Cornell University
Laboratory for Elementary-Particle Physics

THE STATUS OF POSITRON SOURSE DEVELOPMENT AT CORNELL-II

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ACTIVITIES

√ **CODE FOR POSITRON CONVERSION (UNDULATOR → LINAC → further on)**

Choice of undulator parameters → main issue
Choice of target dimensions
Choice of collection optics parameters

√ **UNDULATOR DESIGN** (main activity)

Undulators with period 10 and 12 mm having 8 mm aperture (tested)
Designed undulators with aperture ¼” (7mm magnetic core)

TARGET DESIGN (in addition to Livermore, SLAC, Daresbury

Rotating Tungsten target (including new sandwich type)
Liquid metal target: Bi-Pb or Hg

COLLECTION OPTICS DESIGN

Lithium lens
Solenoid

These positions not closed finally

√ **COLLIMATORS**

Collimator for gammas
Collimators for full power beam

√ **PERTURBATION OF EMITTANCE AND POLARIZATION**

Perturbation of emittance in regular part
Polarization handling

√ **UNDULATOR CHICANE**

Minimal possible parallel shift

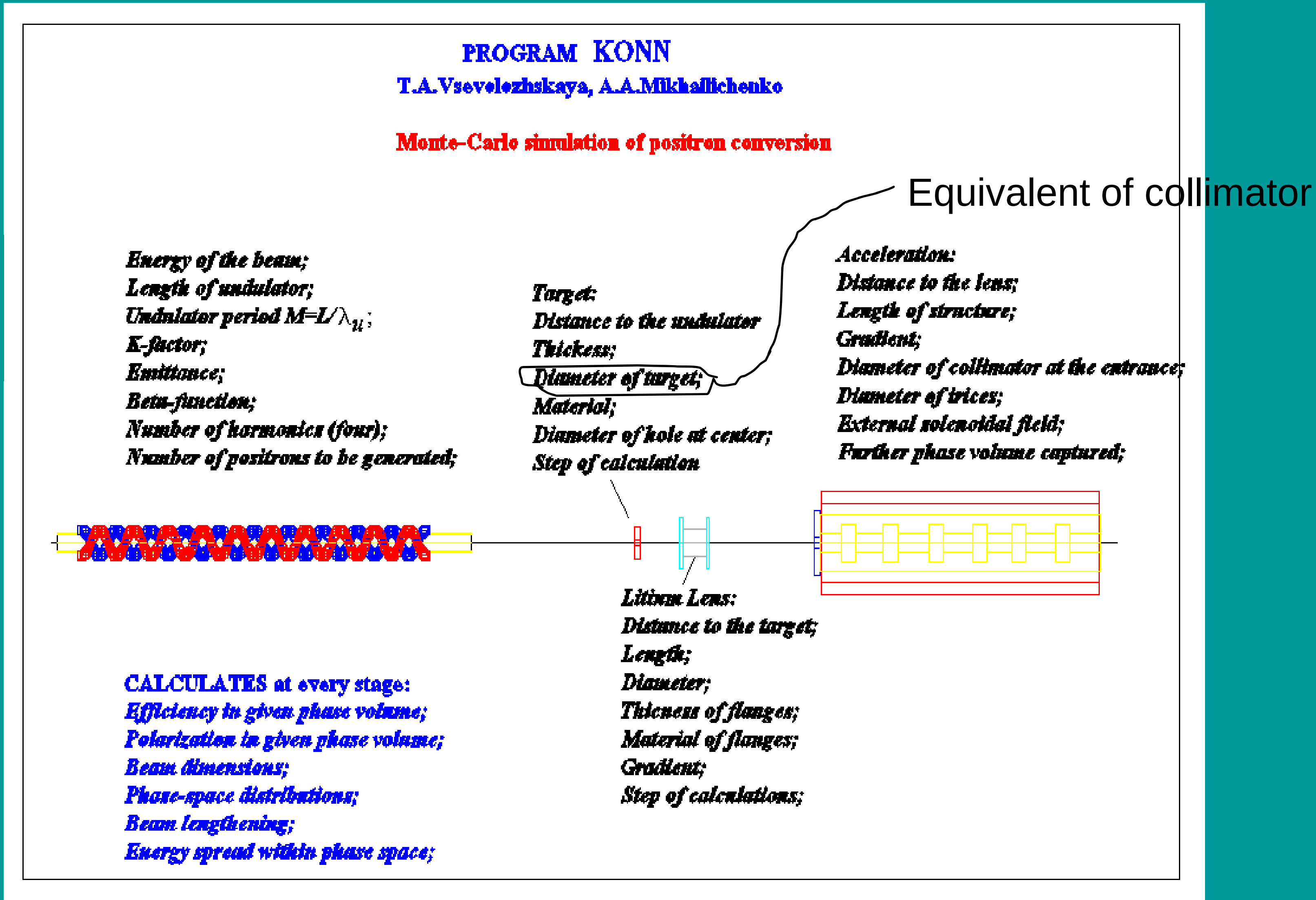
√ **COMBINING SCHEME**

Two-target scheme

CODE FOR POSITRON CONVERSION

Undulator → target → focusing → post acceleration

Written in 1986-1987; restored in 2007



Interactive code; Solenoidal lens will be added soon

Particles described by 2D array (matrix). One parameter numerates particles, the other one numerates properties associated with each particle: energy, polarization, angles to axes

Code has ~1400 rows;

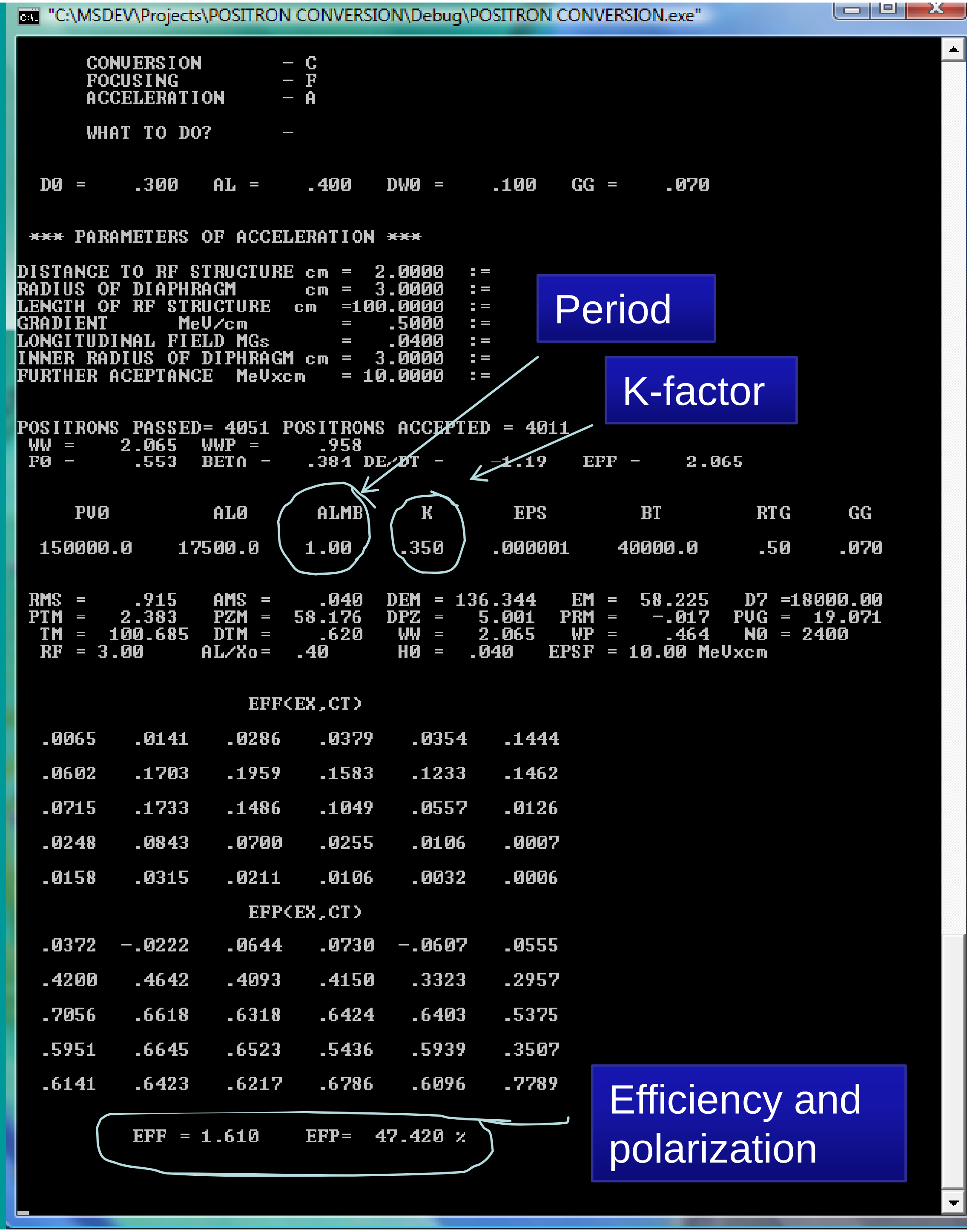
Will be added solenoidal lens;

