Polarization issues and schemes for energy calibration

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General remarks

- Resonant depolarization is limited for the use of up to 80-100 GeV per beam
- Non-polarization methods of the energy monitoring will be presented at WG8 session by Nikolai Muchnoi and Sergey Nikitin. Polarization shall validate these approaches for the use at higher energies.
- CERN's team experience and vision will also be presented there by Mike Koratzinos

Outline

- Physics request to polarization in FCC-ee collider
- Our approach to energy calibration
- Maintaining polarization in a booster synchrotron
- Solenoid type snakes
- Depolarization rates
- Compton scattering based polarimetry
- Conclusion

physics requirements for *FCC-ee*

- highest possible luminosity for a wide physics program ranging from the Z pole to the $t\bar{t}$ production threshold
  - *beam energy range from 45 GeV to 175 GeV*
- main physics programs / energies:
  - *Z (45.5 GeV): Z pole, 'TeraZ' and high precision M_Z & Γ_Z,*
  - *W (80 GeV): W pair production threshold,*
  - *H (120 GeV): ZH production (maximum rate of H's),*
  - *t (175 GeV): $t\bar{t}$ threshold*
- some polarization up to ≥80 GeV for beam energy calibration
- optimized for operation at 120 GeV?!

F. Zimmermann

polarization build up

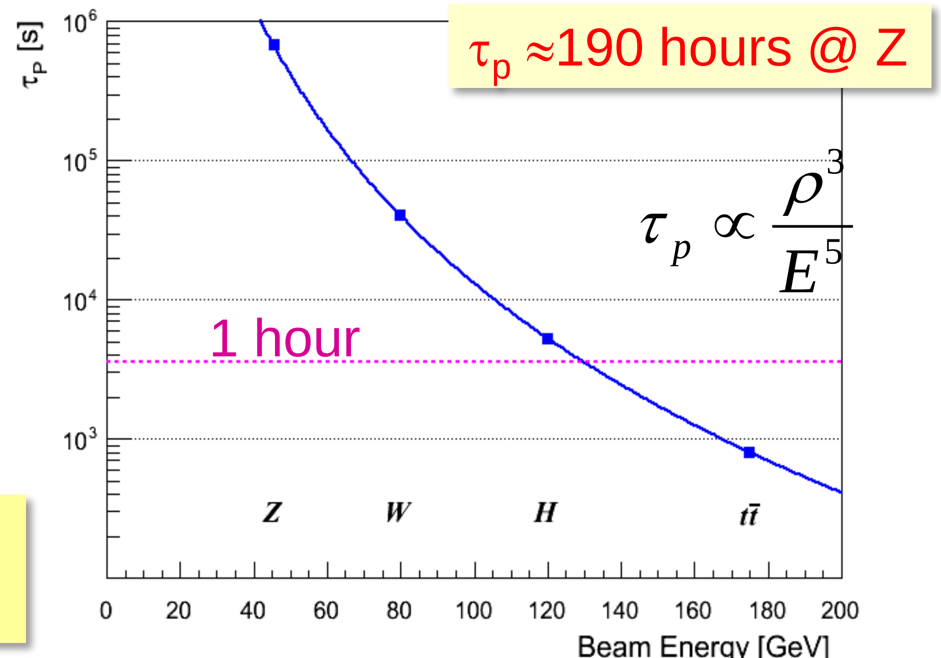
transverse polarization build-up (Sokolov-Ternov) is slow at *FCC-ee* (large bending radius ρ)

build-up is ~40 times slower than at LEP

wigglers may lower τ_p to ~12 h, limited by $\sigma_E \leq$ 60 MeV and power

due to power loss the wigglers can only be used to pre-polarize some bunches (before main injection)

→ $\approx$ OK for energy calibration (few % P sufficient)



longitudinal polarization: levels of ≥ 40% required on both beams; excellent resonant compensation needed

expected to be difficult, requires spin rotators or snakes, most likely only possible at lower intensity and luminosity

