Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Mu2e Operations

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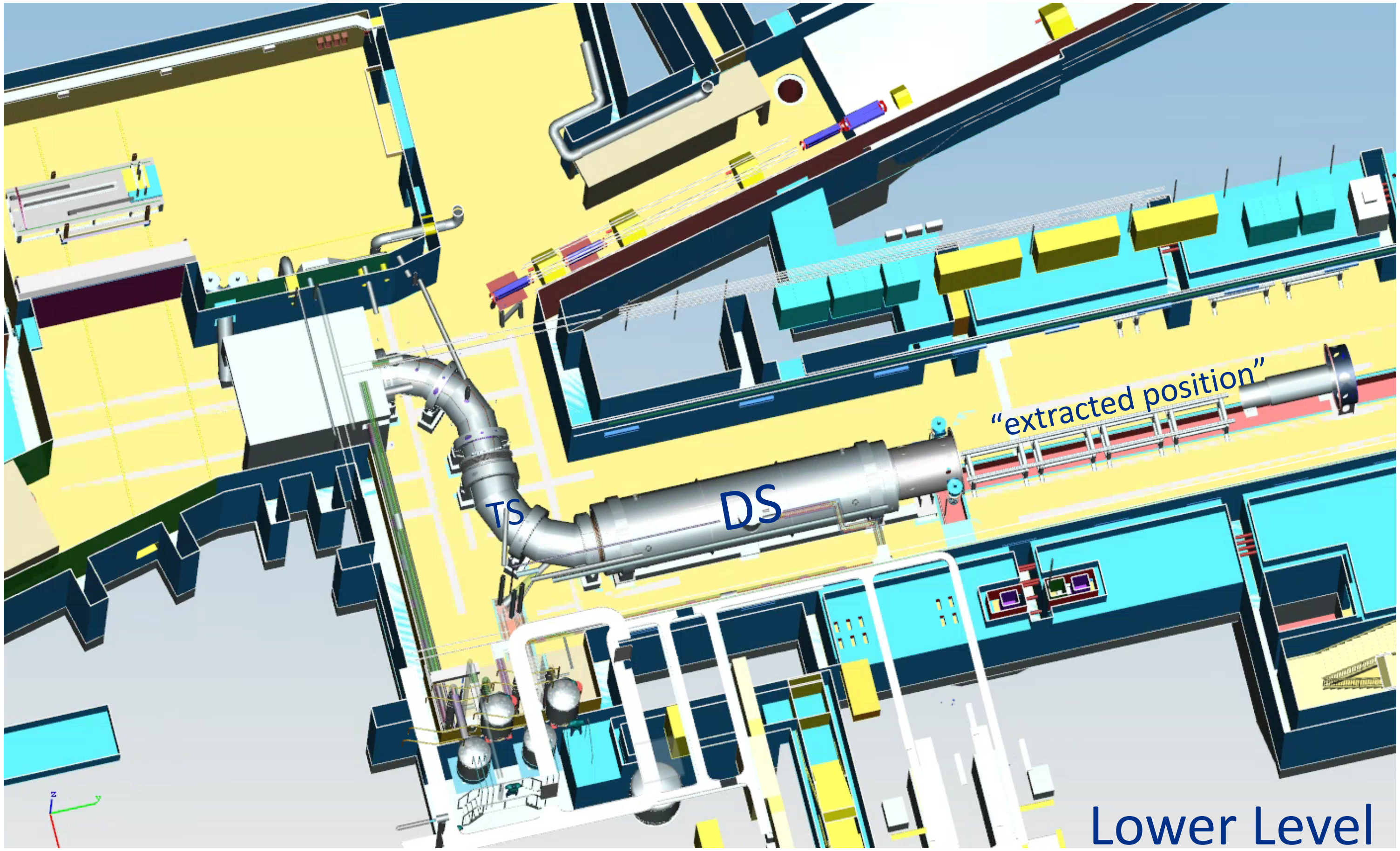
Mu2e CSN1 Referee Meeting
9 September 2020

