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Polarization Study for CEPC

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Acknowledgements:

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Outline

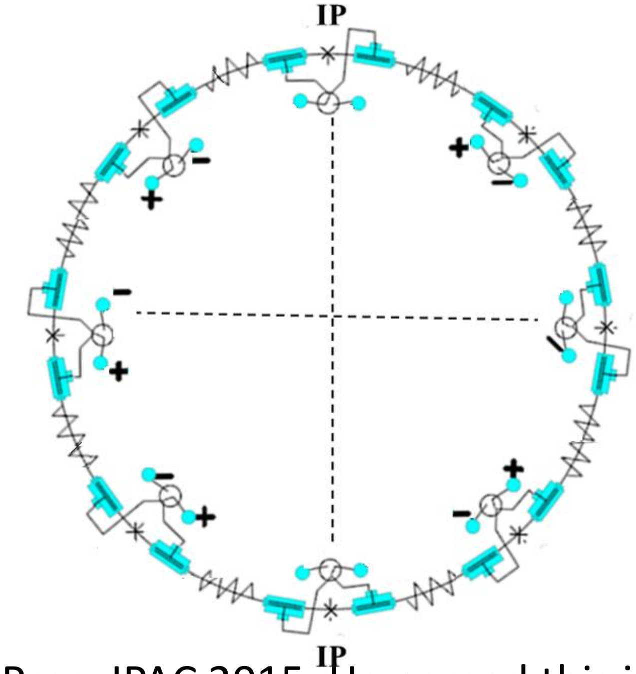
- Motivation
- Analytical Analysis of CEPC polarization
- Simulation Tool Development
- Conclusion

Motivation

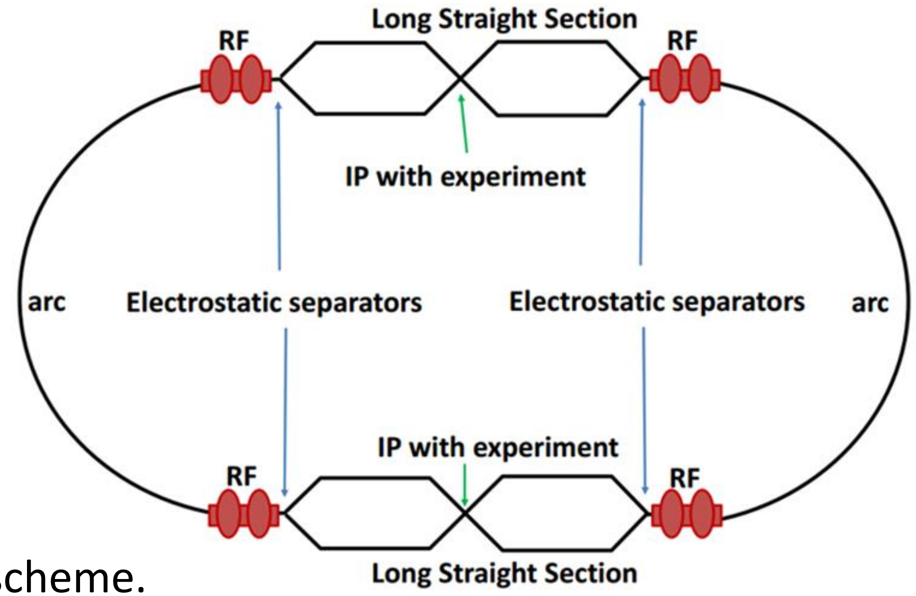
- Energy calibration with polarized beam @ LEP was a major achievement from both accelerator and particle physics point of view.
- CEPC pre-CDR focused on accelerator design for 120GeV, with an appendix considering Super-Z option(U. Wienands & M. Sullivan).
- More detailed study of operation for Z & W are supposed to be contained in CEPC CDR, where beam polarization is one important aspect.

