COLLIMATORS RELATIONS TO MPS

EUROPEAN SPALLATION SOURCE

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14th of May 2014, Collimation Workshop, ESS, Lund, Sweden

CONTENT

- MPS Design Approach
- MPS Risk Analysis: overview, outcome, results
- First Design Ideas and Requirements
- Summary and Conclusions

MACHINE **PROTECTION SYSTEM**

Scope of MPS

Protect the machine's equipment from damage due to

- Beam losses
- Malfunctioning equipment.

MPS Design Function

- Initiate beam stop upon detection of non-nominal conditions.

MPS Design Approach

- Follow IEC61508 standard, where applicable.
- Optimize integrated machine performance according to ESS overall goal of reaching 95% beam availability with high reliability.

PRELIMINARY **HAZARD IDENTIFICATION**

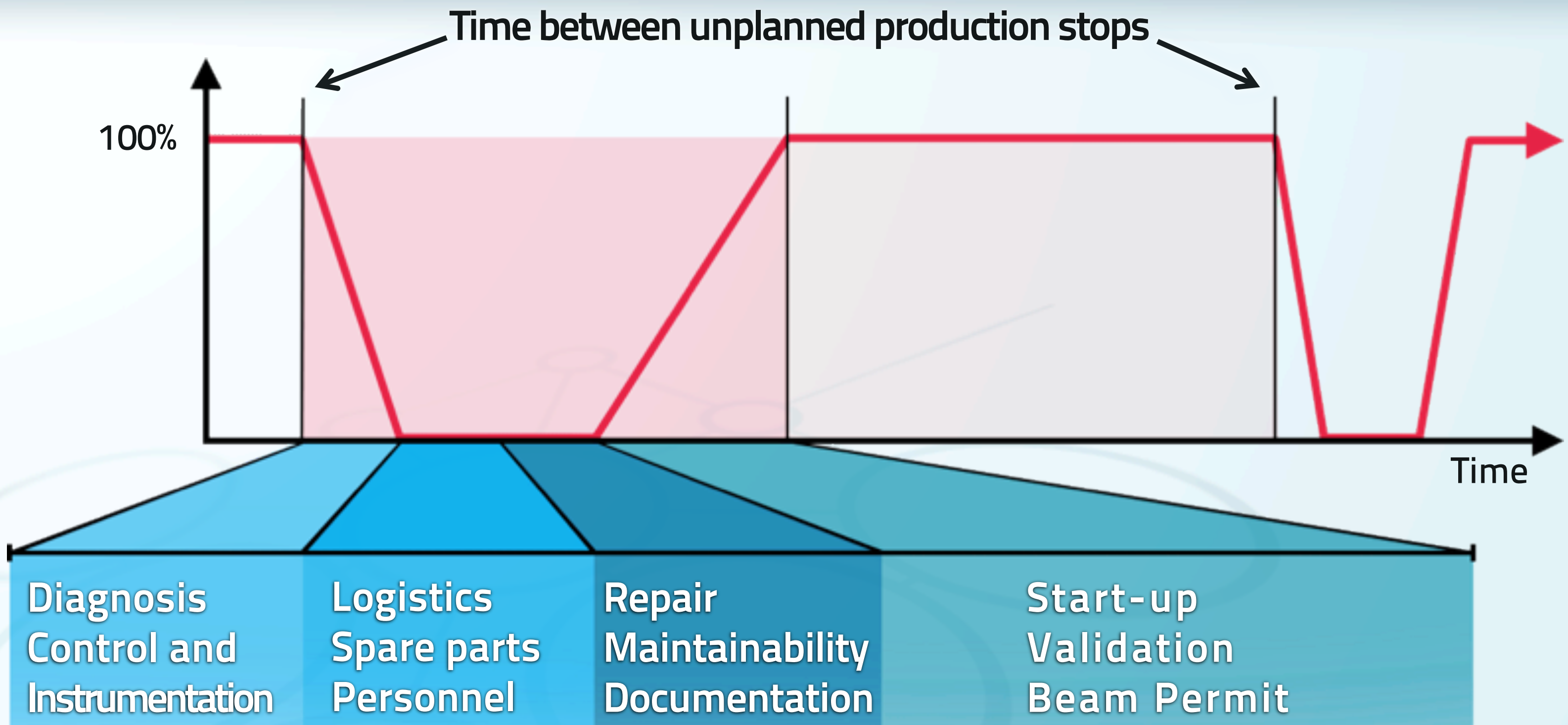
Probability	Consequence Ranking			
Frequent: At least once a year	3	4	5	6
Probable: Once between 1 and 10y	2	3	4	5
Rare: Once between 10 and 100y	1	2	3	4
Exceptional: Not in 100y	1	1	2	3
Severity	**Insignificant**	**Moderate**	**Major**	**Catastrophic**
Production Losses/year	<1 day	<1 week	<2 month	≤1 year
Property Losses	<150 KEUR	<1 MEUR	<8 MEUR	≤50 MEUR

