Fermilab

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Muon Campus

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Fermilab Institutional Review

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Outline

- Introduction
- Common Accelerator Needs for g-2 and Mu2e
- Muon Campus Program
  - Recycler RF AIP
  - Beam Transport AIP
  - Delivery Ring AIP
  - Cryo AIP
  - MC-1 Building GPP
  - Beamline Enclosure GPP
  - MC Infrastructure GPP
- Conclusions

Introduction

- The Mu2e experiment will look for muon to electron conversion
- The g-2 experiment will measure the anomalous magnetic moment of the muon
- Both require muons of a momentum which can be produced using an 8-GeV primary proton beam with similar requirements on bunch structure
- Both require cryogenics for superconducting magnets
- Both planned to re-use infrastructure from the former Antiproton Source (“Pbar”)
- The needs of both experiments are suited to a common solution: the Muon Campus

Introduction to the Muon Campus

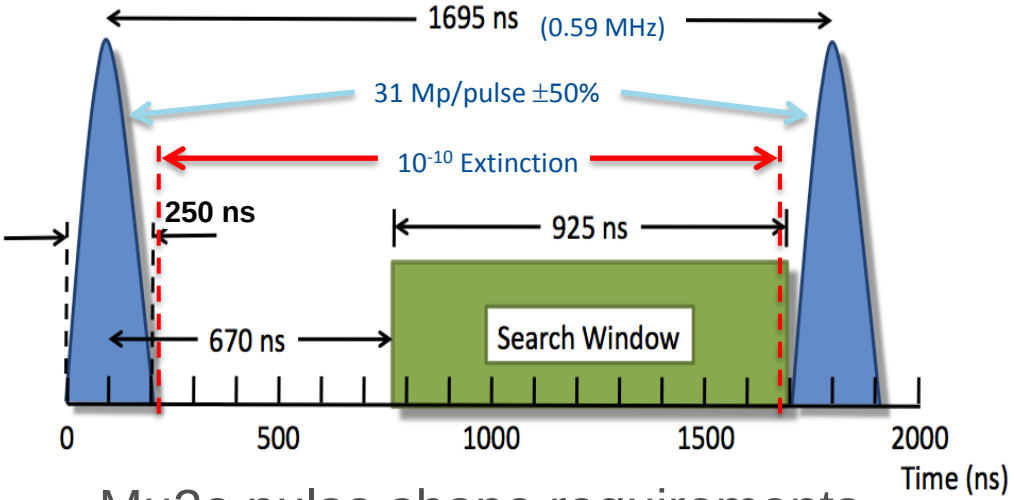
- The Muon Campus Program provides infrastructure and improvements needed to support both Mu2e and g-2
- Based on reusing former Antiproton Source infrastructure
- Made up of 4 Accelerator Improvement Projects (AIPs) and 3 General Plant Projects (GPPs), each with a limit of $10M
  - Recycler RF AIP provides rebunching of proton beam for both expts
  - Beam Transport AIP provides extraction from Recycler to Muon Campus beamlines and beamline improvements for 8-GeV beam
  - Delivery Ring AIP provides infrastructure improvements, new injection and abort components to former antiproton Debuncher ring
  - Cryo AIP provides cryogenics for Mu2e solenoids and g-2 storage ring
  - MC-1 Building GPP provides building to house g-2 experiment, cryo refrigerators, beamline power supplies
  - Beamline Enclosure GPP provides tunnel enclosure for new beamlines
  - MC Infrastructure GPP provides cooling for cryo compressors and extension of MI-52 building needed for new Recycler extraction

Muon Campus Layout

View from Wilson Hall

Beam to Mu2e

- Primary (8 GeV) proton beam resonantly-extracted from former Antiproton Debuncher and transported to target for producing low-momentum muons
- Extinction of out-of-time beam needed for background reduction



Mu2e pulse shape requirements

Beam to g-2

- Rebunch primary (8 GeV) protons so that rate in detectors is not too high, bunch length < ring revolution time of 147ns
- Create 3.1 GeV secondary pions off a target
- Beamline long enough for ~all pions to decay

