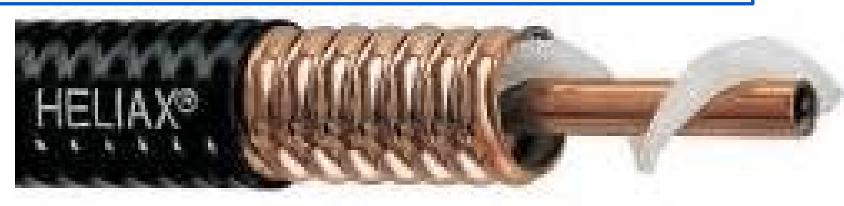
Total Loss Monitor Radiation Safety System

Neutrino Beams and Instrumentation Workshop 2014

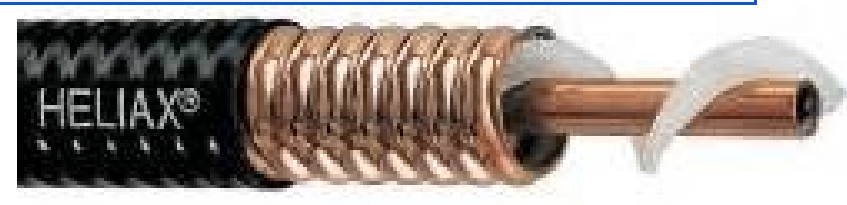
A. Leveling

9/26/14



background:

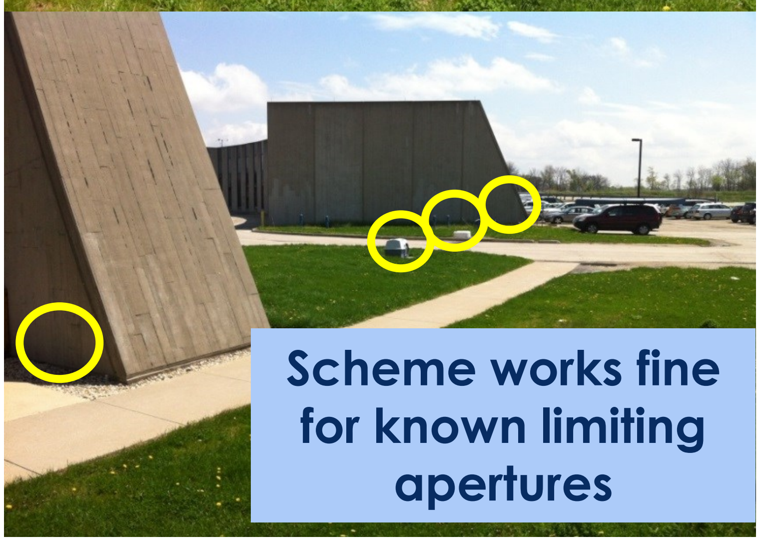
- At Fermilab, high power beams are being planned for existing facilities which have insufficient passive shielding, e.g.,
  - Muon Campus(13 W -> 8 kW)
  - Booster (~35 kW -> 80 kW)
  - Main Injector (700 kW -> 2 MW)
- Supplemental shielding addition is not possible and/or very costly and/or impractical
- Historically, Fermilab has used passive shielding in conjunction with interlocked radiation detectors to provide comprehensive protection necessary to meet the requirements of the Fermilab Radiological Controls Manual (FRCM)

