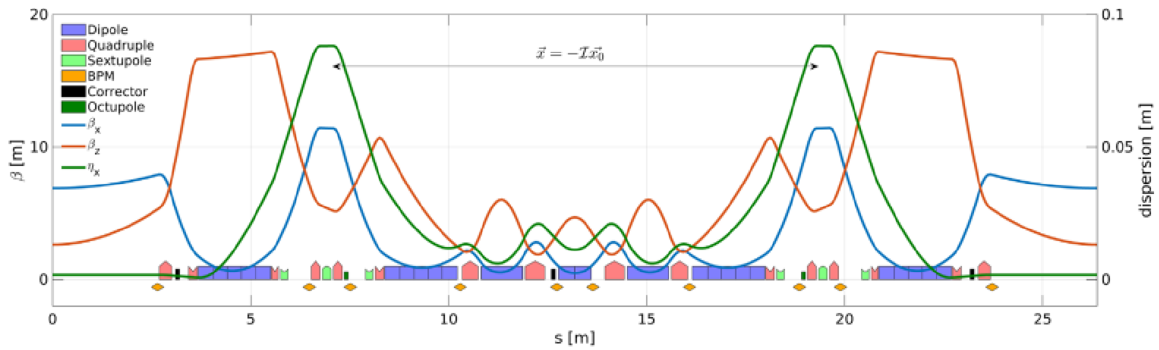
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072

eurizon

European network for developing new horizons for RIs

Proposal for a python accelerator digital twin

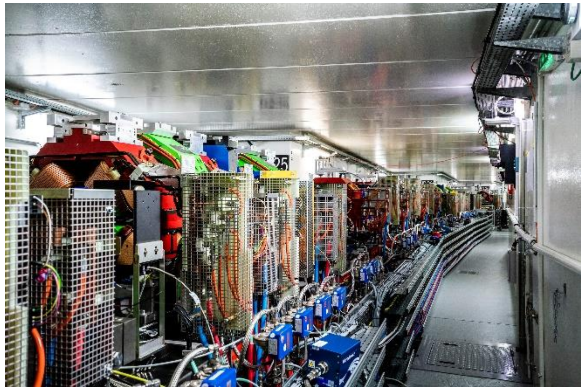
S. White on behalf of the EURIZON Task 4.1 collaboration (formerly CremlinPlus task 4.1)



Define goals and design a lattice to achieve them

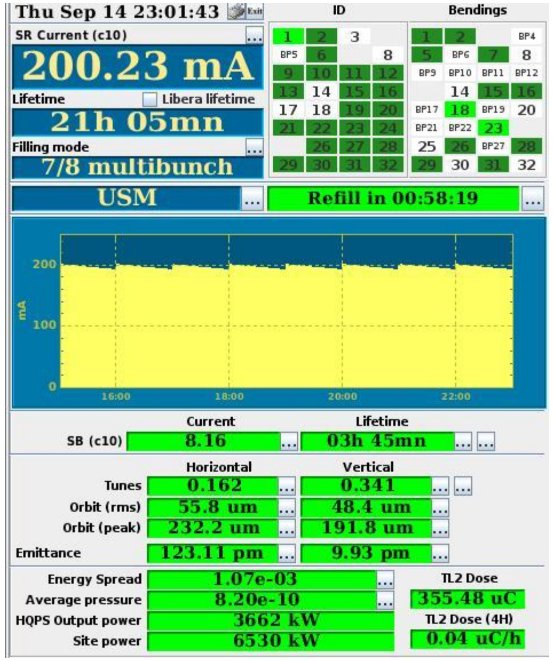
Fully functional machine

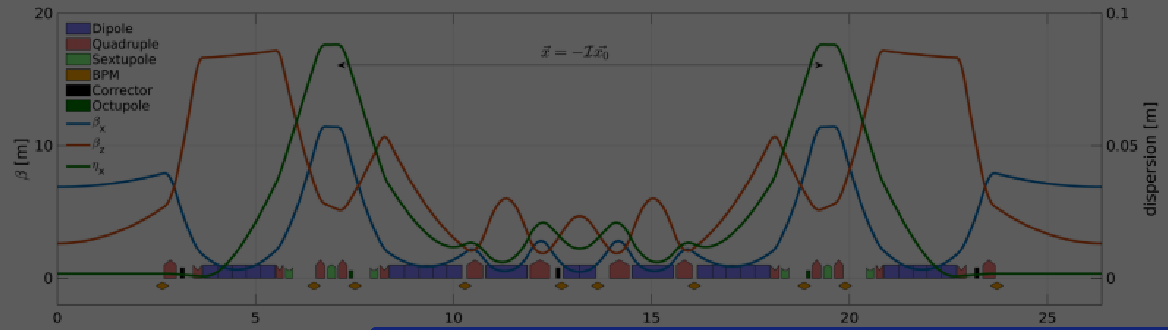
Maintain high performance over the long term



