LBNE Muon System Tests

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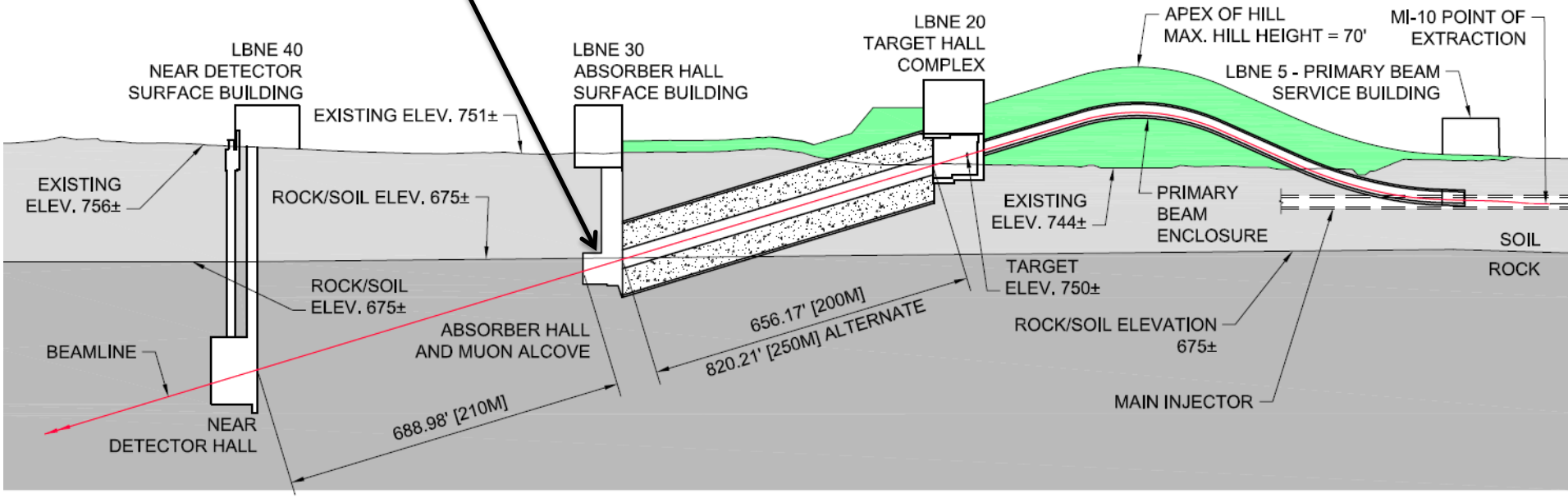
LBNE-NuMI ND Muon System Program

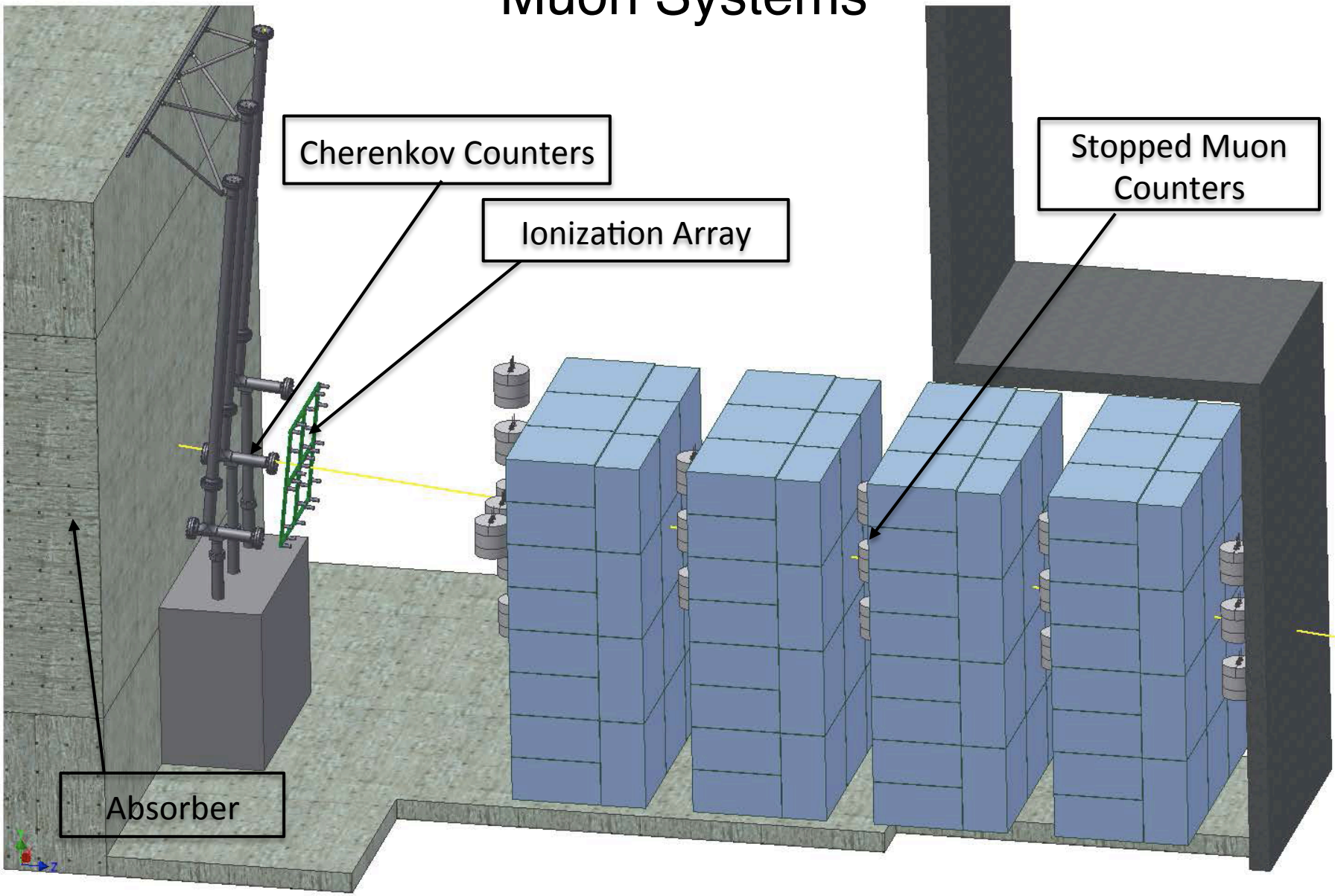
- Collaboration:
  - University of Colorado: A. Marino, Zack Liptak, and Eric Zimmerman +students
  - Drexel University: Chuck Lane +students
  - Los Alamos: Geoff Mills, Jan Boissevain + others
  - Fermilab: Cory Crowley, Paul Kasley, Mark Averett, Tom Zuchnik, Mike Andrews , and others
  - CERN: Heinz Pernegger, Hendrick Jansen, Matevs Cevn
- Muon measurements after the absorber
  - Single particle environment (nearly)
  - Muons are created in pion and kaon decays and bear directly on neutrino production
  - Rely only upon knowing muon energy loss and scattering in the absorber material
  - Complements other flux measurements:
    - external hadro-production measurements don't include horn and decay tunnel
    - ND neutrino measurements rely on knowing neutrino-nucleus cross sections and relative near/far detector efficiencies

LBNE Beam Configuration
(older design…)

