Reliability requirements for the inner triplet protection

Tuesday, 16.10.2018 – Session WP3/WP7

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J. Uythoven, M. Valette, D. Wollmann,
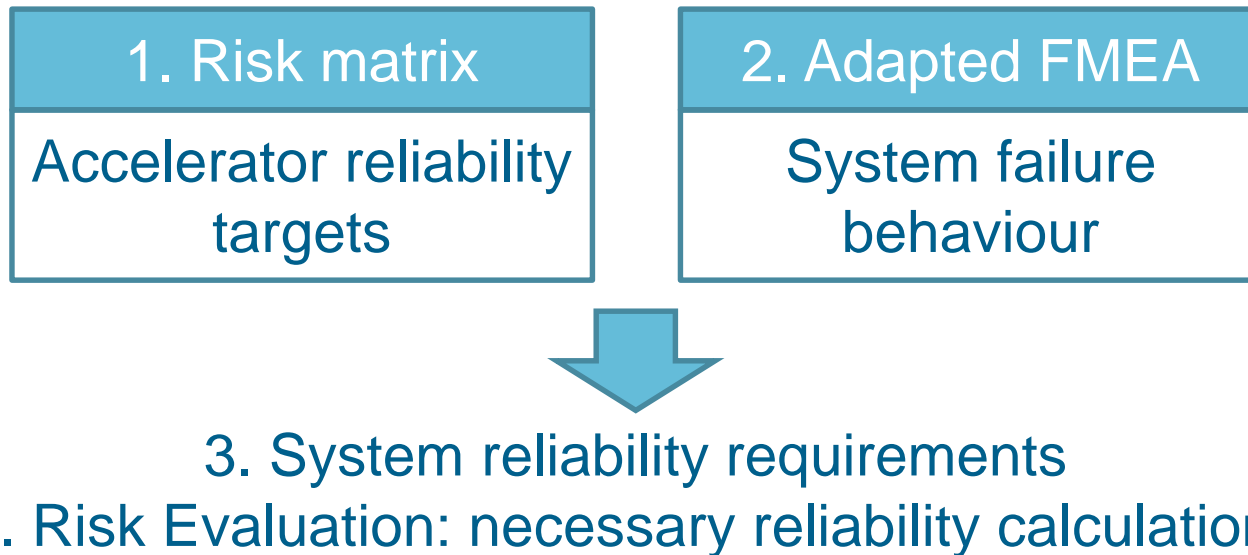
8th HL-LHC Collaboration Meeting, CERN

