

Beam Stimulation Overview

Motivation

Stimulating Simulations for Beam Line Muon Simulations in NuMI for LBNE

Motivation

Design

Prototype Tests at NuMI

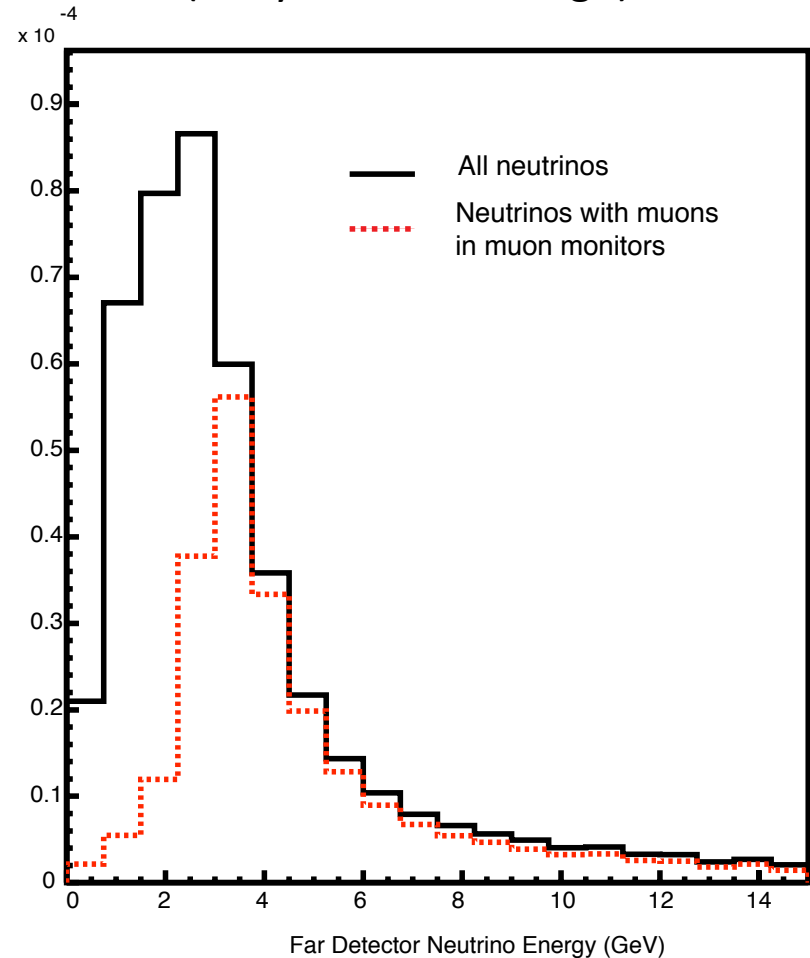
Motivation

- The need for accurate post-absorber muon measurements has grown with Near Detector-less LBNE redesign
- The hope is to rely on detailed beam simulation plus:
 - Extensive hadro-production measurements
 - Tertiary muon measurements in both LBNE and NuMI
 - *NuMI muon + neutrino measurements “translated” to LBNE*
- Onus is upon the muon systems to provide sufficient measurements to characterize the neutrino beam at the far detector

Muon-Neutrino Correlation

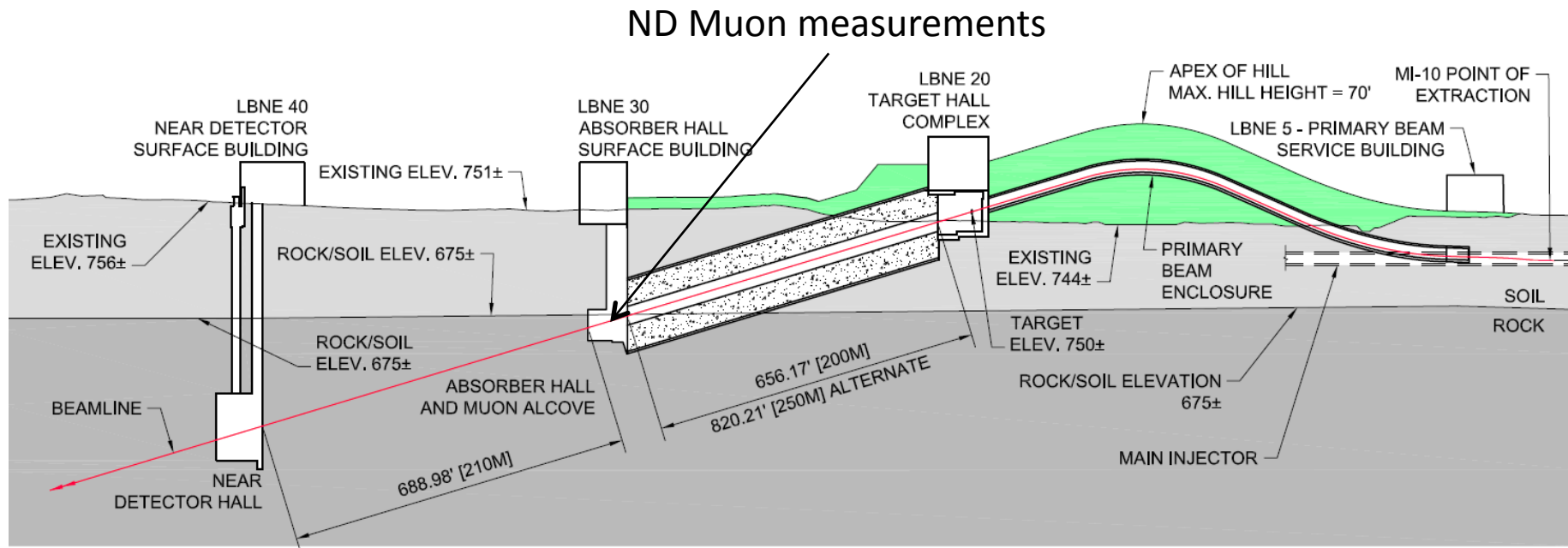
- Muons and neutrinos are anti-correlated in the two-body decays of pions and kaons
- Muons take most of the momentum in the decay
- For pions:
 - $E_\nu = (0-0.43)E_\pi$
 - $E_\mu = E_\pi - E_\nu = (0.57-1.0)E_\pi$

Neutrinos at the Far Detector
(early absorber design)

