HELMHOLTZ ZENTRUM BERLIN
für Materialien und Energie

Automated Operation of the Metrology Light Source Storage Ring

Thomas Birke

based on work of
T. Birke, M. Abo-Bakr, D. Engel, J. Feikes, B. Franksen, M. v. Hartrott, G. Wüstefeld, ...

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What is the Metrology Light Source (MLS)?

- Low energy e^- storage ring
- Metrology and technological developments in UV/XUV as well as IR and THz
- Optimized for generation of coherent SR in FIR/THz
- Owner:
  Physikalisch-Technische Bundesanstalt (PTB)
  German national metrology institute
- Built according to PTB specifications and operated by **BESSY** which is now part of the new **Helmholtz-Zentrum Berlin für Materialien und Energie GmbH**
- In regular user operation since April 2008

Machine and Operating Parameters	
Circumference	48 m
Revolution Time	160 ns
Injection Energy	105 MeV
Operational Energy	105 – 629 MeV
Beam Current	1 pA – 200 mA
Values for momentum compaction factor α	10^{-4} – $3x10^{-2}$
Insertion Device	Electromagnetic Undulator 23 x 180mm

Operating the Metrology Light Source

- Wide range of operating modes and parameter settings
  - Current: **1 pA** (a single electron) up to **200 mA**
  - Energy: **105 MeV – 629 MeV**
  - Momentum compaction factor α: varies by factor of **~1000**
- Electromagnetic Undulator
  - strong **non-linear fields enforce compensation** with correction coils using fully automatic **feed-forward system** – otherwise impossible to accumulate and store beam
- Injection setup differs from operation setup
  - Orbit bump
  - Asymmetric sextupole settings
  - RF frequency modified

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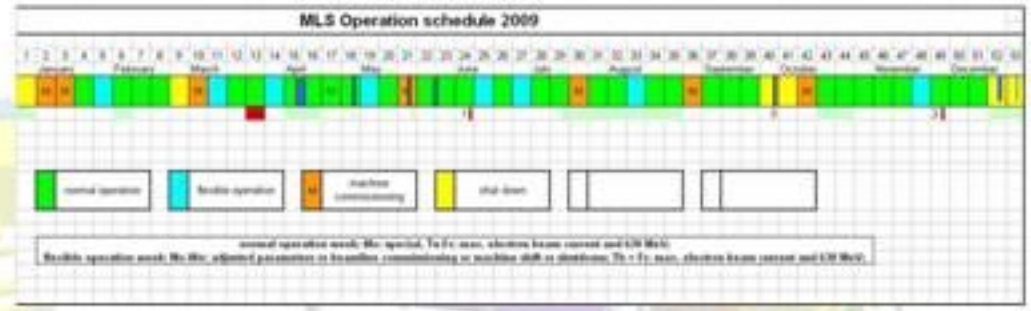
Operating the Metrology Light Source



- Specialties require complex procedures
- Setup changes often according to user demands
  - Even **on short notice**
- **Energy Ramp** before and after injection with minimum loss of beam
  - **Special procedure**
  - **also used as degaussing cycle**
    But: **Magnets not driven into full saturation**
    → Machine performance is very sensitive to magnet-setting-errors

- **Optics Change** program to change momentum compaction factor
  - **Another special procedure** (similar to Energy Ramp)

