Integrating the TRACK beam simulation code to improve ATLAS operations

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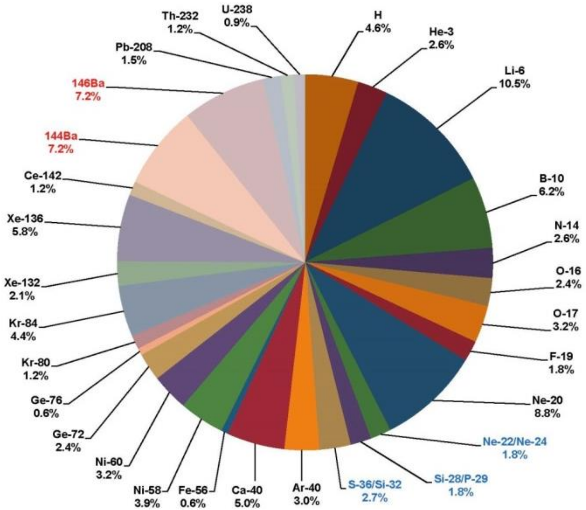
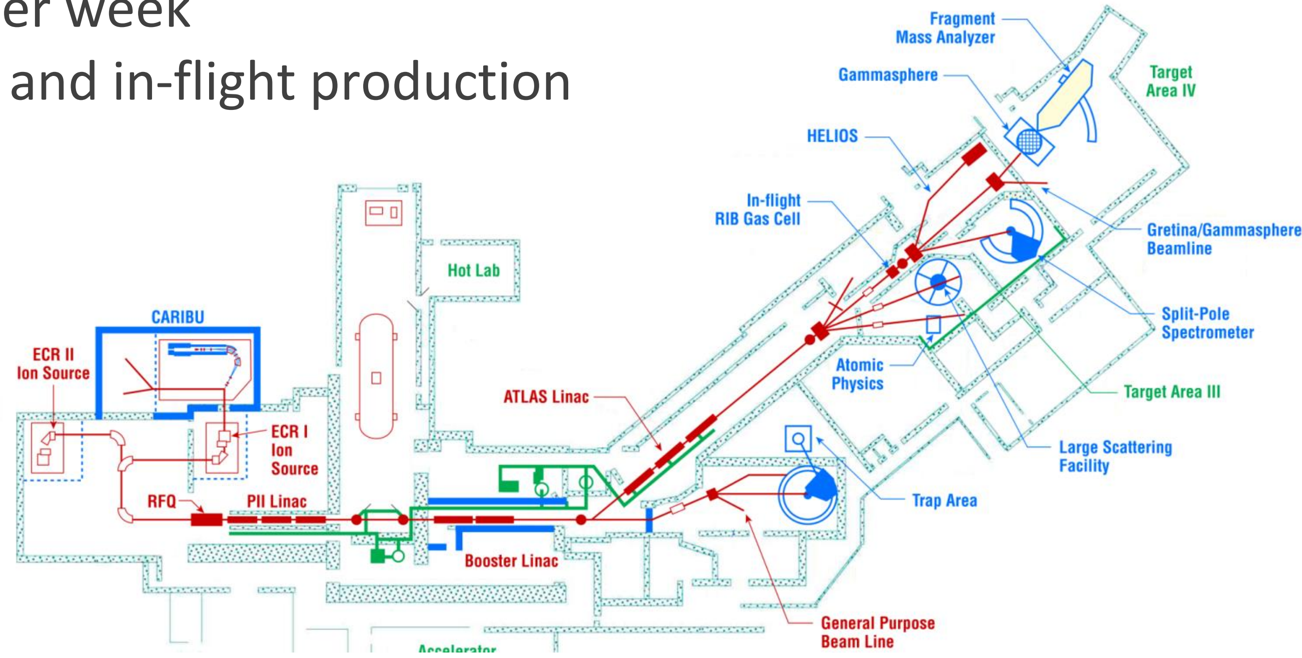
Outline

