



Inverse Compton scattering via laser wakefield acceleration

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SHANGHAI JIAO TONG UNIVERSITY

Outline

- Introduction
- All-optical Inverse Compton Scattering
- Recent Progress



Introduction



➤ Historically, Both Thomson and Compton are fundamental physics

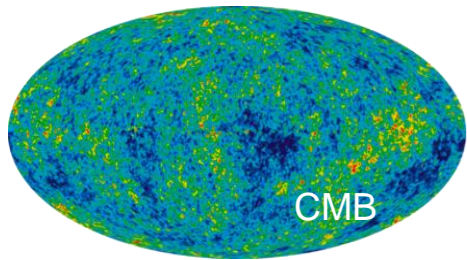


Thomson scattering
Before 1900



Compton scattering
1923

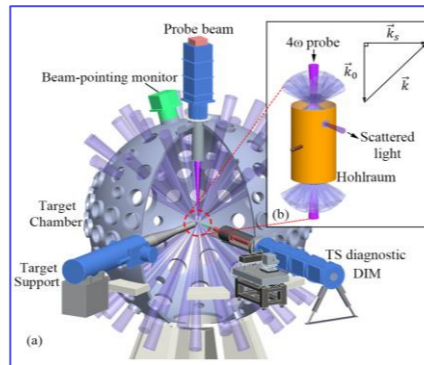
➤ Long-termly, TS and CS are important for fundamental physics and Applications



CMB



Crab Nebula

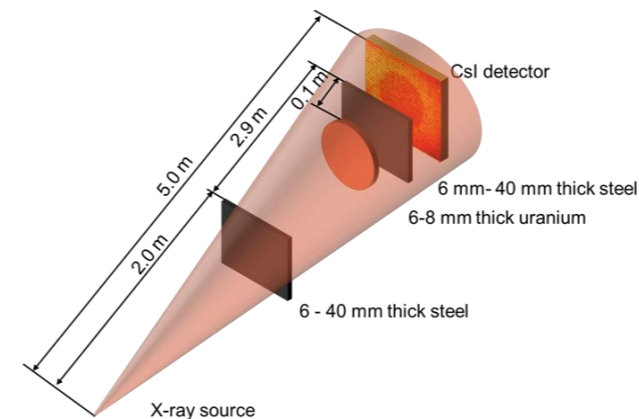


Fundamental Physics → strong interaction

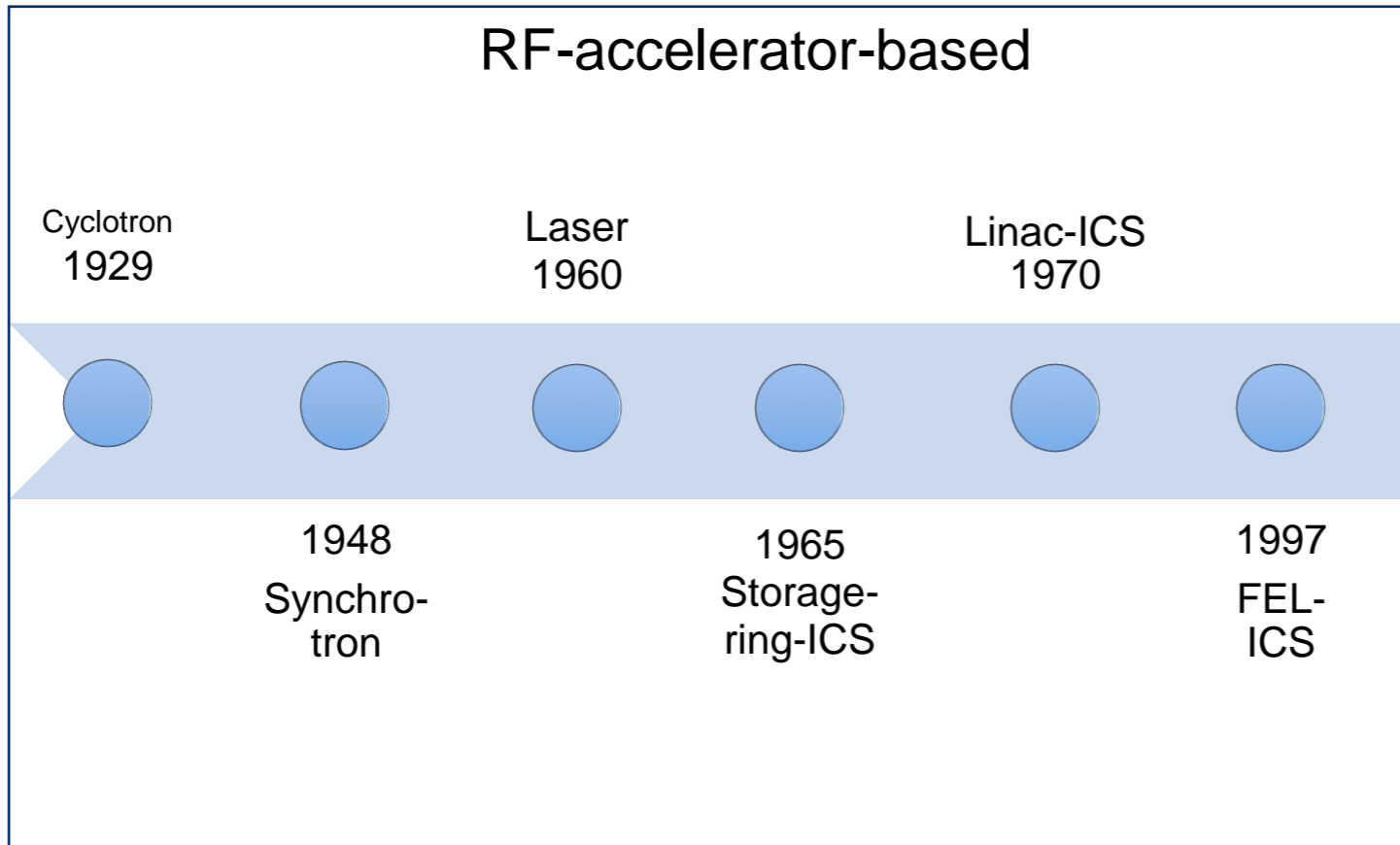
- Cosmic microwave background (CMB) polarization
- Solar k-corona
- Gamma ray from supernovae
- X-ray TS as diagnostics for LPI

Numerous Important Applications → Compact

- Ultra-high field physics
- Ultra-fast science
- Nano-metrology (CD-SAXS)
- Shielded radiography
- Non-destructive evaluation
- Phase-contrast imaging



Development of Laboratory scattering study—ICS



ICS=Inverse Compton Scattering

- Towards Stronger & Compact**
1. **develop ultra-intense laser**
 2. **In an accelerator lab.**

Laser Wake-field Acceleration



High energy electron's in high power laser lab!

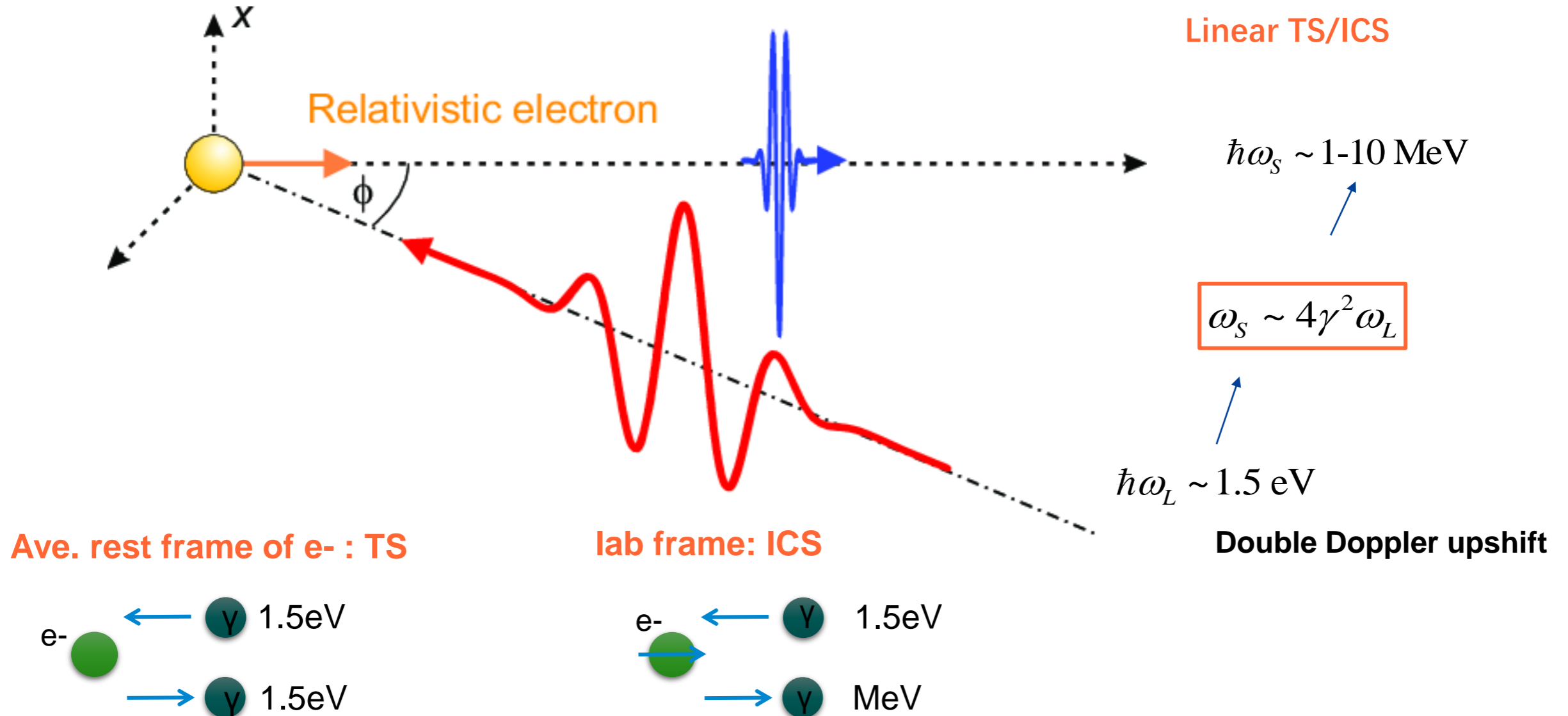
D. Strickland & G. Mourou, *Opt. Comm* (1985)
 T. Tajima & J. Dawson, PRL (1979)

