Irradiation Test Area Proposal (google doc)

ITA Task Force

12 Novemberber 2018

Recent Recommendations from DOE Reviewers

- HL LHC CMS CD-1 Director's Review -- Outer Tracker Recommendation, Page 8 of Final report:

1. The review committee recommends that Fermilab work with the DOE to establish a proton irradiation facility at Fermilab. This is particularly important during LS2 when the CERN PS facility will be down. This is critical not only for the CMS Outer Barrel but also for all the HL-LHC projects.

- HL LHC CMS CD-1 Review, Outer Tracker Comments, Page 8 of Final Report

(now also IPT Tracking item R06)

The Committee encouraged FNAL to establish a proton irradiation facility. This will be of great use for the upgrade program and beyond. In case this facility will not be realized or not be available in time, an alternative needs to be developed. An analysis that supports the preferred alternative needs to be performed.

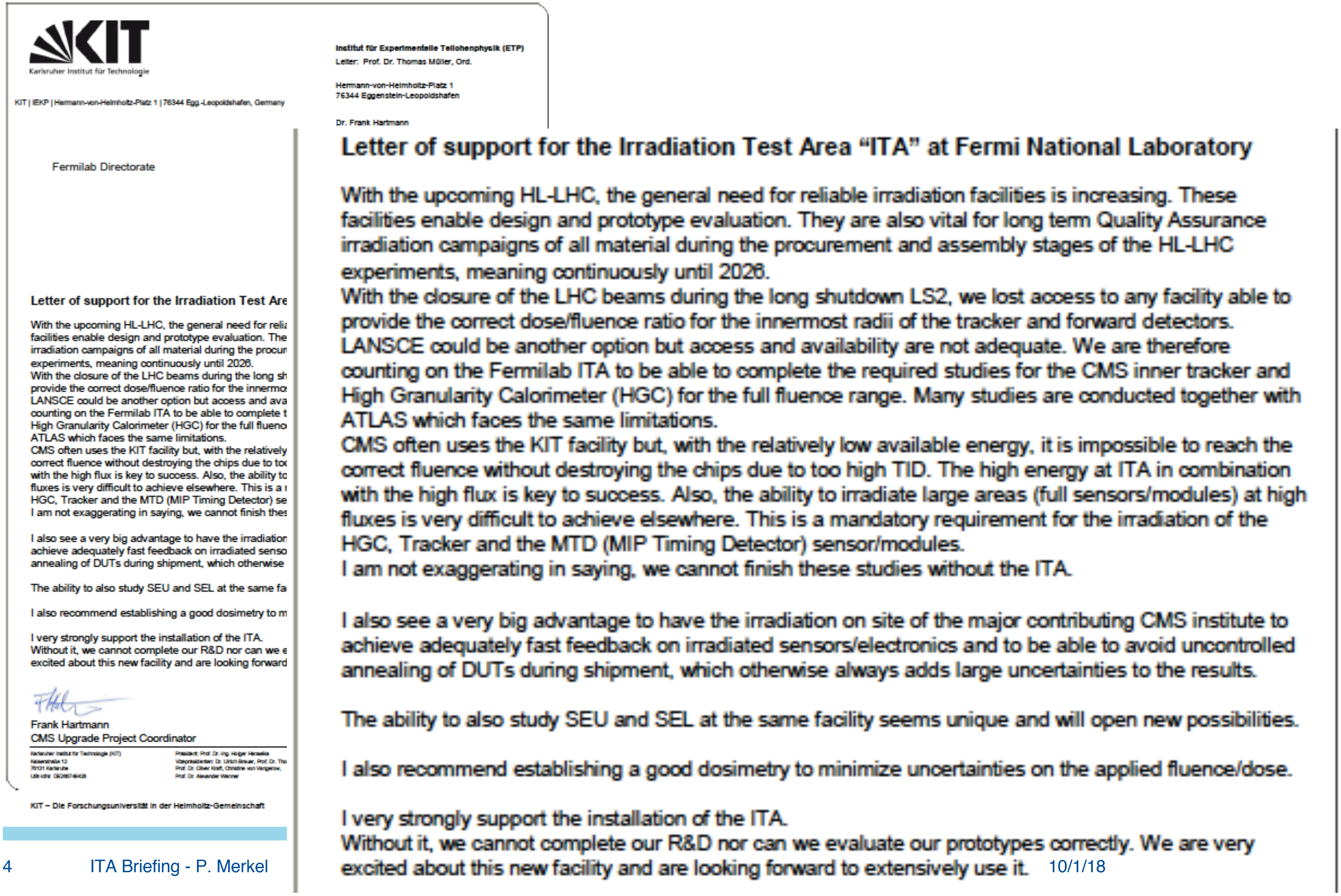
- HL LHC ATLAS CD-1 Review, Pixel Recommendation #3 (available on request)

3, Work with DOE to pursue a dedicated proton irradiation facility in the U.S., e.g. by supporting the proposed irradiation facility at FNAL.

US-CMS Needs

- Outer Tracker upgrade: ~1/3 of tracker modules are built in US
  - Silicon sensor and module QA/QC through irradiation crucial
  - Neutron and proton irradiation planned between 2019-2024
  - QA during prototyping (2019) → decision on sensor design
  - QC on each batch of sensors throughout production (2020-24)
    - One batch every 3 months x 3 sensor types
- Similar needs in HGCal, MIP Timing Detector, Inner Tracker
  - Prototyping of sensors and Fermilab ASICs

Letter of Support from CMS Upgrade Coordinator



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Institut für Experimentelle Teilchenphysik (ETP)
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Dr. Frank Hartmann

Fermilab Directorate

Letter of support for the Irradiation Test Area "ITA" at Fermi National Laboratory

With the upcoming HL-LHC, the general need for reliable irradiation facilities is increasing. These facilities enable design and prototype evaluation. They are also vital for long term Quality Assurance irradiation campaigns of all material during the procurement and assembly stages of the HL-LHC experiments, meaning continuously until 2026.
With the closure of the LHC beams during the long shutdown LS2, we lost access to any facility able to provide the correct dose/fluence ratio for the innermost radii of the tracker and forward detectors. LANSCE could be another option but access and availability are not adequate. We are therefore counting on the Fermilab ITA to be able to complete the required studies for the CMS inner tracker and High Granularity Calorimeter (HGC) for the full fluence range. Many studies are conducted together with ATLAS which faces the same limitations.
CMS often uses the KIT facility but, with the relatively low available energy, it is impossible to reach the correct fluence without destroying the chips due to too high TID. The high energy at ITA in combination with the high flux is key to success. Also, the ability to irradiate large areas (full sensors/modules) at high fluxes is very difficult to achieve elsewhere. This is a mandatory requirement for the irradiation of the HGC, Tracker and the MTD (MIP Timing Detector) sensor/modules.
I am not exaggerating in saying, we cannot finish these studies without the ITA.

I also see a very big advantage to have the irradiation on site of the major contributing CMS institute to achieve adequately fast feedback on irradiated sensors/electronics and to be able to avoid uncontrolled annealing of DUTs during shipment, which otherwise always adds large uncertainties to the results.

