WG8: Polarization Summary

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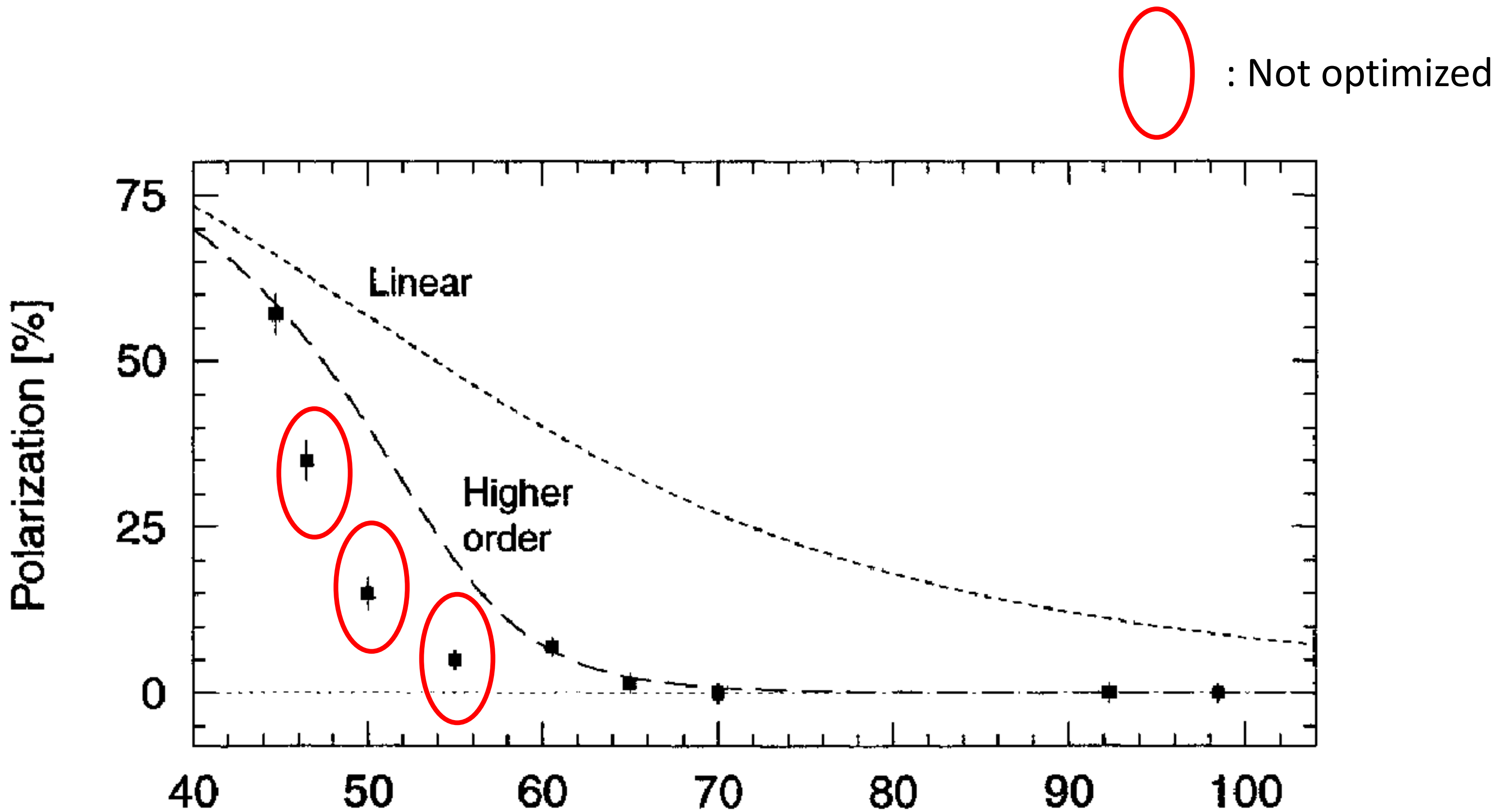
Parallel Session WG8: Polarization

1) Transverse polarization for energy calibration at Z-peak, Michael Koratzinos (U. Geneva)
2) Longitudinal polarization and acceleration of polarized beams, Ivan Koop (BINP, Novosibirsk)
3) FCC-ee beam energy measurement suggestion, Nikolai Muchnoi (BINP, Novosibirsk)
4) Possible applications of wave-beam interaction for energy measurement and obtaining of polarization at FCC e+e- , Sergei Nikitin (BINP, Novosibirsk)

Measurements from LEP



CEPC	**47.6**	**59.5**	**71.4**	**83.2**	**95.1**	**107.0**	**118.9**
TLEP	**55.5**	**69.4**	**83.2**	**97.1**	**111.0**	**124.9**	**138.7**

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Z running: the problem

- At the Z peak we need extremely accurate beam energy knowledge all the time
- There exists a method that gives excellent instantaneous accuracy: resonant depolarization. Error is 100KeV (a big chunk of it is arguably a ‘statistical’ type error, going down with the number of measurements)
- Environmental parameters change the energy by many times this amount in the space of minutes/hours:
  - Tides: time constant of 1h
  - Trains: time constant of few mins
  - Water level: time constant a few months
  - Temperature: few hours
- Other parameters that change the energy is the RF system (standard offsets plus corrections for changing running conditions. This can give also differences between the energy of electrons and positrons)

The problem

- Polarization times at FCC-ee and CEPC are very large:
  - TLEP-45GeV: 250 hours
  - CEPC-45GeV: 42 hours
  - (TLEP 80GeV: 9 hours)
- As we only need polarization levels of 5-10%, you can divide the above numbers by 10 to 20. But this is still too long.
- One solution is to use wigglers to decrease polarization time to something manageable.