Outline

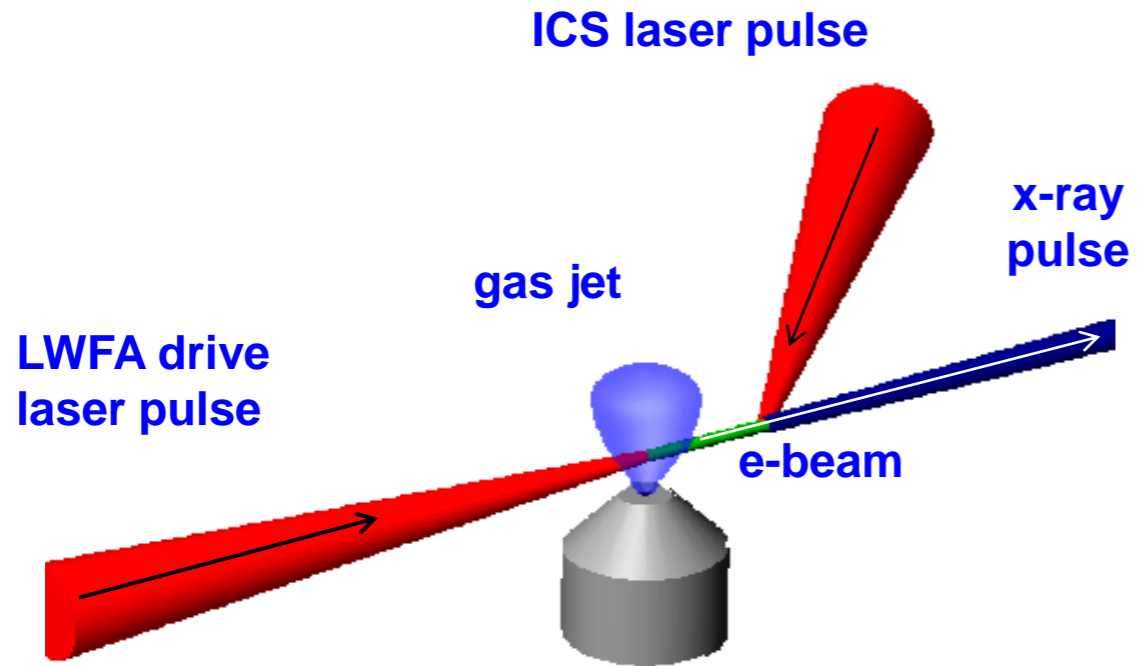
- Introduction
- All-optical Inverse Compton Scattering
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The electron-photon interaction: **Linear regime**



Variable Parameters

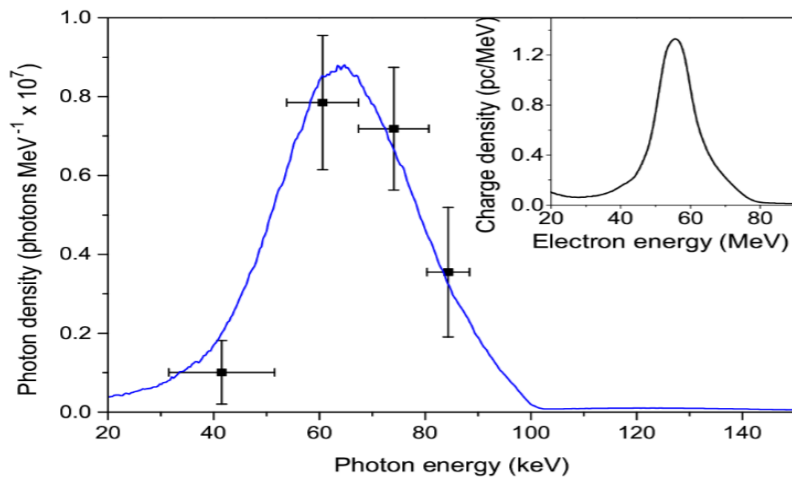
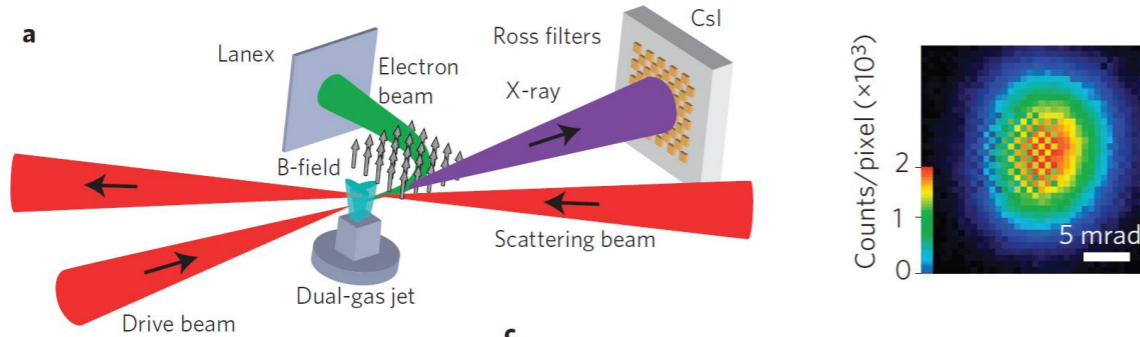


variable controllable parameters :

- **Electron:** energy
- **Laser:** λ , τ , a_0 , more

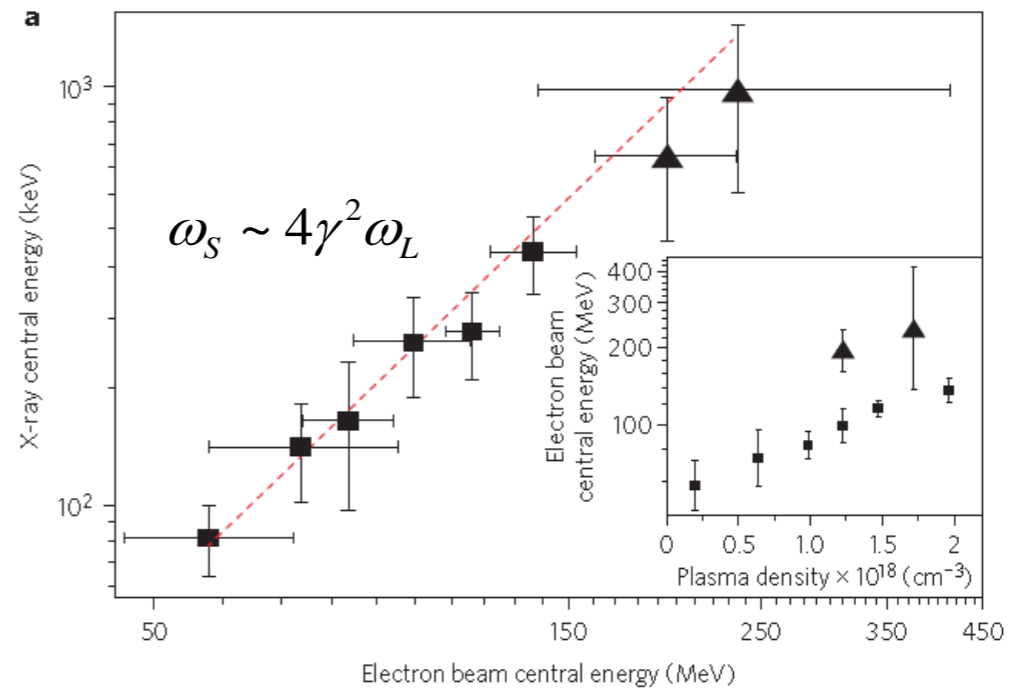
Two-beam configuration: Controlling electron energy

$a_0 \ll 1$
 $I \ll 10^{18} \text{ W/cm}^2$



MeV x-ray source with a peaked spectrum

S. Chen, et al., " *Phys. Rev. Lett.* **110**, 155003 (2013).
 N. Powers et al, " *Nature Photonics* **8**, 28-31 (2014).
 G. Golovin, **W. Yan**, et al *NIMA*, **830** 375-380 (2016)

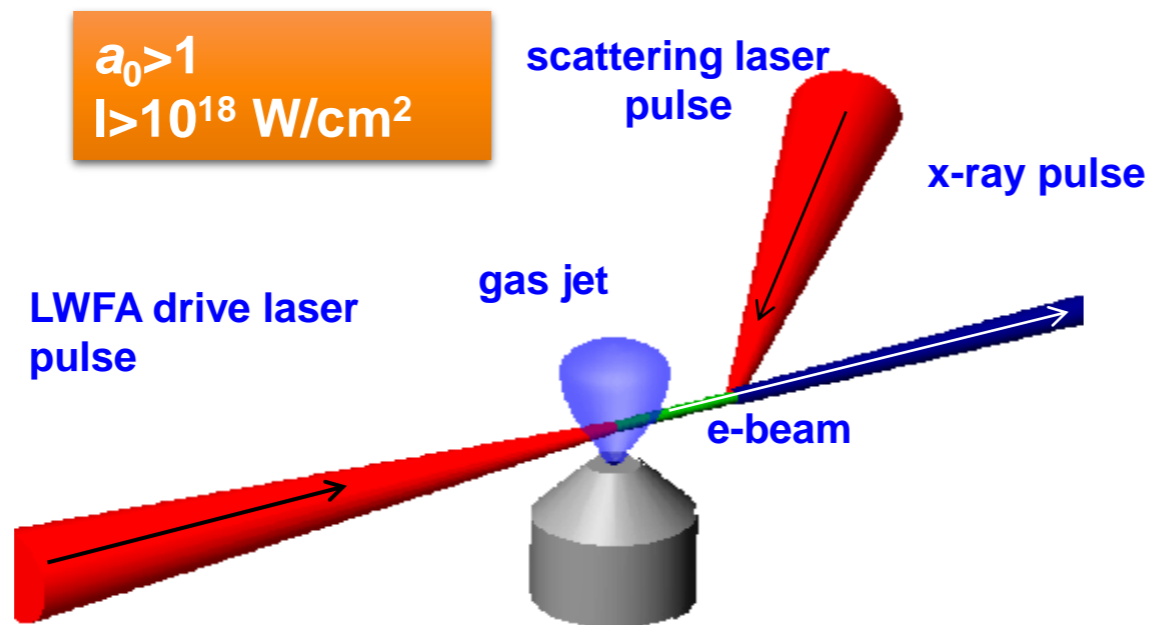


ICS X-ray source

- Collimated
- Narrow bandwidth
- High energy
- Micron source size
- fs pulse duration
- Tunable



