Chiral Belle Spin Rotator Update

Noah Tessema
Yuhao Peng, Mike Roney

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University of Victoria

Sokolov-Ternov Effect

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- Ohnishi-san's calculation with SAD shows that the Sokolov-Ternov Time for the HER would be ~531 minutes.
- Sokolov-Ternov is not yet implemented in Bmad, David Sagan advises that running tracking to see this effect would take too long

Beam-Beam Studies

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- We have begun studying the effect of an opposing beam at the IP on the overall stability of the lattice
- Bmad uses a virtual **beambeam** element to simulate a strong opposing beam
- This beambeam element is sliced and can be prepared with the optical parameters of the LER

The strong beam is divided up into `n_slice` equal charge (not equal thickness) slices. Propagation through the strong beam involves a kick at the charge center of each slice with drifts in between the kicks. The kicks are calculated using the standard Bassetti–Erskine complex error function formula[Talman87].

Even though the strong beam can have a finite `sig_z`, the length of the element is always considered to be zero. This is achieved by adding drifts at either end of any tracking so that the longitudinal starting point and ending point are identical. The longitudinal s–position of the `BeamBeam` element is at the center of the strong bunch. For example, with `n_slice` $= 2$ and with a solenoid field, the calculation would proceed as follows:

1. Start with the particle longitudinally at the `beambeam` element (which is considered to have zero longitudinal length) in laboratory coordinates (§15).
2. Propagate backwards through the solenoid field so that the particle is in the plane of the first beambeam slice. The fact that the plane of the slice may be, due to finite `x_pitch` or `y_pitch` values, canted with respect to the laboratory x-y plane is taken into account.
3. Transform the particle coordinates to the `beambeam` element body coordinates (§15.3).
4. Apply the beam–beam kick due to the first slice including a spin rotation.
5. Transform back to laboratory coordinates.
6. Propagate forwards so that the particle is in the plane of the second slice.
7. Transform the particle coordinates to the `beambeam` element body coordinates.
8. Apply the beam–beam kick due to the second slice.
9. Transform back to laboratory coordinates.
10. Propagate backwards through the solenoid field to end up with the particle longitudinally at the `beambeam` element.

Bmad Manual

https://www.classe.cornell.edu/bmad/manual.html

Beam-Beam Studies

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```
!--------- beam-beam element -------------------
bbi: beambeam, e_tot_strong = 4E9,  sig_x = 10.1E-6, sig_y = 48E-9, sig_z = 6.0E-3,  n_slice = 6,
                n_particle = 9E10/6, x_pitch = 0.00415, alpha_a_strong = 0.01648305, alpha_b_strong = -0.00219240,
                beta_a_strong = 0.07952183, beta_b_strong = 0.00099473, bs_field = -1.453446511511663

! e_tot_strong = ! Beam (LER) energy)
! n_particle = 9E10 ! Particles in a bunch
! Bmad by default uses positive charge particles for simulation, so the LER beam would be negatively charged
! bs_field = <Real> ! Solenoid field strength.
! x_pitch = <rad> ! Half crossing angle
! bbi constant automatically calculated by Bmad (dependant)
! z_crossing = 0
! repetition_frequency !bunch rate (must be high precision - use Bmad and not documented rounded numbers)
!---------- rotator magnets --------------------
```

- Still missing crab-waist details
- Preliminary tracking studies ongoing with the HER lattice.

Beam-Beam Studies

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HER

```
                     A-Mode              |            B-Mode
               Model        Design       |      Model        Design
        Q    45.531001    45.531001         43.580716    43.580716   ! Tune
    Chrom     1.591891     1.591891          1.621569     1.621569   ! dQ/(dE/E)
   J_damp     0.999102     0.999102          0.999771     0.999771   ! Damping Partition #
Emittance  4.43303E-09  4.43303E-09       5.34956E-13  5.34956E-13   ! Unnormalized
Emit (photon vert opening angle ignored)  0.00000E+00  0.00000E+00
Alpha_damp  1.78470E-04  1.78470E-04      1.78590E-04  1.78590E-04   ! Damping per turn
Damping_time  5.63754E-02  5.63754E-02    5.63377E-02  5.63377E-02   ! Sec