The ability to also study SEU and SEL at the same facility seems unique and will open new possibilities.

I also recommend establishing a good dosimetry to minimize uncertainties on the applied fluence/dose.

I very strongly support the installation of the ITA.
Without it, we cannot complete our R&D nor can we evaluate our prototypes correctly. We are very excited about this new facility and are looking forward to extensively use it.

Letter of support for the Irradiation Test Are

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Frank Hartmann
CMS Upgrade Project Coordinator

Letter of Support from the US-ATLAS Project Manager

From: "Kotcher, Jonathan" <kotcher@bnl.gov>

Subject: Radiation testing

Date: September 28, 2018 at 3:41:47 PM CDT

To: Vivian O'Dell <odell@fnal.gov>

Dear Vivian:

The U.S. ATLAS institutions participating in the High Luminosity LHC (HL-LHC) Upgrade Project are developing many different devices that require verification of radiation tolerance to significant levels. The Application-Specific Readout Circuits (ASICs) for the ATLAS inner trackers and calorimeters are good examples of this. Currently operating facilities that can reach the required fluences have limited availability, which often leads to prohibitively long wait times (up to 1 year). Such wait times can have a significant impact on the overall construction schedules. Access to a facility that can meet the highest radiation tolerance test levels required with high availability would significantly reduce the risks associated with ensuring that our designs meet the radiation tolerance specifications. Such a facility available at Fermilab will enhance our ability to meet our international obligations.

If there are any additional details we can provide, please don't hesitate to let us know.

Sincerely,

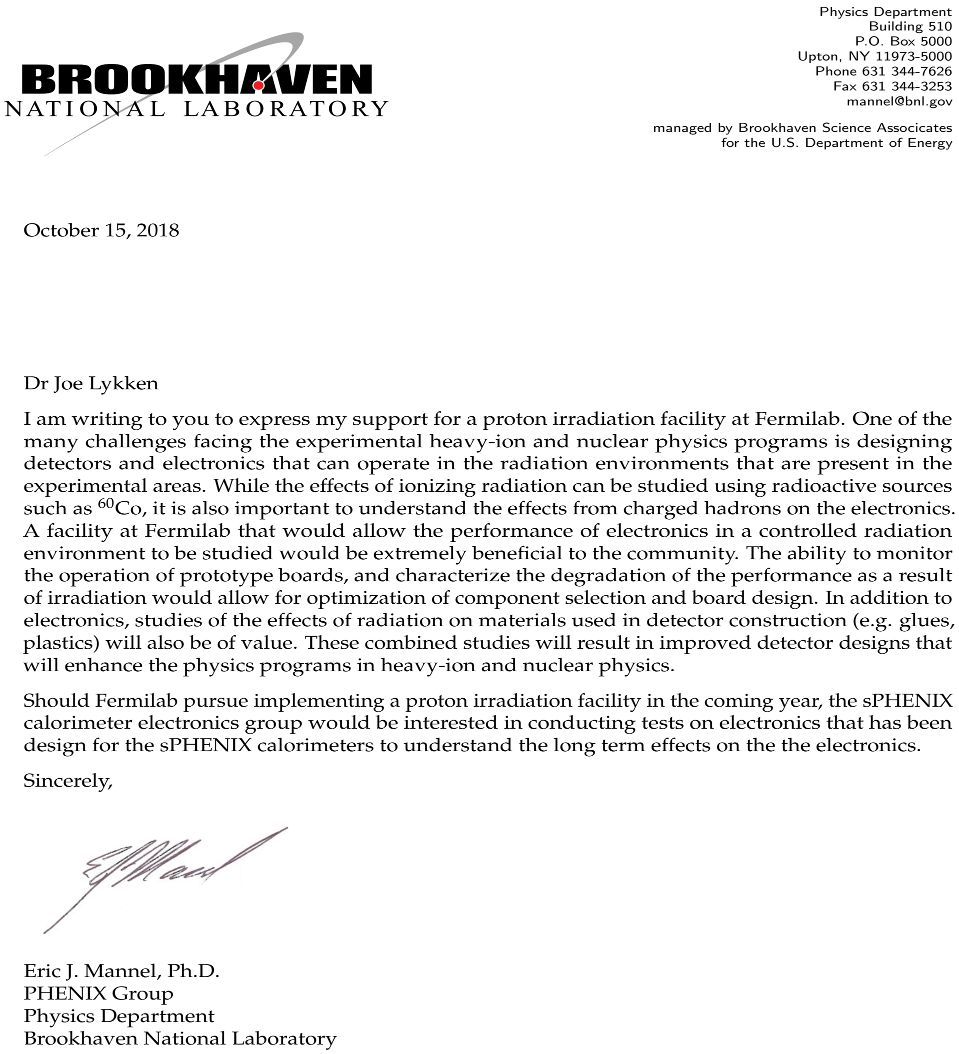
Dr. Jonathan Kotcher
Senior Scientist
Brookhaven National Laboratory
Project Manager, U.S. ATLAS HL-LHC Upgrade Project

Professor Gustaaf Brooijmans
Professor of Physics
Columbia University
Deputy Project Manager, U.S. ATLAS HL-LHC Upgrade Project

Professor Harold Evans
Professor of Physics
Indiana University
Deputy Project Manager, U.S. ATLAS HL-LHC Upgrade Project

Professor Michael Tuts
Professor of Physics
Columbia University
NSF Principal Investigator, U.S. ATLAS HL-LHC Upgrade Project

Letter of Support from sPHENIX Group at BNL



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managed by Brookhaven Science Associcates
for the U.S. Department of Energy

October 15, 2018

Dr Joe Lykken

I am writing to you to express my support for a proton irradiation facility at Fermilab. One of the many challenges facing the experimental heavy-ion and nuclear physics programs is designing detectors and electronics that can operate in the radiation environments that are present in the experimental areas. While the effects of ionizing radiation can be studied using radioactive sources such as ^{60}Co, it is also important to understand the effects from charged hadrons on the electronics. A facility at Fermilab that would allow the performance of electronics in a controlled radiation environment to be studied would be extremely beneficial to the community. The ability to monitor the operation of prototype boards, and characterize the degradation of the performance as a result of irradiation would allow for optimization of component selection and board design. In addition to electronics, studies of the effects of radiation on materials used in detector construction (e.g. glues, plastics) will also be of value. These combined studies will result in improved detector designs that will enhance the physics programs in heavy-ion and nuclear physics.

Should Fermilab pursue implementing a proton irradiation facility in the coming year, the sPHENIX calorimeter electronics group would be interested in conducting tests on electronics that has been design for the sPHENIX calorimeters to understand the long term effects on the the electronics.

