



Elettra
Sincrotrone
Trieste

Automation, performance optimisation & ML @ Elettra

G. Gaio

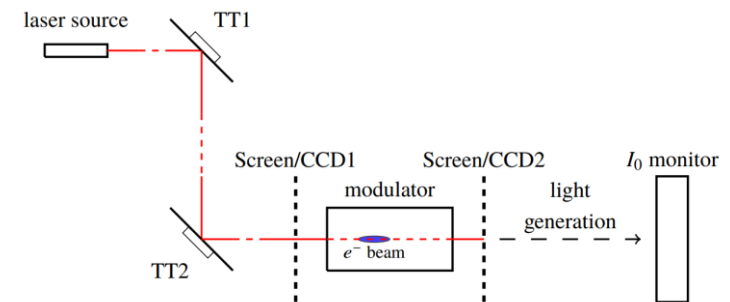
- ✓ Reinforcement Learning in a Free Electron Laser
- ✓ Toward an accelerator autopilot

✓ **Study goal:**

Apply Reinforcement Learning to automatically overlap the seed laser with the electron beam optimizing the radiation intensity

✓ **Seed Laser alignment system:**

- 2 planar Tip-Tilt mirrors (TTs) paired with 2 piezo-motors (hor - ver)
- 2 screens based on Charged-Coupled Devices (CCDs)



