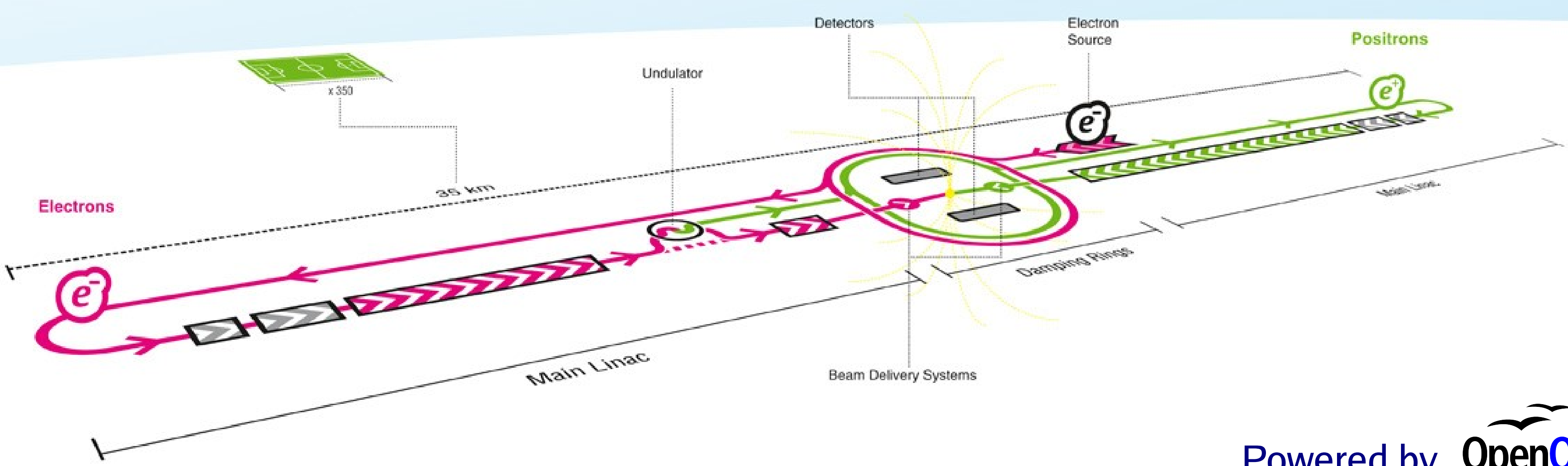
Spin Rotator for Linear Colliders

KURIKI Masao (Hiroshima/KEK)



