Reporting on spin simulations in Madx-PTC

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This work was done as part of the EPFL-CERN collaboration

(indico-meetings, epfl-site)

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Some requirements for spin simulations for the FCC-ee

- Calculation of linear DK polarization levels
- Perform nonlinear spin tracking simulations based on initial conditions
- Multiparticle tracking simulations
- Spin orbit matching for improved control on polarization
- Complete description of machine state
    - nonlinear elements, rotations, magnetic errors, misalignments, …
- Possibility to integrate with other studies
    - Orbit corrections, linear & nonlinear corrections, tapering, tuning..
- Simulations with RF dipole to study resonant depolarization

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Crucial for FCC-ee simulations

Codes of interest to spin dynamics simulations

SITROS/SITF Historically used for FCC-ee CDR spin simulations Eliana Gianfelice 2019

- Has limited lattice & error descriptions.

Bmad Currently actively developed by David Sagan, Georg Hoffstaetter, and Desmond Barber as part of a DoE funded mandate

- FCC-ee spin simulations done by Yi Wu (eeFACT2022 13 September, FCC-FS EPOL 17 March, This workshop)

Zgoubi Significant use in multiple machines including for EIC simulations (Francois Meot This session)

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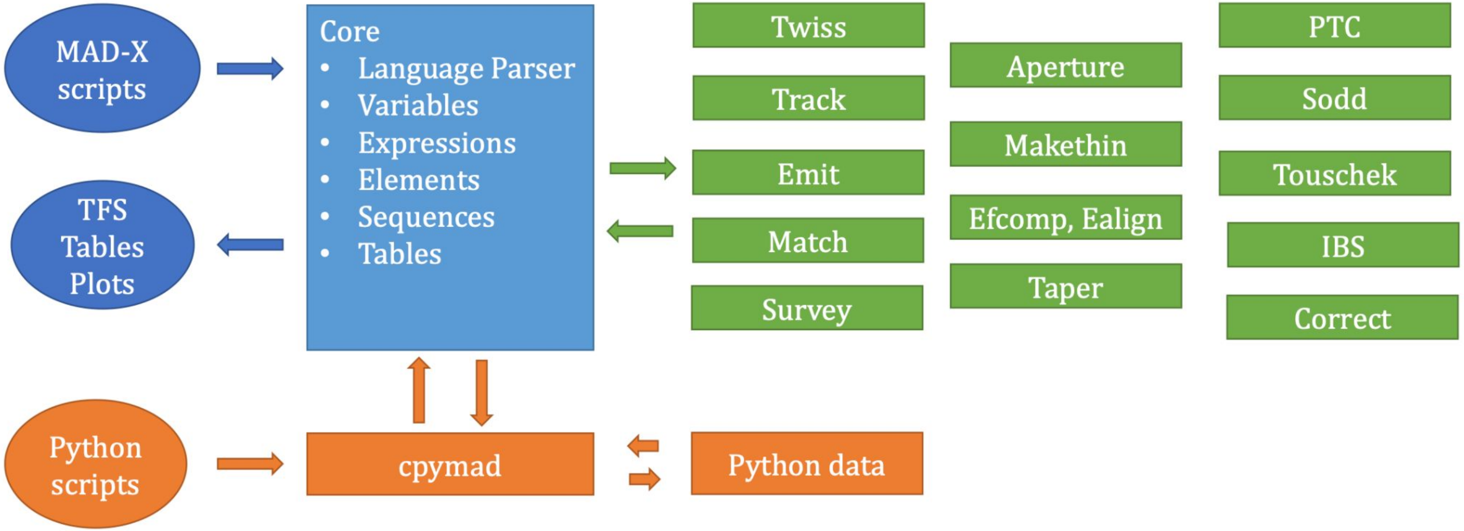
Will report on the recent integration developments of PTC-spin in Madx

Madx is a powerful accelerator physics simulation code

Madx is the default accelerator code for linear and nonlinear optics design optimization at CERN

- Extensively used in hadron machines
- Now also a major code for FCC-ee optics design and tuning studies
- Powerful PTC library also integrated into Madx
- FCC Week 2022 update R. de Maria