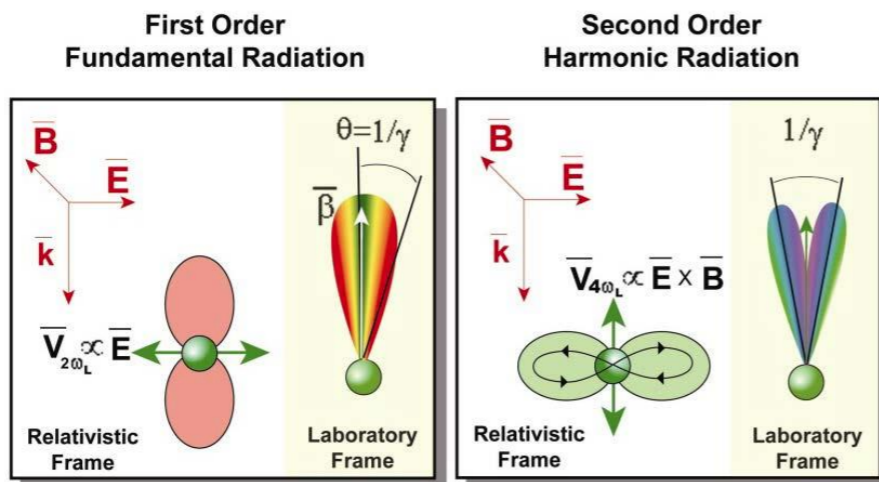
Controlling laser a_0



$$\omega_S \sim 4\gamma^2 \omega_L$$



$$\omega_S \sim n \omega_{\text{Laser}} \frac{2(1 + \beta \cos \theta_I) \gamma^2}{1 + a_0^2/2 + \gamma^2 \theta_0^2}$$



$$\begin{array}{c}
 \theta_x = \frac{1}{\gamma} \\
 \theta_y = \frac{1}{\gamma}
 \end{array}
 \longrightarrow
 \begin{array}{c}
 \theta_x = \frac{a_0}{\gamma} \\
 \theta_y = \frac{1}{\gamma}
 \end{array}$$