Scope

- Identify risks/hazards of MPS related systems and Safety Integrity Level (SIL)
- Identify mitigation methods for all identified (catastrophic) events

Preliminary Hazard Identification done with help from Scandpower

OVERVIEW ON **AVAILABILITY**



Categorize different sources of downtime/mitigation techniques per event and define impact on overall ESS performance.

RESULTS FROM **RISK ANALYSIS FOR LINAC**

Outcome

- Catalogue of risks and failures + mitigation techniques
- Overview on downtime, operational procedures, spare policy
- Recommendations for design considerations
- Information will be stored in ESS risk database: follow up of implementation is as important as identification of risks !

- Signals connected to machine interlock system
- MPS functions and related SIL (SIL 2 is recommended)
- Allocation of functions and SIL to sub-systems
- Required fastest response time to achieve sufficient protection (10μs)

TOP EVENTS FOR COLLIMATORS

Top Events for fixed collimator

- **Loss of cooling**
- **Misalignment of collimator**

Top Events for moveable collimators

- Jaws moved too close to the beam
- Loss of cooling of jaws
- Embrittlement of bellows
- Cooling water leaking on collimator motors
- Mechanical failure of the supporting structure of the collimators

RECOMMENDATIONS I

Fixed collimator

- **Define damage level**
- **Define alignment requirement**
- **Consider remote online alignment option**

Moveable collimators

- Investigate damage level (also in case of lost cooling)
- Investigate dose levels on downstream magnets in case of misalignment/or if jaw position too close to beam
- Maintainability (activation level, cooldown time, etc.)
- Pre-defined procedures stating when to stop beam operation to repair a collimator
- Make sure that position of collimator can be changed manually, in case motors fail

RECOMMENDATIONS II

Moveable collimators

- Consider having a weekly dose measurement report from collimator areas
- Consider having restricted step size for moving the jaws and also consider an operating range limitation in the software
- Consider having the collimator going to a fail-safe position upon failure of the control device or lost communication
- Investigate how long it takes for the temperature to build up in the jaws upon a loss of cooling
- Investigate type of bellows used at other facilities (how is the stress being monitored? Counter of bellow movements needed?)
- Maintainability of the motors
- Spare policy

COLLIMATORS AND MPS

Outcome from risk analysis:

- connect BLMs (and BCM @ MEBT) which are located at collimators directly to the beam interlock system (BIS) and set thresholds according to damage level of collimators

Design a control system for the collimators and take into account the following protection functions:

- Provide temperature control (jaw and cooling water),
- Provide jaw position control (+ mechanical stops preventing large mis-settings)
- Provide flow monitoring (cooling water)
- Provide water filters (in case of contamination)

→ Possible aggregation of these signals into one OK/NOK signal for the BIS for each collimator

