RESONANT DEPOLARIZATION AT THE ILC DR WITH RF DIPOLES

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DESY

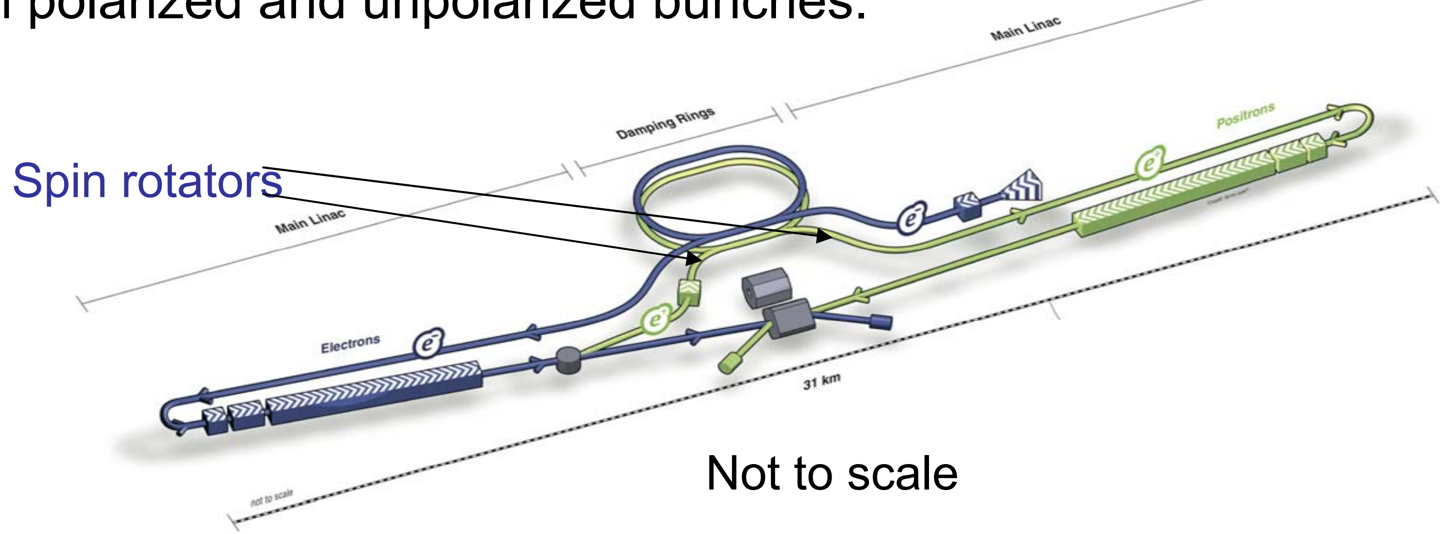
MOTIVATION

•ILC goal is high precision measurement. *All systematic errors have to be identified.*

•The technique of “spin flipping” can be applied. The orientation of the positron beam polarization is controlled by spin rotators.

•*A fast and random flipping* between the beam polarization orientations *reduces systematic uncertainties* substantially.

• *Unpolarized configuration* is needed for control. To *exclude systematic errors* one could *depolarize some of the bunches*, and compare the data from polarized and unpolarized bunches.



SPIN TUNE

In a flat ring, with no solenoids, the design orbit is closed planar curve which turns a total of 2π radians around the vertical dipole fields in one pass.

