Gaius Valerius Catullus, Carma 31

Paene insularum, Sirmio, insularumque
ocelle, quascumque in liquentibus stagnis
marique vasto fert uterque Neptunus,
quam te libenter quamque laetus inviso,
vix mi ipse credens Thuniam atque Bithunos
liquisse campos et videre te in tuto.
O quid solutis est beatius curis,
cum mens onus reponit, ac peregrino
labore fessi venimus larem ad nostrum,
desideratoque acquiescimus lecto?
Hoc est quod unum est pro laboribus tantis.
Salve, o venusta Sirmio, atque ero gaude
gaudente, vosque, o Lydiae lacus undae,
ridete quidquid est domi cachinnorum.

Advanced topics in the physics of Thomson/Compton scattering

Vittoria Petrillo

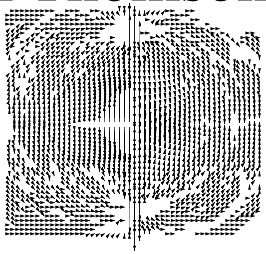
Thanks to: Cesare Maroli, Illya Drebot, Alberto Bacci, Cristina Vaccarezza, Andrea Renato Rossi, Pino Dattoli, Titti Ronsivalle, Paolo Tomassini, Camilla Curatolo, Michela Venturelli, Federico Nguyen, Anna Giribono, Alessandro Variola, Luca Serafini

And also to all the SPARC LAB and ELI-NP groups

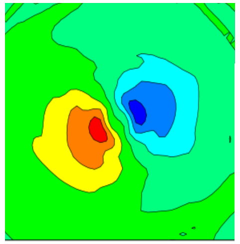
Presentation Outline

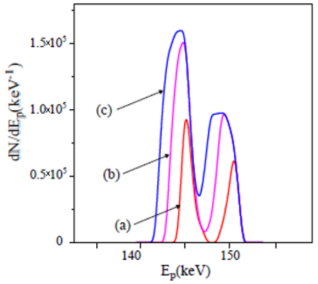
Introduction on Thomson/Compton scattering

Polarization

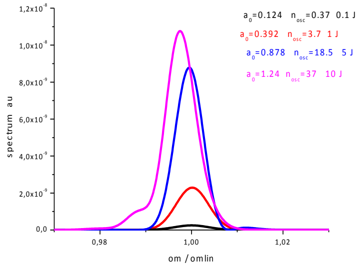


Orbital angular momentum



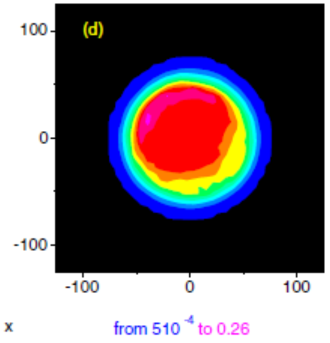


Two-color and multibunch

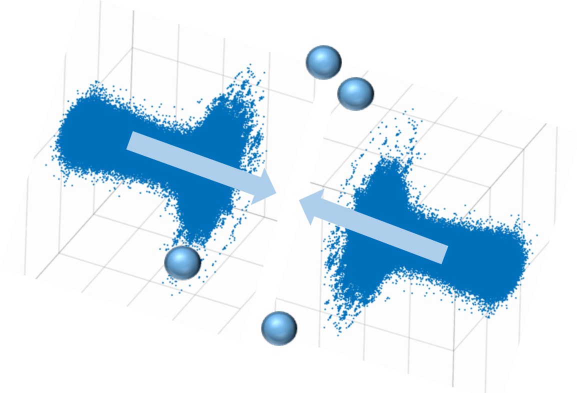


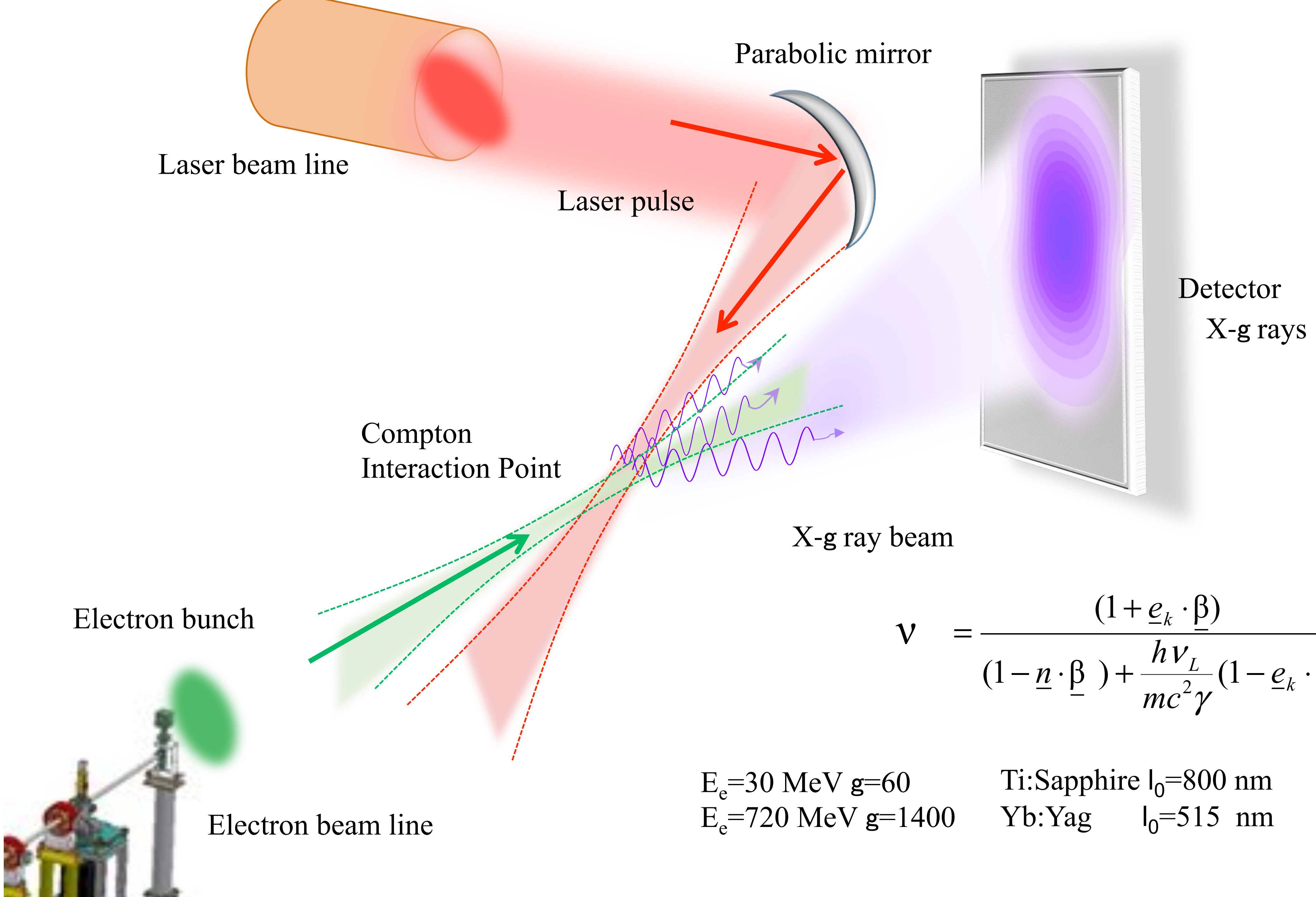
For increasing the spectral density: the chirp

For increasing spectral density, flux and coherence: the collective effects.



Gamma-gamma source





$$\nu = \frac{(1+\underline{e}_k\cdot\underline{\beta})}{(1-\underline{n}\cdot\underline{\beta}) + \frac{h\nu_L}{mc^2\gamma}(1-\underline{e}_k\cdot\underline{n})}\nu_L \approx 4\gamma^2\nu_L$$

E_e=30 MeV g=60	Ti:Sapphire l_0=800 nm	E_{ph}=22 keV
E_e=720 MeV g=1400	Yb:Yag l_0=515 nm	E_{ph}= 19 MeV

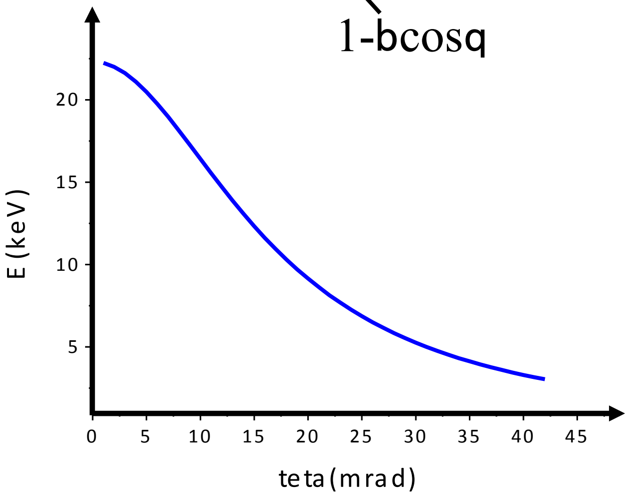
Generalities on Compton scattering

Compton radiation is frequency-angle correlated

Frequency of the radiation in a direction $\underline{n}$

$$\nu = \nu_L \frac{1-\underline{e}_k \cdot \underline{\beta}_0}{1-\underline{n}\cdot\underline{\beta}_0} \approx 4\gamma_0^{\,2}\nu_L$$

1-bcosq

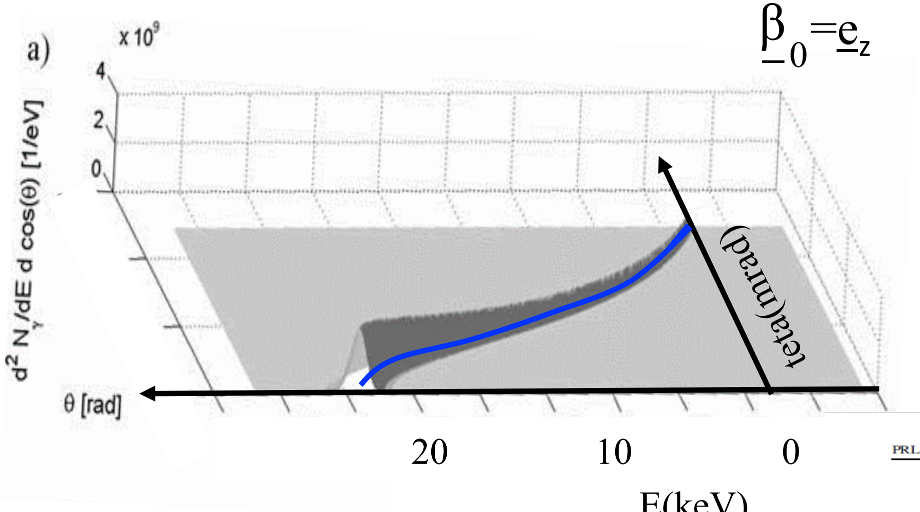


Frequency-angle correlation

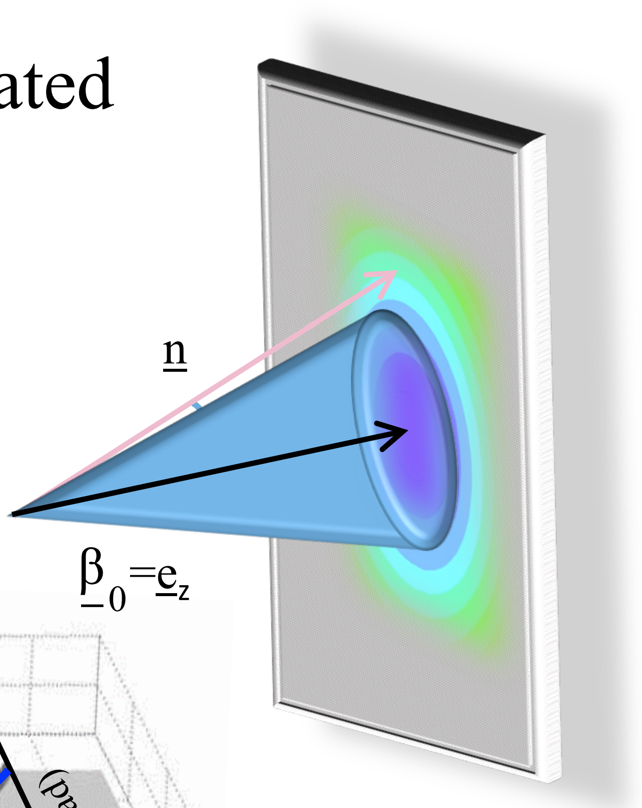
Total acceptance

$Y_{max}=gq_{max}= 1$

$q_{max}= 1/g$



Intensity in frequency-angle plane



Higher frequencies close to axis

Lower frequencies in the outer part

PRL 111, 114803 (2013) PHYSICAL REVIEW LETTERS week ending 13 SEPTEMBER 2013

High Resolution Energy-Angle Correlation Measurement of Hard X Rays from Laser-Thomson Backscattering

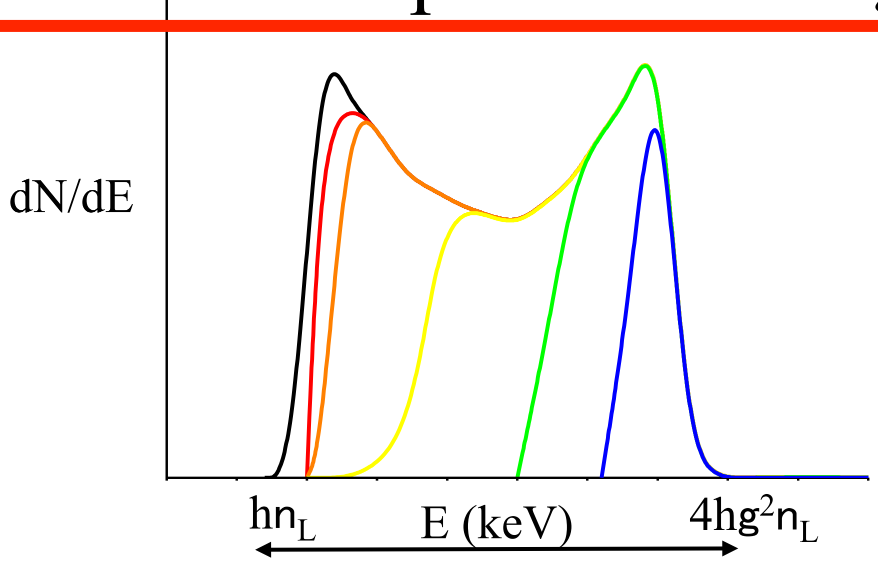
A. Jochmann,[1,2,*] A. Irman,[1] M. Bussmann,[1] J. P. Couperus,[1,2] T. E. Cowan,[1,2] A. D. Debus,[1] M. Kuntzsch,[1,2] K. W. D. Ledingham,[3] U. Lehnert,[1] R. Sauerbrey,[1,2] H. P. Schlenvoigt,[1] D. Seipt,[1,4] Th. Stöhlker,[4,5] D. B. Thorn,[5] S. Trotsenko,[4,5] A. Wagner,[1] and U. Schramm[1,2]

[1]*Institute of Radiation Physics, Helmholtz-Zentrum Dresden - Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany*
[2]*Technische Universität Dresden, 01062 Dresden, Germany*
[3]*SUPA, Strathclyde University Glasgow, UK-07743 Glasgow, United Kingdom*
[4]*Helmholtz-Institut Jena, Friedrich Schiller Universität Jena, 07743 Jena, Germany*
[5]*GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany*

(Received 6 May 2013; published 13 September 2013)

Thomson backscattering of intense laser pulses from relativistic electrons not only allows for the

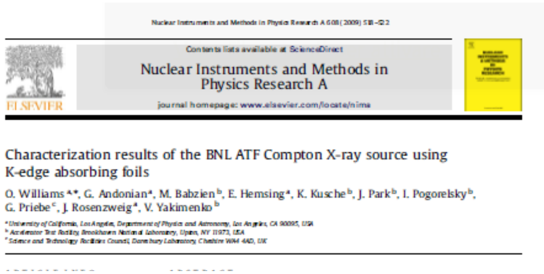
Generalities on Compton scattering



Large natural spectrum

The energy-angle correlation permits the control of bandwidth and divergence

By introducing irides or collimators one can diminish the bandwidth, by selecting the photons close to the axis

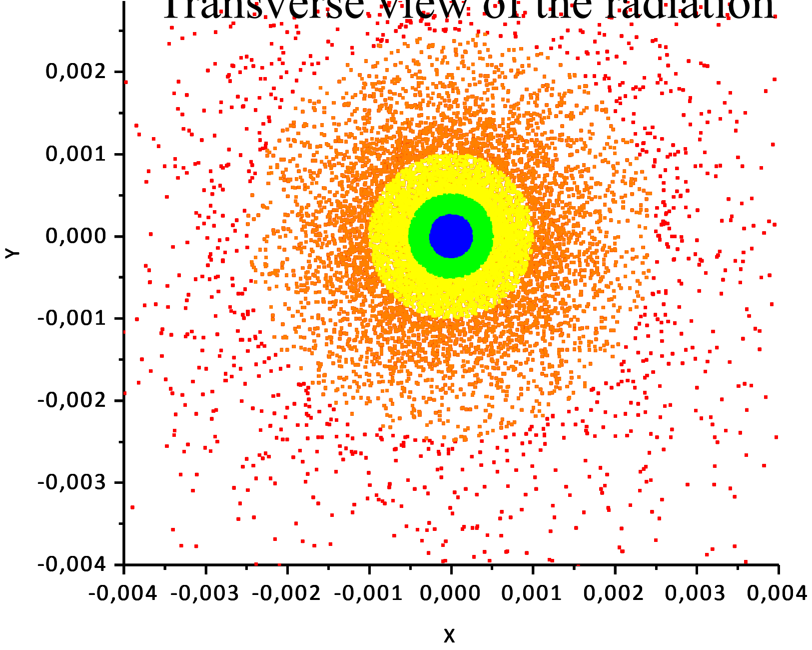


Nuclear Instruments and Methods in Physics Research A

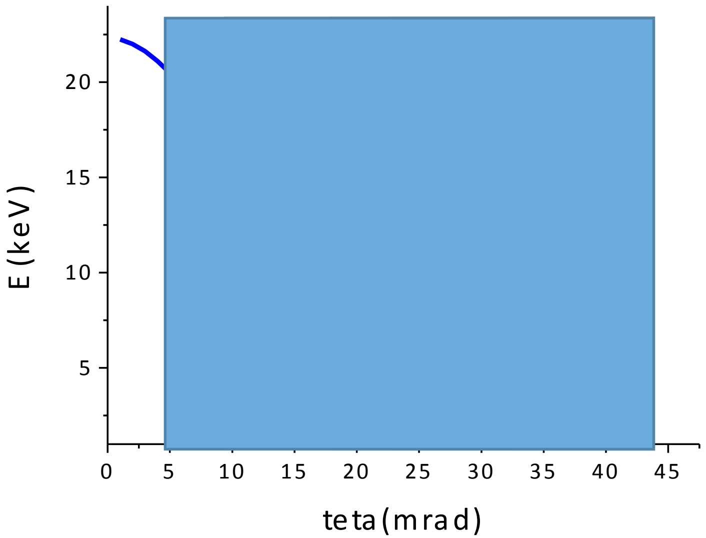
Characterization results of the BNL ATF Compton X-ray source using K-edge absorbing foils

