Beam Polarization Measurement Using Synchrotron Radiation

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Synchrotron Radiation- "Electronic Light"

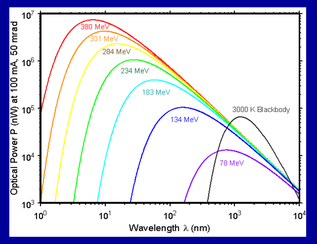
The angular and spectral distribution are well described in Classical E&M

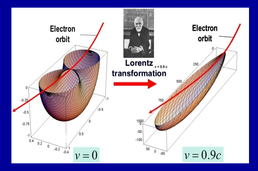
Total Rate

$$P = \frac{dU}{dt} = \frac{2}{3}\frac{e^2\gamma^4 c}{R^2}$$

Angular Distribution

$$\frac{dU}{dt\,d\Omega} = \frac{e^2\gamma^4 c}{4\pi R^2}\frac{(1-\beta\cos\theta)^2-(1-\beta^2)\sin^2\theta\cos^2\phi}{(1-\beta\cos\theta)^5}$$





Spin Dependence of Synchrotron Radiation

Exact QED calculations by A.A. Sokolov and I. M.Ternov (1960s)

QED corrections give electrons spin dependence in the radiated power

$$P = P^{(0)}\left\{1 - \frac{9\sqrt{3}}{16\pi}\sum_s \int_0^\infty \frac{y\,dy}{(1+\xi y)^4} I'_{s\nu}\,P(y)\right\};\quad y = \frac{\omega}{\omega_c};\ \xi = \frac{3}{2}\frac{B}{B_{crit}}\gamma;$$

s = radial quantum #
l = Laguerre func.

For ξ << 1 and electron spin j, j' = ± 1

$$P = P^{(0)}\left\{1 - \frac{55\sqrt{3}}{24}\xi + \frac{64}{3}\xi^2 - \underbrace{\frac{(1+jj')}{2}\left(\frac{5}{9}\xi^2 + \frac{245\sqrt{3}}{48}j\xi^3\right)}_{\text{spin dependent term}} + \underbrace{\frac{(1-jj')}{2}\left(\frac{4}{3}\xi^2 + \frac{315\sqrt{3}}{432}j\xi^3\right)}_{\text{spin-flip dependent term}} + \ldots\right\}$$

To the first order in ξ the difference in SR intensity between polarized and unpolarized electrons is δ = ξj ~ 10^{-4} for 100 μA, 0.5 GeV electrons

Verified experimentally at the VEPP-4 storage ring in Novosibirsk
Belomesthnykh et al., NIM 227, 173 (1984)

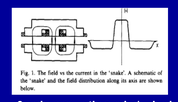


Fig. 1. The field vs the current in the 'snake'. A schematic of the 'snake' and the field distribution along its axis are shown below.

3 pole magnetic snake/wriggler

An RF field used to depolarize the electrons

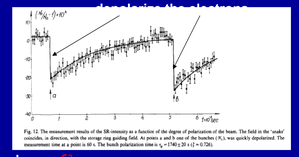


Fig. 12. The measurement results of the SR-intensity as a function of the degree of polarization of the beam. The field in the 'snake' coincides, in direction, with the storage ring guiding field. At points a and b one of the bunches (#2), was quickly depolarized. The measurement time at a point is 60 s. The bunch polarization time is $\tau_p = (740 \pm 20)$ s ($\xi = 0.726$).

The spin-flip term contributes only as ~ ξ^2

This is responsible for the transverse self polarization of electron beams in storage rings: called the Sokolov-Ternov effect

Used to produce polarized electrons at various accelerator such as DESY

Longitudinal "Spin Light"

For longitudinally polarized electrons

Power from n_e electrons (ignoring spin flip and all terms O(ξ^2))

$$P_\gamma(long) = \frac{9}{16\pi^2}\frac{n_e c e^2}{R^2}\gamma^5\int_0^\infty \frac{y^3\,dy}{(1+\xi y)^3}\oint d\Omega\,(1+\alpha^2)^2\left[K^2_{2/3}(z) + \frac{\alpha^2}{1+\alpha^2}K^2_{1/3}(z) + j\xi y\frac{\alpha}{\sqrt{1+\alpha^2}}K_{1/3}(z)K_{2/3}(z)\right]$$