Build the machine that fulfills design specifications

Hours (days… months…) of control room work involving all sorts of experts debugging systems, developing commissioning and analysis scripts



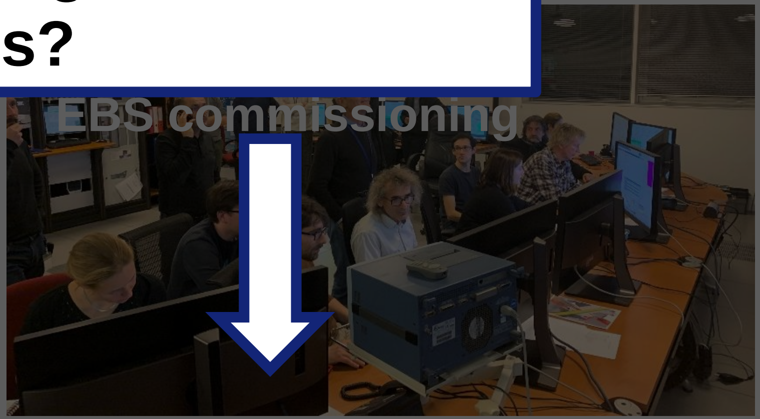


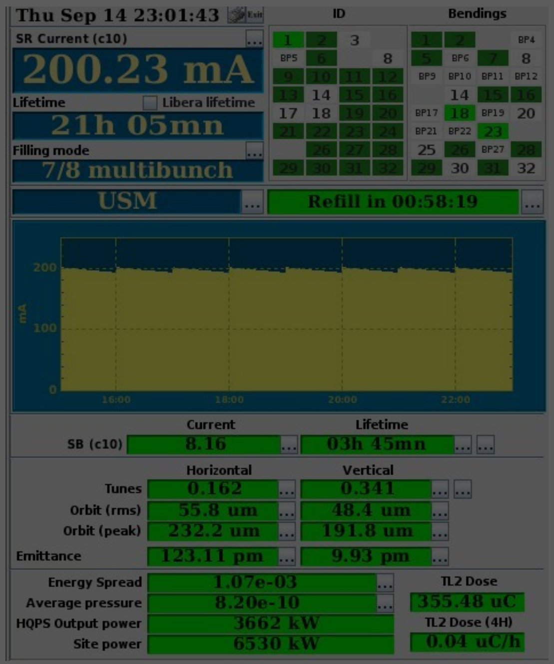
Define goals and design a lattice to achieve them

Fully functional machine

Maintain high performance over the long term

Can we optimize these parts of the process using modern computing tools?





Build the machine that fulfills design specification

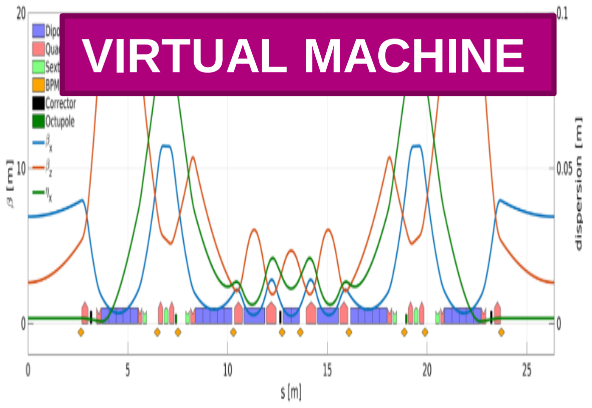
Hours (days… months…) of control room work involving all sorts of experts debugging systems, developing commissioning and analysis scripts

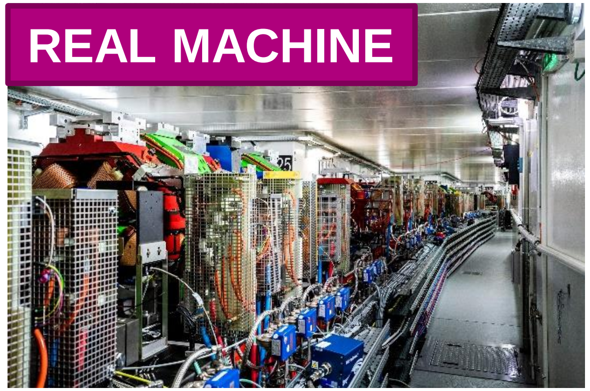
WHAT IS A DIGITAL TWIN?

