Jefferson Lab
Exploring the Nature of Matter

Spin-Light Polarimetry for Low Energy Electron/Positron Beams

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MISSISSIPPI STATE

Low Energy Electron Positron Physics Workshop at Jefferson Lab
March 23-28, 2026

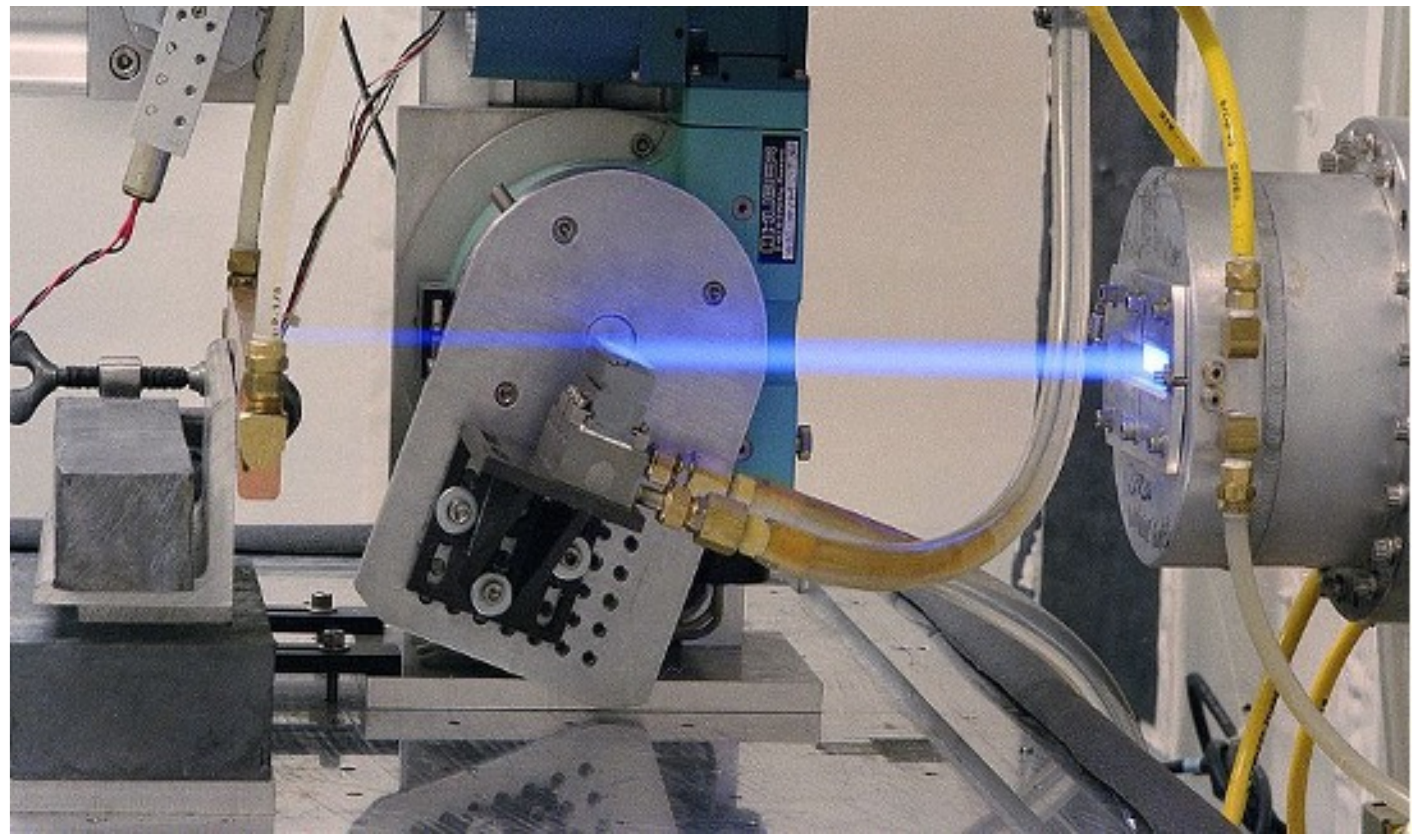
Outline

- Synchrotron Radiation & “Spin-Light”
- Conceptual Design of a Spin-Light Polarimeter
  - Transverse polarimeter
  - Longitudinal polarimeter
- Low energy challenges
- Summary

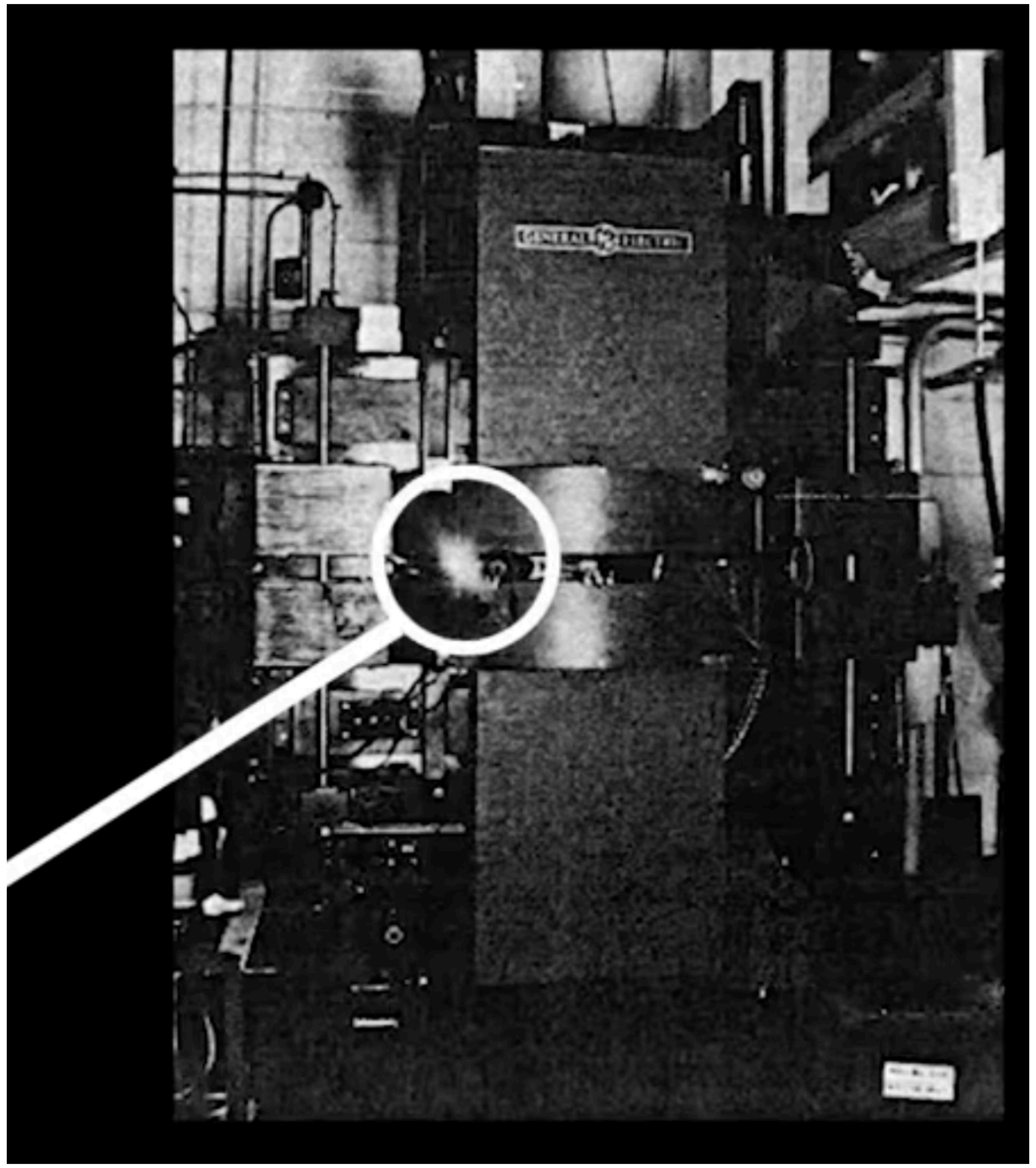
Synchrotron radiation was discovered at the General Electric Research Labs in Upstate NY, in 1947.

Radiation from charged particle accelerated transverse to its velocity (consequence of finite velocity of light)

predicted by Ivanenko and Pomeranchuk(1944)



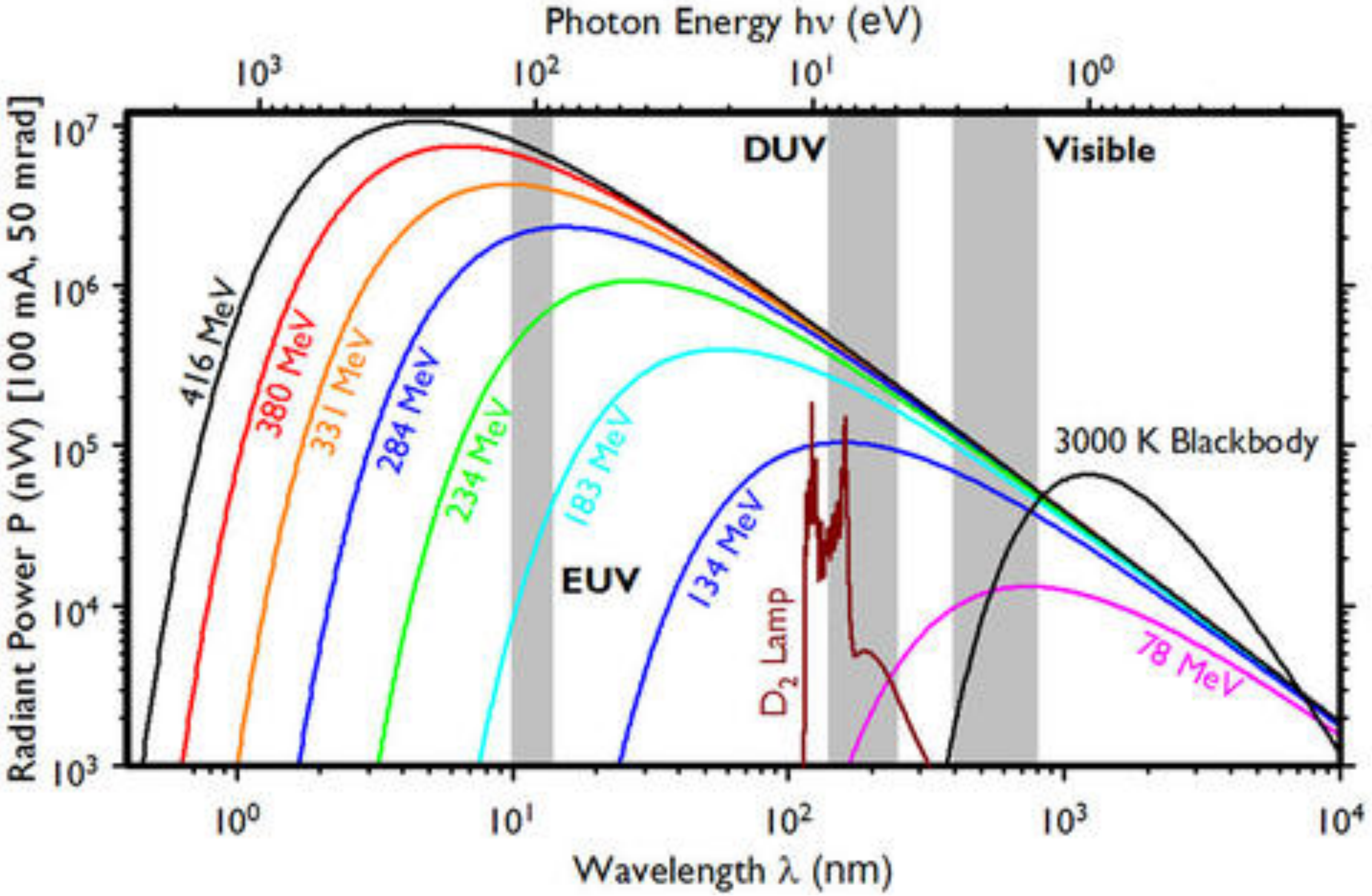
visible radiation from an electron beam of a 70 MeV synchrotron



