Summary of WG4

Applications of High Brightness Beams to Advanced Accelerators and Light Sources

Chaired by Mitsuru Uesaka (Univ.Tokyo)
Scientific secretary: Andrea Rossi (Univ.Milan)

1. Compton Scattering X-ray Sources
2. FEL and RF Photoinjectors
3. Plasma Wakefield Acceleratoion and Innovative Acceleration Schemes

16 contributions

Compton Scattering X-ray Sources

1. Multi-Scattering for More Yield and Medical Applications

Mitsuru Uesaka(Univ.Tokyo)
"Medical Application of Multi-beams Compton Scattering Monochromatic Tunable Hard X-ray Sources"

Haruyuki Ogino(Univ.Tokyo)
"Laser Pulse Circulation System for Compact Monochromatic Hard-X-Ray Source"

2. Strong Focusing and Higher Harmonics Generation

Jae Lim(LLNL)
"A permanent –Magnet Quadrupole Final focusing Optics at PLEIADES Thomson X-ray Source"

Oliver Williams(UCLA)
"Status of the Nonlinear Inverse Compton Scattering Experiment at UCLA"

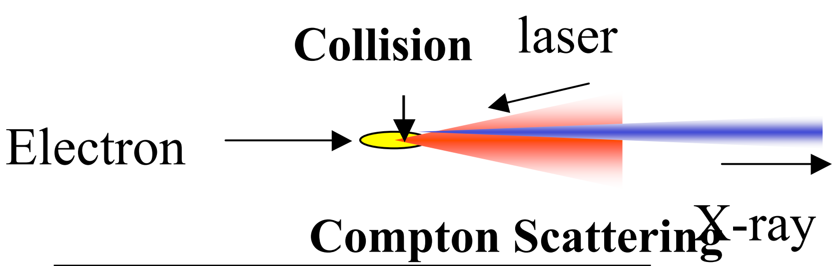
Rodney Yoder(Manhattan College)
"An Inverse Compton Scattering Radiation Source via Self-Guiding in a Plasma"

Vitaly Yakimenko(BNL)
"Nonlinear Compton Scattering at BNL-ATF"

3. Theory and simulation

Vittoria Petrillo(Univ.Milan)
"Study of transverse effects in a collective Thomson Back-scattering Source of X-rays"

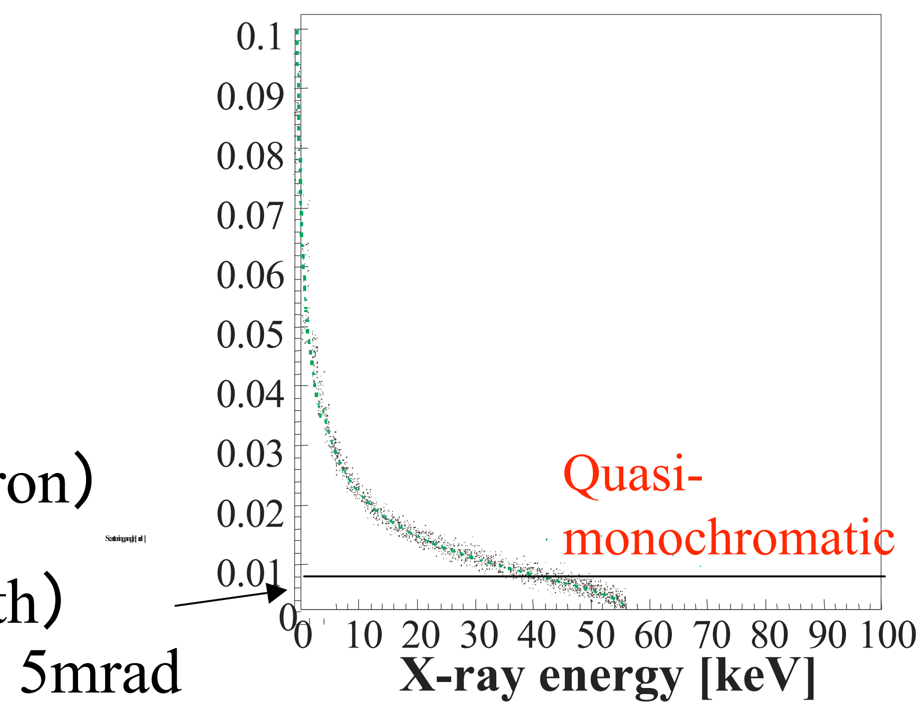
Monochromatic Hard X-ray by Compton Scattering



(*K*: Wiggling angle of electron)

(laser wavelength)

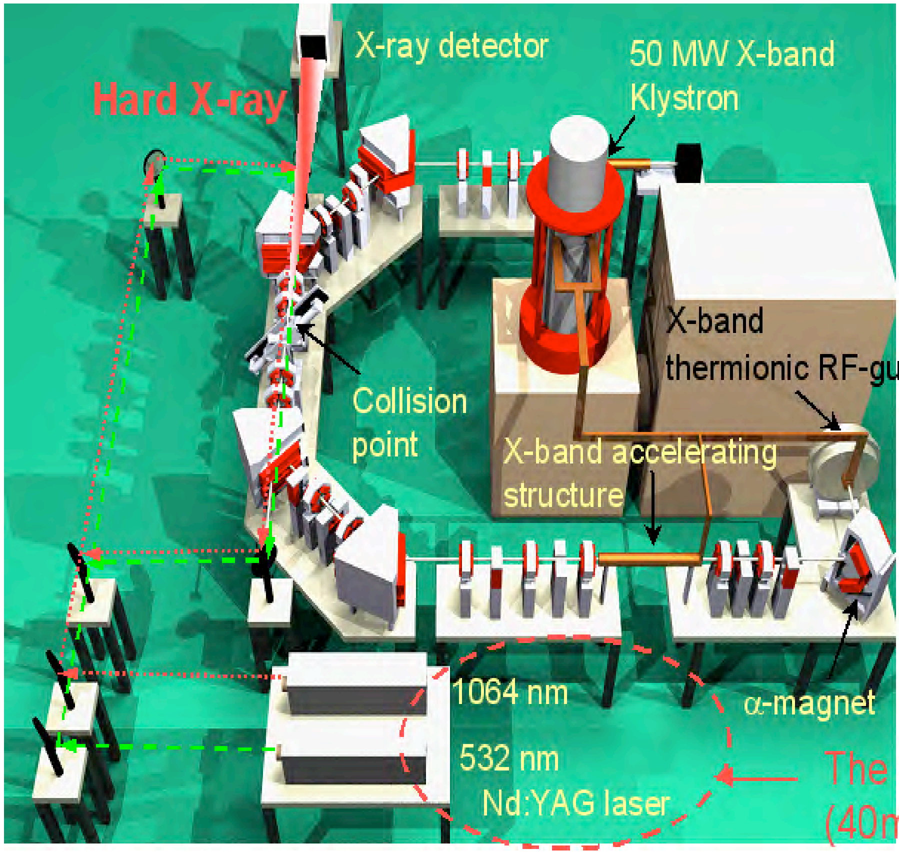
(X-ray)



X-ray energy vs Angle

Compton scattering hard X-ray source

Compact hard X-ray source based on Compton Scattering



Properties of the generated X-ray

Electron beam energy : 35 MeV, Charge : 20 pC/bunch

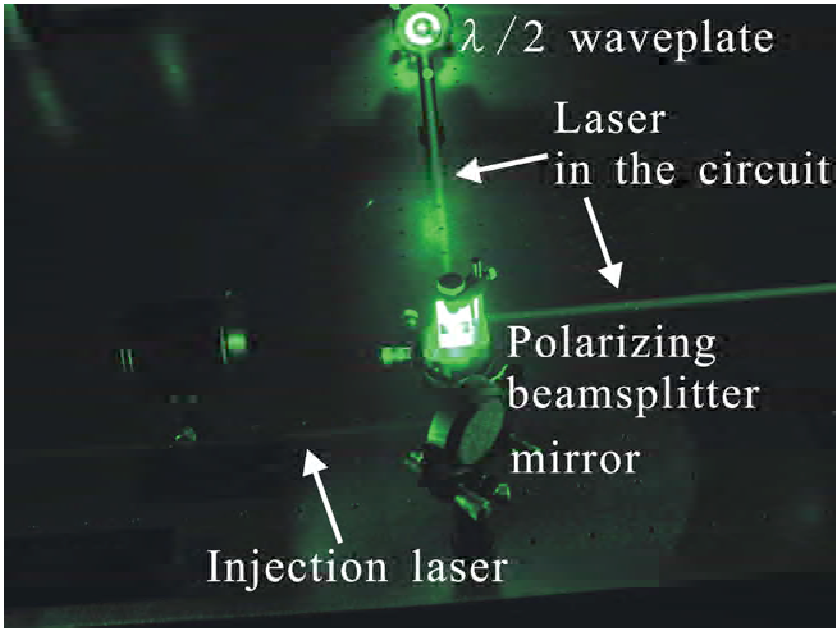
Laser wavelenght (nm)	1064	532
Pulse energy (J/pulse)	2.5	1.4
X-ray yield (photons/pulse)	$9.9x10^{6}$ (10^{8})	$4.4x10^{6}$ (10^{8})
Maximum X-ray energy (keV)	21.9	43.8
Energy spread (%) rms	1-10	

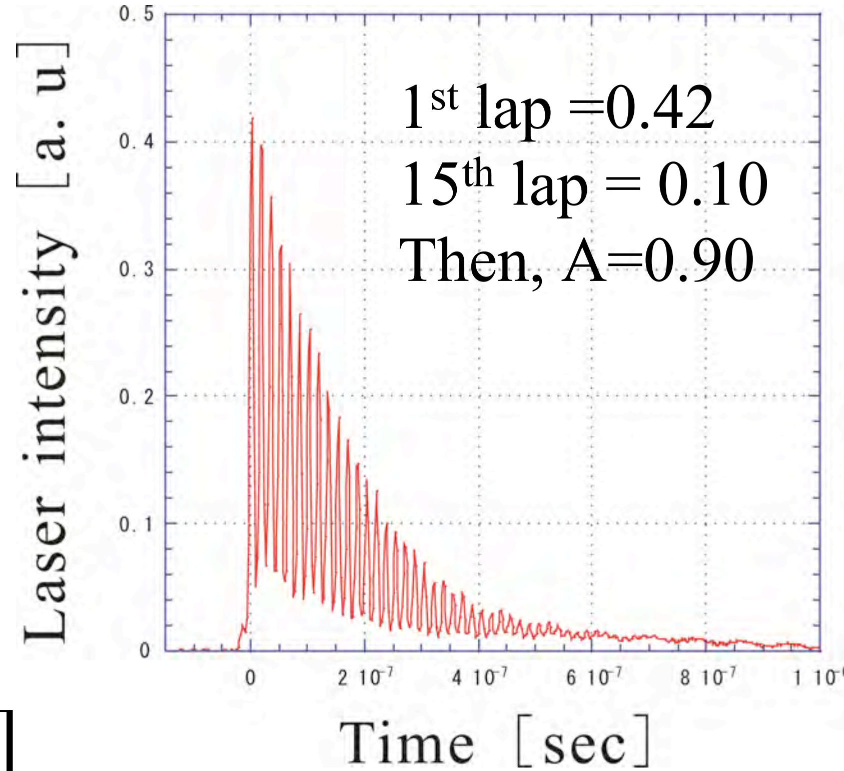
10 pps with laser circulation

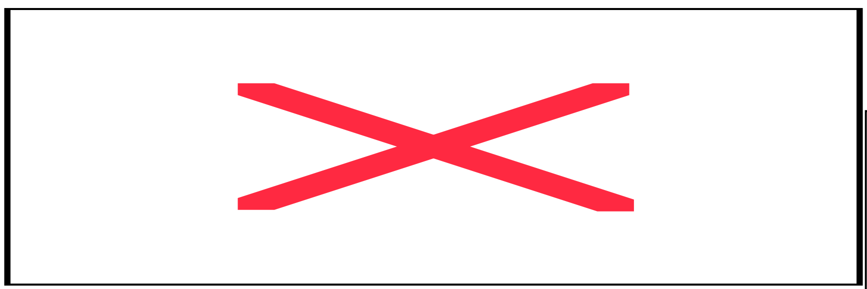
Details are in RPAP006 and WPAP019

The X-ray energy can be changed quickly (40ms) by introducing two lasers

LPCS experiment result, longitudinal direction







A=0.90, n=50

Then, ***10times higher intensity***

I_0: Incident laser pulse energy.

I_n: Laser intensity in the laser pulse circulation system.

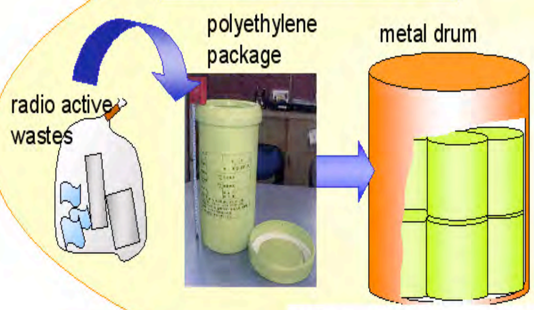
A: Transmission efficiency per one cycle.

n: Total number of the collisions.

Application plans of the compact hard X-ray source

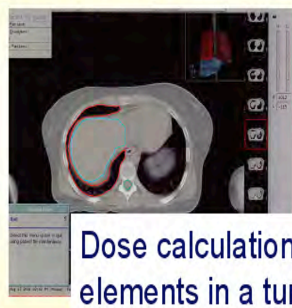
Atomic number identification by dual-energy X-ray CT

Nondestructive test



Element analysis inside a package

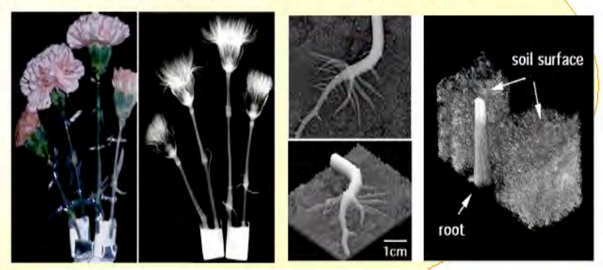
Radiation Treatment Planning



Dose calculation by considering elements in a tumor for advanced radiation therapy

Neutron radiography with X-ray CT

Imaging of water in a plant [3,4]



Movement of a element in a living plant

Compact monochromatic hard X-ray source

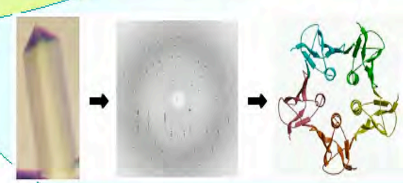
Micro vessel angiography

Image of coronary [5]

Diameter of micro vessel is less than 100μm

Micro vessel angiography will be tested with spatial resolution of 100μm

Protein structural analysis



Structure analysis in a small laboratory

Status of the Nonlinear ICS Experiment at UCLA

Oliver Williams
UCLA Dept. Of Physics and Astronomy
Erice, Sicily
October 9-14 2005

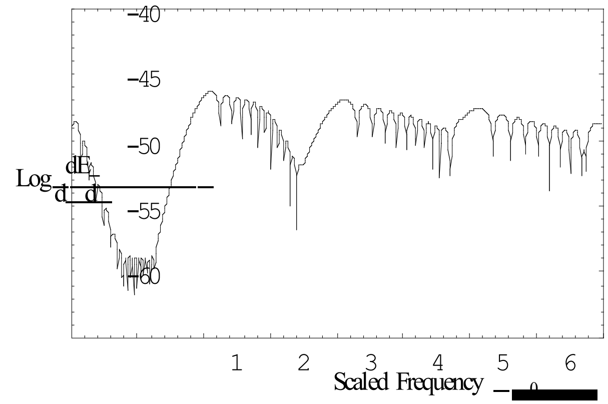
Beam Parameters

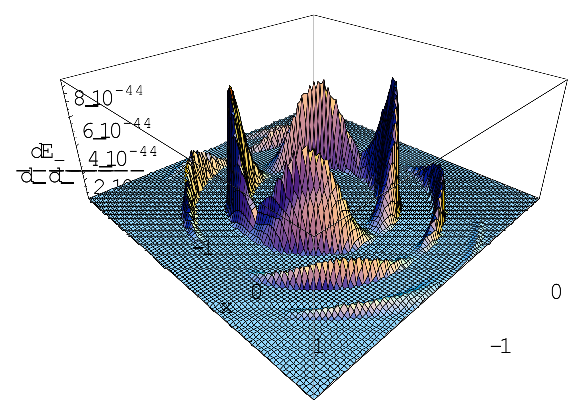
Parameter	Value
Electron Beam Energy	14 MeV
Beam Emmittance	5 mm-mrad
*Electron Beam Spot Size (RMS)	25 μm
Beam Charge	300 pC
Bunch Length (RMS)	4 ps
*CO_2 Laser beam waist at IP	25 μm
*Laser wavelength	10.6 μm
*Laser Rayleigh Range	0.75 mm
*Laser Power	500 GW
Laser Pulse Length	200 ps

Laser guiding in plasma might be an option to increase interaction time and hence ICS photon flux (see talk by R. Yoder)

Expected Spectrum and Intensity Distributions

- Spectral broadening of the ICS photons is expected due to the ponderomotive scattering of the electrons from high laser field
- Even AND odd harmonics are expected to be prevalent off-axis
- Shown are frequency and intensity (2^{nd} harmonic) distributions seen on axis of the ICS photons for a σ -polarized, incident gaussian laser profile

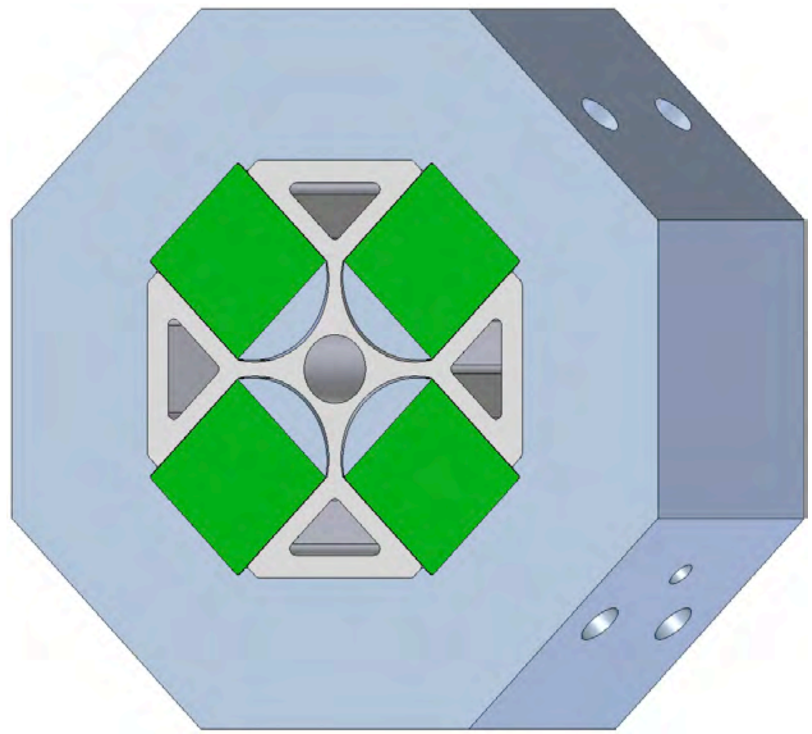




Courtesy of A. Doyuran and G. Krafft

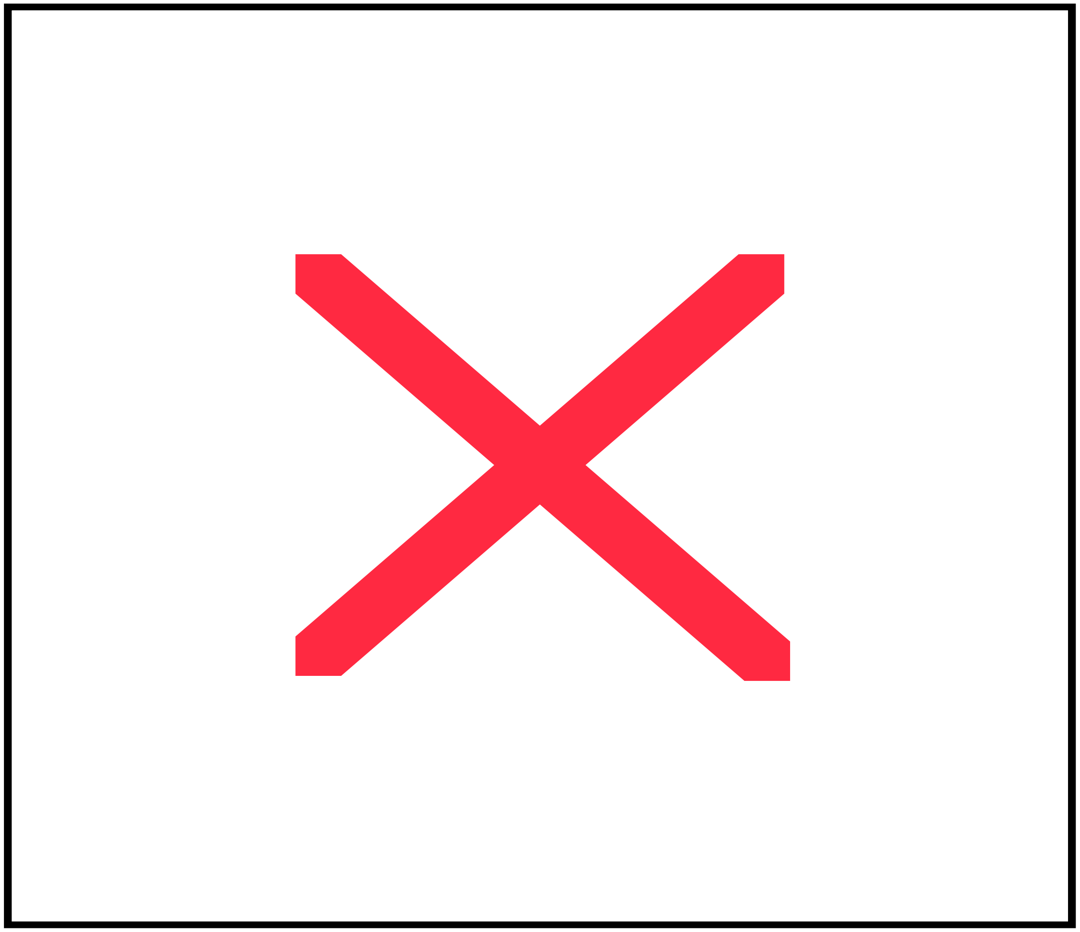
PMQ Performance

- Measured ~110 T/m focusing gradient of PMQ's
- Obtained a 40-50 μm $\sigma_{x,y}$ RMS beam at the IP
- Measurements at only 38.5 kV in the modulator, corresponding to a ~12.5 MeV beam
- Emittance expected to be less than optimal due to low field on cathode and asymmetric laser profile
- PMQ spacing and gradient optimized for 14 MeV beam, therefore smaller spots expected in future with emittance improvement and higher energy electrons