Location of muon alcove for LBNE



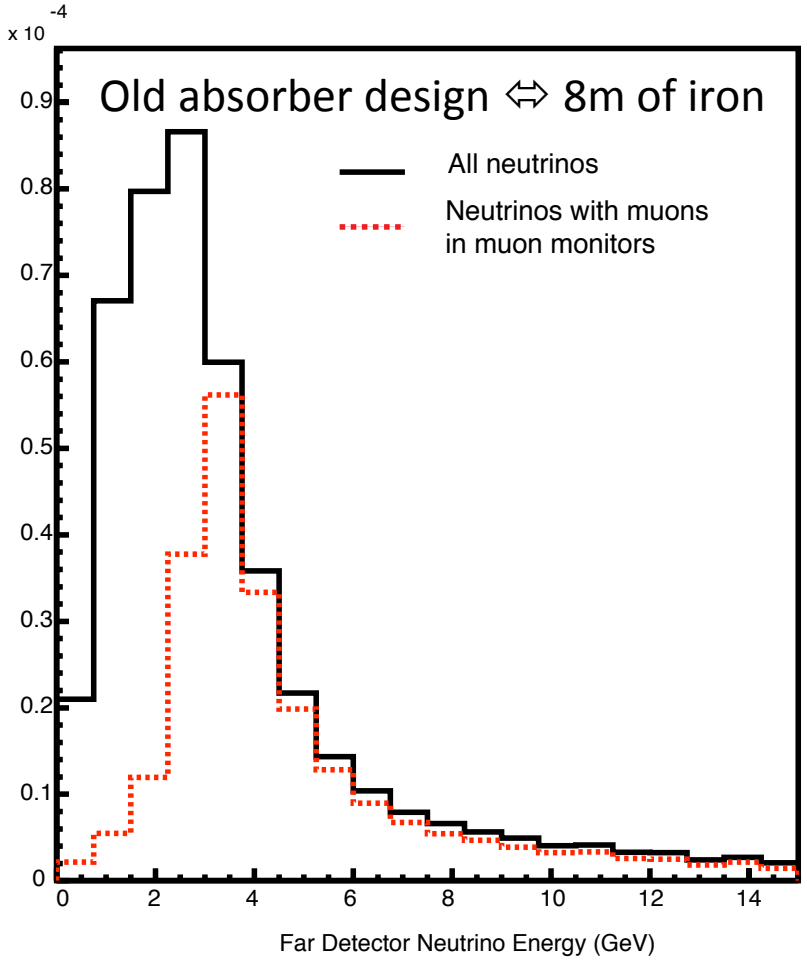
Near Detector Beam Line Muon Systems



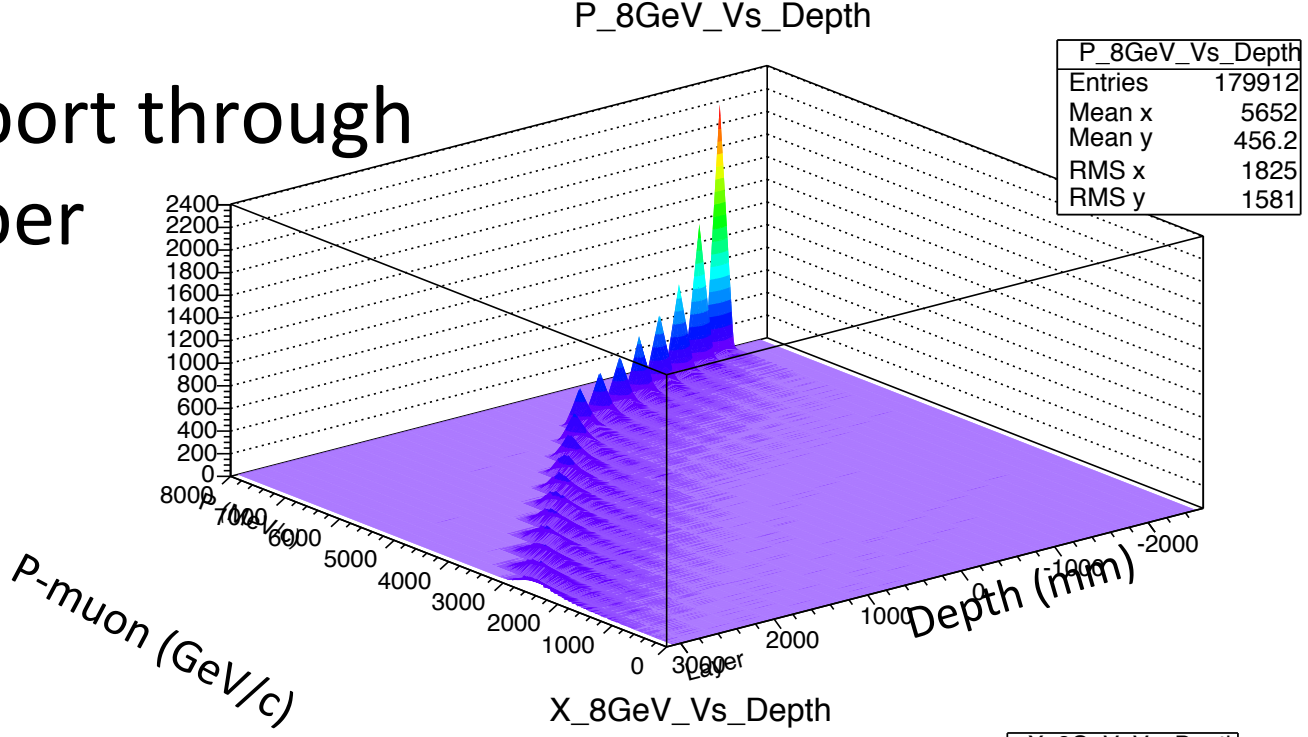
Muon-Neutrino Correlation

- 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:
  - $E_\nu=(0\text{-}0.43)E_\pi$
  - $E_\mu=E_\pi-E_\nu=(0.57\text{-}1.0)E_\pi$

Neutrinos at the Far Detector
(early absorber design)

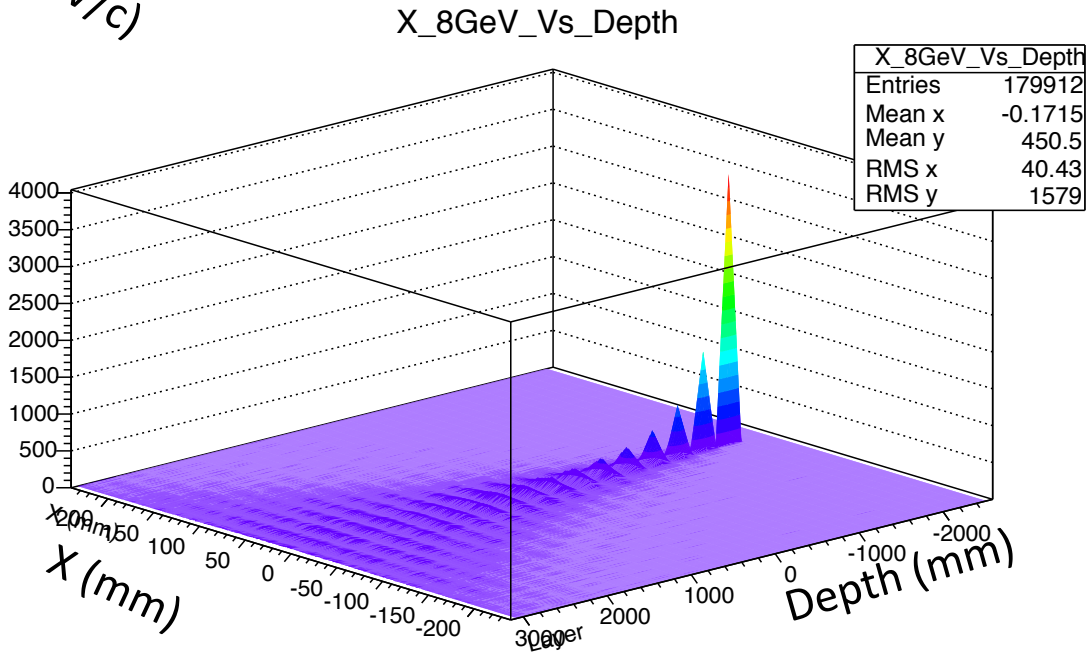


Muon Transport through NuMI Absorber



8 12” Al blocks

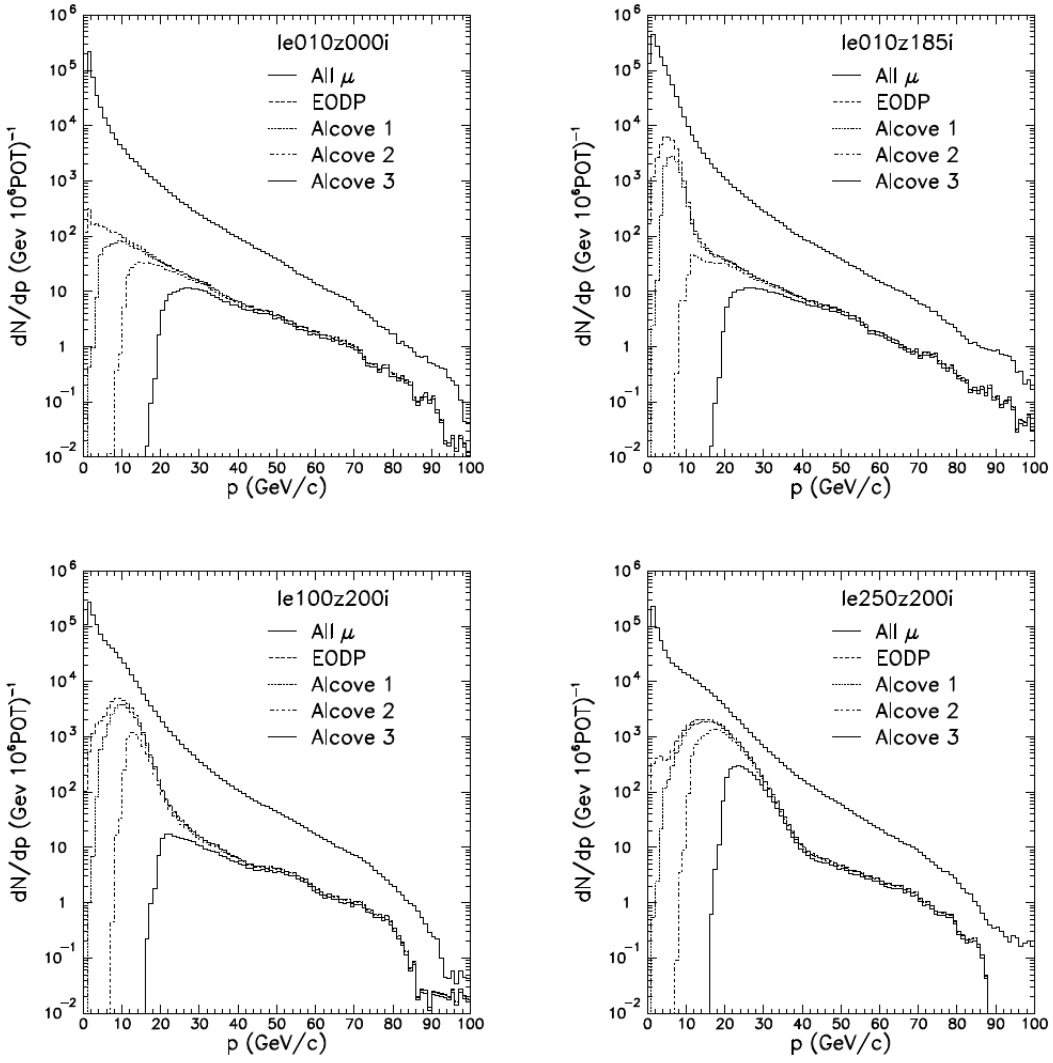
10 12” Fe blocks

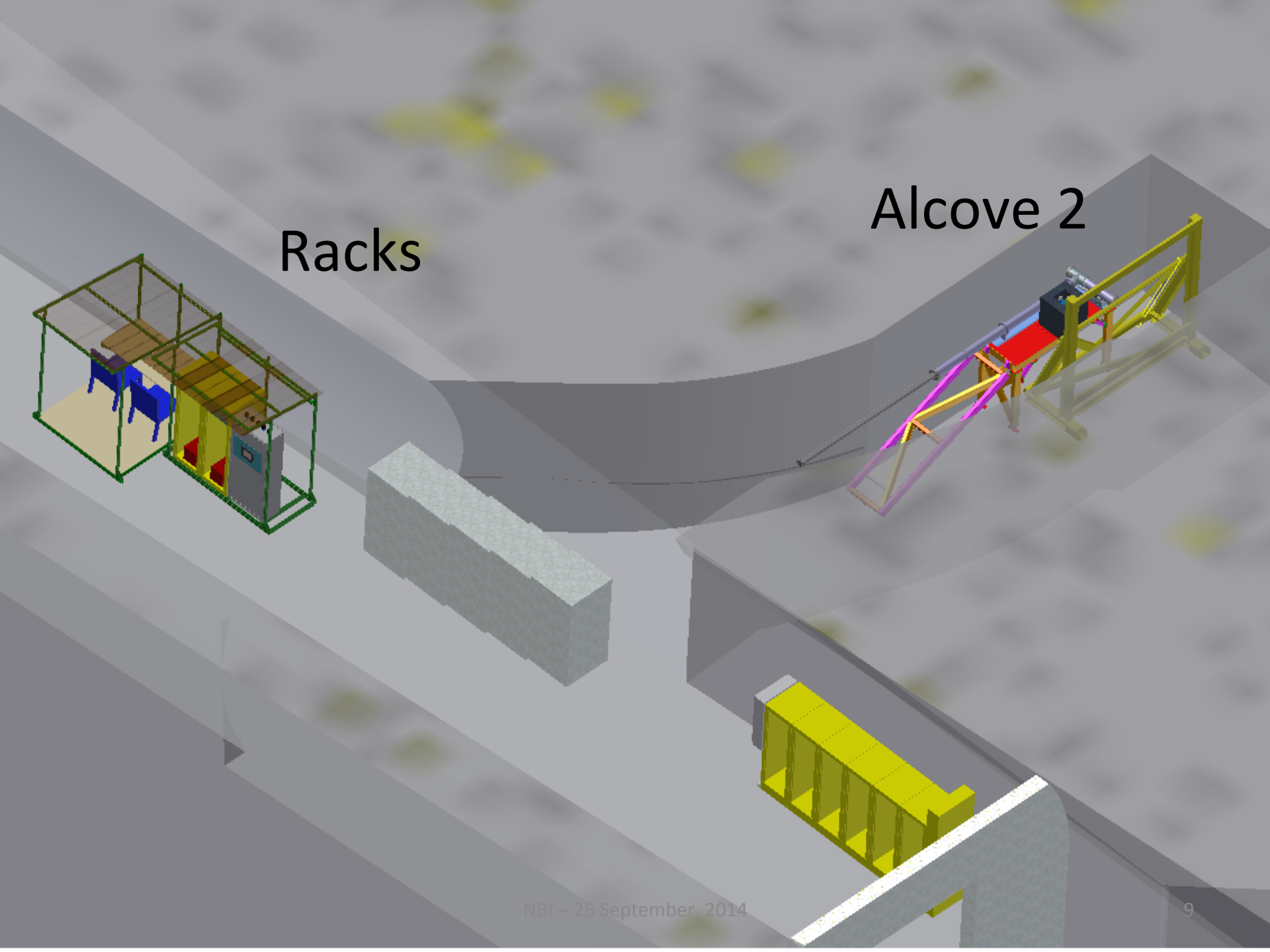


LBNE Prototype Tests at **NuMI**

- Capitalize on opportunity to test those devices in NuMI beam during the Nova run
- Planning started August 2012
- Infrastructure put into place spring 2013
- First Cherenkov detector prototypes in place August-September 2013
- First signals observed in October, 2013
- Alcove Operational Readiness Review in February,2014
- Engineering for Alcove 1 installation in progress
- Alcove 1 installation expected after September Main Injector shutdown

