BLM System Introduction

Internal BLM Workshop

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Wednesday, April 23, 2025

BLM Overview Purpose

- Introduce System
  - Purpose
  - Some Design
  - Use of MPS vs. Diagnostic
  - Requirements
- Calibration
- Operational Experience
- Potential Improvements

Beam Loss Monitor (BLM)

Beam Loss Monitors Purpose:

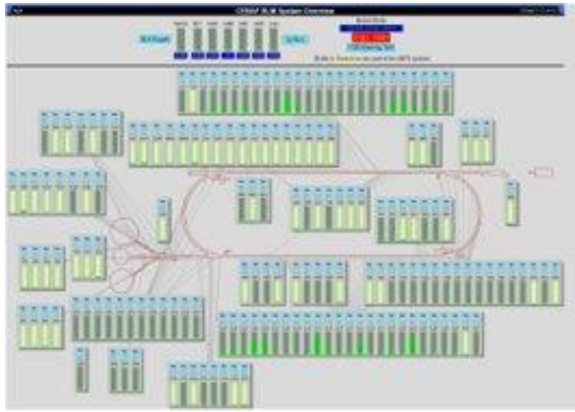
1. **Machine Protection** - Sense beam loss, which may cause physical damage to the accelerator or accelerator equipment and cause unwanted downtime.
2. **Diagnostic -** detect beam loss for beam quality issues

BLMs interface to the Fast Shutdown System:

- Turns off the beam within **50 usec**

Beam Loss Monitor – Hardware and Ops Interface

- Detector used - **PMT** (Photo Multiplier Tube)
- **HV supply** – affects gain of the PMT,
- BLM interface card (VME), 8 channels:
  - linear pre-amp,
  - logarithmic circuit – used for diagnostics read backs,
  - integrating circuit – used for MPS,
    - **BIAS** used to filter out background radiation,
    - **THRESHOLD** used to set trip point,
  - PMT test functionality,
- EPICS screens
  - Read backs for logarithmic and integrated signals
  - Adjustable BIAS and THRESHOLD
  - Activation of Test function
  - Channel masking
- Signals archived as well, for viewing of history

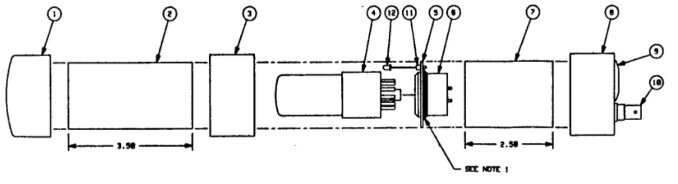


Slide from "BLM Overview", RSR Strategic Meeting , Jerry Kowal 9/27/21

PMT Specs

HAMAMATSU
PHOTON IS OUR BUSINESS

PHOTOMULTIPLIER TUBE
R11558



BLM PHOTOMULTIPLIER TUBE ASSEMBLY DETAIL

Figure 1: Typical Spectral Response

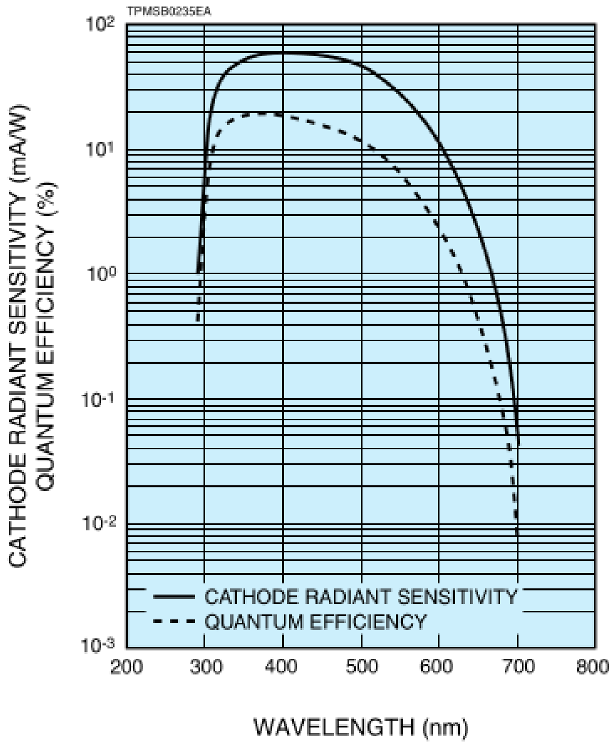
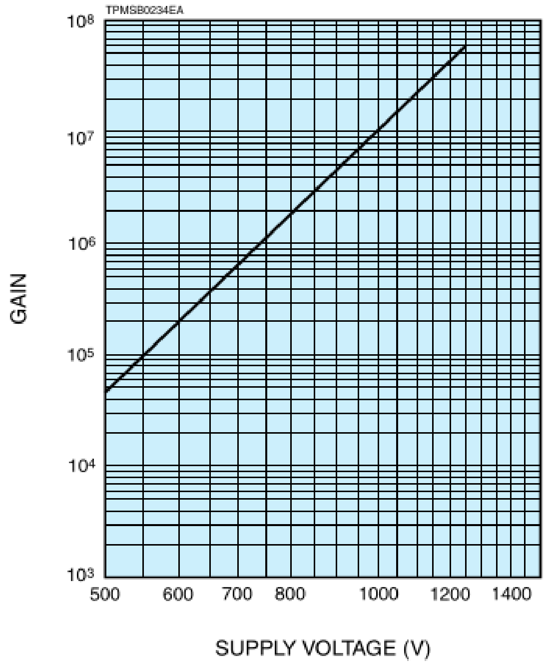


