HZB BESSY II Light Source

OPERATIONAL TOOLS AND ALGORITHMS AT BESSY II AND MLS

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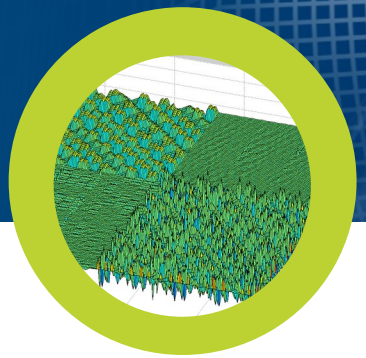


CONTENTS

- Where are we?
  Overview about existing stack of operational tools and algorithms applied at BESSY II and MLS
- What do we do presently?
- Where do we want to go?

HZB / Dirk Laubner

BESSY II

1.7 GeV, 300 mA, TopUp, in operation since 1998

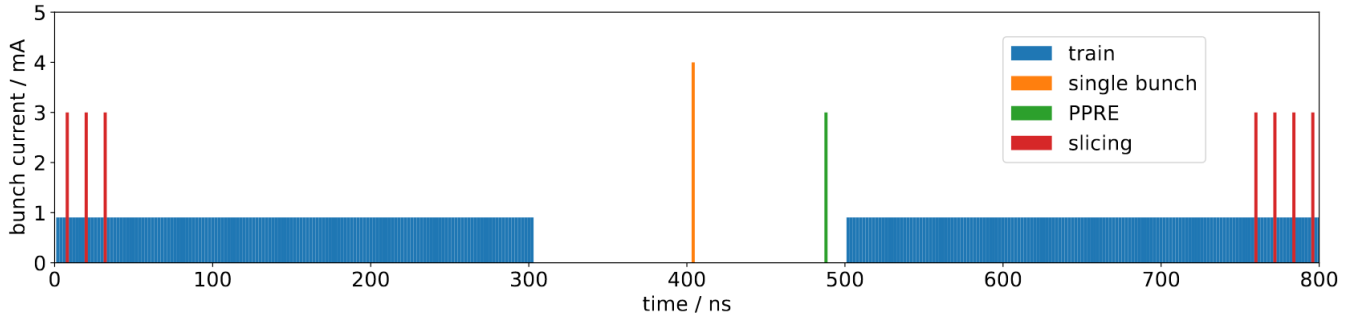
slicing facility, superconducting wavelength shifter (x2), in-vacuum undulator

hybrid filling pattern operation
- flux / brightness
- brilliance
- timing / dynamics

single bunch, few bunch
- timing / dynamics, pulse length ~ 100ps

low-alpha
- coherent THz radiation (timing) 2ps

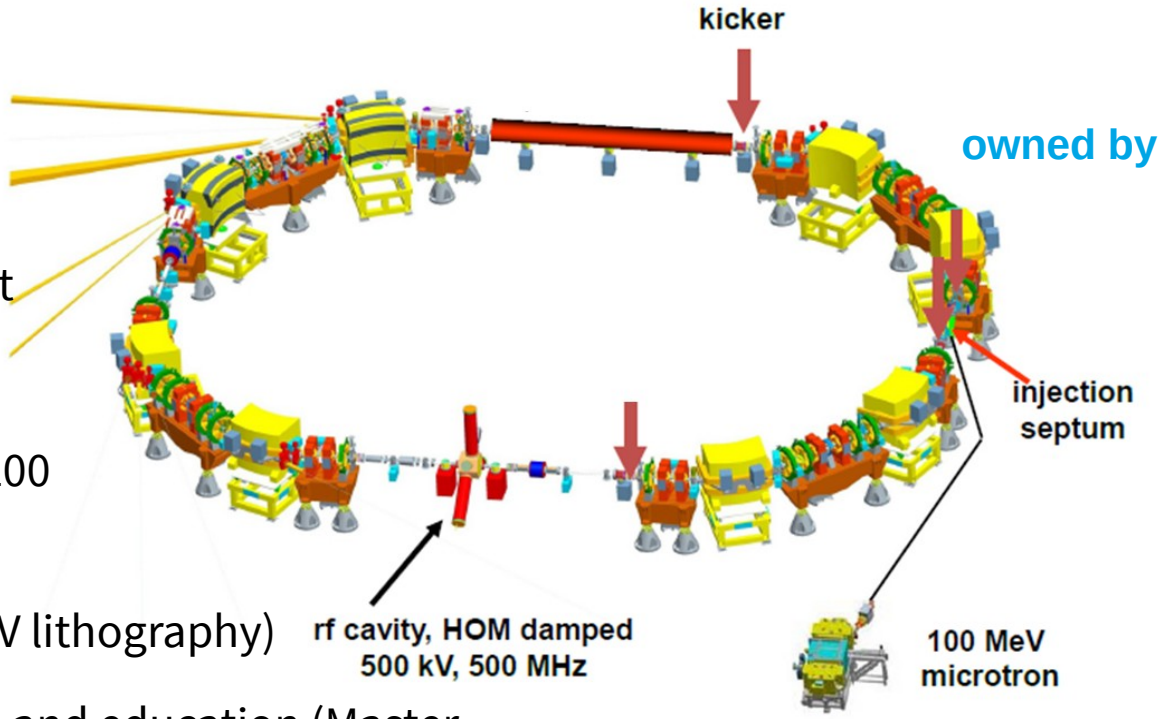
EPICS facility



METROLOGY LIGHT SOURCE

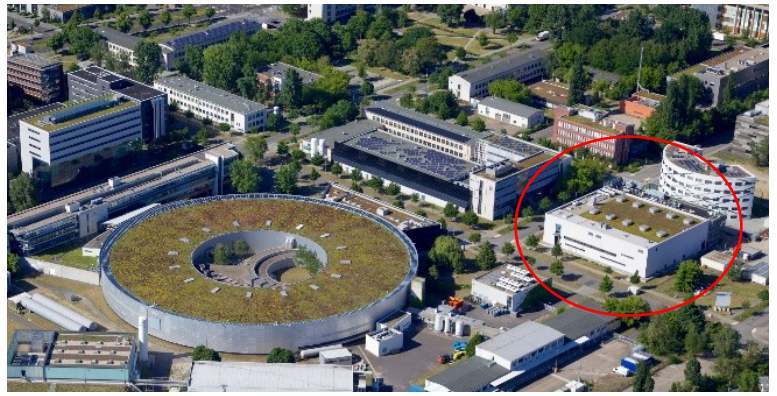
owned by PTB

developed and operated by HZB



- Physikalisch-Technische Bundesanstalt
- user operation since 2008
- E / MeV = 50…630; C / m = 48; I / mA = 200
  design emittance / nradm ~ 100
- EUV reflectometry (next generation EUV lithography)
- important test-bed for accelerator R&D and education (Master, PhD Students)
- first SR optimized for low alpha operation by using a dedicated sextupole and octupole correction scheme.
  → optimized for low-alpha operation (IR / THz generation)
- experimental studies of steady state microbunching (SSMB)
- EPICS facility