QUESTIONS

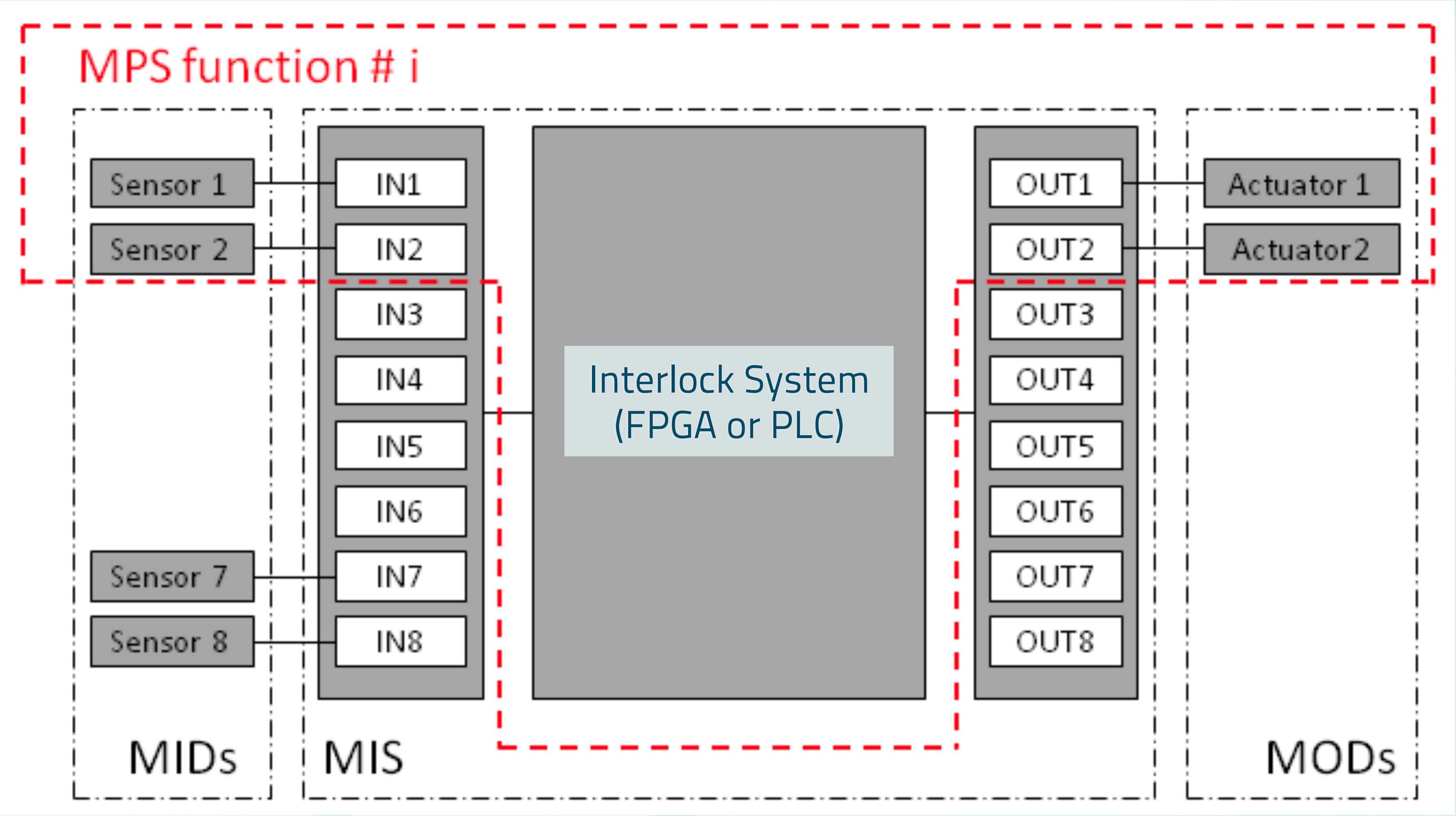
- BLMs at collimators (restriction in dynamic range due to very high losses); do we need special BLMs in the target area?
- How will we set the thresholds?
- What is the experience at other facilities in terms of false trips from the collimation system initiating unwanted beam stops?
- What is interlocked?
- What is used to control the collimators? PLCs? And how reliable is the operation?
- Were special position switches added? Or do you rely fully on the controller (e.g. of the stepper motors)?

