Electromagnetic processes in strong crystalline fields

- exploring the Schwinger field

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Motivation

▪

The critical (Schwinger) field

- Schwinger, 1949

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

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

Quantum corrections to synchrotron radiation emission

Relativistic invariant:

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

Beamstrahlung

Electric field from one bunch boosted by $2\gamma^2$ as seen by the other

SLC:

χ (or Υ) $\approx 10^{-3}$

NLC:

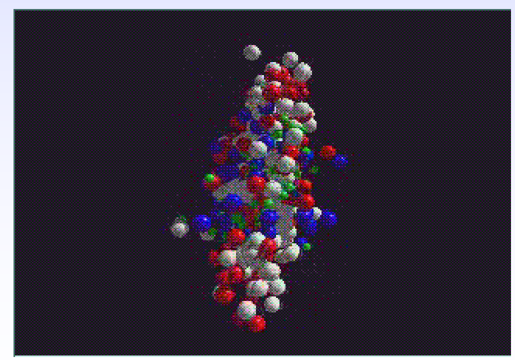
χ (or Υ) ≈ 1

heavy ions

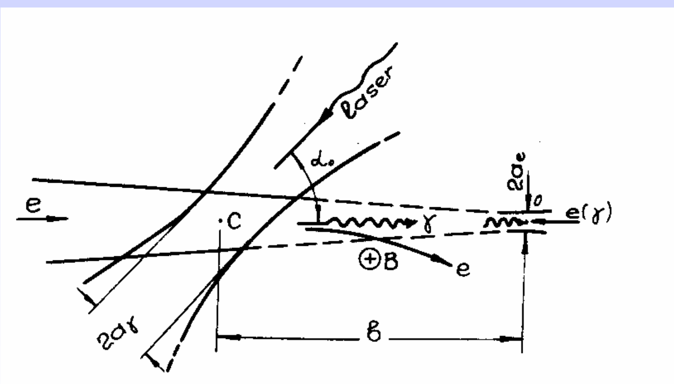
Superstrong field,
but of short duration

$$\mathcal{E}_{1s}/\mathcal{E}_0 = \alpha^3 Z^3$$

Extended nucleus:
$Z \approx 172$



Strong lasers



$\gamma\gamma$-collision scheme
(Telnov *et al.*)

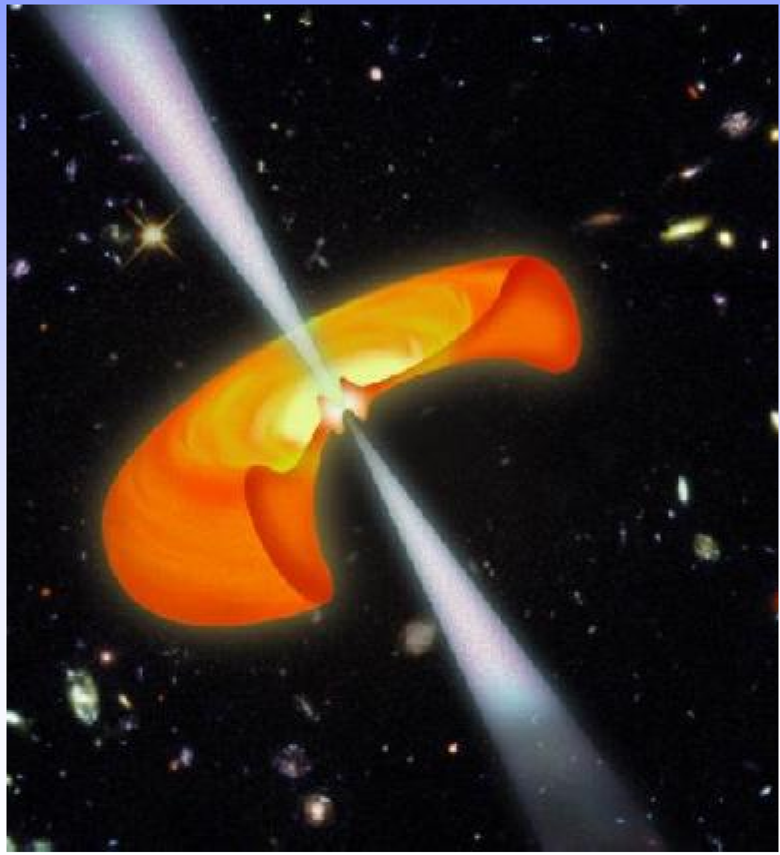
Laser wavelength (and γ energy) limited by non-linear Compton scattering
χ (or Υ) ≈ 1

Magnetars

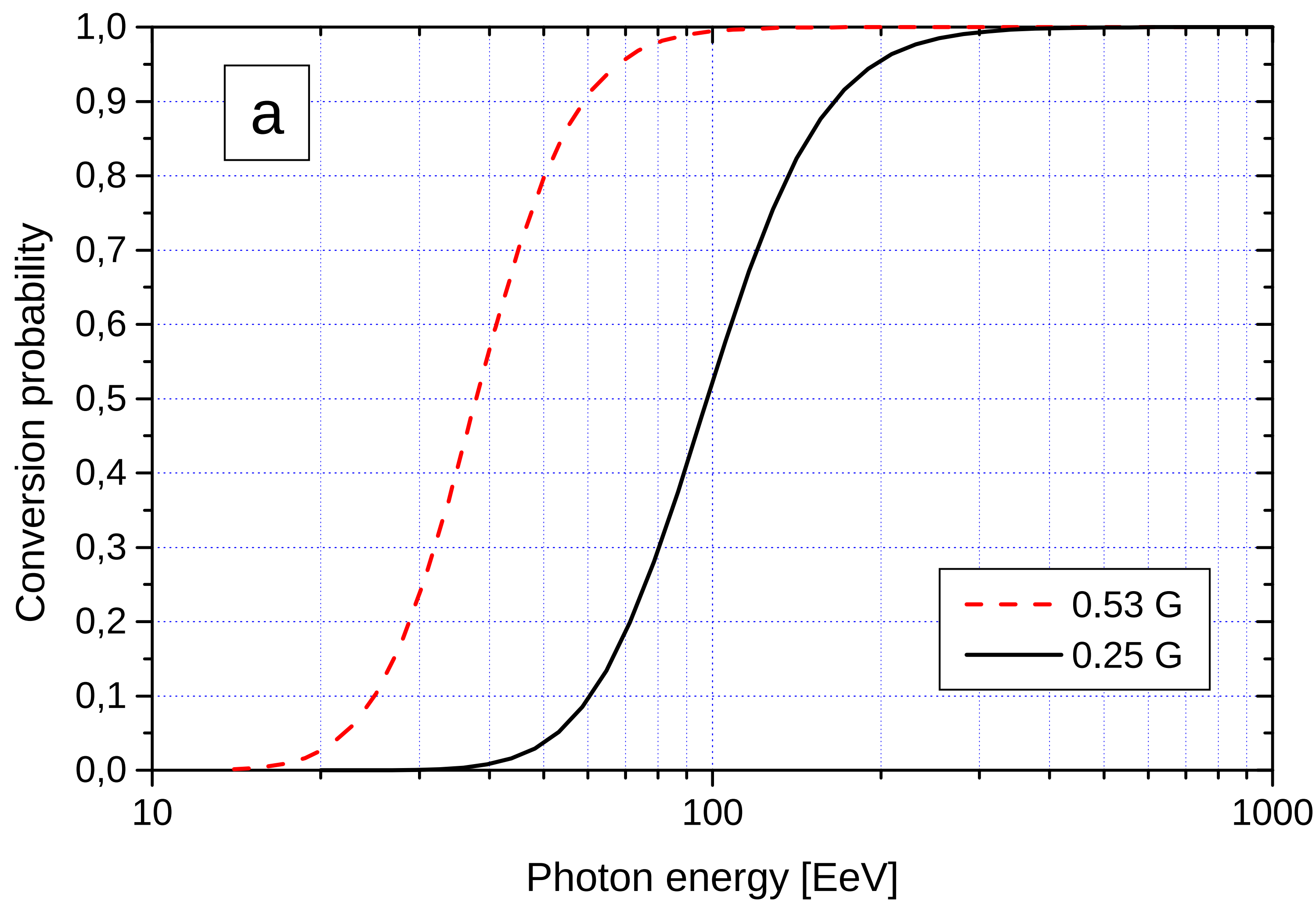
- Magnetars, $B \approx 10^{10}$ T, relativistic gyration:

$$\hbar\omega/mc^2 = \sqrt{B/B_0}$$

- Electrosphere of strange stars – possible signatures from suppressed radiation?



The strong magnetic field of the Earth



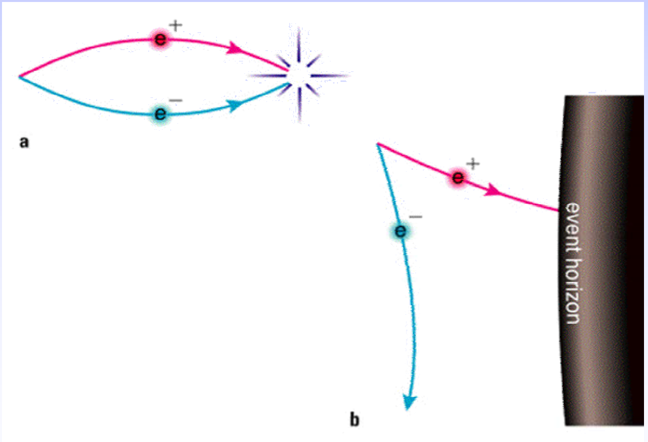
Hawking radiation as a strong field effect

Gravitatonal acceleration at Schwarzschild radius:

$g(R_S)=c^4/4GM$ $\quad\quad$ $R_S=2GM/c^2$

Set equal to critical field acc.:

$g_0=e\mathcal{E}_0/m=c^2/\lambda_c$

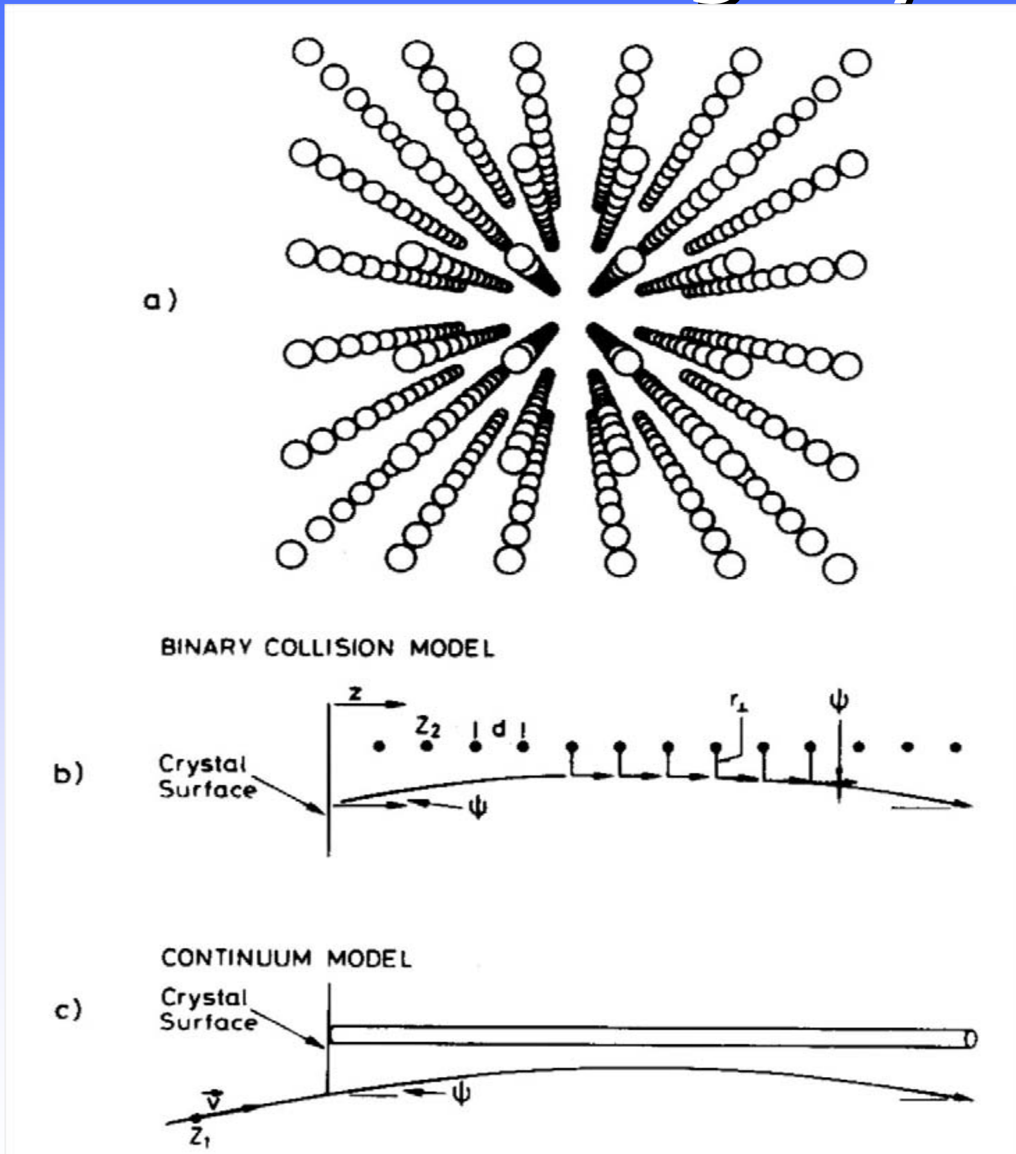


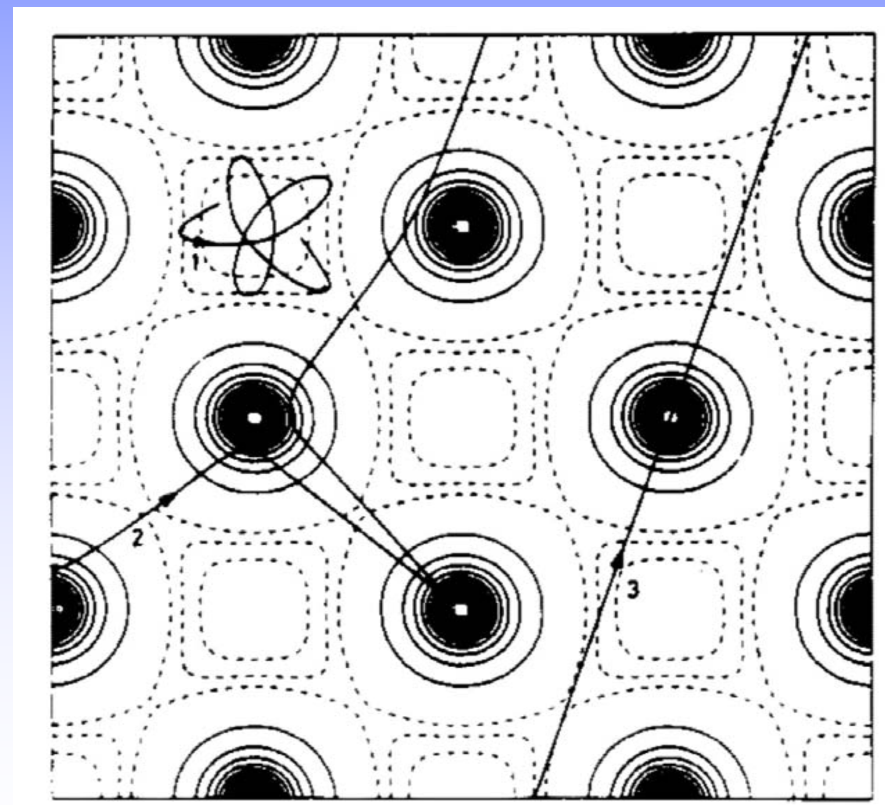
Light black holes are hotter:

$\lambda_c=2R_S$

Strong fields in crystals

Strong crystalline fields

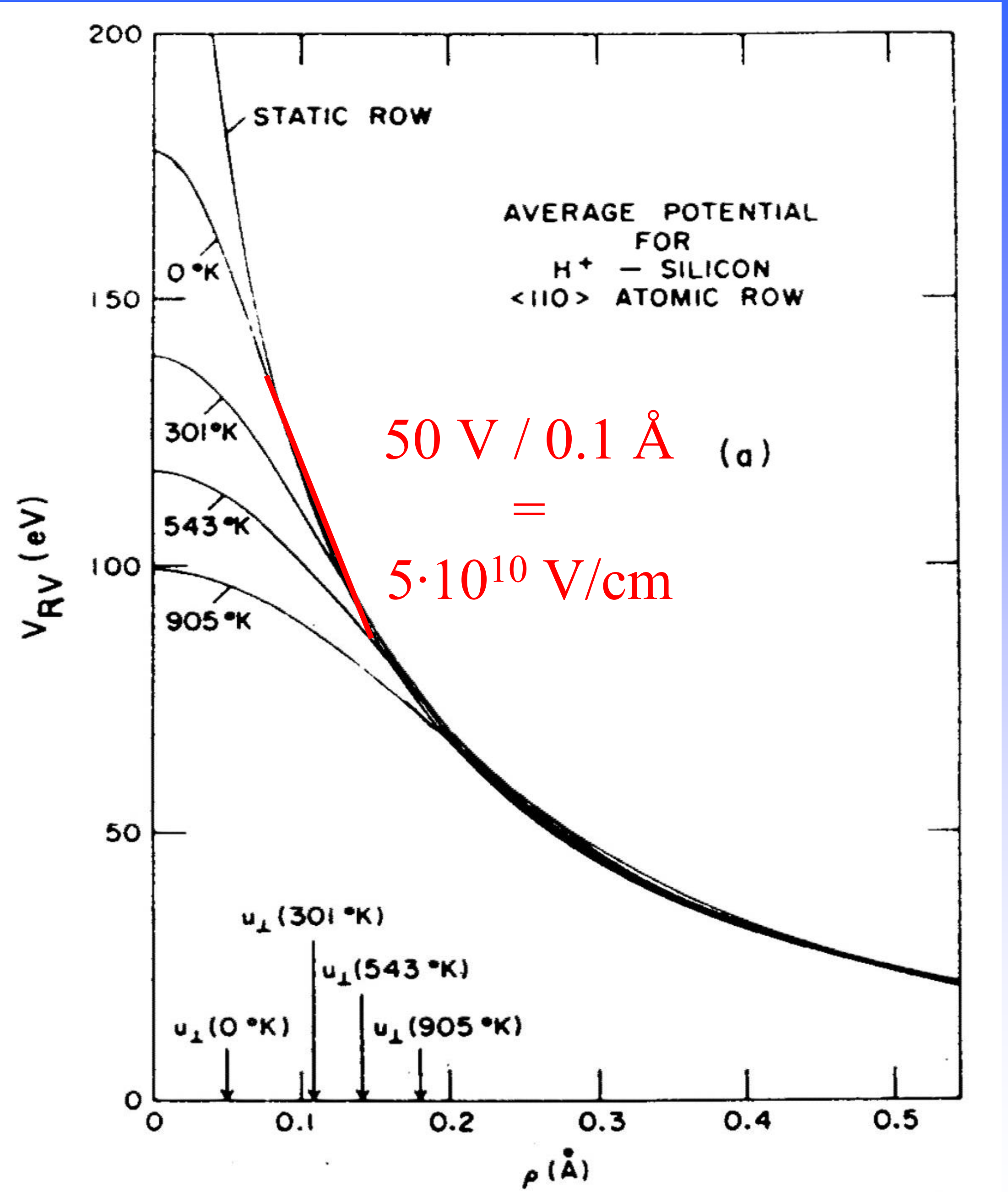




Crystals

Extremely strong electric fields

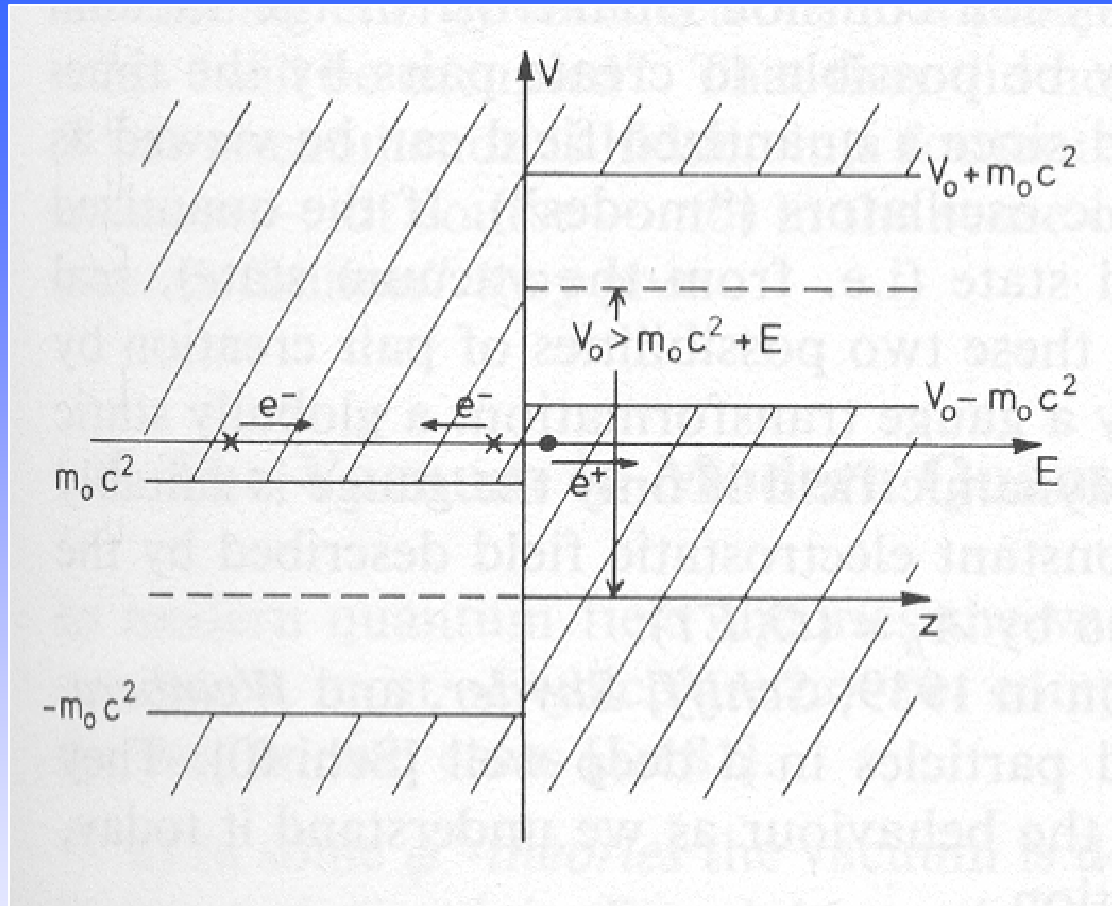
10^{10}-10^{11} V/cm



Klein's paradox

- O. Klein (24.12.1929):
- Probability for reflection of an electron:
- Exceeds 1 at the critical field:

<u>Pair production.</u>



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Klein Paradox in Spatial and Temporal Resolution

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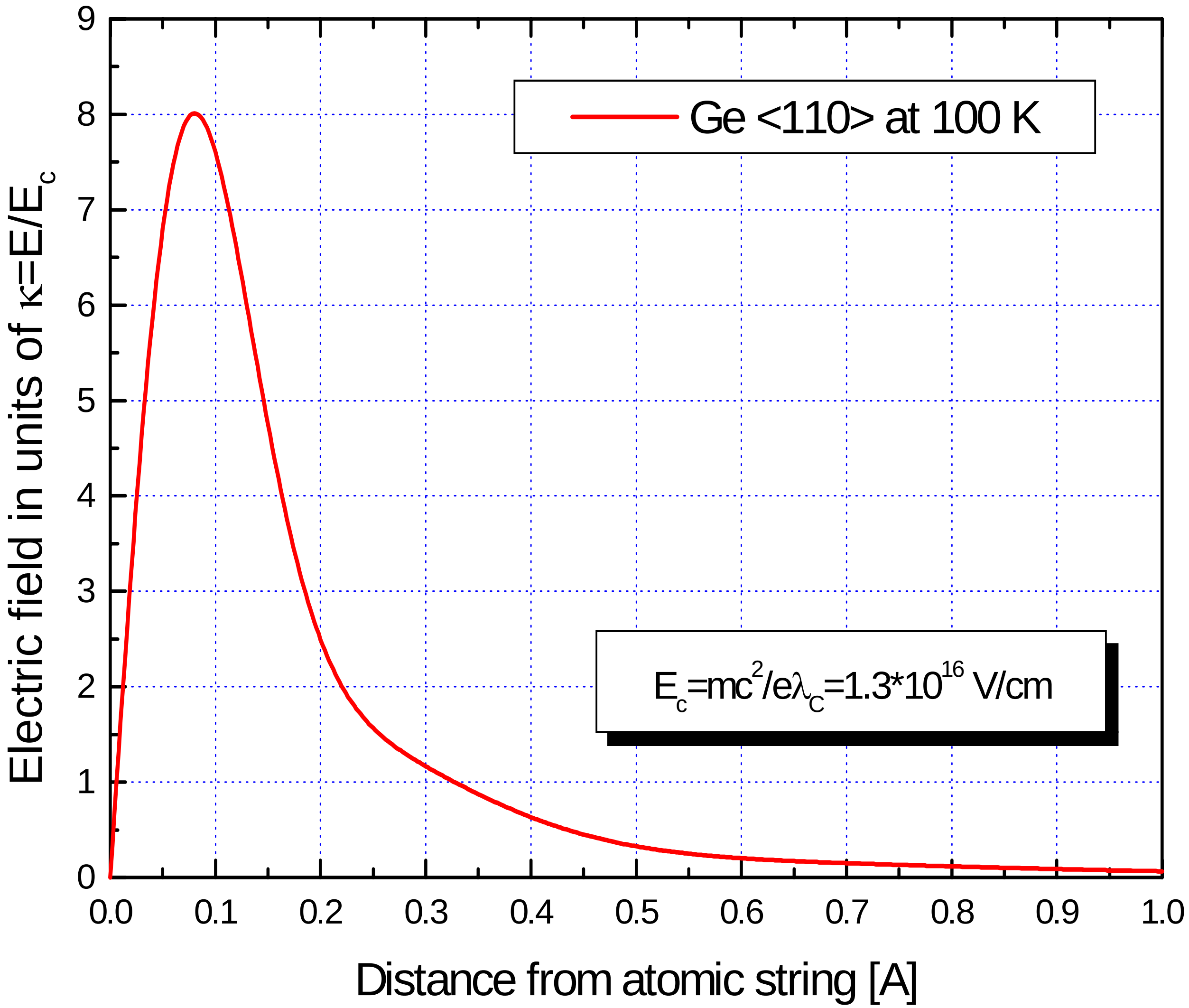
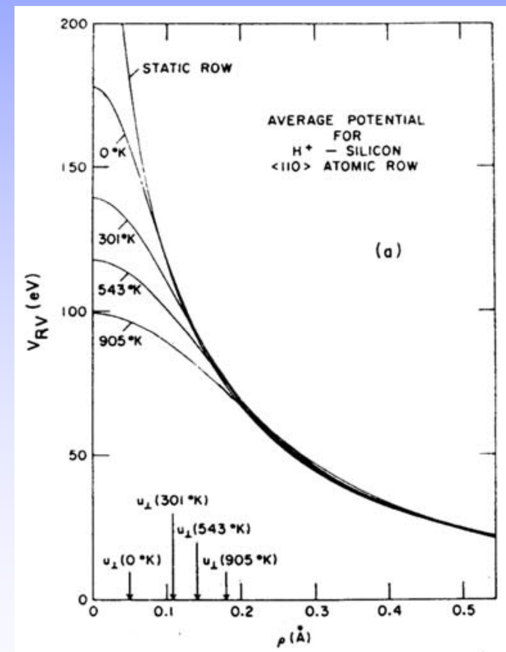
'Super-critical' fields

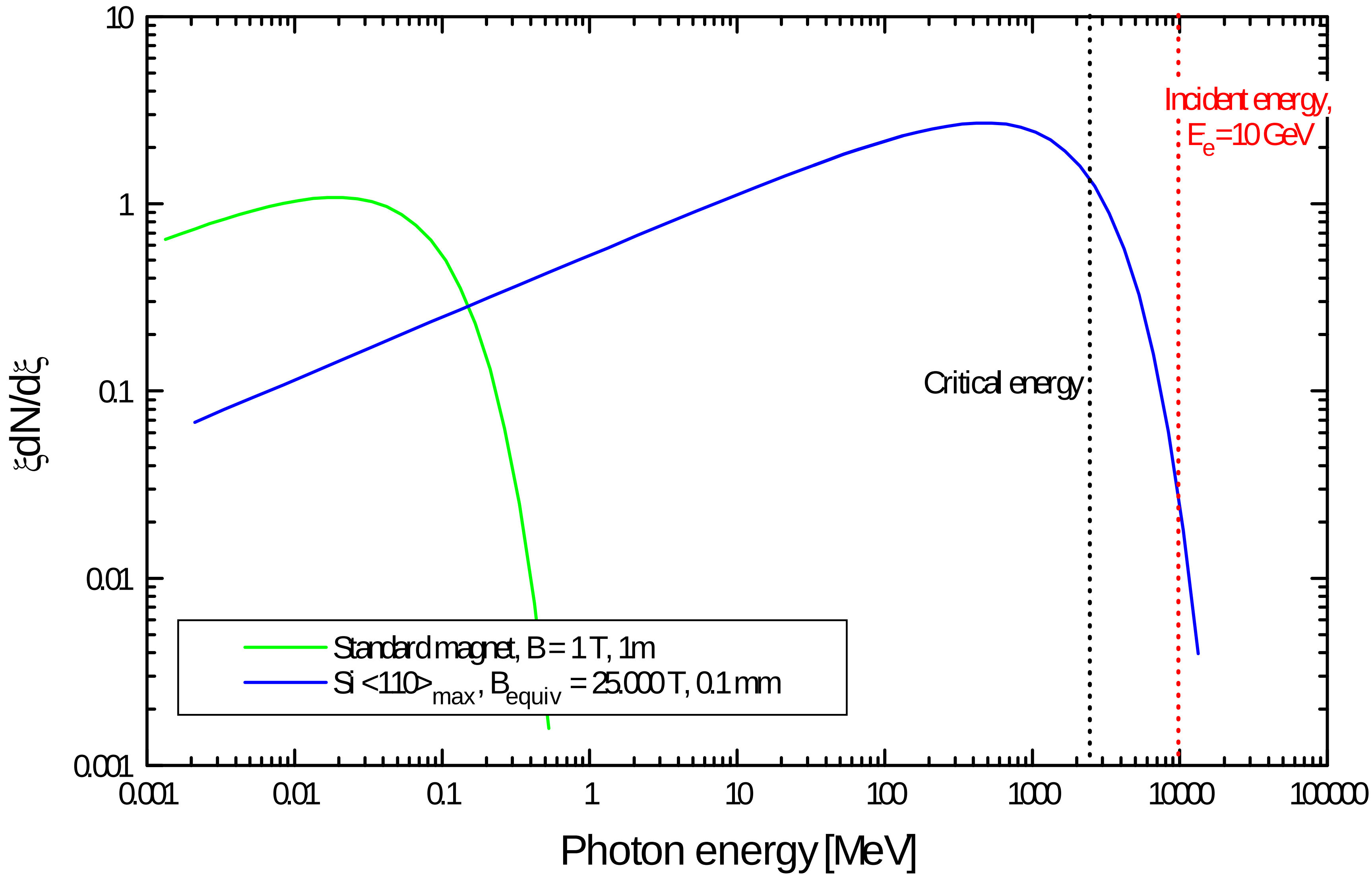


Relativistic invariant:

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



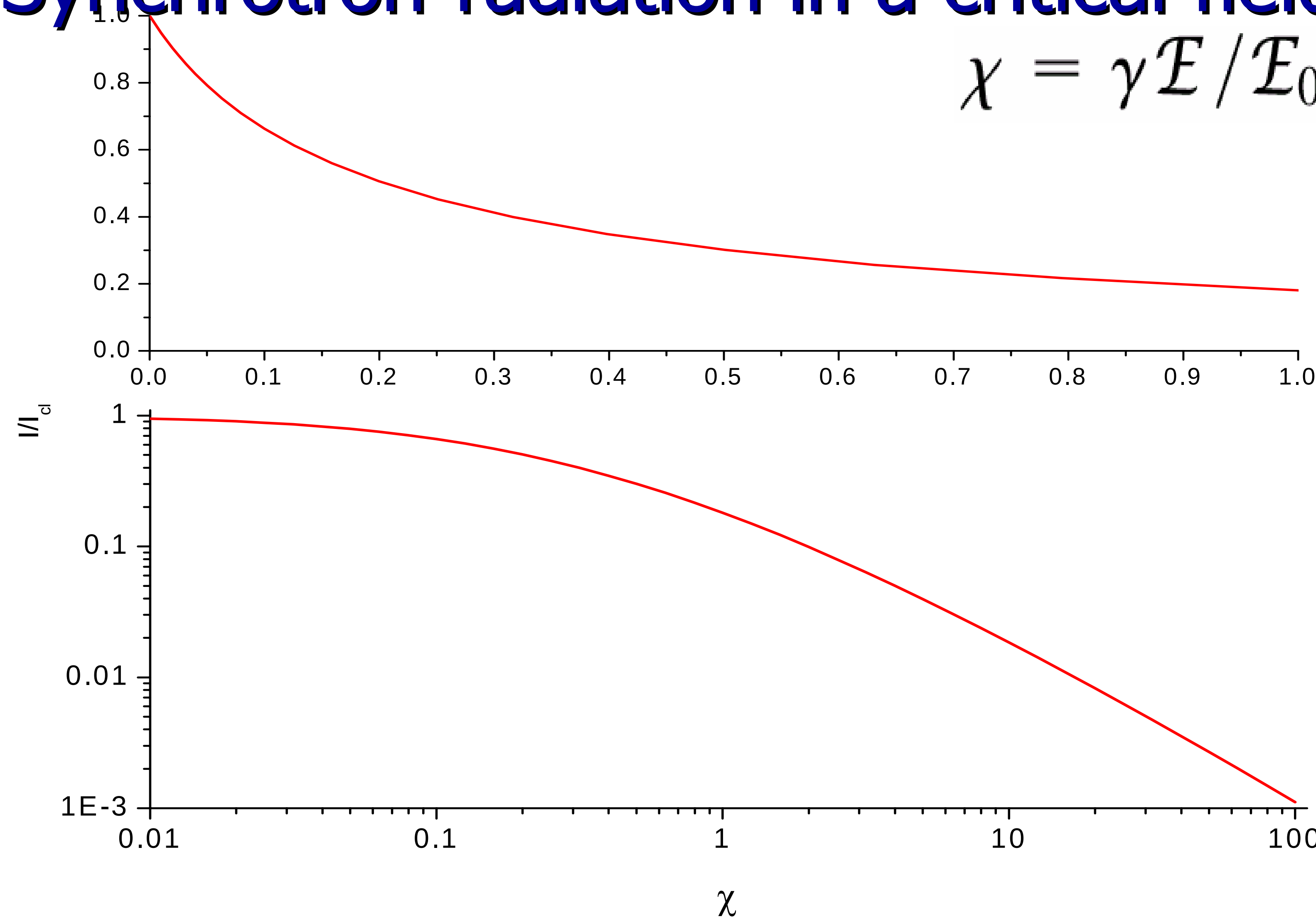
Classical synchrotron radiation



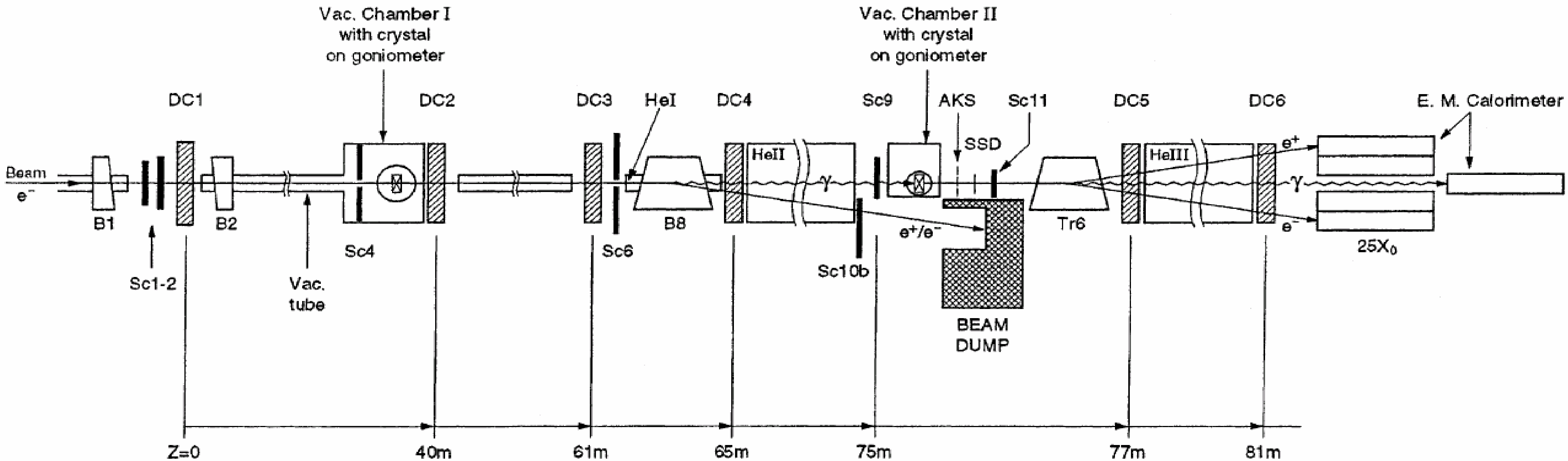
$$\hbar\omega_c / E_e \simeq 3\gamma^3 \hbar e B / 2 p E_e = 3\gamma B / 2 B_0$$

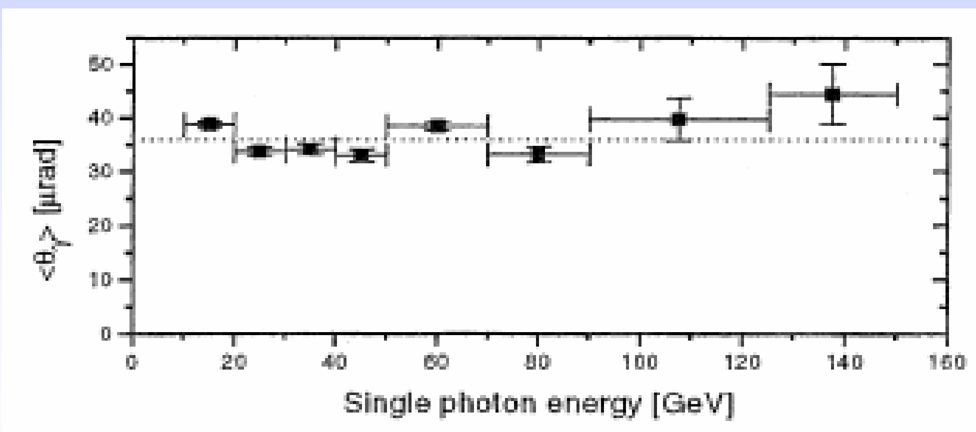
Synchrotron-radiation in a critical field

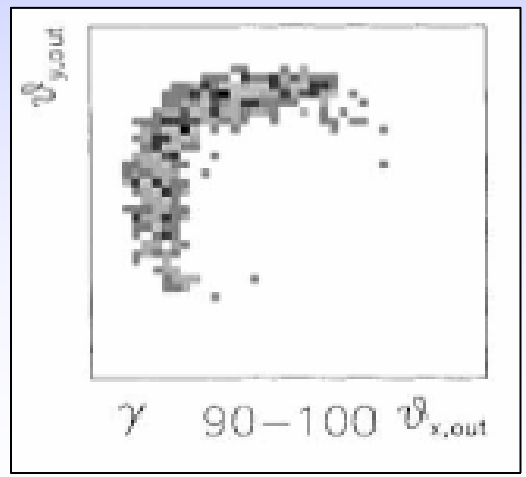
$$\chi = \gamma \mathcal{E} / \mathcal{E}_0$$



