EVALUATING PYORBIT AS UNIFIED SIMULATION TOOL FOR BEAM-DYNAMICS MODELING OF THE ESS LINAC

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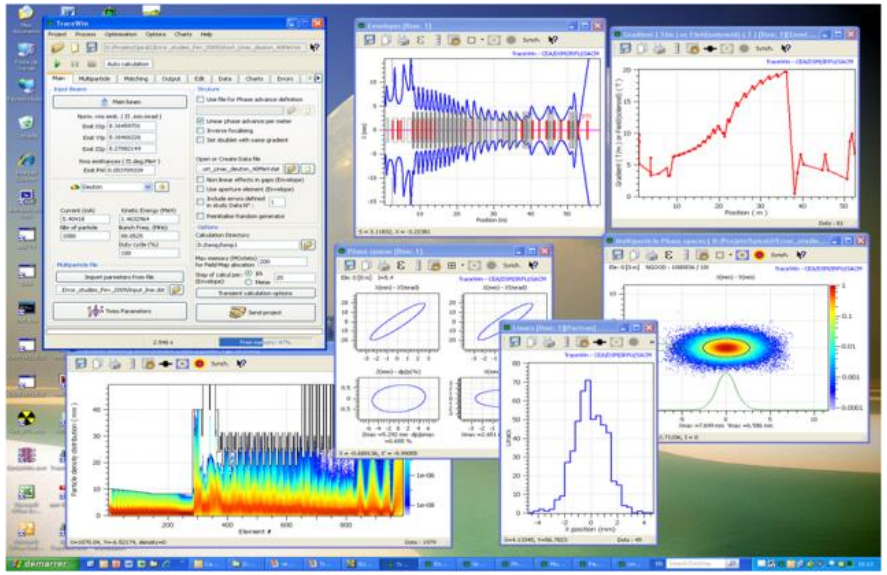
Current status of beam-dynamics simulations at ESS

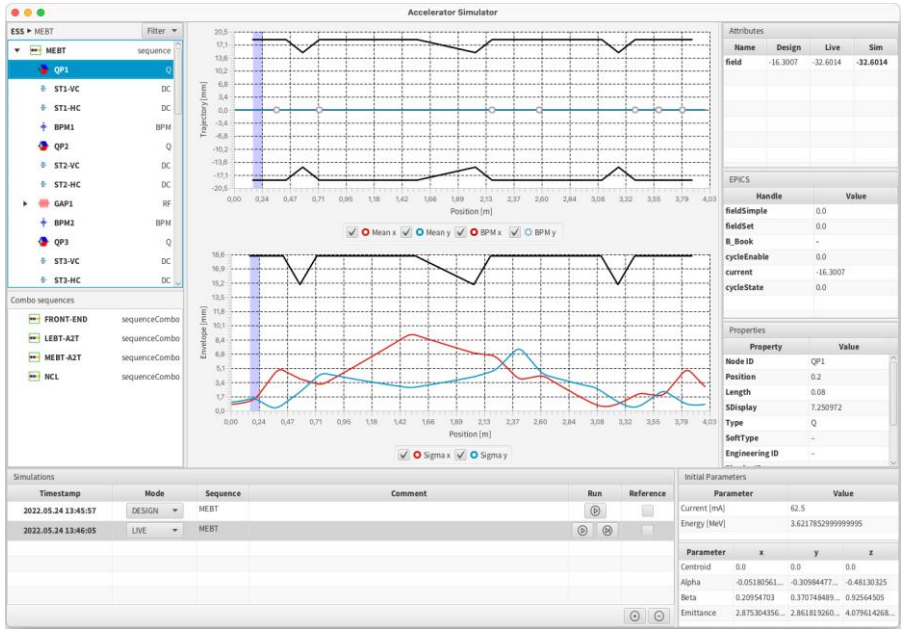
TraceWin: for precise offline simulations

- Envelope model
- Multiparticle tracker
- Feature-rich
- Graphical user interface



Open XAL: for fast simulations and control room beam-physics applications

- Online envelope model
- EPICS integration
- Java and JavaFX for user interfaces



Shortcomings of this approach

- We need to maintain 2 sets of lattice files
- TraceWin can't easily be extended and is closed source
- Users of the simulation framework would prefer a Python API to exploit its advanced data analysis and visualization libraries
- We want to be able to simulate synchrotrons for other projects

ESS neutrino Super Beam plus

International MUON Collider Collaboration

→ We have been assessing the option to use one code for all beam-dynamics simulations

