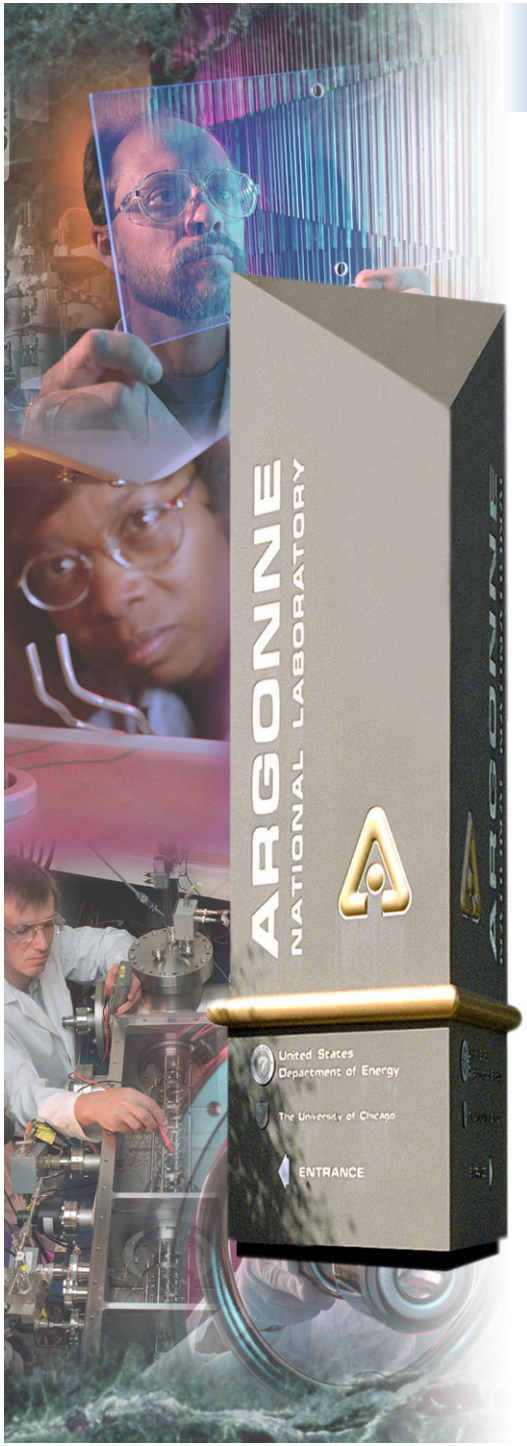

Schemes for 3D laser pulse shaping

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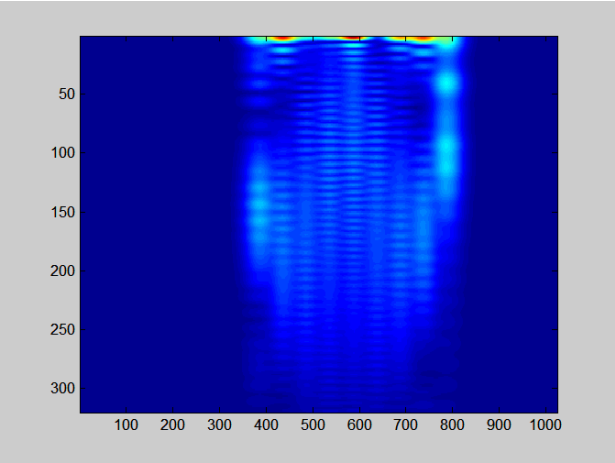
Argonne National Laboratory is managed by
The University of Chicago for the U.S. Department of Energy

Where are we

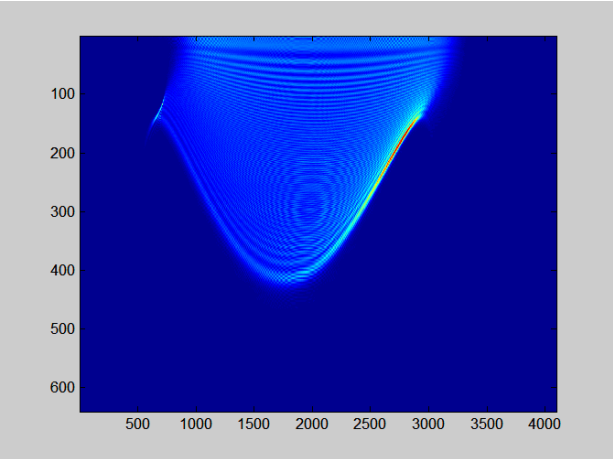
- Beer can to be implemented for LCLS
  - Testing of longitudinal shaping
    - *DAZZLER ()*
    - *Pulse stacking*
  - Commercial optics for transverse shaping
    - *Newport*
    - *Moltech*
- Ellipsoidal is highly desired
  - Totally linear space charge force
  - Schemes
    - *Self generating (Luiten et al)*
    - *Pulse stacking*
    - *Spectral methods (Bolton)*
    - *Fiber bundle + Deformable mirror (Tomizawa)*

Two schemes

- Pulse stacking using zoned lens
  - The concept of a zoned-lens
  - Some effort and initial results
  - Outlook



