Electron-photon beam collisions revisited: a way towards novel radiation sources, advanced secondary beams and new phenomena in astro-physics

255.5 keV photons can stop any relativistic electron

Luca Serafini and Vittoria Petrillo , INFN-Milano and Università degli Studi di Milano

- ***stopping relativistic electrons of "any" energy (MeV's, GeV's, TeV's…) in a single-collision event***

- ***Full Inverse Compton Scattering (FICS) - total transfer of energy and momentum from an electron to a photon***

- ***Possible impacts in other fields like Plasma Physics (e^- trapping), Astro-Physics (Universe opacity to high energy photons, cosmic gamma-ray sources, etc), QED&Relativity (Unruh radiation)***

If you ask Chat-gpt :
"can an electron transfer its total kinetic energy to a photon?"
It will answer "no" - a wrong answer

The mechanism of total energy transfer from an electron to a photon, where the electron essentially stops and transfers all its kinetic energy to a photon, is not typically described within the framework of conventional Compton scattering. However, such an extreme scenario can be considered in specific contexts:

1. **Inverse Compton Scattering**: Inverse Compton scattering is a process where a high-energy electron transfers part of its energy to a low-energy photon, resulting in a higher-energy photon. However, the electron does not typically come to a complete stop; it just loses some of its energy.
2. **Photon Emission in Strong Fields**: In extremely strong electromagnetic fields, such as those generated by intense laser pulses, the dynamics can be different. The interaction of an electron with a strong electromagnetic field can lead to significant energy transfer through a process known as non-linear Compton scattering or non-linear Thomson scattering. Here, the electron can emit high-energy photons and lose a substantial amount of its kinetic energy.
3. **Bremsstrahlung in Extreme Fields**: When electrons decelerate rapidly in the presence of strong electromagnetic fields, they can emit radiation (bremsstrahlung). If the deceleration is extreme, the electron can lose a large fraction of its kinetic energy to the emitted photon(s).
4. **Quantum Effects and Pair Production**: In extremely high-energy environments, quantum electrodynamics (QED) effects become significant. An electron interacting with a high-intensity photon field could potentially transfer a large fraction of its energy to photons, but this process might also involve phenomena like pair production (e.g., electron-positron pairs).

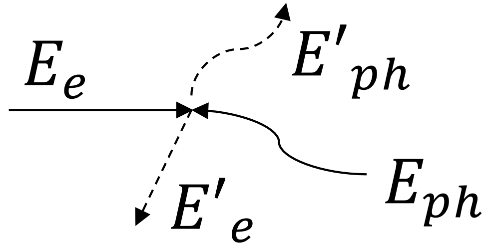
because Chat-gpt doesn't know the correct electron-photon interaction kinematics, it just relies on a compilation of texts…

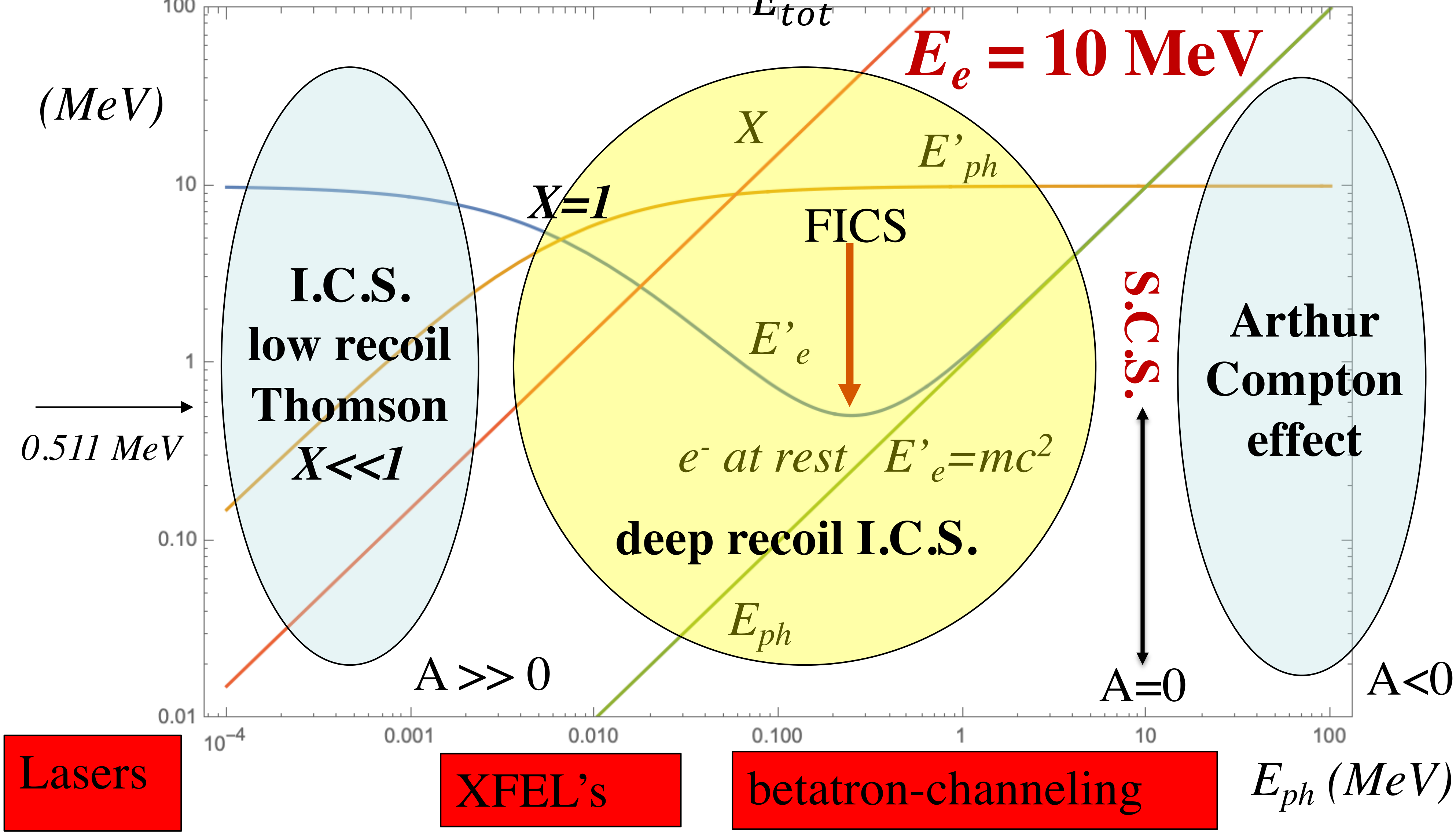
We discovered FICS and we'll tell you about

Courtesy S. Sanae

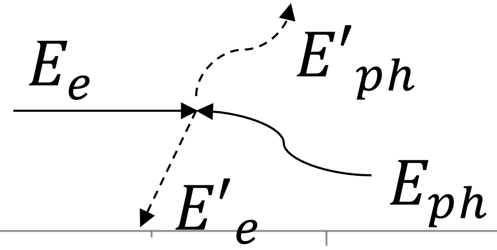
$X = 4\,E_e E_{ph}/(mc^2)^2$ $\quad A = \beta\gamma^2 - X/4$