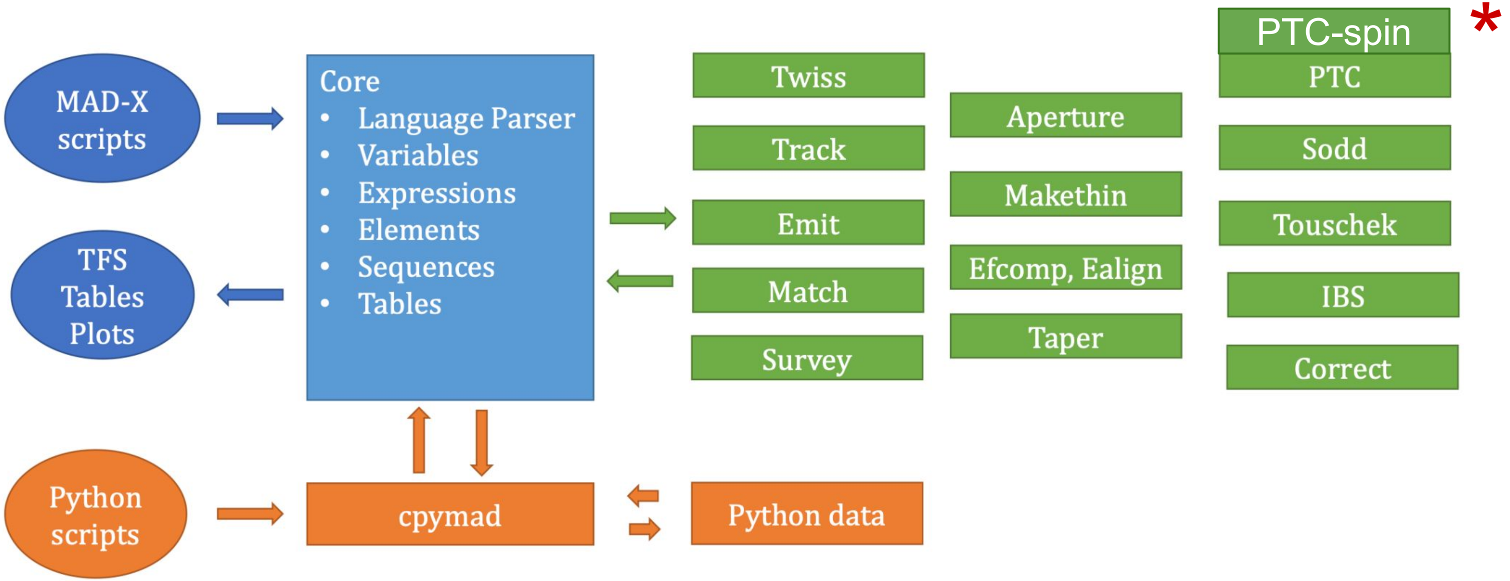


PTC-spin has now been linked in Madx-PTC

Spin calculations were already present in PTC → Now properly interfaced with Madx

The newest Madx release will include PTC-spin calculations (GitHub)

* Only for the closed solution at the moment



Preliminary spin comparisons Bmad-PTC and Madx-PTC

The spin implementation in Madx-PTC is compared to Bmad-PTC using the Advanced Light Source lattice as a testbench.

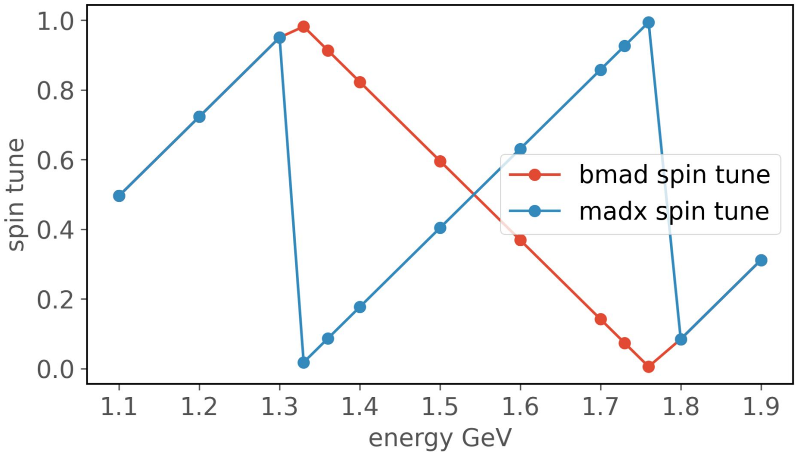
Comparing:

1. Spin tune variation with energy
2. ISF with horizontal field perturbations -> needed to deviate spin from perfect vertical alignment
3. Spin tune variation with horizontal field perturbations

Comparing spin tune for different energies

A notable change in spin tune is observed between Madx and Bmad implementations of PTC.