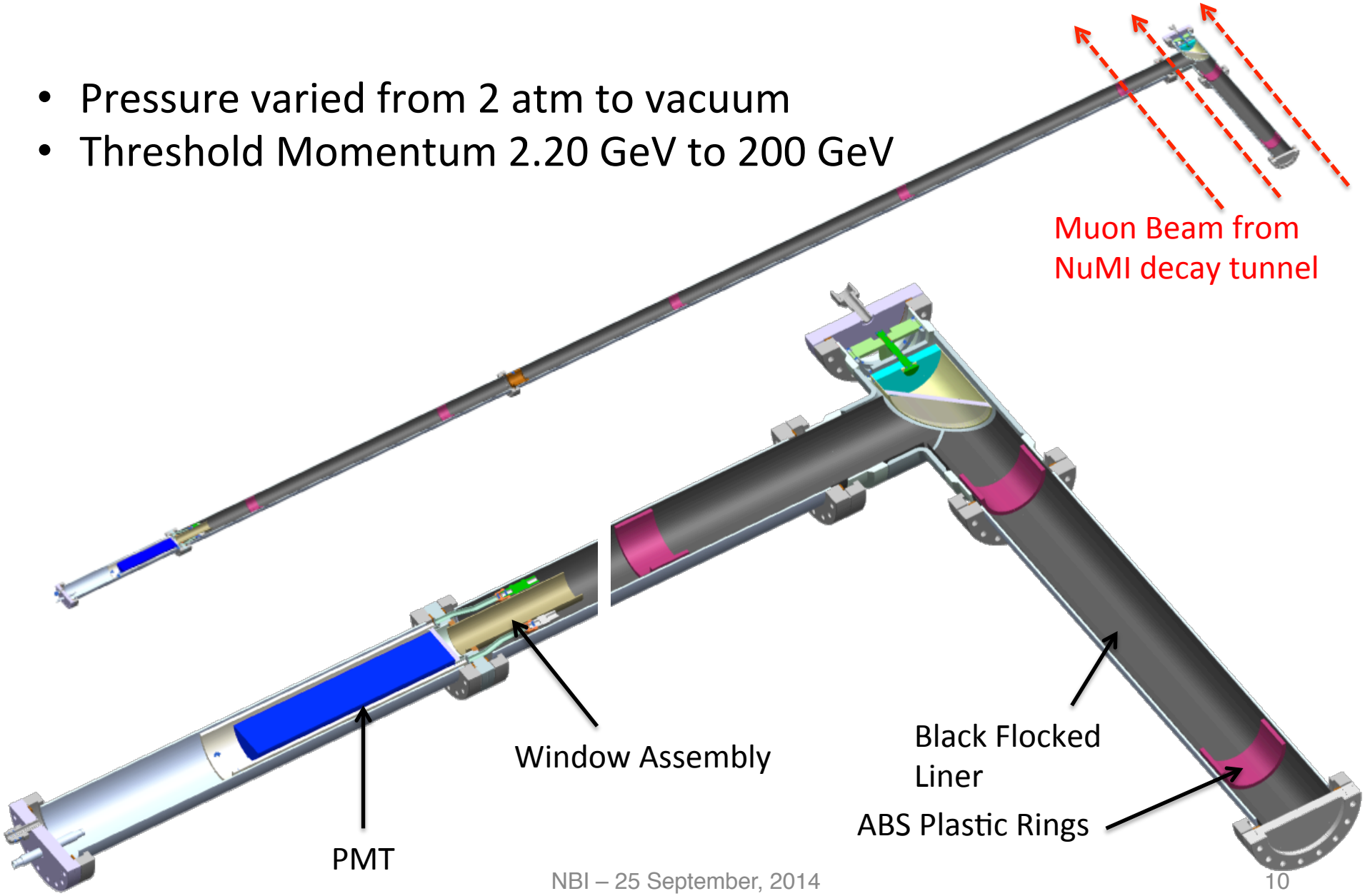
Muon Spectra Before NuMI Absorber




Racks
Alcove 2

LBNE/NuMI Cherenkov Counter

- Pressure varied from 2 atm to vacuum
- Threshold Momentum 2.20 GeV to 200 GeV



Cherenkov Gases

Table 1 Properties of several standard gases used in Cherenkov counters.

Gas	$(n-1)_{STP}$ $(\times 10^6)$	P_0^{STP} (GeV/c)	θ_c^{STP} (mrad), $P \to \infty$	Photons/m
Nitrogen	298	4.33	24.4	22
Oxygen	271	4.54	23.3	20
Argon	281	4.45	20.8	20.7
Neon	67.1	9.12	11.6	5.0
Helium	35.0	12.65	8.37	2.6
CO_2	449	3.52	30.0	33

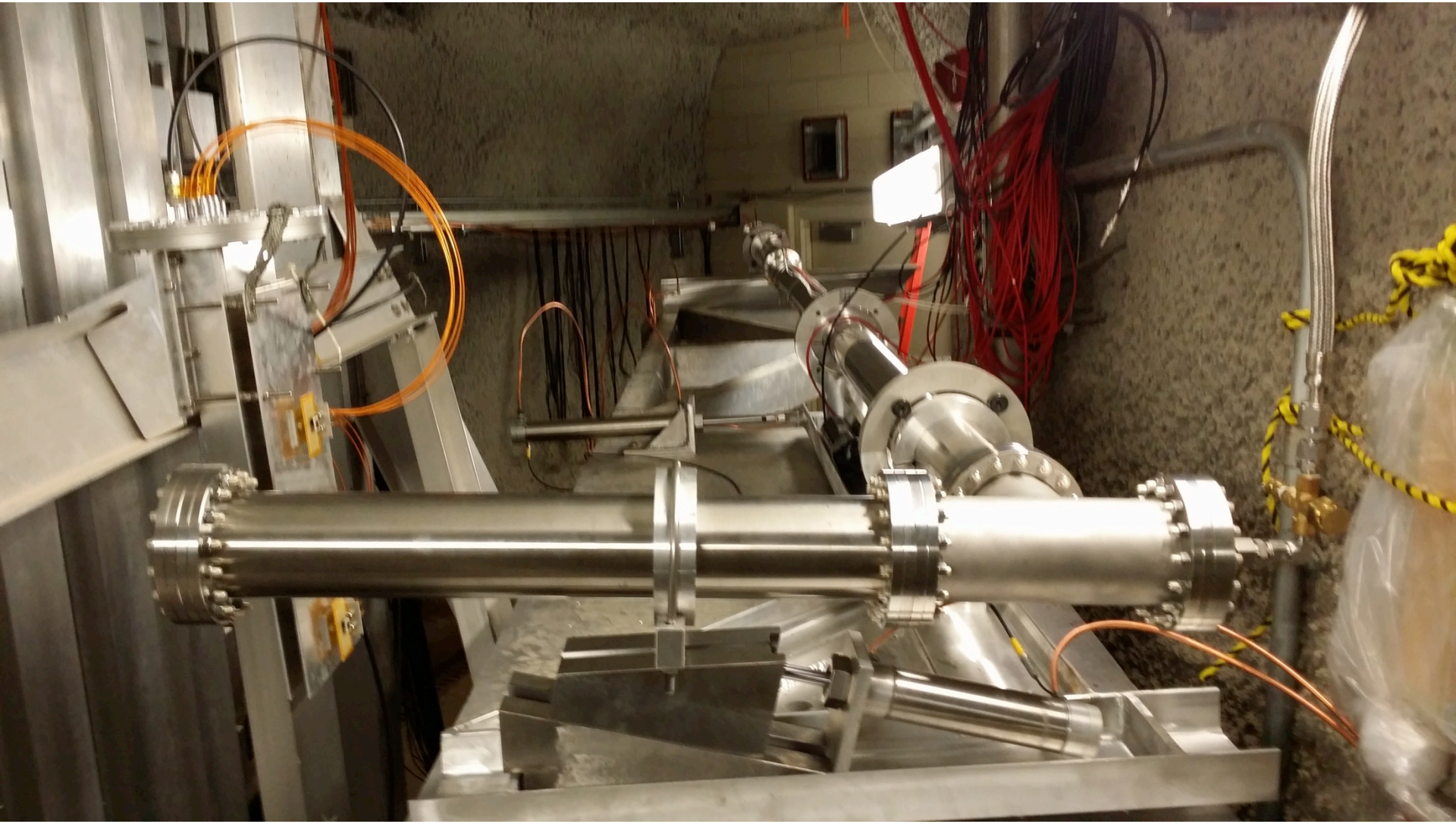
Argon Gas as a Cherenkov Radiator

Table 2 The behavior of visible Cherenkov light from muons in Argon gas.

