Availability of PETRA III from the rf point of view



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PETRA III Availability Review
DESY, May 26th-27th 2016

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Availability of PETRA III from the rf point of view
CWRF 2016, Genoble June 24th

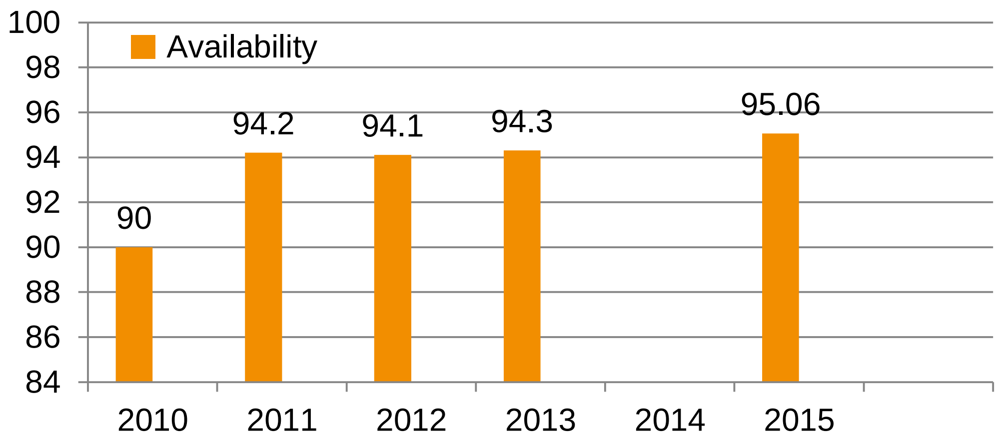
Availability of PETRA III from the rf point of view

Motivation:

Last year the PETRA III extension project was successfully implemented.
Recommissioning with beam started on schedule.
April 2015 - users started experiments at the 14 existing beamlines
After 3815 scheduled user operation hours, an availability of 95 % was obtained in 2015.
In total 116 faults were recorded last year, resulting in a mean time between failures of 31 h.
This is not in line with other 3rd-generation synchrotron light facilities.

To find out the weak points , there was a PETRA III Availability Review in May 2016

Here are the results of this workshop from the rf- point of view



Outline:

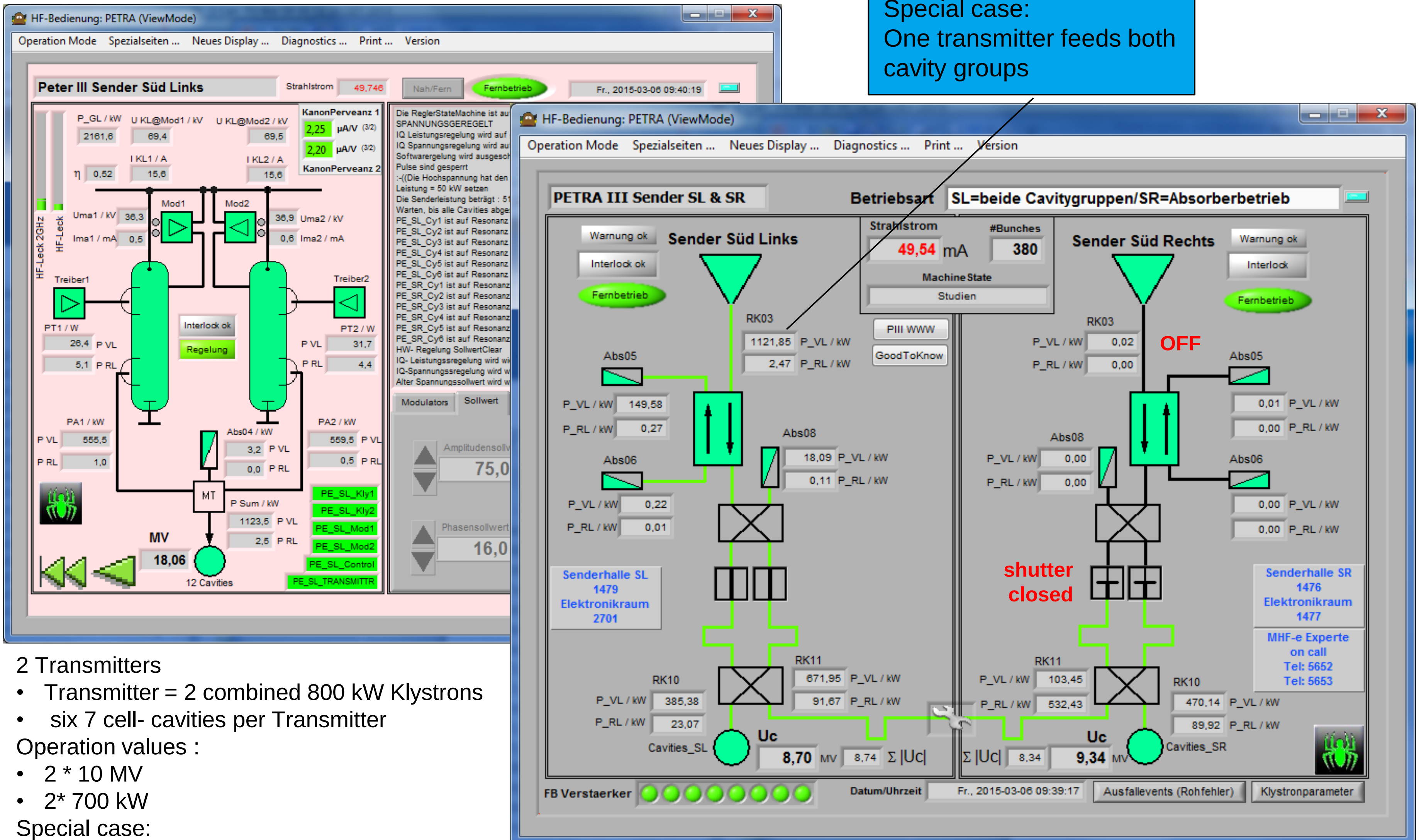
- PETRA III Overview and Parameters
- RF system overview
- Problems and failures
- ṙ-events
- Problems with Cavity SL_Cy2
- Summary and recommendations

PETRA III – Overview and Parameters

Beam Energy: E_0 = 6 GeV
Length: l = 2304 m
Arc radius 191.73 m (7/8) and 22.918 m (1/8)
Beam Current: I_0 = 100 mA (40, 60, 480 or 960 bunches)
loss per turn U_l = ca. 6-7 MeV
Emittance (hor) ε_x = 1 nmrad !
Topping up
14(+5+5) beamlines

PETRA III RF System Overview

Special case:
One transmitter feeds both cavity groups



2 Transmitters

- Transmitter = 2 combined 800 kW Klystrons
- six 7 cell- cavities per Transmitter

Operation values :

- 2 * 10 MV
- 2* 700 kW

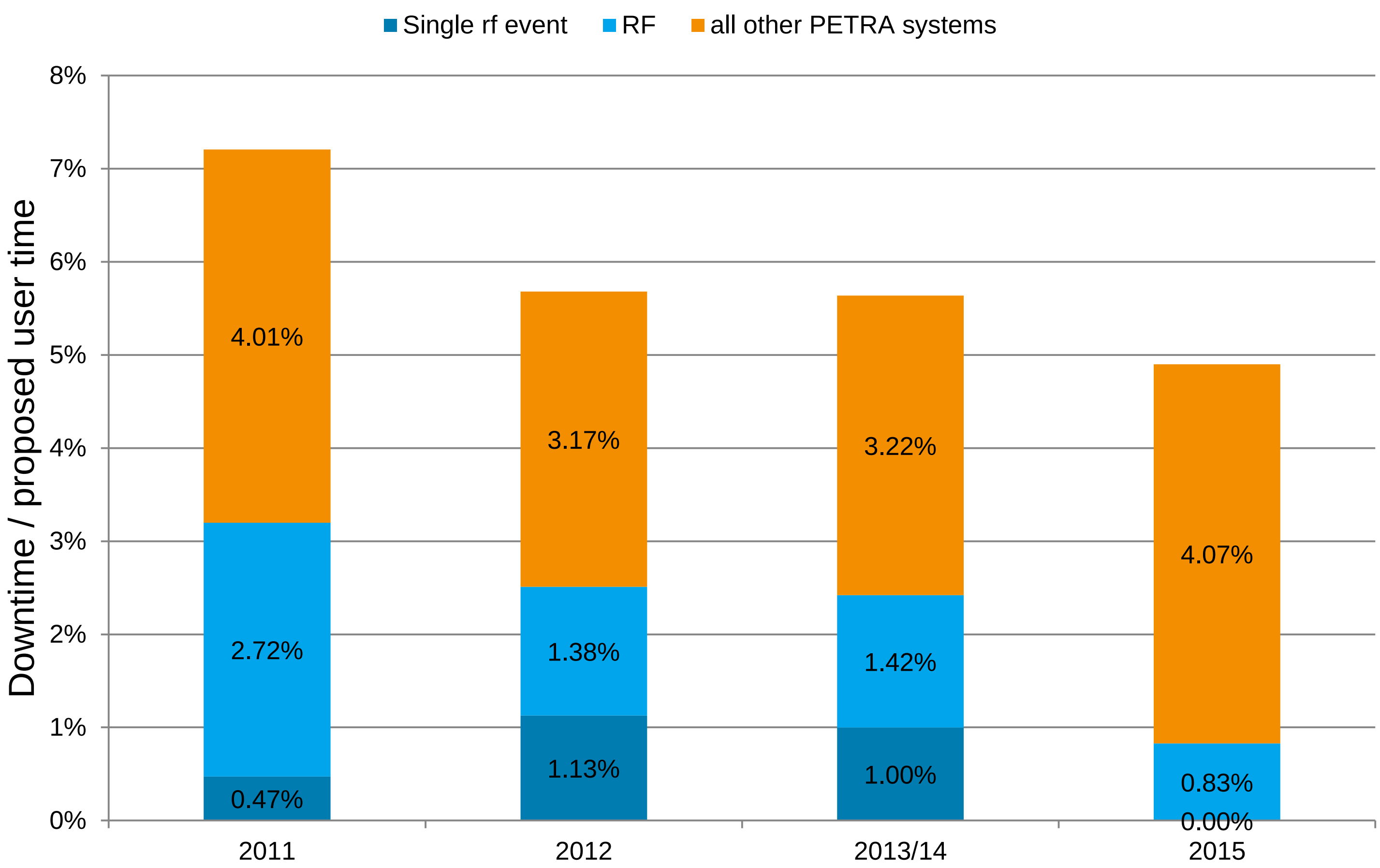
Special case:

- One Transmitter can be switched to all 12 Cavities

DESY

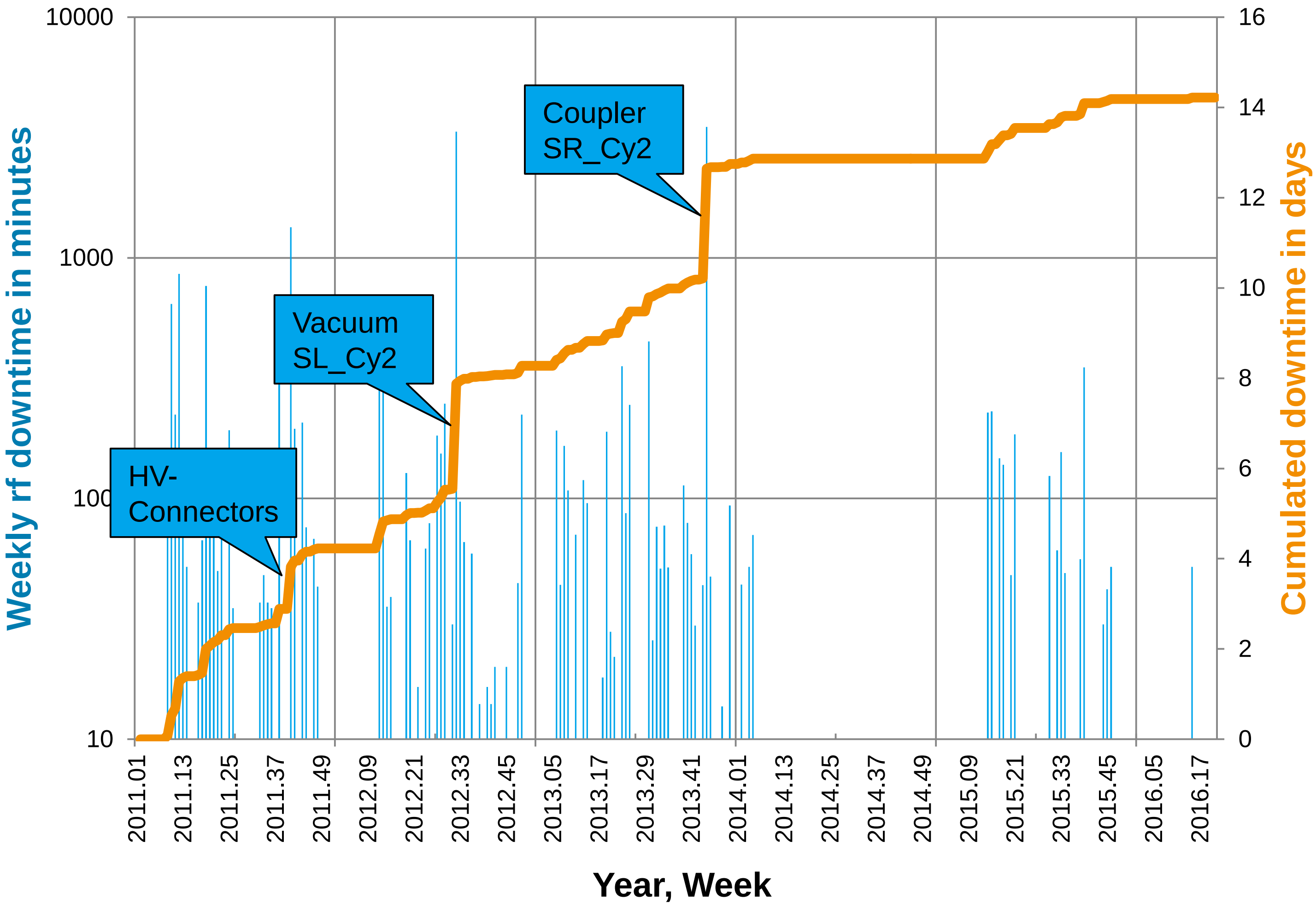
Problems and Failures - Availability

Development of downtime



Problems and Failures - Availability

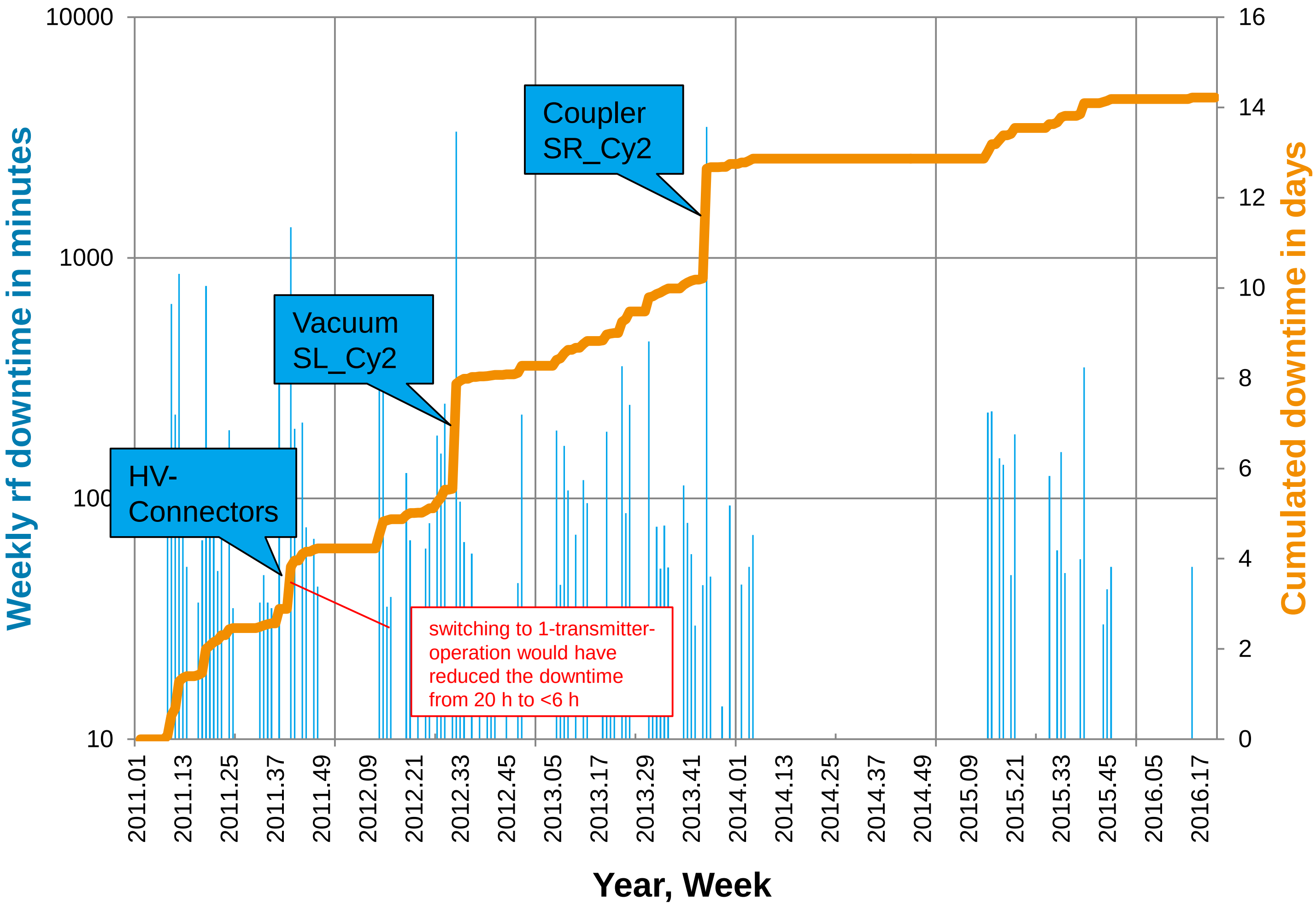
Single rf events caused large downtime



Problems and Failures - Availability

Single rf events caused large downtime

Sometimes the wrong decisions were made in the past



Problems and Failures - Availability

Single rf events caused large downtime

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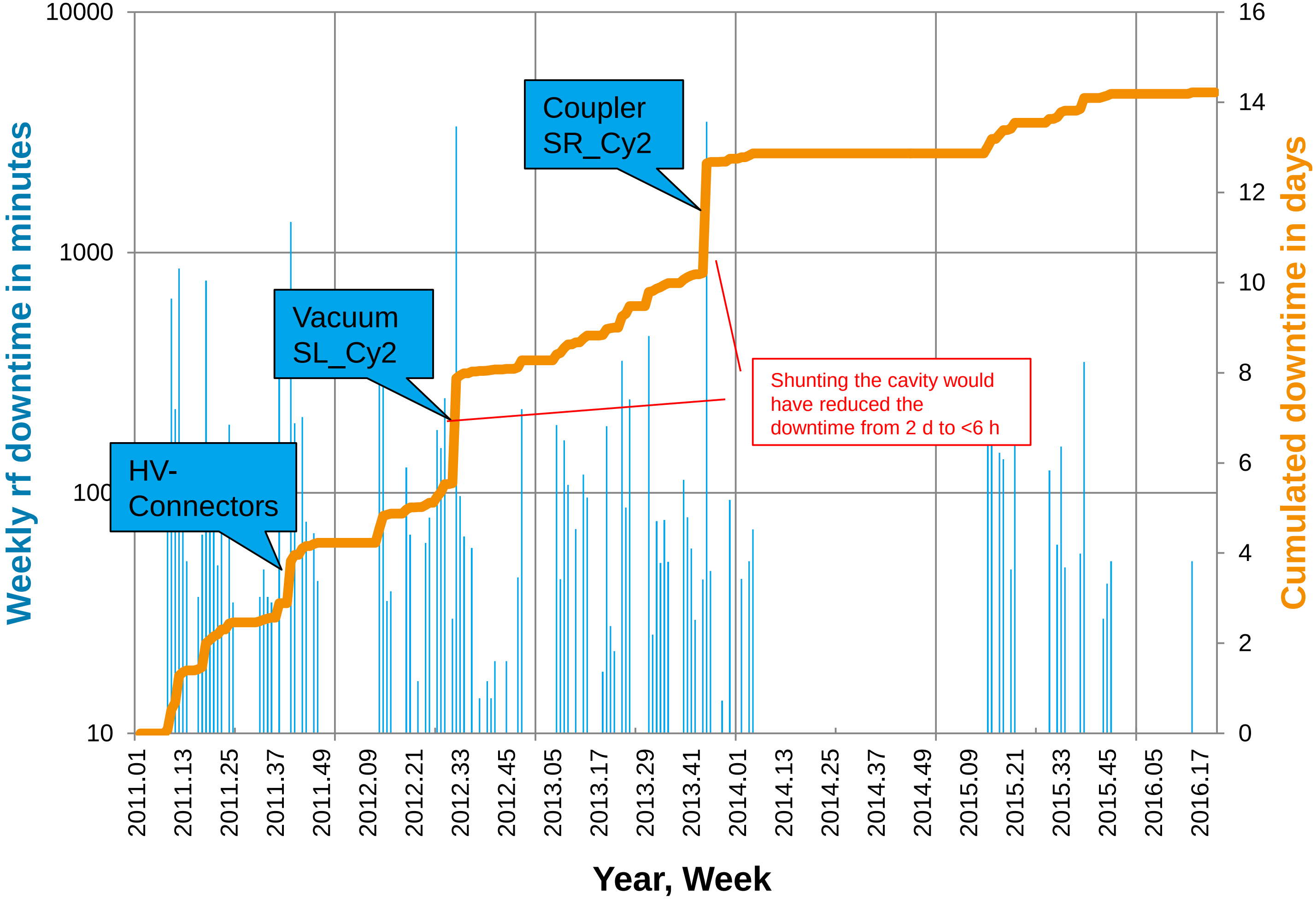
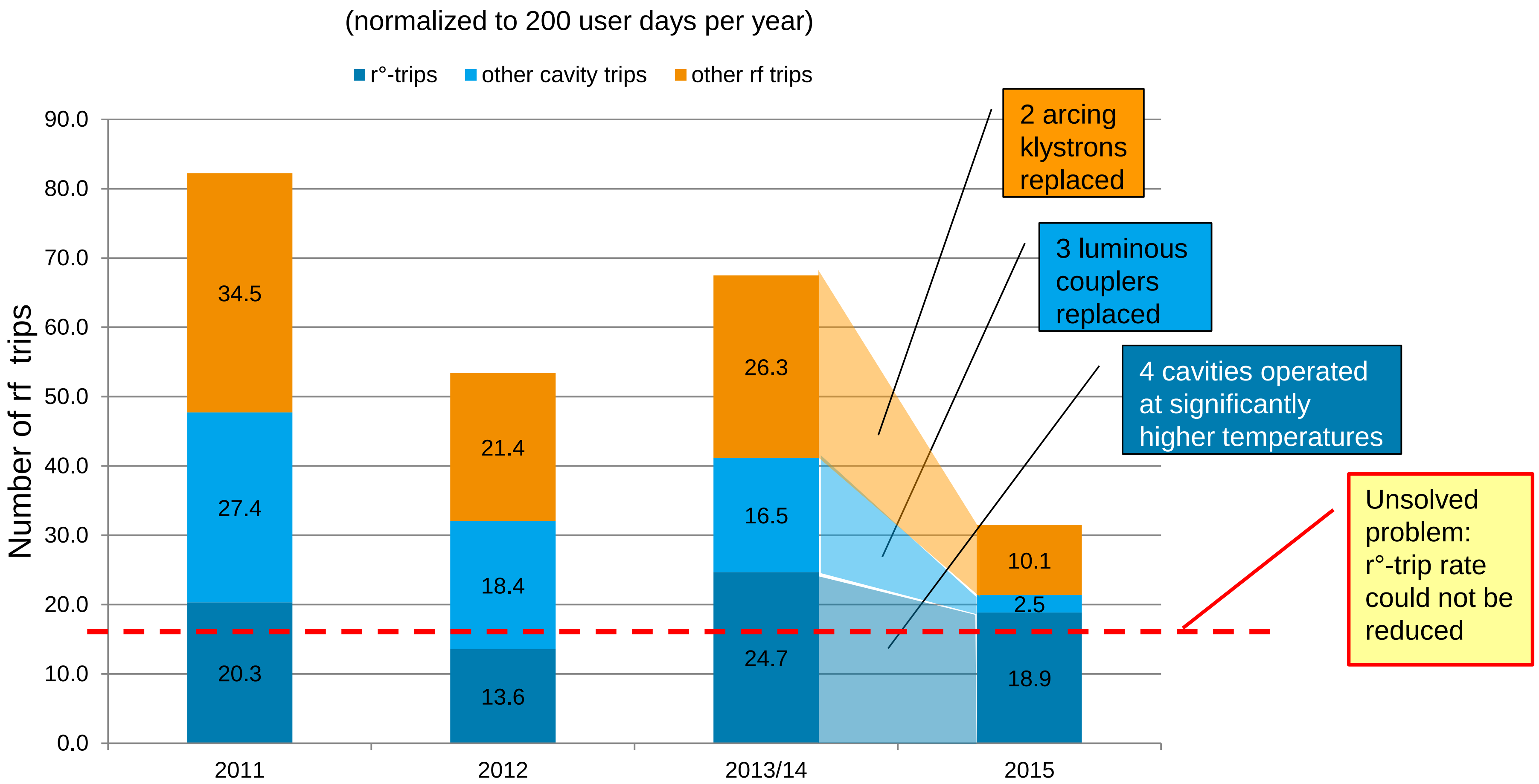