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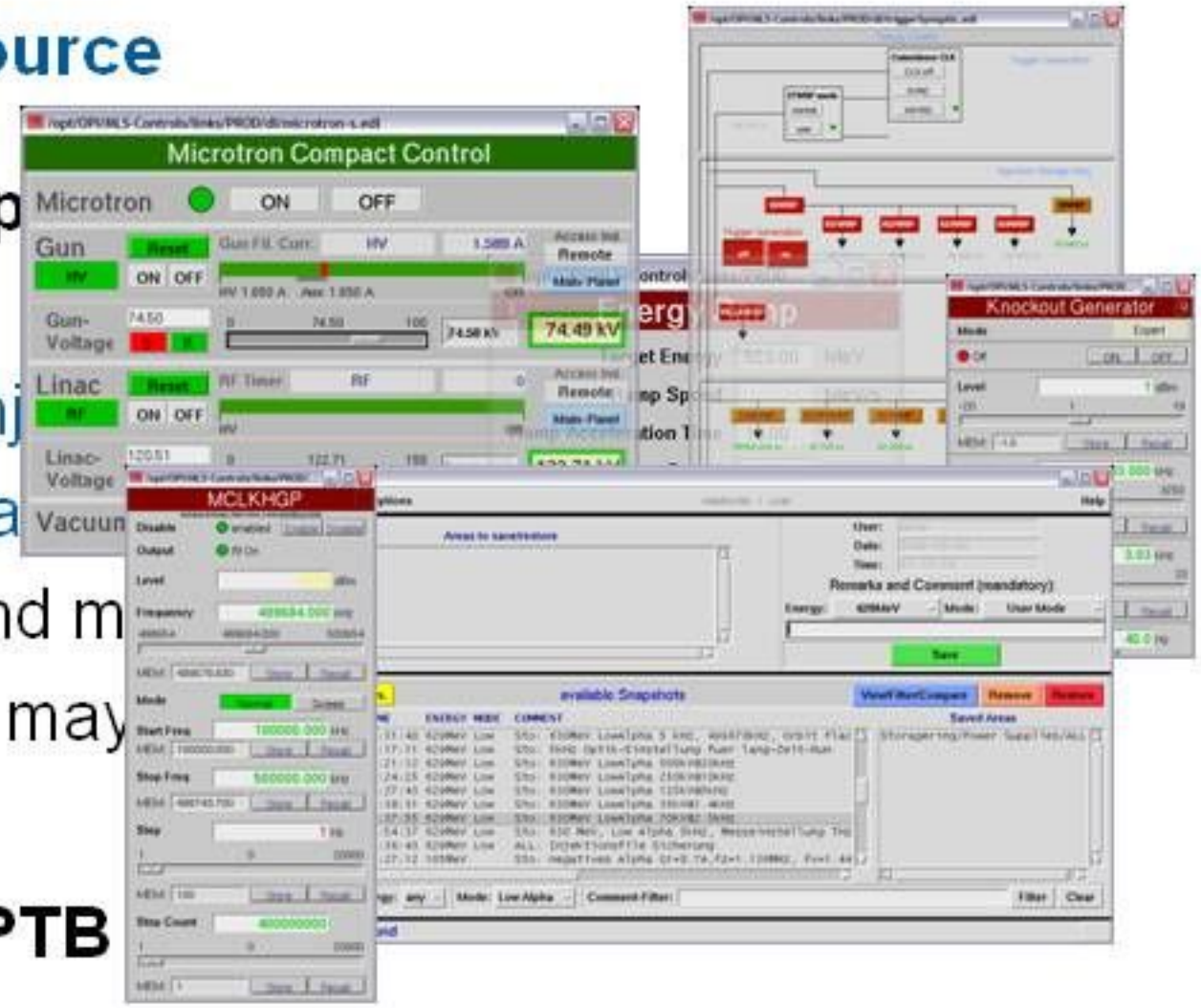
Operating the Metrology Light Source

- Several tasks to be performed by **op**
  - Inject up to desired current
  - Ramp energy – before and after inj
  - Change optics (momentum compa
- All tasks require **several actions** and m
- Any **error** (esp. in magnet settings) may
  performance
- Operated by **BESSY/HZB** staff for **PTB**
  - Paid customer service
  - Deliver **high operational reliability** with maximum transparency and minimum personnel effort
- **High degree of automation required!**