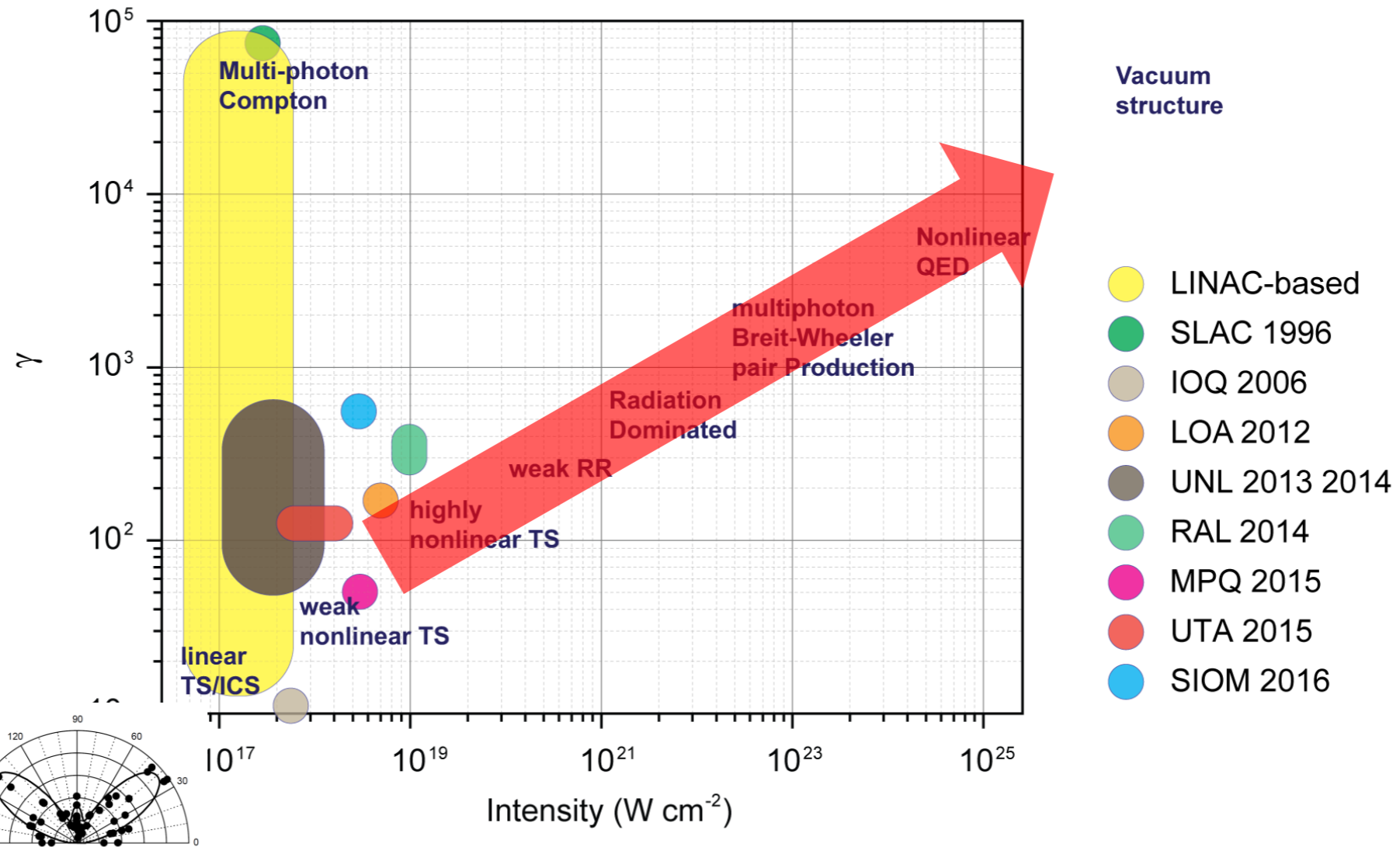
$$a_0 \ll 1$$

$$a_0 \gg 1$$

Radiation angle

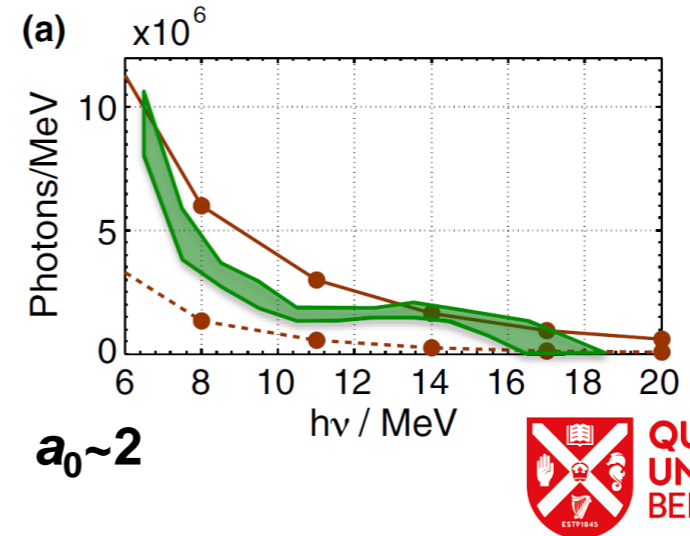
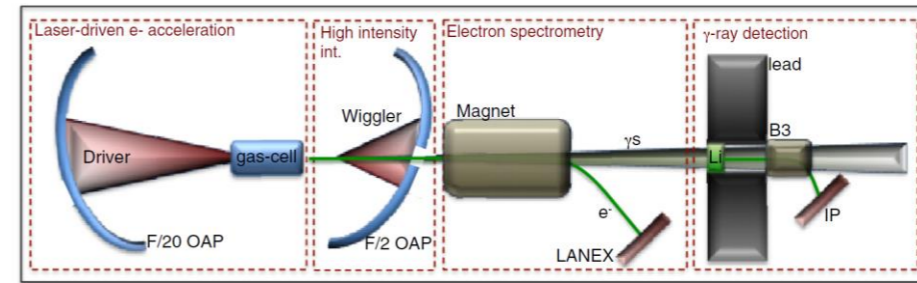
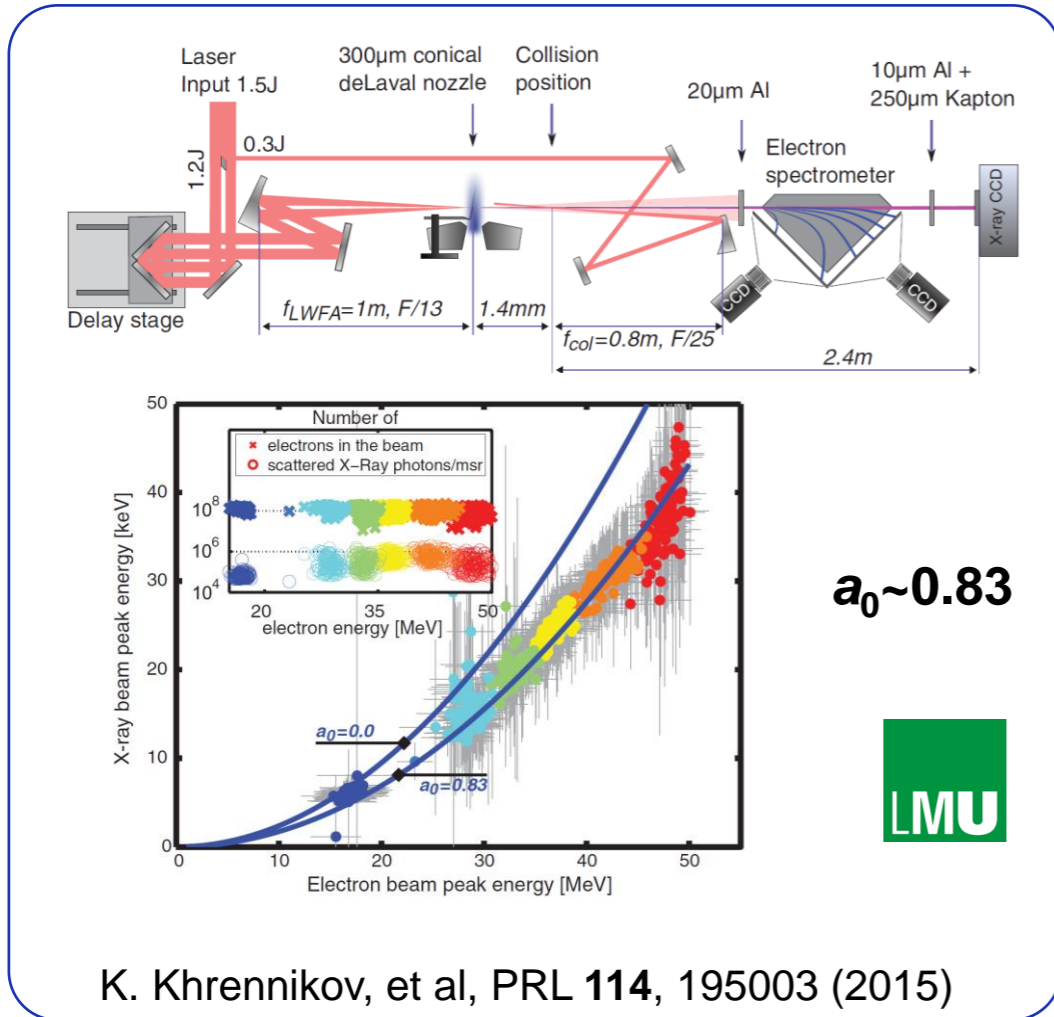
TS/CS in Extreme conditions All-optical ICS x-ray source

Electron-photon interaction



Two-beam configuration: Controlling laser a_0

Moderate Nonlinear regime

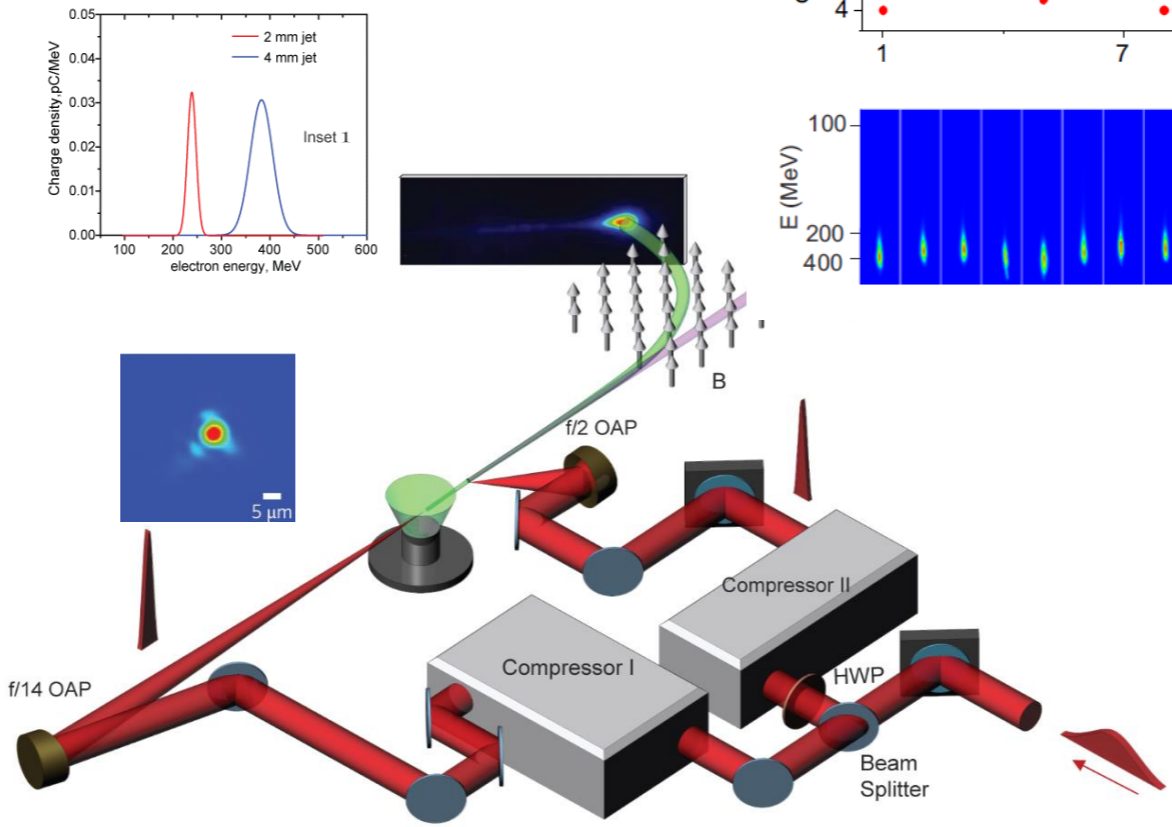
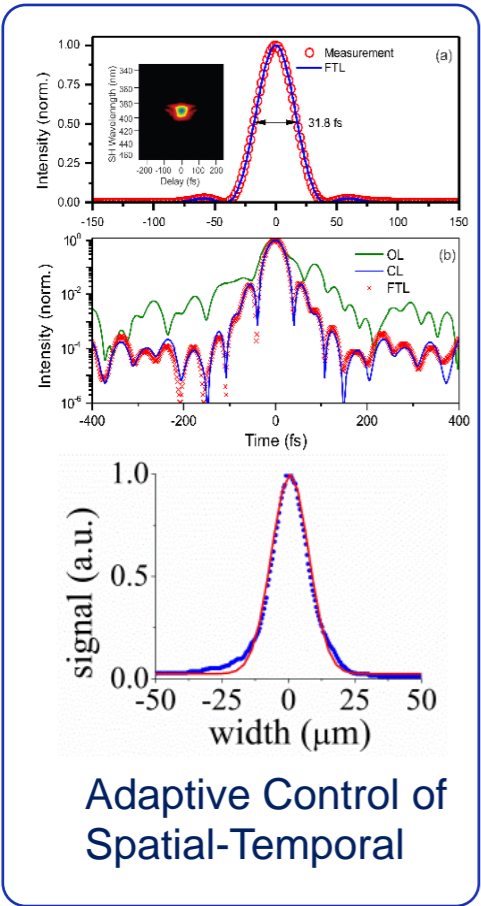


G. Sarri et al, PRL **113**, 224801 (2014)

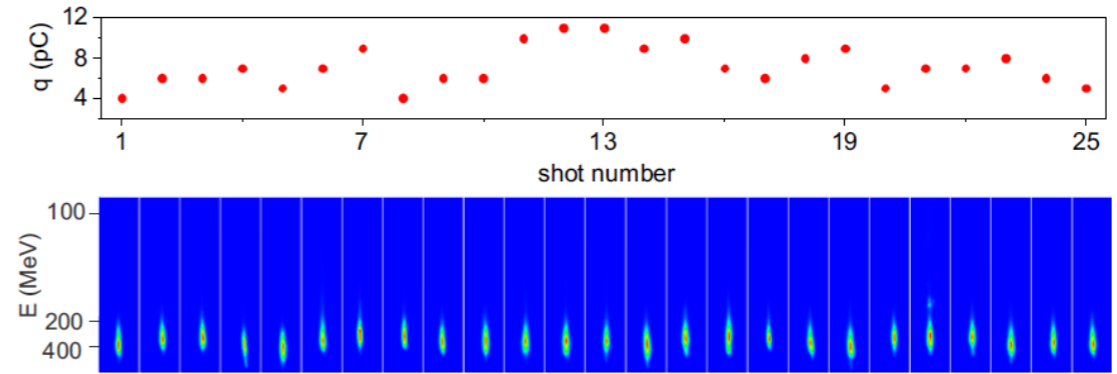
Two-beam configuration: Controlling laser a0