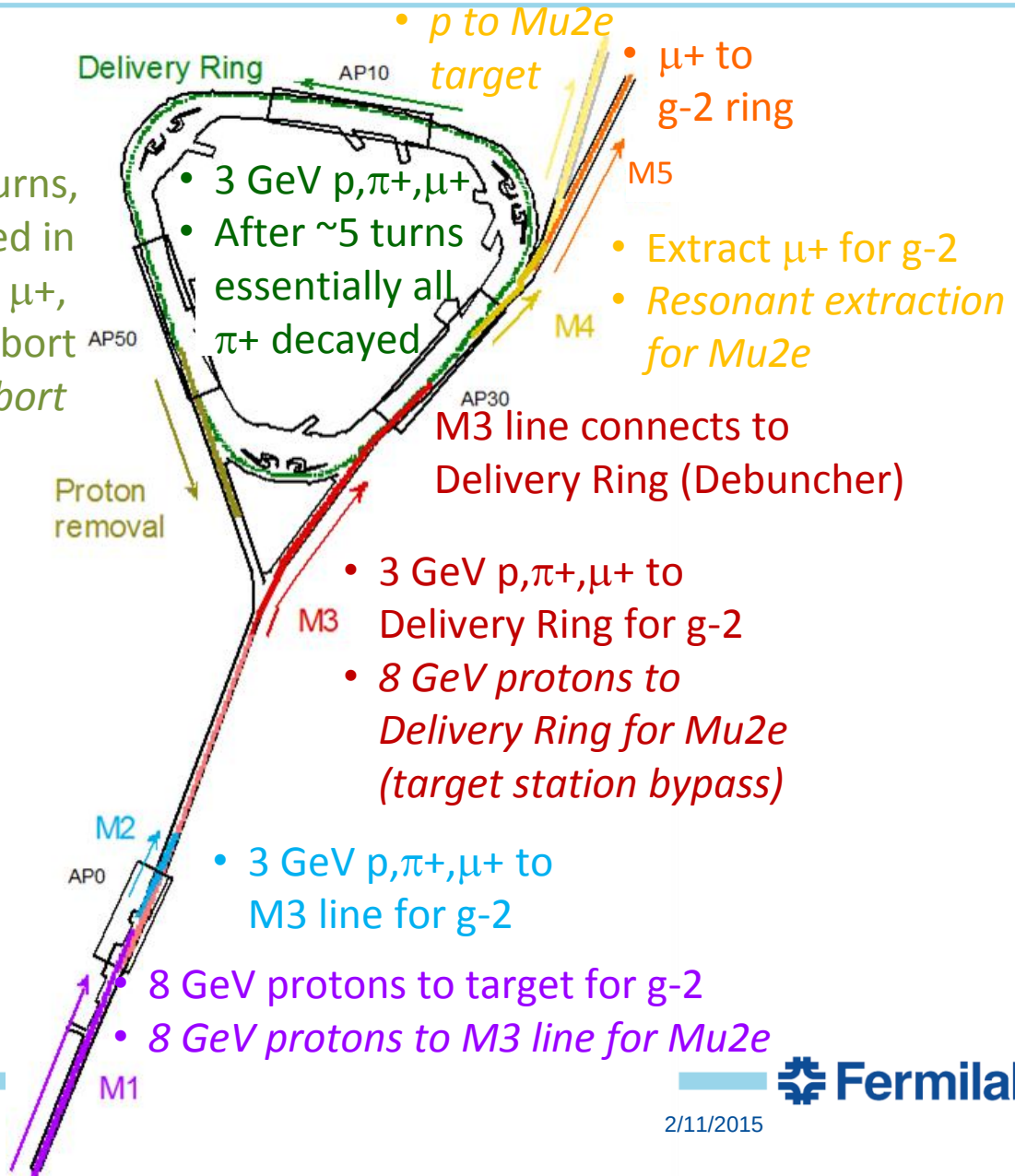
Capture 3.094 GeV ("magic momentum" muons)

  - Aim for 40π acceptance

Limit secondary pions and protons making it into g-2 storage ring (cause "hadronic flash" in calorimeters)

Muon Campus Beamline Plan for Mu2e and g-2

- Plan for combining Mu2e and g-2 allows for expanded capabilities such as g-2 proton removal using abort needed by Mu2e



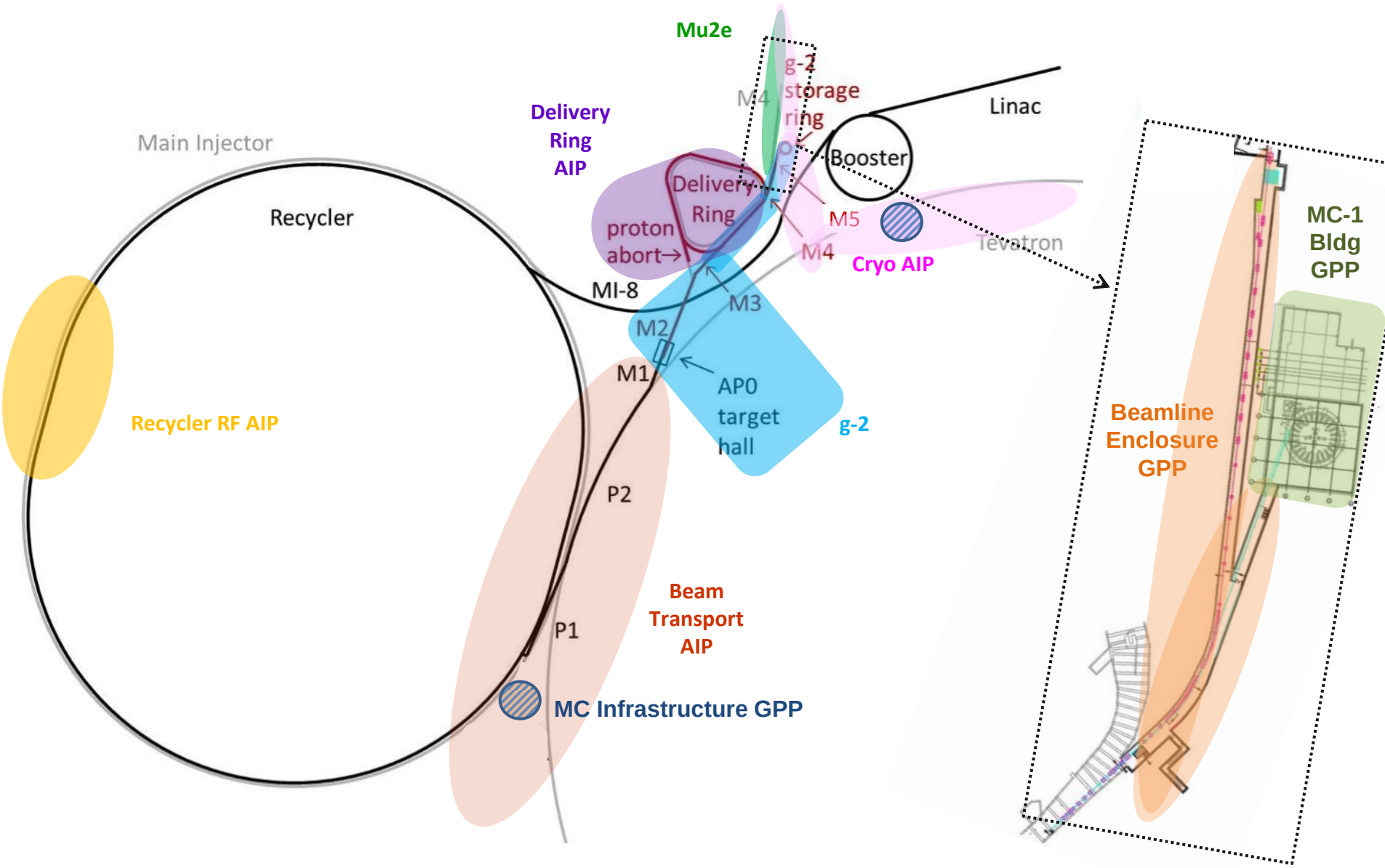
Reusing the Antiproton Source ("Pbar")

