SRF Beam Test Facility Machine Protection System (MPS)

Arden Warner August 8th, 2011

The reason and the goals of the MPS

Machine Damage Potential:
The accelerator is being designed with the capability to operate with up to 3000 bunches per macro-pulse, 5Hz repetition rate and 1.5 GeV beam energy. It will be able to sustain an average beam power of ~72 KW at the bunch charge of 3.2 nC. Operation at full intensity will deposit enough energy in niobium material to approach the melting point of 2500 °C.

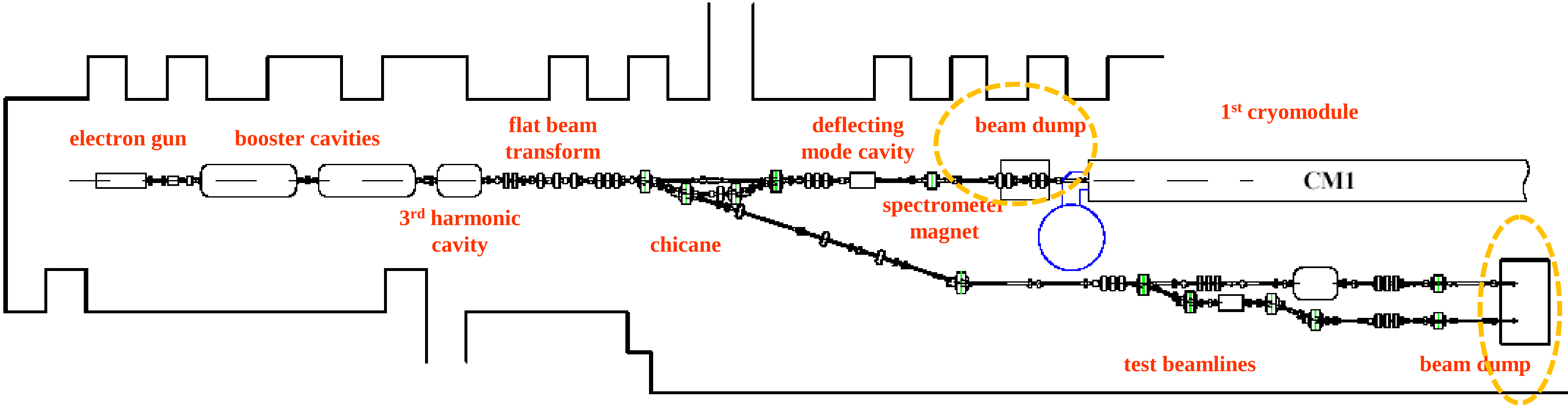
- 3 cryo-modules, 45 KW , 900 MeV

System Goals:

- Protect the accelerator from beam induced damage.
- Manage beam intensity
- Safely switch off or reduce beam intensity in case of failures
- Determine the operational modes of the machine
- Manage and display alarms
- Comprehensive overview of machine status i.e. subsystem status (ok/not-ok)

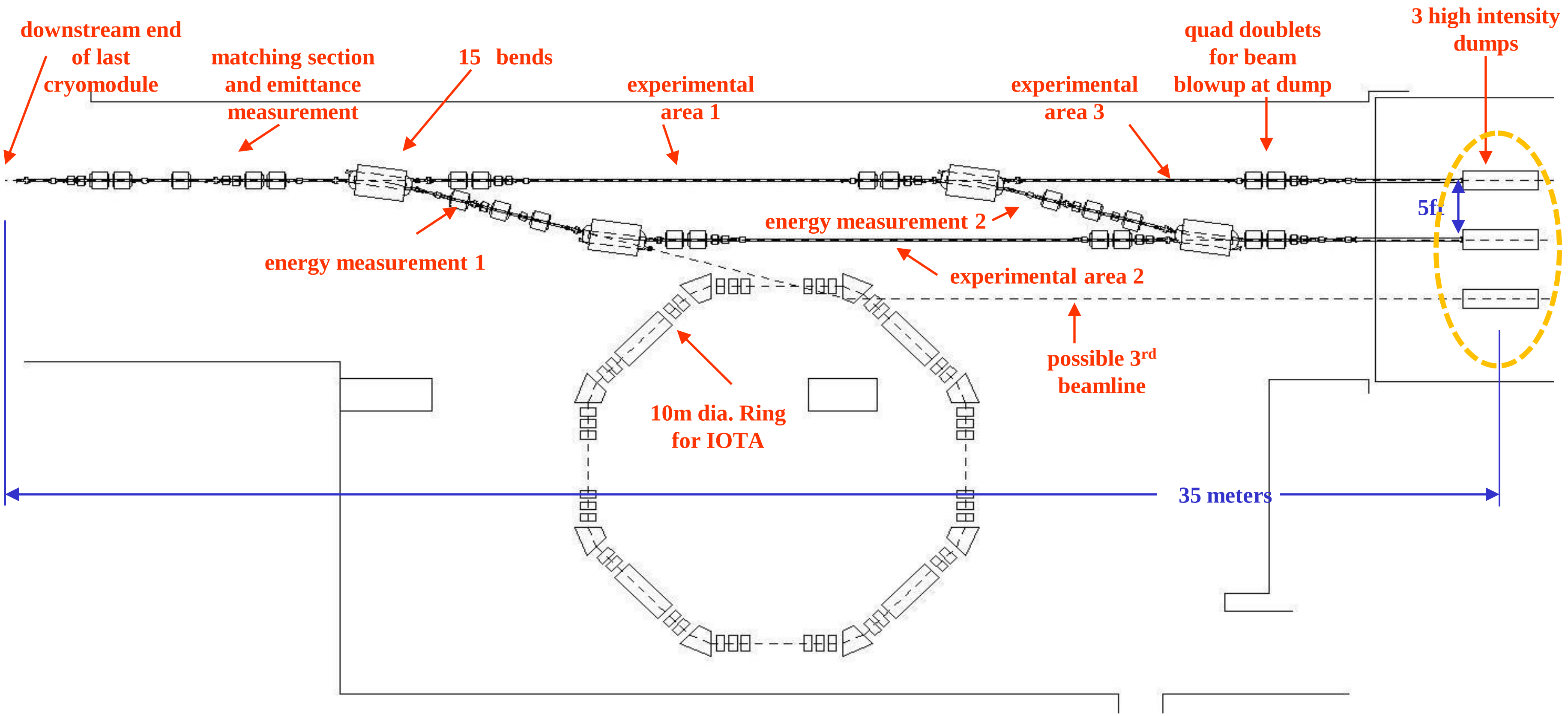
- MPS is Not part of Personnel Protection

