HELMHOLTZ
ZENTRUM BERLIN
für Materialien und Energie

Automated Operation of the Metrology Light Source Electron Storage Ring

Thomas Birke

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

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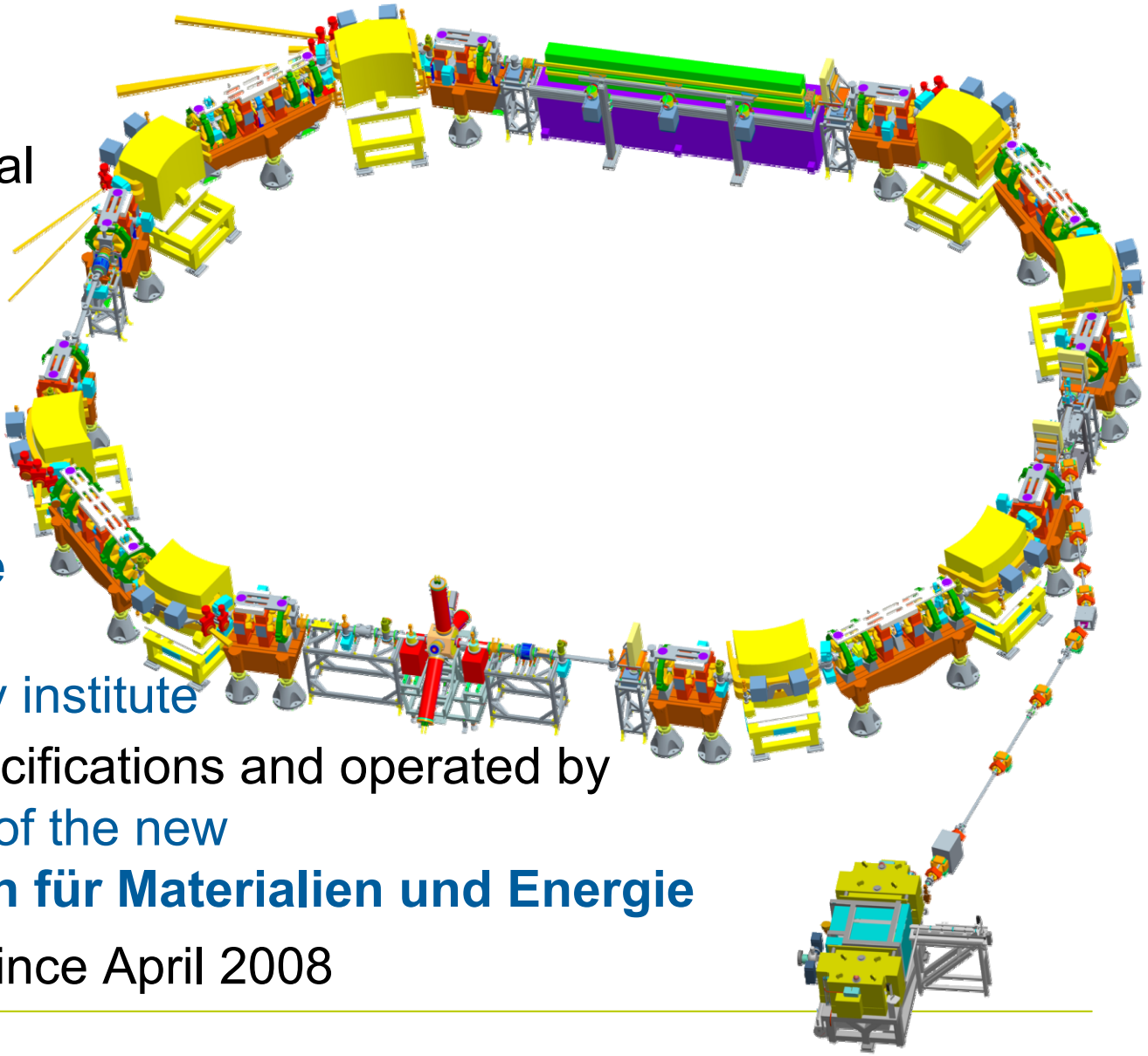
What is the Metrology Light Source (MLS)?

