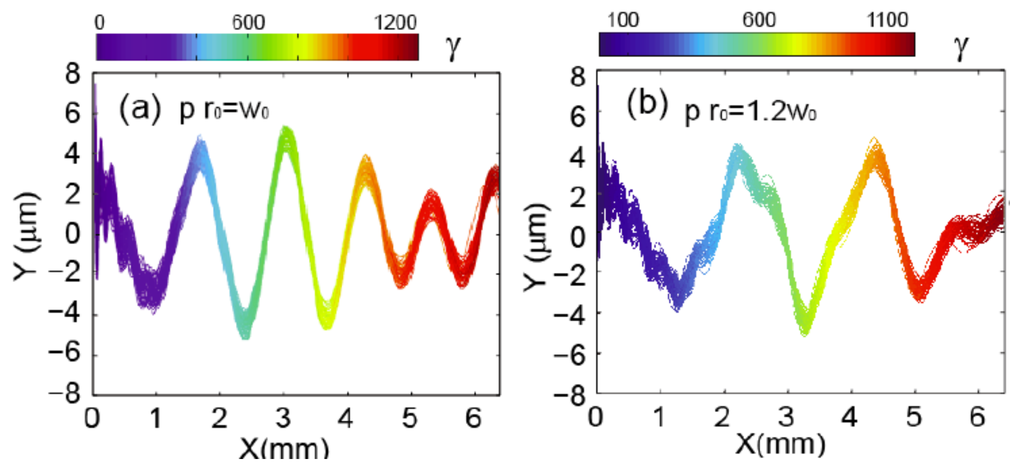
M. Chen *et al.*, arXiv:1503.08311 (2015)

