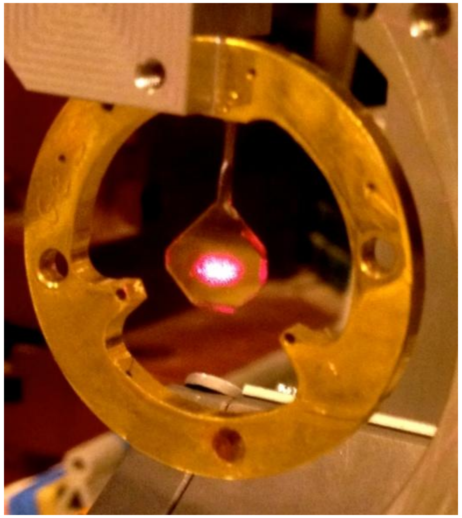
Small Amplitude Short Period Crystal Undulators
- a New Type of Gamma-Ray Source



Ulrik I. Uggerhøj
Department of Physics and Astronomy
Aarhus University, Denmark

On behalf of the collaborations CERN NA63 and SLAC E-212

Strong field effects
- crystalline targets

Strong fields

- Strong – compared to what?

relativistic (c) quantum ($\hbar$) field for electrons (m, e)

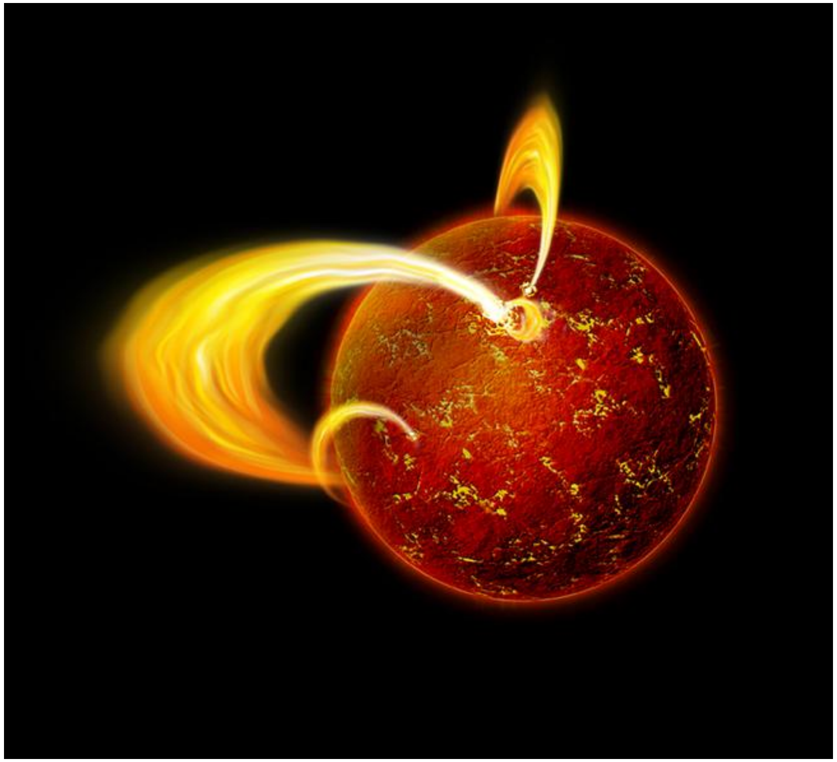
- The critical field:

$$\mathcal{E}_0 = m^2c^3/e\hbar$$
$$= 1.32 \times 10^{16}\ \mathrm{V/cm}$$

$$B_0 = 4.41 \times 10^9\ \mathrm{T}$$

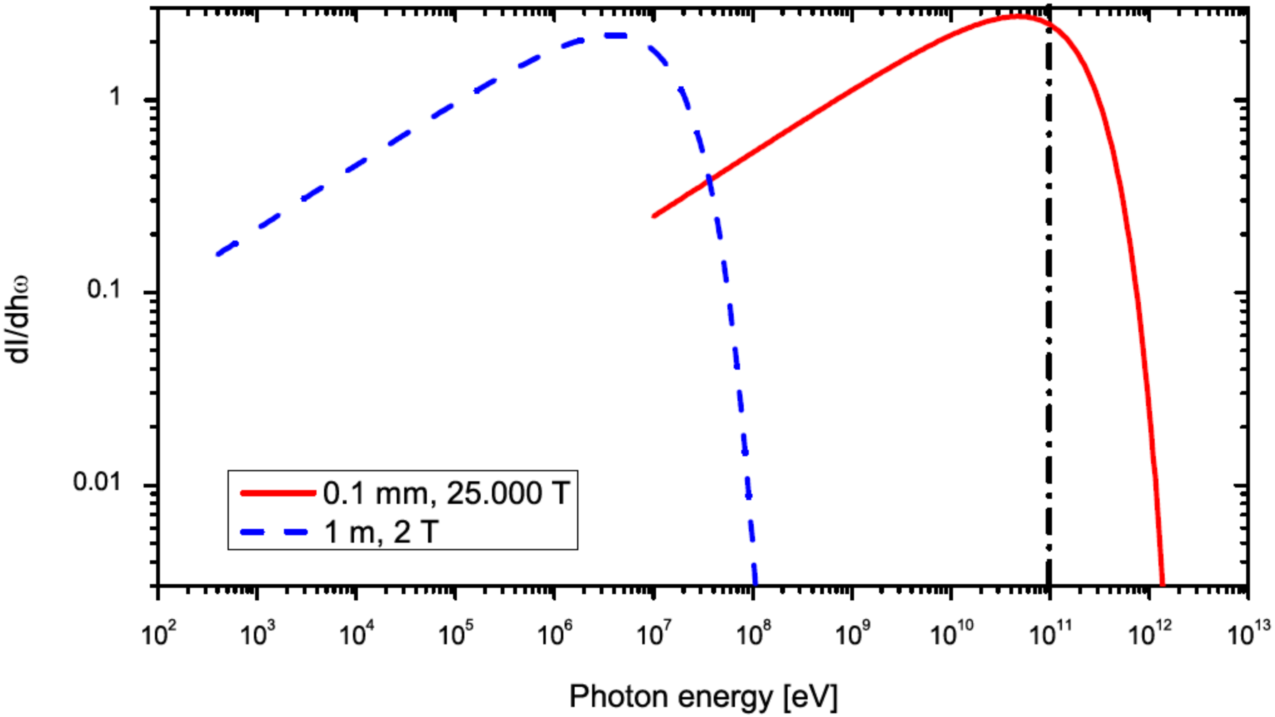
Relativistic invariant:

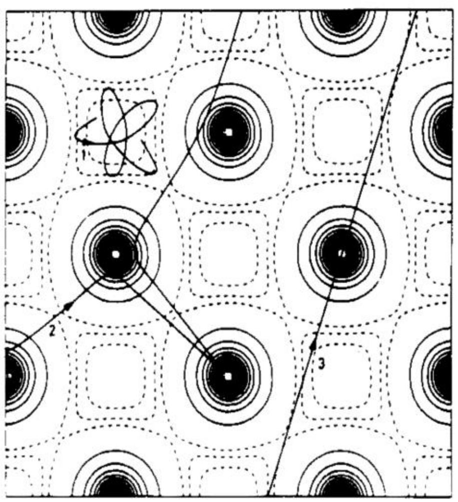
$$\chi = \gamma\mathcal{E}/\mathcal{E}_0$$