Synchrotron radiation = magnetic bremsstrahlung = electronic light

Angular and spectral distribution first worked out in classical theory

Ivanenko and Pomeranchuk(1946), Schwinger (1947)



$$P = \frac{2}{3}\frac{e^2\gamma^4 c}{R^2} \propto E^4$$

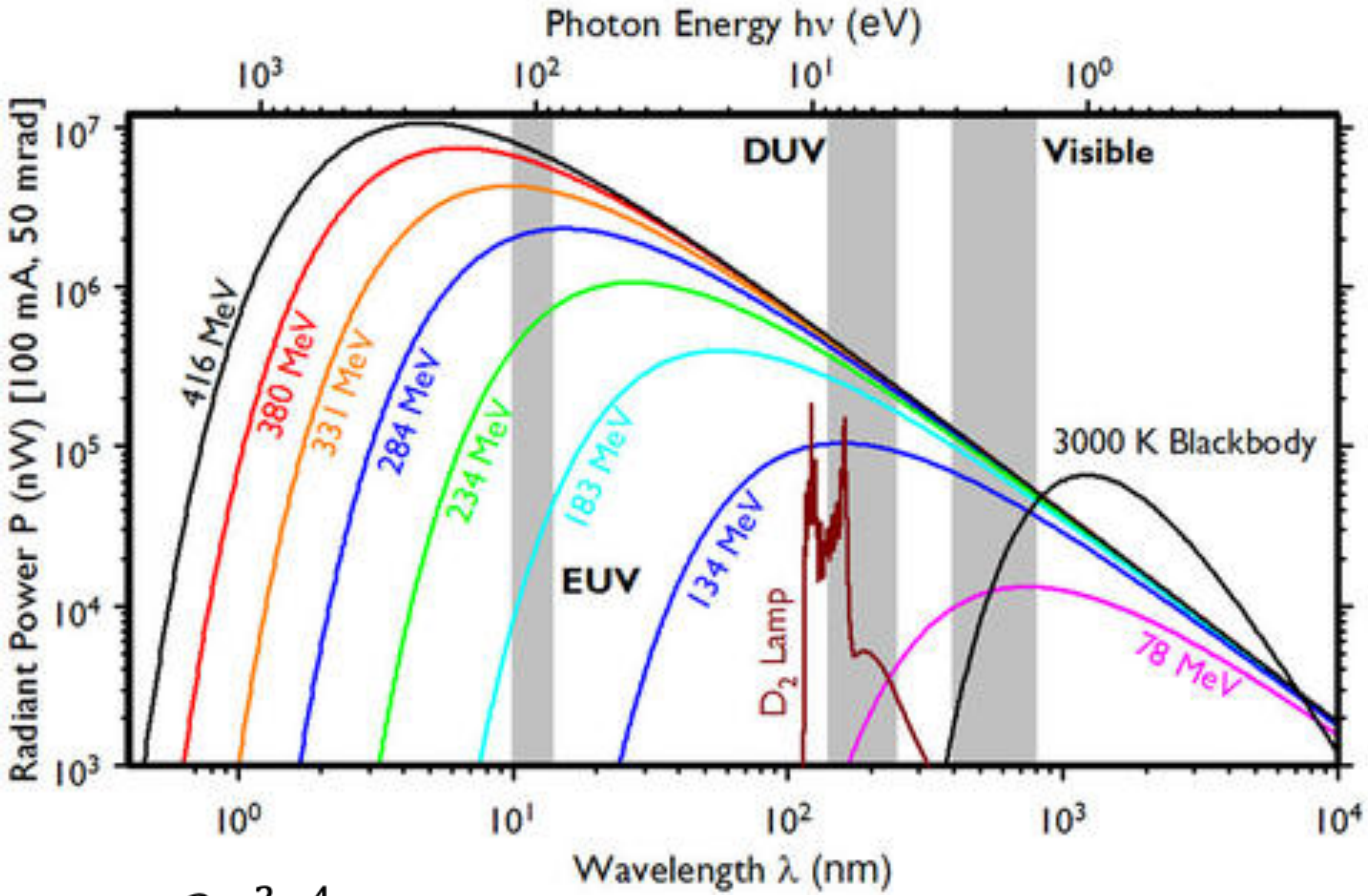
$$dP/d\Omega = \frac{e^2\gamma^4 c}{4\pi R^2}\frac{(1-\beta\cos\theta)^2-(1-\beta^2)\sin^2\theta\cos^2\phi}{(1-\beta\cos\theta)^5}$$

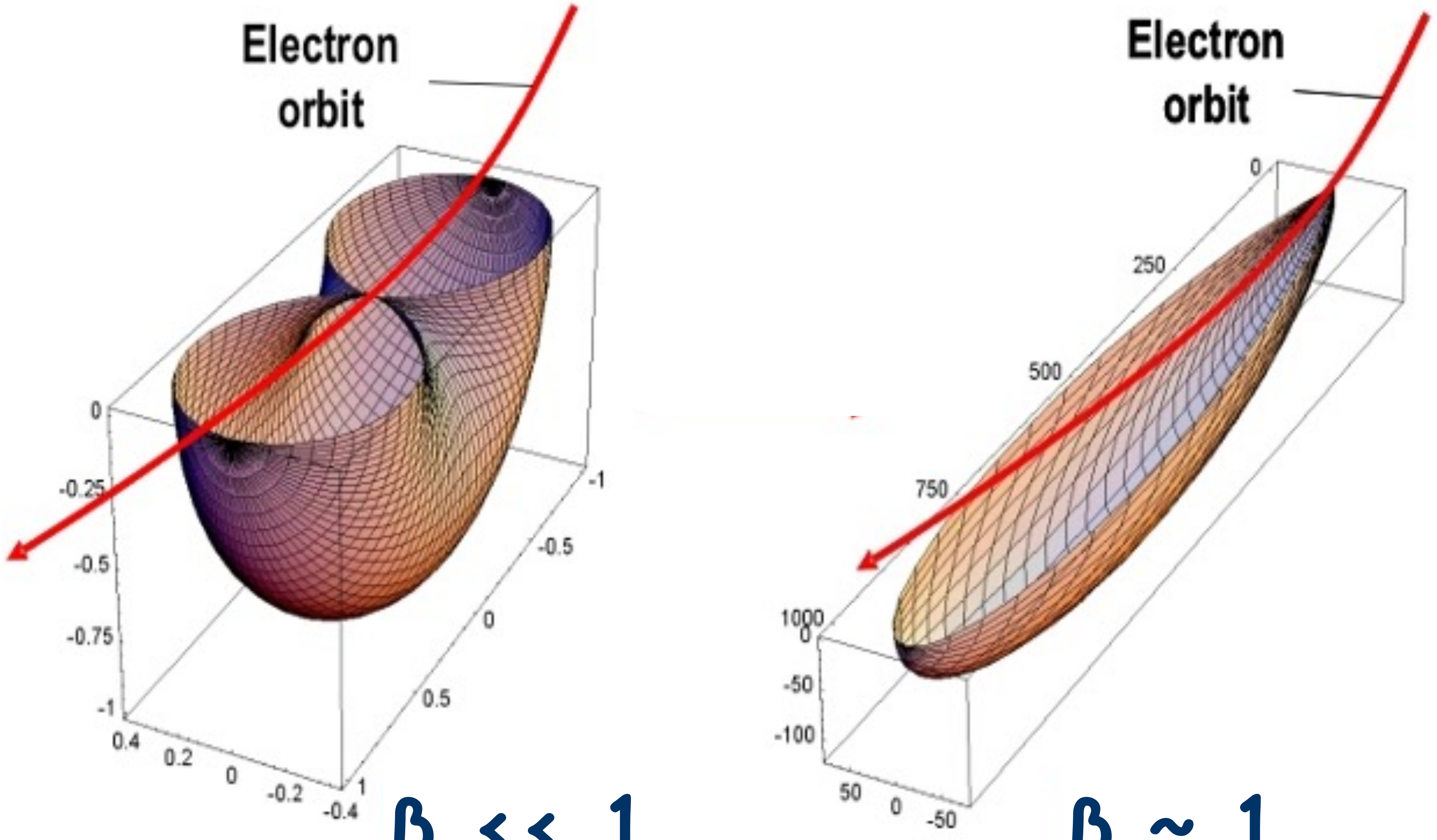
θ, Φ **relative to direction of motion**

spectral width $\Delta\omega \propto \gamma^3$

i.e. continuous

Angular and spectral distribution first worked out in classical theory





β << 1 β ~ 1

For γ >> 1 θ ~ 1/γ

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for 0.1 GeV electrons θ ~ 10 mrad (spot size at 1 m ~ 1 cm)
for 1 GeV electrons θ ~ 1 mrad (spot size at 10 m ~ 1cm)
for 11 GeV electrons θ ~ 90 μrad (spot size at 10m ~ 1mm)

Quantum corrections to SR introduce spin dependence

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

The classical theory (continuous SR spectrum) is valid for $E_{electron} << E_{critical}$

$E_{critical}$ = when a single SR photon carries all of the electron's energy.

$E_{crit} \sim 10^6$ GeV and $B_{crit} \sim 4\times10^9$ T

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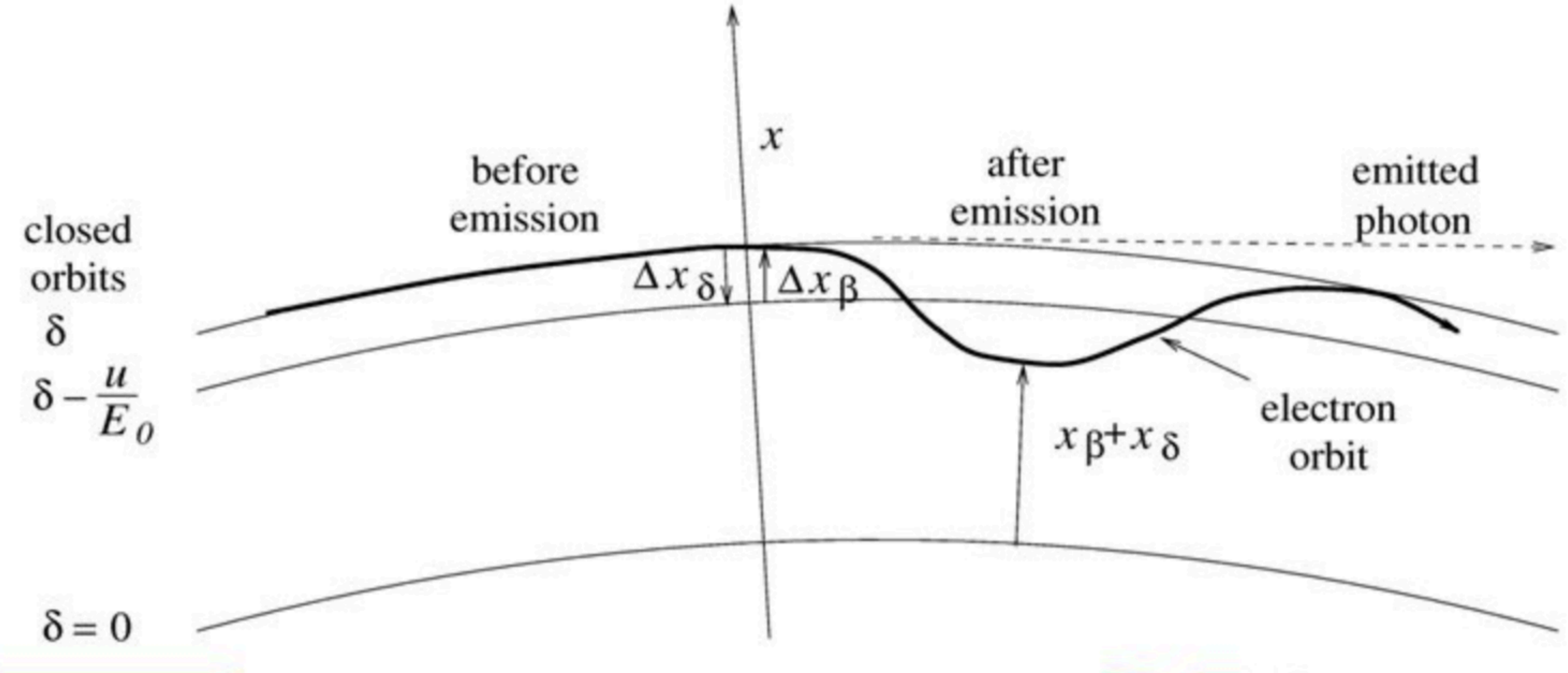
But even for $E_e > 100$ MeV, quantum corrections lead to radial oscillations and widening of trajectories in storage rings



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and QED corrections give electrons spin dependence in the radiated power

$$P = P^{clas} \times \frac{9\sqrt{3}}{16\pi} \sum_{s'} \int_0^\infty \frac{y\,dy}{(1+\xi y)^4} I^2_{ss'}(x) F(y), \qquad y = \frac{\omega}{\omega_c}; \xi = \frac{3}{2}\frac{B}{B_{crit}}\gamma;$$

s = radial quantum #

I = Laguerre func.

