Off Project Installation, KPPs and Scope Contingency

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Off-Project Installation

- The solenoid fields are specified at the percent level. Fields must be validated to this level as part of acceptance criteria.
- To achieve the momentum resolution required to obtain the best possible physics results, the field in the tracker region must be known to high precision.
  - High-precision, fine-grained field maps required at 100%, 70% and 50% of nominal field strength.
  - High precision map is performed off-project. Not required to satisfy KPPs
  - Will take several months.
  - Detectors cannot be installed inside DS while mapping is being performed.
  - Downstream neutron shielding/Cosmic Ray Veto Counters cannot be in the way either
    - Final insertion of detectors inside DS is off-project.

Off-Project Installation

- To optimize transmission of muons to the stopping target and to properly simulate muon transmission, the field lines in the PS and DS must be optimized and known.
  - Some adjustability of coils built into TS design
- Not necessary to satisfy KPPs.
- To map out the PS/TS field lines and to optimize transmission, a movable electron source will be placed at the location of the production target.
- Production target, pbar window, stopping target, neutron shielding, CRV cannot be in place during test.
  - Neutron shielding and CRV preclude TS coil adjustment.
  - Implies that these are all installed off-Project.

Off-Project Installation

- To summarize, once the precision measurements of the solenoid fields have been completed, the following activities remain before the apparatus is ready for beam.
  - Insertion of stopping target, proton absorber, Tracker, Calorimeter into DS
  - Installation of Stopping Target Monitor downstream of DS.
  - Installation of pbar window(s)
  - Installation of production target
  - Installation of vacuum system endcap enclosures
  - Installation of neutron shielding around TS and DS
  - Installation of CRV.
  - Installation of shield blocks in hatches
  - Commissioning of detector in vacuum.

Off-Project Installation

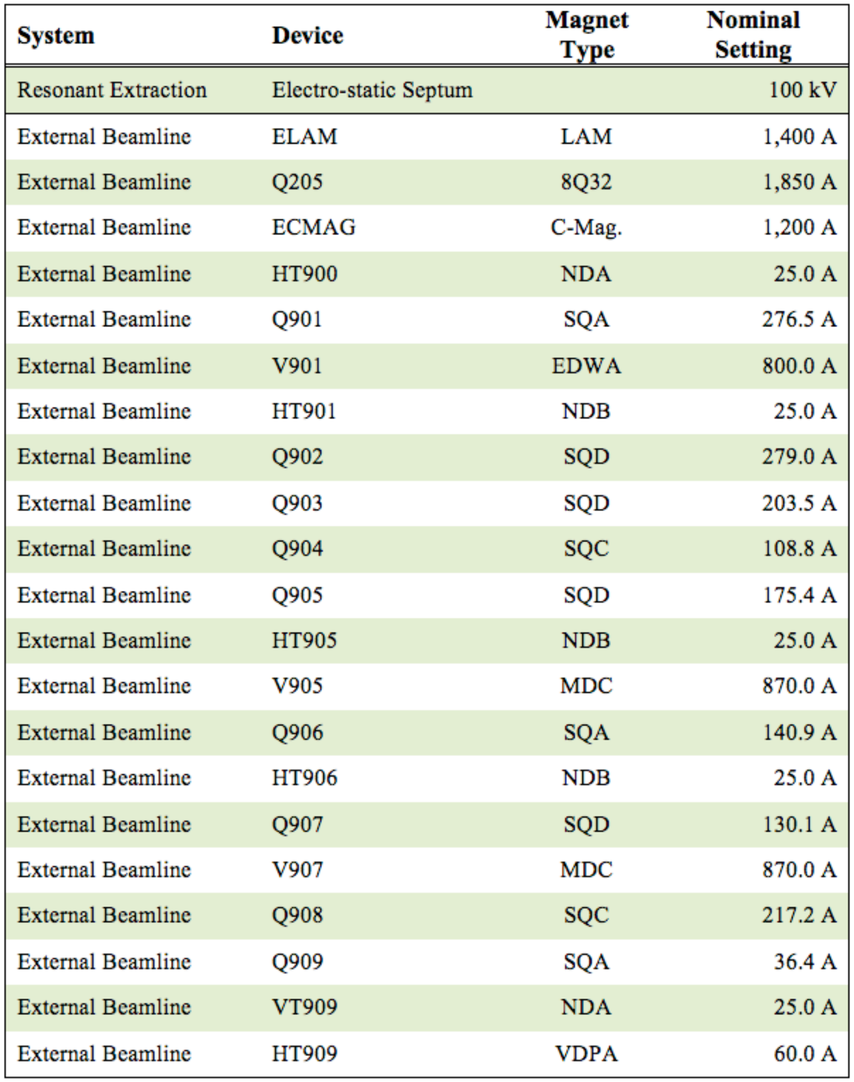
- These activities will take > 1 year.
- Accelerator commissioning to the diagnostic beam dump can proceed in parallel with these activities.
- Operations schedule with links to project schedule developed in P6 (but not costed as part of Project)