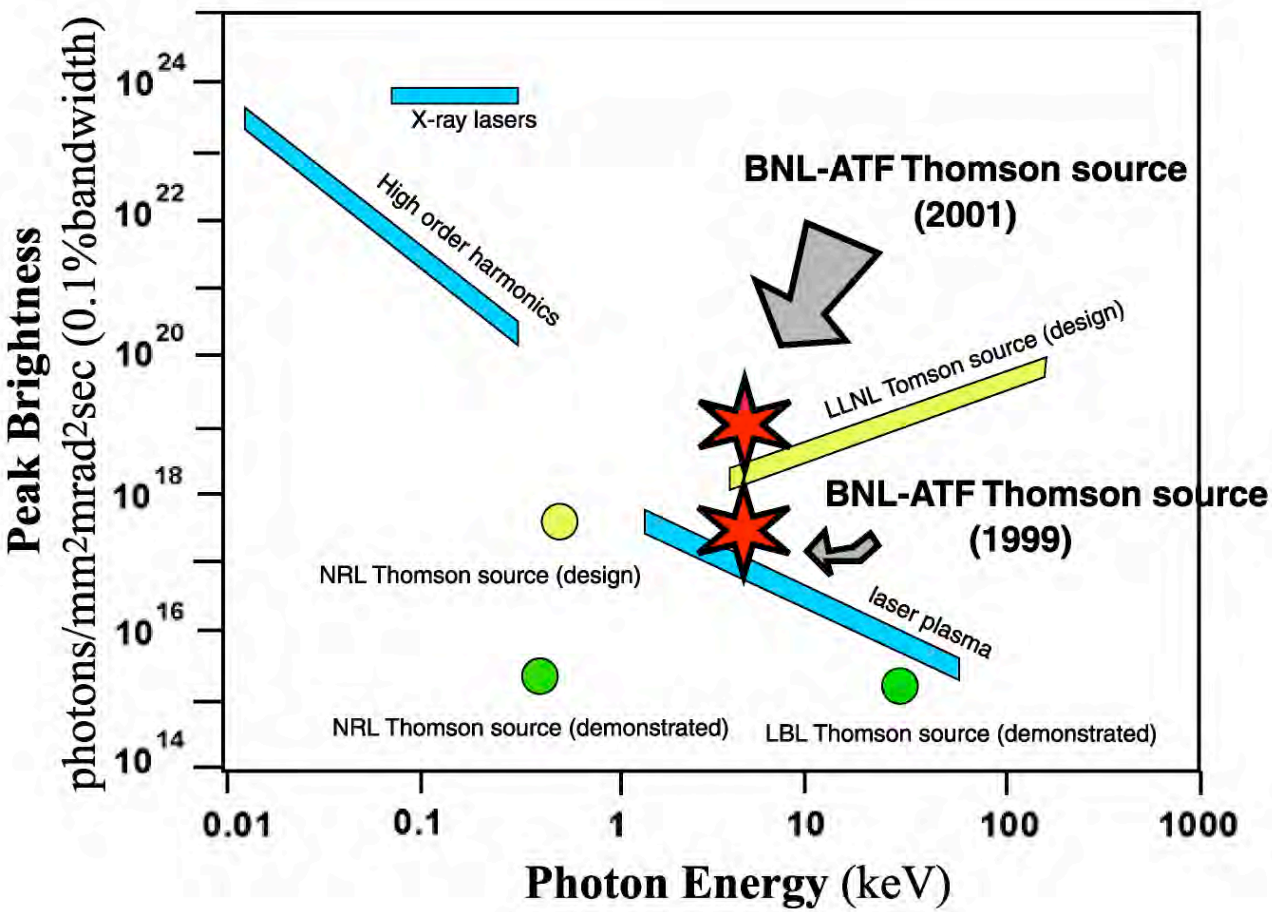


Initial Alignment/Synchronization Results

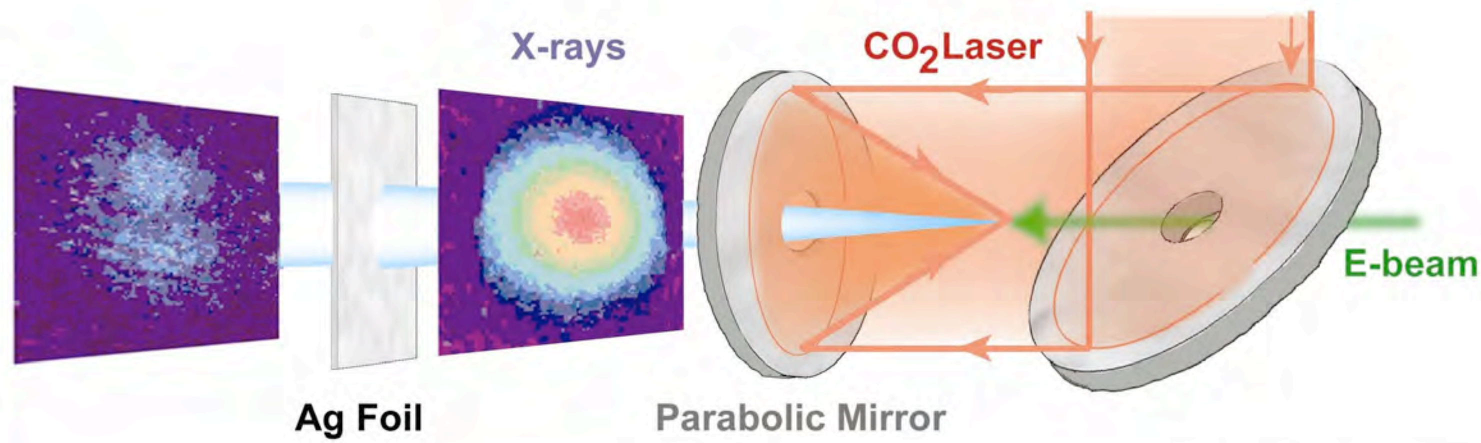
- Initial alignment done using graphite-coated phosphor
- Synchronization achieved using Ge crystal acting as a “gate” to 10.6 μm radiation, where e-beam is the “key”
- 10.6 μm absorbing semiconductor plasma created with formation length approx. e-beam bunch length
- Limits resolution to ~10 ps (but have 200 ps laser pulse)
- This method requires spatial overlap, therefore confident beams are “seeing” each other



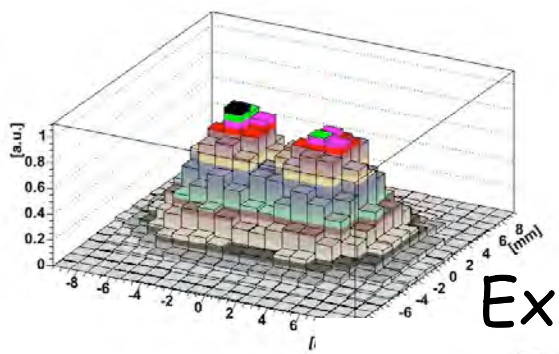
Compton Scattering of Picosecond Electron and CO_2 Laser Beams



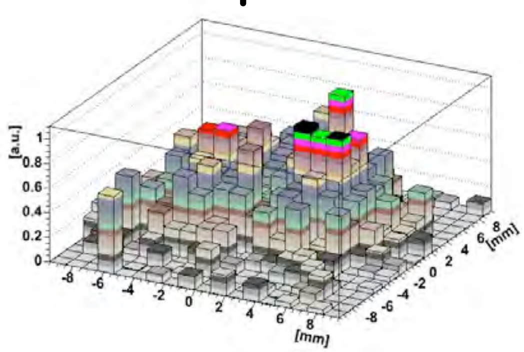
Nonlinear Compton Scattering at ATF, Brookhaven (submitted to PRL)

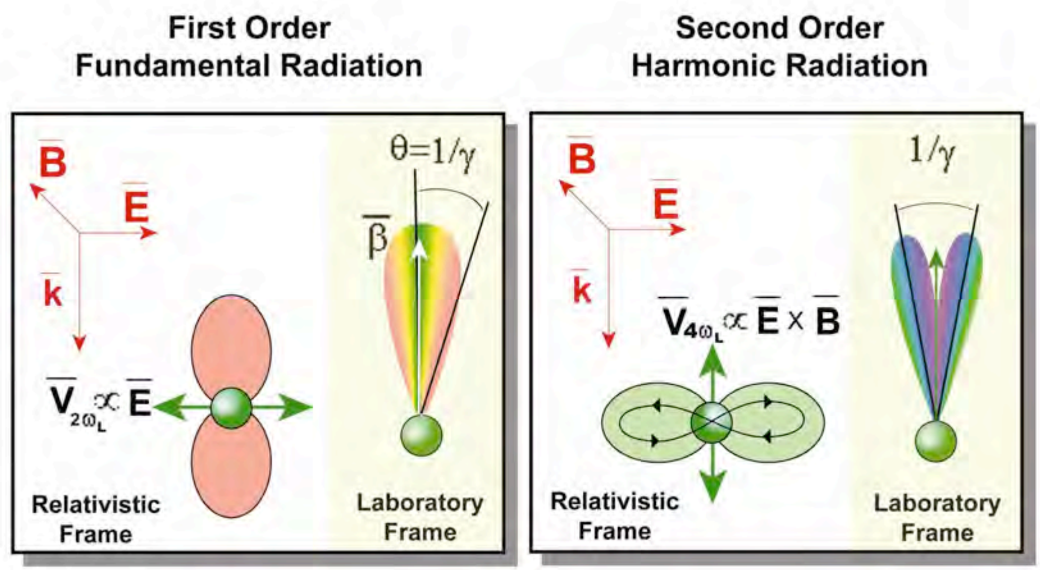


Simulations



Experiment





Study of transverse effects in a back-scattering coherent Thomson source of X-rays

A.Bacci, M.Ferrario*,
C. Maroli, V.Petrillo, A.Rossi, L.Serafini
Università e Sezione I.N.F.N. di Milano (Italy)
*LNF, Frascati (Italy)

If the laser pulse is long enough, collective effects can develop.
The system electron beam + laser pulse behaves like a free-electron laser with an electromagnetic wiggler.

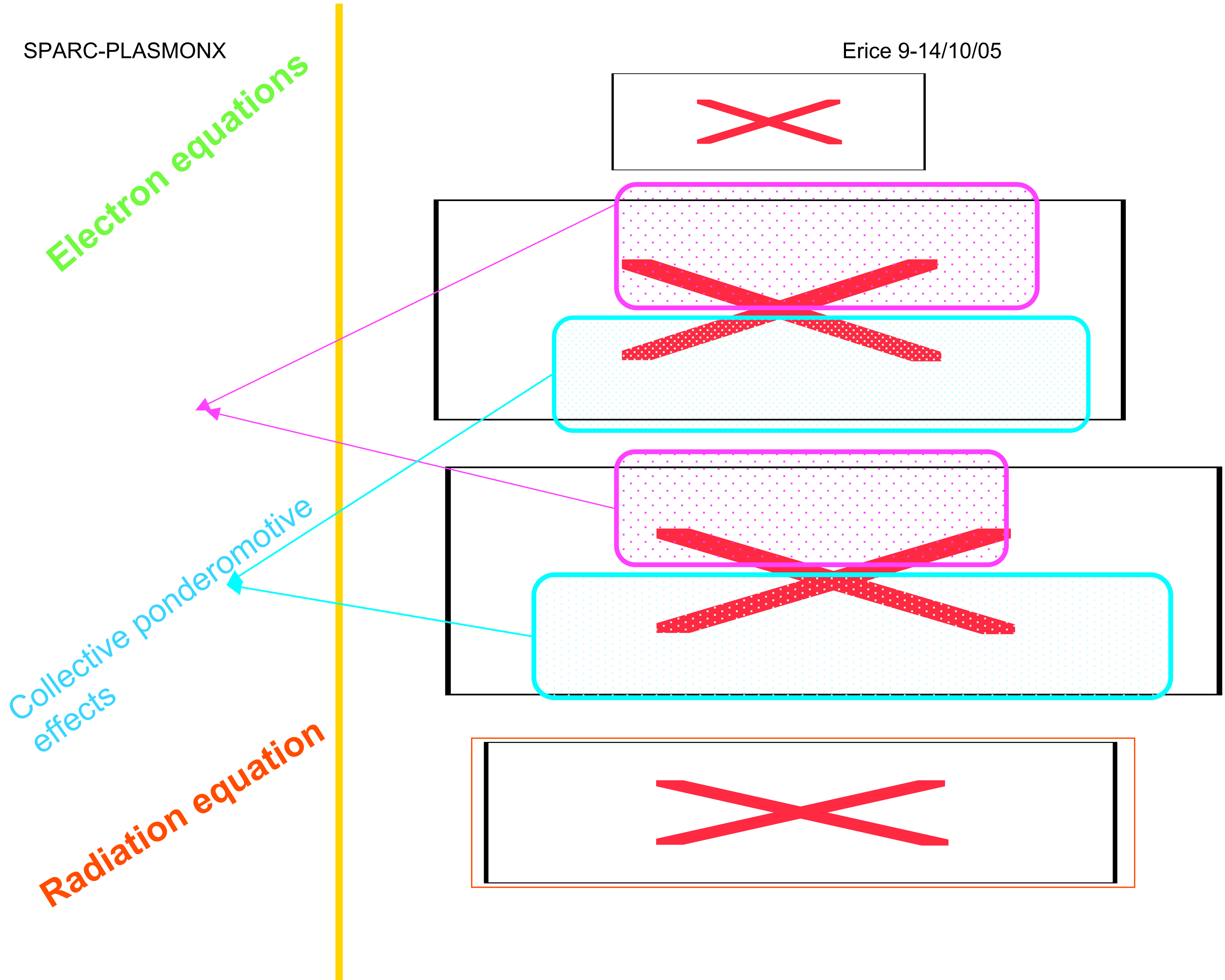
J. Gea-Banacloche, G. T. Moore, R.R. Schlicher, M. O. Scully, H. Walther, IEEE Journal of Quantum Electronics, QE-23, 1558 (1987).
B.G.Danly, G.Bekefi, R.C.Davidson, R.J.Temkin,T.M.Tran,J.S.Wurtele, IEEE Journ. of Quantum Electronics, QE-23,103(1987).
Gallardo, J.C., Fernow, R.C., Palmer, R., C. Pellegrini, IEEE Journal of Quantum Electronics 24, 1557-66 1988.

In particular, if the time duration of the laser pulse ΔT_L is larger than a few gain lengths, i.e. if

$$\Delta T_L > (10)\, L_g/c$$

the electron of the beam can bunch and the f.e.l. instability can develop.

The coherent radiation is expected to have a spectrum bandwidth very much narrower than the incoherent radiation, a less broad angular distribution and (if the saturation is reached) a larger intensity.


Electron equations
Collective ponderomotive effects
Radiation equation

Laser pulse: time duration up to 5 psec power 1-3 TW, varying w0, λ=0,8-1 micron

Electron beam counterpropagating respect the laser pulse

Q=1nC, Lb=100-300micron, radius σ_0=10-20 micron, I=1-2,5 KA

Energy=15 MeV (γ=30), transverse norm emittance up to 3 mm mrad, $\delta\gamma/\gamma=10^{-4}$.

$\rho=5\ 10^{-4}$ gain length L_g= 100-150 micron

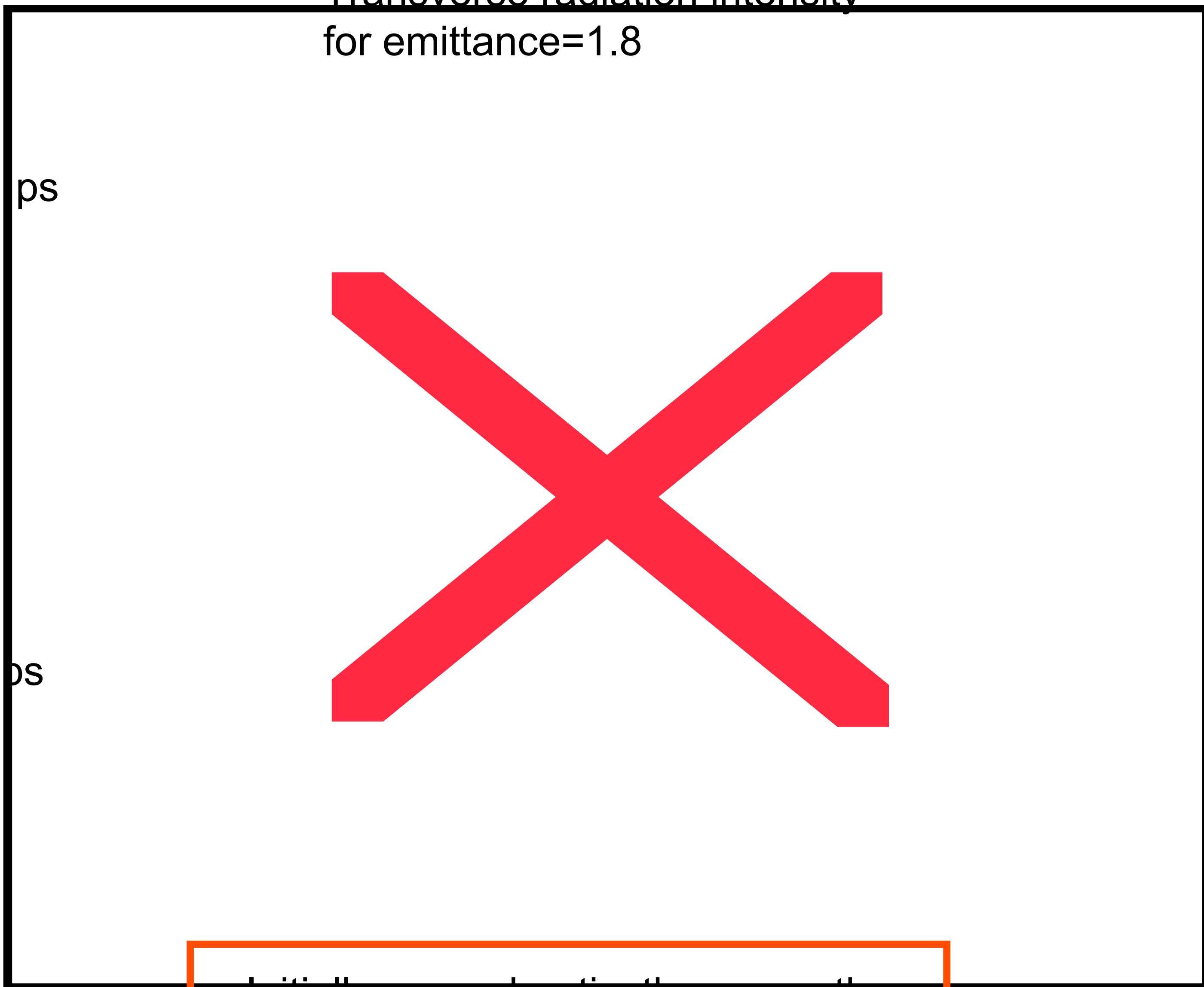
Radiation λ=3,5 Ang Z_R=1-4m

ρbar=2 → no quantum effects

Transverse radiation intensity for emittance=1.8

t=1 ps

t=2psec



t=3ps

t=4ps

Initially more chaotic, then smoother

Conclusions

The growth of collective effects in the back scattering Thomson process is possible provided that:

A low-energy , high-brigthness electron beam is available with short gain length

The optical laser pulse is long enought to permit the bunching and the instauration of the instability.

In the interaction region the laser transverse and longitudinal profiles are flat.

PARTICLE BEAM PHYSICS LABORATORY

A Permanent-Magnet Quadrupole Final-Focusing Optics at PLEIADES Inverse Compton X-ray Source

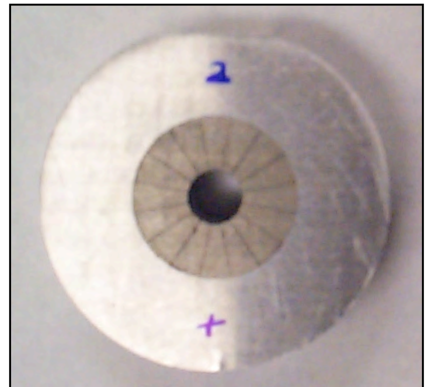
J. K. Lim*, P. Frigola, J. B. Rosenzweig
& G. Travish (UCLA)
S. G. Anderson, D. J. Gibson, F. V. Hartemann
& A. M. Tremaine (LLNL)

* jlim@physics.ucla.edu

High-field Gradient obtained from PMQ

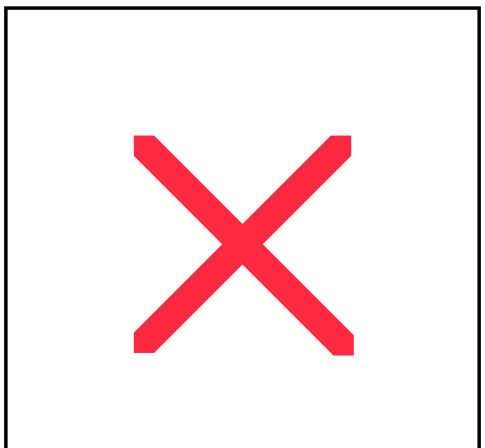
$$B' = 2B_r\left(\frac{1}{r_i} - \frac{1}{r_o}\right)$$

For r_i=7.5mm, r_o=5mm and B_r=1.2T
Field gradient of idealized PMQ is
640T/m

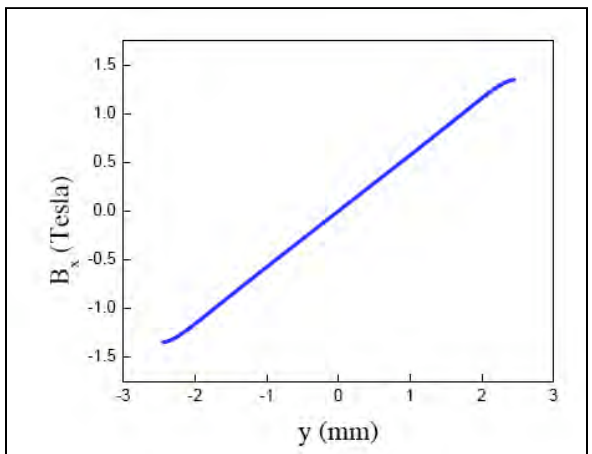


PMQ unit

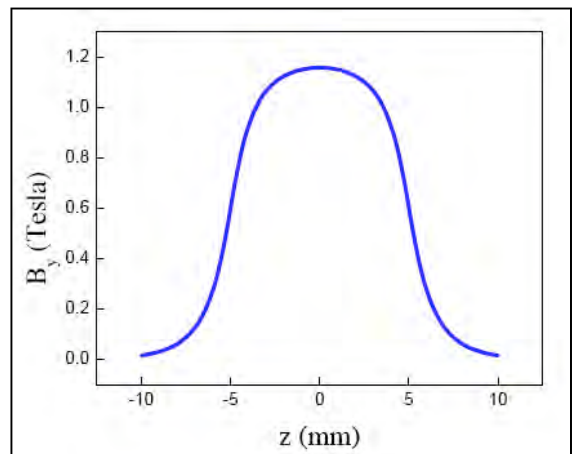
RADIA – 3D magnet simulation:



2D field plot
in bore region



Linearity good to r ~ 2 mm
B' = 573 T/m



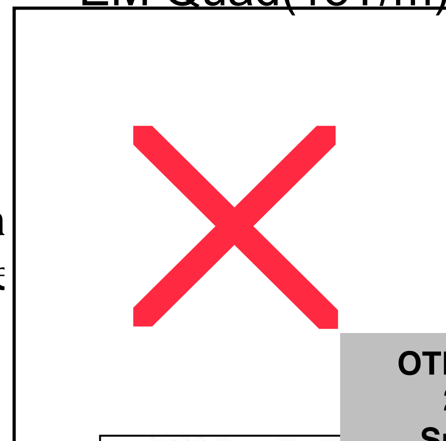
Effective length = 10.4 mm

Final focus performance is enhanced with PMQ system

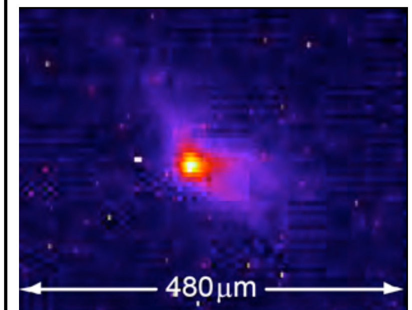
- Final focus procedure:
  - Twiss parameters obtain from quad scan with up-stream magnets
  - Use Trace3D to compute EM quad settin ~ few meter β_0 and PMQ positions for be focus