R = bending radius, $y = \frac{\omega}{\omega_c}$; $\xi = \frac{3}{2}\frac{B}{B_{crit}}\gamma$; $\alpha = \gamma\psi$; $z = \frac{\omega}{2\omega_c}(1+\alpha^2)^{3/2}$

$K_{1/3}$, $K_{2/3}$ modified Bessel function

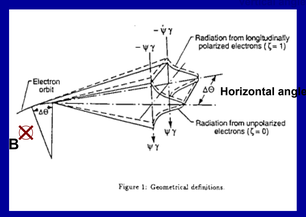


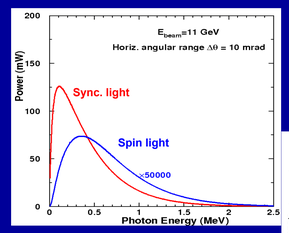
Figure 1: Geometrical definitions.

An odd function of the vertical angle

Integrated over all vertical angles the total SR power is spin independent

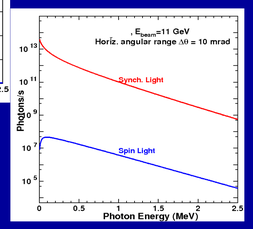
# of photons radiated above and below the orbital plane are not equal

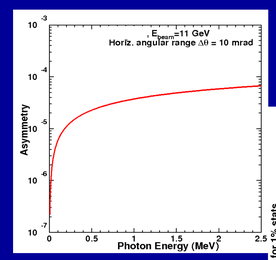
"Spin Light" - Some Characteristics



Radiated power peak at different frequencies for Sync vs Spin light

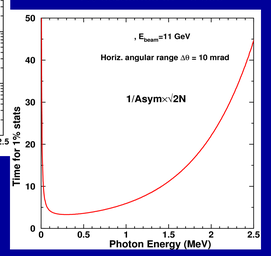
Number of photons ~ 10^5 different

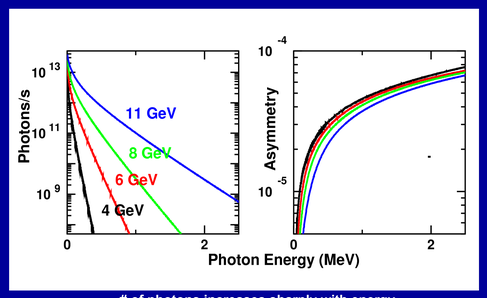




small asymmetry

But high rates imply 1% statistics in ~ 5 sec





# of photons increases sharply with energy but relatively small change in asymmetry

Conceptual Design of "Spin Light" Polarimeter

A Source of Spin light

A 3 pole wiggler magnet

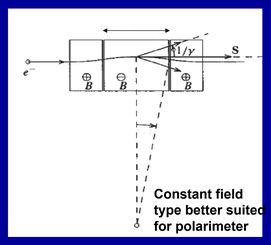
$$\oint B\,dl = 0$$

$$R_{bend} = \frac{\gamma m_e c}{e B}$$

$$L = R_{bend}\,\Delta\theta$$

Horizontal angular acceptance Δθ fixed to 10 mrad

For E_e = 11 GeV, spot size = 90 μrad
i.e. 10m from the source ~ 1 mm dia.

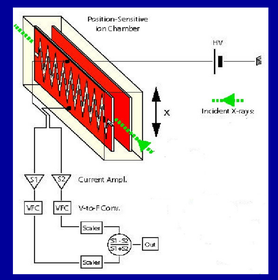


Pole length and figure of merit have similar dependence on the B- field.

Choose B = 4T

A Detector of Spin light (X-rays)

A differential ionization chamber



Twin chamber design can reduce systematics

Visible portion can be used to center chamber

Gas – Xe or Kr

Can handle high rates
Radiation hard
Low dark current/noise
Resolution ~ 5 μm
Wide range of ICs commercially available

K. Sato, J. of Synchrotron Rad., 8, 378 (2001)
T. Gog, D. M. Casa, I. Kuzmenko, CMC-CAT@ the APS

Putting it all together

B_{wrig} = 4 T; L ~ 10cm

Spacing between wriggler poles
have to be optimized

Differential ionization chamber
Placed 10 m from source
Twin chamber design with common collector