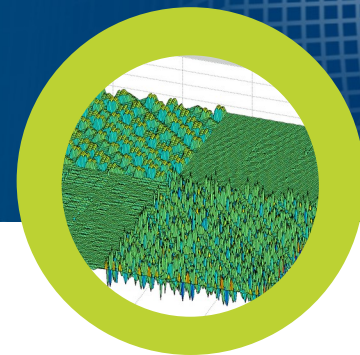


# OPERATIONAL TOOLS AND ALGORITHMS AT BESSY II AND MLS

19.06.2024, T. Birke, W. Sulaiman Khail,  
T. Olsson, M. Ries, A. Schälicke, P. Schnizer et al.





## 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

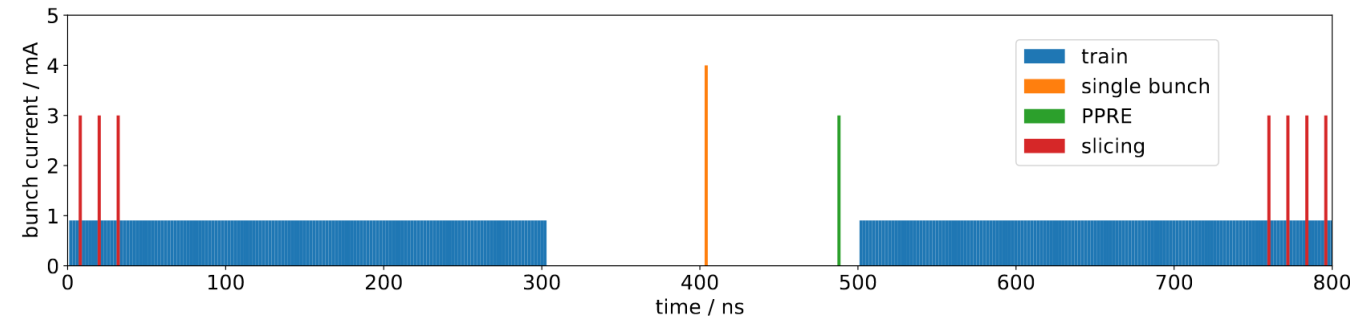
single bunch, few bunch

timing / dynamics, pulse length ~ 100ps

low-alpha

coherent THz radiation  
(timing) 2ps

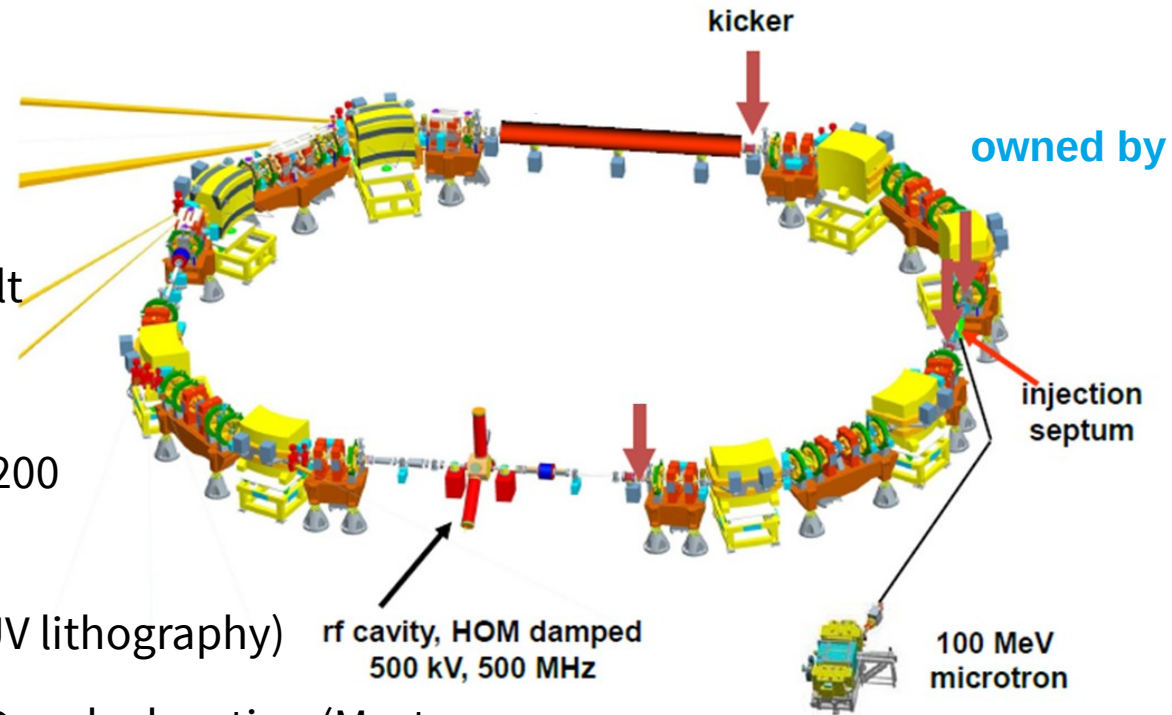
EPICS facility



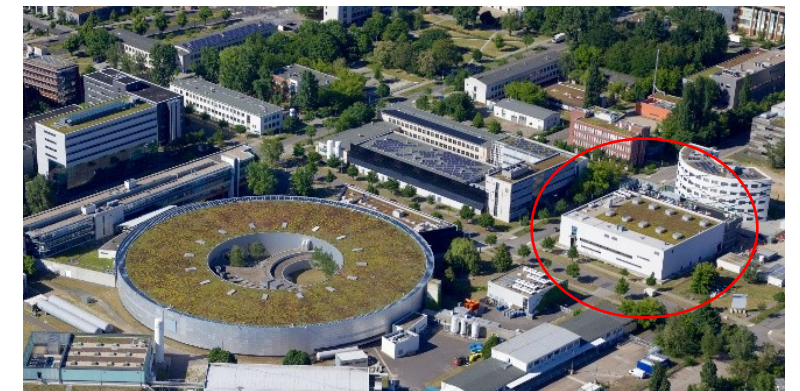


# METROLOGY LIGHT SOURCE

- Physikalisch-Technische Bundesanstalt
- user operation since 2008
- $E / \text{MeV} = 50 \dots 630$ ;  $C / \text{m} = 48$ ;  $I / \text{mA} = 200$   
design emittance / nradm  $\sim 100$
- 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

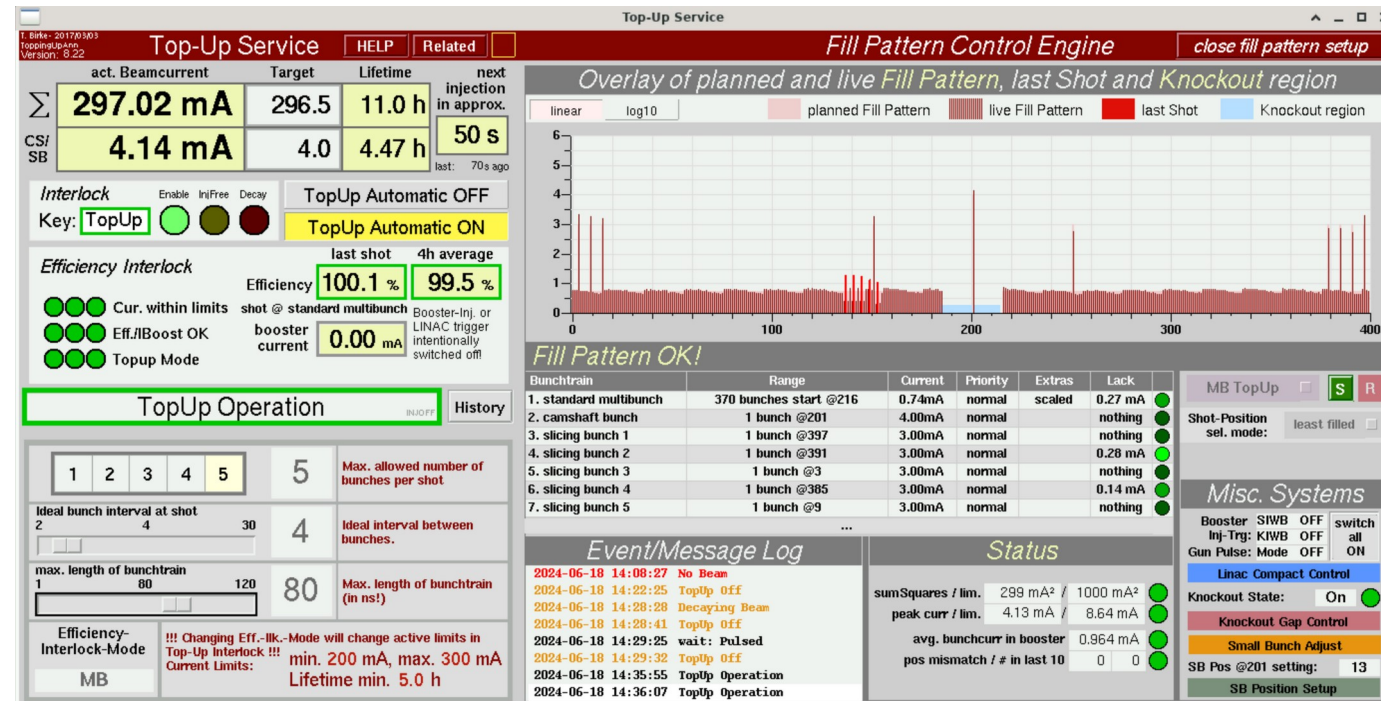


ASML



# 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**

**MLS Operation Master Control Panel**

opip@opic11cp/2706549  
Version: V4.308 - (rel. 240606-1105)