SLIM, PETROS, SITF simulations being prepared

E. Gianfelice

A. Blondel, U. Wienands, J. Jowett, R. Rossmanith, J.Wenninger

The proposed scenario

- No self-polarization in a collider - too slow with r=11 km : τ=190 hours at Z

- Request for the longitudinal polarization at Z demands: use of a source of polarized e- and acceleration of a beam by linac (to 10-20 GeV) and then by a synchrotron (to 45-175 GeV)

- Preservation of a polarization in a booster ring by the use of odd number of Siberian Snakes , then spin tune is ν=0.5.

The proposed scenario, cont.

- Injection of a polarized beam in the collider with spins lying in the horizontal plane

- Measuring of free precession frequency using Compton backscattering of a laser light and subsequent Fourier analysis like in the muon g-2

- Advantage: determination of the energy every short!
- e+ self-polarization in 1-2 GeV intermediate damping ring (for energy calibration use only!)

Polarized beam acceleration with Siberian Snakes

Derbenev, Kondratenko, 1973

$$\tau_p^{-1} = \frac{5\sqrt{3}}{8}\lambda_e r_e c\gamma^5 \left\langle \frac{1 - \frac{2}{9}(\vec{n}\vec{v})^2 + \frac{11}{18}\vec{d}^2}{|r|^3} \right\rangle$$

$\vec{d} = \gamma \frac{\partial \vec{n}}{\partial \gamma}$ is the spin – orbit coupling vector

With N spin transparent snakes: $\left\langle \vec{d}^2 \right\rangle = \frac{\pi^2}{3}\frac{\nu_0^2}{N^2}$

Betatron oscillations could increase |d|!
Spin transparency for the snake is desirable.

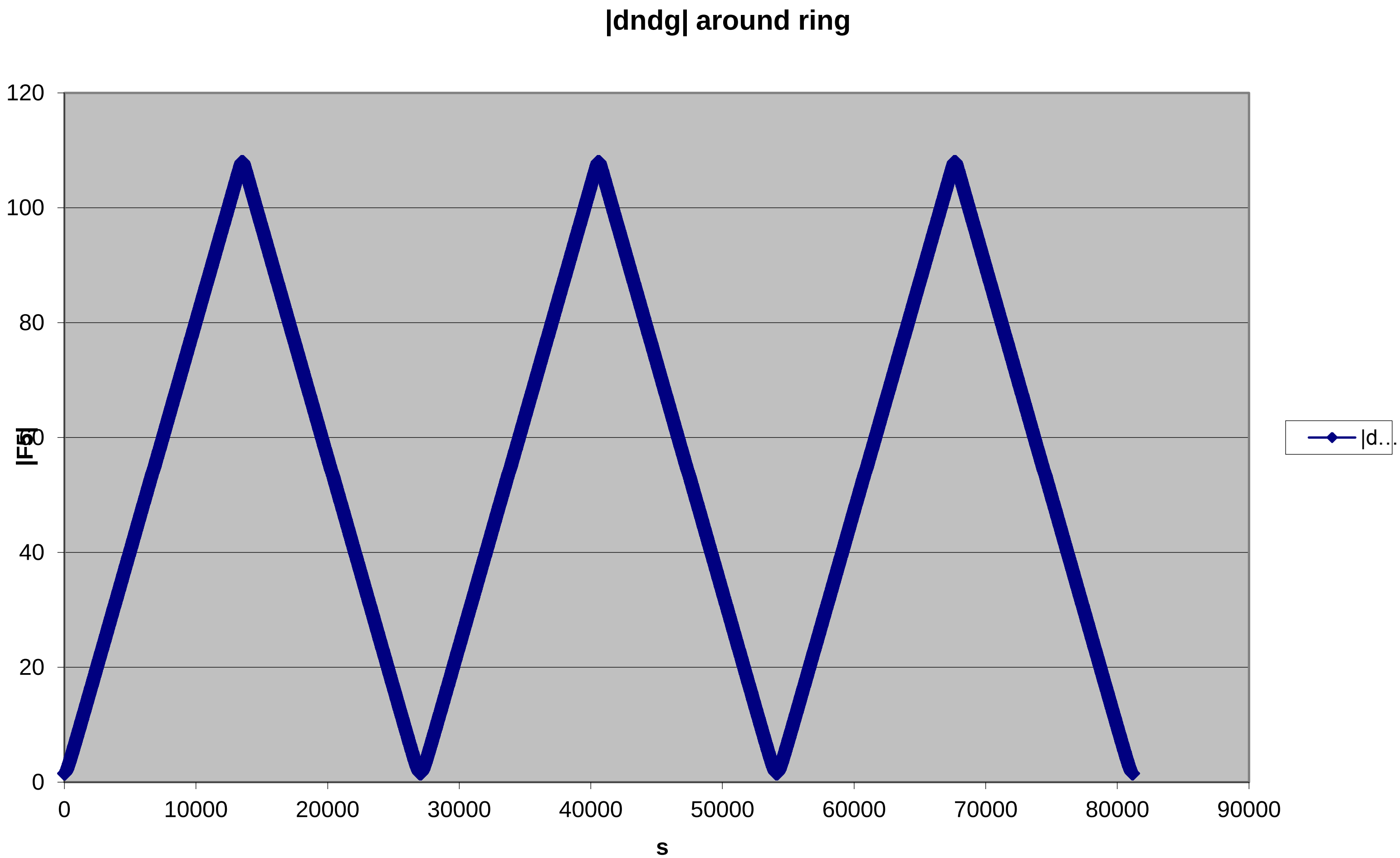
For $E = 45.5$ GeV ($\nu_0 = \gamma a = 103.28$), $r = 11$km, $\tau_p = 320$ s

