# Update on the Beam Energy Tracking System

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# Open Issues
## *Machine Protection Review*

- Acquisition of the beam energy for the generation of the kicker settings and for the tracking interlock logics relies on a single technology *(Bending magnet current + BEA + BEM):*
  - Conceptual design failure in this system can result in a common mode failure to the BETS reference and interlock logic.
- Absolute estimated value of the beam energy rely on external interlock *(Orbit corrector & Radio-frequency):*
  - The BETS is unable to detect and manage absolute beam energy variation induced by these systems.
- Use of look-up tables and their management….

# Outline

- Beam Energy Tracking System
- Reference Settings
- Tracking Interlock
- Look-Up Table
- Safety
- Performance
- Status
- Summary

# Beam Energy Tracking System
## *Definition*

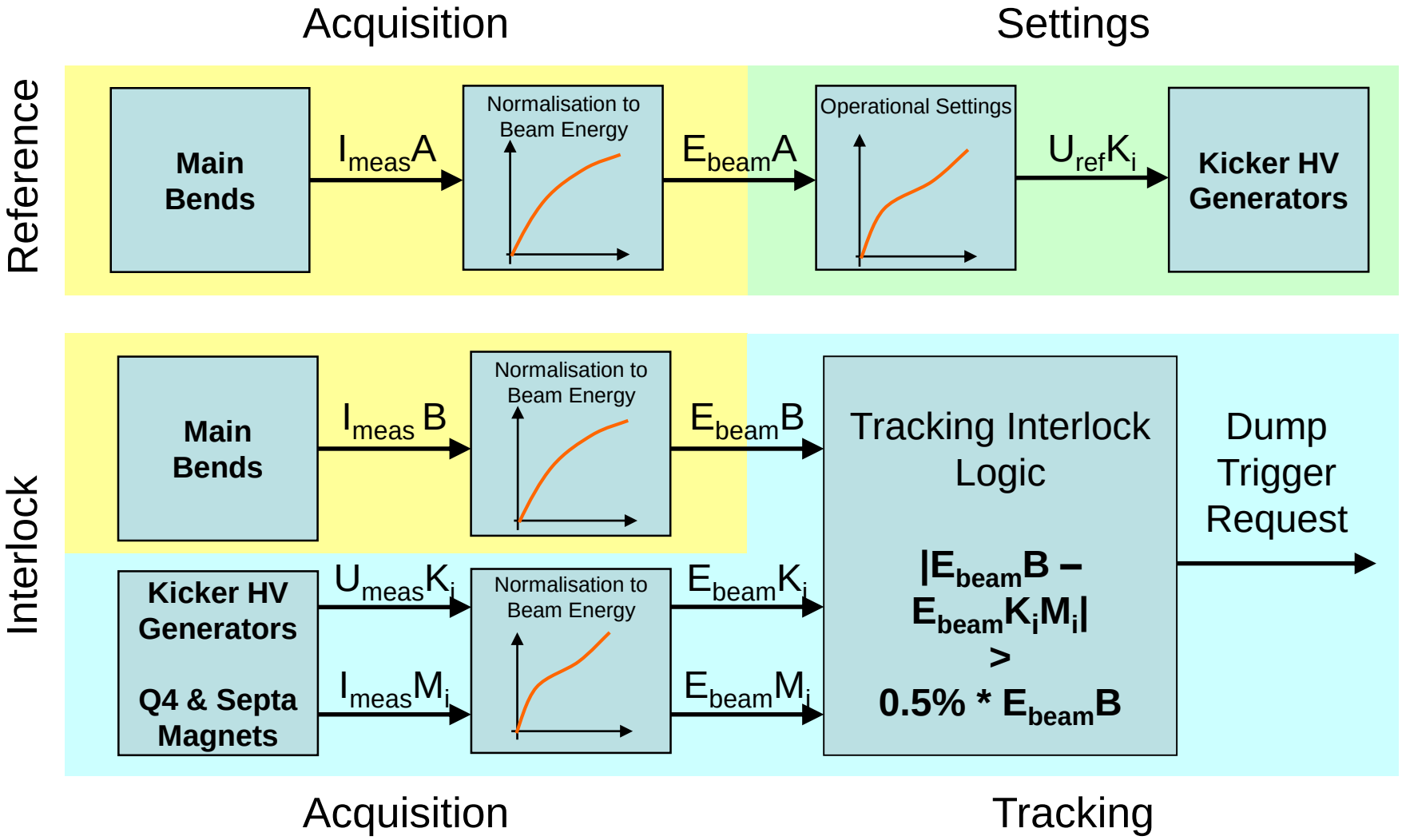
The Beam Energy Tracking System (BETS) binds the deflection strength of each active sub-system of the LHC Beam Dumping System (LBDS) with the beam energy in order to get the correct extraction trajectory over the complete LHC operational range and under all operational conditions.

# Beam Energy Tracking System
## *Functions*

1. Acquisition of the machine *“beam energy”,*
2. Generation of the kick strength reference signals for LBDS extraction and dilution kicker high voltage generators w.r.t. the beam energy,
3. Continuous surveillance that the charging voltages of the different capacitors within the kicker high voltage generators follow their references within predefined tolerance windows (extraction trajectory aperture),
4. Continuous surveillance that the LBDS extraction septa and ring quadrupole Q4 currents are within predefined tolerance windows (extraction trajectory aperture),
5. Generation of a dump request after detection of an upcoming tracking fault if the measured values are not within predefined tolerance windows relative to the beam energy,
6. Distribution of the beam energy to external clients.

# Beam Energy Tracking System

## *Principle*

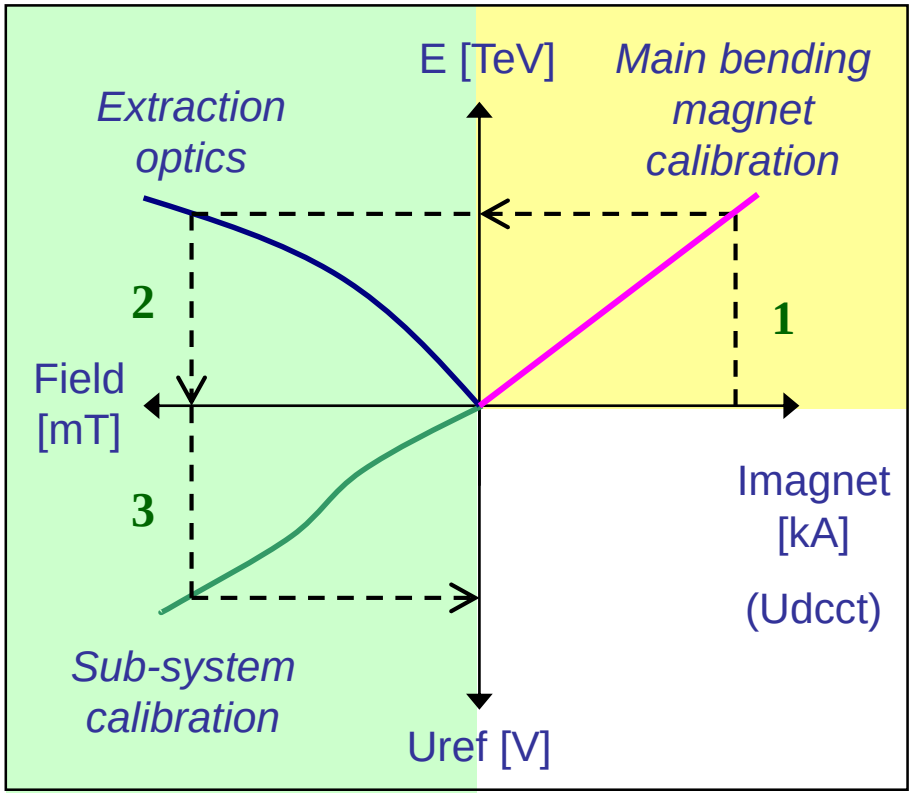


# Beam Energy Tracking System
## *Input Signals*

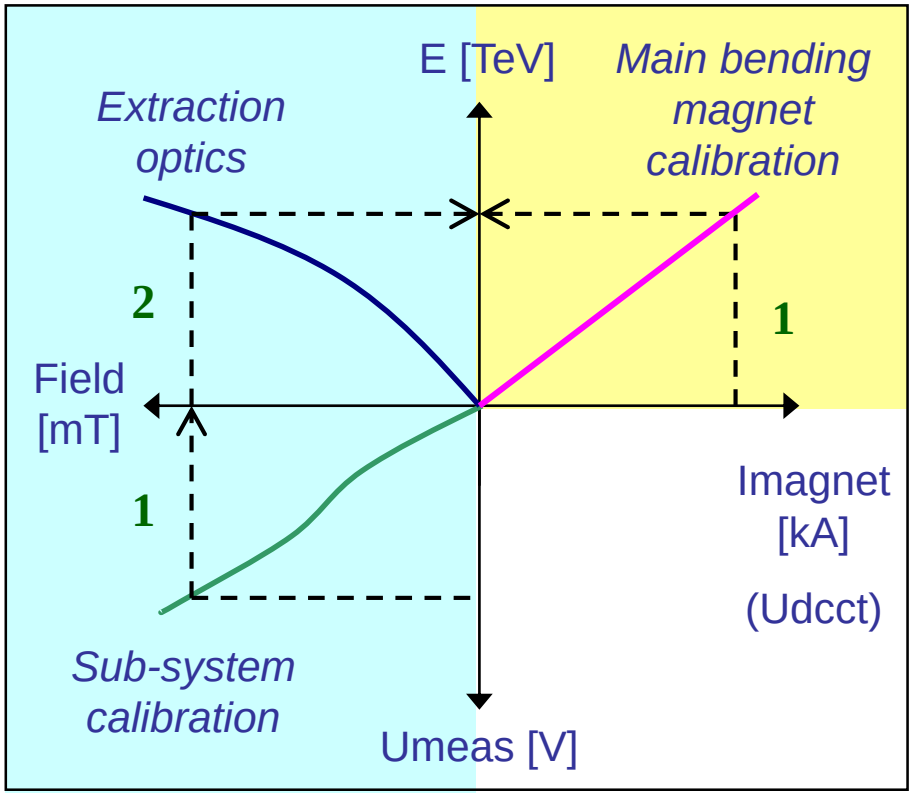
- At least, **two independent sources** of the "*beam energy*" are necessary in order to verify the correct operation of the Beam Energy Tracking System
  - One information will be used as **reference** signal for the generation of the kick strength references
  - One information will be used as reference for the **tracking interlock** logic
- All the interlock input signals will be normalised to values relative to their corresponding beam energy for cross-correlation and comparison
  - High precision calibration measurements