Channel width effects on laser & e⁻ oscillation







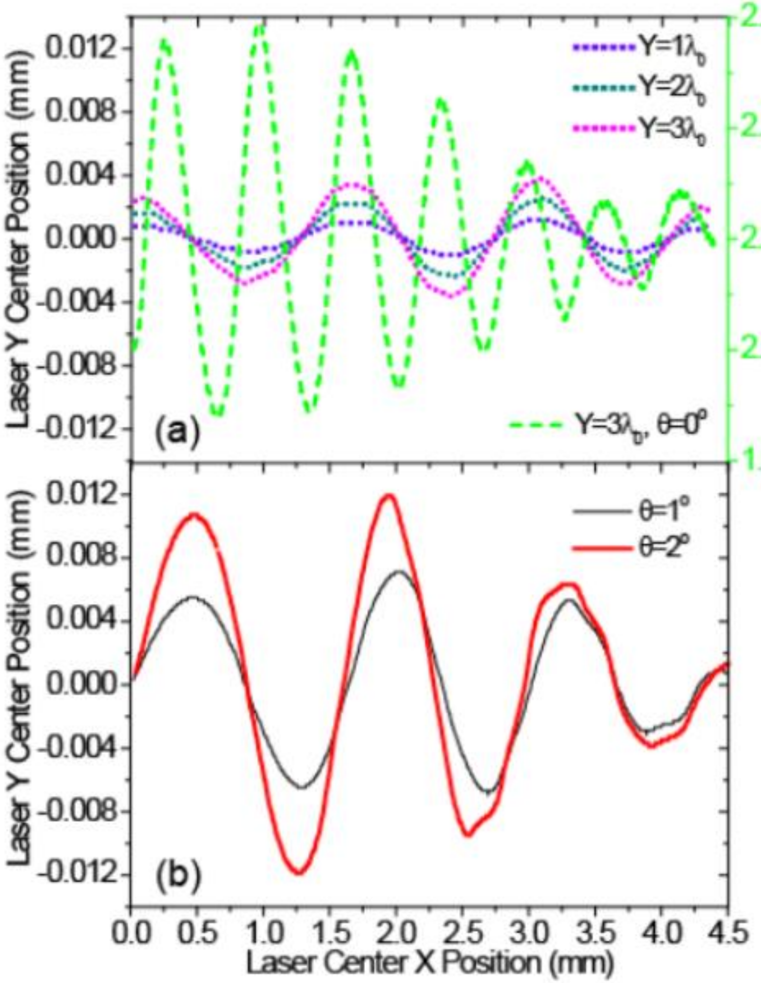


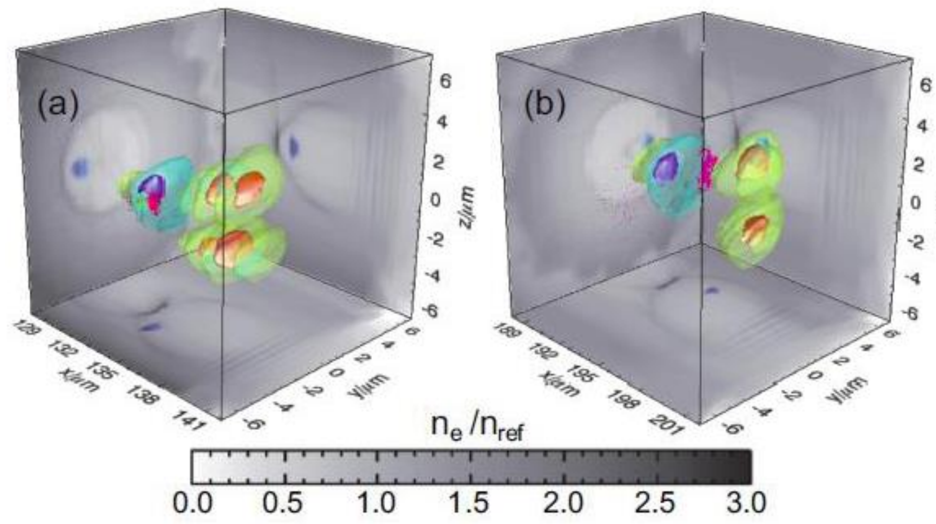
M. Chen *et al.*, arXiv:1503.08311 (2015)

S.G. Rykovanov et al., PRL,14,145003 (2015)

Pathak VB, Proceedings of the 41st EPS (2014)

Off-axis distance & injection angle effects

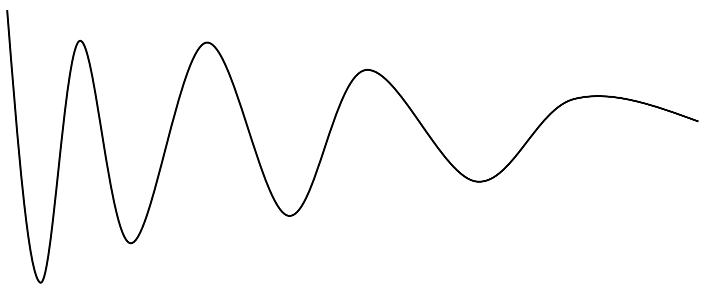


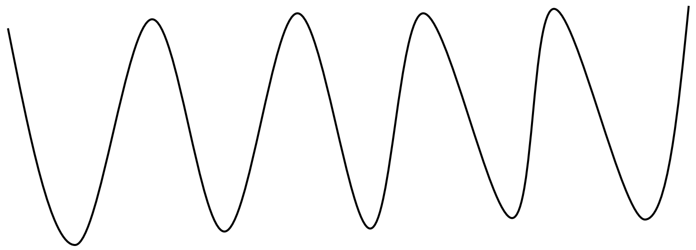


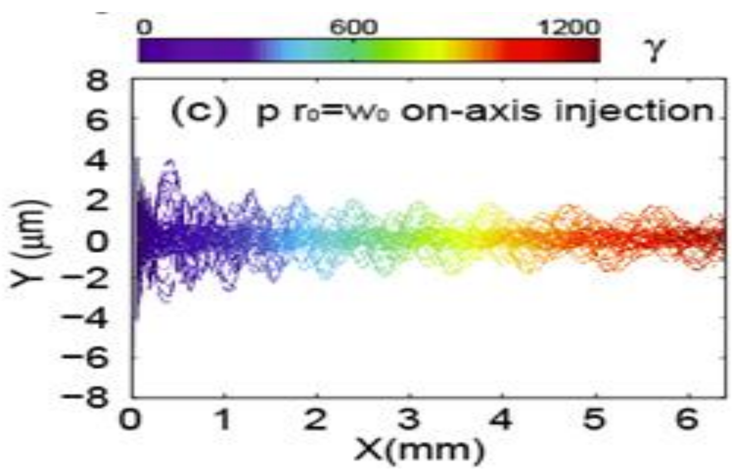
3D PIC Simulations

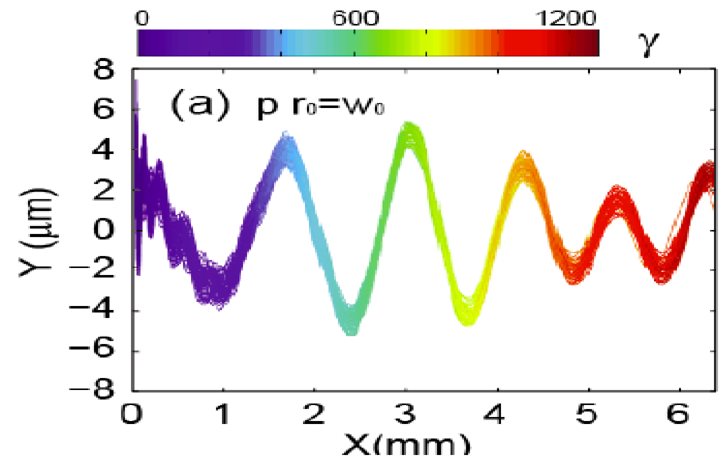
M. Chen *et al*, arXiv:1503.08311 (2015)

