Personnel Protection of the CERN SPS North Hall in Fixed Target Primary Ion Mode

San Francisco, California, USA
6-11 October 2013

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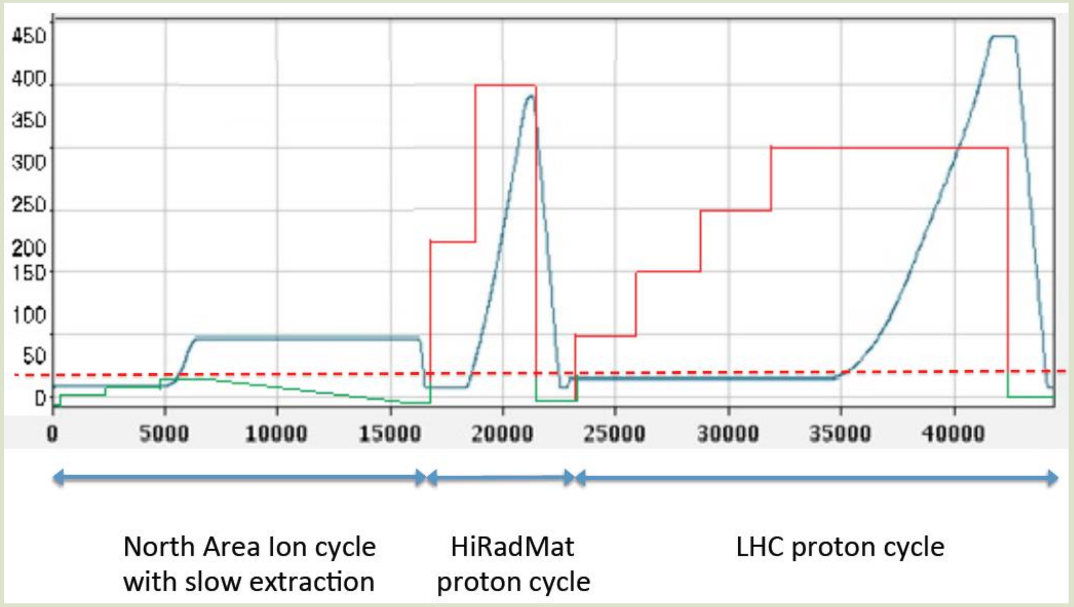
While CERN's Super Proton Synchrotron (SPS) is able to deliver both secondary proton and primary ion beams to fixed targets in the North Area, the experimental areas (North Hall) are widely accessible during beam. In ion mode all normal safety elements involved in producing secondary beams are removed, so that an accidental extraction of a high-intensity proton beam into the North Hall would expose personnel to a radiation hazard. This has required an injector reconfiguration restricting operation to either ions or protons. However, demands for operational flexibility of CERN accelerators have led to a need to mix within the same SPS super-cycle both high-intensity proton cycles for LHC or HiRadMat and ion cycles for the North Area. We present an active interlock designed to mitigate this hazard: Beam Current Transformers are used to measure the beam intensity, and if above a set threshold, pulsing of the extraction septa is vetoed. The safety function is implemented by means of two logically equivalent but diverse and separate interlock chains. This interlock is expected to be in place once the SPS resumes operation after the first Long Shutdown in 2014.

Future Operation of the SPS

- **CERN Super Proton Synchrotron (SPS)** accelerates protons and heavy ions (Pb, Xe, Ar) of various energies and intensities.
- Two main modes: **proton mode** for pure proton cycles and **ion mode** for mixed proton and heavy ion operation.
- Several cycle types can be used:
  - High-intensity protons to LHC with fast extraction to TT40 or TT60 (p = 450 GeV/c, $I_{max} = 4\times10^{13}$)
  - High-intensity protons into TT41 tunnel with fast extraction to TT40 (p = 400 GeV/c, $I_{max} = 4\times10^{13}$)
  - High-intensity protons to HiRadMat with fast extraction to TT60 (p = 410 GeV/c, $I_{max} = 10^{13}$)
  - Low-intensity ions to North Hall with slow extraction to TT20 (p = 13.9-158 GeV/c/u, $I_{max} = 10^{11}$)
- Acceleration cycles to different destinations are organized into super cycles.