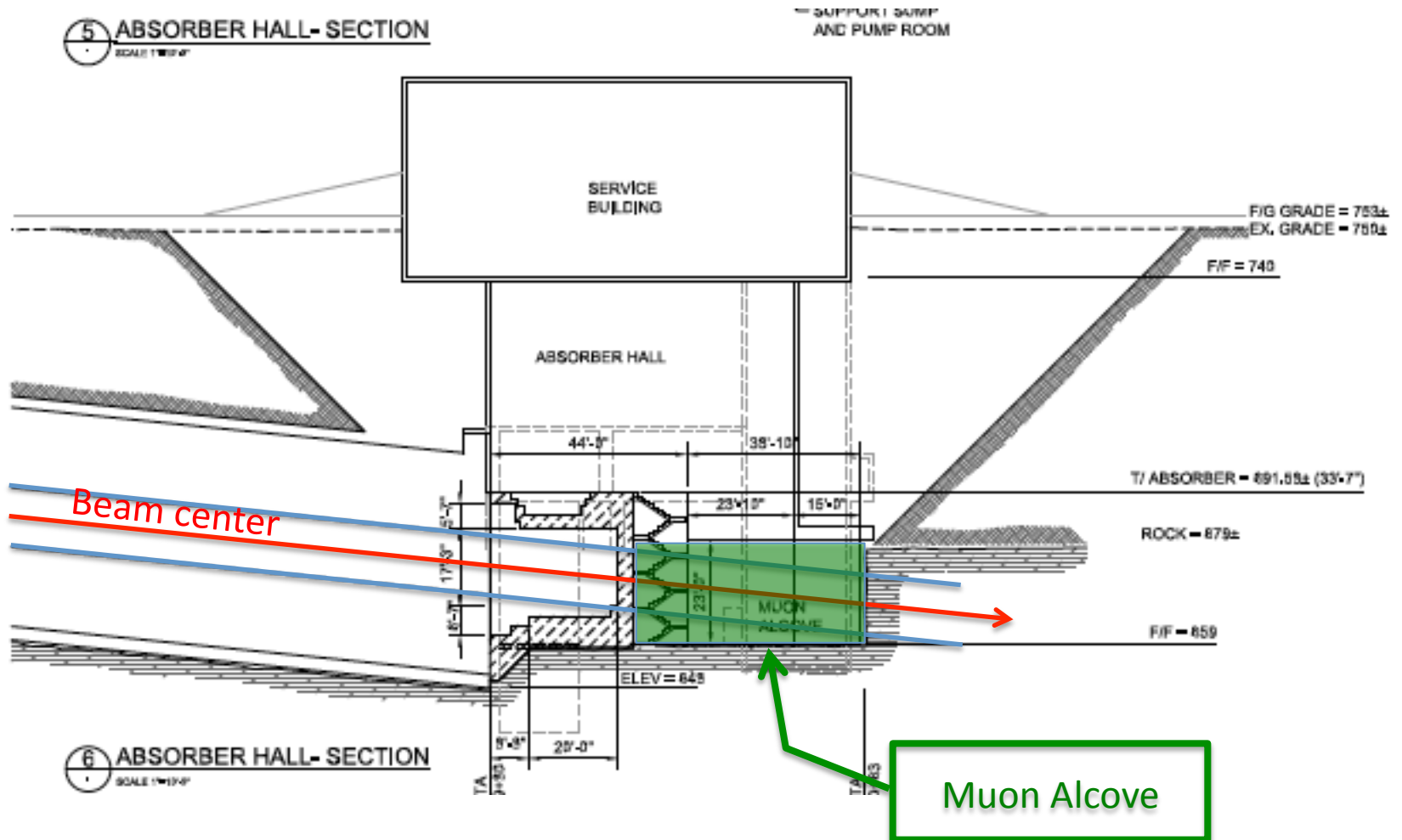


BLM Scope

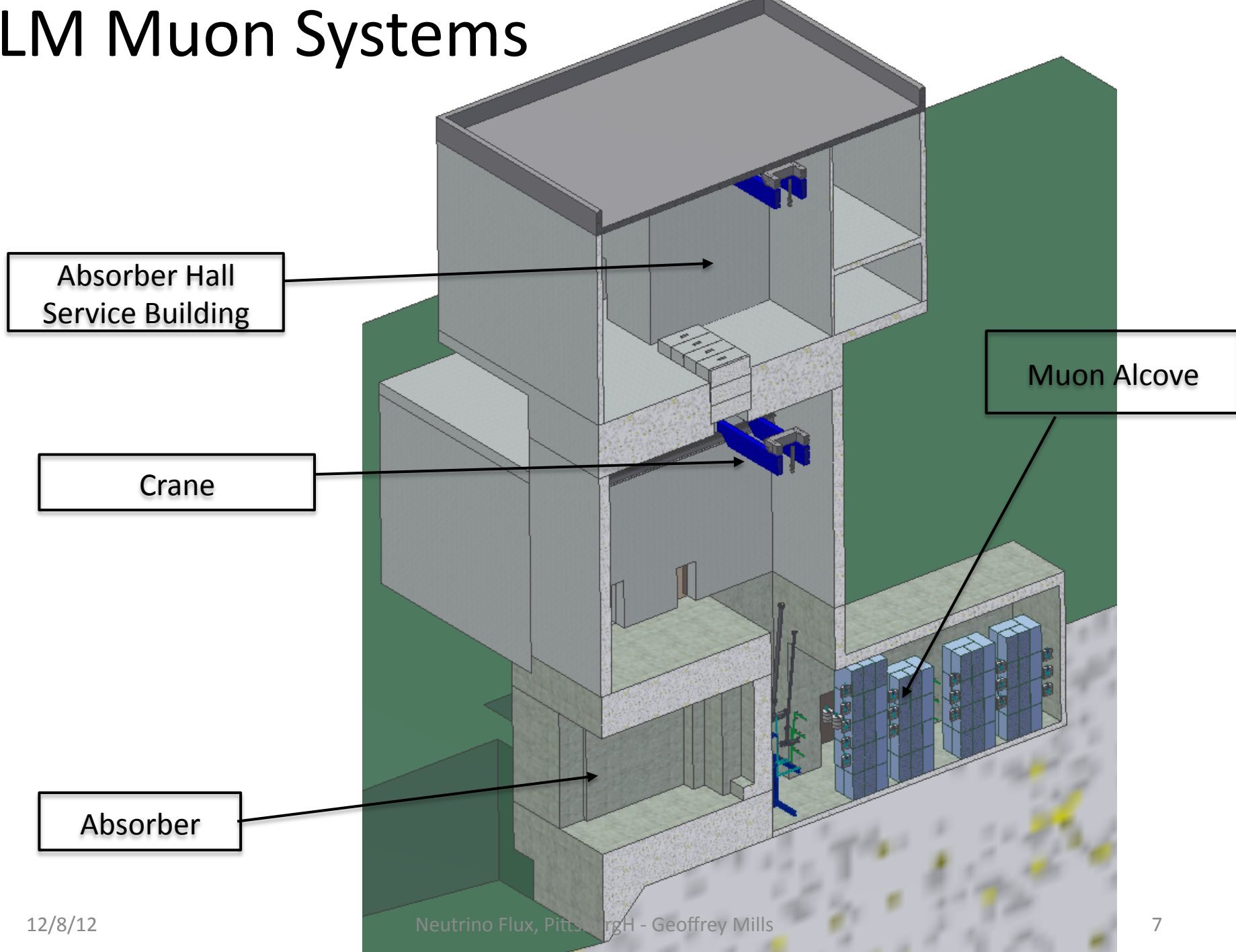
- Location of in-situ measurements



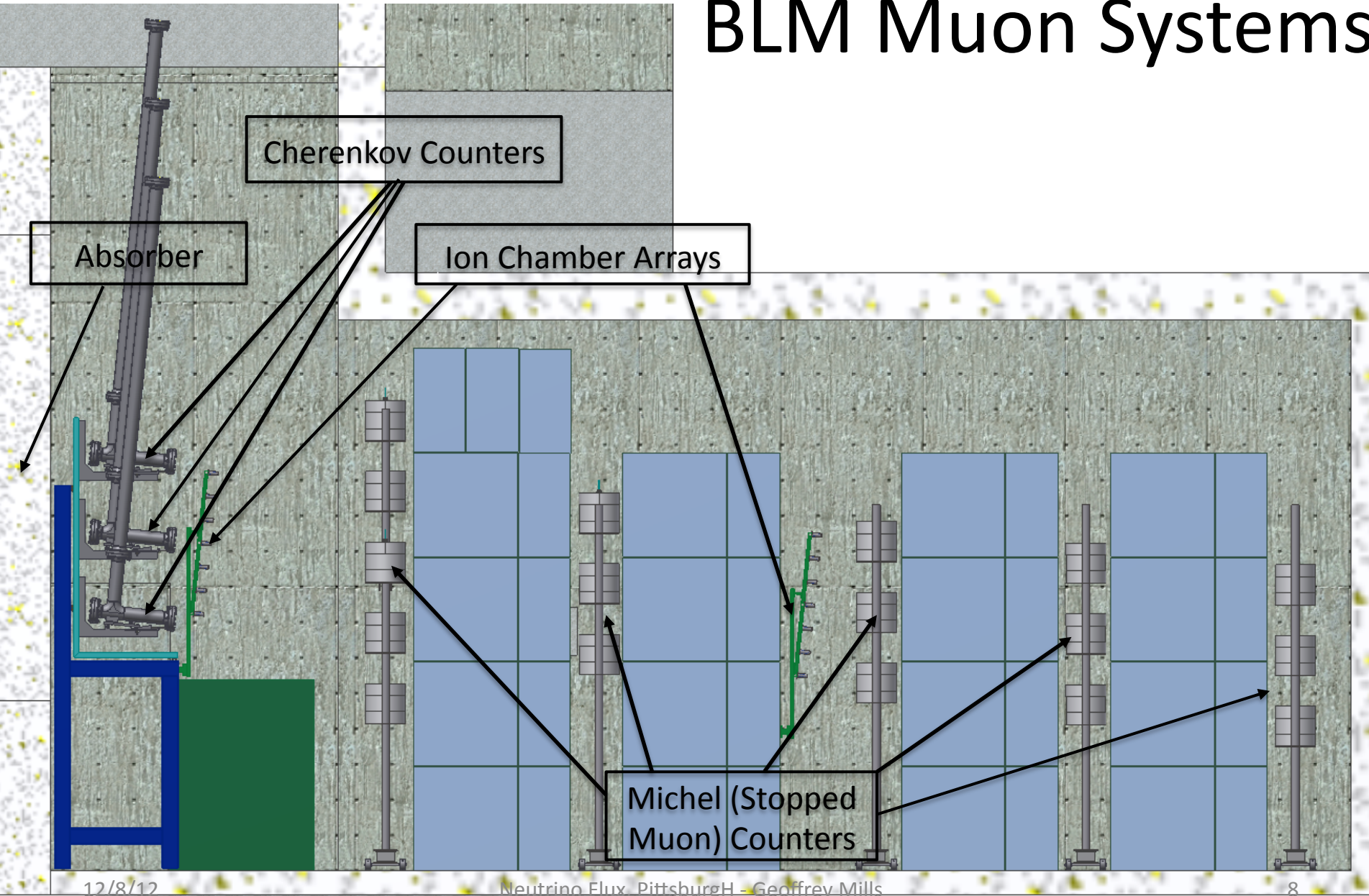
Absorber Hall Elevation



BLM Muon Systems



BLM Muon Systems



BLM Muon Systems

Cherenkov Counters

Absorber

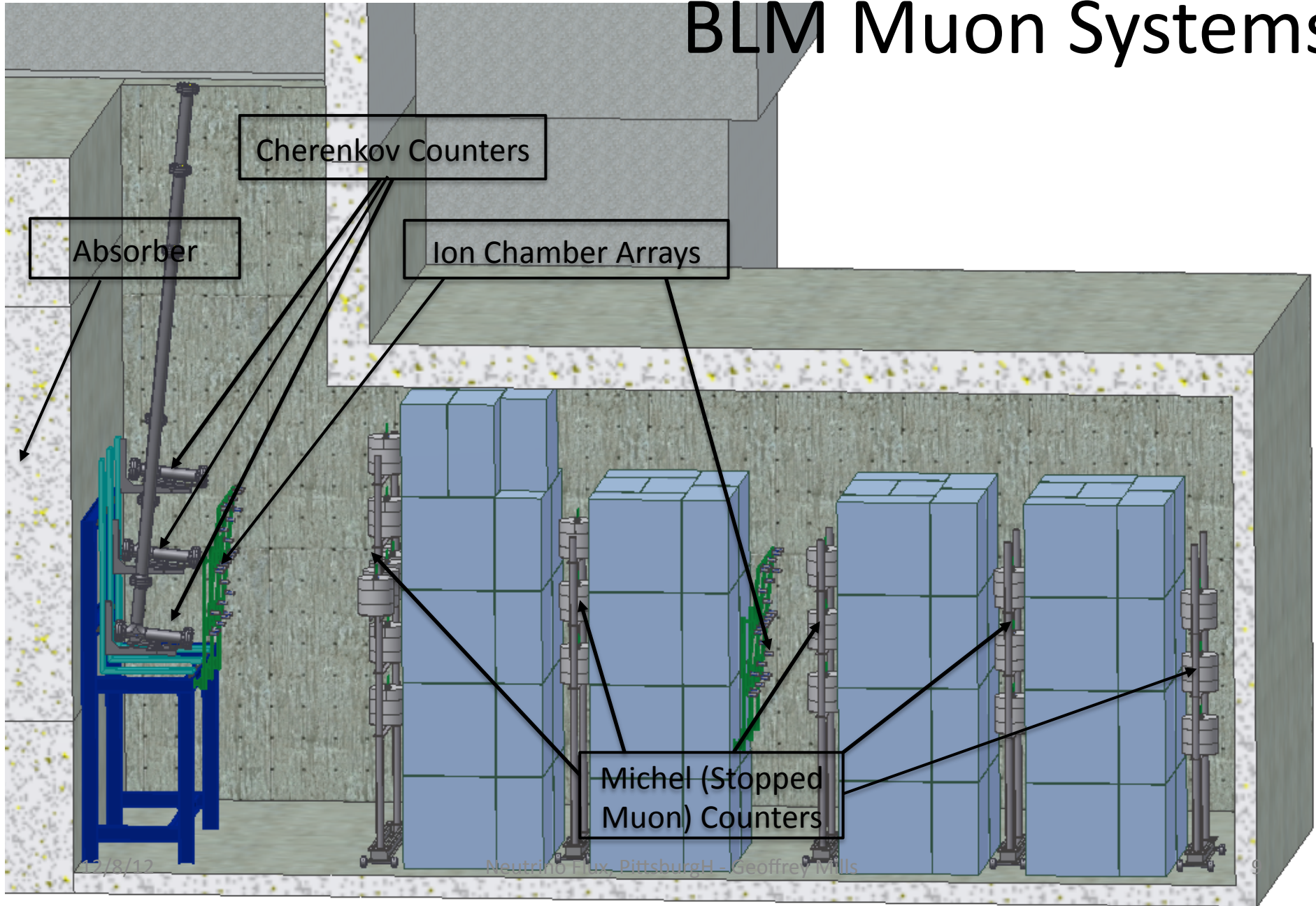
Ion Chamber Arrays

Michel (Stopped Muon) Counters

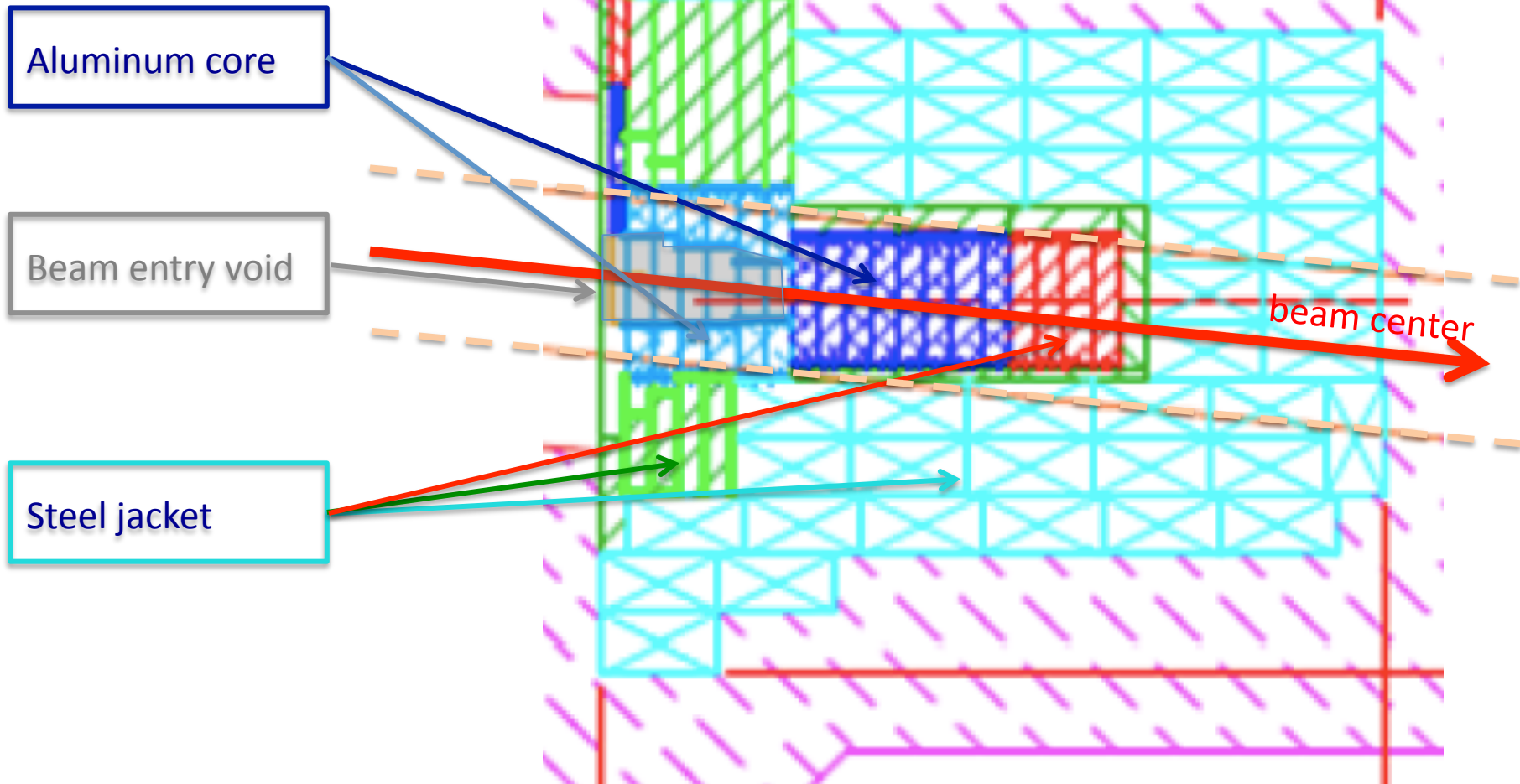
12/8/12

Neutrino Flux, Pittsburgh - Geoffrey Mills

9



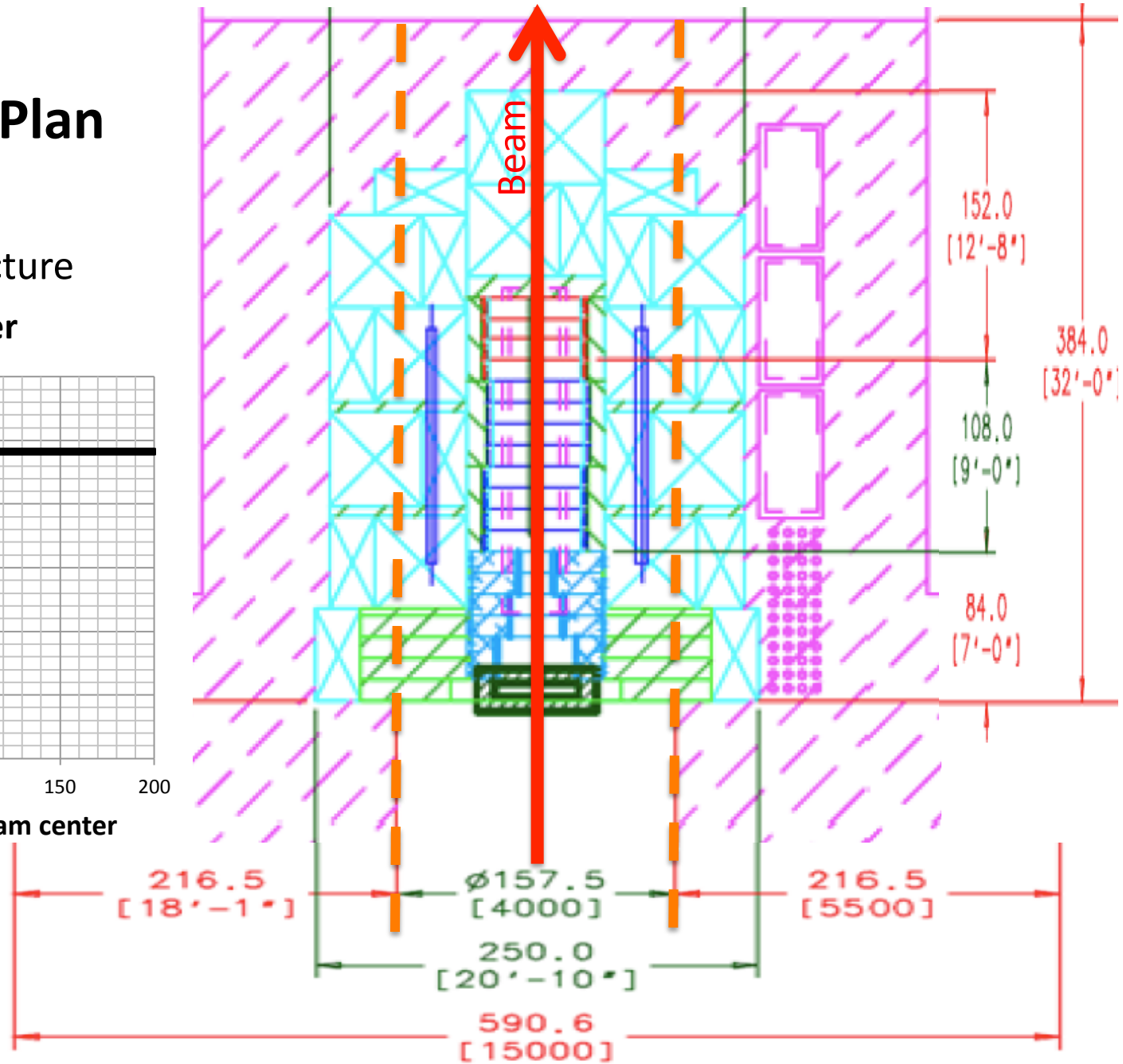
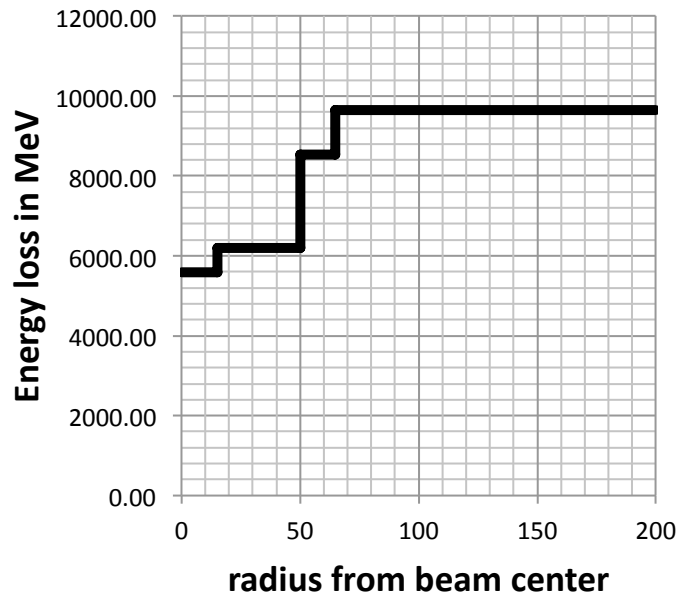
Complex Absorber Structure