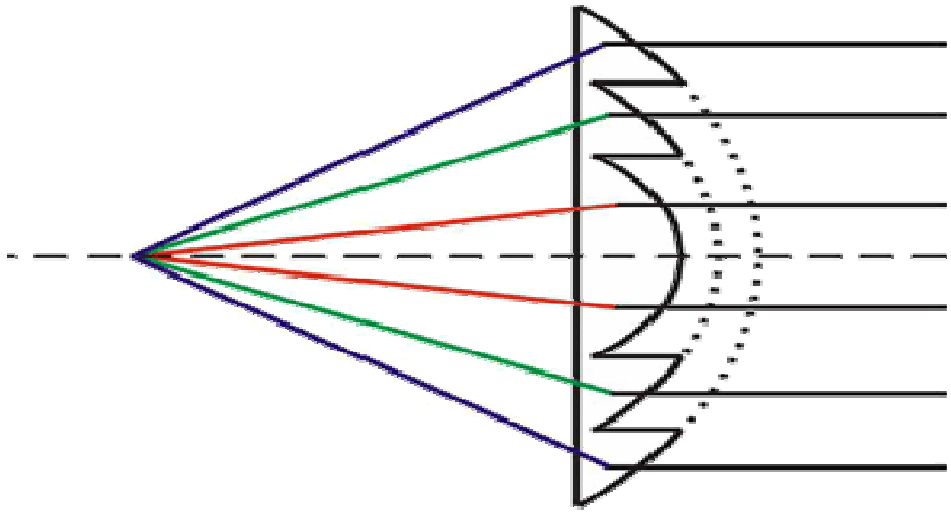
- Phase space manipulation with diffraction/dispersion
  - Concept of laser phase manipulation
  - Chromatic effect in optics
  - Quasi ellipsoidal beam generation
  - Outlook



3-D laser pulse shaping by pulse stacking: zoned lens

- A zoned lens is a lens with circular zones like a Fresnel lens
- Temporal shaping: by controlling the thickness of each zone and its transmission
- Transverse shaping: shape and transmission of each zone

