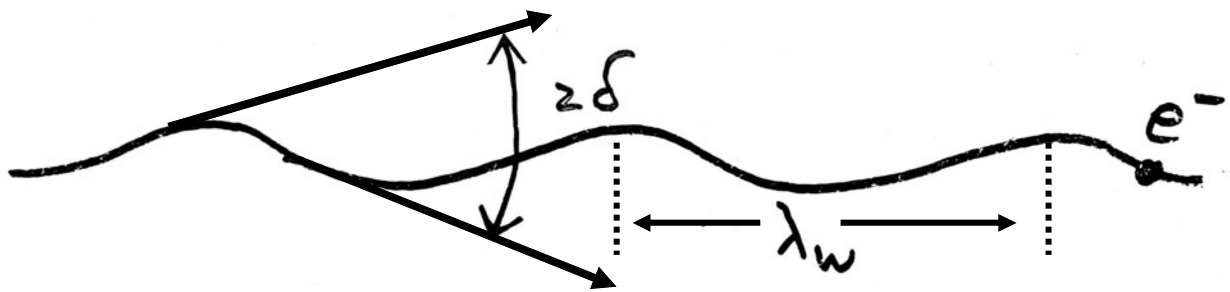
INSERTION DEVICES

Wigglers and Undulators

Presentation at JASS02 Seminar; Jordan, Oct. 19-28, 2002
Herman Winick, SSRL/SLAC, Stanford University

Wigglers & Undulators

$$B_0 \cos\left[\frac{2\pi}{\lambda_w} z\right] \qquad y_0 \cos\left[\frac{2\pi}{\lambda_w} z\right]$$



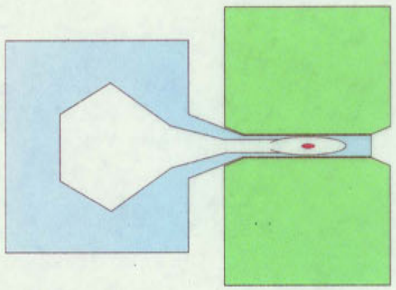
$$K = \gamma\delta = .934\, B_0(T)\, \lambda_w(cm) \qquad \gamma = \frac{E}{mc^2}$$

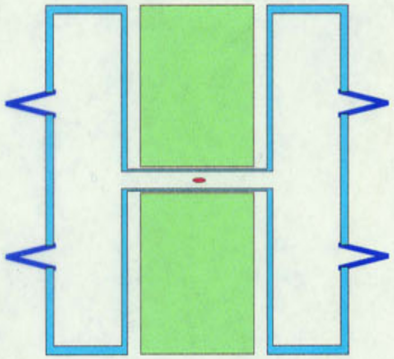
Define 2 regimes

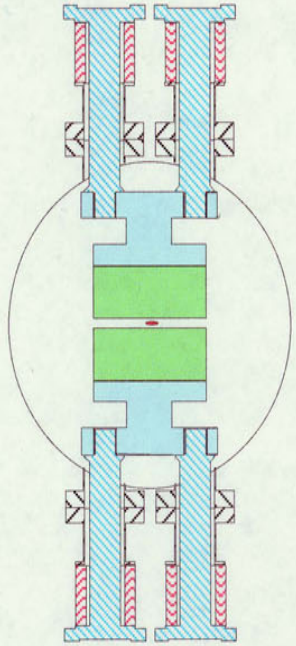
a) $\underline{K \lesssim 1}$; $\delta \lesssim \gamma^{-1}$ (Undulator)

b) $\underline{K \gg 1}$; $\delta \gg \gamma^{-1}$ (Wiggler)

Types of undulators







Out-of-Vacuum

- x Thickness of the chamber wall
- x Conservative gap-height margin for injection or unordinary operation of the ring

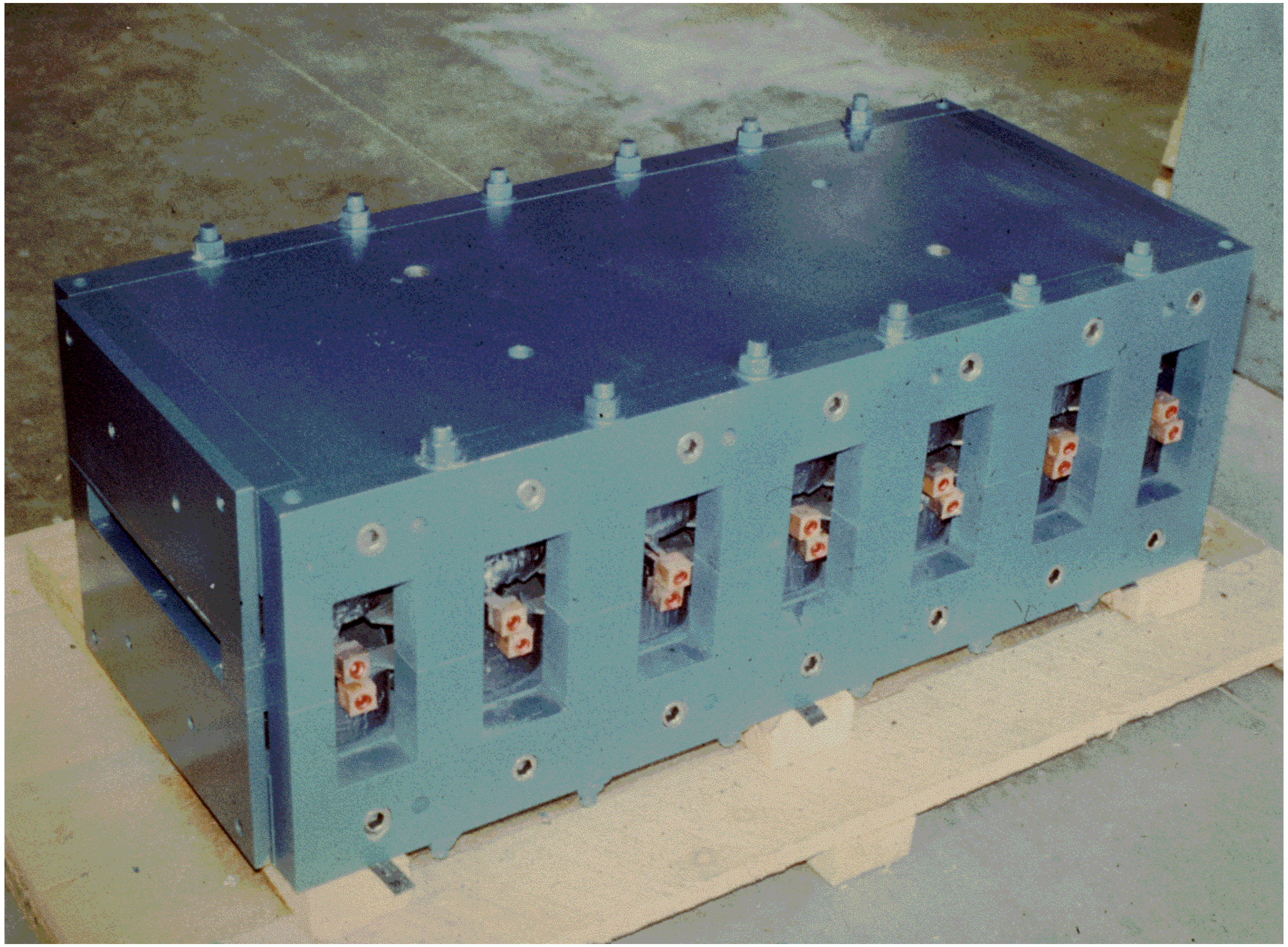
Flexible

- o Flexibility against any operation of the ring
- x Thickness of the chamber wall
- x Long devices?

In-Vacuum

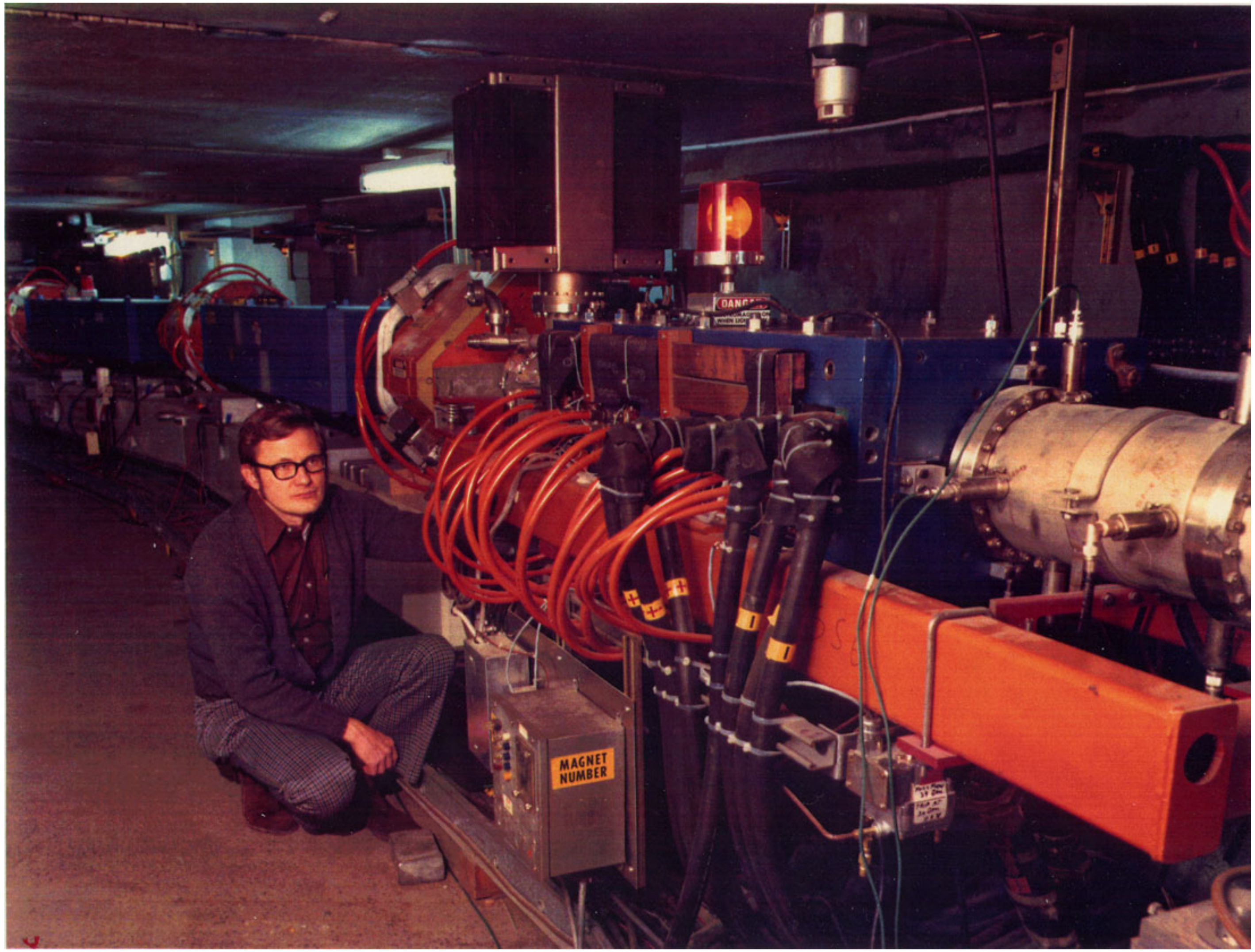
- o Flexibility against any operation of the ring
- o Vacuum gap = magnet gap
- o Long devices
- x Difficulty in making devices
  UHV?
  demagnetization