Equilibrium selfpolarization degree $\zeta \sim \vec{b}\vec{n} = 0$!!! (Here $\vec{b} = \vec{B}/B$)

Spin response function |F5|=|d|

Calculated by the code ASPIRRIN written by V.Ptitsyn, upgraded by S.R.Mane

Booster storage ring with 3 full snakes, E=45.5 GeV

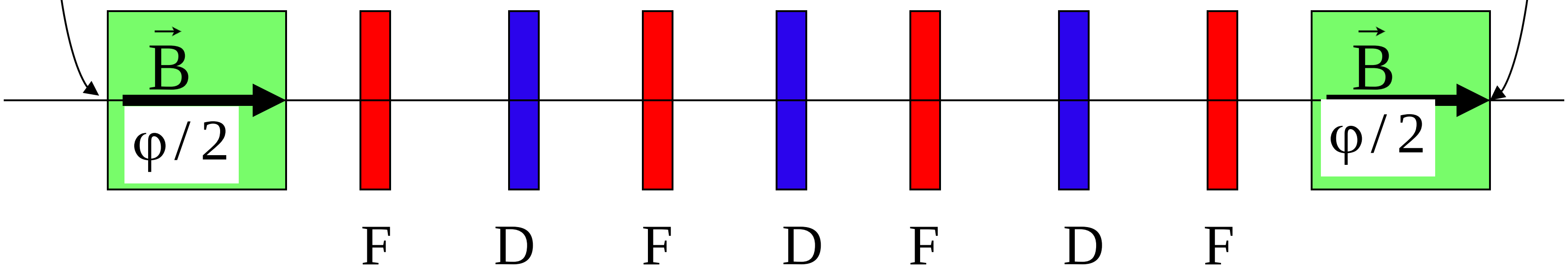


Spin transparent rotator for the solenoid type Snake

For decoupling should be $T_x = -T_y$ ← Litvinenko, Zholentz, 1980

$$T_x = \begin{pmatrix} -\cos\varphi & -2r\sin\varphi \\ (2r)^{-1}\sin\varphi & -\cos\varphi \end{pmatrix}$$ for the spin transparency!

$$r = pc/eB$$



Two solenoids, each L=40 m B=5 T, provide spin rotation by $\varphi = 180^0$ at E=45.5 GeV. Extension to 120 GeV with B=10 T looks feasible.