Problems and Failures - Reliability

Development of reliability



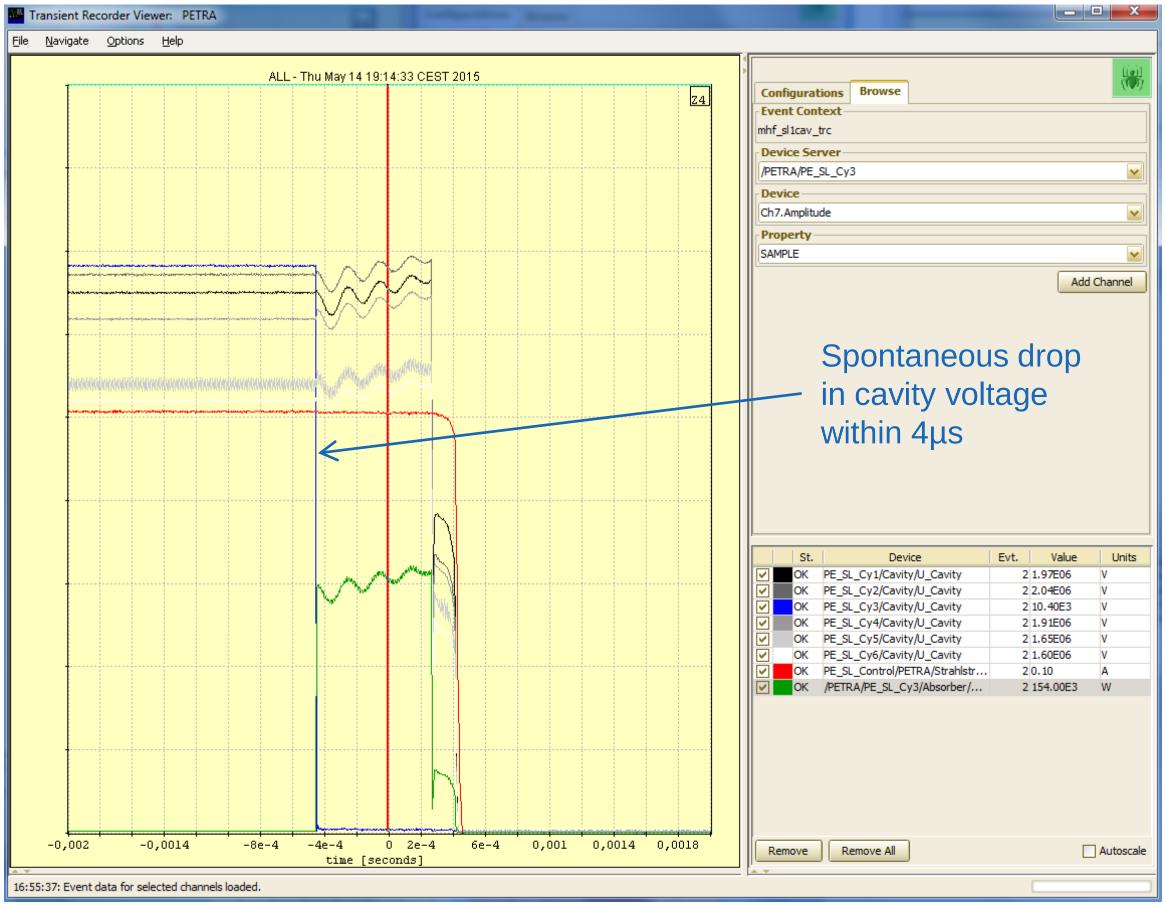
PE III 2015: 116 trips in 159 user days
(corresponds to 145 trips in 200 user days)

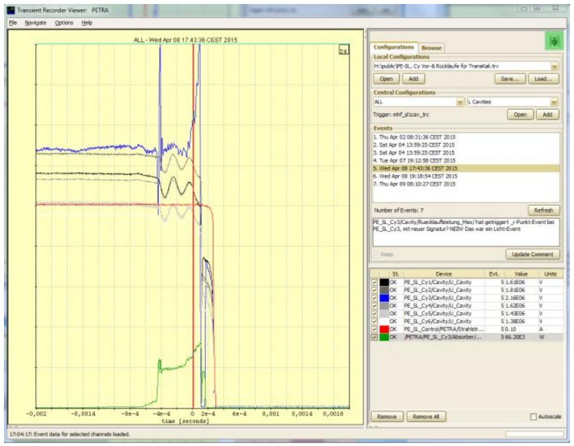
Problems and Failures, ṙ- events

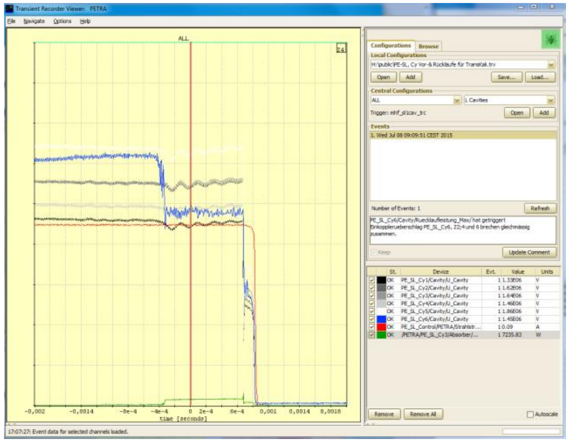
ṙ-event

Typical signature of a ṙ-event,
triggered by fast rising reflected cavity power

For comparison: Typical signatures of coupler arc events, detected by light.







Problems and Failures, $\dot{r}$- events

Reason for the $\dot{r}$-events?

We don't know!

But we observed the following:

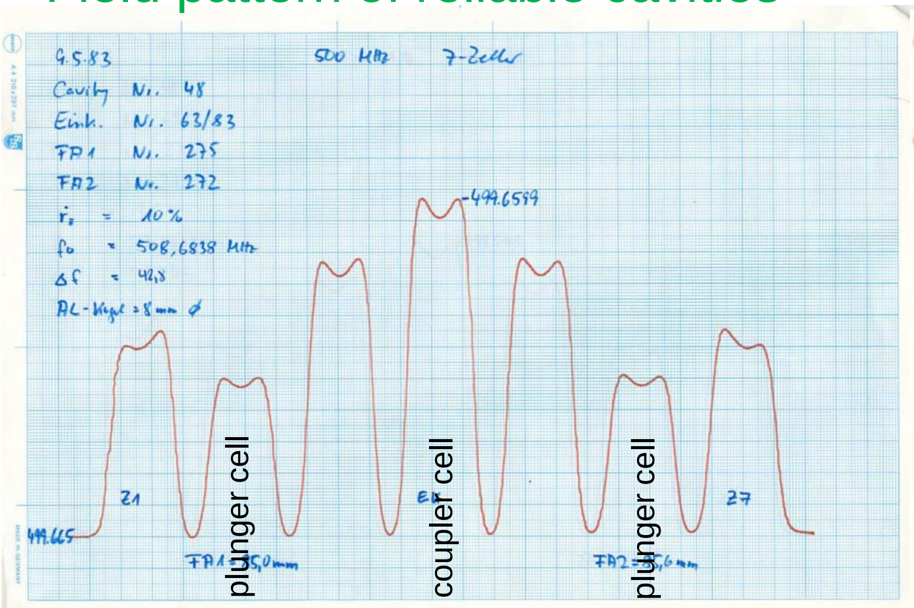
- > Breakdown of cavity-voltage occurs within the order of 10 µs without any prior indication
- > Events can be triggered by changes in cavity temperature
  (But not reliable. Sometimes a vacuum breakdown occurs, sometimes nothing happens)
- > ¾ of the $\dot{r}$-events occur in timing mode
- > Event rate is constant at about one trip per week(1) since years
- > ¾ of the $\dot{r}$-events are triggered in 4 certain cavities
- > These 4 cavities must have something in common

