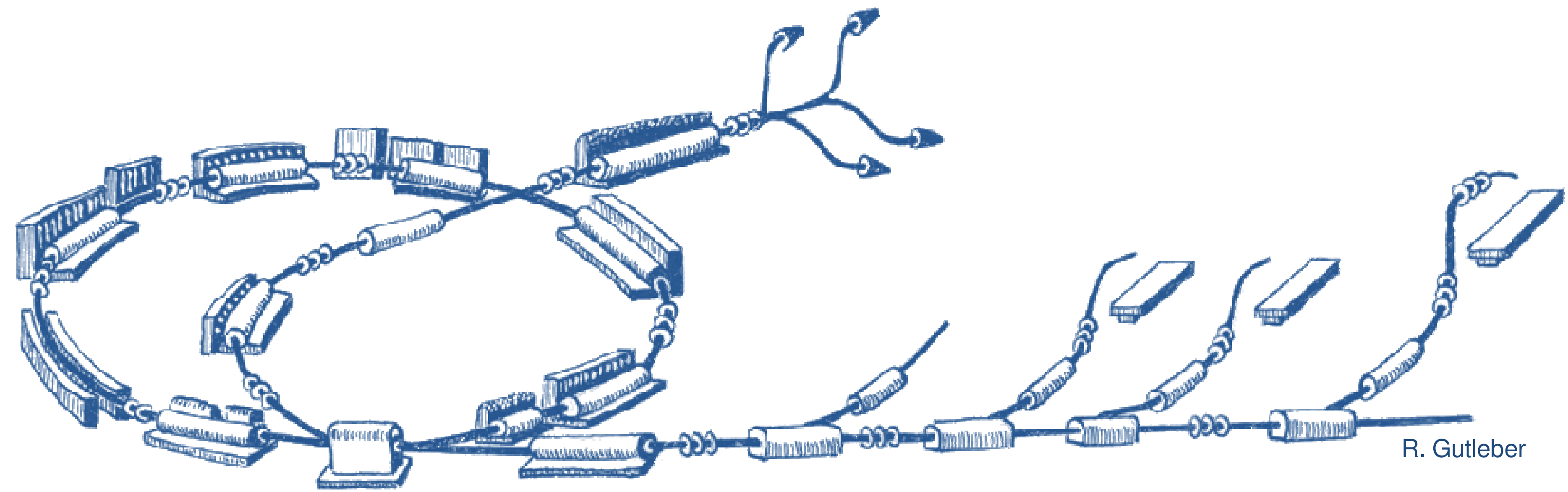
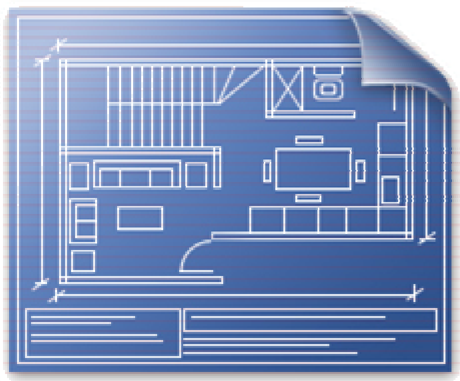
Work Package Controls

Inception Phase Review

February 5th, 2010

Johannes Gutleber



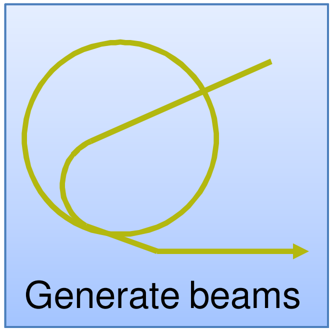


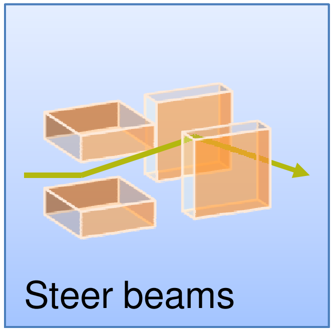
Scope and Goals of Work Package

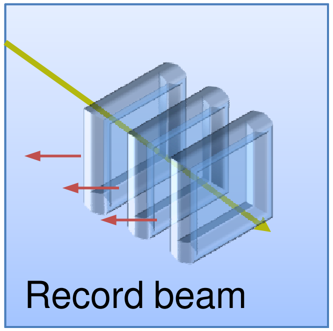
Goals of the System

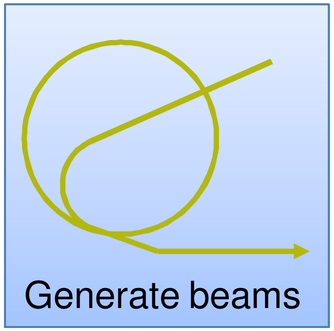
Provision of a system to

1. **Generate** beams according to a list of beam characteristics
2. **Steer** generated beams in real-time over target area by controlling the applied intensity (incl. activation/abort) and
3. **Record** actually generated beam characteristics







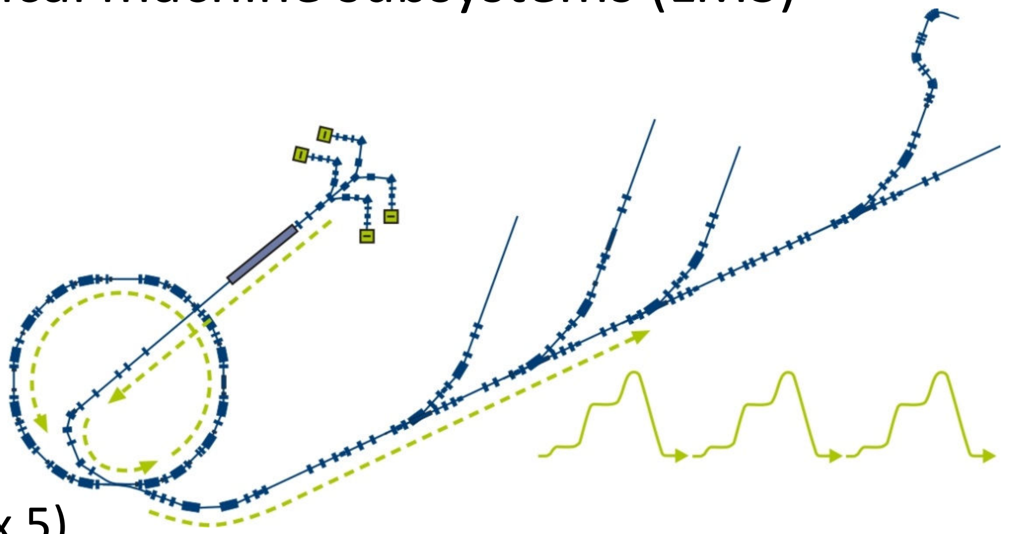

Generate beams

Beam Generation Tasks

- Accelerator consists of a number of devices for which the described system
  - creates **configurations**,
  - issues **commands** and
  - **records actions** and their effects
- coordinated and timely for the following subsystems
  - Sources (SRC)
  - RFC
  - Linac/IH, RFQ
  - Magnets (MAG)
    - Conventional
    - Special
  - Vacuum (VAC)
  - Beam interception devices (BID)
  - Power converters (PCO)
  - Beam diagnostics and instrumentation (BDI)

Operation Principle

- Accelerator is split into logical machine subsystems (LMS)
  - Sources (x 4)
  - LEBT
  - Linac
  - MEBT
  - Main Ring
  - Extraction Line
  - Individual irradiation lines (x 5)



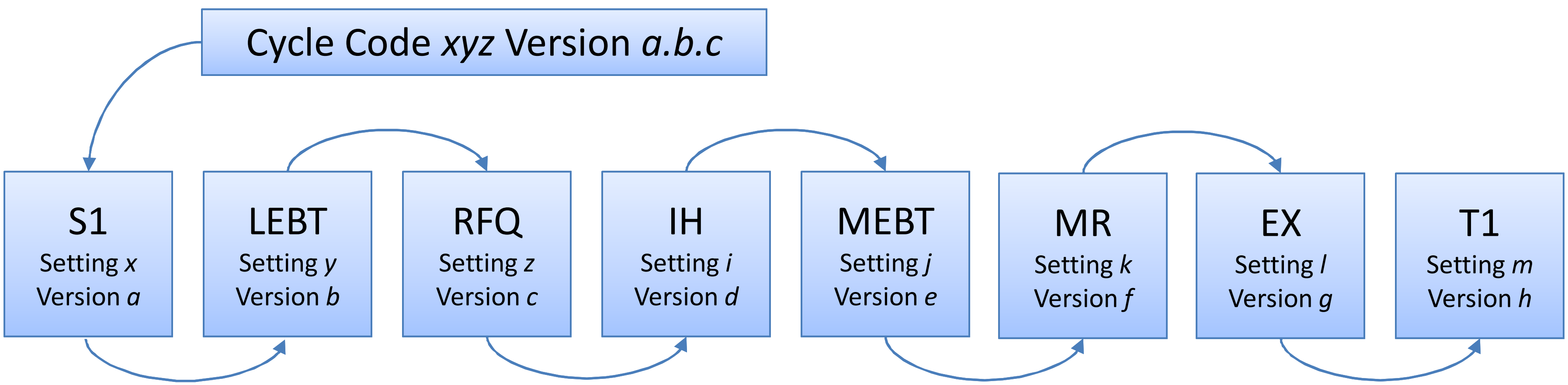
- Accelerator works on a "cycle" basis
  - Each cycle represents a set of parameters for each LMS
  - Cycles define characteristics of beam to be delivered

Cycle – Beam Characteristics

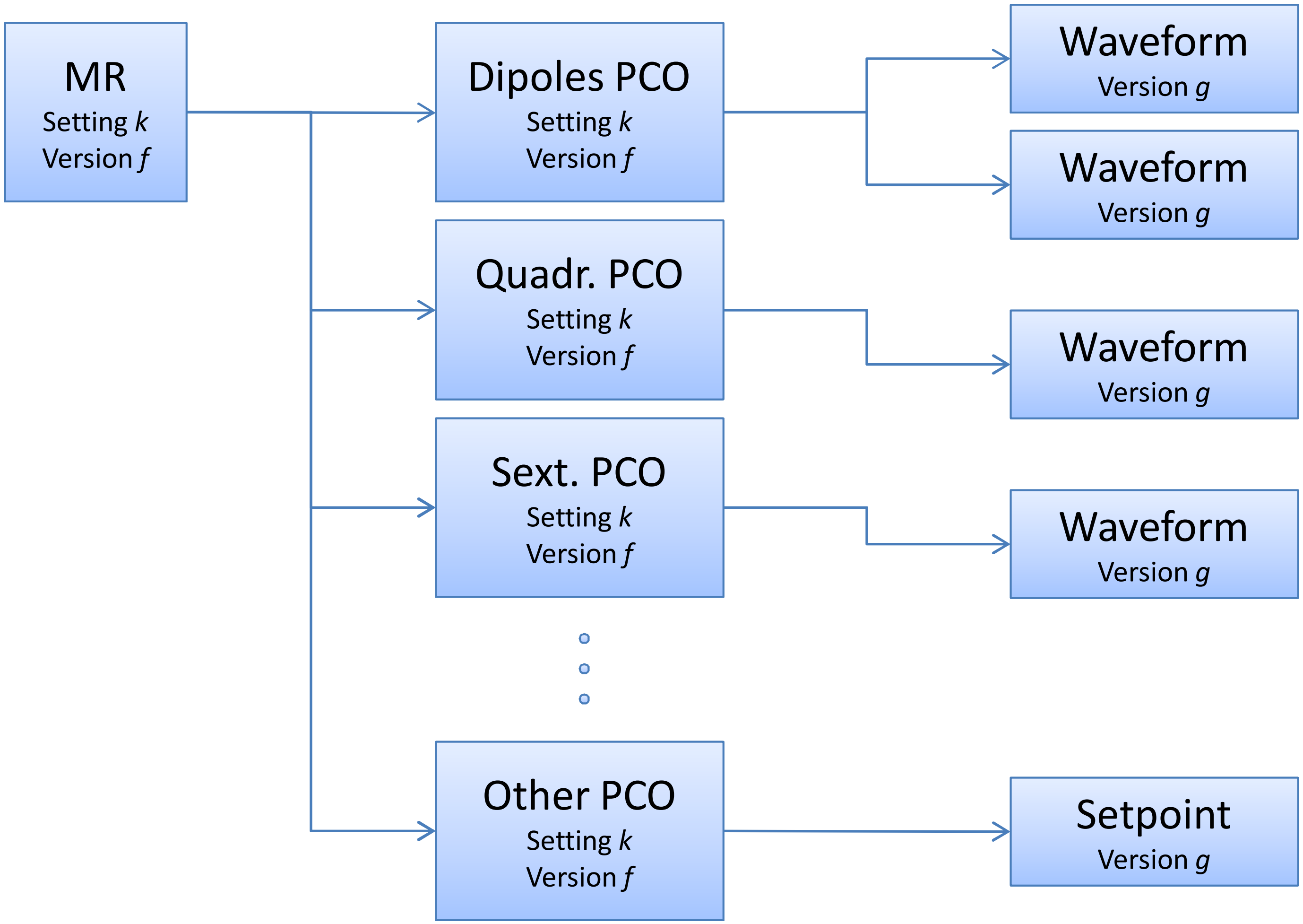
- A cycle defines (FS-090714-a-UDO, PP-091106-a-UDO)
  - Ion type (source, max 4)
  - Particle species (max 8)
  - Target of beam (destination, max 8)
  - Energy (max 255 steps)
  - Dimension in x and y (2 x 16 steps)
  - Intensity (8 steps)
  - Spill length (16 steps)
  - Usage mode (clinical, physics, service)
- Cycles are versioned and each version is uniquely identified
  - Cycle code identifier as opaque key value

Cycle Creation

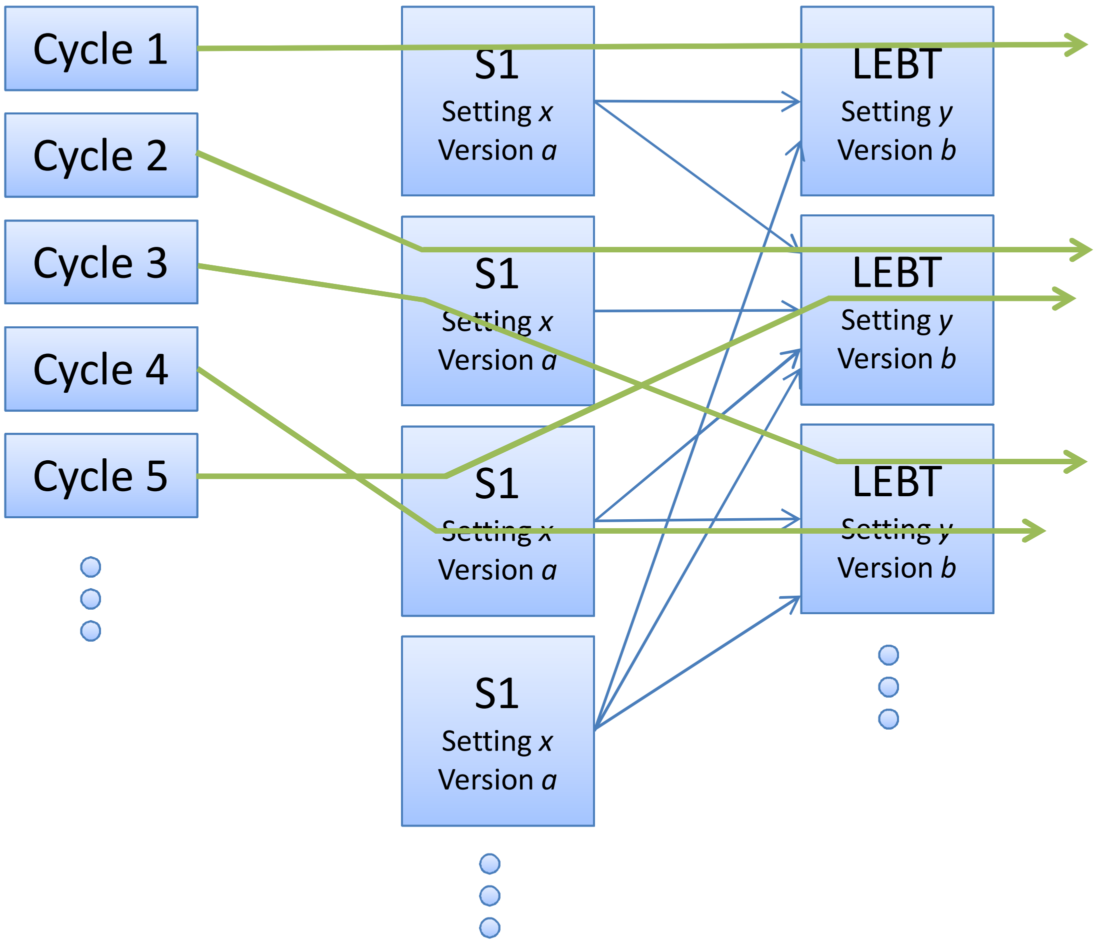
- Cycles are created by
  - Creating sets of machine settings
  - Combining settings into new sets of cycle settings
- Scalable principle
  - Cycles are not individually defined, but built from defining existing sets
  - Sets can be tested once and can be re-used in newly built cycles
  - At later point, machine interface conditions could be defined