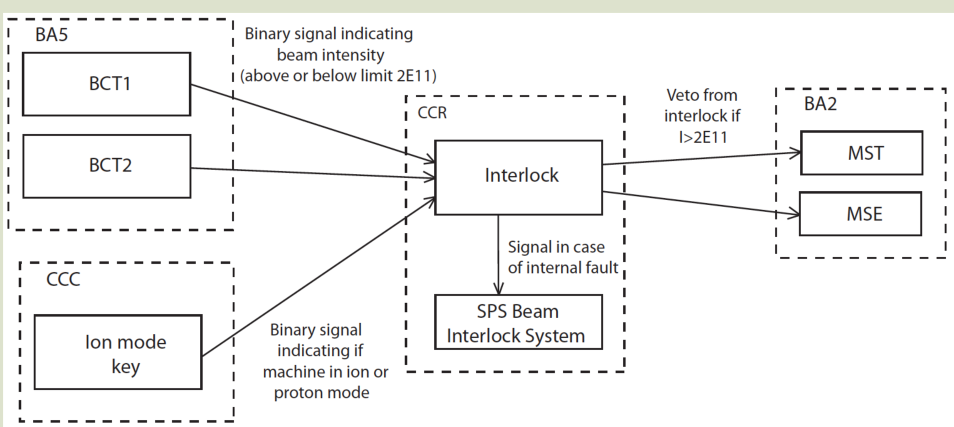
Left: A typical SPS super cycle during a primary ion mode run, comprising a North Area ion cycle at 80 GeV/c/u, a HiRadMat cycle at 400 GeV/c and an LHC cycle at 450 GeV/c. The blue line represents the magnetic rigidity, the green line (red above the 2×10^{11} threshold) the number of charges. The threshold level (dotted line) is exaggerated for the drawing to be readable. The momentum scale is in GeV/c, the time scale is in ms.

Hazard Scenario – What We Must Protect Against

- When the SPS is **in primary ion mode, various absorbers and collimators used to produce secondary beams in the North Area are removed** to allow primary beam to reach the target areas.
- The North Area experimental facilities are accessible during beam. Therefore, **erroneously extracting a high-intensity proton beam towards the North Area on an ion cycle would expose people there to a radiation hazard**. This could happen due to a cycle programming or filling error. While the probability is low, it cannot be completely excluded.
- An erroneous extraction could proceed as follows:
  1) The extraction line TT20 is parameterized to receive an ion beam of fixed energy.
  2) A proton beam destined to, say, the LHC or HiRadMat is injected into the SPS.
  3) With injections complete, ramping starts. Before reaching the beam energy corresponding to the parameterization of the TT20 line an extraction is triggered towards the North Area.
  4) Given a slow extraction taking up to 10 s, a fraction of the beam depending on the ramp speed and the energy tolerance of the beam line bending magnets (plus-minus around 2%) would reach the target area.