Figure 2: Typical Gain Characteristics



BLM Capabilities

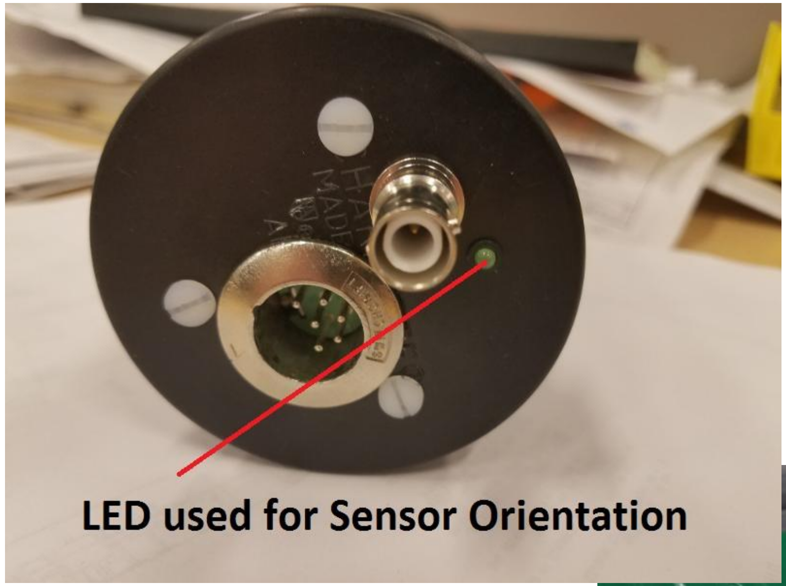
- Local and area protection detection of beam loss
- High sensitivity (beam loss <<0.1uA) adjustable by PMT high voltage,
- Fast response << 1 us,
- Configurable function of individual channels:
  - MPS using integrating amplifier (trip set at 15,000 uA-us loss)
  - Diagnostic using logarithmic amplifier
  - Linear signal available on the DSUB-9 connector (not available to FPGA now)
- Glass of the PMT tubes darkens with high exposure leading to sensitivity reduction
- PMT noise level can be reduced through Dark Aging
- "Safe" calibration with use of Tune Beam
- Low cost ~ $600 per channel
- Deployment is very flexible

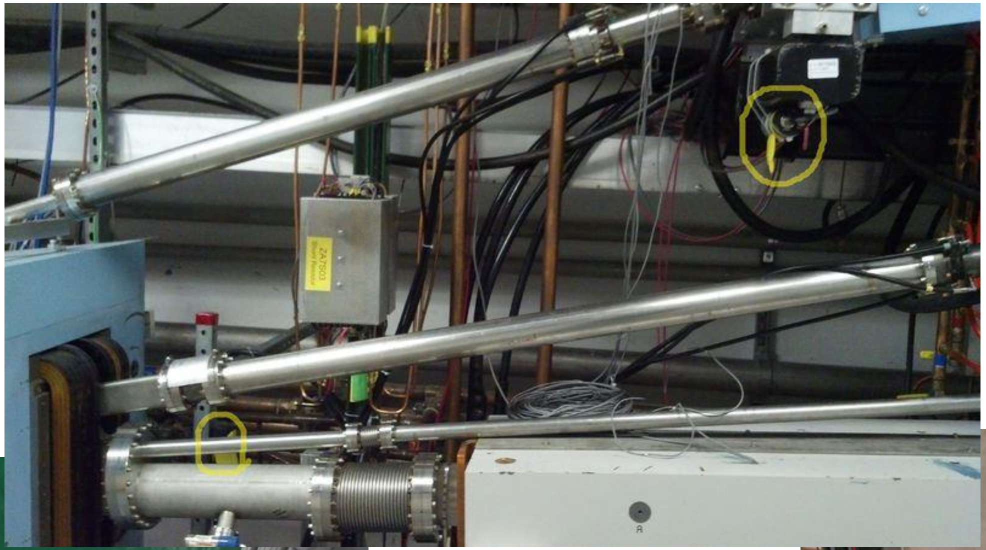
Slide from "BLM Overview", RSR Strategic Meeting , Jerry Kowal 9/27/21

Card Design

- **CAMAC Card**:
  - Discussed in **CEBAF-TN-92-003** (John Perry and Eric Woodworth)
  - Operational Limitation – this older card only had a diagnostic interface or MPS interface.
  - MPS only tripped, no readout of signal level over time – improved in the 12 GeV VME design
- **VME** card designed for 12 GeV Upgrade
  - Not sure where or if design specifications exist for the upgraded card.
  - As of just a few years ago, these are all converted to VME … I think?

Machine Locations





Machine Locations

- **MPS Locations:**
  - **68 Locations** with **~%22 in the Injector** (No BLA protection in the Injector)
  - Placement
    - likely loss scenarios
    - protect equipment that had lack of spares (ex. ZA Septa vacuum chamber)
    - Some locations?? Legacy!
- **Diagnostic:**
  - **103 BLMs** are Diagnostic
  - Spread out through out the machine
  - Linacs are all diagnostic, except for beginning of each