O. Williams, G. Andonian, M. Babzien, E. Hemsing, K. Kusche, J. Park, I. Pogorelsky, G. Priebe, J. Rosenzweig, V. Yakimenko

Transverse view of the radiation



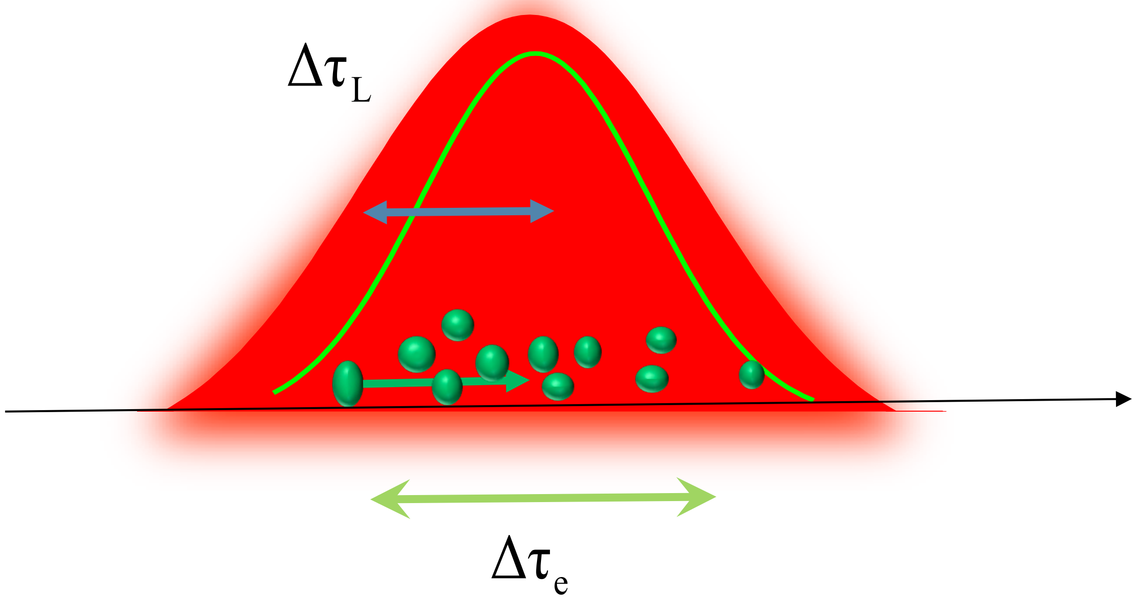
Effect of the collimator

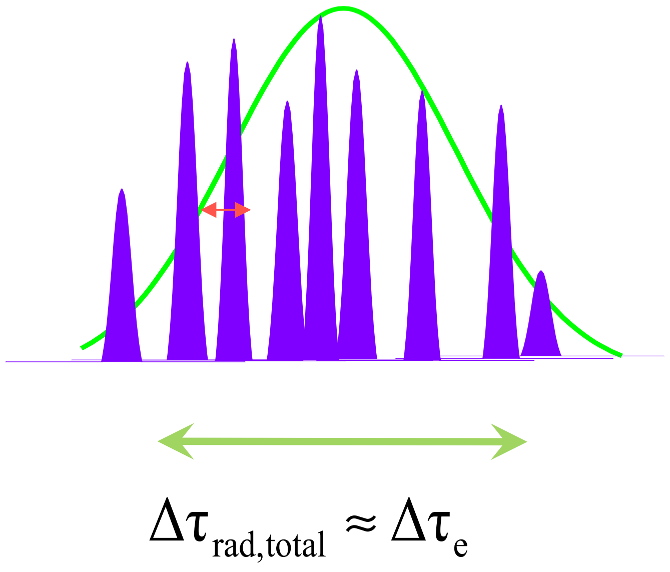


Generalities on Compton scattering

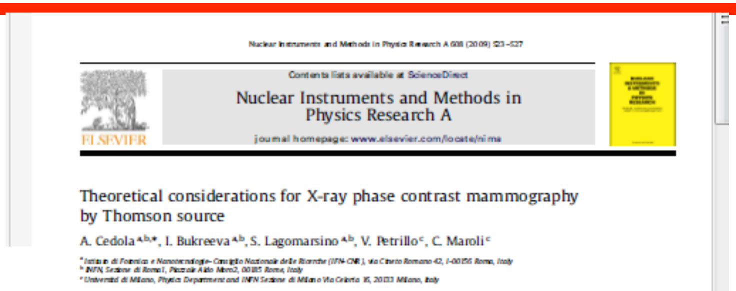
Temporal structure of the radiation

All electrons emit out of phase and the longitudinal structure of the radiation is totally incoherent





Generalities on Compton scattering



Nuclear Instruments and Methods in Physics Research A 608 (2009) S23–S27

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Theoretical considerations for X-ray phase contrast mammography by Thomson source

A. Cedola[a,b,*], I. Bukreeva[a,b], S. Lagomarsino[a,b], V. Petrillo[c], C. Maroli[c]

Transverse coherence

Transverse structure of spectral components

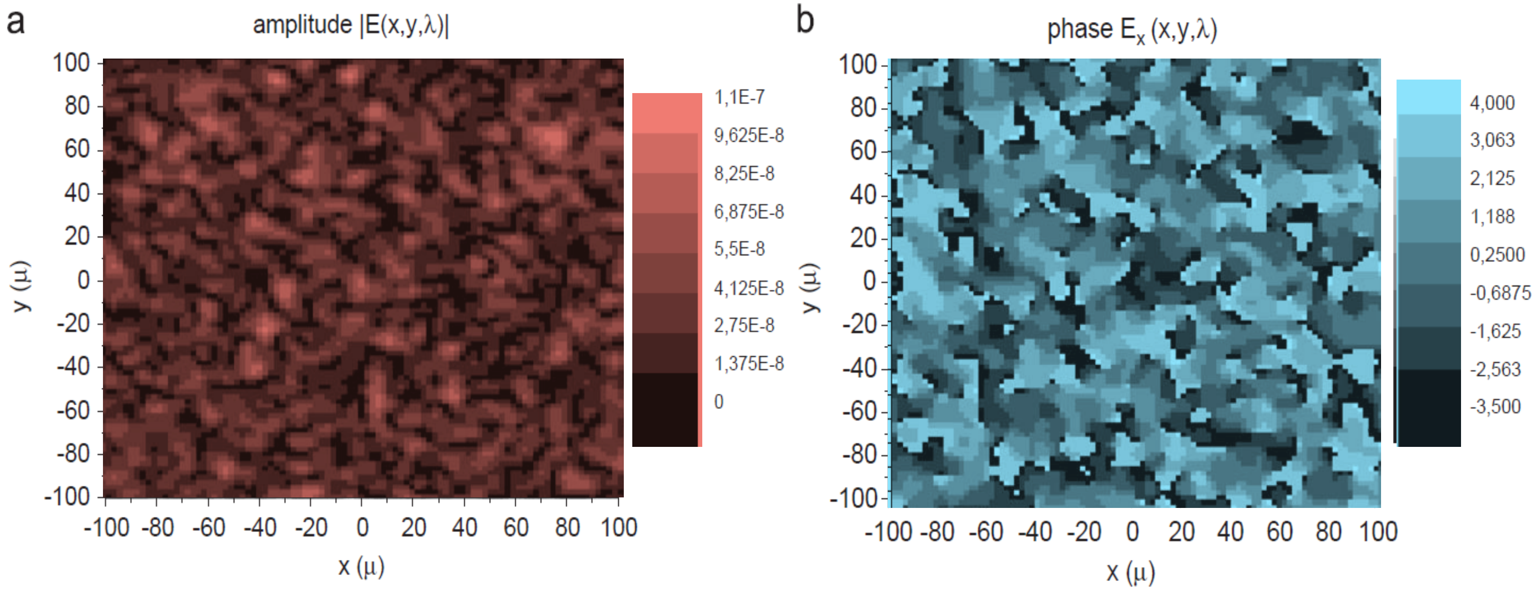


Fig. 3. Amplitude |**E**(*x*,*y*,*λ*)| (a) and phase of $E_x(x,y,\lambda)$ (b) for $\lambda = 0.7$ Å at $r = 10$ m from the source. Coordinates *x* and *y* in microns, Fourier time-transform of electric field in V s/m.

Coherence length=lR/s

E_e=30 MeV g=60
E_e=720 MeV g=1400

Ti:Sapphire l_0=800 nm
Yb:Yag l_0=515 nm

E_{ph}=22 keV
E_{ph}= 19 MeV

L=8 micron at 1 m
L = 10^{-2} micron at 1 m

Polarization

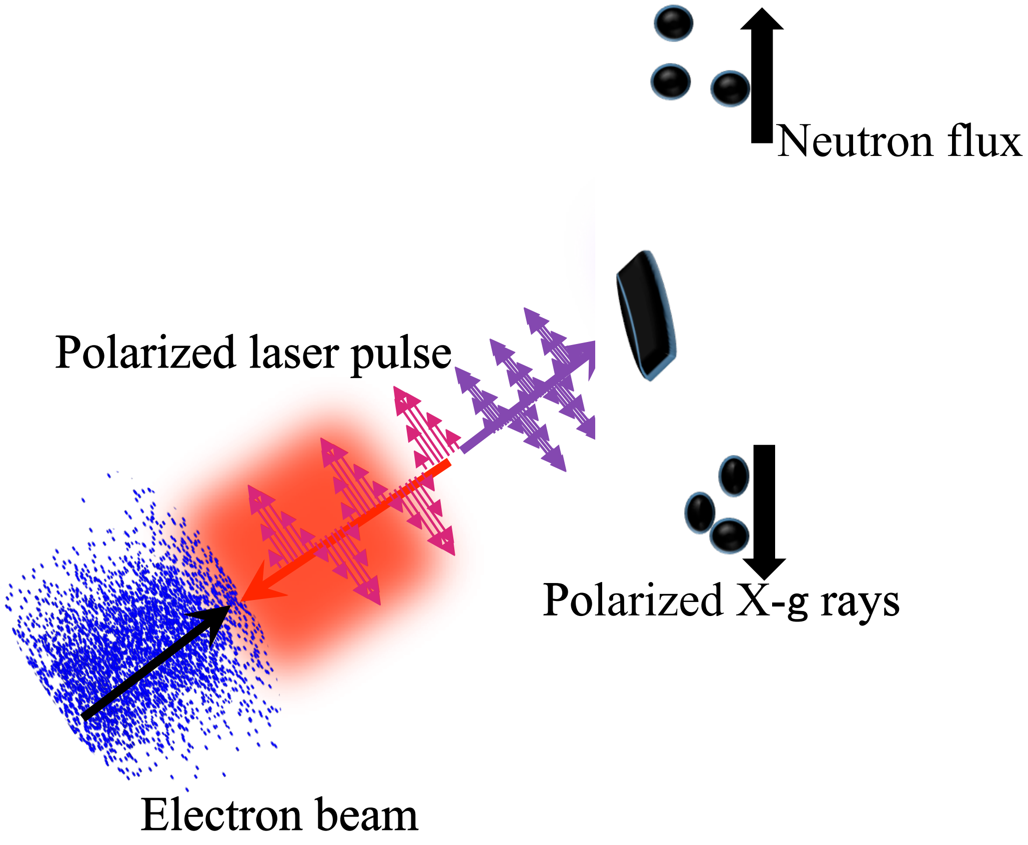
Why studying gamma ray polarization?

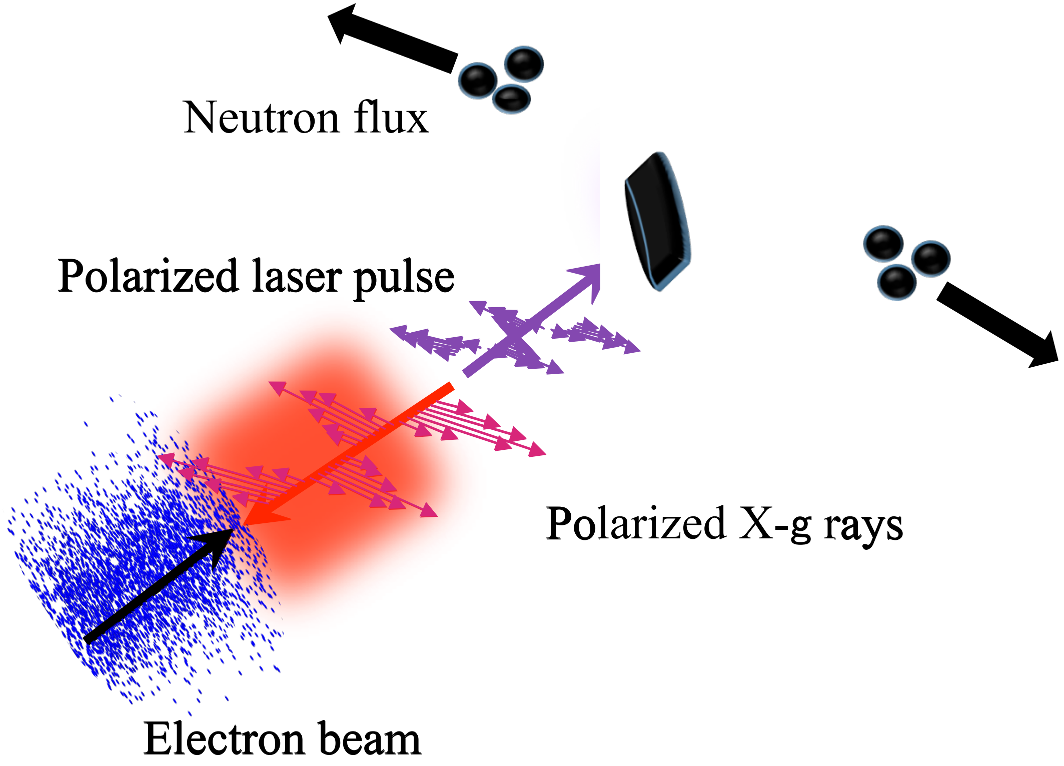
In nuclear photonics experiments, the kinematics of neutrons is strongly influenced by the polarization of the gamma rays

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **14**, 044701 (2011)

Theoretical and simulation studies of characteristics of a Compton light source

C. Sun[*,†] and Y. K. Wu
Department of Physics, Duke University, Durham, North Carolina 27708-0305, USA
and DFELL, Triangle Universities Nuclear Laboratory, Durham, North Carolina 27708-0308, USA
(Received 25 January 2011; published 21 April 2011)





Polarization: ELI-NP case

PHYSICAL REVIEW SPECIAL TOPICS—ACCELERATORS AND BEAMS **18**, 110701 (2015)

Polarization of x-gamma radiation produced by a Thomson and Compton inverse scattering

V. Petrillo,[1,2] A. Bacci,[2] C. Curatolo,[1,2] I. Drebot,[2] A. Giribono,[4] C. Maroli,[1] A. R. Rossi,[2] L. Serafini,[2] P. Tomassini,[1] C. Vaccarezza,[3] and A. Variola[3]
[1]*Università degli Studi di Milano, via Celoria 16, 20133 Milano, Italy*
[2]*INFN-Sezione di Milano, via Celoria 16, 20133 Milano, Italy*
[3]*INFN Laboratori Nazionali di Frascati,Via E. Fermi 44, 00044 Frascati, Roma, Italy*
[4]*Università La Sapienza, Via Antonio Scarpa, 14 00161 Roma, Italy and INFN-Roma1, Piazzale Aldo Moro, 2 00161 Rome, Italy*
(Received 24 June 2015; published 19 November 2015)

ELI-NP Parameters

E=234-529 MeV
Q=250 pC
e=0.5 mm mrad
DE/E=7 10^{-4}
l=520 nm
E_L=0.2-0.4 J
d=8°
w_0=28 mm
E_{ph}=2-10 MeV

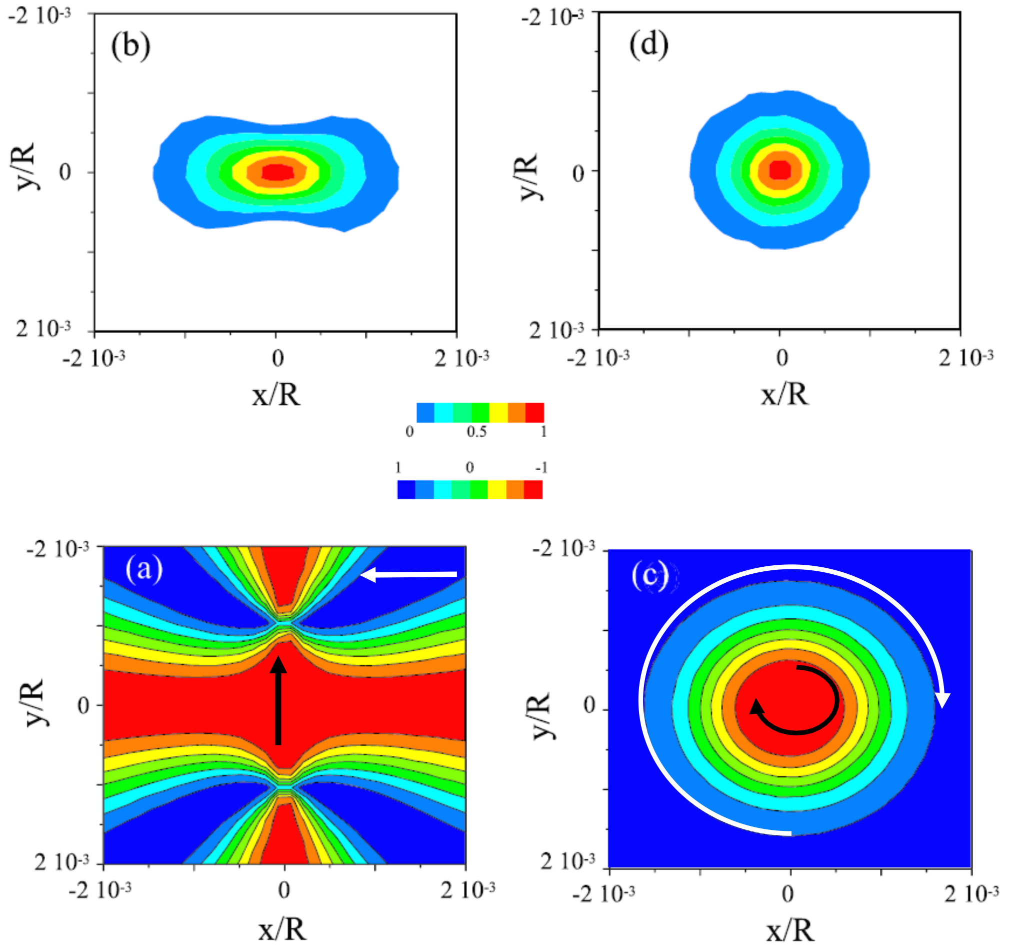
Total intensity I
on the screen at 1 m
E_{ph}=10 MeV

Stokes parameter

$$\frac{(|E_x|^2-|E_y|^2)}{(|E_x|^2+|E_y|^2)}$$

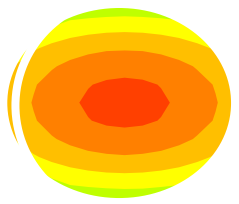
Linear polarization of the laser

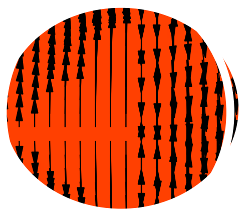
Circular polarization of the laser



Polarization: ELI-NP case

With a **linear polarization** of the laser:





Total intensity

Stokes parameter

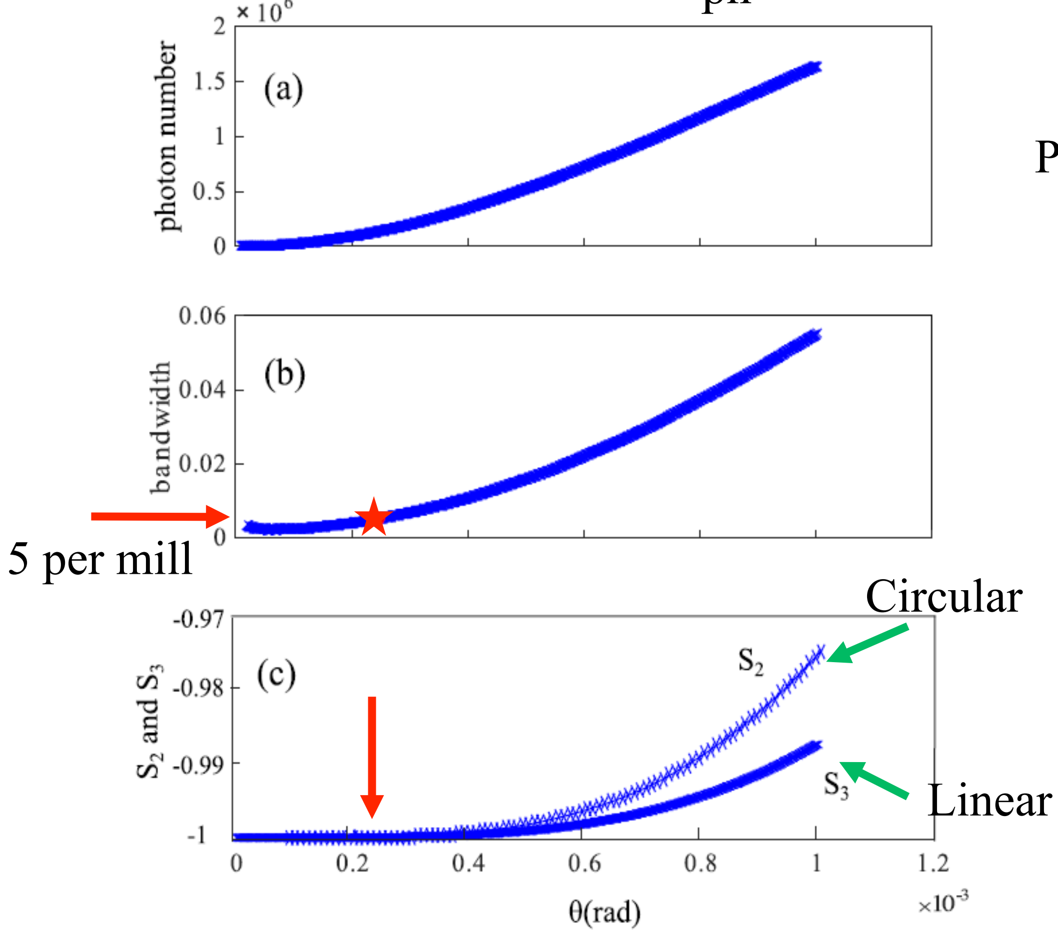
$(|E_x|^2-|E_y|^2)/(|E_x|^2-|E_y|^2)$

on the screen at 1 m,
the circle is 1/g

Polarization: ELI-NP case, calculations by Illya Drebot

E=235 MeV E_{ph}=2 MeV

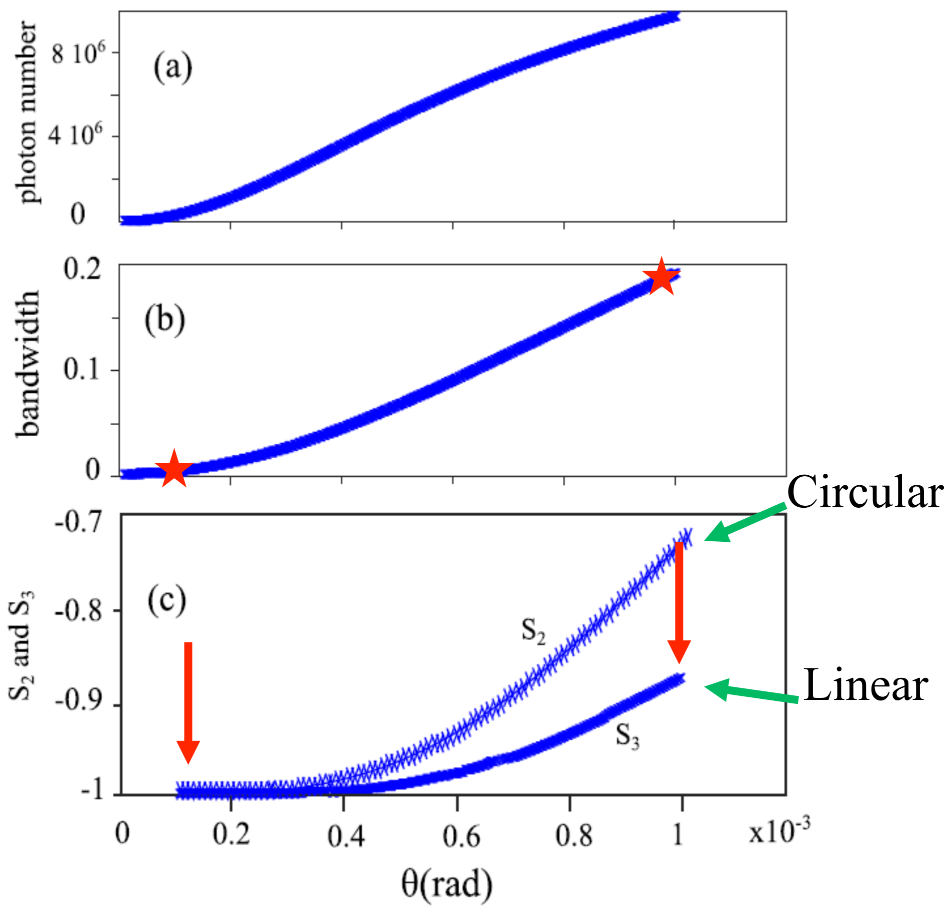
E=530 MeV E_{ph}=10 MeV



Photon number

Bandwidth

Polarization



Bandwidth 5 per mill Polarization 100%

Bandwidth 20 % Polarization 85-70%

ELI-NP e-beam optimized in emittance

Polarization: typical plasma accelerated beam

NATURE PHOTONICS | LETTER

All-optical Compton gamma-ray source

K. Ta Phuoc, S. Corde, C. Thaury, V. Malka, A. Tafzi, J. P. Goddet, R. C. Shah, S. Sebban & A. Rousse

Affiliations | Contributions | Corresponding authors

Nature Photonics 6, 308–311 (2012) | doi:10.1038/nphoton.2012.82
Received 15 November 2011 | Accepted 16 March 2012 | Published online 22 April 2012

Q=120 pC
e=1 mm mrad
s=1.5 mm
DE/E=1 10^{-2}
l=520 nm
E_L=0.2-0.4 J
d=8°
w_0=28 mm
E_{ph}=2-10 MeV

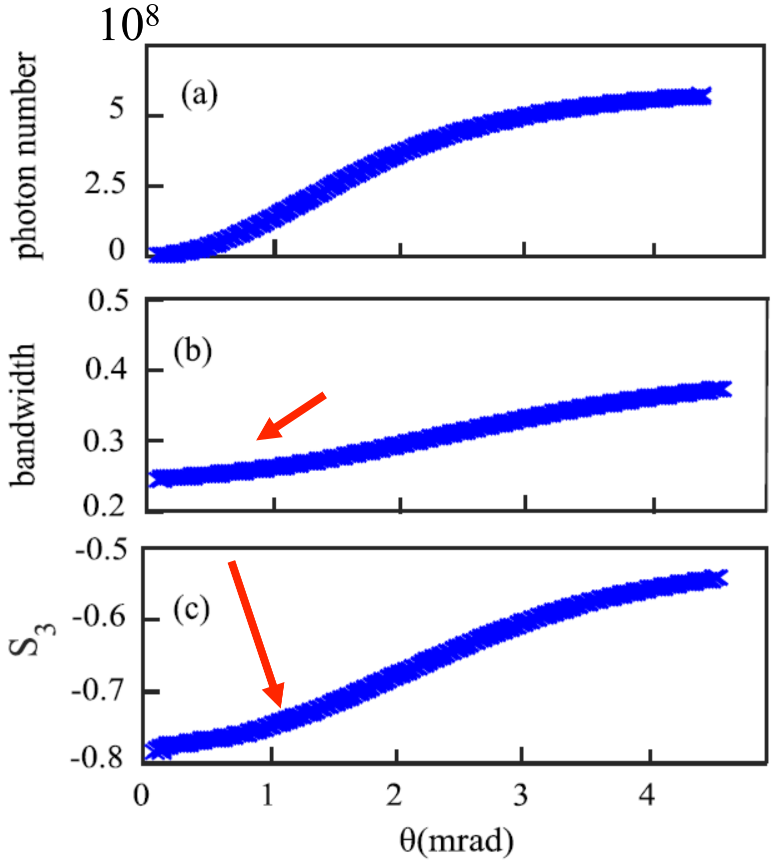
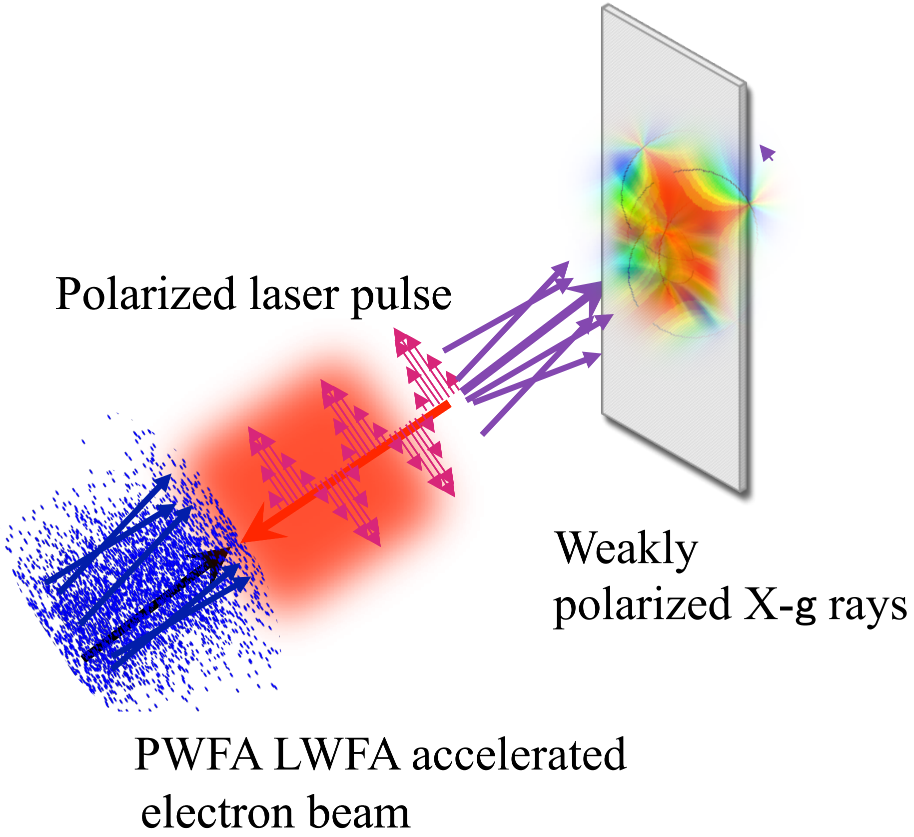


FIG. 10. (a) Photon flux, (b) bandwidth, and (c) Stokes parameter S_3 vs acceptance angle for a typical plasma beam.

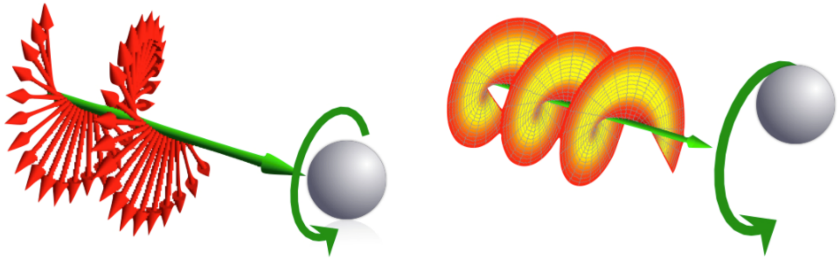


Bandwidth > 25%, polarization <0.75

Orbital Angular Momentum (OAM)

Why studying radiation with orbital angular momentum?

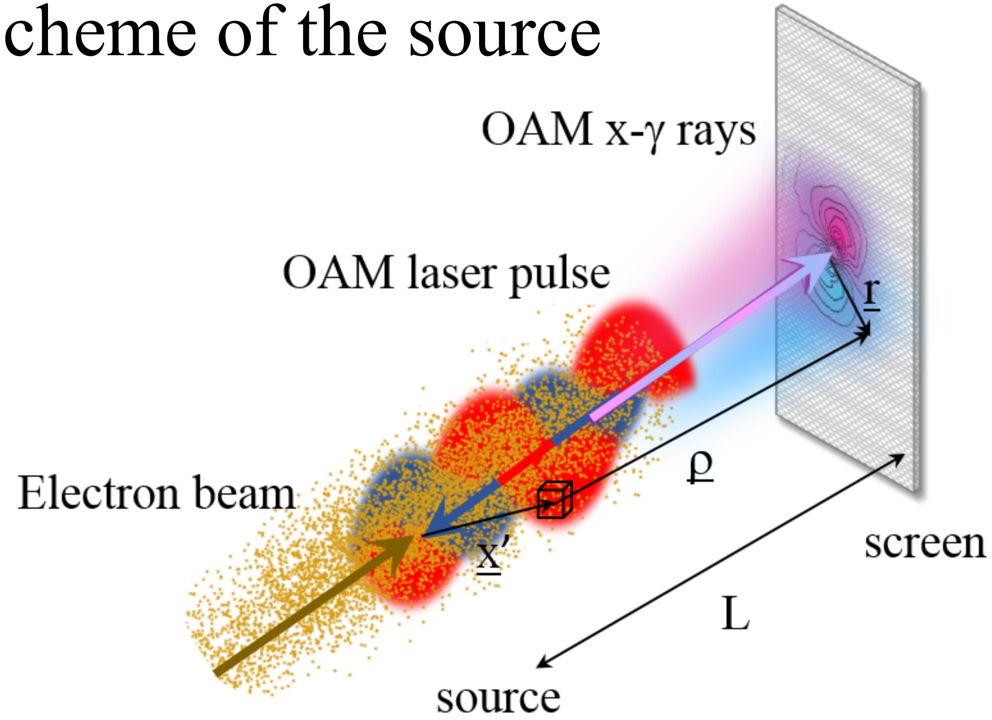
In exp. of photoinization forbidden decays can be excited, molecules in rotational states can resonate in vortex,dipolar and quadrupolar transition can be distinguished.



Spin Ang Mom interaction   Orb Ang Mom interaction

s= ½ħ   j=s+ mħ

Scheme of the source



'Wild type' electron beam generated by linac

Proposals for OAM X-beams are based on manipulation of electrons in FEL emission. The electrons are treated in such a way that they carry OAM and tranfer it to the radiation.

Compton Scattered X-Gamma Rays with Orbital Momentum
V. Petrillo, G. Dattoli, I. Drebot, and F. Nguyen
Phys. Rev. Lett. **117**, 123903 (2016) – Published 16 September 2016
Show Abstract

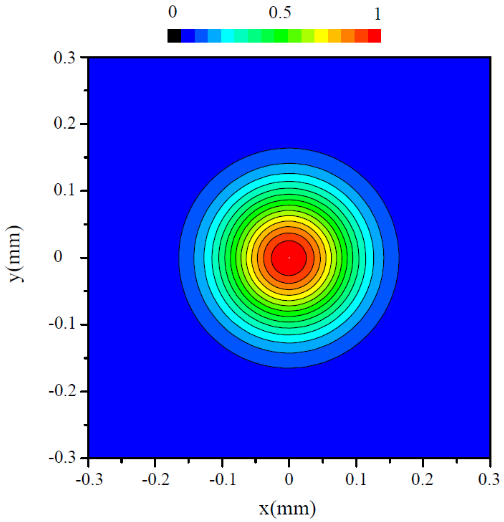
Orbital Angular Momentum, laser structure

Expression and propagation of an OAM laser mode

L. Allen, M. W. Beijersbergen, R. J. C. Spreeuw, and J. P. Woerdman, Phys. Rev. A **45**, 8185 (1992).

$$\underline{\tilde{E}}_L(x,y,z,t) = \underline{e}_y f(z+ct) E_m(x,y,z) e^{i(\omega t + k_z z)}$$

$$E_m(x,y,z) = \pi \left(\frac{w_0}{w_z}\right)^2 H_m(\xi,\alpha) e^{-\frac{x^2+y^2}{2w_z^2}}$$



$$H_m(\xi,\alpha) = m! \sum_{r=0}^{[m/2]} \frac{\alpha^r \xi^{m-2r}}{r!(m-2r)!}$$