SSRL 7 pole Electromagnet Wiggler - 1978



Herman Winick on First SSRL Wiggler - 1978

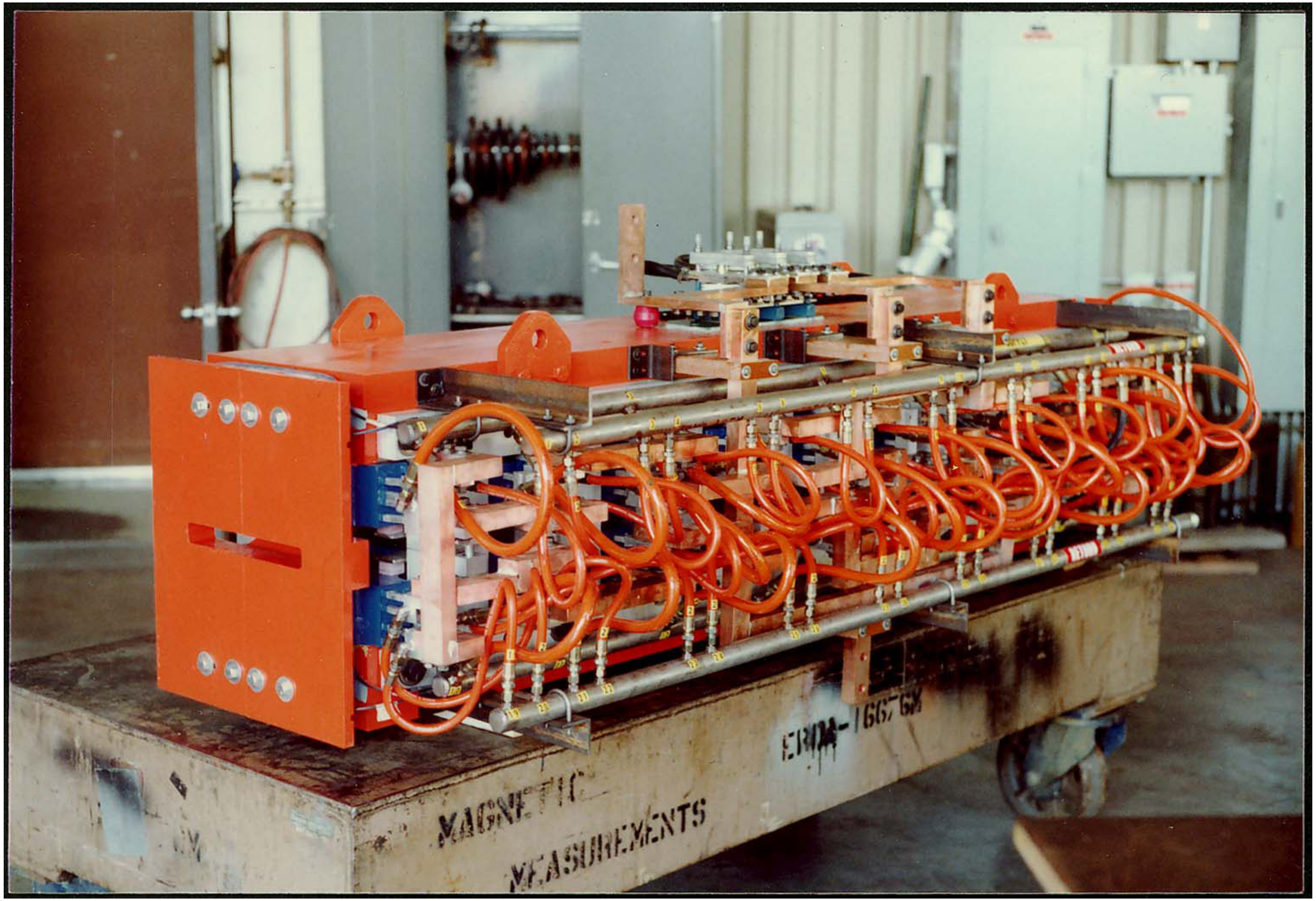
J. Spencer; Designer of 1st Wiggler - 1978

