The Abdus Salam International Centre for Theoretical Physics

2369-10

CIMPA/ICTP Geometric Structures and Theory of Control

1 - 12 October 2012

Physics issues and challenges in HEDS with table top lasers: some examples

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ICTP-IAEA College on Plasma Physics, October 2012
Lectures by G. Ravindra Kumar, TIFR Mumbai

1. Intense Laser- Matter Interaction: Some Basics [mainly for ultrashort (femtosecond) pulses]

2. High energy density science (HEDS) experiments with table top terawatt lasers: the why and how

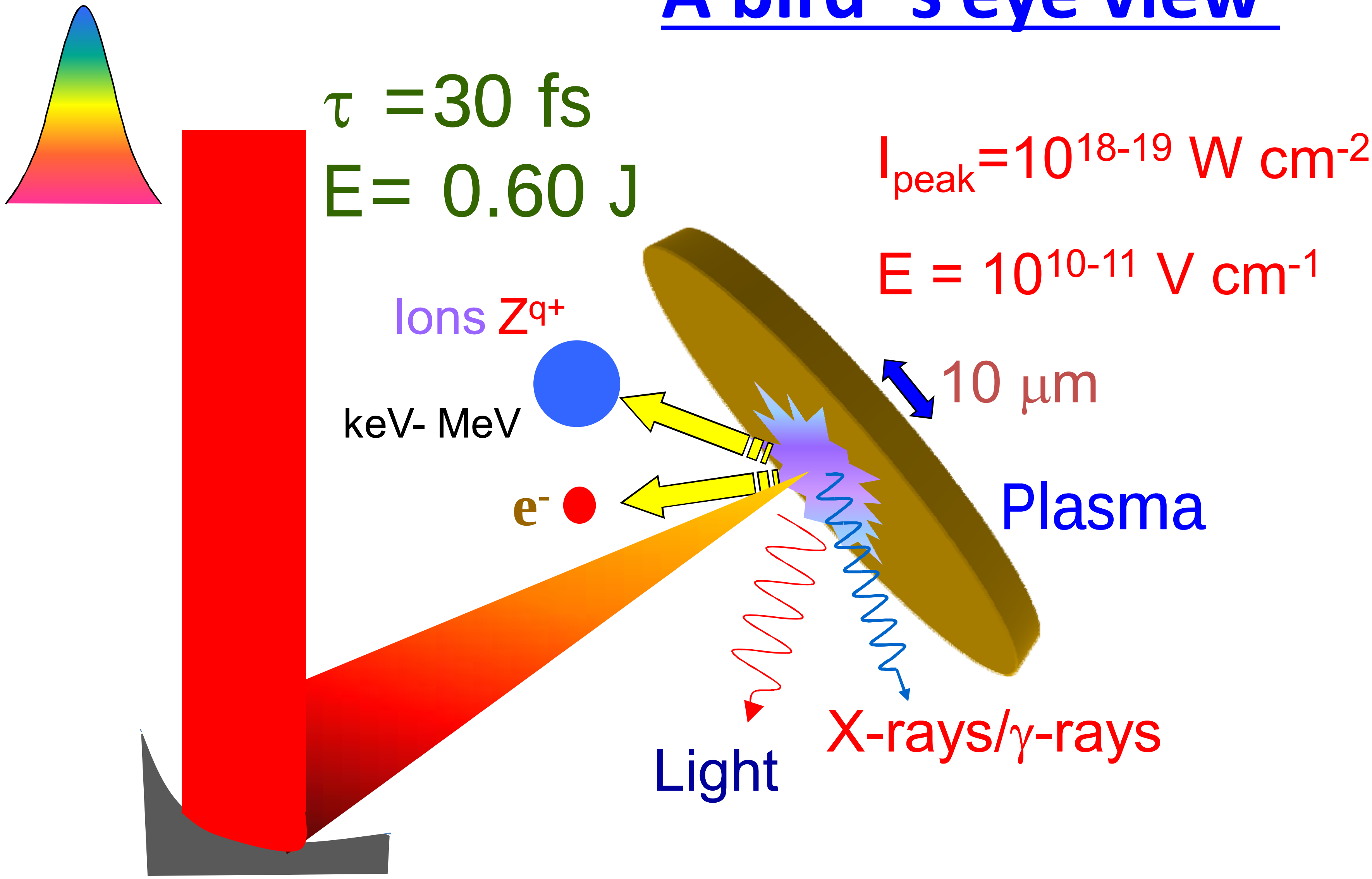
3. Physics issues and challenges in HEDS with table top lasers: some examples - ***TODAY!***

Physics issues and challenges in HEDS with table top lasers: some examples

G. Ravindra Kumar
Ultrashort Pulse High Intensity Laser Laboratory (UPHILL)
Tata Institute of Fundamental Research, Mumbai, India
www. tifr.res.in/~uphill

ICTP-IAEA College on Plasma Physics, 2012 Oct 01-12; Talk 2

A bird's eye view



Pulse `**Peak**' power
20 x 10^{12} W

Plan of the Talk

- Measuring Hot Electron Characteristics
- Enhancing Hot Electron Generation
- Monitoring Hot Electron Transport Via Their Own Giant Magnetic Fields
- Conclusions

HEDS with Lasers

Light Absorption- key issue

Polarization Independent Mechanism

Collisional absorption (inverse bremsstrahlung)

- electron transfers energy to other particles via collisions
- electron repeatedly gains energy from the laser field
- responsible for the 'bulk temperature' of the plasma
- the fraction of energy absorbed for a linear density profile is

$$f_A = 1 - \exp\left(-\frac{32\nu_{ei}^{*} L}{15c}\cos^5\theta\right)$$

L – plasma length

$\nu^* - \nu_{ei}(n_{cr}/n_e)$, the e^--i collisional frequency

$$\nu_{ei} \propto \frac{n_e Z}{T_e^{3/2}}$$

- since $T_e \sim I^{2/3}$, collisional absorption is important only in the low intensity regime (< 10^{14} W cm^{-2})

POLARIZATION DEPENDENT ABSORPTION IN PLASMAS

Resonance Absorption (> $\mathbf{10^{15}}$ W cm^{-2})

P-polarized light at oblique angle of incidence, exciting a plasma wave**.**

'Hot' electrons ('Fast' electrons)
(different from the bulk plasma electrons)

WHY study Hot electrons?

Important for Fast Ignition Fusion
Emitters of very hard X-ray pulses

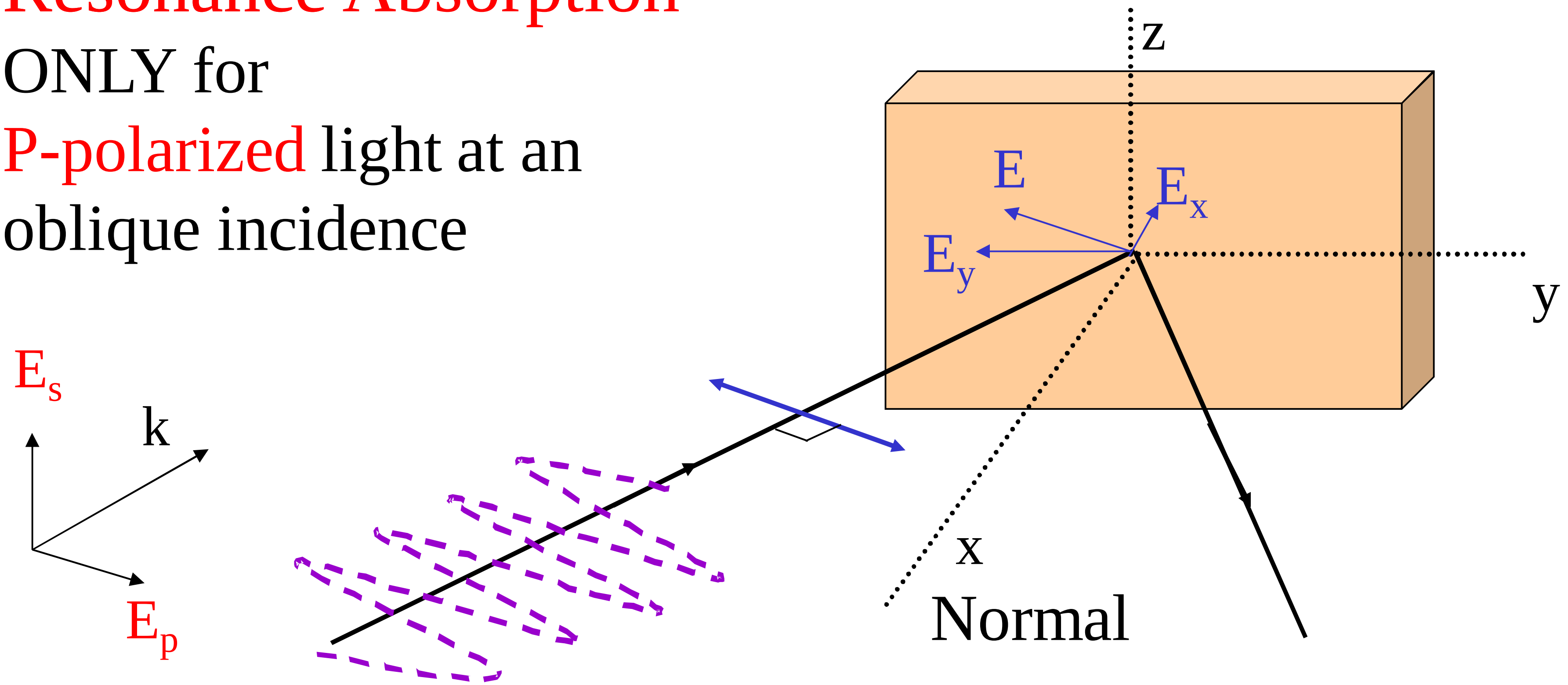
High Energy Density Electron Pulses

10^{21} electrons /cc at keV –MeV Temperatures

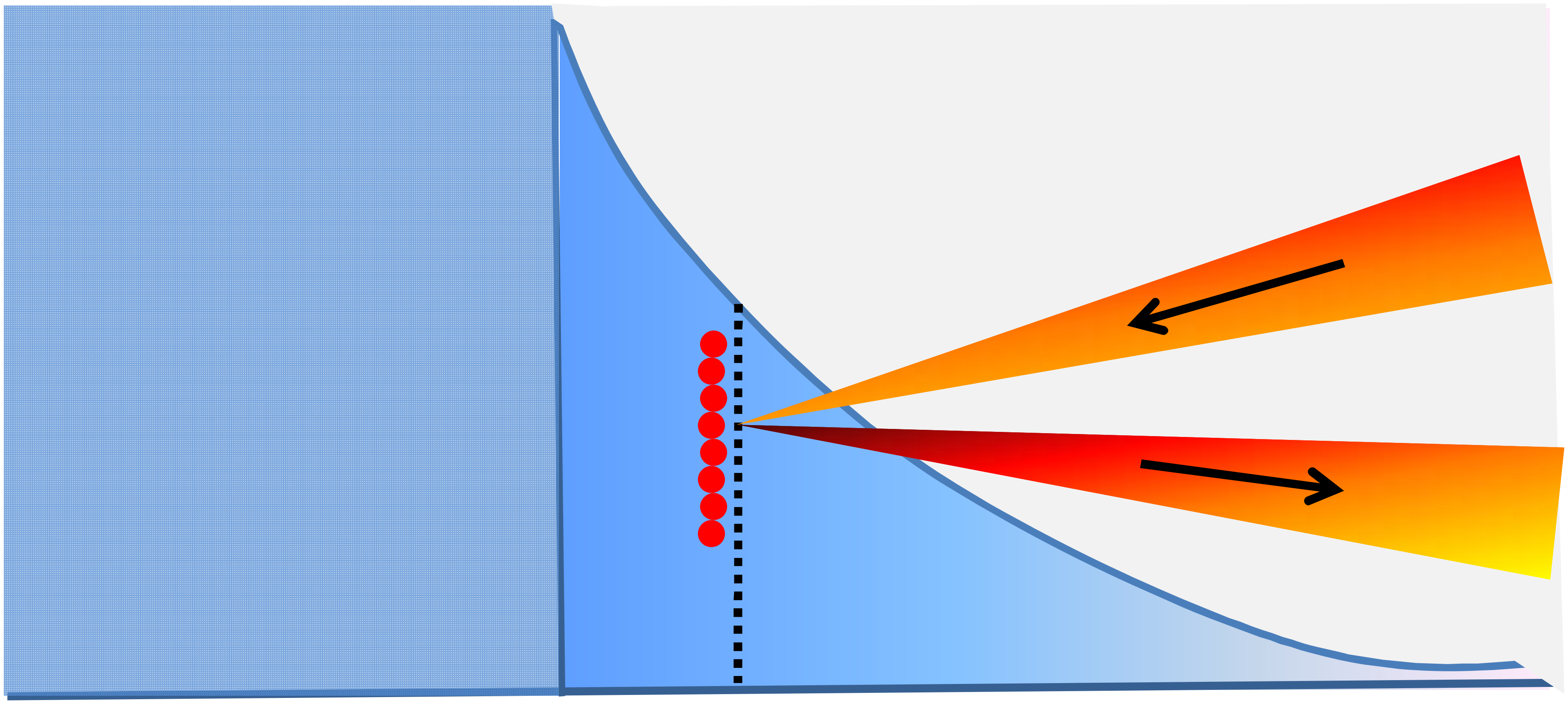
(*Light works on matter via these electrons*)

Collective Mechanism

Resonance Absorption
ONLY for
P-polarized light at an
oblique incidence



Component E_x along density gradient drives Plasma Oscillations.



Relay Race!

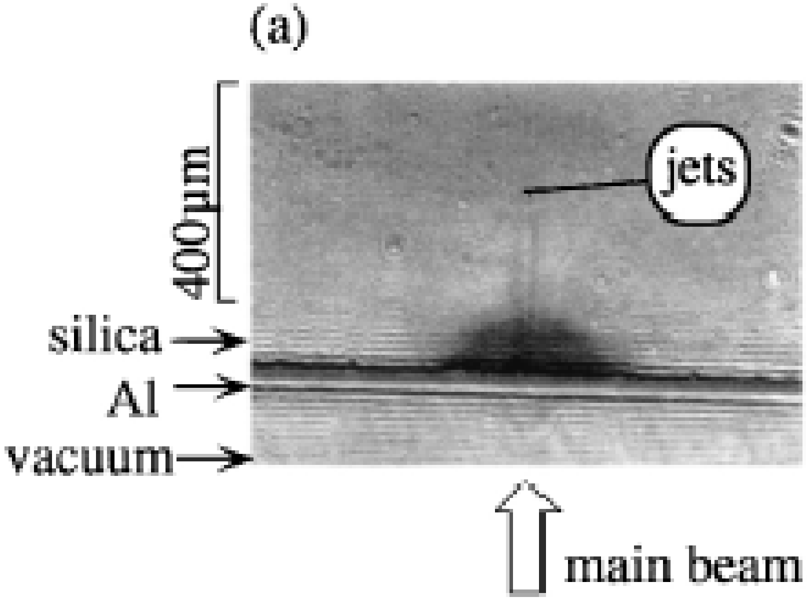
Femtosecond Light pulse → Femtosecond Electron Pulse

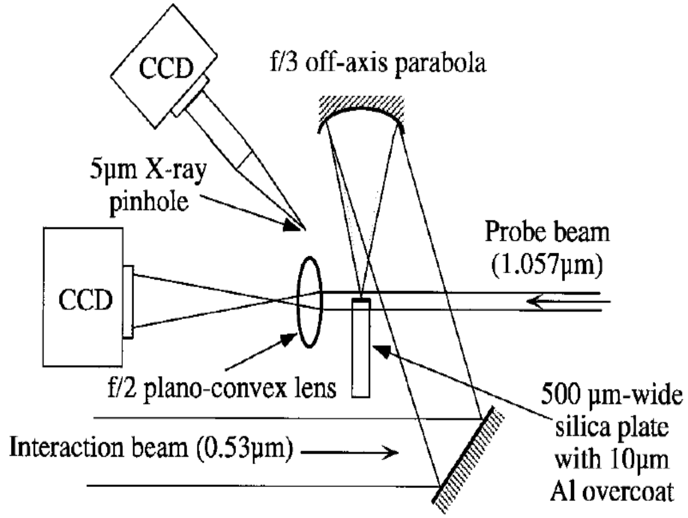
‘Hot’ electrons, created by
Collective absorption processes
are the carriers of Laser energy
(~ 40%)

How do you ‘see’ these hot electrons?

