SPIN SIMULATIONS WITH BMAD AND PTC

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Current spin work is based in part upon work supported by the U.S. Department of Energy, Office of Science, Office of High Energy Physics, under Award Number DE-SC0018370.

In the Beginning…

What is Bmad?

- Bmad is a software toolkit (library) for the simulation of charged particles and X-rays.

A Brief History of Bmad:

- Born at Cornell in mid 1990's
- Started life as modest project for the calculation of Twiss functions and closed orbits from within control system programs running the CESR e-/e+ storage ring.
- Initially Bmad used a subset of the MAD lattice syntax. Hence the name: "Baby MAD" or "Bmad" for short.

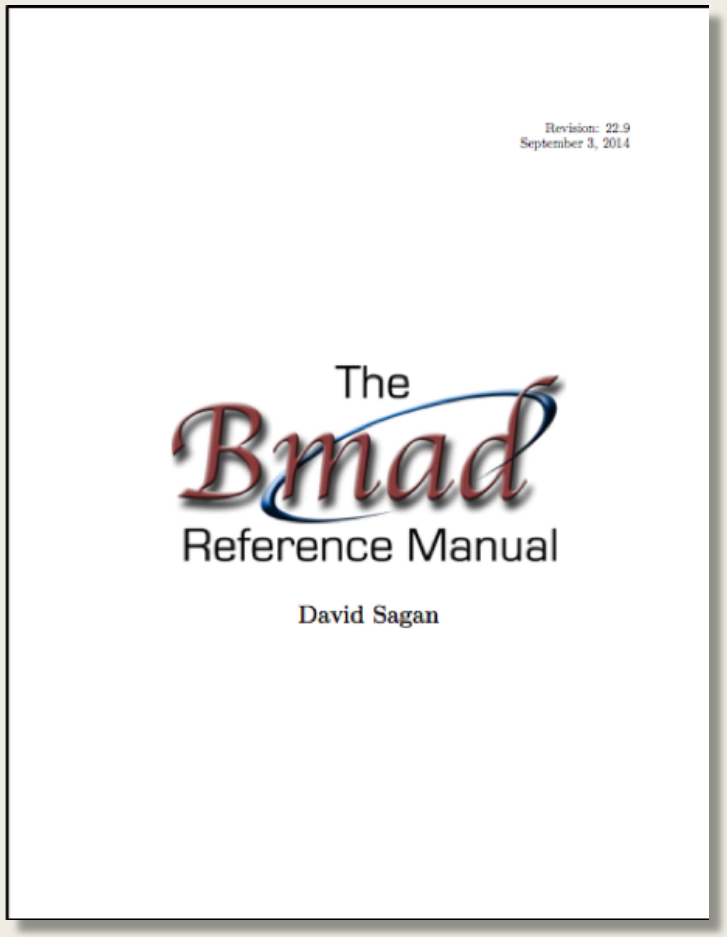
And Baby Grows Up…

Currently:

- >100,000 lines of code
- ~1,000 routines

And Bmad can do Much More:

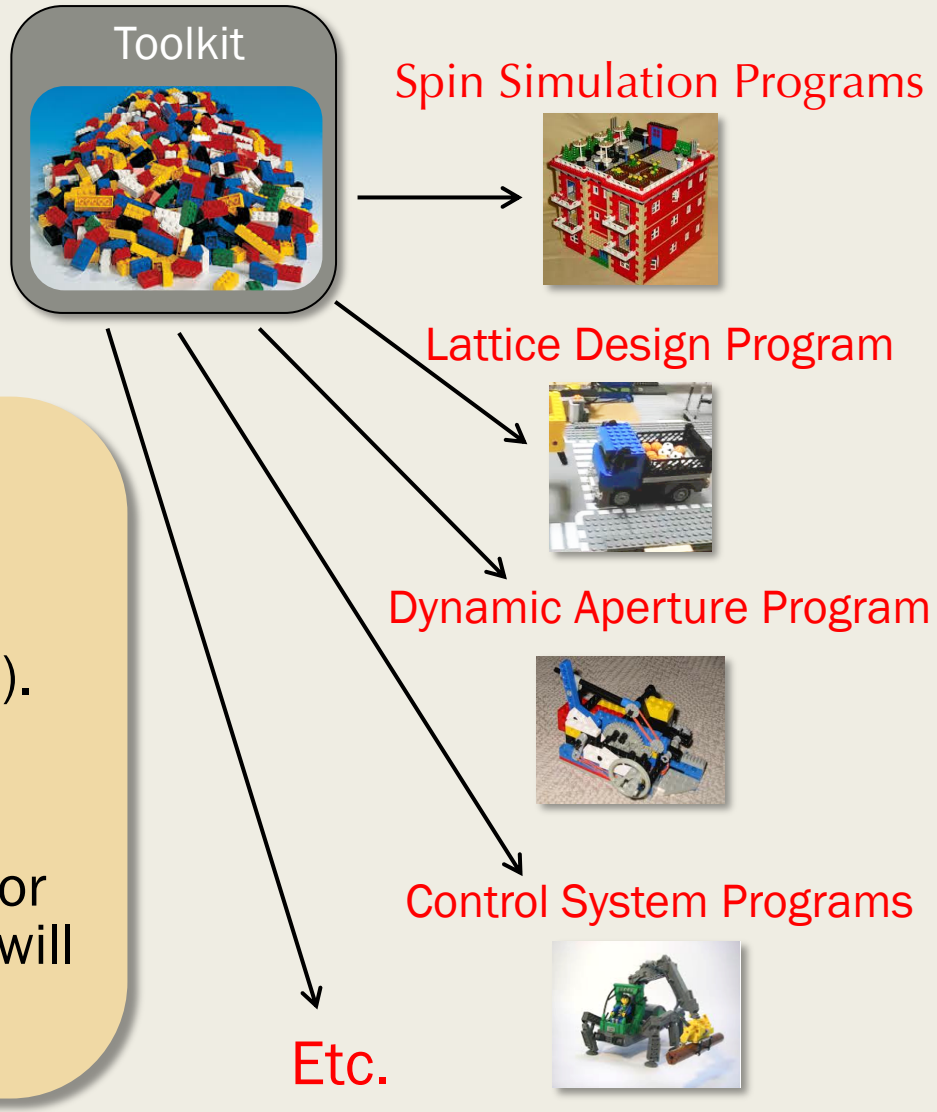
- Lattice design
- X-ray simulations
- **Spin simulations**
- Wakefields and HOMs
- Beam breakup (BBU) simulations in ERLs
- Intra-beam scattering (IBS) simulations
- Coherent Synchrotron Radiation (CSR)
- Touschek Simulations
- Frequency map analysis
- Dark current tracking
- Etc., etc.



