Status of the Electron Ring Design for eRHIC
(mini-workshop Sept.5-6)

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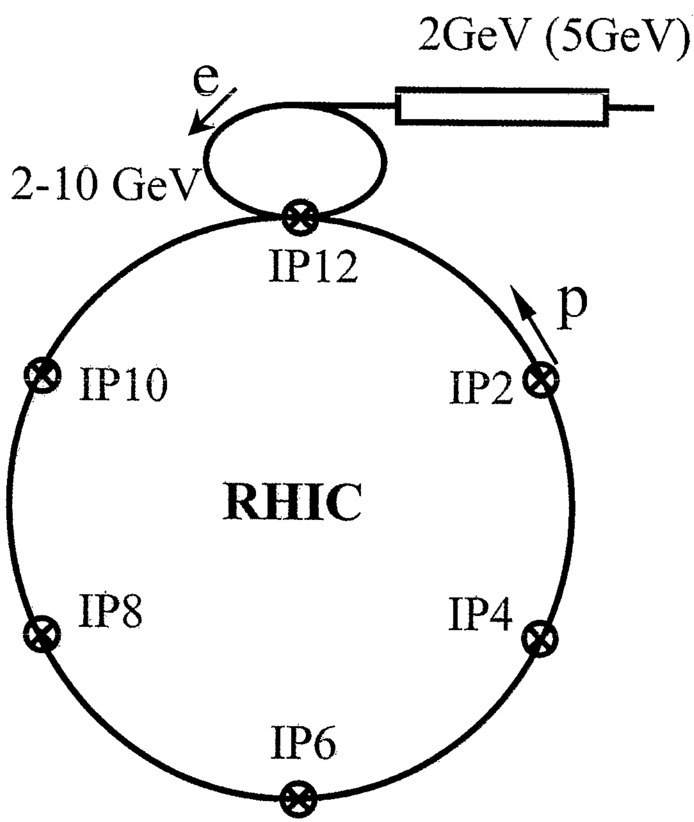
EIC Objectives

- e-p and e-ions collisions
- 5-10 GeV electrons; 25-250 Gev protons; 100 Gev/u Au
- Luminosity:
  - $L \approx (0.3-0.5)\cdot 10^{33}\frac{1}{\mathrm{sec}\cdot\mathrm{cm}^2}$ for e-p collisions
  - $L \approx 10^{30}-10^{31}\frac{1}{\mathrm{sec}\cdot\mathrm{cm}^2}$ for e-Au collisions
- Polarized electron and proton beams
- Longitudinal polarization at collision point; 70% .
- 35 nsec minimum separation between bunches

Layout with electron storage ring



- e-ring is ¼ of RHIC ring length
- Collisions in one interaction point (at IR12)
- Collision e energies: 5-10 GeV
- Injection linac: 2-5 GeV
- Polarization build-up due to ”superbend” magnets
- Polarization time: 4-16 minutes

Luminosity and beam-beam limits

Beam-beam parameters (round beams):

$$\xi_e = \frac{N_i}{\epsilon_e}\left(\frac{r_e Z}{4\pi\gamma_e}\right) \qquad (1)$$

$$\xi_i = \frac{N_e}{\epsilon_i}\left(\frac{r_i (v/c)_i}{4\pi Z}\right) \qquad (2)$$

Emittance subscripts are correct! For example, e-cooling reduces ϵ_i and allows N_e to be reduced.

Reasonably achievable values:

(1) → 0.05

(2) → 0.005

Electron-ion luminosity can be written

$$L = F_c \, \xi_e \xi_i \, \sigma_e'^{*} \sigma_i'^{*} \left(\frac{4\pi\gamma_e\gamma_i}{r_e r_i}\right) \qquad (3)$$

- When beam-beam limits and angular apertures have been met, $\xi_e \xi_i \sigma_e'^{*} \sigma_i'^{*}$ is fixed.

Additional issues

- HERA (and SPS) experience: matching of the beam sizes is very important; With unmatched sizes: bad lifetime, higher background even with moderate beam-beam tune shifts (R.Brinkmann,F.Willeke)
- The total proton current is limited to 0.5A or by beam-beam limit 360 bunches with maximum number and $1*10^{11}$ p and $1*10^{9}$ Au of particles per bunch.
- Electron emittance defined by synchrotron radiation-> electron ring lattice
- Ion/proton beam emittance defined by electron cooling (on injection energy for protons)

Main parameters calculation

	p	e	Au
Circumference,m	3833	958.25	3833
Energy,GeV	250	5-10	100/u
Number of bunches	360	90	360
Bunch population,1.e11	1	1	0.01
Beam current, A	0.45	0.45	0.36
Normalized emittance, Pi mm.mrad	15-21		6-8
Rms emittance, mm.murad	9-13	45-63	9-13
Beta function at IP, m	0.5	0.1	0.5
Beam size at IP, mm	.07-.08	.07-.08	.07-.08
Beam-beam parameter	.005	.05 .04	.005
Luminosity, 1.e33	0.5		.005

Round colliding beams concept

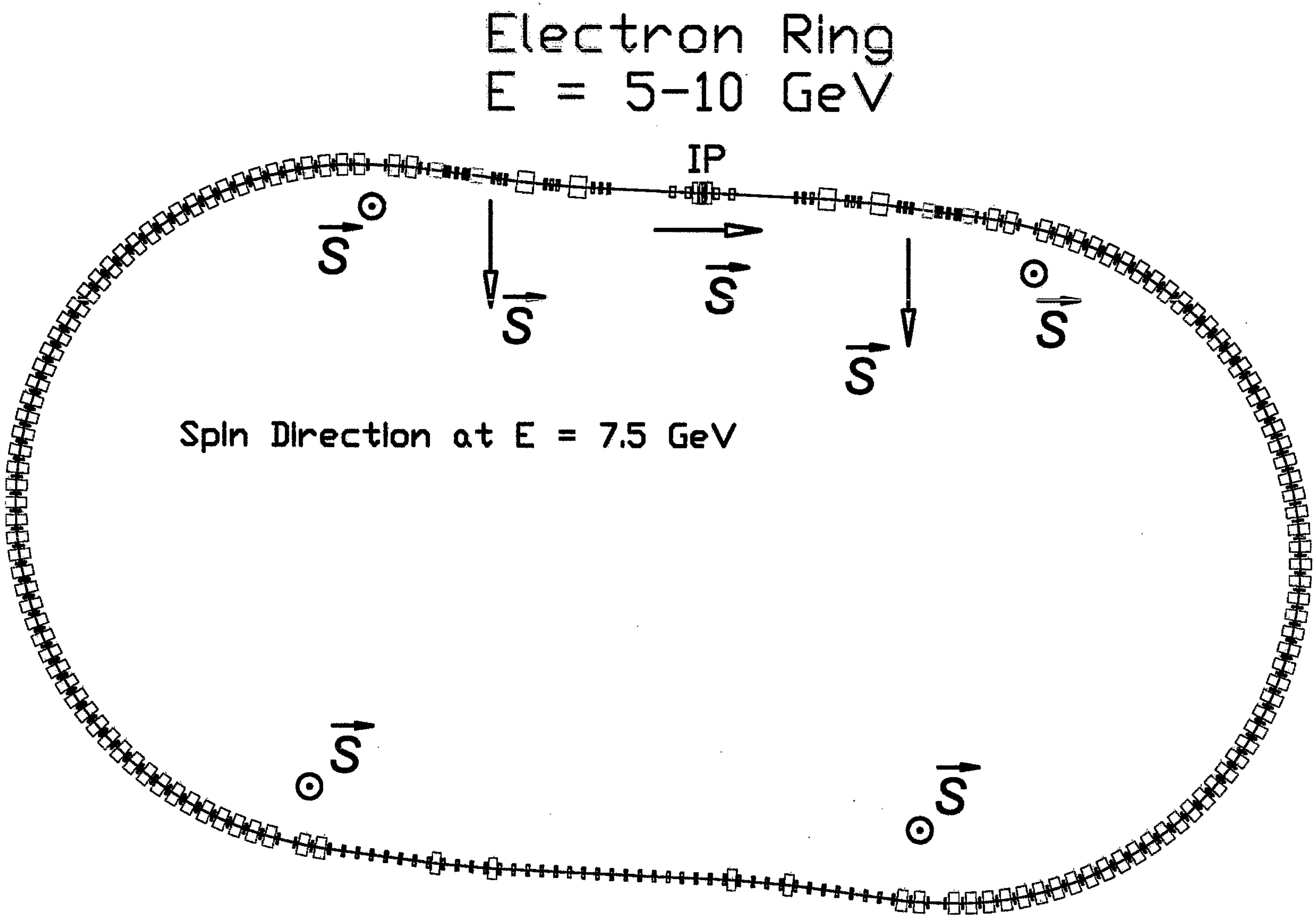
- Equal emittances: $\varepsilon_x = \varepsilon_y \quad , \quad \varepsilon_p = \varepsilon_e$
- Equal β^* : $\beta_x^* = \beta_y^*$
- Equal tunes: $\nu_x = \nu_y$
- Luminosity:

$$L = \left(\frac{4\pi\gamma_e\gamma_i}{r_e r_i} \right) \cdot \xi_e \cdot \xi_i \cdot \frac{\varepsilon}{\beta^*} \cdot F_c$$

- Simulations show a suppression of the beam blowup from beam-beam interactions. $\xi_e \approx 0.1 \qquad \xi_i = ?$

IR design issues

- Separation scheme to avoid parasitic beam-beam collisions (10m or 35nsec distance between bunches)
- Focusing to low beta
- Longitudinal polarization in interaction point and spin transparency conditions
- Detector background, protection from synchrotron radiation issues
- Suggested are two different schemes: one with horizontal and another with vertical beam separation.


Electron Ring
E = 5-10 GeV
IP
Spin Direction at E = 7.5 GeV

Radiative polarization

DK formula:
(1973)

$\hat{\mathbf{n}}$ - Spin closed "orbit"

$\mathbf{d} = \frac{\partial \hat{\mathbf{n}}}{\partial p_\sigma}$ - Spin-orbit coupling

$$P_{eq} = -\frac{8}{5\sqrt{3}}\frac{\alpha_-}{\alpha_+}$$

$$\tau^{-1} = \frac{5\sqrt{3}}{8}\frac{\hbar\, r_0}{m}\gamma^5\,\alpha_+$$

$$\alpha_- = \frac{1}{R_0^3}\langle\frac{\hat{\mathbf{b}}}{|K|^3}(\hat{\mathbf{n}} - \mathbf{d})\rangle$$

$$\alpha_+ = \frac{1}{R_0^3}\langle\frac{1}{|K|^3}[1 - \frac{2}{9}(\hat{\mathbf{n}}\hat{\mathbf{v}})^2 + \frac{11}{18}|\mathbf{d}|^2]\rangle$$

Spin transparency

$$\frac{d\mathbf{S}}{d\theta} = (\mathbf{W_0} + \mathbf{w}) \times \mathbf{S}$$

Precession on the ideal (reference) orbit

Precession due to betatron/synchrotron motion and closed orbit error

$$\hat{\mathbf{n}}_0(\theta + 2\pi) = \hat{\mathbf{n}}_0(\theta)$$

$\nu = \phi/(2\pi)$ (Spin tune)

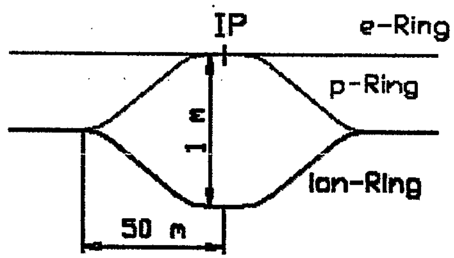
$(\hat{\mathbf{n}}_0, \hat{\eta}_1, \hat{\eta}_2)$

(Orthogonal spin basis)

$$\begin{cases} w_x = \nu_0 y'' + K_x \frac{\Delta\gamma}{\gamma} \\ w_y = -\nu_0 x'' + K_y \frac{\Delta\gamma}{\gamma} \\ w_z = K_z \frac{\Delta\gamma}{\gamma} \end{cases}$$

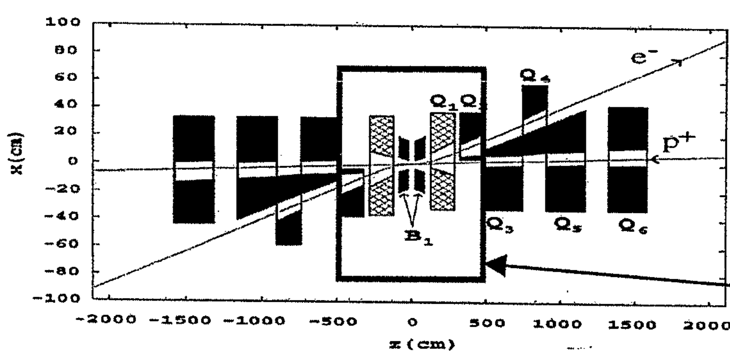
$$I = \int_{\theta_1}^{\theta_2} (\vec{w} \cdot \vec{\eta})\, d\theta = 0$$ - spin transparency condition

Horizontal separation scheme (BINP design)