# Beam Energy Tracking System
## *Signal Normalisation*

Reference



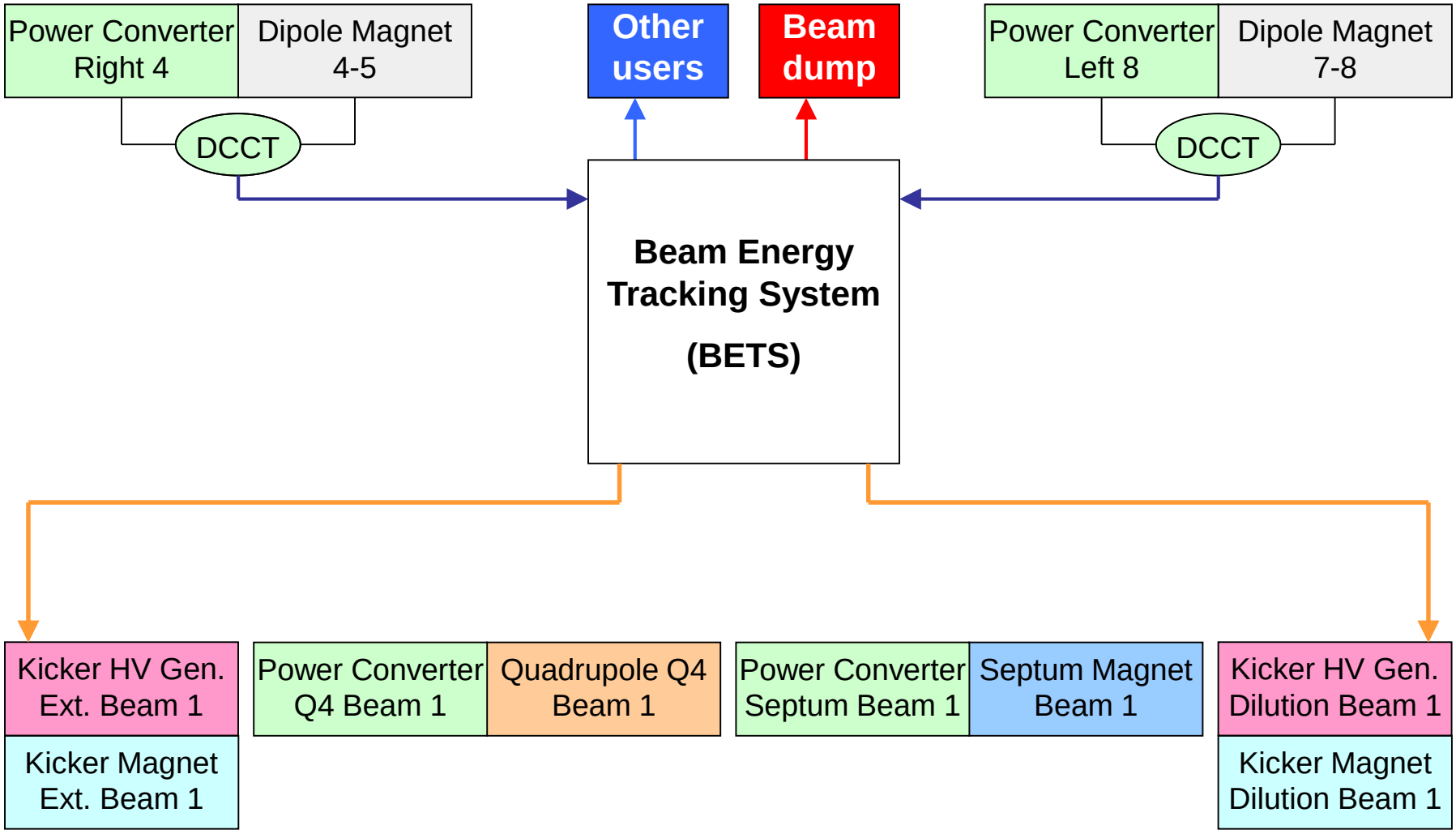

Interlock




Reference and tracking systems rely on a precise knowledge of the magnetic characteristics of the different LBDS sub-system → Good calibration measurements over the complete operational range are mandatory for each sub-system.

