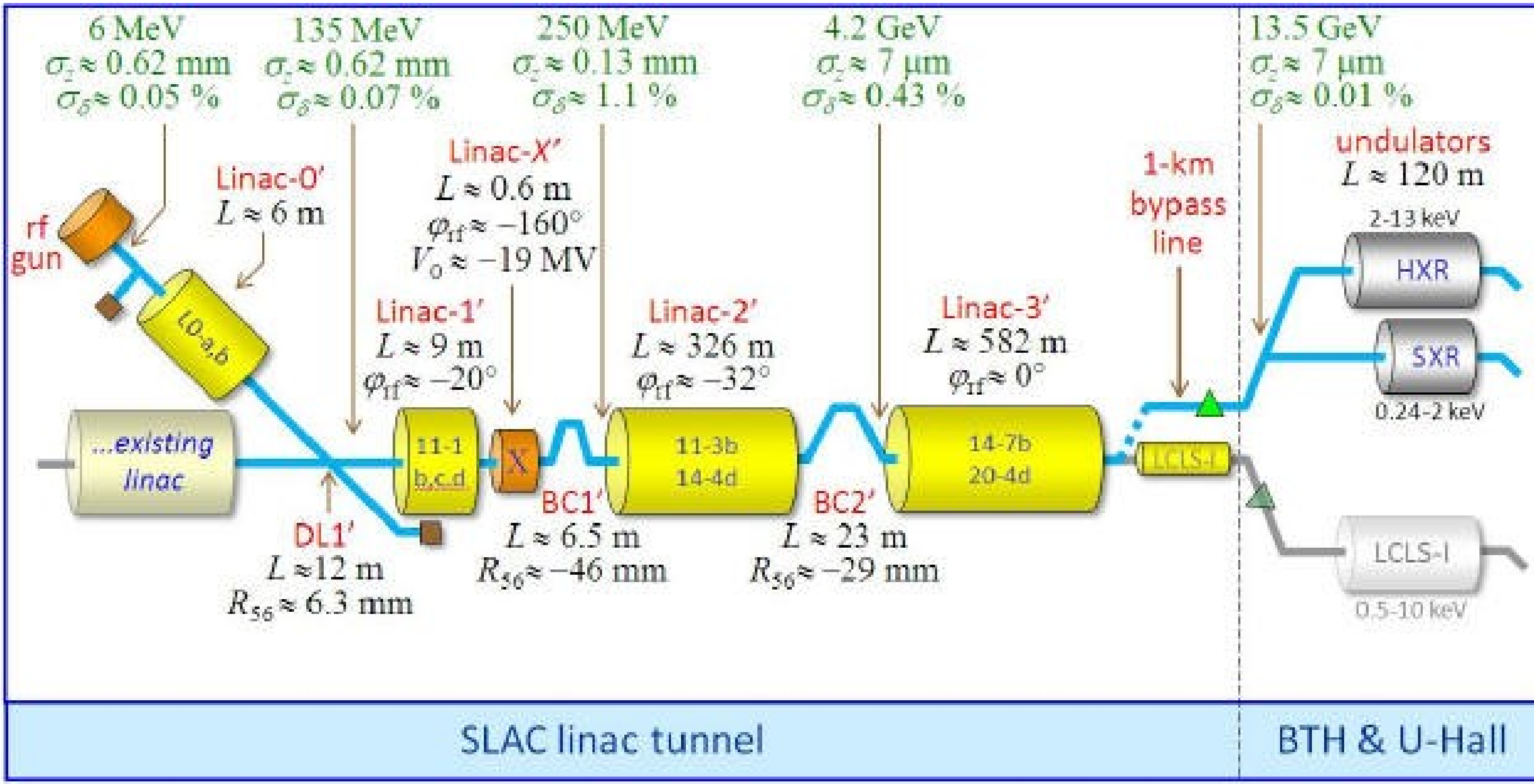
LCLS Parameters

Undulator Type	planar NdFe:B	planar NdFe:B	
Wavelength	15	1.5	Å
Norm. RMS Emittance	1.2	1.2	mm mrad
Peak Current	3.4	3.4	kA
Electron Energy E	4.54	14.35	GeV
Average b -Function	7.3	18	m/rad
s $_E$/E (X-rays)	0.47	0.13	%
Pulse Duration (FWHM)	230	230	fs
Pulses per macropulse	1	1	
Repetition Rate	120	120	Hz
Undulator Period	3.0	3.0	cm
Peak Field	1.32	1.32	T
FEL parameter r	1.45	0.50	10^{-3}
Power Gain Length	1.3	4.7	m
Saturation Length	27	86	m
Peak Power	19	8	GW
Average Power	0.61	0.25	W
Coherent Energy per Pulse	2.6	2.3	mJ
Coherent Photons per Pulse	27.9	1.1	10^{12}
Peak Brightness	0.64	8.5	
Average Brightness	0.2	2.7	
Transverse RMS Photon Beam Size	40	33	
Transverse RMS Photon Beam Divergence	3.4	0.42	

** photons/(s,mm^2,mrad^2,0.1%BW)

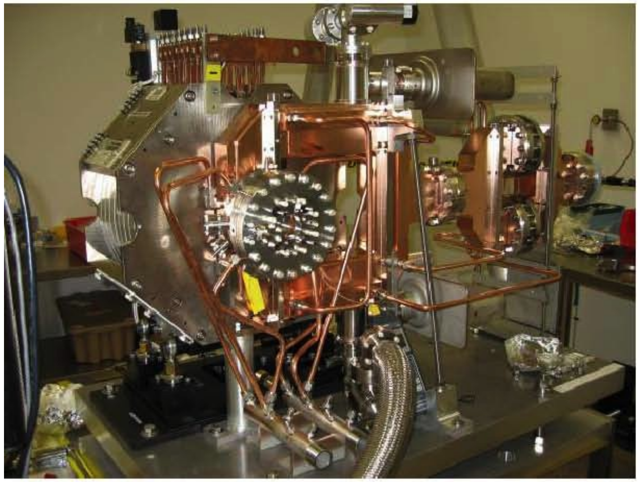
Machine Parameters FLASH

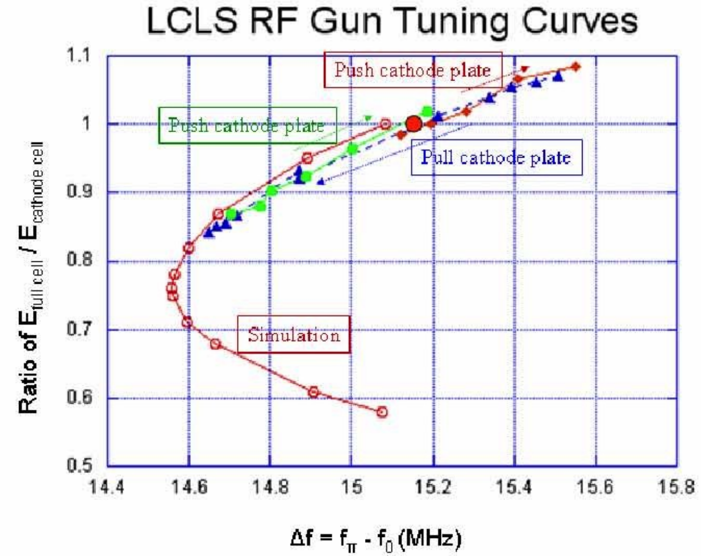
	Before FLASH upgrade (Sep. 2009)	After FLASH Upgrade (Feb
Electron energy (max.)	1.0 GeV	1.25 GeV
Length of the facility	315 m	315 m
Normalized emittance	2 mm mrad (rms)	1.5 mm mrad (rms)
Emittance	1 nm rad (rms)	0.6 nm rad (rms)
Bunch charge	1 nC	0.1 – 1 nC
Peak current	2 kA	2 kA
Bunches per second (typ. andmax.)	150 and 4000	300 and 2500
Lasing parameters		
Photon energy (max.)	180 eV (fundamental)	301 eV (fundamental)
Wavelength (min.)	6.9 nm (fundamental)	4.12 nm (fundamental)
Pulse duration (FWHM)	10 - 50 fs	<70 - 200 fs
Peak power	1 - 5 GW	1 - 3 GW
Bunch energy (average)	10 -100 μJ	up to 300 μJ
Photons per bunch	10^{12} - 10^{13}	10^{12} - 10^{13}
Average brilliance	10^{17}-10^{19} photons/sec/mm^2/mrad^2/0.1%	10^{18}-10^{21} photons/sec/
Peak brilliance	10^{29} - 10^{30} photons/sec/mm^2/mrad^2/0.1%	10^{30} - 10^{31} photons/sec.



