NOvA Test Beam

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for the NOvA Collaboration

Fermilab Test Beam Committee Meeting

November 3, 2017

UNIVERSITY OF Cincinnati

Motivation - NOvA Physics Reach

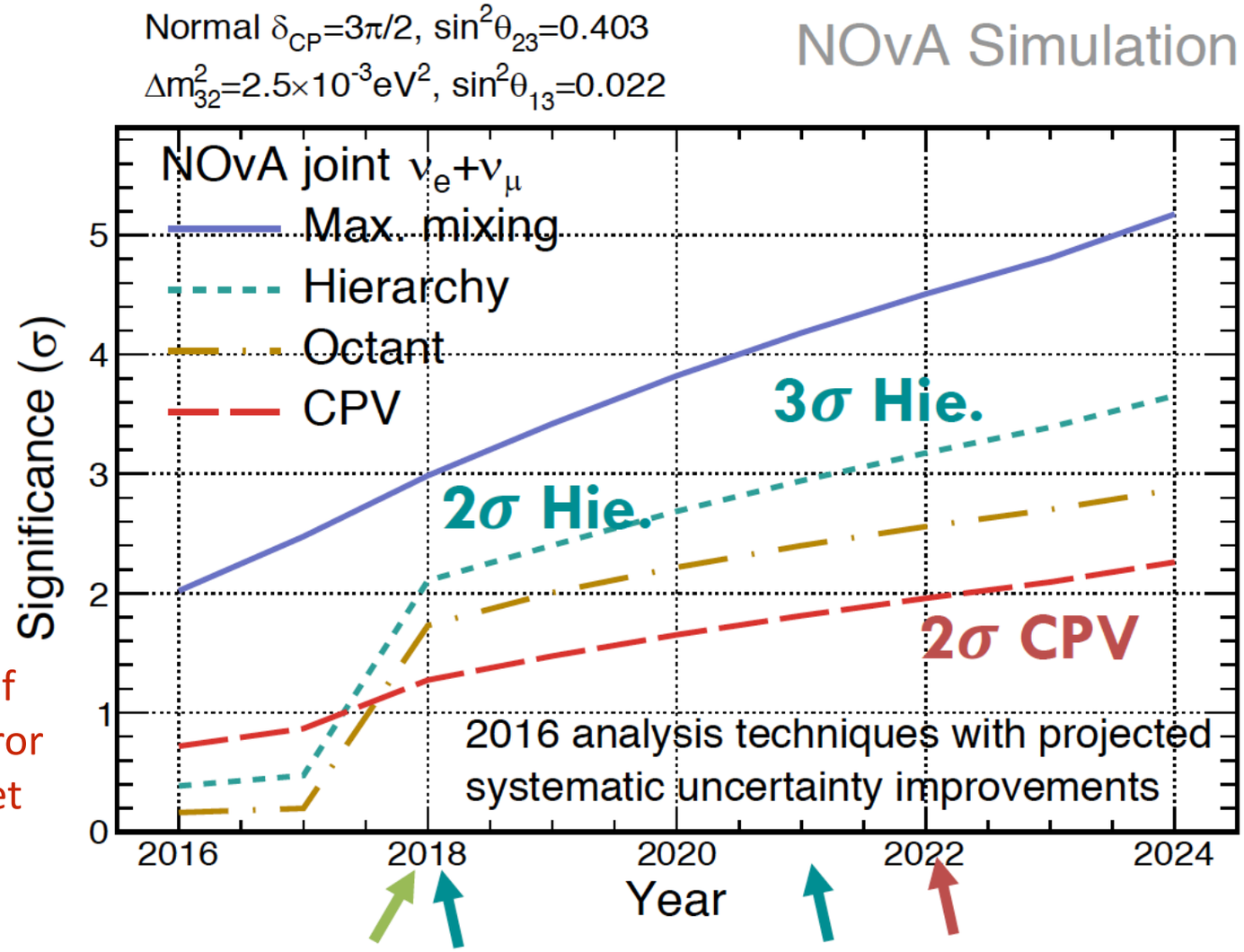
- Plot shows NOvA physics reach based on 2016 joint nue/numu analysis [Phys. Rev. Lett. **118**, 231801 (2017)]
  - From 2018 onwards, analysis benefits from nu + antinu
  - Systematics improvements assume 2% muon scale, 3% hadronic scale uncertainties

	$\sin^2\theta_{23}$ uncertainty in units of 10^{-3}
Muon scale [2% Abs.⊕2% Rel.]	±12
Hadron scale [5% Abs.⊕5% Rel.]	±12
Normalization [±5%]	±5
Cross-sections	±3
Neutrino flux	±2
Beam backgrounds [±100%]	+3/−6
Scintillation model	+4/−3
Total systematic	+17/−19
2024 statistics	±7

90% of syst. error budget

- Systematics reduction by factor of 2 would bring systematic errors to level of final statistic error in 2024

Lower octant, $\delta_{CP} = 3\pi/2$



Complete first analysis with antineutrino data

In direct competition with T2K, T2K-II, JUNO, ORCA

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  - From 2018 onwards, analysis benefits from nu + antinu
  - Systematics improvements assume 2% muon scale, 3% hadronic scale uncertainties
  - Further improvements: after 2019, gain effective exposure: 25% from analysis, increased beam power (800/900 W),17% from beam target

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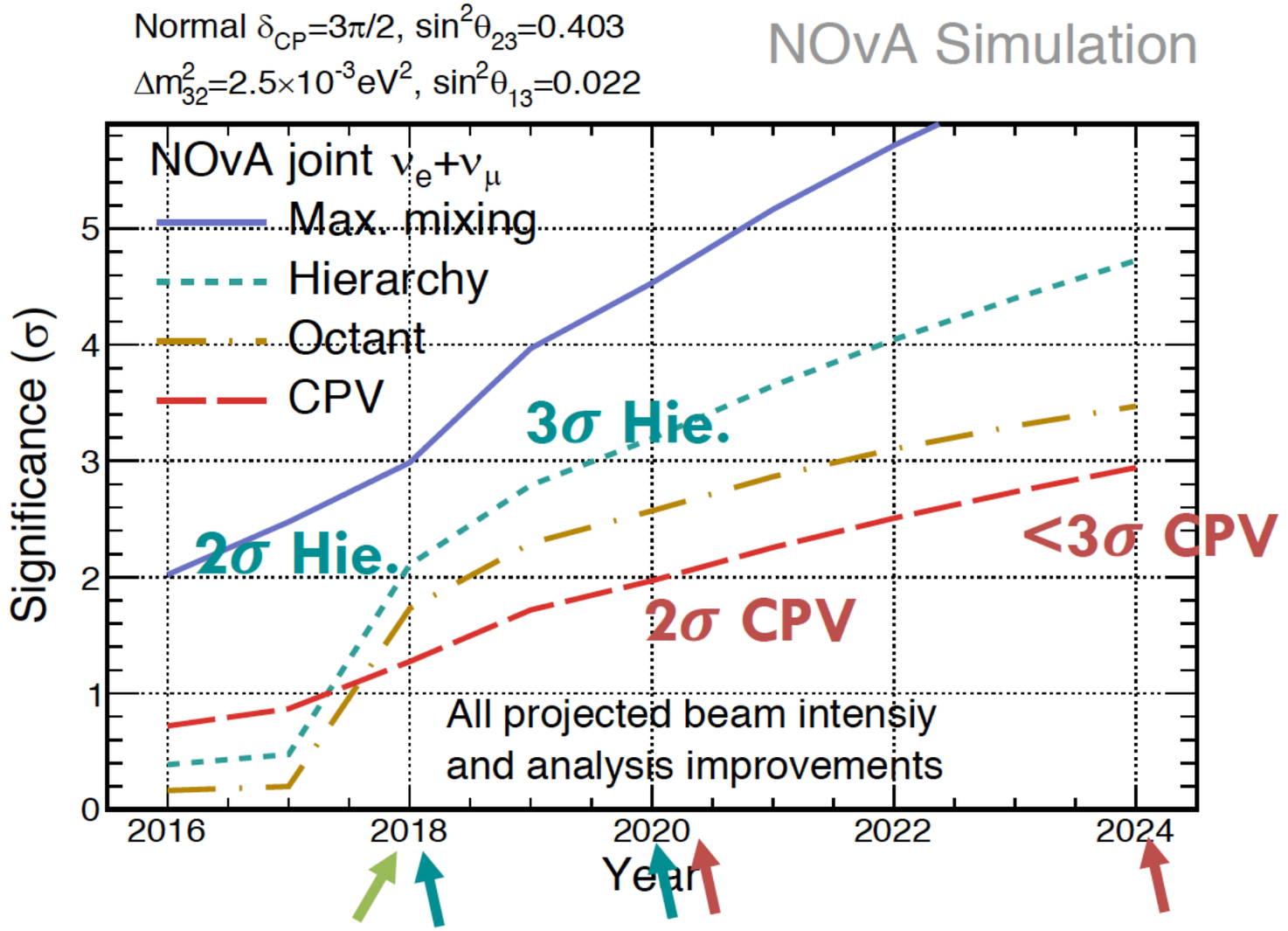


- In optimal scenario, NOvA may reach 3σ lepton CPV evidence. Test beam essential to achieve systematics improvements and validate them

Complete first analysis with antineutrino data

In direct competition with T2K, T2K-II, JUNO, ORCA

Motivation - MINERvA Test Beam

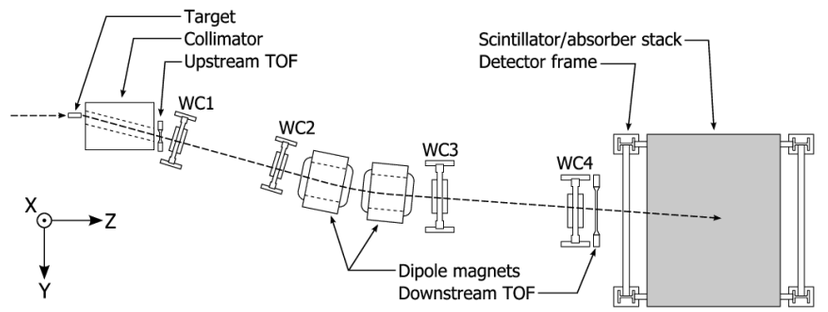
Systematic Errors

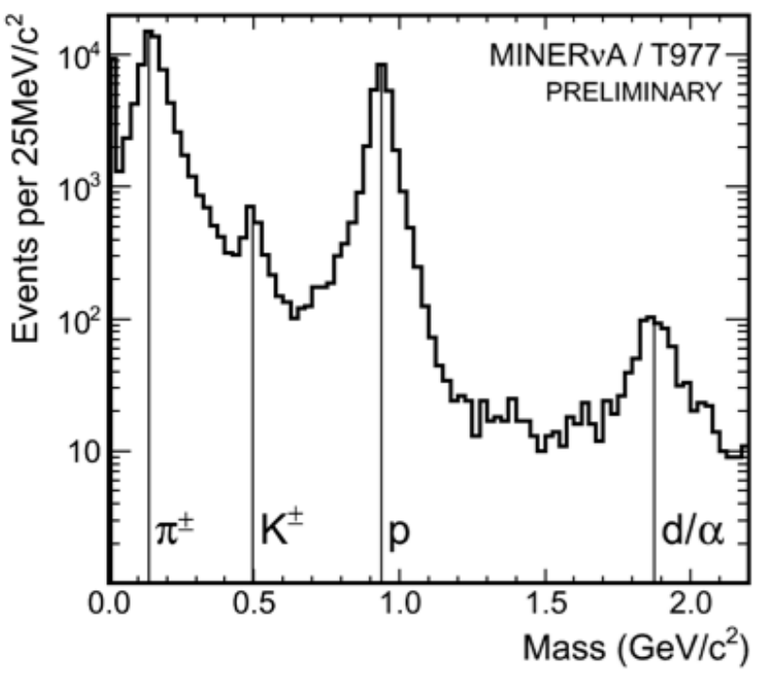
EH = ECAL+HCAL; TE = Tracker+ECAL

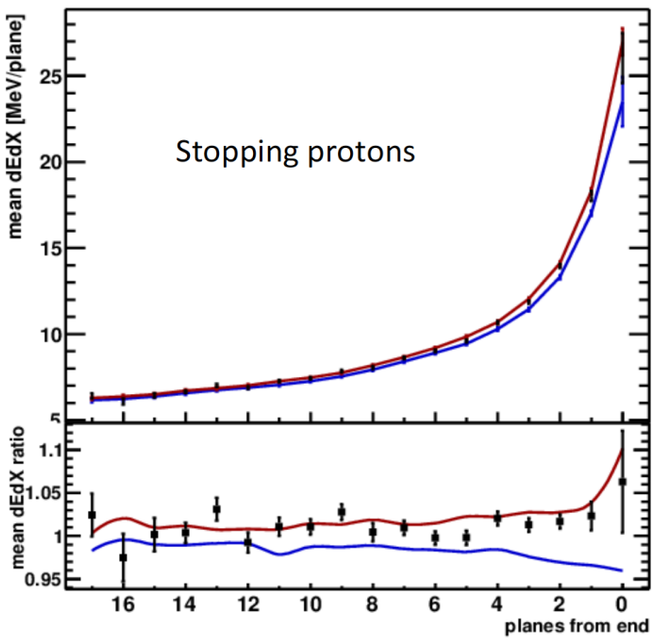
Source	TE p	EH p	EH π^+	EH π^-	EH e	TE e
Beam momentum	1.9%	1.9%	1.0 to 2.0%	1.0 to 2.0%	1.0	1.0
Beamline mass model	0.7	0.7	<0.2	<0.2	<0.2	<0.2
Birks' parameter	2.0 to 0.9	2.0 to 1.2	1.0	1.0	0.3	0.3
Correlated late activity	0.3	0.6	1.4	1.4	<0.2	<0.2
Temperature stability	1.0	1.0	1.0	1.0	1.0	1.0
Relative energy scale	0.6	0.6	0.6	0.6	0.6	0.6
PMT nonlinearity	0.7	0.7	0.9	0.9	0.4	0.2
Event selection	<0.2	<0.2	0.7	1.5	1.1	1.1
Crosstalk	0.7	0.9	0.5	0.5	0.5	0.5
Statistical	~1.0	~1.0	~1.0	~1.0	1.7	1.1
Total	3.3 to 2.7%	3.4 to 2.9%	2.6 to 3.4%	2.9 to 3.6%	2.6%	2.3%

*MINERvA, NIM A, **789**, 21 (2015)*

Data collected over 6 weeks in Summer 2010







Birks' law parameter calibration

$$\text{Suppression factor} = \frac{1.0}{1.0 + \text{Birks Parameter} \times (dE/dx)}$$

dE/dx trend compared to nominal 0.133 $^{+0.040}_{-0.040}$ mm/MeV

best fit: 0.0905 ± 0.015 mm/MeV

Test Beam Goals

- Provide calibration of NOvA detector response beyond that from stopping cosmic muons, Michel electrons, and π^0 mass peak
  - Reduce hadronic energy scale uncertainties by factor of ~2
  - Cross-check muon and electromagnetic calibration