- IP spot measured with OTR + 3 µm/pixel video camera
  - < 20 µm spots directly measured
  - Beam image aberration problem?
- PMQ scan analysis indicates σ* = 15 µm

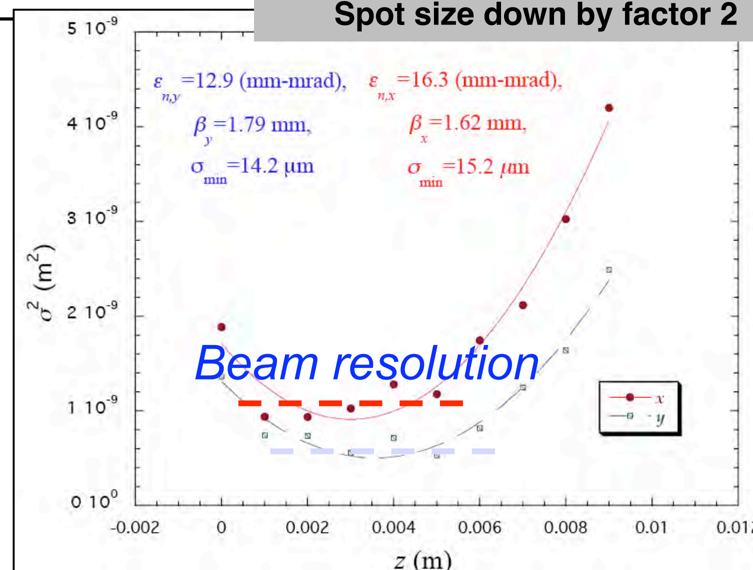
EM Quad(15T/m)



PMQ(560T/m)



OTR image of 70 MeV, 200pC, 20 µm (rms) final focus. Spot size down by factor 2

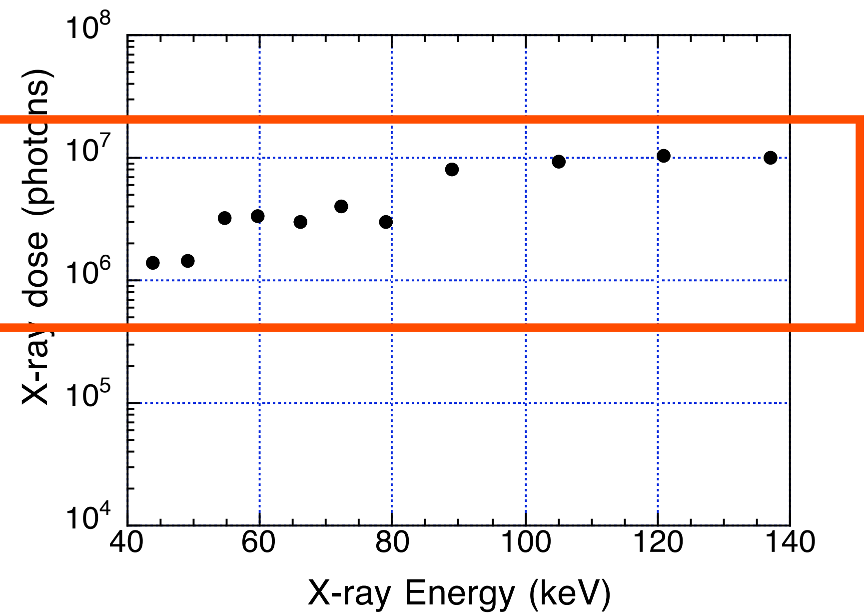


PMQ scan shows β^* = 3 mm

The PLEIADES energy-tunable x-ray source

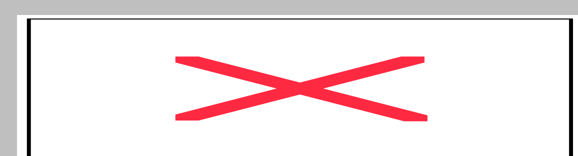
- Tunable, bright, ICS hard x-ray source
- 810 nm, 250 mJ, 54 fsec, Ti:Sapphire laser
- Under 20 micron beam spotsize w/ PMQ at ICS interaction

X-ray flux vs. energy



RF Gun+LINAC
➢ 100 MeV/m
➢ Charge = 0.3 nC
➢ ε_n = 5 mm-mrad
➢ f = 2.85 GHz (S-Band)
➢ E = 20 - 100 MeV
¬ σ_t = 3 ps (uncompressed)
¬ σ_t < 300 fs (compressed)

PMQ FINAL FOCUSING LENS has significantly increased source flux and brightness.

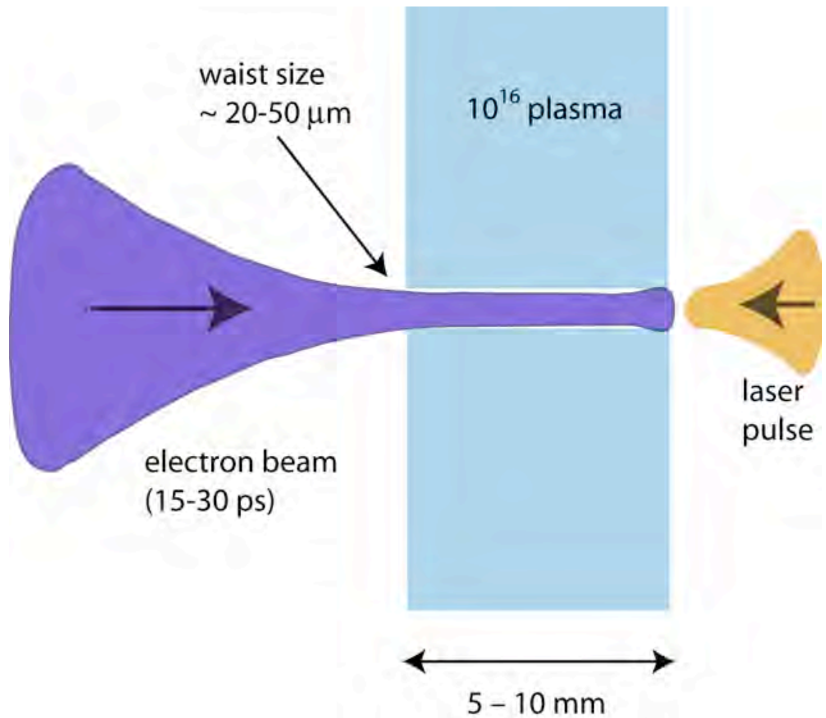


An Inverse-Compton-Scattering Source via Self-Guiding in a Plasma

R. B. Yoder
Manhattan College, New York
J. B. Rosenzweig
UCLA Dept. of Physics and Astronomy

ICFA Workshop on High-Brightness Beams,
Erice, October 2005

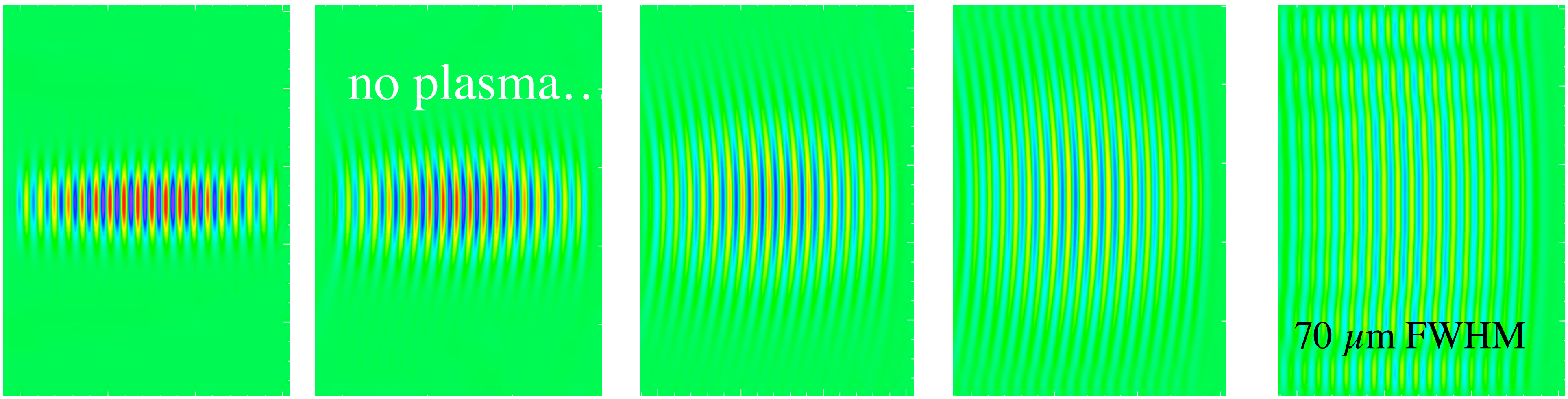
Beam-driven channel scenario



- long electron beam (3–4 mm), high charge (~10-100 nC)
- laser pulse arrives when beam head exits plasma
- laser guiding over 5–10 Z_R through plasma-formed channel

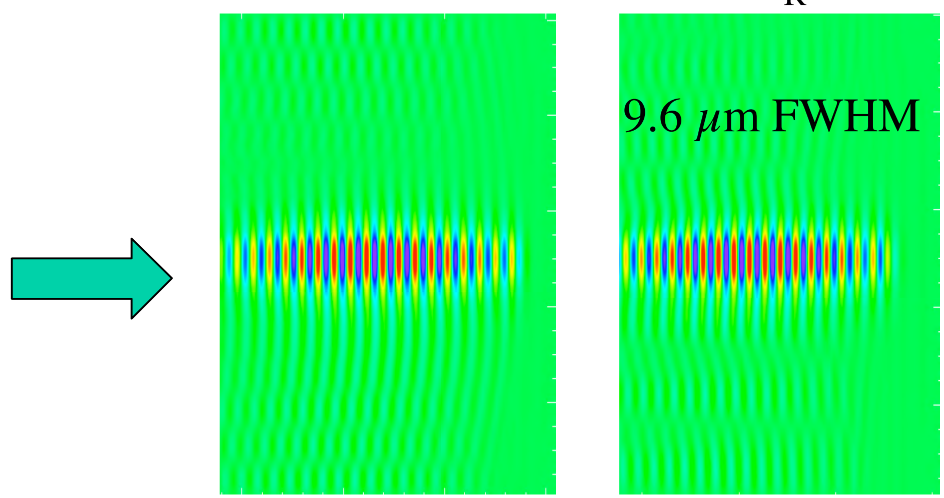
R.Yoder and J.Rosenzweig

Laser guiding: 2D simulation
800 nm, 50 fs pulse



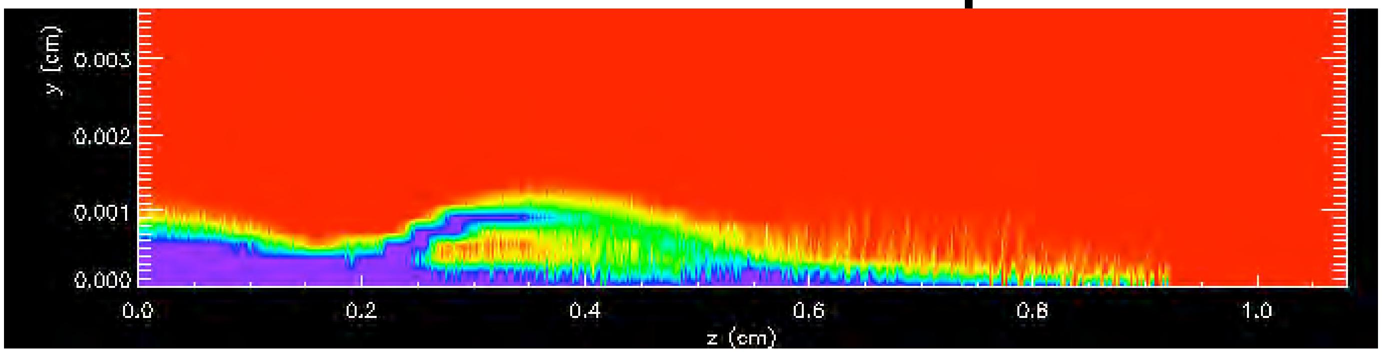
6.6 Z_R

3×10^{18} cm^{-3} plasma
8 μm pre-formed channel
(= w_0)
Z_R = 250 μm



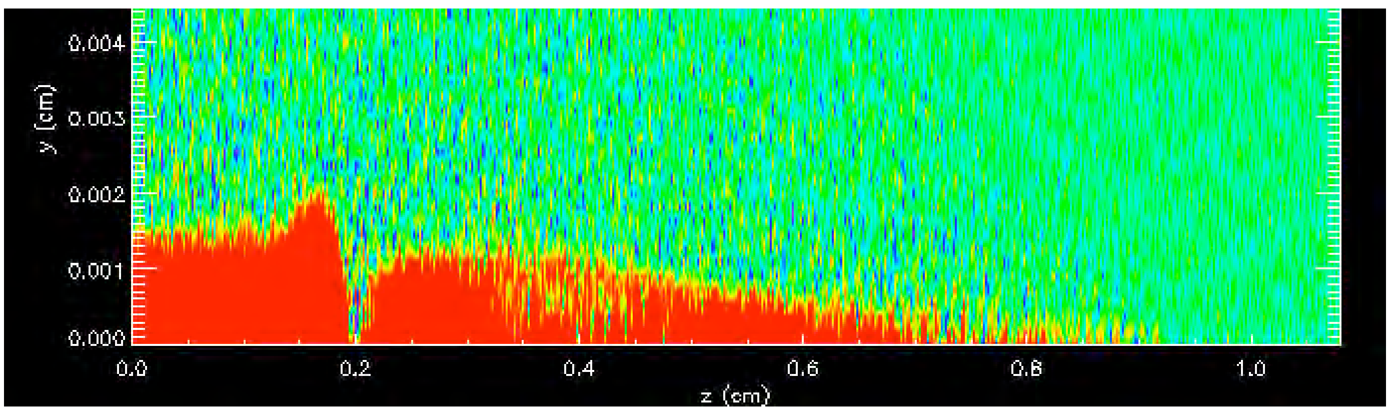
Plasma channel formation
t = 300 ps

n_b



self-pinching (overfocusing)

n_p



10 nC beam
1.6 GeV
5 μm σ_r
3 mm σ_z
27 mm mrad ε_n

Spectral order; red = 0

Projected Photon Flux

Approximately: $$N_x = \sigma_T \frac{N_b N_\gamma}{A} f$$

A is transverse overlap area; *f* is ratio of lengths (≤1);
σ_T = 0.6 barn

Assume 800 nm laser, 1 TW, 500 fs, 20 μm spot:
- $N_\gamma \sim 10^{18}$, $N_b = 6 \times 10^{11}$, entire laser pulse is usable energy, $a_L < 0.1$

⇨ photon yield roughly 10^9– 10^{10} / pulse

With 10.6 μm, N_γ goes up, but $a_L \sim 0.5$–1

Very challenging simulation problem!

- resolve laser wavelength over ~ $10Z_R$ = 3000 λ
- symmetry problem: e-beam cylindrical, laser Cartesian

Conclusion

- Self-guiding in plasma by electron beam has potential to create a high-brightness, long-pulse x-ray source through inverse Compton scattering
  - *conceptually simple*
  - *easy to time*
  - *high photon number output*

- Output looks competitive with other x-ray and γ-ray generation methods involving pre-formed channels or multiple lasers
- **Not** necessary to use 10.6 μm laser!
  - increase in photon number offset by high a_L
  - similar performance from 800nm systems

- Simulation of yield is tough — ongoing project

Summary of Compton Scattering X-ray Sources

1. Multi-scattering system to increase the X-ray yield has been proposed and to be constructed for medical and other applications (Uesaka, Ogino(Univ.Tokyo)).

2. The higher harmonics are being measured by using a strong permanent focusing magnet and so on (Yakimenko(BNL-ATF), Lim(LLNL)).

3. Collective effects for the interaction of longer laser and lower energy-electrons have been proposed and the simulation has been performed (Petrillo(Univ.Milan)).

3. A new scheme to use the plasma channel guided electron beam is proposed (Yoder(Manhatten College)).

FEL and RF Photoinjectors

1. FEL

Gerald Andonian

"Observation of Ultra-wide Bandwidth SASE FEL"

Takahiro Watanabe

"Numerical simulation and experimental demonstration of seeded FEL at BNL-NSLS

Kwang-Je Kim

"Quantum Effects in Gain and Start-up of Free Electron Lasers—Wigner Function Approach "

William Graves

"Longitudinal aspects of an ellipsoidal electron distribution and its effects on seeded FEL performance"

2. Application of RF Photoinjectors to Radiation Chemistry

Akira Sakumi

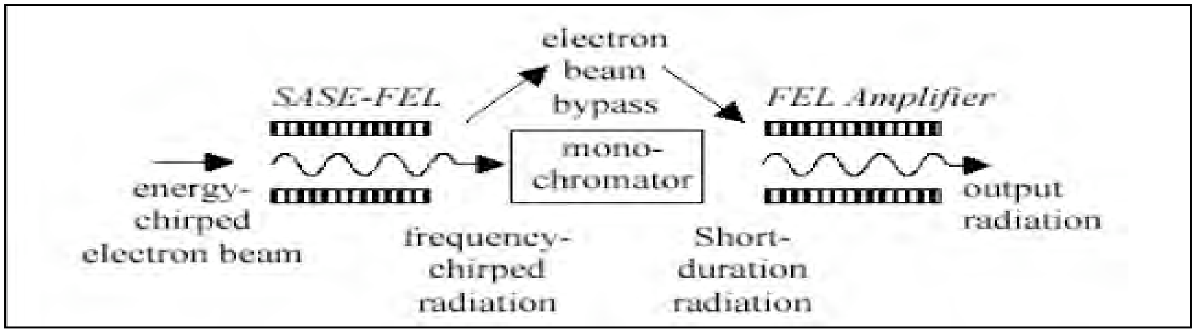
"Review of RF photoinjectors for radiation chemistry in the world"

Observation of Ultra-Wide Bandwidth SASE FEL

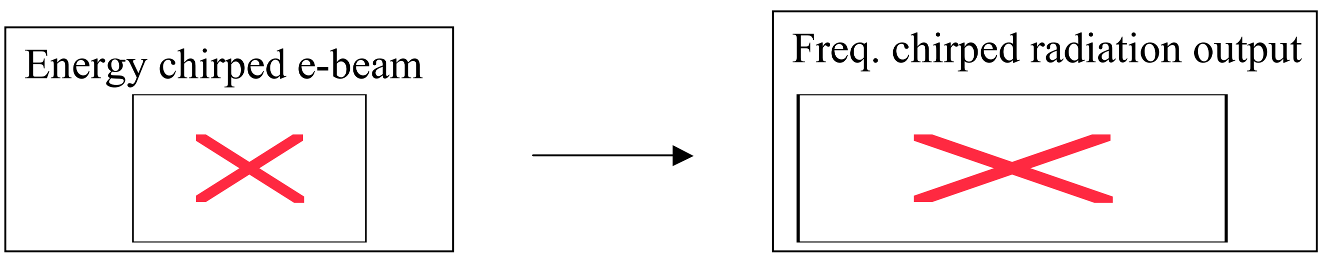
Gerard Andonian
Particle Beam Physics Laboratory
University of California Los Angeles

The Physics and Applications of High Brightness Electron Beams
Erice, Sicily,
October 9-14, 2005

Motivation

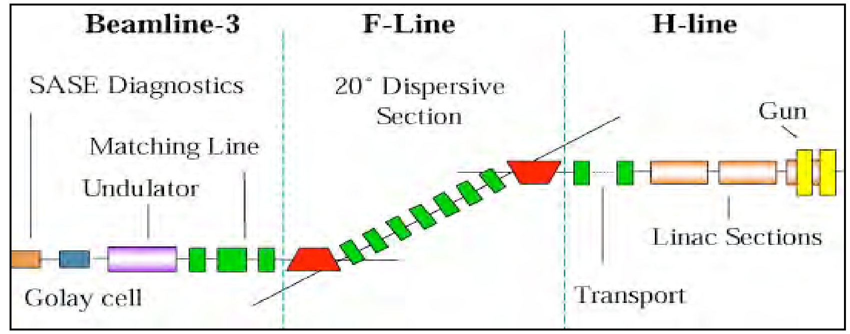


- Proposed Scheme for ultra short pulses
  - Energy chirped e-beam ➔FEL➔ freq. chirped radiation
- Explore Limits of SASE FEL with energy chirped e-beam
- Develop advanced beam manipulation & measurements



Experiment Layout

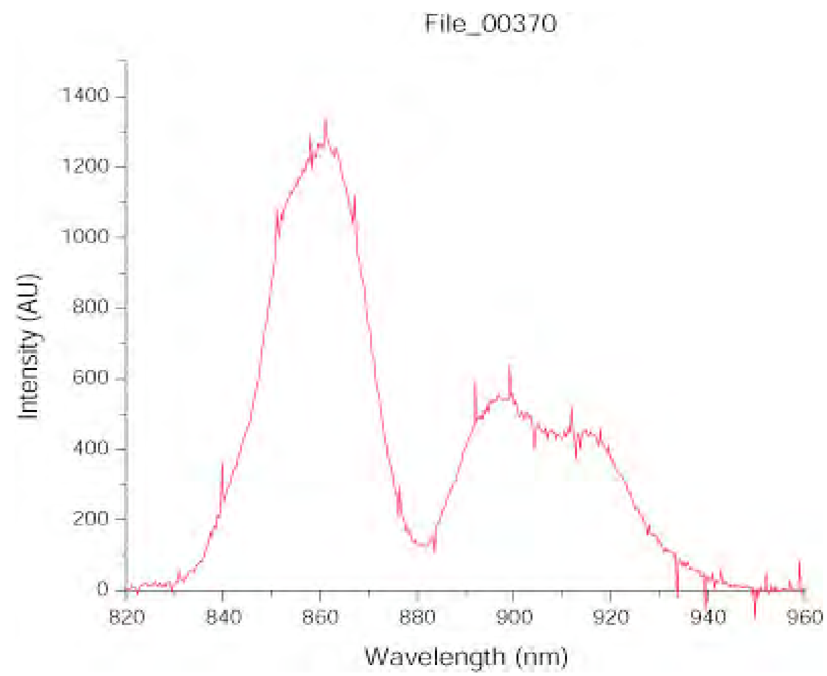
- Accelerator Test Facility (ATF) at BNL
  - Host for VISA I & II
  - 70 MeV beam
  - 28 m beam transport
    - 20 deg bend (F-line)
- Undulator
  - 4 x 1m sections
  - FODO lattice superimposed (25 cm period) –strong focusing
  - External steering coils (8)
  - Intra-undulator diagnostics
    - 50 cm apart
    - double-sided silicon
    - SASE FEL
    - e-beam (OTR)



VISA Undulator Parameters	
Undulator type	Planar (NdFeB)
Number of periods (N_u)	220
Peak field (B_{pk})	.75 T
Undulator Period (λ_u)	1.8 cm
Gap (g)	6 mm
Undulator Parameter (K)	1.26

VISA IB: Experiment

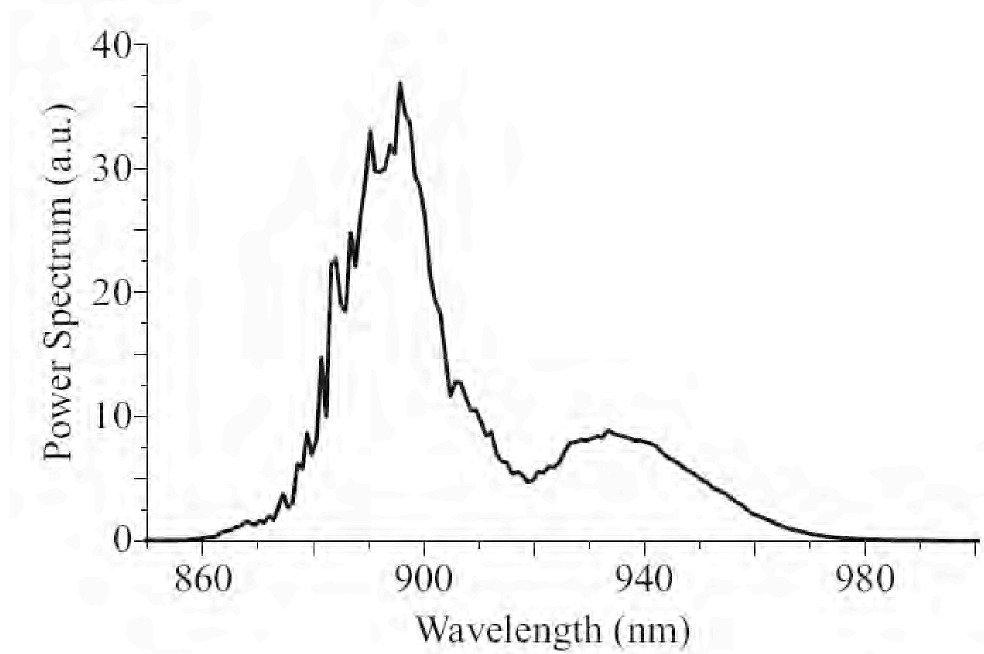
- High gain FEL
  - Chirped beam amplification
  - SASE energy ~2 μJ
  - close to saturation
- Up to 15% bandwidth observed
- Very reproducible and unusually stable
  - insensitive to RF drifts and phase jitter
- Characteristic double-spike structure



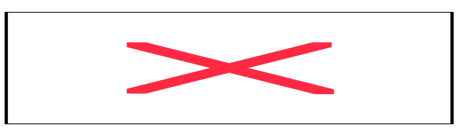
Wavelength Spectrum of FEL at VISA measured with Ocean Optics USB2000 Spectrometer.