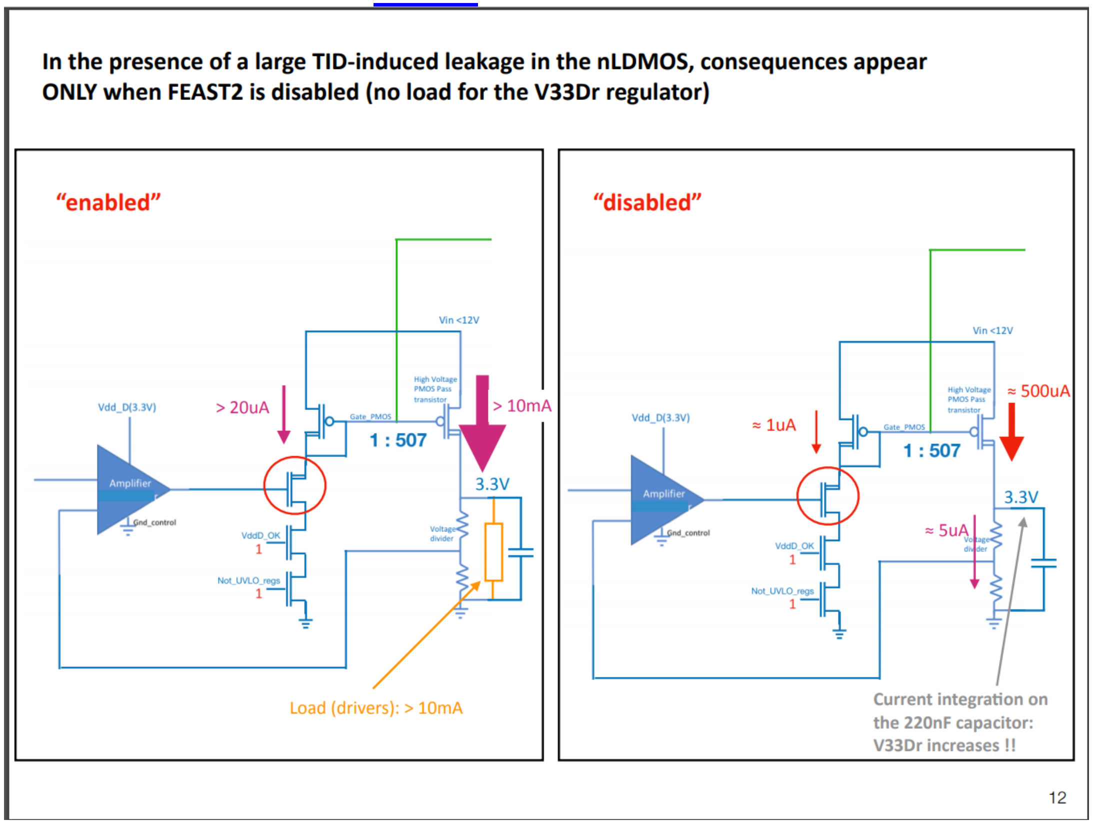
Sincerely,

Eric J. Mannel, Ph.D.
PHENIX Group
Physics Department
Brookhaven National Laboratory

CMS Pixels, HCAL, ATLAS Phase 1 – FEAST Chip

- Current mirror amplifies radiation-induced leakage current
- Charges internal capacitor to input voltage
- Damages internal interlock circuitry
- Catalyzed by SEU in data concentrator ASIC needing disable-enable cycle

Link to F. Faccio talk



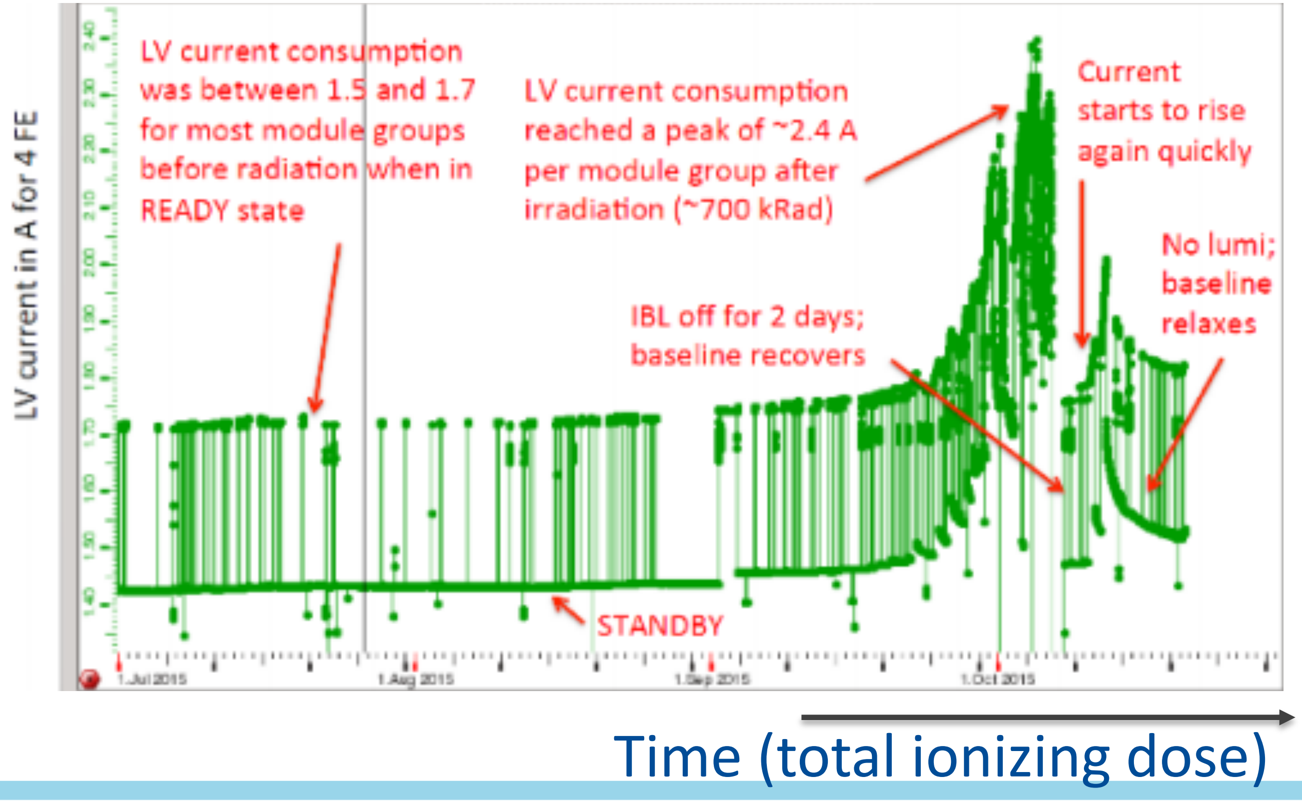
In the presence of a large TID-induced leakage in the nLDMOS, consequences appear ONLY when FEAST2 is disabled (no load for the V33Dr regulator)

Could have been known with extensive irradiation campaign
→ safer operating procedures

ATLAS IBL - skyrocketing FE currents

- Unexpected additional current draw from IBL Front end at intermediate dose
  - Traced to radiation-induced charge traps in FE chip transistors

Would have been known with extensive irradiation campaign



LV current consumption was between 1.5 and 1.7 for most module groups before radiation when in READY state

LV current consumption reached a peak of ~2.4 A per module group after irradiation (~700 kRad)