               Model        Design
     Z_tune:  2.73892E-02  2.73892E-02
    Sig_E/E:  6.42272E-04  6.42272E-04
      Sig_z:  5.14535E-03  5.14535E-03   ! Only calculated when RF is on
Emittance_z:  3.30419E-06  3.30419E-06   ! Only calculated when RF is on
Energy Loss:  2.50344E+06  2.50344E+06   ! Energy_Loss (eV / Turn)
     J_damp:  1.99931E+00  1.99931E+00   ! Longitudinal Damping Partition #
 Alpha_damp:  3.57138E-04  3.57138E-04   ! Longitudinal Damping per turn
  damp_time:  2.81721E-02  2.81721E-02   ! Longitudinal Damping time (sec)
    Alpha_p:  4.53858E-04  4.53858E-04   ! Momentum Compaction
      Eta_p:  4.53853E-04  4.53853E-04   ! Slip factor
gamma_trans:  4.69396E+01  4.69396E+01   ! Gamma at transition
  Spin Tune:  9.76895E-02  9.76895E-02   ! Spin Tune on Closed Orbit (Units of 2pi)
       <pz>:  4.73833E-06  4.73833E-06   ! Average closed orbit pz (momentum deviation)
```

HER + BB

```
                     A-Mode              |            B-Mode
               Model        Design       |      Model        Design
        Q    45.587894    45.587894         43.357465    43.357465   ! Tune
    Chrom     1.204034     1.204034          0.153774     0.153774   ! dQ/(dE/E)
   J_damp     1.031258     1.031258          0.999773     0.999773   ! Damping Partition #
Emittance  0.00000E+00  0.00000E+00       3.55095E-13  3.55095E-13   ! Unnormalized
Emit (photon vert opening angle ignored)  0.00000E+00  0.00000E+00
Alpha_damp  1.84217E-04  1.84217E-04      1.78592E-04  1.78592E-04   ! Damping per turn
Damping_time  5.46169E-02  5.46169E-02    5.63369E-02  5.63369E-02   ! Sec

               Model        Design
     Z_tune:  2.73891E-02  2.73891E-02
    Sig_E/E:  6.42284E-04  6.42284E-04
      Sig_z:  5.14549E-03  5.14549E-03   ! Only calculated when RF is on
Emittance_z:  3.30434E-06  3.30434E-06   ! Only calculated when RF is on
Energy Loss:  2.50347E+06  2.50347E+06   ! Energy_Loss (eV / Turn)
     J_damp:  1.99921E+00  1.99921E+00   ! Longitudinal Damping Partition #
 Alpha_damp:  3.57126E-04  3.57126E-04   ! Longitudinal Damping per turn
  damp_time:  2.81731E-02  2.81731E-02   ! Longitudinal Damping time (sec)
    Alpha_p:  4.53855E-04  4.53855E-04   ! Momentum Compaction
      Eta_p:  4.53850E-04  4.53850E-04   ! Slip factor
gamma_trans:  4.69398E+01  4.69398E+01   ! Gamma at transition
  Spin Tune:  9.76897E-02  9.76897E-02   ! Spin Tune on Closed Orbit (Units of 2pi)
       <pz>:  4.73834E-06  4.73834E-06   ! Average closed orbit pz (momentum deviation)
```

Beam-Beam Studies

R156 snippets using the 7070MeV model

R156

```
                    A-Mode              |           B-Mode
                 Model       Design     |      Model       Design
        Q     45.530913    45.530913       43.579229    43.579229  ! Tune
    Chrom      1.599932     1.599932        1.739517     1.739517  ! dQ/(dE/E)
   J_damp      0.965298     0.965298        1.000525     1.000525  ! Damping Partition #
Emittance   4.68164E-09  4.68164E-09     1.20592E-11  1.20592E-11  ! Unnormalized
Emit (photon vert opening angle ignored)   0.00000E+00  0.00000E+00
Alpha_damp  1.77125E-04  1.77125E-04     1.83589E-04  1.83589E-04  ! Damping per turn
Damping_time  5.68035E-02  5.68035E-02   5.48035E-02  5.48035E-02  ! Sec