Will be added more graphics;

Possibility for the file exchange with graphical and statistical Codes (JMP);

Possibility for the file exchange with PARMELA;

Few seconds for any new variant



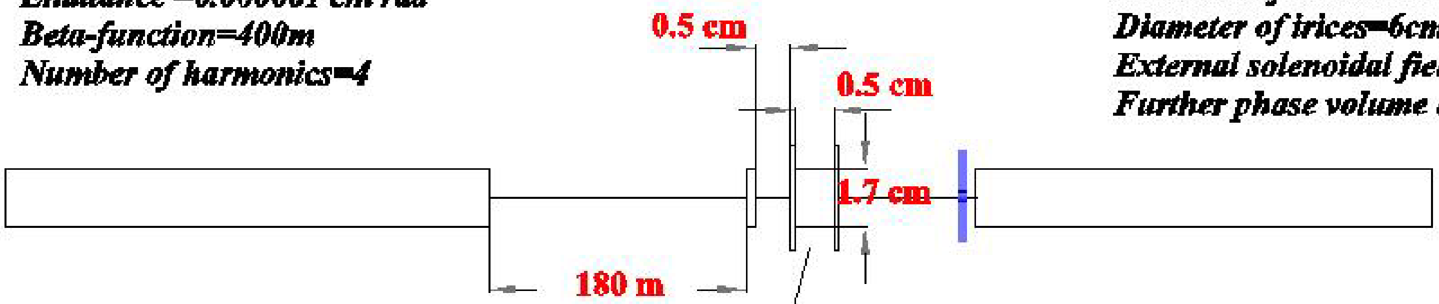
Parameters optimized with KONN

Monte-Carlo simulation of positron conversion example

General parameters:
Energy of the beam=150 GeV
Length of undulator=175m
Undulator period 10mm
K-factor=0.35
Emittance =0.000001 cm rad
Beta-function=400m
Number of harmonics=4

Target:
Distance to the undulator=180m
Thickess=0.5rad length=1.75mm
Diameter of target=0.8cm
Material=W

Acceleration:
Distance between2 lens-structure=2 cm
Gradient in RFstructure=50MeV/m
Length of RF structure =1m
Diameter of collimator at the entrance=4cm
Diameter of irices=6cm
External solenoidal field=40kG
Further phase volume captured=10MeVxcm



Litium Lens:
Distance to the target=0.5 cm
Length=0.5 cm
Diameter=1.7 cm
Thicness of flanges=0.5mm
Material of flanges=Be
Gradient=70kG/cm

For parameters above : Efficiency =1.54   Polarization =50%

So K-factor can be small, K<0.4, what brings a lot of relief to all elements of system