NA43 1993-1997





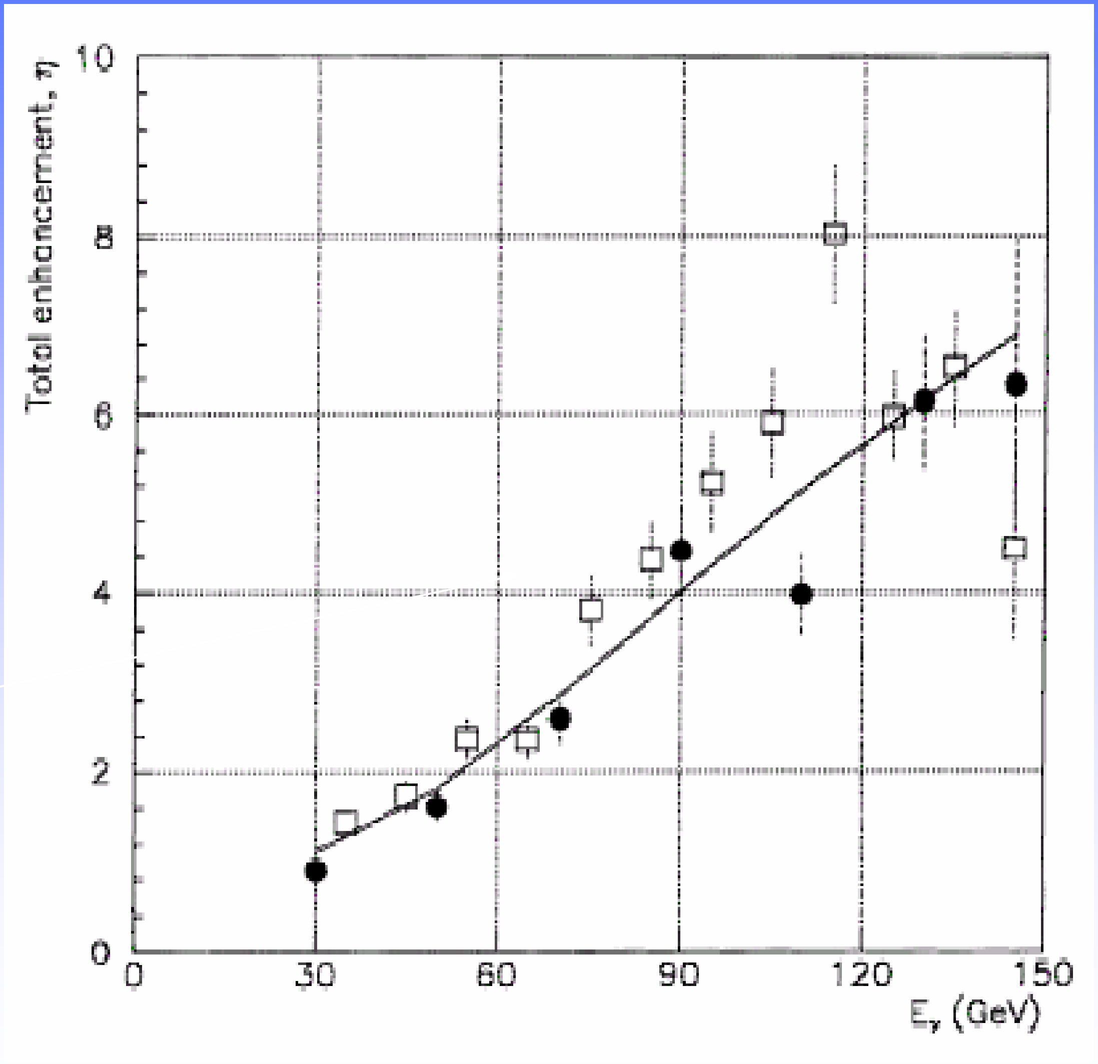


150x150 µrad

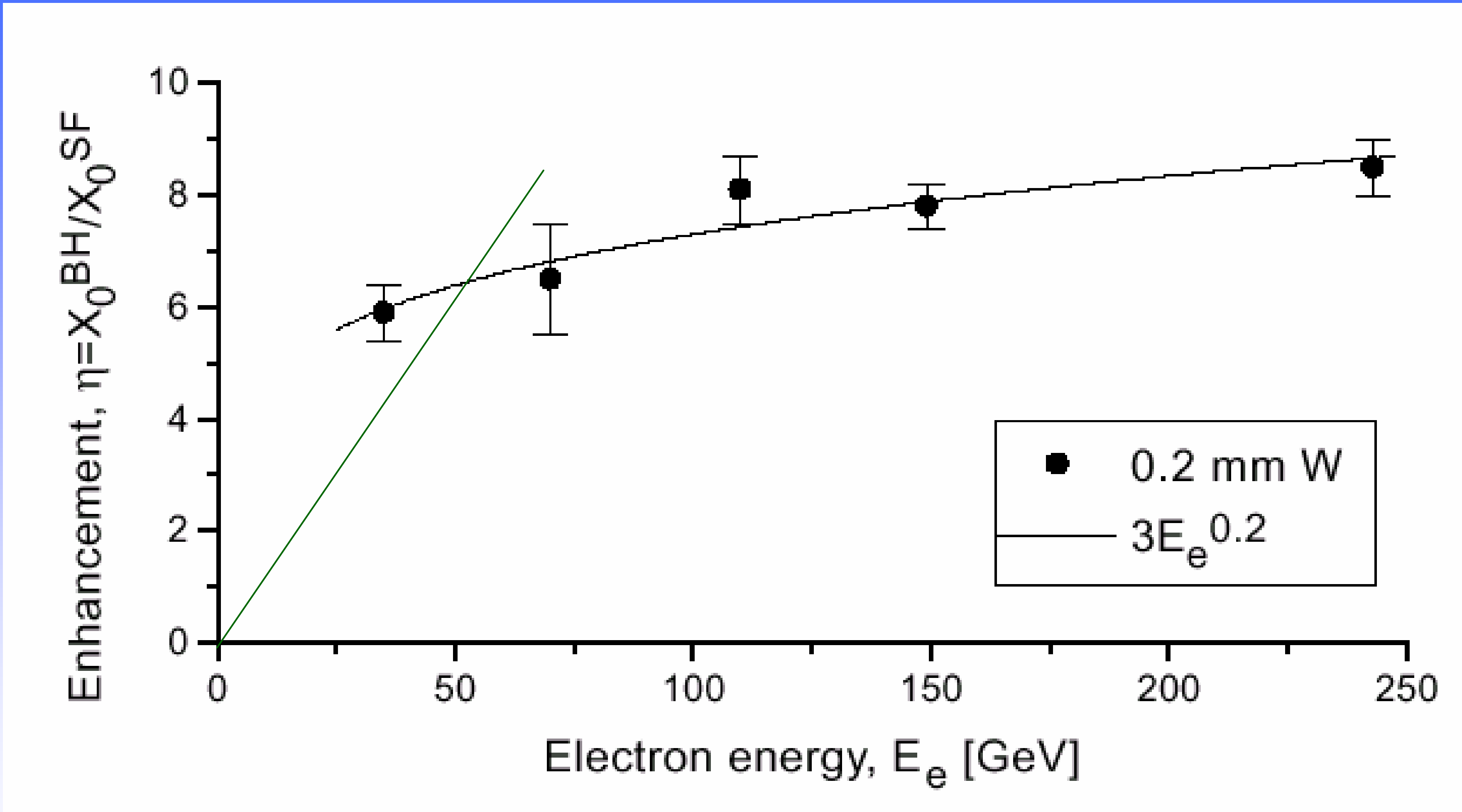
Strong crystalline fields

- Critical fields can be simulated in a crystal.

- Example: Pair production in Ge



Quantum-synchrotron

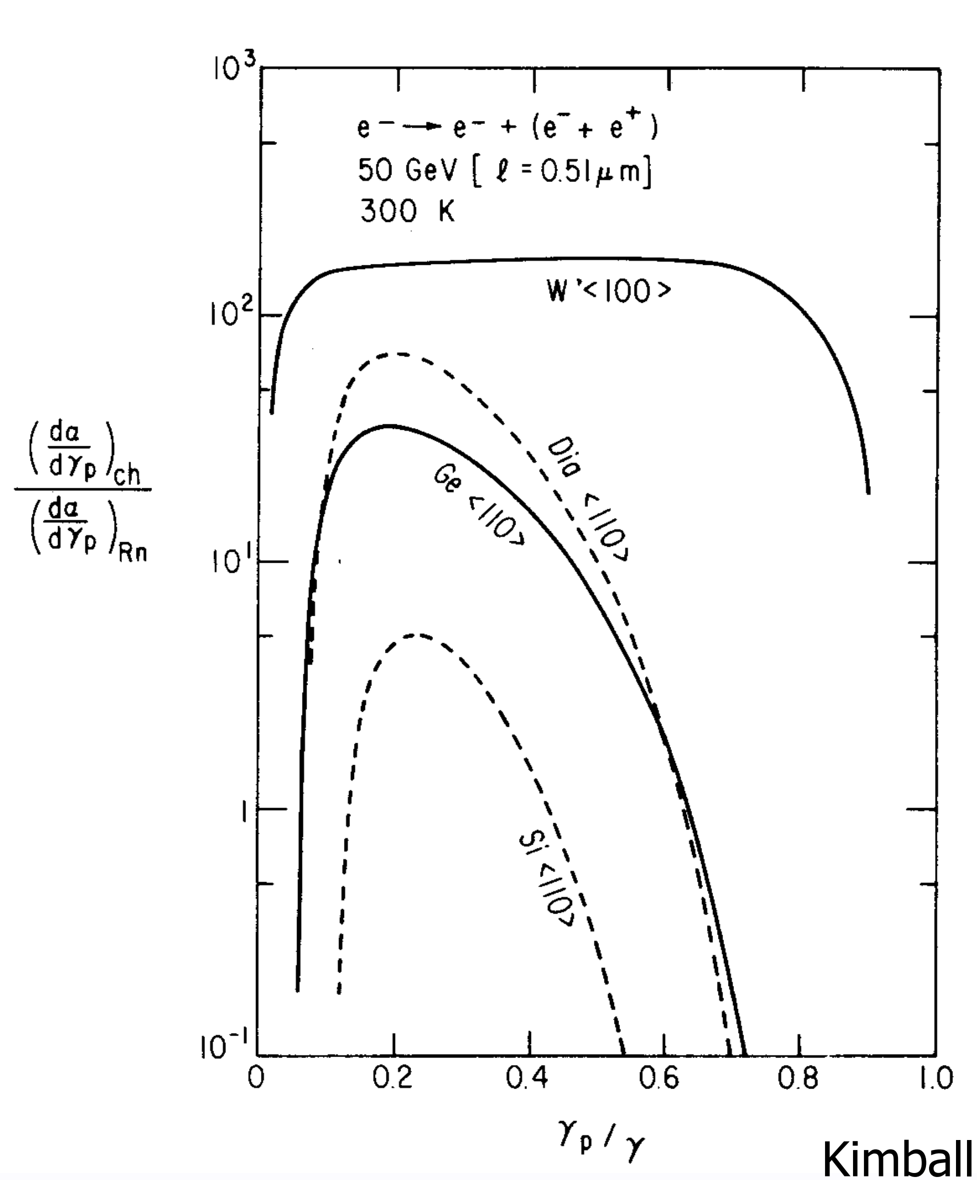


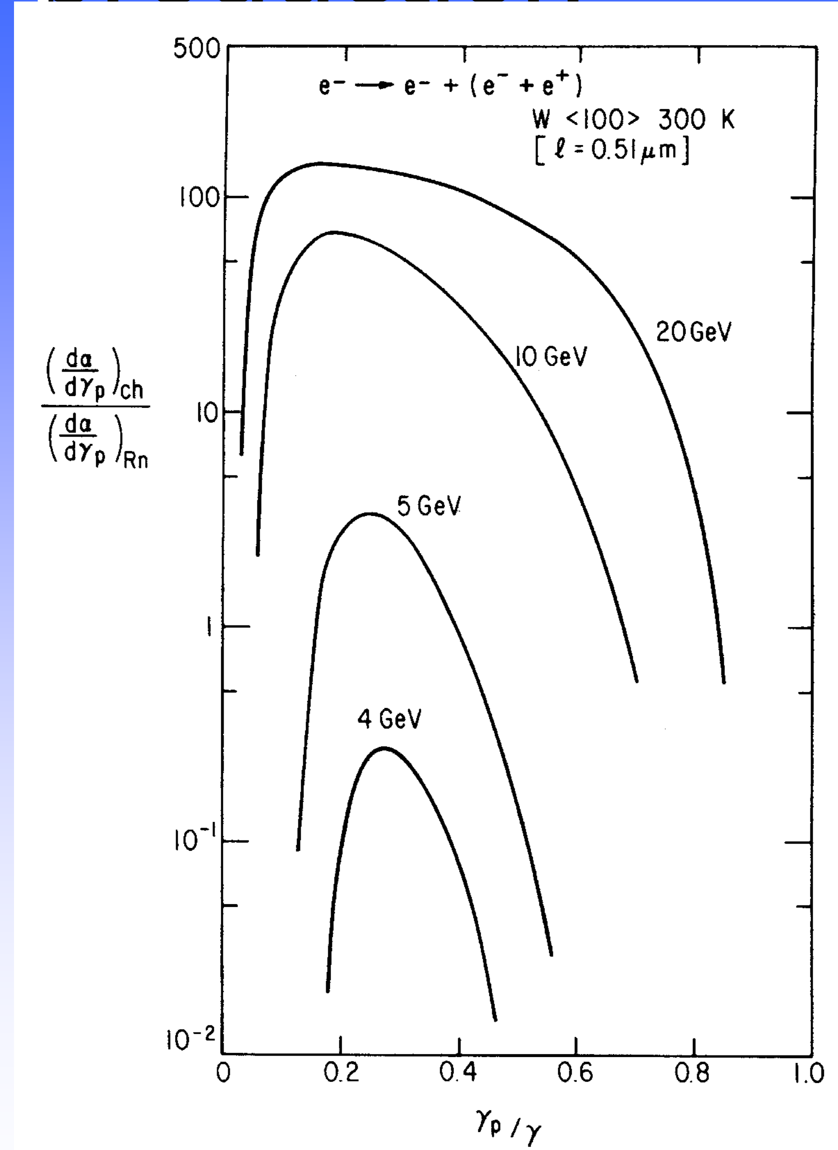
$$\Delta E/\Delta E_{\mathrm{cl}} \simeq 1.2\chi^{-4/3} \qquad \chi \gg 1$$