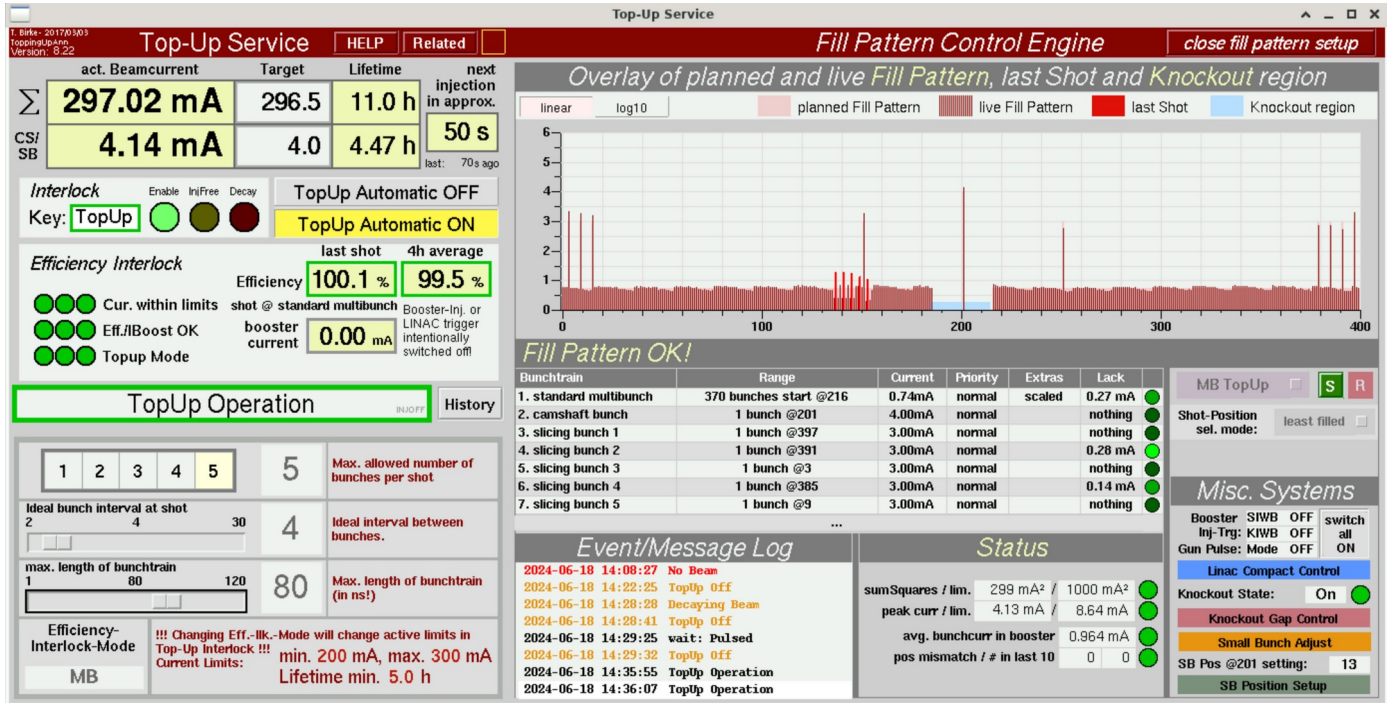
ASML ZEISS



HZB BESSY II Light Source

TOPUP MASTER – BESSY II

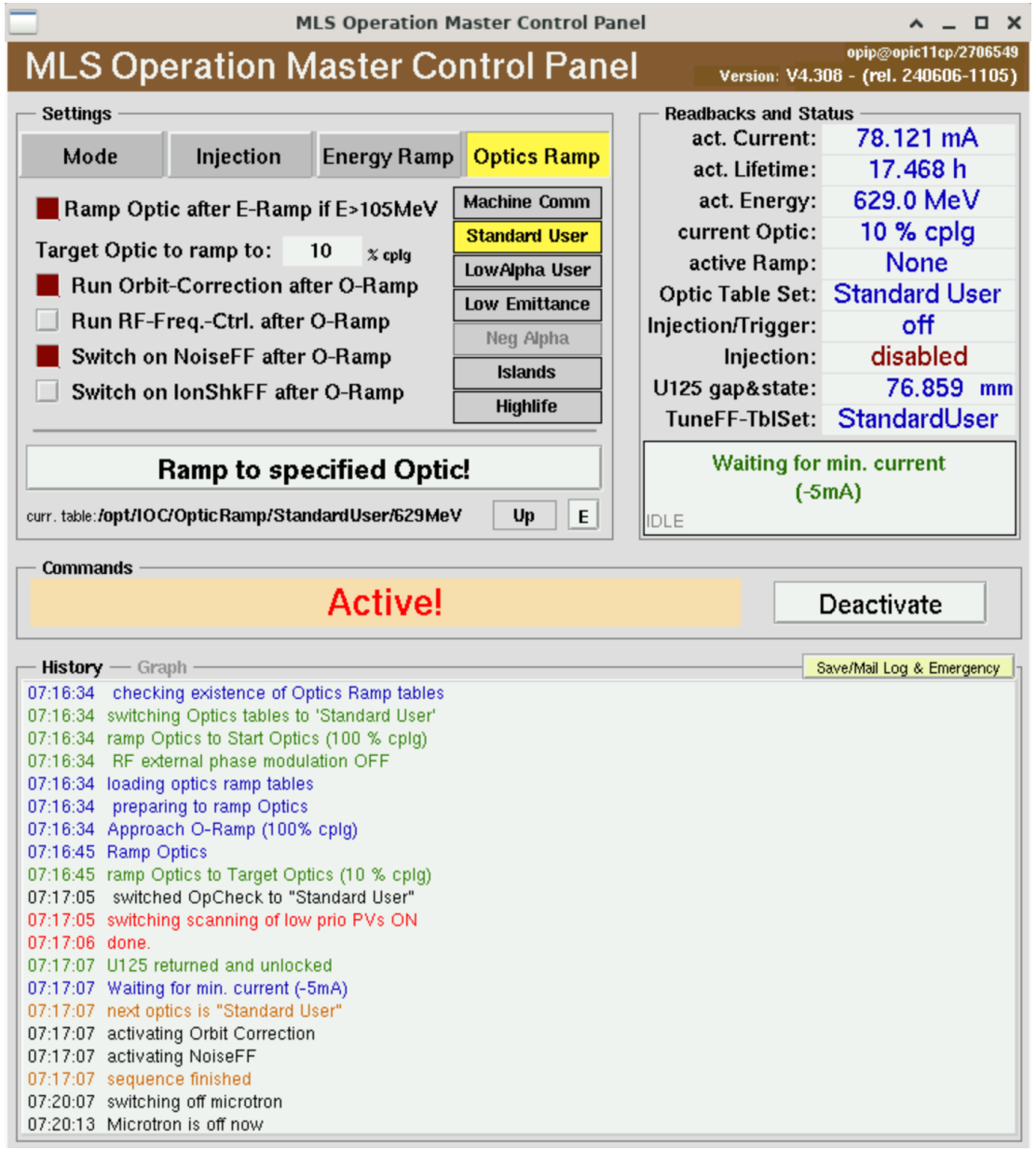
- BESSY II, self-written, maintained, EPICS State Notation
- automatized TopUp operation including helper functions
- lines of code ~600 state machine, ~600 next shot config, ~400 fill pattern and TopUp simulation for testing
- Running on an IOC, interface is EPICS (including panels, alarms, archiving…)
- cleanup planned, rewrite for next-shot config



OPERATION MASTER MLS

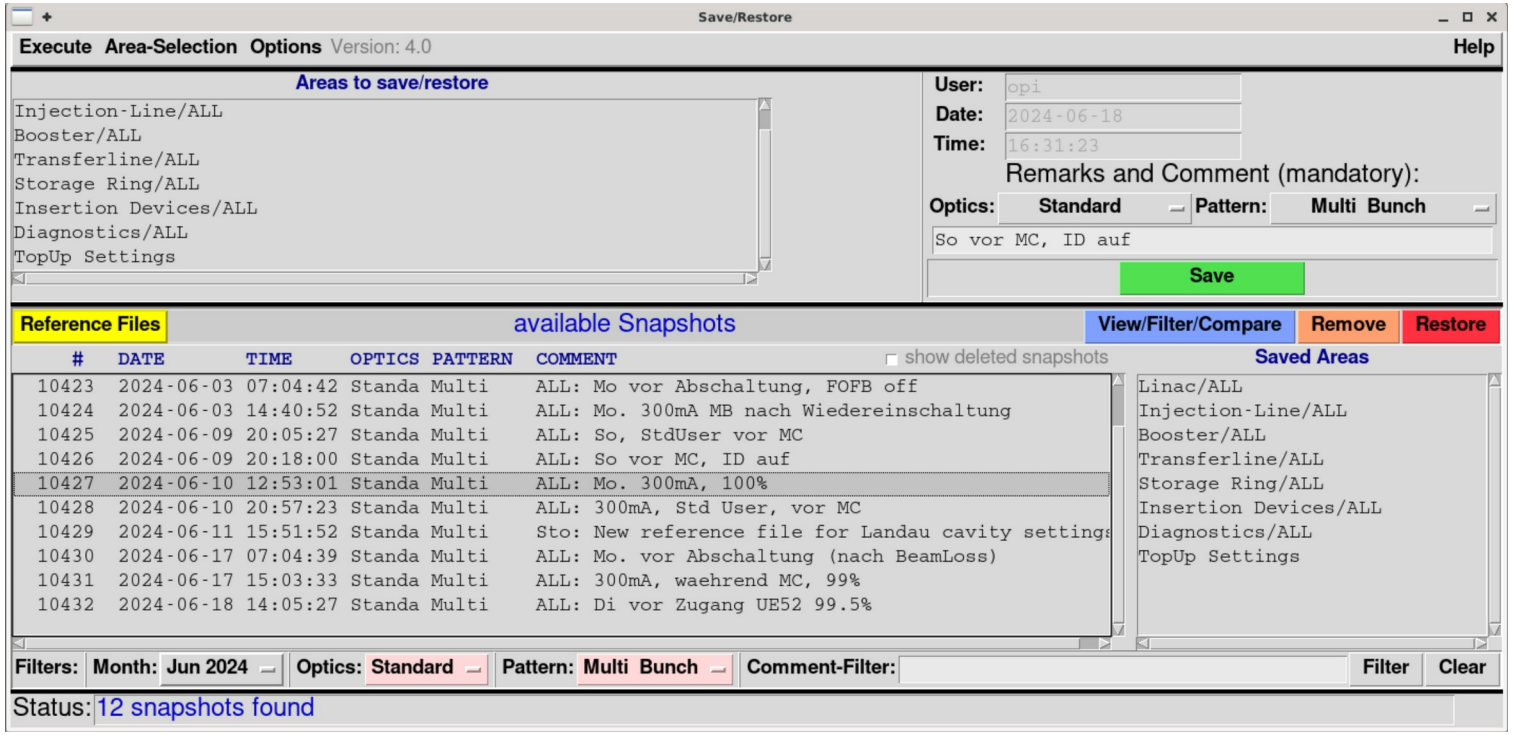
- MLS, self-written, maintained, Tcl
- fully automatized operation including all transitions
- lines of code ~250 generic state machine, ~500 MLS Operation Master, ~2000 initialization & helper functions
- running as a service, interface is EPICS-DB (including panels, alarms, archiving…)
- rewrite with cleanup planned

Fully automatized operation is key to efficient and reliable operation of the Metrology Light Source



SAVE & RESTORE

- BESSY II & MLS, Tcl/Tk
- configuration – hierarchy of files listing PVs to save/restore (in engineering units)
- 10000 machine snapshots so far
- lines of code ~3700
- running as application on the user terminal, no python or command line interface
- probably switch to Phoebus S&R in the future