- 1km of tunnel complete with electrical infrastructure, cable trays, cooling water distribution system and safety interlocks
- g-2 reusing Pbar Target Station including target, lithium lens, pulsed momentum-selection magnet, collimation system, target vault, cooling systems, hot work cell, and tunnel access points with overhead crane coverage
- Service buildings with HVAC, cooling water, controls communication infrastructure, extensive electrical infrastructure, electronics racks, access roads and parking lots, etc
- Repurposing >250 Pbar magnets, g-2 using ~30 BNL magnets, plus 505m Pbar Debuncher used in-place as Delivery Ring
- Power supplies will also be repurposed where practical
- Reusing instrumentation from Antiproton Source

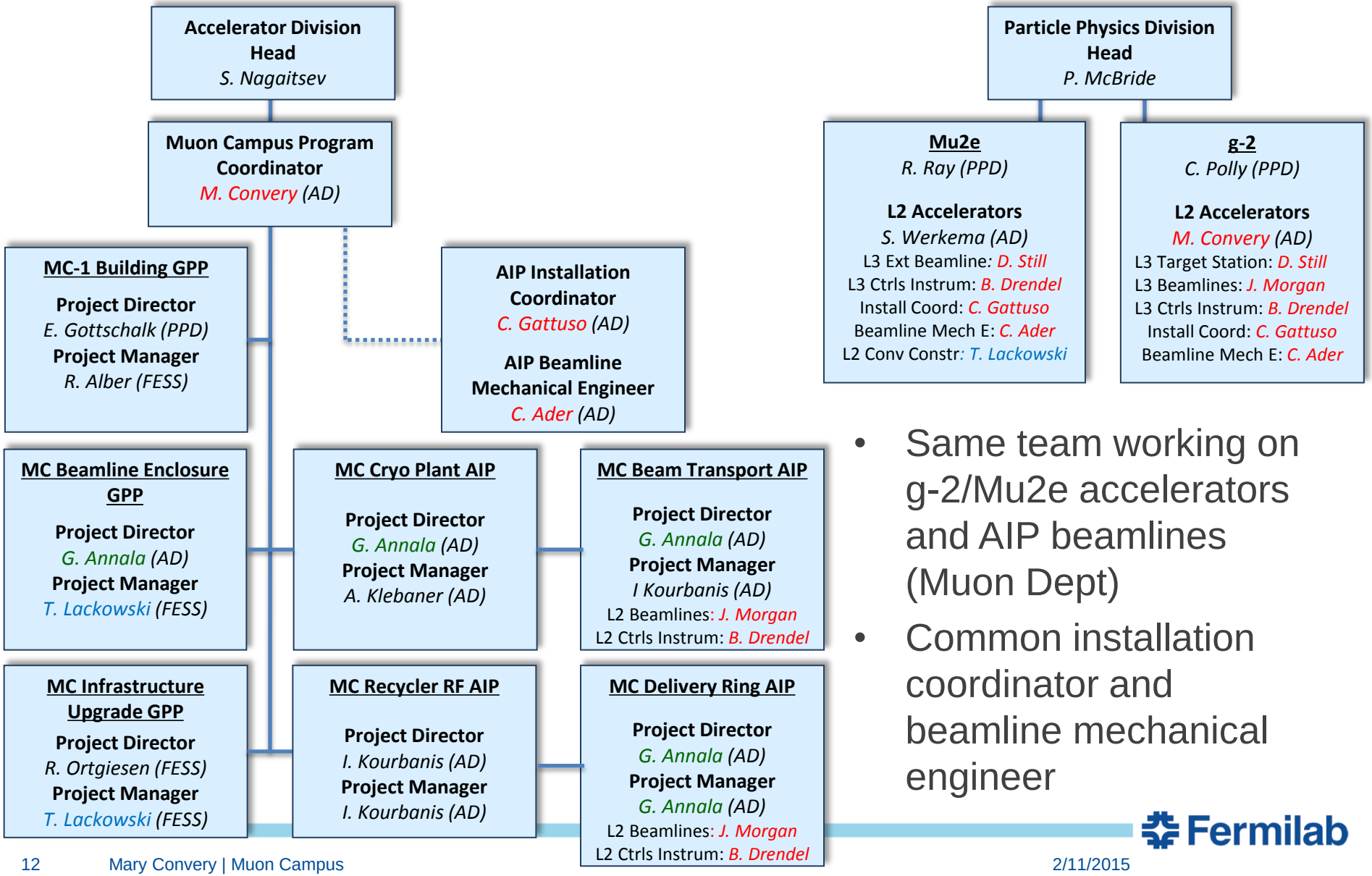
Shared Infrastructure

- Any shared infrastructure needs to be ready for g-2
  - No common infrastructure on Mu2e project
- Make use of Accelerator Improvement Projects (AIPs) and General Plant Projects (GPPs)
  - $10M limit, funding comes from lab operations
  - No Critical Decision process like DOE Projects, implementation of one piece can proceed while other pieces still in design phase

Muon Campus Program "Geographic" Scope



Muon Campus Program Organization



- Same team working on g-2/Mu2e accelerators and AIP beamlines (Muon Dept)
- Common installation coordinator and beamline mechanical engineer

Muon Campus Program Plans

- Muon Campus Program Plan
  - Includes discussion of requirements documents and interface milestones between projects
- MC-1 Building Project Plan
- MC Beamline Enclosure Project Plan
- MC Infrastructure Project Plan
- Cryo AIP Project Plan
- Recycler RF Project Plan
- Beam Transport Project Plan
- Delivery Ring Project Plan
  - Include scope, change control, etc

Integration

- Interfaces and dependencies between Mu2e, g-2 and the Muon Campus AIPs/GPPs are ensured through actively managed *Interface Milestones*
