OAK RIDGE National Laboratory

SNS Credited Beam Power Limit System

Preliminary Design

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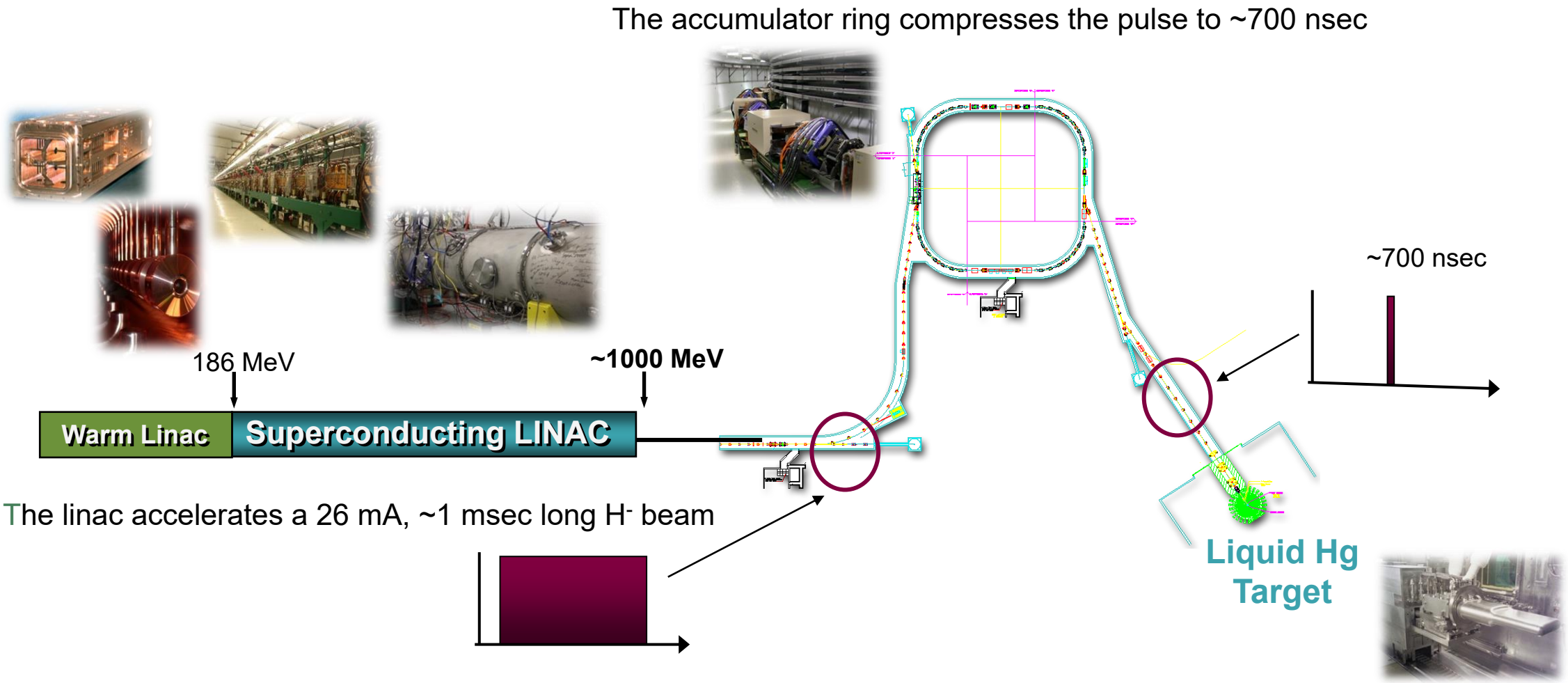
U.S. DEPARTMENT OF ENERGY

Abstract

The Controls Section at the Spallation Neutron Source (SNS) is designing a programmable signal processor based credited safety control[j] that calculates pulsed beam power based on beam kinetic energy and charge. The system must reliably shut off the beam if the average power exceeds 2.145 MW averaged over 60 seconds. This paper discusses architecture and design choices needed to develop the system under the auspices of a programmable radiation-safety credit control.