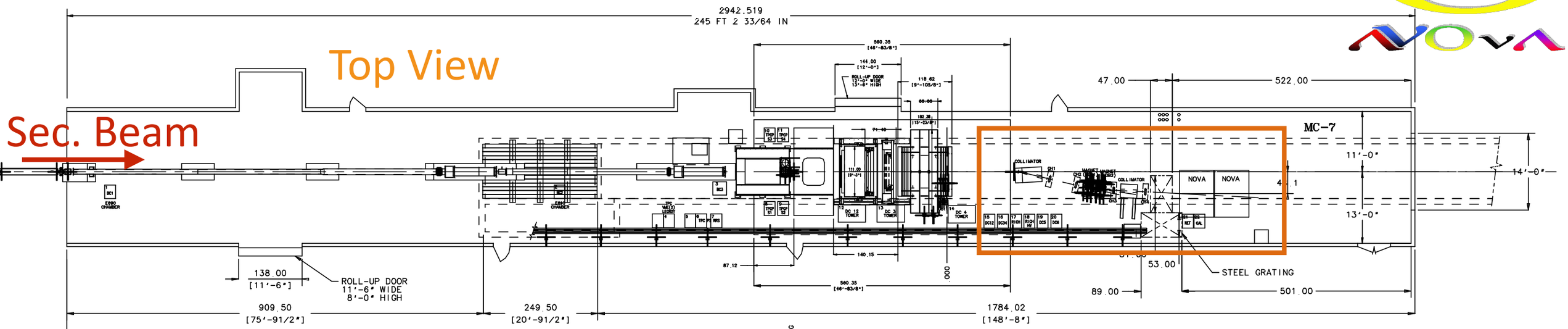
- Tune/Validate simulation of detector response
  - Measure nonlinearity of scintillator response (Birks' Law)
  - Measure nonlinearities due to Cherenkov light generation in scintillator
  - Topological features of particle interactions
  - Response of non-normal incident particles

- Accumulate library of data events for algorithm training (e.g. CVN) and for development of a CNN-based ProngID
  - Verify and improve PID algorithms for nue appearance analysis
  - Potential excellent input for data-driven event generation using Generative Adversarial Networks (GANs)
  - Help factor the product [flux $\times$ (cross section) $\times$ (detector response)] improving future cross-section measurements.

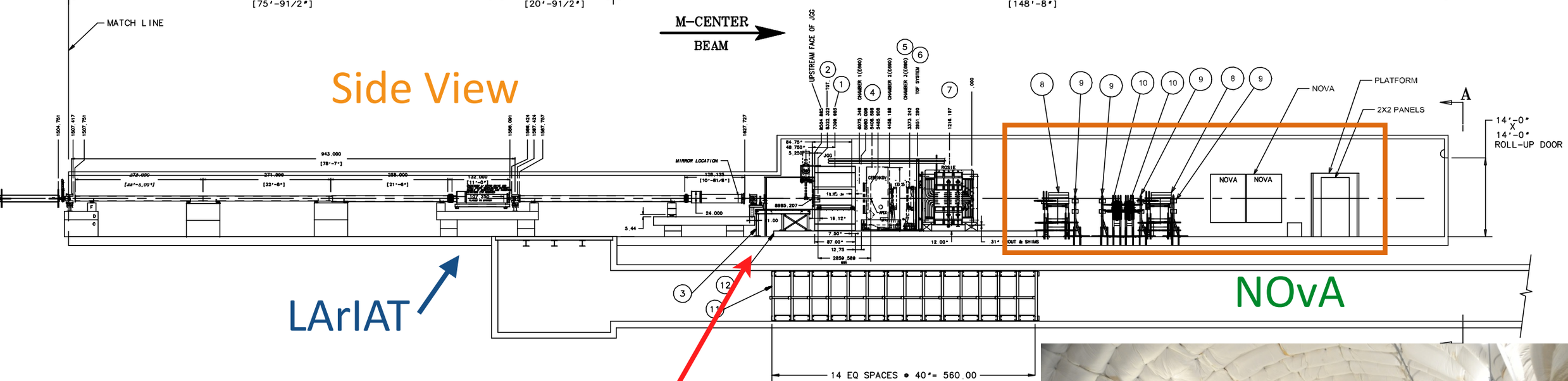
NOvA Test Beam @ MC7

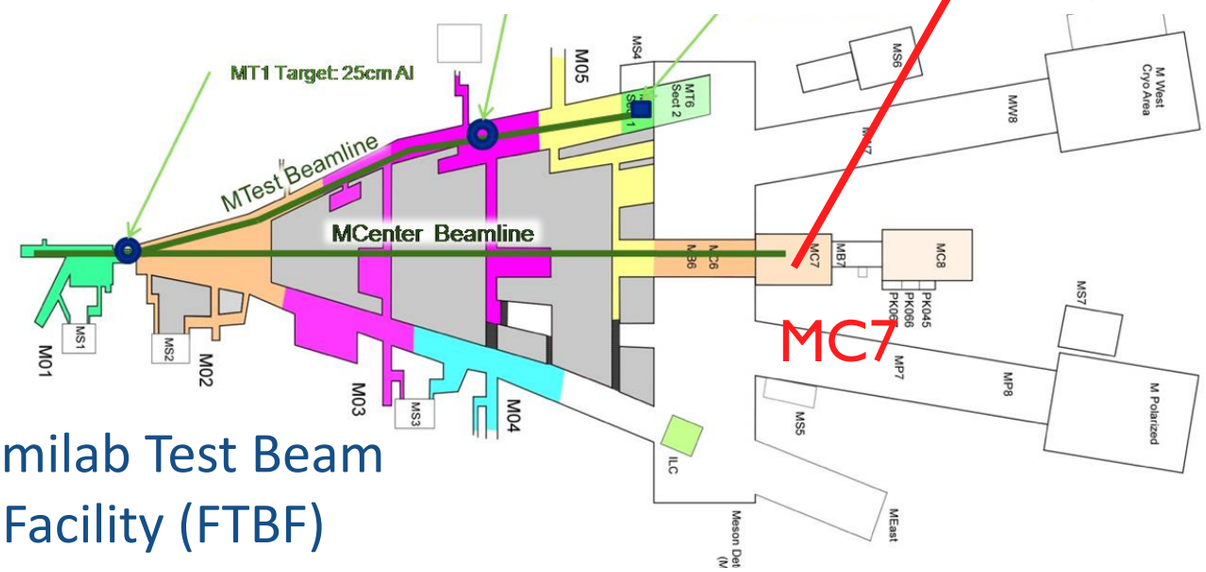
Top View

Sec. Beam



Side View

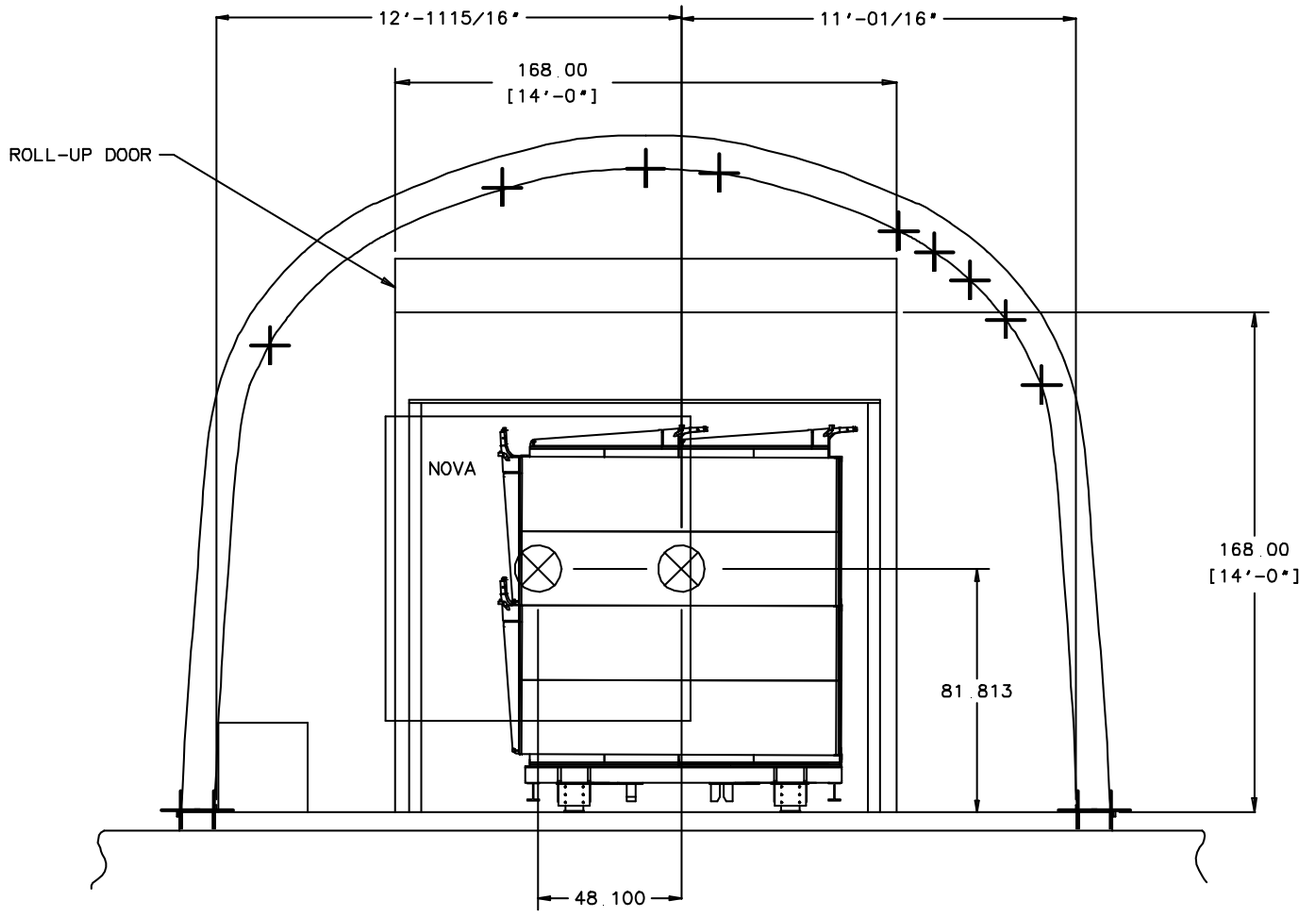


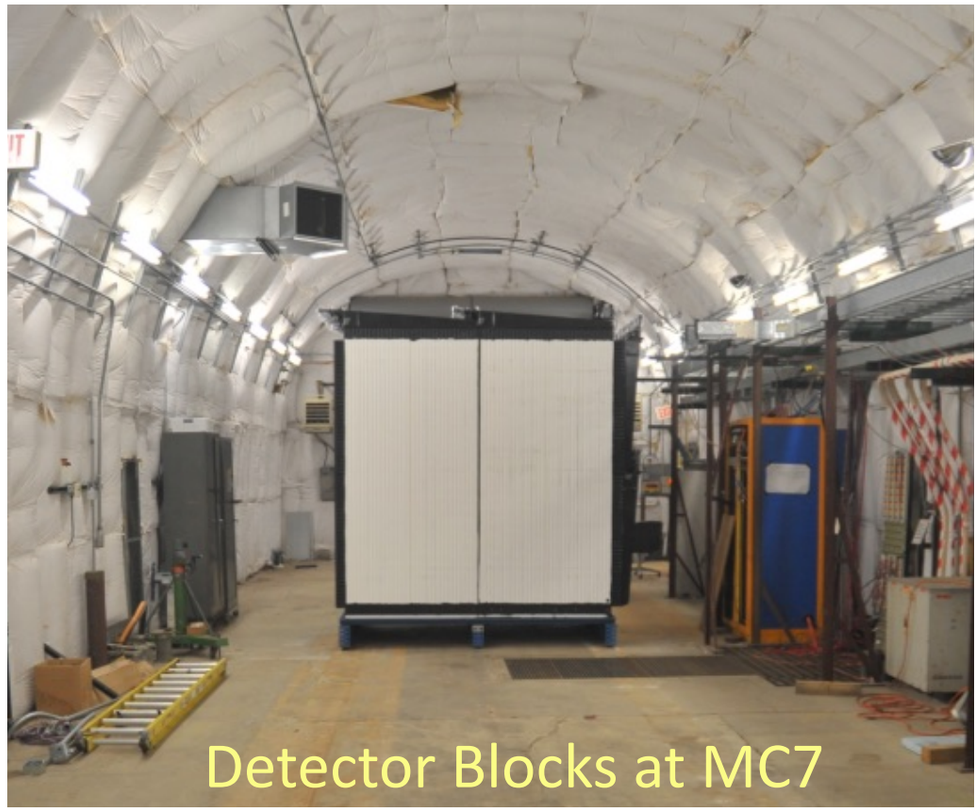


Fermilab Test Beam Facility (FTBF)

NOvA Test Beam @ MC7

Transverse View





Detector Configuration	Two 2×2 31-plane blocks
Dimensions W(m)× H(m)× L(m)	2.6×2.6×4.0
Scintillator/plane (gallons)	86
Total Scintillator Volume (gallons)	5332
PVC Mass/plane (kg)	171.2
Adhesive Mass/plane (kg)	3.1
Total Empty Mass (kg)	10800
Total Scintillator Mass (kg)	17329
Total Detector Mass (kg)	28129
#APDs = #FEBs	124
#DCMs	2

Two 31-plane 2x2 blocks placed at FTBF's MC7.

Expose them to MCenter-sourced e, μ, π, p, K, π^0 tertiary beam with momentum from 0.2 - 2.0 Gev/c.

