Studies on Reliability

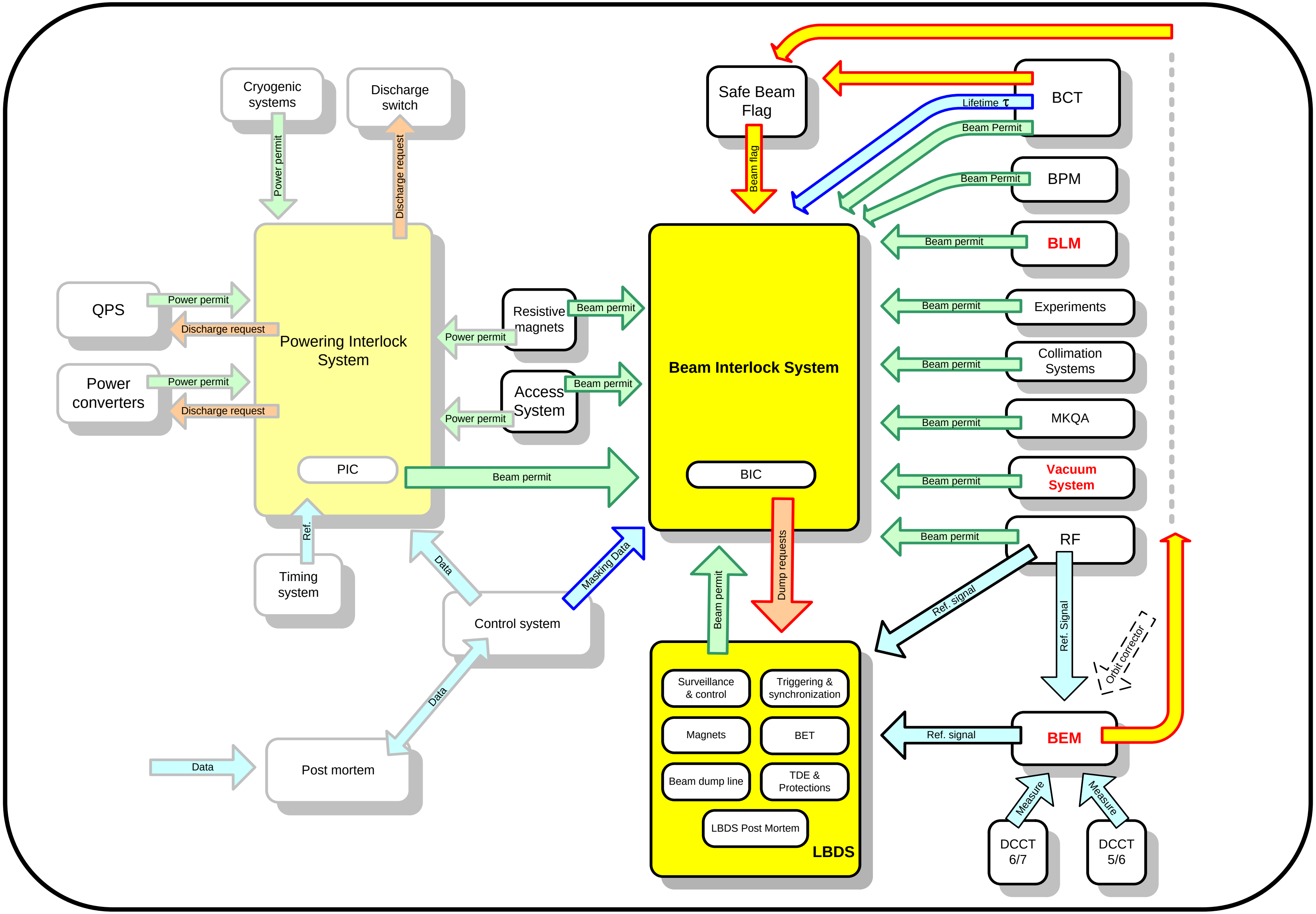
A General Approach

Topics of the Presentation

- Some guidelines to the **modeling of complex systems**.
- **Addressing dependability problems** of complex systems.
- **Application** to the LHC Machine Protection System and examples.

Introduction

- **The aim** is to manage complexity when addressing dependability issues for very large critical systems.
- **The proposal** is based on a **hierarchical functional modeling approach.**
  - Abstraction and modularity principles hold.
  - A top-down iterative procedure permits to build the hierarchy starting from the system functional specification. It can be detailed up to the desired level.
  - Dependability problems find a powerful support in the hierarchical functional structure.


