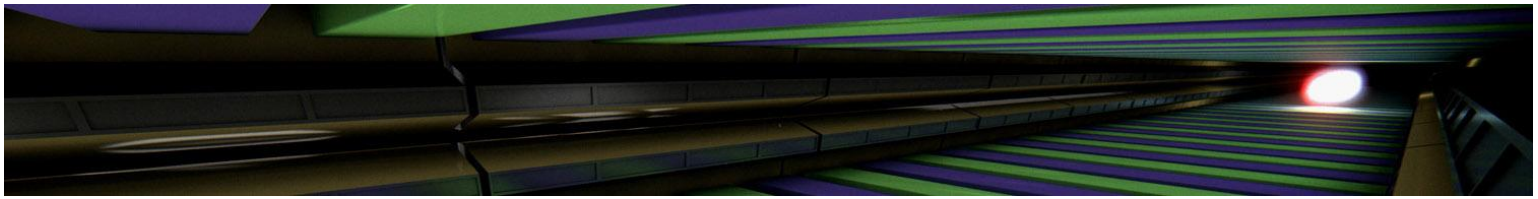


LLRF System Requirements Engineering for the European XFEL

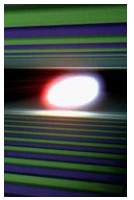
Z.Geng

G.Ayvazyan, M.Grecki, S.Simrock

Deutsches Elektronen-Synchrotron DESY

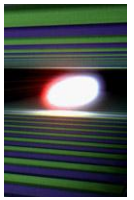
ICALEPCS 2009, Kobe, Japan

Outline



- Introduction to the European XFEL and the Low-Level RF (LLRF) system
- Introduction to the Systems Modeling Language (SysML)
- Requirements engineering processes for the LLRF system
- Conclusion and outlook

European XFEL



Introduction to the European XFEL and the LLRF System

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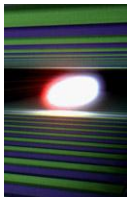
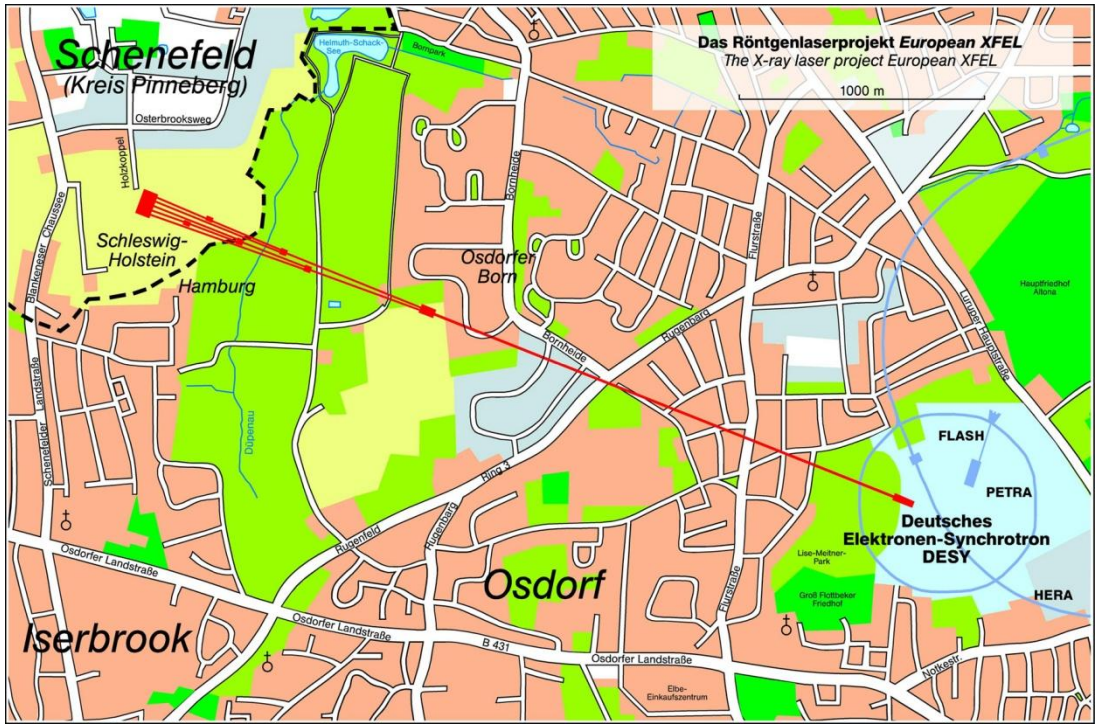
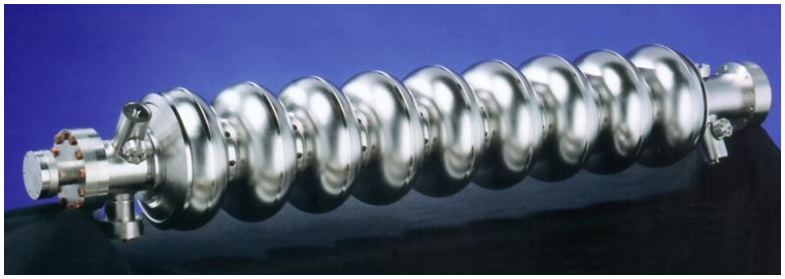
DESY HELMHOLTZ ASSOCIATION

European XFEL



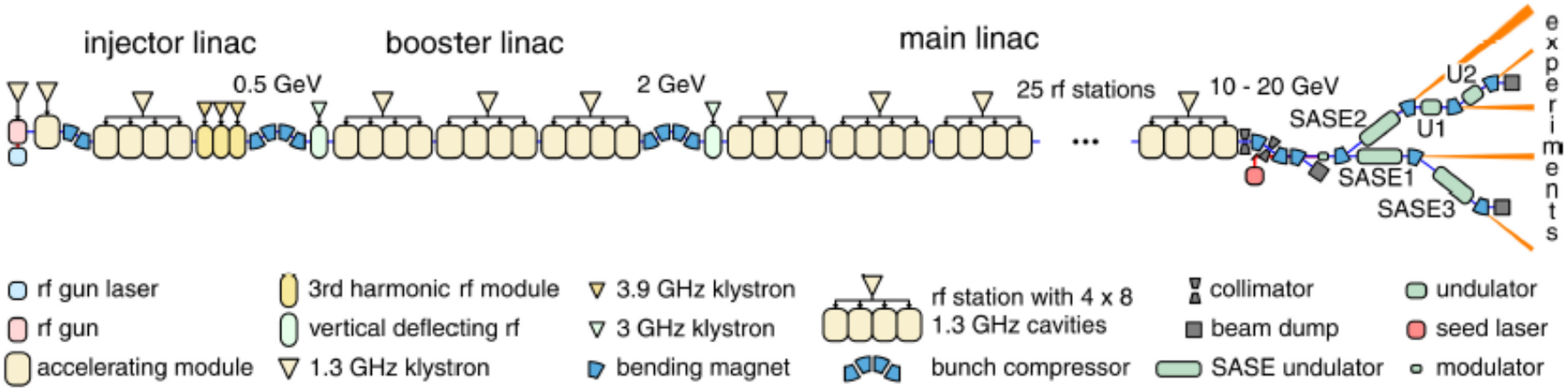
- European XFEL is a 4th generation light source under construction at Hamburg, Germany
- A 2.1km-long superconducting linear accelerator based on TESLA technology
- Beam energy 17.5GeV
- SASE wavelength 0.1~6nm