                 Model       Design
   Z_tune:  2.71513E-02  2.71513E-02
  Sig_E/E:  6.42750E-04  6.42750E-04
    Sig_z:  5.15353E-03  5.15353E-03   ! Only calculated when RF is on
Emittance_z:  3.31189E-06  3.31189E-06   ! Only calculated when RF is on
Energy Loss:  2.59470E+06  2.59470E+06   ! Energy_Loss (eV / Turn)
   J_damp:  2.03225E+00  2.03225E+00   ! Longitudinal Damping Partition #
Alpha_damp:  3.72904E-04  3.72904E-04   ! Longitudinal Damping per turn
damp_time:  2.69810E-02  2.69810E-02   ! Longitudinal Damping time (sec)
  Alpha_p:  4.50023E-04  4.50023E-04   ! Momentum Compaction
    Eta_p:  4.50018E-04  4.50018E-04   ! Slip factor
gamma_trans:  4.71393E+01  4.71393E+01   ! Gamma at transition
Spin Tune: -2.17443E-01 -2.17443E-01   ! Spin Tune on Closed Orbit (Units of 2pi)
     <pz>:  5.54203E-06  5.54203E-06   ! Average closed orbit pz (momentum deviation)
```

R156 + BB

```
                    A-Mode              |           B-Mode
                 Model       Design     |      Model       Design
        Q     45.530913    45.530913       43.579229    43.579229  ! Tune
    Chrom      1.599932     1.599932        1.739517     1.739517  ! dQ/(dE/E)
   J_damp      0.965298     0.965298        1.000525     1.000525  ! Damping Partition #
Emittance   4.68164E-09  4.68164E-09     1.20592E-11  1.20592E-11  ! Unnormalized
Emit (photon vert opening angle ignored)   0.00000E+00  0.00000E+00
Alpha_damp  1.77125E-04  1.77125E-04     1.83589E-04  1.83589E-04  ! Damping per turn
Damping_time  5.68035E-02  5.68035E-02   5.48035E-02  5.48035E-02  ! Sec

                 Model       Design
   Z_tune:  2.71513E-02  2.71513E-02
  Sig_E/E:  6.42750E-04  6.42750E-04
    Sig_z:  5.15353E-03  5.15353E-03   ! Only calculated when RF is on
Emittance_z:  3.31189E-06  3.31189E-06   ! Only calculated when RF is on
Energy Loss:  2.59470E+06  2.59470E+06   ! Energy_Loss (eV / Turn)
   J_damp:  2.03225E+00  2.03225E+00   ! Longitudinal Damping Partition #
Alpha_damp:  3.72904E-04  3.72904E-04   ! Longitudinal Damping per turn
damp_time:  2.69810E-02  2.69810E-02   ! Longitudinal Damping time (sec)
  Alpha_p:  4.50023E-04  4.50023E-04   ! Momentum Compaction
    Eta_p:  4.50018E-04  4.50018E-04   ! Slip factor
gamma_trans:  4.71393E+01  4.71393E+01   ! Gamma at transition
Spin Tune: -2.17443E-01 -2.17443E-01   ! Spin Tune on Closed Orbit (Units of 2pi)
     <pz>:  5.54203E-06  5.54203E-06   ! Average closed orbit pz (momentum deviation)
```

Beam-Beam at IP

R156 snippets using the 7070MeV model

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HER

```
Twiss at end of element:
                          A                B          Cbar                         C_mat
 Beta (m)          0.05997836       0.00099678  |  -0.00000396   0.00005083    -0.00003064   0.00000039
 Alpha             0.00013026       0.00011511  |  -0.00000091  -0.00000442    -0.00011726  -0.00000057
 Gamma (1/m)      16.67267943    1003.22935166  |   Gamma_c =    1.00000000     Mode_Flip = F
 Phi (rad)         0.00000000       0.00000000        X              Y              Z
 Eta (m)           0.00000077       0.00000000     0.00000077    0.00000000     0.00000000
 Etap             -0.00005526      -0.00000061    -0.00005526   -0.00000061     1.00000000
 Sigma             0.00001632       0.00000002     0.00000000    0.00000000