Overview

- Written in object-oriented Fortran 2008.
- With certain restrictions, Bmad can be run multi-threaded.
- Lattice files use a MAD like syntax.
- Well documented (Manual is >500 pages).
- *Open Source:*
  classe.cornell.edu/bmad

A Toolkit is like a bunch of Lego blocks



Advantages of a toolkit:

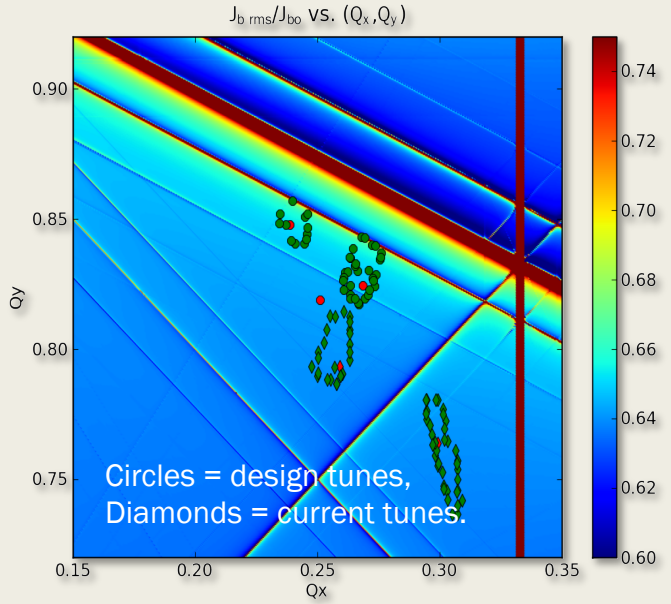
- Cuts down on the *time* needed to develop programs.
- Cuts down on programming *errors* (via module reuse).
- *Standardizes* sharing of lattice information between programs.
- Increased *safety*: Modular code provides a firewall. For example, a buggy module introduced into the toolkit will not affect programs that do not use it.

Bmad Ecosystem

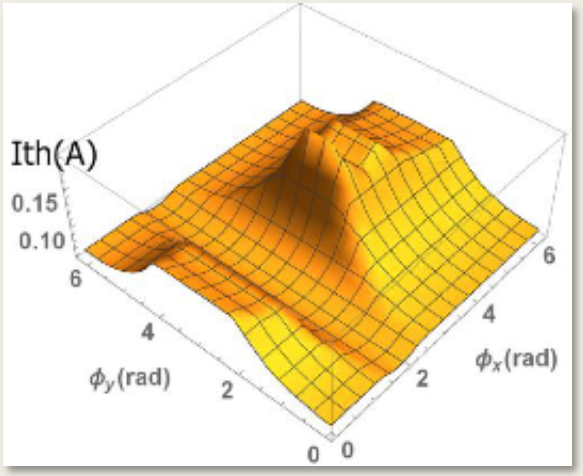
Due to its flexibility, Bmad has been used in a number of programs including:

- Tao: General purpose design and simulation program including spin tracking
- spin_stroboscope: Spin stroboscopic averaging
- g-2: Fermilab muon g-2 machine simulation
- long_term_tracking: Multi-turn beam tracking with spin
- touschek_track: Tracking of Touschek particles
- freq_map: Frequency map analysis
- MOGA: Multi-Objective Genetic Algorithm optimization
- Lux: Photon tracking in X-ray beam lines
- etc...

Code reuse: Modules developed for one program can, via Bmad, be used in other programs.