Z energy calibration

- The solution (brute-force if you want) if one needs ultimate precision is to
  - Measure resonant depolarization every few minutes
  - Measure independently electrons and positrons
  - Measure continuously from the beginning of physics to the end of physics

Wigglers – the flip side

- Wigglers have two undesired effects:
- They increase the energy spread
- They contribute to the SR power budget of your machine
- Strategy is to use them is such a way that
  - The energy spread is less than some manageable number (so that no resonances are encountered). This number was determined by A. Blondel to be between 48MeV and 58MeV, say 52MeV “for the sake of discussion”, judging from the LEP experience
  - Switch them on only where necessary

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SR budget

Work in progress!

Machine	Energy	No. of wigglers	B+	Polarization time	Energy spread	Wiggler SR power
TLEP	45	0	0	253 hours	17MeV	0
TLEP	45	12	0.62T	21 hours	52MeV	20MW
TLEP	45	1	1.35T	24 hours	52MeV	9MW
CEPC	45	0	0	41 hours	23MeV	0
CEPC	45	12	0.72T	7 hours	52MeV	17MW
CEPC	45	1	1.58T	7 hours	52MeV	7

The SR budget for a single wiggler looks manageable, especially considering that they can be switched off after a short period of time

Wigglers introduce more damping and might help to achieve higher beam-beam parameters partly compensating the loss due to wiggler SR power– to be investigated

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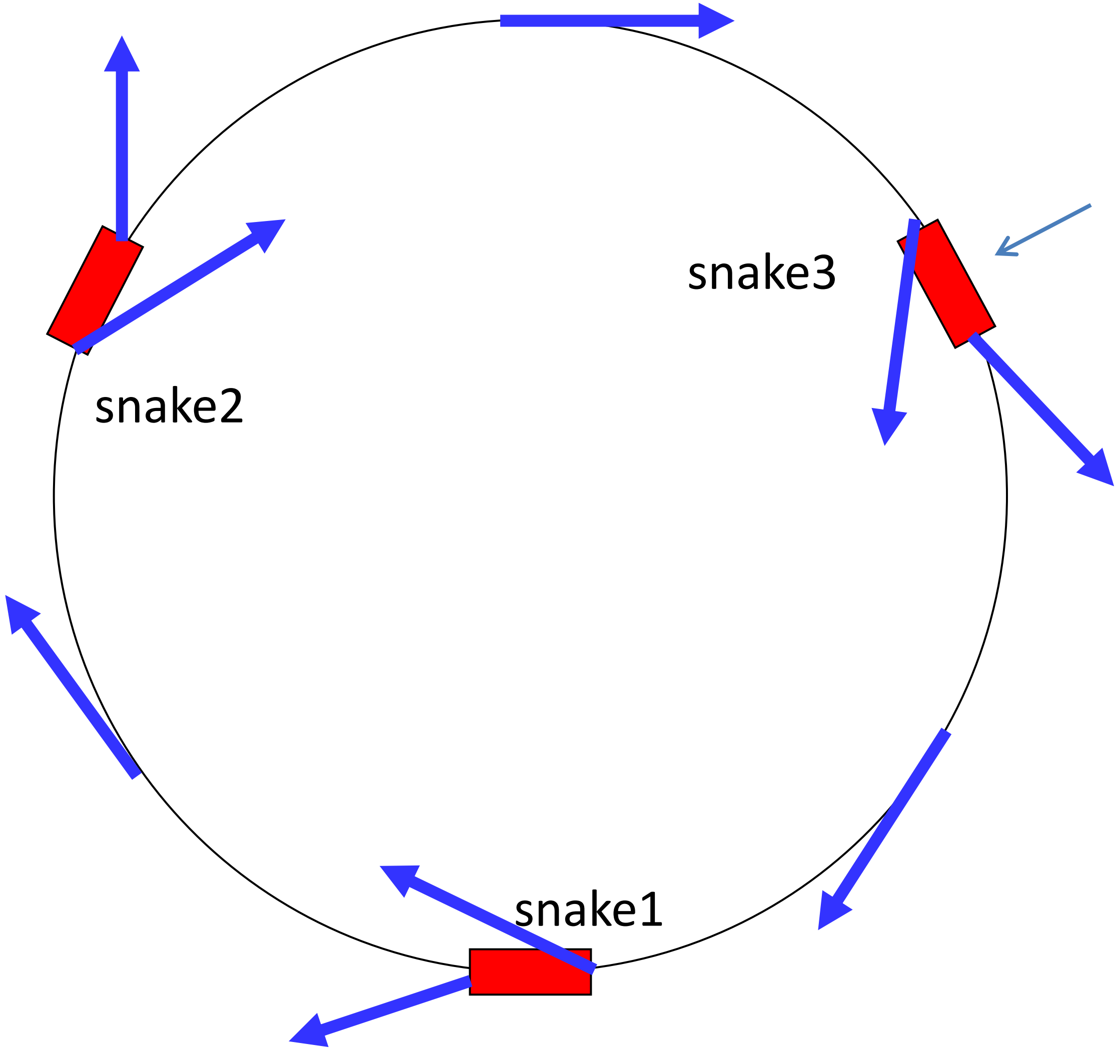
Duration of wiggler operation

