Coherent Synchrotron Emission in Ultraintense Laser Foil Interactions

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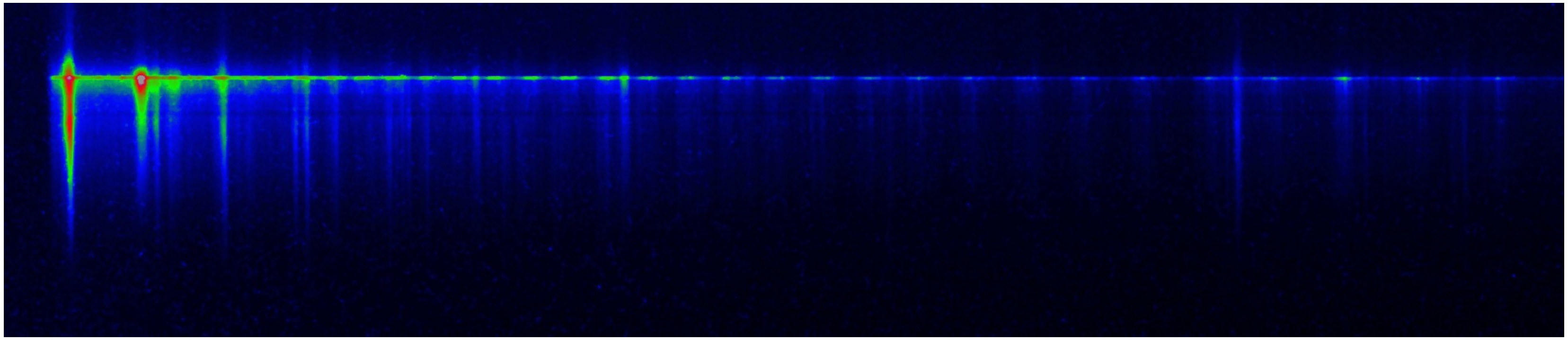

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- D. Jung
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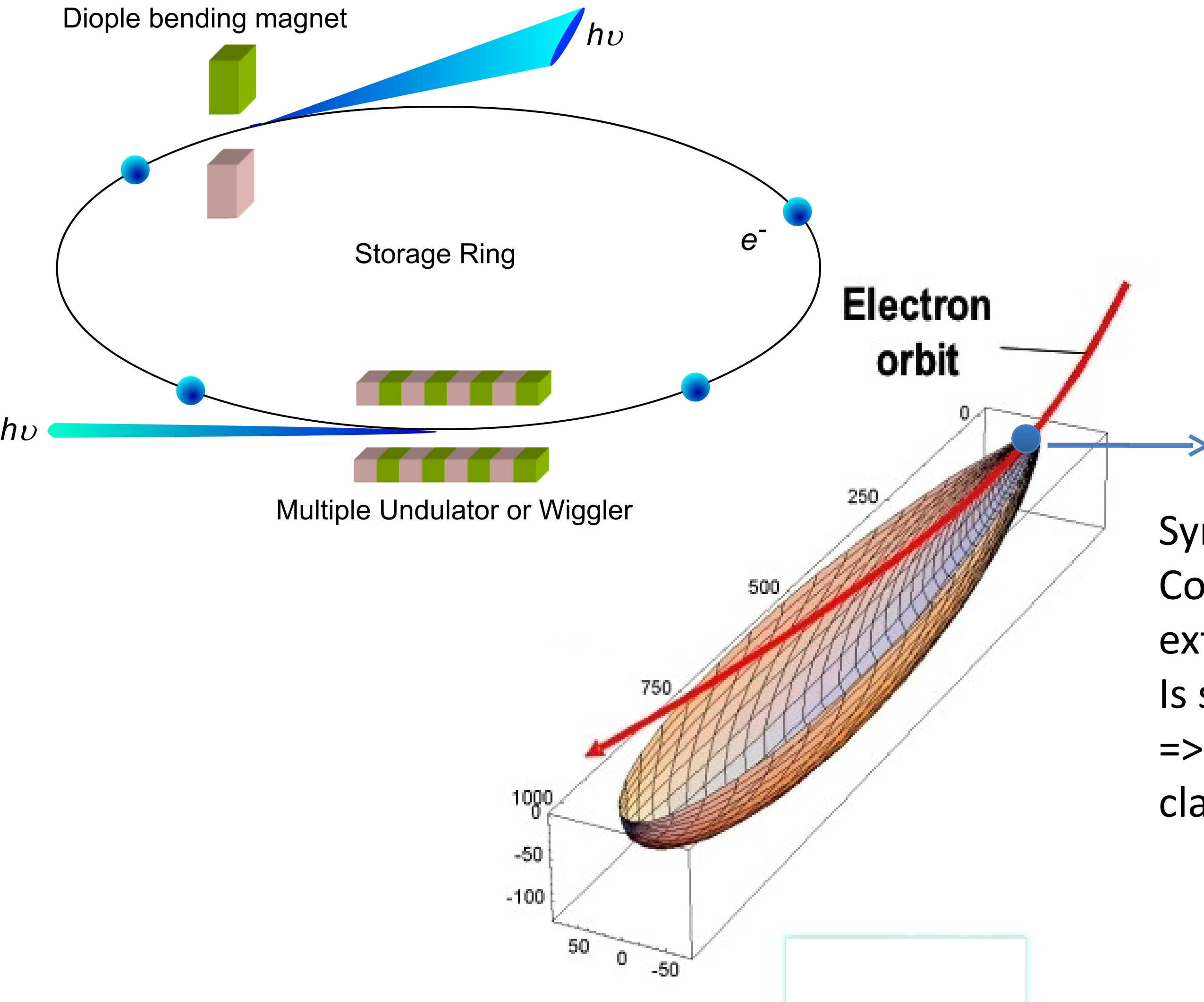
Coherent Synchrotron Radiation

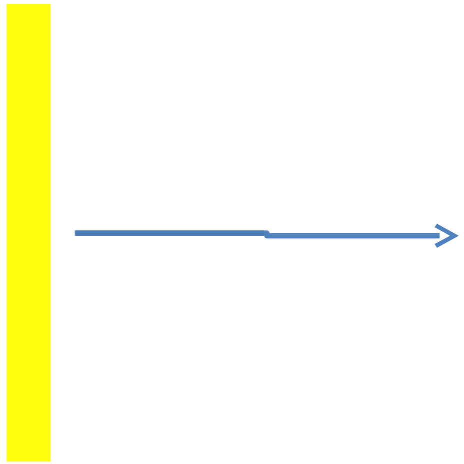


Synchrotron radiation is Coherent when the spatial extent of the electron bunch Is smaller than one wavelength => Typically not true for classical accelerators

Typical approach: Storage ring with bending magnets => incoherent
Laser driven trajectories and nanobunches => coherent process possible

Relativistic plasma harmonics in transmission

I~1020Wcm2
a0~10

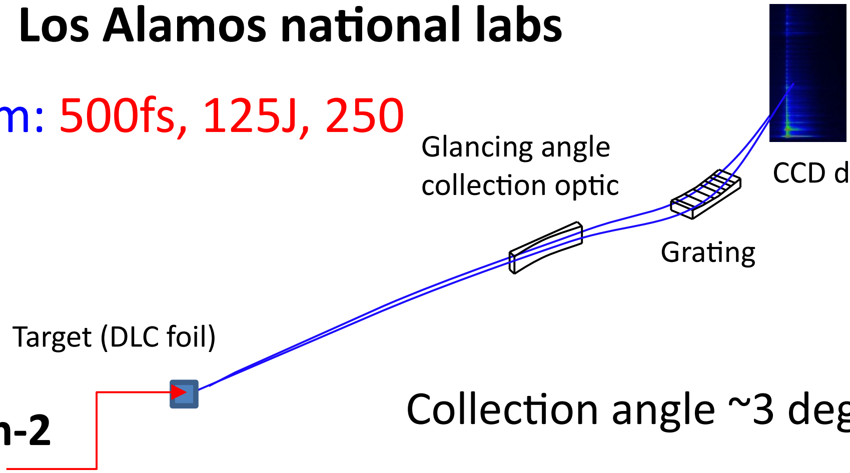


Trident laser - Los Alamos national labs

Shortpulse-Beam: 500fs, 125J, 250 TW (1054nm)

F/3 focusing

Int: 4 ×1020 Wcm-2

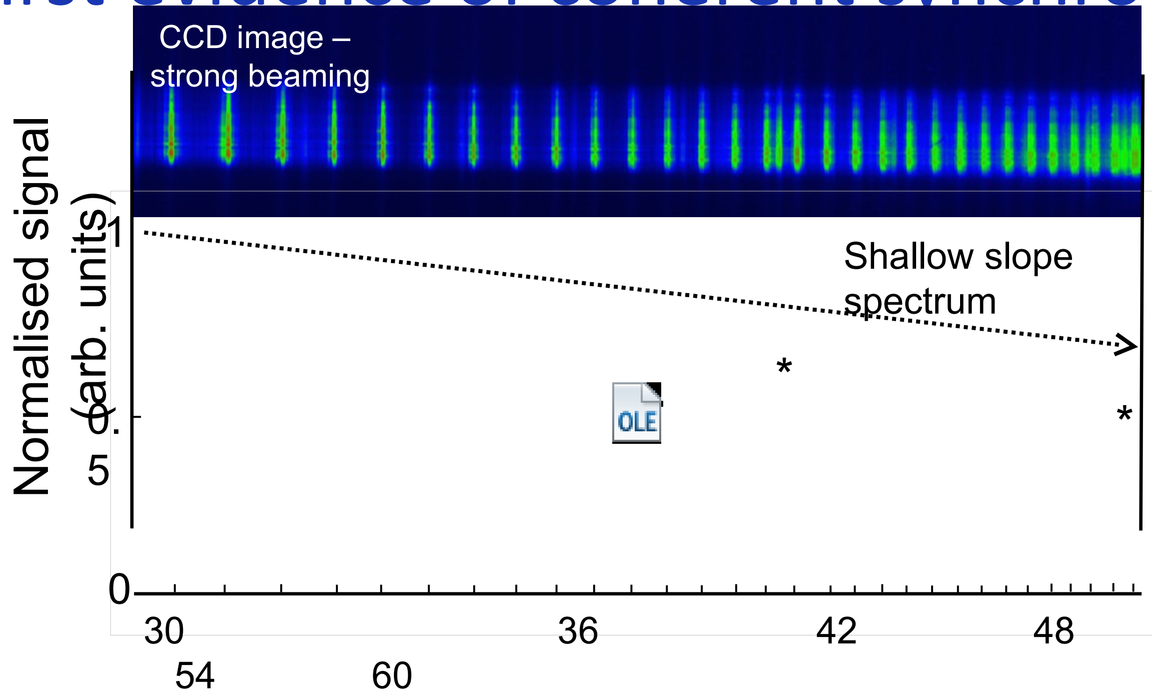


Collection angle ~3 degree

Theoretical low frequency cut off for DLC
- 28th order

Harmonic spectrum in transmission

- first evidence of coherent synchrotron emission



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Coherent synchrotron emission from electron nanobunches formed in relativistic laser–plasma interactions

