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High-brightness Radiation Enabled by Dielectric Laser Accelerator

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OUTLINE

1. Dielectric laser accelerator (DLA)

2. Short-bunch radiation

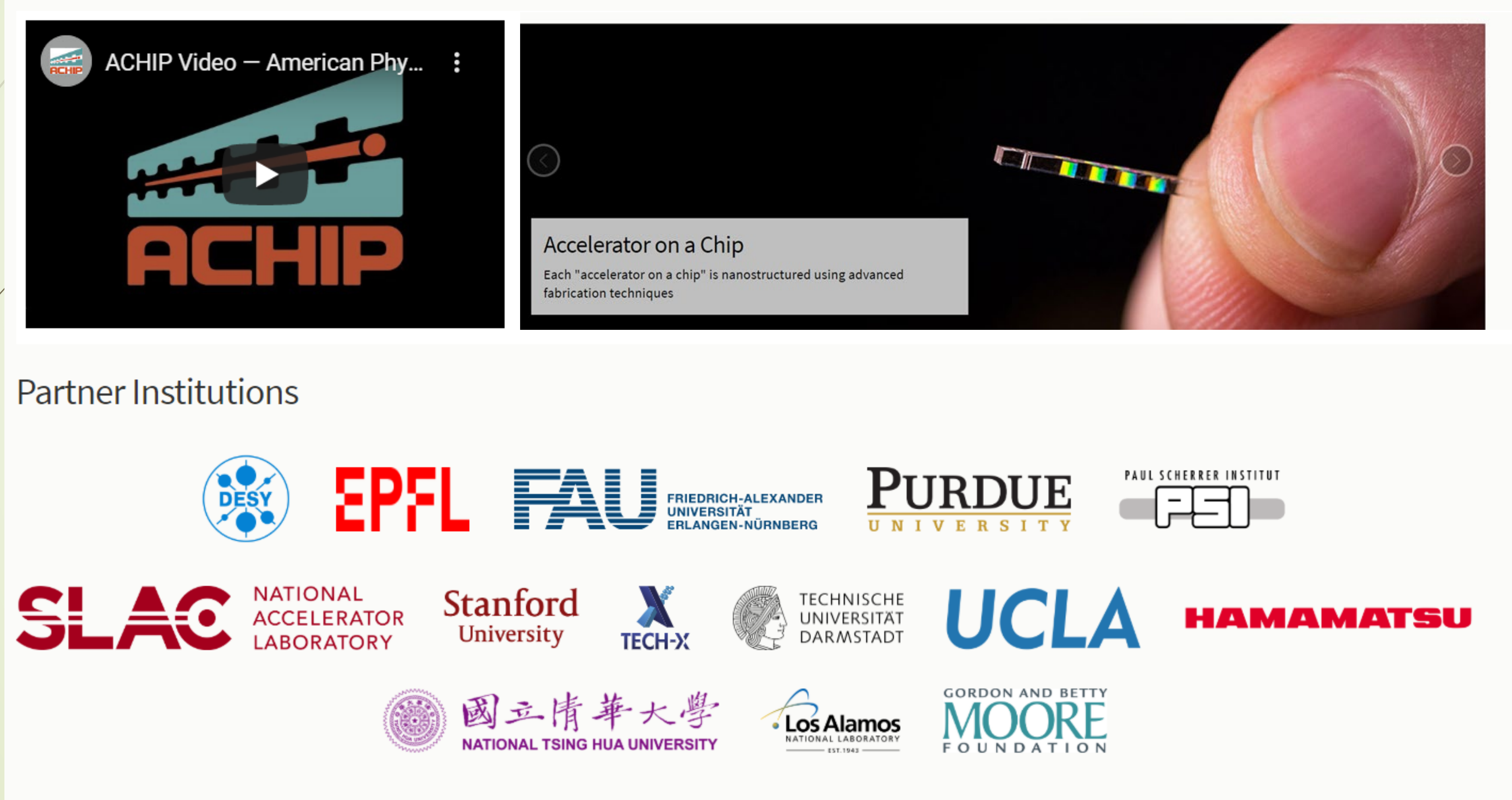
3. Brilliance of DLA-driven coherent undulator radiation

