Electromagnetic processes in strong crystalline fields, H4 Oct. '07

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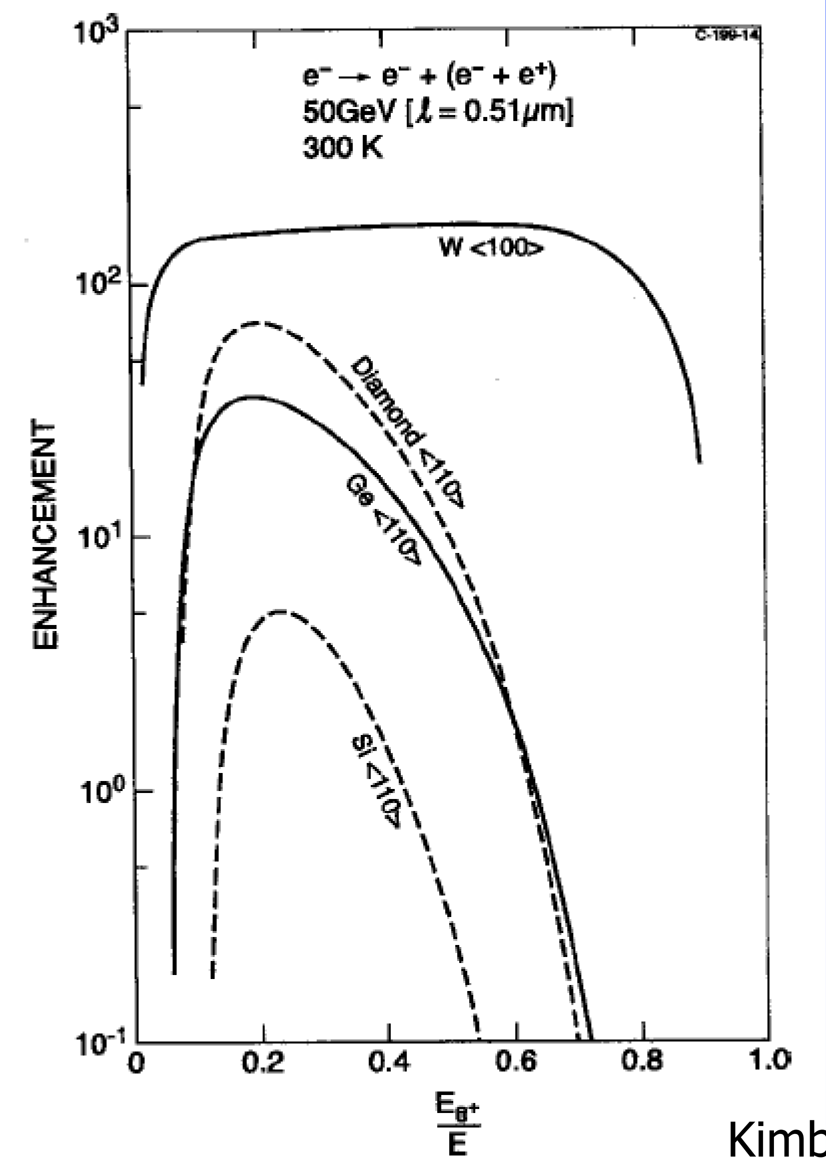
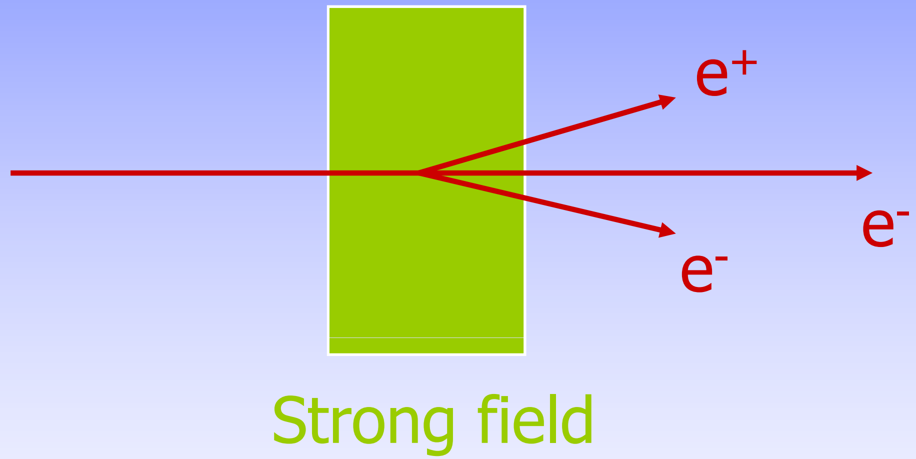
Run in H4
Oct. 2007

Plans

Trident 'Klein-like' production



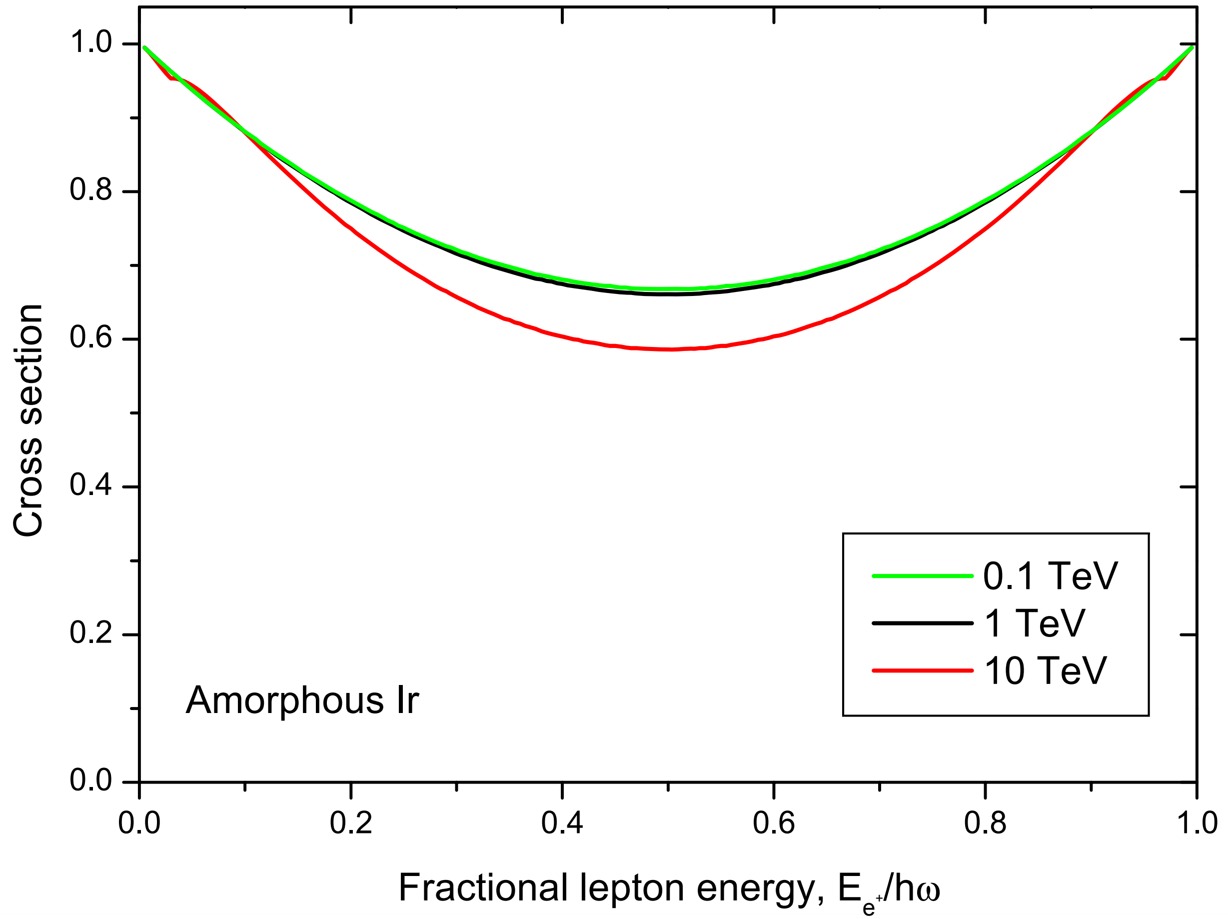


Kimball and Cue, Phys. Rep. **125**, 69 (1985)

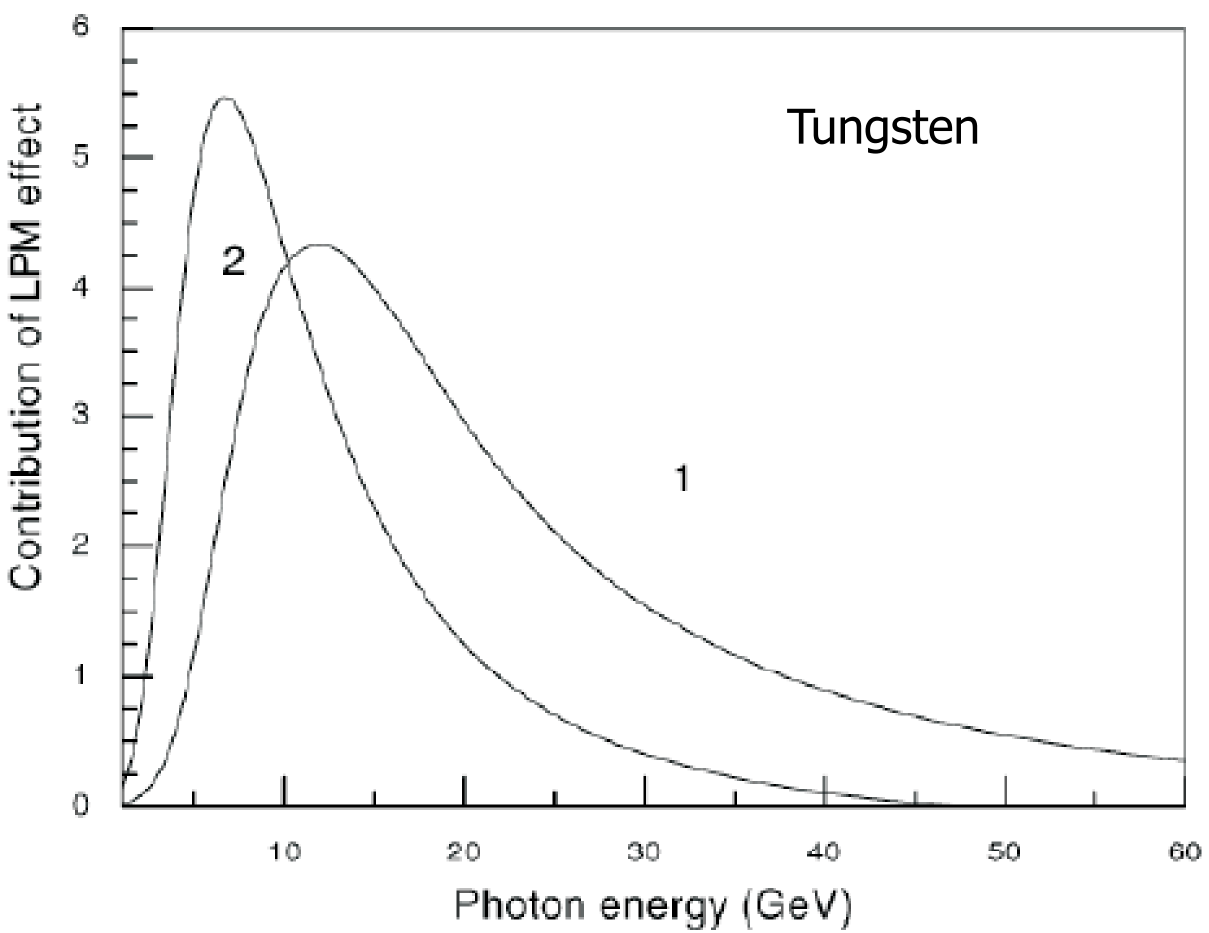
Pair production LPM effect

<u>LPM:</u>
Strong multiple scattering within formation length leads to suppression