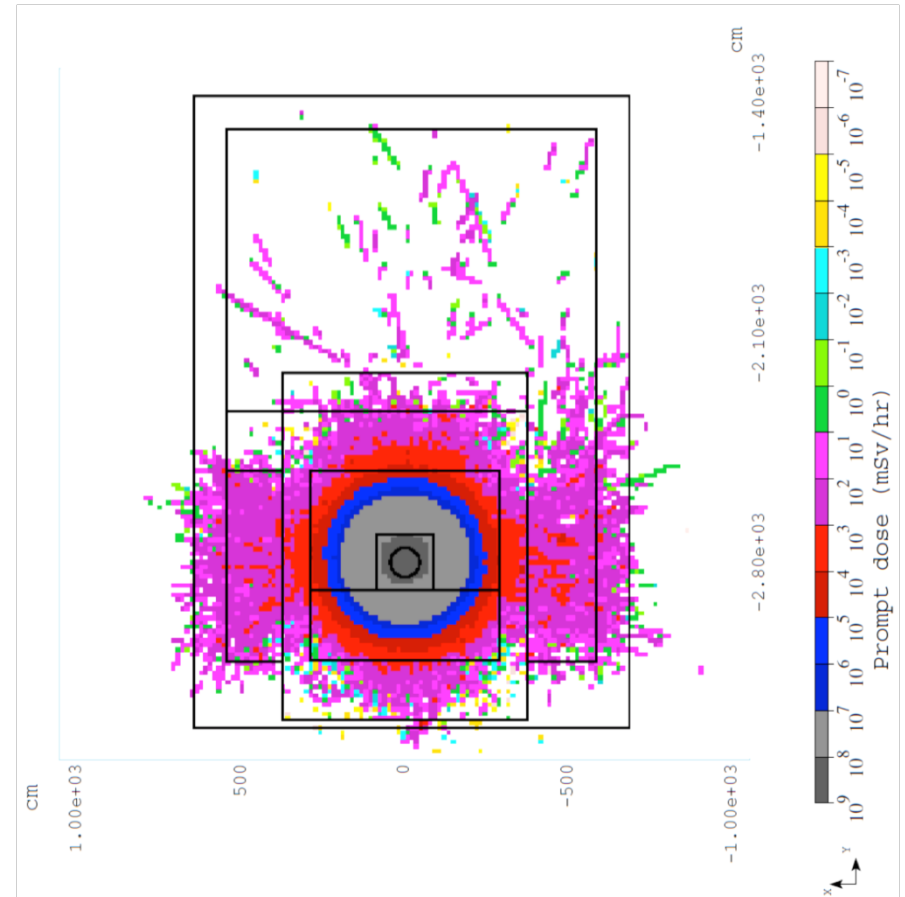
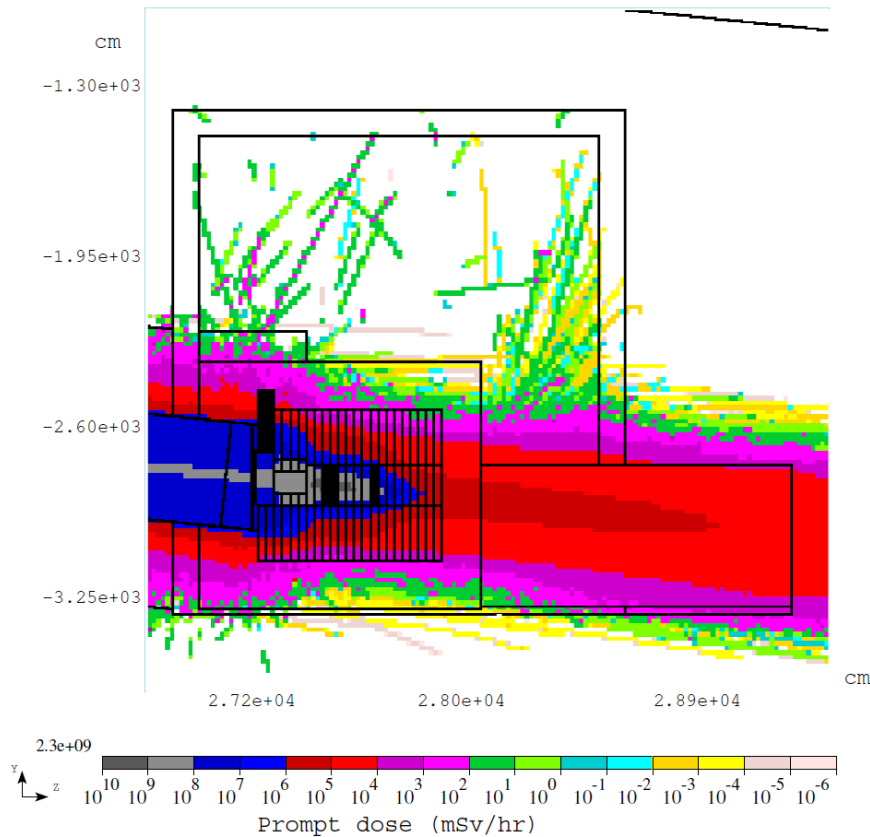
Absorber Pile Plan

- Complex structure

LBNE Absorber



Prompt Dose (mSv/hr)



(N. Mohkov)

1 particle/cm²/pulse $\sim 2 \times 10^{-8}$ mSv/hr

Muon Alcove Environment

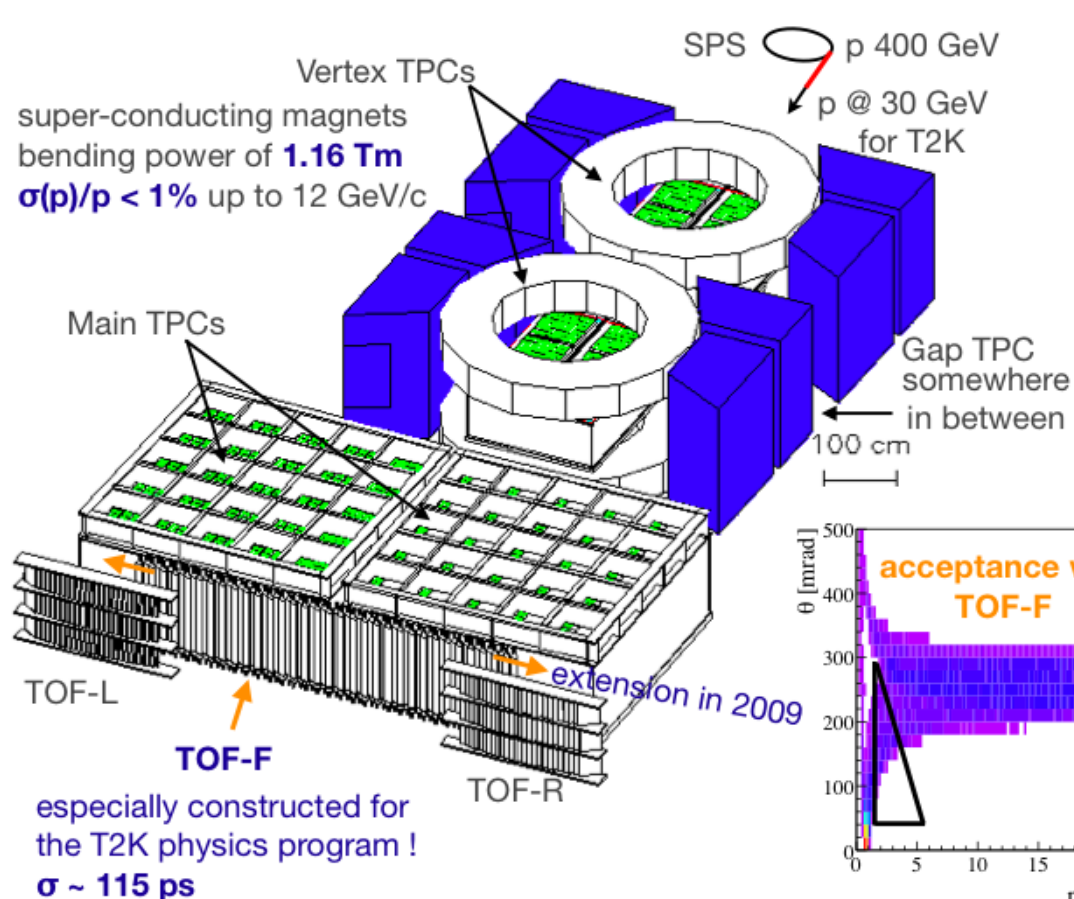
- Intense flux of muons
 - $\sim 10^8$ muons/cm²/pulse
 - Muons energy: ~ 0 -50 GeV
- ~ 1 rad/pulse
 - Rad hard materials only in direct muon beam
- $\sim 10^3$ - 10^4 stopped muons/cm³

System Overview

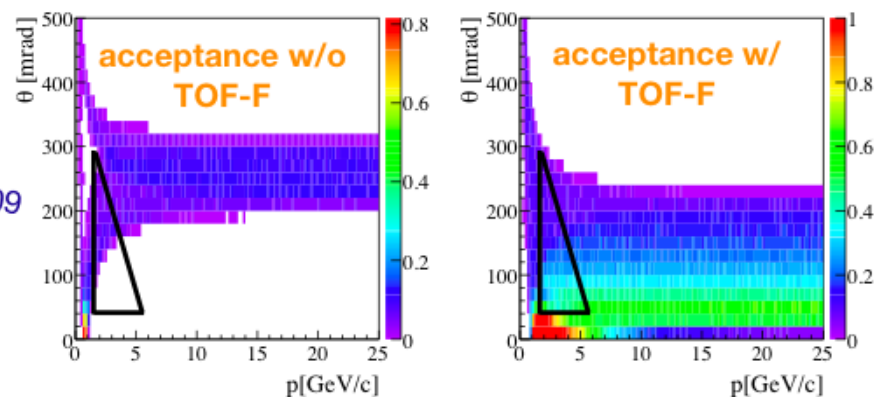
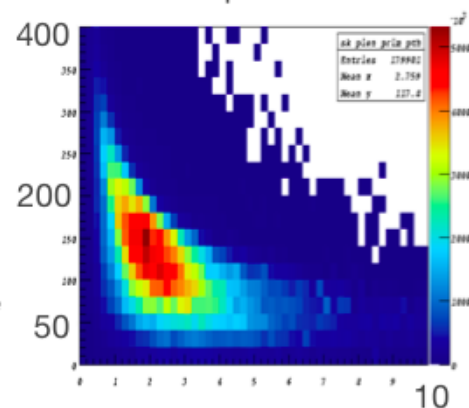
- Hadron production (base program)
 - Evaluate hadron production measurements relevant for LBNE
 - Oversee and plan for any measurements deemed needed for LBNE
- Michel (stopped muon) counters:
 - Determine the stopped muon rate at several absorber depths ($\sigma \sim 4-5\%$)
 - Separate μ^+ from μ^- decays ($\sigma \sim 4-5\%$)
- Ion chamber array:
 - Measure the muon profile and centroid after the absorber on a pulse-by-pulse basis ($\sigma \sim 10\text{cm}$)
- Muon cherenkov counters:
 - Measure muon spectrum as a function of position across the rear of the absorber ($\sigma \sim 4-5\%$)

NA61 Hadron Production

- Large spectrometer on the H2 beamline of the SPS at CERN:



phase space of secondary
 $\pi \rightarrow \mu + \nu$ at SK



NA61/SHINE fully covers the phase space of interest

- Took data with both thin & long targets

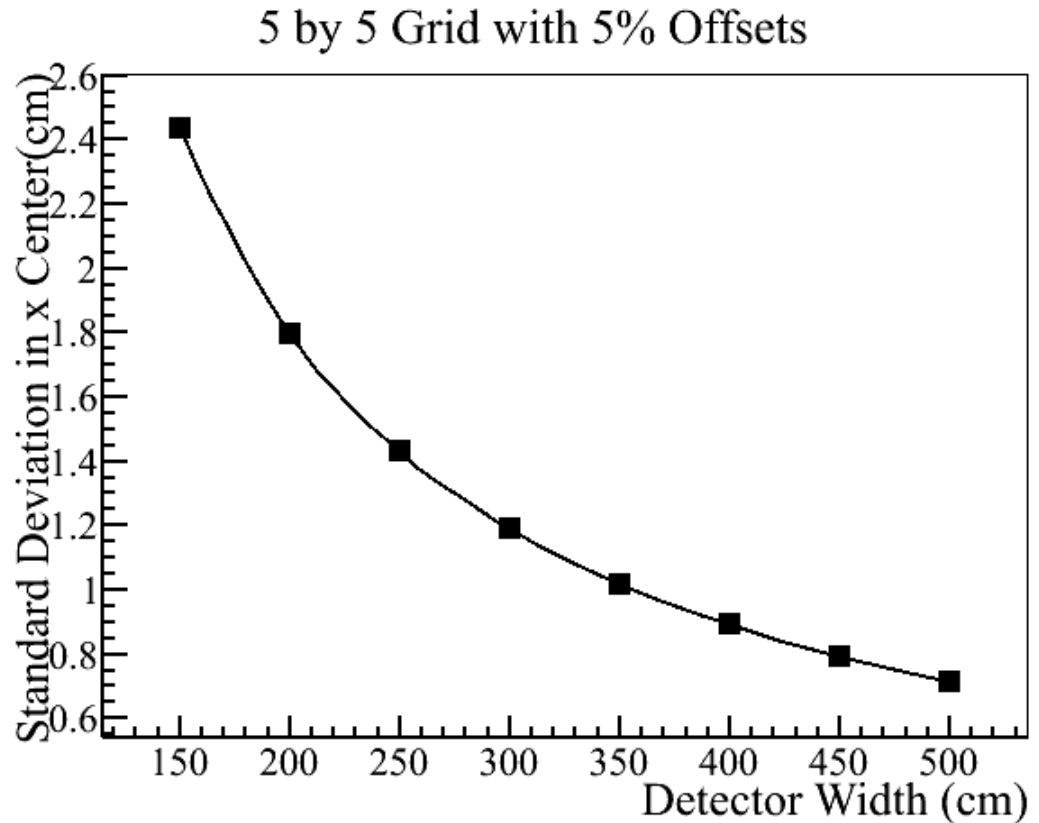
2

From A. Blondel T2K presentation)