Powered by OpenOffice.org

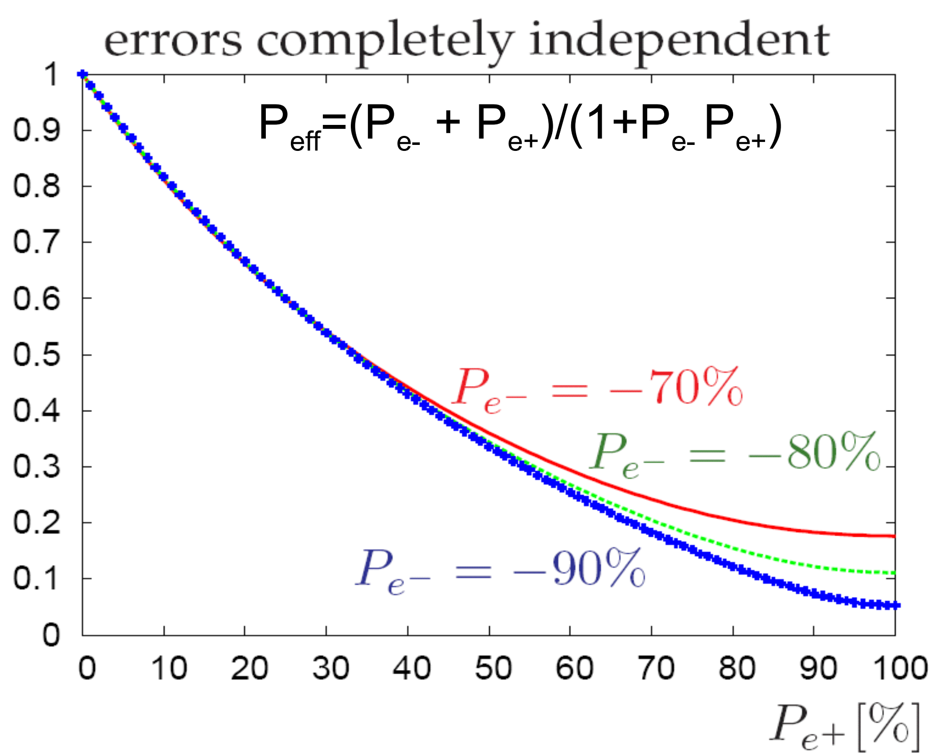
Outline

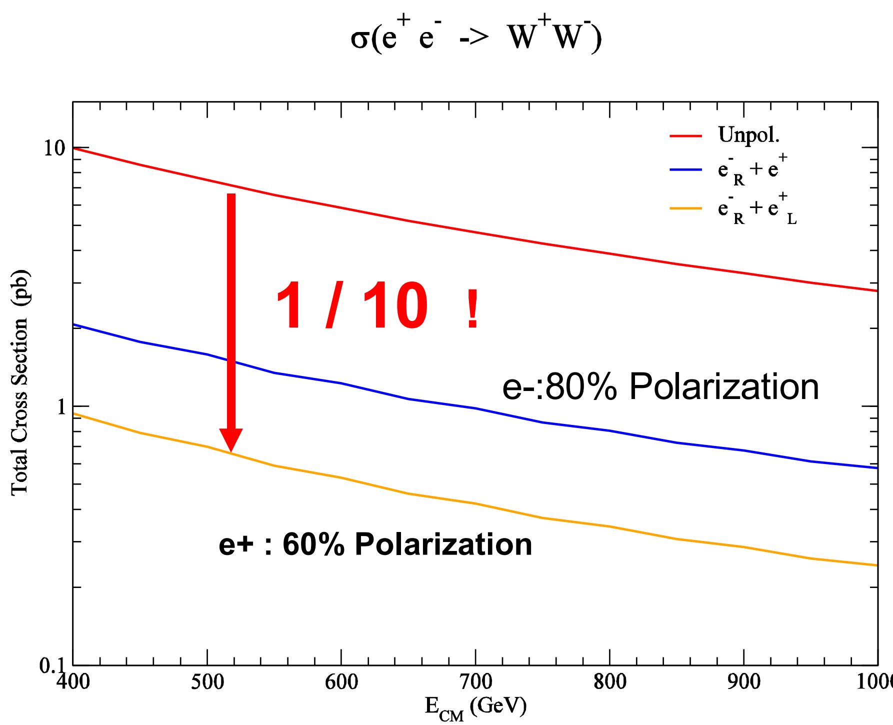
- Introduction.
- Fundamentals of Spin dynamics.
- ILC Spin Rotator.
- Summary.

Introduction (1)

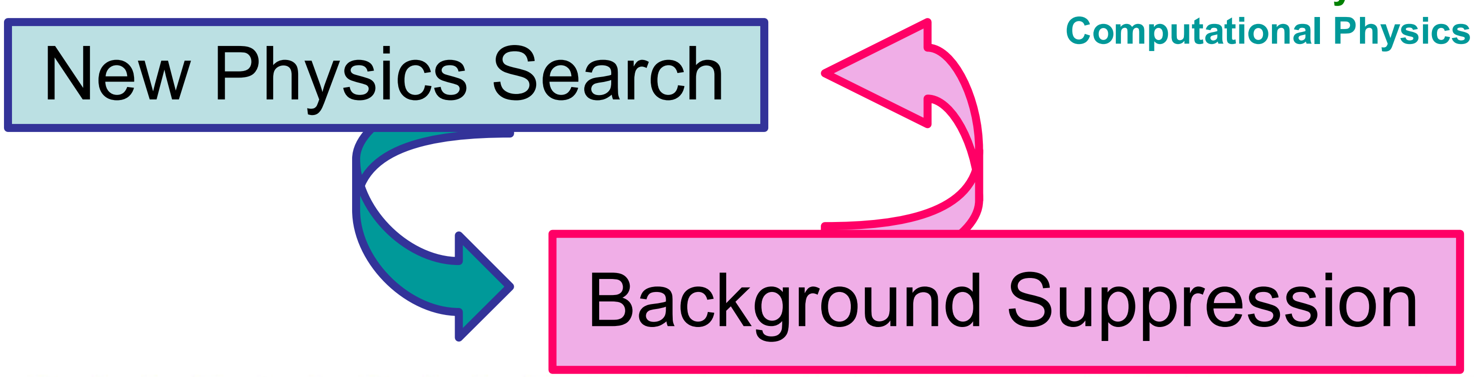
- Spin Control : Spin is one of the most important parameter in LC.
  - Determine the initial states.
  - Compensate the background processes through helicity selection.
  - Then, Spin direction of electrons (optionally positrons) at IP should be controlled as desired.
- Polarization Preserve :
  - Spin precession in DR with Energy Spread will destroy the polarization.
  - To preserve the polarization, spin direction has to be right perpendicular to the DR orbit plane.

Introduction (2)