Current starts to rise again quickly

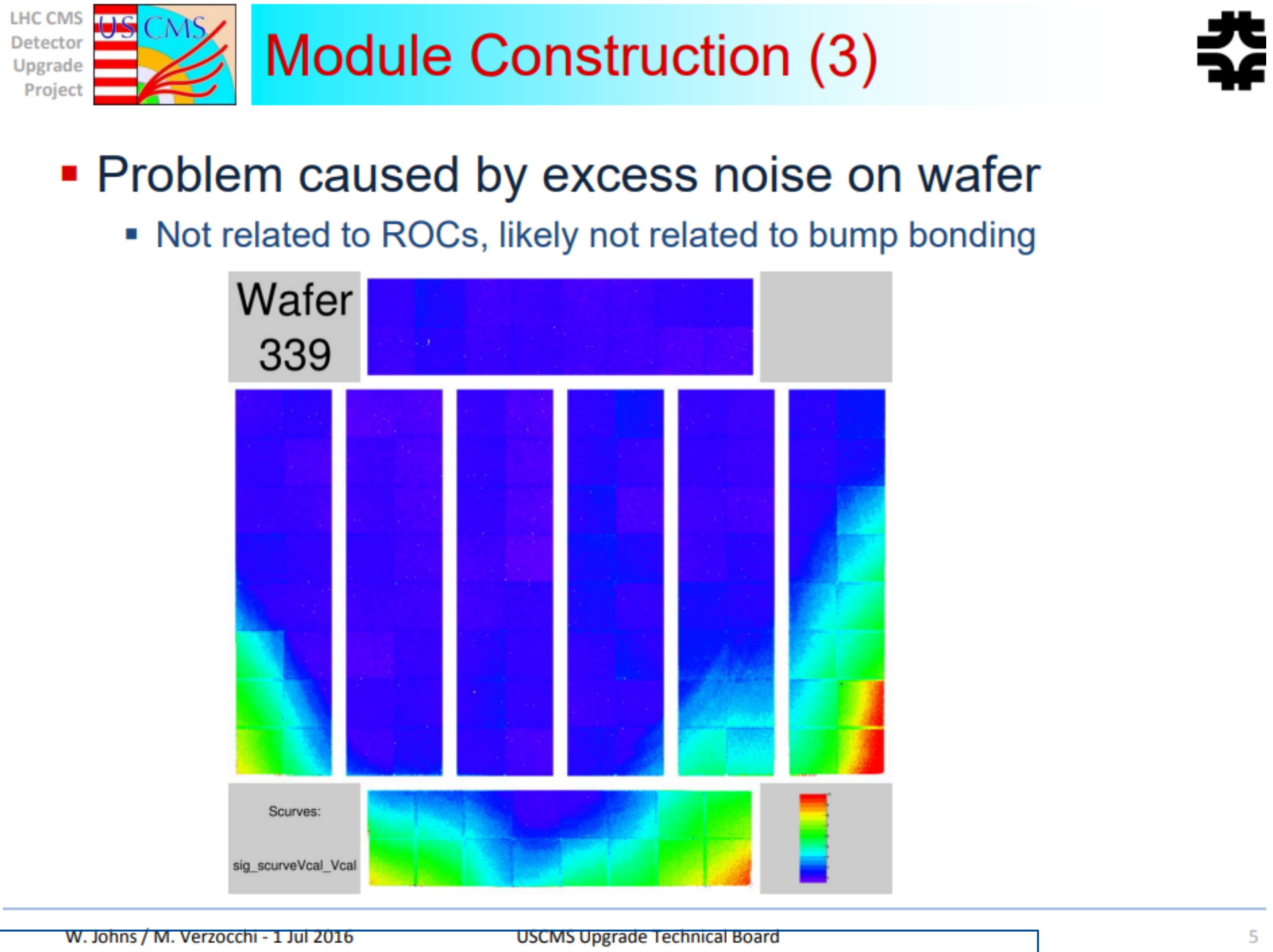
No lumi; baseline relaxes

IBL off for 2 days; baseline recovers

STANDBY

Beneficial Irradiation: CMS Phase 1 – FPIX Sensors

- Final batch of sensors show increased noise
  - Traced to excess surface charge traps not properly annealed during sintering
  - Cured with exposure to ~ 10 fb^{-1}



LHC CMS Detector Upgrade Project

Module Construction (3)

- Problem caused by excess noise on wafer
  - Not related to ROCs, likely not related to bump bonding

W. Johns / M. Verzocchi - 1 Jul 2016 USCMS Upgrade Technical Board 5

Threatened delay to Project's Critical Path

Not sure if we needed to order more parts and build more modules

Other users beyond CMS/ATLAS

- We distributed a survey to potential users
  - Not comprehensive but indicative of extent of the need for this type of beam facility
  - https://www.dropbox.com/s/z4lfshhl7b2lrqw/Responses_All_180522.pdf?dl=0

- The need is strong enough to support a variety of radiation testing areas, world-wide:
  - CMS, ATLAS, Mu2e-II, DUNE, LHC-B, sPHENIX, TOTEM, RD50, RD53, CubeSats

- Need within aeronautics industries:
  - Boeing used 2000 hours of beam time at Indiana cyclotron until that facility closed

Existing Facilities

	Particle Type	Beam Energy	Beam Size	Time to 2x10^{16}/cm^2	SEE Tests	Availability
CERN	protons	24 GeV	0.5-1.5 cm	111h	yes	LS2 shutdown
Birmingham	protons	40 MeV	1 cm	1h	yes	
Louvain	heavy ions	100s MeV		not feasible	yes	Being built
Ljubljana	neutrons	-	-	1.4h	no	
KIT (operated by ZAG company)	protons	23.5 MeV	0.5 cm	1.5h	(yes) too expensive	4h/week 6 week turnaround
Rhode Island	neutrons	-	-		no	limited
ANL (LEAF)	electrons neutrons	55 MeV 0.5 MeV		7h		Might be planned
BNL (BLIP)	protons+ neutrons	65-200 MeV		20h	no	Might be planned
TRIUMF	protons	5-500 MeV	0.5-1 cm	not feasible	yes	
FSU	protons	17 MeV				limited
LANL	protons	800 MeV		72h	no	2x/year
FNAL ITA	protons	400 MeV	1-7 cm	0.7h	yes	40x/year

Beam extraction in Fermilab LINAC

- “Pulses” from the LINAC can be extracted during the 6 second flattop of the SY120 spill and thus have minimal effect on Neutrino pulses
- By running the Irradiation Test Area simultaneously with FTBF, we have no impact on the rest of the program:
  - NuMI requires the Main Injector, as does FTBF.
  - G-2 and FTBF share a common section of beamline, and cannot run simultaneously.
  - BNB is rate limited.
  - Conservative estimate is 40 pulses available.