Mu2e: Project ➞ Operations transition

- In general, the Project provides the materials and labor up until the point a subsystem has met its Key Performance Parameter (KPP)
  - As the KPP is completed, ownership and responsibility for operations is transferred to the collaboration and FNAL

- Mu2e Operations is broken up into phases
  - "Pre-operations"→ time period before KPP completed (i.e., now)
    - Pre-operations is ongoing now, while the Project is ongoing
  - "Operations" → time period after KPP completed
    - Final installation and prepare for beam
    - Commission with beam on target
    - Physics data taking
    - Summer shutdown

State of Mu2e to satisfy detector subsystems' KPP



When operations begins, the primary tasks to prepare for beam are:

- Map the solenoid fields precisely
- Install the external shielding and CRV
- Establish operations of detectors with vacuum & B-field
- Establish beam to the Mu2e production target

Mu2e Operations planning

OHEP Operations Planning Process

"In response to a COV recommendation and since HEP needs credible and defensible operations plans in place in time to support budget planning, we have developed a phased-process of planning and reviews… The results of this process will be used to inform HEP planning."

Mu2e was asked by DOE to develop an "Operations Plan" (OP) with:

- a review of the **preliminary OP**, which took place on **5-6 May 2020**
- a review of the **detailed OP** sometimes in mid-2022

Mu2e Detector & Computing operations plan

- D&C operations includes experiment facilities, solenoids, detector subsystems, and computing operations
- Staggered start in FY22 as the project KPP's are achieved
- Resource / cost estimates through Run-1, i.e., up to start of the LBNF/PIP-II shutdown
  - Experience with beam in Run-1 is needed to inform activities during LBNF/PIP-II shutdown
  - Mu2e requires significant running after shutdown (Run-2) to achieve sensitivity goal
- Relies on significant contributed effort from the collaboration, supported on university and lab research budgets
- Mu2e D&C Operations budget managed by PPD
- Incremental costs of computing included in D&C Operations plan (supported by SCD)
- Solenoid and cryo costs included in D&C operations plan (supported by APS-TD)
- Proton beam and production target ops by **Mu2e Accelerator Operations**

Operations Planning Team

Operations planning team, organized by Mu2e Spokespersons and FNAL:

Bob Bernstein (FNAL): Mu2e Co-spokesperson (since 20 March 2020)
Doug Glenzinski (FNAL): Mu2e Co-spokesperson (through 20 March 2020) & CPO
Jim Miller (U. Boston): Mu2e Co-spokesperson
Greg Rakness (FNAL): Mu2e Ops co-Coord & Head of Mu2e Prelim Ops Planning
George Ginther (FNAL): Deputy Head of Mu2e Preliminary Operations Planning and member of Mu2e Project Integration Coordination team
Jemila Adetunji (FNAL): Mu2e Quality Manager
Jerry Annala (FNAL): AD Muon Department Head
Karen Byrum (ANL): Mu2e Project Head Electrical Integration
Ray Culbertson (FNAL): PPD Mu2e Group Leader
Gary Drake (FNAL): Mu2e Lead Electrical Engineer
Bertrand Echenard (Caltech): Mu2e Trigger Working Group Co-Leader
Simona Giovannella (INFN Frascati): Mu2e Project L3 Calorimeter Crystals
Craig Group (U. Virginia): Mu2e Project L3 CRV Module Fabrication
Dee Hahn (FNAL): Mu2e ES&H Coordinator
Andy Hocker (FNAL): Mu2e Project L2 Solenoids Deputy Project Manager
Matthew Jones (Purdue): Mu2e Project L4 Extinction Monitor FEE & DAQ
Rob Kutschke (FNAL): Mu2e SCD Computing Liaison and Comp & SW Coordinator
Fran Leavell (FNAL): Project Controls Lead
Raymond Lewis (FNAL): ES&H PPD Division Safety Officer
Kevin Lynch (CUNY York): Stopping Target Monitor
Russ Rucinski (FNAL): Mu2e Lead Mechanical Engineer
Monica Tecchio (U. Michigan) – Mu2e Tracker electronics systems dev & testing
Terry Tope (FNAL): Mu2e Project L3 Cryogenics Distribution
Steve Werkema (FNAL): Mu2e Project L2 Accelerator Project Manager