High-order Nonlinear regime



Electron stability



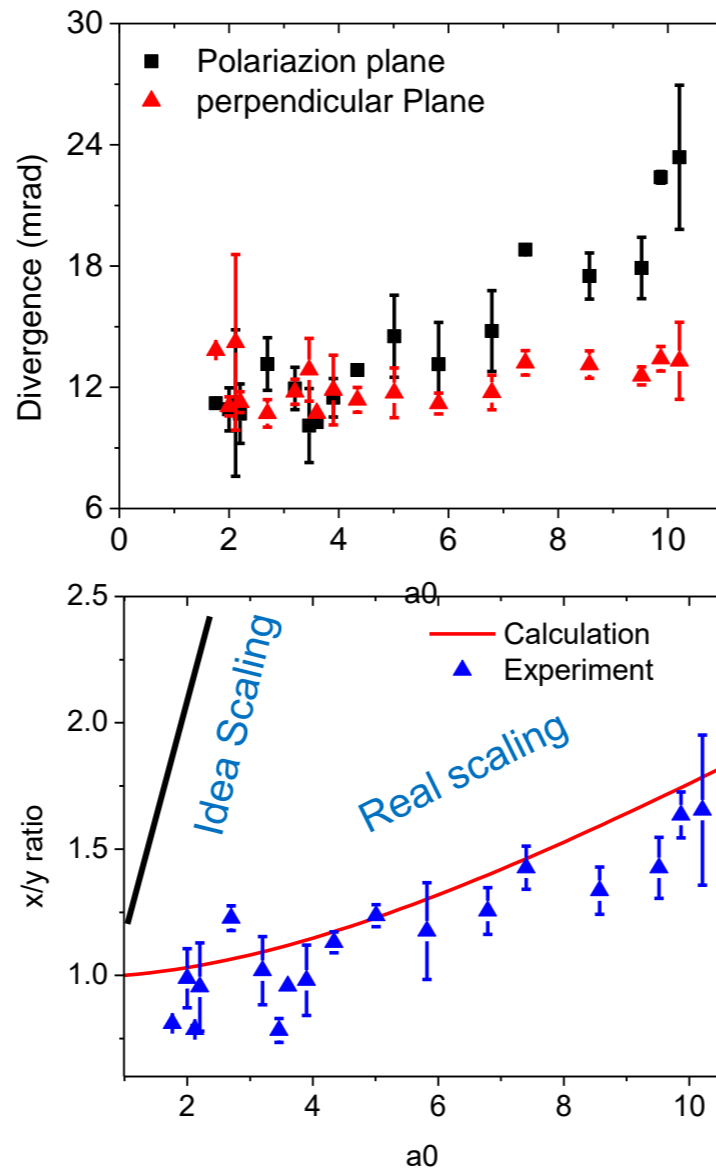
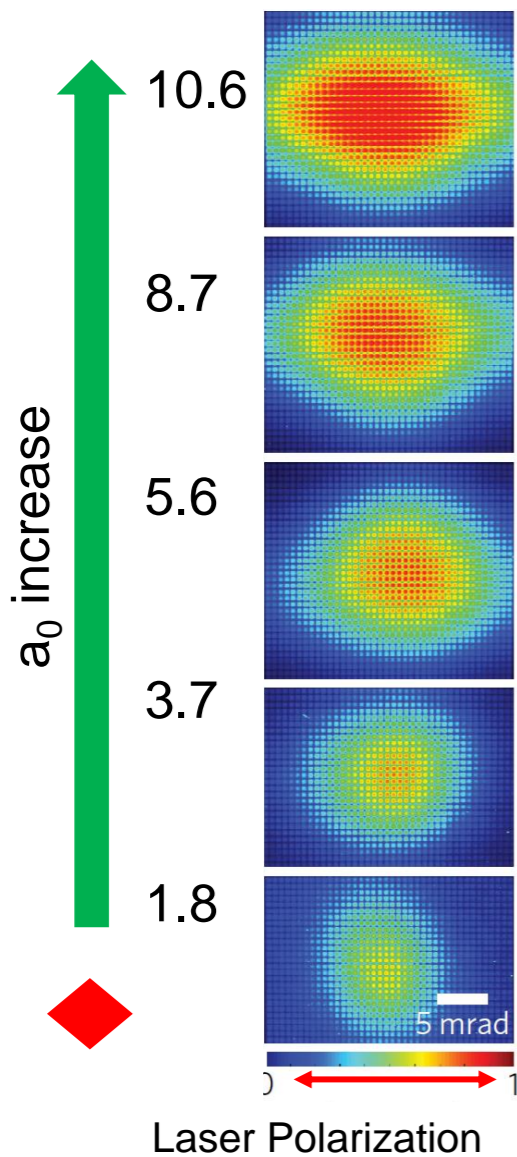
LWFA	
Gas	He
Nozzle	2/4 mm
electron	200 /350 MeV

Scattering laser		
Energy	E_{Lmax}	3 J
Intensity	a_0	1.5~12

W. Yan et al, *Nature Photonics*, **11**, 514. (2017)
 S. Banerjee, et al, PRAB, (2012)
 G. Golovin, W. Yan, et al NIMA, 830 375-380 (2016)



Two-beam configuration: Controlling laser a_0



Experimental parameters	
Electron	200 MeV e-
Scater	a_0 : 1.5 ~ 12

$$\theta_x = \frac{a_0}{\gamma} \Rightarrow \theta_x = \sqrt{\frac{a_0^2}{\gamma^2} + \theta_e^2}$$

$$\theta_y = \frac{1}{\gamma} \Rightarrow \theta_y = \sqrt{\frac{1}{\gamma^2} + \theta_e^2}$$

- Electron oscillation in the P plane getting larger with increase a_0 .
- **Confirmed $a_0 > 10$**

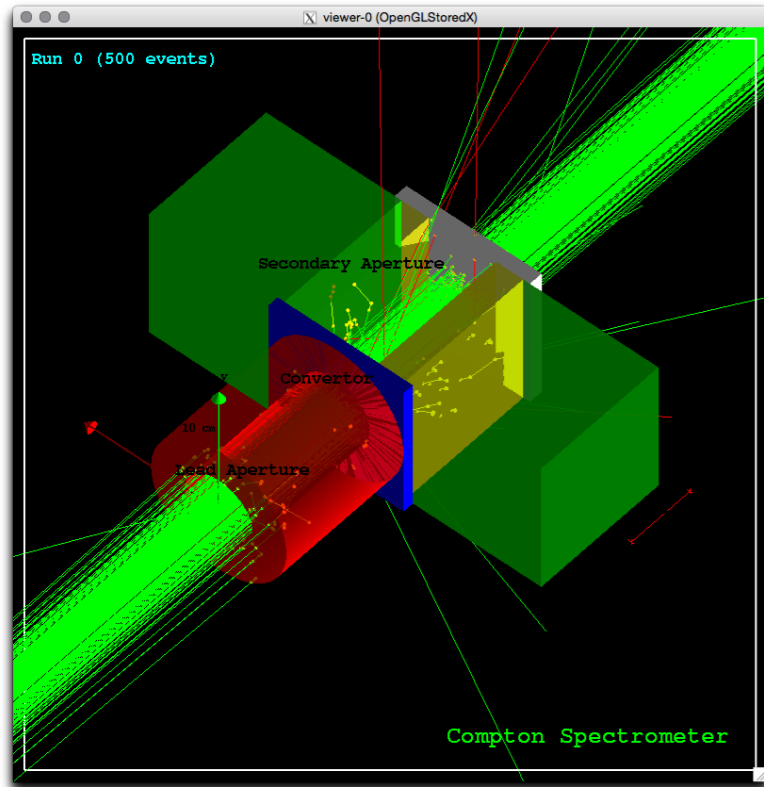
W. Yan et al, *Nature Photonics*, 11, 514. (2017)



Two-beam configuration: Controlling laser a_0

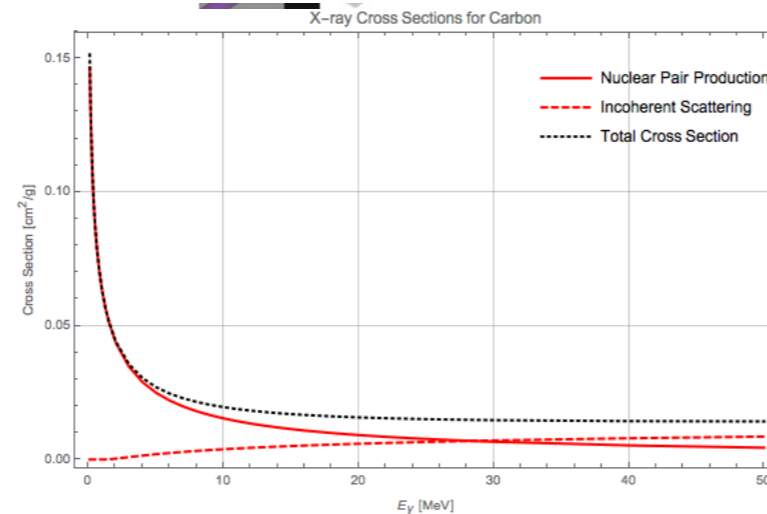
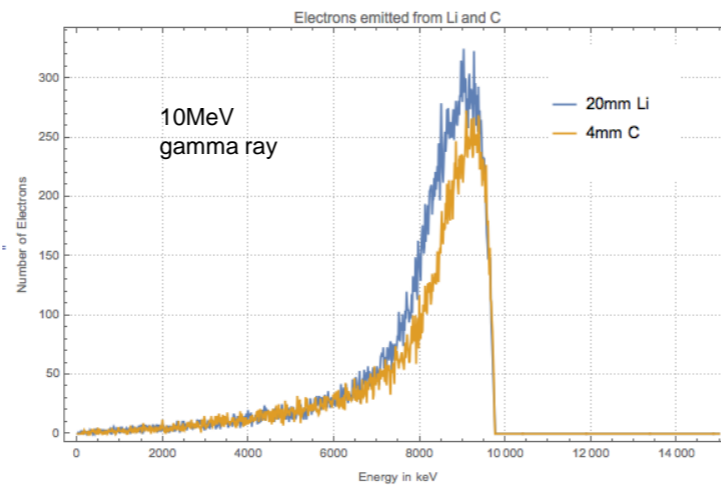