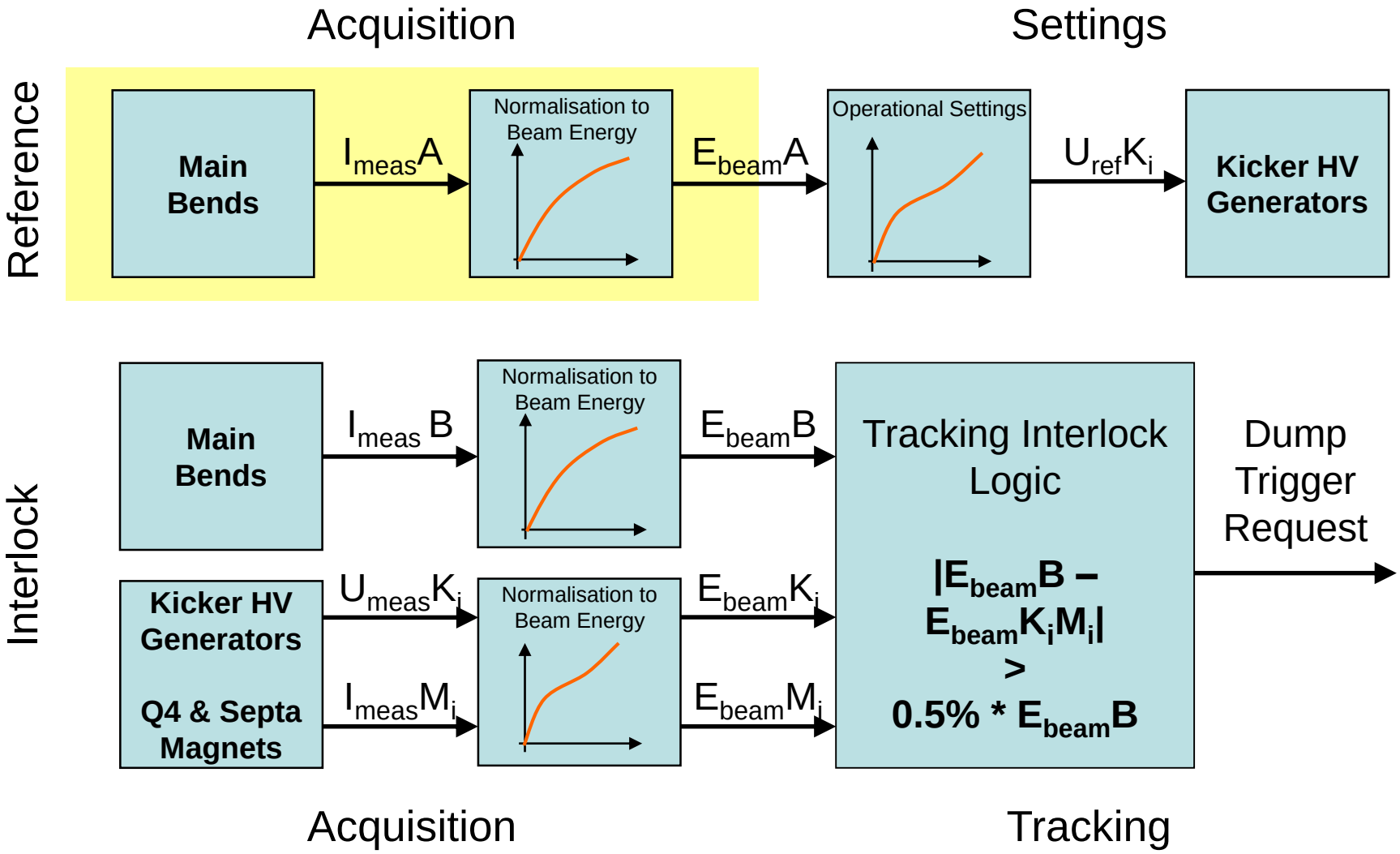
# Reference Settings

## *General*

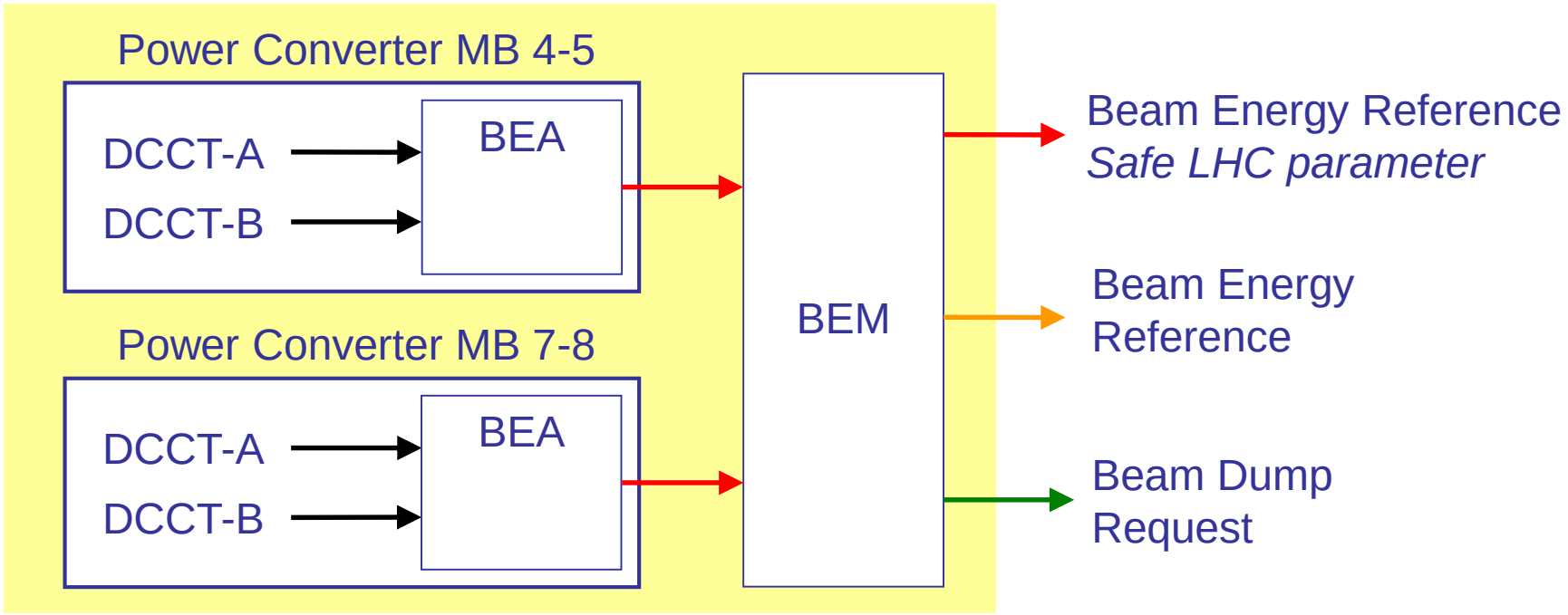


# Reference Settings

## *Beam Energy Acquisition*



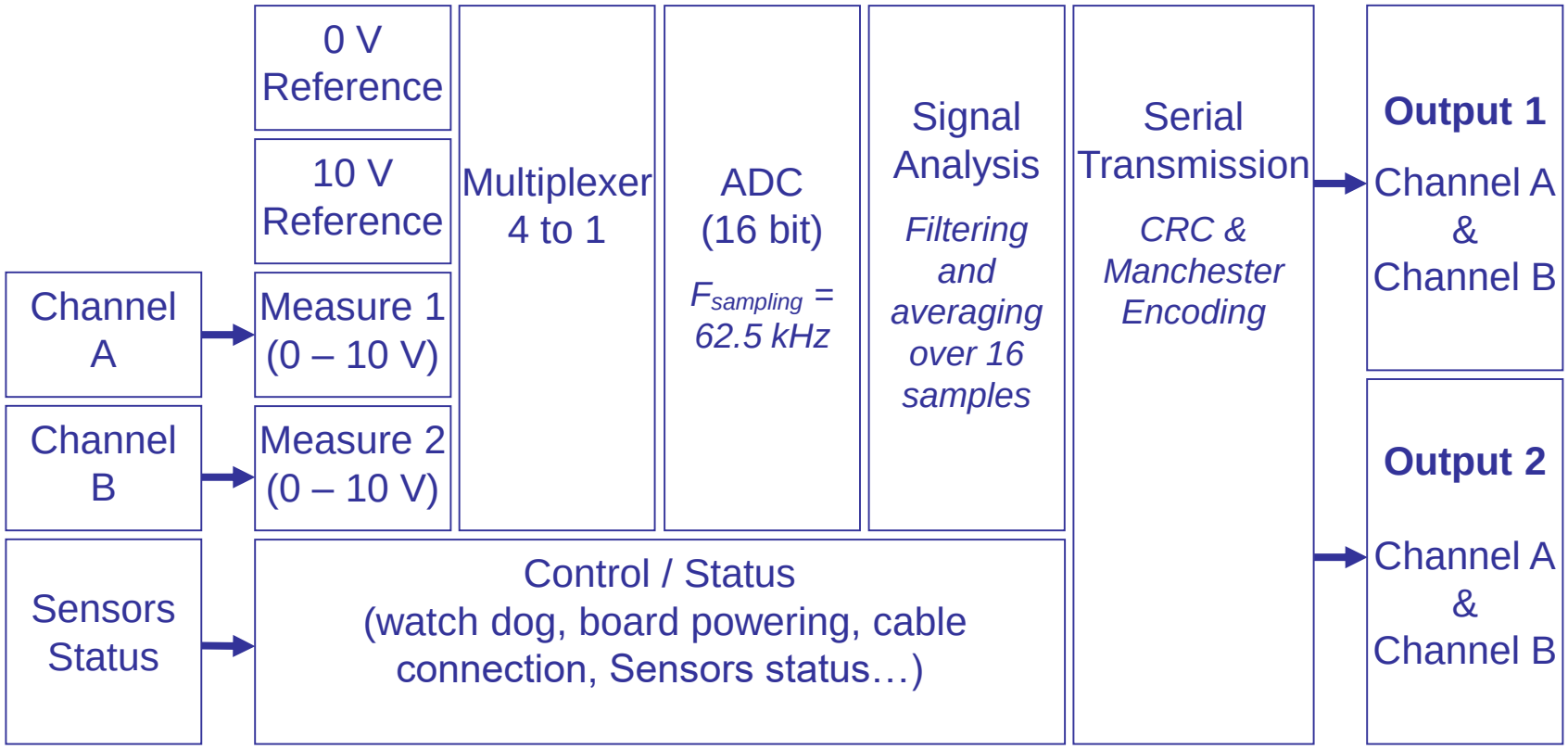
# Beam Energy Acquisition
## *Layout*




Analog signal
Optical fibre
Differential signal
Current loop

# Beam Energy Acquisition (BEA)

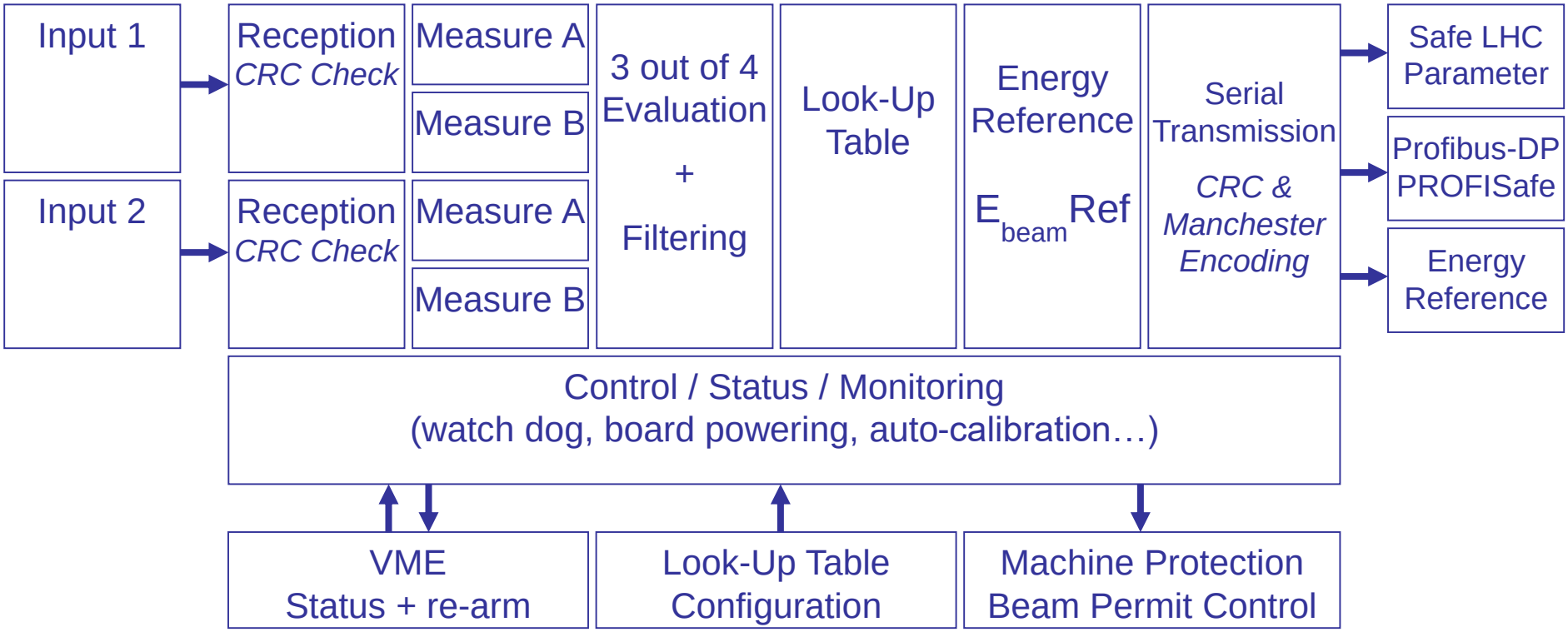
## *Hardware*




The BEA acquires and digitises 2 independent unipolar channels with 16bit resolution. Signals are digitally filtered before secure transmission through optical fibre. Two high precision reference signals are simultaneously digitised, modulated and transmitted in order to survey the linearity of the ADC and probing the transmission.