- 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**
- In regular user operation since April 2008



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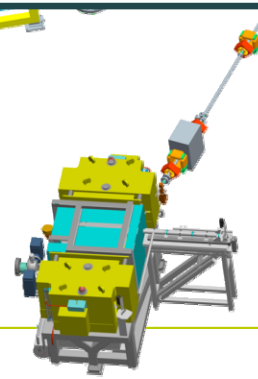
Machine and Operating Parameters	
Circumference	48 m
Revolution Time	160 ns
Injection Energy	105 MeV
Operational Energy	105 – 630 MeV
Beam Current	1pA – 200 mA
Values for momentum compaction factor α	10^{-4} – $3x10^{-2}$
Insertion Device	Electromagnetic Undulator 23 x 180mm



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 – 630 MeV**
  - Momentum compaction factor α: varies by factor of **~1000**
- Electromagnetic Undulator
  - strong **non-linear fields enforce compensation** with correction coils using **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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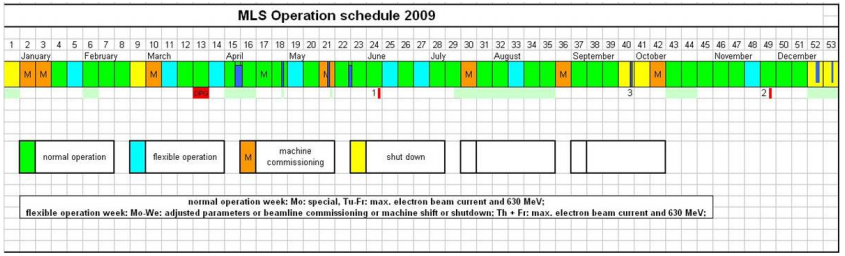
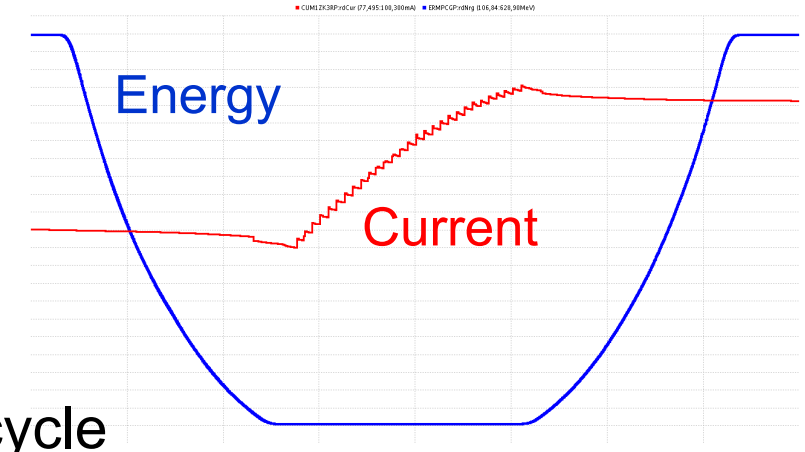
Operating the Metrology Light Source



- Specialties require complex procedures
- Setup changes often according to user demands
  - Even **on short notice**
- Energy ramped before and after injection with minimum loss of beam
  - **Special procedure**



- Energy Ramp 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
  - Currently done manually – program is in development

Operating the Metrology Light Source

- Several tasks to be performed by **operation personnel**
  - Inject up to desired current
  - Ramp energy – before and after injection as well as on user-demand
  - Change momentum compaction factor
  - All tasks require **several actions** and may require **sub-tasks**
  - Any **error** (esp. in magnet settings) may **strongly deteriorate** machine performance
- Operated by **BESSY/HZB** staff for **PTB**
  - Paid customer service
  - Deliver **high operational reliability** with minimum personnel effort
  - **High degree of automation required!**