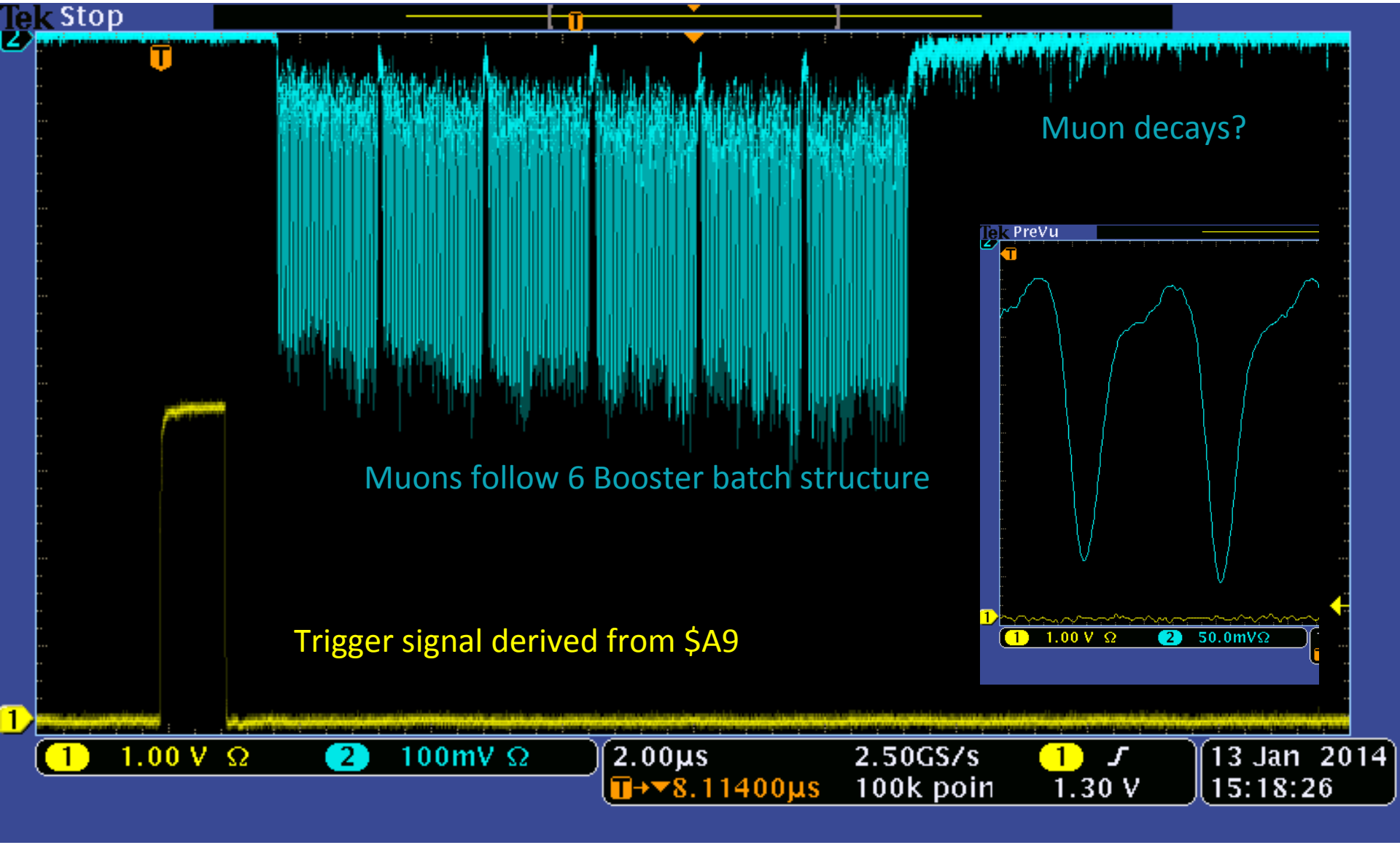
Pressure (atm)	P_0 (GeV/c)	θ_c (mrad) $P \to \infty$	Photons/m $P \to \infty$
5×10^{-4}	200	0.5	0.5
0.1	44.5	2.1	2.1
.5	6.29	6.6	6.5
1	4.45	14.7	14.6
3	2.57	20.8	20.7
10	1.41	36.0	35.9
20	1.00	93.0	92.6