CEPC schemes regarding energy calibration

- Single ring (pretzel orbit)
  - Similar to LEP
  - Energy calibration of one beam
  - Energy calibration only after physics



- Partial double ring[1]+crab waist
  - Similar to FCC-ee
  - Energy calibration of both beams possible
  - Beam energy monitoring throughout each fill with non-colliding bunches



[1] M. Koratzinos, Proc. IPAC 2015. He named this idea as the “bowtie” scheme.

CEPC self-polarization parameters (54km)

Wangdou 20160325 & Wangdou 20160329

Parameters	Single Ring Z	Partial Double Ring Z	Partial Double Ring W
beam energy(GeV)	45.5	45.5	80
radius of curvature(km)	6.1	6.1	6.1
circumference(km)	54	54	54
momentum compaction factor	3.4e-5	3.5e-5	2.4e-5
energy spread(MeV) σ_ε	22.75	22.75	72.
synchrotron tune Q_z	0.097	0.039	0.057
polarization build-up time(hour)	44.9	44.9	2.67
spin tune spread $\sigma_v = a\gamma\, \sigma_\varepsilon$	0.052	0.052	0.16
modulation index $\sigma = \sigma_v / Q_z$	0.530	1.34	2.86

It was experimentally shown in LEP increased energy spread leads to reduced equilibrium polarization. According to A. Blondel, 52MeV is tentatively regarded as the maximum energy spread allowing useful polarization for beam calibration. Need detailed simulation to justify.

CEPC self-polarization parameters (88km)

Wangdou 20160329

Parameters	Partial Double Ring Z	Partial Double Ring W
beam energy(GeV)	45.5	80
radius of curvature(km)	9.	9.
circumference(km)	88	88
momentum compaction factor	1.9e-5	1.9e-5
energy spread(MeV) σ_ε	18.2	56.
synchrotron tune Q_z	0.027	0.052
polarization build-up time(hour)	159	9.5
spin tune spread $\sigma_v = a\gamma\, \sigma_\varepsilon$	0.041	0.127
modulation index $\sigma = \sigma_v / Q_z$	1.51	2.42

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CEPC self-polarization parameters (100km)

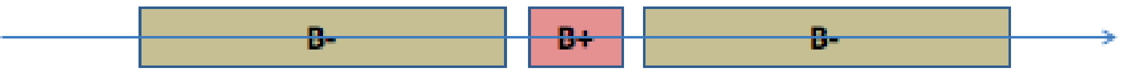
Wangdou 20160329

Parameters	Partial Double Ring Z	Partial Double Ring W
beam energy(GeV)	45.5	80
radius of curvature(km)	11	11
circumference(km)	100	100
momentum compaction factor	1.3e-5	1.4e-5
energy spread(MeV) σ_ε	16.8	52.
synchrotron tune Q_z	0.0194	0.038
polarization build-up time(hour)	270.	16.1
spin tune spread $\sigma_v = a\gamma\, \sigma_\varepsilon$	0.038	0.118
modulation index $\sigma = \sigma_v / Q_z$	1.97	3.10

It was experimentally shown in LEP increased energy spread leads to reduced equilibrium polarization. According to A. Blondel, 52MeV is tentatively regarded as the maximum energy spread allowing useful polarization for beam calibration. Need detailed simulation to justify.