Machine Set Settings



Cycle Creation



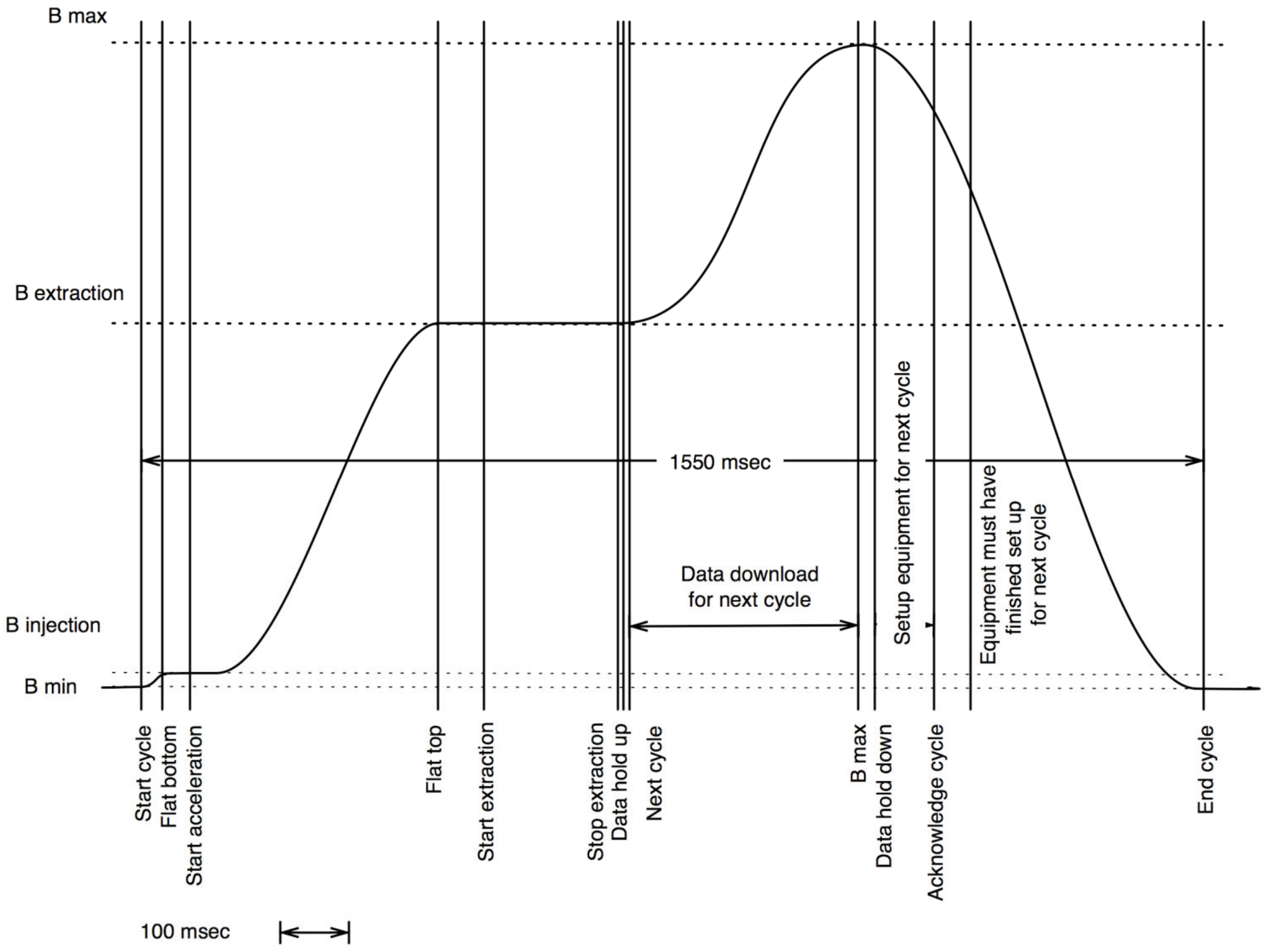
Combination of settings results in large set of possible cycles by concurrently limiting complexity to a limited amount of individual settings per machine.

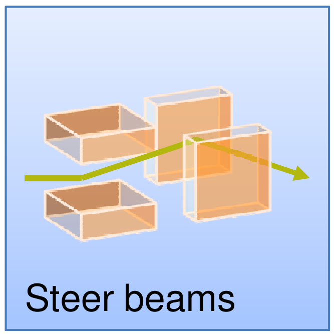
Requires support from a configuration repository management software ebg MedAustron

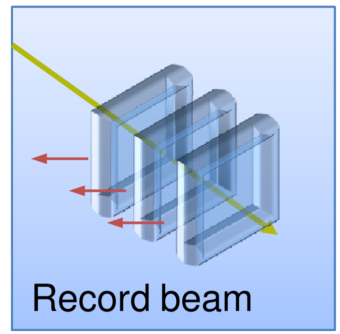
Main Timing System

- Coordinates devices in each subsystem (**ES-090512-a-JGU**)
  - Precision of ordinary timing events O (1 μsec) – medium jitter
  - Precision with particular receivers O(50 nsec) – low jitter
  - Master clock up to O(50 MHz) if needed
  - Events synchronized with 50 Hz network
- Broadcasts events
  - Occurrences in time that are assigned a logical name
  - E.g. start injection, start acceleration, Start extraction, etc.
- **Cycle definition** comprises
  - Record of settings (**WHAT**)
  - Sequence of timing events (**WHEN**)

Typical Timing Events




Steer beams


Record beam

Beam Steering and Recording

- Request accelerator cycles from accelerator control system
- Perform “scanning”
  - Steer beam in real-time over target area according to “scan” plan
  - Control applied dose in real-time
  - Record in real-time actually applied beam characteristics
- Activate/deactivate beam in real-time
  - In course of planned “scanning” application
  - In case of deviation from expected behaviour

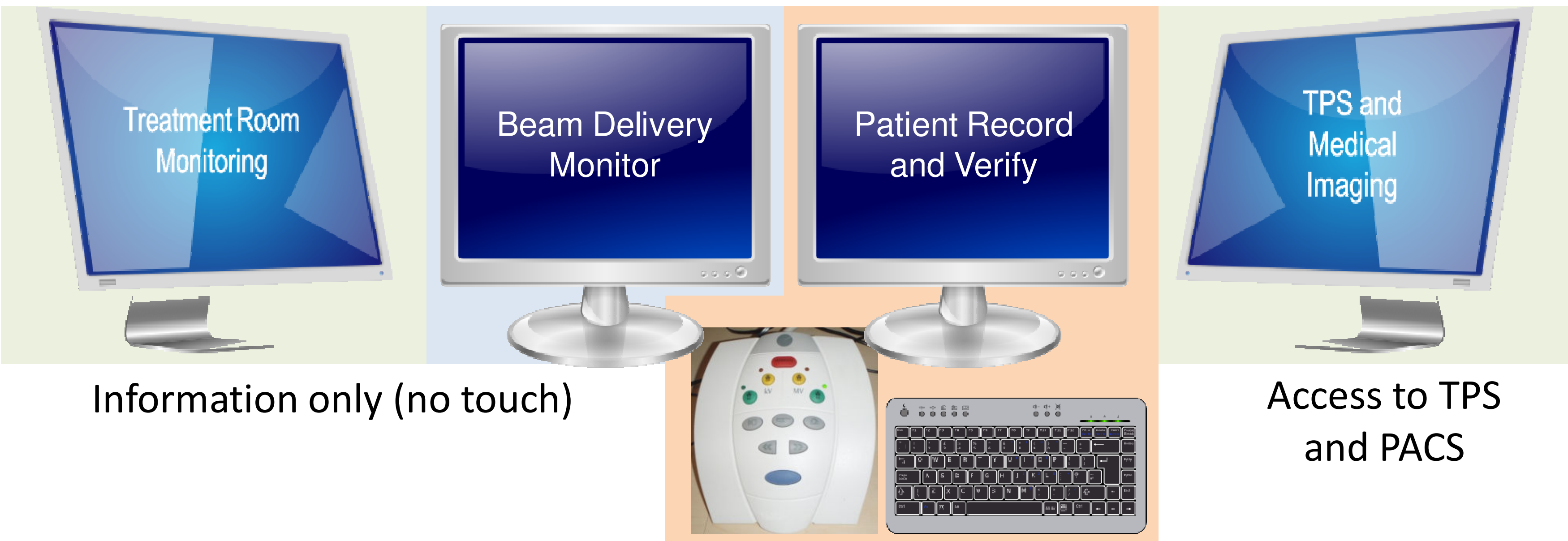
Modes of Operation

- **Clinical**
  - **Only mode for irradiating persons**
  - No change of operational parameters possible
  - Only "qualified" parameter sets can be used
  - Beam delivery is controlled by medical software (PRVS)
- **Physics**
  - Operation with all parameter sets
  - Update of parameters at cycle boundaries possible
  - Beam delivery is a supervisory procedure
- **Service**
  - Not intended for beam generation
  - Devices and device groups can be controlled individually
  - Device software can be updated

Operation in Clinical Mode

- Central control room hands over control to local control room
- Local control room according to best-practice layout

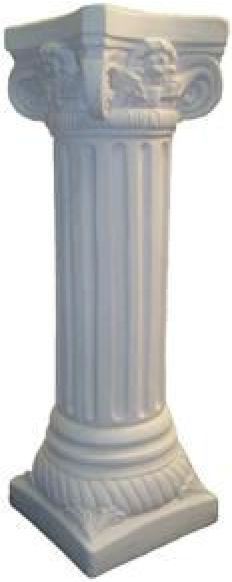
COTS | Inhouse | COTS | COTS



Information only (no touch)

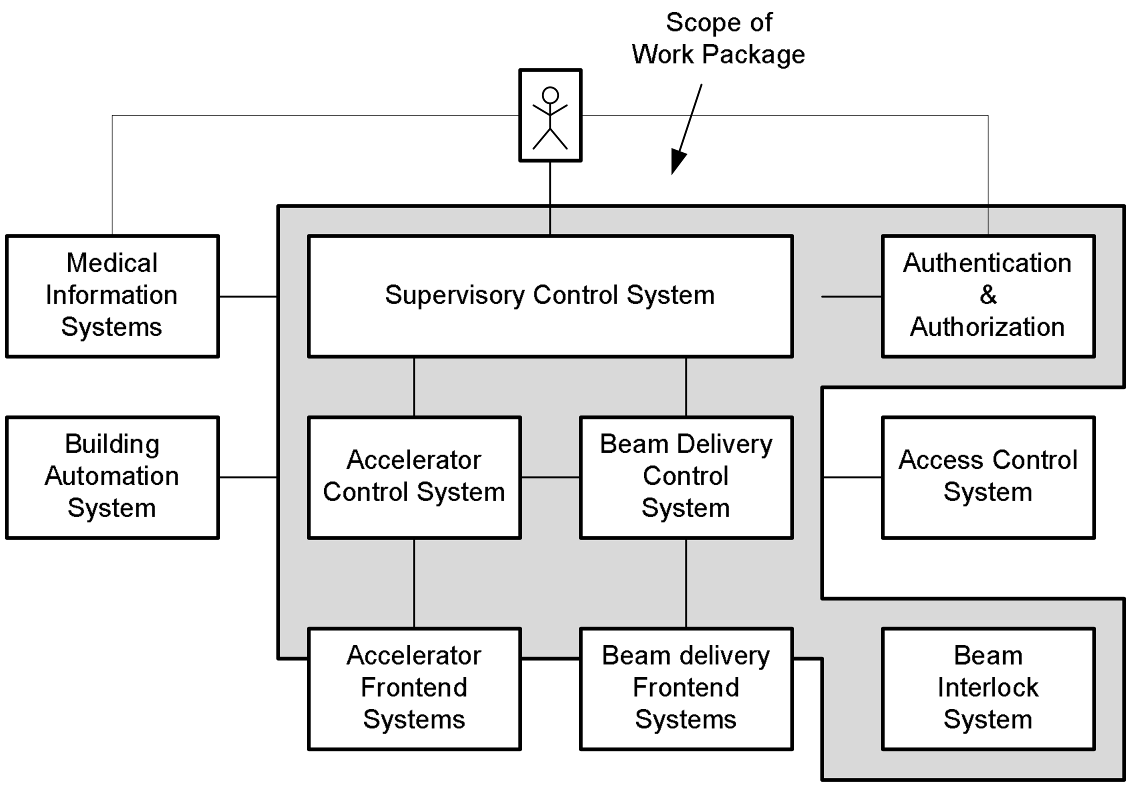
Access to TPS and PACS

Interaction and irradiation control via medical device standards compliant software and hardware