# Beam Energy Meter (BEM)

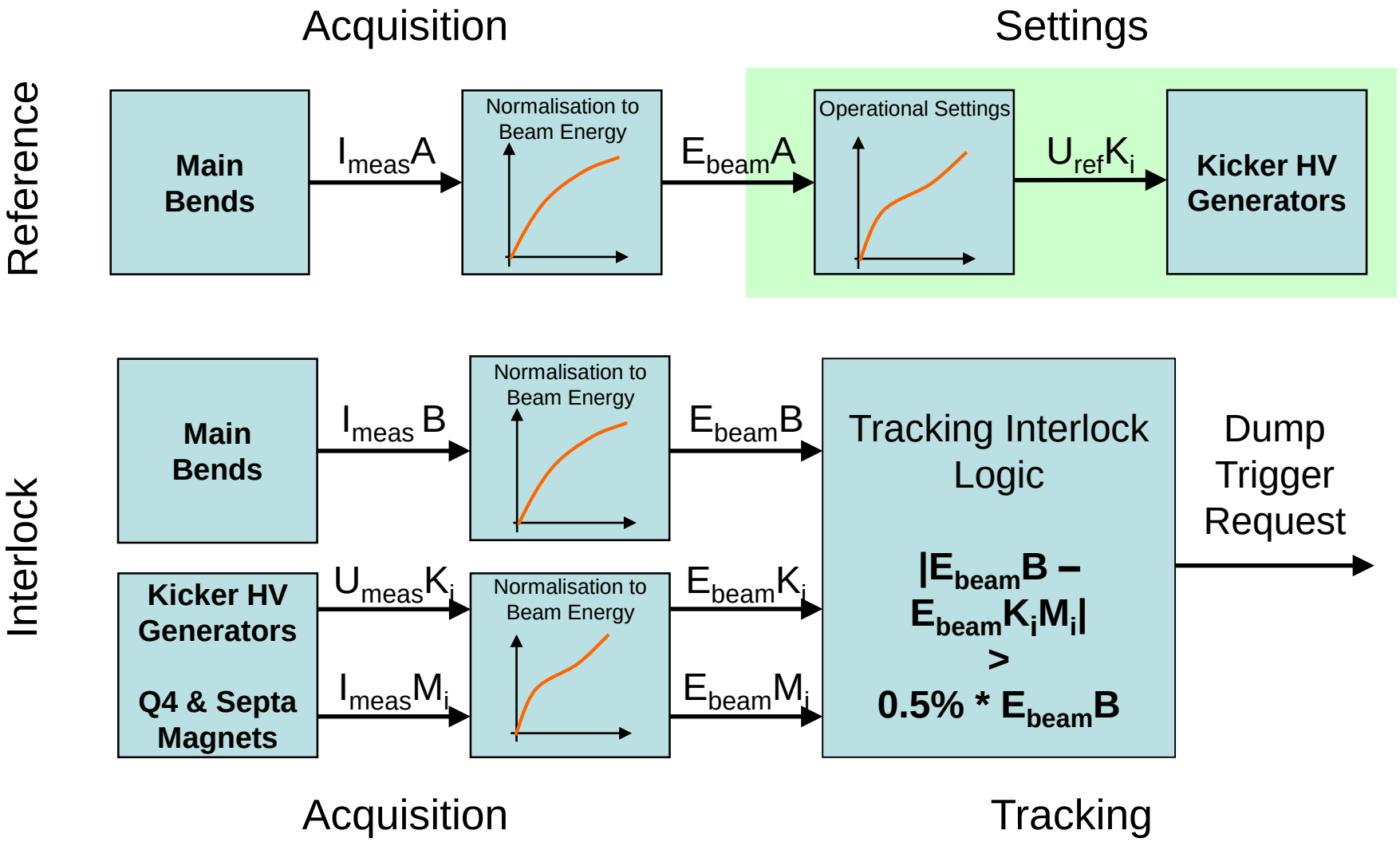
## *Hardware*




The BEM receives 4 digital measurements proportional to beam energy from BEA. These measurements are compared within the BEM with a 3 out of 4 logic and a relative error of ± 0.5%. Failure results in a beam dump request. The mean value of the 4 measurements is then converted into an absolute beam energy reference through a calibration look-up table.