Reference: http://www.xfel.eu/

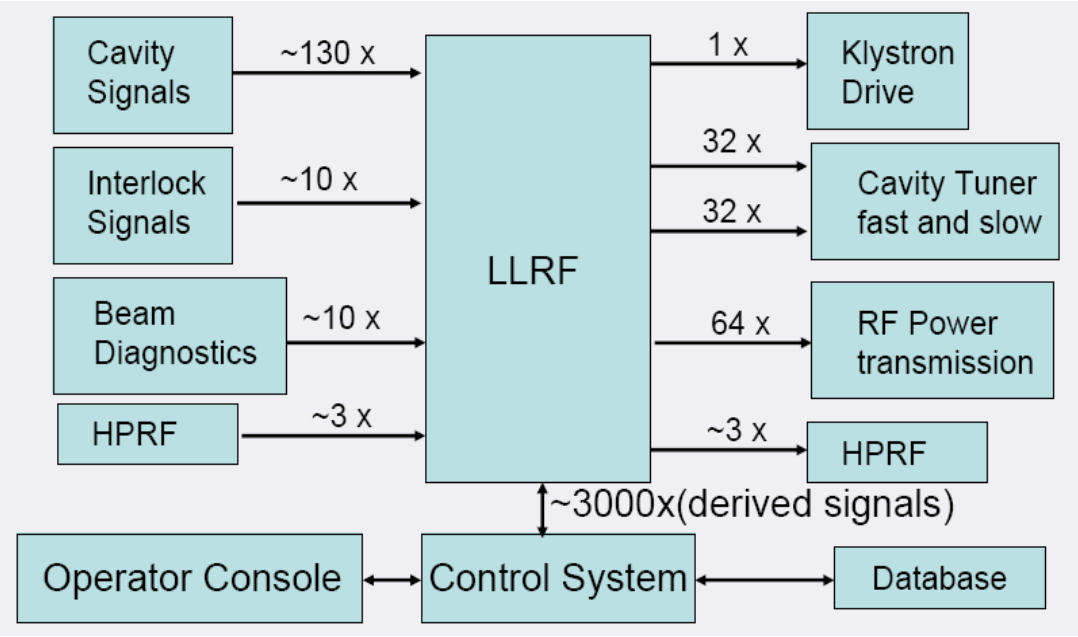
RF Subsystems for European XFEL



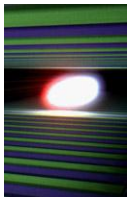
- ~ 30 RF stations
- High field stability required: up to 0.003% for amplitude and 0.005 deg. for phase
- LLRF control systems are necessary to maintain the field stability!

Features of the LLRF System

- High field stability requirements
- Large scale
  - ~ 30 RF stations
  - Up to 32 cavities per RF station
  - ~ 300 physical signals and ~ 3000 digital signals to be processed per RF station
- Complex context with multiple closely interacting subsystems
  - High Power RF system, Cavities, Control System, Beam Diagnostic System, …
- International context
- Many technological domains + methods + tools
- Researching + engineering



- Formal requirements / systems engineering methods will be used for handling the complexity of the LLRF system
- SysML will be used for system description



Introduction to the SysML

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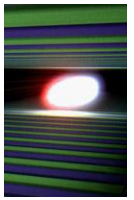
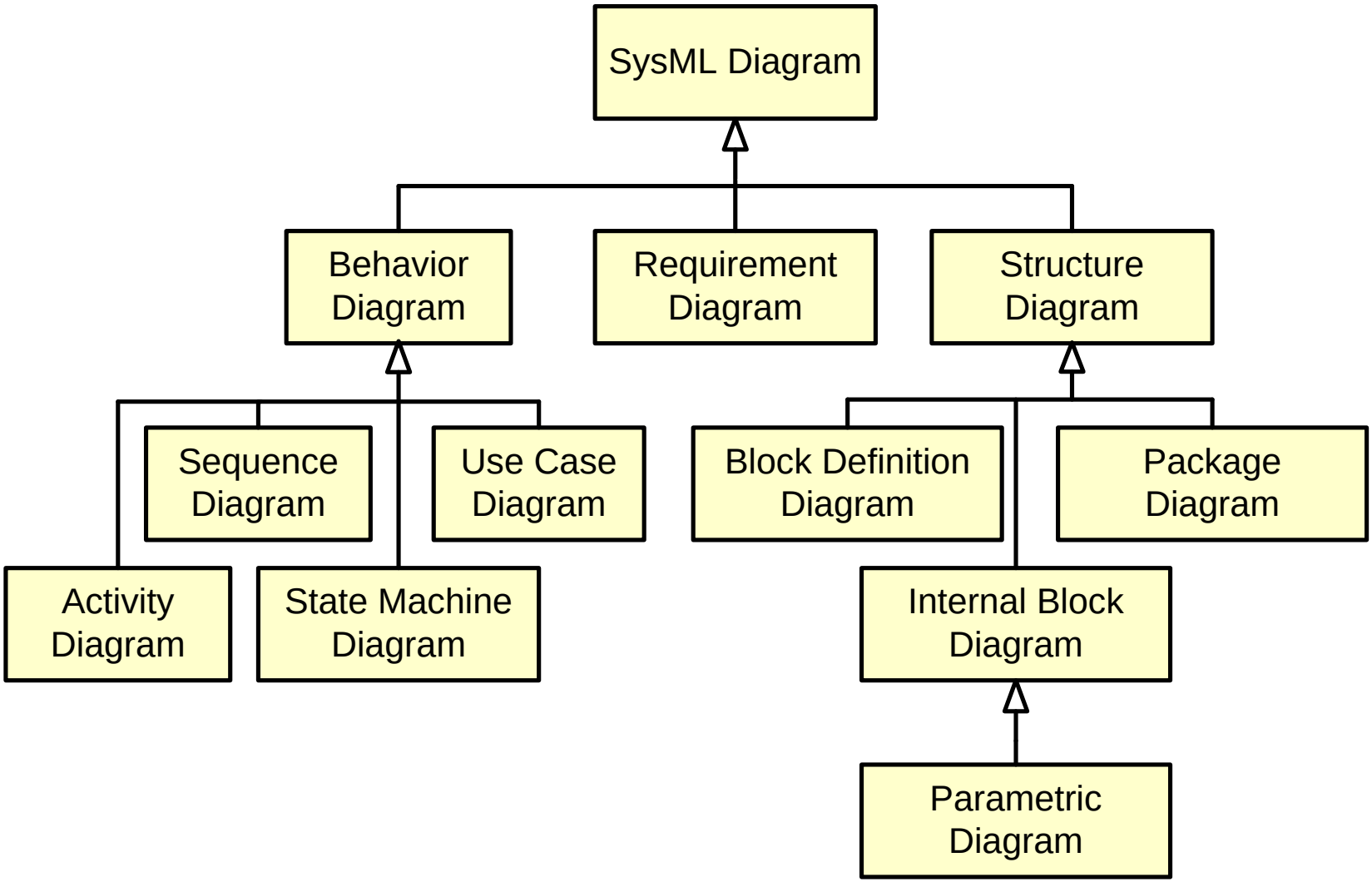
The System Modeling Language (SysML)