- A “standard” we have been using consists of
  - Single pulse of 5E12 protons per LINAC batch, 400 MeV
  - Nominally 15 Hz
  - 12 hours availability one day per week
  - A typical run would have beam impacting on 4.7 cm of Si (10%Λ)
  - Cooldown period of 1 day
  - One user per week.
  - 40 weeks/year

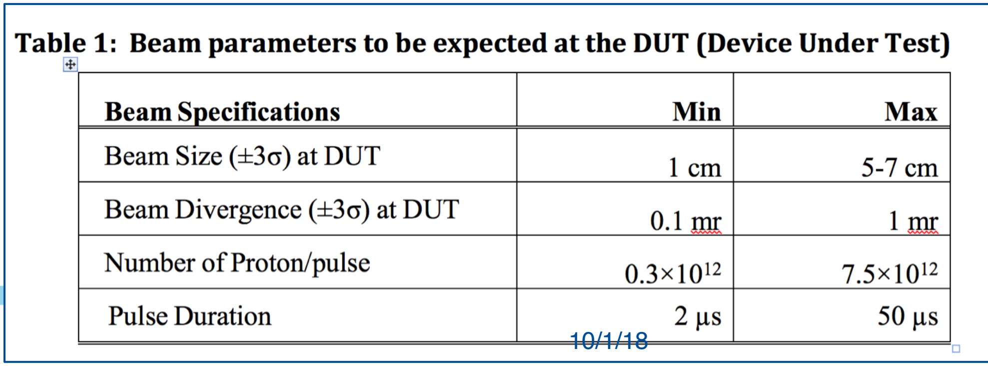
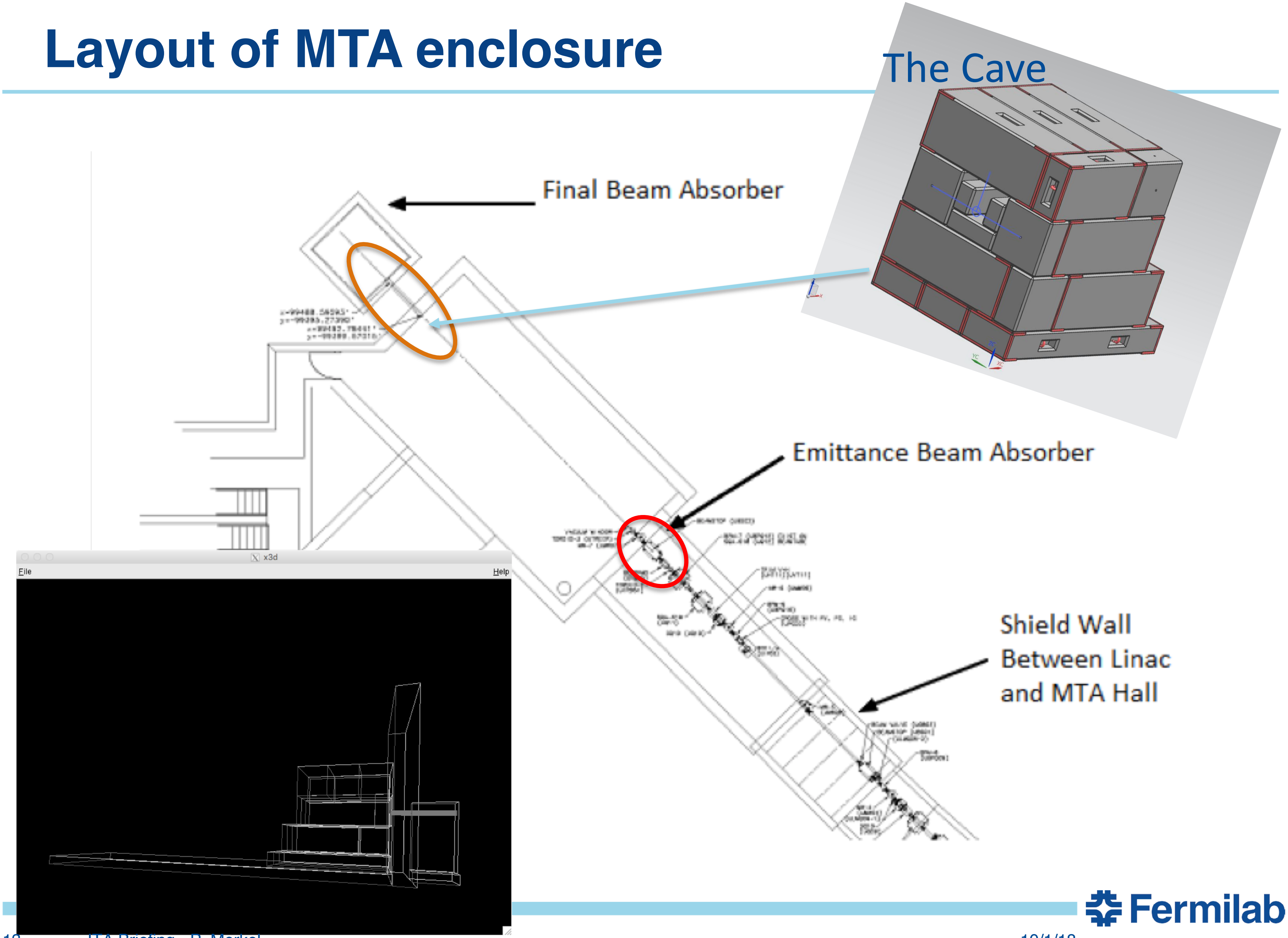


Table 1: Beam parameters to be expected at the DUT (Device Under Test)

Beam Specifications	**Min**	**Max**
Beam Size ($\pm 3\sigma$) at DUT	1 cm	5-7 cm
Beam Divergence ($\pm 3\sigma$) at DUT	0.1 mr	1 mr
Number of Proton/pulse	0.3×10^{12}	7.5×10^{12}
Pulse Duration	2 µs	50 µs

Layout of MTA enclosure



The Cave

Final Beam Absorber

Emittance Beam Absorber

Shield Wall Between Linac and MTA Hall

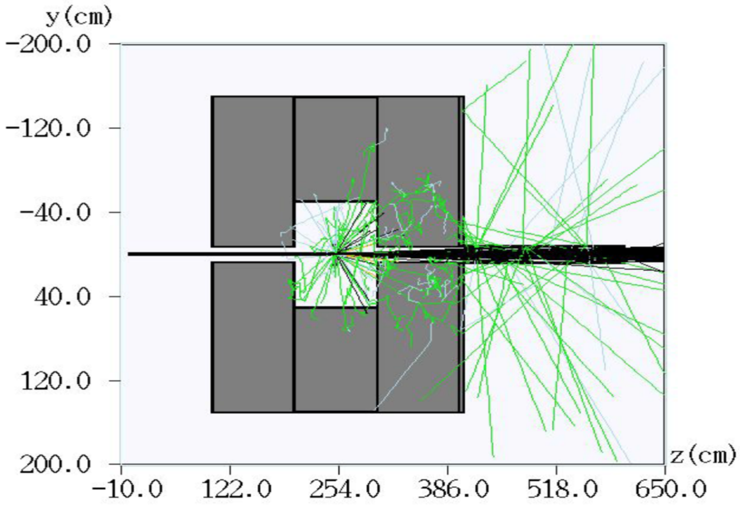
Residual activation of outside (of cave) surfaces