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
12	ME-397567	JGG CONCRETE PAD	1
11	ME-397580	M-BOTTOM STRUCTURAL BRACING LOCATION LAYOUT	1
10	ME-466259	TRIM MAGNETS	2
9	ME-466282	MWPC STAND	4
8	ME-466139	COLLIMATOR	2
7	ME-421025	ROSIE MAGNET	1
6		TOF SYSTEM	1
5	ME-421104	E907 DRIFT CHAMBER 3(E690)	1
4	ME-421016	E-907 CERENKOV CHAMBER#1(690)-CHAMBER#2(690)	1
3	ME-421104	E-907 TCP-CART-STAND-JGG	1
2		TARGET	1
1	ME-397657	JOLLY GREEN GIANT MAGNET	1

PARTS LIST

UNLESS OTHERWISE SPECIFIED
±.X ±.XX ±.XXX ±X/X ±X°
BREAK ALL SHARP EDGES .015 MAX.
DO NOT SCALE DRAWING
DIMENSIONS BASED ON ASME Y14.5-2009
MAX. ALL MACH SURFACES
DRAWING UNITS: INCHES

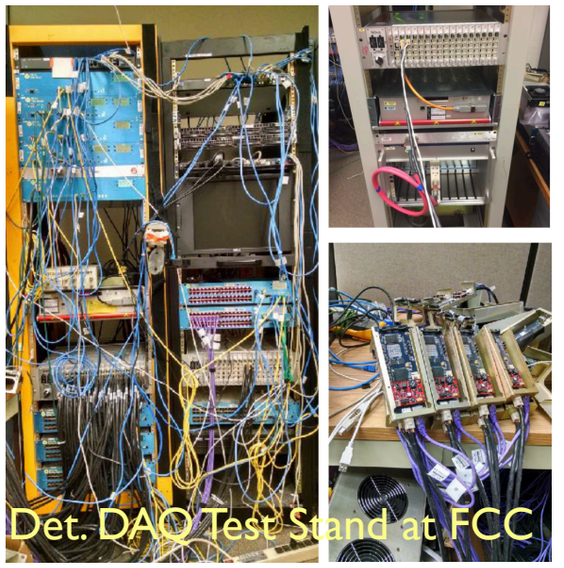
DRAWN B.ELLISON DATE
CHECKED J.RAUCH DATE
APPROVED J.RAUCH DATE
USED ON
MATERIAL SEE PARTS LIST
GROUP: Particle Physics Mechanical Support CAGE CODE:

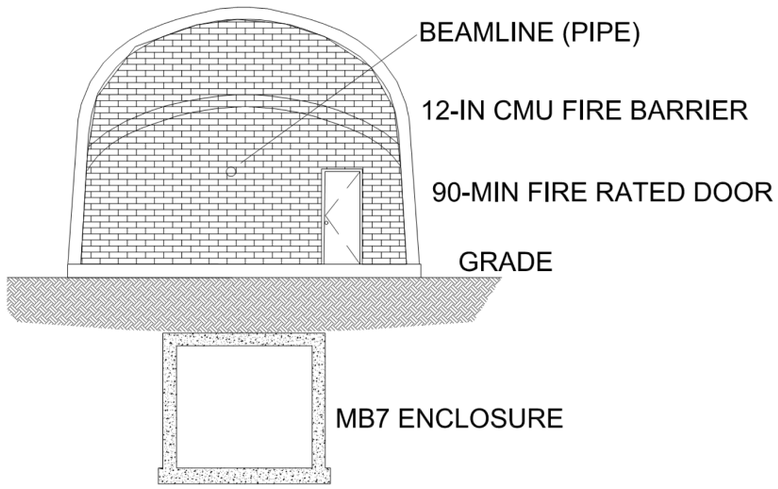
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
NAME E907 EQUIPMENT LAYOUT NX SHT1-3
SCALE 1:64 OR NOTED | SIZE E | DRAWING NUMBER F10059283 | SHEET 1 OF 1 | REV -

NOvA Test Beam Status

- Detector blocks already at MC7. Scintillator reserved at tank farm. Full complement of APDs and FEBs available from NOvA spares pool
- New beamline components mostly procured, with exception of dipole magnet being refurbished. FTBF manufacturing wire chambers. Beamline simulations ongoing
- Magnet power supply and LCW system identified and being tested
- Full-scale detector DAQ system successfully took first data in FCC test stand last week. Beamline DAQ development ongoing
- APD dry gas/cooling system components purchased
- Firewall design and budget in hand. Need approval by PPD and Neutrino Division
- Multiple detector systems experts trained over the summer


Lower Half of M1 grit-blasted


Det. DAQ Test Stand at FCC



Personnel

- Institutions that have volunteered to provide support and personnel to the NOvA Test Beam effort

Institution	Task	Personnel
U. Cincinnati	General Coordination; DAQ/APD Exp.	PI + PD + Student
U. Dallas	DAQ/DCS Coordination; TOF System	PI + Student
Illinois Inst. of Technology	Beamline Simulations	PI
Fermilab	Various	Various
Indiana University	DAQ Expert	Student
U. Pittsburgh	APD Exp.; Beamline DAQ Exp.	PI + Student + PD later
U. South Carolina	Detector DAQ Expert	PD + Two Students
U. Texas-Austin	Det./Beamline Sim.; FEB Expert	PI + PD + student
U. College London	TOF system	PI
U. Virginia	LV/HV Expert/DCS Expert	PD + Student

Table 2: Currently pledged university contributions to test beam effort. PI=Faculty; PD=Postdoc.

- Cable running, power distribution, DCM install. - Min. 2 people
- Scintillator Filling - Min. 2 people
- Rack Installation, TDUs, sensors - Min. 2 people
- APD testing/Experts - 2 people
- FEB testing/Experts - 2 people
- Dry gas/water cooling Expert - 1 person
- DCS Expert - 1-2 people
- Detector DAQ - 4 to 6 experts
- Beamline DAQ - 3-4 experts
- Data Monitoring Experts - 1-2 people
- Calibration - 2 people
- Operations - All Experts
- Data analysis - Experts + 4-5 People (4-5 student theses)

Milestones

- FY '17 - Complete procurement and production of components for tertiary test beamline
- Dec. ’17 - Feb. ’18 - Installation of tertiary test beamline
- Jan. '18 - Beam line and detector DAQ integration testing
- Feb. ’18 - March '18 - Commission tertiary beamline components and DAQ, if MCenter beam available
- March '18 - Construction of Firewall
- March ’18 - April ’18 - Install detector at MC7, survey
- May ’18 - Oct. ‘18 - Detector outfitting and commissioning
- Dec. ’18 - Jan ‘19 - Commission and tune beam line + detector
- Jan. ’19 - June ‘19 - Operations and data taking
- 2019 - 2021 - Test beam data analysis and integration with NOvA analyses
- 2021 - First NOvA results benefiting from test beam data

Outlook

- The NOvA Test Beam run is an excellent one-time opportunity to improve and validate NOvA's future analyses, and extend NOvA's physics reach and competitiveness in CPV measurements in the pre-DUNE era

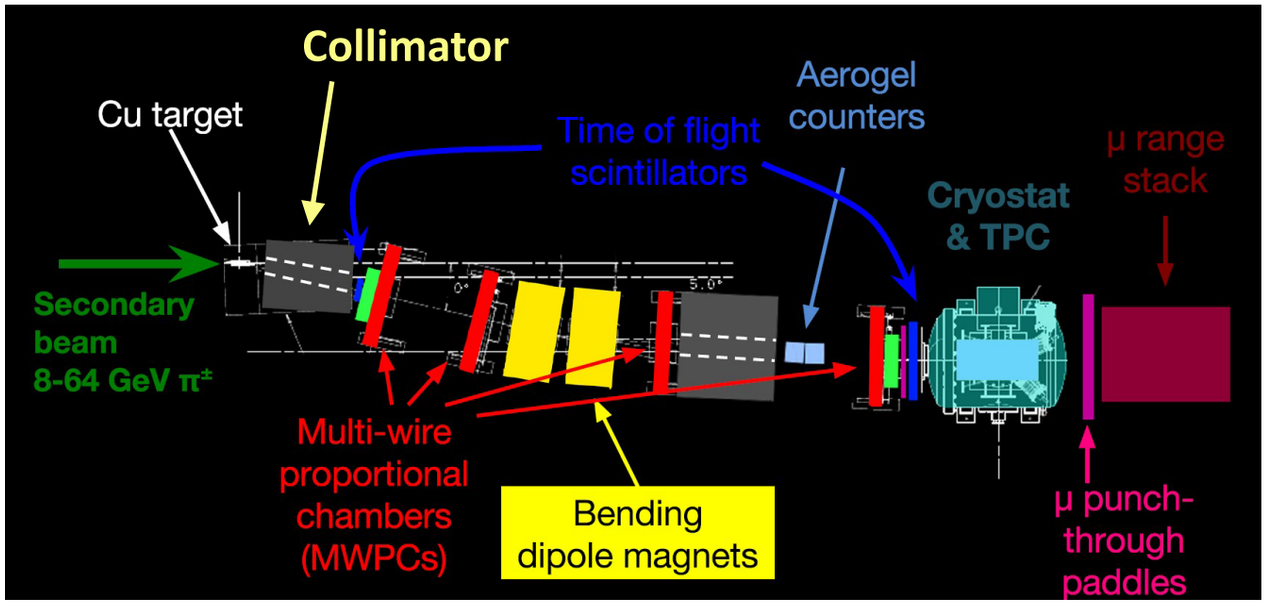
- Have strong support from NOvA Collaboration and interest from DOE in funding personnel to work on this effort

- Well on track for running during 2019. Aiming to accumulate ~2×10^6 particles over 5 months.
  - Delaying running till 2020 or splitting run between 2019 and 2020 will significantly curtail positive impact of test beam on NOvA's analysis milestones before 2024

- Many thanks to Mandy R. and FTBF crew for all the help in planning and carrying out the effort!

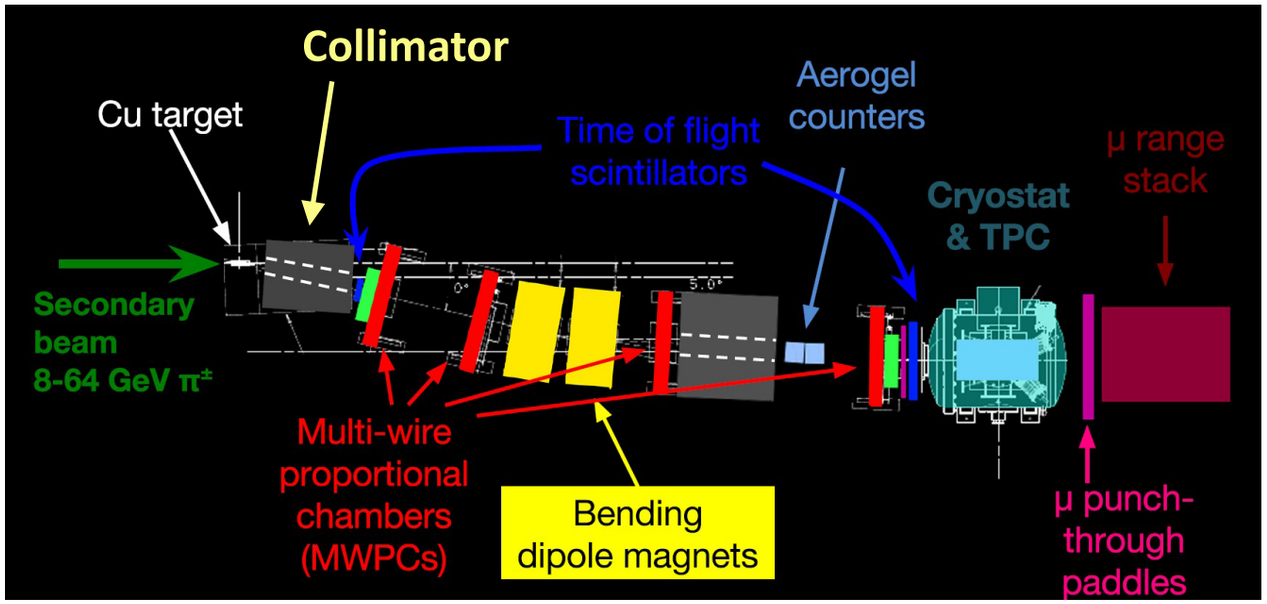
Backup

Beamline Dipole Magnet



- 20” dipole magnets used in LArIAT’s beam line not available due to new muon campus beamline. Converged on replacing with a single 42” sweeping dipole stored in PB6. One spare magnet available

Beamline Dipole Magnet



- 20” dipole magnets used in LArIAT’s beam line not available due to new muon campus beamline. Converged on replacing with a single 42” sweeping dipole stored in PB6. One spare magnet available
- Both magnets (M1 and M2) removed from PB6 on Aug. 22. Sent to IB2 for refurbishing and testing

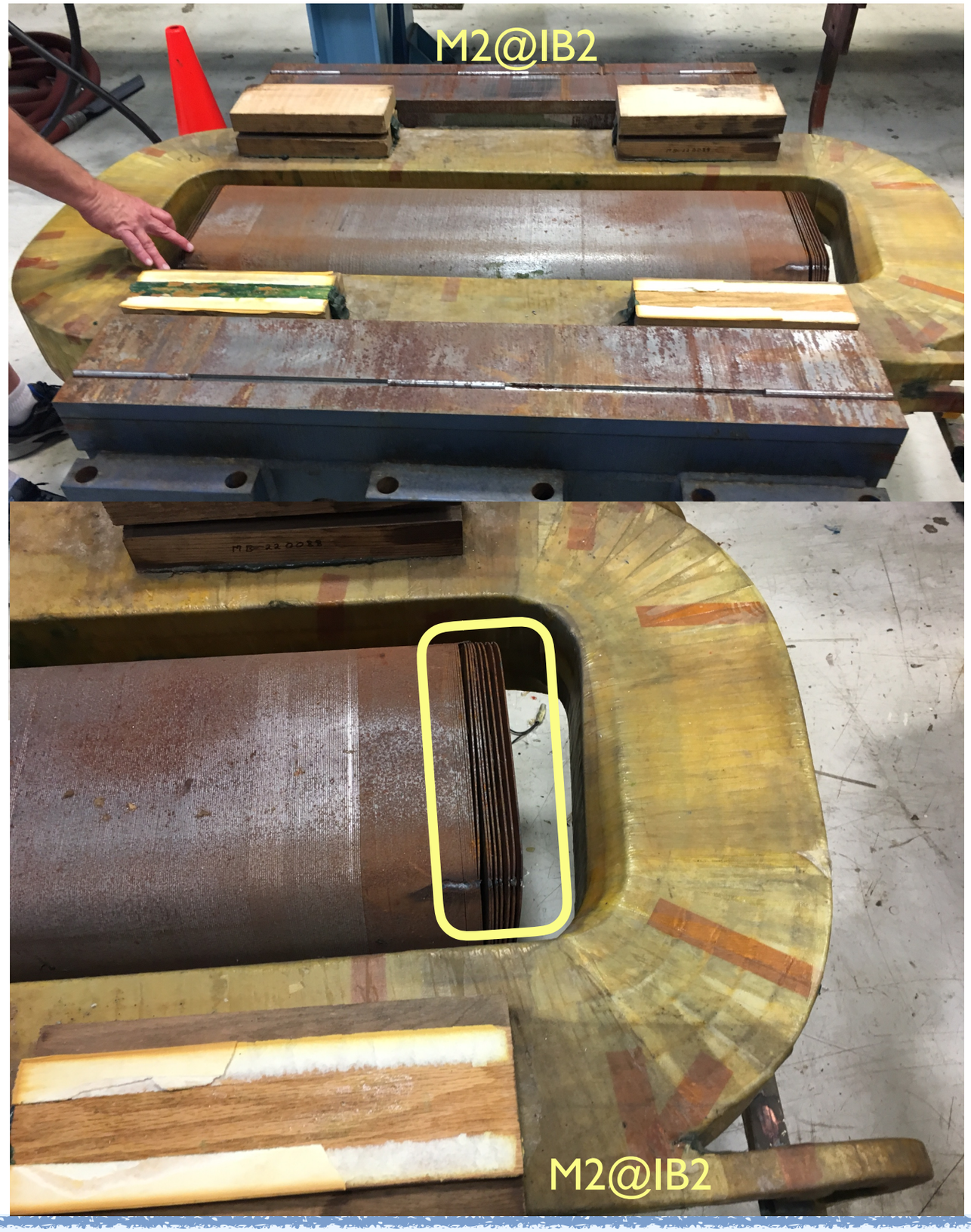
Beamline Dipole Magnet

- Inductance tests showed both magnets in good shape. Physical inspection showed delamination issue for M2. No issues with M1 other than rust

- Fermilab Magnets group developed plan and budget to refurbish both magnets (in next slide).