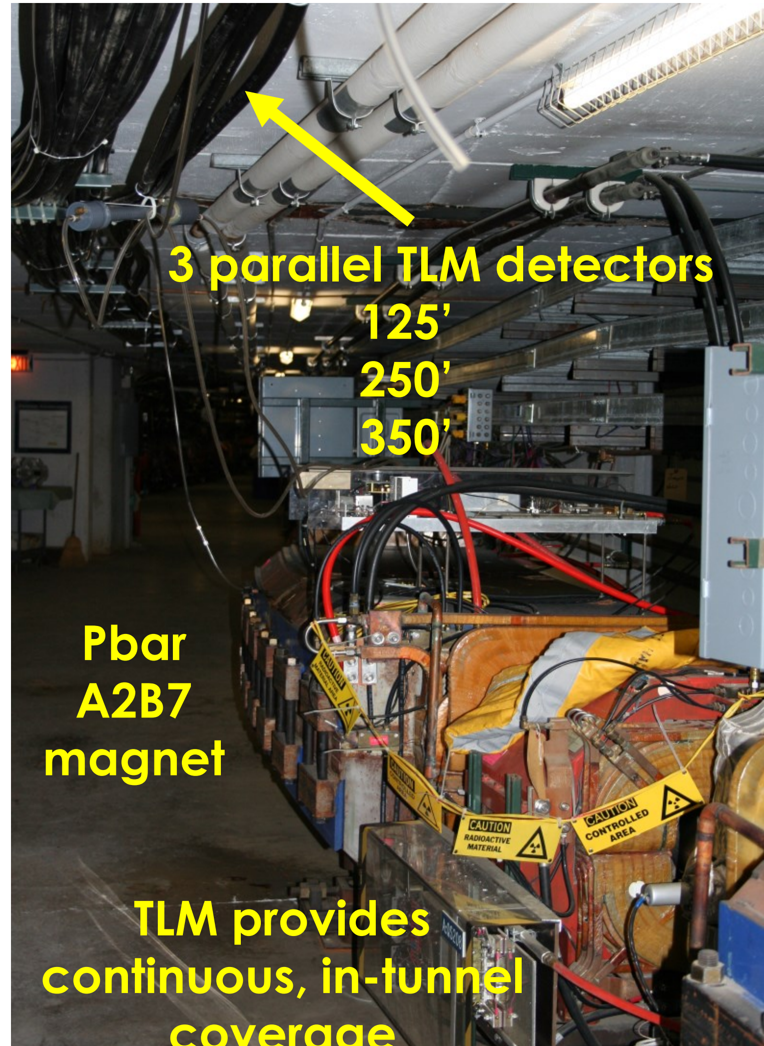


Motivation for TLM:

- Large numbers of additional interlocked detectors (chipmunks) would be required for some installations, e.g.,:
  - Muon campus (42->200 - mu2e experiment)
  - Booster (48->? – PIP/PIP-II)
- AD received encouragement from the Fermilab ESH&Q Section in May 2011 to pursue development of a long detector system

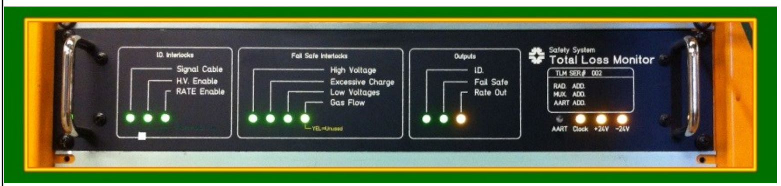
Examples of Chipmunk and TLM installations