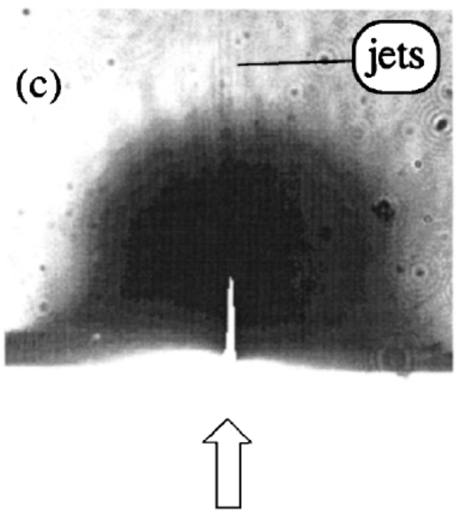
'Shadowing' Relativistic Electrons

Input Laser pulse
300fs





1.2 ps after laser pulse

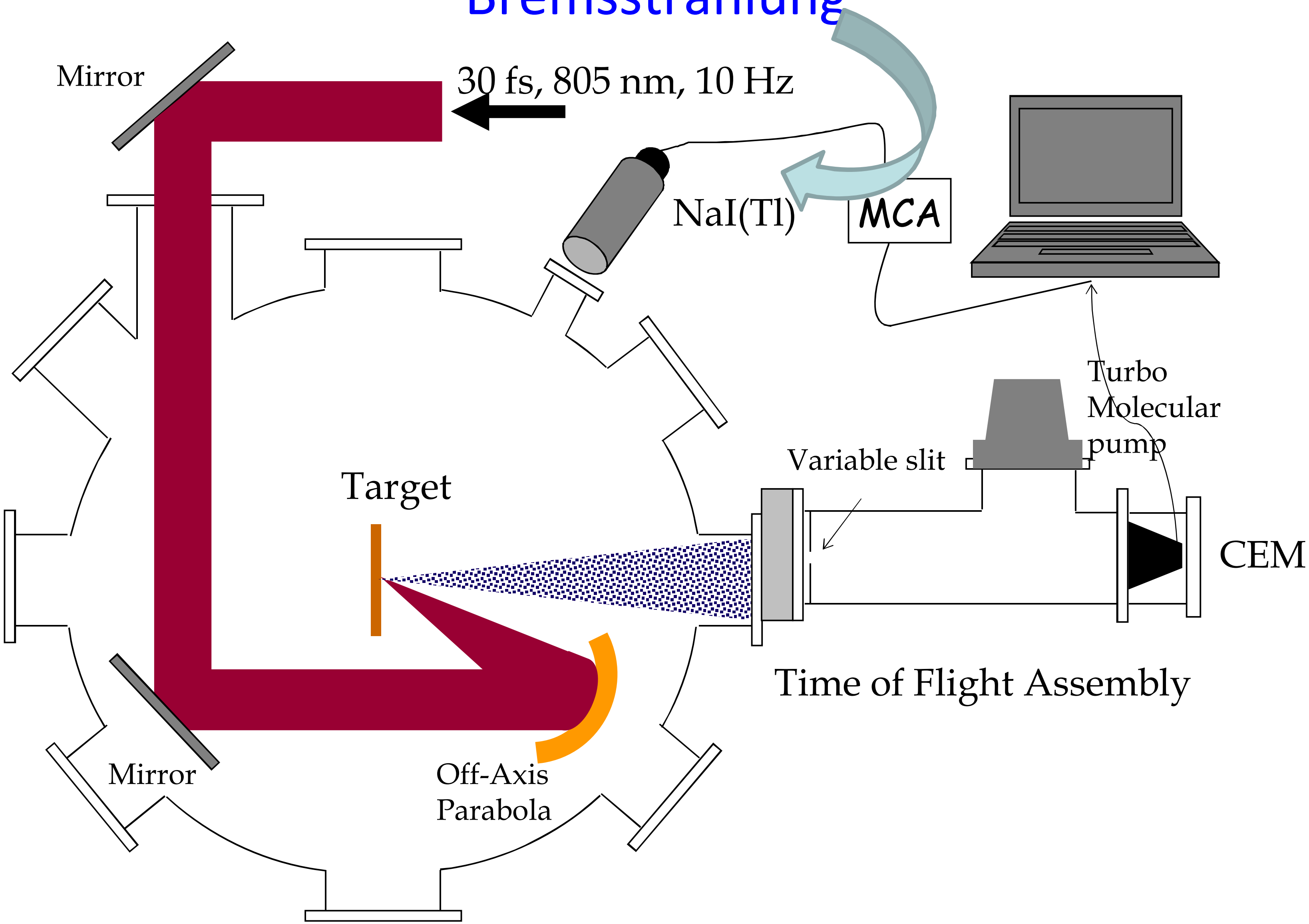


Speed: (0.6-0.7) x speed of light

3 ps after laser pulse

Gremillet et al., PRL **83** (1999) 5015

Hard X-ray emission by Hot Electrons via Bremsstrahlung

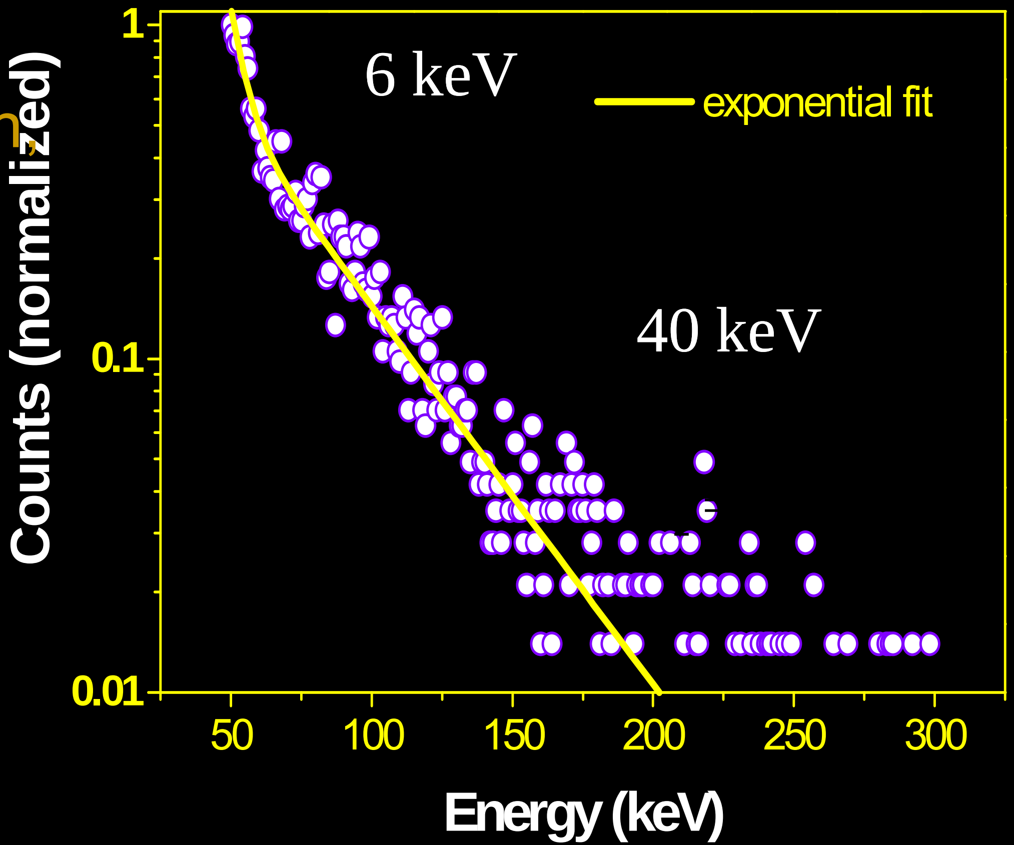


Measuring `hot' electrons via bremsstrahlung

- radiation emitted during *e-ion, e-neutral* interaction mainly in the bulk.

- for a Maxwellian *e-* velocity distribution, the spectral intensity

$$W_B \sim T_e^{-1/2} n_e^2 Z e^{-E/kT_e}$$

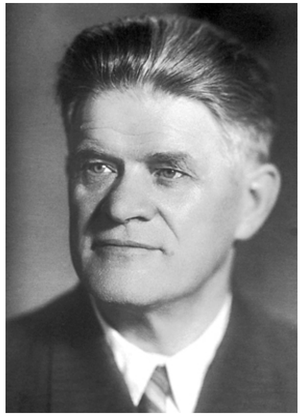


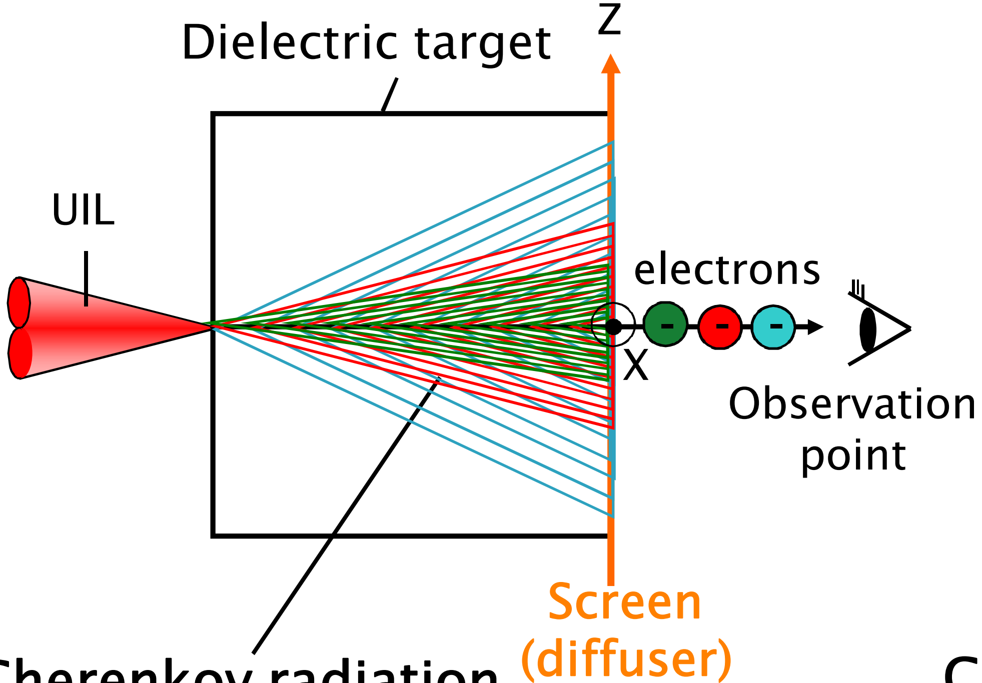
Copper plasma at 2 x 10^{16} W cm^{-2}

P. P. Rajeev *et al.*
Phys. Rev. A , 65, 052903(2002)

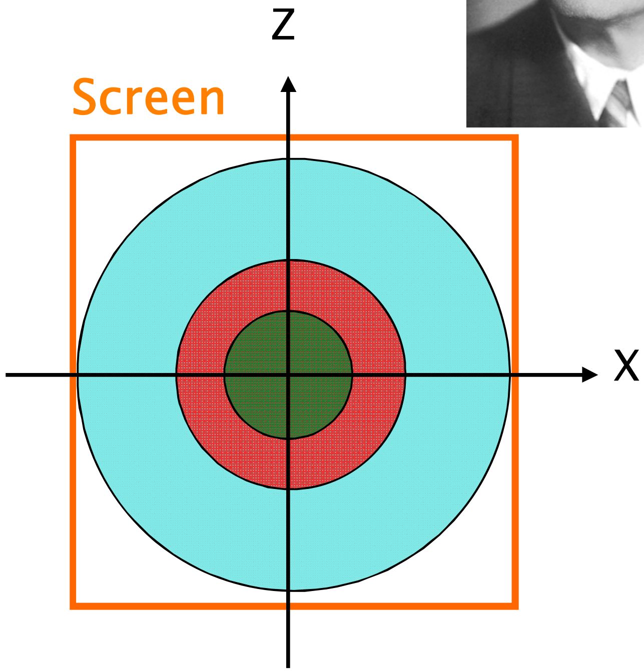
A <u>more direct</u> measurement of the Hot Electrons

Electrons travel faster than light in the target, emit light via CHERENKOV process





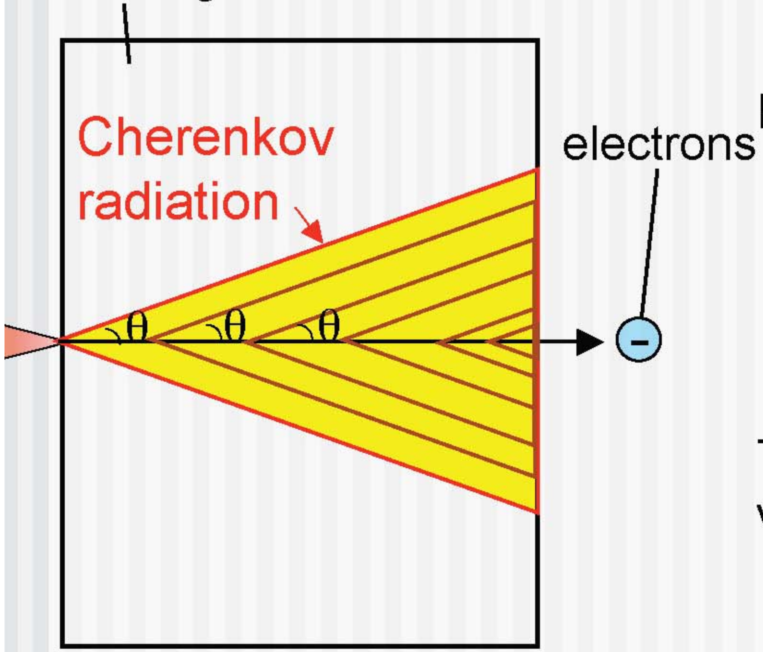
Cherenkov radiation
(The energy of fast electrons :
Green<Red<Blue)



Cherenkov radiation pattern

Emission angle and radiation efficiency of Cherenkov radiation depend on energy of fast electrons.

lectric target



L : **U**ltra high **I**ntensity **L**aser
: refractive index
velocity of electron
: speed of light
: target thickness
: fine structure constant (1/137)

Emission angle of Cherenkov radiation is

$$\theta = \arccos\frac{1}{n(\lambda)\beta} \quad , \quad n(\lambda)\beta \geq 1 \qquad (1)$$

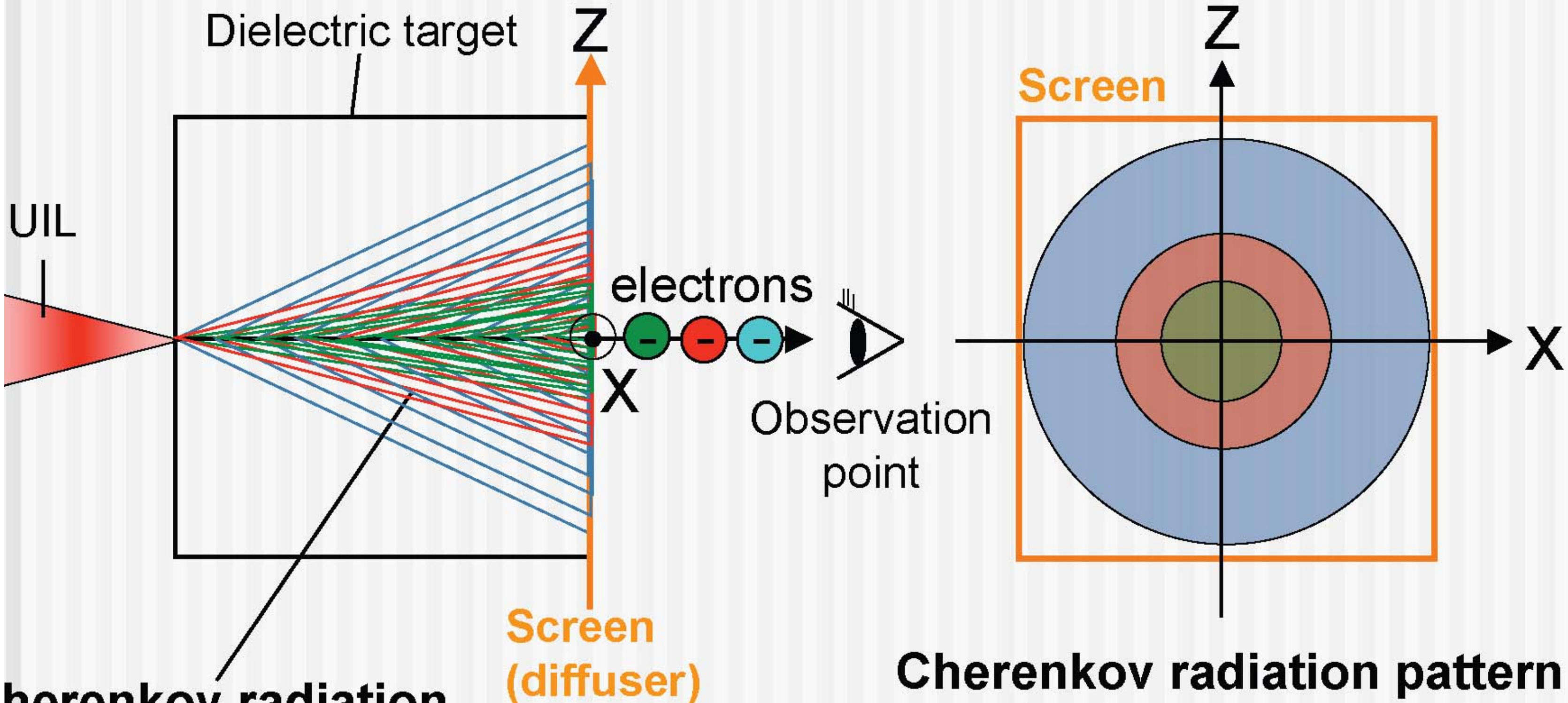
$$\beta = v/c$$

The number of Cherenkov photons N_p whose wavelength are between λ_1 and λ_2 is given by

$$N_p = 2\pi\alpha L\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)\cdot\left(1 - \frac{1}{n(\lambda)^2\beta^2}\right) \qquad (2)$$

Emission angle (1) and radiation efficiency (2) of Cherenkov radiation is decided by "**n**" and "**β**".

f the plane target was used, energy spectrum of ast electrons can't be obtained.