CONCLUSIONS

- MPS must support operations to assure maximum protection AND beam availability.
- MPS must provide support already during commissioning→ must be flexible though static
- Collimators are insert able devices und thus must be dealt with carefully→ their position must be interlocked
- Most dangerous scenario is probably when a collimator is closing unintentionally during beam operation or when jaws are being positioned too close to the beam
- Collimator status will be interlocked (OK/NOK) however the logic and response time need to be defined

BACKUP **SLIDES**

DEFINITION OF MPS **FUNCTIONS**



PROTECTION INTEGRITY **LEVELS**

Integrity Level for high demand or continuous mode of operation

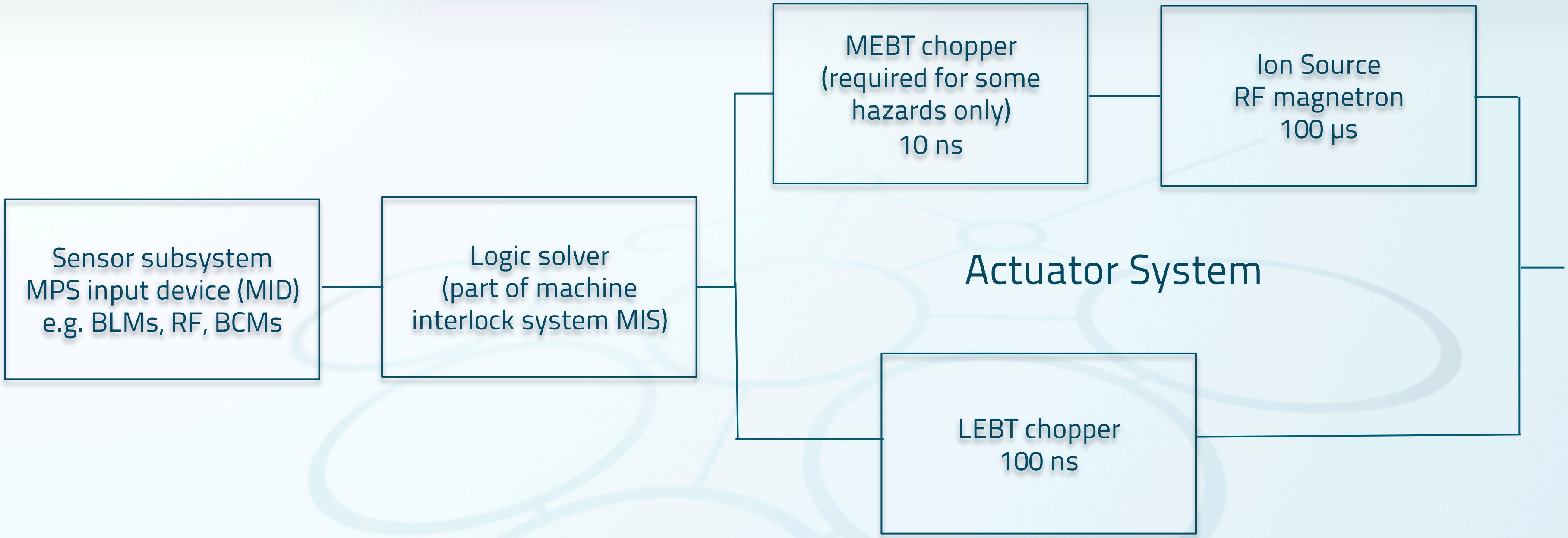
Integrity Level (IL)	PFH of the MPS function	PFH of the MIS
4	$\geq 10^{-9}$ to $< 10^{-8}$	$< k \cdot 10^{-8}$
3	$\geq 10^{-8}$ to $< 10^{-7}$	$< k \cdot 10^{-7}$
2	$\geq 10^{-7}$ to $< 10^{-6}$	$< k \cdot 10^{-6}$
1	$\geq 10^{-6}$ to $< 10^{-5}$	$< k \cdot 10^{-5}$

Note: Typically $0 < k < 0.15$

PFH: Probability of Failure per Hour

The Integrity Level sets requirements for **random failure rates for hardware**, **diagnostic coverage and fault tolerance** for the entire MPS function and on techniques and measures to minimize the propensity for systematic failures. The higher the SIL, the more stringent the requirements. For valves: use table for low demand of operation.