with GRACE System Developed by
Computational Physics Group in KEK

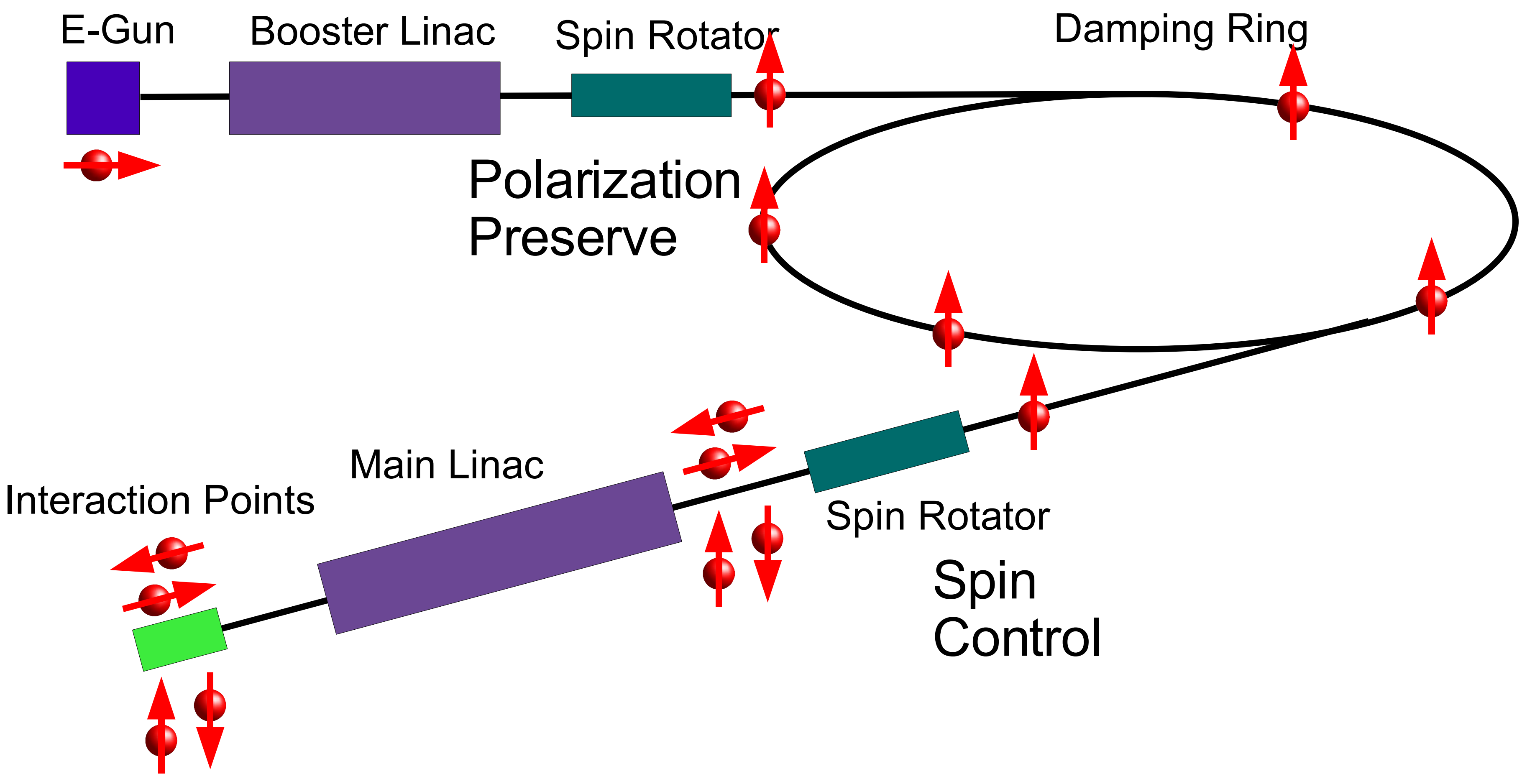


H. Shimizu/
S. Riemann

Polarization Preserve

- If the spin direction is not perpendicular to the horizontal plane, spin precesses during the storage.
- Because the precession frequency depends on the beam energy, the precession phase is randomized by energy spread.
- This randomization causes a significant depolarization. The spin direction has to be perpendicular to the horizontal plane to avoid this depolarization effect by the precession.

Spin Rotators in LC



Thomas-BMT Equation

$$\frac{d\vec{P}}{dt} = \vec{\Omega}_0 \times \vec{P}$$

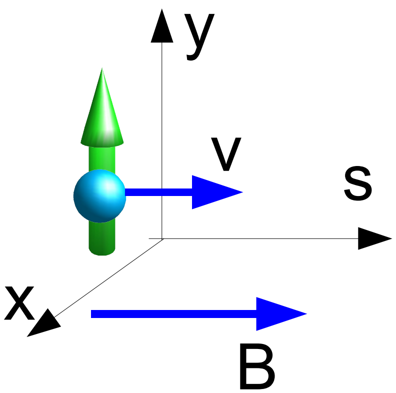
$$\vec{\Omega}_0 = \frac{-e}{m\gamma}\left[(1+G\gamma)\vec{B}_\perp + (1+G)\vec{B}_\parallel + \left(G\gamma + \frac{\gamma}{1+\gamma}\right)\frac{\vec{E}\times\vec{v}}{c^2}\right]$$

- $\vec{P}$: polarization vector.
- $G = \frac{g-2}{2}$ is anomalous magnetic moment, g is gyro-magnetic ratio ; G~0.00115965 for electrons.
- $\vec{E}, \vec{B}$: Electro and magnetic field.
- Do not worry if you can not imagine this complicated geometry.