[j] A credited control is a documented and approved means to mitigate hazards to people or environmental.

SNS Overview: Short Pulse Neutron Source



@ 60 Hz, this represents a 1.4 MW proton beam power

Slide from N. Evans, SNS. 2021

SNS Proton Power Upgrade (PPU) upgrade power can exceed target power rating

- PPU doubles SNS proton beam capability from 1.4 MW to 2.8 MW
  - 30% energy increase, 50% current increase
  - 2 MW target
  - Largely an extension of existing accelerator technology
  - Leverages built-in upgrade provisions


Space in tunnel for new cryomodules

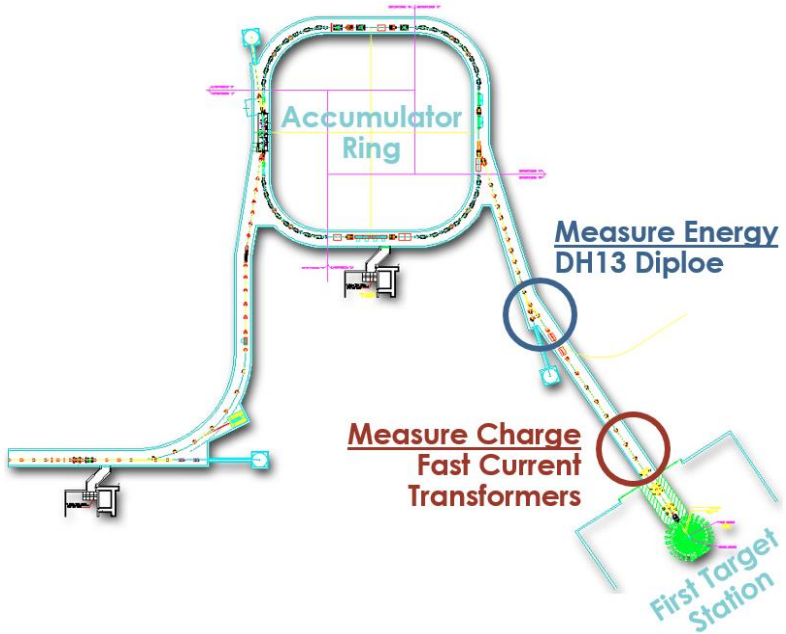
BPLS is critical to safely meeting KPP Objectives

Key performance parameter	Threshold	Objective
Beam power on target (MW)	1.7	2.0
Beam energy (GeV)	1.25	1.3
Target operation without failure (hours)	1250 × 1.7 MW	1250 × 2.0 MW
Stored beam in ring (ppp)	1.6×10^{14} at 1.25 GeV	2.24×10^{14} at 1.3 GeV
Number of installed PPU cryomodules	6	7

Slide from N. Evans, SNS. 2021

Beam Power Limiting System (BPLS) Calculates Both PPS and MPS Thresholds Based on Measured Beam Energy and Charge

Nominal Current Pulse Width	$0.75 \pm 0.1\ \mu sec$
Kinetic Energy	1.3 GeV
Nominal Rep Rate	60 Hz
Peak Current	130 A
Average Current	2.15 mA
Bandwidth	$\leq 22\ MHz$