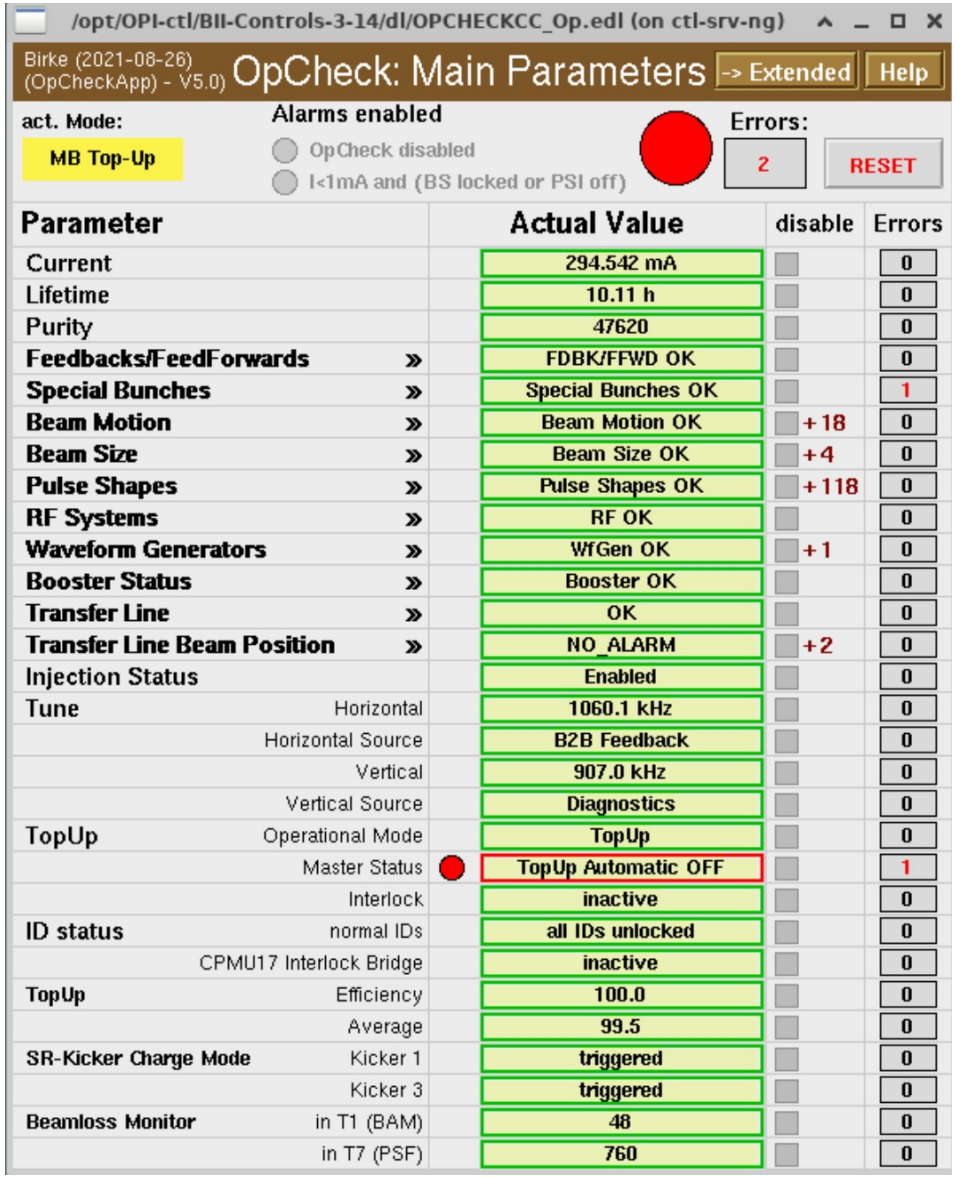


OPERATIONAL PARAMETERS CHECK

- BESSY II & MLS, self-written, maintained, EPICS
- automatized monitoring of beam parameters and machine configuration (in contrast to device health ALH)
- lines of code ~3000 automatic generation of EPICS-DB & config data for BESSY II and MLS
- Running as a service, interface is EPICS (including panels, alarms, archiving…)
- 16500 records for BESSY II and 5000 records for MLS

Very important for high availability & reliability

“eyes” of virtual supervisor / operator



ENERGY & OPTICS RAMP

- used at MLS, self-written, maintained, EPICS State Notation
- linear transition of complex ramps with human maintained fixed points
- lines of code ~300 generic state machine, ~500 python
- running as a service, interface is EPICS-DB (including panels, alarms, archiving…)
- rarely operated by humans, but daily but Operation Master

Mandatory ingredient for maintaining the complex state space of MLS

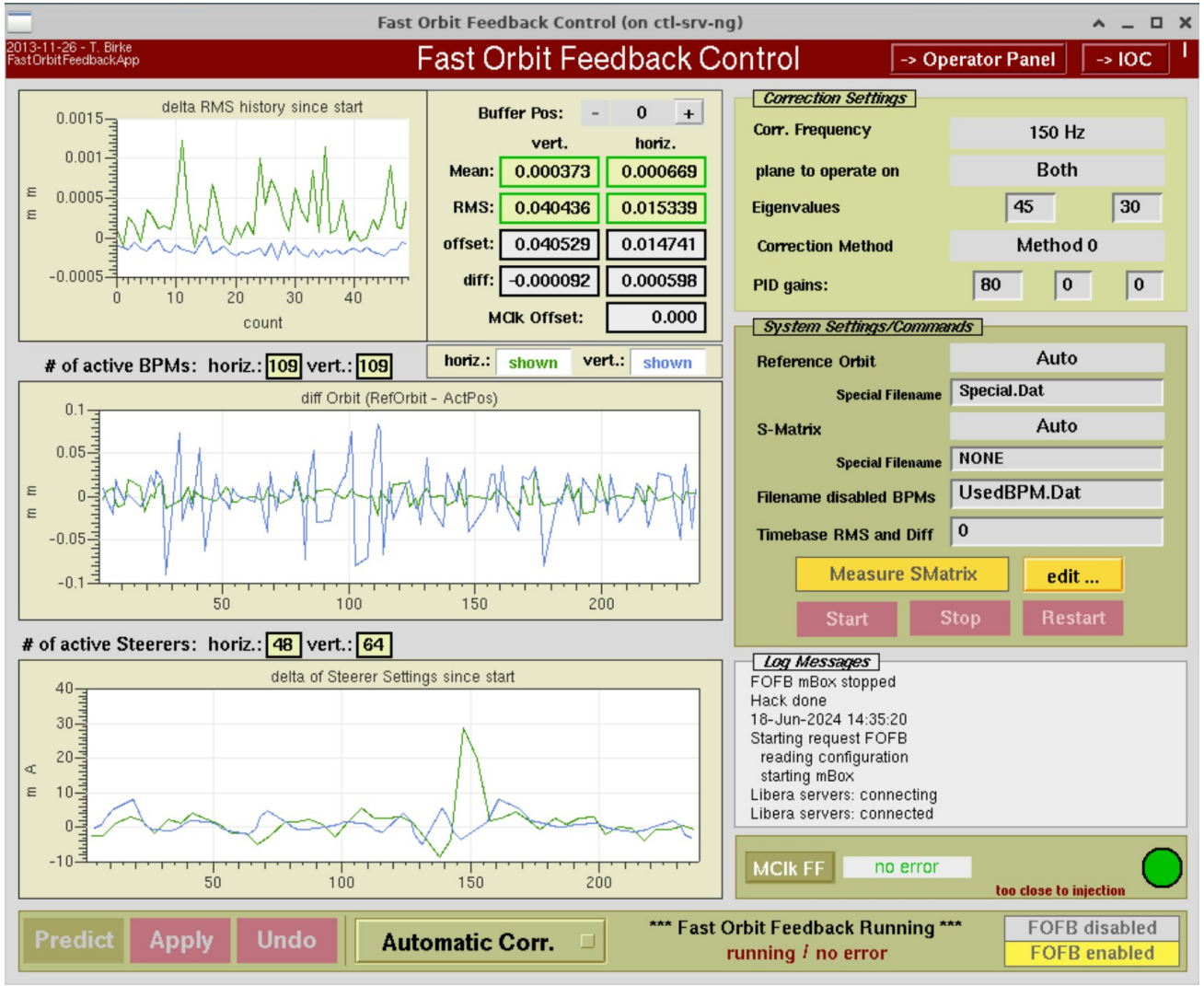
SLOW ORBIT FEEDBACK

- BESSY II & MLS, self-written, legacy, C++
- slow (1/6 s) orbit correction, visualization & bumps
- lines of code ~20000 orbit, ~37000 mapper (GUI - motif)
- local running application with GUI
- legacy code 32bit

We need urgently replacement(s) for correction and visualization
Community solution? Outsourcing?

