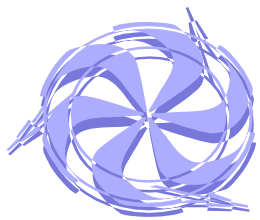
Tracking and Simulation Tools for the Beta-Beam Decay Ring

1. Motivation and methodology

2. Codes: from Tracking to Simulation
   - MARS and STRUCT
   - Geant4
   - Accsim

3. Prospects for integration (somewhat speculative)

4. Preliminaries: some possible development/test strategies



Frederick Jones
TRIUMF
Vancouver, Canada

Personnel

Mats Lindroos and Elena Wildner, CERN

Fred Jones, TRIUMF

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V. Ivantchenko, D. Kaltchev, N. Mokhov, M. Maire, L. Moritz, P. Truscott, H.-P. Wellisch

Motivations for Tracking/Simulation

- The Decay Ring is a machine with 100% beam loss.
  - Want to predict, moderate, and control losses
  - Identify high-loss areas in an operating scenario
  - Provide input to activation studies
  - Evaluate collimation schemes
  - Optimize collimation and other relevant design features
  - Dynamics of the ring operation (injection, bunch merging, decay) and the variability of machine parameters suggest that a comprehensive computer model incorporating particle tracking and interactions in matter would be useful.

Tracking (accelerator, multiparticle, multiturn)

- Code characteristics:
  - Map-based machine model with defined apertures
  - Macroparticle ensemble, parameterized or user-defined distributions, possibly with realistic injection and stacking.
  - ~ 10^5-10^6 particles $\times$ ~10^4-10^5 turns is possible
  - Tabulates macroparticles lost on apertures
- Examples
  - Without space charge:
    - MAD, DIMAD, SIXTRACK… not always tailored to the “full problem”: injection, stacking, detailed apertures, etc.
    - STRUCT: tailored to loss prediction and management
  - With space charge:
    - Accsim (TRIUMF), Orbit (ORNL), SIMBAD (BNL)
    - MAD-9, Simpsons (KEK), Track3d (C.Prior)

Particle simulations in matter

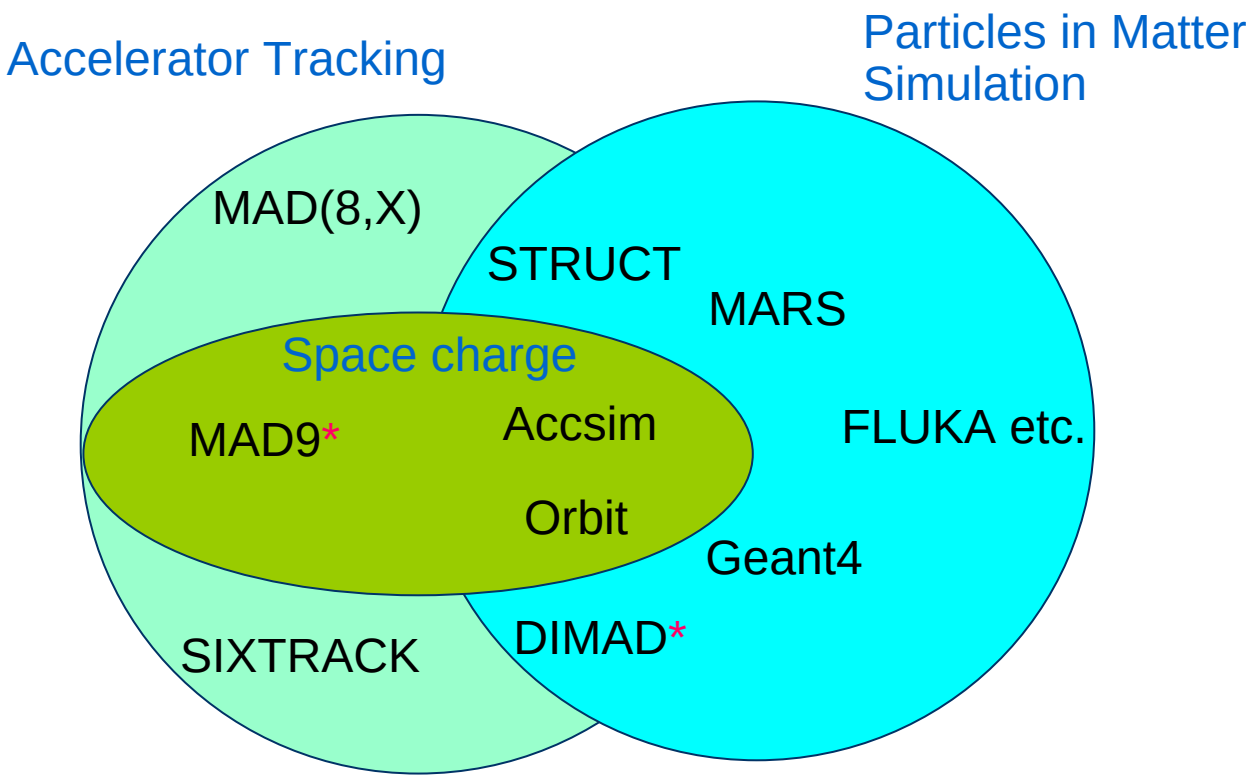
- Particle tracking (stepwise with R-K integration in fields) in materials with physics models:
  - multiple scattering,
  - energy loss,
  - other EM physics
  - nuclear interactions
    - elastic
    - inelastic…
- Production and tracking of secondary particles via stack mechanism.
- Measurements e.g. energy deposition & radiation dose
- Examples:
  - FLUKA, MARS, Geant4: support for complex geometries
  - With simplified or partial physics models and/or geometry: STRUCT, Accsim, DIMAD (D.Kaltchev)