4. Conclusions

Accelerator on a Chip (ACHIP)

https://achip.stanford.edu/

- Direct-field acceleration
- High laser damage resistance on dielectric



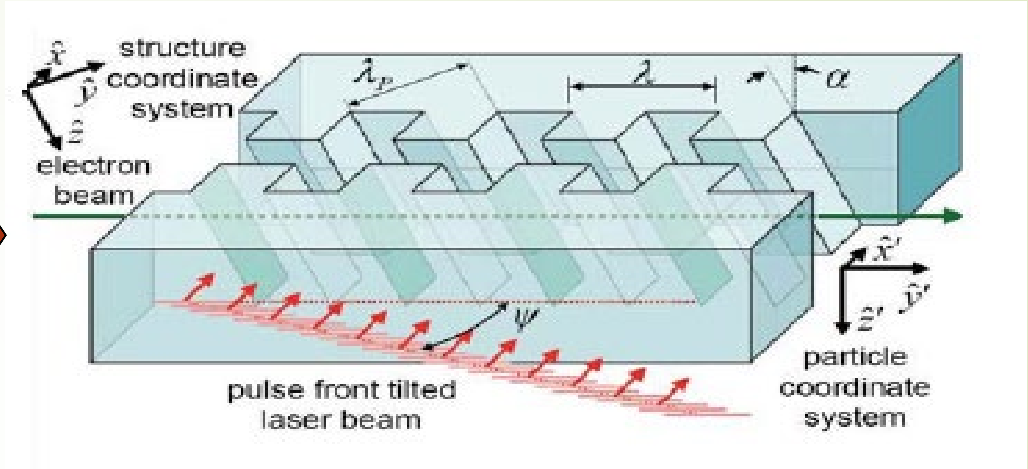
Envisaged DLA-driven Coherent Undulator Radiation

Dielectric laser accelerator (DLA)

~50 cm (GeV/m)

electron bunch length ~ 1 nm
Bunch Charge = ~ 1 fC
Gamma = ~500 MeV

Dielectric undulator



T. Plettner, R. L. Byer, Phys. Rev. ST Accel. Beams **11**, 030704 (2008).

100 cm

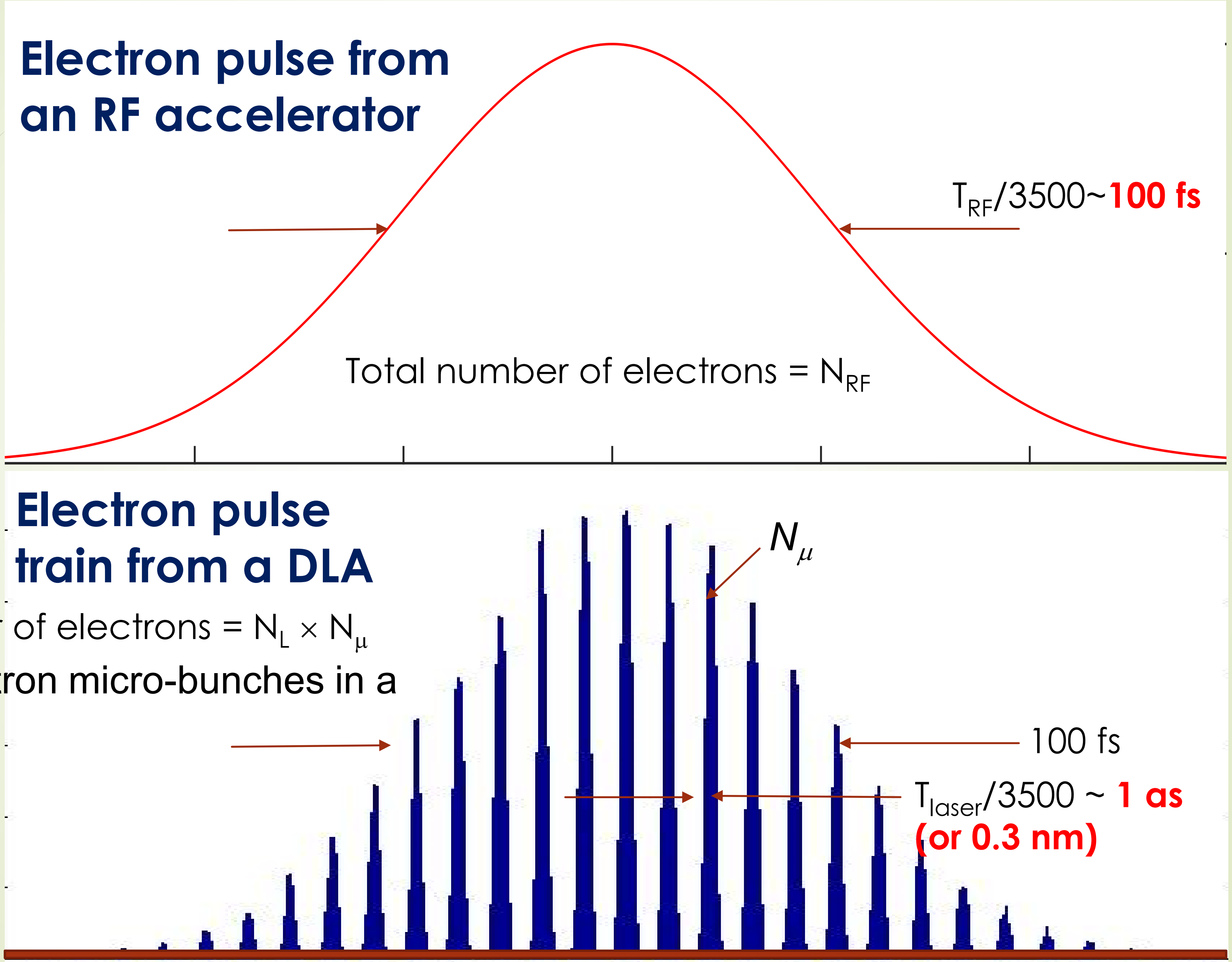
λ_u = 1 mm (N_u = 1000)

