Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

M4 Magnets and Mechanical Systems

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10/6/2015

Outlook

- Beamline Overview
- Magnet Selection
- Beamline Vacuum
- Beamline LCW
- Beamline Diagnostic Absorber
- Beamline Fixed Magnet Supports
- Beamline Target Scans
- Beamline Commissioning

Scope of Beamline Design

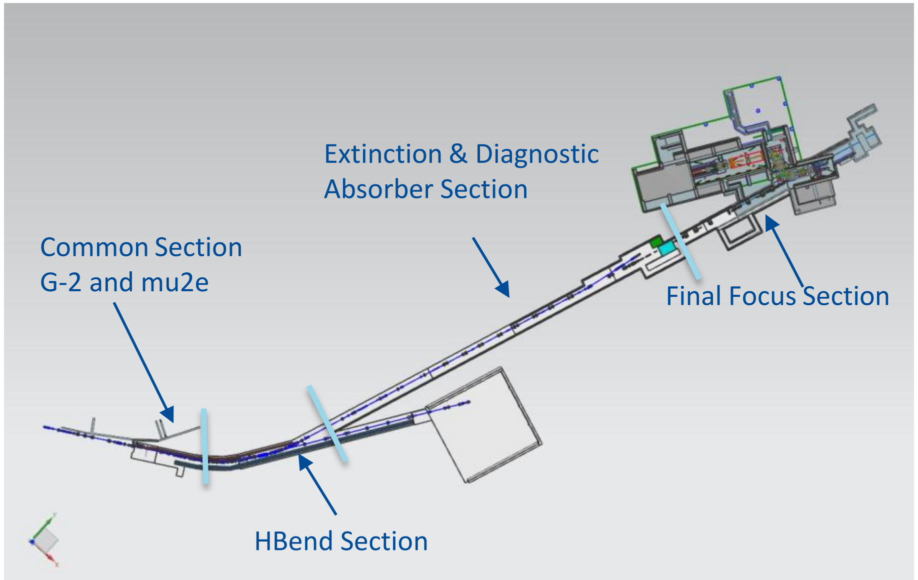
Scope of the External Beamline work includes all the design and implementation including the following areas:

- Beamline Optics/Lattice
- Magnets
- Magnet power supply
  - Power supplies
  - Power supply controls
  - Bus or Cabling
  - Infrastructure or Distribution Power.
- Mechanical Systems including:
  - Beamline vacuum
  - Beamline Low Conductivity Water (LCW or cooling water system)
  - Magnet Supports
  - Beam Stops
- Diagnostic Absorber
- Installation of all these devices

- Just for scale, of this portion of the project it is **$ 9.1M** of ($50.1M for Accelerator) and ($271M for Total Mu2e Project)

	M&S	Labor	Total	Estimate Uncertainty (on remaining budget)	% Contingency (on remaining budget)	Total Cost
475.02.07.01 External Beamline Magnets		238	238	42	30%	280
475.02.07.02 External Beamline Magnet Power Supplies		198	198	22	30%	220
475.02.07.03 External Beamline Mechanical & Vacuum Systems		373	373	36	33%	409
475.02.07.04 External Beamline Diagnostic Absorber	26	65	91		0%	91
475.02.07.05 External Beamline Optics		199	199	38	32%	237
475.02.07.06 Oversight and Technical Documentation		517	517	70	22%	587
475.02.07.07 Implementation	3,387	2,237	5,624	1,622	29%	7,245
Grand Total	3,412	3,827	7,240	1,830	29%	9,069

Mu2e Section of the M4 Beamline



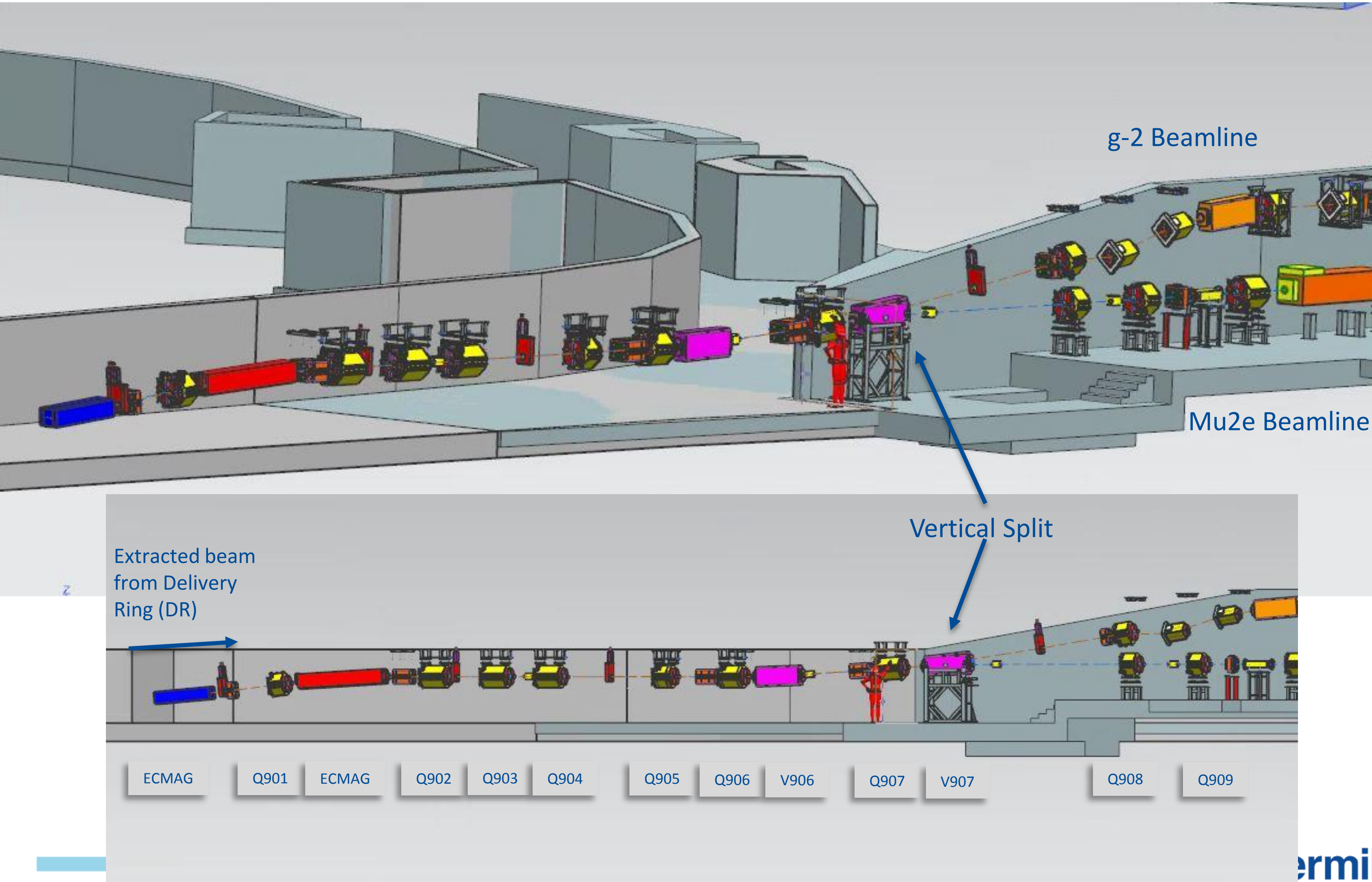
The beamline is broken into 4 distinct sections for beam function & installation.

Part of the M4 beamline is shared with g-2. Split is at 908. Mu2e will be responsible for on the cost of installation of the M4 beamline from 908 to 943.