Tracking in accelerator + Simulation in materials

- An all-in-one model has many advantages:
  - Simplify and streamline large-scale studies
  - Easier version control
  - Easier data handling
  - Great for exploratory or “what-if” scenarios
- Can be important for collimation studies, due to outscattering (emergence of primary or secondary particles from absorber blocks) and its impact on downstream losses.

- Accelerator tracking codes tend to be single-species: simulating particle decay itself is no problem but what to do with decay products?
- Marriage of a tracking code with a simulation code is “difficult”. A toolkit or library approach is preferred.

Codes: Map of the territory



* Variant versions

MARS and STRUCT

- Nikolai Mokhov FNAL and numerous contributors
- Not open-source, sketchy doc, enthusiastic support.
- Comes from accelerator community rather than HEP
- Extensive recent work on ion physics models:
  - Elastic and inelastic cross sections from JINR model (recent study Baraschenkov & Kumawat 2003)
  - Utilizes LAQGSM03 for particle & heavy-ion projectiles from 10 MeV/u to 800 GeV/u. *Waiting for LANL approval to distribute.*
  - Correlated ionization energy loss and multiple Coulomb scattering via new algorithm (Striganov)
  - Light ions 0.5-3.65GeV/u in lead benchmarked against SHIELD and measured data (Vassil'kov & Yurevich 1990)

- STRUCT (Drozhdin & Mokhov): accelerator tracking with limited physics from MARS and elsewhere. MAD lattice input.
  - Has not been comparably upgraded: supports e and p only.
  - See N.Mokhov for employment on upgrade project!

Geant4

- Originates in HEP community (cf. GEANT 3) but has spread into many fields from underground physics to space physics, medical physics and accelerator physics.
- >100 collaborators … world's largest (?) integrated code repository of particle and nuclear physics models, keV to TeV.
- O-O toolkit architecture, open source code, pluggable models and cross section data.
- Extensive work on support for arbitrary ions, motivated e.g. by space physics (ESA is a member institution of Geant4)
  - Radioactive decay (ENSDF nuclear data)
  - EM processes extended (M.Maire, L.Urban, V.Ivantchenko)
  - Ion-ion cross sections: Tripathi for light ions; parameterizations from Shiver, Kox, and Shen.
  - Qinetiq contributions: abrasion-ablation < 10 GeV/u, EM dissociation 100MeV-500GeV/u (P.Truscott & F.Lei)
  - Quark Gluon String Model, ready in 1Q05? (T.Koi et al.)
  - Several others: survey on http://reat.space.qinetiq.com/ionmarse/