At NuMI Alcove 2, about 10^5 muons/cm^2 are expected

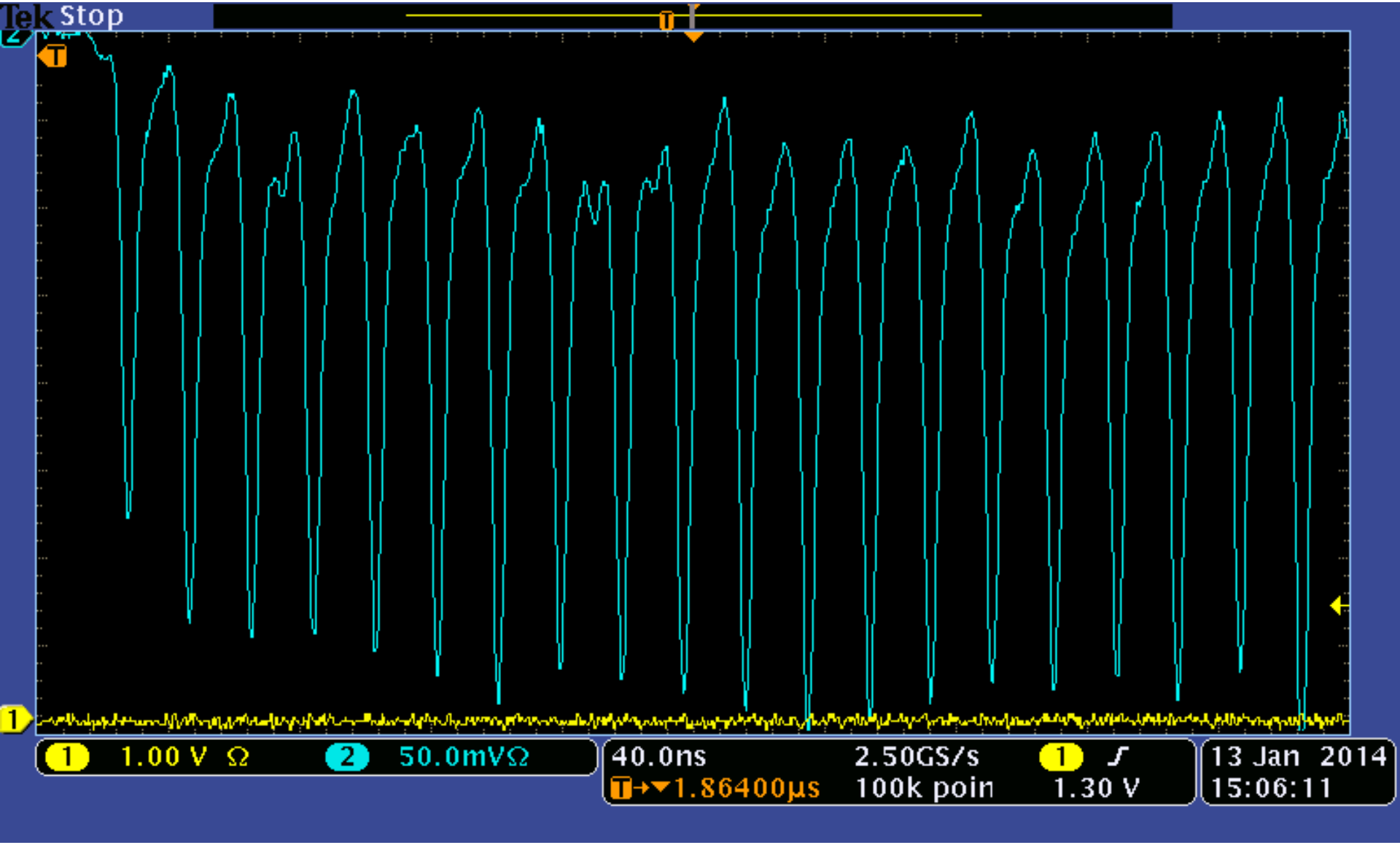
Radiator Section



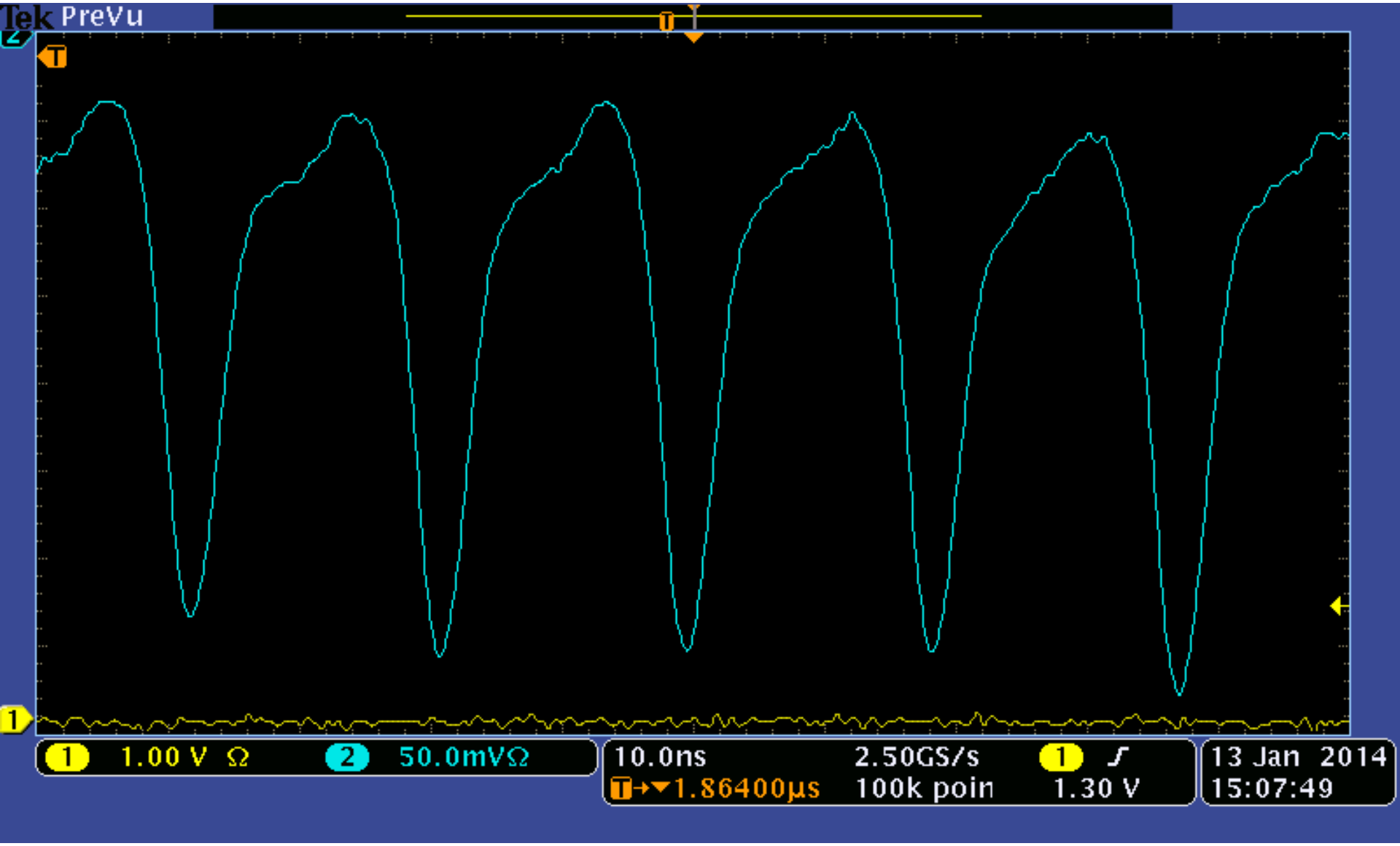
Typical NuMI Beam Pulse



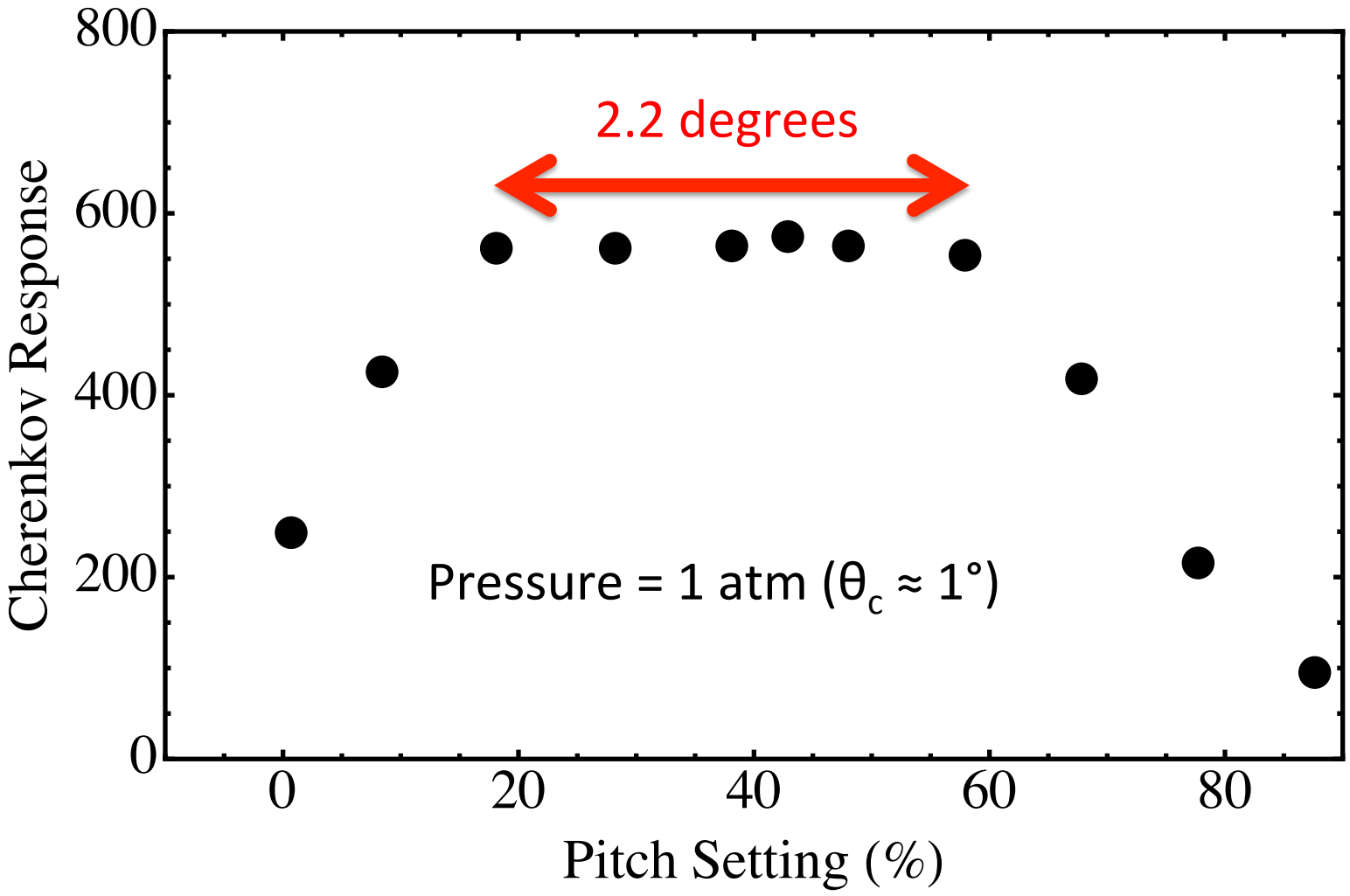
Beginning of Pulse Train (50 MHz RF)