**Settings**

Mode Injection Energy Ramp **Optics Ramp**

☒ Ramp Optic after E-Ramp if E>105MeV **Machine Comm**

Target Optic to ramp to: 10 % cplg **Standard User**

☒ Run Orbit-Correction after O-Ramp **Low Alpha User**

☐ Run RF-Freq.-Ctrl. after O-Ramp **Low Emittance**

☒ Switch on NoiseFF after O-Ramp **Neg Alpha**

☐ Switch on IonShkFF after O-Ramp **Islands**

**Highlife**

**Ramp to specified Optic!**

curr. table: /opt/IOC/OpticRamp/StandardUser/629MeV Up E

**Readbacks and Status**

act. Current: 78.121 mA  
act. Lifetime: 17.468 h  
act. Energy: 629.0 MeV  
current Optic: 10 % cplg  
active Ramp: None  
Optic Table Set: Standard User  
Injection/Trigger: off  
Injection: disabled  
U125 gap&state: 76.859 mm  
TuneFF-TblSet: StandardUser

Waiting for min. current (-5mA)

**Commands**

**Active!** Deactivate

**History** — Graph Save/Mail Log & Emergency

07:16:34 checking existence of Optics Ramp tables  
07:16:34 switching Optics tables to 'Standard User'  
07:16:34 ramp Optics to Start Optics (100 % cplg)  
07:16:34 RF external phase modulation OFF  
07:16:34 loading optics ramp tables  
07:16:34 preparing to ramp Optics  
07:16:34 Approach O-Ramp (100% cplg)  
07:16:45 Ramp Optics  
07:16:45 ramp Optics to Target Optics (10 % cplg)  
07:17:05 switched OpCheck to "Standard User"  
07:17:05 switching scanning of low prio PVs ON  
07:17:06 done.  
07:17:07 U125 returned and unlocked  
07:17:07 Waiting for min. current (-5mA)  
07:17:07 next optics is "Standard User"  
07:17:07 activating Orbit Correction  
07:17:07 activating NoiseFF  
07:17:07 sequence finished  
07:20:07 switching off microtron  
07:20:13 Microtron is off now

# 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 Phoebe S&R in the future

Save/Restore Version: 4.0

Execute Area-Selection Options Help

**Areas to save/restore**

Injection-Line/ALL  
Booster/ALL  
Transferline/ALL  
Storage Ring/ALL  
Insertion Devices/ALL  
Diagnostics/ALL  
TopUp Settings

User: opi  
Date: 2024-06-18  
Time: 16:31:23  
Remarks and Comment (mandatory):  
Optics: Standard Pattern: Multi Bunch  
So vor MC, ID auf

**Save**

**Reference Files** available Snapshots View/Filter/Compare Remove Restore

#	DATE	TIME	OPTICS	PATTERN	COMMENT
10423	2024-06-03	07:04:42	Standa	Multi	ALL: Mo vor Abschaltung, FOFB off
10424	2024-06-03	14:40:52	Standa	Multi	ALL: Mo. 300mA MB nach Wiedereinschaltung
10425	2024-06-09	20:05:27	Standa	Multi	ALL: So, StdUser vor MC
10426	2024-06-09	20:18:00	Standa	Multi	ALL: So vor MC, ID auf
10427	2024-06-10	12:53:01	Standa	Multi	ALL: Mo. 300mA, 100%
10428	2024-06-10	20:57:23	Standa	Multi	ALL: 300mA, Std User, vor MC
10429	2024-06-11	15:51:52	Standa	Multi	Sto: New reference file for Landau cavity settings
10430	2024-06-17	07:04:39	Standa	Multi	ALL: Mo. vor Abschaltung (nach BeamLoss)
10431	2024-06-17	15:03:33	Standa	Multi	ALL: 300mA, waehrend MC, 99%
10432	2024-06-18	14:05:27	Standa	Multi	ALL: Di vor Zugang UE52 99.5%

show deleted snapshots

**Saved Areas**

Linac/ALL  
Injection-Line/ALL  
Booster/ALL  
Transferline/ALL  
Storage Ring/ALL  
Insertion Devices/ALL  
Diagnostics/ALL  
TopUp Settings

Filters: Month: Jun 2024 Optics: Standard Pattern: Multi Bunch Comment-Filter: Filter Clear

Status: 12 snapshots found



## 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**

/opt/OPI-ctl/BII-Controls-3-14/dl/OPCHECKCC\_Op.edl (on ctl-srv-ng)

Birke (2021-08-26)  
(OpCheckApp) - V5.0

### OpCheck: Main Parameters

act. Mode: **MB Top-Up**

Alarms enabled

☐ OpCheck disabled

☐ I<1mA and (BS locked or PSI off)

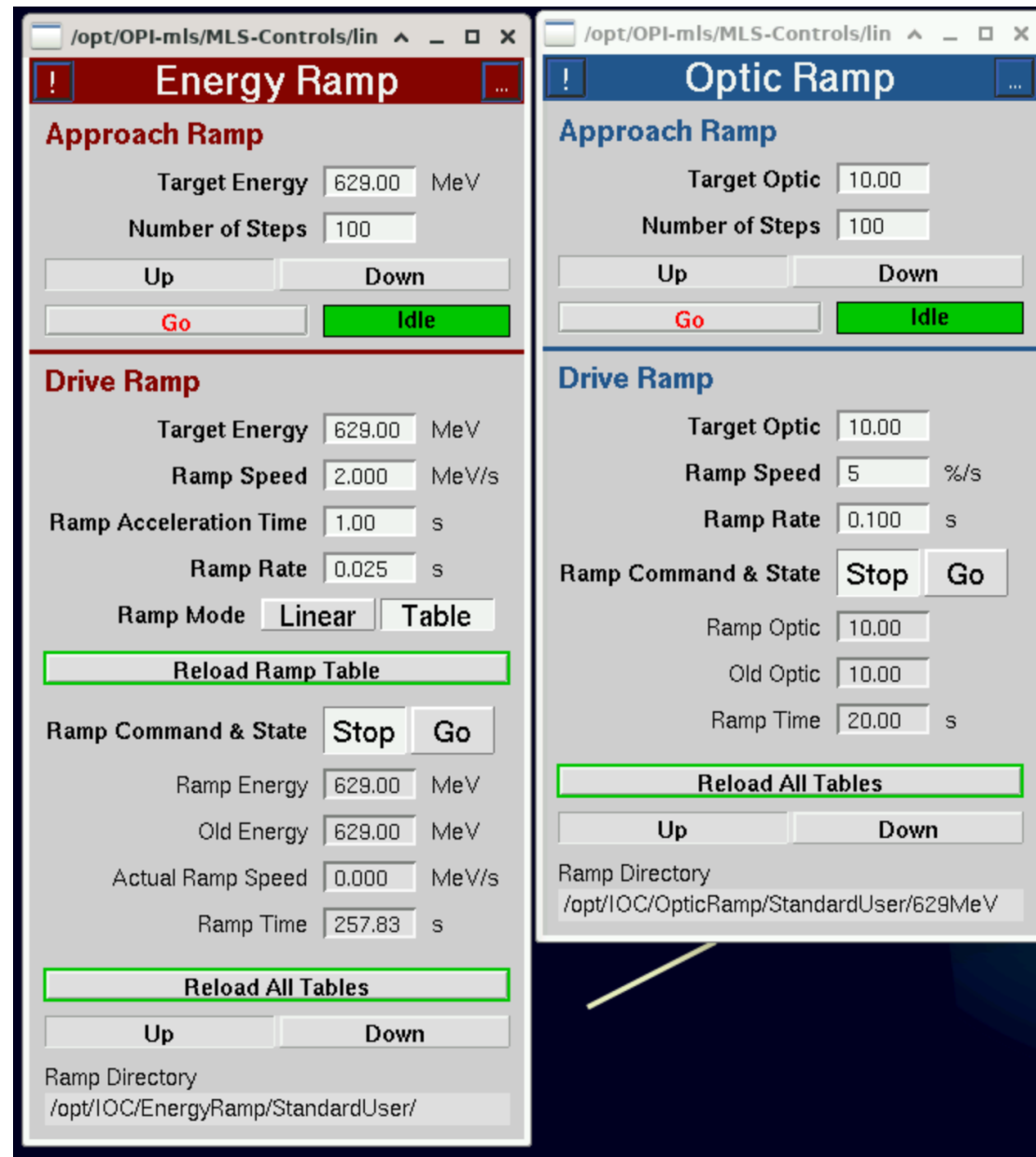
Errors: **2** **RESET**

Parameter	Actual Value	disable	Errors
Current	294.542 mA	<input type="checkbox"/>	0
Lifetime	10.11 h	<input type="checkbox"/>	0
Purity	47620	<input type="checkbox"/>	0
Feedbacks/FeedForwards	FDBK/FFWD OK	<input type="checkbox"/>	0
Special Bunches	Special Bunches OK	<input type="checkbox"/>	1
Beam Motion	Beam Motion OK	<input type="checkbox"/> +18	0
Beam Size	Beam Size OK	<input type="checkbox"/> +4	0
Pulse Shapes	Pulse Shapes OK	<input type="checkbox"/> +118	0
RF Systems	RF OK	<input type="checkbox"/>	0
Waveform Generators	WfGen OK	<input type="checkbox"/> +1	0
Booster Status	Booster OK	<input type="checkbox"/>	0
Transfer Line	OK	<input type="checkbox"/>	0
Transfer Line Beam Position	NO_ALARM	<input type="checkbox"/> +2	0
Injection Status	Enabled	<input type="checkbox"/>	0
Tune	Horizontal	<input type="checkbox"/>	0
	Horizontal Source	<input type="checkbox"/>	0
	Vertical	<input type="checkbox"/>	0
	Vertical Source	<input type="checkbox"/>	0
	Diagnostics	<input type="checkbox"/>	0
TopUp	Operational Mode	<input type="checkbox"/>	0
	Master Status	<input checked="" type="checkbox"/> TopUp Automatic OFF	1
	Interlock	<input type="checkbox"/> inactive	0
ID status	normal IDs	<input type="checkbox"/> all IDs unlocked	0
	CPMU17 Interlock Bridge	<input type="checkbox"/> inactive	0
TopUp	Efficiency	<input type="checkbox"/> 100.0	0
	Average	<input type="checkbox"/> 99.5	0
SR-Kicker Charge Mode	Kicker 1	<input type="checkbox"/> triggered	0
	Kicker 3	<input type="checkbox"/> triggered	0
Beamloss Monitor	in T1 (BAM)	<input type="checkbox"/> 48	0
	in T7 (PSF)	<input type="checkbox"/> 760	0