Side view

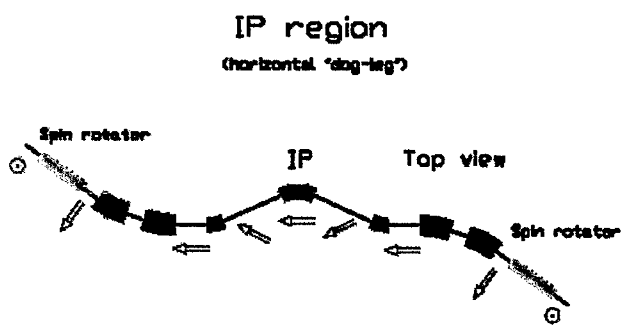
$\beta^* = \beta^* = 10\ cm$

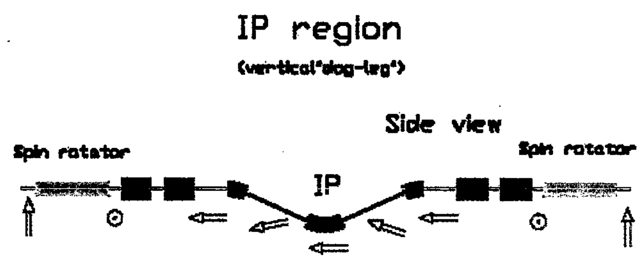


Inside detector

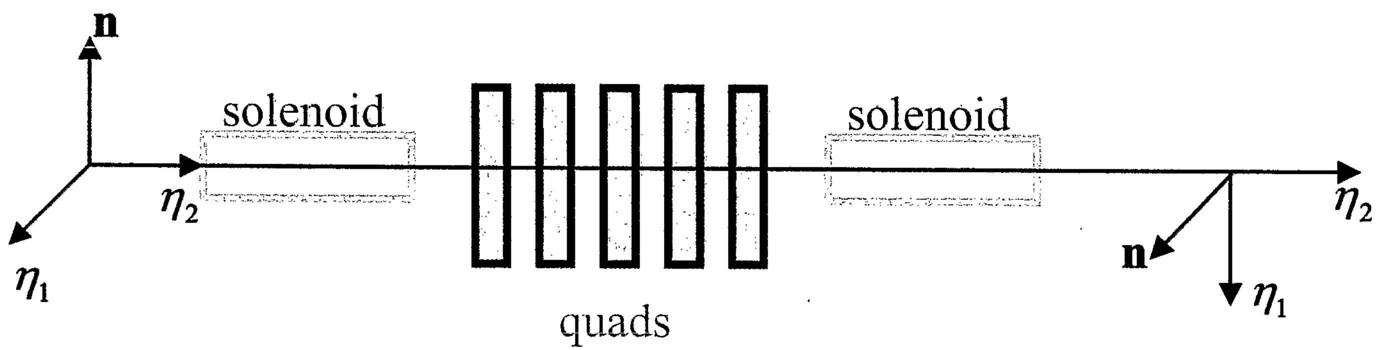
Spin rotator

- Simplest solution -> solenoidal spin rotator
- Perfect longitudinal polarization at one energy (7.5GeV); ~15% reduction at 5 or 10 GeV.
- Spin transparency conditions on optics



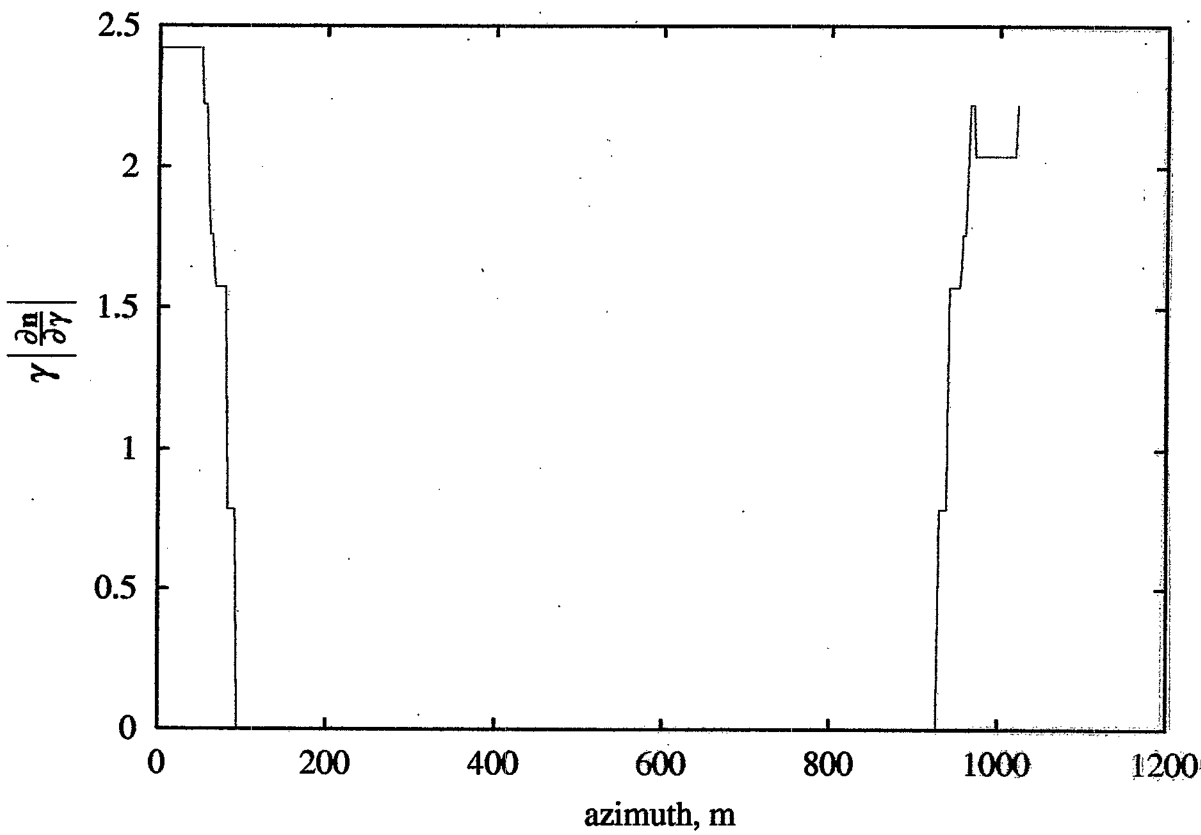


Solenoidal rotator insertion



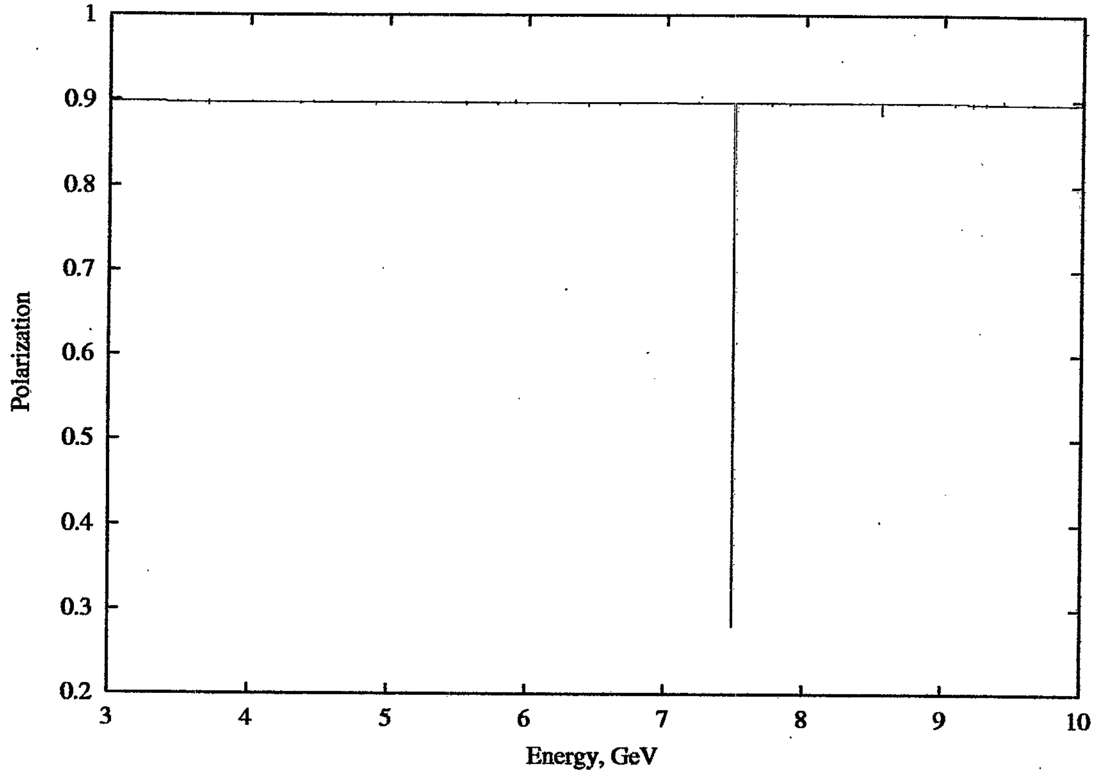
$$T = \begin{pmatrix} T_x & 0 \\ 0 & T_y \end{pmatrix}$$ - insertion transfer matrix