Software System – Status at the Beginning

- Several localized sub-tasks already realized in separate applications
  - Energy Ramp, Optics Change (Momentum Compaction Factor)
  - Optimizing microtron output
  - Orbit Correction, RF Master Clock Controller, ID-controls…
- ***What*** action to perform ***how*** and ***when***? – Organized by operator
  - Expertise is in the heads – sometimes even documented
  - All signals needed to decide what to do and when are available in control system (**EPICS** – Experimental Physics and Industrial Control System)
- Decided to develop one **central application** to coordinate necessary tasks
  - ***Operation Master***
  - Software model: **Finite State Machine**

Software System – Finite State Machine (FSM)

- Set of ***States*** of a described system
  - *States* represent all possible (known) states of the machine
  - Active *state* resembles current machine-state
  - Software and machine are to be kept in sync
- **Transitions** between these states
  - Well defined conditions unambiguously force *transitions* into other states
  - All *transitions*/conditions of active state checked on every incoming event
    - Change of a control system process variable
    - Timeout
- **Actions** may be performed on transition and/or when entering a state

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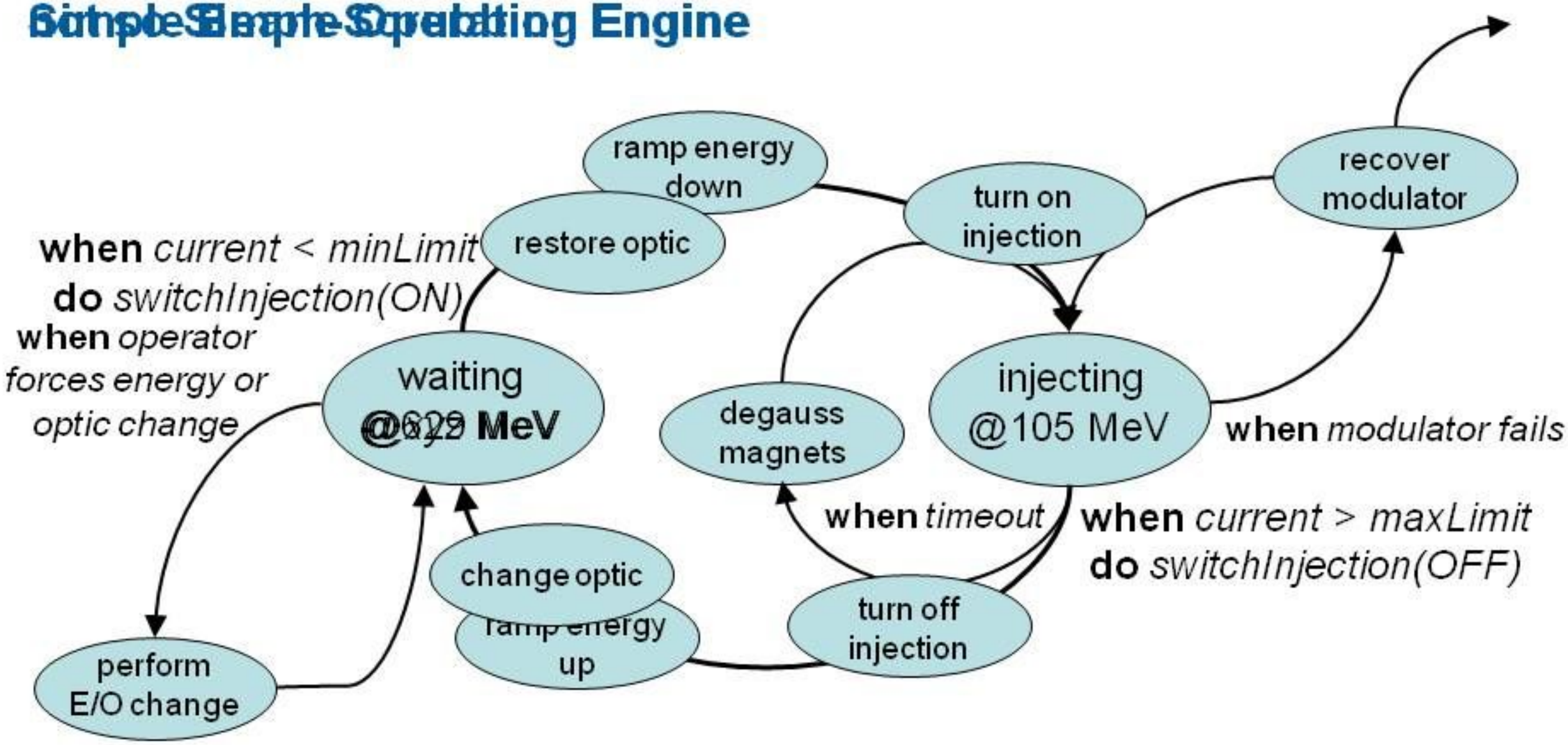
Software System – Finite State Machine