B_{peak} = 3 T (subject to laser damage)

a_u = ~0.22 (undulator parameter)

***good scheme to keep a_u for small λ_u**

Pulse structures from DLA vs. RF Accelerator



Total number of electrons = $N_L \times N_\mu$

N_L: # of electron micro-bunches in a laser pulse

Short-bunch enhanced radiation - superradiance

Total radiation Spectral Energy in one driver laser pulse $W_N = N_L \boxed{[N_\mu + N_\mu (N_\mu - 1) b^2(\omega)] W_1}$

$W_{1,N}$ radiation spectral energy of 1 & N electrons

$b(\omega)$: bunching factor, Fourier transform of the micro-bunch profile

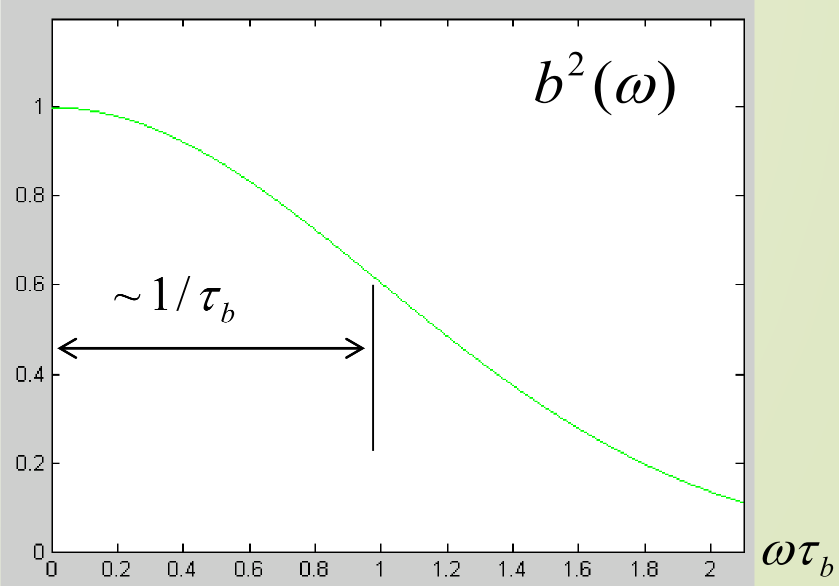
N_μ: # of electrons in a DLA micro-bunch

