Recent Progress in the Theory of the Crystalline Undulator

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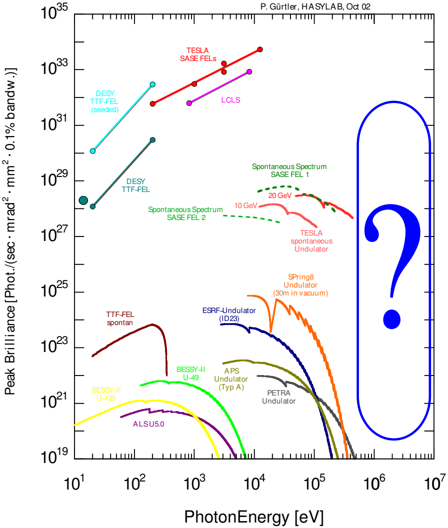
Motivation



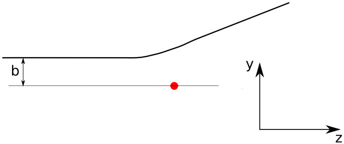
Based on
R.Brinkmann *et al.* (Ed.) 'Tesla FEL. Technical design report. Supplement.'

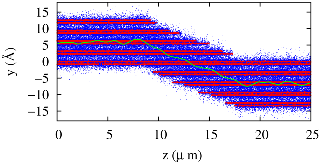
Method

ChaS
Channeling Simulator

a recently developed Monte Carlo code

- Based on the binary collision algorithm
- Simulates the 3D crystal lattice
- Uses *ab initio* distribution of electrons in the crystal
- Allows for analysis of the channeling, dechanneling and rechanneling of the projectile
- Calculates the spectral-angular distribution of the emitted radiation

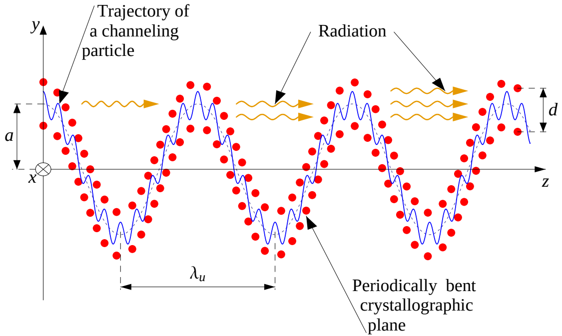




Reliability of the Model

Photon energy shift due to recoil	$\hbar\omega \sim E$	$\hbar\omega / E < 0.05$
Projectile energy losses due to the photon emission	$E \gtrsim 10$ GeV	
Quantum effects in the motion of the projectile	$E \lesssim 100$ MeV	$E = 855$ MeV
Influence of the crystal medium on the emission and propagation of the radiation	$\hbar\omega \lesssim 200$ keV	$\hbar\omega > 1$ MeV

Crystalline Undulator



V.V. Kaplin, S.V. Plotnikov and S.A. Vorob'ev, Zh. Tekh. Fiz. **50**, 1079-1081 (1980), (Sov. Phys. – Tech. Phys. **25**, 650-651 (1980)),
V.G. Baryshevsky, I.Ya. Dubovskaya and A.O. Grubich, Phys. Lett. A, **77**, 61-64 (1980).

Conditions for the Undulator Effect

$$L \sim \min\left[L_{\rm d}(C), L_{\rm a}(\omega)\right]$$ - *moderate dechanneling and, and photon attenuation*

$$N_{\rm u} = L/\lambda_{\rm u} \gg 1$$ - *large number of periods*,

$$\Delta\varepsilon/\varepsilon \ll 1$$ - *low radiative losses*,

$$C = F_{\rm cf}/U'_{\max} = 4\pi^2 Ea/U'_{\max}\lambda_{\rm u}^2 < 1$$ -*stable channeling*,

$$a > d$$ - *large-amplitude regime.*

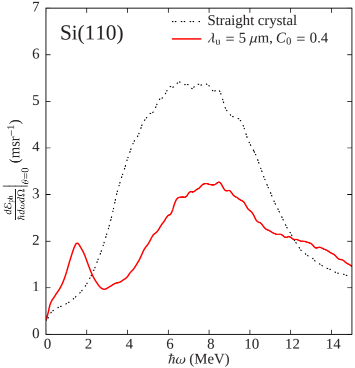
A.V. Korol, A.V. Solov'yov, W. Greiner,
J. Phys. G **24**, L45 (1998); Int. J. Mod. Phys. E **8**, 49 (1999);
Int. J. Mod. Phys. E **13**, 867 (2004).