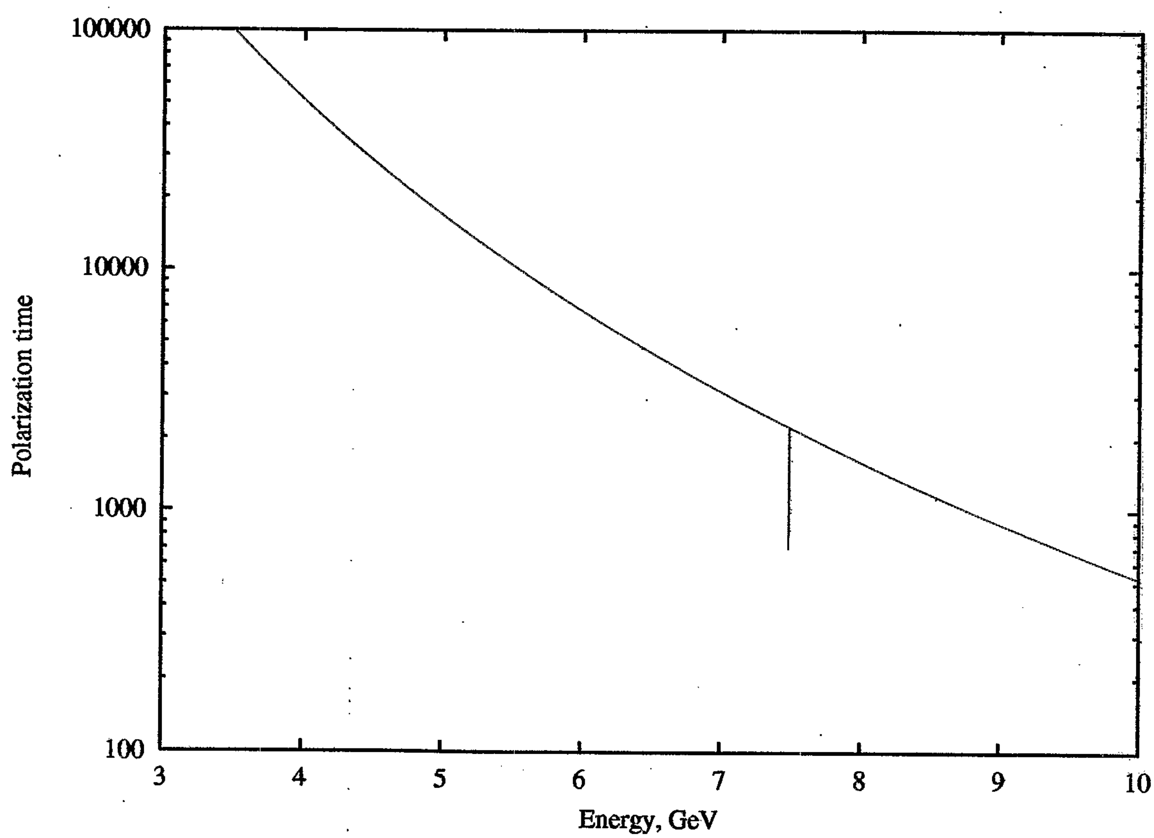
$$T_x = \begin{pmatrix} 0 & -2r \\ (2r)^{-1} & 0 \end{pmatrix} \quad ; \quad T_y = \begin{pmatrix} 0 & 2r \\ -(2r)^{-1} & 0 \end{pmatrix} \quad ; \quad r = \frac{K_z \rho}{K_y}$$



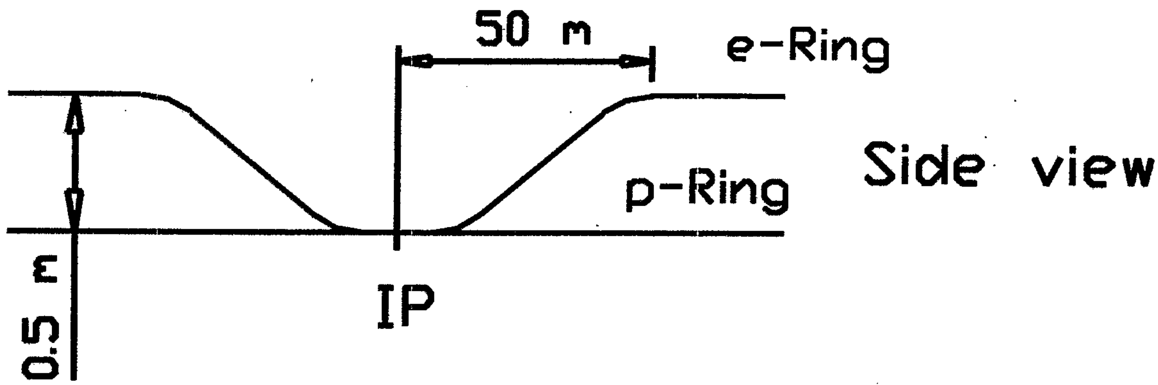
2.5
2
1.5
1
0.5
0
$\gamma \left|\frac{\partial \mathbf{n}}{\partial \gamma}\right|$
0
200
400
600
800
1000
1200
azimuth, m