Difference with the normal Betatron Oscillation





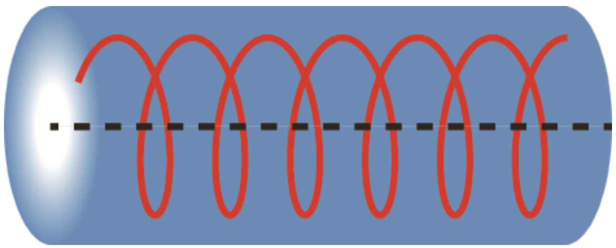


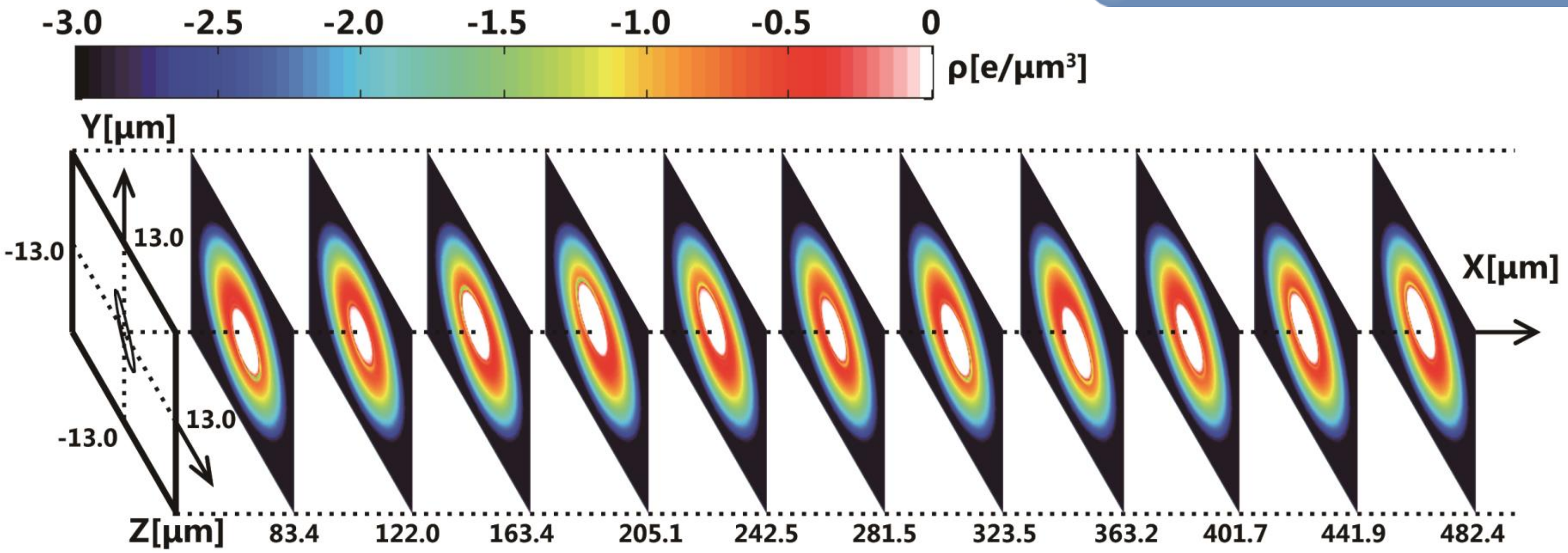


Both oscillation amplitude and period can be tuned in this new scheme.

Helical motions of wake and e^-

When the laser is obliquely and off-axis injected:
There will be spiral motions.