Classical = linear

Proposals

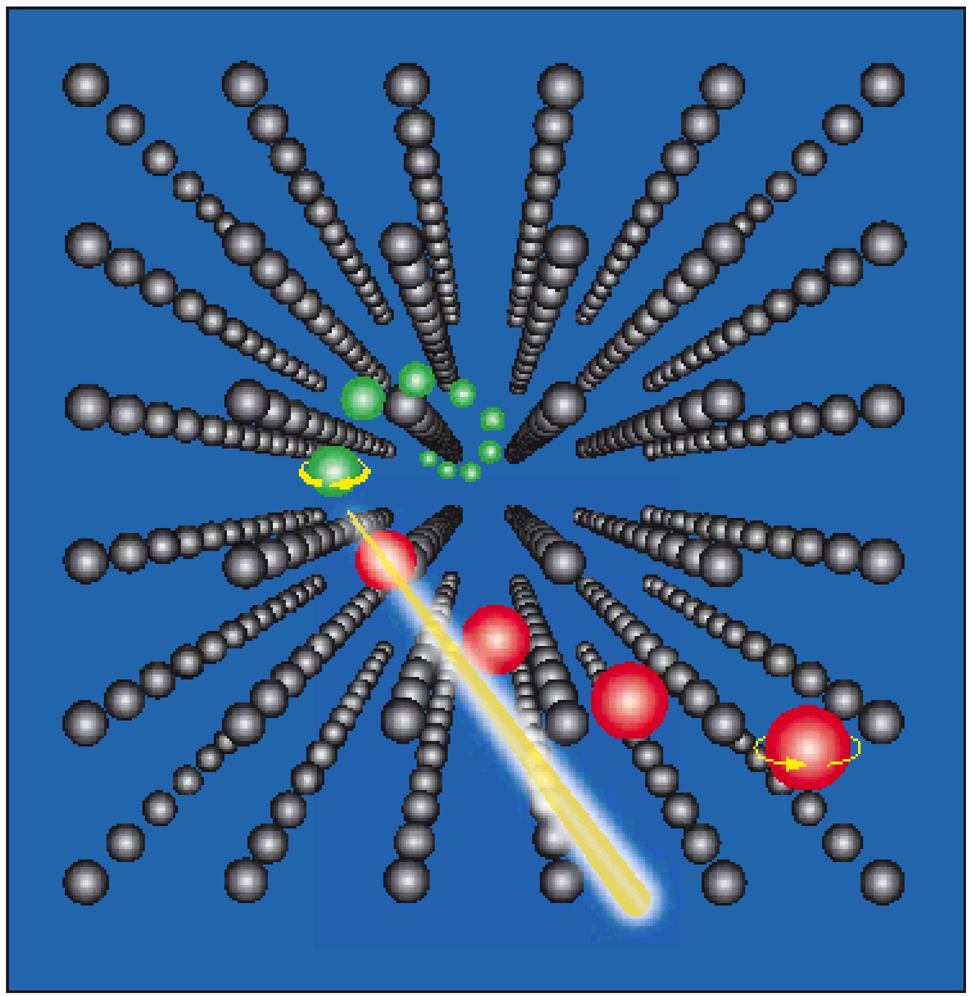
Trident 'Klein' production





Kimball and Cue, Phys. Rep. **125**, 69 (1985)

Spin-flip



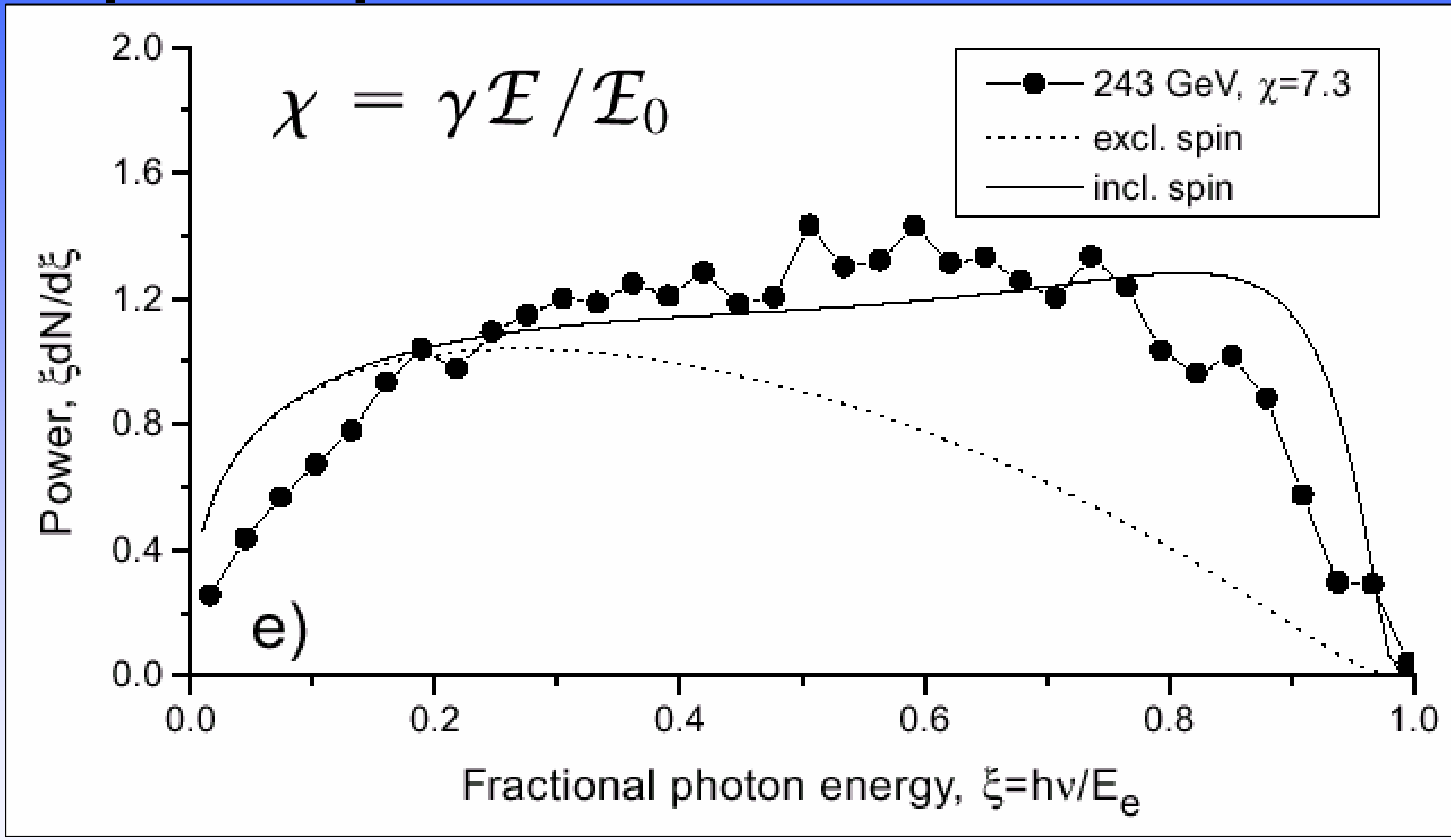
$$B = \gamma\beta\mathcal{E}_{\text{lab}}$$

$$W_{\text{mag}} = -\overline{\mu}\cdot\overline{B}$$

$$\Delta W = e\hbar B/mc$$

$$\Delta W = \gamma^2\beta\,\frac{\mathcal{E}}{\mathcal{E}_0}\,mc^2$$

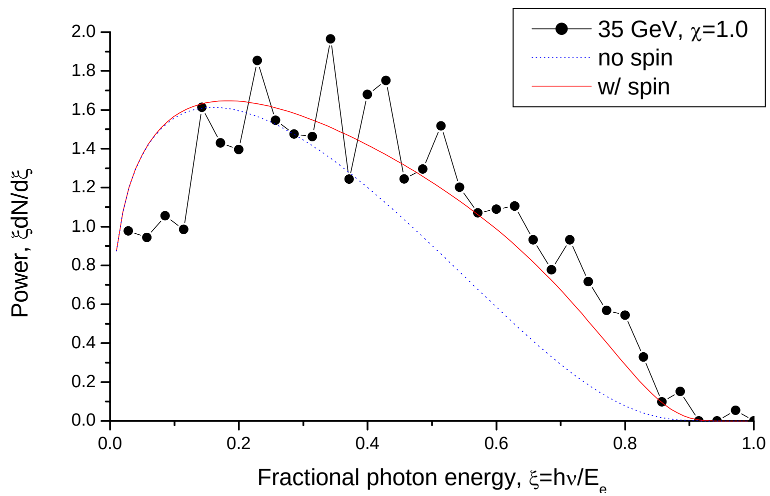
Spin-flip

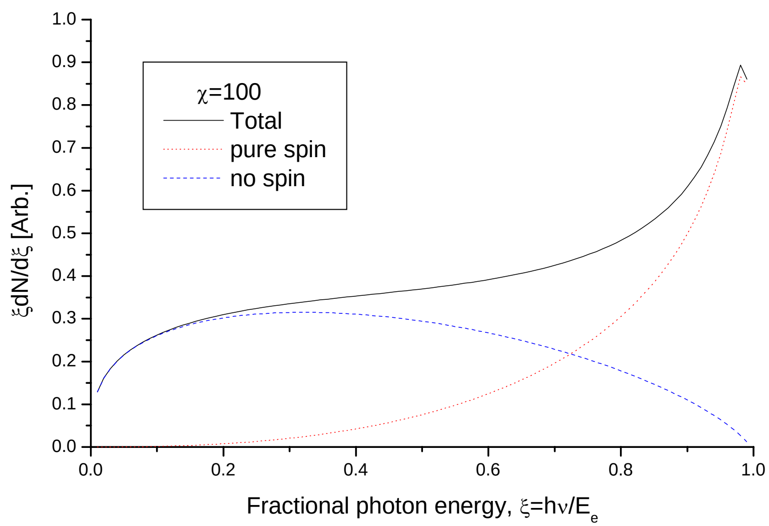


$$\Delta W = \gamma^2 \beta \frac{\mathcal{E}}{\mathcal{E}_0} mc^2$$

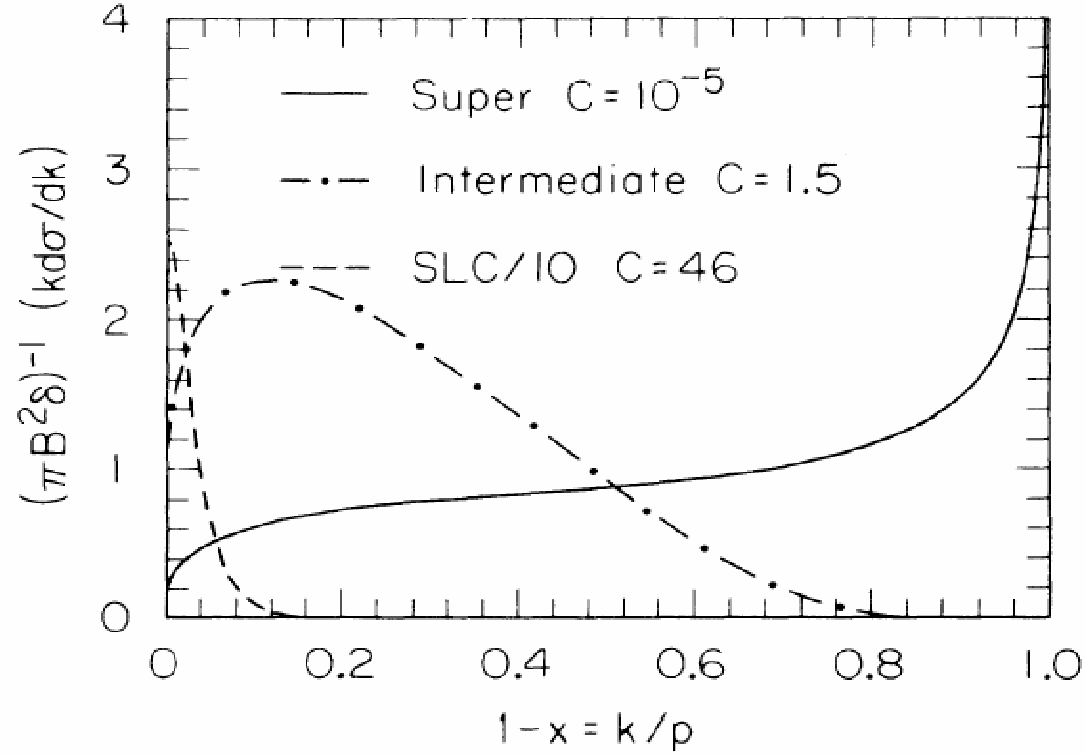
$$\tau = \frac{8\hbar}{5\sqrt{3}\,\alpha m} \left(\frac{B_0}{B}\right)^3 \frac{1}{\gamma^2} = \frac{8\hbar}{5\sqrt{3}\,\alpha m} \frac{\gamma}{\chi^3}$$