Simple Sequencing Engine



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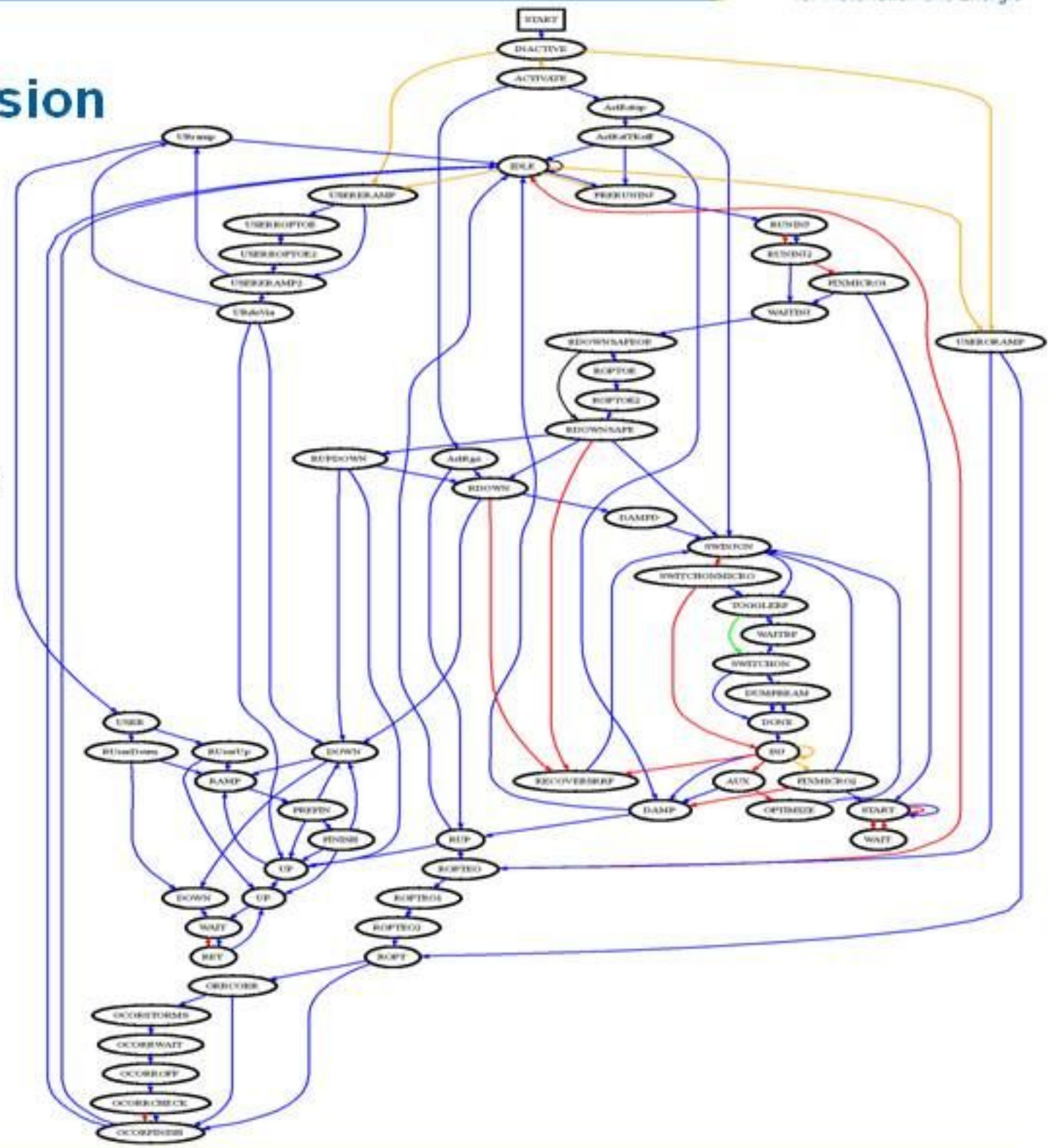
State Machine – Current Version