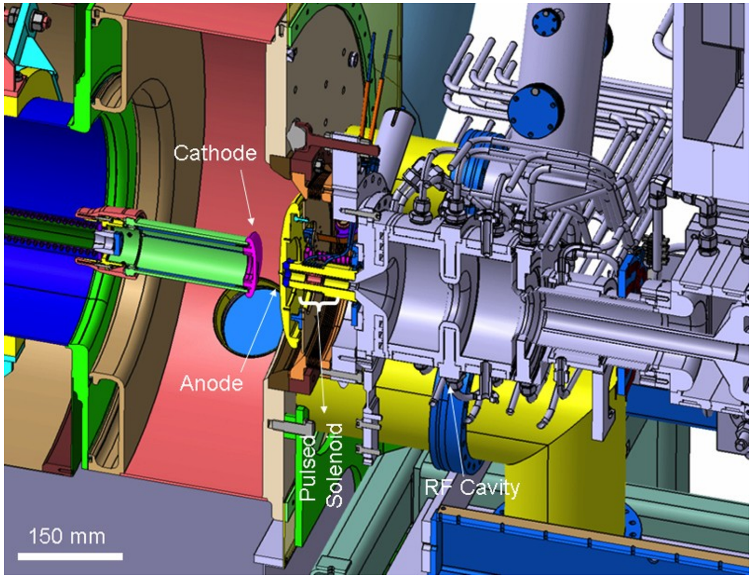
6 MeV
$\sigma_z \approx 0.62$ mm
$\sigma_\delta \approx 0.05$ %
135 MeV
$\sigma_z \approx 0.62$ mm
$\sigma_\delta \approx 0.07$ %
250 MeV
$\sigma_z \approx 0.13$ mm
$\sigma_\delta \approx 1.1$ %
4.2 GeV
$\sigma_z \approx 7$ µm
$\sigma_\delta \approx 0.43$ %
13.5 GeV
$\sigma_z \approx 7$ µm
$\sigma_\delta \approx 0.01$ %
rf gun
Linac-0′
$L \approx 6$ m
L0-a,b
Linac-X′
$L \approx 0.6$ m
$\varphi_{rf} \approx -160°$
$V_0 \approx -19$ MV
Linac-1′
$L \approx 9$ m
$\varphi_{rf} \approx -20°$
Linac-2′
$L \approx 326$ m
$\varphi_{rf} \approx -32°$
Linac-3′
$L \approx 582$ m
$\varphi_{rf} \approx 0°$
1-km bypass line
undulators
$L \approx 120$ m
2-13 keV
HXR
SXR
0.24-2 keV
...existing linac
11-1 b,c,d
X
11-3b 14-4d
14-7b 20-4d
LCLS-I
LCLS-I
0.5-10 keV
DL1′
$L \approx 12$ m
$R_{56} \approx 6.3$ mm
BC1′
$L \approx 6.5$ m
$R_{56} \approx -46$ mm
BC2′
$L \approx 23$ m
$R_{56} \approx -29$ mm
SLAC linac tunnel
BTH & U-Hall

RF gun



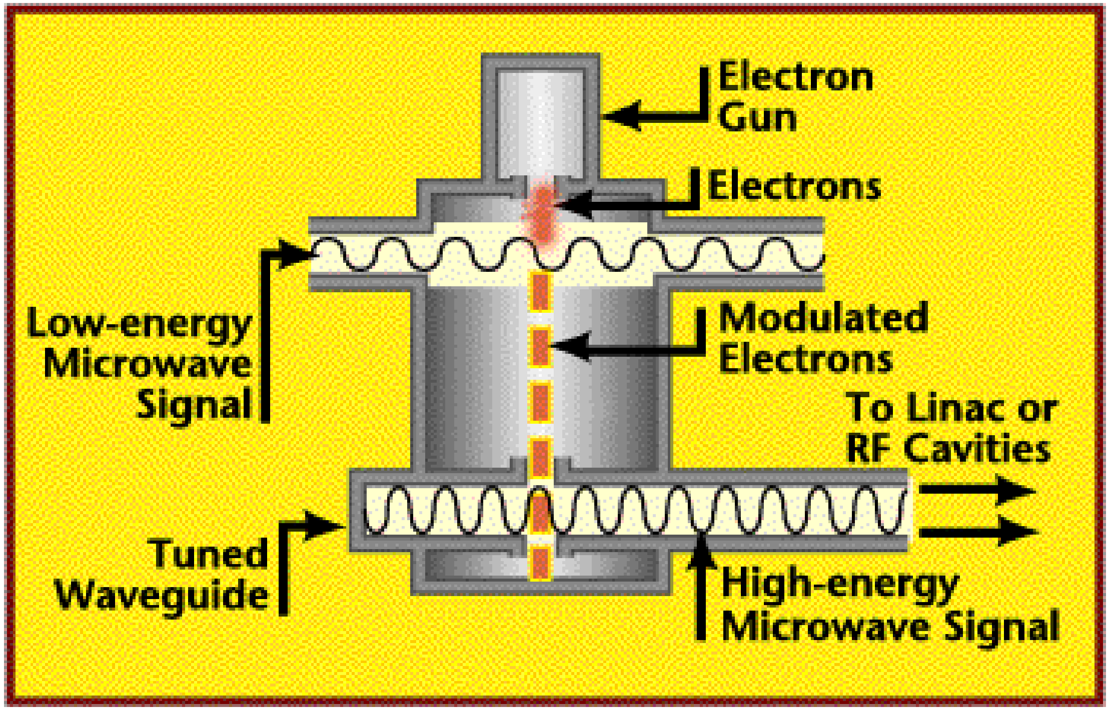


LCLS RF Gun Tuning Curves
Push cathode plate
Push cathode plate
Pull cathode plate
Simulation
1.1
1
0.9
0.8
0.7
0.6
0.5
14.4
14.6
14.8
15
15.2
15.4
15.6
15.8
Ratio of $E_{full\ cell}$ / $E_{cathode\ cell}$
$\Delta f = f_{\pi} - f_0$ (MHz)

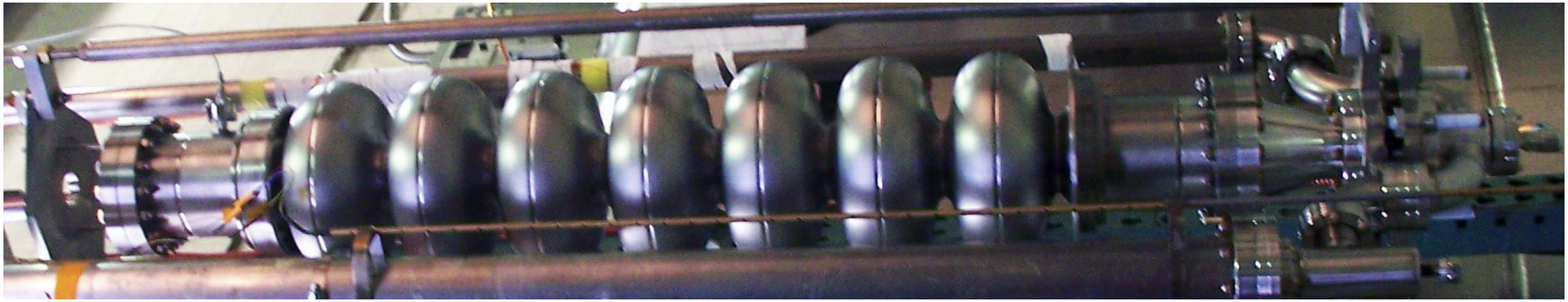


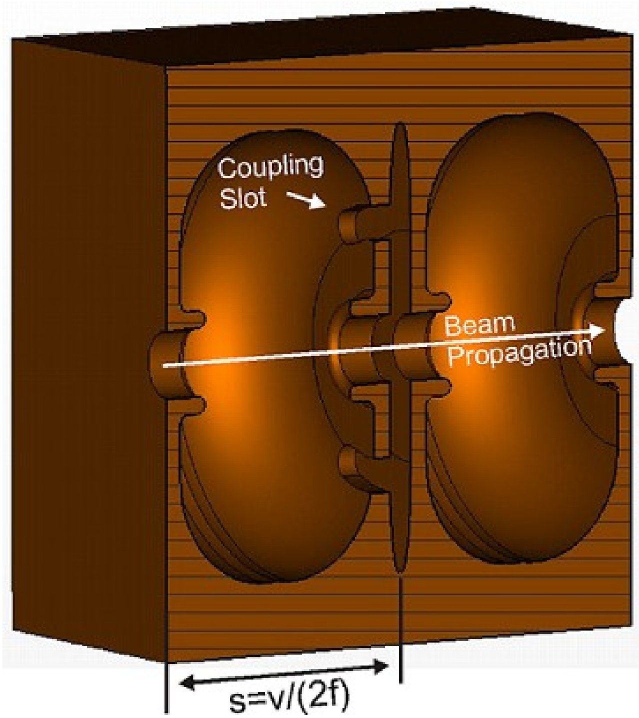
Cathode
Anode
Pulsed Solenoid
RF Cavity
150 mm