- Work on M1 started last week. Refurbishing will take another 2 weeks, followed by 2 weeks of detailed testing
  - Before "closing" magnet in 2 weeks, need to define survey and field monitoring instrumentation

- Depending on testing results, will consider need for a spare and for repairing M2 laminations



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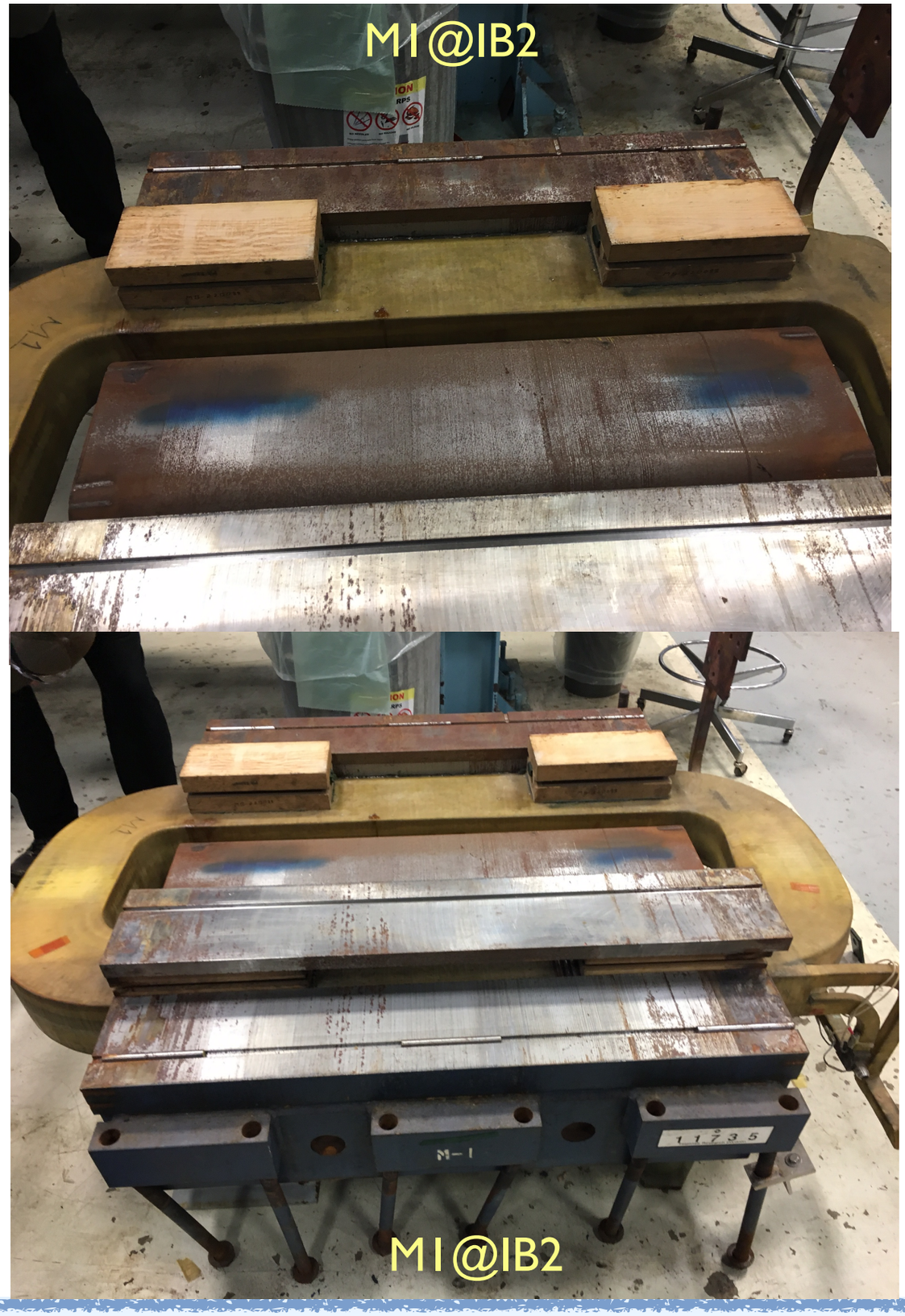


Magnet Work Budget and status

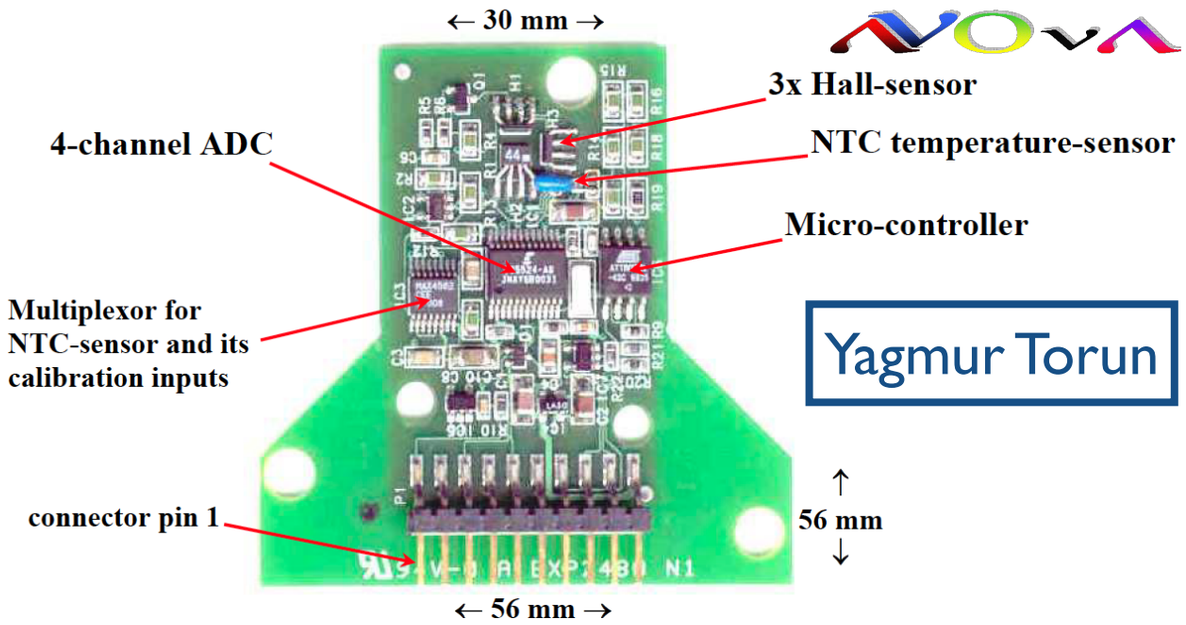
Magnet Work Budget and status

Material							$	2,000
Tooling		unit	amount/mag	Q mags	Tot amt	$/unit	$	-
	Winding	ea		2	1	$ -	$	-
	Potting	assy		2	1	$ -	$	-
	Stamping	lot		2	1	$ -	$	-
Magnet parts		unit	amount/mag	Q mags	Tot amt	$/unit	$	2,000
	Steel	lbs		2	0	$ 0.80	$	-
	Stamping	ea		2	0	$ 1.00	$	-
	Copper	lbs		2	0	$ 11.00	$	-
	DER Epoxy	lbs		2	0	$ 2.75	$	-
	DMP Epoxy	lbs		2	0	$ 1.92	$	-
	NMA			2	0		$	-
	Wedges	lbs		2	0	$500	$	-
	Misc hardware	lot	1	2	2	$1,000	$	2,000
Labor							$	15,803
Technician		techs	hrs/tech	qty parts/mag	Q mags	Tot Hrs	Rate	$	9,040
	Clean debris	1	3	1	2	6	$54.00	$	324
	Replace Cut Hoses	1	8	1	2	16	$54.00	$	864
	Weld @$73/hr	1	1	1	2	2	$73.00	$	146
	Add G10 Insulator block	1	4	1	2	8	$54.00	$	432
	Rust cleanup	1	4	1	1	4	$54.00	$	216
	Clean/silver coat power flags	1	2	1	2	4	$54.00	$	216
	Insulate leads	1	8	1	2	16	$54.00	$	864
	Epoxy Paint leads	1	4	1	2	8	$54.00	$	432
	Grit blast/cleanup	1	16	1	2	32	$54.00	$	1,728
	Replace All Hoses	1	8	1	2	16	$54.00	$	864
	Epoxy Paint Coil Surfaces	1	10	1	2	20	$54.00	$	1,080
	Prime and paint exterior	1	8	1	2	16	$54.00	$	864
	Survey Nests	1	1	1	2	2	$54.00	$	108
	Welder Survey Nests	1	1	1	2	2	$73.00	$	146
	New Wood Shims	1	2	1	2	4	$54.00	$	216
	Clean "replace" bolts	1	4	1	2	8	$54.00	$	432
	New stickers Stenciling	1	1	1	2	2	$54.00	$	108
EDIA	**Discipline**					**Hours**	**Rate**	$	**6,763**
	Engineering					40	$ 92.00	$	3,680
	Drafting					0	$ 58.93	$	-
	Process Eng (Traveler)					12	$ 58.93	$	707
	Procurement					12	$ 54.00	$	648
	Inspection					16	$ 54.00	$	864
	Admin					16	$ 54.00	$	864

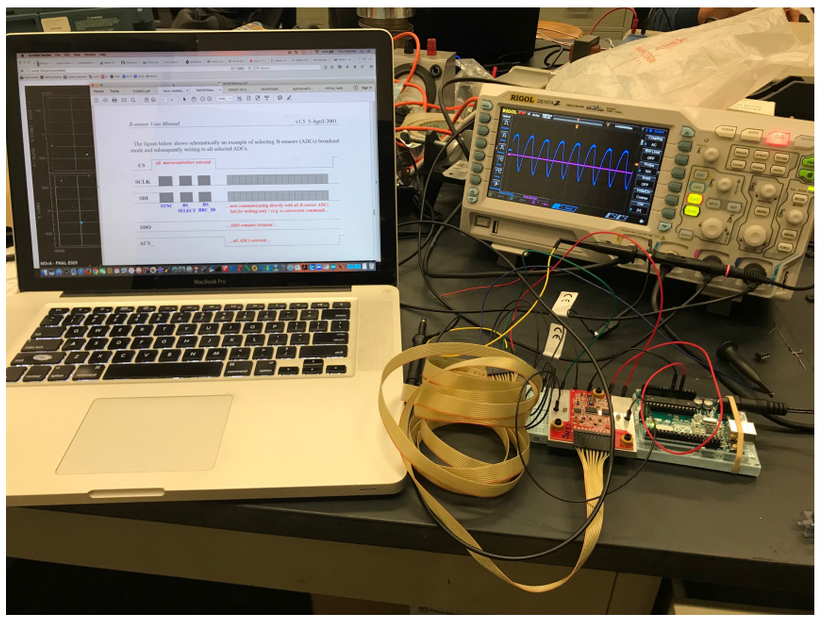
- All necessary materials parts procured, work moving quickly!

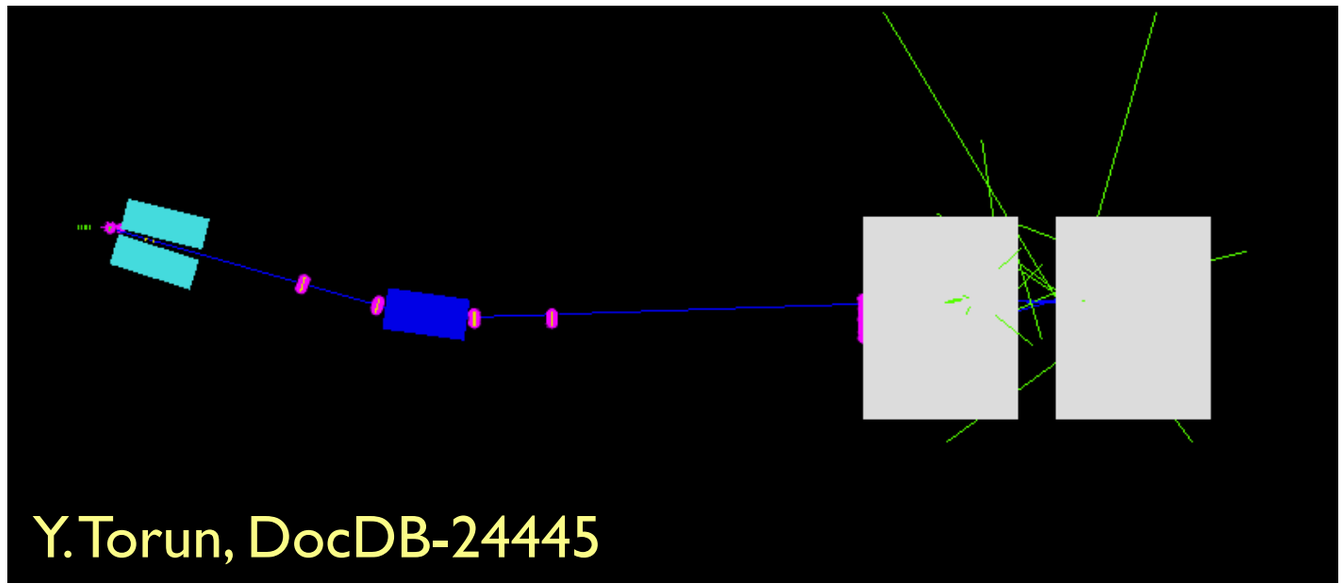
Magnet Instrumentation and Survey

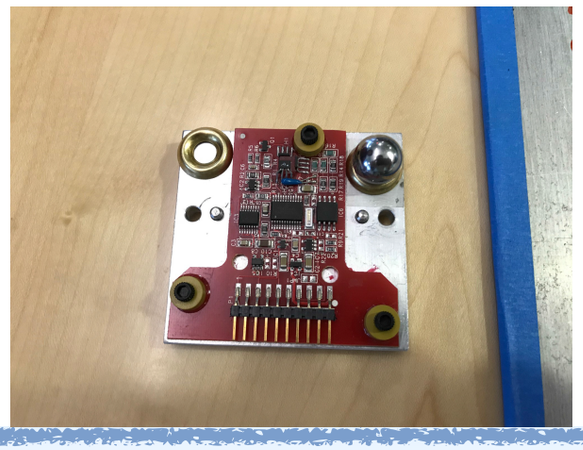
- Would like to monitor field magnitude spill by spill during run.
- Need to install sensors before magnets are reassembled (difficult access afterward)
- Use sensors during field measurements to correctly tie them to the measured map
- Working on communicating with sensor boards