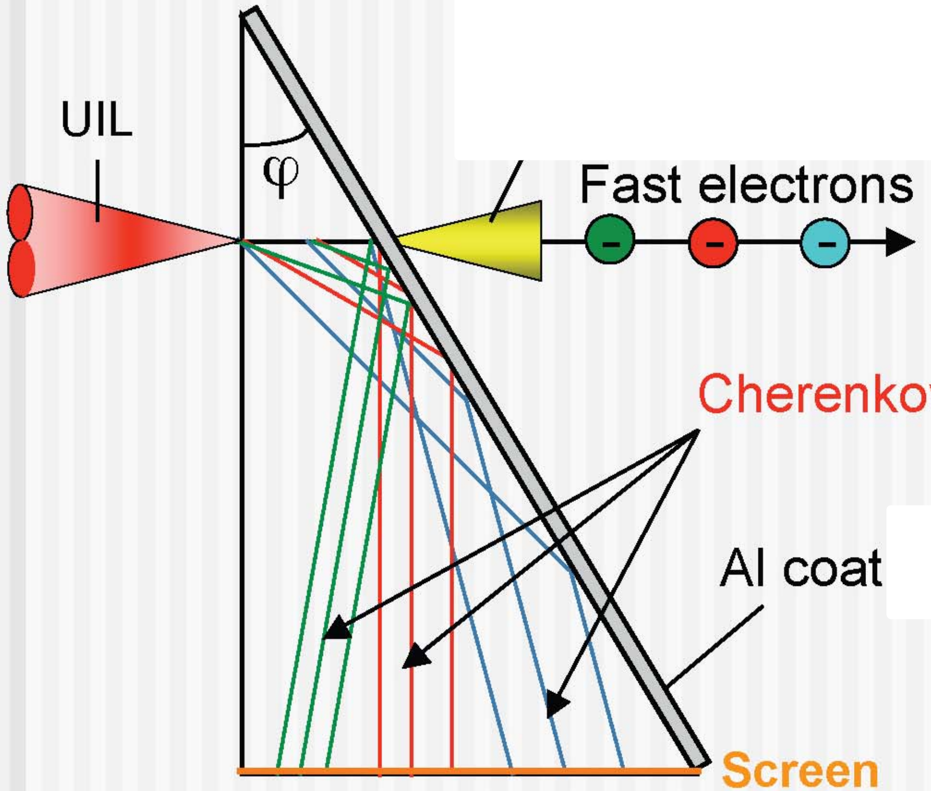


herenkov radiation
The energy of fast electrons :
reen < Red < Blue)

Cherenkov radiation pattern
(totally overlap)

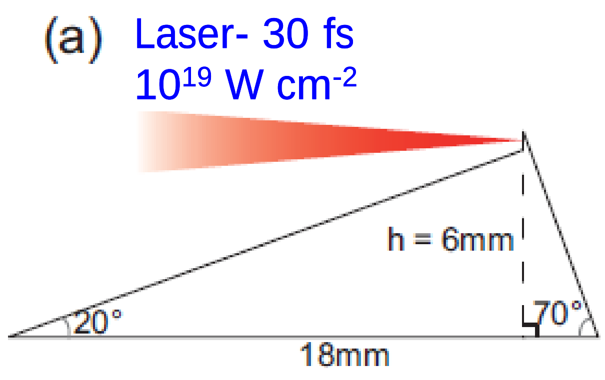
Cherenkov radiations emitted from low energy fast electrons are totally verlapped by radiations from high energy fast electrons.

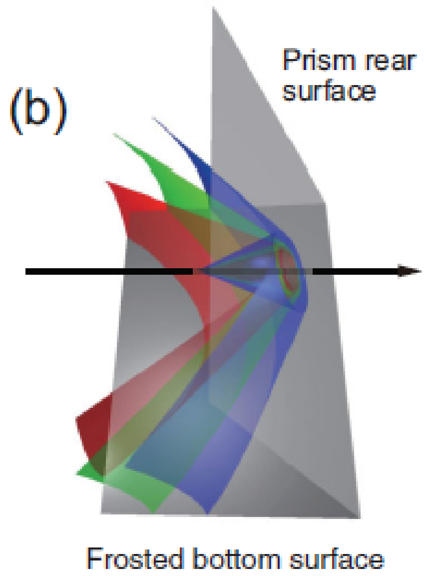
Prism Target for Spectral Dispersion: Unique Mapping of 'Electron Energy - Radiation Colour'



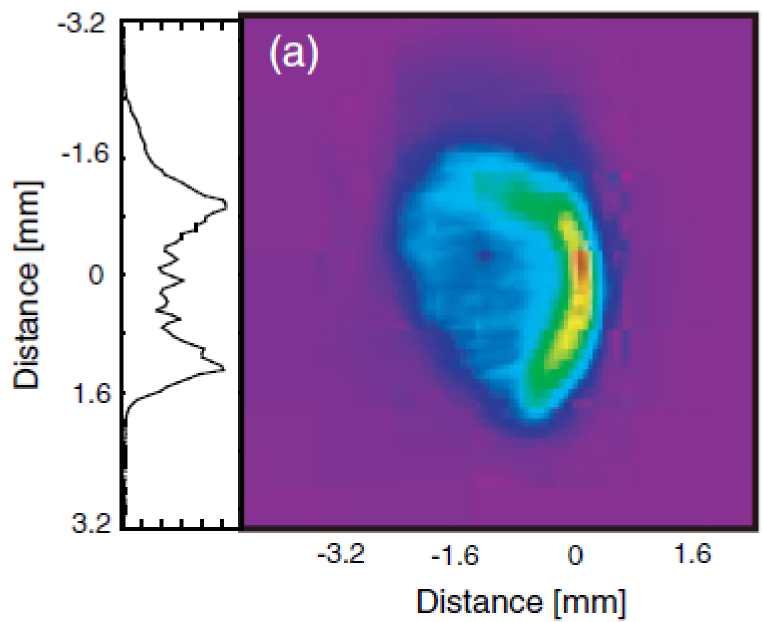
(The energy of fast electrons : Green < Red < Blue)

Direct, Absolute, and *In Situ* Measurement of Fast Electron Transport via Cherenkov Emission

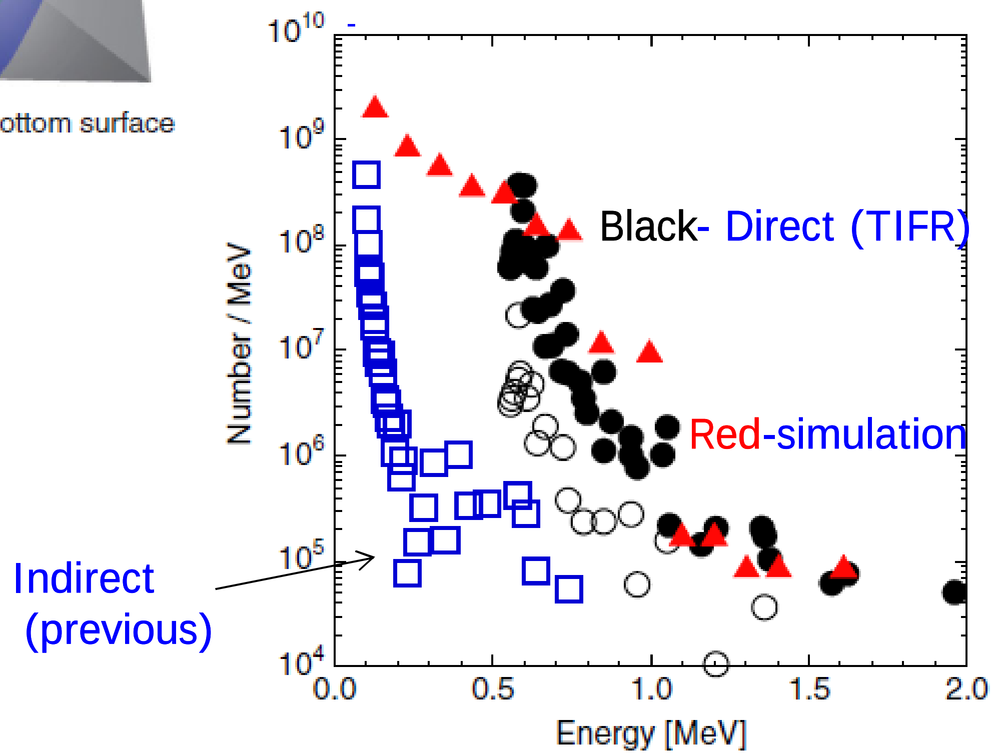




TIFR- ILE Osaka Collab
Expt. done at TIFR



Spectrum of relativistic electrons



Direct, Absolute, and *In Situ* Measurement of Fast Electron Transport via Cherenkov Emission

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(Received 6 February 2009; published 3 February 2010)

We present direct measurements of the absolute energy distribution of relativistic electrons generated in intense, femtosecond laser interaction with a solid. Cherenkov emission radiated by these electrons in a novel prism target is spectrally dispersed to obtain yield and energy distribution of electrons simultaneously. A crucial advance is the observation of high density electron current as predicted by particle simulations and its transport as it happens inside the target. In addition, the strong sheath potential present at the rear side of the target is inferred from a comparison of the electron spectra derived from Cherenkov light observation with that from a magnet spectrometer.

DOI: 10.1103/PhysRevLett.104.055001 PACS numbers: 52.38.−r, 52.59.−f, 52.70.Kz

HEDS with Lasers

Light Absorption- <u>key</u> issue

Can we manipulate absorption?

plasmas reflect a large fraction of laser light we send in (40-50%)

This is a serious problem for HEDS

More coupling ⇒ More hot electron excitation

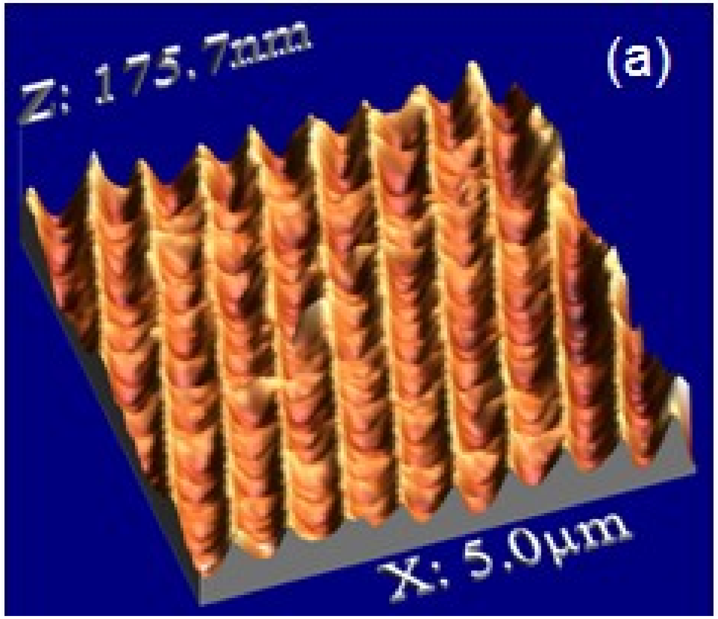
How do we couple more light in?

Ans: Bring in more mechanisms……..

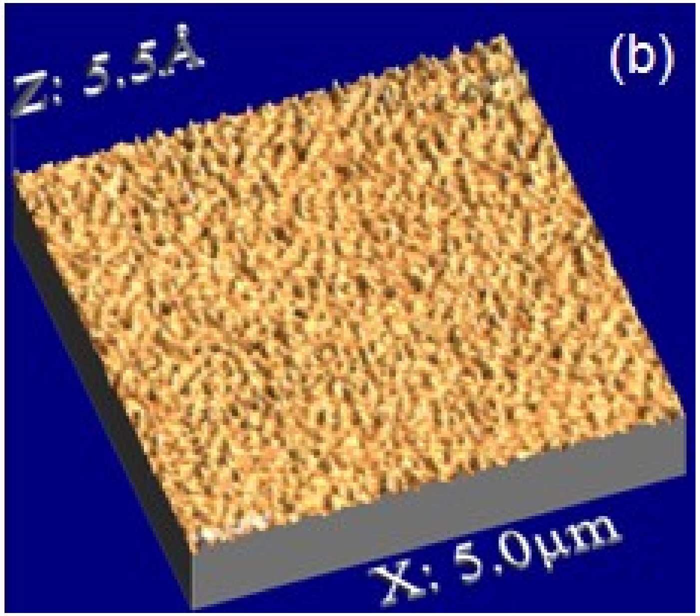
Coupling more light to the target

Sub-wavelength Gold grating (AuGR)

[compared to Polished Gold Surface (Au)]



AuGR



Au

Grating spacing: 550 nm   Laser wavelength - 800 nm

Why sub-λ grating ?

The Grating Equation

$$d(\sin\theta_m - \sin\theta_i) = m\lambda \quad \Longrightarrow \quad \sin\theta_m = \sin\theta_i + m\lambda / d$$

If $m > 0$; → RHS > LHS → not allowed

$m = 0$, → $\theta_i = \theta_m$ → specular reflection

$m < 0$, → ✓ → diffraction possible

even then for $\theta_{c,m} > m\lambda/d - 1$, then the mth order diffraction is **not possible**

consider only first order, in this case $\theta_c = 23^o$

so if the angle of incidence is greater than the critical angle then there will be no diffraction and a large amount of the incident optical energy will be absorbed

Reflectivity Measurement

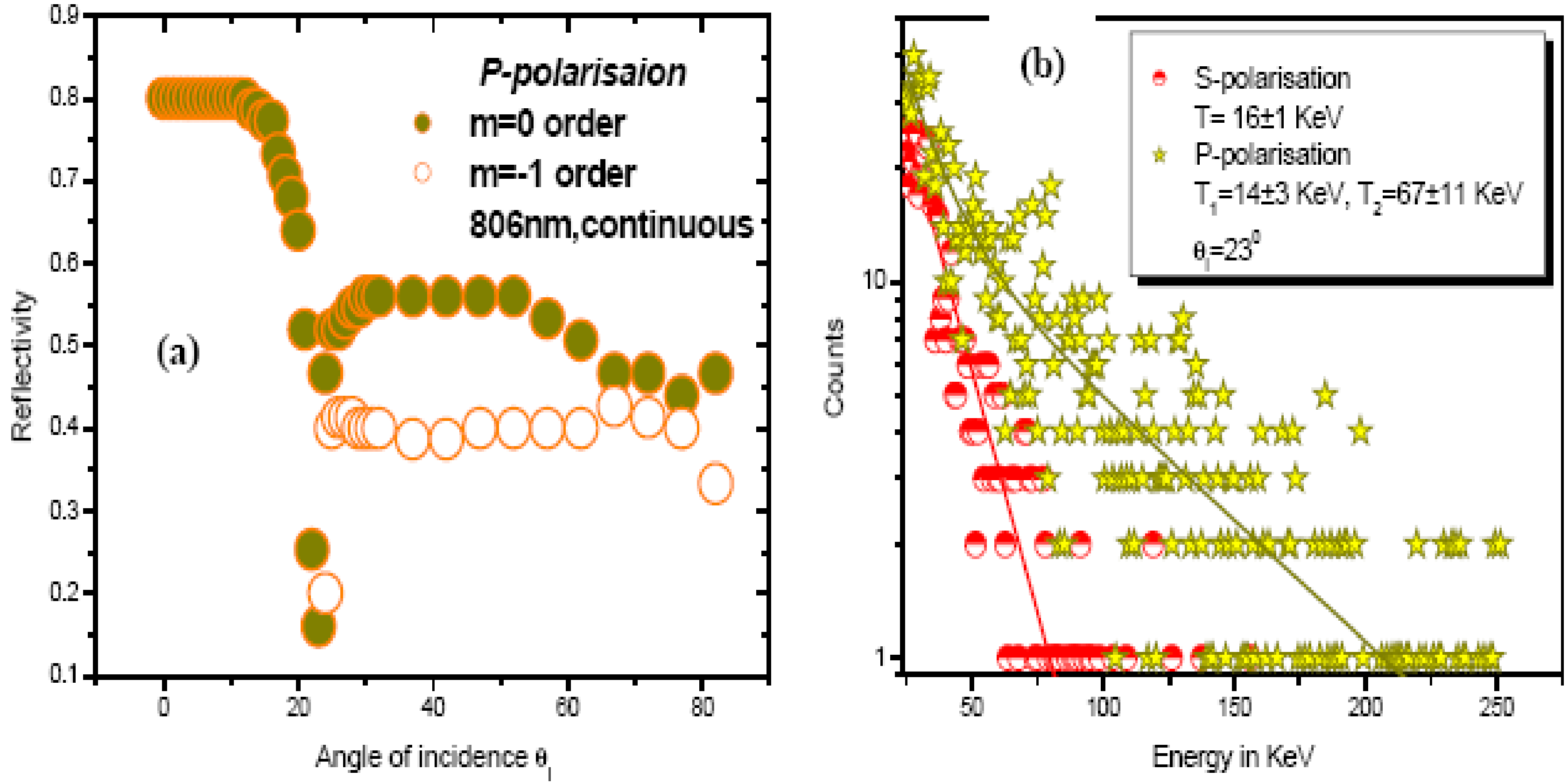


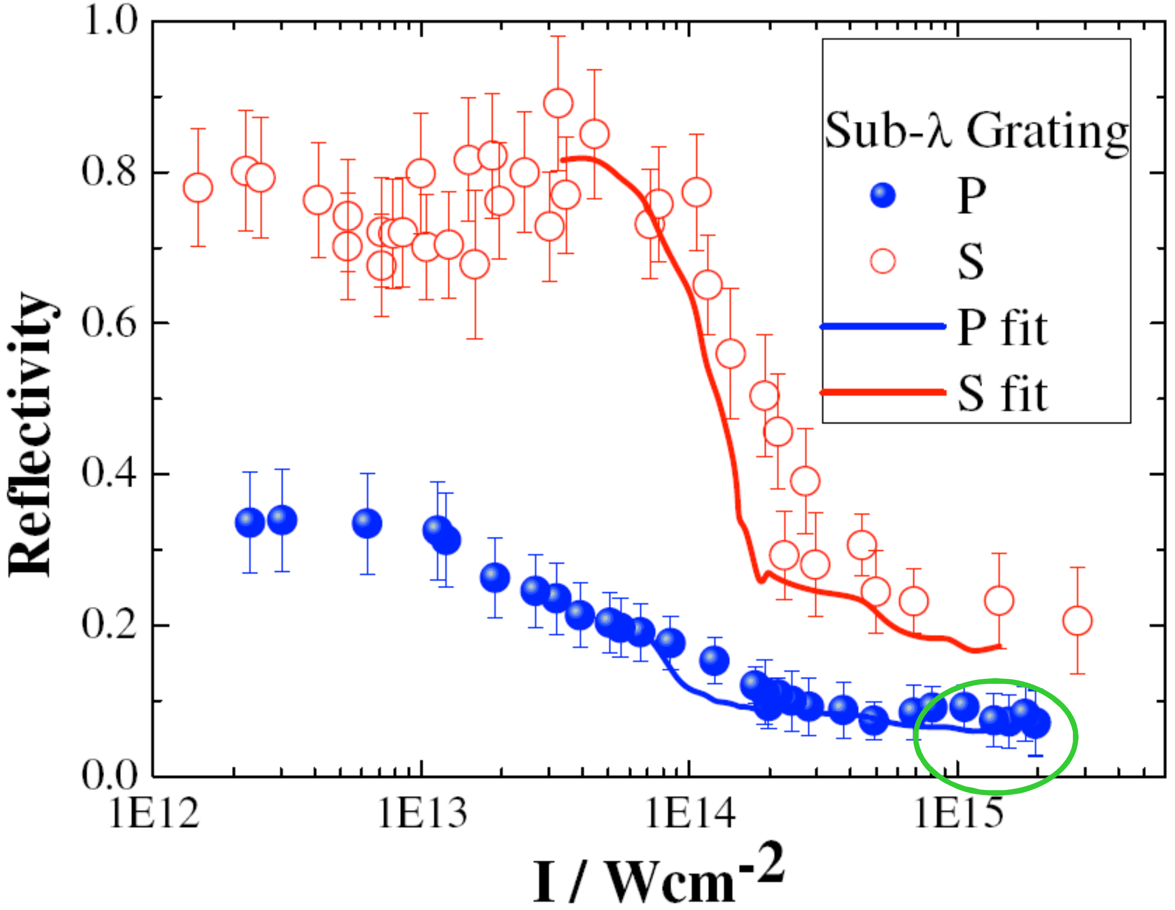
FIGURE 3. (a) Reflectivity of P- polarized 80 mW, 806 nm continuous laser from sub-λ grating (ruling spacing ~ 555 nm); dips for different diffraction orders. (b) Hard x-ray spectrum from grating plasma with intense laser (806 nm@100 fs, 10 Hz, I = 3.8 x 10^{15} Wcm^{-2}) incident at 23^0 i.e angle of the dip in (a).