Alternative solutions

- Develop a new framework from scratch

  → Estimated effort ~2-3 person-year

- Extend Open XAL with a multiparticle tracker and good Python bindings

  → Java performance limitations

- Find an existing code that fulfills at least partially our requirements and that can be extended

  → Simplest solution if we find a good match

PyORBIT

Open-source code written in Python and C++

Developed for SNS at ORNL

Features:

- Multiparticle tracker for linacs and synchrotrons
- 3 different algorithms for space charge
- Numerical integrator for tracking particles under arbitrary electromagnetic fields
- Routines for beam-coupling impedance and beam-matter interaction
- MPI integration for parallel computing

Porting to Python 3

Existing version:

- Compatible only with Python 2.7 (or older), deprecated in 2020
- Complicated build system: users need to compile a Python interpreter that loads PyORBIT library as builtin modules

We released a new version on https://github.com/PyORBIT-Collaboration/pyorbit3

- Ported PyORBIT to Python 3
- Improved build mechanism: can generate a pip wheel for simpler deployment

Lattice description (files)

PyORBIT supports MAD-X, SAD, and a custom XML format

We are exploring the option to generate our lattice in Python

Pros	Cons
▪ No need to learn a new syntax ▪ Can programmatically describe machine sections, auto-generate signal names for integration with the control system, etc. ▪ Takes advantage of IDE features such as auto-completion, syntax highlighting, error detection, and display documentation ▪ Deployment via pip	▪ Every time lattice is modified may require reinstalling the pip package ▪ Switching between different lattices at runtime can become more cumbersome

Lattice description in Python

Example

```python
from typing import List
from orbit.lattice import AccNode
from orbit.py_linac.lattice import LinacAccLattice, Sequence
import lattice_builder as builder

# Instantiating a Lattice element
lattice = LinacAccLattice("ESS Lattice")
frequency = 352.21e6
maxDriftLength = 0.005

accSeqs: List[Sequence] = []
thinNodes: List[AccNode] = []

# Adding the DTL sequence
dtl_seq = builder.addSequence(lattice=lattice, accSeqs=accSeqs, name="DTL", length=33.1528945,
                              bpmFrequency=7.0442e+08, start_position=0)

# Adding a cavity element
dtl_tank_1 = builder.addCavity(sequence=dtl_seq, name="DTL-010:EMR-Cav-001", amplitude=0.003,
                               phase=-35.0, frequency=frequency, position=0)

# Adding a quadrupole magnet
builder.addQuad(sequence=dtl_seq, name="DTL-010:BMD-PMQ-001", length=0.05, field=-59.9444,
                aperture=0.02, aprt_type=1, pos=0.025, maxDriftLength=maxDriftLength)

# Adding an RF gap to a cavity element
ttfs_element = builder.TTFs(beta_max=0.99, beta_min=1e-06, polyT=[1.07731, -0.00257565, -1.17398e-05])

builder.addRFGap(sequence=dtl_seq, cavity=dtl_tank_1, name="DTL-010:EMR-Cav-001:G1",
                 amplitude_factor=0.781302, length=0.0752368, mode=0, EzFile="?", aperture=0.02,
                 aprt_type=1, pos=0.0626084, ttf=0.780607, ttfs_element=ttfs_element)

# Performs sanity checks and add drifts
builder.processNodes(lattice=lattice, sequence=dtl_seq, thinNodes=thinNodes, maxDriftLength=maxDriftLength)

lattice.initialize()
```