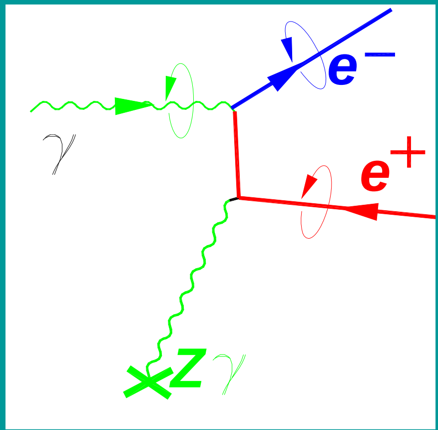
Modeling of E-166 experiment

Phase space right after the target

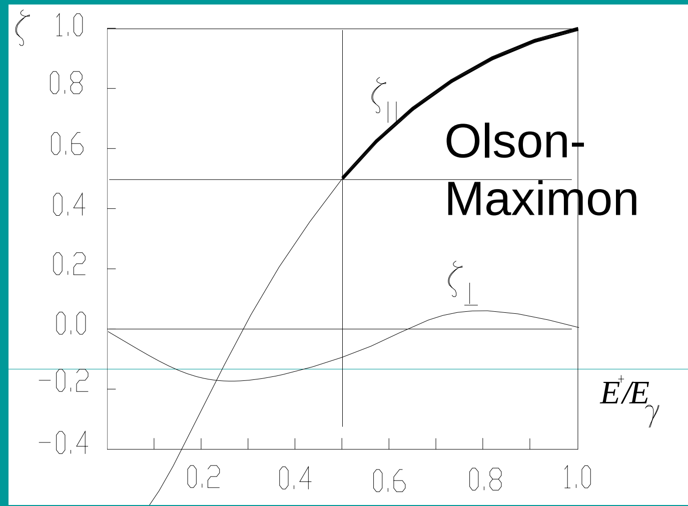
```
"C:\MSDEV\Projects\POSITRON CONVERSION\Debug\POSITRON CONVERSION.exe"
      WHAT TO DO?      -

  *** SYSTEM PARAMETERS ***

INITIAL MOMENTA ,MeV      =150000.0  :=49000
LENGTH OF UNDULATOR,cm    = 17500.0  :=100
K FACTOR                  =     .350  :=.17
PERIOD OF ONDULATOR, cm   =   1.000  :=.254
DISTANCE TO THE TARGET    = 18000.0  :=3200
RADIUS  OF  TARGET, cm    =     .500  :=.15
RADIUS  OF  HOLE          =     .000  :=
EMITTANCE, cmxrad         = 1.000E-06:=
BETTA-FUNCTION,      cm   = 40000.0  :=4000
LENGTH OF TARGET/Xo       =     .400  :=.5
STEP OF CALCULATION       =     .100  :=
HARMONICS INDEX    0; <5 =    0       :=
NUMB.OF PART ON 1 H       =2400       :=
 TOTAL NUMBER OF PHOTONS =     1.014
 MAX ENERGY OF QUANTA    =    8.741  MeV
 GAMMA                   =    95890.4


  POSITRONS ACCEPTED = 5000    POSITRONS GENERATED =  30820

ENERGY OF QUANTA =    8.741   BETA =    1.274 EFF =     .003 PV0 = 49000.0
LENGTH OF UNDUL. =    100.0 PERIOD =     .25   PT2 =  .03    EPT =  .0000010
BT =   4000.0 RTG =  .15          F0 = -.091   RMS = 1.138   AMS =  .894
XU =  .072     NUMBER OF PARTICLES BY FIRST HARMONIC = 2400
PHOTONS/e =     1.014  GAMMA=    95890.4

                    EFF(EX,CT)

  .0000   .0000   .0000   .0001   .0001   .0001
  .0001   .0001   .0002   .0002   .0002   .0003
  .0000   .0001   .0001   .0002   .0002   .0004
  .0000   .0000   .0000   .0000   .0001   .0002
  .0000   .0000   .0000   .0000   .0000   .0000

                    EFP(EX,CT)

 -.0336  -.0927   .0143  -.0414  -.0172  -.0734
  .4099   .4170   .4039   .3911   .3971   .2796
  .7835   .7675   .7085   .7309   .7255   .6872
  .8858   .8004   .8221   .8011   .8528   .8420
  .6790   .6925   .7001   .6678   .7615   .7450
```