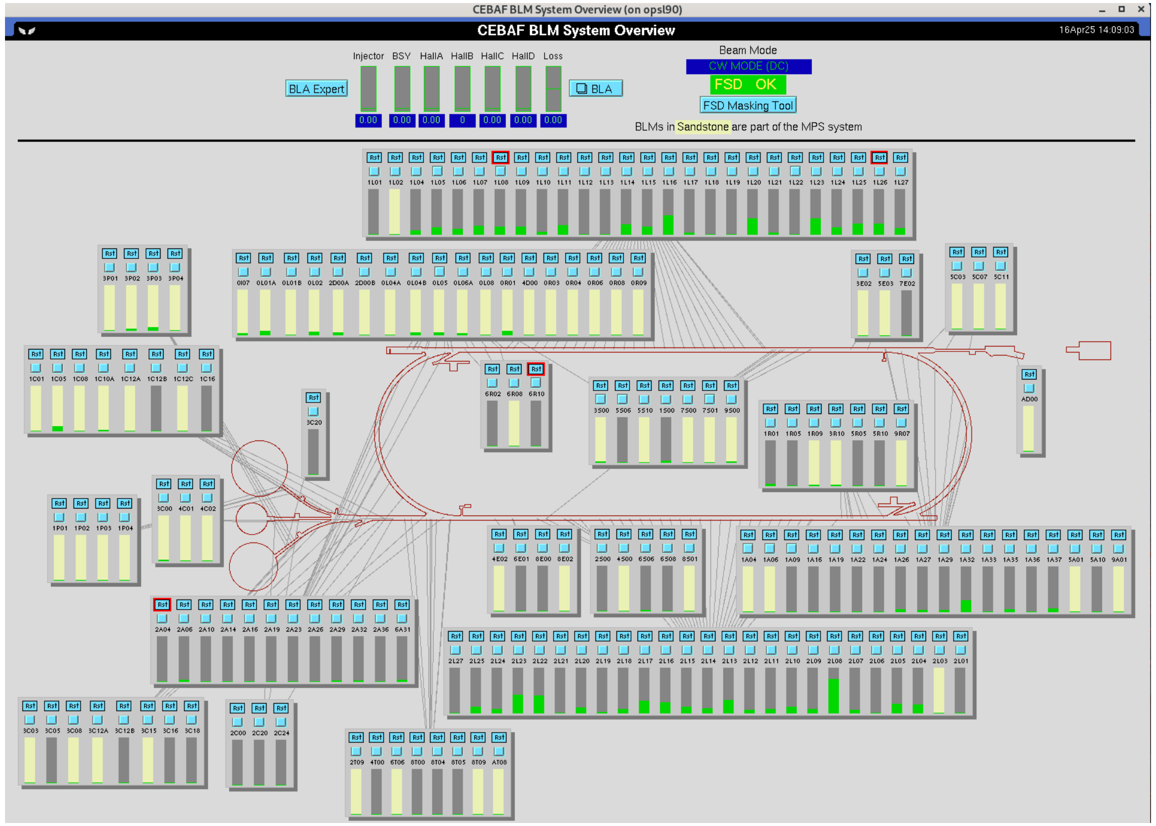


Image above - Ops screen show MPS locations as yellow bars, and grey bars are diagnostic BLMs.

BLM Diagnostics and Testing

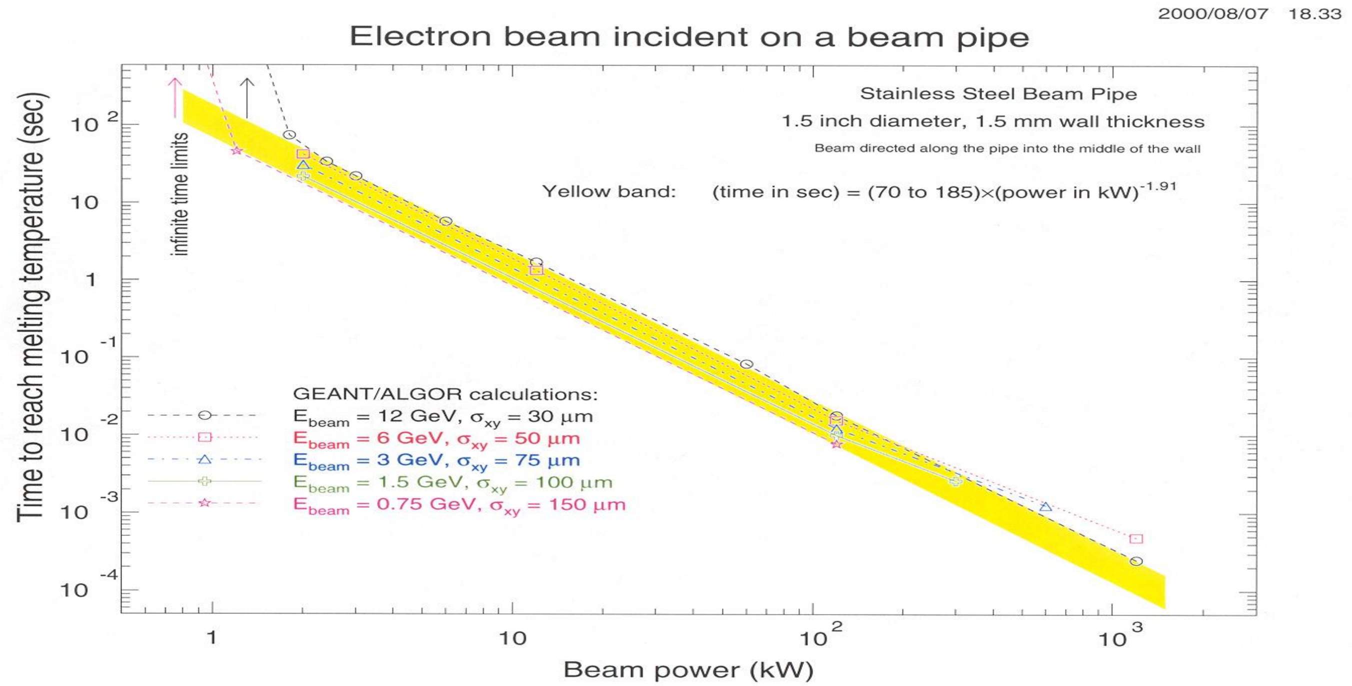
- **Monitoring**
  - HV and Card setpoints in CED
  - PMT HV setpoint and readback in the Alarm Handler
  - High Voltage PS and BLM card faults FSD

- **Built-in test functions**
  - Card test of the front-end electronics with signal injection,
  - Detector response test with remotely controlled built-in LED

Slide from "BLM Overview", RSR Strategic Meeting , Jerry Kowal 9/27/21

System Requirements – C.K. Sinclair TN-92-046/ TN-94-024

- System designed around 2 main performance requirements:
  - **How fast - 50 usec (TN-92-046)**
  - **Threshold for Acceptable Loss** (BLM) – **2500 uA-usec (TN-94-024)**
- Basis of documents - calculated power deposition with beam normal to a thin-walled stainless bellows



Above is an analysis that was done for 12 GeV – From a talk by Kelly Mahoney in 2007.