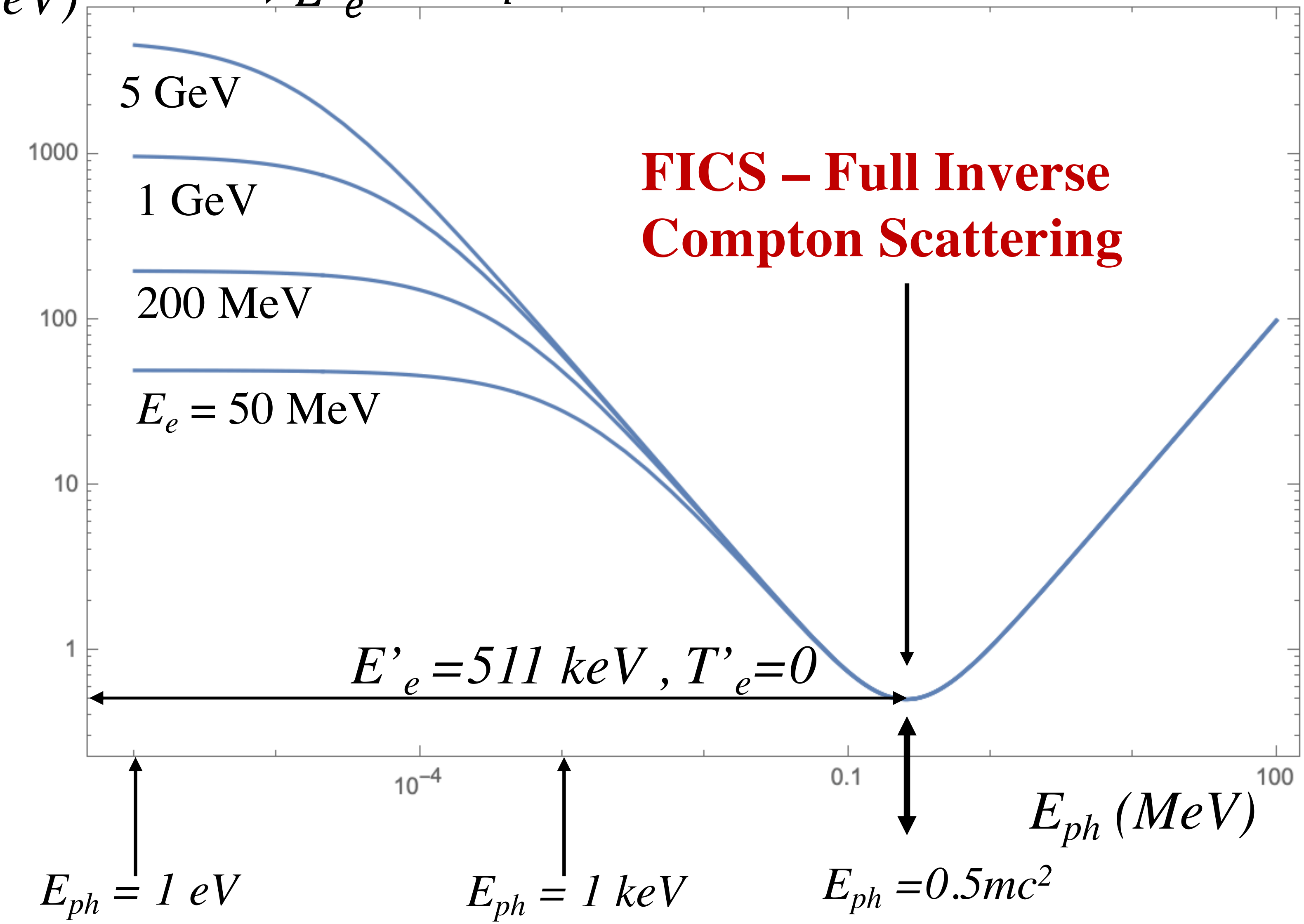
$$E'_{ph} = \frac{4\gamma^2 E_{ph}}{1+X} \qquad E'_e = \underbrace{E_e + E_{ph}}_{E_{tot}} - \frac{4\gamma^2 E_{ph}}{1+X}$$



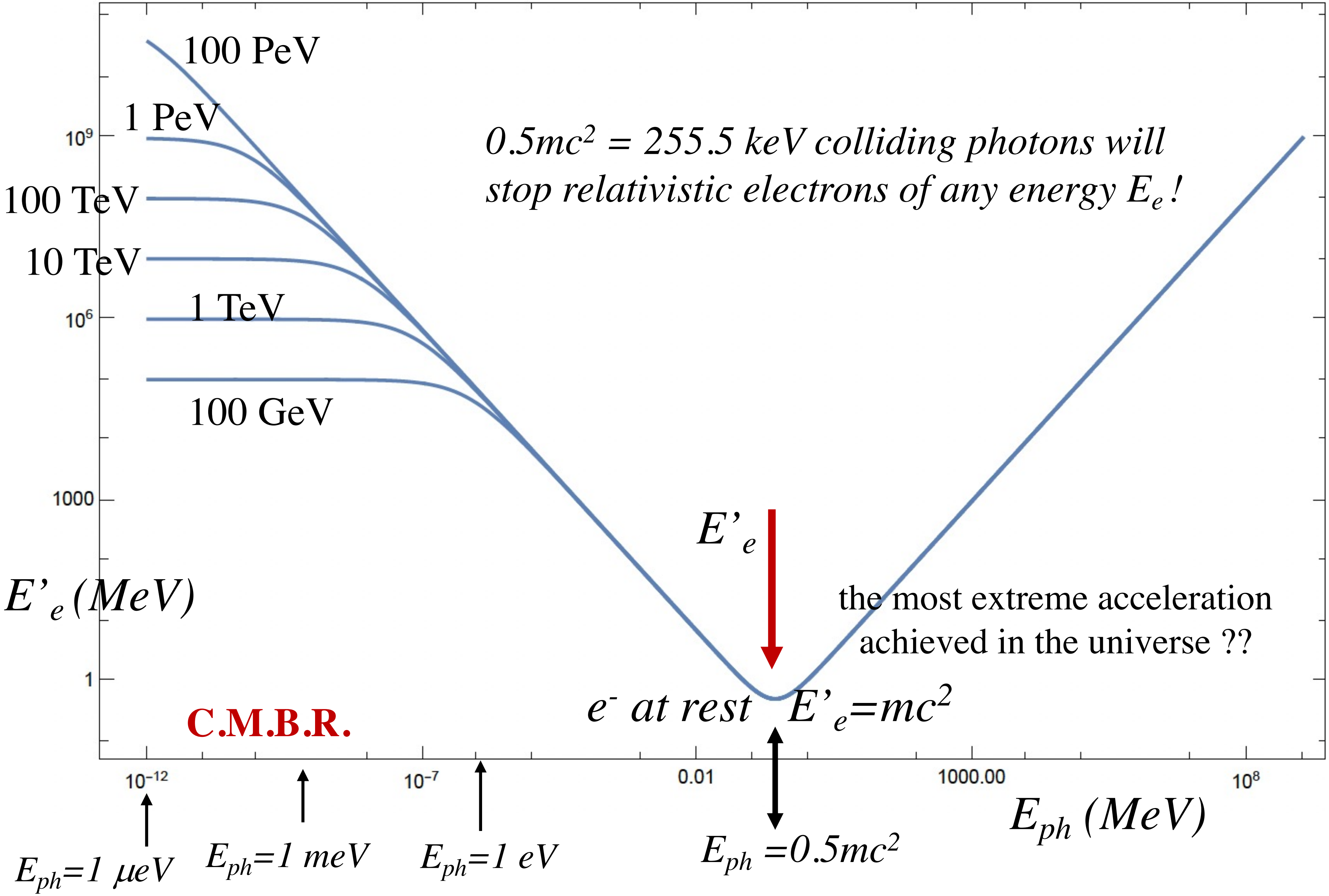


in vacuum electron-photon collision





Full Inverse Compton Scattering: amazing power of 255.5 keV photons to stop ANY colliding electron



*hadronic threshold (E_{cm} < 600 MeV) with 255.5 keV photons ≈ 360 GeV

So suprising that FICS was not mentioned nor described
in the previous literature on Compton direct/inverse Scattering
that
we really wanted to re-examine the first historical phases
of the studies on electron-photon QED interaction

How comes that nobody yet identified FICS as the only regime
of complete/full transfer in-vacuum of
energy and momentum between an electron and a photon?

Second Series May, 1923 Vol. 21, No. 5

beginning of the story – the photon, quantum of energy

THE

PHYSICAL REVIEW

A QUANTUM THEORY OF THE SCATTERING OF X-RAYS BY LIGHT ELEMENTS

By Arthur H. Compton

Abstract

The change in

A quantum theory of the scattering of X-rays and γ-rays by light elements. —The hypothesis is suggested that when an X-ray quantum is scattered it spends all of its energy and momentum upon some particular electron. This electron in turn scatters the ray in some definite direction. The change in

$$\lambda' - \lambda = \lambda_c (1+\cos\Delta\vartheta)$$

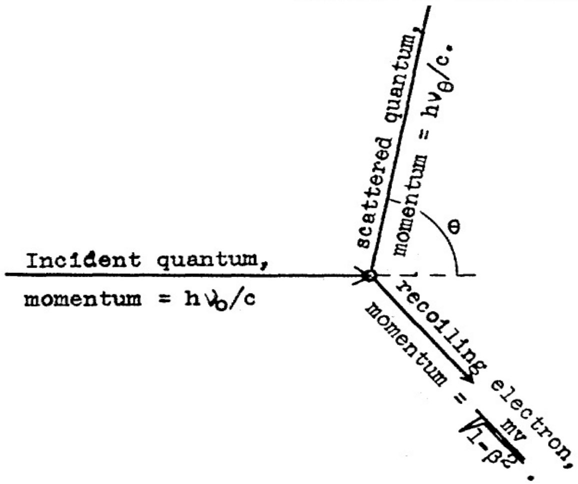


Fig. 1 A

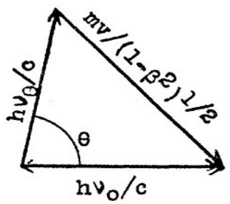
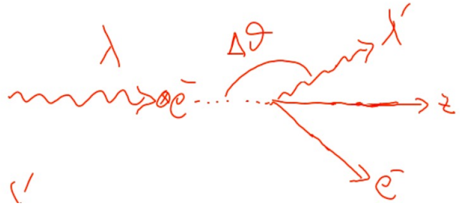