Dependence of polarization seen in experiment

Polarized e± production

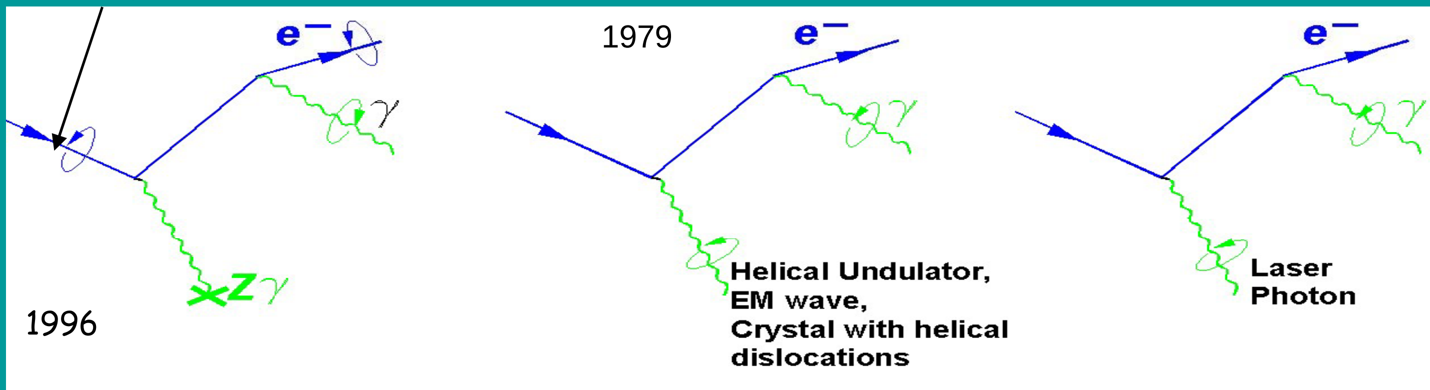


The way to create circularly polarized positron, left. Cross-diagram is not shown. At the right-the graph of polarization – as a function of particle's fractional energy



The way to create circularly polarized photon

Polarized electron



E.Bessonov

1992

Polarization of positrons is a result of positron selection by energy

$$\vec{\varsigma} = \xi_2 \cdot \left[f(E_+,E_-)\cdot \vec{n}_\parallel + g(E_+,E_-)\cdot \vec{n}_\perp \right] = \vec{\varsigma}_\parallel + \vec{\varsigma}_\perp$$

Polarization effects implemented in KONN

```
!    POLARIZATION CURVE APPROXIMATION
!
      EP4=EP-0.4
      EP6=EP-0.6
      PP=0.305+2.15*EP4
      IF(EP.LT.0.4)PP=PP-0.05*EP4-2.5*EP4**3
      IF(EP.GT.0.6)PP=PP-0.55*EP6-2.65*EP6**2+0.7*EP6**3    ! PP=PP-0.55*EP6-2.6*EP6**2
      IF(PP.GT.1.)PP=1.
!
```

EP=POSITRON ENERGY/ Egamma-2mc²

Sentinel

Depolarization occurs due to spin flip in act of radiation of quanta having energy $0 < \hbar\omega_\gamma \le E_1$ where E_1 stands for initial energy of positron. Depolarization after one single act

$$D = 1 - \left| \frac{d\sigma_{\gamma e}(\zeta_1,\zeta_1) - d\sigma_{\gamma e}(\zeta_1,-\zeta_1)}{d\sigma_{\gamma e}} \right|$$

Where $d\sigma_{\gamma e}(\zeta_1,\zeta_1)$ stands for bremstrahlung cross section without spin flip, $d\sigma_{\gamma e}(\zeta_1,-\zeta_1)$ –the cross section with spin flip and $d\sigma_{\gamma e}$ is total cross section.

$$D = \frac{\hbar^2\omega_\gamma^2 \cdot [1 - \frac{1}{3}\zeta_\parallel^2\,]}{E_1^2 + E_2^2 - \frac{2}{3}E_1 E_2}$$

Energy after radiation

$$L_{dep} \cong \frac{1}{n\int D(\vec{p}_1,\zeta_1)\,d\sigma} \longrightarrow L_{dep} \cong \frac{2X_0}{1 - \frac{1}{3}\zeta_\parallel^2} \cong 3X_0$$

Rad. length

Depolarization ~5%

Multiple scattering in a target

Fragment from

A.Mikhailichenko, CBN 06-1, Cornell LEPP, 2006.

Kinematical perturbations due to multiple scattering in a target

Let us consider the possible effect of *kinematical* depolarization associated with rotation of spin vector while particle experience multiple scattering in media of target before leaving. Typically polarized positron carries out ~(0.5-1)$\hbar\omega$ –energy of gamma quanta. As positrons/electrons created have longitudinal polarization, it is good to have assurance that during scattering in material of target polarization is not lost. Each act of scattering is Coulomb scattering in field of nuclei. So BMT equation describing the spin $\vec{\zeta}$ motion in electrical field of nuclei looks like

$$\frac{d\vec{\zeta}}{dt} = \frac{e}{mc^2\gamma}\left\{G\gamma + \frac{\gamma}{\gamma+1}\right\}\cdot\vec{\zeta}\times\left(\vec{E}\times\vec{v}\right), \qquad \text{(A16)}$$

where $\vec{E} \sim Ze\vec{r}/r^3$ stands for repulsive (for positrons) electrical field of nuclei, factor $G = \frac{g-2}{2} \cong 1.1596\times10^{-3} \approx \frac{\alpha}{2\pi}$. Deviation of momentum is simply $d\vec{p}/dt = e\vec{E}$.