Solenoid Magnet

- In solenoid field (only longitudinal B field):

$$\frac{d\vec{P}}{dt} = \frac{-e}{m\gamma}(1+G)\vec{B}_0 \times \vec{P}$$



- Integrating this equation,

$$\vec{P}(t) - \vec{P}(0) = \frac{e}{m\gamma}(1+G)\int B_0 \times \vec{P}\, dt$$

$$\phi(t) = \frac{\vec{P}(t) - \vec{P}(0)}{\vec{P}} = \frac{e}{m\gamma}(1+G)\sin\theta \int B_0\, dt$$

- If the initial polarization is purely transverse to B_0 and convert dt -> dt/ds ds,

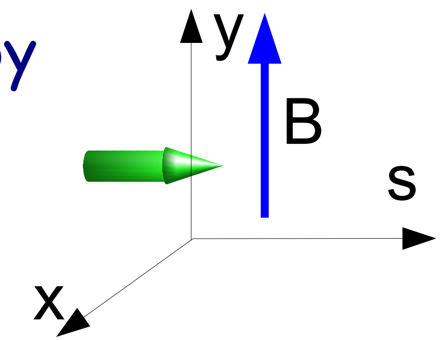
$$\phi(t) = \frac{e}{m\gamma\beta c}(1+G)\int B_0\, ds$$

Bending Magnet

- In dipole magnet (only vertical B field):

$$\frac{d\vec{P}}{dt}=\frac{-e}{m\gamma}(1+G\gamma)\vec{B}_0\times\vec{P}$$

- Bending angle of the particle trajectory by the dipole field is



$$\frac{d\vec{v}}{dt}=\frac{-e}{m\gamma}\vec{B}_0\times\vec{v}$$

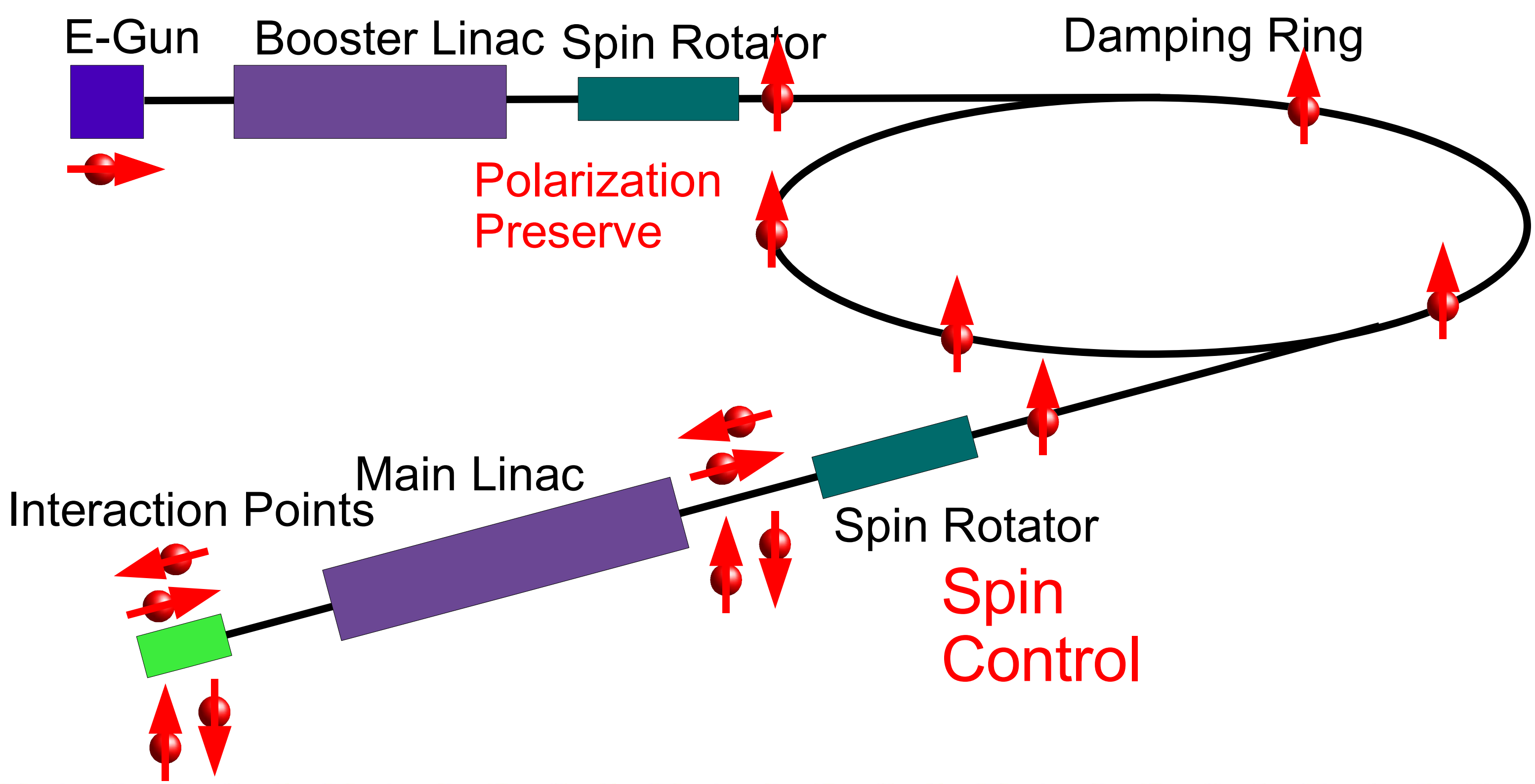
- Then, if we see the polarization vector co-moving frame with the particle velocity,

$$\frac{d\vec{P}'}{dt}=\frac{eG}{m}\vec{B}_0\times\vec{P}$$

$$\phi'(t)=\frac{\vec{P}'(t)-\vec{P}'(0)}{\vec{P}'}=\frac{eG}{m\beta c}\sin\theta\int B_0\,ds$$