KPPs

Key Parameters	Threshold Performance	Objective Performance	Comments
Accelerator	All accelerator components, RF and resonant extraction components are installed and tested at nominal voltages and currents. All target station components are complete, delivered to Fermilab and tested. Heat and Radiation Shield is installed in Production Solenoid. Other components are ready to be installed after field mapping. Shielding designed for 1.5 kW operation delivered.	Protons are delivered to the diagnostic absorber in the M4 beamline. Shielding designed for 8 kW operation delivered.	Delivery of beam is beyond the control of the Project, so it must be an Objective parameter. In addition, there are various program planning issues associated with g-2 running and accelerator shutdowns that impact delivery of beam to Mu2e. Running at 1.5 kW eliminates the need for heavy concrete shielding.

Objective KPPs assume that Threshold KPPs have been met.

Accelerator Component Parameters for Accelerator Threshold KPP



System	Device	Magnet Type	Nominal Setting
Resonant Extraction	Electro-static Septum		100 kV
External Beamline	ELAM	LAM	1,400 A
External Beamline	Q205	8Q32	1,850 A
External Beamline	ECMAG	C-Mag.	1,200 A
External Beamline	HT900	NDA	25.0 A
External Beamline	Q901	SQA	276.5 A
External Beamline	V901	EDWA	800.0 A
External Beamline	HT901	NDB	25.0 A
External Beamline	Q902	SQD	279.0 A
External Beamline	Q903	SQD	203.5 A
External Beamline	Q904	SQC	108.8 A
External Beamline	Q905	SQD	175.4 A
External Beamline	HT905	NDB	25.0 A
External Beamline	V905	MDC	870.0 A
External Beamline	Q906	SQA	140.9 A
External Beamline	HT906	NDB	25.0 A
External Beamline	Q907	SQD	130.1 A
External Beamline	V907	MDC	870.0 A
External Beamline	Q908	SQC	217.2 A
External Beamline	Q909	SQA	36.4 A
External Beamline	VT909	NDA	25.0 A
External Beamline	HT909	VDPA	60.0 A