Requires extreme precision to measure in amorphous materials for PP



Pair production LPM effect

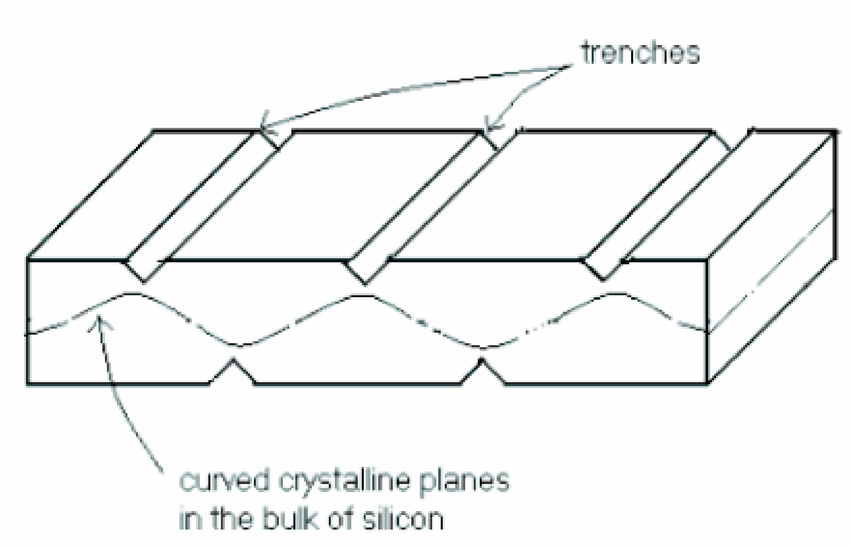


Equivalent effect in amorphous materials for photon energies
$\omega \approx 5$ TeV

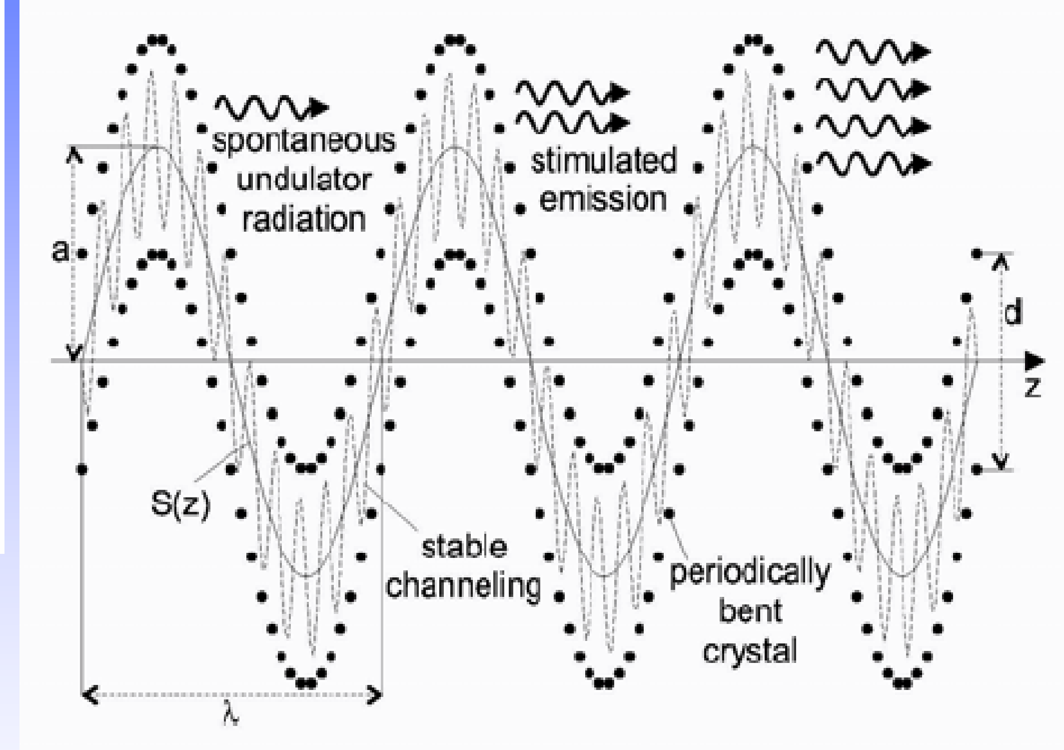
Calculations underway for Ge

The relative contribution of the LPM effect (in percent) in tungsten, axis $< 111 >$. Curve 1 is for $T = 293$ K and curve 2 is for $T = 100$ K.

Crystal undulator

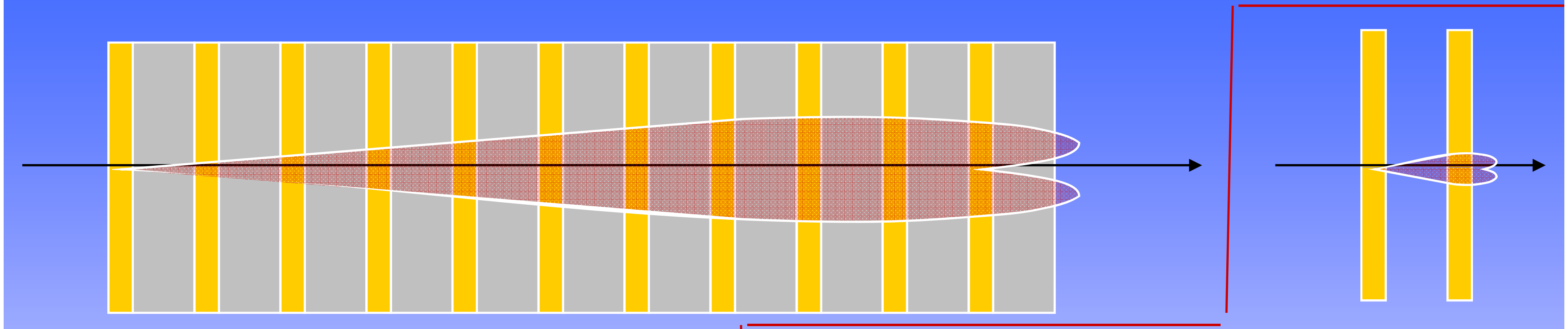


Solov'yov,
Greiner *et al.*



Not to scale

Sandwich target

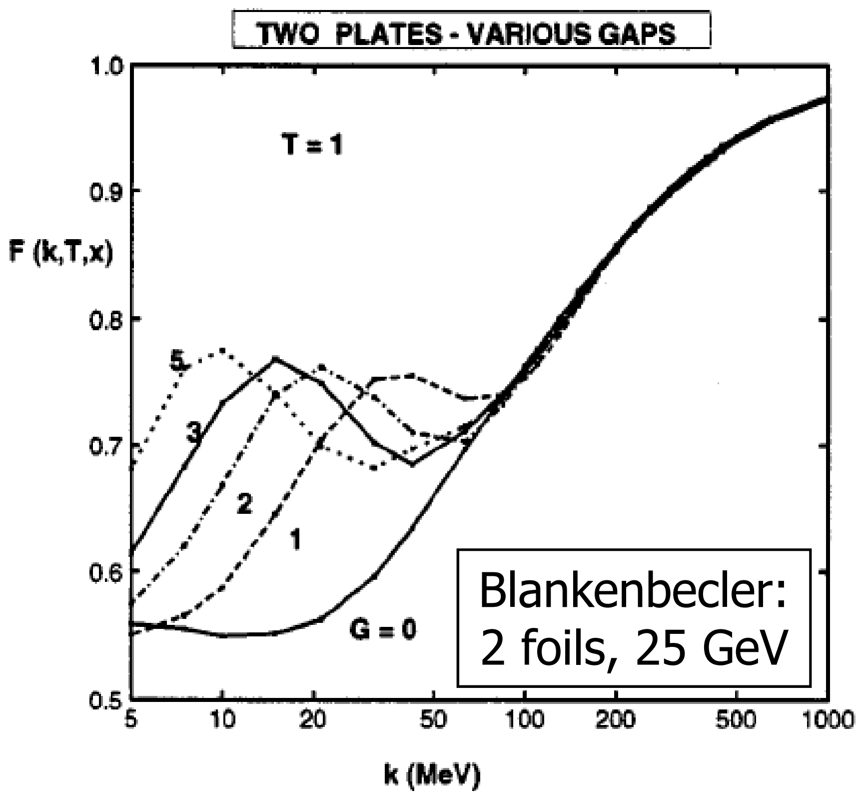


- Sandwich target
- 20 layers:

Ta – Al – Ta – Al – :

$Z_{Ta}^2/Z_{Al}^2 = 32$

- Resonances within formation length



Motivation

(why still do QED experiments?)

The critical (Schwinger) field

- Schwinger, 1949

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

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

$$\mathcal{E}_0 = mc^2/e\lambdabar_c$$

Quantum corrections to synchrotron radiation emission

Relativistic invariant:

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

Beamstrahlung

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

SLC:

χ (or Υ) $\approx 10^{-3}$

ILC:

χ (or Υ) ≈ 1

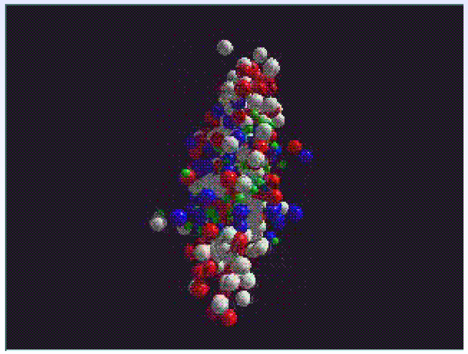
heavy ions

Superstrong field, but of short duration

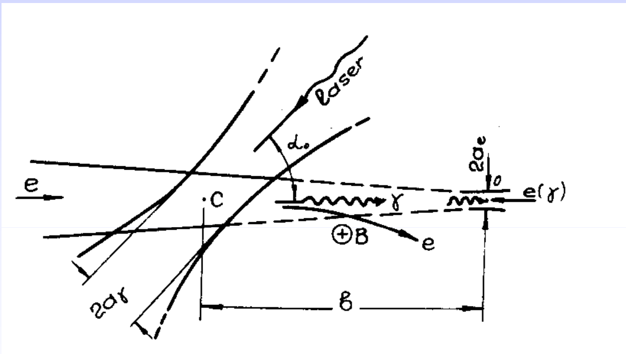
$$\mathcal{E}_{1s}/\mathcal{E}_0 = \alpha^3 Z^3$$

Extended nucleus:

$Z \approx 172$



Strong lasers

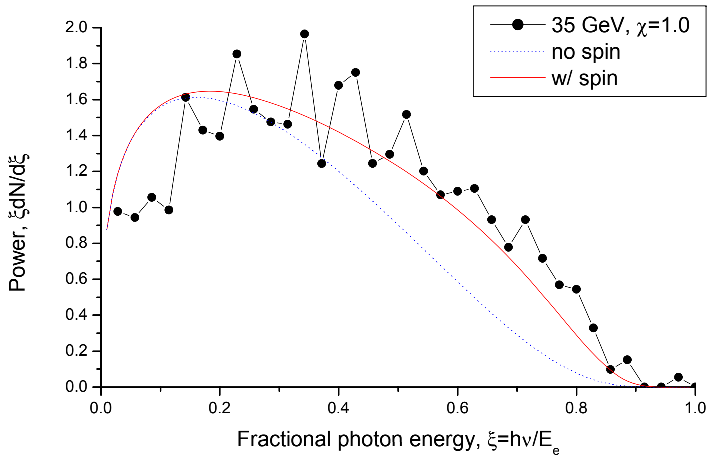


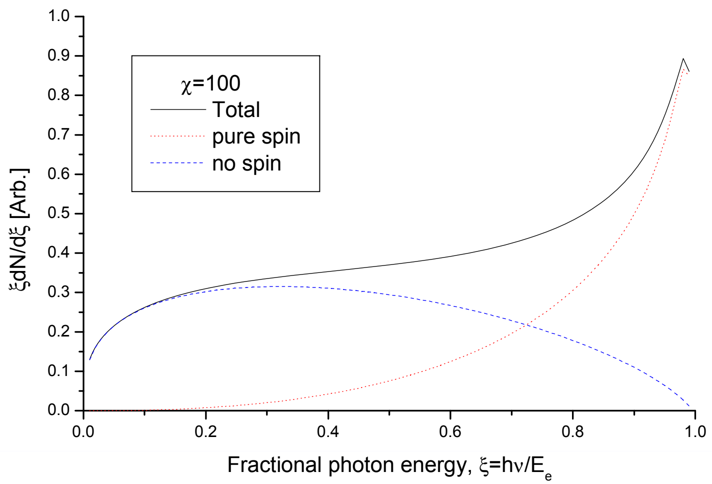
$\gamma\gamma$-collision scheme
(Telnov *et al.*)