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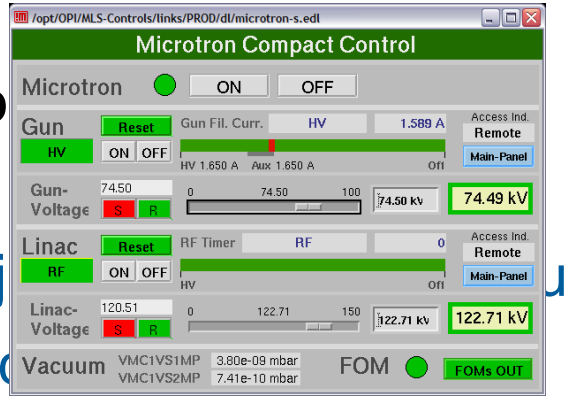

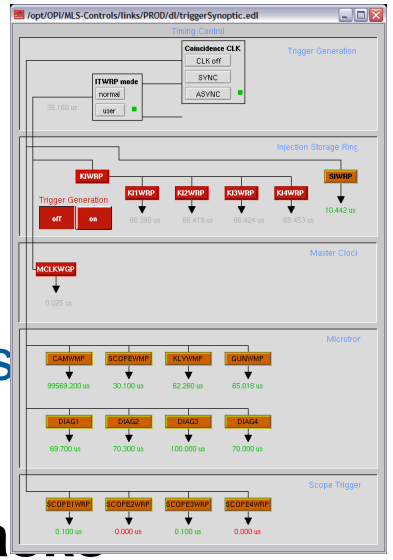

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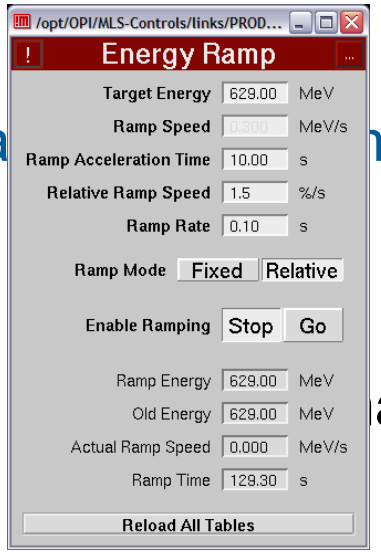

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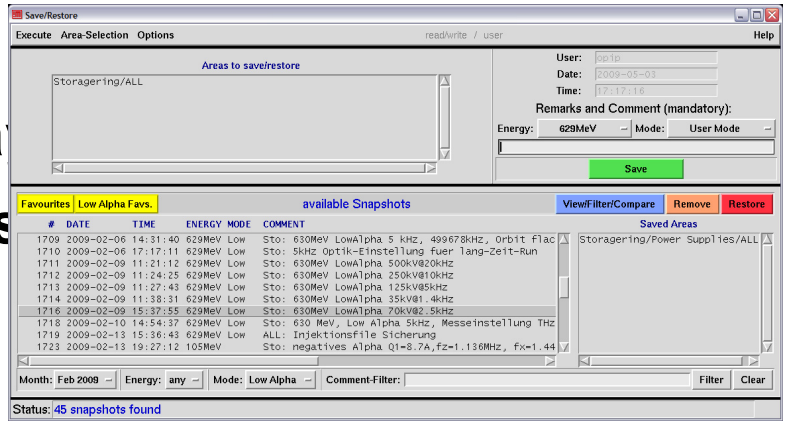

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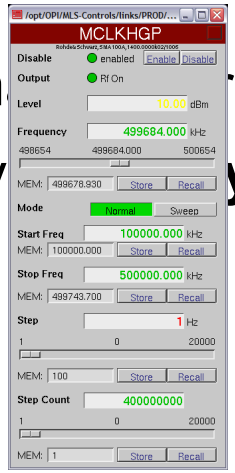