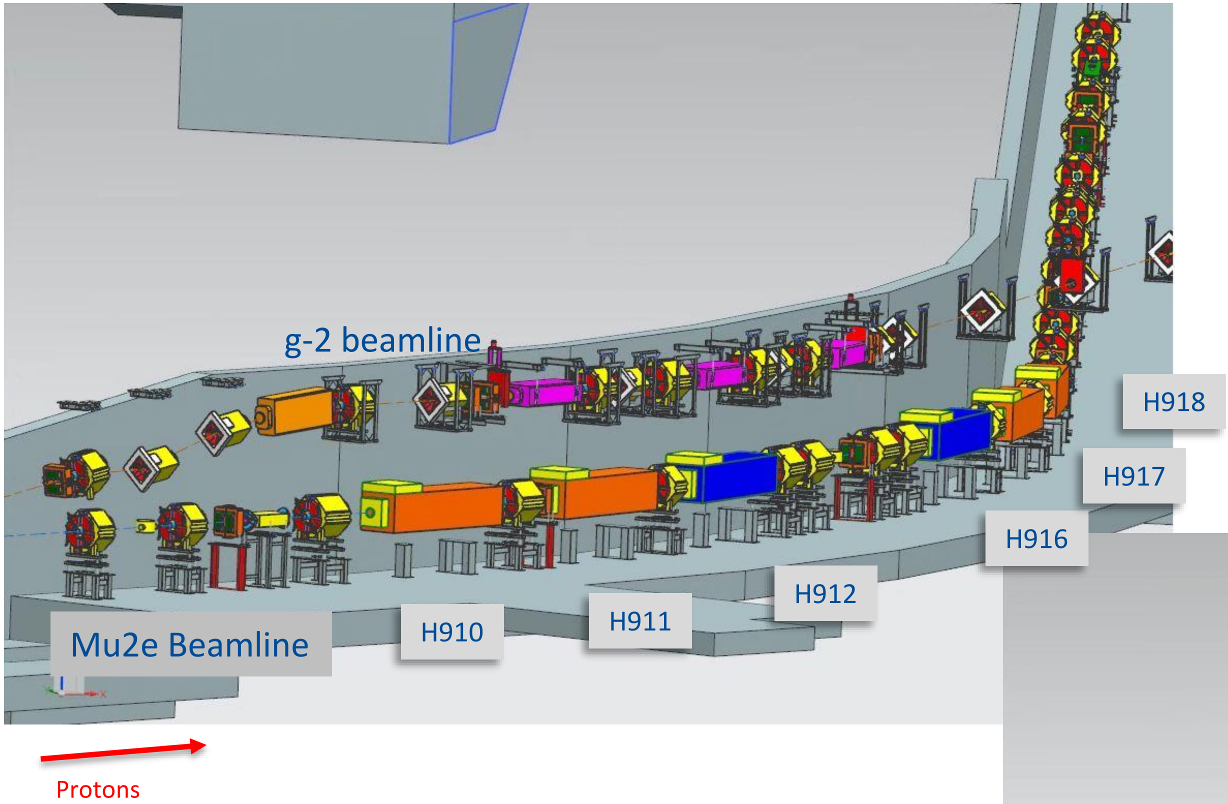
Installation will includes all magnets, magnet supports , main & trim power supplies, vacuum system & controls, LCW and compressed air for tunnel and Mu2e building as well as two beam stops.

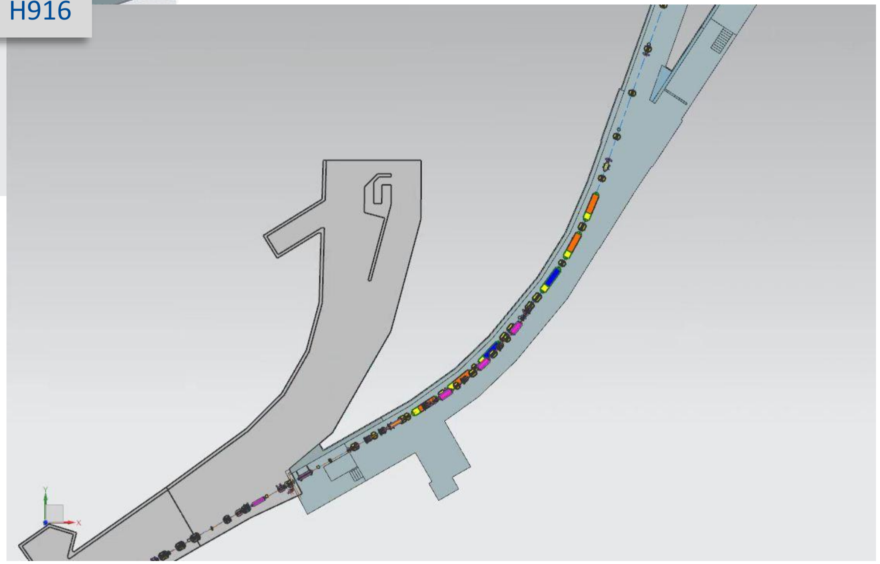
The schedules have pushed together so that g-2 running will overlap Mu2e installation 2017 - 2019