Cryogenic systems
Discharge switch
Power permit
Discharge request
Safe Beam Flag
Beam flag
BCT
Lifetime τ
Beam Permit
BPM
Beam Permit
BLM
Beam permit
QPS
Power permit
Discharge request
Powering Interlock System
Power converters
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Ref.
Data
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Masking Data
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Ref. signal
Ref. Signal
Orbit corrector
Data
Post mortem
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Surveillance & control
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Beam dump line
TDE & Protections
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LBDS
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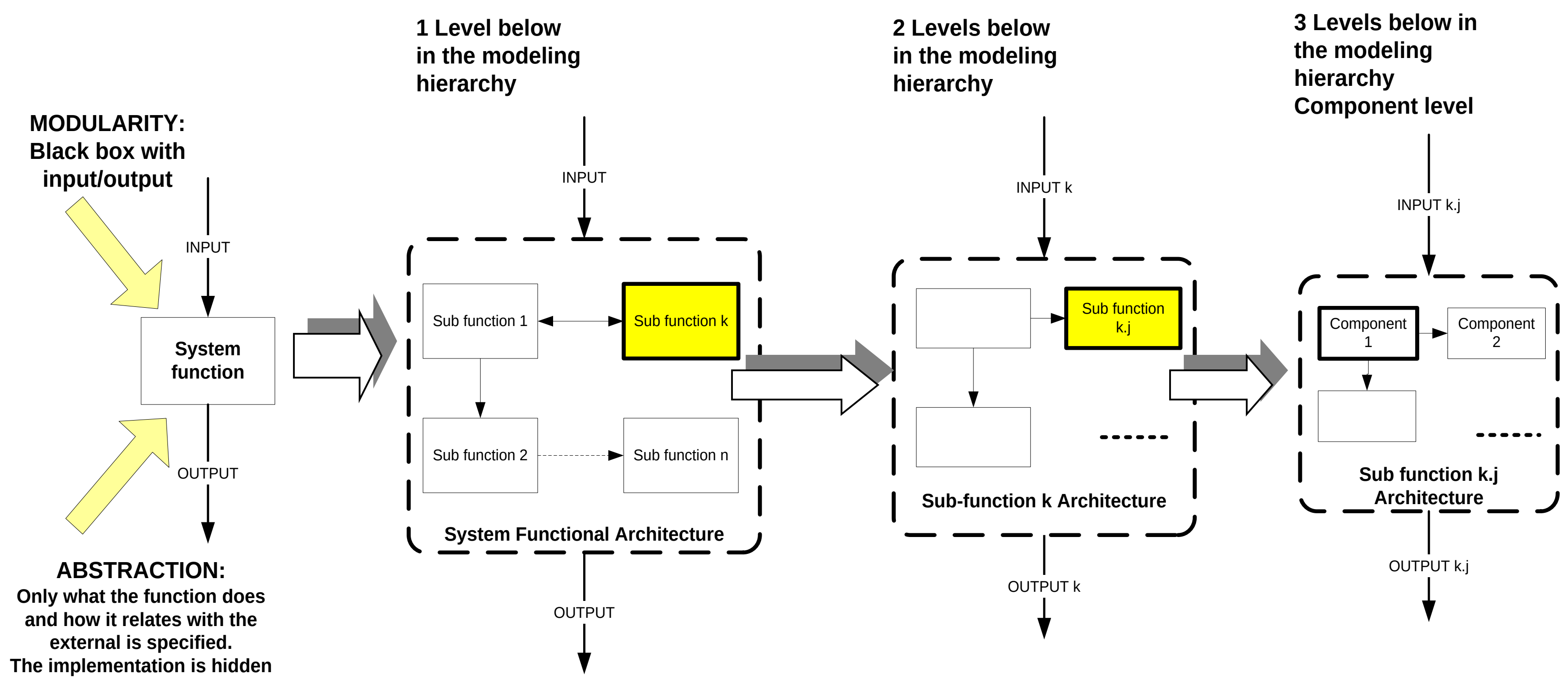
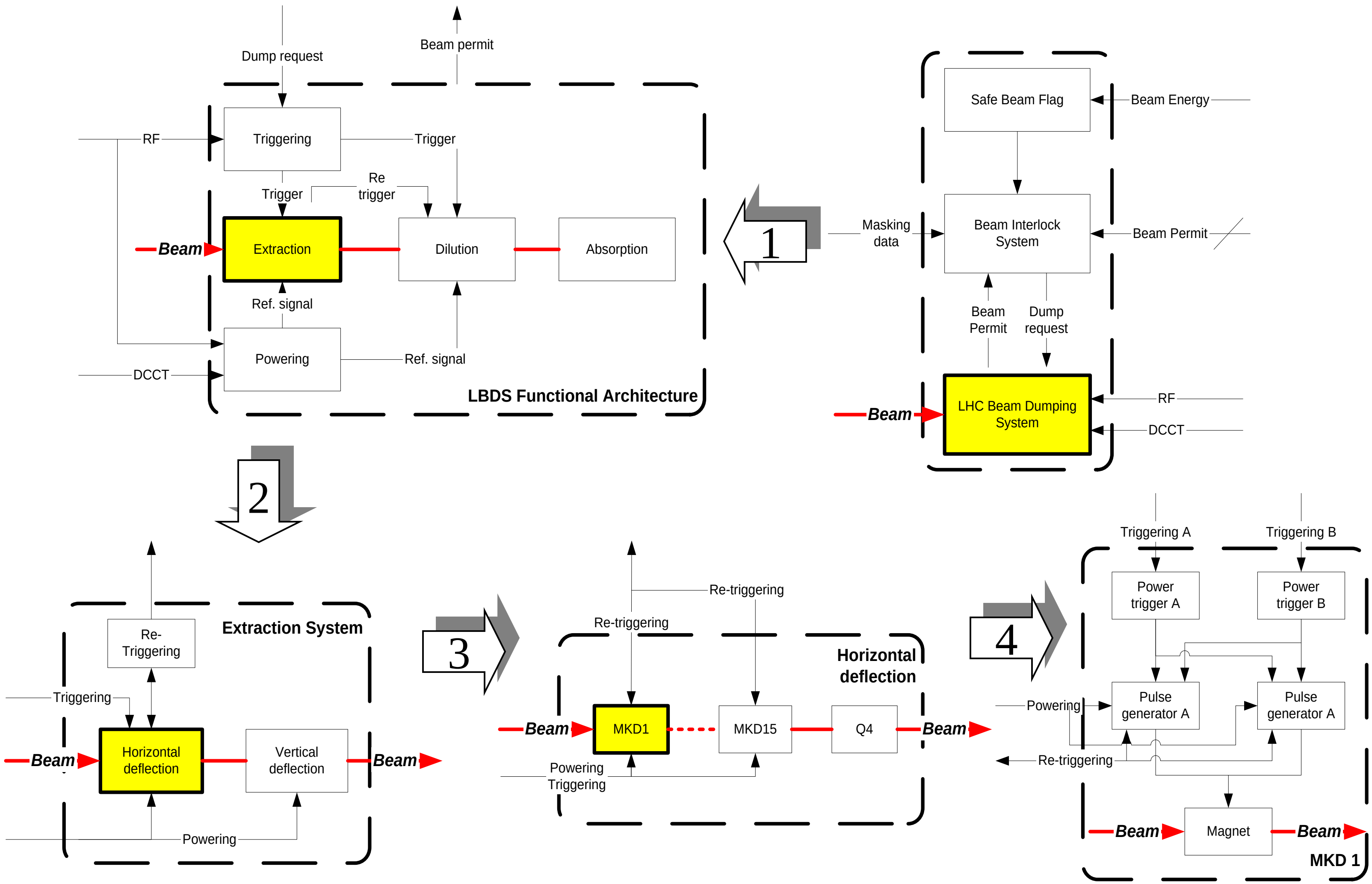
BEM
Measure
Measure
DCCT 6/7
DCCT 5/6