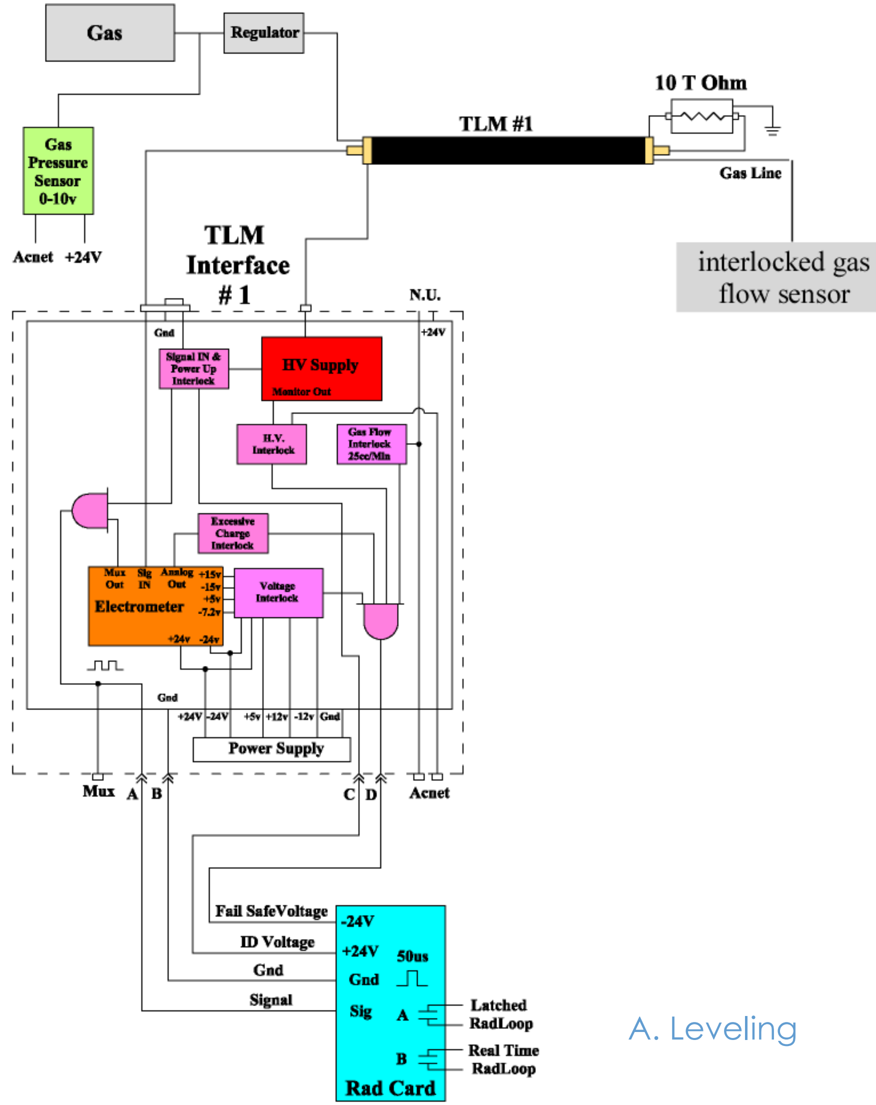


TLM system diagram

- Detector works in ion chamber mode
  - 800 volt detector bias
- Argon/CO_2 detector gas
  - Nominally 25 cc/min



- Electrometer output is calibrated in units of nC/TTL pulse
- Heartbeat provided by 10 Tohm resistor (83 pA = 5 nC/min)



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TLM system design requirements:

- Limit beam losses to the level of 1 watt/meter
- The TLM electrometer must be able to collect charge with a 100% duty factor, i.e., no dead time for integrator reset
- TLM system must connect directly to the existing Radiation Safety System (RSS), via existing radiation interlock cards
- Include a rigorous testing program and calibration schedule
- The response of the TLMs must be characterized and /or predictable for a wide range of beam loss conditions
- The TLM system must be fail safe; i.e., the (RSS) must be disabled if:
  - TLM chassis loses power
  - Motherboard voltages go out of tolerance
  - TLM detector is disconnected from its electrometer
  - TLM heartbeat is lost (provided by 83 pA leakage current)
  - TLM bias voltage falls outside tolerance
  - The TLM gas flow is lost, (nominally 25 cc/min)

Setting TLM trip levels:

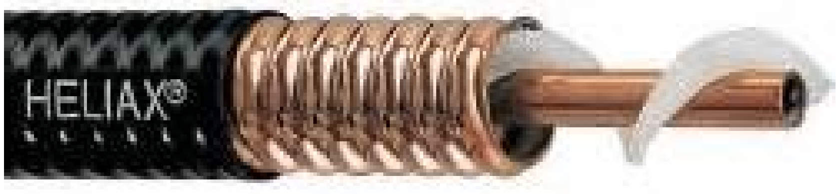
- Determine the worst case beam loss condition by:
  - Evaluation of the possibilities, then
    - MARS simulation(s), and/or
    - Measurement
- The worst case condition includes consideration of:
  - Beam enclosure geometry
  - Maximum beam intensity lost (MBL)
  - Beam energy
  - Amount of shielding present

Setting TLM trip levels:

- Posting and controls for region determined allowable beam intensity lost (ABL)
- The TLM response to the worst case condition (TLM_{max}) is determined by:
  - Measurement, or
  - By MARS simulation
- TLM trip level is set by scaling:
  - Trip Level = TLM_{max} x ABL / MBL