Threshold for Loss– C.K. Sinclair TN-94-024

- Minimum melt through times calculated:

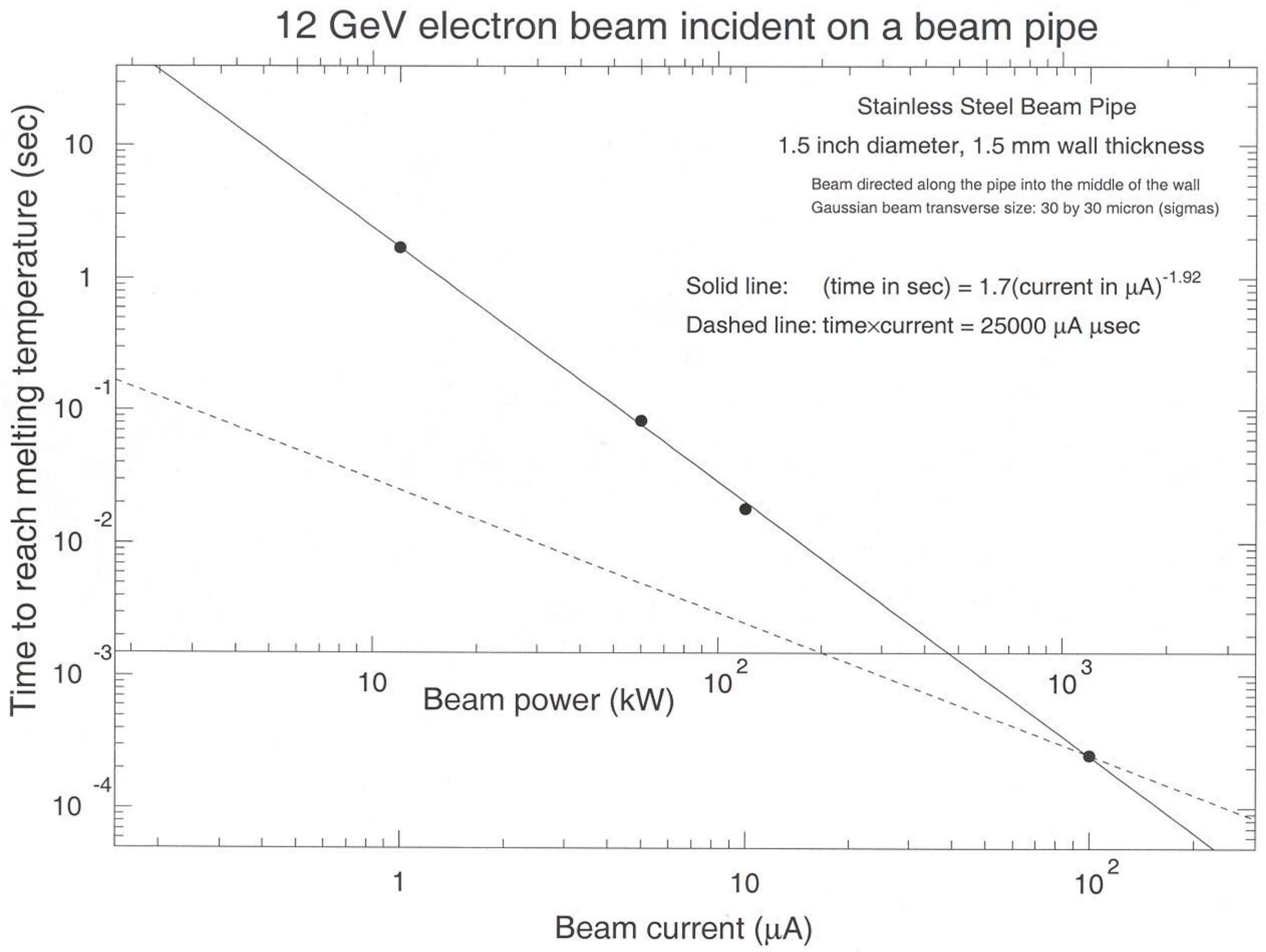
Stainless steel: $\Delta T_m = 1392$ C, $C_p = 0.50$ J/gm-^{o}C, yields $t_{min} = 137$ μsec

Niobium: $\Delta T_m = 2435$ C, $C_p = 0.268$ J/gm-^{o}C, yields $t_{min} = 128$ μsec

  - Integrated beam current of **25600 uA-usec** to burn through
  - Assume 10%, acceptable beam allowable loss yields ~2500 uA-usec
  - Assuming the 50 usec previously calculated, corresponds to 10000 uA-usec of beam loss

- This yields a total of **12,500 uA-usec** or %50 of the integrated beam current burn through scenario

12 GeV Beam @ 30 um beam size



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BLM Calibration

- Calibration is crucial to get HV setpoints that meet the specification
- ***Beam Loss Monitor Setup Procedure, John Perry 10/28/94***
- SSG maintains the official procedure now which is,
  - **SSG-PR-10-001, *Beam Loss Monitor (PMT based BLM) Calibration Procedure***
- **Process:**
  - Use Tune mode beam, to mis-steer and direct radiation to sensor
  - Adjust PMT gain using an O'Scope in the field

BLM Calibration

- **Limitations:**
  - Requires beam time
  - Time consuming, **68 MPS** BLMs x 30min = 34hrs (at least)
  - Requires “pairing” of each BLM with dedicated magnet used for calibration
  - Requires missteering beam in all directions to find the least sensitive direction
  - BLM placement and orientation as well as set up critical for effective protection
  - **Difficult to calibrate upper passes**
    - Hard to direct beam long enough without vacuum consequences

Operational Experience

- **The Machine Protection BLM system works**
  - to protect the Machine from burn through
  - In my time here (~20 yrs), we have had **NO** burn through incidents in the CEBAF Accelerator
  - We have had flanges and vacuum connections heated up and cause a loss of vacuum.
    - Some caused from inadequate BLM coverage (we added some) (ex. 1S00 and 2S00)
    - or not an optimal location chosen (we moved it).
  - Works **"too" well,** threshold is too sensitive?? **- *More from Jay***

Operational Experience – So we have loss?