X-ray spectrum measurement

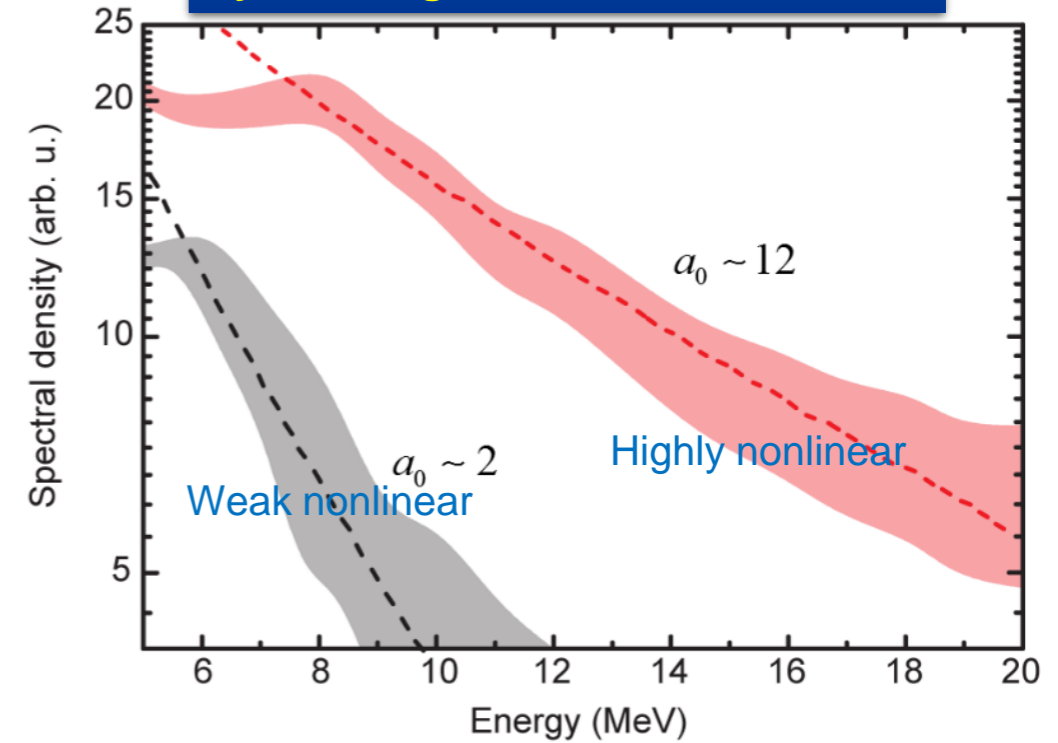


Geant4 Simulation

1. W. Yan et al, *Nature Photonics*, **11**, 514. (2017)
2. D. Haden, W. Yan, et al *RSI* (2019)



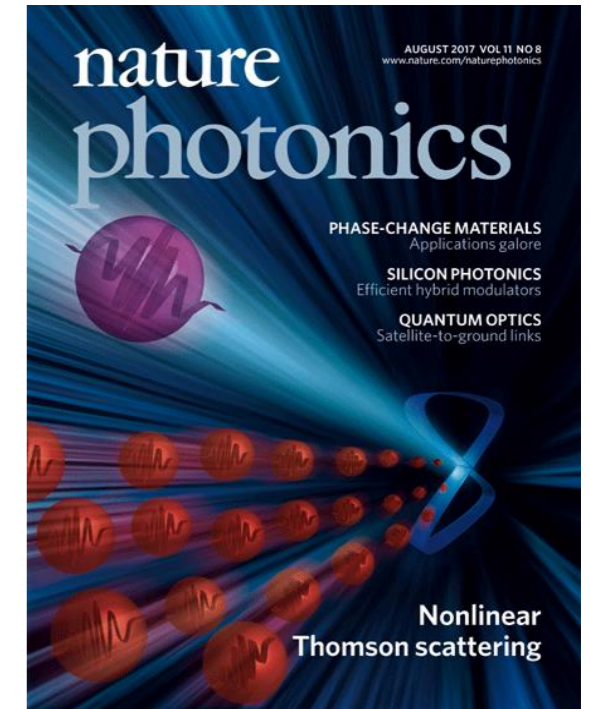
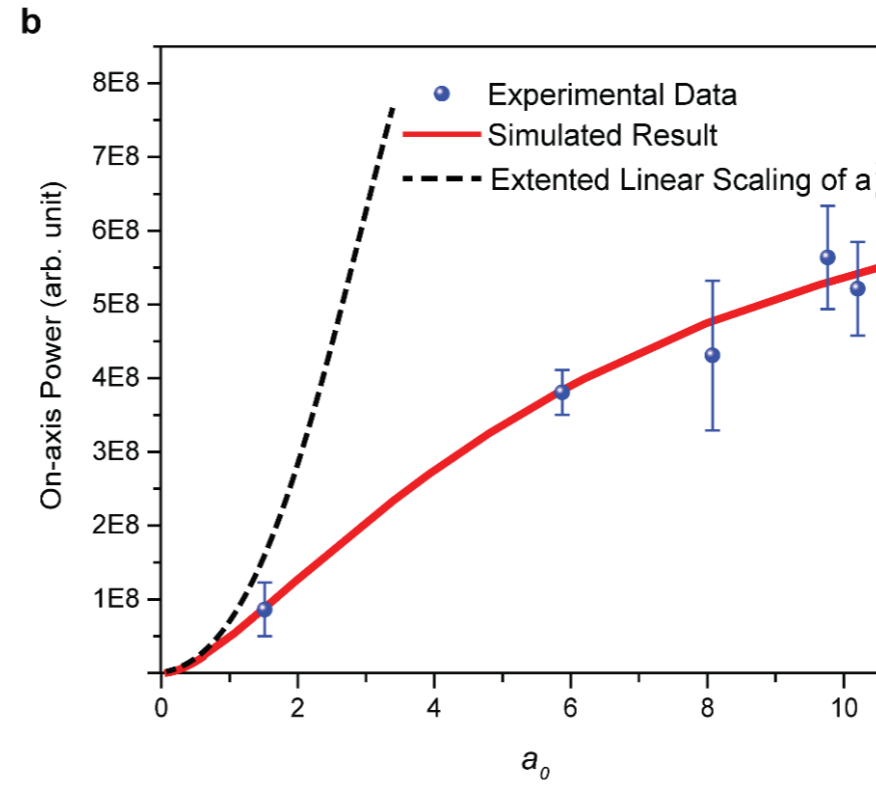
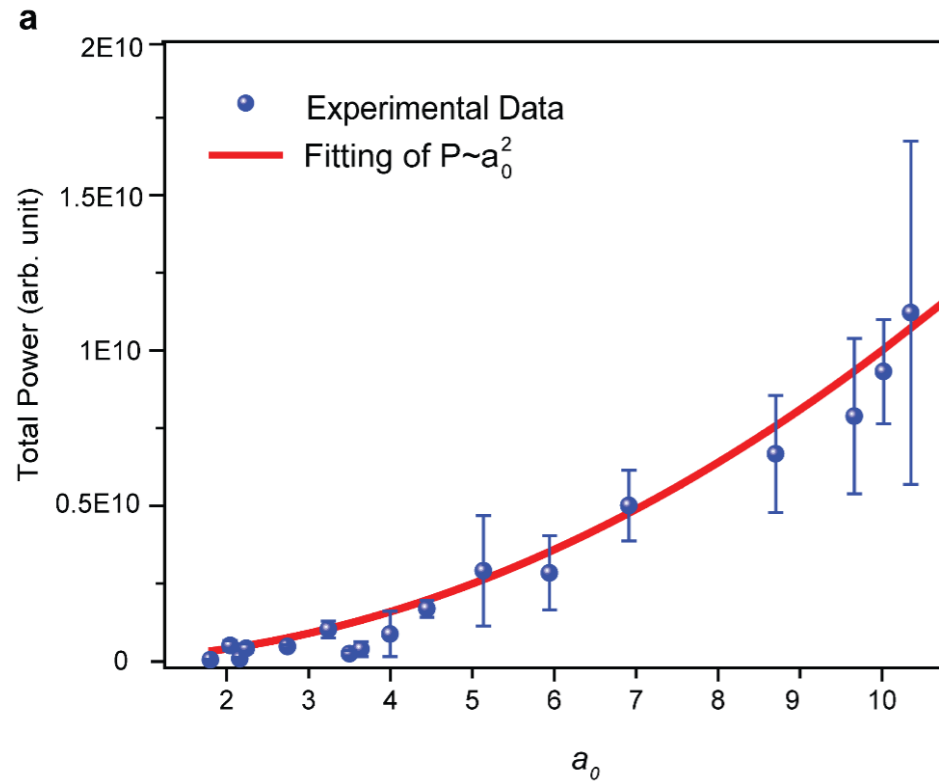
Observation 500 photons scattered by one single electron via HMTS



X-ray spectrum

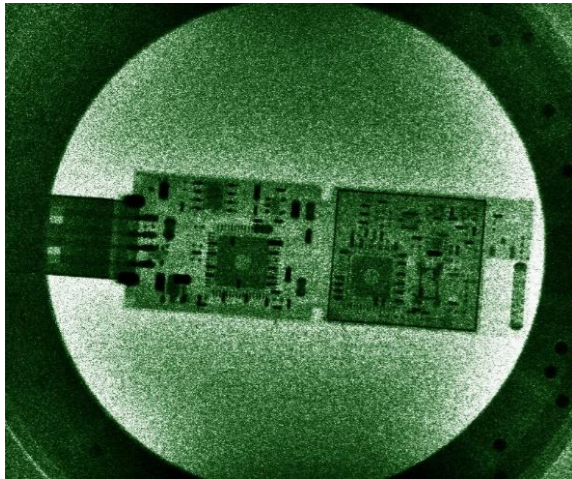
$$\omega_S \sim 4\gamma^2 \omega_L \implies \sim n \omega_{\text{Laser}} \frac{2(1 + \beta \cos \theta_I) \gamma^2}{1 + a_0^2/2 + \gamma^2 \theta_0^2}$$