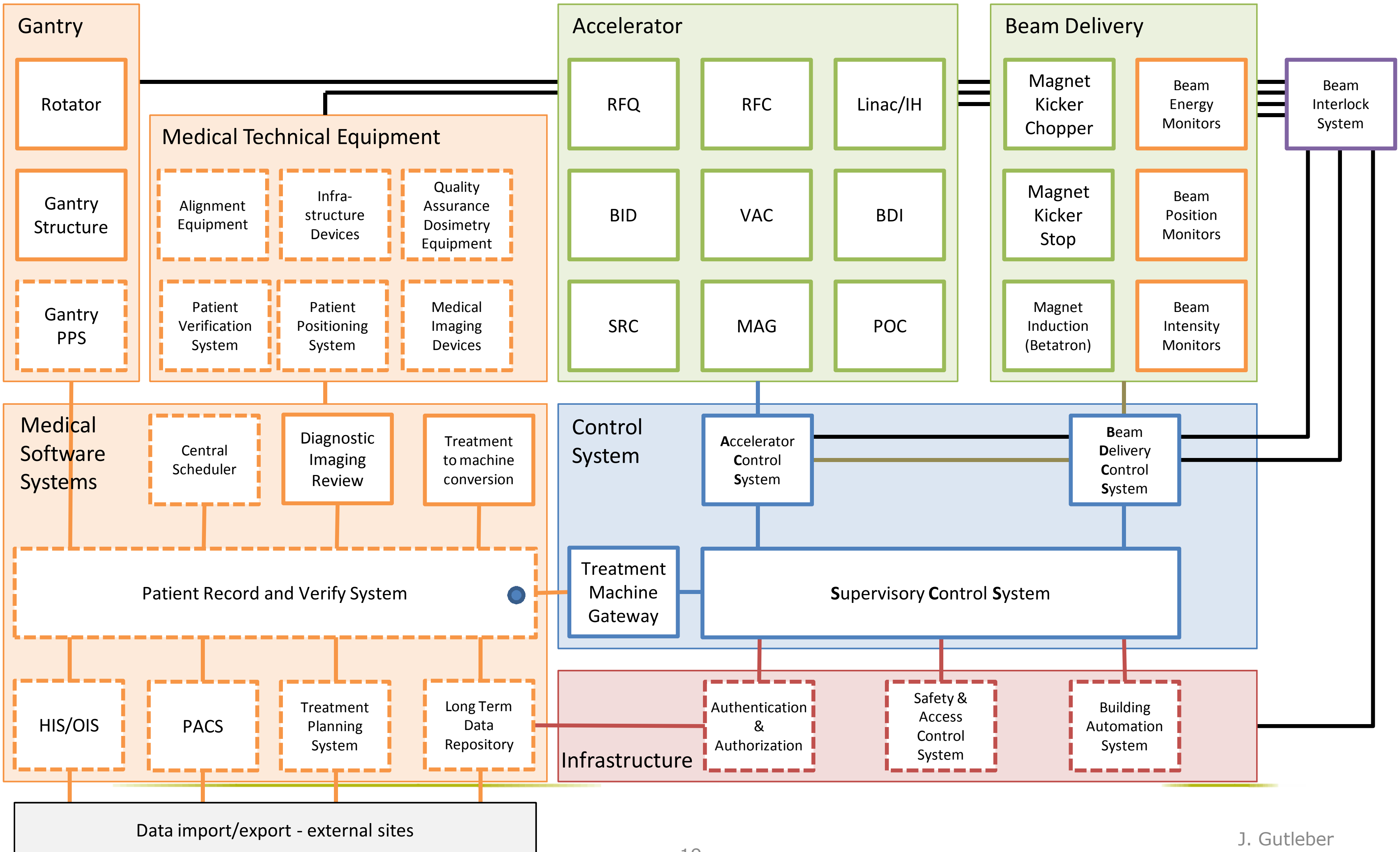
ARCHITECTURE

Scope of the Work Package



Described in Product Breakdown Structure **PM-090902-a-JGU**

Map of Software Systems



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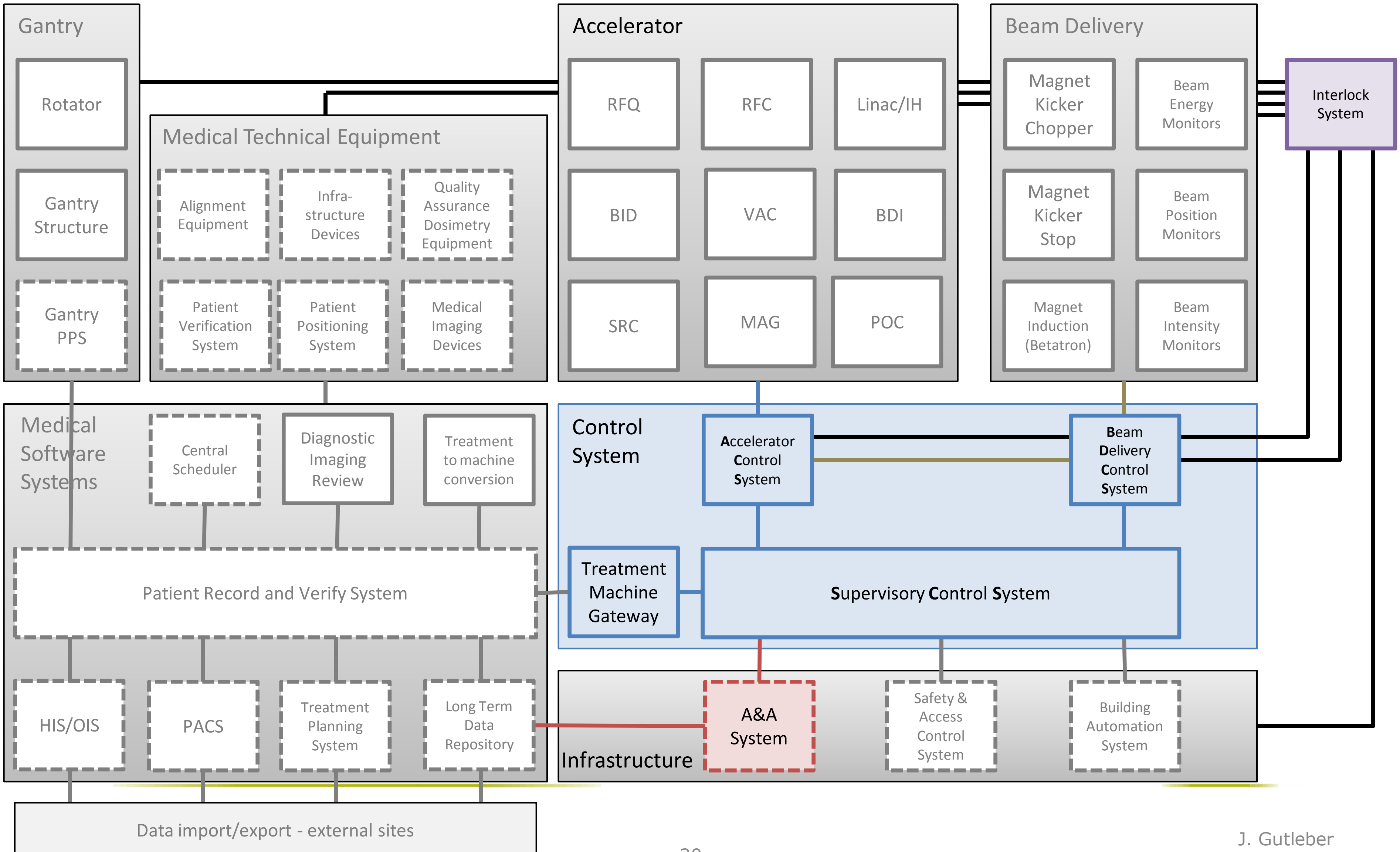
Scope of WP Controls



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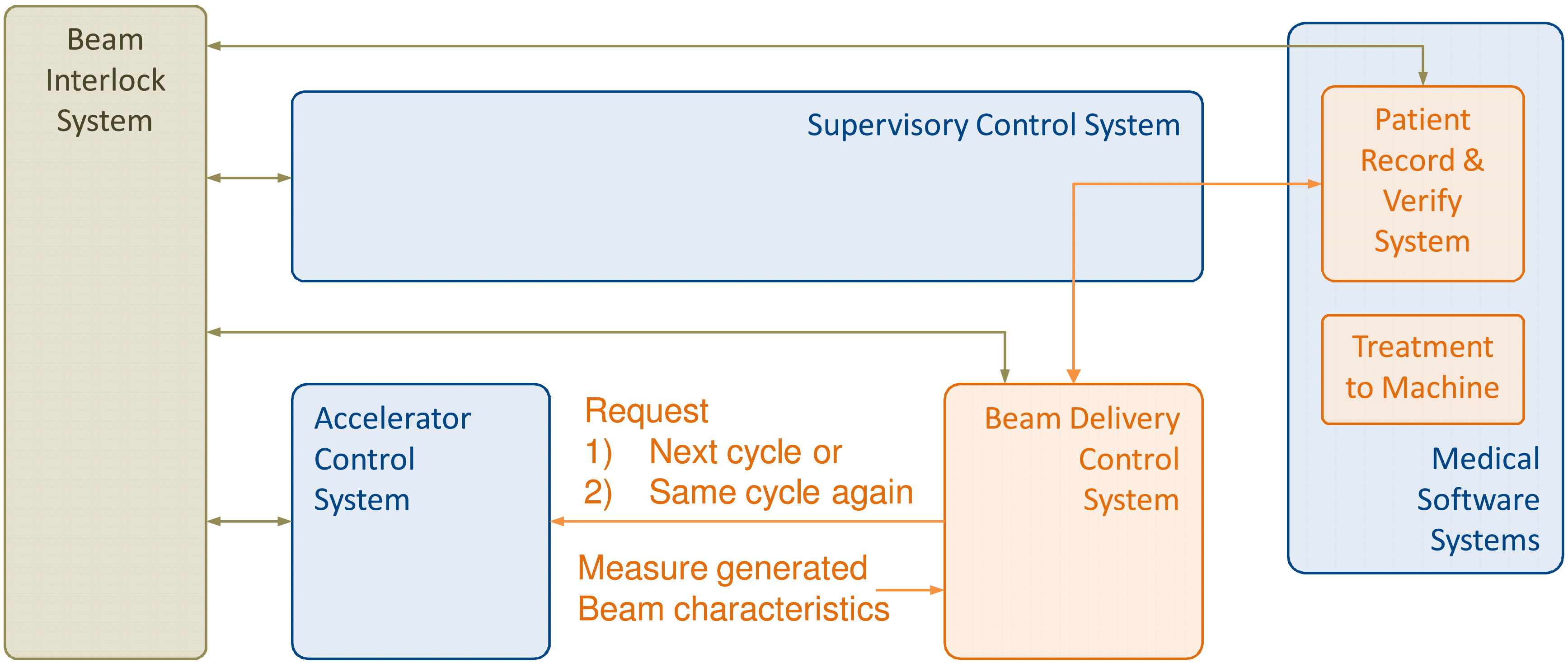
Separation of Concerns

- **Supervisory** and **Accelerator** Control Systems
  - **Generate beam**
  - Developed according to accepted and documented process
- **Beam delivery** control system
  - **Applies beam**
  - Needs to be developed according to quality assurance standards
  - Safety functions as result of top-down risk management process
- Patient **Record & Verify** + **Treatment to Machine** Conversion
  - Used to **carry out therapy** (master)
  - Rely on “medical device compliant” products
  - Find company who is partner of PRVS supplier to perform job
- **Beam Interlock** system
  - **Prevent harm and machine damage** due to conflicting actions
  - Specify and buy developed according to IEC 61508 - SIL 2

Safety Concept

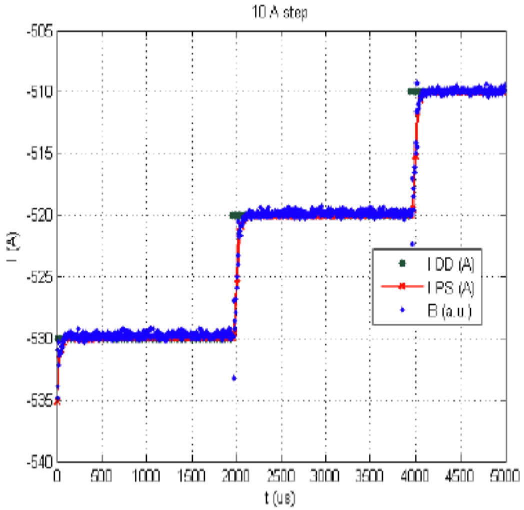
- BDCS according to medical device standards
- Documented path for medical data and beam verification
- Beam Interlock System according to safety standard

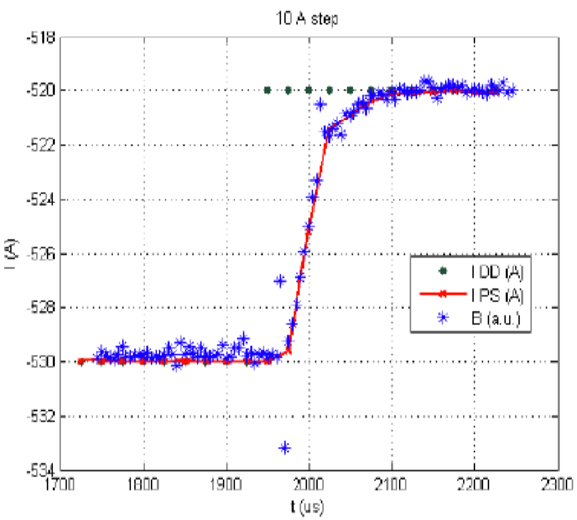


Spot Scanning

- **Individual spots**
- Beam **kept "on"** between spot-to-spot movement
- Minimum time on single spot 300 µsec
- Average time on single spot 1.5 msec
- Movement from spot-to-spot
  at 1/3 distance of spot size (overlap)
- Movement from spot-to-spot at max. 20m/sec (2cm/ms)
- Time to move between **adjacent spots** about **150 µsec**
- New set point to power converter every 10 µsec (oversample)
- Beam switch-off time about 250 µsec (> than move time)

CNAO Spot-To-Spot Move

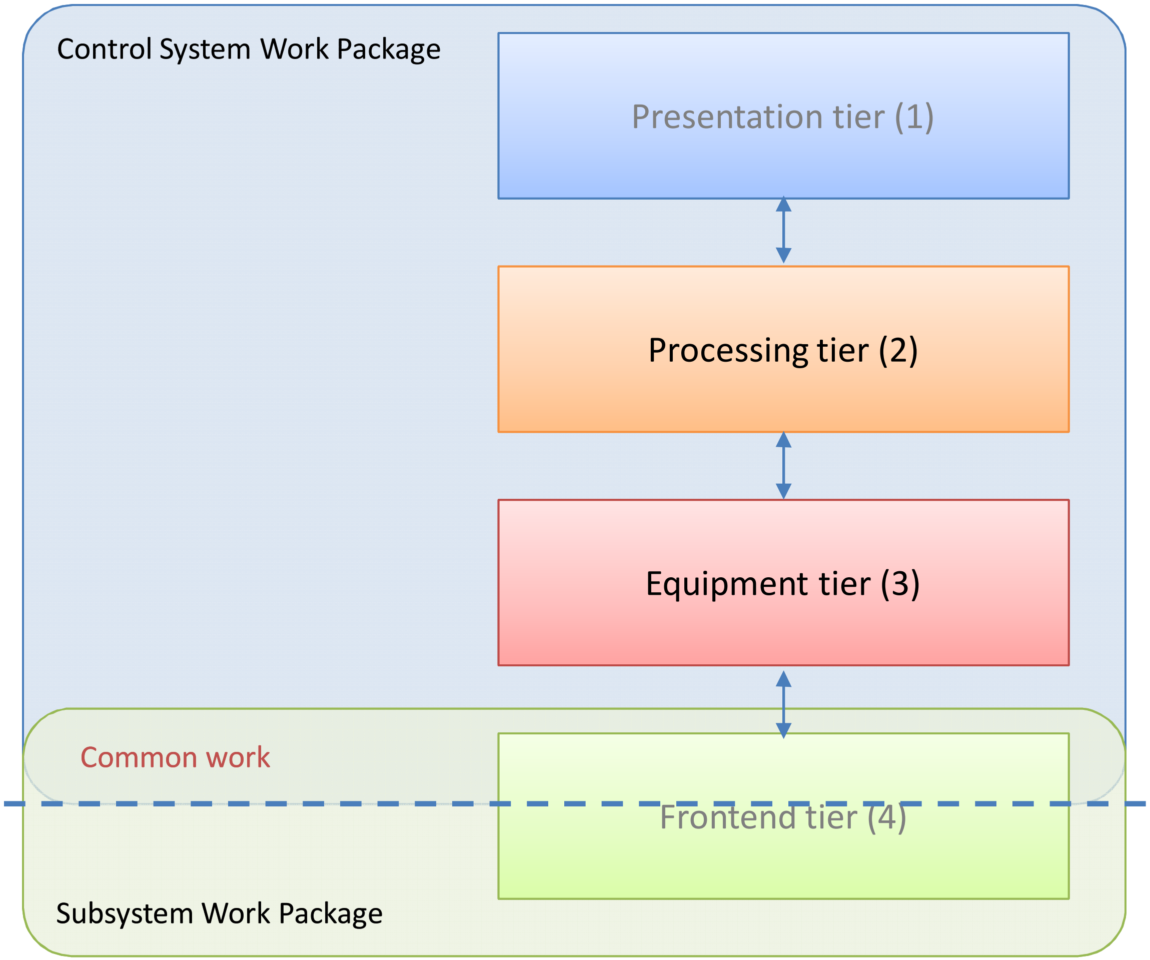




- 10A steps correspond to ca. 1.3mm
- Step time is about 150 µsec
- I (IDD) current set rate is 40 kHz
- I (IPS) power converter current measurement rate is 40 kHz
- B measurement via Hall probe 200 KHz