MPS ACTUATORS & RESPONSE TIMES

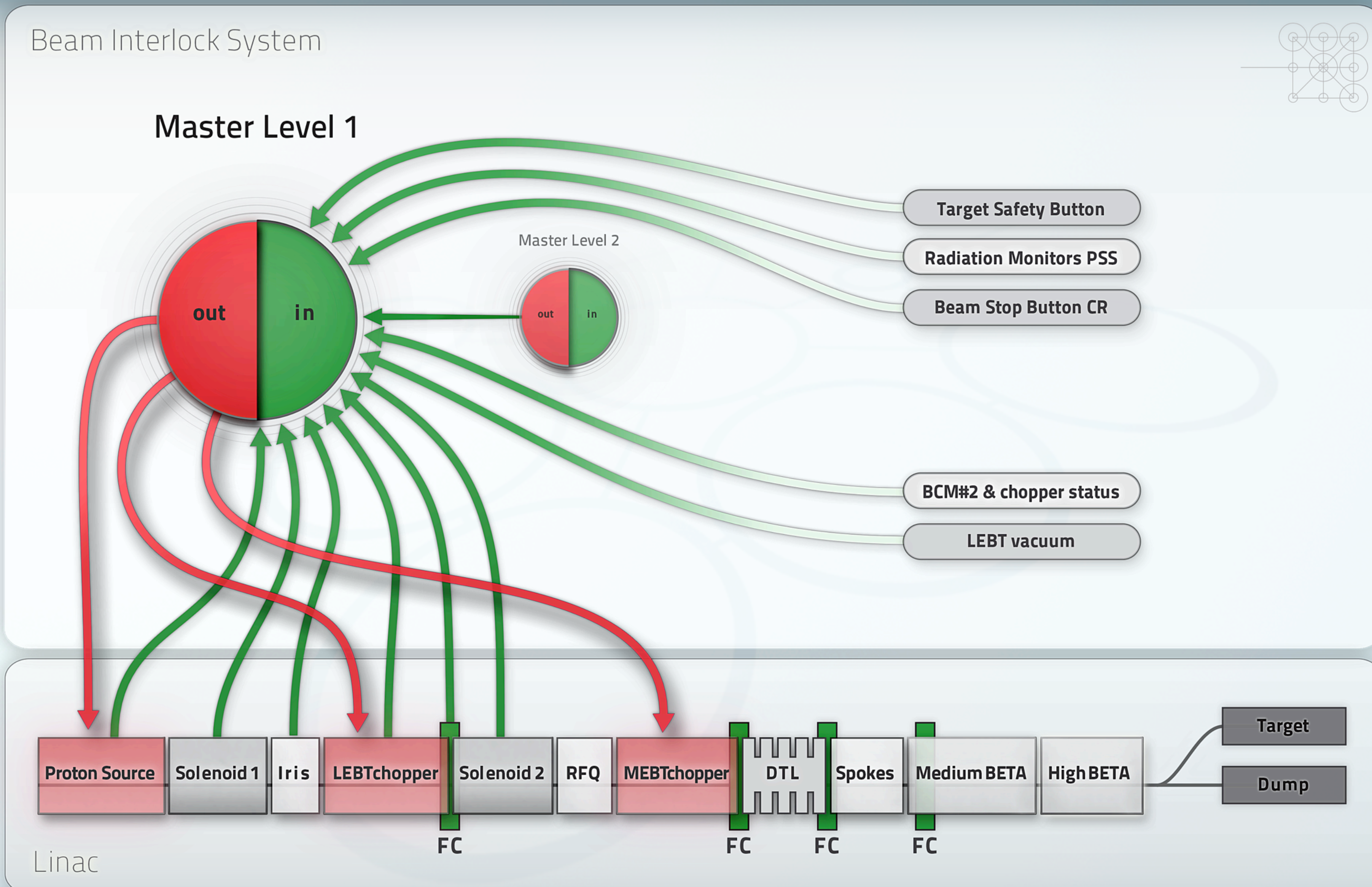


Two different mitigation techniques will be implemented

Intra-pulse (within a pulse): fast beam stop

Inter-pulse (in between pulses): let the current pulse pass (safe beam parameters) BUT inhibit the next *n* pulses