- 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

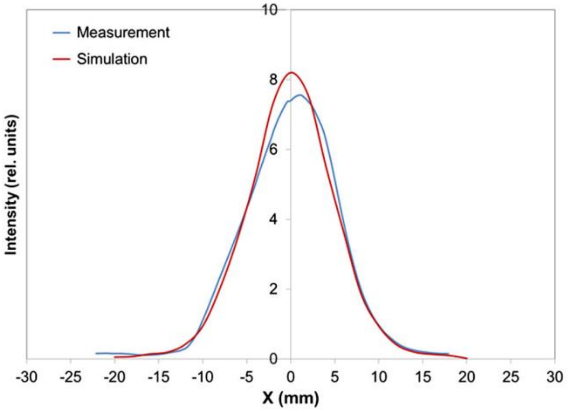
TRACK for accelerator operations

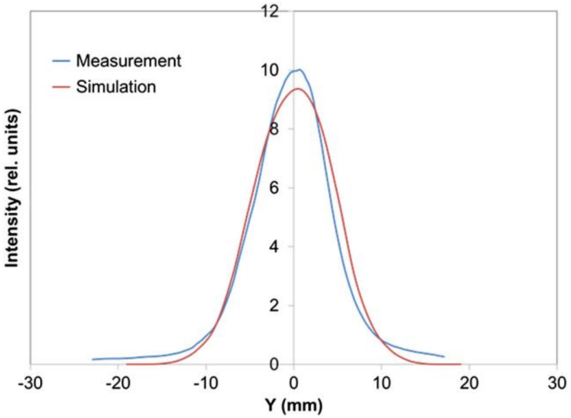
- Pros
  - Very accurate
    - Integration steps can be defined per element
    - Macro-particles more realistic than envelope codes
    - Space charge effects are included
  - Code development on site

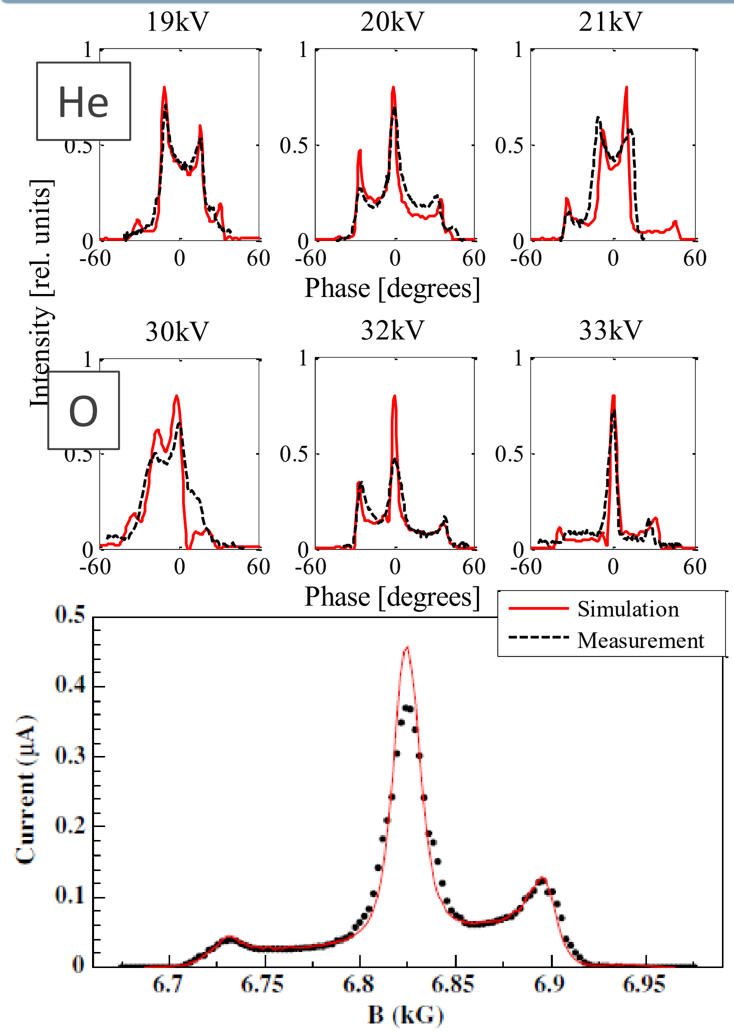
- Cons
  - Too slow for real time beam simulation