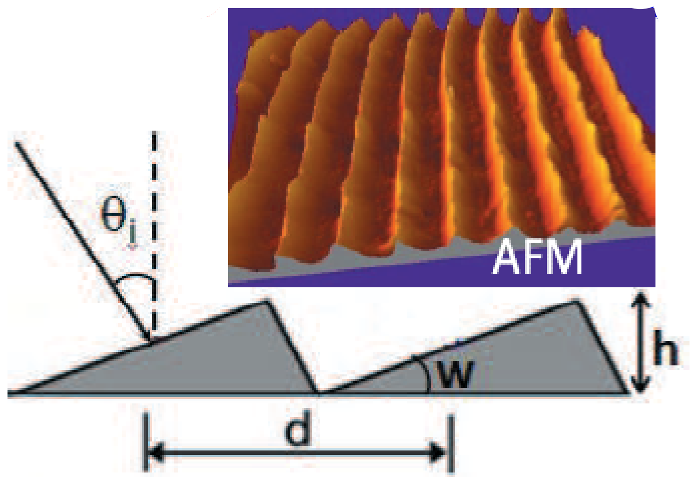
P. P. Rajeev et. al., AIP Conf. Proc.,2006

Efficient Hot Electron Creation

Good for kHz X-ray Sources!

Intense light gets into the groove!

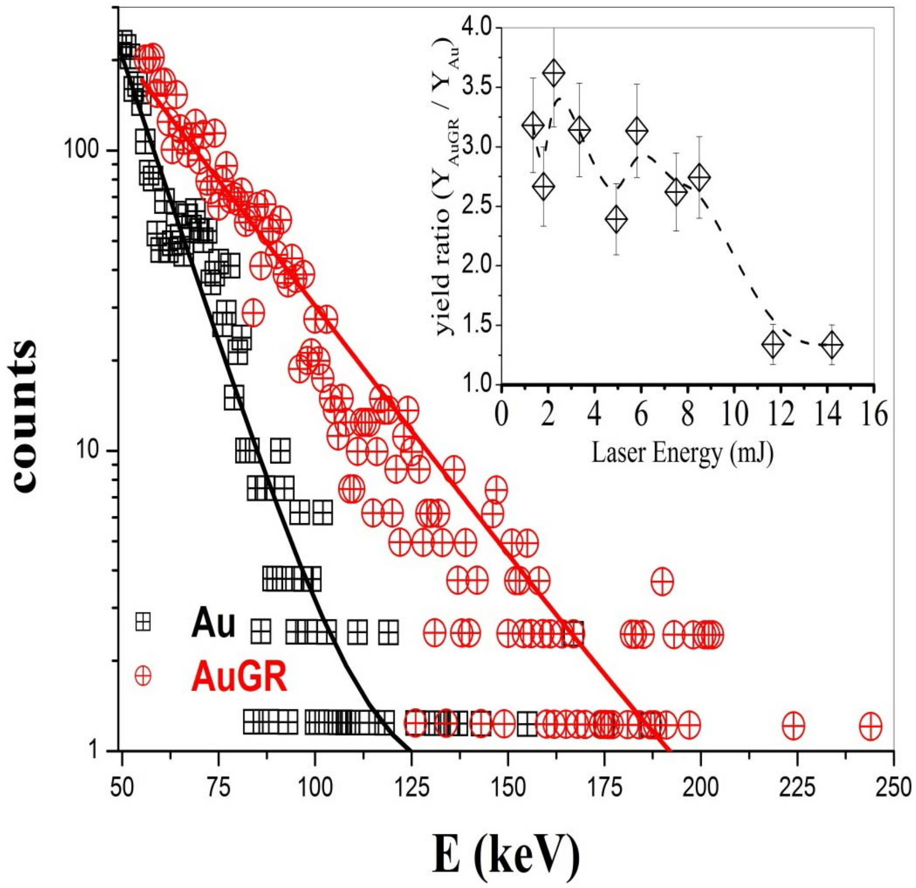




S. Kahaly et al.,
Phys.Rev.Lett.,
03 Oct 2008

~100 % absorption of intense light by SUB-λ GRATING target !
(Surface plasmons at work)

Bremsstrahlung Spectra



T_{AuGR} = 26 ± 2 keV

T_{Au} = 11 ± 1 keV

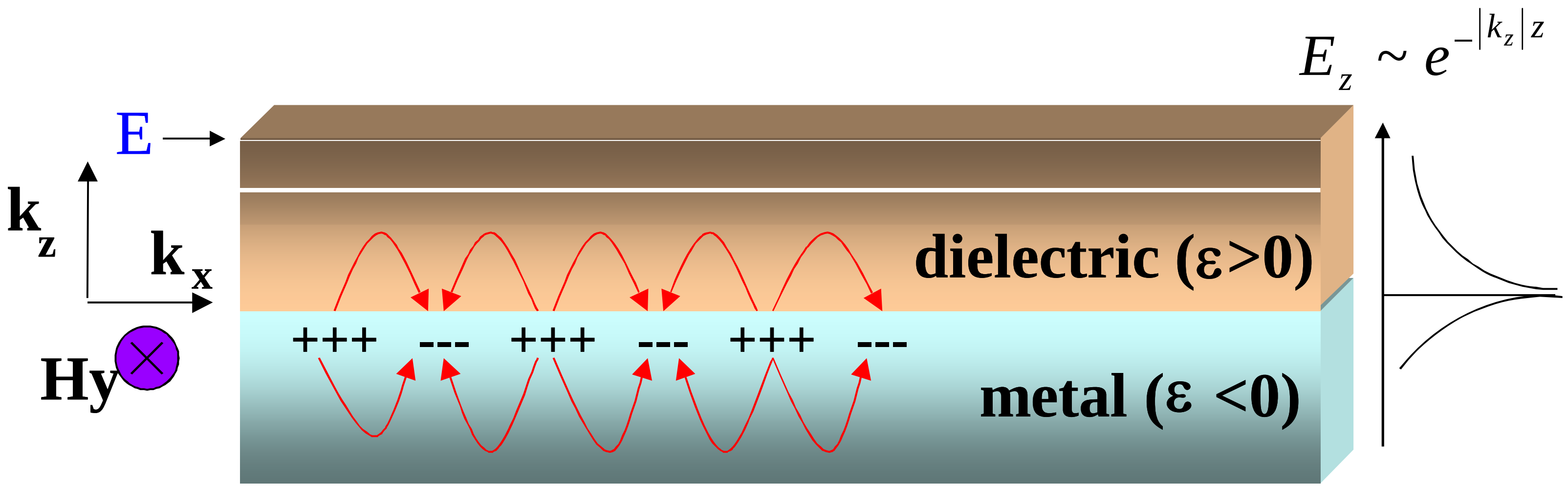
More x-ray emission from grating because of <u>more and hotter</u> Electrons
(consistent with more laser absorption)

RED- Gold Grating
Black- Planar Gold target

Efficient Hot Electron Creation

Rough (modulated) surfaces support

"Surface Plasmons"



Surface plasma oscillations:

fluctuations of the charge on a metal boundary

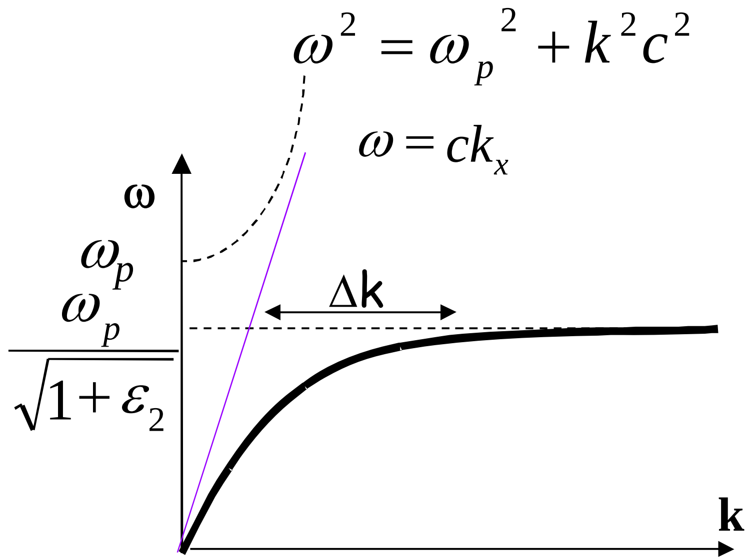
Coupling light to plasmons

- Maxwell's theory: EM waves propagating along a metallic surface

- dispersion relation (Vacuum): $$k_x = k_x' + ik_x'' = \sqrt{\frac{\varepsilon}{1+\varepsilon}}\left(\frac{\omega}{c}\right)$$

- ω(k) is to the right of light line in smooth surfaces: can't couple light in to the plasmon mode: non-radiative

Surface structures provide that Δk



Near-Complete Absorption of Intense, Ultrashort Laser Light by Sub-λ Gratings

Subhendu Kahaly,[1] S. K. Yadav,[2] W. M. Wang,[3] S. Sengupta,[2] Z. M. Sheng,[3,4] A. Das,[2] P. K. Kaw,[2] and G. Ravindra Kumar[1]

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[2]*Institute for Plasma Research, Bhat, Gandhinagar 382428, India*
[3]*Beijing National Laboratory of Condensed Matter Physics, Institute of Physics, CAS, Beijing 100190, China*
[4]*Department of Physics, Shanghai Jiao Tong University, Shanghai 200240, China*
(Received 18 January 2008; published 29 September 2008)

We demonstrate near-100% light absorption and increased x-ray emission from dense plasmas created on solid surfaces with a periodic sub-λ structure. The efficacy of the structure-induced surface plasmon resonance, responsible for enhanced absorption, is directly tested at the highest intensities to date (3×10^{15} W cm^{-2}) via systematic, correlated measurements of absorption and x-ray emission. An analytical grating model as well as 2D particle-in-cell simulations conclusively explain our observations. Our study offers a definite, quantitative way forward for optimizing and understanding the absorption process.

DOI: 10.1103/PhysRevLett.101.145001 PACS numbers: 52.38.Dx, 52.38.Ph, 73.20.Mf

How do we measure fast electron current?

- Ans: Measure its magnetic field!

Hot Electron Transport

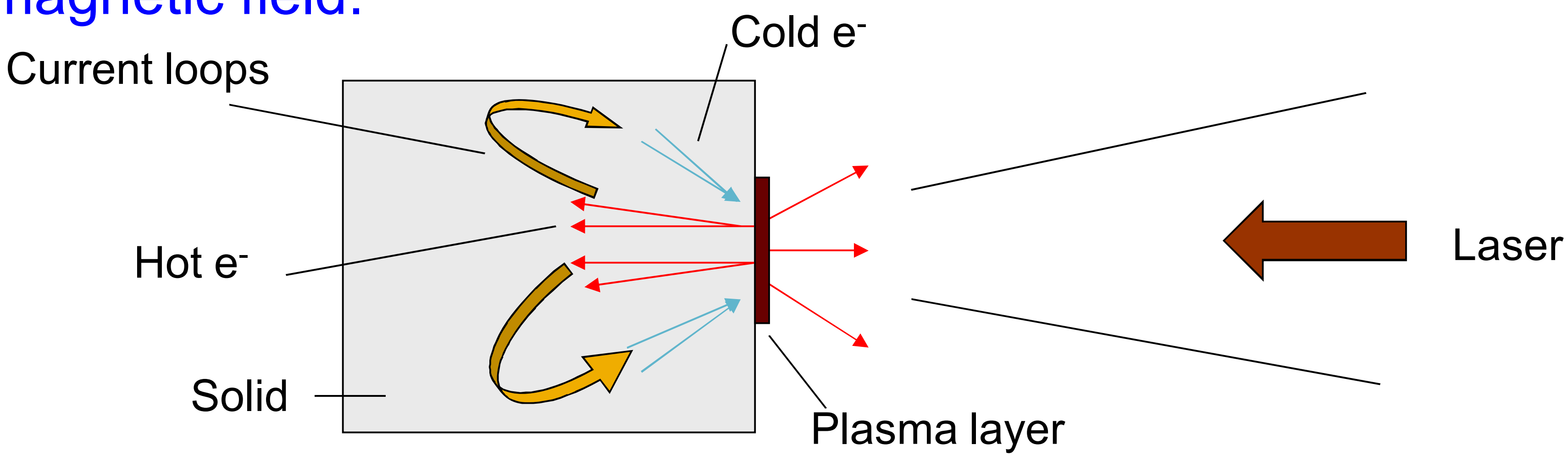
Generation and damping of B

- Hot electrons J_{hot} stream into bulk
- Return plasma currents compensate
- The electrical resistivity ($1/\sigma$) limits buildup and determines decay of magnetic field.

$$\frac{dB}{dt} = \frac{c}{\sigma}\left(\vec{\nabla} \times \vec{J}_{hot}\right) + \frac{c^2}{4\pi\sigma}\nabla^2\vec{B}$$

Source Diffusion

(for a homogeneous target)



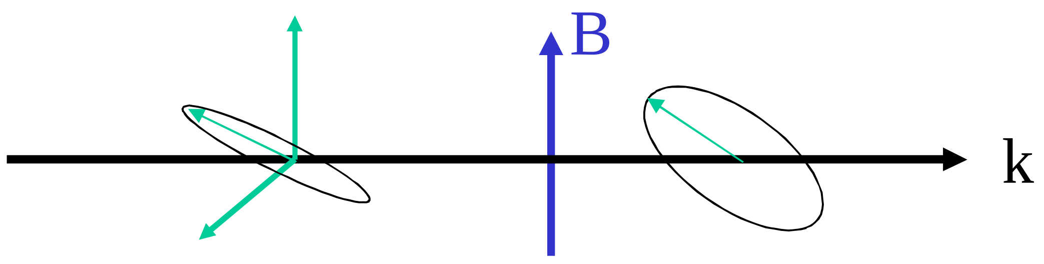
Measuring "B" by Polarimetry

Presence of Magnetic field defines preferred direction in space (Anisotropy) $\Rightarrow$ Refractive index depends on polarization of laser

Cotton-Mouton Effect: ($B \perp k$)

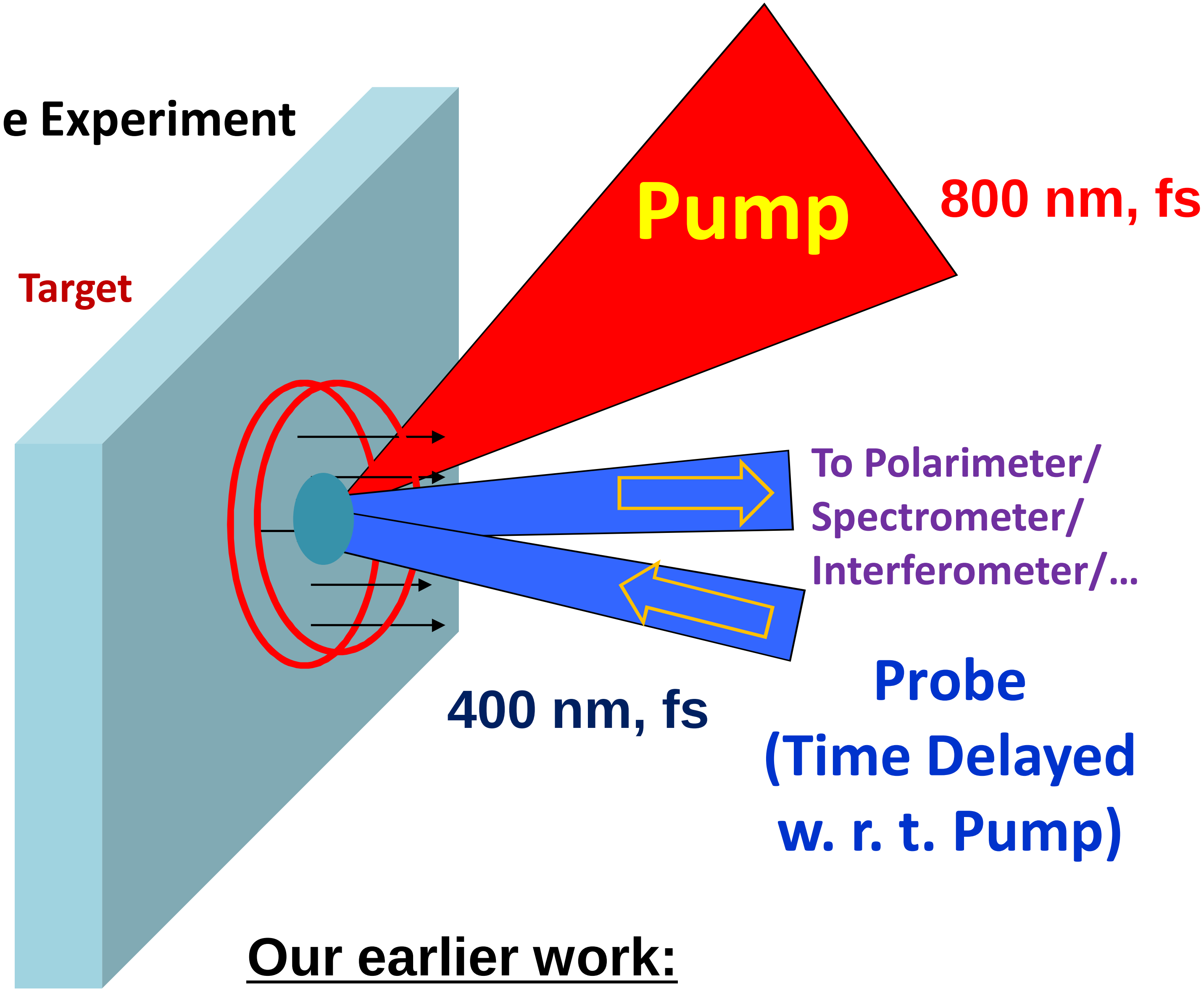
Linearly polarized light gains ellipticity,

Reason: Difference in refractive index for component of Electric field parallel and perpendicular to magnetic field.