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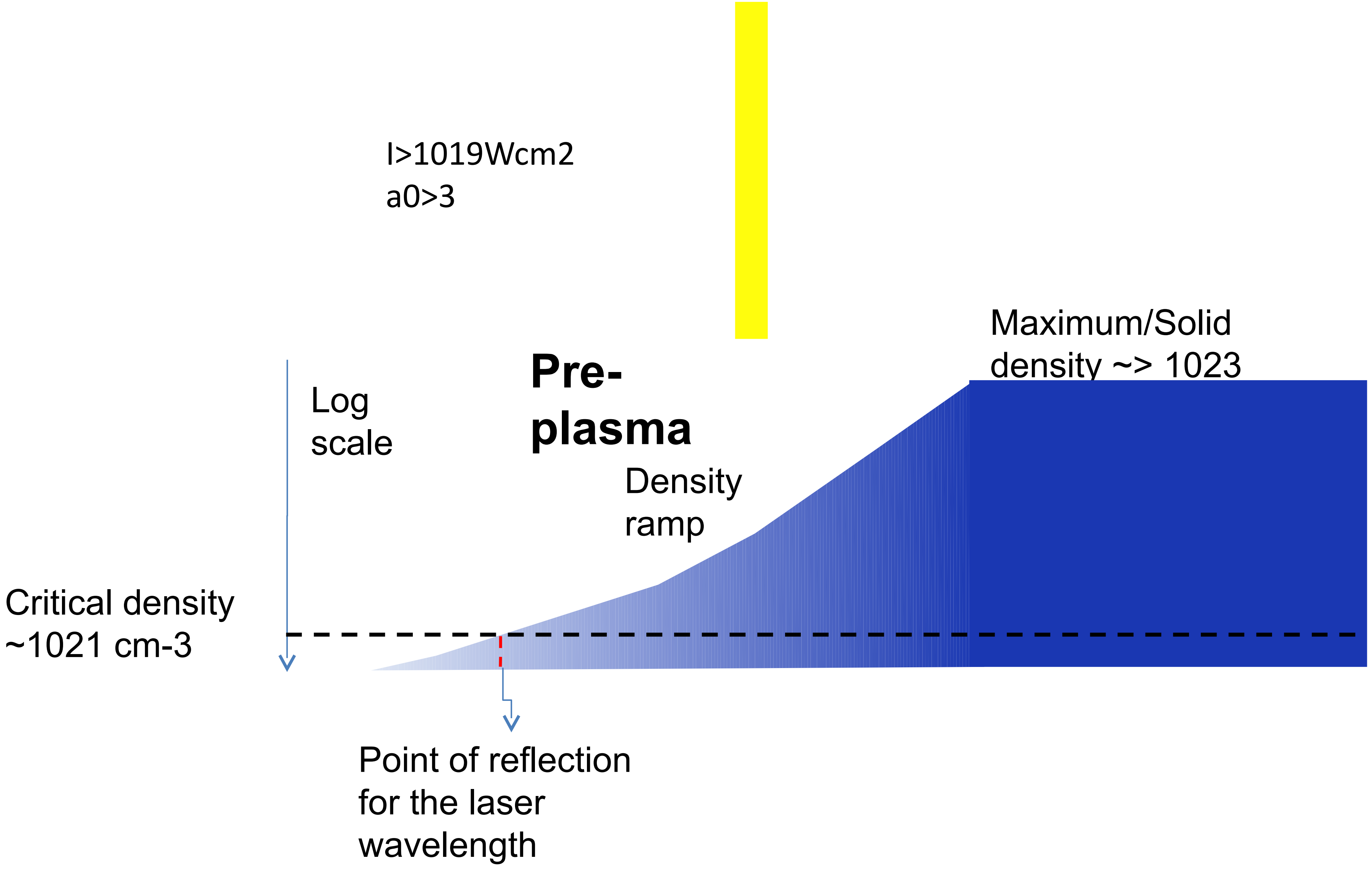
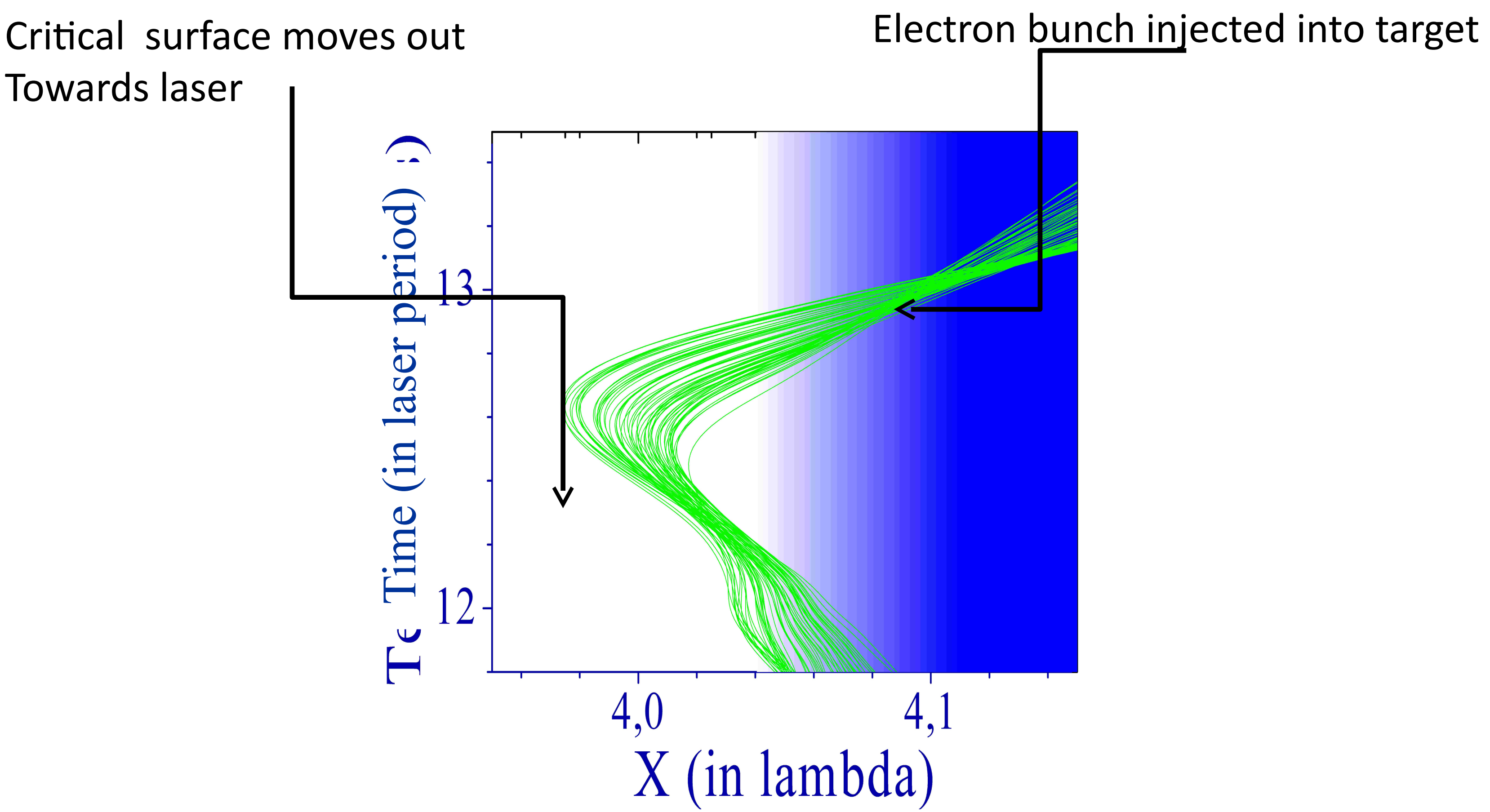
The relativistic plasma medium - bulk