Planning and development of the supporting documentation for the preliminary review: requirements, Work Breakdown Structure, Resource Loaded Schedule

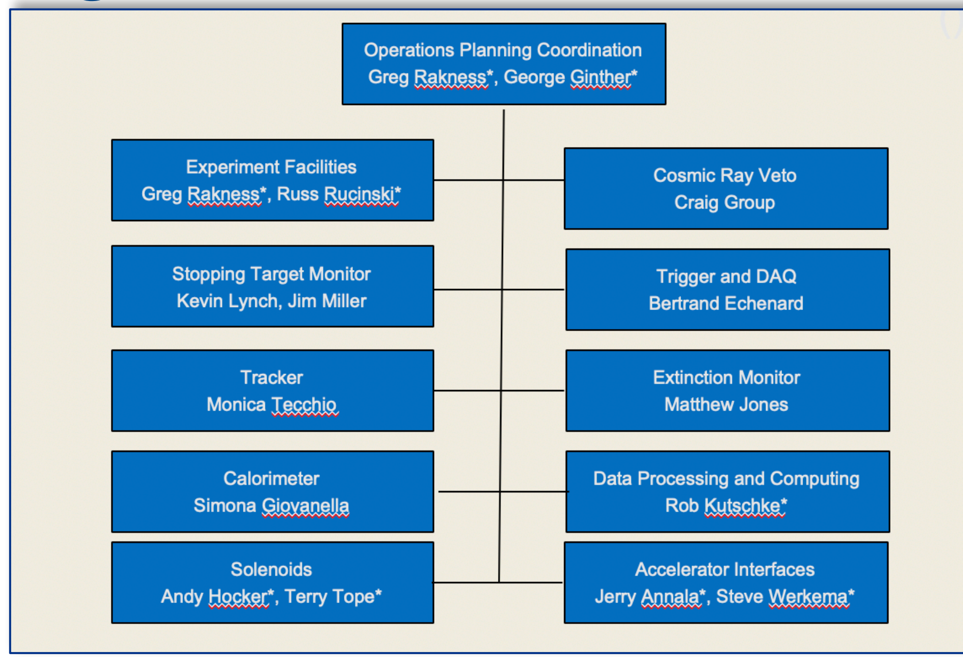
Includes representatives from collaboration, FNAL Particle Physics, Accelerator, Scientific Computing, and Technical Divisions, ES&H and Quality Sections, and Mu2e Project

Material presented at the Preliminary Ops Plan

- Requirements documents for all Operations needs
- Work Breakdown Structure (WBS) to address Requirements
- Cost and labor estimates down to L2 or lower
  - Estimates based on scaling from previous experiments, but not necessarily bottom-up at this stage
  - Estimate of labor required from collaboration
  - FTE broken down by L2 and by skills type
- Risks – preliminary assessment
- Preliminary ES&H plan
- Preliminary Experiment Operations Plan
- Plan to achieve the Detailed Plan

Mu2e Operations L2/L3 organization

- Operations WBS parallels Project structure: L2 for each distinct sub-system representing different technologies



- Common L3's defined for all subsystems to facilitate coherent planning and roll-up
- Main phases of work:
  - prepare for beam
  - commission with beam
  - physics data taking
  - summer shutdown

