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Machine Protection backbone: Upgrades

Session 5: Machine Protection and availability

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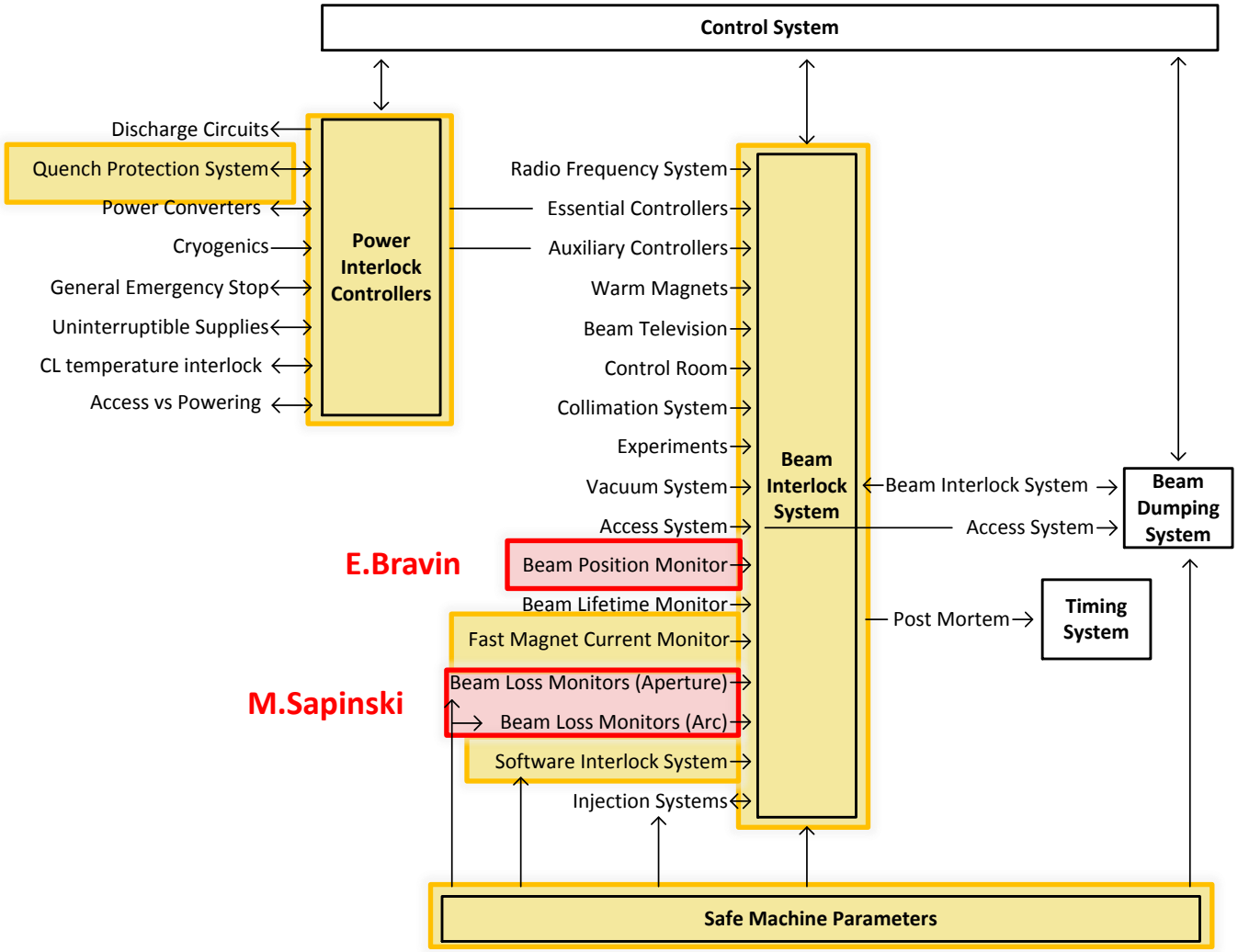
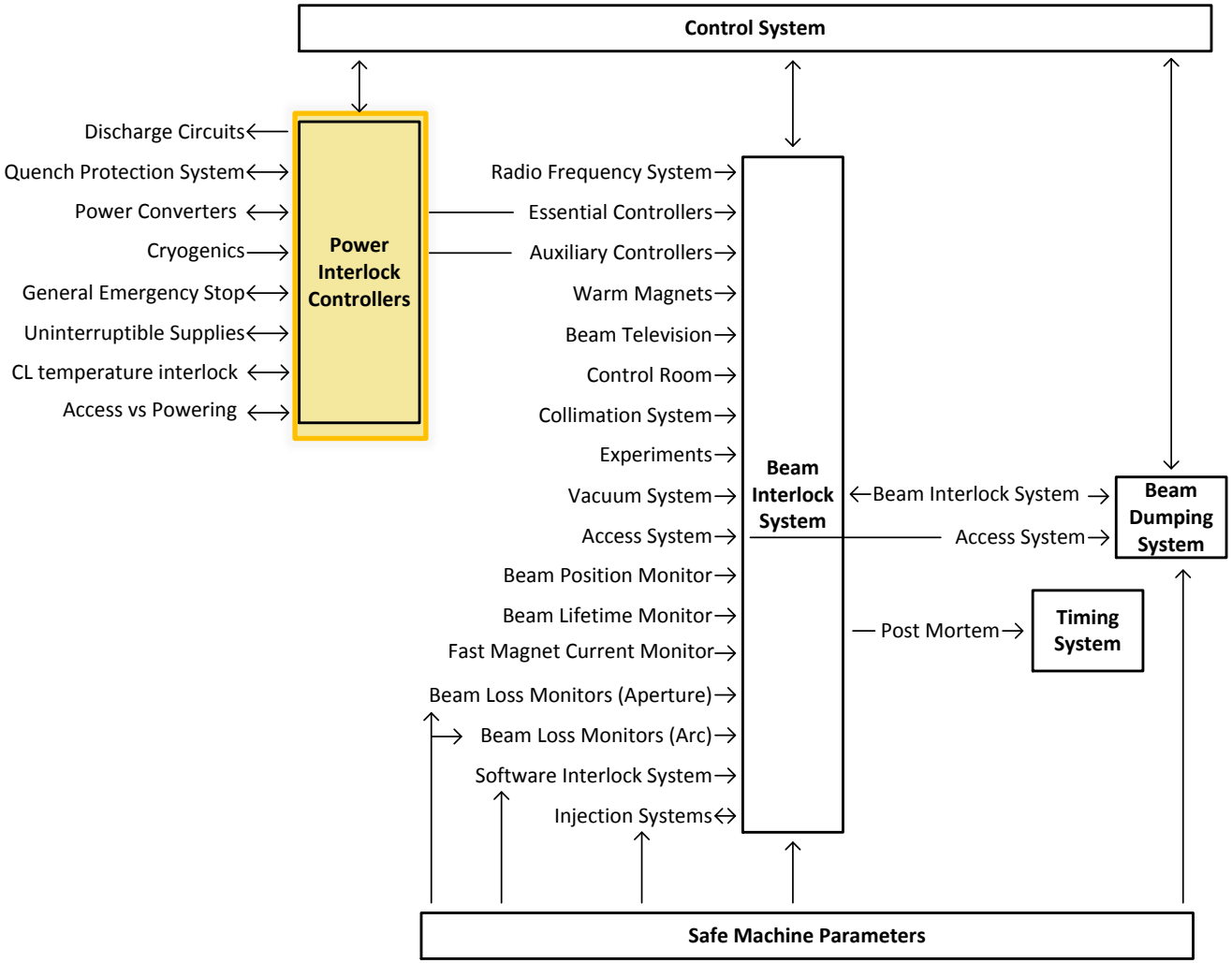
Acknowledgments: R.Denz, S. Gabourin, J.Wenninger, M.Zerlauth and many other colleagues