Yagmur Torun

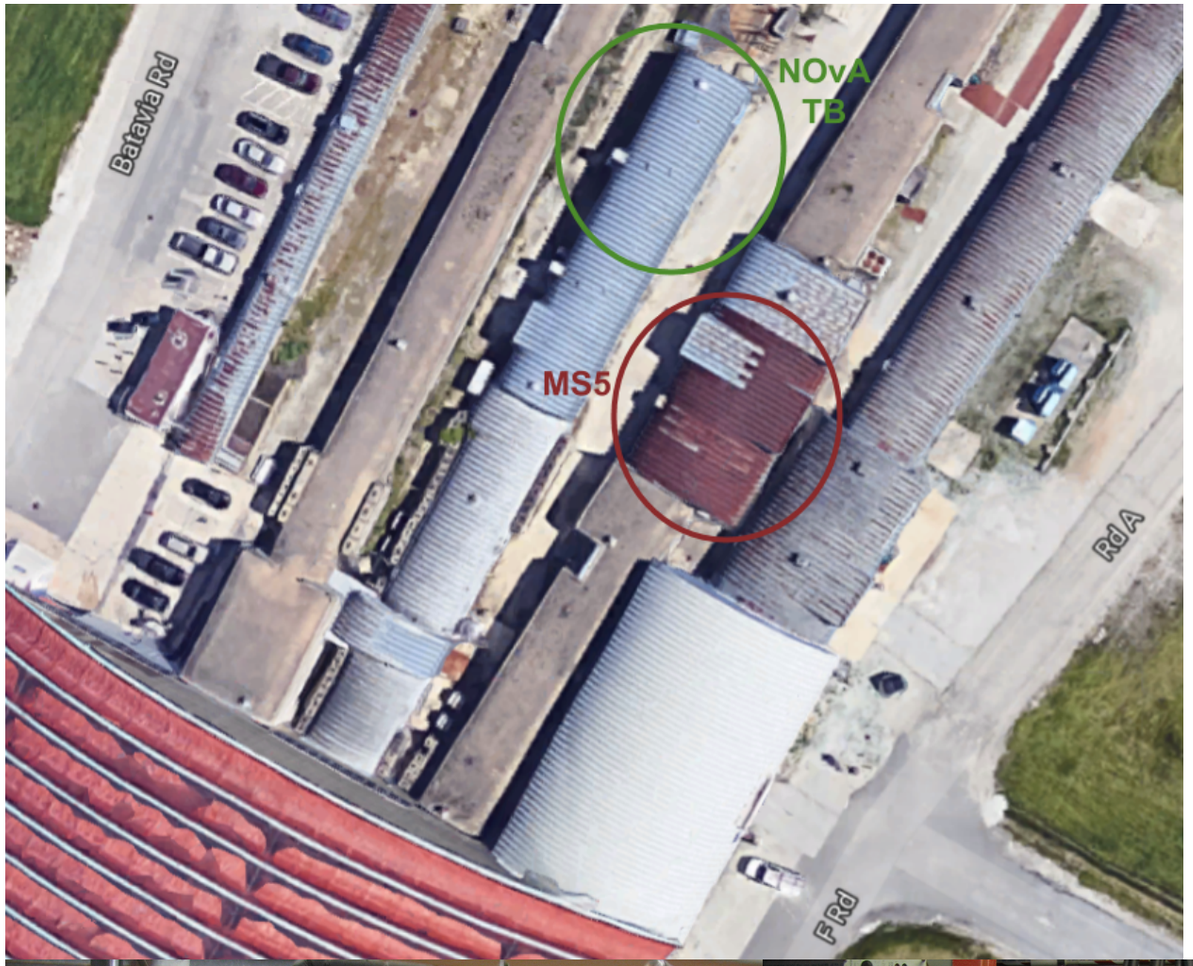


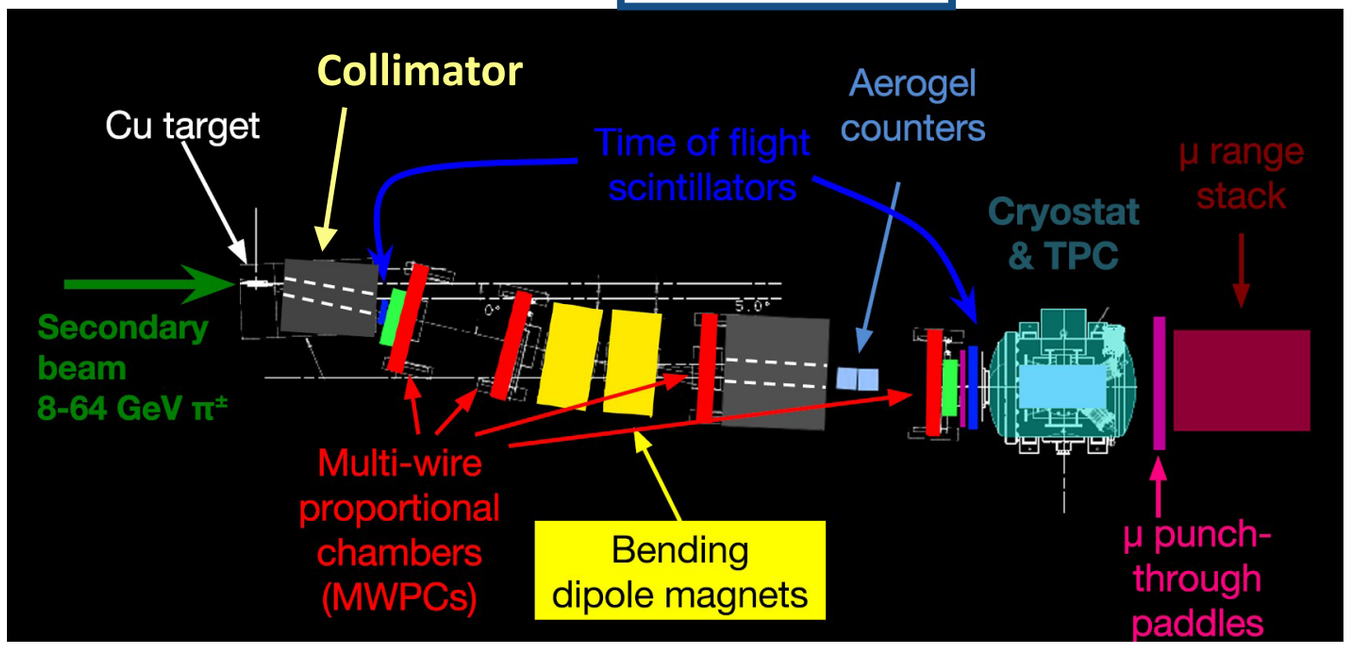




- Yagmur met with John Kyle (PPD) to discuss magnet survey targets. Targets will be installed after magnet cleanup. Will also survey field monitoring boards in place
- Ongoing beamline simulations based on Geant4 target geometry and g4Beamline - Additional effort needed here

Beamline Components





Adam Watts

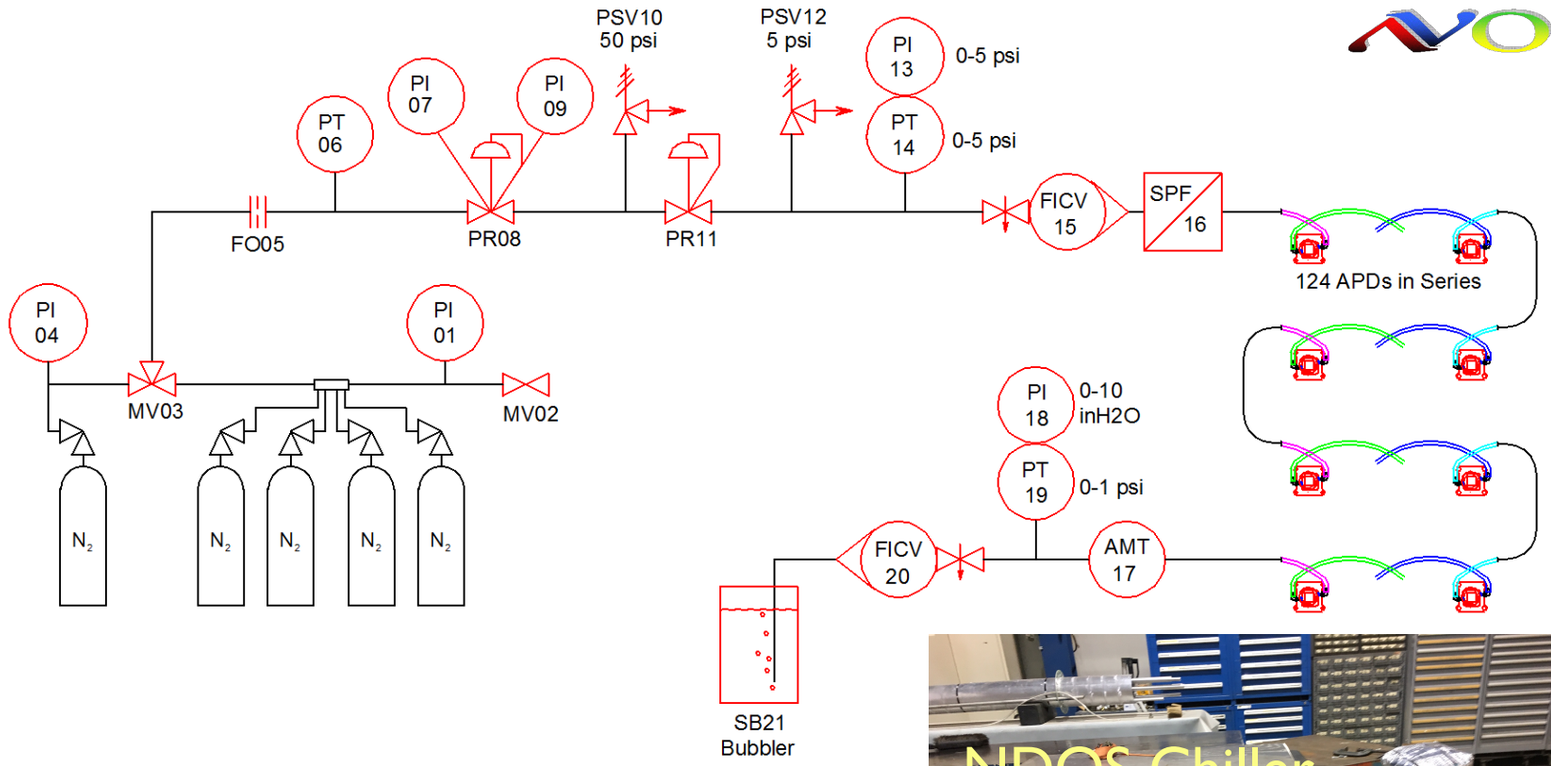
- Adam Watts (AD) located Transrex 500 kW power supplies in MS5. Will need to insulate cables and connectors inside MC7
  - Water/Glycol LCW system next door can be used for magnet cooling. Testing in progress
- 4 wire chambers (identical to LArIAT's design) are being produced at FTBF
- TOF system will be prototyped at U. Dallas (Will Flanagan). Will procure PMTs for TOF at UCL (Ryan Nichol)

Dry Gas/Water Cooling

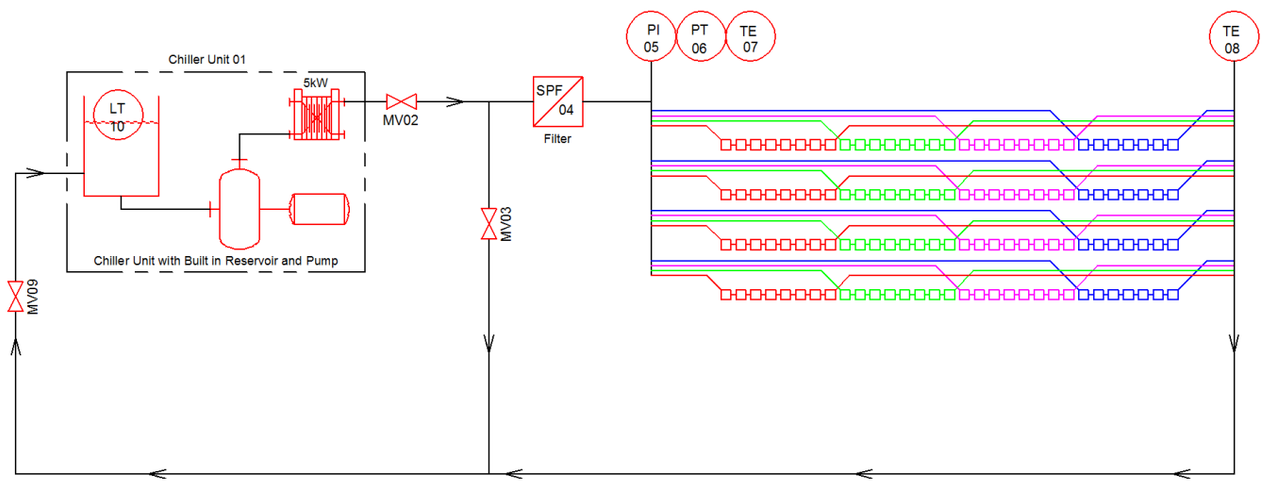
Erik Voirin

Total Dryer System	**$**	**2,280.19**
Total Water System	**$**	**1,617.05**
PLC and Controls Hardware ???	**$**	**3,500.00**
Grand Total	**$**	**7,397.24**