Polarization wigglers

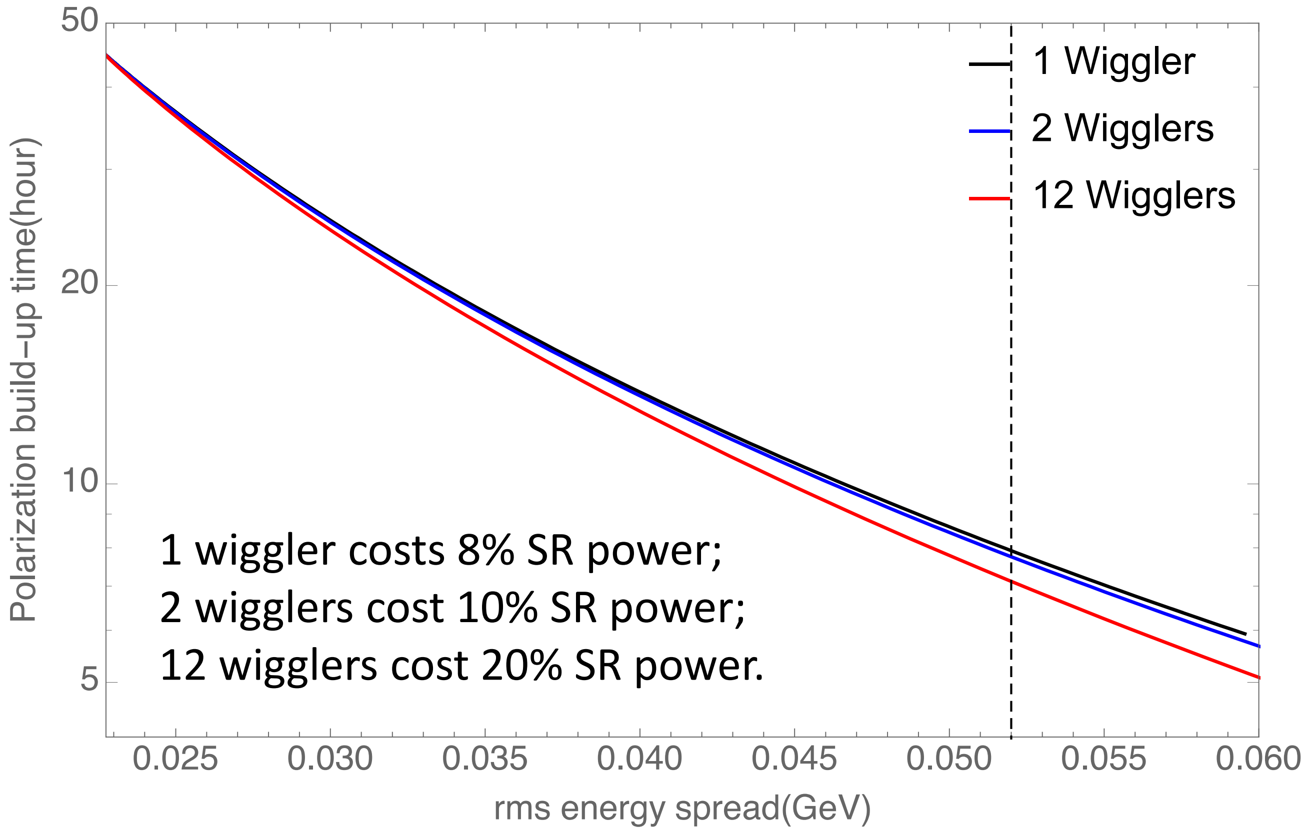
- 5~10% polarization is needed for energy calibration. ~ 1/10 polarization build-up time is needed. Polarization wigglers can further boost the process.



- LEP type polarization wiggler is assumed,

B+ / B- = 6.25.

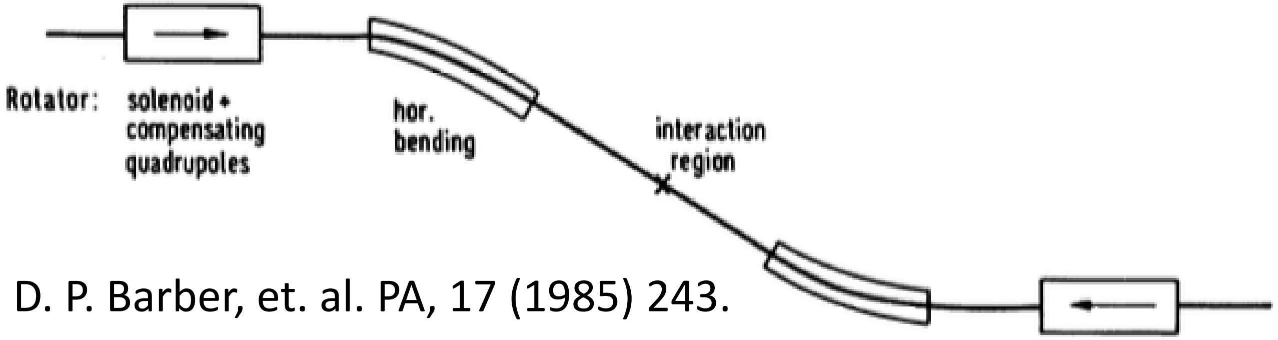
- ~ 40min to reach 10% polarization.
- In partial double ring scheme, a scheme similar to FCC-ee can be adopted. A small fraction of non-colliding bunches, after 45min, every 10min one bunch is depolarized to continuously monitor beam energy.