## 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**

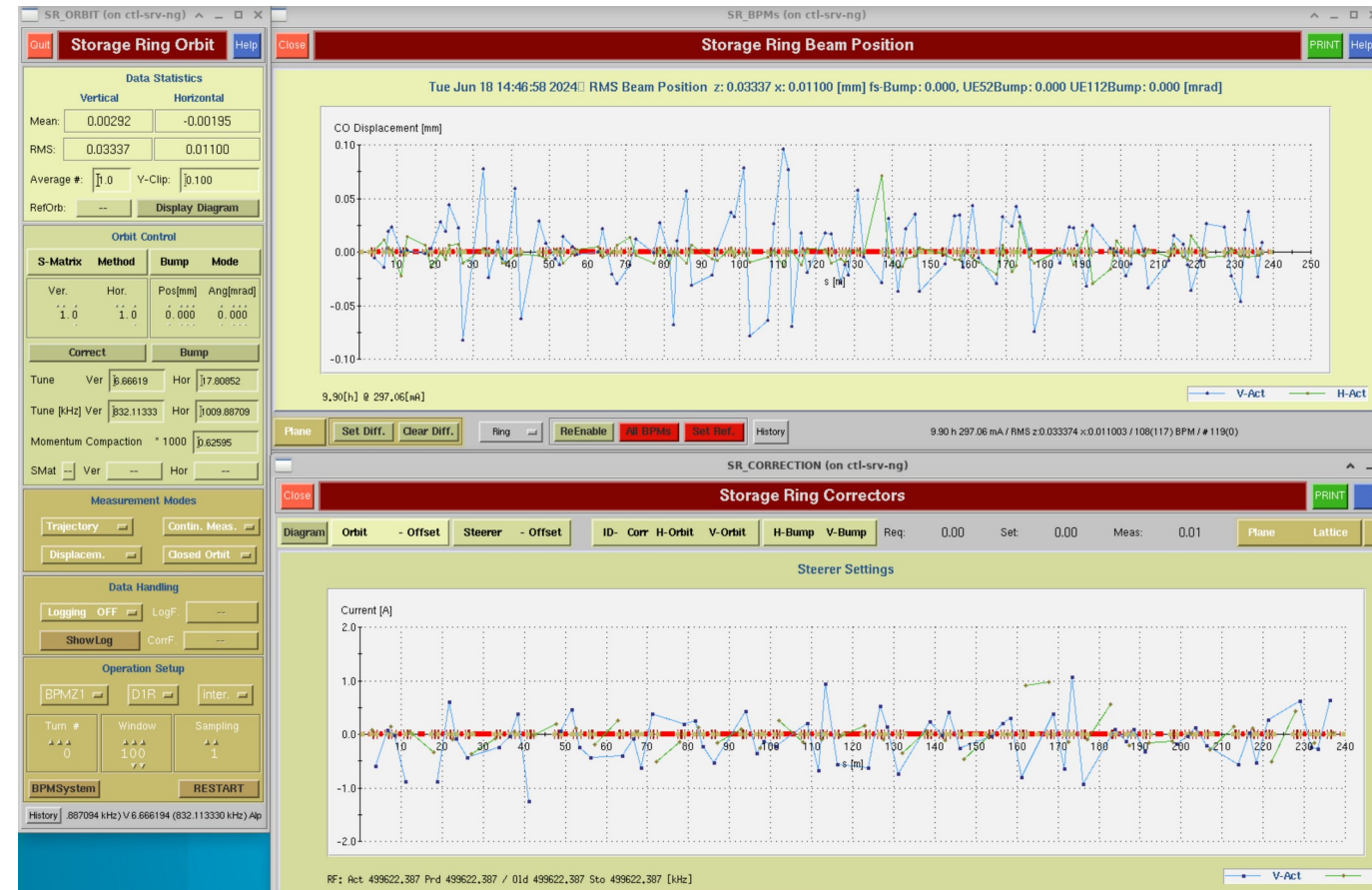




# SLOW ORBIT FEEDBACK

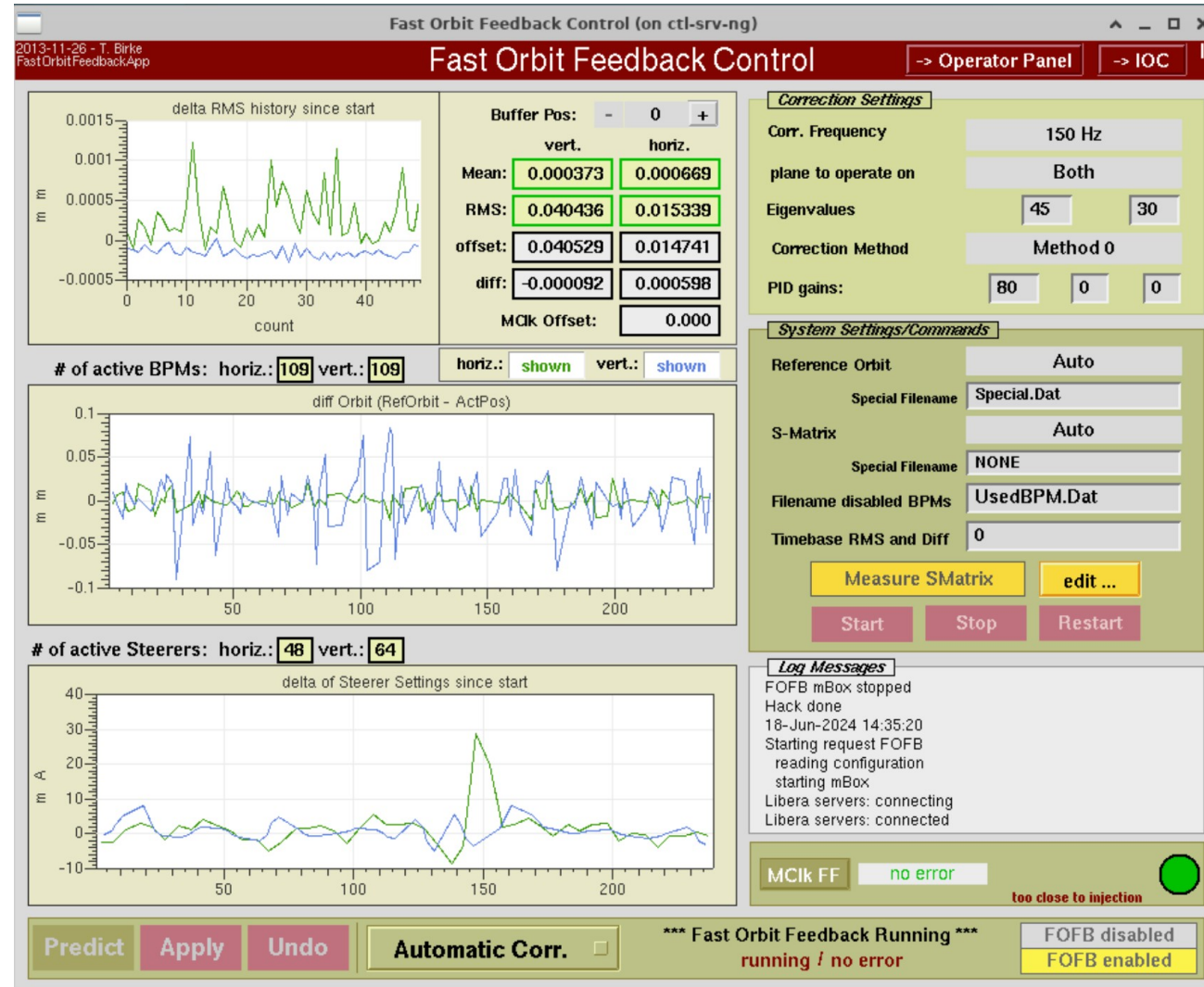
- BESSY II & MLS, self-written, legacy, C++
- slow (1/6 s) orbit correction, visualization & bumps
- lines of code ~20000 orbit, ~37000 mapper (GUI - motif)
- local running application with GUI
- legacy code 32bit