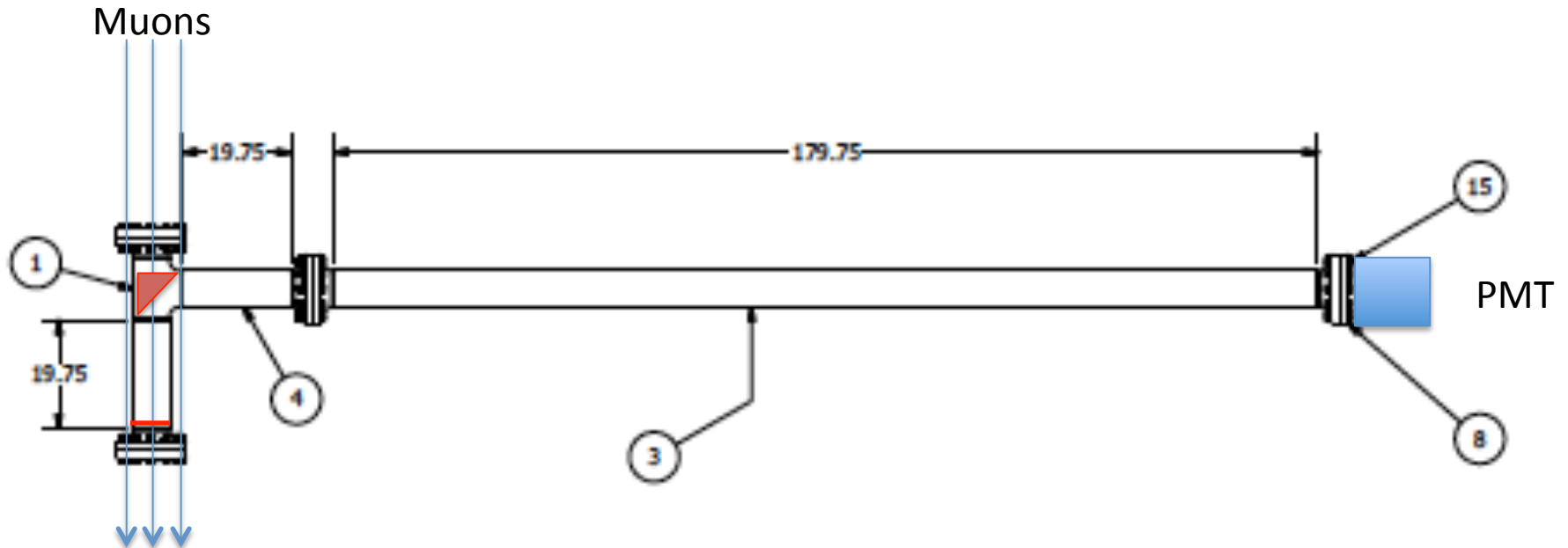
Ion Chamber Beam Centroid Simulation

- In this toy* simulation beam centroid is measured to $\sim 1\text{-}2\text{ cm}$ corresponding to a beam angular resolution of $< 0.1\text{ mrad}$

* Early absorber design



Cherenkov Counter



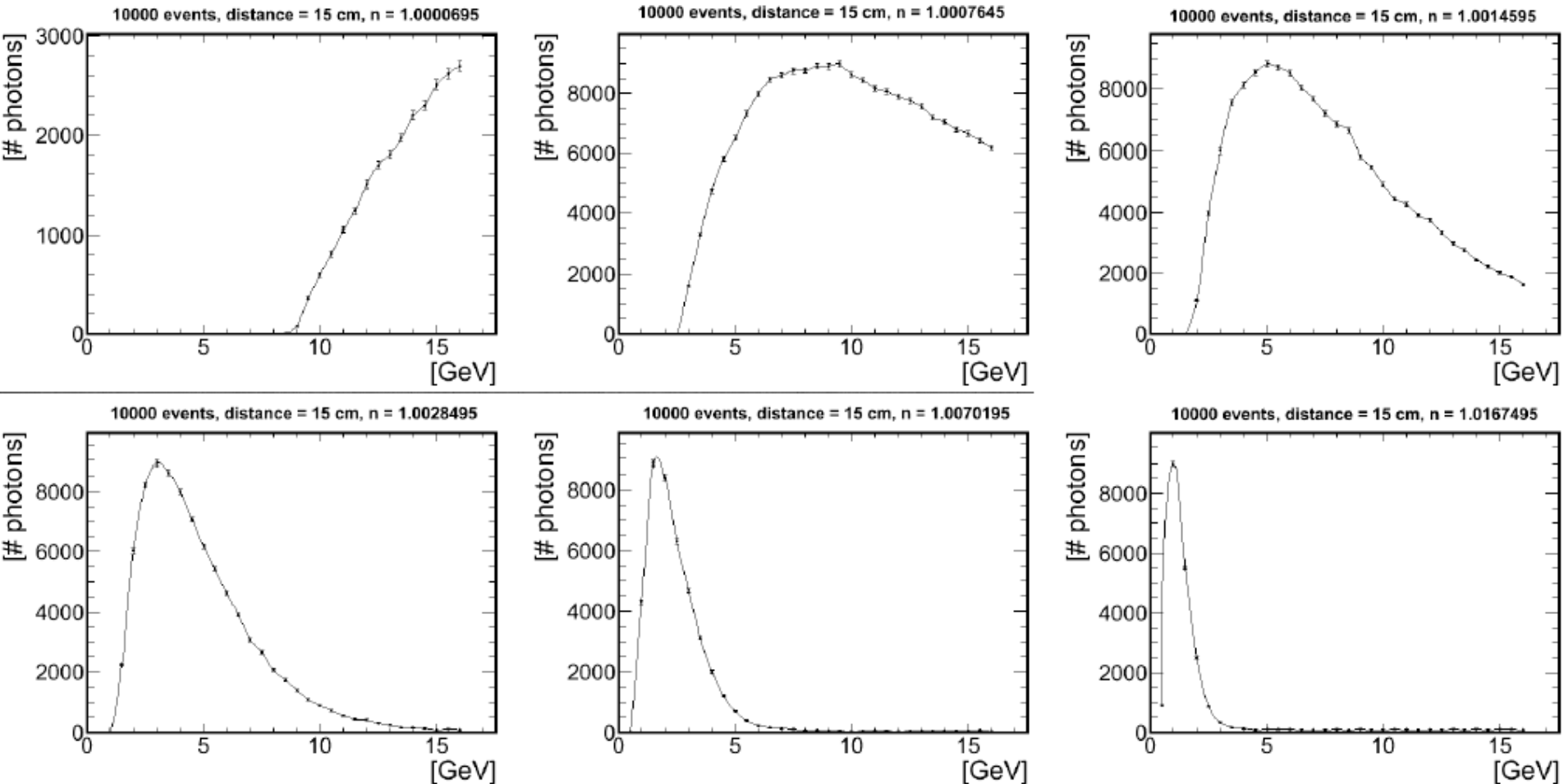
SS can able to withstand 20 atm (~300 psi)

- Pressure varies from vacuum to ~20 atm
- Collect forward light from muons near Cherenkov threshold
- Flat mirror optics

Choice of Cherenkov Radiator Gas

- Radiation damage to materials
 - Noble gas (?)
- Light yield
 - Index of refraction
- Dispersion
 - Threshold variation versus wavelength
- Scintillation light
 - can be minimized with small impurities of O₂ (?)

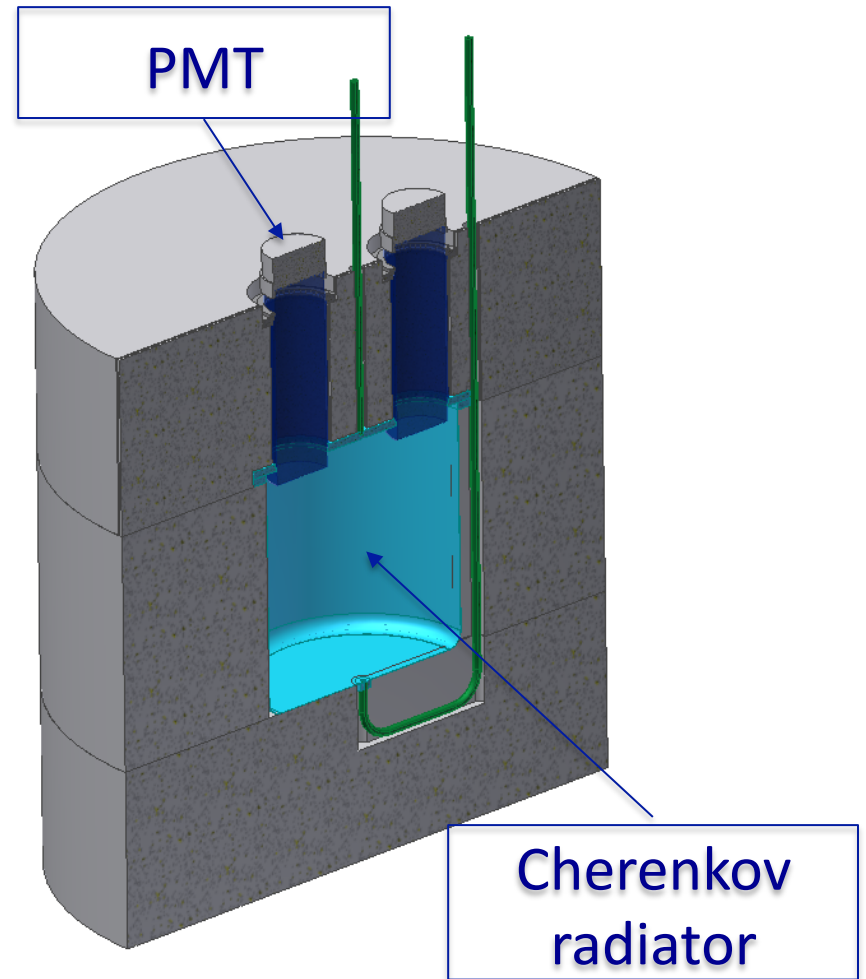
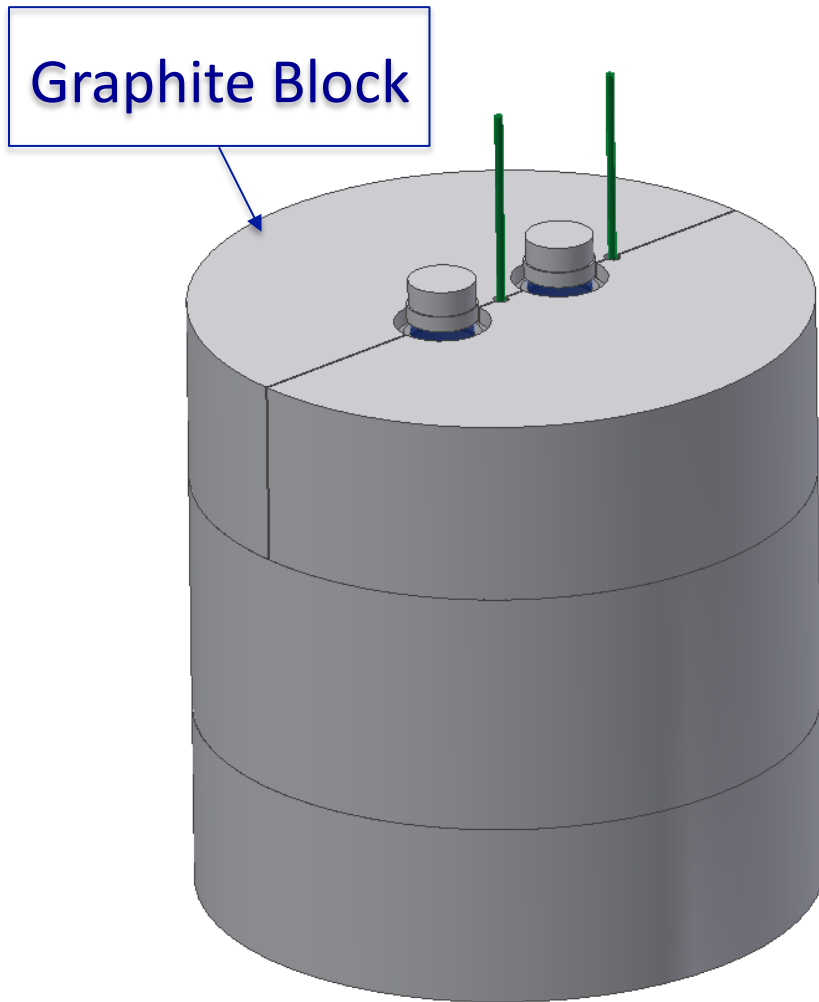
Cherenkov Response for Several Indexes of Refraction