Longitudinal Polarized e+/e- colliding beams

- SLC vs. LEP
- Longitudinally polarized e+ / e- beams @45GeV, tentatively speaking, pol > 40% is needed.
- Self-polarization needs too long time. Injection of pol e+/e- beams is needed.
- A whole chain of polarized beam generation, transportation, acceleration and storage is needed.

Longitudinal polarization maintenance @Z-pole

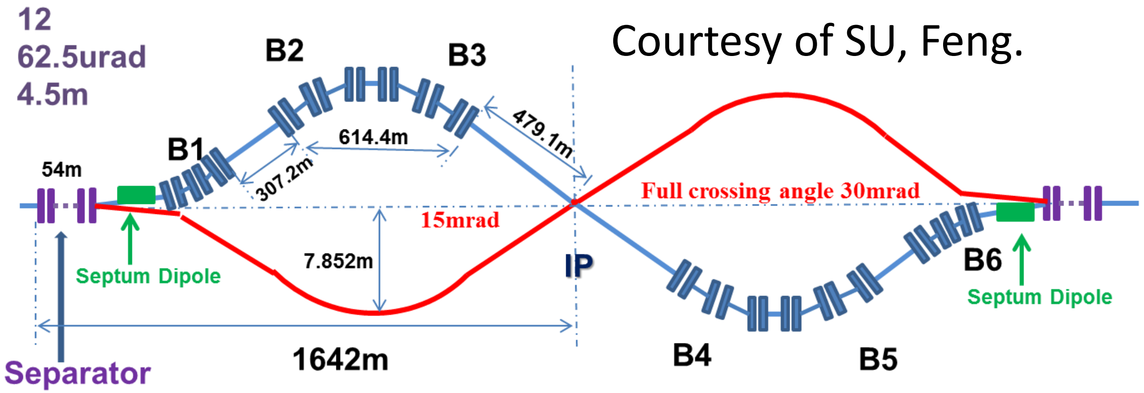


D. P. Barber, et. al. PA, 17 (1985) 243.

FIGURE 3a A rotation system with antisymmetric dipole arrangement.

- $\pi/2$ spin rotation around vertical direction requires a 15mrad horizontal bending @ 45GeV. (I. Koop HF2014)
- CEPC partial double ring scheme is compatible with such a layout & spin rotator design.
- Solenoid section can be spin matched.
- Spin matching requires spin transparency btw two solenoid sections.

Courtesy of SU, Feng.



For CEPC 120GeV beam:

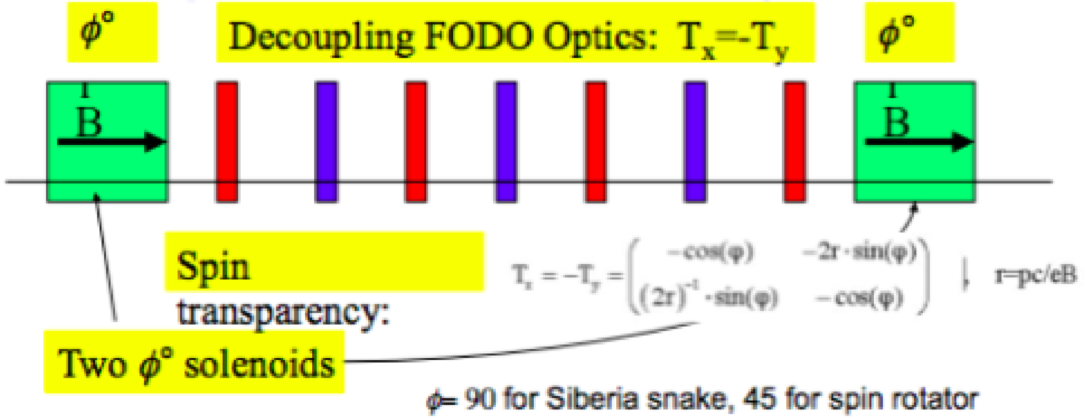
➢Max. deflection per separator is 66μrad.