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







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

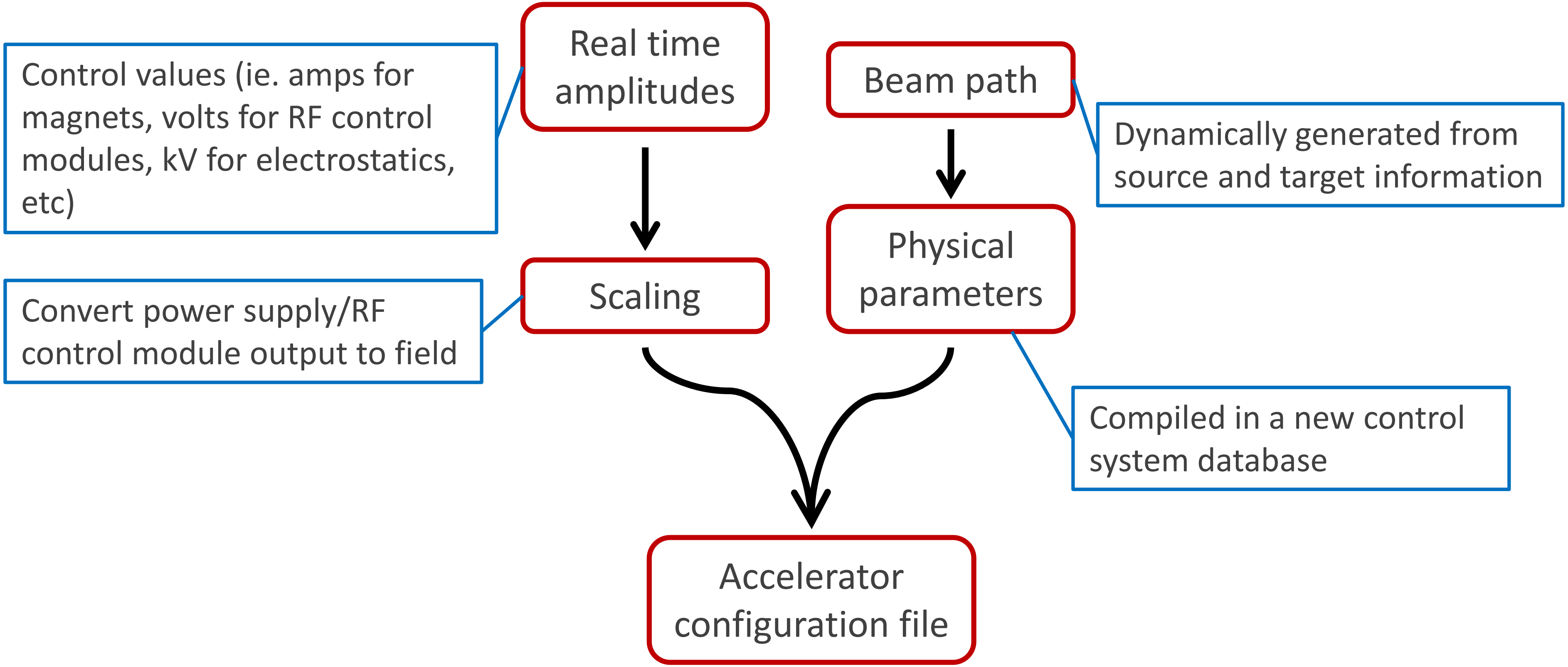
ATLAS control system

- TRACK input files are build 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

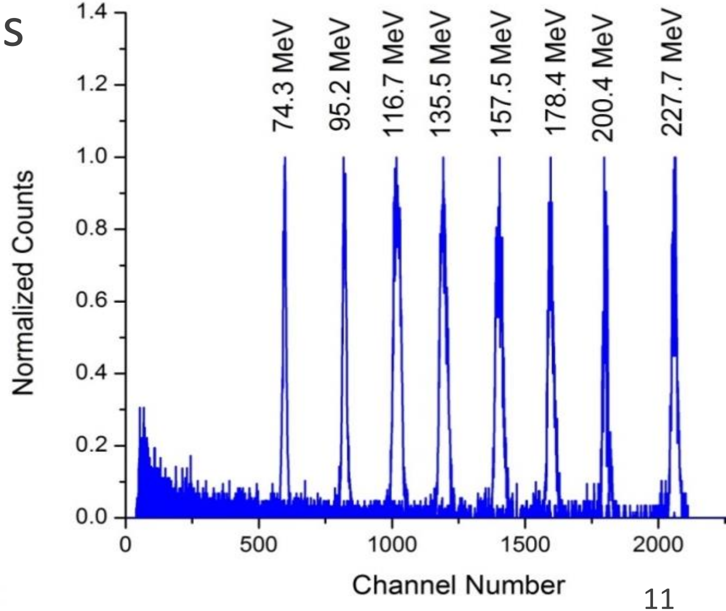
Accelerator configuration file generation