5th Evian Workshop – 2-4 June 2014

LHC Machine Protection System

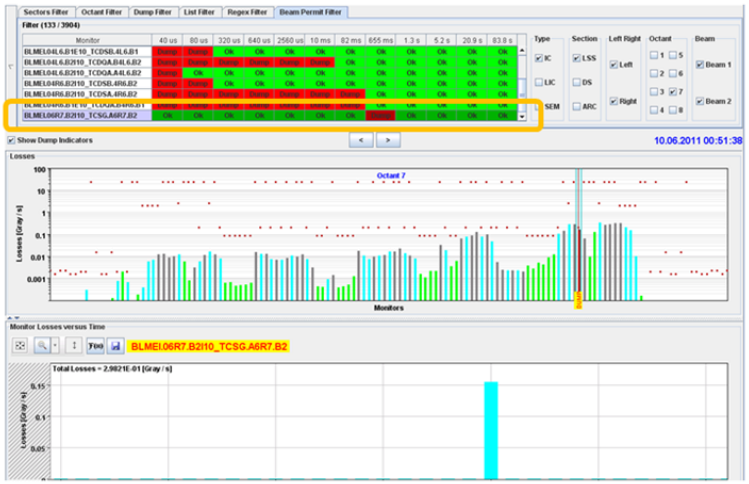


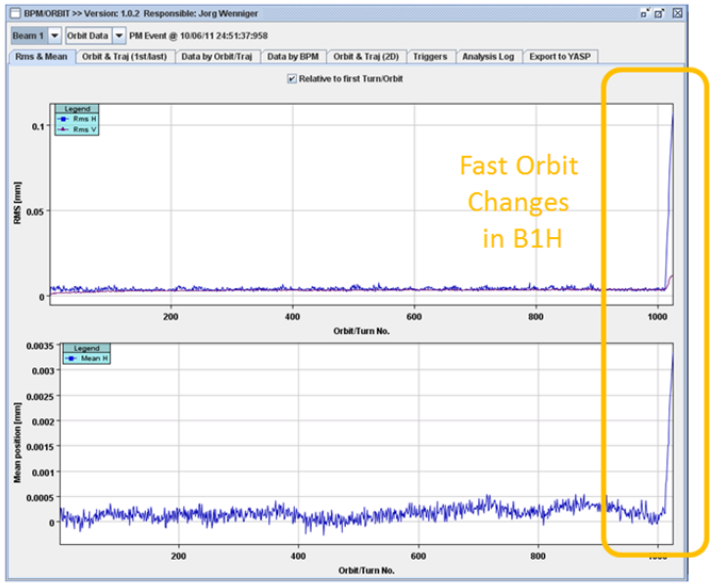
Magnet Protection



Electrical circuit definitions

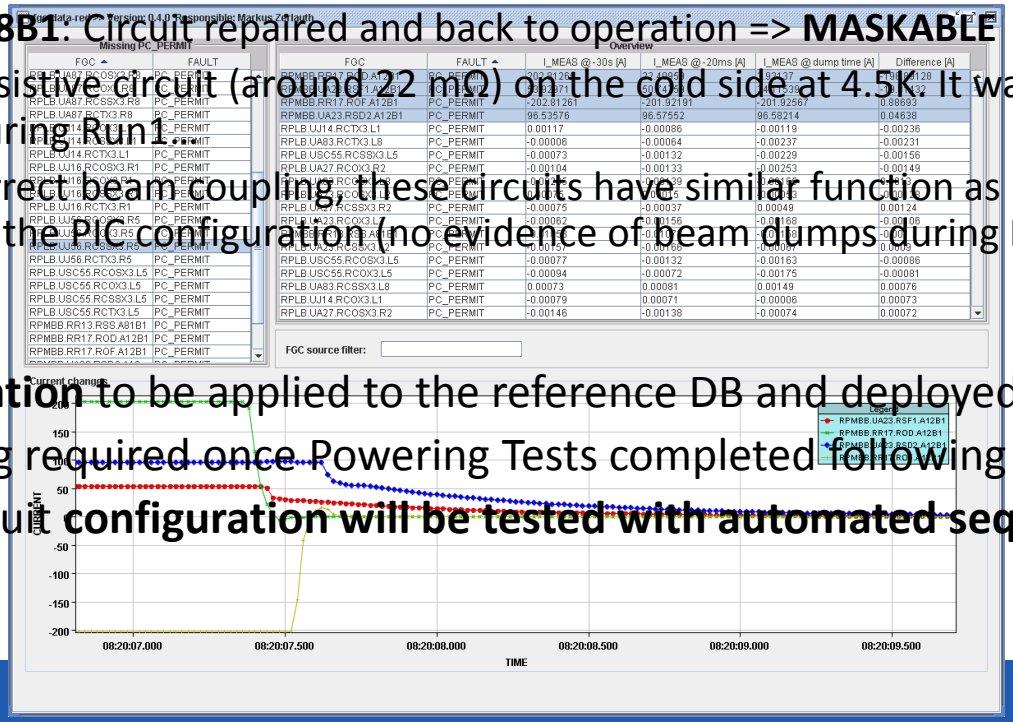
- Definition of **essential and auxiliary circuits** embedded on the PIC
  - "**Essential circuits**" => Beam dump under any condition (including safe beams)
  - "**Maskable circuits**" => Beam dump if unsafe beams - can be masked as f(SBF)
  - "**None**" => No impact on beam
- **No difference** between Essential and Maskable definition **with unsafe beams!**
- **RQSX3 included in the list of maskable circuits** during Run1 after trip provoking fast orbit changes and beam losses in SR7 [1]





