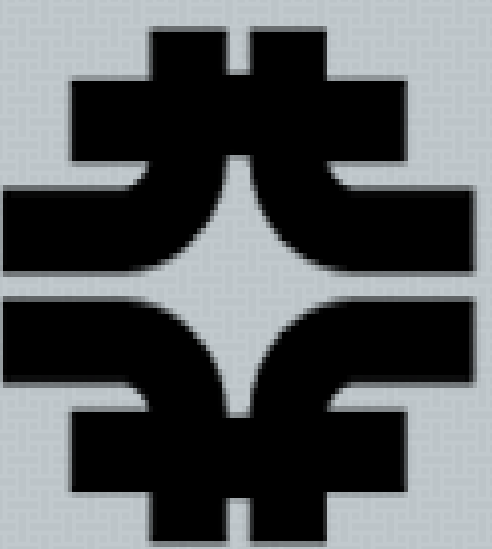# Commissioning and Design of the Machine Protection System for FERMILAB'S FAST Facility*

L. Carmichael #, A. Warner , R. Neswold , N. Liu , D. Crawford and J. Wu

FNAL, Batavia IL, U.S.A,

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†warner@fnal.gov

Abstract

The Fermilab Accelerator Science and Technology (FAST) facility will provide an electron beam with up to 3000 bunches per macro-pulse, 5Hz repetition rate and 300 MeV beam energy. The completed machine will be capable of sustaining an average electron beam power of close to 15KW at the bunch charge of 3.2nC. A robust Machine Protection System (MPS) capable of interrupting the beam within a macro-pulse and that interfaces well with new and existing controls system infrastructure has been developed to mitigate and analyze faults related to this relatively high damage potential. This paper describes the component layers of the MPS system, including a FPGA-based Permit Generator and Laser Pulse Controller, the Beam Loss Monitoring system design and the controls and related work done to date.

Introduction

The FAST Facility comprises of an electron injector based on the Advanced Superconducting Test Accelerator (ASTA) [3], a RFQ based proton injector and the Integrable Optics Test Accelerator (IOTA) storage ring. The electron beam is produced by a 1.3 GHz RF photo-injector and then accelerated to ~50 MeV by two 1.3 GHz SRF cryomodules, each containing a single 9-cell cavity. The beam will then be injected into the linear accelerator which consists of a 12-m long, 1.3 GHz 8-cavity superconducting cryomodule (CM2). This is a Tesla type III+ cryomodule[1] driven by a 5 MW klystron. The electron beam energy gain will be approximately 300 MeV at this stage. The facility is also being expanded to accommodate further advanced accelerator research and development with the installation of a 2.5 MeV proton/H- RFQ accelerator. This accelerator starts with a 50 kV, 40 mA proton (or H-ion) source coupled to a pulsed 325 MHz RFQ to 2.5 MeV with a 1ms pulse duration for injecting into IOTA. This ring is 39 meters in circumference and will also be capable of storing electrons from 50 to 150 MeV in energy. Figure 1 shows the placement of the ring in the FAST facility layout.
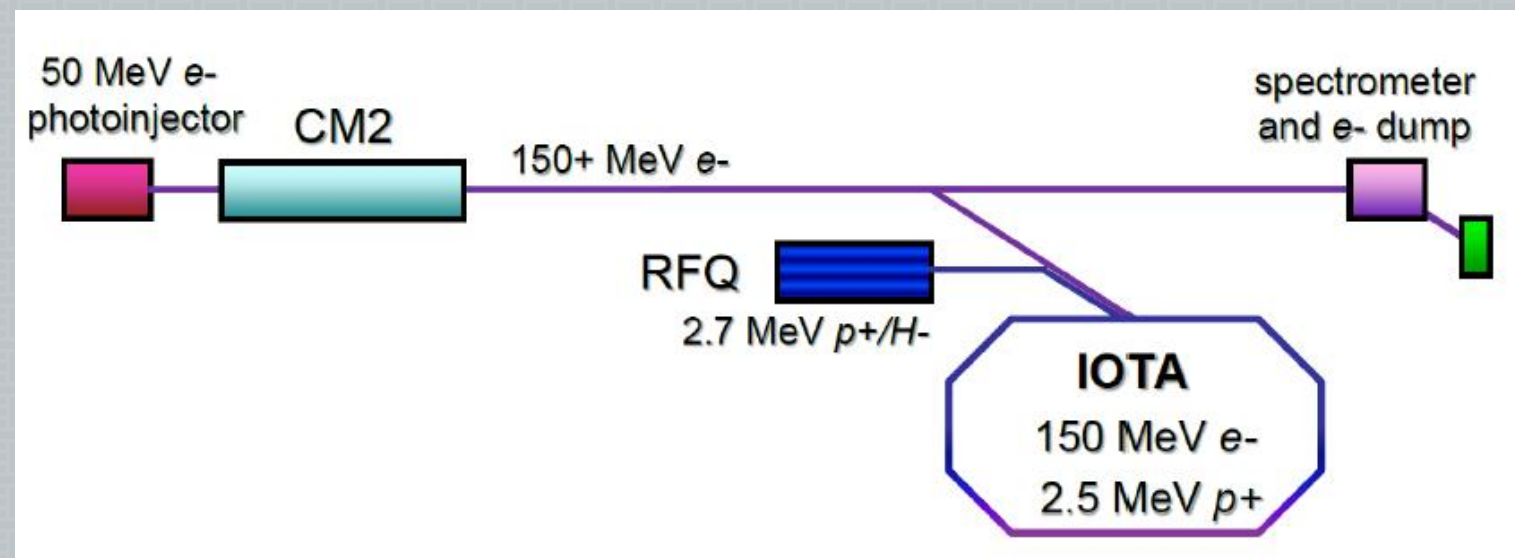