Tune Scan for CESR Ring Upgrade

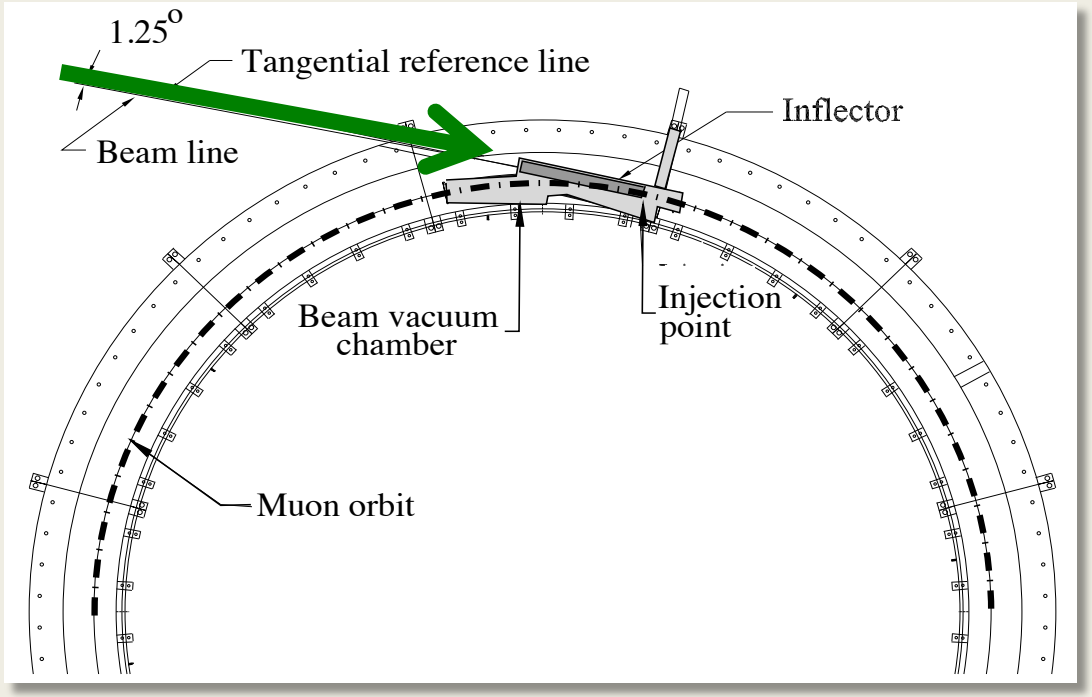


BBU threshold current for CBETA as a function of the phase advance between cavities.

G-2 Simulation Program

- Dave Rubin at Cornell has been developing a simulation program to simulate the **Muon g-2 experiment** at Fermilab.
- Need to track the polarized muons with:
  - *Injection line into a storage ring.*
  - *Three dimensional field of the injection line.*
  - *Scattering of muons as they cross the inflector wall*
  - *Electrostatic quadrupoles*
  - *Muon decay*
  - *Tracking of electron decay product*

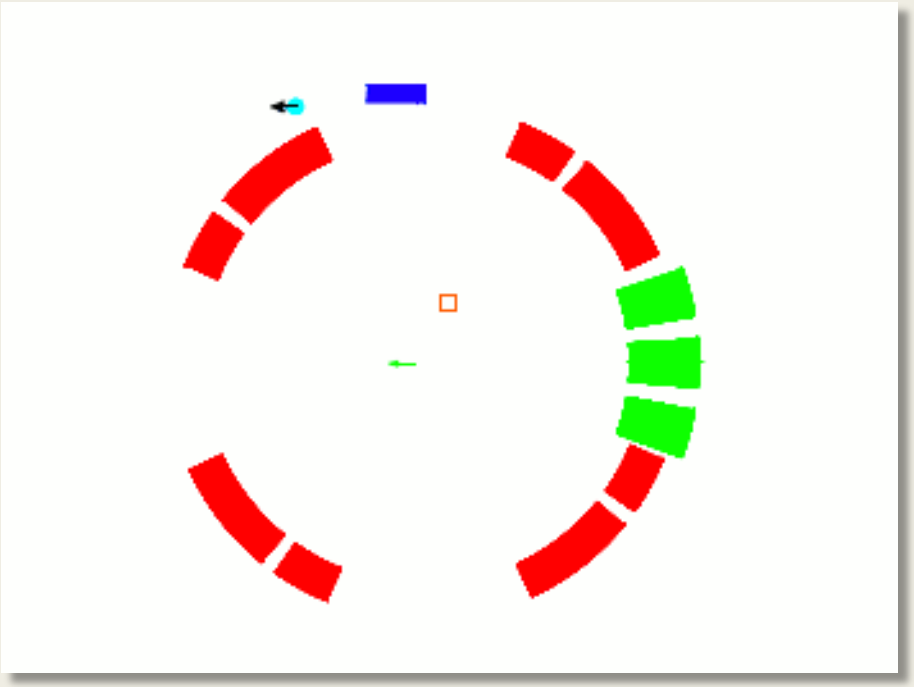
Polarized Muons

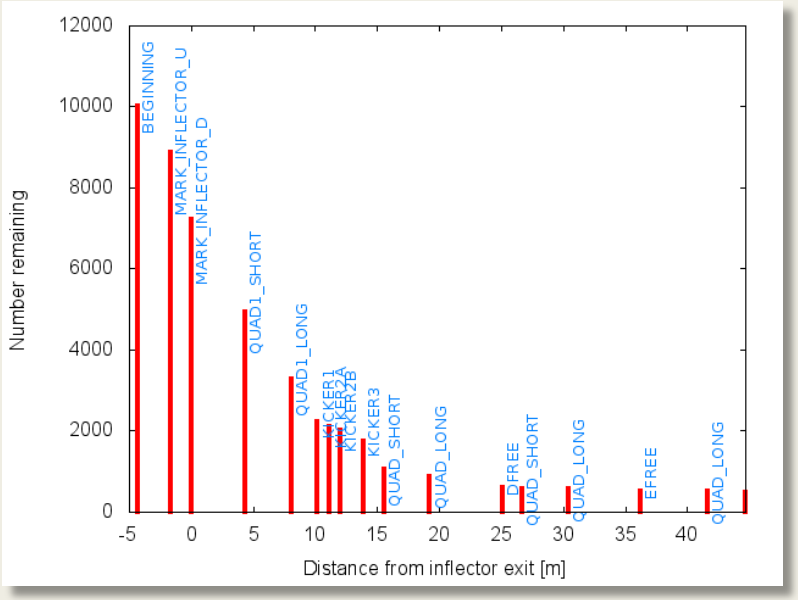


G-2 Simulation

- At the start of program development **Bmad provided**:
  - *Ability to define the geometry of the injection line and storage ring.*
  - *Ability to define the geometry of the inflector wall*
  - *Ability to define custom fields for the injection line and the ability to simulate electrostatic quadrupoles*
- **Needed to develop for the program:**
  - *Scattering of muons through the inflector wall*
  - *muon decay.*
  - *etc.*