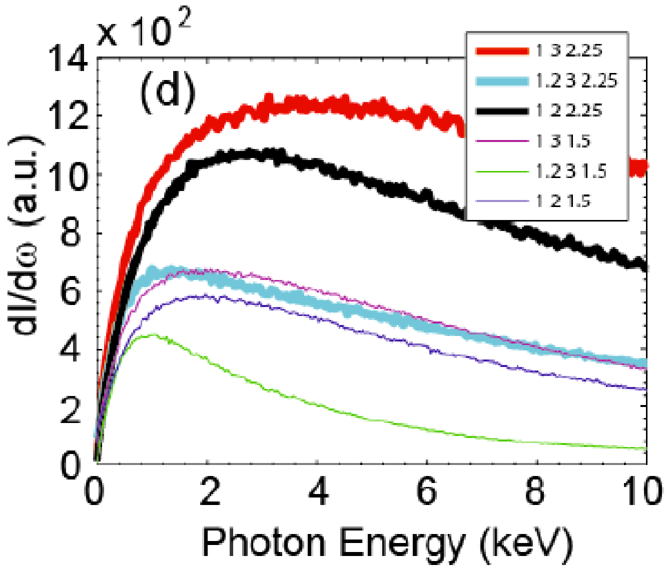




Wake center evolution along acceleration distance

J. Luo *et al*, to be submitted (2015)

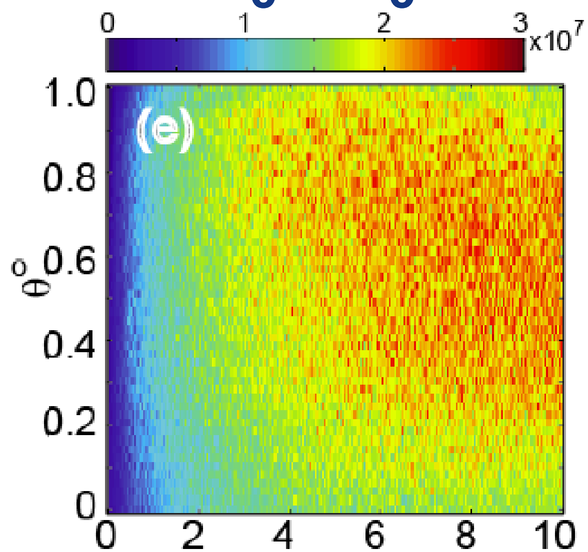
Radiation spectra from plasma undulators