Laser wavelength (and γ energy) limited by non-linear Compton scattering

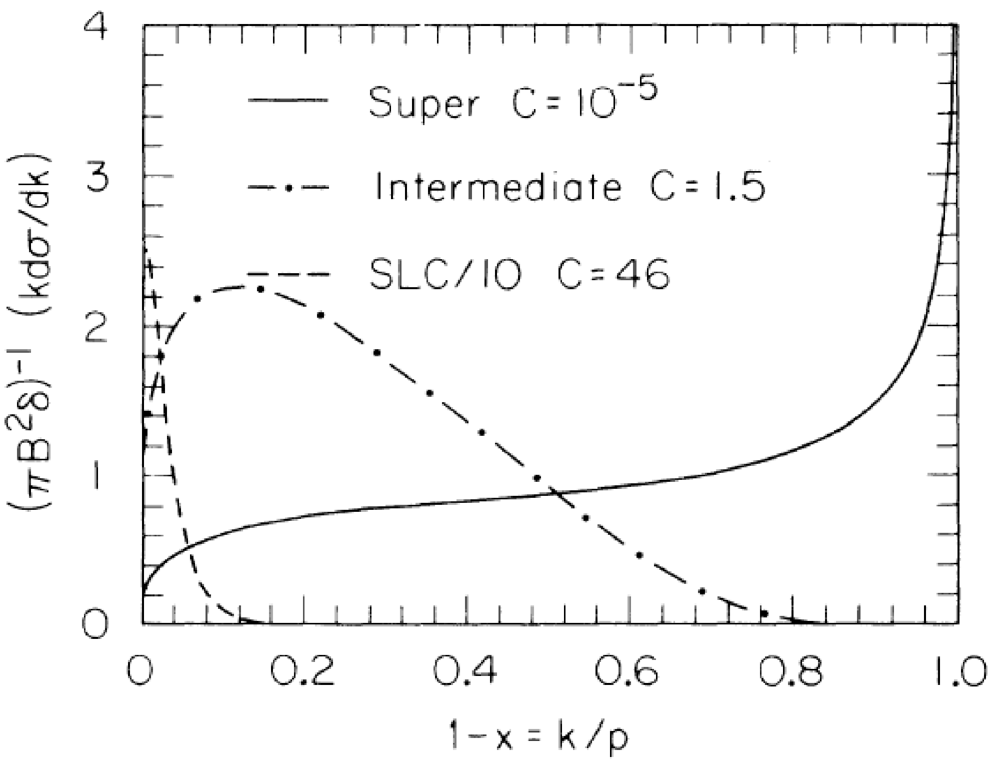
χ (or Υ) ≈ 1

Spin-flip and beamstrahlung





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



GeV electron beams from a centimetre-scale accelerator

nature physics | VOL 2 | OCTOBER 2006 |

Plasma wakefields

Transverse focusing forces:

$$F_{\perp} \approx m\omega_p^2 r/2$$

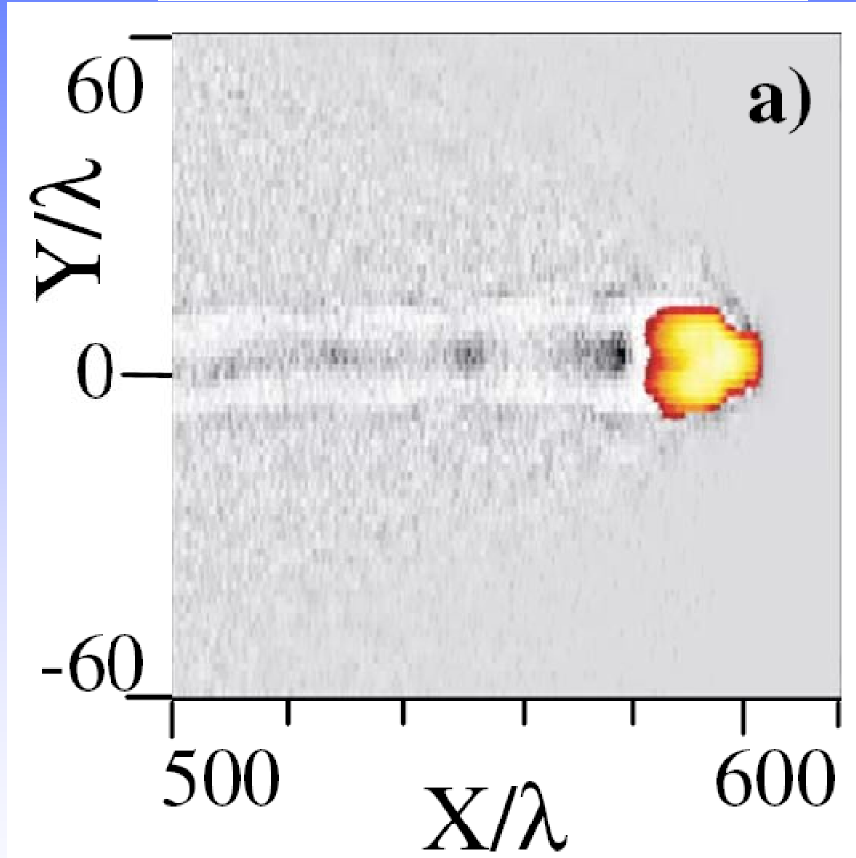
Lead to values

$$\chi \approx \gamma(F_{\perp}/eE_{cr}) \approx 10^{-6}\gamma$$

for realistic parameters:

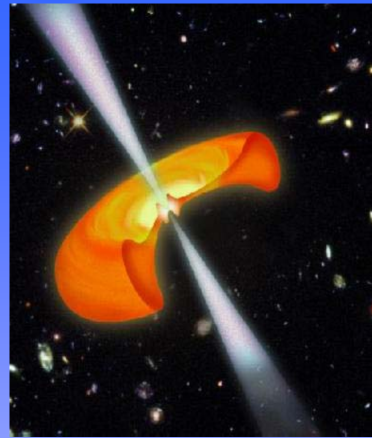
$$n_0 \approx 10^{19}\ \mathrm{cm}^{-3} \ \text{ and } \ r = 15\ \mu\mathrm{m}$$

cavitation or bubble regime



PHYSICAL REVIEW E **75**, 057401 (2007)

Magnetars



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

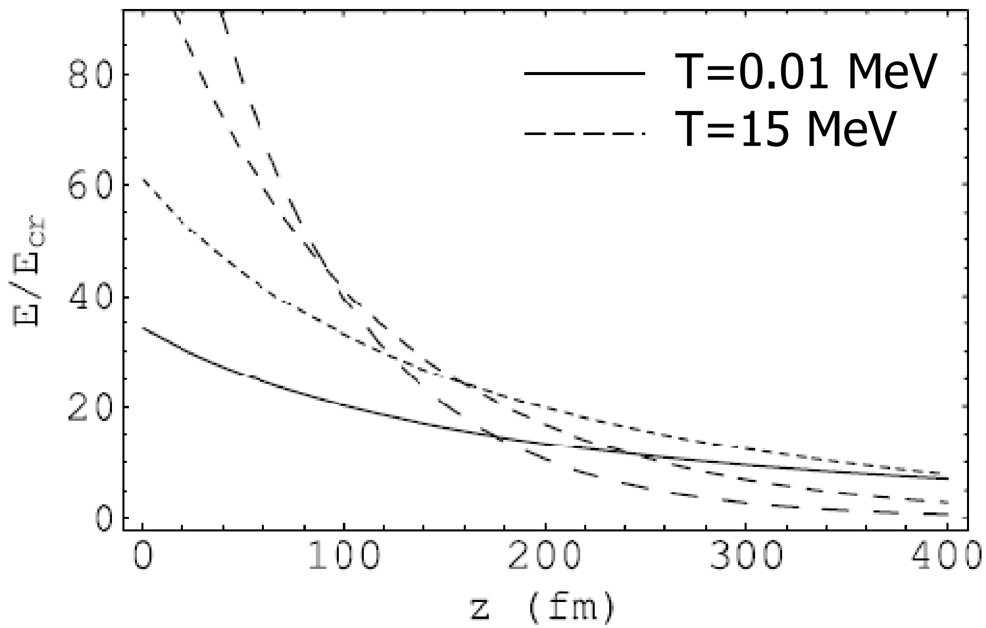
$$\hbar\omega/mc^2 = \sqrt{B/B_0}$$

- Electrosphere of strange stars:

$$\chi \approx 5\text{-}100$$

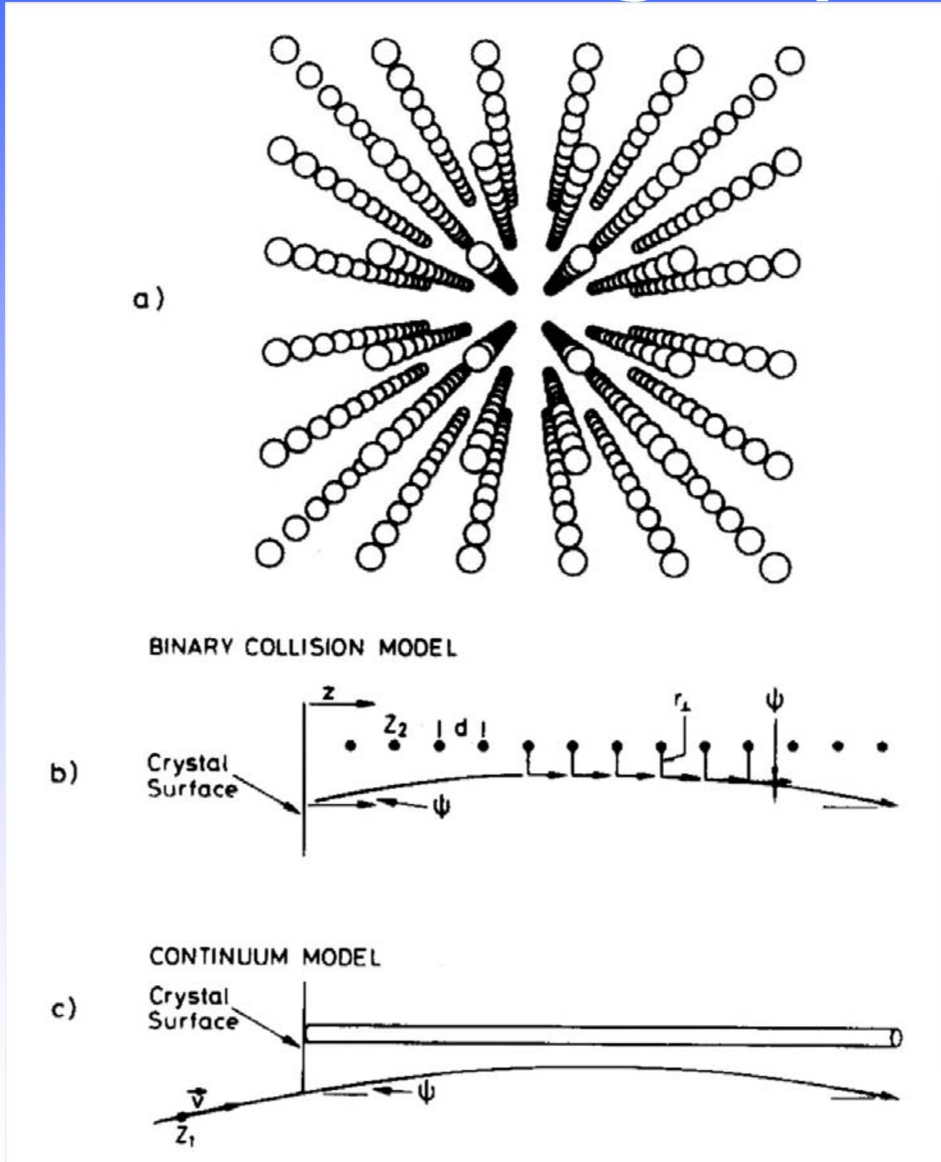
THE ASTROPHYSICAL JOURNAL, 643:318–331, 2006 May 20