Scaling - resonator fields

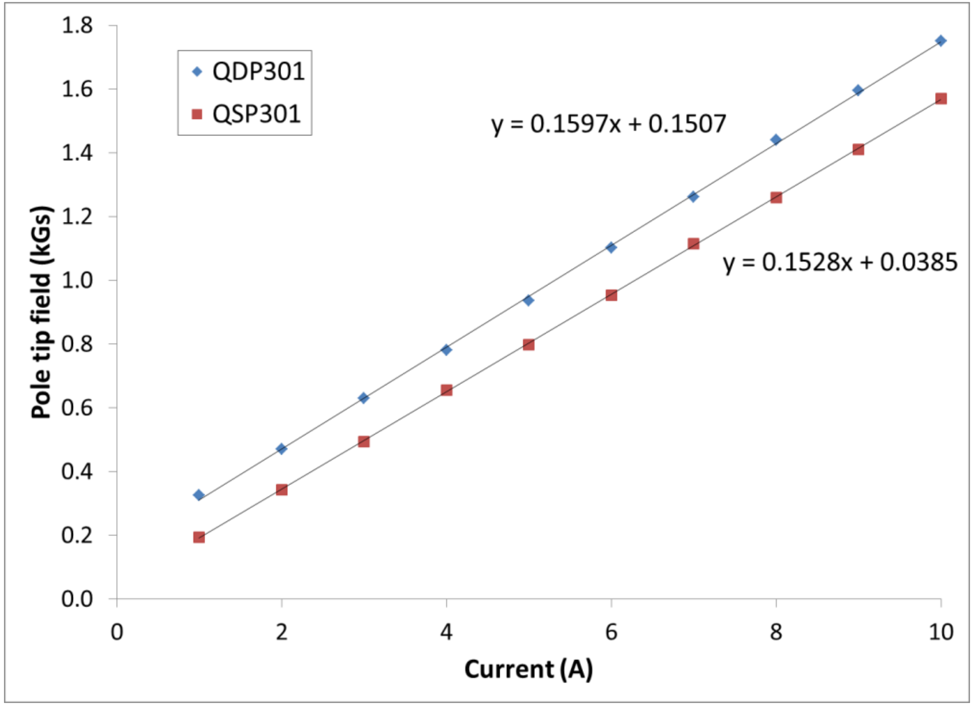
- From resonator phase scans
  - $V_{EFF} = \Delta E/[q\ TTF \cos(\phi_s)]$
- With TRACK field normalization and RF control module control voltage → scale factor from machine control to TRACK amplitude
- Better statistics available with logged scans

Res. #	$^{45}Sc^{11+}$ ΔE (φ_S=0), MeV	V_{EFF}, MV
R211	25.7	2.45
R212	26.86	2.47
R213	23.51	2.14
R214	26.38	2.41
R215	25.18	2.35
R216	26.77	2.55
R217	31.48	3.05