$y \propto 1/\gamma^3$

$x = f(y, \xi)$

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$F(y) \propto$ electron spin j, j'

+ modified Bessel fns.

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For $\xi << 1$ and electron spin j, j' = ± 1

$$P = P^{clas}\left[\left(1 - \frac{55\sqrt{3}}{24}\xi + \frac{64}{3}\xi^2\right) - \left(\frac{1+jj'}{2}\right)\left(j\xi + \frac{5}{9}\xi^2 + \frac{245\sqrt{3}}{48}j\xi^2\right) + \left(\frac{1-jj'}{2}\right)\left(\frac{4}{3}\xi^2 + \frac{315\sqrt{3}}{432}j\xi^2\right) + \ldots\right]\left(\int \text{mod. Bessel dy}\right)$$

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lowest order spin dependent term

lowest order spin flip dependent term

Spin dependent SR - "Spin Light" was demonstrated in the 1980s

$$P^{pol} - P^{unpol} = P^{spin} = -j\xi P^{clas} \int_0^\infty \frac{9\sqrt{3}}{8\pi} y^2 K_{1/3}(y) dy.$$

$K_{1/3}$ modified Bessel function

To the first order in ξ the difference in SR intensity between polarized and unpolarized electrons is $\delta = \xi j \sim 10^{-4}$ for 100 μA, 5 GeV electrons, 2T field, 0.9 degree of polarization

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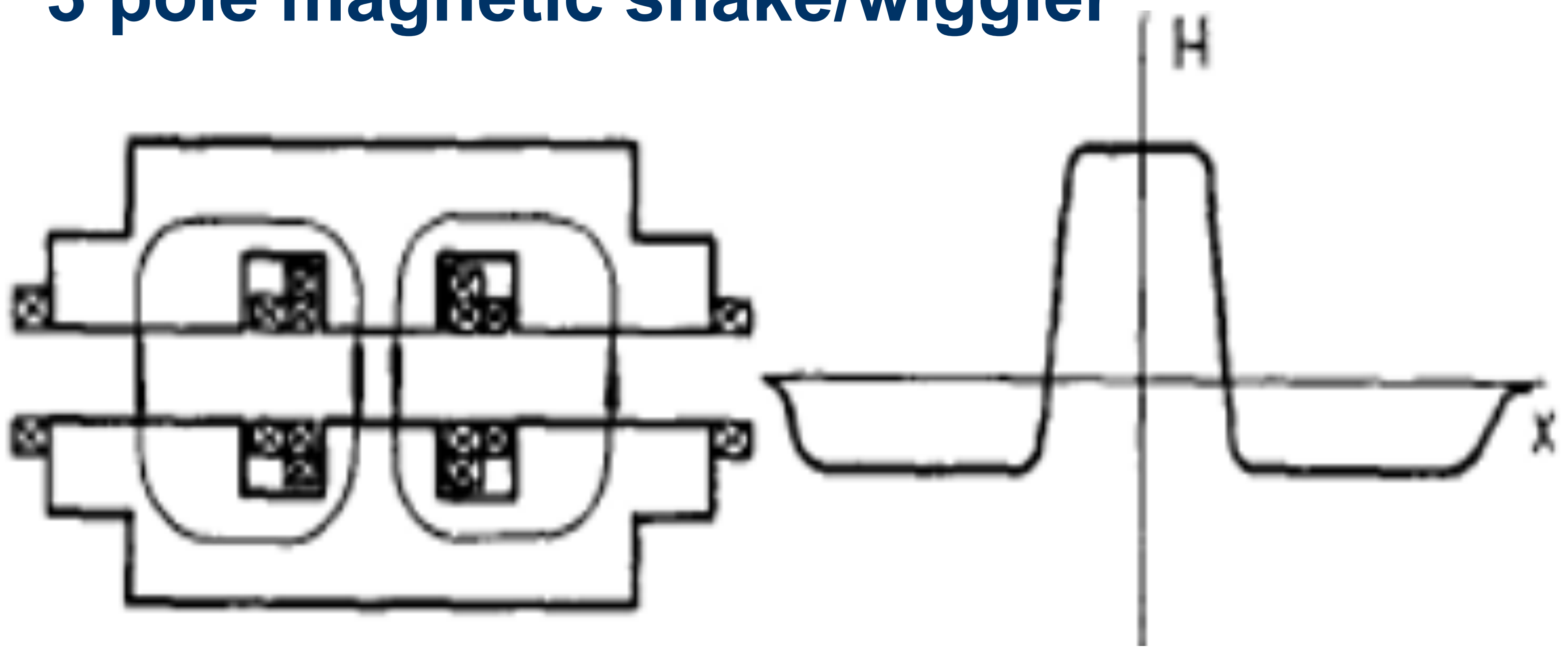
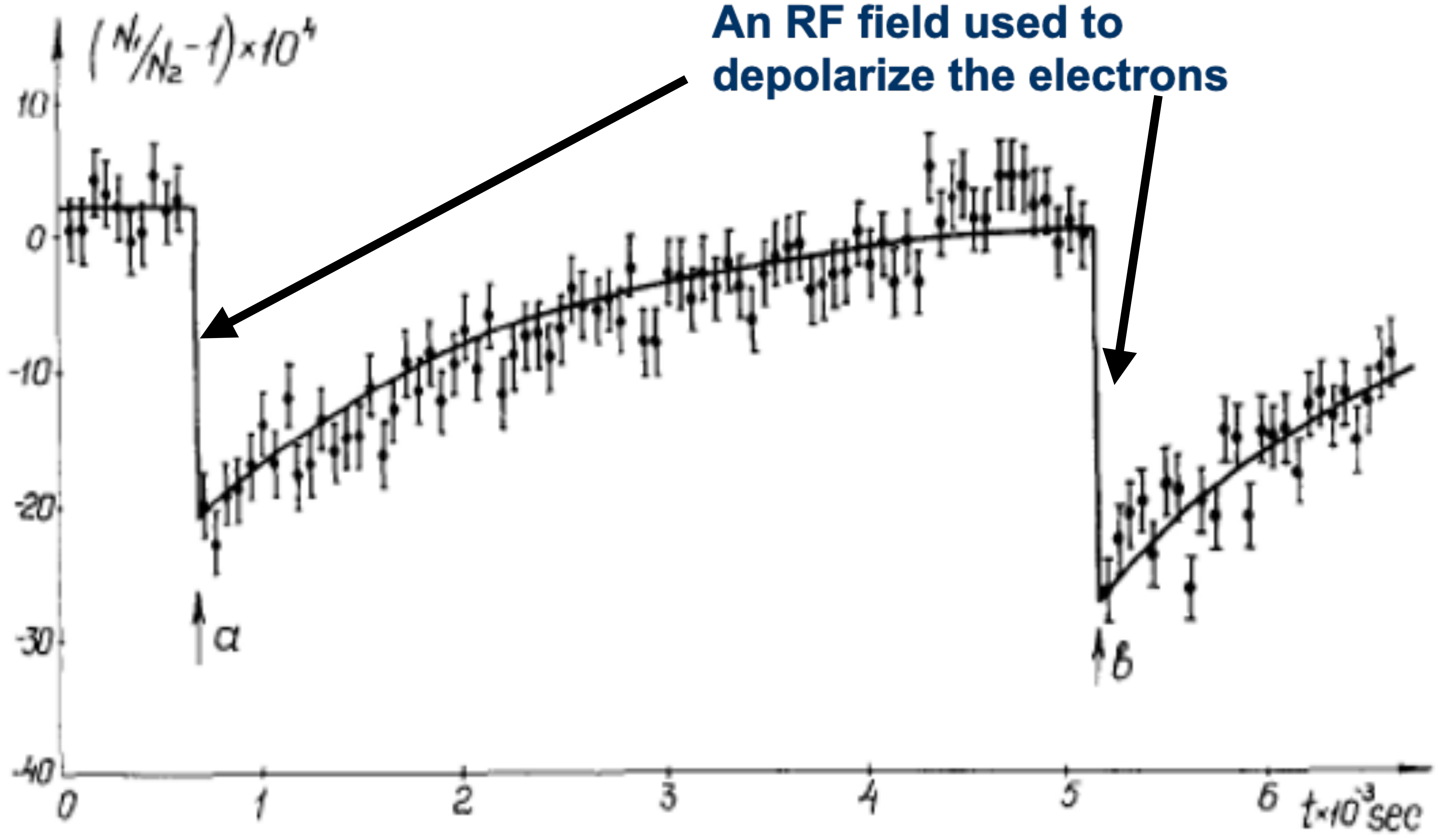
Verified experimentally at the VEPP-4 storage ring in Novosibirsk
Belomesthnykh et al., NIM 227, 173 (1984)

3 pole magnetic snake/wiggler



2T field



An RF field used to depolarize the electrons

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4mm Pb converter in front of scintillator