Spin-flip and beamstrahlung

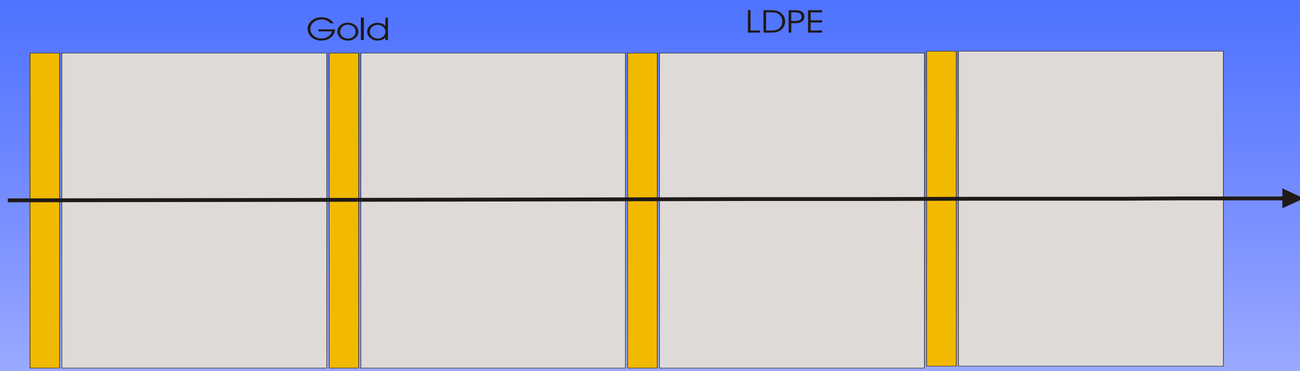




Blankenbecler and Drell, ”Quantum treatment of beamstrahlung”, PRD **36**, 277 (1987)

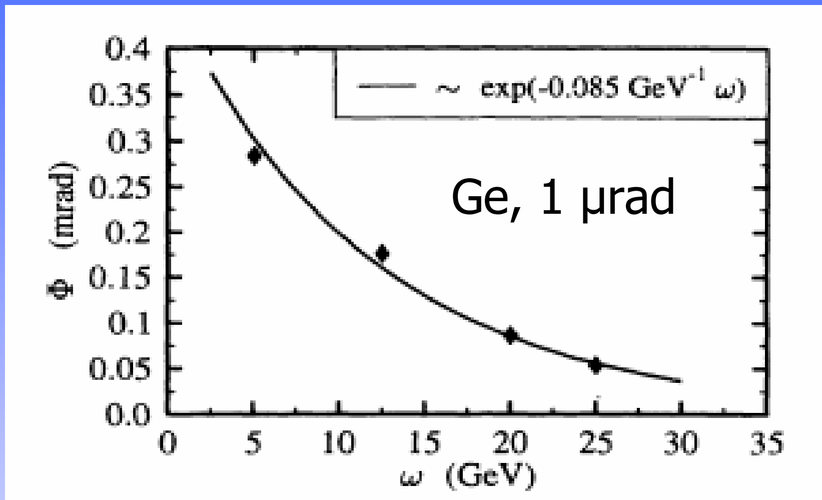


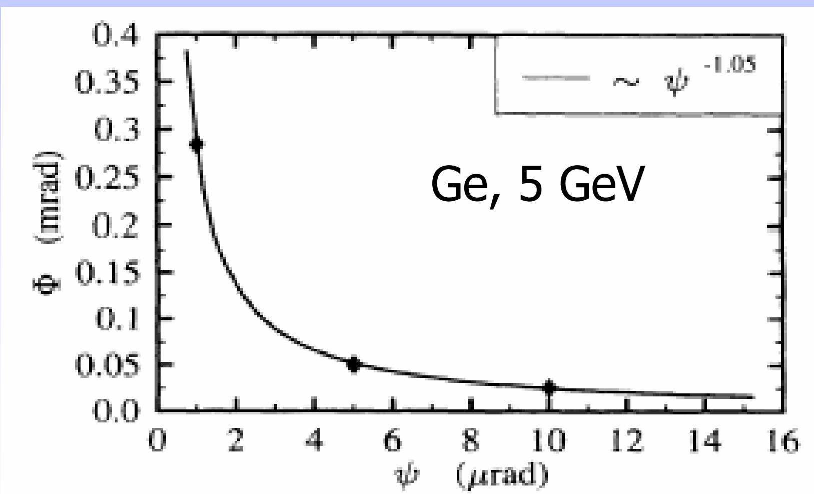
Sandwich target



- Sandwich target, 60 layers
- 'Squeezing' the formation length
- For: $l_\gamma = \frac{\alpha}{4\pi} X_0 < t < \lambda^{\mathrm{rad}}_{\mathrm{coh.}} = \frac{2\gamma^2 c}{\omega^*} = \frac{2E(E-\hbar\omega)}{\hbar\omega m c^2}\chi$
- Intensity prop. to ln(*t*) for small ω – photon source?

Delbrück scattering

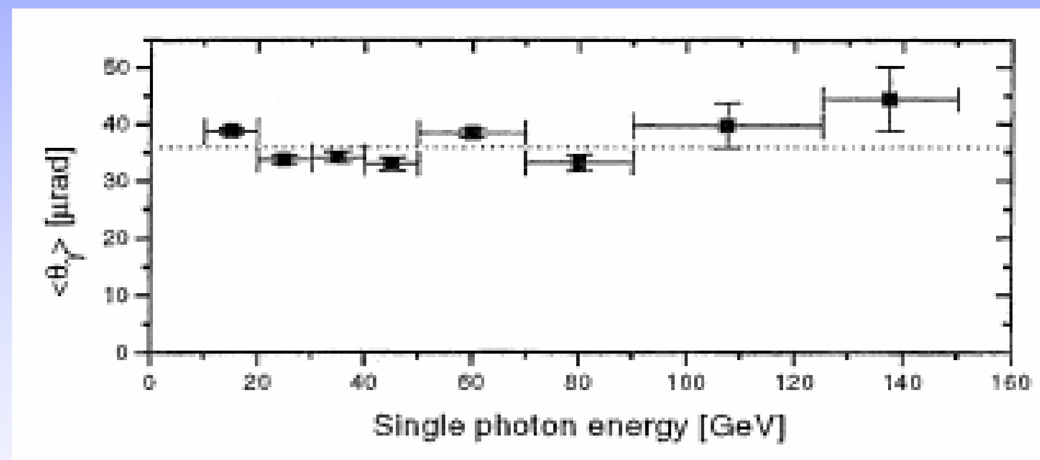




J. Klenner et al., Phys. Rev. A **50**, 1019 (1994)

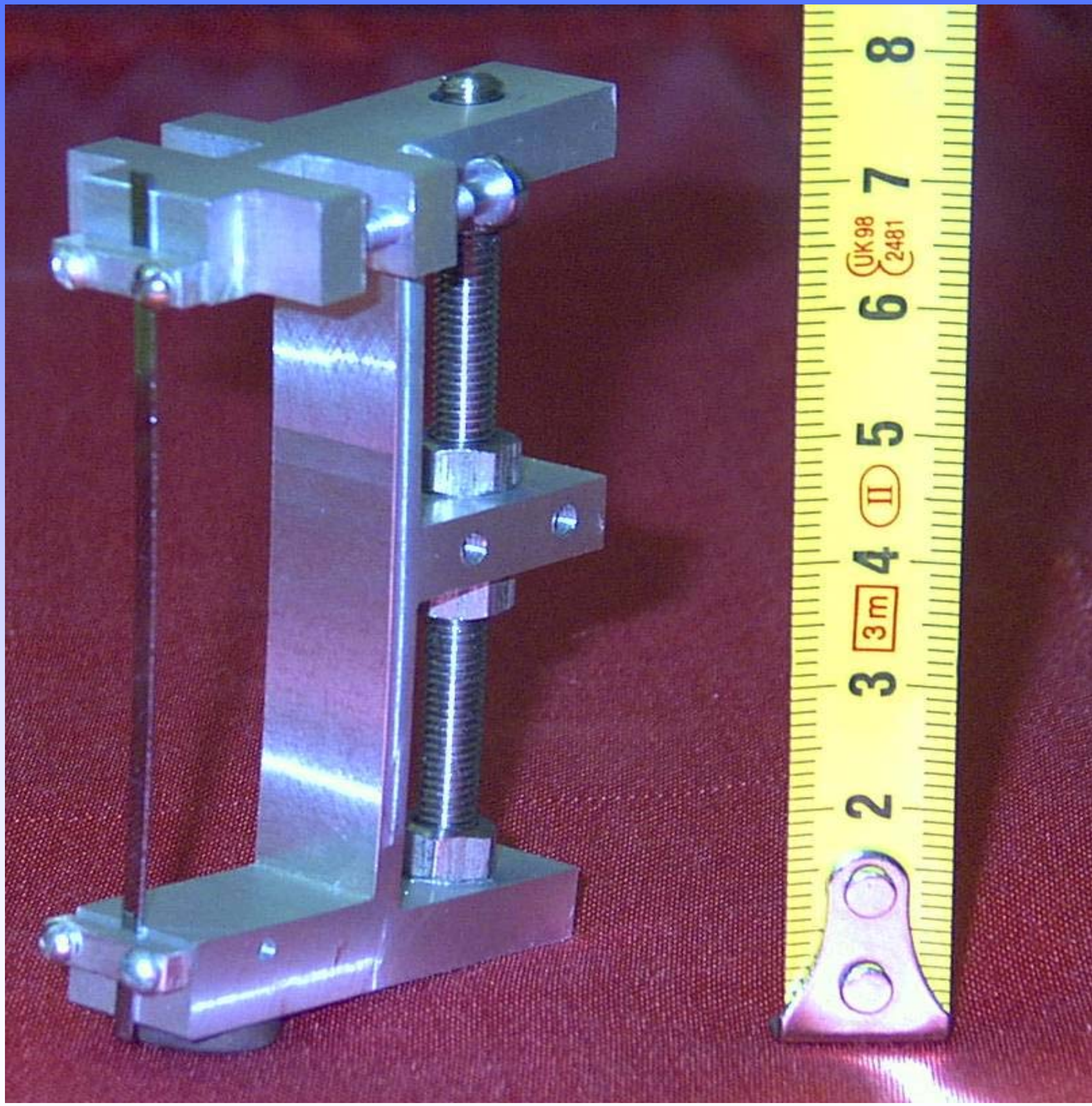
V.N. Baier: 'Delbrück scattering in a strong field is a very difficult theoretical problem'

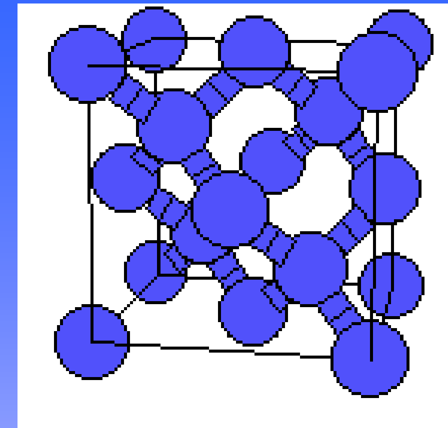
'Threshold' for strong field effects in Ge:
E ≈ 200 GeV ($\chi = 1$)