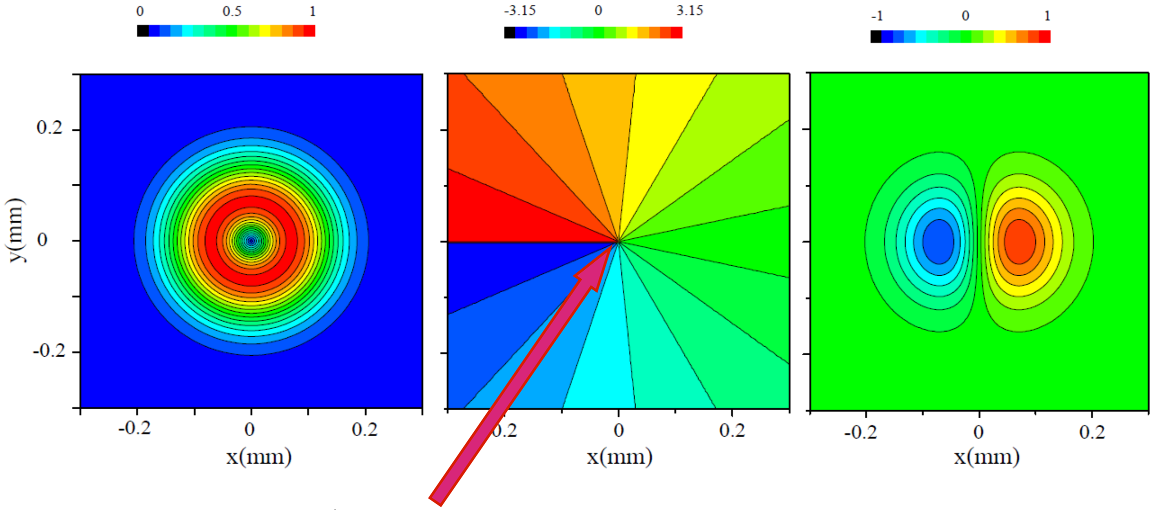
Gaussian mode

Transverse shape of a laser with OAM, intensity, phase and real part

m=1, $x_0=y_0=0$

$$\xi = \frac{1}{w_0}\left[\left(\frac{w_0}{w_z}\right)^2(x+i\varepsilon y) - (x_0 + i\varepsilon y_0)\right]$$

$$\alpha = \frac{i}{2}(1-\varepsilon^2)\frac{\lambda z}{w_z^2}.$$

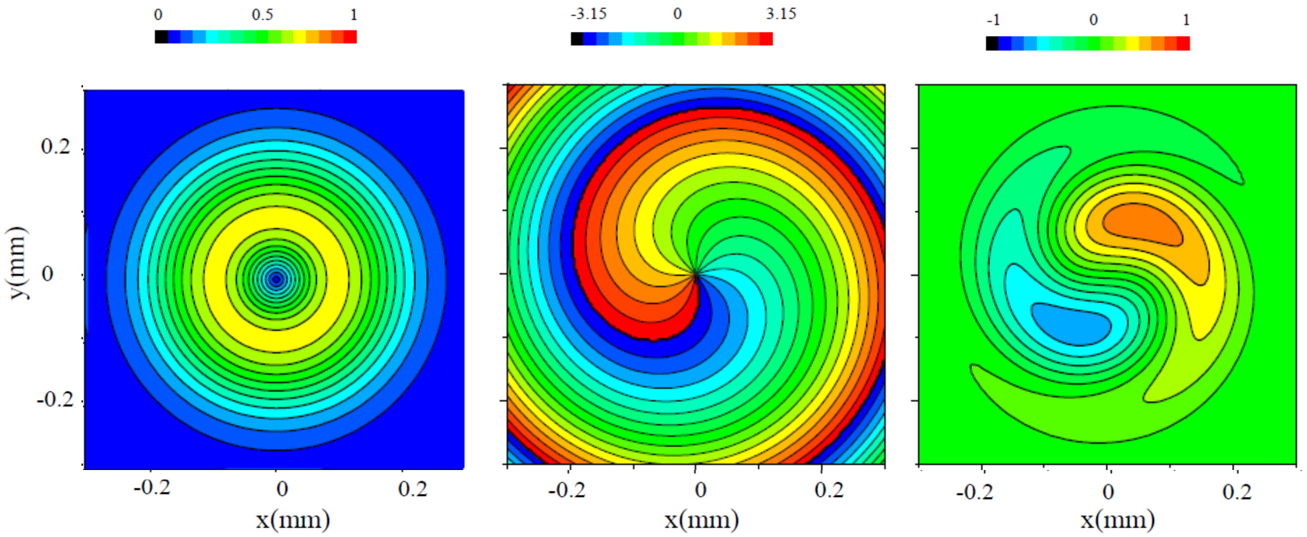


vortex

OAM laser modes are generated with fork holograms or phase masks

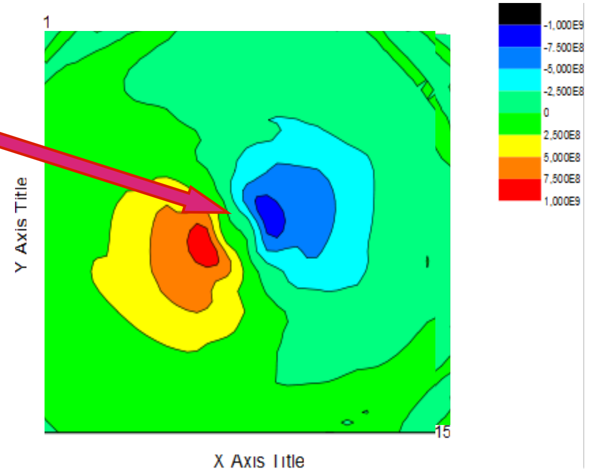
Orbital Angular Momentum, radiation calculation

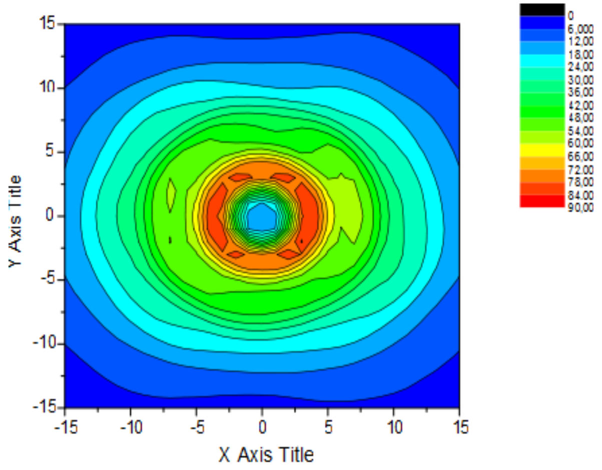
Propagation of the laser:



X radiation the screen, classical treatment:

vortex





Lienard-Wiechert electric field:

$$\underline{E} = \frac{e}{c}\sum_j \left[\frac{\underline{n} \times ((\underline{n} - \underline{\beta}_j) \times \dot{\underline{\beta}}_j)}{(1 - \underline{\beta}_j \cdot \underline{n})^3 R} \right]_{ret}$$

$$\dot{\underline{\beta}}_j = -\frac{e}{mc\gamma_j} \boxed{\underline{E}_L} \left(1 - \underline{\beta}_j \cdot \underline{e}_k\right) + \quad + \underline{\beta}_j \cdot \boxed{\underline{E}_L} \left(\underline{e}_k - \underline{\beta}_j\right)]$$

Quantum treatment:

Generation of High–Energy Photons with Large Orbital Angular Momentum by Compton Backscattering

U. D. Jentschura[1,2] and V. G. Serbo[2,3]

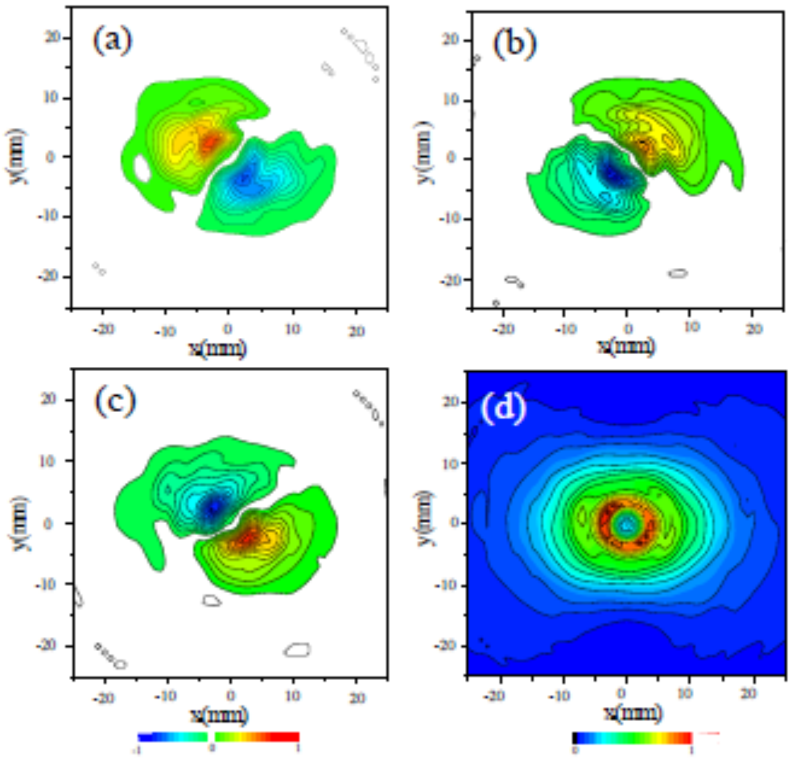
[1]Department of Physics, Missouri University of Science and Technology, Rolla, Missouri 65409, USA
[2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany
[3]Novosibirsk State University, Pirogova 2, 630090, Novosibirsk, Russia

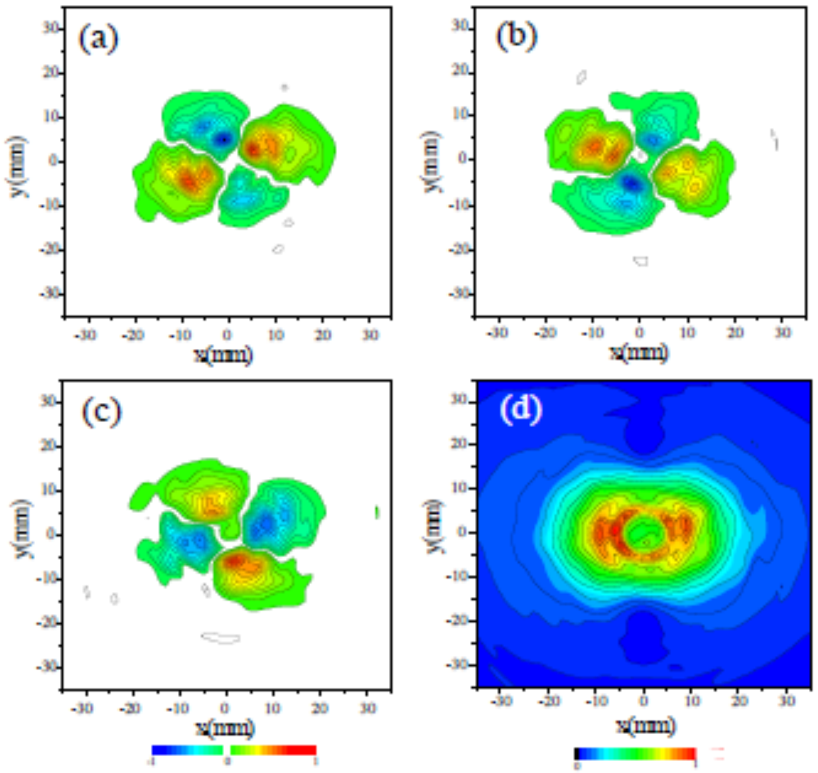
cattering of twisted light: angular distribution and polarization of scattered photons

S. Stock,[1,2,*] A. Surzhykov,[1] S. Fritzsche,[1,2] and D. Seipt[1,†]

[1]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany
ich-Schiller-Universität Jena, Theoretisch-Physikalisches Institut, 07743 Jena, Germany

Orbital Angular Momentum, radiation structure

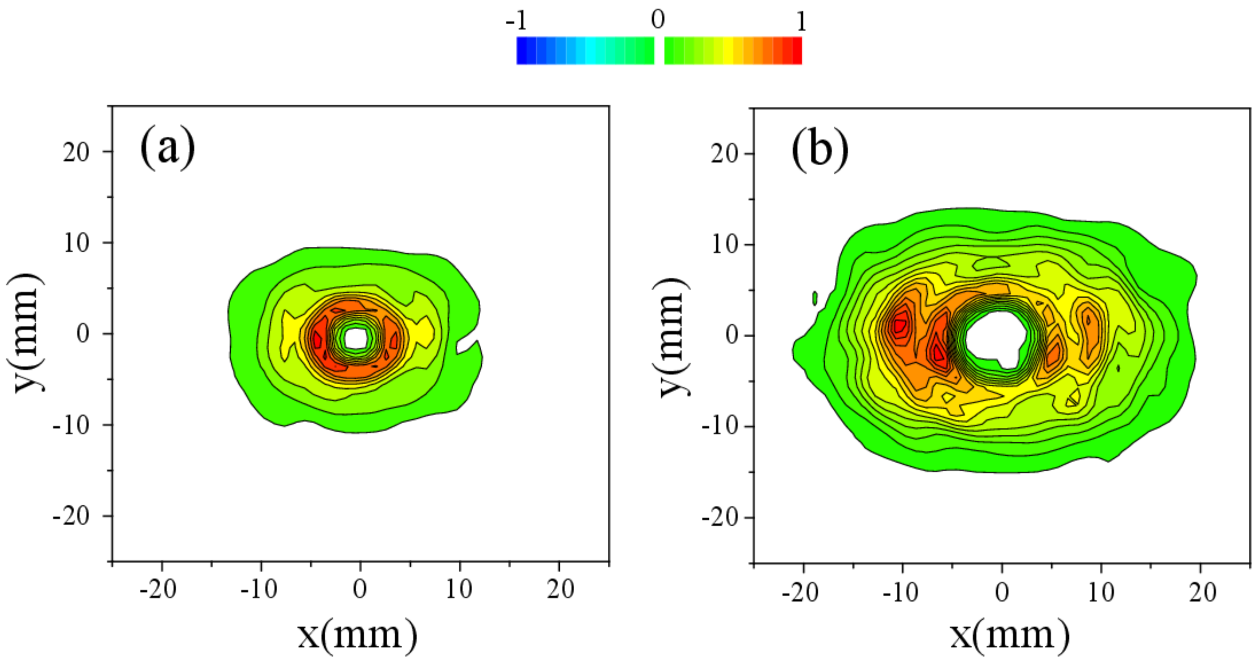




Electric field at different time and averaged intensity on the screen

m=1 m=2

Orbital Angular Momentum



Orbital Angular Momentum on the screen

m=1 m=2

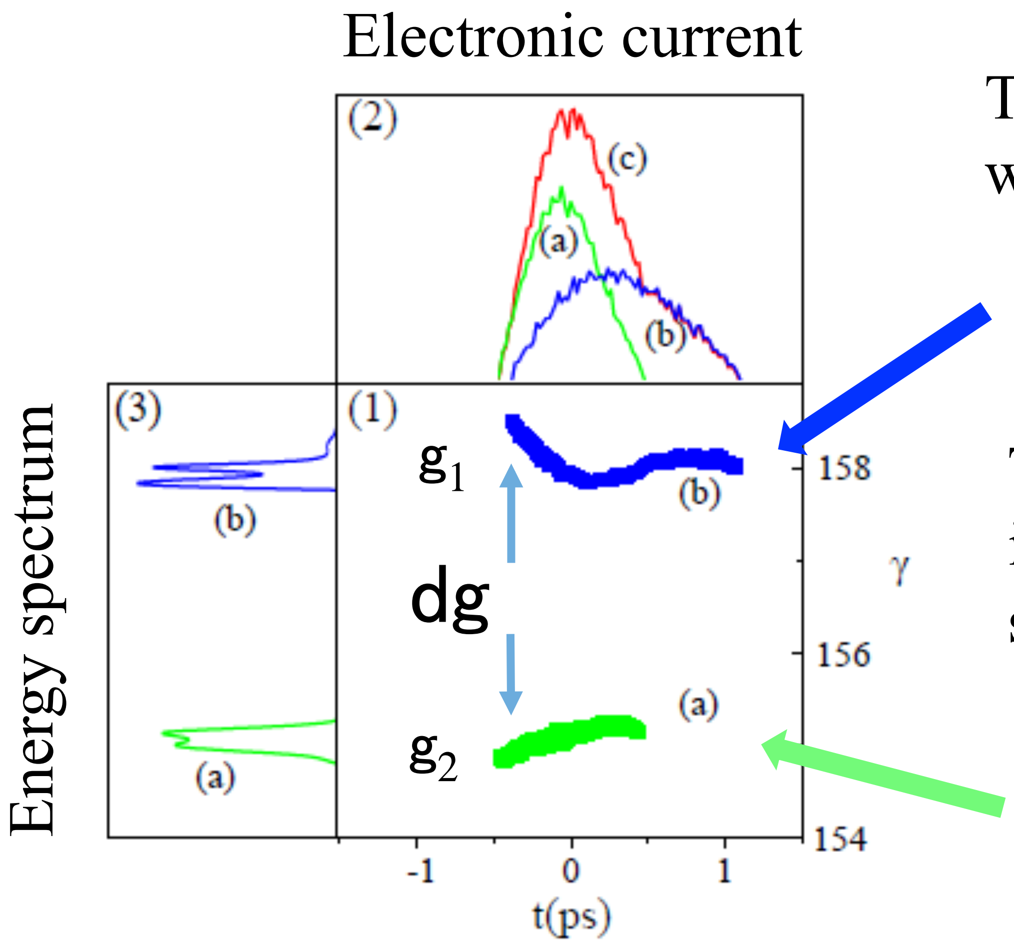
N_{ph}= 6 10^6
E_{ph}= 8 keV

$$\frac{dL_z^{OM,rad}}{dV} \approx \frac{m}{4\pi\omega} |E_y|^2$$

$$L_z^{OM,rad} = 1.7 \times 10^{-27} \text{ J·s}$$

Electron Energy	25 MeV
Electron Charge	1 nC
Electron Radius	0.1 mm
Electron Length	1 mm
Laser wavelength	800 nm
Laser energy	1 J
Laser waist	0.02 mm
Laser duration	1 ps
Repetition rate	10 Hz

Two color with a two energy e-beam



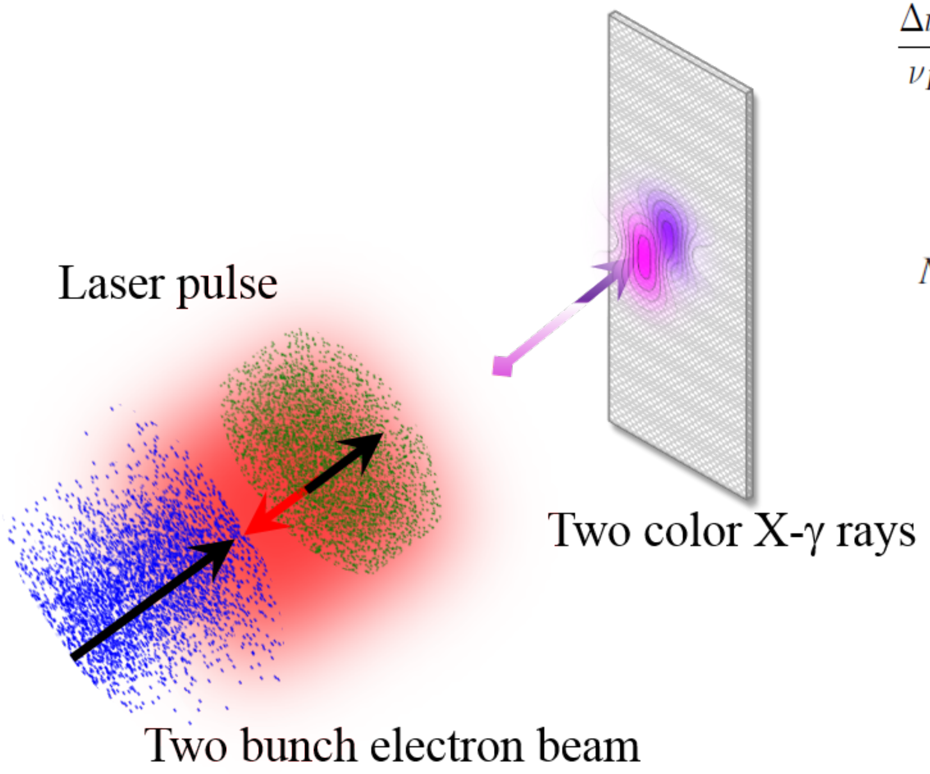
Typical electron phase space of an e-beam with two energies

$n_{p,1}=4n_L g_1^2$

The total radiation spectrum is the superposition of the spectra of the two beamlets