Orbit:  Positron   State: Alive
         Position[mm] Momentum[mrad]        Spin     |
 X:      -0.00000136     -0.00000552   0.00172628   | t_particle [sec]:        -2.39029332E-15  E_tot: 7.00732E+09
 Y:      -0.00000051     -0.00007223   0.99999272   | t_part-t_ref [sec]:     -2.39029332E-15  PC:    7.00732E+09
 Z:       0.00071659      0.00474590   0.00340158   | (t_ref-t_part)*Vel [m]:  7.16591907E-07  Beta:  0.999999997
```

HER + BB

```
Twiss at end of element:
                          A                B          Cbar                         C_mat
 Beta (m)          0.02207012       0.00314158  |   0.00027235  -0.00054408     0.00178413  -0.00000453
 Alpha             0.24817545      -0.73662176  |  -0.00065434  -0.00020260    -0.08072271  -0.00002549
 Gamma (1/m)      48.10082123     491.02995026  |   Gamma_c =    1.00000021     Mode_Flip = F
 Phi (rad)        -0.00161518      -1.04916723        X              Y              Z
 Eta (m)           0.00000249       0.00000000     0.00000249    0.00000000     0.00000000
 Etap             -0.00013994       0.00000162    -0.00013994    0.00000167     1.00000000
 Sigma             0.00001274       0.00000003     0.00000000    0.00000000

Orbit:  Positron   State: Alive
         Position[mm] Momentum[mrad]        Spin     |
 X:      -0.00045115     -0.00062491   0.00172629   | t_particle [sec]:        -2.39021983E-15  E_tot: 7.00732E+09
 Y:      -0.00000033     -0.00023255   0.99999272   | t_part-t_ref [sec]:     -2.39021983E-15  PC:    7.00732E+09
 Z:       0.00071657      0.00474592   0.00340339   | (t_ref-t_part)*Vel [m]:  7.16569875E-07  Beta:  0.999999997
```

R156

```
Twiss at end of element:
                          A                B          Cbar                         C_mat
 Beta (m)          0.05983954       0.00097285  |  -0.03174248  -0.00692414    -0.24908362  -0.00005283
 Alpha             0.00032111       0.00246180  |  -0.00093276  -0.01311310    -0.12514549  -0.00167171
 Gamma (1/m)      16.71136068    1027.91371115  |   Gamma_c =    0.99979509     Mode_Flip = F
 Phi (rad)         0.00000000       0.00000000        X              Y              Z
 Eta (m)          -0.00000090      -0.00000006    -0.00000089   -0.00000006     0.00000000
 Etap             -0.00003550       0.00000294    -0.00003549   -0.00000579     1.00000000
 Sigma             0.00001675       0.00000011     0.00000000    0.00000000

Orbit:  Positron   State: Alive
         Position[mm] Momentum[mrad]        Spin     |
 X:       0.00001486      0.00064757   0.01387267   | t_particle [sec]:        -1.95693639E-15  E_tot: 7.07033E+09
 Y:       0.00007082     -0.00001150   0.05480256   | t_part-t_ref [sec]:     -1.95693639E-15  PC:    7.07033E+09
 Z:       0.00058667      0.00554833   0.99840084   | (t_ref-t_part)*Vel [m]:  5.86674768E-07  Beta:  0.999999997
```

R156 + BB

```
Twiss at end of element:
                          A                B          Cbar                         C_mat
 Beta (m)          0.05983954       0.00097285  |  -0.03174248  -0.00692414    -0.24908362  -0.00005283
 Alpha             0.00032111       0.00246180  |  -0.00093276  -0.01311310    -0.12514549  -0.00167171
 Gamma (1/m)      16.71136068    1027.91371115  |   Gamma_c =    0.99979509     Mode_Flip = F
 Phi (rad)         0.00000000       0.00000000        X              Y              Z
 Eta (m)          -0.00000090      -0.00000006    -0.00000089   -0.00000006     0.00000000
 Etap             -0.00003550       0.00000294    -0.00003549   -0.00000579     1.00000000
 Sigma             0.00001675       0.00000011     0.00000000    0.00000000