N_L: # of micro-bunches in a driver-laser pulse

$N_L \times N_\mu$: total number of electrons in a driver laser pulse

For Gaussian bunch $f(t) = \dfrac{\exp\left(-t^2 / 2\tau_b^2\right)}{\sqrt{2\pi}\tau_b}$

$$\Rightarrow \quad b(\omega) = \exp\left(-\frac{\omega^2 \tau_b^2}{2}\right)$$



Brilliance of undulator radiation

photons/s/mm²/mrad²/0.1%BW

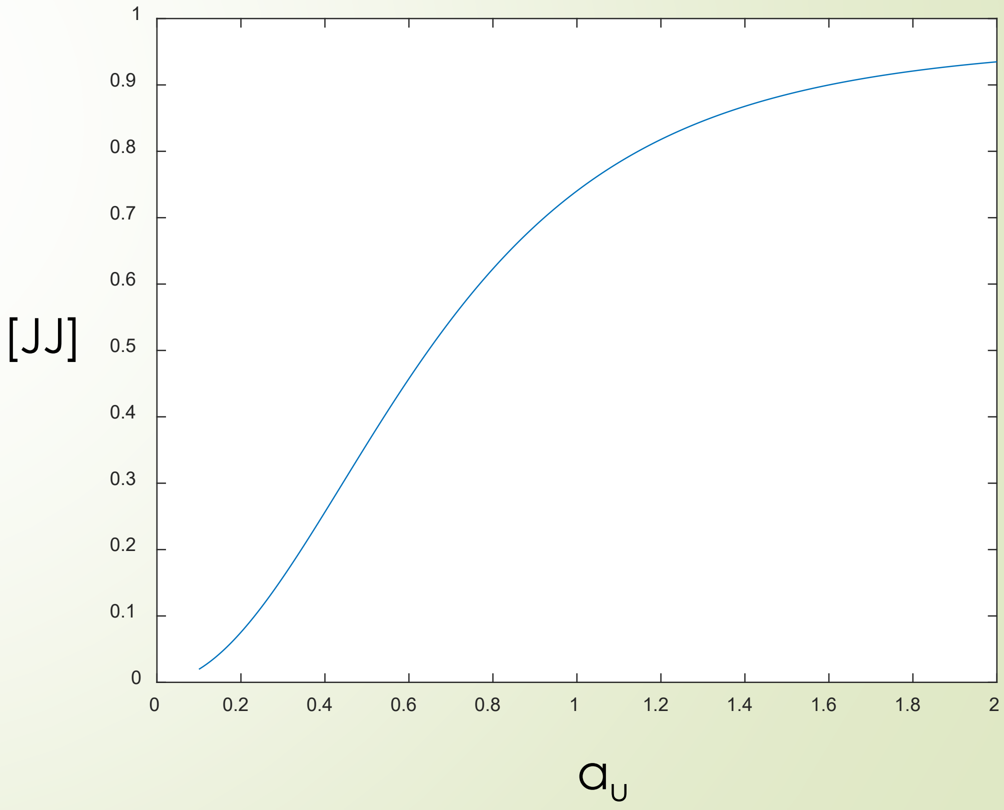
$$B(\omega) \propto [\boxed{(N_\mu - 1)|b(\omega)|^2} + 1]) \times N_u I(\mathrm{A}) \times [JJ]$$

Short-bunch enhancement

where $[JJ] \equiv 4M \times [J_0(M) - J_1(M)]^2 \sim 1$ with $M \equiv a_u^2 / 2(1 + a_u^2)$

N_μ : # of μ-bunch electrons
N_U : # of undulator period
I : current ∝ bunch rate