Outside Surfaces after 1 day	10% X_0 (0.9 cm Si)	10% λ (4.7 cm Si)	Worst Case (45 cm Fe)
Upstream wall	0.06	0.12	1.16
Side walls	0.96	0.97	5.00

mRem/hour

(for comparison: Radiation Area at Fermilab: 5-100 mRem/hr)

Table 2. Results from MARS calculation. [4] Predicted residual activation in mrem/hour of the outer surfaces of the shielding cave blocks following twelve hours of irradiation by 400 MeV protons at 5×10^{12} protons/second and one day of cool-down time. [5]



Work to be performed

Creating an irradiation facility at the MTA beamline will require removing the remnants of the muon cooling experiment, reconfiguring and instrumenting the beamline, and construction of the shielding cave. The major activities are:

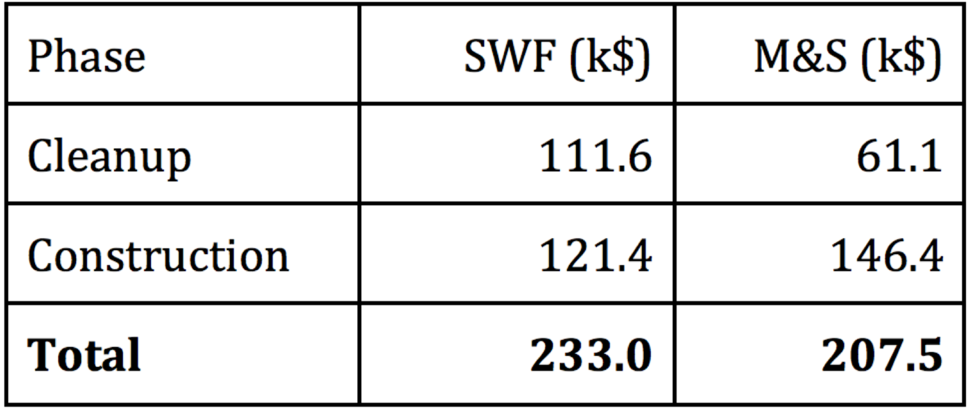
- Cleanup of beryllium from MTA vacuum window failure
- Repair of the broken sprinkler pipes
- Removal of muon cooling solenoid, RF cavity, and associated services and instrumentation
- Filling penetration for ODH fan to improve shielding
- Reposition beamline elements
- Build new vacuum window
- Add vacuum pumps
- Repair and replace MWPC beam profile detectors
- Construct stripping station
- Construct shielding cave

~3 months to build

Cost

Fermilab engineering & technical

Construction:



Phase	SWF (k$)	M&S (k$)
Cleanup	111.6	61.1
Construction	121.4	146.4
Total	**233.0**	**207.5**

Table 3: Fully loaded costs for creation of the Irradiation Test Area

Operation:

~2 FTE needed (1 AD + 1 PPD) for beamline support and delivery and user support

Operation costs only apply while ITA is being used

US CMS could contribute to operation cost

Cost recovery through users in general?

Summary

- The HL-LHC will deliver a radiation environment to its inner core that is unparalleled.

- We must perform QA/QC through irradiation testing to ensure that the detector upgrades will survive this environment.

- It is highly recommended that the U.S. embark on providing such a facility on-shore for quick turnaround and high reliability.

- After getting input and comments from the HEP (and other) communities, we believe that a radiation facility could be built cheaply and quickly in the MTA enclosure at the end of the LINAC beam line.

- Proximity to the Fermilab Test Beam Facility is highly synergistic for quick turnaround on testing new devices.

BACKUP

Existing Facilities in the U.S.

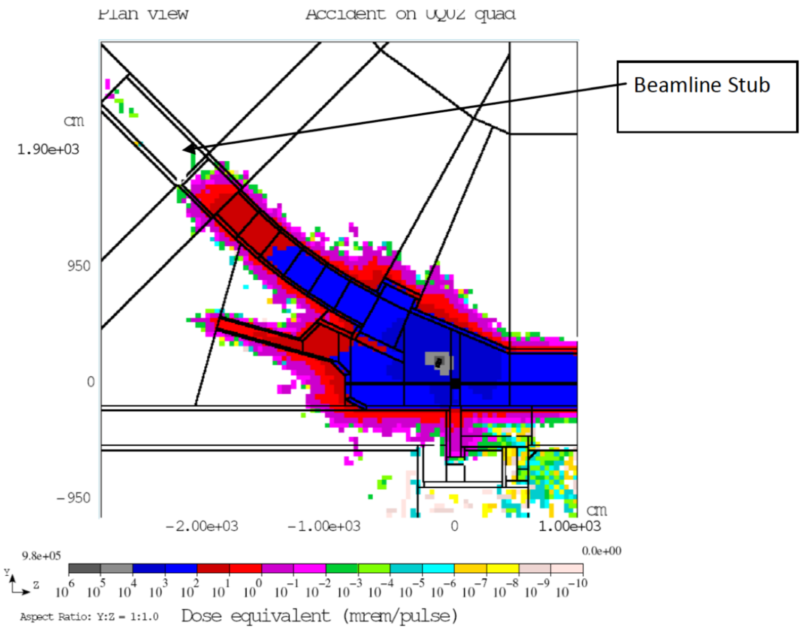
- There are few other facilities in the U.S., and typically have different characteristics than needed:
  - Los Alamos 800 MeV pion beam
    - Difficult availability (150 hours per year)
  - Florida State University 17 MeV LINAC
    - Energy too low
  - Argonne interested in Low Energy Accelerator Facility (LEAF)
    - 55 MeV electron beam and 100 MRad level gamma source
    - Would be highly synergestic with hadron beam at FNAL
  - BLIP (Brookhaven Linac Isotope Producer) could provide 65-200 MeV protons with similar fluence (10^{15} per cm^2 per hour). Putting detectors in beam is somewhat problematic (water shield)
  - Rhode Island research reactor: neutrons