Orbit:  Positron   State: Alive
         Position[mm] Momentum[mrad]        Spin     |
 X:       0.00001486      0.00064757   0.01387267   | t_particle [sec]:        -1.95693639E-15  E_tot: 7.07033E+09
 Y:       0.00007082     -0.00001150   0.05480256   | t_part-t_ref [sec]:     -1.95693639E-15  PC:    7.07033E+09
 Z:       0.00058667      0.00554833   0.99840084   | (t_ref-t_part)*Vel [m]:  5.86674768E-07  Beta:  0.999999997
```

Spin Tune and Polarization Lifetime

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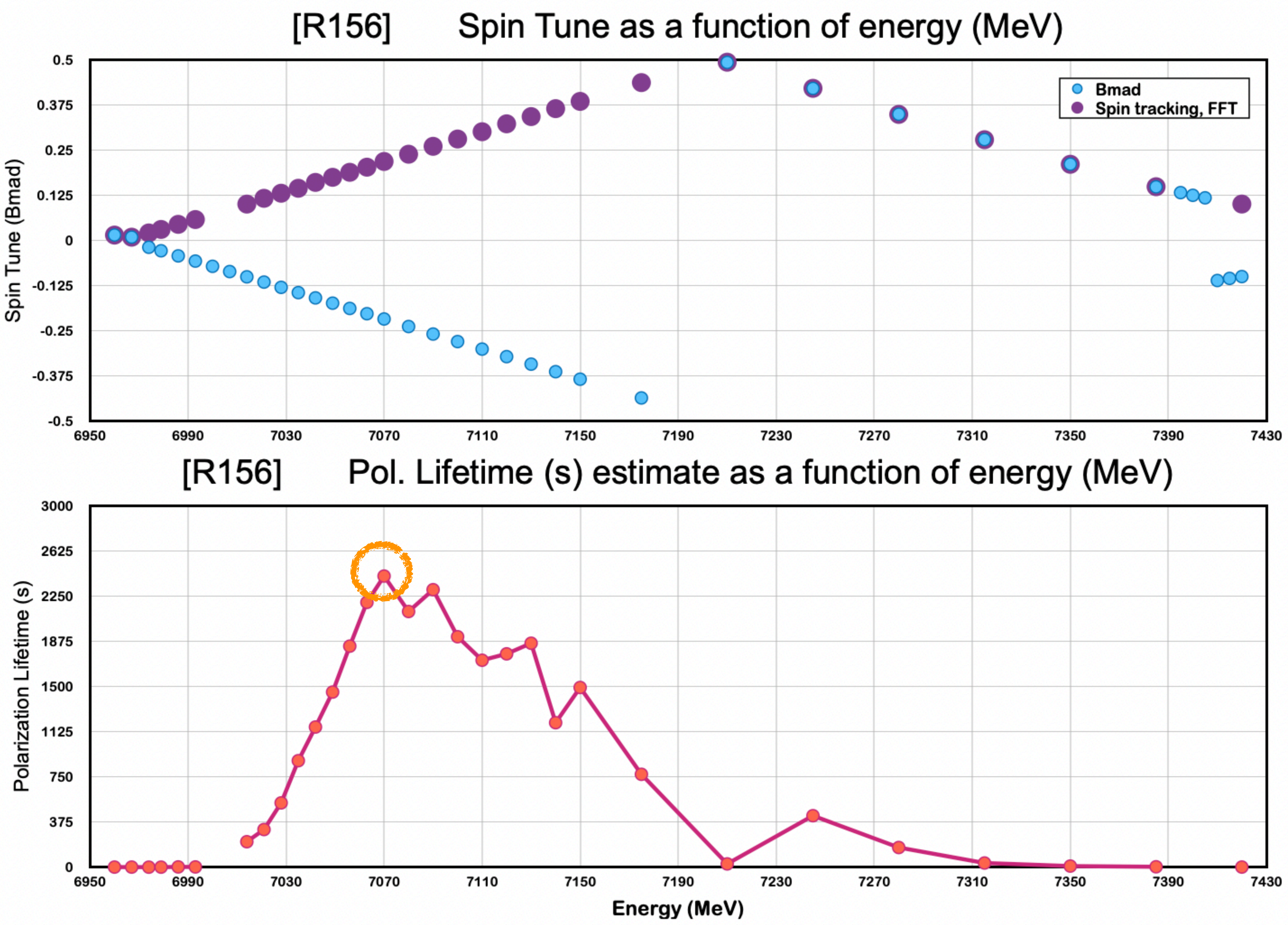

