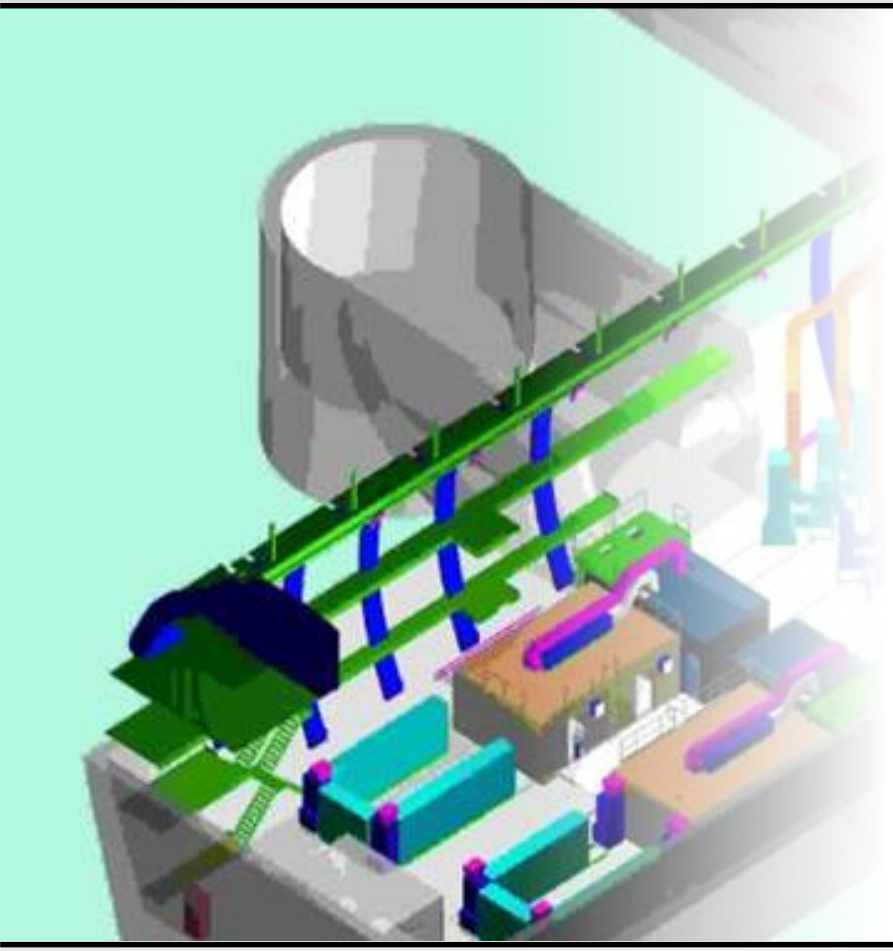
LHC RF system reliability

obrunner

With grateful appreciation to L. Arnaudon and the RF standby members