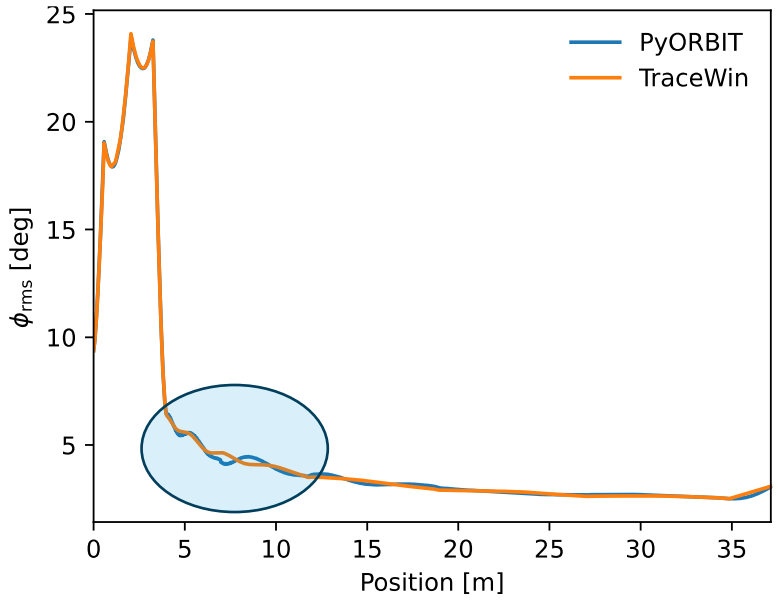
Benchmark against TraceWin

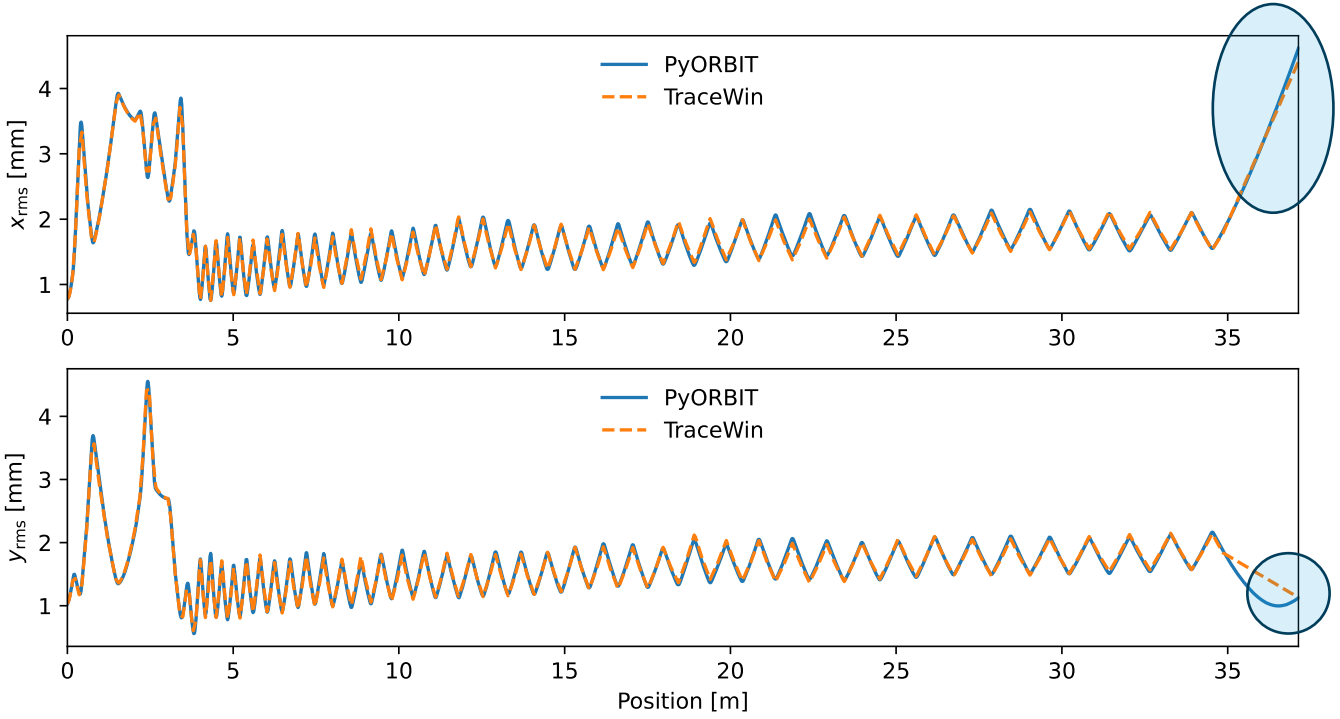
ESS linac – from MEBT to DTL tank 4

3D space-charge model (Poisson solver)

Same initial distribution (~10^6 protons)

Design parameters





Small differences probably due to different meshing strategies in the space-charge solver