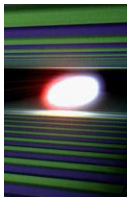


- A graphical modeling language for Systems Engineering developed by the OMG, INCOSE, and AP233
- Based on UML2.0
- Supports the specification, analysis, design, verification, and validation of systems that include hardware, software, data, personnel, procedures, and facilities
- Is a visual modeling language but not a methodology or a tool

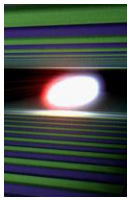
Diagrams of SysML



Benefits of Using SysML in LLRF System Design



- Shared understanding of system requirements and design
  - All collaborators speak the same language!
    - → Validation of requirements
    - → Common basis for analysis and design
    - → Facilitates identification of risks
- Assists in managing complex system development
  - Separation of concerns via multiple views of integrated model
  - Supports traceability through hierarchical system models
  - Facilitates impact analysis of requirements and design changes
  - Supports incremental development
- Enhances knowledge capture



Requirements Engineering Processes for the LLRF System

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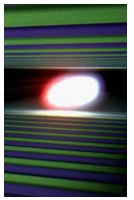
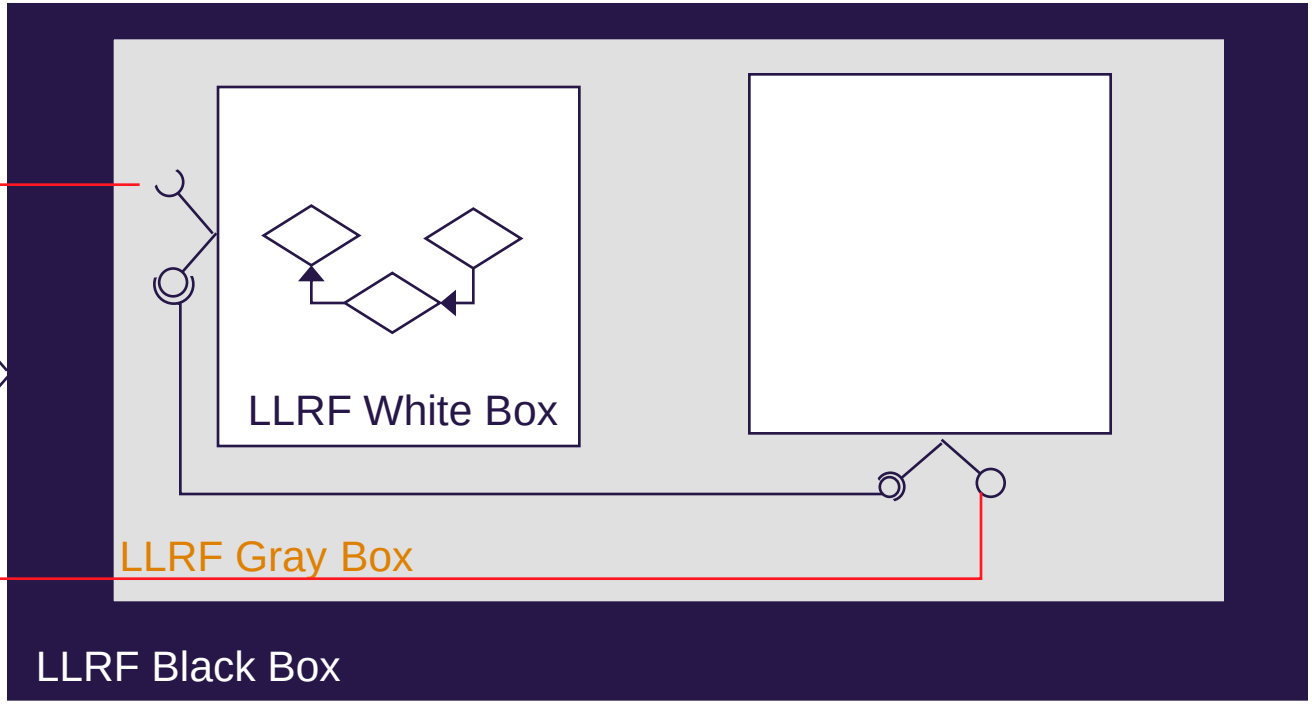
Goals of LLRF Requirements Engineering



- Create LLRF system specification and documentation for collaboration contract with international development teams and for project reviews

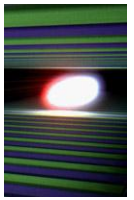
- Establish methods for requirements elicitation, documentation and tracking within LLRF team

Strategy: Staged & Recursive Development



- **4 milestones**
  - M0 – „XFEL – System“ (out of scope)
  - M1 – „LLRF System“
  - M2 – „LLRF Subsystems“
  - M3 – „LLRF Components“