Injection Beamline and Low Energy Test Beamline Layout



Dumps designed to handle max 100 KW

Potential Downstream Beam Experimental Areas

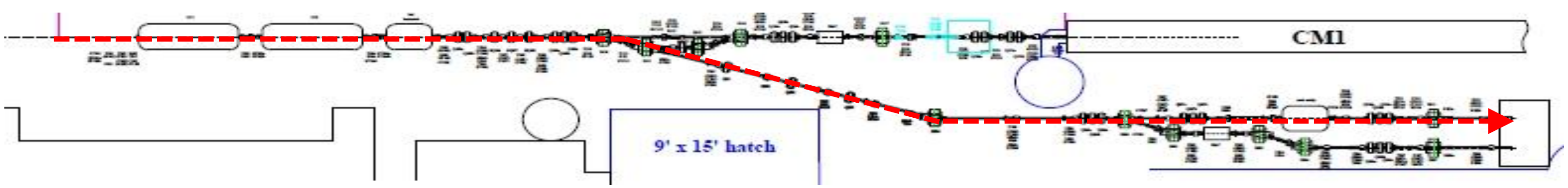


Dumps designed to handle max 100 KW

Machine Lay-out/Operational modes

LE dump mode 1

LE dump mode 2

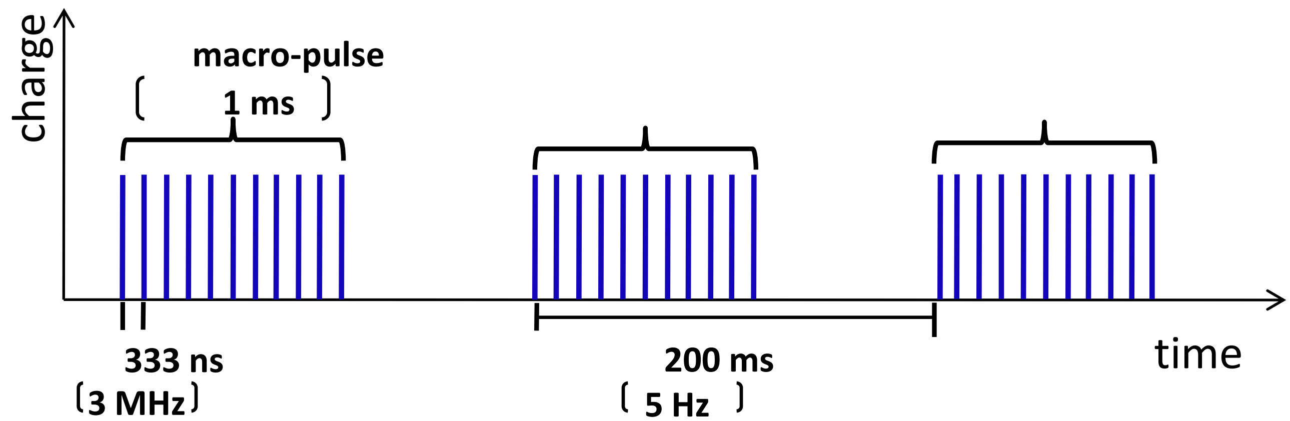


LE dump mode 3

Operational modes define the path beam have to take to reach dumps

An operational mode represents a valid beam path through the machine. All modes are defined by a unique list of critical components with their valid states.

Important time scales for MPS



Fast Signals (nano-second sensor response, microsecond system reaction times) :

- Required for switching the beam off or reducing intensity within a bunch train.
  - Fast Beam Loss Monitors (ns response, single bunch resolution)
  - Toroids (~ 100 MHz bw, 1% accuracy, 500 mV/ns sensitivity, < 1μs ~ 500 ns at 120 metres)
  - RF related signals, …)

Slower signals (PLC related processes):

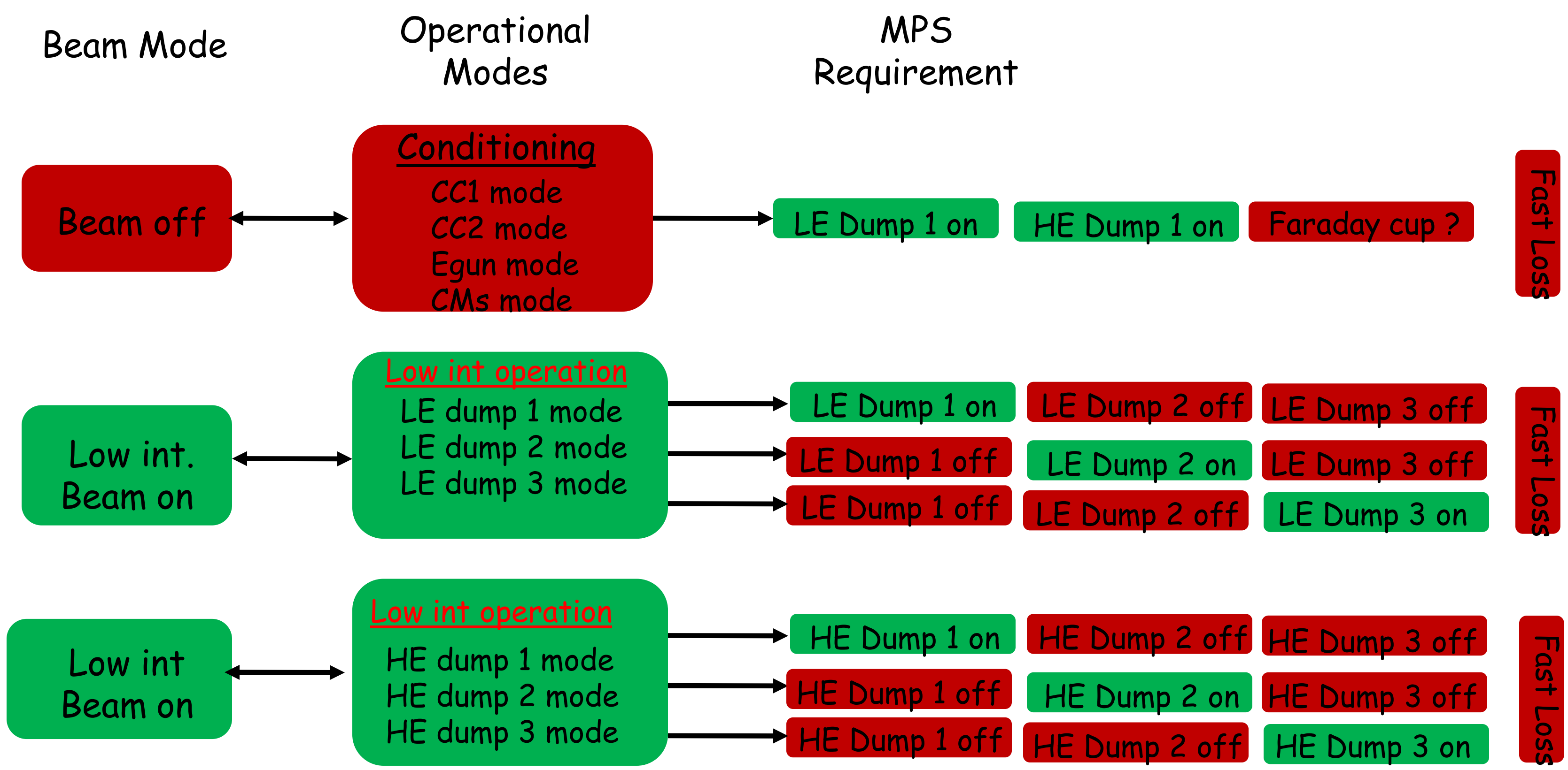
- < 200 ms reaction time determined by max rep rate of 5Hz.
  - Magnet power supplies
  - OTR/YAG screens (movable devices)
  - Vacuum valves
  - Laser Shutter

Operational Modes For Low Intensity Operation

Operational modes define the path beam have to take to reach dumps

Low Intensity Mode (a few bunches with total charge ~ maybe typical A0 conditions) which allows the minimal beam intensity needed for OTR diagnostics. This is below the threshold potential for beam induced damage. In this mode there is no fast reaction to beam loss within a bunch train.