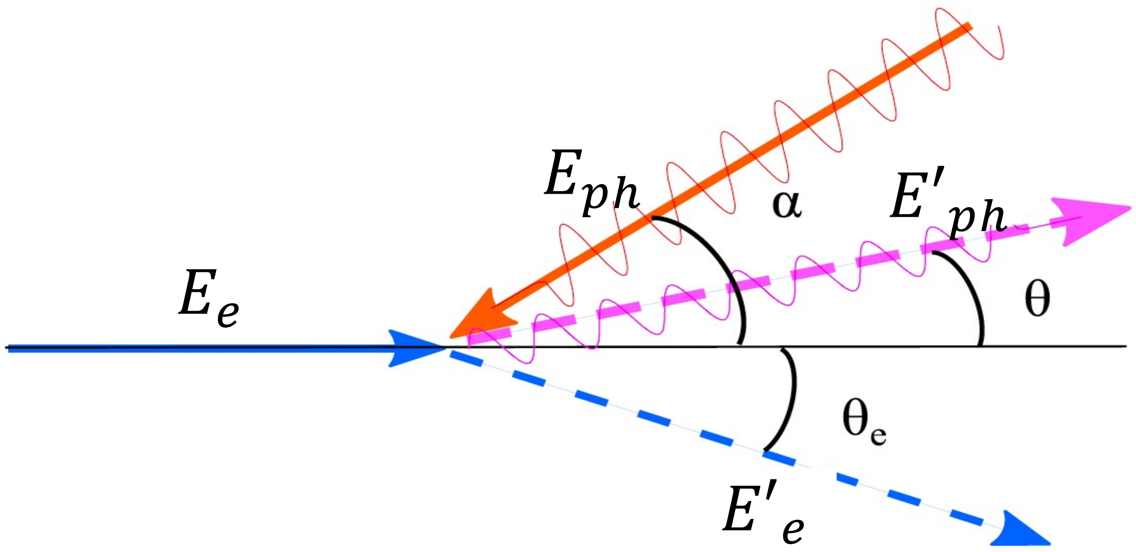
Fig. 1 B



$$E'_{ph} = \frac{E_{ph}}{1 + \frac{E_{ph}}{mc^2}(1+\cos\vartheta)}$$

that an X-ray quantum of frequency ν_0 is scattered by an electron of mass m. The momentum of the incident ray will be $h\nu_0/c$, where c is

General Compton Scattering geometry between an incident eletron E_e and a photon E_{ph} at a collision angle α, photon E'_{ph} scattering angle θ and electron E'_e scattering angle θ_e

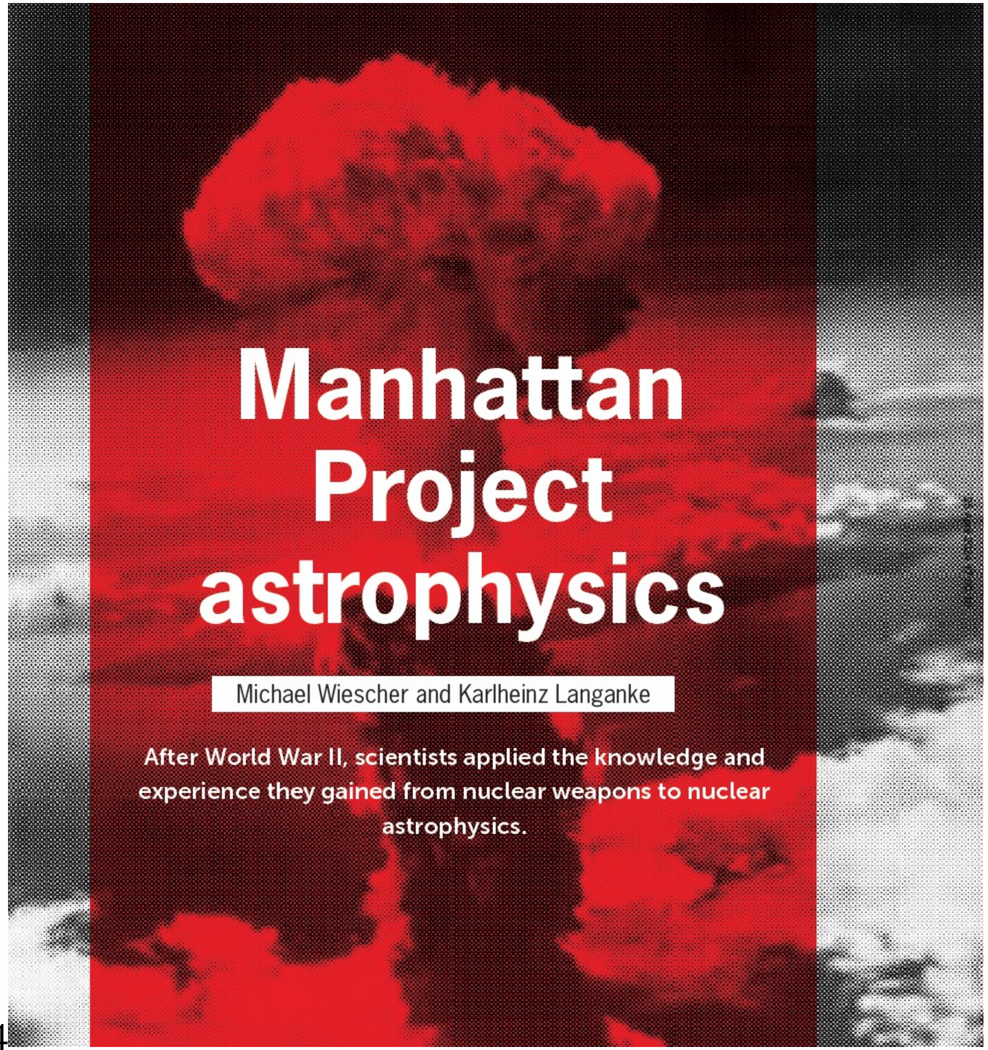


A. Compton 1923 - Direct Compton effect

First consideration and study of Inverse Compton Scattering….

During the development of the nuclear bomb!
The Manhattan Project

Will the back-scattered photons, by hot electrons of the plasma created in the initial stage of the nuclear bomb explosion, release energy from the fire-ball decreasing its temperature???



Istituto Nazionale di Fisica Nucleare

AIP

PHYSICS TODAY

Manhattan Project astrophysics

After World War II, scientists applied the knowledge and experience they gained from nuclear weapons to nuclear astrophysics.

Michael Wiescher; Karlheinz Langanke

Check for updates

Physics Today **77** (3), 34–41 (2024);
https://doi.org/10.1063/pt.jksg.hage

of initiating nuclear fusion of the whole atmosphere!!!

an ignition could not be deemed impossible. The Trinity test took place in July 1945, and the atomic bombs were dropped on Hiroshima and Nagasaki shortly thereafter. Despite the bombs' tremendous damage, they did not set the atmosphere on fire.

Theory mitigates fear

The year after the test, Teller, his graduate student Emil Konopinski, and local technician Cloyd Marvin Jr wrote a classified Los Alamos National Laboratory report in which they summarized theoretical considerations on the possible ignition of the atmosphere by an atomic explosion.[1] The paper, declassified in 1979, argues that propagation of nuclear burning in the atmosphere is possible only if the energy gained from nuclear reactions is greater than the energy loss through the emitted gamma and beta radiation.

Konopinski, Teller, and Marvin considered the fusion of two ^{14}N nuclei as the most important energy-producing reaction, because ^{14}N is the dominant component in Earth's atmosphere. On the other hand, when compared to the stable oxygen-16 isotope, ^{14}N nuclei can easily be broken up. Therefore, the fusion of two ^{14}N atoms should lead mainly to a rearrangement of the nucleons by the nuclear force and produce a light fragment and a heavy fragment. Energetically, the most favorable result would be their breakup into alpha particles and a magnesium-24 nucleus.

Up to 17.7 MeV of kinetic energy from the reaction can be

FIGURE 2. J. ROBERT OPPENHEIMER in typical postures—at the blackboard and with a cigarette. His goal as scientific director of the Manhattan Project was to develop a nuclear device that exploded from the fission of uranium-235 and plutonium-239. (Illustration by David McMacken.)

The electron gas cools by inelastic scattering and by emitting bremsstrahlung in the form of a continuous x-ray spectrum. Because the atmosphere is transparent to that radiation, it loses energy. Konopinski, Teller, and Marvin found that the rate of gen content. Of even more concern were the tests of 20-megaton thermonuclear weapons (so-called hydrogen bombs), and scientists even considered the possibility of the fusion of ^{16}O atoms in ocean water.[2] Their explosions would increase the sudden energy release by up to three orders of magnitude. The uncertainties in the initial crude energy release and cooling calculations required experimental verification.