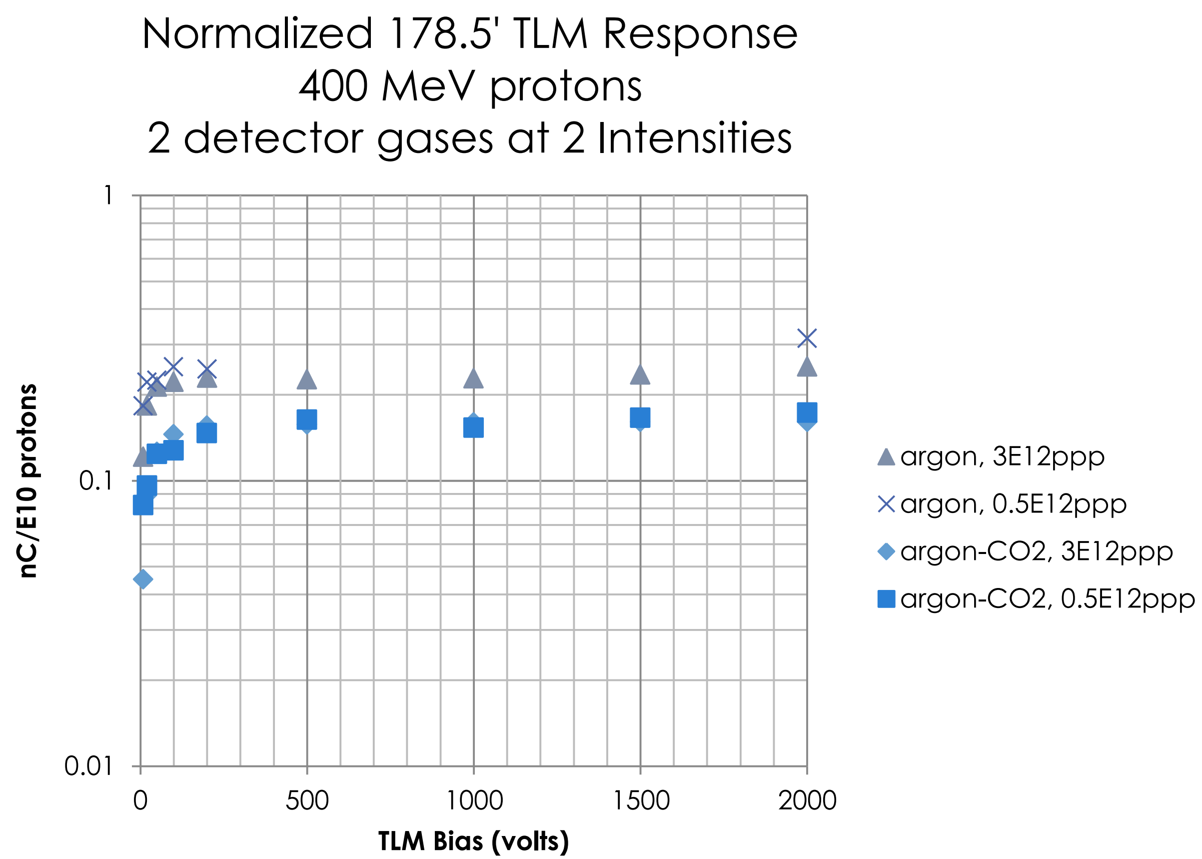
TLM trip level philosophy:

- The trip level has to be safe AND it has to allow normal losses with reasonable margin for variances in operation
  - Avoid spurious/unnecessary system trips
- TLM cannot distinguish between single point, localized losses and losses distributed over its entire length
  - This implies the trip levels are conservative
- Trip levels are to be determined by the laboratory's well-developed, shielding assessment process



Possible applications:

- Limit effective dose rate outside of radiation shields
  - Implicitly includes control of radiation skyshine
- Limit beam loss to 1 W/m
- Limit surface water, ground water, and/or air activation


Normalized 178.5' TLM Response
400 MeV protons
2 detector gases at 2 Intensities
1
0.1
0.01
0
500
1000
1500
2000
nC/E10 protons
TLM Bias (volts)
argon, 3E12ppp
argon, 0.5E12ppp
argon-CO2, 3E12ppp
argon-CO2, 0.5E12ppp

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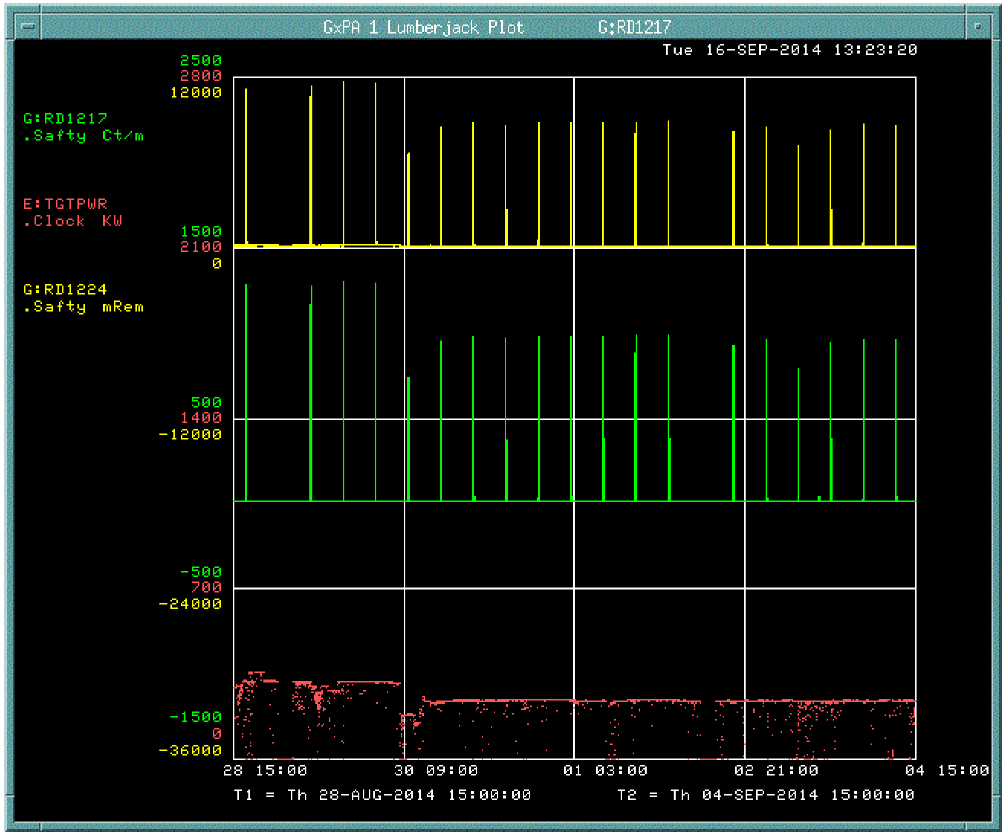
Example application: NuMI groundwater protection