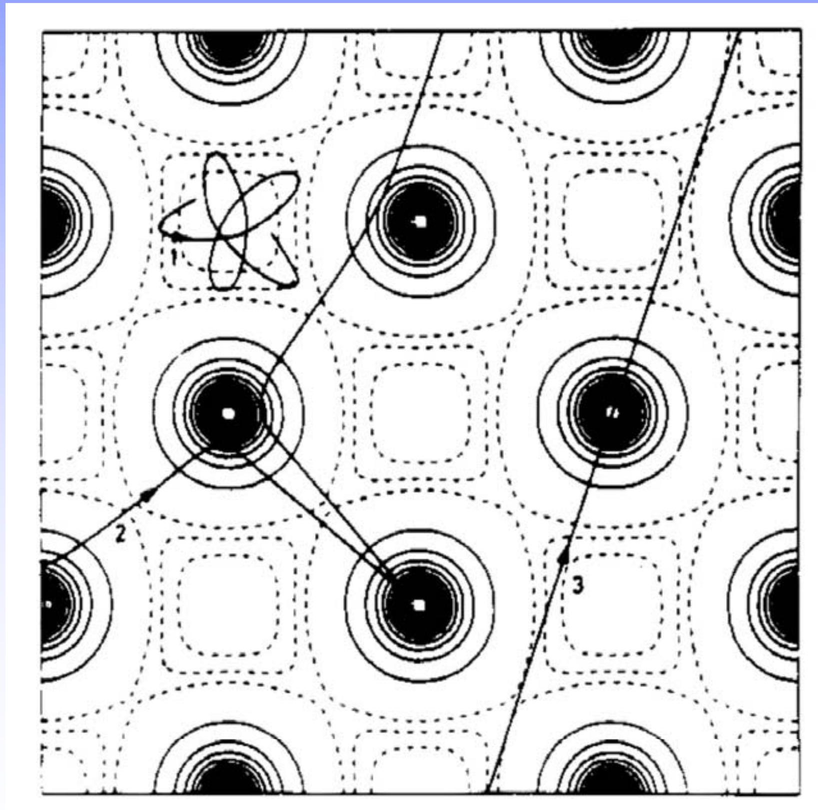
e^-e^+ PAIR PRODUCTION IN ELECTROSPHERE



Strong fields in crystals

Strong crystalline fields



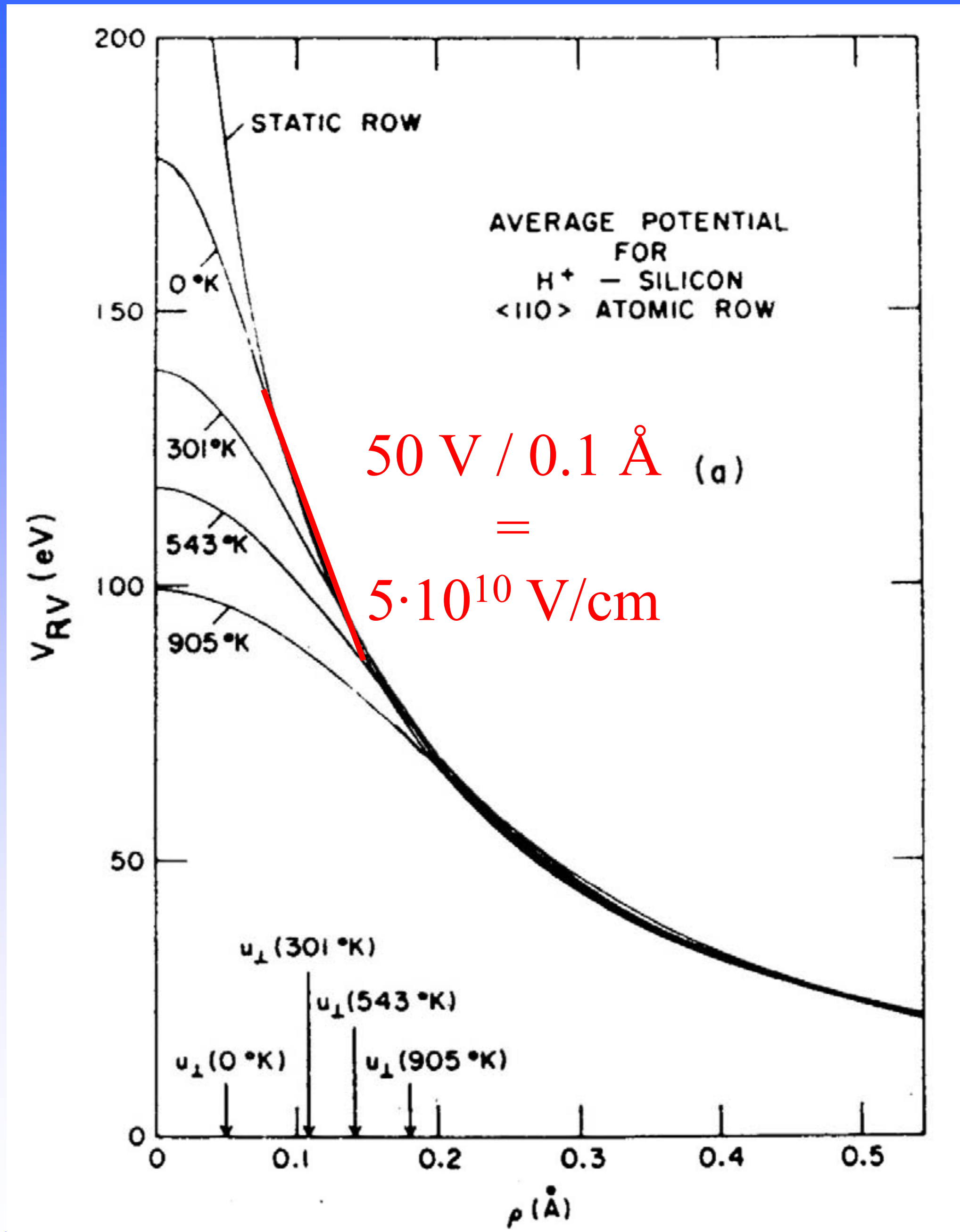


Crystals

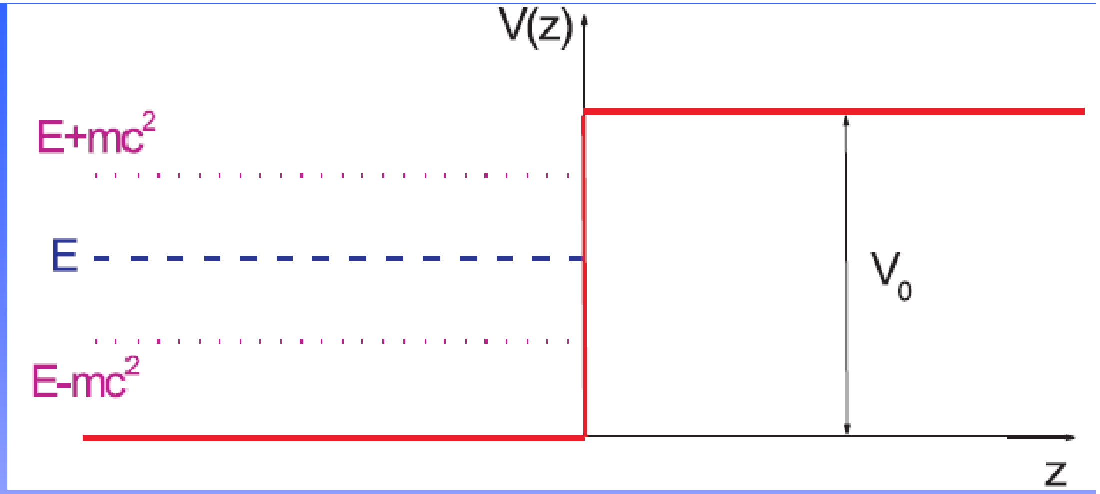
Extremely strong electric fields

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

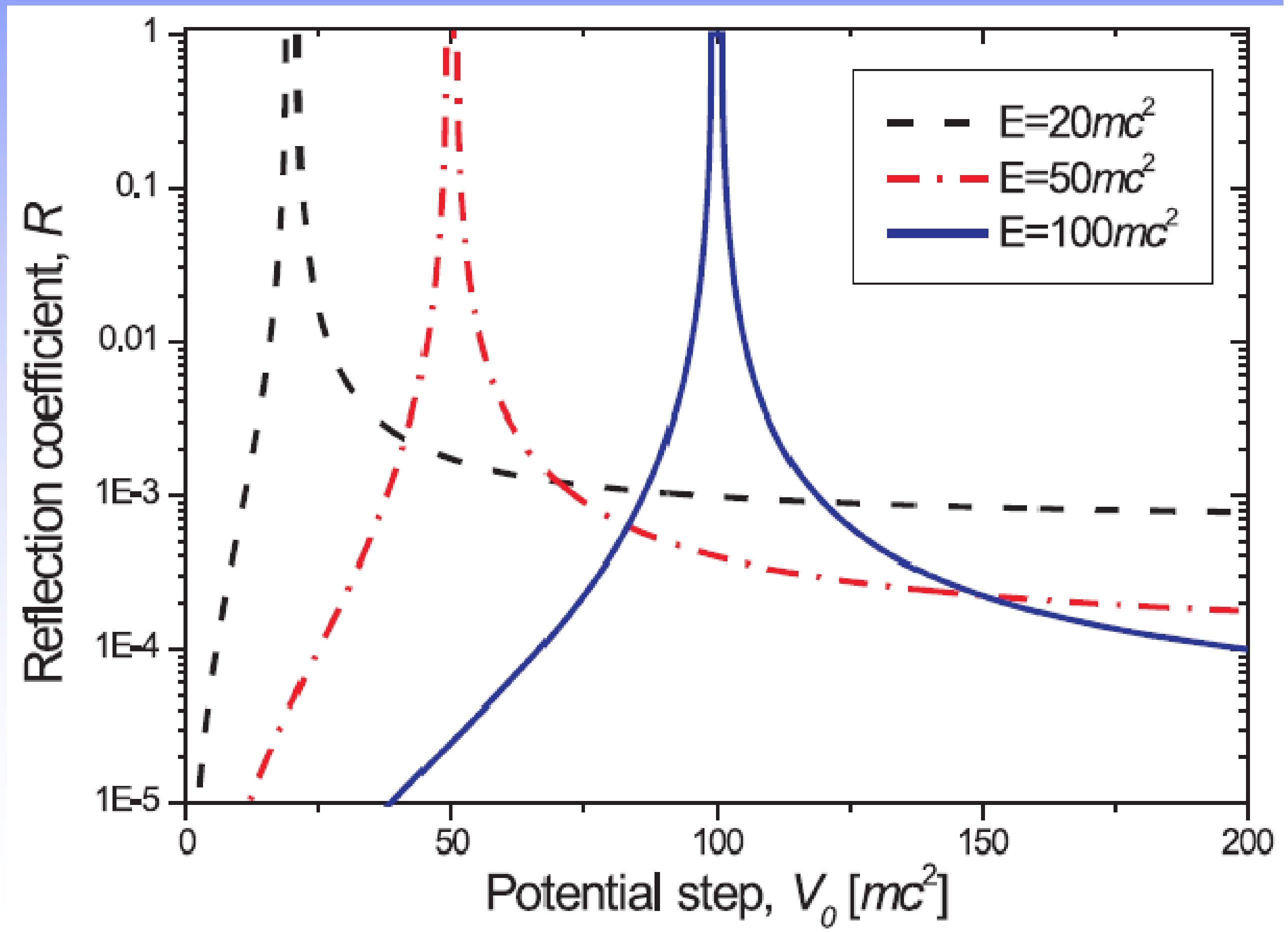
$$\chi = \gamma \mathcal{E} / \mathcal{E}_0$$