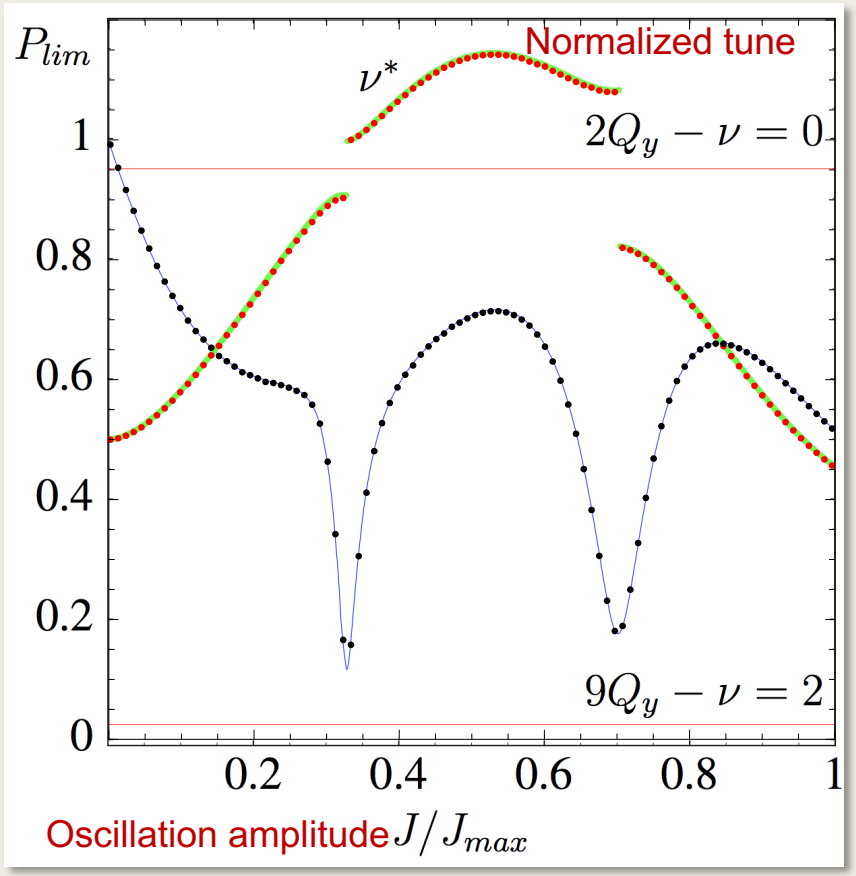
➔ Bmad reduced the development time for creating the program and provides a flexible framework for future program modifications.





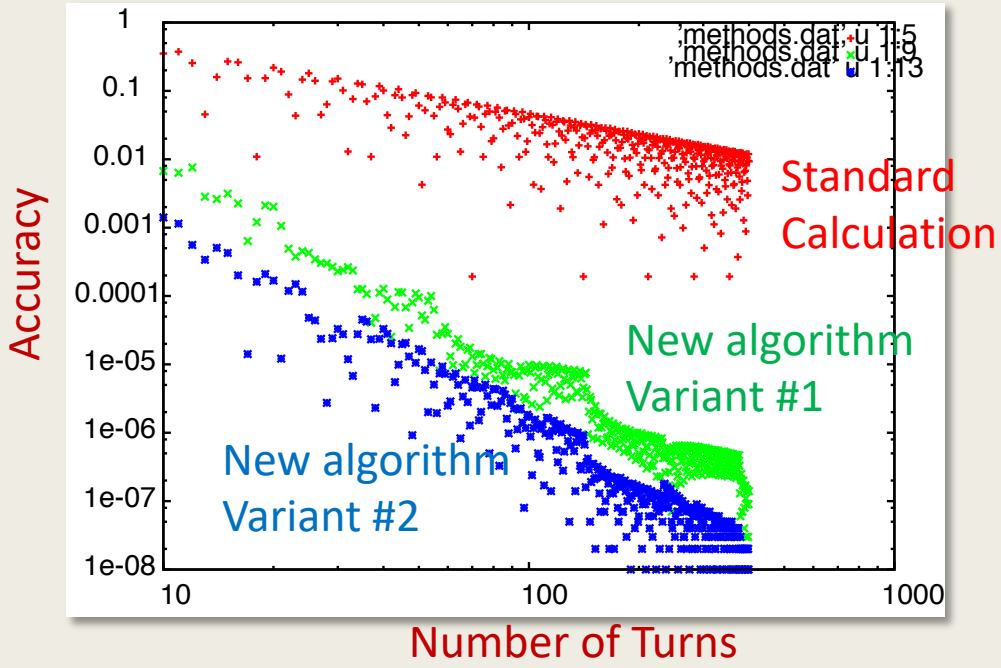
Stroboscopic Spin Averaging

Polarization limit



Dots: Bmad
Lines: Hoffstaetter [Fig 4.19 "High-Energy Polarized Proton Beams: A Modern View"]