Electrical circuit definition – Run2 proposal

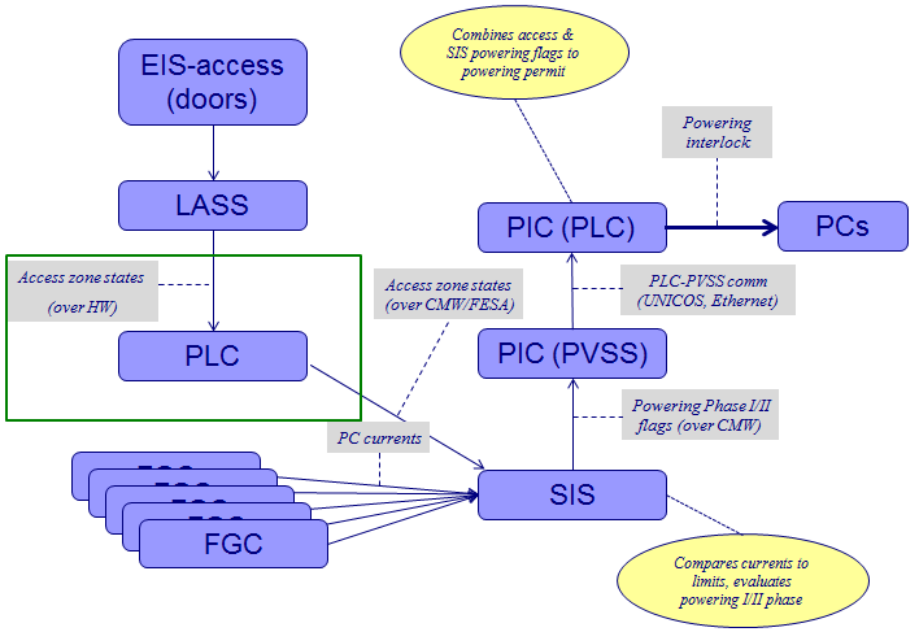
- During Run1:
  - RB, RQD, RQF, RQX, RD1-4, RQ4-RQ10 as **ESSENTIAL**
  - RCS, RQT%, RSD%, RSF%, RCBXH/V and RCB% as **MASKABLE**
  - RCD, RCO, ROD, ROF, RQS, RSS **no impact**
- Run 2:
  - **ROD/ROF**: Trips on such circuits provoked several dumps due to EMC on neighbouring circuits (typically RSF and RSD) => **MASKABLE**
  - **RCBCHS5.L8B1**: Circuit repaired and back to operation => **MASKABLE**
    - Highly resistive circuit (around 22 mΩ) on the cold side at 4.5K. It was replaced by a nc circuit during Run1…
  - **RQS**: To correct beam coupling, these circuits have similar function as RQSX3, which were included in the PIC configuration (no evidence of beam dumps during Run1…) => **MASKABLE**

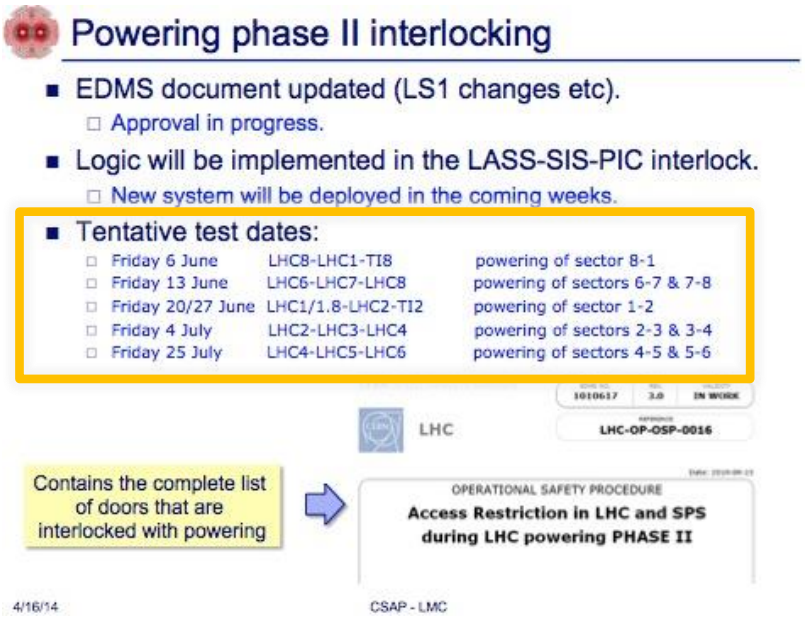


- **New configuration** to be applied to the reference DB and deployed in the PIC
- Commissioning required once Powering Tests completed following the procedure [2]
- Consistent circuit **configuration will be tested with automated sequence** in ACCTESTING

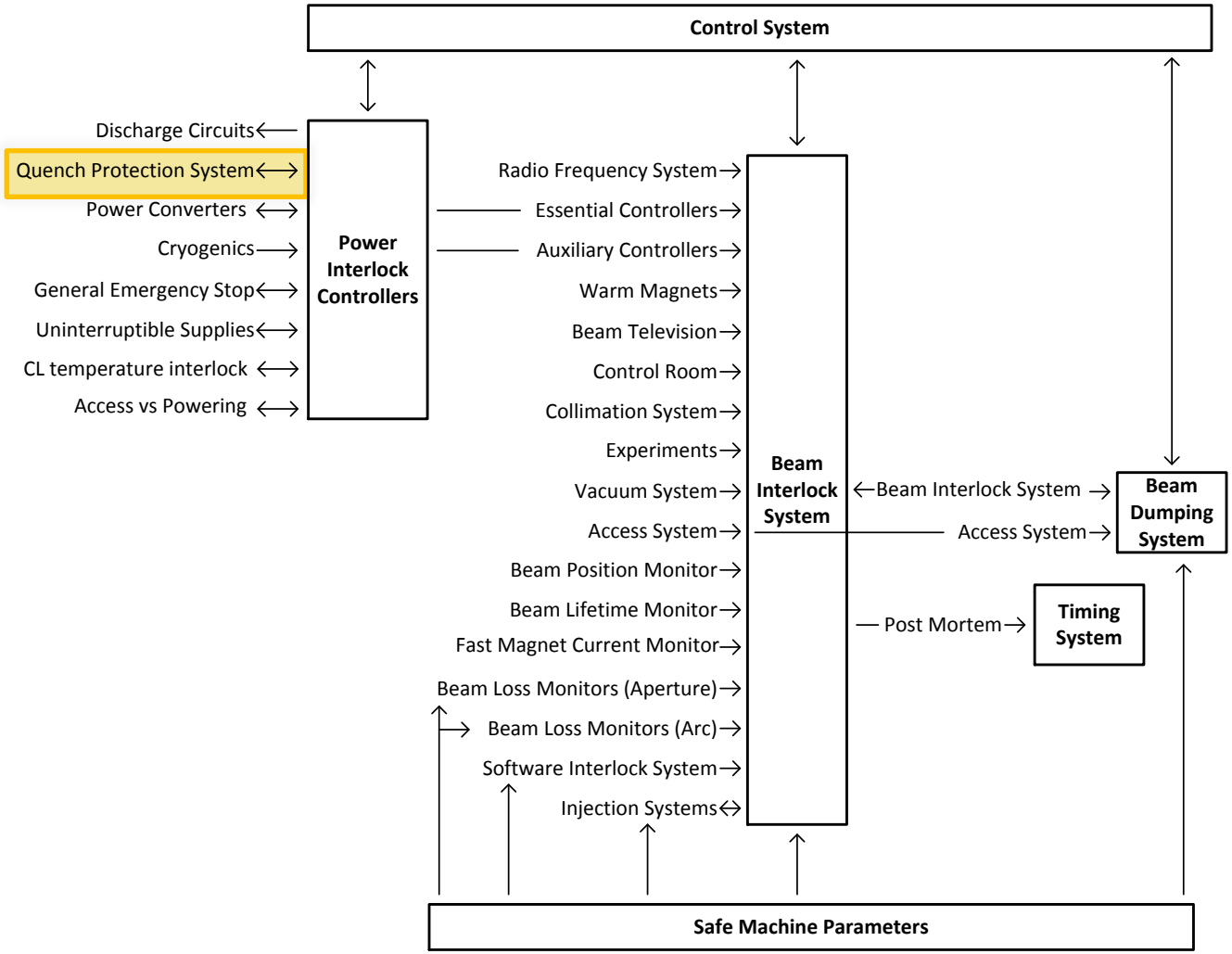
How to ensure access while powering

- **New interlock system** between access and powering systems [3]
- **Improves reliability** in the transmission of the access status to the SIS
- **Prevent access** while magnets are powered and current levels **above phase I limit**
- System to be commissioned during the **sector access tests starting on 6th June**
- **"Access restriction in LHC and SPS during LHC powering phase II" released!**