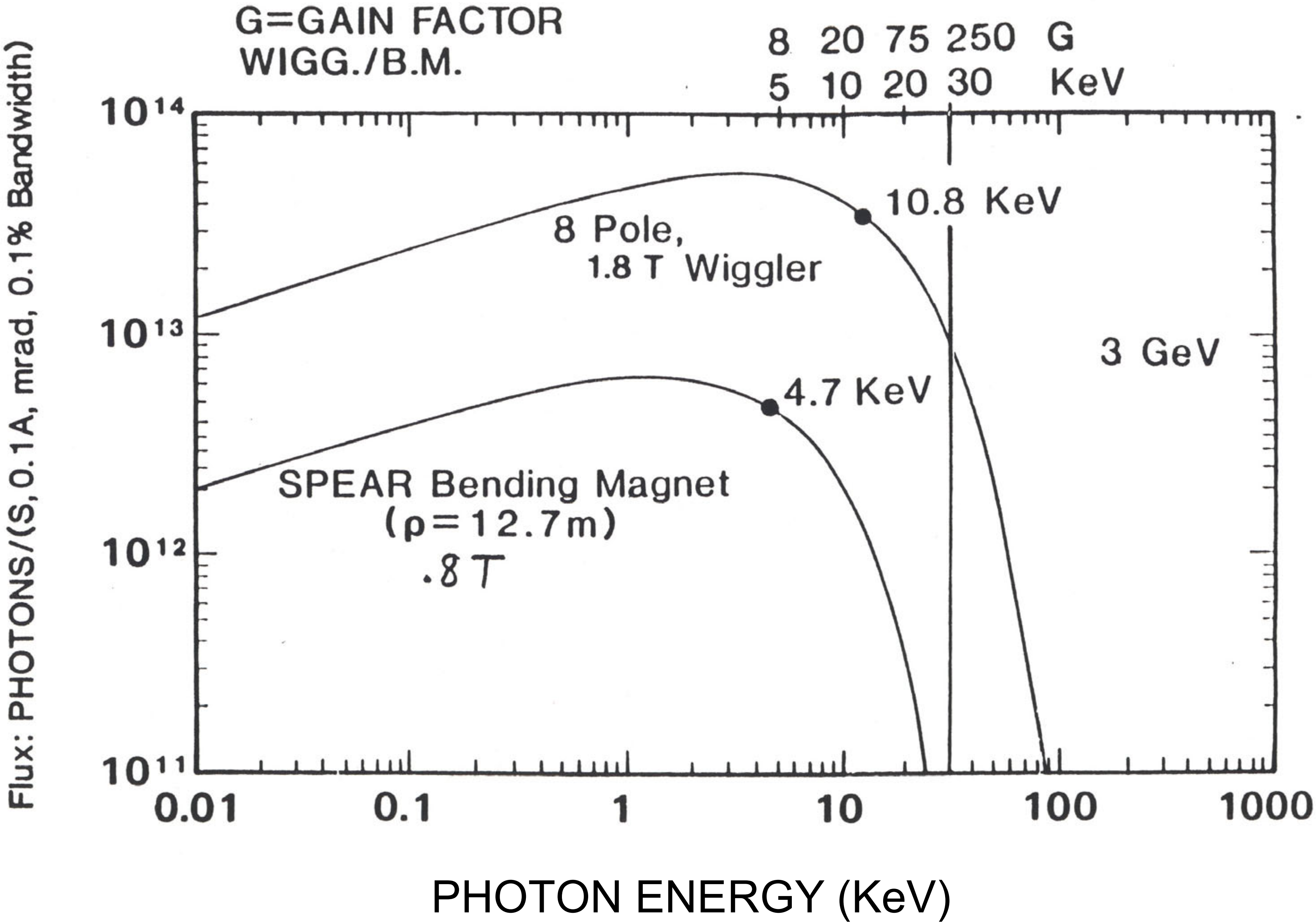


First Radiation from SSRL 7 pole Electromagnet Wiggler - 1979

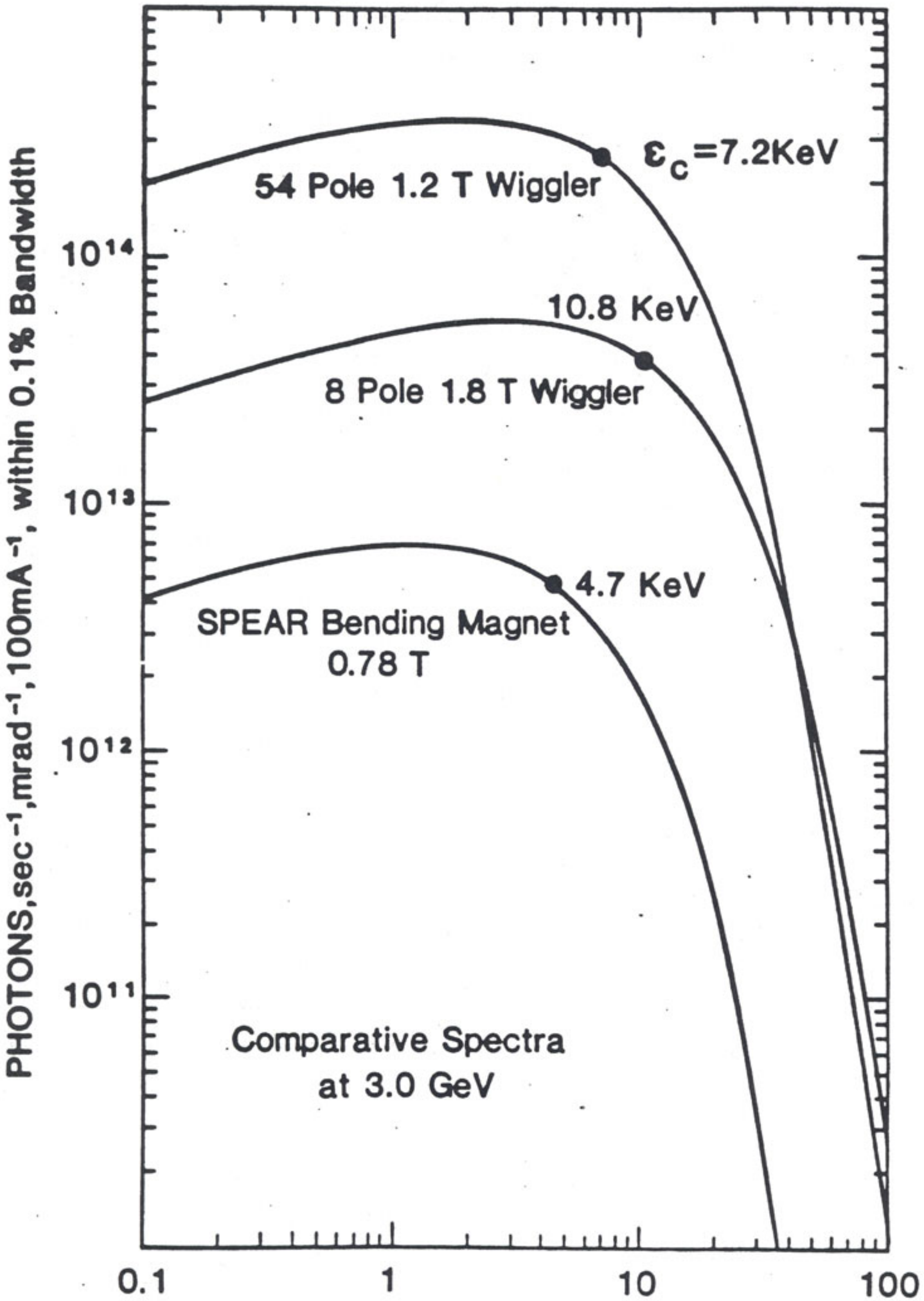
Display of 1st Wiggler at SSRL/SLAC

SSRL 9-Pole Electromagnet Wiggler - 1980

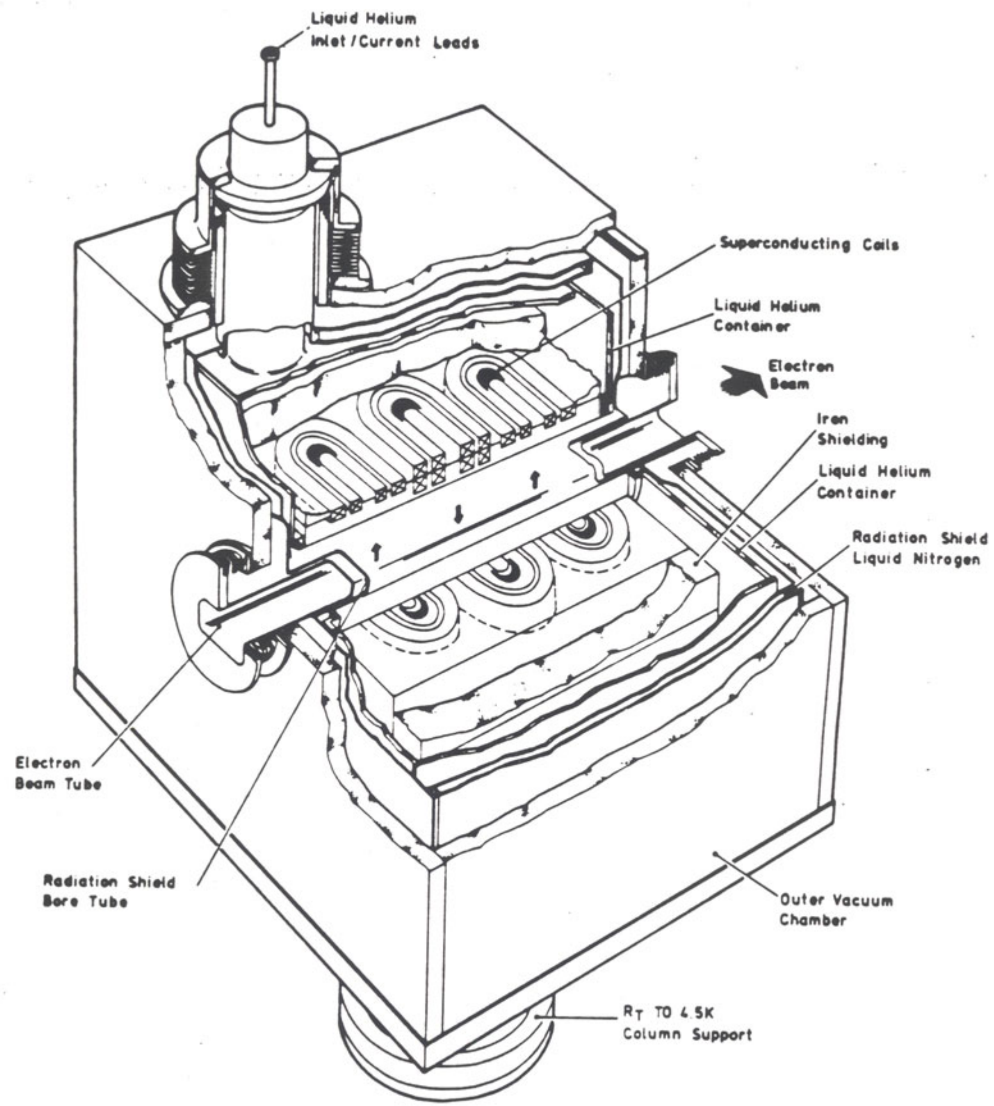




G=GAIN FACTOR
WIGG./B.M.
8 20 75 250 G
5 10 20 30 KeV
10.8 KeV
8 Pole,
1.8 T Wiggler
3 GeV
4.7 KeV
SPEAR Bending Magnet
(ρ=12.7m)
.8 T
Flux: PHOTONS/(S, 0.1A, mrad, 0.1% Bandwidth)
10^14
10^13
10^12
10^11
0.01
0.1
1
10
100
1000
PHOTON ENERGY (KeV)

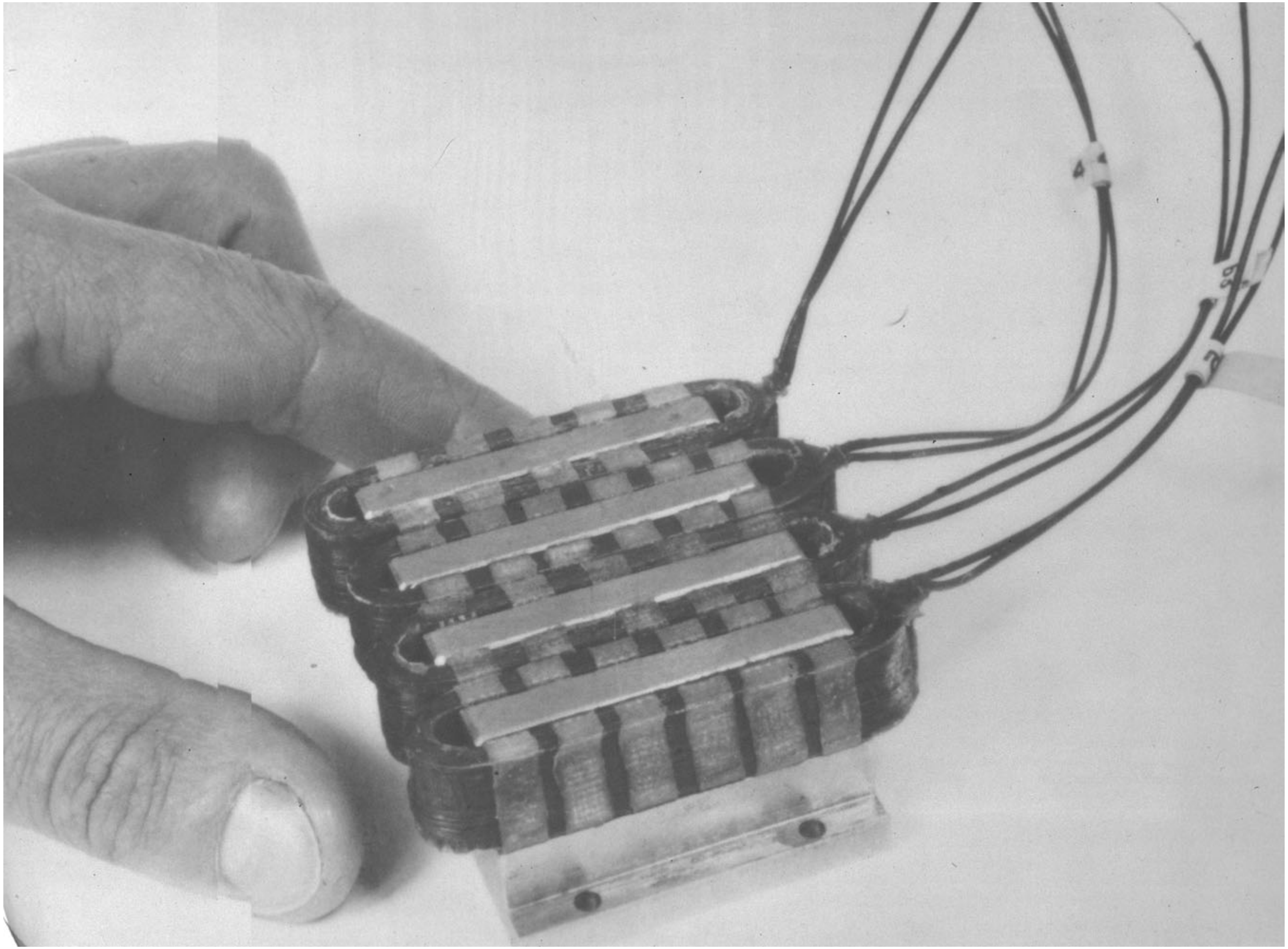


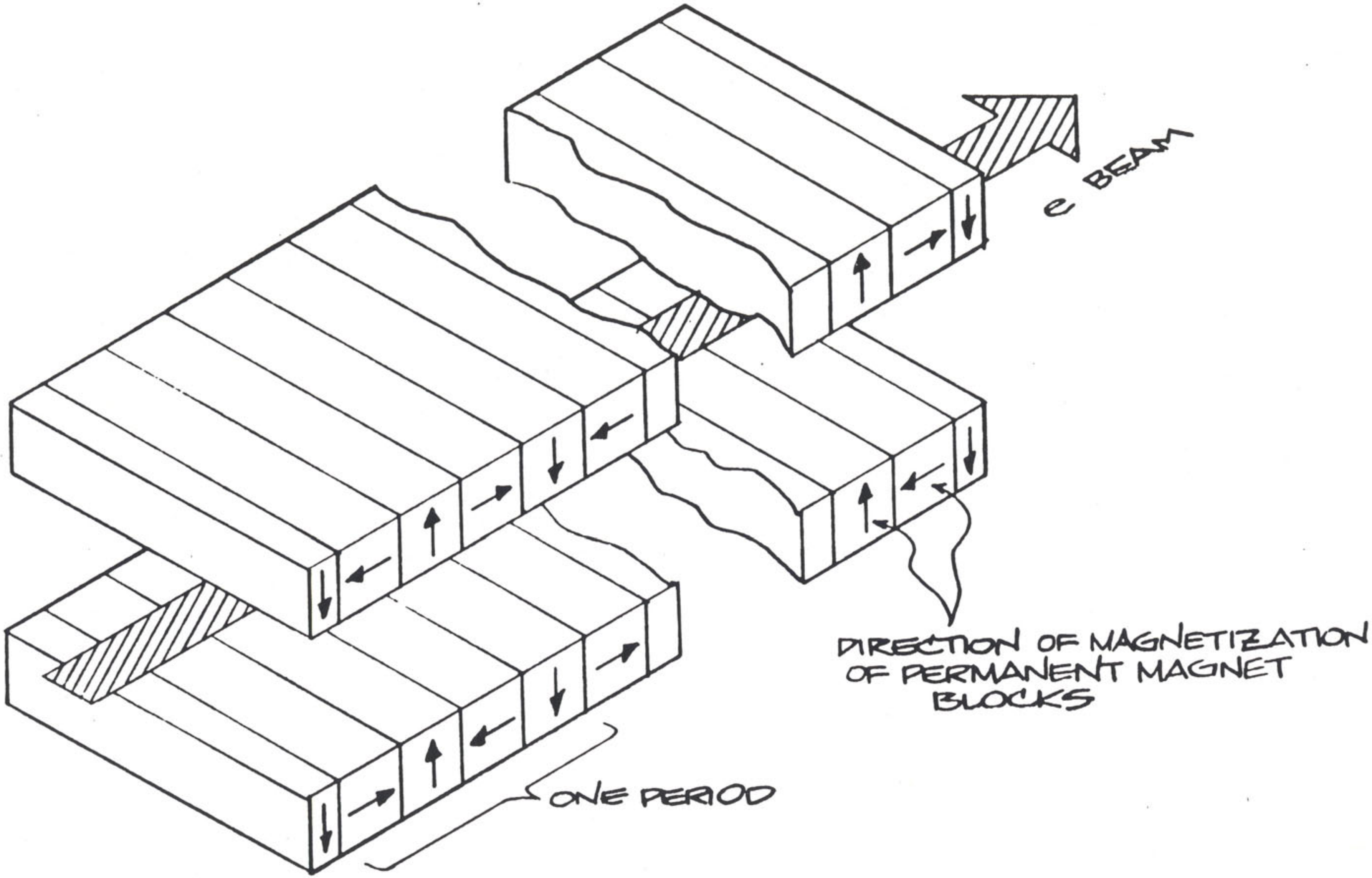
PHOTON ENERGY (KeV)