- Single BLM can "see" loss from multiple passes. So which pass?
- Many times, when we know we have loss, it is difficult to diagnose where.
- Loss is hard to tune out:
  - BLMs sometimes do not have the dynamic range to see the loss in Tune Mode.
  - Unless the loss is bad enough
- Ww will always have to tune out losses in the machine, even if we decrease BLM sensitivity.

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Improvements

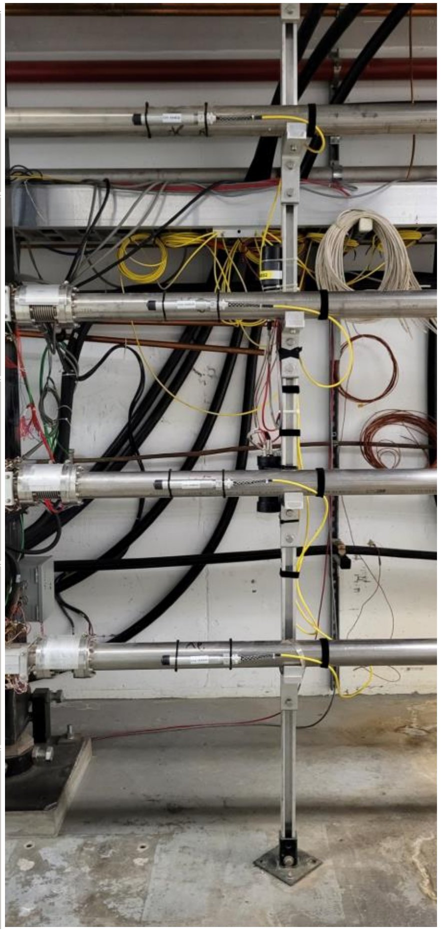
- Requirements
- Diagnostics –
  - Lots of time lost to finding and improving loss
  - Hard to detect pas-by-pass loss
- RF vs. MPS BLMs – RF Diagnostics
- Fold in additional protection
- New BLMs, more discrete protection
- Calibration Improvements
- Software – Diagnostics
- Procedural

Improvements - Requirements

- Revisit assumptions and calculations made
  - Are all of Charlie's assumptions valid today?
  - Which assumptions should we revisit and why?
- Brainstorm any new requirements?
  - Decreasing the BLM sensitivity will have consequences,
    - we should be prepared
    - What threshold of activation should we allow for?
- Start fresh on locations – what do want or need to protect now vs. 30 yrs. ago?
- Incorporate the additional protections, like BLA and vacuum system that can also work to protect the machine.
- Document this.

Additional Diagnostic Loss detection

- Continue to supplement additional diagnostics (NDX/IDX) - ***More from Pavel***
- Images to the right show an example of the IDX detectors after the YA septas.
- Theses detectors/electronics have a better dynamic range
  - Show signal in Tune Mode
- Pass-by-pass loss detection possible when stacking sensors in a row (see images to the right).
- Better halo monitoring and control throughout the machine



Diagnostics – Calibrated Wiresums

- Loss detection through BPM wire sums
  - All the BPMs are inherently current detectors
  - If we had a better sense of calibrated wire sums from sensor to sensor, we could easily tell where the loss is

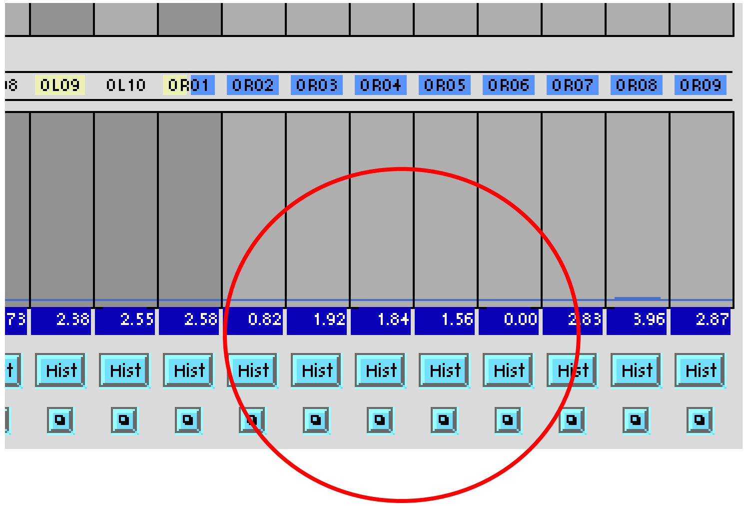


Image shows the Injector wiresums, how accurate is this from BPM to BPM? If we can establish some trust in these, it could help to diagnose and improve loss.