- The wigglers need to be on just enough time to polarise enough non-colliding bunches:
  - TLEP: 250 non-colliding bunches
  - CEPC: 40 non-colliding bunches
- They can be switched on as soon as the machine starts filling up (which takes ~30 mins)
- They can be switched off when 5% polarization is achieved
  - TLEP: 40 minutes after filling is completed
  - CEPC: ready after filling has been completed
- Using and replacing 5 bunches for 5 depolarization measurements per hour, the machine will have naturally polarized to 5% by the time the last non-colliding bunches are exhausted.

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

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

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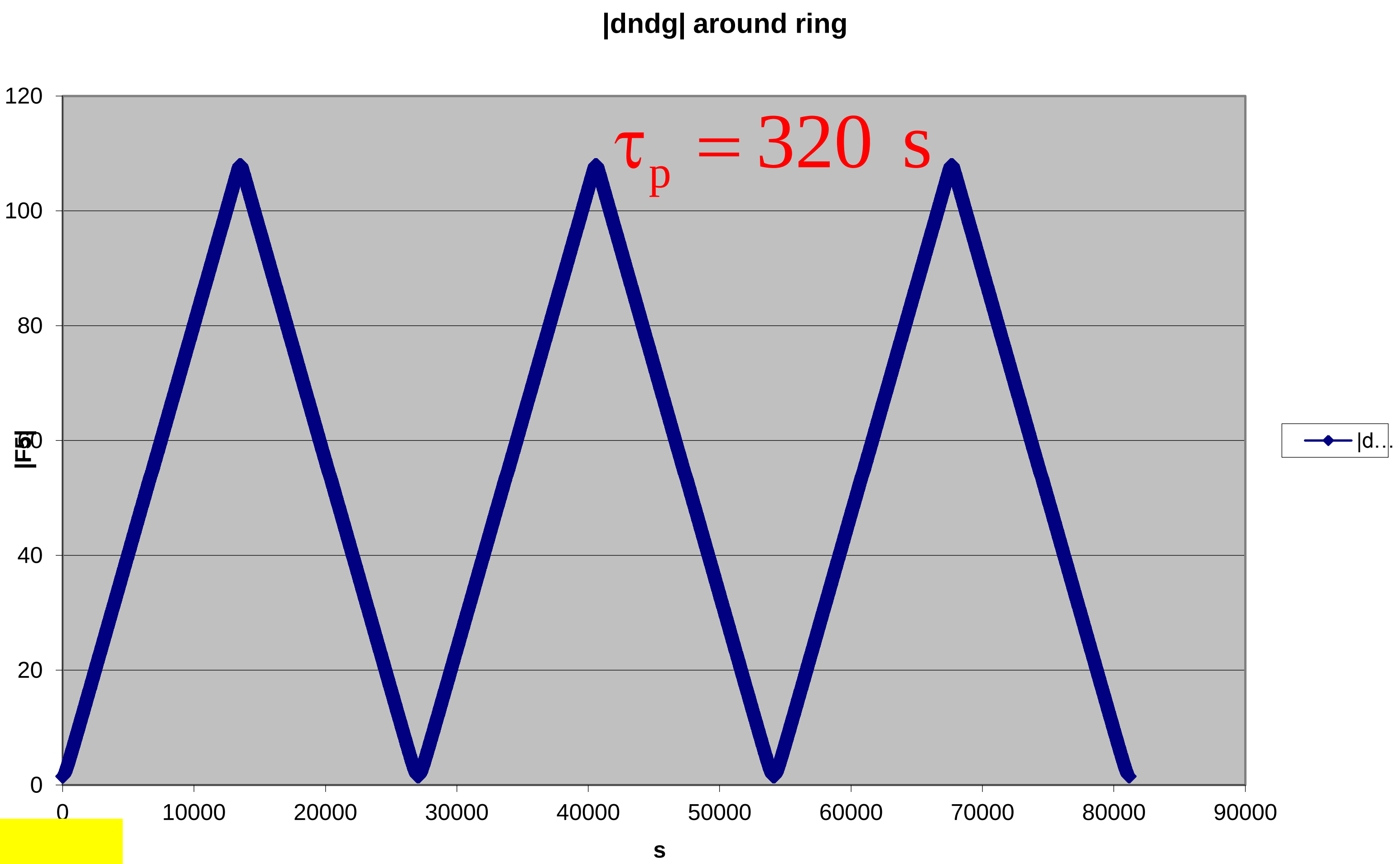
Spin response function |F5|=|d|

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



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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 $E_T = 80\ \text{GeV} \quad \tau_T = 6\ \text{s}$:

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

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

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

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

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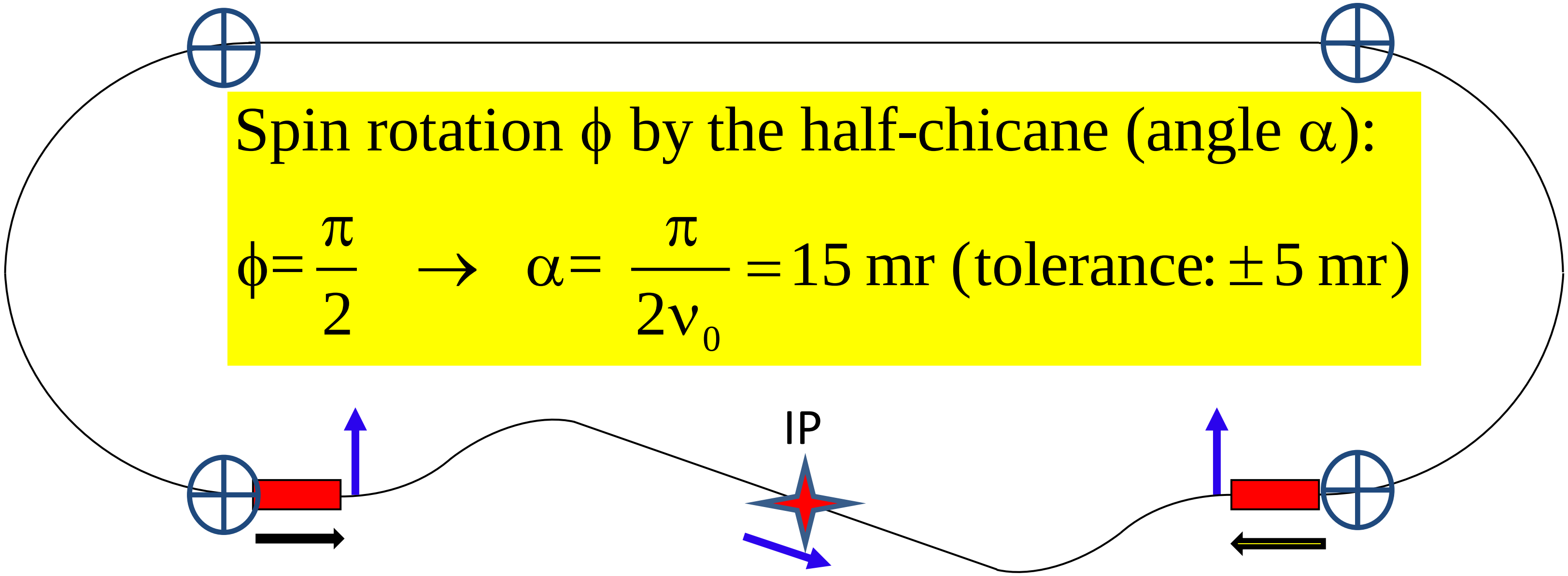
Longitudinal polarization at Z peak

Anti-symmetric layout of the Interaction Region Chicane provides the longest depolarization time!

Spin rotation ϕ by the half-chicane (angle α):

$$\phi = \frac{\pi}{2} \quad \rightarrow \quad \alpha = \frac{\pi}{2\nu_0} = 15\,\text{mr (tolerance: } \pm 5\,\text{mr)}$$



Advantage: Spin direction in arcs is vertical and achromatic: $|d|_{arcs}=0$.
Chicane magnets only contributed to the radiative depolarization, therefore the spin relaxation time exceeds 24 hours!

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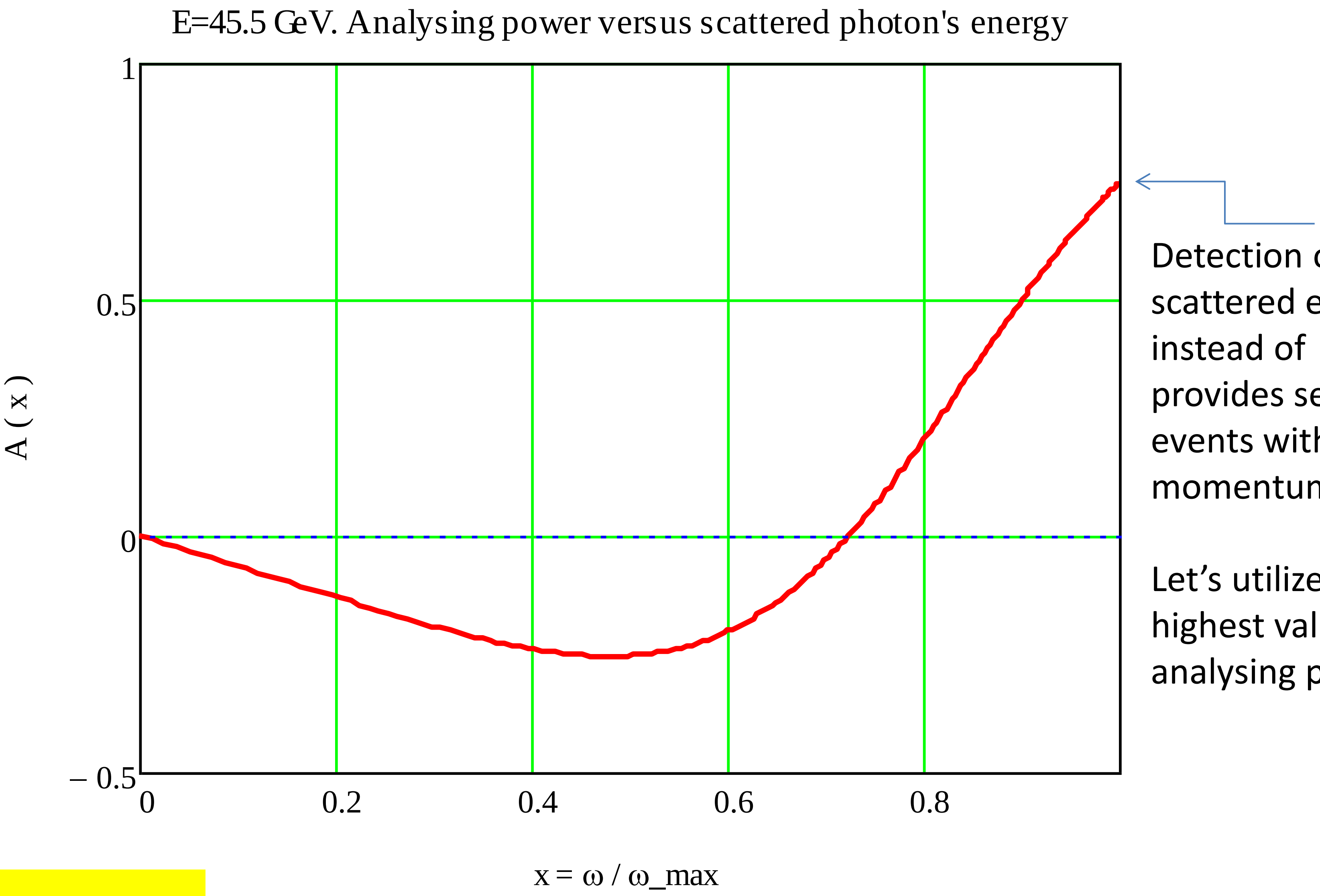
Compton scattering of a laser light