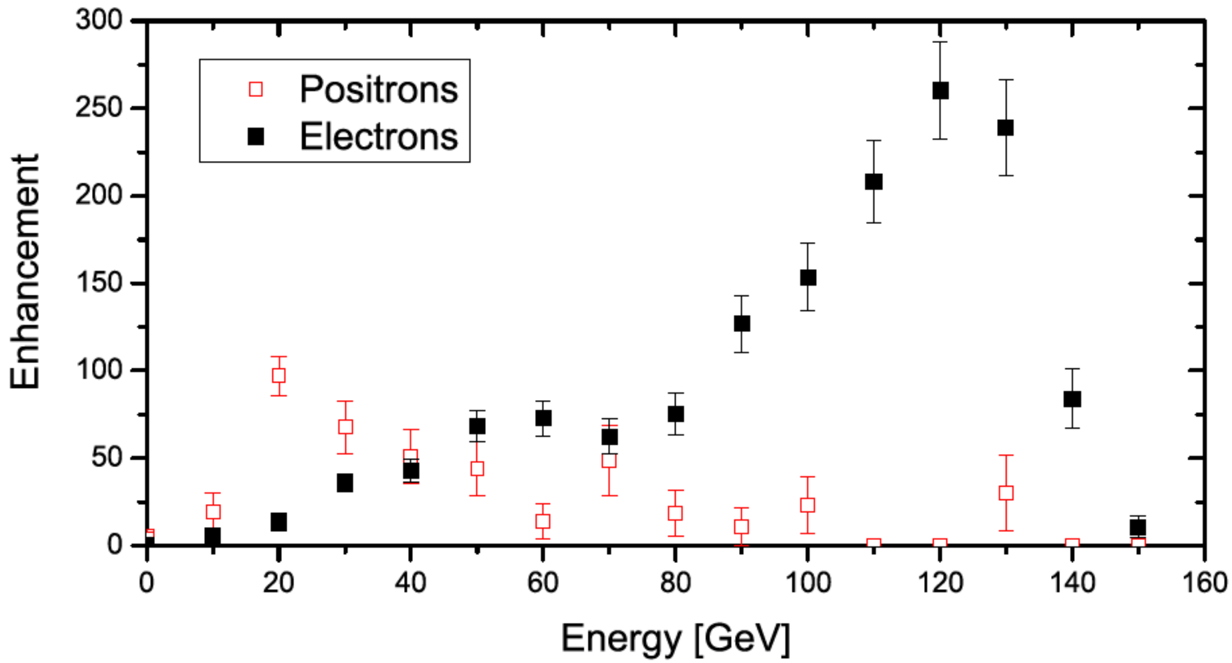


Radiation emission

$$\chi = \gamma \mathcal{E} / \mathcal{E}_0$$







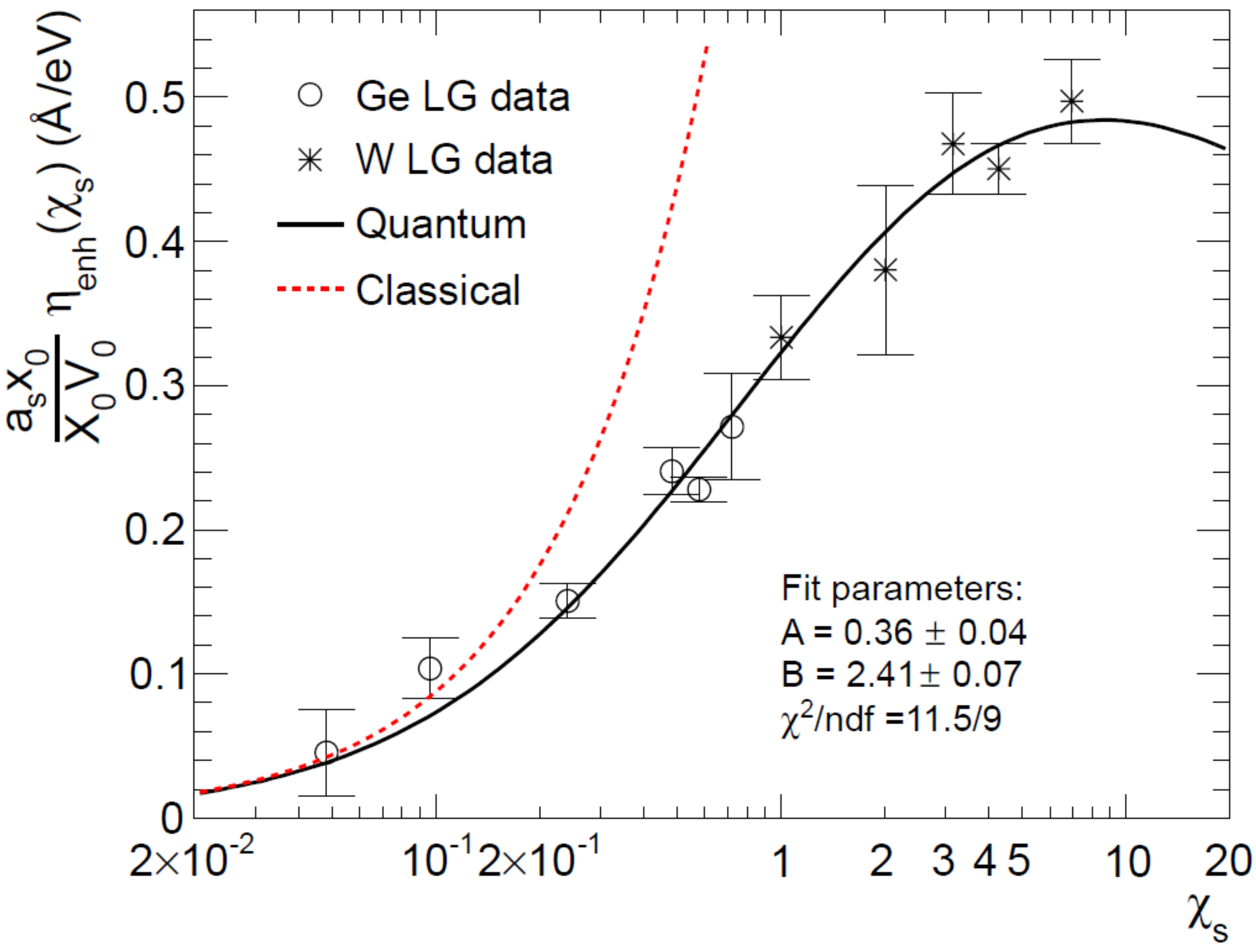
PHYSICAL REVIEW D 86, 072001 (2012)

Experimental investigations of synchrotron radiation at the onset of the quantum regime

K. K. Andersen,[1] J. Esberg,[1] H. Knudsen,[1] H. D. Thomsen,[1] U. I. Uggerhøj,[1] P. Sona,[2] A. Mangiarotti,[3]
T. J. Ketel,[4] A. Dizdar,[5] and S. Ballestrero[6]

(CERN NA63)

$$\frac{I_e}{I_{\mathrm{cl}}} = (1 + 4.8(1+\chi)\ln(1+1.7\chi) + 2.44\chi^2)^{-2/3}.$$



Classical ->
Quantum
synchrotron

Beamstrahlung – synchr.rad.

PHYSICAL REVIEW D VOLUME 36, NUMBER 1 1 JULY 1987

Quantum treatment of beamstrahlung

Richard Blankenbecler and Sidney D. Drell

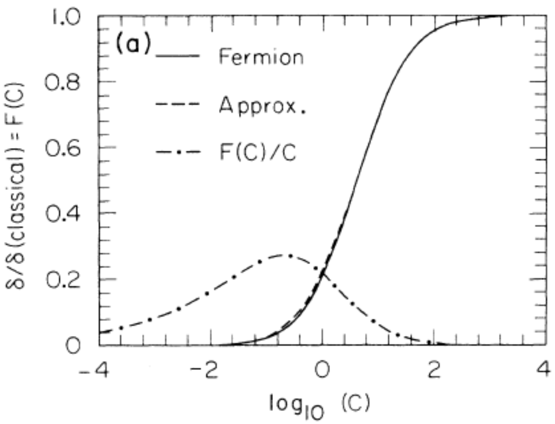
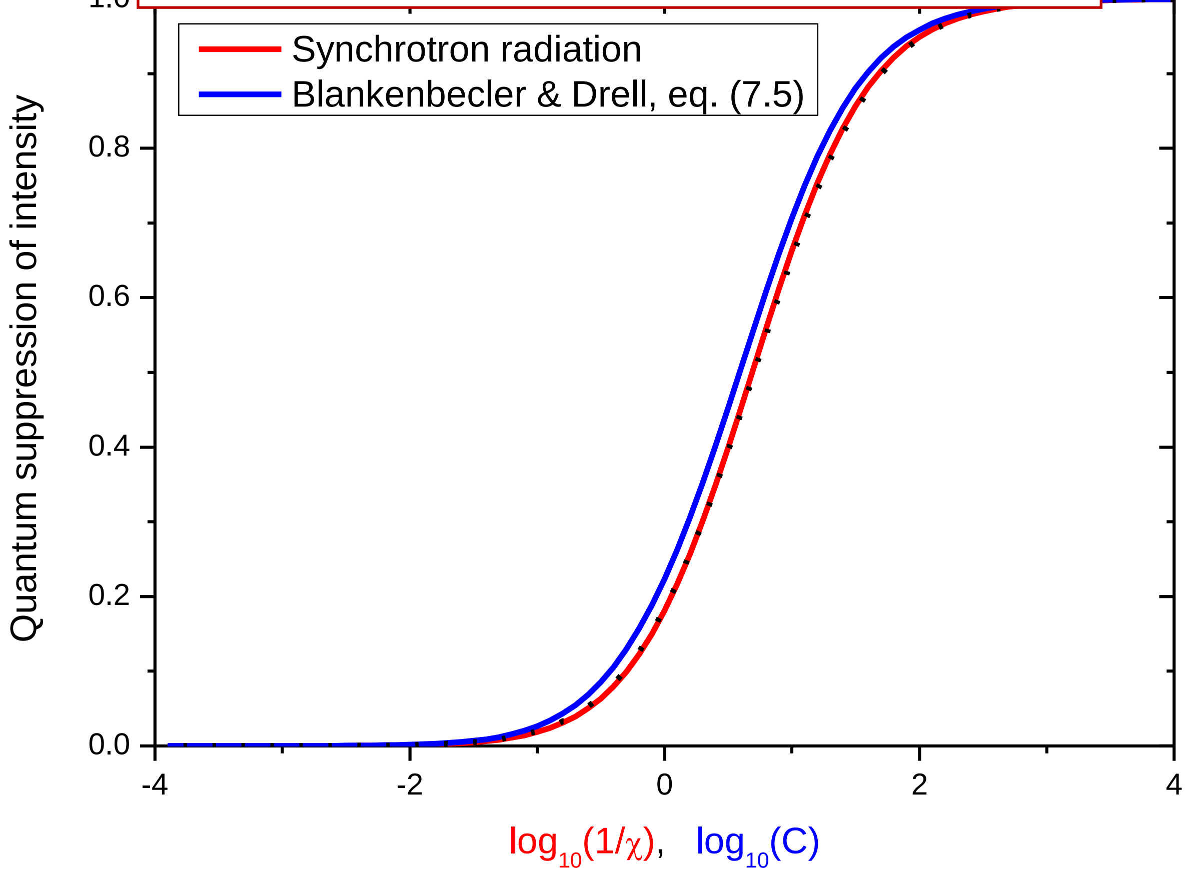


FIG. 1. (a) The form factor

From their paper

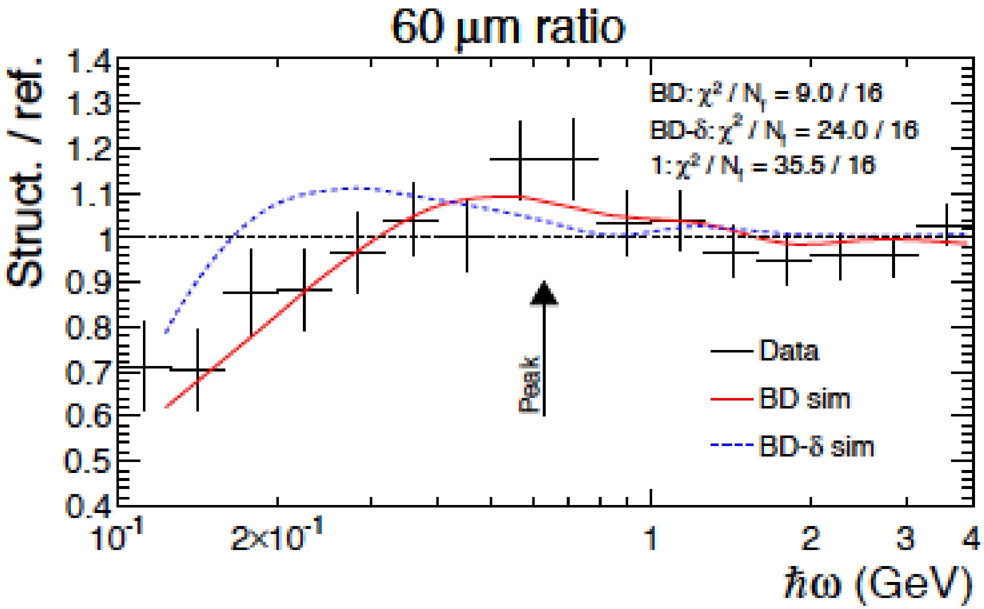
$$\frac{I_e}{I_{\mathrm{cl}}} = (1 + 4.8(1+\chi)\ln(1+1.7\chi) + 2.44\chi^2)^{-2/3}.$$