✓ **Final output:**

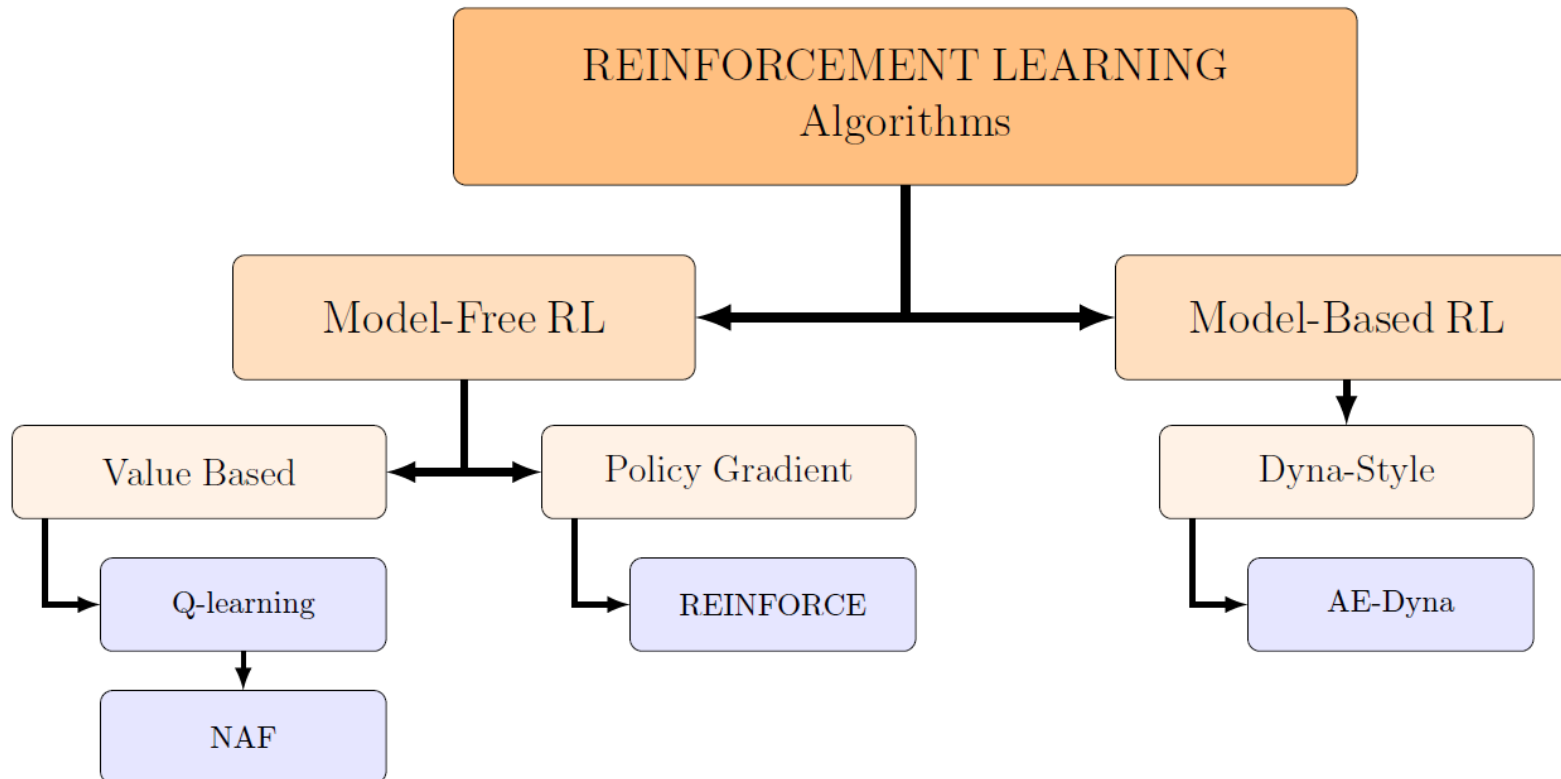
Intensity acquired by I_0 monitor

Optimization of 4 variables

Niky Bruchon, PhD of University of Trieste

https://arts.units.it/retrieve/handle/11368/2982117/362563/PhD_Thesis_Final_NikyBruchon.pdf

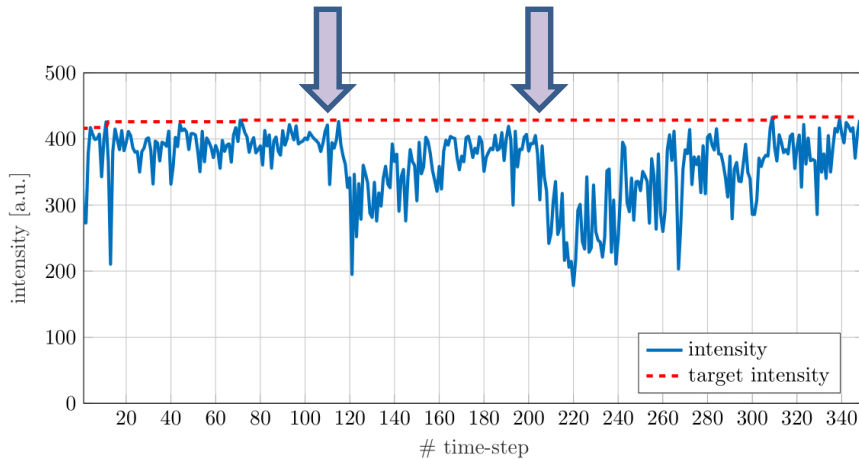
Reinforcement Learning algorithms applied on FERMI



collaboration with CERN
(V. Kain, S. Hirlander)

Reinforcement Learning results

Recover from manually imposed perturbation (NPG Reinforce)



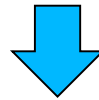
Policy gradient methods for free-electron laser and terahertz source optimization and stabilization at the FERMI free-electron laser at Elettra
F. H. O'Shea, N. Bruchon, G. Gaio – PRAB 2020

Attainment of the optimal working point starting from random initial conditions

	Algorithm	Training data points	Mean num. of steps	Normalized final intensity
	Q-learning	3128	11.28	-
	NAF	1074	2.56	1.0019
	NAF2	824	2.64	0.9995
	AE-Dyna (TRPO)	450	4.46	1.0150
	AE-Dyna (SAC)	500	3.28	1.0427
Not RL	GradAscent	1024	3.82	0.9911
	iLQR	1024	2.54	1.0019

Toward an accelerator autopilot

- ✓ **Decrease “virtually” to 0 the number of clicks** on graphical panels in the control room



- ✓ Move human knowledge and logics inside GUIs **to server side** (*TANGO devices*)



- ✓ Develop an infrastructure that can scale easily with the complexity of the logics and allows a fast deployment of automatic optimization / feedback systems



- ✓ Machine physicists and operators should become the developers / maintainers of the logic of the infrastructure

Behavior Trees (BT)