FAST ORBIT FEEDBACK

- BESSY II, self-written, Matlab (7.7/2008)
- “fast” (150 Hz) orbit correction, visualization
- lines of code ~1300 orbit, ~2000 C-code auf IOCs
- local running application with GUI
- legacy system and software
  (reflective memory)
  planned to be rewritten soon as new BPM
  electronics are deployed

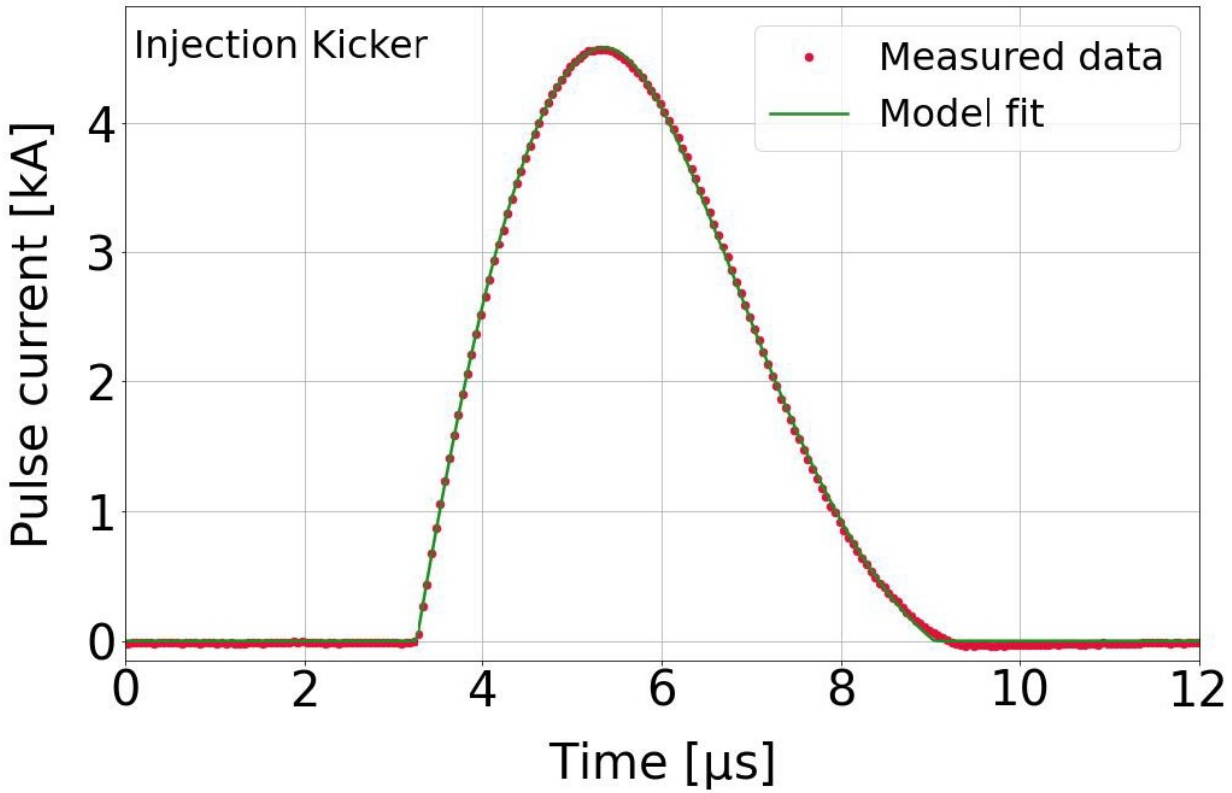


ADVANCED PULSED ELEMENT ANALYSIS

- BESSY II, self-written, maintained, python
- online model-based analysis of pulse currents for half-wave and full wave pulses
- lines of code ~ 400
- running as a service, interface is EPICS (including panels, alarms, archiving…)

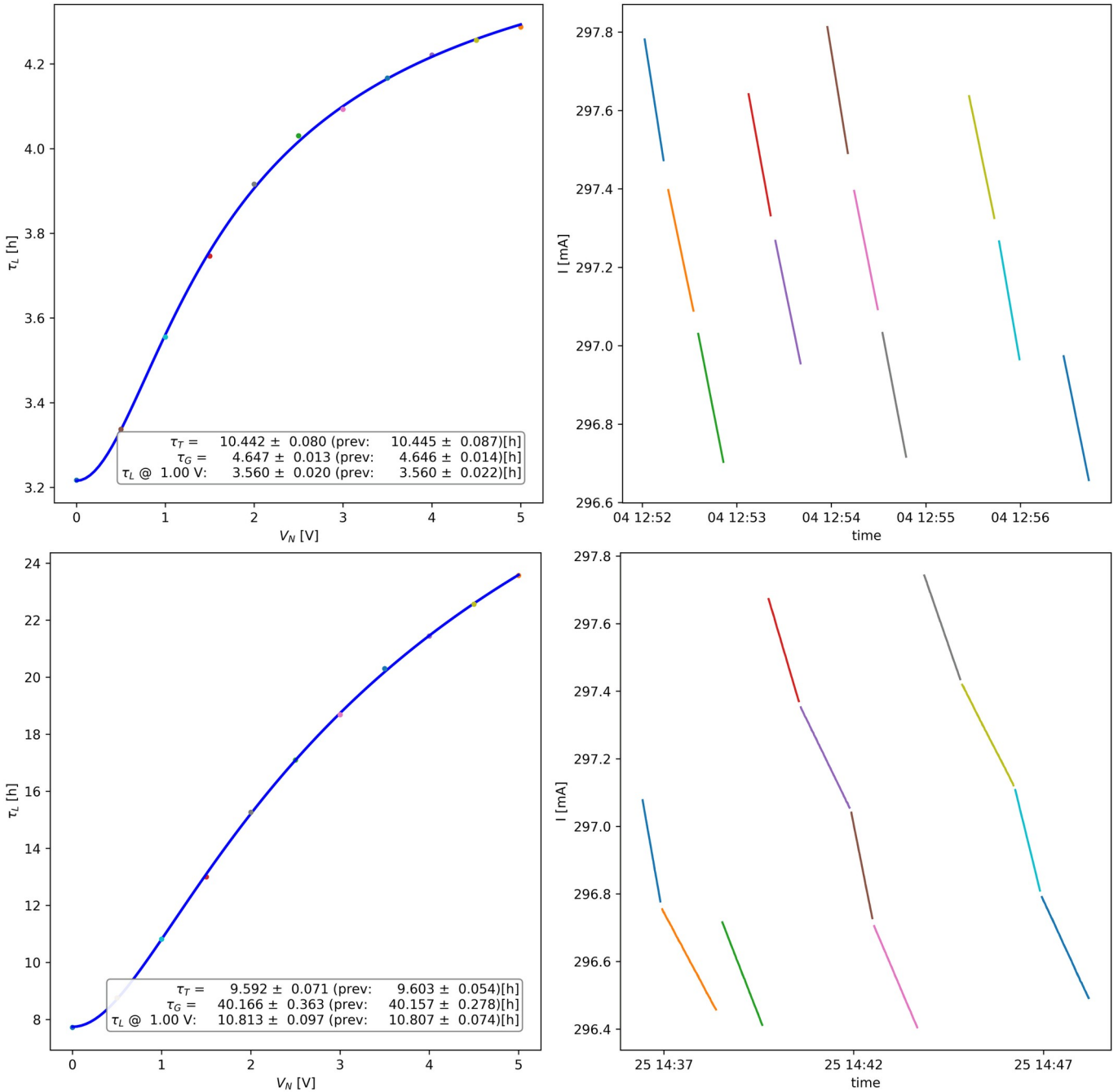
Permanent monitoring of amplitudes of septum currents in the range is extremely helpful for TopUp with 99% injection efficiency

$$I_{\text{model}}(t) = \begin{cases} 0 & , t < t_0 \ \& \ t > t_2 \\ I_{\text{rising}}(t) & , t_0 \leqslant t < t_1 \\ I_{\text{falling}}(t) & , t_1 \leqslant t \leqslant t_2 \end{cases}$$