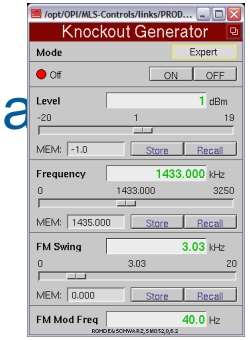

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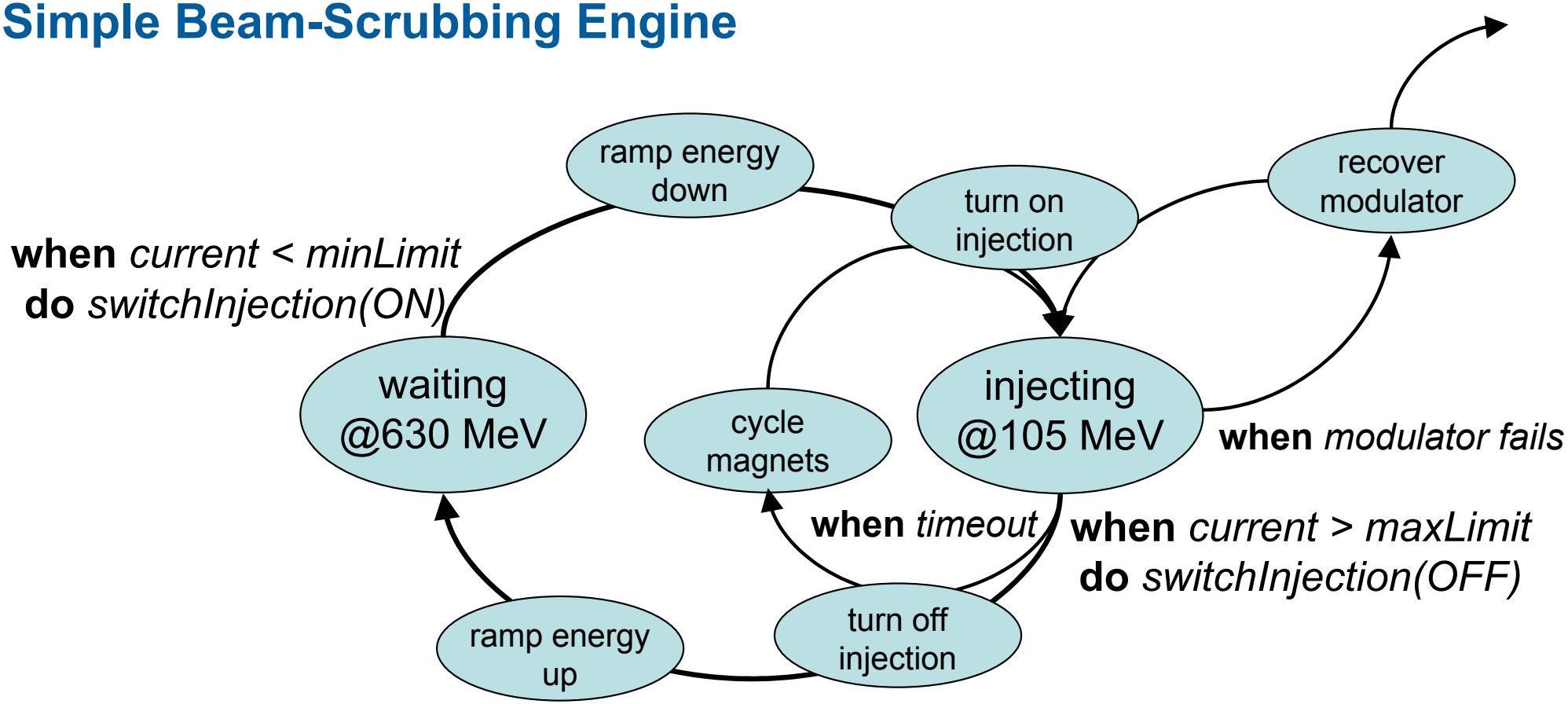
Software System

- Several localized sub-tasks already realized in separate applications
  - Energy Ramp
  - Optimizing microtron output
  - Momentum compaction factor – semi-automatic by restoring snapshots of magnet-settings and manually adjust the RF-Frequency
- *What* action to perform *how* and *when*? – Organized by operator
  - Expertise is in the heads – sometimes even documented
  - All signals needed for deciding what to do 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: **State Machine**