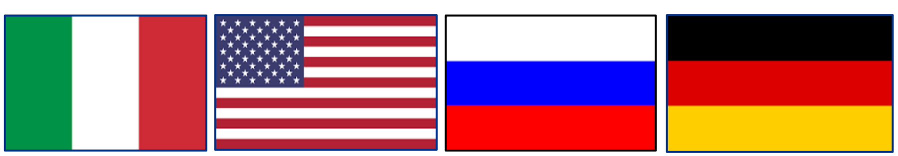
Example implementation in p6:

- MO.06 Mu2e Tracker Operations
  - MO.06.01 Milestones
  - MO.06.02 Leadership, Consumables, and Spares
  - MO.06.03 Prepare for Beam
  - MO.06.04 Commission with Beam
  - MO.06.05 Physics Data Taking Y1
  - MO.06.06 Summer Shutdown Y1

Calorimeter: involved institutions

Institutions expressing interest in calorimeter operations:

1. Caltech
2. JINR, Dubna
3. INFN-LNF, Frascati
4. HZDR, Dresden
5. INFN-Lecce
6. Marconi University, Rome
7. INFN -Pisa
8. INFN-Trieste



Mu2e Operations Responsibilities by Institution (draft 23 December 2019)

	Proton Beamline & Extinction	Solenoids & Field Mapping	Tracker	Calorimeter	Cosmic Ray Veto	Extinction Monitor	Stopping Target Monitor	TDAQ	Software & Computing	Calibrations & Data Processing	Analysis Preparations	Data Analysis & Interal Review	Miscellaneous
Argonne National Laboratory		X			X				X	X	X	X	
Boston University							X		X	X	X	X	
Brookhaven National Laboratory													
University of California, Berkeley			X					X	X	X	X	X	
University of California, Davis	X					X					X	X	
University of California, Irvine													
California Institute of Technology				X				X	X	X		X	
City University of New York	X						X		X			X	
Joint Institute for Nuclear Research, Dubna				X	X							X	X
Duke University			X							X		X	
Fermi National Accelerator Laboratory	X	X	X			X		X	X	X	X	X	X
Laboratori Nazionali di Frascati				X					X	X	X	X	
INFN, Genova		X											
Helmholtz-Zentrum Dresden-Rossendorf				X					X			X	
University of Houston			X									X	
Institute for High Energy Physics, Protvino					X							X	X
Kansas State University					X					X	X	X	
Lawrence Berkeley National Laboratory			X					X	X	X	X	X	
INFN Lecce & Universita' del Salento				X						X	X	X	
Lewis University					X							X	X
University of Liverpool							X		X	X	X	X	
University College London							X		X	X	X	X	
University of Louisville									X				
University of Manchester							X					X	
LNF & Universita' Marconi Roma				X					X	X	X	X	
University of Michigan			X							X		X	
University of Minnesota			X						X	X	X	X	
Institute for Nuclear Research, Moscow												X	X
Muons, Inc.													
Northern Illinois University	X											X	
Northwestern University		X							X	X	X	X	
Novosibirsk State University / Budker Institute of Nuclear Physics									X		X	X	X
INFN, Pisa				X					X	X	X	X	
Purdue University						X	X		X	X	X	X	
University of South Alabama									X			X	X
Sun Yat-Sen University									X		X	X	
INFN, Trieste				X						X			X
University of Virginia					X				X	X	X	X	
University of Washington													
Yale University								X	X		X	X	
No. Contributing Instiutions (of 40 total)	3	4	7	8	6	3	5	4	20	18	18	32	8