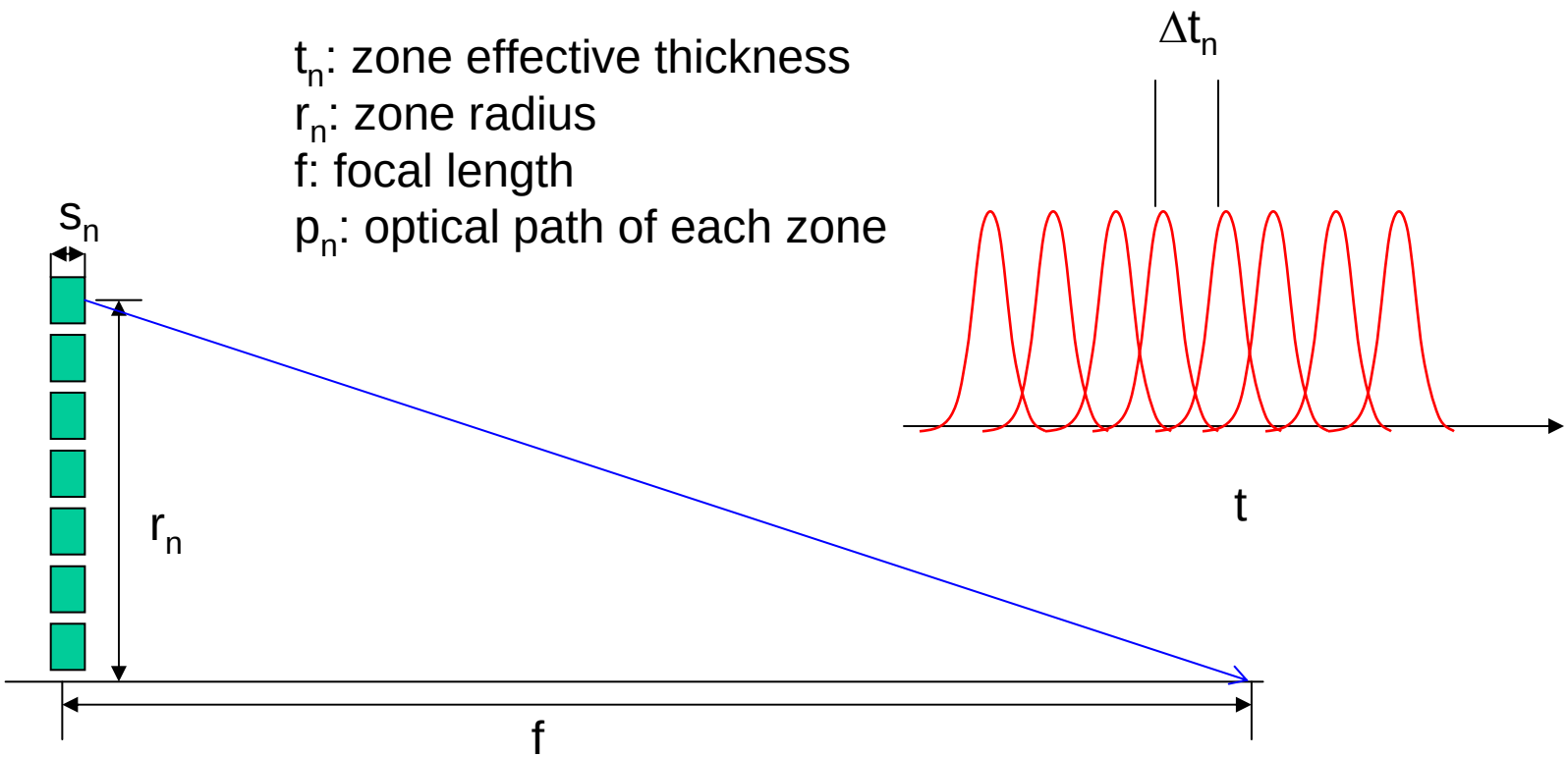
A Fresnel lens



Timing control

$$p_n = \sqrt{r_n^2 + f^2} + \eta s_n$$

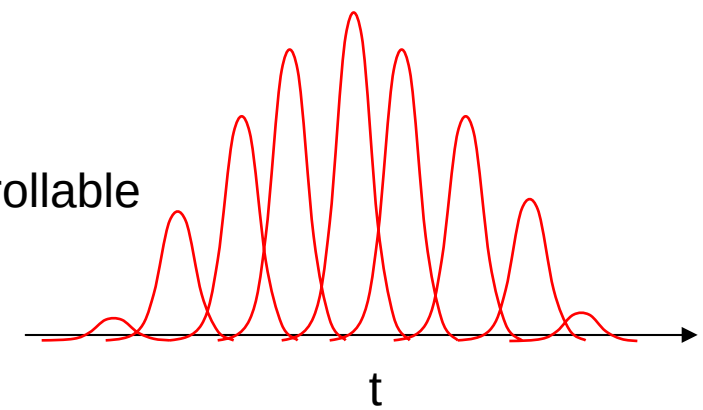
t_n: zone effective thickness
r_n: zone radius
f: focal length
p_n: optical path of each zone