November 1, 2010

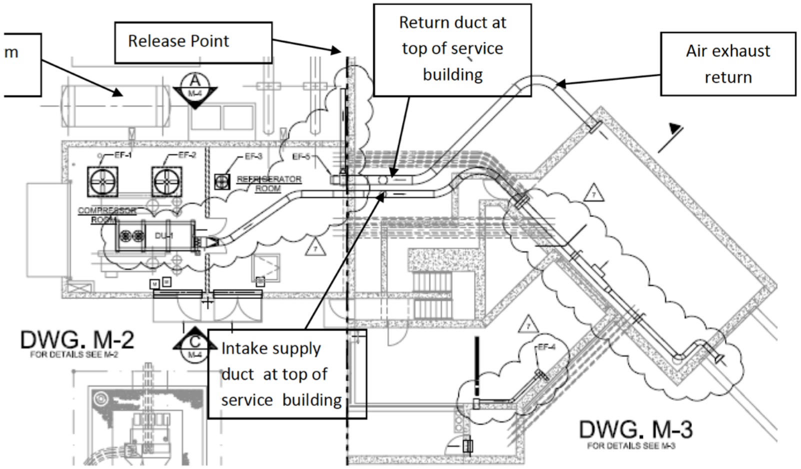
MuCOOL Facility Shielding Assessment

C. Johnstone, I. Rakhno, N. Mokhov, W. Higgins

Edited by M. Gerardi



Beamline Stub



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Release Point

Return duct at top of service building

Air exhaust return

Intake supply duct at top of service building

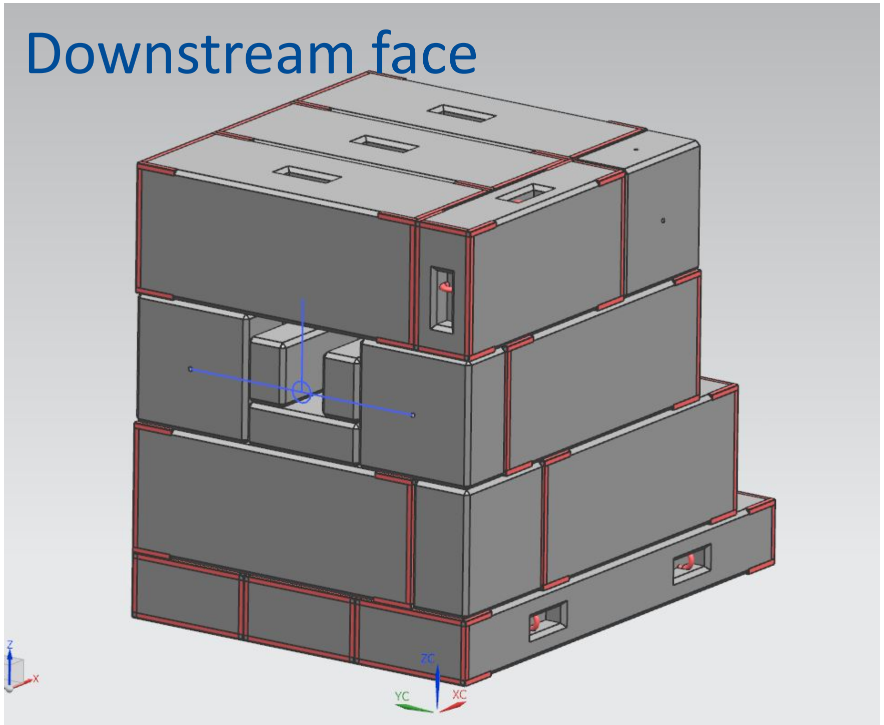
Figure 4. Prompt dose in experimental hall enclosure from worst-case loss in Linac for 1.6 x 10^{13} protons/pulse.

This is an example of the cosiderable amount of beam simulation, already performed for an activation analysis of the MTA program. The ITA will have different requirements, but we can build on this work.

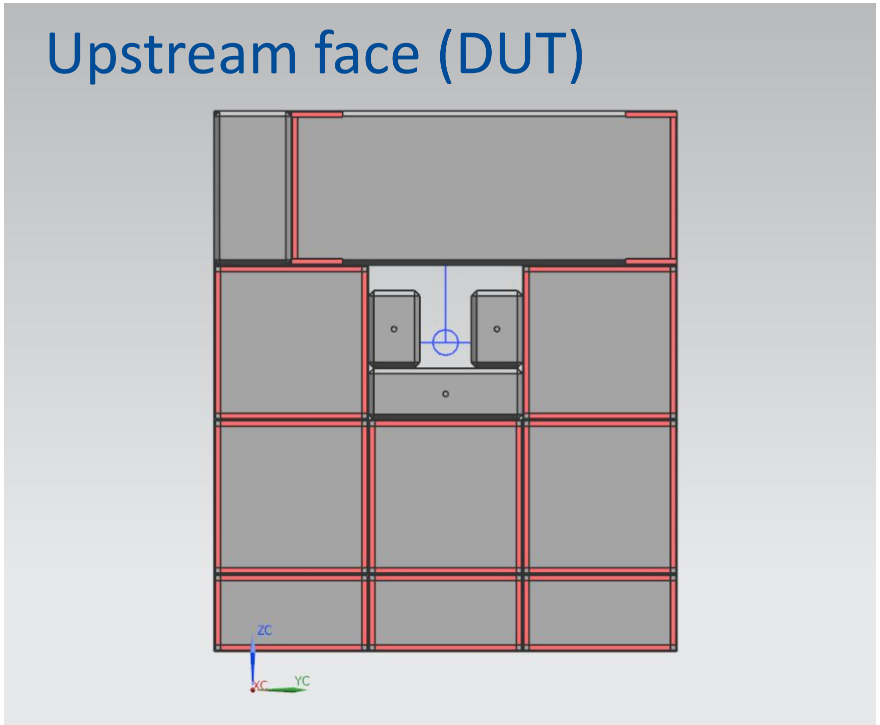
Upstream "stub" of beamline

- Trio of quads can be moved to maximize focusing at the cave
- New tracking MWPC to monitor beam position
- Stripping of electrons from negative ion beam done in downstream area