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 mm => 0.156 kGs/A



Quadrupole results

Beam configuration file generation

Beam distribution

Current species information

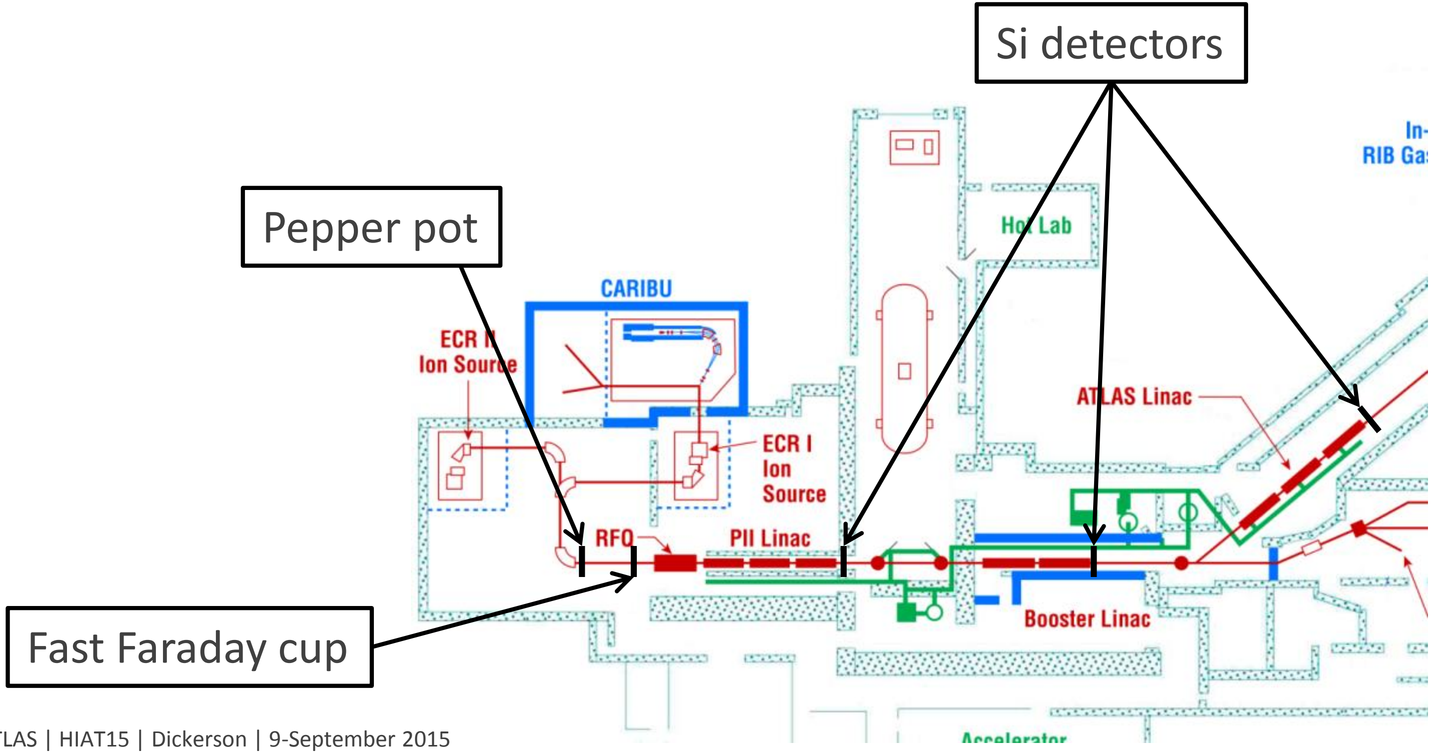
Beam configuration file

Transverse: pepper pot emittance meter (installed), quadrupole scanning algorithm (future)
Longitudinal: Si detectors, fast Faraday cups