$$P = R_{rate} E_b \int_{t_o}^{t_o+w} I(t)dt$$

$$E_b = \sqrt{E_0^2 + \left(\frac{cBL(I)}{\theta}\right)^2} - E_0$$

$$C_i = \max\{t_j \in cycle\}\left(\int_{t_j}^{t_j+T_{pulse}} dt\, I(t)\right)$$

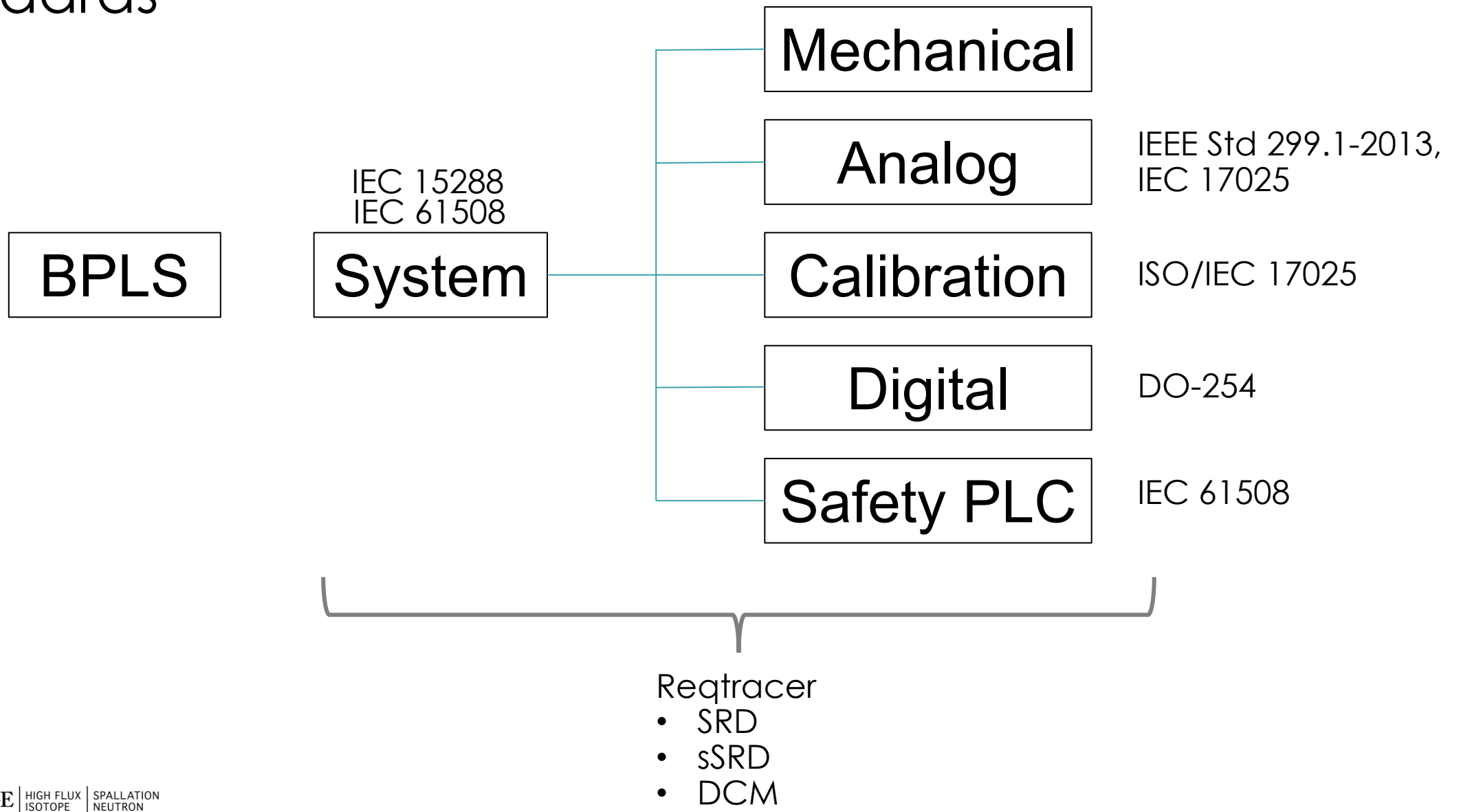
$$P_{ave}^{PPS} = \frac{1}{60}\sum_{m=0}^{3599} E_b C_i\,, \quad \text{Accelerator Safety Envelope}$$

$$P_{ave}^{MPS} = \frac{1}{10}\sum_{m=0}^{599} E_b C_i\,, \quad \text{Operations Envelope}$$