Horizontal "dog-leg" scheme



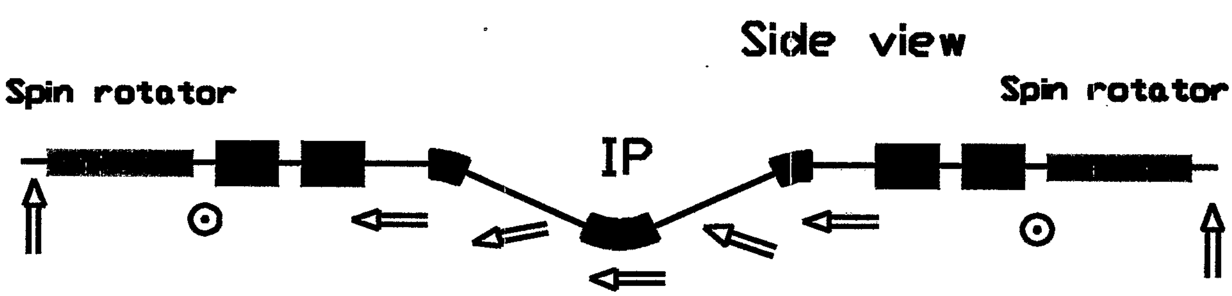


Vertical"dog-leg" scheme

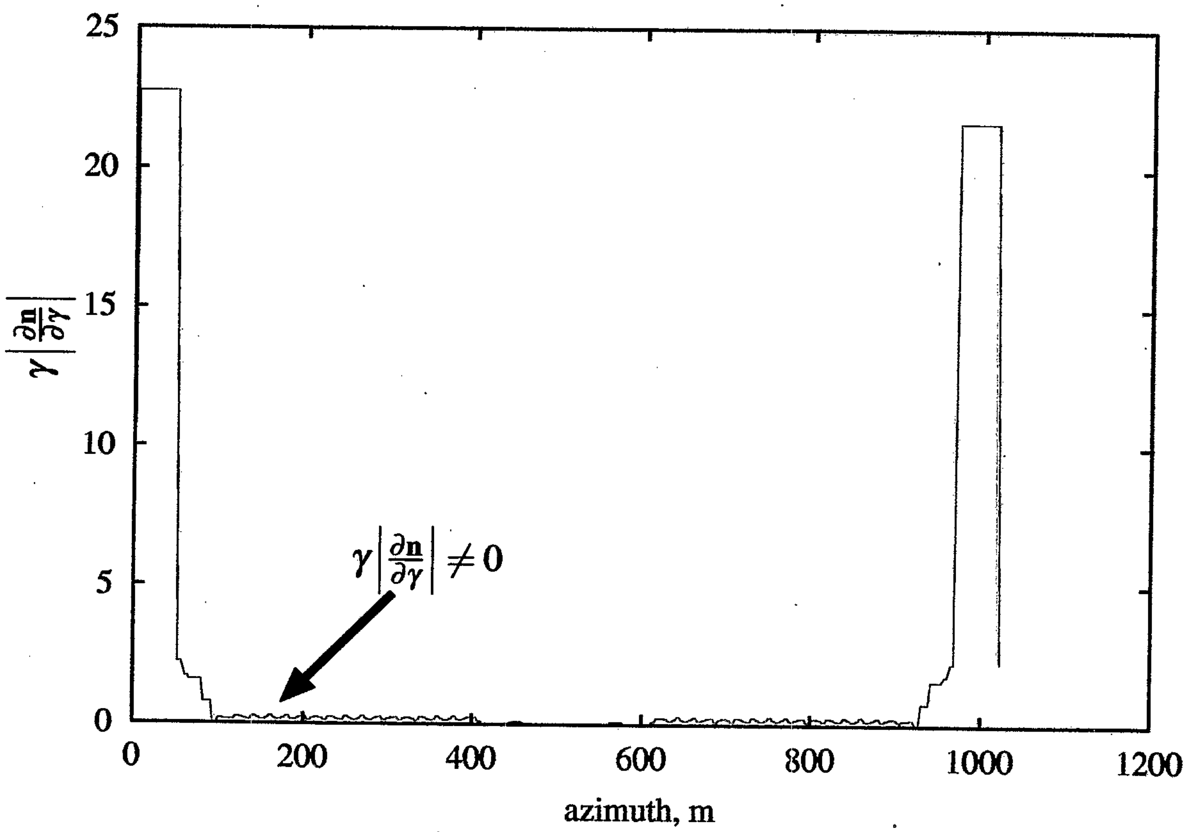


IP region

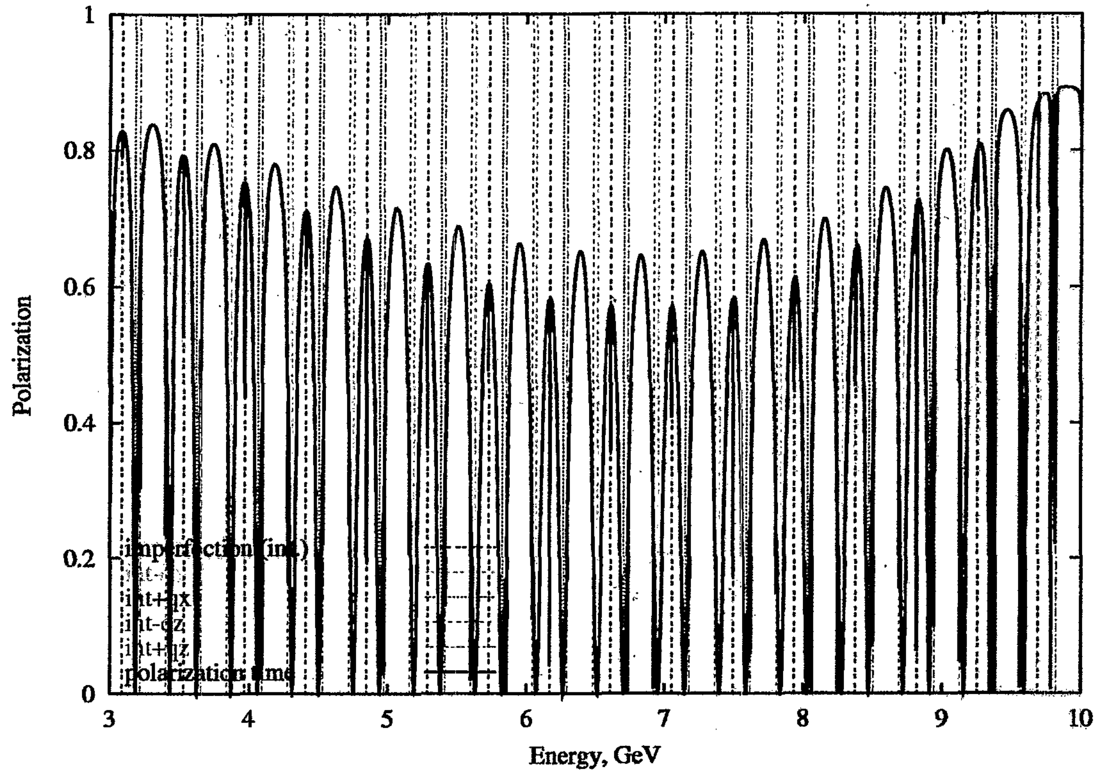
(vertical"dog-leg")