VISA IB: Analysis

- Start-to-End
  - Experimental Spectrum features reproduced
  - Angles Important
    - Off-axis Doppler Shift



FEL output Spectrum reproduced by Genesis (~10% bandwidth)



Conclusions

- VISA yields rich data sets
  - VISA I, VISA IB
    - Observed ultra wide bandwidth
    - High gain chirped beam FEL
    - Further studies on hollow modes
  - Confidence in Start-to-end suite
- Develop new diagnostics
- Seeded amplifier runs & data forthcoming

Numerical simulation and experimental demonstration of seeded FEL at BNL-NSLS

T. Watanabe, X.J. Wang, D. Liu, J.B. Murphy, J. Rose, T. Shaftan and L.H. Liu,
BNL, USA
P. Sprangle, NRL, USA
S. Reiche, UCLA, USA

Outline
- Directed energy application of FEL
- Numerical simulation of MW amplifier
- Experimental demonstration of seeded FEL

BROOKHAVEN
NATIONAL LABORATORY

Directed energy application of FEL

IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. 40, NO. 12, DECEMBER 2004 1730

Design of a Compact, Optically Guided, Pinched, Megawatt Class Free-Electron Laser

Phillip Sprangle, *Fellow, IEEE*, Bahman Hafizi, *Member, IEEE*, and Joseph R. Peñano

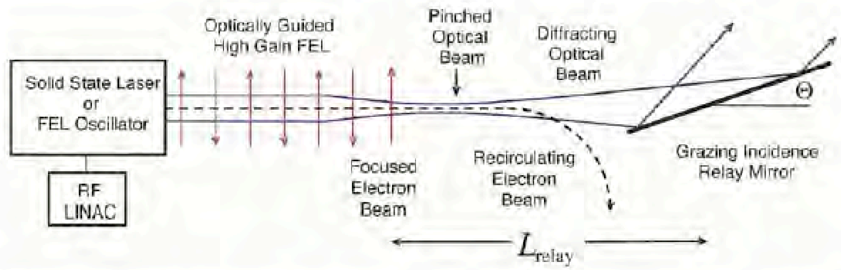


Fig. 1. Schematic of high-gain FEL amplifier with a grazing relay mirror. The input signal can be obtained from a solid-state laser or FEL oscillator. The radiation beam is optically guided in the wiggler and optically pinched at the exit. The pinched optical beam has a shortened Rayleigh range and undergoes rapid diffraction upon exiting the wiggler. Employing a grazing incidence configuration, the resultant footprint on the relay mirror can be made sufficiently large to avoid damage.

Key issues

- Megawatt ave. power
- Compact
- No optical damage

This work

2-m VISA undulator
w/ strong focusing

1 µm FEL

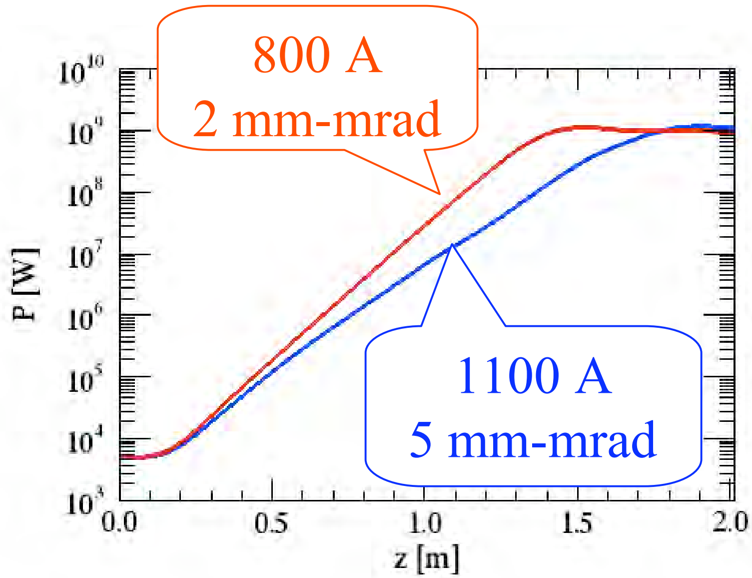
seed laser

e-beam
65 MeV

mirror

K = 1.26, λ_u = 1.8 cm

Final design

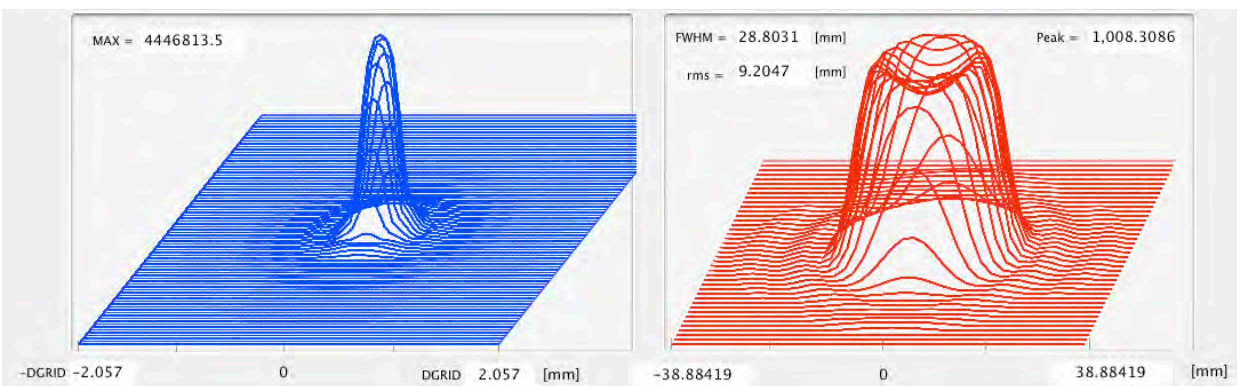


FEL @ 1 μm: peak power = 1 GW

Amplification

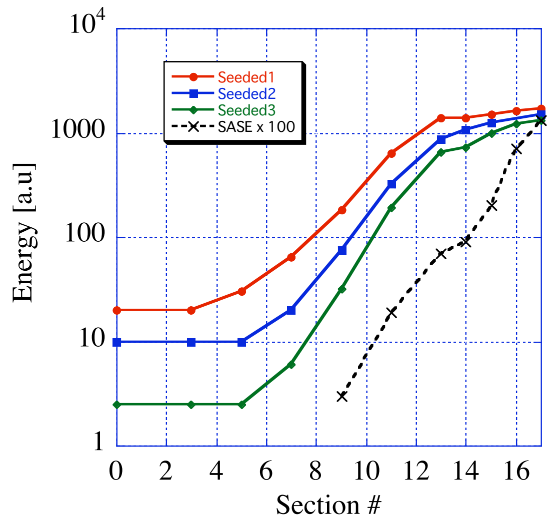
Seed laser: peak power =5 kW

Duty factor = 1.4 [ps] x 700 [MHz] = 0.1 [%]



$$\frac{1.0\,[\mathrm{MW}]}{\sqrt{2}\times\pi\times(1.5[\mathrm{cm}])^2}\approx 100\,[\mathrm{kW/cm^2}]$$ ~ damage threshold of mirror

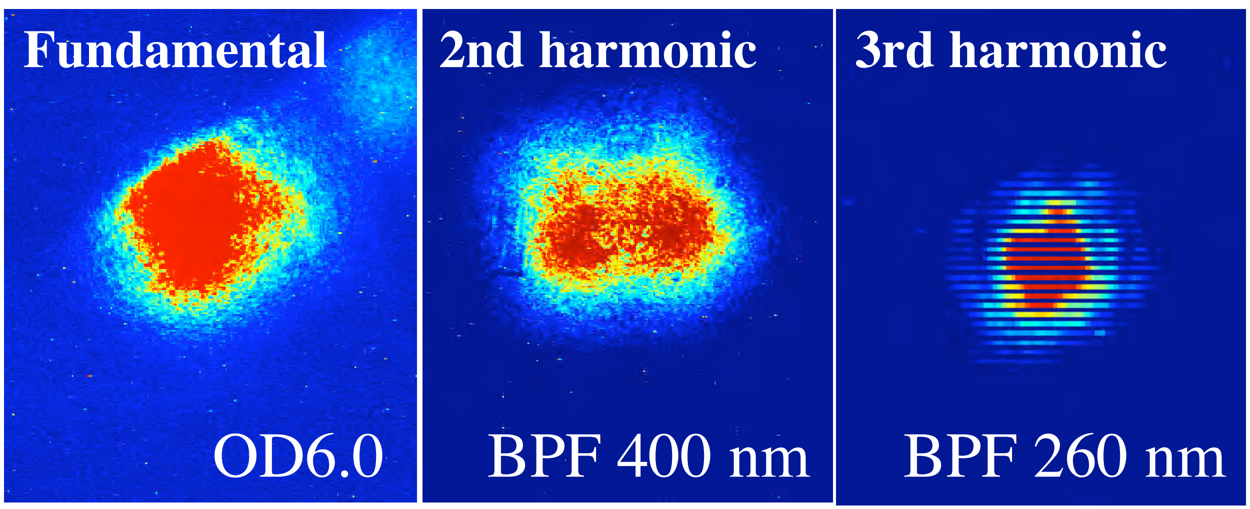
Gain curves of seeded FEL



Gain length when radiation size is larger than e-beam size

$$L_G^{-1} = \frac{4\pi}{\lambda_u} \frac{3^{3/4}}{2} \sqrt{\frac{I}{\gamma I_A} \frac{K^2[JJ]^2}{\left(1 + K^2/2\right)}}$$

Spatial profiles of harmonics



* Magnification of each image is different.

Conclusion

MW class FEL was conceptually designed and seeded FEL in IR was experimentally demonstrated.

- SASE from 0.8 to 1.0 μm observed.
- Gain curve of seeded FEL obtained.
- Spatial distributions of harmonics observed.
- Spectrum broadening due to laser chirp considered.
- Longitudinal distributions of harmonics measured.

Future work

Repeat the experiment to verify
- Gain length v.s. input seed power
- Ratio of radiation size between each harmonic
- Longitudinal pulse duration at each harmonic

Longitudinal Studies of Ellipsoidal Bunches

William S. Graves

MIT

2005 Erice High Brightness Beams Workshop

Electron Beam Properties for Seeded FEL

Beam needs depend on application:

1) Sufficient flat-top to allow harmonic cascade FEL using fresh bunch method (including timing jitter)
2) Long x-ray pulses generating meV bandwidth
3) Low energy spread allowing many harmonic cascade stages

Electron beam parameters do not need to be extreme, but we always want constant values of current and energy spread

•Ideal beam has 1 kA, ΔE < 1 keV, FWHM ~ 1 ps

•Current variations -> FEL optical phase shifts due to gain variations

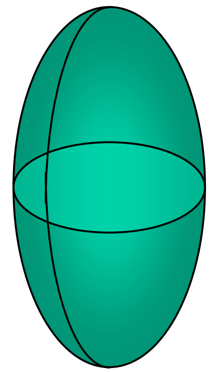
•dE/E variations -> inconsistent bunching -> FEL optical phase shifts

Parmela Photoinjector Simulations

S-band injector

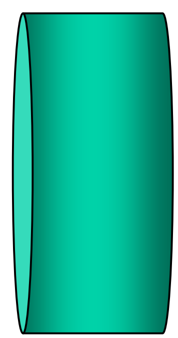
Compare ellipsoidal bunch with flattop.

RMS dimensions were set equal in
each case



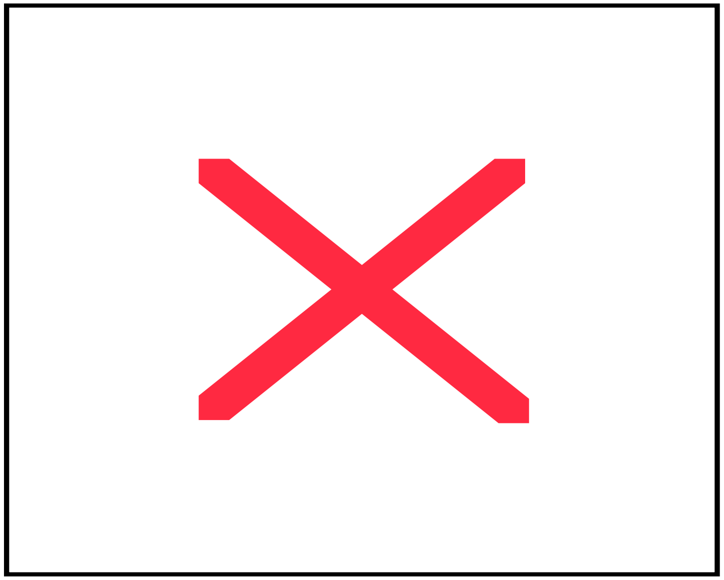
Ellipsoidal bunch

300 pC, ~1 mm radius,
~5 ps full width

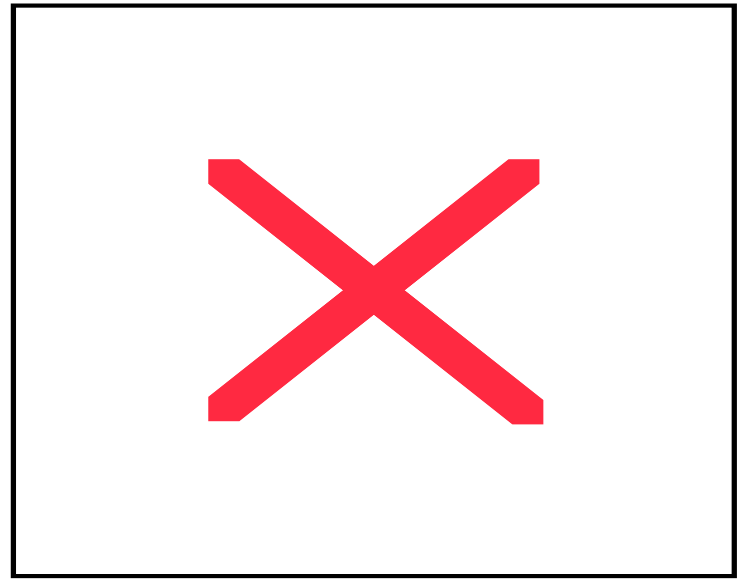


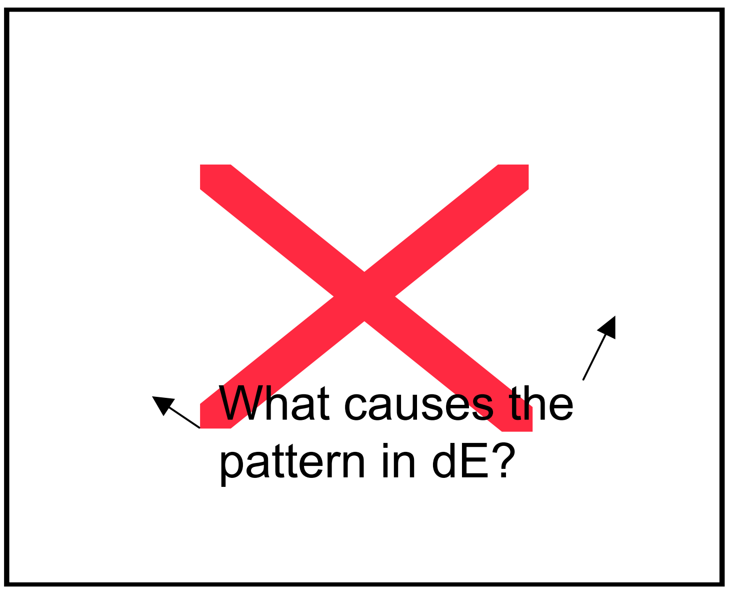
Flattop bunch

300 pC, ~1 mm radius,
~5 ps full width

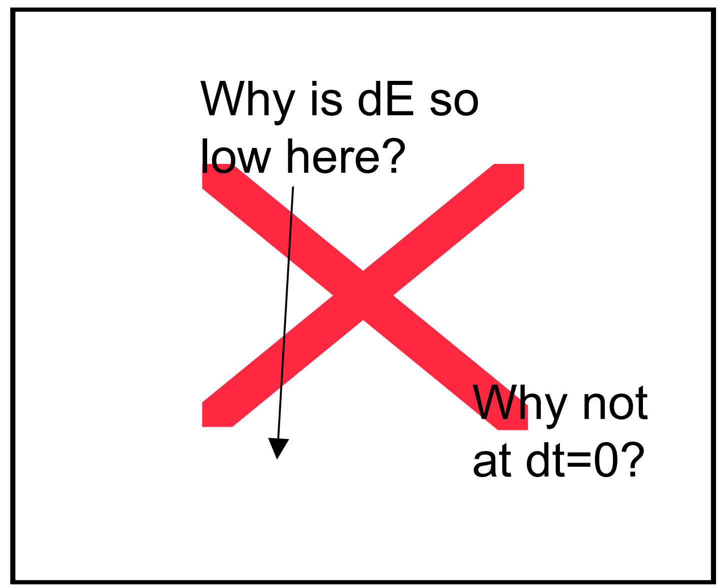


Current profiles for ellipsoid (left) and flattop (right).

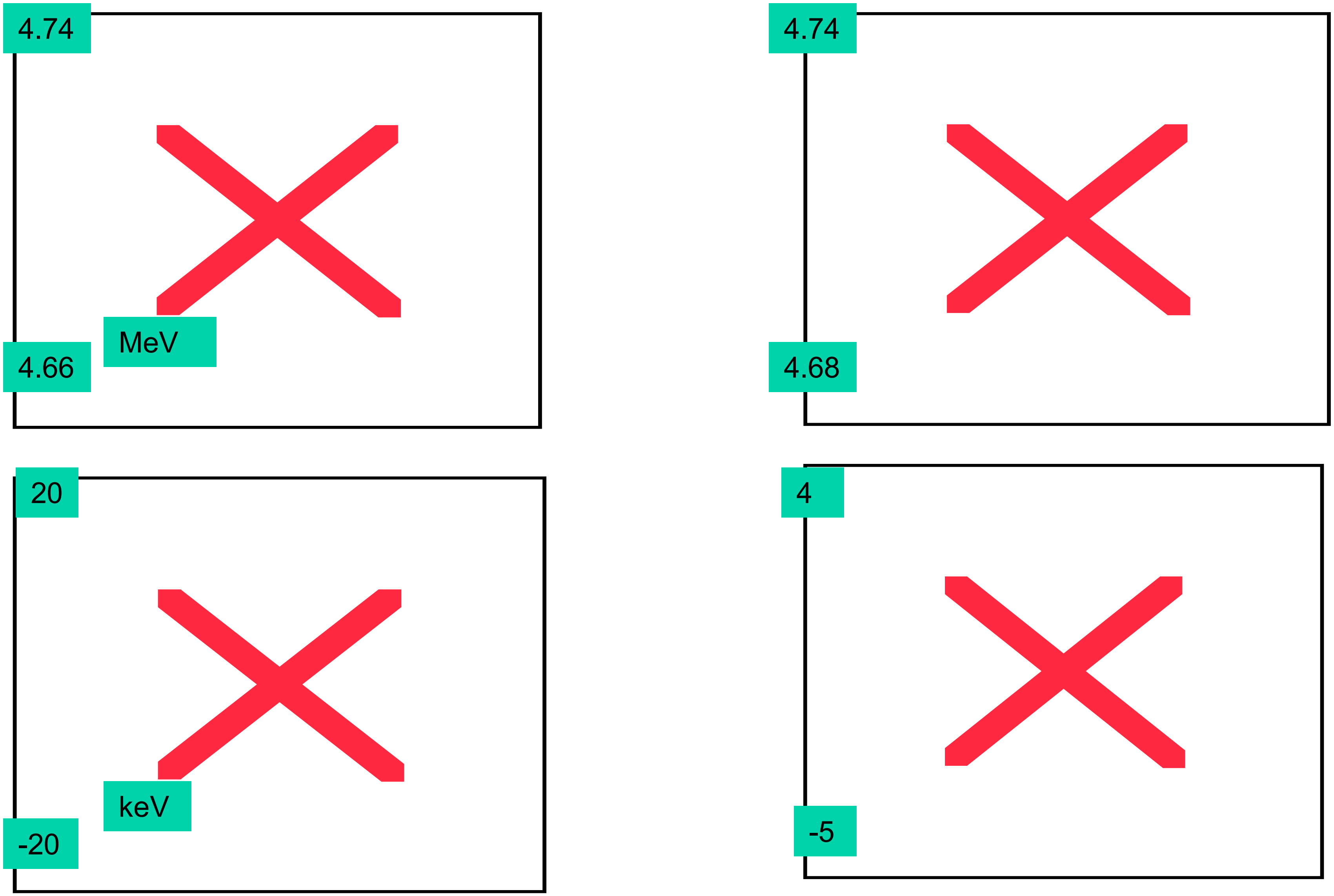




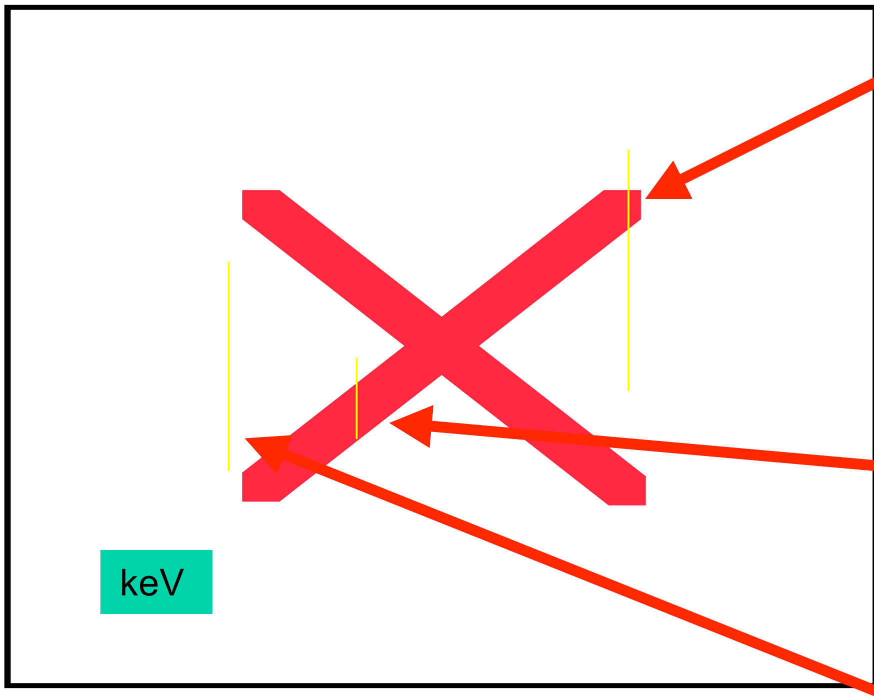
Energy spread for ellipsoid (left) and flattop (right).