The g-2 and Mu2e Common Section



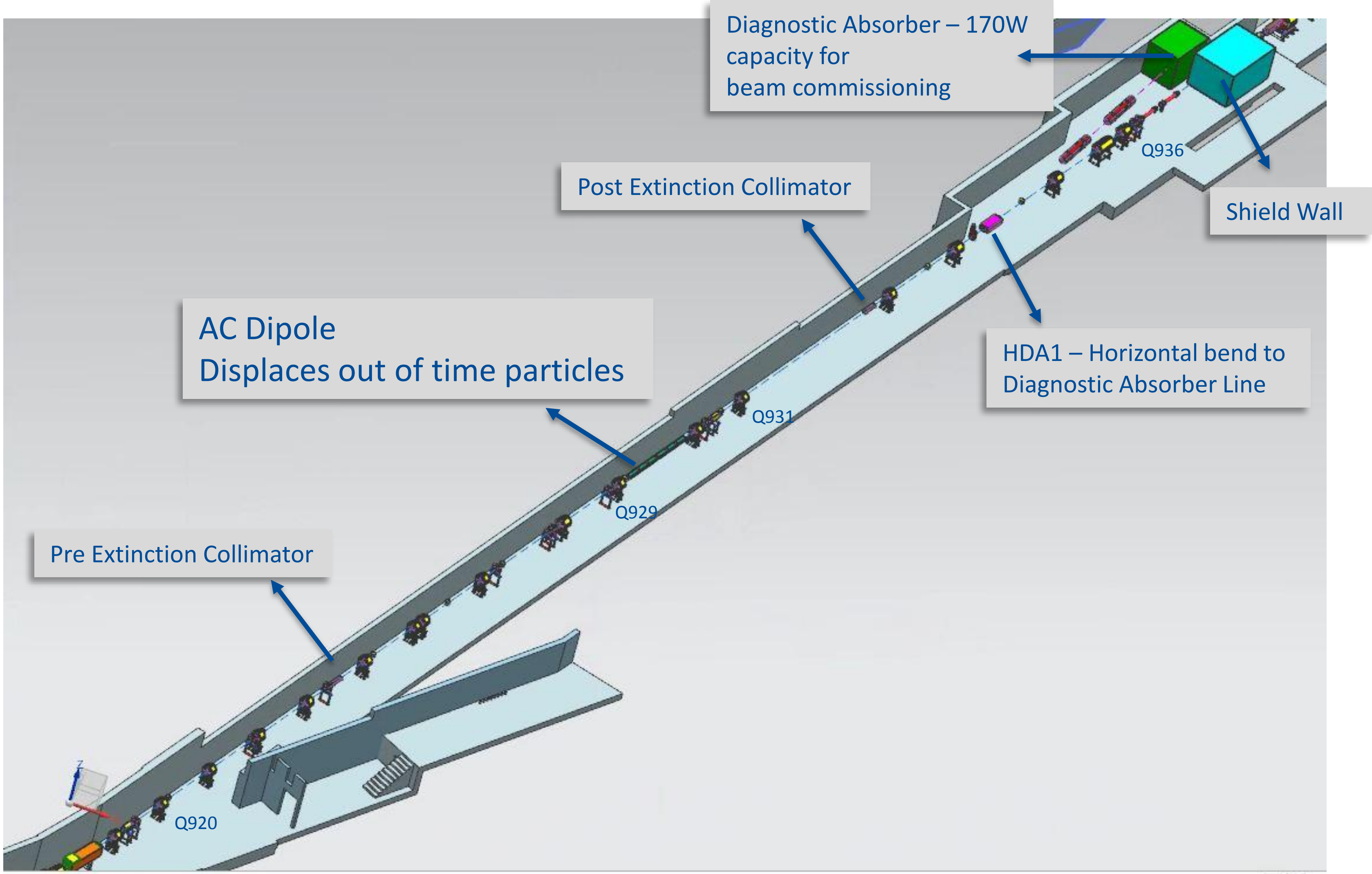
The Horizontal Left Bend Section



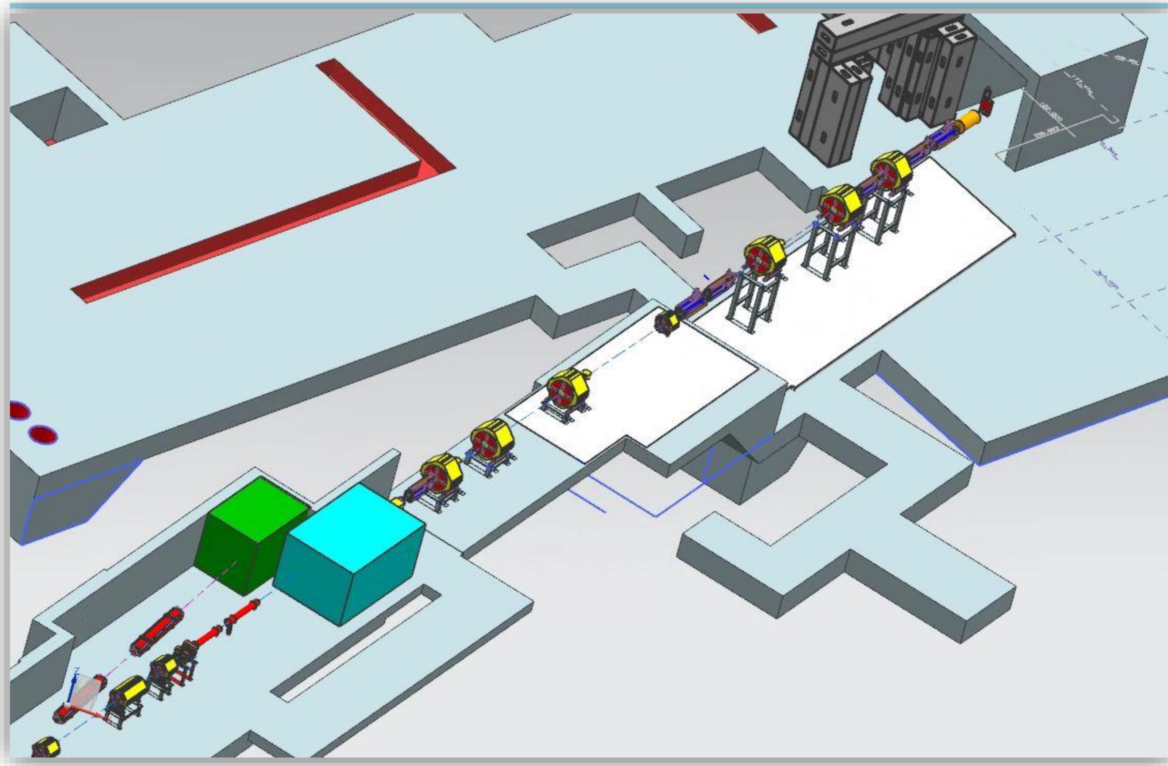


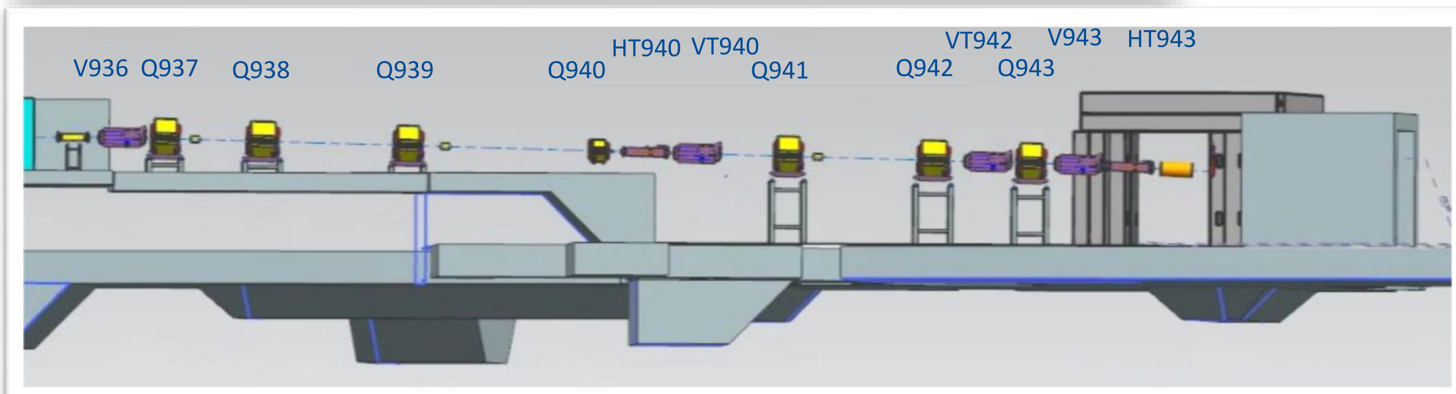
Left bend section use 4 SDFW and 2 SDF dipoles to Bend beam 41° to the mu2e target.

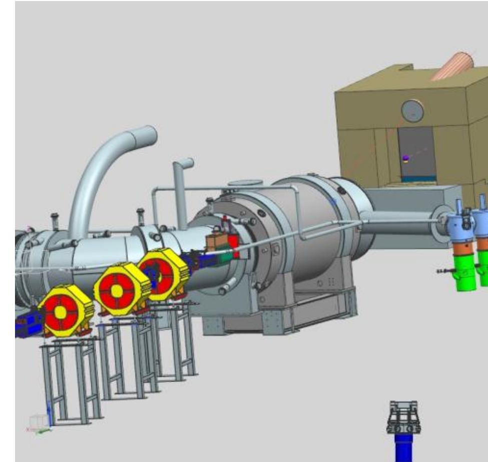
The Extinction & Diagnostic Absorber Section

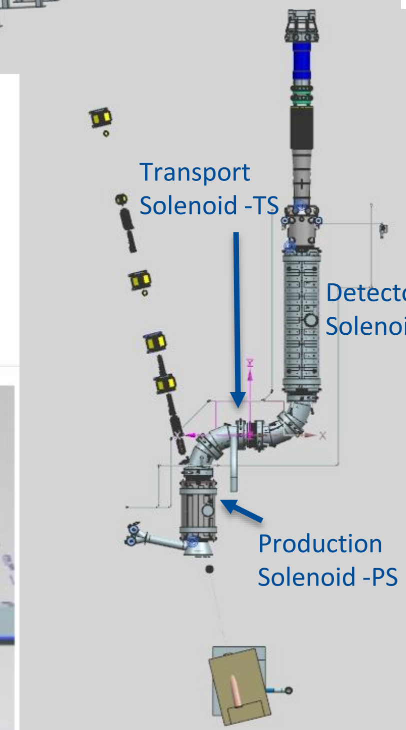


The Final Focus Section









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Magnet Selection

Requirements:

- To save cost, magnets were to be reused from the Antiproton Source where possible.
- All magnets repurposed from the Antiproton Source where considered working spares with no need to rebuild or refurbish unless stated.
- Since the pool of magnets is limited, there may be a need to fabricate new magnets of the same type.
- Using magnets outside of the Antiproton Source pool may require refurbishment or rebuilding assessed on a case by case.

beamline: M4

Row Labels	Count of Magnet
Repurpose	**62**
3Q120	2
LQC	4
LQD	2
NDA	15
NDB	3
SDF	2
SDFW	4
SQA	18
SQB	4
SQC	3
SQD	4
SQE	1
Fabricated	**1**
MDC	1
Refurbished	**6**
CDA	6
Grand Total	**69**

M4 beamline proper

beamline: M4/M5

Row Labels	Count of Magnet
Repurpose	**15**
8Q24	1
EDWA	1
MDC	2
NDA	1
NDB	3
SQA	2
SQC	1
SQD	4
Fabricated	**2**
C-Mag.	1
LAM	1
Grand Total	**17**