BIS ARCHITECTURE: MASTER 1

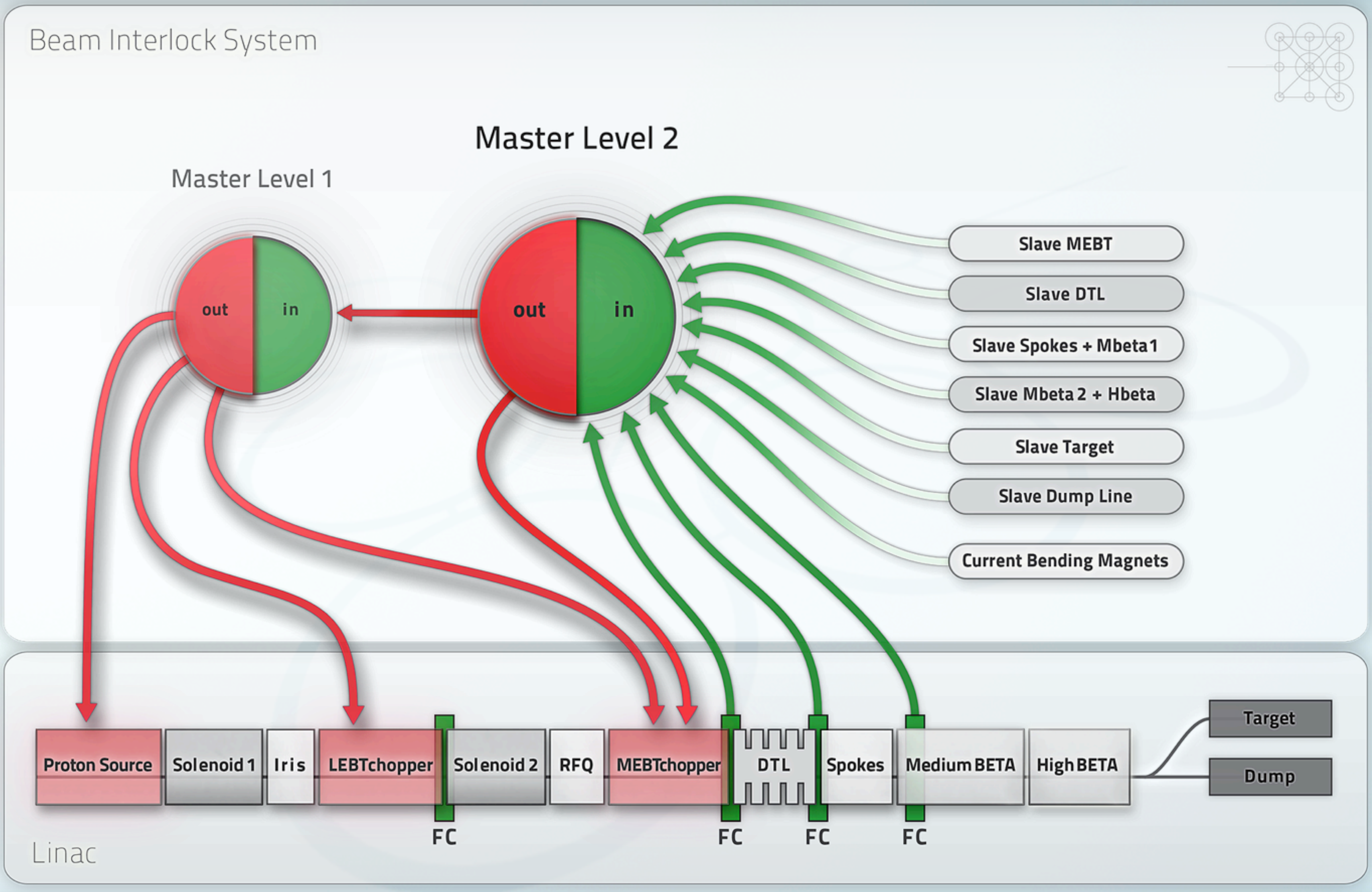


IDEAS FOR **FBIS LOGIC: MASTER 1**

Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	OUT
Interlock Element	SIS	Source Status	Iris status (cooling)	Solenoid 1 + Steerer 1 status	Solenoid 2 + Steerer 2 status	LEBT Chopper status	LEBT Faraday Cup IN	LEBT Faraday Cup OUT	EMU position?	Control Room Button	Radiation Monitors (PSS)	From Destination Master	LEBT Vacuum	TSS Button	BCM2 + Chopper status		Master 1: Beam_Permit
	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	x	1
	1	1	1	1	x	1	1	0	x	1	1	x	1	x	x	x	1