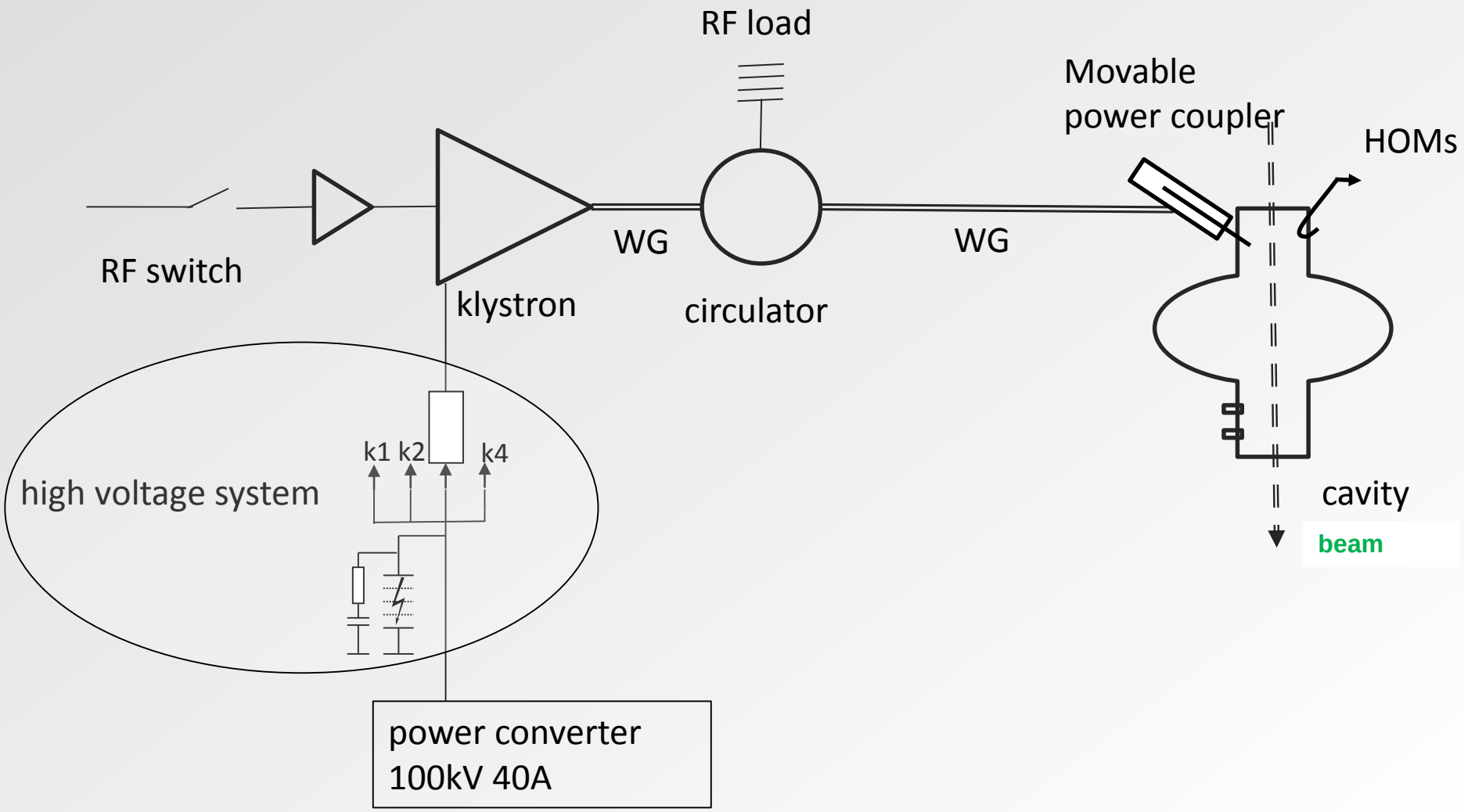
The LHC RF System



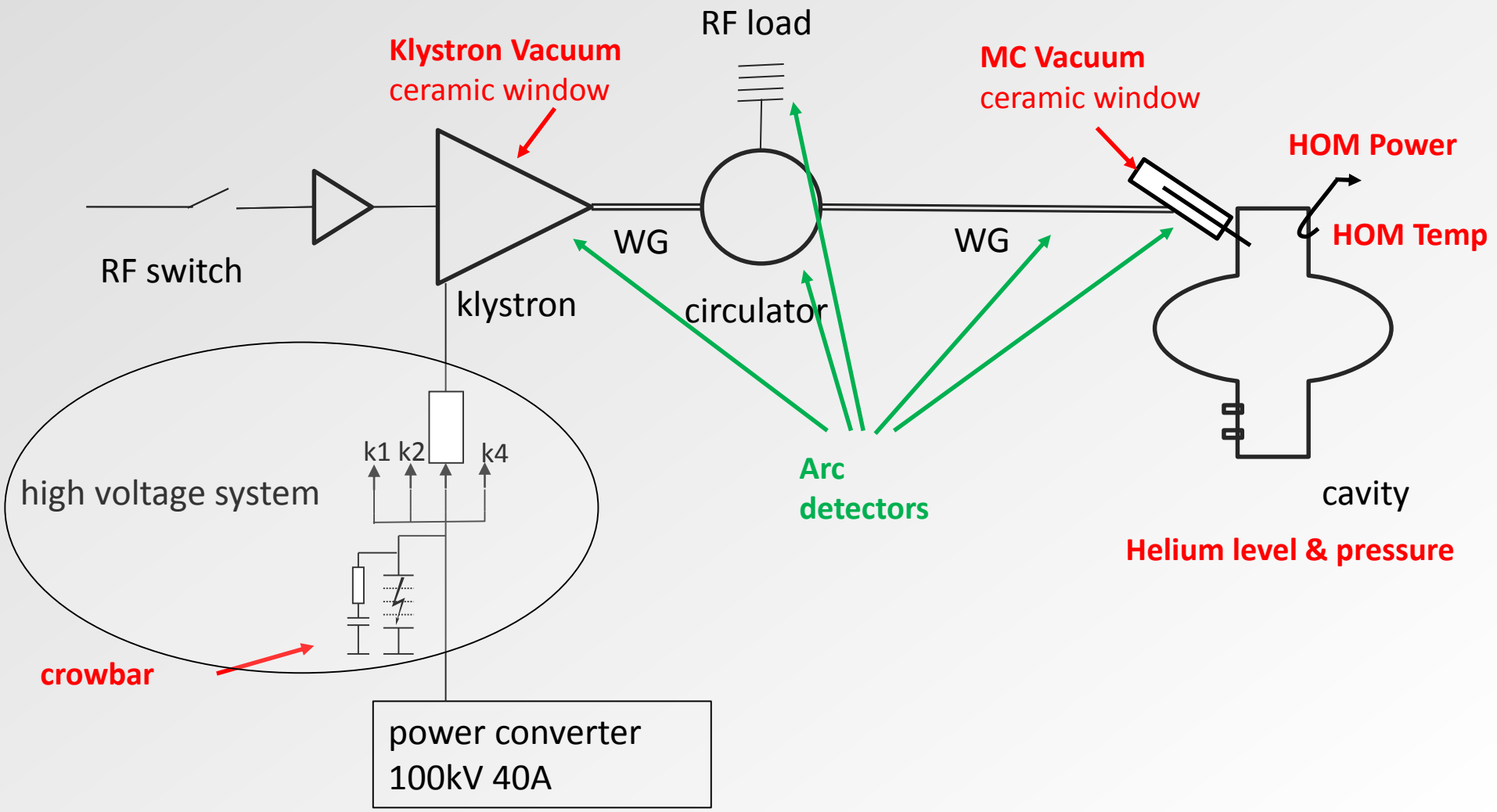
- 16 Klystrons
- 4 SC Cavity Modules
- 300 kW @ 400 MHz