Daresbury SRS Superconducting Wiggler – Wavelength Shifter

Wide fan – Serves 7 experimental stations

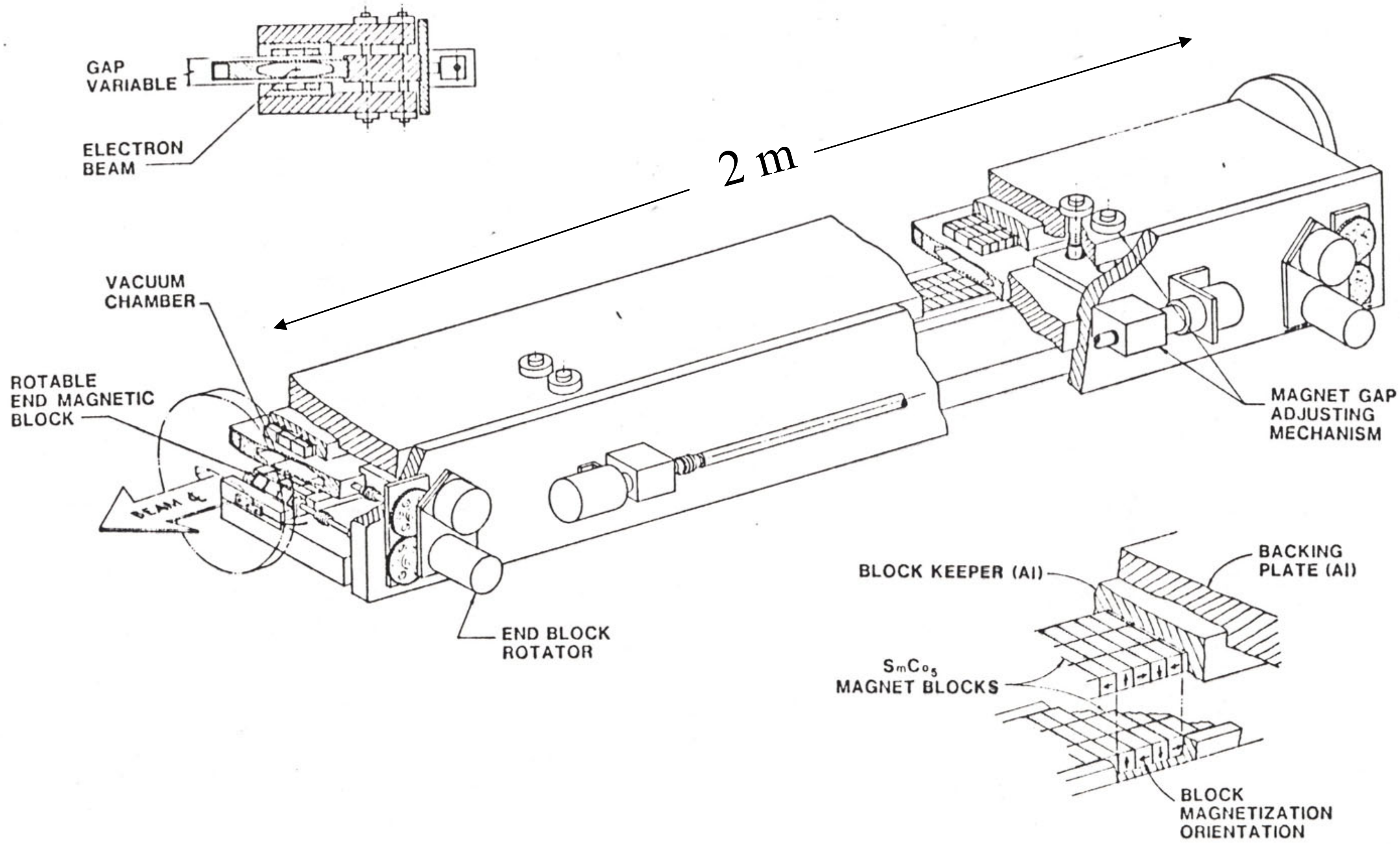




PERMANENT MAGNET UNDULATOR
CONCEPTUAL DRAWING

Klaus Halbach & Grandson Chris
Lawrence Berkeley Lab

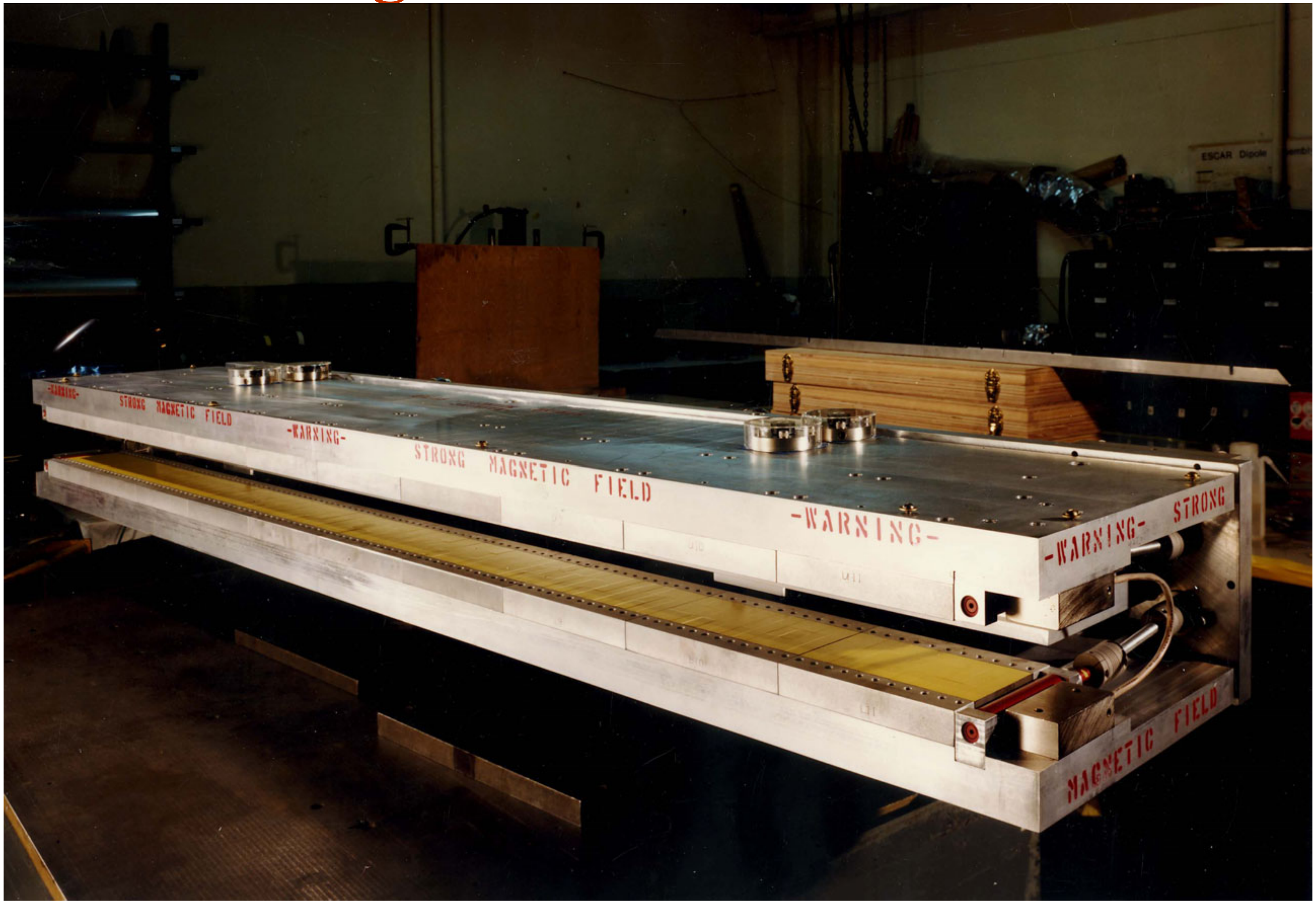
Nikolay A. Vinokurov – Budker Institute, Novosibirsk, Russia