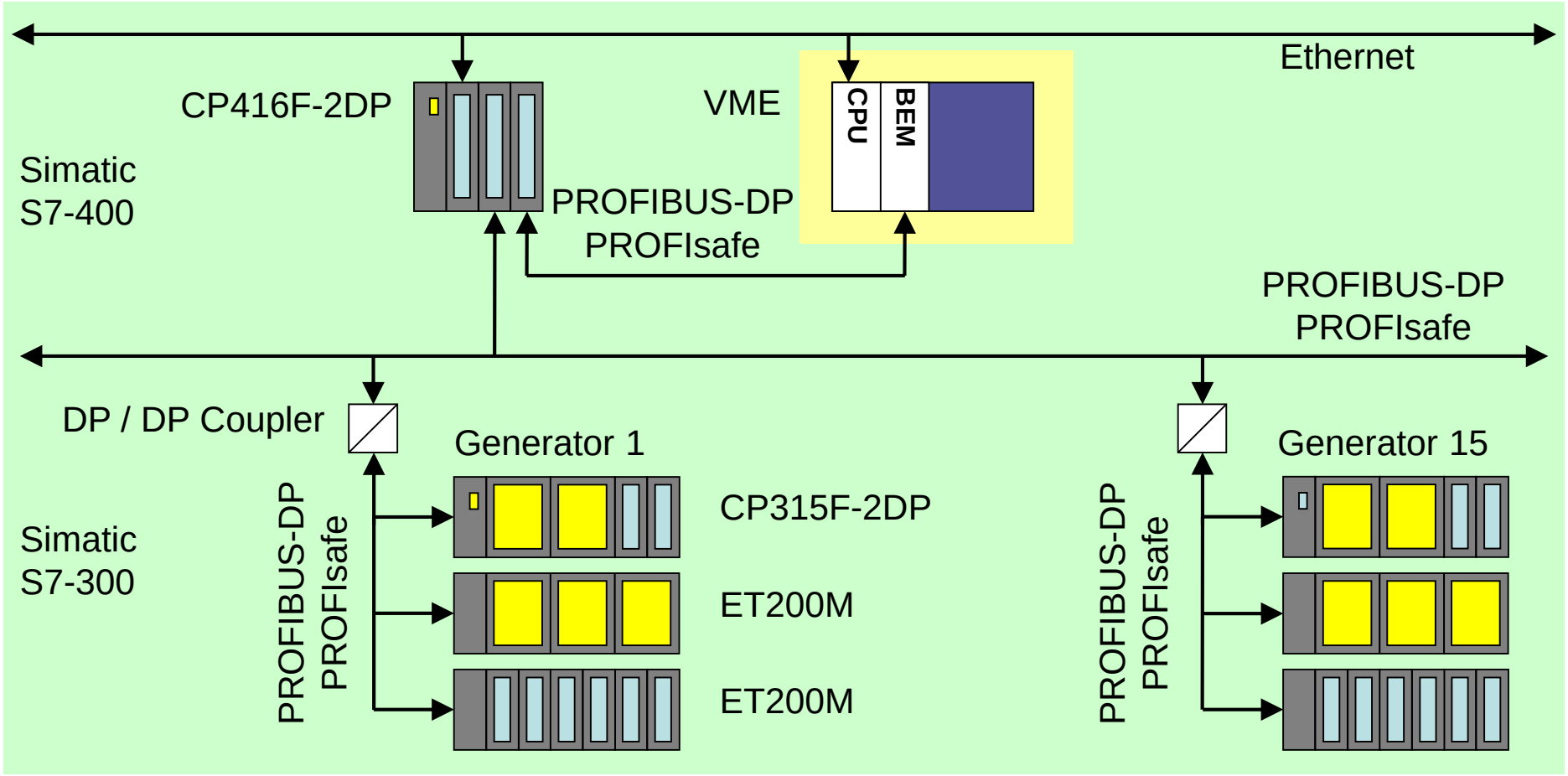
# Reference Settings

## *Generation & Distribution*



# Reference Settings

## *Generation & Distribution Layout*

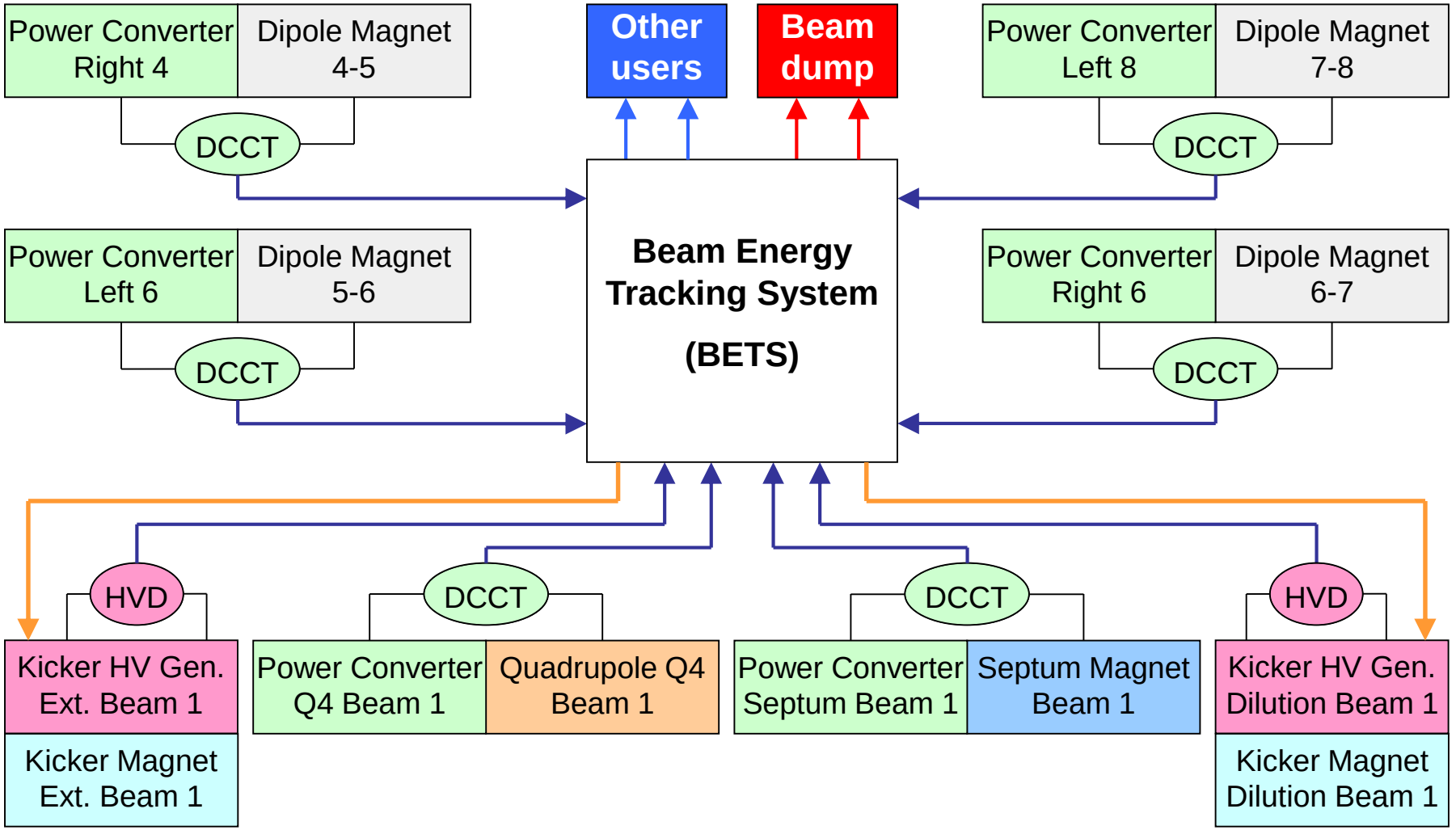



S7-300 fail-safe modules used in safety mode

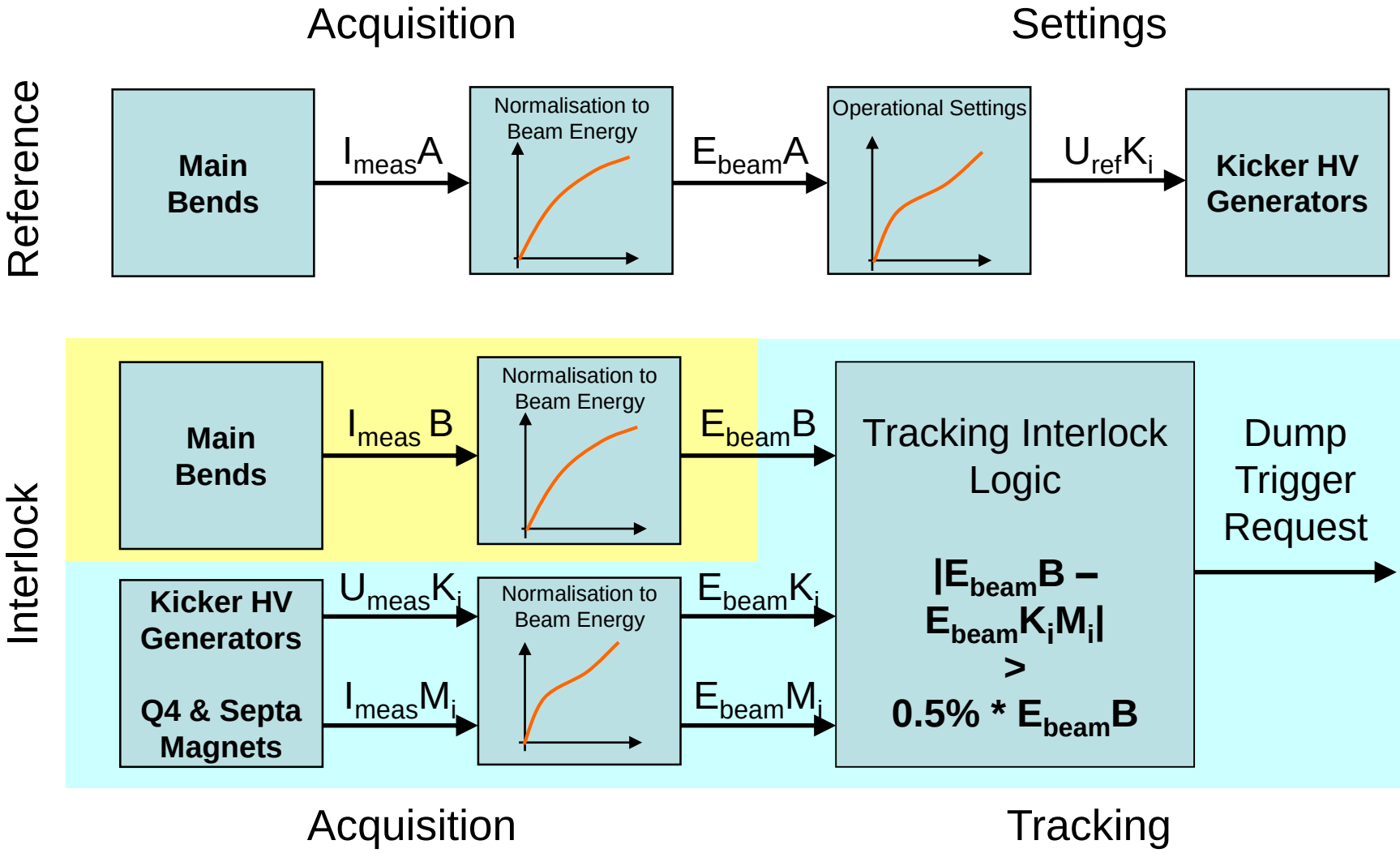
S7-300 modules used in standard mode

# Tracking Interlock

## *General*



# Tracking Interlock
## *Principle*



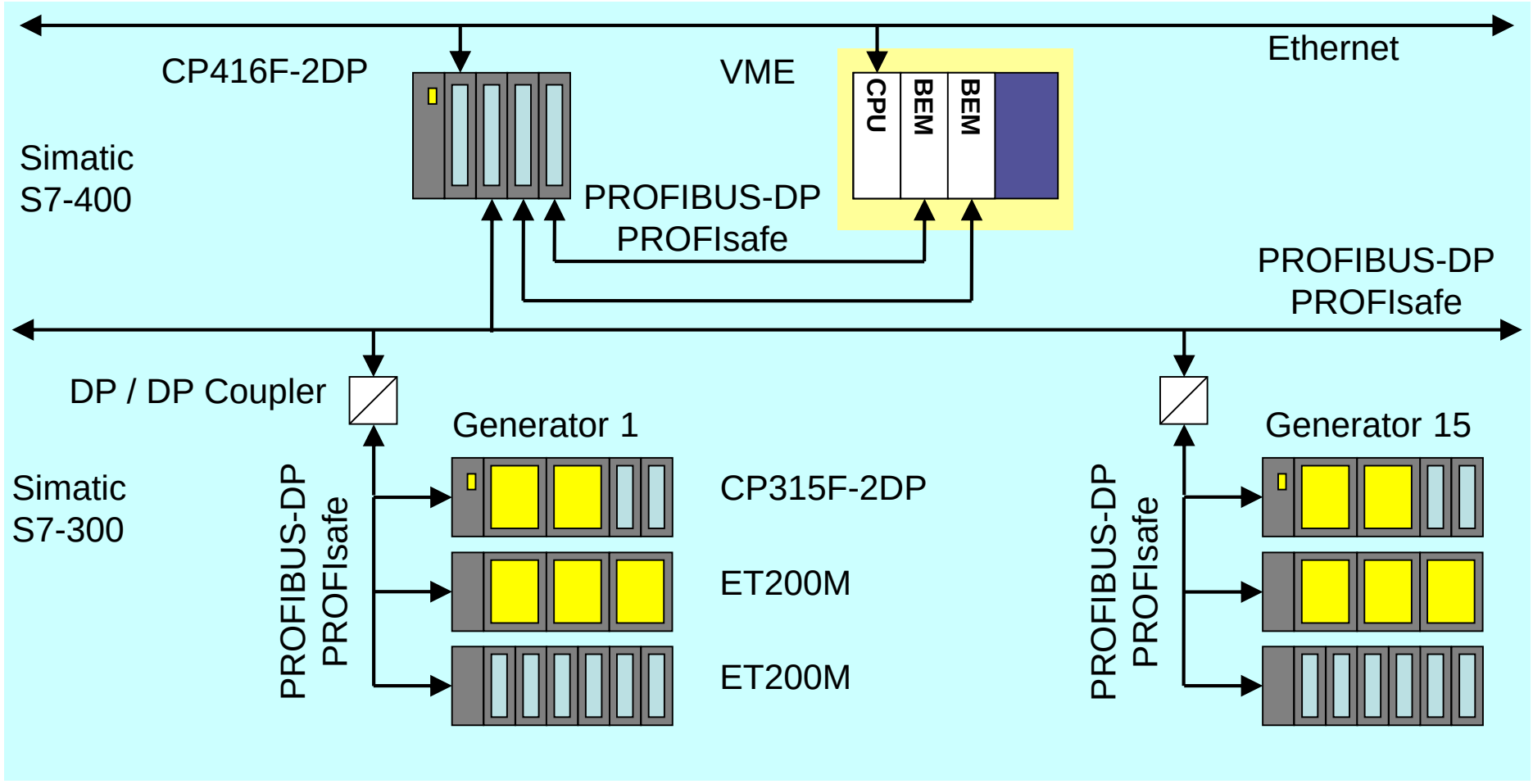
# Tracking Interlock
## *Architecture*

- The Tracking interlock logic will be based on two redundant systems built on the basis of two different technologies:
  - One system will be based on fail-safe SIEMENS SIMATIC S7-F Programmable Logic Controllers for the extraction and dilution kickers.