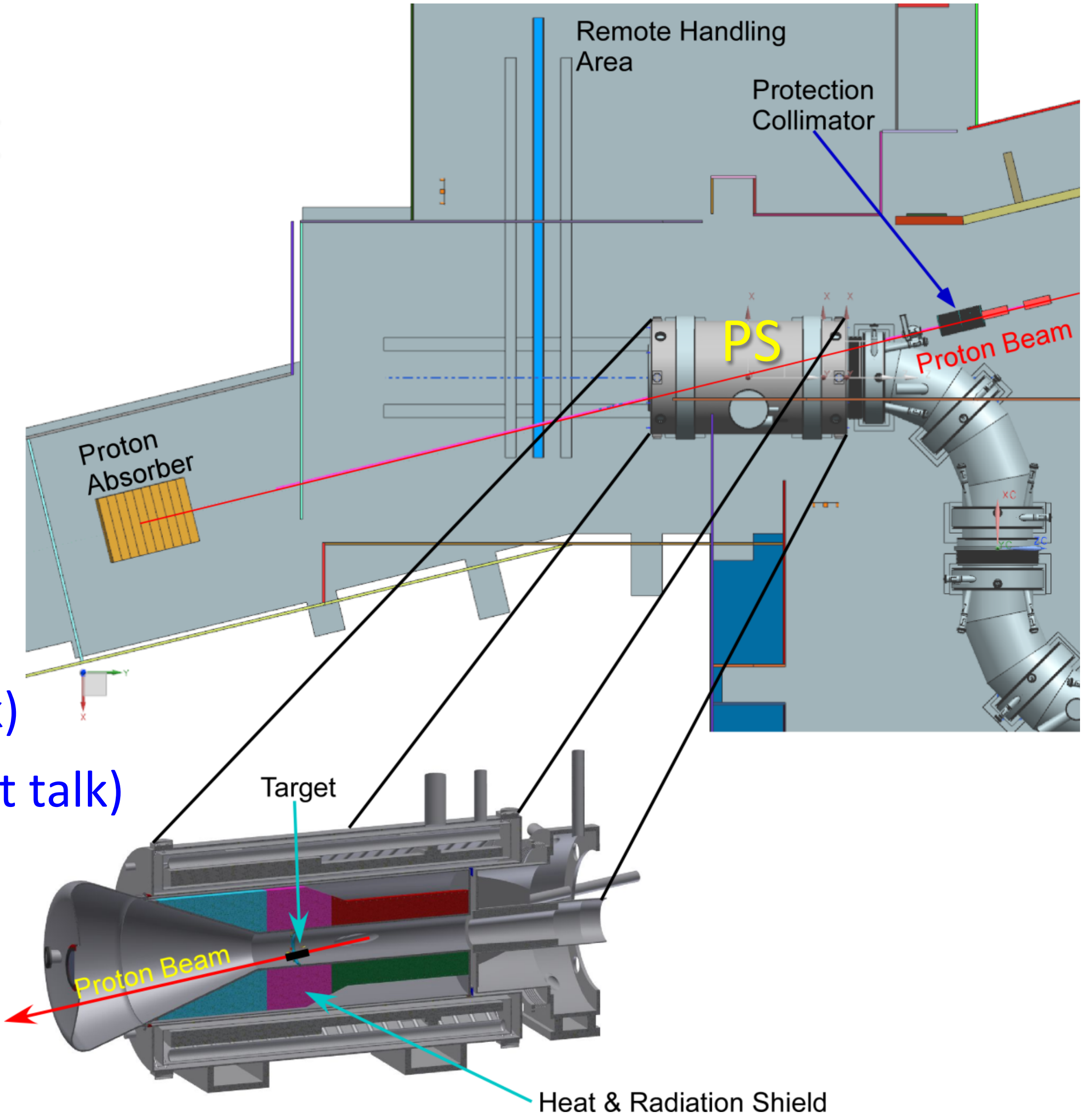
Full Table (nearly 4 pages) appears in docdb # 4665.