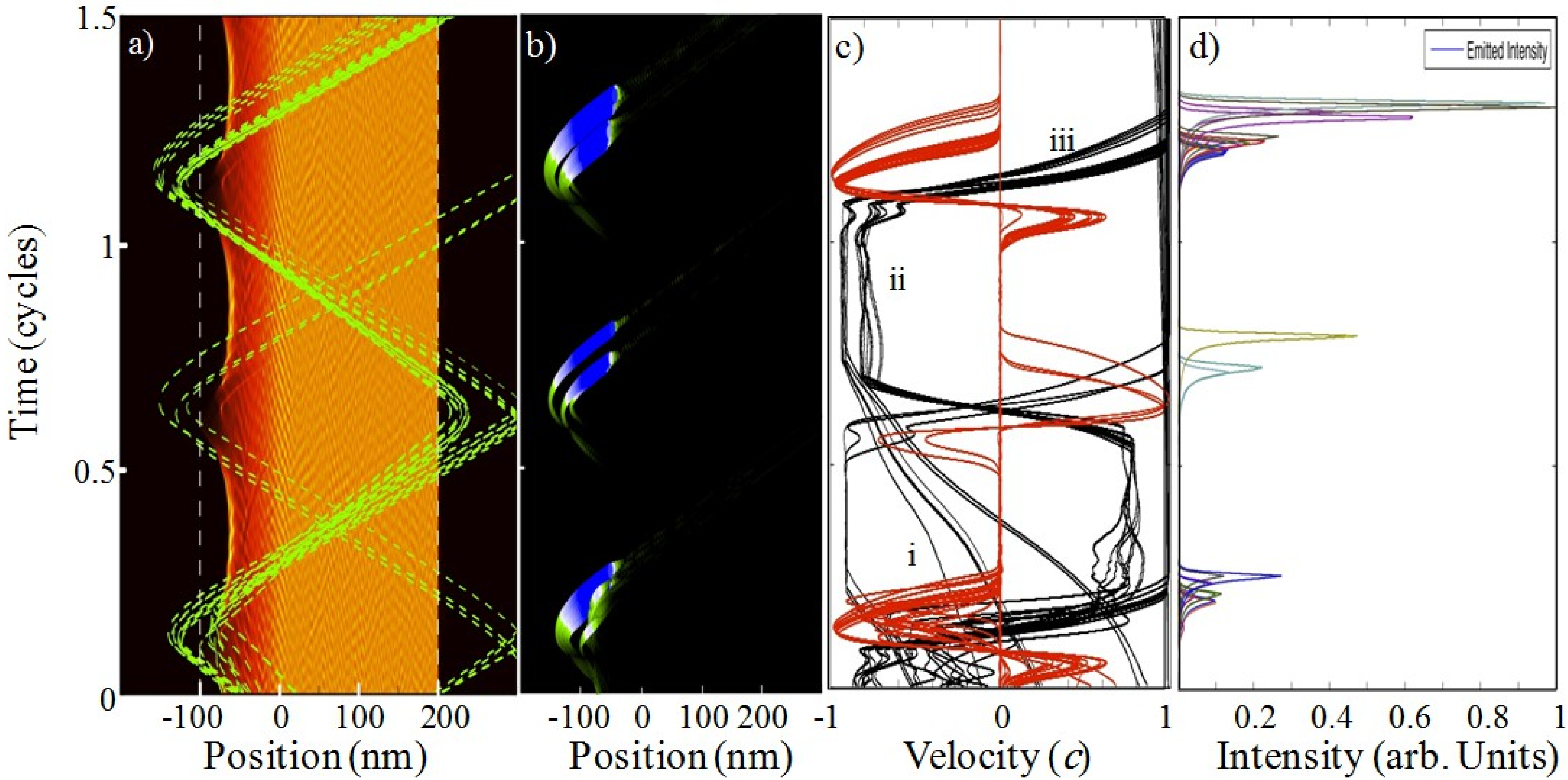
Relativistic electron dynamics – PIC simulation



CSE in transmission

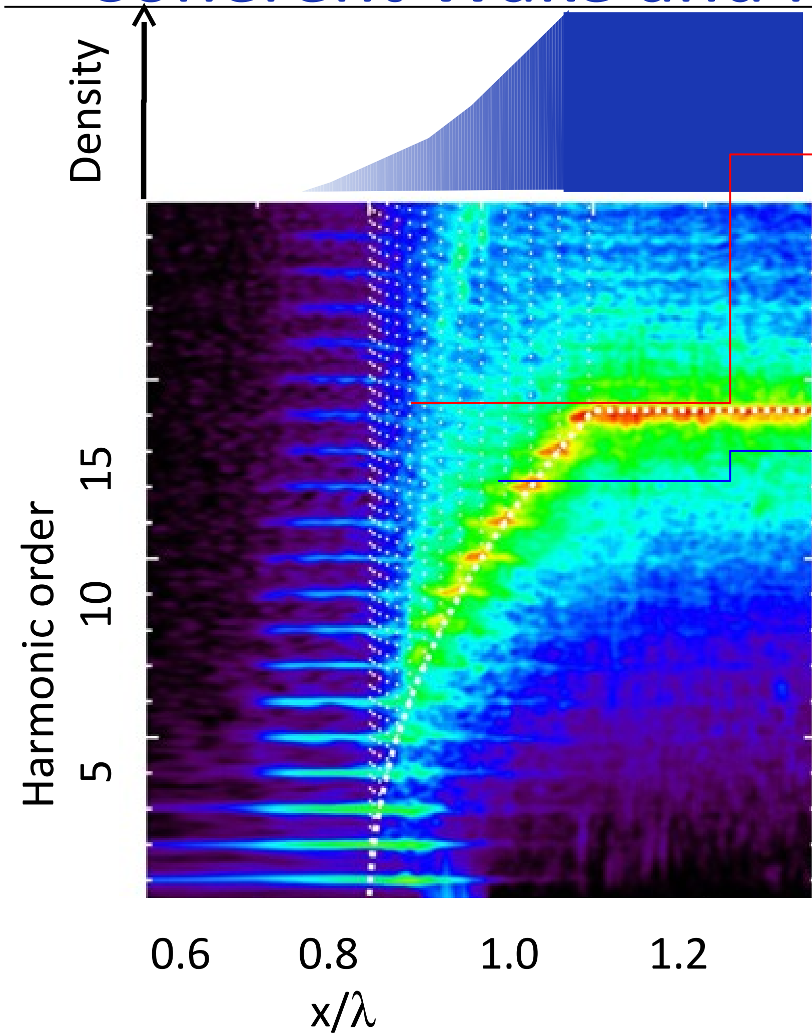
Overview of the mechanism - 1-D simulations

A few cycle super Gaussian pulse, normal incidence on a 200nm thick solid density (800Nc)



Bursts of intense, sub laser cycle laser emission - CSE

Competing Mechanisms – Coherent Wake and Relativistic Oscillating Mirror.

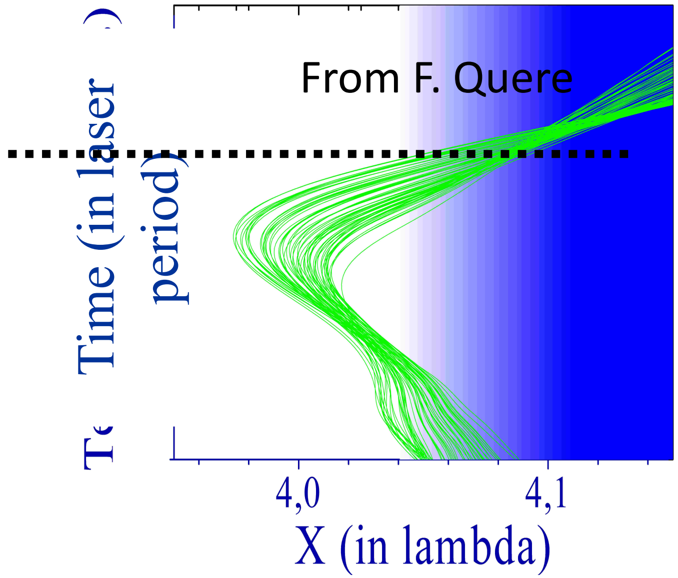


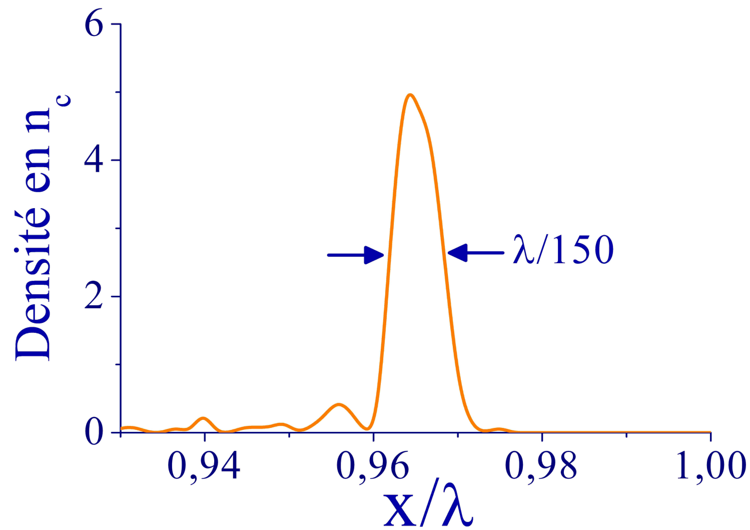
Also: emission at Ncrit surface: –
extends to much <u>higher</u> orders
Relativistically Oscillating Mirror

CWE Emission from overdense plasma
At density nq=q2ncrit
Highest order limited by maximum
Plama frequency.

Note: CWE is not possible for normal incidence

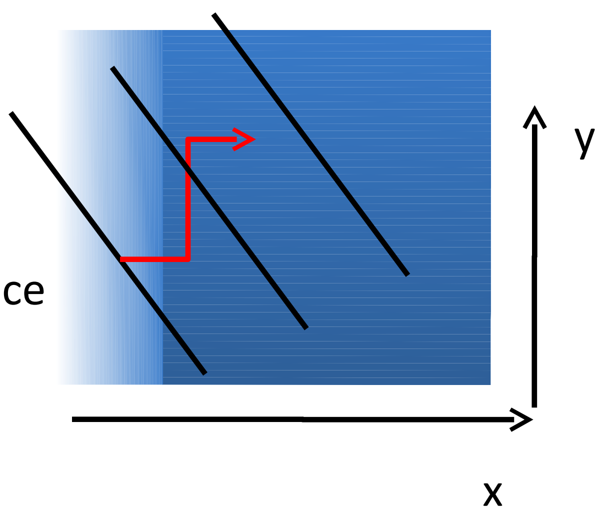
Competing mechanisms –
Coherent Wake Emission (CWE)





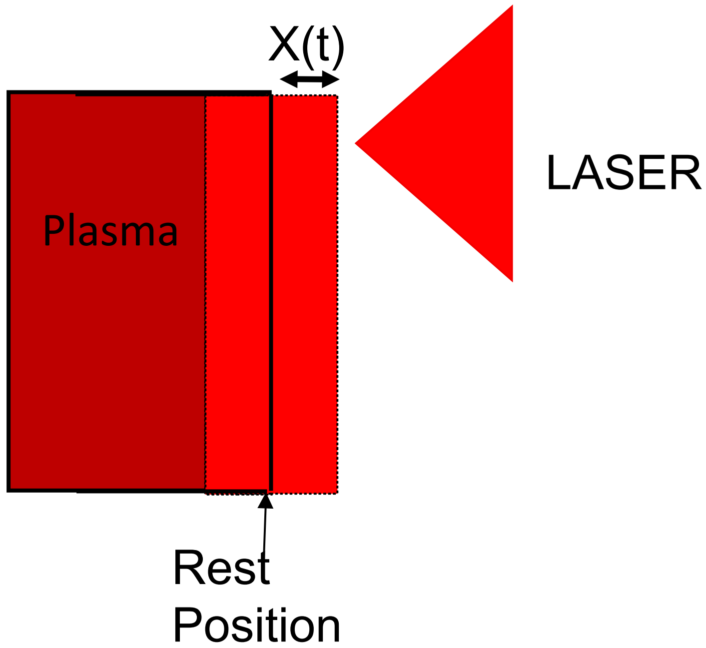
Electron bunches
Injected each
laser cycle

Oblique incidence
Is essential!