Experiment confirms theory

To experimentally clarify the troubling situation, a dedicated accelerator was built at Oak Ridge National Laboratory in the early 1950s, which made it possible to measure fusion cross sections for $^{14}N + {}^{14}N$, $^{16}O + {}^{16}O$, and other reactions of medium-heavy nuclei.[3] Alexander Zucker, one of the young scientists who was to measure the effective cross sections and who would later be director of Oak Ridge, noted that for security reasons he and other experimentalists were not directly told why there was interest in those data.

After the detonation of the Soviet 50-megaton "Tsar Bomba" in 1961 above Novaya Zemlya—a

fire-ball becomes transparent to photons, that can take energy off the fire-ball, limiting the maximum temperature down to a safe level

sphere is heated only to temperatures of a few million degrees, the energies of the fusing nuclei—a few hundred kiloeletron volts—are well below the Coulomb barrier, and the likelihood of fusion is low.

The Oak Ridge fusion tests were not confined to nitrogen and oxygen nuclei; they also included tests on light isotopes such as deuterium and tritium and were meant to inform Teller's plans and ideas for developing the "Super," his label for a thermonuclear weapon based on fusion. The idea for the fusion bomb based on the fusion of deuterium and tritium

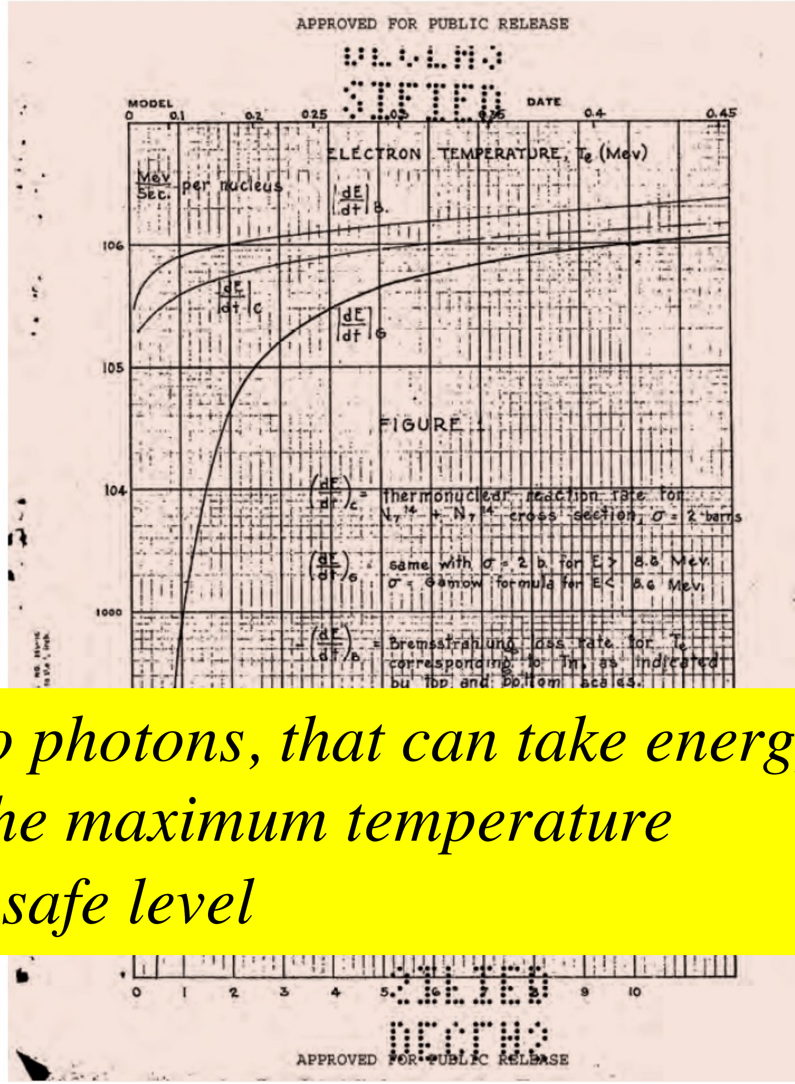


FIGURE 3. A CRITICAL PLOT of the rate of energy production as a function of temperature (in megaelectron volts), from the originally classified 1946 Los Alamos report *Ignition of the Atmosphere with Nuclear Bombs*.[1] Three curves characterize the energy-transport conditions for different temperatures in the nuclear fireball. The $(dE/dt)_C$ curve shows the reaction rate for the fusion of two nitrogen-14 nuclei when a constant cross section is assumed. The $(dE/dt)_G$ curve shows the $^{14}N + {}^{14}N$ fusion reaction rate when the cross section is assumed to rapidly decrease at low energies, as predicted by George Gamow. And the $(dE/dt)_B$ curve shows the radiative energy loss through x-ray emission, as predicted by Arthur Compton. (From ref. 1.)

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A. Compton 1923 - Direct Compton effect

J. Follin 1947 - Inverse Compton Scattering

*first published (non classified) study on ICS**

PROPAGATION OF COSMIC RAYS THROUGH

INTERSTELLAR SPACE

Thesis by

James Wightman Follin, Jr.

Second motivation to study ICS in the '40s was understanding why electrons are almost missing in cosmic rays bombarding the upper atmosphere

In Partial Fulfilment of the Requirements for the

Degree of Doctor of Philosophy

Both lines (nuclear bomb and astrophysics) were looking for a mechanism capable to transfer maximum energy from the electrons to the photons

California Institute of Technology

Pasadena, California

1947

* *but unknown and not credited in the whole literature on ICS*

Publication referenced by everybody in ICS community as the first published paper on ICS

PHYSICAL REVIEW VOLUME 73, NUMBER 5 MARCH 1, 1948

Interaction of Cosmic-Ray Primaries with Sunlight and Starlight*

E. Feenberg and H. Primakoff
Washington University, St. Louis, Missouri

(Received November 20, 1947)

This paper discusses collision processes between cosmic-ray primaries (protons and electrons) and the thermal photons of sunlight and starlight. In particular, electron-positron pair production and Compton scattering in interplanetary, intragalactic, and intergalactic space are treated in detail. It is found that the number of collisions between primary particles and thermal photons in single traversals energetic scattered photons. The same statement holds for the primary protons even on an intergalactic scale. On the other hand, energetic primary electrons may experience a sufficient number of Compton collisions in intergalactic space (travel time of the order 2×10^9 years) to eliminate them effectively from the cosmic radiation reaching the neighborhood of the earth.

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* The research described in this paper was supported in part by contract N60RI-117, U.S. Navy Department.

[1] T. H. Johnson, Rev. Mod. Phys. **11**, 208 (1939); M. Schein, W. P. Jesse, and E. O. Wollan, Phys. Rev. **59**, 615 (1941); **59**, 930 (1941).

[2] Collisions between high energy photons, considered as cosmic-ray primaries, and thermal photons, with resultant electron-positron pair creation have been considered by G. Breit and J. A. Wheeler, Phys. Rev. **46**, 1087 (1934); **45**, 134 (A) (1934). Extensive calculations similar to the present have been carried out by J. W. Follin, Bull. Am. Phys. Soc. July 11, 1947, Abstract D5. Through the courtesy of Dr. J. R. Oppenheimer, we have seen a manuscript copy of Dr. Follin's paper.

First idea by Milburn: use electron accelerators to perform Inverse Compton Scattering in the laboratory vs. the cosmos

PHYSICAL REVIEW LETTERS

VOLUME 10 | 1 FEBRUARY 1963 | NUMBER 3

ELECTRON SCATTERING BY AN INTENSE POLARIZED PHOTON FIELD*

Richard H. Milburn

Department of Physics, Tufts University, Medford, Massachusetts

(Received 26 December 1962)

Compton scattering by starlight quanta has been postulated by Feenberg and Primakoff to be a mechanism for the energy degradation of high-energy electrons in interstellar space.[1] We shall discuss here the possibility of observing this phenomenon directly in the laboratory by scattering a multi-GeV electron beam against the intense flux of visible photons produced by a typical laser. It will be shown that using existing laser systems and electron accelerators, one may expect to obtain of the order of several thousand collimated high-energy scattered photons during each accelerator pulse, and that these quanta retain to a high degree the polarization of the original beam of optical photons.