Target Station

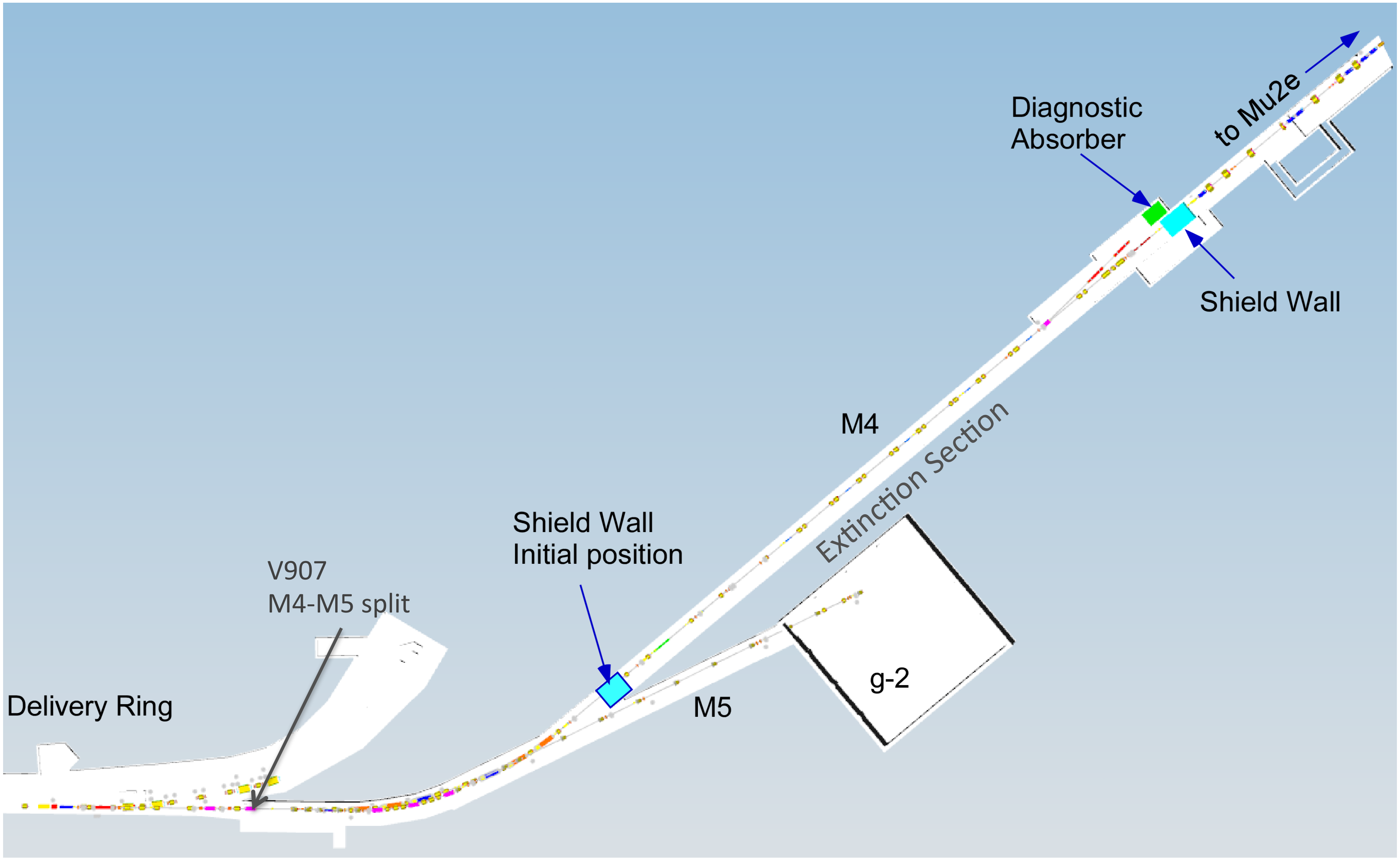
Target Station Layout

There are four requirements documents governing target station components.

- Target
- Heat & Radiation Shield (HRS)
- Proton Absorber (breakout talk)
- Protection Collimator (breakout talk)



Diagnostic Dump



KPPs

Key Parameters	Threshold Performance	Objective Performance	Comments
Superconducting Solenoids	The Production, Transport and Detector Solenoids have been cooled and powered to the settings necessary to take physics data.	The Production, Transport and Detector Solenoids have been cooled and powered to their nominal field settings.	The threshold parameter is adequate to take physics data, though perhaps not fully optimized.
Detector Components	Cosmic ray tracks are observed in the full Tracker, full Calorimeter and a subset of the Cosmic Ray Veto and acquired by the Data Acquisition System after they are installed in the garage position behind the DS. Balance of CRV counters are at Fermilab and ready for Installation.	The cosmic ray data in the detectors is acquired by the Data Acquisition System, reconstructed in the online processors, visualized in the event display and stored on disk.	Online reconstruction algorithms are designed for spiraling tracks while cosmic rays are straight. May require some specialized code. Work done by uncosted scientists. The Cosmic Ray Veto is installed off project after all field mapping is complete. Only a few modules would be used to satisfy the KPPs.