- ✓ BT are used for **in-game AI player opponents**, **UAV** and **robotics**
- ✓ They are able to create very complex tasks composed by simple decoupled self-contained tasks, regardless how they are implemented
- ✓ The tree-structure is composed by:
 - a root node
 - intermediate nodes (composite, selector, decorator) that control the flow
 - leaf nodes
- ✓ In the control system:
 - Each **leaf/node is a TANGO device** that executes a specific task (leaf) or launch in series or parallel other tasks (intermediate/root node)
 - In-house basic scripting language to execute simple reading/setting of variables after receiving a Start command; it supports if/else statement;
 - Can execute *Python, Matlab, bash* scripts...
 - Native support of **retry** and **fallback** actions
 - It controls a programmable TANGO device server which implements **feedback / numerical optimization schemes**
 - At Elettra BT are known a **SEQUENCERS**

A framework for high level machine automation based on behavior tree - in submission to ICALEPCS2021

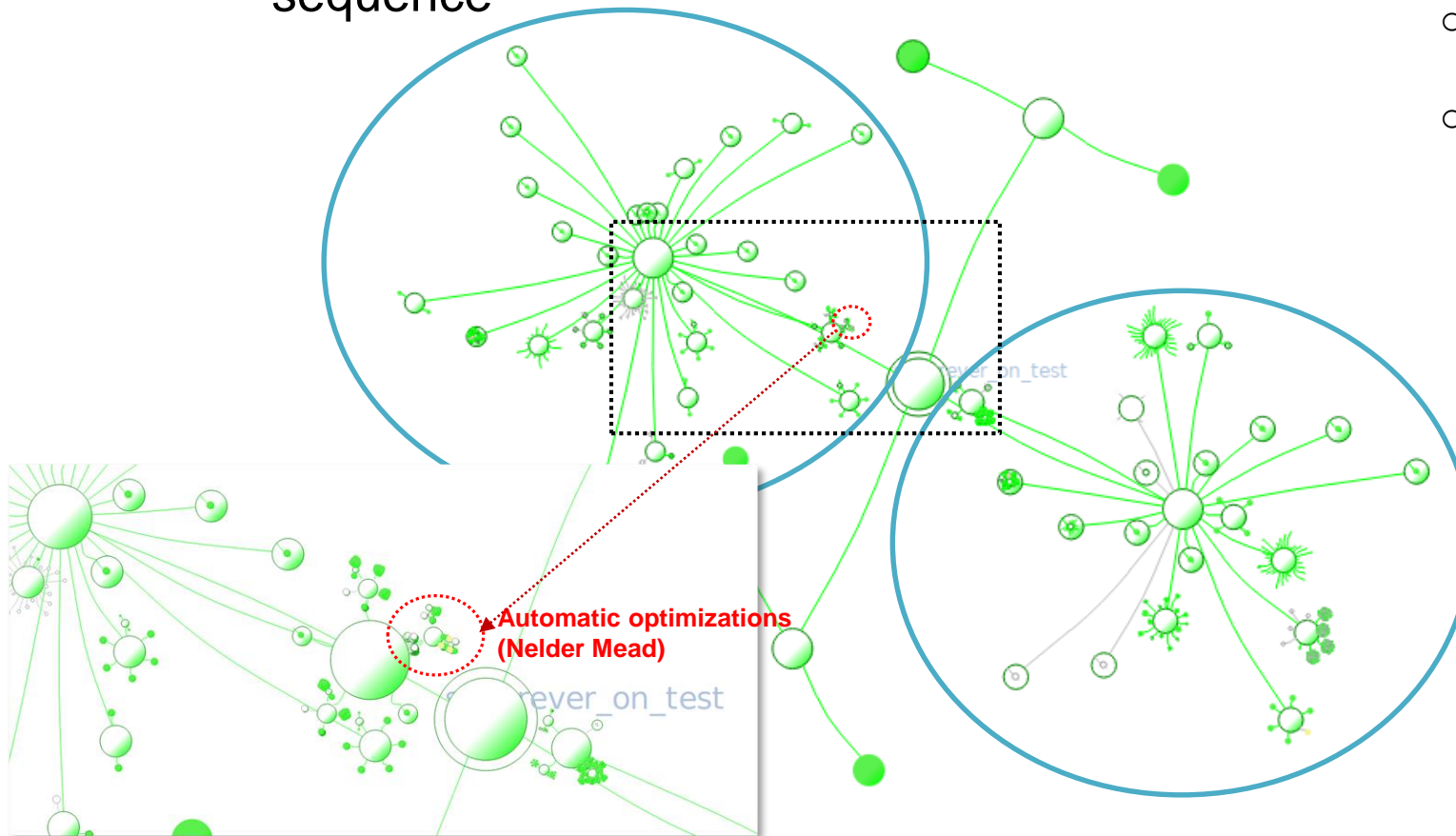


Elettra full automation

- ✓ Recover beam loss
- ✓ Injection, beam to users

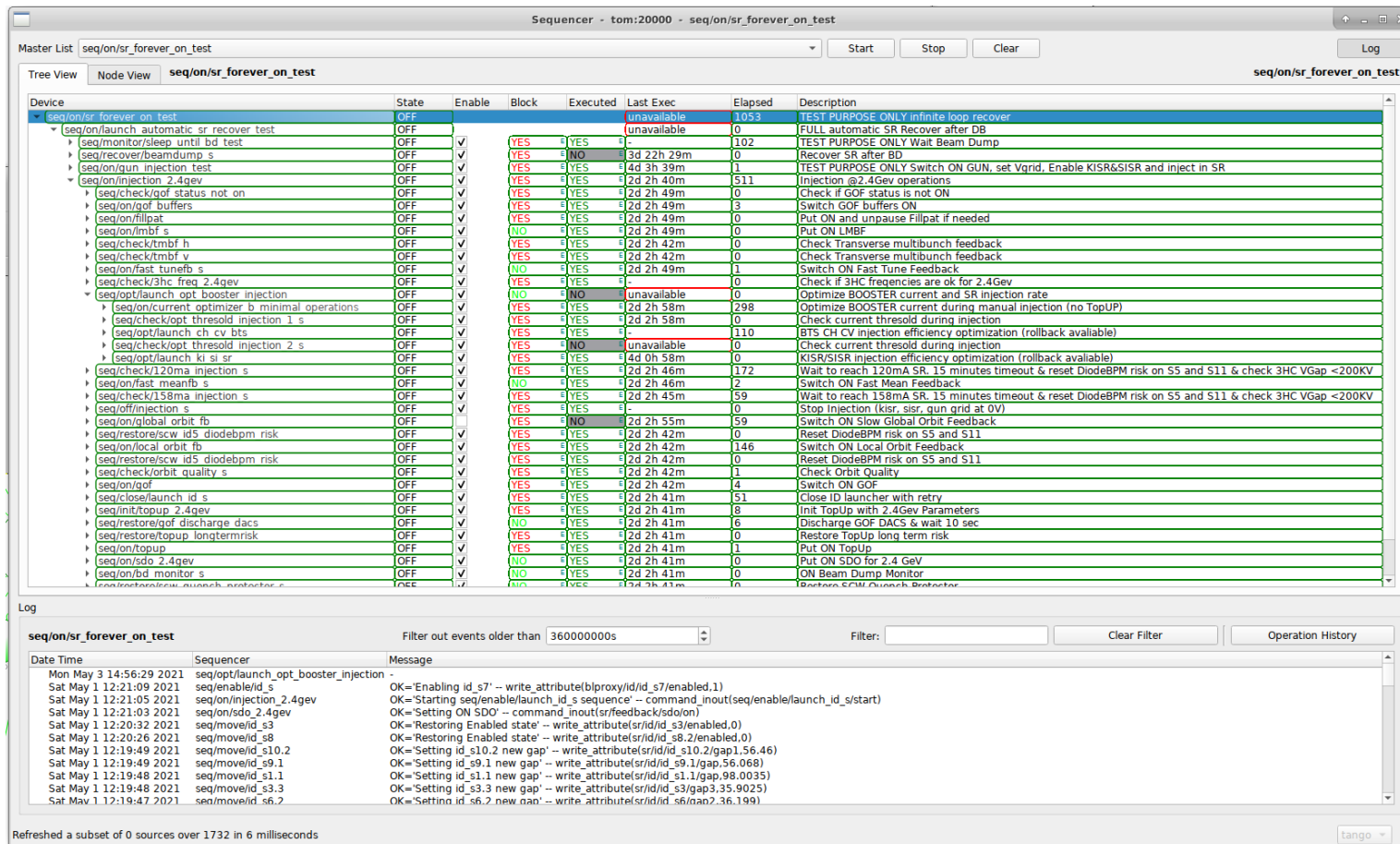
- ✓ It manages:
 - *HW devices*
 - *Optics correction*
 - *Slow/Fast Orbit Feedbacks*
 - *Automatic Optimizations*