Combined g-2 & mu2e beamline

Beamline Magnet Type, Current , Bussing, Field

Magnet	Type	Current (A)	Power Supply	Integrated Field (T)
ELAM	**LAM**	**1,400**	**D:ELAM**	
Q205	8Q24	2,318 (1,138)	D:QT205	
ECMAG	**C-Mag.**	**1,200**	**D:ECMAG**	
HT900	NDA	25.0 A	D:HT900	
Q901	SQA	324.2 A	D:Q901	-6.05
V901	**EDWA**	**800**	**D:V901**	
HT901	NDB	25.0 A	D:HT901	
Q902	SQD	212.6 A	D:Q902	7.268
Q903	SQD	226.3 A	D:Q903	-7.73
Q904	SQD	250.7 A	D:Q904	8.555
Q905	SQA	72.8 A	D:Q905	-1.39
HT905	NDB	25.0 A	D:HT905	
Q906	SQC	181.2 A	D:Q906	-5.292
HT906	NDB	25.0 A	D:HT906	
V906	**MDC**	**870**	**D:V906**	
Q907	SQD	160.6 A	D:Q907	5.507
V907	**MDC**	**870**	**D:V907**	
Q908	SQA	273.6 A	D:Q908	-5.156
Q909	SQA	213.7 A	D:Q909	-4.053
VT909	NDA	25.0 A	D:VT909	
HT909	NDA	60.0 A	D:HT909	
Q910	SQC	210.7 A	D:Q910	6.15
H910	**SDFW**	**805**	**D:H910**	
Q911	SQC	202.6 A	D:Q911	-5.916
VT911	NDA	25.0 A	D:VT911	
H911	**SDFW**	**805**	**D:H910**	
Q912	SQA	186.7 A	D:Q912	3.547
H912	**SDF**	**805**	**D:H910**	
Q913	SQD	321.2 A	D:Q913	10.862
Q914	SQD	287.2 A	D:Q914	-9.762
VT914	NDA	25.0 A	D:VT914	
Q915	SQD	287.2 A	D:Q914	-9.762
Q916	SQD	321.2 A	D:Q913	10.862
H916	**SDF**	**805**	**D:H910**	
Q917	SQA	186.7 A	D:Q912	3.547
H917	**SDFW**	**805**	**D:H910**	
Q918	SQC	202.6 A	D:Q911	-5.916
H918	**SDFW**	**805**	**D:H910**	
Q919	SQA	187.0A	D:Q919	3.552

Magnet	Type	Current (A)	Power Supply	Integrated Field (T)
HT919	NDA	25.0 A	D:HT919	
VT919	NDA	25.0 A	D:VT919	
Q920	SQA	187.0 A	D:Q919	-3.552
Q921	SQA	187.0 A	D:Q919	3.552
VT921	NDA	25	D:VT921	
Q922	SQA	187.0 A	D:Q919	-3.552
Q923	SQA	187.0 A	D:Q919	3.552
VT923	NDA	25.0 A	D:VT923	
Q924	SQA	173.8 A	D:Q924	-3.303
Q925	SQA	115.3 A	D:Q925	2.195
Q926	SQA	107.8 A	D:Q926	-2.053
Q927	SQA	107.8 A	D:Q927	2.052
HT927A	NDA	25.0 A	D:HT927A	
HT927B	NDA	25.0 A	D:HT927B	
VT927	NDA	25.0 A	D:VT927	
Q928	SQB	203.5 A	D:Q928	-5.387
HT928	NDB	25.0 A	D:HT928	
Q929	SQA	142.5 A	D:Q929	2.713
Q930	SQA	154.9 A	D:Q930	2.947
HT930	NDB	25.0 A	D:HT930	
VT930	NDB	25	D:VT930	
Q931	SQA	188.7 A	D:Q931	-3.585
Q932	SQA	109.8 A	D:Q932	-2.091
Q933	SQB	253.8 A	D:Q933	6.706
VT933	NDA	25.0 A	D:VT933	
HDA1	***MDC***	***1,165***	***D:HDA1***	
QDA01	*3Q120*	*80.0 A*	*D:QDA01*	
QDA02	*3Q120*	*80.0 A*	*D:QDA02*	
Q934	SQB	192.2 A	D:Q934	-5.091
Q935	SQE	201.6 A	D:Q935	10.93
Q936	SQB	273.5 A	D:Q936	-7.212
VT936	NDA	25.0 A	D:VT936	
HT936A	NDA	25.0 A	D:HT936A	
HT936B	NDA	25.0 A	D:HT936B	
V936	**CDA**	**970**	**D:V936**	
Q937	LQC	787.8 A	D:Q937	4.522
Q938	LQD	1,364.1 A	D:Q938	-8.119
Q939	LQC	814.2 A	D:Q939	4.667
Q940	SQA	208.6 A	D:Q940	-3.959

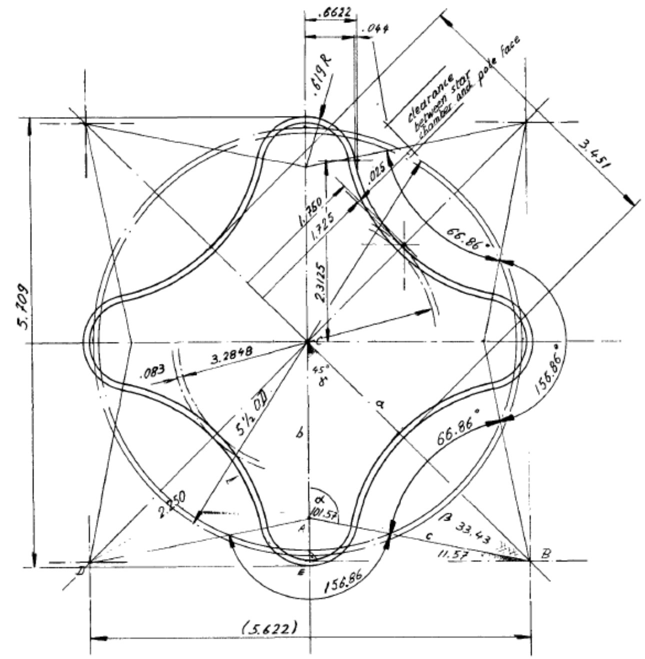
Magnet	Type	Current (A)	Power Supply	Integrated Field (T)
HT940	CDA	970	D:H940	
VT940	CDA	970	D:V940	
Q941	LQC	814.2 A	D:Q939	4.667
Q942	LQD	1,364.1 A	D:Q938	-8.119
VT942	CDA	910.0 A	D:VT943	
Q943	LQC	787.8 A	D:Q937	4.522
V943	**CDA**	**970**	**D:V944**	
HT943	CDA	585.0 A	D:HT944	

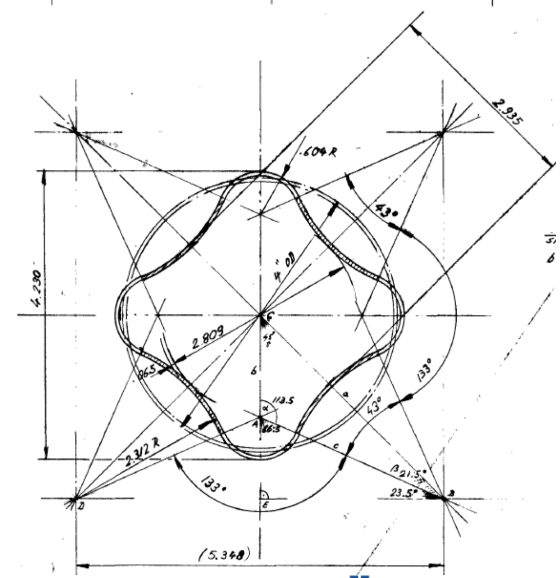
*indicates common M4/M5 section of the beamline

** indicates magnets are bussed together

TeV I Small Quadrupole

- Five Lengths, all with identical magnet apertures
  - 3.5” pole gap, 6” pole width
  - From shortest to longest, SQA, SQB, SQC, SQD & SQE
  - Effective lengths 18.0”, 25.2”, 27.6”, 32.6” & 51.6”
  - Integrated field 7.2 T for SQA, 20.9 T for SQE @400 Amps
  - All types used in the beamlines
- Two beam pipe variations
  - Large star chamber for Pbar beamlines and Debuncher (3.29” circular aperture, 5.62” on axis)
  - Small star chamber in Accumulator for bake-out insulation (2.81” circular aperture, 4.02” on axis)
  - Large star chambers can be installed in Accumulator quads (but would need to be built)
  - Both beam pipe variations are used in the beamlines