- Start up conditions
- Meets threshold for instrumentation

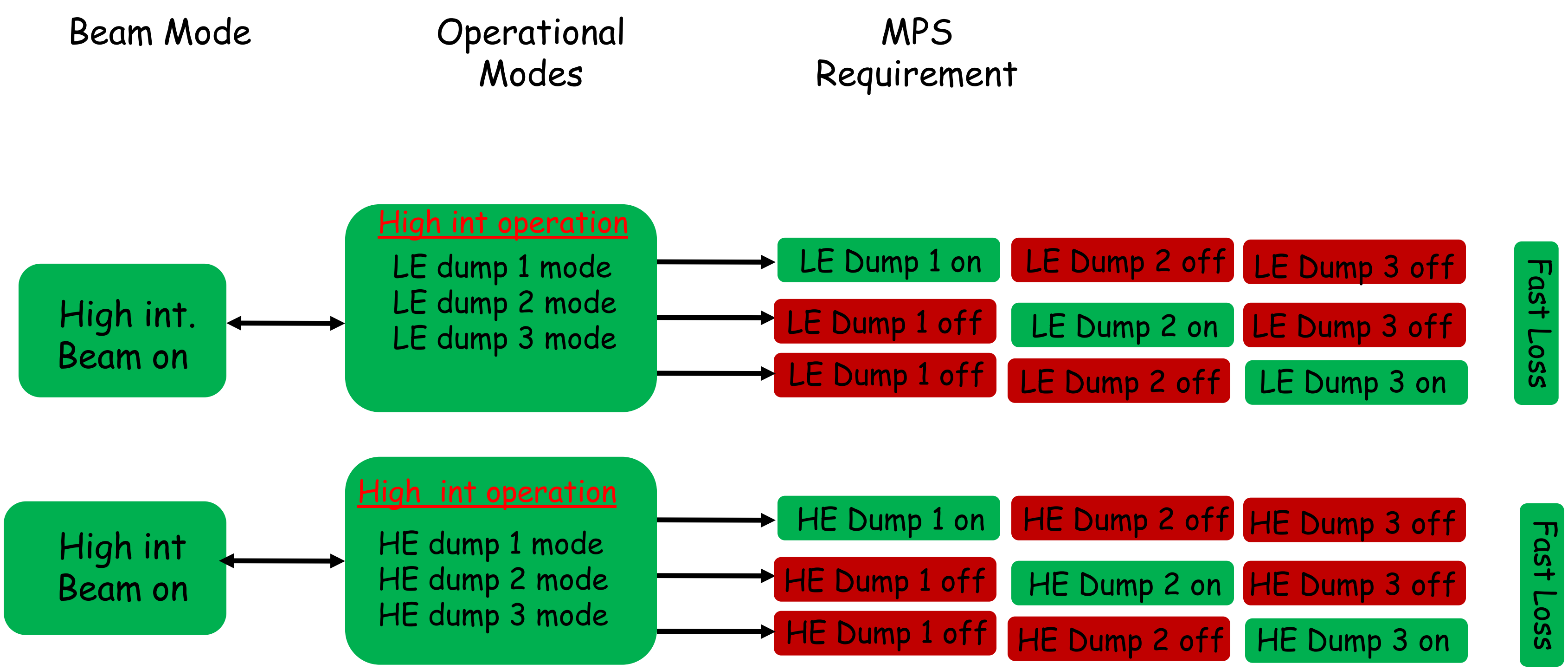


Operational Modes For High Intensity Operation

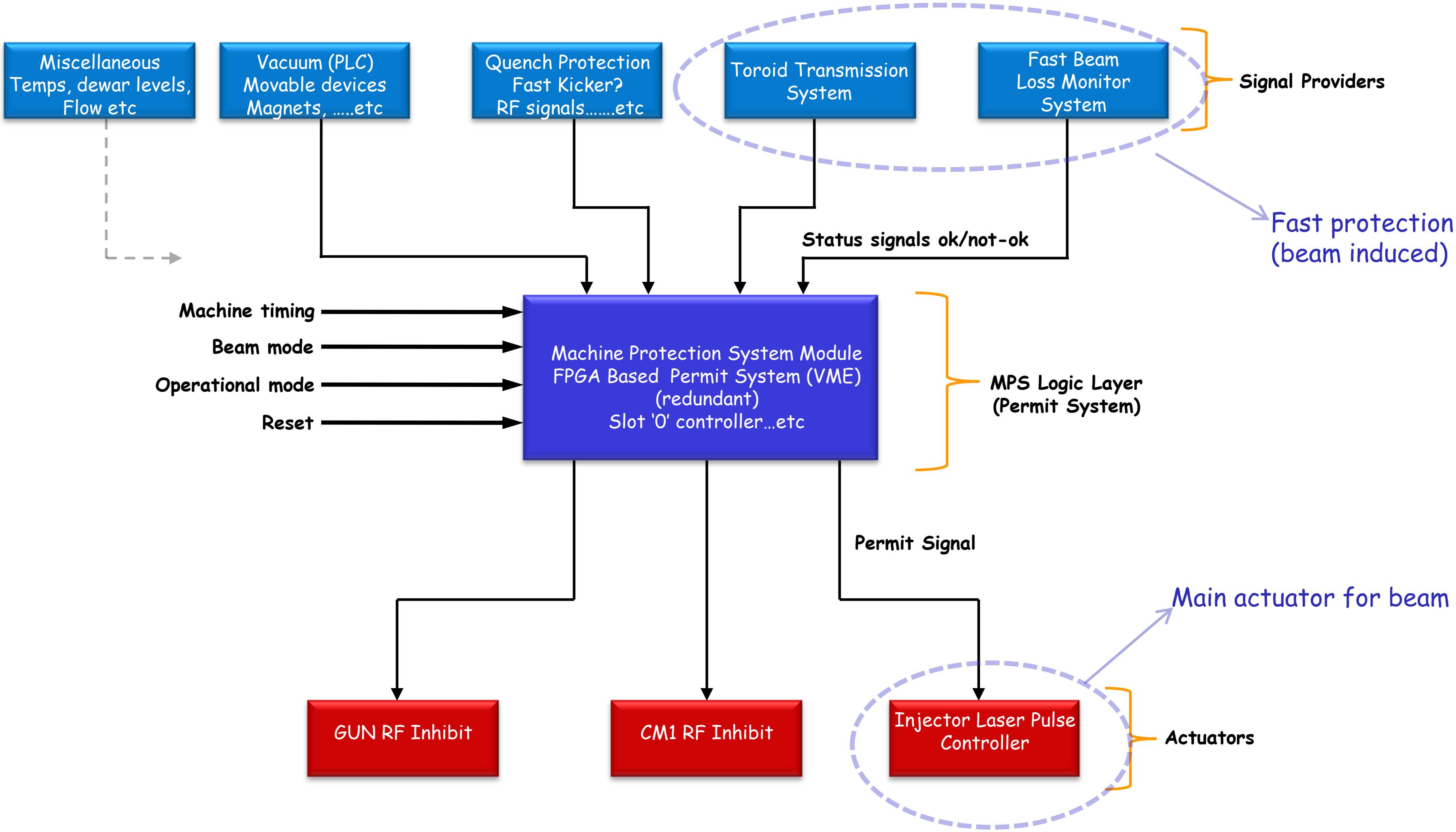
Operational modes define the path beam have to take to reach dumps

High Intensity Mode (full Beam Current(3000 bunches max))
which does not impose a limit on the number of bunches, but enables fast intra-train protection by the MPS.