Plasma Dynamics – Extremely Important
Need to See Plasma Dynamics "as it happens"

Pump-Probe Experiment

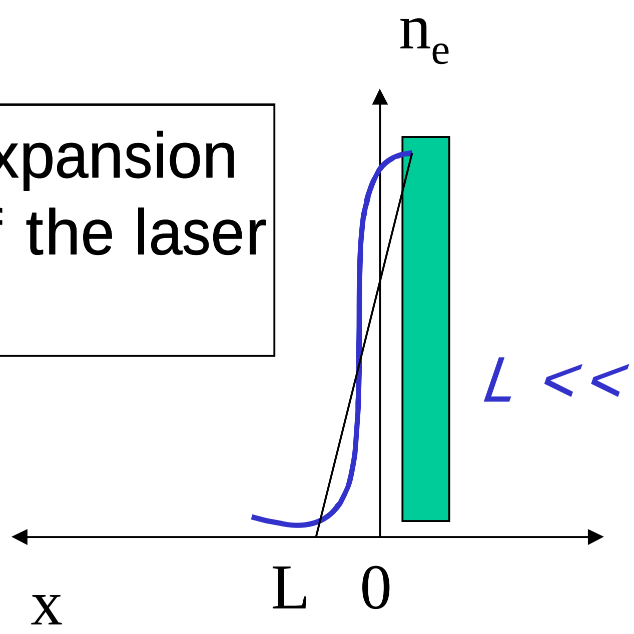


Our earlier work:

PRL (2002): PRE (2006); POP (2009)

Plasma Creation in Femtoseconds

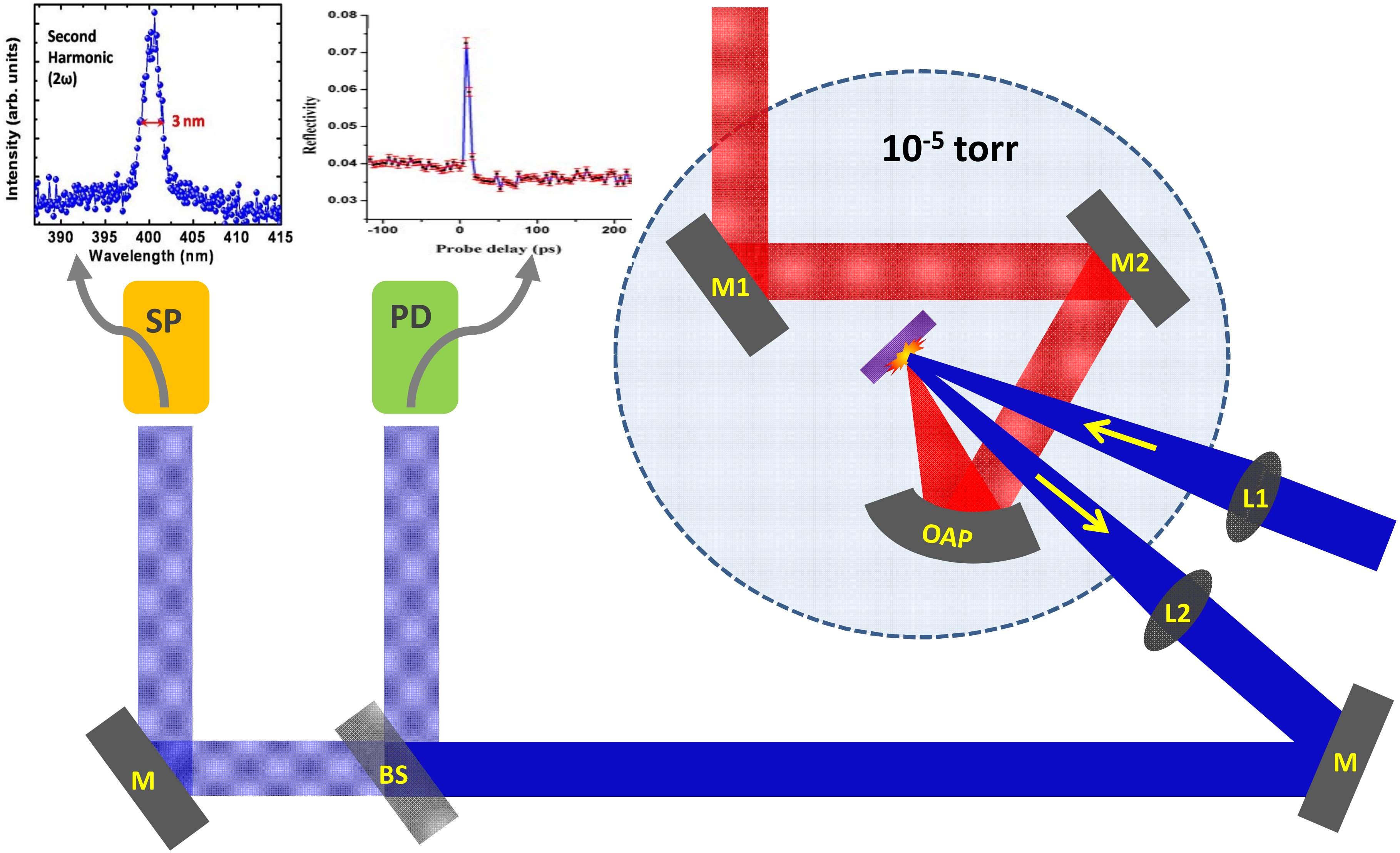
Hardly any plasma expansion during the lifetime of the laser pulse



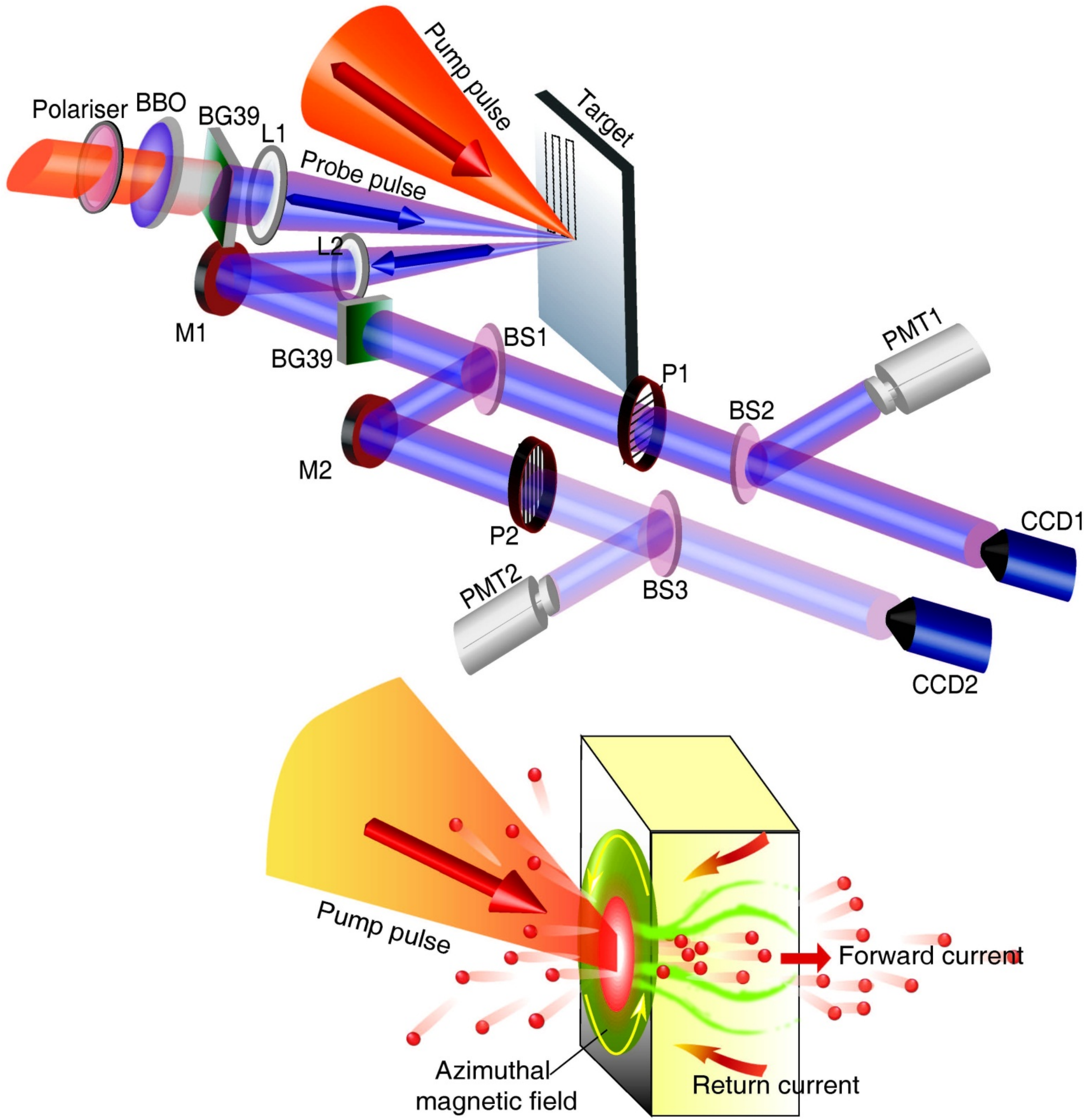
$L << \lambda$, 10's of nanometers

Flat like a mirror, specular,
Fresnel like,
but much HOTTER &DENSER

Femtosecond pulses heat matter at high densities!!



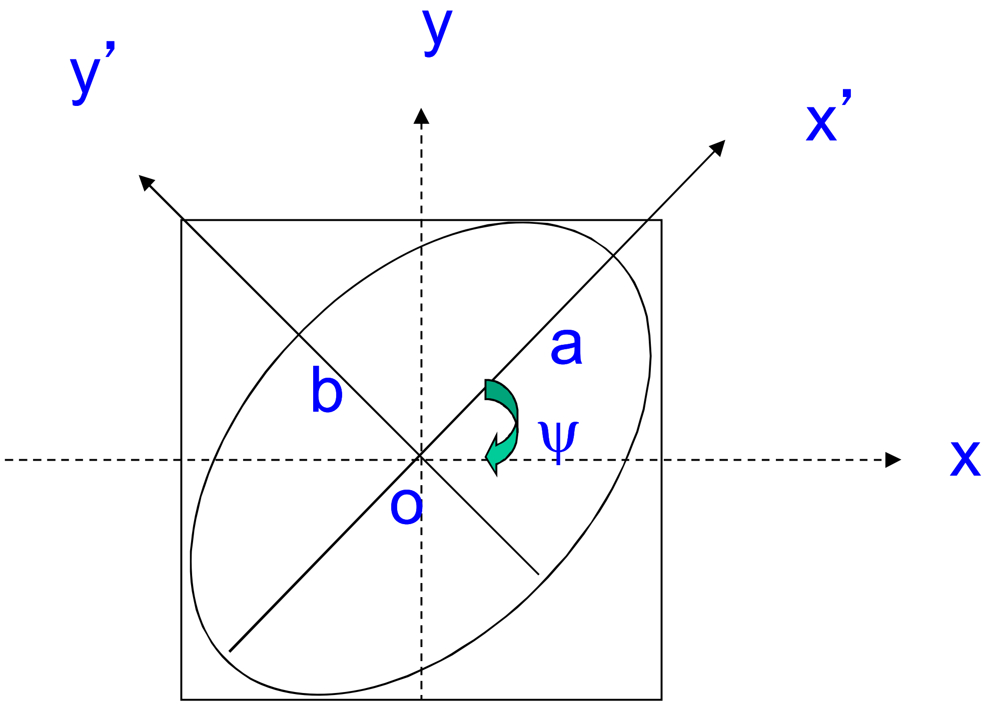
Second
Harmonic
(2ω)
3 nm
Intensity (arb. units)
390 395 400 405 410 415
Wavelength (nm)
0.08
0.07
0.06
0.05
0.04
0.03
Reflectivity
-100 0 100 200
Probe delay (ps)
10-5 torr
M1
M2
OAP
L1
L2
M
SP
PD
M
BS



Pump pulse
Target
Polariser
BBO
BG39
L1
Probe pulse
L2
M1
BG39
BS1
P1
PMT1
BS2
M2
P2
CCD1
PMT2
BS3
CCD2
Pump pulse
Forward current
Azimuthal magnetic field
Return current

ellipticity

$$\frac{E_x^2}{E_{0x}^2} + \frac{E_y^2}{E_{0y}^2} - \frac{2E_x E_y \cos\delta}{E_{0x}E_{0y}} = \sin^2\delta$$



ellipticity = b/a

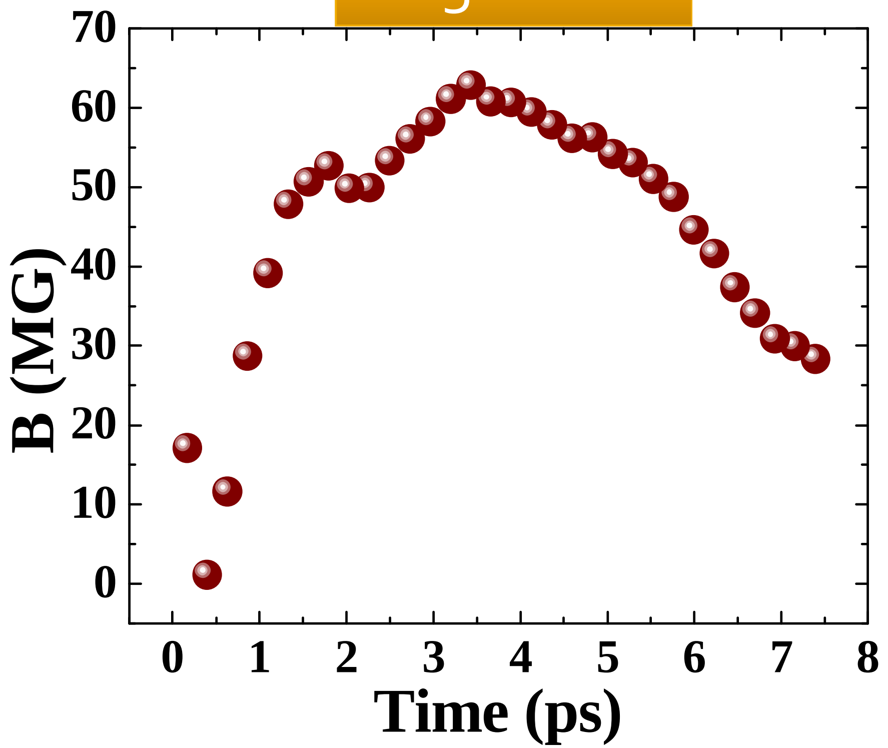
Measured Magnetic Field of Relativistic Electrons