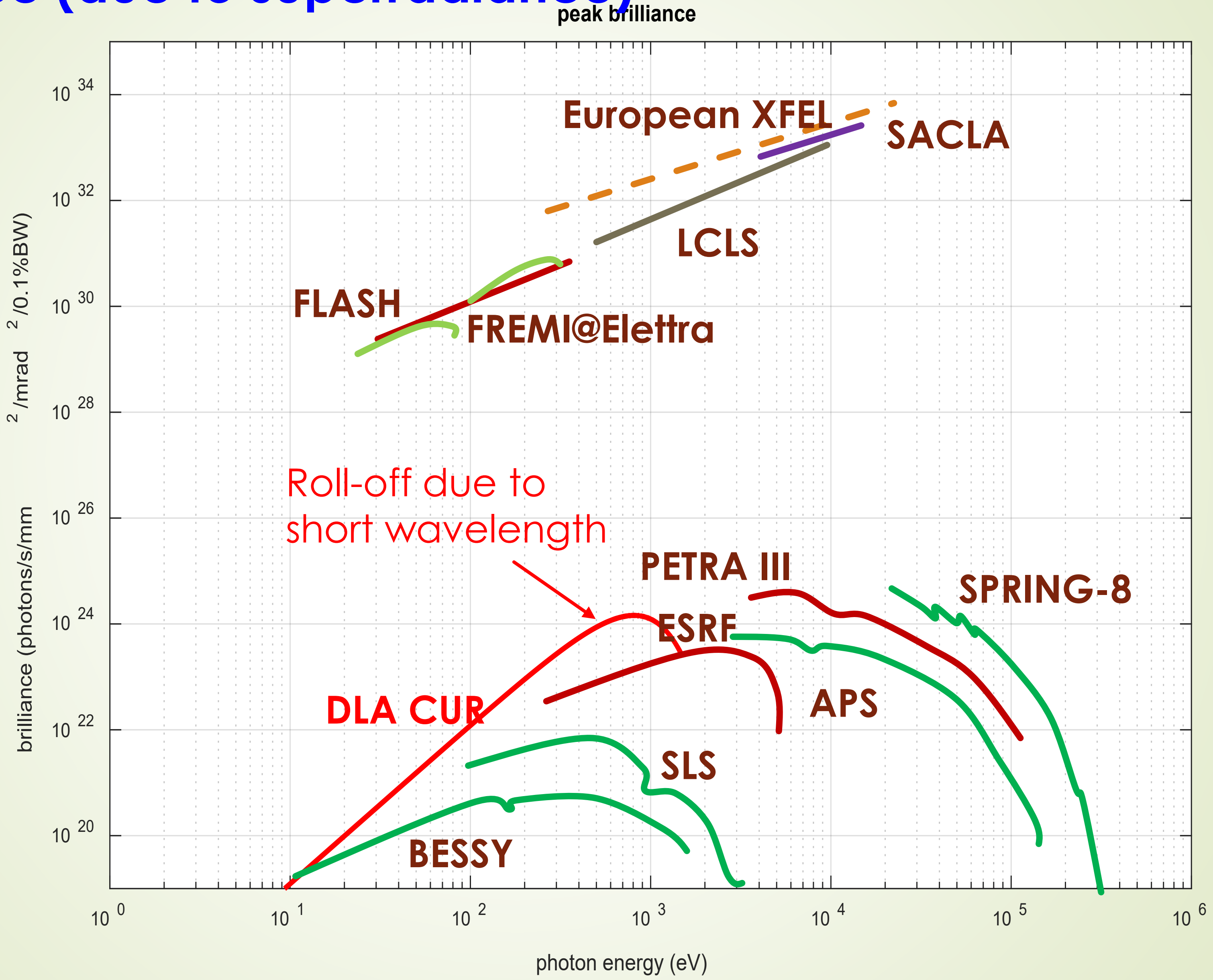
Given a design wavelength, it is desirable to have a large N_μ, N_U, and I (high bunch rate).



System parameters for calculating peak and average brilliances of coherent undulator radiation (CUR) driven by DLA