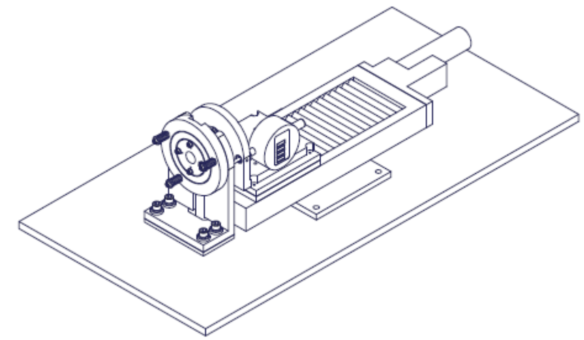


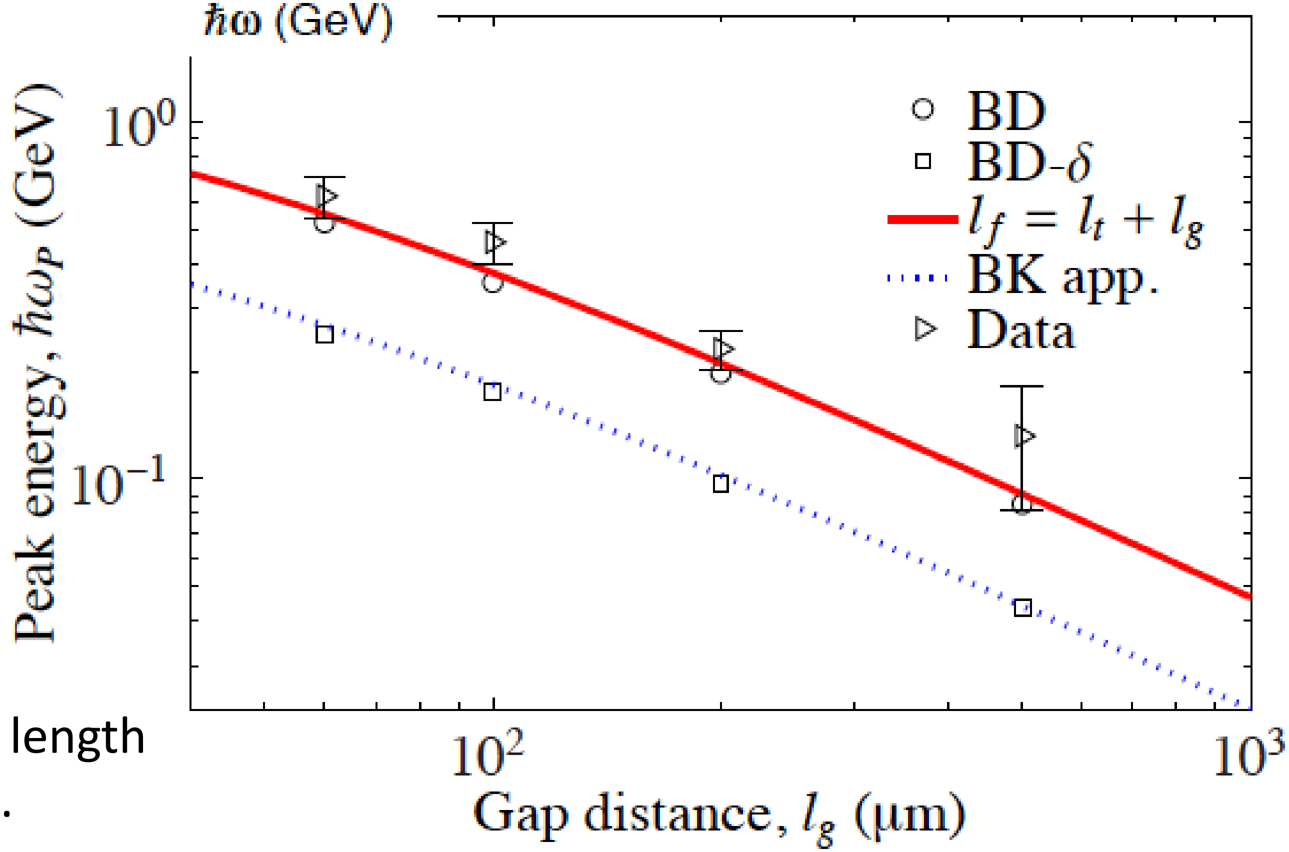
Our curves, supported by meas. in crystals

Formation length effects
- amorphous targets

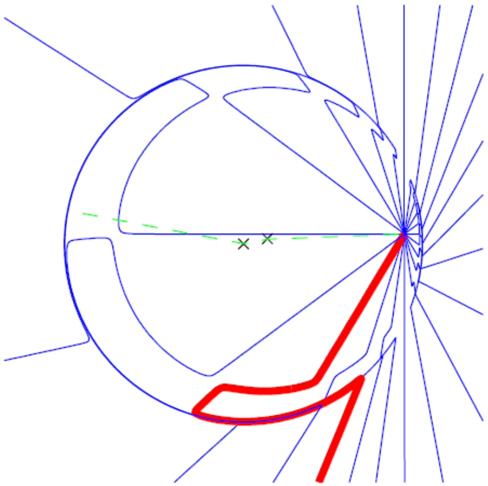
Structured targets







Measuring the formation length with a micrometer screw....



Logarithmic t dependence

Transition between Bethe-Heitler and LPM regimes:

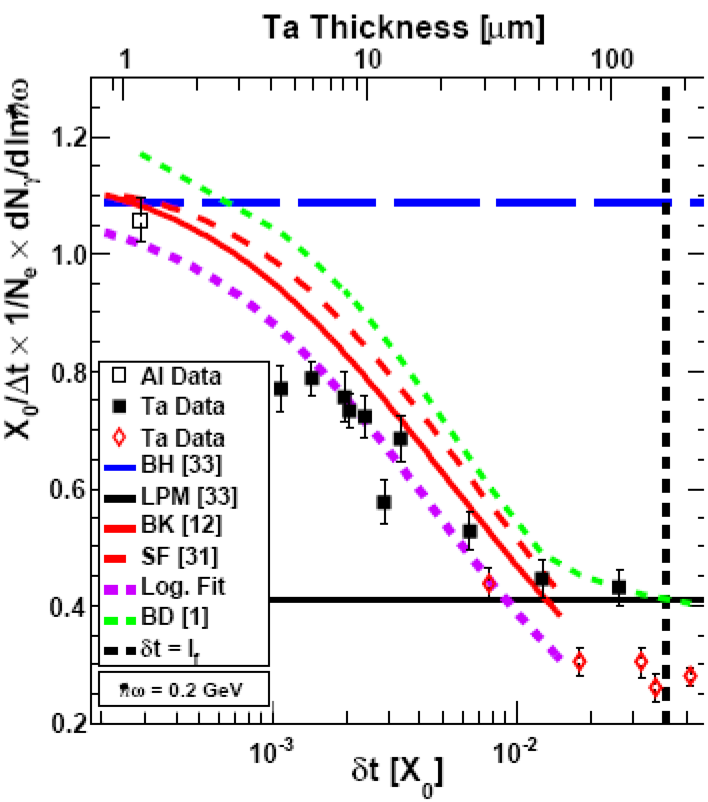
$$1/N_e \times \frac{dN_\gamma}{d\ln\hbar\omega}$$

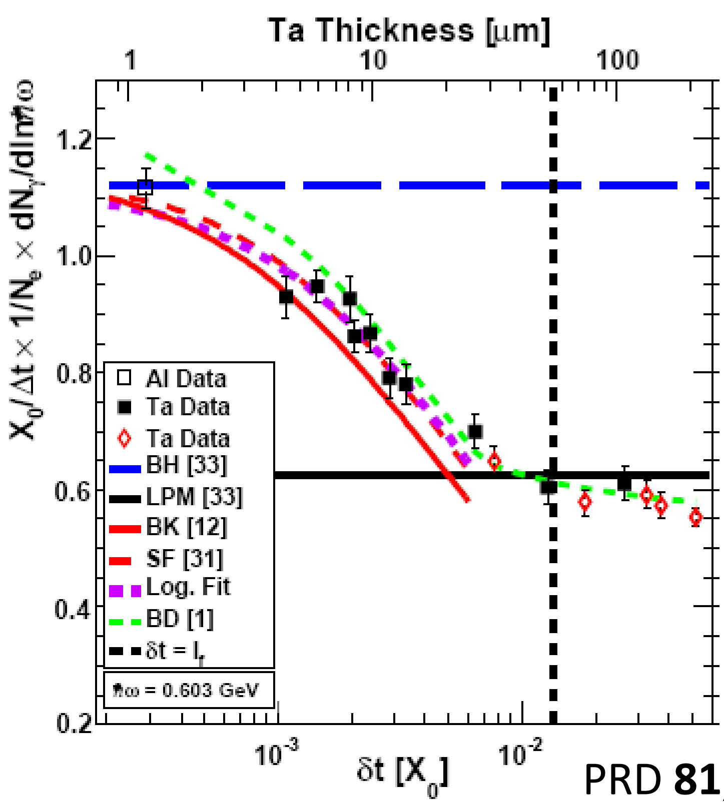
$$\simeq a \times \frac{\ln(b\times\delta t+1)}{b\times\delta t}$$

$$\boxed{\ln(b\times\delta t+1)}$$

$$\boxed{b = 2\pi/3\alpha X_0 \simeq 287/X_0}$$

'Radiation per interaction as a function of number of scatterings'



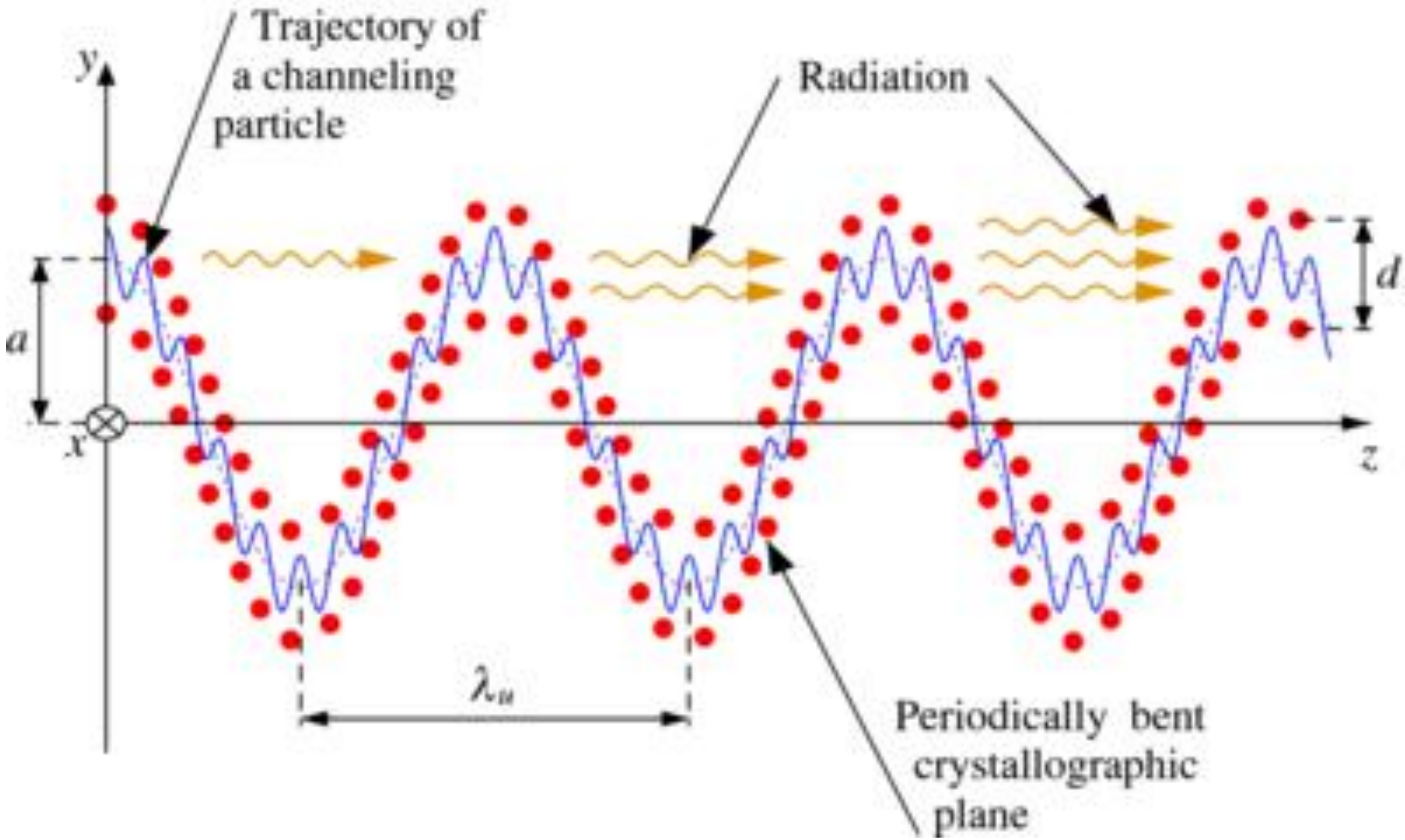


PRD **81**, 052003 (2010)