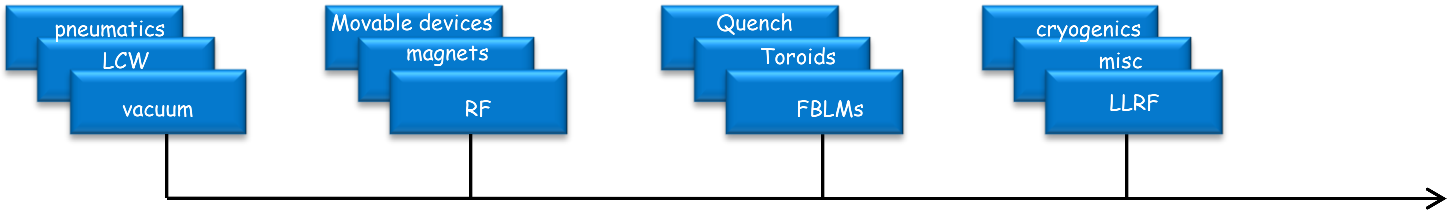
- Meets threshold requirements for beam losses and transmission losses
- Valves and dipoles are set to correctly guide beam to a dump



Simplified Over-view of MPS



Sub-System List



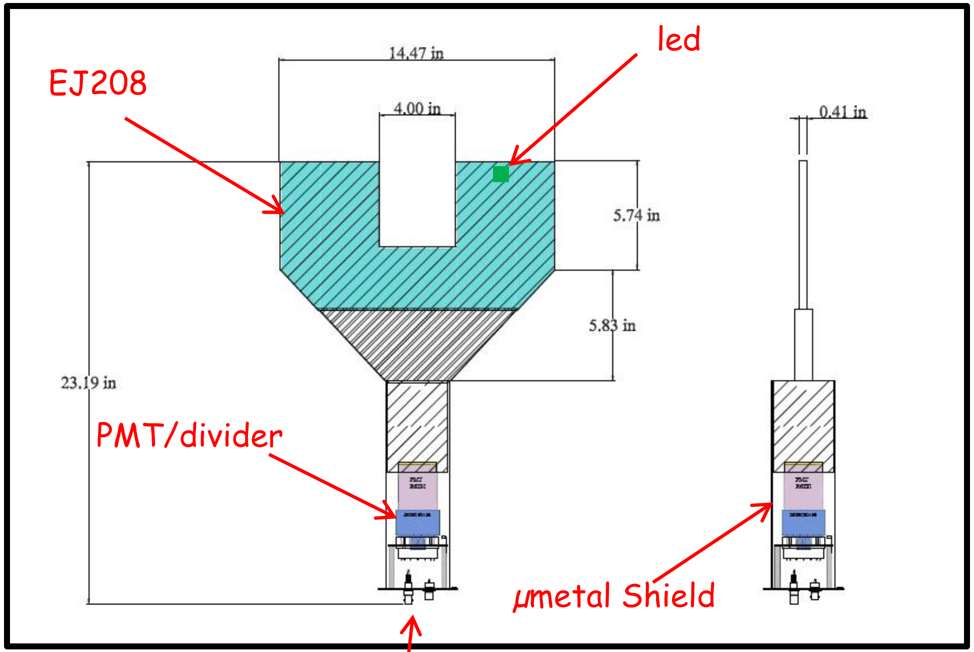
Need to integrate with several subsystems:

- LCW (Jerzy Czajkowski) "Yurick")
- Vacuum (Lucy Nobrega, Tom Zuchnik)
- RF interlocks etc (Peter Prieto)
- LLRF (Brian Chase)
- Movable diagnostics (OTR,YAG..) (Amber Johnson)
- Pneumatics (air, water, gas) dumps (?)
- Toroids (Manfred Wendt?)
- Laser (Jinhao Ruan)
- Magnets (Kermit Carlson)
- Timing (Mike Kucera)
- BLMs (Marvin Olson, Arden Warner)

- Rad Safety (Gary Lauten)

Fast Beam Loss Monitors

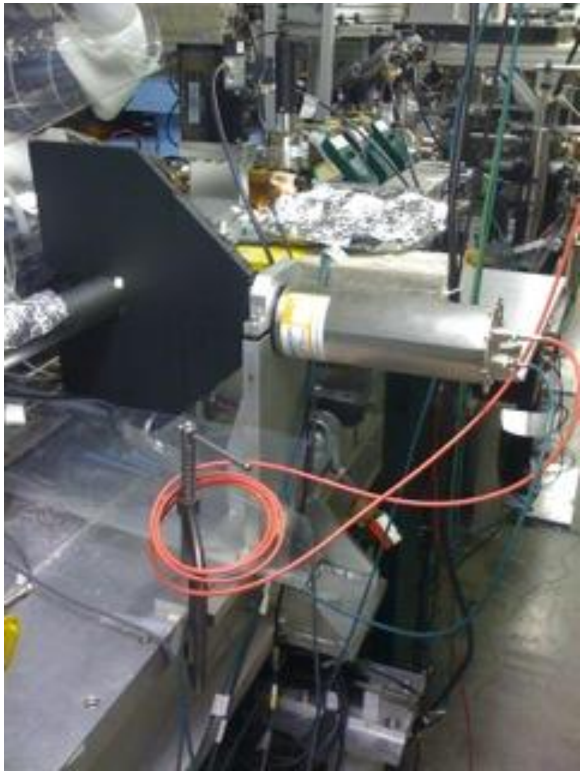
The fast protection system is being designed to interrupt the beam within a macro-pulse and will rely heavily on the ability to detect and react to losses within a few nanoseconds; for this reason monitors made of plastic scintillator with PMTs have been built.