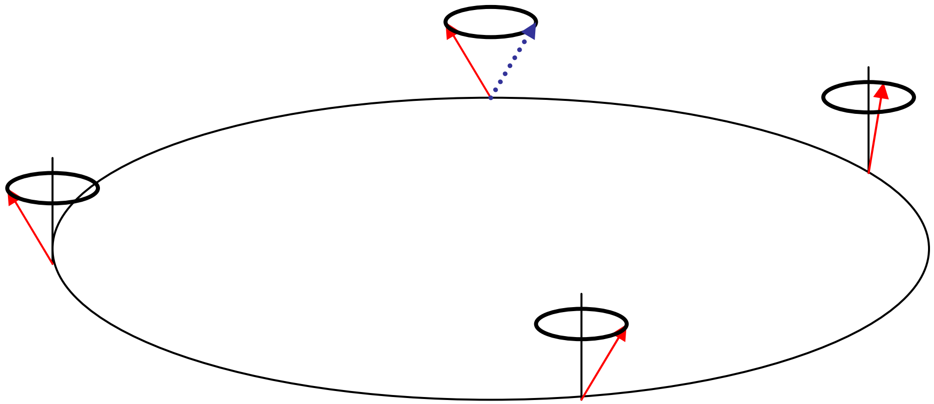
W.r.t. this orbit, a spin precesses by 2πGγ around the vertical.

Spin tune is the number of spin precessions during each turn around the ring.

ILC DR 5 GeV:

$$\nu = G\gamma = \left(\frac{g-2}{2}\right)\gamma = 11.35$$

e±: g = 2 .0023



RESONANT DEPOLARIZATION

- Resonant depolarization is produced by exciting the beam with an oscillating magnetic field (kicker).

- A resonance occurs when the rf magnetic field's frequency f_r is synchronized with the spin tune ν_s and the circulation frequency f_c:

$$f_r = f_c(n \pm \nu_s)$$

- When the kicker frequency is close to the resonant frequency, the kicks add up coherently, and the cumulative effect of the kicks is to tilt the spins strongly away from the vertical.

FROISSART-STORA FORMULA

Froissart and Stora (1960)

$$\frac{P_f}{P_i} = 2\exp\left\{\frac{-\pi\,|\,\varepsilon\,|^2}{2\alpha}\right\} - 1$$

$$\varepsilon = \frac{(1+G\gamma)\int B_\perp dl}{4\pi B\rho}$$

is resonance strength of one rf dipole.

Application of Froissart–Stora formula assumes that the *depolarizing resonances are narrow and well-separated*. Hence the beam *crosses only one resonance* at a time.

α is the rate of resonance crossing (crossing speed).
If the rf dipole tune is swept across an interval ΔQ in N turns, then $\alpha = \frac{\Delta Q}{2\pi N}$

Three distinct conditions for the variation rate crossing ΔQ are:

Rate	Polarization	Effect
Fast crossing	$P_f = P_i$	No depolarization
Medium crossing	$P_i > P_f > -P_i$	Partial depolarization
Slow crossing	$P_f = -P_i$	Spin-flip

NUMERICAL SIMULATION MODEL

Spin vector gets precessed around the horizontal X-axis at every *m*th turn $\frac{(1+G\gamma)\cdot B_m L}{B\rho}$

$B_m L = B_\perp L \cos(\varphi_{dip})$ is the field of the rf dipole on the *m*th turn

At each revolution period, the dipole phase increases by $\Delta\varphi_{dip} = 2\pi\nu_{dip}$