Competing Mechanisms –

Relativistic Oscillating Mirror - ROM



Harmonics above the plasma frequency emitted by Relativistic Oscillating Mirror:

Plasma surface oscillates periodically towards laser

Doppler-Upshift

max Frequency ~81/2γ 3ω 0

1)Upshifting is restricted to a short time Δτ~T0/   max.

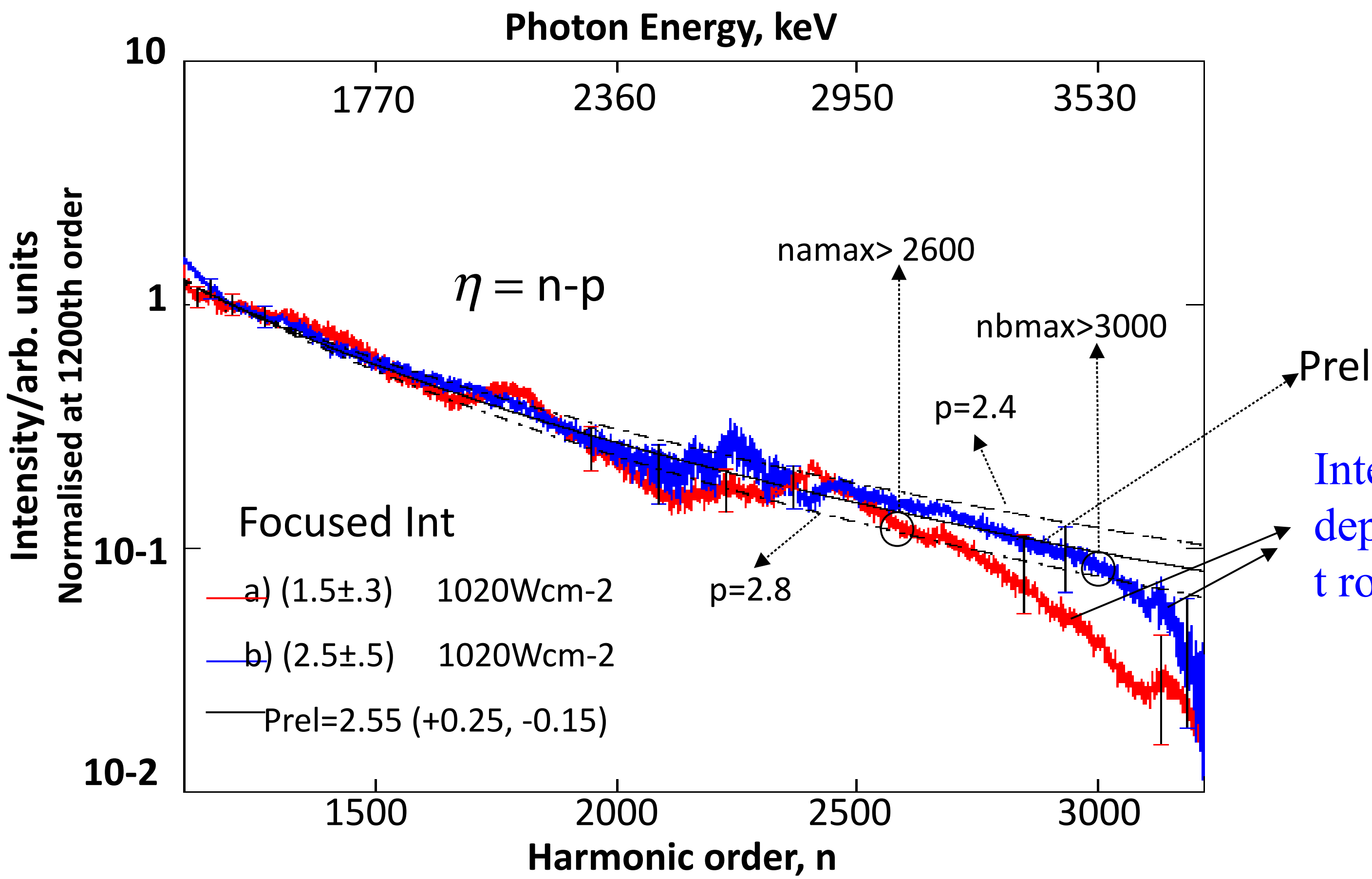
2)The upshifted pulse has a duration of O~ Δτ/   ~ T0/

From Fourier theory, the spectrum must extend to frequencies O~

Competing Mechanisms –

Relativistic Oscillating Mirror - ROM

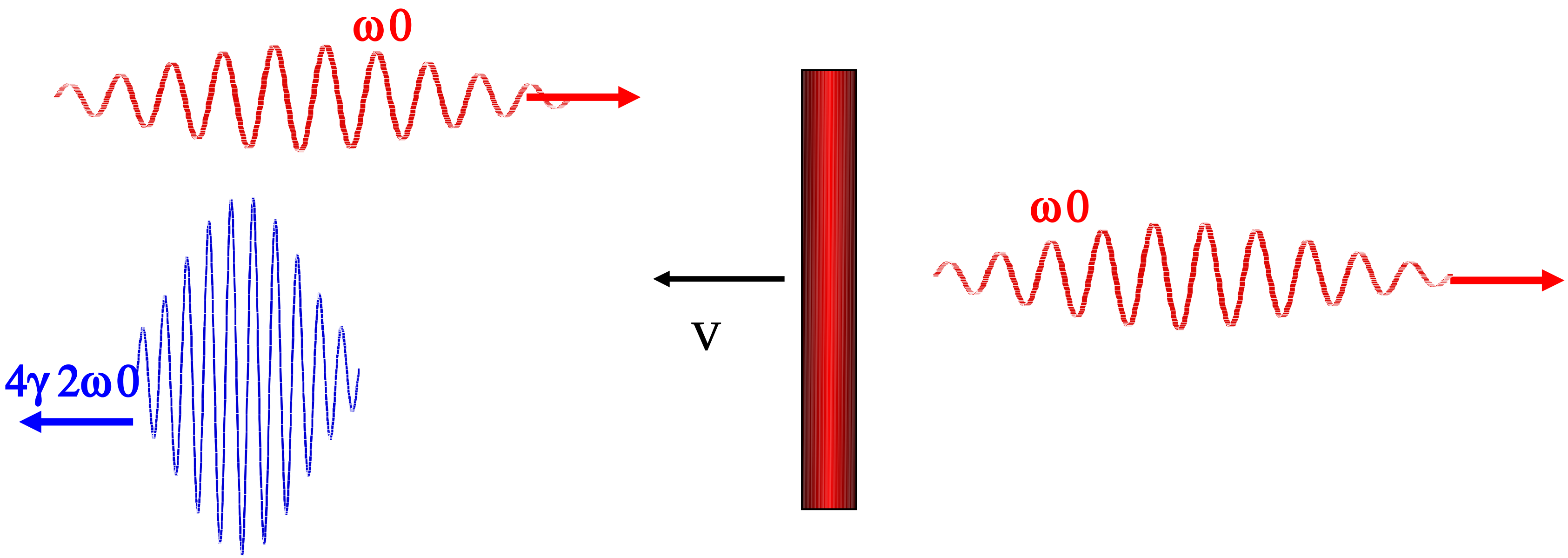
keV ROM harmonics and the efficiency roll-over



Intensity dependent rollover

B. Dromey *et al*., ***Phys*. Rev. Lett. 99, 085001 (2007)**

But ROM cannot produce upshifted light in transmission



Doppler upshift cancels in transmission – ROM mechanism
Cannot generate photons in the transmitted direction!