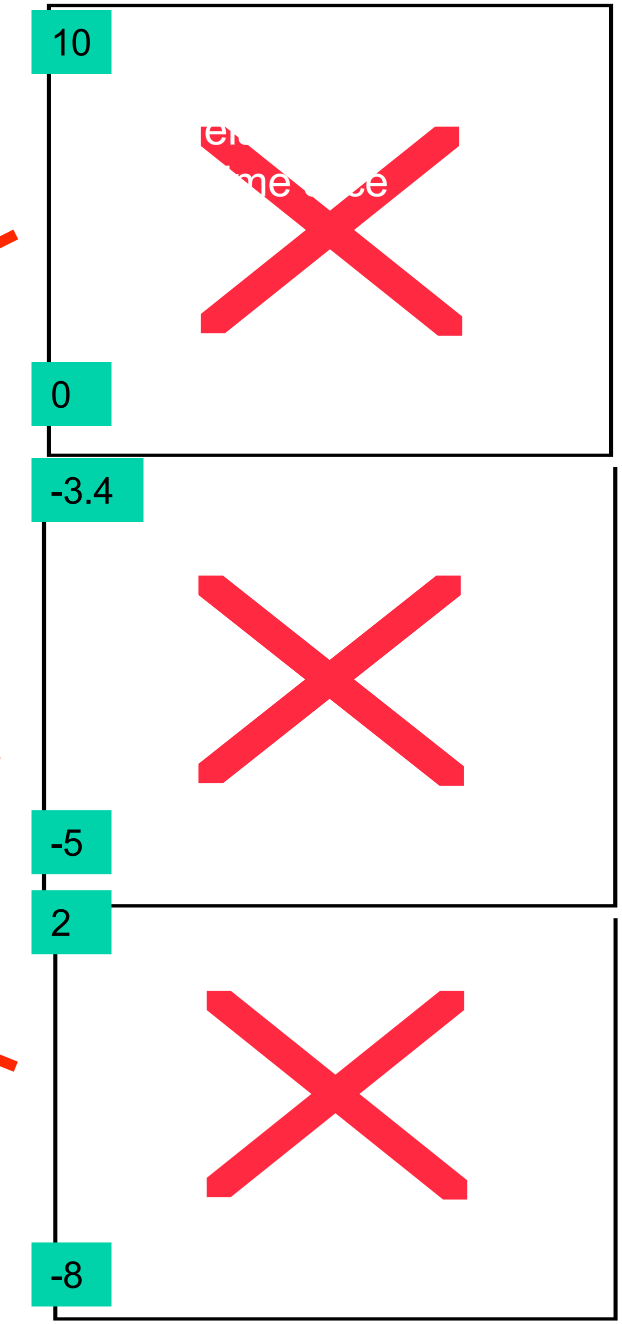


Longitudinal Phase Space Density



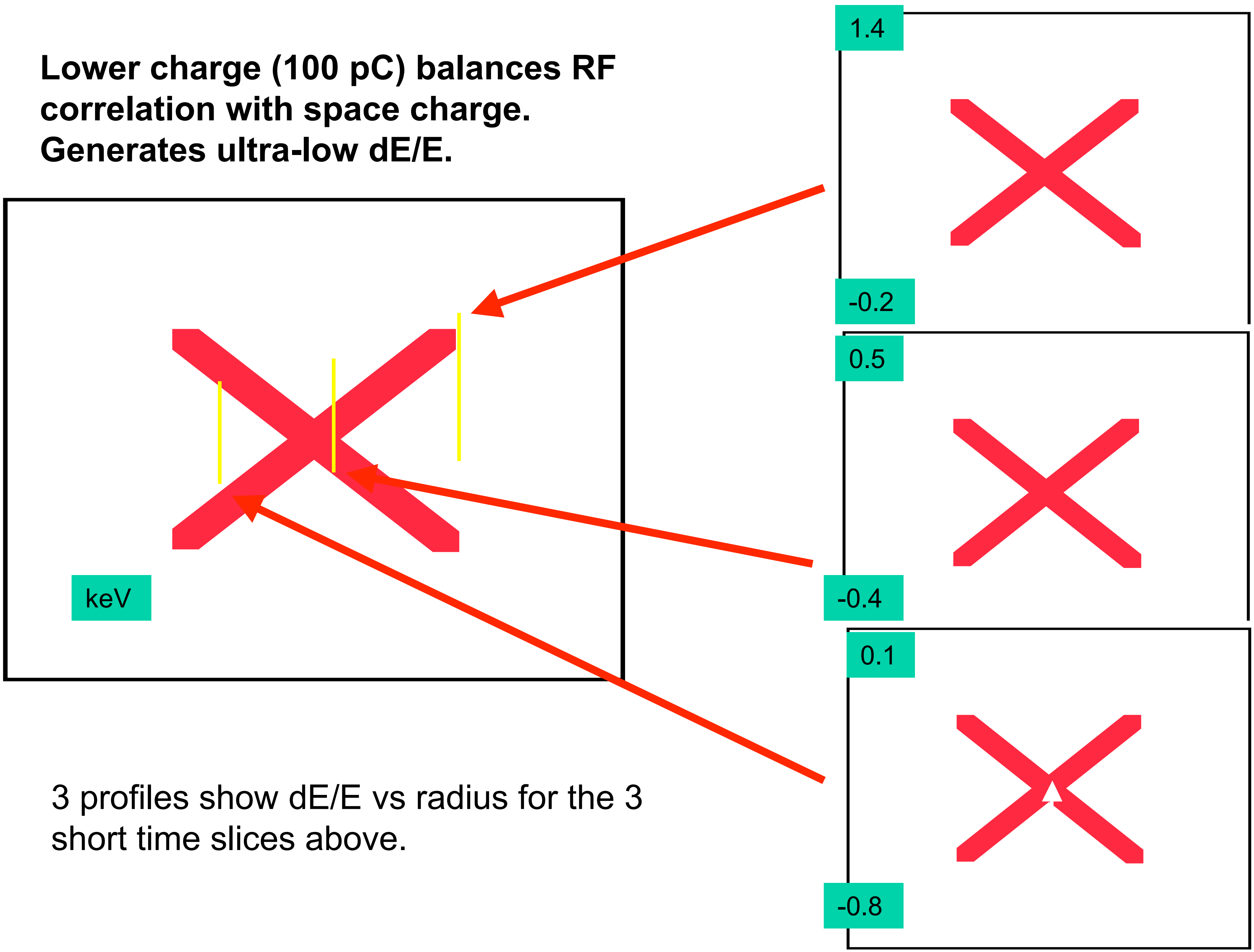
Radial energy correlation reverses slope from head to tail for flattop bunch





3 profiles show dE/E vs radius for the 3 short time slices above.

Lower charge (100 pC) balances RF correlation with space charge. Generates ultra-low dE/E.



3 profiles show dE/E vs radius for the 3 short time slices above.

Summary

•Seeded FELs require constant current and energy spread for optimum performance.

•Ellipsoidal bunch distribution produces linear correlation of energy and time. Substantially improved over flat-top bunch.

•For thin time slices, all distributions show a strong correlation of energy with radius. Interesting new dynamics to study.

- ➢RMS dE/E ~ 100 eV when radial correlation removed
- ➢Slope of correlation due to radial variation of RF field is opposite to that of space charge for ellipsoidal bunch
- ➢Slope of radial correlation for flattop bunch reverses sign from head to tail

Quantum Effects in Gain and Start-up of Free-Electron Lasers — Wigner Function Approach

Zhirong Huang and Kwang-Je Kim

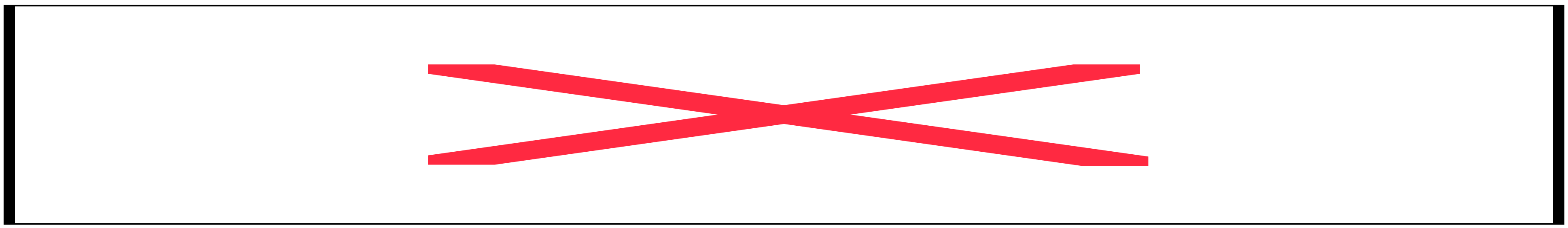
The Physics and Applications of High Brightness Electron Beams

Erice, Sicily

October 9-14, 2005

Wigner Distribution Function

Given a wave-field, such as coherent EM field or quantum wave field as a function of spatial coordinate θ, the W-function is a function of phase space coordinate (θ, p)



- W is the closest object corresponding the classical phase space distribution. However, it is not a true distribution of particles since it can in general have negative values due to the fact that one cannot specify coordinate and conjugate momentum at the same time
- However W is useful because:
  - It tranforms as classical phase space distribution function
  - integrals of W are positive and have a physical meaning :

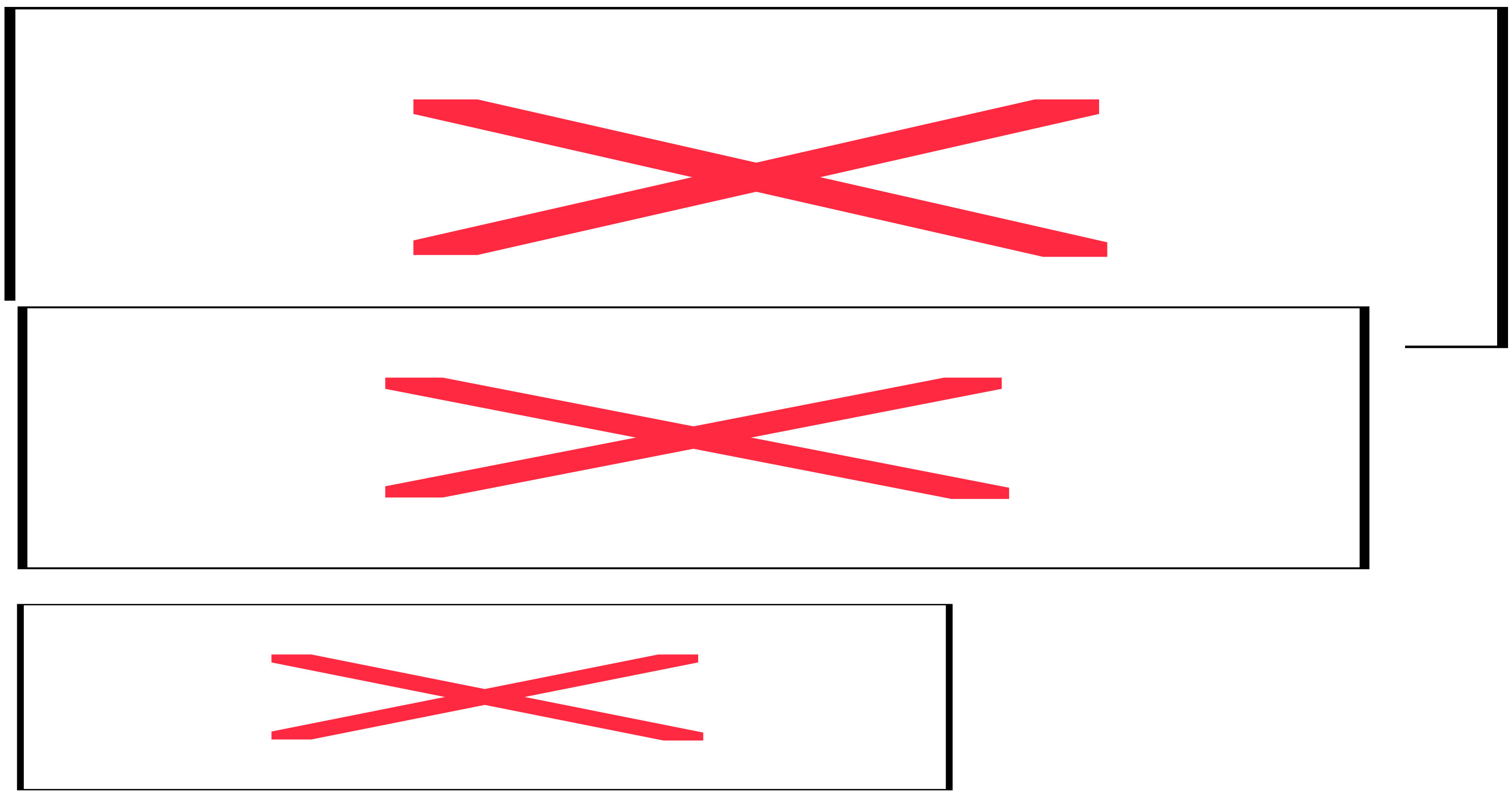
$F(\theta, \tau)=\int dp\, W(\theta,p,\tau) = |\_(\theta,\tau)|^2$: density

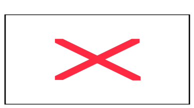
$V(p, \tau)=\int d\theta\, W(\theta,p,\tau) = |\int d\theta\, e^{ip\theta} f(\theta,\tau)|^2$:energy distribution

Solve Quantum Vlasov-Maxwell Equation for SASE

- Follow the classical derivation (KJK,1986)

  Laplace transform→solve in terms of initial values→inverse Laplace Transform



 is classical, smooth, average distribution

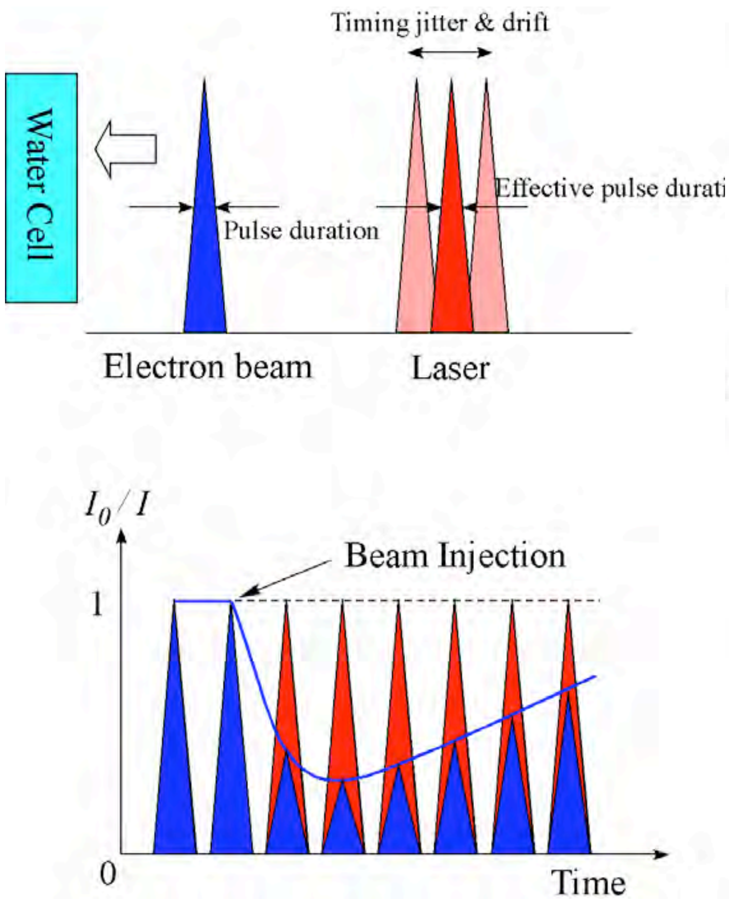
Review of RF photoinjector for radiation chemistry

Univ. Tokyo

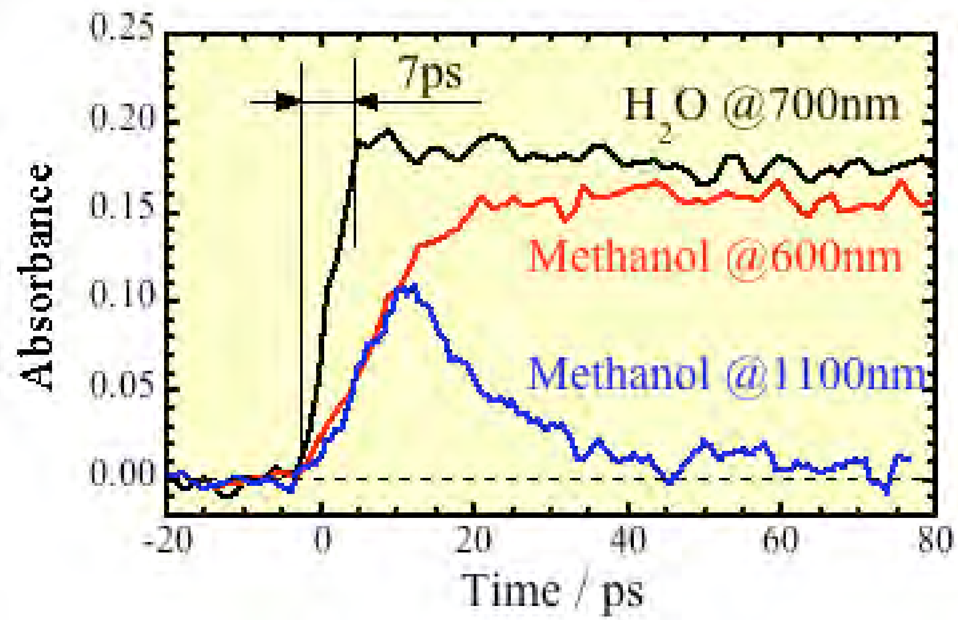
A. Sakumi, M. Uesaka, Y. Muroya, Y. Katsumura

Radiation Chemistry

Pulse radiolysis method



Chemical reaction of water

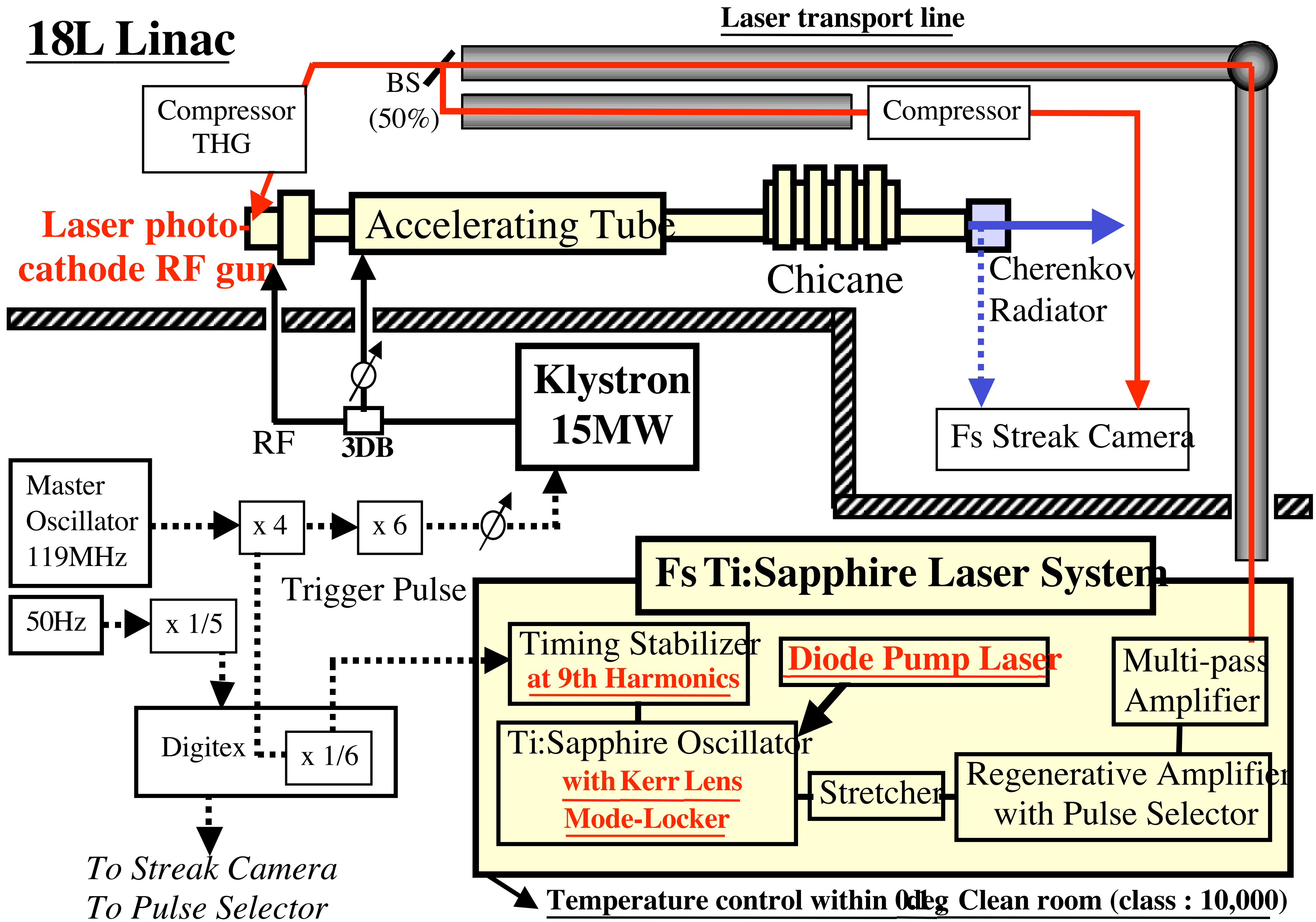


NERS U. Tokyo Y. Muroya et al.,

Precise Synchronization System at UTNS

Beam-Material Interactions

www.utns.jp/~beam



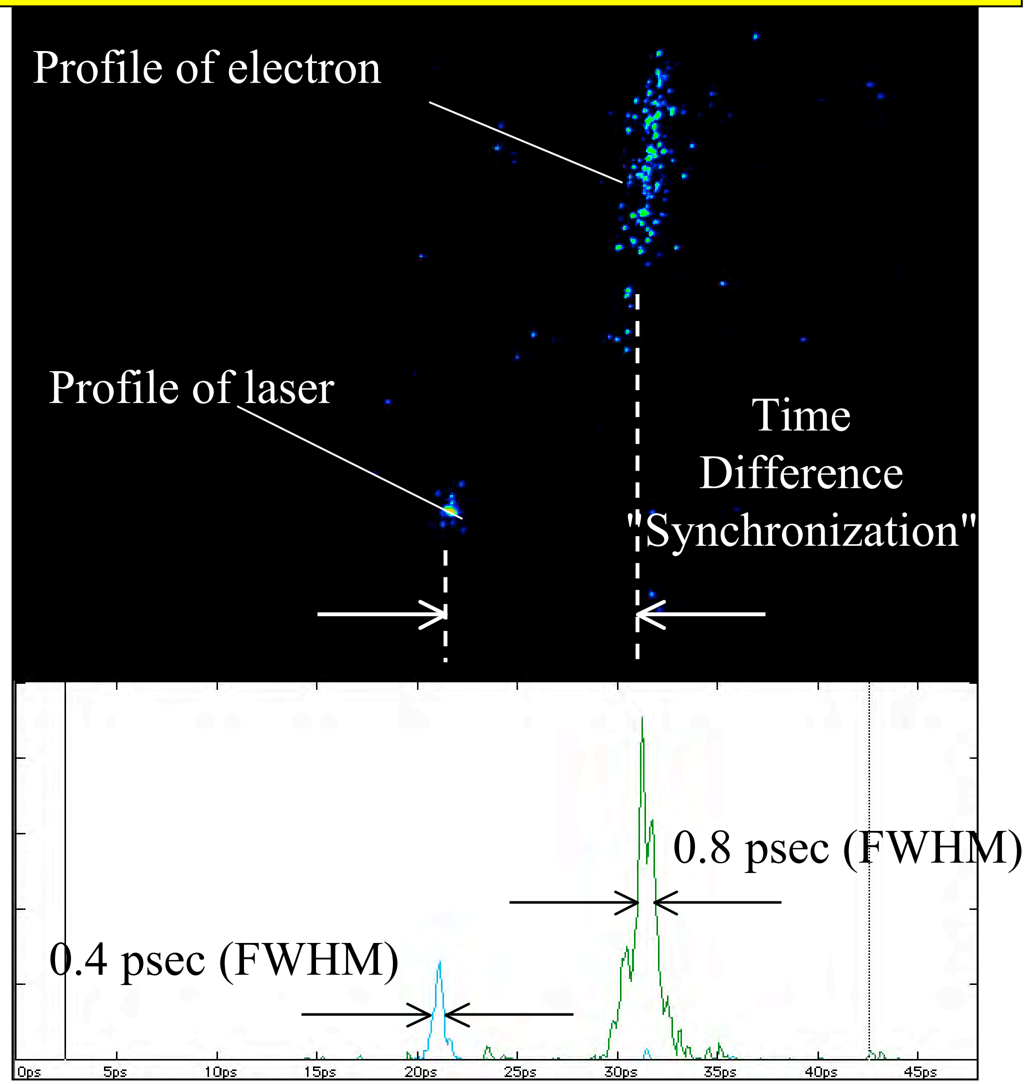
ELYSE,Orsay

ELYSE, Picosecond Pulse Radiolysis

	Beam energy	Beam Current	Beam width	Beam size	Target path Length	Synchro-nization	Laser pulse width	Total time Resolution
U. Tokyo	4+18= 22MeV	2nC	1ps	3mm	1mm	<1ps(rms)	100fs(532nm-2600nm)OPA (400-1100nm) white light made by Ti:Sa	3ps(white light)
LEAF,BNL, USA	9MeV	2-8nC	≥ 7 ps		10mm(right water)	Pico-sec.	100fs(240-2600nm)OPA	>7ps(pulse-probe)
ELYSE, France	4 to 9 MeV	≥ 1 nC	≤ 7 ps	2-20mm				~7ps?
Waseda Univ.	4MeV	0.4-0.6nC						8ps
Osaka Univ.	38MeV	>0.2nC	<1ps				100fs	~5ps