$n_{p,2}=4n_L g_2^2$

Two color: condition on acceptance Y=qg

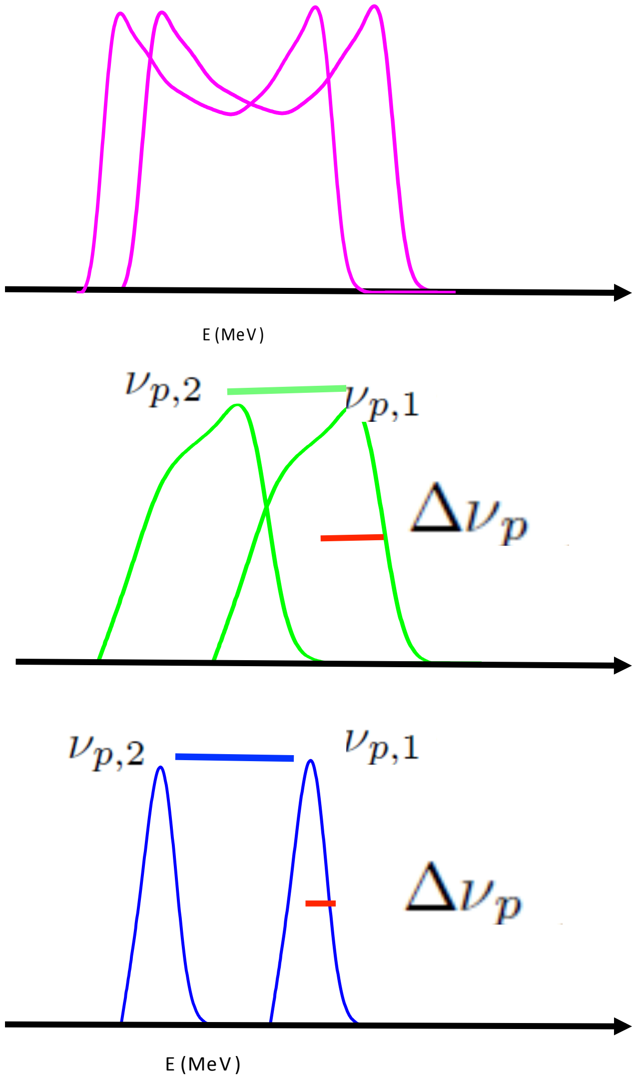


$$\frac{\Delta\nu_p}{\nu_P} \approx \sqrt{0.09\Psi^4_{max} + \left[\frac{\epsilon_n}{\sigma_x}\right]^4 + \left[\frac{\Delta\gamma}{\gamma}\right]^2 + \left[\frac{\Delta\nu_p}{\nu_P}\right]^2_L}$$

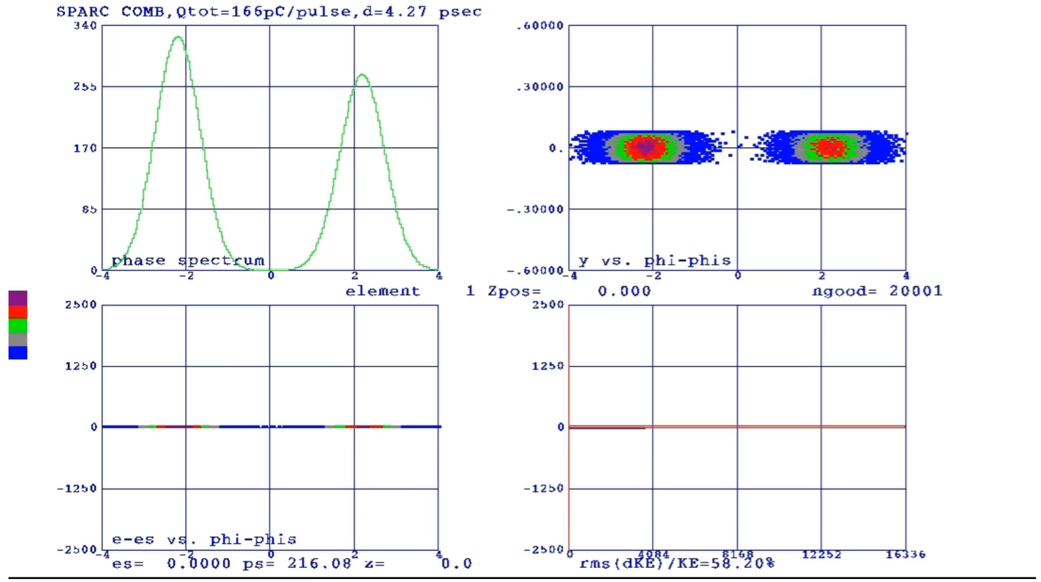
$$N \approx \frac{2\ 10^8 E_L Q \Psi^2_{max}}{h\nu_L \sigma_x^2}$$

$$\frac{2|\delta\gamma|}{<\gamma>} \geq \left[\frac{\Delta\nu_p}{\nu_p}\right]_{FWHM}$$

$$\frac{2|\delta\gamma|}{<\gamma>} \geq 0.68\Psi^2_{max}$$



Two color: TSTEP simulation



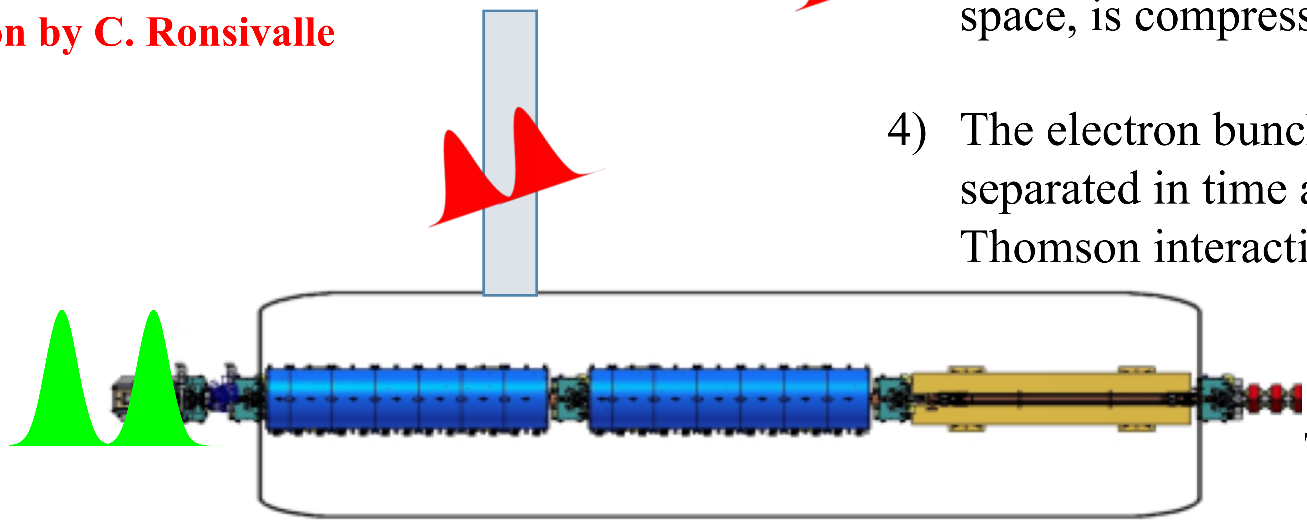
TSTEP simulation by C. Ronsivalle

1) Generation of a combed laser pulse by passing the Ti:Sapphire pulse through a birefringent crystal that decomposes the two orthogonal polarizations and introduces a time delay of few ps between them.

2) The combed radiation illuminates the cathode and extracts an electron packet with two beamlets.

3) The electron bunch is injected in the linac for velocity bunching (injection off crest) and, rotating in the phase space, is compressed and accelerated.

4) The electron bunch, composed by two beamlets differently separated in time and energy, could be transported to the Thomson interaction point (IP).



To the Thomson IP

Two color: e-beam data, experiment at SPARC_LAB

Combination of multipulse laser techiques and velocity bunching in the linac

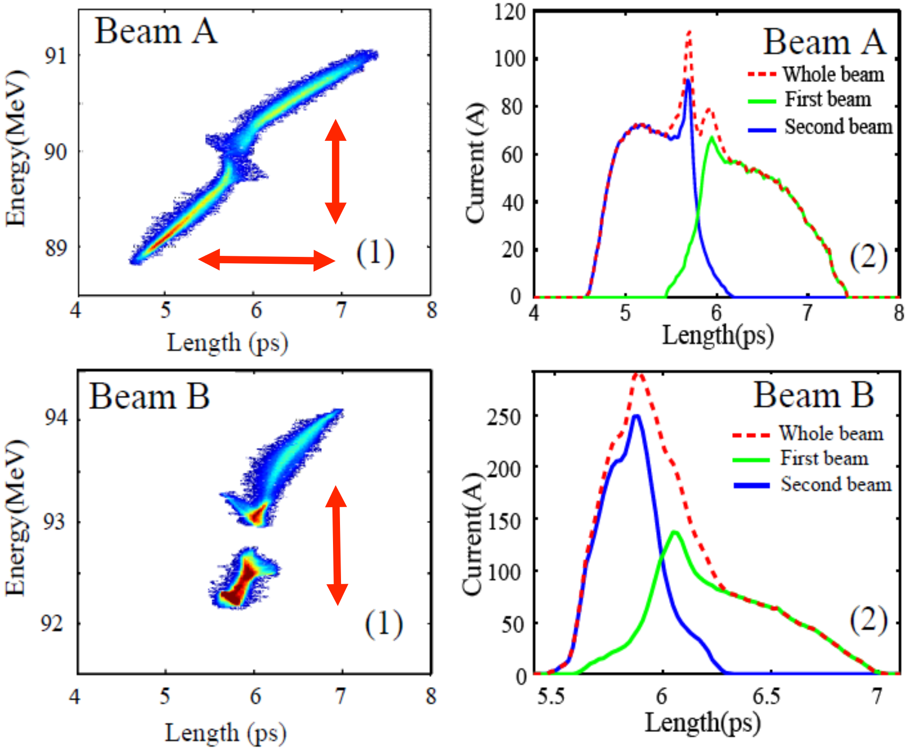
Whole beam

	Beam A	Beam B
Energy	90 MeV	93 MeV
Charge	150 pC	160 pC
Current	120 A	300 A
Energy spread	0.6%	0.6%
Emittance	1.6 mm mrad	1.7 mm mrad
Duration	630 fs	300 fs

Single bunch

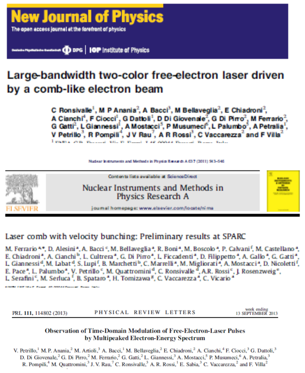
Energy separation	**1.01 MeV**	**1.1 MeV**
Time separation	0.7 ps	0.4 ps
Energy spread	0.2%	0.3%
Duration Dt	250-400 fs	100-250 fs

Data from SPARC_LAB experiments



Over compression

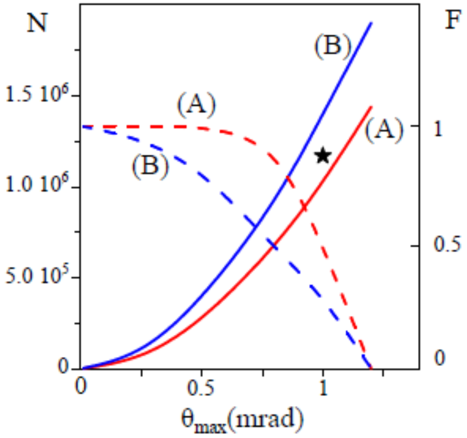
Maximum compression

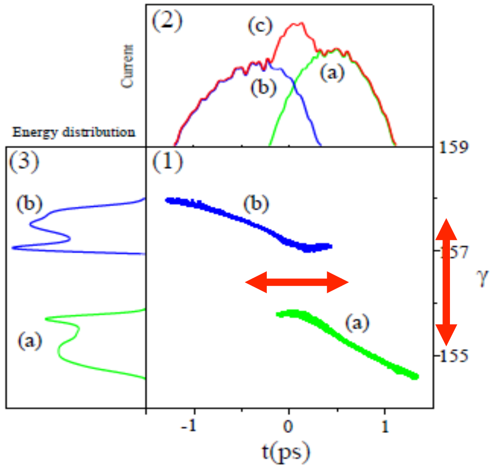


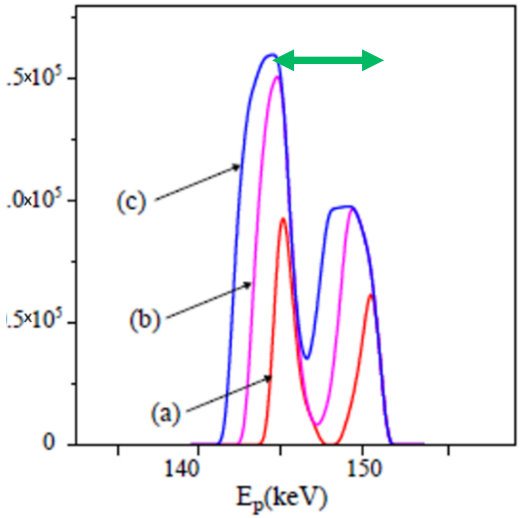
Two color: X rays spectra

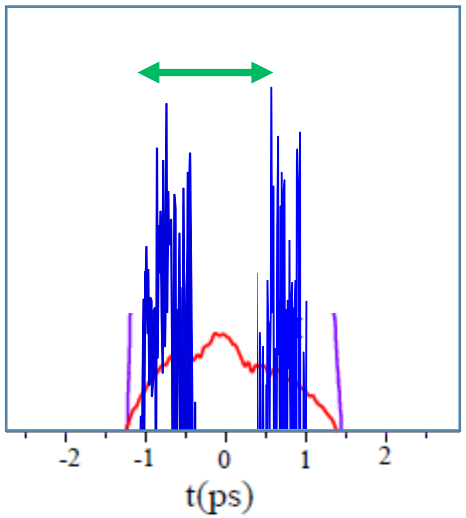
Spectral domain

Time domain



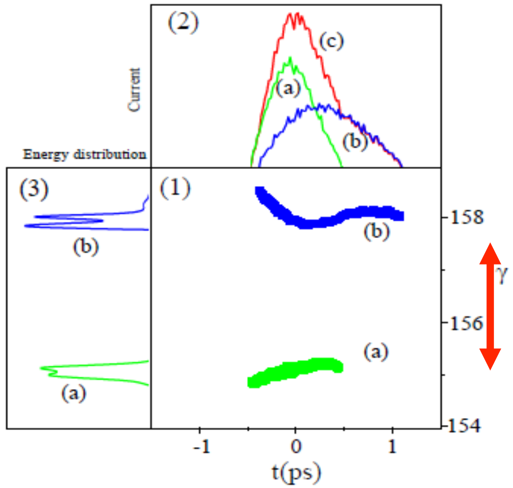


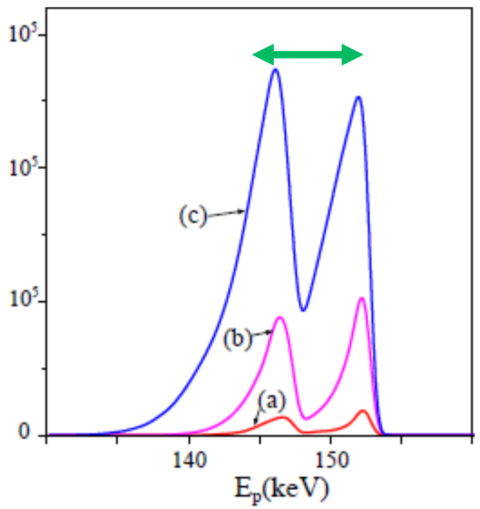


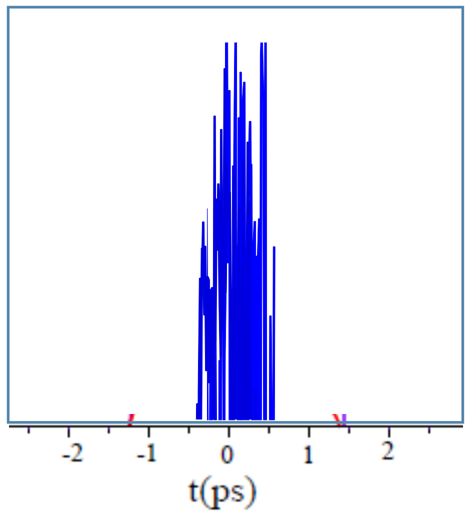


Laser energy	**1 J**
Waist	**25 mm**
Time duration	**4 ps**
Wavelength	**800 nm**

Photon energy	**150 KeV**
Photon number	**1.5 10^6**
Angle	**<1 mrad**
Visibility	**>80%**