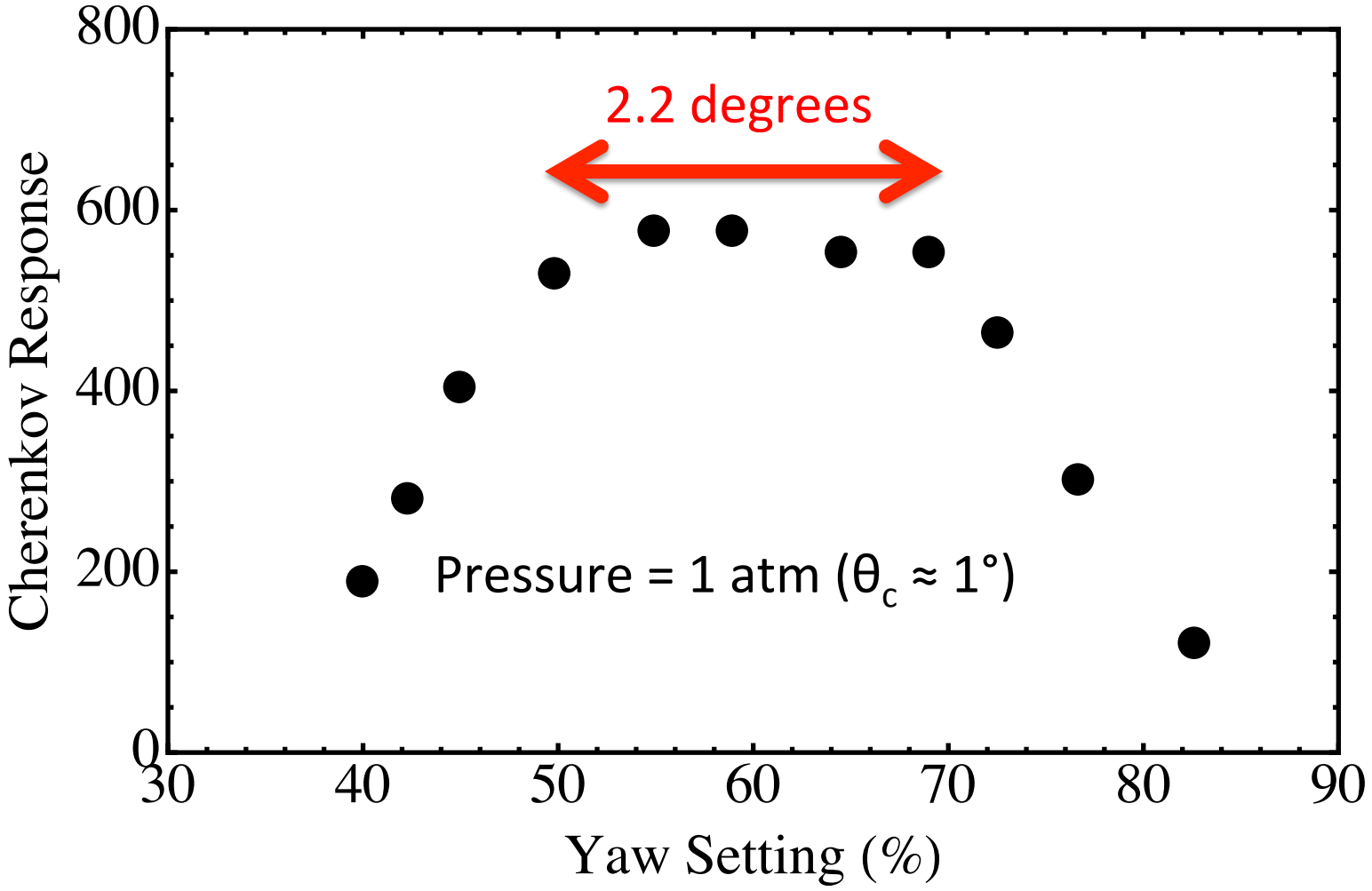
Individual RF Buckets



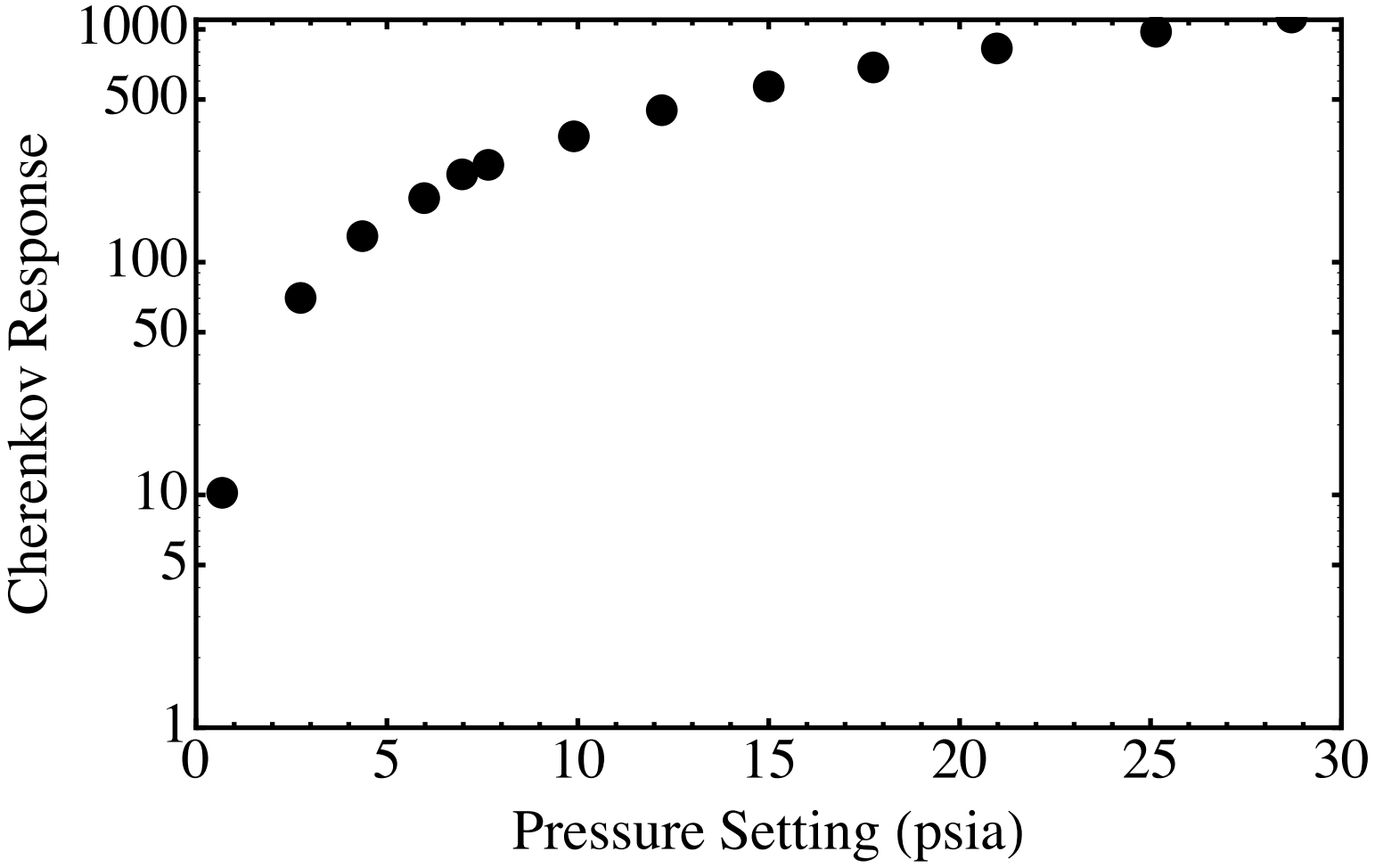
Cherenkov Response Versus Pitch Angle



Cherenkov Response Versus Yaw Angle



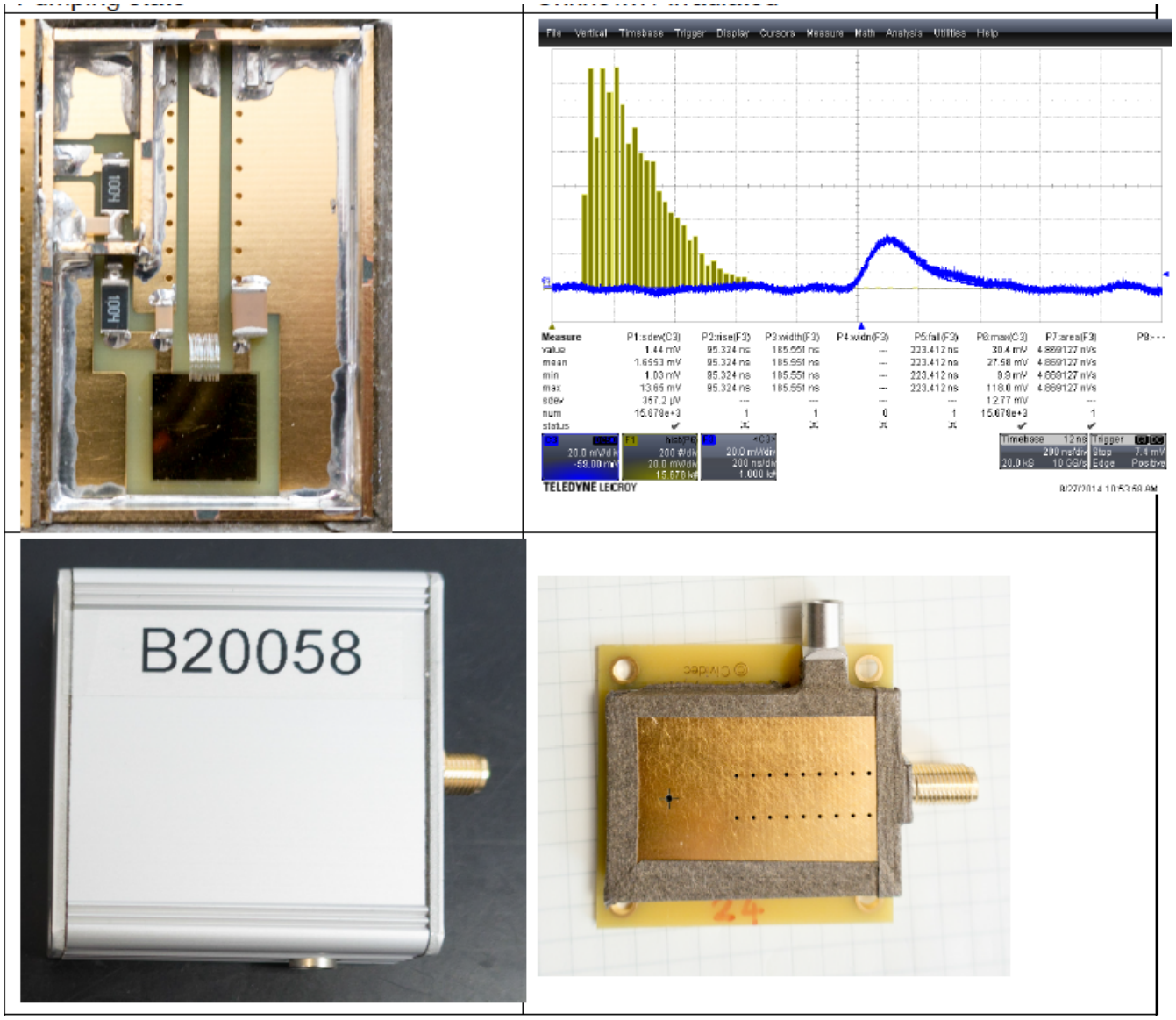
Cherenkov Response Versus Pressure



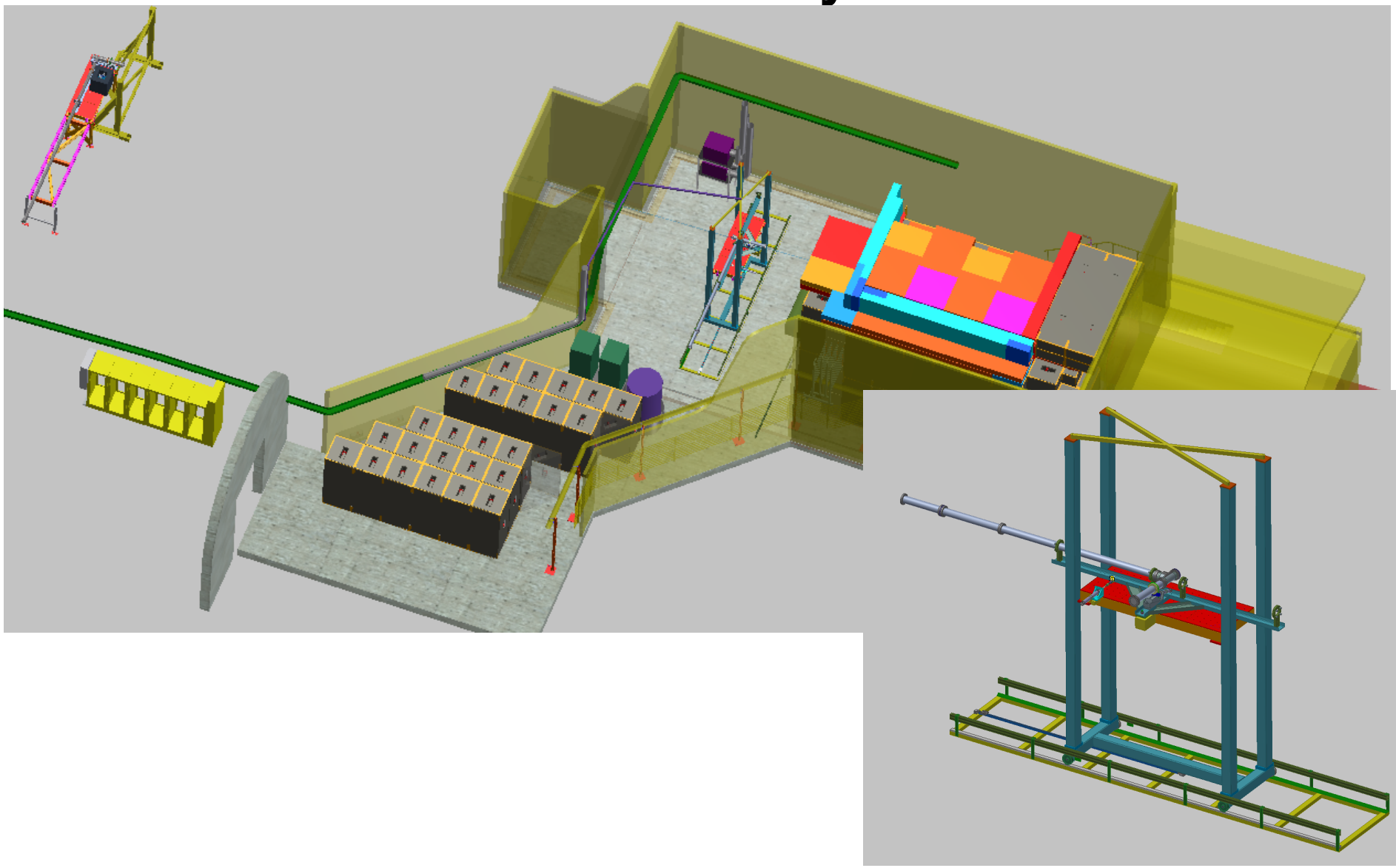
Future Plans

- Alcove 2 Cherenkov counter phase II upgrade to full pressure operation (nearly complete)
- Installation of diamond ionization detectors (DDs) (CU & CERN)
- Installation of Alcove 1 Cherenkov counter system
- Development of Stopped Muon Counter (SMCs) (see next talk)

CERN Diamond Detectors (H. Pernegger et. al.)