Crystalline undulators

Undulator Radiation
from **Positron** Channeling in a Single Crystal

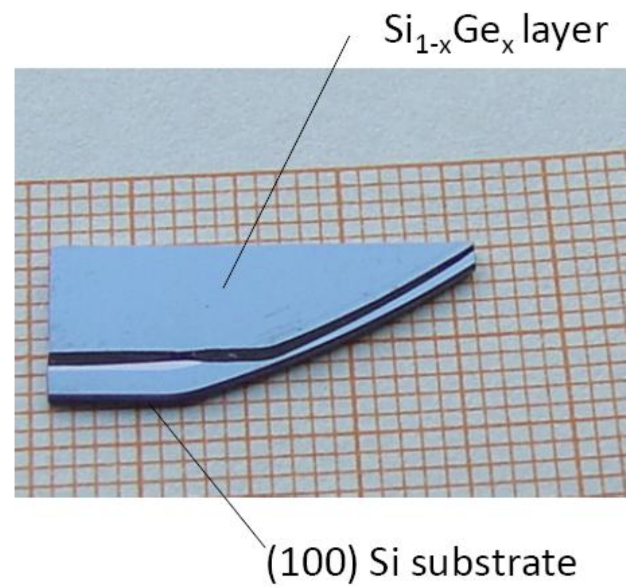
A. Solov'yov, A. Korol, W. Greiner *et al.*



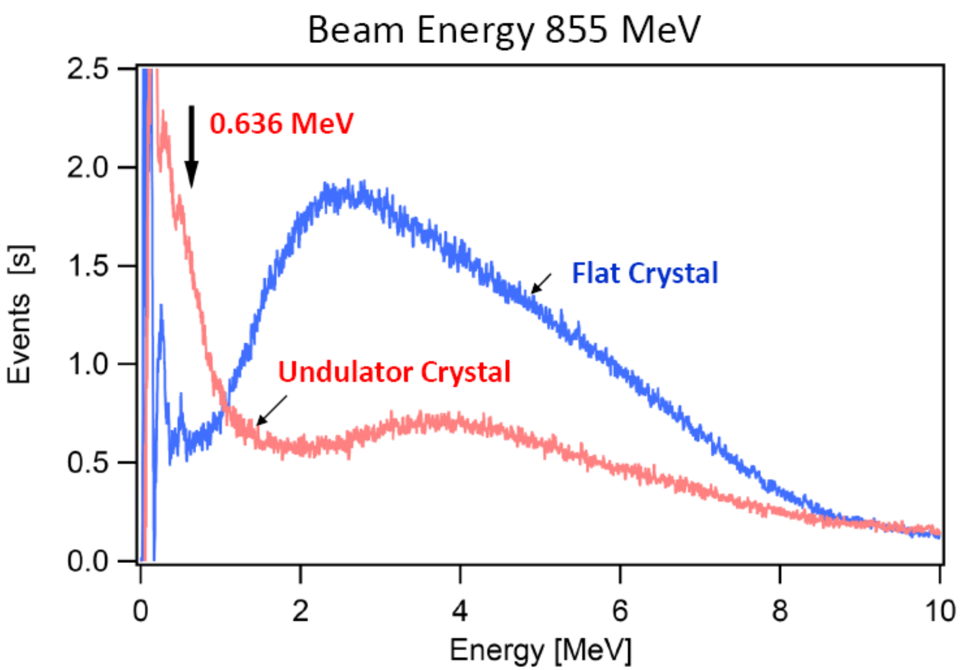
Crystalline undulator radiation (?)

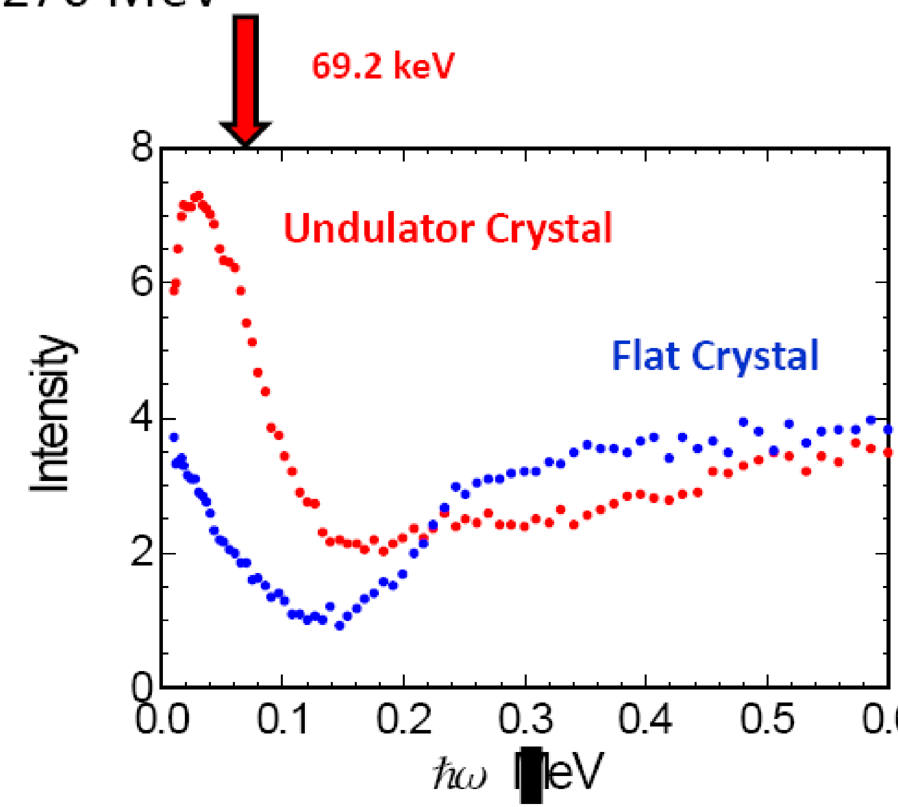
H. Backe(1), D. Krambrich(1), W. Lauth(1),
J. Lundsgaard Hansen (2) and Ulrik I. Uggerhøj (2)

IL NUOVO CIMENTO C **34**, 175 (2011)

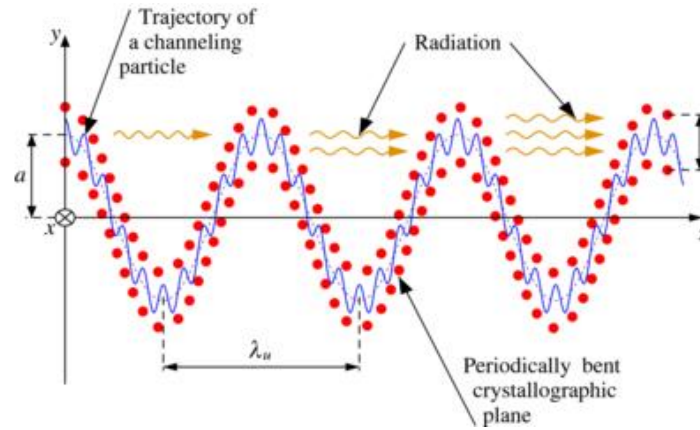


Electrons





Large amplitude, long period (LALP):

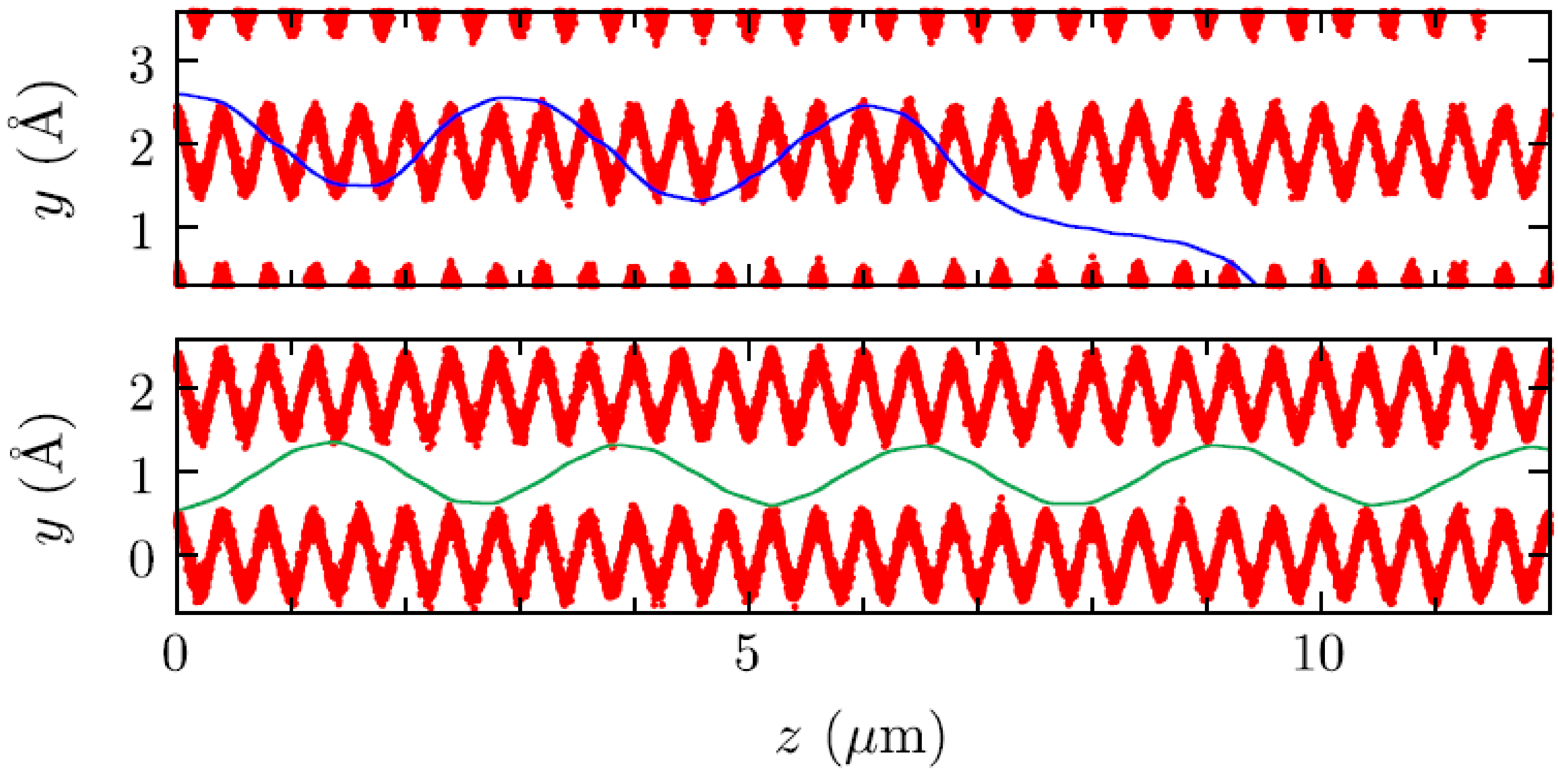


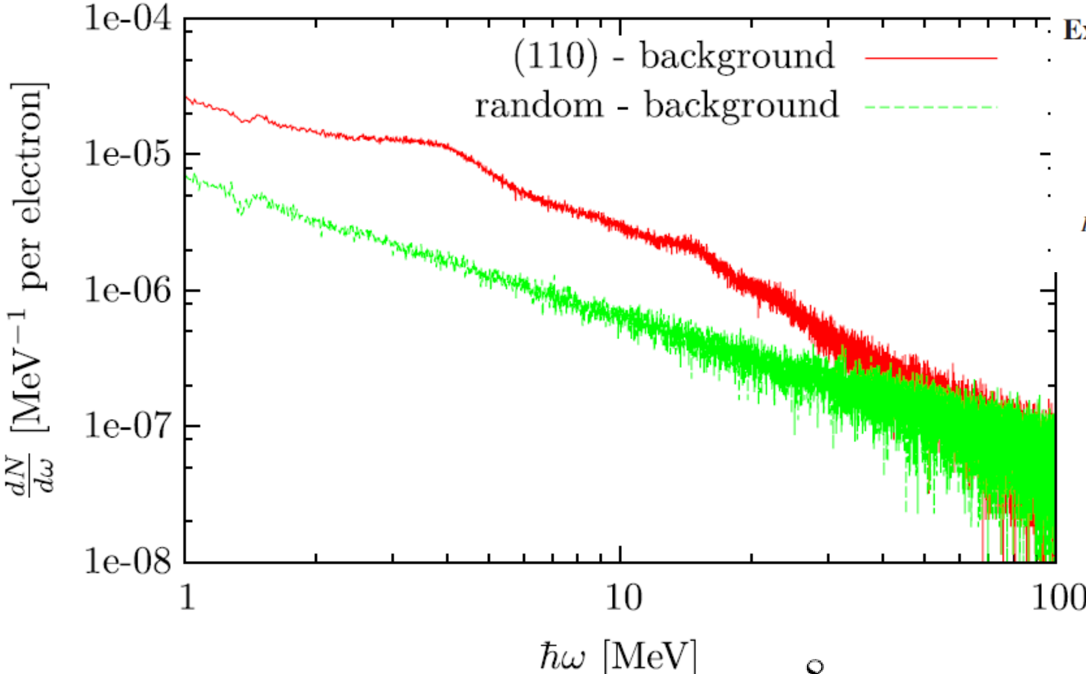
Crystalline Undulator with a Small Amplitude and a Short Period