Bmad does not use the calculated spin tune from PTC, which can explain the use of the opposite solution $(1-\nu_s) \leftrightarrow \nu_s$



Too short introduction of invariant spin field (ISF)

The spin polarization can be described through the closed solution of the equilibrium spin field **n**(**z**, θ)

- The ISF will point in the vertical direction in a perfect machine with purely vertical magnetic fields on the closed orbit.
- Horizontal magnetic fields will cause deviations of **n** from the vertical direction.
    - So vertical orbits through quadrupoles are particularly perturbative

From the invariant spin field we can calculate the linear polarization limits and (de)polarisation times

- For example, Derbenev-Kondratenko polarization including stochastic excitation of beam:

$$P_{dk} = \pm \frac{8}{5\sqrt{3}} \frac{\oint ds \left\langle g^3 \hat{\mathbf{b}} \cdot \left(\mathbf{n} - \frac{\partial \mathbf{n}}{\partial \delta} \right) \right\rangle}{\oint ds \left\langle g^3 \left(1 - \frac{2}{9} (\mathbf{n} \cdot \hat{\mathbf{s}})^2 + \frac{11}{18} \left| \frac{\partial \mathbf{n}}{\partial \delta} \right|^2 \right) \right\rangle}$$

Functions of ISF obtained from Bmad or Madx-PTC

Radiation integrals

Comparing ISF for ALS lattice with quadrupole offsets

A perfect lattice will have a vertically oriented $\mathbf{n_0}(\theta)$.

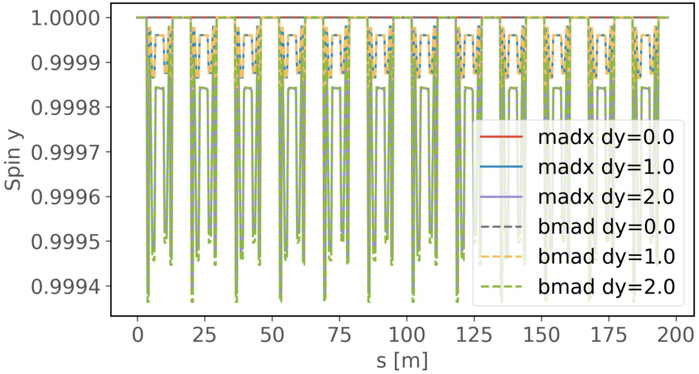
- Vertical alignment errors are introduced in quadrupoles to generate horizontal magnetic fields and perturb the spin motion.

The ALS lattice is generated with different sizes of vertical offsets in the quadrupoles

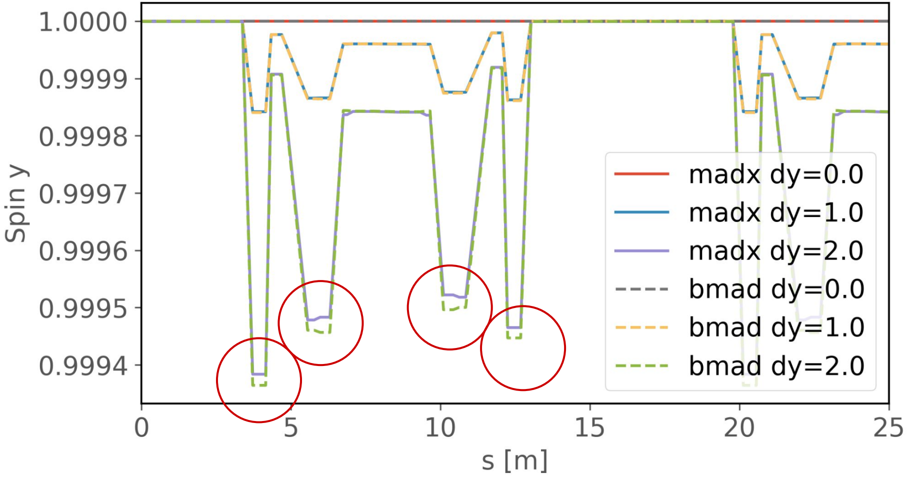
- QF* → dy = {0; 1; 2} [mm]
- QD* → dy = -{0; 1; 2} [mm]