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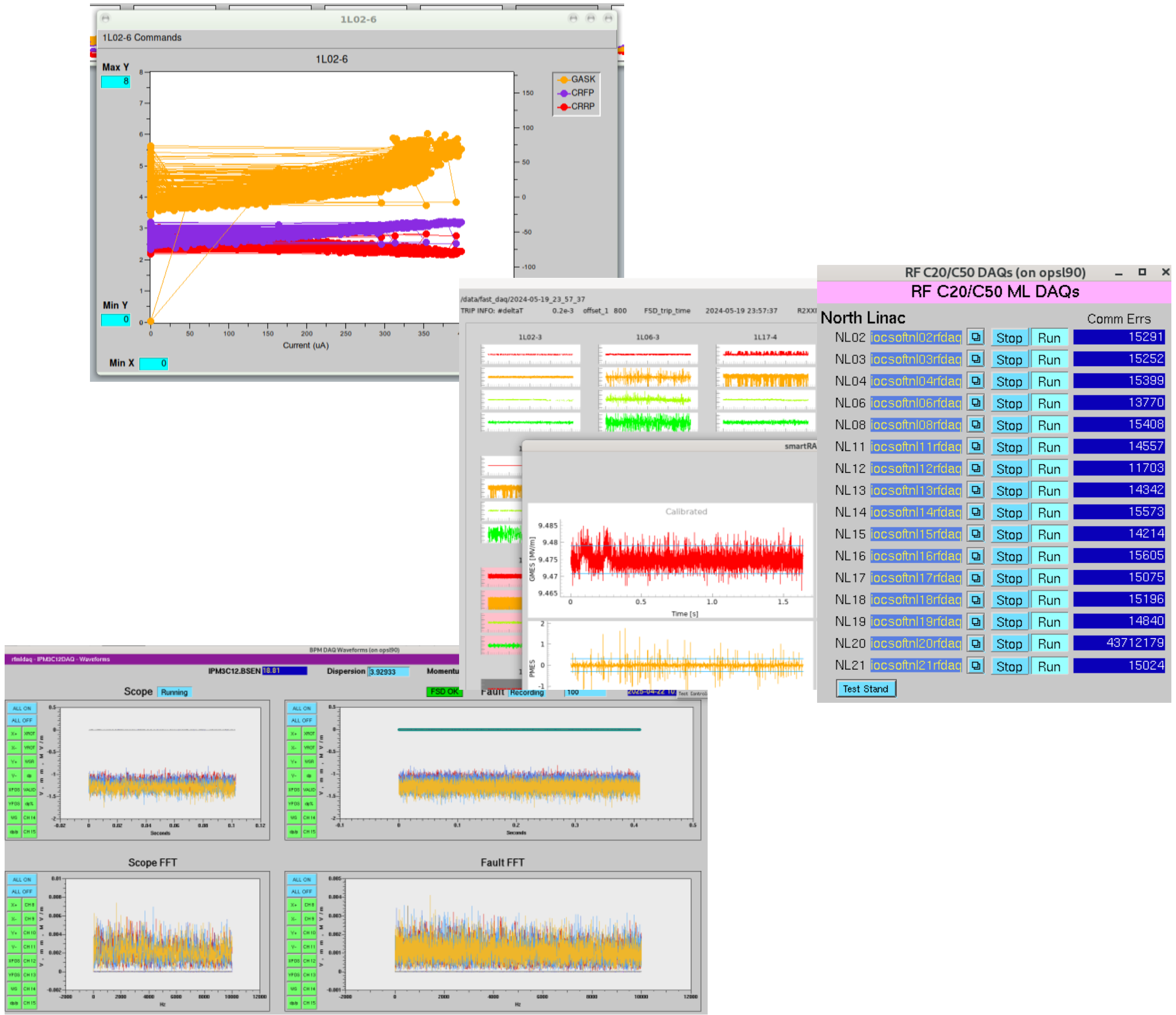
Diagnostics – Global Timing and Synchronization

- Global timing and synchronization of diagnostics BLMs, vacuum, BPMs, etc...
- If diagnostics and their electronics were synchronized with the beam and data readouts though EPICS were all synchronized
    - we could easily correlate signals to help find pass-by-pass loss more efficiently.

BLMs vs. RF - RF Diagnostics

- **Beam Loss or Angry RF?**
  - Improvements in diagnosing and distinguishing between bad performing RF is a benefit.
  - Newer and improved tools will help:
    - RF Health Check - w/ appropriate guidance
    - RF Analyzer Tool (RAT)
    - smartRAT with C25 and C50 fast DAQ – NL Only as of now
    - LAB Jack BPMs at Dispersive BPMs
    - Guidance from experts to tune RF systems under full beam loaded conditions



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Fold in additional layers protection

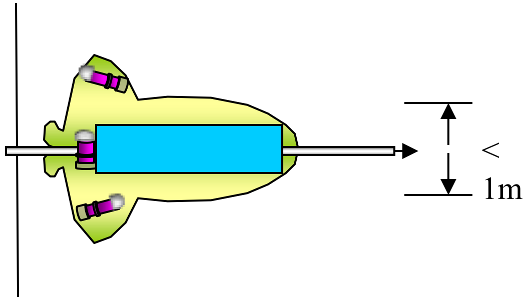
- We have chosen not to interlock magnets to FSD
- We could add a layer of protection and interlock magnets to the FSD system, increasing our protection.
- This would add defense in depth and potentially allow us to allow for more beam loss, as the devices that we are trying to protect, will protect themselves.

Imag shows that 2 PMTs protect a stack of magnets. If magnets were interlocked, we could be more conservative with allowable loss

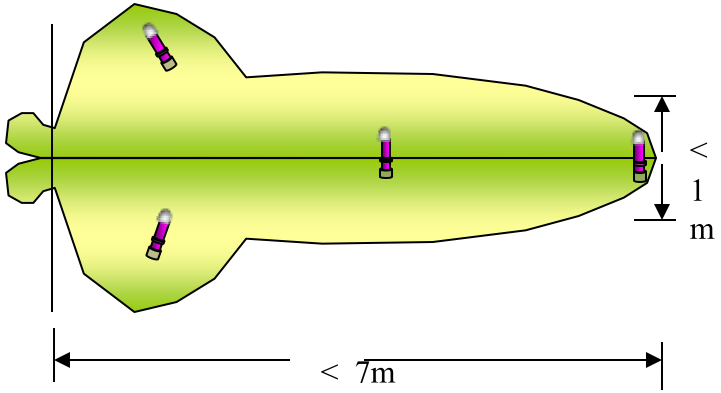
More BLMs – Device Protection vs. Area Loss

- Look at back scatter from front of magnets, opposed to forward cone of radiation
- Protect the device only, instead of loses from all passes.