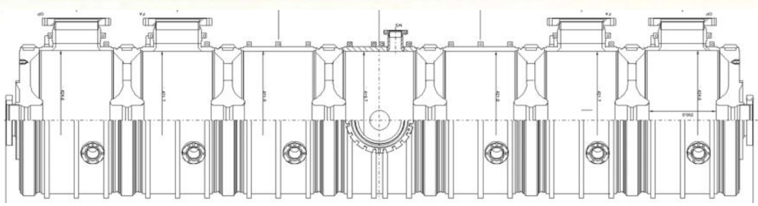
(1) during timing mode

Problems and Failures, ṙ- events

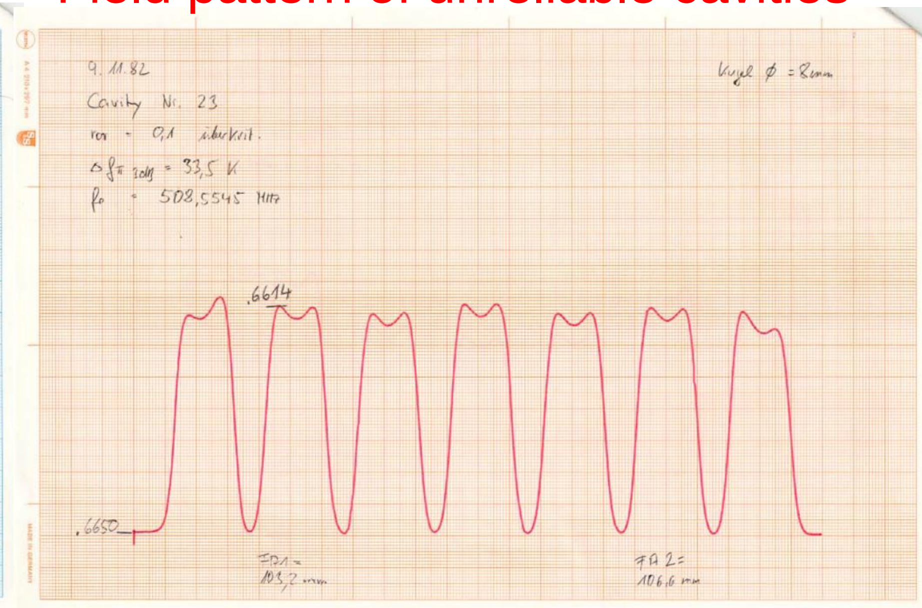
Bead- pull measurements

Field pattern of reliable cavities





Field pattern of unreliable cavities



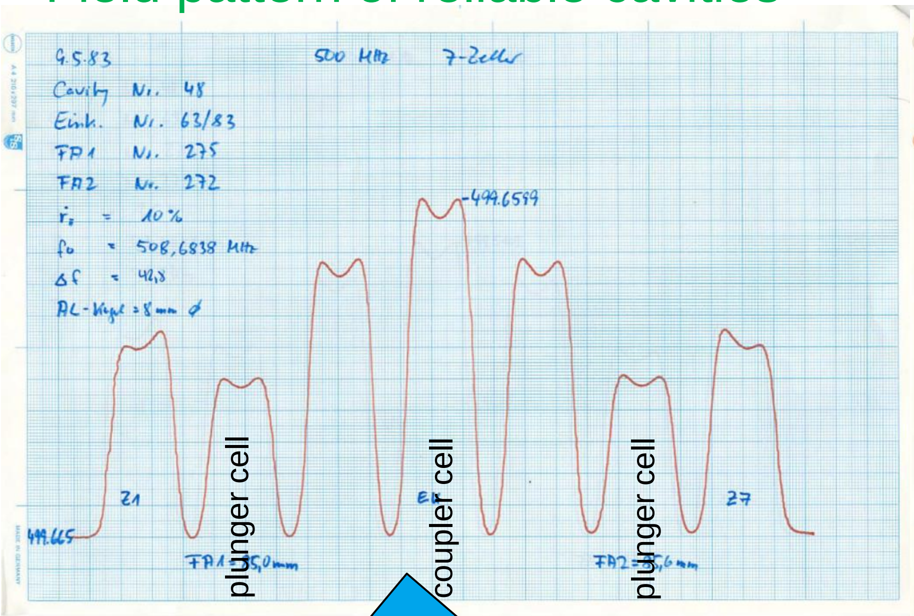
The cavities with highest ṙ-event rate are characterized to have a homogeneous field distribution!

We do not know the mechanism yet.
But the problem seams to be related to the plungers somehow

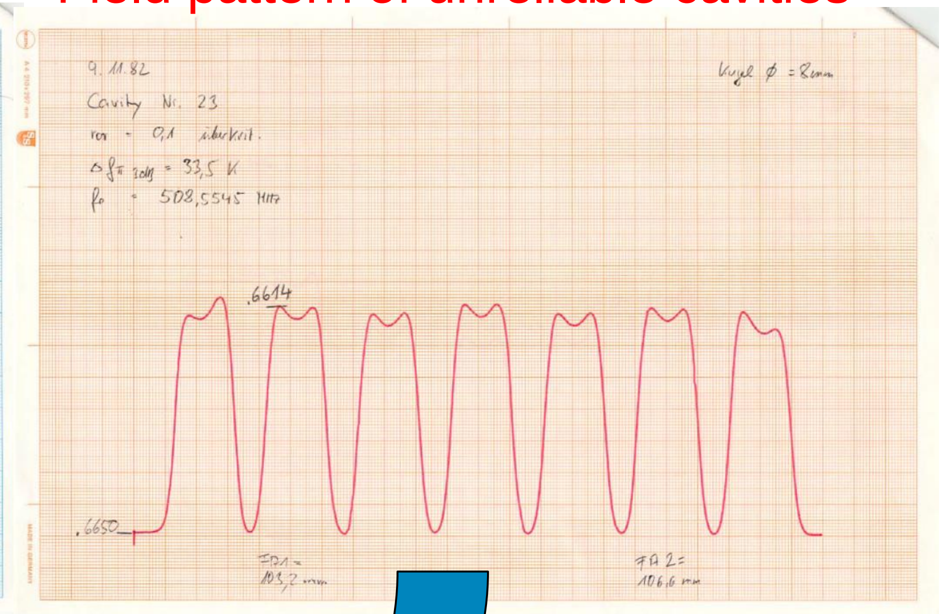
Problems and Failures, $\dot{r}$- events

IDEA

Field pattern of reliable cavities



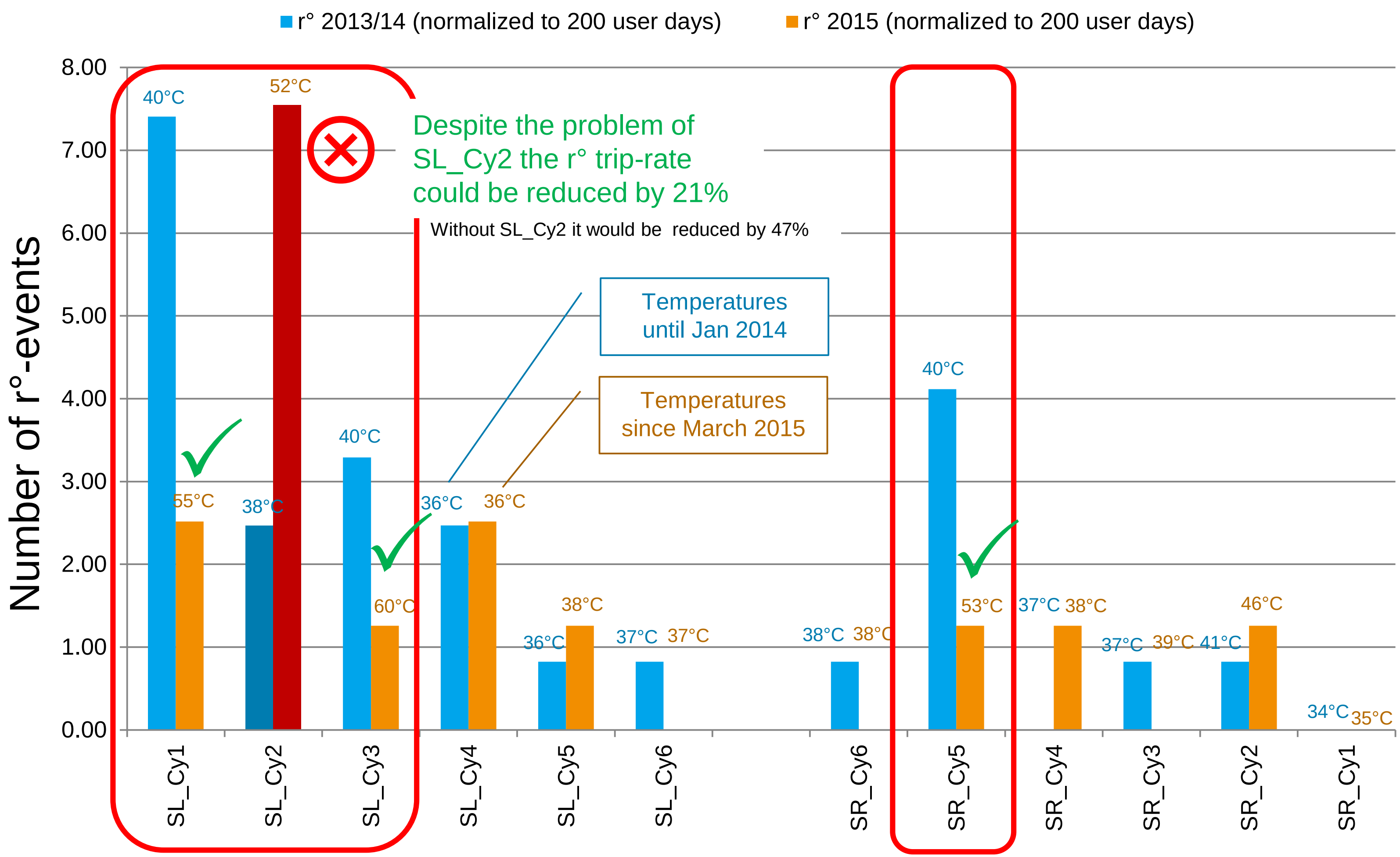
Field pattern of unreliable cavities



Field pattern can be turned from unreliable to reliable by increasing the cavity temperature