- The establishment of requirements and specifications of the common elements involves all stakeholders
- Configuration Management and Change Control processes in place and incorporate relevant stakeholders
- We recognize the need to manage the interfaces and dependencies and have the necessary processes in place to do so

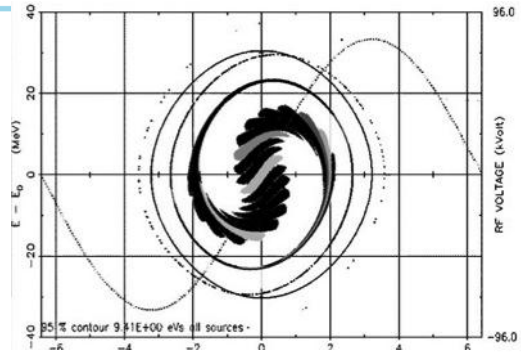
Interface Milestones

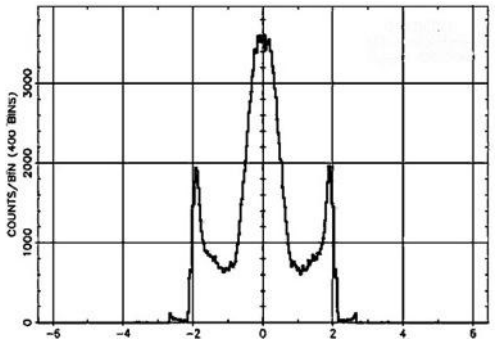
- Interface milestones are the basis for communicating schedule impacts between the AIP's, GPP's, g-2 and Mu2e
- The integration of these into the g-2 and Mu2e schedules shows the impact of any change

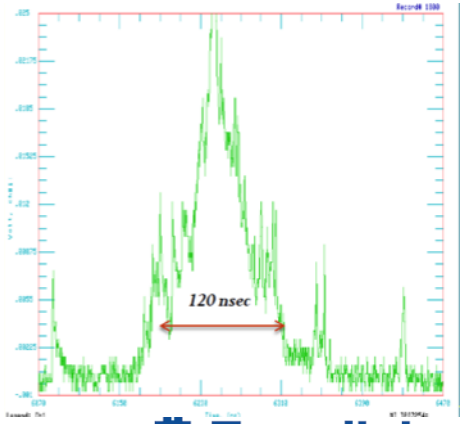
Milestone Name	Responsibility	Impacts	Forecast	Needed by	Actual
MC-1 Bldg Beneficial Occupancy for Cryo	MC-1 Building GPP	Cryo AIP	1/8/14	as soon as possible	1/8/2014
MC-1 Bldg Beneficial Occupancy for g-2 Ring	MC-1 Building GPP	g-2	4/10/14	as soon as possible	4/10/2014
End of Circulating Beam Studies	g-2, Mu2e	g-2, Mu2e, Delivery Ring AIP	4/25/14	6/30/14	4/25/2014
MC-1 Cryo Room Controls Available	MC-1 Building GPP	Cryo AIP	9/22/14	as soon as possible	6/6/2014
Cryo Compressor Cooling Established	MC Infrastructure GPP	Cryo AIP	9/30/14	10/31/14	8/15/2014
Cryo g-2 acceptance tests complete	Cryo AIP	lower-level milestone for g-2	10/24/14	as soon as possible	10/2/2014
Cryo Ready to Cool g-2	Cryo AIP	g-2	3/15/15	as soon as possible	11/30/2014
D30 Straight Section Ready for New Installation	g-2	Delivery Ring AIP	2/5/15	5/17/16	1/31/2015
MI-52 Bldg Extension Beneficial Occupancy	MC Infrastructure GPP	Beam Transport AIP	6/30/15	9/30/15	
Beamline Enclosure Beneficial Occupancy	Beamline Enclosure GPP	g-2	2/1/16	2/15/16	
Beam Transport Complete	Beam Transport AIP	g-2, Mu2e	2/1/16	3/31/17	
Recycler RF Complete	Recycler RF AIP	g-2, Mu2e	9/30/16	3/31/17	
Delivery Ring Complete	Delivery Ring AIP	g-2, Mu2e	9/30/16	3/31/17	
Shield Wall Installation	g-2	Mu2e	1/5/17	before g-2 running	
Cryo: Mu2e Distribution Box Cold	Cryo AIP	Mu2e	7/15/17	9/15/17	