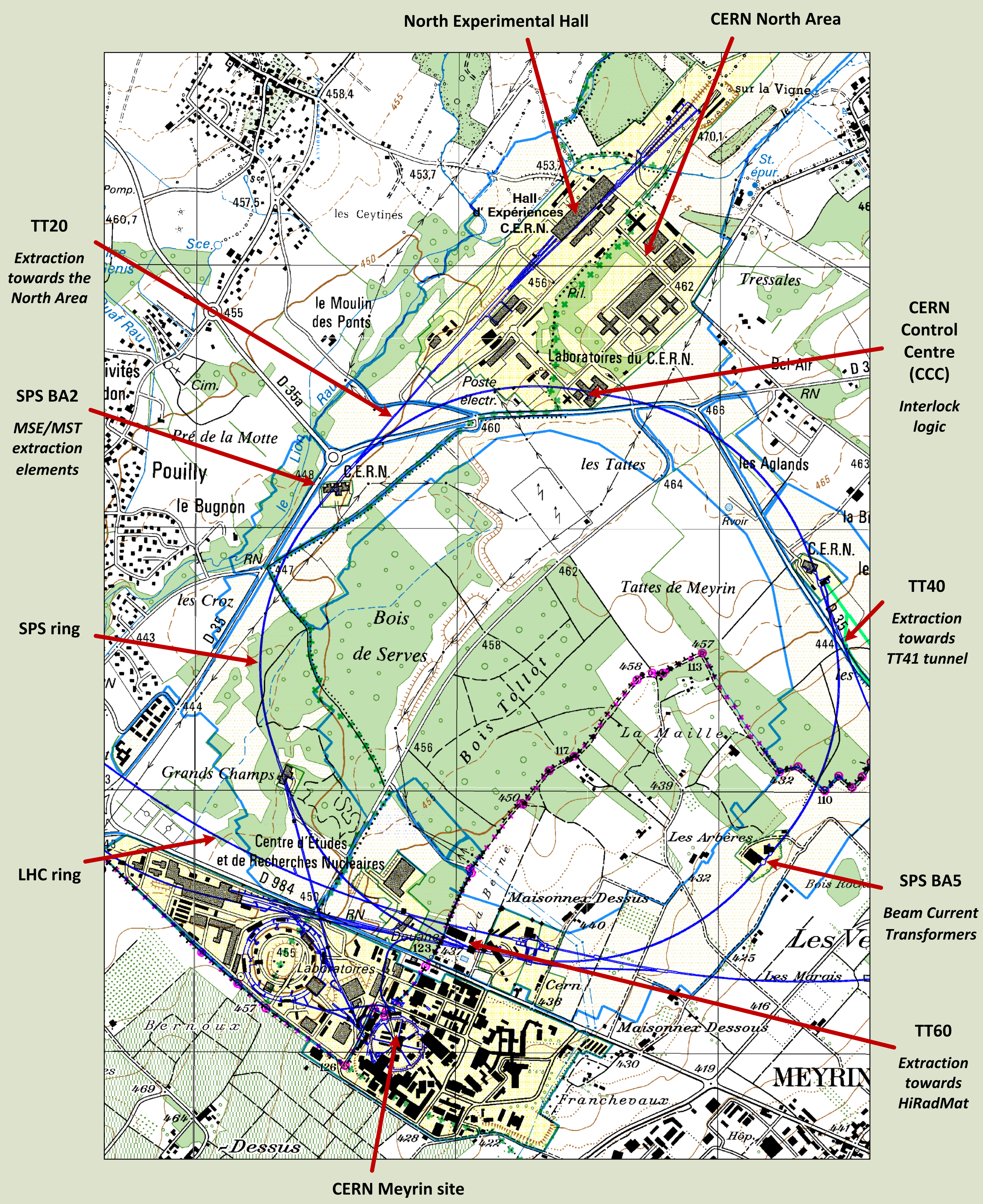
Design of the Safety System – Principle of Protection

- The **interlock is to be independent** of the beam control system and any related timing information.
- The **safety system will only be active in ion mode**. A key switch in the CCC selects between ion and proton modes.
- During an ion run the interlock will be solicited continuously. Given the projected annual SPS run time in ion mode, the **interlock switching count will likely amount to some 1-2 million annually**.
- The **response time of the safety system should remain below 570 ms** corresponding to the worst case of injecting a high intensity proton beam on an ion cycle set to extract at the lowest energy.



Above: In ion mode two beam current transformers (BCT) at SPS BA5 measure continuously the SPS beam intensity, and if it is above a **set threshold of 2×10^{11} charges**, the interlock maintains a veto on the MSE and MST extraction elements at BA2 to inhibit pulsing.