Quench Protection



Dependability improvements

Machine Protection Workshop Annecy'13 (B.Todd)

QPS Failure Mode	#	Total [hours]	Average [hours]
Radiation Induced Malfunction	39	35	0.9
Internal Communications Lost	25	15.5	0.6
Spurious Signal	23	23	1.0
Power Converter Trigger	13	13	1.0
WorldFIP Fault	12	17	1.4
DFB / Current Lead Fault	9	18	2.0
Mains Perturbation	8	9	1.1
600A Energy Extraction Fault	7	13	1.9
13kA Energy Extraction Fault	6	11	1.8
Electro-Magnetic Interference	2	3	1.5
CMW	1	0.5	0.5
13kA Power Supply Fault	1	2.5	2.5
Others	9	6	0.7
Combined	**155**	**166.5**	**1.1**

QPS/EE provoked dumps in 2012

External
Random Hardware
Radiation Hardware
Exploitation

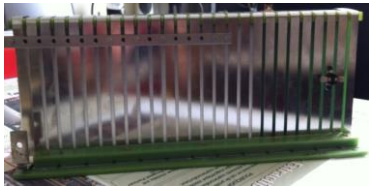
- **Equipment relocation** previously installed in in UJ14, UJ16 and UJ56 for inner triplet protection
- **Deployment of radiation tolerant hardware** for the protection of IPD, IPQ and 600A circuits in RR13, 17, 53, 57, 73, 77 where relocation was not possible during LS1
- Radiation tests indicates that new board will be about a **factor 100 less sensitive** to SEU
- **Instrumentation cabling for IPQs** optimised with respect to EMC => Less trips expected during storms and power outages
- **Enhanced power-cycle options** for DAQ systems including automatic restart of field-bus couplers (minimize access)

Main circuits protection

- Upgrade of the **main dipole protection racks** (1232 yellow racks)
- Enhanced **quench heater supervision**
  - Upgrade reduce the risk of **damage to the quench heater circuits**
  - New system records both **discharge voltage and current** at 192kHz/16bits
- New AC-DC power supplies fully adapted to **redundant UPS powering**
  - Ensures adequate magnet protection **if losing a UPS distribution** power path
- Installation of **earth voltage feelers** for main circuits
  - Monitor **electrical insulation strength** during fast discharges
  - Identification of the fault position on the half-cell level
- **nQPS upgrades**
  - **Symmetric quench detection firmware** adapted to higher operating currents
  - **Splice protection board firmware** to provide better SEU immunity
- **General revision of the EE [4]**
  - Main dipole dump resistors reconfigured (discharge time **increased to 102 secs**)
  - Main quad dump resistors reconfigured (discharge time **increased to 32 secs**)
  - Installation of snubber capacitors for voltage transient suppression during commutation

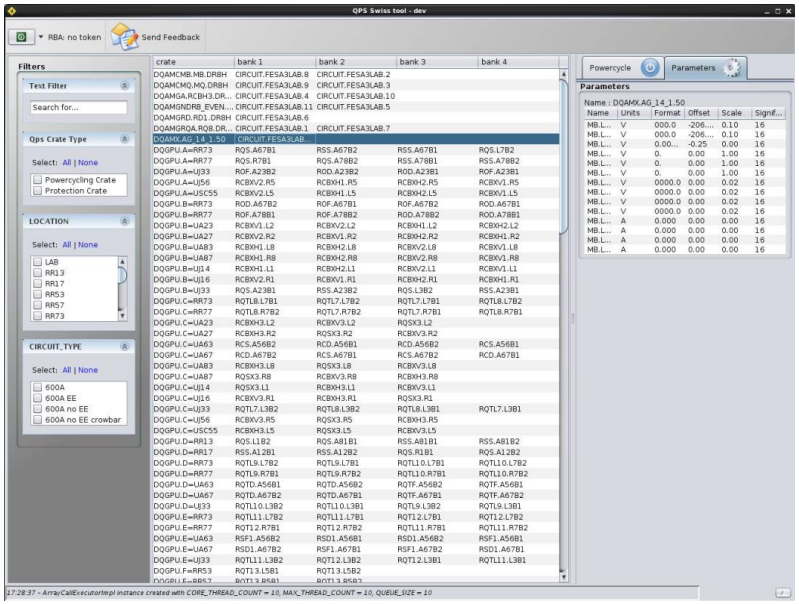
600A detection thresholds and EE changes

- **Detection thresholds**
  - QPS thresholds **on both busbar and magnets** for all 600A circuits reviewed
  - New thresholds **aimed to reduce the sensitivity while maintaining protection**
  - Detection involves a voltage threshold (**Uth**) and evaluation time (**dt**)
  - **Max. hotspot temperatures** set to 300K for busbars and 200K for magnets
  - For all 600A circuits powered via the N-line, **the busbar detection determines the maximum allowable threshold parameters (Uth, dt)**
- **Energy extraction [5]**
  - **Several 600A exhibit coupling-current induced quenches** (quench back) during FPA
  - Study of **quench back current**, impact on **reduced R_{EE}** on the limits for QPS detection parameters, **temperature increase in the modified EE** resistor during FPA and the increase in **coil peak temperature** after a magnet quench due to a slower current decay
  - **0.4Ω EE resistors** for all eight RQTL9 circuits