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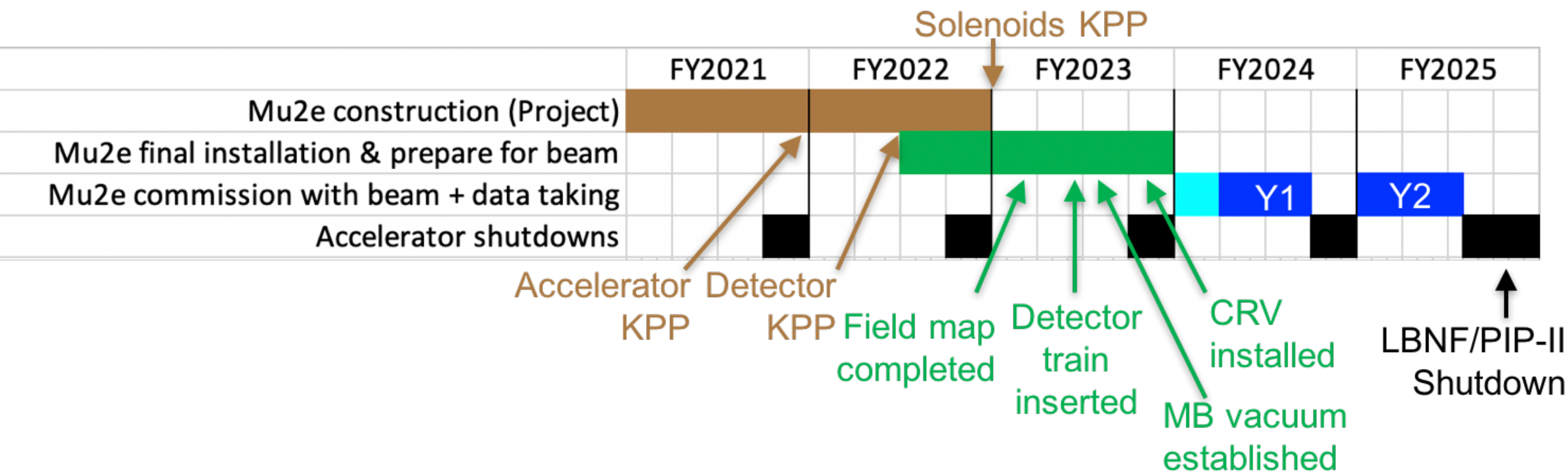
Status of calorimeter at project handoff

- Calorimeter Ops begins with Project Detector KPP:

  Calorimeter installed in an extracted position and cosmic ray data collected using TDAQ



Status of calorimeter at project handoff

- At Project handoff we expect to have:
  - each channel tested with a scope and digital board readout
  - slice test of ½ disk at a time with cosmics and laser runs (low and high rates) before moving to Mu2e assembly hall
  - entire calorimeter powered in an extracted position
  - Cosmic Rays data taking with TDAQ
  - laser system operational
  - source plumbing installed and operated (calib not performed)
  - calorimeter operated with cooling station at room temperature
  - preliminary version of Detector Control System (DCS) tested
  - Needed ORCs done (HV/LV supplies, electronics, source and laser)