Recent Results

Time Resolved, Space Integrated

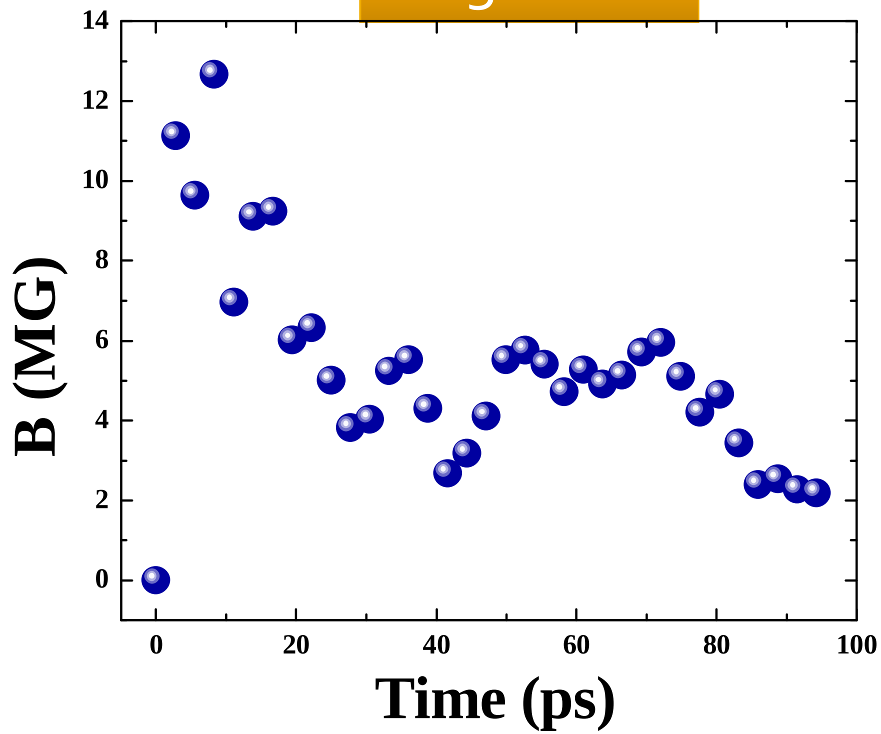
Aluminium film coated glass

Target Front

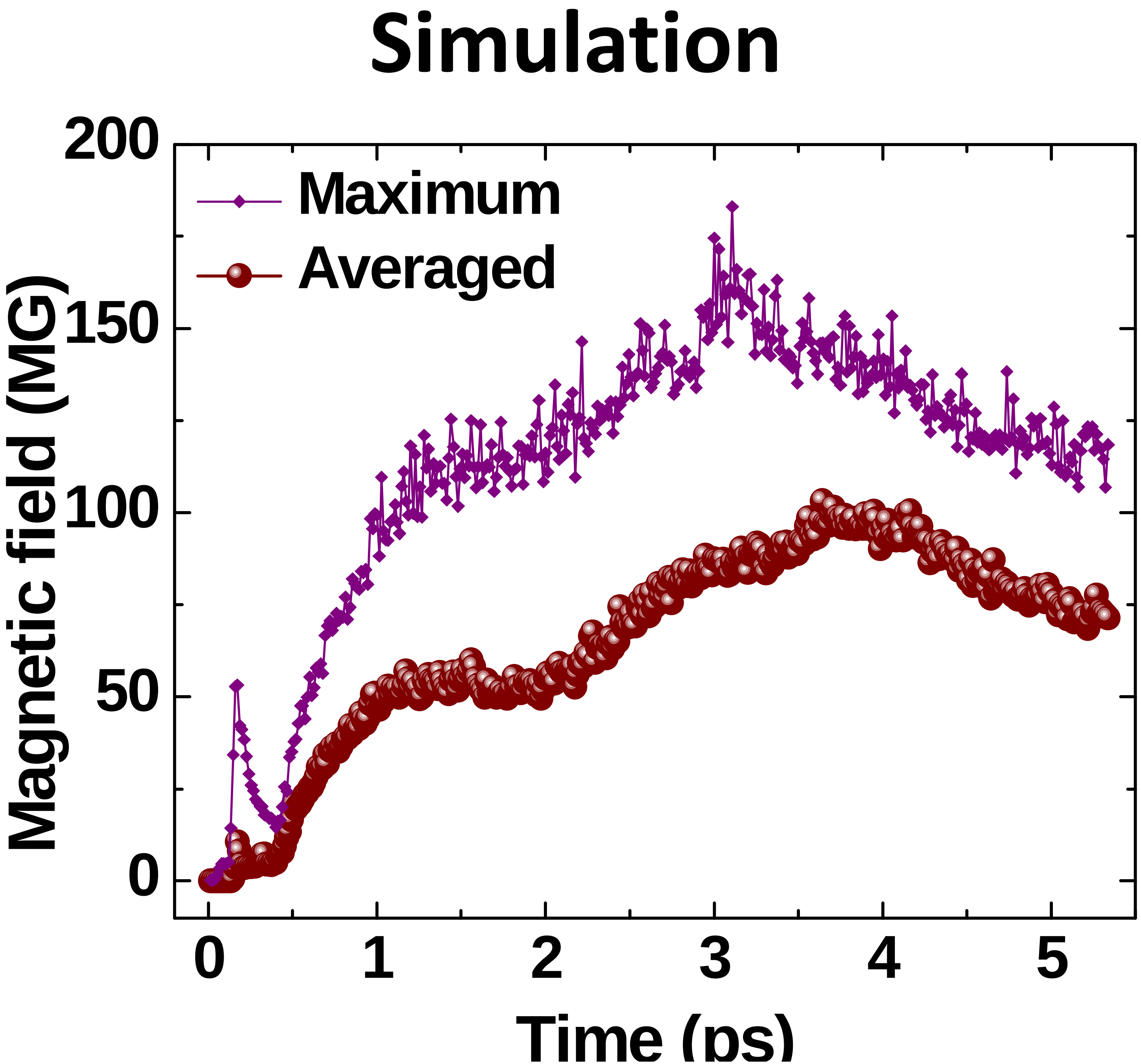


5×10^{18} W cm^{-2}

Target Back



2×10^{18} W cm^{-2}


Simulation
Maximum
Averaged
Magnetic field (MG)
Time (ps)
0
50
100
150
200
0
1
2
3
4
5

Hot electron currents

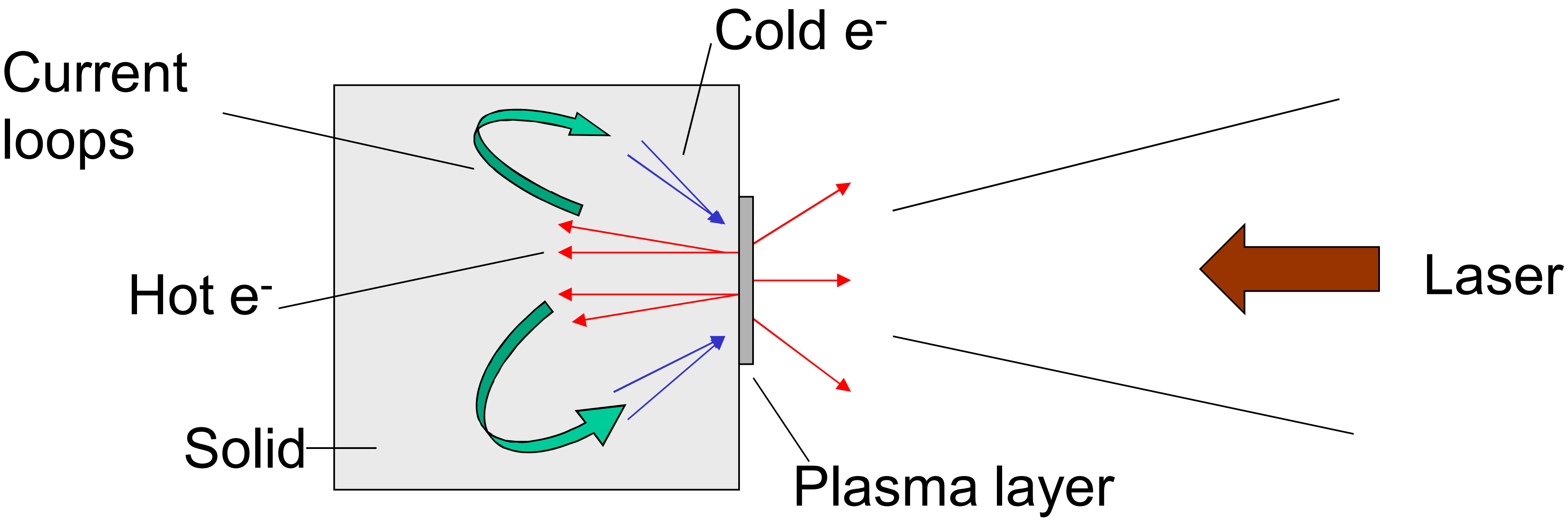
- Megaampere, Femtosecond pulses (10^6 A, fs)

Generation and damping of B

$$\frac{dB}{dt} = \frac{c}{\sigma}\left(\vec{\nabla} \times \vec{J}_{hot}\right) + \frac{c^2}{4\pi\sigma}\nabla^2 \vec{B}$$

Source Diffusion

- Hot electrons J_{hot} stream into bulk
- Return plasma currents compensate
- The electrical resistivity σ^{-1} limits buildup and
- determines decay of magnetic field.

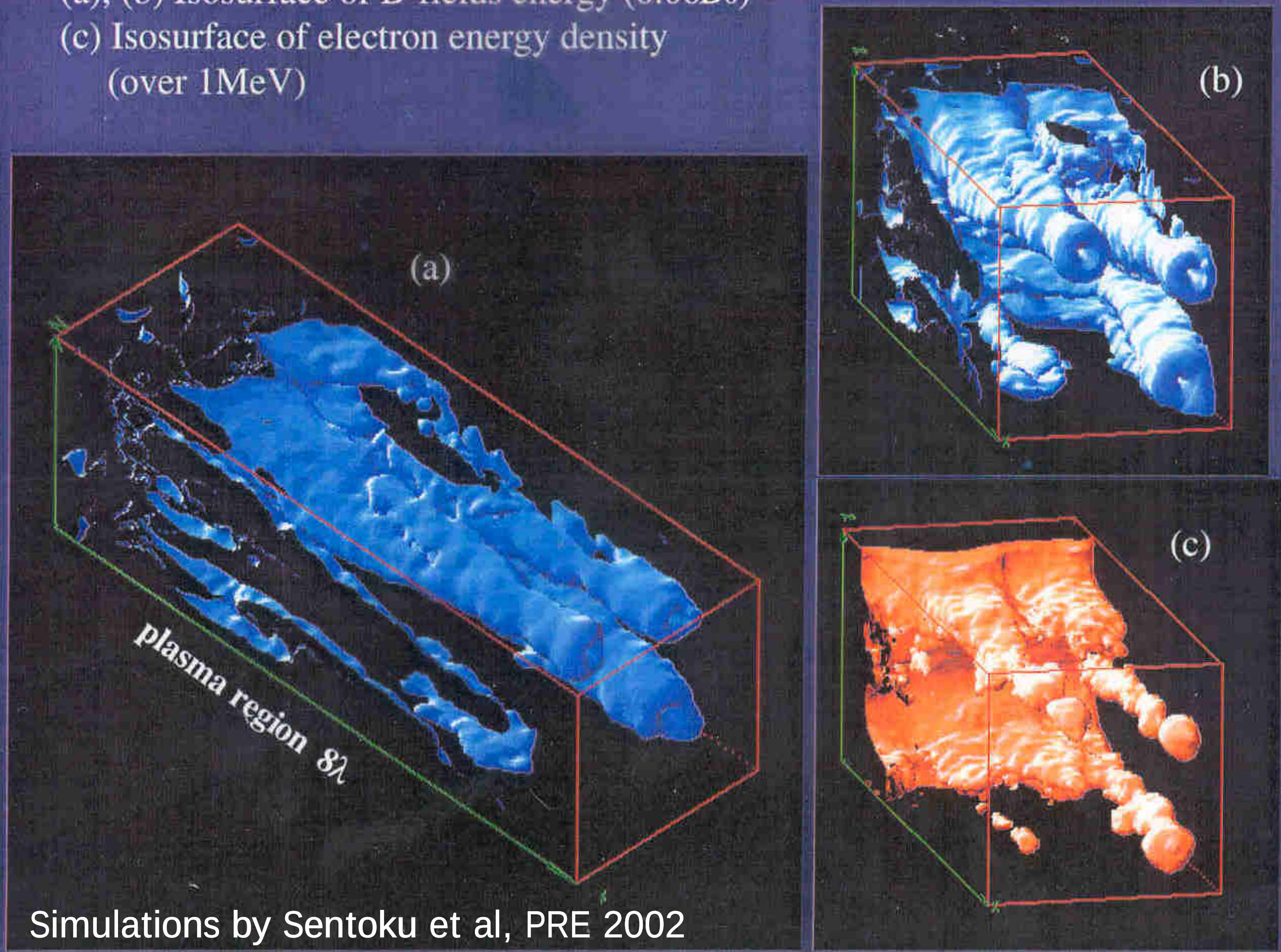


3D magnetic structure in over dense plasma

(a), (b) Isosurface of B-fields energy (0.06B0)

(c) Isosurface of electron energy density (over 1MeV)

t = 28 τ



Simulations by Sentoku et al, PRE 2002

Relativistic Electron Transport

'Hot electron' currents and 'Cold return' currents interact with each other

Currents become unstable (Weibel instability- B dependent)

Electron beam breaks up into filaments

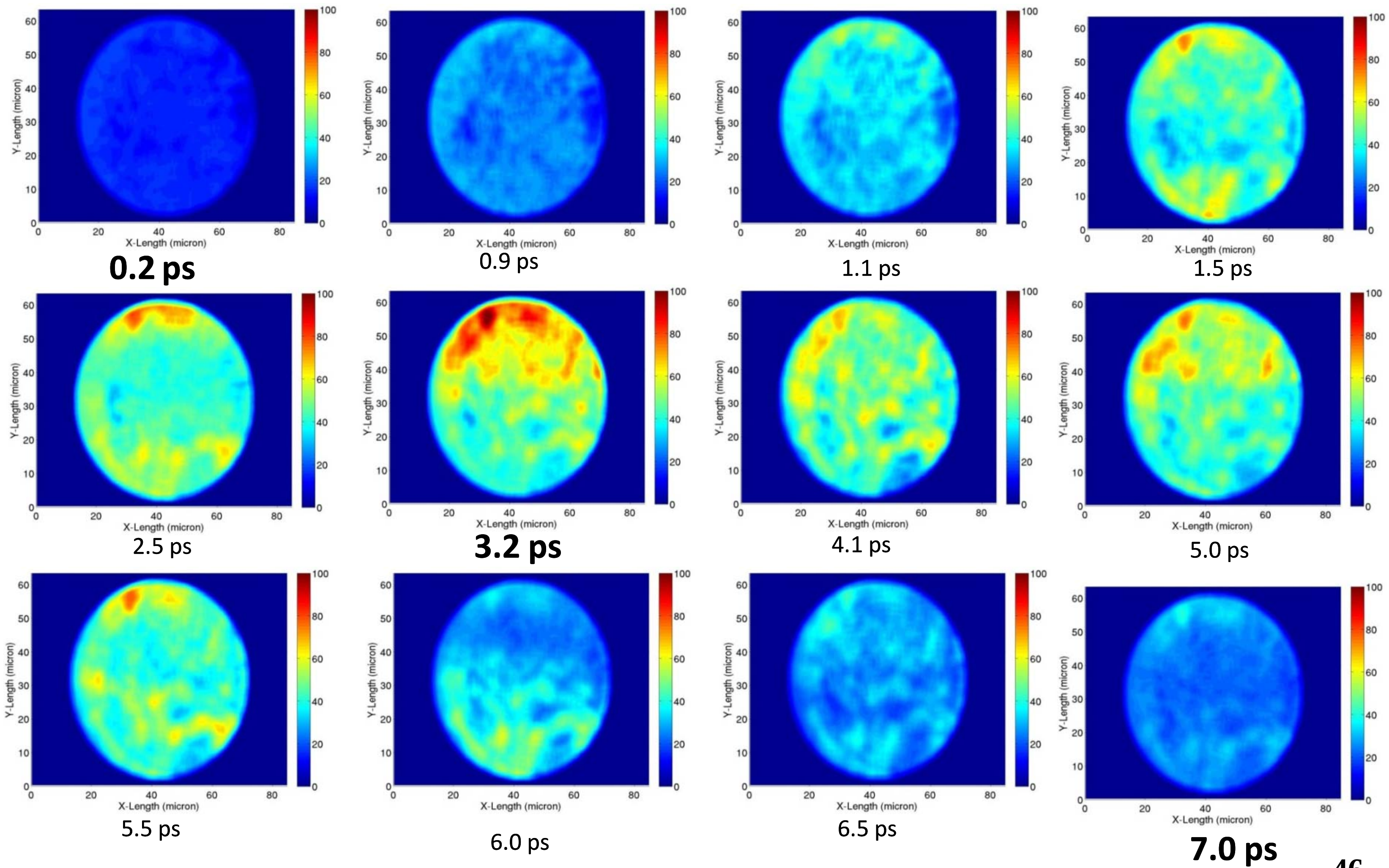
Magnetic field gets localized and inhomogeneous

Not directly observed till we came on the scene......................