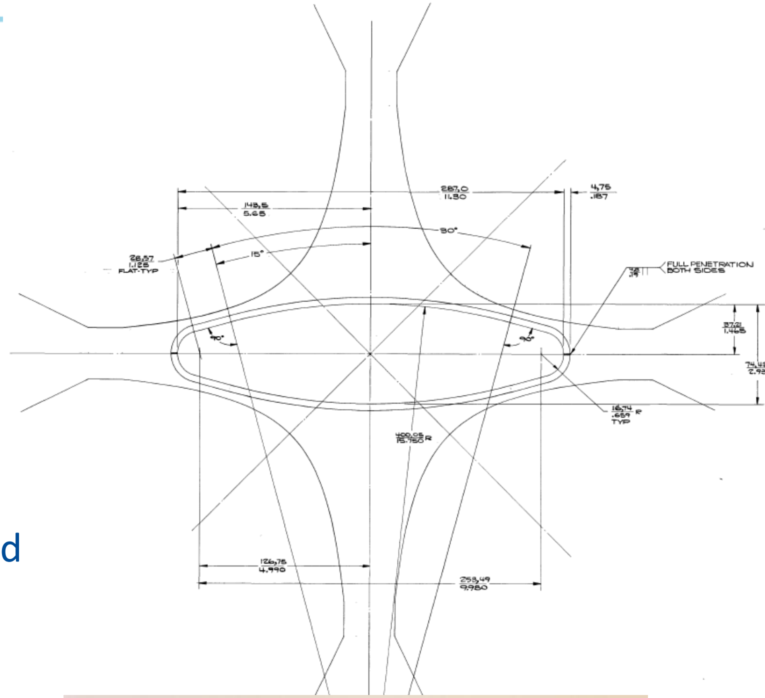




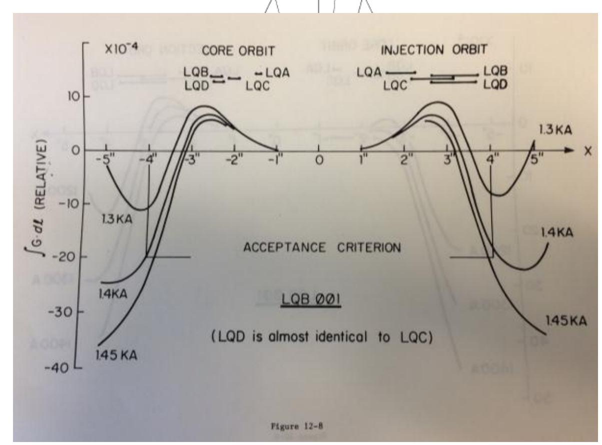
Debuncher SQC

TeV I Large Quadrupole

- Six Lengths, all with identical magnet apertures
  - 6.625" pole gap, 13" pole width
  - Good field region extends over +/- 5"
  - From shortest to longest, LQA, LQB, LQF, LQC, LQD & LQE
  - Effective lengths 17.3", 25.3", 30.4", 30.5", 32.4" & 34.3"
  - Integrated field 1.9 T for LQA, 7.5 T for LQE @1,350 Amps
  - LQC and LQD types used in the Final Focus
- Several beam pipe variations
  - Elliptical pipes used in Accumulator (12" on axis!)
  - Star Chamber pipe is appropriate for Final Focus since need large transverse displacement for target angle scans.



(Courtesy J. Morgan) Debuncher LQE

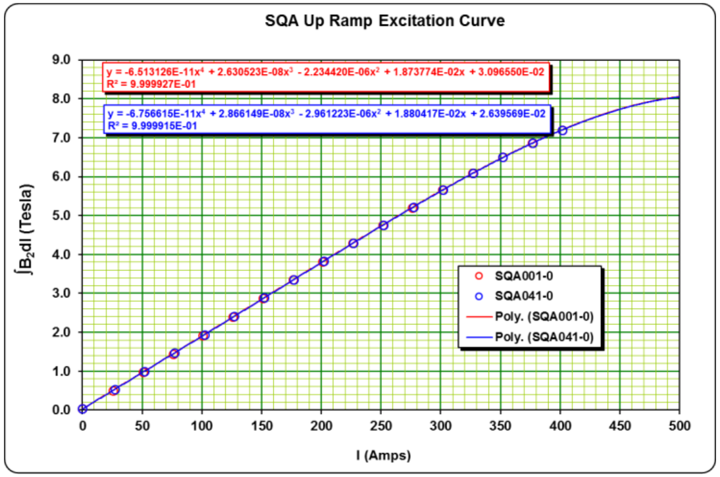


LQD field quality

Quadrupole Magnet Selection

Finding magnet types from pool to match lattice:

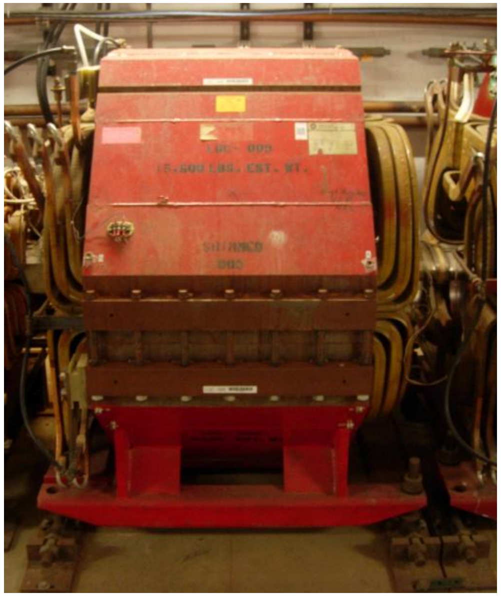
- Take MAD k factors and find integrated field
  - $B_{\text{integrated}} = k_{MADfactor} * B\rho * Lmagnet_{effective}$
- Look up field in historical antiproton magnetic measurement files



(Courtesy J. Morgan)

- Balance magnet type with power supply and power needs.

Small Quad Style - SQC

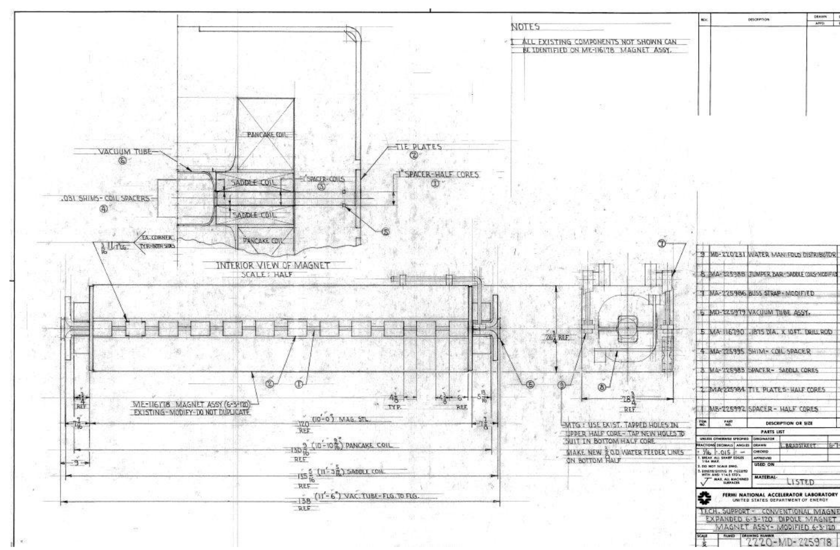


Large Quad Style -LQC

SDF & SDFW Dipole Magnets

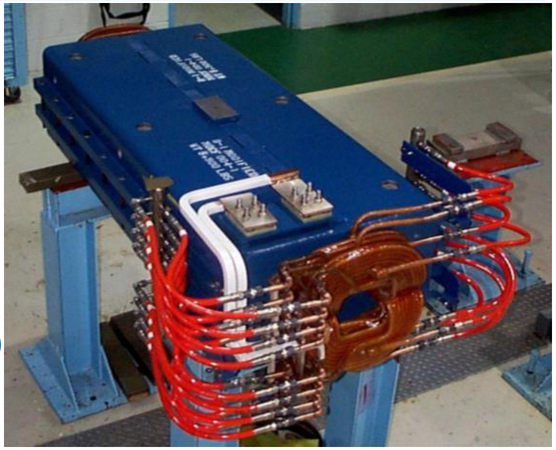
- Several variations that are functionally the same
  - 120 inch length, 68 turns
  - 3” SDF or 4” SDFW pole gap, 6” pole width
  - Slight length difference
  - Water cooling manifolds are the same
  - Maximum bend angle ~120 mr at 8.89 GeV/c
  - SDFW is a “wide gap” additional 1” spaced between half cores increasing aperture to 6” wide x 4” height.
  - Used in Pbar beamlines
- 2 SDF & 4 SDFW will be reused
  - These 6 dipoles make up the 41° left bend