Components of the SPS and the Ion Interlock



Expected System Performance

- BCTs: < 20 ms from measurement to output.
- Interlock: < 25 ms wired chain, < 55 ms PLC chain.
- MSE/MST power converters: < 20 ms to safe state.
- **Total reaction time to critical event: < 100 ms.**

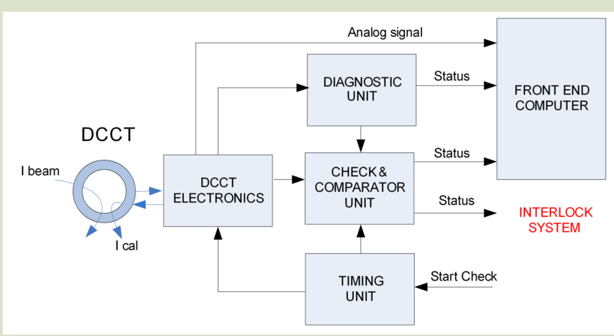
References

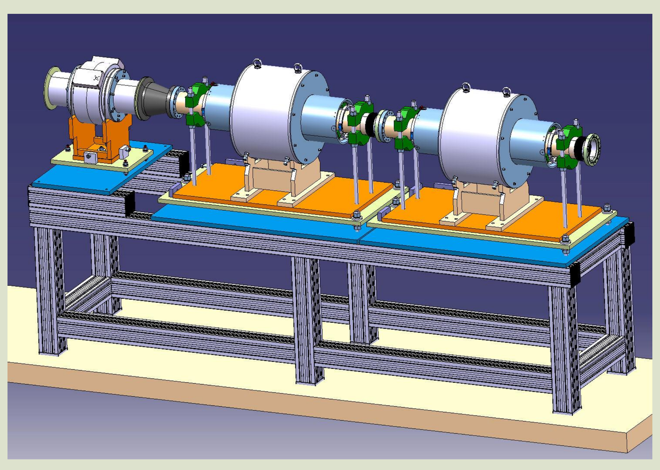
[1] D. Manglunki et al., "Performance of the CERN Heavy Ion production complex," IPAC12, May 20-25, 2012, New Orleans, USA.
[2] http://www.iec.ch
[3] P. Odier, "DCCT Technology Review," CARE-Workshop, December 2004, Lyon, France, CARE-Note-2004-023-HHH.
[4] http://www.automation.siemens.com
[5] http://www.hima.com/products/Planar4_default.php

Beam Current Transformers

- The beam current transformers are of type Direct Current Current Transformer (DCCT), which measures the mean value of the total beam current, corresponding to the flow of charged particles, continuous in case of a coast beam or discontinuous in case of a bunched beam.
- The BCT subsystem produces a defined signal when the measured intensity is below the set charge threshold of 2×10^{11}.
- BCTs designed and built at CERN.
- Implemented in hardware with no remote manipulation possible.
- A self-diagnostic facility to automatically assess equipment status.
- Two identical DCCTs are installed as part of the safety system.
- One Fast BCT, which measures instantaneous current, installed for monitoring.

Right: Each DCCT delivers two status signals to the interlock, which indicate the level of beam intensity and the state-of-health of the DCCT.

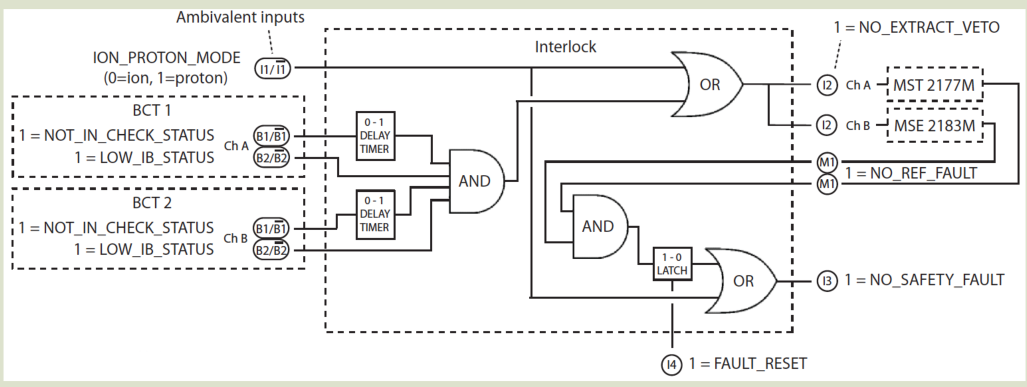




Left: A 3D CAD model of one Fast BCT (on the left) and two DCCT type BCTs.