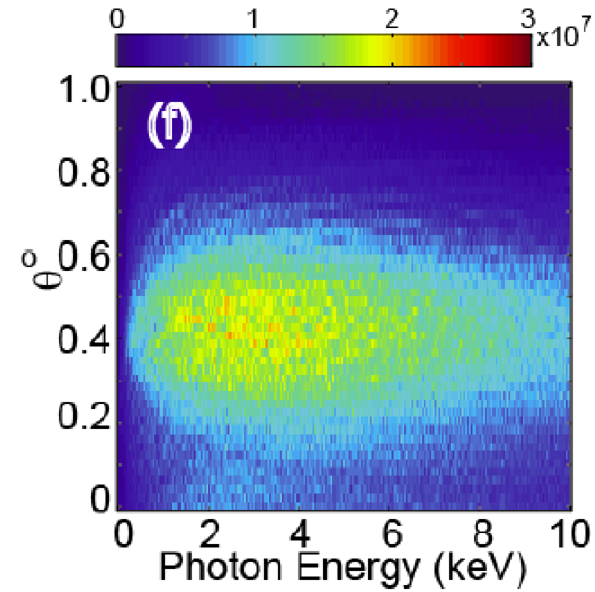
Spectra $(r_0/w_0, Y_0, L_{acce})$

Angular distribution

r_0=w_0

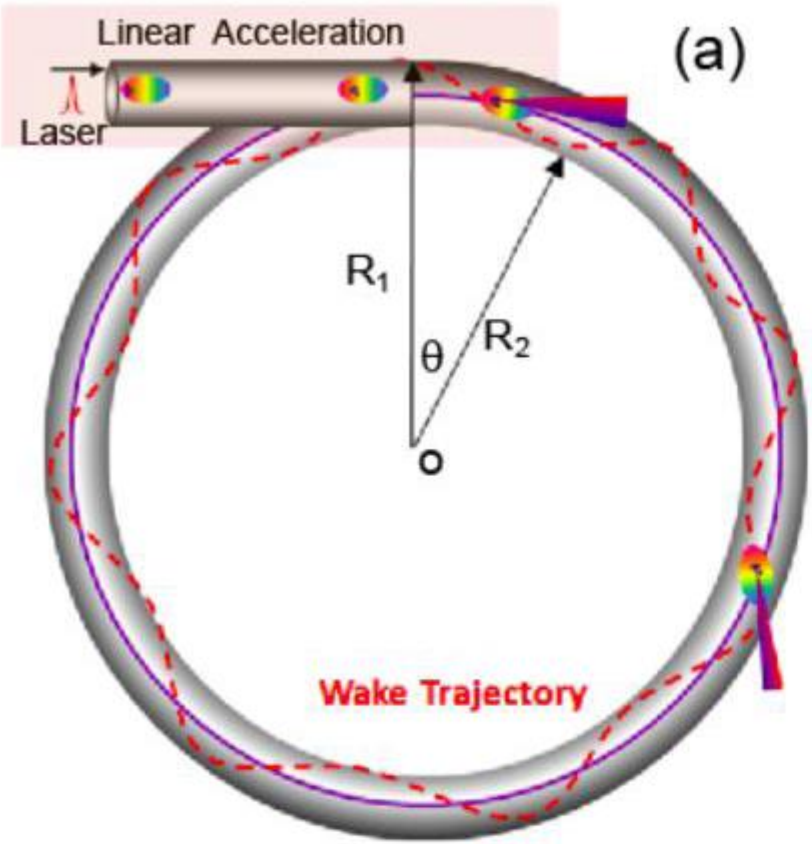


r_0=1.2w_0

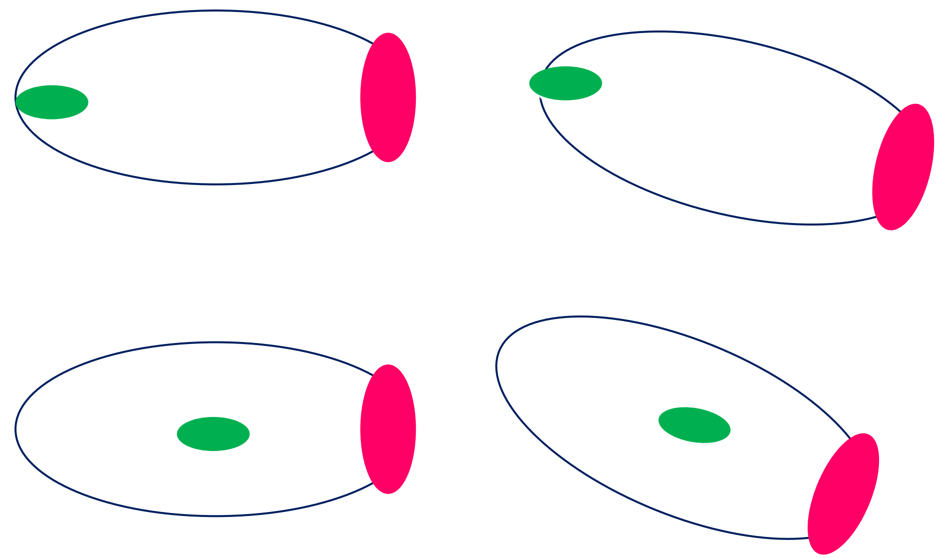


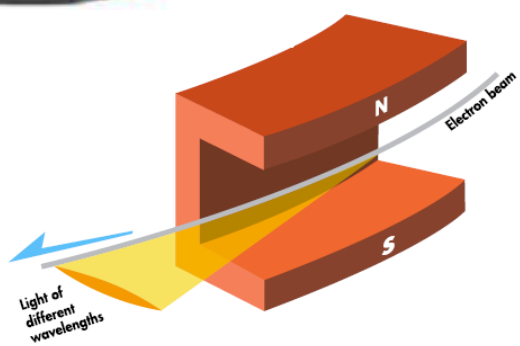
M. Chen *et al*, arXiv:1503.08311 (2015)

Electron acceleration in a curved plasma channel



Linear acceleration part is used to control the electron energy and avoid transverse loss of the electrons