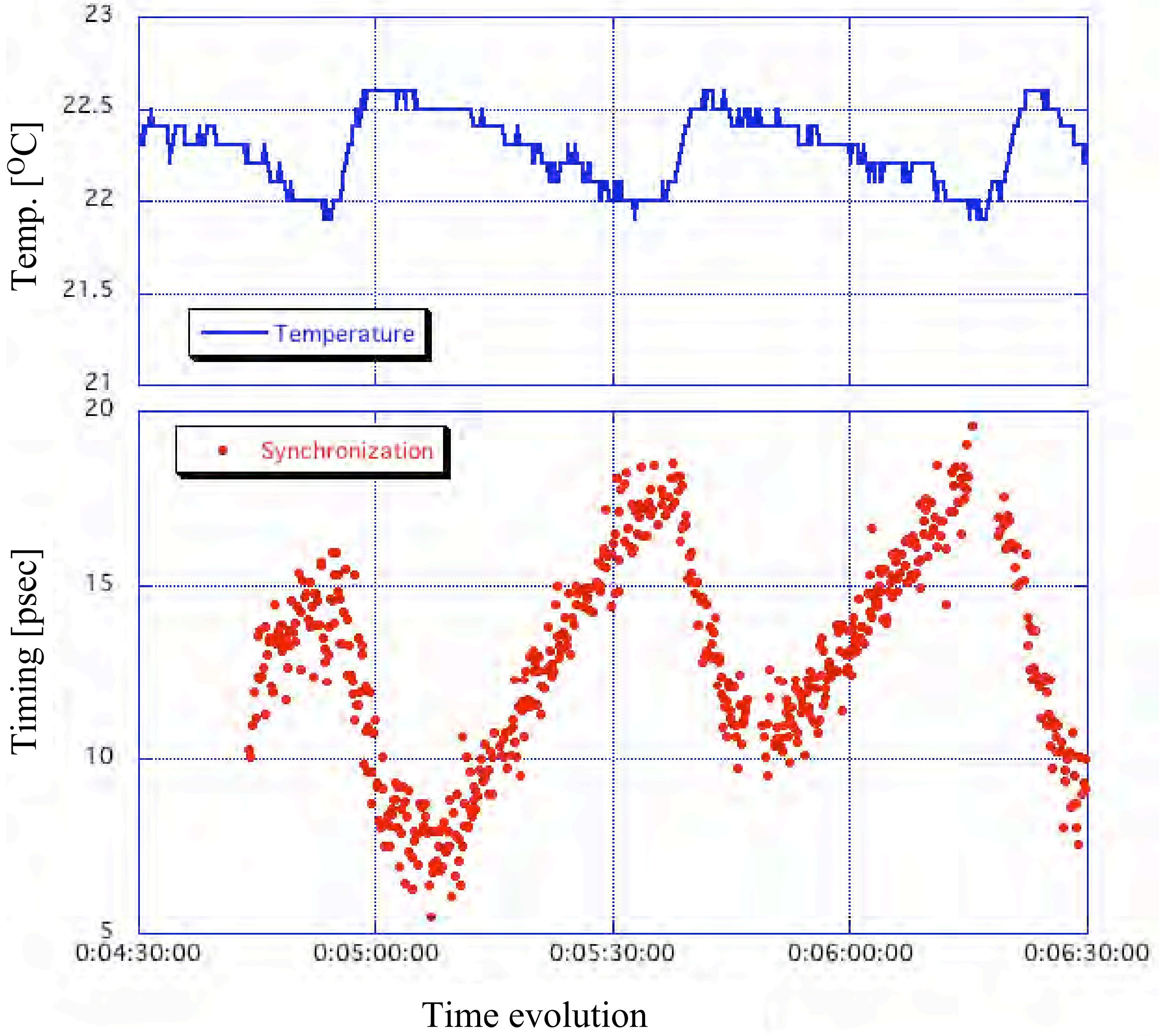
Requirement of stable synchronization

Typical Femtosecond Streak Camera Image of Synchronization



- The S-band linac with Mg photocathode RF injector has been developed for radiation chemistry.
- The radiation chemistry experiment requires a time resolution in a range of sub-picosecond.
- The time resolution is defined by… *pulse duration of pump-beam, and probe-laser, synchronization between the beam and laser, and the beam intensity*.

The drift of the Laser-room temperature has much effort to Synchronization between laser and electron beam



Summary of FEL and Photoinjector

1. Ultra-wide bandwidth (15%) SASE FEL has been observed at VISA, BNL-ATF (Andonian(UCLA)).

2. Gain curve of seeded FEL and spatial profiles of harmonics has been experimentally demonstrated and 1 GW system design is shown. (Watanabe(BNL)).

3. Longitudinal studies of ellipsoidal/flattop bunches were done to achieve low energy spread in the whole bunch. Ellipsoidal bunch distribution produces linear correlation of energy and time. Substantially improved over flat-top bunch. (Graves(MIT))

4. Discussion on the QFEL was done (Kim(ANL)).

5. Photoinjectors for radiation chemistry in the world are introduced, because they are the second-major users. Suppression of the timing-jitter and long-term drift between electron- and laser-pulses are discussed (Sakumi(Univ.Tokyo)).

Plasma Wakefield Accelerations and Innovative Acceleration Schemes

1. PWA

Kenichi Kinoshita

"Application of Laser Plasma Cathode to Radiation Chemistry, All Thomson Scattering and Electron Microscopy"

2. Innovative Acceleration Schemes

Gil.Travish

"Preliminary Results from the UCLA/SLAC Ultra-High Gradient Cerenkov Wakefield Accelerator Experiment"

Rodney Yoder

"Coupling Laser Power into a Slab-Symmetric Acceleration Structure"

S. Dabagov

"Channeling Projects at LNF"

Generation of energetic electrons from a laser plasma cathode and the future applications for pulse radiolysis, Thomson scattering X-ray generation, and electron microscopy

K. Kinoshita, T. Hosokai, A. Zhidkov[1], T. Ohkubo, A. Maekawa,

K. Kobayashi and M. Uesaka

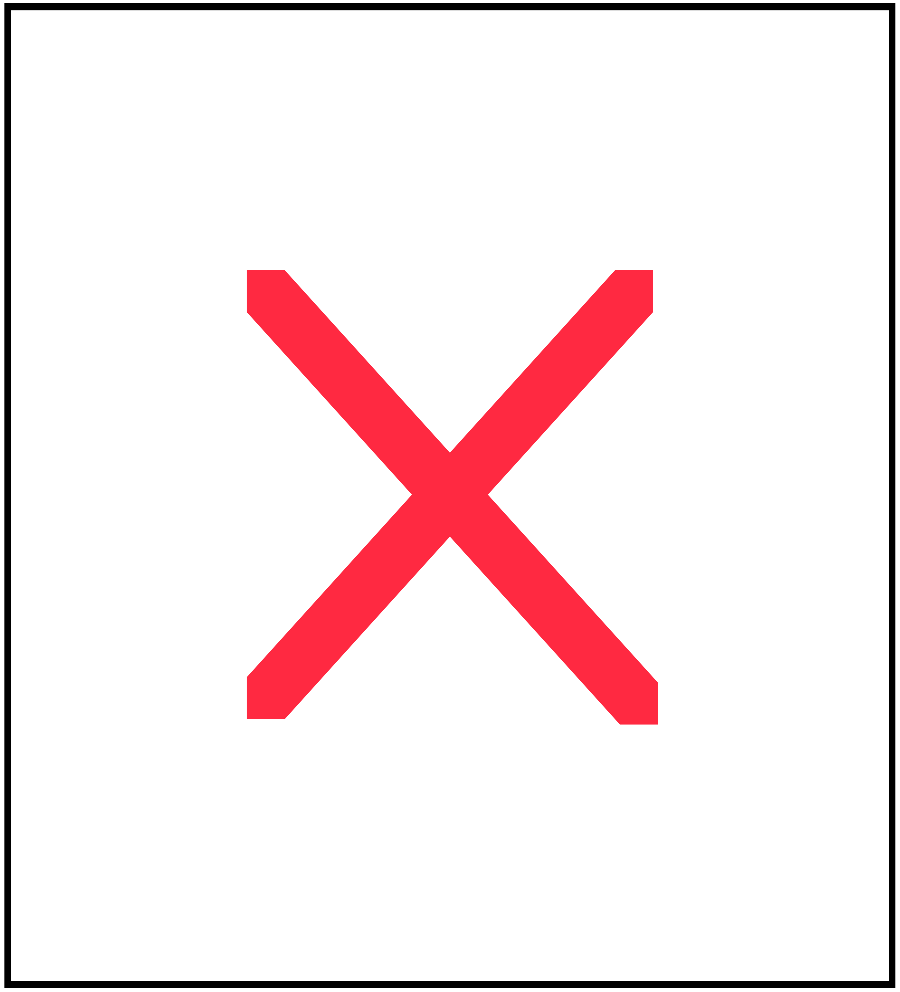
Nuclear Professional School, School of Engineering, University of Tokyo

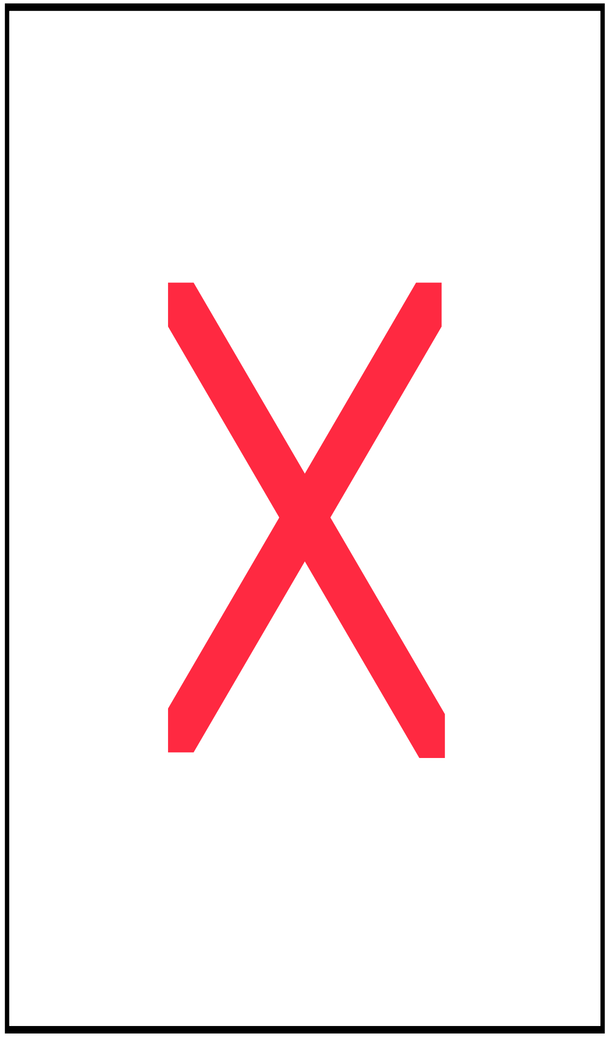
[1]National Institute of Radiological Sciences JAPAN

The physics and Applications of High Brightness Electron Beams, Erice (Italy), 10th-14th Oct. 2005.

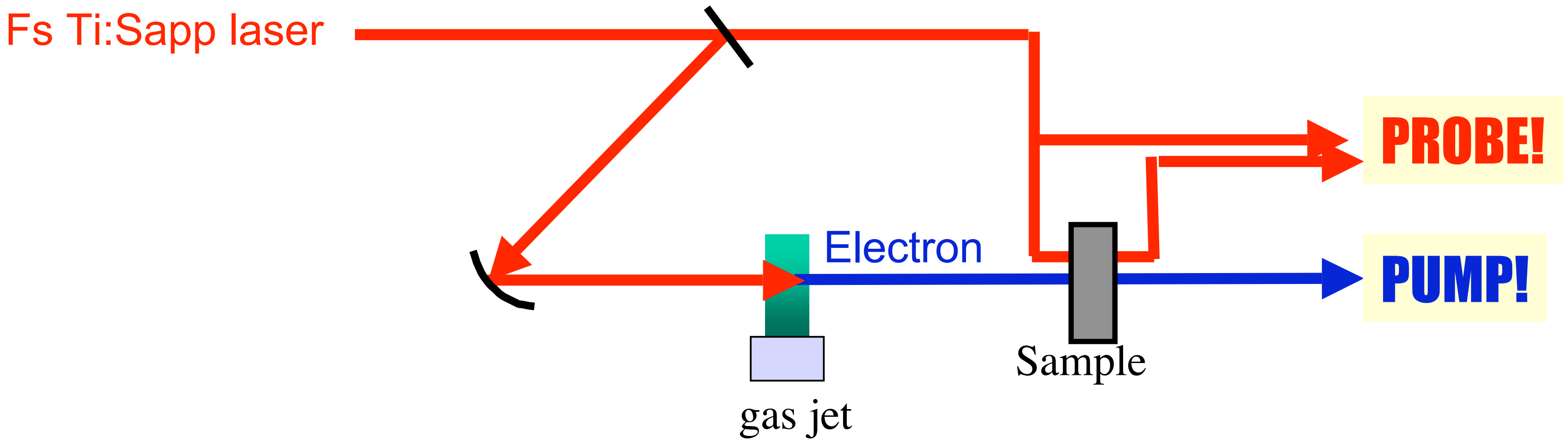
Mono energetic electron beam from laser plasma cathode

Qasi mono energetic electron spectrum





Pulse radiolysis with laser plasma cathode



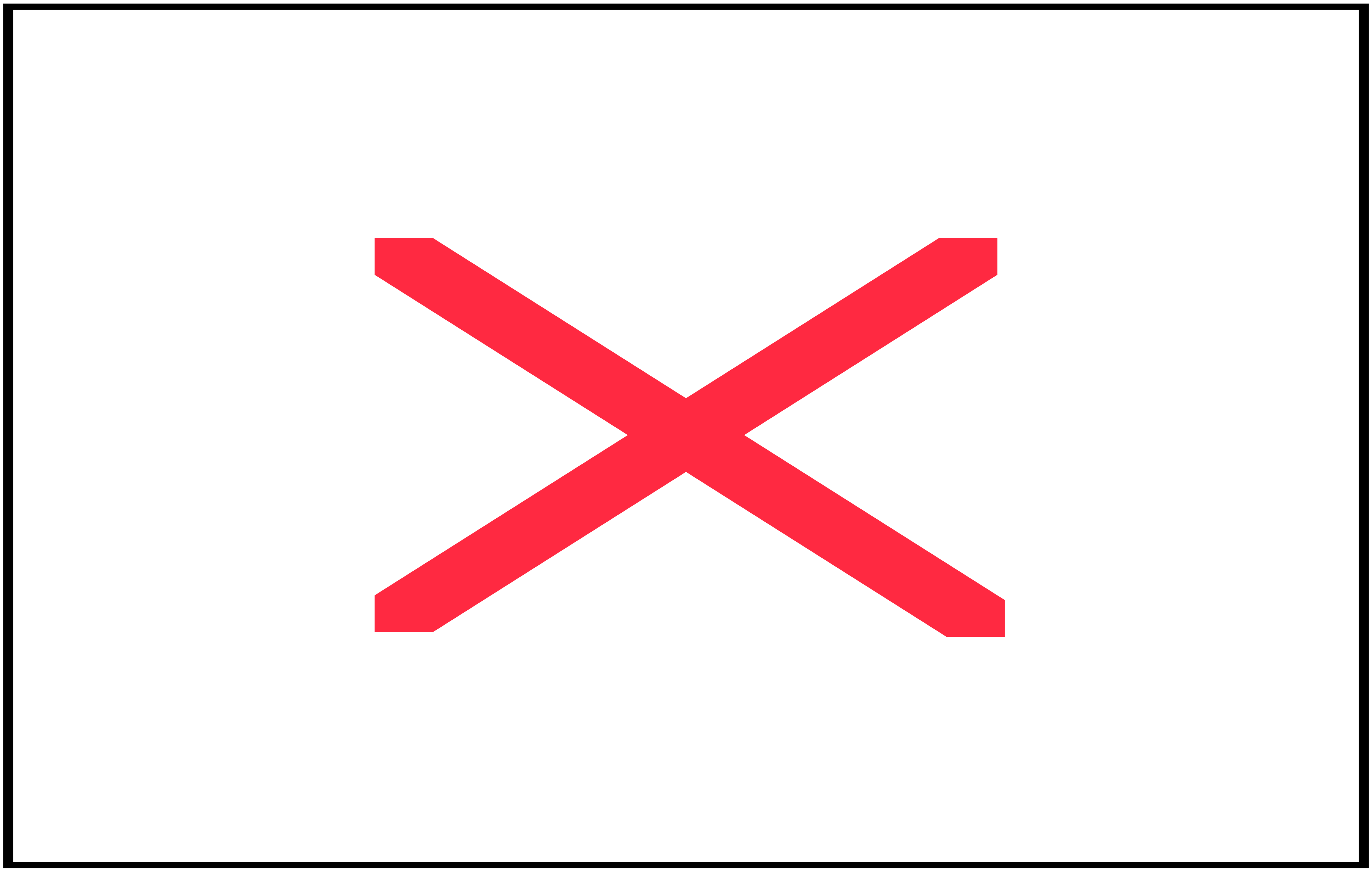
A laser pulse divided into electron generation pulse and probe pulse

- Jitter-free
- Femtosecond pulses

Femtosecond resolution!

Very simple setup!

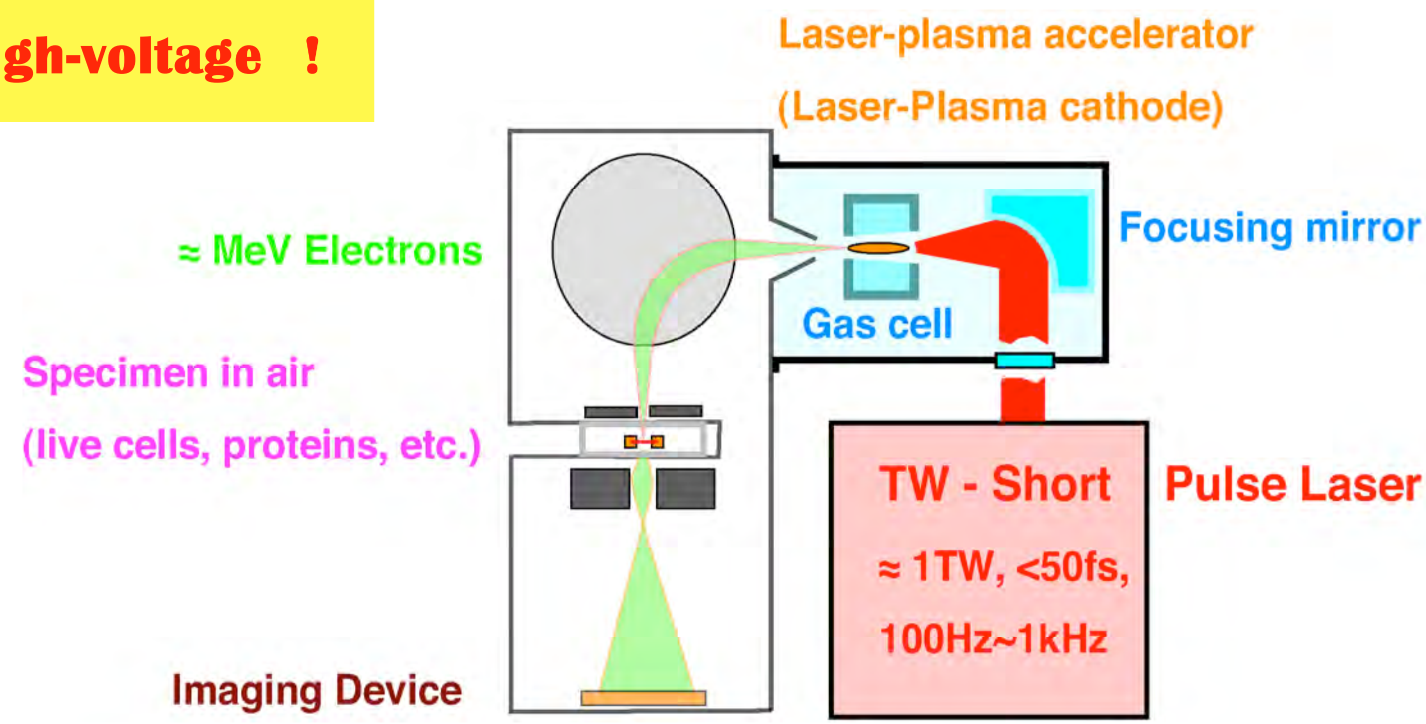
Laser Thomson scattering with laser plasma cathode



A Strawman Design of Laser-driven Microscope

National Institute of Advanced Industrial Science and Technology AIST

No high-voltage !