The tune of the dipole oscillation is $\nu_{dip} = \nu_0 + m(\nu_1 - \nu_0)/N$

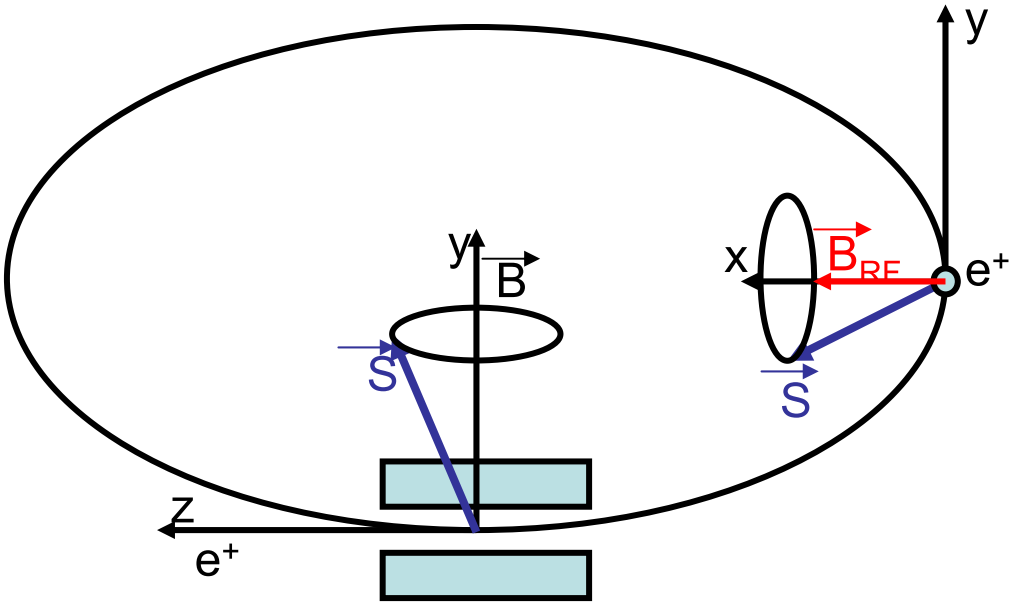
$$\nu_1 = \nu_s + \pi\alpha N \qquad \nu_0 = \nu_s - \pi\alpha N$$

Scan dipole frequency across spin resonance to depolarize the beam

$$\alpha = \frac{\nu_1 - \nu_0}{2\pi N}$$

A spin resonance is observed

$$\nu_{dip} = \nu_s$$



SAMM and SPRINT

- SAMM code: Simple Accelerator Modelling in Matlab
(by Andy Wolski, University of Liverpool and Cockcroft Institute)

http://pcwww.liv.ac.uk/~awolski/

- SPRINT code written by: G.H. Hoffstaetter (Cornell University) and M. Vogt (DESY).

G.H.Hoffstaetter, ``High-Energy Polarized ProtonBeams, A Modern View'', Springer Publishing, Tracts in Modern Physics (2006).

M. Vogt, ``Bounds on the maximum attainable equilibrium spin polarization of protons in HERA'', DESY-THESIS-2000-054 (Dec.2000).

SAMM

Tracking particles through components achieved by applying *dynamical maps.*

The dynamical map for any component is obtained by:

1. Writing down the scalar and vector potentials for the electromagnetic fields in the component;

2. Constructing the Hamiltonian using the expressions for the scalar and vector potentials;

3. Integrating Hamilton's equations over the length of the component.

SAMM and SPRINT

Spin dynamics is described by Thomas-BMT equation:

$$\frac{d\vec{S}}{dt} = \vec{\Omega} \times \vec{S}$$

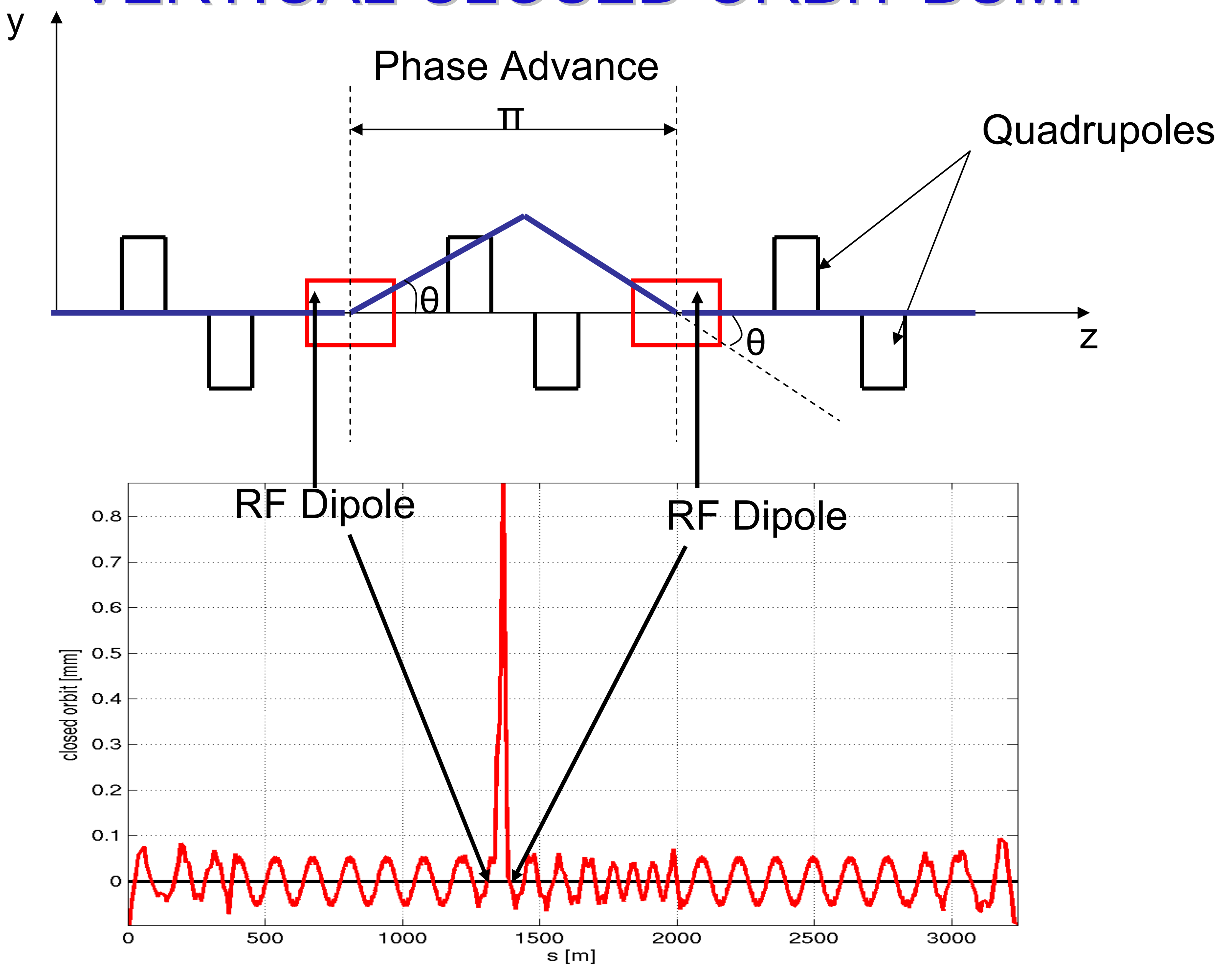
Instantaneous polarization: $$\vec{P}_{inst}\Big|_{turn\ j} = \frac{1}{m}\sum_{i=1}^{m} \vec{S}_i\Big|_j$$

$If \quad \left\{\vec{S}_i\right\}_{1\le i\le m}$ is not an equilibrium ensemble, then instantaneous polarization will vary (more or less) strongly.

Spin tracking in SPRINT is based on transport of Unit Quaternion with the spin-orbit coupling by a renormalized 1-st order expansion in the orbital coordinates.

Multiturn polarization: $$\vec{P}_{mult} = \frac{1}{N}\sum_{j=1}^{N} \vec{P}_{inst}\Big|_j$$