The kinematic formulas for Compton scattering on moving electrons are given by Feenberg and Primakoff.[2] We shall consider the special case of an extreme-relativistic electron of energy $E = \gamma mc^2$, $\gamma = 1/(1-\beta^2)^{1/2} \gg 1$, incident head-on upon a beam of photons of energy $k_i = (1-3)$ eV propagating in the opposite direction. An observer moving with the incident electron will see a photon of energy $k_0 = 2\gamma k_i$. In Table I are listed for various laboratory electron energies, E, the corresponding values of k_f tabulated in terms

The approximation fails only near $x = 1$, for which $k_f = k_i$ is required. However, for large $\gamma = E/mc^2$ the bulk of the scattered photons is folded back and emerges in the laboratory in the direction of motion of the incident electron, making angles with that direction given by $\theta = 2\tan(\frac{1}{2}\theta) = (1/\gamma) \times \cot(\frac{1}{2}\theta_0)$. Thus for 1-GeV electrons, all photons having $23° < \theta_0 < 180°$ will end up within 0.0025 radian of the electron direction. We shall confine our discussion to these high-energy quanta. The

Table I. Energy, λ, polarization, and cross section for highest energy photons produced by ruby-laser photons scattered on electrons of energy E. The quantity $\sigma_{1/2}$ is the cross section for higher half of k_f spectrum.

E (GeV)	λ	$(k_f)_{max}$ (MeV)	P_{max}	$\sigma_{1/2}$ (mb)
1.02	0.014	28	1.00	320
2.92	0.040	216	1.00	310
4.16	0.057	426	0.99	300
4.60	0.063	515	0.99	290
5.11	0.070	628	0.99	290
5.48	0.075	715	0.99	290
5.84	0.080	806	0.99	280

1) R. Rabinowitz et al., Proc. Inst. Radio Engrs. (correspondence) 50 (1962) 2365.
2) A. Javan, E. A. Ballik and W. L. Bond, J. Opt. Soc. Am. 52 (1962) 96.
3) S. Jacobs and P. Rabinowitz, Proc. of the 3rd Quantum Electronics Conf., Paris, 1963 (to be published).
4) K. D. Froome and R. H. Bradsell, J. Sci. Instr. 38 (1961) 458.
5) J. Terrien, J. phys. radium 19 (1958) 390.
6) G. R. Hanes, Can. J. Phys. 37 (1959) 1283.
7) C. F. Bruce and R. M. Hill, Australian J. Phys. 14 (1961) 64; 15 (1962) 152.
8) R.M.Hill and C.F.Bruce, Australian J. Phys. 15 (1962) 194.

* * * * *

Almost at the same time as Arutyunian and co-workers

THE COMPTON EFFECT ON RELATIVISTIC ELECTRONS AND THE POSSIBILITY OF OBTAINING HIGH ENERGY BEAMS

F. R. ARUTYUNIAN and V. A. TUMANIAN
Physical Institute of the State Committee of the Council of Ministers of the USSR for the Use of Atomic Energy

Received 20 February 1963

A characteristic feature of the Compton effect on relativistic electrons is the appearance of photons with energies exceeding those of the primary photons. As a result, even when light photons are scattered on extremely relativistic electrons, the energies of the scattered photons will be of the same order of magnitude as those of the electrons. This feature may possibly be exploited for obtaining high energy γ-ray beams in electron accelerators. An important point to be mentioned is that the characteristics of such γ-beams will significantly differ from those obtained by bremsstahlung.

In the Compton effect involving moving electrons

Of course in order to obtain γ-beams by the method considered here high photon fluxes will be required. A high intensity photon source that should be feasible is the laser. At present ruby lasers seem to be the most reliable.

For ruby laser photons (λ = 6943 Å) scattered on 6 GeV electrons one gets $\omega_{2\ \max.}$ = 848 MeV. This effect rapidly grows with increase of the electron energy. Thus for the same ruby lasers and ϵ_1 = 40 and 500 GeV the maximal energy is correspondingly $\omega_{2\ \max.} \sim$ 21 and 497 GeV.

Of course if lasers emitting shorter wave lengths or other sources of high energy photons be employed,

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

Theoretical and simulation studies of characteristics of a Compton light source

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(Received 25 January 2011; published 21 April 2011)

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **14**, 050703 (2011)

Design of narrow-band Compton scattering sources for nuclear resonance fluorescence

F. Albert,* S. G. Anderson, D. J. Gibson, R. A. Marsh, S. S. Wu, C. W. Siders, C. P. J. Barty, and F. V. Hartemann

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(Received 20 December 2010; published 13 May 2011)

Reviews of Accelerator Science and Technology
Vol. 3 (2010) 147–163
© World Scientific Publishing Company
DOI: 10.1142/S1793626810000440

World Scientific
www.worldscientific.com

Many studies in the literature on electron-photon beam collisions collective/statistical properties (phase spaces, etc)

Compton Sources of Electromagnetic Radiation*

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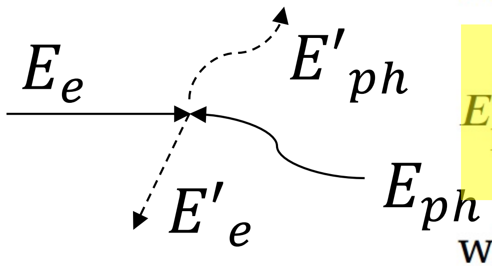


Considering the Compton interaction between photon pulses and counter-propagating electrons, we can derive the well-known equation for the photon energy ($E'_{\mathrm{ph}} = \hbar\omega'$, with ω' being the photon angular frequency and $\hbar$ the reduced Planck constant) scattered at an angle θ. Following the notation of Eq. 3 in Ref. [18], we can write:

$$E'_{\mathrm{ph}}(\theta) = \frac{(1+\beta)\gamma^2}{\gamma^2(1-\beta\cos\theta) + \frac{X}{4}(1+\cos\theta)} E_{\mathrm{ph}}, \tag{1}$$

where the incident photon energy is $E_{\mathrm{ph}} = \hbar\omega$, $\beta = v_e/c$ is the dimensionless electron velocity v_e (c being the speed of light), $\gamma = 1/\sqrt{1-\beta^2}$ is electron Lorentz factor and X is the electron recoil factor that introduces an important contribution at high energy of both incident photons and electrons. X has been defined in [17] (eq. 4) as:

$$X = \frac{4E_e E_{\mathrm{ph}}}{(m_0c^2)^2} = \frac{4\gamma E_{\mathrm{ph}}}{m_0c^2} = 4\gamma^2\frac{E_{\mathrm{ph}}}{E_e}, \tag{2}$$

with m_0 the electron rest mass and $E_e = \gamma m_0 c^2$. Eq. (1) can be cast in a more schematic form as a function of the incident particle energies.

$$E'_{\mathrm{ph}} = \frac{(1+\beta)\,E_{\mathrm{ph}}E_e}{(1-\beta\cos\theta)\,E_e + (1+\cos\theta)\,E_{\mathrm{ph}}}$$