Injection- beam to user
sequence



Recover from
beam-loss
sequence

Qt-based dynamic panel explores and monitors the execution of sequences (web interface available)



Device	State	Enable	Block	Executed	Last Exec	Elapsed	Description
seq/on/sr_forever_on_test	Off	✓		unavailable	1053	0	TEST PURPOSE ONLY infinite loop recover
seq/on/launch automatic sr recover test	OFF	✓			unavailable	0	FULL automatic SR Recover after DB
seq/monitor/sleep until bd test	OFF	✓	(YES) (YES)	-	-	102	TEST PURPOSE ONLY Wait Beam Dump
seq/recover/beamdump s	OFF	✓	(YES) (NO)	3d 22h 29m	0	0	Recover SR after BD
seq/on/gun injection test	OFF	✓	(YES) (YES)	4d 3h 39m	1	1	TEST PURPOSE ONLY Switch ON GUN, set Vgrid, Enable KISR&SISR and inject in SR
seq/on/injection 2.4gev	OFF	✓	(YES) (YES)	2d 2h 40m	511	0	Injection @2.4GeV operations
seq/check/gof status not on	OFF	✓	(YES) (YES)	2d 2h 49m	0	0	Check if GOF status is not ON
seq/on/gof buffers	OFF	✓	(YES) (YES)	2d 2h 49m	3	0	Switch GOF buffers ON
seq/on/fillpat	OFF	✓	(YES) (YES)	2d 2h 49m	0	0	Put ON and unpause Fillpat if needed
seq/on/lmbf s	OFF	✓	(NO) (YES)	2d 2h 49m	0	0	Put ON LMBF
seq/check/tmbf h	OFF	✓	(YES) (YES)	2d 2h 42m	0	0	Check Transverse multibunch feedback
seq/check/tmbf v	OFF	✓	(YES) (YES)	2d 2h 42m	0	0	Check Transverse multibunch feedback
seq/on/fast tune fb s	OFF	✓	(NO) (YES)	2d 2h 49m	1	0	Switch ON Fast Tune Feedback
seq/check/3hc freq 2.4gev	OFF	✓	(YES) (YES)	-	-	0	Check if 3HC frequencies are ok for 2.4GeV
seq/opt/launch opt booster injection	OFF	✓	(NO) (NO)	unavailable	0	0	Optimize BOOSTER current and SR injection rate
seq/on/current optimizer b minimal operations	OFF	✓	(YES) (YES)	2d 2h 58m	298	0	Optimize BOOSTER current during manual injection (no TopUP)
seq/check/opt threshold injection 1 s	OFF	✓	(YES) (YES)	2d 2h 58m	0	0	Check current threshold during injection
seq/opt/launch ch cv bts	OFF	✓	(YES) (YES)	-	-	110	BTS CH CV injection efficiency optimization (rollback available)
seq/check/opt threshold injection 2 s	OFF	✓	(YES) (NO)	unavailable	0	0	Check current threshold during injection
seq/opt/launch ki si sr	OFF	✓	(YES) (YES)	4d 0h 58m	0	0	KISR/SISR injection efficiency optimization (rollback available)
seq/check/120ma injection s	OFF	✓	(YES) (YES)	2d 2h 46m	172	0	Wait to reach 120mA SR. 15 minutes timeout & reset DiodeBPM risk on S5 and S11 & check 3HC Vgap <200KV
seq/on/fast meanfb s	OFF	✓	(NO) (YES)	2d 2h 46m	2	0	Switch ON Fast Mean Feedback
seq/check/158ma injection s	OFF	✓	(YES) (YES)	2d 2h 45m	59	0	Wait to reach 158mA SR. 15 minutes timeout & reset DiodeBPM risk on S5 and S11 & check 3HC Vgap <200KV
seq/off/injection s	OFF	✓	(YES) (YES)	-	-	0	Stop Injection (kISR, sISR, qun grid at 0V)
seq/on/global orbit fb	OFF	✓	(YES) (NO)	2d 2h 55m	59	0	Switch ON Slow Global Orbit Feedback
seq/restore/scw id5 diodebpm risk	OFF	✓	(YES) (YES)	2d 2h 42m	0	0	Reset DiodeBPM risk on S5 and S11
seq/on/local orbit fb	OFF	✓	(YES) (YES)	2d 2h 42m	146	0	Switch ON Local Orbit Feedback
seq/restore/scw id5 diodebpm risk	OFF	✓	(YES) (YES)	2d 2h 42m	0	0	Reset DiodeBPM risk on S5 and S11
seq/check/orbit quality s	OFF	✓	(YES) (YES)	2d 2h 42m	1	0	Check Orbit Quality
seq/on/gof	OFF	✓	(YES) (YES)	2d 2h 42m	4	0	Switch ON GOF
seq/close/launch id s	OFF	✓	(YES) (YES)	2d 2h 41m	51	0	Close ID launcher with retry
seq/init/topup 2.4gev	OFF	✓	(YES) (YES)	2d 2h 41m	8	0	Init TopUp with 2.4GeV Parameters
seq/restore/gof discharge dacs	OFF	✓	(NO) (YES)	2d 2h 41m	6	0	Discharge GOF DACS & wait 10 sec
seq/restore/topup longtermrisk	OFF	✓	(YES) (YES)	2d 2h 41m	0	0	Restore TopUp long term risk
seq/on/topup	OFF	✓	(YES) (YES)	2d 2h 41m	1	0	Put ON TopUp
seq/on/sdo 2.4gev	OFF	✓	(NO) (YES)	2d 2h 41m	0	0	Put ON SDO for 2.4 GeV
seq/on/bd monitor s	OFF	✓	(NO) (YES)	2d 2h 41m	0	0	ON Beam Dump Monitor