SDFW 6-4-120 Dipole



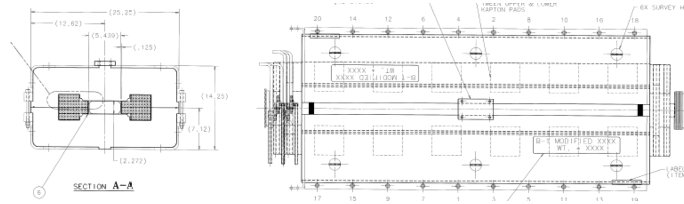
TeV I MDC (modified B-1) dipole

- Several variations that are functionally the same
  - 60 inch length, 68 turns
  - 2.25” pole gap, 6” pole width
  - Slight length difference
  - Most differences due to water manifolding or assembly
  - Maximum bend angle 87.3 mr at 8.89 GeV/c
  - Used in Accumulator and Pbar beamlines



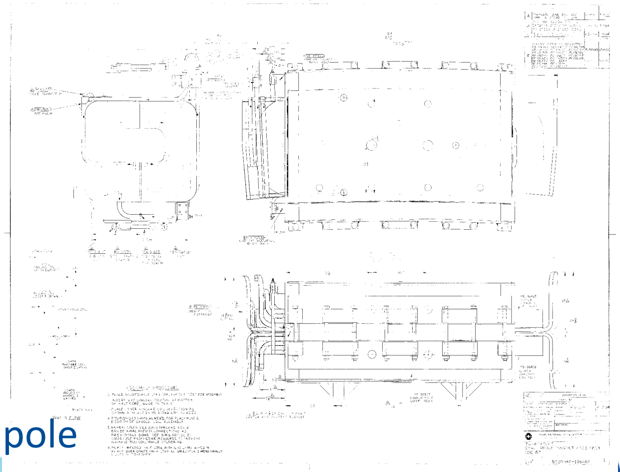
(Courtesy J. Morgan)

- 1 MDC will need to be fabricated
  - HD1 horizontal switch dipole for diagnostic absorber



MDC Dipole

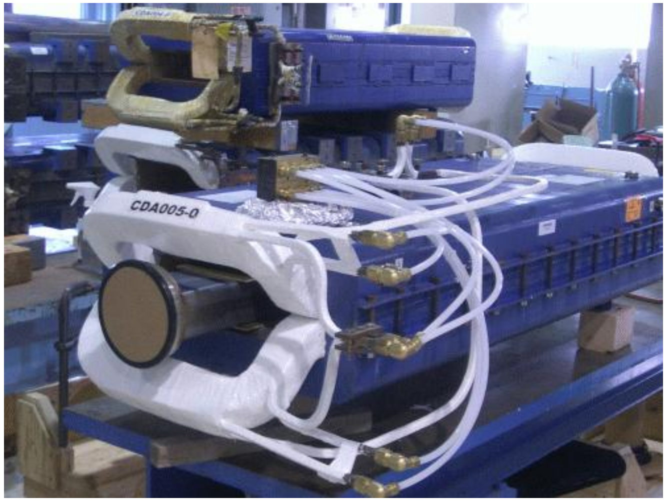
- Possible Replace with an SDC
  - Considering replacing the MCD with an SDC
  - Save cost of fabrication since there are a pool of existing SDC’s.
  - 60 inch arc length, 56 pancake turns
  - 2.37” pole gap, 8” pole width
  - Sagitta with radius of curvature of 687.6”
  - Maximum bend angle 87.3 mr at 8.89 GeV/c
  - Used in Accumulator



SDC Dipole

CDA Dipoles

- Few variations that are functionally the same
  - 48 inch length, 40 turns
  - 3.25” pole gap, 12” pole width
  - Maximum bend angle 24 mr at 8.89 GeV/c
  - Maximum current of 1199 A
- 6 CDA’s will need refurbished
  - All 6 CDA’s used in the final focus.
  - They have a large horizontal aperture to accommodate target angle scans.



CDA Dipole

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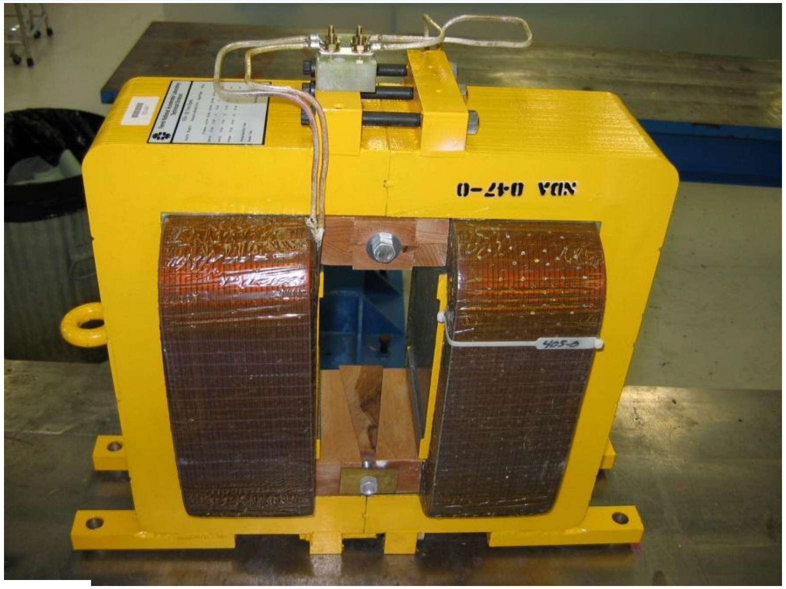
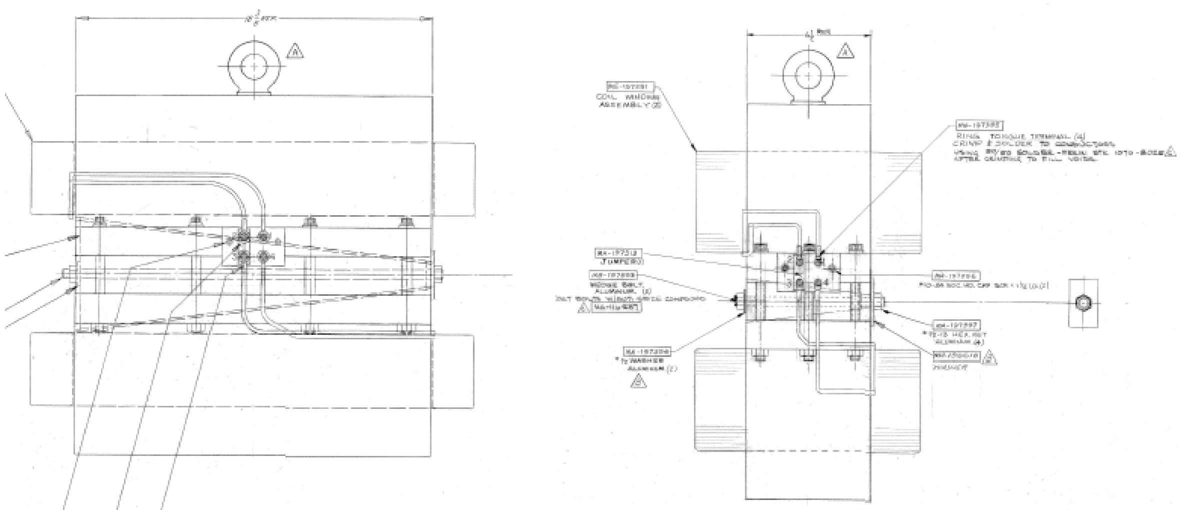
NDA and NDB trims