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

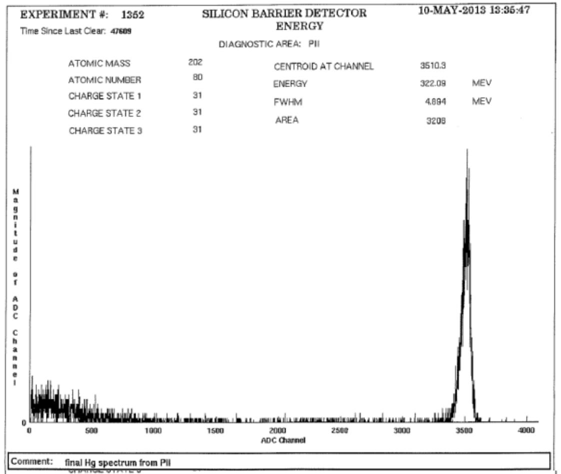
Current beam distribution diagnostics

- Quads and profile monitors throughout

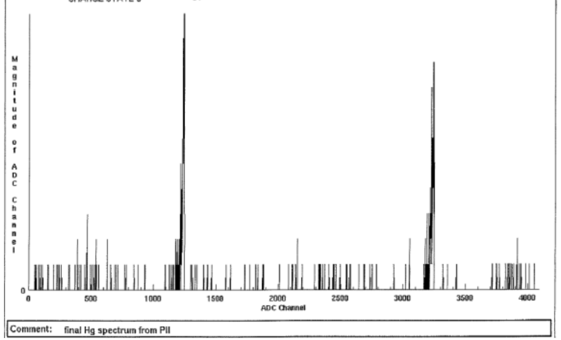


Beam distributions

Si detector spectra



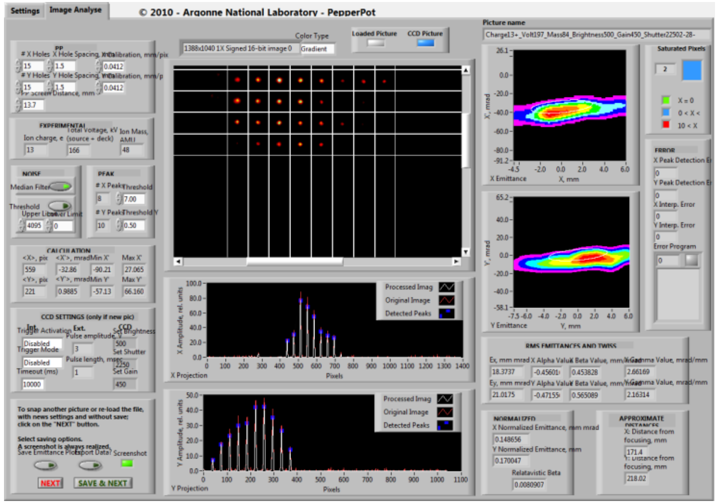
Energy spectrum
FWHM=1.5%



Time spectrum
FWHM=0.975 nsec

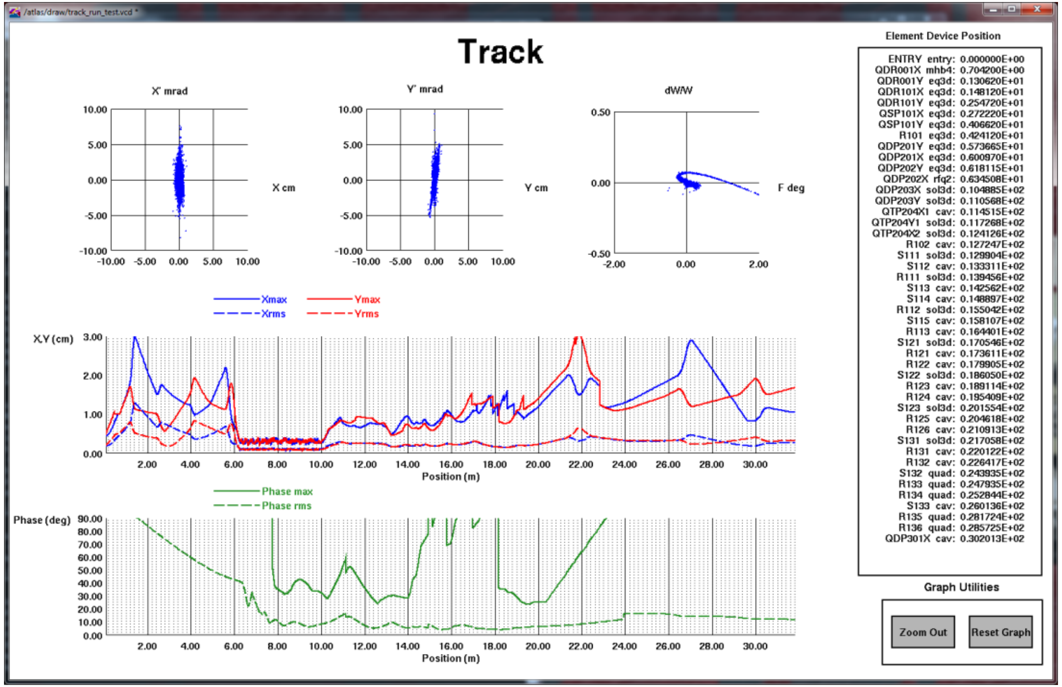
Pepper pot meter and software

- 3^{rd} party software
- ε_x, ε_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