Inverse Compton Scattering of photons on relativistic electrons

$$E'_{ph} = \frac{4\gamma^2 E_{ph}}{1 + \gamma^2 \vartheta^2 + X}$$

$$X = \frac{4 E_{ph} E_e}{(mc^2)^2}$$

Thomson limit: X << 1

$$E'_{ph} = \frac{4\gamma^2 E_{ph}}{1 + \gamma^2 \vartheta^2}$$

Deep recoil Compton: X >> 1

$$E'_{ph} \sim \left(1 - \frac{1}{X}\right) E_e \quad ; \quad E'_e \sim mc^2$$

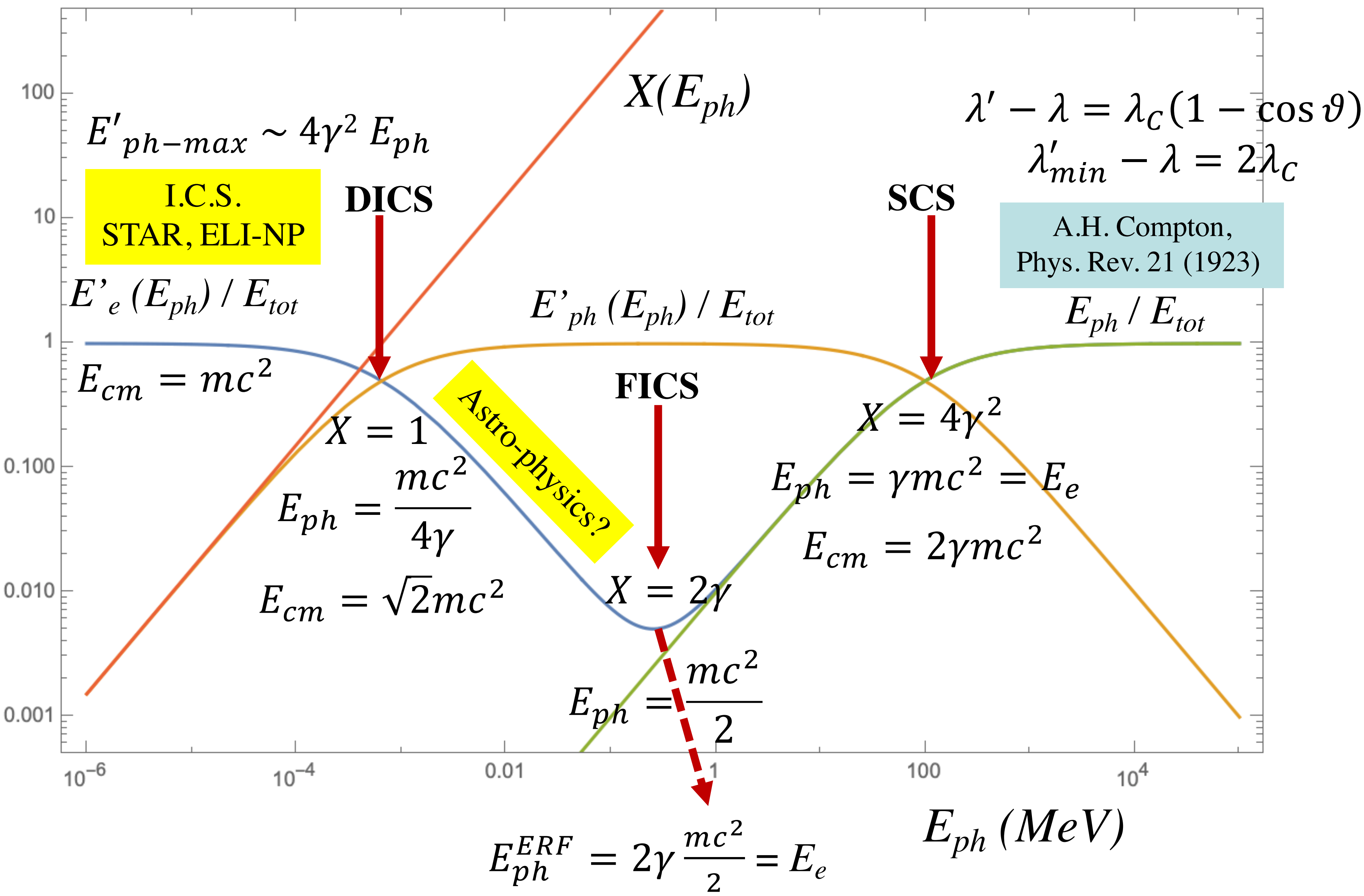
$$note\ that\ \ E_{cm} = mc^2\sqrt{1 + X}\,, \qquad if\ X \gg 1 \Rightarrow X \sim \left(\frac{E_{cm}}{mc^2}\right)^2$$

$$\frac{E'_{ph}}{E_{tot}} = \frac{X}{(1+X)(1+\frac{X}{4\gamma^2})}$$

$$\frac{E'_{e}}{E_{tot}} = 1 - \frac{X}{(1+X)(1+\frac{X}{4\gamma^2})}$$

All quantities normalized to the total energy $E_{tot} = E_e + E_{ph}$

E_e = 100 MeV



Relevance of recoil in electron-photon beam-beam collisions

PHYSICAL REVIEW ACCELERATORS AND BEAMS **20,** 080701 (2017)

Analytical description of photon beam phase spaces in inverse Compton scattering sources

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(Received 9 March 2017; published 3 August 2017)

PHYSICAL REVIEW ACCELERATORS AND BEAMS **21,** 030701 (2018)

Simulation of inverse Compton scattering and its implications on the scattered linewidth

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(Received 17 November 2017; published 6 March 2018)

Istituto Nazionale di Fisica Nucleare

applied sciences

MDPI

Article

Electrons and X-rays to Muon Pairs (EXMP)

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Fundamental Plasma Physics 7 (2023) 100026

Contents lists available at ScienceDirect

Fundamental Plasma Physics

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

ELSEVIER

Original research article

Symmetric Compton Scattering: A way towards plasma heating and tunable mono-chromatic gamma-rays

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PHYSICAL REVIEW ACCELERATORS AND BEAMS **19,** 020702 (2016)

Narrow-band GeV photons generated from an x-ray free-electron laser oscillator

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(Received 17 July 2015; published 16 February 2016)

We propose a scheme to generate narrow-band GeV photons, γ-rays, via Compton scattering of hard x-ray photons in an x-ray free-electron laser oscillator. Generated γ-rays show a narrow-band spectrum with a sharp peak, ~0.1% (FWHM), due to large momentum transfer from electrons to photons. The γ-ray beam has a spectral density of $\sim 10^2$ ph/(MeV s) with a typical set of parameters based on a 7-GeV electron beam operated at 3-MHz repetition, Such γ-rays will be a unique probe for studying hadron physics. Features of the γ-ray source, flux, spectrum, polarization, tunability and energy resolution are discussed.

DOI: 10.1103/PhysRevAccelBeams.19.020702

Deep Recoil
and its 2 benefits:
spectral purification
and
suppression of $\gamma^2\theta^2$ desease

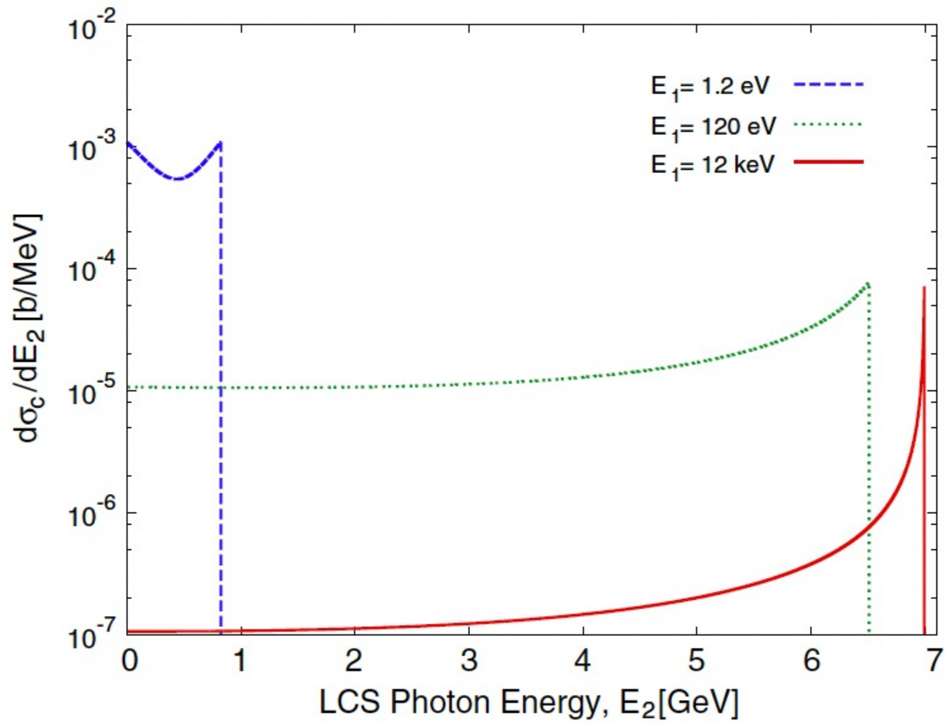

FIG. 3. Energy-differential cross section of Compton scattering for 7 GeV electrons and laser photons at three different energies of 1.2 eV, 120 eV and 12 keV.

Largest value of recoil factor X achieved in experiments so far is *X=1.8* at SLAC in 1999

PHYSICAL REVIEW D, VOLUME 60, 092004

Studies of nonlinear QED in collisions of 46.6 GeV electrons with intense laser pulses

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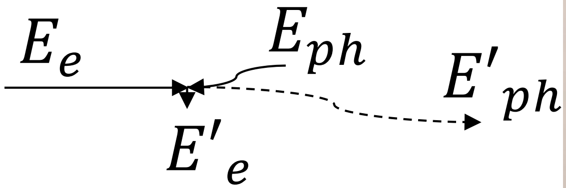
(Received 1 February 1999; published 8 October 1999)

We report on measurements of quantum electrodynamic processes in an intense electromagnetic wave, where nonlinear effects (both multiphoton and vacuum polarization) are prominent. Nonlinear Compton scattering and electron-positron pair production have been observed in collisions of 46.6 GeV and 49.1 GeV electrons of the Final Focus Test Beam at SLAC with terawatt pulses of 1053 nm and 527 nm wavelengths from a Nd:glass laser. Peak laser intensities of $\approx 0.5\times 10^{18}$ W/cm^2 have been achieved, corresponding to a value of ≈ 0.4 for the parameter $\eta = eE_{\rm rms}/m\omega_0 c$ and to a value of ≈ 0.25 for the parameter $\Upsilon_e = E^\star_{\rm rms}/E_{\rm crit} = eE^\star_{\rm rms}\hbar/m^2c^3$, where $E^\star_{\rm rms}$ is the rms electric field strength of the laser in the electron rest frame. We present data on the scattered electron spectra arising from nonlinear Compton scattering with up to four photons absorbed from the field. A convolved spectrum of the forward high energy photons is also given. The observed positron production rate depends on the fifth power of the laser intensity, as expected for a process where five photons are absorbed from the field. The positrons are interpreted as arising from the collision of a high-energy Compton scattered photon with the laser beam. The results are found to be in agreement with theoretical predictions. [S0556-2821(99)02519-9]

PACS number(s): 13.40.−f, 12.20.Fv, 13.10.+q, 42.65.−k

Colliding the XFEL photon beam (12 keV) with the 19.5 GeV electron beam would achieve *X=3585* !!!