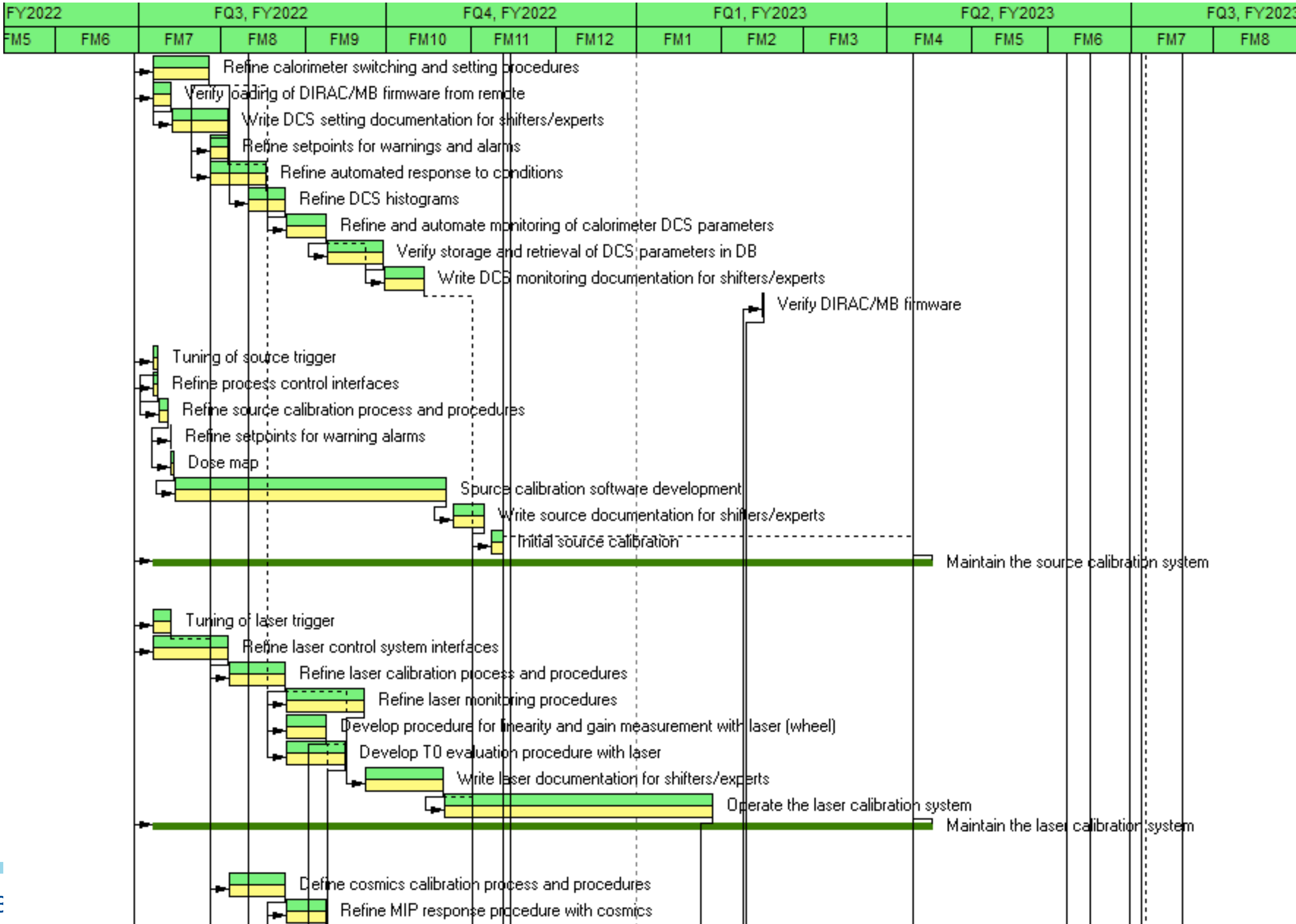
Summary of calorimeter operations requirements

To reach its performance, we need to achieve the following requirements through a 3-step commissioning phase (extracted, inserted, beam):

1. Number of single readout dead channels at % level
2. Dark current on SiPMs < 2 mA ⇨ Noise level < 2 MeV/channel
3. Noisy channels below 1%
4. Continuous and reliable monitoring of:
   - DCS detector parameters: LV/HV, SiPM temperatures and currents
   - DCS calorimeter environmental parameters: temperature, ionization dose, neutron flux on calorimeter surface and crates
   - DQM detector parameters: dead channels, noise level, energy and time offsets, detector response
5. Calibration with laser, cosmics, source and physics data to achieve:
   - Equalization of time/energy at <50ps/1% level
   - Energy scale at 1% level
6. Calibration of energy/time scale w.r.t. tracker (relevant for PID)