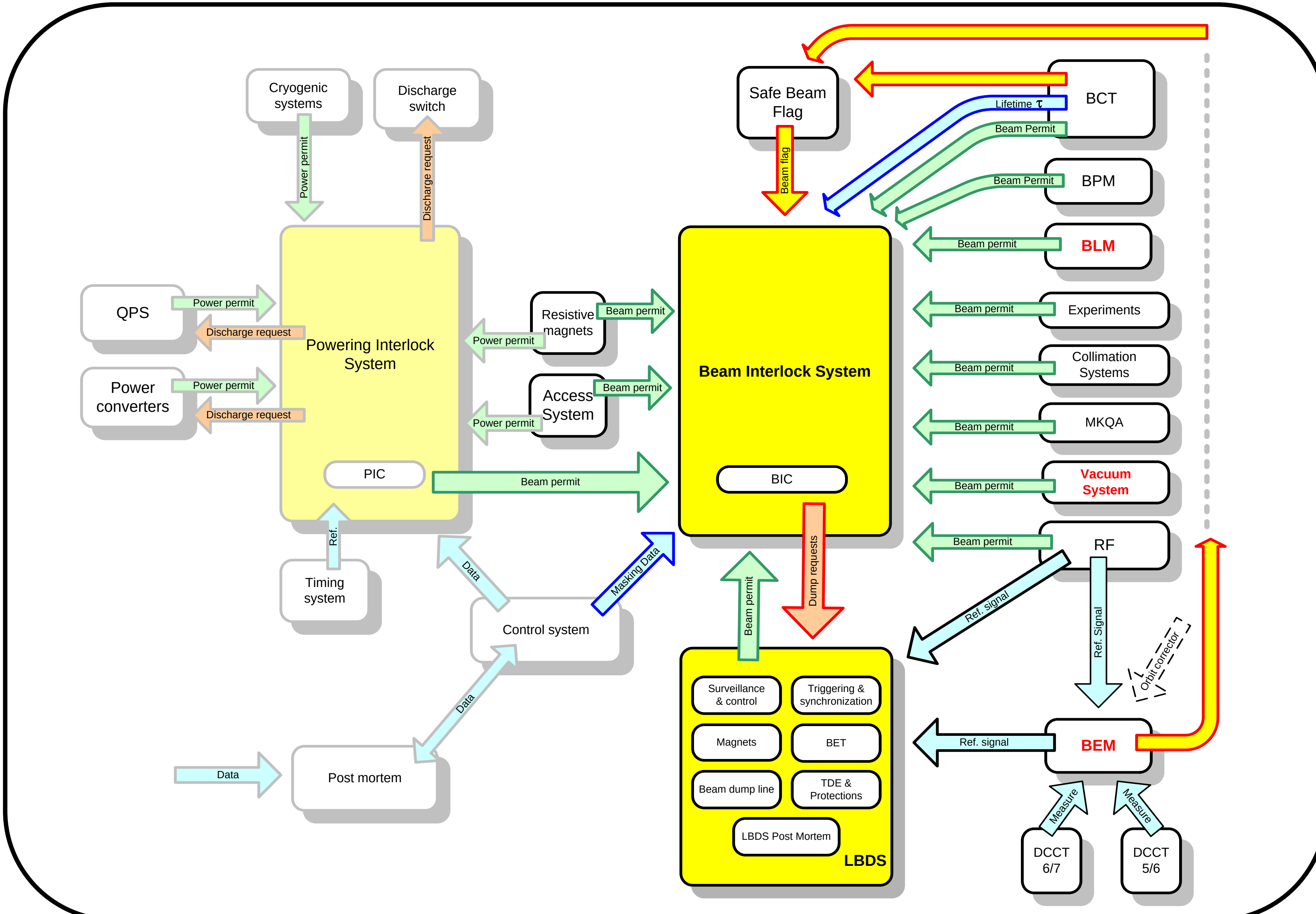
Hierarchical Modeling:
Managing complexity



Example of Hierarchical Modeling:

From the BIS to the MKD

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Addressing Dependability

Formula Composition

Top

RELIABILIT Y OF LBDS

$$R_{LBDS}(t) = R_{Extr}(t) R_{Pow}(t) R_{Tri}(t) R_{Dil}(t) R_{Abs}(t)$$

1

2

......

RELIABILIT Y OF EXTRACTION

$$R_{Extr}(t) = R_{H-Extr}(t) R_{V-Extr}(t)$$

RELIABILIT Y OF HORIZONTAL DEFLECTION

$$R_{H-Extr}(t) = R_{Q_4}(t)\{R_{MKD}^{15}(t) + 15 R_{MKD}^{14}(t)[1 - R_{MKD}(t)]\}$$

......

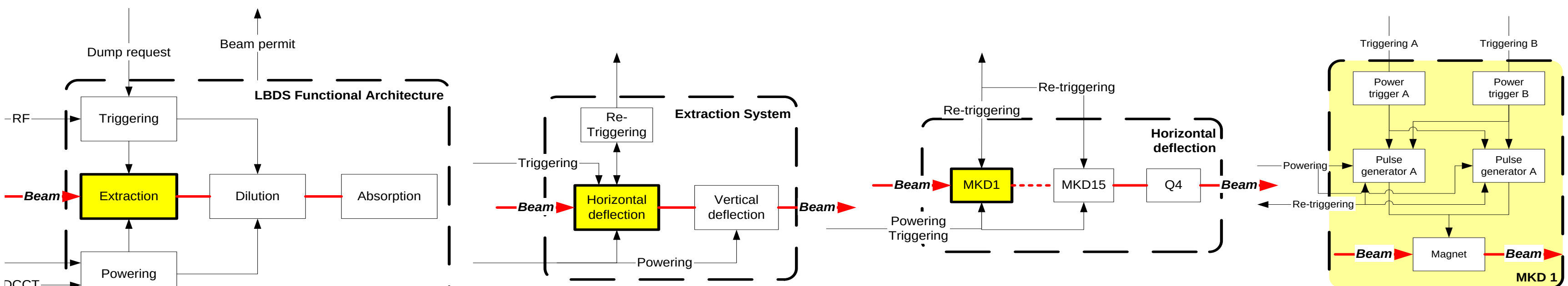
3

Down

......