50% Contingency Included

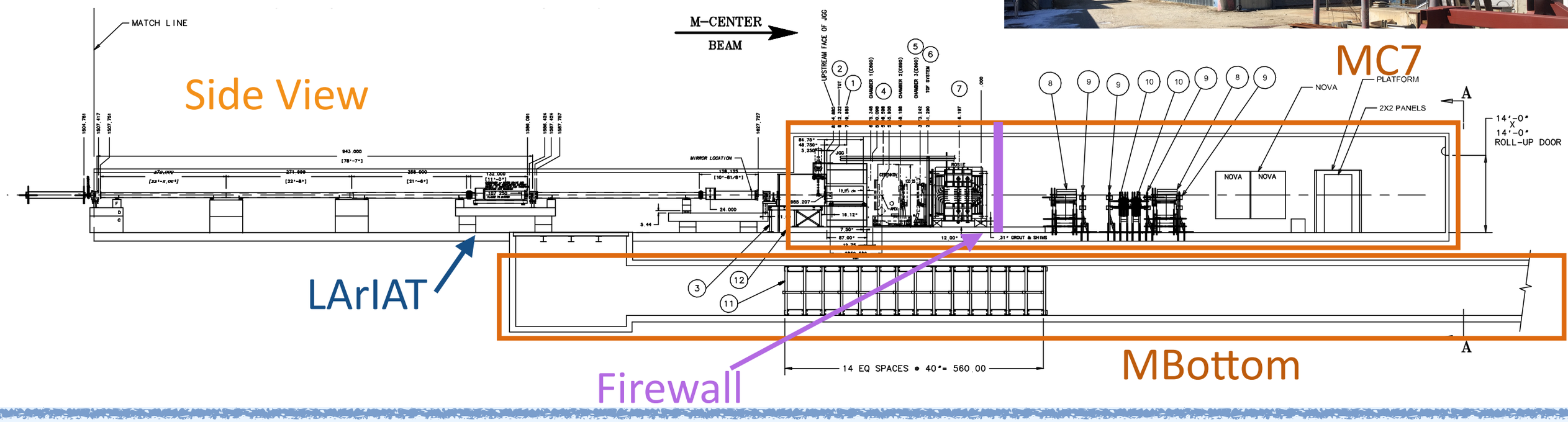


- Erik Voirin designed simplified system
  - Dryer system based on 4 nitrogen bottles
  - Reusing NDOS Water Chiller ($5k savings)
  - 10% of overall cost of the ND system
- Procured and purchased all necessary components for the system (~$5k) still in FY17



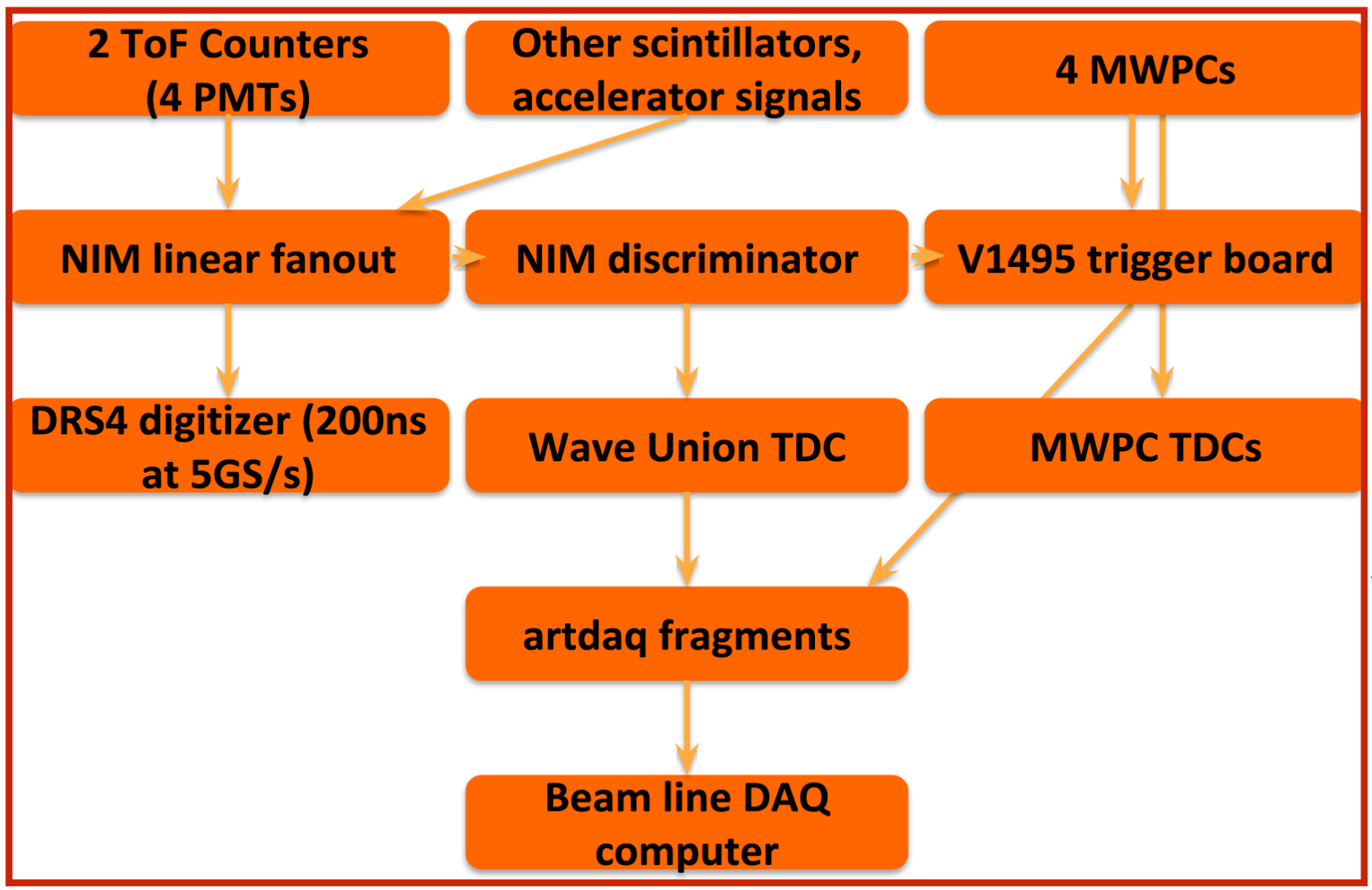
Fire Protection/Suppression

- Primary concern is no access to MC7 by fire engines and the 5500 gallons of oil+scintillator in detector
- PPD and Neutrino Division have agreed a firewall with no water mist system in MC7 is an acceptable solution
  - Jim Priest (Fermilab Fire Safety Officer) is producing official hazard/consequence statement for PPD and Neutrino Division to sign
- Jim Niehoff (Fermilab Fire Safety) deliver budget for firewall and associated work ($27k total)
- Completed an Environmental Review form required by Angela Aparicio at FESS (Mandy Rominsky with input from AS). Only input missing is coolant type and volume in NDOS Chiller



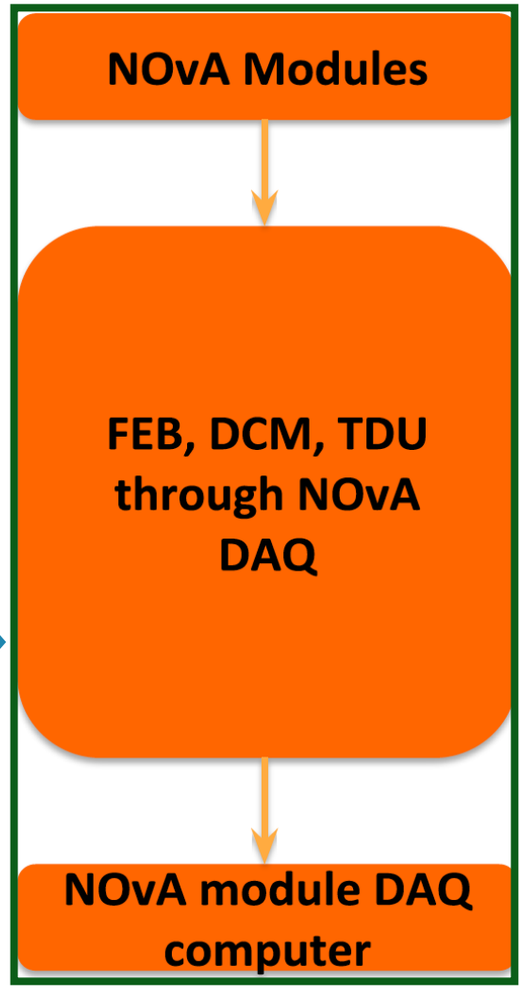
Test Beam DAQ

Will Flanagan, Andrew Norman



NOvA Beamline DAQ

NOvA Master TDU

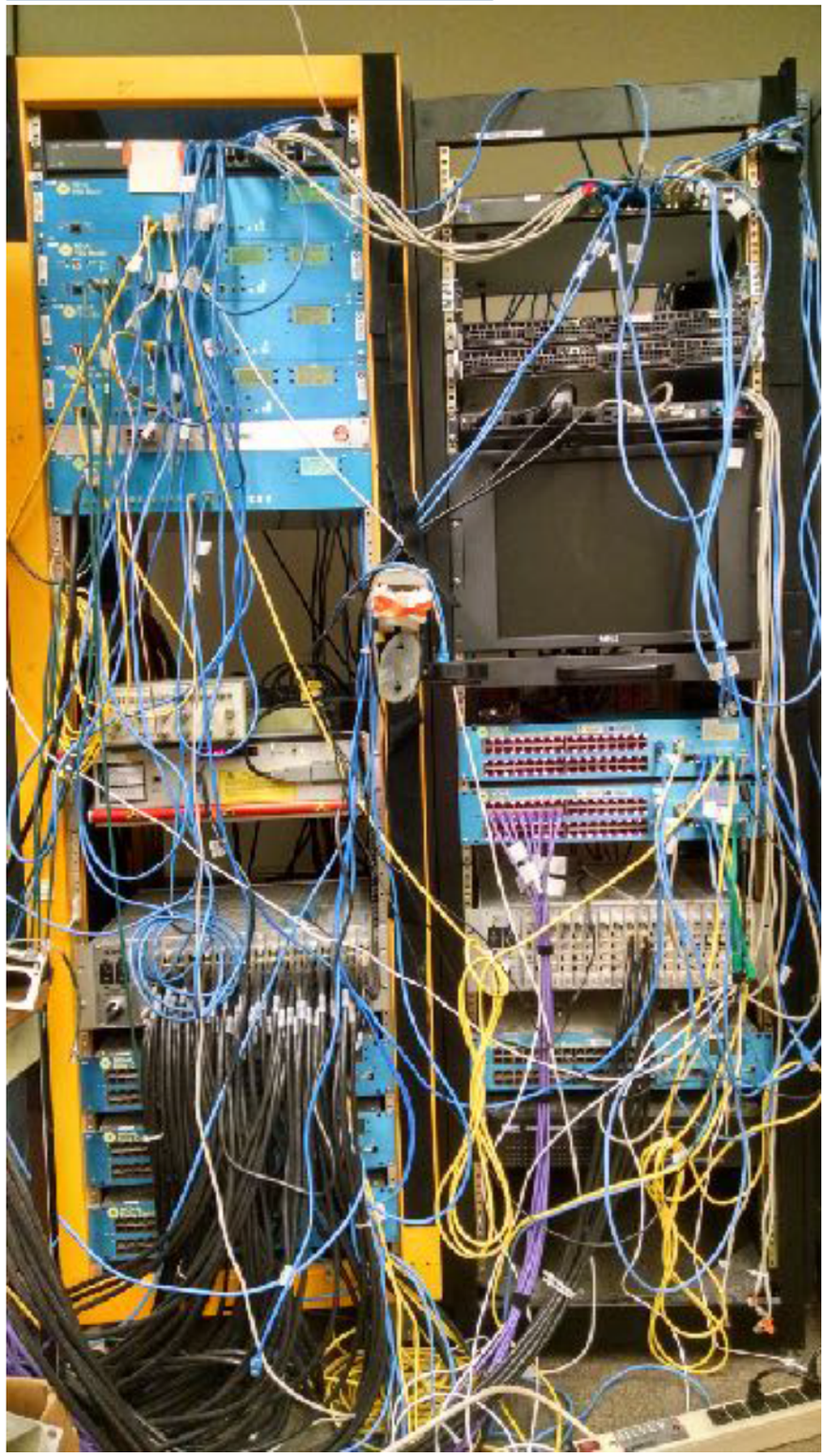


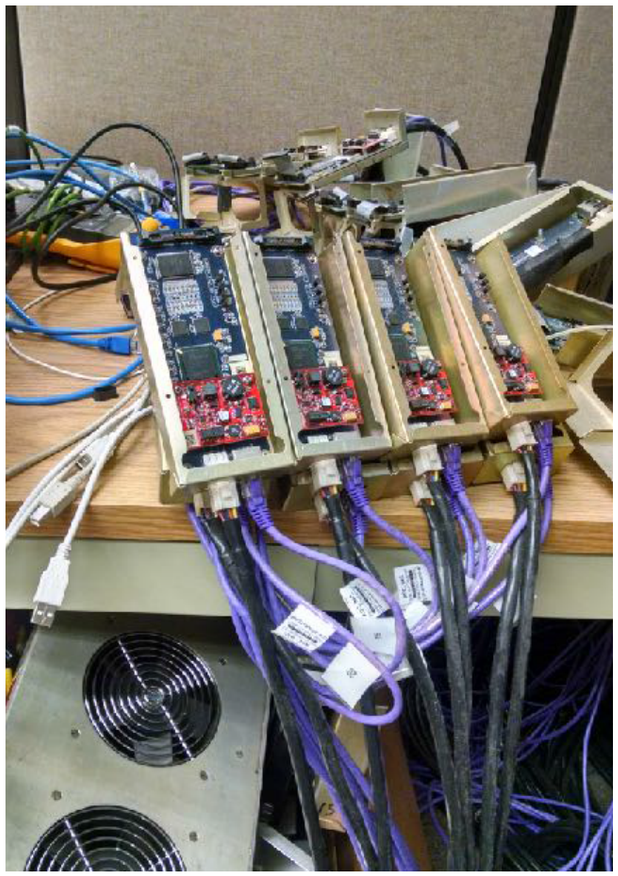
NOvA Detector DAQ

- DAQ system will consist of two independent DAQ systems synced together
  - Detector DAQ adapted from existing NOvA Near and Far Detector DAQ
  - New artdaq-based beamline DAQ, which needs extensive development
  - Synced through NOvA Master Timing Distribution Unit (TDU) timestamps
- Formal request for support of DAQ work presented to SCD on Aug. 10 - was granted

Detector DAQ Test Stand at FCC3

Teresa Lackey et al.