HV, Anode signal and LED connections

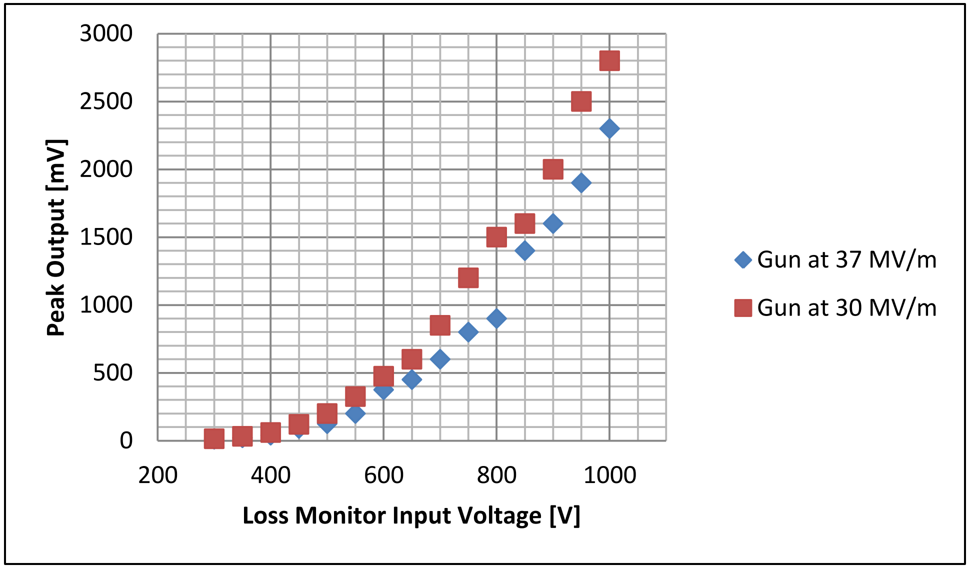
EJ208 Scintillator properties	Value
Rise time	1.0 ns
Scintillator Brightness	76 p.e./ MeV
Wavelength of max emission	435 nm
Detector sensitivity	7.0 pC/Mev
Decay time	3.3 ns
Density	1.023 g/cc
Light attenuation length 1/e	210 cm
Number of electrons	3.37/cm^3
PMT Specifications	
Rise time	3-5 ns
Gain (min)	2.7 x 10^5
Supply voltage (max)	2000 volts
Sensitivity	0.1 – 200 A/lm

Fast Beam Loss Monitors

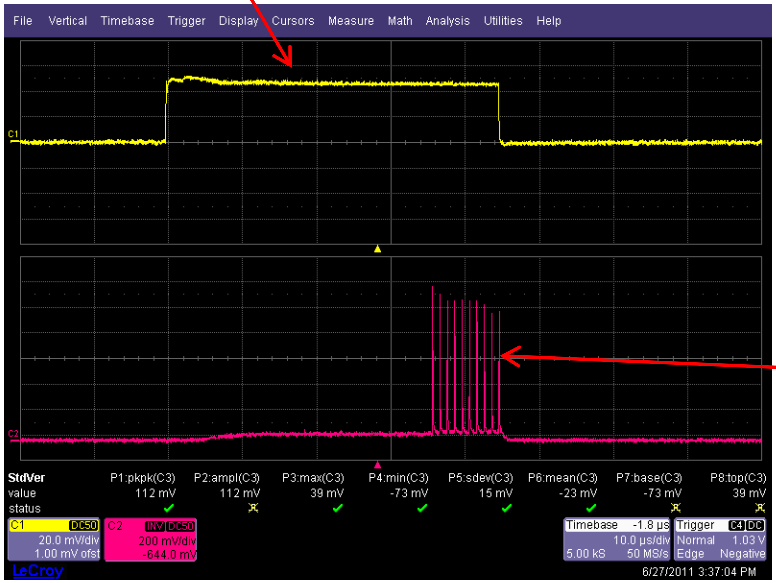


Fast Beam Loss Monitors Test

Tubes proven to be very gain stable and we have plenty of range and signal
We have 40 units and we have tested more than 10%



Gun at 30 MV/m

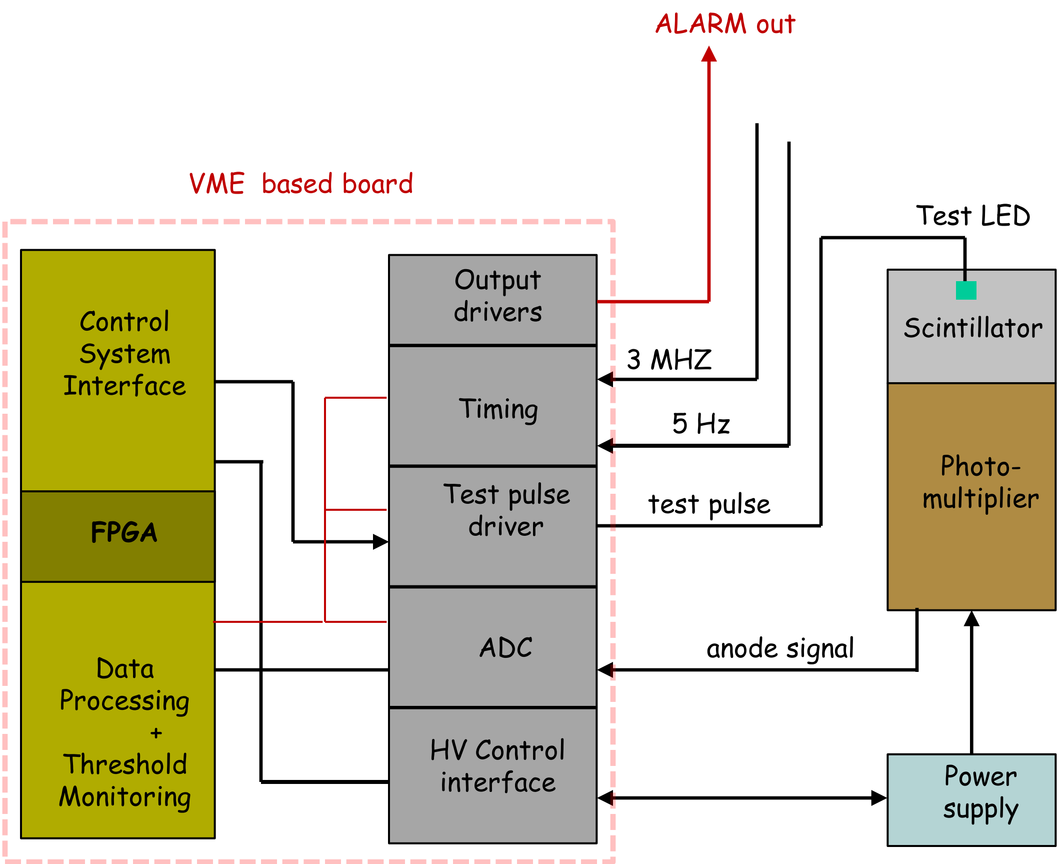


10 bunches, low charge < 50 nc

Fast Beam Loss Monitor system (Concept)

The fast beam loss monitors must be integrated into a robust beam loss monitoring system capable of generating an alarm condition that is derived by comparing the outputs of the PMT signals with various programmable thresholds. This alarm output is a critical component for machine protection.

- The desire is to provide a machine protection trip well before the beam can damage accelerator components.
- If one of the programmed thresholds is exceeded or if an error condition such as a high voltage failure or failed monitor is detected the system should report this to the MPS logic which in turn reduces the intensity or inhibits the beam.