$E'_e = \mathrm{m}c^2$

$T'_e = 0$

Let’s focus on the “turning point” where electron starts to be back-scattered: FICS - Full Inverse Compton Scattering

$$\beta\gamma mc^2 - E_{ph} = 0 + E'_{ph}$$

$$\gamma mc^2 + E_{ph} = mc^2 + E'_{ph}$$

$$E_{ph} = \frac{mc^2}{2}\left(1 - (1-\beta)\gamma\right)$$

$$E'_{ph} = mc^2\left(\gamma\,\frac{1+\beta}{2} - \frac{1}{2}\right)$$

$$E_e = \gamma mc^2$$

$$E'_e = mc^2$$

for any value of γ !

$$
\begin{cases}
E_{ph} = \dfrac{mc^2}{2}\left(1 - (1-\beta)\gamma\right) \\[2ex]
E'_{ph} = mc^2\left(\gamma\,\dfrac{1+\beta}{2} - \dfrac{1}{2}\right) \\[2ex]
E_e = \gamma mc^2 \\[2ex]
E'_e = mc^2
\end{cases}
$$

From Compton Scattering of photons on targets to Inverse Compton Scattering of electron and photon beams

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(Dated: May 2, 2024)

arXiv:2405.00343v1 [physics.acc-ph] 1 May 2024

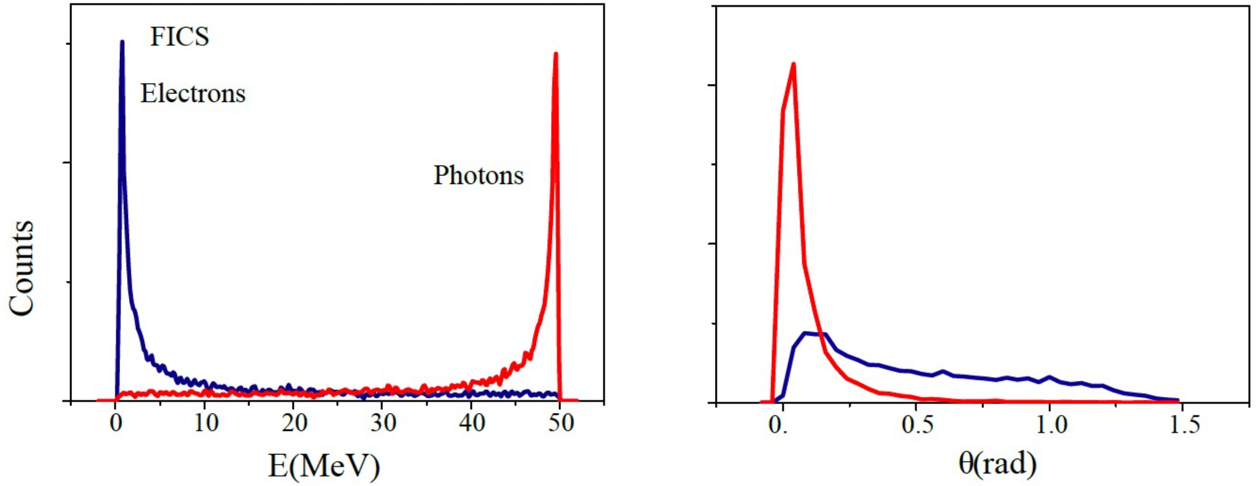
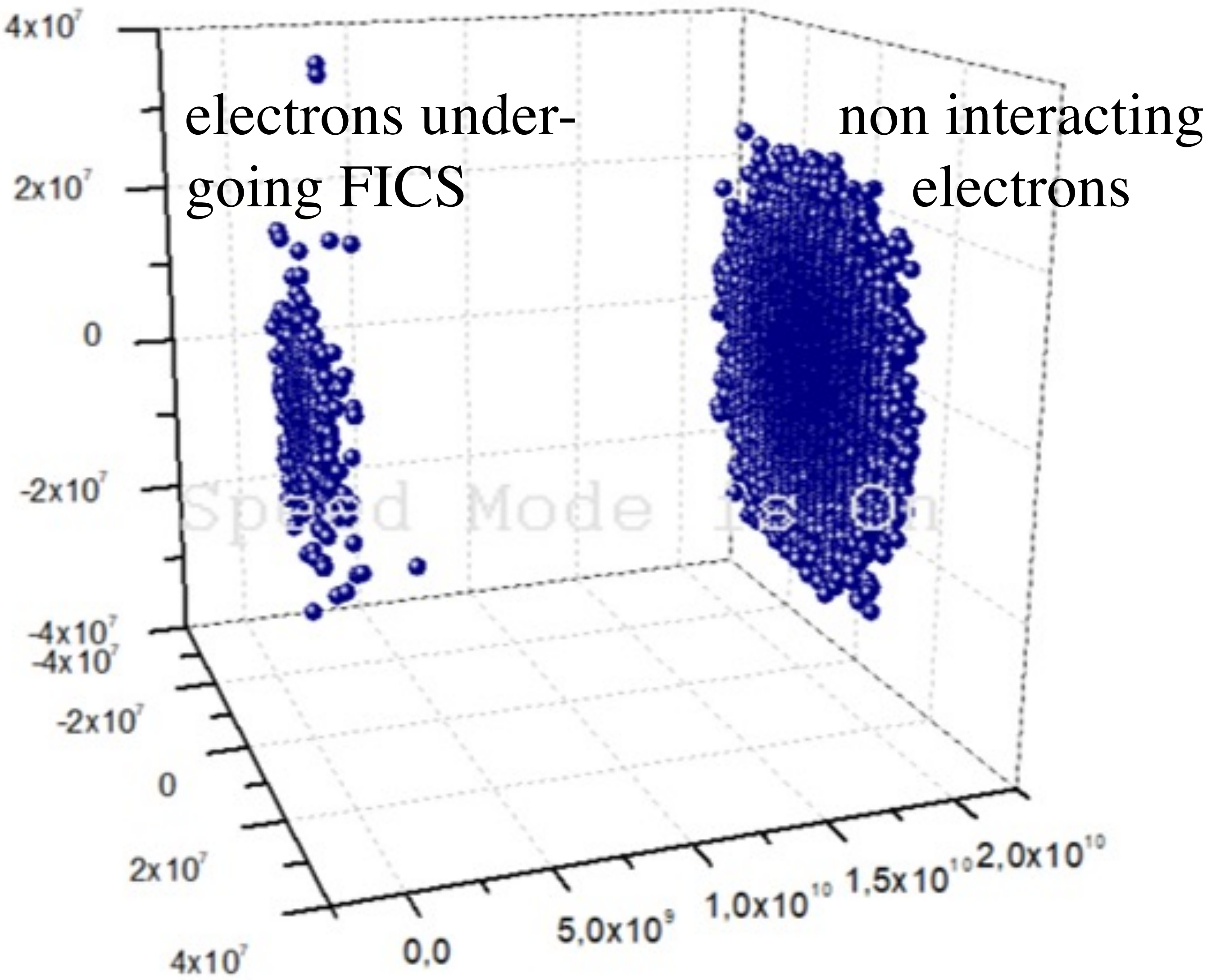


FIG. 5: Full Inverse Compton Scattering (FICS). Left: energy distribution, right: angular distribution. Red: scattered photons, blue:scattered electrons.$E_{ph} = 255.5 keV$, E_e=50 MeV, $bw_{ph} = 5\%$