Recycler RF AIP

- Reform 53-MHz bunches of $4x10^{12}$ 8-GeV protons from Booster into four bunches of 10^{12} protons using 2.5-MHz RF
- Bunches with 95% of beam within 120ns
  - g-2 needs beam pulses shorter than muon storage ring revolution time 147ns
  - Balance efficiency, momentum spread, and longitudinal extent
- Beam pulses separated by 10ms for the muons to decay in the g-2 storage ring and data to be recorded
- Mu2e specs are less stringent than g-2



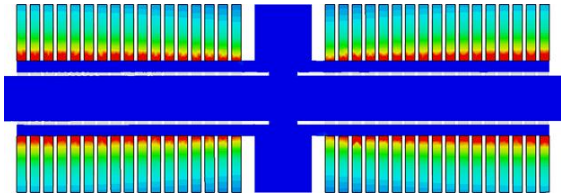


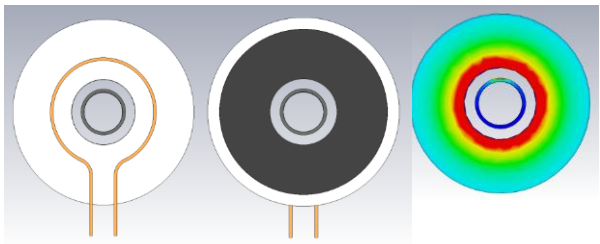


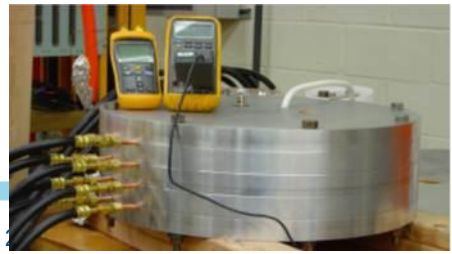
Very good agreement between simulations and beam data using 2.5-MHz MI coalescing cavities

RF Cavity Design and Production

- Building and installing 7 RF cavities and power amplifiers for Recycler and 2 for Mu2e in Delivery Ring
- Reusing ferrites from MI coalescing and Pbar cavities (worth $1M today), purchased additional
- Previous 2.5MHz RF cavities in MI were used for coalescing beam to Tevatron ~once a day
- Beam to g-2/Mu2e at high repetition rate requires active cooling in the RF cavities
- Cavity cooling designed and tested, cooling plates purchased
- Beginning cavity assembly

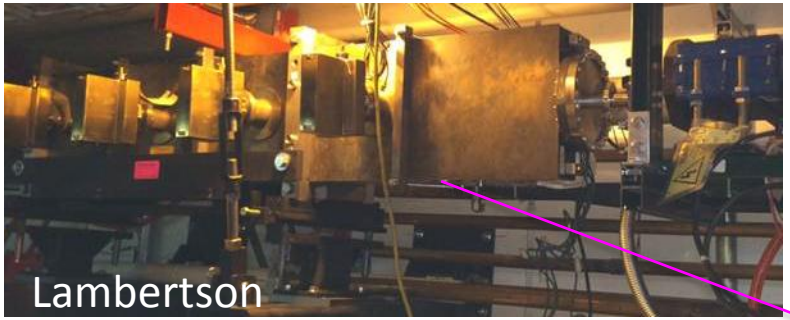


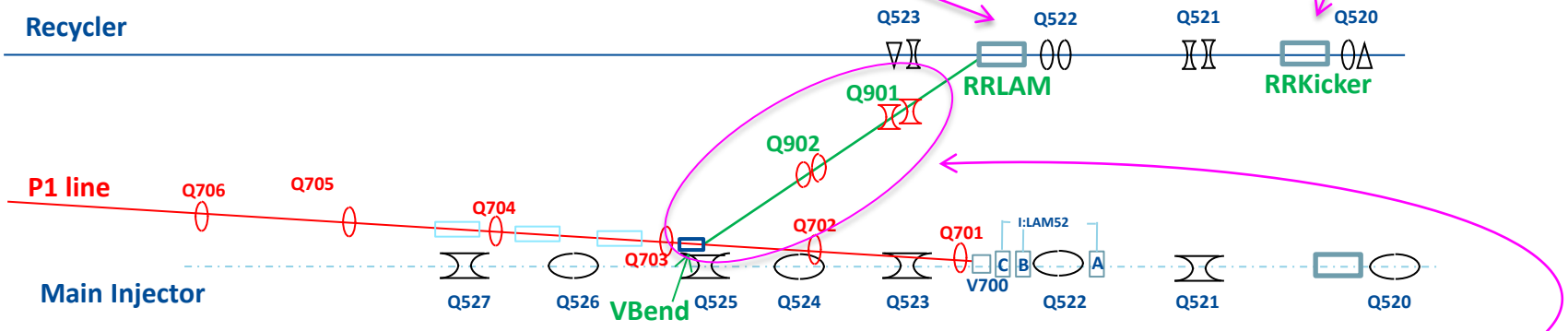




Beam Transport AIP

- Allows re-bunched 8 GeV proton beam to be extracted to the P1 line and transported towards the experimental areas
- Extraction kickers and Lambertson installed in Recycler last year