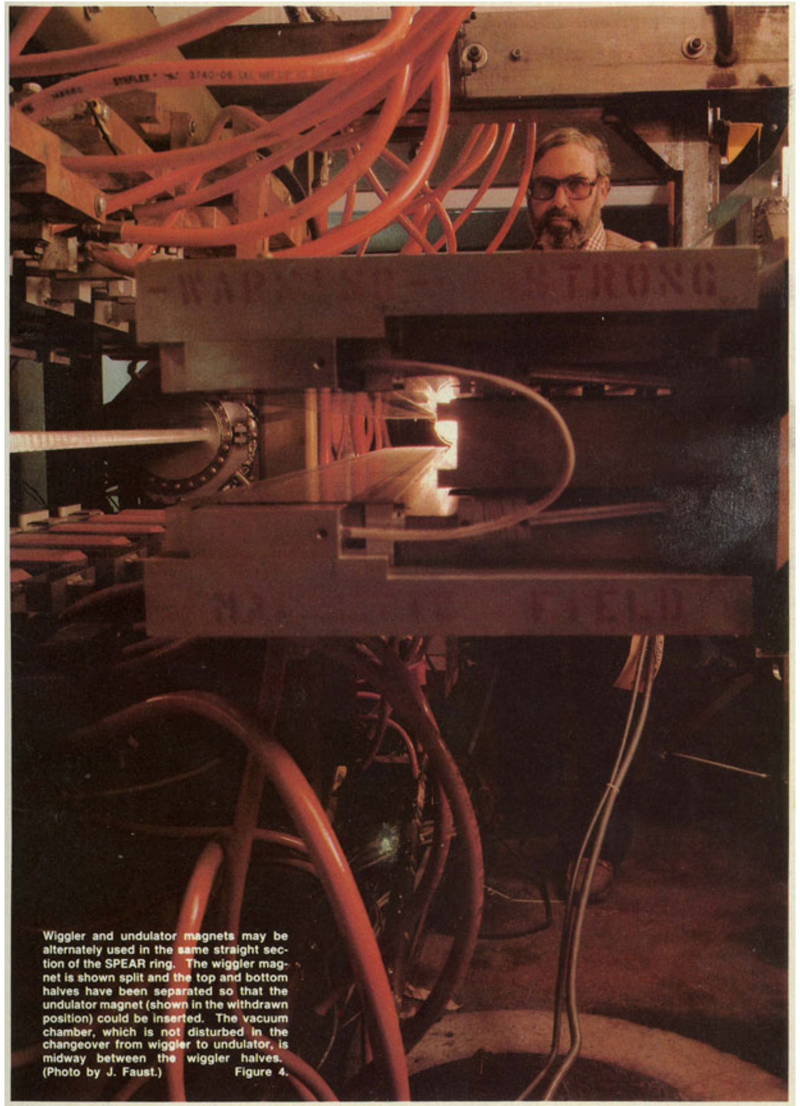
LBL - SSRL UNDULATOR

1980

LBL/SSRL 30 Period Permanent Magnet Undulator -1980

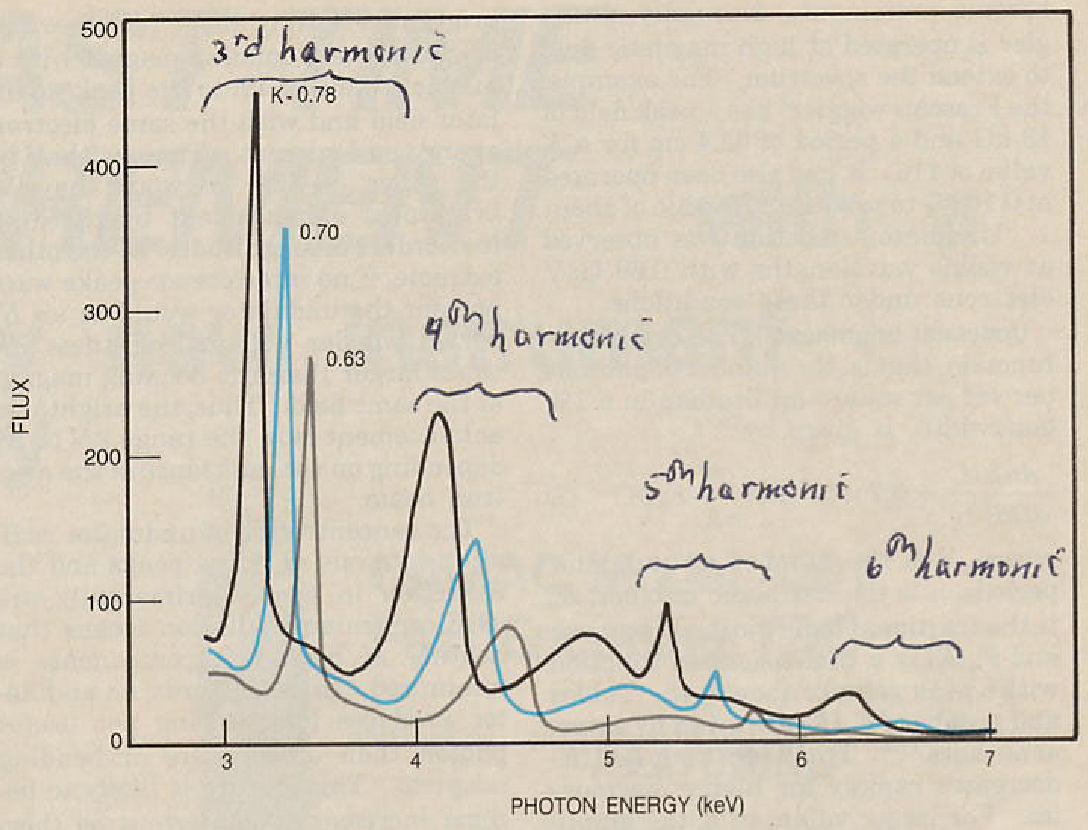


Testing of First Undulator in SPEAR Tunnel - 1980



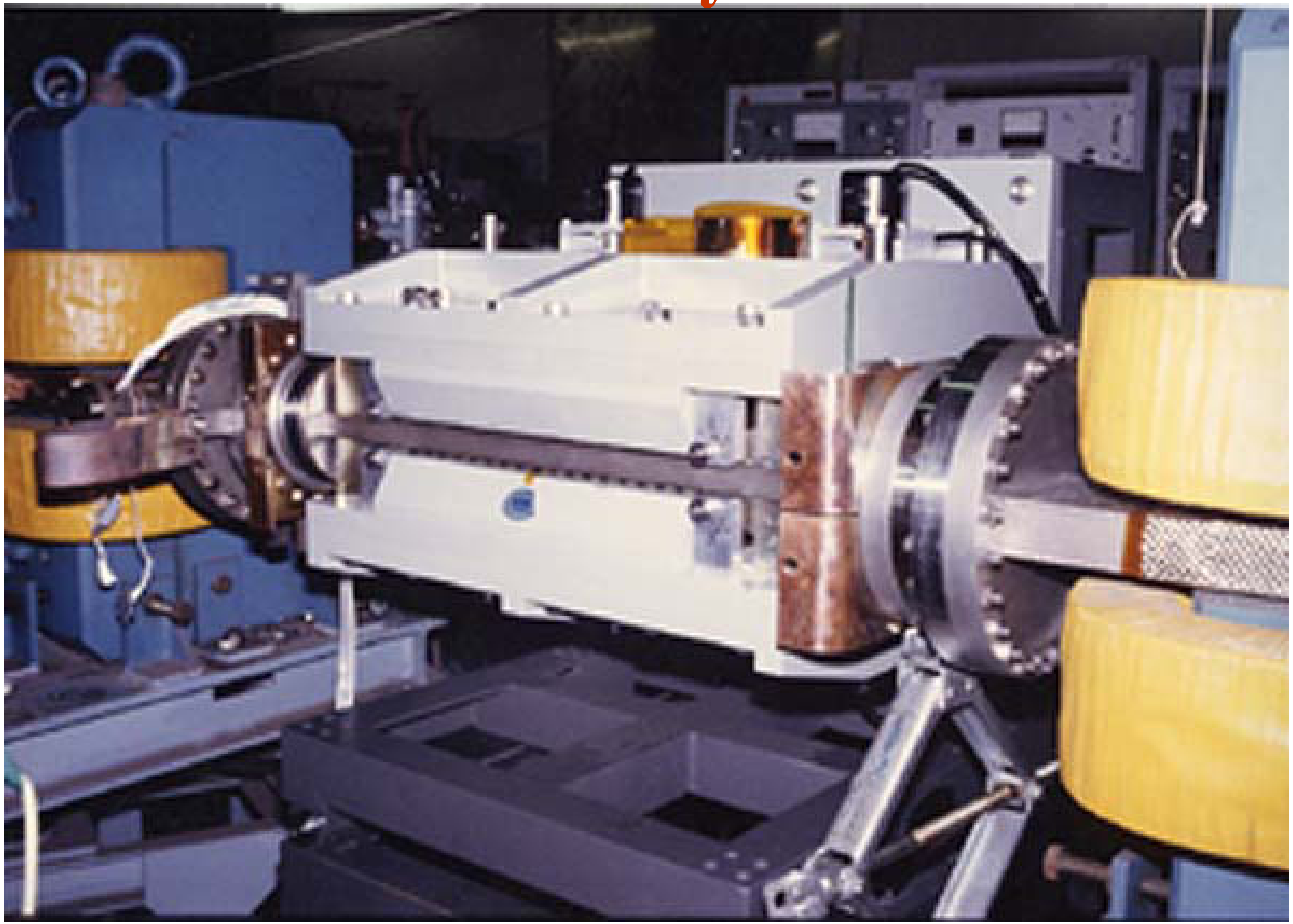
Wiggler and undulator magnets may be alternately used in the same straight section of the SPEAR ring. The wiggler magnet is shown split and the top and bottom halves have been separated so that the undulator magnet (shown in the withdrawn position) could be inserted. The vacuum chamber, which is not disturbed in the changeover from wiggler to undulator, is midway between the wiggler halves. (Photo by J. Faust.) Figure 4.

First X-ray Undulator Spectrum; SSRL, 1980

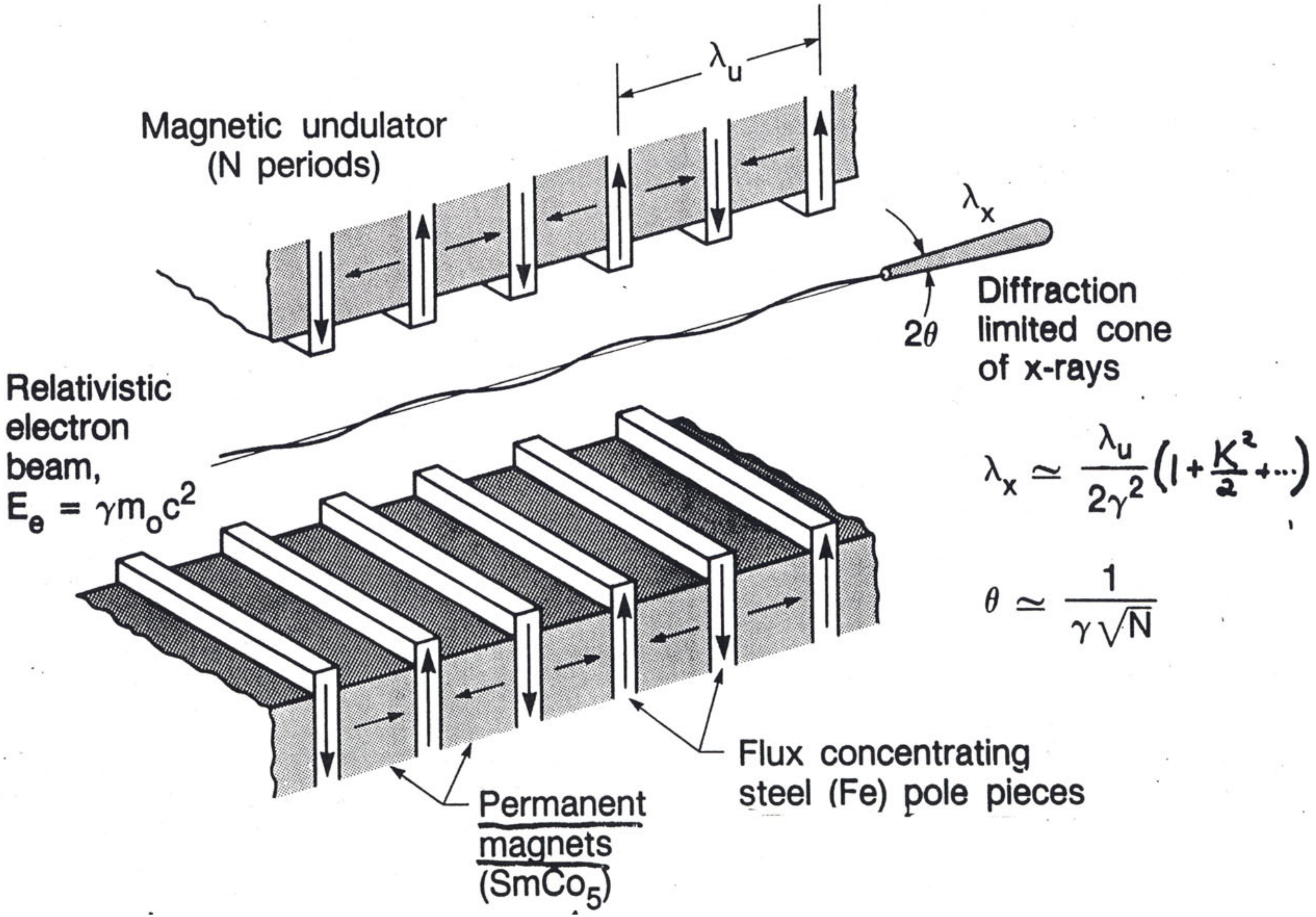


Higher-harmonic spectrum produced by 3-GeV electrons in the LBL–SSRL 30-period permanent-magnet undulator. Slits were used to define a very small angular acceptance (18×10^{-6} radians horizontal, 8.8×10^{-6} radians vertical.) Figure 9.