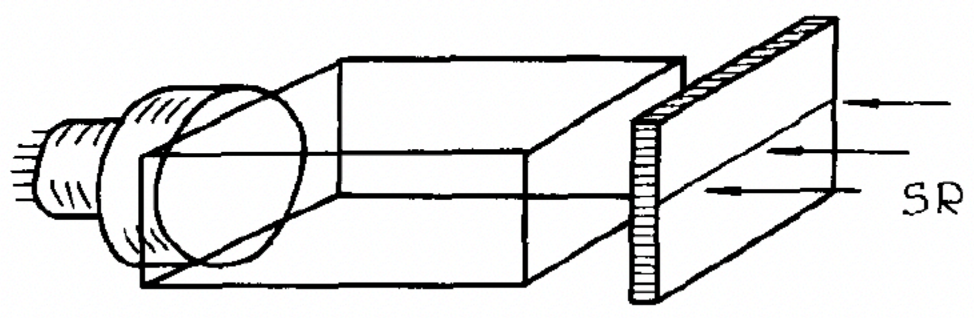
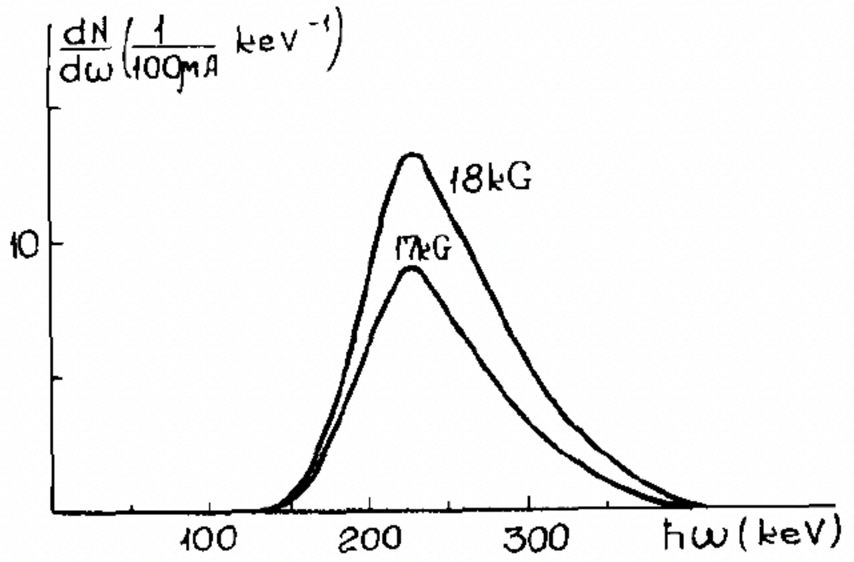
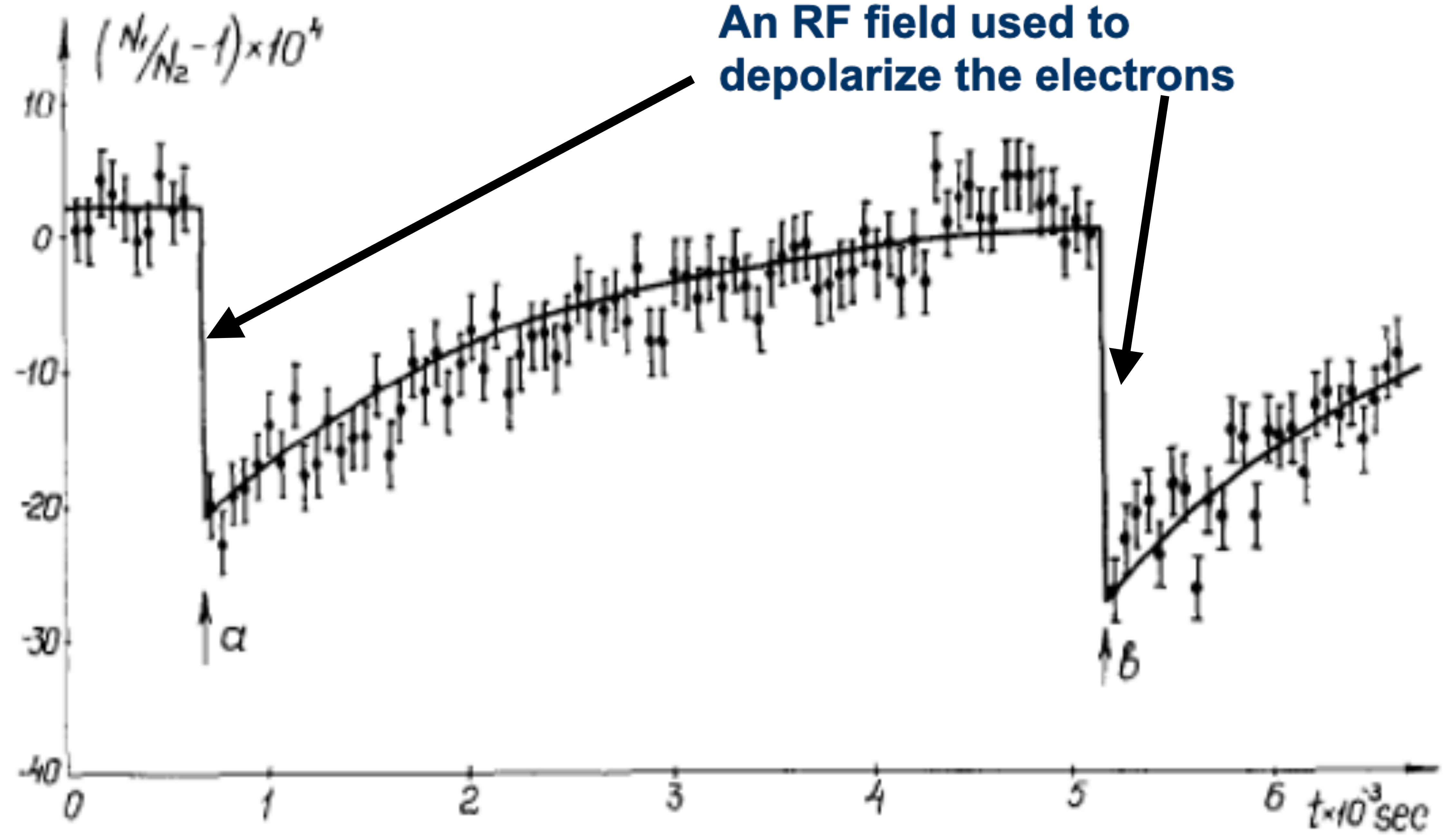


Fig. 2. Layout of the detector.

Spectrum of highest energy SR photons





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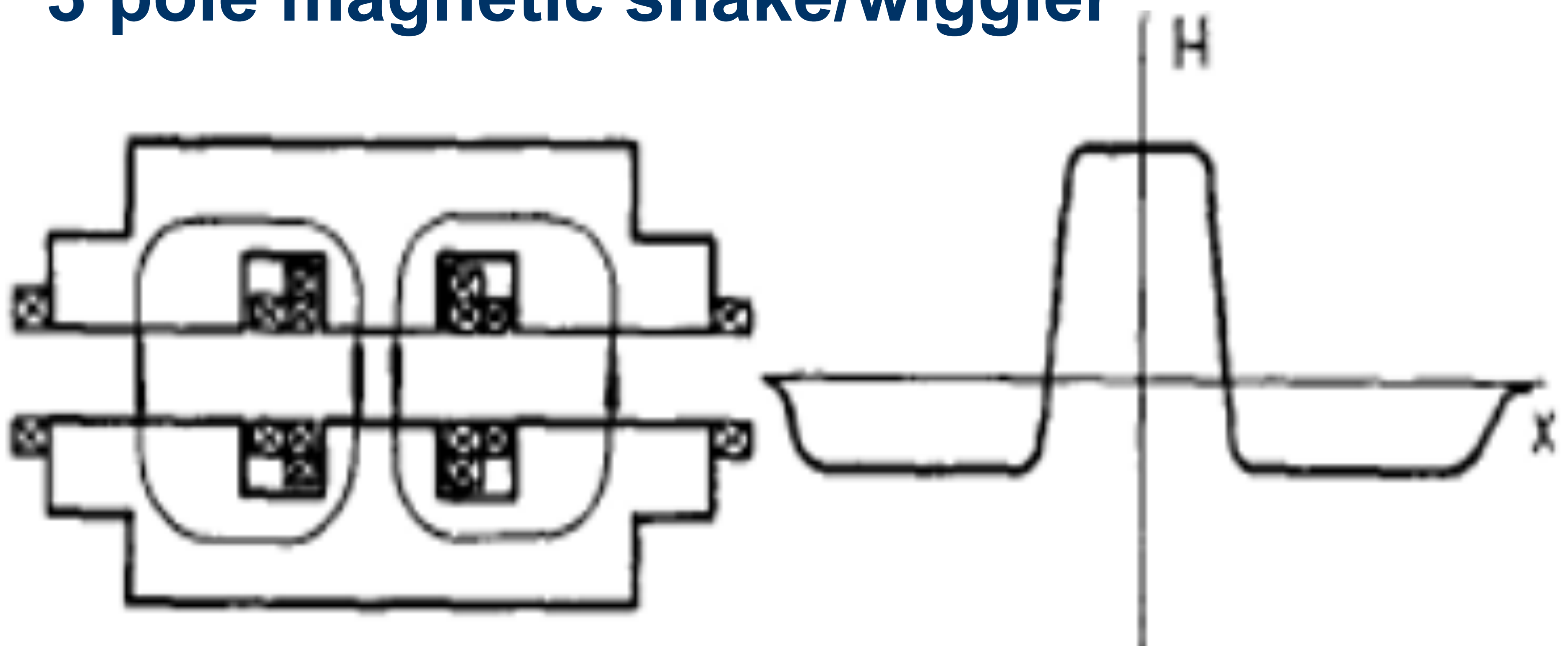
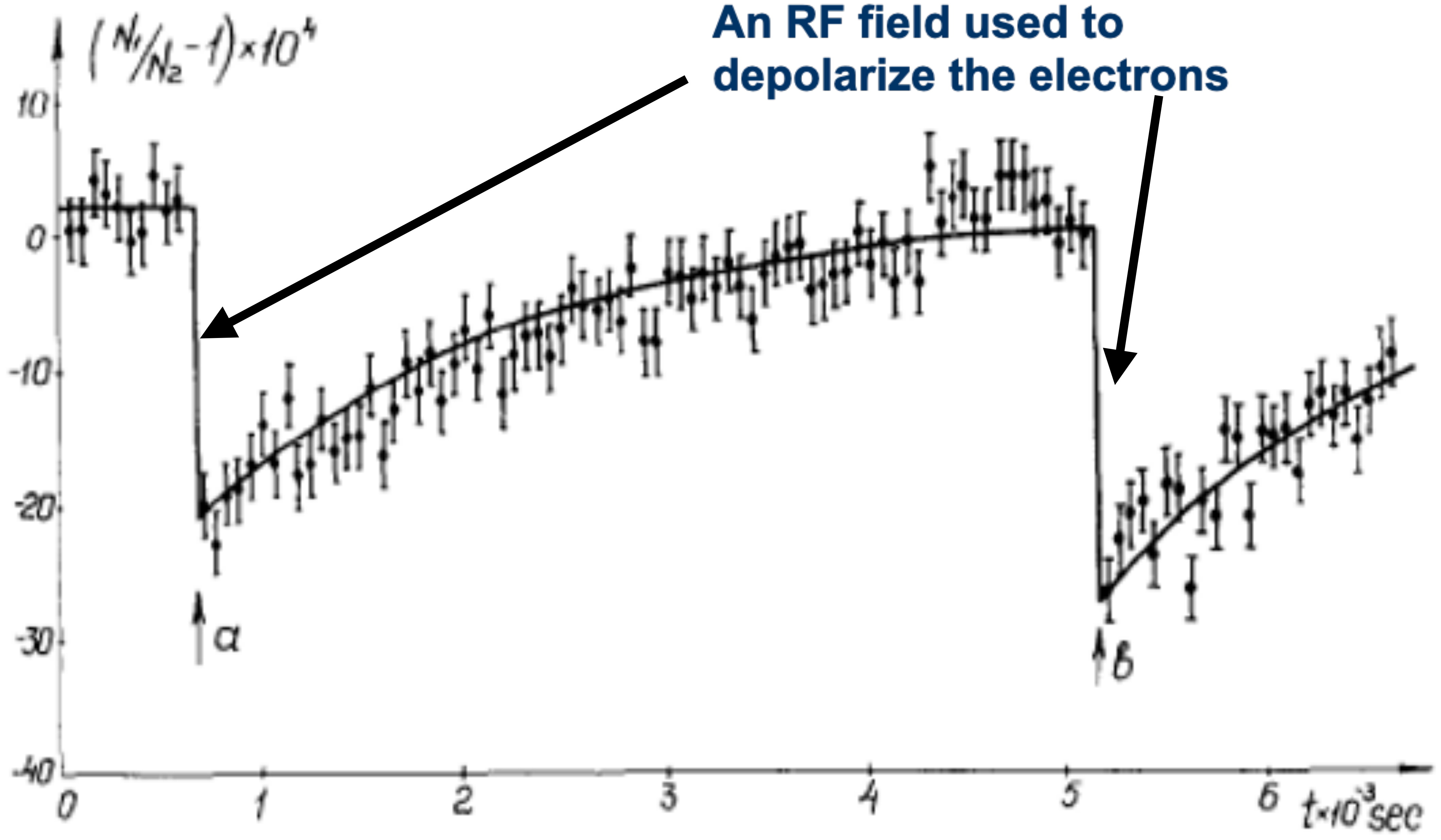
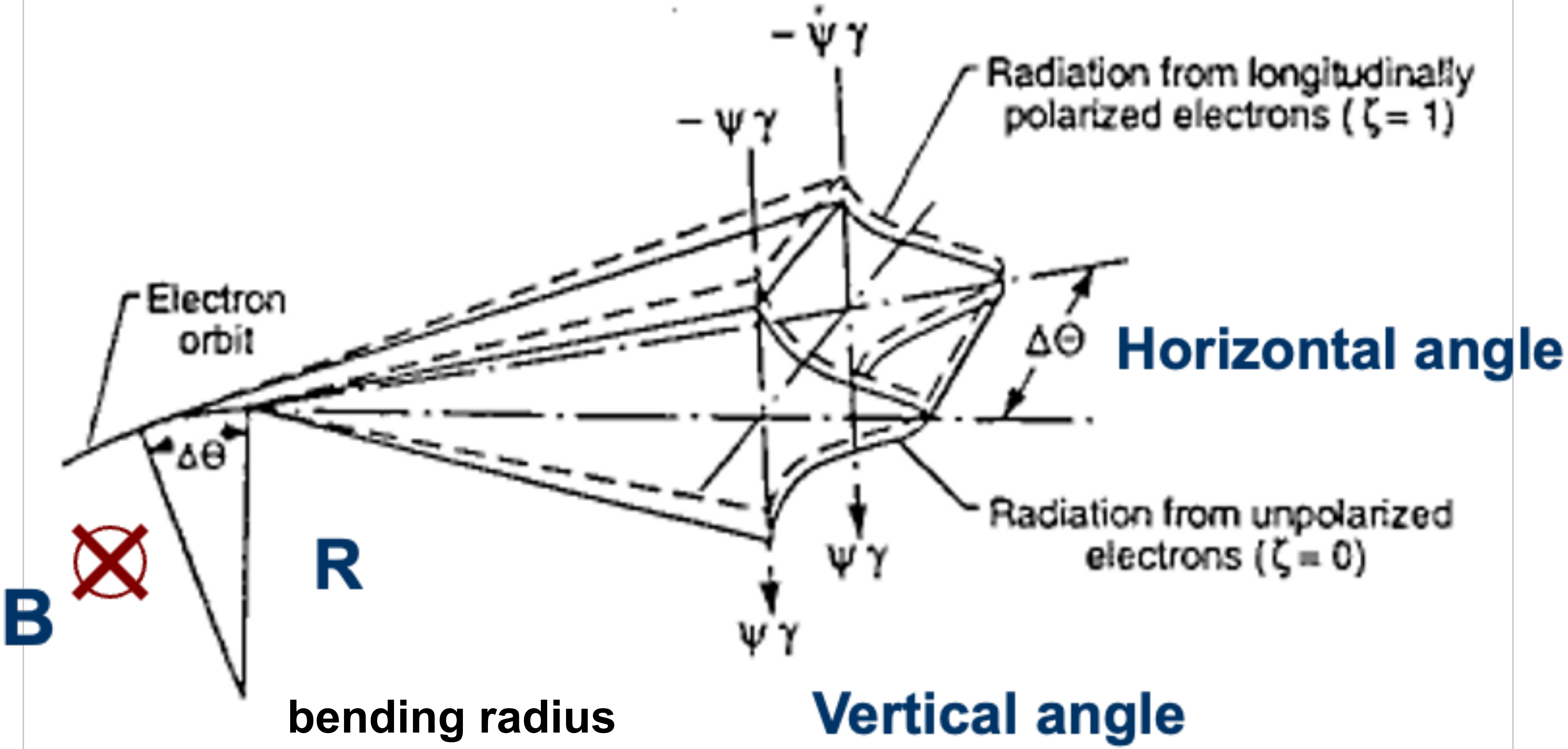