RELIABILIT Y OF MKD1

$$R_{MKD1}(t) = \{1 - [1 - R_{TriggerA}(t)][1 - R_{TriggerB}(t)]\}\{1 - [1 - R_{PulseA}(t)][1 - R_{PulseB}(t)]\} R_{Magnet}(t)$$

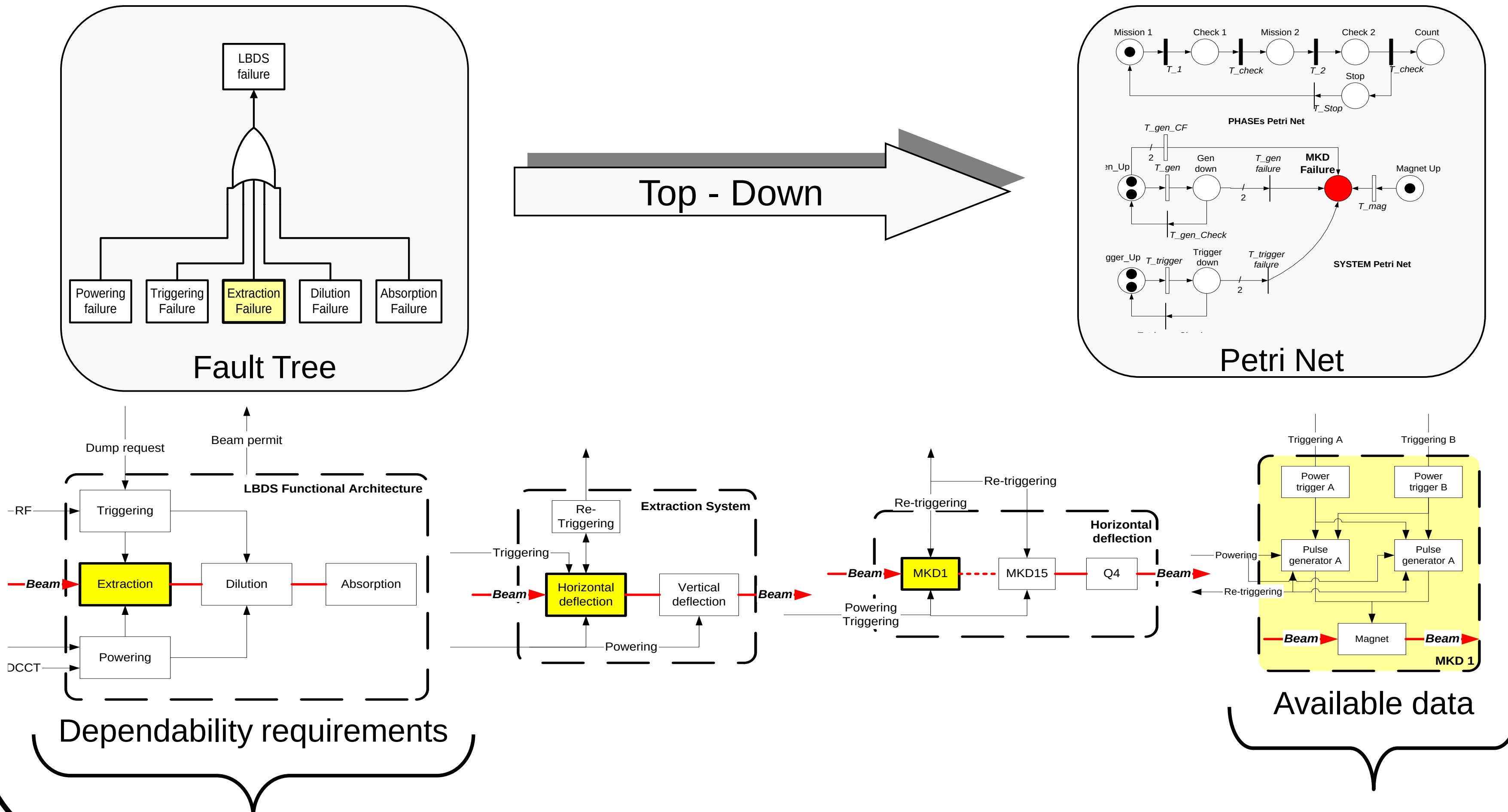


Dependability requirements

Data available

Addressing Dependability

Hierarchical Modeling of Failure Processes



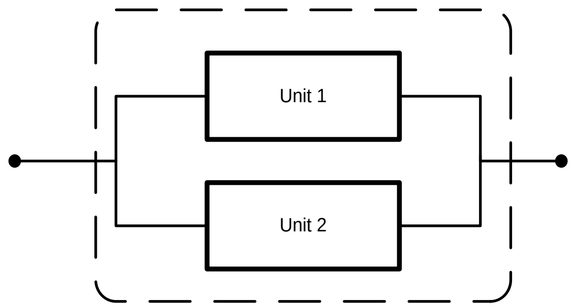
Comments on
Hierarchical Modeling

1. When **addressing reliability/availability issues**:
   - **Statistical independency** of failure processes must be checked.
   - <**?**> R(component j | component k is failed) = R(component j)
2. When **addressing safety issues**:
   - **Linearity of hazards** consequences must be checked.
   - <**?**> Risk {H1 U H2} = Risk {H1} + Risk {H2}.

- Whenever 1) or 2) are not true, the **modularity principle is violated** from a statistical point of view.
  - Reliability and availability will be overestimated.
  - Risk will be underestimated.
- Two **examples** following.