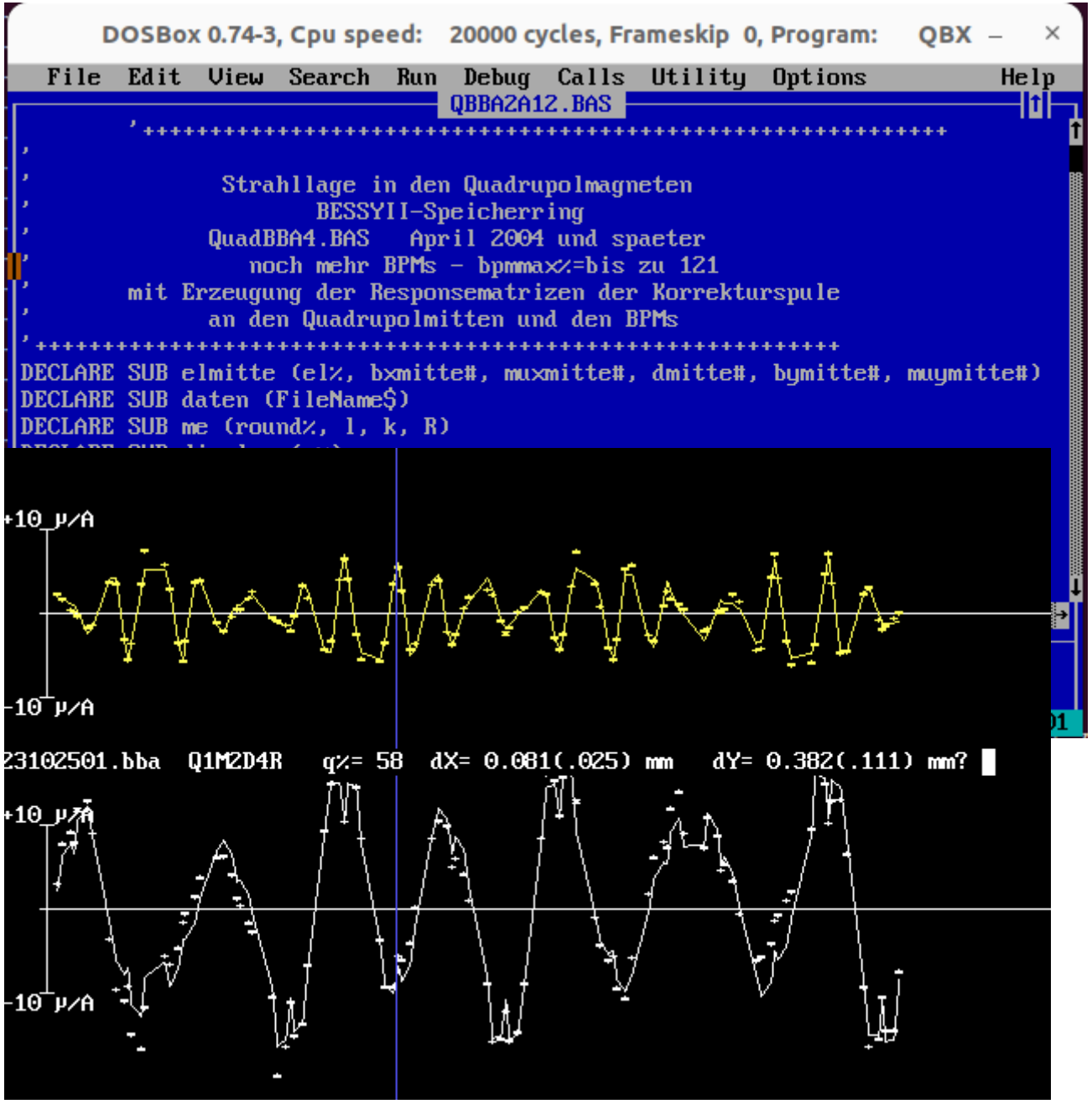
LIFETIME MEASUREMENT

- BESSY II, self-written, maintained, python
- weekly monitoring ratio of Touschek lifetime and gas lifetime
- operator friendly → fully automatized measurement, analysis and documentation (automated ELOG posts)
- local application including GUI



BBA-OLD

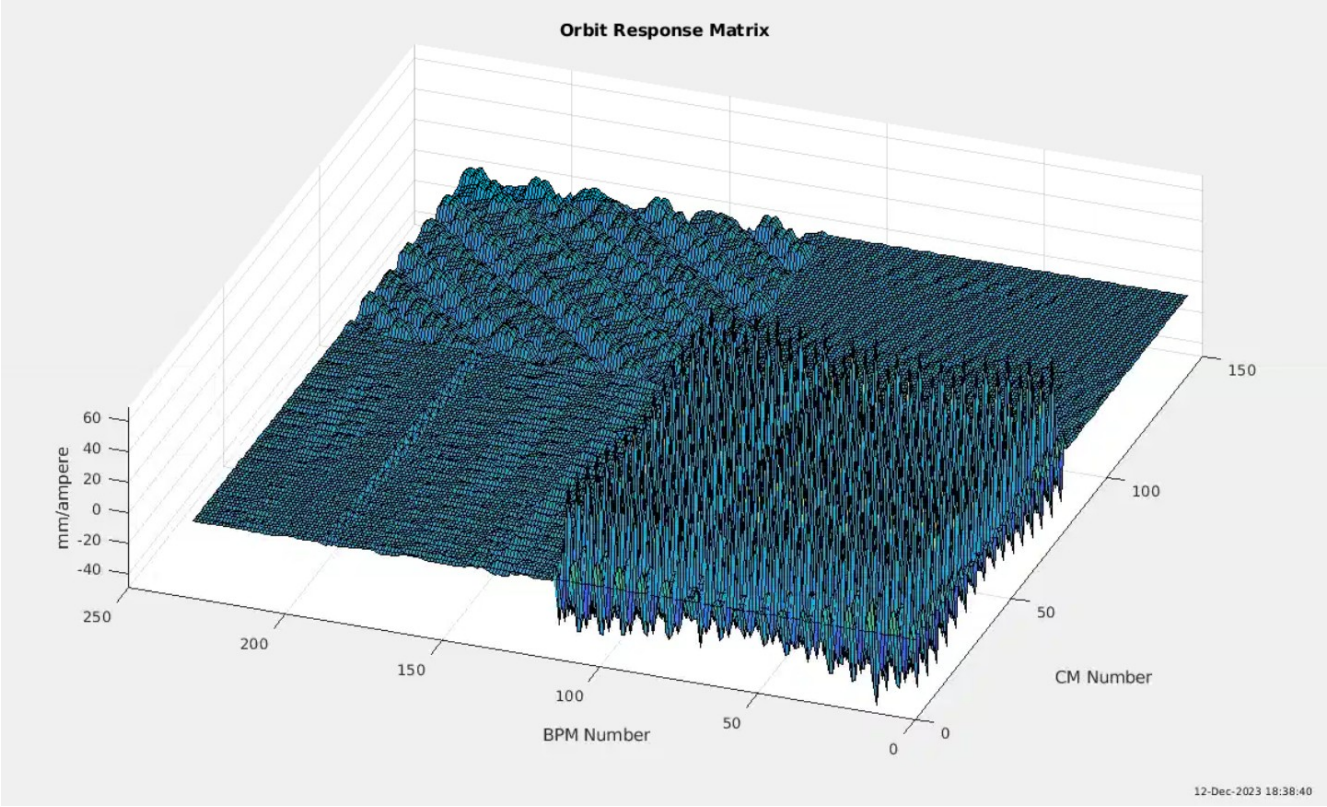
- BESSY II, self-written, unmaintained, QBasic (dosbox)
- model based beam-based alignment procedure (much faster) including golden orbit generation
- ~700 lines of code
- competitive at the time, but clearly out of date



In the process of being replaced by a modern rewrite and complemented by MML BBA (quadcenter)

MML

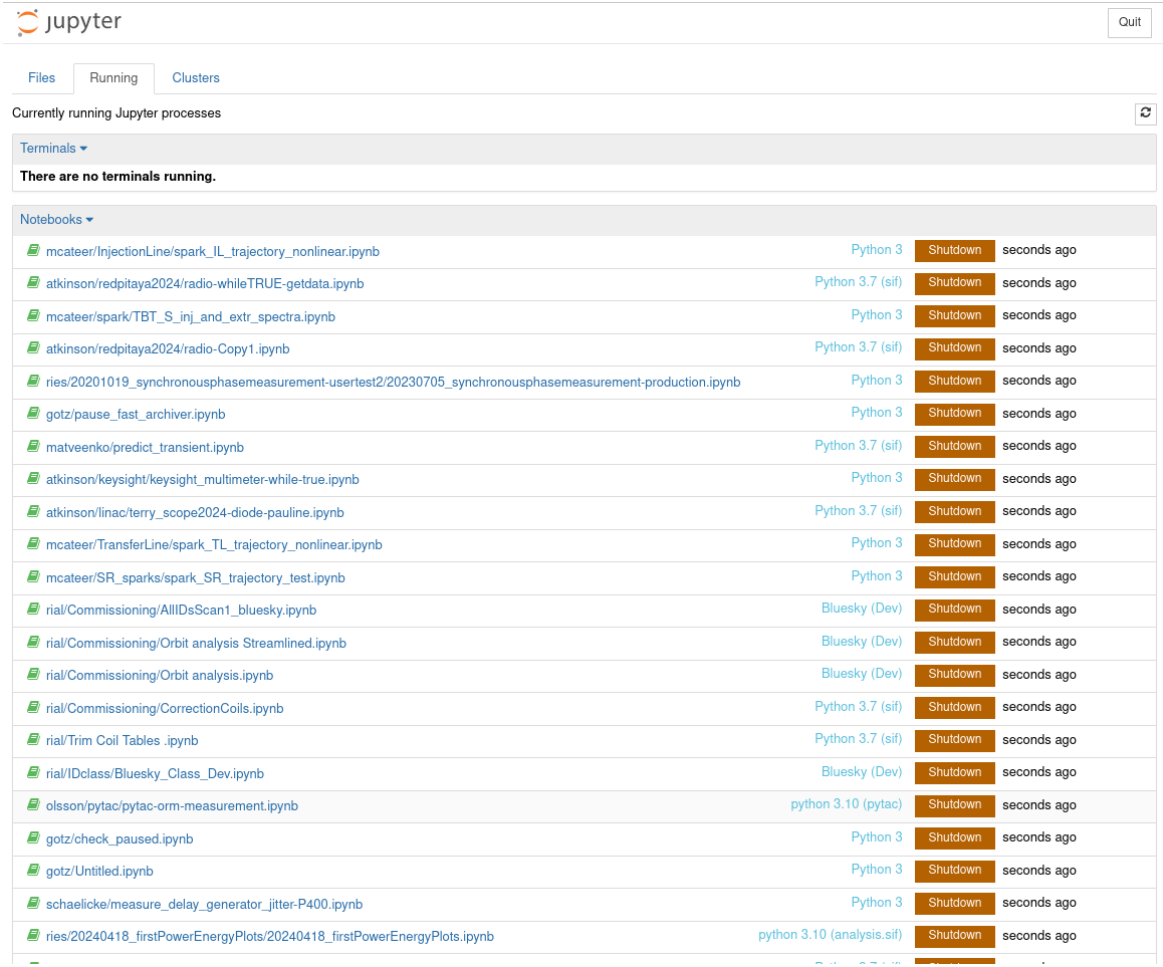
- established at BESSY II and MLS
- around for a decade, but not intensely used, maintained or developed, not part of the production eco system
- since half a year: complete model review, pyAT model input for MML
- extending MML setup and capabilities on both machines to connect to the community for preparing our contribution towards a new accelerator middle layer process
- orbit correction, generate bumps, quadcenter, ORM, LOCO