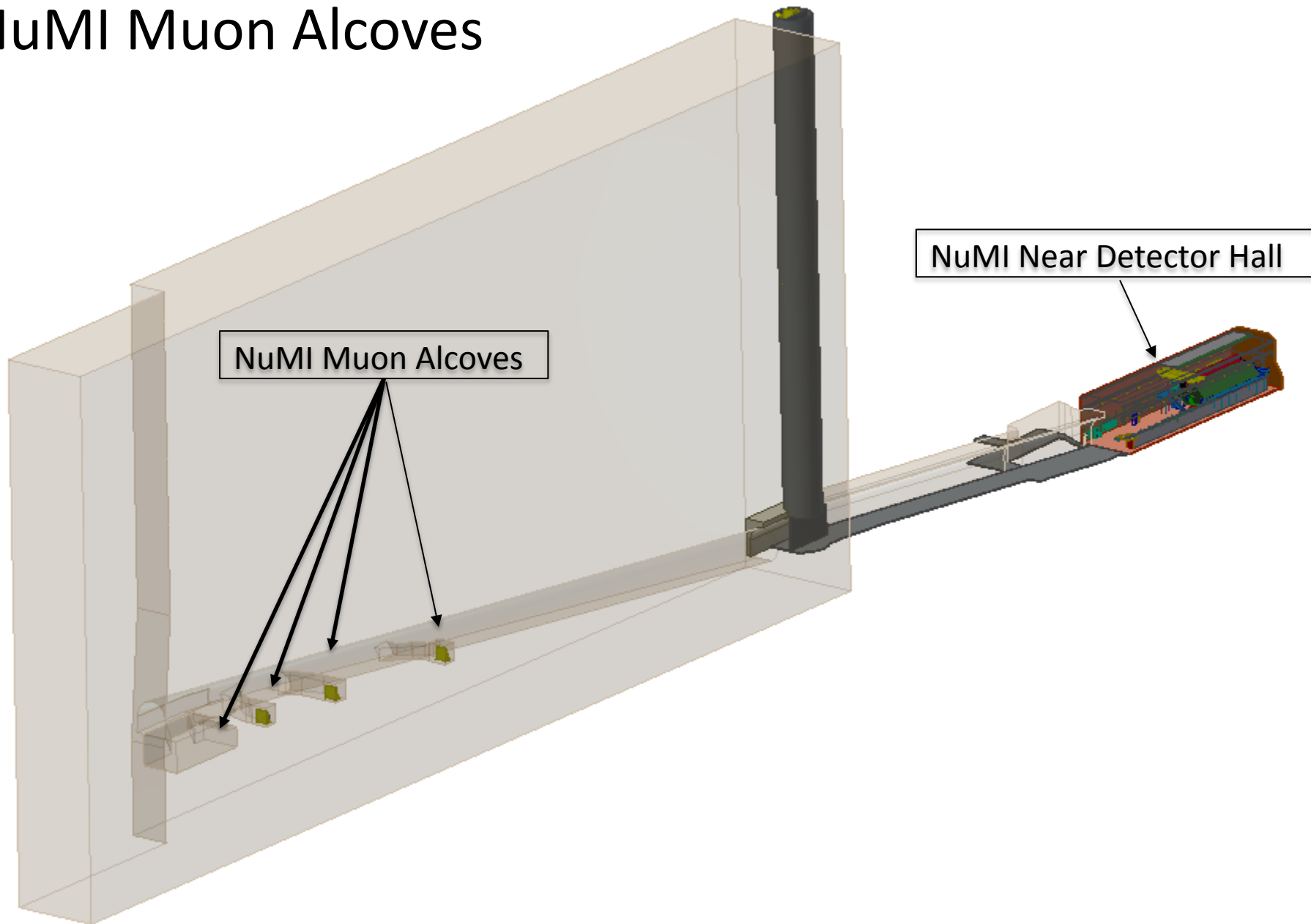
G4 simulation of optics with an assumed distribution of input muons in momentum and angle

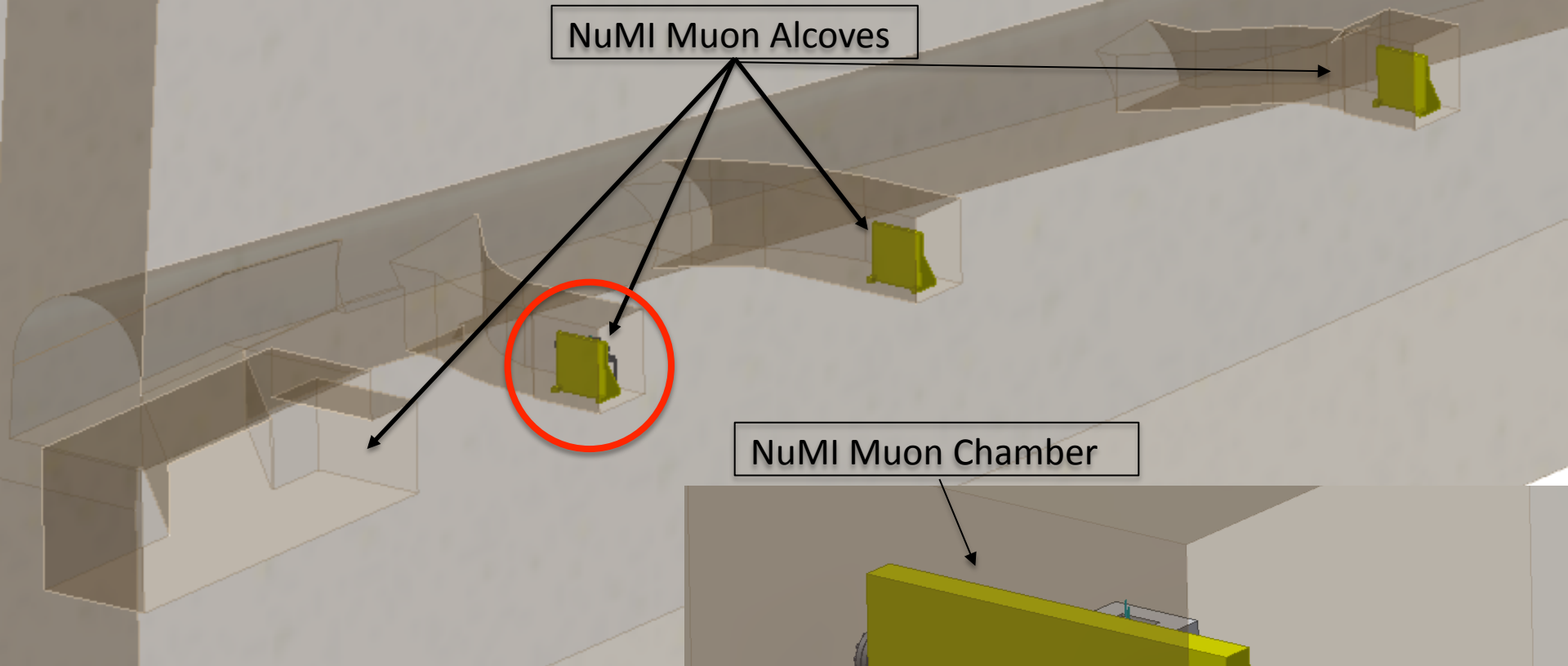
Stopped Muon Counter

- Measures rates of stopped muons
 - Sensitive to μ^+ and μ^- separately
 - μ^+ seen through usual Michel decay
 - 2.2 μs lifetime with a 52.8 MeV endpoint
 - μ^- seen through capture reaction:
 - $^{12}\text{C}(\mu^+, \nu_\mu)^{12}\text{B}(\text{GS})$
 - $^{12}\text{B}(\text{GS})$ beta decays with 30ms lifetime with a 13 MeV endpoint energy
- Sensitive to neutrino and antineutrino fluxes separately



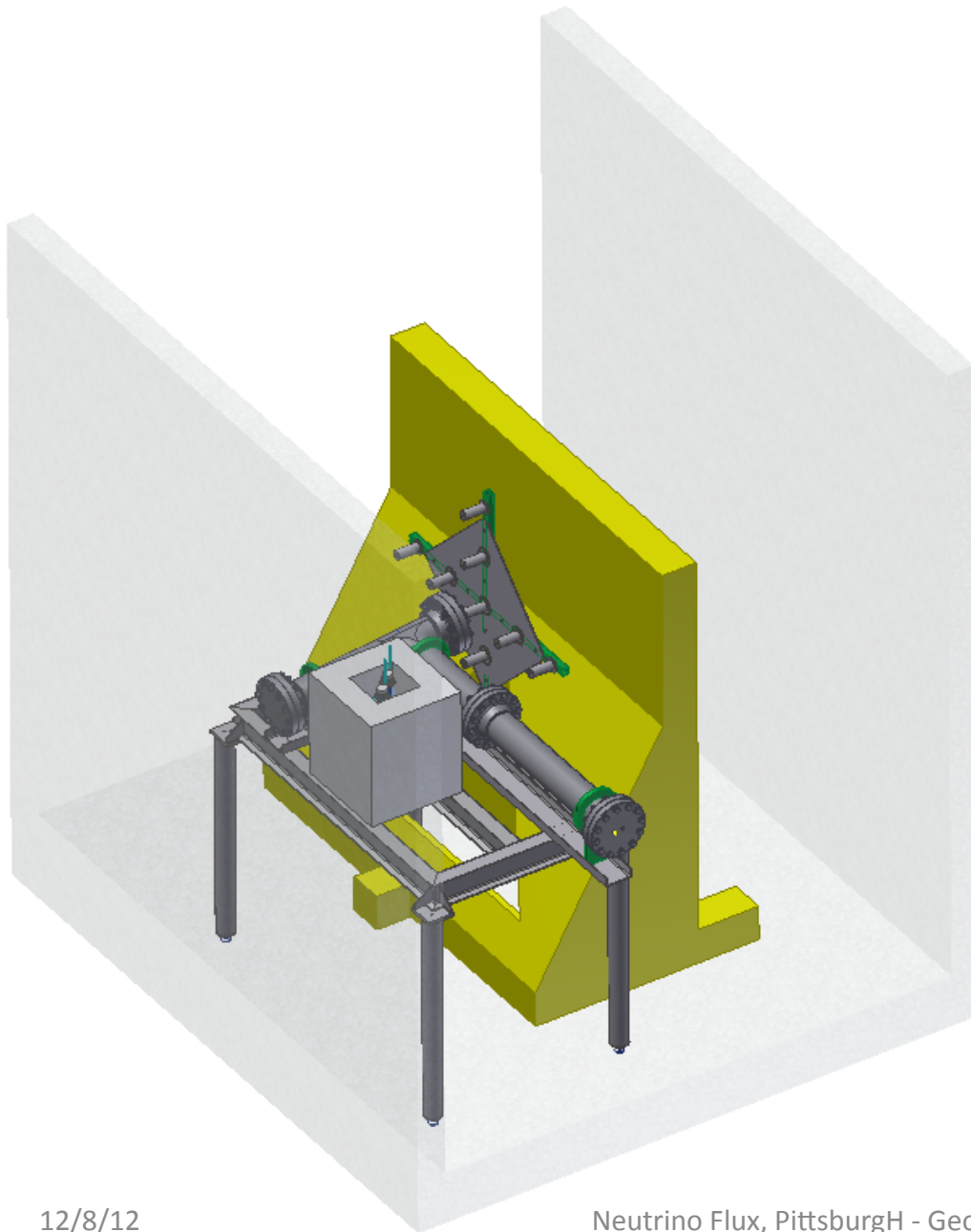
NuMI Muon Alcoves



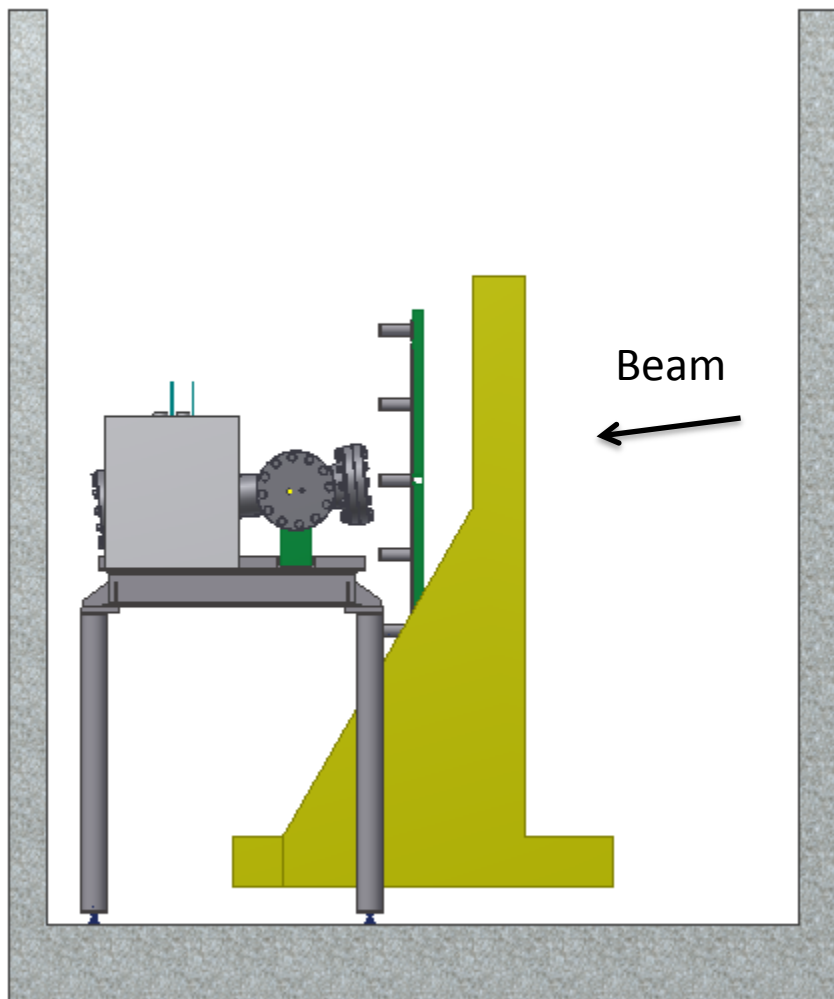


Current idea to use second alcove

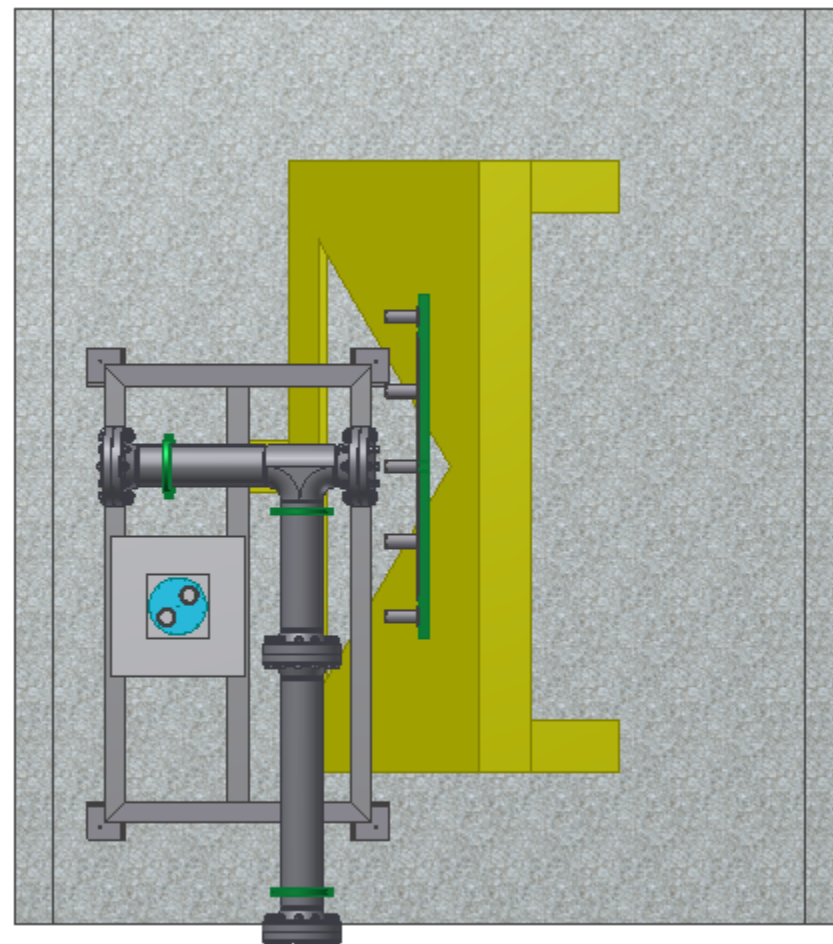
Proposed arrangement in alcove 2



Side view



Top View



Planning

- First step is to arrange for modifications to the NuMI underground areas for services
 - Power, racks, gas system, water system, DAQ, electronics
- Goal is to have services in place prior to May turn-on