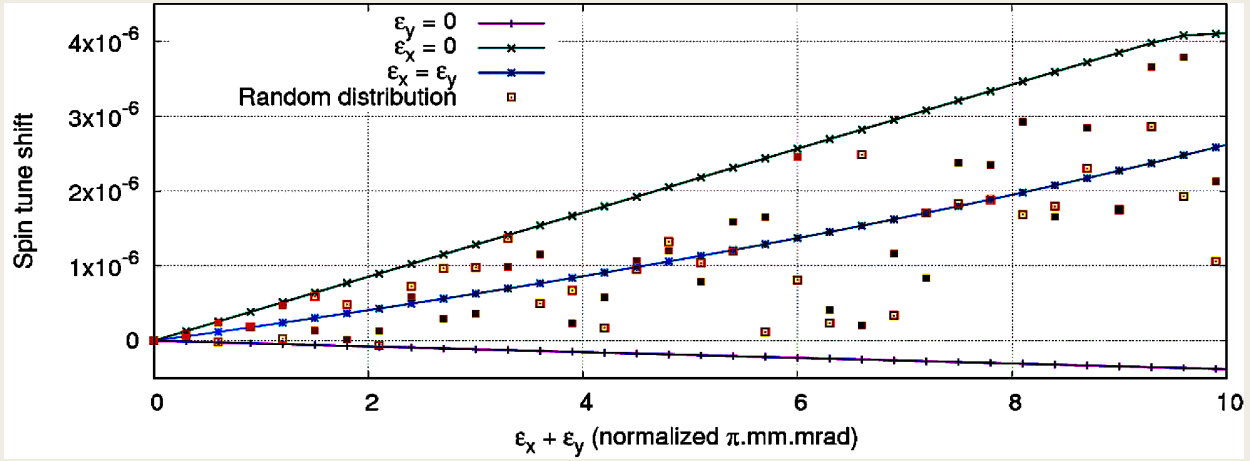
spin_stroboscope program: Track a particle at a given orbital oscillation amplitude for N turns and from the track calculate the spin tune and maximum achievable polarization.