JUPYTER NOTEBOOK / LABS

- aka “commission tools”, managed to get all physicists under one umbrella
- daily accelerator physicists working place (debugging, data analysis and visualization…)
- lots of code snippets
- bad for many reasons (in particular sustainability)
- very low threshold – ideal for getting students on board
- ~5000 notebooks

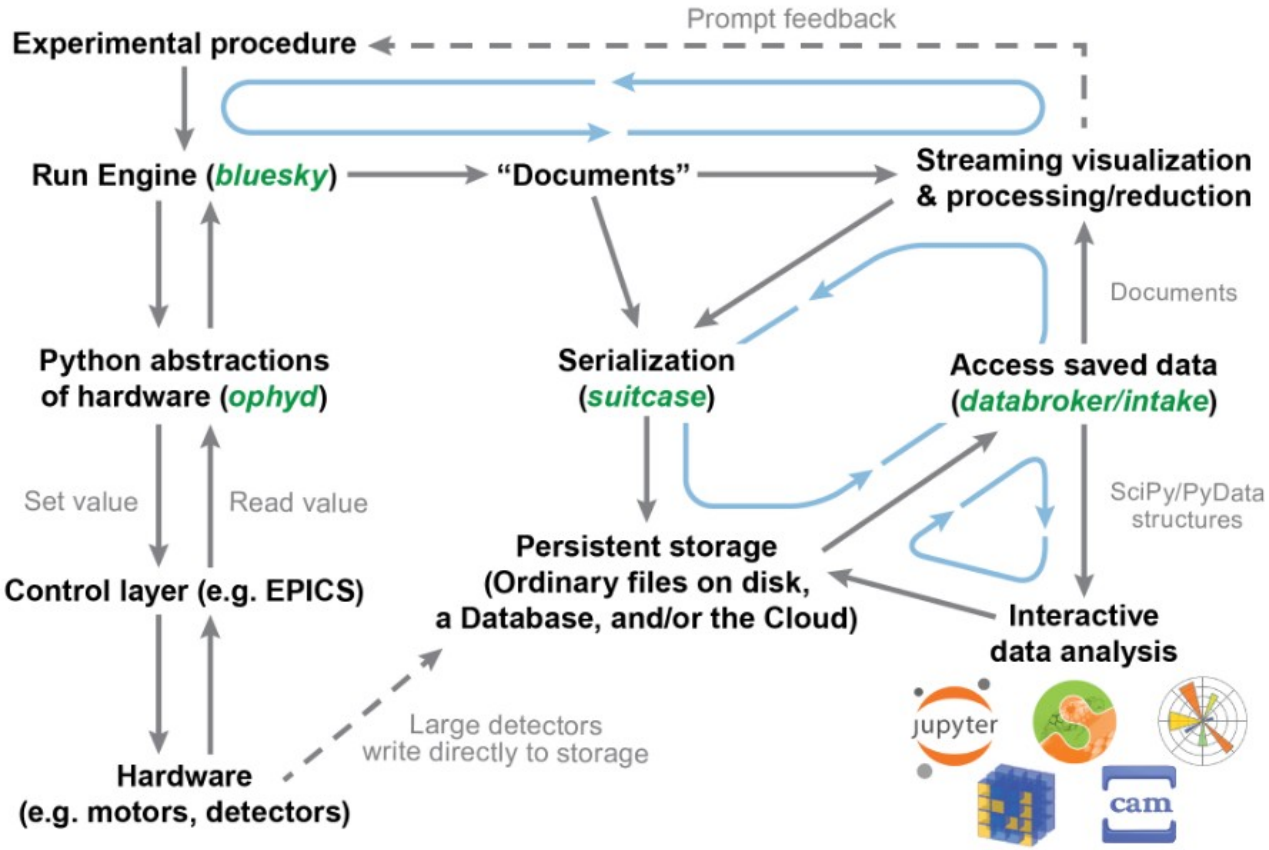
Seems to be a necessary evil for the time being



OPHYD / BLUESKY

- motivation: frameworks towards better – in particular more structured and sustainable physicists code
- ophyd → key / bottleneck are sustainable complex devices
- Bluesky → structured measurements / data acquisition
- needs some time to get used to database use (used to archive data or manually generated files)
- higher level integration enables much more complex possibilities than bare-metal

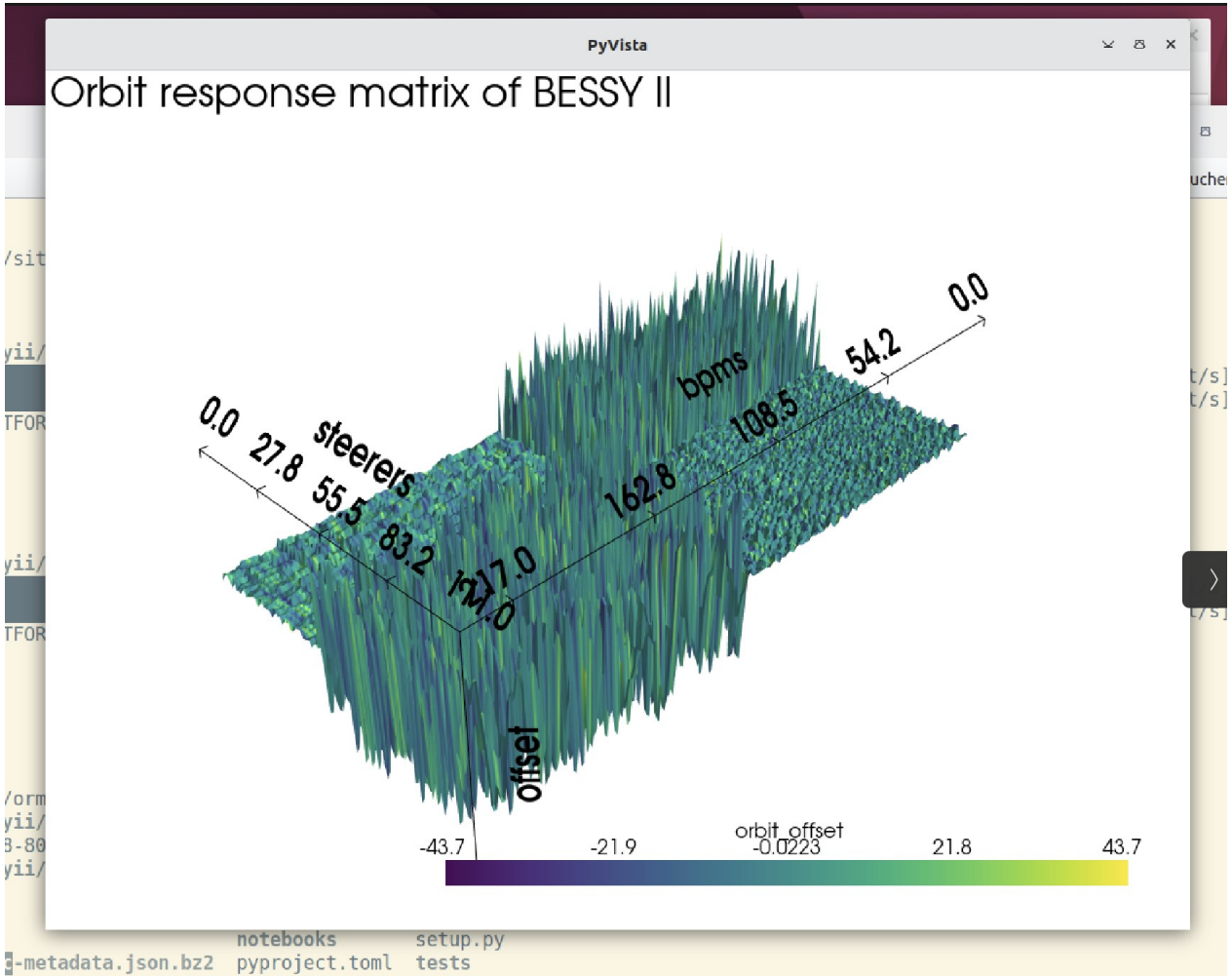
Work in progress, trying to deploy to "user" for some time now… quite a threshold to breach



ORM AND NEW BBA

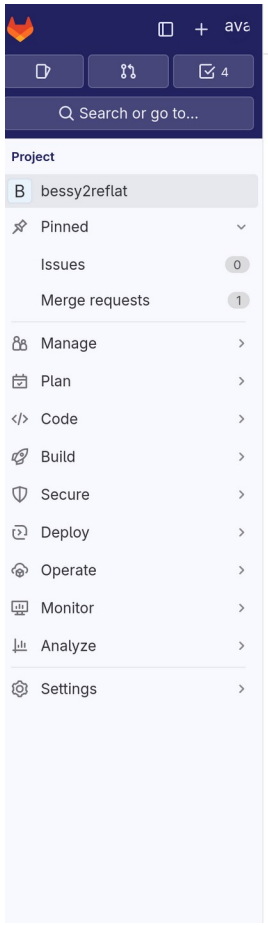
- BESSY II, self-written, development, python
- complete rewrite of the model old model-based BBA
- ophyd + bluesky + database
- runs on digital twin and machine
- in physics review
- Target: production method for BBA at BESSY II & MLS

Could be contributed as an application to a new accelerator middle layer as a standard tool



THE MACHINE MODEL

- 505 drift sections
- 35 dipole magnets
- 145 quadrupole magnets
- 112 sextupole magnets
- 112 (121) BPMs
- python interface → pyAT
  calculating tune & closed orbit ~ 80 ms without any optimization on a laptop
- using this model also in MML now
- in-depth model review ongoing
- targeting a model to describe the real machine