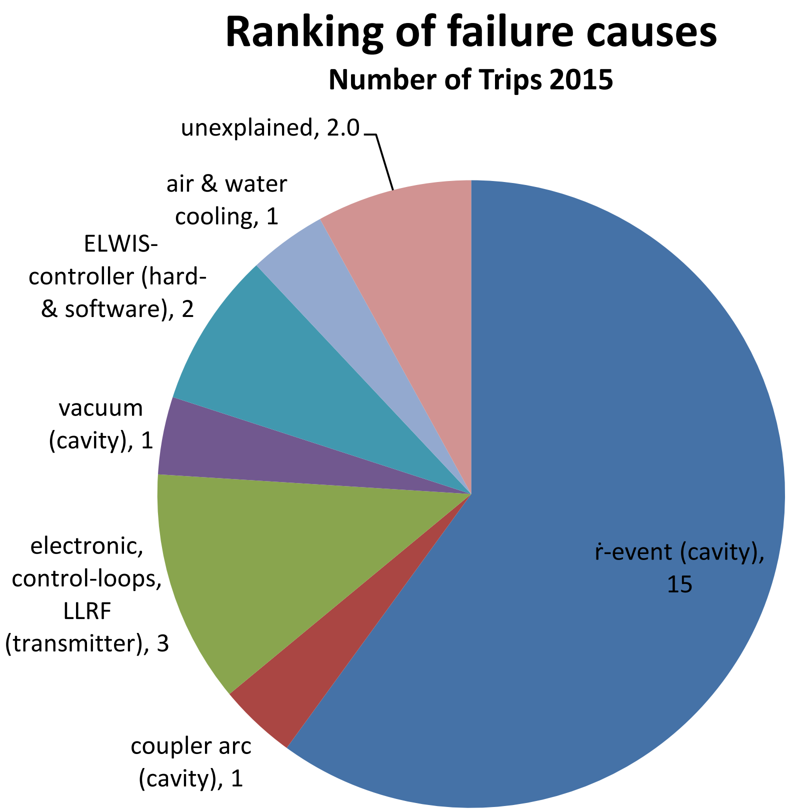
Problems and Failures, ṙ- events

Effect of increased cavity temperatures



Problems and Failures - Reliability

We have just to overcome the ṙ-problem



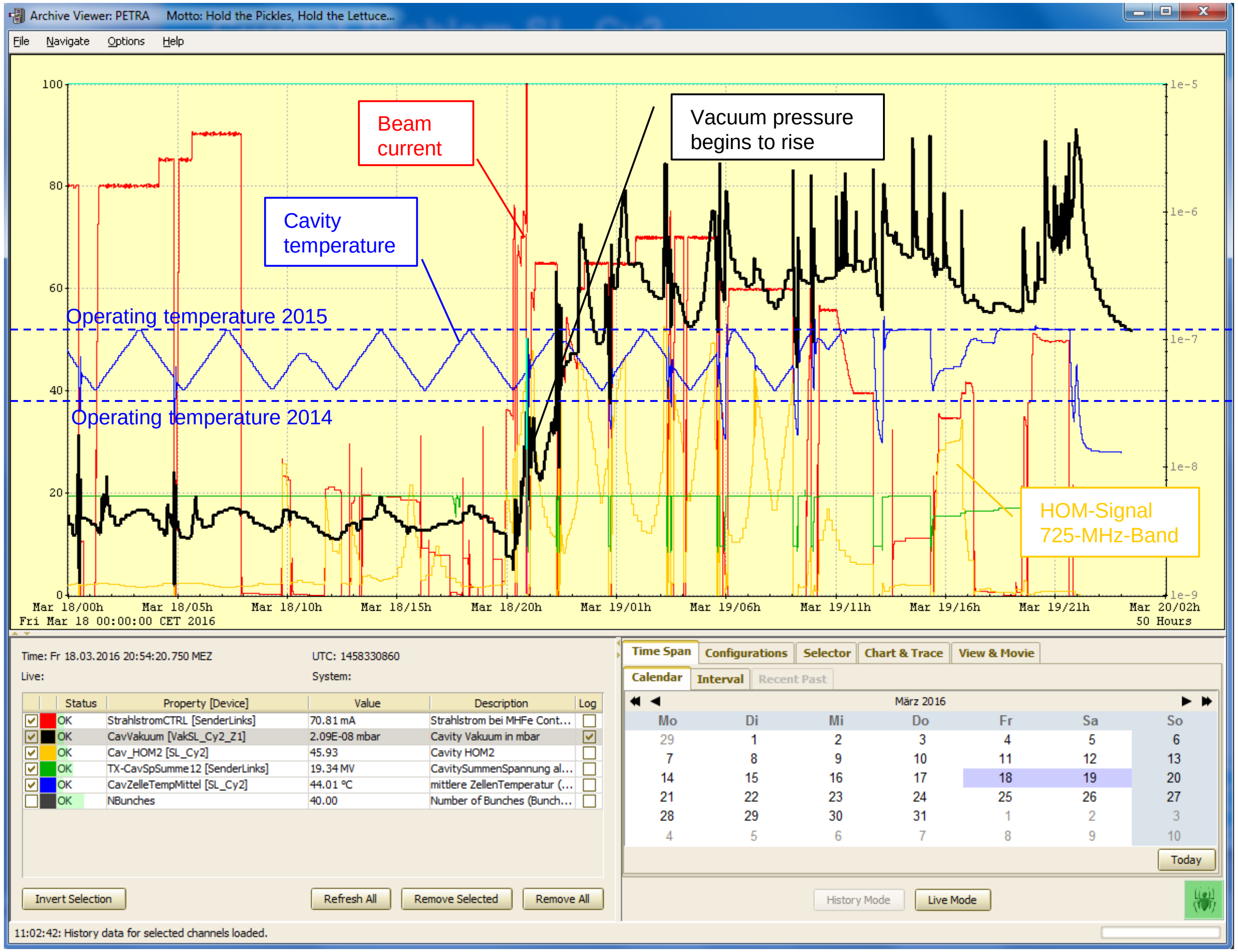
- ṙ-problem seems to be quite persistent
- So far, no source found by precise CST-MWS modeling of the cavity and Eigenmode analysis.
- Currently, we suspect HOM in 3.8GHz range.
- CST-MWS Eigenmode analysis is extended to this range.
- 200 GSa/s scope has been connected to the cavity with highest ṙ-trip rate in the past and is waiting for an event.

But so far, we have to deal with it.

Current Problem SL_Cy2

A vacuum problem occurs 18 days before start of user operation

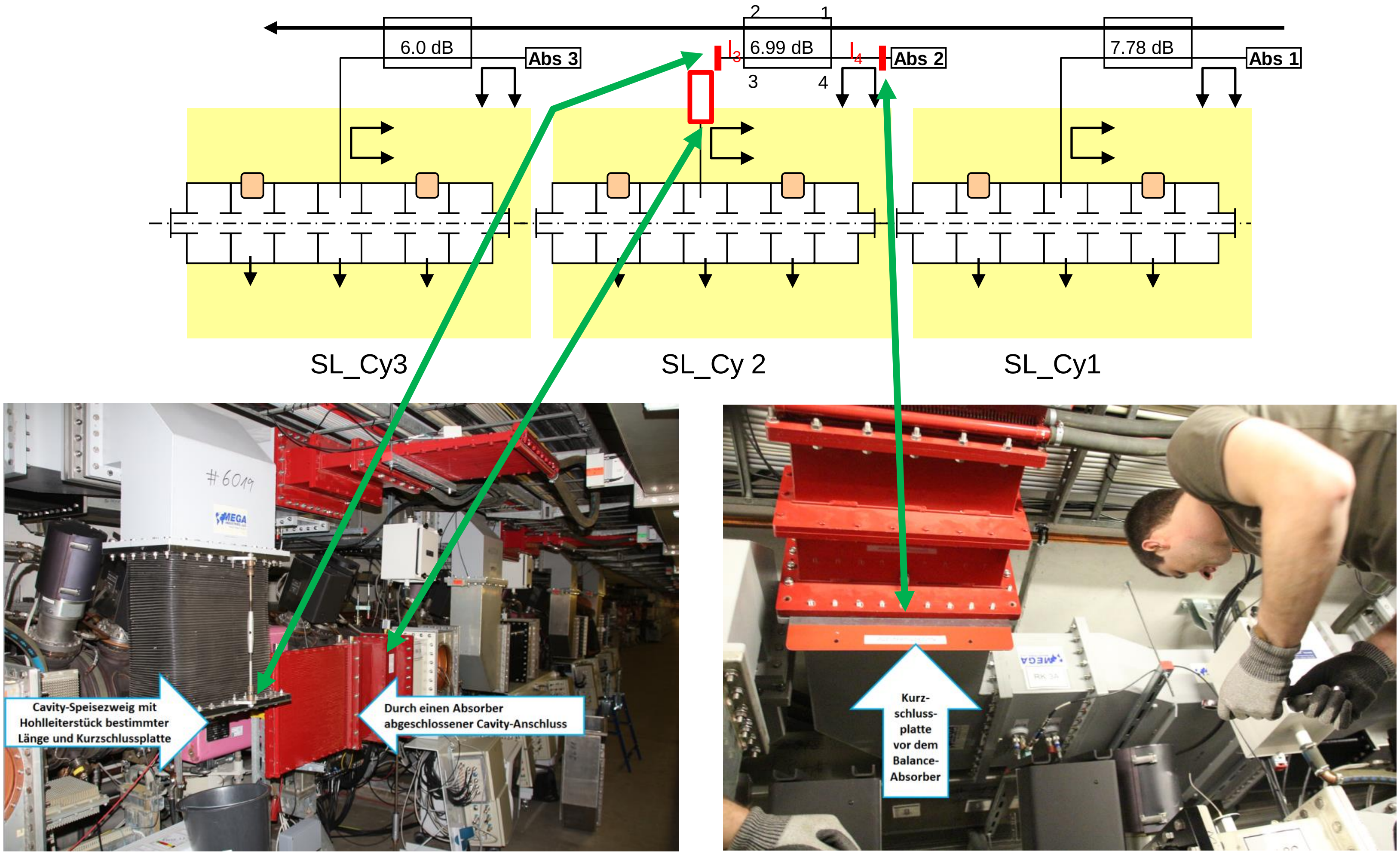
Actually the goal was to scan cavity temperatures for sensitive ṙ-event ranges



- Instead of the expected ṙ- events, we got plunger temperature and vacuum events.
- The vacuum behavior looked like a leakage. But no leakage could be found!
- A similar event has occurred at this Cavity already in 2012!
- In order to avoid venting the vacuum system the cavity was disconnected from rf system.

Current Problem SL_Cy2

Disconnecting SL_Cy2 from RF system



Current Problem SL_Cy2

Plan for troubleshooting

- With some chance one plunger could be the culprit.
- We plan to replace both plungers of this cavity during the service week in August.
- Afterwards the cavity is reconnected to the RF system again.
- Should turn out that not a plunger, but the cavity itself has a vacuum problem, it could be replaced at the next suitable service-break.

Spare Cavities

In principle about 30 spare cavities would be available from HERA.

BUT …

Current Problem SL_Cy2

Spare Cavities

- The cavities were N_2-vented when HERA shut down in July 2007 and not touched since then.
- Their condition may have suffered.
- For PETRA III we would prefer to use a freshly processed and tested one.
- But since 2010 we have no more cavity test stand!

2010 it was more important to have a spare transmitter station for DESY II (DESY II is the booster for PETRA III).
Due to lack in budget the klystron & cavity test stand was turned into a 2nd DESY-transmitter.