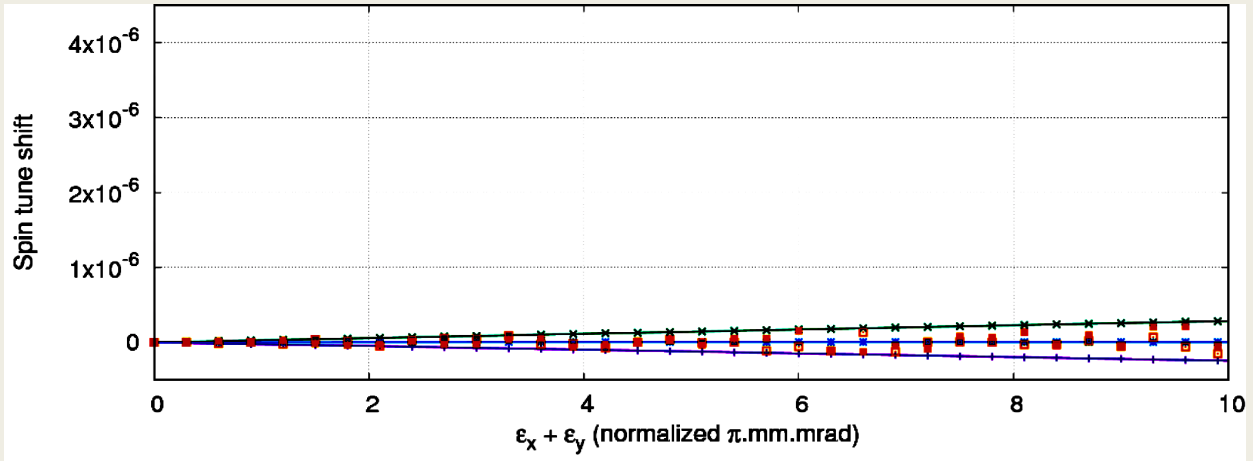
Spin Optimization

Amplitude Dependent Spin Tune Deuteron case

Before optimization

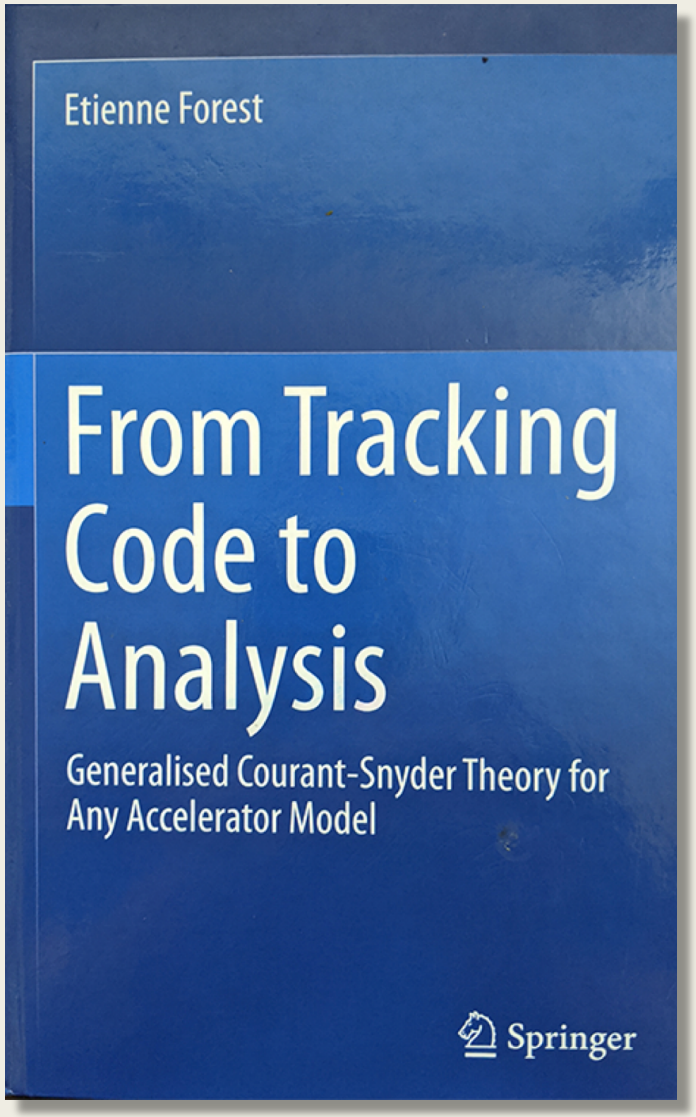


After optimization



y.dutheil@fz juelich.de

IPAC 16 satellite meeting on spin tracking



Etienne Forest's FPP/PTC Toolkit

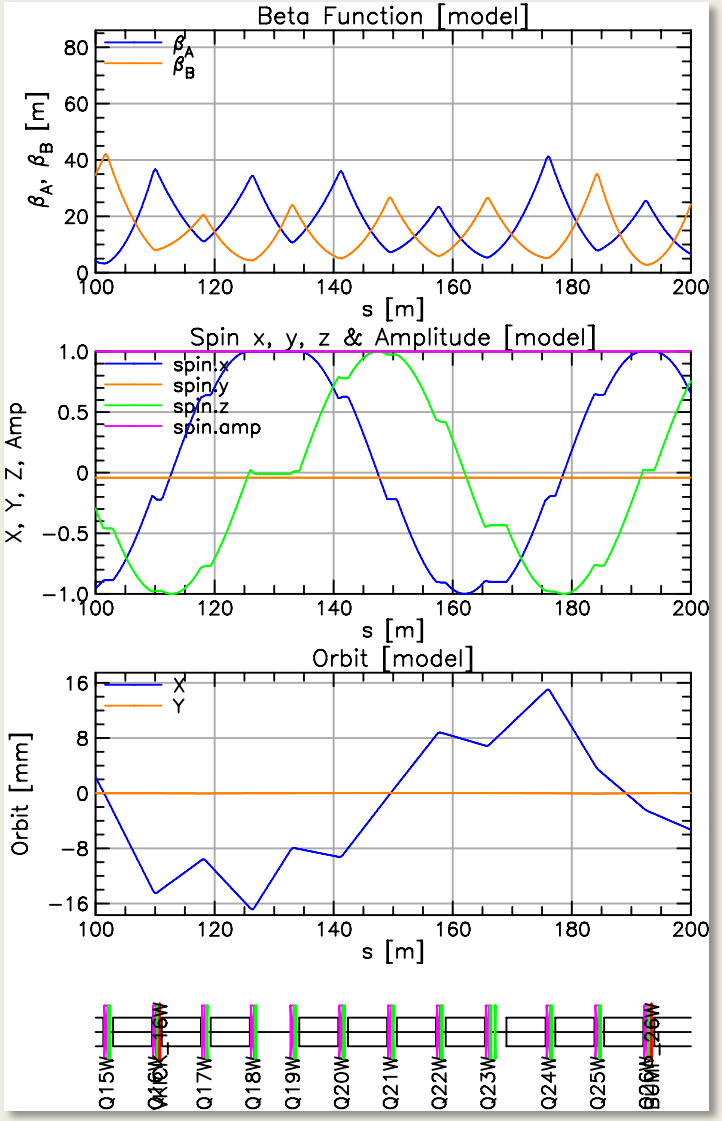
Wednesday 13:45 - Oleksii Beznosov
Fast spin tracking and spin matching with stochastic one turn maps

- *Can construct Taylor maps to arbitrary order via symplectic integration.*
- *Normal form analysis to extract:*
  - Resonance strengths.
  - Invariant spin field
  - G-matrices
  - Nonlinear orbital and spin tunes
  - Etc., etc.

```
Out     Coef          Exponents
-------------------------------
S1:   -0.87067631    0 0 0 0 0 0
S1:   -0.01294703    1 0 0 0 0 0
S1:   -0.00647350    0 1 0 0 0 0
S1:    0.00244198    0 0 0 0 0 1
-------------------------------
Sx:    0.01373670    0 0 1 0 0 0
Sx:    0.00686821    0 0 0 1 0 0
-------------------------------
Sy:   -0.49185643    0 0 0 0 0 0
Sy:    0.02291863    1 0 0 0 0 0
Sy:    0.01145929    0 1 0 0 0 0
Sy:   -0.00432275    0 0 0 0 0 1
-------------------------------
Sz:   -0.00000012    0 0 1 0 0 0
Sz:    0.47801977    0 0 0 1 0 0
```

Quaternion Spin Map

PTC Integration with Bmad



- Collaboration with Etienne to develop interface routines which allows communication between Bmad and PTC modules.

Example: PTC routines are used within the Tao program to calculate the spin-orbital G-matrix which is used for "spin-matching" lattice design to minimize synchrotron radiation induced depolarization.

```
Tao> show spin -ele Q10W -n 0,1,0 -l 1,0,0  ! G-matrix for Q10W

G-Matrix:
 0.9526   0.5905   0.0000   0.0000   0.0000  -0.0002   0.0000   0.0000
-0.1565   0.9526   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
 0.0000   0.0000   1.0481   0.6095   0.0000  -0.0000   0.0000   0.0000
 0.0000   0.0000   0.1616   1.0481   0.0000  -0.0000   0.0000   0.0000
 0.0000  -0.0002  -0.0000  -0.0000   1.0000   0.0000   0.0000   0.0000
 0.0000   0.0000   0.0000   0.0000   0.0000   1.0000   0.0000   0.0000
 0.0000  -0.0000   0.0335   0.0414   0.0000  -0.0000   1.0000   0.0000
 0.0000  -0.0000  -2.1178  -0.6298   0.0000   0.0000   0.0000   1.0000
```