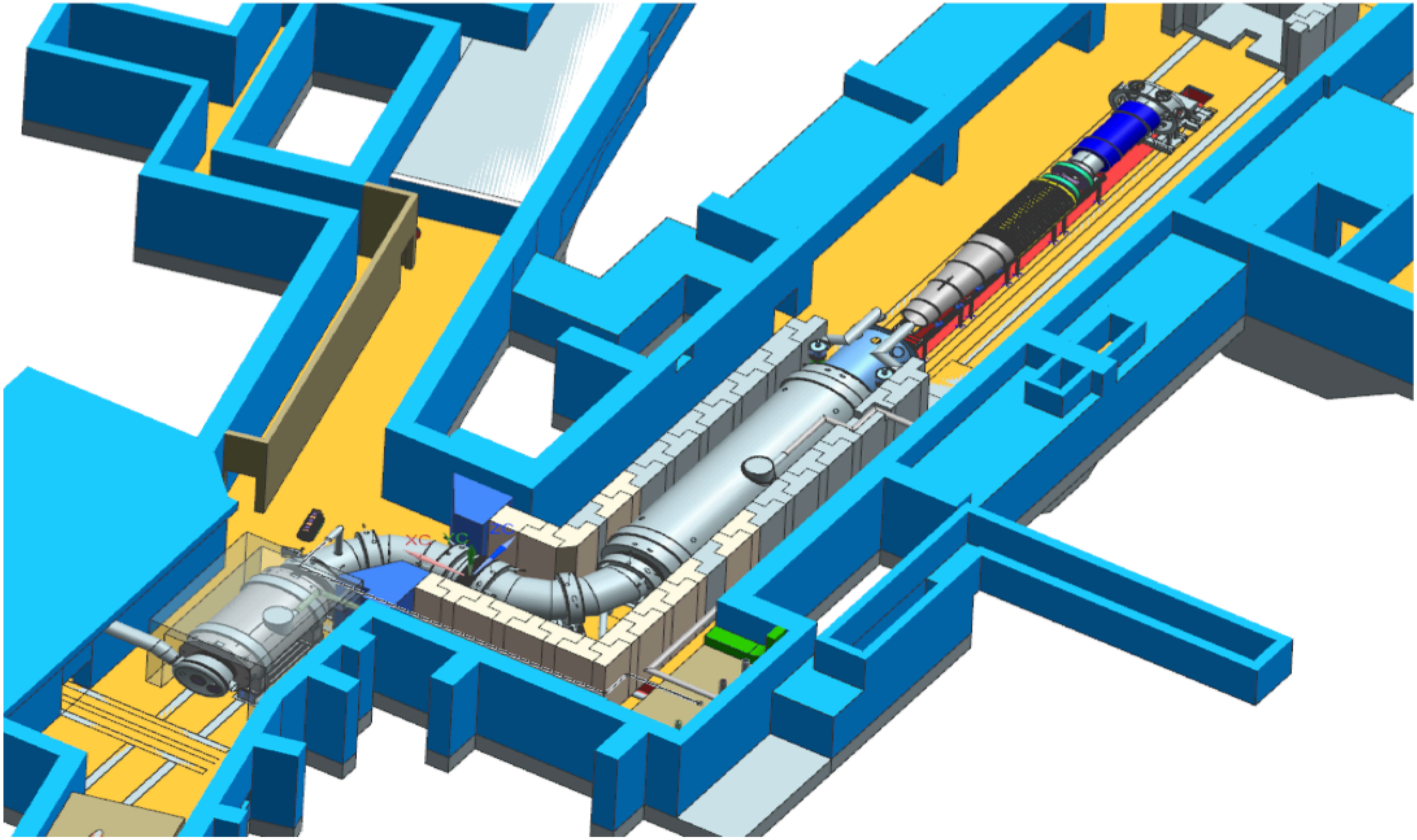
Objective KPPs assume that Threshold KPPs have been met.