Date Time	Sequencer	Message
Mon May 3 14:56:29 2021	seq/opt/launch_opt_booster_injection	
Sat May 1 12:21:09 2021	seq/enable/id_s	OK='Enabling id_s7' -- write_attribute(bproxy/id/id_s7/enabled.1)
Sat May 1 12:21:05 2021	seq/on/injection_2.4gev	OK='Starting seq/enable/launch_id_s sequence' -- command_inout(seq/enable/launch_id_s/start)
Sat May 1 12:21:03 2021	seq/on/sdo_2.4gev	OK='Setting ON SDO' -- command_inout(sr/feedback/sdo/on)
Sat May 1 12:20:32 2021	seq/move/id_s3	OK='Restoring Enabled state' -- write_attribute(sr/id/id_s3/enabled.0)
Sat May 1 12:20:26 2021	seq/move/id_s8	OK='Restoring Enabled state' -- write_attribute(sr/id/id_s8.2/enabled.0)
Sat May 1 12:19:49 2021	seq/move/id_s10.2	OK='Setting id_s10.2 new gap' -- write_attribute(sr/id/id_s10.2/gap.1.56.46)
Sat May 1 12:19:49 2021	seq/move/id_s9.1	OK='Setting id_s9.1 new gap' -- write_attribute(sr/id/id_s9.1/gap.56.068)
Sat May 1 12:19:48 2021	seq/move/id_s1.1	OK='Setting id_s1.1 new gap' -- write_attribute(sr/id/id_s1.1/gap.98.0035)
Sat May 1 12:19:48 2021	seq/move/id_s3.3	OK='Setting id_s3.3 new gap' -- write_attribute(sr/id/id_s3(gap3.35.9025)
Sat May 1 12:19:47 2021	seq/move/id_s6.2	OK='Setting id_s6.2 new nan' -- write_attribute(sr/id/id_s6(nan2.36.199)

✓ Next steps:

- Integration of *scikit-learn* and *OpenAI Gym* (optimizers)
- Analyze drifts in the execution time to detect anomalies
- Add BT learning capabilities to achieve more flexibility



Elettra
Sincrotrone
Trieste

Thank you!

N. Bruchon, P. Cinquegrana, G. Gaio, S. Krecic, G. Scalamera, G. Strangolino, F. Tripaldi,
M. Trovo', L. Zambon