Data and plots from Simona Giordanengo 2009

3 + 1 Tier Architecture



Graphical user interfaces
Remote operation

Configuration for devices
Supervisory state machines
Data logging, SCADA

Protocols and data format adapters, fan-out and data concentration

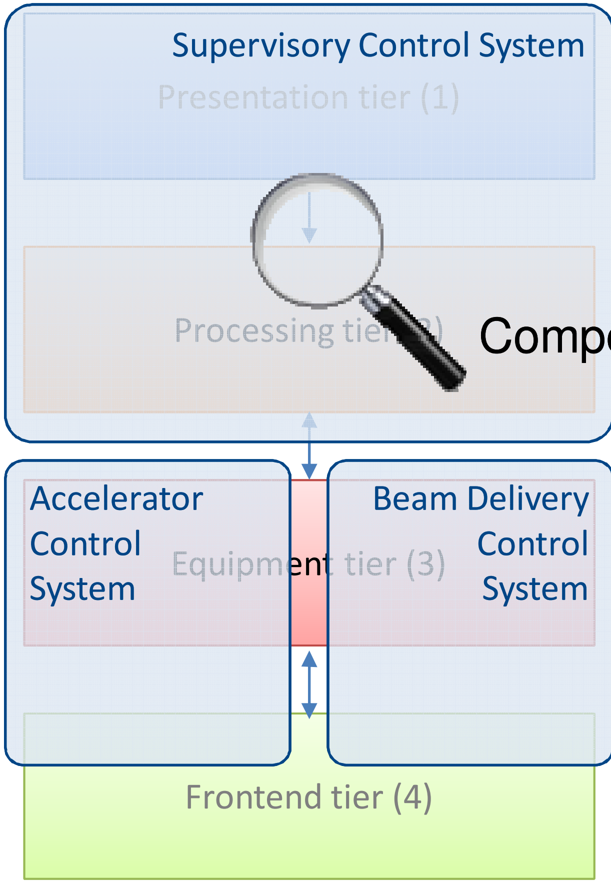
Front-end adaptation and lean framework layer

Control logic and closed
Real-time control loops

General Approach

- Real-time closed control loops are in scope of individual accelerator work-packages
- WP controls
  - Configures T4 devices
  - Commands T4 devices
  - Changes and records state of T4 devices
  - Provides main timing system events and low-level trigger signals
  - Accepts and provides signals for beam interlock system
- T4 platforms should follow WP controls recommendations

Three Control Subsystems



Components of Supervisory Control

Configures, performs high Level control and records actions

Generates beam cycles

Steers beam and verifies beam characteristics in real-time

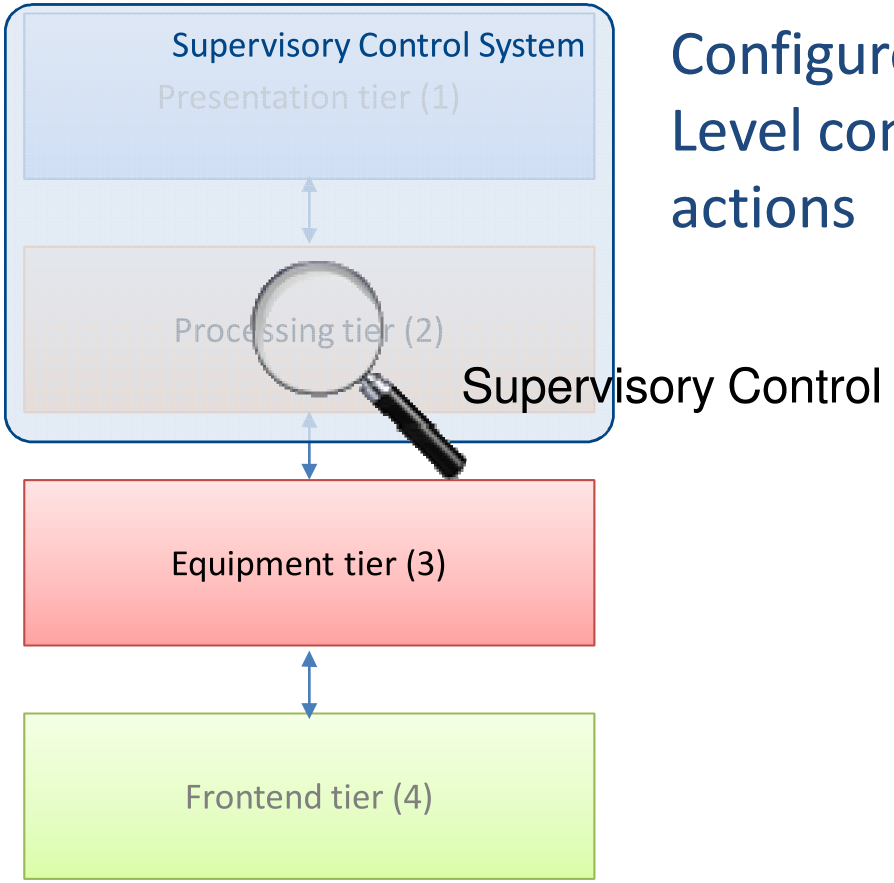
Tier 1 Overview

Presentation tier (T-1) takes care of presenting information produced by the system to the users, processes user inputs and interfaces to external systems.

T-1 Components

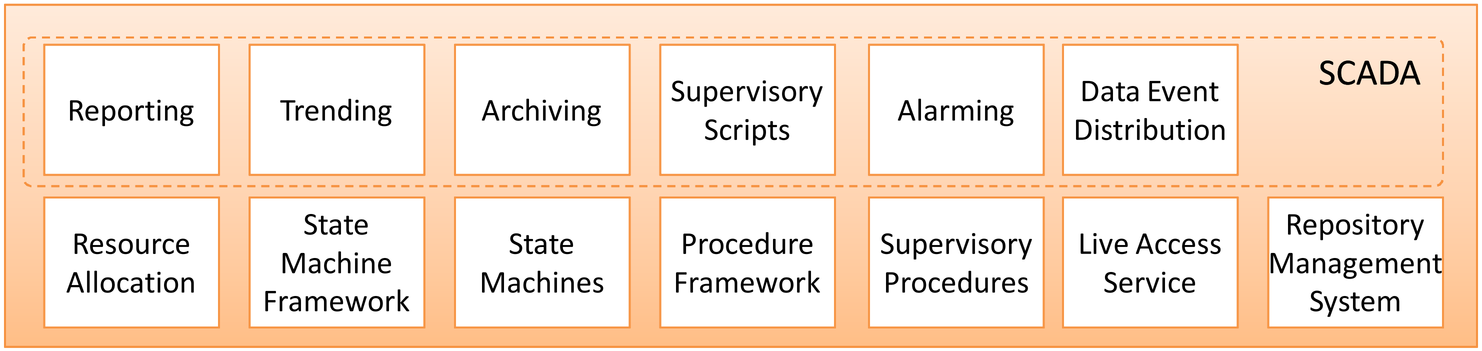
- Human Machine Interfaces
  - GUI panels
  - Any hardware input/output devices including
    - authentication devices
    - Medical control devices
    - Locking systems
    - Annunciator panels
- Virtual Instruments
  - Programs and GUIs to interact with point-to-point with devices
- External System Interfaces
  - Medical Software Systems (e.g. PRVS)
  - Authentication and Authorization
  - Access control
  - Building automation

Three Control Subsystems



Configures, performs high Level control and records actions ebg MedAustron

Tier 2 Overview



Processing tier (T-2) configures and **supervises equipment and front end tiers**. Goal in cooperation with presentation tier is to achieve facility that can perform its tasks with only a small amount of operation personnel. Includes execution of supervisory procedures that include quality assurance and irradiation sequences. **C**ommercial **O**ff-**T**he-**S**helf **SCADA** software foreseen with in-house extension to satisfy accelerator control needs.

T-2 SCADA Components

- **Reporting**
  - Automatically generate reports on system health status and history
  - Includes reports of individual subsystems
- **Trending**
  - Time dependent analysis of acquired field-data for on-line monitoring and alarming as well as reporting
- **Archiving**
  - Persistency of acquired field-data
- **Supervisory scripts**
  - Capability to program SCADA tool to integrate with other systems and to realize “macro” functionalities easing the operators life
- **Alarming**
  - Notification and persistent recording of system and subsystem deviation from specified behaviour
- **Data Distribution**
  - Acquisition of field-data and distribution to SCADA and in-house developed processing components at low rate/bandwidth (1 Hz)

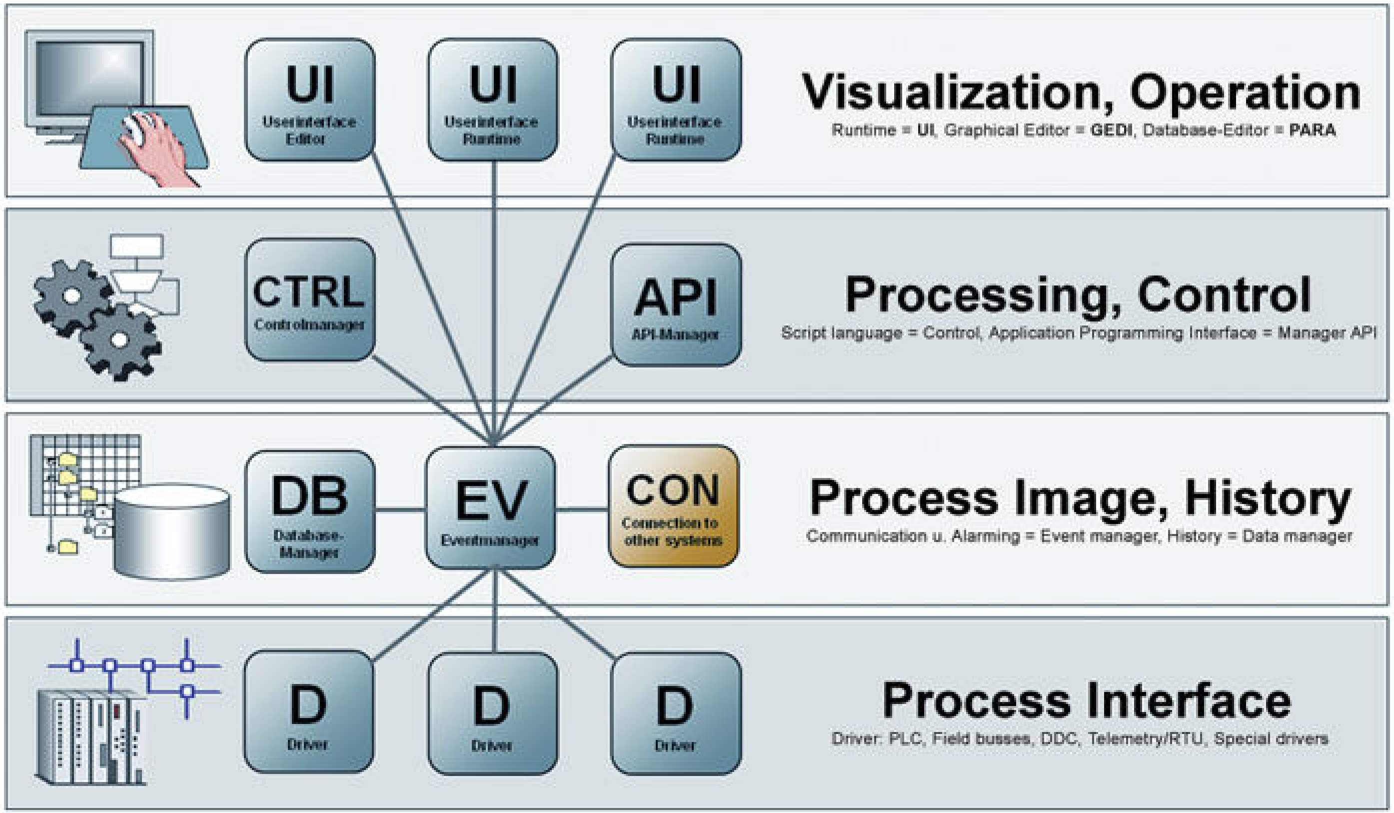
T-2 In-house Components

- **Resource Allocation**
  - Book and manage access to devices and sets of devices to regulate concurrent usage and partitioning of the system
- **State machine** framework and state machines
  - To complete SCADA functionality with high-level control capabilities
  - Each subsystem and device implements a “standard state-machine”
  - Device specific extensions will be possible
- **Procedure framework** and procedures
  - Automate measuring and control operations
  - Possibility to add-in user-defined libraries and external programs
- **Life access** service
  - High rate/bandwidth field-data distribution (kHz rate and Gbps bandwidth)
- **Repository Management System**
  - Management of all configuration data in the entire accelerator facility
  - Management of hardware, software and documentation

PVSS SCADA Software

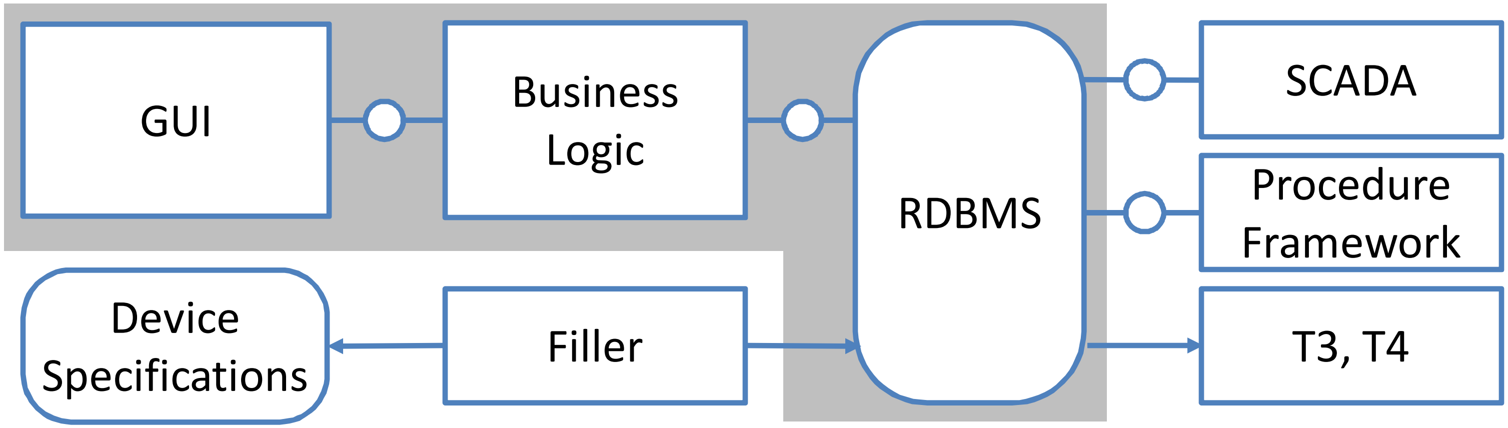
- Supervisory Control And Data Acquisition Software
  - Collect data using different protocols
  - Archiving, Alarming, Reporting, Trending, GUI building, scripting
  - Acquired 2 development licenses
- About the tool
  - Austrian product supported at CERN
  - Used at and “improved” by CERN for 9 years
  - Integrated with many industry standard protocols
  - Uses Oracle for data archive
  - Flexible enough to integrate with in-house software and tools
- Usage in medical environment
  - FDA 21 CFR Part 11 clearance
  - IEC 61508 SIL 3 certificate by TÜV Süd

PVSS Architecture



Repository Management Software

Purpose of the repository management software is to create and administer all **configuration data** that is needed to operate a particle accelerator for medical application and to provide information to specific control system software packages in a technology and product independent manner.