- NDA's made for Accumulator
  - 8 inch steel length
  - 4.5 inch pole gap
  - Maximum DC current 25 Amps
  - Maximum bend 1.5 mr @ 8.9 GeV/c
- NDB's made for beamlines and Debuncher
  - 20 inch steel length
  - 5.625 inch pole gap
  - Maximum DC current 25 Amps
  - Maximum bend 1.5 mr @ 8.9 GeV/c

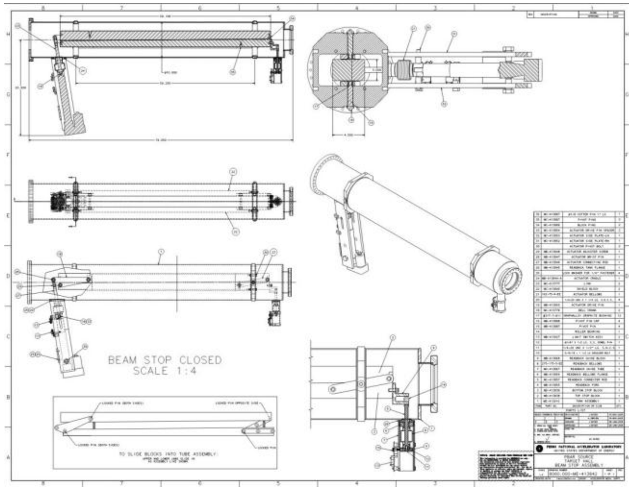




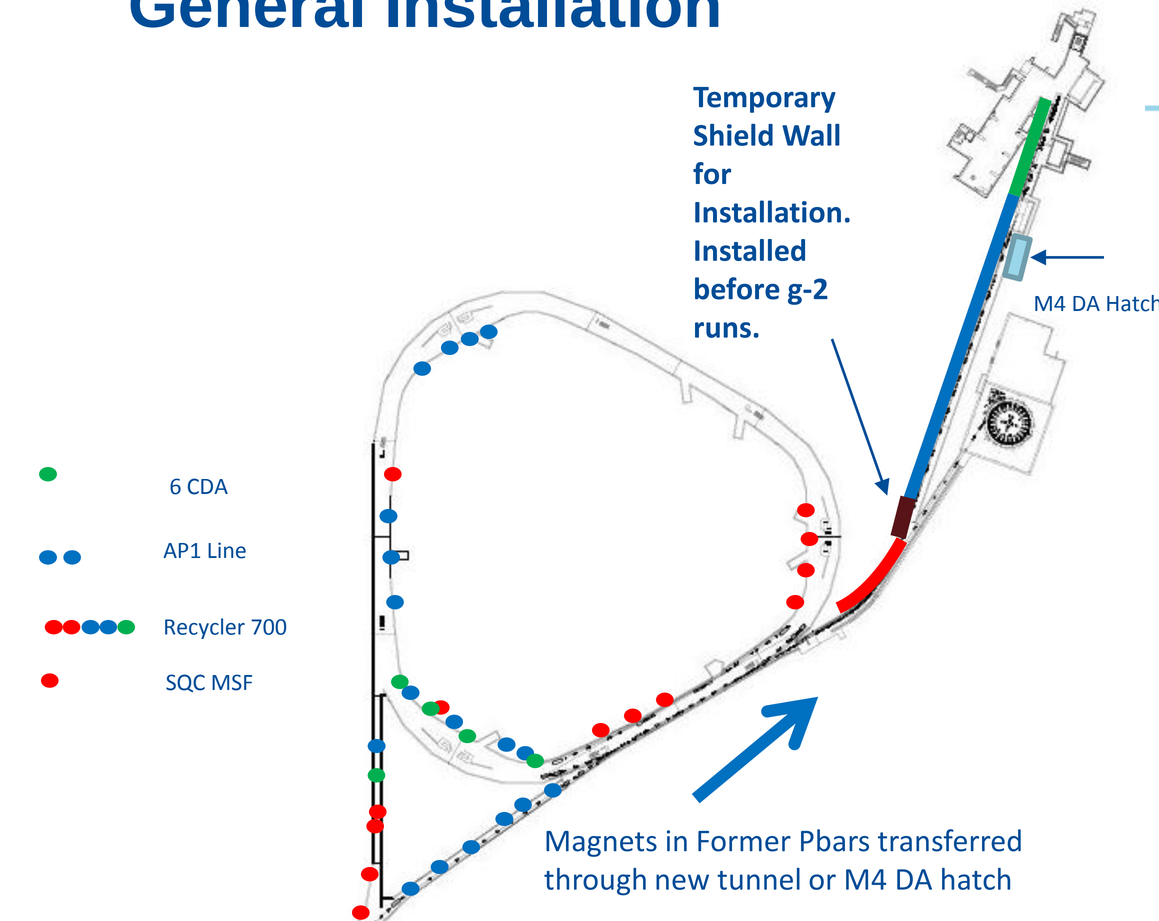
(Courtesy J. Morgan)

Beam Stop

- Made for AP2 Beamline
  - 74.050” length
  - Used as a critical device to stop beam from entering enclosure
  - Motor driven
  - Maximum bend 1.5 mr @ 8.9 GeV/c
- 2 Beam stops will be needed for M4 beamline
  - 1 beam stop will be reused from AP2 line
  - 1 beam stop will be fabricated.
  - We will use existing design & update drawings
  - Will change motor drive to pneumatic
  - Used as a critical device to stop beam from going past the diagnostic absorber shield wall.



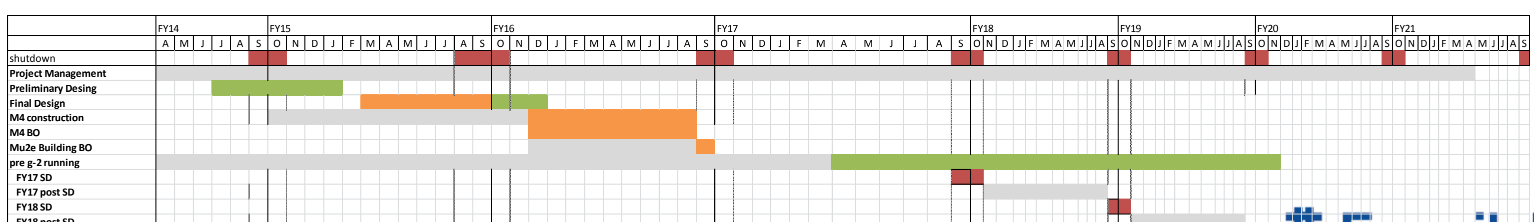
General Installation



M4 Beamline is broken into 3 sections for installation: (Majority of components for M4 will be repurposed from the Antiproton Source.)

- HBend 908 to 920 (Shield wall) 26 Elements, 24% of length
- Extinction & Diagnostic Absorber 920 to 945. 58 Elements, 57% of length
- Final Focus 945 to 952. 19 Elements, 19% of length.

Installation of HBend and transporting magnets from Accumulator will occur during shutdowns after g-2 running.