See docdb-22786 for details

Example of Calo WBS schedule: prepare for beam



ESH Hazard Mitigation Requirements

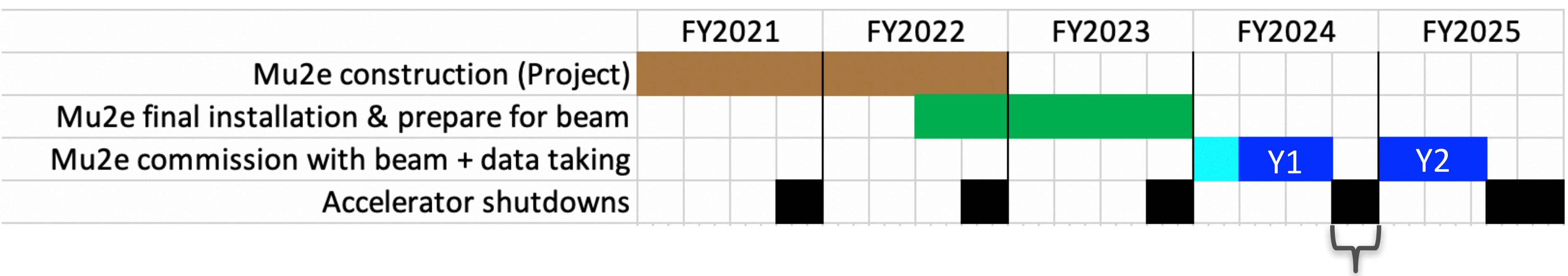
Hazard Description	Mitigation	Notes
Deuterium-tritium (DT) generator	Shielded and locked	Only while without beam
Calibration source exposure	Minimize operation in access mode, personal dosimeter required	Only while DT operating and FC-770 circulating
Laser, primary source and primary distribution	Training, enclosed area, PPE	All phases
Laser secondary distribution	Warning labelling on launching fibers	During access periods
High Voltage exposure	Fermilab Electrical Safety Program	All phases
Low Voltage, high current	Fermilab Electrical Safety Program	All phases
Moving heavy equipment	Operation restricted to qualified personnel	During movement of detector train or during maintenance
Fall	Fall protection system, training, PPE	During calorimeter servicing

Risks/Opportunities

Event description	Probability / year (%)	Date risk could be retired	Technical Impact	Response	M&S Cost Impact (k$)	FTE Cost impact (FTE)	Schedule Impact (weeks)	Mitigation(s)	Notes
Calorimeter full system to be tuned beyond KPP	10%	After Detector KPP	Noisy/dead channels, swapped cables	Replace SiPM/FEE/boards, correct cable connections	$20k	0	2 weeks	Spares and trained personnel available	Cost includes replacement of ~25 (2%) readout channels (2 SiPMs+2 FEE), 2 DIRAC+MEZZANINE boards
Irradiation larger than expected	20%	Never	SiPM, FEE boards damaged	Replace damaged components	$80k	3	3 weeks	Spares and trained personnel available	Full replacement of innermost ring of disk0 (~100 channels). Easier than random replacement (see previous risk)
Inadequate cooling of detector	5%	Never	SiPM dark current too high	Decrease HV working point	0	1	1 week	Tune chiller working point	
Laser fiber coating damaged during disk movements, maintenance	10%	Never	Deterioration of light tightness	Replace broken fiber	0	2	1 week	Skilled personnel, no light inside DS	Spare bundles up to final distribution system, spare fibers in bundles to crystals
Pile-up in crystals larger than expected	10%	Never	Reduced cluster capabilities in innermost region	Study pile-up algorithm using two independent laser sources	$14k	2	4 weeks	Perform pile-up MC studies, reduce beam intensity	Cost of an additional laser head
Leak in the Cooling System inside DS	1%	Never	DS vacuum level compromised	Extract detector train, clean and repair the circuit	$10k	1	4 weeks	Check leaks before operating in vacuum, safety system emptying cooling circuit if pressure drops down, coolant safe for detectors, quick evaporating	Cost includes crate lines and pipes. Impact does not include extraction/insertion of detector train (see next risk for this)
Leak in the Source System inside DS	<0.1%	Never	DS vacuum level compromised	Extract detector train to let the coolant evaporate	$79k	0,5	6 weeks	Check leaks before operating in vacuum, source circuit empty while not calibrating, coolant safe for detectors, quick evaporation	Small leaks, vacuum not compromised: source calibration will not be performed until the next planned shutdown. Cost is extract/insert detector train