Adopt and adapt CNAO software system

RMS Justification

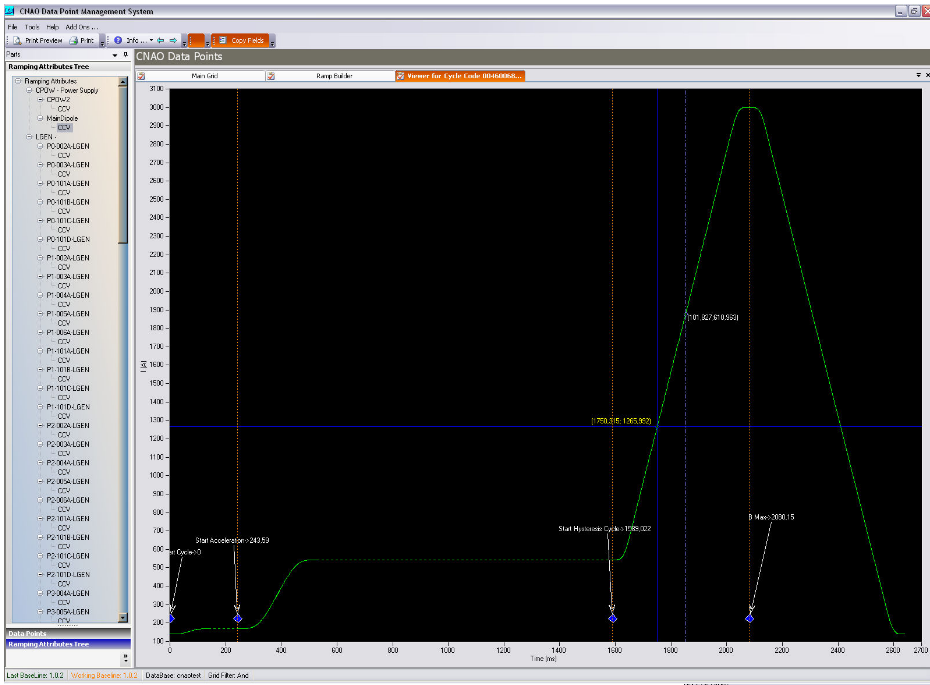
- **Single source** for **device information** and **settings**
  - Accelerator elements, E/E/P devices, software, documents
- All configuration data **configuration controlled**
- Legal requirement to trace all data and documentation
- Give developers a **common specification framework**
- Give the developers a **common data definition reference**
- Give the experts a common place to **keep related information**
- Accommodate SCS/ACS software release changes easily
- Accommodate additional devices/data easily
- Reuse software components in on-line system

RMS Contents

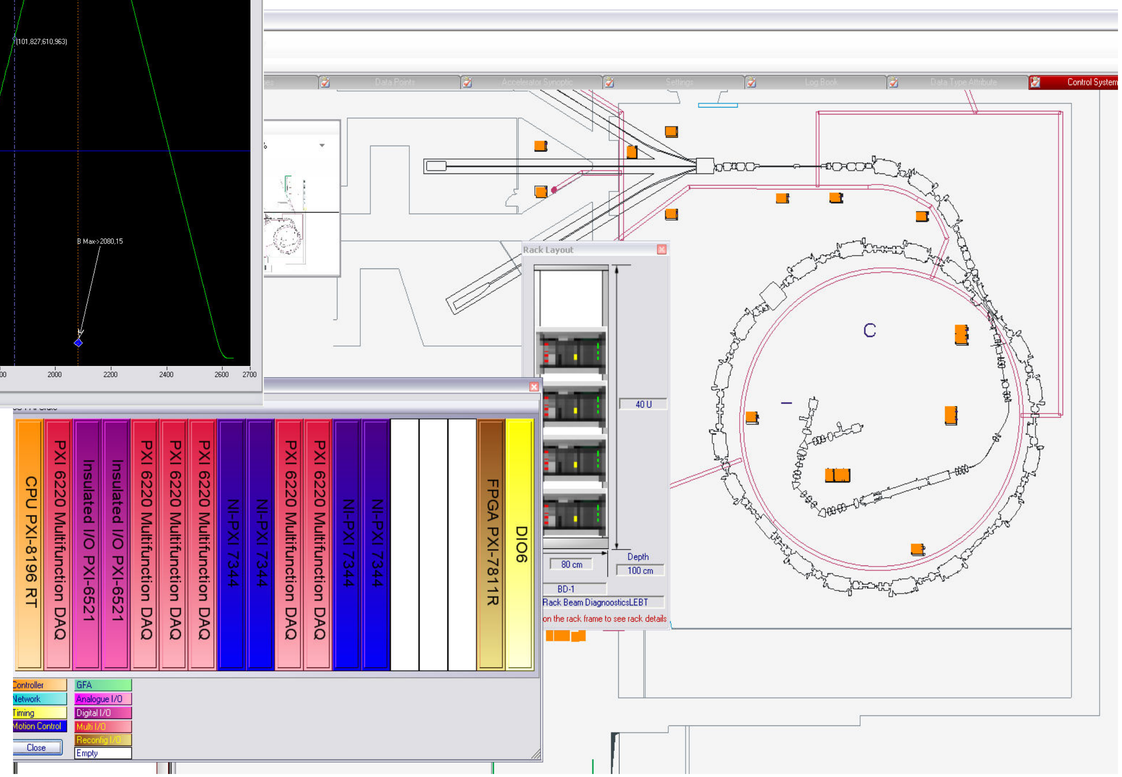
- Data Types, Data Points and Working Sets
- Waveforms
- Control system interconnection information
- Geometries of all elements (accelerator and electronics)
- Machine physics dependent data
- Timing system information
- Accelerator interactive drawing
- Devices, crates, racks, cables
- User manuals, technical specifications

All information combined into
version controlled machine **settings** and
accelerator **version controlled cycle definitions**

Examples

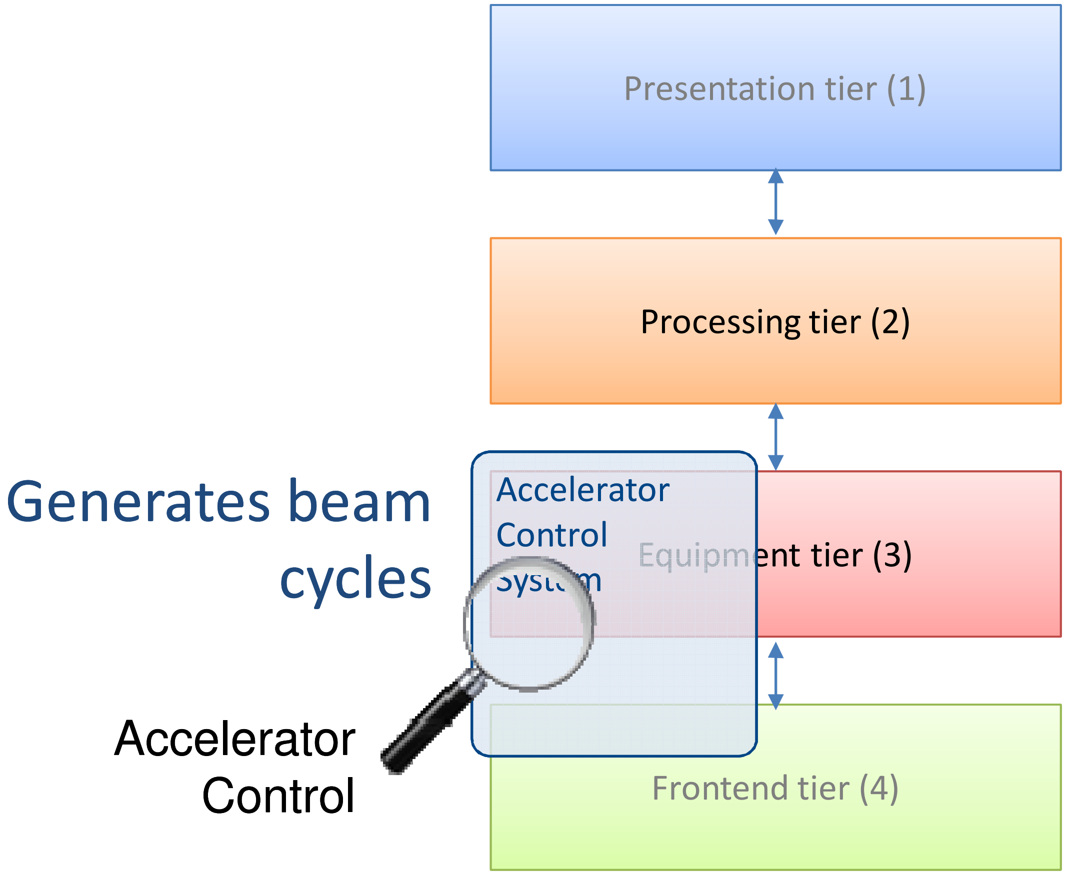


Waveform and ramp builder

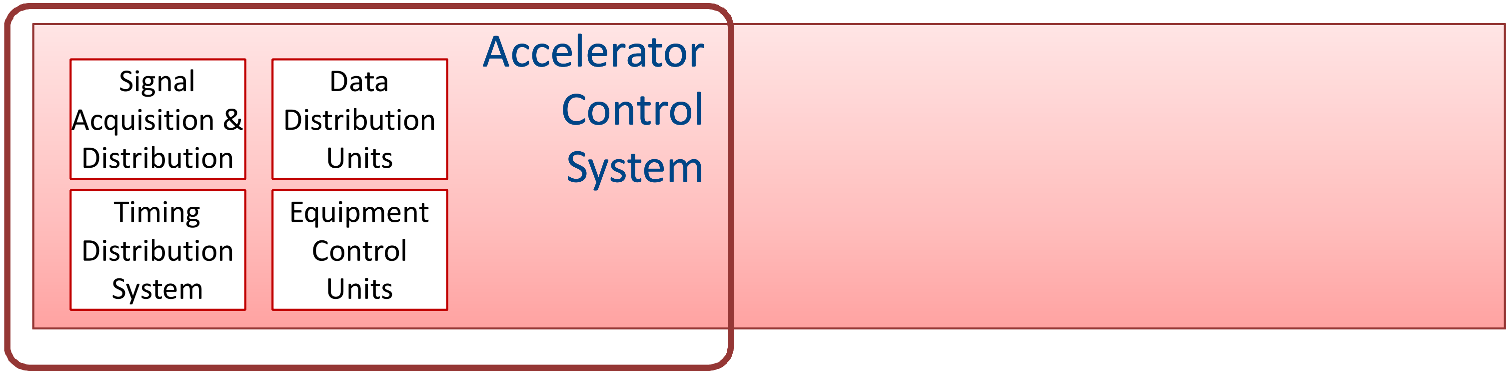


Accelerator synoptic and
Rack/crate/device manager

Three Control Subsystems



Tier 3 Overview

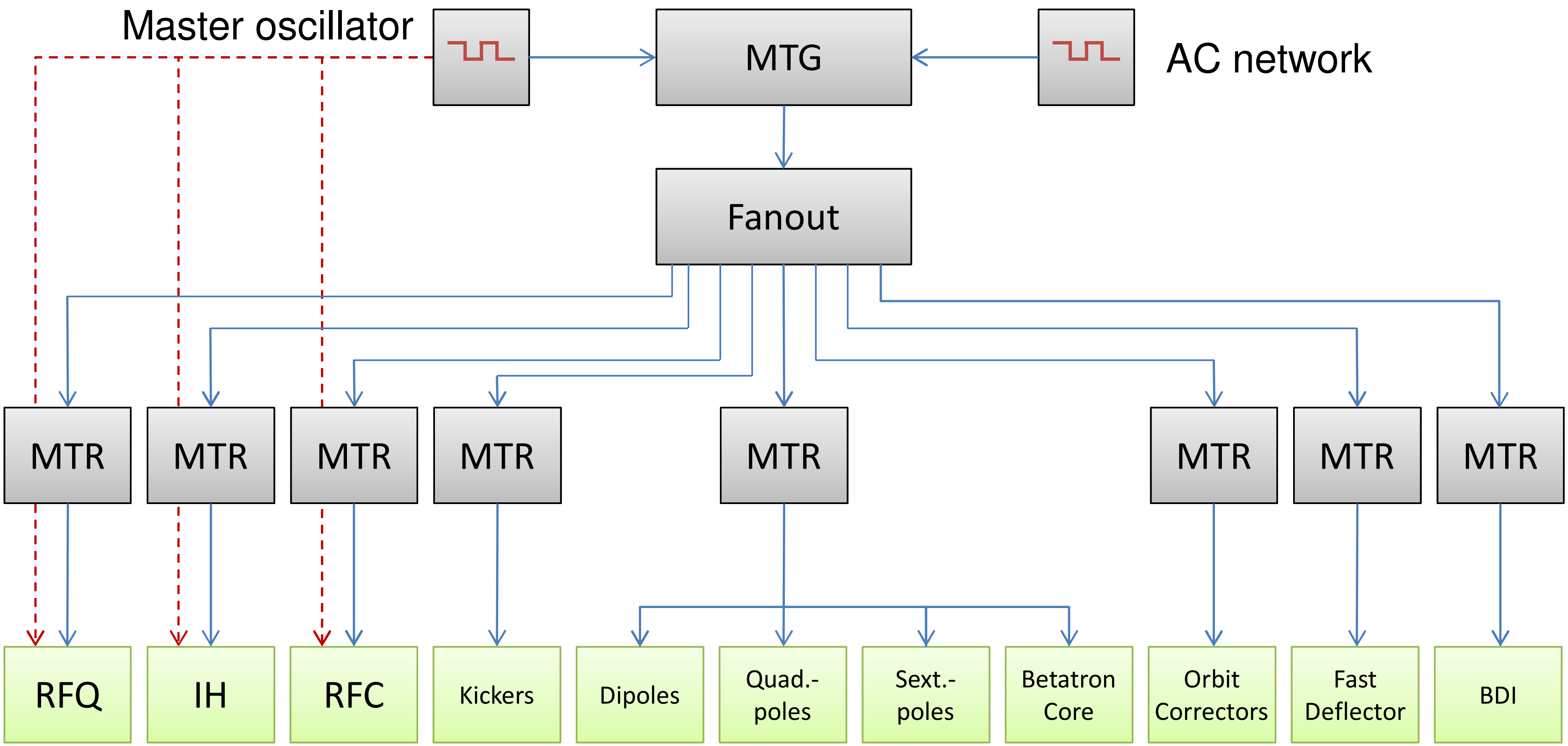


Equipment tier (T-3) contains processes that supervise individual accelerator and beam delivery components. Characterized by short reaction times, soft real-time and safety requirements. Includes a timing-event distribution system, which allows the timely coordination of all equipment under control. Configuration data distribution services and data acquisition concentrators are.