Klystron

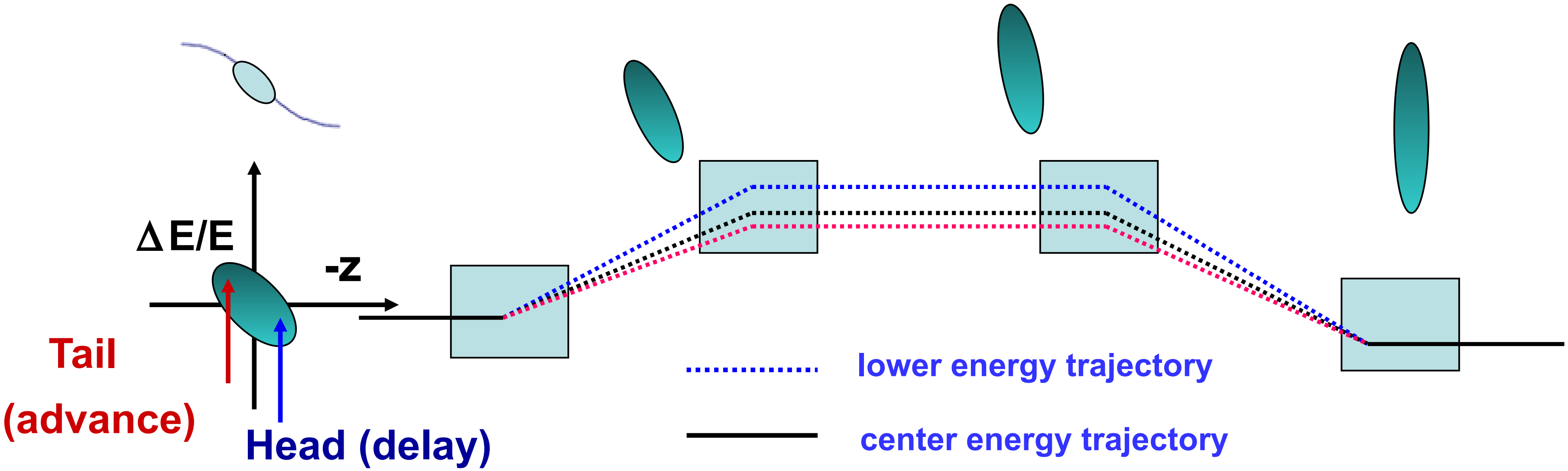

Electron
Gun
Electrons
Low-energy
Microwave
Signal
Modulated
Electrons
To Linac or
RF Cavities
Tuned
Waveguide
High-energy
Microwave Signal