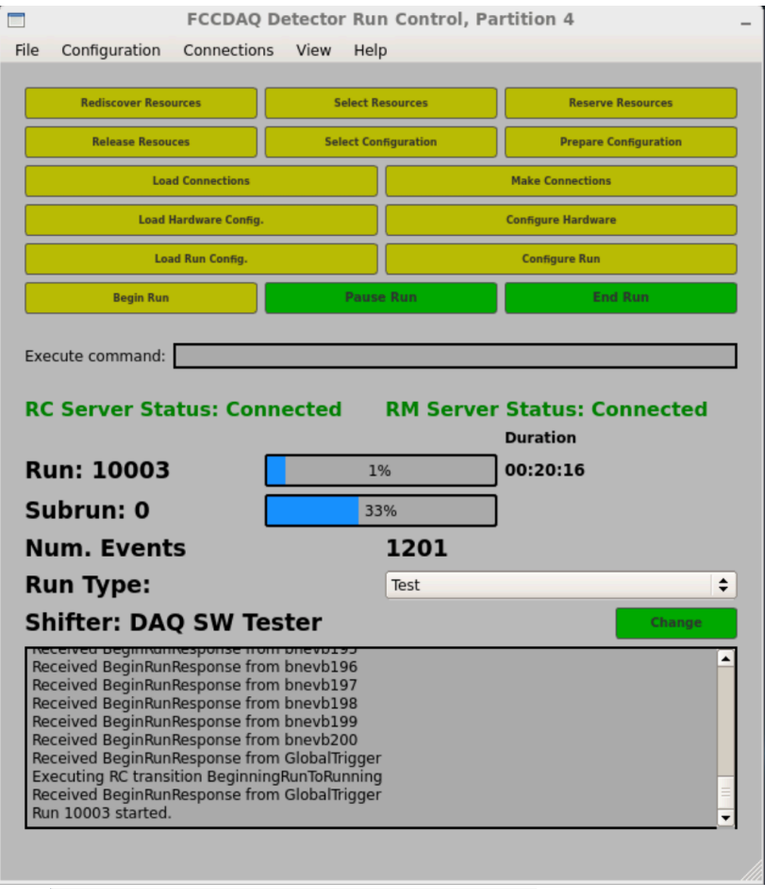


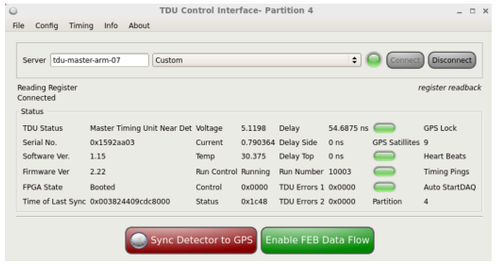


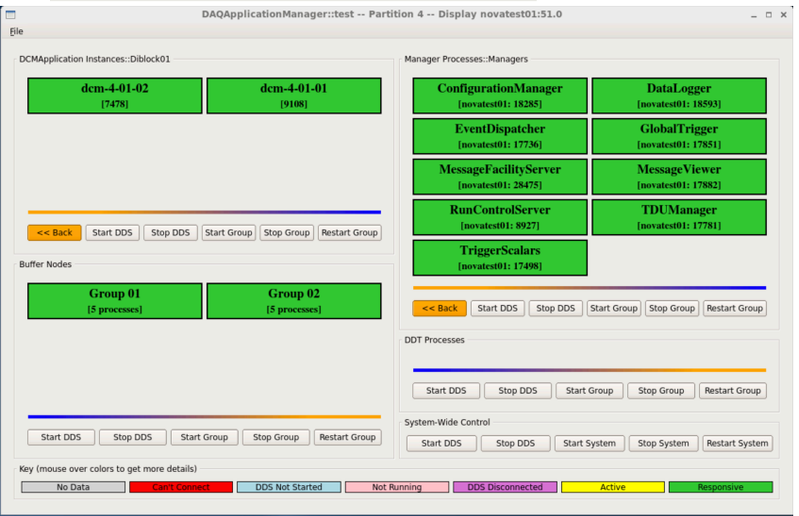
- During the Summer, great work by Will F. in putting together a NOvA DAQ test stand at FCC
  - LV/HV power supplies installed (with help from Ralf Ehrlich and Andrew Sutton)
  - TDUMaster from Ash River
  - 2 DCMs, one with 8 FEBs attached
  - Gas/water cooling system, to be installed by Erik Voirin
  - DCM Emulators used for FEB testing at Harvard
- Teresa Lackey, Pengfei Ding, Dung Phan, Bing Guo, and Will Flanagan have been working on standing up the test stand

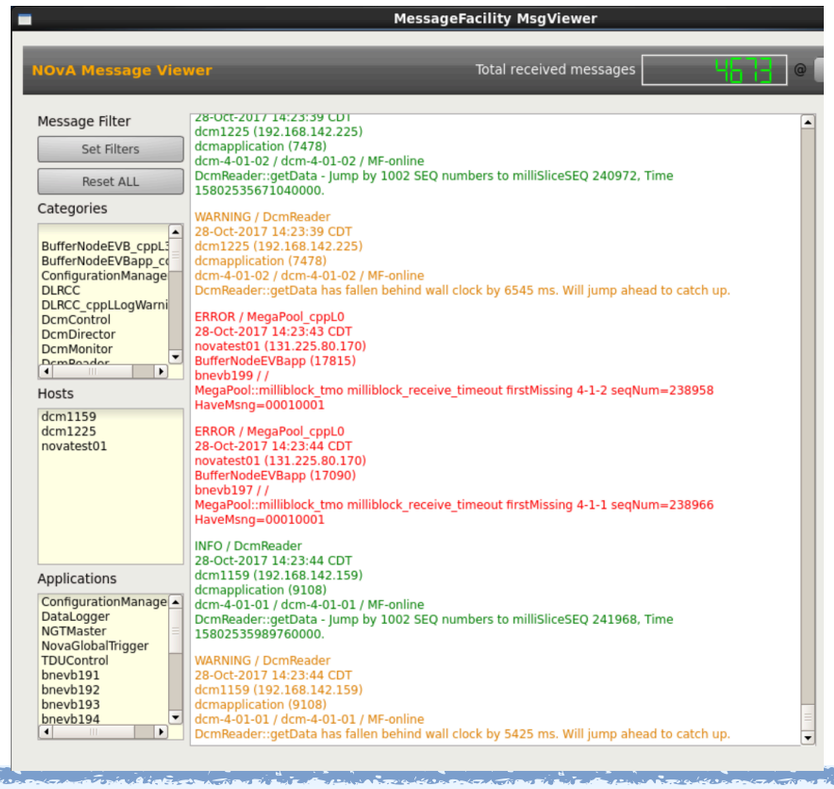
Detector DAQ Test Stand at FCC3

Teresa Lackey et al.





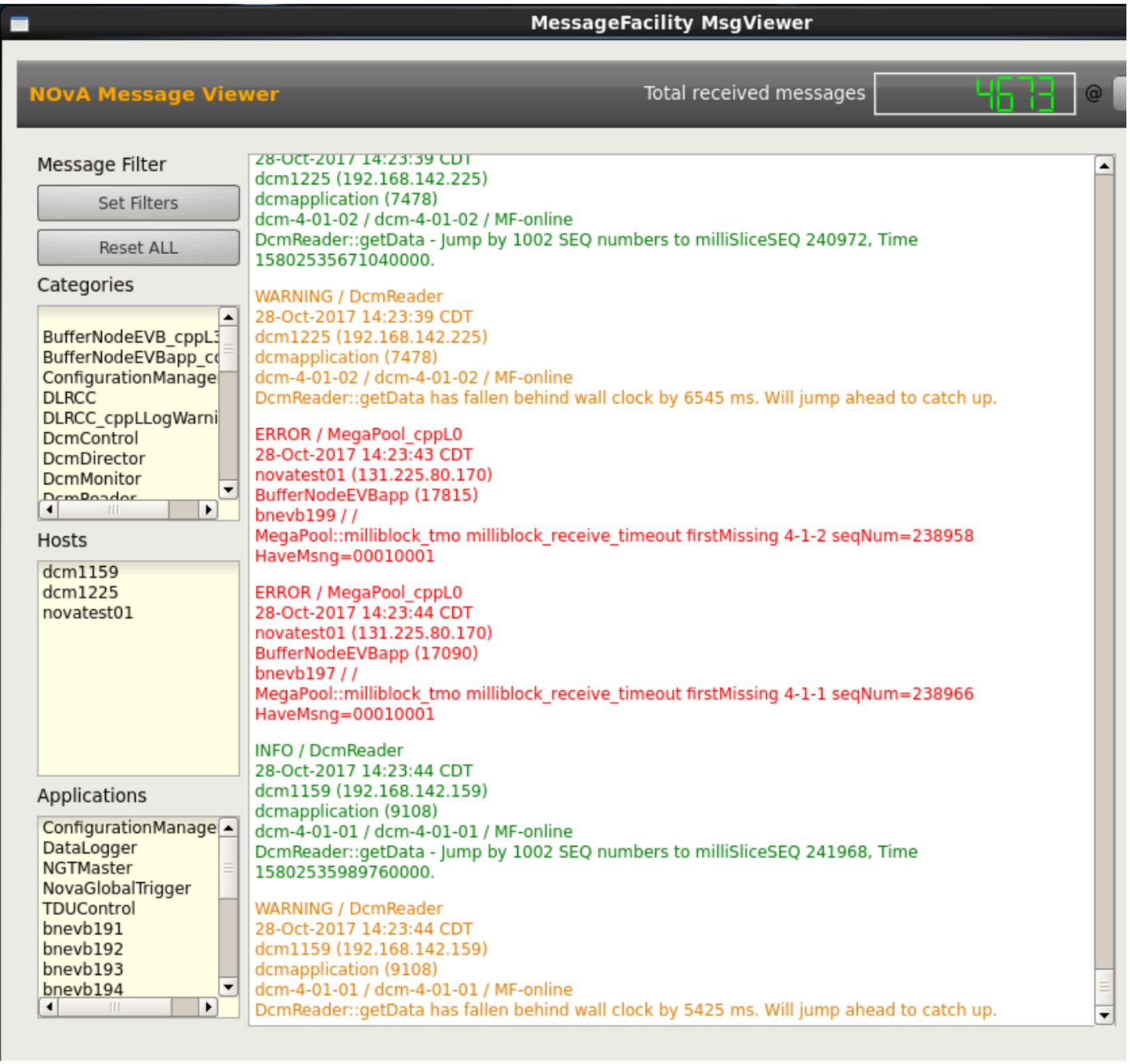




- Teresa Lackey, Pengfei Ding, Dung Phan, Bing Guo, and Will Flanagan have been working on standing up the test stand - Successful subrun taken yesterday!
- VNC session setup to control the DAQ
- 1.28 MB worth of cosmic triggers written out
- Need expert eyes on error messages

Detector DAQ Test Stand at FCC3

Teresa Lackey et al.



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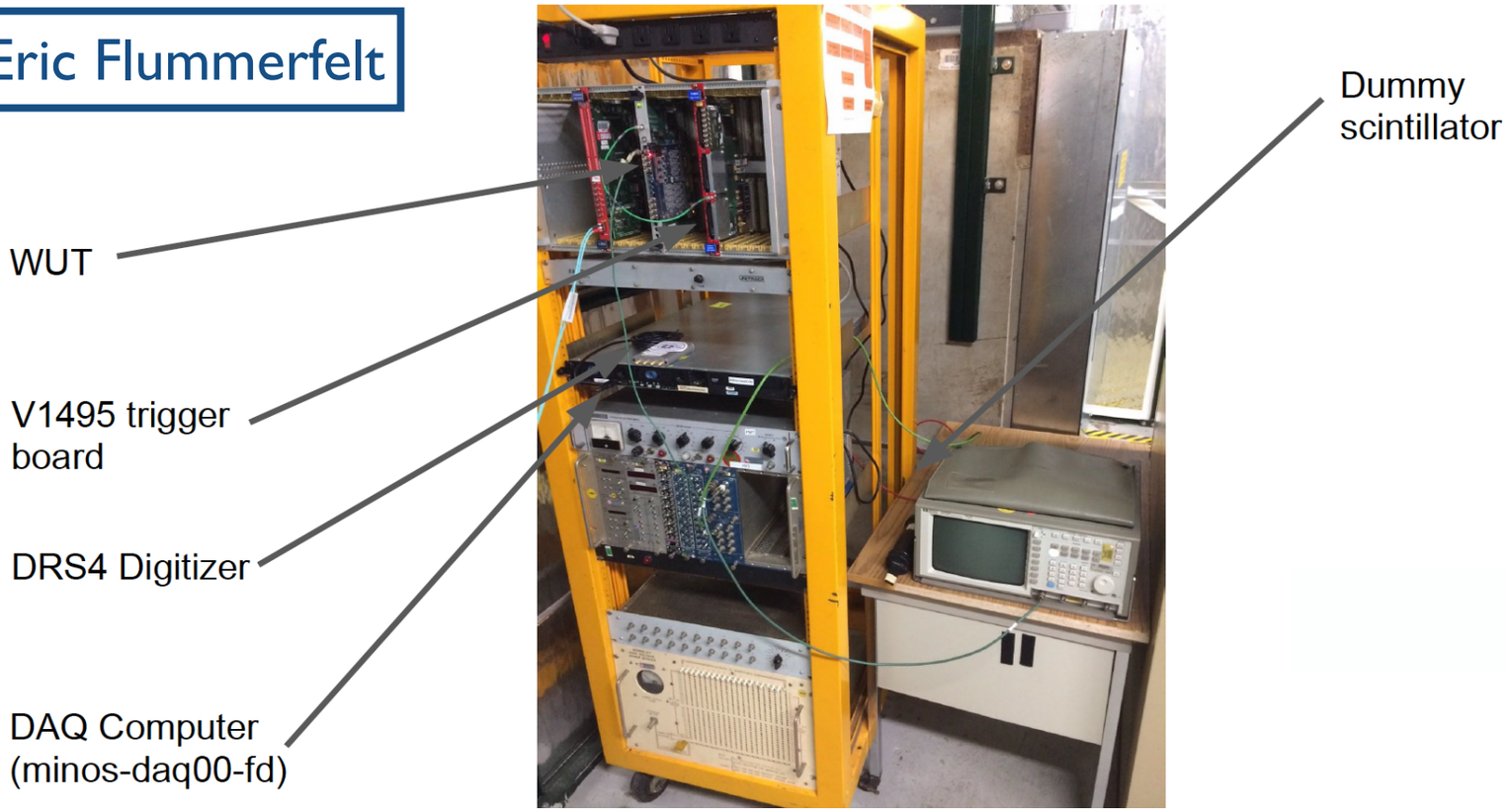
Beamline DAQ Test Stand at FTBF

Bill Badgett, Eric Flummerfelt

- Beamline Components + DAQ readout
  - Time-of-Flight, DRS4, 4 wave form input channels
  - Four FTBF Wire Chambers - 16 TDCs each
  - V1495 Trigger Board, V2718 VME crate controller
  - A3818 PCIe server resident readout master
  - Wave Union TDC, fine grain timing
- Have existing LArIAT artDAQ-based readout interfaced to beam-line timing and readout elements
  - Adapt for NOvA use

Beamline DAQ Test Stand at FTBF

Bill Badgett, Eric Flummerfelt



- Approved and ordered new SuperMicro server compatible ($3k) with CAEN A3818 PCIe interface
  - One or two weeks delivery from today
- NOvA TDUMaster box installed - will provide cross-synchronization with main NOvA DAQ
- Needs access to NOvA firmware boot files. Need to get network switch in FTBF to tunnel through NOvA boot server - loan from CD
- DRS4 box hooked to paddles, talking to old DAQ server fine through USB
- Will is buying A3818, V2495, V2718 cards. Talking to FNAL CD/PREP to prioritize purchasing these cards for their inventory
- Major DAQ milestone in January 2018 - Integration test of Detector and Beamline DAQ systems

Personnel

- Louise S. organized one week DAQ training from Aug. 28 to Sept. 1.