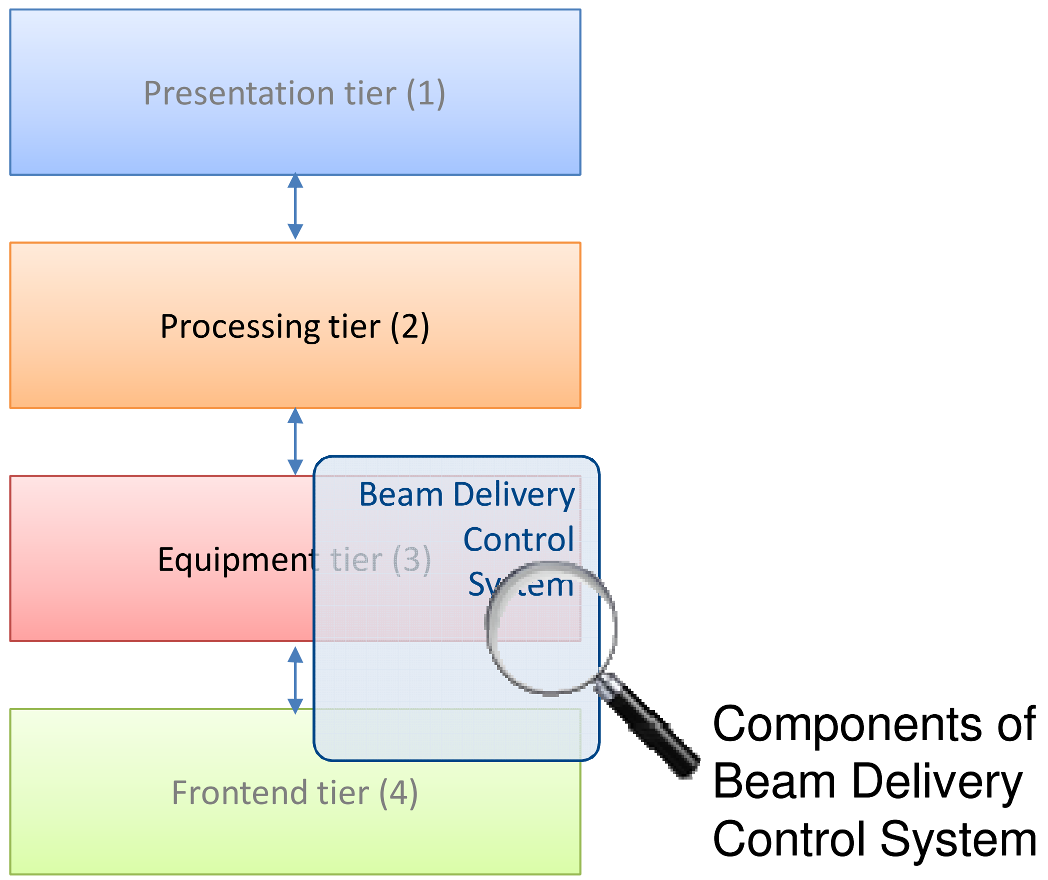
T-3 ACS Components

- **SADS**
  - Acquire and re-distribute analogue and video signals
  - “Virtual oscilloscope” functionality
- **Timing Distribution System (Main Timing System)**
  - Coordinates activities of accelerator devices
    in microsecond range at nanosecond precision
  - Sequenced distribution of timing events, timestamps and trigger signals
- **Data Distribution Units**
  - Provide frond-end devices (FEDs) with data from repository management system
- **Equipment Control Units**
  - Command and monitor FEDs
  - Acquire field data from T4 and relay to T2
  - Adapt protocols between T2 and T4

Main Timing System Concept



Three Control Subsystems



T-3/-4 Beam Delivery Control System

- One system per irradiation line
- Commanded by Patient Record and Verify
- Same system used everywhere is a preference
- “No trust” in any other system
  - Particularly no reliance on what accelerator delivers

BDCS Components

Switches from spot to spot according to off-line prepared plan "scan file"

Beam Delivery Control System

- Beam Positioning System
- Beam Verification System
- Beam Activation System

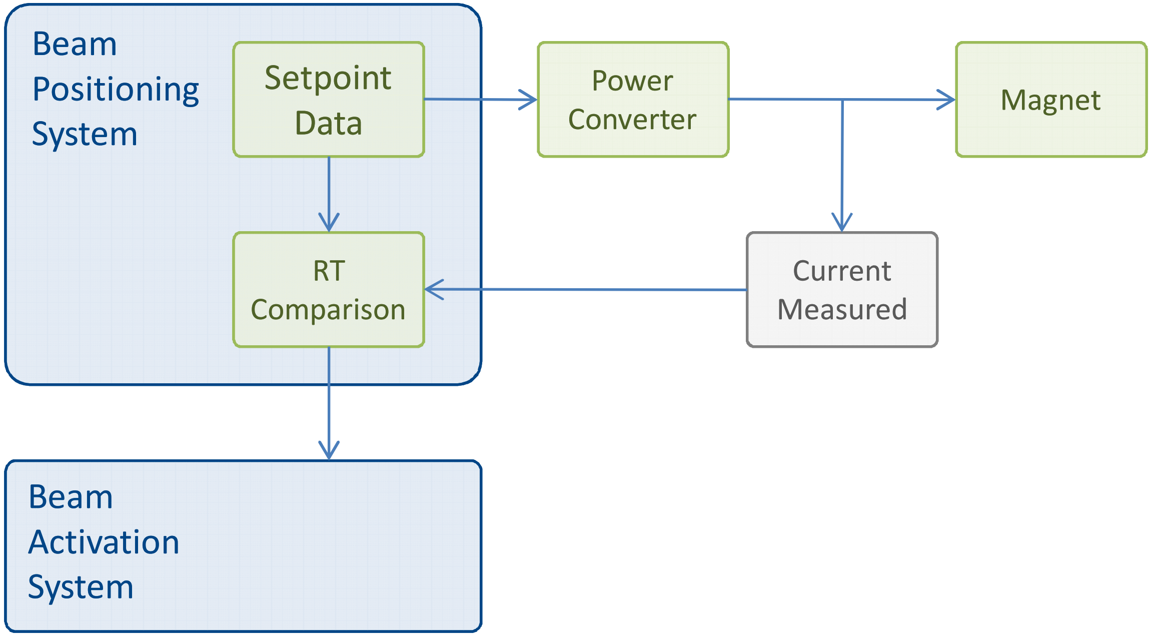
Request beam and position beam as prescribed by PRVS according to sequence in "scan" file

Verify in real-time that beam characteristics are within defined limits and according to "scan" file

Activate and de-active beam in O(µsec) upon request of BVS and as result of BDCS internal interlock conditions.

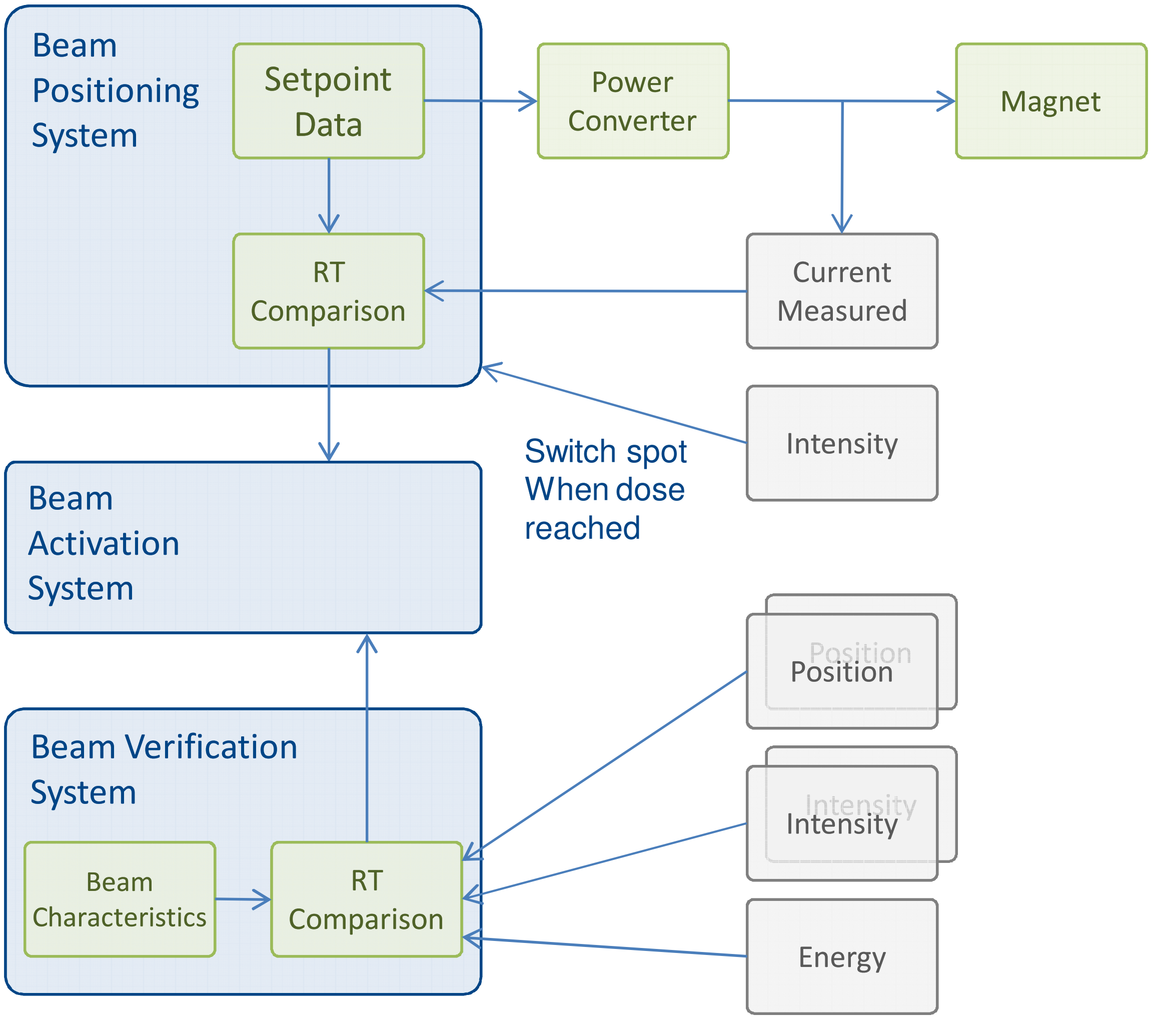
Example for “Safe Set”

- Current through the coils is measured and compared in realtime with target value, without other involvement. Deviation beyond tolerance triggers interlock to BAS
- Requires “close” cooperation of work package “controls”, “beam delivery” and “power converters”



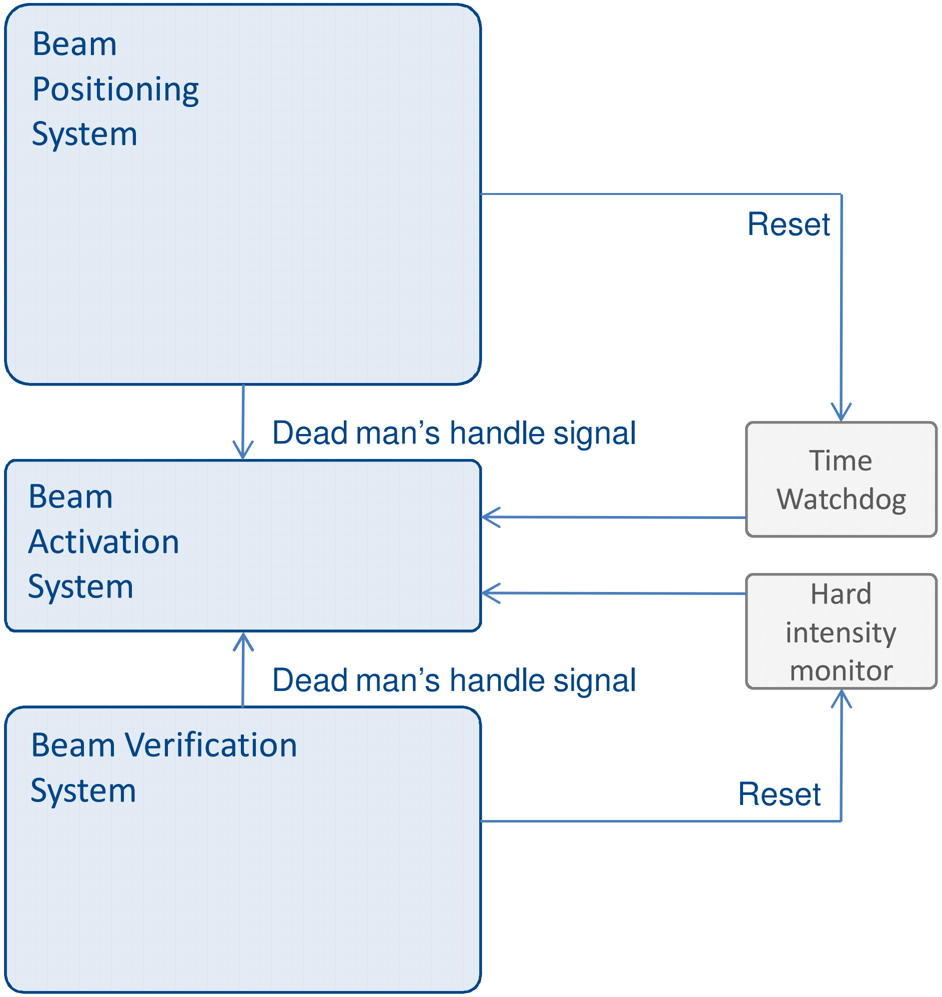
Example for “Check”

- Actuation and verification are physically separate, work asynchronously and do not interact
- Verification devices will be redundant and realized using different technologies

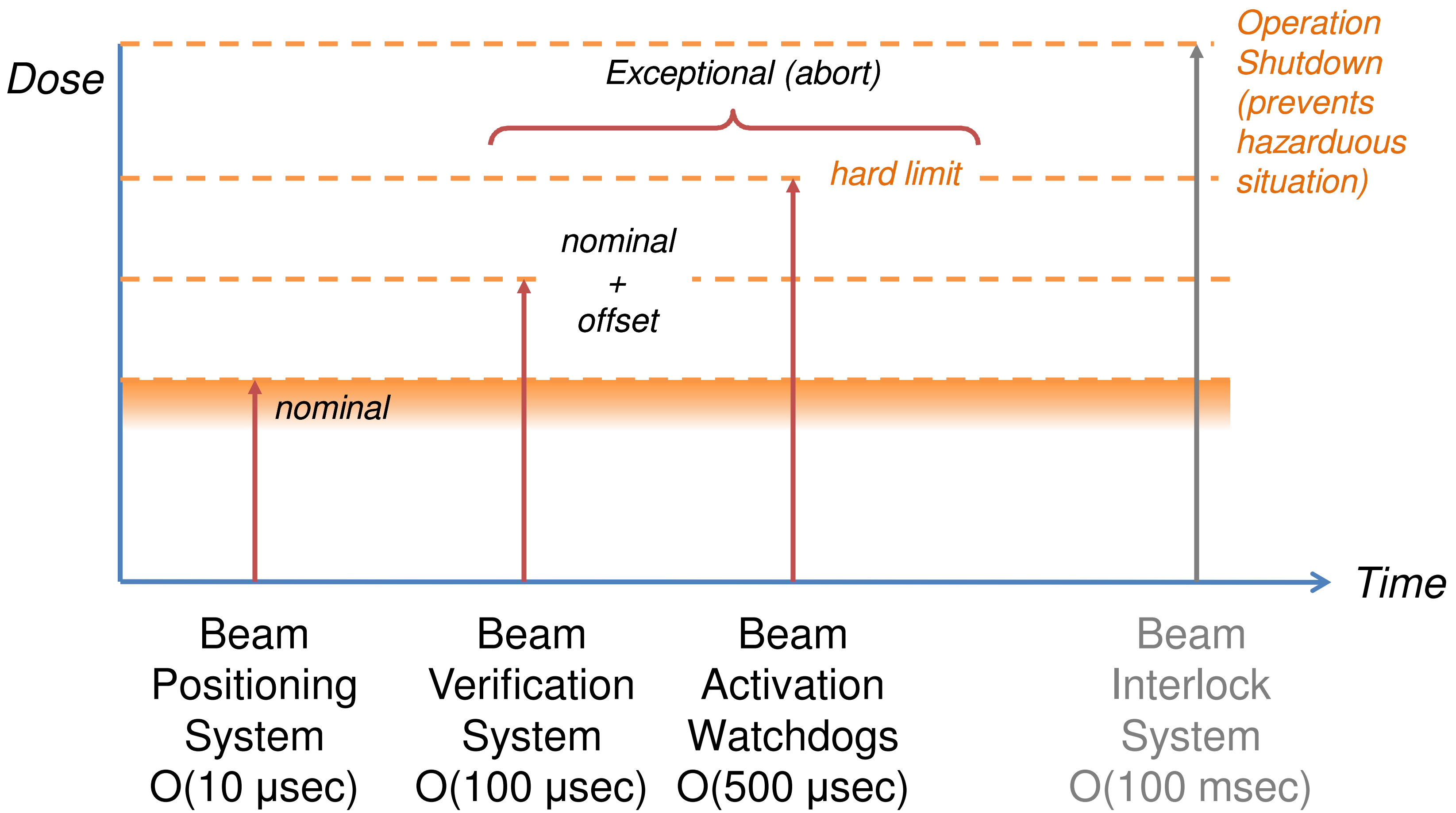


Example for "Supervise"