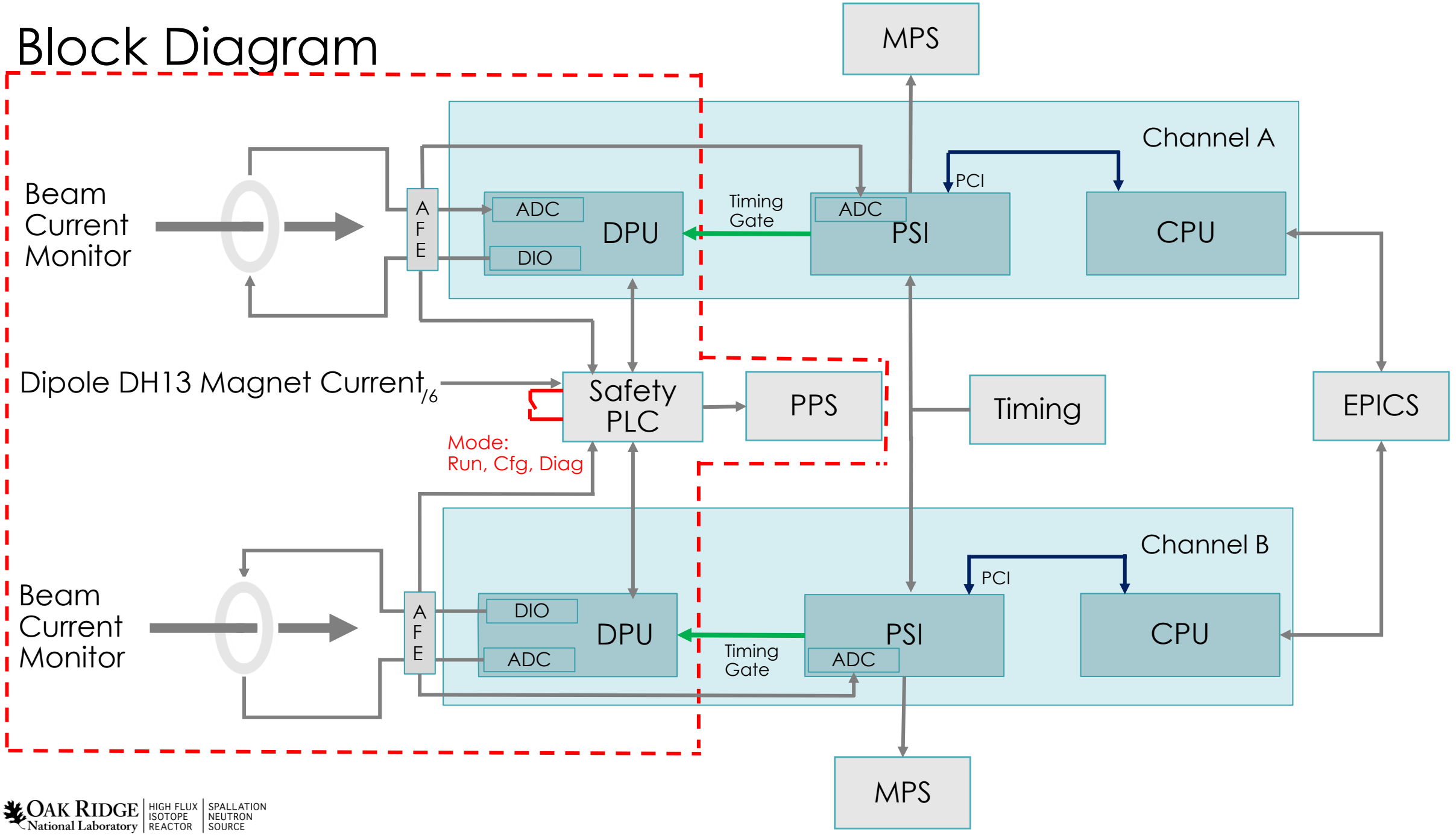
Requirements are for a credited system that…

- Provides highly reliable and accurate means to measure beam power
- Shuts off the proton beam through the PPS if beam power exceeds 2MW for one minute
- Shuts off the proton beam through the MPS if the beam power exceeds 2 MW for 10 seconds [not part of the credited system]
- Incorporates self test, diagnostics, and modes for calibration
- Uses commercial off the shelf technology where possible