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!

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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
n tune chromaticity reduction compared to the case of same signs.

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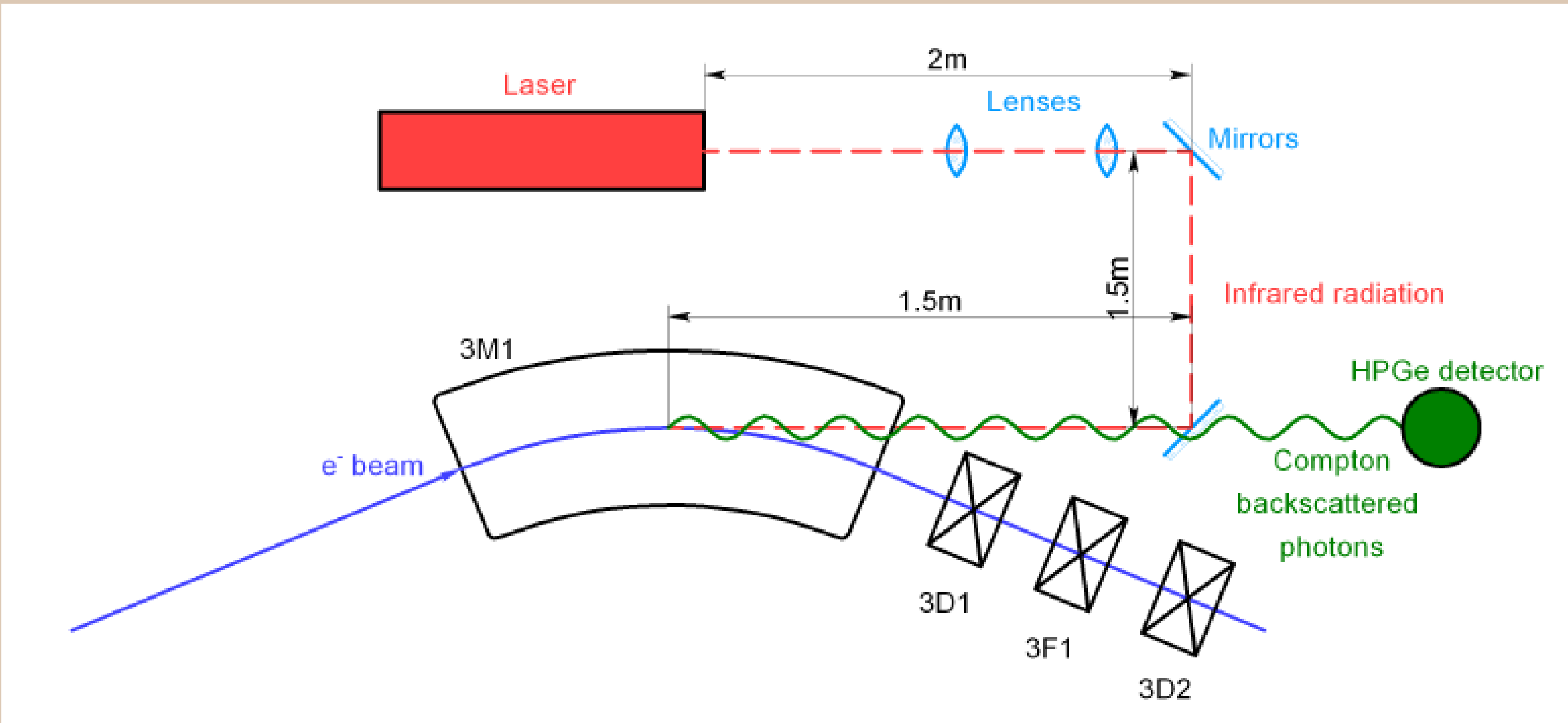
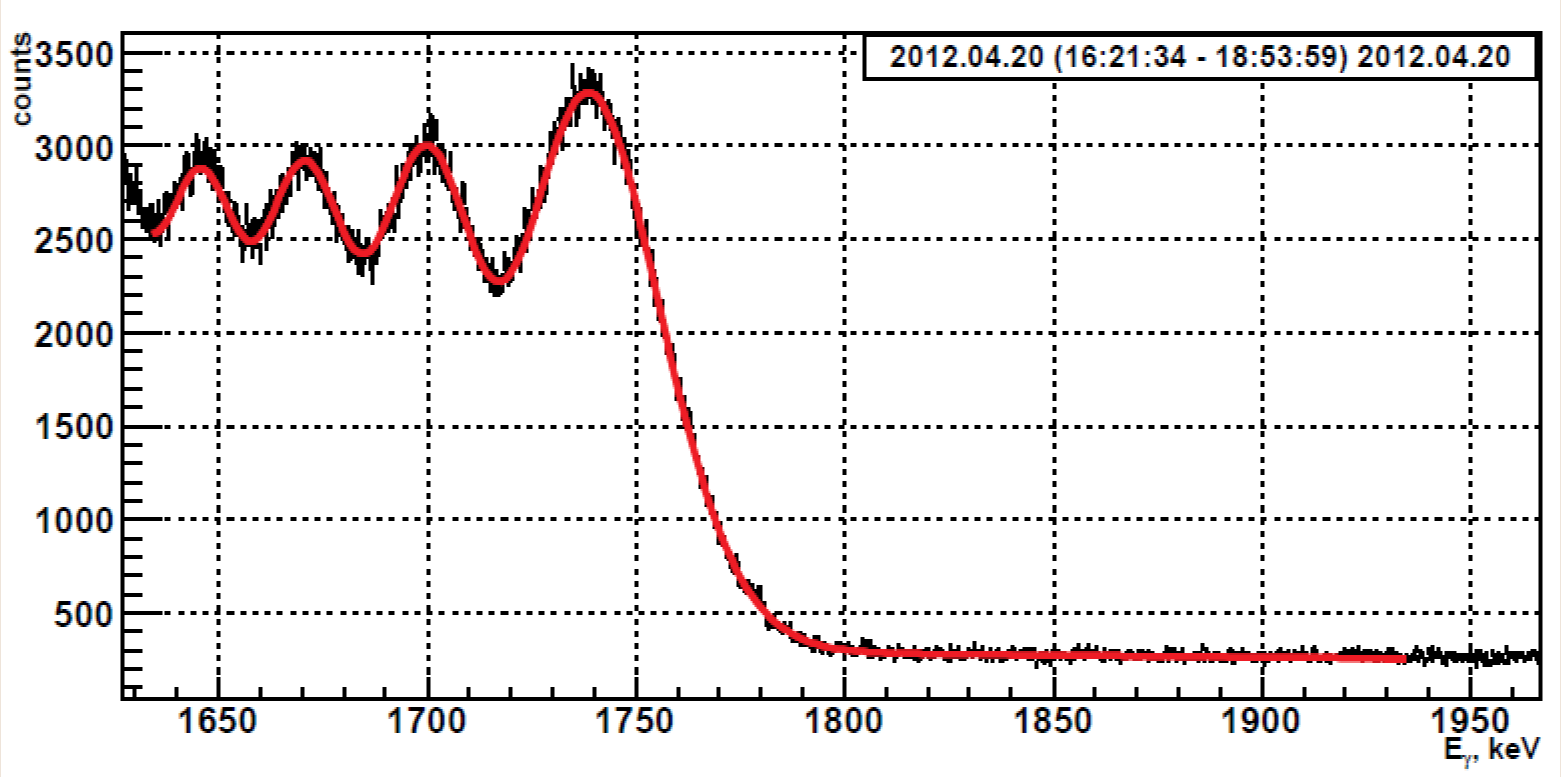
FCC-ee beam energy measurement suggestion, N.Muchnoi