The spin-flip term contributes only as ~ ξ^2 (Sokolov-Ternov effect), responsible for the transverse self polarization of electron beams in storage rings (first observed at Orsay). J. Le Duff, P. C. Marin, J. L. Manson, and M. Sommev, Orsay - Rapport Technique, 4-73 (1973).

Longitudinal Spin Light radiates different number of photons above and below the orbital plane



Pγ (long) = odd function of 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

$$\Delta N_\gamma(j) = \frac{3}{\pi^2}\frac{1}{137}\frac{I_e}{e} j\xi\gamma\Delta\theta \int_{y_1}^{y_2} y^2 dy \int_0^{\alpha} \alpha(1+\alpha^2)^{3/2} K_{1/3}(z) K_{2/3}(z) d\alpha$$

α = vertical angle

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

Transverse Spin Light has an absolute spin dependent asymmetry

Pγ (trans) = even function of vertical angle

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

$$\Delta N_\gamma(j) = \frac{3}{\pi^2}\frac{1}{137}\frac{I_e}{e} j\xi\gamma\Delta\theta \int_{y_1}^{y_2} y^2 dy \int_{-\alpha}^{\alpha} (1+\alpha^2)^{3/2} K_{1/3}(z) K_{2/3}(z) d\alpha$$

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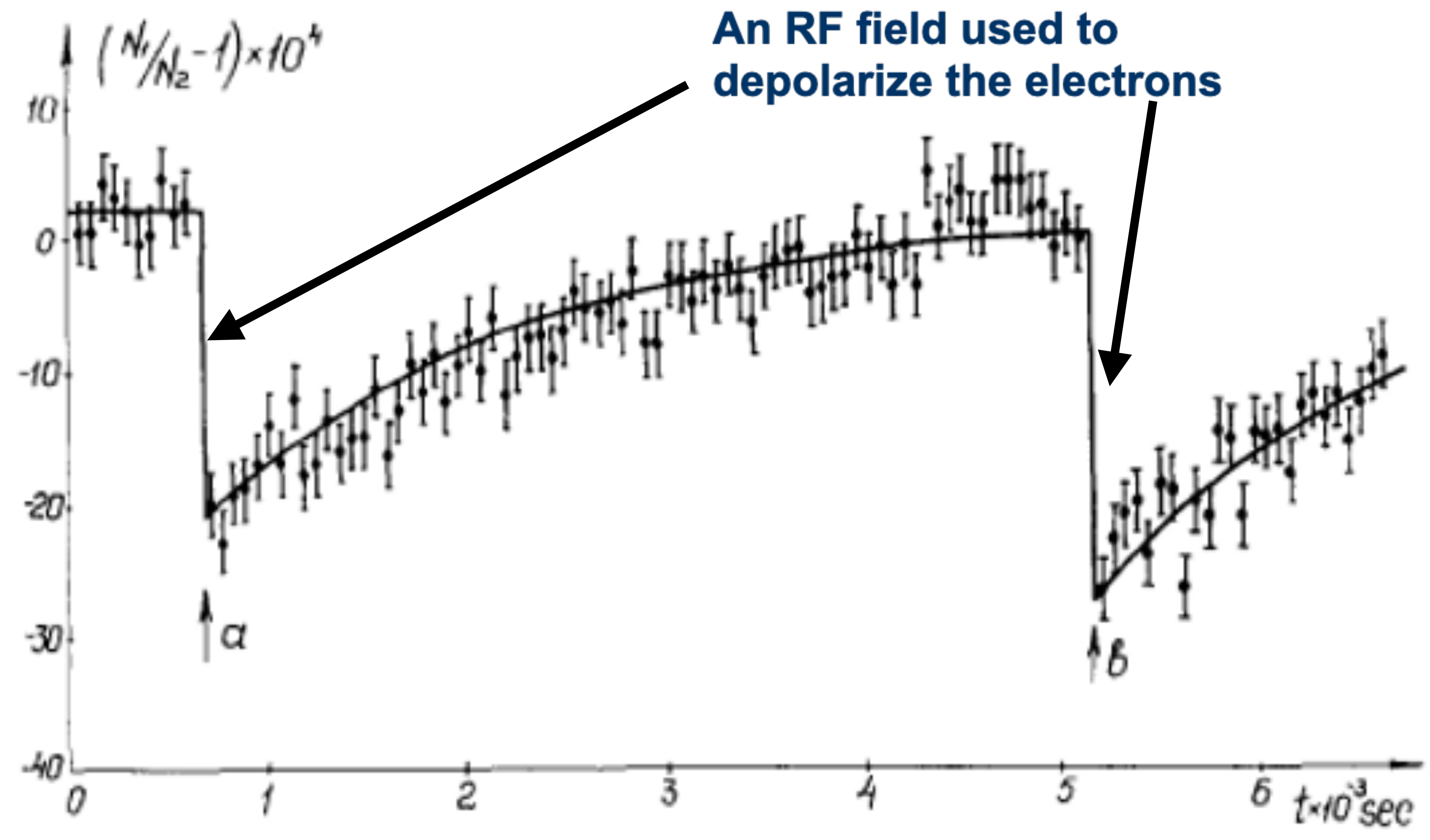

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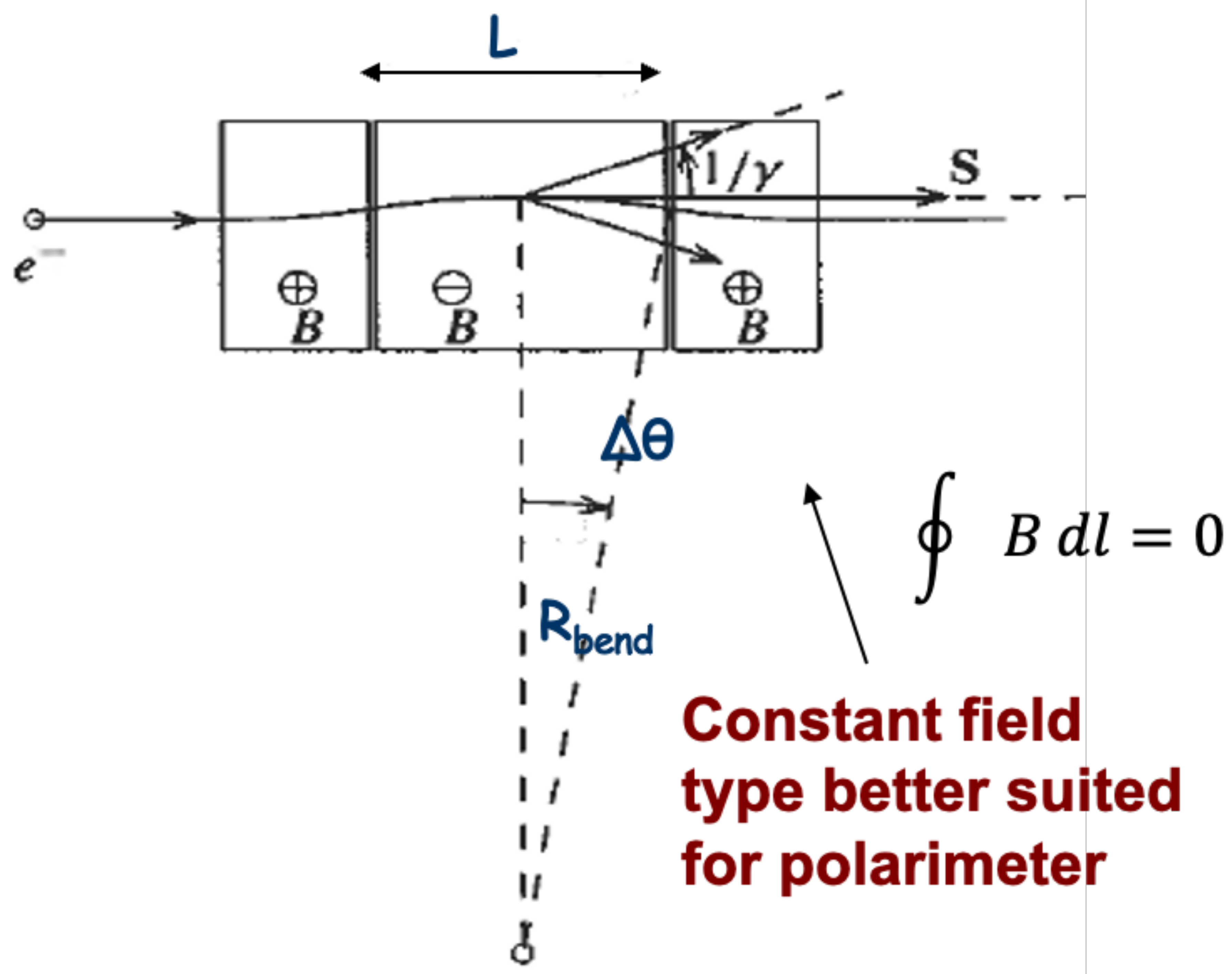
A Source of Spin light : a 3 pole wiggler