- Using the R156 Rotator+HER lattice (most stable)
- Peak lifetime: ~40 minutes at 7070 MeV
- Midway between the integer and half-integer Spin Tune resonances

Spin Tune and Polarization Lifetime

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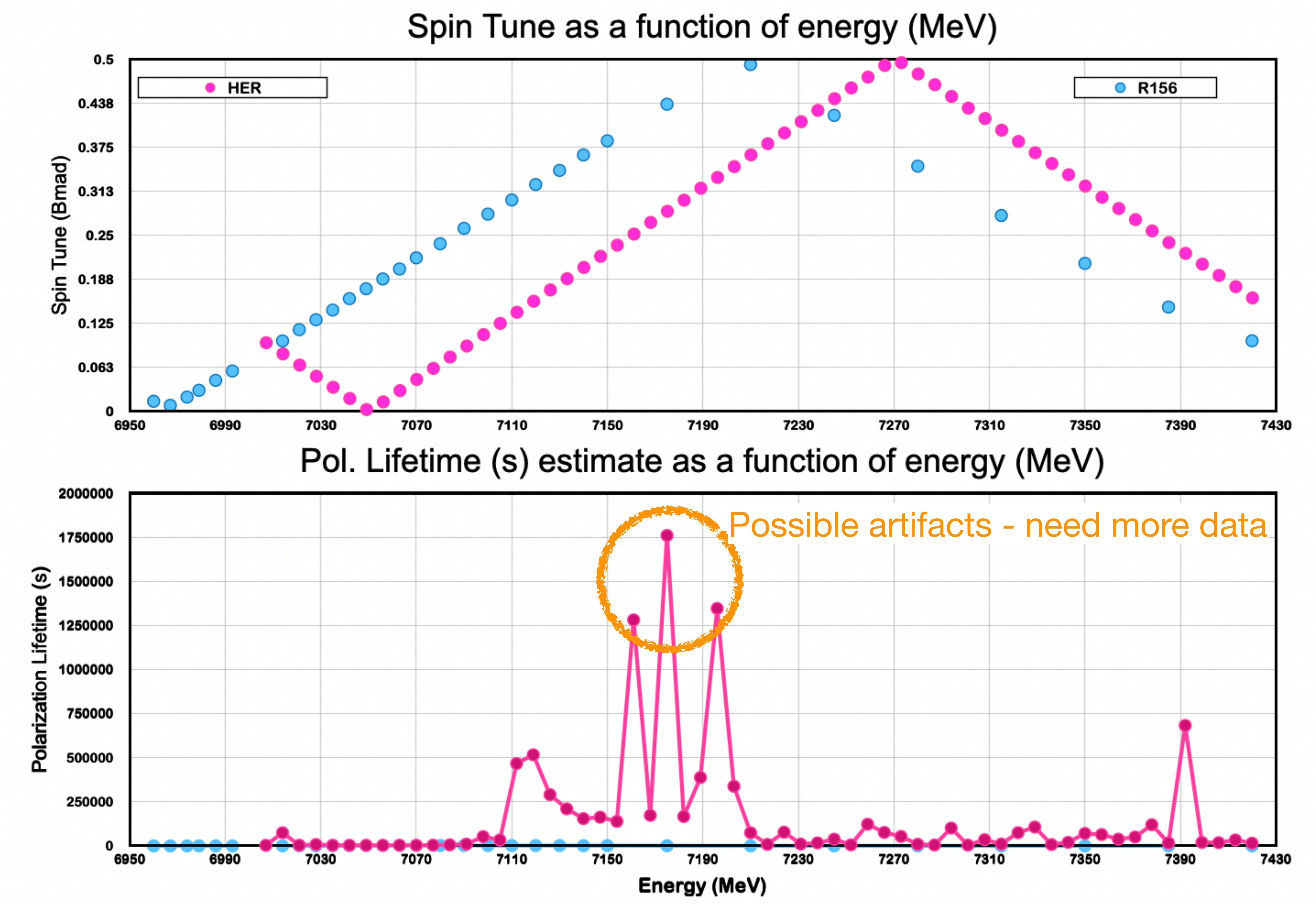
Transverse Polarized HER



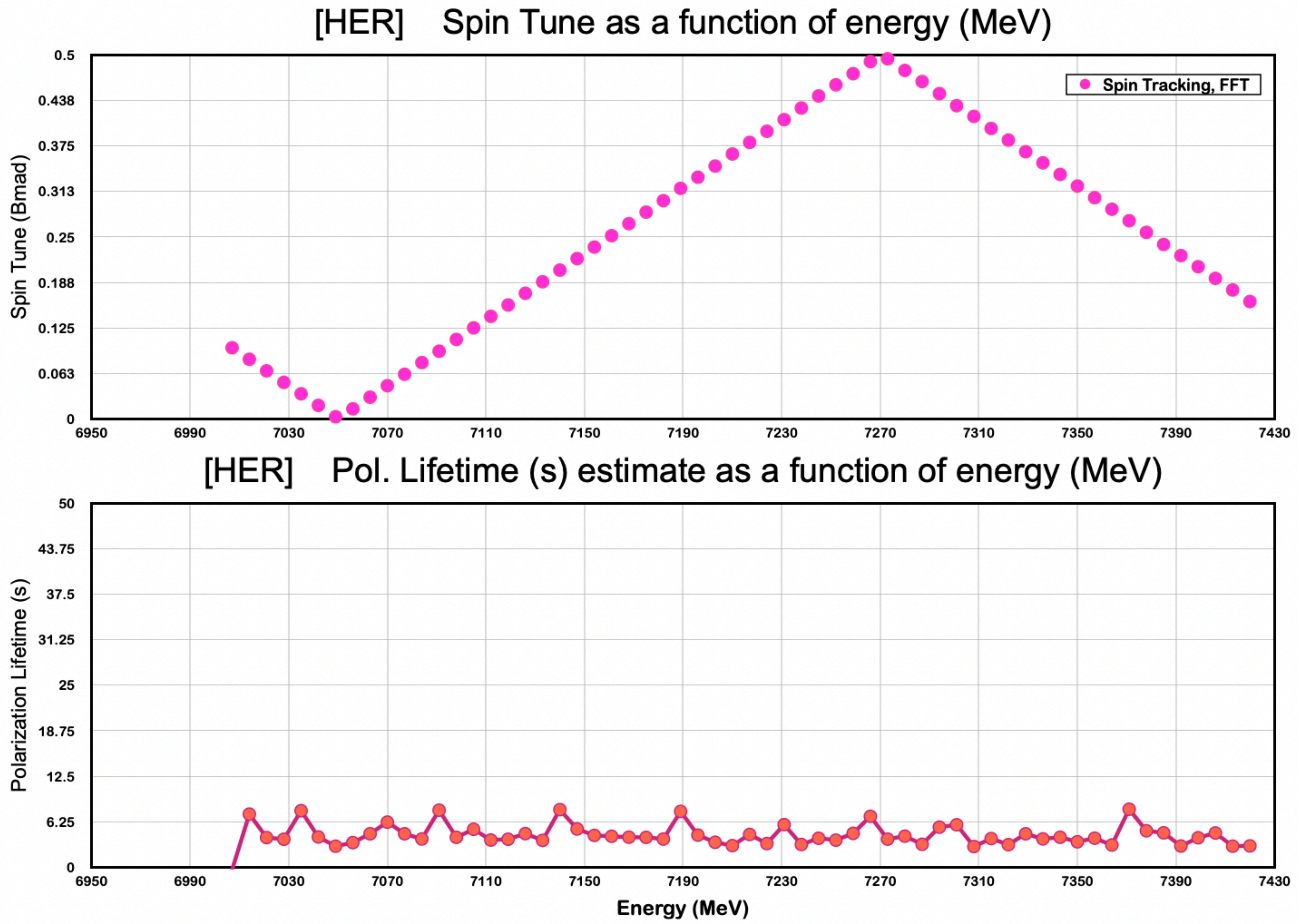
Model	Spin Tune	Polarization Lifetime
HER (transverse) (SAD)	0.0977091	~530 min
LER (SAD)	0.0773338	~3630 min
HER (transverse) (Bmad)	0.0976895	~1200 min