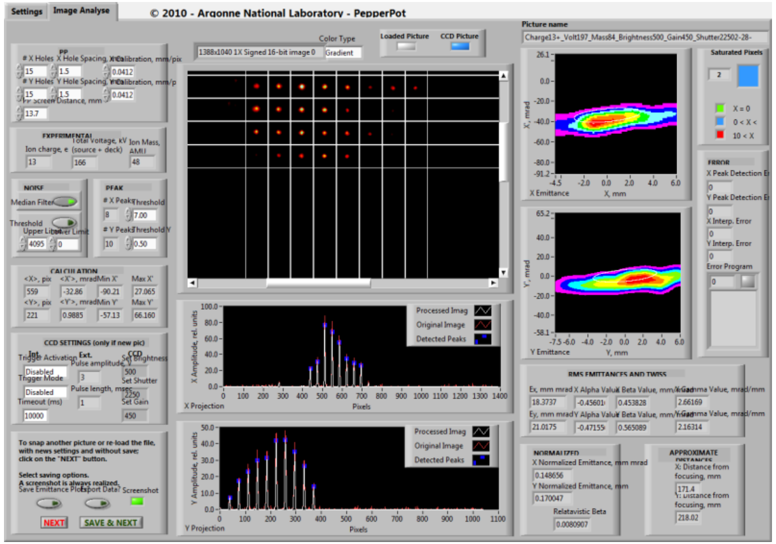


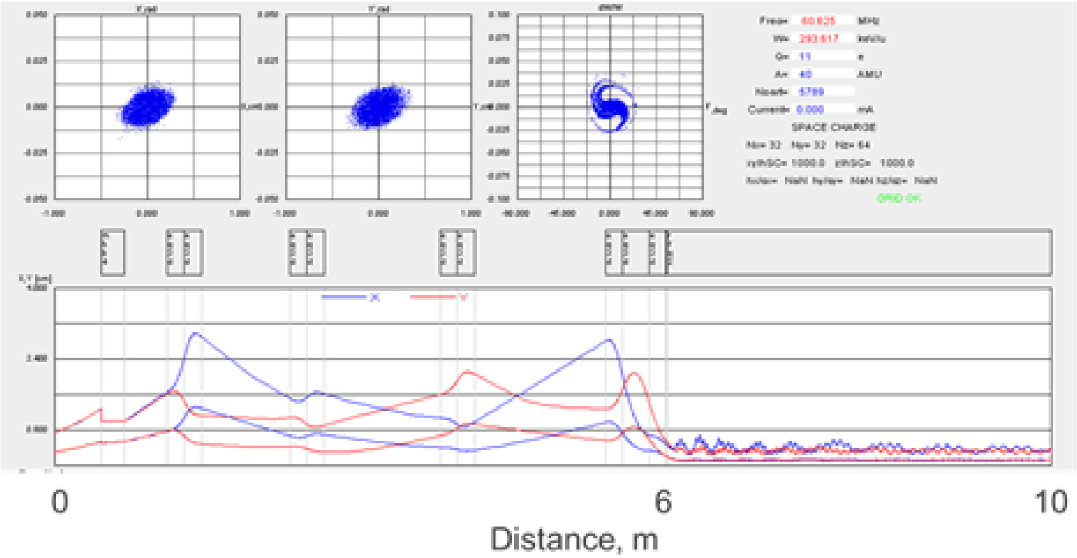
TRACK use for ATLAS operations

- In the past ~3 years ATLAS has been significantly re-configured
  - New LEBT line
  - RFQ installation
  - Re-configuration of first cryostat of low β 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

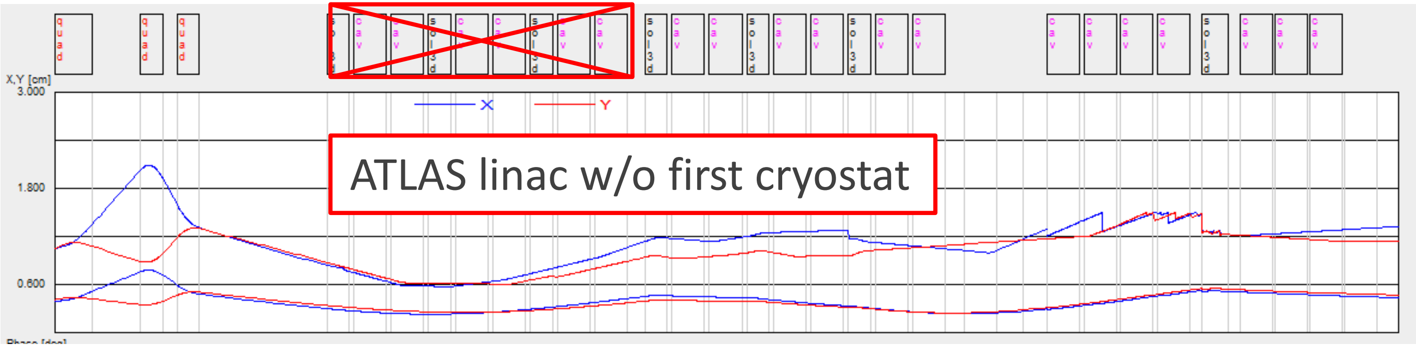
- Predicted the electrostatic injection line configuration for the beam into the RFQ for commissioning
  - Pepper pot beam distribution
  - RFQ acceptance matched for minimum emittance and losses





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}C)
  - Equipment failure and loss of functionality



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