Maintaining polarization in synchrotrons

I.Koop
Novosibirsk State University,
Novosibirsk State Technical University,
Budker Institute of Nuclear Physics,
630090, Novosibirsk, Russia

55th ICFA Advanced Beam Dynamics Workshop on
High Luminosity Circular e+e- Colliders – Higgs Factory
(HF2014), 9 – 12 October 2014, Beijing

Contributors to this talk also are:

S.R.Mane, A.V.Otboev and Yu.M.Shatunov

Outline

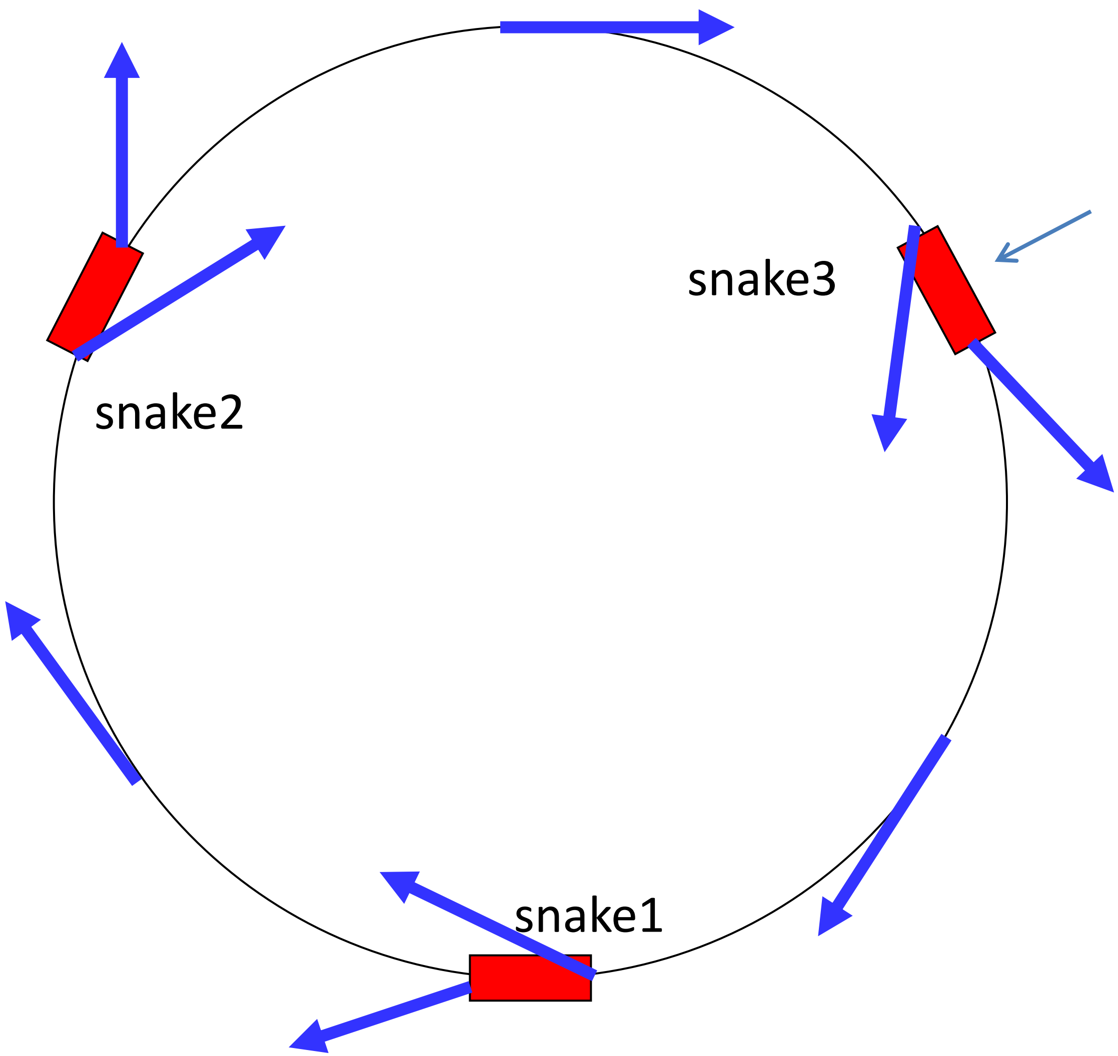
- Odd number of Siberian Snakes - a universal tool to suppress all spin resonances
- Solenoid type snake features
- Minimization of the spin tune chromaticity
- Depolarization rates evaluation
- Conclusion

The proposed acceleration scenario

- Preservation of a polarization in a booster ring by use of odd number of Siberian Snakes , then the spin tune is always $\nu=0.5$, independently from the energy!