Nonlinear scaling law of total power



Applications of all-optical ICS

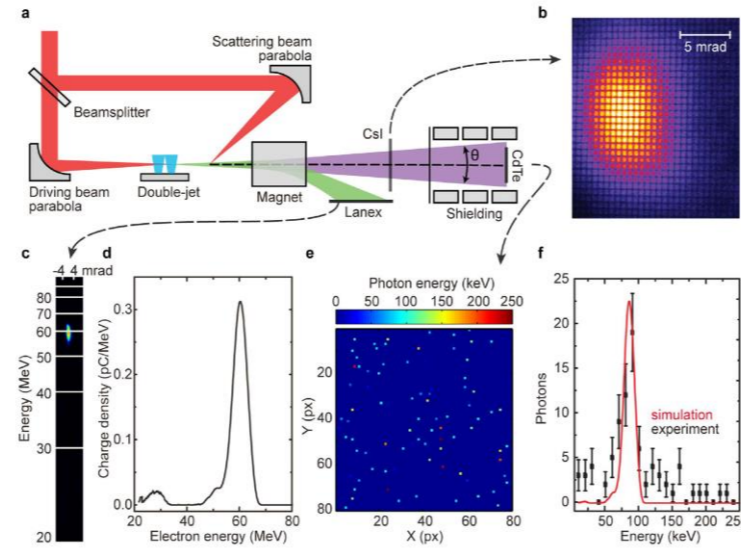
As light source



X-ray source size
= $4 \pm 1 \text{ \mu m}$ (RMS)

S. Chen et al., NIMB (2016).

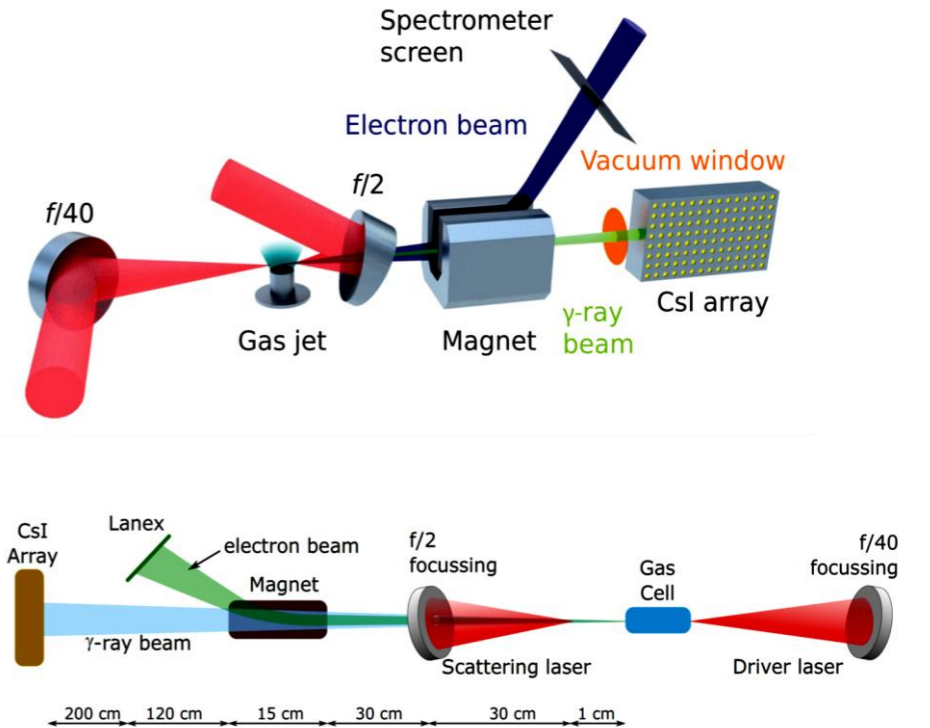
As Diagnostics



Intrinsic LWFA beam emittance
of measured via ICS

G. Golovin et al scientific Reports 6, 24622 (2016)

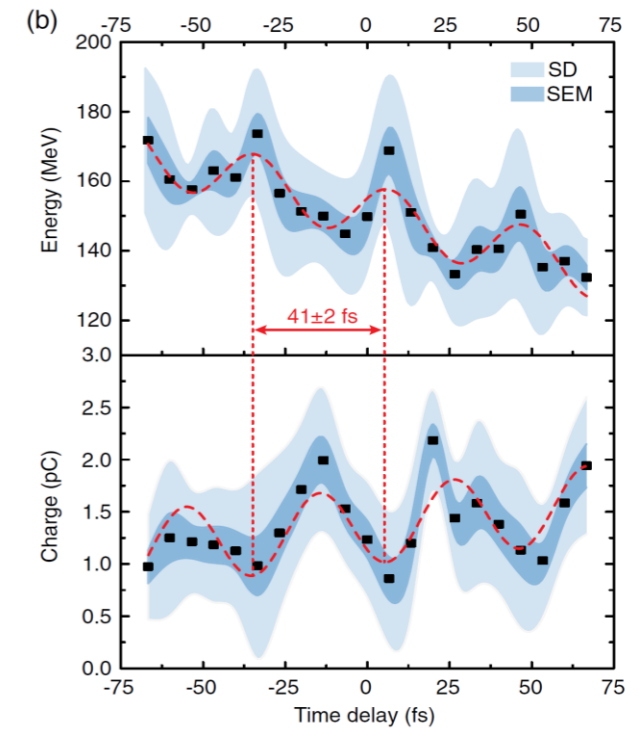
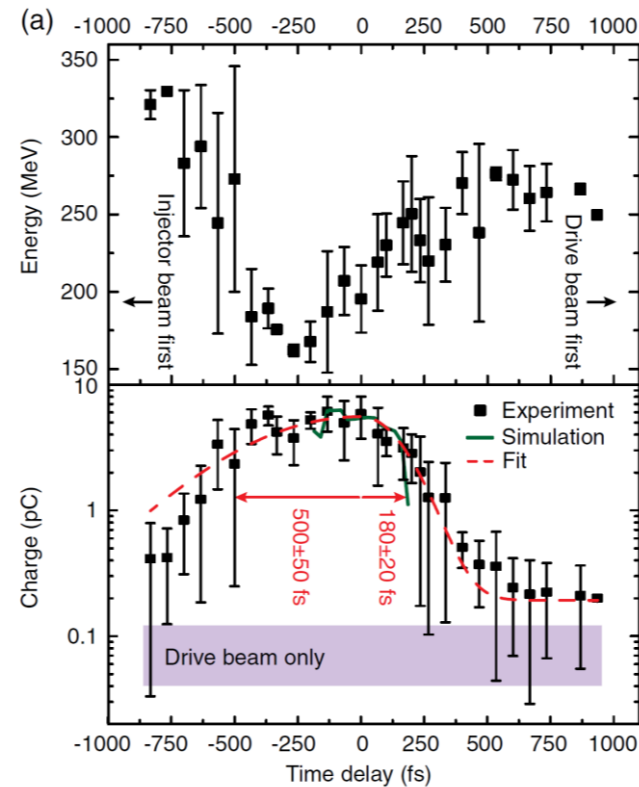
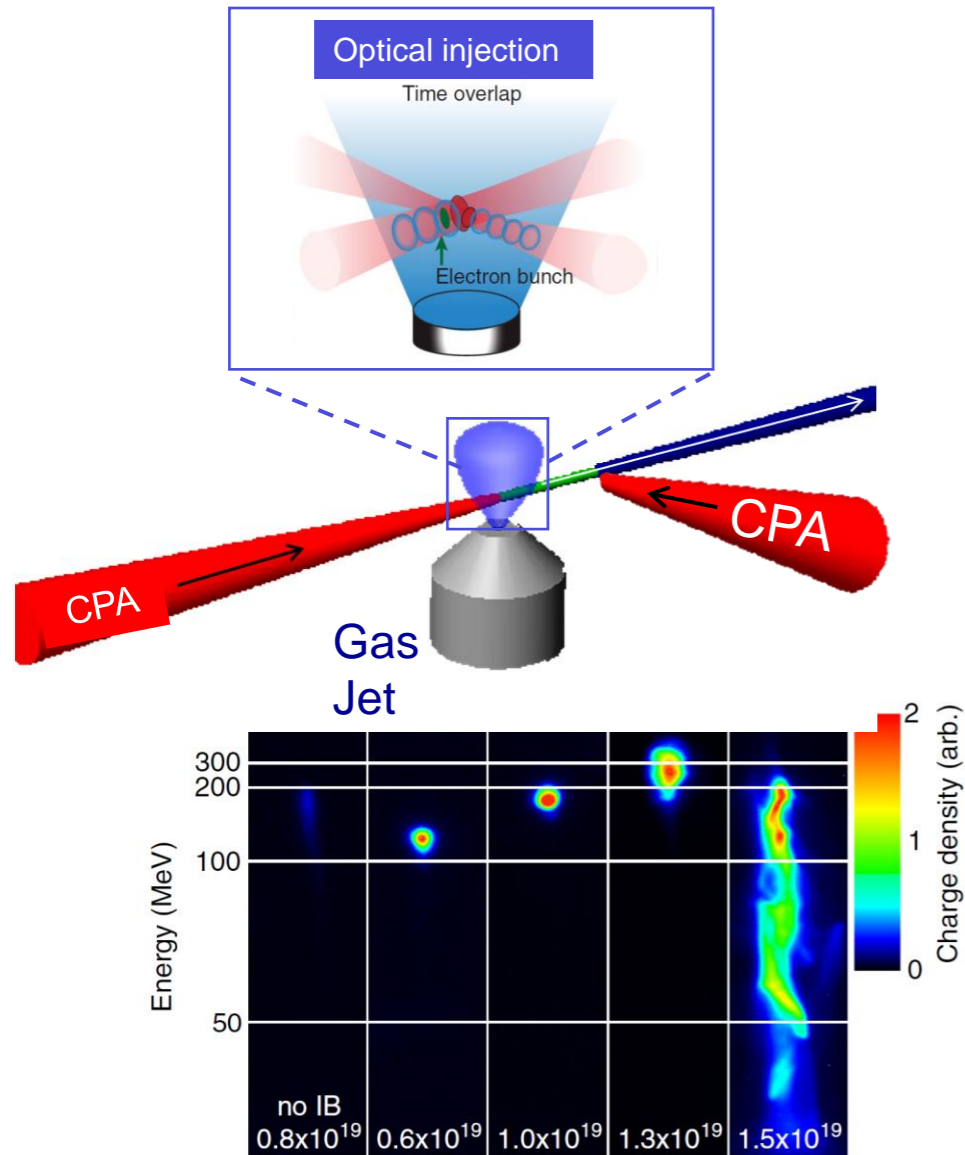
For fundamental study