Nominal Solenoid Field Settings for Solenoid Objective KPP

Region	Length (m)	s_{min} (m)	s_{max} (m)	$B_{initial}$ (T)	B_{final} (T)	Measurement Position
PS1	1.5	-10.6	-9.08	> 4.5 T at s = 9.4m	N/A	No local minimum
PS2	2.5	-9.08	-6.58	n/a	2.5	dB/B < 0.05 about a uniform negative axial gradient from the peak field in PS1 to the TS1 $B_{initial}$ field.
TS1	1	-6.58	-5.58	2.5	2.4	dBs/ds <-.02 T/m
TS3	1.95	-0.98	0.98	2.4	2.1	dBs/ds <-.02 T/m
TS5	1	5.58	6.58	2.1	2	dBs/ds <-.02 T/m
DS1 Gradient	3	6.58	9.58	2	1.18	|dB/B| < 0.05, dBs/ds = -0.25+/- 0.05 T/m,
DS2 Transition	1.2	9.58	10.78	1.18	1	Gradient decreasing
DS3 Uniform	3.6	10.78	14.39	1	1	|dB/B| < 0.01, dBs/ds negative
DS4 Uniform	1.5	14.39	15.85	1	1	|dB/B| < 0.05, dBs/ds negative

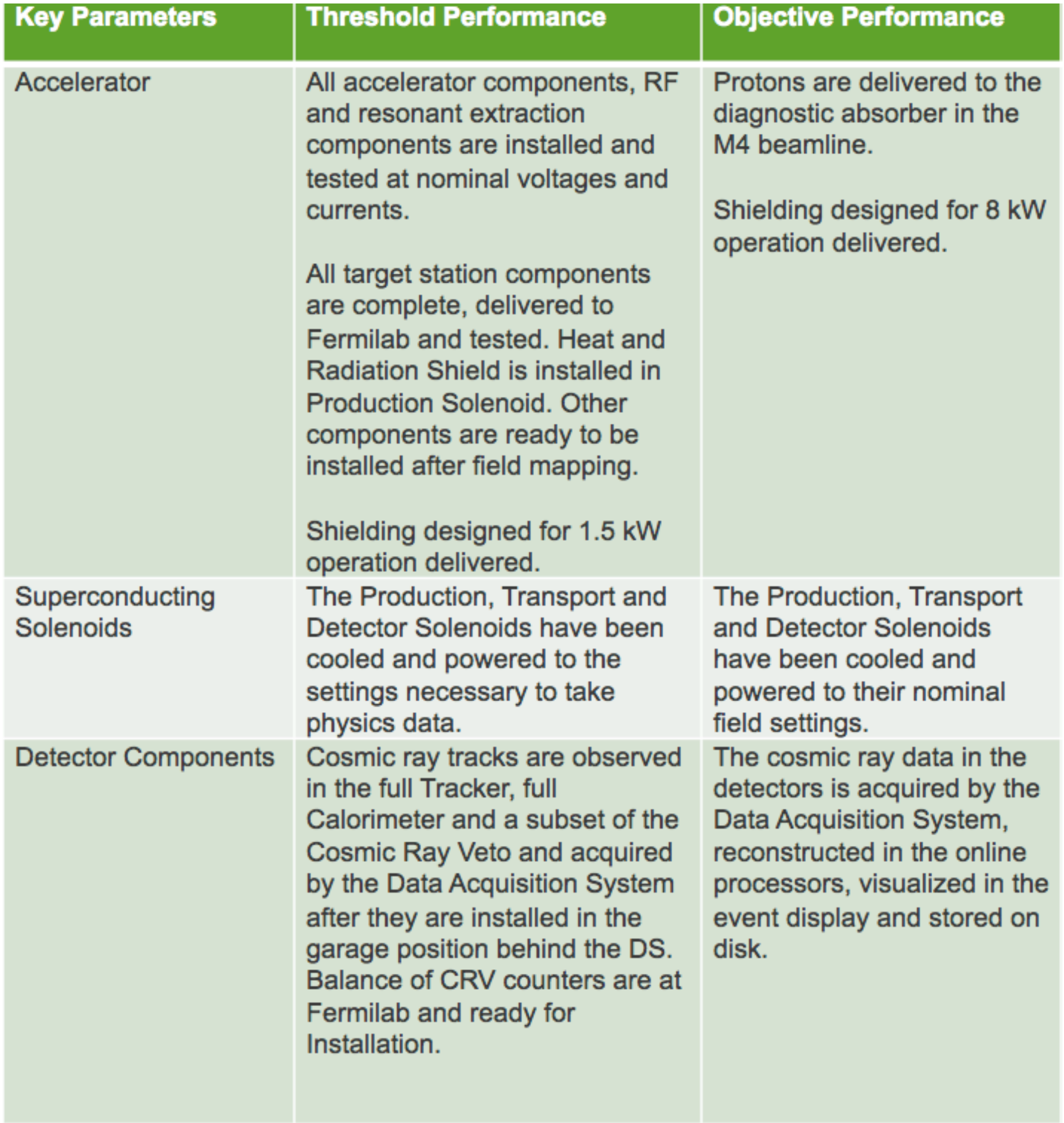
From docdb # 4665.