- Suppression of the synchrotron satellites of the integer resonances by minimization of the spin tune chromaticity for off-momentum particles.

Closed spin orbit in a ring with 3 snakes



Spin rotation by 180^0 around the longitudinal axis

Depolarization time in presence of 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.

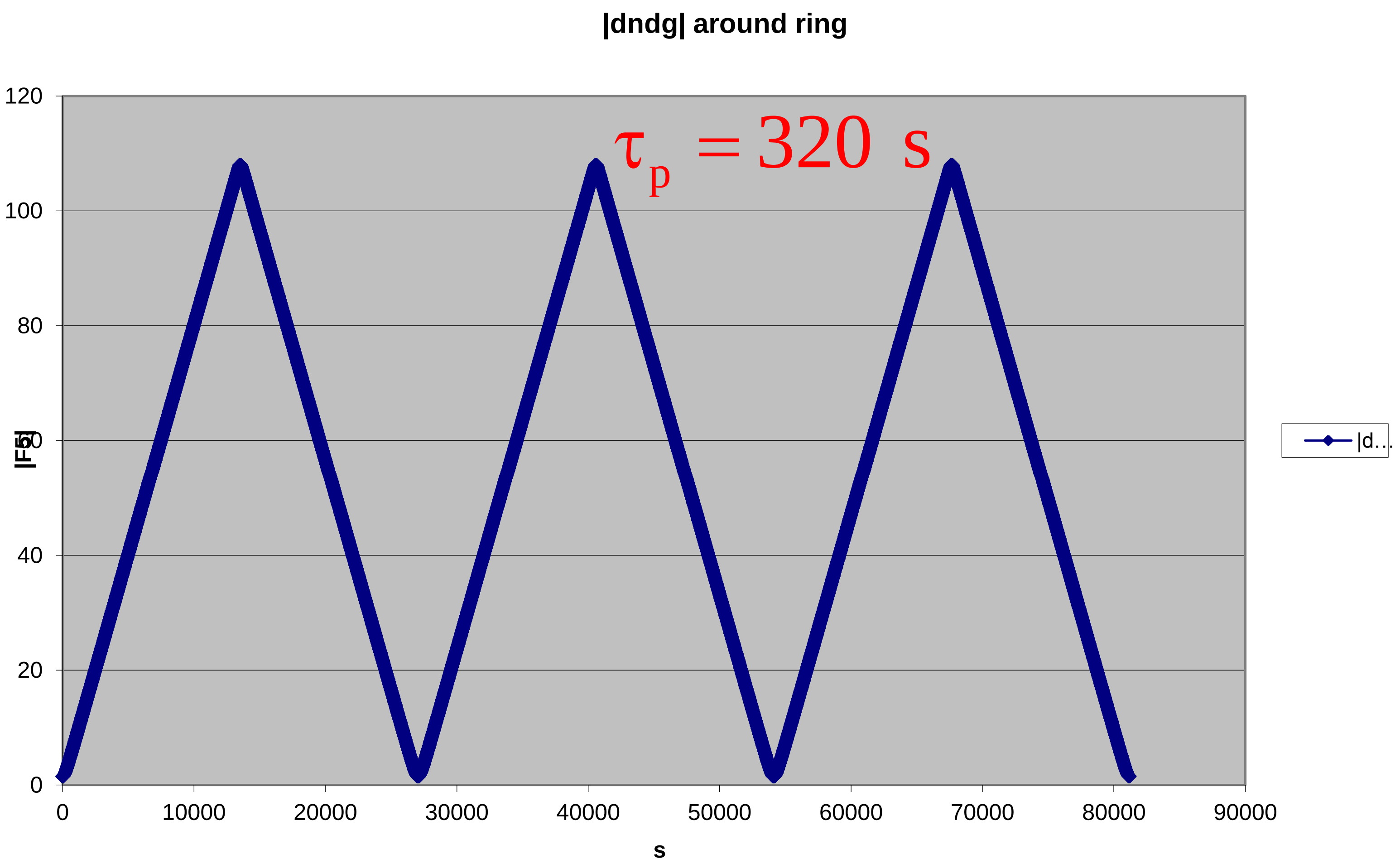
For $E = 45.5$ GeV $(\nu_0 = \gamma a = 103.28)$, $r = 11\,\text{km}$, $\tau_p = 320$ s

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 and upgraded by S.R.Mane

Booster ring toy-model with 3 full snakes, E=45.5 GeV



Acceleration to 80 GeV

Energy scaling of the depolarization time:

With $\rho = \text{const}$, $\tau_p \sim \gamma^{-7}$ and $\tau_p \sim N^2$

With 3 snakes: $\tau_{45.5\ \text{GeV}} = 320\ \text{s}$

$\tau_{80\ \text{GeV}} = \tau_{45.5\ \text{GeV}} \cdot 0.019 = 6.2\ \text{s}$ - 10 s ramping time is OK?