Permanent magnet undulator in SOR ring, Univ. of Tokyo ~1982

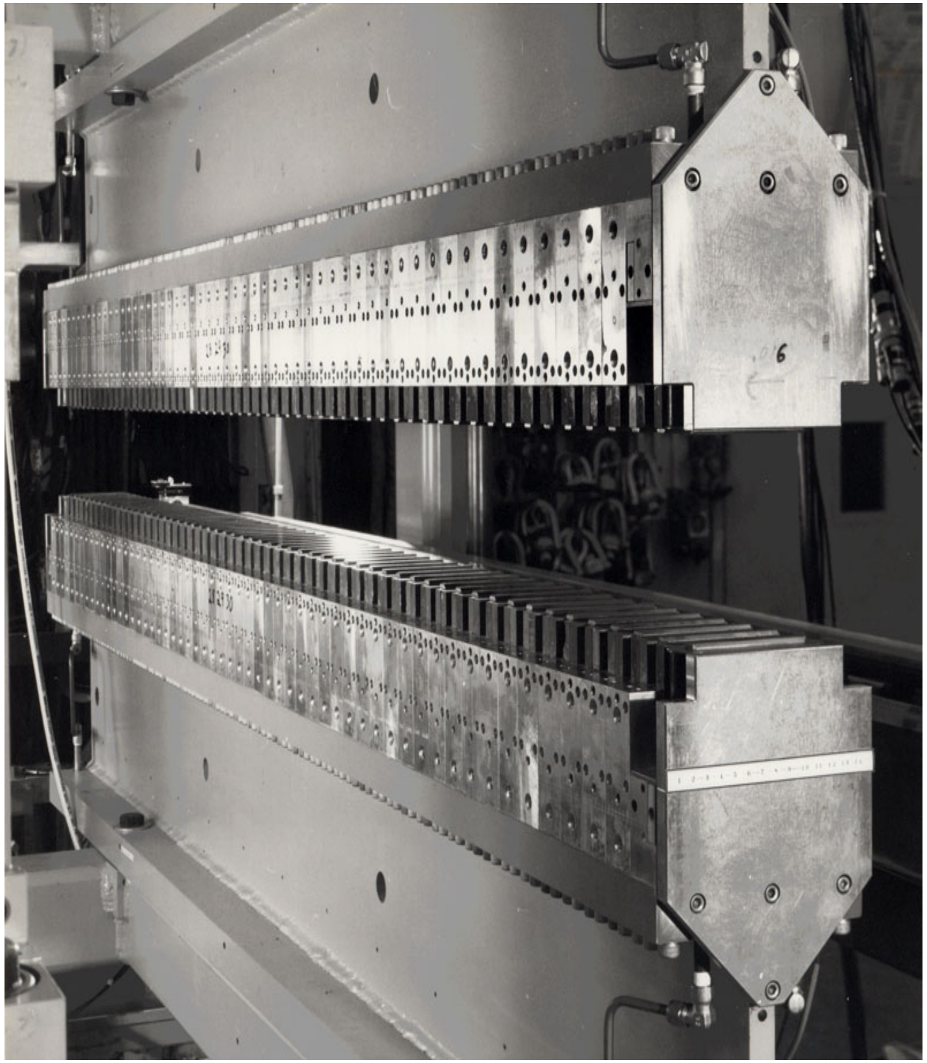


Coherent X-Rays, Tuneable Across A Broad Spectral Region, are Generated.

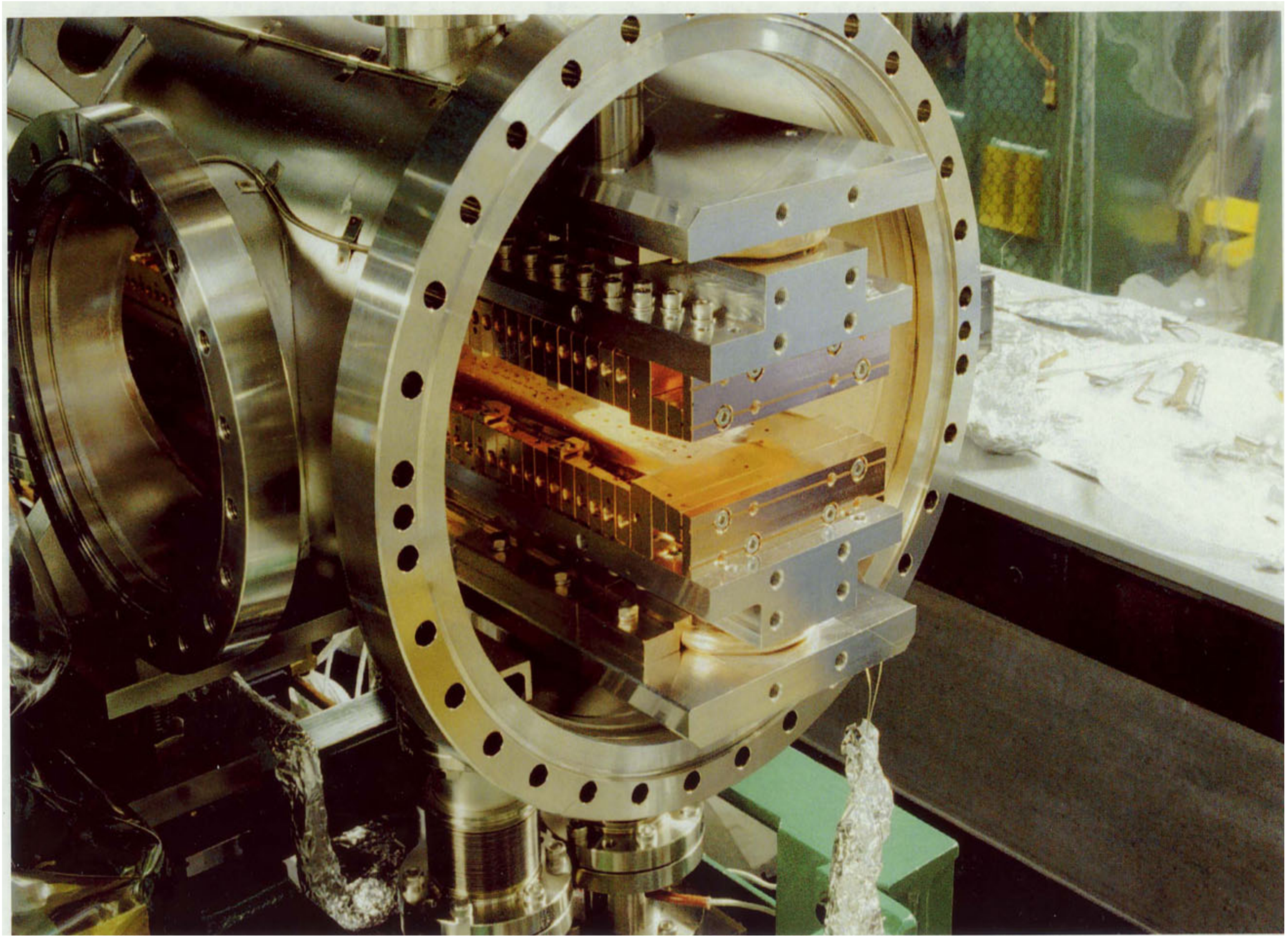


Hybrid Design; K. Halbach & N. Vinokurov

LBL-SSRL 54 Pole Permanent Magnet Hybrid Wiggler ~1985



In-Vacuum Permanent Magnet Undulator in SPring-8 – H. Kitamura



Undulator Radiation

Interference effects in the radiation by an electron in a periodic field

Simple case to illustrate basis Physics

Weak field approximation & radiation on axis only

λ_u = undulator period $\quad \lambda = \frac{h\nu}{c}$ = photon wavelength

Electron takes longer than photon to go from 1-2 because electron travels at BC rather than C.

$$t_{e^-} - t_{h\nu} = \Delta t = \lambda / c \quad \text{for constructive interference}$$

$$t_{e^-} - t_{h\nu} = \frac{\lambda_u}{\beta c} - \frac{\lambda_u}{c} = \frac{\lambda_u}{c}\left[\frac{1-\beta}{\beta}\right] \approx \frac{\lambda_u}{c}\left[\frac{1}{2\gamma^2}\right] = \frac{\lambda}{c}$$

$$\boxed{\lambda = \frac{\lambda_u}{2\gamma^2}}$$

All the radiation occurs at this wavelength in the weak field approximation

$$\gamma = \frac{1}{(1-\beta^2)^{1/2}} = E/mc^2$$

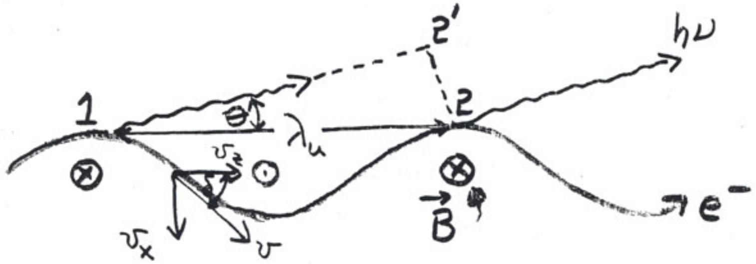
If we take into account the extra distance traveled by the electron & also the angle of emission of the radiation (Θ) we get

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left[1 + \frac{K^2}{2} + \gamma^2\theta^2\right] \qquad K = .934\, B_{max}(T)\, \lambda_u(cm)$$

Correlation between photon wavelength and emission angle

Undulator Radiation

More realistic treatment: Take into account sinusoidal electron motion & off axis radiation



$$v^2 = v_x^2 + v_z^2 \qquad v_x \ll v_z \approx v \qquad \delta \ll 1 \qquad \theta \ll 1$$

Electron flight time from 1 to 2: $t_{e^-} = \lambda_u / \langle v_z \rangle$

Photon flight time from 1 to 2: $t_{h\nu} = \frac{\lambda_u \cos\theta}{c} \approx \frac{\lambda_u}{c}\left[1 - \frac{\theta^2}{2}\right]$