- **Blue**
  - In-Sequence transitions "expected"
- **Orange**
  - Out-of-Sequence transitions "unexpected" or Operator interaction
- **Red**
  - Error transitions
- Image created by *GraphViz (www.graphviz.org)*
- Input to *GraphViz* created by *Operation Master*



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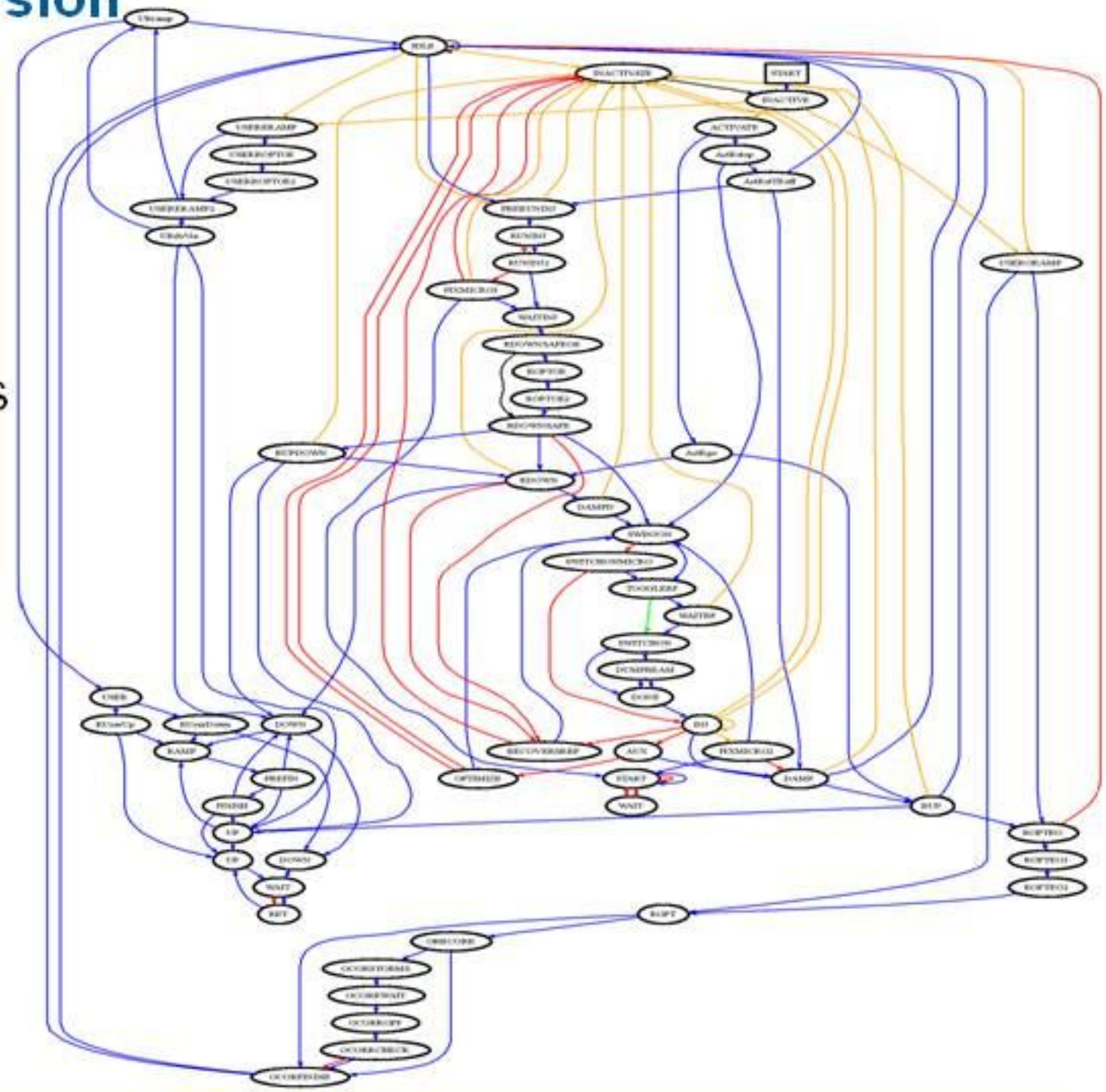
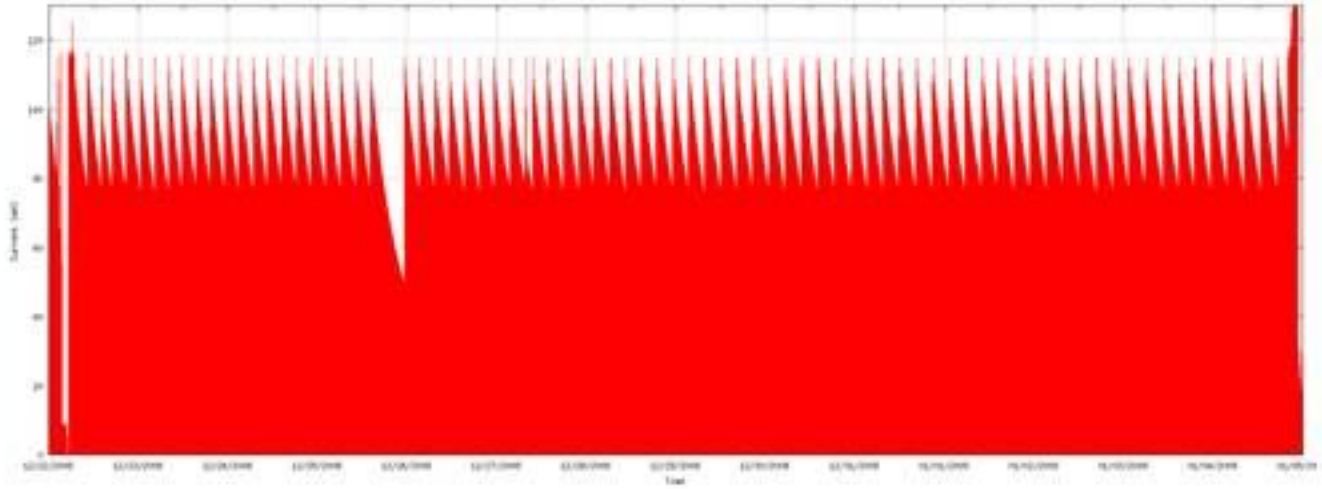


Operation Master – Development

- Whole system *not* developed by design according to full specification
  - **State Engine** – as generic as possible/necessary
  - **State Machine** – unspecified, very simple first version
- **Evolutionary** development process (still going on after 18 months)
  - **Experiences** of **commissioning** and **daily use** of application itself
  - Yet unhandled states only identified when using the application
  - Solutions to problems often roughly sketched → **refinement phase**
  - Clear view of solution often arises during discussions between developer and users/scientists → **close cooperation** drives development
  - Numerous **small development steps**
    - Some removed in favor of other solution or have proven obsolete during further commissioning