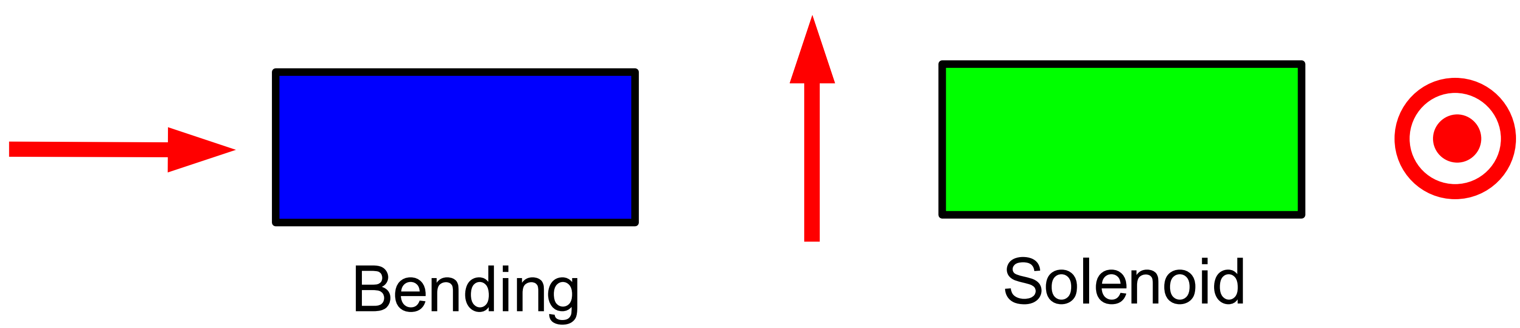
Spin Rotator in LC

- Longitudinal Polarization should be perpendicular before DR injection.
- Polarization control after DR.



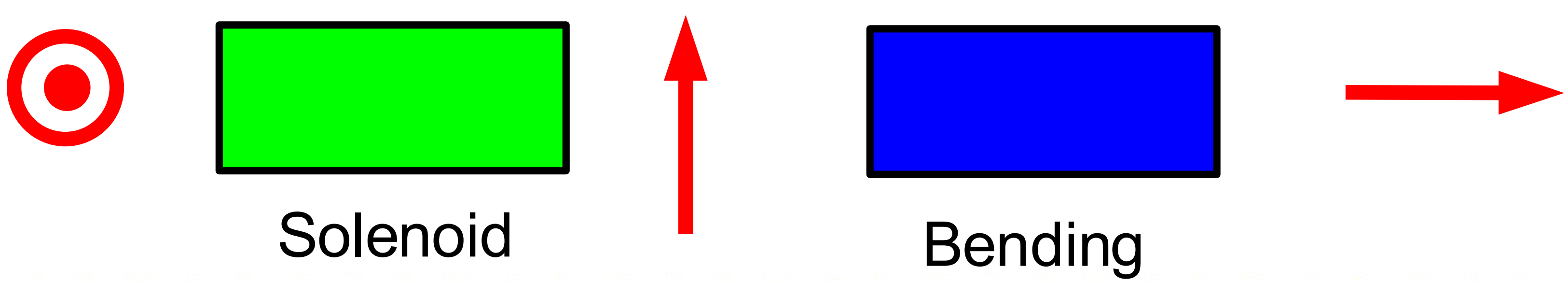
Before DR

- Spin direction of generated beam from the polarized electron source (or polarized positron source) is longitudinal.
- By passing many bendings, Spin precession in the horizontal axis.
- Spin direction can not be perpendicular to the horizontal plane only with bendings -> solenoid rotators are necessary.