$t_{e^-} - t_{h\nu} = \Delta t = \lambda / c$ for constructive interference

$$\Delta t = \frac{\lambda_u}{\langle v_z \rangle} - \frac{\lambda_u}{c}\left(1 - \frac{\theta^2}{2}\right) = \frac{\lambda}{c}$$

$$\lambda = \lambda_u\left[\frac{c}{\langle v_z \rangle} - 1 + \frac{\theta^2}{2}\right] \qquad \langle v_z \rangle = \left[v^2 - \langle v_x^2 \rangle\right]^{1/2} \approx v\left[1 - \frac{\langle v_x^2 \rangle}{2v^2}\right]$$

$$\lambda = \lambda_u\left[\frac{c - v\left(1 - \frac{\langle v_x^2 \rangle}{2v^2}\right)}{v} + \frac{\theta^2}{2}\right] = \lambda_u\left[\frac{1-\beta}{\beta} + \frac{\langle v_x^2 \rangle}{2v^2} + \frac{\theta^2}{2}\right]$$

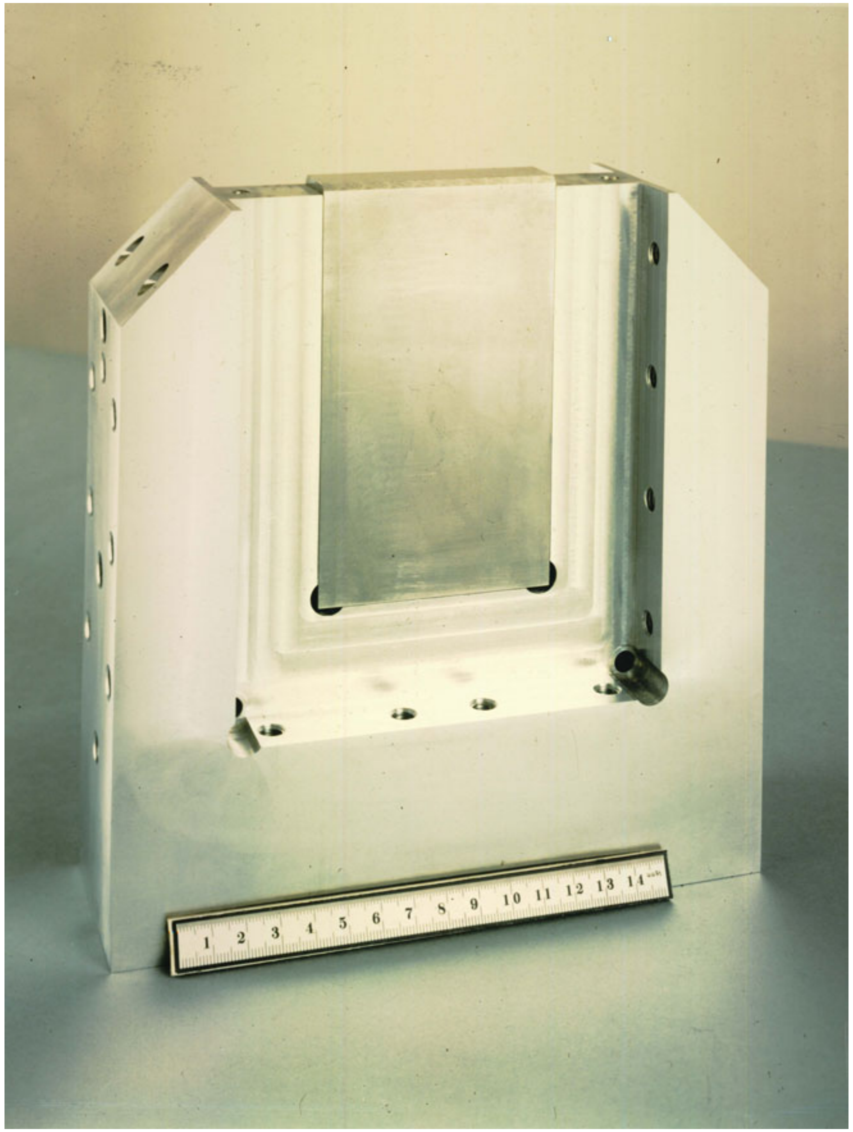
$$\frac{1-\beta}{\beta} = \frac{1}{2\gamma^2}; \quad \frac{\langle v_x^2 \rangle}{v^2} = \frac{v_{x\,max}^2}{2v^2} = \frac{\delta^2}{2}$$

$$\lambda = \lambda_u\left[\frac{1}{2\gamma^2} + \frac{\delta^2}{4} + \frac{\theta^2}{2}\right] = \frac{\lambda_u}{2\gamma^2}\left[1 + \frac{\gamma^2\delta^2}{2} + \gamma^2\theta^2\right] = \frac{\lambda_u}{2\gamma^2}\left[1 + \frac{K^2}{2} + \gamma^2\theta^2\right]$$

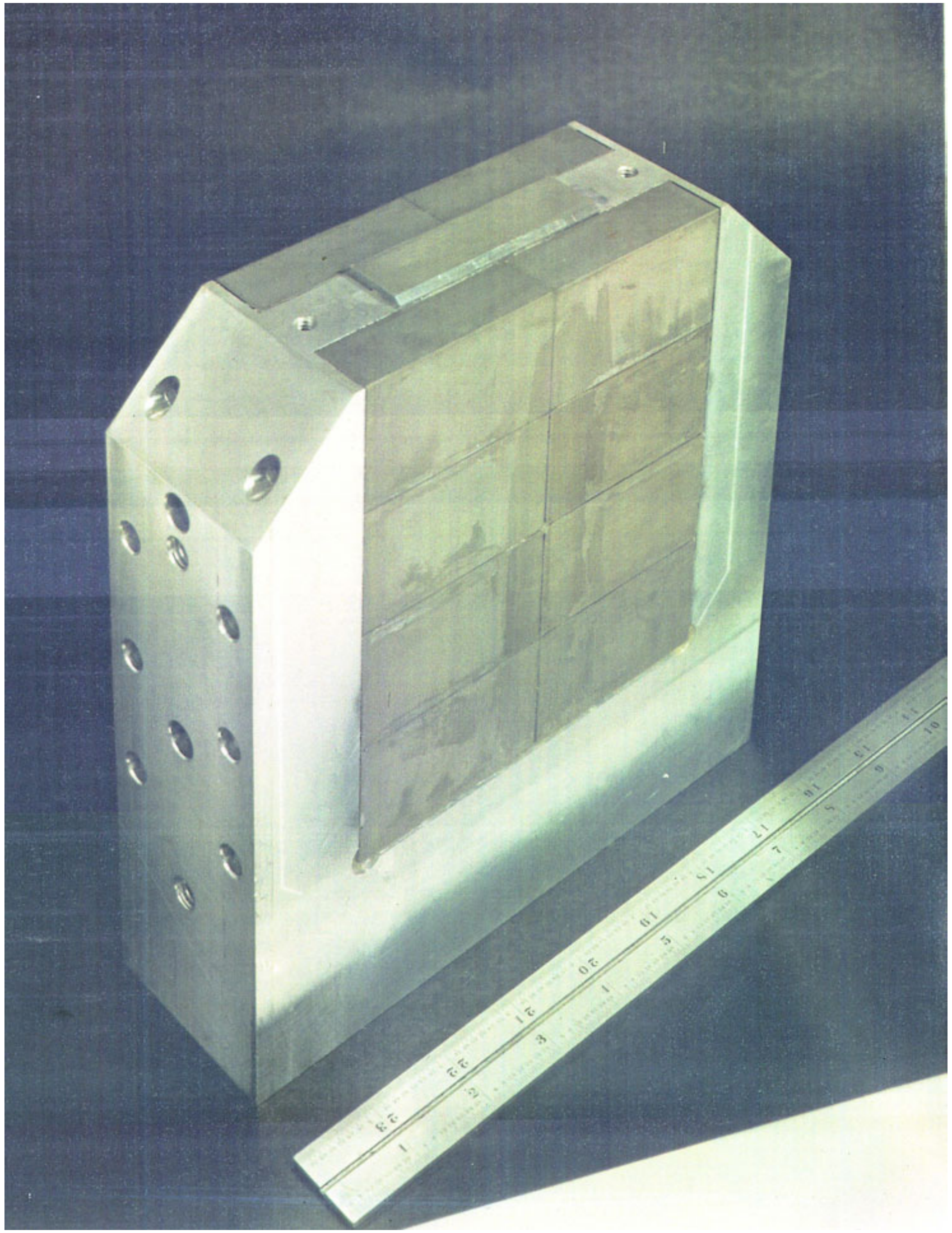
$K = \gamma\delta = .934\, B(T)\, \lambda_u(cm) \lesssim$ 1 or 2

Correlation between wavelength & viewing angle

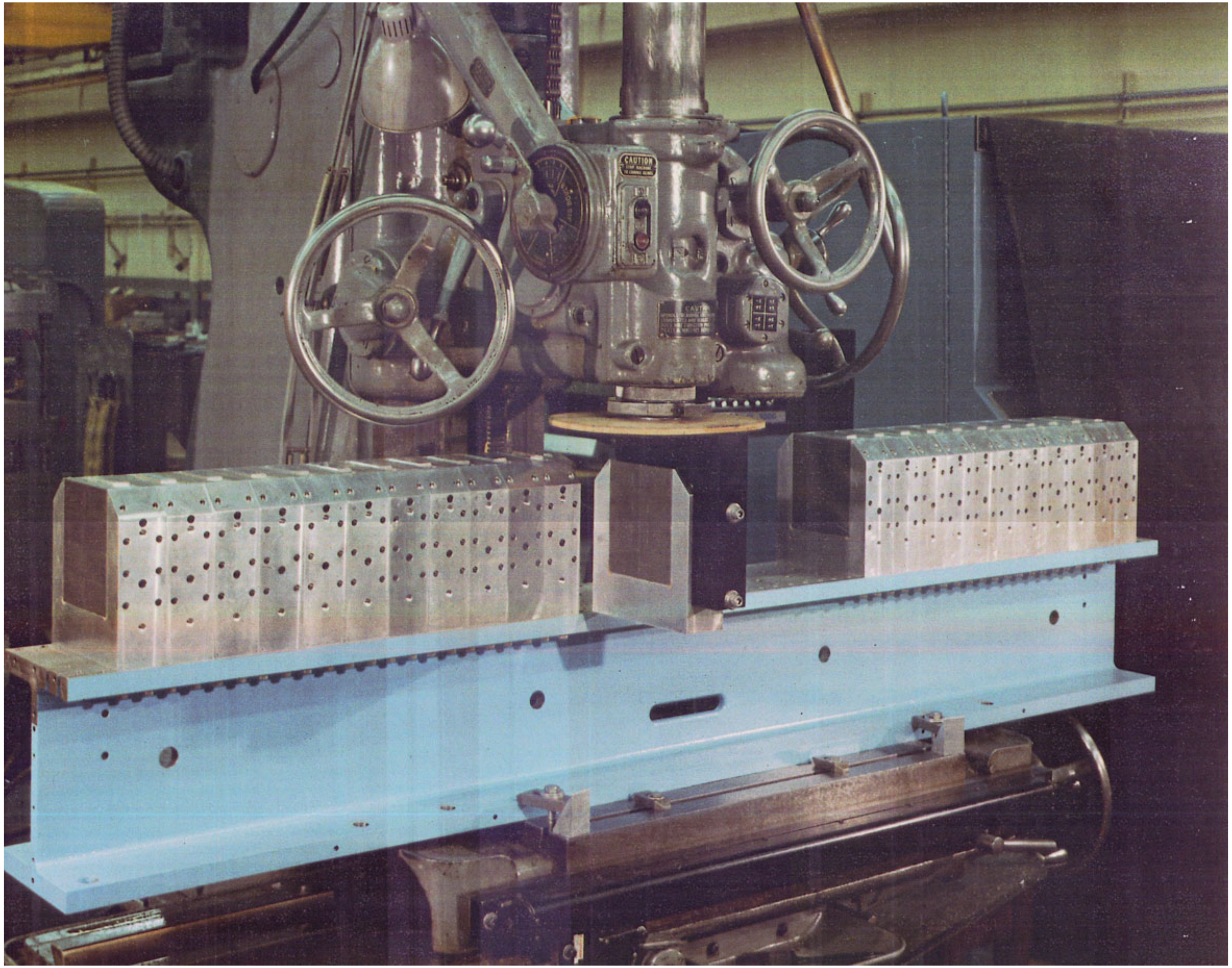
Steps in producing an insertion device; Al keeper + high permeability steel pole