Interlock and Signal Paths

- Interlock design done respecting as much as possible the norm IEC 61511.
- Redundancy and diversity are provided by two separate safety chains implementing the same logic but with different technologies:
  - Chain-A based on Siemens S7 PLC with Profibus DP fiber channel I/O.
  - Chain-B based on HIMA Planar4 safety-certified rack-mounted wired logic.
- Wired signal paths either doubled-complementary (ambivalent) or denergize-to-trip (failsafe). For isolation, optocouplers used for durability.

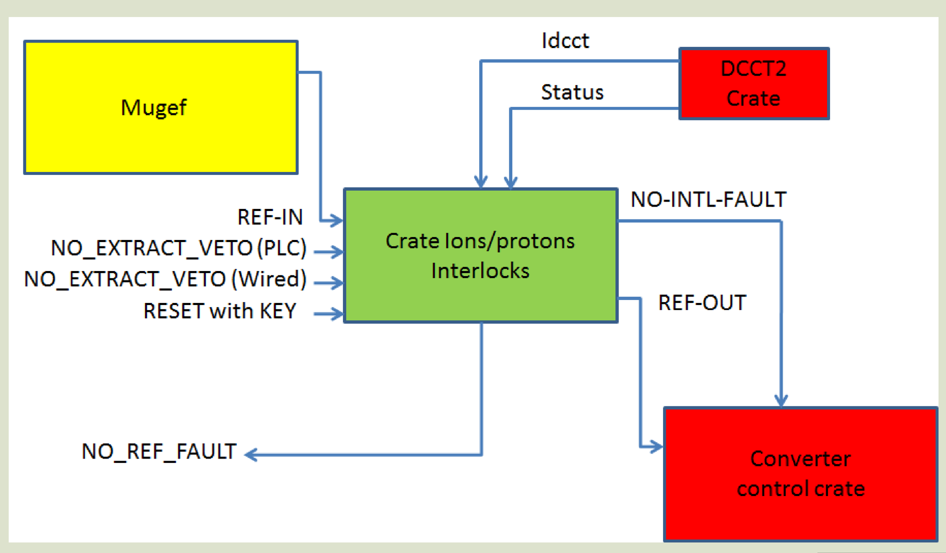


Above: The interlock logic. Delay timers provide a safeguard against a BCT self-check malfunction. MSE/MST internal fault is latched and only resettable with key.

Left: The wired and PLC interlocks in the test bench. The HIMA rack is on the left hand side at the bottom and a switch matrix to simulate different signals at the top. The PLC rack with remote I/Os in separate sub-racks is on the right.

MSE/MST Extraction Elements

- The power converters of the extraction septum MSE2183M and the first dipole MST2177M will act as actuators to the safety system.
- The interlock normally holds a signal high to allow extraction. When the beam intensity exceeds the threshold, the interlock logic sets this signal low.
- A control card on the power converters will then set the current reference from the SPS power converter control system (Mugef) to its minimum value causing immediate discharge of the extraction elements.
- A supplementary DCCT is installed to measure the power converter current. If it detects that the current hasn't decreased to the level required after a delay, it signals an error, which is delivered to the beam control system by the interlock to request the beam to be dumped.
- Any internal error condition must be reset with key by the safety officer after investigation before continuing operation.



Above: Power converter signal diagram. The reference is sent as an analog signal directly from the SPS power converter control system (Mugef). Interlock signals from both PLC and wired channels are shown as well as the internal safety-check signals from the supplementary DCCT installed