Example: Electron-Based Crystalline Undulator

$E = 855$ MeV

$a = 1.74$ Å
$a/d = 0.91 < 1$

$L_{\rm d} = 8.3\ \mu$m
$L_{\rm d}/\lambda_{\rm u} = 1.7$
$N_{\rm u} \sim 1$



Undulator Conditions Revisited

$a > d$ - *large-amplitude regime.*

Is it necessary?

$$\left.\frac{d\mathcal{E}}{d\omega\, d\Omega}\right|_{\theta=0} \sim a^2\omega^4$$

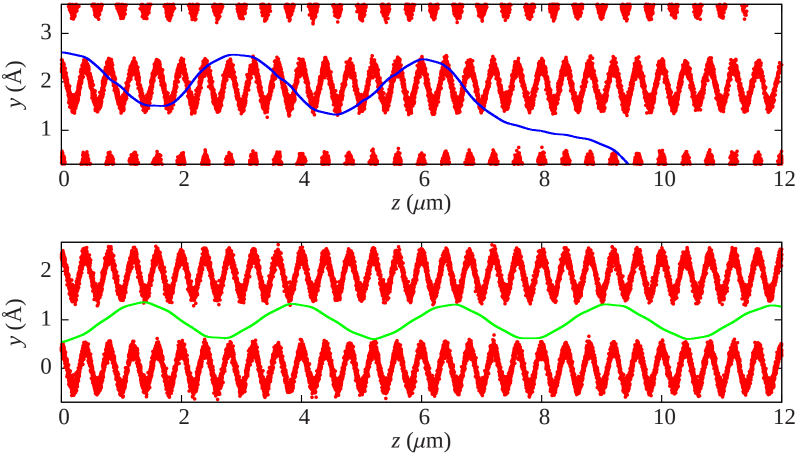
$a < d$ is OK if $\omega_{\rm u} > \omega_{\rm c} \Leftrightarrow \lambda_{\rm u} < \lambda_{\rm c}$

$C = F_{\rm cf}/U'_{\max} = 4\pi^2 E a / U'_{\max}\lambda_{\rm u}^2 < 1$ -*stable channeling.*

Does violating this condition destroy the undulator effect?

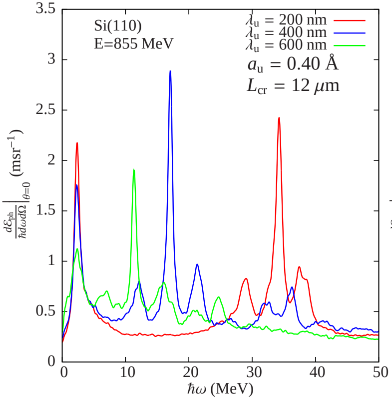
Centrifugal Factor Is Irrelevant!!!

$$\lambda_\mathrm{u} << \lambda_\mathrm{c}, \qquad a < d$$

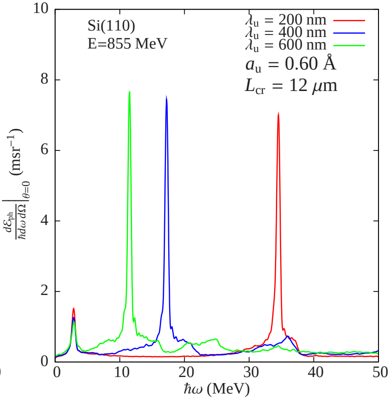


Spectra

Electron beam



Positron beam

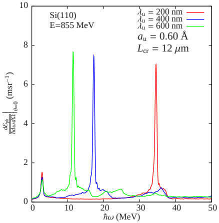


SASP CU

Small Amplitude Short Period Crystalline Undulator

$$a < d \qquad \lambda_{\rm u} < \lambda_{\rm c}$$

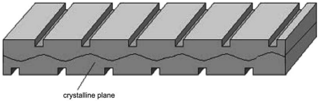
- The condition $N_{\rm u} = L/\lambda_{\rm u} \gg 1$ can be easily fulfilled even for electrons.
- Much smaller relative width of the undulator peak.
- The undulator photons are harder than the channeling one: $\hbar\omega_{\rm u} > \hbar\omega_{\rm c}$.
- Much smaller ratio $\hbar\omega_{\rm u}/E \Leftrightarrow$ cheaper accelerator!.



Challenges

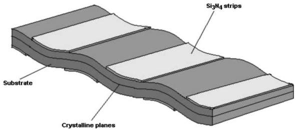
Ultrasound

W. Wagner et al.



Picture From V. Guidi *et al.*,
Nucl. Inst. and Meth. B234, (2005) 40.

S. Bellucci *et al.*, V. Guidi *et al.*,
P. Balling *et al.*



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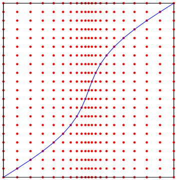
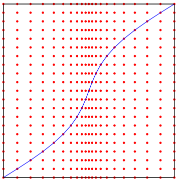
V. Guidi *et al.*



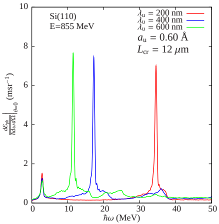
M. B. H. Breese,
U. Mikkelsen and E. Uggerhøj

Challenges

Ultrasound ?	
	 M. B. H. Breese, U. Mikkelsen and E. Uggerhøj

Conclusion

Small Amplitude Short Period Crystalline Undulator (SASP CU) ($a < d$, $\lambda_{\mathrm{u}} < \lambda_{\mathrm{c}}$) is predicted to be much superior in comparison to the crystalline undulator with large amplitude and long period ($a > d$, $\lambda_{\mathrm{u}} > \lambda_{\mathrm{c}}$)



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Thank you for your attention!