So the spin equation becomes

$$\frac{d\vec{\zeta}}{dt} = \frac{1}{mc^2\gamma}\left\{G\gamma + \frac{\gamma}{\gamma+1}\right\}\cdot\vec{\zeta}\times\left(\frac{d\vec{p}}{dt}\times\vec{v}\right). \qquad \text{(A17)}$$

We neglected variation of energy of particle during the act of scattering, so $\frac{d\vec{p}}{dt} \cong m\gamma\frac{d\vec{v}}{dt}$ and vector $\vec{p}$ just changes its direction. Introducing normalized velocity as usual $\vec{\beta} = \vec{v}/c$, equation of spin motion finally comes to the following

$$\frac{d\vec{\zeta}}{dt} = \left\{G\gamma + \frac{\gamma}{\gamma+1}\right\}\cdot\vec{\zeta}\times(\dot{\vec{\beta}}\times\vec{\beta}) = \left\{G\gamma + \frac{\gamma}{\gamma+1}\right\}\cdot\vec{\zeta}\times\frac{d\vec{\varphi}}{dt}, \qquad \text{(A18)}$$

where $\boldsymbol{\varphi}$ stands for the scattering angle and the vector $d\vec{\varphi}/dt$ directed normally to the scattering plane. For intermediate energy of our interest $\gamma \sim 40$, so the term in bracket ~1 and, finally

$$\frac{d\vec{\zeta}}{dt} \cong \vec{\zeta}\times\frac{d\vec{\varphi}}{dt}. \qquad \text{(A19)}$$

The last equation means that spin rotates to the same angle as the scattering one, i.e. spin follows the particle trajectory.

Spin flip in undulator

Positron or electron may flip its spin direction while radiating in magnetic field. Probability:

$$\frac{1}{\tau}[\sec^{-1}] = w_{flip} = \frac{5\sqrt{3}}{16}\frac{r_0^2}{\alpha}\frac{\omega_0^3}{c^2}\gamma^5\left(1 - \frac{2}{9}\zeta_\parallel^2 - \frac{8\sqrt{3}}{15}\frac{e}{|e|}\zeta_\perp\right)$$

Probability of radiation:

$$w_{rad} \cong \frac{I}{\hbar\omega_0 2\gamma^2} = \frac{2}{3}\frac{e^4H^2\gamma^2}{m^2c^3}\frac{1}{\hbar\omega_0 2\gamma^2} = \frac{1}{3}\alpha\gamma^2\omega_0$$

$$\bar{\lambda}_c = r_0/\alpha = e^2/mc^2/\alpha \cong 3.8616\cdot 10^{-11}$$

The ratio

$$\frac{w_{flip}}{w_{rad}} = \frac{15\sqrt{3}}{16}\frac{\bar{\lambda}_c^2}{\bar{\lambda}_u^2}\gamma^3\left(1 - \frac{2}{9}\zeta_\parallel^2 - \frac{8\sqrt{3}}{15}\frac{e}{|e|}\zeta_\perp\right) \qquad \text{(K\textasciitilde 1)}$$

Effect of spin flip still small (i.e. radiation is dominating).