Measured Magnetic Field of Relativistic Electrons

Fron

Time AND Space Resolved (Polarigram): Target Front

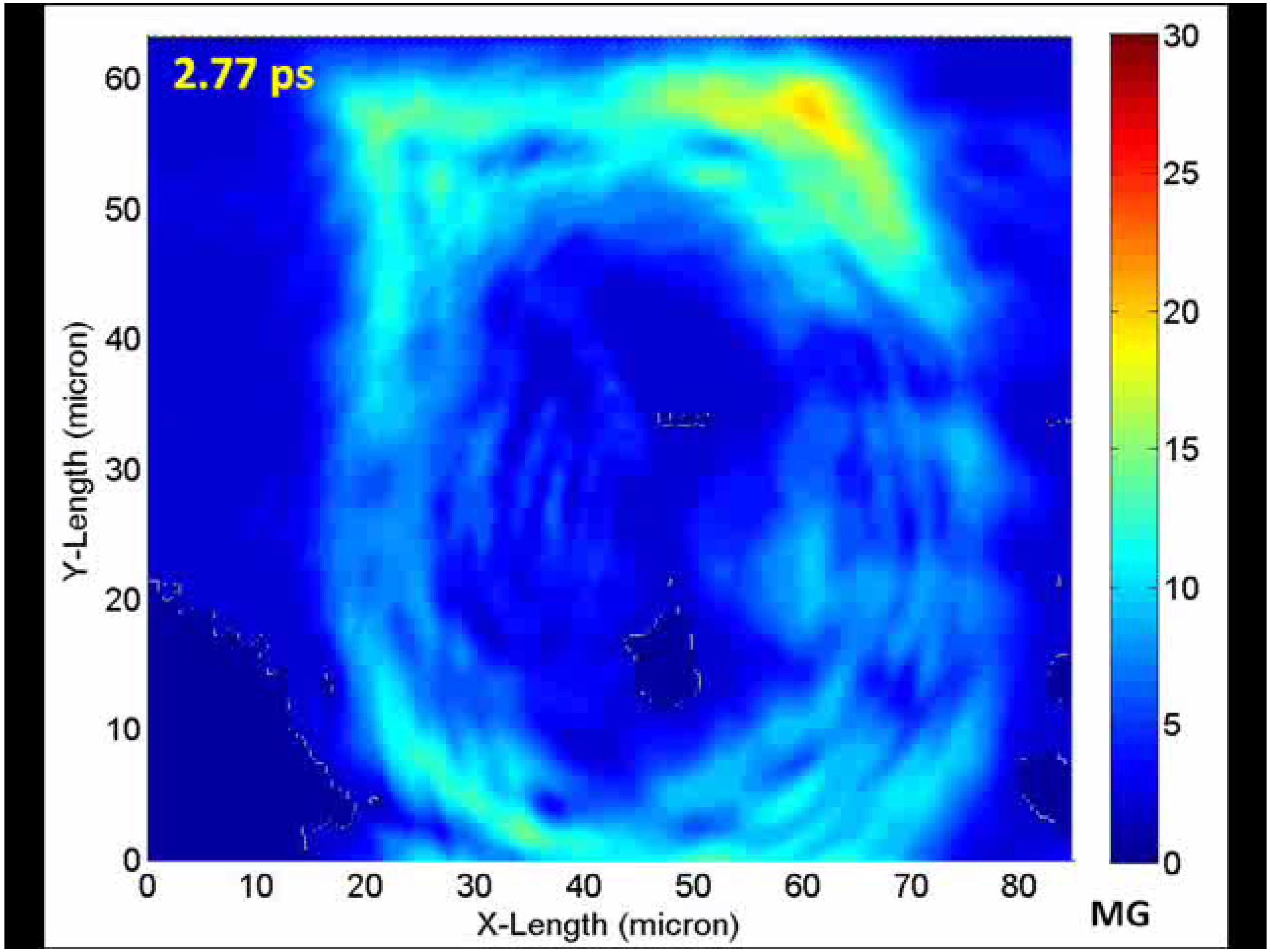


Filamentary Structures directly captured!

Measured Magnetic Field of Relativistic Electrons

Back

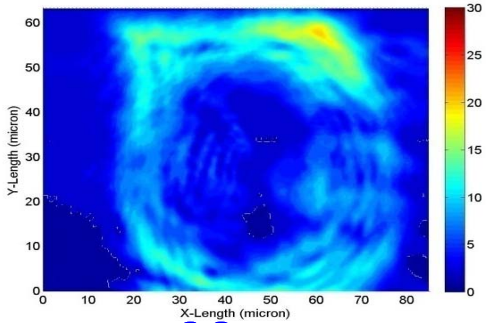
Time AND Space Resolved (Polarigram): Target BACK



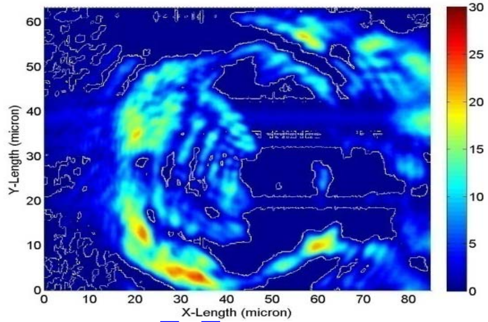
Measured Magnetic Field of Relativistic Electrons

Back

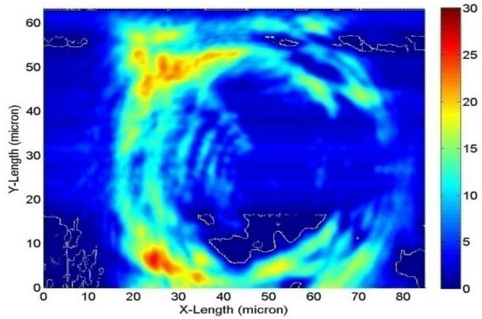
Time AND Space Resolved (Polarigram): Target BACK



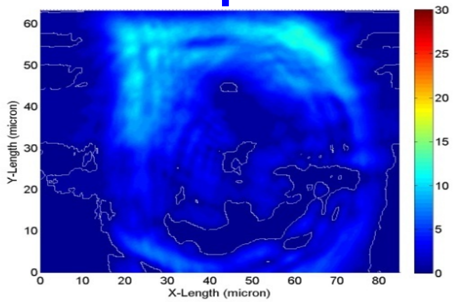
2.8 ps



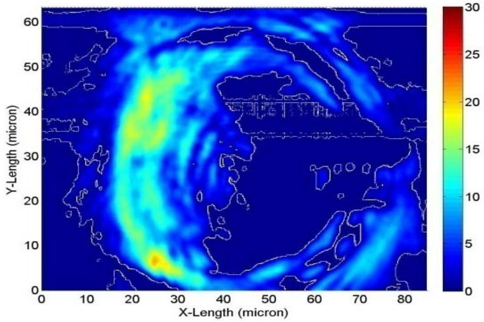
5.5 ps



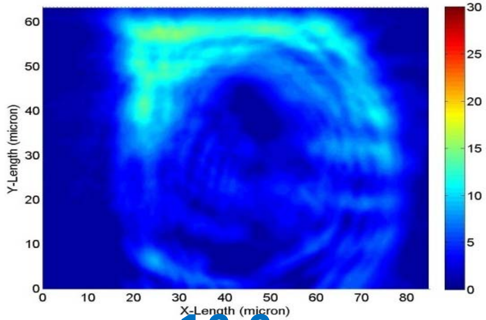
8.3 ps



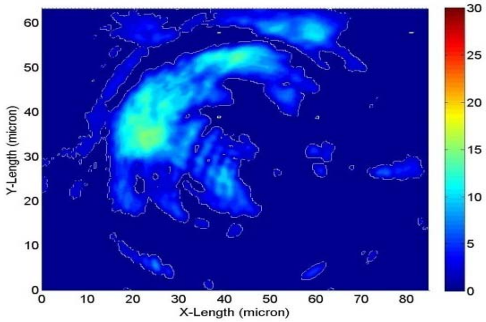
Time Delay=11.1



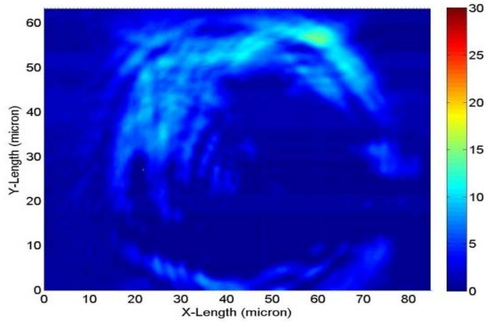
13.9 ps



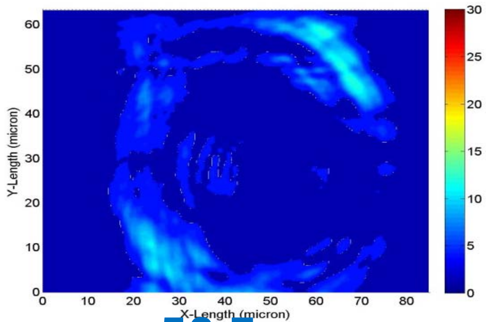
16.6 ps



33.3 ps

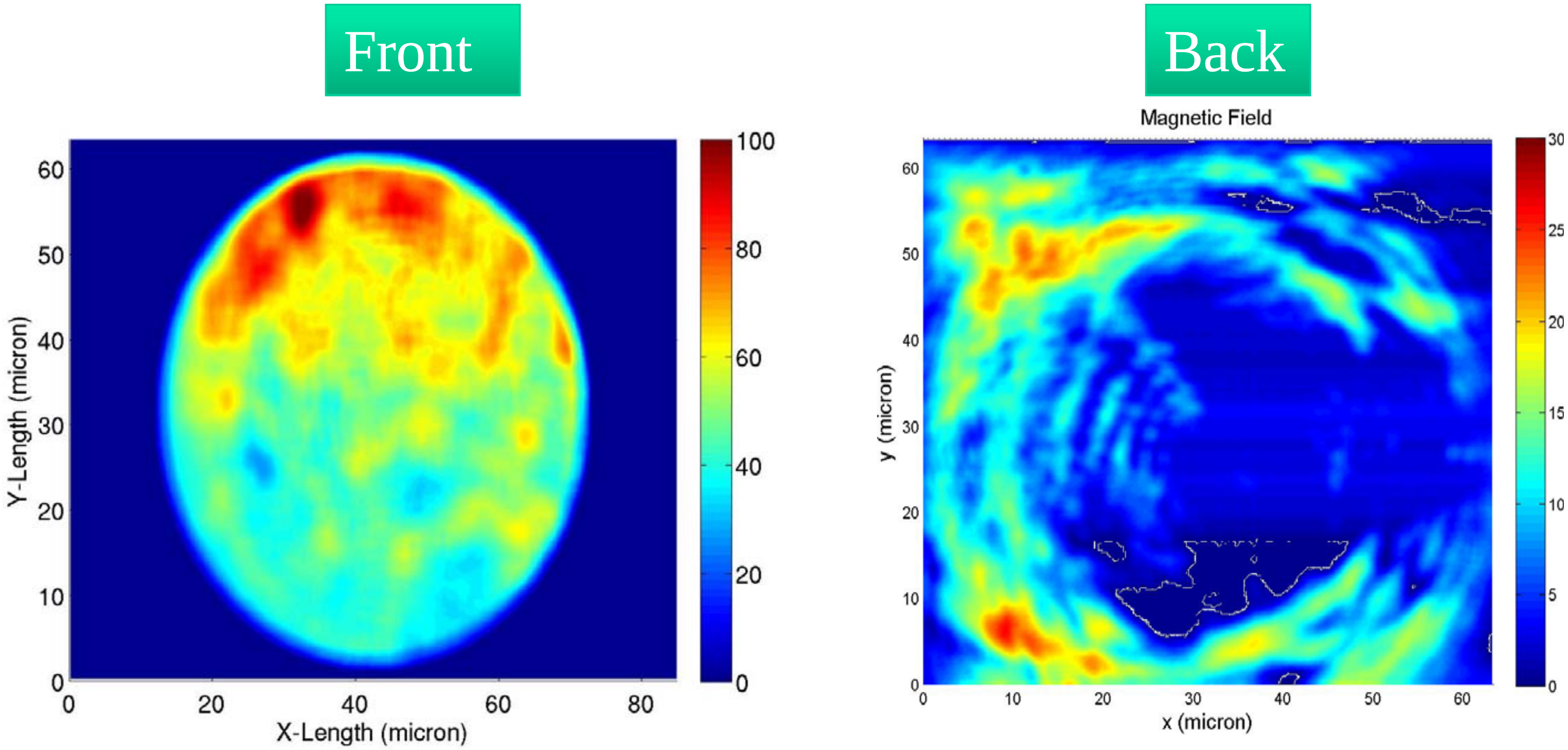


49.9 ps



52.7 ps

Magnetic Field



First direct observation of filamentation and inhomogeneity!
(TIFR expts; 2008-2009, manuscript in prep.)

Alert !

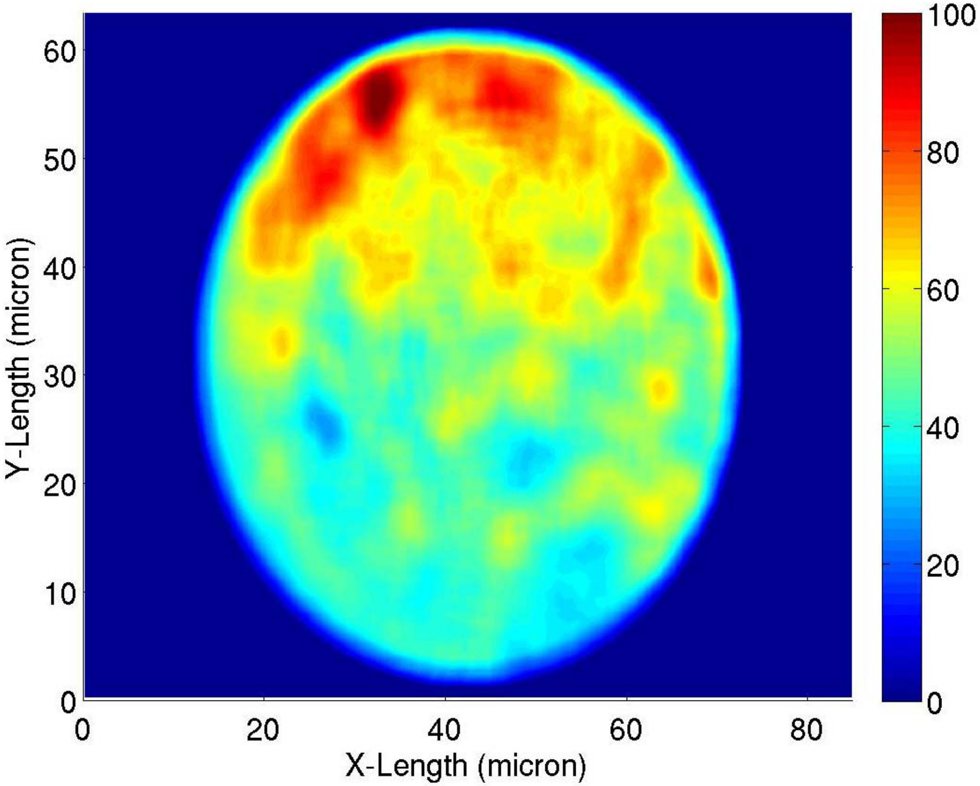
Watch Gourab Chatterjee ʹs poster today

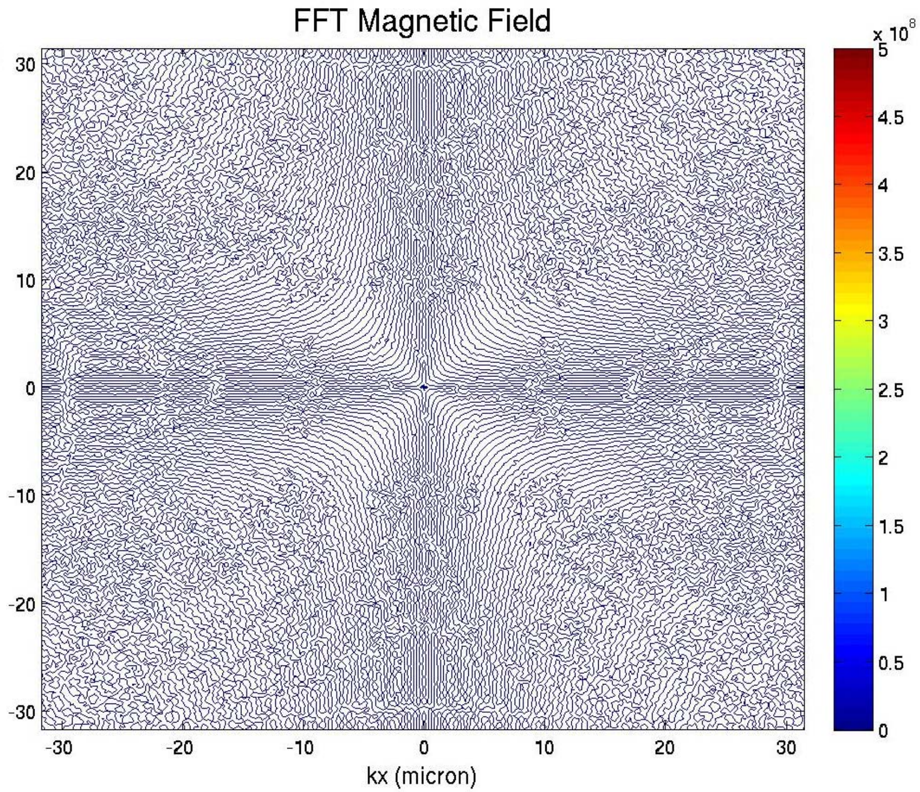
What more can we say about

these *Giant* magnetic fields?