The Cave



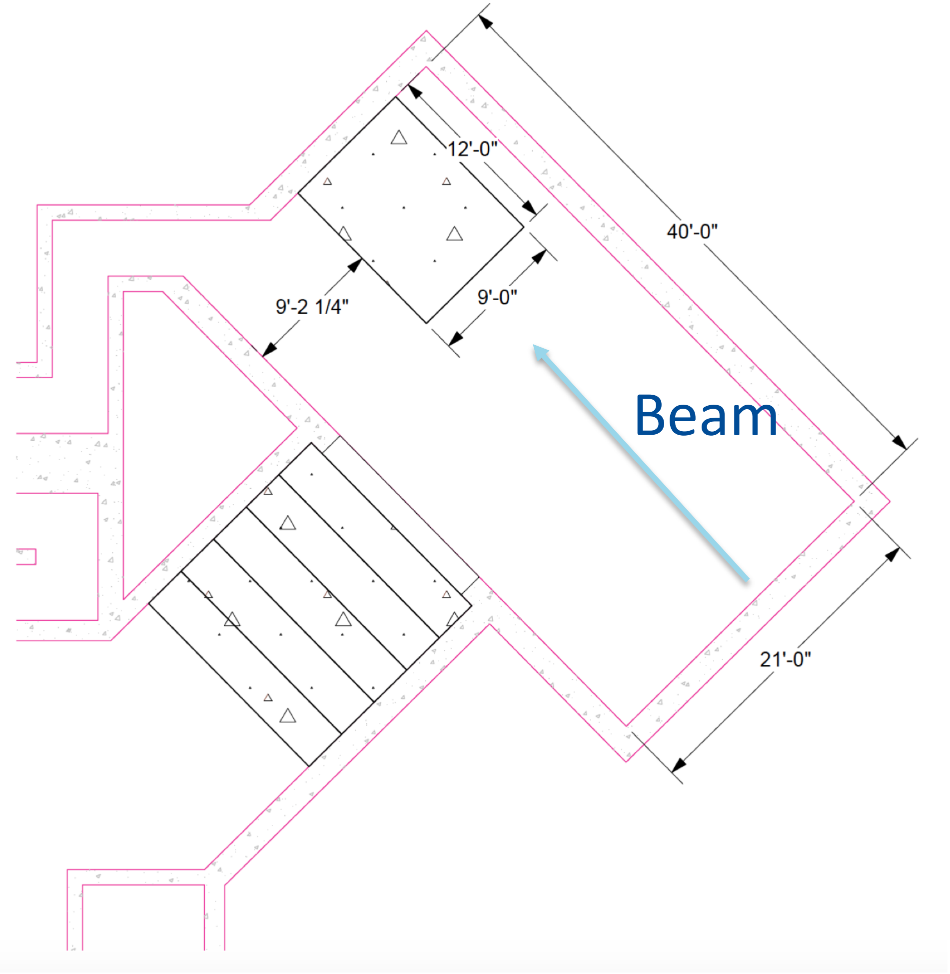
Downstream face



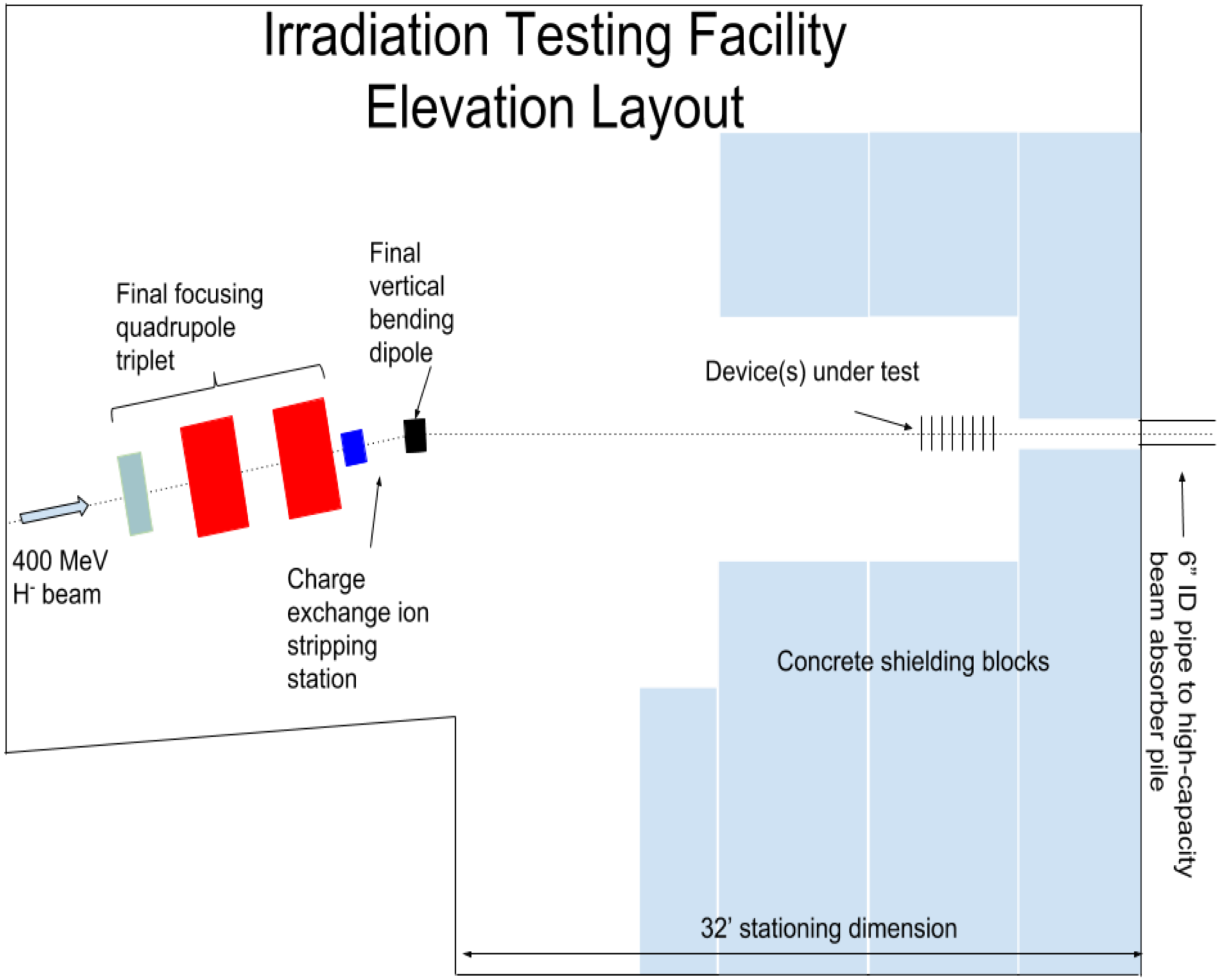
Upstream face (DUT)

- Placement of detectors will be ensured with fixtures and trolley system
- We have outlined a schematic for shielding block placement
- Upstream face is open for ease of installation of DUT

Placement of Cave



Side View



Irradiation Testing Facility
Elevation Layout

Final focusing quadrupole triplet

Final vertical bending dipole

Device(s) under test

400 MeV H^- beam

Charge exchange ion stripping station

Concrete shielding blocks

6" ID pipe to high-capacity beam absorber pile

32' stationing dimension

Residual Activation of Cave

Secondaries, residual activity (short-term)

After 12 hours of irradiation at 5x10^{12} protons/second, different cooldown times:

Residual Activity (mrem/hr) of cave

Outside surfaces at **1 hour**	10% X_0 (0.9 cm Si)	10% λ (4.65 cm Si)	45 cm Fe (worst case)
10 Upstream wall	1.815E-01	7.028E-01	5.436E+00
6 Side walls	6.062E+00	6.347E+00	3.155E+01

Outside surfaces at **1 day**	10% X_0 (0.9 cm Si)	10% λ (4.65 cm Si)	45 cm Fe (worst case)
10 Upstream wall	5.660E-02	1.165E-01	1.159E+00
6 Side walls	9.604E-01	9.668E-01	4.997E+00

Inside surfaces at **1 hour**	10% X_0 (0.9 cm Si)	10% λ (4.65 cm Si)	45 cm Fe (worst case)
3 Upstream wall	1.084E+02	1.017E+02	1.869E+03
5 Side walls	4.428E+02	4.515E+02	2.369E+03
7 Downstream wall	5.443E+02	4.870E+02	4.256E+02

Inside surfaces at **1 week**	10% X_0 (0.9 cm Si)	10% λ (4.65 cm Si)	45 cm Fe (worst case)
3 Upstream wall	1.507E-01	1.410E-01	2.294E+00
5 Side walls	1.190E+00	1.271E+00	4.646E+00
7 Downstream wall	1.827E+00	1.638E+00	1.086E+00

Backup for 0.75 + 0.25 FTE

Monitor systems, such as vacuum and LCW, daily.
Liaison between PPD and AD to establish schedule.
Tune up beamline prior to irradiation run.
Develop metrics for Linac which will allow rapid tune up.
Analyze proton-on-target data.

Maintenance work on power supplies, LCW, and vacuum.
Specifications of replacement parts.