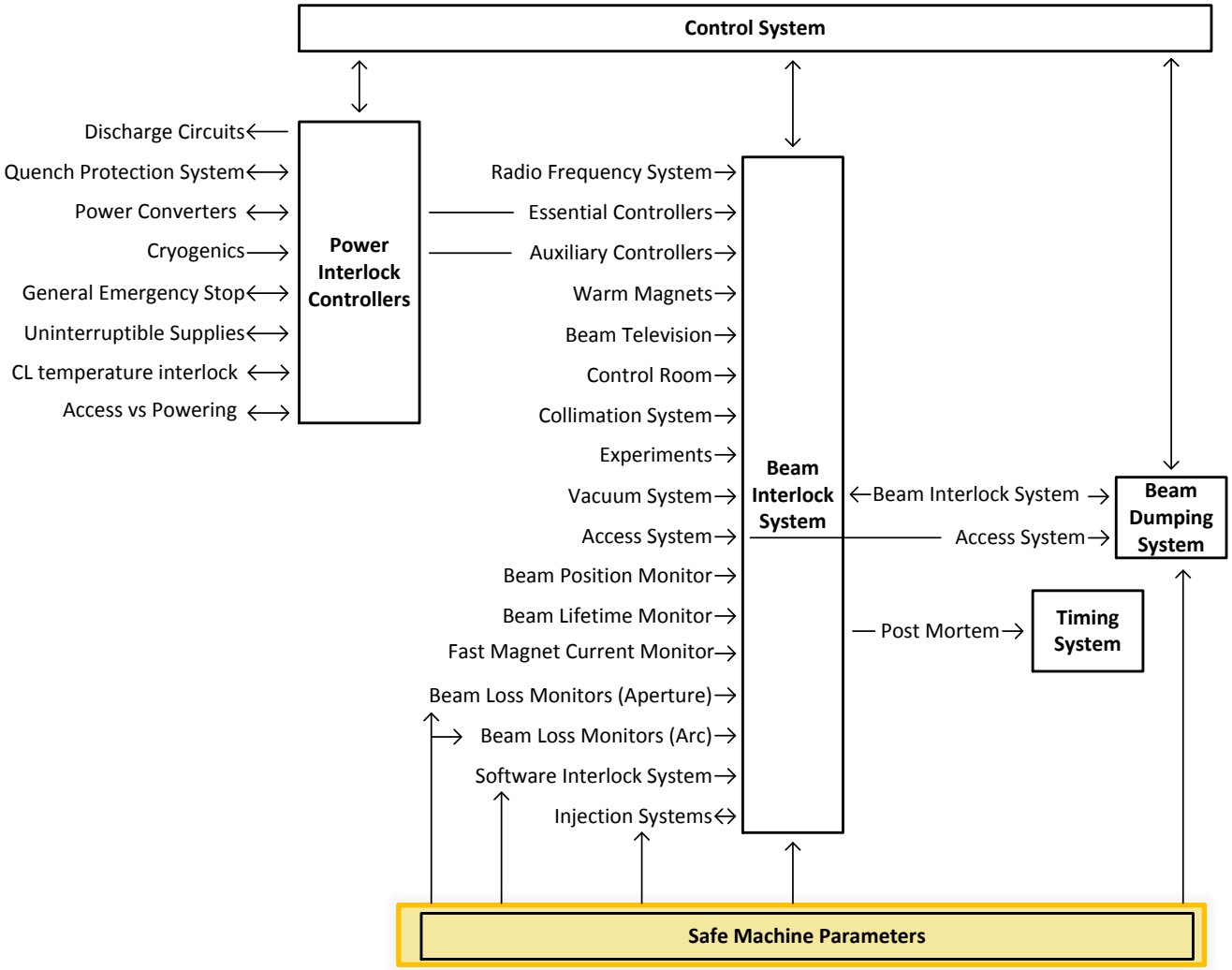


Operational software tools

- QPS parameters and **settings integrated in LSA DB** (consistency HW checks)
- Changes in the **PM data retrieval** (redundant boards visible, higher resolution and sampling rate which will also imply longer data collection, despite having doubled the field-bus segments)
- **Pre-operational checks** for the QPS device configuration and integrity of signals to be sure that the detection systems are up and running
- **New power cycle tools** only active under safe operational conditions (no beam, power converter in idle mode…)

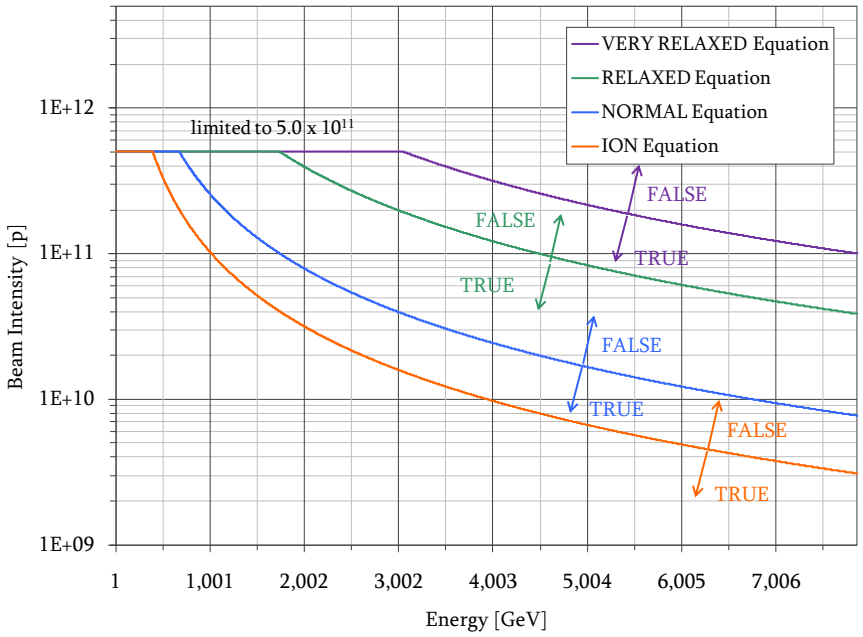


Beam Protection



Setup Beam Flag equations

- **Safe Machine Parameter** system **holds the SBF equations** used to configure the MPS
- SBF defines the intensity limit below which **beam can be considered safe**
  - "**SBF = TRUE**" => Beam intensity and energy **below damage limit**
  - "**SBF = FALSE**" => Beam intensity and energy **above damage limit**
- Maskable inputs of the BIS can be **masked if SBF=TRUE** (BLM, Collimation, RF,…)