Geant4 in accelerators and beam lines

- Development
  - Very flexible electric and magnetic field mapping and integration, using built-in or user-written components.
  - Fermilab Beam Tools: solenoids, magnets, pillbox cavities, absorbers (Elvira, Lebrun, Spentzouris)
  - BDSIM: accelerator-style tracking in beam pipe + Geant-style tracking in materials, particle production, spoilers, collimators, MAD-format optics input, beam distributions (G.Blair)
  - MPI parallelization available for large simulations

- Applications
  - MuCool (Elvira et al.)
  - CLIC beam delivery system (G.Blair)
  - Muon backgrounds in CLIC combined beam delivery and detector system (H.Burkhardt)
  - Backgrounds at JLC IR (H.Aihara et al.)

Accsim in a nutshell

- A 3D tracking and simulation code with space charge (longitudinal and transverse) and some particle interactions in materials (protons, ~100MeV - 10GeV, no secondaries)
  - Foils, collimators, wire septa, vacuum chambers, internal targets
  - Detailed loss tabulation and summaries
- Fast basic tracking engine using matrix/thin-lens model
- Feature-laden: many additions to support specific studies
- Easy to modify and customize
- Multiturn injection and RF gymnastics are specialties
- Some validation:
  - LANL PSR loss profiles
  - KEK 12 GeV PS space charge effects
  - J-PARC 3GeV ring STRUCT qualitative comparison
  - Theoretical studies (space charge resonances)
- Potentially useful even without ion-material interactions

Accsim in practice

- Some applications
  - Spallation sources: LANL PSR, SNS, future CSNS Beijing
  - CERN PS booster (collimation, space-charge @ injection, future H- injection)
  - Tsukuba Hitachi medical synchrotron (injection problems)
  - KEK 12 GeV PS (intensity upgrade for K2K)
  - J-PARC 3 GeV ring (injection and collimation studies)
  - European HIDIF study - multi-bunch and multi-species driver rings (H.Schönauer)

- Some limitations
  - Missing: errors, impedances
  - No natural model for chromaticity (use thin sextupoles)
  - Single precision (check and compensate for round-off)
  - 2nd order thick elements are in, but not symplectified

Accsim application: H.I. Fusion driver fast multi-bunch rotation (H. Schönauer)