Alcove 1 Layout

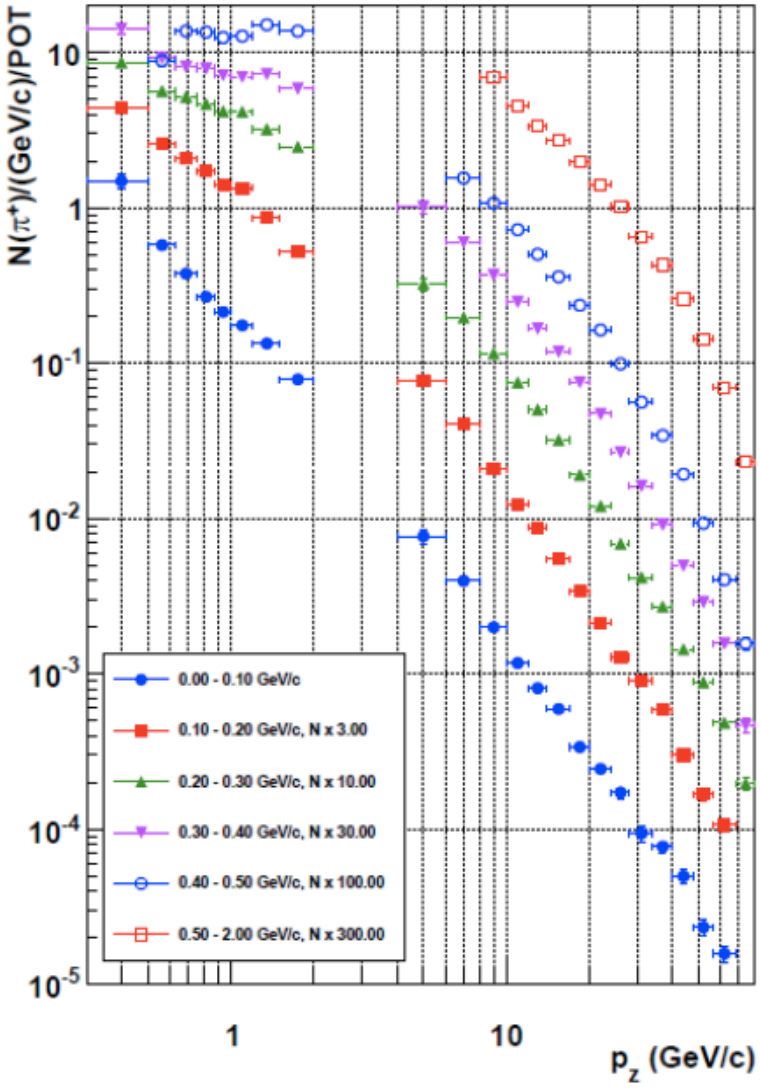


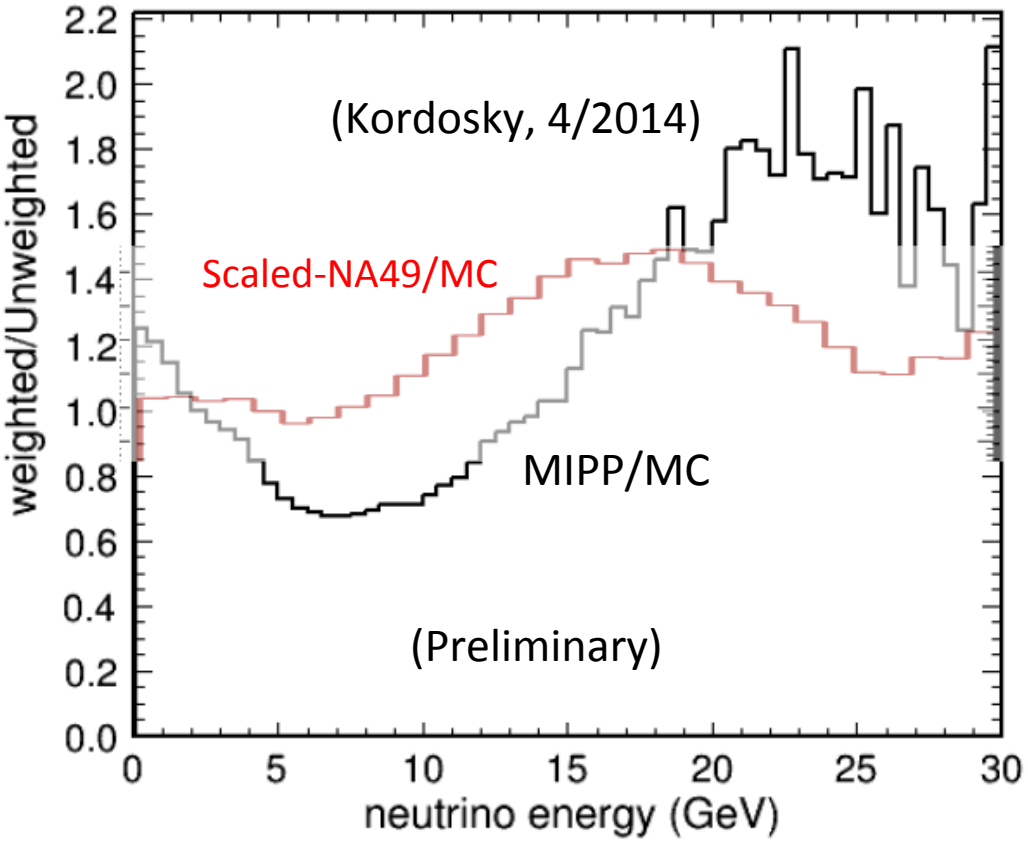
Summary

- Alcove 2 Cherenkov System seems to functioned well in phase I operation
- Phase 2 operation at full pressure will commence after shutdown
- Signals from Cherenkov counter look very encouraging
- Future installations into alcove 1 including DDs and SMCs

- Backup Slides

MIPP π^+ NuMI-Target Data and NA49 Data Reweighting

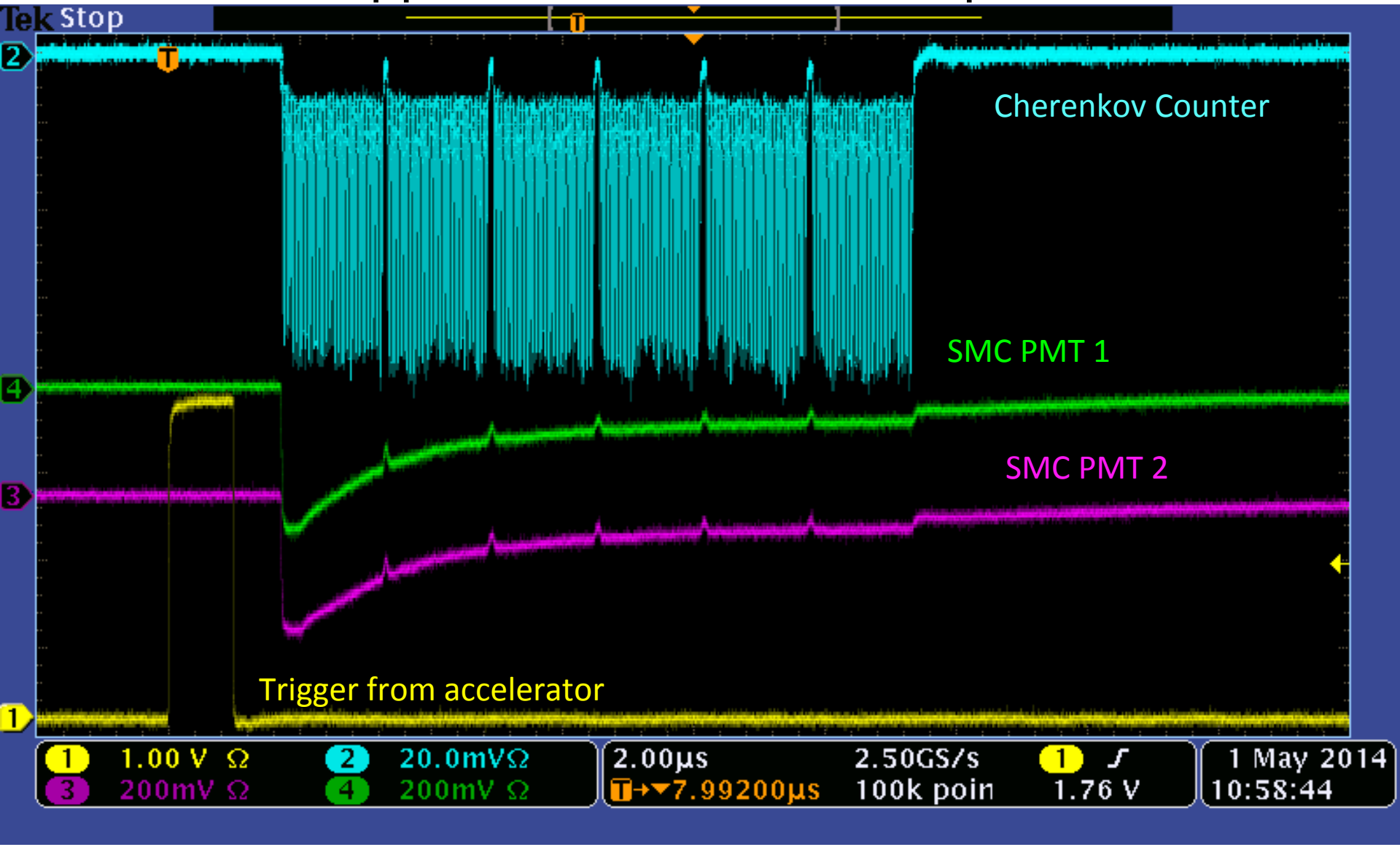




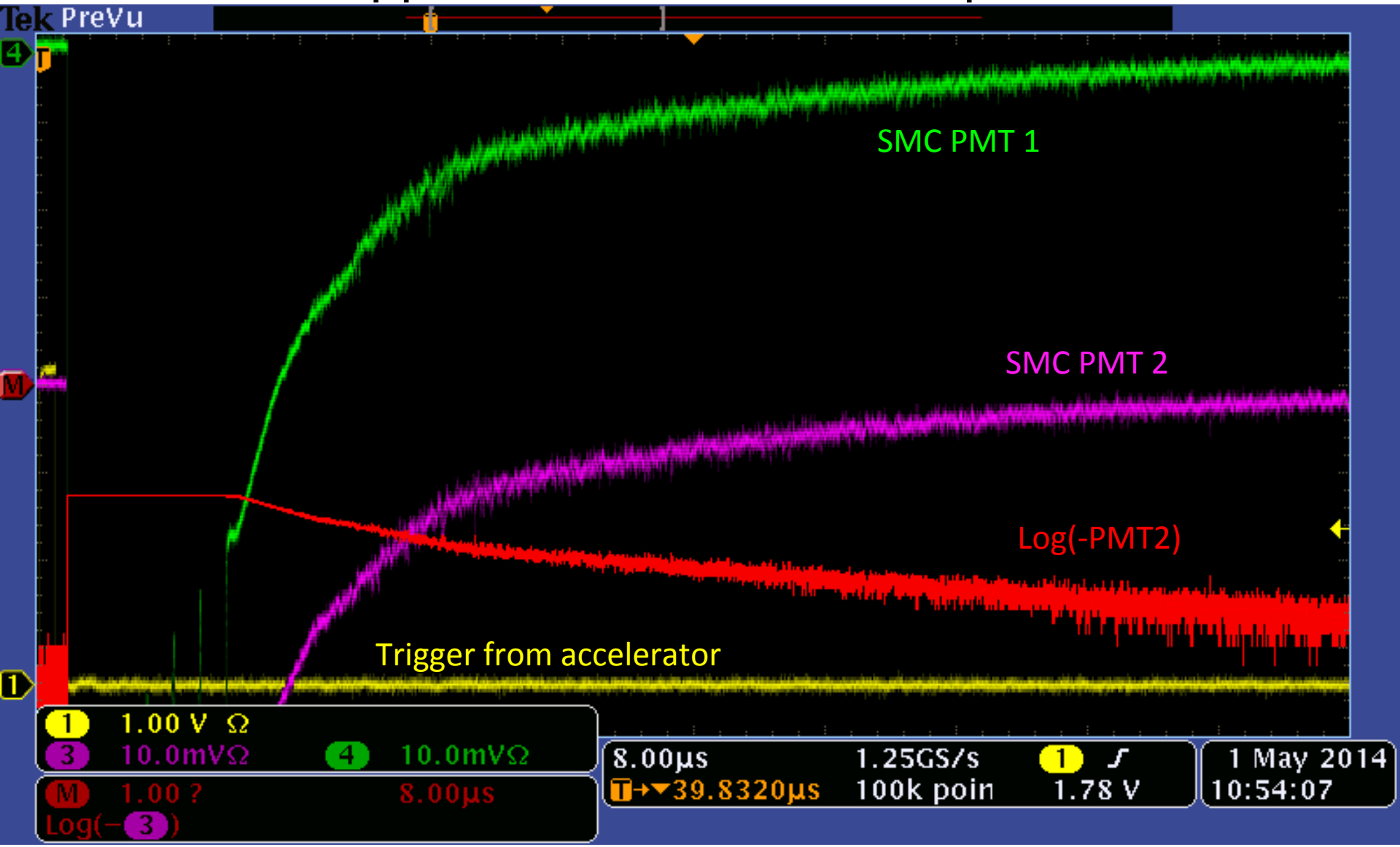
Significant differences in scaled thin-target versus direct thick target neutrino flux predictions

Stopped Muon Counter (Drexel University)