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



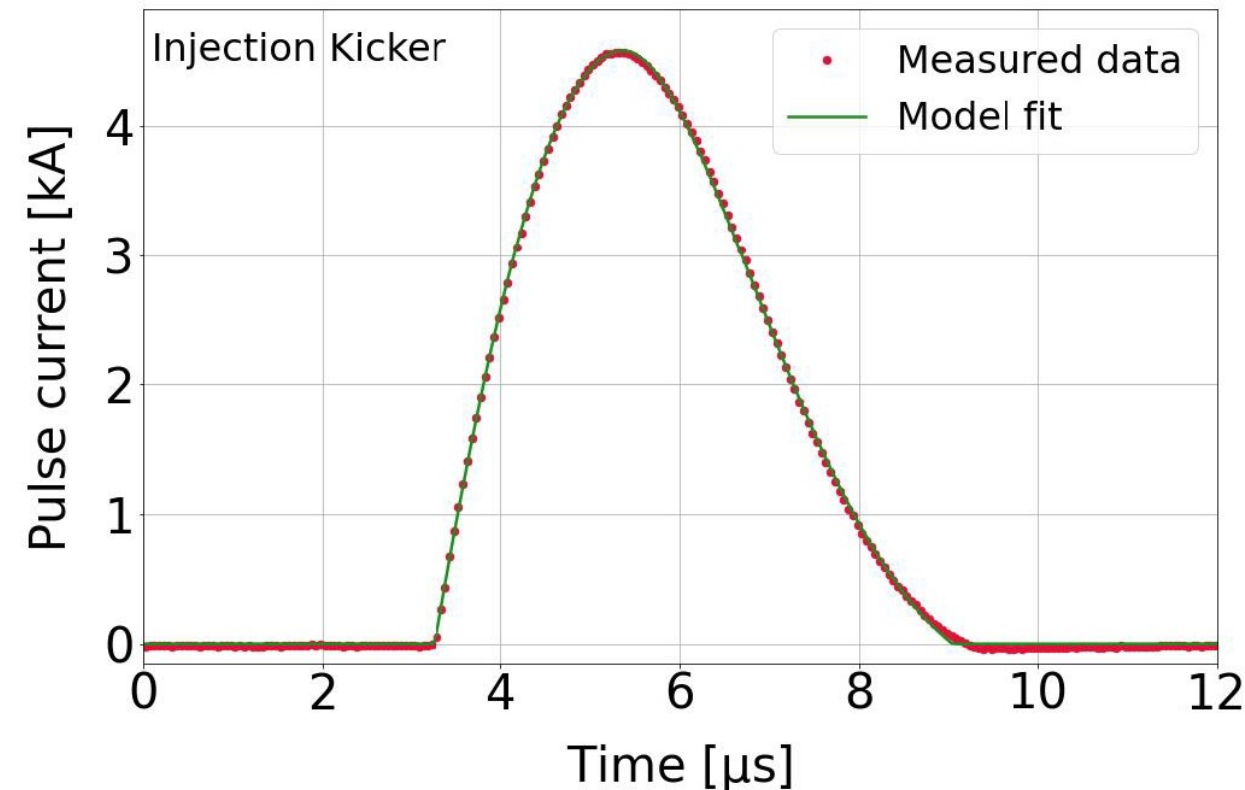


## ADVANCED PULSED ELEMENT ANALYSIS

- 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...)

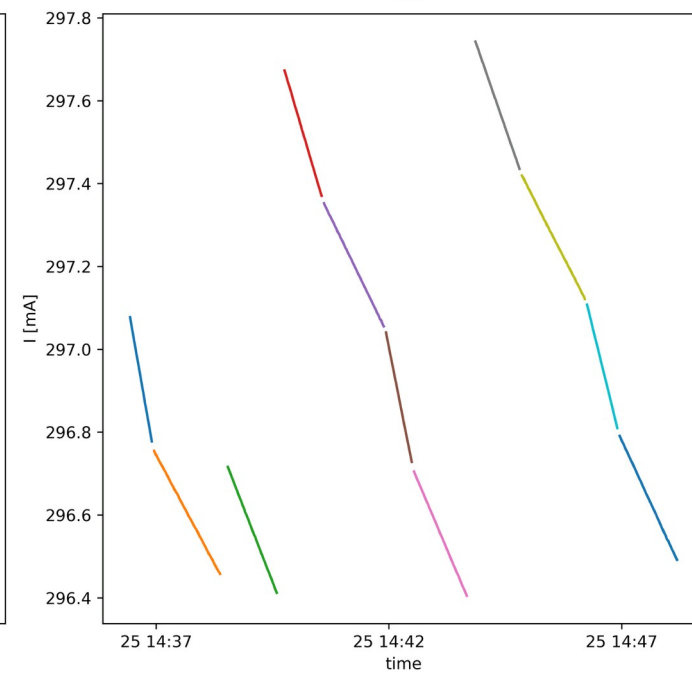
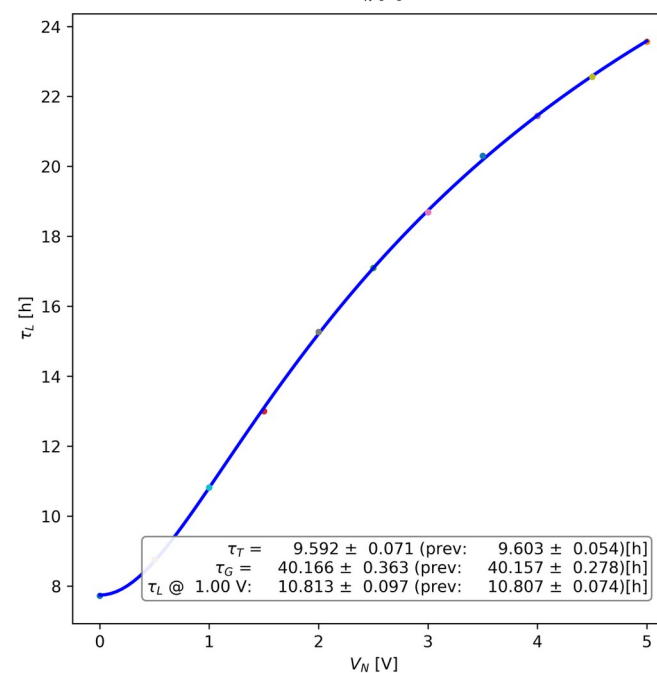
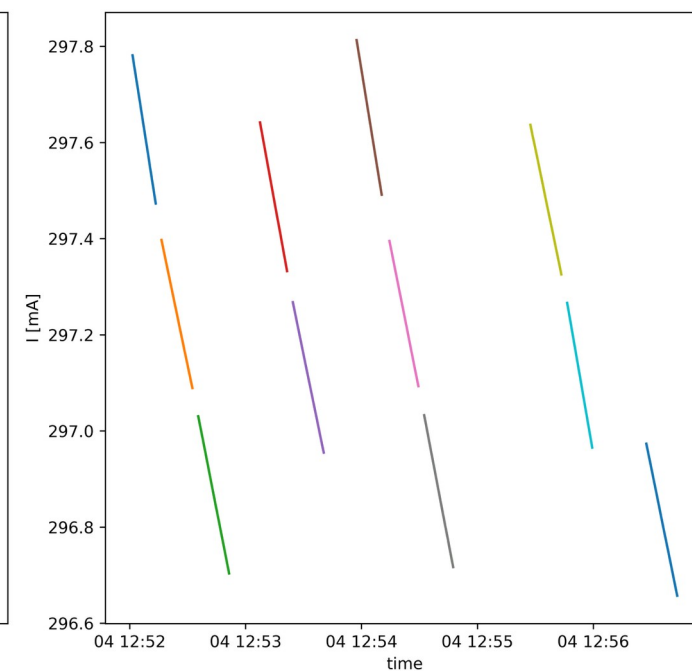
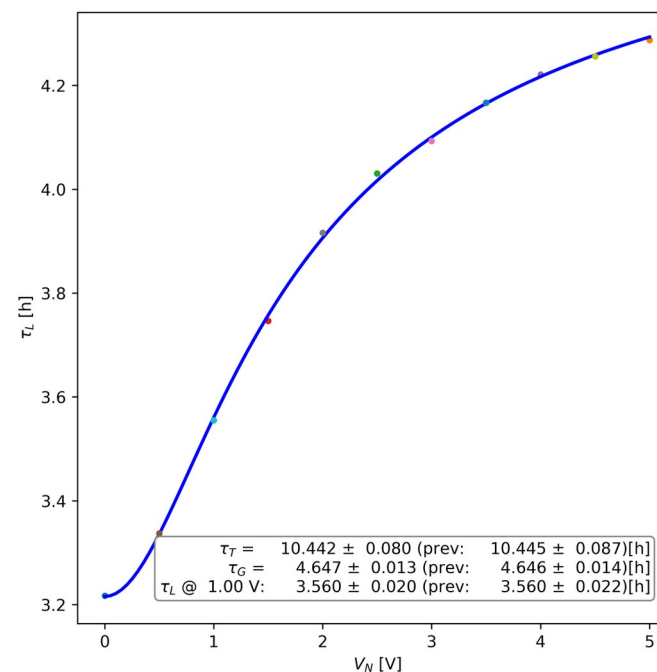
**Permanent monitoring of amplitudes of septum currents in the range is extremely helpful for TopUp with 99% injection efficiency**