Envelope tracker

Purpose: fast simulations for control room applications and quick analisys

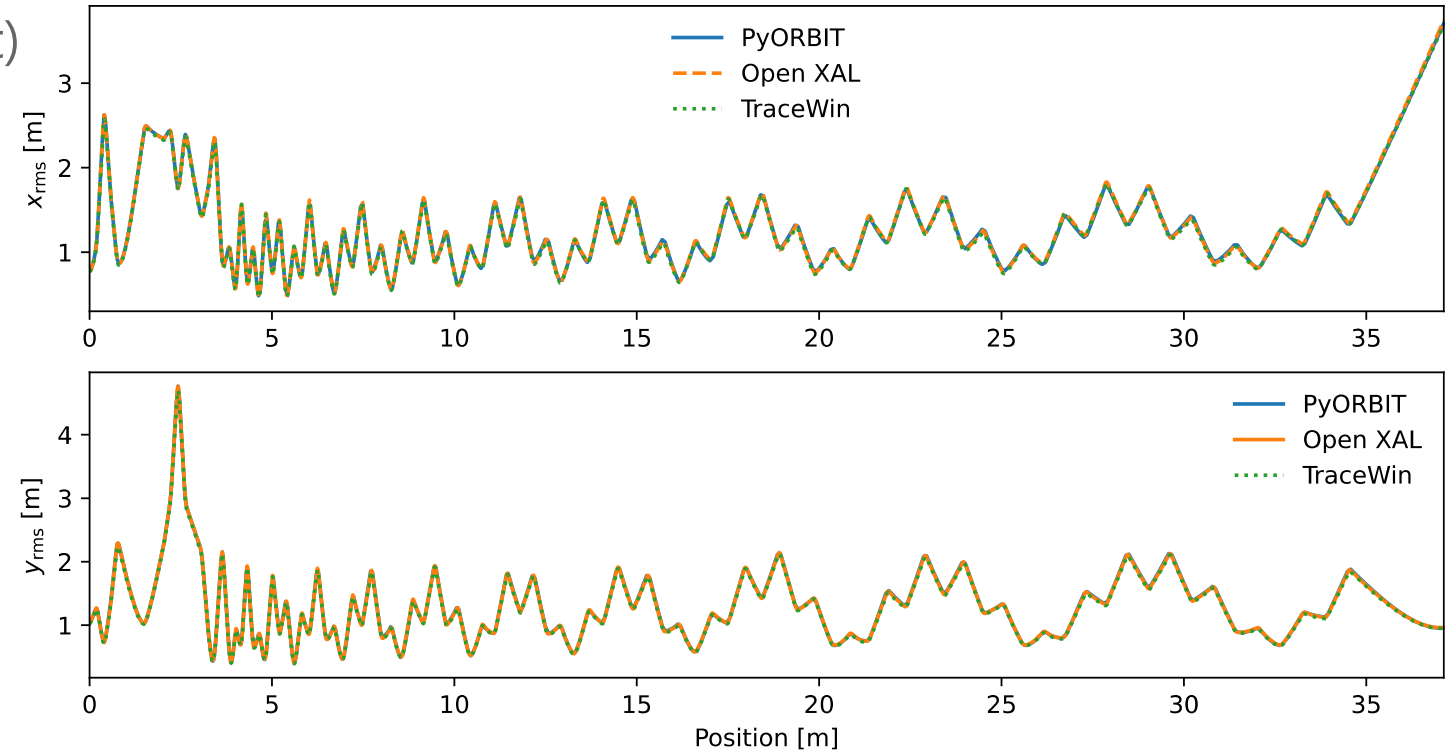
Prototype including RF cavities and quadrupoles

No bends, no space-charge (yet)

Almost perfect agreement

Runtime ~10 ms

(multiparticle ~4 min)



Control system integration

EPICS

The ESS control system is based on EPICS

We developed a PyORBIT extension to add EPICS PVAccess support based on p4p

```
from orbit.epics import channels

# Adding EPICS channels to a quadrupole magnet
channels.addMagnetChannels(node=quad_1, current_channel="MEBT-010:PwrC-PSQV-001:Cur-R",
                           current_set_channel="MEBT-010:PwrC-PSQV-001:Cur-S",
                           convFactor=-0.162)

# Adding EPICS channels to an RF cavity
channels.addCavityChannels(node=cavity_1, amplitude_channel="MEBT-010:RFS-LLRF-101:SPRampingA",
                           amplitude_set_channel="MEBT-010:RFS-DIG-101:AI0-SMonAvg-Mag",
                           phase_channel="MEBT-010:RFS-DIG-101:RFCErrLimSBCmp1",
                           phase_set_channel="MEBT-010:RFS-LLRF-101:SPRampingPhase")
```

Code at https://gitlab.esss.lu.se/ess-crs/pyorbit-epics

Summary and future steps

PyORBIT fulfills our requirements for beam-dynamics simulations for both offline and online applications

Good agreement with our current models

Only reasonable amount of software development required

Plan:

- More exhaustive benchmark (with misalignments, mismatches, etc.)
- Complete implementation of envelope tracker (bends, space-charge)
- Finish EPICS integration (diagnostics)
- Study GPU optimization of multiparticle tracker
- UI framework

Thank you!

2023-10-10