Klein's paradox



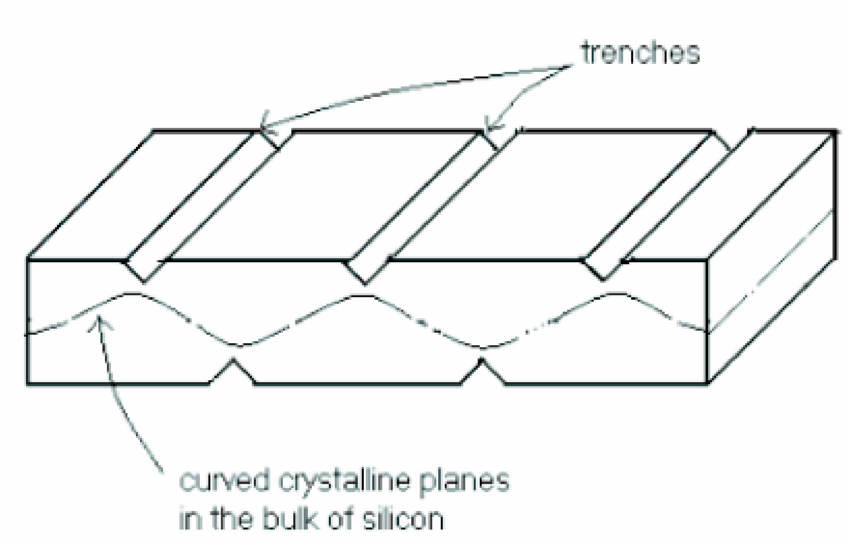
- Reflection coefficient approaches 0 beyond the critical field:

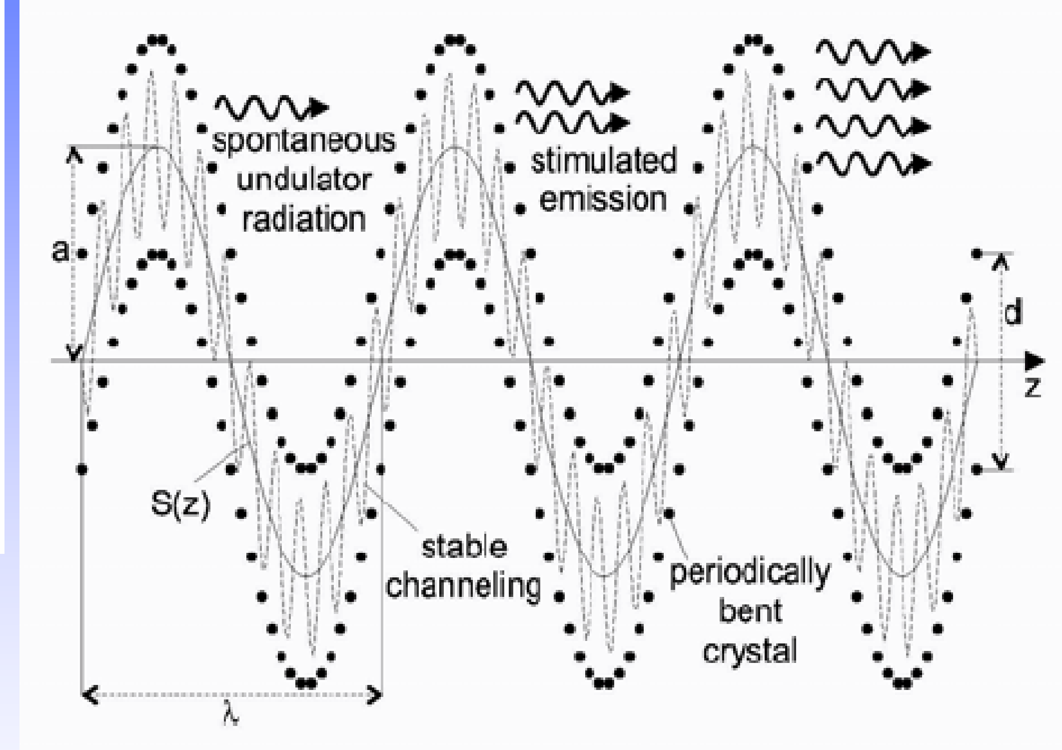


<u>Pair production.</u>

Crystal undulator

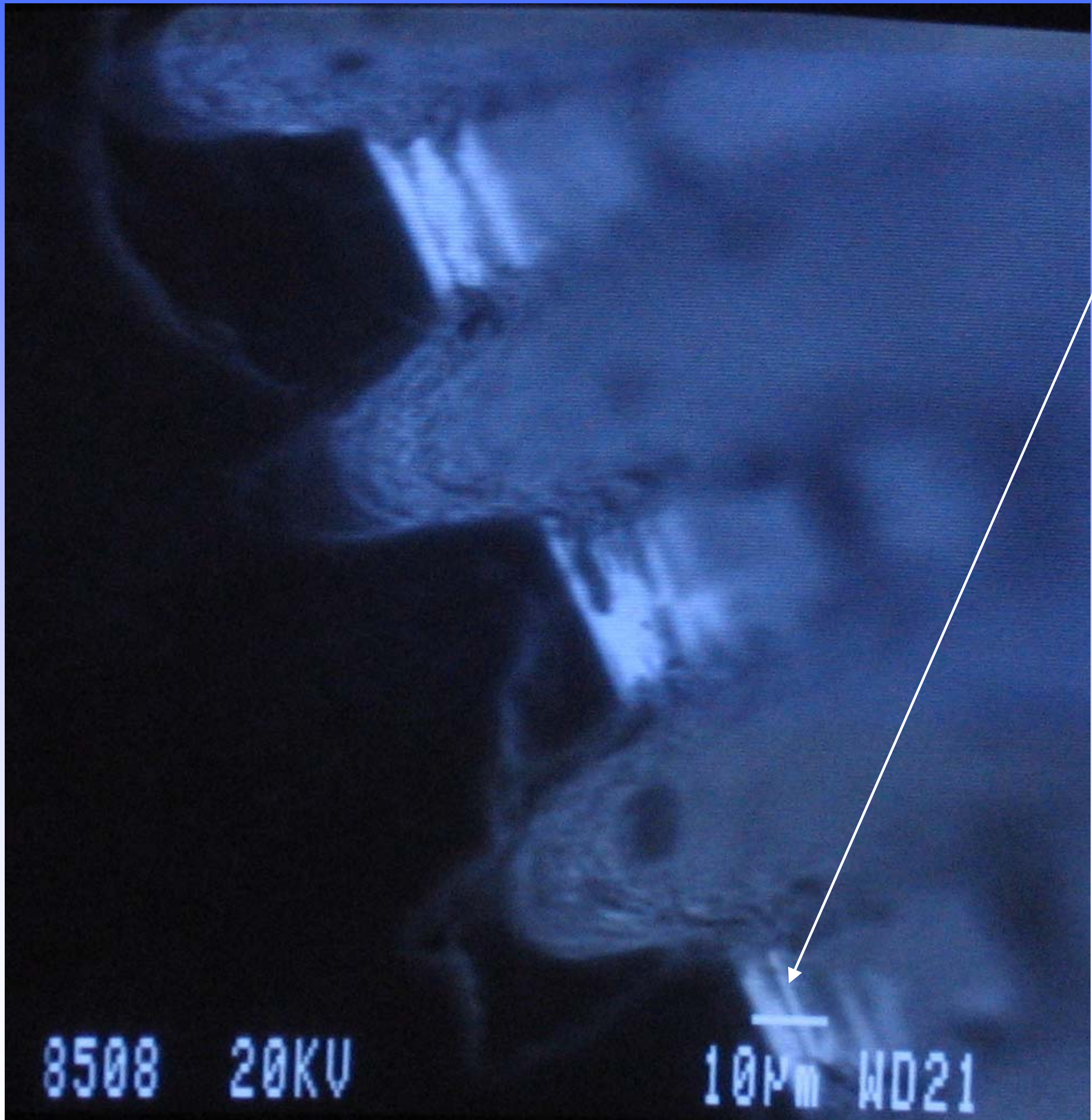
Crystal undulator





Not to scale

Femtosecond laser-ablated crystals



10 microns, laser

200 microns, diamond-blade (state-of-the-art, 2003)