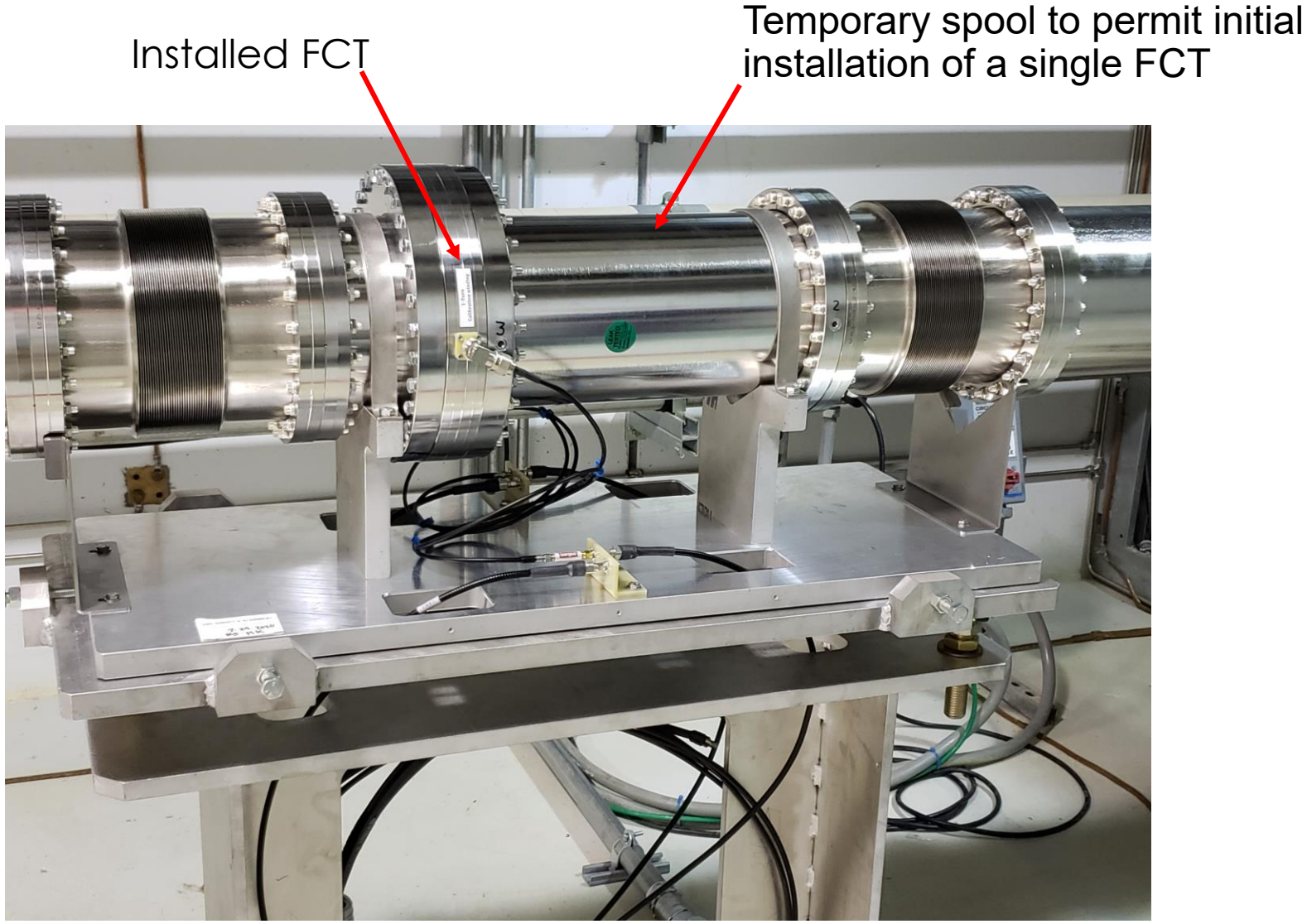
Credited Control Requires Design Pedigree Traceable to Standards