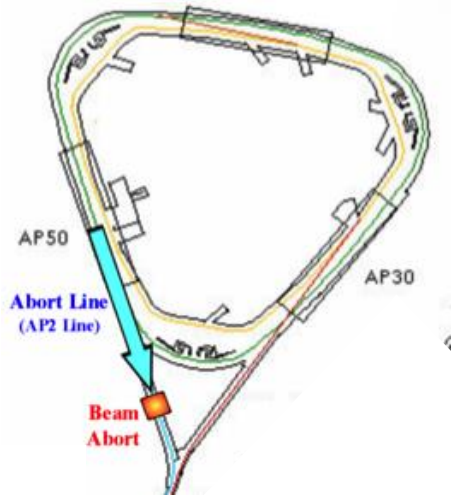




- New beamline connection from Recycler to P1 line to be installed during this year's shutdown as well as aperture improvements in P1, P2, M1 lines for 8-GeV beam

Delivery Ring AIP

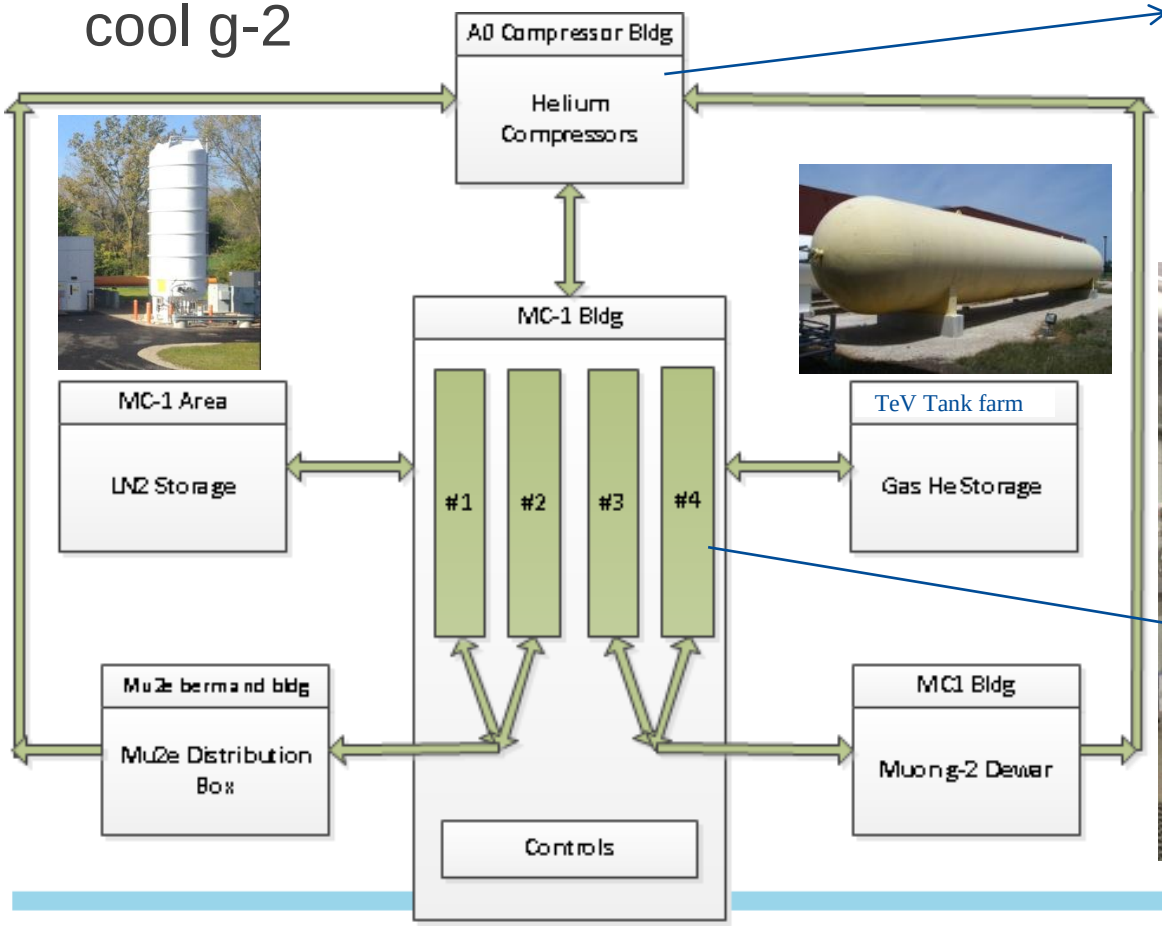
- Upgrades to Delivery Ring (former antiproton Debuncher) to support Mu2e and g-2, including injection into Delivery Ring
- Collider equipment (e.g. stochastic cooling tanks) removed to improve aperture and make room for new components
- Controls re-routed around new M4/M5 beamline enclosure
- Electrical infrastructure upgrades in progress
- Work beginning on Delivery Ring abort
  - Mu2e: remove beam left after resonant extraction
  - g-2: proton removal
  - Repurposing steel shielding already in enclosure from old experiment, retrofitted with new steel central core and surrounded by concrete