    **→ Feedback Tracking**
  - One system will be based on dedicated hardware housed in a LynxOS VME front-end for the extraction kickers, the quadruplole Q4, the extraction septa and the dilution kickers,

    **→ Real-time Tracking**
- Both systems have to be continuously in agreement:
  - 2 out of 2 logic,
  - Independent and redundant sensors will be used,
  - In case of discrepancy within a system or between the two systems, a dump request will be issued.

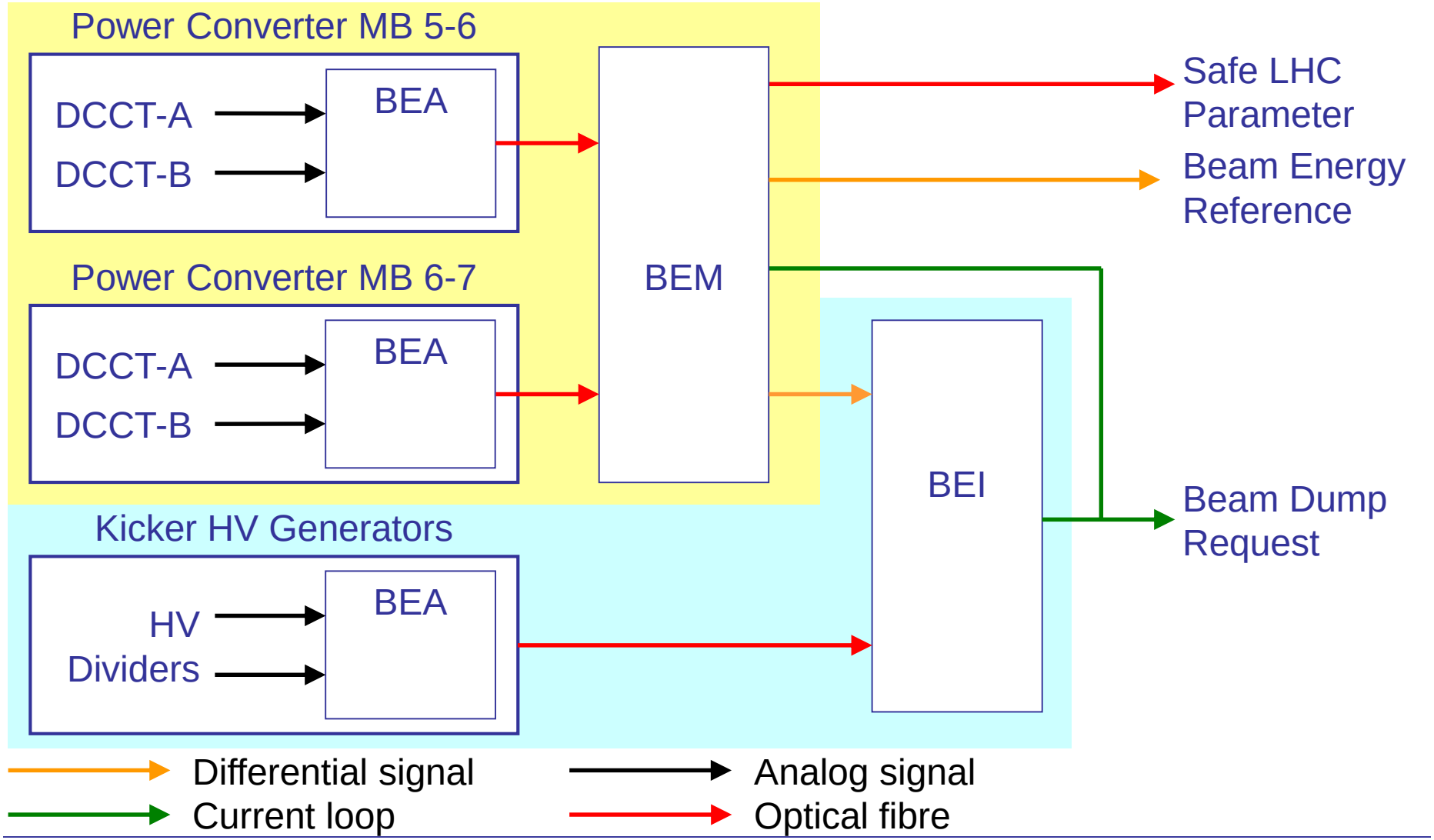
# Tracking Interlock
## *Feedback Tracking*