Figure 1 : Machine Layout of FAST Facility

Figure 2 : FAST Facility

Protection System Overview

The Machine protection System (MPS) is being developed in stages that are commensurate with the commissioning goals for FAST. The primary objectives from the MPS point of view are to mitigate beam induced damage to the machine components and to provide a comprehensive over-view of the entire accelerator based on the input status of all the relevant subsystems [2].

The overall MPS design is divided into 3 layers; a sensor layer to collect sub-system status, a process layer that utilizes the status to generate the permits and an actuator layer to receive the permits and inhibit the beam. The initial stage of this development involves the design of the Laser Pulse Controller.
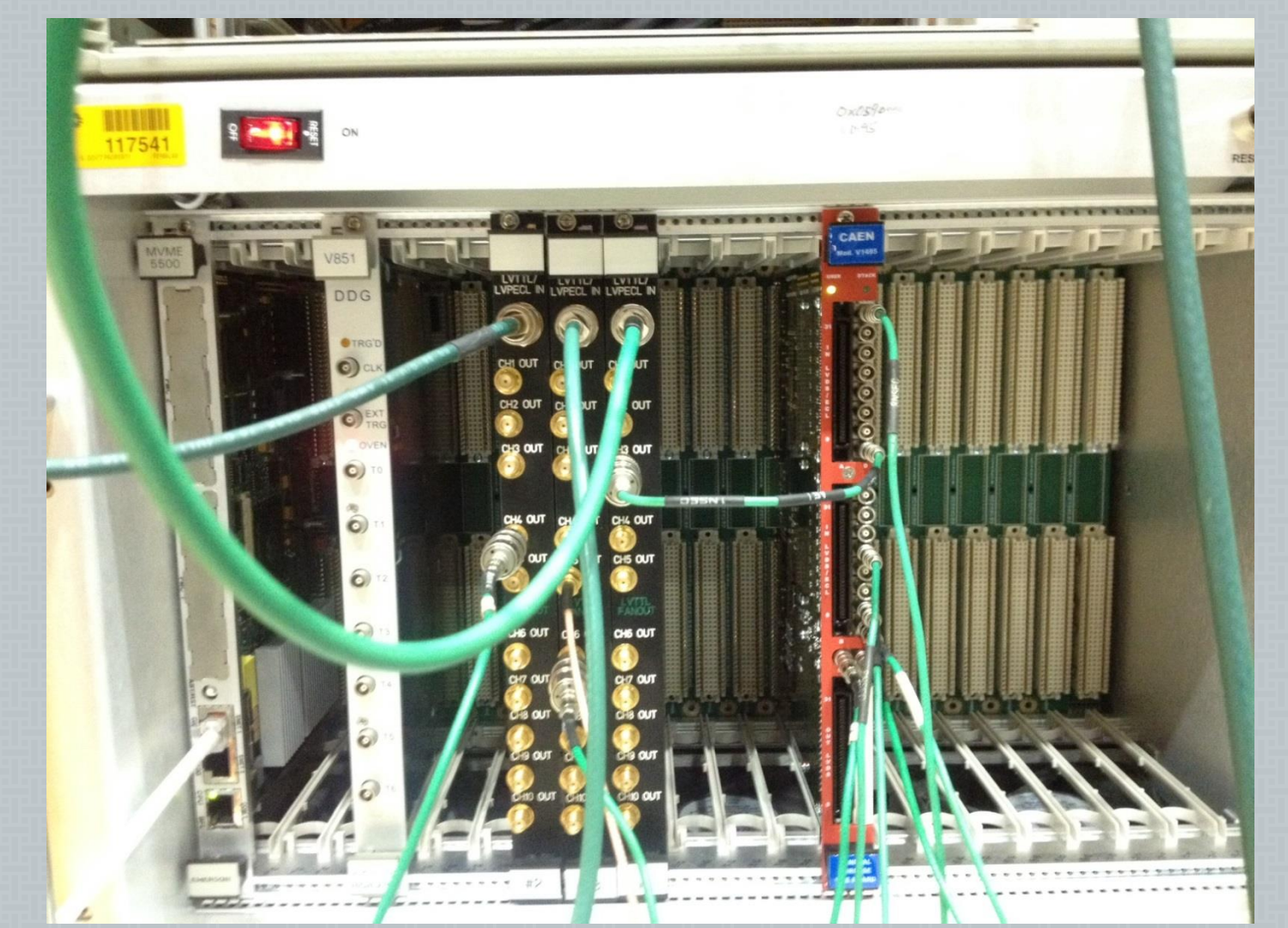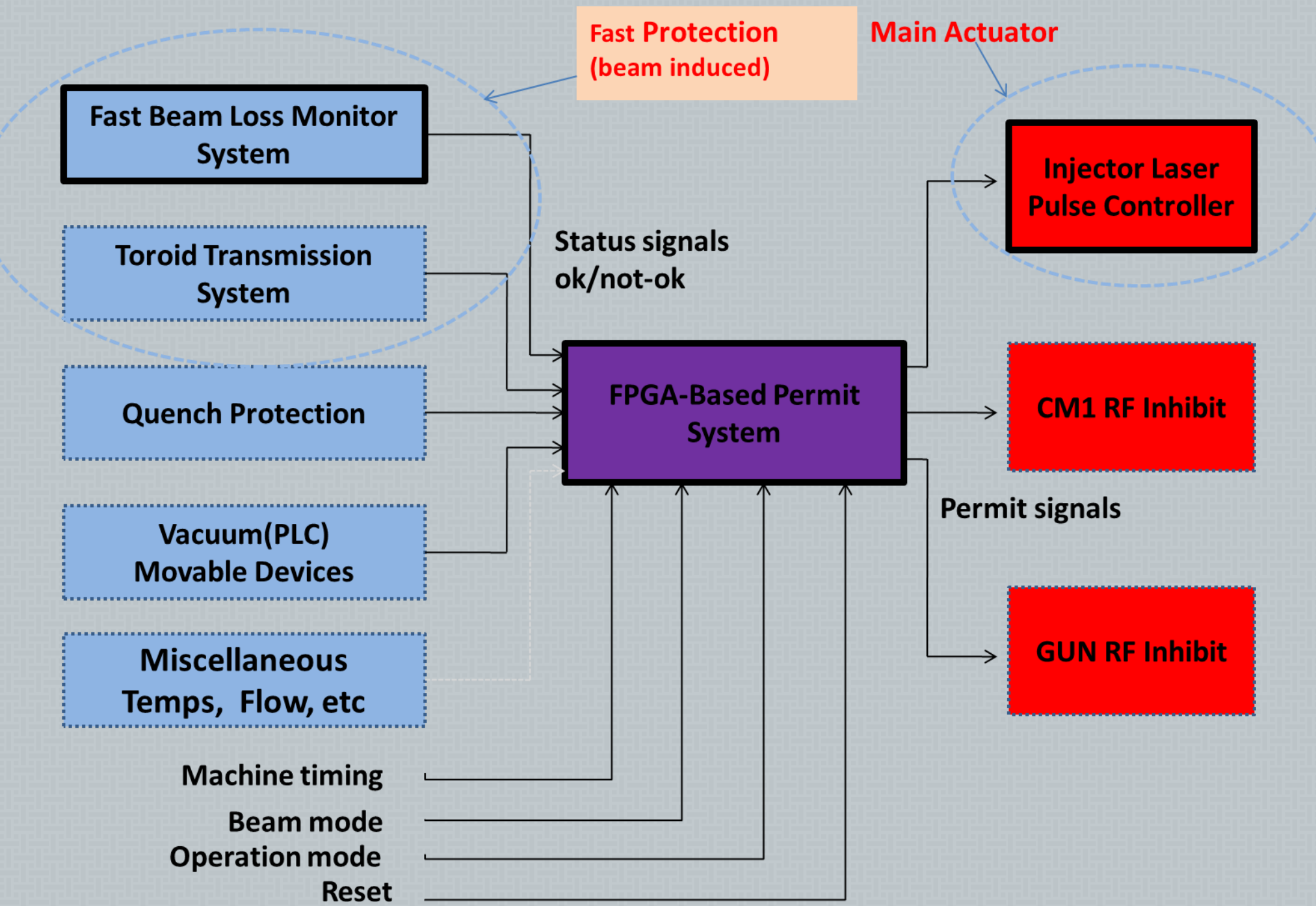