LER (Bmad)	0.0822813	—
HER + R156 (Bmad)	Nominal: 0.086361 Stable: 0.217443	~40 min (stable)
HER + BB (Prelim)	0.0976895	Tracking ongoing

SAD data provided by Ohnishi-san

Spin Tune and Polarization Lifetime

University of Victoria

Longitudinally Polarized HER



Model	Spin Tune	Polarization Lifetime
HER (transverse) (SAD)	0.0977091	~530 min
LER (SAD)	0.0773338	~3630 min
HER (transverse) (Bmad)	0.0976895	~1200 min
LER (Bmad)	0.0822813	—
HER + R156 (Bmad)	Nominal: 0.086361 Stable: 0.217443	~40 min (stable)
HER + BB (Prelim)	0.0976895	Tracking ongoing

SAD data provided by Ohnishi-san

What's Next

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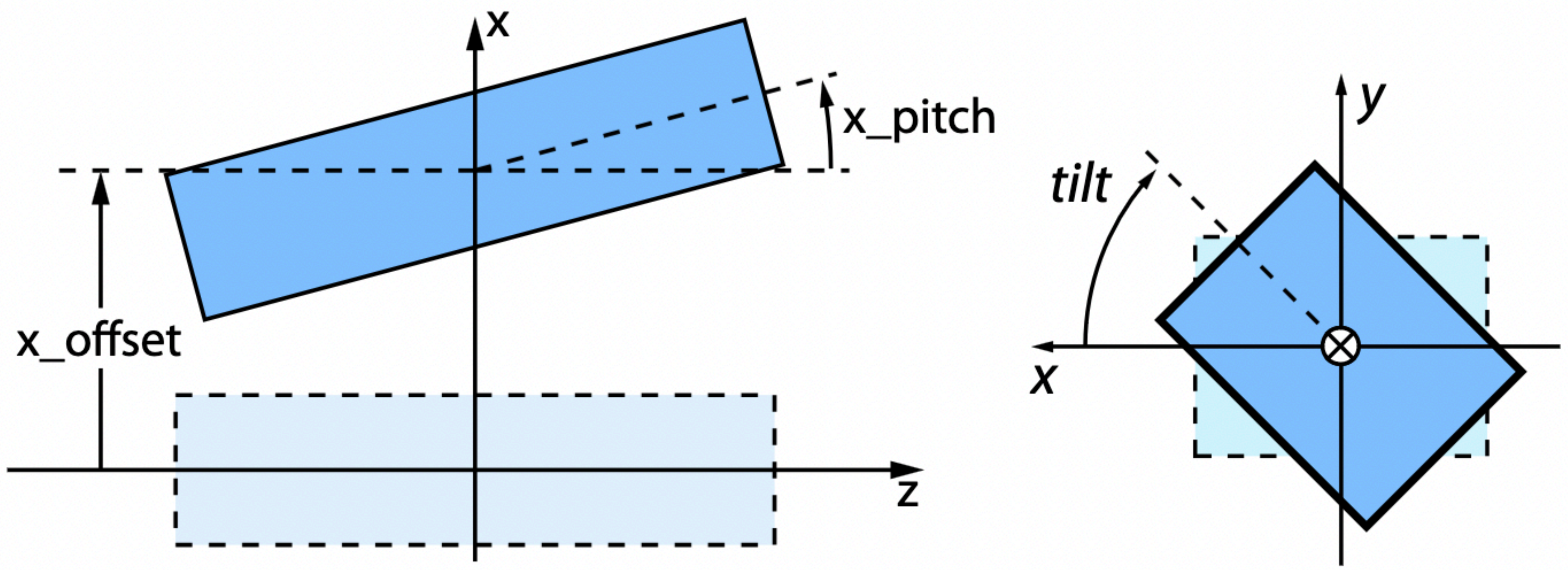
- Beam-beam long-term tracking
- HER polarization lifetime artifact issue
- Magnet Tolerances (Element Misalignments) - need a comprehensive list of various magnet tolerances within the ring



(a) Effect of x_offset and x_pitch on a straight line element

(b) Effect of a tilt on a straight line element.

Figure 19

Bmad Manual

https://www.classe.cornell.edu/bmad/manual.html