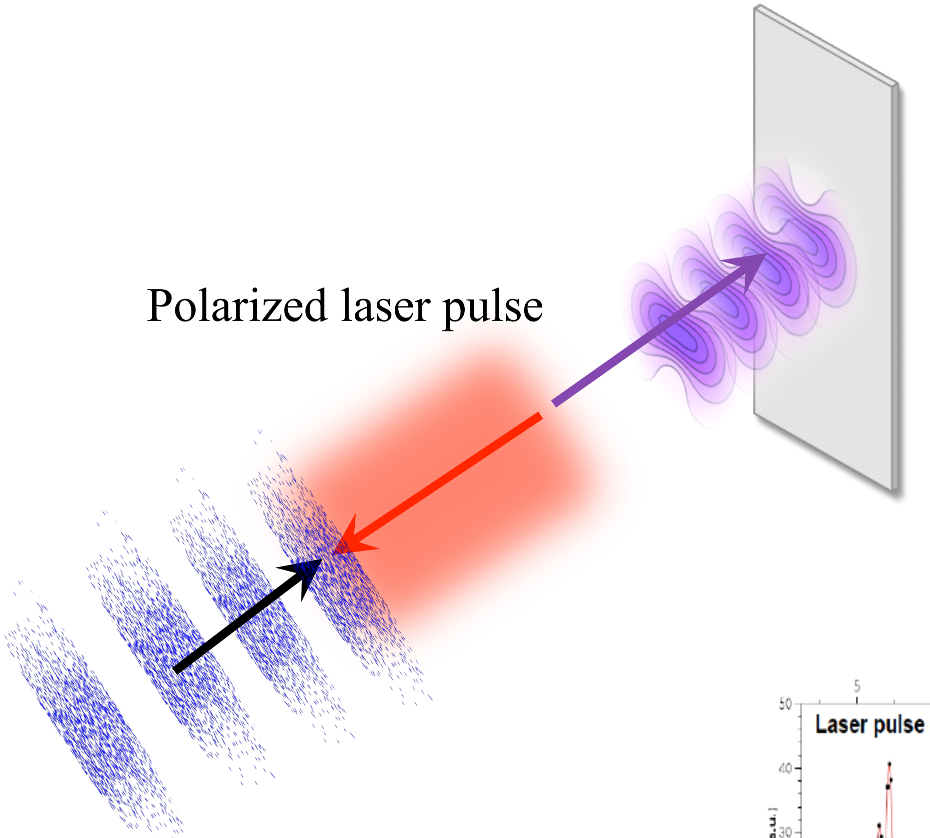






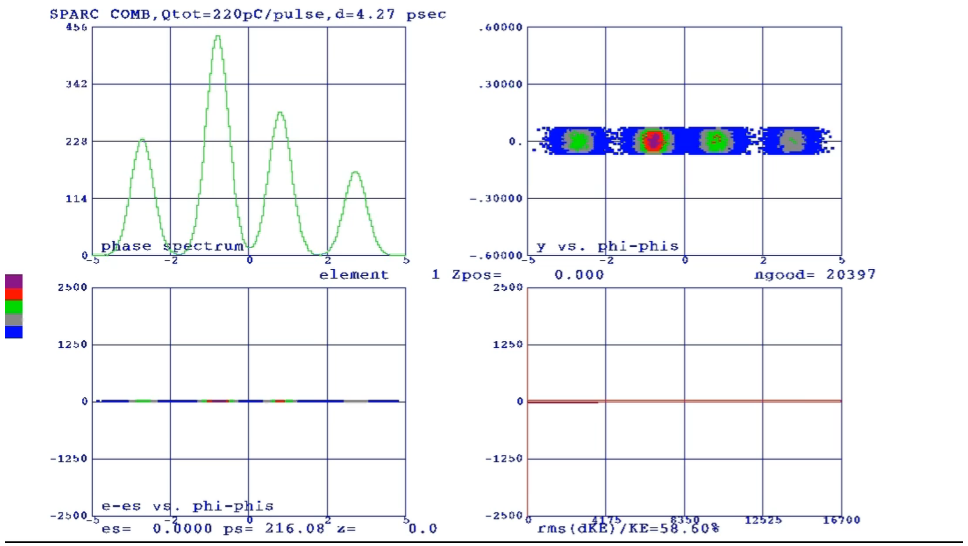
Two color: four bunches

Polarized laser pulse

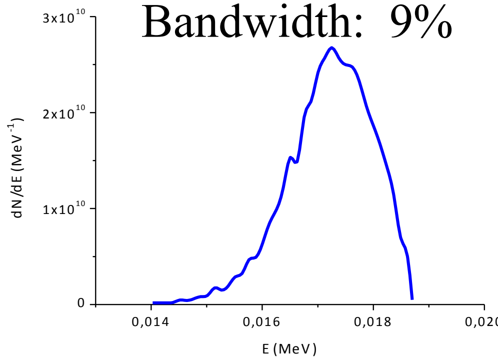


Multibunch electron beam

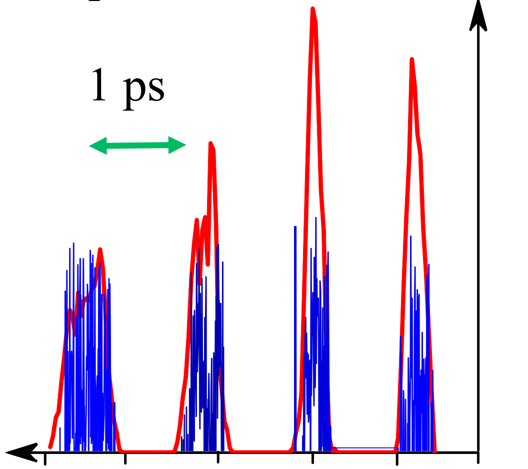
TSTEP simulation by C. Ronsivalle



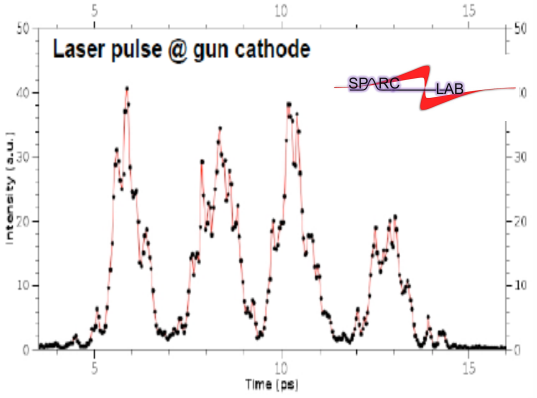
Radiation spectrum



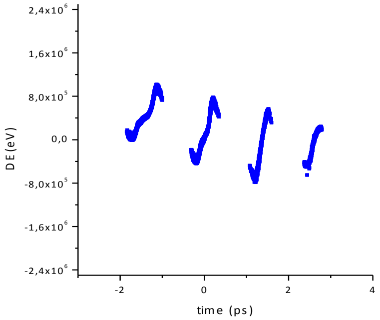
Total photon number: $5\ 10^7$



Radiation time dependence

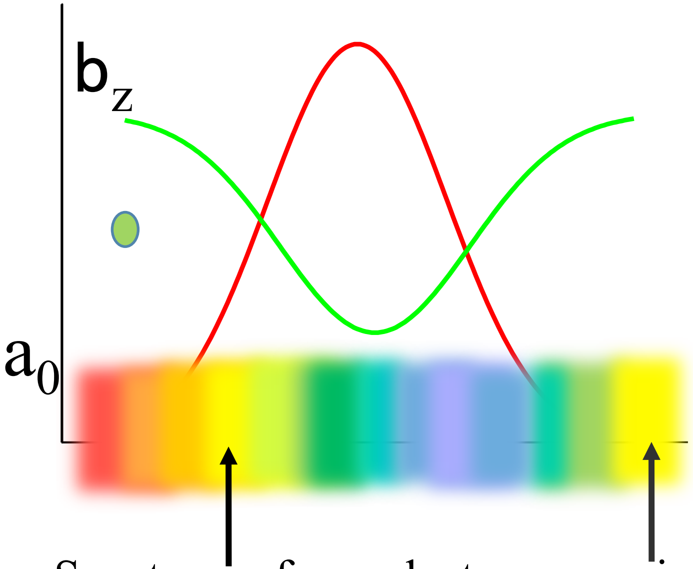


Electron phase space

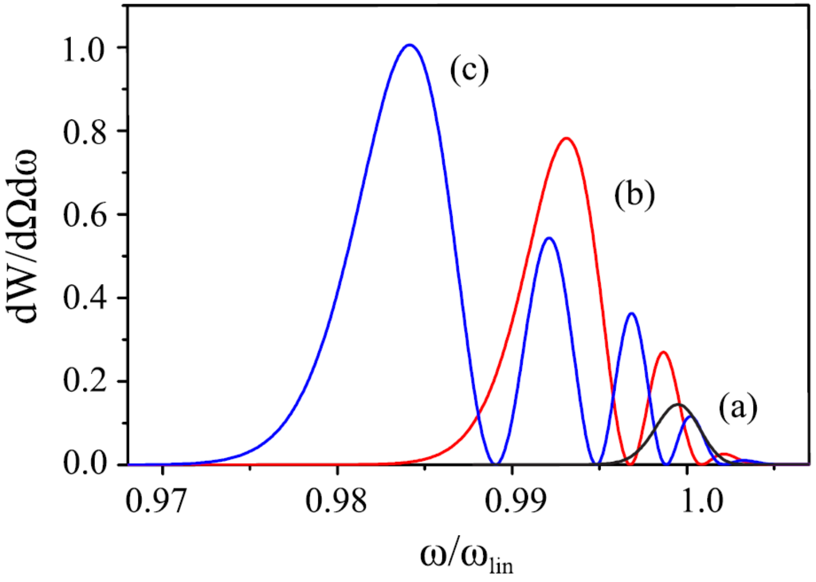


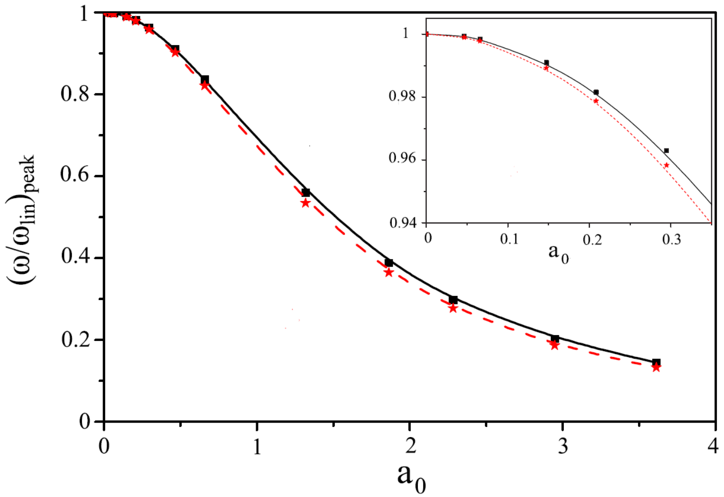
Chirping the laser for enhancing the spectral density

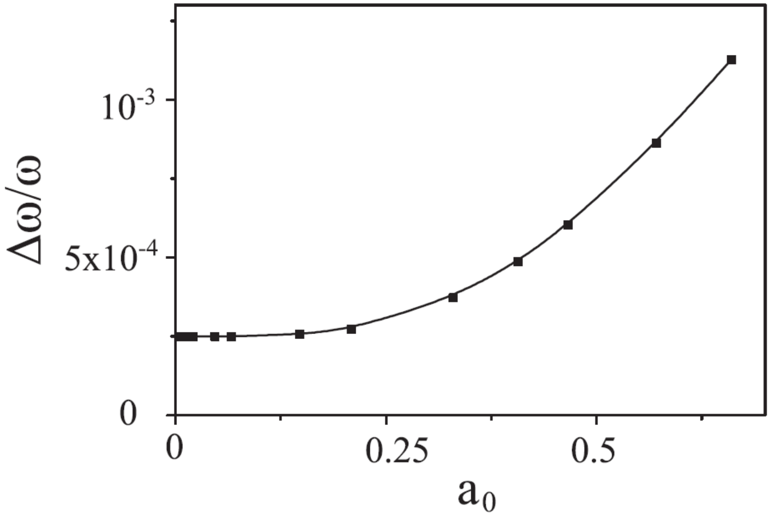
Increasing the laser intensity, the peak frequency shifts towards lower values, the spectrum broadens and secondary peaks appear. $N_{osc}=240\ a_0^2\ Dt(ps)$



Spectrum of one electron on axis







The electron experiences a variable laser parameter
Its longitudinal velocity changes.

$$\omega = \frac{(1+\beta)}{(1-\beta\ )}\omega_L \qquad a_0=0.85lI^{1/2}.$$

And therefore also the local emitted frequency changes.

Chirp

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 16, 030705 (2013)

Spectral bandwidth reduction of Thomson scattered light by pulse chirping

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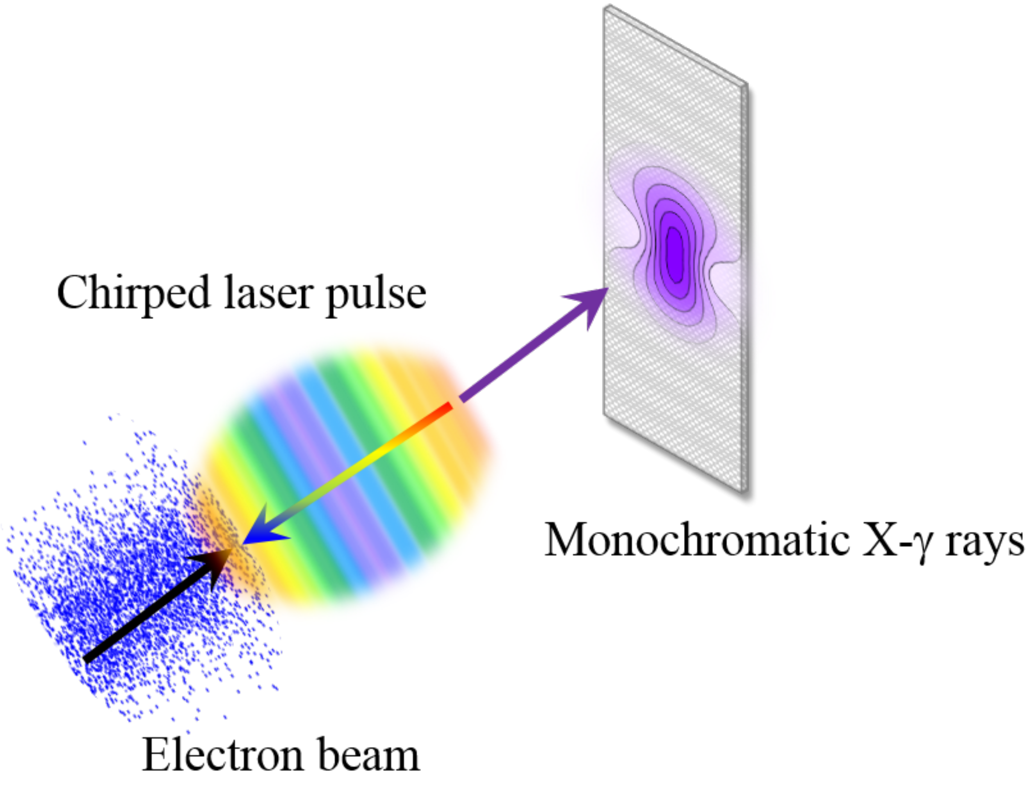
Department of Physics and Astronomy, University of Nebraska-Lincoln, Lincoln, Nebraska 68588, USA
(Received 2 July 2012; published 19 March 2013)

Controlling the spectral shape of nonlinear Thomson scattering with proper laser chirping

S.G. Rykovanov,[1,*] C.G.R. Geddes,[1] C.B. Schroeder,[1] E. Esarey,[1] and W.P. Leemans[1]
[1]*Lawrence Berkeley National Laboratory, Berkeley, CA 94720*

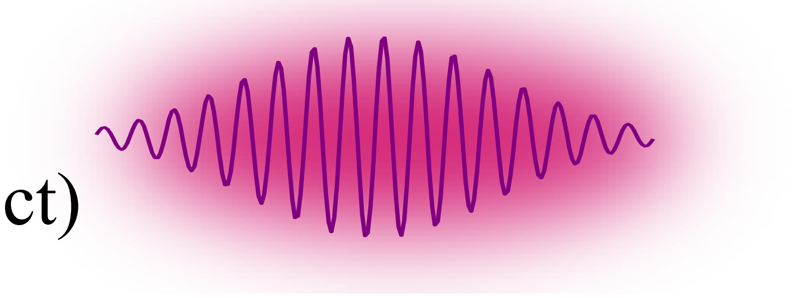
The idea is to compensate the dependence on z of b_z by introducing in the laser a longitudinal dependence of $w_L(z+ct)$

$$E(\underline{x},t) = E_0(\underline{x},t)\sin\Gamma$$



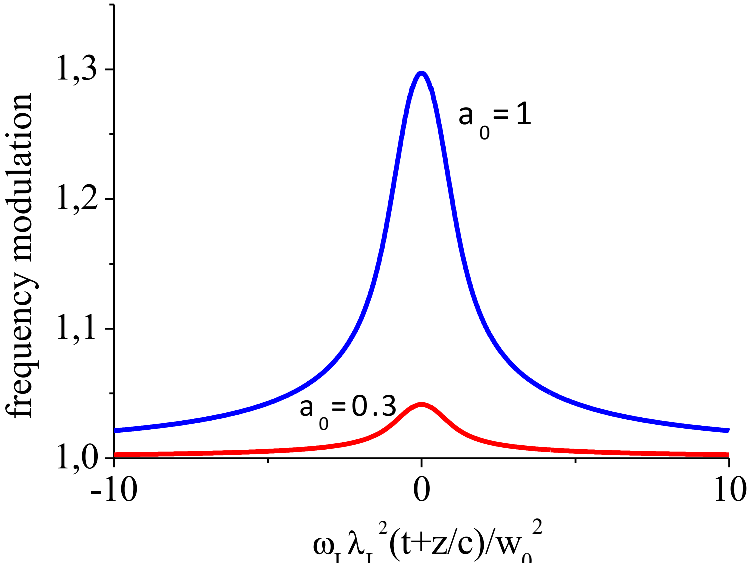
No chirp

$$\Gamma = k_L(z+ct)$$



Chirp

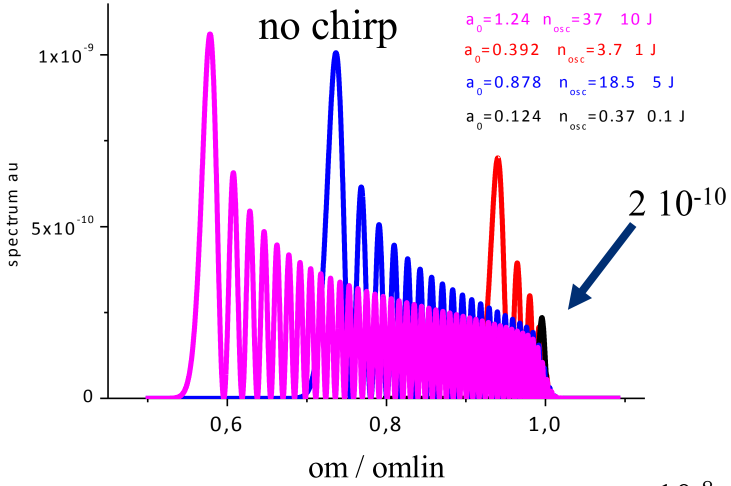
Calculations with the stationary phase method gives the optimum expression of f(z+ct):

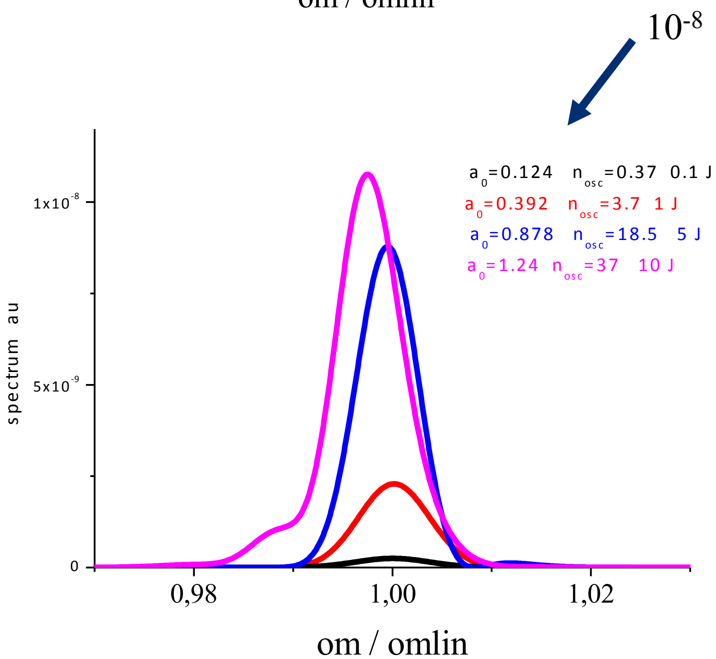


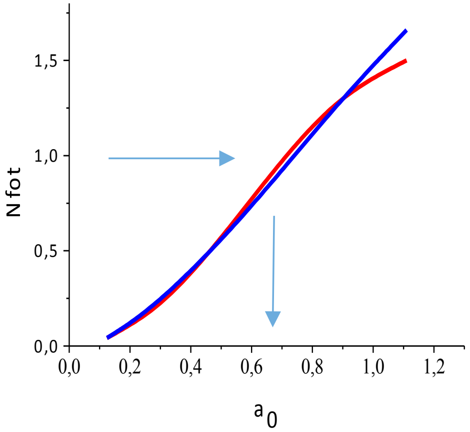
The total number of photon increases with a_0, but is the same with and without chirp.