28-Aug-2017	29-Aug-2017	30-Aug-2017	31-Aug-2017	1-Sep-2017
System Restarts	Global Trigger Overview	DSO Scans	Timing	
Nuking the System	Data Driven Triggering	DDS	Spill Server Chain	Power Outage
Run Control		Network	DCMs	Release/Opps
Ganglia and CheckMK		FTS	FEBs	Float for other topics
Dashboard	Logfile Mining	Run Control	APDs	
	Expert Desktops	DAM	DCS Stuff	

- Very good turnout from people who expressed interest in contributing to test beam work (in green)

Name	Mon	Tues	Wed	Thur	Fri
Yagmur Torun	Y	PM	Y	PM	Y
Micah Groh	Y	Y	Y	Y	Y
Michael Baird	Y	Y	Y	Y	Y
Teresa Lackey	Y	Y	Y	Y	Y
Shiqi Yu	N	N	Y	Y	Y
Pavel Snopok	Y	Y	Y	N (on shift)	N (on shift)
Hongyue Duyang	Y	Y	Y	Y	N
Kanika	Y	Y	Y	Y	Y
Chatura Kuruppu	Y	Y	Y	Y	Y
Bing Guo	Y	Y	Y	Y	Y
Aristeidis	Y	Y	Y	Y	Y
Pengfei Ding	Y	Y	Y	Y	Y
Matt Judah	Y	Y	Y	Y	Y
Reddy	Y	Y	Y	Y	Y
Shih-Kai Lin	Y	Y	Y	Y	Y
Leo Aliaga	Y	Y	Y	Y	Y
Dung Phan	Y	Y	Y	Y	Y

SCD Support Request (x3 conting.)

- In August 10, presented formal request for SCD support for Test Beam at SPPM Meeting, which was successful (many thanks to Andrew N. and Will F.)

- NOvA TDU integration with artdaq (FY17)
  - 3 person-weeks
- TDU firmware development for test beam, which was originally developed for NuMI inputs (FY17)
  - 3 person-weeks
- artdaq readout of new boards for beamline devices, i.e. MWPCs, TOF (FY17)
  - 2-4 person-weeks per device type (4-8 person-weeks total)
- Sys. Admin. support to build up DAQ computer cluster using former NDOS machines (FY17)
  - 2 person-weeks
- Follow-up to Jan. ’’18 detector/beamline integration test (FY18)
  - 4 person-weeks
- Cisco 2960 network switch loan (FY18) - remote operation of detector/beamline at MC7

Logistic Items

- AS discussing with FTBF several logistic items related to MC7:
  - HVAC, temperature/humidity requirements for detector?
    - Main concern is 10 °C dew point (electronics condensation). Late months of running (May, June) may be too hot. ND typically runs at 70 °F ± 5 °F.
  - Location of tornado shelter?
    - Same location as LArIAT should work, but need access through firewall
  - Networking?
    - Only need one network switch, should be able to get a loaner for the 6-months run
  - Cable infrastructure, location of electronics and power supplies?
    - Electronics are mounted on detector, power racks will be next to detector. Only additional cables will be to network switch
  - Rack protection system?
    - Provided by PLC used in the dry gas/water cooling system
  - Frequent access through roll-up door?
    - Not anticipated if we have access through firewall. Would be necessary a couple of times if we need to rotate detector for non-normal beam incidence running

Secondary and Tertiary Beam Comps.

Jeff Nelson and Cora Karamitsos

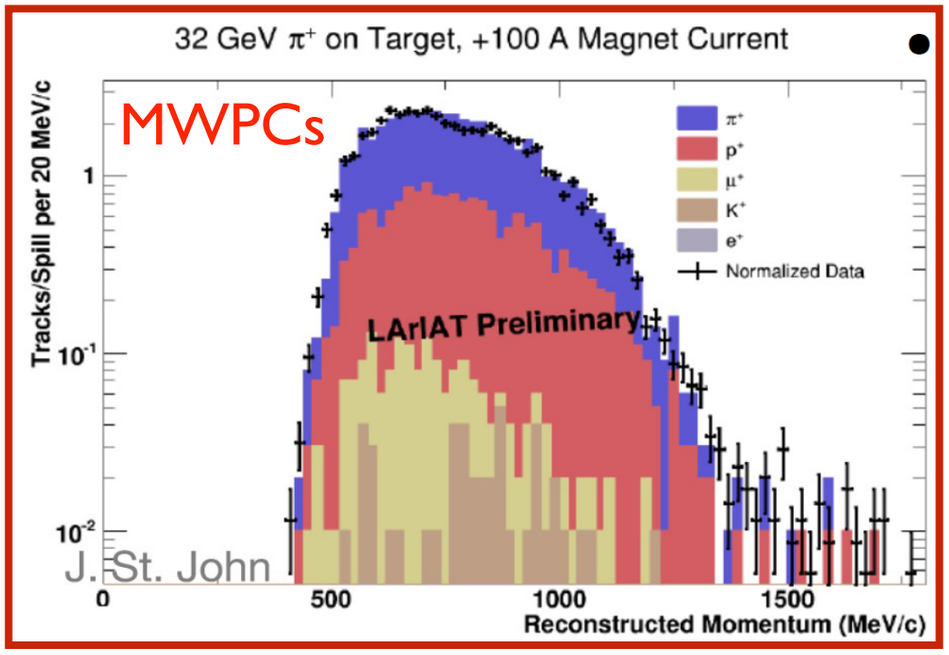
Table 7: Percent Beam Composition at Different Momentum

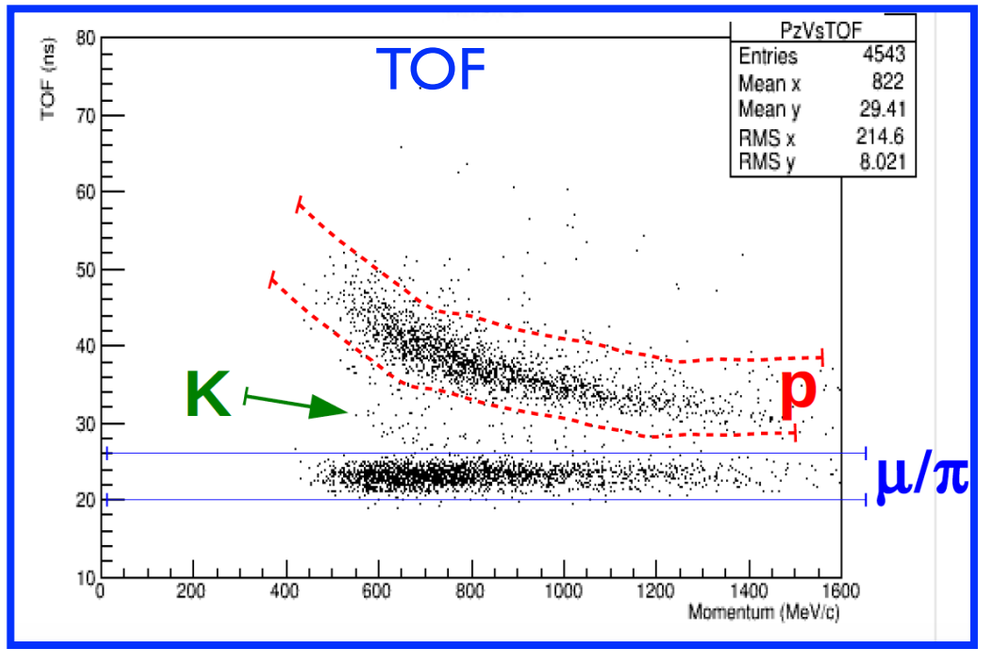
Momentum	Electrons	Pions	Protons	Unidentified
1.55 GeV	96.662 ± 0.003	0.692 ± 0.0003	0.3849 ± 0.0002	2.657 ± 0.0003
2 GeV	96.994 ± 0.003	1.034 ± 0.006	0.5124 ± 0.0002	1.4596 ± 0.0003
4 GeV	84.929 ± 0.002	11.794 ± 0.002	2.5071 ± 0.0004	0.7699 ± 0.0003
6 GeV	71.754 ± 0.002	23.443± 0.001	4.2682 ± 0.0007	0.5348 ± 0.0002
8 GeV	56.627 ± 0.001	35.188 ± 0.002	6.7145 ± 0.0006	1.4705 ± 0.0002

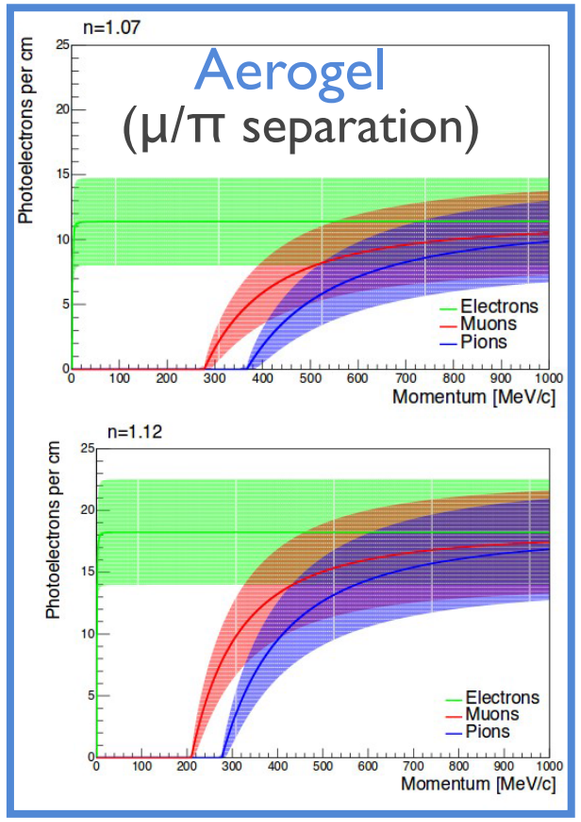
William Foreman, arXiv:1511.00305

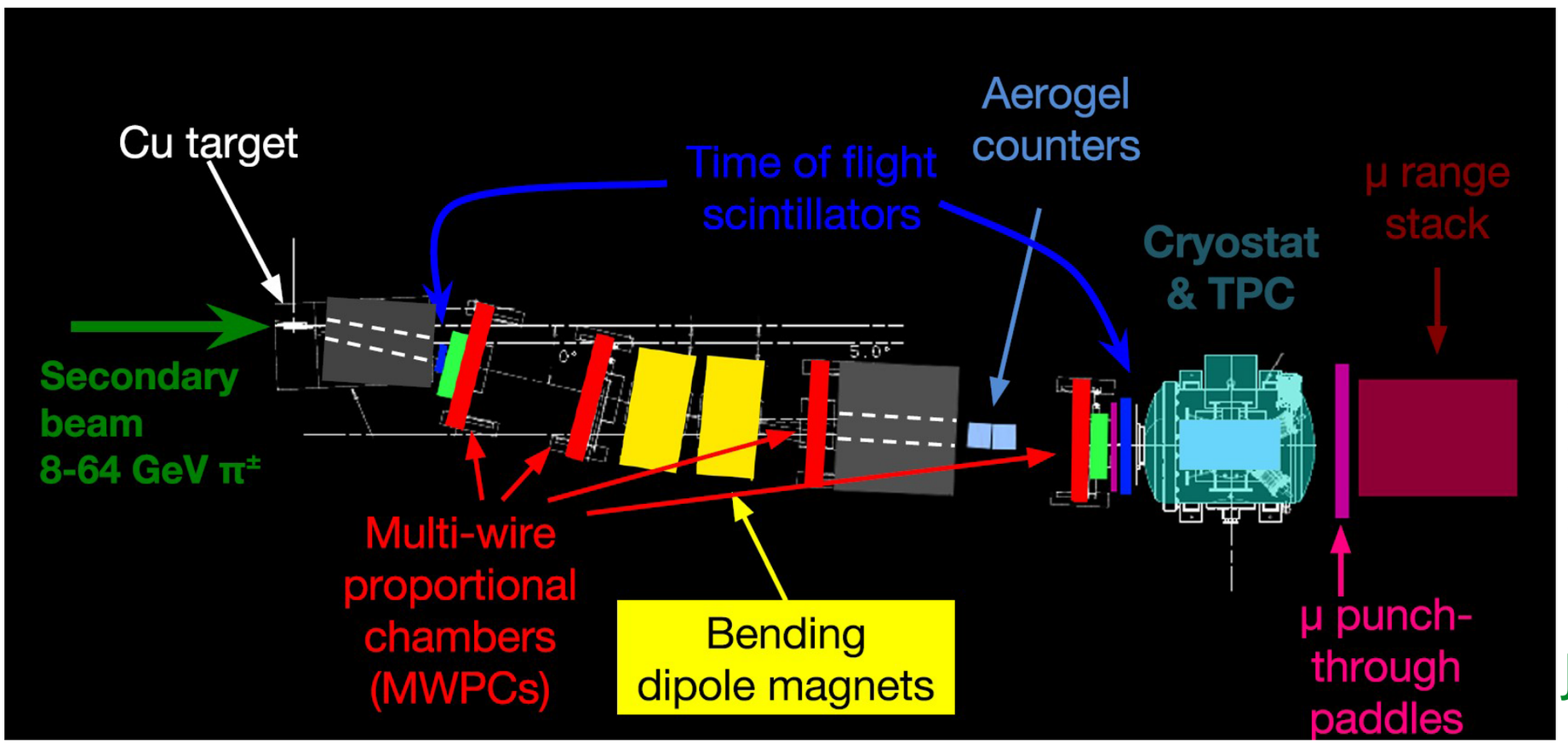
Particle type	+0.14 Tesla field	+0.35 Tesla field
$\pi+$	32.6%	59.2%
$e+$	55.2%	13.3%
γ	4.0%	2.3%
$p+$	6.7%	23.5%
$\mu+$	1.9%	1.9%
$K+$	0.005%	0.06%

LArIAT Tertiary Beam

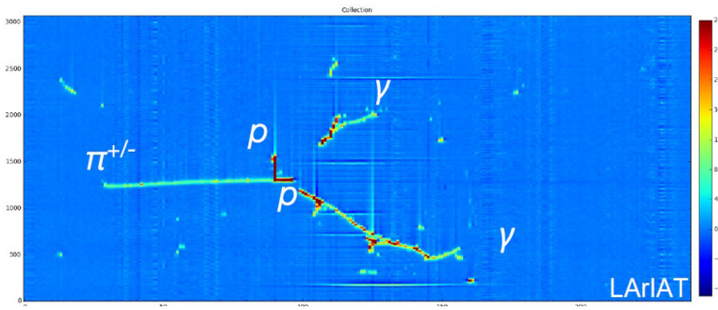








- μ/π separation also from range in muon stack



Jonathan Asaadi, Yale Seminar 09/2015

Why should you get involved?