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



# LIFETIME MEASUREMENT

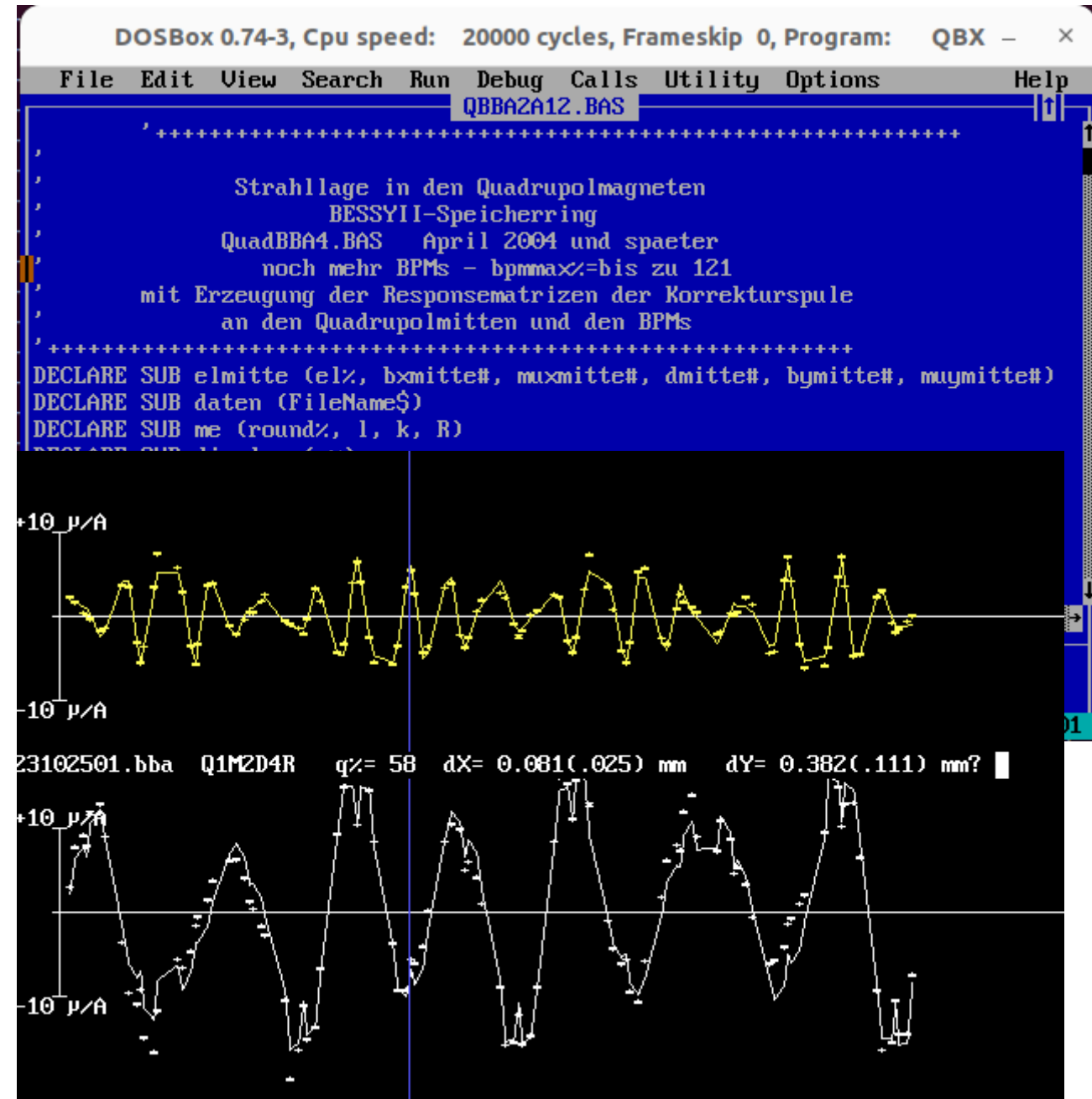
- BESSY II, self-written, maintained, python
- weekly monitoring ratio of Touschek lifetime and gas lifetime
- operator friendly → fully automatized measurement, analysis and documentation (automated ELOG posts)
- local application including GUI



## 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

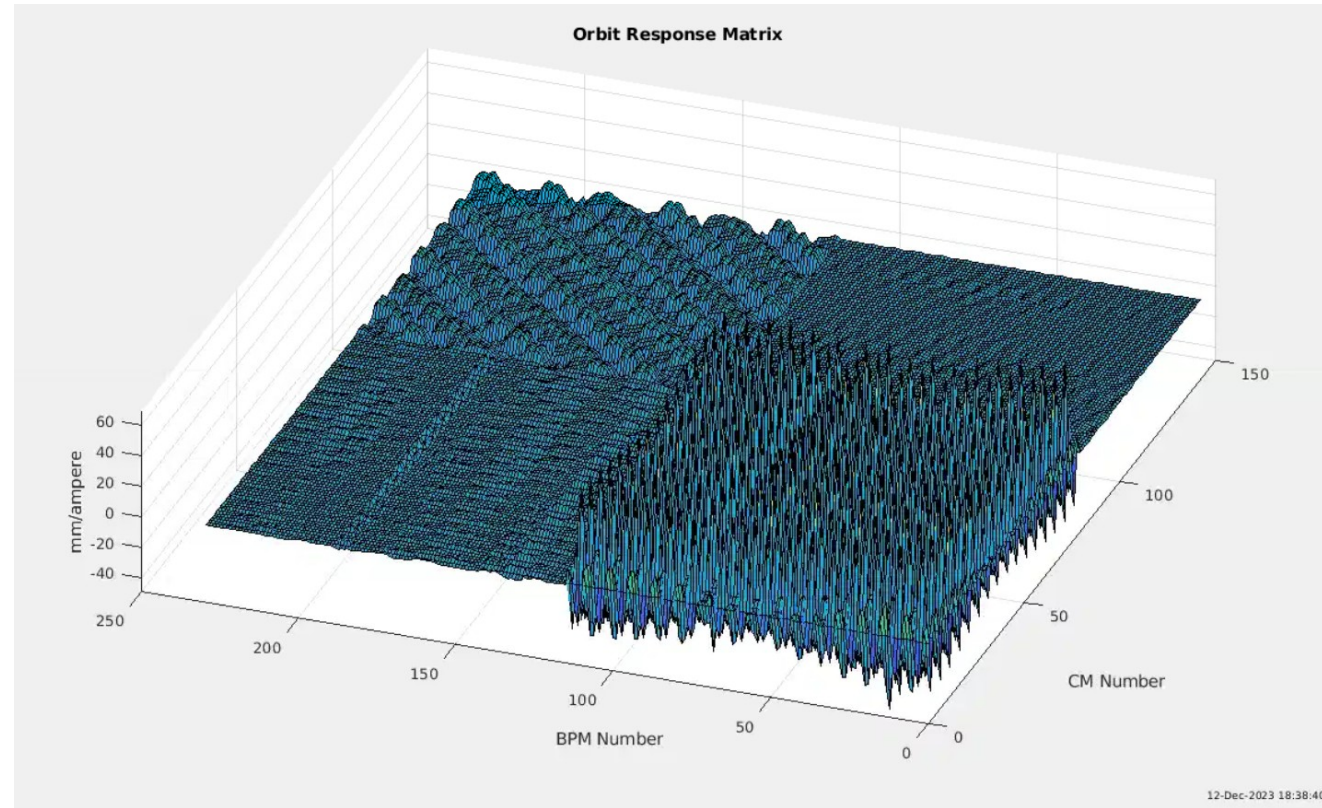
**In the process of being replaced by a modern rewrite and complemented by MML BBA (quadcenter)**





## MML

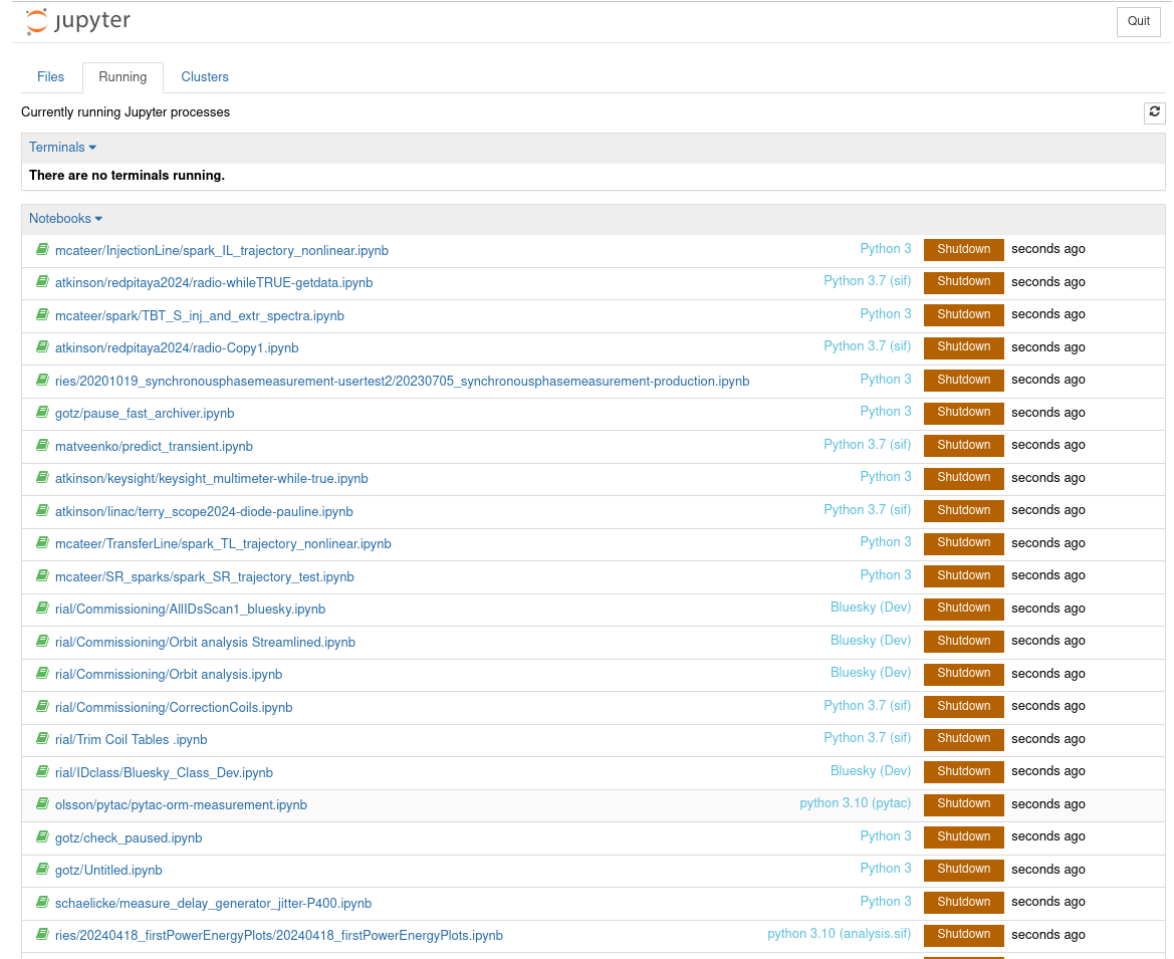
- established at BESSY II and MLS
- around for a decade, but not intensely used, maintained or developed, not part of the production eco system
- since half a year: complete model review, pyAT model input for MML
- extending MML setup and capabilities on both machines to connect to the community for 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