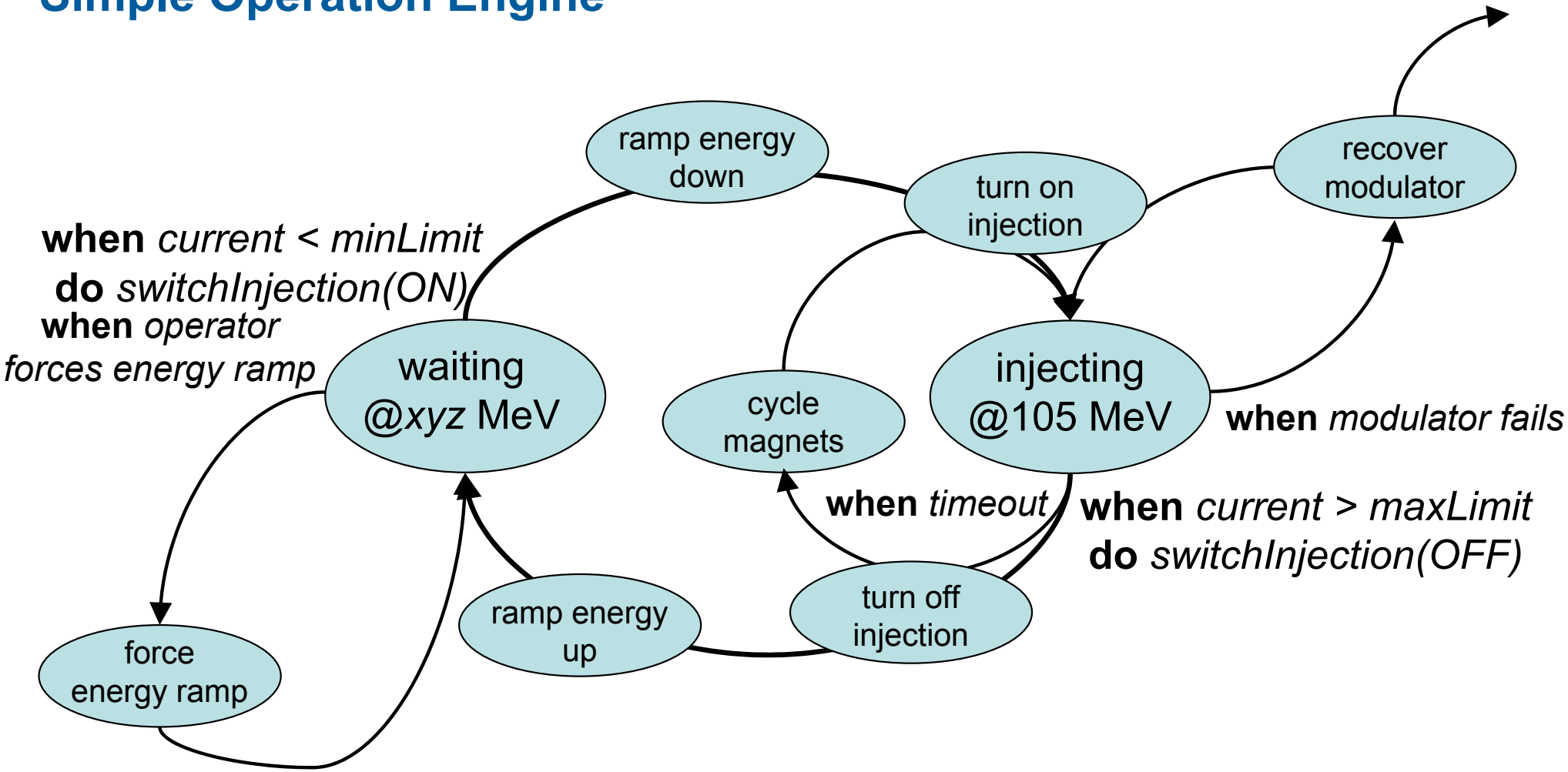
Software System – Finite State Machine (FSM)

- Set of States of a described system
  - States describe all possible 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 force transitions into other states
  - All transitions/conditions of active state checked on every incoming event
  - Change of a control system process variable
  - Timeout
  - User interaction through graphical user interface
  - Actions may be performed when entering a state and/or on transition