Specifications for NMLTA Loss Monitor System

Purpose and functionality:

- Provide both machine protection (alarm signal) and diagnostic functions for the machine; allowing to tune-up and monitor beam operations while machine protection is integrating the same signal (linear, logarithmic and integrating amplifiers)
- Instantaneous read-back of beam loss
- Fast response << 1 μs

- Macro-pulse repetition rate 1-5 Hz
- Sampling frequency of ADC output (3MHz)
- FPGA controlled
- VME interface and fully integrated into ACNET
- Built-in-self-test (voltage monitor) and onboard signal injection
- Local data buffer for beam loss transient play-back

- Minimum ADC buffer length per macro-pulse 1 ms (rf gate length)
- Max reaction time from analog beam loss signal to digital alarm ~ 1-2 μs (3-6 bunches)
- ADC resolution 12 bits (16 bits)
- Full ADC resolution for single\multi-bunch thresholds
- Signal discrimination between two successive ADC samples
- Resolution for integration over RF gate
- Pulse beam monitoring + continuous monitoring
- channels per board (8?) to handle a total ~40 fast loss monitors at NML

JLAB BLM board

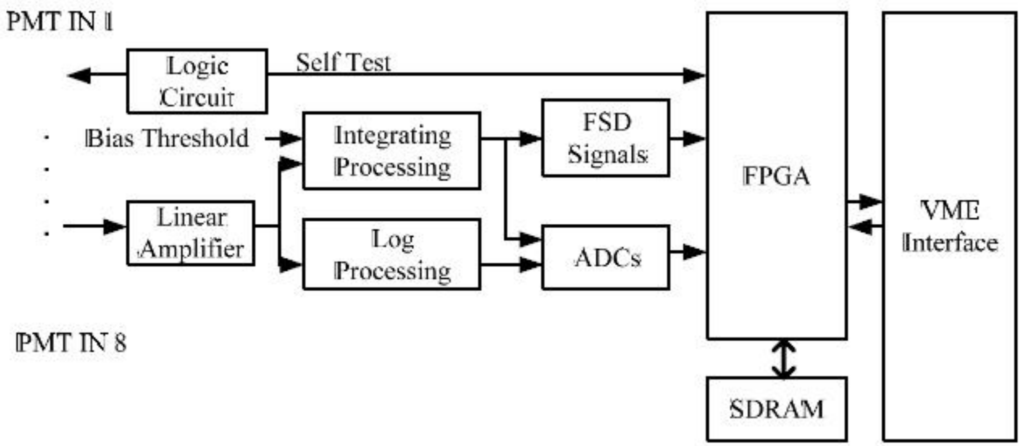


Figure 1: The system block diagram of the BLM board.

Meets most of the specifications but digitization rates are different and timing details will be different as well.

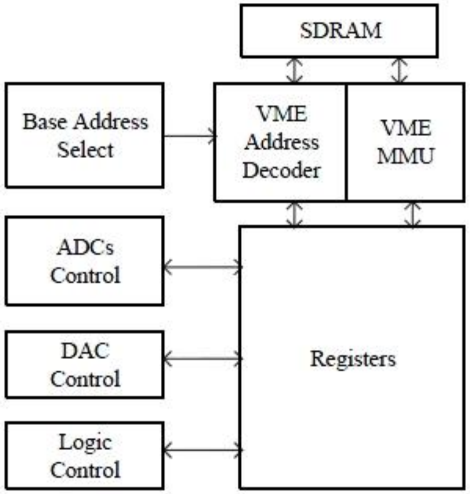


Figure 3: Functional Modules of FPGA Code.

Loss monitors system Programmable HV supplies

Several power supply control options:

- OPC Client/Server
- H.S Caenet
- C library
- TCPIP

Fermilab VME FE already setup and under test for ACNET control

System provides monitoring and individual control of all channels (6 x 24). Adds redundancy to the system. (very important to maintain integrity of the fast loss system)

Monitors: I, V, errors, trigger on/off, startup/reset etc….

Loss monitors system Programmable HV supplies

- Houses up to 6 boards, HV/LV or "branch controllers"
- Ad-hoc boards and peripheral systems
- Communications via RS232 and TCP/IP
- OPC Server for easy integration in DCS
- Programmable handling of parameters and errors
- Fast, accurate setting and monitoring of channel parameters
- Sophisticated channel trip handling
- Multilevel management of user profiles
- Live insertion of boards

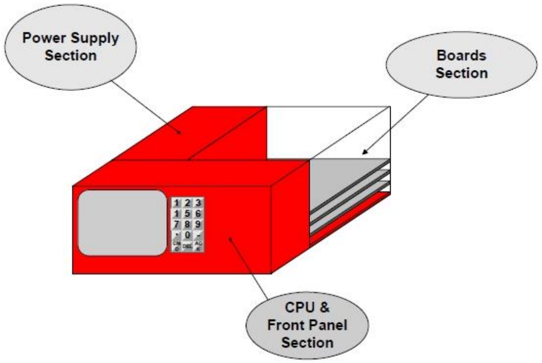
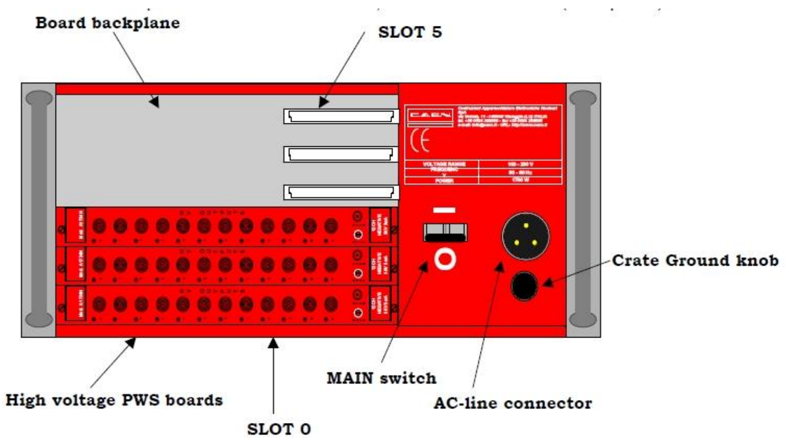


Fig. 2.1 – Layout of the main mechanical sections of the SY2527 mainframe



Laser Pulse Control

Main Purpose - Main actuator for beam inhibits: Controls the number and spacing of bunches in a macro-pulse by varying the width of the Gate to Pockels cell.