Garage Position



Scope Contingency

- Difference between Threshold and Objective KPPs represent scope contingency.

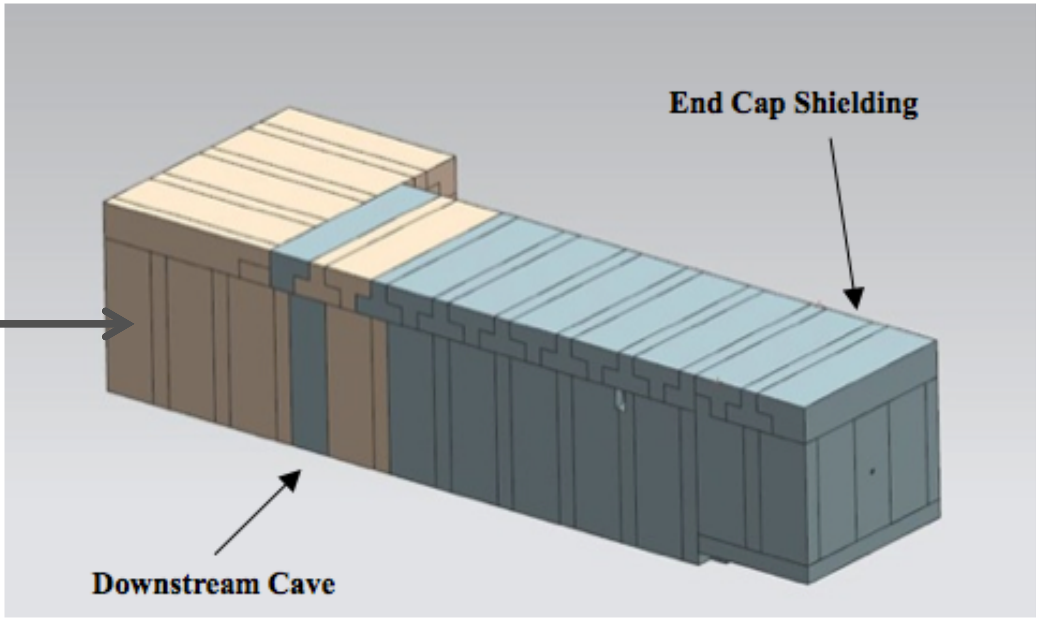


Key Parameters	Threshold Performance	Objective Performance
Accelerator	All accelerator components, RF and resonant extraction components are installed and tested at nominal voltages and currents. All target station components are complete, delivered to Fermilab and tested. Heat and Radiation Shield is installed in Production Solenoid. Other components are ready to be installed after field mapping. Shielding designed for 1.5 kW operation delivered.	Protons are delivered to the diagnostic absorber in the M4 beamline. Shielding designed for 8 kW operation delivered.
Superconducting Solenoids	The Production, Transport and Detector Solenoids have been cooled and powered to the settings necessary to take physics data.	The Production, Transport and Detector Solenoids have been cooled and powered to their nominal field settings.
Detector Components	Cosmic ray tracks are observed in the full Tracker, full Calorimeter and a subset of the Cosmic Ray Veto and acquired by the Data Acquisition System after they are installed in the garage position behind the DS. Balance of CRV counters are at Fermilab and ready for Installation.	The cosmic ray data in the detectors is acquired by the Data Acquisition System, reconstructed in the online processors, visualized in the event display and stored on disk.

Scope Contingency

Reduction of instantaneous beam intensity by a factor of 5 allows substitution of regular concrete for heavy concrete shielding – Threshold KPP.