S7-300 fail-safe modules used in safety mode

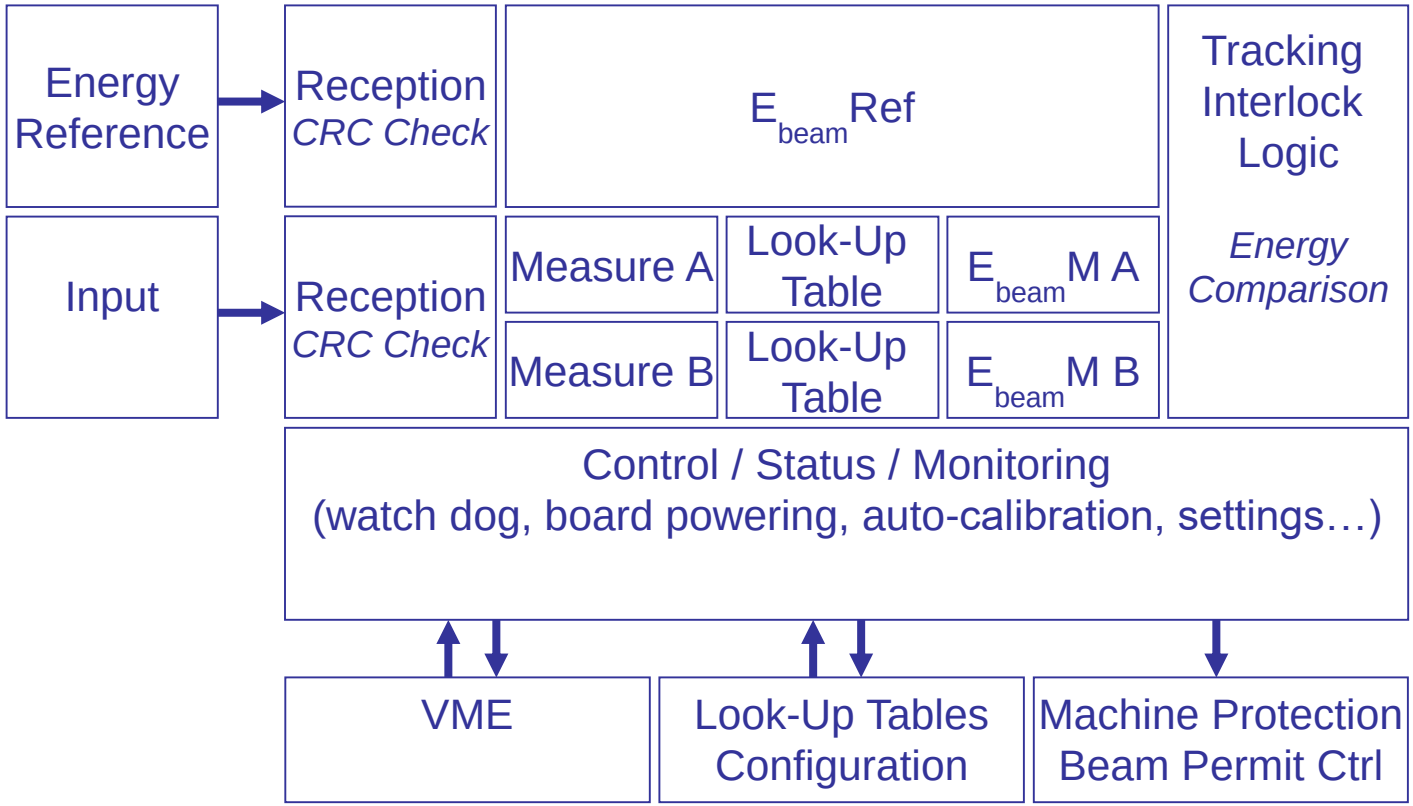
S7-300 modules used in standard mode

# Tracking Interlock
## *Real-time Tracking*



# Beam Energy Interlock (BEI)

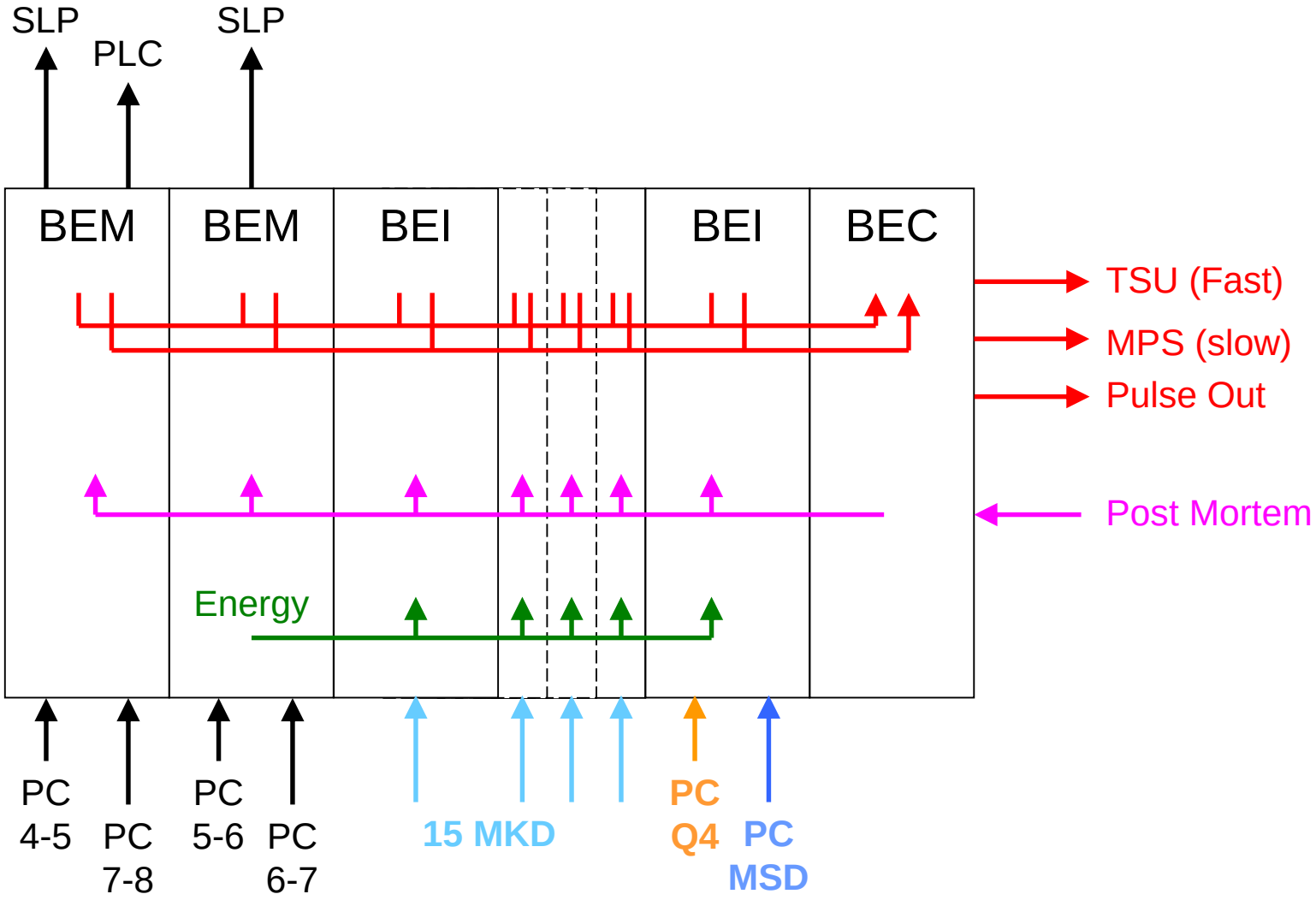
## *Hardware*




The BEI receives the beam energy reference signal and two independent measurements. It normalises the two measures to values proportional to the energy through independent calibration look-up table. These normalised values are then compared with the reference signal and if a discrepancy larger than a predefined tolerance is detected, a dump request is issued.

# Beam Energy Tracking System

## *VME Hardware Integration*



# Look-Up Tables
## *General*

- Look-up table will be used within the system for conversion physical measurements of  to energy
  - Conversion of main bending currents to energy
  - Conversion of energy to kicker voltage references
  - Conversion of extraction septa currents to energy
  - Conversion of ring quadrupole Q4 currents to energy
  - Conversion of kicker voltages to energy

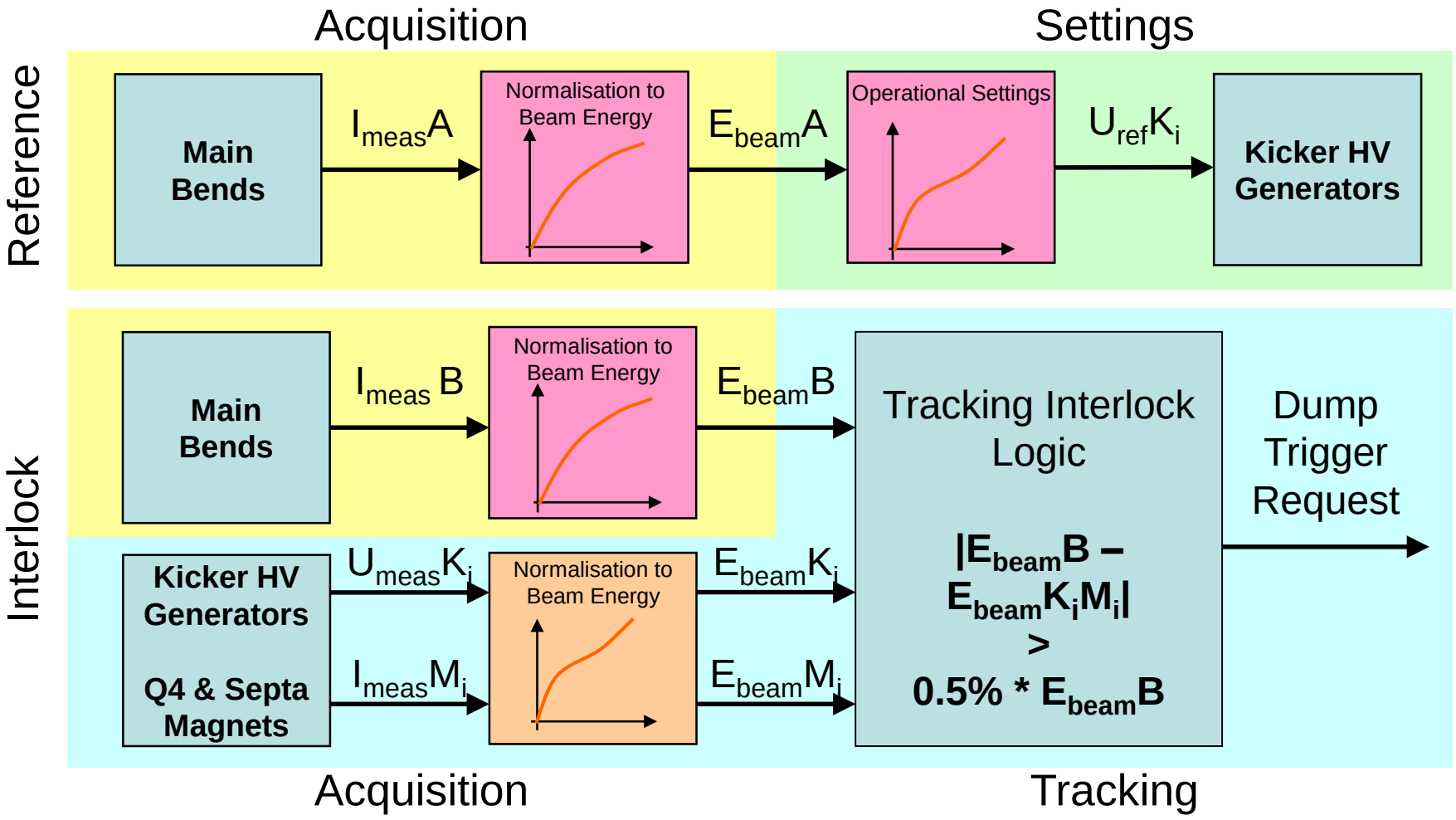
# Look-Up Tables
## *Types*

- First order Interpolation table
  - Up to 64 reference points in the table
  - Linear interpolation between two points to obtain the energy value
  - Error is defined by the number of interpolation points