RF accelerator cavity

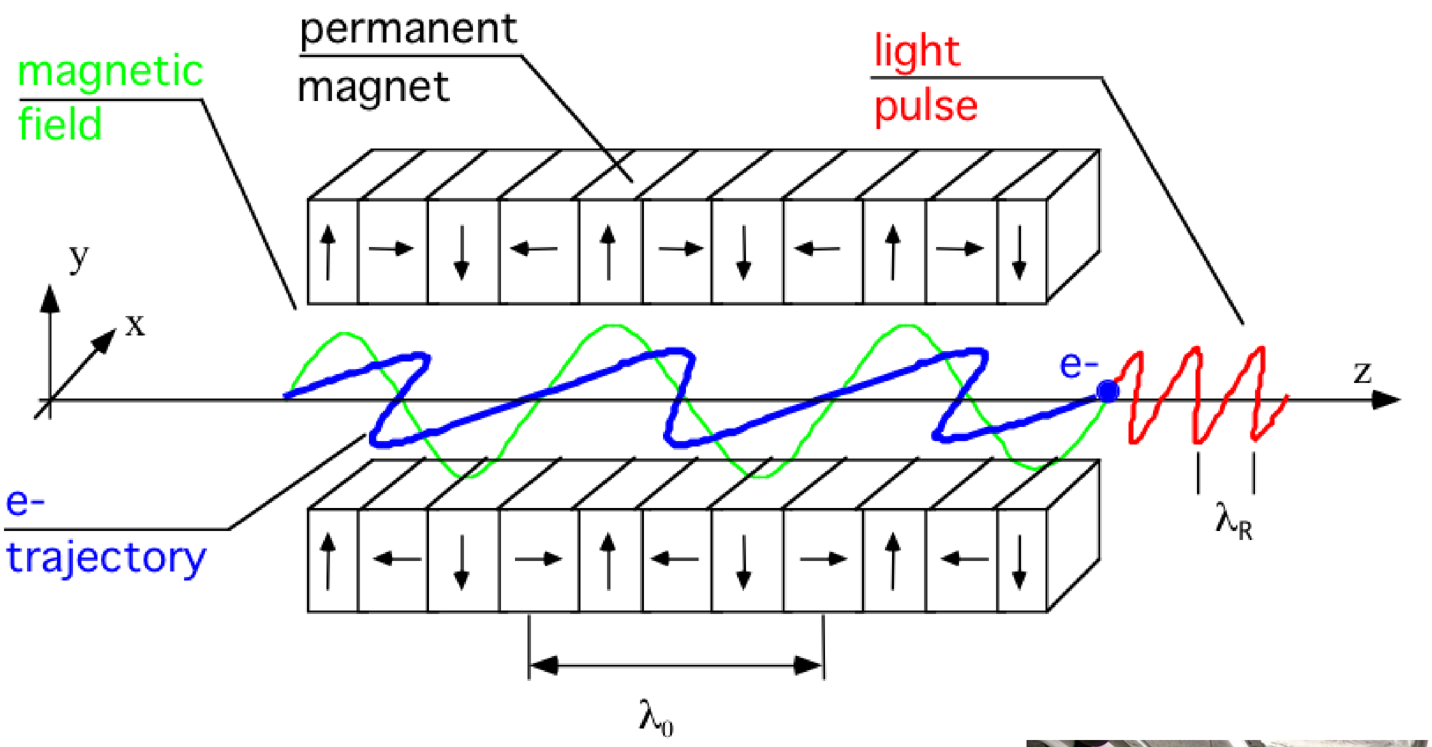


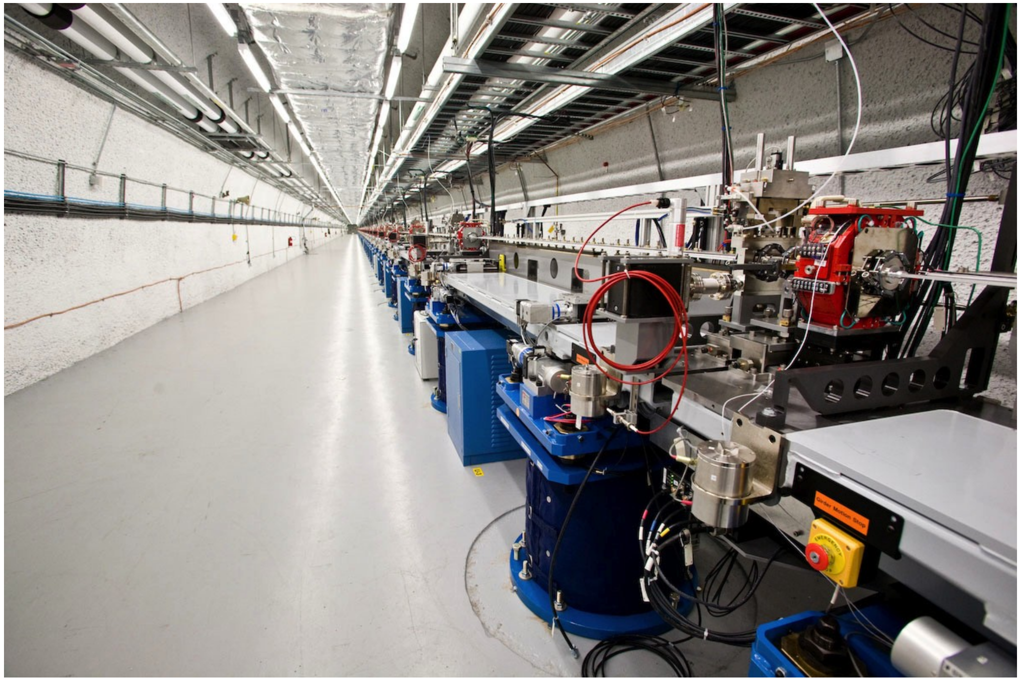


Bunch compressor - Chicane



Undulator


permanent
magnet
magnetic
field
light
pulse
y
x
e-
z
e-
trajectory
λ_R
λ_0

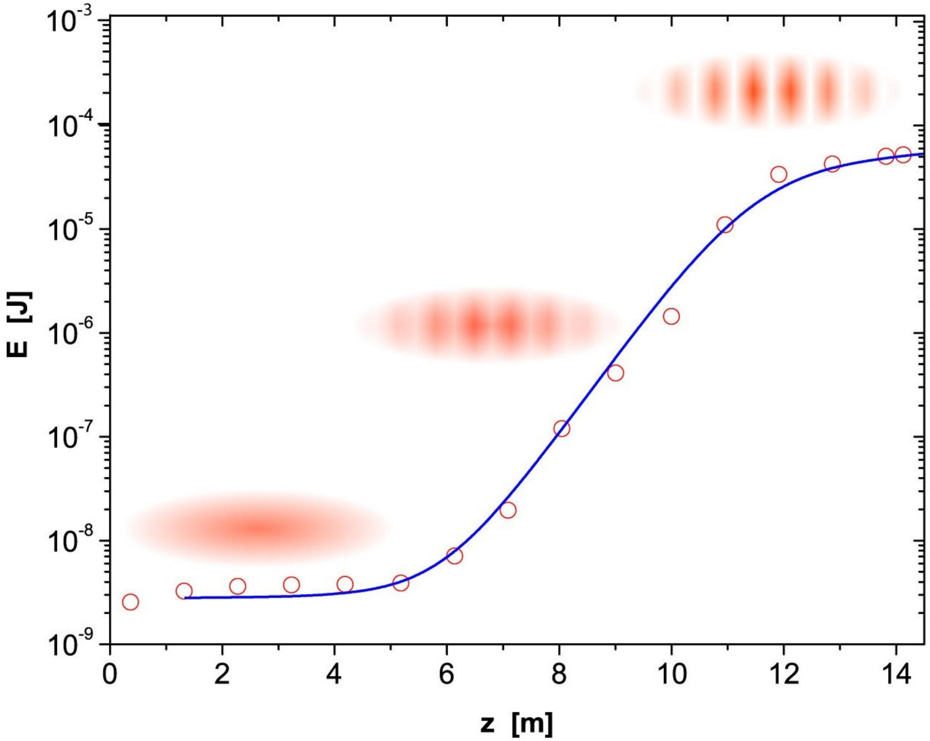


Emittance

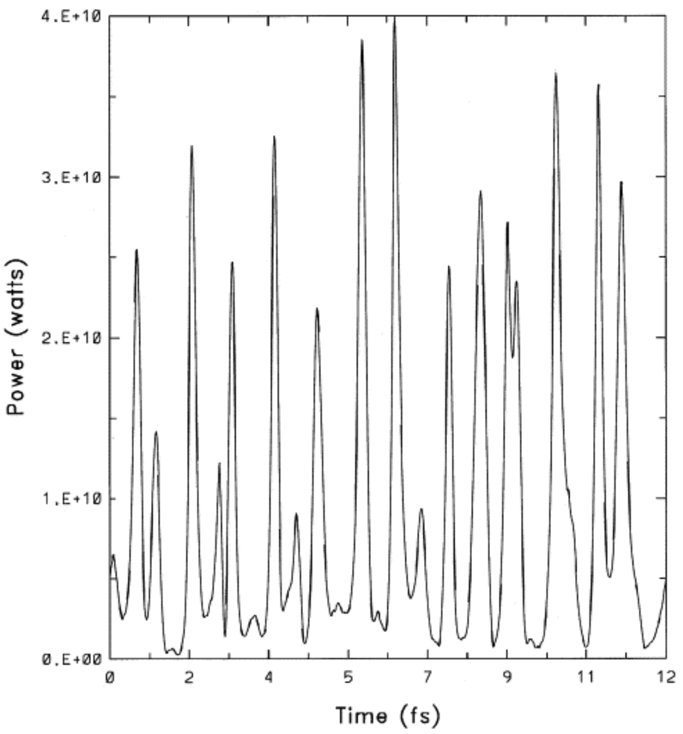
$$\text{emittance} = \frac{6\pi\left(\text{width}^2 - D^2\left(\frac{\mathrm{d}p}{p}\right)^2\right)}{B}$$

Emittance is conserved due to Liouville's theorem.

Microbunching

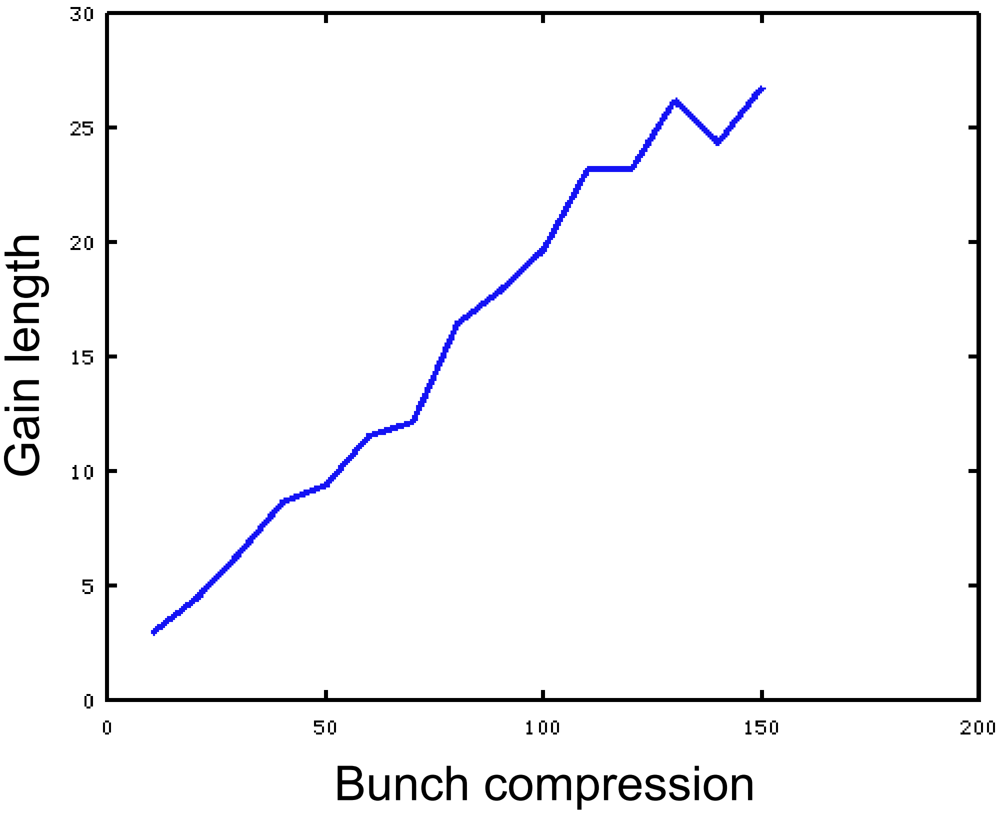


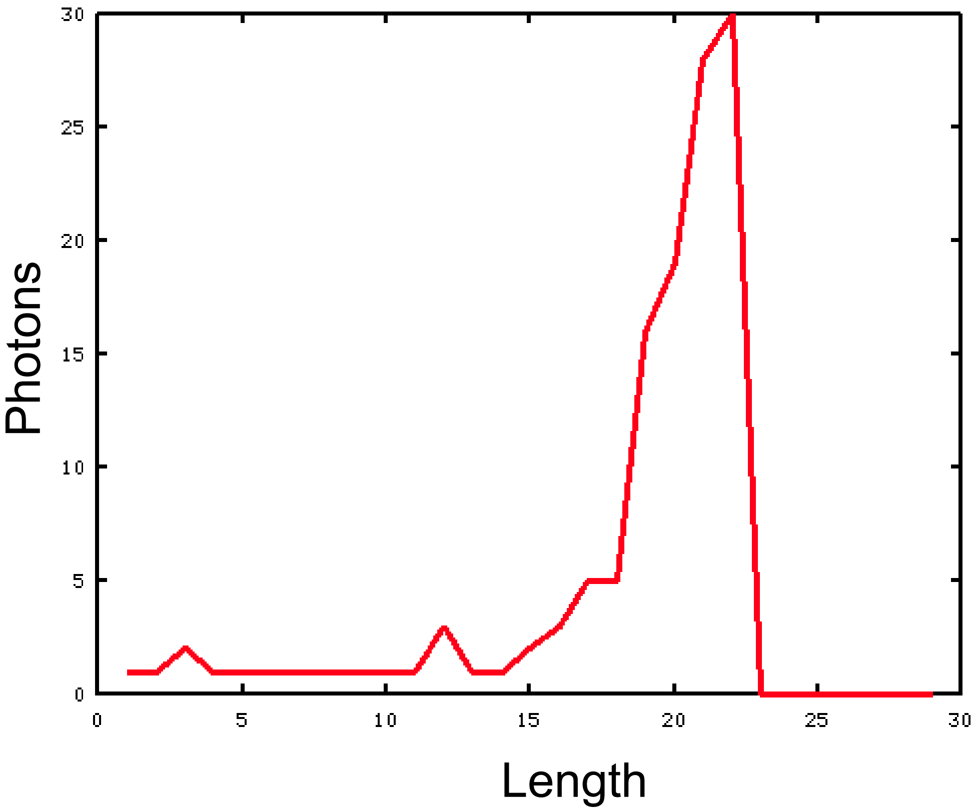
FLASH



LCLS

Student FEL: Microbunching

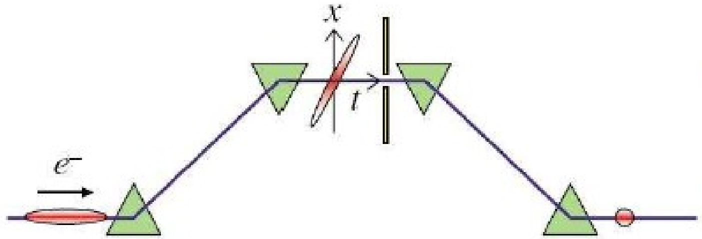




Attosecond pulses from FEL

	Emittance spoiler	Slicing wavelength	Slicing current	HC FEL seed	Energy chirp	Single spike
Pulse length	< 1fs	300 as	250 as	100 as	200 as	300 as
Photon per pulse	10^{10}	10^{8}	10^{9}	10^{6}	10^{10}	10^{8}
contrast	poor	poor	poor	good	good	excellent
Rep rate	LINAC	Laser seed pulse	Laser seed pulse	Laser seed pulse	Laser seed pulse	LINAC
synchronisa tion	NO	YES	YES	YES	YES	NO
stability	poor	-	-	-	-	poor
Diagnostics	OK	OK	OK	OK	OK	difficult