- 1000 Interlocks (60 types)
- All connected to the beam dump

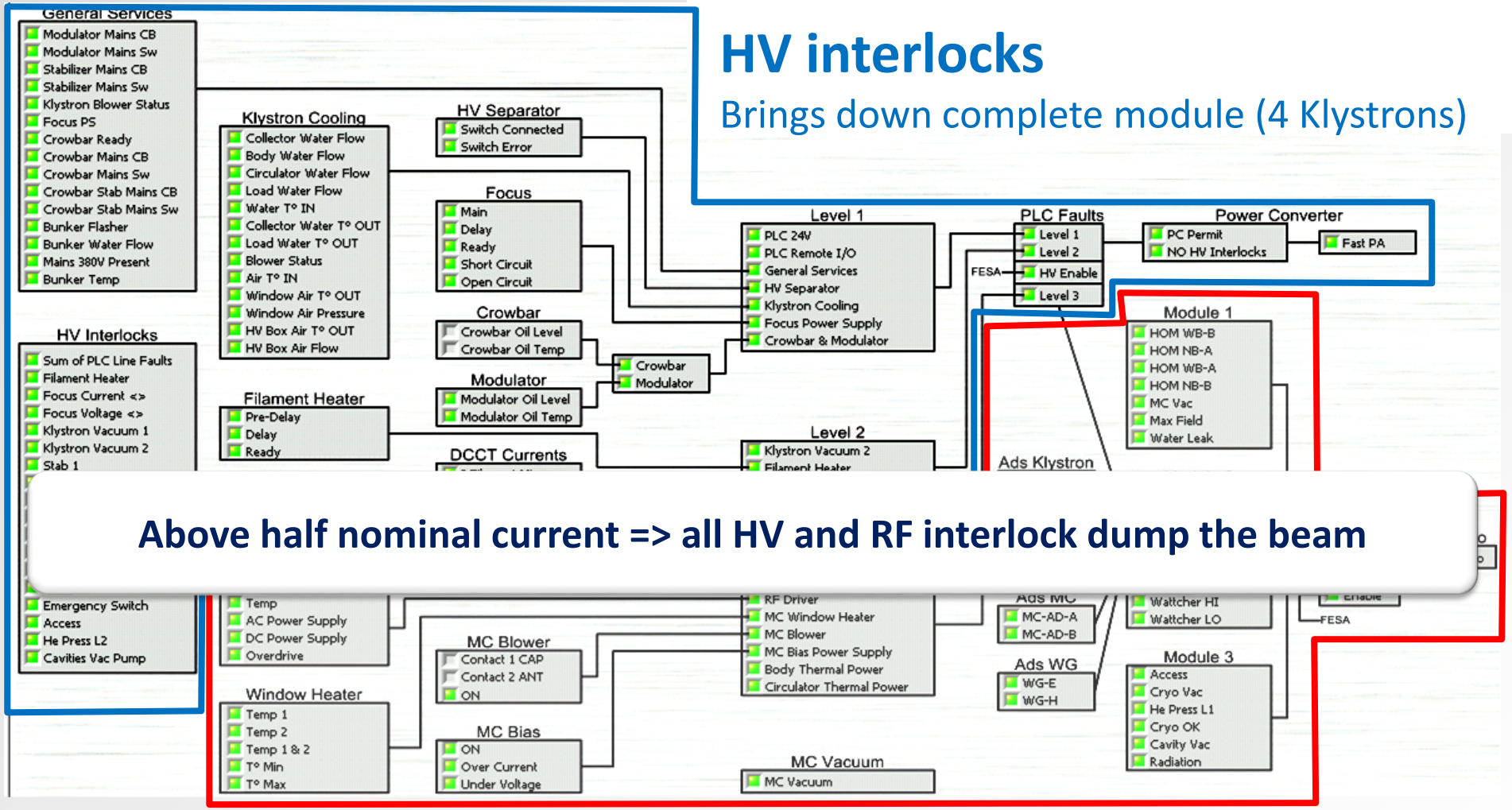
RF Unit


RF load
Movable
power coupler
HOMs
RF switch
WG
WG
klystron
circulator
high voltage system
k1 k2
k4
cavity
beam
power converter
100kV 40A