Stopped Muon Counter Response



Stopped Muon Counter Response



Dispersion in Argon

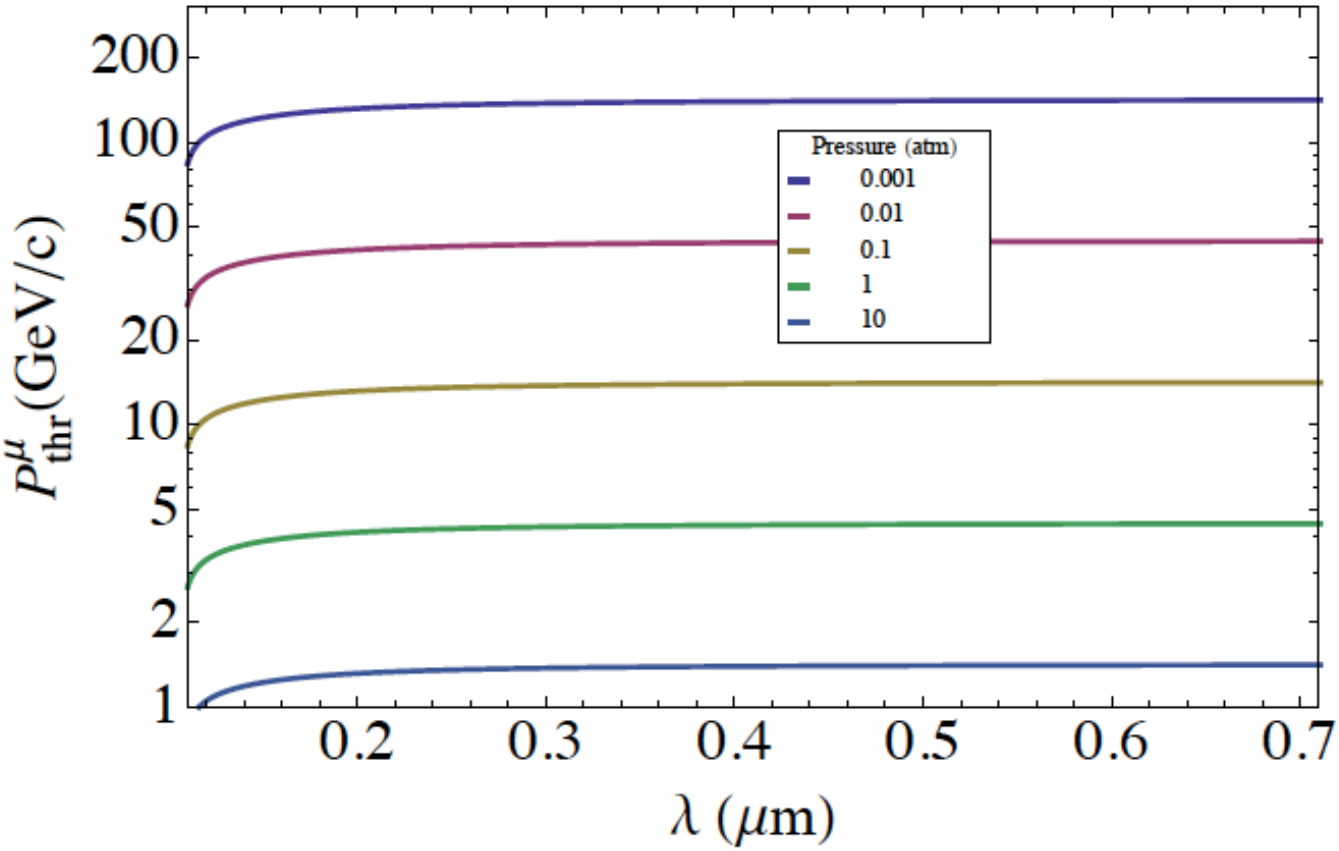
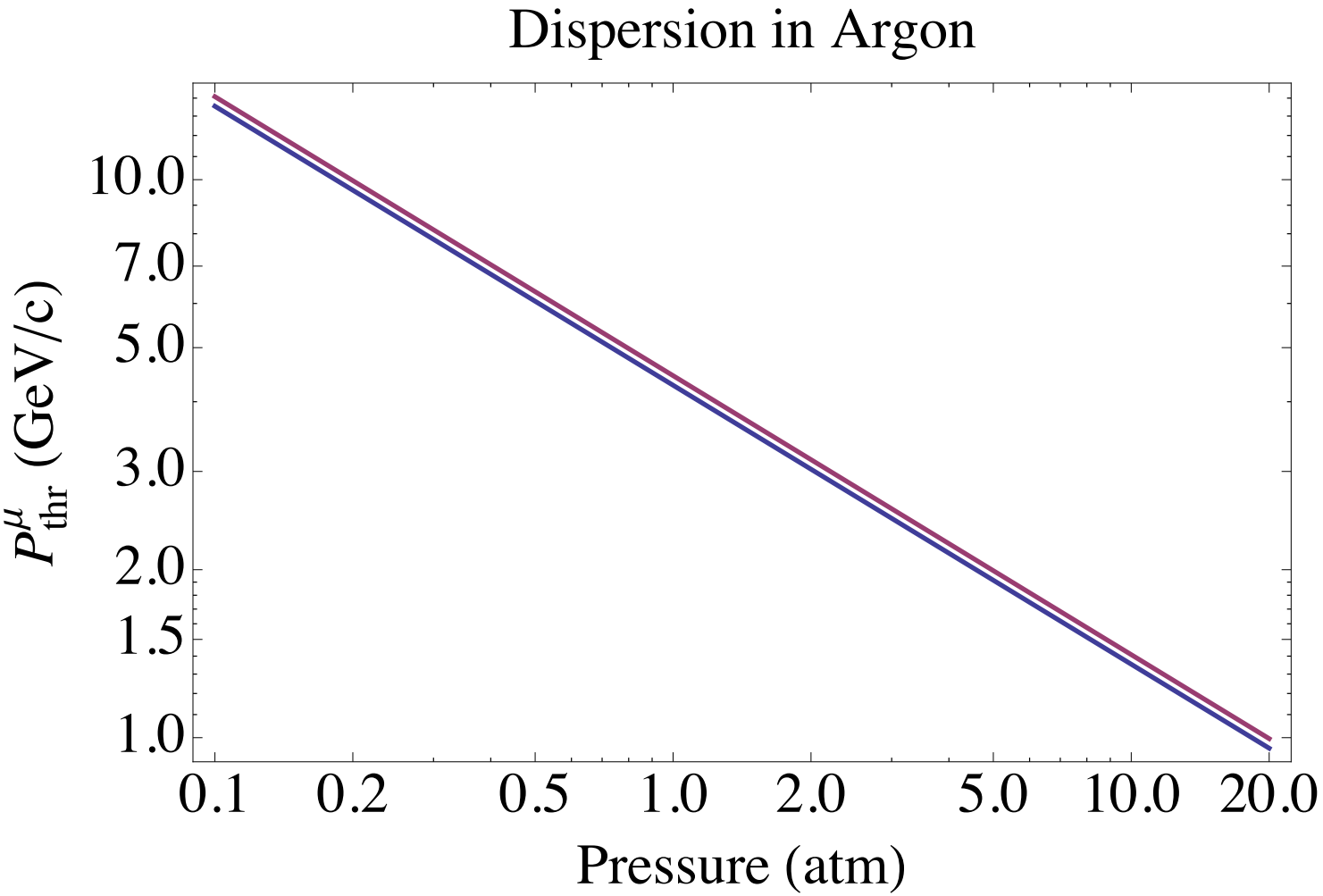
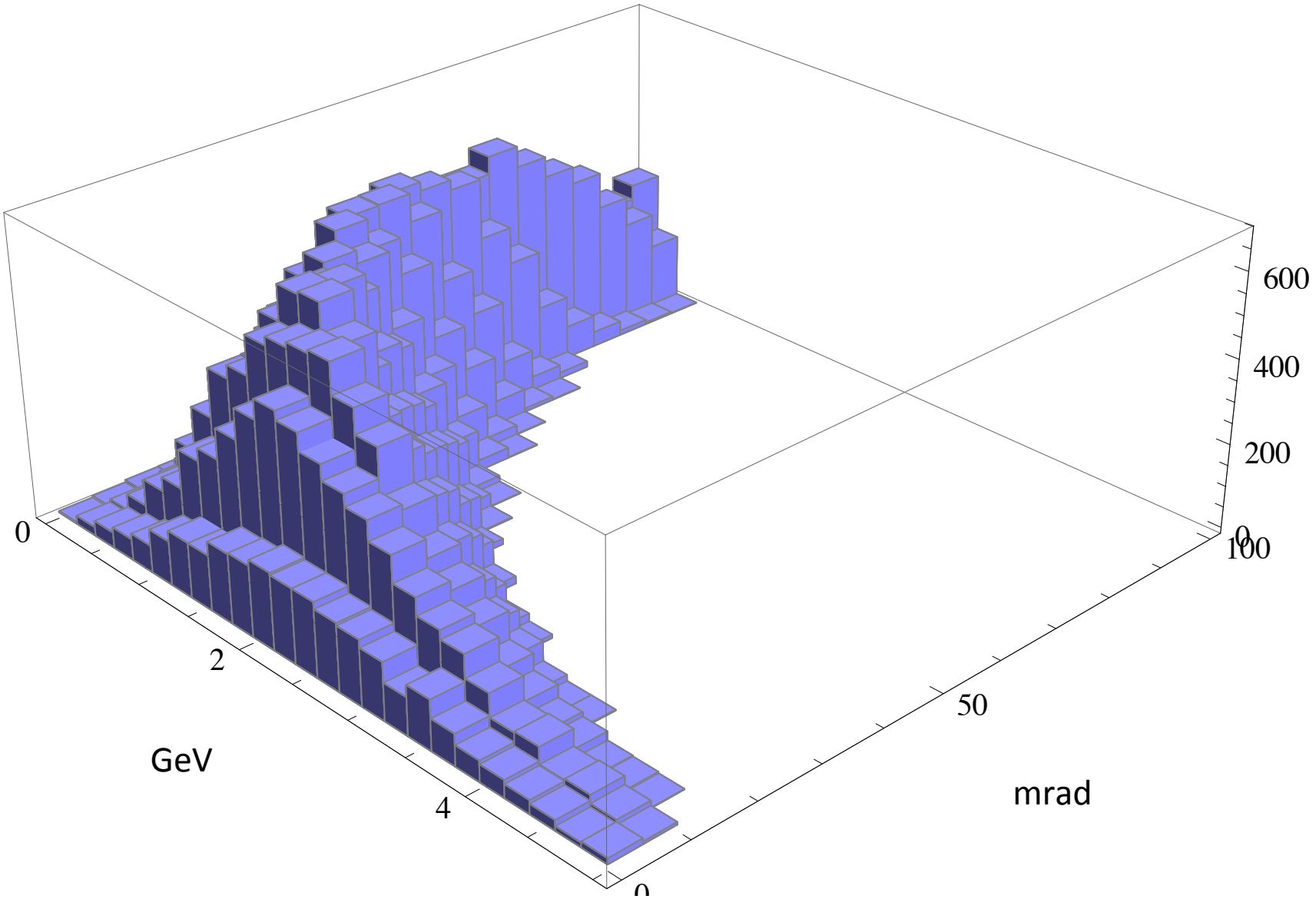


Figure 9 Wavelength dependence of the muon threshold momentum for argon for several gas pressures.

$\Delta P_{thr}/P_{thr}$~4% over 250nm-650nm



Nues from Pion - Muon Decay Chain