Using Septum Dipole after separator to acquire 15 mrad

Version 1.0

sufeng

2015.12.20



I. Koop, talk on SuperB Workshop, SLAC (2006).

Simulation of equilibrium beam polarization

- The DK formula of the equilibrium beam polarization:

$$P_{\rm dk} = -\frac{8}{5\sqrt{3}} \frac{\oint \mathrm{d}s \langle \frac{1}{|\rho|^3} \hat{b} \cdot (\hat{n} - \frac{\partial \hat{n}}{\partial \delta}) \rangle_s}{\oint \mathrm{d}s \langle \frac{1}{|\rho|^3} (1 - \frac{2}{9} (\hat{n} \cdot \hat{s})^2 + \frac{11}{18} (\frac{\partial \hat{n}}{\partial \delta})^2) \rangle_s} \qquad (1)$$

- Various algorithms have been developed for evaluation of $\hat{n}$ and $\frac{\partial \hat{n}}{\partial \delta}$.
  - SLIM, ASPIRRIN, . . . : linearized orbital and spin motion
  - SODOM: linearized orbital and nonlinear spin motion(nonperturbative)
  - SMILE: linearized orbital and nonlinear spin motion
  - SpinLie: nonlinear orbital and spin motion

The Monte-Carlo approach[1]

It is a good approximation

$$P_{\text{eq}} = \frac{92.4\%}{1 + \tau_p/\tau_d}. \qquad (2)$$

The depolarization rate τ_d can be simulated in a Monte-Carlo manner, τ_p is easy to compute with knowledge of $\hat{n}$.

- Implementation of synchrotron radiation in a tracking code.
- Launch a beam of particles on the closed orbit, spin initialized parallel to the $\hat{n}$-axis.
- Track the beam for several damping times, and compute the beam polarization as an ensemble average of the particle spins.
- Fit τ_d using the turn-by-turn polarization, following