- **Ultra-short pulse of ≈10fs might be possible to accelerate electrons in the atmospheric pressure.**
- **Laser-plasma cathode technique will enable us to observe live specimen by the electron microscope.**
- **Pump-probe technique with fs-resolution will be possible.**

Preliminary Results from the UCLA/SLAC Ultra-High Gradient Cerenkov Wakefield Accelerator Experiment

M. C. Thompson†, H. Badakov, J. B. Rosenzweig, G. Travish*
UCLA Dept. of Physics and Astronomy

M. Hogan, R. Ischebeck, N. Kirby, R. Siemann, D. Walz
Stanford Linear Accelerator Center

P. Muggli – University of Southern California

A. Scott – UCSB Dept. of Physics R. Yoder - Manhattan College

*Spokesman for the Collaboration at Erice
†Current Affiliation:
Lawrence Livermore National Laboratory

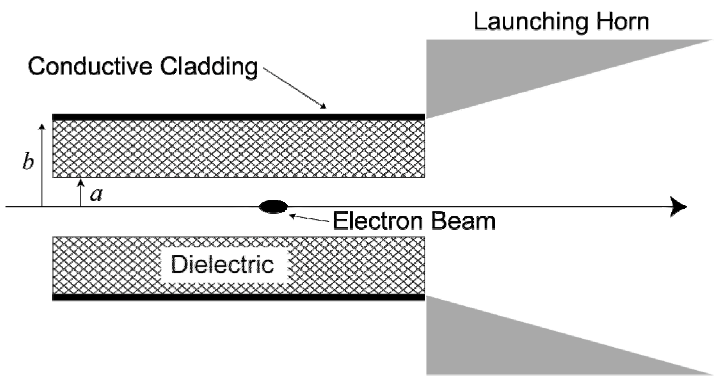
High Frequency Dielectric Accelerators

Dielectric accelerating structures can be driven by many different mechanisms at frequencies from microwave to optical, but electron driven structures operating at THz frequencies have several advantages:

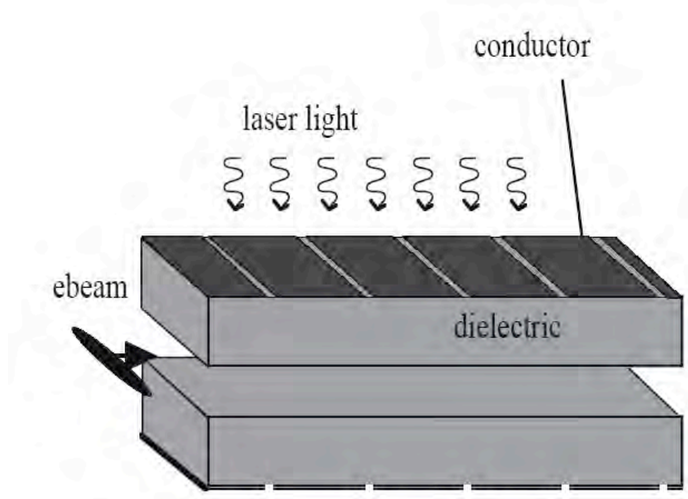
High power THz range operation without external THz source.

Possible breakdown suppression due to relatively low drive beam field photon energies.

Plasma accelerator class GV/m accelerating fields without the problem of ion collapse.



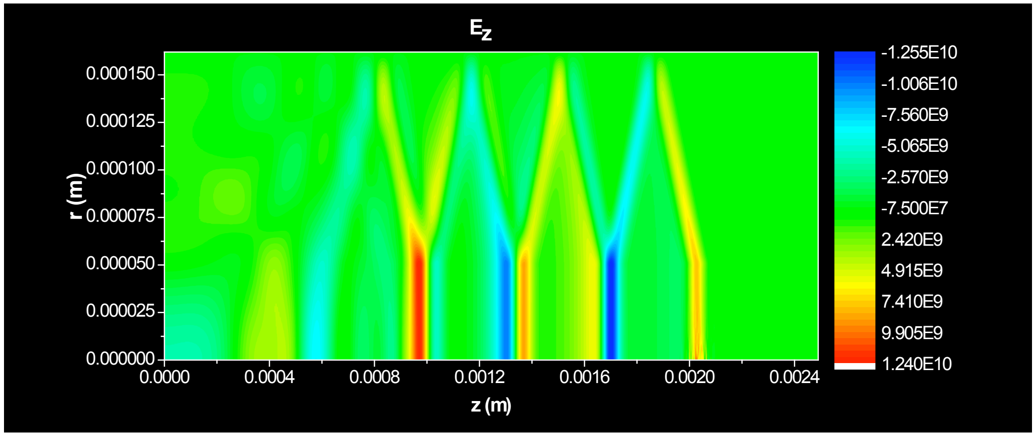
Schematic of a Electron Beam Driven Dielectric Wake Accelerator.



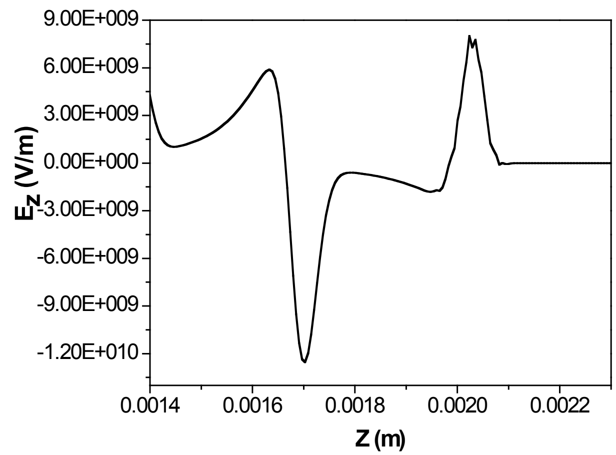
Courtesy R. Yoder

Schematic of a Laser Driven Dielectric Accelerator Structure.

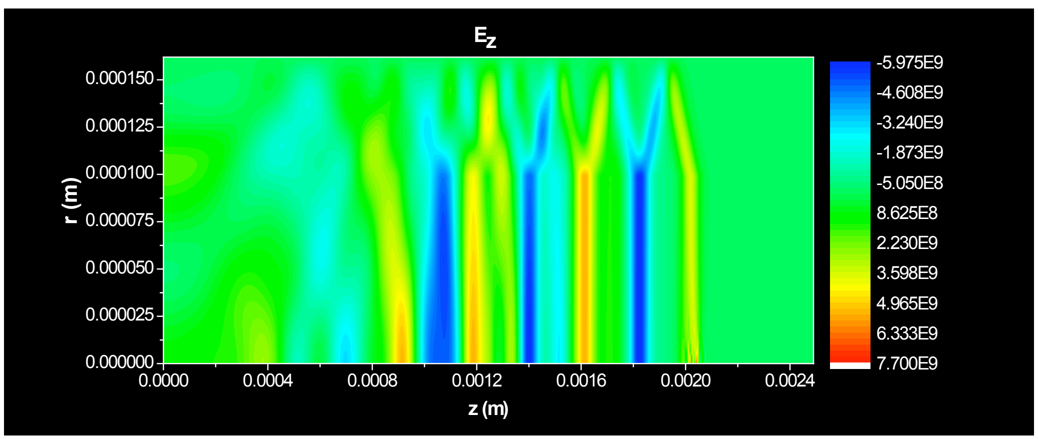
OOPIC Simulations for _$_z$ = 20 μm



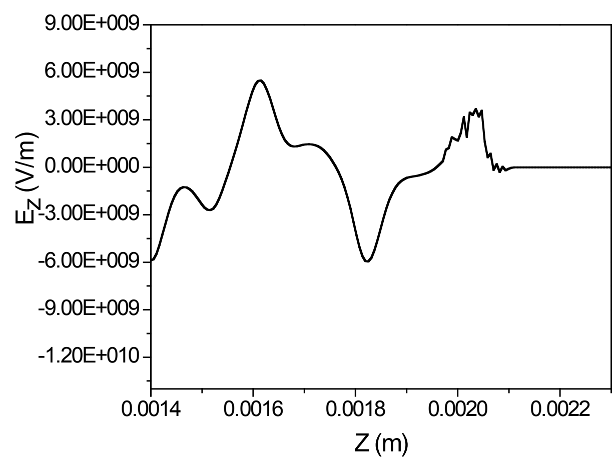
Contour plot showing E_z for a = 50 μm



Line out of E_z at
r = 10 μm with a = 50 μm



Contour plot showing E_z for a = 100 μm



Line out of E_z at
r = 10 μm with a = 100 μm

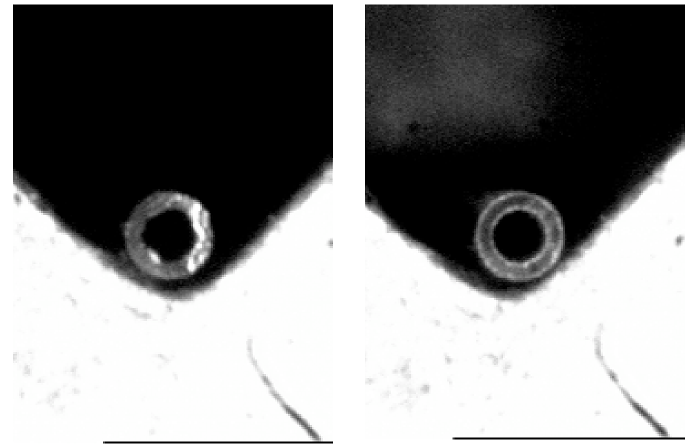
Realizing the Experiment

Dielectric Tube Samples for this experiment were modified from off the shelf synthetic fused silica capillary tubing (_ ≈ 3), which we were able to purchase in 100 and 200 μm ID sizes and coat on the outside with aluminum.

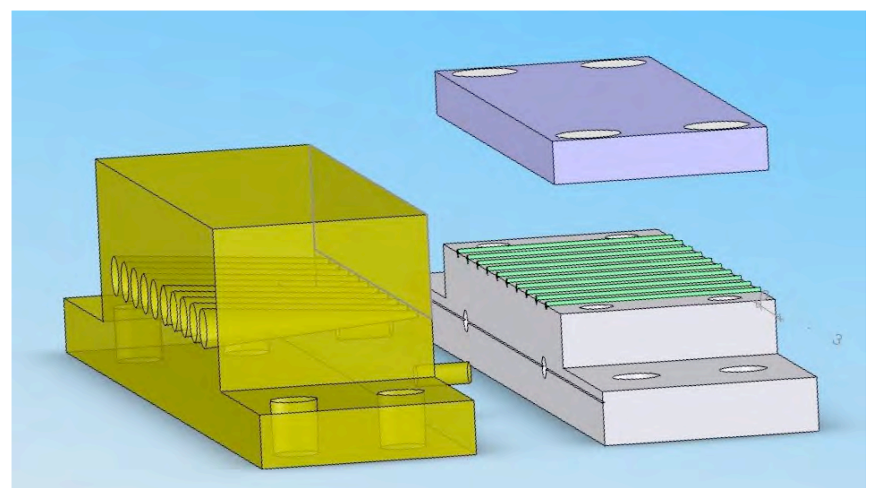
Mounting Blocks are used to hold 10 dielectric tube samples for the experiment. The mounting block are placed on motorized optics mounts and stages so the various samples can be placed onto the beam orbit.

High-Resolution Video Cameras look for optical emissions associated with the breakdown events. We also examine the dielectric tubes after the run to analyze structure damage from breakdown.

Launching Horns, similar to those used in microwave antennas, will boost amount of CCR delivered to the pyroelectric detectors.



Fiber viewed end on with a microscope. Unpolished at left and polished at right.



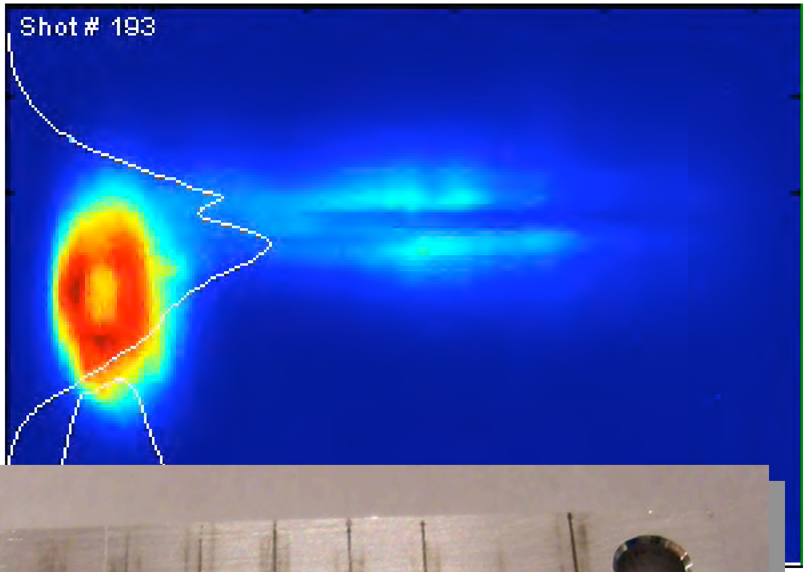
CAD rendering of the capillary tube mounting block with detachable launching horns.

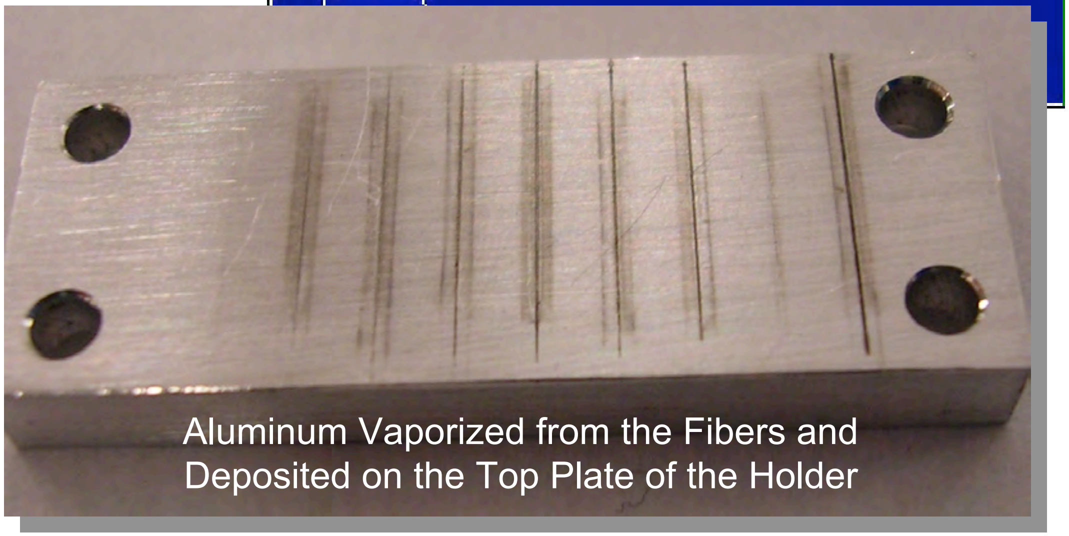
Phase One of the Experiment

The first run of the experiment occurred in Aug 2005. The objective of the run was to examine breakdown thresholds. Direct Measurements of CCR will be attempted in the next run.

Major Observations:

- A sharp increase in visible emission from the capillaries near the mid-range of beam current, probably indicating breakdown.
- Principle form of damage to the dielectric wake structures appear to be vaporization of the aluminum cladding. The fused silica appeared substantially intact.





Aluminum Vaporized from the Fibers and Deposited on the Top Plate of the Holder

Breakdown Observations

Most of the observations were of 200 μm ID fibers and the general impression is that the visible light output of the fibers jumped up sharply in the middle of the beam pulse length range. We theorize that the initiation of breakdown discharges are responsible for the increase.

Visible Light Sources Below Threshold:
- **Incoherent Cerenkov Radiation, Incoherent Transition Radiation, Scintillation**

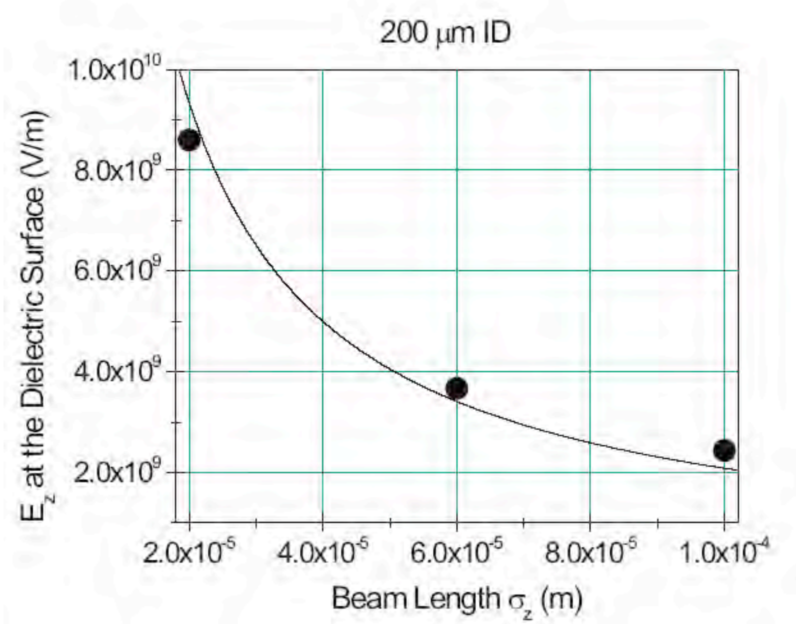
Visible Light Sources Above Threshold:
- **All of the above plus emissions from Plasma formed during breakdown events.**

Breakdown fields implied by these preliminary observations should they be confirmed by further analysis:

~ 4 GV/m at the dielectric surface

~ 2 GV/m on axis accelerating field

We are working to quantify these observations.



Conclusions

- The prospects for developing GV/m class dielectric accelerators look promising.
- It appears that fused silica holds up well under fields at the GV/m level.
- Resistive heating of the conductive cladding is a significant problem in this extreme environment.

Future Directions

- Further data analysis on all aspects of the experiment should give more insight.
- Clearly the fiber cladding will need to be redesigned with the aim of reducing resistance and increasing thermal coupling.
- The next round of experiments will include measurements of the coherent Cerenkov radiation emitted from the fiber, which will give us more information about the field strengths within the fiber.

Coupling Laser Power into a Slab-Symmetric Accelerator Structure

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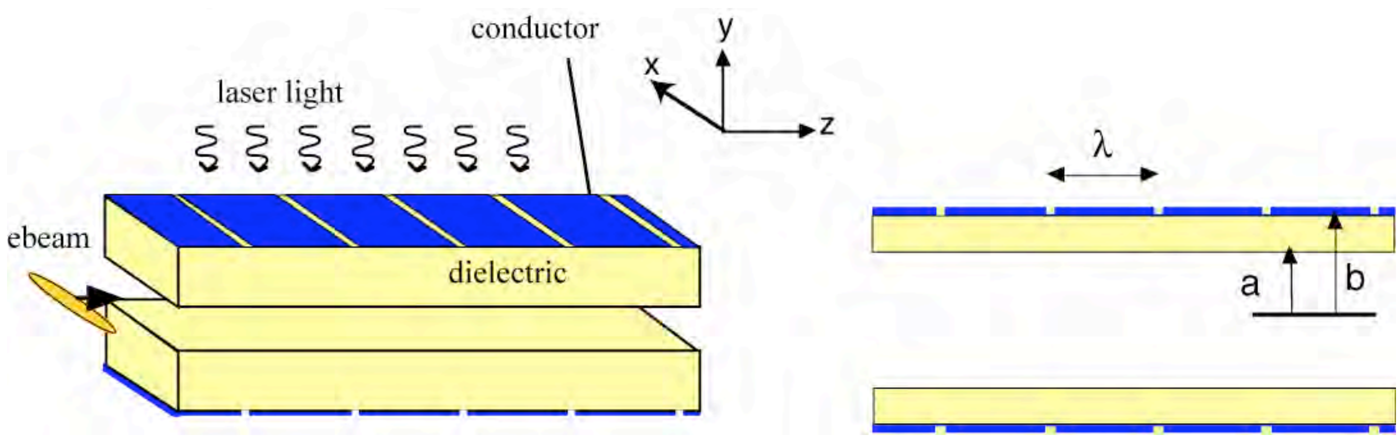
Manhattan College, New York
J. B. Rosenzweig
UCLA Dept. of Physics and Astronomy

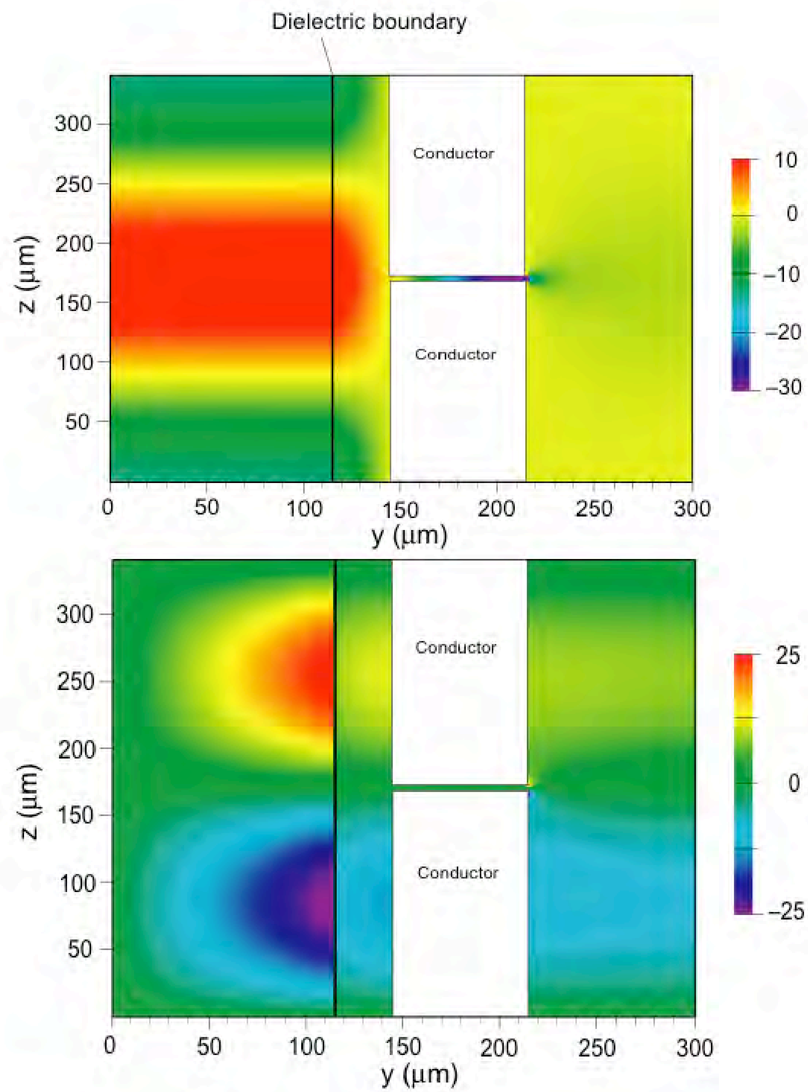
ICFA Workshop on High-Brightness Beams,
Erice, October 2005

The Structure: cartoon



Typical dimensions: λ matches drive wavelength (10 μm - 340 μm)
Length (in z) ~ width (in x) ~ laser spot size (a few cm)
a, *b* are a fraction of λ