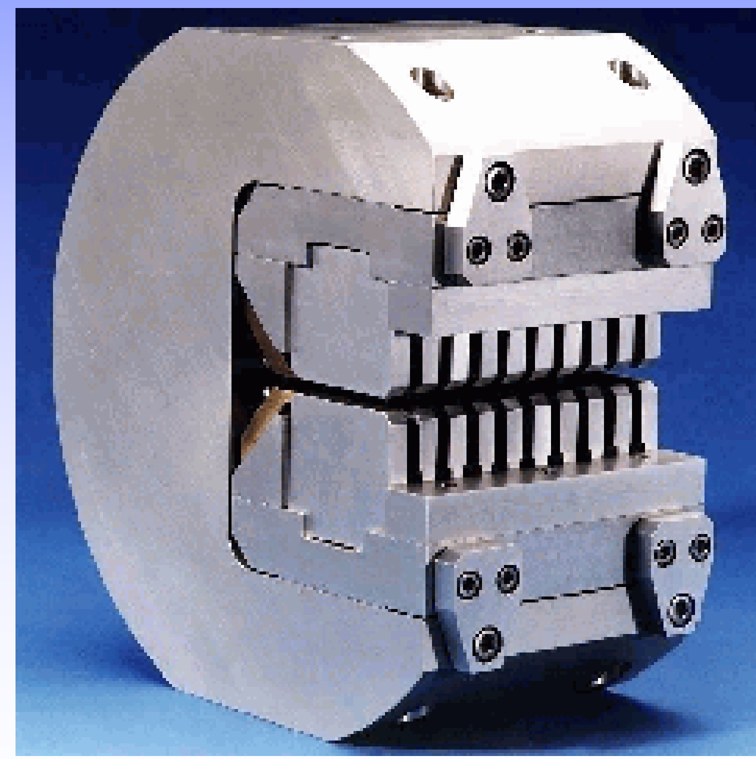


Expected accuracy: few μrad

Crystal undulator

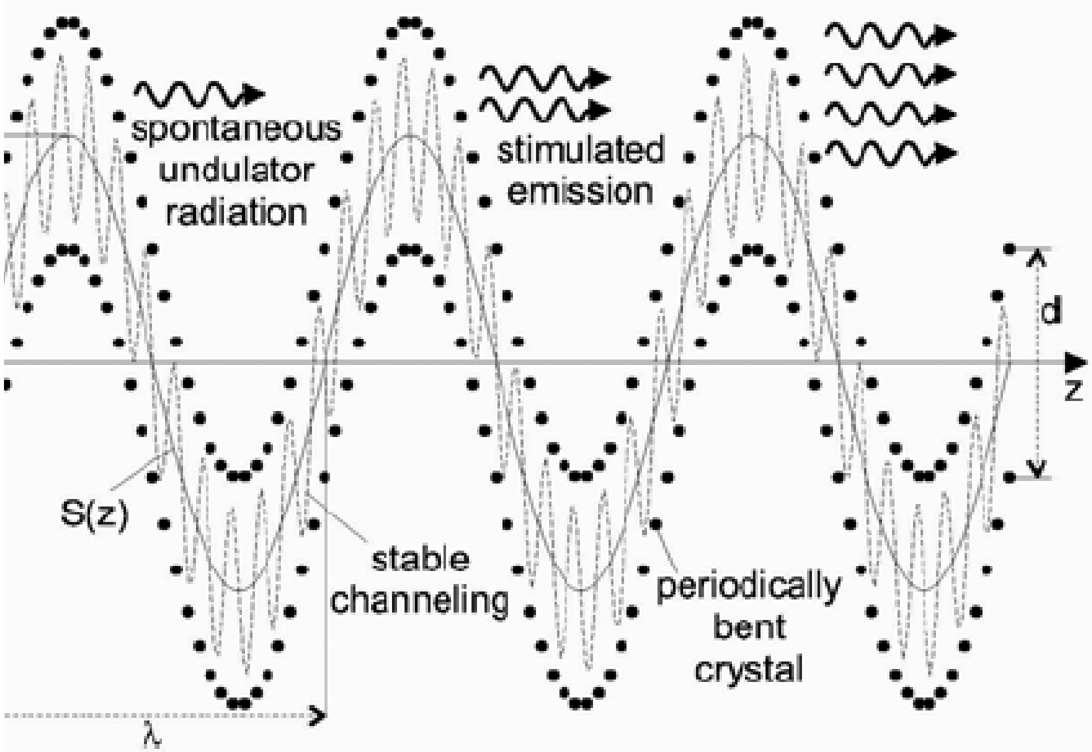






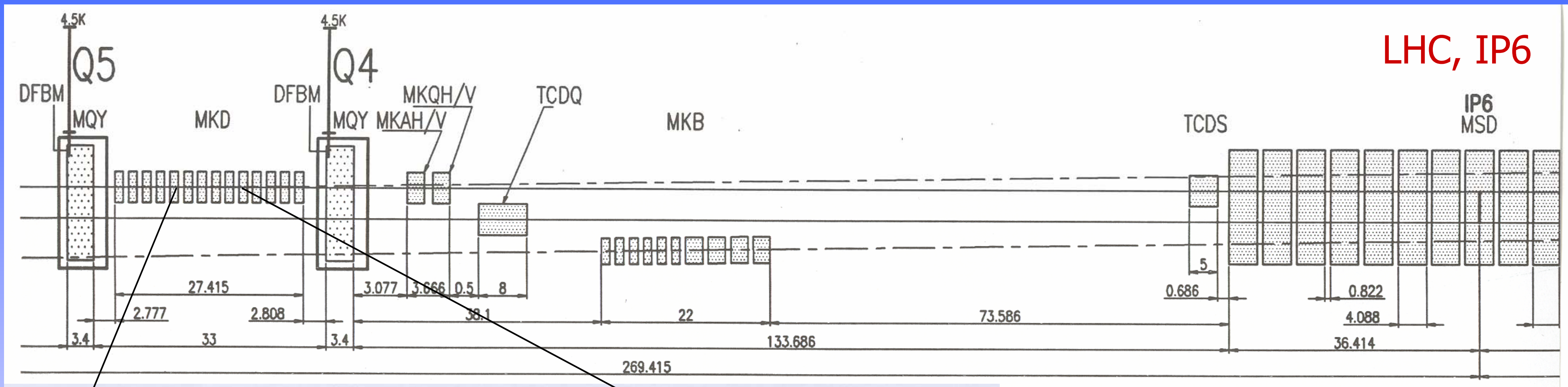
Crystal undulator

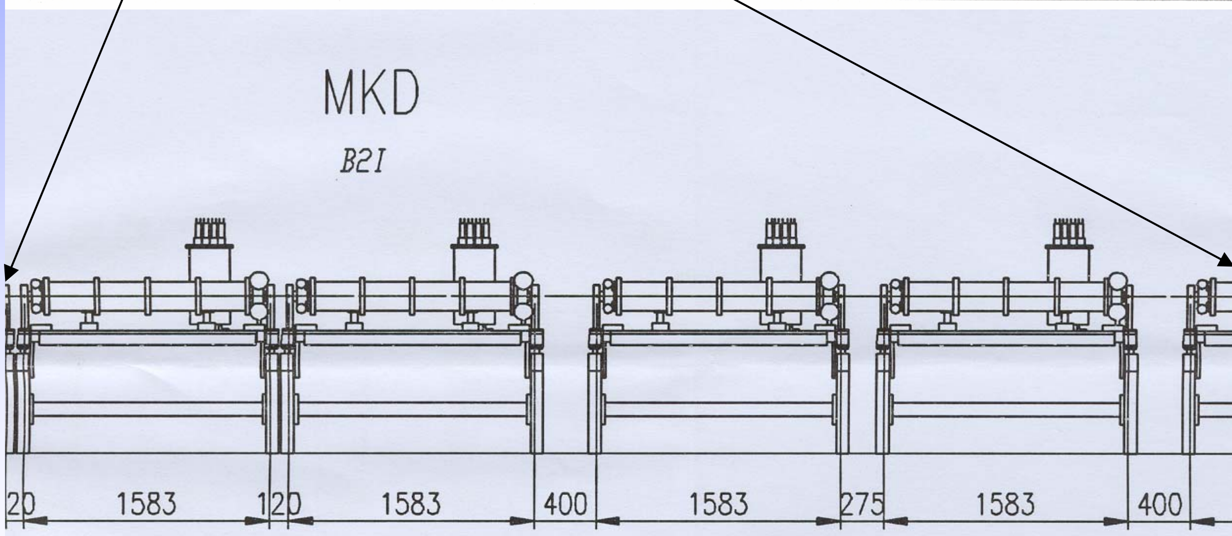
	0.2 GeV/c	2 GeV/c	10 GeV/c
$\hbar\omega_{\max}$	(7.2 keV)	718 keV	17.9 MeV
$\hbar\omega_{\mathrm{ChR}}$	0.2 MeV	7 MeV	57 MeV
p_{u}	0.41	1.89	5.51
A	18 Å	38 Å	65 Å
$x_{\max}$	2.8%	1.3%	0.77%
N	9	20	27
κ_c/κ	5.0	5.0	5.0
N_{ω_K}	0.68	1.5	2.0
$\hbar\omega_1$	32.6 keV	274 keV	402 keV
θ_0	0.73 mrad	0.34 mrad	0.20 mrad
$\Delta\omega/\omega$	0.22	0.10	0.073
L_D	0.10 mm	0.87 mm	3.99 mm
Δt	0.1 mm	1 mm	4 mm
$\Delta E/E$	0.1%	1.1%	4.1%
ψ_p	361 μrad	114 μrad	51 μrad

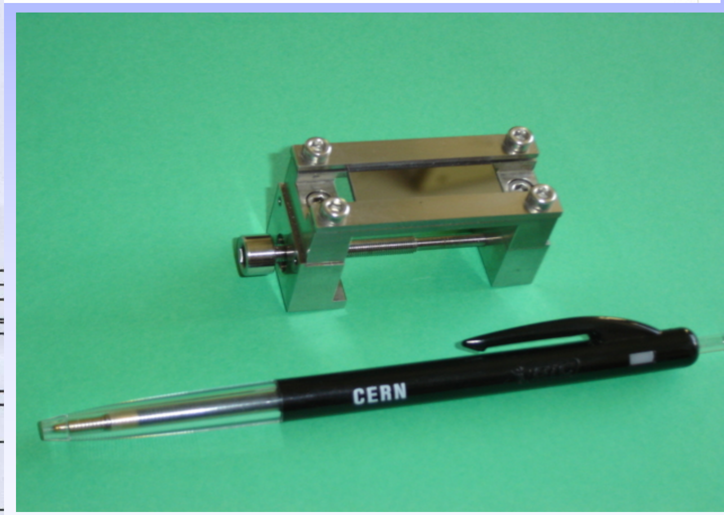


Lasing (?)

If time allows…







Strong (bent) crystalline fields - a possibility for extraction from the LHC:
1e8 7 TeV protons/s – ’smart’ collimation.