VEPP-2000



Beam orbit radius in the VEPP-2000 dipole $R = 140$ cm

VEPP-2000 puzzle



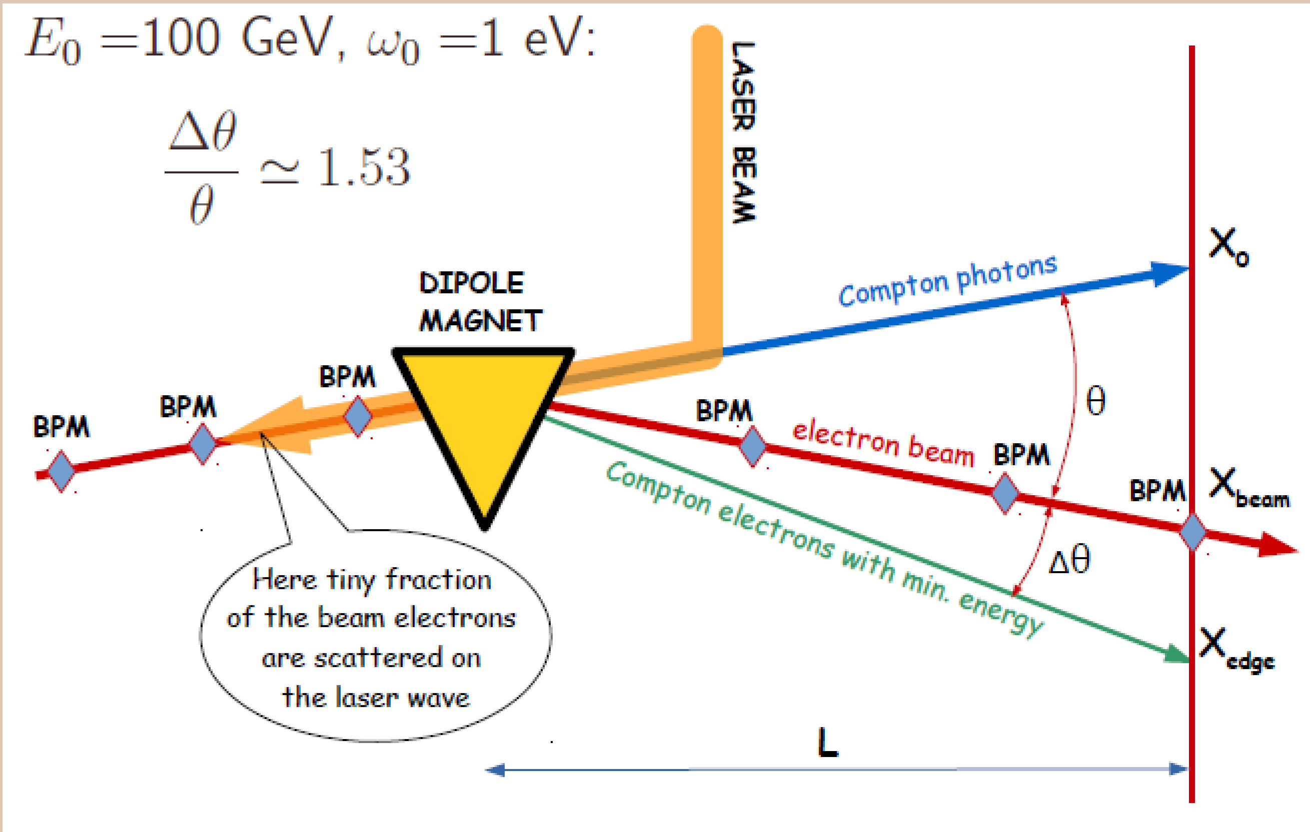
$\chi^2/NDF = 773/745$, Prob. $= 0.23$,

$E = 993.662 \pm 0.016$ MeV, $B = 2.388 \pm 0.004$ T, $\sigma = 810 \pm 40$ ppm.

Phys. Rev. Lett. 110 (2013) 140402

N.Muchnoi

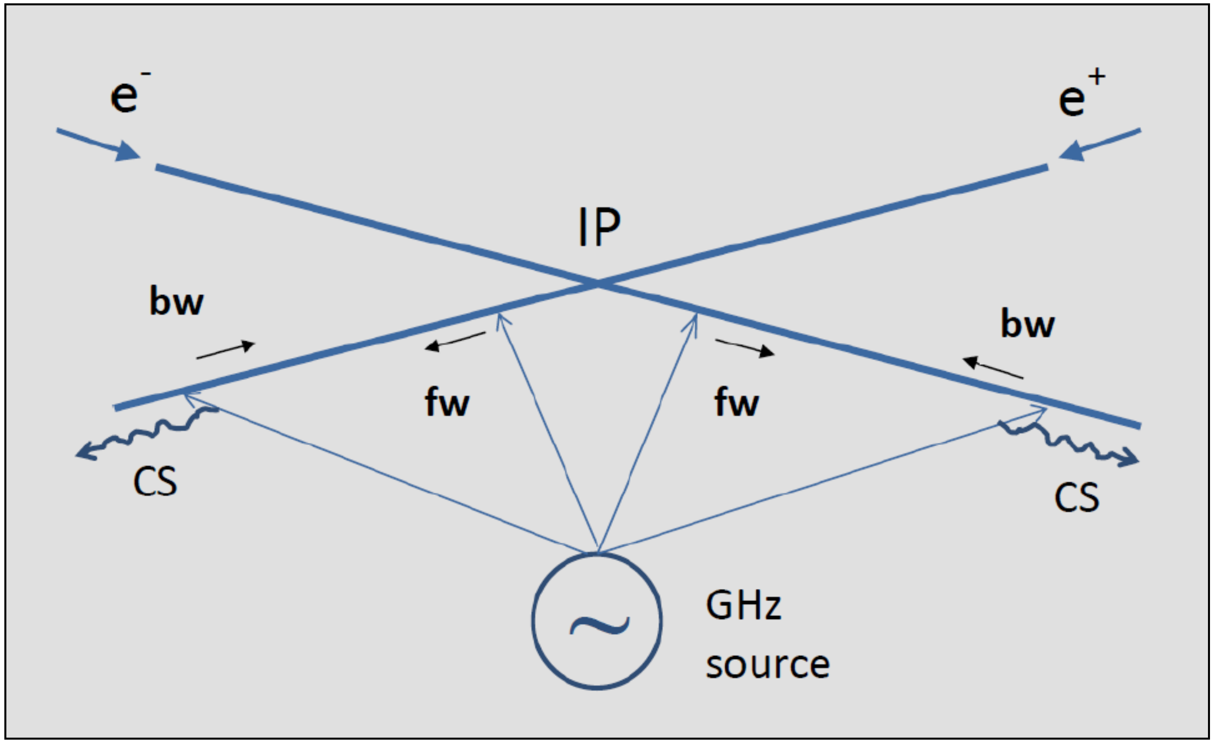
Spectrometer with laser calibration (suggestion)