2D time-dependent simulation



340 µm wavelength

a = 115 µm, b–a = 30 µm

quarter-wavelength slots

slot width = 5 µm

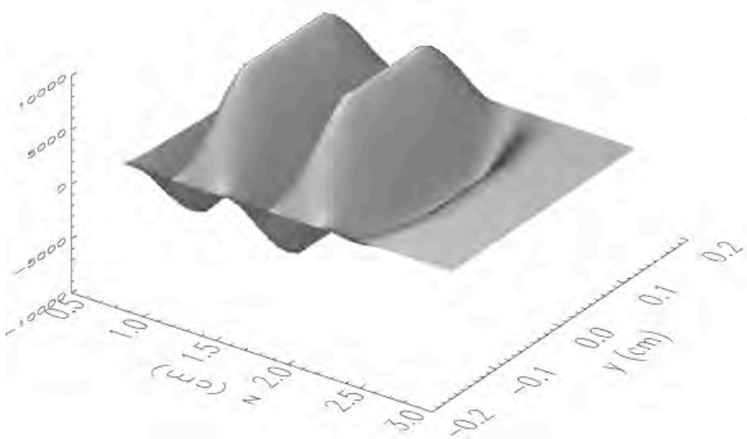
Axial field:

- flat wavefronts (no perturbation)
- large field in slot (3x peak)

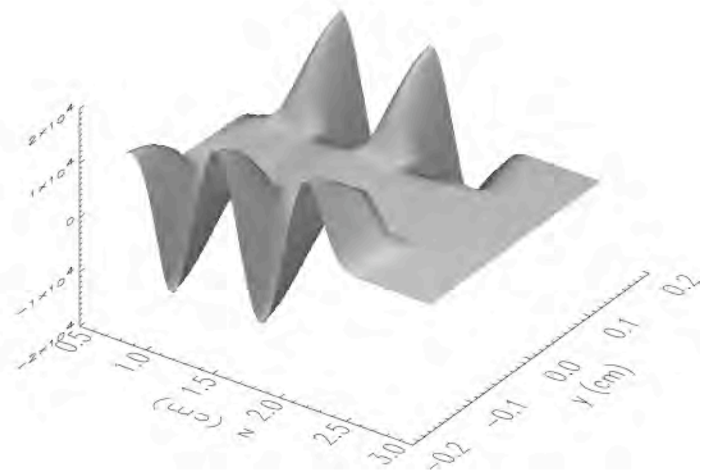
Transverse field:

- zero at y=0
- zero at peak acceleration

Wakefields: Without slots

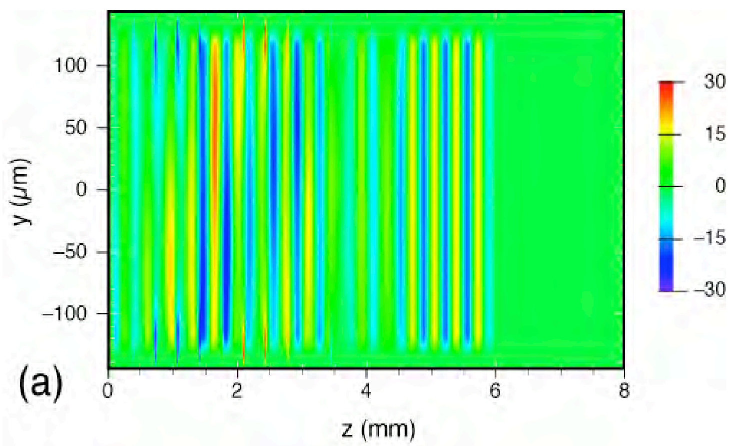


Longitudinal wakefield
(only about 10-50 kV/m, depending on beam σ_z, charge)



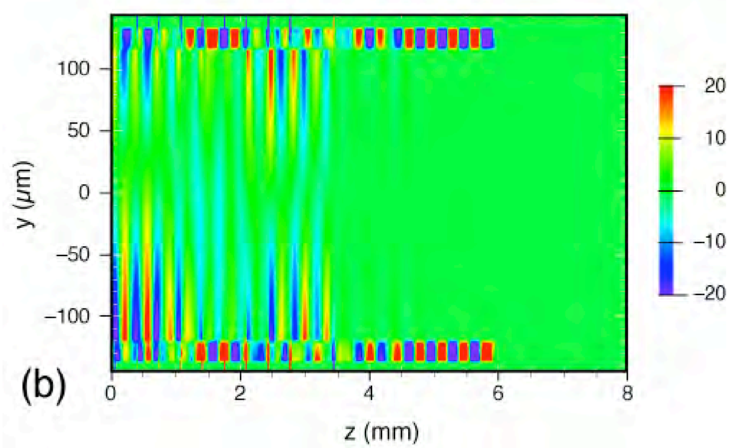
Transverse wakefield
(suppressed in the vacuum region for all beams, because of slab geometry)

Wakefields: With slots



longitudinal

(kV/m)



transverse

(kV/m)

- *Fields are altered*
- *Transverse wakes $\neq 0$*
- *Multimode*
- *Wake sizes still small*
- *Wake group velocities less than c*

Conclusion

•Laser-driven structure analysis must include consideration of the coupling
•Distributed side-coupling seems advantageous in view of the damage limits on end-coupling

Slot-coupling scheme:

•Slot dimensions control fill and axial field
•High fields: possible breakdown limit
•Resonant frequency perturbation: design must be adjusted
•Slots do not cause energy loss or strong perturbation, but
•Slots add multimode component to wakefields

INFN
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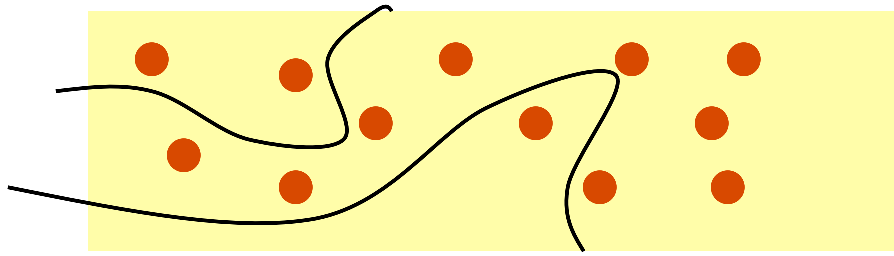
CHANNELING projects at LNF: From Crystal Undulators to Capillary Waveguides

Sultan Dabagov, Massimo Ferrario, Luigi Palumbo and Luca Serafini

PAHBEB - 2005, Erice, 13 October 2005

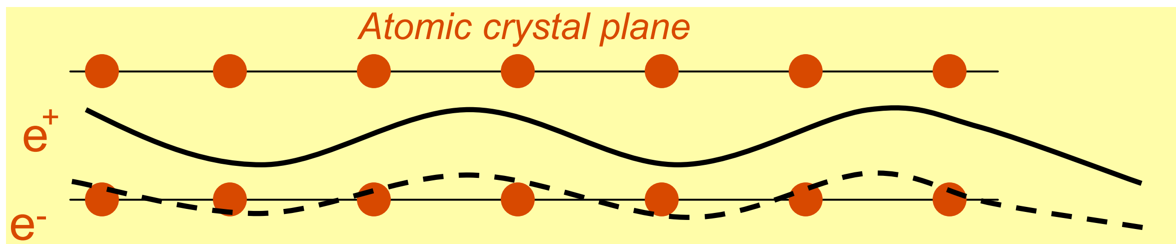
Channeling of Charged Particles

@ Amorphous:

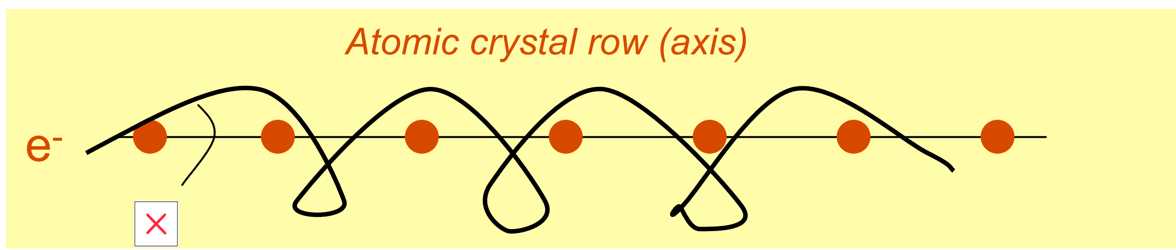


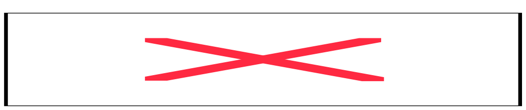
@ Channeling:

planar channeling



axial channeling

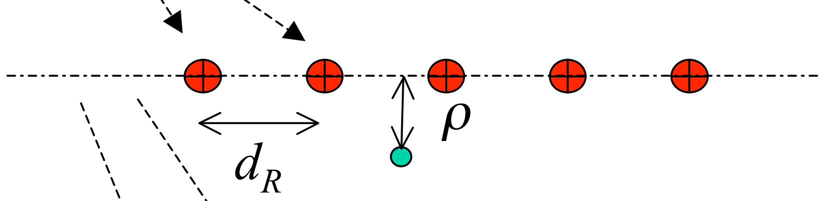




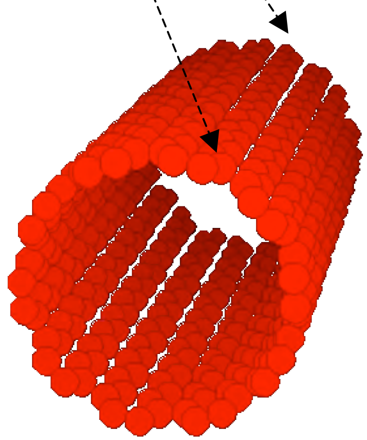
- *the Lindhard angle is the critical angle for channeling*

Potentials: Doyle-Turner approximation

$$f(\mathbf{k}) = 4\pi Ze \sum_{j=1}^{N} a_j \exp(-k^2/4b_j^2)$$ - *form-factor for the separate fullerene*



$$V_R(\rho) = (4Ze^2/d_R) \sum_{j=1}^{N} a_j b_j^2 \exp(-b_j^2\rho^2)$$



$$U(\mathbf{r}) = \sum_i V_R(|\mathbf{r} - \mathbf{r}_i|)$$ *continuum potential as sum of row potentials*

$$U(r) = (16\pi d Ze^2/3\sqrt{3}\,l^2) \sum_{j=1}^{N} a_j b_j^2 \exp\{-b_j^2[r^2 + (d/2)^2]\} I_0(b_j^2 r d)$$

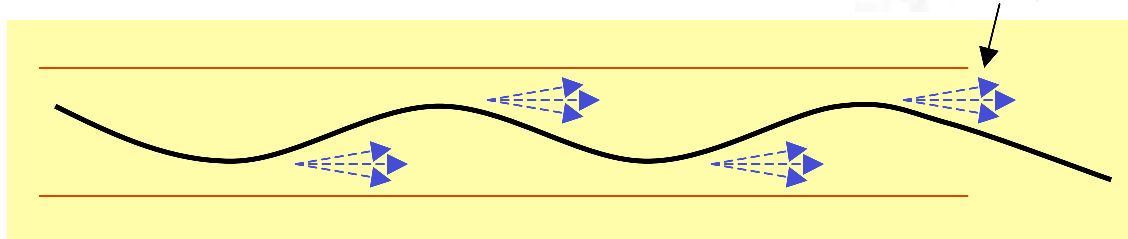
r – distance from the tube

$I_0(x)$ – mod. Bessel function

Phys. Lett. A250 (1998) 360
NIM B143 (1998) 584

@ Channeling Radiation:

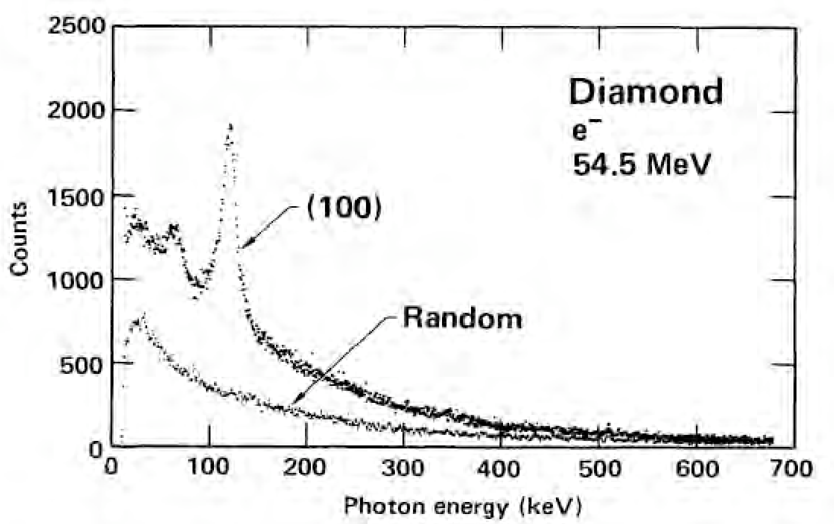
$$\Delta\vartheta \simeq \gamma^{-1}$$

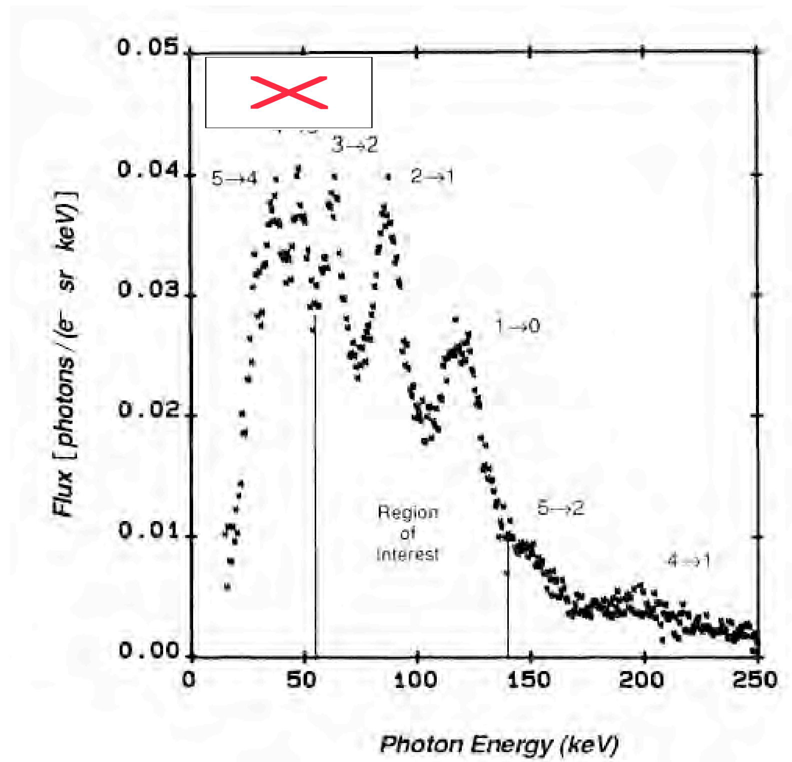


- *optical frequency* → *Doppler effect* →

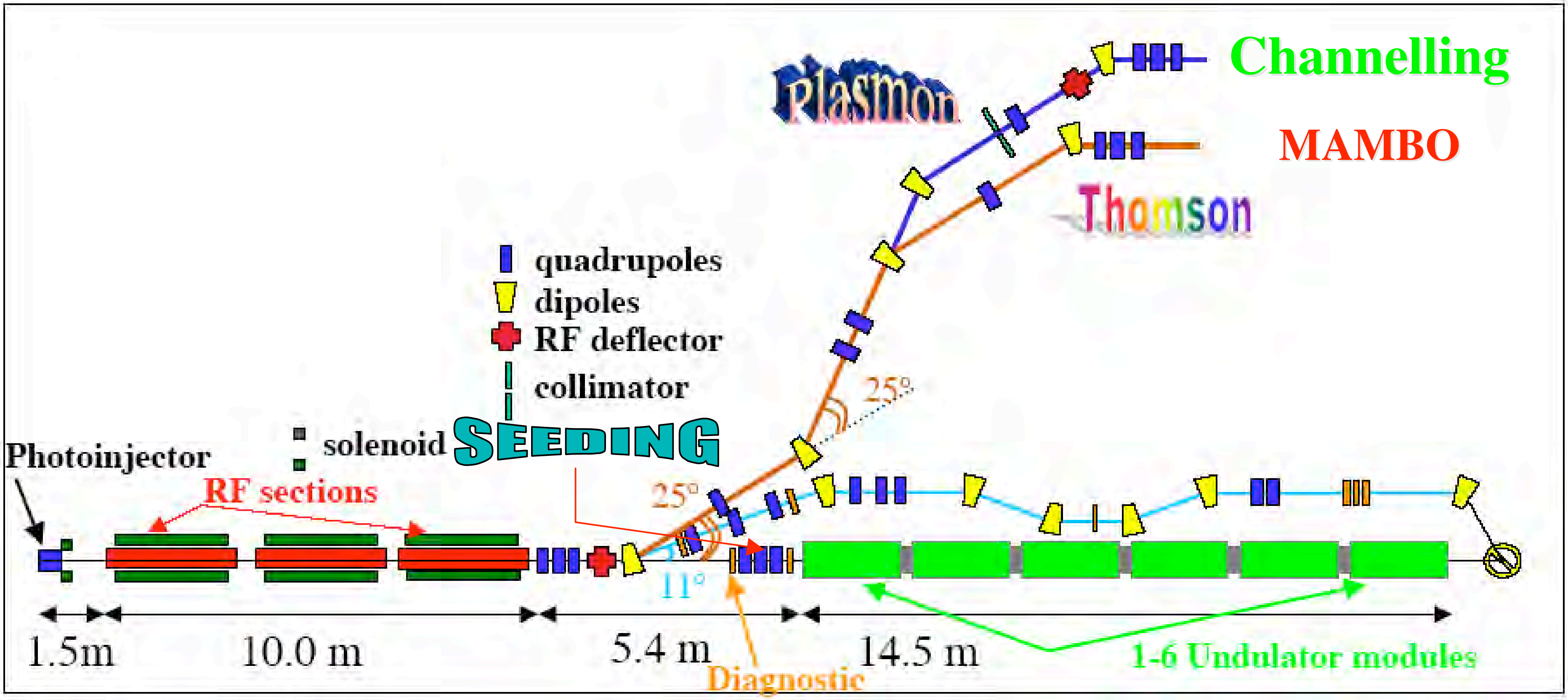
Powerful radiation source of X-rays and γ-rays:

- polarized
  - tunable
    - narrow forwarded

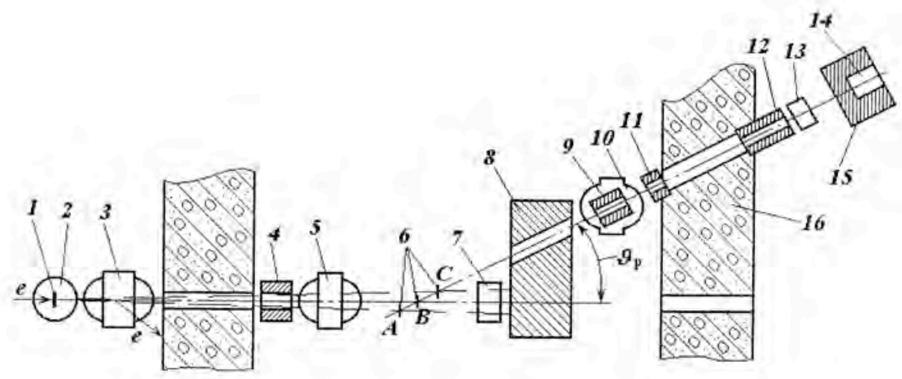




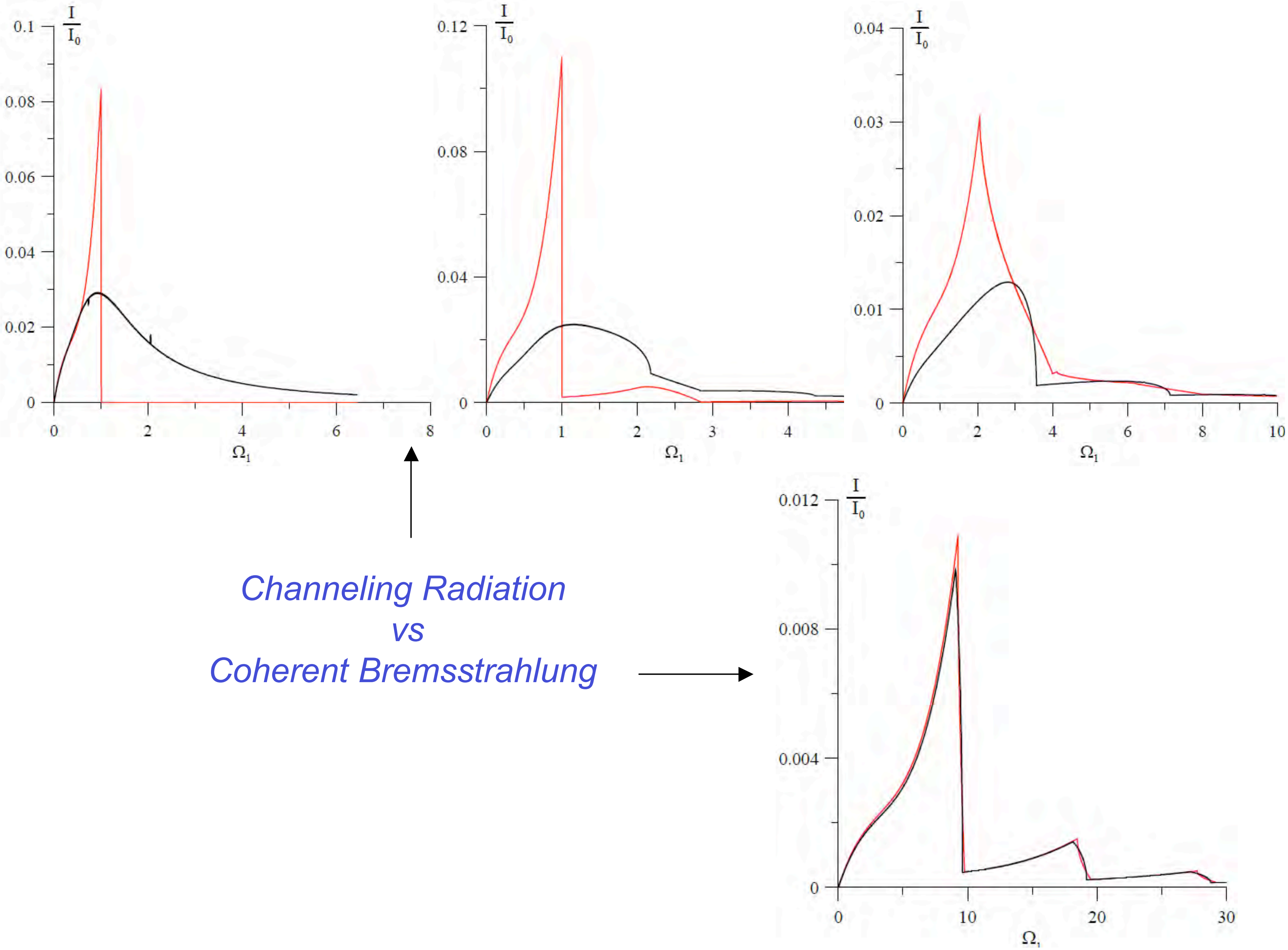
Experimental scheme



"Channeling" line layout
by Kharkov group



Calculation of ChR spectra



Channeling Radiation
vs
Coherent Bremsstrahlung

Summary of LPWA and New Schemes

1. Generation of monoenergetic electrons from a laser plasma cathode and the future applications for pulse radiolysis, Thomson scattering X-ray generation, and electron microscopy. (Kinoshita(Univ.Tokyo))

2. Preliminary Results from the UCLA/SLAC Ultra-High Gradient Cerenkov Wakefield Accelerator Experiment. (Travish(UCLA))

3. Coupling Laser Power into a Slab-Symmetric Accelerator Structure. (Yoder(Manhatten College))

4. CHANNELING projects at LNF: From Crystal Undulators to Capillary Waveguides. (Sultan Dabagov(INFN))

Thank you very much for cooperation and nice discussion
to all contributors and participants.

Applications of High Brightness Beams
gives

Many important subjects to be solved,
but also,

Many Dreams !!

Grazie!

ありがとうございます！！