- Truth table for master 1
- All input signals are combined with a logical AND
- "x" means the signal can be ignored
- Beam goes either to the FC in the LEBT or further (Beam permit must be 1 for either line)

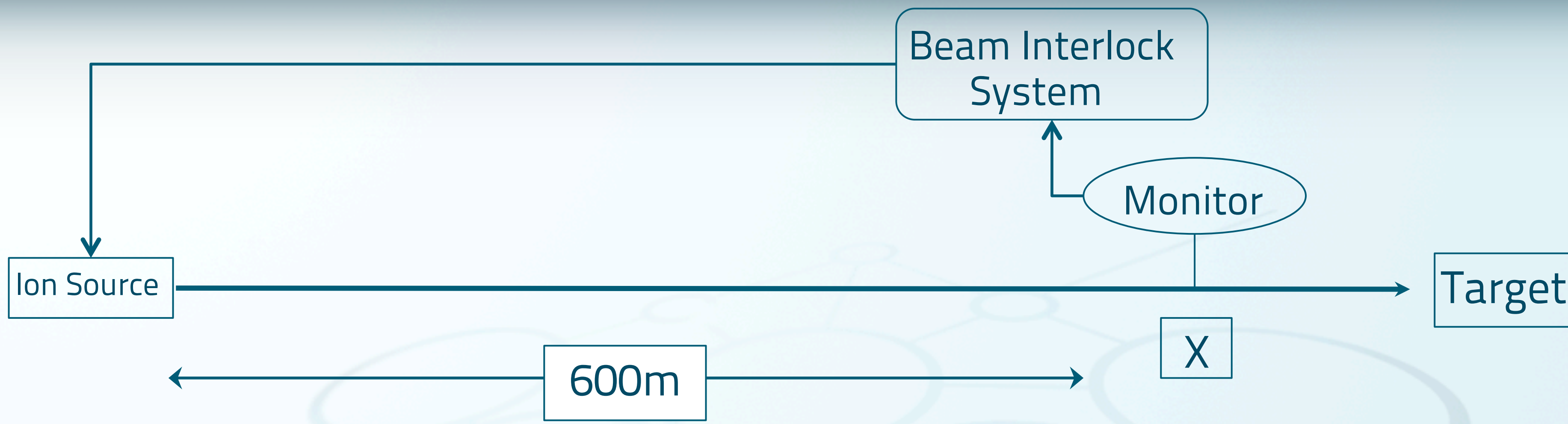
BIS ARCHITECTURE: MASTER 2



IDEAS FOR **FBIS LOGIC: MASTER 2**

Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	OUT	
Interlock Element	**MEBT OK**	**Faraday Cup MEBT IN**	**Faraday Cup MEBT OUT**	**DTL OK**	**Faraday Cup DTL IN**	**Faraday Cup DTL OUT**	**Spokes + Mbeta1 OK**	**Faraday Cup Mbeta 1 IN**	**Faraday Cup MBeta 1 OUT**	**Mbeta 2 + HBeta OK**	**Current TARGET OK**	**Target Line OK**	**Current DUMP OK**	**Dump Line OK**		**Master 2: Beam_Permit**	
	1	1	0	x	x	x	x	x	x	x	x	x	x	x	x	1	Beam to MEBT FC
	1	0	1	1	1	0	x	x	x	x	x	x	x	x	x	1	Beam to DTL FC
	1	0	1	1	0	1	1	1	0	x	x	x	x	x	x	1	Beam to MBeta FC
	1	0	1	1	0	1	1	0	1	1	0	x	1	1	x	1	Beam to Dump
	1	0	1	1	0	1	1	0	1	1	1	1	0	x	x	1	Beam to Target