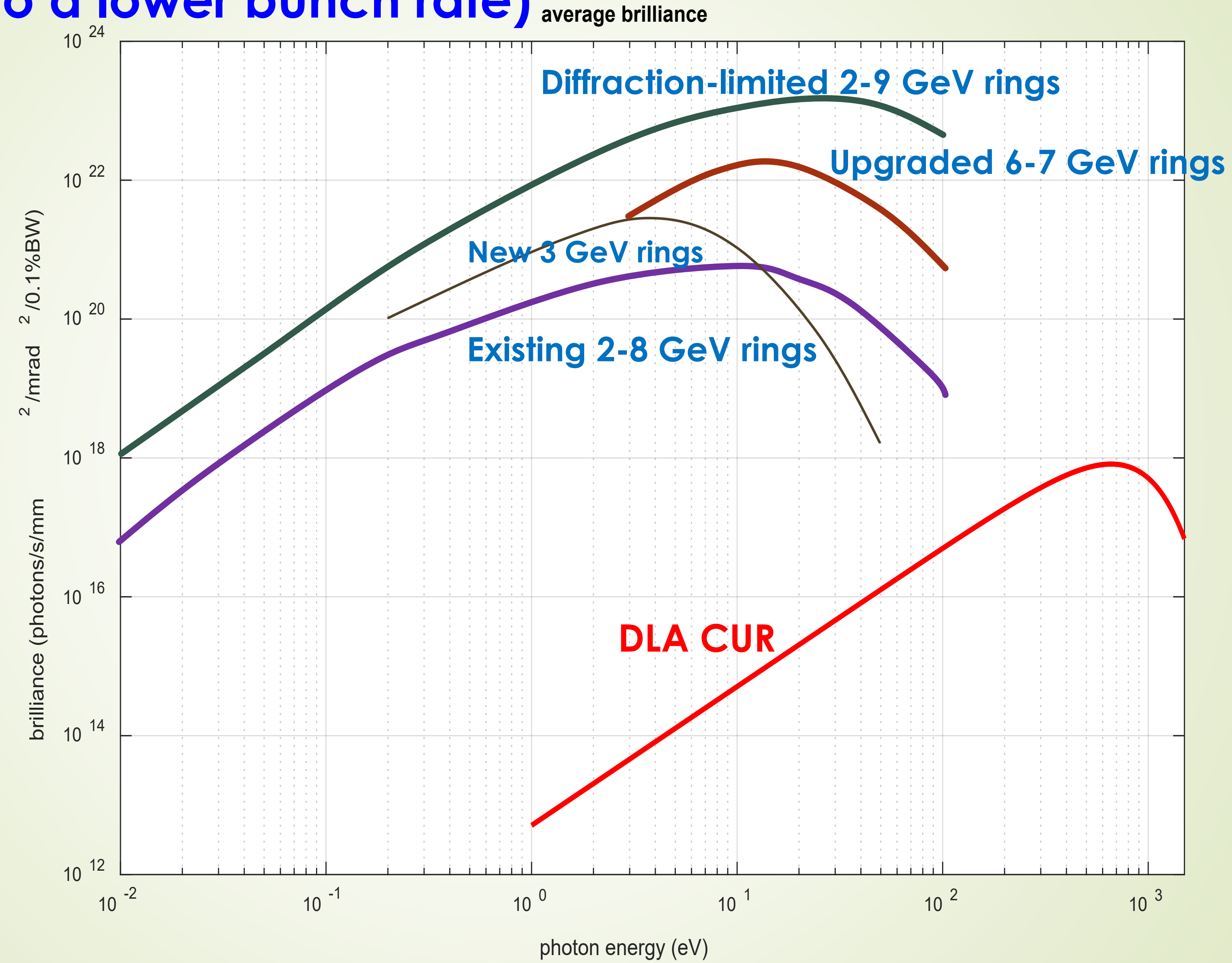
System parameters		DLA CUR	remark
Bunch Charge	fC	0.5	~3000 electrons/bunch
bunch Rep Rate	MHz	100	30 optical cycles in a 100-fs pulse repeating at 3 MHz or 100 cycles in a 300 fs pulse repetition at 1 MHz
Max photon Energy	keV	1.5	For a shorter wavelength, CUR is not effective.
Undulator Length	m	1	1000 undulator periods with a 1-mm period (0.1% bandwidth)
rms Electron Bunch Length	as	1	Wavelength divided by 3500 times scaled from the demonstrated 100 fs bunch length for an RF-accelerator driven SASE FEL
Electron Energy	MeV	~500 MeV	~1-nm radiation wavelength
Undulator parameter	NA	0.217	Laser undulator field (3.3 T, peak) at laser damage of dielectric

Peak brilliance higher or comparable to 3rd-generation light source (due to superradiance)



*Curves other than DLA CUR are adapted from Zirong Huang, SLAC-PUB-15449.

average brilliance lower than 3rd-generation light source (due to a lower bunch rate)