LLRF Requirements Engineering Processes for Black Box Analysis



- Stakeholder analysis
- Requirements collection and analysis
- Identify external interfaces and model interactions
- LLRF functional structure break down
- Requirements verification

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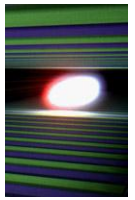
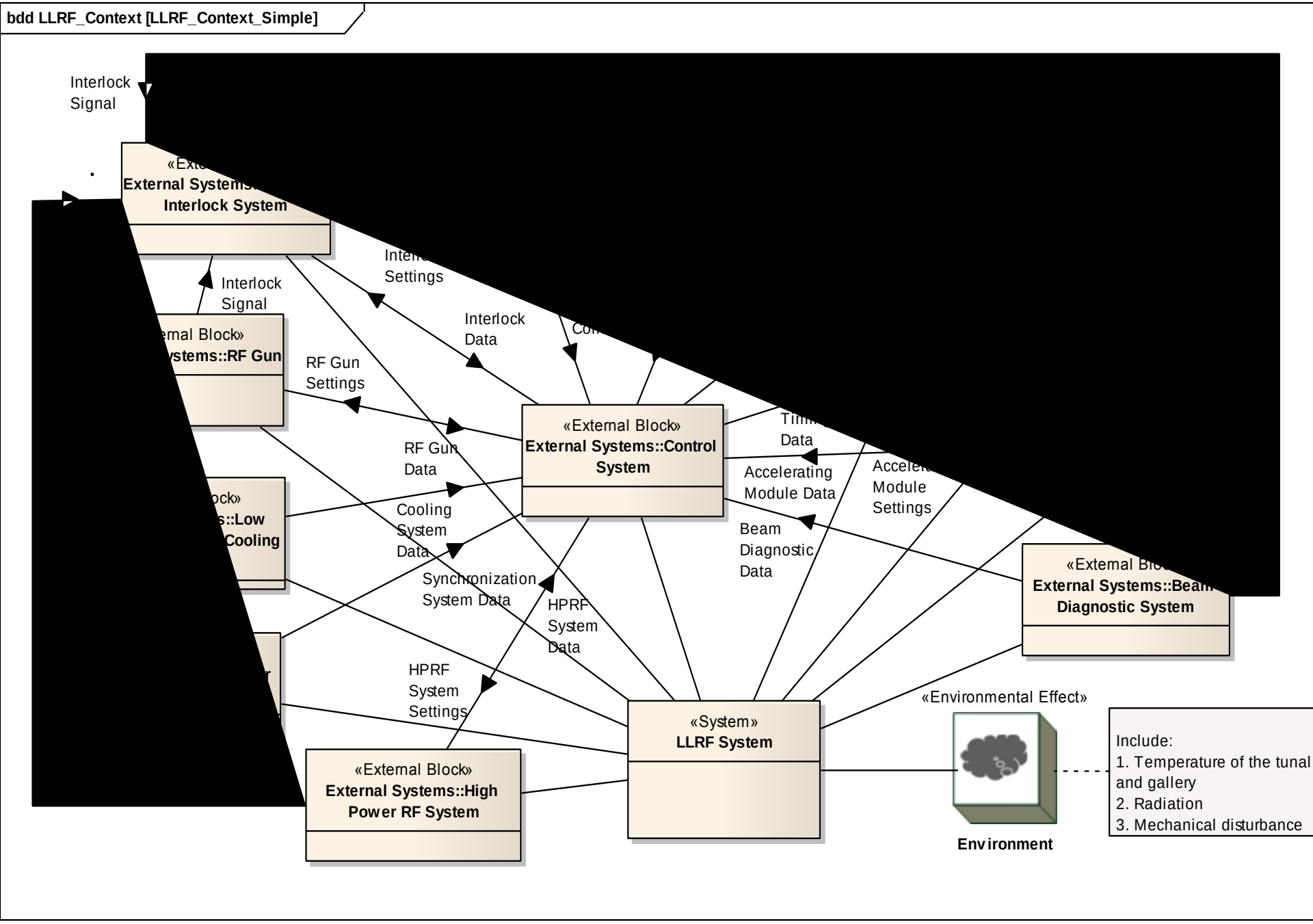
Stakeholder Analysis



- Which persons are involved in the project?
- Which roles can be differentiated?
- Which are the most important stakeholders (priorization)?
- How can external stakeholder be involved ?