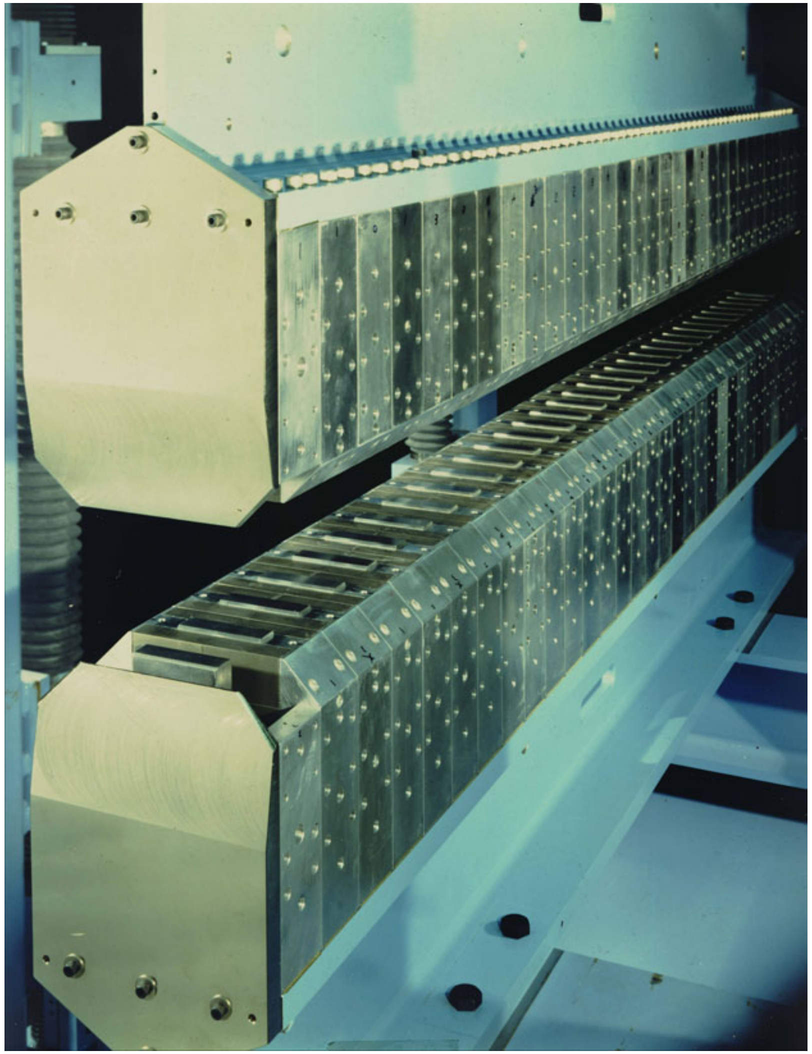
Adding magnetic material to each unit



Assembling the individual units on a strongback

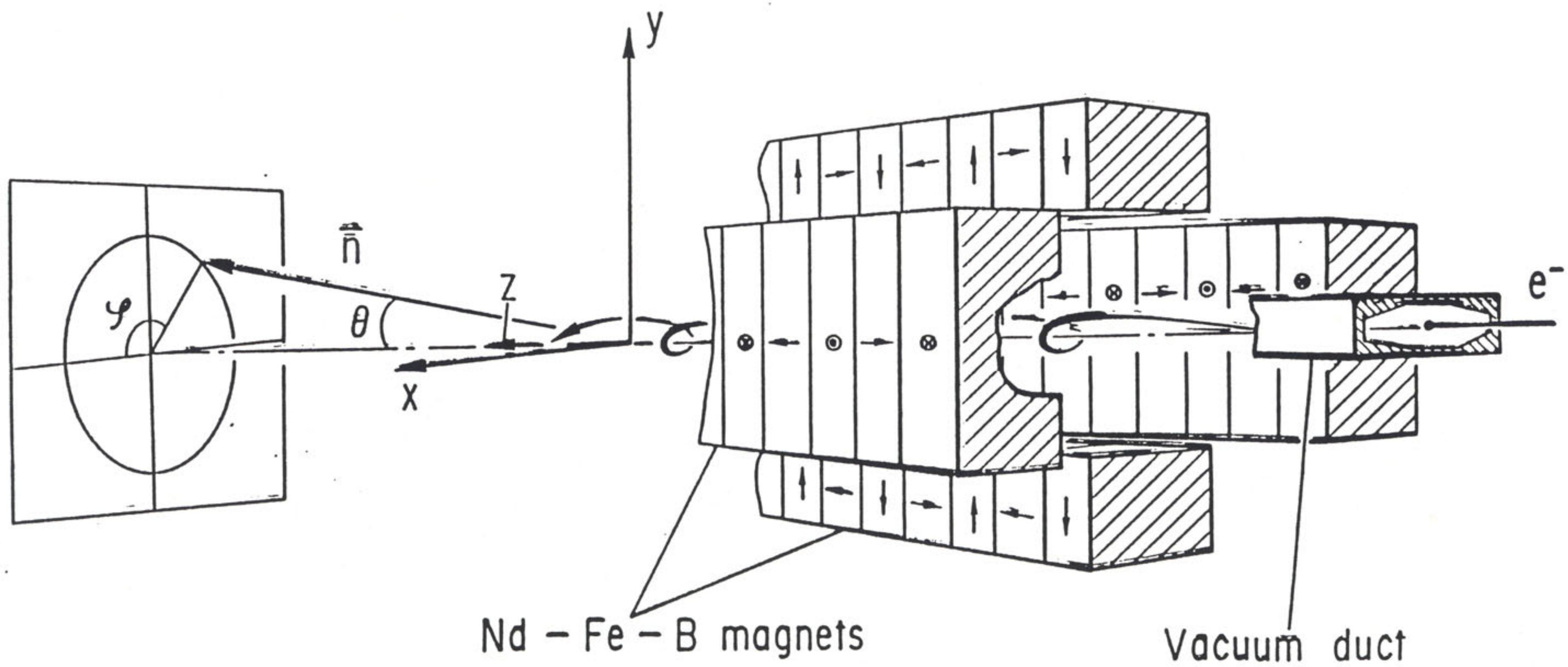


LBL/SSRL 54 Pole Permanent Magnet Hybrid Wiggler ~1985

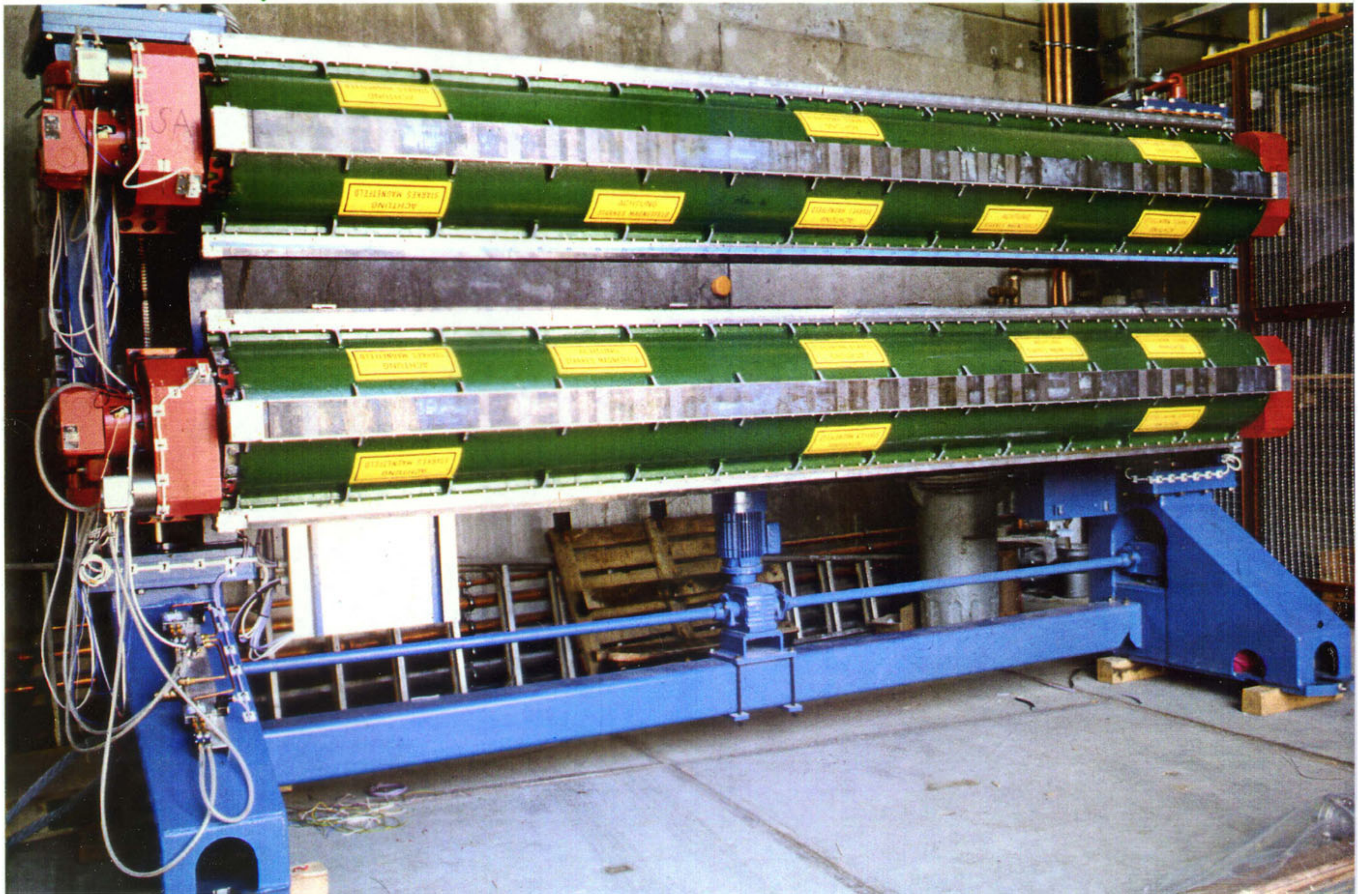


Completed wiggler in support frame; ready for installation of the vacuum chamber

Elliptical Undulator, Photon Factory, Japan
H. Kitamura, S. Yamamoto



Quadruple Undulator - DORIS Bypass-HASYLAB



End of this part of presentation