Contents

RIRE ☺
Reliability Requirements and Initial Risk Evaluation

1. Principle of RIRE
2. RIRE for Inner Triplets Protection
3. Conclusions

1. Principle of RIRE

Reliability Requirements and Initial Risk Evaluation – RIRE ☺

1. Risk matrix	2. Adapted FMEA
Accelerator reliability targets	System failure behaviour

⬇

3. System reliability requirements
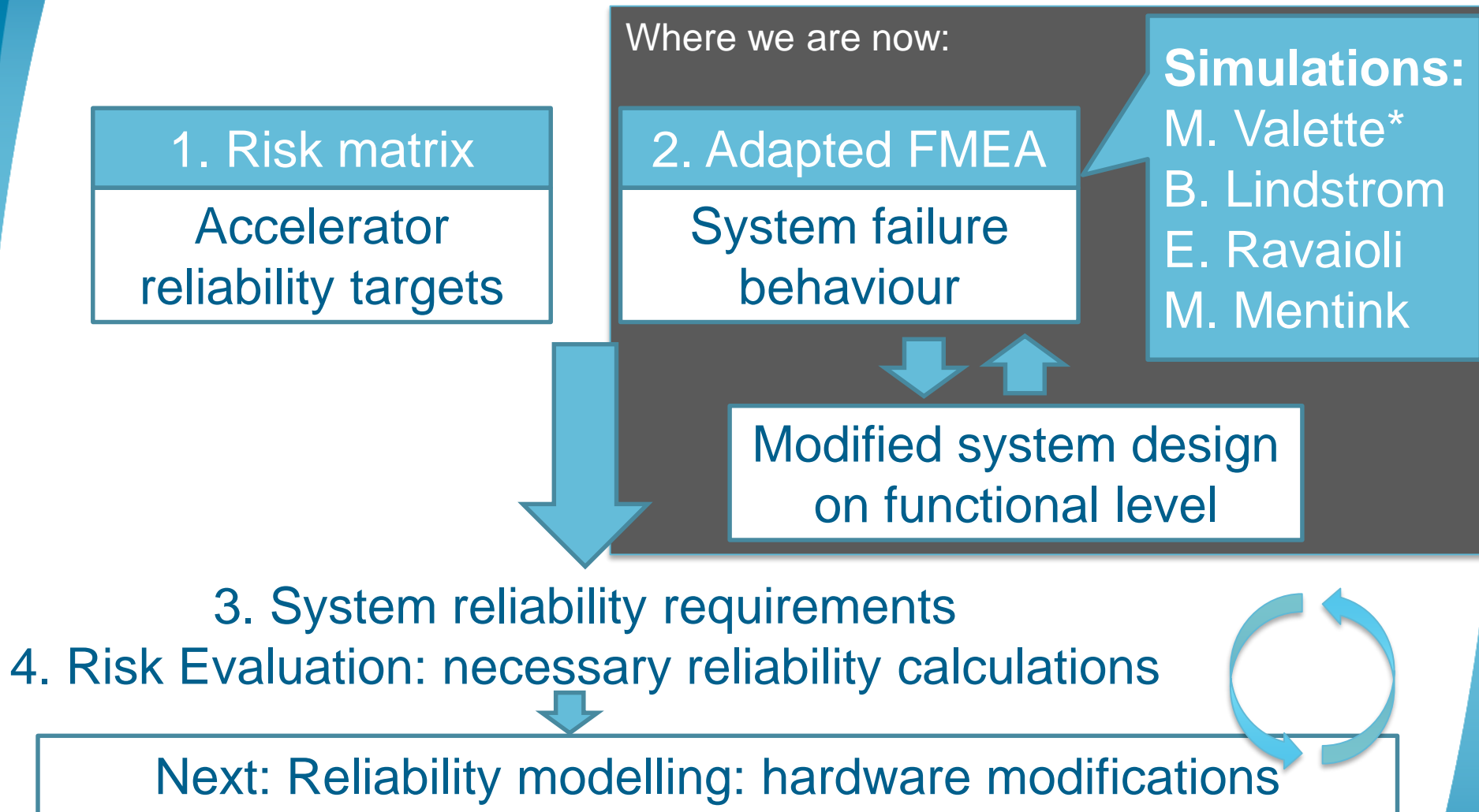### 4. Risk Evaluation: necessary reliability calculations

Successfully applied to

✓ Definition of reliability requirements for DYPQ

✓ Identification of DYPQ trigger link as critical part: reliability calculation, modification of system design on hardware level

✓ Definition of 11T reliability requirements (D. Sollich*) ongoing

*Reliability requirements for the 11T quench protection system, 17.10.2018, Session Wednesday PM - WP5/WP7/WP9/WP11

2. RIRE for the Inner Triplet protection

Where we are now:

Simulations:
M. Valette*
B. Lindstrom
E. Ravaioli
M. Mentink

1. Risk matrix
Accelerator reliability targets

2. Adapted FMEA
System failure behaviour

Modified system design on functional level

3. System reliability requirements

4. Risk Evaluation: necessary reliability calculations

Next: Reliability modelling: hardware modifications

* Fast failures from CLIQ and QH, 16.10.2018, Session Tuesday AM – WP3/WP7
Effect of beam screen shielding, 17.10.2018, Session Wednesday AM - WP2;3;6B;7;12