Figure 3 : MPS Overview

Figure 4 : Main MPS System setup

Laser Pulse Control

The Laser Pulse Controller (LPC) is designed to be the primary actuator for beam inhibits. Its main function is to provide a gate to the gun laser system via the Pockels cells with a width that corresponds to the total number of 3 MHz pulses allowed without crossing the programmable threshold for losses. The maximum width of the gate is 1 ms which would accommodate a maximum of 3000 bunches. It is designed to inhibit the system within the 1ms macro-pulse window
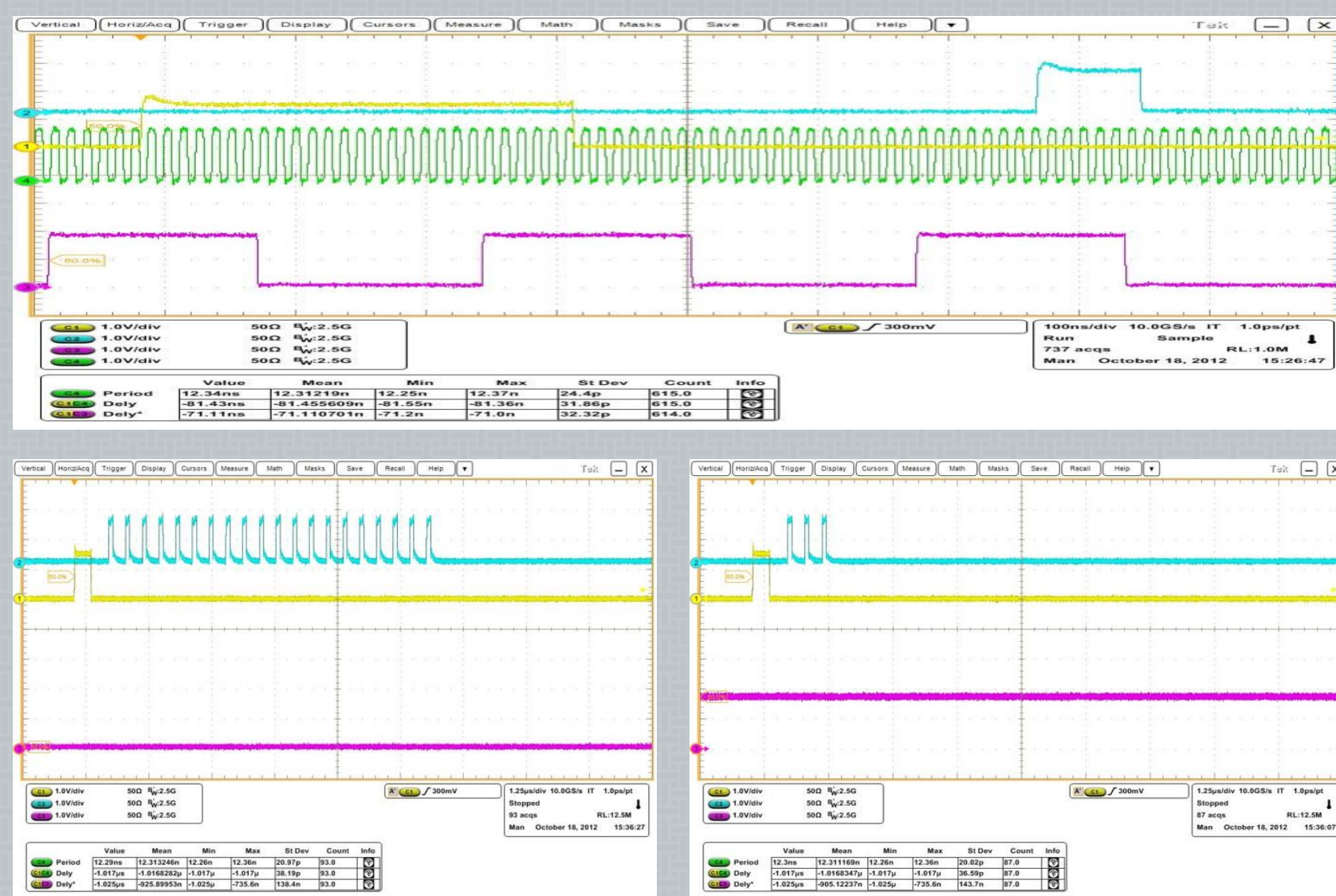