Summary of Costs

Item	M&S Cost	Total Cost
NuMI Services	30k	125k
Electronics	25k	
Ion chambers	11k	30k
Cherenkov counter	55k	92k
Stopped muon counter	20k	62k
Total	141k	310k (+70k project)

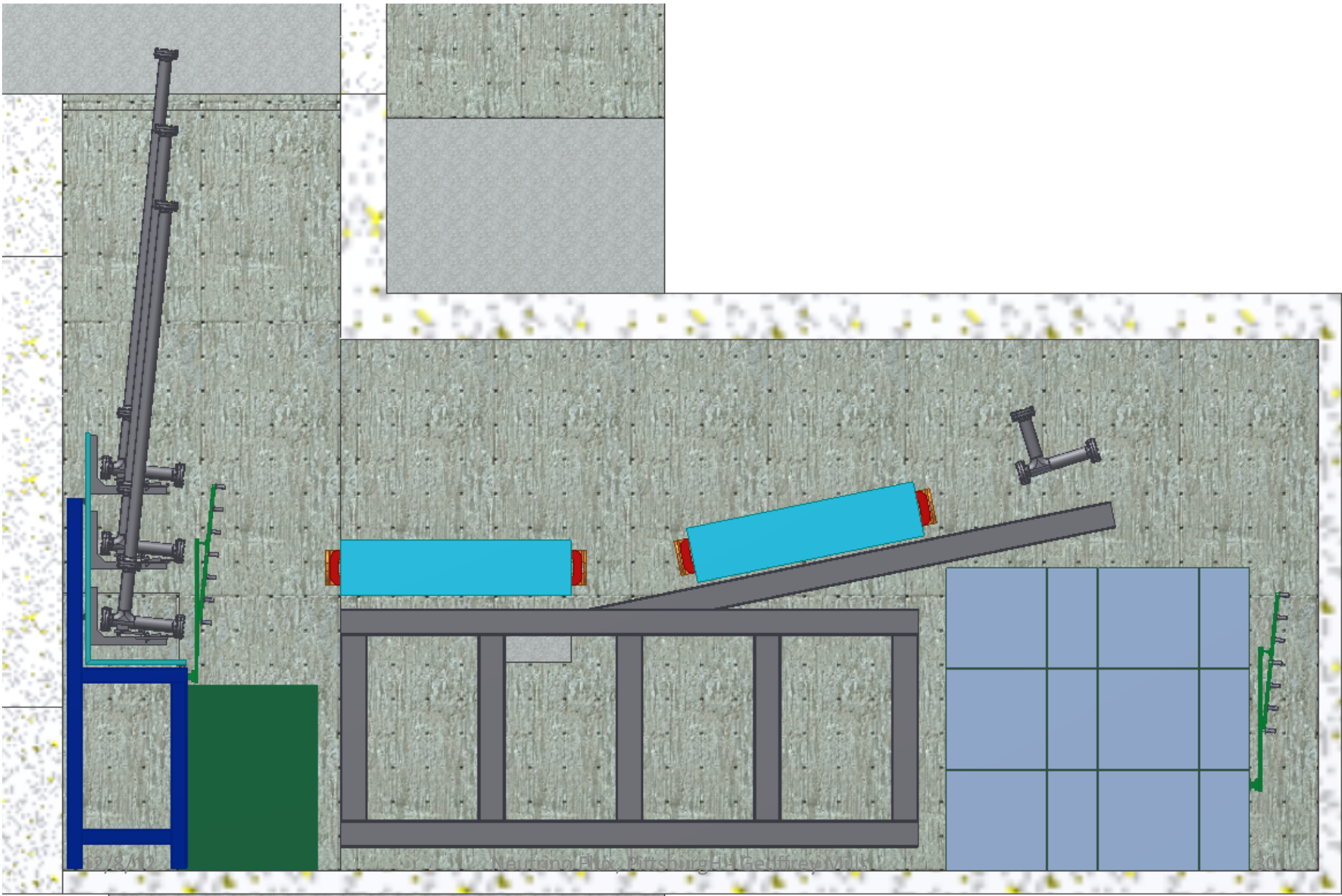
- M&S split: 70k FNAL, 70k LANL/CU
- Priority should be on services to alcoves

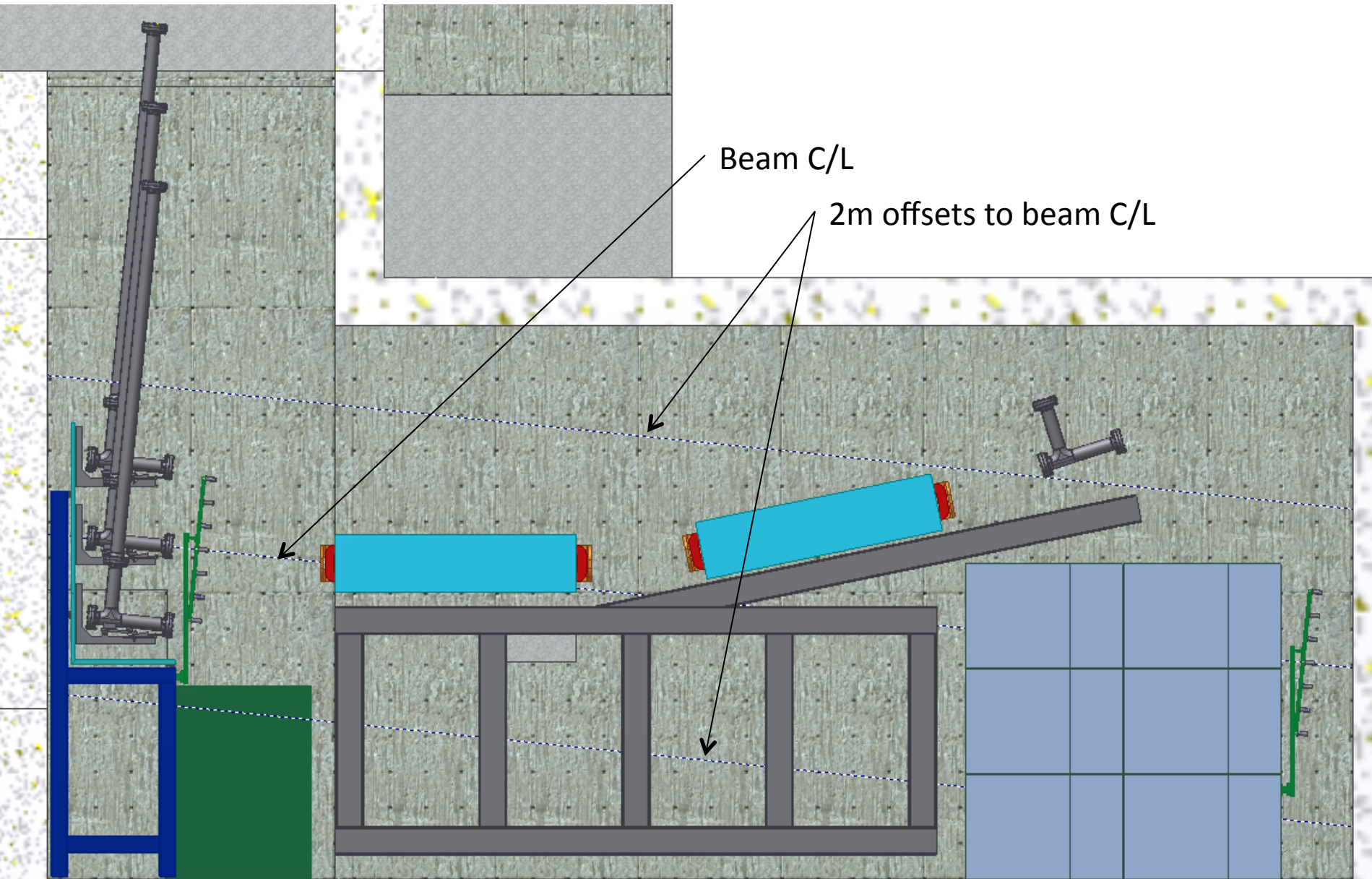
Current Plan

- Develop services for prototype detectors prior to beam start up in March
 - Power, signal/HV cables, stand, gas lines, racks, ACNET(?), etc.
- Will work to produce prototype modules for February installation, but...
 - Tight schedule: might not be ready for installation until summer (2013)
 - Would require short (1 day?) shutdown for alcove access if alcoves are prepped properly

Possible Improvements

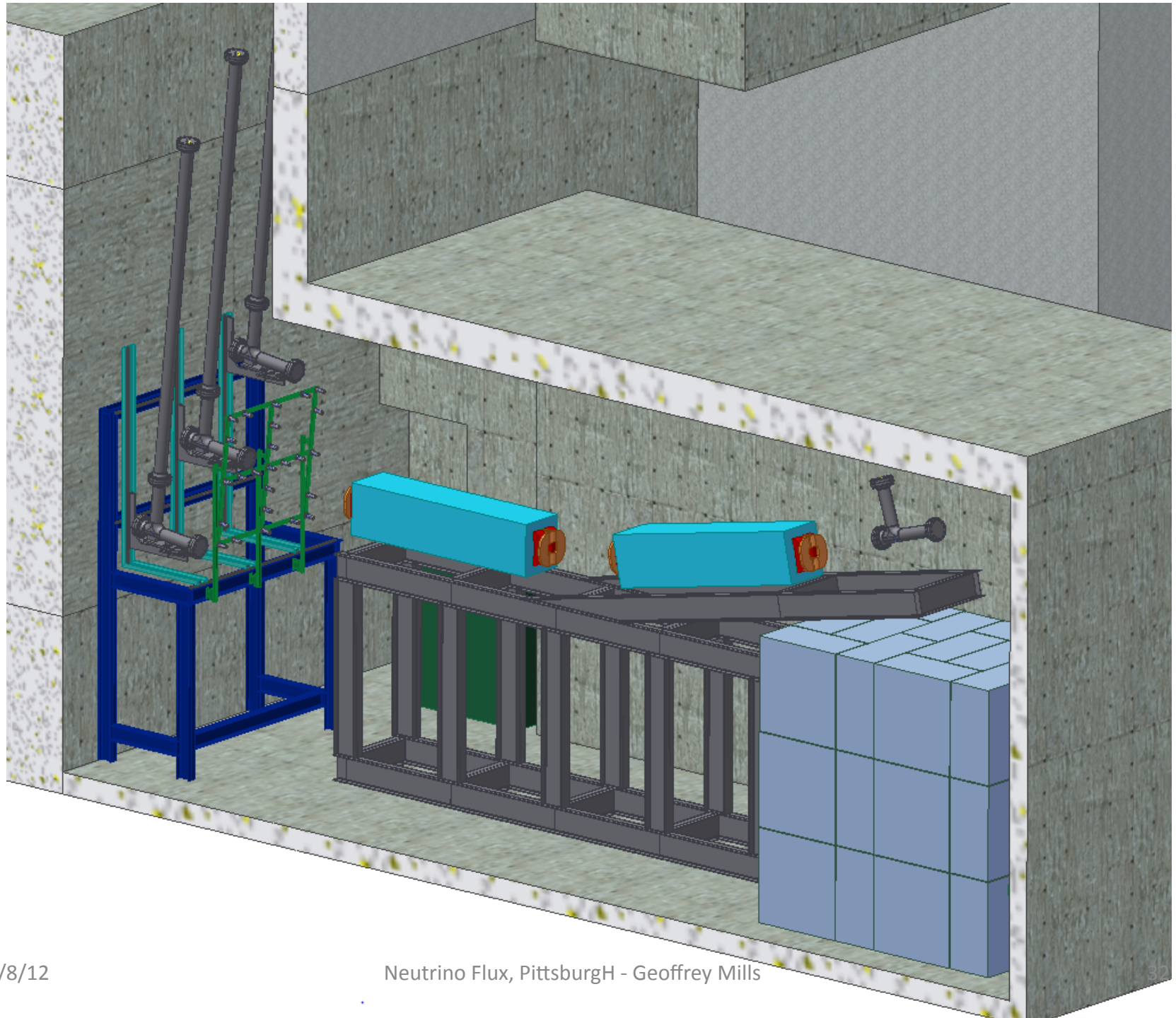
- Magnetic spectrometer concept:
 - Use dipole magnets to bend muons out of high radiation field
 - Momentum and charge selection
 - Competitive in terms of cost
- Investigate installing stopped muon counters inside the absorber
 - Lower muon energy threshold (less absorber for muons to penetrate)
 - Difficulties: higher radiation field