Inputs –

- MPS Alarm state
- Beam Mode (user request) i.e. Low intensity/ High intensity
- 3 MHz machine timing
- 1 MHz machine timing
- First Toroid (beam intensity)
- Laser diode (light intensity)
- Macro-pulse Trigger (5 Hz)

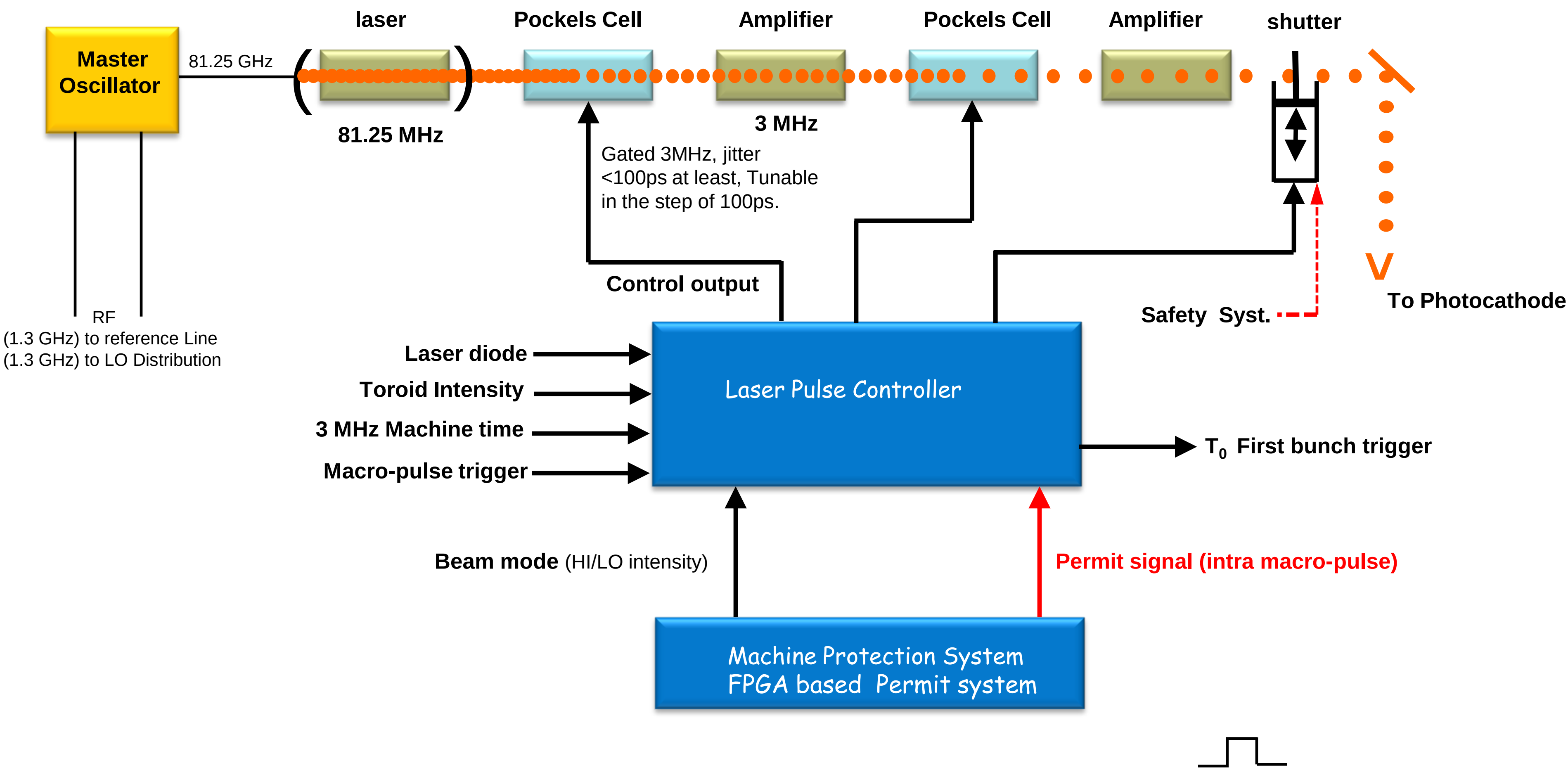
Outputs –

- Laser Gate
- Line to close Mechanical shutter
- T_0 first bunch trigger

Design Feature: VME based card with FPGA that

- Stops beam or reduce to low intensity (depends on nature of alarms)
- Enforce the limits on number of bunches defined by beam mode
- Close shutter (depends on alarm state).

MPS Laser pulse control



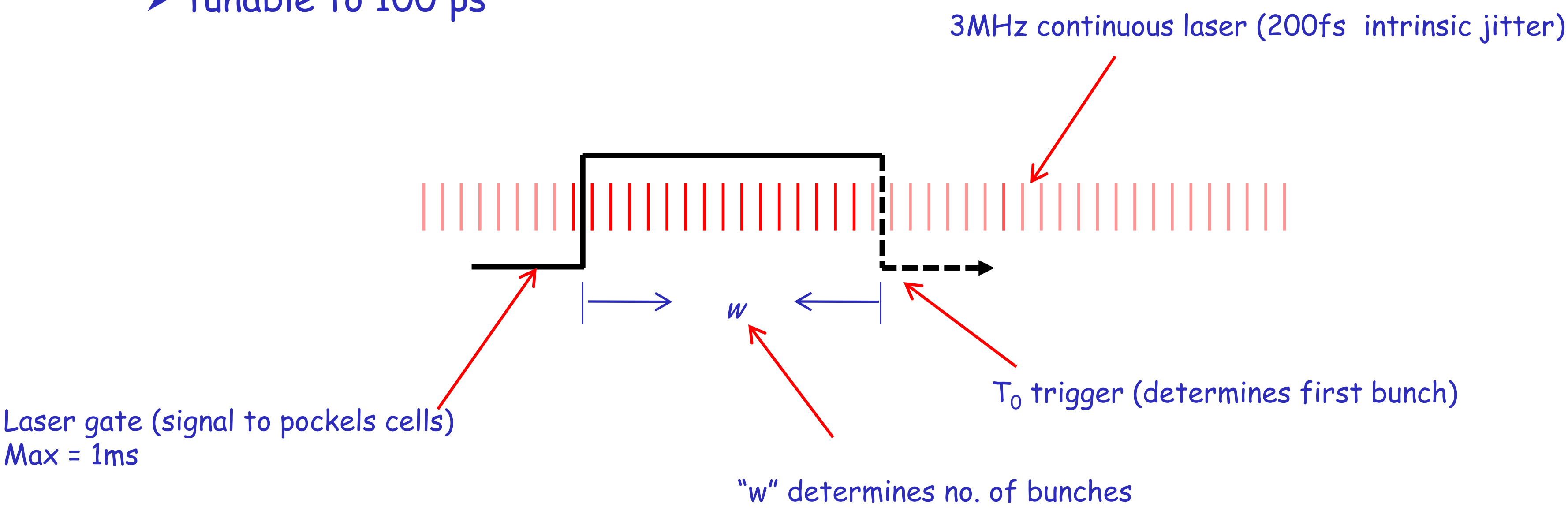
- Block the Pockels cell based pulse kickers as long as the MPS input is in an alarm state.
- Enforce the limit on the number of bunches as given by the currently selected beam mode.
- Close the laser shutter on request of the MPS. This may happen when there is no valid operational mode or when some combination of loss monitors exceed thresholds which trigger a dump condition.