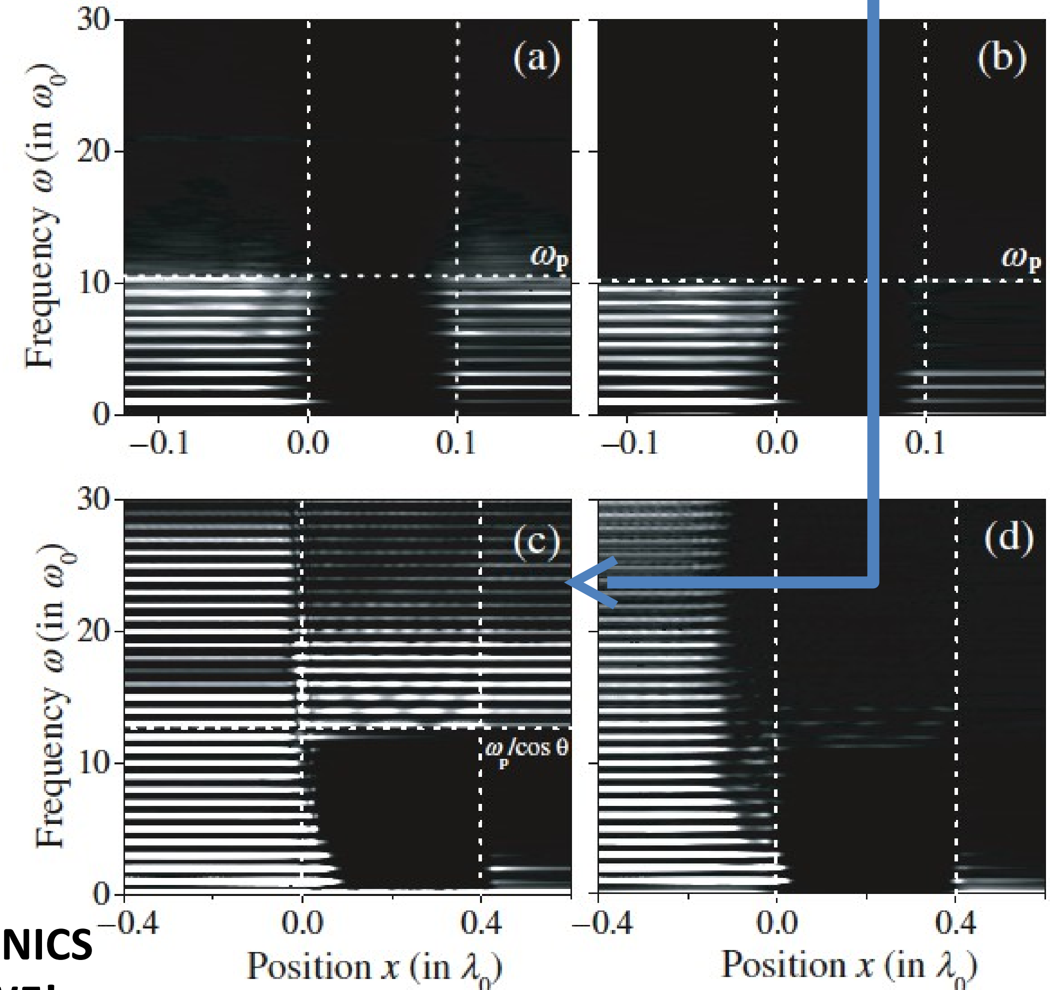
What causes Harmonics above ωp in transmission?

PIC simulations show different coherent processes.

OBLIQUE INCIDENCE

So what's this ?

a0=0.5
LF=0.02
LR=0.01
FRONT CWE
REAR CWE



a0=0.5
LF=0.02
LR=0
FRONT CWE
NO REAR CWE

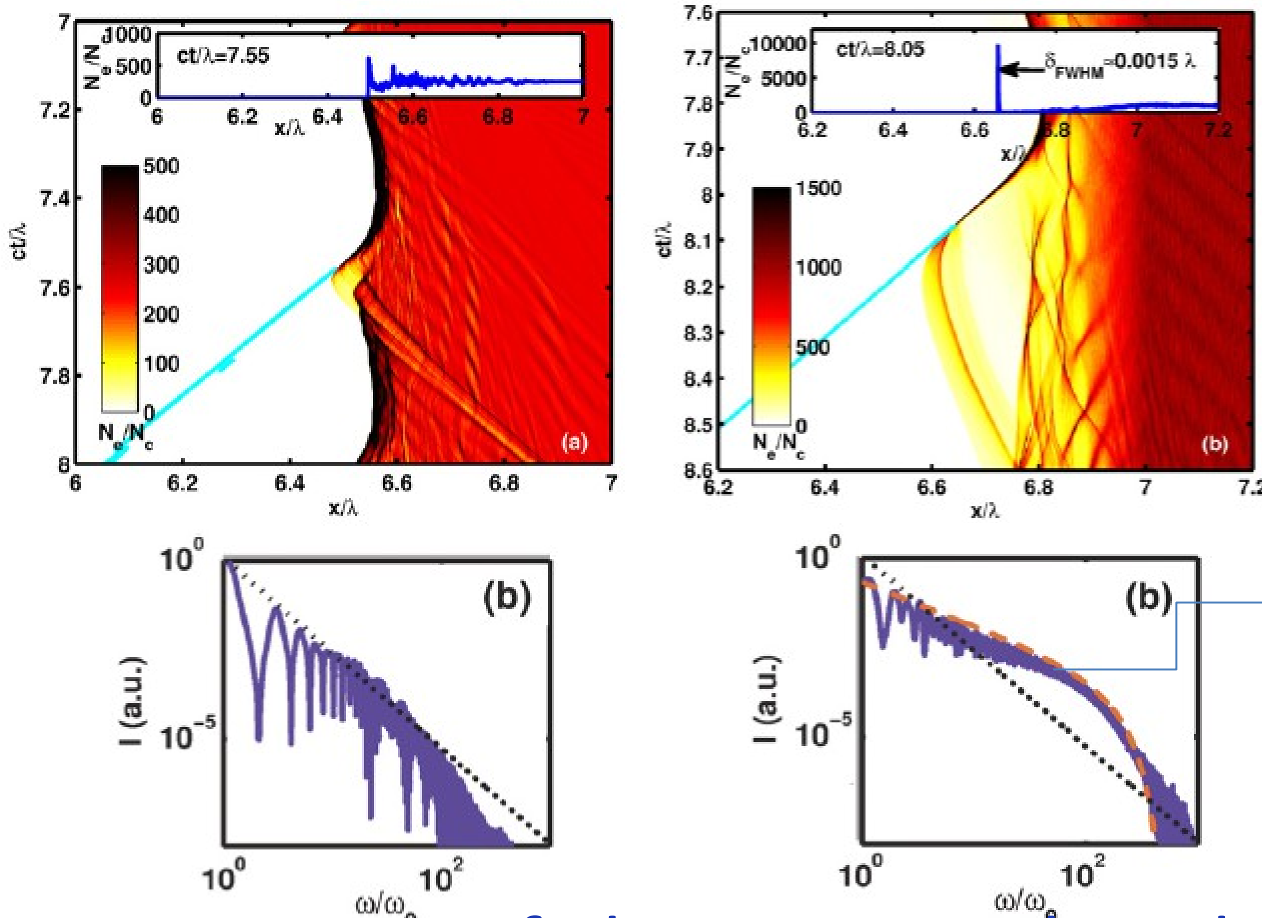
a0=9
LF=0.01
LR=0
FRONT ROM
NO REAR CWE

+REAR HARMONICS
Not ROM or CWE!

a0=9
LF=0.06
LR=0
FRONT ROM
NO REAR CWE
NO REAR Harmonics

From Quere et al. New Journal of Physics 2009

Coherent Synchrotron Emission

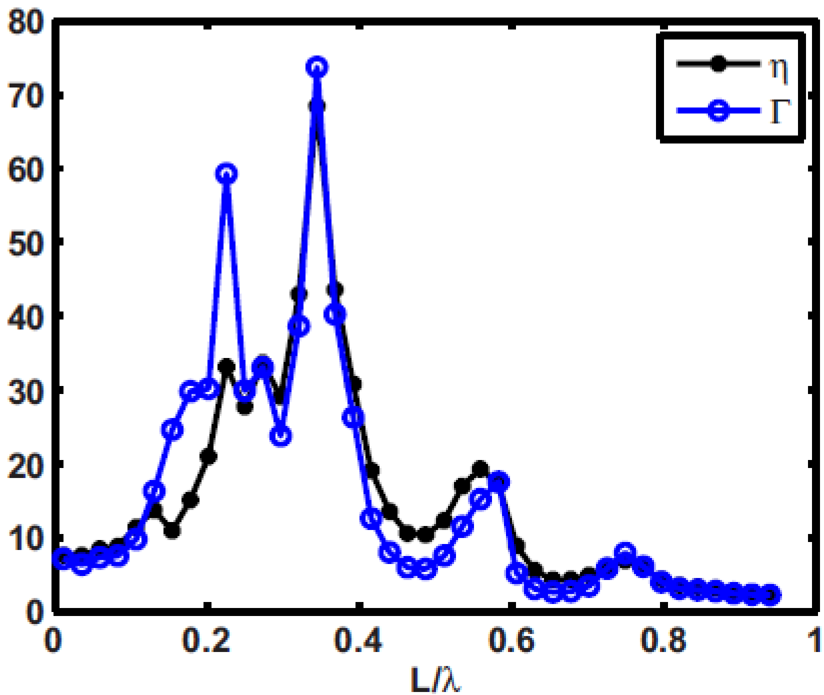


Shallower than
In n-8/3 ,
steeper cut off

Formation of electron nanobunches
CSE – but here in reflection
Problem: Competing mechanisms

Pukhov, A., *et al.*, **Plasma Phys. Control. Fusion 52** 124039 **(2010)**

The role of plasma scalelength



For the coefficients = 1

ROM like spectra

For the coefficients >>1

CSE like spectra

An der Brugge, D., Pukhov, A., **Phys. Plasmas 17**, 033110 (2010)

For longer laser pulse lengths (typically 50fs – 500fs)

- require ultrahigh contrast pulses

The mechanisms of harmonic generation

	Scalelength (units of laser wavelength)	Intensity (Wcm-2)	Geometry	Spectrum Scaling	Origin
Coherent Wake emission	<<1	>1016	Oblique Incidence only	Depends on plasma gradient	Density waves driven by electron bunches
Relativistically Oscillating Mirror	0.1< <~1	>~1018	Normal and Oblique	*In 1/n8/3 @a0>>1*	Relativistic Doppler effect at surface
Coherent Synchrotron Emission	0.1< <~0.5	>> 1018	Only Oblique studied to date	*In 1/n4/3*	Relativsitic electron nanobunches electrons performing trajectories