Critical interlocks



RF and HV interlock chains



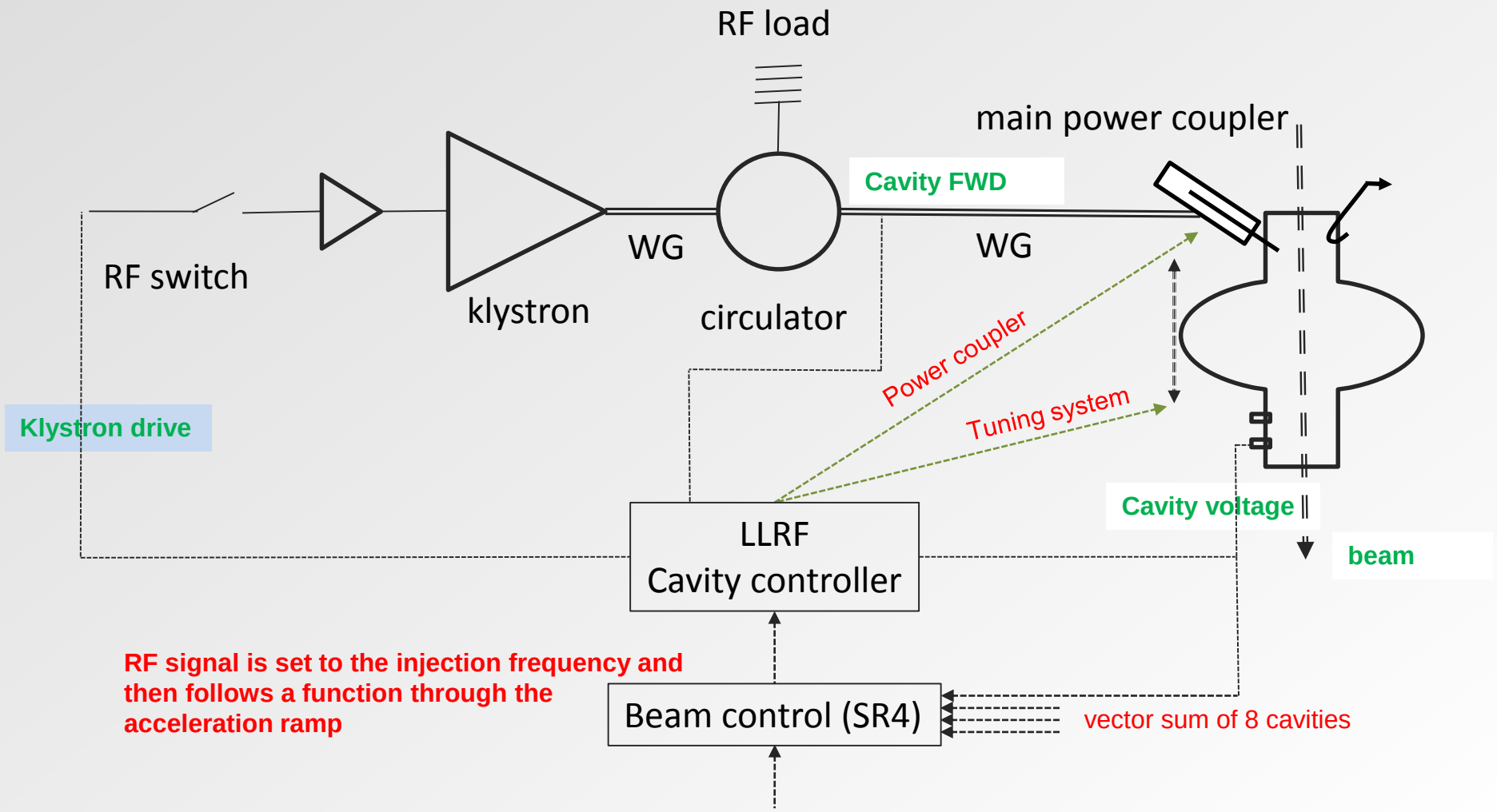
HV interlocks

Brings down complete module (4 Klystrons)

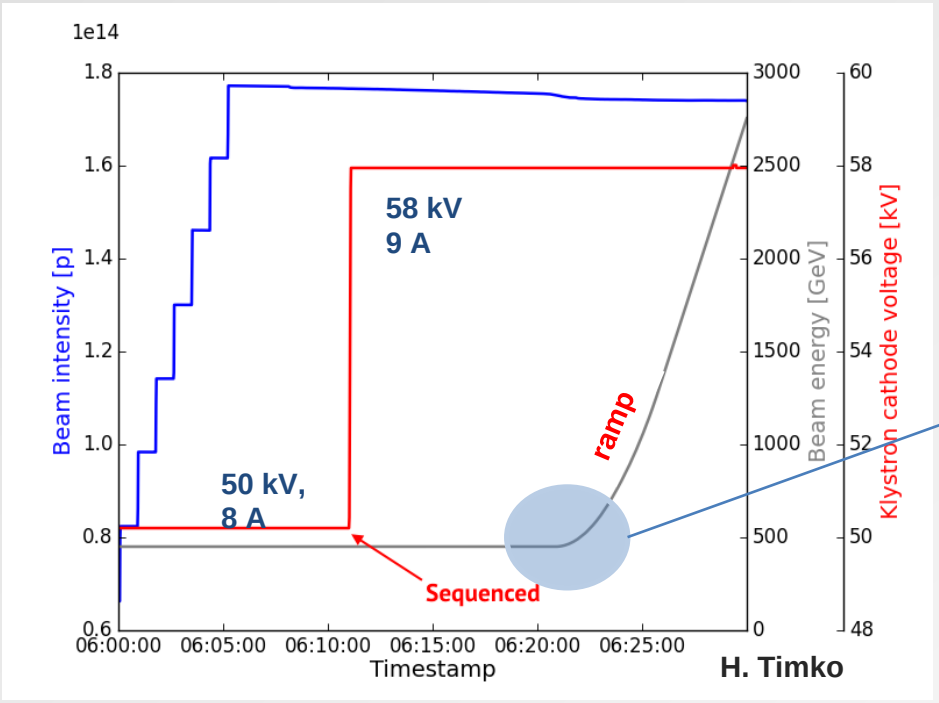
Above half nominal current => all HV and RF interlock dump the beam