Andriy Kostyuk*

PRL **110**, 115503 (2013)

Small amplitude, short period (SASP):



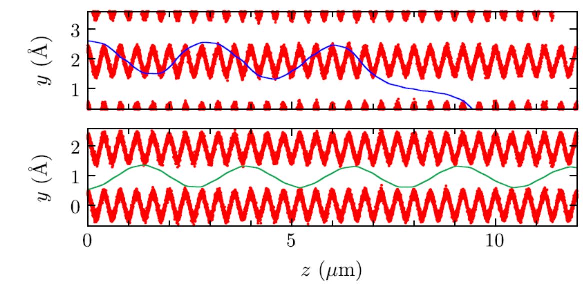


Experimental Realization of a New Type of Crystalline Undulator

Tobias N. Wistisen, Kristoffer K. Andersen, Serdar Yilmaz, Rune Mikkelsen,
John Lundsgaard Hansen, and Ulrik I. Uggerhøj
Department of Physics and Astronomy, Aarhus University, 8000 Aarhus, Denmark

Werner Lauth and Hartmut Backe
Institut für Kernphysik, Johannes Gutenberg Universität Mainz, 55099 Mainz, Germany
(Received 15 March 2014; published 24 June 2014)

PRL **112,** 254801 (2014)

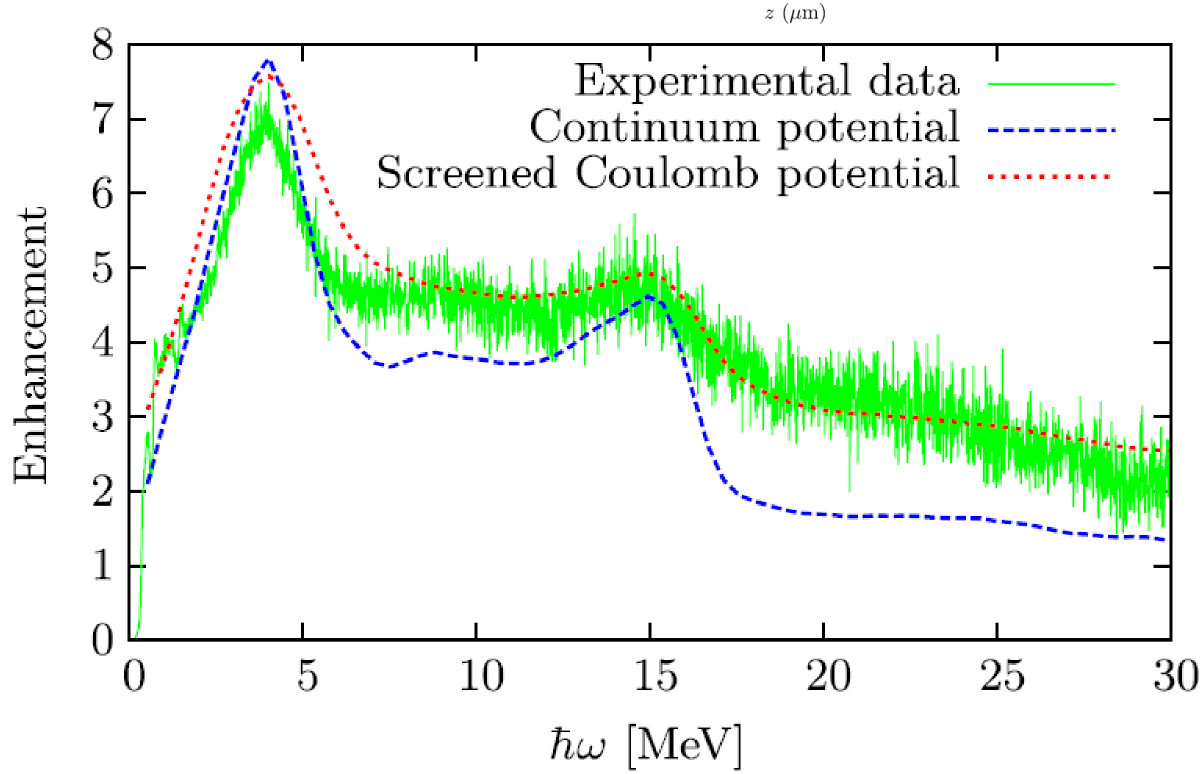


$Si_{1-x}Ge_x$-graded composition

10 periods

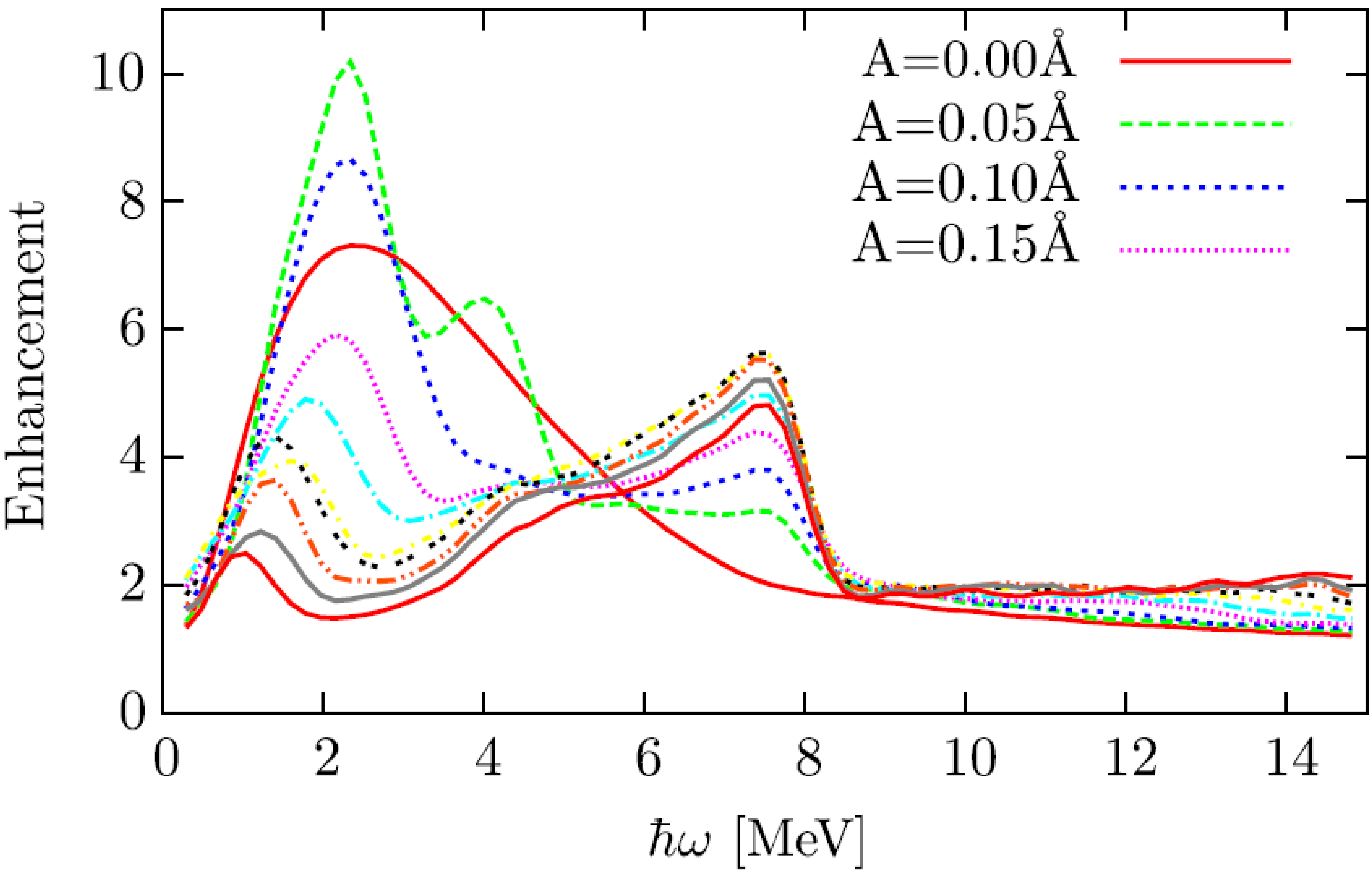
$\lambda_u = 0.43 \pm 0.004\ \mu$m

$a_u = 0.12 \pm 0.034$ Å.



Calculations for other amplitudes

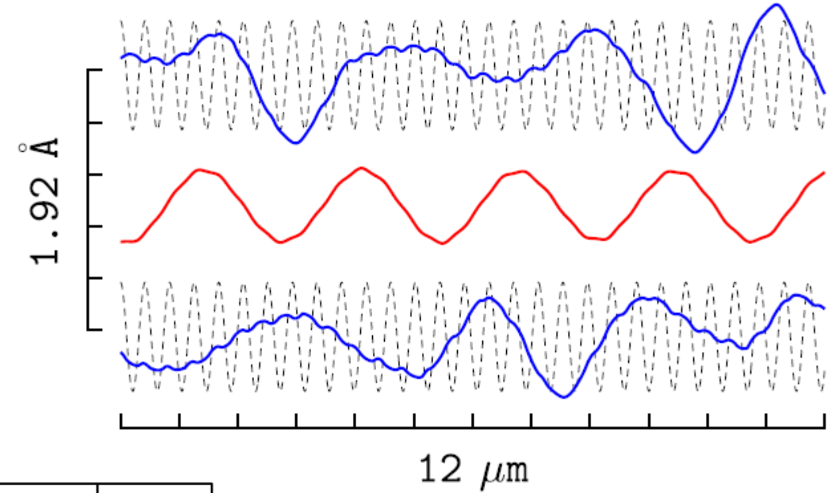
Narrowing ChR, increasing undulator radiation:

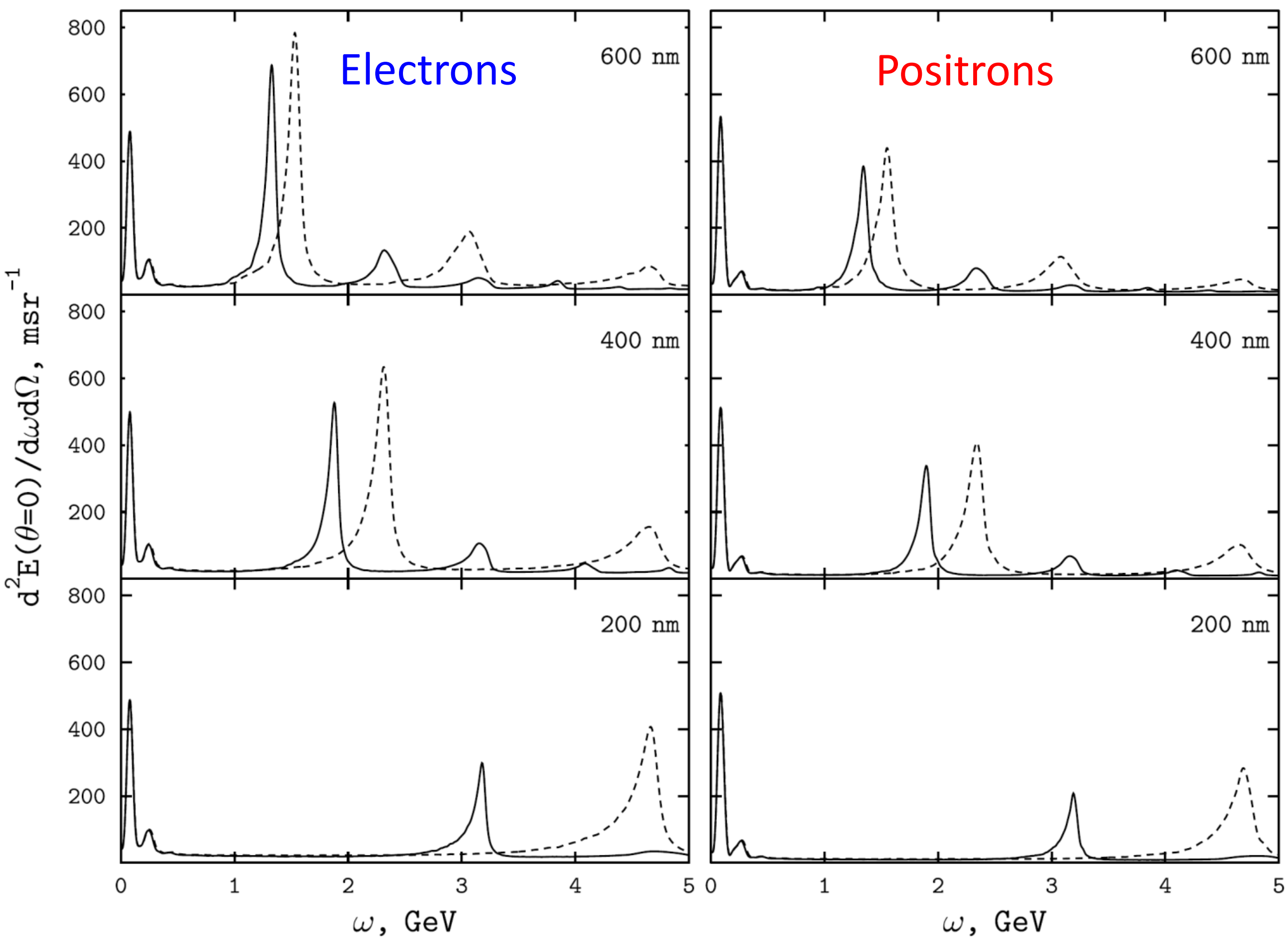


Radiation from multi-GeV electrons and positrons in periodically bent silicon crystal

Victor G. Bezchastnov[1] ‡, Andrei V. Korol[2] § and Andrey V. Solov'yov[2] ||

arXiv:1405.6525v1 [physics.acc-ph] 26 May 2014

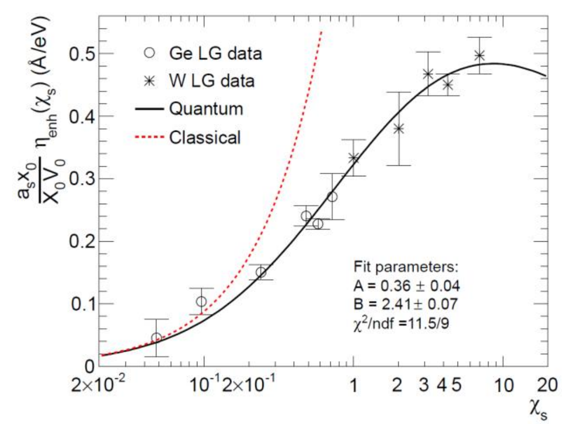




10 GeV, 12 μm Si, a=0.4 Å

______ incl. Quantum corr.

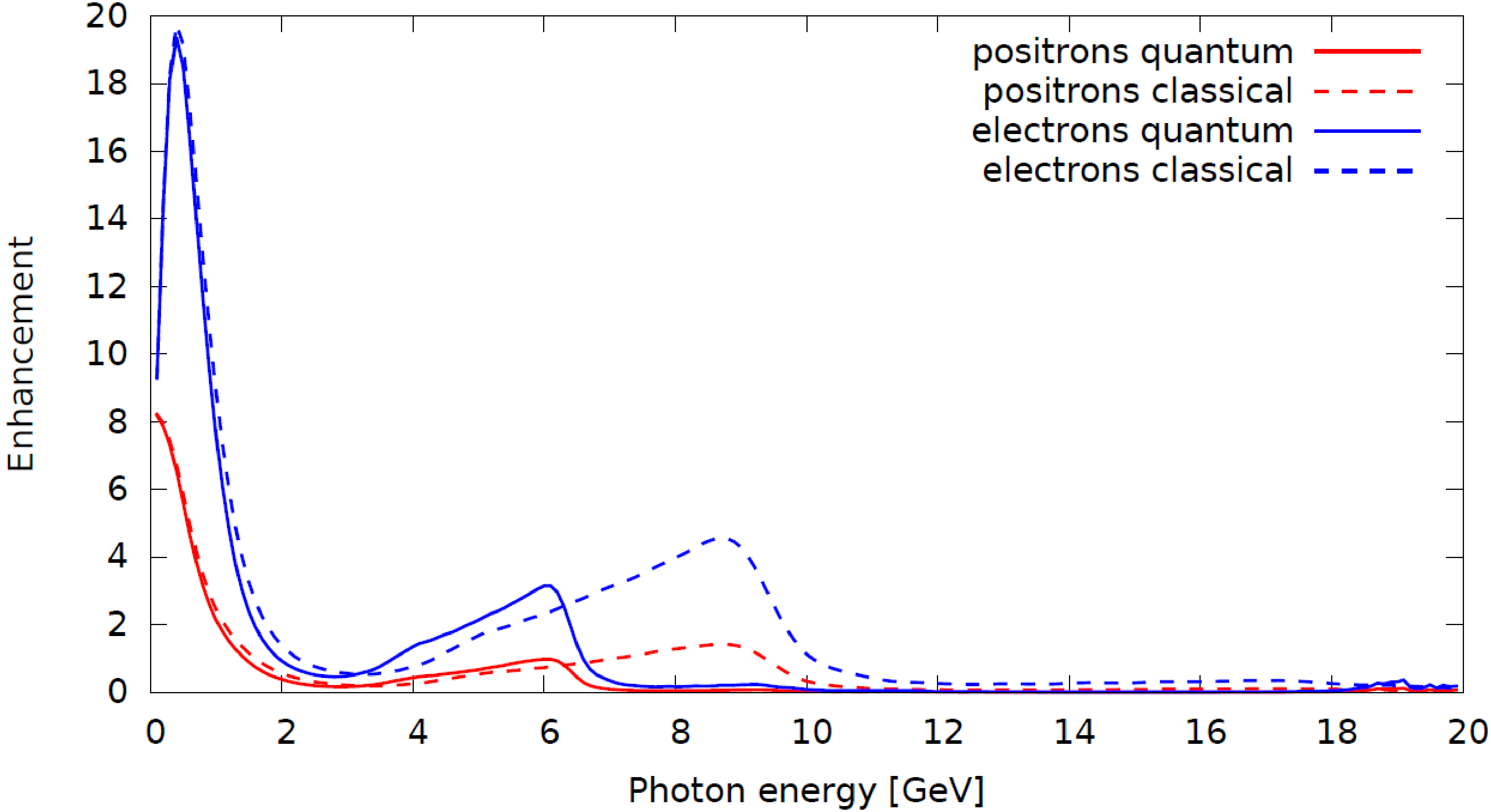
-------- excl. Quantum corr.



MBN Explorer

Next step, SLAC E-212

20 GeV electrons and positrons, strong fields, quantum regime undulator



CALCULATIONS OF GAMMA RAY INCINERATION OF ^{90}Sr AND ^{137}Cs

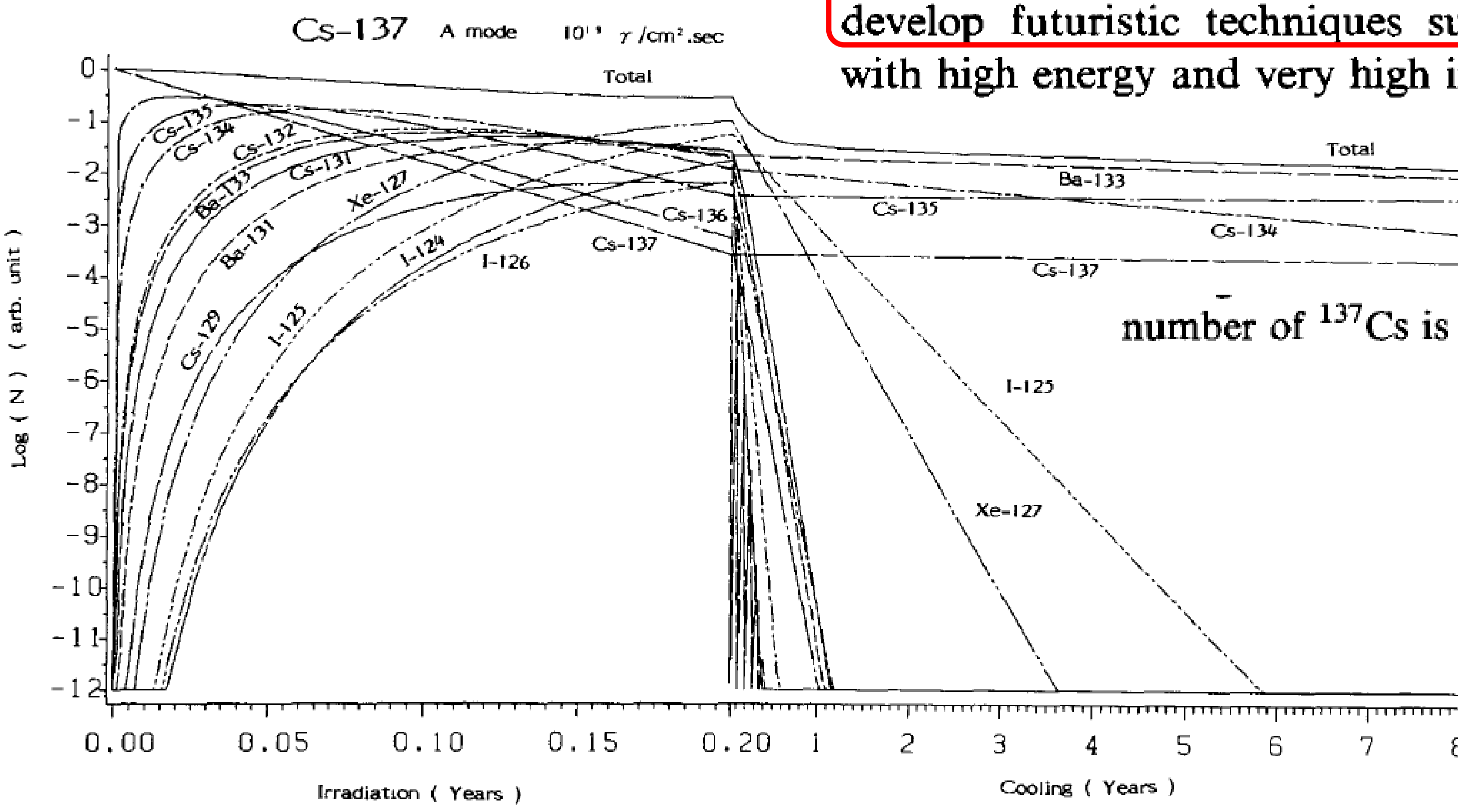
Takaaki MATSUMOTO

Nuclear Instruments and Methods in Physics Research A268 (1988) 234–243

Department of Nuclear Engineering, Hokkaido University, North 12, West 8, Sapporo 060, Japan