All quads don't need to be skewed! Spin transparency require:

Full Snake: $\cos\varphi = -1, \quad \sin\varphi = 0;$ 90^0 - spin rotator: $\cos\varphi = 0, \quad \sin\varphi = 1$

Compton scattering of a laser light

F.Lipps and H.A.Tolhoek, Physica 20,85,395,(1954)

The scattered photon energy in electron mass units m_e is:

$$\omega(x) = \frac{\gamma a(1-x)}{1+a(1-x)} \qquad \text{with} \quad a = 2\gamma\omega_0, \qquad x = \cos\theta$$

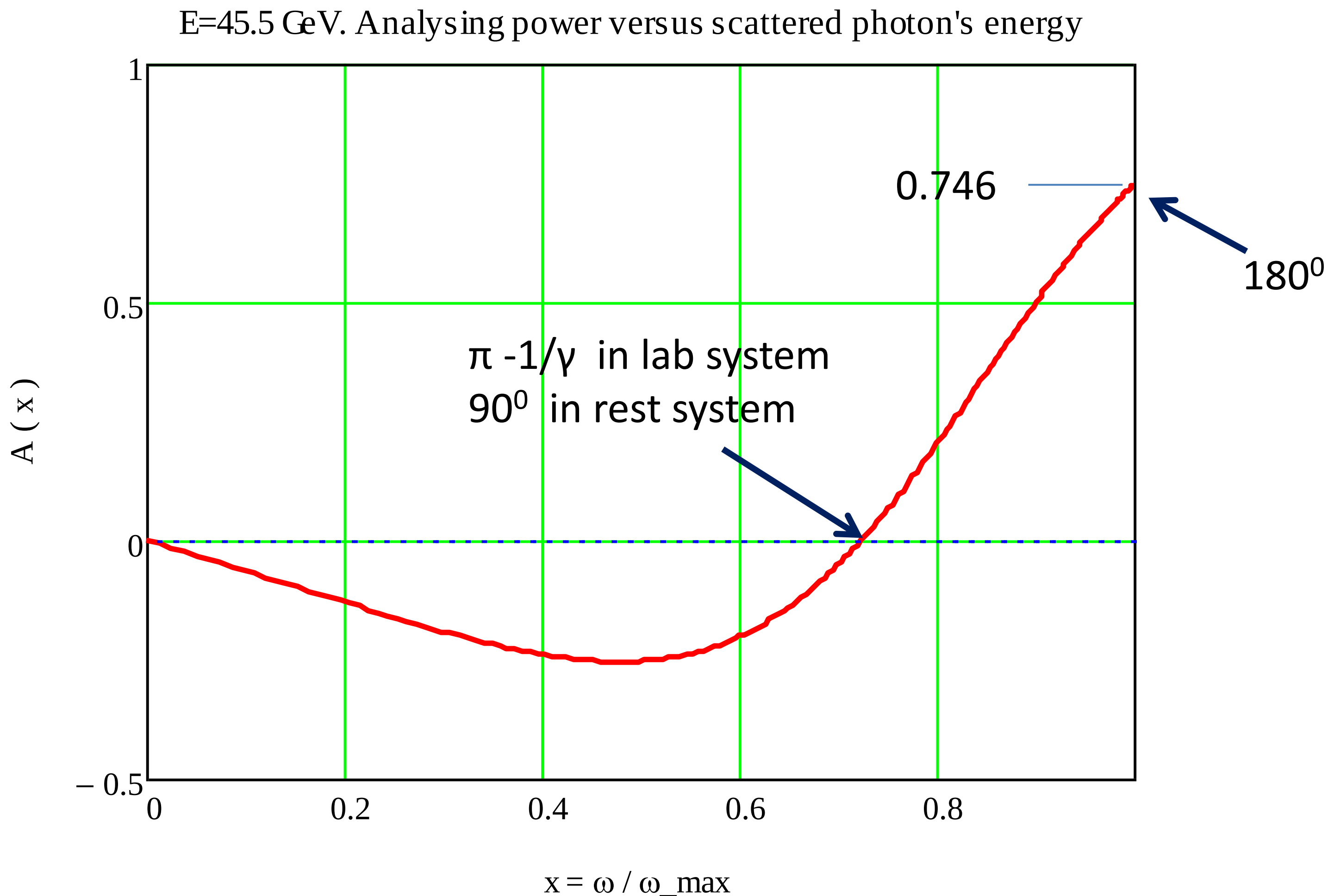
Differential unpolarized/polarized light scattering cross-sections:

$$\sigma_0(a,x)/\pi r_e^2 = \frac{1}{1+a(1-x)} + \frac{1}{\left[1+a(1-x)\right]^2} - \frac{1-x^2}{\left[1+a(1-x)\right]^3}$$

$$\sigma_1(a,x)/\pi r_e^2 = -a\left[1+\frac{1}{1+a(1-x)}\right]\frac{x(1-x)}{\left[1+a(1-x)\right]^2}$$

At $E = 45.5\ GeV \quad a = 0.812, \quad \omega_{\max} = 28\ GeV$ if $\omega_0 = 2.33\ eV$.

Compton scattering of a laser light, cont.



We shall select events with the highest energy loss by the scattered electrons – get larger asymmetry! Magnetic momentum analysis, like used for two photon physics.

Compton scattering of a laser light, cont.2

Integrated over $x = \cos(\theta)$ unpolarized/polarized cross-sections:

$$\Sigma_0(a)/\pi r_e^2 = \frac{1}{a}\ln(1+2a) - \frac{2(1+a)}{a^3}\ln(1+2a) + \frac{4}{a^2} + \frac{2(1+a)}{(1+2a)^2}$$

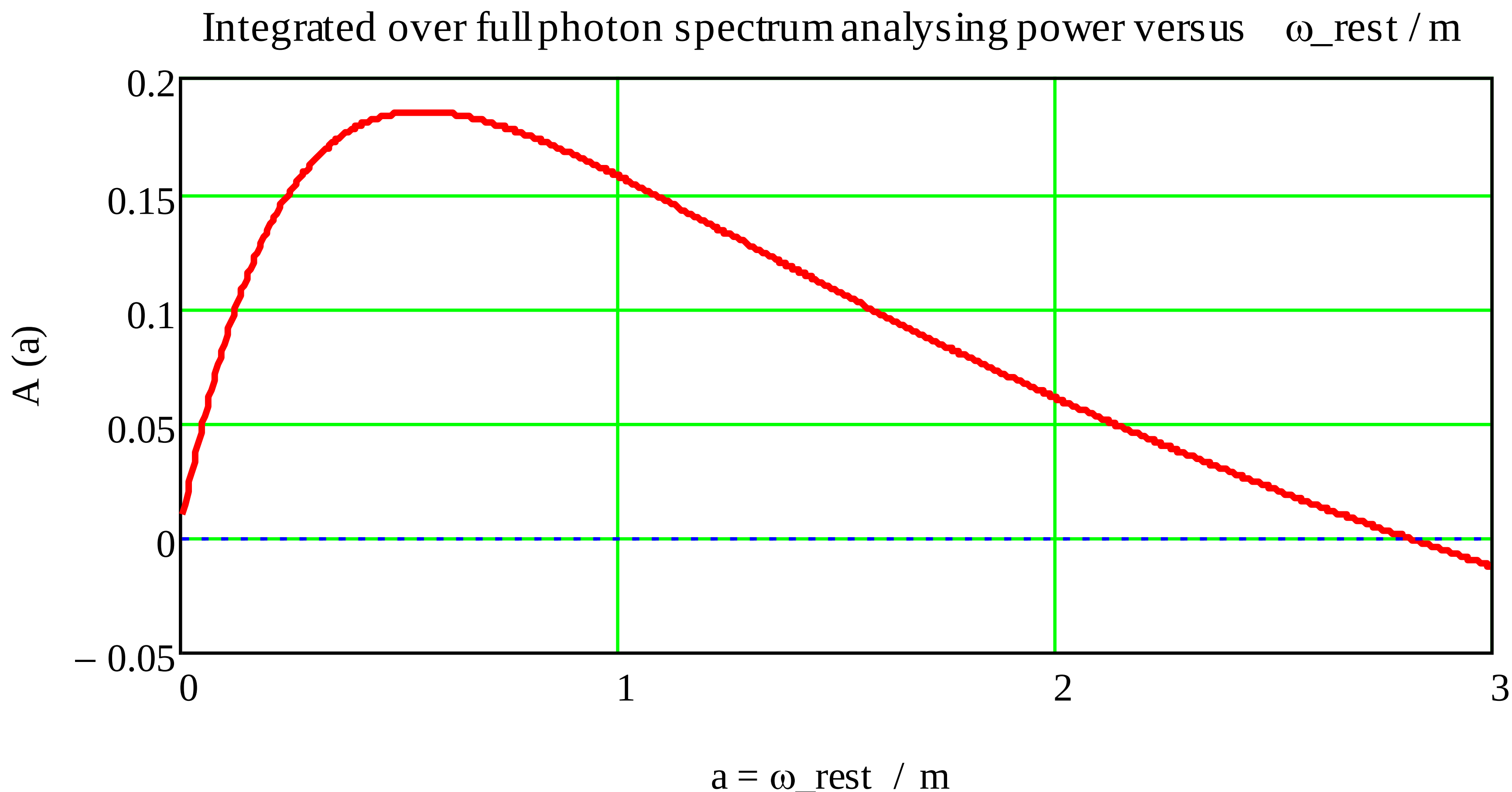
$$\Sigma_1(a)/\pi r_e^2 = \frac{2\left(1+4a+5a^2\right)}{a(1+2a)^2} - \frac{(1+a)\ln(1+2a)}{a^2}$$

Integrated over full spectrum asymmetry:

$$A(a) = \Sigma_1(a)/\Sigma_0(a)$$

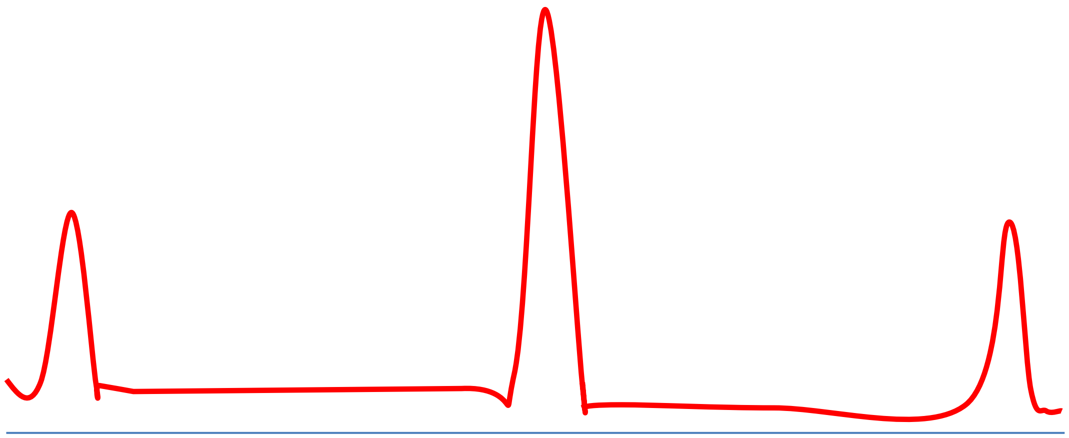
Is much smaller than the highest differential!