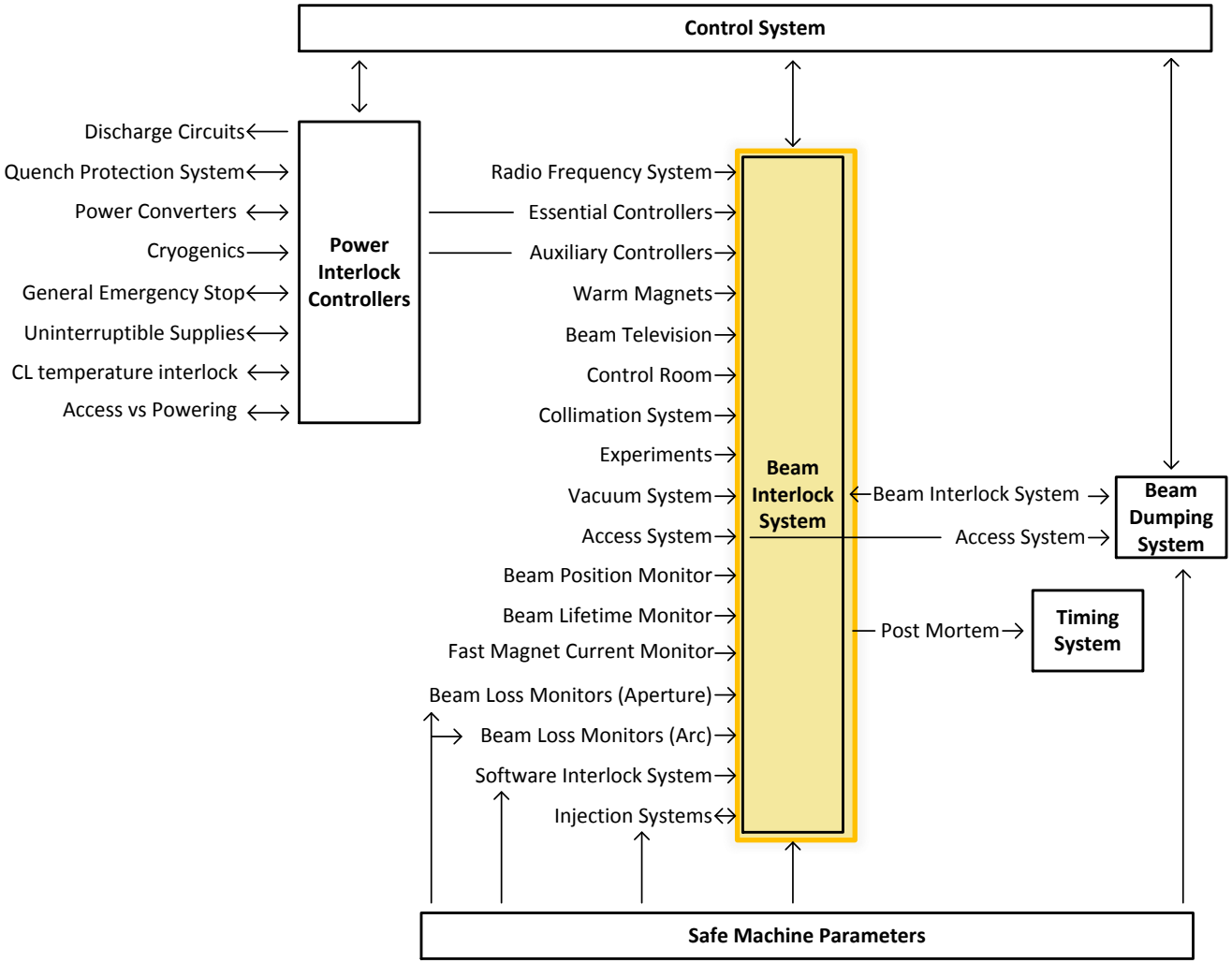


- **NORMAL** was defined a factor 2 below the damage limit
- **RELAXED** has been established to allow 1 nominal bunch at high energy
- **VERY RELAXED** has been established to allow 3 nominal bunches at high energy

After LS1, the LHC will operate to an energy close to 7Tev => Normal SBF would allow an intensity of ~1x10^{10} (**pilot beam**)

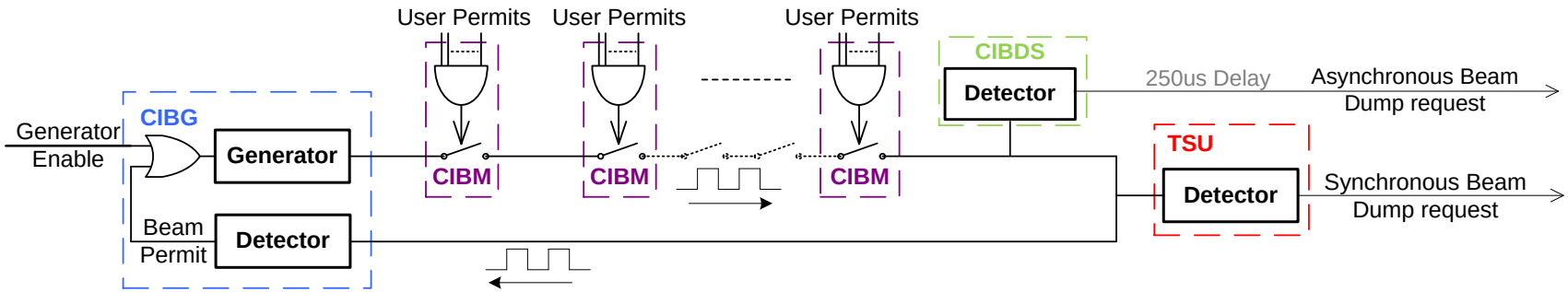
SBF proposal -> See L.Ponce's talk

Beam Interlock System



Redundant BIS-LBDS re-triggering link

- **New direct link** from the BIS to the LBDS re-triggering lines (**RTS**)
- Motivation is to reduce the potential **risk for common mode failures** (e.g: +12 Vdc LBDS powering) following an extraction demand from the BIS
- Additional electronic boards **CIBDS** included in the **Beam Permit Loops**
- **Asynchronous Beam Dump** to be requested with a **250us delay**



- Dependability studies to analyse the impact on **machine availability** [6]:

Energy [GeV]	REQUIREMENTS	DEPENDABILITY STUDIES
Asynchronous dump	2 per 10 years	0.025 per 10 years
Synchronous dump	2 per year	0.011 per year

New user channels

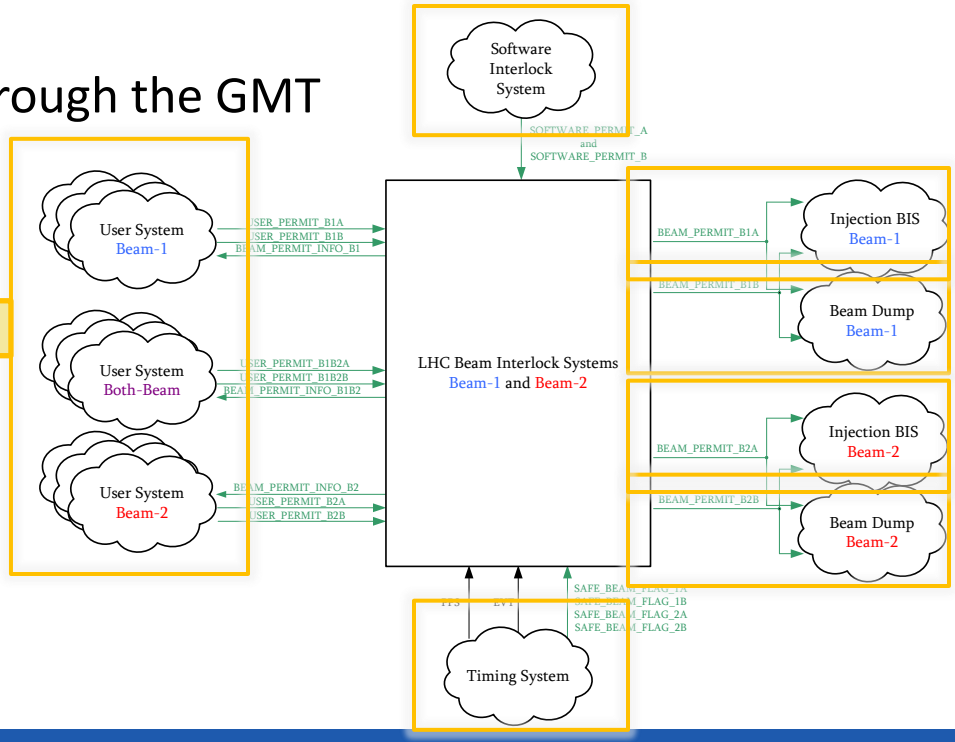
LOCATION	INPUT	USER	ACTION
LHC P1	7	LHCf detector	**ADDED**
LHC P4	2,9,14	FBCCM/DIDT **See E.Bravin's talk**	**ADDED**
	7	WIC	**DISABLED** but maintained
LHC P5	13	CMS magnet	**UPDATED** (trigger on FPA)
LHC P6	6	CIBDS (BIS-LBDS retriggering)	**ADDED** to both left and right BICs
	14	TCDQ Beam 1&2 (BETS interlock)	**ADDED**
LHC P7	11	Crystal collimator experiment	**ADDED**