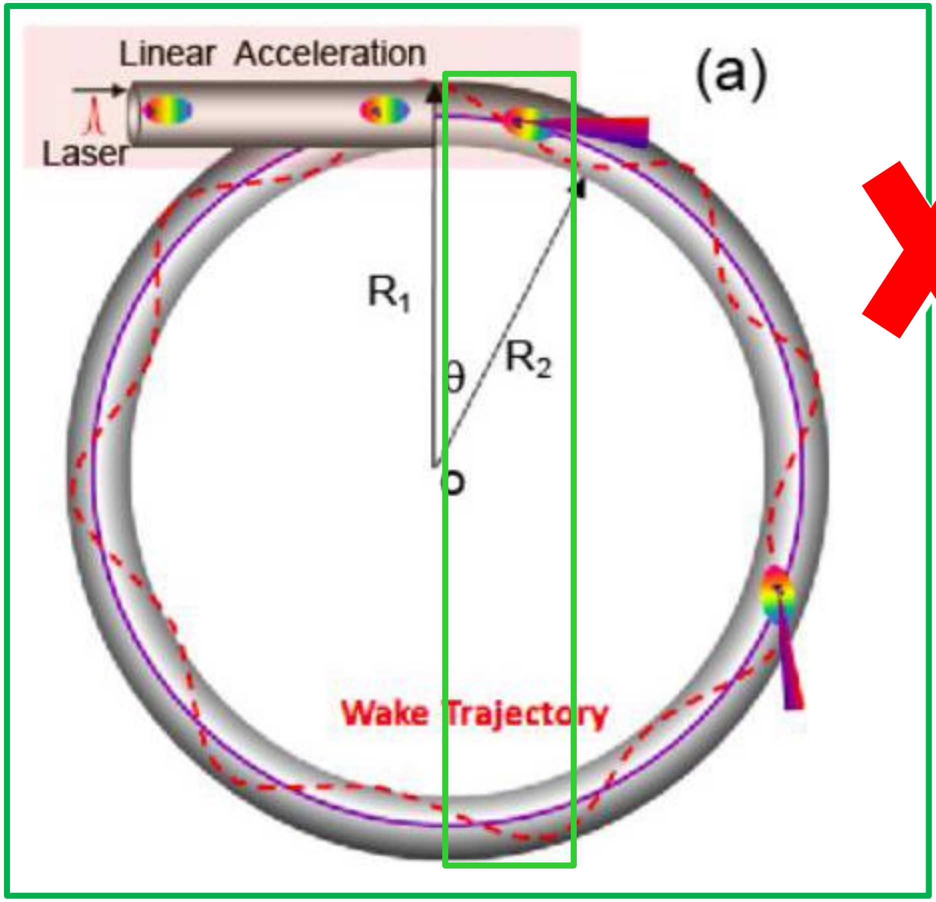




No Transverse loss and energy evolution

M. Chen *et al*, arXiv:1503.08311 (2015)
Reitsma A, EEE Trans Plasma Sci 36, 1738 (2008)

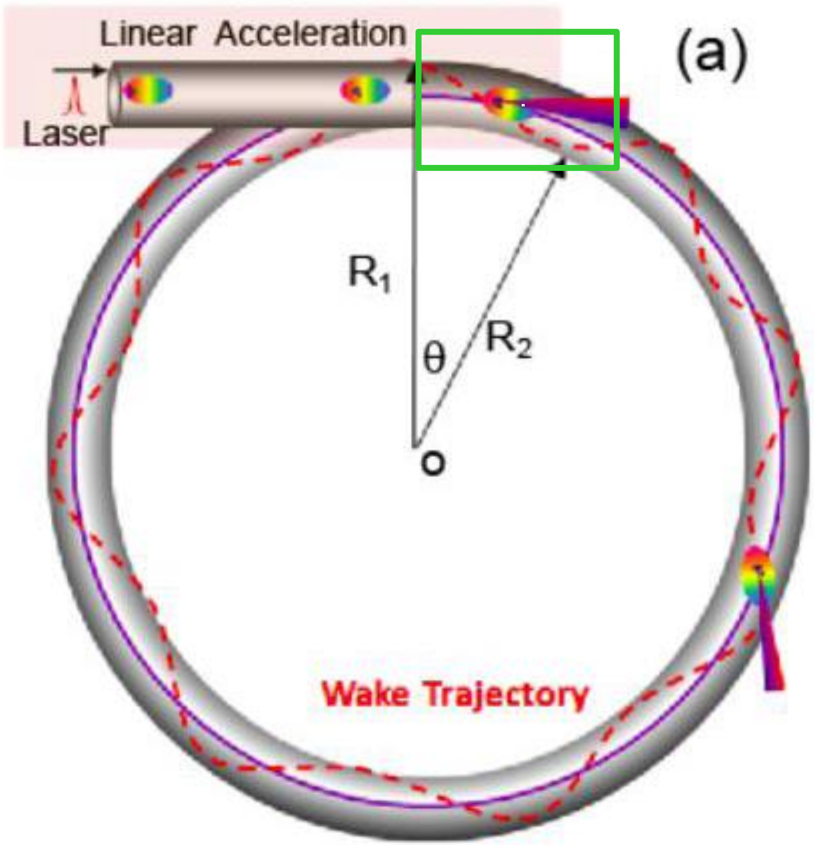
Open questions for simulations

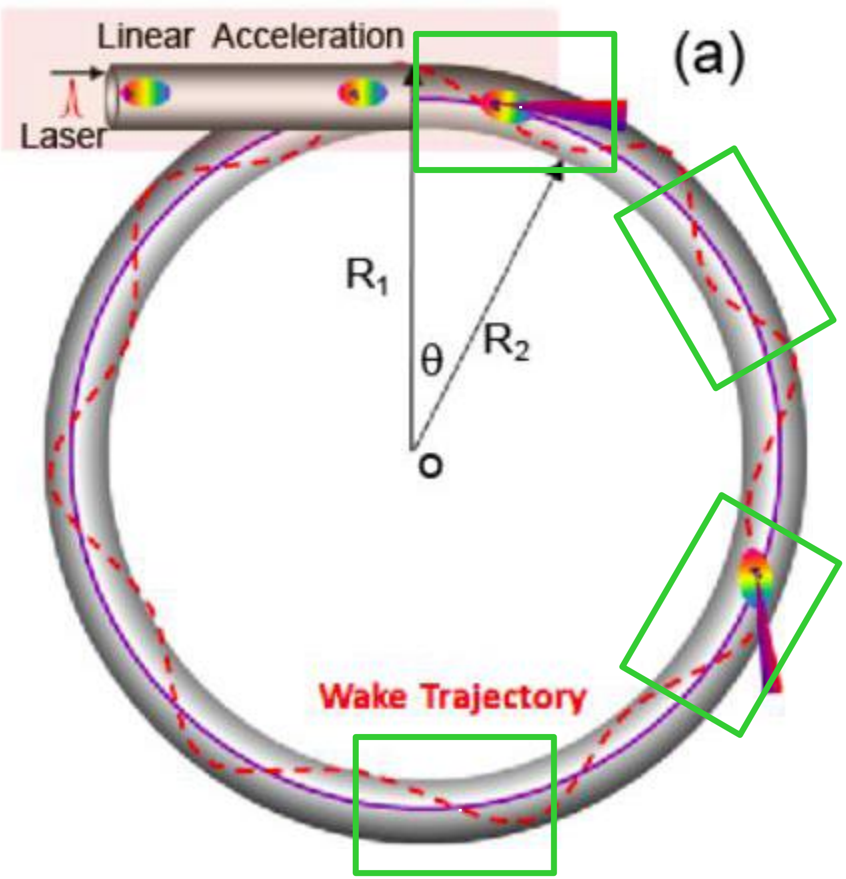


We cannot afford such a large simulation box: diameter 6cm

Too big transverse size and only half circle simulation.