Instead of area monitoring, move PMTs upstream, and add one per stack.



Example of device monitoring, discrete coverage protecting the magnet



Example of area monitoring, more coverage from forward cone of radiation

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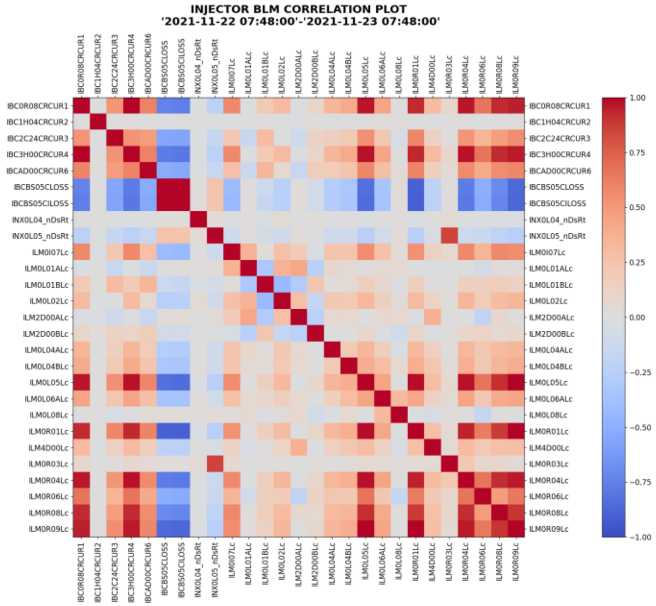
Calibration Improvements

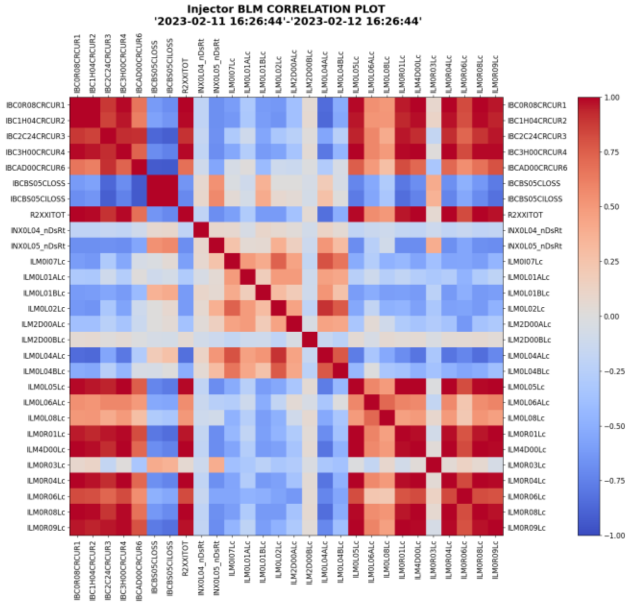
- Review placement of the BLMs are MPS BLMs appropriate?
- Pre-identify magnets for calibration for each BLM
- Simulate loss scenarios and calculate magnet settings ahead of time
- Automate the calibration process with software
- Eliminate the use of the oscilloscope with the modified BLM card firmware/hardware
  - Digital Scope mode
  - FPGA change needed?

Some slide content from "BLM Overview", RSR Strategic Meeting , Jerry Kowal 9/27/21

Software

- Develop software that will analyze signal correlations and report "areas" of concern.
- Diagnostic synchronization would be useful in such software

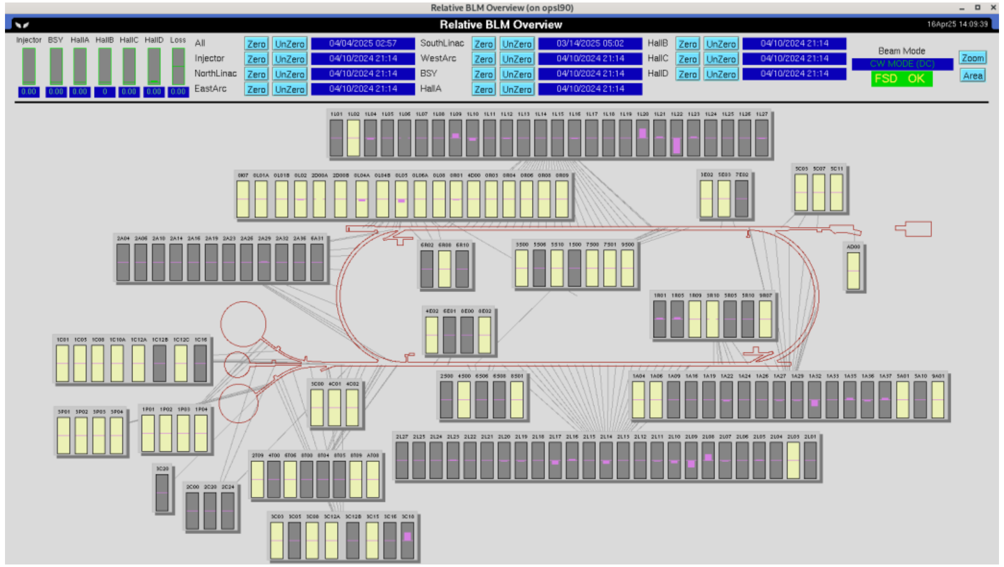




- BLM heat maps, looking at the degree of linear correlation of BLM signals.
- 1 dark red, and –1 dark blue shows a high degree on linearity
- Left image shows less loss, and right image shows more loss
- Could do the same with BLMS , Vacuum, and BPMs to further pinpoint loss

Software – Relative signals

- Lots of work went into, allowing us to take a snapshot of loss and then show relative loss
- Very useful in visualizing loss
- Could do the same for vacuum signals, to allow further troubleshooting of loss areas



Procedural

- Produce machine safe process for temporarily decreasing BLM voltages
  - Could help diagnose loss
  - Allow other things to trip first.
- Don't be afraid to move BLMs, if we identify weaknesses, or test better locations
  - Proposed locations and equipment protection list would be useful to inform decisions
- Procedurally, use other diagnostics to inform our decisions about setting HVs for the BLMs (IDX, NDX, etc...)
- Use **Bias** and **Threshold** settings to further tune desired response
  - All MPS BLMs are currently the same.