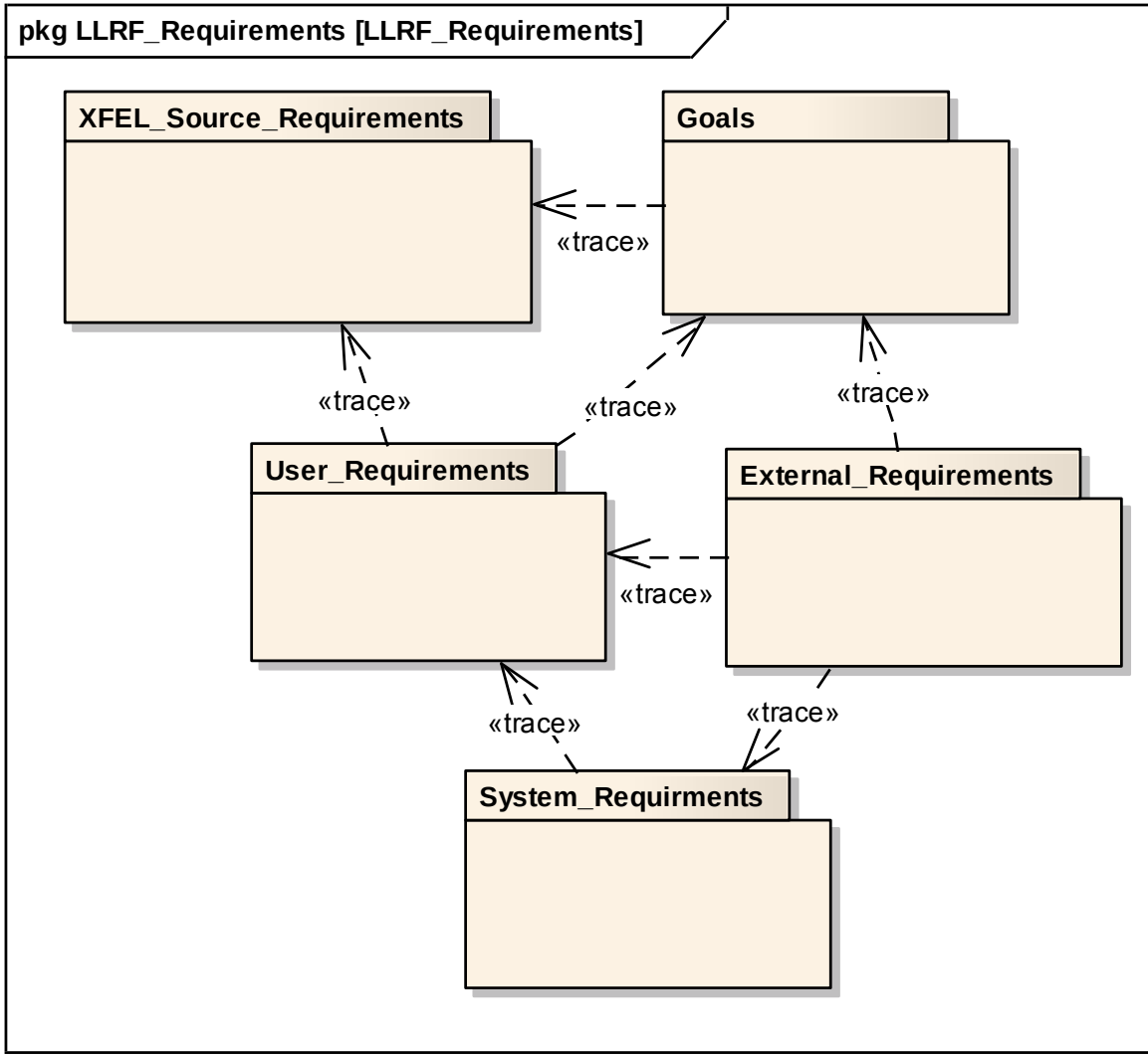
External Stakeholder	Affiliation	Influence to LLRF	Importance Rank	Influence Rank	Key	Rationale for ranking
Kay Rehlich	Controls group / DOOCS / controls data timing system	provides framework, tools, editors, timing, interface reviews	4	2	CG1	LLRF interfaces with DOOCS, therefore the interface requirements both influence development and need t be priortized
Reinhard Bacher	Controls group / DOOCS / timing system (Head)	provides framework, tools, editors, timing. LLRF needs to define interface with control group, interface reviews	3	2	CG2	LLRF interfaces with DOOCS, therefore the interface requirements both influence development and need t be priortized
Stefan Choroba	WP01 RF WPL & DESY Group Leader for high power group	essential connection, high and low power RF are highly integrated: LLRF is fallback for HLRF -> machine protection, LLRF	4	4	HPG1	High power system limitations and characteristics (including machine safety interlock must be considered in

Context of LLRF System

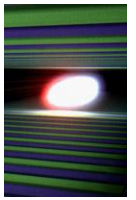


Requirements Collection and Analysis

- XFEL source requirements are needed as input for LLRF specification
- LLRF goals present the objective of the system
- User requirements are collected from stakeholders, which concern to the LLRF external visible services
- System requirements are derived from the user requirements, which concern to the system design
- External requirements present the requirements to external subsystems by LLRF



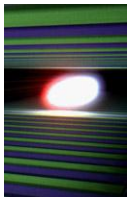
User Requirements Examples



[USER REQUIREMENTS]

ID	Name	Text
UR1	Set RF field voltage and phase for each RF station	The user should be able to set the RF field voltage and phase to defined working point for each RF station with the LLRF system
UR1.1	Change rate of the RF field voltage and phase	The change rate of the RF field voltage and phase in different linac sections are: * Gun, L0: Once per day * L1, L2: Once per shift * L3: Frequently, +/- 1.5% within pulse train, larger voltage and phase change may happens within 1 minute
UR1.2	RF field voltage setting range	The required range for RF field voltage settings of an RF station is: * 0 * V_min to V_max The V_max is defined by the cavity limits and klystron power limits experimentally
UR1.3	Time available for RF field voltage change	Changing the RF field voltage for beam energy adjustment in the main linac should take less than 1 minute
UR2	Maintain RF field stability	Maintain stability of voltage and phase of the RF field of individual RF stations within given tolerances for the range of useable operating parameters
UR2.1	Phase and amplitude stability definition	The stability of the RF field is defined by the amplitude and phase error referred to the set point (may be time varying)
UR3	Provide RF reference signals	Provide highly stable RF references at specified frequencies at selected locations,

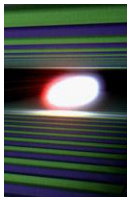
System Requirements Examples



[SYSTEM REQUIREMENTS]

ID	Name	Text	Derived From
SR1	Control the vector sum	Provide HW/SW for field control of the vector-sum of 8~32 cavities driven by one klystron in pulsed mode. 1. Detect the RF field phase and amplitude 2. Provide a controller for real time vector sum control 3. Provide RF actuators 4. Provide computation powers for performing the measurement and control [PERFORMANCE] 1. RF gun: $dA/A < 5*10^{-4}$, $d\varphi < 0.01°$ @1.3GHz 2. I0: $dA/A < 3*10^{-5}$, $d\varphi < 0.01°$ @1.3GHz 3. 3rd harmonic: $dA/A < 1*10^{-4}$, $d\varphi < 0.03°$ @3.9GHz 4. L1: $dA/A < 3*10^{-4}$, $d\varphi < 0.03°$ @1.3GHz 5. L2: $dA/A < 3*10^{-4}$, $d\varphi < 0.03°$ @1.3GHz 6. L3: $dA/A < 1*10^{-3}$, $d\varphi < 0.1°$ @1.3GHz	UR2
SR2	RF gradient and phase setting	Provide necessary applications and procedures for setting the RF gradient and phase for each RF station [PERFORMANCE] 1. RF gradient and phase setting should happen within 1 minute 2. RF gradient setting should be able to up to the klystron peak power output level of 0.9*P_sat	UR1