Software System – Finite State Machine
Simple Beam-Scrubbing Engine



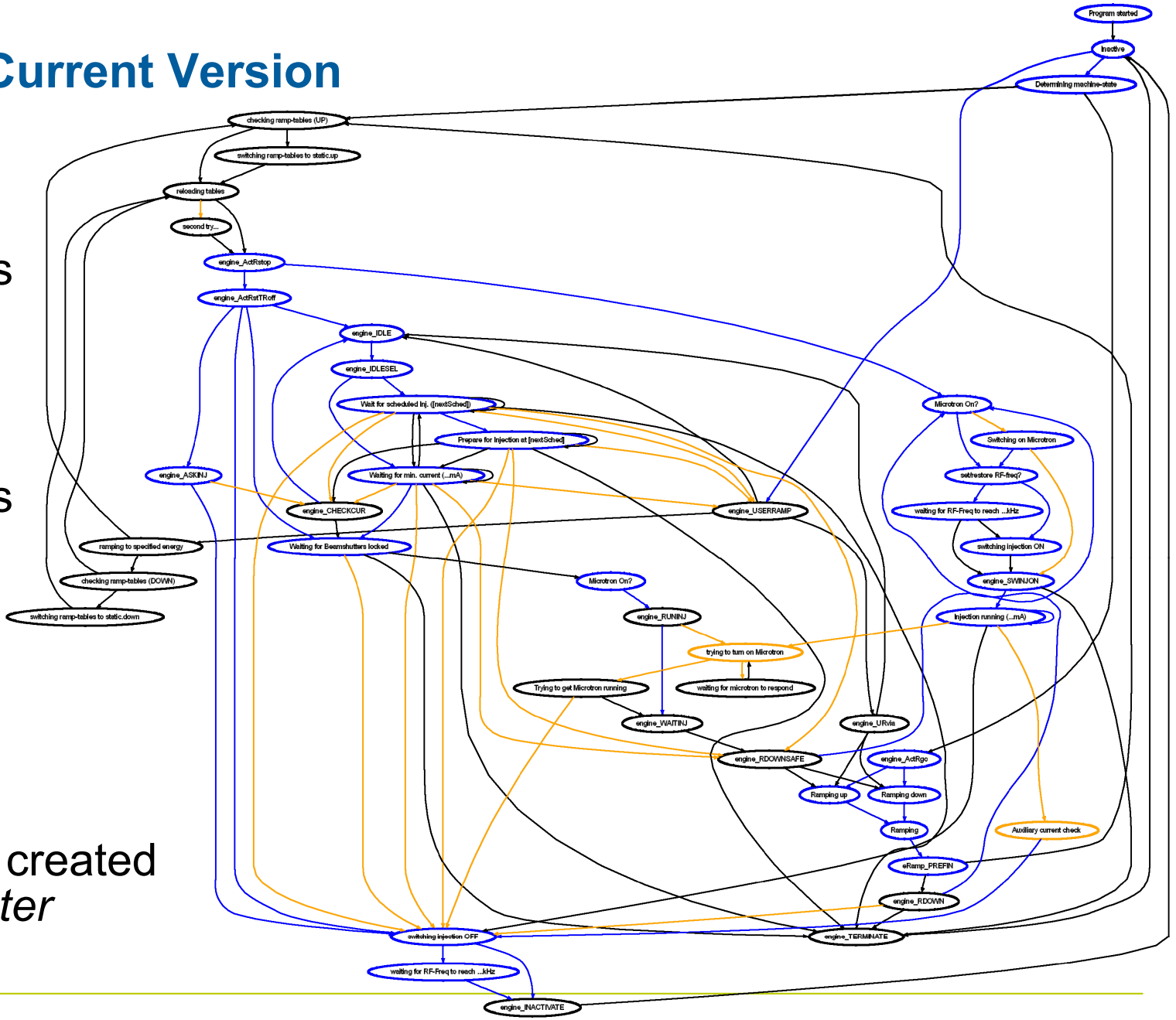
Software System – Finite State Machine
Simple Operation Engine



State Machine – Current Version

- **Blue**
  – in sequence states/transitions “expected”
- **Orange**
  – out of sequence states/transitions “unexpected”