With 9 snakes: $\tau_{80\ \text{GeV}} = 55.5\ \text{s}$ - 60 s ramp time fits well!

With 15 snakes: $\tau_{80\ \text{GeV}} = 154\ \text{s}$ - too large margin?

Remind: 10% polarization level is sufficient!

In the collider at 80 GeV $\tau_p \sim 4\ \text{h}$, so,

selfpolarization can be explored as well?

Dynamic depolarization during acc.

Dynamic depolarization during acceleration developes due to presence of spin resonances produced by the orbit distortions and the betatron oscillations (intrinsic).

According to S.Mane's spin tracking simulation the polarization loss does not exceed $2 \cdot 10^{-4}$ for acceleration from 10 to 86 GeV in 55 s.

He introduced random errors in quads positions which led to 1mm of a maximum orbit deviation in the vertical and horizontal directions. The horizontal and the vertical emittances were taken 3 pm and 30 fm, respectively. The modeled ring contains 3 snakes.

So, this effect is negligible, because all these resonances are very far from the half-integer spin tune value.

Radiative depolarization during acc.

$$\tau_p \sim E^{-7} \qquad P_{rad}(T) = \exp\left(-\int_0^T \frac{dt}{\tau(t)}\right) = \exp\left(-\frac{T}{8\tau_T}\frac{1-\left(\frac{E_0}{E_T}\right)^8}{1-\frac{E_0}{E_T}}\right)$$

For 3 snakes ring and for $E_T = 80\ \text{GeV}$ $\tau_T = 6\ \text{s}$:

$T = 10\ \text{s}$ $P_{rad}(T) = 0.79$

$T = 20\ \text{s}$ $P_{rad}(T) = 0.62$

$T = 30\ \text{s}$ $P_{rad}(T) = 0.49$ - looks OK!

$T = 60\ \text{s}$ $P_{rad}(T) = 0.24$ - too high loss!

Spin transparent rotator for the solenoid partial Snake

For decoupling should be $T_x = -T_y$

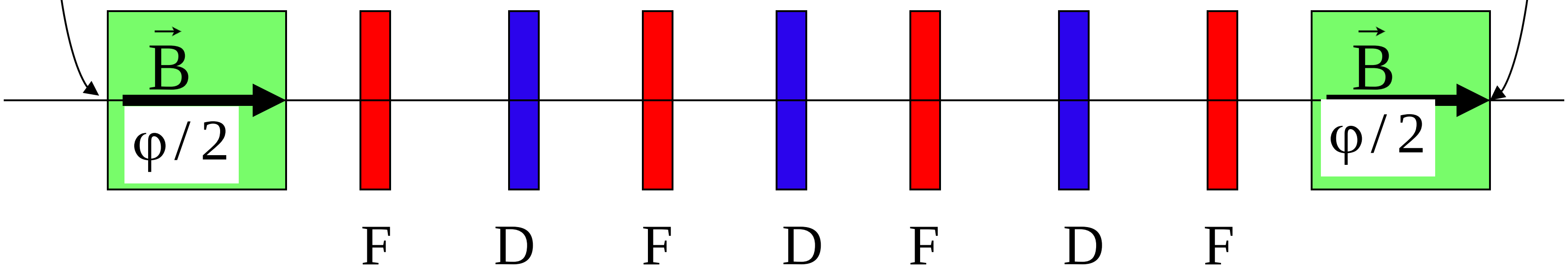
Litvinenko, Zholentz, 1980

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

for the spin transparency!