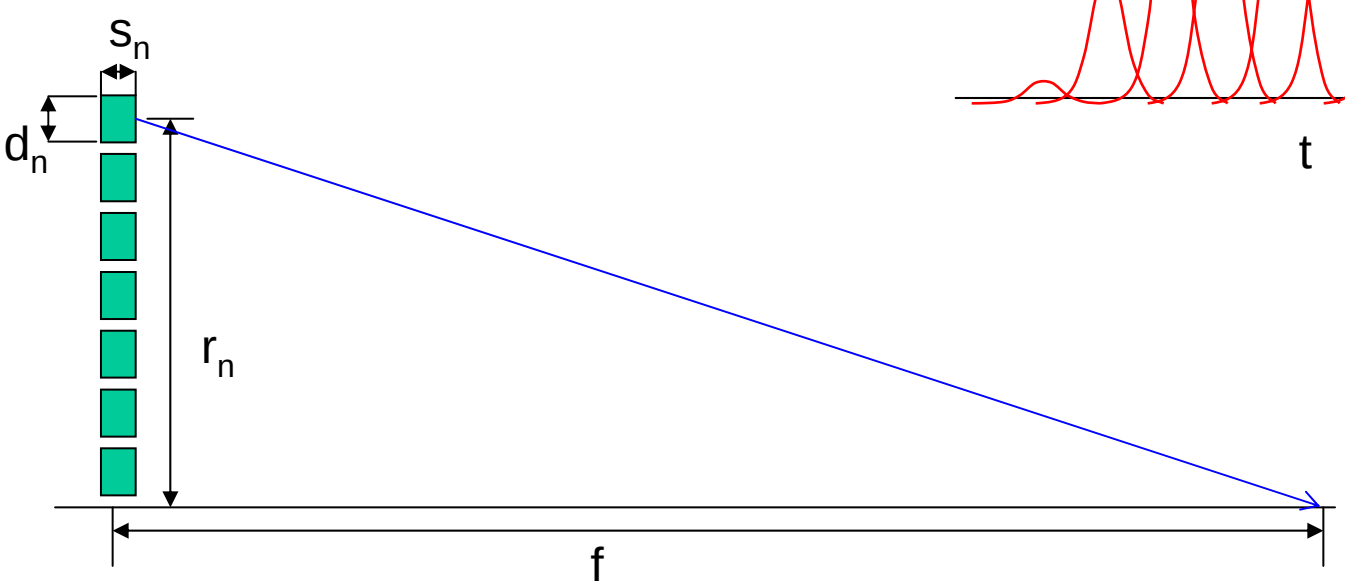


Intensity profile control

$$F_n = 2\pi r_n d_n I_n(r) T_n(r)$$

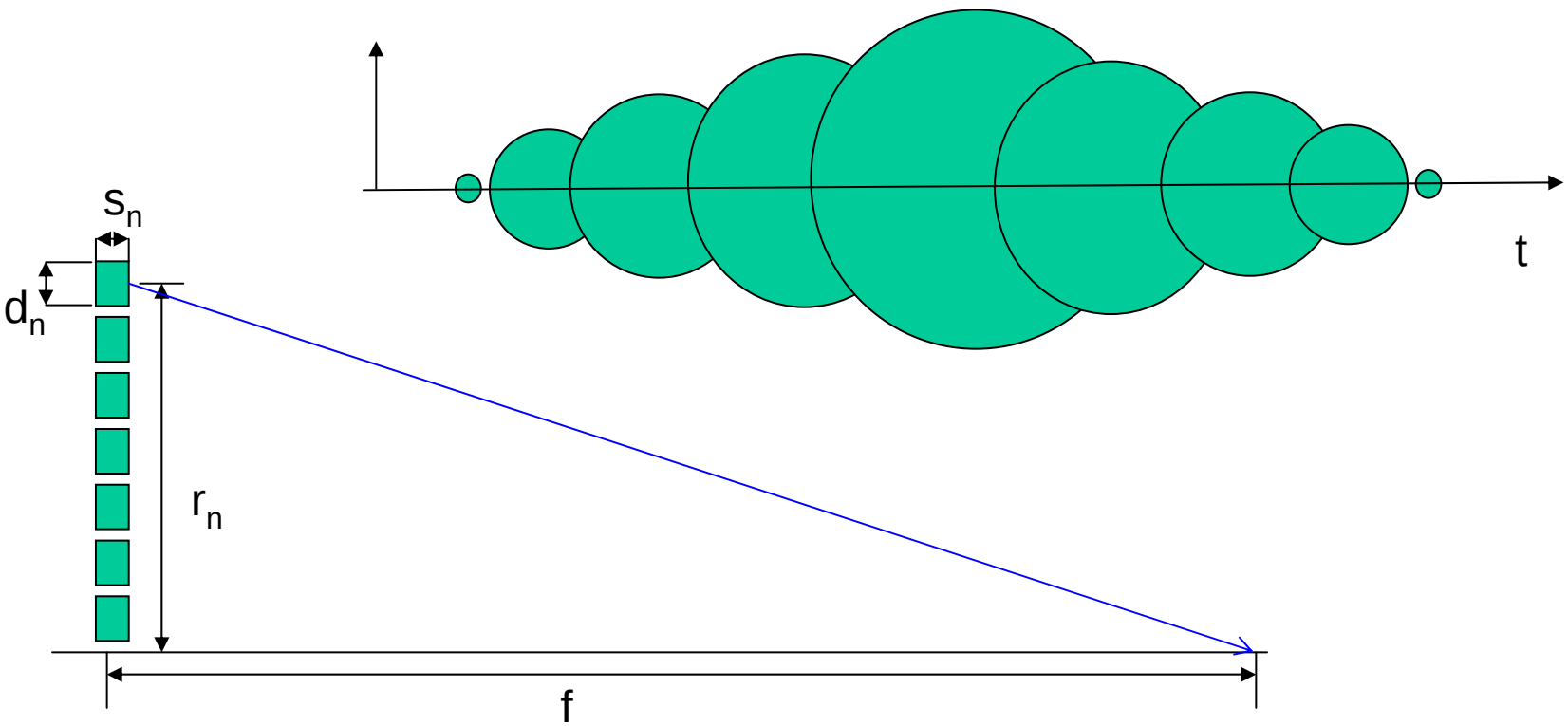
Fn: Total flux
d_n: Zone size, controllable
I_n: input laser distribution, controllable