MINIMUM TIME TO **STOP BEAM**



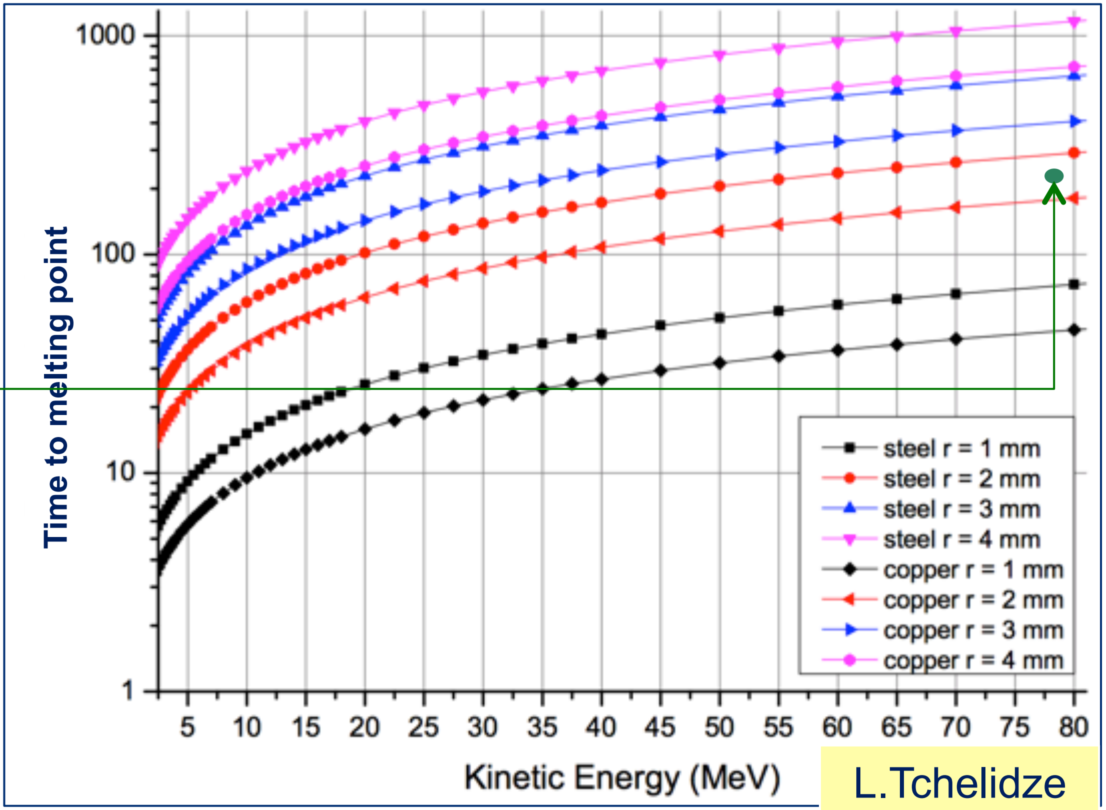
Beam impact at Position X (shown are estimated time-scales !)	
Monitor detects a failure (e.g. beam loss goes above threshold)	2 µs
Monitor validates failure and informs beam interlock system	1 µs
Beam interlock system records failure and issues beam stop request	<1 µs
Signal transmission from Beam Interlock System to Source / Chopper	2-3 µs
Time to receive stop request at LEBT chopper	0.1 µs
Maximum beam in the LINAC (see from source)	4 µs
Sum	10-11 µs

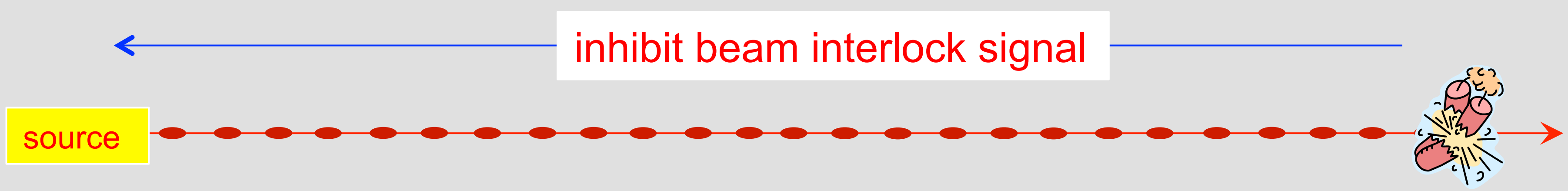
Example for ESS

Example:

After the DTL normal conducting linac, the proton energy is 78 MeV. In case of a beam size of 2 mm radius, melting would start after about 200 μs.

Inhibiting beam should be in about 10% of this time.





dT = dT_detect failure + dT_transmit signal + dT_inhibit source + dT_beam off