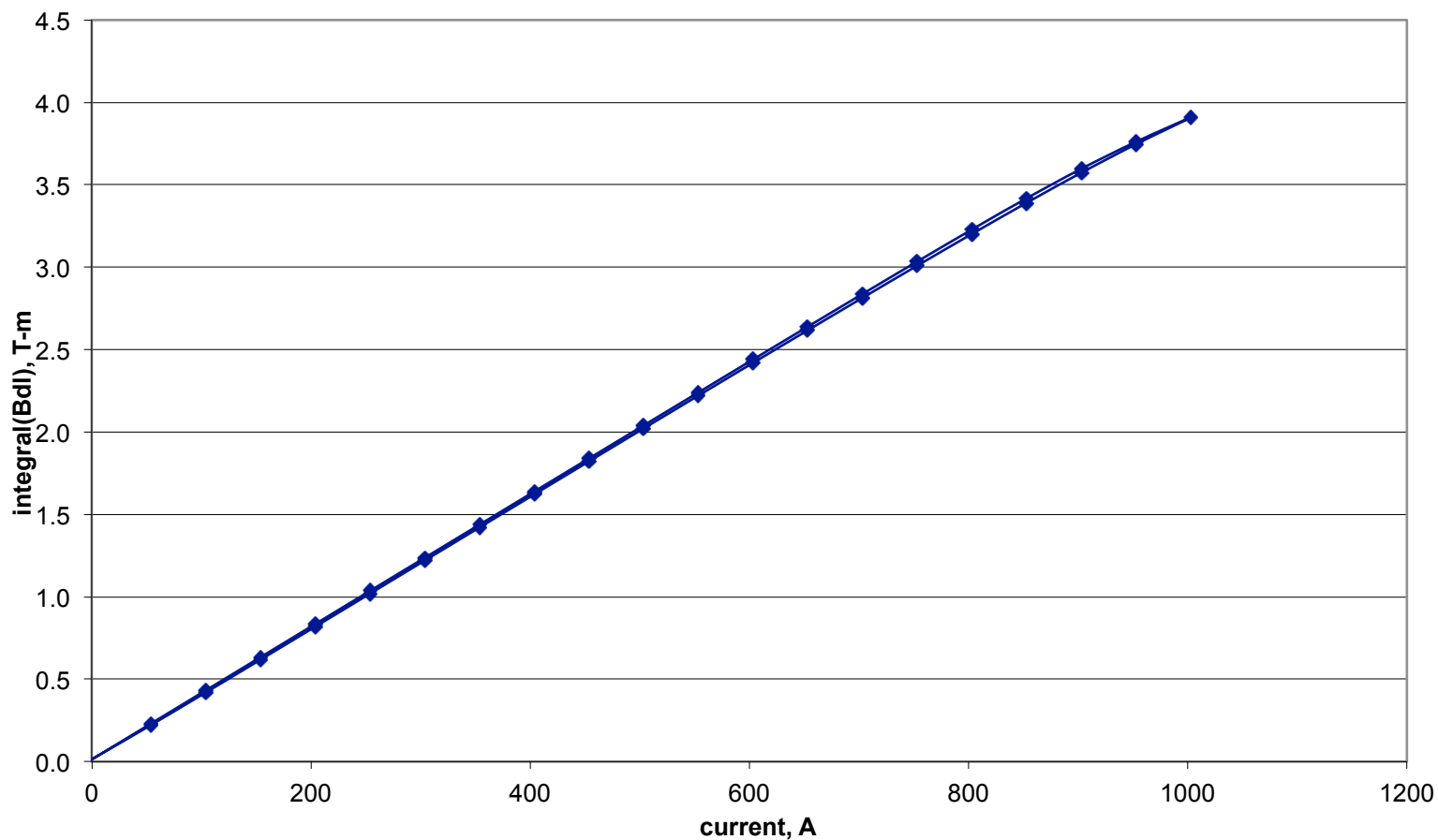
Beam C/L

2m offsets to beam C/L

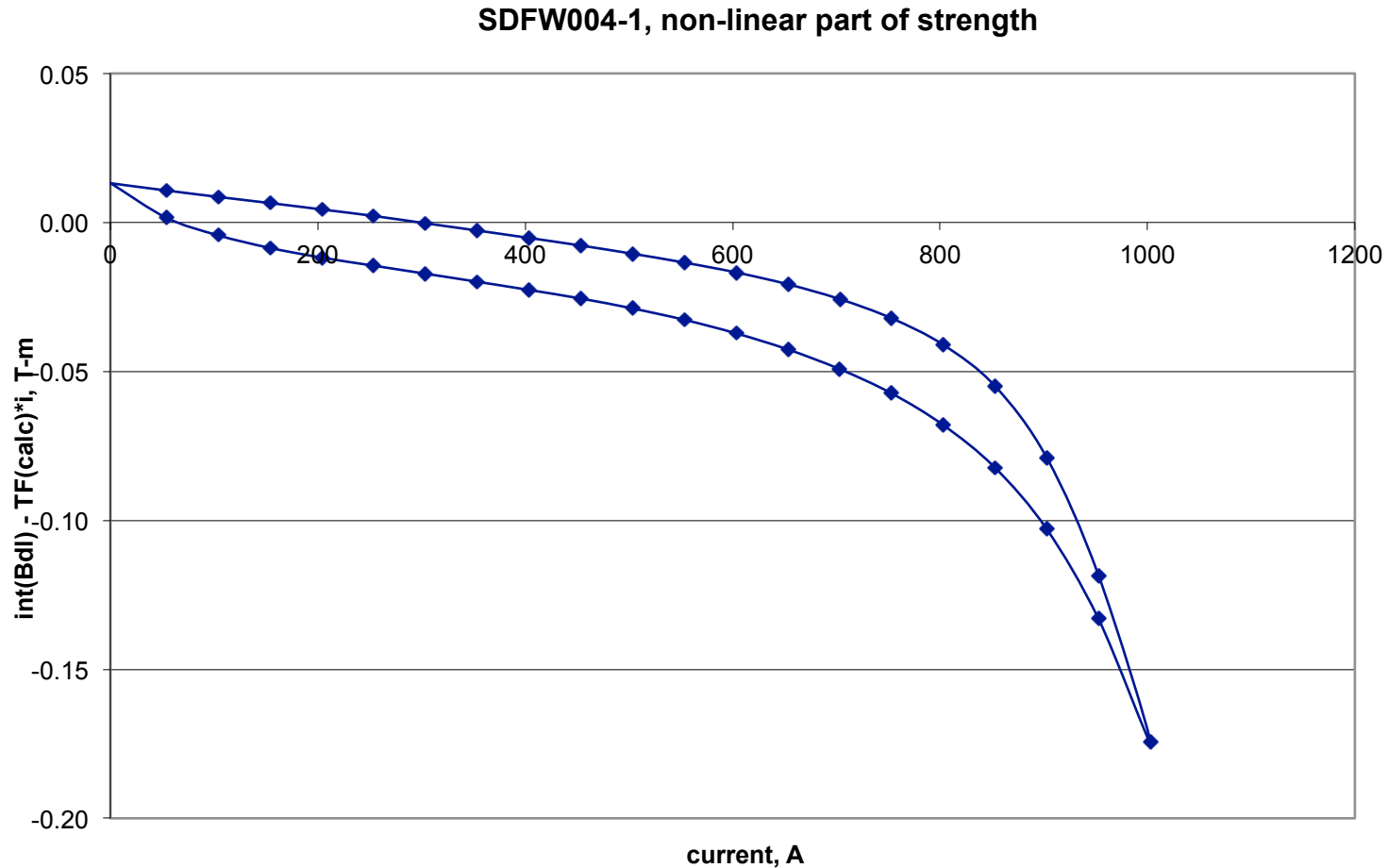


FNAL SDWF004-1 Dipole

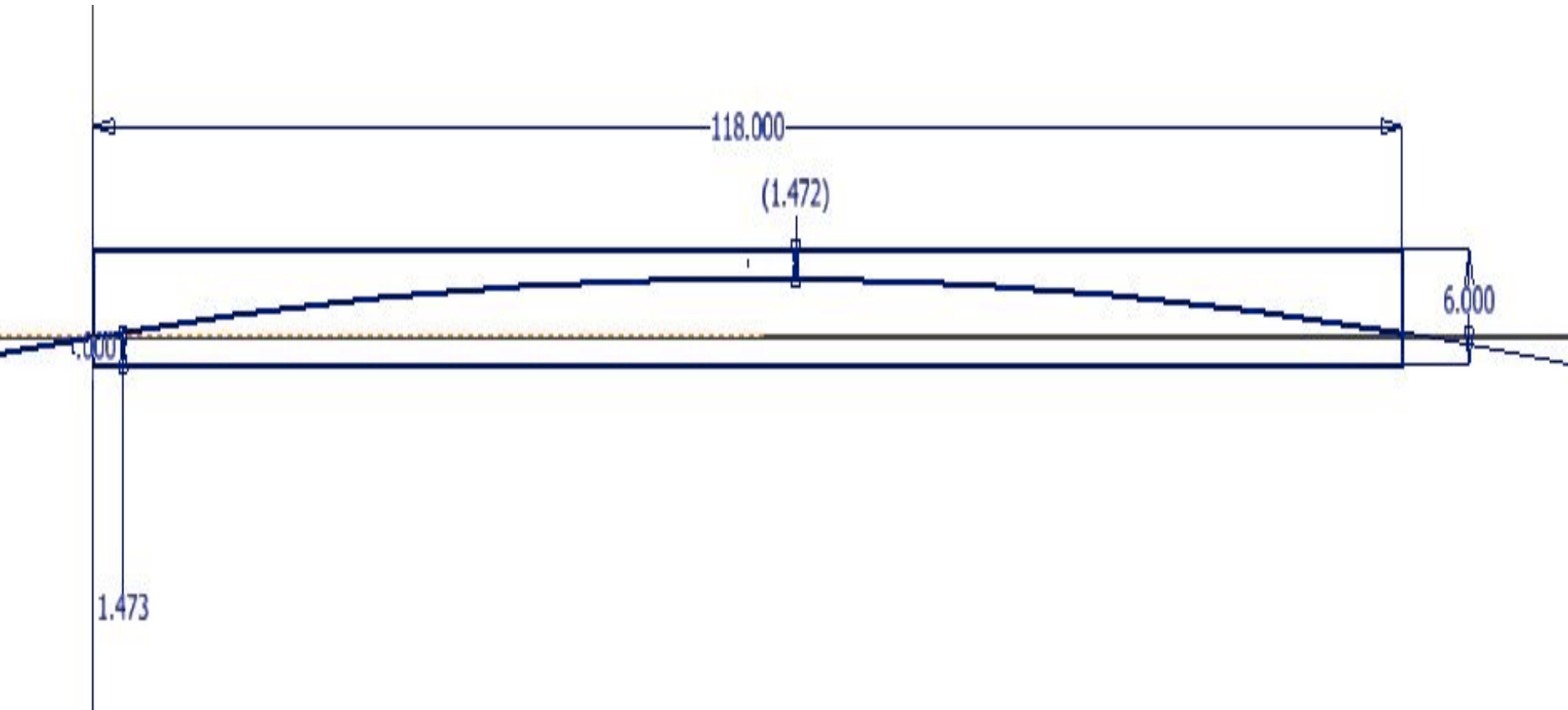
SDFW004-1 integrated strength



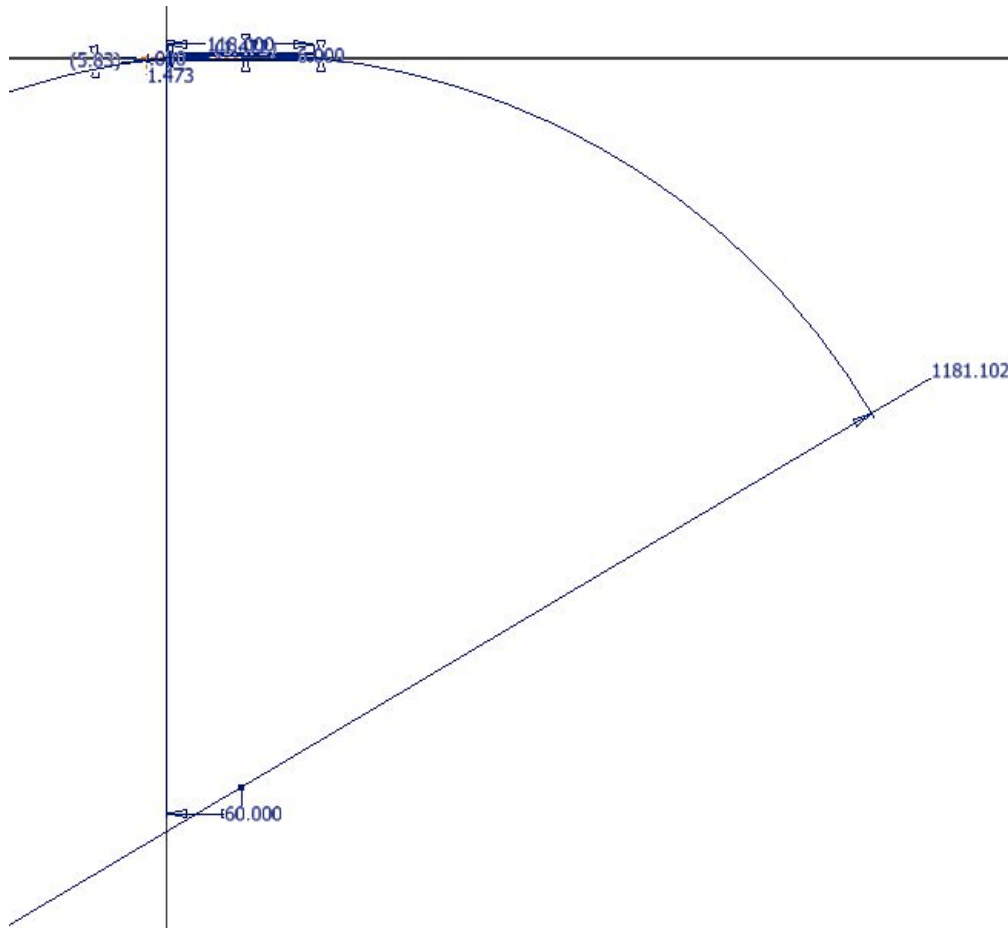
FNAL SDWF004-1 Dipole



Magnet Concept



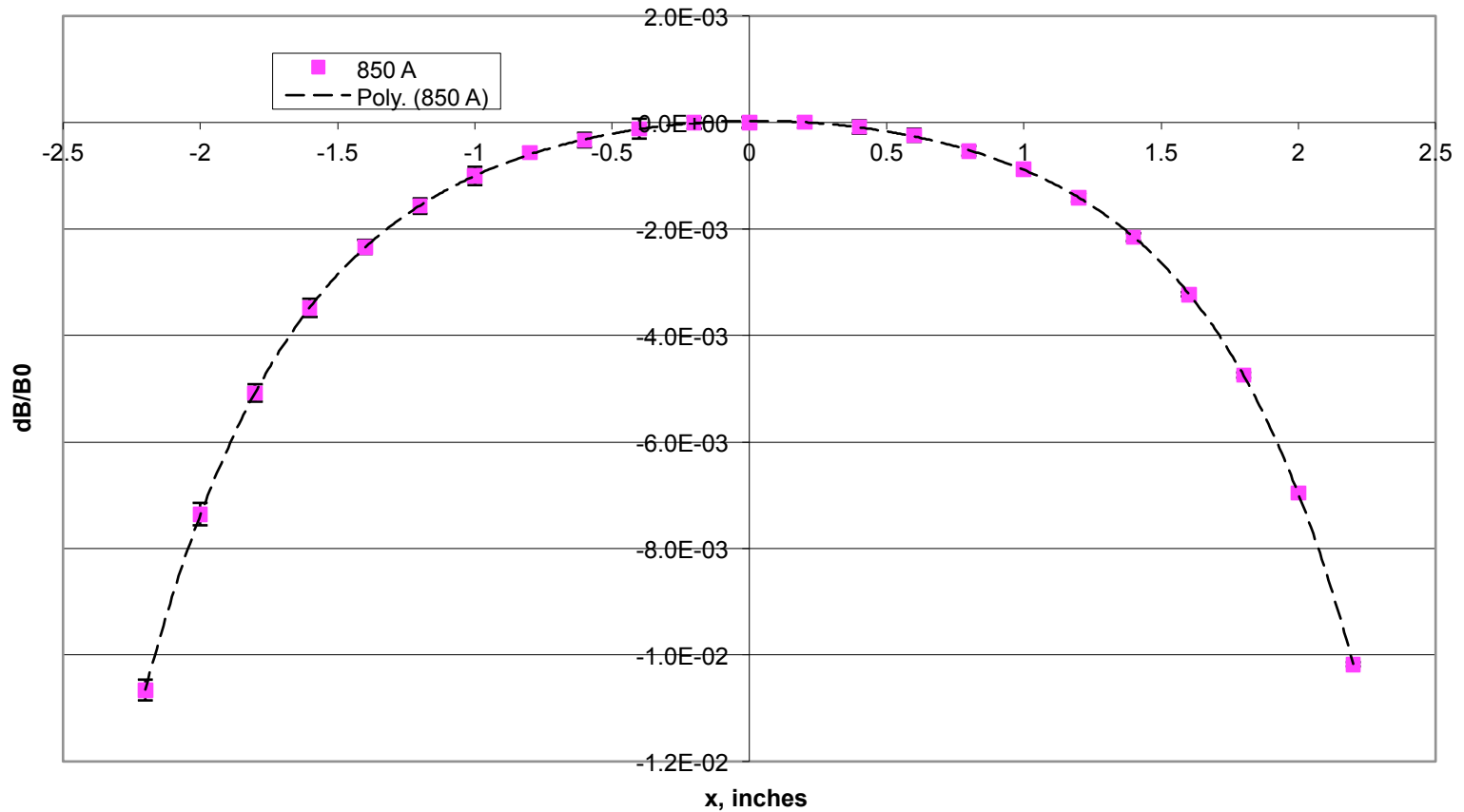
Magnet Concept



SDWF004-1

SDFW004-1 transverse scan

$$y = -4\text{E-}05x^6 - 7\text{E-}07x^5 - 8\text{E-}05x^4 + 2\text{E-}05x^3 - 0.0009x^2 + 4\text{E-}05x + 3\text{E-}05$$



Summary

- Opportunity to optimize muon systems
- Potential cost savings
- Needs to be addressed prior to CD-2

ID	Task Name	Duration	Start	Finish	Cost	Predecessors	ter	1st Quarter				2nd Quarter			3rd Quarter			4th Quarter	
								Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1	Total Cost Roll-Up	188 days	Mon 12/3/12	Wed 8/21/13	\$356,236.48														
2	Management	155 days	Mon 12/3/12	Fri 7/5/13	\$29,060.00														
3	Engineering Support	155 days	Mon 12/3/12	Fri 7/5/13	\$34,100.00														
4	Cherenkov Detector Gas System	61 days	Mon 12/3/12	Mon 2/25/13	\$25,839.20														
5	Conduct OOH	7 days	Mon 12/3/12	Tue 12/11/12	\$1,507.60														
6	Develop Specifications for Gas Bottle Mechanics	7 days	Mon 12/3/12	Tue 12/11/12	\$1,507.60														
7	Install Gas Bottle Platform with Restraints	6 days	Mon 1/7/13	Mon 1/14/13	\$768.64														
8	Install Vacuum Pump	11 days	Tue 1/15/13	Tue 1/29/13	\$768.64	7													
9	Install Gas Tube	11 days	Tue 1/15/13	Tue 1/29/13	\$4,664.56	855													
10	Review Gas System Schematic and Revise as Needed	17 days	Mon 12/3/12	Tue 12/25/12	\$2,947.60														
11	Procure Gas System Components	29 days	Wed 12/26/12	Mon 2/4/13	\$10,600.00	10													
12	Install Gas System Components	15 days	Tue 2/5/13	Mon 2/25/13	\$3,074.56	11													
13	Mechanical Stand for Alcove 2 Test	51.5 days	Mon 12/3/12	Tue 2/12/13	\$20,279.76														
14	Design Stand	12.5 days	Mon 12/3/12	Wed 12/19/12	\$11,905.20														
15	Procure Stand Fabrication	35 days	Wed 12/19/12	Wed 2/6/13	\$5,300.00	14													
16	Install Stand in Alcove 2	4 days	Wed 2/6/13	Tue 2/12/13	\$3,074.56	15													
17	Install Racks	75 days	Mon 12/3/12	Fri 3/15/13	\$12,715.28														
18	Review Rack Installation Plan	27 days	Mon 12/3/12	Tue 1/8/13	\$2,947.60														
19	Identify and Locate Suitable Existing Racks	6 days	Mon 1/28/13	Mon 2/4/13	\$1,462.40	18FS+13 days													
20	Install Mechanical Wedge to Support Racks	10 days	Tue 2/5/13	Mon 2/18/13	\$1,537.28	19													
21	Install Drip Ceiling Over Racks	15 days	Mon 2/25/13	Fri 3/15/13	\$3,074.56	20FS+4 days													
22	Install Level Platform for Table Near Alcove 4	15 days	Mon 2/25/13	Fri 3/15/13	\$768.64	20FS+4 days													
23	Connect Racks to Clean AC Power	15 days	Mon 2/25/13	Fri 3/15/13	\$2,924.80	20FS+4 days													
24	Install Cables	69 days	Mon 12/3/12	Thu 3/7/13	\$16,348.82														
25	Review Proposed Cable Plant Design	12 days	Mon 12/3/12	Tue 12/18/12	\$1,507.60														
26	Review Network Capacity	17 days	Mon 12/3/12	Tue 12/25/12	\$376.90														
27	Update Cable Plant Design	5 days	Mon 12/24/12	Fri 12/28/12	\$3,015.20	25FS+3 days													
28	Procure Cable Assemblies	30 days	Mon 12/31/12	Fri 2/8/13	\$4,240.00	27													
29	Install Cable Patch Panels in New Racks	5 days	Mon 2/11/13	Fri 2/15/13	\$2,597.28	28													
30	Install Cable Assemblies	14 days	Mon 2/18/13	Thu 3/7/13	\$3,074.56	29													
31	Replace Network Repeater in MINOS ND Hall	11 days	Mon 1/14/13	Mon 1/28/13	\$1,537.28														
32	Install Electronics into Racks	75 days	Mon 12/3/12	Fri 3/15/13	\$42,895.52														
33	Review DAQ Strategy	6 days	Mon 12/3/12	Mon 12/10/12	\$0.00														
34	Decide on DAQ Components Required	10 days	Tue 12/11/12	Mon 12/24/12	\$0.00	33													
35	Procure DAQ Components	40 days	Tue 12/25/12	Mon 2/18/13	\$7,420.00	34													
36	Install Electronics	19 days	Tue 2/19/13	Fri 3/15/13	\$3,989.12	35													
37	Purchase Oscilloscope	20 days	Mon 12/3/12	Fri 12/28/12	\$26,500.00														
38	Procure Temperature Sensor and Electronics	20 days	Mon 12/3/12	Fri 12/28/12	\$0.00														