Evaluate physics
Develop , test and debug controls and scripts
Optimize, tune correct
Prepare commissioning and beam experiments

Integrate developments in the real control system

Optimize beam time usage
Continuous integration without interference with physics runs





Compare with models
Identify issues
Improve, train model.
Can be analytical, numerical of even a neural network

Update model with machine data

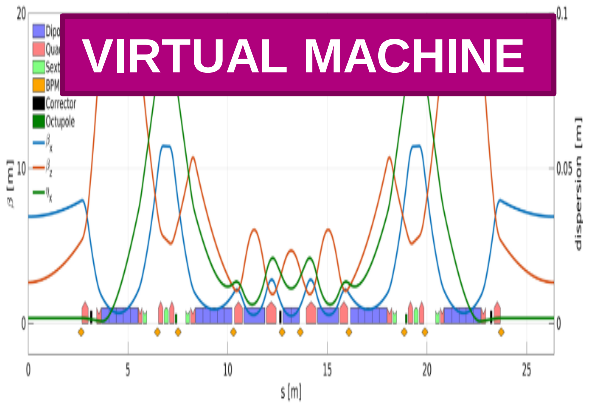
Beam observations
Optimize, tune, correct
Monitoring real life behavior

WHAT IS A DIGITAL TWIN?

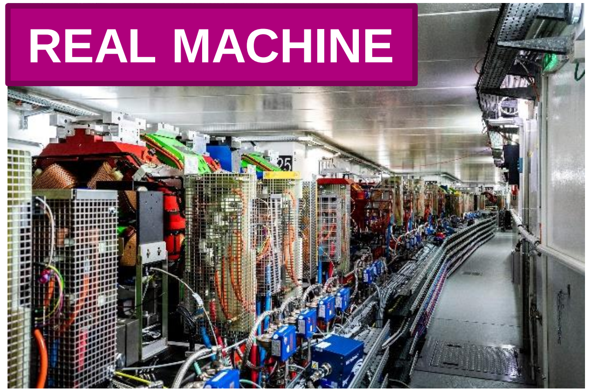
Evaluate physics
Develop , test and debug controls and scripts
Optimize, tune correct
Prepare commissioning and beam experiments

Integrate developments in the real control system

Optimize beam time usage
Continuous integration without interference with physics runs



A digital twin integrates the virtual accelerator and all the framework allowing to switch from the model to the real machine (and back)



Compare with models
Identify issues
Improve, train model.
Can be analytical, numerical of even a neural network

Update model with machine data

Beam observations
Optimize, tune, correct
Monitoring real life behavior

```
>> switch2online;
```

tango

EPICS

Home made

Operation phase

Matlab Middle Layer (MML)

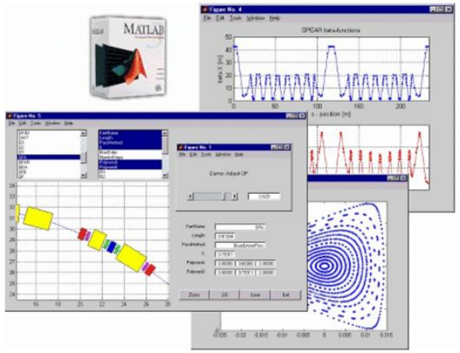
Allows to develop high level applications and tuning tools based on simulations and use the same identical tools for operation.

It is control system agnostic

Scripts and developments can be shared between users

Code configuration for a new SR is clear

Operation of many facility strongly rely on MML



MML IS used as an SR DIGITAL-TWIN with great profit in many labs since several years.