Current Problem SL_Cy2

Cavity Test Stand


Former DORIS transmitter station


New constructed cavity test bunker

- Completion delayed due to higher priority of XFEL (plumbing & personal interlock)
- The chosen spare cavity was refurbished by electro polishing but must be complained
- Earliest completion date: July 2016 (depends on personal interlock)


For PETRA intended spare cavity

Summary and Recommendations

Summary

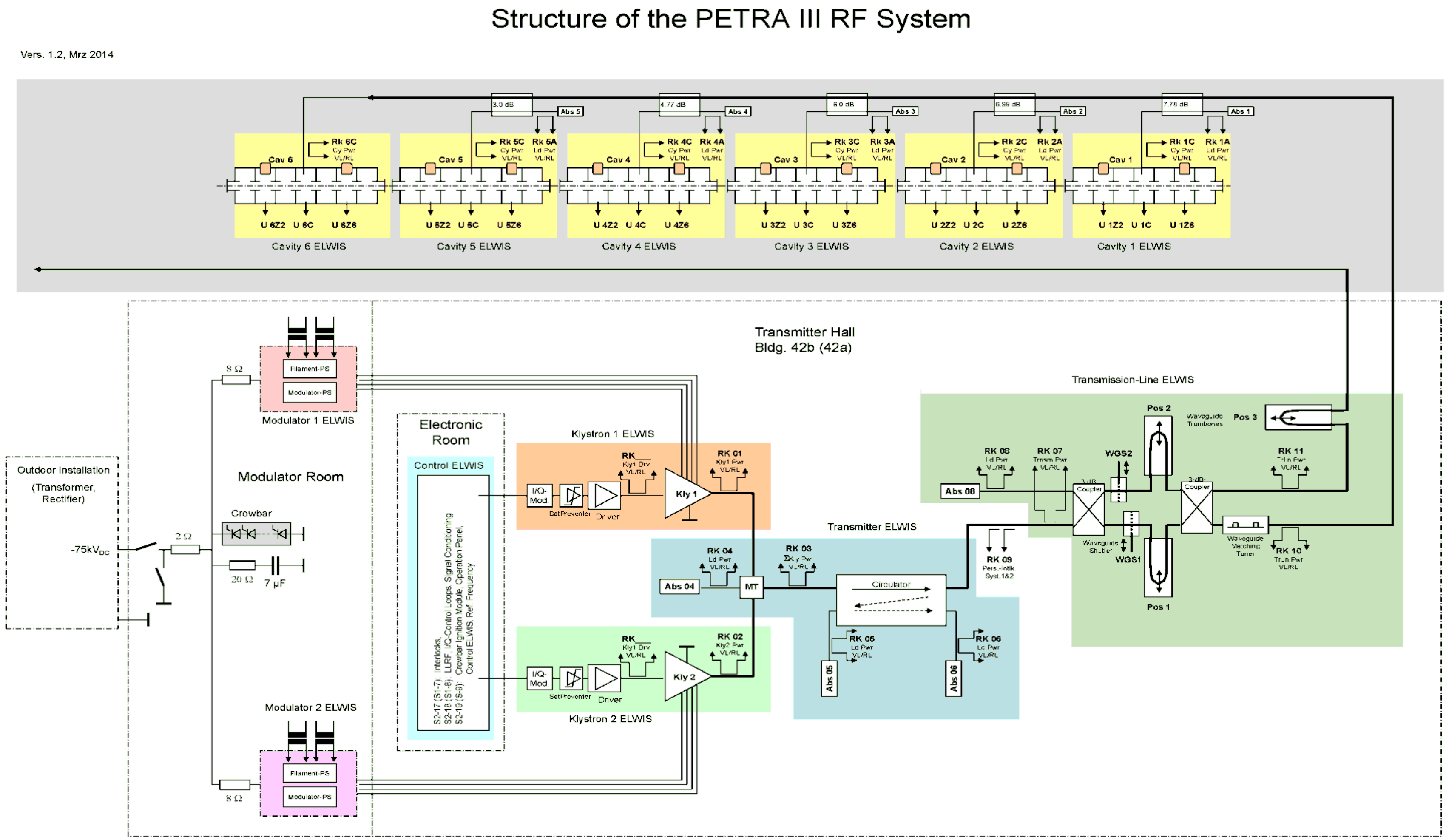
- Most of the failures have been understood and corrective actions have been done
- Downtime is substantially reduced
  - Strategies for “big events”
    - e.g. when to switch to 1 transmitter- operation
    - e. g. when to shunt a cavity
  - Future plan is a FSM to react on ṙ- events
- Reflected power interlocks are still not understood, perhaps tuner?

Recommendations

- Further investigations in ṙ-events should be made
- Exchange tuners at the shunted Cavity inspect them, bring the cavity back to operation
- Put RF- power test stand in operation a.s.a.p.
- Condition spare cavities
- Replace cavities that cause lots of reflected power interlocks

Annex

RF System Overview



Maintenance, Troubleshooting

To prevent trouble we do:

- Daily inspection of important logging data and transient recorder snapshots
- Several times a year test of coupler interlocks, klystron crowbar interlocks, cooling interlocks
- Several times a year exercising one-transmitter operation
- Once a year test of all functions & interlocks

For efficient fault location we use:

- Transient recorders: 220 channels, resolution: 4 µs
- Data logger: 290 channels, resolution: 1 s

For fast fault repair we provide:

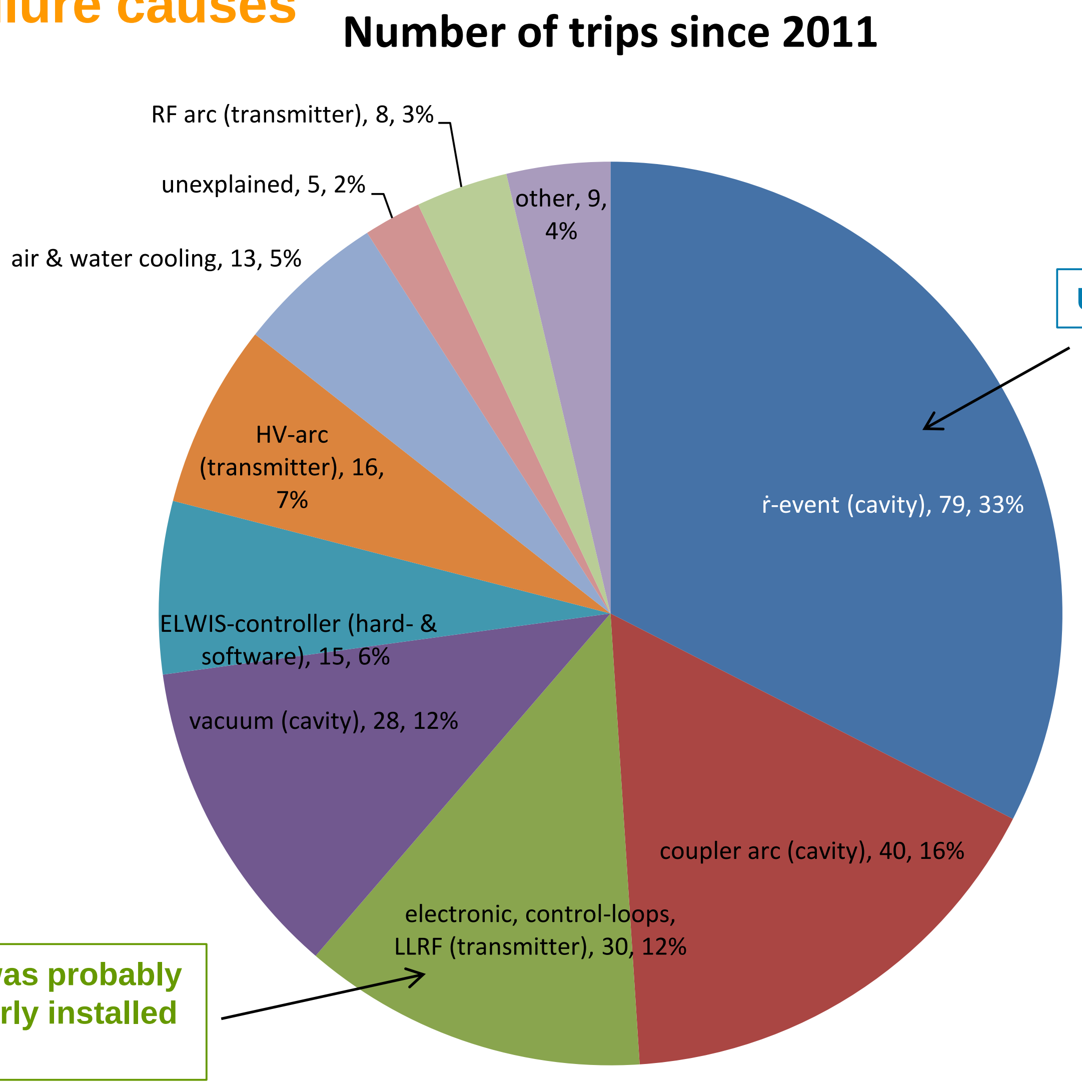
- 24/7 on-call duty
- Written troubleshooting instructions
- Spare parts on site

Summary

- The downtime of the rf systems could be reduced over the last few years more and more and was <1% in 2015
- Operating 4 cavities at significantly higher temperatures reduced the r° trip-rate by 21%
- Despite this, the rf trip-rate is still dominated by the ṙ-problem.
  Solving the ṙ-problem would increase the $MTBF_{RF}$ from 6,4 d to 15,9 d (and the $MTBF_{PETRA}$ from 1,4 d to 1,6 d)
- We believe to have the vacuum problem of SL_Cy2 under control
- We hope that we do not really need to replace the cavity
- We do not give up hope, to find the cause for the ṙ-events someday