Poder et al PRX 2018
Cole et al. PRX 2018



Bonus As a platform : optical injection



Injection mechanisms of ponderomotive drift and wake wake interference is tested in the experiments

G. Golovin, **W. Yan** et al, PRL, 121, 104801 (2018)

G Golovin, V Horný, **W Yan**, et al, PoP 27 (3), 033105 (2020)

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- Recent Progress





Facility (I) SJTU



New Building for IFSA center

- Laser will be updated to 200TW+300 TW with fs synchronization ability

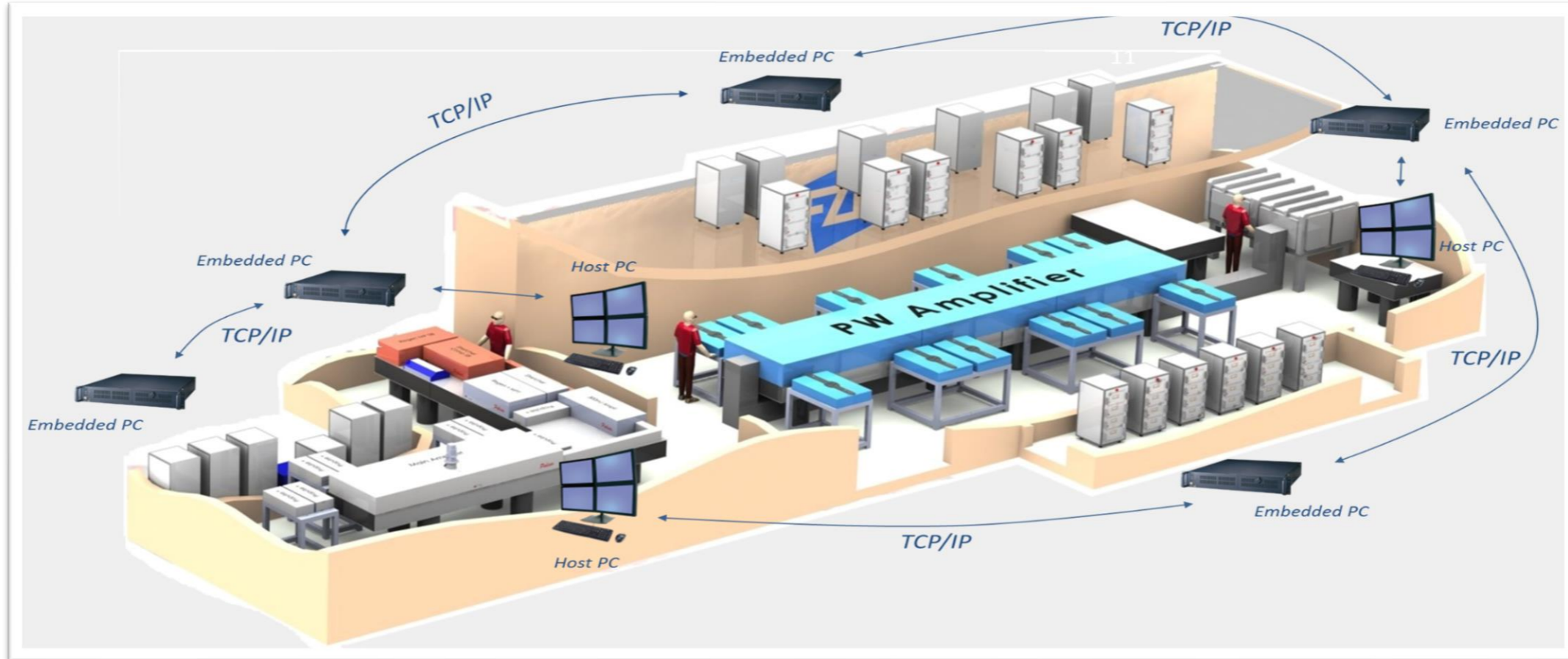




Facility (II) TDLI institute & SJTU



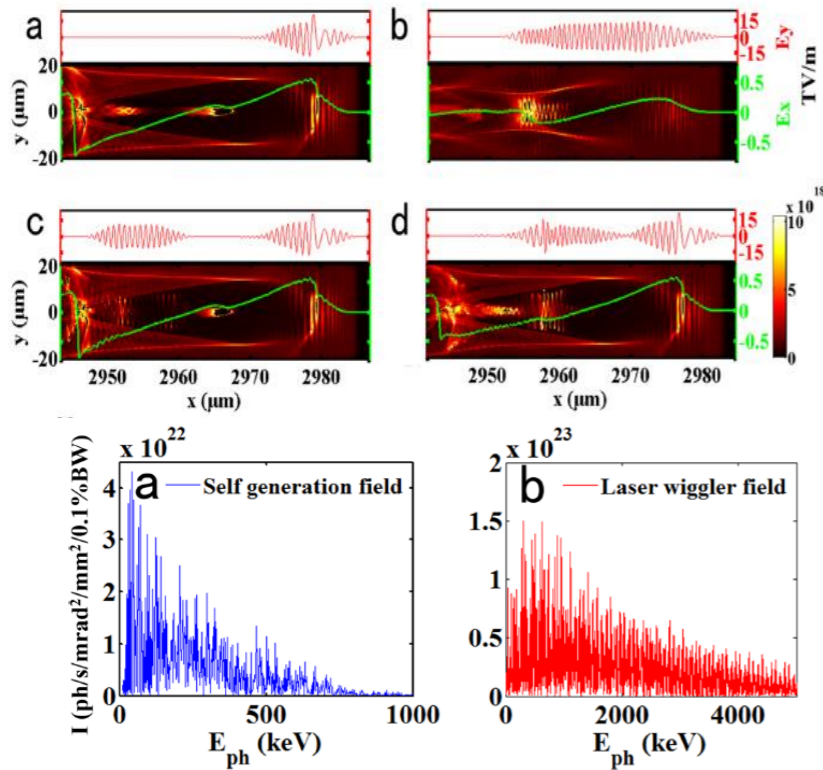
Lab-Astrophysics platform: QED, nuclear astrophysics etc



Two beam betatron radiation



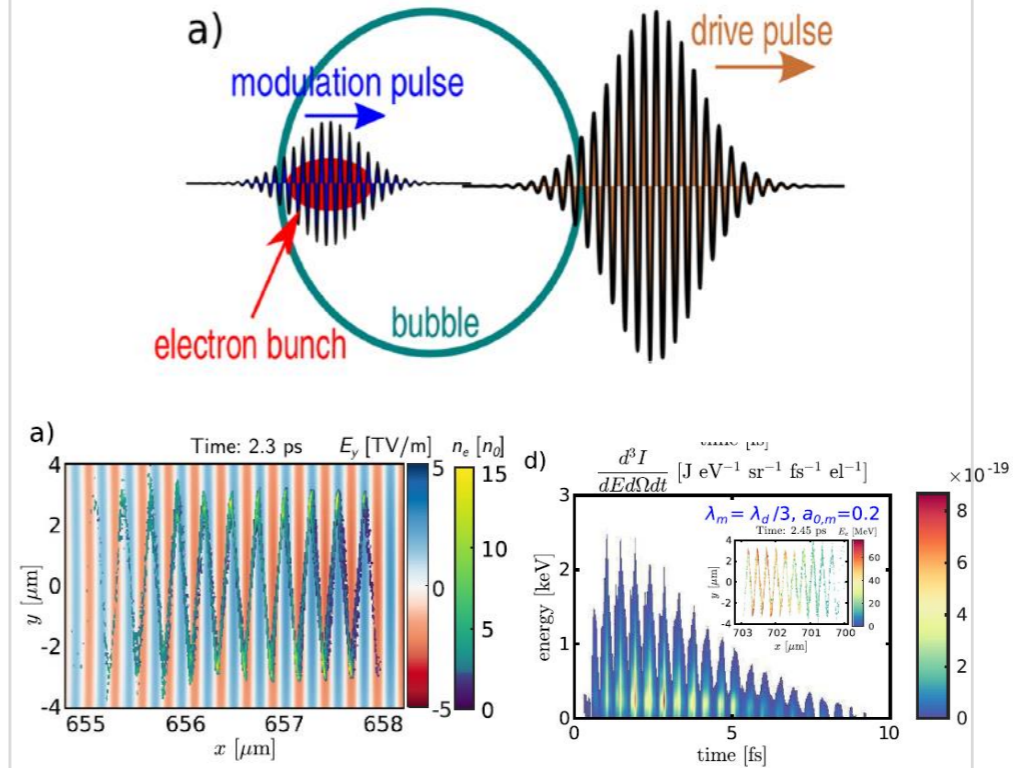
Betatron radiation enhancement



- ☆ enhancement on the betatron radiation
- ☆ $B \sim 1.2 \times 10^{23}$ ph/s/mrad²/mm²/0.1%BW (1MeV)

Scientific reports 9(1): 2531 (2019)

Attosecond Betatron pulse train



Scientific Reports 10:15074(2020)

Collaborators



University of Nebraska, Lincoln



ELI-Beamlines



Xi'an Jiao Tong University



Chinese Academy of Sciences



FZU, CAS

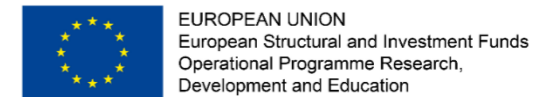


Università degli Studi di Milano



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Acknowledgements



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Development and Education



MINISTRY OF EDUCATION,
YOUTH AND SPORTS

Thank You!



Postdoc Positions Opening:
LWFA&Rad, QED, Nuclear Physics,
Low-dose Ghost Image

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