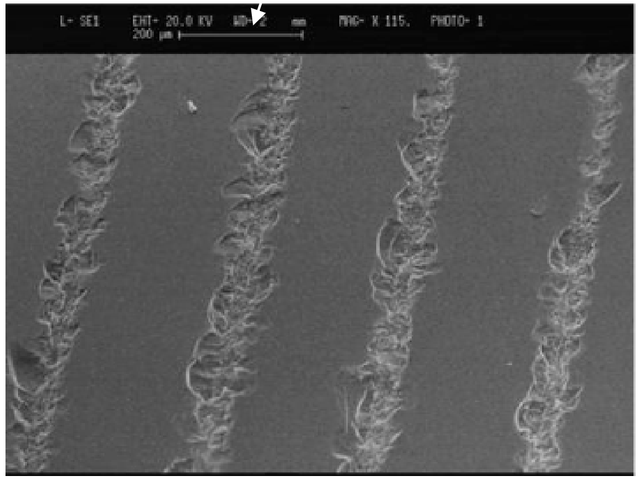
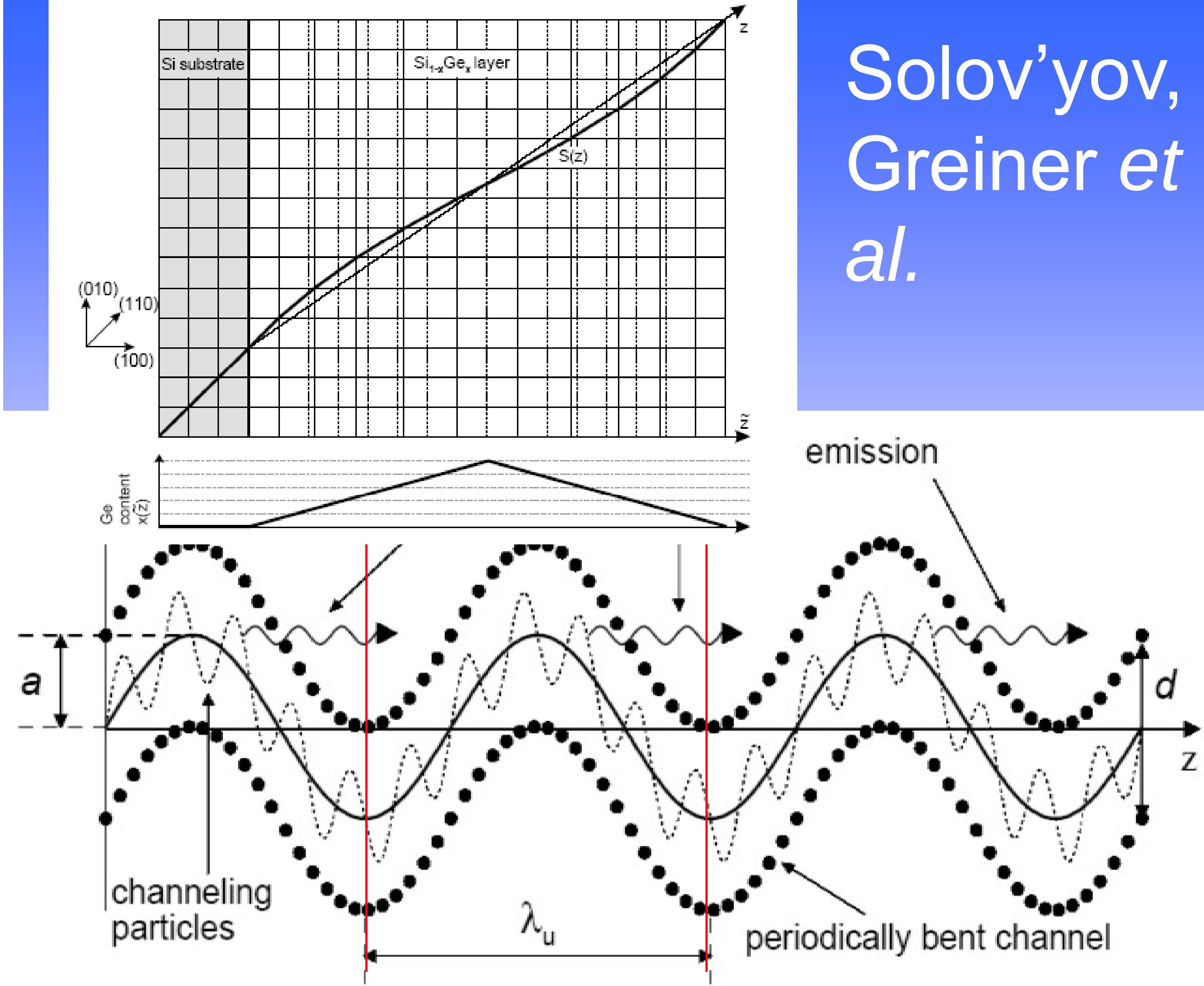
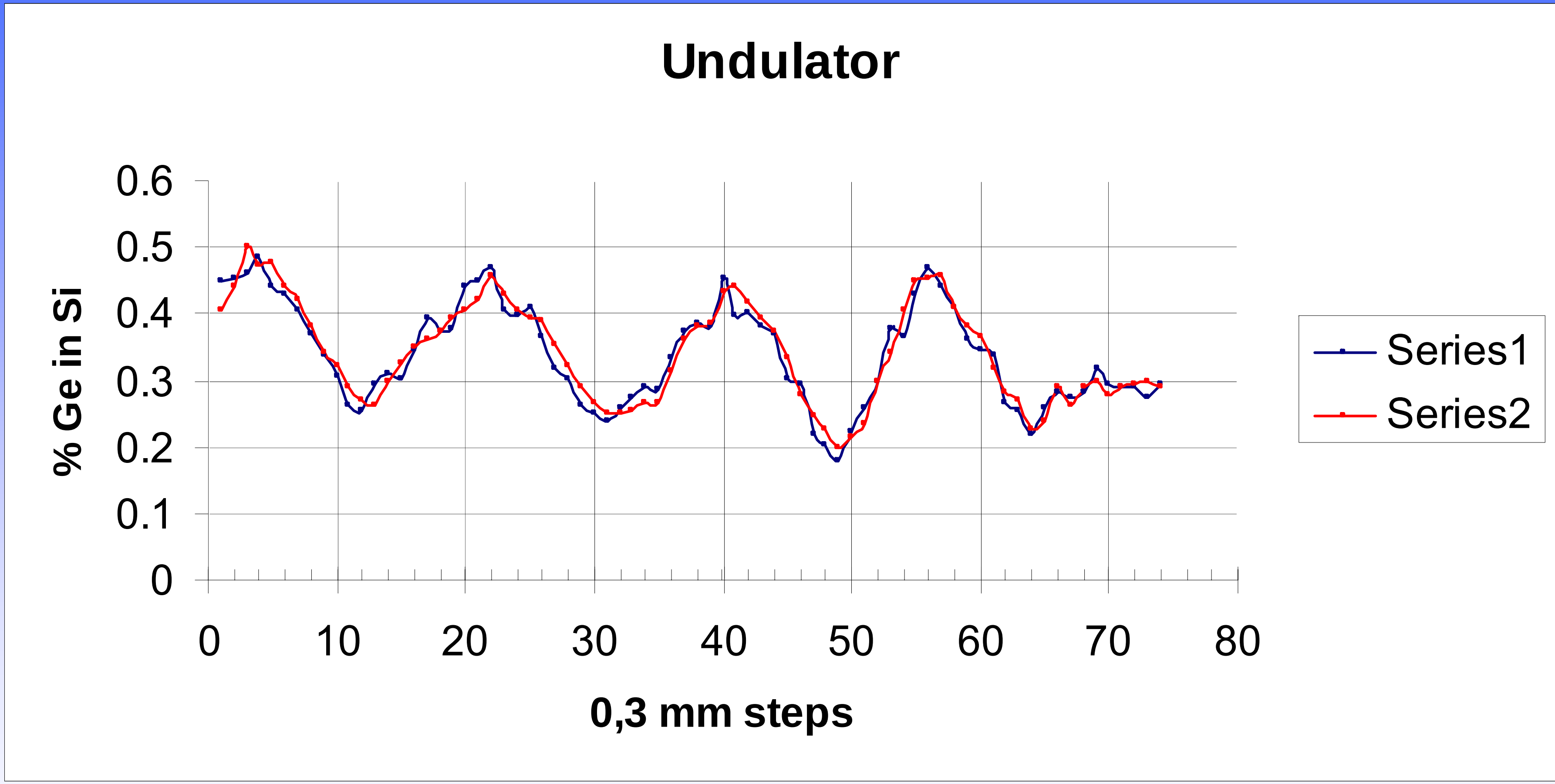


FIG. 2. Surface fragment of one of the manufactured crystal undulators seen by a microscope.