Emittance spoiler

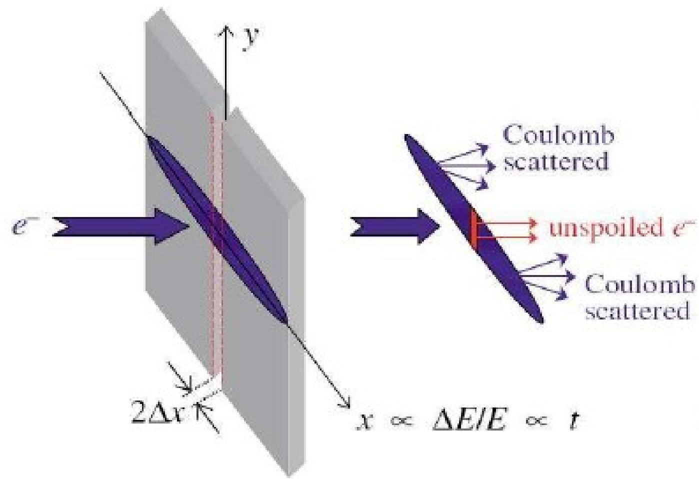


energy chirped e⁻ bunch

(off crest RF acceleration)

dispersive chicane

energy chirp → transverse displacement



slotted foil at the centre of the chicane

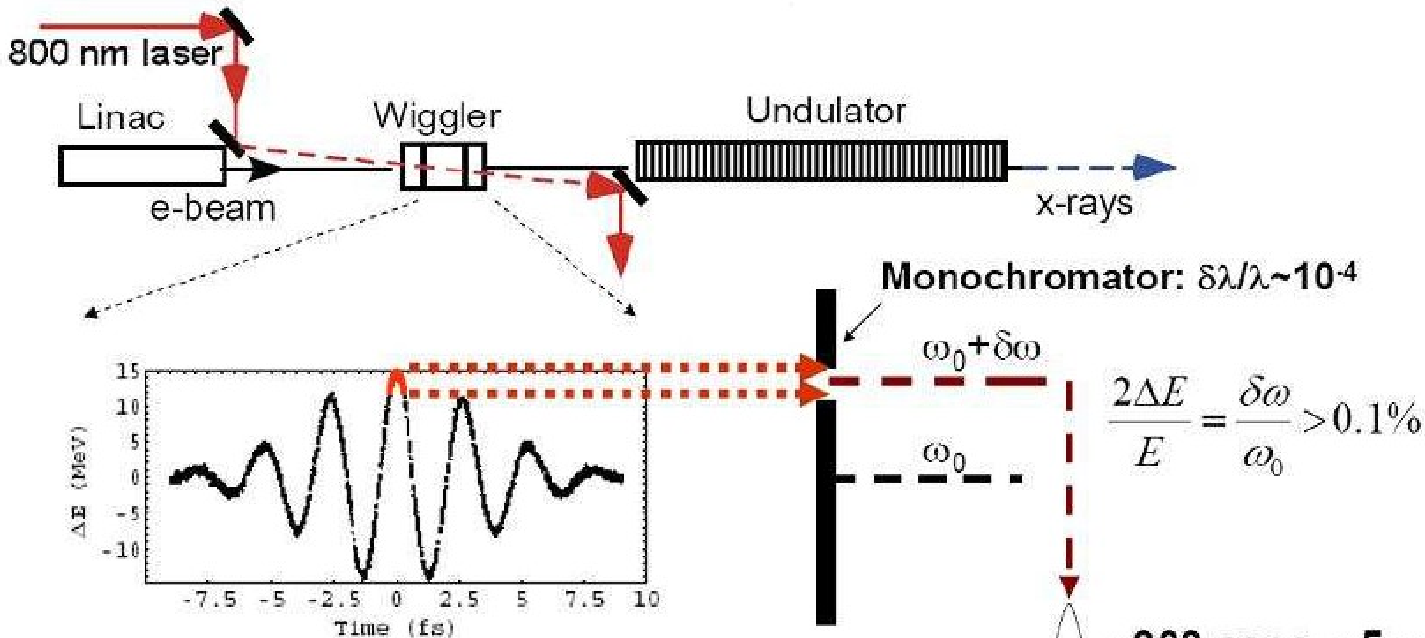
emittance is spoiled through the foil

except a narrow unspoiled slice

the spoiled part will not have beam quality to lase

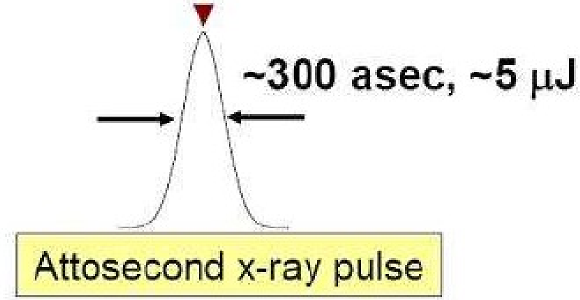
the central slice can still lase

Slicing: wavelength selection

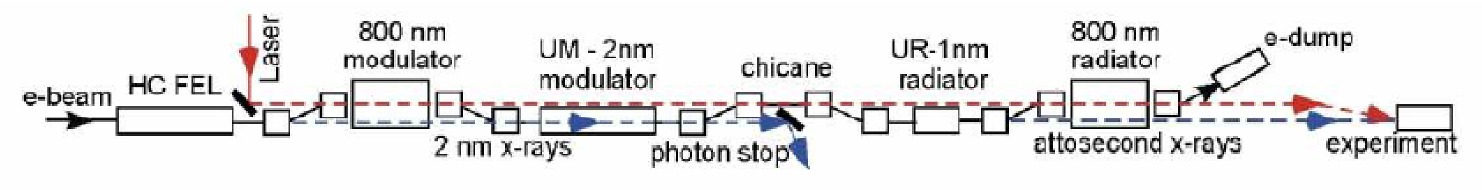


The laser needs to have sufficient energy per pulse

The modulation must ensure enough energy separation of the peak slice



Slicing: from Harmonic Cascade FEL



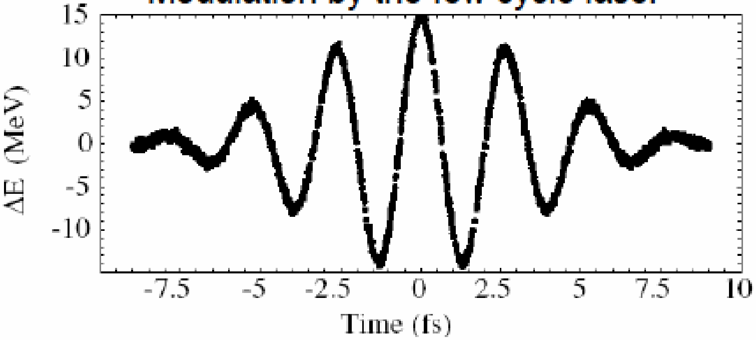
Based on the combination of a seed from an external few cycle pulse (800 nm) and an X-ray pulse from the Harmonic Cascade FEL (2 nm);

The few cycle pulse modulates the electron energy in the first wiggler

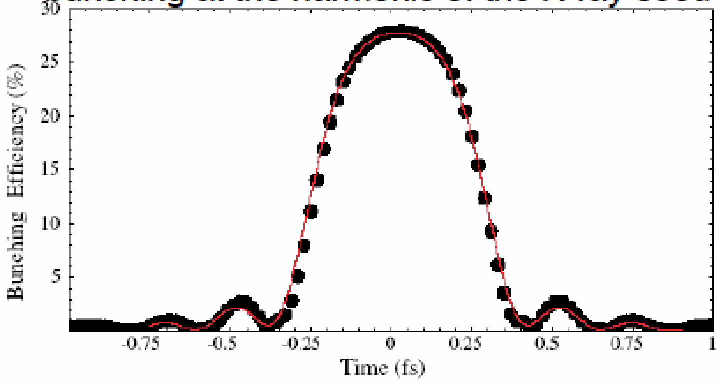
In a second modulator tuned at 2 nm the X-ray pulse is amplified and the electron bunch gets a modulation also at higher harmonic, e.g. 1 nm

A short radiation pulse at 1 nm wavelength is emitted in a third undulator and can be synchronised with the radiation from a fourth undulator