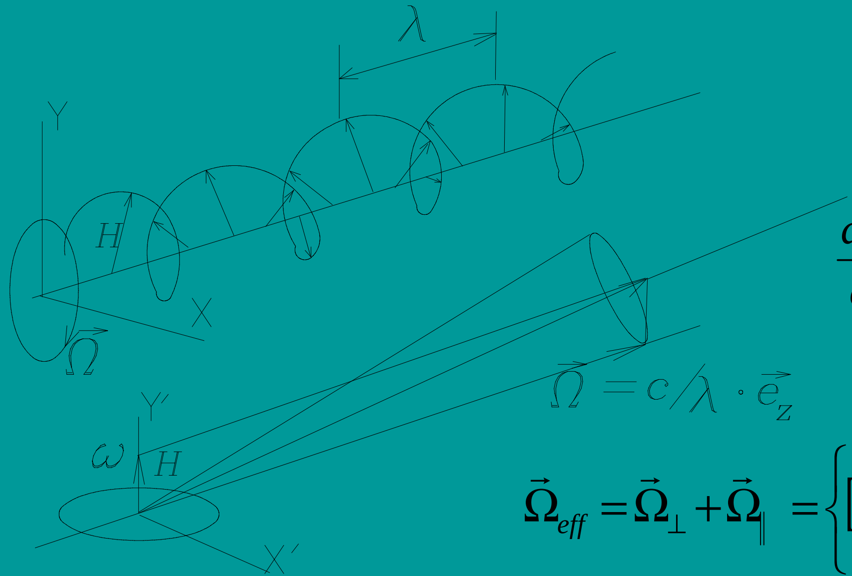
Depolarization at IP

- Depolarization arises as the spin changes its direction in coherent magnetic field of incoming beam. Again, here the deviation does not depend on energy, however it depends on location of particle in the bunch: central particles are not perturbed at all. Absolute value of angular rotation has opposite sign for particles symmetrically located around collision axes.
- This topic was investigated immediately after the scheme for polarized positron production was invented. This effect is not associated with polarized positron production exclusively because this effect tolerates to the polarization of electrons at IP as well. Later many authors also considered this topic in detail. General conclusion here is that depolarization remains at the level ~5%

E.A. Kushnirenko, A. A. Likhoded, M.V. Shevlyagin, *“Depolarization Effects for Collisions of Polarized beams”*, IHEP 93-131, SW 9430, Protvino 1993.

Kinematic depolarization in undulator

Process can be considered in a system of reference rotating with frequency $\vec{\Omega} = \dfrac{c}{\lambda_u}$



$$\frac{d\vec{\zeta}}{dt} = \vec{\zeta} \times (\vec{\Omega}_s - \vec{\Omega}) \equiv \vec{\zeta} \times \vec{\Omega}_{eff}$$ where

$$\vec{\Omega}_{eff} = \vec{\Omega}_{\perp} + \vec{\Omega}_{\parallel} = \left\{ [1+\gamma G] \cdot \frac{eH_{\perp}\lambda_u}{mc\cdot\gamma} \cdot \frac{c}{\lambda_u}; 0; \frac{c}{\lambda_u} \right\} \equiv \left\{ [1+\gamma G] \frac{K}{\gamma} \cdot \frac{c}{\lambda_u} \vec{e}_{\perp}; 0; \frac{c}{\lambda_u} \vec{e}_{\parallel} \right\}$$

$G=(g-2)/2$ can be represented as $G = 1/\gamma_0$ where γ_0 corresponds to 440.65 MeV

so $$\vec{\Omega}_{eff} = \vec{\Omega}_{\perp} + \vec{\Omega}_{\parallel} = \left\{ \left[1+\frac{\gamma}{\gamma_0}\right] \cdot \frac{eH_{\perp}\lambda_u}{mc\cdot\gamma} \cdot \frac{c}{\lambda_u}; 0; \frac{c}{\lambda_u} \right\} \cong \left\{ \frac{K}{\gamma_0} \cdot \frac{c}{\lambda_u} \vec{e}_{\perp}; 0; \frac{c}{\lambda_u} \vec{e}_{\parallel} \right\}$$

Does not depend on Energy→
depolarization $\approx (K/\gamma_0)^2$

During passage through undulator spin rotates around *y'* $\varphi = \Omega_{\perp} t = \dfrac{K}{\gamma_0} \cdot \dfrac{c}{\lambda_u} \cdot \dfrac{L}{c} = \dfrac{KL}{\gamma_0 \lambda_u} \cong$ 50 rad

This needs to be taken into account while preparing polarization at IP

CONCLUSIONS

Restored start to end code for Monte-Carlo simulation of conversion;
Confirmed low K factor possible here; K<0.4 with period 10 mm

Calculations with KONN show that these parameters satisfy ILC

Perturbation of spin is within 10% total (from creation).

This number could be reduced by increasing the length of undulator, making target thinner (two targets) and beams more flat at IP.

UNDULATOR DESIGN

Complete design done;

System for magnetic measurement designed;

Undulator includes correctors and BPMs;