(Koop et al., SPIN2006)

$$r = pc/eB$$

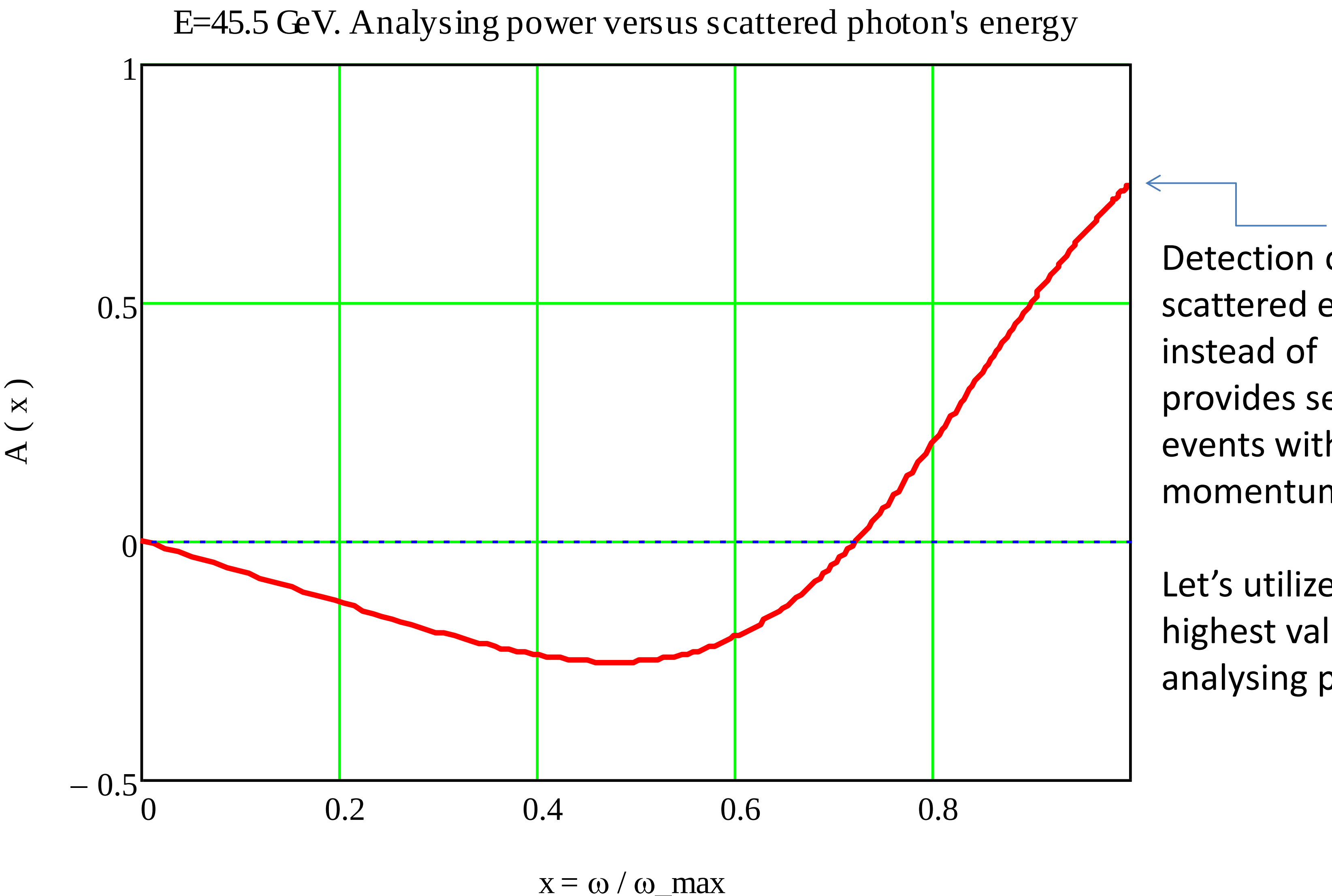


Two solenoids, each L=40 m B=5 T, provide spin rotation by $\varphi = 180^0$ at E=45.5 GeV. Extension to 120 GeV with B=10 T looks feasible.