Small discrepancies for large quad offsets (2 mm)

- Most likely from numerical differences in closed orbit

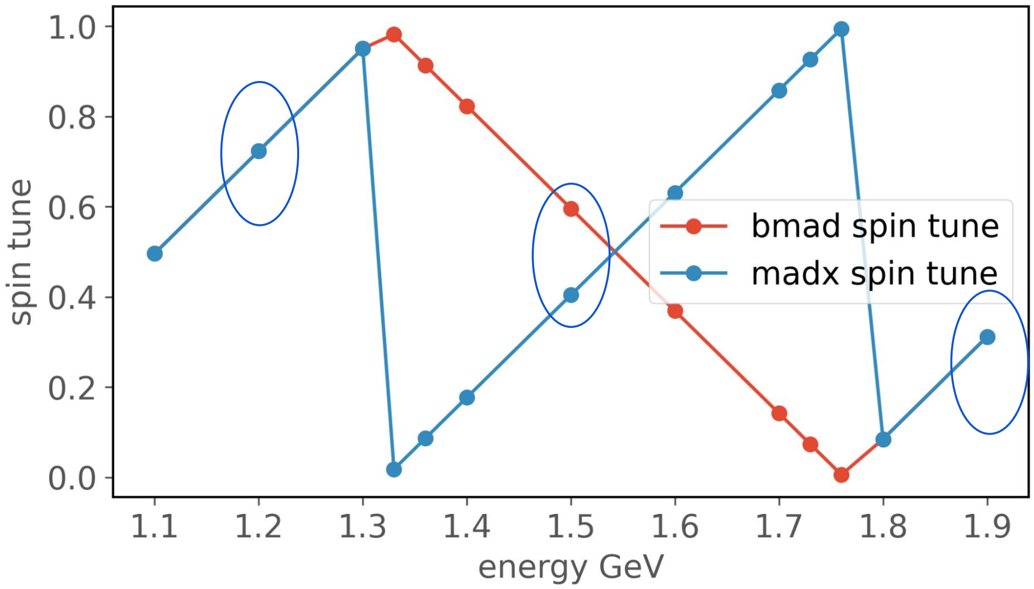


ZOOM →



Do we see a sign change in ISF at the different energies?

Check ISF for different energies where spin tune agrees and where it does not agree.



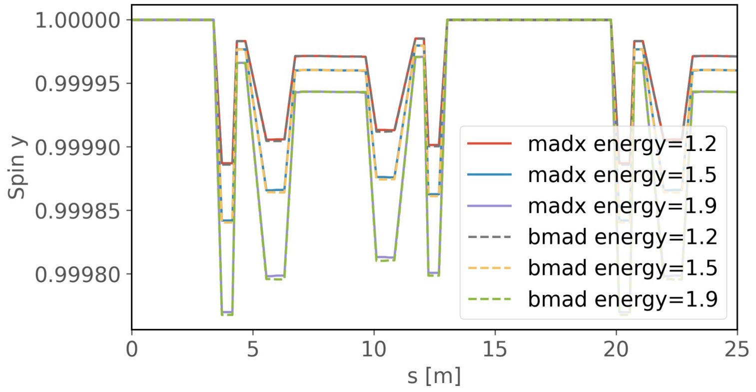
Comparing ISF at different energies with ‘dy’ in quads