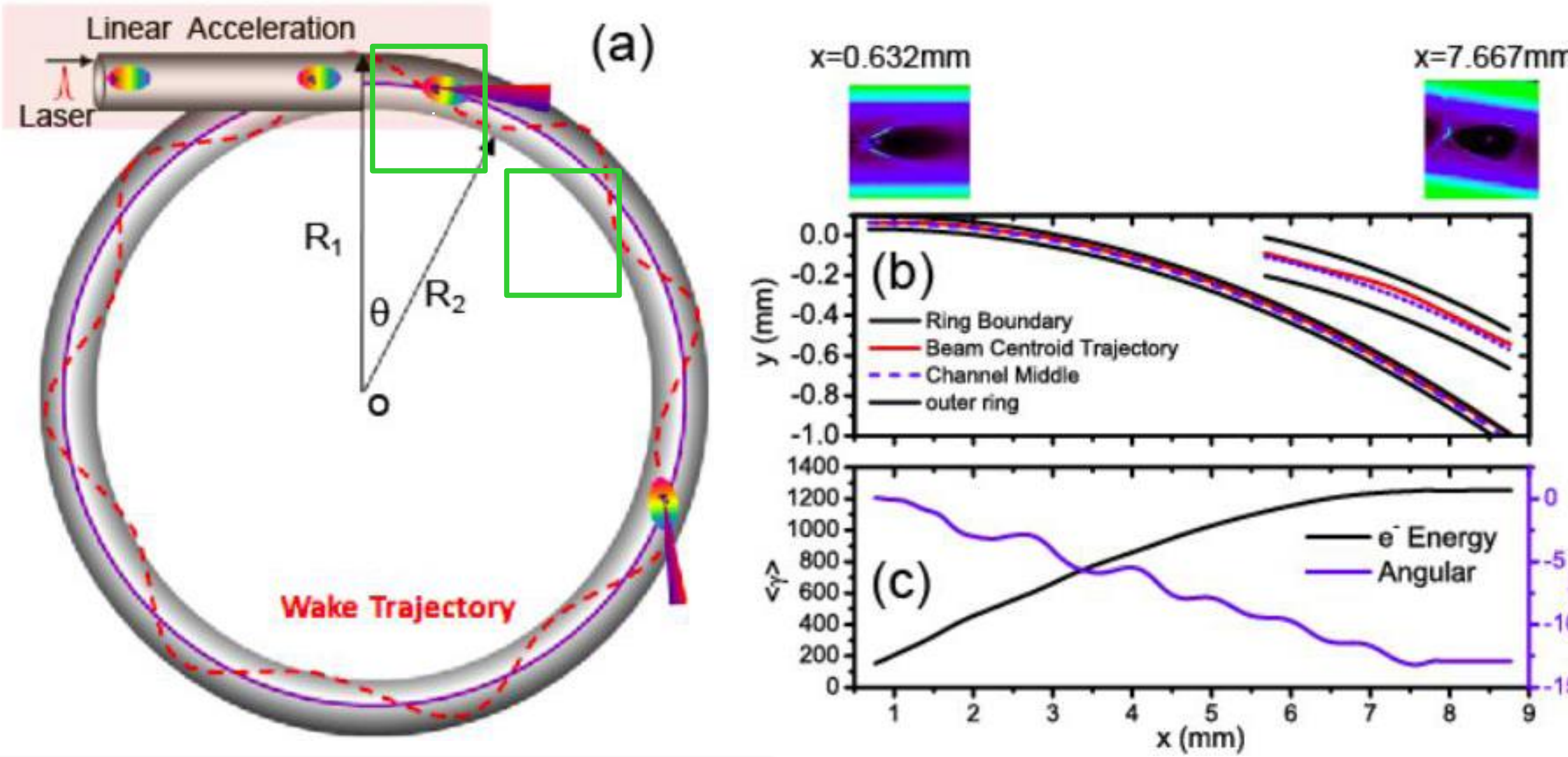
For the whole ring simulation





Box moving and rotating along the ring trajectory

Initial results for a synchrotron radiation ring

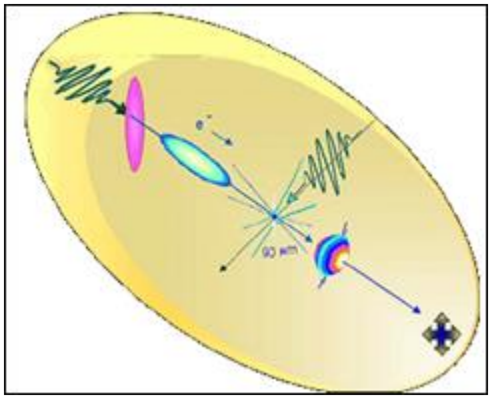


We reduced the transverse box size and used transverse periodic condition both for fields and particle motion.
It makes a part of curved plasma simulation affordable and successful.

The critical radiation frequency is about $\omega_c \sim \gamma^3 c/R$. There are $\gamma \simeq 1200$ and $R = 3cm$. This corresponds to the critical photon energy of 7 keV.

Other potential applications

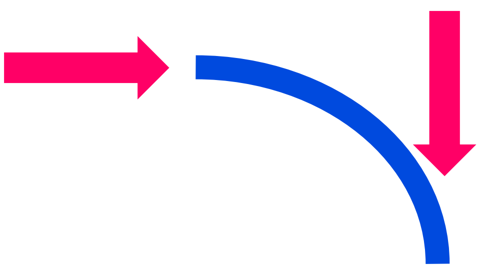
1. Guided laser electron Thomson scattering



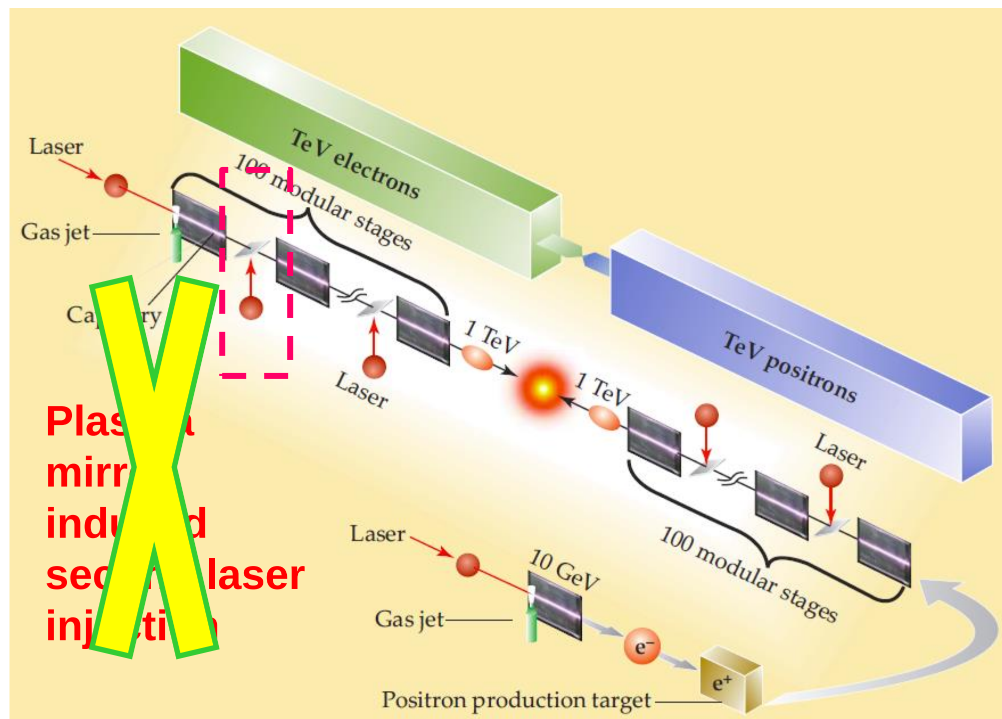
Laser electron beam overlapping in space and time is very difficult!

Using plasma channels!
Wide open channel guiding both of the two lasers and electron beam.

2. Staged acceleration



Second laser



~~Plasma mirror induced second laser injection~~

Summary

- Guided LWFA in plasma channels can be used for both undulator and deflection magnet radiation.
- A palmtop size synchrotron like radiation source is possible by using curved plasma channel.
- Plasma devices (mirror, lens, undulator, bending magnet, …) need to be further developed.

References:
M. Chen *et al.*, arXiv:1503.08311 (2015)
M. Chen et al., accepted by *Light-Science & Applications*.
doi: 10.1038/lsa.2016.15.
Helical plasma undulators, J. Luo *et al*, to be submitted (2015)
Contact information: minchen@sjtu.edu.cn

Thanks for your Attention!