T_n: segment optical transmission, controllable





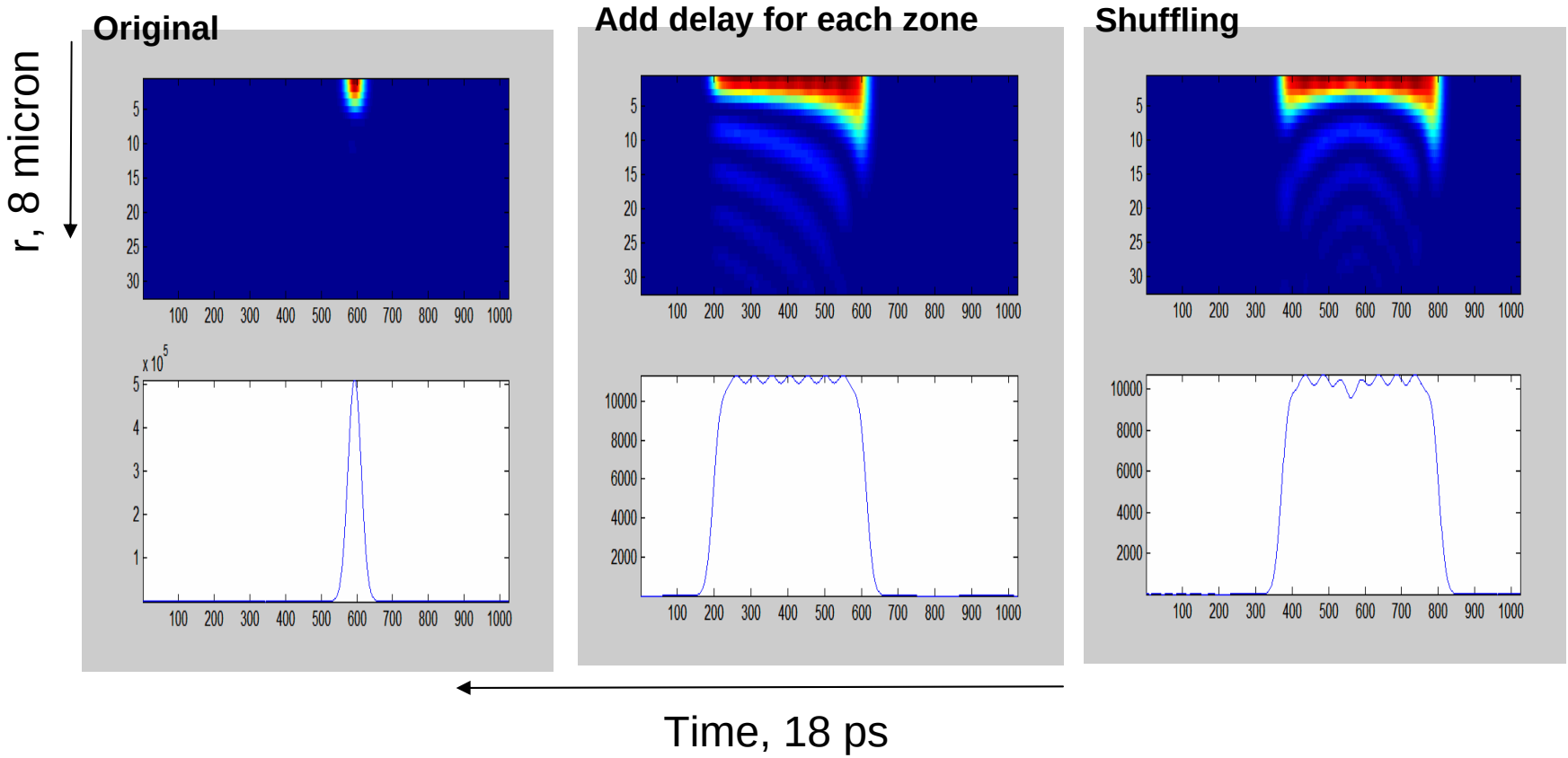
Spatial profile: ideally

By tailoring the shape of each zone, it is possible to control the size and the shape of the beam at the focus, maybe flattop disks with different sizes.