$$P(t) = P_0 \exp(-t/\tau_d). \qquad (3)$$

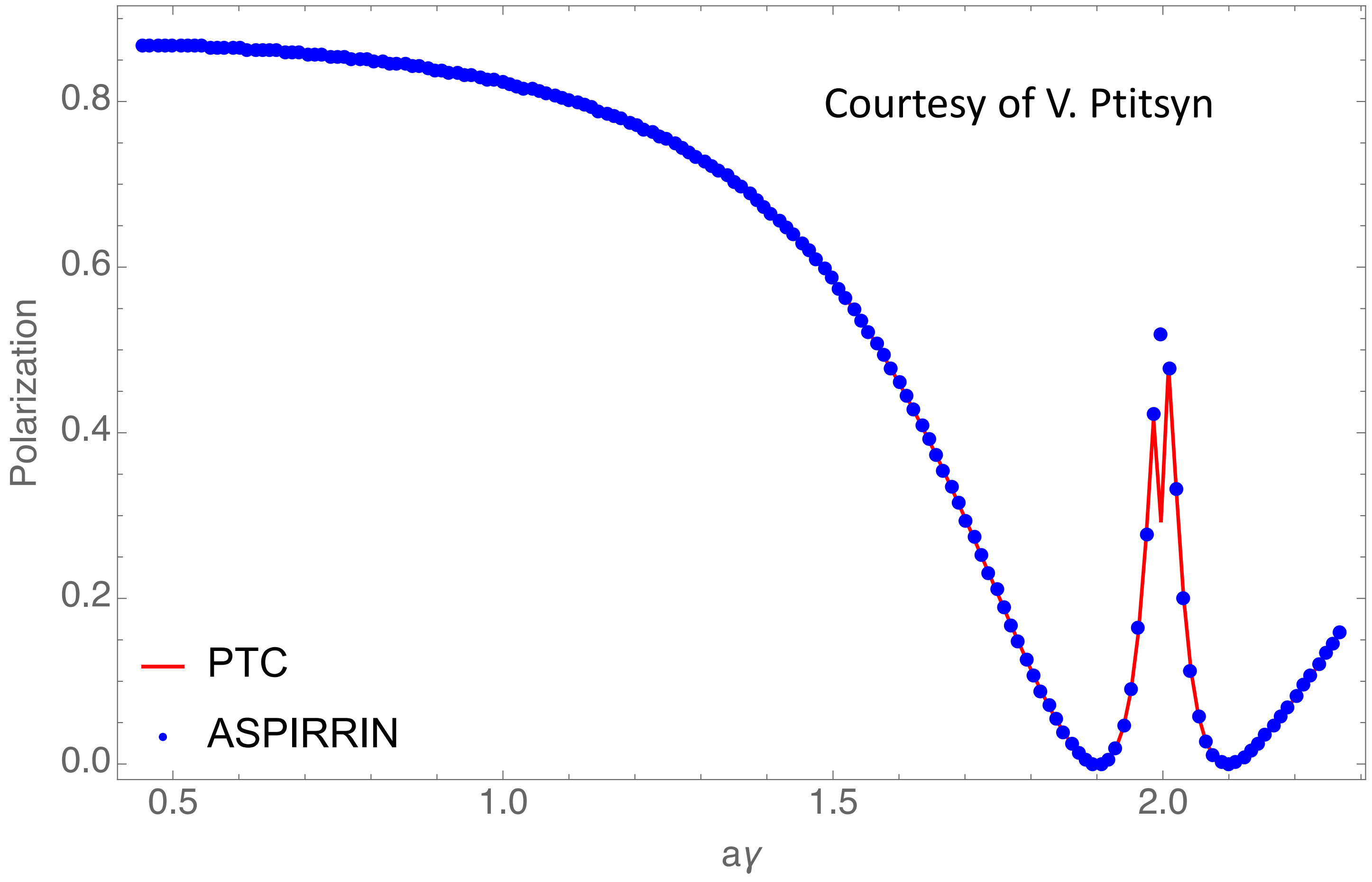
[1] J. Kewisch, R. Rossmanith, and T. Limberg, Phys. Rev. Lett. 62, 419 (1989).

Polarization Simulation with PTC

- Polymorphic Tracking Code(PTC) [1] is capable of orbital & spin tracking, as well as normal form analysis of one turn map.
- Lattice imperfection & correction can be implemented with MADX or BMAD and exported to PTC format. Fortran scripts are developed calling PTC as a library.
- Equilibrium polarization calculation including linear spin resonances:
  - First order normal form to obtain $\hat{n}$ & $\frac{d\hat{n}}{d\delta}$, then apply DK formula.[2]
- Equilibrium polarization calculation including linear & nonlinear spin resonances.
  - Monte-Carlo simulation of depolarization rate, similar to SITROS & SLICKTRACK.
  - This is essential for higher beam energy as in CEPC and FCC-ee.

[1] F. Schmit, E. Forest and E. McIntosh, CERN-SL-2002-044, 2002.
[2] E. Forest, KEK Report KEK-2010-39, 2010.

Benchmark with first order spin resonance only



One version of VEPP-2000 lattice, solenoid around IPs are not spin matched and lead to reduced polarization near resonances.

ASPIRRIN does not take into account of synchrotron motion.