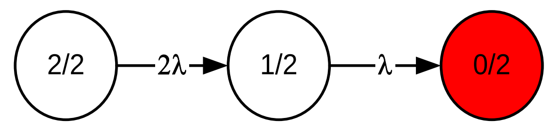
Example 1:
Overestimating Reliability

- **<u>The function</u>**: MKD pulse generator in the LBDS extraction function (horizontal deflection).
  - It consists of a parallel structure of two identical units.



- **<u>Reliability overestimate</u>**:
  - We ignore the common mode failure.

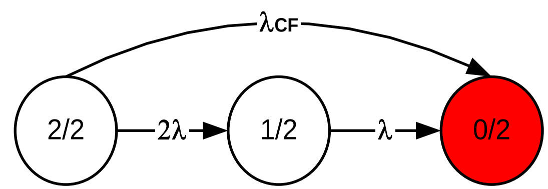
$R_{PG}(t) = 1-[1-R(t)]^2$; $R(t) = e^{-\lambda t}$



A: Statistical independent failure processes

- **<u>Reliability (true value):</u>**
  - We consider the common mode failure.

$\underline{R}_{PG}(t) = \{1-[1-R(t)]^2\}R_{CF}(t) < R_{PG}(t)$

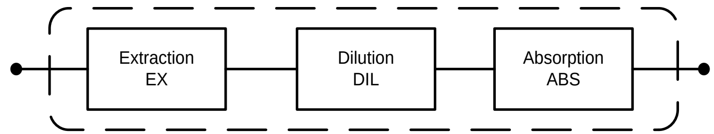


B: Statistically dependent failure processes

Example 2:

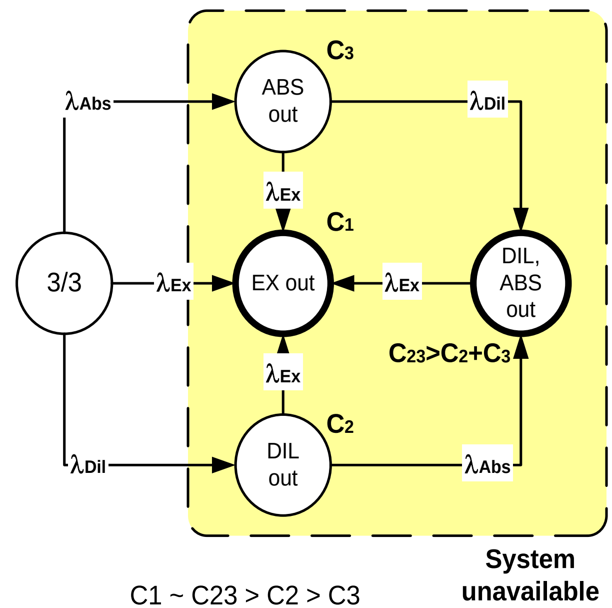
Underestimating risk

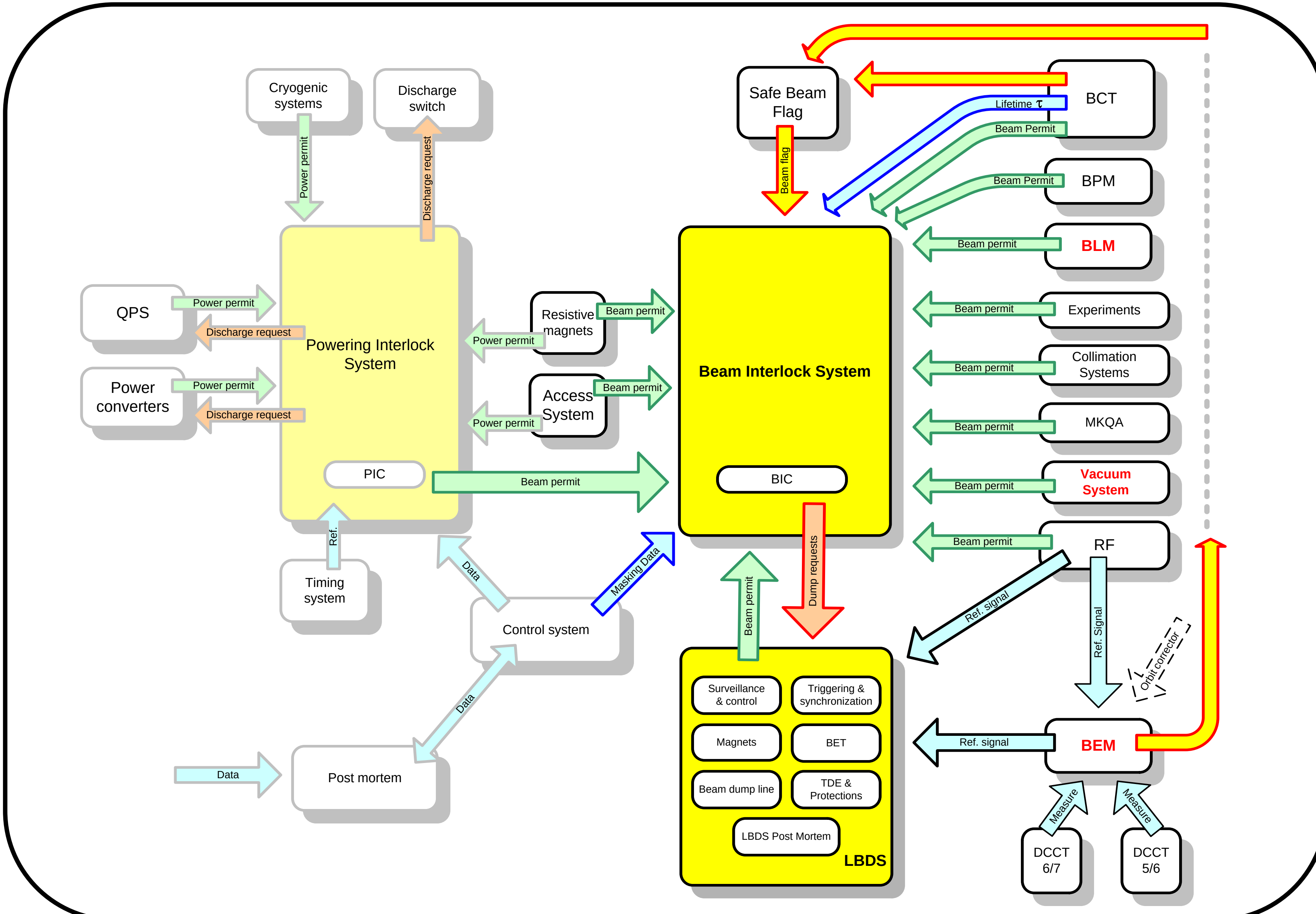
- **<u>The function</u>**: LBDS (simplified).
  - Three sub-functions in series: Extraction, Dilution and Absorption.