Summer shutdown: working assumption

- For the first summer shutdown, we assume that we will extract the detector train to perform maintenance on the tracker and calorimeter
  - Requires considerable resources in Facilities, CRV, and STM to extract detector train and insert detector train
    - … in addition to the work by the Tracker and Calorimeter
  - Nominal summer shutdown is 12 weeks, so this is also a useful exercise to understand the durations needed for these task



Mu2e Detector & Computing Ops: total effort

Mu2e DETECTOR AND COMPUTING OPS EFFORT		Begin prep for beam after KPP (**partial FY**)	Prepare for beam	Comm w/beam + physics Y1 + summer Y1	From docdb-32497
		FY22	FY23	FY24	Notes
SUBTOTALS		*13.9*	*33.4*	*23.8*	excluding shifts
	Engineer	1.7	5.5	4.9	
	Technician	5.2	14.9	7.0	
	Other	2.5	4.3	2.6	
	Scientist	4.5	8.7	9.2	
	Scientist (uncosted)	18.5	25.9	27.1	excluding shifts
Shifts		*4.8*	*4.8*	*4.8*	costed subtotal
	Operations shifter	4.8	4.8	4.8	1 shifter 24/7
	Exp Shifter (uncosted)	1.0	9.5	9.5	2 shifters 24/7 starting in Q2 FY23
TOTALS					including shifts
	TOTAL costed effort (FTE)	*18.7*	*38.2*	*28.5*	
	TOTAL uncosted effort (FTE)	*19.5*	*35.4*	*36.7*	
	TOTAL Scientist effort (FTE)	*24.0*	*44.1*	*45.9*	scientists (costed + uncosted + shifts)
	TOTAL effort (FTE)	*38.2*	*73.6*	*65.2*	

- In this table “Uncosted” effort = comes from the collaboration
  - Labeled in green
  - Total includes needed operations effort, including shifts

Physics running: working shift model

- Working model assumes that steady-state running of the experiment is done with a central shift crew + subsystem on-call experts
  - Shift model to be discussed with collaboration
- Solenoid strategy: once magnets are cold, goal = keep them cold
  - 1x Operations shifter 24/7
- Experiment strategy: central shifters + subsystem on-calls
  - 2x Experiment shifters 24/7 in ROC 1W when taking data
  - 1x on-call per subsystem when system powered
  - 2x Run Coordinators (one primary, one secondary)
  - In prelim ops plan, experiment shifts start with cosmic rays during Prepare for Beam… subsystems expected to join as soon as they are ready
- Computing: processing, data quality, and calibration/alignment
  - 1x Data Processing on-call
  - 1x DQM monitor per subsystem
  - 1x Calibration + alignment monitor per subsystem

Summary of outcome of review

- Closeout presentation: one recommendation and several comments
- Recommendation: "Apply the same methodology used by the Detector and Computing Operations team for cost escalation to the Accelerator Operations scope and update the operations plan to include detailed budget data before the next operations review."
- Some comments snippets
  - "Levels of management reserve and baseline uncertainties consistent with the expectations of a preliminary operations plan. It is important to continue a conservative approach to contingency in the development of the detailed operational plan."
  - "… more emphasis on development of the trigger in future reviews"
  - "… the role… of non-lab personnel in the main phases of work could be more clearly defined and specified"
  - "Magnetic fringe fields… will introduce hazards at levels that are unfamiliar to many of the staff and users of the facility… Care should be taken to ensure that all persons who enter the building are trained to understand the potential hazards. This is especially important for students and new employees. In addition, policies and procedures should be developed to rigorously control loose ferromagnetic materials in the vicinity of the solenoids."
- We interpret the closeout report as an endorsement of Mu2e Ops planning procedure