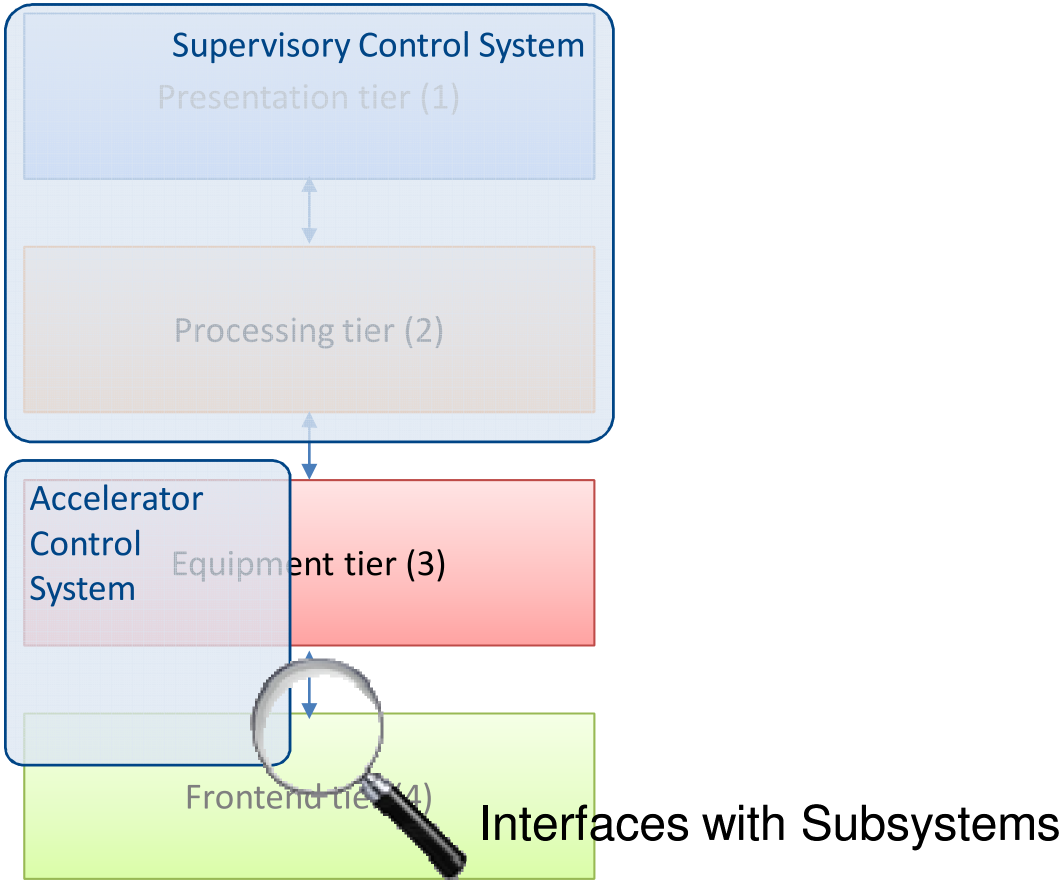
- Watchdogs and dead man's handle principles
- Hard countdown must be reset regularly when moving to next spot – avoids staying too long on single spot
- Hard maximum intensity monitor must be reset for each spot before overrun – avoids overdose on spot.
- Allows to detect failures of BPS and BVS.



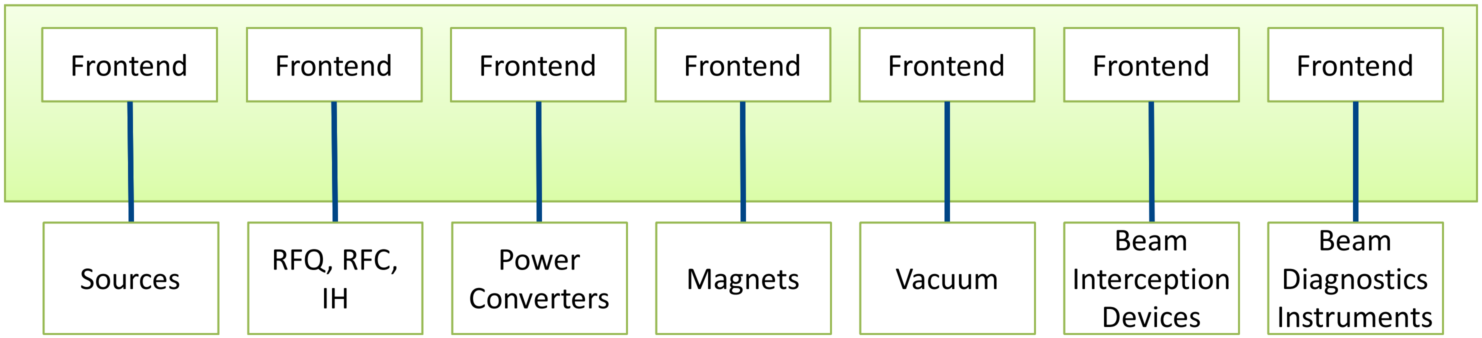
Staged Beam De-activation



Three Control Subsystems



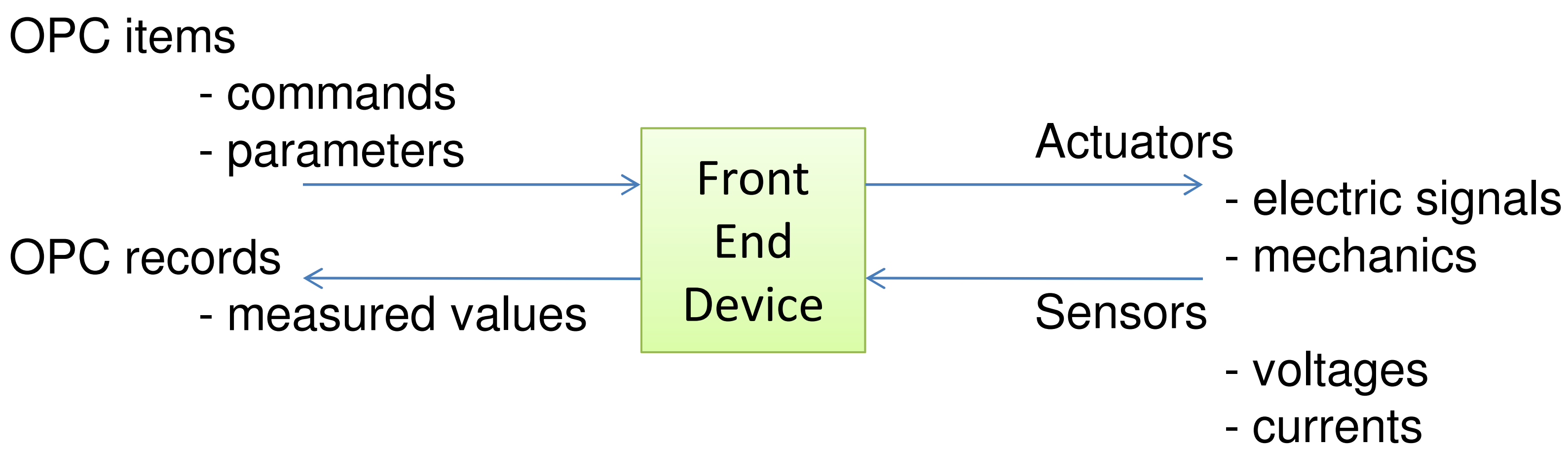
Tier 4 Overview



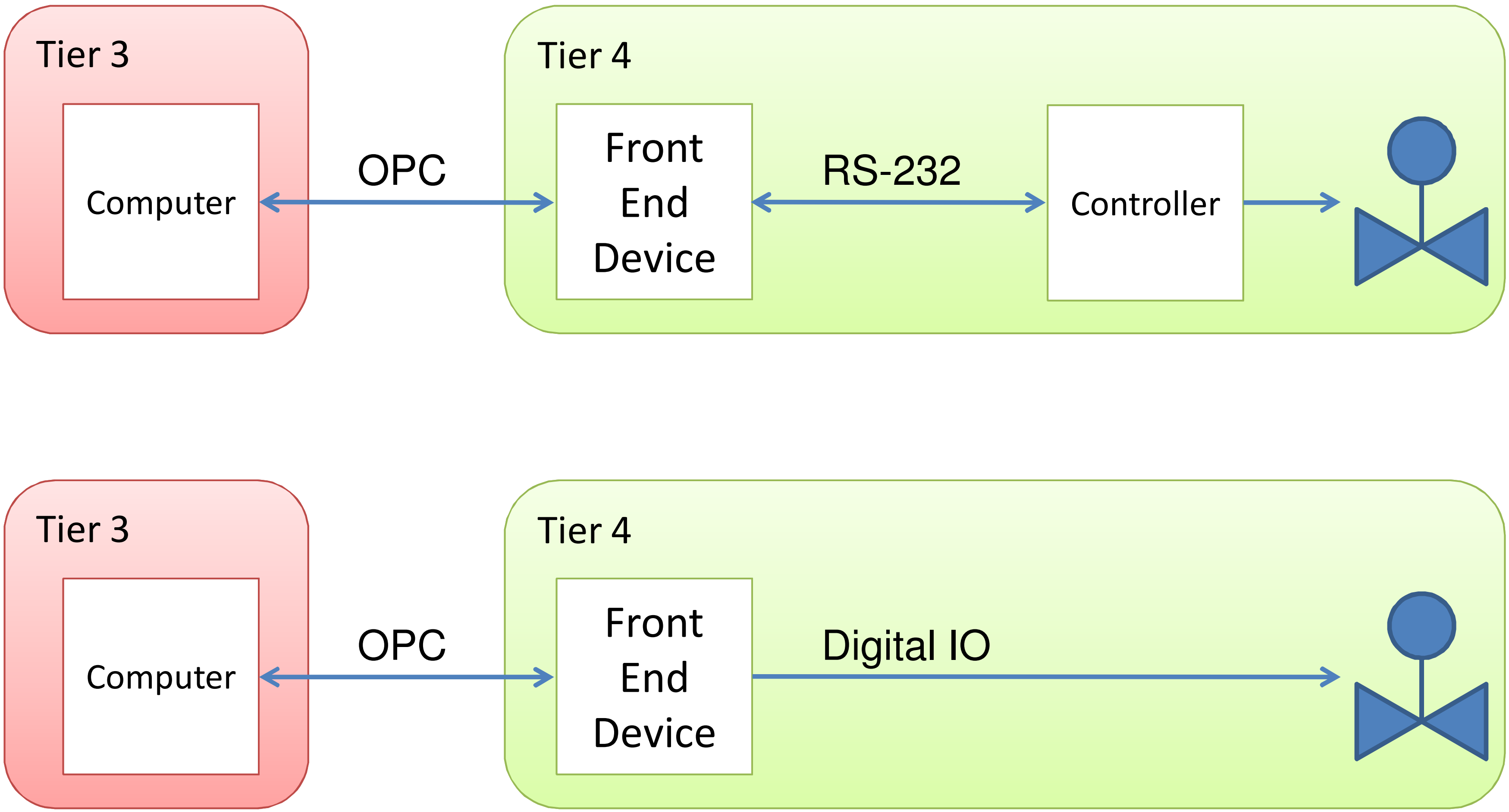
Frontend tier (T-4) is in the **scope of individual accelerator work packages**. Contains electronics and software that interfaces to work package “controls” software components **through recommended interfaces**. Provide and accept beam interlock signals.

Front End Device (FED)

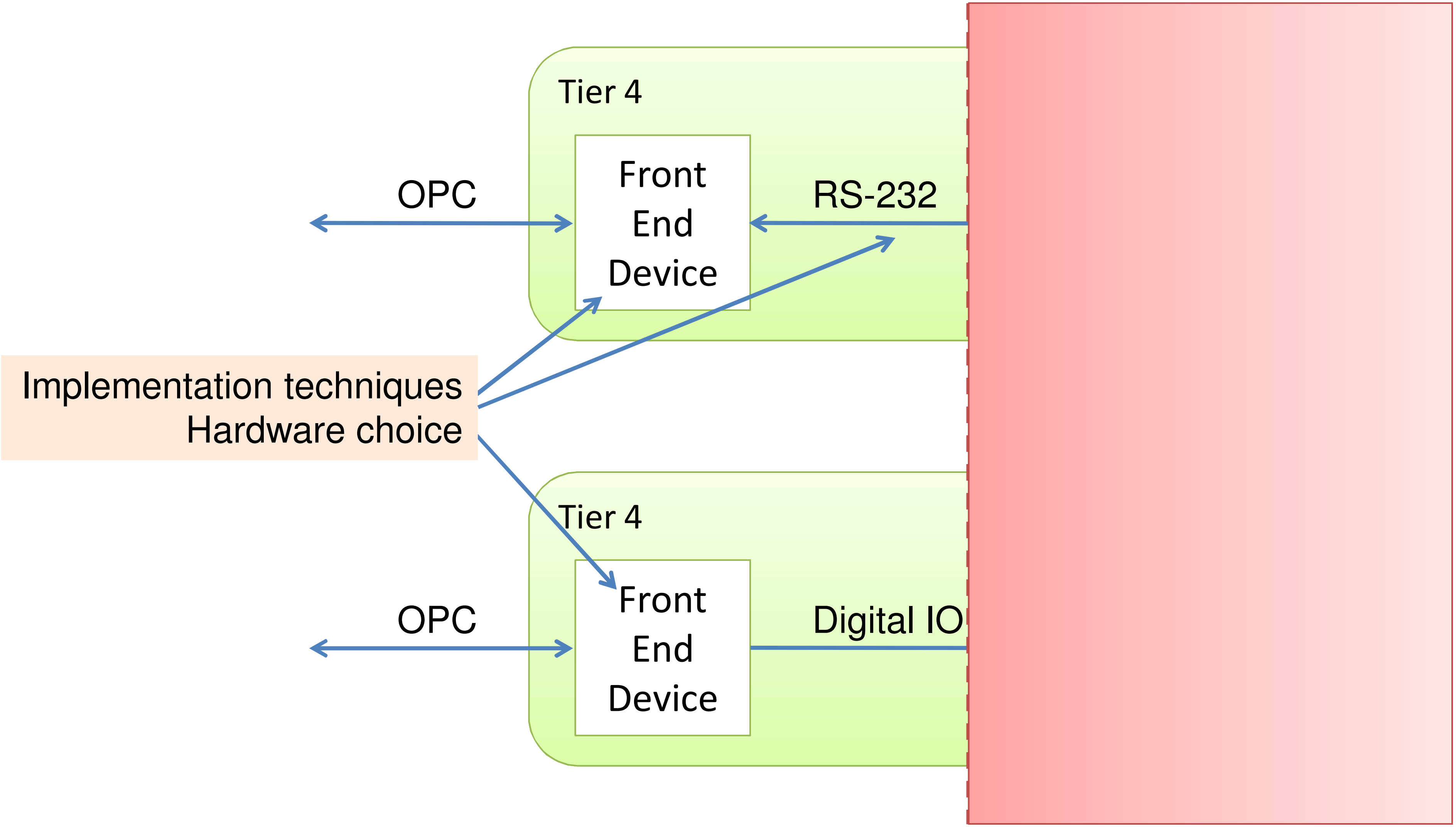
- An processing device that **autonomously** can **carry out control** actions on physical devices (actuators, sensors)
- Reacts to commands from control system components (T-3)
- **Programming** of devices in **scope of individual work packages**