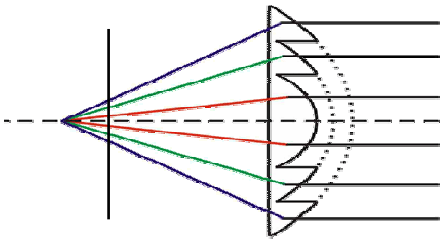
Preliminary results on zoned lens: Temporal shaping is straight forward

- A 9-zone lens with an 1.5 ps. 249 nm Gaussian pulse with 150 mm focal length

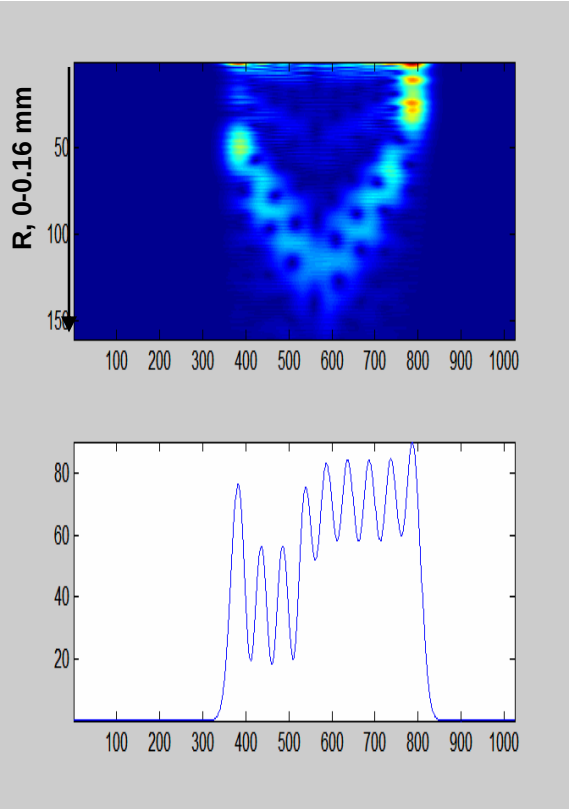


When off focus by 1.5 mm

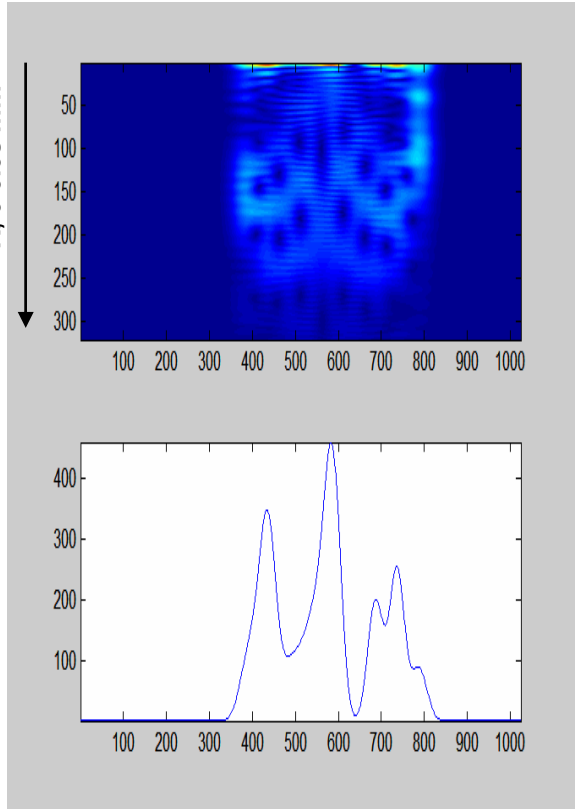
- Spatial shaping is still difficult



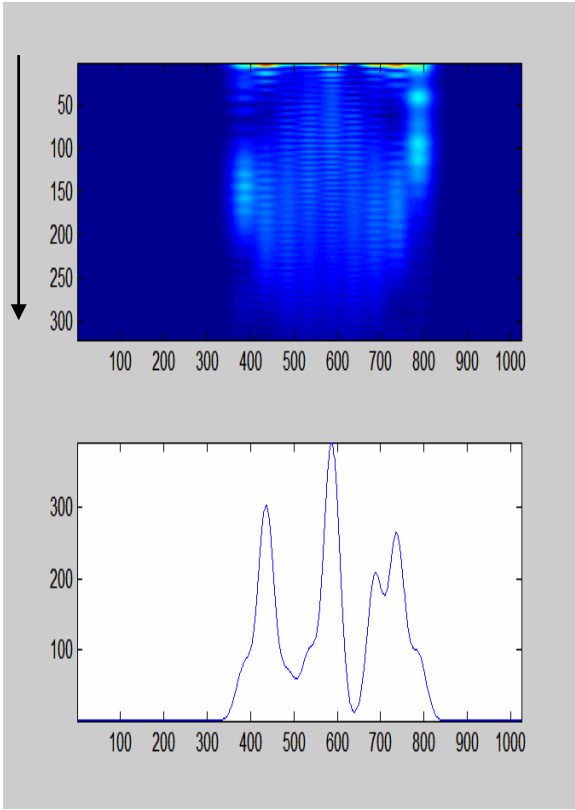
Just off focus



Tuning the focii



Polarization separation



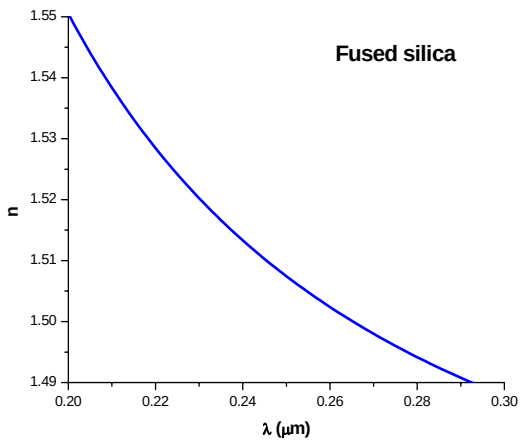
Conclusion on zoned lens

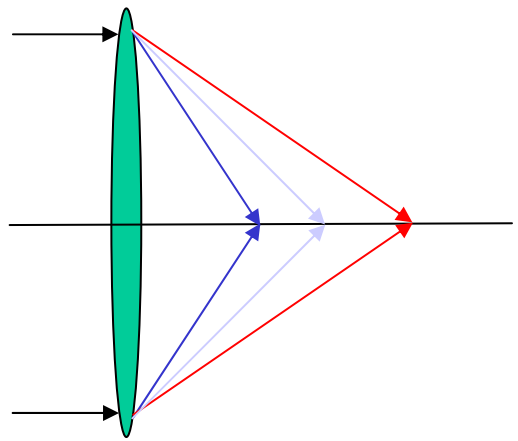
- Pulse stacking is highly possible
  - Temporal shaping is straight forward
  - Spatial shaping needs more effort and can be very difficult
  - Vast space for parameter control
  - Cost?

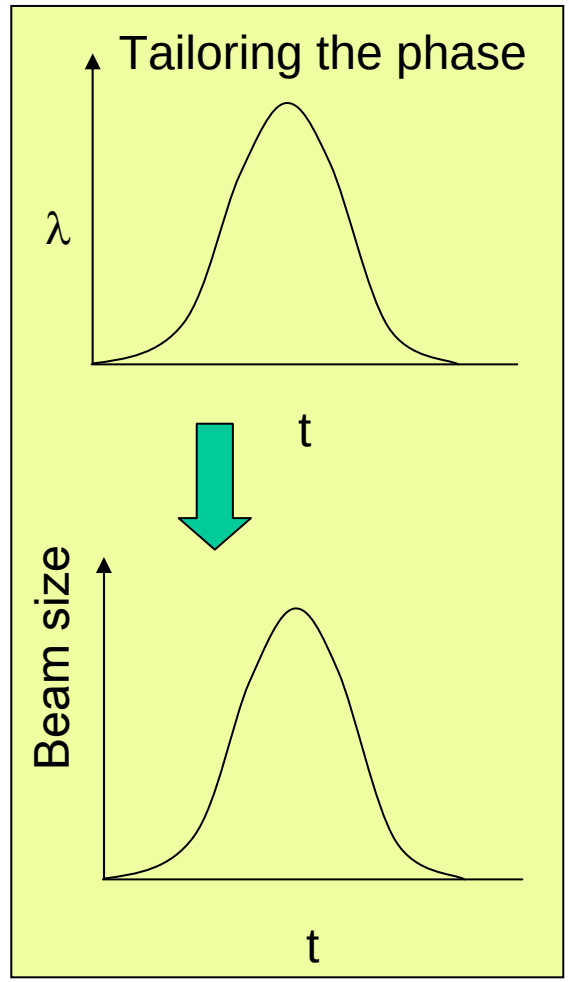
- More flexible stacking schemes ?

Laser phase space manipulation

- Focal length is a function of wavelength
- Therefore tuning the arrival time of the particular wavelength will change the beam size







$$f = \frac{R}{n(\lambda) - 1}$$

$$df = -\frac{f}{n_0 - 1}\frac{dn}{d\omega}d\omega$$

$$\frac{df(\omega)}{d\omega} = -\frac{f}{n_0 - 1}\frac{dn}{d\omega}$$

$$w(\omega) = w_0\left[1 + \left(\frac{\lambda df}{\pi w_0^2}\right)^2\right]^{1/2}$$