- Image created by *GraphViz*
- Input to *GraphViz* created by *Operation Master*



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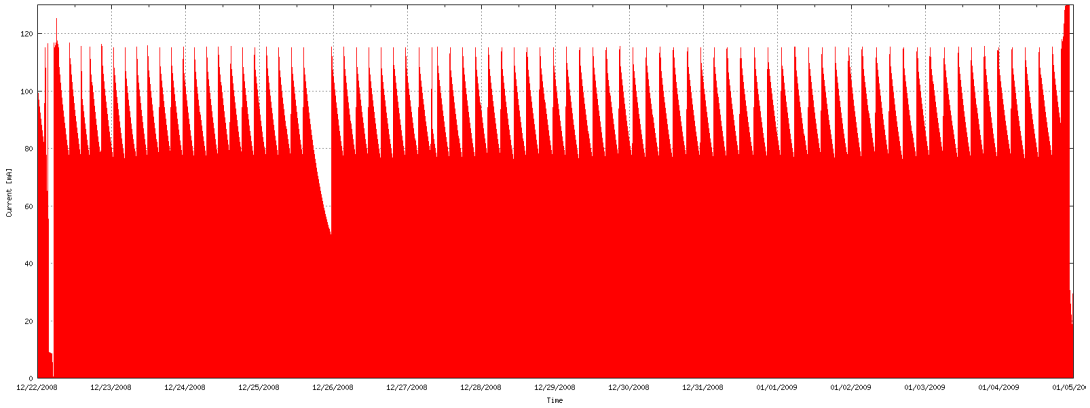
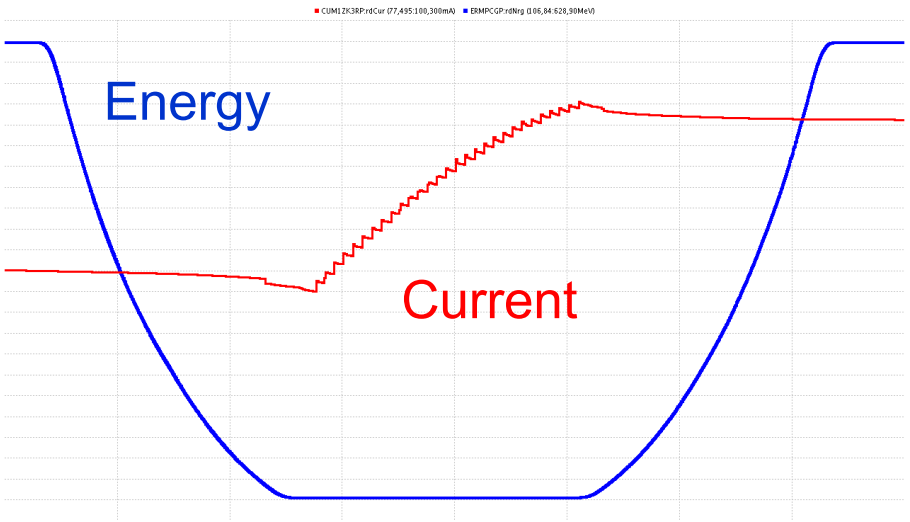
Operation Master – Successful Run

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



beamcurrent over two weeks

one injection cycle



Operation Master – Development

- Whole system *not* developed by design according to full specification
  - **State Engine** – as generic as possible
  - **State Machine** – unspecified, very simple first version
- **Evolutionary** development process
  - **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