Scarecrow in NuMI tunnel (existing GW protection)

800' TLM response

NuMI beam power

A seven day operating period August 20 -> September 4, 2014

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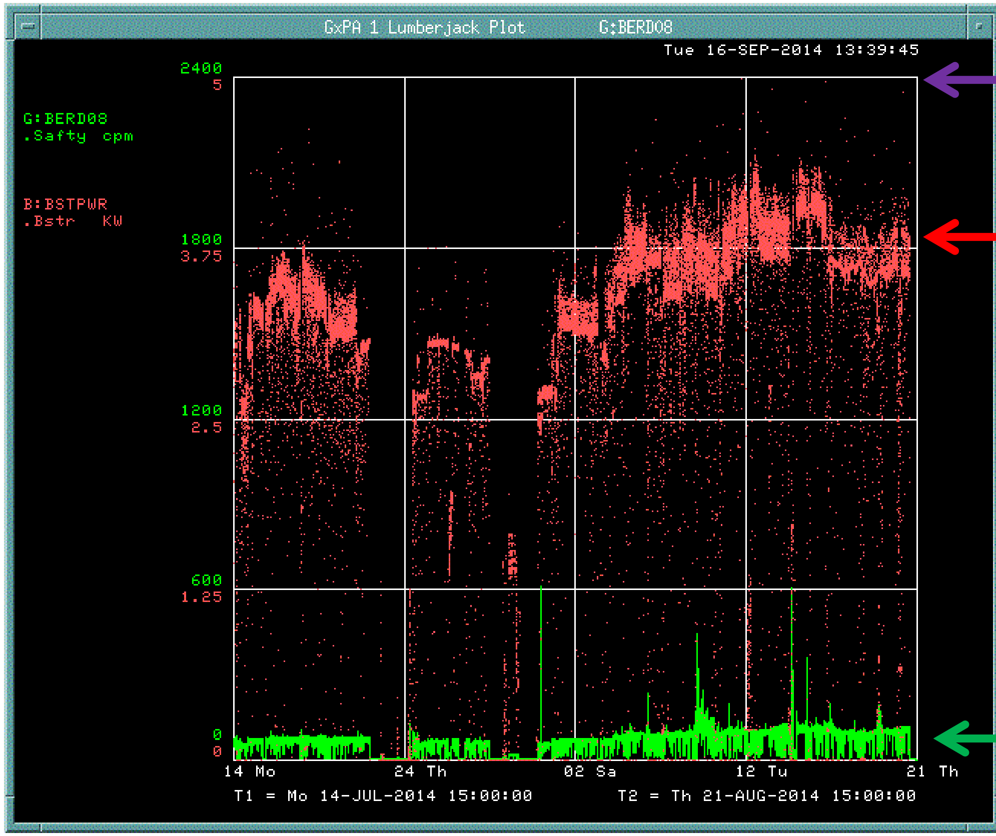
Example application: Booster shielding



Proposed TLM trip limit

Booster beam power

180' TLM response

A thirty-eight day operating period July 14 -> August 21, 2014

A. Leveling

Timeline:

- Development began in May 2011
- Extensive detector response testing October 2011 to present
- Preliminary approval granted by Fermilab ESH&Q in May 2014
- Full demonstration application begins October 2014
  - Entire Booster Ring covered by 8 systems
  - In parallel with the existing system of 48 chipmunks
  - One redundant detector cable
- Accelerator Division will seek final approval of the system in CY2015