Problems and Failures - Reliability

Ranking of failure causes

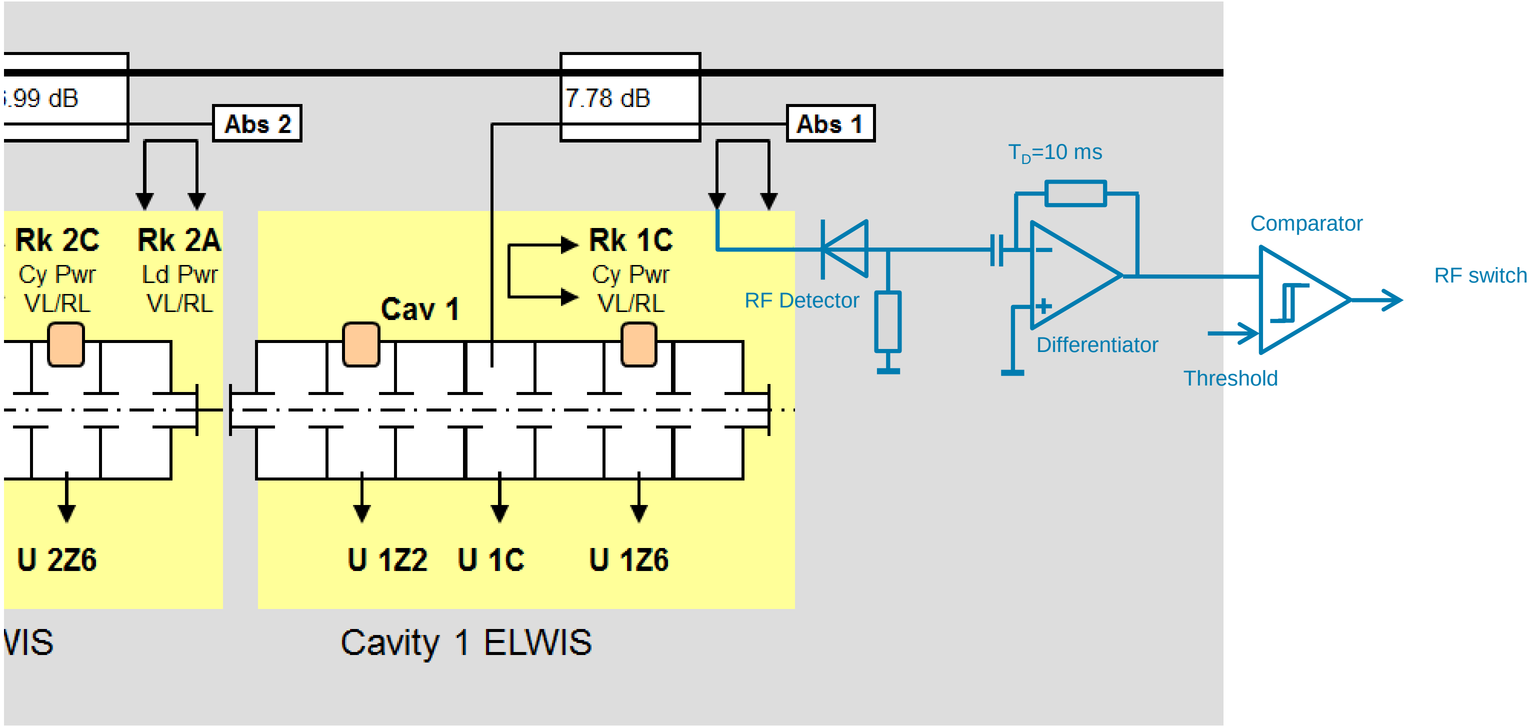


Unsolved problem

A significant part was probably caused by improperly installed RF connectors

Problems and Failures, ṙ- Interlock

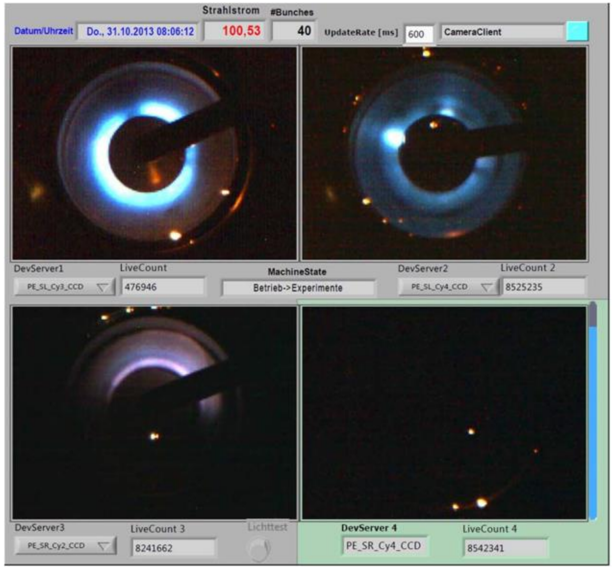
Technical realization of the ṙ-Interlock



Current Problem SL_Cy2

Cavity Test Stand

- 2013 we started to search a suitable place for a new cavity test stand.
- 2014 was decided to turn a former DORIS transmitter into a new klystron and cavity test stand.
- 2014: The problem of luminous couplers seemed to be more important at that time. Instead to built up a cavity test stand, a coupler test stand was built up next to a DESY transmitter.

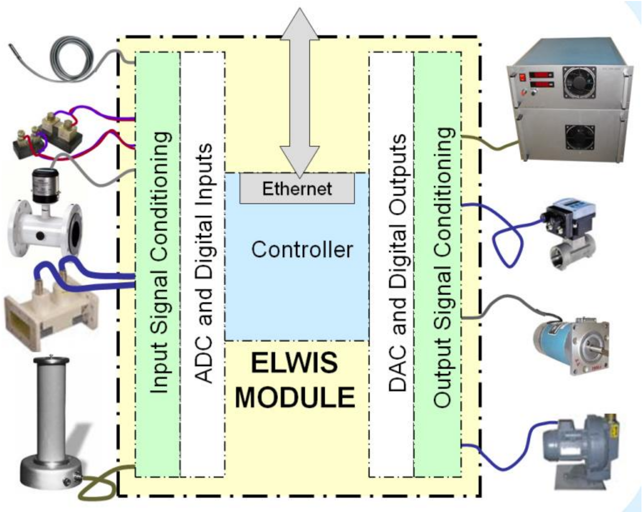


- 2015: Work on cavity test stand restarted
- Goal: Commissioning 1st quarter 2016
- **BUT** …

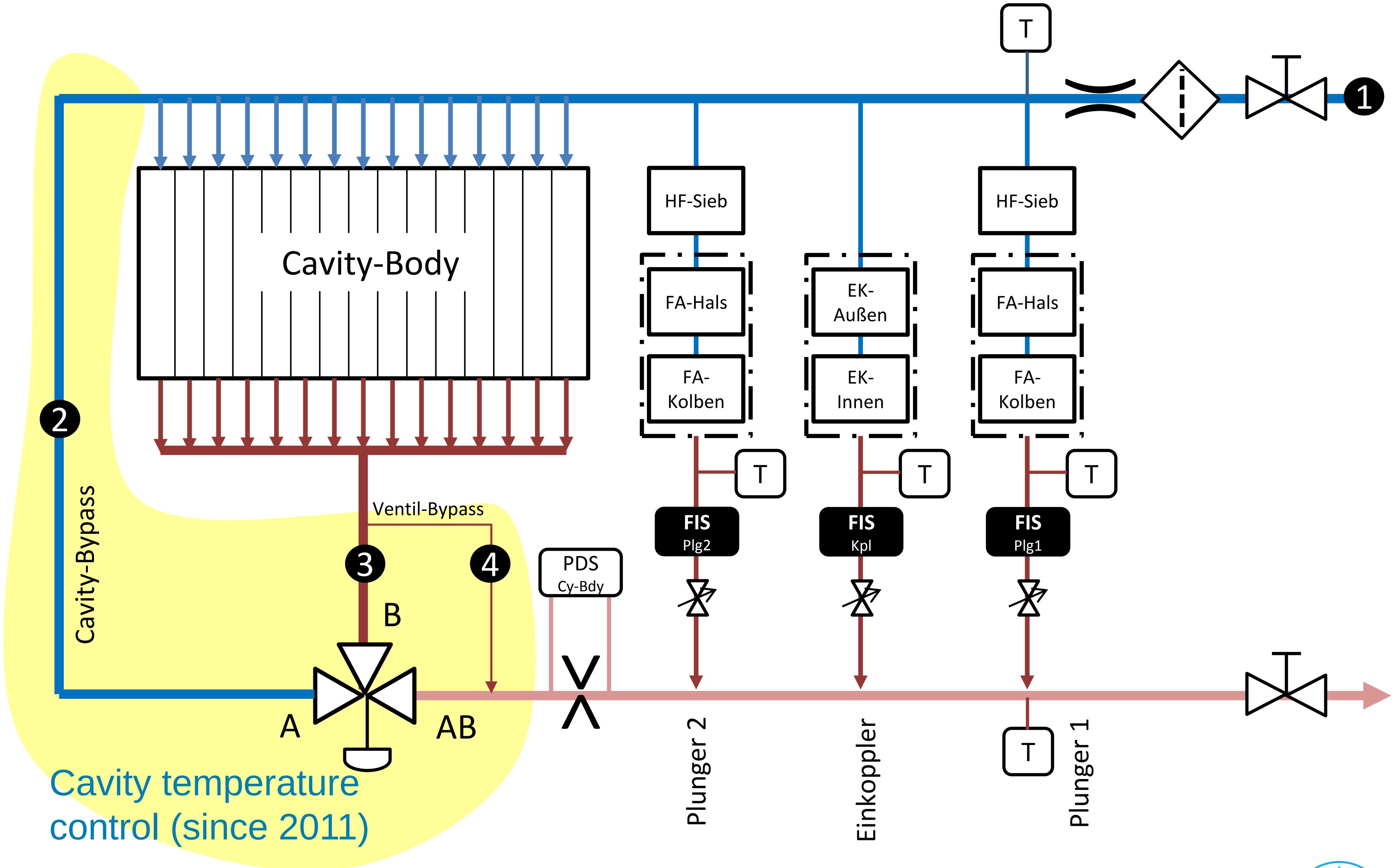
Maintenance, Troubleshooting

The automation system *ELWIS* was designed for fast & easy troubleshooting

- Consists on a distributed system of universal & identical control and interlock boxes
- The *ELWIS* modules are identical for all rf system components (klystron, cavity, modulator, etc.)
- Due to the distributed structure the signal cabling is minimized and clear
- **In many cases troubleshooting is reduced to simple replace, plug & play**



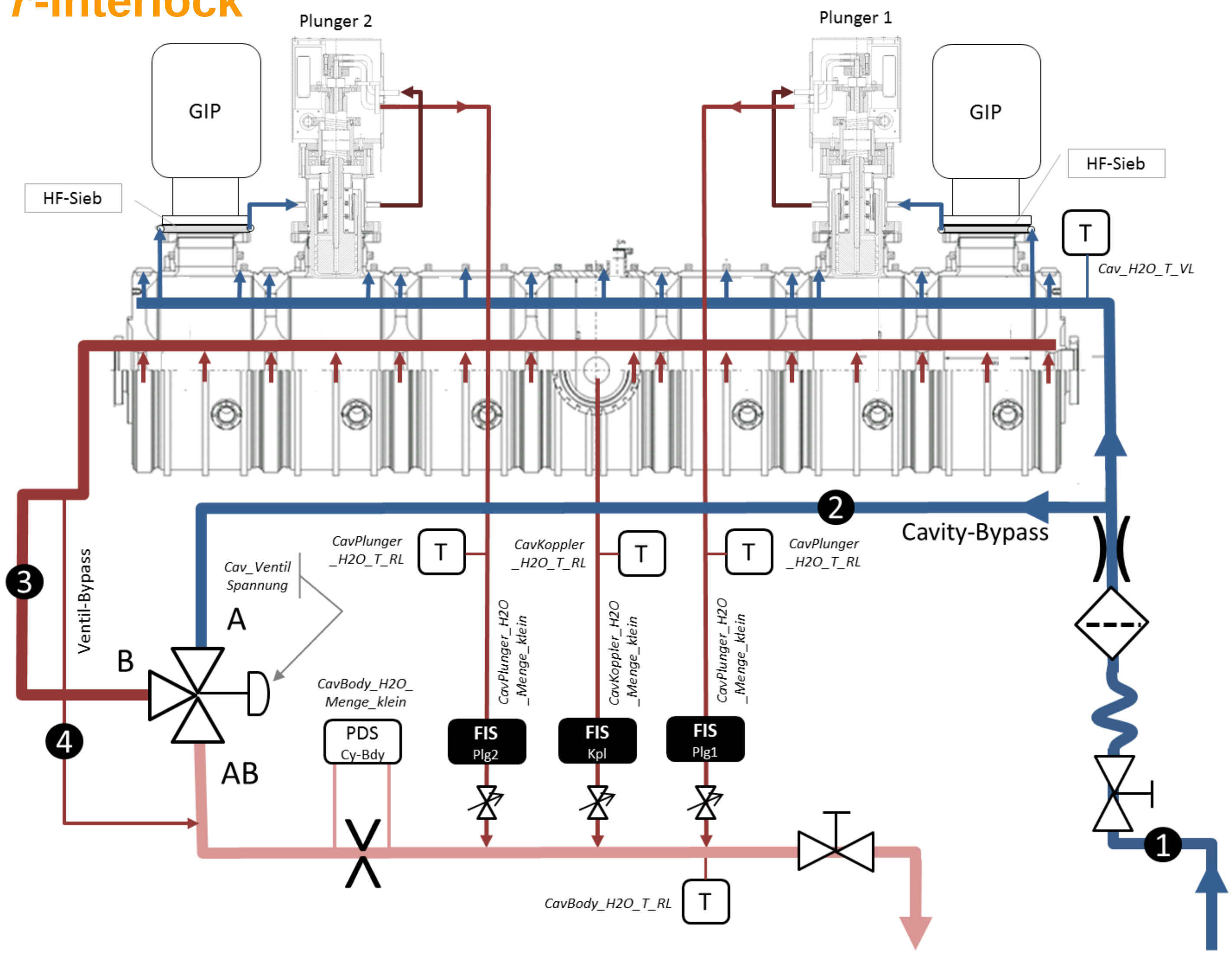
Problems and Failures, ṙ- events



Cavity temperature
control (since 2011)

Betriebserfahrungen und Maßnahmen seit 2009

ṙ-Interlock



2011

Ab März waren alle Cavities mit Temperaturregelungen ausgestattet.