$$R_{bend} = \frac{\gamma m_e c}{eB}$$

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

Horizontal angular acceptance $\Delta\theta$ fixed to 10 mrad



Constant field type better suited for polarimeter

Transverse Spin Light polarimetry is a well demonstrated technique

P_γ (trans) = even function of vertical angle

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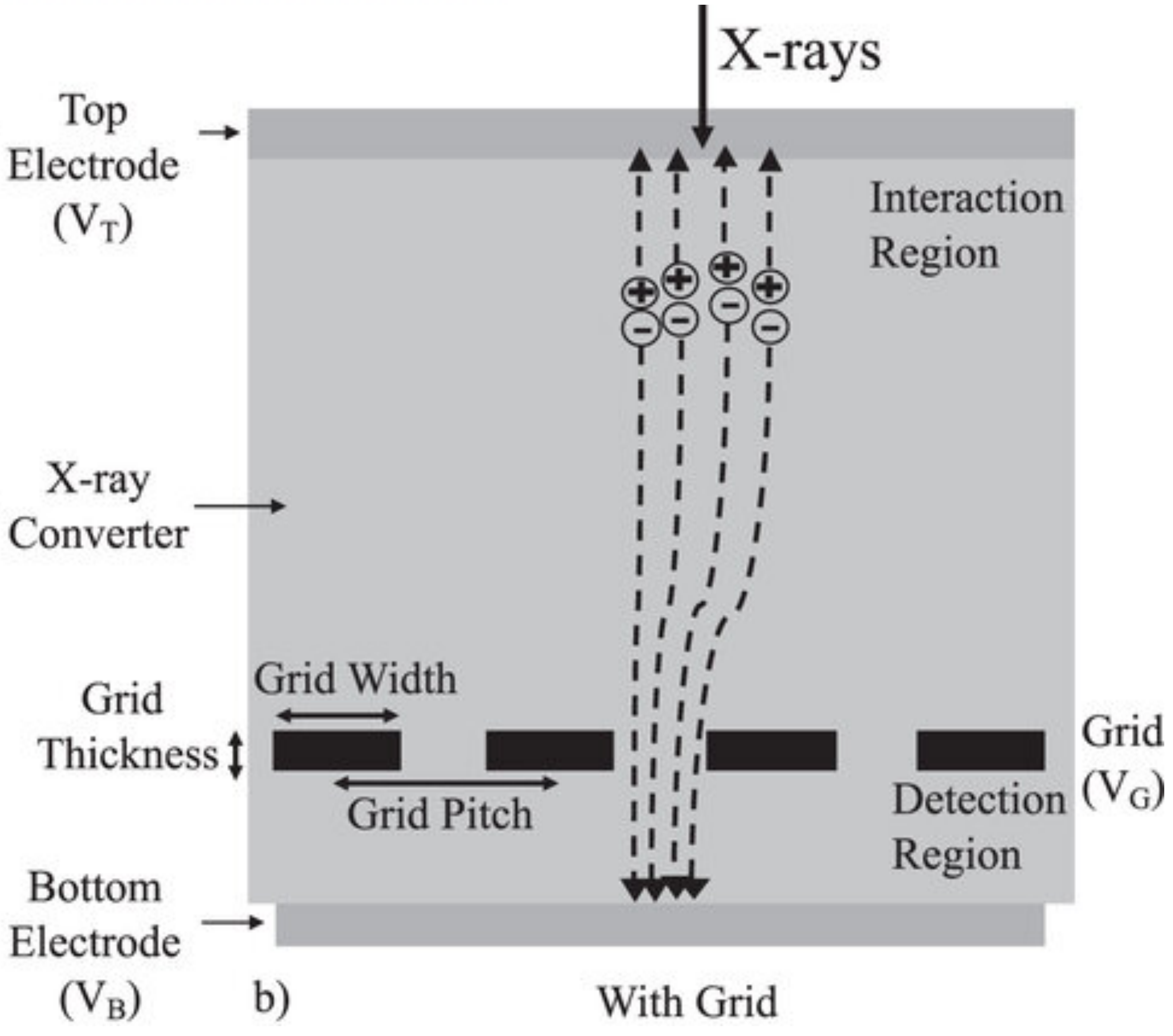
α = vertical angle

detector frequency response

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

A Spin light Detector : ion chamber
or converter + scintillator

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



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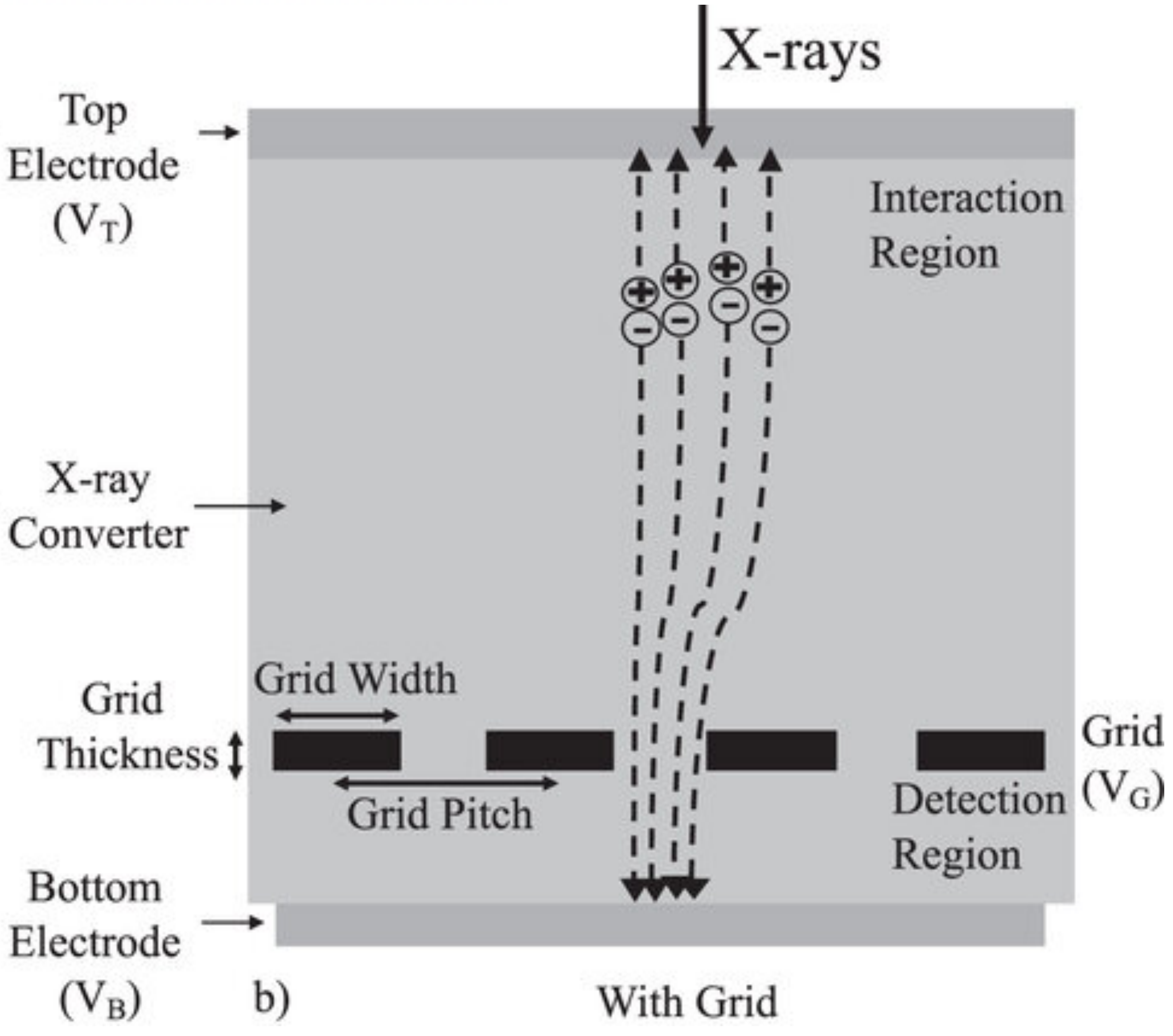
A Spin light Detector : ion chamber or converter + scintillator

$$\text{Asym} = \frac{(N^{h+}_{SR} + \Delta N^{h+}_{spin} - N^{h-}_{SR} - \Delta N^{h-}_{spin})}{(N^{h+}_{SR} + \Delta N^{h+}_{spin} + N^{h-}_{SR} - \Delta N^{h-}_{spin})} \propto 2P_e \xi\gamma A_{det}$$



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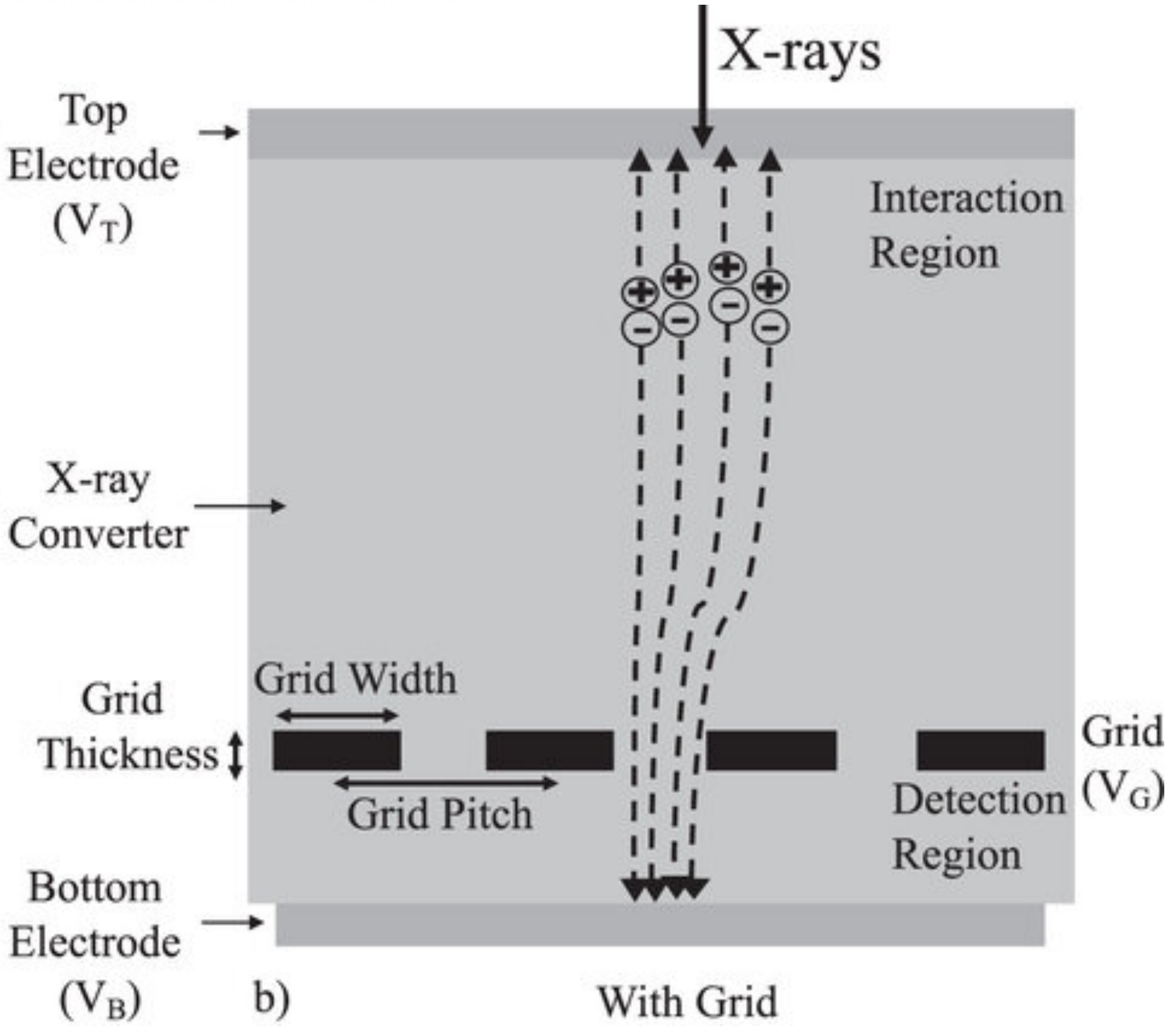
acceptance function from simulation or calibration with RF depolarizer