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

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

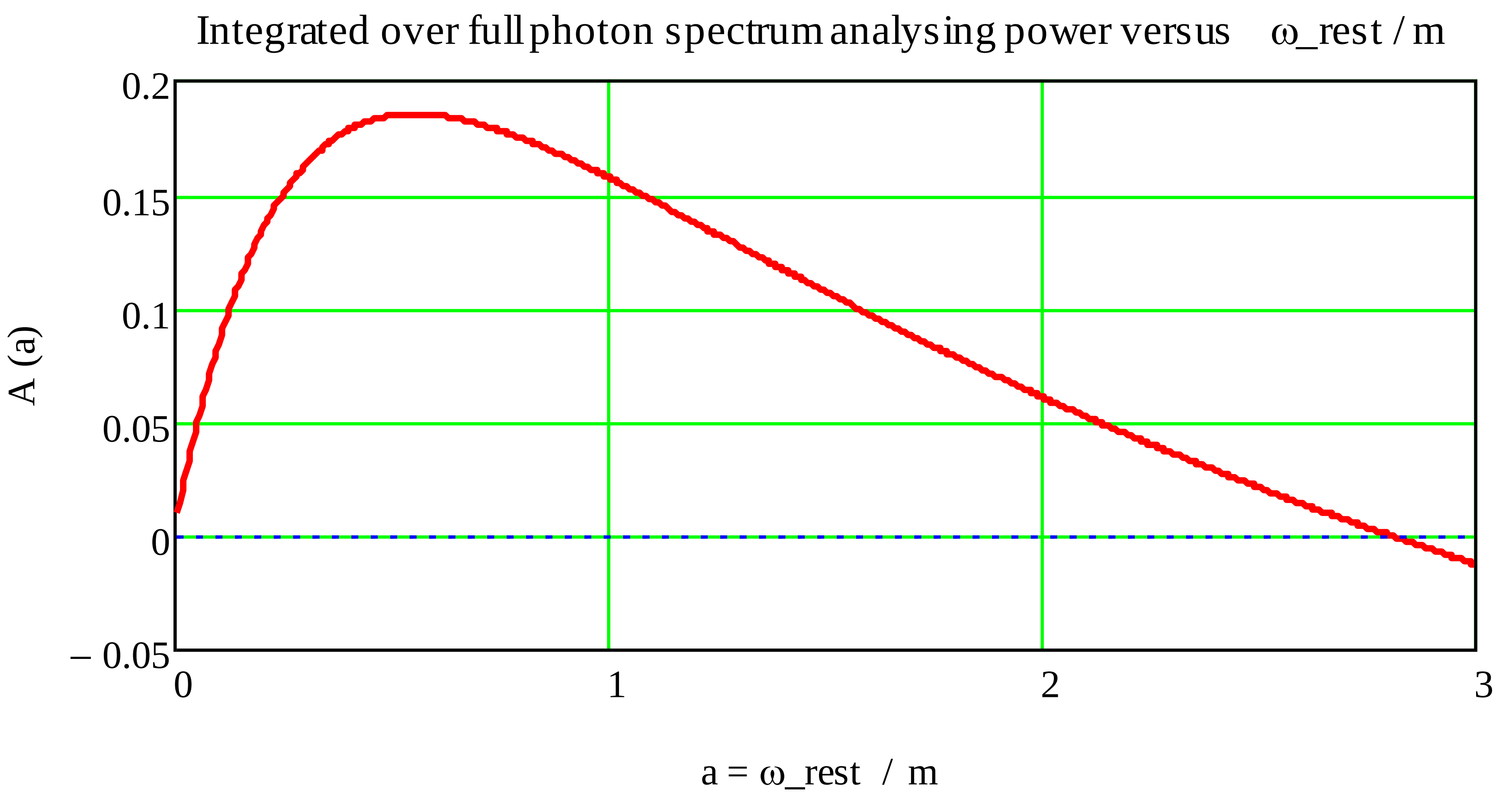
Compton scattering of a laser light



Detection of the scattered electrons instead of photons provides selection of events with maximal momentum loss!

Let's utilize the highest value of the analysing power!

Compton scattering of a laser light, cont.



Here a is incident photon energy in a rest system of an electron. A(0.555) = 0.185.
HERA team has used just this approach! see M.Beckmann et al, NIM A479 (2002) 334-348

Minimization of the spin tune chromaticity

Spin tune chromaticity in a flat ring without snakes:

$$\gamma \frac{\partial \nu}{\partial \gamma} = \nu_0 = 180 \quad \text{at 80 GeV}$$

Chromaticity of a ring with single snake: $\gamma \frac{\partial \nu}{\partial \gamma} \leq \frac{1}{2}$

Ring with N snakes: $\gamma \frac{\partial \nu}{\partial \gamma} \leq \frac{N}{2}$ $\quad (\text{worst case}: \ \nu_0 = kN)$

Ring with odd N snakes + altering field sign: $\gamma \frac{\partial \nu}{\partial \gamma} \leq \frac{1}{2}$

Alternating the sign of the solenoid field one gains additionally factor of N in spin tune chromaticity reduction compared to the case of same signs.

Conclusion

- Use of Siberian Snakes for the acceleration of a polarized beam in a synchrotron is an obvious tool to solve such a difficult task.
- 3 to 9 snakes (odd number) will ensure preservation of the polarization in a booster synchrotron of the FCC-ee complex up to 80 - 100 GeV.
- Spin tracking simulations should validate this statement and provide the solid basis for the choice of the number of snakes needed to solve a task.
- Remark: the radiative diffusion effects need to be incorporated into the tracking code!