Giant Magnetic Field

Fourier analysis of spatial image





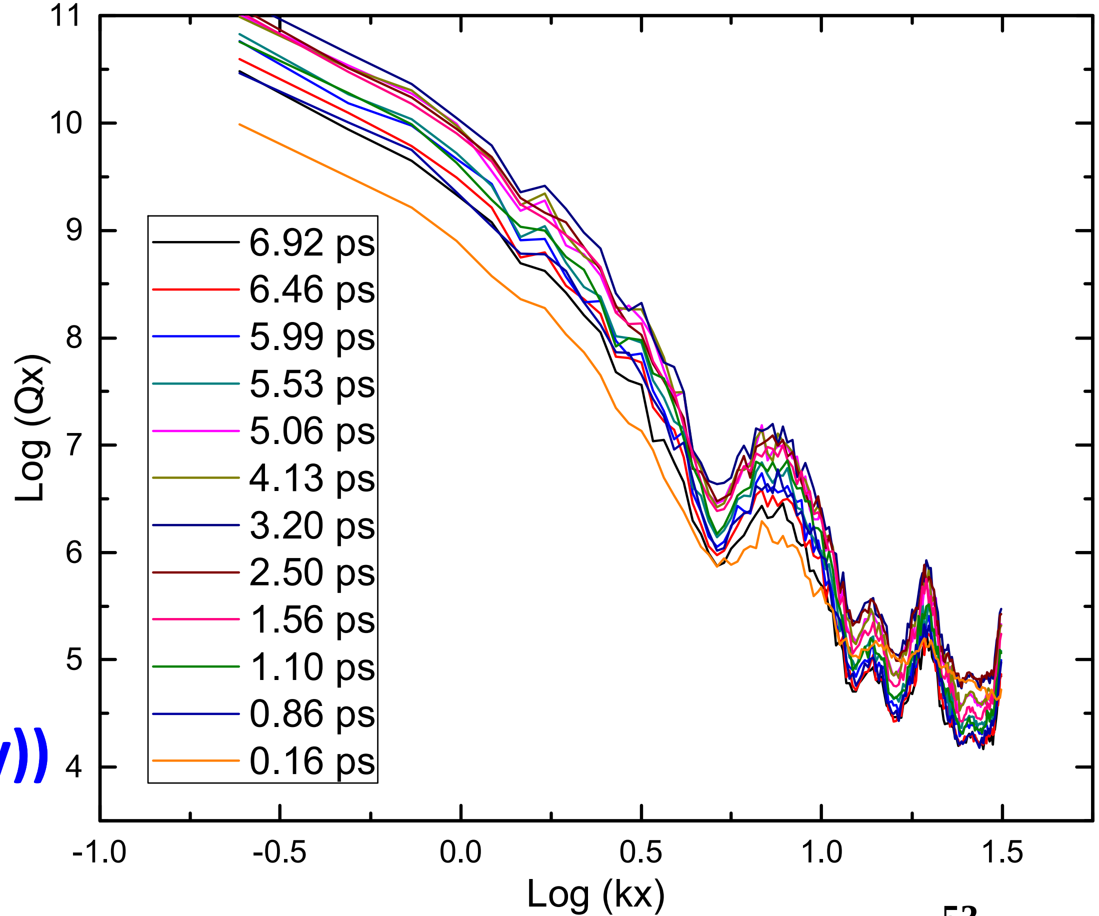
Megagauss Magnetic Field

The k-spectrum follows a power law !

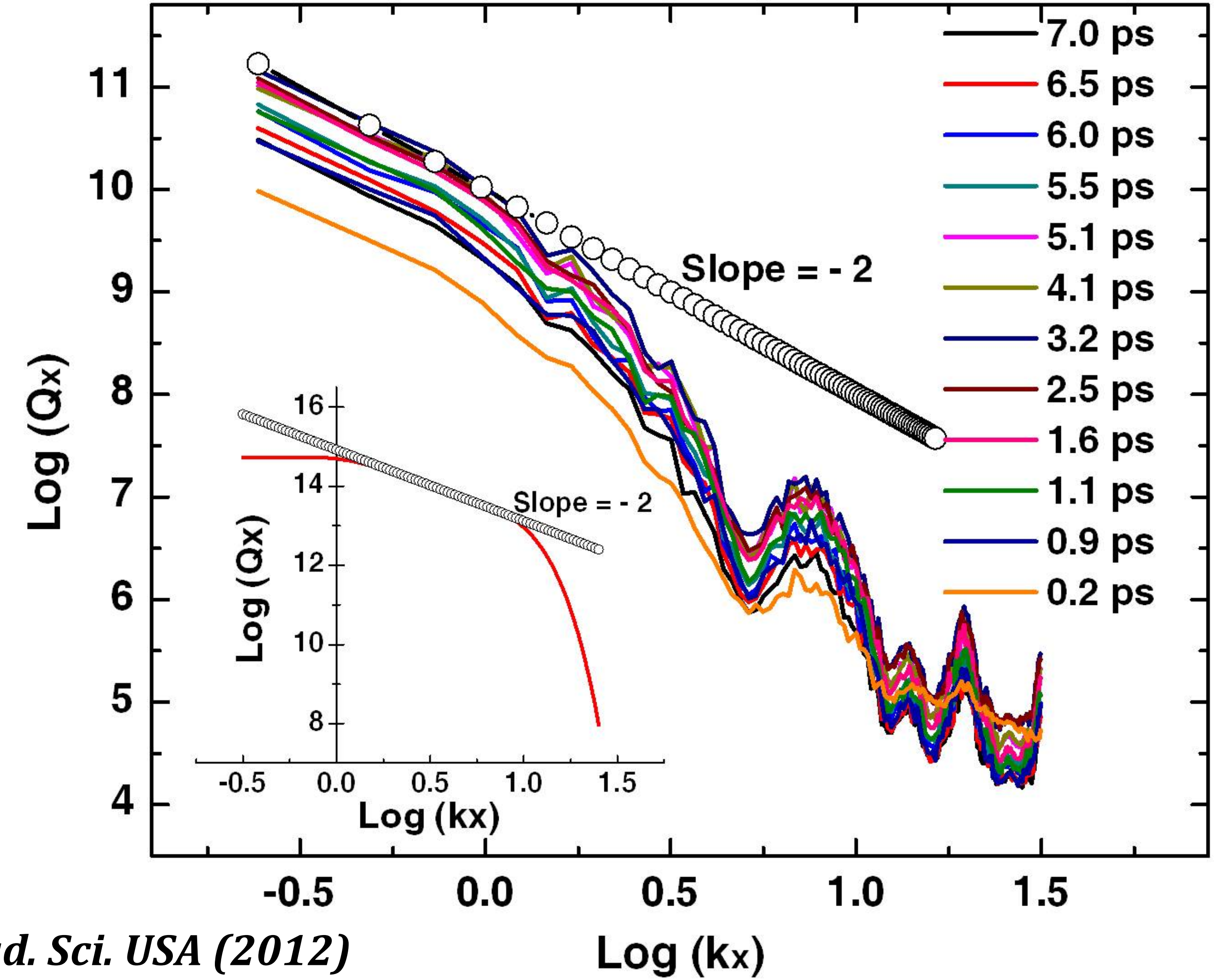
Magnetic field profiles at different times Fourier Analyzed.

$$Q(kx) = \int P(kx, ky)\, dky$$

where
P(kx,ky) =
B(kx,ky) * conjg (B(kx,ky))



Power spectrum of Spatial Images shows that
The Magnetic Field is Turbulent!



Mondal et al.,
Proc. Natl. Acad. Sci. USA (2012)

PNAS

Direct observation of turbulent magnetic fields in hot, dense laser produced plasmas

Sudipta Mondal[a], V. Narayanan[a], Wen Jun Ding[b], Amit D. Lad[a], Biao Hao[b], Saima Ahmad[a], Wei Min Wang[b], Zheng Ming Sheng[b,c,1], Sudip Sengupta[d], Predhiman Kaw[d], Amita Das[d,1], and G. Ravindra Kumar[a,1]

[a]Tata Institute of Fundamental Research, 1- Homi Bhabha Road, Mumbai 400005, India; [b]Beijing National Laboratory of Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China; [c]Laboratory for Laser Plasmas (Ministry of Education) and Department of Physics, Shanghai Jiao Tong University, Shanghai 200240, China; and [d]Institute for Plasma Research, Bhat, Gandhinagar 382428, India

Edited by* Margaret M. Murnane, University of Colorado at Boulder, Boulder, CO, and approved April 9, 2012 (received for review January 24, 2012)

Turbulence in fluids is a ubiquitous, fascinating, and complex natural phenomenon that is not yet fully understood. Unraveling turbulence in high density, high temperature plasmas is an even bigger challenge because of the importance of electromagnetic forces and the typically violent environments. Fascinating and novel behavior of hot dense matter has so far been only indirectly inferred because of the enormous difficulties of making observations on such matter. Here, we present direct evidence of turbulence in giant magnetic fields created in an overdense, hot plasma by relativistic intensity (10^{18} W/cm^2) femtosecond laser pulses. We have obtained magneto-optic polarigrams at femtosecond time intervals, simultaneously with micrometer spatial resolution. The spatial profiles of the magnetic field show randomness and their *k* spectra exhibit a power law along with certain well defined peaks at scales shorter than skin depth. Detailed two-dimensional particle-in-cell simulations delineate the underlying interaction between forward currents of relativistic energy "hot" electrons created by the laser pulse and "cold" return currents of thermal electrons induced in the target. Our results are not only fundamentally interesting but should also arouse interest on the role of magnetic turbulence induced resistivity in the context of fast ignition of laser fusion, and the possibility of experimentally simulating such structures with respect to the sun and other stellar environments.

These parameters are not easily obtainable by other methods. In the present study, we take a further leap by spatially resolving the giant magnetic field on a micrometer scale at each temporal delay. These spatial maps clearly show the filamentary structures of electron currents in the plasma. A spectral analysis of these maps indicates that the magnetic fields are turbulent in nature (18). We use pump-probe Cotton–Mouton polariscopy (15–17, 19) to measure the temporal and spatial evolution of the giant magnetic field (the former on picosecond time scale and the latter on micrometer scale). These polarigrams capture the temporal evolution of the filamentation process and a Fourier analysis of the spatial images clearly shows a broad spectrum with a power-law behavior for the magnetic energy. Our analytical studies and two-dimensional particle-in-cell (2D-PIC) simulations support the broad power-law spectrum and clearly demonstrate the presence of turbulence (20, 21).

Magnetic Field: Temporal and Spatial Profiles

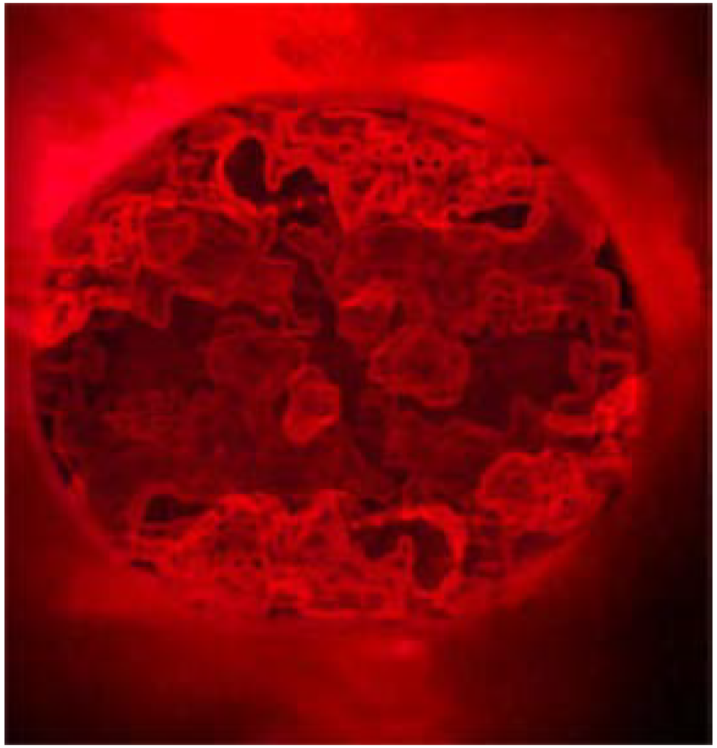
Our measurements of the giant magnetic field (shown by the schematic of Fig. 1) are based on the modification of the polarization state of a weak probe beam (400 nm wavelength, 80 fs duration) launched into the plasma at a certain time delay from the plasma producing pump beam of intensity 10^{18} W/cm^2 (800 nm wavelength, 30 fs duration). The plasma is created on an optically planar solid target. The probe beam is reflected from

PNAS Highlight, May 2012

Physics

Sun-like magnetic turbulence reproduced in lab plasma

Physicists have long theorized that extremely hot and dense matter, such as the plasma interior of stars, behaves like a highly complex fluid in which currents of electrons flow at relativistic speeds through turbulent electromagnetic fields. Unraveling the unique aspects of plasma turbulence could improve energy technologies, but the violent nature of these environments has confounded direct observation. Sudipta Mondal et al. used ultrashort, ultrahigh-intensity laser pulses to generate relativistic electron transport in plasma and report direct evidence of turbulence in the resulting giant magnetic fields. The authors obtained highly detailed measurements of the evolving fields—micrometer spatial resolution at femtosecond intervals—and identified filamentary structures that likely correspond to relativistic electron currents. In subsequent computer simulations, the authors revealed additional details that match theoretical predictions, including forward currents of so-called “hot” electrons and “cold” return currents. The findings, apart from their intrinsic theoretical value, can potentially contribute to building better fast ignition systems needed for laser fusion and to experimentally simulating processes in stellar environments, according to the authors. — T.J.



Turbulence in the giant magnetic field of a laser-produced plasma.

"Direct observation of turbulent magnetic fields in hot, dense laser produced plasmas"
by Sudipta Mondal, et al.
[Abstract] **OPEN ACCESS ARTICLE**

A few of our other papers relevant to the themes of this talk

Macroscopic Transport of Mega-ampere Electron Currents in Aligned Carbon-Nanotube Arrays

Gourab Chatterjee,[1] Prashant Kumar Singh,[1] Saima Ahmed,[1] A. P. L. Robinson,[2] Amit D. Lad,[1] Sudipta Mondal,[1] V. Narayanan,[1] Iti Srivastava,[3] Nikhil Koratkar,[4,3] John Pasley,[5,2] A. K. Sood,[6] and G. Ravindra Kumar[1,*]

[1]*Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai, 400005, India*
[2]*Central Laser Facility, Rutherford-Appleton Laboratory, Chilton, Didcot, OX10 0QX, United Kingdom*
[3]*Department of Materials Science and Engineering, Rensselaer Polytechnic Institute, Troy, New York 12180, USA*
[4]*Department of Mechanical, Aerospace and Nuclear Engineering, Rensselaer Polytechnic Institute, Troy, New York 12180, USA*
[5]*York Plasma Institute, University of York, Heslington, York, YO10 5DQ, United Kingdom*
[6]*Department of Physics, Indian Institute of Science, Bangalore, 560 012, India*
(Received 28 January 2012; published 8 June 2012)

We demonstrate that aligned carbon-nanotube arrays are efficient transporters of laser-generated mega-ampere electron currents over distances as large as a millimeter. A direct polarimetric measurement of the temporal and the spatial evolution of the megagauss magnetic fields (as high as 120 MG) at the target rear at an intensity of $(10^{18}\text{–}10^{19})$ W/cm^2 was corroborated by the rear-side hot electron spectra. Simulations show that such high magnetic flux densities can only be generated by a very well collimated fast electron bunch.

VOLUME 90, NUMBER 11 PHYSICAL REVIEW LETTERS week ending 21 MARCH 2003

Metal Nanoplasmas as Bright Sources of Hard X-Ray Pulses

P. P. Rajeev, P. Taneja, P. Ayyub, A. S. Sandhu, and G. Ravindra Kumar*
Tata Institute of Fundamental Research, 1, Homi Bhabha Road, Mumbai 400 005, India
(Received 11 April 2002; published 18 March 2003)

We report significant enhancements in light coupling to intense-laser-created solid plasmas via surface plasmon and "lightning rod" effects. We demonstrate this in metal nanoparticle-coated solid targets irradiated with 100 fs, 806 nm laser pulses, focused to intensities $\sim 10^{14}$–10^{15} W cm^{-2}. Our experiments show a 13-fold enhancement in hard x-ray yield (10–200 keV) emitted by copper nanoparticle plasmas formed at the focal volume. A simple model explains the observed enhancement quantitatively and provides pointers to the design of structured surfaces for maximizing such emissions.

DOI: 10.1103/PhysRevLett.90.115002 PACS numbers: 52.25.Os, 42.65.Re, 52.38.–r, 52.50.Jm

Nanostructures, local fields, and enhanced absorption in intense light–matter interaction

P. P. Rajeev,* P. Ayyub, S. Bagchi, and G. R. Kumar

Tata Institute of Fundamental Research, 1 Homi Bhabha Road, Mumbai 400 005, India

Received May 21, 2004

Recent literature has reported impressive enhancements in hard-x-ray emission from short-lived solid plasmas by modulation of the interacting surface with nanostructures. We show that the modification of local electric fields near surface structures results in excessive absorption and enhanced x-ray production. A simple model based on local field variations explains the observed x-ray enhancements quantitatively.

OCIS codes: 240.5770, 240.6680, 350.5400, 340.7480.

Laser-Generated Ultrashort Multimegagauss Magnetic Pulses in Plasmas

A. S. Sandhu,[1] A. K. Dharmadhikari,[1] P. P. Rajeev,[1] G. R. Kumar,[1] S. Sengupta,[2] A. Das,[2] and P. K. Kaw[2]
[1]*Tata Institute of Fundamental Research, 1 Homi Bhabha Road, Mumbai 400 005, India*
[2]*Institute for Plasma Research, Bhat, Gandhinagar, Ahmedabad 382428, India*
(Received 13 April 2002; published 11 November 2002)

We demonstrate ultrashort (6 ps), multimegagauss (27 MG) magnetic pulses generated upon interaction of an intense laser pulse (10^{16} W cm^{-2}, 100 fs) with a solid target. The temporal evolution of these giant fields generated near the critical layer is obtained with the highest resolution reported thus far. Particle-in-cell simulations and phenomenological modeling is used to explain the results. The first direct observations of anomalously rapid damping of plasma shielding currents produced in response to the hot electron currents penetrating the bulk plasma are presented.

DOI: 10.1103/PhysRevLett.89.225002 PACS numbers: 52.38.Fz, 52.65.Rr, 52.70.Ds, 52.70.Kz

Conclusions of G. Ravindra Kumar's Three Talks

- Femtosecond, Terawatt Laser Pulses enable High Energy Density Science experiments on a table top

- Ultrafast dynamics in the target plasma extremely important

- Generation and Transport of Megaampere, Femtosecond electron pulses crucial for many areas ex:Fast Ignition of Laser Fusion

Very exciting times ahead, jump right in and let us race ahead !