Extra slides

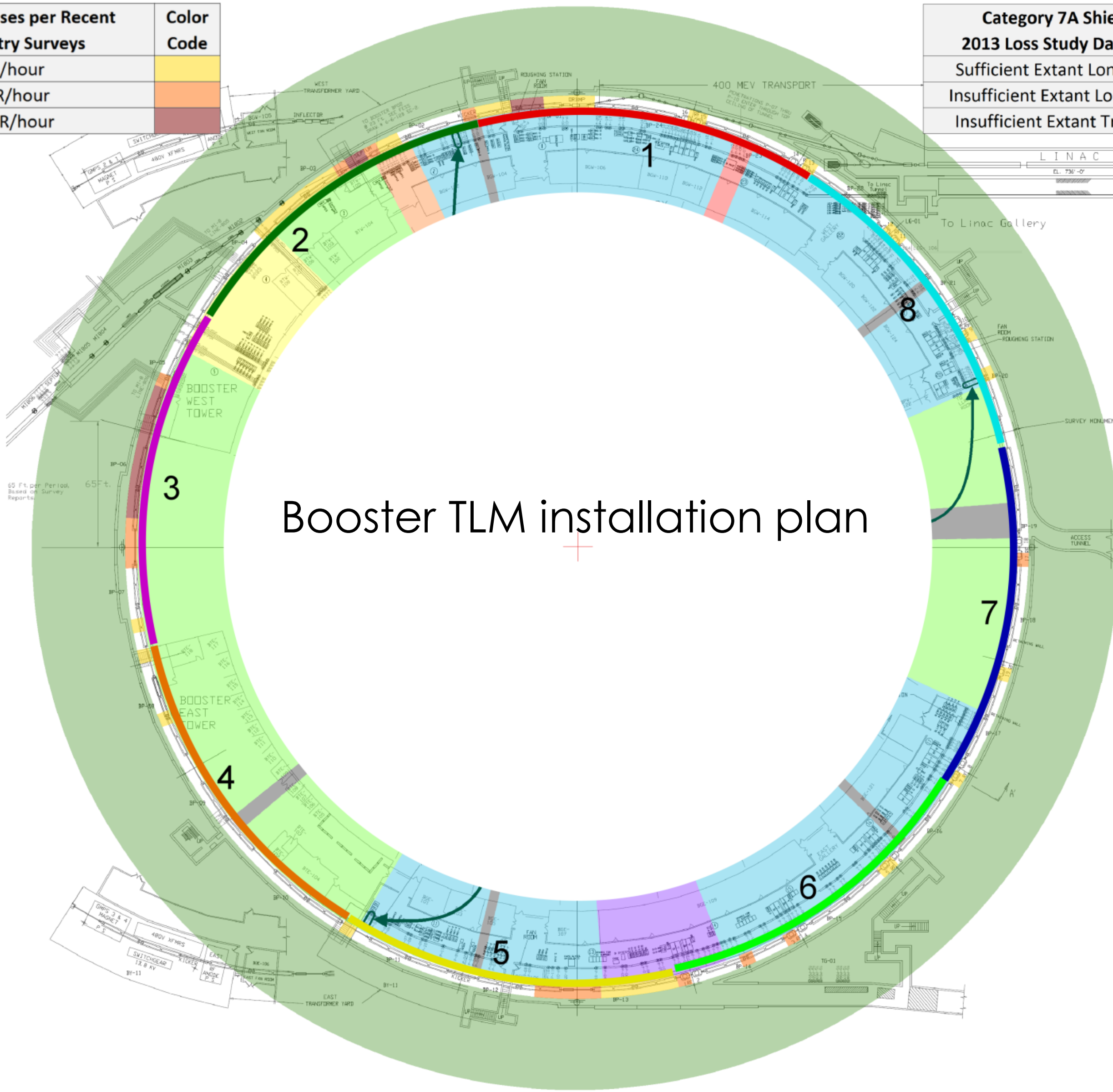
Detector Cable

- HJ5-50, HELIAX® Standard Air Dielectric Coaxial Cable, corrugated copper, 7/8 in,
- black PE jacket