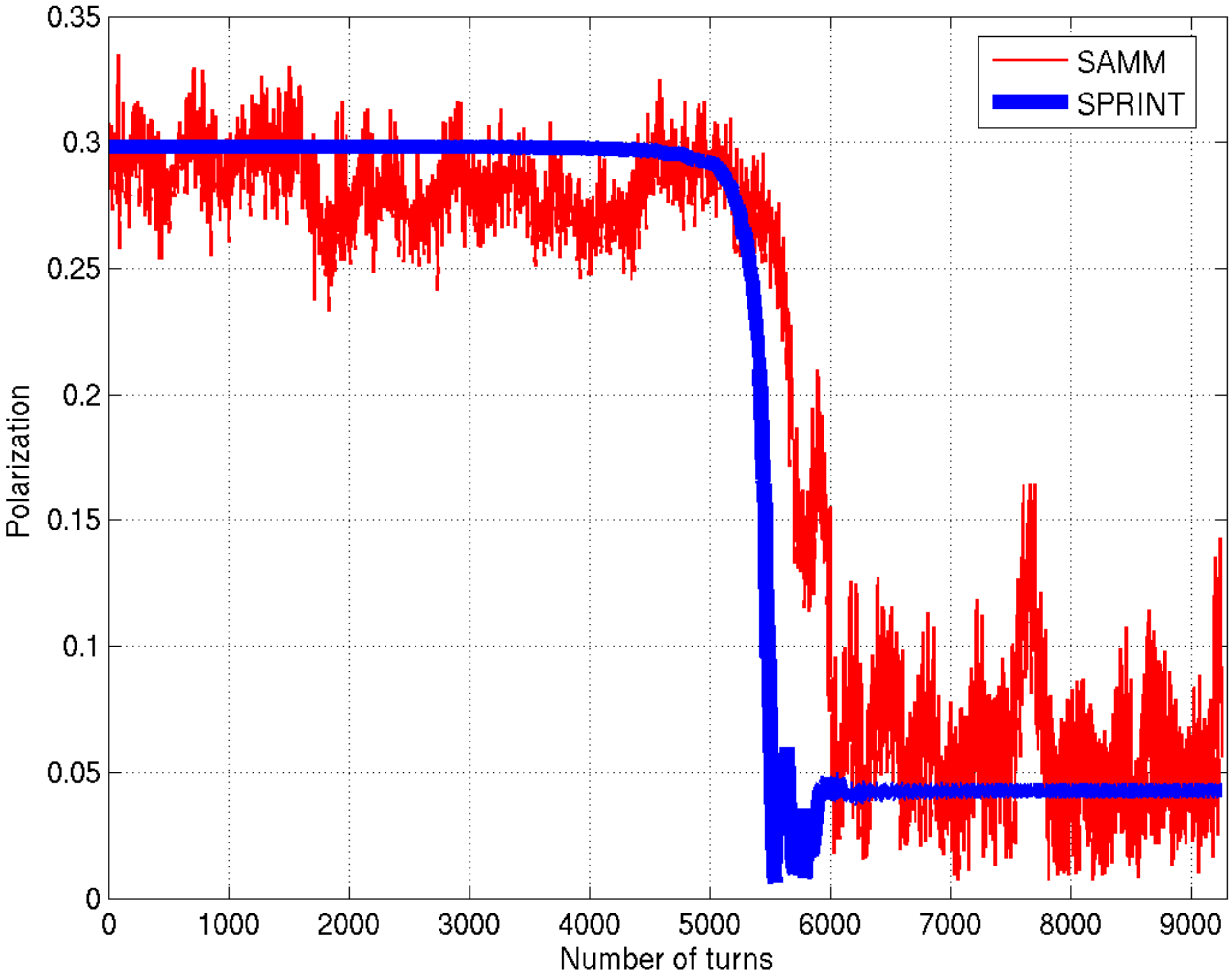
VERTICAL CLOSED ORBIT BUMP



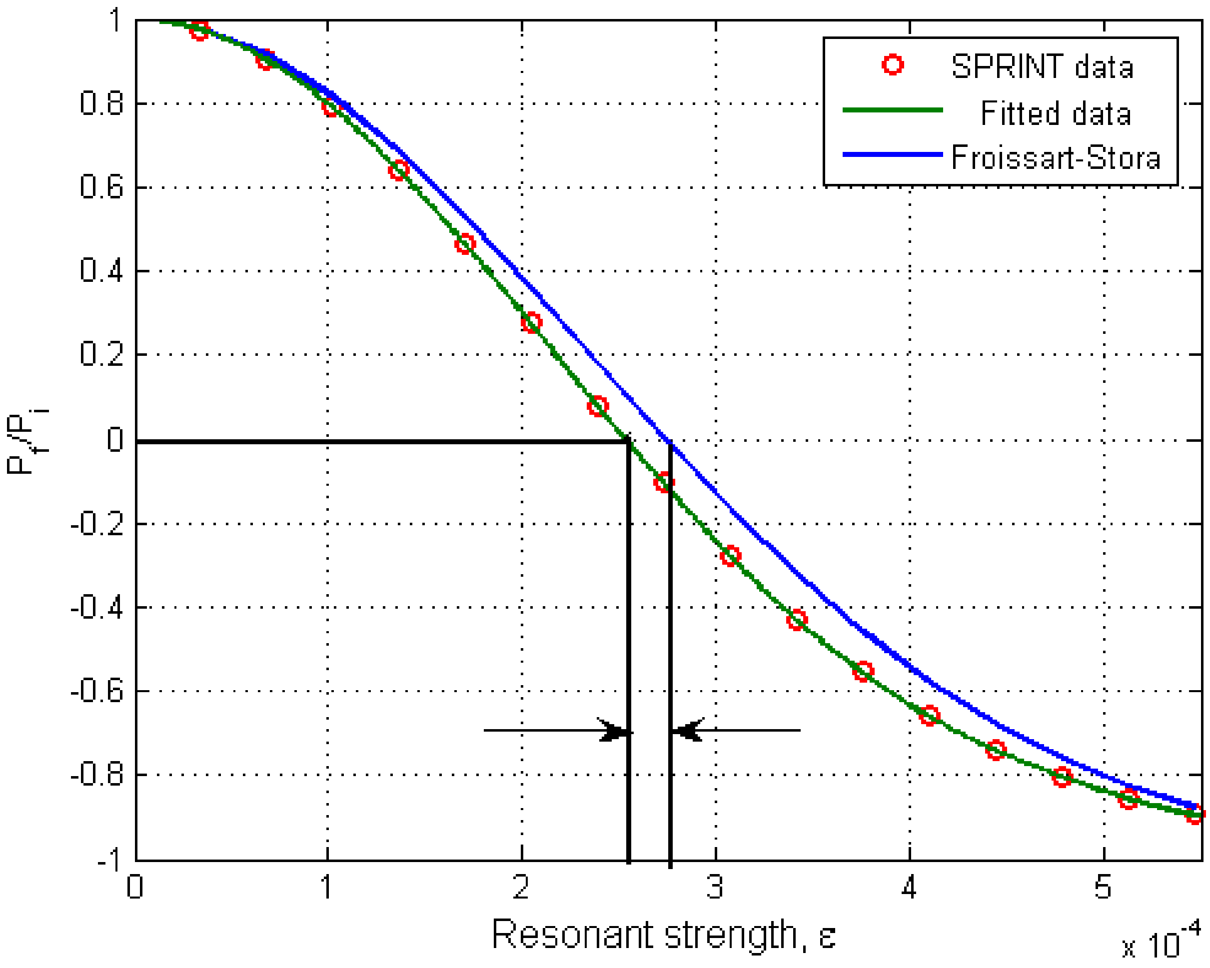
SIMULATION PARAMETERS

- Initial polarization (vertical): 30%
- Spin tune Gγ=11.35
- Revolution frequency f_c=92.56 kHz
- Resonance frequency=60.17 kHz
- Store time T_{store}=100 ms
- Number of turns= $T_{store} \cdot f_c = 9256$
- Normalized emittances: $\varepsilon_{n,x} = \varepsilon_{n,y} = 0.05$ m rad
  $\varepsilon_{n,z} = 0.01$ m rad