Accelerator Toolbox (**AT**) simulations

Development phase

```
>> switch2sim;
```

MATLAB MIDDLE LAYER HAS WORLD WIDE USERS (INCOMPLETE LIST)

USA: ALS, Stanford (Spear3), Duke FEL, Brookhaven (VUV or X-Ray rings), B-Factory

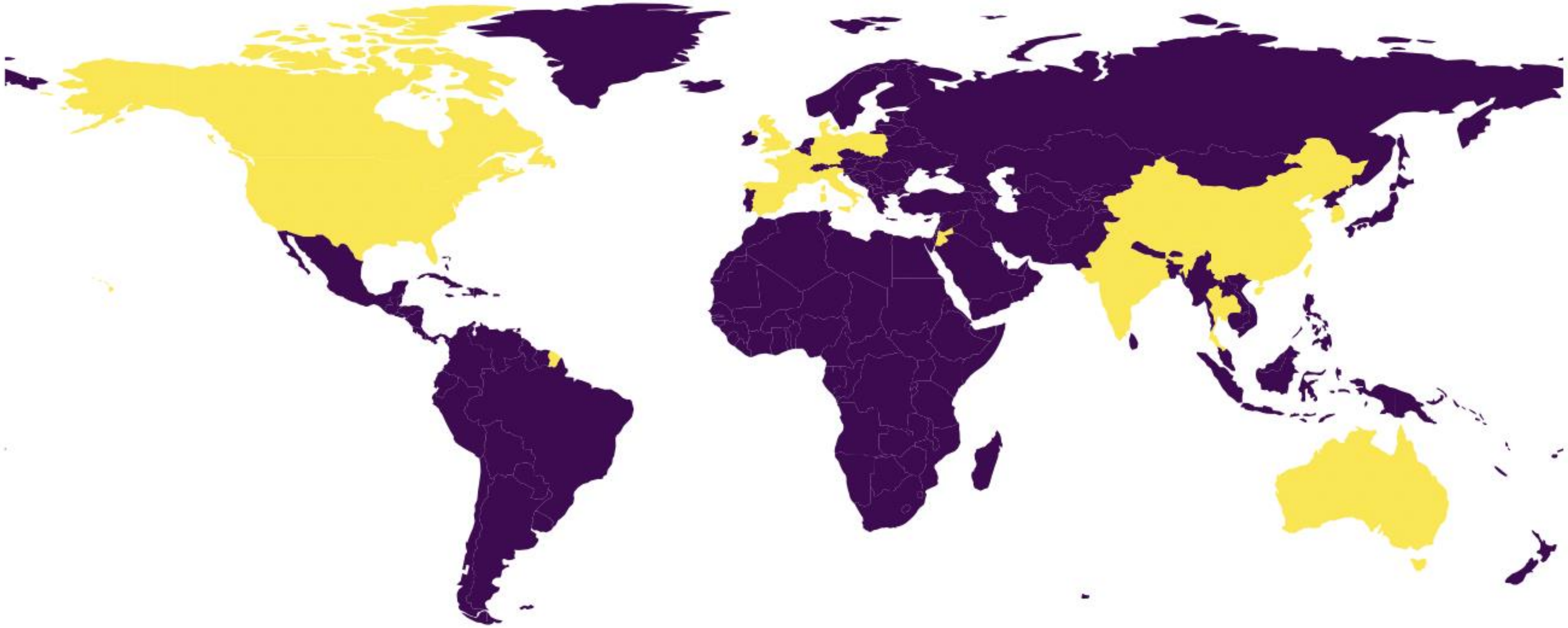
Canada: CLS

Europe: SOLEIL (France), DIAMOND (England), ALBA (Spain), SOLARIS (Poland), MAX-IV (Sweden)

Asia: PLS2 (Korea), SLS (Thailand), SSRF (Shanghai), NSRRC (Taiwan)

Middle East: SESAME (Jordan)

Australia: ASP



MATLAB MIDDLE LAYER ISSUES

`>> switch2online;`

tango

EPICS

Home made

Operation phase

Matlab Middle Layer

Matlab is a proprietary programming language

Collaborative development very difficult: last update in 2018, diverged in many private versions

Does not benefit from modern computing, not possible to interface with more recent developments

Does not implement scientific open data management

- **MML will soon become obsolete**
- **Operation of many facilities at risk**
- **Users community looking for long term alternatives**

MML IS used as an off-line SR DIGITAL-TWIN with great profit in many labs since several years.