Arden Warner, FNAL

Laser Gate and Pulse Control

Gate signal Specifications:

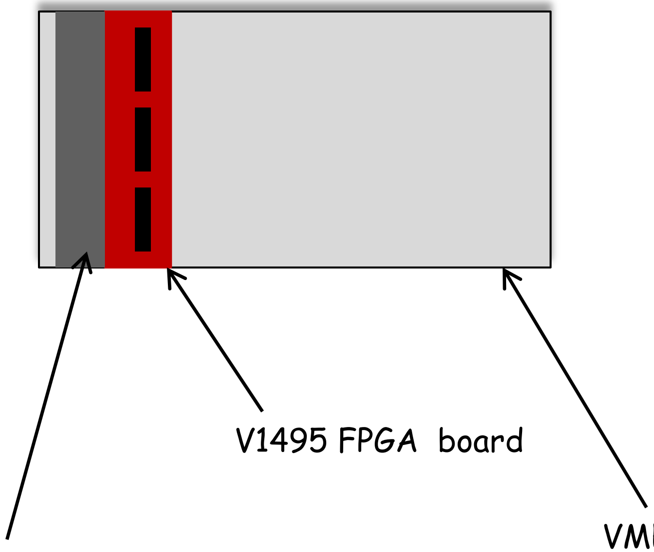
- < 100 ps jitter
- tunable to 100 ps

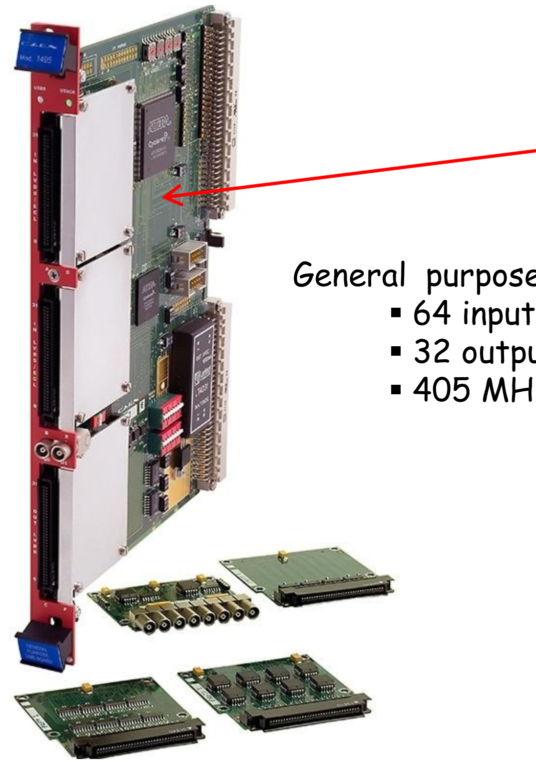


Q.E of gun/laser system determined from measured inputs :

- Diode (light)
- Charge measured (toroid)
- number of bunches

Laser Gate and Pulse Control FPGA Board



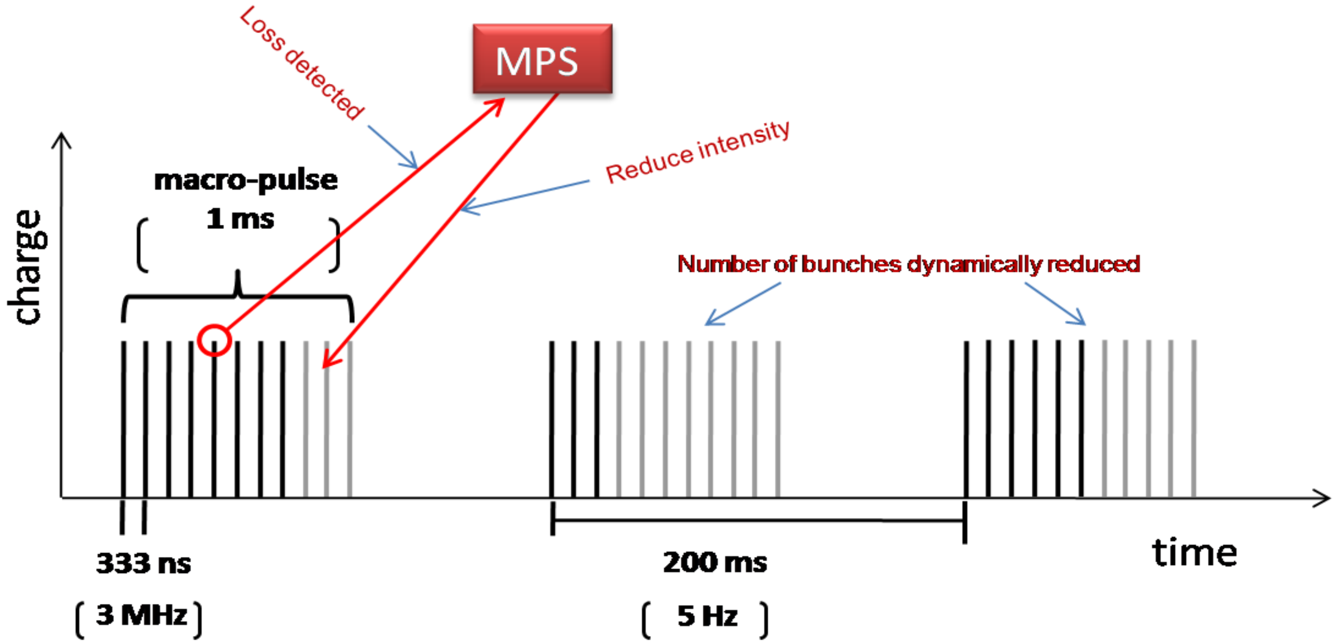


General purpose FPGA Board
- 64 inputs expandable to 162
- 32 outputs
- 405 MHz max for registered logic

The FPGA "User" can be programmed "on the fly" via VME, without any external hardware tools, without disconnecting the board from the set up, and without resetting it or turning the crate off. A flash memory on the board stores the programming file, which can be loaded to the FPGA "User" at any moment. Four (independent, digital, programmable, asynchronous, chainable) timers, are available for Gate/Trigger applications.

Possible Operational Scenario

MPS should allow the machine to be up most of the time for user operations: We could dynamically reduce the intensity by some factor based on the type of loss, where it occurs and no. of trips. Do this until we are below damage limits.



Controls and Software

The MPS will need server support for the various hardware systems:
We need to View, Configure and Diagnose the system

- Loss monitor system
  - SY2527
  - FPGAs
  - Alarm Generators
- MPS Permit system
- Gun Pulse controller
- PLC

Post mortem analysis:

- Requires precise time-stamps to correlate losses with alarms generated and permits removed

- Local data logging at each Front-end

Services :

- Data loggers
- DAEs
- OACs
- FSMs

Applications:

Sequencers, Synoptic ……etc.

Linden Carmichael, Rich Neswold. Jimmy You

Summary and Plans

- Lots to consider operationally for this system but the first order task is to make a fail safe system that protects the machine.

- Integration with others is going to be very important

- Want to make the system as modular, expandable and user-friendly

- Requires some redundancy in places

Considering other instrumentation :

- Secondary emission monitors (SEMs) or Aluminum cathode PMTs near dumps
- Fast Kicker
- Cryogenic Loss monitors sensitive to dark current as close to the beam pipe as possible (5K)
- Diamond loss monitors also close to the beam pipe (1.8K)

- The overall length of the NML accelerator is 133.5 meters. Based on expected FPGA processing times of ~1ns and cable delay times of ~ 0.4 μs it would be reasonable to expect total response times of about 1-2 μs from the protection system. This implies that for high intensity operation at the design bunch frequency of 3MHz, approximately 3-6 bunches can be present in the machine even when the MPS reacts (~ 45 - 90 watts). Depending on no. of cryo-modules.