- **<u>The hazards</u>:**
  - H_1 {extraction failure} $[\lambda_{H1}(t), C_1]$
  - H_2 {dilution failure} $[\lambda_{H2}(t), C_2]$
  - H_3 {absorption failure} $[\lambda_{H3}(t), C_3]$
- **<u>Risk (underestimated)</u>**: we ignore hazards combinations.
  - $\text{Risk}(t) = \lambda_{H1}(t)C_1 + \lambda_{H2}(t)C_2 + \lambda_{H3}(t)C_3$
- **<u>Risk (true value):</u>** we consider hazards combinations
  - $\underline{\text{Risk}}(t) = \lambda_{H1}(t)C_1 + \underline{\lambda}_{H2}(t)C_2 + \underline{\lambda}_{H3}(t)C_3 + \lambda_{H2,3}(t)C_{23} > \text{Risk}(t)$

    $\underline{\lambda}_{H2}(t) < \lambda_{H2}(t)$; $\underline{\lambda}_{H3}(t) < \lambda_{H3}(t)$;





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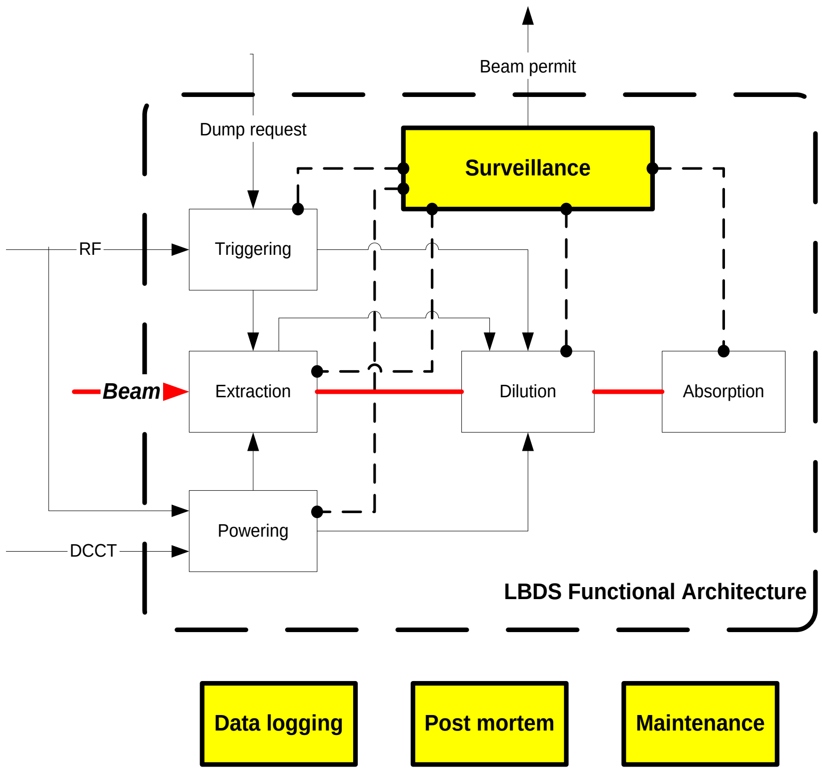
Auxiliary functions

- **Auxiliary functions** are functions that do not play a relevant role for the functional ability of the system but they **play a relevant role for the system dependability**.
- **Monitoring** prevents hazards (in mission).
- **Maintenance** prevents wearing and aging.
- **Diagnostics (Post mortem)**
  - checks for the healthy state of the system (out of mission).
  - gives the green light (beam permit).
- Two **examples** following.

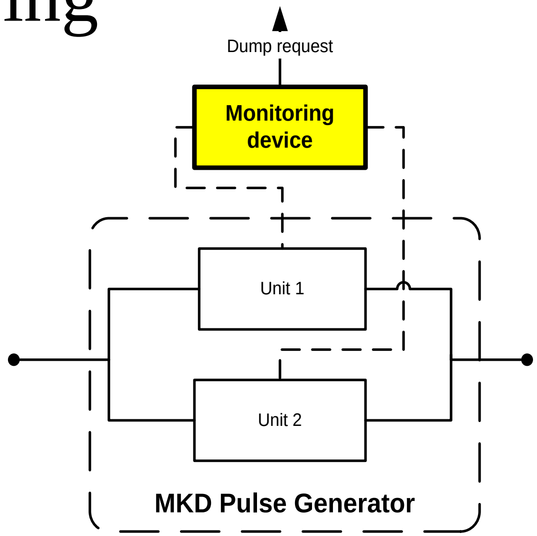
EXAMPLE: LBDS

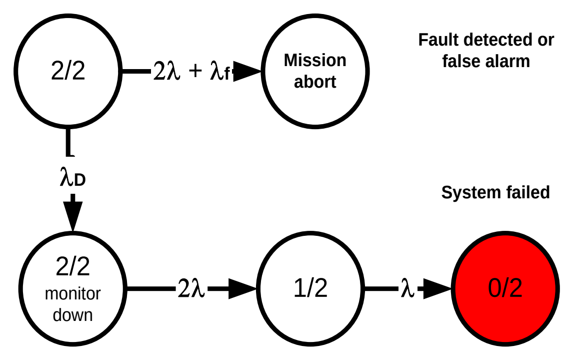


Example 3:

System Monitoring

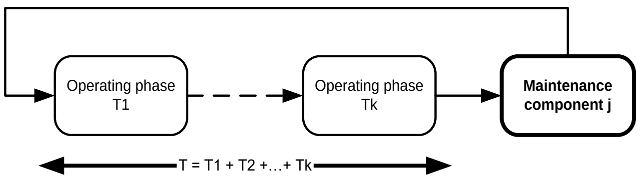
- **<u>Monitoring function</u>** for the MKD pulse generators generates a mission abort (before the mission time T) if at least one unit has failed.
- **<u>Monitoring parameters</u>:**
  - Failure rate: λ_D
  - Detection coverage = 1 (by simplicity).
  - False alarm λ_f
- **<u>Expected improvement</u>** (not for common mode failures).
  - $\underline{R}(t) = 1 - [1-R_D(t)][1-R(t)]^2 > 1 - [1-R(t)]^2$
  - $R(t) = e^{-\lambda t}$
- **<u>What we pay</u>**:
  - Mission abort rate: $2\lambda + \lambda_f$
  - Mission length = Min(T, $T_{\text{mission abort}}$) < T



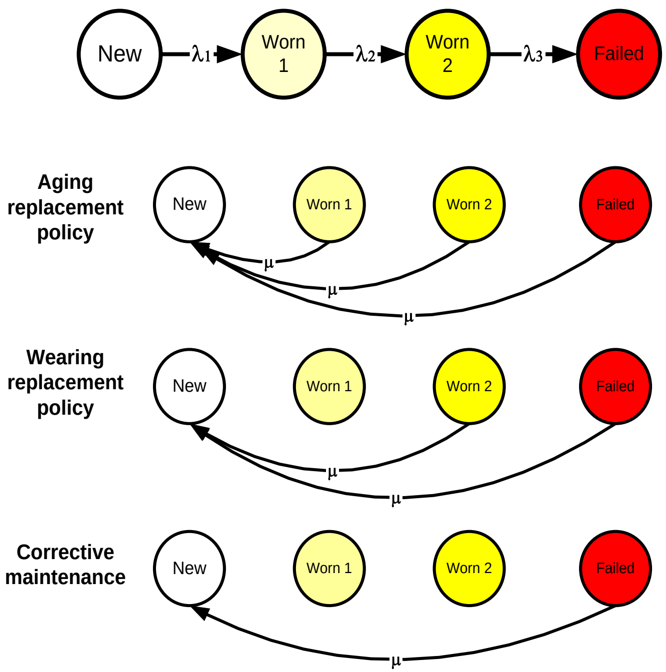


Example 4:
Maintenance Policies

- **<u>Maintenance policies</u>** prevent components from aging and wearing. Wearing and aging affect the failure rate.
- **<u>Three policies</u>**:
  - **Aging replacement**: the component is replaced after k operating phases (t = T).
  - **Wearing replacement**: the component is checked after k operating phases and is replaced only if it is worn above a threshold.
  - **Corrective maintenance**: the component is replaced only if it has failed.
- **<u>Expected improvement</u>:**
  - $R_A(t) = R(t\text{-}nT)R(T)^n > R_W(t) > R_C(t) = R(t)$
- **<u>What we pay</u>:**
  - Cost of replacement/maintenance.
  - $C_A(t) > C_W(t) > C_C(t)$