Figure 5 : LPC Test and Jitter measurements

Main Permit Board

The main MPS permit generator board is the central component of the system that serves to collect status (OK/Not-OK) information from the various machine subsystems. The information is used in conjunction with user input such as operational mode and beam mode requests to generate a permit condition. The subsystems interface with the system through several modules that are designed to maintain signal integrity and provide noise immunity by converting input signals to Low Voltage differential signal levels (LVDS).
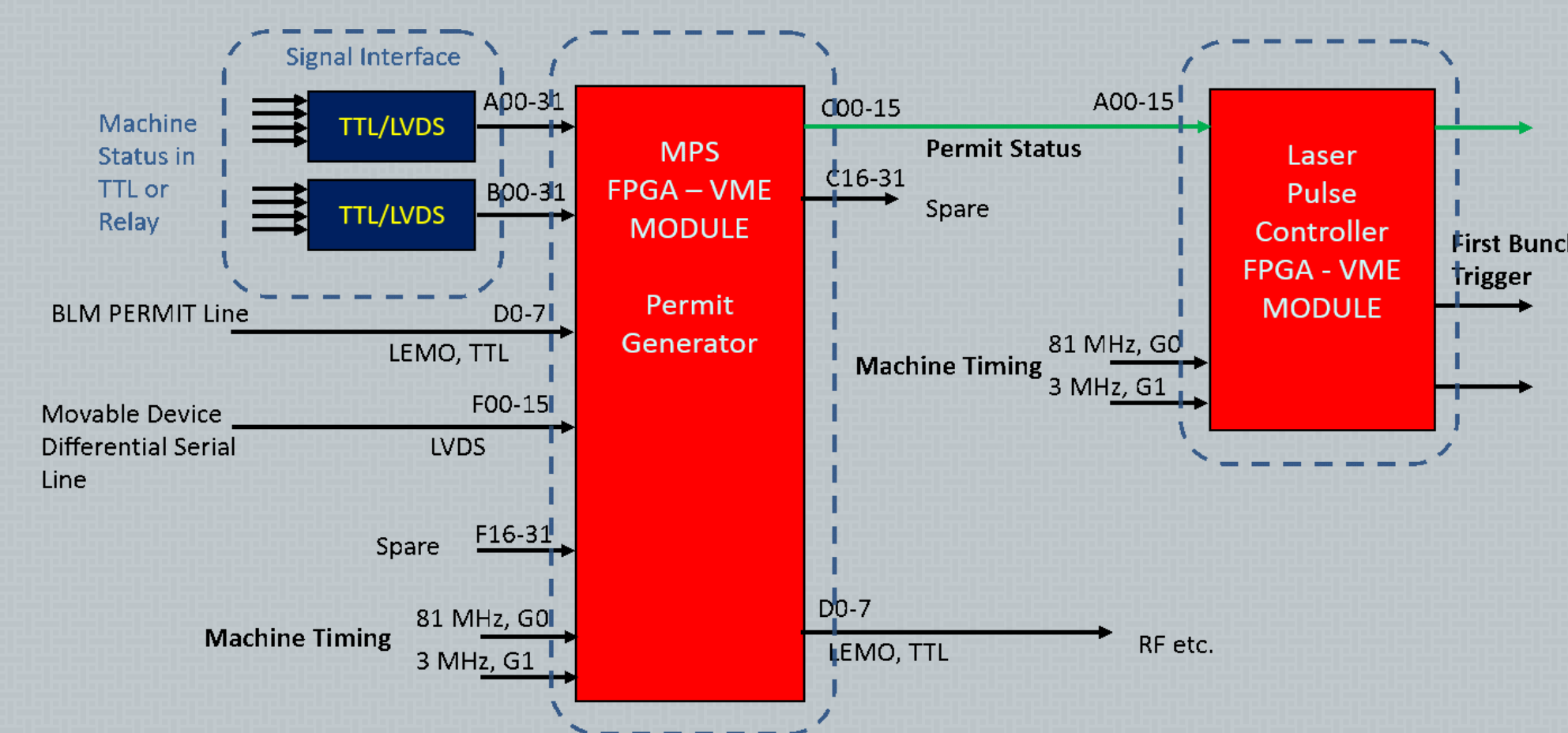