Beam Interlock System – Commissioning

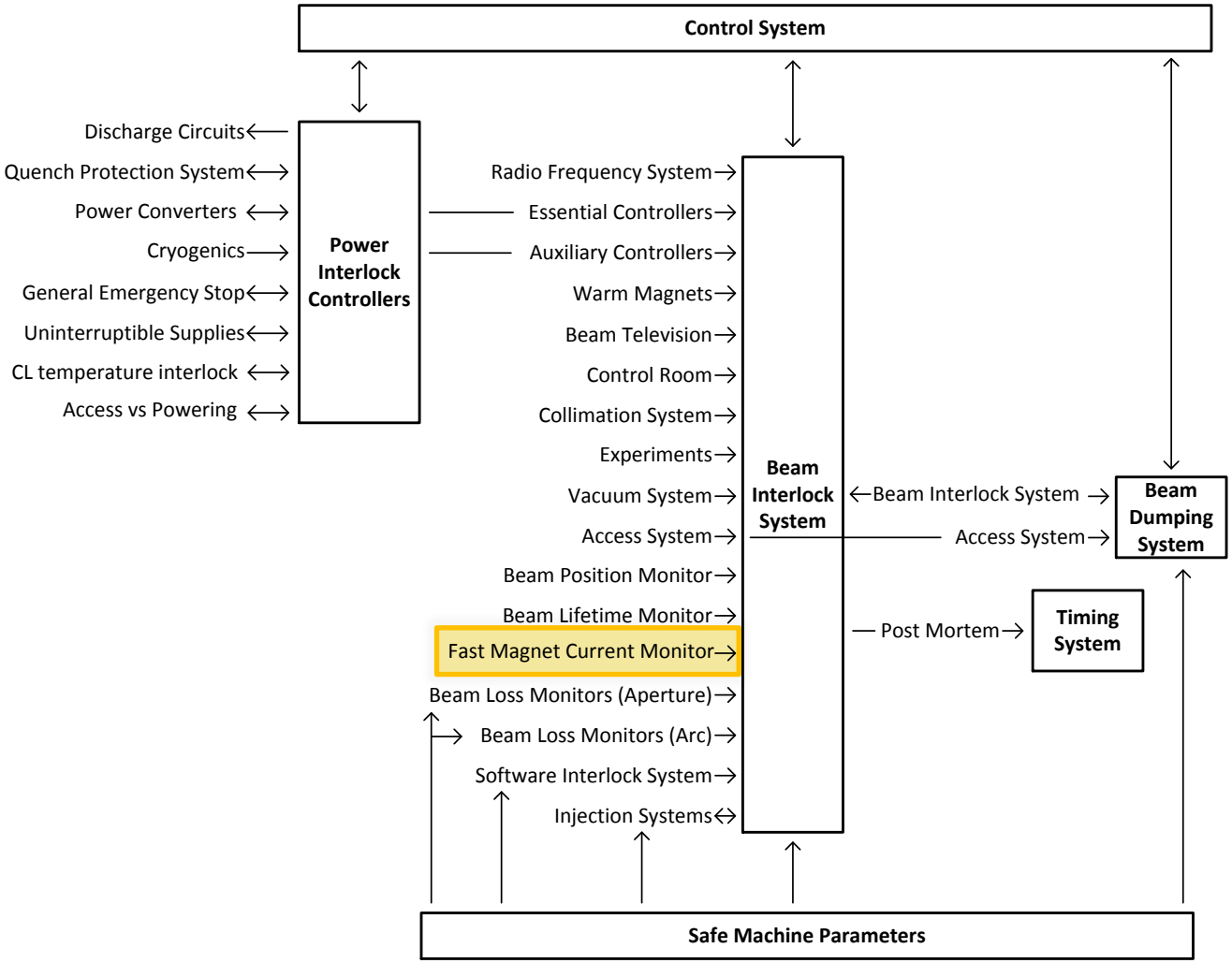
- "MPS aspects of the Beam Interlock System commissioning" reviewed [7]
- **User permit** validation (some clients automated in ACCTESTING)
- **Software Interlock Permit** – Applied to 2 BICs (CCR+SR3)
- **Setup Beam Flag** transmission through the GMT
- **Beam Permit to LBDS (CIBDS)**
  - Reliability run
  - Optical interfaces validation