Accelerator Tools / Reference Lattices / **bessy2reflat**

```
        at.Quadrupole('Q4M1D1R',0.5,k=k4d1),\
        at.Drift('DU_S4M1D1R',0.153),\
        at.Sextupole('S4M1D1R',0.16,h=h4d1,Corrector='H',KickAngle=[0,0]),\
        at.Drift('DU_BPMZ4D1R',0.07),\
        at.Monitor('BPMZ4D1R',Group='BPM'),\
        at.Drift('DU_KIK1D1R',0.2295),\
        at.Drift('KIK1D1R',0.595),\
        at.Drift('DU_BPMZ41D1R',0.1265),\
        at.Monitor('BPMZ41D1R',Group='BPM'),\
        at.Drift('DU_BPMZ42D1R',0.20939),\
        at.Monitor('BPMZ42D1R',Group='BPM'),\
        #at.Drift('DU_KIK2D1R',0.13289-0.00639),\
        at.Drift('DU_KIK2D1R',0.12011),
        at.Drift('KIK2D1R',0.595),\
        at.Drift('DU_FOMZ1D1R',0.3465),\
        at.Monitor('FOMZ1D1R'),\
        at.Drift('DU_MRING_END',0.514),\
        at.Marker('MRING_END'),\
        ]

    # Ring definition
    ring=[D1_secondhalf, T1, D2, T2, D3, T3 , D4, T4, D5, T5, D6, T6, D7, T7, D8, T8, D1_firsthalf]

    # Expand ring until list completely flattened
    while any(isinstance(x, list) for x in ring):
        ring = list(chain.from_iterable(i if isinstance(i, list) else [i] for i in ring))

    # Build the lattice
    ring = at.Lattice(ring,name='BESSY II',energy=energy)

    # Turn cavity and radiation on
    ring.enable_6d()

    # Set cavpts to point to main cavities
    ring.cavpts = ring.get_uint32_index('CAV*')

    # Set only main cavity phases
    ring.set_cavity_phase(cavpts=ring.cavpts)

    return ring

if __name__ == '__main__':
    ring = bessy2Lattice()
```

DIGITAL TWIN

- core motivation: enable accelerator physics software development, testing and training outside the control room without machine time
- creates PVs with prefix and manages
- architecture with different engines → pyAT & thor-scsi
- twin for everyone → shall be running on office laptops
- container available

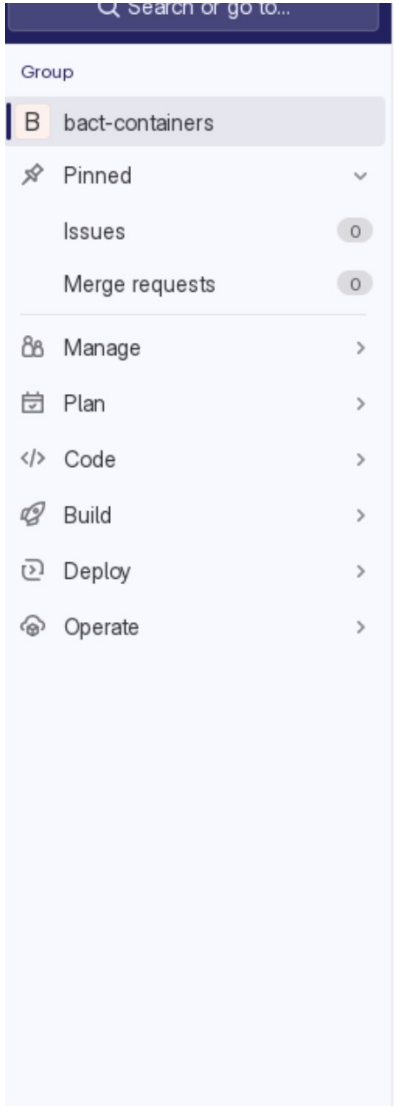
First friendly users profit,
e.g. bluesky @ BESSY II digital twin

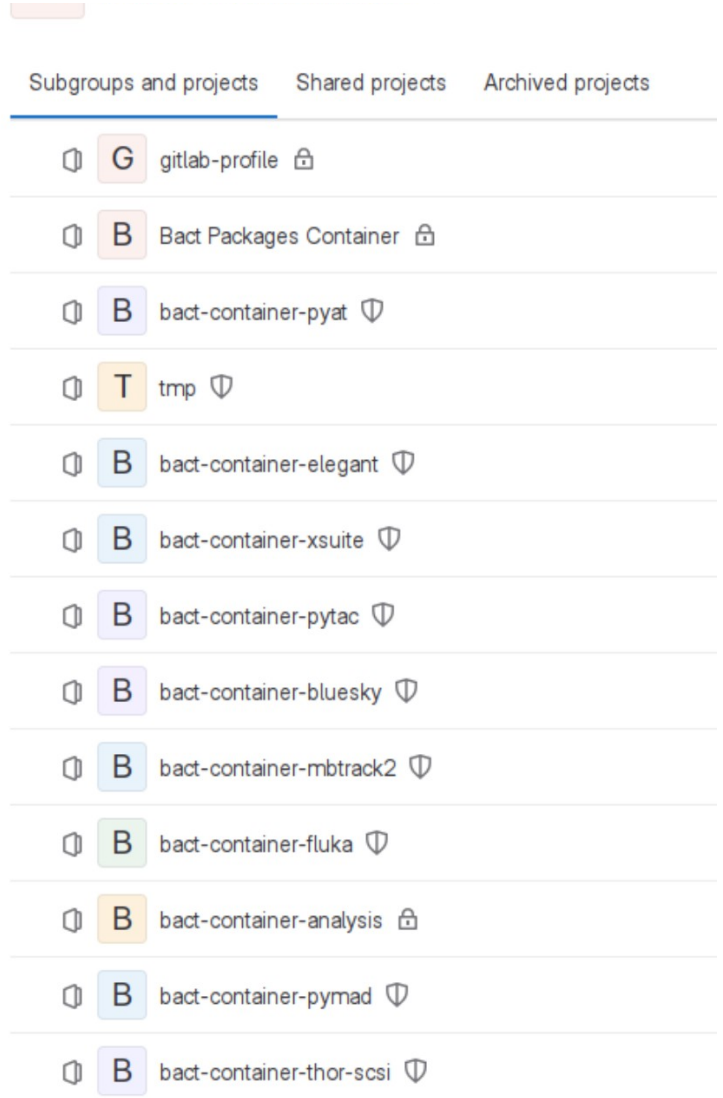
```
Starting iocInit
################################################################################
## EPICS R7.0.8.1-DEV
## Rev. R7.0.8-20-gc77f32b19cc81d309740
## Rev. Date Git: 2024-05-03 04:04:41 +0900
################################################################################
Forward-link uses Channel Access without pointing to PROC field
    Teresia:DT:dt:updates.FLNK => Teresia:DT:dt:im:update:fanout
recGblRecordError: scanAdd: I/O Intr not valid Error (65535,65535) PV: Teresia:D
_main_: dbProcess of 'Teresia:DT:PMUXZR:off'
_main_: dbProcess of 'Teresia:DT:QSPAZR:im:set'
_main_: dbProcess of 'Teresia:DT:par:mode'
_main_: dbProcess of 'Teresia:DT:mux:im:set'
_main_: dbProcess of 'Teresia:DT:mux:out'
_main_: dbProcess of 'Teresia:DT:QSPAZR:rdbk'
_main_: dbProcess of 'Teresia:DT:beam:orbit:found'
_main_: dbProcess of 'Teresia:DT:beam:publish'
iocRun: All initialization complete
epics> pyat orbit calculation starting (find_orbit)
pyat twiss calculation starting (get_optics)
label Teresia:DT:beam:orbit:found = True type(<class 'bool'>)
cbLow: dbProcess of Active 'Teresia:DT:beam:orbit:found' with RPRO=0
label Teresia:DT:beam:names
Executing Python code: mux.off(0)
ERROR: triggering calculation needs to be implemented
Executing Python code: publish(what='lattice')
Need to implement publishing lattice?
Executing Python code: pydev.iointr('Teresia:DT:beam:orbit:found')
epics>
```

CONTAINERS

- We try to establish a container based eco system for central maintenance and usage at
  - laptop
  - control room
  - HPC
  - Collaborating with partners
- recipes maintained in gitlab
- automatic building and testing via CI/CD
- containers can be access through a registry or download
- very helpful with students