Figure 6 : MPS FPGA Block Diagram

Fast Protection

The front-end signal processing boards used are based on electronics designed by Jefferson Lab for their 12 GeV loss monitor system upgrade [4]. These BLM boards have been modified to meet the specific machine requirement at FAST. The main design change was to process the amplified signals from these boards using faster 125 MHz digitizer boards. The signals are further processed by an on-board Field programmable gate array to provide the required threshold levels and protection system shut-down signals.
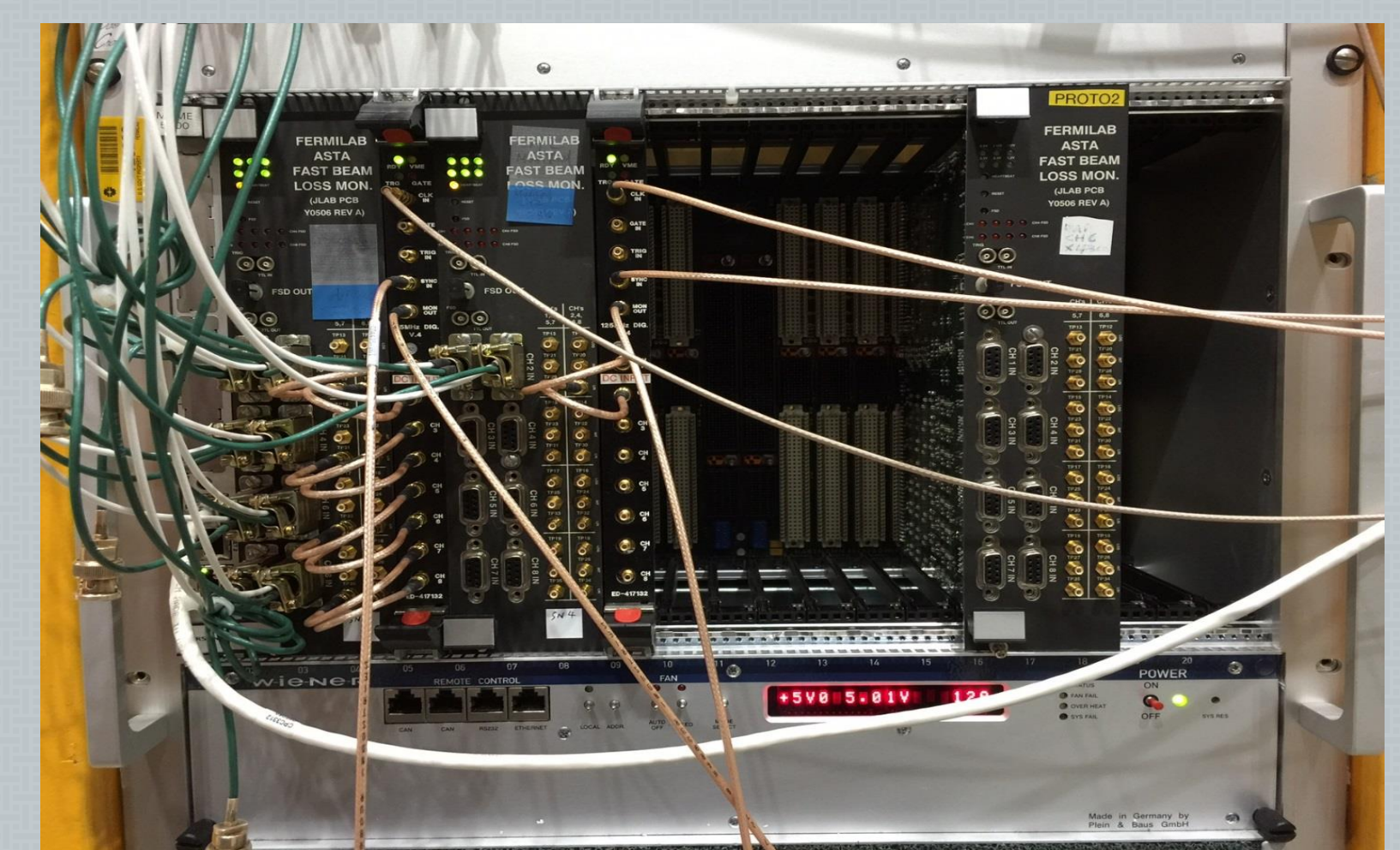