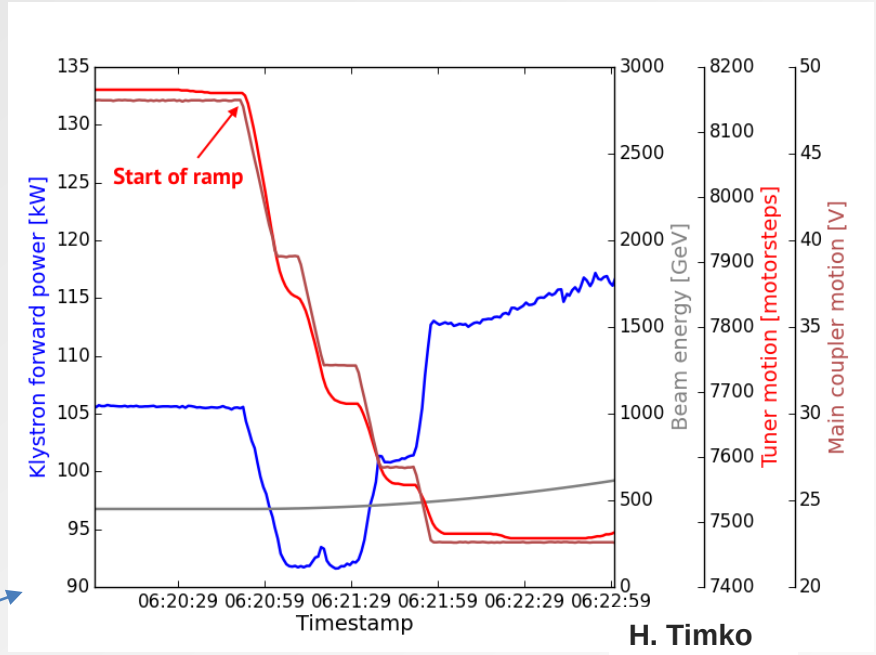
RF interlocks (Trips 1 Klystron)

LLRF system


RF load
main power coupler
Cavity FWD
RF switch
WG
WG
klystron
circulator
Power coupler
Tuning system
Klystron drive
Cavity voltage
beam
LLRF
Cavity controller
RF signal is set to the injection frequency and then follows a function through the acceleration ramp
Beam control (SR4)
vector sum of 8 cavities

LLRF gymnastics

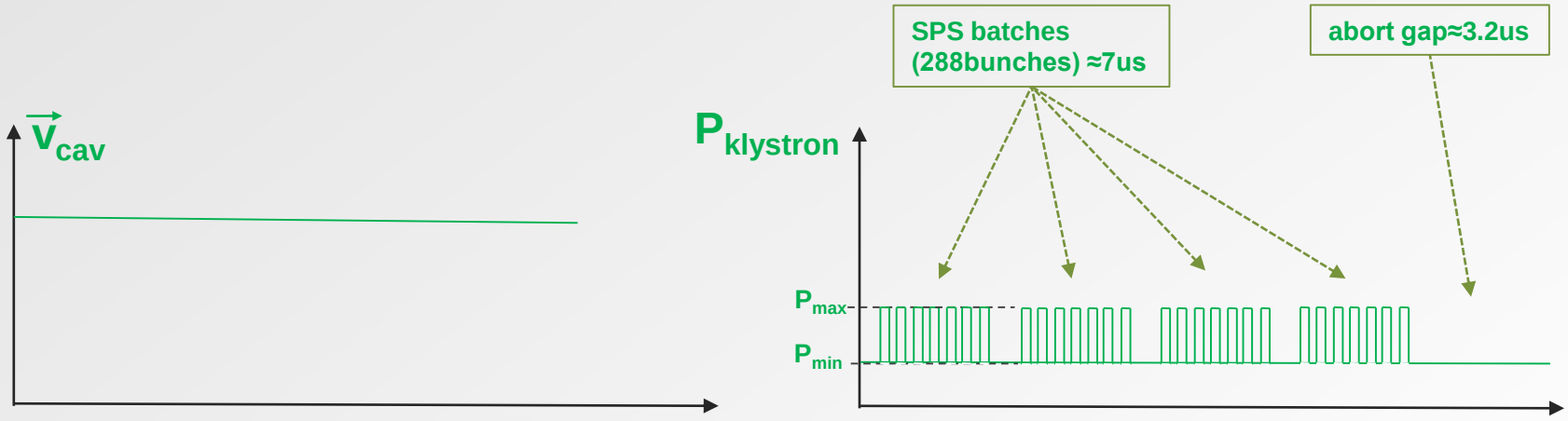




See Helga's presentation

LHC operating scheme

- The LHC beam consists of alternating bunch trains and gaps
- To keep the beam stable in the machine, the beam loading effects have to be compensated
- Klystrons consume constant DC power => minimise the RF power over one turn (in coast)
- The “half detuning scheme” is optimum:
  - the cavity is detuned to half the value corresponding to minimum for a beam without gaps
  - the klystron power toggles between beam and no beam segments



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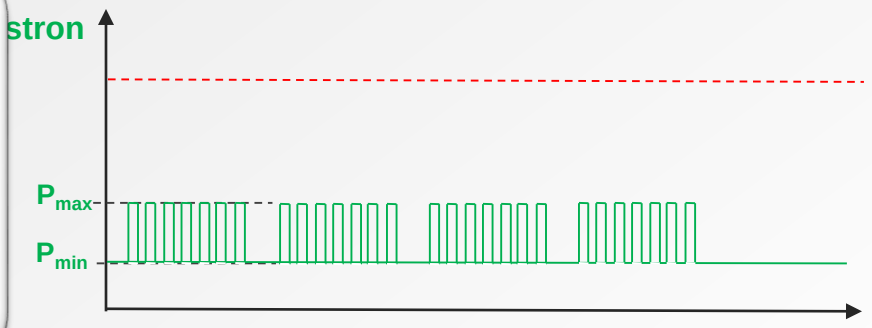
With the increased beam current, the tuning loops around the RF cavities require more RF power and finer adjustments

2015: nominal intensity : 1.15e11 p/bunch
2244 bunches, 10MV => at the limit with 250 – 280 kW)