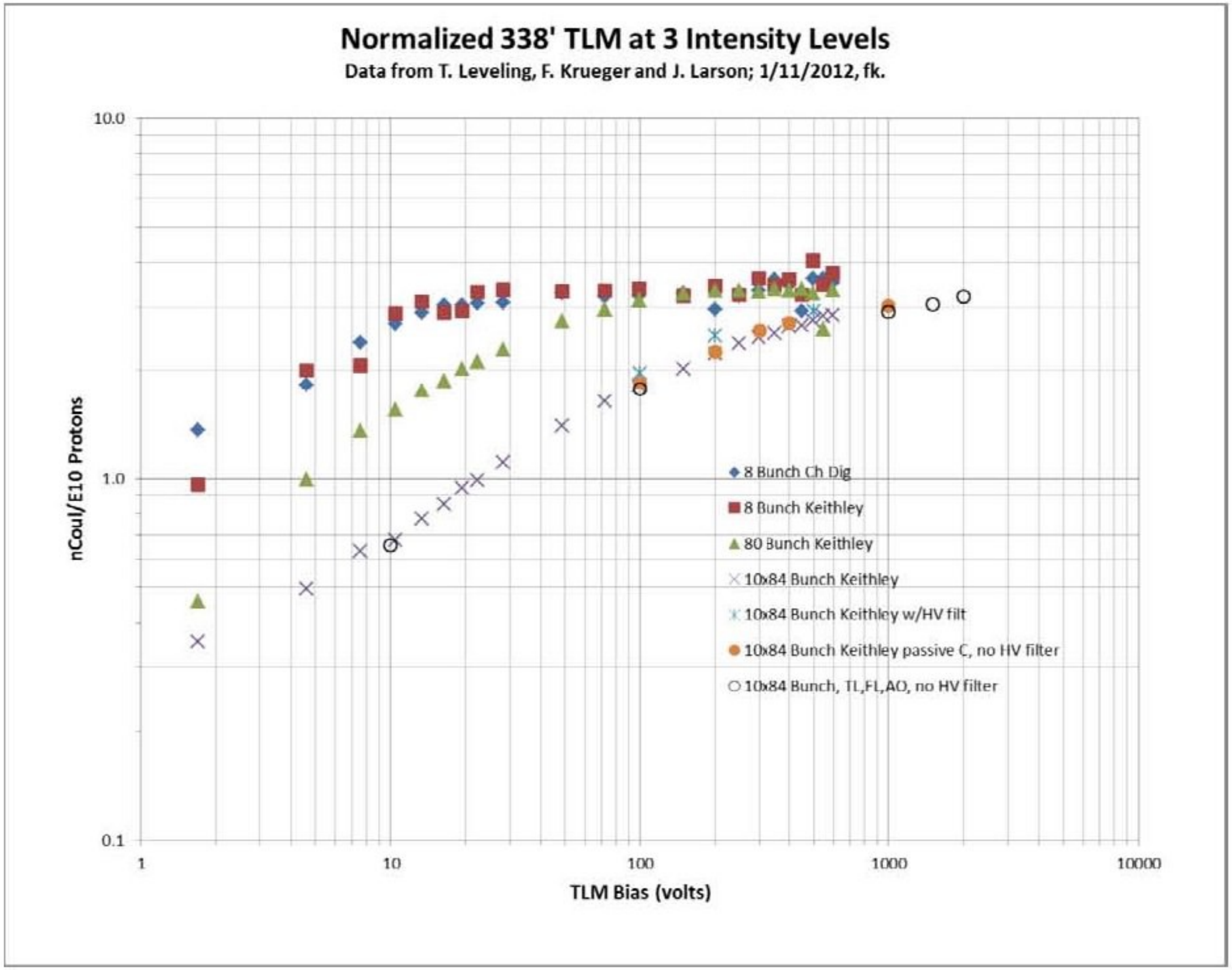
Penetration Type	Color Code	Total Number of Each Type	Description of Penetration	R (ft)	d (ft)	400MeV Exit Dose Rate (mrem/pulse)	8GeV Exit Dose Rate (mrem/pulse)	Notes on Exit Dose Rates
1		151	19' long single-leg 6.5" by 6.5" penetration	3.30	1.38	3.17E-03	3.48E-02	*with 12' of poly beads (MARS attenuation for single pen. used)*
2		4	16.6' long single-leg 6.5" by 6.5" penetration in ceiling of Period 23	4.60	1.33	1.84E-03	2.02E-02	*with 12' of poly beads (MARS attenuation for single pen. used)*
3		8	Four-leg, 6" diameter circular penetration in Period 2	3.30	1.38	4.42E-12	4.85E-11	*for an empty penetration*
4		17	16.25' long single-leg 6.5" by 6.5" penetration high on wall of Period 13	2.50	6.27	3.58E-04	3.93E-03	*with 12' of poly beads (MARS attenuation for single pen. used)*
5		12	Three-leg, 5" diameter circular penetrations from Periods 4 & 5 to West Booster Tower	3.30	1.38	4.15E-14	4.55E-13	*for an empty penetration*
None		N/A	No penetrations in this region	N/A	N/A	N/A	N/A	*N/A*
Labyrinth		N/A	Some kind of labyrinth	N/A	N/A	N/A	N/A	*labyrinth calculations are not included here*