Laser phase manipulation result

One needs

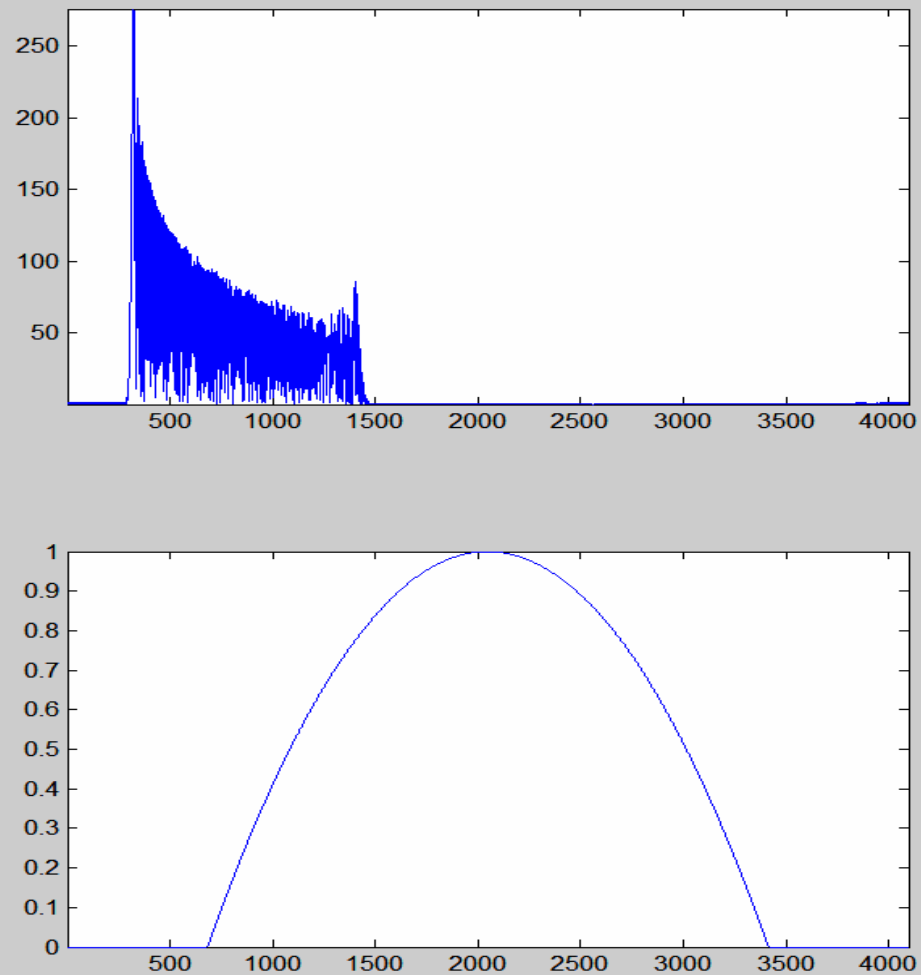
$$w(\omega) \cong \frac{|df|}{N}$$

$$E(t) = E_0\left[1-\left(\frac{t}{T}\right)^2\right]^{1/2}$$

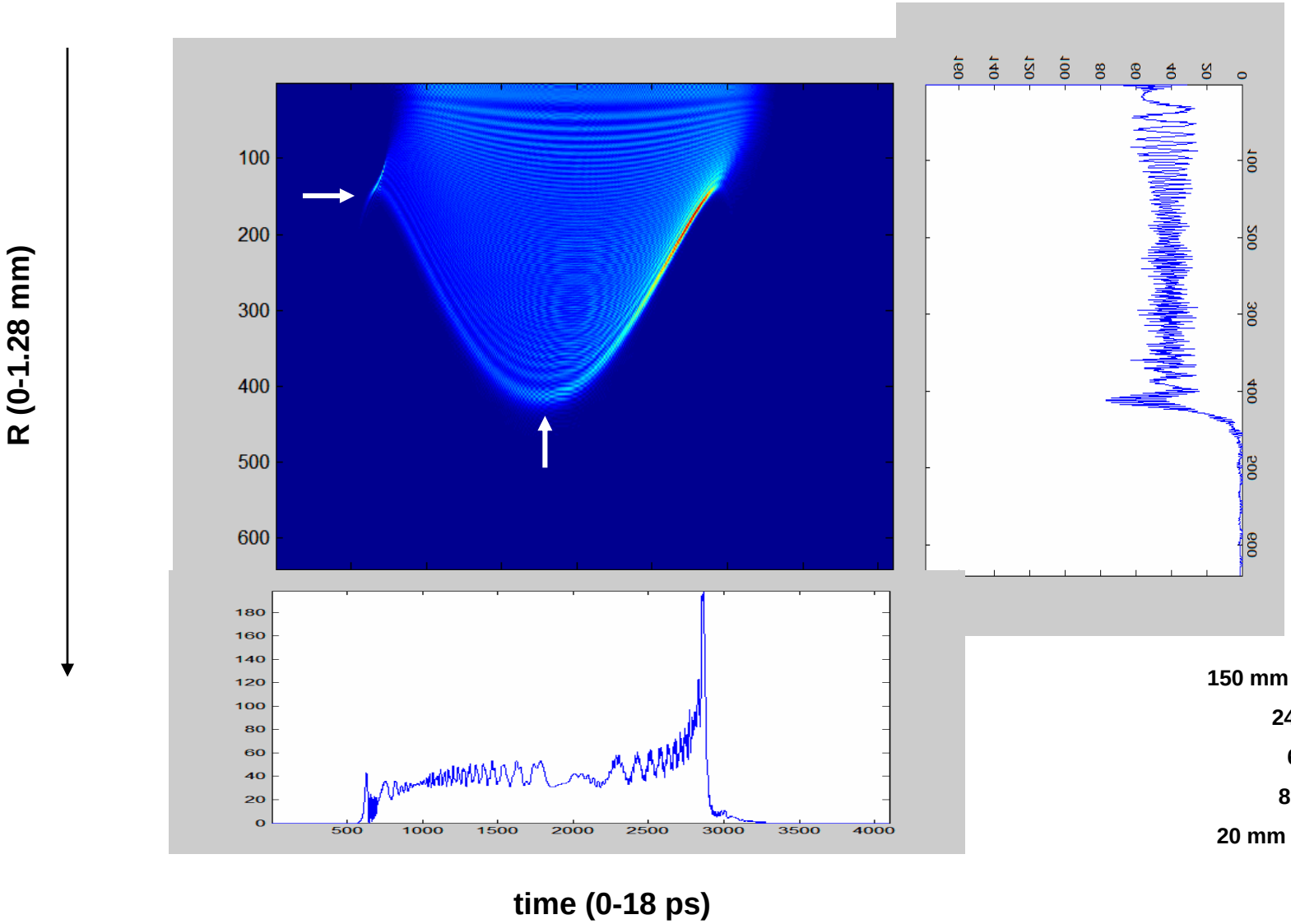
Therefore

$$|d\omega| = \Delta\omega\left[1-\left(\frac{t}{T}\right)^2\right]^{1/2}$$

$$\phi(t) = i\omega_0 t \pm i\frac{\Delta\omega}{2}\left[t\left(1-\left(\frac{t}{T}\right)^2\right)+T\sin^{-1}\frac{t}{T}\right]$$