COMPARISON BETWEEN SAMM AND SPRINT

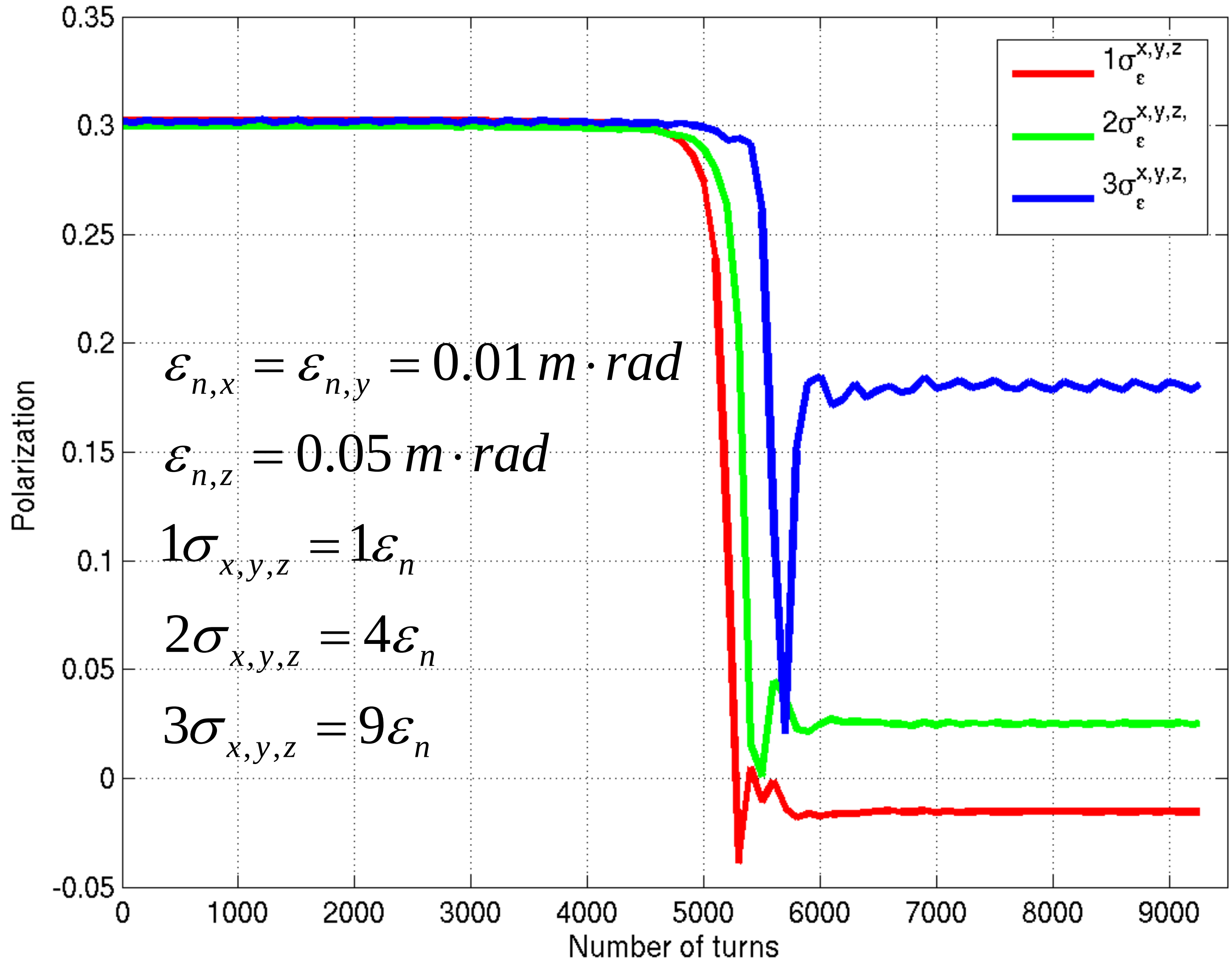


SPRINT AND FROISSART-STORA



$\Delta\varepsilon/\varepsilon = 0.2 \cdot 10^{-4} \,/\, 2.5 \cdot 10\text{-}4 = 8\%$

DIFFERENT BEAM SIZES



CONCLUSIONS AND OUTLOOK

•Our first results have indicated that it is feasible to apply an unpolarized configuration mode via resonant depolarization technique at the ILC.

•Different codes were used for simulation of resonant depolarization through the ILC DR lattice. SAMM and SPRINT simulation data are in a reasonable agreement.

•Effects of synchrotron radiation and radiation damping have to be included.

•Beam dynamics and spin tracking have to be investigated for both polarized and unpolarized modes.