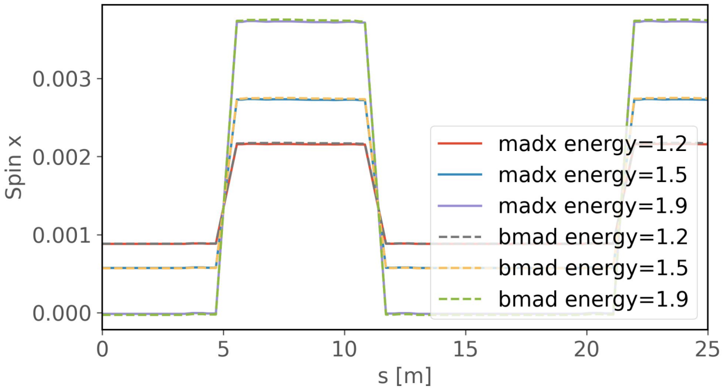
Identical ISF functions are obtained while the spin was different (with vertical quad offsets 1 mm)

➡ Possibly spin tune swap in one of codes?

Possible causes:

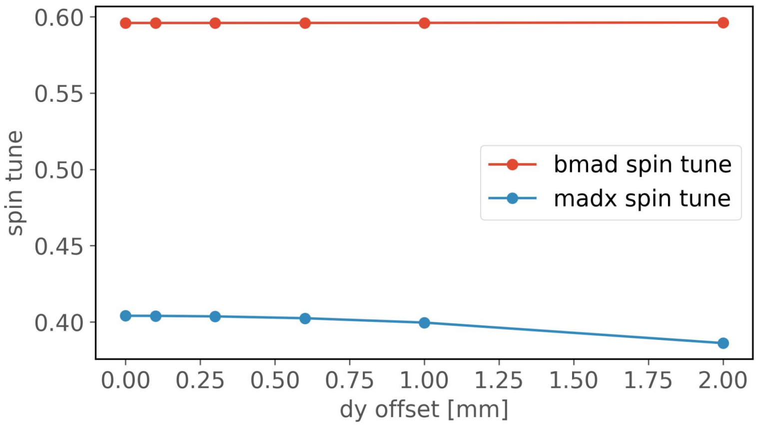
- Choice of opposite sign for spin tune by E. Forest (From Tracking Code to Analysis)?
- Does Bmad sometimes use opposite solution compared to PTC?



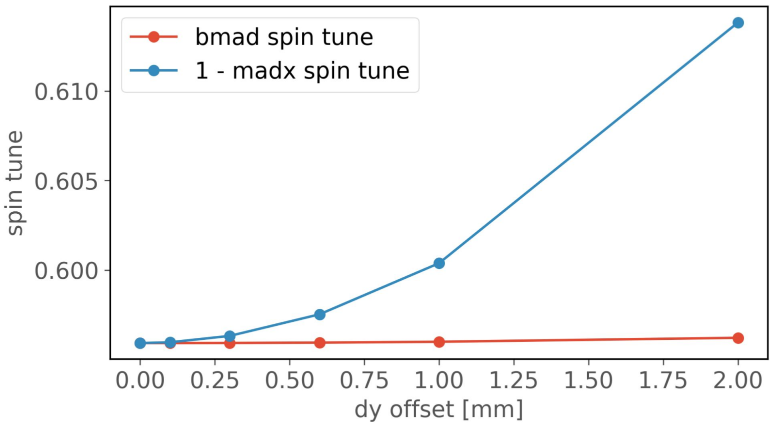


Spin tune for changing quadrupole offsets

- Spin tune change vs. quadrupole vertical offset does not agree.
- Even accounting for the different spin tune solutions.
- Points to a deeper issue in the spin tune calculations between the codes
- To be studied in more detail …



In case of $1 - \nu_s$ flip



Conclusions and next steps

1. The closed spin solution from Madx-PTC agrees well with Bmad-PTC
2. Initial tests show no obvious discrepancy in the ISF when compared to Bmad-PTC output
3. Discrepancy observed in spin tune calculations between Madx and Bmad

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1. Discover and understand the current inconsistencies in spin tune.
    - Sign change in certain regimes, different change in spin tune with orbit
2. Code first calculation of linear DK polarization limits using Madx-PTC output
4. Develop and test initial conditions for spin in Madx-PTC to allow tracking simulations

➡ These efforts would allow a closer integration of spin simulations to the ongoing tuning studies performed in Madx