Structure in the pulse: using a zone plate



150 mm focal length

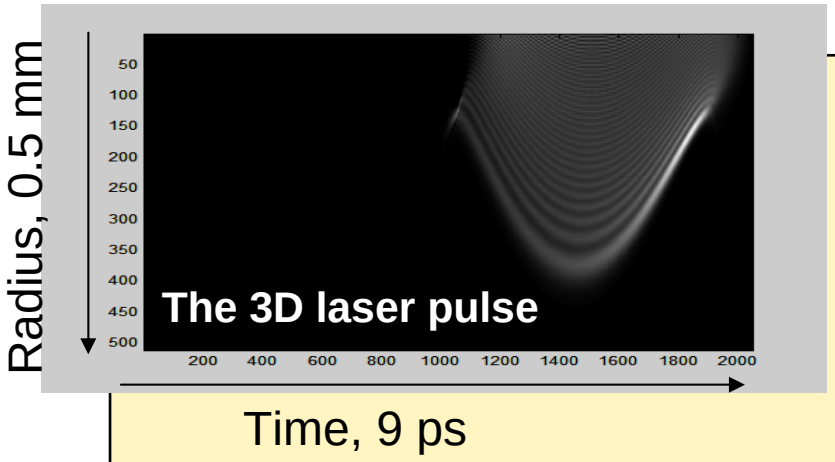
249 nm

6 ps

8% bw

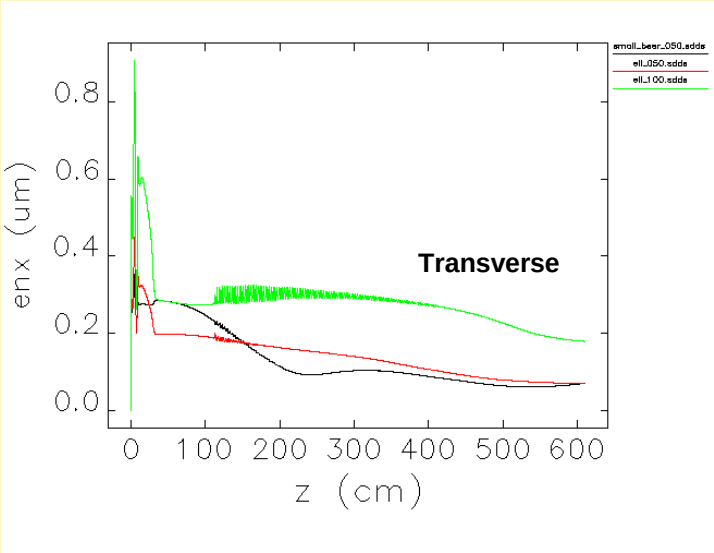
20 mm 2600 zones

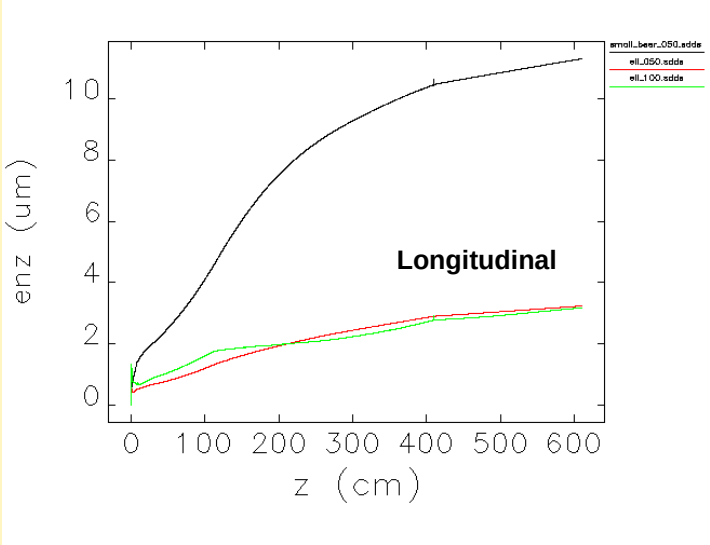
First ellipsoidal laser beam: beam simulation



PAMERLA simulation

Emittance as a function of propagation distance from the cathode. (Green, 100 pC, Red: 50 pC, Black: Beer Can 0.05 nC. Courtesy of J. Lewellen)





Details to pay attention

- Laser pulse preconditioning is required
  - Currently need flattened transverse beam
  - Need a particular temporal waveform
- To do those
  - Need beam with large BW
  - No initial chromatic effect
- Better lens material may reduce BW requirement
- Zone plat with large aperture can be difficult to make

Conclusion

- 3 D laser pulse shaping is possible using different schemes
- To fully take control of the 3D shaping, one must take the full advantage of the current technological advances in laser phase manipulation and laser pulse shaping
- More simulation is needed to determine the influence of inevitable structures in the resulting pulses, which is determined by the cathode material and response time.
- Though in general complicated, there is no showstop.

Acknowledgement

- John Lewellen, Kwang-Je Kim, Kathy Harkay
- DOE