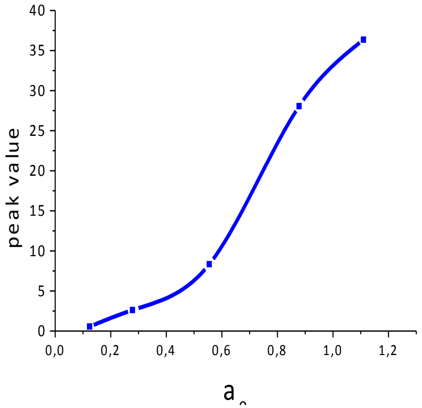
The brightness increases by 5 order of magnitude.

Spectrum on axis of one electron









Compton enhanced source: collective effects lead to FEL emission

What a challenge!!! So, why studying Optical Undulators ? Compactness of the set-up. Dimension of the spot. Tunability at high frequency.

In the FEL emission: $\frac{\Delta\lambda}{\lambda} \approx \rho$.

$$\rho = \frac{1}{2\gamma}\left(\frac{I}{I_A}\frac{\lambda_L^2 a_{L0}^2}{4\pi^2\sigma_x^2}\right)^{1/3} = \frac{Z_R}{L_g}\frac{\lambda_L^2\gamma^2}{2\pi^2\sigma_L^2}$$

Condition on emittance:

$$\frac{\Delta\lambda}{\lambda} \approx \frac{\varepsilon_n^2}{\sigma_0^2}$$

$$\boxed{\varepsilon_n < \sigma_0\sqrt{\rho}}$$

$$\approx \sqrt{\frac{Z_R}{L_g}\frac{\lambda_L\gamma}{\sqrt{2}\,\pi}}$$ Pellegrini criterion

Condition on energy spread:

$$\frac{2\Delta\gamma}{\gamma} < \frac{\Delta\lambda}{\lambda} \approx \rho$$

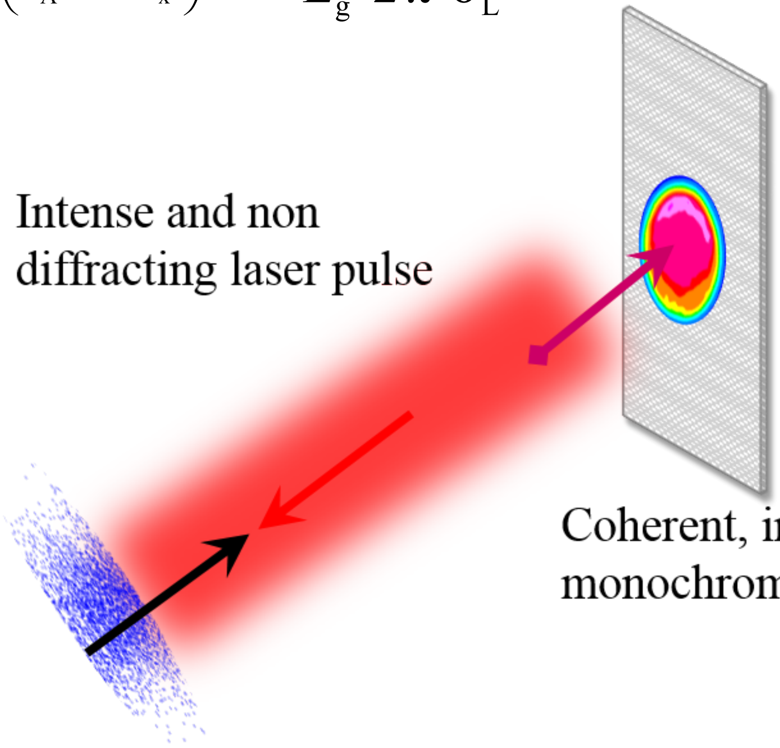
$$\boxed{\frac{\Delta\gamma}{\gamma} < \frac{\rho}{2}}$$

Condition on laser profiles :

$$\boxed{\frac{\Delta a_0^2}{a_0^2} < \rho}$$

$$\frac{w_0}{\sigma_e} \geq \frac{\sqrt{2}}{\sqrt{\rho}}$$

$$N_{period} = \frac{\sigma_{\parallel}}{\lambda_w} \geq \frac{1}{\rho^{3/2}}$$

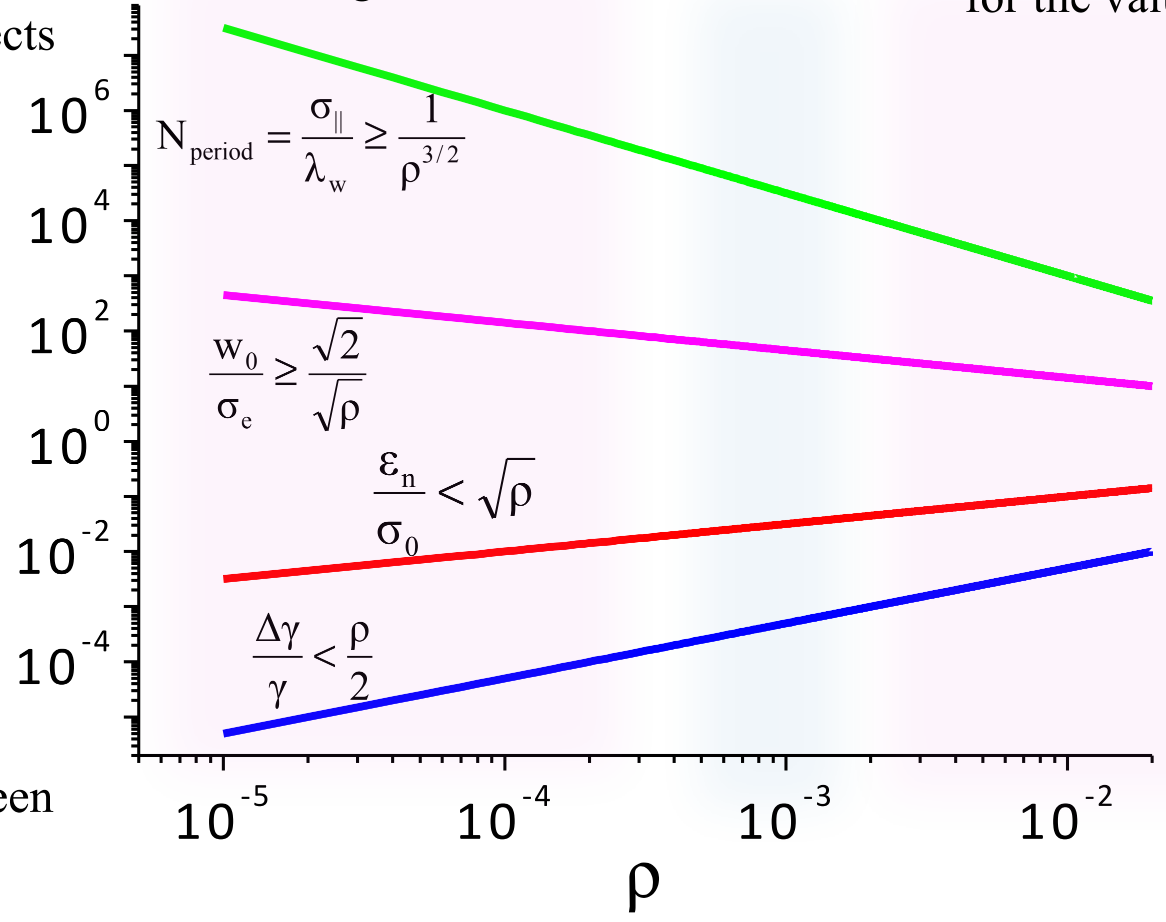


A.R. Rossi, Cuba conference

High challenge for laser energy, transverse and inhomogeneous effects

Possibilities

High challenge for the value of rho



A,B,C,D tolerance factors between 1 and 10

ρ	$\Delta\gamma/\gamma$	ε_n/σ_e	w_0/σ_e	N_L (Gauss) $= \sigma_{\|}/\lambda_w$
10^{-4}	A x 10^{-4}	B 10-2	141/C	900000/D
10^{-3}	A x 10^{-3}	B 0.03	43/C	30000/D
10^{-2}	A x 10^{-2}	B x 0.1	14/C	930/D

Linac accelerated beams

λ_R	12 nm	0,75 μm	1.08 Å	1 nm
laser	CO_2	CO_2	Ti:Sa	Ti:Sa
I (A)	150	1000	3000	600
r_b (μm)	30	25	7	10
l_b (mm)	1	1	0.3	1
ε_x	1.06	0.3	0.26–0.8	0.26–0.8
$\Delta E/E$	1.3×10^{-4}	10^{-4}	10^{-4}	10^{-4}
γ	16.5	60	55	18,11
a_{L0}	0.2	0.3	0.8	0.8
ρ (10^{-4})	7.01	2.91	3.82	5.36
L_{1D}	654 μm	1.57 mm	121 μm	68 μm
P (MW)	0.1–10	1.93	9.4–1.5	1

Plasma accelerated beams

I(kA)	r	g	Dg/g total	s	e	Dg/g slice
20	$3\ 10^{-3}$	55	$2\ 10^{-2}$	5 mm	0.3mm	$3\ 10^{-3}$

TABLE II. Radiation parameters.

	P_{max} (W)	E (μJ)	L_R (μm)	L_{sat} (mm)	λ_R (nm)	$\delta\lambda_R/\lambda_R$
Case 1	7.5×10^8	0.4	0.5	2.5	1.36	0.82%
Case 2	6×10^8	0.5	0.6	2.7	1.43	0.16%
Case 3						
First peak	2×10^8	0.05	0.05	1	1.35	0.81%
Saturation	1.5×10^8	0.12	0.5	4.5		

Collective effects

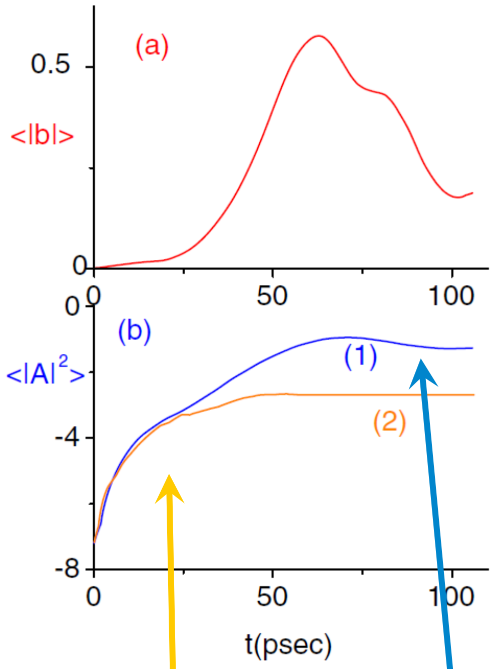


FIG. 1. (Color) (a) average bunching ⟨|b|⟩ in the middle of the bunch vs time, (b) logarithmic plot of ⟨|A|²⟩ vs time in picoseconds in the (1) coherent and (2) incoherent case. In the calculation $w_0 = 50\ \mu m$ with a flat laser profile, $\bar{a}_L = 0.3$, $Q = 3$ nC, $I = 0.9$ kA, $\langle\gamma\rangle = 60$, $\Delta p_z/p_z = 10^{-4}$, $\varepsilon = 0.6\ \mu m$, $\Delta\omega/\omega = -10^{-4}$.

Spontaneous emission

FEL emission factor 10^3 larger than SE

At R=1 m

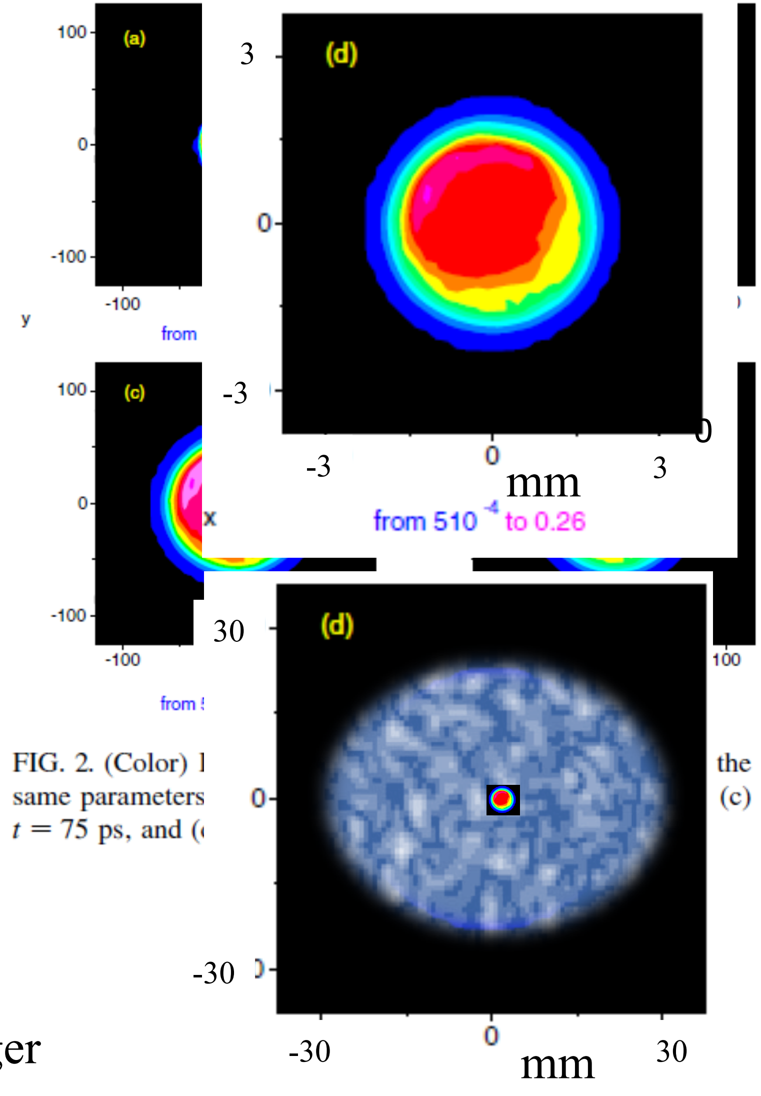
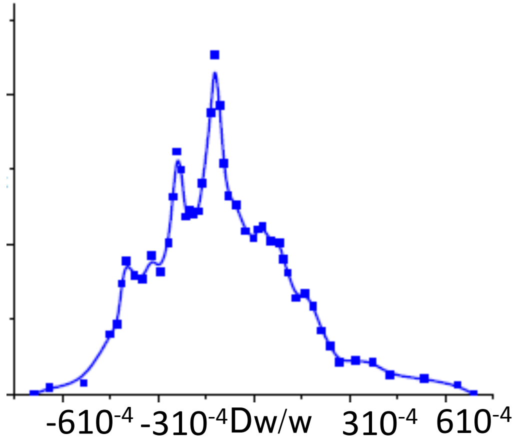
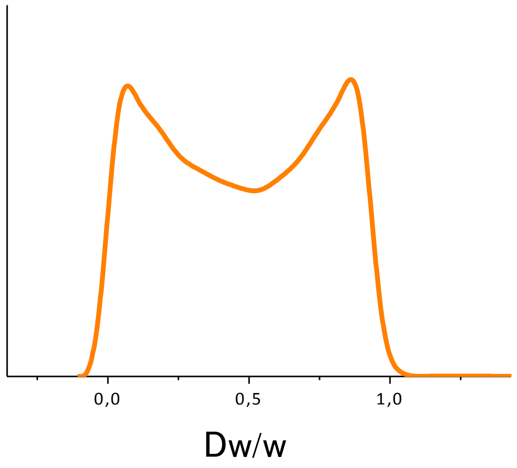


FIG. 2. (Color) I ... the same parameters ... (c) $t = 75$ ps, and (



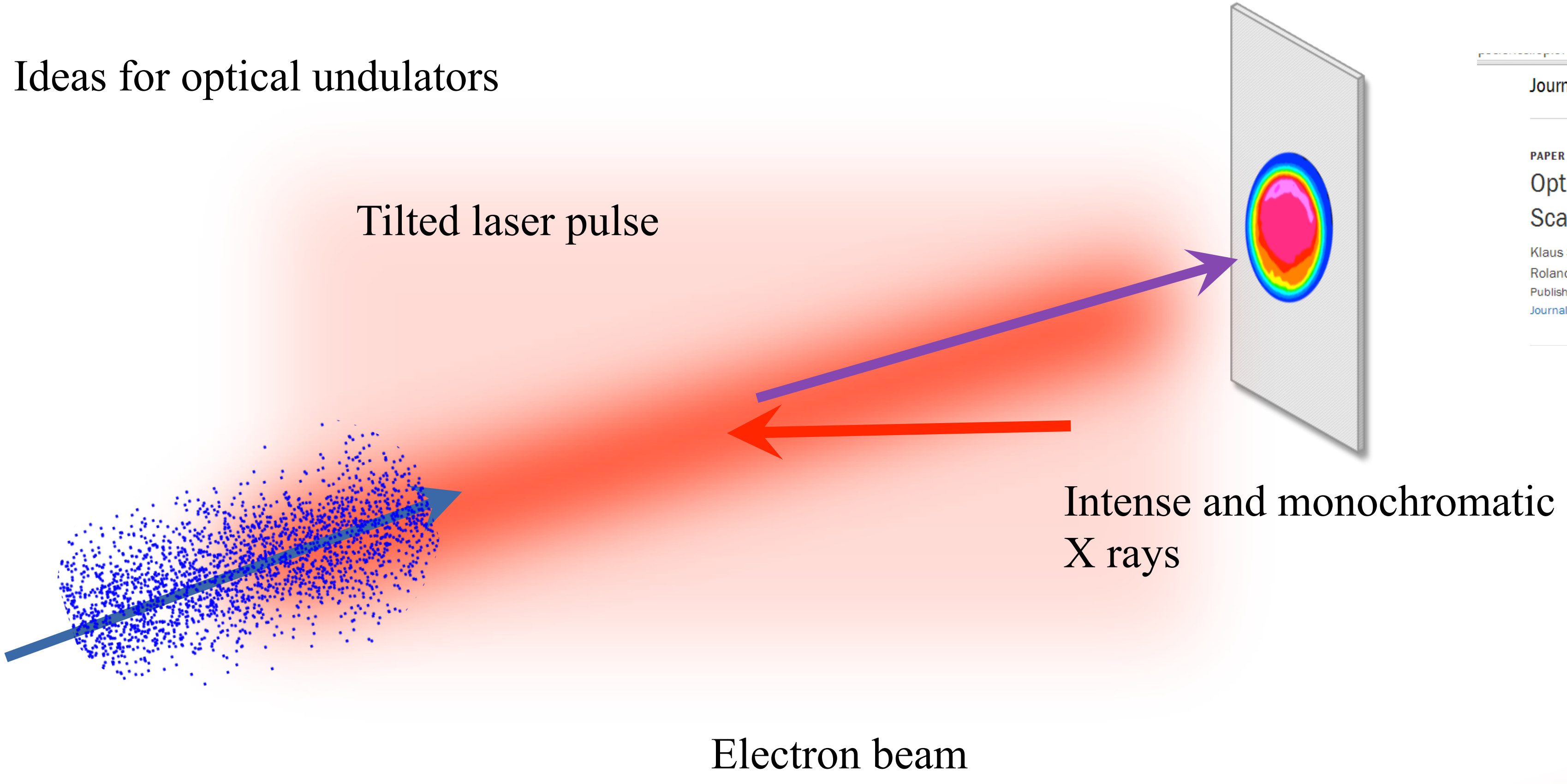


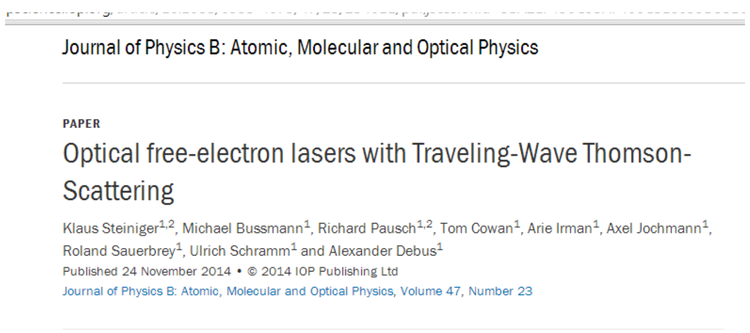
Collective effects

$$\rho = \frac{1}{\gamma}\left(\frac{\omega_p^2 a_{L0}^2}{16\omega_L^2}\right)^{1/3} = \frac{1}{2\gamma}\left(\frac{I}{I_A}\frac{\lambda_L^2 a_{L0}^2}{4\pi^2\sigma_x^2}\right)^{1/3}$$