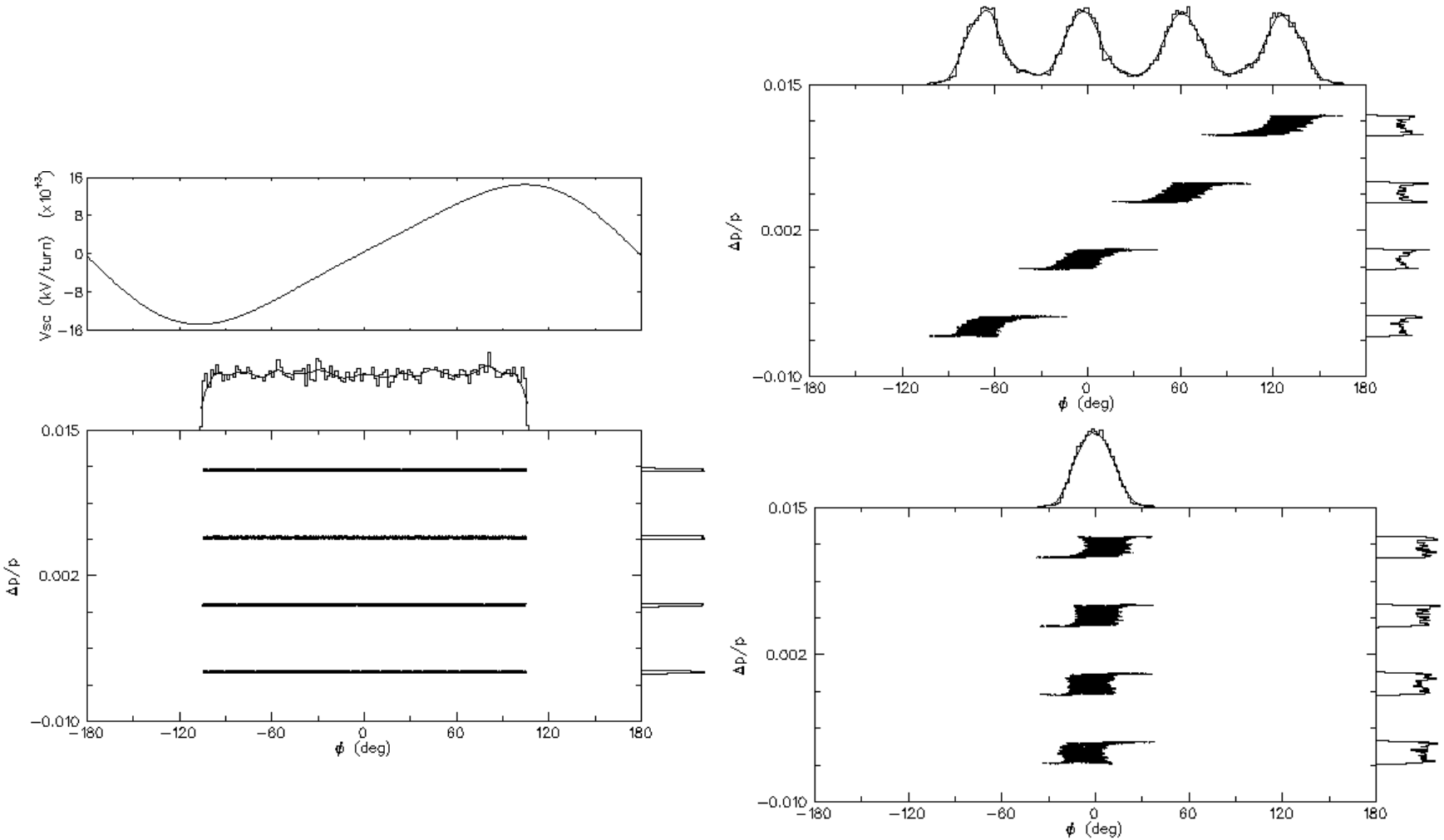
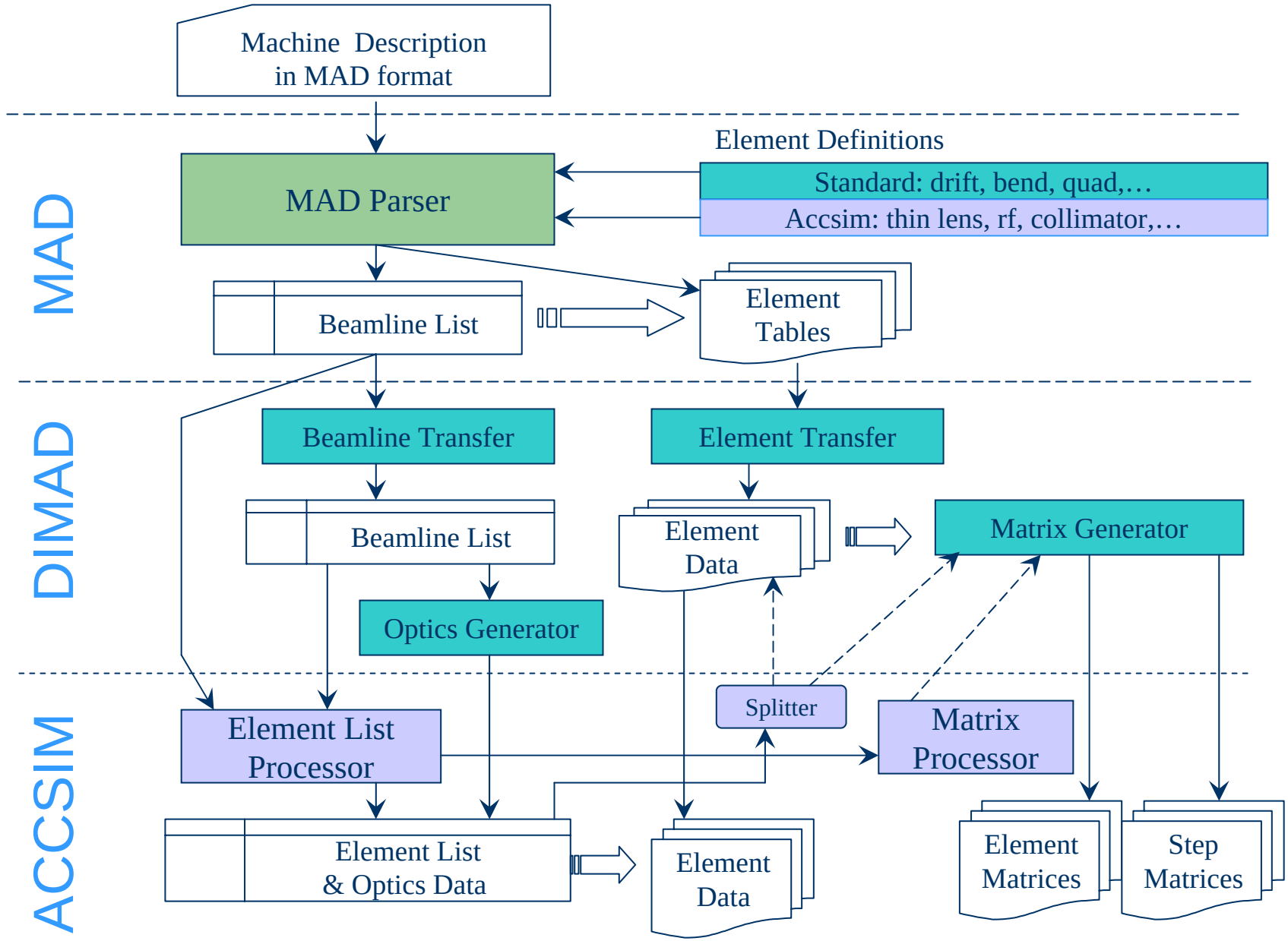