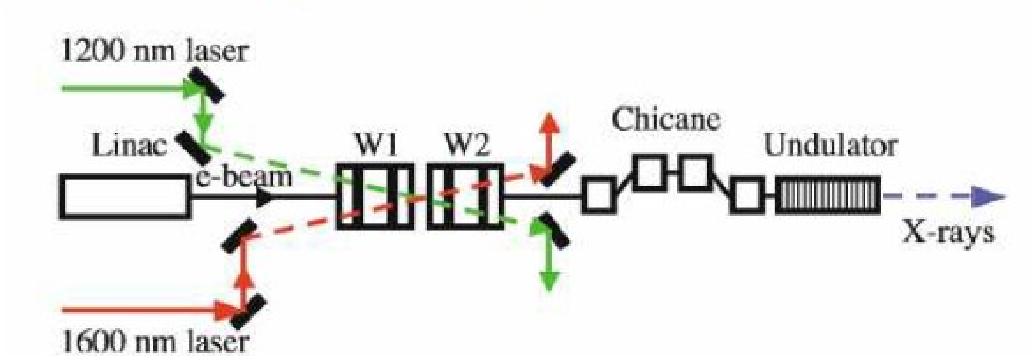
Modulation by the few cycle laser



bunching at the harmonic of the X-ray seed



Slicing: current enhancement



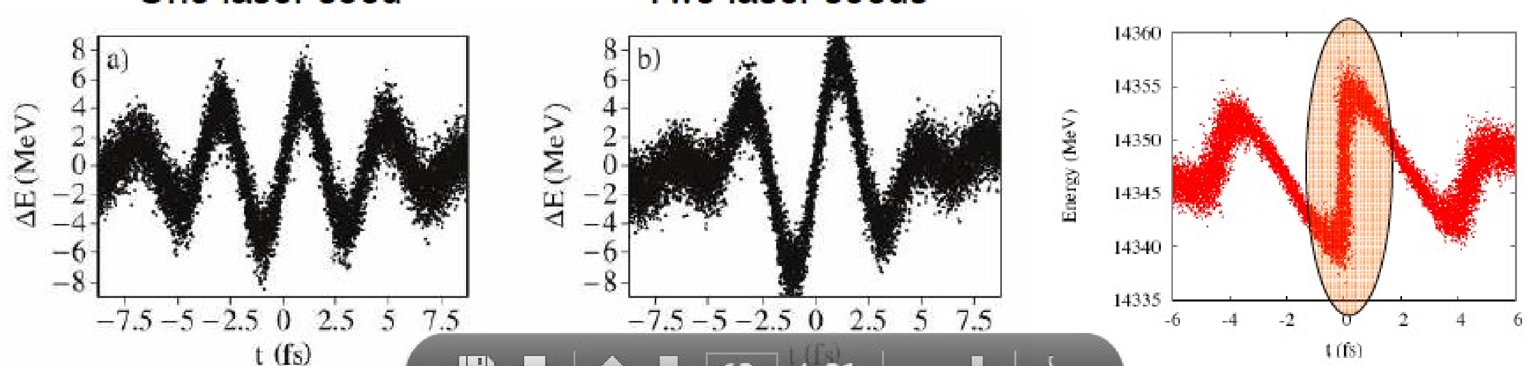
A magnetic chicane is placed before the undulator to enhance the microbunching

The energy modulation from the external laser is used to <u>enhance locally the peak current</u>; the laser needs to have sufficient energy per pulse

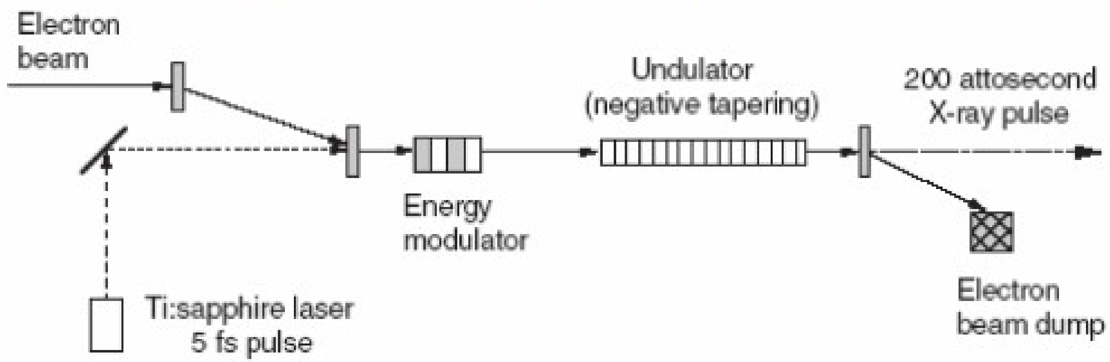
Two lasers are used to depress the adjacent peaks to obtain one clean pulse