V. Petrillo, ad-hoc developed Montecarlo code for linear QED

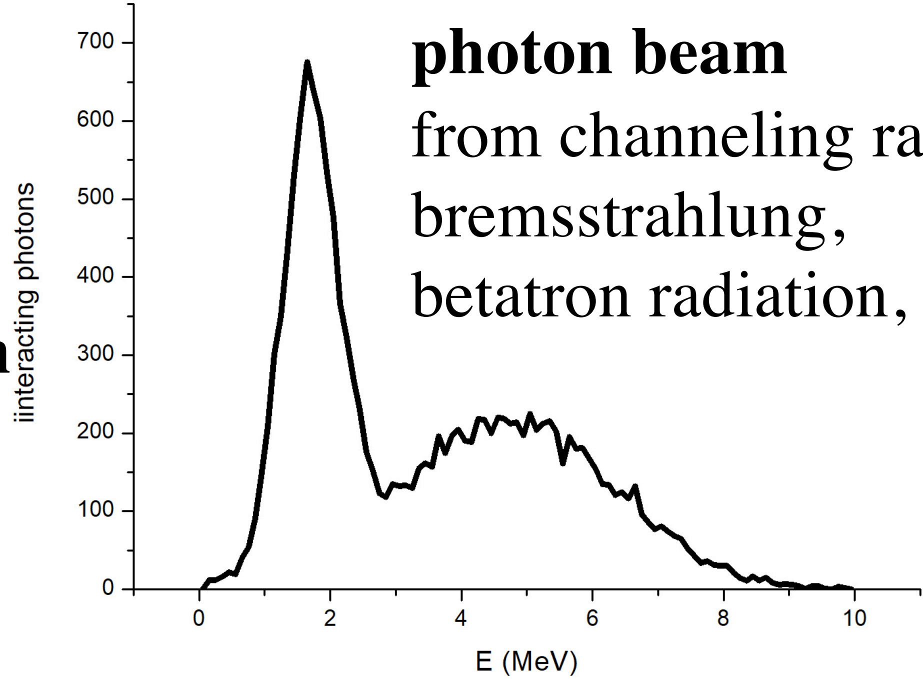
$E_e = 200\ MeV$; $E_{ph}=255.5\ keV$

electron momenta distribution after FICS

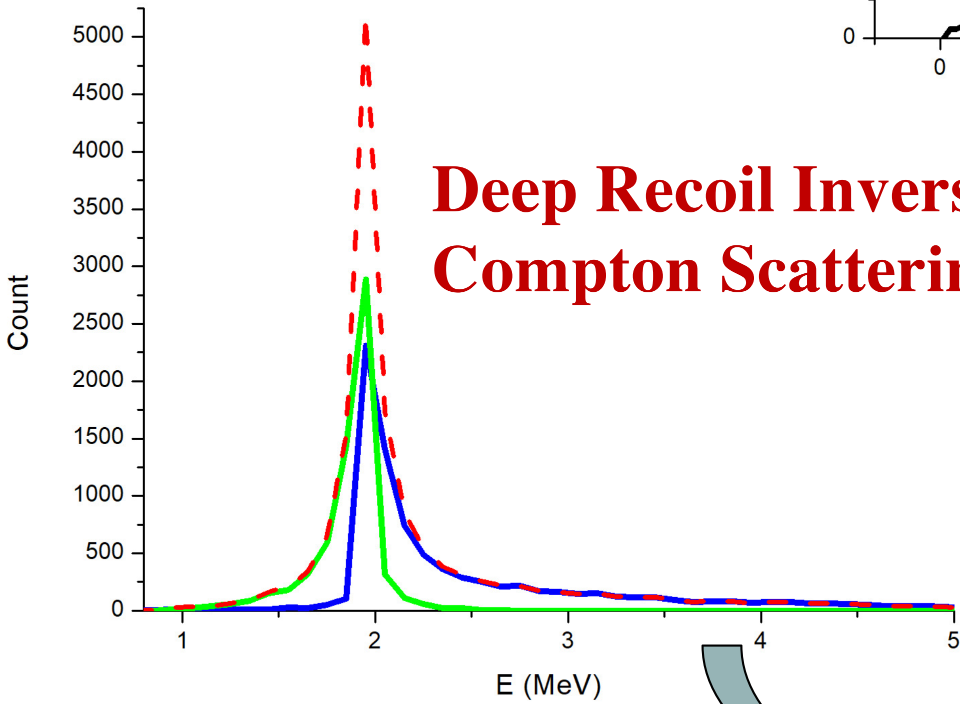


Broad-band incident photon beam

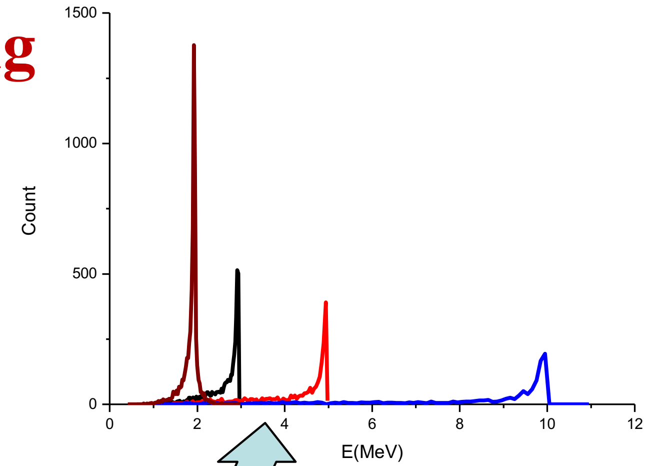
from channeling radiation,
bremsstrahlung,
betatron radiation, etc



spectral purification



Deep Recoil Inverse Compton Scattering



tunability

The Unruh effect gives rise to a Planckian photon spectral distribution at a temperature

$$T = \frac{\hbar a}{2\pi k_B c}, \tag{91}$$

where a is the acceleration and k_B the Boltzmann con-

The **Unruh temperature**, sometimes called the Davies–Unruh temperature,[5] was derived separately by Paul Davies[3] and William Unruh[4] and is the effective temperature experienced by a uniformly accelerating detector in a vacuum field. It is given by[6]

$$T = \frac{\hbar a}{2\pi c k_B} \approx 4.06 \times 10^{-21}\ \mathrm{K \cdot s^2 \cdot m^{-1}} \times a,$$

where $\hbar$ is the reduced Planck constant, a is the proper uniform acceleration, c is the speed of light, and k_B is the Boltzmann constant. Thus, for example, a proper acceleration of 2.47×10^{20} m·s^{-2} corresponds approximately to a temperature of 1 K. Conversely, an acceleration of 1 m·s^{-2} corresponds to a temperature of 4.06×10^{-21} K.

Black-hole $a=10^{10}$ $T=4.1\cdot 10^{-11}$ K

Plasma acceleration (100 GV/m) $a=1.8\cdot 10^{22}$ $T=74$ K

?? ***how about FICS*** ??

PRL 97, 121302 (2006) PHYSICAL REVIEW LETTERS week ending 22 SEPTEMBER 2006

Signatures of the Unruh Effect from Electrons Accelerated by Ultrastrong Laser Fields

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(Received 18 April 2006; revised manuscript received 23 June 2006; published 22 September 2006; publisher error corrected 22 September 2006)

We calculate the radiation resulting from the Unruh effect for strongly accelerated electrons and show that the photons are created in pairs whose polarizations are perfectly correlated. Apart from the photon statistics, this quantum radiation can further be discriminated from the classical (Larmor) radiation via the different spectral and angular distributions. The signatures of the Unruh effect become significant if the external electromagnetic field accelerating the electrons is not too far below the Schwinger limit and might be observable with future facilities. Finally, the corrections due to the birefringent nature of the QED vacuum at such ultrahigh fields are discussed.

Unruh radiation during FICS and SCS

$$a_{FICS} = \frac{\Delta v}{\Delta t} = \frac{c-0}{\frac{1}{\nu'_{ph}}} = \frac{c}{\frac{h}{E'_{ph}}} \overset{FICS}{\simeq} \frac{cE_e}{h}$$

$$a_{FICS}\,(m/s^2) = 7.3 \cdot 10^{28} * E_e(MeV)$$

$$T_{Unruh\text{-}FICS}\,(K) = 3.1 \cdot 10^{8} * E_e(MeV)$$

$$T_{Unruh\text{-}FICS}\,(MeV) = 0.026 * E_e(MeV)$$

going from 100 MeV up to 2 GeV electrons the Unruh photons at FICS would cover the 2.6 – 52 MeV range (easy detection in vacuum with low background)

$$a_{SCS} = 2 \cdot a_{FICS}$$

but *E_{ph} must be = E_e in SCS, while in FICS E_{ph} = 255.5 keV*

Conclusions

Old Physics revisited shows new regimes of extreme electron-photon beam collisions with potentials towards:

New generation Radiation Sources based on Spectral Purification (ICS in deep recoil)

Amazing tests of stopping ultra-relativistic electrons in vacuum, attaining extreme accelerations (many orders of magnitude higher than any other mechanism)

Trapping/charging plasma mirror devices with electrons via S.C.S.

Universe opacity to high energy (TeV, PeV) photons: a Compton relay based on FICS&Breit-Wheeler cosmic cascade. Cosmic gamma ray sources and the role of FICS.

Istituto Nazionale di Fisica Nucleare

Grazie per l'attenzione