- Shielding is not procured until FY19.
- Saves ~$3M. Can replace regular concrete with heavy concrete at a later date.



Light colored blocks are heavy concrete

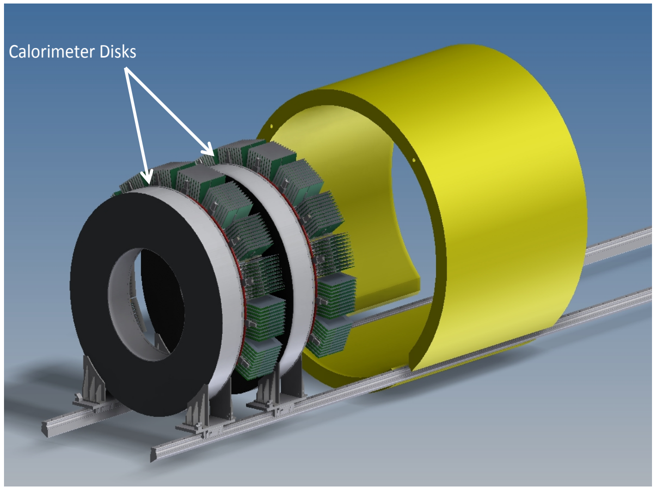
B-Fields, how good is good enough?

- At 4.6 T, PS conductor has a 30% current margin (ie.I_{op}/I_c ~0.7), 1.5K temp. margin when beam is hitting target.
- Our stopped-μ yield deceases by ~10% if peak field is only 4.1 T instead of 4.6 T.
- TS conductor has a 55% current margin, 2K temperature margin.
- Studies have been performed scaling the PS, TS fields
  - Mu2e-docdb-652
  - Stopped-muon yield scales roughly linearly with peak PS field
  - More an issue of run-time than success/failure of experiment
  - Trim power supplies can be connected to the TS to optimize the field

B-Fields, how good is good enough?

- DS conductor has a 50% current margin, 2K temperature margin
  - Least risky magnet. Lowest field and lowest radiation environment.
- Can tolerate a 10% reduction in our DS field in the region of the tracker with no significant impact on experiment sensitivity.
  - Acceptance and background rates have been checked and are OK.
- Margin in magnetic field configuration required to do physics (Threshold KPP) provides technical scope contingency relative to nominal field requirements (Objective KPP).

Additional Scope Contingency



One calorimeter disk could be eliminated, deferred or provided by another agency or International partner.

- Impacts acceptance but not data quality
- No impact on KPPs
- Saves ~$4M
  - Reduces acceptance by almost a factor of 2.
  - Second disk could be added later.
    - We could decide as late as April 2018 to purchase balance of crystals and APDs without impacting schedule.
    - In the meantime we could look for additional partners to fund the second disk.
  - Downside – Impacts important university partner (Caltech)

Additional Opportunities to Reduce DOE Scope

Outside agencies/International partners like to fund detector systems

- Extinction Monitor (~$1M)
  - Downstream Monitor required by experiment
  - NIU is asking NSF to fund this.
- Stopping Target Monitor (~$0.5M)
- Calorimeter disk (~$4M)
- The later two cases provide additional opportunities to bring in more Universities and/or International partners. Discussions underway with potential International partners on both fronts.

Potential Cost Savings

- We could outsource more detector work to Universities
  - Final tracker assembly, Tracker electronics, CRV photosensors and electronics
  - Brings in more universities and reduces cost (~$1M)
- May be able to use CsI (pure) crystals instead of BaF2
  - Saves $1.5M
  - This is under study, with a final technology decision scheduled for spring of 2015.
- >$4M for Technical Documentation in Accelerator Subsystem
  - This is a Lesson Learned from NOvA, but it still seems high, so we will review this.

Potential Cost Savings

Bottom Line:

- Between scope contingency, possible reductions in DOE scope and potential cost savings we could generate up to $10M of additional contingency
  - Increase contingency from $53M to $63M.
  - Scope contingency decisions can be made late
  - Other opportunities will be pursued over the next year.
    - Some of these efforts are already underway