See N.Magnin's talk

- **LHC Beam Permit** propagation to the injection BICs

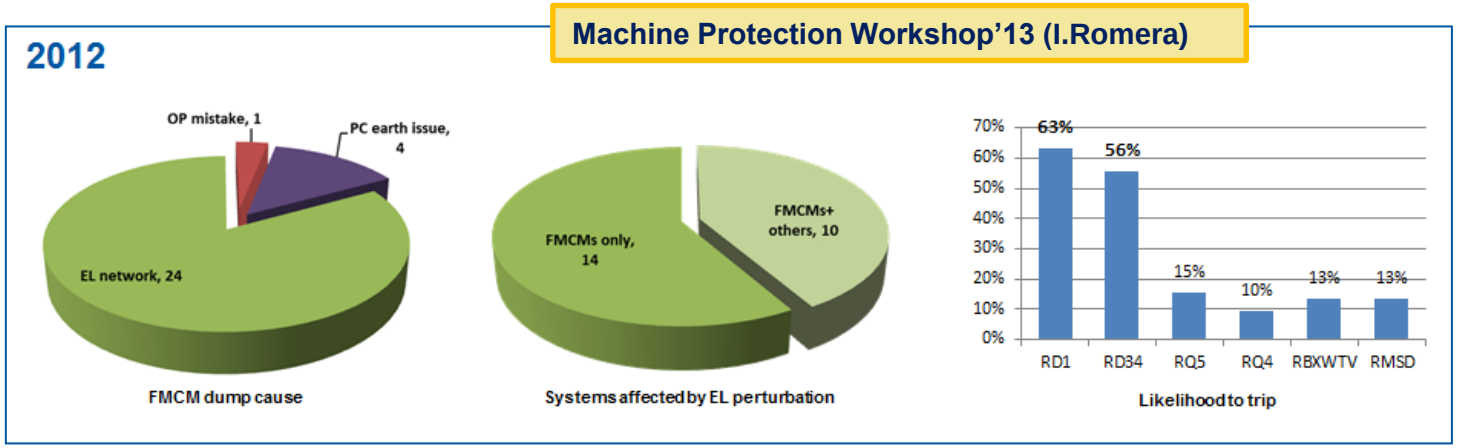


FMCM

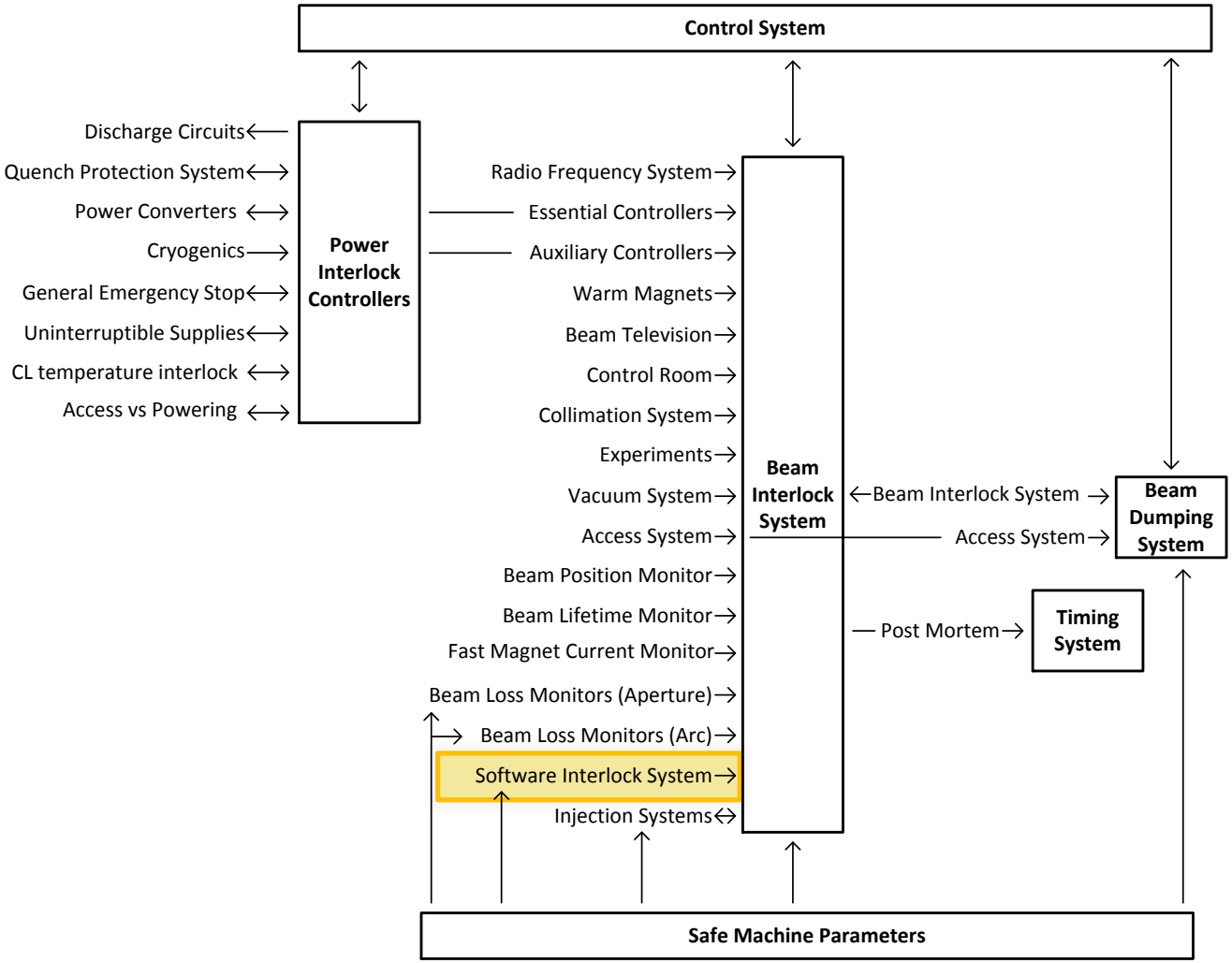

Control System
Discharge Circuits
Quench Protection System
Power Converters
Cryogenics
General Emergency Stop
Uninterruptible Supplies
CL temperature interlock
Access vs Powering
Power Interlock Controllers
Radio Frequency System
Essential Controllers
Auxiliary Controllers
Warm Magnets
Beam Television
Control Room
Collimation System
Experiments
Vacuum System
Access System
Beam Position Monitor
Beam Lifetime Monitor
Fast Magnet Current Monitor
Beam Loss Monitors (Aperture)
Beam Loss Monitors (Arc)
Software Interlock System
Injection Systems
Beam Interlock System
Beam Interlock System
Access System
Beam Dumping System
Post Mortem
Timing System
Safe Machine Parameters

Sensitivity to electrical network perturbations

- Electrical network glitches became one of the **main dump causes from powering systems**
- A large fraction **only affecting RD1 and RD34** circuits with no other equipment trip
- EPC **working on a new switch mode power converter** to replace the existing RPTG thyristor converters
- Current plans:
  - **LS1**: Power converter design, infrastructure preparation (cooling, electricity…)
  - **2015**: Production of the two RD1 and commissioning during 2015-16 Xmas
  - So far budget only approved for RD1, **no big gain without replacing RD34 as well!**



Software interlocks



New interlocks ADDED

- Currently **52 interlock types** implemented on SIS
- **Collimator BPMs**: interlock on the beam offset wrt collimator center
  - Current strategy is to prepare interlocks to dump if the beam is too far off from the center, but to activate later – need some experience with the new BPMs
- **Abort gap monitoring** (BSRA): See E.Bravin's talk
  - Activation of cleaning & dump
- **Virtual beta* for TLs**:
  - Similar concept as for ring collimators
  - For each TL optics, define all quad currents in LSA together with virtual β^*
  - SIS reads currents and compares to reference settings (every cycle)
  - If within tolerance publish the virtual β^* value associated with the optics
  - On TCDI side read β^* from MTG and check if in limit

Existing interlocks UPDATED

- **Access-Powering Interlock**: simpler and more robust link from LASS to SIS
  - Only active with no beam in the LHC. Ready for the restart of powering tests
- **COD interlock:** remained active in 2012 in parallel to the PC interlock server
  - Should be moved from SIS since PC interlock server was shown more powerful
- **PC current interlocks:**
  - Surveys the current for a series of PCs (QD/QF at injection) -> can be done better in the PC interlock server
- **TCDQ-beam interlocking**:
  - incorporate the TCSG6 BPM – more accurate!
- **Particle type interlock**: avoids that protons are sent into a ring setup for ions and vice-versa (injection)
  - So far tricky identification of the particle type with the current of SPS injection line (TT10) dipoles. To be replaced with information from the SPS telegram

Summary

- Quite some changes and upgrades implemented on the MPS backbone aiming at **increasing the machine dependability** and to adapt to new operational requirements

- **Consolidations will reduce machine downtime from magnet powering systems** mainly due to the reduced number of radiation induced spurious trips, improved rejection against mains perturbations, …

- MP3 has **reviewed the powering procedures** and acceptance criteria to qualify all electrical circuit families

- Few changes on beam protection related systems (SBF equations, re-triggering BIS-LBDS link, SIS,…) will be validated **following dedicated MPS procedures already reviewed by the MPP**

Thanks a lot for your attention!

REFERENCES:

- [1] I.Romera, “Change of PIC configuration data for inner triplet corrector circuits RQSX3”, EDMS 1203408
- [2] I.Romera, “MPS aspects of the Powering Interlock System commissioning”, EDMS 896390
- [3] I.Romera, T.Ladzinski, “Change of the Interlocking of Powering and Access Systems”, EDMS 1246780
- [4] MP3, “MP3 Recommendation on the Decay Time Constants of the 13 kACircuits after LS1”, EDMS 1320722
- [5] MP3, D.Rasmussen, “MP3 Recommendation for the Reduction of Energy-Extraction Resistor Values in Selected 600A Circuits”, EDMS 1343241
- [6] V.Vatansever, “Dependability studies on the connection between LHC BIS and LBDS re-triggering system”
- [7] B.Todd et all, “MPS aspects of the Beam Interlock System commissioning”, EDMS 889281