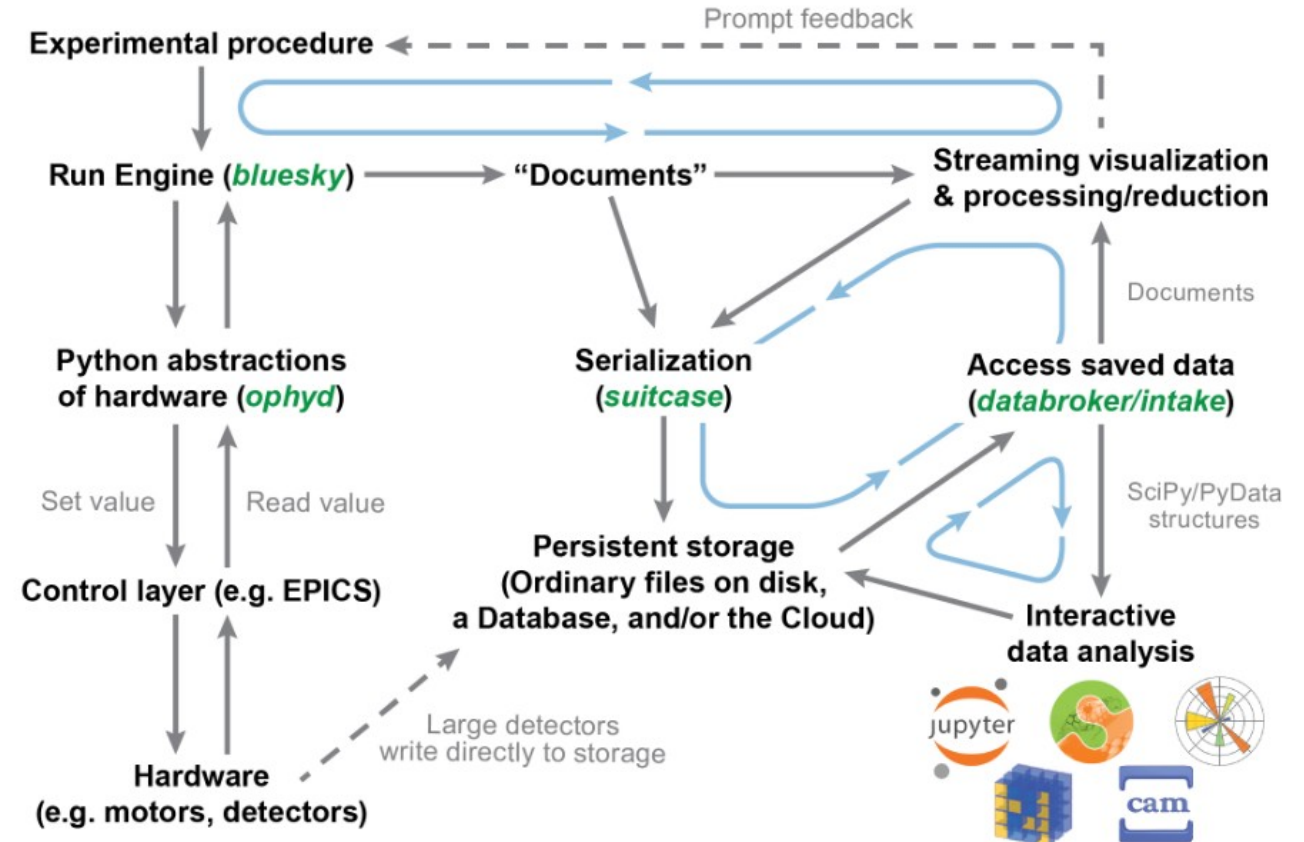
The screenshot shows the JupyterLab interface with the 'Running' tab selected. It displays a list of currently running Jupyter processes. Each row includes a file icon, the notebook name, the kernel name and version, a 'Shutdown' button, and a timestamp 'seconds ago'.

Currently running Jupyter processes				
Terminals ▼				
There are no terminals running.				
Notebooks ▼				
	mcateer/InjectionLine/spark_IL_trajectory_nonlinear.ipynb	Python 3	Shutdown	seconds ago
	atkinson/redpitaya2024/radio-whileTRUE-getdata.ipynb	Python 3.7 (sif)	Shutdown	seconds ago
	mcateer/spark/TBT_S_inj_and_extr_spectra.ipynb	Python 3	Shutdown	seconds ago
	atkinson/redpitaya2024/radio-Copy1.ipynb	Python 3.7 (sif)	Shutdown	seconds ago
	ries/20201019_synchronousphasemeasurement-userstest2/20230705_synchronousphasemeasurement-production.ipynb	Python 3	Shutdown	seconds ago
	gotz/pause_fast_archiver.ipynb	Python 3	Shutdown	seconds ago
	matveenko/predict_transient.ipynb	Python 3.7 (sif)	Shutdown	seconds ago
	atkinson/keysight/keysight_multimeter-while-true.ipynb	Python 3	Shutdown	seconds ago
	atkinson/linac/terry_scope2024-diode-pauline.ipynb	Python 3.7 (sif)	Shutdown	seconds ago
	mcateer/TransferLine/spark_TL_trajectory_nonlinear.ipynb	Python 3	Shutdown	seconds ago
	mcateer/SR_sparks/spark_SR_trajectory_test.ipynb	Python 3	Shutdown	seconds ago
	rial/Commissioning/AllIDsScan1_bluesky.ipynb	Bluesky (Dev)	Shutdown	seconds ago
	rial/Commissioning/Orbit analysis Streamlined.ipynb	Bluesky (Dev)	Shutdown	seconds ago
	rial/Commissioning/Orbit analysis.ipynb	Bluesky (Dev)	Shutdown	seconds ago
	rial/Commissioning/CorrectionCoils.ipynb	Python 3.7 (sif)	Shutdown	seconds ago
	rial/Trim Coil Tables .ipynb	Python 3.7 (sif)	Shutdown	seconds ago
	rial/IDclass/Bluesky_Class_Dev.ipynb	Bluesky (Dev)	Shutdown	seconds ago
	olsson/pytac/pytac-orm-measurement.ipynb	python 3.10 (pytac)	Shutdown	seconds ago
	gotz/check_paused.ipynb	Python 3	Shutdown	seconds ago
	gotz/Untitled.ipynb	Python 3	Shutdown	seconds ago
	schaelicke/measure_delay_generator_jitter-P400.ipynb	Python 3	Shutdown	seconds ago
	ries/20240418_firstPowerEnergyPlots/20240418_firstPowerEnergyPlots.ipynb	python 3.10 (analysis.sif)	Shutdown	seconds ago