Accelerator Toolbox simulations

Development phase

`>> switch2sim;`

```
>>> switch_to_hardware()
```

Python Digital-Twin

Most used language in the world
Free and open-source
Very large users/developers community
Huge number of scientific libraries

The python digital twin would provide a long term solution in an open source license free environment:

- **Simplified collaborative development, integrate modern CI/CD approach**
- **Clean and simple installation procedure**
- **Easy to interface with others recent developments using modern techniques such as advanced correction algorithms (pySC) or AI/ML optimizers (Badger/Xopt) and HPC implementation of pyAT (MPI/GPU)**
- **Clear automatically generated documentation**
- **Works for any accelerator (ring, linac, transfer lines) and control systems**

EPICS

Home made

Operation phase

Development phase

Python Accelerator Toolbox simulations

```
>>> switch_to_physics()
```

A solid and benchmarked python Accelerator Toolbox (pyAT) package for storage ring simulations

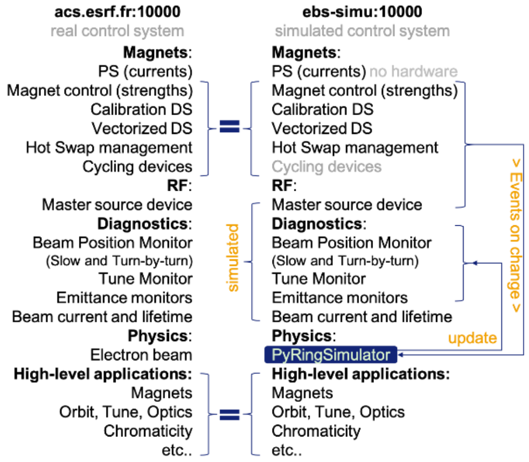
Very wide user experience from MML and (py)AT within a well established collaborative environment

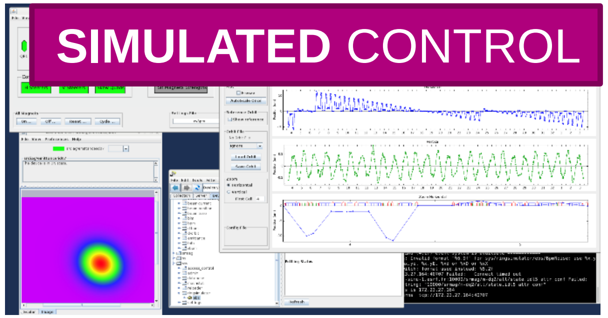
Very strong experiment in development of controls, lattice correction and optimization algorithms:

- Well established and tested methods: ESRF-EBS commissioning
- Python Simulated Commissioning (outcome of EURIZON ~ 1year of collaboration ESRF-DESY)
- Python ESRF-EBS and Diamond virtual accelerators
- Fully benchmarked python optimization algorithms and software (Badger, Xopt developed at SLAC)

Standalone laboratory specific applications: building a common framework to merge and integrate all these developments and coordinating the effort in a collaborative manner would bring strong benefits for the whole community

ESRF-EBS virtual accelerator





This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072

eurizon
European network
for developing new horizons for RIs

25 world-wide laboratories

Extremely positive, active and fruitful collaboration within EU project. **TO BE CONTINUED and EXTENDED.**

Expression of interest from many institutes, contact person identified:

ESRF: Simone Liuzzo, S.White, L.Farvacque
DESY: Ilya Agapov, Lukas Malina, Yong-Chul Chae
SOLEIL: Laurent Nadolski, Alexis Gamelin
ALBA: Zeus Marti, Gabriele Benedetti
MAXIV: Marco Apollonio, Magnus Sjostrom
HZB: Teresia Olsson, Pierre Schnizer
IJClab-ThomX: Vyacheslav Kubytskyi
DIAMOND: Hung-Chun Chao, Tobyn Nicolls, Martin Gaughran, Richard Fielder
ELETTRA: Stefano Krecic
SOLARIS: Jacek Biernat
SESAME (Jordan): Samira kasaei
ALS LBNL (USA): Thorsten Hellert
IHEP (China): Daheng Ji, Mengyu Su
ANSTO (Australia): Paul Bennetto
NSLS-2 (USA): Xi Yang

List added to the project summary shared with LEAPS RDB

PROJECT PRELIMINARY DRAFT BUDGET / HUMAN RESSOURCES

2 Post-Docs/COD for 4 years (or equivalent): experts of python programming (either physicist or software engineer) one of those two positions would need to be based at ESRF 100%. ~ 150kEuros/year/person (1.2 MEuro over 4 years)

Finances for travelling (~10kEuro/year/lab) (assuming 5 labs participating, ~200 kEuros)

Finances for conferences/workshops (~10kEuro/conference) (~40 kEuros)

Finances for office material (computers for the hired people) (~10 kEuros)

Finances to finance external colleagues to work on the project for limited amount of time even if not members of the project (50kEuro)

For a total of about 1.5 MEuro over 4 years.