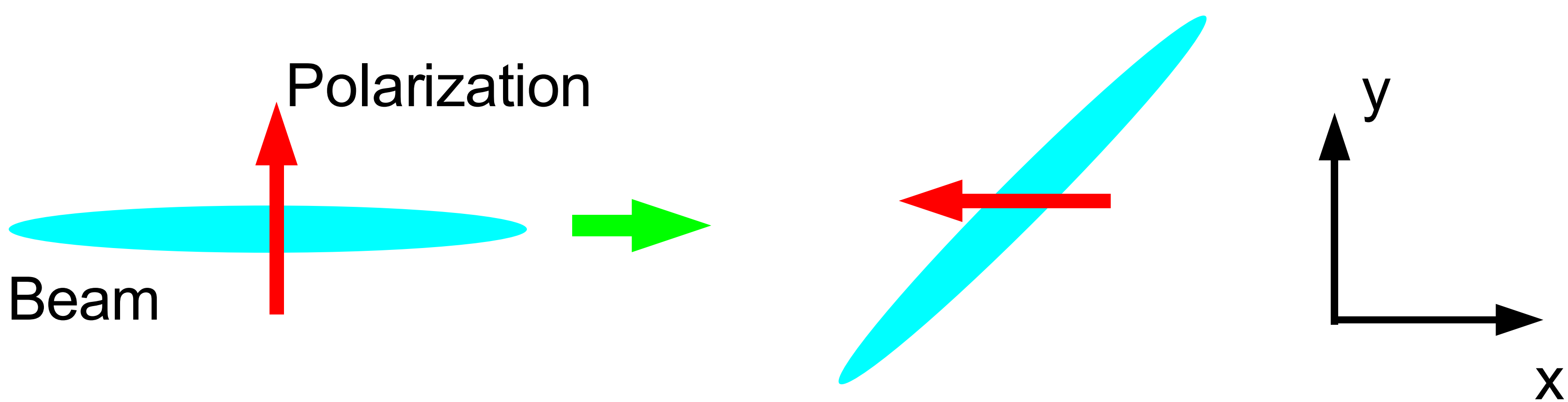
After DR

- Spin in DR is aligned to perpendicular to the horizontal plane.
- In RTML (Ring To Main Linac), this perpendicular polarization is preserved (unchanged) by bendings.
- This perpendicular polarization should be operated as desired:
  - Forward and backward longitudinal polarization.
  - Any transverse directions.



Emma Rotator (1)

- The transverse beam emittance has a large aspect ratio : 8μm in horizontal and 20 nm in vertical.
- Solenoid field rotates not only the spin, but also transverse phase spaces.
  - Solenoid increases the vertical emittance via the coupling between the horizontal and vertical motion.

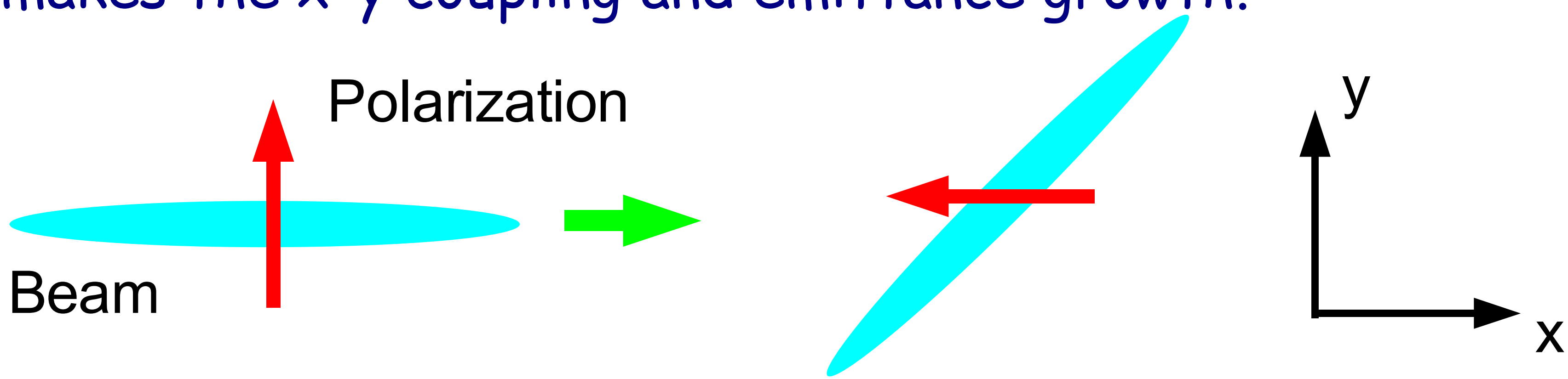


Emma Rotator (2)

- Roll by a solenoid magnet (φ_b) is one half of the spin rotation angle(φ_s)

$$\phi_s = 2\phi_b$$

- Spin rotation simultaneously rotate the beam orbit and makes the x-y coupling and emittance growth.



- Vertical emittance after this rotation is

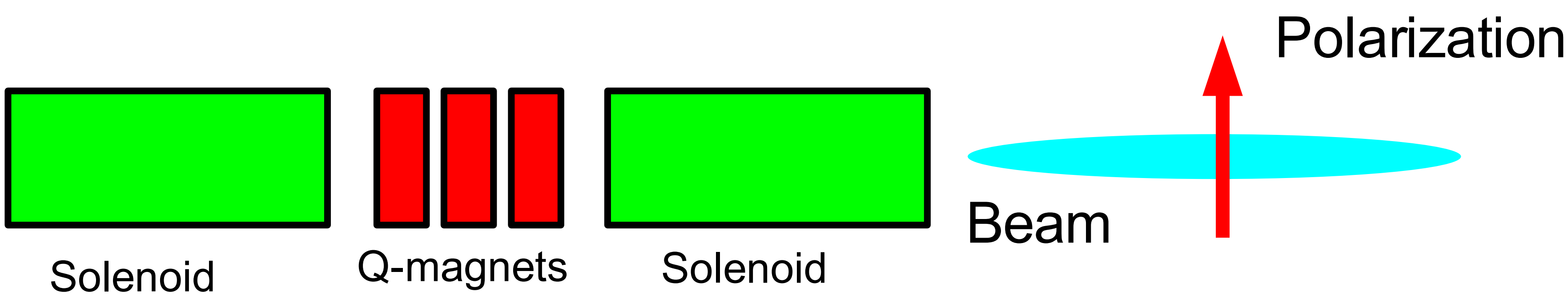
$$\epsilon_y^2 = \epsilon_{x0}^2 S^4 + \epsilon_{y0}^2 C^4 + \epsilon_{x0}\epsilon_{y0} C^2 S^2 (\beta_x \gamma_y - 2\alpha_x \alpha_y + \beta_y \gamma_x)$$