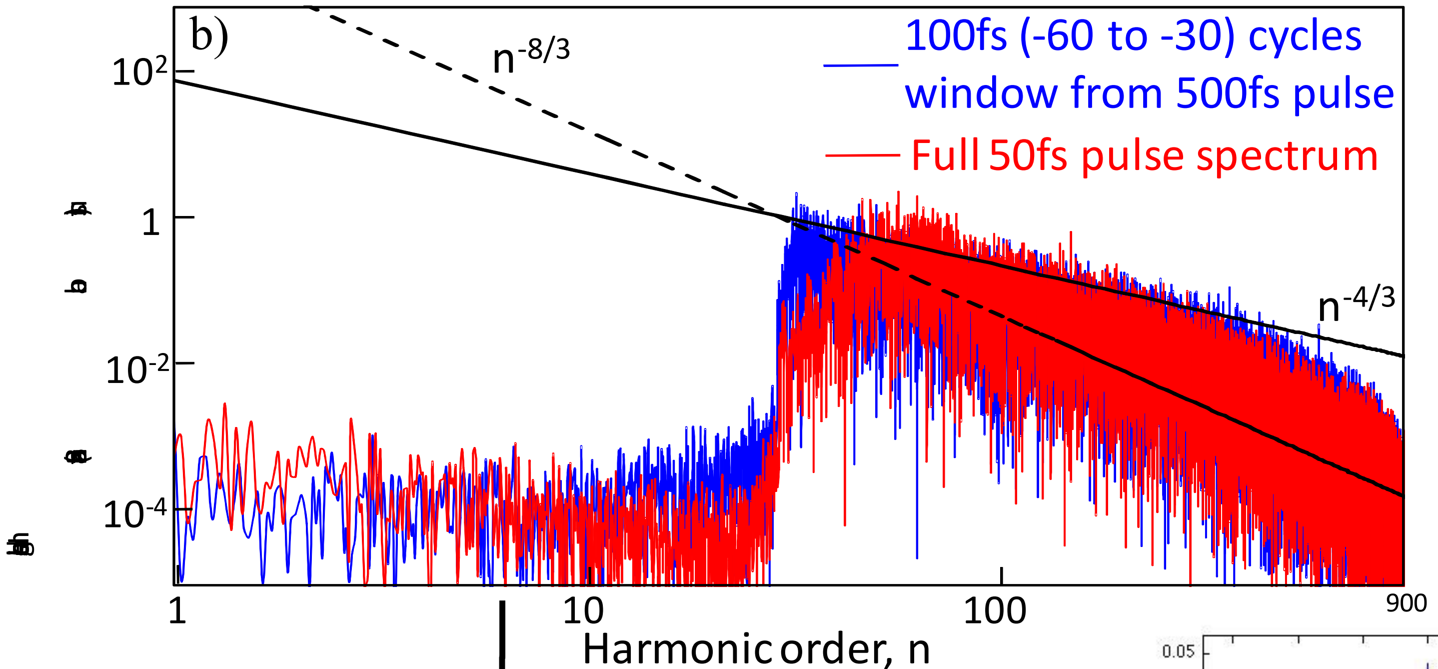
Normal incidence in transmission allows CSE to be seen in isolation

In this geometry

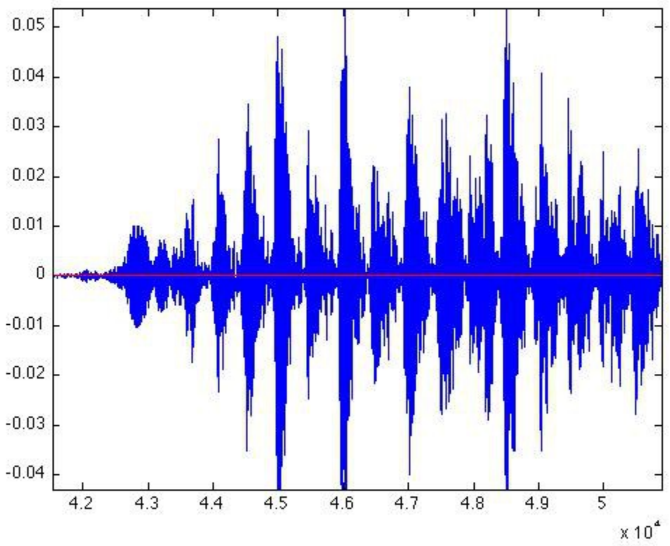
- **ROM not possible – no reflection**
- **CWE not possible – no oblique incidence**

Do normal incidence in transmission interactions allow CSE?

Spectrum of emitted radiation

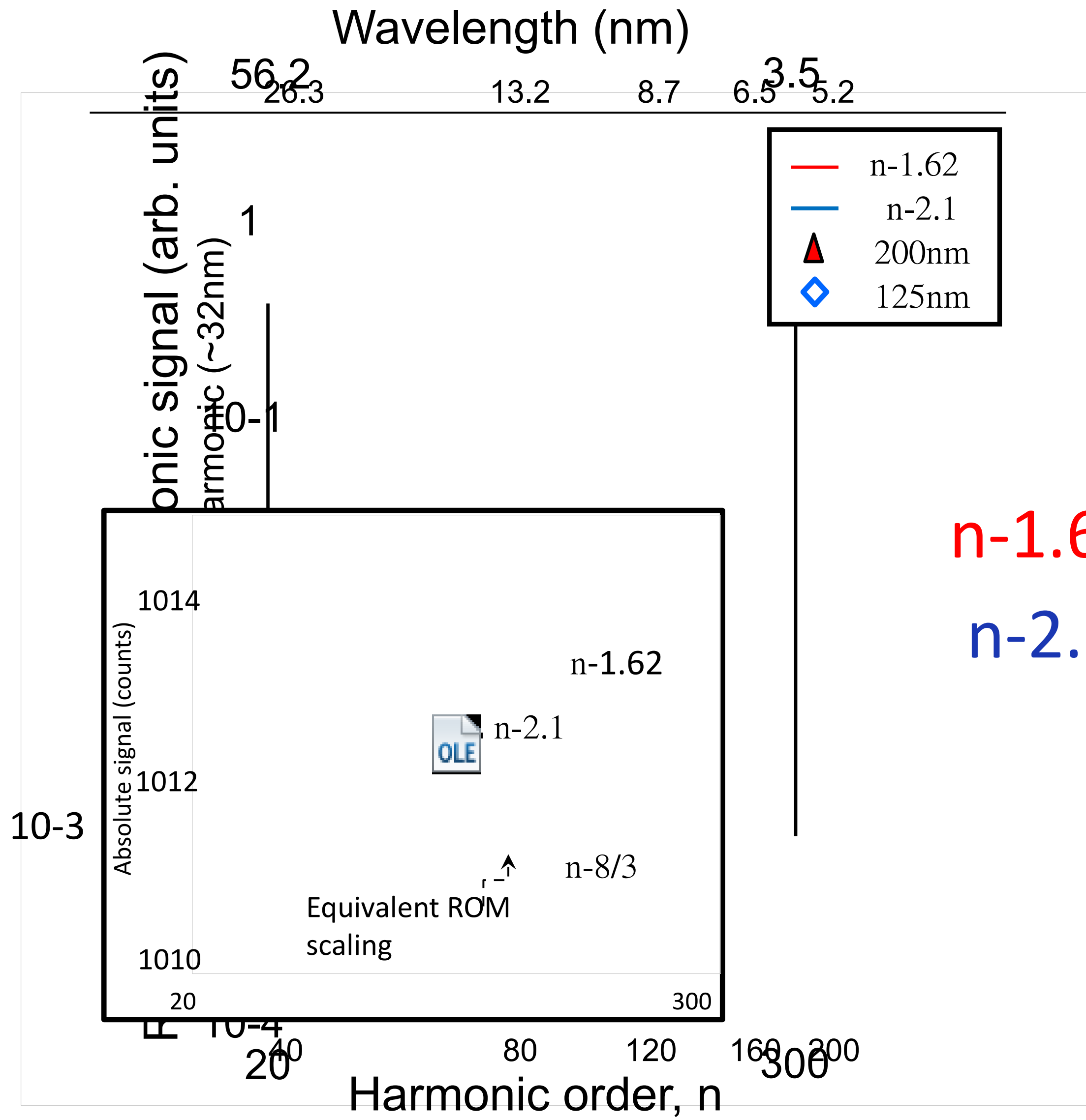


Self filtered attosecond pulse train



10 cycle super Gaussian pulse, normal incidence on a 200nm thick solid density (800Nc), a0 = 20

Scaling of harmonics in transmission (CSE)