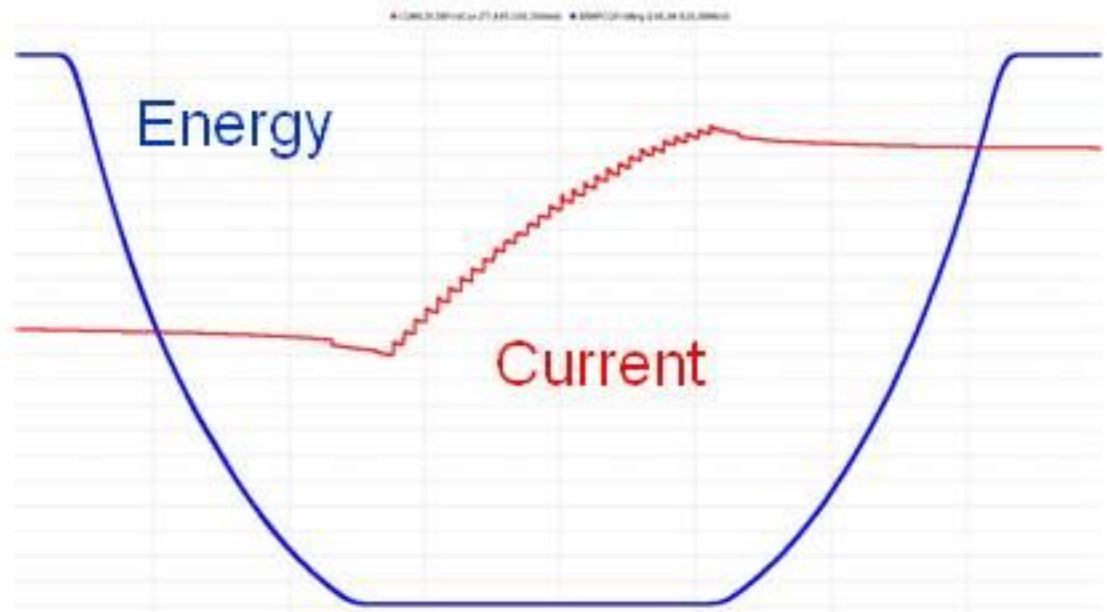
Operation Master – First successful longer Run

- Performed well for two unmanned weeks during holiday break 2008/2009
  - Just one unidentified problem with microtron modulator PLC
  - Manual intervention necessary
  - Action became part of command sequence to recover from PLC errors