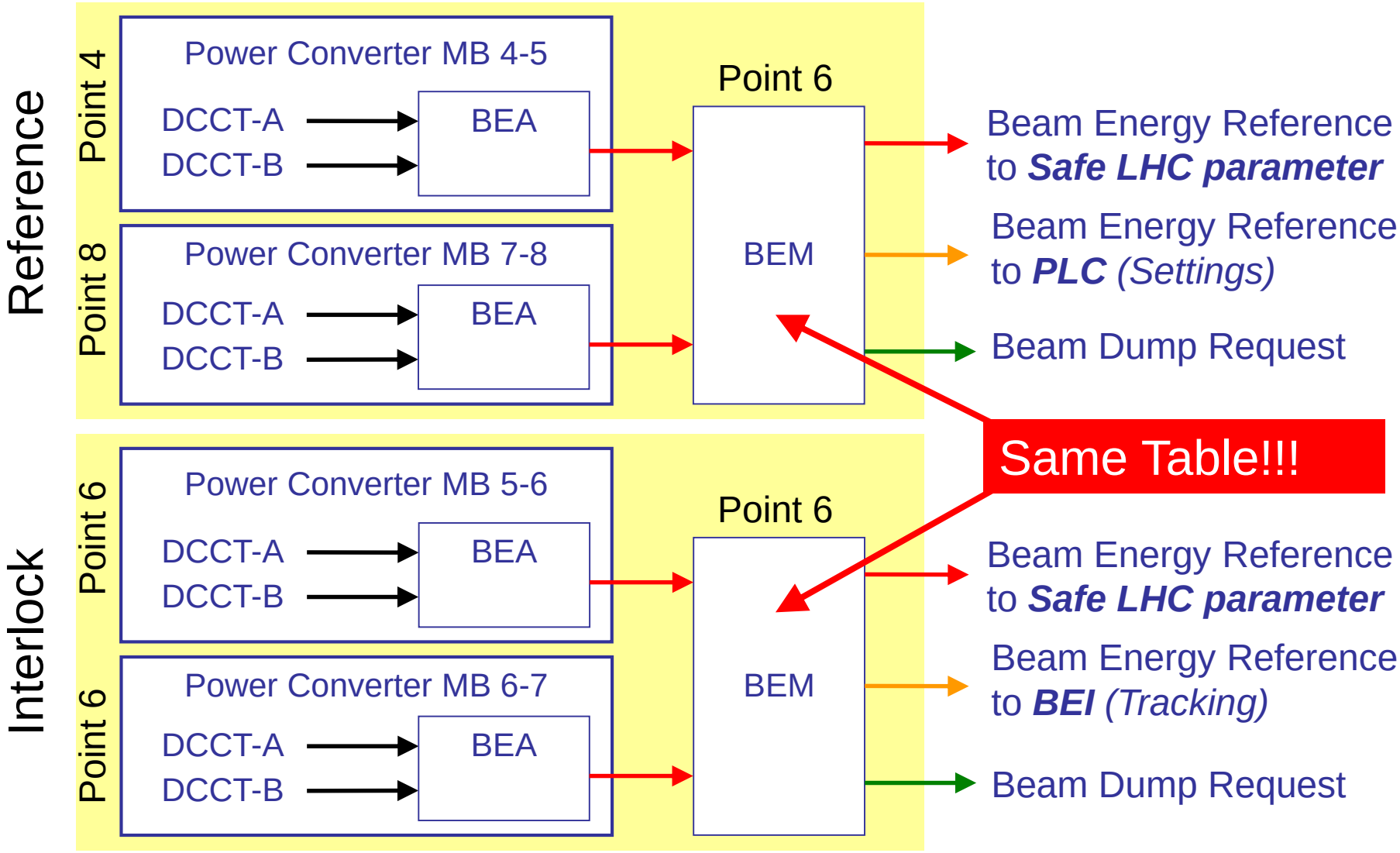
  ➔This type of table will be used within BEM and PLC
- Memory Map table
  - 64 kword reference points in the table
  - ADC output (16bit) is used as the address. Data located at this address correspond to the energy.
  - Error is defined by the precision of the calibration measurements

  ➔ This type of table will be used within the BEI

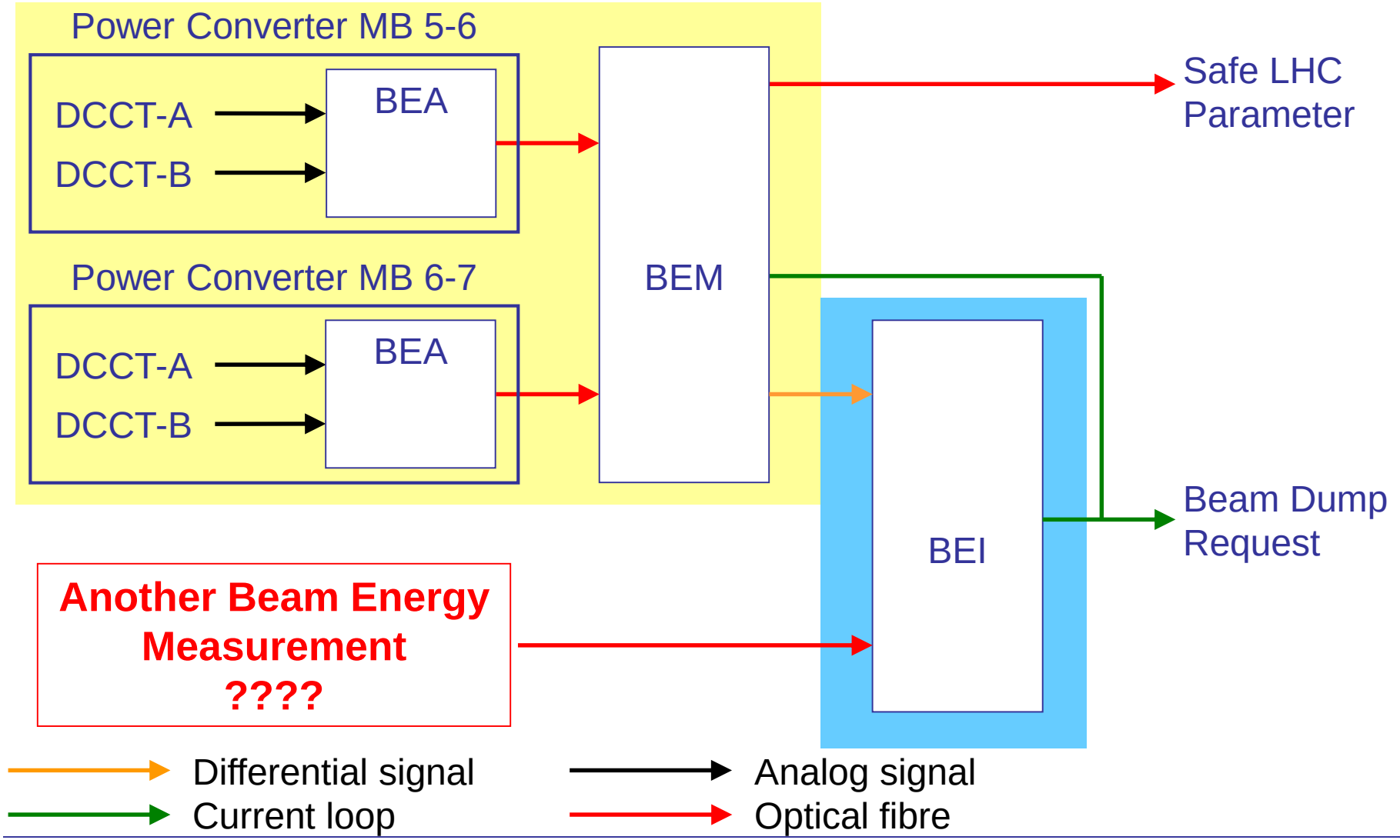
# Look-Up Tables
## *Which Type and Where*



# Look-Up Tables
## *Weakest Point*



# Look-Up Tables
## *How to Improve ?*



# Safety Consideration

- **BETS** is fully based on a **fail-safe** logic.
- All the electronic included within the **BETS** will be **powered** by 230V **Uninterruptible Power Supply** (UPS).
- BEM and BEI modules housed within **VME crate** will be **powered** by **redundant power supplies**.
- **Data transmission** between BEA, BEM, BEI and SLP will be based on **Manchester encoding** including a **Cyclic Redundancy Check** (CRC) for transmission error detection.
- **Look-up tables** will be **stored** in Flash **EEPROM**. **Modification** of the tables will be **only possible locally** through an external RS232 interface.
- The use of **SIEMENS SIMATIC S7-F** Programmable Logic Controllers and **PROFIsafe** protocol over PROFIBUS-DP guarantees a Safety Integrated Level 3 (**SIL3**).

# Performances

| | |
|---|---|
| Power converter DCCT precision | ±0.1 % |
| Kicker HV divider precision | ±0.2 % |
| BEA sampling frequency | 65 kHz |
| BEA resolution | 16 bit |
| BEA–BEM / BEI transmission rate | ~100 kbit/s |
| Error during ramp (10 A/s) | < 0.01% |
| Bending magnet look-up table precision | ±0.1 % |
| Kicker magnet look-up table precision | ±0.2 % |
| Beam energy reference error (with interlock on RF & Sextupole) | ±0.4 % |
| BEI tracking frequency | 1 kHz |
| BEI tracking reaction time | 1 ms |
| Bending magnet tolerance window | ≥ ±0.3 % |
| Kicker magnet tolerance window | ≥ ±0.5 % |

# Status

- **Settings generation** and **distribution** implemented, tested and validated
  - Validation of the first order look-up table
  - Pulse to pulse reproducibility better than 0.2%
- Implementation of the **Feedback Tracking** is under progress
  - Signal acquisition implemented
  - Feedback comparison algorithm to be defined
- **Real-time Tracking** is under development
  - BEA:  prototype developed & tested
  - BEM: prototype developed & tested
  - BEI: prototype developed & currently under evaluation
  - BEC: under development
- Monitoring and post-mortem analysis of BETS will start in August (Technical student)

# Summary

- BETS will be built on the basis of a fail-safe logic
  - Each failure within the system will issue a dump request
  - Sensitivity of tracking tolerance windows could be an issue
- Tracking interlock logic will be based on a redundant approach relying on two different technologies
  - No “voting” is foreseen (nor possible)
- RAMS calculations are in progress
  - Part of the system is de-facto SIL3 with the use of SIEMENS S7-F Programmable Logic Controller
- BETS relies on a good knowledge of the magnetic characteristics of its different sub-systems over the complete LHC operational range
  - High precision calibration measurements are mandatory for all the sub-system included in the BETS.