Integrating the TRACK beam simulation code to improve ATLAS operations

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Outline

- The ATLAS accelerator
- Goals for the TRACK implementation
- TRACK particle tracking software
  - Background
  - Accuracy
- Integration into the ATLAS control system
- TRACK results with ATLAS
- Summary
ATLAS flexibility

- 2 sources, 6 experimental target lines
- Ions: H to U; energies: ~0.5 to >15 MeV/u
- 1-2 experiments per week
- RIBs from CARIBU and in-flight production
Goals for TRACK at ATLAS

- Increase tuning efficiency
  - Highlight areas of beam loss or distortion
  - Predict component fields for previously unencountered situations
    - Machine reconfiguration, planned (AIRIS) or unplanned (F cryostat He leak)
    - In-flight RIB production
- Graphics outputs – beam evolution through the accelerator – are a great training aid
- Highlight differences between expected and observed accelerator performance to develop a more accurate understanding and model of the machine
TRACK

- Developed by ANL personnel
- 3 dimensional particle tracking software
- Integrates the equations of motion
- Includes Poisson solver to account for space charge forces
- Internal analytic field solutions for some basic elements
- User defined fields from 3rd party solvers
- Matching and optimization routines
TRACK for accelerator operations

- **Pros**
  - Very accurate
    - Integration steps can be defined per element
    - Macro-particles more realistic than envelope codes
    - Space charge effects are included
  - Code development on site

- **Cons**
  - Too slow for real time beam simulation
**TRACK accuracy**

- Good agreement between simulation and measurement for RFQ commissioning
- RFQ input measured with pepper pot
- Outputs measured with wire scanner, bunch shape monitor, and analyzing dipole magnet

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Ostroumov et al., PRST AB, 15 (2012) 110101; Perry et al., NIM A, 735 (2014) 163-168
ATLAS control system

- TRACK input files are built from the ATLAS control system databases
- The ATLAS control system runs on LINUX based machines
- We use the LINUX version of TRACK
  - Unfortunately no graphical output
- Control software is Vsystem (Vista Control Systems LLC)
Building the TRACK input files

- Two main TRACK input files

  - Accelerator component configuration: accelerator layout, device lengths, apertures, field amplitudes, effective lengths, bend radii, etc

  - Beam configuration: A, q, starting energy, 4d or 6d distribution, ΔE, matching conditions, optimization parameters
Accelerator configuration file generation

Control values (ie. amps for magnets, volts for RF control modules, kV for electrostatics, etc)

Convert power supply/RF control module output to field

Real time amplitudes → Scaling → Accelerator configuration file

Beam path

Dynamically generated from source and target information

Physical parameters

Compiled in a new control system database
Scaling - resonator fields

- From resonator phase scans
  \[ V_{\text{EFF}} = \Delta E / [q \ \text{TTF} \ \cos(\phi_s)] \]
- With TRACK field normalization and RF control module control voltage \( \rightarrow \) scale factor from machine control to TRACK amplitude
- Better statistics available with logged scans

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<th>Res. #</th>
<th>(^{45}\text{Sc}^{11+}) (\Delta E (\phi_s=0)), MeV</th>
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Scaling - magnets

- Hall probe
  - Uniform field region for dipoles
  - Pole tips for quadrupoles
- Quad manufacturer specification 4.9 Gs/(mm-A)
- Pole tip at \( r = 31.75 \text{ mm} \) \( \Rightarrow \) 0.156 kGs/A

Quadrupole results

- Quadrupole manufacturer specification
  - QDP301: \( y = 0.1597x + 0.1507 \)
  - QSP301: \( y = 0.1528x + 0.0385 \)
Beam configuration file generation

**Transverse:** pepper pot emittance meter (installed), quadrupole scanning algorithm (future)

**Longitudinal:** Si detectors, fast Faraday cups

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**Beam distribution**

**Current species information**

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**Beam configuration file**

Standard accelerator information for display and data logging plus energies at the exits of each linac
Current beam distribution diagnostics

- Quads and profile monitors throughout
Beam distributions

Si detector spectra

Energy spectrum
FWHM=1.5%

Time spectrum
FWHM=0.975 nsec

Pepper pot meter and software
- 3rd party software
- $\varepsilon_x$, $\varepsilon_y$ manually xfer to config file
- In future software incorporated into control system
TRACK graphical output for ATLAS

- TRACK.exe for LINUX has no graphical output, so it is being recreated with V-system libraries
- Data
  - Envelope functions created for each integration step
  - Phase space distributions logged after each component
TRACK use for ATLAS operations

- In the past ~3 years ATLAS has been significantly re-configured
  - New LEBT line
  - RFQ installation
  - Re-configuration of first cryostat of low $\beta$ resonators
  - Installation of new 72.75 MHz cryostat of QWR
- Many and sometimes all of our logged operating conditions were invalidated
- Recent He leak in old split-ring cryostat also resulted in a practical reconfiguration: 6 resonators and 3 solenoids became inoperable
TRACK use for ATLAS operations

- Predicted the electrostatic injection line configuration for the beam into the RFQ for commissioning
  - Pepper pot beam distribution
  - RFQ acceptance matched for minimum emittance and losses
TRACK use for ATLAS operations

- With good accuracy TRACK has been able to configure SC solenoids
  - Prior to phase scanning resonators
  - Transport of low energy beam through high energy sections (eg. 0.5 MeV/u \(^{12}\text{C}\))
  - Equipment failure and loss of functionality

ATLAS linac w/o first cryostat
Future work

- Finalize the graphics to maximize understanding of beam evolution through the accelerator (component labels, user defined ranges of phase and envelope plots, etc)
- Measure scaling factors for all elements
- Refine the accelerator model by improving component accuracy
- Implement quad scan algorithm
- Log longitudinal characteristics when data is taken
- Develop a user interface to control TRACK operation
Summary

- TRACK is very accurate 3d macro-particle tracking software
- Accuracy relies on realistic component parameters and initial distributions
- TRACK has been successfully used to predict fields for previously unencountered configurations
- Visualization of beam evolution will be valuable training aid
- Refinement of the ATLAS accelerator model and development of quality user interface will be a powerful tool for the operations staff