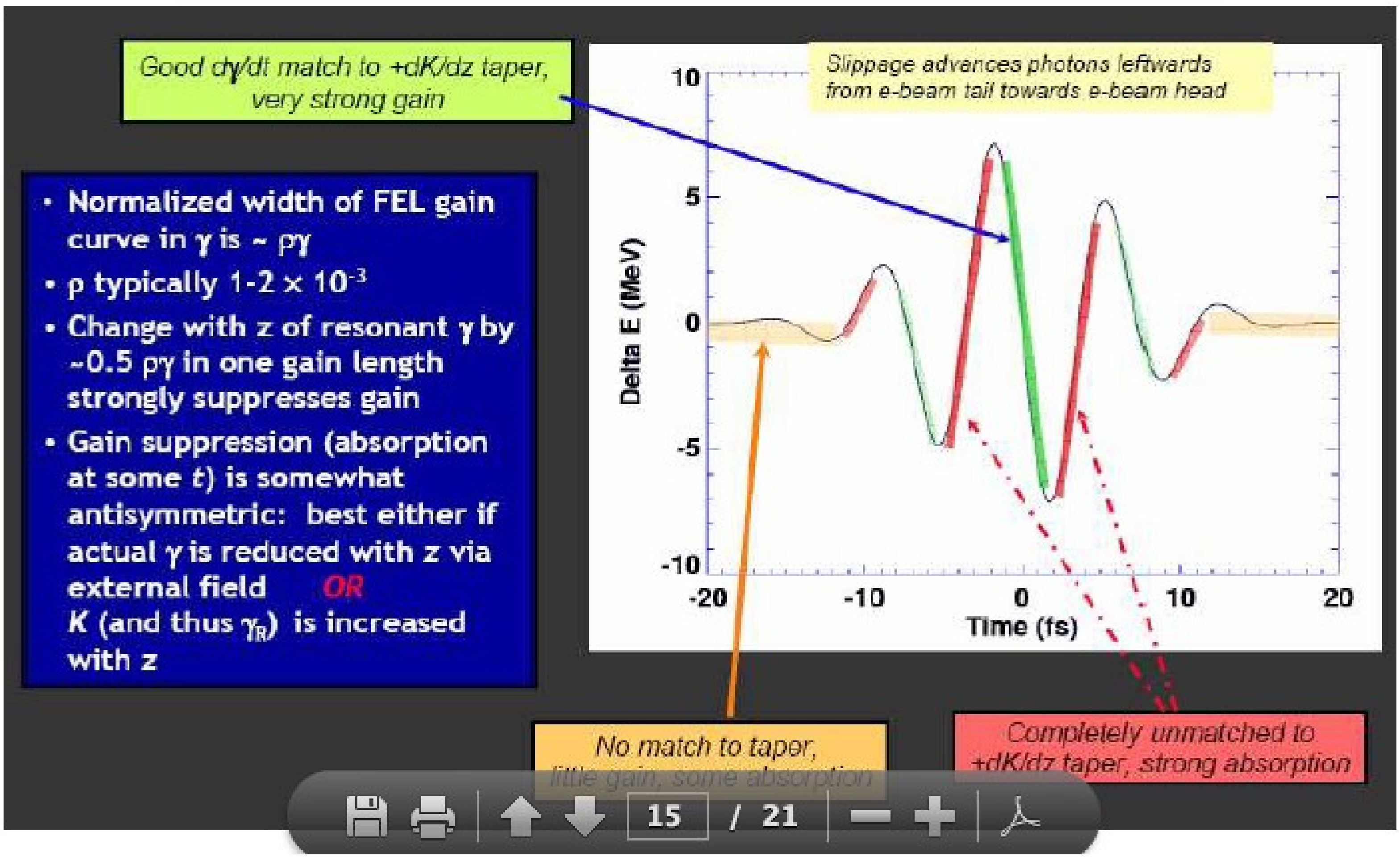
One laser seed

Two laser seeds



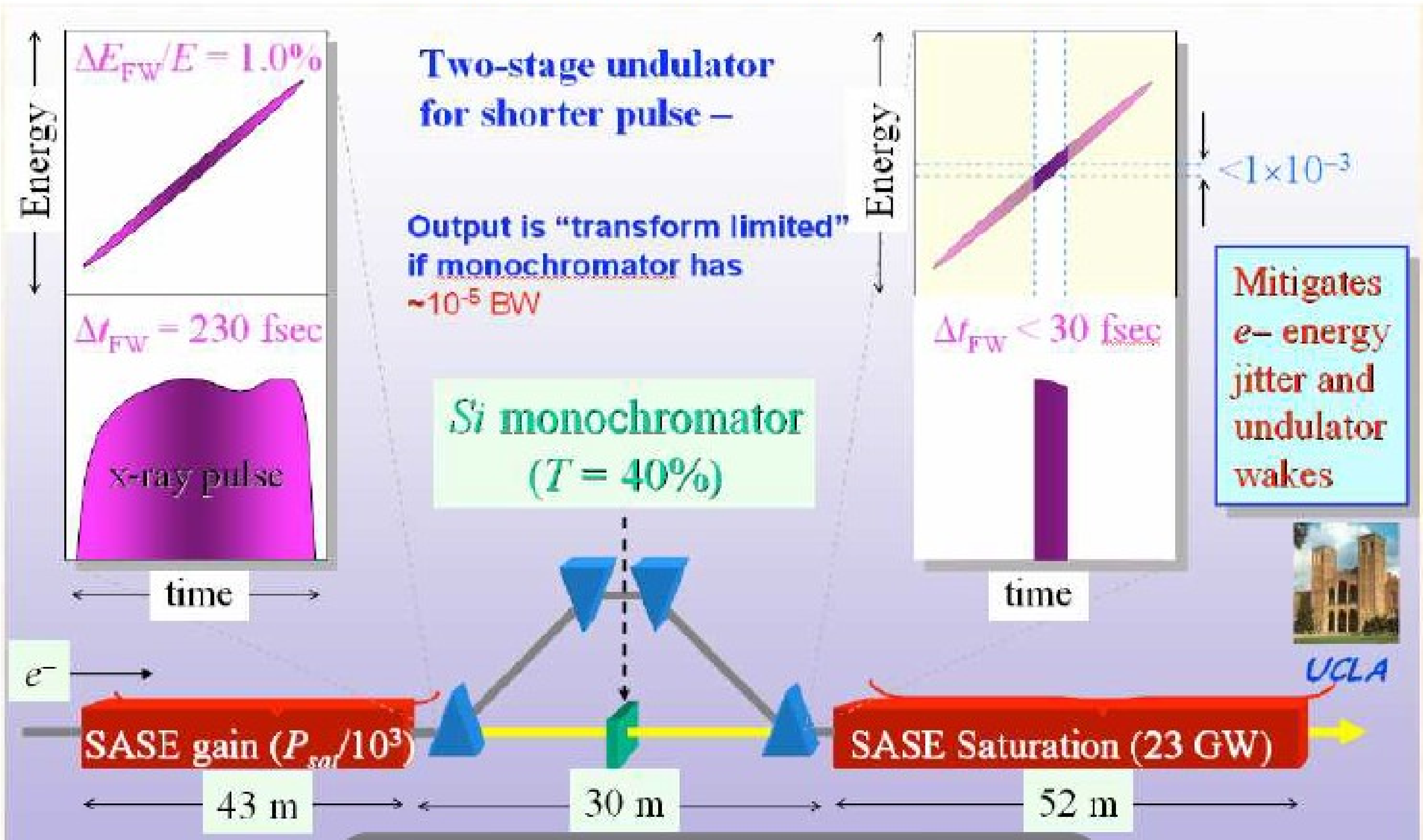
Slicing: energy chirp revisited





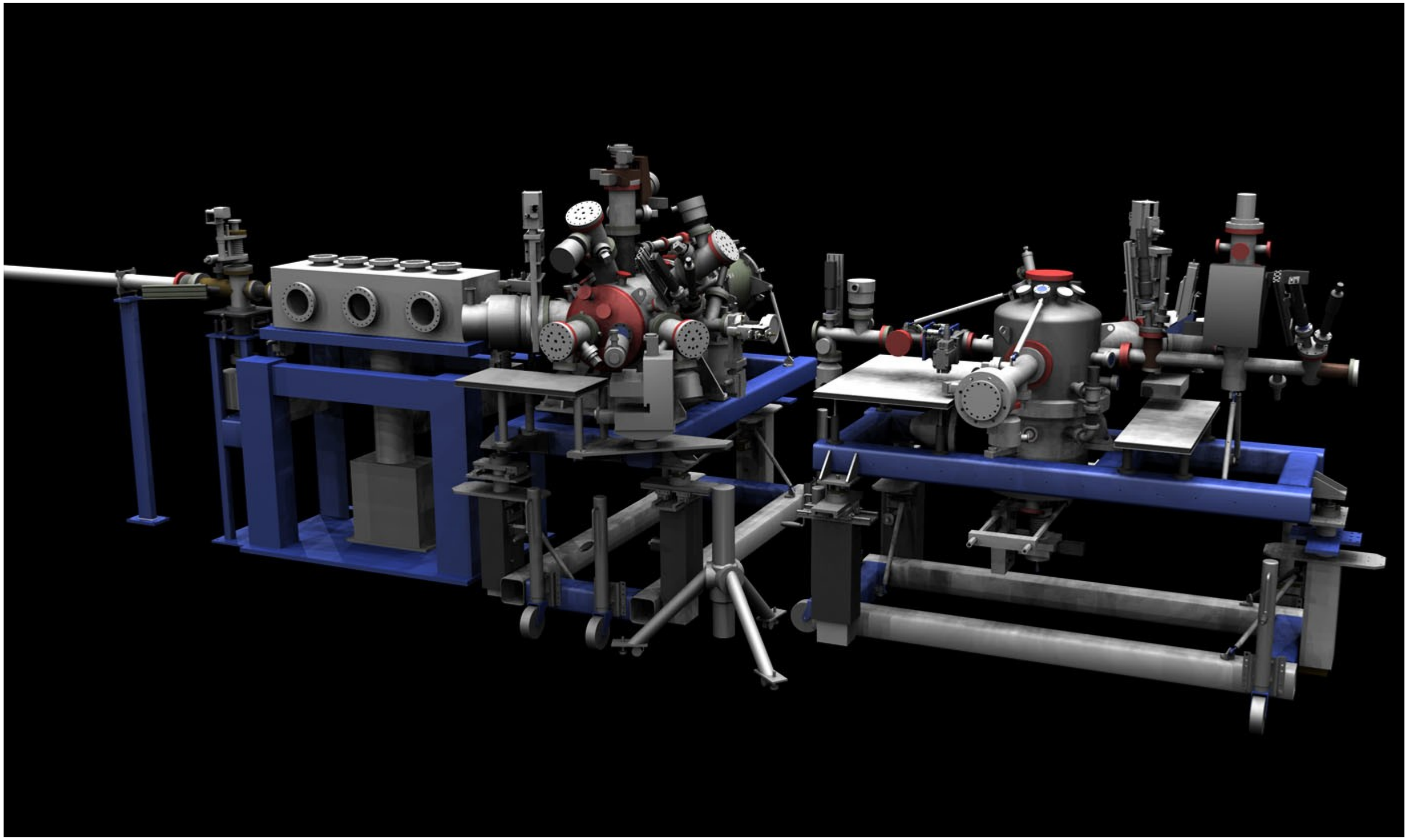
Energy chirp

An energy chirped electron bunch emits a frequency chirped pulse in the first undulator. The pulse from the first undulator is sliced in a monochromator and acts as a seed for the second undulator