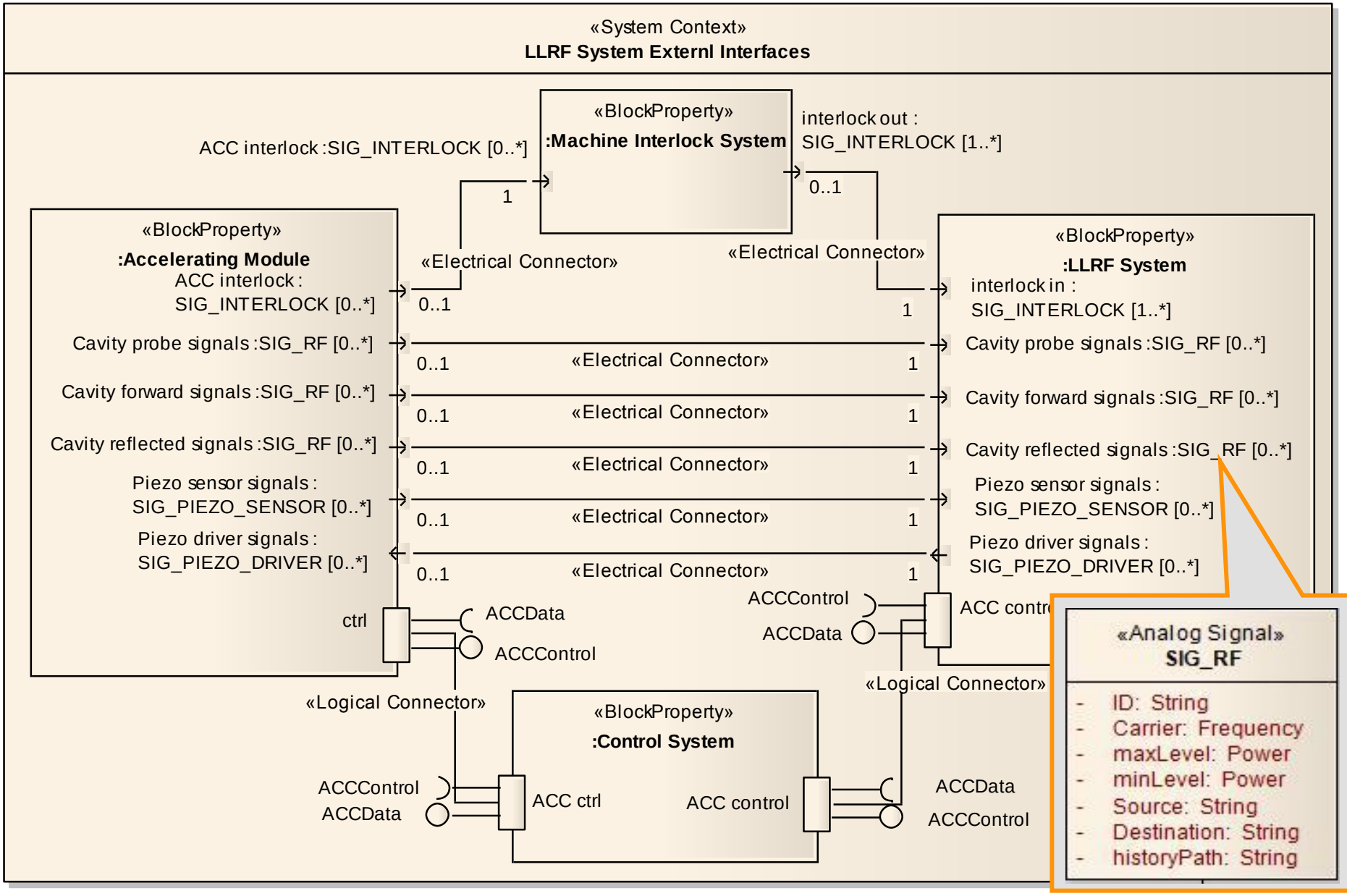
External Visible Interfaces of LLRF System



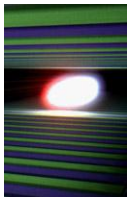
- The external visible interfaces define the boundary of the LLRF system as a black box
- Define the interfaces between the LLRF system and the external systems
  - High Power RF System
  - Accelerating Module
  - Control System
  - Beam Diagnostic System
  - Timing System
  - Laser Synchronization System
  - Machine Interlock System
  - Special Diagnostic System
- Define the signal / data types through the interfaces

External Interfaces - Example

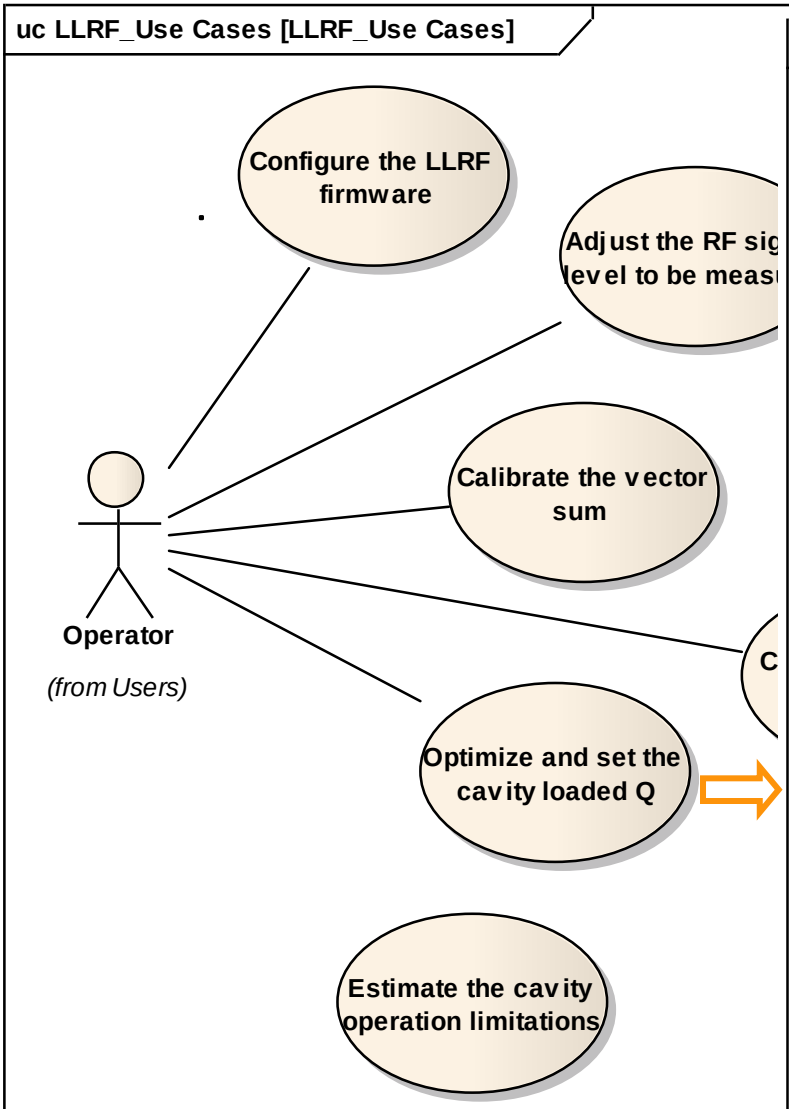
ibd LLRF System Externl Interfaces [Interfaces_Accelerating Module_Conceptual] ...