Benchmark against SODOM

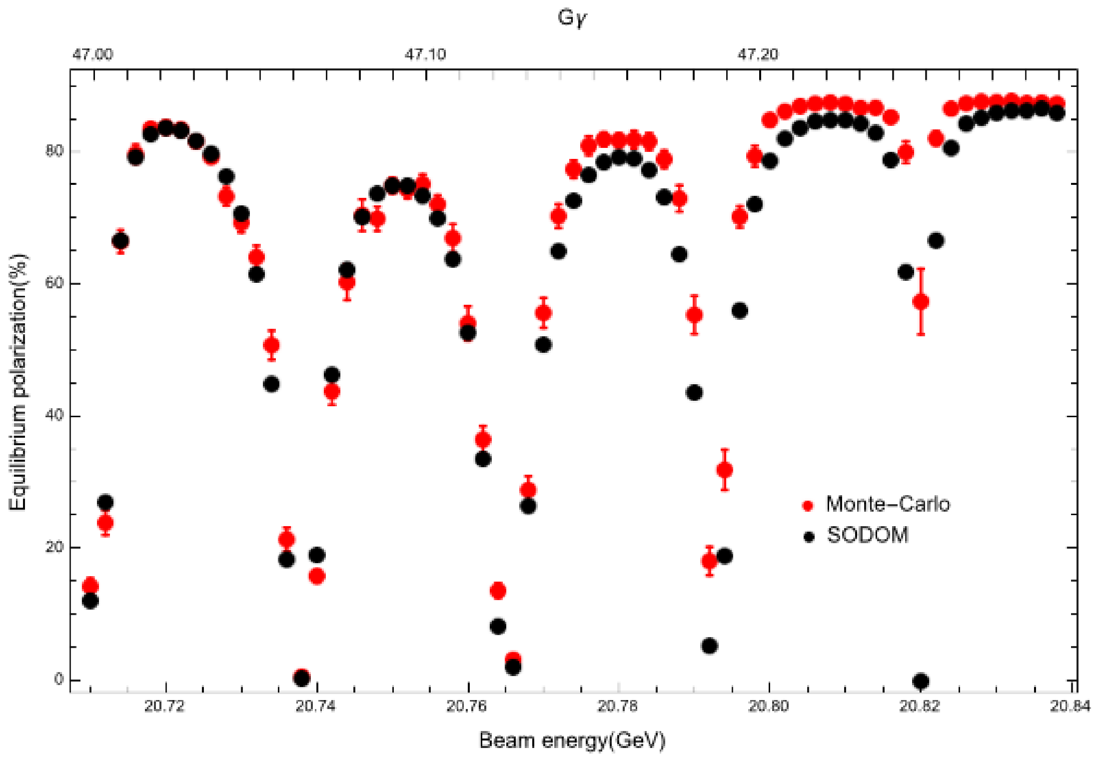


Figure .3: Comparison of the computed equilibrium polarizations for Model 1. "SODOM" is taken from the Yokoya's paper [16] with his permission. "Monte-Carlo" is the Monte-Carlo simulation result with 50 particles, the statistical error is calculated with 20 such simulations. The agreement is good.

A model ring (2112m) of FODO cells with several vertical bend.
Qx/Qy/Qz = 0.265/0.380/0.0623.

It took around 1 minute to track a particle for 3000 turns(5 damping time) on Hopper cluster @NERSC.

Comparison of Monte-Carlo simulation code

Code\features	orbit map	Photon emission	Speed
SITROS	2nd order matrix	"Big photon" localized at several points	
SLICKTRACK	1st order matrix	"Big photon" localized at several points	
PTC	nonlinear symplectic integrator	at each integration step of each dipole.	much slower compared to the others.

- It is not clear now if the more precise treatment in PTC have large effects on the simulation results.
- The lumped treatment in SITROS & SLICKTRACK can also be implemented within PTC with some effort.