High energy (10–20 MeV) γ-rays

For fluxes greater than 10^{19} γ/cm^2 s, ^{90}Sr and ^{137}Cs, as well as the by-products mentioned above, can be incinerated to a significant degree. However, this would require a 20 MeV electron beam with many MW of beam power which would not be sensibly dissipated in a gamma production target. In order to obtain these extremely high γ-ray fluxes, it will be necessary to develop futuristic techniques such as a gamma laser with high energy and very high in the using.



number of ^{137}Cs is reduced to 0.26×10^{-3}

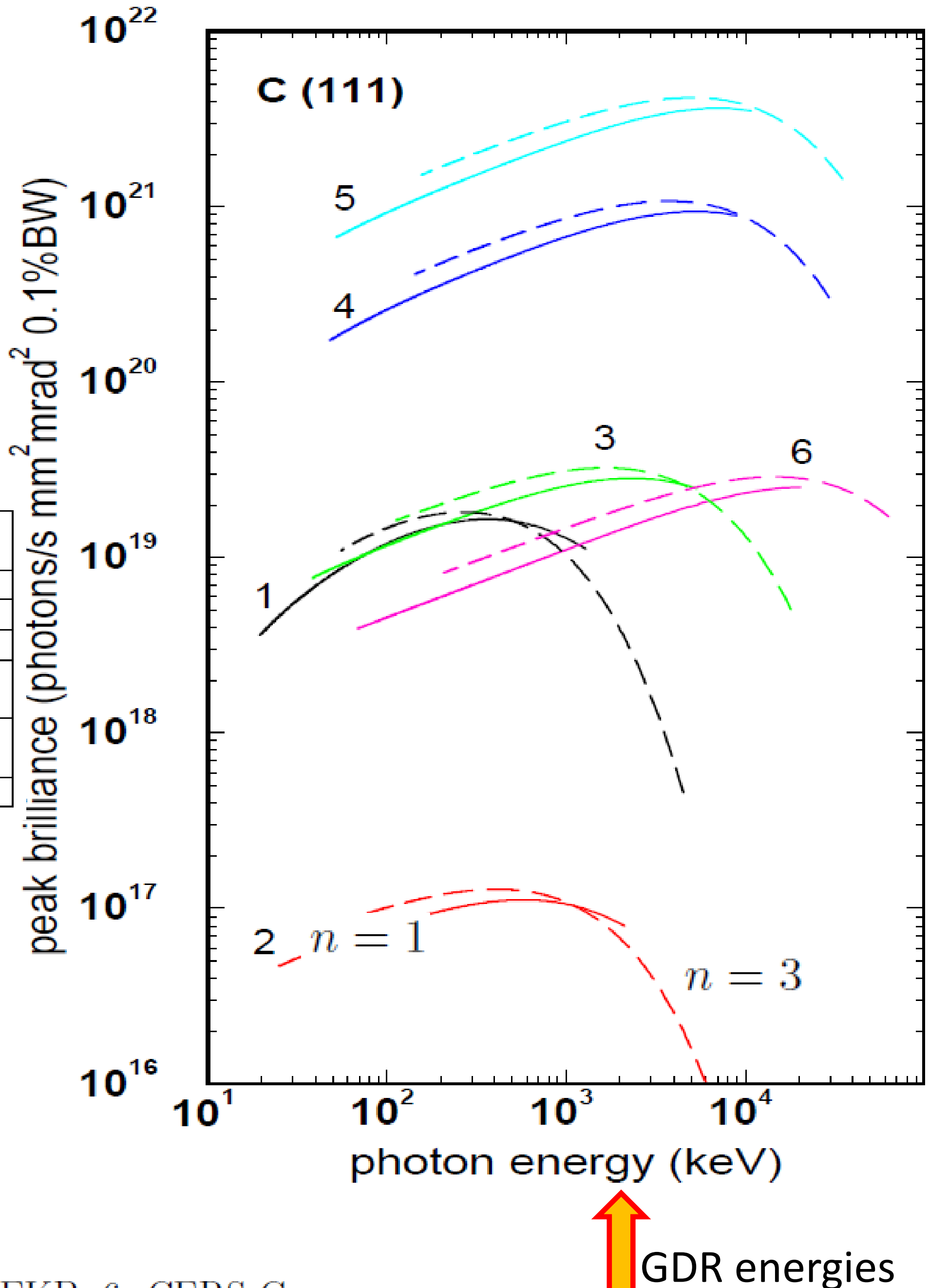
Fig. 9. Time variation of radioactive nuclei for ^{137}Cs irradiation.

Number of photons and brilliance of the radiation from a crystalline undulator

A. V. Korol[a], A. V. Solov'yov[b] and W. Greiner[b]

arXiv:physics/0412101v1 [physics.acc-ph] 16 Dec 2004

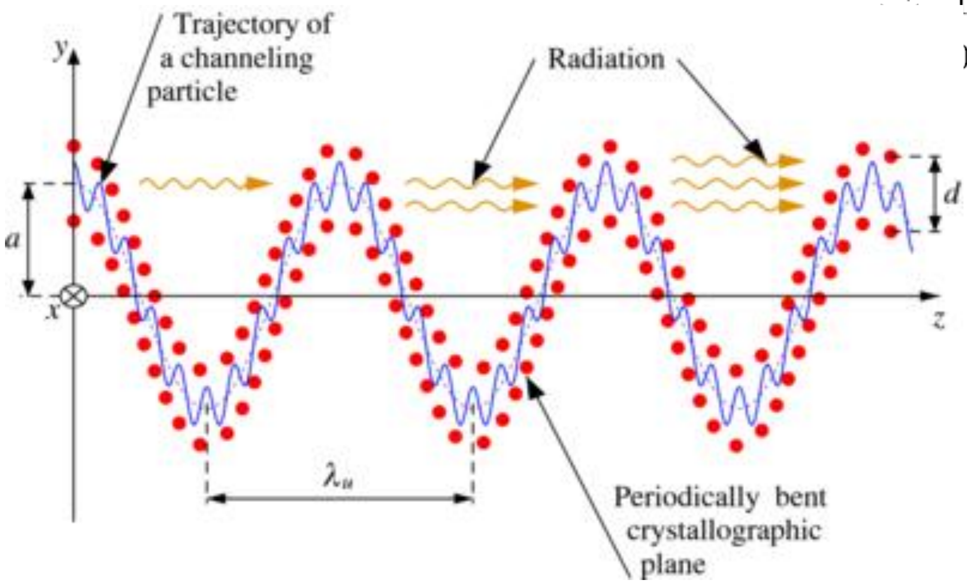
	DAΦNE (Frascati)	VEPP-2000 (Russia)	BEPC-II (China)	PEP-II (SLAC)	KEKB (KEK)	CERS-C (Cornell)
ε (GeV)	0.700	1.0	1.9-2.1	2.5-4	3.5	6
l (cm)	1-2	4	1.3	1	0.65	1.2
$\mathcal{N}$ (units 10^{10})	3-9	16	4.8	6.7	7.3	1.15
σ_x (mm)	0.800	0.125	0.380	0.157	0.110	0.300
σ_y (mm)	0.0048	0.125	0.0057	0.0047	0.0024	0.0057
ϕ_x (mrad)	0.375	2	0.379	0.153	0.164	0.500
ϕ_y (mrad)	0.208	2	0.544	0.319	0.417	0.439
I (A)	144-216	192	177	322	539	46

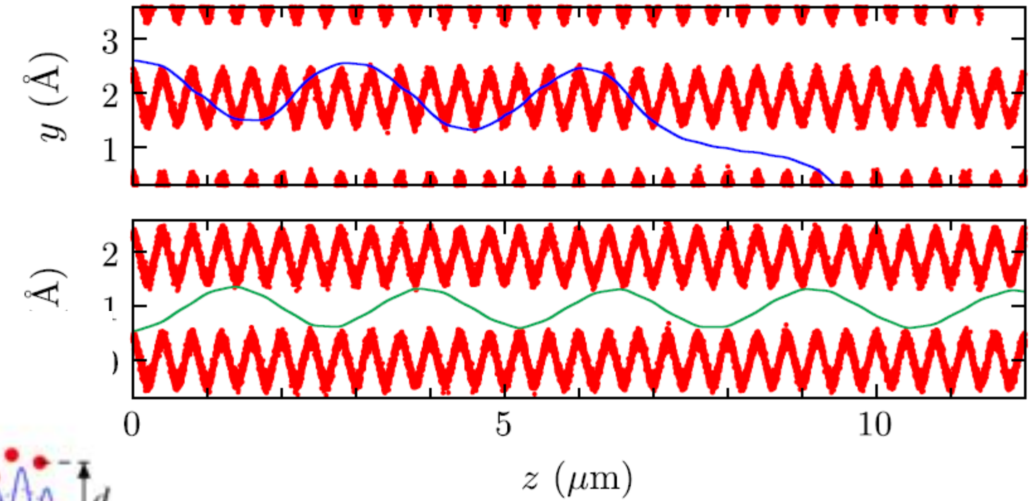


1: DAΦNE, 2: VEPP-2000, 3: BEPC-II, 4: PEP-II, 5: KEKB, 6: CERS-C.