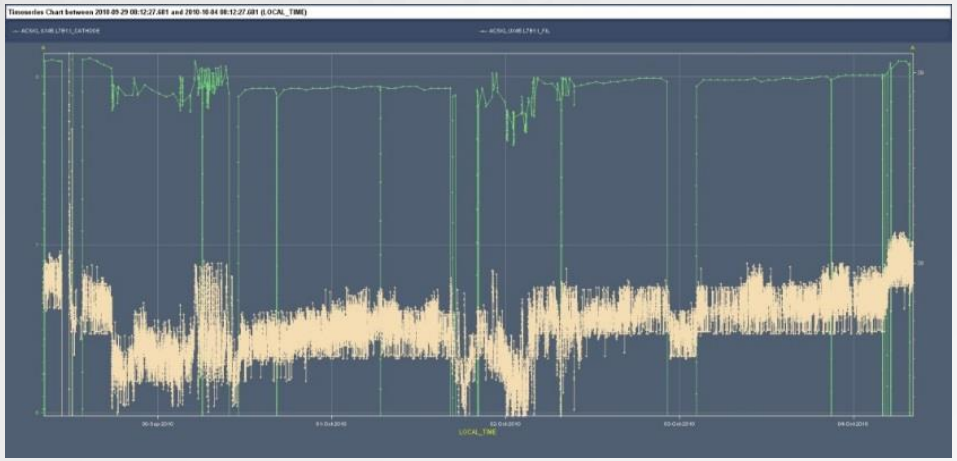
2016: klystrons, MC couplers & cavities will be conditioned to 300 kW



Performances in operation

Summary of Run 1 & LS1

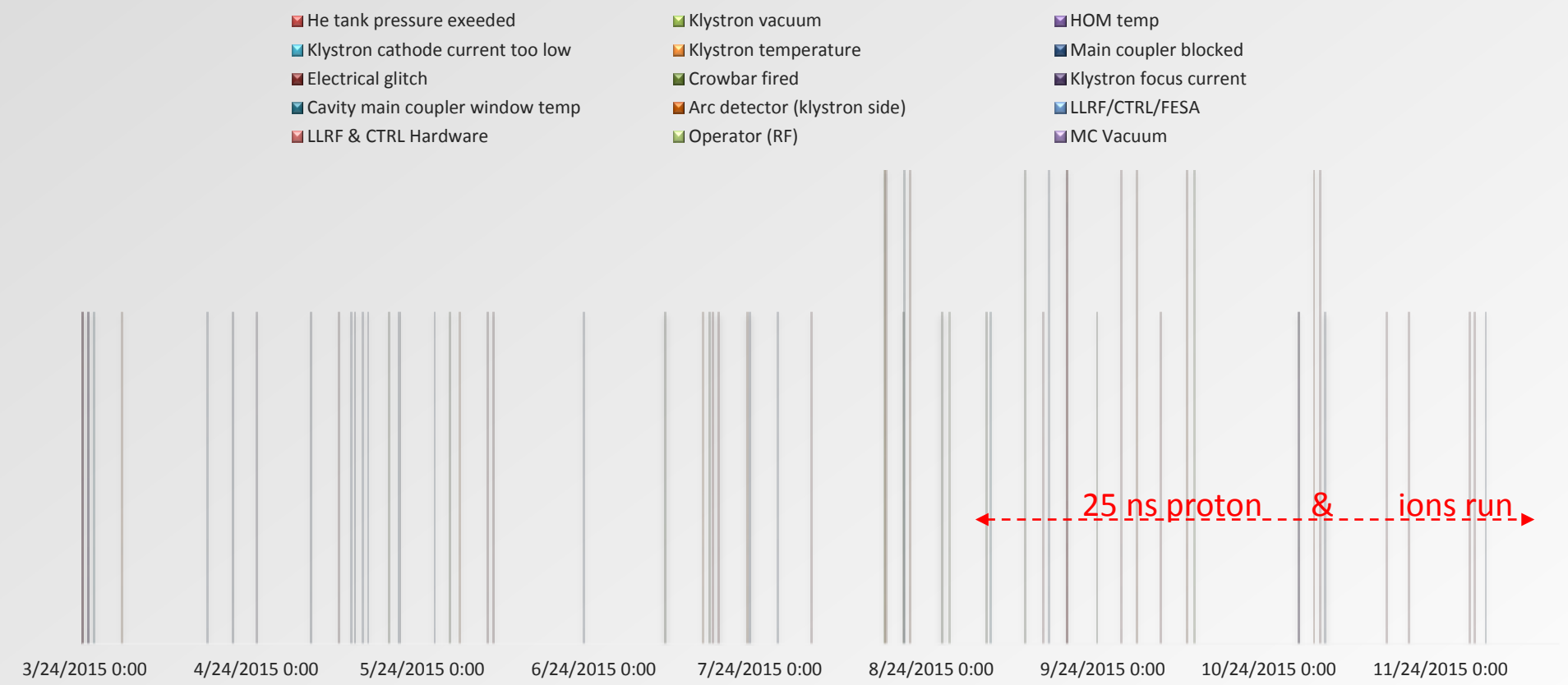
- Statistic of RF faults dominated by:
  - Spurious crowbar trips
  - Klystron filament glitches



- All HV connectors were found defective => repair campaign
- Crowbars: Thyratrons replaced by Solid State devices (better performances & reliability)
- 8/16 klystrons replaced – age profile