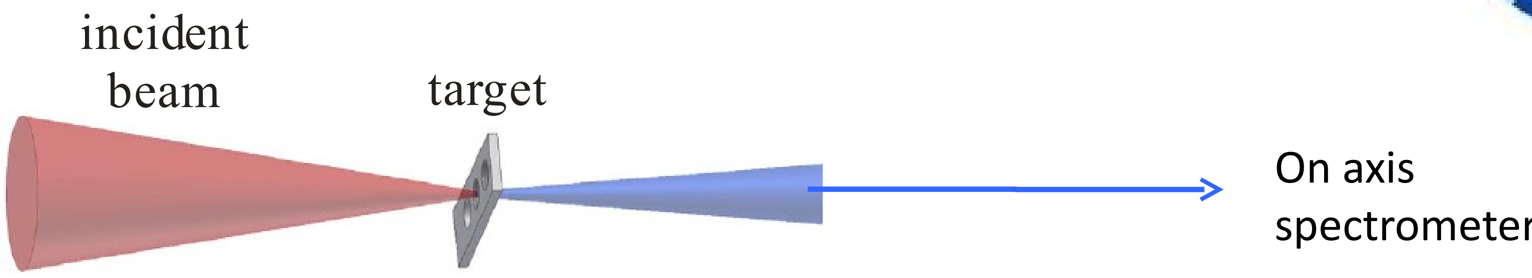
n-1.62,+0.13,-0.12

n-2.1,+0.15,-0.22

Coherent control of CSE

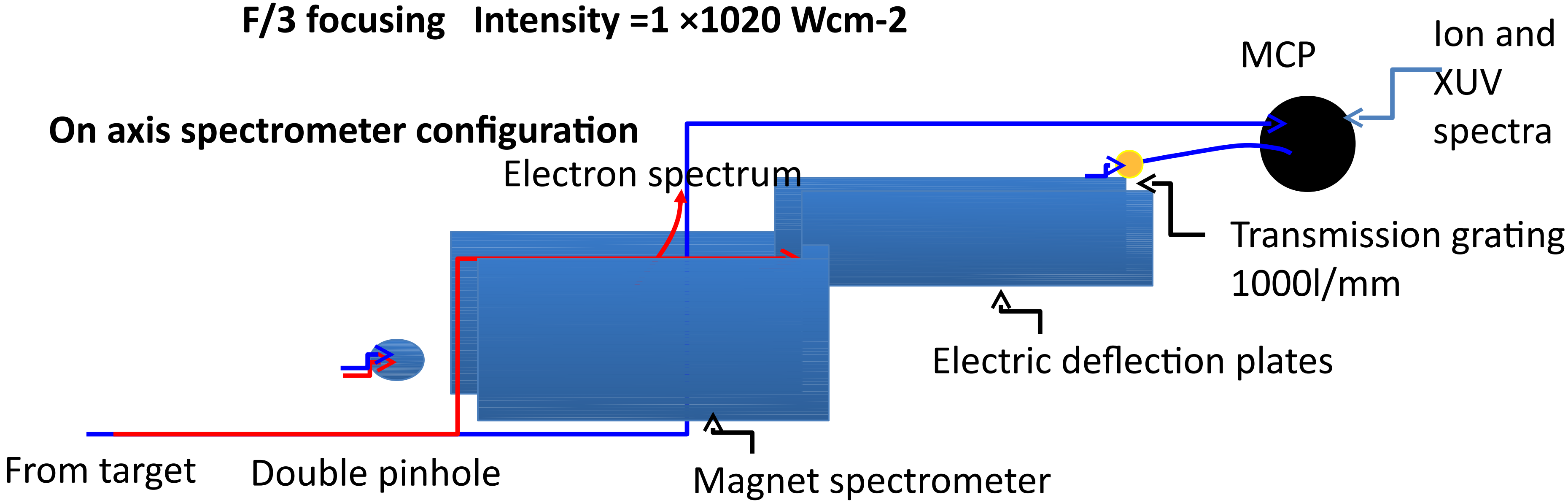
Gemini laser – Central laser facility

50fs, 12J (800nm)