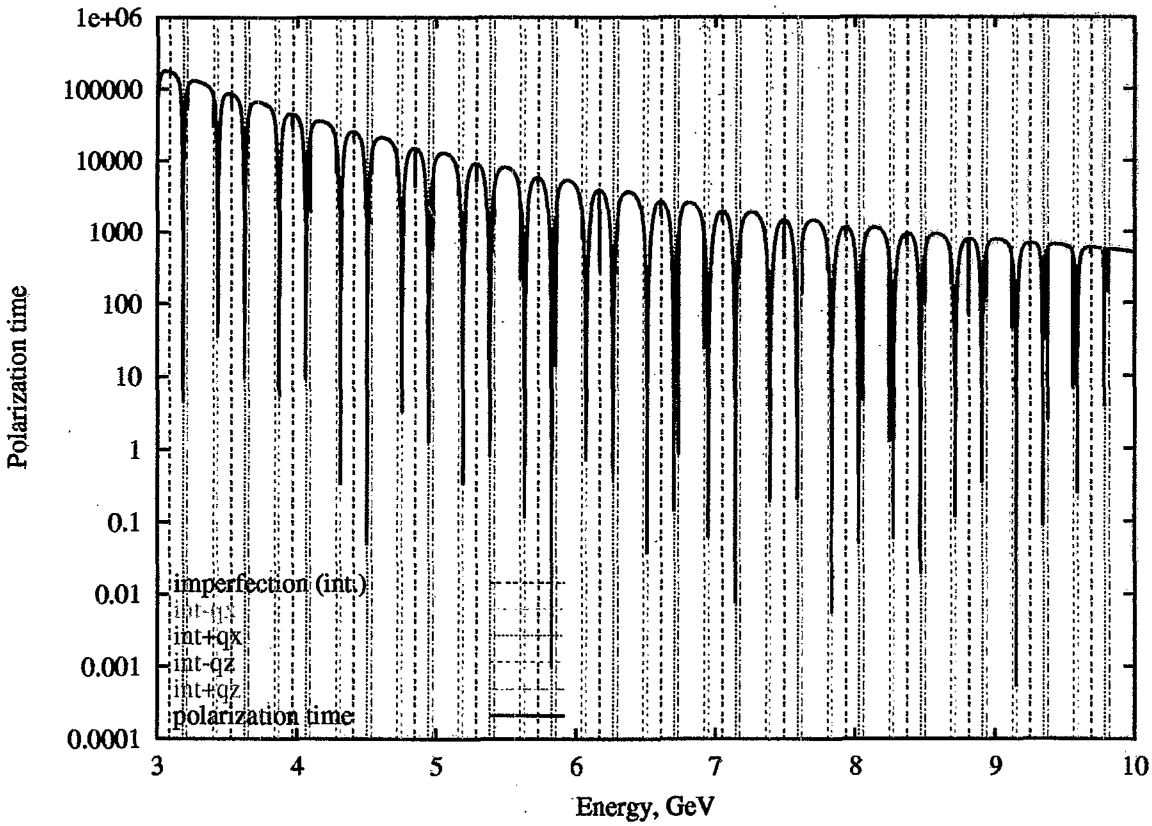


Vertical "dog-leg" scheme
No spin trancparency

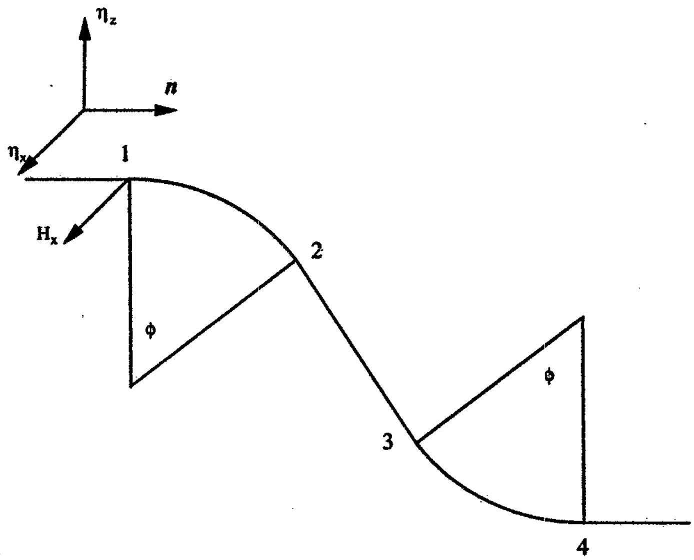


Vertical "dog-leg" scheme
No spin trancparency





Spin Transparency Conditions



The spin transparency condition we have to fulfill reads:

$$\int_1^4 \vec{w}\cdot\vec{\eta}\, d\theta = 0$$

The components of spin perturbation are:

$$w_x = v_0 z'' + v_0 H_x \frac{\Delta\gamma}{\gamma}$$

$$w_z = -v_0 x''$$

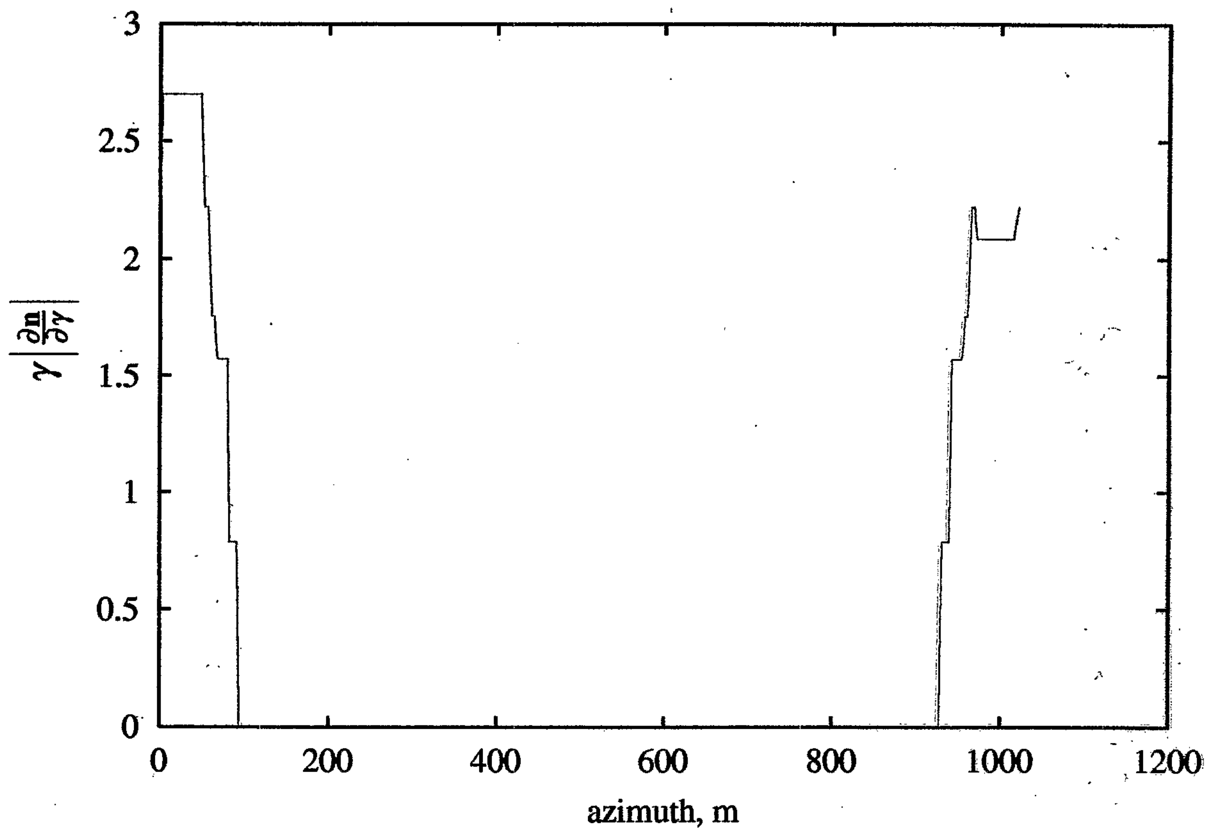
X component of the scalar product in integral gives:

$$z_4' - z_1' = 0$$

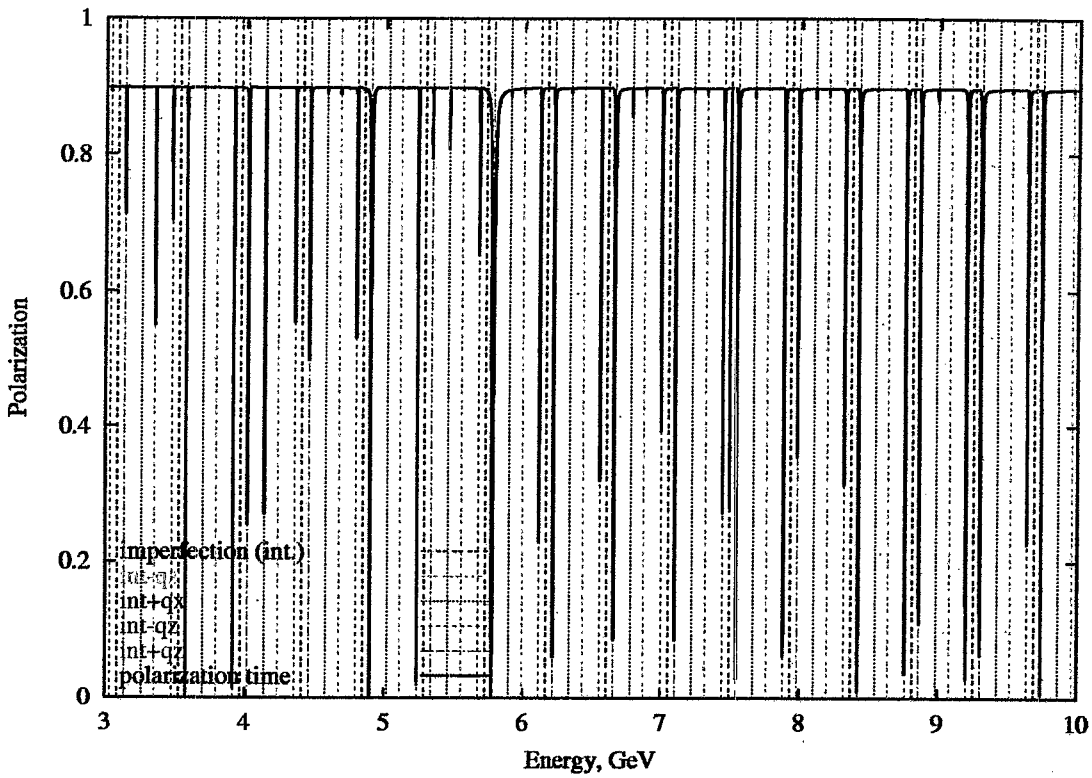
Considering Z component leads to:

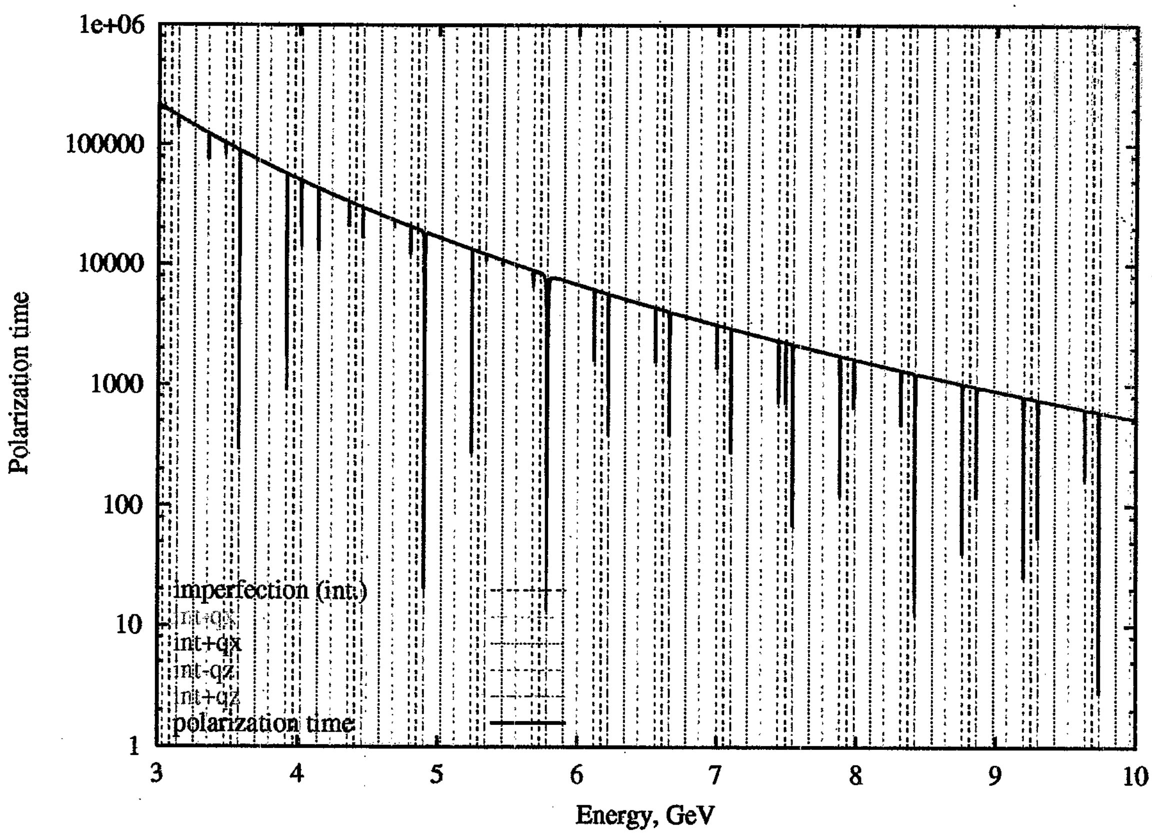
$$x_3' - x_2' = 0$$

Vertical "dog-leg" scheme



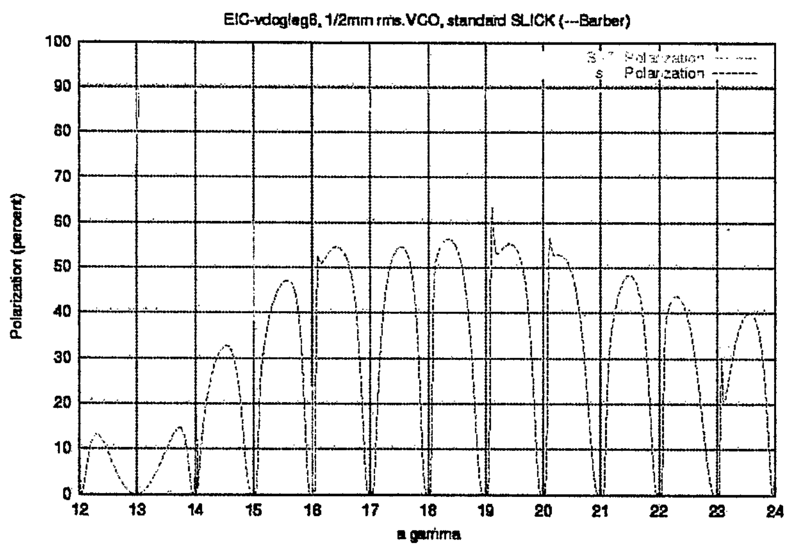
Vertical "dog-leg" scheme





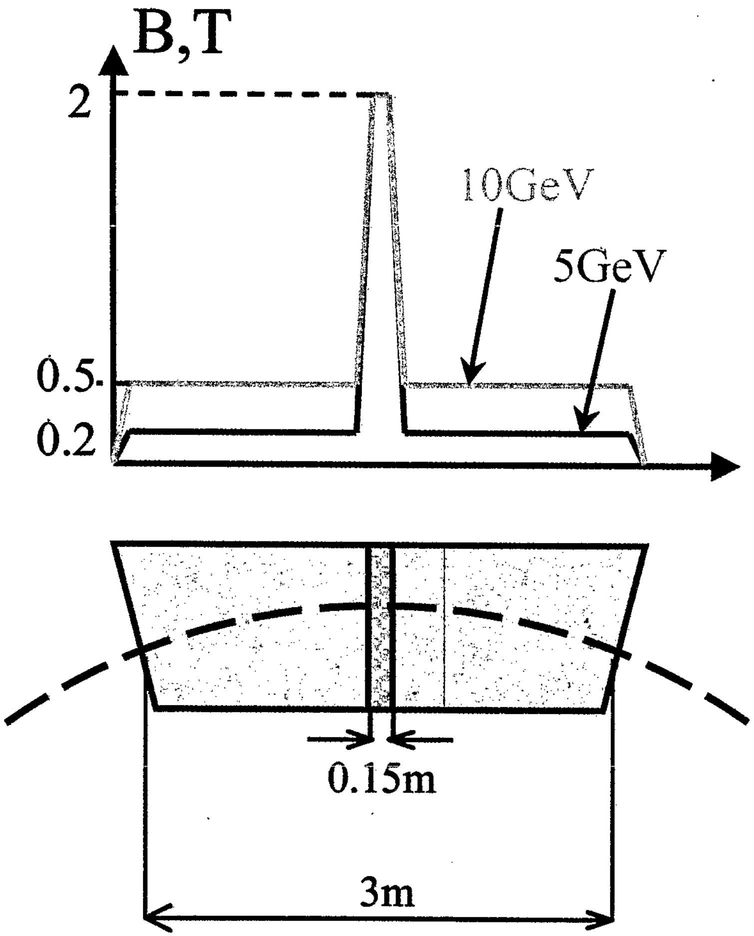
Equilibrium polarization

Depolarization from ring imperfections considerably decreases polarization level (D.Barber's calculations)



- 0.5mm rms closed orbit error assumed
- The correction scheme should be assumed in the design
- What polarimeters are available (for both longitudinal and transverse polarization?

Superbend magnet

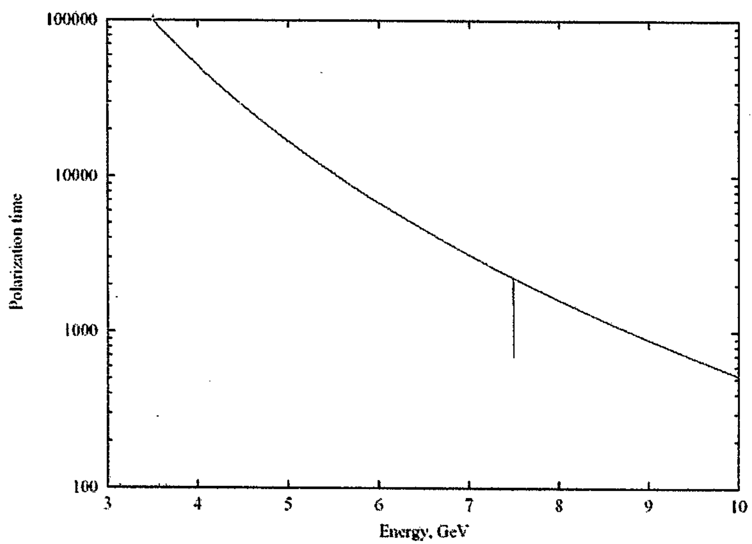


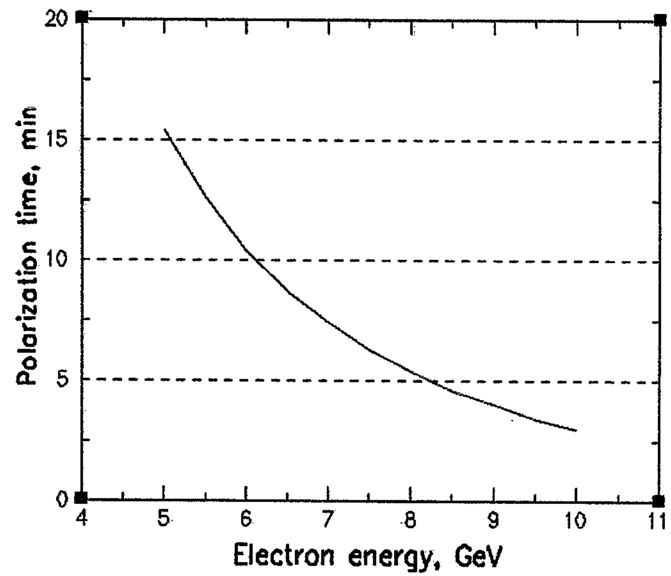
$$\tau_{pol}^{-1} \propto \gamma^2 H^3$$

Issues:

- Accomodation of radiated power (9MW radiated at 10 GeV)
- Orbit change inside the magnet versus beam energy (~1mm)
- Revolution frequency control ($\frac{\Delta f}{f} \approx 10^{-5}$)
- Emittance control

Polarization time with superbend





- All magnetic bending field scaled proportionally with energy

$$\tau_{pol}^{-1} \propto \frac{\gamma^5}{\rho^3}$$

- The central part of the superbend kept at constant field at any energy

$$\tau_{pol}^{-1} \propto \gamma^2 H^3$$

Conclusions

- The basic working design for electron beam is a self-polarizing storage ring based on adjustable superbend magnets
- Evaluation of p and e beam parameters shows that at current design the luminosity up to 5*E32 1/(s*cm2) is achievable at the 250 GeV p energy.
- The electron cooling of Au and proton beams is necessary to achieve and maintain the required beam emittances
- The more studies are needed to understand the beam-beam effects together with the electron cooling of RHIC ion beam
- The possibility to use smaller emittances and lower beta* at the interaction point should be evaluated. That should allow to relax requirements for the p and e beam currents
  - The small emittance electron beam lattice (like synchrotron source lattices) should be considered for this purpose
  - The lattice with superbends provides more flexibility for the emittance control

- Basic scheme to get longitudinal polarization of electron beam is the local spin rotator insertion using solenoidal field magnets.
- There are two basic schemes for interaction region design (with horizontal and vertical e-p beam separation respectively). More work is required to evaluate what is the better choice, particularly what is more suitable for redesign of the existing RHIC interaction regions and for experiment physics needs.
- Further studies to understand the effect of misalignments and field errors on the achievable level of electron beam polarization to define tolerances and determine possible correction schemes.
- It is important to look at what the polarimeter design might be. Preferably 2 polarimeters: for longitudinal and transverse polarization measurements.