## 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

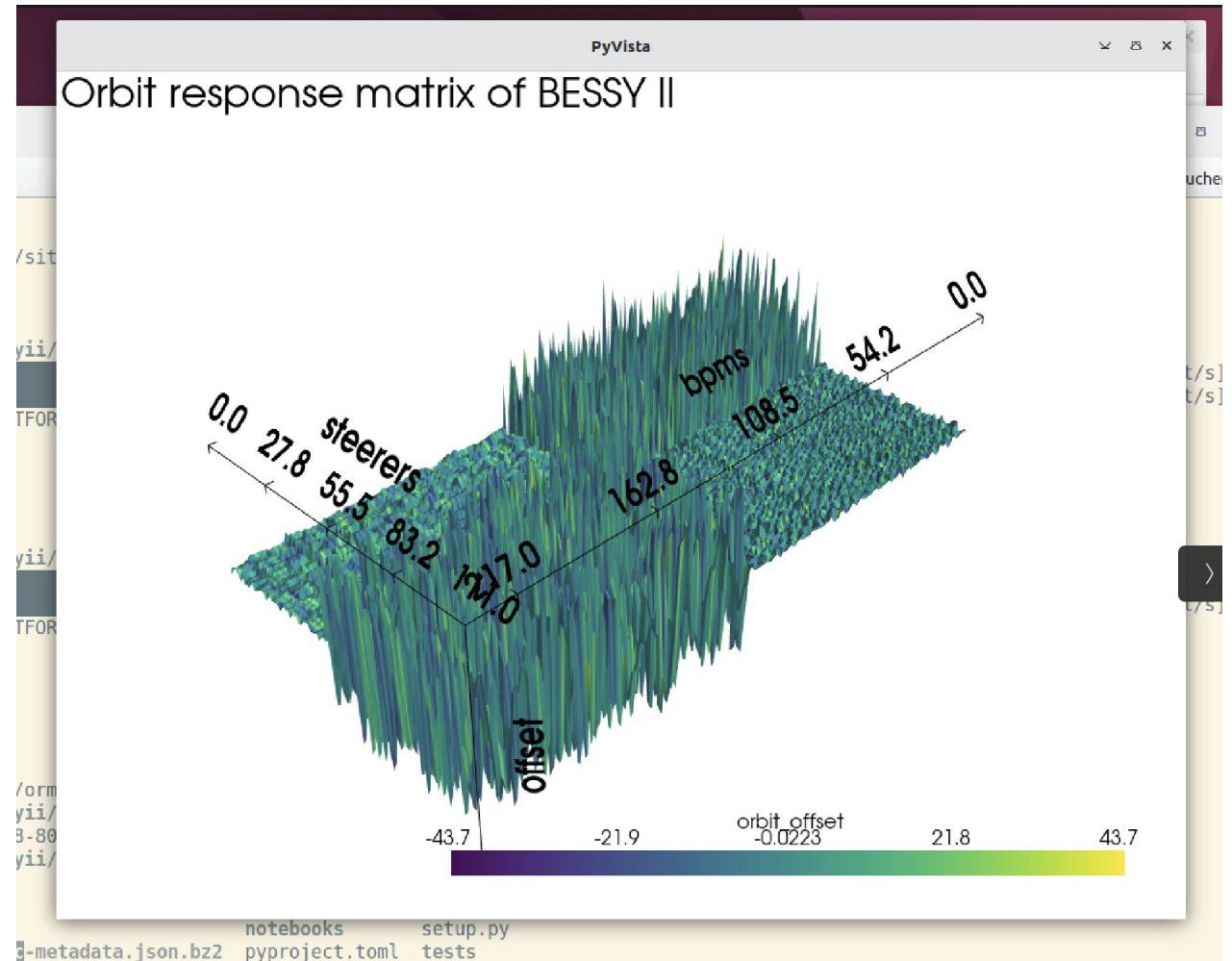




## ORM AND NEW BBA

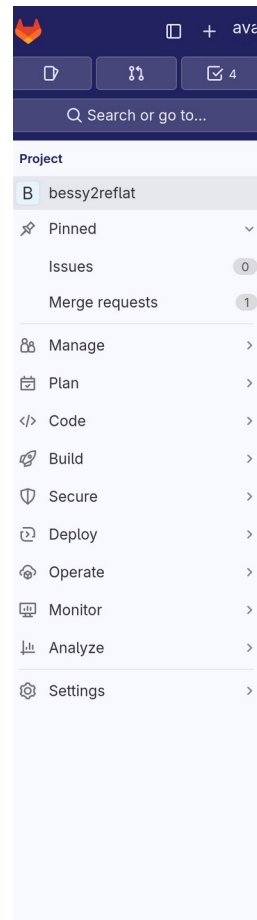
- BESSY II, self-written, development, python
- complete rewrite of the model old model-based BBA
- ophyd + bluesky + database
- runs on digital twin and machine
- in physics review
- Target: production method for BBA at BESSY II & MLS

**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

```

1240 at.Quadrupole('Q4M1D1R',0.5,k=k4d1),\
1241 at.Drift('DU_S4M1D1R',0.153),\
1242 at.Sextupole('S4M1D1R',0.16,h=h4d1,Corrector='H',KickAngle=[0,0]),\
1243 at.Drift('DU_BPMZ4D1R',0.07),\
1244 at.Monitor('BPMZ4D1R',Group='BPM'),\
1245 at.Drift('DU_KIK1D1R',0.2295),\
1246 at.Drift('KIK1D1R',0.595),\
1247 at.Drift('DU_BPMZ41D1R',0.1265),\
1248 at.Monitor('BPMZ41D1R',Group='BPM'),\
1249 at.Drift('DU_BPMZ42D1R',0.20939),\
1250 at.Monitor('BPMZ42D1R',Group='BPM'),\
1251 #at.Drift('DU_KIK2D1R',0.13289-0.00639),\
1252 at.Drift('DU_KIK2D1R',0.12011),\
1253 at.Drift('KIK2D1R',0.595),\
1254 at.Drift('DU_FOMZ1D1R',0.3465),\
1255 at.Monitor('FOMZ1D1R'),\
1256 at.Drift('DU_MRING_END',0.514),\
1257 at.Marker('MRING_END'),\
1258 ]
1259
1260 # Ring definition
1261 ring=[D1_seconddhalf, T1, D2, T2, D3, T3, D4, T4, D5, T5, D6, T6, D7, T7, D8, T8, D1_firsthalf]
1262
1263 # Expand ring until list completely flattened
1264 while any(isinstance(x, list) for x in ring):
1265     ring = list(chain.from_iterable(i if isinstance(i, list) else [i] for i in ring))
1266
1267 # Build the lattice
1268 ring = at.Lattice(ring,name='BESSY II',energy=energy)
1269
1270 # Turn cavity and radiation on
1271 ring.enable_6d()
1272
1273 # Set cavpts to point to main cavities
1274 ring.cavpts = ring.get_uint32_index('CAV*')
1275
1276 # Set only main cavity phases
1277 ring.set_cavity_phase(cavpts=ring.cavpts)
1278
1279 return ring
1280
1281 if __name__ == '__main__':
1282     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**

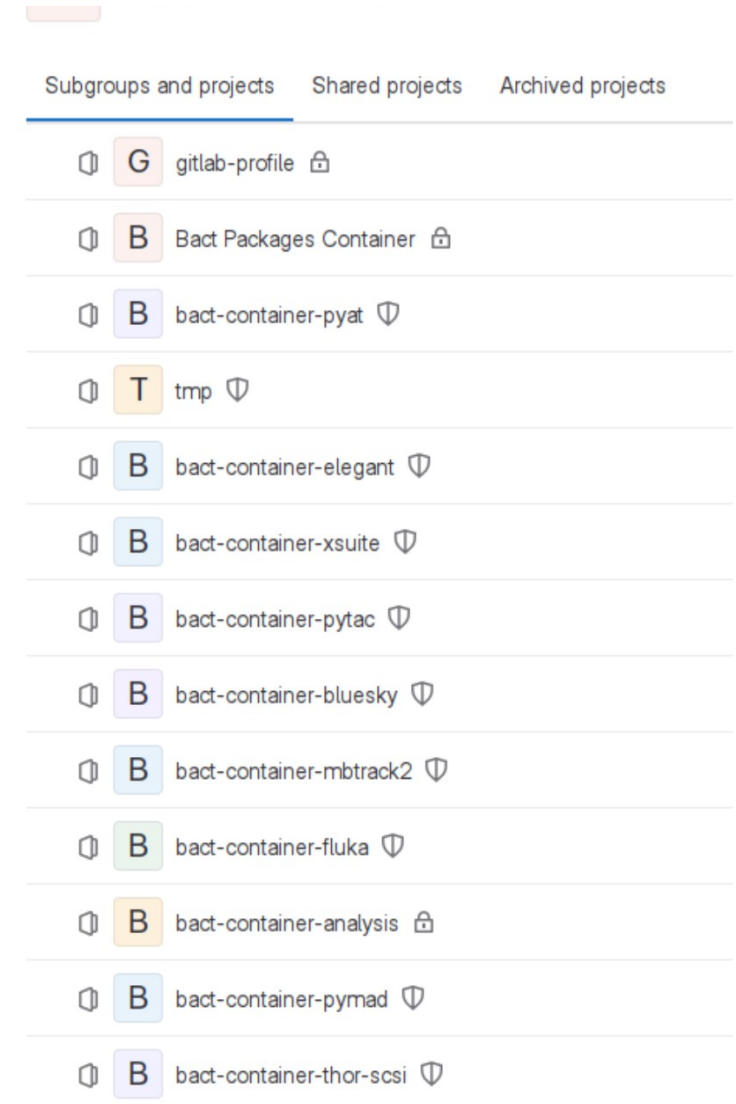
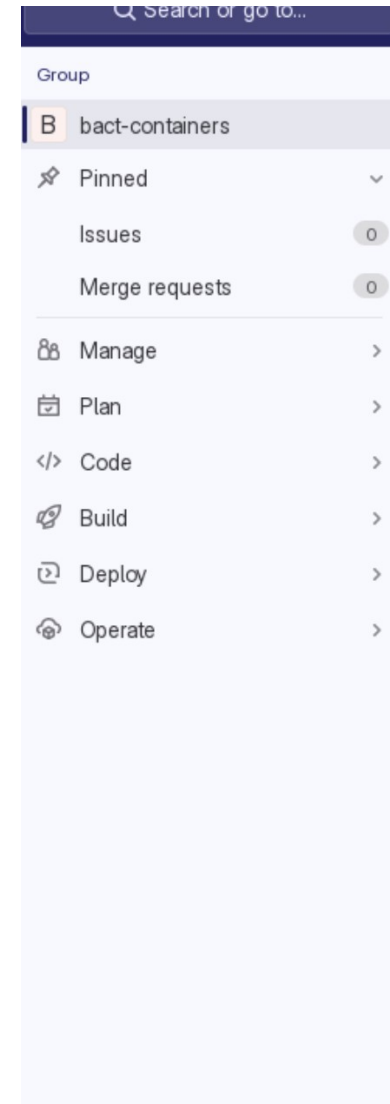
```
Starting iocInit
#####
## EPICS R7.0.8.1-DEV
## Rev. R7.0.8-20-gc77f32b19cc81d309740
## Rev. Date Git: 2024-05-03 04:04:41 +0900
#####
Forward-link uses Channel Access without pointing to PROC field
    Teresa:DT:dt:updates.FLNK => Teresa:DT:dt:im:update:fanout
recGblRecordError: scanAdd: I/O Intr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