Fig 6: Phases of final bunch rotation : Initial barrier-held flat bunches, rotated and phase-aligned for extraction after ~2 turns, and after final drift of 300 m.

Accsim 4 Data Management



Prospects for Integration

- No all-in-one solution is currently available
  - Time-scale of STRUCT upgrade is unknown
  - Upgrade Accsim or other tracker with ion physics package?
- Source of ion physics package:
  - MARS and FLUKA are proprietary-source
  - Geant4 incomplete but good prospect
  - Other source?
- Short term alternative:
  - Accsim, possibly with quick-fix to EM physics and some new cross-section data, as preprocessor for MARS.
- Other considerations:
  - Average lifetime of primary ion is ~0.5 million turns
  - Fundamental machine cycle -- short or long -- has implications for tracking/simulation. If machine stays close to equilibrium, just need to do enough injection cycles to gather statistics.
  - A lot of questions to be answered quantitatively.
  - Various loss control scenarios (eg.'s A.Jansson 2003)

Preliminary tasks

- Outscattering issue may be important
  - Look at Coulomb and nuclear elastic scattering
  - Look at clean collection of stable ions (cf. Jansson, Spiller)
  - Look at transverse halo and momentum collimation (rf bucket losses)
  - Survey and comparison of available physics models
    - MARS and Geant4
    - Others
- Baseline configuration for Accsim
  - Lattice ✓, injection, bunch merging
  - Introduce radioactive decay (cf. stacking)
  - Test and time trials
- Baseline for MARS -- simple benchmark case in arc cell(s)
  - Survey MARS input and output streams
- Compare Accsim and STRUCT
  - Estimate for possible development work.