2. Step 1: Accelerator reliability requirements

HL- LHC requirements correspond to LHC requirements

HL-LHC/ LHC risk matrix		Recovery						
		∞	year	month	week	day	hours	minutes
		S7	S6	S5	S4	S3	S2	S1
Frequency	1 / hour							
	1 / day							
	1 / week							
	1 / month					✖		
	1 / year							
	1 / 10 years							
	1 / 100 years							
	1 / 1000 years							

2. Step 2.1: System structure

1. LHC
    1. Beam
    2. Inner triplet
        1. Inner triplet protection, n=6
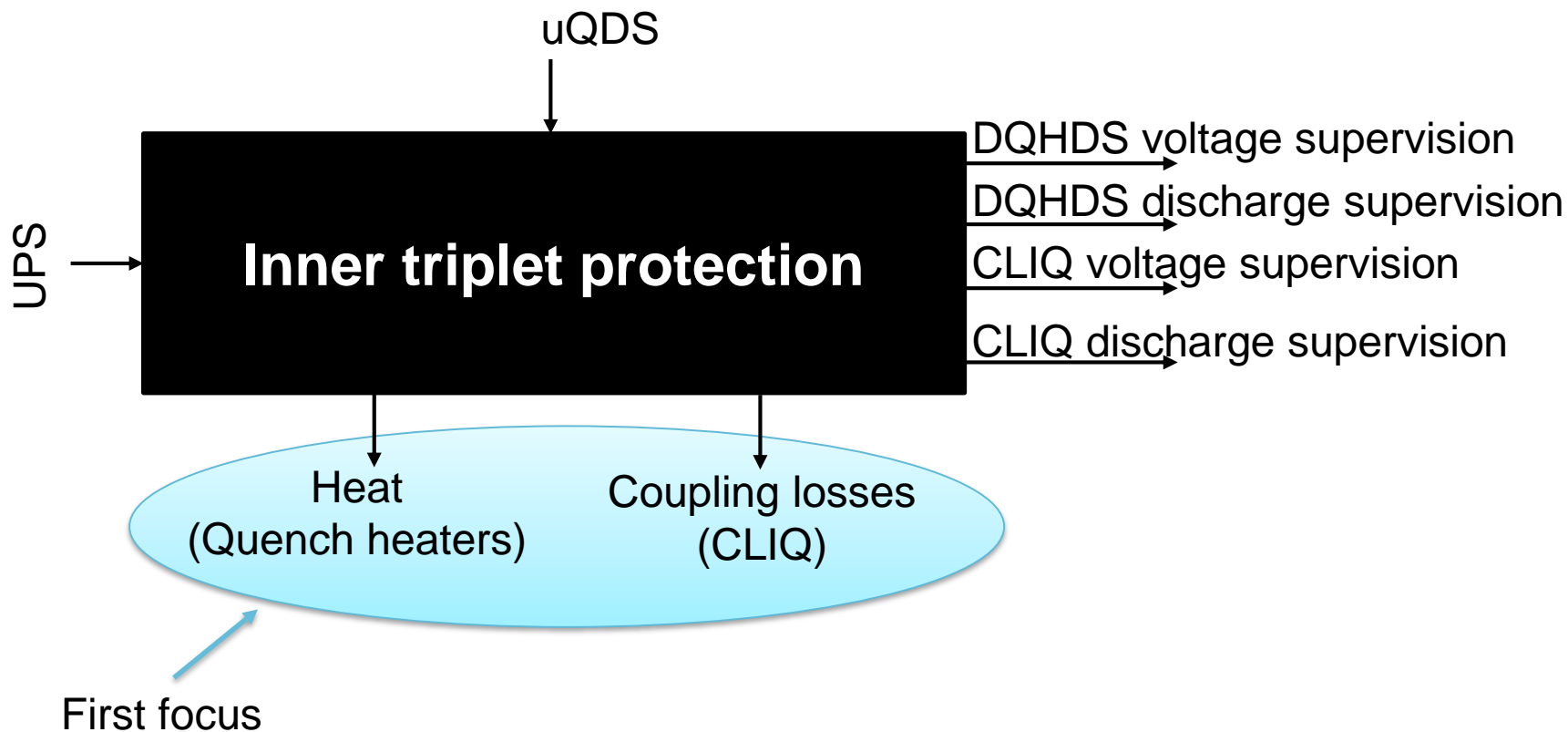   1. Outer layer quench heaters, n=8
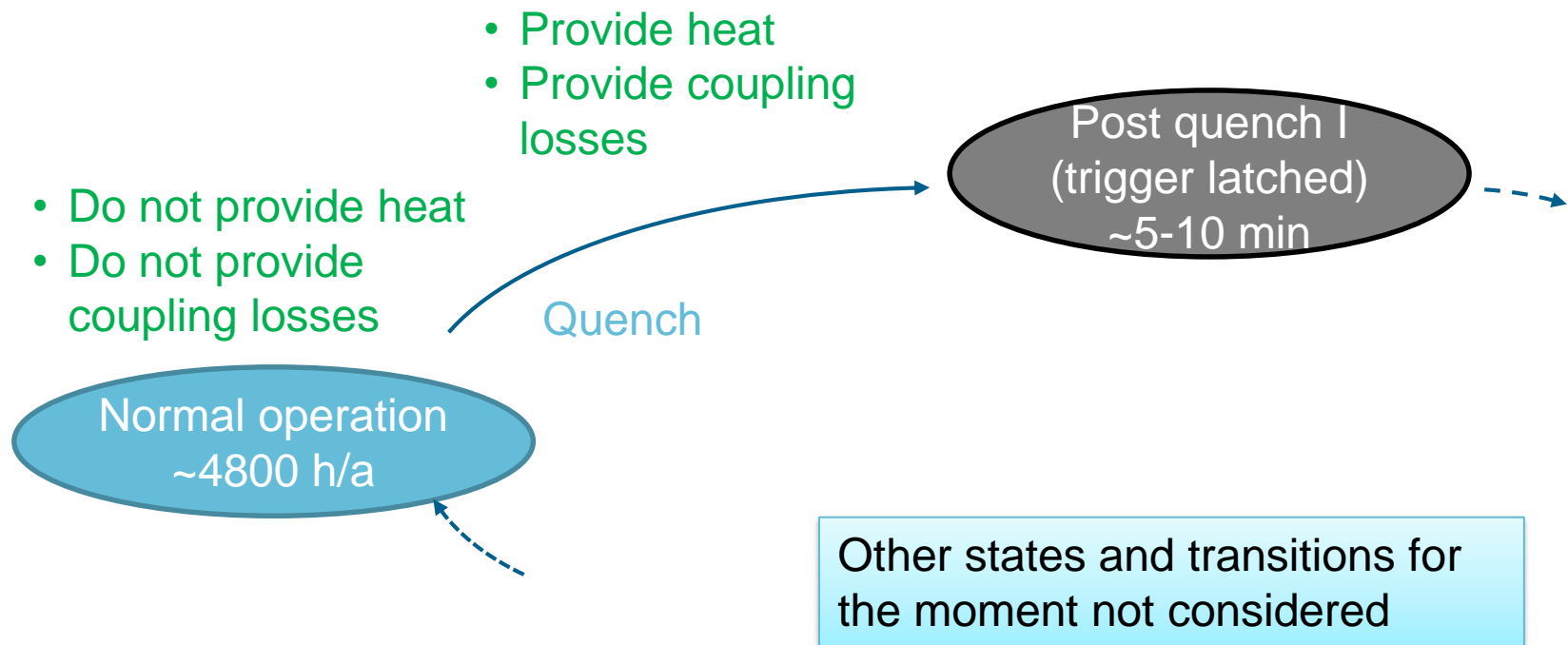   2. CLIQ, n=1
        2. Quench detection