Future

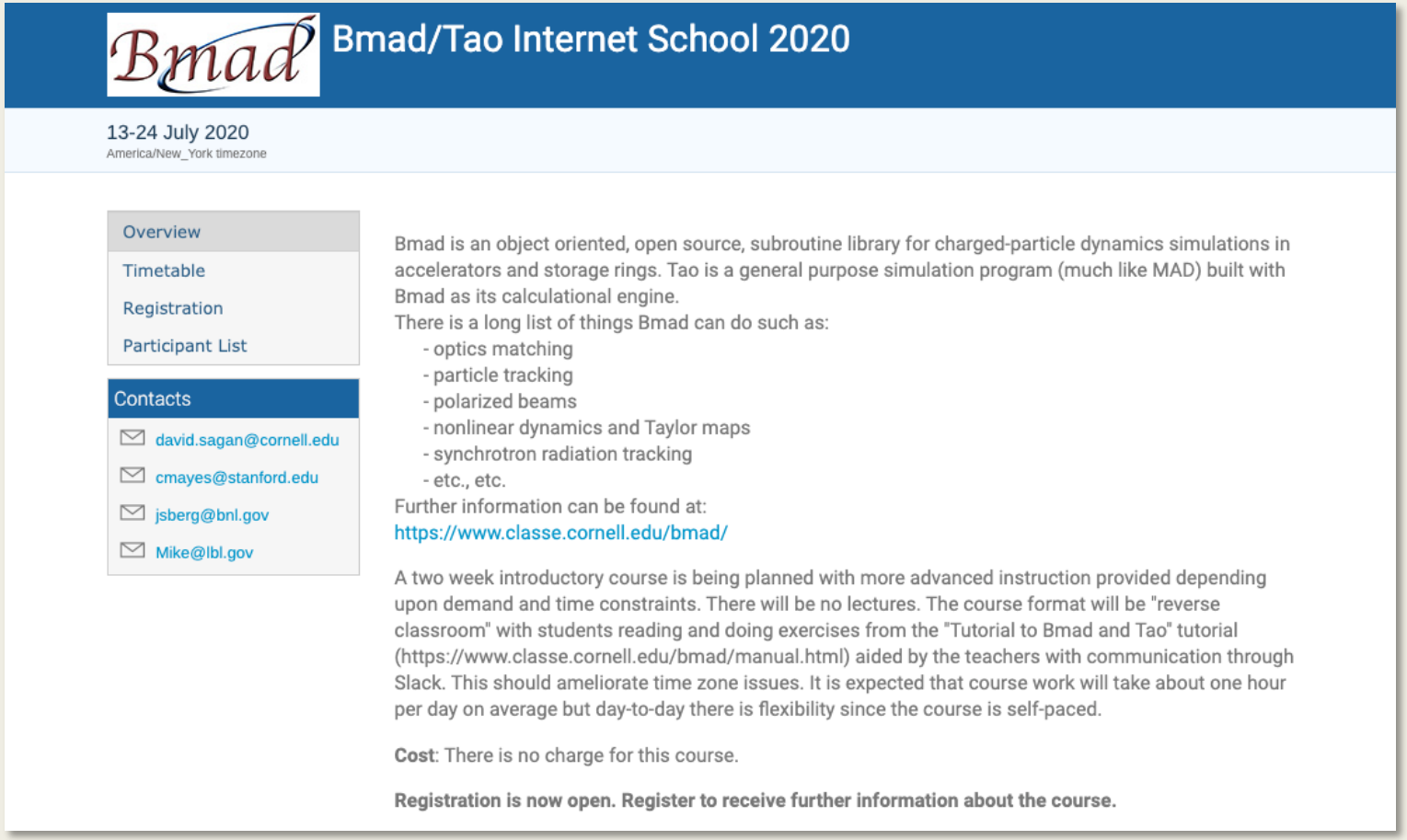
Collaboration to develop spin simulation code:

- Desmond Barber (DESY)
- Oleksii Beznosov (UNM)
- Jim Ellison (UNM)
- Etienne Forest (KEK)
- Klaus Heinemann (UNM)
- Georg Hoffstaetter (Cornell)
- David Sagan (Cornell)

Ongoing work:

- Long term tracking using SLIM/SLICK G-matrix formalism
- Further integration between Bmad and PTC
- Positron converter tracking module
- EIC Simulations
- …etc…

Bmad School



Bmad/Tao Internet School 2020

13-24 July 2020
America/New_York timezone

Overview
Timetable
Registration
Participant List

Contacts
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cmayes@stanford.edu
jsberg@bnl.gov
Mike@lbl.gov

Bmad is an object oriented, open source, subroutine library for charged-particle dynamics simulations in accelerators and storage rings. Tao is a general purpose simulation program (much like MAD) built with Bmad as its calculational engine.
There is a long list of things Bmad can do such as:
- optics matching
- particle tracking
- polarized beams
- nonlinear dynamics and Taylor maps
- synchrotron radiation tracking
- etc., etc.