Transverse polarimetry is feasible for ≧0.5 GeV beams

For E_{beam} = 0.5 GeV

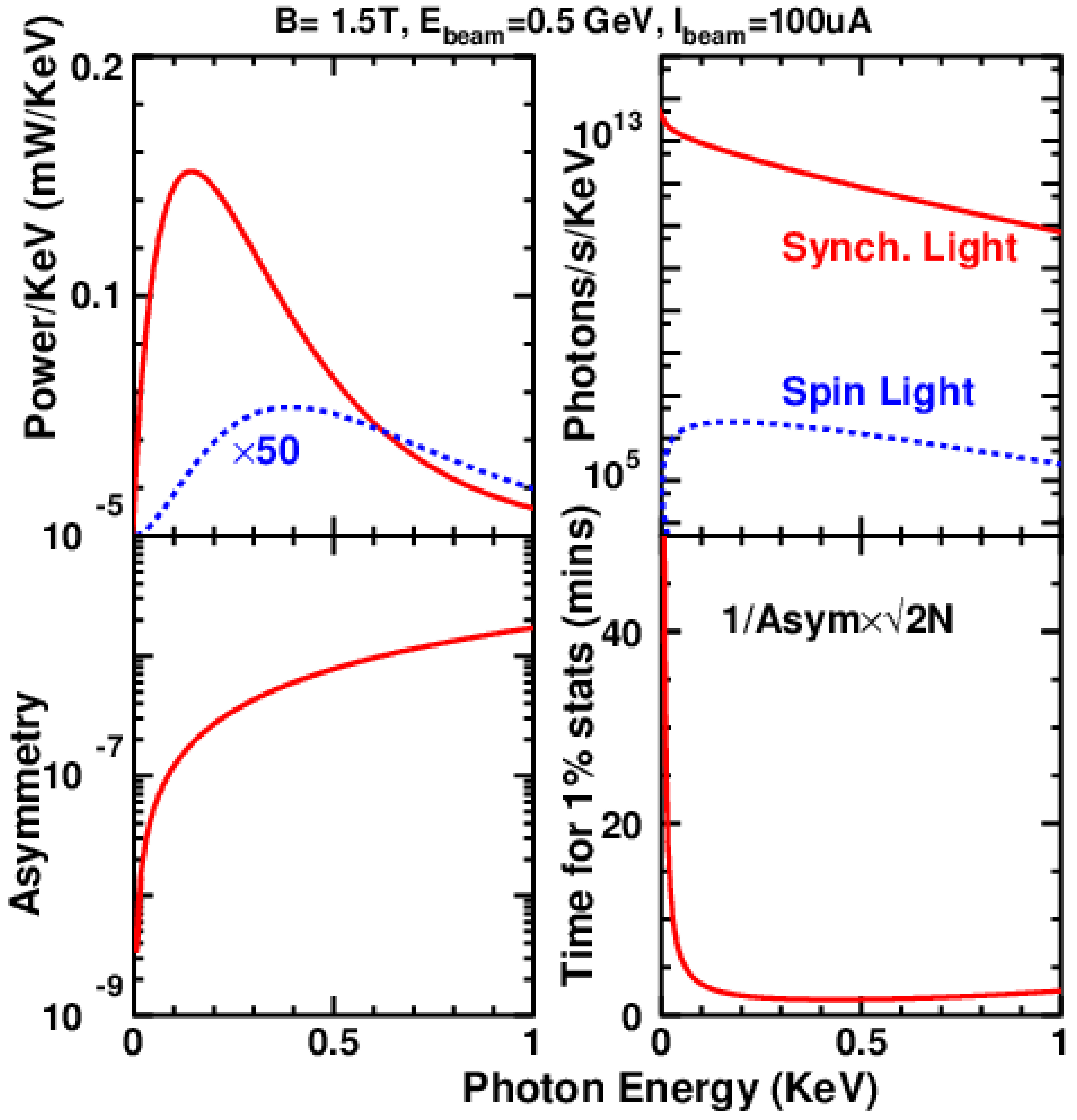
B = 1.5 T

Peak spin light power @ 0.35 KeV

Asym (0.35KeV) ~ 0.6 ppm

For 100uA current

1% statistics in few minutes



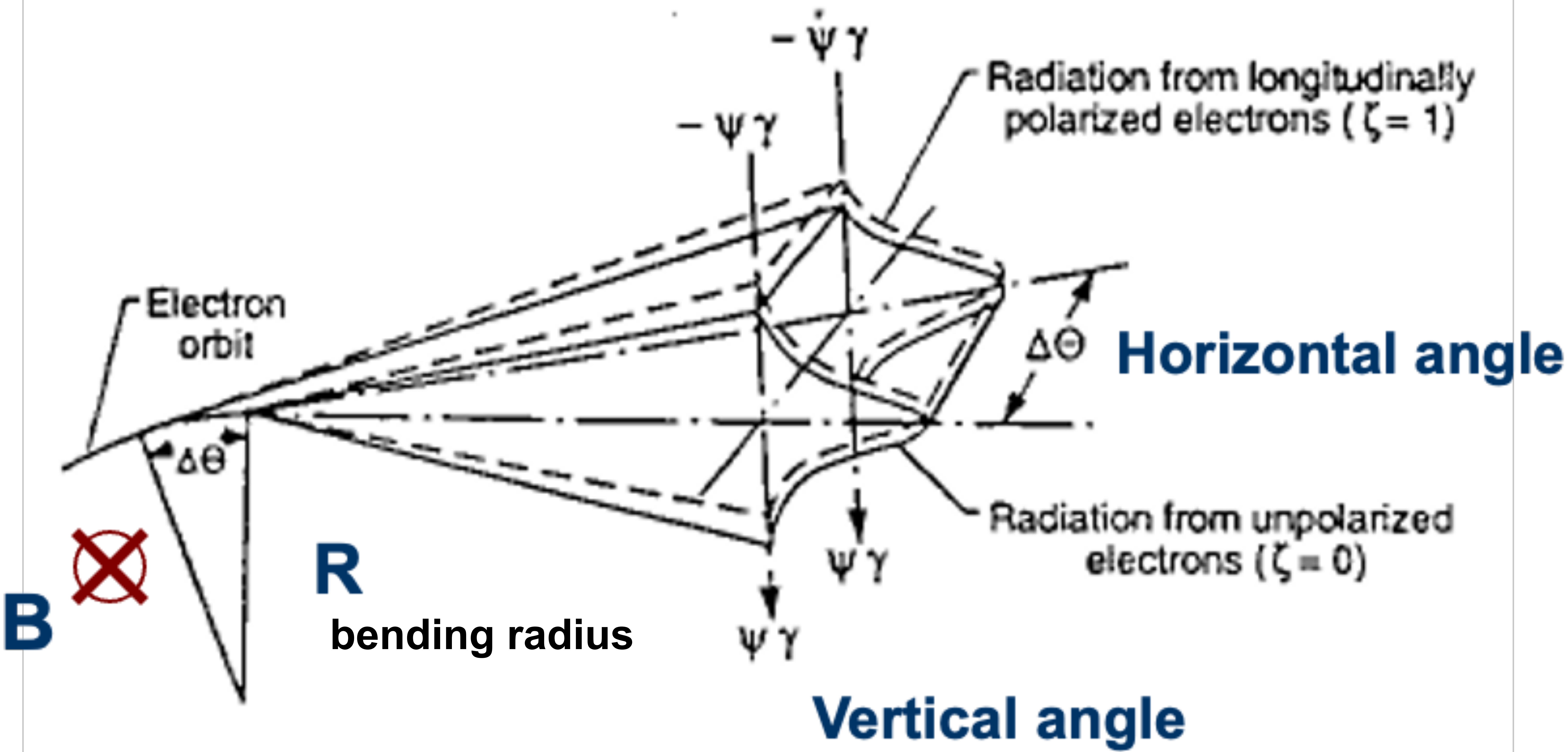
Asym ∝ E^2_{beam}

Asym ∝ B

Transverse polarimeters is easier for E_{beam} > 0.5 GeV

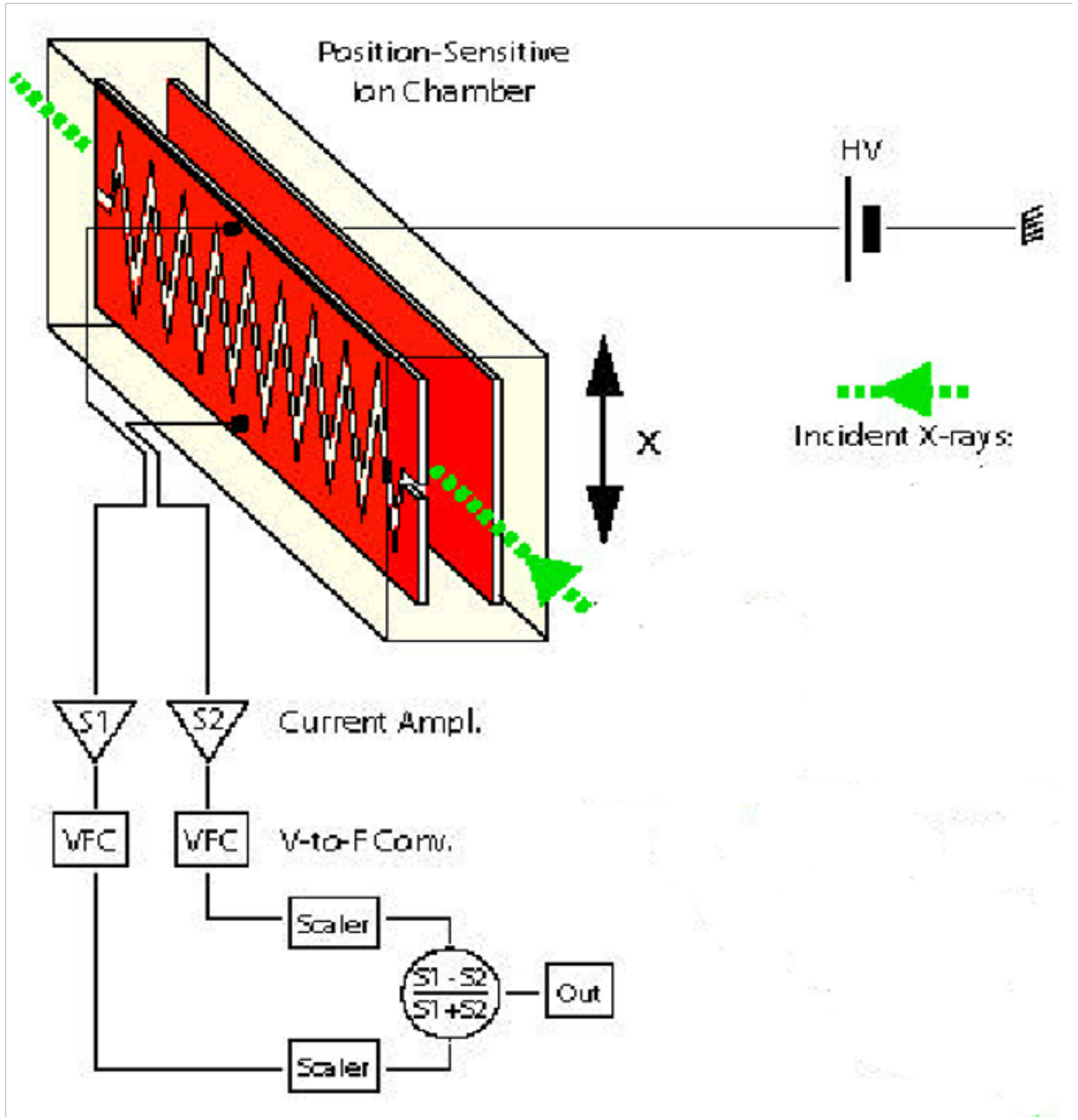
with higher field wiggler magnets it maybe feasible at ~ 0.2 GeV

Longitudinal Spin Light radiates different number of photons above and below the orbital plane



Position dependent asymmetry

Longitudinal polarimetry is more complex but still feasible for few GeV beams (relative only)