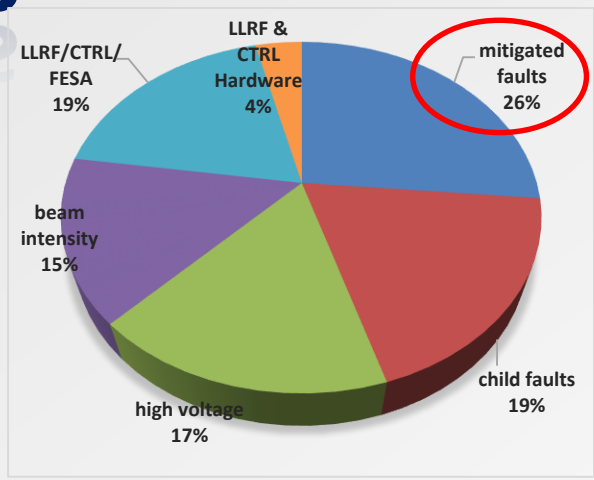
No more klystron filament glitches
No more spurious crowbars trips

LHC run 2: all RF trips



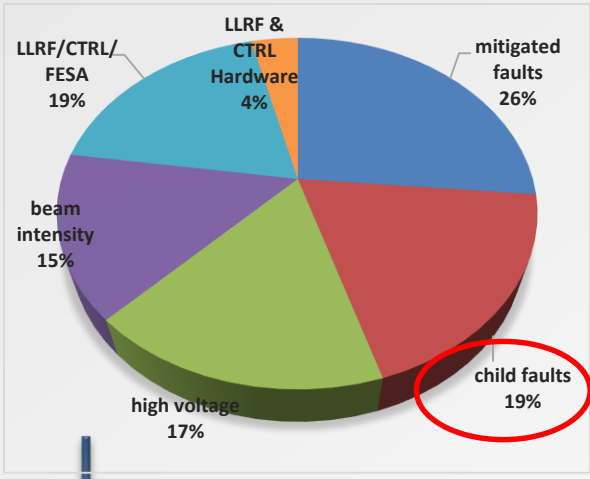
- 57 trips recorded
- 13 beam dumps (higher bars) – 7 during 25 ns run
- 15 categories

Mitigated faults



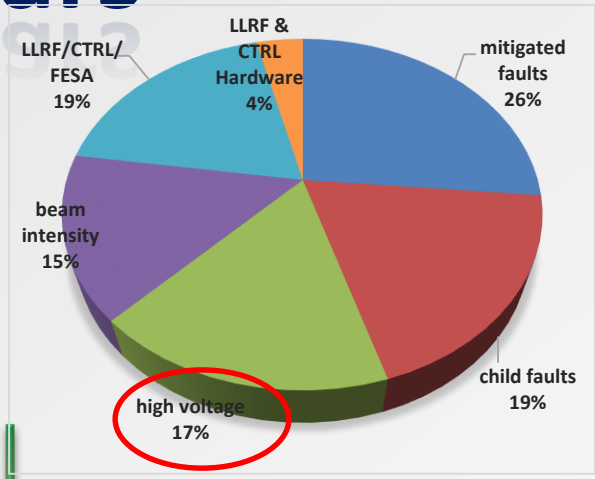
- Interlock levels
- Main coupler blocked: communication protocol error in control card. Solved during TS1
- Temperature glitches: Solved during TS2
- No trips since mid-September

“Child” faults



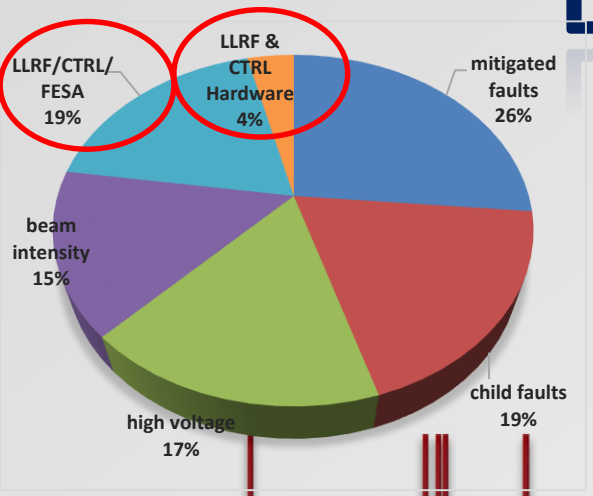
- Electrical glitches : e.g. thunderstorms
- Loss of cryogenic conditions: related to the increase of beam intensity (heat load on beam screen)
- 2/13 beam dumps

HV system: crowbars



- Major cause of trips during run1
- All “real” crowbars (klystron vacuum activity)
- ALL (except 1) soon after restarting the RF system (in particular after long periods at 10kV)
- 1 beam dump

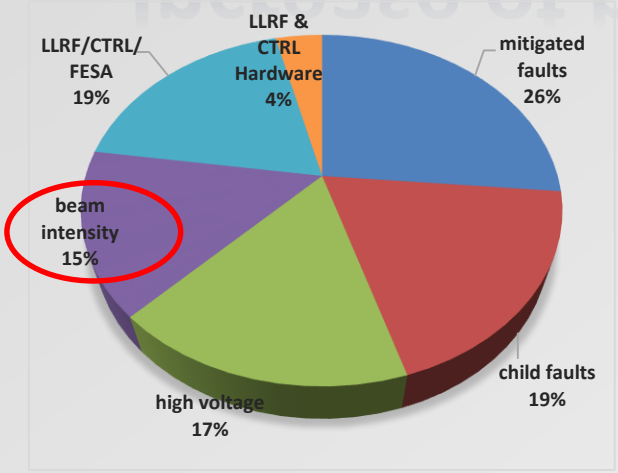
LLRF and control



More and more frequent trips
Aging of equipment ?
Spare management is essential

- Reboot, FESA hiccups, loss of RF frequency reference
- Several LLRF cards, PLC/CTRL IO modules, 5V power supplies replaced
- 3/13 beam dumps