Access to the beam energy: $E_0 = \frac{\Delta\theta}{\theta} \times \frac{m^2}{4\omega_0}$

N.Muchnoi

Waveguide Compton monitor of FCCee beam energy

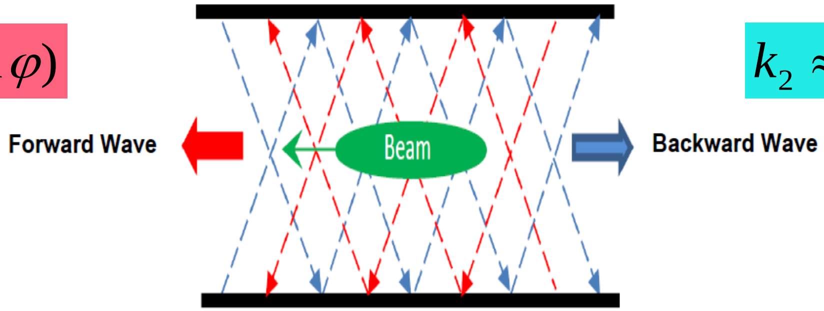


Spectrum edge at λ=5.5 cm (5.45 GHz) for the set of FCCe+e- energy:
0.55 MeV, E=45 GeV (Z)
2.21 MeV, E=90 GeV (W)
3.93 MeV, E=120 GeV (H)
8.35 MeV, E=175 GeV (t)

S.Nikitin

Backward and Forward waveguide waves for CBS edge measurement

$$k_2^* \approx 2\gamma^2 k_1(1-\sin\varphi)$$



$$k_2 \approx 2\gamma^2 k_1(1+\sin\varphi)$$

- Measure CBS spectrum edges at **BW** and **FW** to find their ratio $R = k_2 / k_2^*$
- Calculate $\sin\varphi = \dfrac{R-1}{R+1}$
- Determine beam energy from $$\gamma = \sqrt{\frac{k_2}{2k_1}\cdot\frac{(R+1)}{R}} = \sqrt{\frac{k_2 + k_2^*}{2k_1}}$$

Knowledge of waveguide size is not at all required!

To example above (λ=5.5 cm): $R=k_2/k_2^*=(1+\sin\varphi)/(1-\sin\varphi)=3.9$

S.Nikitin

Circularly polarized photons for obtaining of polarization in super high energy e+e- storage rings

<u>BINP Proposals in the end of 70s (“LEP is on the horizon”):</u>

Ya.S.Derbenev, A.M.Kondratenko, E.L.Saldin/NIMA 165 (1979) 15; NIMA 165 (1979) 201

Use of the spin dependence of Compton Scattering for polarizing of high energy electrons and positrons by opposite circularly polarized photon beam

<u>Two methods proposed and theoretically substantiated:</u>

- “Hard Photons” ($\chi = 2\gamma\hbar\omega / m >> 1$) Paramount kick out of the electrons of one of helicity signs from a beam. Requires an organization of equilibrium longitudinal direction of polarization at the wave-beam interaction section.
- “Soft Photons” ($\chi = 2\gamma\hbar\omega / m << 1$) Multiple scattering of electrons in the wave field. No output of scattering particles from a beam. Principle role of special spin-orbital coupling created, for instance, with a solenoid of a fixed field integral.

<u>Authors noted</u> :

the usual quantum lasers can be applied in certain cases. In the long term more wide possibilities would be realized using Free Electron Lasers.

S.Nikitin

E.Gianfelice

Available codes for radiative polarization computation

- SLIM by A. Chao: analytical, linear orbit and spin motion; poor description of machine errors.
- SMILE by S. R. Mane: perturbartive, convergence problem at high energy (HERA-e and beyond).
- SITROS by J. Kewisch: tracking non-linear orbit (2th order) and spin motion; accurate description of machine errors.
- SLICKTRACK by D. P. Barber: tracking non-linear orbit and spin motion, based on a thick lenses version of SLIM formalism.

Available to me now: SLIM and SITROS, but quite some work needed to get them running again!

SLICKTRACK soon available from Desmond and collaborators!

ASPIRRIN by V.Ptitsyn, linear orbit and spin motion, spin response functions, no tracking simulation

Concluding remarks for Polarization

We should be aggressive in pursuing the polarization goals:

1) Energy calibration

2) Acceleration of polarized beams

3) Longitudinal polarization experiments

4) Production of polarized positrons

Let's do it!