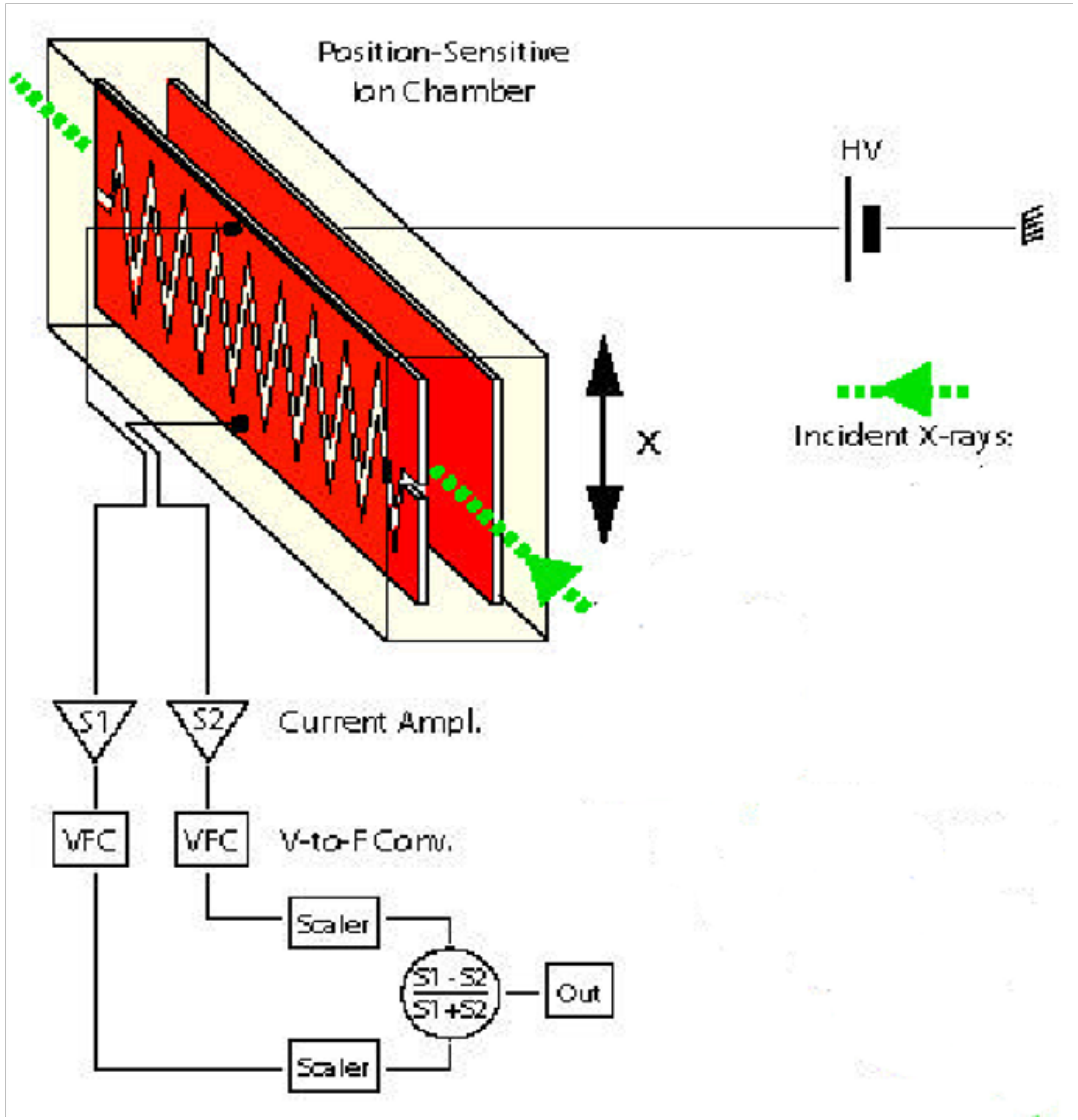
K. Sato, J. of Synchrotron Rad., 8, 378 (2001)

Source is same 3 pole wiggler

But detector must pick out a small position sensitive asymmetry

A transparent differential ionization chamber or converter+ diamond strip detector

Longitudinal polarimetry is more complex but still feasible for few GeV beams (relative only)



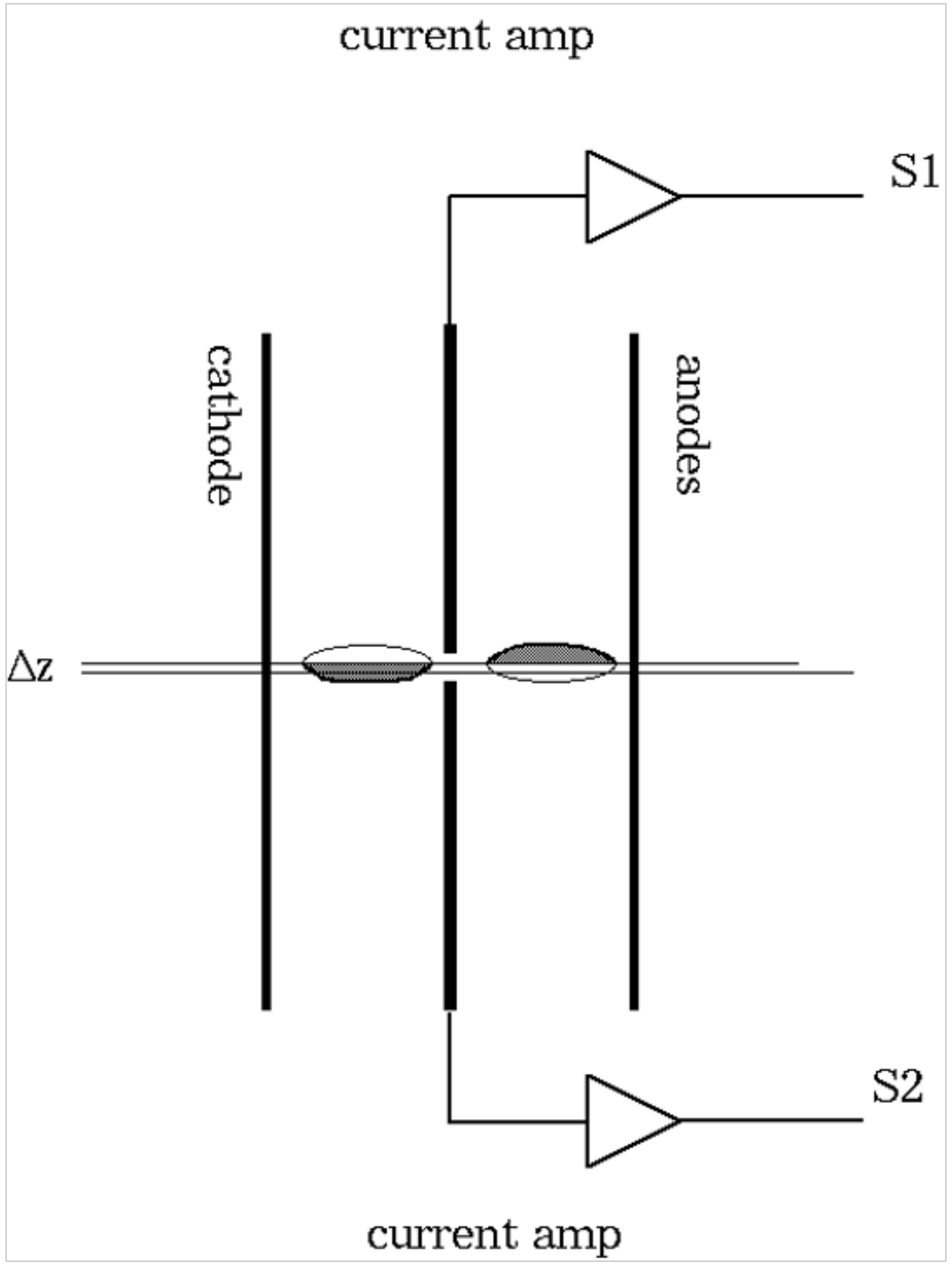
K. Sato, J. of Synchrotron Rad., 8, 378 (2001)

A transparent differential ionization chamber

Split plane chamber design helps detect small position sensitive X-ray signal (5μm resolution)

Visible portion of SR can be used to align chamber

Longitudinal polarimetry is more complex but still feasible for few GeV beams (relative only)



P. Mohanmurthy and D.D., IEEE Trans in Nucl. Sci.,61, 528 (2014)

$$S1 = (N^l_{SR} + \Delta N^l_{spin} + \Delta N^l_z) - (N^r_{SR} - \Delta N^r_{spin} + \Delta N^r_z)$$

Vertical beam motion cancels out

$$S2 = (N^l_{SR} - \Delta N^l_{spin} - \Delta N^l_z) - (N^r_{SR} + \Delta N^r_{spin} - \Delta N^r_z)$$

$$(S1 - S2) = 4\Delta N_{spin}$$

$$(S1 + S2) = 0$$

The sum of the two helicities can be used to measure efficiency and B-field related dilutions.

Longitudinal polarimetry is challenging for 0.5 GeV beams, but maybe feasible for few GeV beams

For E_{beam} = 0.5 GeV

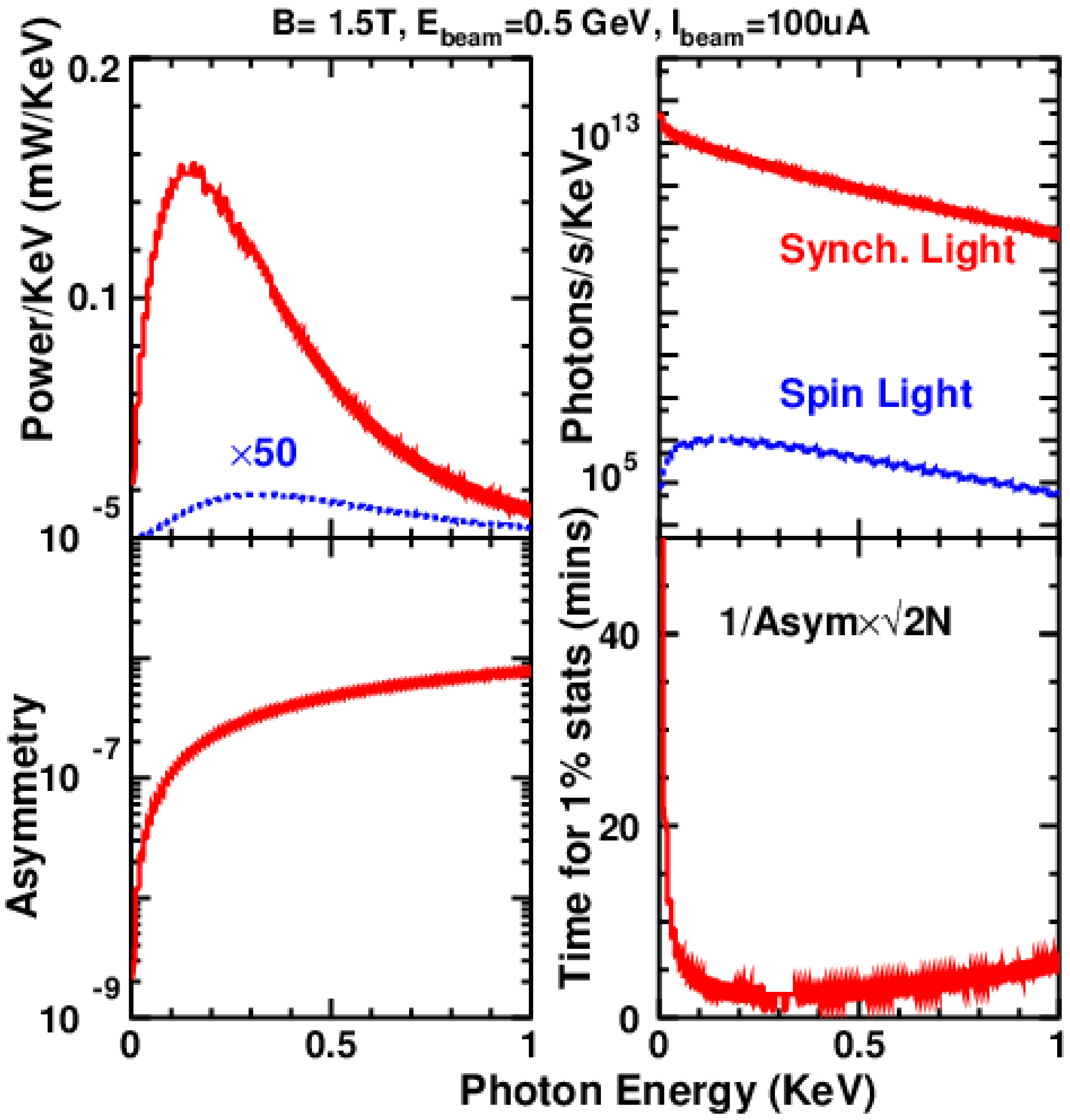
B = 1.5 T

Peak spin light power @ 0.35 KeV

Asym (0.35KeV) ~ 0.3 ppm

For 100uA current

1% statistics in few minutes



Asym ∝ E^2_{beam}

Asym ∝ B

Longitudinal polarimeters marginally easier for E_{beam} > 0.5 GeV

or with higher field wiggler magnets

P. Mohanmurthy and D.D., IEEE Trans in Nucl. Sci.,61, 528 (2014)

Summary

Spin light based polarimeter is a viable option for precision non-invasive polarimetry

It is based on a well demonstrated concept (for transversely polarized electrons), the necessary technology is readily available and widely used in light sources across the world.

It is most viable for beam energies $\geqq$ 0.5 GeV as a absolute transverse polarimeter

Longitudinal polarimetry is more complicated but relative measurements are feasible

Spin light based polarimetry may be marginally viable for 0.2 - 0.5 GeV beams.