Early phase… usage is ramping up now

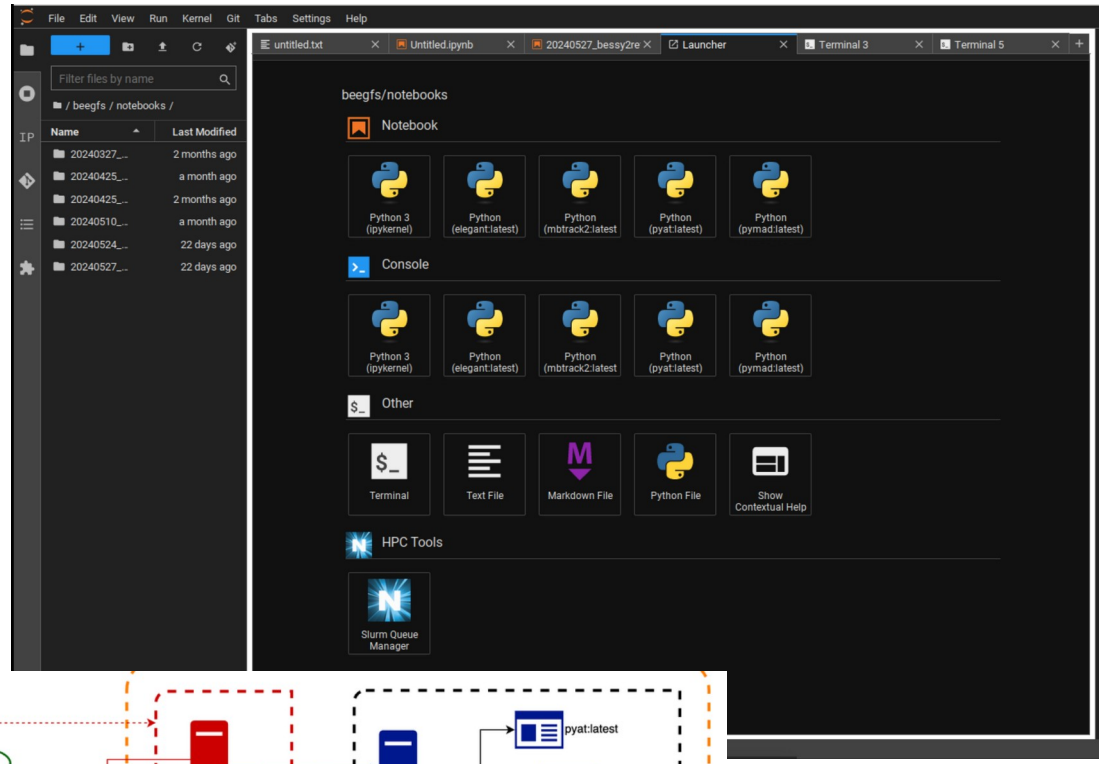


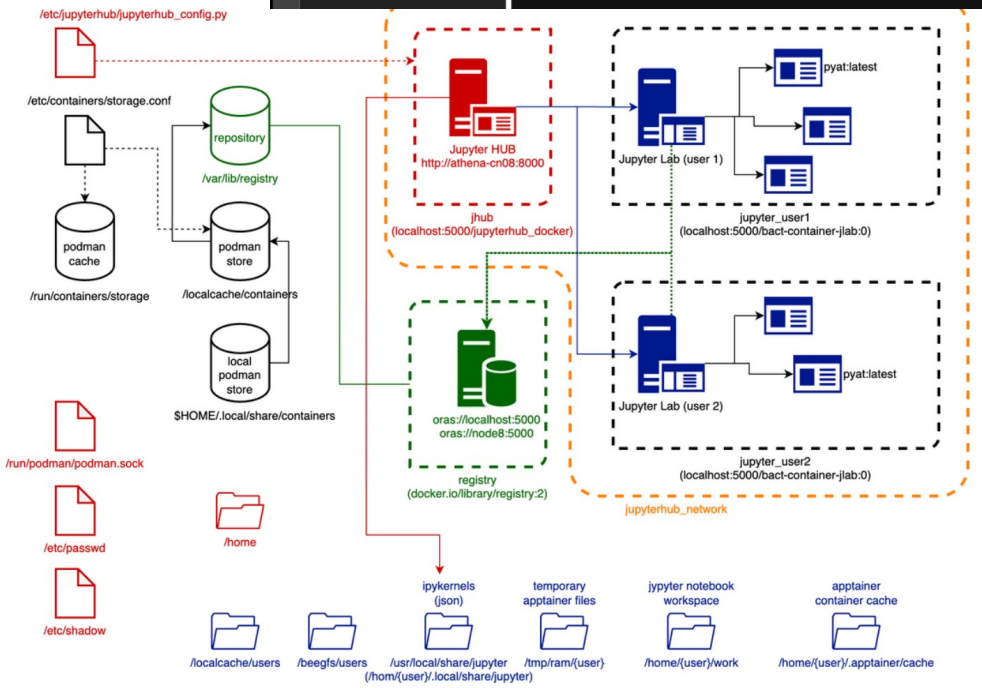


HPC

- 8 nodes
  total: 1536 cores, 3072 threads, 8TB RAM
- 1 x interactive + 7 x Slurm
- file system BeeGFS
- devoted to storage ring physics
- quite some backlash through cyber attack
  (fully self setup and maintained)

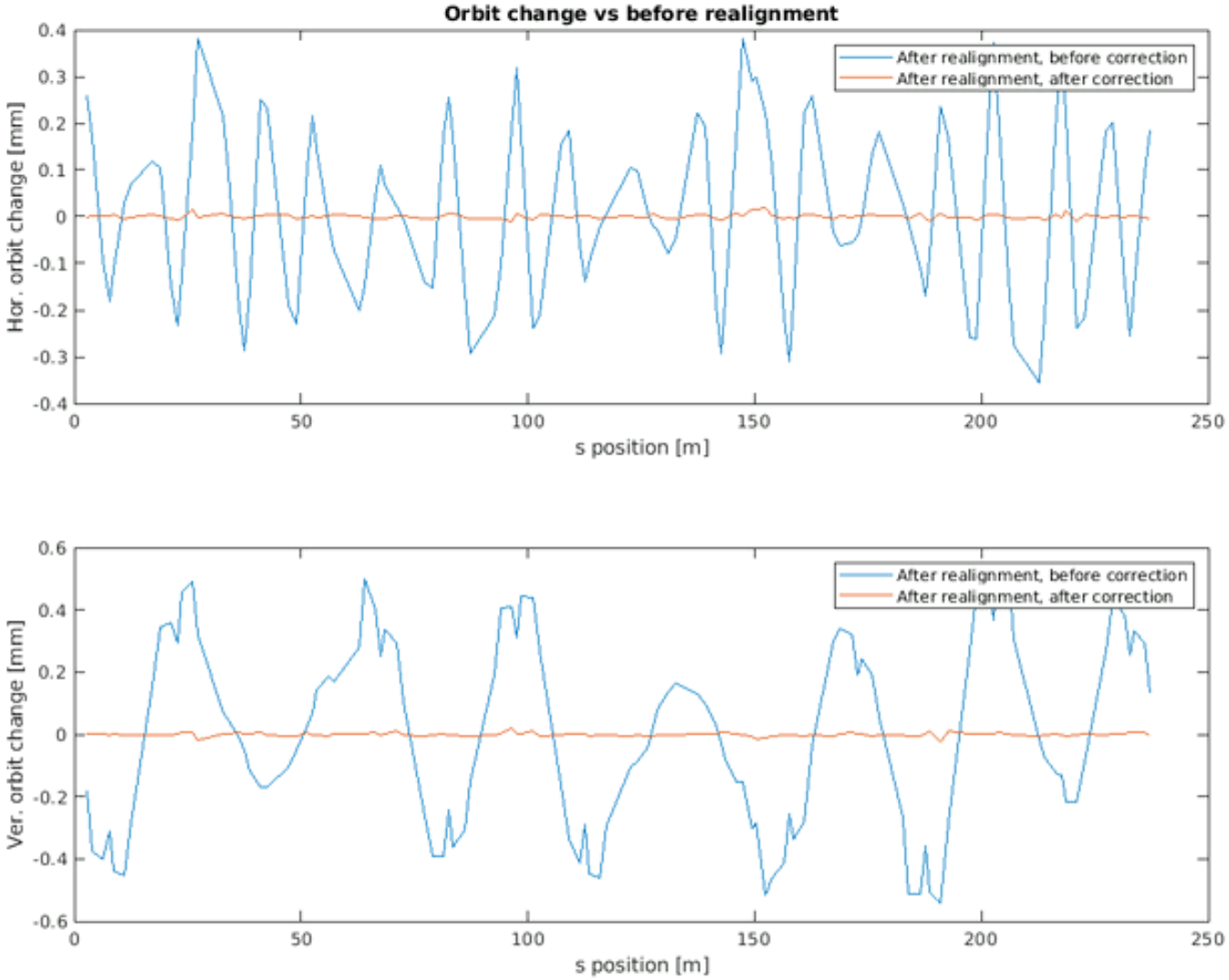
Friendly users are already getting used to lots of resources





BESSY III

- preparing at BESSY II, e.g.
- moving dipole by ~300µrad roll and 600µrad pitch cross checking with beam and pyAT model
- sufficient model for the flawed machine
- benchmark real simulated commissioning at BESSY II (not accelerator physics robustness analysis)



FUTURE

- end of the year we will have access to TbT data → new set of data & tools required
- use of more sustainable code, i.e. standardized and maintained by a larger community of multiple machine
  → participate, contribute and deploy to new middle layer effort
- “physics ready data”, data models, database
- fire up the use of the digital twin
- connect / align the tool stack with storage rings community
- trying to attract the interest of machine learning people

We do not want do drive island projects / solutions.
We want to share what we develop.

CONCLUSION

- operational tools are the backbone of high performance and reliability user operation and mandatory for more handling complex machines and operational states
- team moved to python, moving to pyAT, keep other codes supported as crosscheck
- difficult transition from “physicists demo code” to a real operations tool
- BESSY II and MLS are running fine, but…
  - deploy state of the art
  - sustainable codes are an issue
  - a lot of potential in the transition from bare-metal to a higher level
- BESSY III … is a long way to go, but we try to find the path an prepare at the existing facilities

We can and want to contribute!
We have excellent machine access (2!)
and a young team of coding physicists + software engineer

THE EXPECTATION / DREAM / ILLUSION