$$C \equiv \cos(\phi_s/2) \quad S \equiv \sin(\phi_s/2)$$

$$\alpha_{x,y}, \beta_{x,y}, \gamma_{x,y} : \textit{Twiss parameters}$$

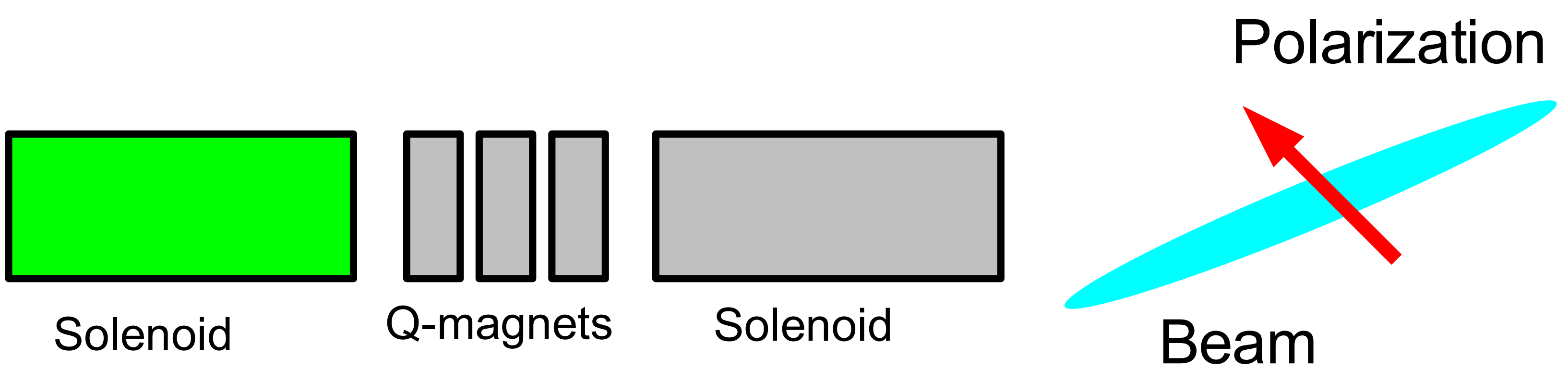
Emma Rotator (3)

- Is it possible to rotate only the spin and not the particle phase space? -> Yes, that is Emma rotator = Solenoid + Q magnets + Solenoid.
- Each solenoid rotates spin and phase space with exactly same amount.
- Q magnets change the betatron phase with 360 deg in x and 180 deg in y. Rotation by the two solenoids are canceled out (no emittance growth).
- The total rotation angle of Emma spin rotator is 2φ, where φ is rotation angle by a single solenoid.



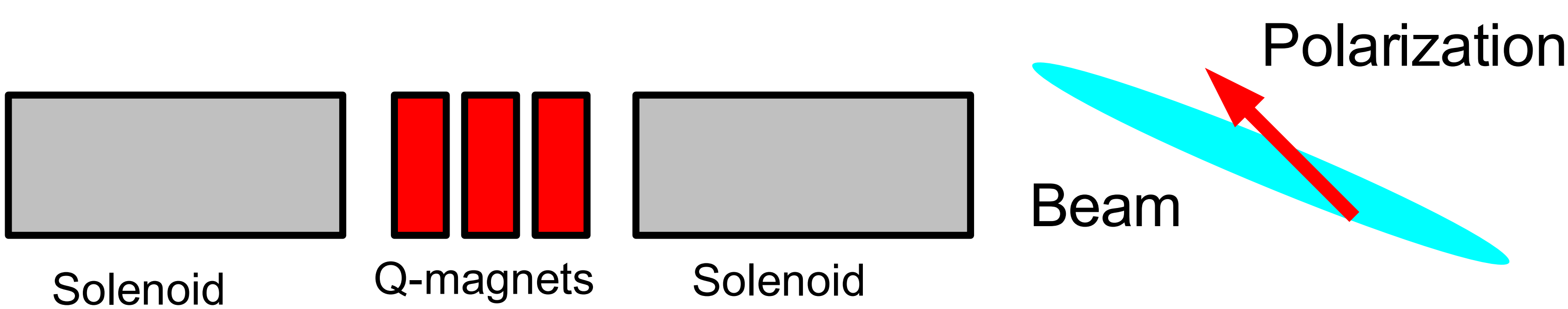
Emma Rotator (3)

- Is it possible to rotate only the spin and not the particle phase space? -> Yes, that is Emma rotator = Solenoid + Q magnets + Solenoid.
- Each solenoid rotates spin and phase space with exactly same amount.
- Q magnets change the betatron phase with 360 deg in x and 180 deg in y. Rotation by the two solenoids are canceled out (no emittance growth).
- The total rotation angle of Emma spin rotator is 2φ, where φ is rotation angle by a single solenoid.