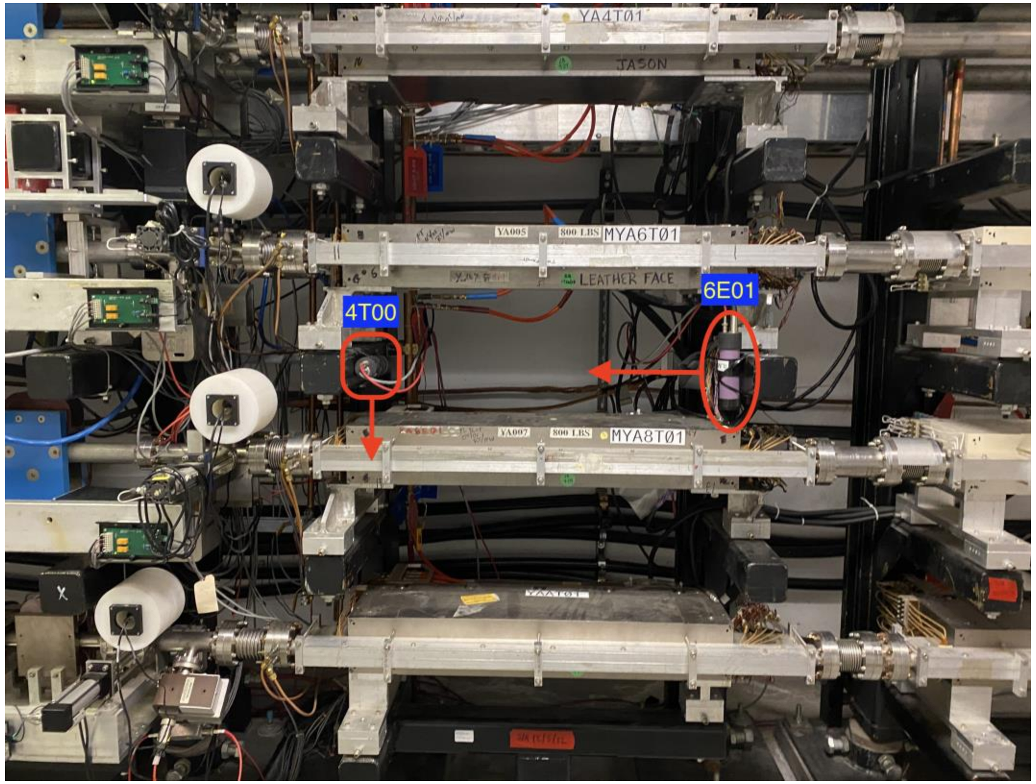


Image shows new monitoring setup to test new locations for YA MPS BLMs

Questions?

- Introduction to BLMs
- Some Operational Experience
- My view on some improvements

Some Links

- SSG Docushare - https://jlabdoc.jlab.org/docushare/dsweb/View/Collection-27505
- BLM Locations - https://opswiki.acc.jlab.org/wiki/BLM_List

How Fast– C.K. Sinclair TN-92-046

- **Power deposition calculated using:**
  - 200 uA of beam current
  - Uniform beam size of 100 microns
  - Stainless Steel Density of 7.9 gm/cm^3
  - Thickness size of small stainless steel bellows wall = 0.006" or 0.015 cm
  - DE/dx for minimum ionizing particles = 1.67 MeV/(gm/cm^2)
  - P = (dE/dx)*density*thickness*current = 40.2W of power deposited, with initial deposition area of 0.785X10^-4 cm^2

How Fast - More details – C.K. Sinclair TN-92-046 (Cont.)

- Estimate is temperature reached where radiation is the only heat loss
  - Assumptions used:
    - 1 mm emitting area, which is ten times larger than the 100-um beam size
    - Emissivity of 0.4
    - Used 2 surfaces to a 0K surface
    - Approach used yields 5760K to dissipate the 40 W (304 Stainless melts ~1400 Celsius)
- Next Charlie calculates the instantaneous temperature rise, using:
  - Specific Heat of Stainless = 0.50 j/gm-K
  - And for the 40 W and 100 um beam size yields:
    - DT/dt=8.6X10^6 K/sec
      - Melting time would be 166 usec
      - Melting time would of course be different
        - Beam not uniformly 100 um
        - Hole may occur faster due to atmospheric pressure
        - Some radial conduction (not much)

How Fast (Cont.) – C.K. Sinclair TN-92-046 (Cont.)

- Copper estimated using the same assumptions – **98 usec**
- Niobium also considered, but not listed in the TN
- In conclusion and a little hand waving -
  - Estimated time to burn through is **100 usec**
  - Thus, a conservative and realistic time response of the FSD system is **50 usec**, with an assumption that the beam could persist for **20 usec** after a shutdown.
- **Design goal** for MPS FSD -
  - 10 usec from FSD logic
  - 10 usec from BLM logic
  - 4 usec for signal transmission
  - ~21 usec of beam in the machine

Threshold for Loss – Cont.– C.K. Sinclair TN-94-024

- A further discussion is made, and Charlie's conclusion is that for niobium at 4K, there is no reasonable beam loss scenario that would result in **quickly** burning through.
  - For this reason, there are no MPS BLMs in the Linacs, only diagnostic?
- Final parameters are a time of **50 usec**, and an integrated current threshold of **2500 uA-usec** for loss detection.
- Charlie warns specifically about RF Seperator power loss, that would damage the extraction septas in a much shorter time than the **21 usec** time specified for beam dwell time after a trip.