Undulator Radiation from Channeling in a Single Crystal

LALP





SASP

FACET

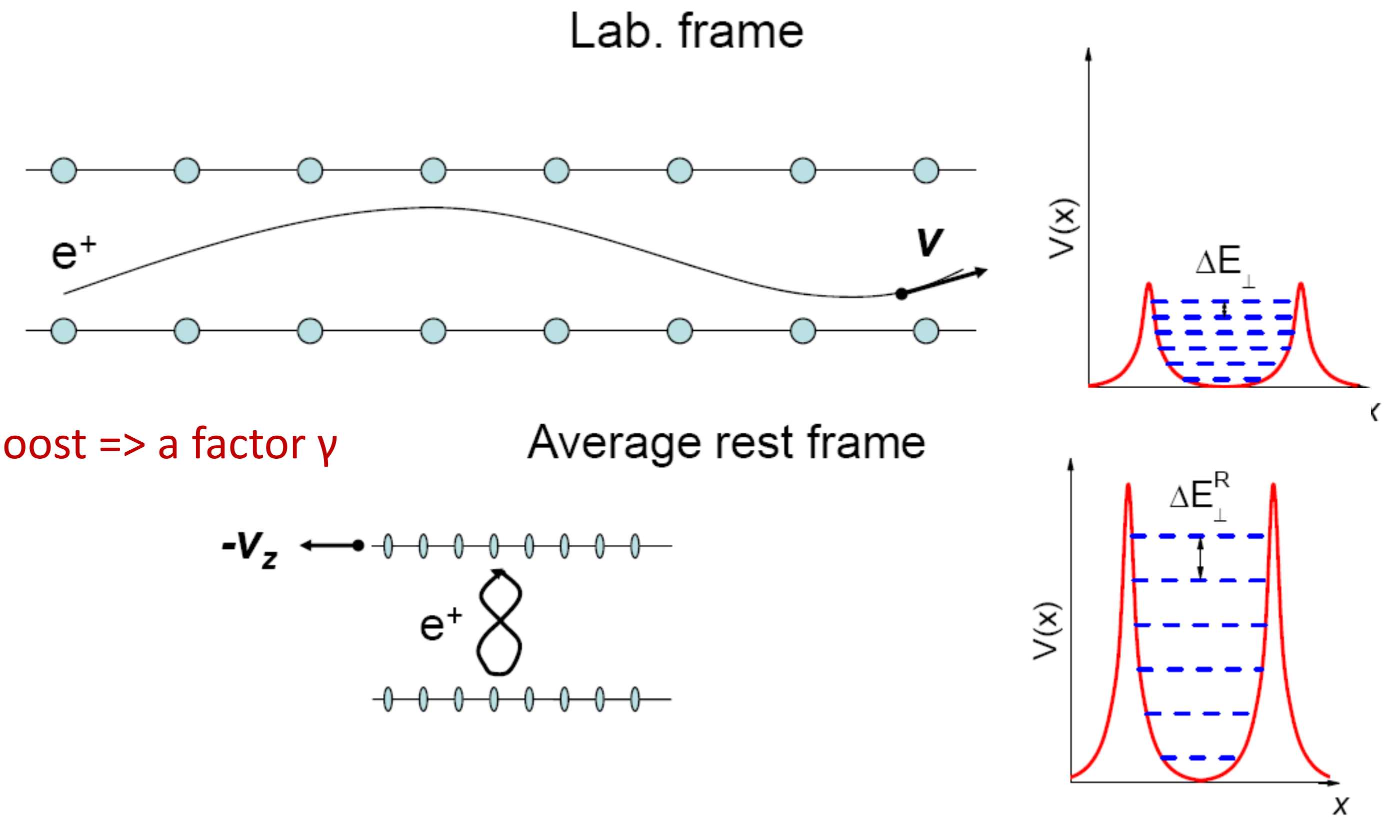
SLAC E-212

A possible route to a gamma-ray laser?

Thank you!

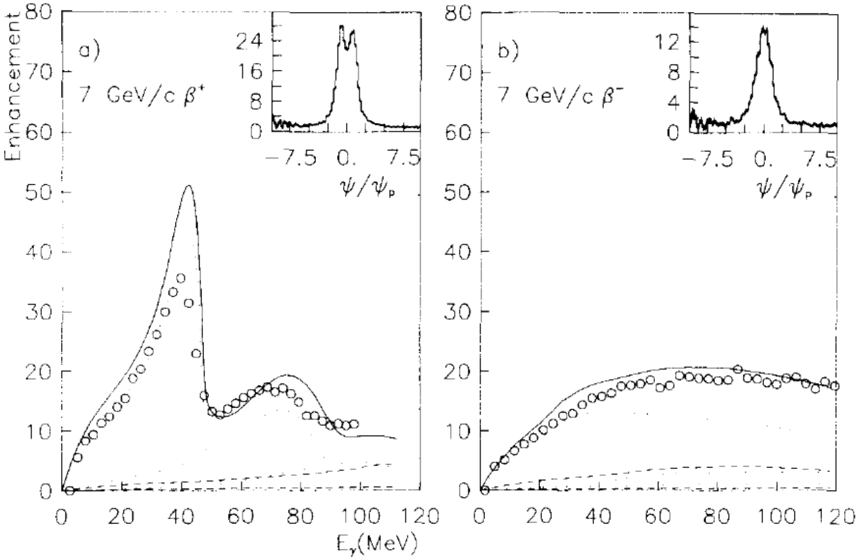
Transverse energy states

Harmonic potential for positrons
equidistant transverse energy states
'Population inversion' from high-lying transverse energy states



Lorentz boost => a factor γ

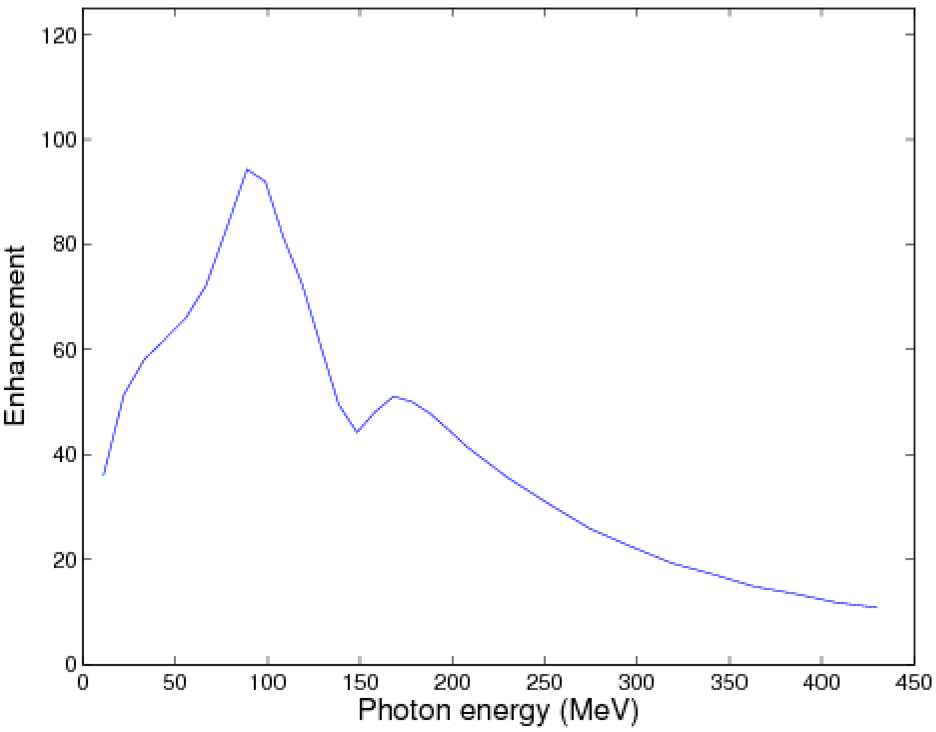
Doppler-shift back to the lab => another factor 2γ



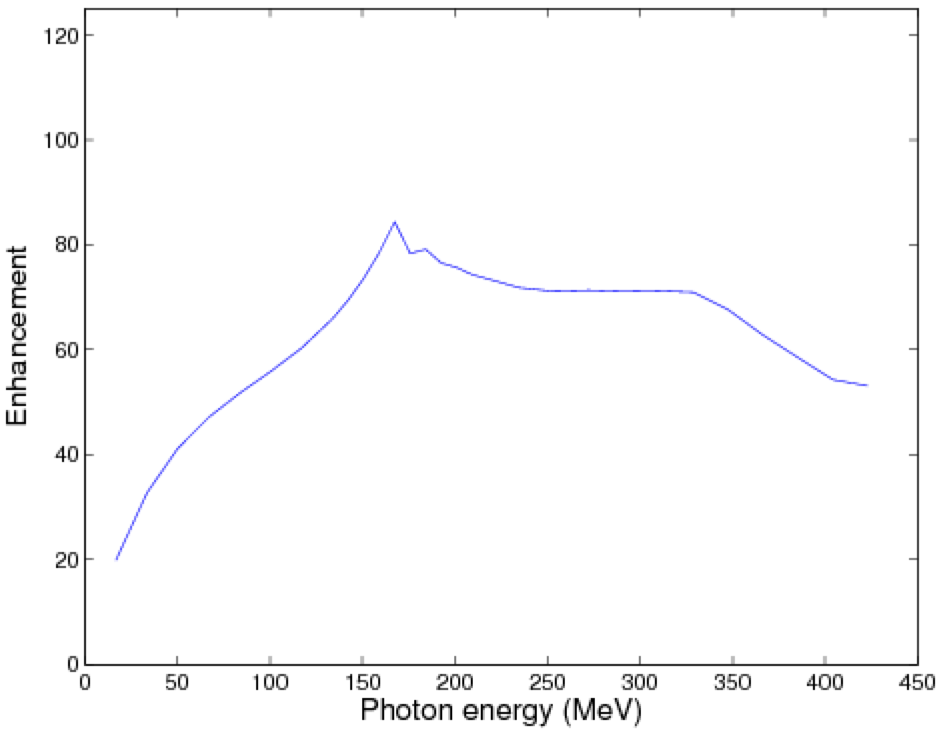
Measurements in Si (1980's), event-based

Enhancements of 80-100...

10 GeV positrons along diamond (110)

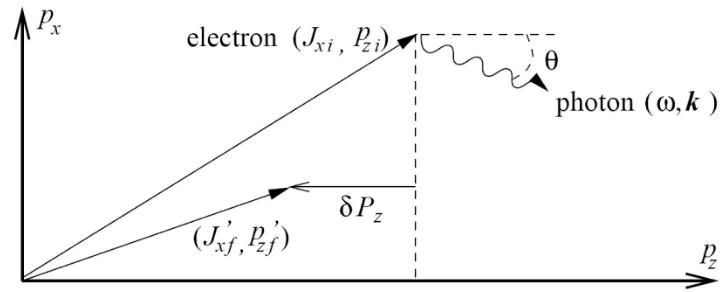


20 GeV positrons along diamond (110)

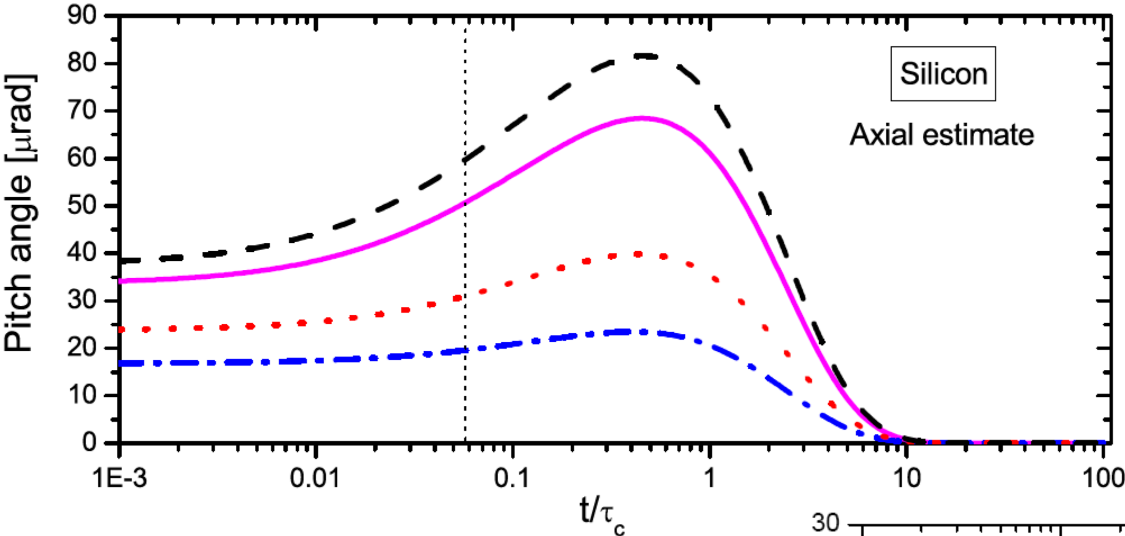


Radiation cooling

Based on ideas from: Z. Huang, P. Chen and R.D. Ruth, Nucl. Instr. Meth. B 119 (1996), 192



Z. Huang, SLAC-R-527



Qualitative agreement with measurements

Radiation cooling for diamonds of >1 cm (?)