FED Example: Valve



Recommendations



Interfaces With Subsystems (1/3)

PCO (ES-091111-a-JGU, ES-091203-a-JGU, ES-091216-a-JGU)

- Provide set points and waveforms to power converters
- Provide triggers to power converters

Magnets (ES-091021-a-MMA)

- Read out temperature and flow status
- Send control commands to magnet positioning system (septa)

Vacuum (ES-090916-a-MMA)

- Interface to vacuum local control system (LCS)
- LCS designed and implemented according to controls guidelines

Beam Interception Devices (TBD)

- Command devices
- Record device status

Interfaces With Subsystems (2/3)

Ion Sources (ES-091113-a-MMA in progress)

- Configure devices and command device parameters
- Change and record device status

RFQ, IH structure and RFC (TBD)

- Configure RFC local control system
- Change and record LCS states
- Provide main timing system events and triggers

Beam Diagnostics and Instrumentation (TBD)

- Provide T4 programming framework and guidelines
- Configure T4 processing equipment
- Change and record T4 processing equipment states
- Provide main timing system events and triggers
- Provide Signal Acquisition and Distribution System (SADS)

Interfaces With Beam Delivery (3/3)

Beam positioning devices (power converters)

- Configure devices and record states
- Provide set point every 10 μsec

Beam monitors

- Acquire digital signals and transmit to BDCS
- Record operational conditions

Beam activation/de-activation devices

- Configure devices and record states
- Provide triggers to activate/de-active beam

Infrastructure

Authentication & Authorization System

- Specified and realized in cooperation with all work packages

Database Management System

- Specify and realize a scalable RDBMS with local data recovery
- Specify and elaborate facility-wide off-site backup

Framework and Tools

- Specified and provided by work package also for other work packages

Operating Systems

- Specified and provided by work package also for other work packages

Processing Platforms

- Specified and realized in cooperation with all work packages
- Work packages acquire platforms individually in centrally managed procurement process according to needs

Interfaces With External Systems

Med. Software Systems (IS-090903-a-RTR, PM-090825-a-RTR)

- Interface elaborated in cooperation with MSS work package
- Mastership in clinical mode lies within PRVS
- PRVS controls patient positioning, gantry and MTE devices

Building Automation System (TBD)

- Request uniform Authentication & Authorization solution
- Receive and report status

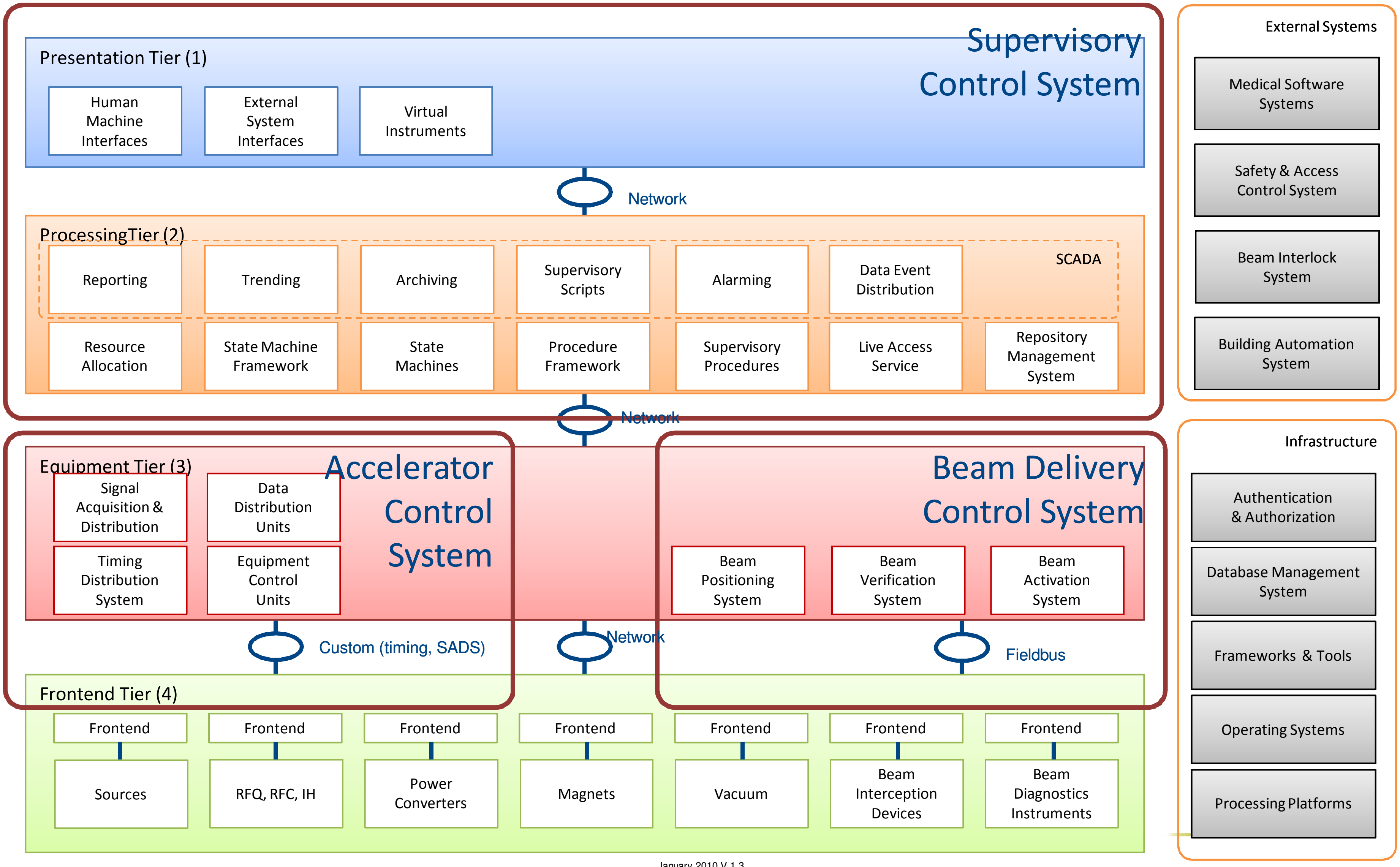
Access Control System (TBD)

- Request uniform Authentication & Authorization solution
- Receive and report status

Beam Interlock System (ES-100107-a-MMA)

- Safety system that is orthogonal to operational functions
- Covered by work-package

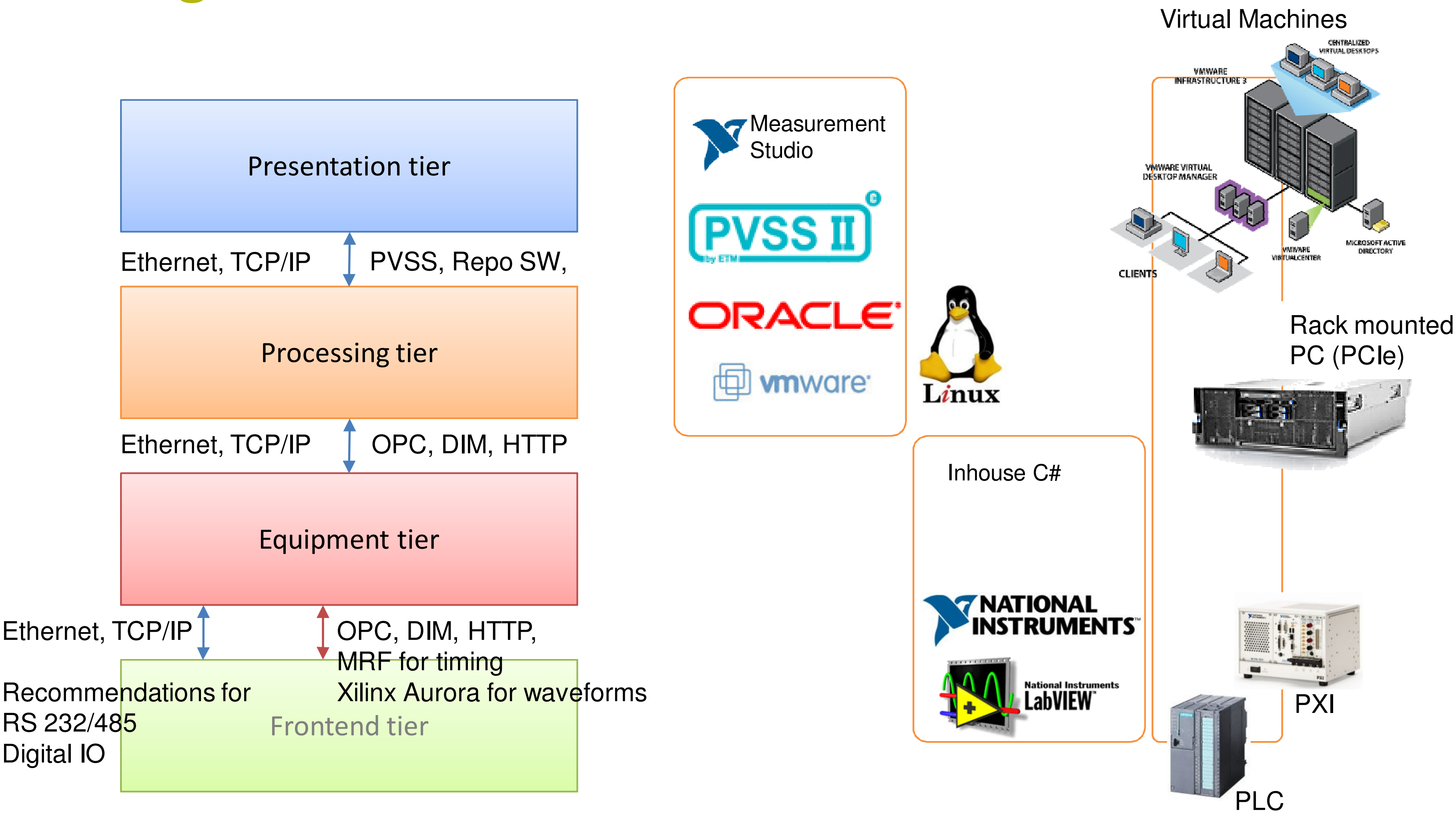
Architecture Overview



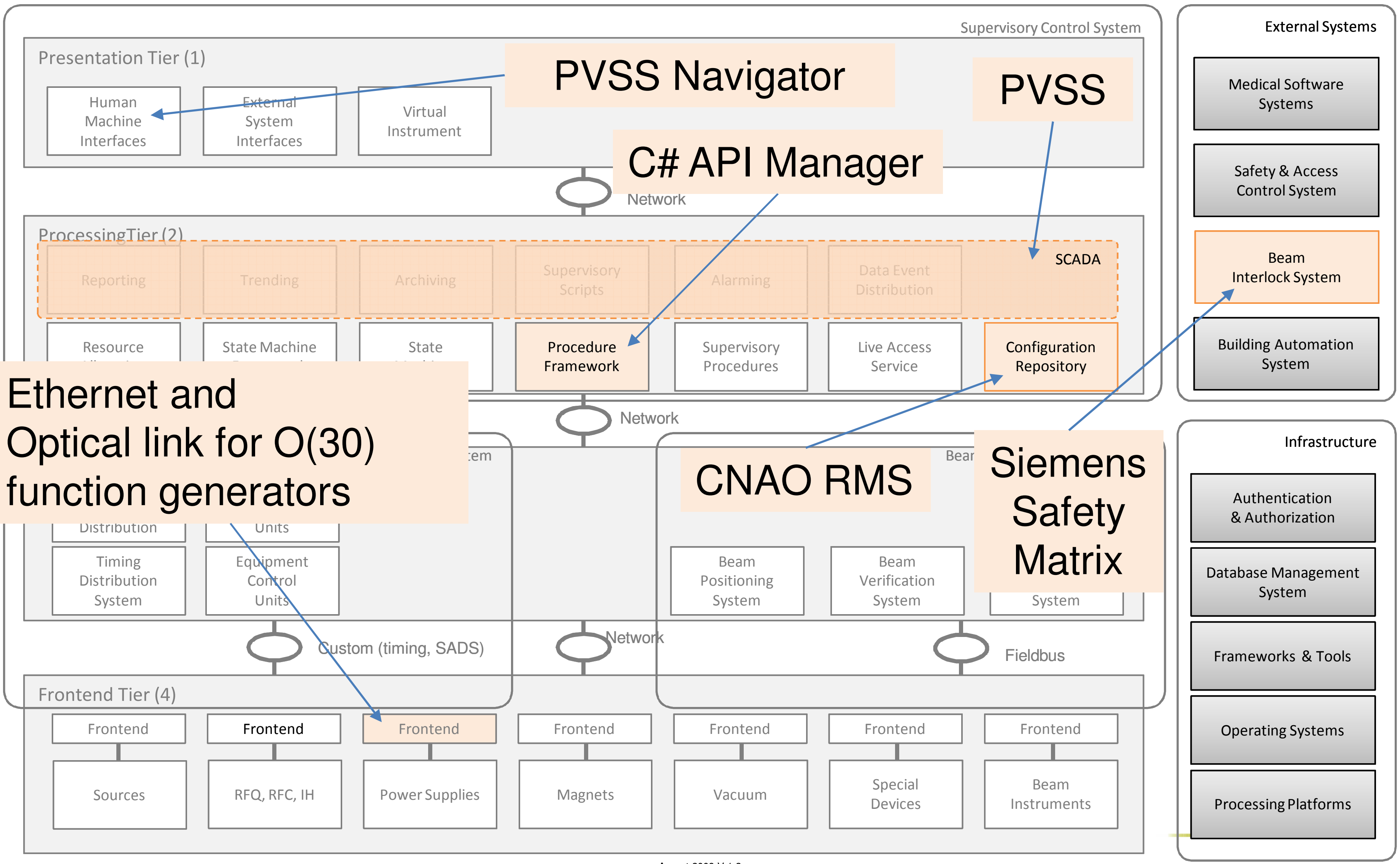
Detailed Architecture and Design

- 2nd step (Design) after 1st step (Requirements)!
- Limit to high-level recommendations at this point
  - Primary means of communication with front-end:
    - Transport: Ethernet + TCP/IP, RS 232/485, digital I/O for interlocks
    - Protocols: OPC + DIM + HTTP
    - Data contents: To be defined
  - Platform for SCADA + GUIs: "virtualized" MS Windows + PVSS II
  - Platform for Frontend: Labview-RT where RT needed, FPGAs
- Investigated CERN solutions for different areas (timing, function generation, software, analogue & digital IO)
- Need to initiate negotiations with companies
  - Main Timing System (Micro Research Finland)
  - SCADA (ETM with PVSS II)
  - Frontend systems (National Instruments with PXI + CompactRIO)

Design Candidates



Design Work in Progress



OUTLOOK AND SUMMARY

Summary

- Work package scope and goals defined
  - Supervisory Control (T1, T2)
  - Accelerator Control (T3)
  - Beam Delivery Control (T3, T4)
  - Beam interlock
  - Authentication & Authorization
- Separation of concerns (SCS, ACS, BDCS)
  - Method to interface with MSS for medical operation described
- Development taking into consideration safety standards
- Requirements specification in progress
- Architectural cornerstones defined
- Elaboration of foundation blocks about to begin