Regions of Booster Losses per Recent AD ES&H Initial Entry Surveys	Color Code
Losses ≥ 5 mR/hour	
Losses ≥ 20 mR/hour	
Losses ≥ 100 mR/hour	

Category 7A Shielding Based on 2013 Loss Study Data Scaled to 8GeV	Color Code
Sufficient Extant Longitudinal Shielding	
Insufficient Extant Longitudinal Shielding	
Insufficient Extant Transverse Shielding	

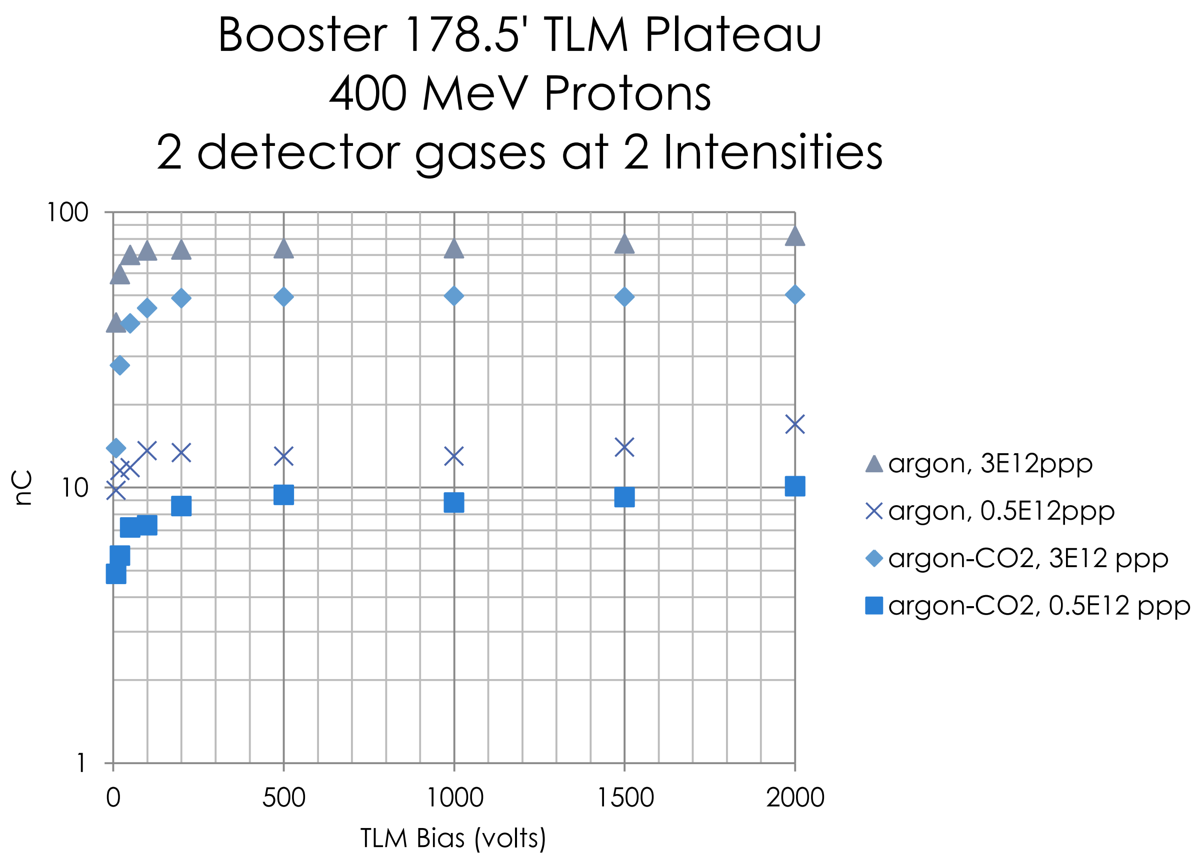


TLM response to 8 GeV proton beam loss at A2B7 magnet at Accumulator



Argon detector gas

A. Leveling


Booster 178.5' TLM Plateau
400 MeV Protons
2 detector gases at 2 Intensities
100
10
1
nC
0
500
1000
1500
2000
TLM Bias (volts)
argon, 3E12ppp
argon, 0.5E12ppp
argon-CO2, 3E12 ppp
argon-CO2, 0.5E12 ppp

A. Leveling

Critical shielding thickness

- A layer of shielding which must be present to limit the delivered dose over an interval at which the TLM system can respond
- The resulting dose that could be delivered must fall below limits established by the Fermilab Radiological Controls Manual for the desired posting and occupancy condition