Block Diagram

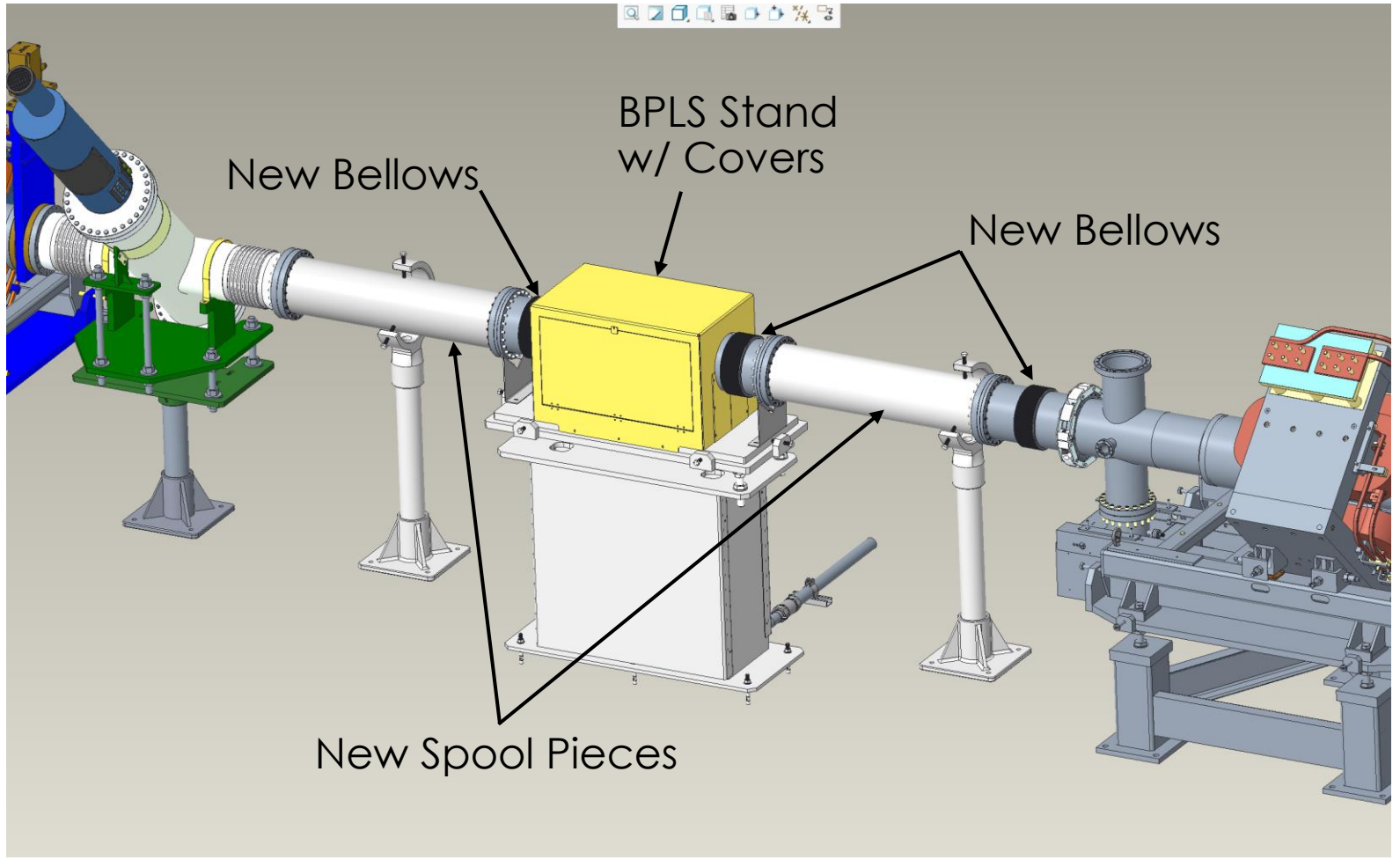


BPLS Test FCM Installed in proton beam line



D. Willis

BPLS Components Installed



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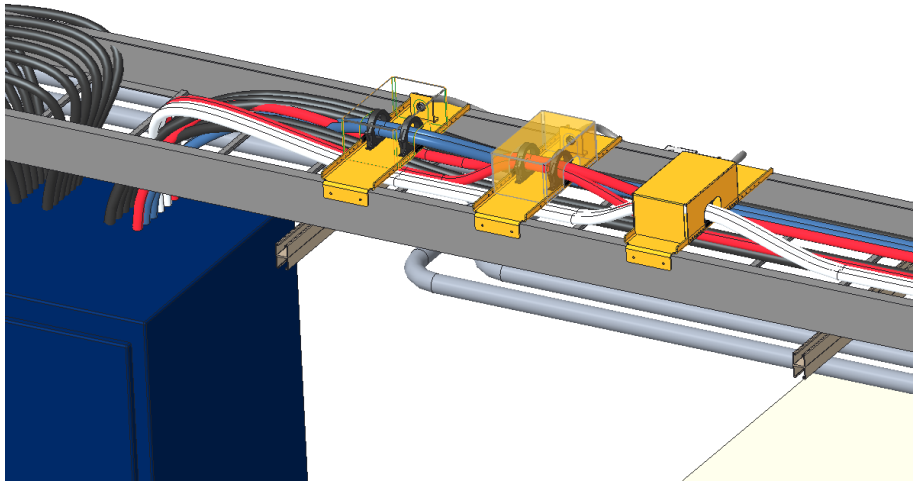
DCCT Supports and Covers in SNS-8550, RTBT Support Building

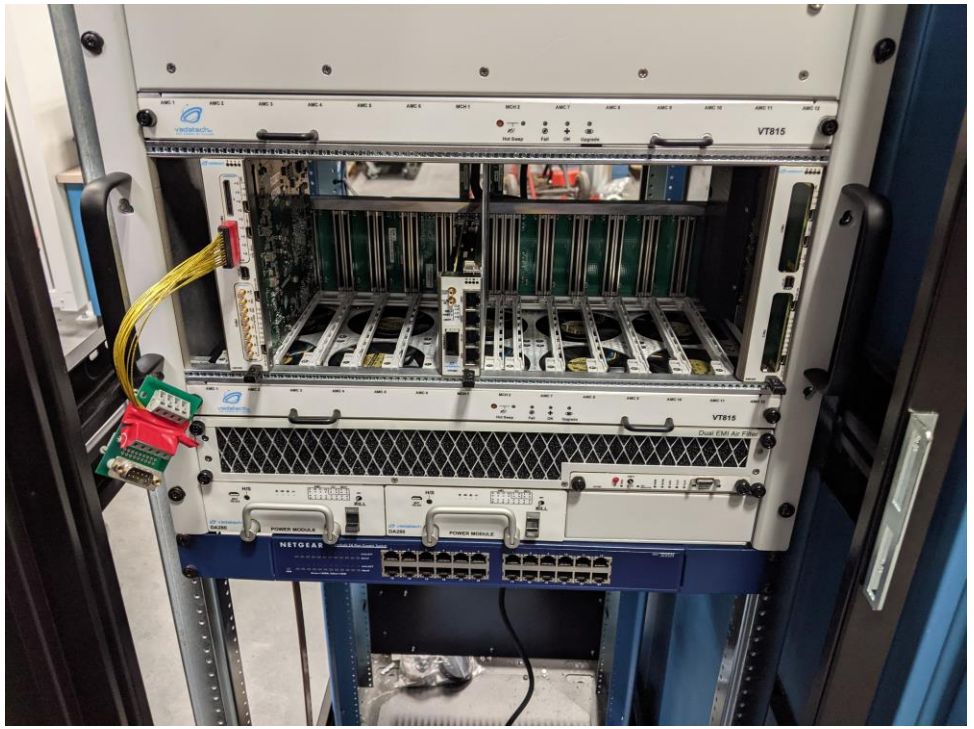


1oo2 voting scheme. 2x3 DCCTs measured with the safety PLC to calculate beam energy

Test-stand progress

Beam Simulator

Safety PLC



MicroTCA and FPGA

The design and test are progressing well

- Status
  - System and subsystem requirements complete – making revisions after preliminary design review (PDR)
  - One FCM installed and tested with beam
  - One set of DCCTs are installed and accurately calculating beam energy
  - Micro-TCA based FPGA detail design in process
  - Integrated test stand incorporating analog, digital, and PLC hardware installed