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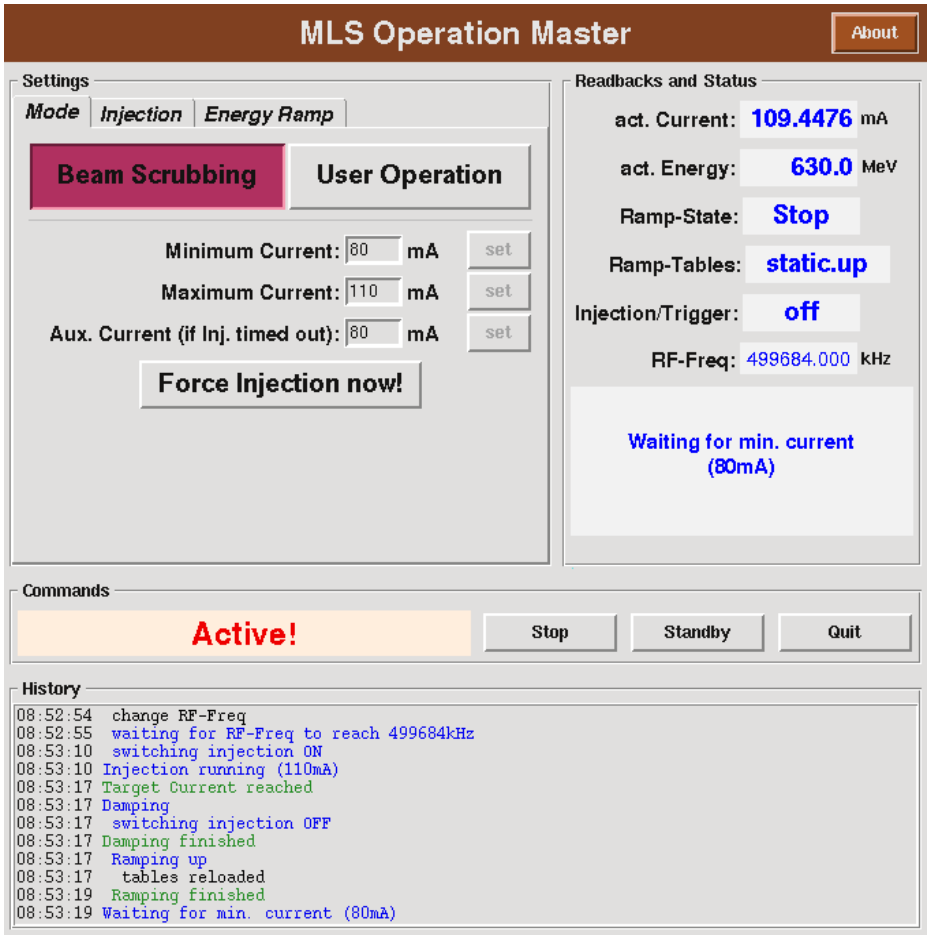
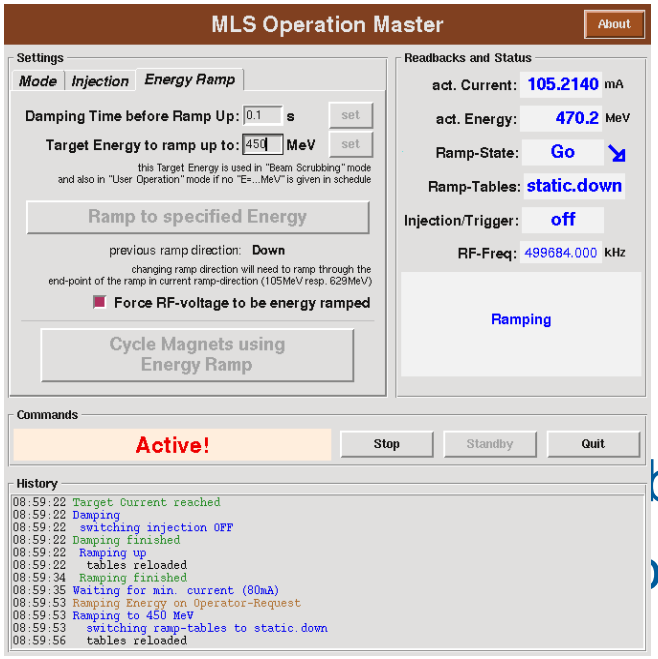
Operation Master – Implementation

- Current version written in **Tcl/Tk**
  - Proper choice for **rapid prototyping**
  - **Monolithic** application
  - State machine, state engine, graphical user interface (GUI)
  - be running at a time
  - n a **single screen**





Operation Master – Future

- *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 application

- 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

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 tasks** at MLS as well

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