Compton scattering of a laser light, cont.3



Here a – incident photon energy in a rest system of an electron. A(0.555) = 0.185, while the differential analysing power for scattering at 180^0 asymptotically approaches the unity for extreme values of gamma-factors.

Free spin precession data analysis



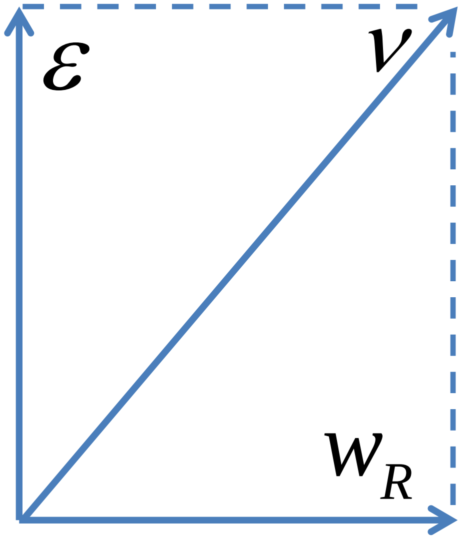
$\{\nu\}-\nu_s$ $\{\nu\}$ $\{\nu\}+\nu_s$

Could be observed also other picks, say from coherent betatron oscillations. But the central pick always will dominate.

Free spin precession data analysis, cont.

Resonance frequency: $\nu_R = k \pm \nu_s \pm m\nu_x \pm n\nu_y$

Detuning: $\varepsilon = \nu_0 - \nu_R$ with $\nu_0 = \gamma a$



Resonance perturbation w_R

Corrected energy formula:

$$\nu_0 = \nu_R \pm \sqrt{\nu^2 - w_R^{\,2}}$$

Energy can not be determined without measuring w_R !!!

Spin precession frequency must be measured in few energy points near a point of interest!
Spin Harmonic Matching should be applied to minimize the nearby resonances strength!

Free spin precession data analysis, cont.2

- Spin decoherence may limit energy determination accuracy achievable in one injection short. Some very rough estimation for Z-peak :

$$\sigma_{\langle\delta\rangle} \simeq \sigma_{\delta}{}^{2} \simeq 1.6 \cdot 10^{-7}$$ - energy spread $\left(\sigma_{\delta} \equiv \sigma_{\Delta E/E} \simeq \pm 4 \cdot 10^{-4}\right)$

$$\sigma_{\langle\nu\rangle} = \sigma_{\langle\delta\rangle} \cdot \nu_{0} \simeq 1.6 \cdot 10^{-5}$$ - spread of average spin tunes

$$N_{Cohr} = \frac{1}{2\pi\sigma_{\langle\nu\rangle}} \approx 1 \cdot 10^{4}$$ - spin coherence time (in turns)

Is sufficient to determine E_b with 44 keV or 10^{-6} accuracy!

Energy limits for polarization

- First limit comes from the high order synchrotron satellites. Can be cured by the use of Siberian Snakes in the booster ring! Still the collider shall operate without any snake!
- The second limit is more fundamental: due to high rate of the spin tune diffusion, caused by fluctuations of SR. For FCC-ee it is 80-100 GeV ?

  (see talk by Yu.Shatunov at the SPIN14 conference)
- Above that limit only Compton based methods could work, be proofed at lower energies.

Conclusion

- Polarization is useful for direct energy calibration of up to W threshold. Free precession method, based on use of the Compton polarimeter, shall provide the energy determination with 10^{-6} accuracy in one short!

- Polarization will help calibrate@validate Compton based methods of the energy control/monitoring.

- Acceleration of a polarized e-beam in a synchrotron, equipped with Siberian Snakes, opens possibility to perform experiments with longitudinal polarization at IP (Z-peak).