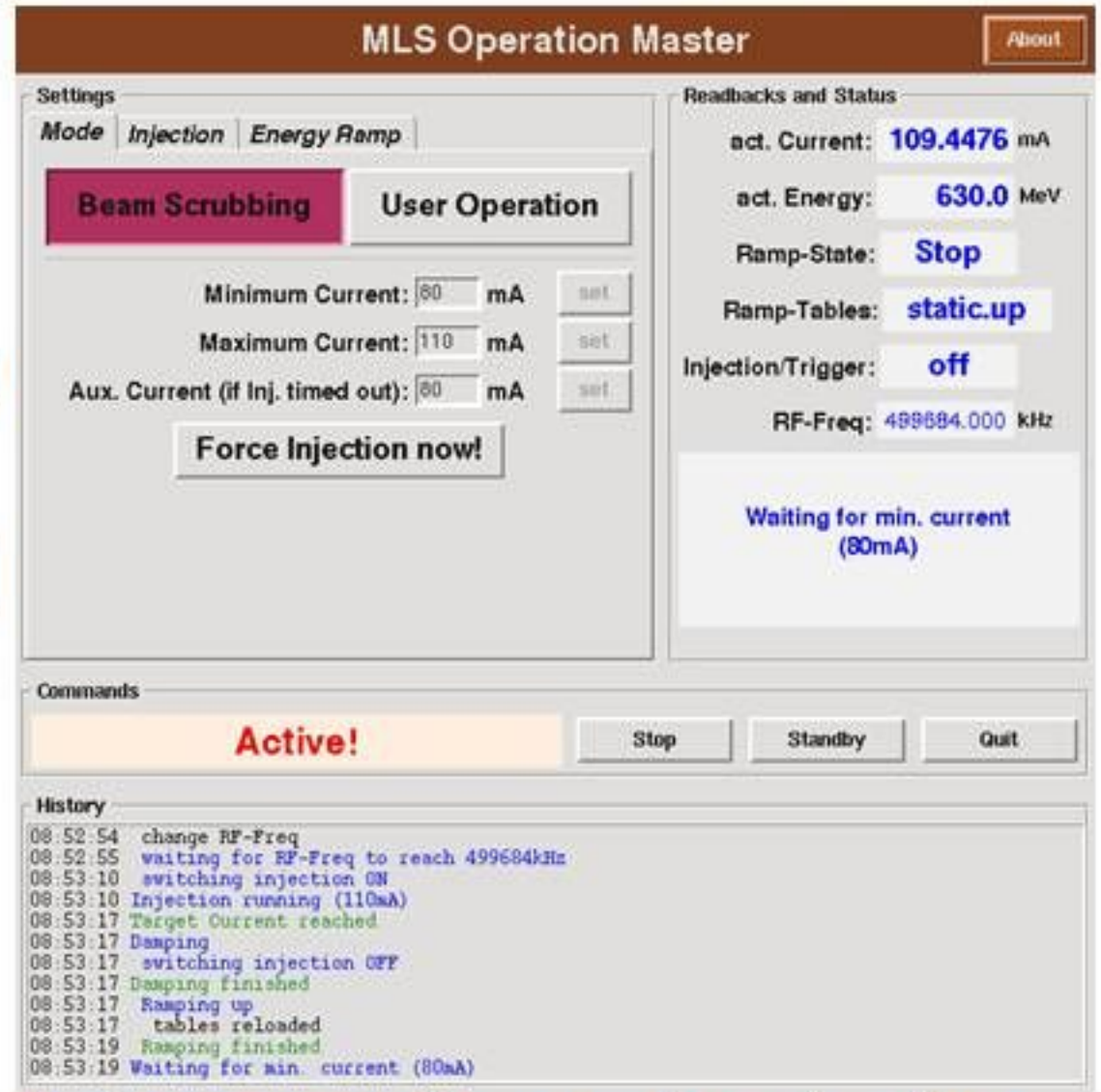
beamcurrent over two weeks

one injection cycle



Operation Master – Implementation

- First version written in **Tcl/Tk**
  - Proper choice for **rapid prototyping**
  - **Monolithic** application
    - State machine, subprocess-control graphical user interface (GUI)



- **But:**
  - Only one instance can be running at a time
  - Application only visible on a single screen
  - **Idea:** split FSM and GUI, simplify interfaces
  - Rewrite in *Python* considered

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Operation Master – Future (as planned in spring 2009)

and modified

- *Operation Master* redesigned and ~~new implementation in progress~~
  - **Headless server** process
    - State machine and state engine only
    - ~~Written in Python programming language~~
  - All interaction using **control system process variables**
    - **Remote-control** from other applications

to keep the well-known, easily maintainable and settled but still evolving State Machine code

- Use of **standard control system tools** (EPICS-Toolkit) for
  - **Display** – graphical display manager can be run on **any screen**
    - EPICS Channel Access Security used to control permissions
  - **Alarm monitoring** and **logging** – operator notification and analysis
  - **Archiving** – for later analysis and debugging

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Operation Master – Implementation

- Current version written in **Tcl**/Tk
  - **GUI** has been factored out
  - All interaction via **EPICS PVs**
    - User as well as other software components (IPC)

- **So:**
  - *Operation Master* now is a windowless background process (run on a central server)
  - Can be monitored/controlled from anywhere
  - Simplified interfaces lead to even more stable machine operation

Conclusion

- *Operation Master:* **indispensable operator instrument** since day one
- **Minimizes errors** by performing complex command sequences
- Implements **standard mechanisms** to set up certain states as well as to recover from failure situations
- Will be **extended** to cover all **future standardized tasks** at MLS as well

Experiences and success encourage using the same system for existing as well as future projects at BESSY/HZB