Cryo AIP

- Provide for independent operation of g-2 storage ring and Mu2e solenoids
- Refrigerators are operational; ready to cool g-2

Much of cryo equipment refurbished / reengineered Tevatron equipment

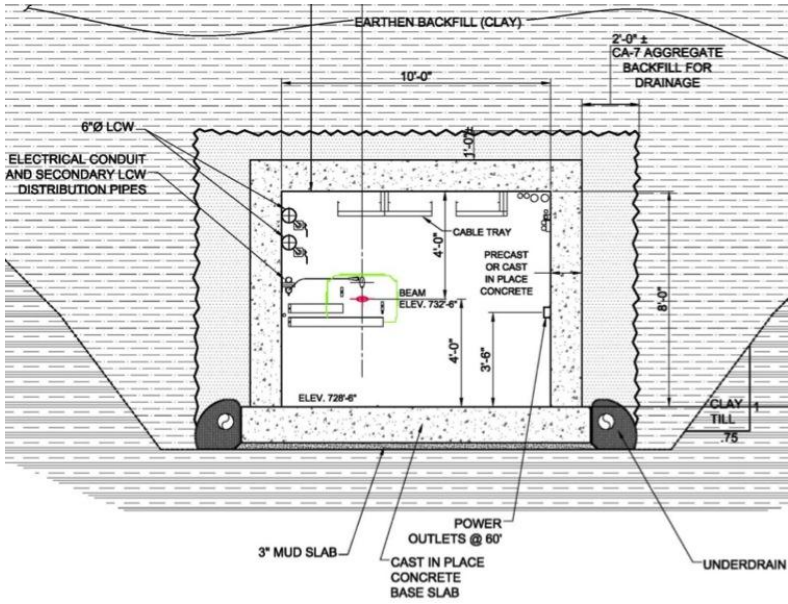


MC-1 Building GPP

- MC-1 building designed to house g-2 and future experiments, cryo refrigerator system for g-2 and Mu2e, and power supplies for some beamline components
- Beneficial occupancy 4/10/14, construction complete 12/31/14, ~$100k of unspent contingency returned to lab

Beamline Enclosure GPP

- Design based on existing (Main Injector) enclosure
- Shielding earth/concrete
- Same subcontractor as Mu2e bldg
- Construction began in December
- Beneficial occupancy Feb 2016, in time for scheduled g-2 beamline installation



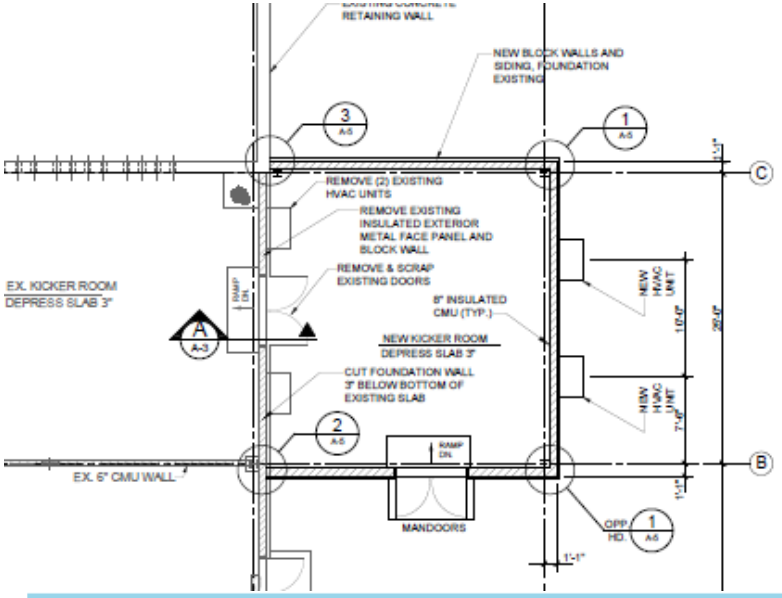

AP30


IMPERIAL


AP30

MC Infrastructure GPP

- Cooling system for the cryo compressors complete
- Extension of MI-52 service building needed for new RR extraction kickers
  - Foundation already completed during last year's shutdown
  - Remaining construction expected to take less than 3 months, Beneficial Occupancy before start of this year's shutdown



Safety

- Minimizing exposure to risks by staging work: 1) electrical disconnection, 2) power cable removal, 3) vacuum system removal, 4) magnet removal; installation in reverse order
- Written Hazard Analyses where needed, e.g. magnet rigging
- ALARA plans for work near target hall, F0 Lambertson
  - g-2 target station dump replacement (place current beam dump in coffin and transport to Target Service Bldg for onsite storage)
- Environmental safety in decommissioning Antiproton Source
  - Reusing magnets, vacuum components, cables, instrumentation
  - Storing some magnets as spares
  - Rad waste coordinator disposing of components which can't be reused
- Construction safety coordinator and regular meetings
  - ERM providing additional ES&H oversight for the lab