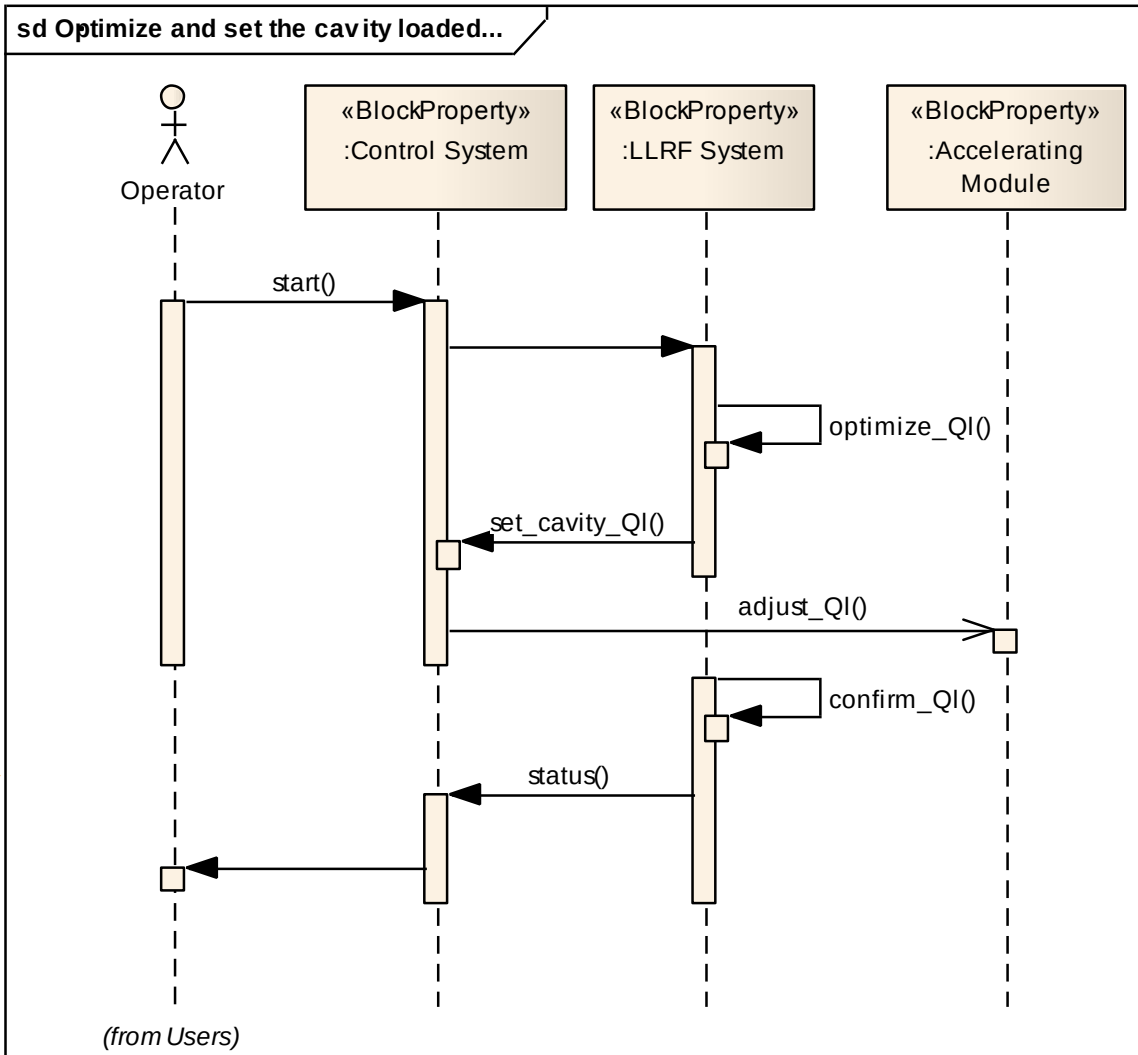


Model the Interactions at the Interfaces – Use Cases and Sequence Diagram

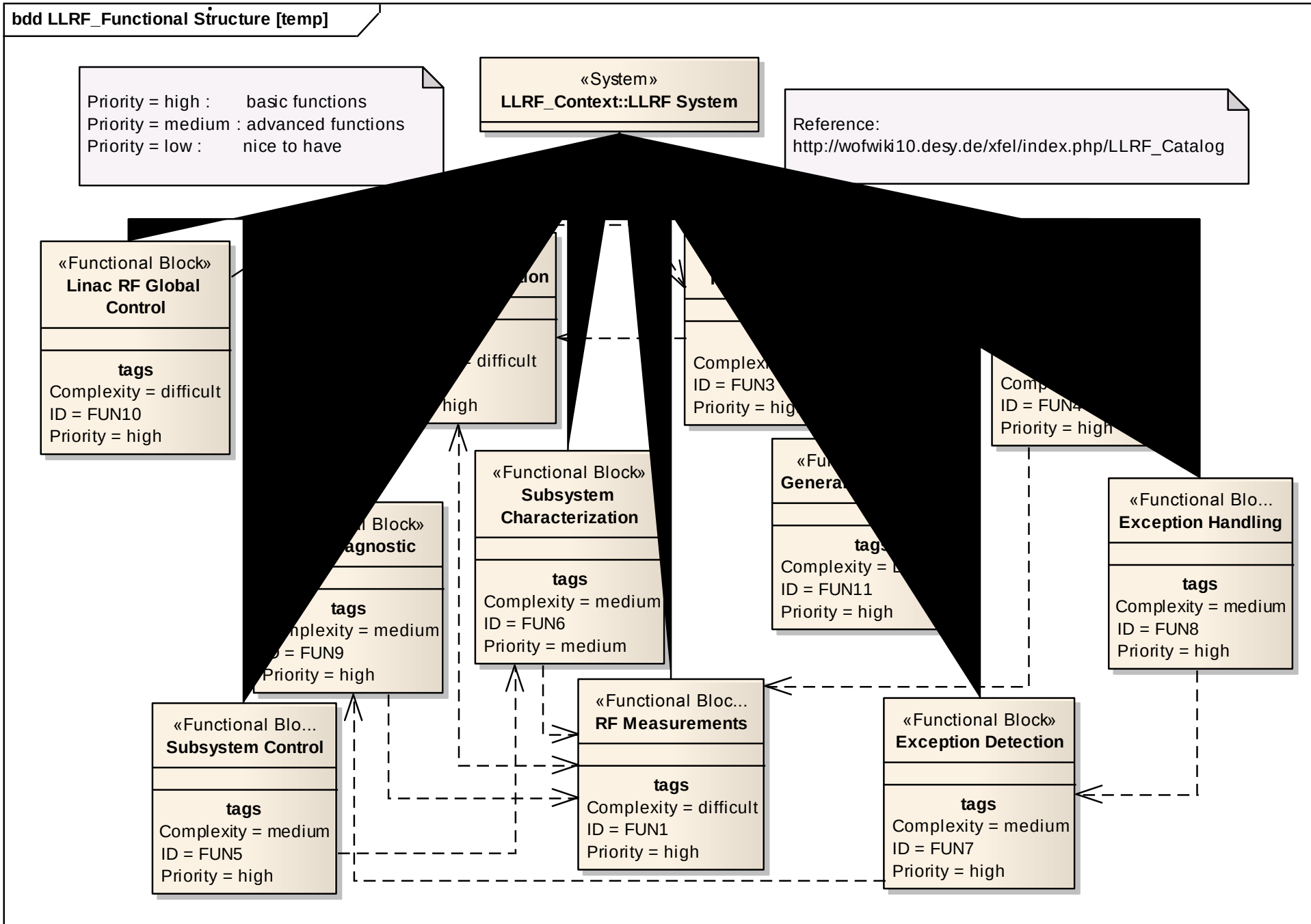


- Use cases describe the interaction between the LLRF system and the external systems and perform a defined task concern to the services provided by the LLRF system



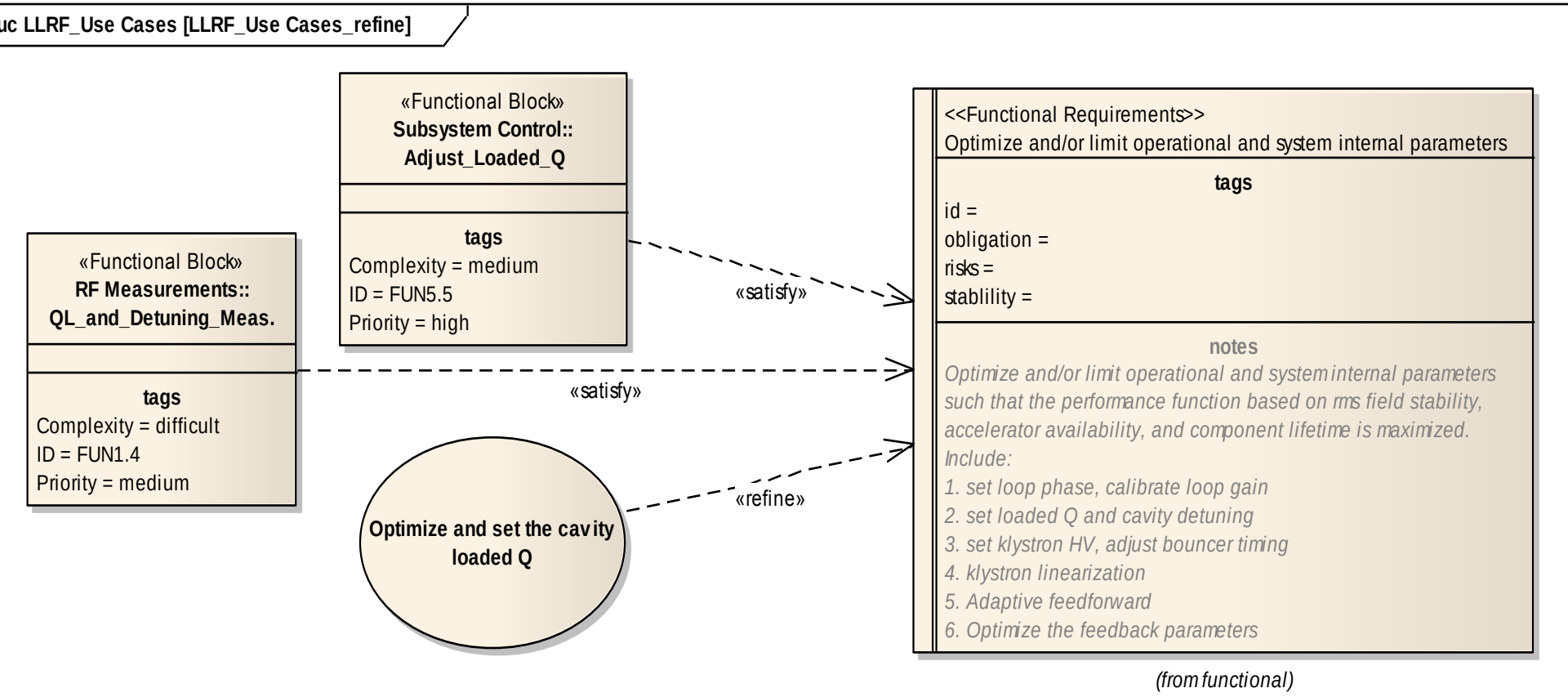


Functional Structure of the LLRF System

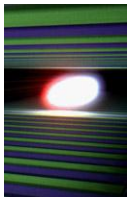


Verify High-Level Models against High Level Requirements

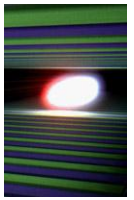
- Are all the use cases to refine the functional requirements?
- Are all the interfaces and signal/data types are necessary to satisfy the system requirements?
- Can the functional blocks satisfy all functional requirements?



Conclusion and Outlook



- New physics projects like European XFEL have reached a complexity comparable to large industrial projects
- Conventional engineering methods (start with simple goal, prototype, evaluate and evolution) are not very efficient for large projects
- Requirements / systems engineering methodology with description language (SysML) and tools provide systematic approaches for good documentation and enabling communication within the international collaboration
- Requirements engineering approach is successful for LLRF requirements capture and analysis
- LLRF black box analysis is ready for the Conceptual Design Review (CDR)
- Future plan
  - Grey box (subsystem level) analysis
  - Finish the full requirements specification for the LLRF system



Thank you!