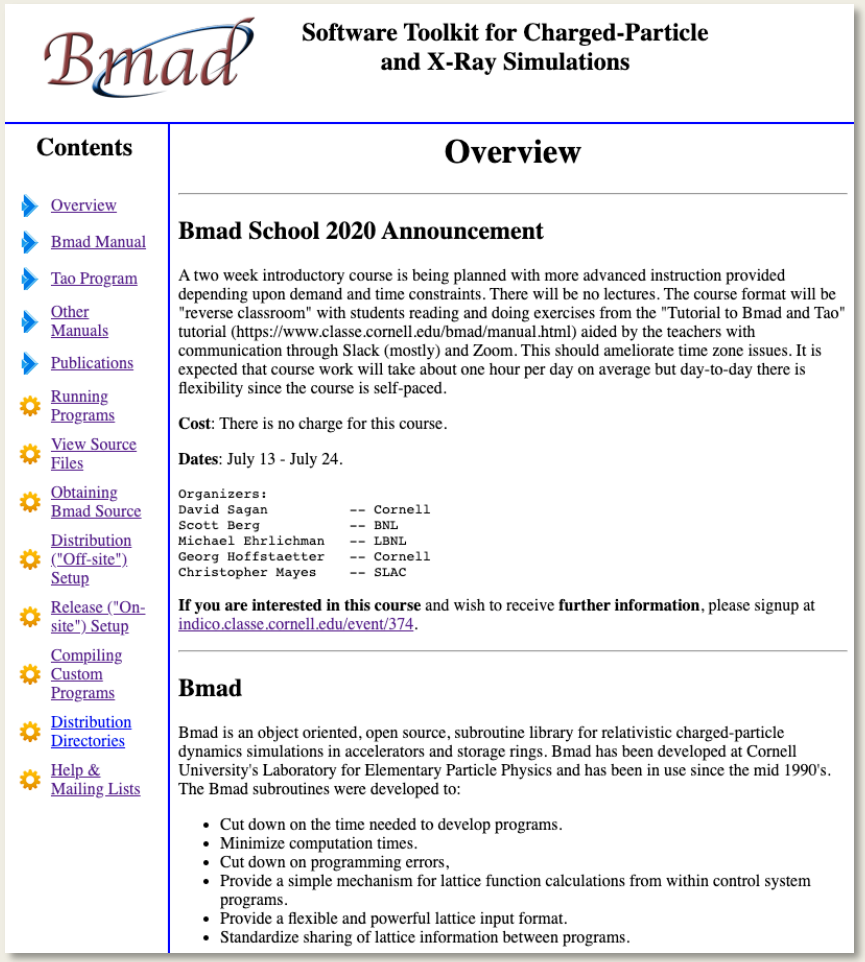
Further information can be found at:
https://www.classe.cornell.edu/bmad/

A two week introductory course is being planned with more advanced instruction provided depending upon demand and time constraints. There will be no lectures. The course format will be "reverse classroom" with students reading and doing exercises from the "Tutorial to Bmad and Tao" tutorial (https://www.classe.cornell.edu/bmad/manual.html) aided by the teachers with communication through Slack. This should ameliorate time zone issues. It is expected that course work will take about one hour per day on average but day-to-day there is flexibility since the course is self-paced.

Cost: There is no charge for this course.

Registration is now open. Register to receive further information about the course.

indico.classe.cornell.edu/event/374



Bmad

Software Toolkit for Charged-Particle and X-Ray Simulations

Contents

- Overview
- Bmad Manual
- Tao Program
- Other Manuals
- Publications
- Running Programs
- View Source Files
- Obtaining Bmad Source
- Distribution ("Off-site") Setup
- Release ("On-site") Setup
- Compiling Custom Programs
- Distribution Directories
- Help & Mailing Lists

Overview

Bmad School 2020 Announcement

A two week introductory course is being planned with more advanced instruction provided depending upon demand and time constraints. There will be no lectures. The course format will be "reverse classroom" with students reading and doing exercises from the "Tutorial to Bmad and Tao" tutorial (https://www.classe.cornell.edu/bmad/manual.html) aided by the teachers with communication through Slack (mostly) and Zoom. This should ameliorate time zone issues. It is expected that course work will take about one hour per day on average but day-to-day there is flexibility since the course is self-paced.

Cost: There is no charge for this course.

Dates: July 13 - July 24.

```
Organizers:
David Sagan          -- Cornell
Scott Berg           -- BNL
Michael Ehrlichman   -- LBNL
Georg Hoffstaetter   -- Cornell
Christopher Mayes    -- SLAC
```

If you are interested in this course and wish to receive **further information**, please signup at indico.classe.cornell.edu/event/374.

Bmad

Bmad is an object oriented, open source, subroutine library for relativistic charged-particle dynamics simulations in accelerators and storage rings. Bmad has been developed at Cornell University's Laboratory for Elementary Particle Physics and has been in use since the mid 1990's. The Bmad subroutines were developed to:

- Cut down on the time needed to develop programs.
- Minimize computation times.
- Cut down on programming errors,
- Provide a simple mechanism for lattice function calculations from within control system programs.
- Provide a flexible and powerful lattice input format.
- Standardize sharing of lattice information between programs.

Overview

- Bmad and PTC are open source software libraries for simulating charged particle beams in general and spin in particular.
- There is a Bmad based ecosystem of programs for spin simulations as well as programs for lattice design, dynamic aperture calculations, Touschek simulation, etc., etc.
- With Bmad and PTC, if new types of simulations are needed, new simulation programs can be developed in less time and with less effort and with fewer bugs.
- Bmad and PTC have been successful due to their modular, object-oriented design which allows adaptation to ever changing simulation needs.
- Bmad and PTC are in continual development.

Thanks

Dan Abell
Desmond Barber
Ivan Bazarov
Moritz Beckmann
Martin Berz
Oleksii Beznosov
Joel Brock
Sarah Buchan
Avishek Chatterjee
Jing Yee Chee
Christie Chiu
Joseph Choi
Robert Cope
Jim Crittenden
Attilio De Falco
Gerry Dugan
Michael Ehrlichman
Jim Ellison
Ken Finkelstein
Etienne Forest
Mike Forster
Hans Grote
Klaus Heinemann
Richard Helms
Georg Hoffstaetter
Chris Mayes
Karthik Narayan
Katsunobu Oide
Mark Palmer
Tia Plautz
Matt Randazzo
Matt Rendina
Dave Rubin
Michael Saelim
Frank Schmidt
Jim Shanks
Jeff Smith
Jeremy Urban
Mark Woodley
Demin Zhou