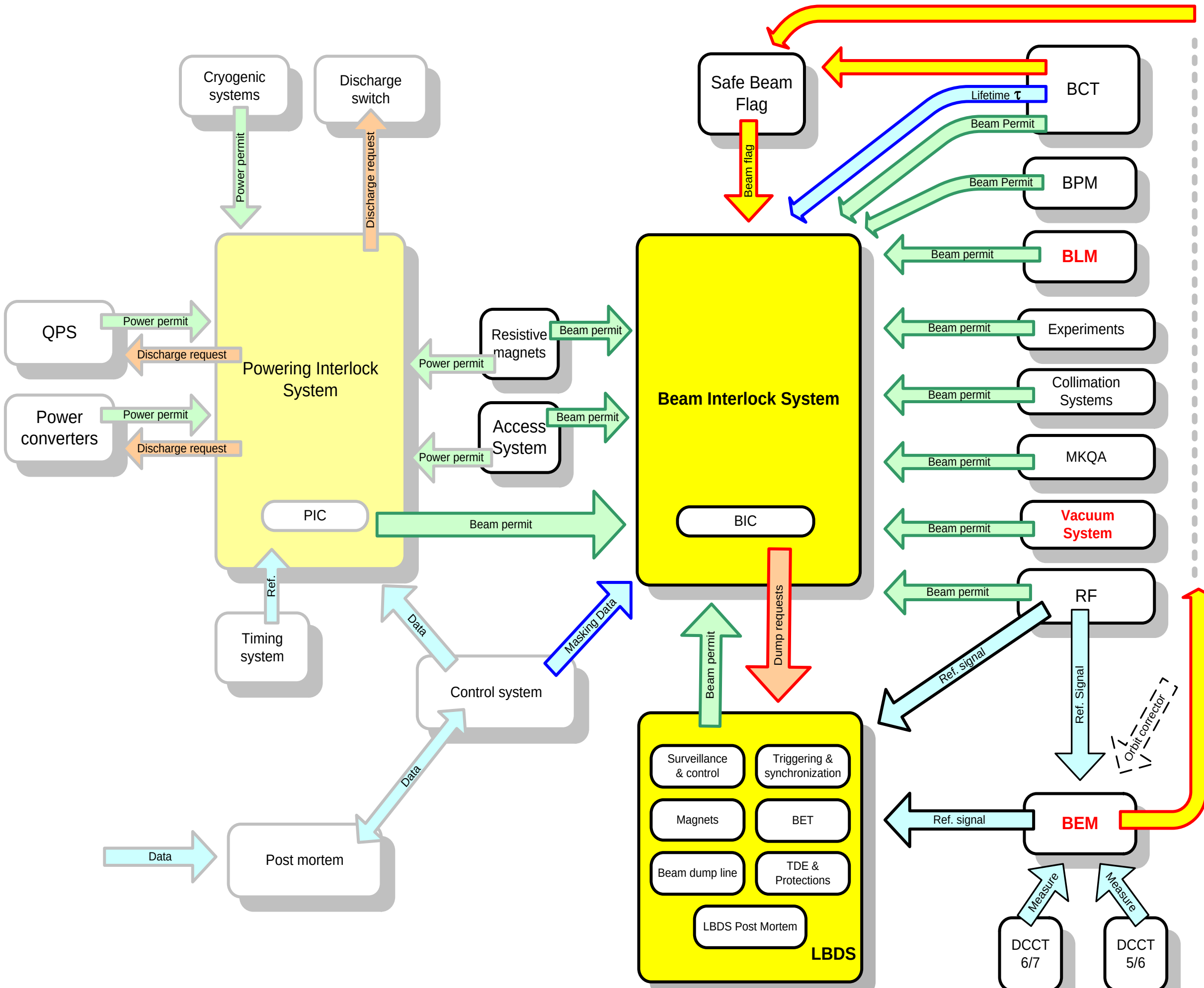


3 - Stages wearing process $\lambda_1 < \lambda_2 < \lambda_3$



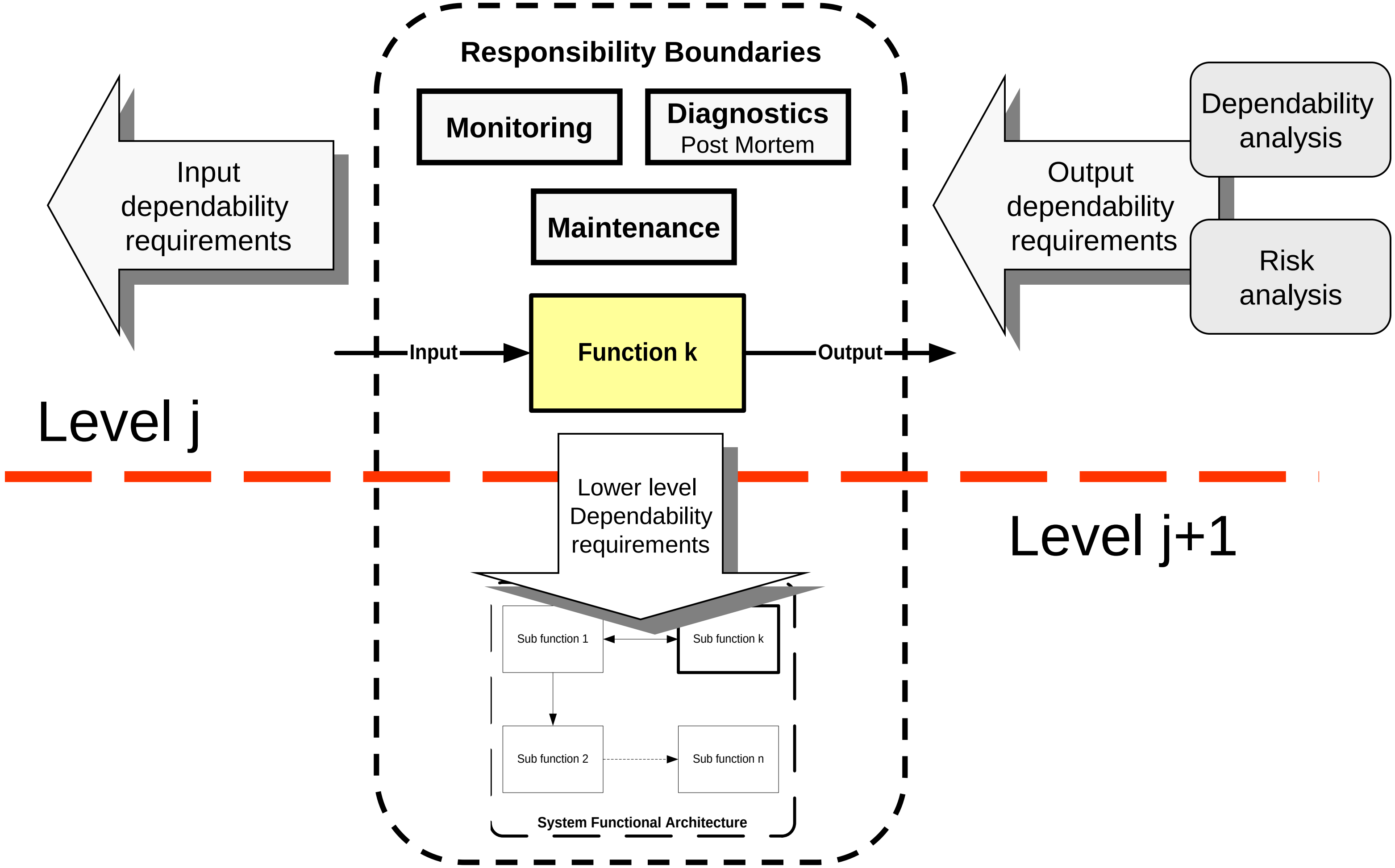
Some Questions to Be Asked by MPWG

- **BCT.**
  - Will lifetime generate a beam abort? Noise?
- **BLMs.**
  - Different families?
  - Redundancy.
- **BEM.**
  - RF frequency: energy changes allowed to 0.1% maybe to 0.3% ?
  - Orbit correctors.
- **Collimation system.**
  - Is the opening of collimators going into the BIC?



Dependability

Who Is Responsible of What



Conclusions

- **<u>Hierarchical modeling</u>** permits to manage complexity by:
  - Understanding interactions among different systems.
  - Defining relevant and not relevant modules/systems with respect to the analyzed function.
  - Addressing very complex dependability/performability problems in a hierarchical fashion.
  - Clarifying role and responsibility with respect to the global task.
  - Driving decisions top-down and vice versa.
- **<u>Responsibility of the MPWG</u>** is:
  - To built the structure of such a framework, similar to the one proposed in this presentation.
  - To fill each box with the information relevant for the dependability issues (including monitoring and maintenance).