Immediate effect

End effect

2. Step 2.2: System functions

2. Step 2.3: Context dependent functions

- Provide heat
- Provide coupling losses

- Do not provide heat
- Do not provide coupling losses

Quench

Post quench I
(trigger latched)
~5-10 min

Normal operation
~4800 h/a

Other states and transitions for the moment not considered

2. Step 2.4: Failure modes and effects

RIRE tailored FMEA table

Context	Previous slide
Function	
Failure mode	
Immediate Effect	
End effect	
Severity of end effect	
Detection method	
Recommendations	

Simulations: M. Valette, B. Lindstrom E. Ravaioli, M. Mentink

Beam, IT

LHC

Recovery time, risk matrix

Modifications of system design on functional level

- The table needs to be filled in for all
  - Magnets: Q1, Q2a/b, Q3
  - MQXF circuit currents: low current (1.5 kA), nominal current (16.47 kA), ultimate current (17.8 kA)
- Worst cases (combination of Magnet and circuit current) define the end effect for which reliability requirements are defined

2. Step 2.4: FMEA table example

Context	Normal operation, all magnets, all currents
Function	**Keep DQHDS charged**
Failure mode	Xoo8 QH circuits discharge
Immediate Effect	1. Dipole kick due to the field generated by the QH circuit depending on X
	2. Discharge is detected as quench by uQDS
End effect	1. Depending on X: beam losses; damage of collimators: …
	2. All QH of all six magnets are fired, beam dump, power abort
Severity of end effect	Depends on X
Detection method	HDS discharge supervision (< 80 µs)
Recommendation	Depends on X

Detailed table

2. Step 2.4: FMEA table example

Detailed table for worst case: Q2a/b at ultimate current

FM	Xoo8 QH circuits discharge		
	1oo8 QH-circuits	**2oo8 QH-circuits**	**8oo8 QH-circuits**
Immediate effect			
End effect, Recovery			
Severity [recovery]			
Recomm-endations			

Objective: Complete list of end effects

2. Step 2.4: List of end effects without additional protection

Beam

- IT_EE1: Possible damages of collimator, S5 (month)
  - FM: Spurious kick of 1oo8 QH-circuits
- IT_EE2: Damage of collimator, S5 (month)
  - FM: Spurious kick of 2oo8 QH-circuits
  - FM: Spurious kick of CLIQ-unit
- IT_EE3: Damage of experiment, S6 (year)
  - FM: Spurious kick of 8oo8 QH-circuits

Inner triplet

- IT_EE4: Damage of inner triplet, S5 (month)
  - FM: Missing QH-circuits 0oo8 (CLIQ only)
- IT_EE5: Injection delayed (analysis, revalidation) S3 (day)
  - FM: Missing QH-circuits 7oo8; 6oo8
  - FM: Missing CLIQ (QH only)

2. Step 3: Reliability requirements *without* additional protection

LHC risk matrix	Recovery						
	∞	year	month	week	day	hours	minutes
	S7	S6	S5	S4	S3	S2	S1
1 / hour							
1 / day							
1 / week							
1 / month							
1 / year					EE5		
1 / 10 years							
1 / 100 years			EE1, EE2, EE4				
1 / 1000 years		EE3					

Frequency

2. Step 3: Reliability requirements *with* additional protection

LHC risk matrix	Recovery						
	∞	year	month	week	day	hours	minutes
	S7	S6	S5	S4	S3	S2	S1
1 / hour							
1 / day							
1 / week							
1 / month							
1 / year						EE5	
1 / 10 years							
1 / 100 years			EE1, EE2, EE4				
1 / 1000 years		EE3					

Fast beam dump trigger (CLIQ, QH)

CLIQ able to protect at low current

\+ EE of Additional protection

3. Conclusions

- RIRE, a systematic four-step procedure for the experienced based derivation of quantitative reliability targets is presented.

- RIRE is applied to different systems at CERN with success.

- RIRE is being applied to the IT quench protection:
  - At level 2 out of 4: design phase
  - Additional protection requirements have been defined (functional level)

- NEXT: RIRE method and resulting reliability studies to guide further design and hardware development of the IT protection system.

Thank you for your attention!