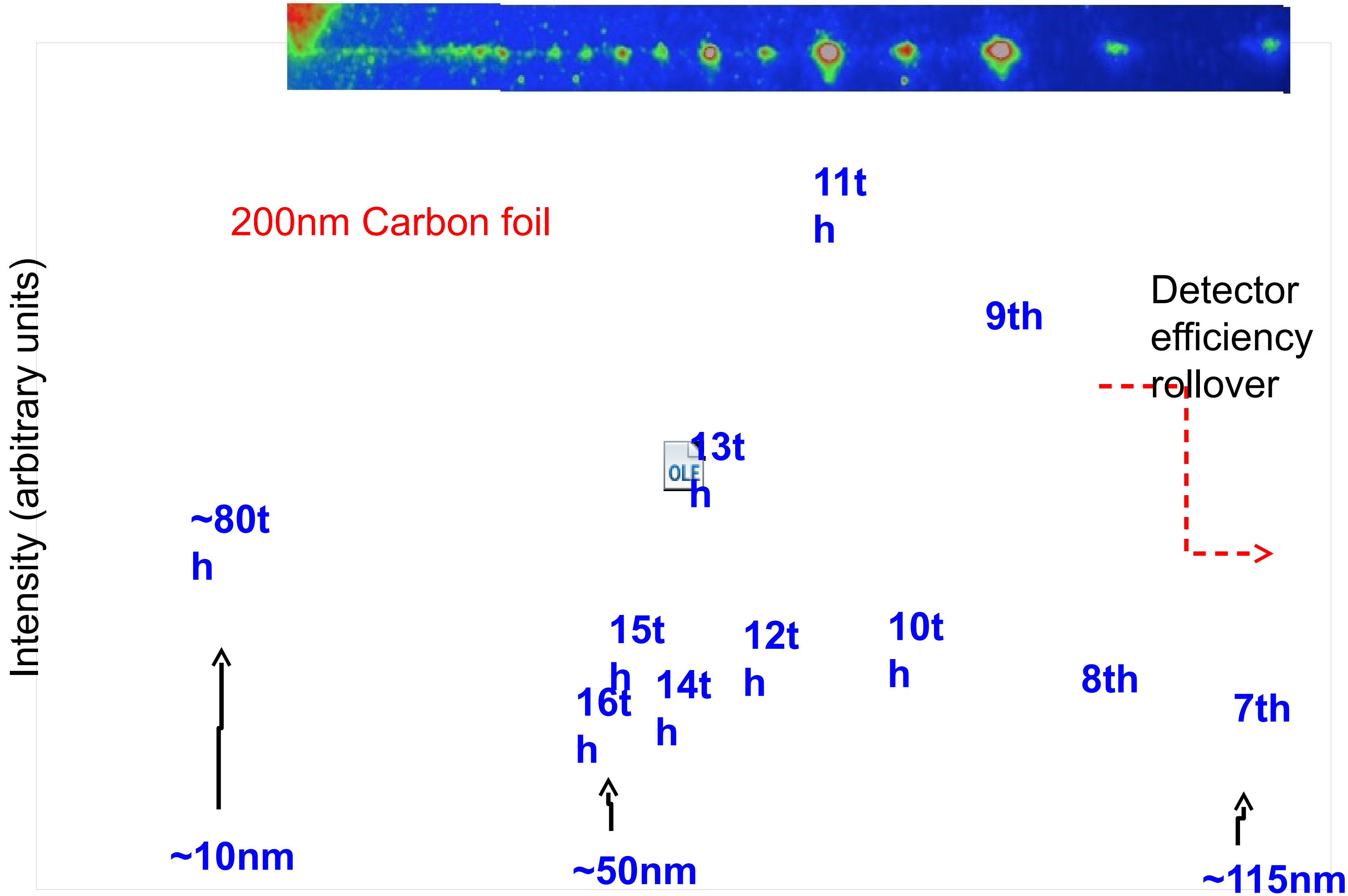


F/3 focusing   Intensity =1 ×1020 Wcm-2

On axis spectrometer configuration

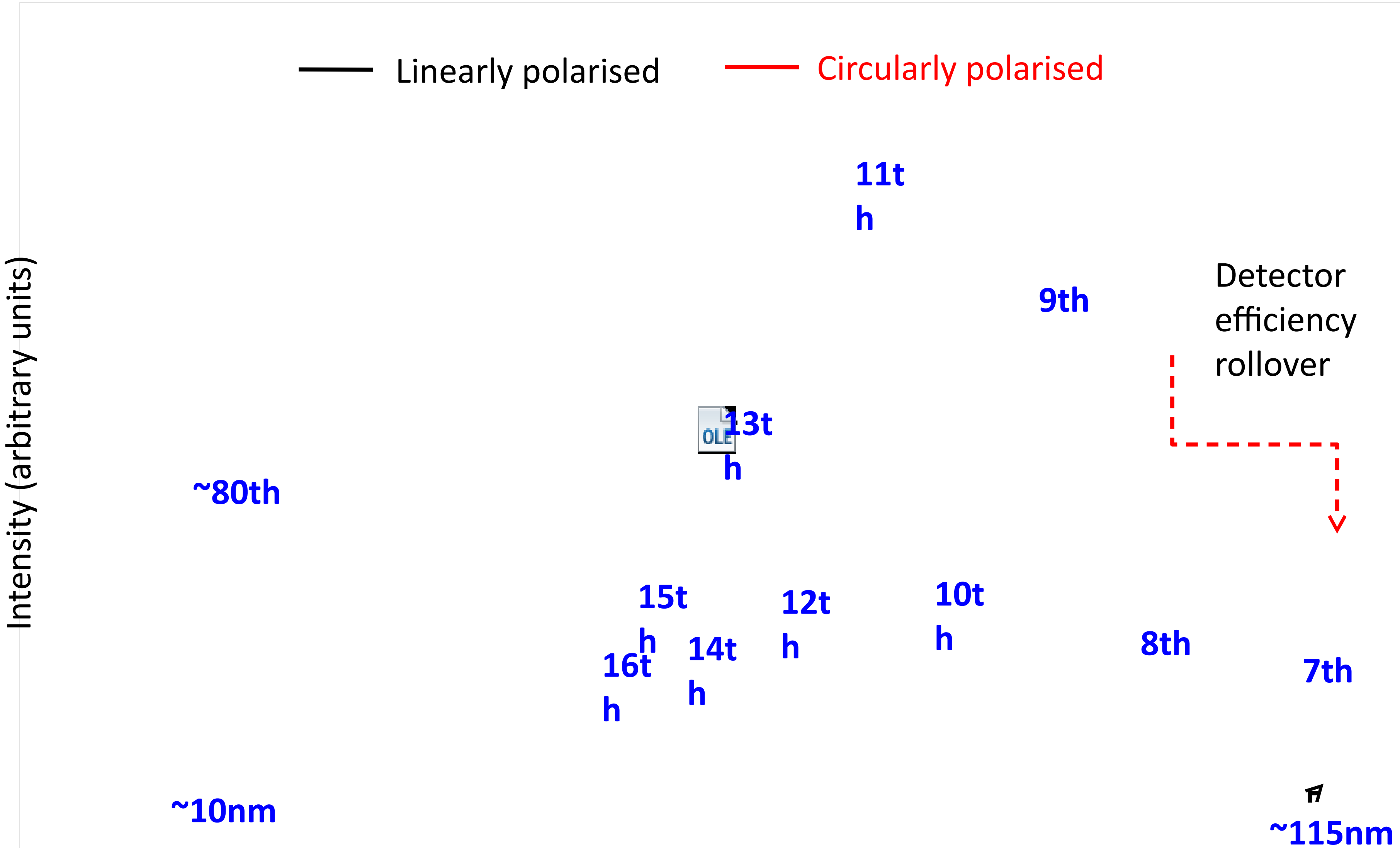


Relativistic harmonics in transmission

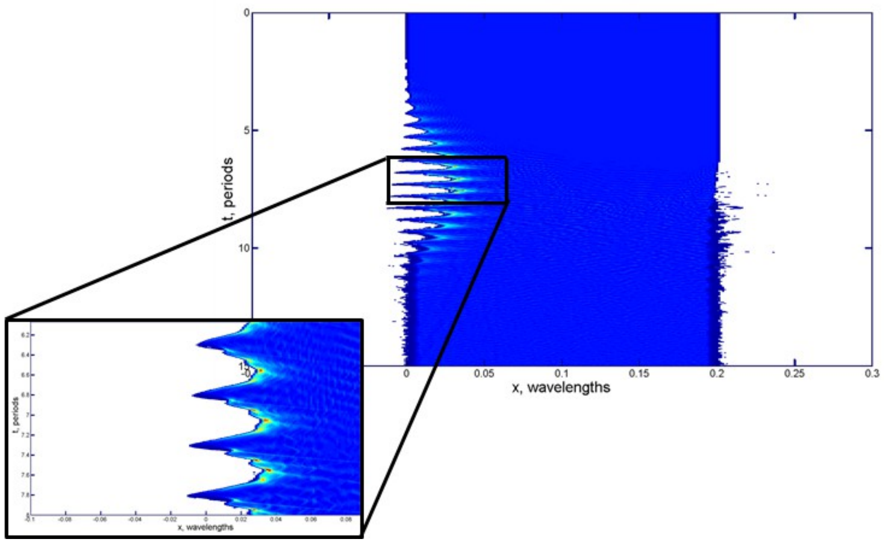


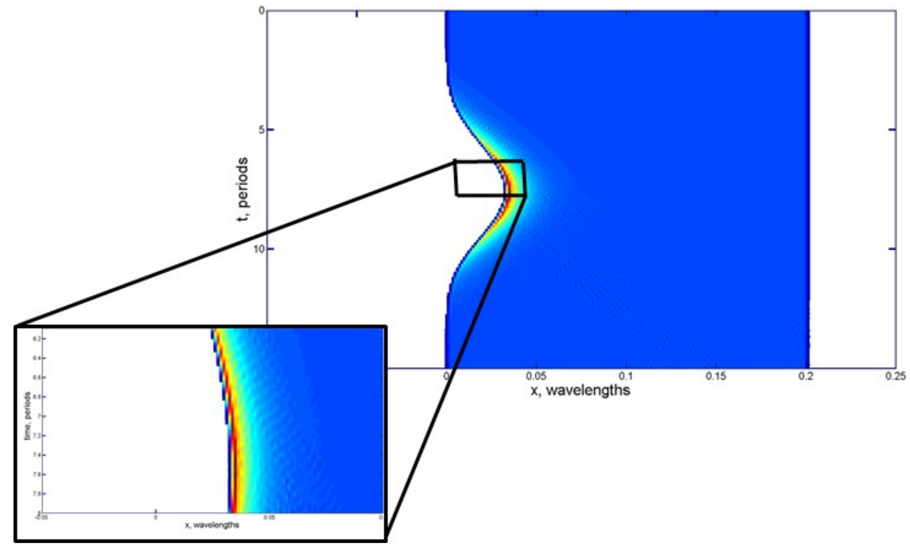
Very clear asymmetry between odd and even orders

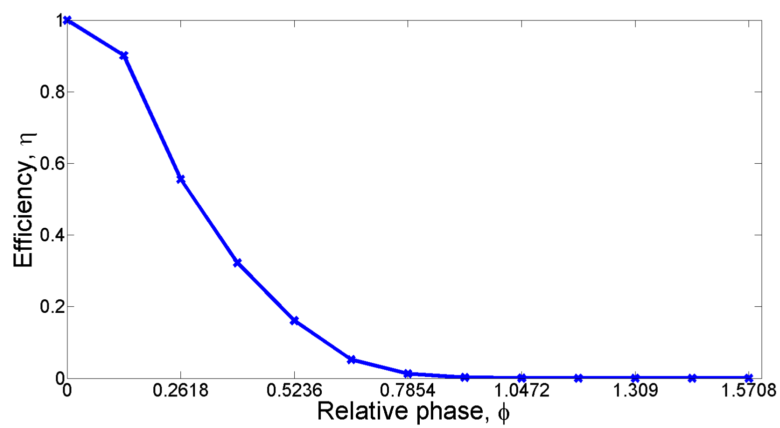
Coherent control of relativistic plasmas



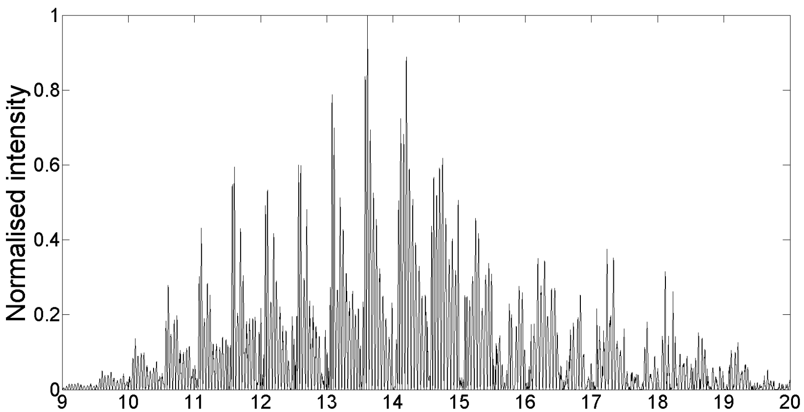
Laser Ellipticity – PIC code results

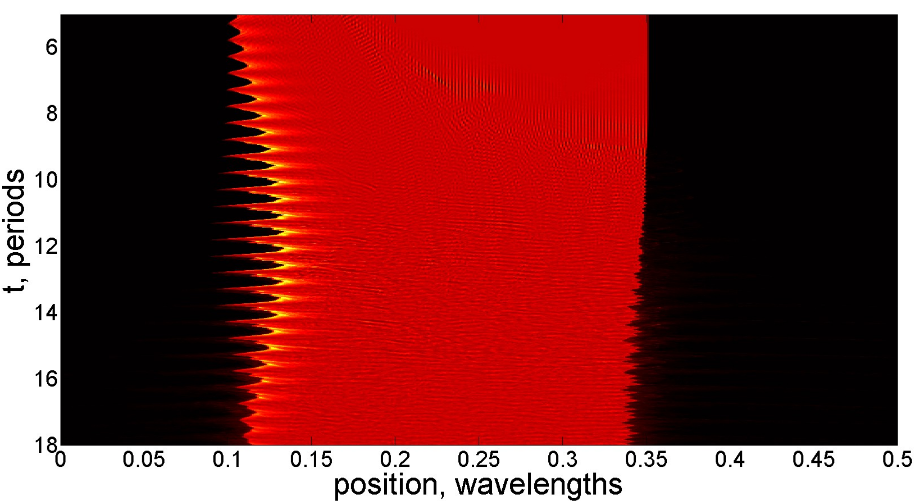




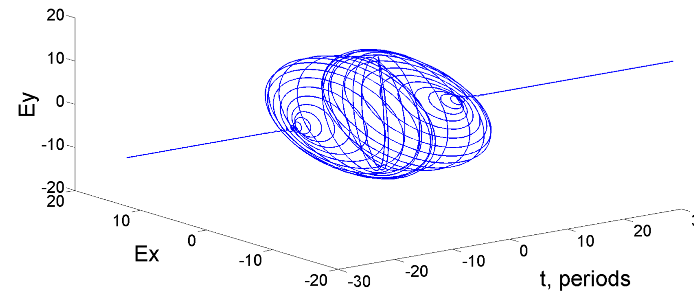


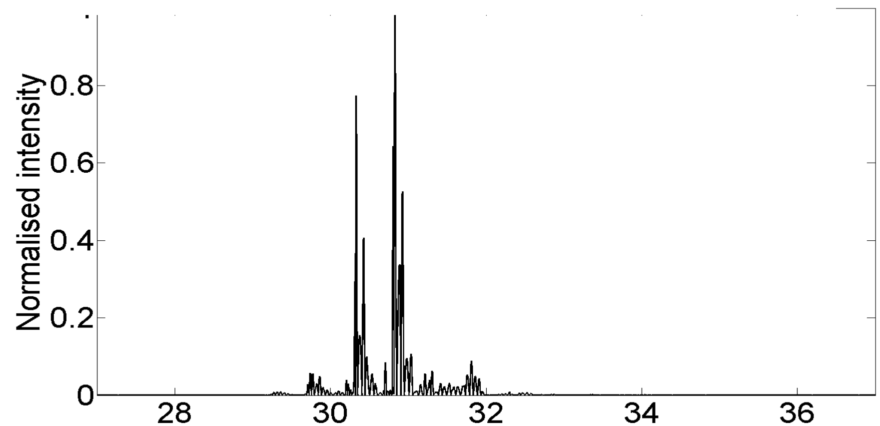
Ungated 10 cycle pulse

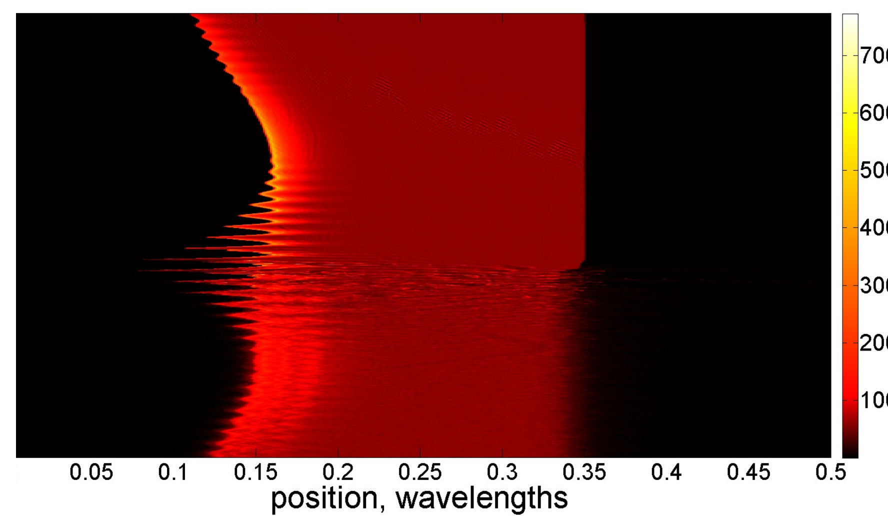




Gated Pulse







Summary

- Identified a method to isolate CSE – normal incidence in transmission
- Confirmed the mechanism for CSE in transmission
- Characteristic shallow scaling with harmonic order
- Use of elliptically polarised pulses to coherently control CSE
  - Gating of individual atto pulses.