On top of the 2 positions above, an additional ~2 full time equivalent (8-10 FTE for the 4 years) will be needed for the project to be completed. Those are intended as the time spent by members of each lab on the project activities.

TIMELINE

July-202(3) to Mar-202(4) : establishment of a group of partner laboratories and preparation of detailed project proposal.

Mar-202(4): submission of LEAPS project as part of a larger INFRA-TECH project

Year #1 : analysis of the existing MML. Collaborative work on the definition of the main structure of the code. Kick-off Workshop.

Year #2 : documentation and first draft with basic features: digital twin, magnet calibrations, correction of tune, orbit and chromaticity. Yearly Workshop.

Year #3 : use as a commissioning simulations tool. Extension with additional tuning features for optics correction (LOCO). Yearly Workshop.

Year #4 : test in at least 4 labs (ex: ESRF, DESY, ELETTRA, SOLEIL), refinement of installation procedures, improve documentation, additional correction tools. Final Workshop.

Python Accelerator Digital-Twin

Would benefit to a large community of laboratories
in Europe (PETRAIV, SOLEIL, ALBA, ..) and outside Europe
Especially those that foresee a new SR or an upgrade in the near future.

Not a single laboratory in Europe has sufficient resources to support such project on its own.

It is thus a perfect topic for an EU project

with welcome participation of non-European laboratories (not financial).

Extremely positive, productive and rewarding previous experience from EURIZON Task 4.1

REFERENCES

MML: https://indico.ijclab.in2p3.fr/event/2075/attachments/3275/4037/LALseminarMML_nadolski.pdf

AT: https://github.com/atcollab/at

pySC: https://github.com/lmalina/pySC

S. White, L. Carver, L. Farvacque, and S. Liuzzo, "Status and recent developments of python Accelerator Toolbox", presented at the IPAC'23, Venice, Italy, May 2023, paper WEPL031.

A.Terebilo, "Accelerator Modeling with MATLAB Accelerator Toolbox", in *Proc. PAC'01*, Chicago, IL, USA, Jun. 2001, paper RPAH314, pp. 3203-3205.

W. A. H. Rogers, N. Carmignani, L. Farvacque, and B. Nash, "pyAT: A Python Build of Accelerator Toolbox", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 3855-3857. doi:10.18429/JACoW-IPAC2017-THPAB060

B. Nash *et al.*, "New Functionality for Beam Dynamics in Accelerator Toolbox (AT)", in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 113-116. doi:10.18429/JACoW-IPAC2015-MOPWA014

S. Liuzzo *et al.*, "Commissioning simulations tools based on python Accelerator Toolbox", presented at the IPAC'23, Venice, Italy, May 2023, paper MOPA142, unpublished.

S. M. Liuzzo *et al.*, "The ESRF-EBS Simulator: A Commissioning Booster", in *Proc. ICALEPCS'21*, Shanghai, China, Oct. 2021, pp. 132-137. doi:10.18429/JACoW-ICALEPCS2021-MOPV012

G. J. Portmann, W. J. Corbett, and A. Terebilo, "An Accelerator Control Middle Layer Using Matlab", in *Proc. PAC'05*, Knoxville, TN, USA, May 2005, paper FPAT077, pp. 4009-4011.

S. M. Liuzzo *et al.*, "UPDATE ON THE EBS STORAGE RING BEAM DYNAMICS DIGITAL TWIN", in *Proc. ICALEPCS'23*, Cape Town, South Africa, Oct. 2023, THPDP010

L. Malina *et al.*, "Python Library for Simulated Commissioning of Storage-Ring Accelerators", in *Proc. ICALEPCS'23*, Cape Town, South Africa, Oct. 2023, FR2AO05