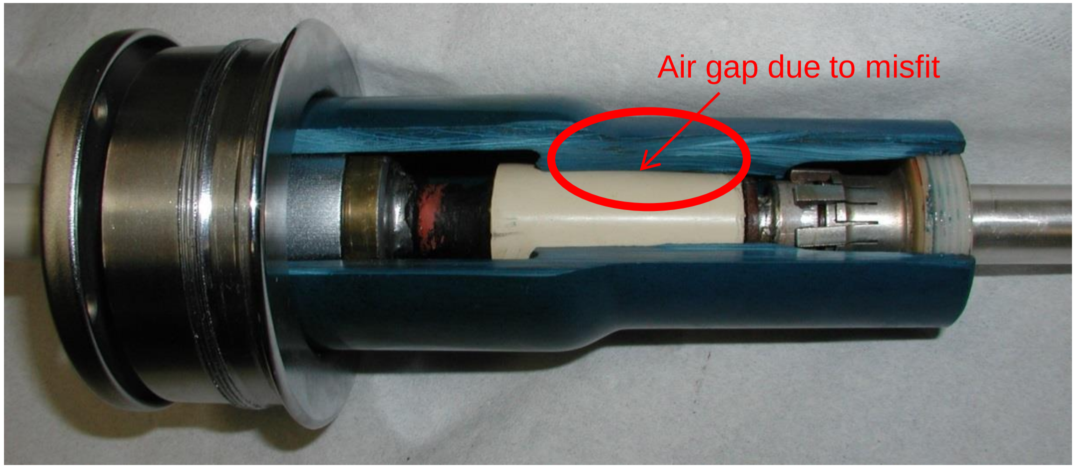
Empirisch wurde für jede Cavtiy eine „Wohlfühltemperatur“ gesucht.

Der Anteil der ṙ-Interlocks sank von 50% auf 30%.

Oder war es „nur“ ein Konditioniereffekt?

Large downtime causing single rf events

Klystron HV Connectors, 22 hours downtime



October 2011: Repeated crowbar-ignitions. Subsequent (unsuccessful) Troubleshooting led to an integrated downtime of 22 h in one week.

Cause: Flashovers inside plug and female connectors.

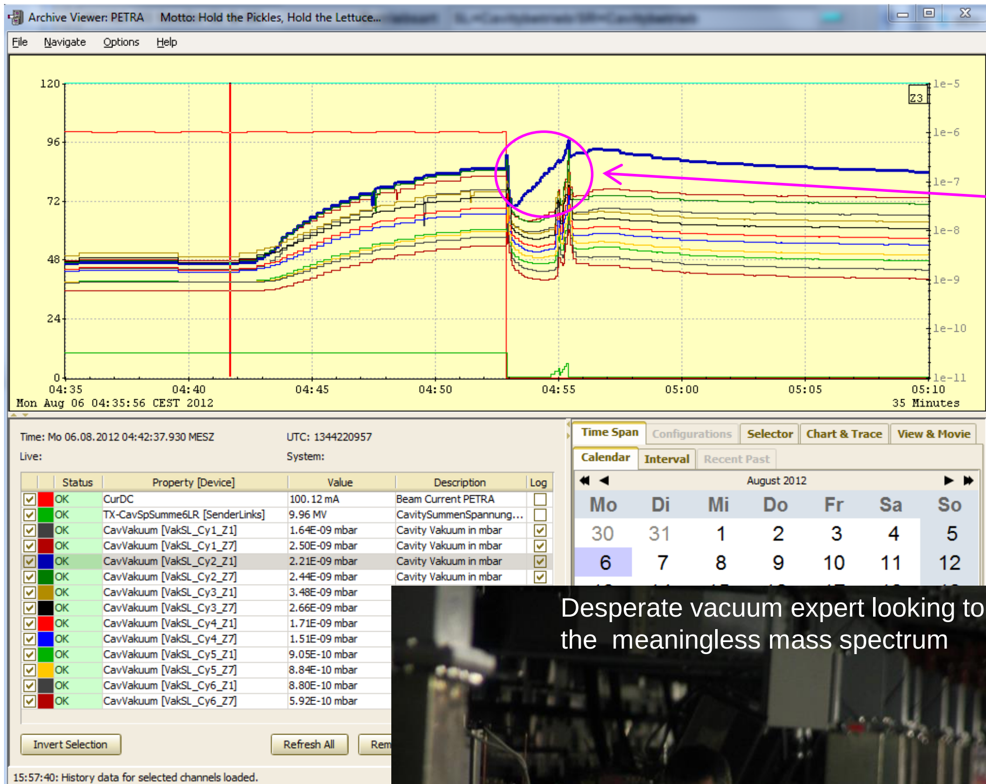
Analysis had shown, that the plugs of the new HV cables, not exactly fit to the older female connectors of the klystrons.

The misfit led to field-increasing air gaps inside the plug-female sets.

After all 32 male-female sets were revised the failure no longer occurred.

Large downtime causing single rf events

Cavity Vacuum (SL_Cy2), 56 hours downtime



August 2012: During the user-run the vacuum pressure began to increase. After 10 minutes the interlock shut off the transmitter.

Despite RF had been switched off, the pressure of one pump continued to rise!?

The vacuum experts could not find a leak.

The input coupler was vaguely suspected and has been changed – without real success.

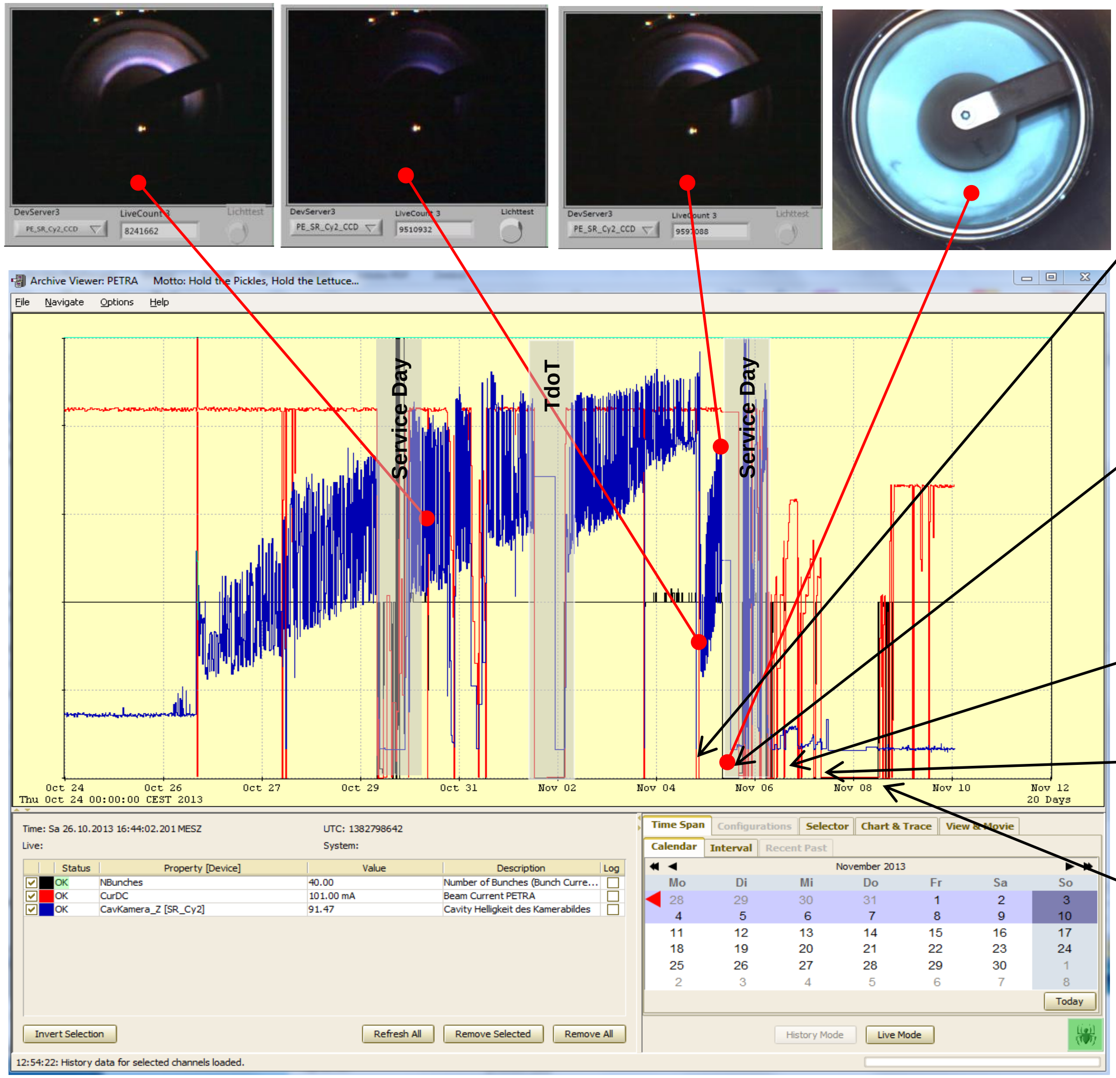
For further leak detection cooling circuits were drained and dried – again experts could find no leak.

Last desperate act: RF gently turned on and beam current slowly increased.

It worked. But the cause was not found until today.

Large downtime causing single rf events

Input Coupler SR_Cy2, 58 hours downtime



KW 45 2013:

5.11.2013:
2 x coupler arcing.
After cavity has been detuned by 6 degree, the problem seems to be solved.

6.11.2013:
Visual coupler inspection showed grey smear on the ceramic. But this is not uncommon and must not be a problem

6.-7.11.2013:
Lots of coupler arcing & vacuum events.

8.11.2013:
On Friday morning was decided to replace the coupler

9.11.2013:
On Saturday afternoon gently restart of beam operation