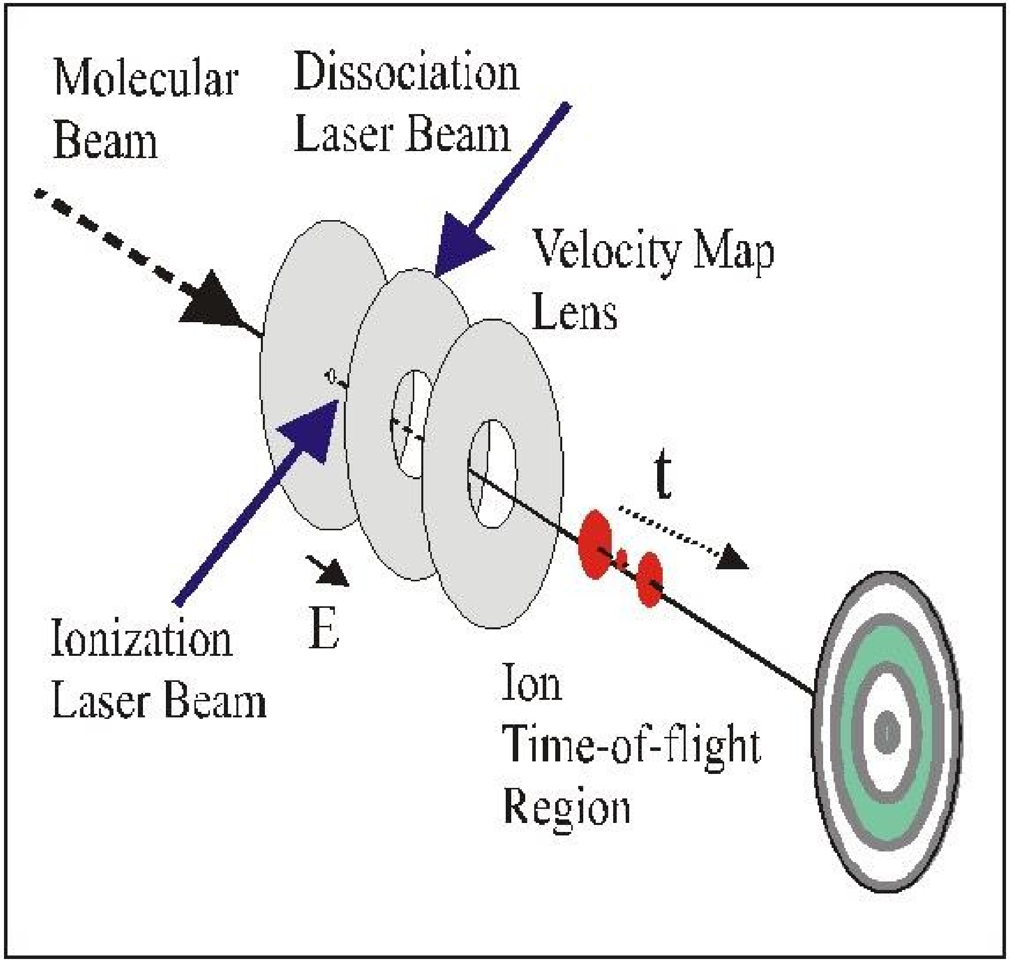


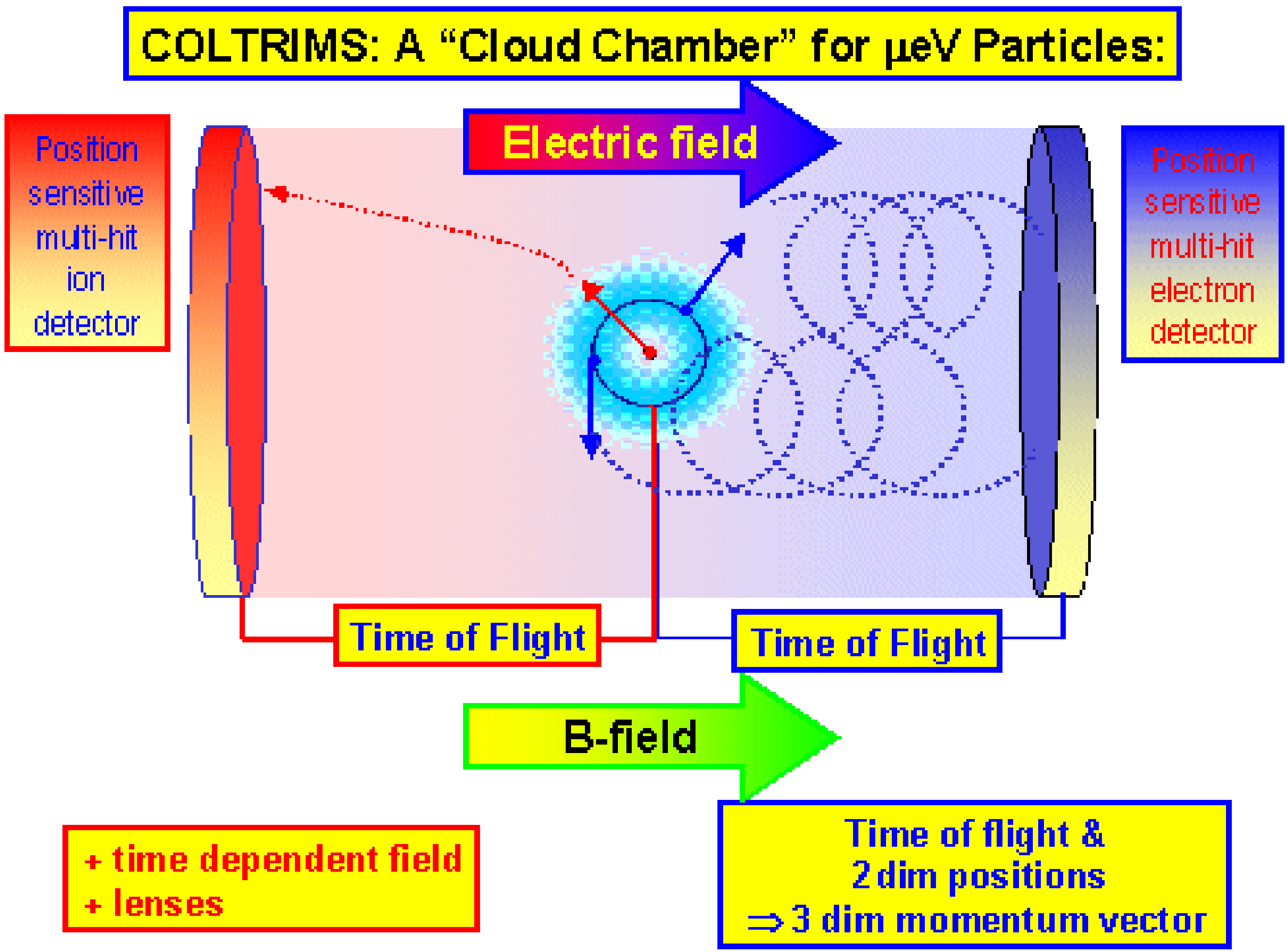
20 / 21

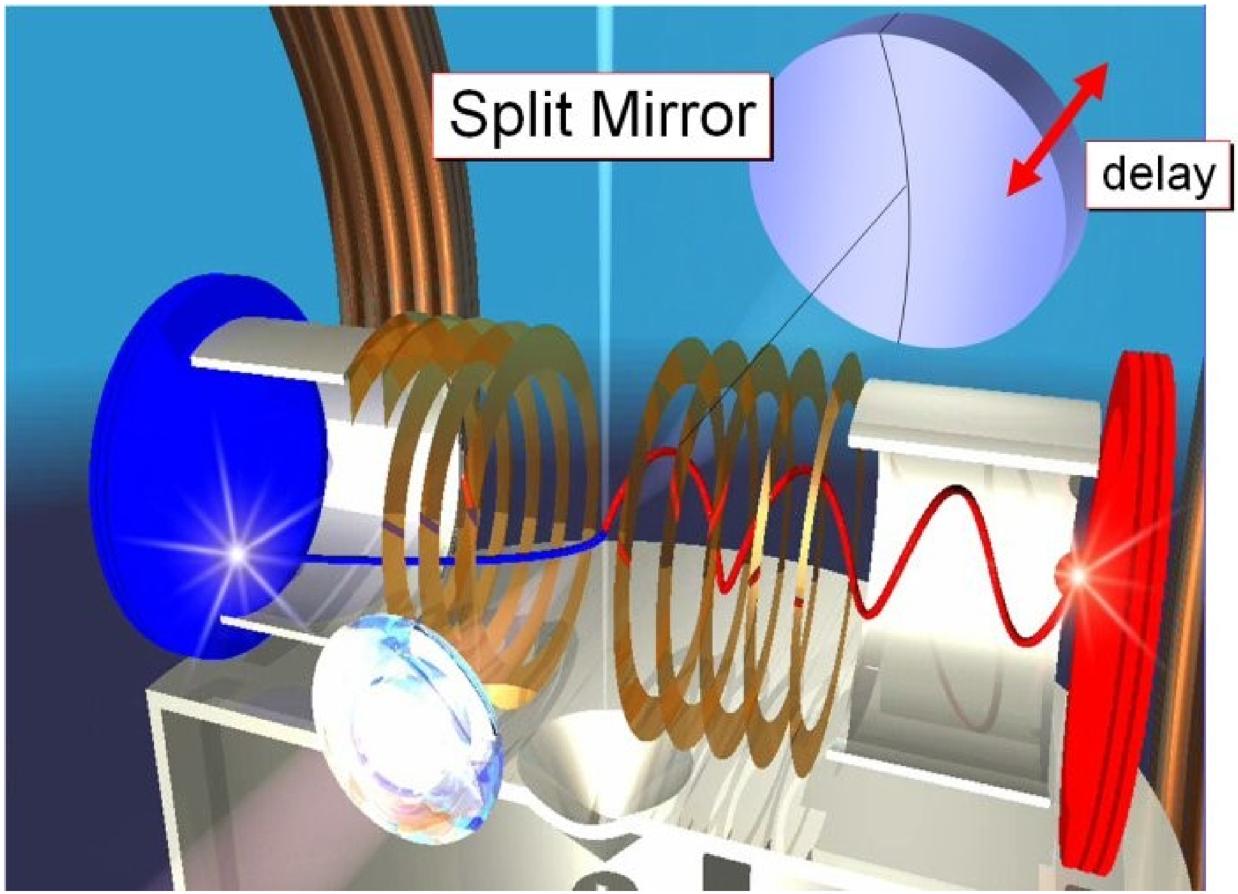
LCLS AMO station



Velocity map imaging




COLTRIMS: A "Cloud Chamber" for µeV Particles:
Electric field
Position sensitive multi-hit ion detector
Position sensitive multi-hit electron detector
Time of Flight
Time of Flight
B-field
+ time dependent field
+ lenses
Time of flight &
2 dim positions
⇒ 3 dim momentum vector


Split Mirror
delay