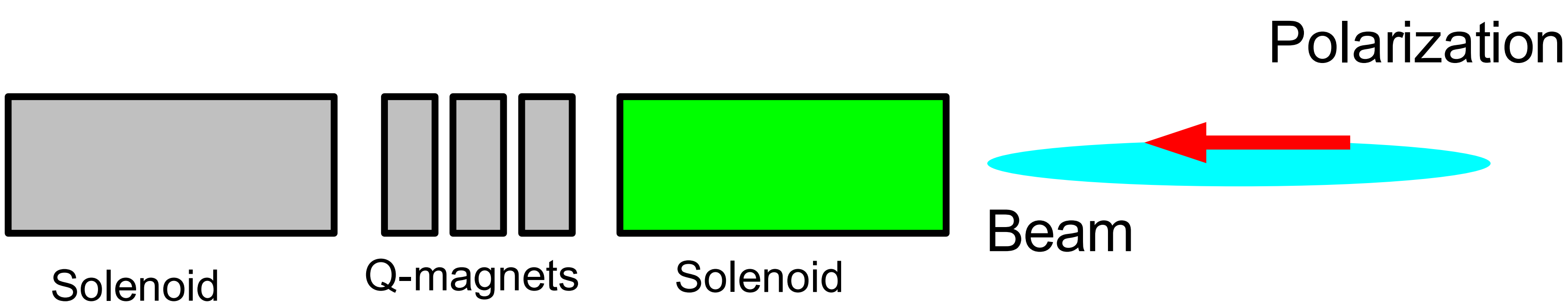
Emma Rotator (3)

- Is it possible to rotate only the spin and not the particle phase space? -> Yes, that is Emma rotator = Solenoid + Q magnets + Solenoid.
- Each solenoid rotates spin and phase space with exactly same amount.
- Q magnets change the betatron phase with 360 deg in x and 180 deg in y. Rotation by the two solenoids are canceled out (no emittance growth).
- The total rotation angle of Emma spin rotator is 2φ, where φ is rotation angle by a single solenoid.



Emma Rotator (3)

- Is it possible to rotate only the spin and not the particle phase space? -> Yes, that is Emma rotator = Solenoid + Q magnets + Solenoid.
- Each solenoid rotates spin and phase space with exactly same amount.
- Q magnets change the betatron phase with 360 deg in x and 180 deg in y. Rotation by the two solenoids are canceled out (no emittance growth).
- The total rotation angle of Emma spin rotator is 2φ, where φ is rotation angle by a single solenoid.



Transfer Matrix

- Transfer matrix of a solenoid

$$R_S = \begin{bmatrix} C^2 & SC/k & SC & S^2/k \\ -kSC & C^2 & -kS^2 & SC \\ -SC & -S^2/k & C^2 & SC/k \\ kS^2 & -SC & -kSC & C^2 \end{bmatrix}$$

- Inserting a reflector beam line between two solenoids, the matrix is

$$R_S \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix} R_S = \begin{bmatrix} C & S/k & 0 & 0 \\ -kS & C & 0 & 0 \\ 0 & 0 & -C & S/k \\ 0 & 0 & kS & -C \end{bmatrix}$$

- X-Y coupling terms are vanished by this insertion. Emittance growth by the coupling is cured.

Spin Manipulation Summary

- Spin rotator = Solenoid Rotator + Dipole Rotator + Solenoid Rotator.
  - Solenoid rotator consists of two solenoid magnets and one reflector between them.
- Changing the angle of the solenoid rotators, spin direction can be controlled as desired.

Initial	Solenoid 1	Dipole	Solenoid 2	Final
↑	90	90	90	→
↑	0	90	0	↑
↑	0	90	90	◎
↑	180	90	0	↓
↑	180	90	90	×
↑	-90	90	0	←

Summary

- Spin rotators in LC has two rolls.
  - Polarization preservation (spin rotation before DR).
  - Spin control (spin rotation after DR).
- Spin rotation without any xy coupling (vertical emittance growth), is implemented by Emma rotator.
- With these Spin rotators, the longitudinally polarized beam generated at E-Gun (positron source) is transported without any significant depolarization and collisions with any combination of spin directions at interaction point are implemented.

References

- P. Emma, "A Spin Rotator System for the NLC", NLC note 7 (December 1994)
- P. Schmid and N. Walker, "A Spin Rotator for the ILC", EUROTeV-Report-2006-68 (June 2006)
- P. Schmid "A Spin Rotator for the ILC", EUROTeV-Report-2005-24 (Feb 2006)

Home Work

- 4-1) Derive Precession angle by Solenoid rotator (page 8) from Thomas-BMT Equation.
- 4-2) Calculate the bending magnetic field (T.m) to rotate the spin vector with 90 deg.