	Number of photons	Bandwidth	Spectral density	Longitudinal Coherence	Transverse Coherence	Divergence
Compton Spontaneous Emission	$N \approx \frac{2\,10^8 E_L Q \Psi_{max}^2}{h\nu_L \sigma_x^2}$	$\frac{\Delta\nu_p}{\nu_p} \approx \sqrt{0.09\Psi_{max}^4}$	$\frac{dN}{db} \approx \frac{4.1 10^8 Q E_L}{h\nu_L \sigma_x^2}$	$L_C \approx \lambda$	$L_C \approx \frac{\lambda R}{\sigma}$	$\sigma' \approx \frac{1}{\gamma}$
Opt. Und. FEL regime	$N \approx \rho \frac{7.8 10^{11} Q}{h\nu_L 4\gamma}$	$\frac{\Delta\nu_p}{\nu_p} \approx \rho$	$\frac{dN}{db} \approx \frac{7.8 10^{11} Q}{h\nu_L 4\gamma}$	$L_C \approx \frac{\lambda}{4\pi\sqrt{3}\rho}$	$L_C \approx \frac{\lambda R}{4\pi\sqrt{3}\rho\sigma}$	$\sigma' \approx \frac{\lambda_L}{4\gamma^2\sigma_e} + \frac{\varepsilon_n}{\gamma\sigma_e}$

Ideas for optical undulators





Journal of Physics B: Atomic, Molecular and Optical Physics

PAPER

Optical free-electron lasers with Traveling-Wave Thomson-Scattering

Klaus Steiniger[1,2], Michael Bussmann[1], Richard Pausch[1,2], Tom Cowan[1], Arie Irman[1], Axel Jochmann[1], Roland Sauerbrey[1], Ulrich Schramm[1] and Alexander Debus[1]

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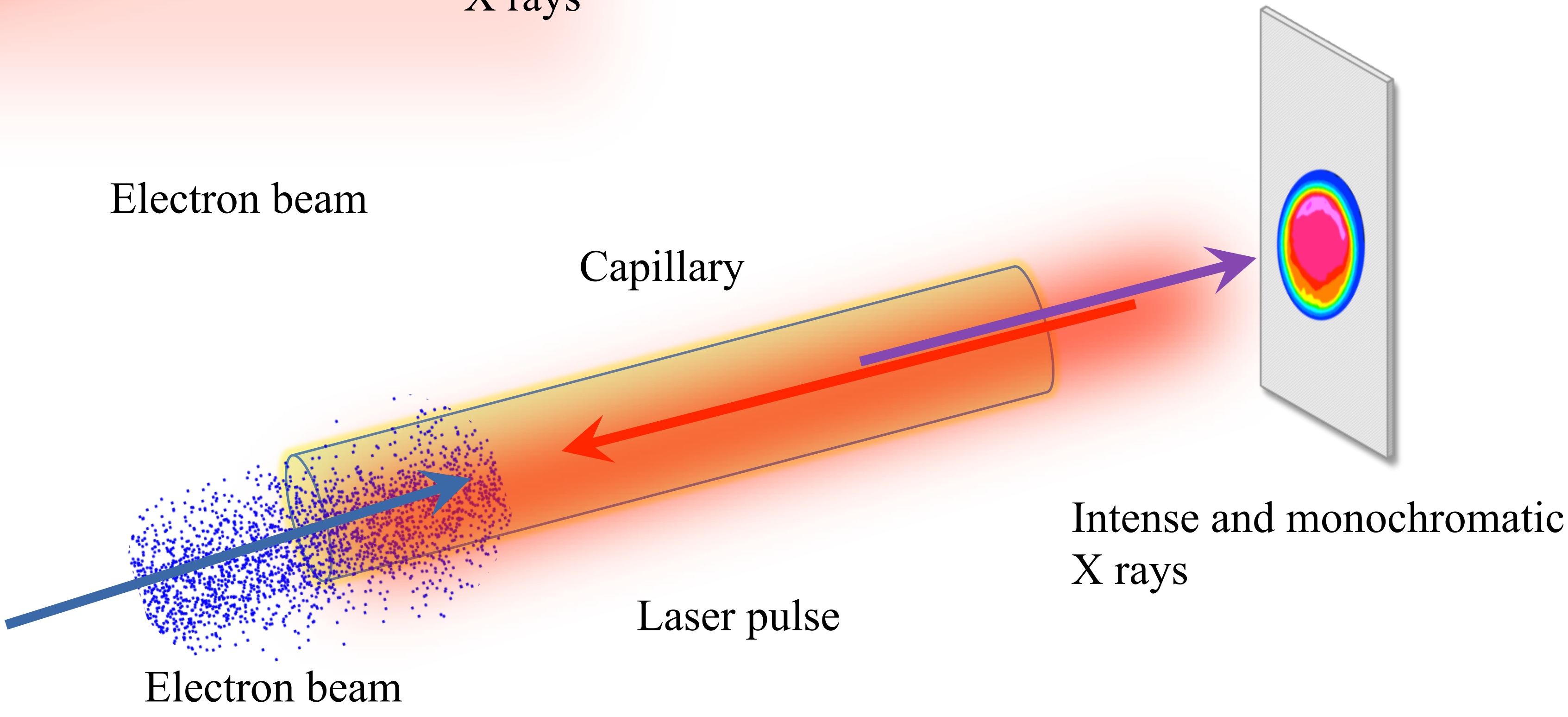
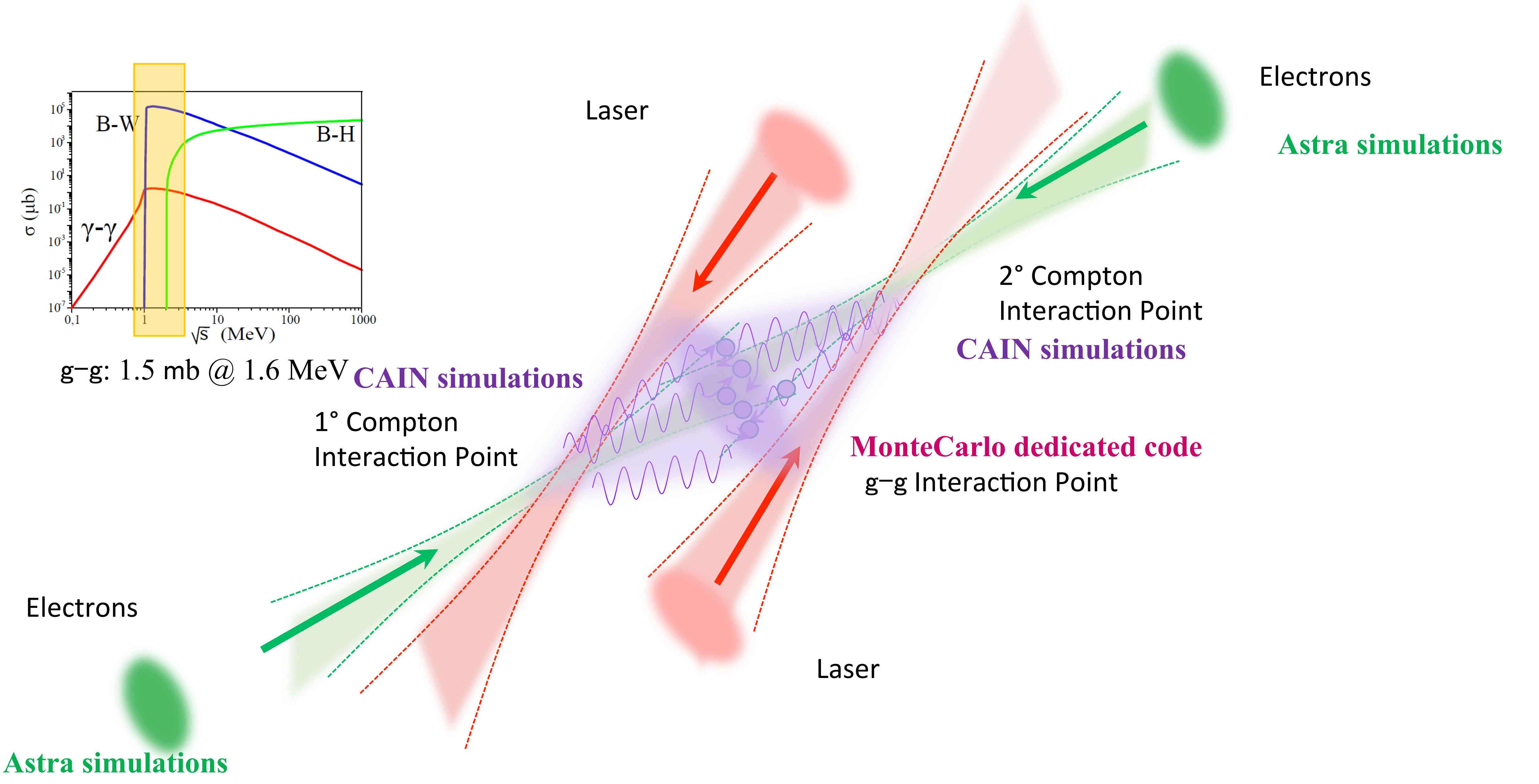
Journal of Physics B: Atomic, Molecular and Optical Physics, Volume 47, Number 23



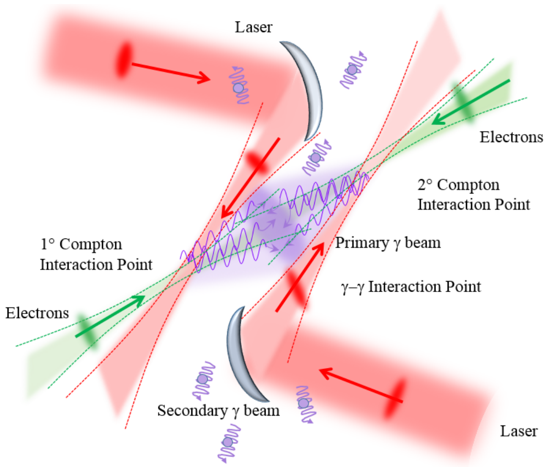


Gamma-gamma collider for g–g events generation, Illya Drebot (later on)

Conclusions

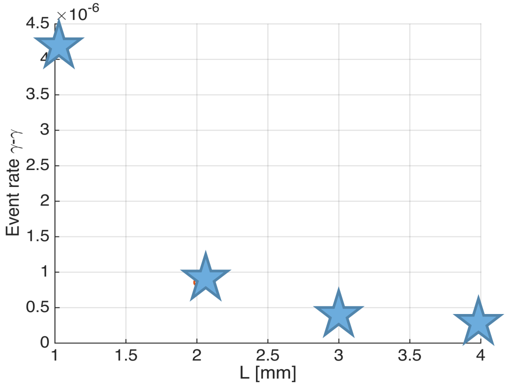
Thank You for the attention

Gamma-gamma collider for the study of g−g events generation



Results of a Monte Carlo dedicated code

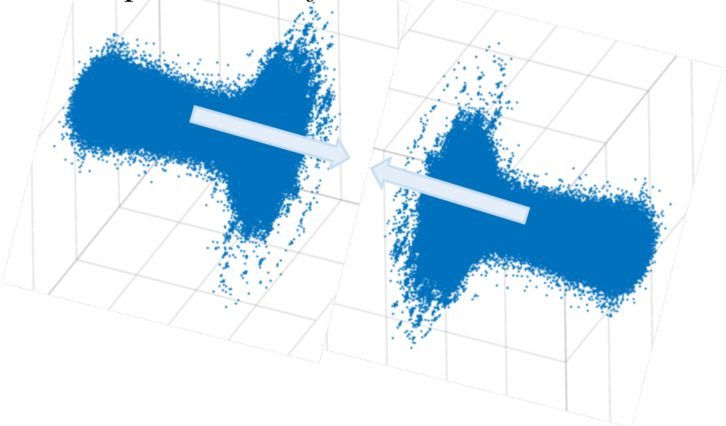
1 event/h



$L \approx 2.7\ 10^{26}\ cm^{-2}/s$

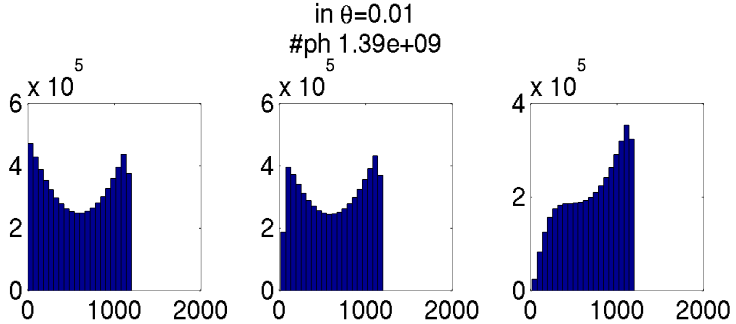
Parameter of the Compton sources

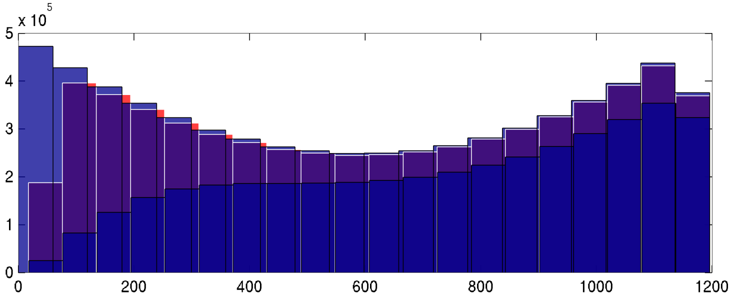
Total energy of the g−g system: 2 MeV
Electron energy: 250 MeV
Electron emittance: 0.4 mm mrad
Electron energy spread: $0.7\ 10^{-4}$
Charge: 250 pC
Transverse electron width:1 mm
Laser wavelength: 1000 nm
Laser waist: 10 micron
Laser Energy: 1 J
Photon energy: 1 MeV
Transverse photon beam dimension: 1 mm
Transverse photon beam dimension at IP: 10 mm
Repetition rate *f*: 100 Hz



See poster section

ELI-NP-like Compton sources focused at 1 mm give $1.5\ 10^{9}$ primary photons at 1 MeV.





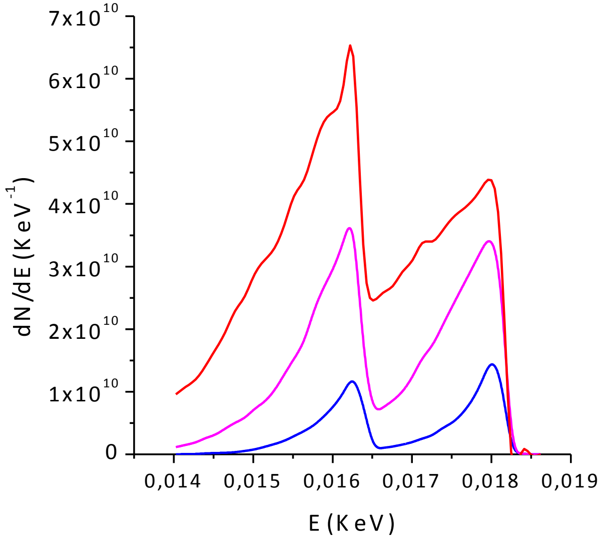
Two color: spectra at 30 MeV

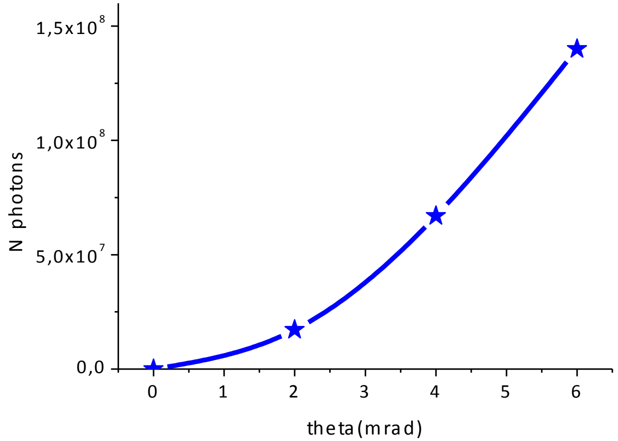
$$N \approx \frac{2\,10^8 E_L Q \Psi^2_{max}}{h\nu_L \sigma_x^2} \approx \frac{0.29\,10^9 E_L Q}{h\nu_L \sigma_x^2} \frac{|\nu_{p,1} - \nu_{p,2}|}{\langle \nu_p \rangle}$$

favourable scaling

Acceptance angle: 2 mrad,4 mrad, 6 mrad

>95% linear polarization





Laser energy	**5 J**
Waist	**25 mm**
Time duration	**6 ps**
Wavelength	**800 nm**

Photon energy	**18 KeV**
Photon number	**1 10^8**
Angle	**<4 mrad**
Visibility	**>80%**

The factor ρ is about 3.8×10^{-4}, and the radiation wavelength is about $\lambda_R = 1.1$ A. In this case we are at the limit of validity of the classical model, because the quantum factor q is 0.9, and quantum effects, arising when $q>1$, can play an important role [16,17]. However, the previous condition on q relies on one-dimensional models. Three-dimensional considerations [18] seem to point out a relaxation of the above condition due to the enlargement of the bandwidth associated to non-ideal and geometrical effects so that the requirement $q>1$ should be rather replaced by $q\rho > \max\left(\rho, \Delta\gamma/\gamma, \varepsilon_{n,x}^2/\sigma_x^2\right)$, where $q\rho$ is the relative energy separation between the quantum lines, ρ is the one-dimensional natural bandwidth and $\Delta\gamma/\gamma$ and $\varepsilon_{n,x}^2/\sigma_x^2$ are, respectively, the inhomogeneous line broadening due to energy spread and emittance effects [19]. In our case, we have $q\rho = 3.5\times10^{-4}$, but for the case (a) $\varepsilon_{n,x}^2/\sigma_x^2$ never goes under 7×10^{-4}. The cases with larger emittance are, in this sense, even less critical respect to the presence of quantum effects. The cases presented require an amount of laser power still outside the present status of the art, but achievable in the near future [20]. In fact, for instance, in the case (b) with emittance $\varepsilon_x = 0.54$ mm mrad, at saturation the beam has a maximum radius of about 15 μm; assuming for the laser in the waist a spot size of 20 μm, we obtain the needed laser power of more than 17 TW for at least 1.5 mm, corresponding to a total laser energy of about 85 J.