Conclusion

- For CEPC partial double ring scheme, continuous monitor of both beam energies is possible as in FCC-ee.
- At what larger ring size can CEPC achieve useful polarization at W needs more simulation justification.
- Simulation tool based on PTC has been developed and benchmarked.
- Simulation study of a model ring for CEPC is under way.

Backup

Monte-Carlo simulation based on PTC

- Symplectic integrator for orbit & spin motion
- Modeling of synchrotron radiation (Added)

- Deterministic effect is modeled by

$$\delta = \delta - \frac{1}{2}\langle n\rangle\langle u\rangle.$$

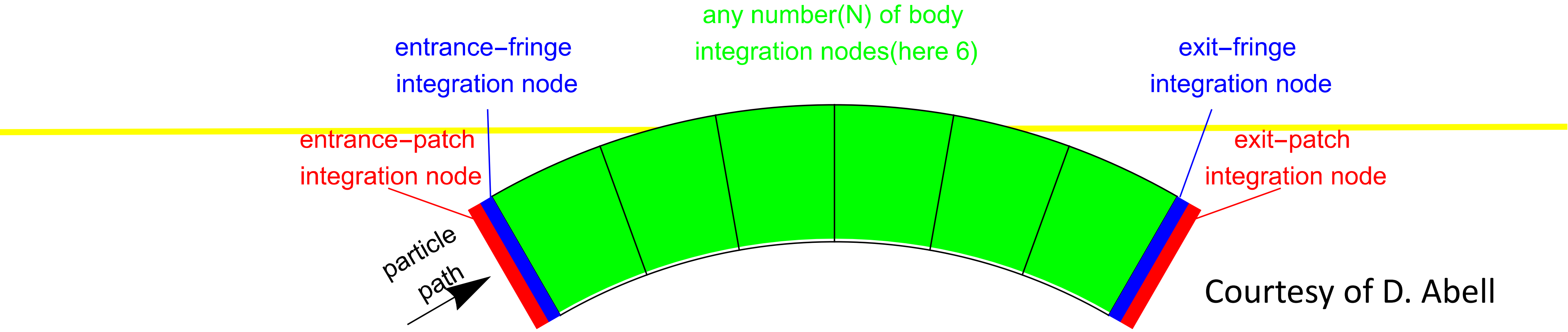
- Stochastic effect is modeled by

$$\delta = \delta - \sum_{1}^{\mathrm{nphot}} \xi u_c / E_{beam} + \frac{1}{2}\langle n\rangle\langle u\rangle.$$

GEANT 4 implementation

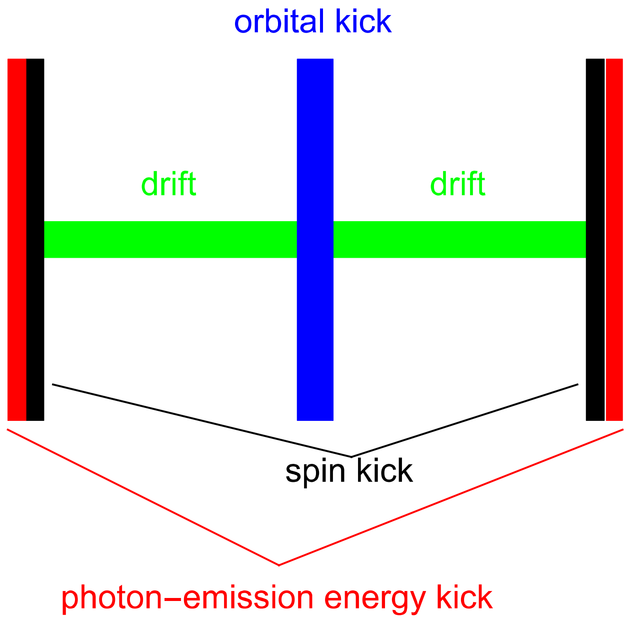
Poisson distribution

N+4 integration nodes cover an element



Courtesy of D. Abell

The symplectic integrator of a body integration node



synchrotron radiation photons emitted at each integration step. Normally only photon emission in dipoles are taken into account.