Figure 7 : Loss Monitor Boards

User Interface

Trip visualization is provided through several Synoptic displays (Figure 8) which allow users to view the overall trip status and then to drill down to a specific trip.
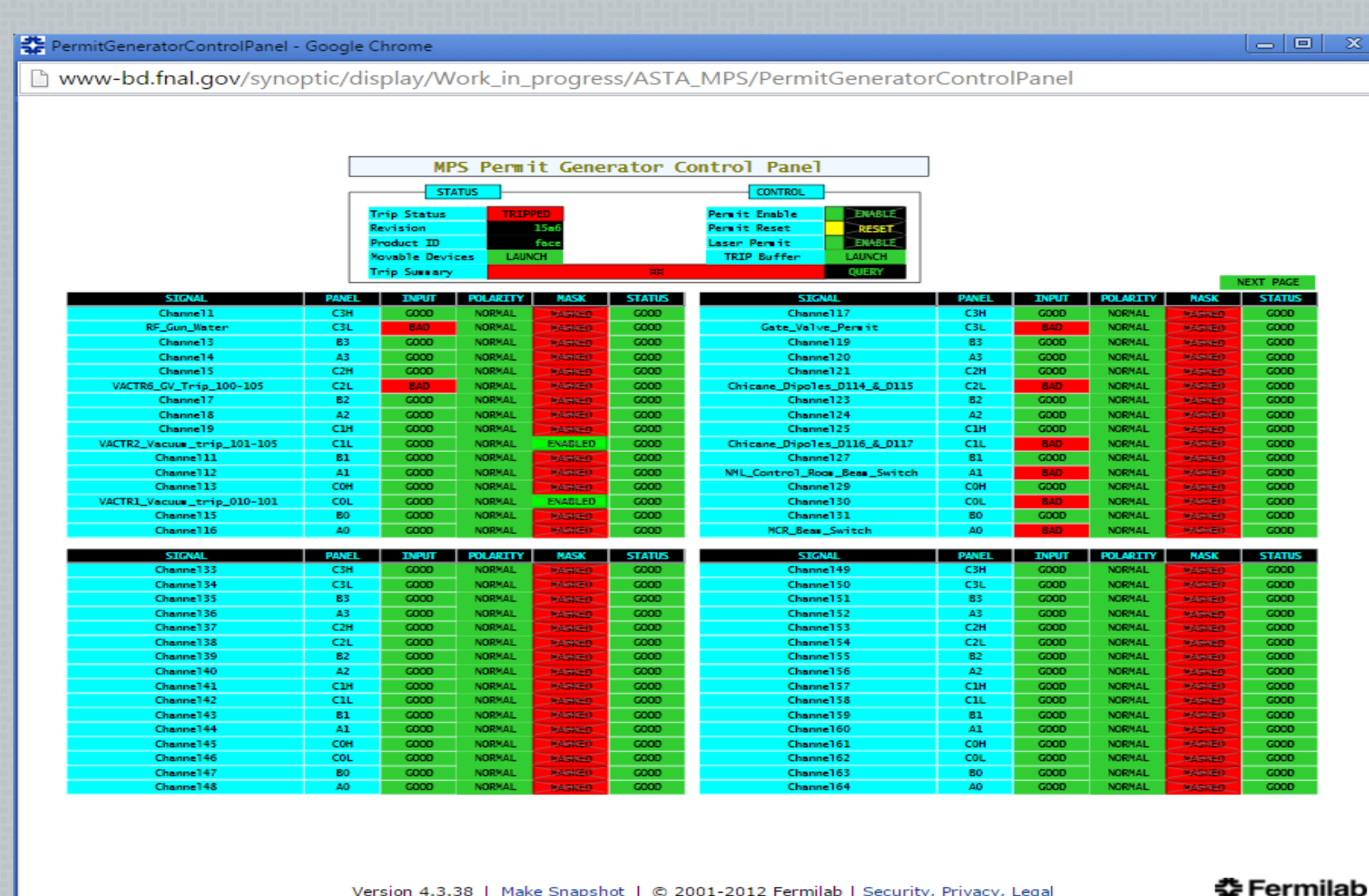
A web page, as shown in Figure 9, serves as the entry point to the user interface. This page provides a global view of the permit system, a list of all pertinent applications and has a global log of all critical MPS messages.
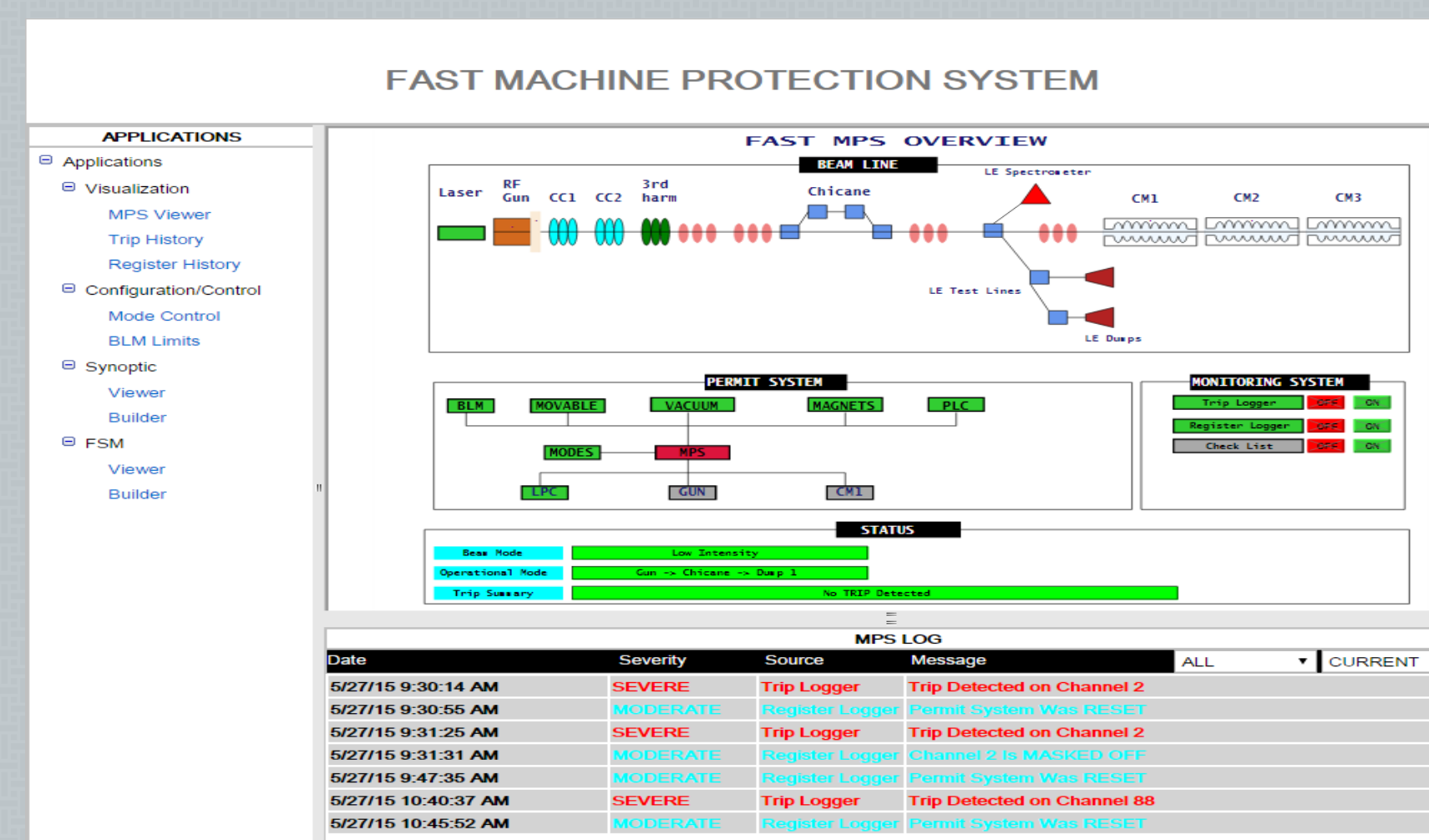
General purpose applications provide configuration control through the setting of subsystem status masks and BLM limits and a view of the trip and register history.
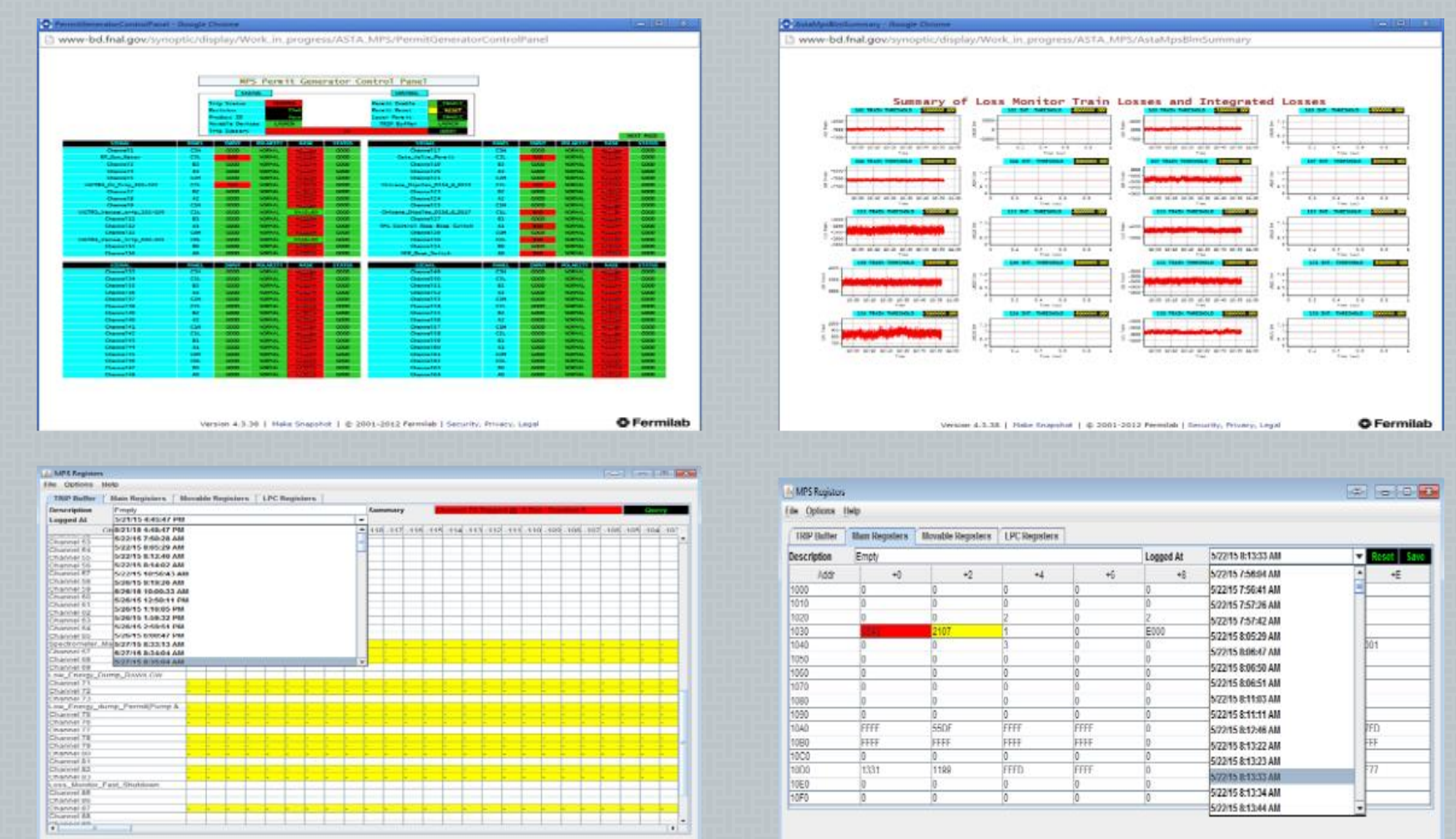

Figure 8 : Trip Visualization

Figure 9 : MPS Web Portal

Figure 10 : Configuration Control and Post-mortem analysis

Summary

The main components for the FAST Machine Protection System have been successfully commissioned. Commissioning began with successfully delivering 20 MeV beam to the low energy 50MeV dump for this first stage. The reaction time of the system is less than 1 us. The loss monitor system is sensitive to losses < 10 pC/bunch. The LPC meets the jitter specifications for tuning and controlling the number of bunches and bunch spacing. The main permit board was successfully interfaced to the control system. Trip visualization, configuration control and post-mortem analysis applications have been successfully developed. For the next phase of commissioning, the system will be expanded to protect the machine from 150MeV injection into IOTA.

References

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[4]   J. Yan, k. Mahoney "New Beam Loss Monitor for 12 GeV Upgrade", ICALEPCS'09, Kobe, Japan, October 2009, WEP092; http://www.JACoW.org.