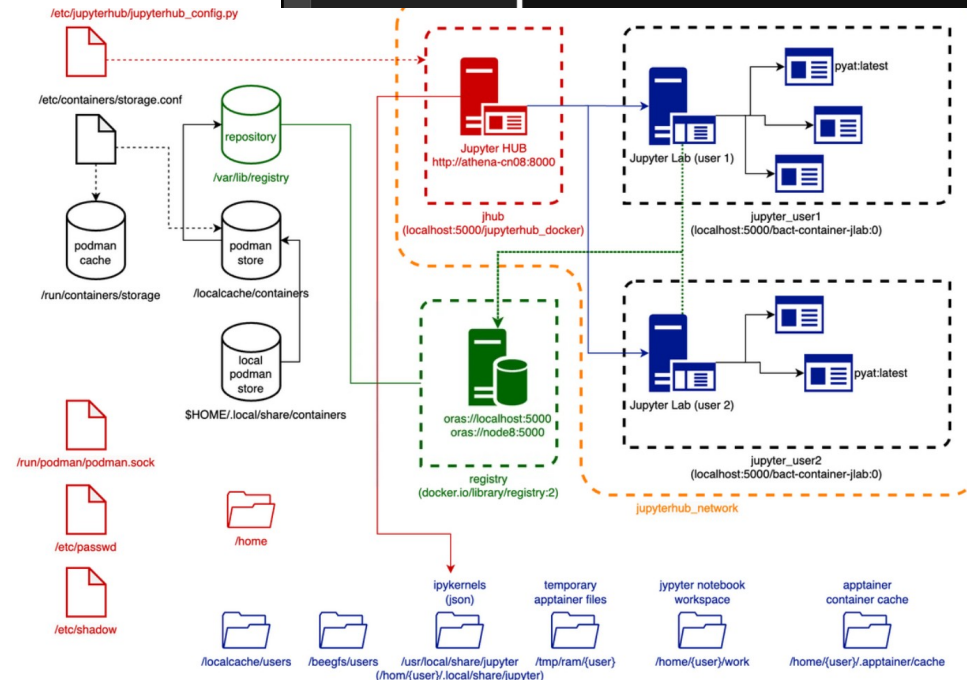
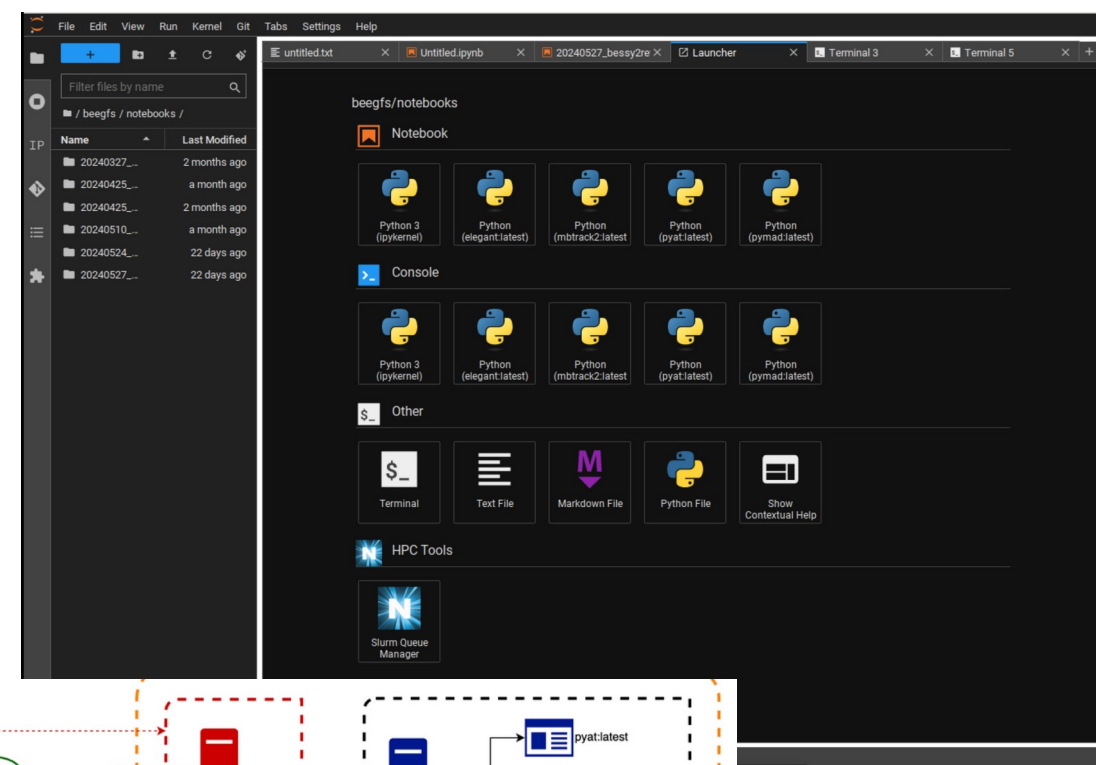
**Early phase... usage is ramping up now**



# HPC

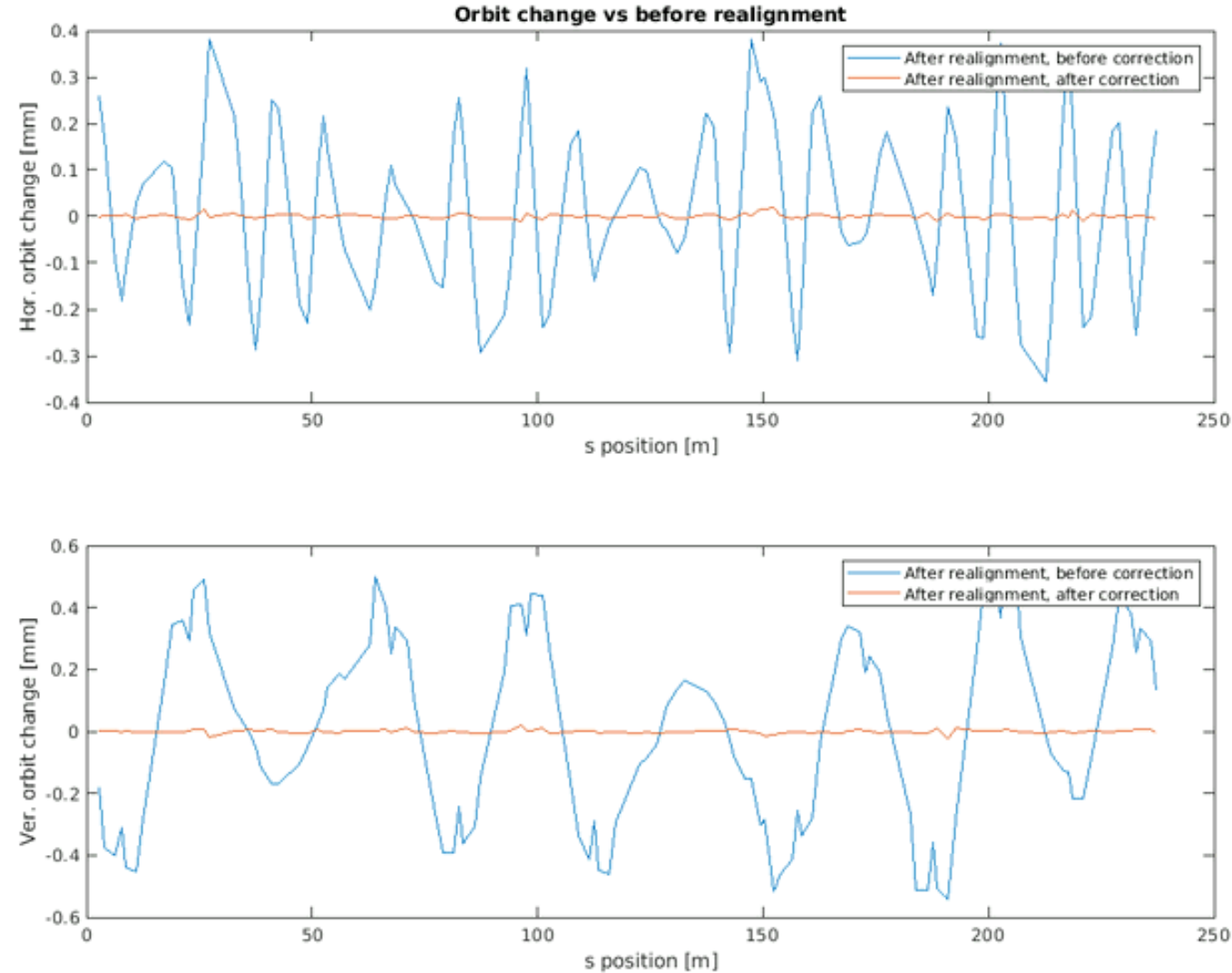
- 8 nodes  
total: 1536 cores, 3072 threads, 8TB RAM
- 1 x interactive + 7 x Slurm
- file system BeeGFS
- devoted to storage ring physics
- quite some backlash through cyber attack  
(fully self setup and maintained)

**Friendly users are already getting used to lots of resources**



## BESSY III

- preparing at BESSY II, e.g.
- moving dipole by  $\sim 300\mu\text{rad}$  roll and  $600\mu\text{rad}$  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 to 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 and 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