Solov'yov, Greiner *et al.*

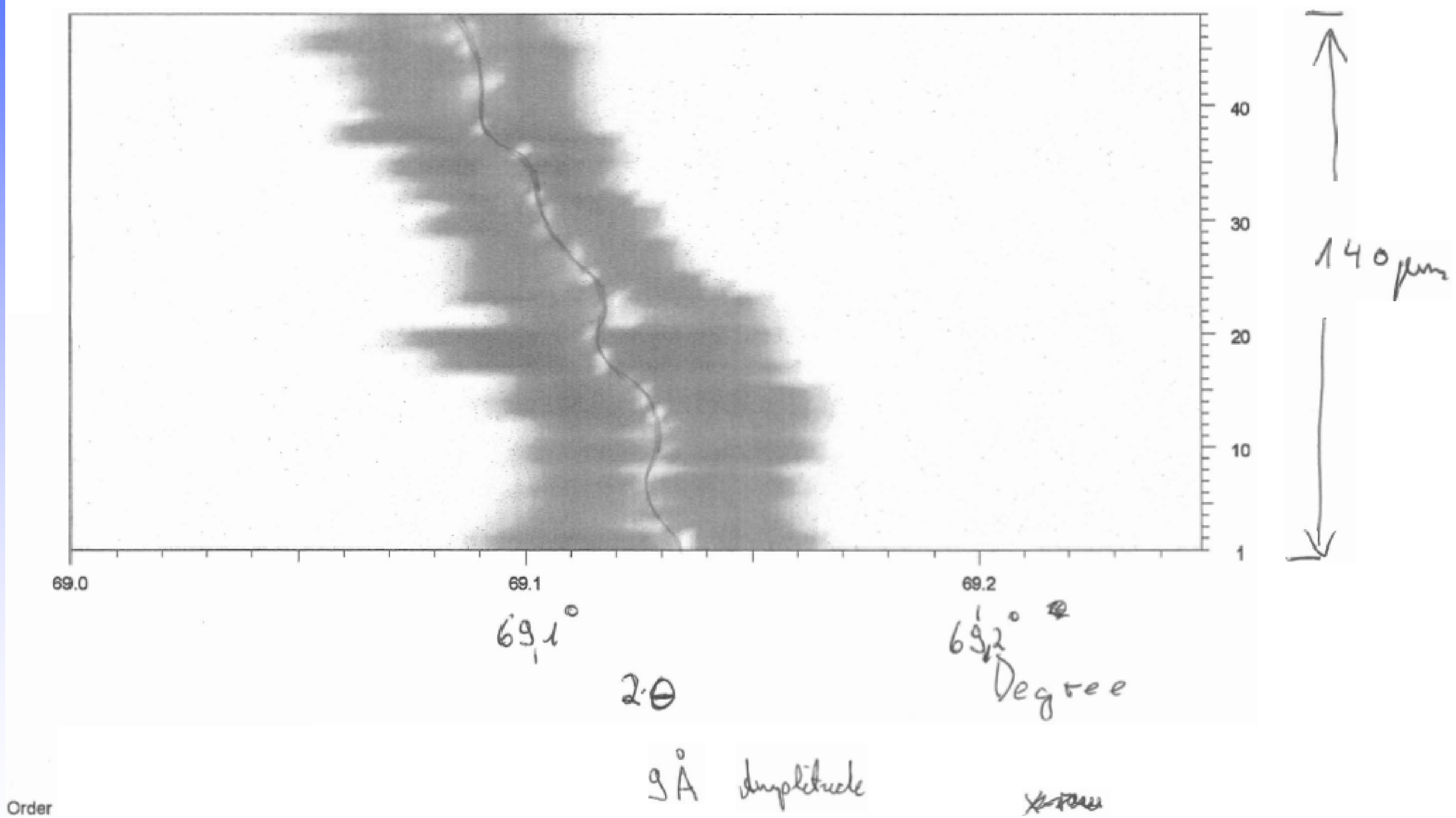


MBE grown crystal



1.5 MeV proton RBS, 0.3 mm beamspot

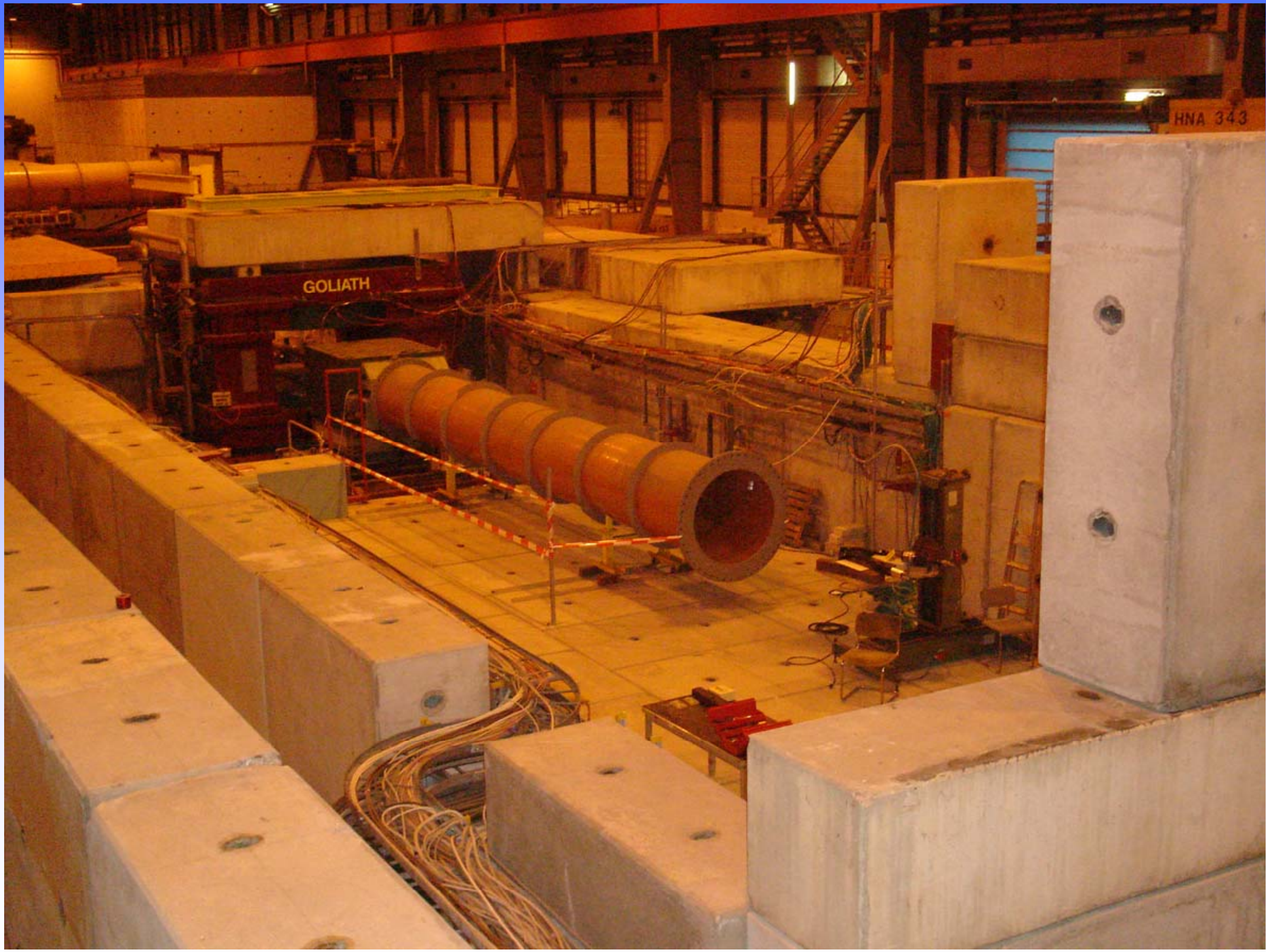
X-ray measurements



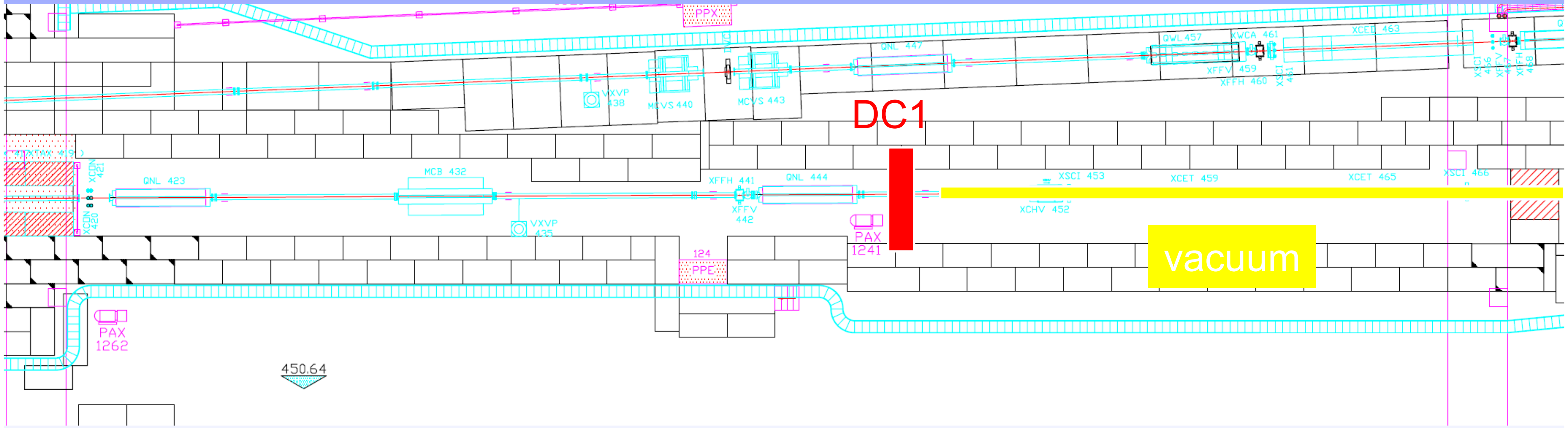
Run in H4
Oct. 2007

Setup

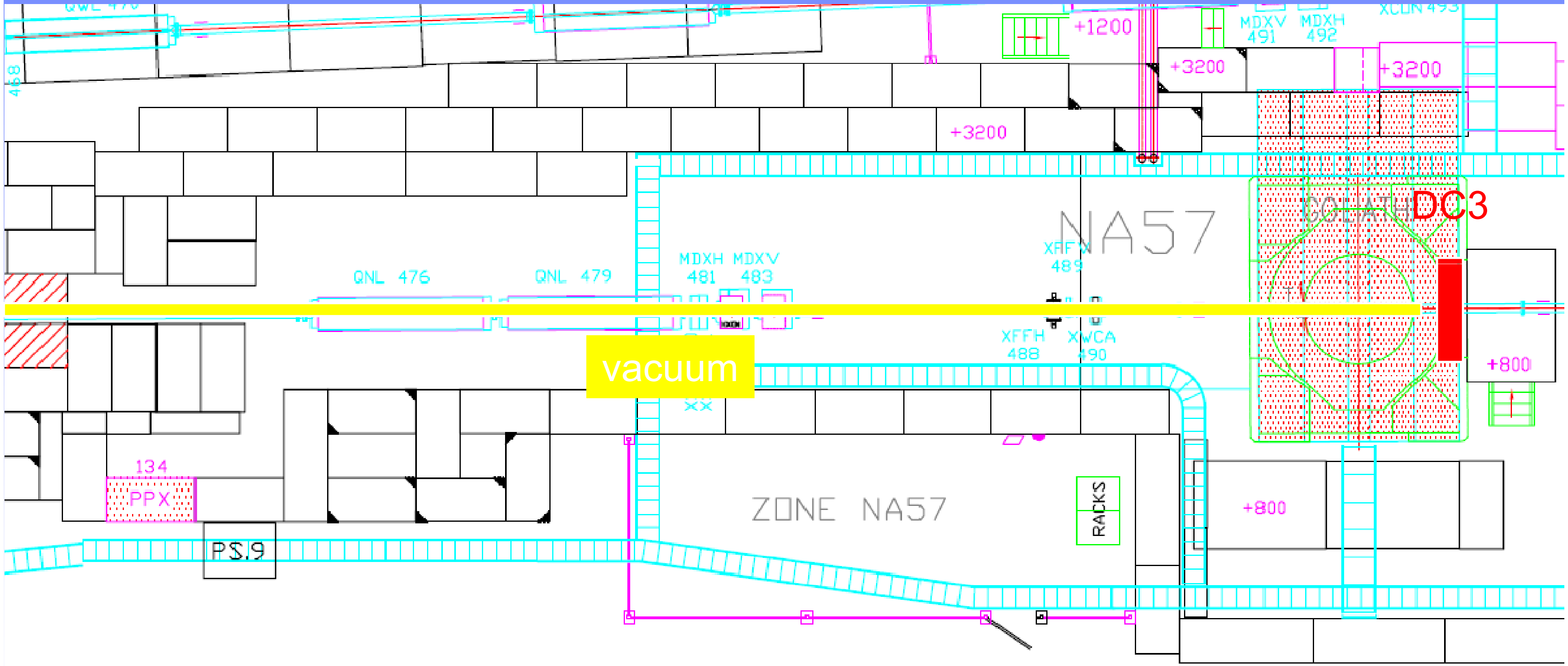
H4 zone



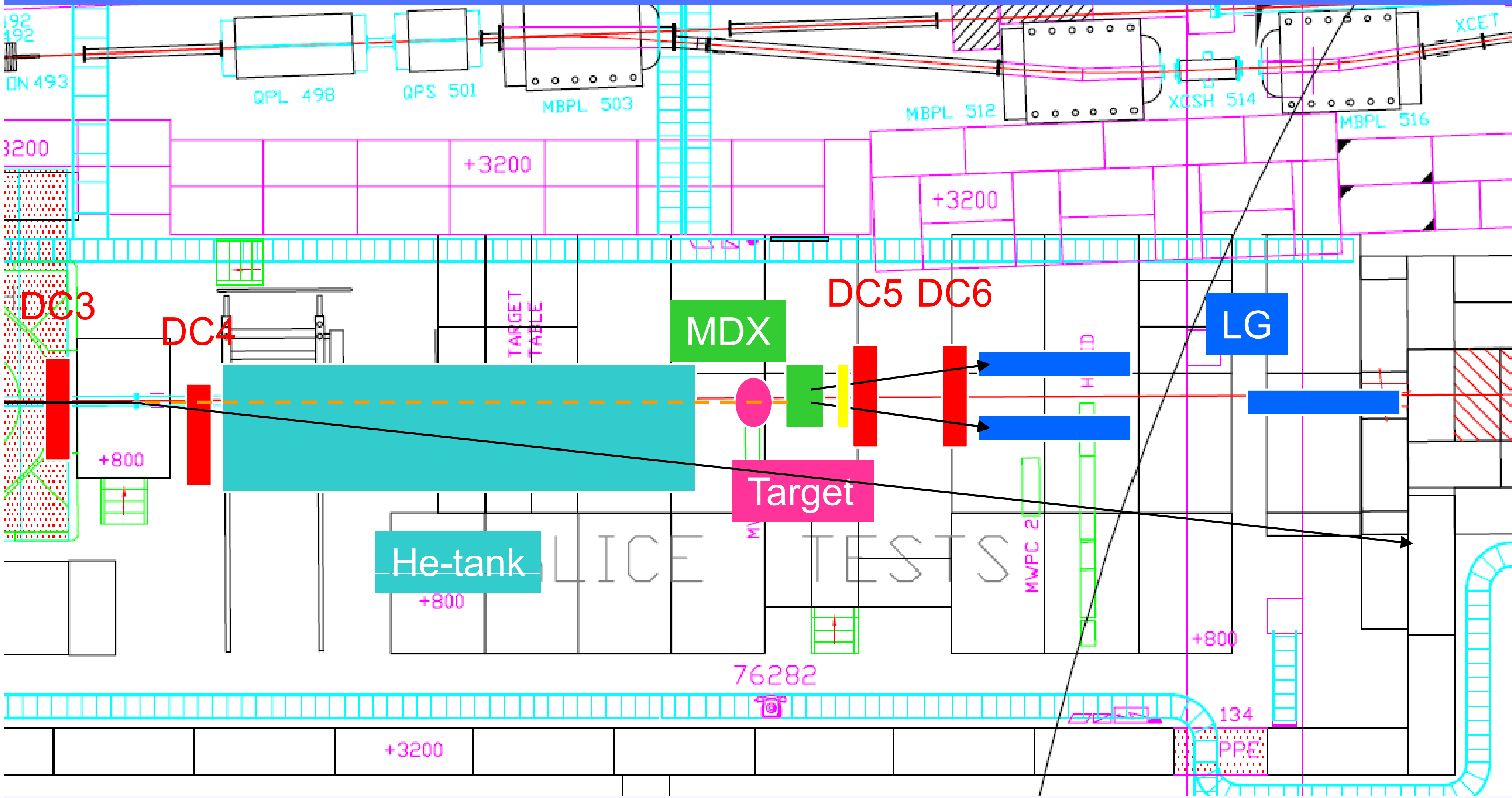
Tunnel zone


DC1
vacuum
PAX
1241
PAX
1262
PPX
PPE
QNL 423
MCB 432
QNL 444
QNL 447
XFFH 441
XSCI 453
XCET 459
XCET 465
XCHV 452
VXVP
450.64

