AI-ML DEVELOPMENTS FOR THE ATLAS ION LINAC FACILITY

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Abstract: ATLAS is a DOE/NP User Facility for the study of low-energy nuclear physics with heavy ions. It operates ~6000 hours per year. In addition to delivering any stable beam from proton to uranium, the facility also provides radioactive beams from the CARIBU source or via the in-flight radioactive ion separator, RAISOR. The facility uses 3 ion sources and services 6 target areas at energies from ~1-15 MeV/u. To accommodate the large number and variety of approved experiments, ATLAS reconfigures once or twice per week over 40 weeks of operation per year. The startup time varies from $\sim 12 - 48$ hours depending on the complexity of the tuning, which will increase with the upcoming Multi-User Upgrade to deliver beam to two experimental stations simultaneously. DOE/NP has recently approved a project to use AI/ML to support ATLAS operations. The project aim is to significantly reduce the accelerator tuning time and improve machine performance by developing and deploying artificial intelligence methods. These improvements will increase the scientific throughput of the facility and the quality of the data collected. Our recent developments and future plans will be presented and discussed.

Project Plan & Objectives

Project Motivation & Goals

At ATLAS, we switch ion beam species every 3-4 days \rightarrow Using AI could streamline beam tuning & help improve machine performance

The main project goals are:

- **Data collection**, organization and classification, towards a fully automatic and electronic data collection for both machine and beam data
- **Online tuning model to optimize operations and** shorten beam tuning time and make more beam time available for the experimental program

Virtual machine model to enhance our understanding of the machine behavior, improve machine performance and optimize particular and new operating modes

2	SBD Energy			SBD Timing		TO	TOF	Last Accel F	CP202 1	CP301 FC	P303 FCB0	B000 FC	8001 FC	B101 FC	8201	FCA001 X3	atten	Sweeper		Time of readings		Comments	
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4	131.29	none	430.76	0.802	none	1.757	none	ATLAS	640	545	420	460	460	480	380	420	no	no		3/10/2020	7:04		
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6	8.01	40.07	none	1.315	0.905	none	70.03	ATLAS	62	125	84	76	74	70	68	52	no	no		2/13/2020 21:07		Jerry nolen experiment.	
7	31.76	50.92	none	1.546	2.495	none	none	Booster	2200	1800	1700	1700	1750	1550	1500	1450	no	no		2/9/2020 7:45		Cup readings taken at 2,	
8	67.42	none	none	1.198	none	none	294.03	ATLAS	115	98	90	87	82	75	67	72	no	no		11/22/2019 21:04		The paradox load had a	
9	124.94	none	none	0.633	none	none	731.86	ATLAS	0.9	0.7	0.62	0.68	0.7	0.68	0.7	0.6	no	no		11/19/2019 13:24		This experiment started	
10	110.78	318.11	none	1.225	0.51	none	530.34	ATLAS	4.8	3.8	1.05	2.2	1	1.05	0.88	0.82	no	no		11/21/2019 7:58		No paradox values for B	
11	182.58	none	none	0.431	none	none	809.13	ATLAS	48	36	16	18	15.5	14	11.5	14.5	yes	yes		11/5/2019 1:52		Multiple paradox loads	
12	27.36	none	none	1.311	none	none	none	ATLAS	1400	1600	1250	1150	1050	960	900	890	no	no		10/30/2019	9 14:44	Separate pa	radox for Li
13	7.9	none	none	0.652	none	none	77.06	ATLAS	250	500	420	425	375	360	360	340	no	no		10/22/2019	9 20:18	ATLAS was a	autoscanne
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3	qtp001_y1	qtp001_x1	qtp001_y2	qtp002_x1	qtp002_y1	qtp002_x2qsp1	01_x qdp101_	x qdp101_y	qdp102_	x qdp102_y	qdp201_>	qdp201_y	qdp202_	x qdp202_	y qdp20	3_x qdp203_y	qtp204_>	1qtp204_x2	qtp204_y	1qdp301_x	qdp301_	y qsp301_x	qdp302_x
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7	0	0	0	0	0	0 NULL		0 (0	0 0	7.550003	6.2834134	4 4.49955	1 5.46107	72 4.052	3.863909	4.62087	8 6.420873	5.420747	4,706317	7.46601	5 4.758496	4.266023
8	6.479634	4.953148	4.013539	3.56993	4.937285	5.289687 NULL		0 (D	0 0	7.072115	6.563176	5 5.55228	3 5.02318	3.554	519 4.020467	3 5.40533	2 2.749565	5.010511	5.338346	7.43398	5 3.373083	3.60673
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12	0	0	0	0	0	0 NULL		0 0	0	0 0	4.373953	4.425449	8 2.2314	5 3.19850	2.693	876 2.971370	7 3.57992	3 3.372345	3.901182	3.323067	5.24733	3 3.435506	3.130081
12	0	0	0	0	0	0 NULL		0 (0	0 0	4.465054	3.3600004	\$ 5.97986	9 6.94619	93 5.119	999 6.19002	1 7.87001	1 7.349992	8.839997	1.989977	3.49664	6 2.00464	2.59528

DA Sample of historic machine tunes and beam data

Data Collection

Some of the data is collected manually in paper form!

Part of the project is to move to fully automatic and electronic data collection \rightarrow A new e-logbook is added

The online tuning model consists of an initial tune model based on machine tunes data and a set of optimization and feedback loops fed by online data

□ A first version of the online tuning model leverages already existing machine and beam data, the model will be further enhanced with new data and specific measurements

Online Tuning Model / Virtual Machine Model

The virtual machine model will be particularly useful for multibeam transport and acceleration as part of the upcoming ATLAS multi-user upgrade, as well as for high-intensity beams

Since full beam physics models, which usually include particle tracking in 3D fields, are slow and not very useful to support online accelerator operations, we are developing a surrogate Al models for different sections of the linac.

A Surrogate model can be trained on beam simulation data to reliably reproduce the physics results in very short time, then be enhanced with experimental data

□A preliminary surrogate model was developed for the ATLAS RFQ

Surrogate model vs. 3D Simulations

Surrogate Models for ATLAS RFQ



Model Convergence





- ✓ We used a neural network for this model, which is fully based on simulations data
- ✓ Excellent convergence for 1D results, will need more data for the 5D case!
- Excellent agreement with TRACK 3D beam simulations, similar to results form different codes!
- ✓ Much much faster than TRACK, speed-up factor ~ $30,000 \rightarrow$ can be used to support online operation



simulation results. From top to bottom are twiss parameters: αx , βx , αy , βy , and beam transmission for a DC beam (no MHB)

Surrogate Models for Particle Tracking



1) Classification problem: Is particle accepted or not? **2)** Regression problem: Can we predict output coordinates? → Different ML and DL models were developed & compared

Comparison criteria: higher Accuracy, precision and Recall \rightarrow TFC0, TFC2 and Tree are the best performer for predicting particle acceptance

and Tree performed well on both problems \rightarrow can be the basis for an ML model for particle tracking



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