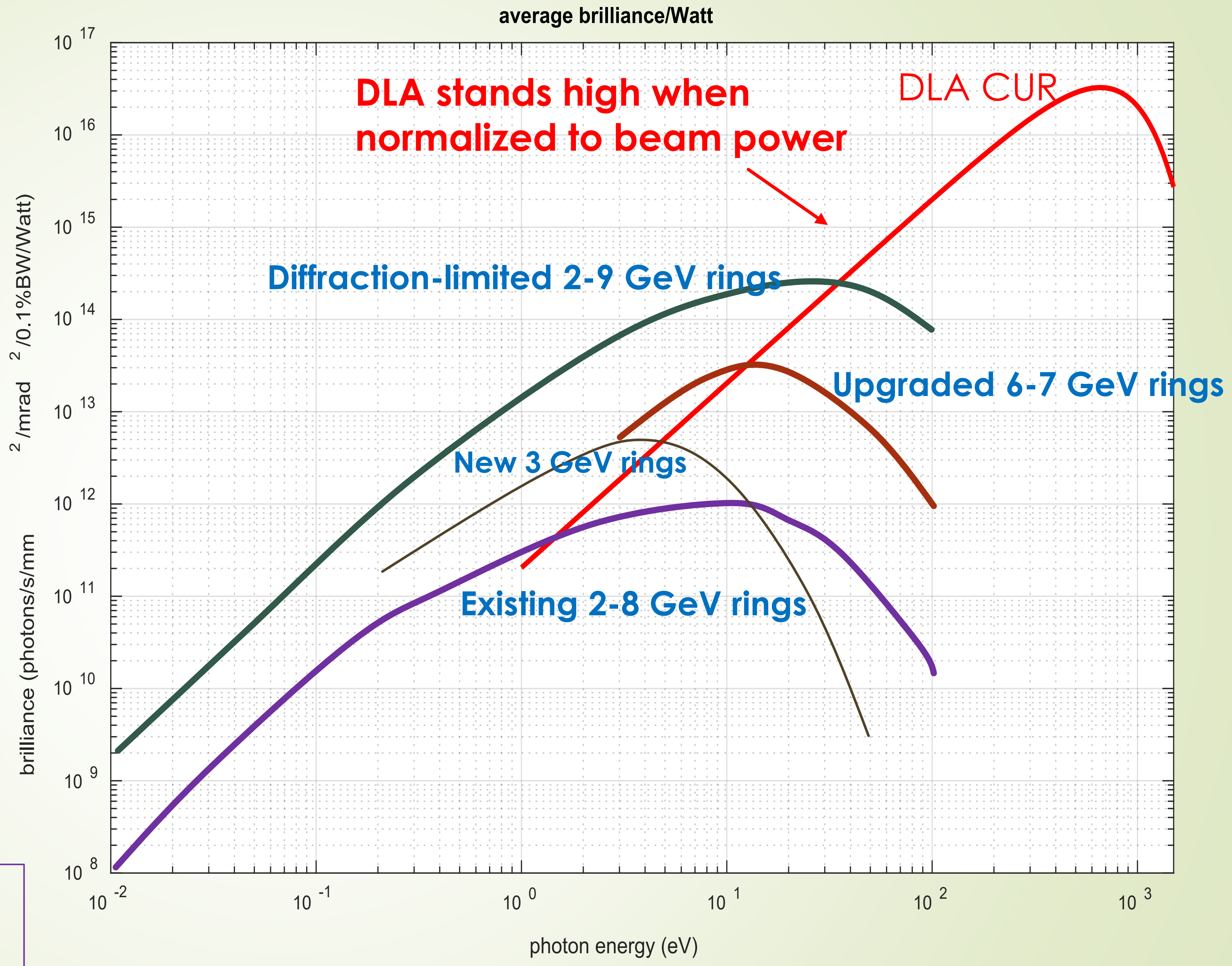


*Curves other than DLA CUR are adapted from Zirong Huang, SLAC-PUB-15449.

~GW circulating power
(Taiwan photon source)

~25W power

Normalized to average beam power (DLA average beam power is much smaller)



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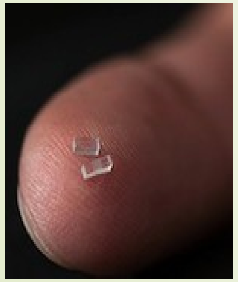
CONCLUSIONS

~GW circulating power (Taiwan photon source)



~25W power

1. Dielectric laser accelerator (DLA) is potentially compact, stable, and high-gradient.

2. Nano-bunches from DLA permit high-brightness superradiance in the soft x-ray with small γ. DLA-driven CUR is predicted to have a peak brilliance comparable to a synchrotron.

3. DLA-driven coherent undulator radiation has a much higher brilliance/watt than a synchrotron.