Beam definition zone

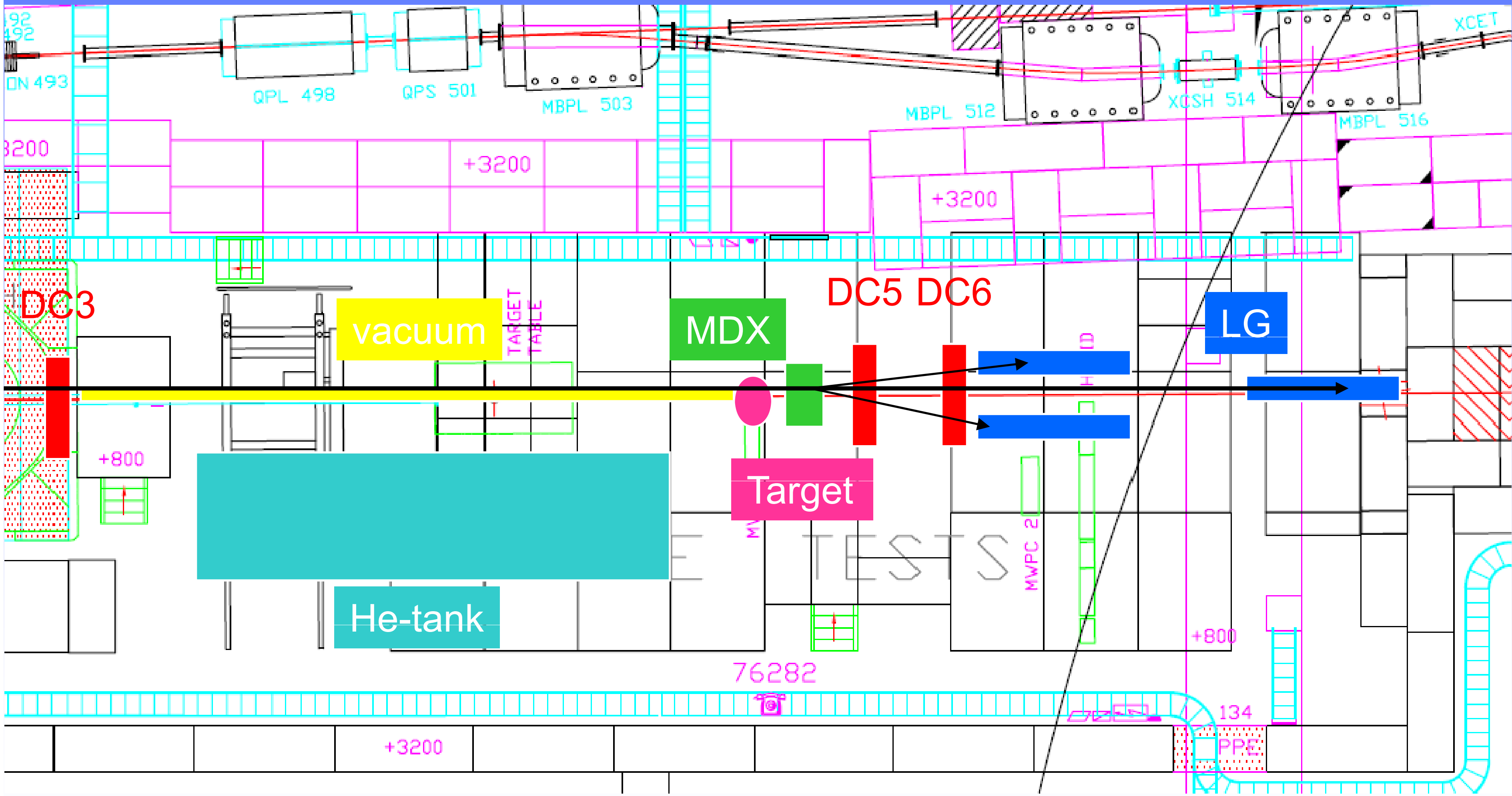


Pair spectrometer zone (photons)



All signal and HV cables and DC gas piping has been installed during week 24

Pair spectrometer zone (trident)



Roll out He-bag, install vacuum

Financing and manpower

Money:

- Essentially all the equipment is existing and has been tested to be fully functioning
- Travel and accomodation (for the danish/german/italian groups) have an allocated budget of about 60 kCHF from FP6, STREP/NEST funding.

Manpower:

- 3 staff members, 3 technicians and 3 students from Aarhus
- Similar numbers from the participants from Italy and South Africa.
- Dutch, German, Russian and Turkish participants active during the run, but with fewer persons.
- About 20 active members during the beam time, excluding students.

We are ready for the October run.

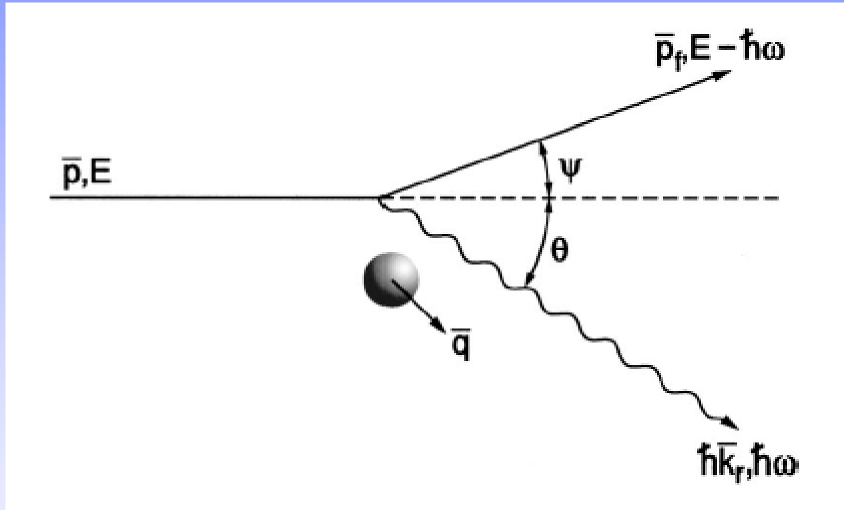
Formation length

- Underlying concept for all our proposed expts.

$$l_f = \frac{2\gamma^2 c}{\omega^*} \quad \text{with } \omega^* = \omega \frac{E}{E - \hbar\omega} \simeq \omega$$

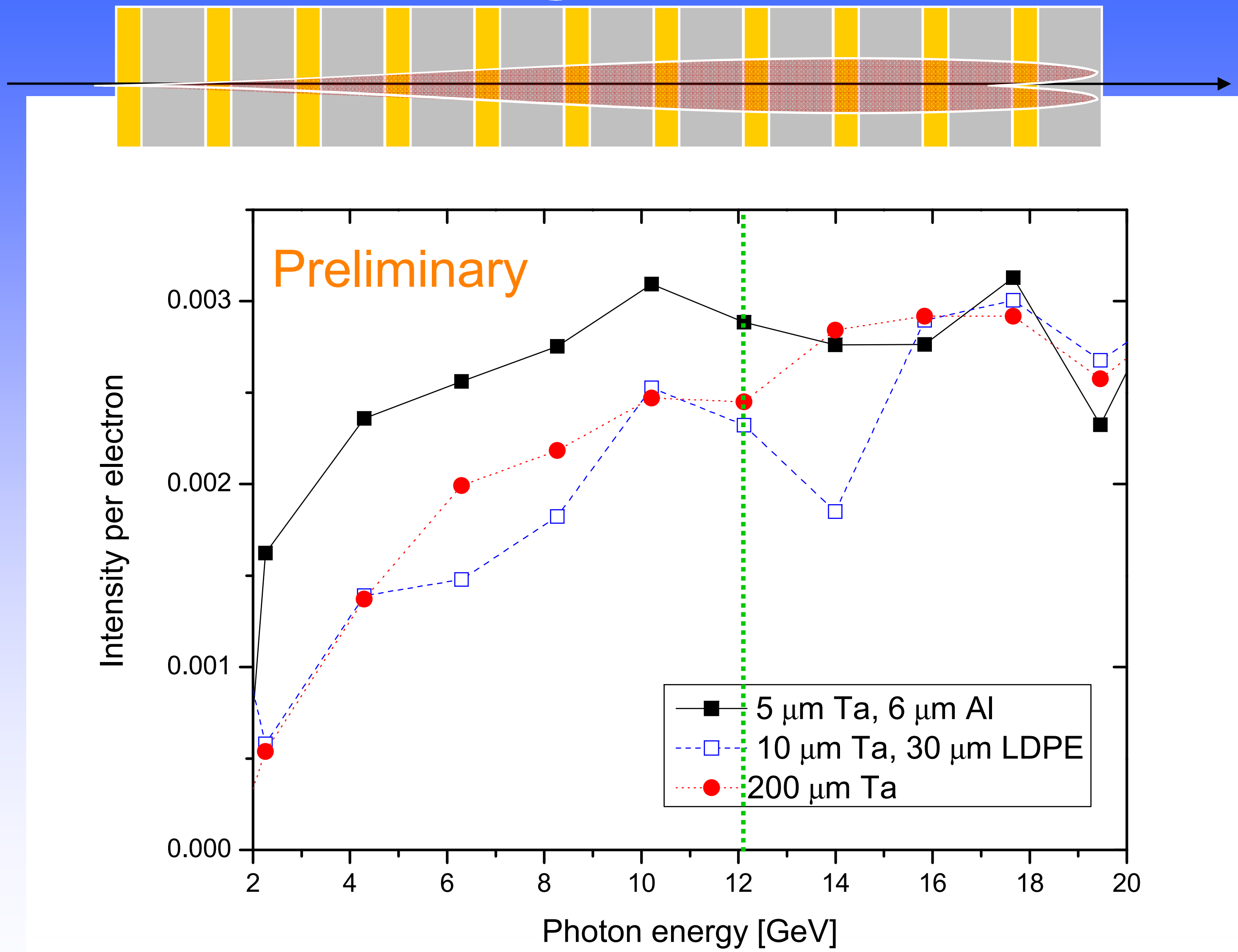
$$l_f^{\text{pair}} = 2\gamma_p \lambda\!\!\!^{-}_c \frac{2\gamma_p^2 c}{\omega}$$

$$\gamma_p \equiv \hbar\omega / mc^2$$

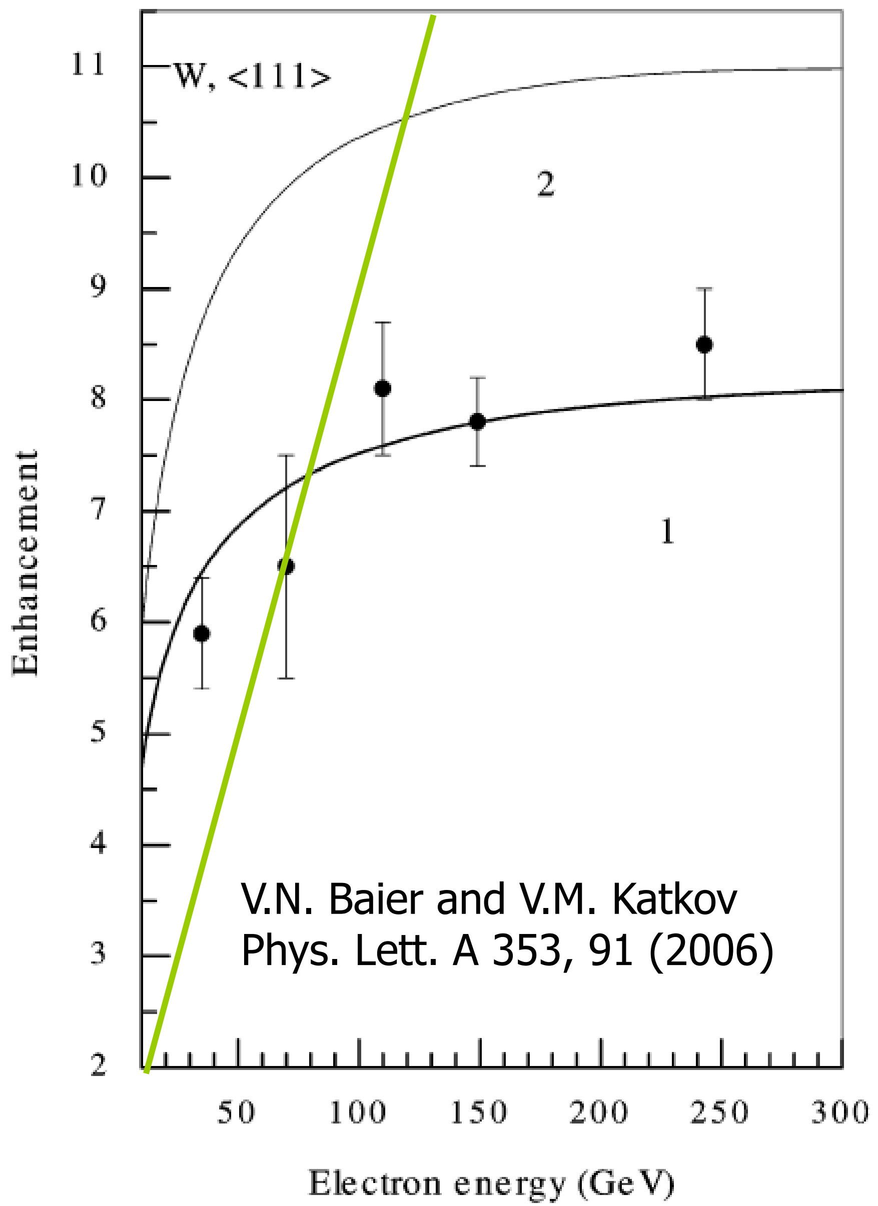


Example: 250 GeV electron emitting 1 GeV photon: l_f = 0.1 mm

Sandwich target – H4, Oct. 2006



Quantum-synchrotron



Thin target (negl. energy loss)

Thick target, 0.2 mm W, NA43 data
K. Kirsebom *et al.*
Phys. Rev. Lett. 87 (2001) 054801

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

$$\gamma^{2/3}/\gamma^2 \propto \chi^{2/3}/\chi^2$$

Classical = linear

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