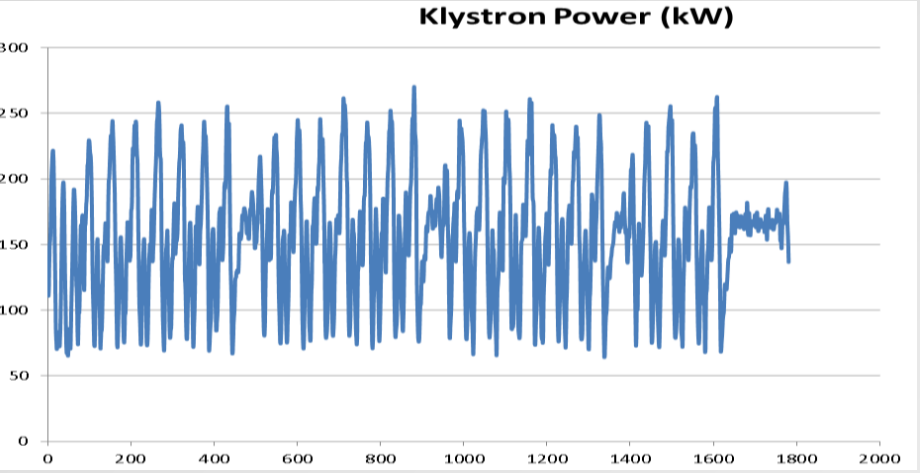
Increase of beam intensity (& RF power)

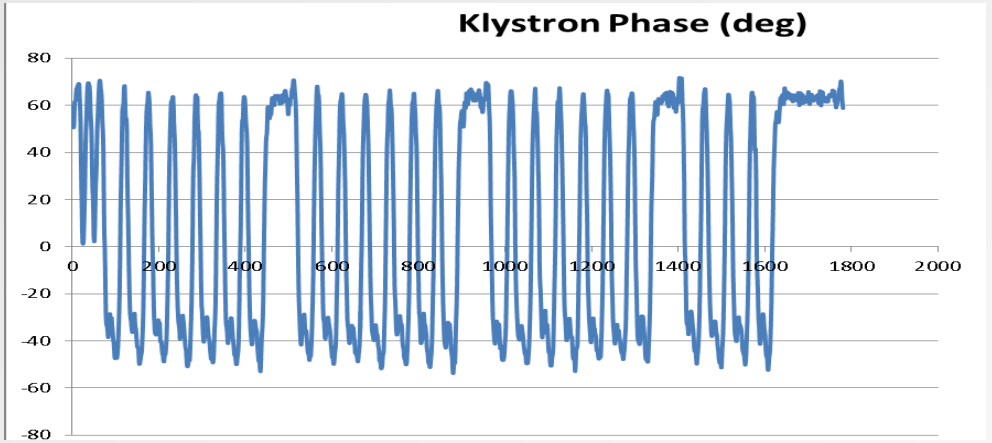


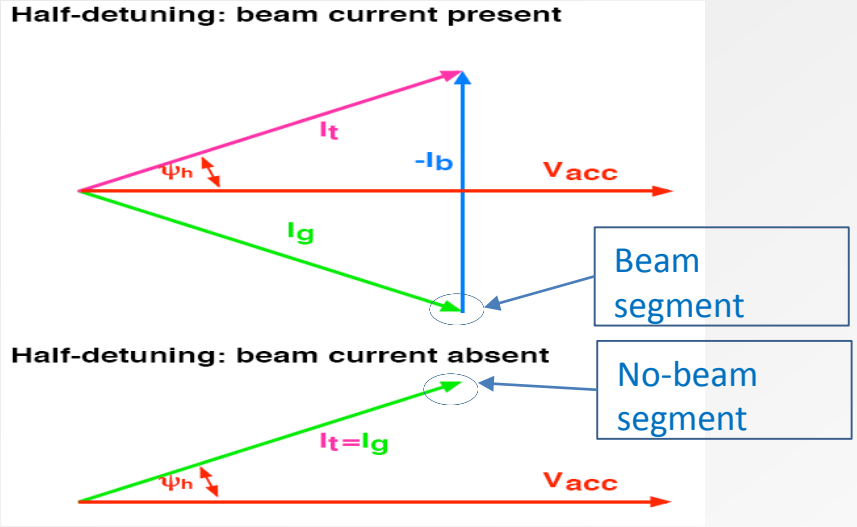
- Klystron vacuum: Klystron oversaturated => LLRF fine adjustment
- Cavity main coupler window overheated => Better cooling system under study
- Arc detector: no evidence of real arcs!. Maybe radiation induced? =>YETS: modif + diagnostic system
- 7 beam dumps (50%)

Conclusions

- Work done during LS1 and along run 2 proved to be effective -> No spurious trips since TS2
- More frequent (minor) hardware failures!
  - Only very few LLRF spares!
  - Replacement campaign during YETS (e.g. 5V P.S.)
- With increasing beam intensity the system is more sensitive:
  - The RF system is approaching its limits - > time needed for RF conditioning & LLRF setup
  - Arc detectors trips do not seem –all- real! -> new configuration and new diagnostic system installed during YETS







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