39	Install Temperature Sensor & DAQ	5 days	Mon 12/31/12	Fri 1/4/13	\$4,986.40	38													
40	Ion Chambers	102 days	Mon 12/3/12	Tue 4/23/13	\$29,557.28														

Project: MuonProto1120 Date: Mon 11/26/12	Task		Project Summary		Inactive Milestone		Manual Summary Rollup		Deadline
	Split		External Tasks		Inactive Summary		Manual Summary		Progress
	Milestone		External Milestone		Manual Task		Start-only		Finish-only
	Summary		Inactive Task		Duration-only		Finish-only		Finish-only

ID	O	Task Name	Duration	Start	Finish	Cost	Predecessors	Timeline											
								1st Quarter	2nd Quarter	3rd Quarter	4th Quarter								
								Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
41		Decide on Initial Commercial Detector Model	5 days	Mon 12/3/12	Fri 12/7/12	\$0.00			Univ Uncosted Physicist										
42		Procure Commercial Detector	12 days	Mon 12/10/12	Tue 12/25/12	\$1,060.00	41		M&S[1,000]										
43		Design Mounts	5 days	Wed 12/26/12	Tue 1/1/13	\$2,160.00	42		LANL Engineer										
44		Produce Mount Drawings	5 days	Wed 1/9/13	Tue 1/15/13	\$2,160.00	43FS+5 days		LANL Engineer										
45		Procure Ion Chamber Mount Parts	10 days	Wed 1/16/13	Tue 1/29/13	\$2,120.00	44		M&S[2,000]										
46		Choose Detector Technology	10 days	Wed 1/30/13	Tue 2/12/13	\$0.00	45		Univ Uncosted Physicist										
47		Update Detector Mount Design	5 days	Wed 2/13/13	Tue 2/19/13	\$1,440.00	46		LANL Engineer										
48		Procure Ion Chamber Detector	20 days	Wed 2/20/13	Tue 3/19/13	\$4,240.00	47		M&S[4,000]										
49		Procure Ion Chamber Detector Mount Components	20 days	Wed 3/20/13	Tue 4/16/13	\$4,240.00	48		M&S[4,000]										
50		Install Ion Chamber Detector in Alcove	5 days	Wed 4/17/13	Tue 4/23/13	\$1,537.28	49		FNAL Mech Tech										
51		Cherenkov Detector	110 days	Mon 1/14/13	Fri 6/14/13	\$83,888.80													
52		Review/Update Current Cherenkov Detector Design	5 days	Mon 1/14/13	Fri 1/18/13	\$5,895.20			LANL Engineer, FNAL Engineer, Univ Uncosted Physicist										
53		Design Baffles/Determine PMT Location	5 days	Mon 1/21/13	Fri 1/25/13	\$2,880.00	52		LANL Engineer										
54		Generate Baffle Drawings	5 days	Mon 1/28/13	Fri 2/1/13	\$2,880.00	53		LANL Engineer										
55		Procure PMTs	15 days	Mon 1/21/13	Fri 2/8/13	\$10,600.00	52		M&S[10,000]										
56		Update Safety Requirements	5 days	Mon 2/4/13	Fri 2/8/13	\$2,947.60	54		FNAL Engineer, LANL Engineer										
57		Design PMT Mount and Feedthroughs	5 days	Mon 1/28/13	Fri 2/1/13	\$3,600.00	53		LANL Engineer[50%]										
58		Design Remote Control Adjustable Mount	10 days	Mon 2/11/13	Fri 2/22/13	\$5,895.20	56		FNAL Engineer, LANL Engineer										
59		Procure Remote Controlled Adjustable Mount Components	65 days	Mon 2/25/13	Fri 5/24/13	\$42,400.00	58		M&S[40,000]										
60		Assemble and Test Cherenkov Detector	10 days	Mon 5/27/13	Fri 6/7/13	\$4,484.88	59		FNAL Mech Tech, FNAL Engineer, LANL Eng										
61		Install Cherenkov Detector in Alcove	5 days	Mon 6/10/13	Fri 6/14/13	\$2,305.92	60		FNAL Mech Tech										
62		Stopped Muon Detector	163 days	Mon 1/7/13	Wed 8/21/13	\$61,551.84													
63		Review/Update Current Muon Detector Design	6 days	Mon 1/7/13	Mon 1/14/13	\$2,880.00			LANL Engineer, Univ Uncosted Physicist										
64		Select PMT to be used	5 days	Tue 1/15/13	Mon 1/21/13	\$10,600.00	63		M&S[10,000], Univ Uncosted Physicist										
65		Design HV Gating Electronics	49 days	Tue 1/22/13	Fri 3/29/13	\$23,460.00	64		M&S[1,000], LANL Technologist										
66		Design Muon Detector and Generate Drawings	8 days	Mon 4/1/13	Wed 4/10/13	\$6,440.00	65		M&S[2,000], LANL Engineer										
67		Generate Layout of Graphite Blocks	5 days	Thu 4/11/13	Wed 4/17/13	\$1,440.00	66		LANL Engineer										
68		Design Graphite Block Can and Generate Drawings	15 days	Thu 4/18/13	Wed 5/8/13	\$4,320.00	67		LANL Engineer										
69		Specify Graphite Blocks	5 days	Thu 5/9/13	Wed 5/15/13	\$1,440.00	68		LANL Engineer										
70		Procure Graphite Blocks	30 days	Thu 5/16/13	Wed 6/26/13	\$6,360.00	69		M&S[6,000]										
71		Assemble Graphite Blocks	19 days	Thu 6/27/13	Tue 7/23/13	\$3,074.56	70		FNAL Mech Tech										
72		Install Stopped Muon Detector	21 days	Wed 7/24/13	Wed 8/21/13	\$1,537.28	71		FNAL Mech Tech										