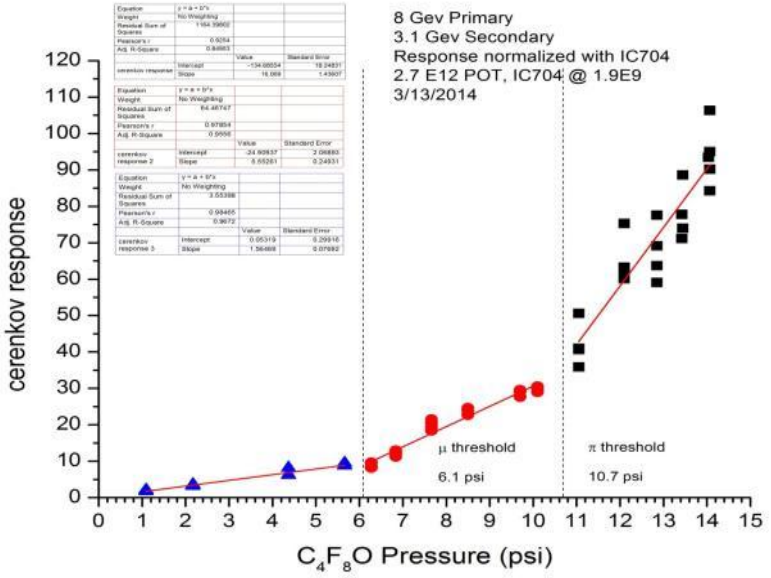
Technical expertise and leadership

Jerry Annala	Muon	Dept head, AIP PM, technical expert
Jim Morgan	Muon	Technical expert: former antiproton source, beamlines
Brian Drendel	Muon	Technical expert: former antiproton source, ctrls/instrum
Dean Still	Muon	Technical expert: g-2 target station, Mu2e beamlines
Jim Budlong	Muon	Technical expert, electrical coordinator
Tony Leveling	Muon	Technical expert: former antiproton source, rad safety
Dave VanderMulen	Muon	Technical expert: former antiproton source
Al Sondgeroth	Muon	Technical expert: former antiproton source
Steve Werkema	Muon	Scientist, Mu2e L2 PM
Vladimir Nagaslaev	Muon	Scientist: Mu2e resonant extraction
Peter Kasper	Muon	Scientist: Mu2e extinction monitoring
Mary Convery	Muon	Scientist, g-2 L2 PM, Muon Campus Prog Coord
Ioanis Kourbanis	MI/RR	Dept head, AIP PM, scientist
Meiqin Xiao	MI/RR	Scientist: beamline design
Eric Prebys	APC	Scientist: Mu2e extinction
Eliana Gianfelice	APC	Scientist: Mu2e beamline design
John Johnstone	APC	Scientist: g-2 beamline design
Carol Johnstone	Ext Beam	Scientist: g-2 beamline design
Rick Coleman	Ext Beam	Scientist: Mu2e target station
Cons Gattuso	HQ	Technical expert, installation coordinator
Stan Johnson	Ops	Muon operations specialist, controls
Arkadiy Klebaner	Cryo	Cryo engineer, AIP PM
Bill Soyars	Cryo	Cryo engineer
Greg Johnson	Cryo	Cryo engineer
Alex Martinez	Cryo	Cryo engineer
Joe Dey	RF	MI/RR RF engineer
Chuck Worel	ES&H	Interlocks
Randy Zifko	ES&H	Interlocks

Chris Jensen	EE	Kicker engineer
George Krafczyk	EE	PS engineer slow extractt
Dan Wolff	EE	Dept head, PS engineer
Howie Pfeffer	EE	PS engineer
Steve Hays	EE	PS engineer
Ken Quinn	EE	PS engineer
Christine Ader	Mech	Engineer, coordination
Rob Reilly	Mech	Engineer: beamlines
Ron LeBeau	Mech	Engineer: vacuum
Dez Deshpande	Mech	Engineer: fluids, stands
Maurice Ball	Mech	Engineer: fluids
Corey Crowley	Mech	Engineer: shielding
Dave Tinsley	Mech	Engineer: res extr septum
Matthew Alvarez	Mech	Engineer: slow extraction
Ryan Schultz	Target	Engineer: g-2 target station
Mike Campbell	Target	Engineer: Mu2e target
Dan Vrbos	Mech	Lead tech Muon
M Rauchmiller	Mech	Lead tech MI/RR
Greg Brown	Ctrls	Network
Greg Vogel	Ctrls	Engineer: clock
Dan McArthur	Ctrls	Engineer: readout
Dan Schoo	Instrum	Engineer: profile mon
Peter Prieto	Instrum	Engineer: spill monitoring
Gianni Tassotto	Instrum	Technical expert: profile
Aisha Ibrahim	Instrum	Engineer: toroids
Randy Thurman	Instrum	Scientist: beam loss mon
Dave Peterson	RF	Engineer: electronics

University involvement

- Univ of Mississippi (Breese Quinn) updated Cerenkov counter from BNL g-2 experiment used for beam studies and to be used for commissioning g-2 beam



- RAL responsible for Mu2e production target

Conclusions

- Muon Campus Program supports g-2 and Mu2e
- Based on reusing former Antiproton Source infrastructure
- Provides common infrastructure in a way that enhances the capabilities of the experiments
- Current schedule provides Muon Campus ready for beam in time to meet current g-2 and Mu2e schedules