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M4 Diagnostic Absorber Line

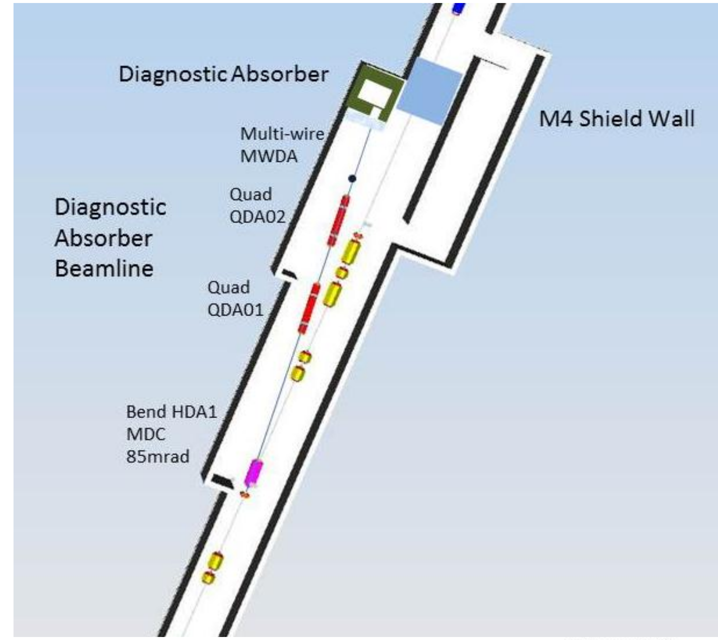
The M4 beamline requires a diagnostic absorber for commissioning the beamline and commissioning resonant extraction during mu2e

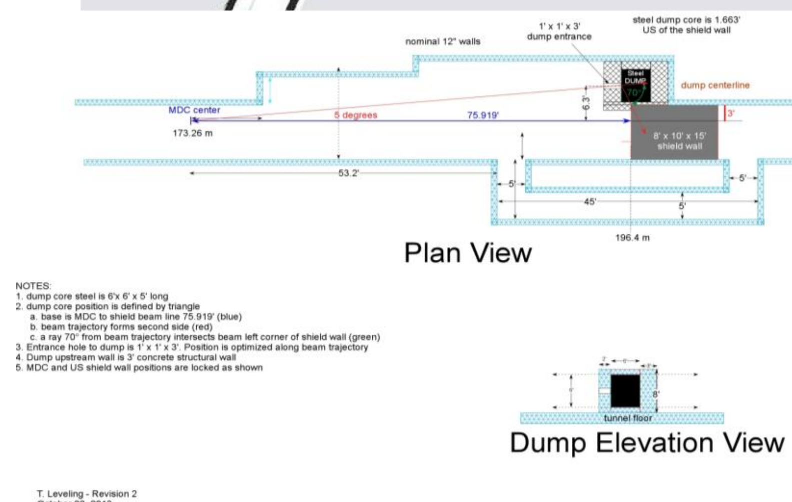
The absorber has a 170 W capacity derived from 2 modes of commissioning:

> **Mode 1** - Low intensity commissioning kicked beam (does not matter if people are present downstream). This is roughly 5E10 protons/pulse every 10 sec or so.
>
> **Mode 2**- Resonant Beam commissioning. Takes 4 pulses at 1E12 per pulse or 4E12 total protons/pulse every 30sec or so.
> Beam Power Calculations for the 2 Modes:

Beam is bent horizontally outward to the diagnostic beamline by an MDC dipole at 5 °(85mrad).

There are 2 quads (QDA01 & QDA02) in the beamline to control optics in the line. (optics not critical but diagnostic capability depends on the ability to change phase and observe phase space evolution)





Diagnostic Absorber

- The M4 Diagnostic Absorber is a series of 6’x6’x5’ long stacked steel plates using 108 steel plates.
- It is surrounded by 1’ of concrete on the top & bottom and 3’ in the back.
- The absorber has 1’x1’x3’ albedo trap angled at 5° to match the beamline.
- The absorber is passive with no water cooling.
- The steel for the absorber has been and cut , prepared, assembled and will be installed in the tunnel walls surrounded by concreate. The for installation has been transferred for Mu2e project to the tunnel GPP.
- The absorber was designed on by the External beamline WBS but cost transferred to the tunnel GPP for installation because it is part of the tunnel wall.

Diagnostic Absorber before concrete pour

Tunnel View of Diagnostic Absorber after surrounded in concrete

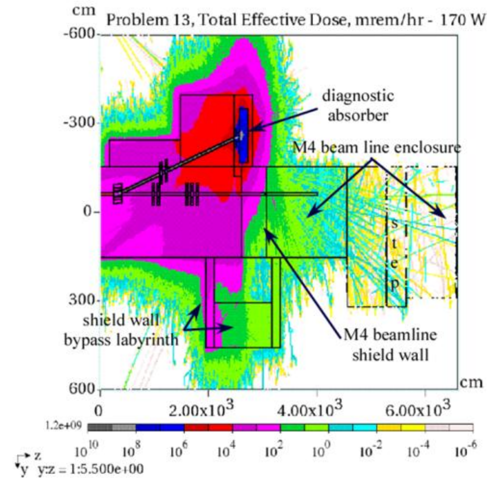
Diagnostic Absorber MARS Results

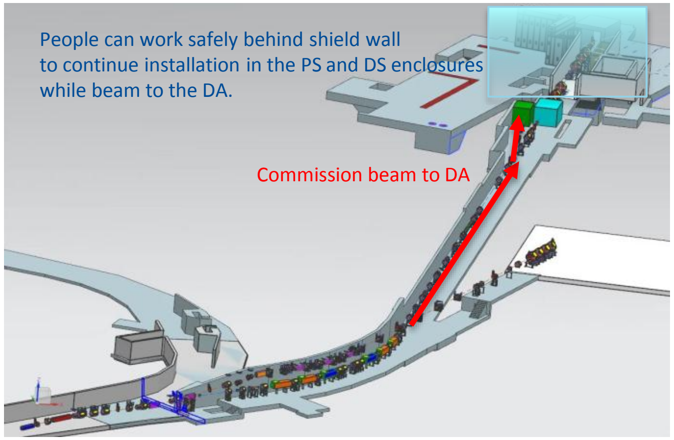
- MARS was used to estimate integrated radiation dose downstream of the DA for occupancy of the Detector and Production Solenoid enclosures.

- Radiological effects for ground and surface water activation were also estimated. The results were all found to be under limits and standard Fermilab requirements.

- The effective dose rate at the location of the Detector Solenoid is less than 0.05 mrem/hr during normal beam operation to the diagnostic absorber.

- An accident condition in which the 170-watt proton beam is lost on the MDC switching magnet was also considered. The resulting dose rate at the Production Solenoid was calculated to be about 250 mrem/hr. A TLM will be located in the M4 line upstream of shield wall. The TLM trip level for this operating mode will have to be reduced from the nominal 248 nC/minute to about 6.5 nC/minute in order to permit non-radiation workers unrestricted access to the area around the Production Solenoid





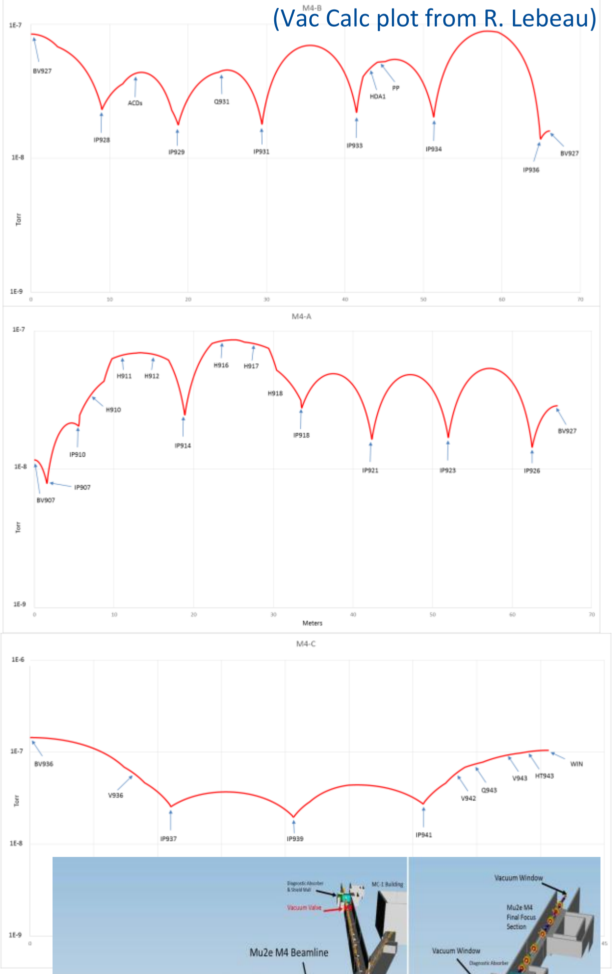
M4 Beamline Vacuum Requirements

- The beam line needs to maintain a pressure of 1.0×10^{-8} Torr or better.
- All vacuum components being reused from the Antiproton Ring need to inspected and tested prior to installation into the beamline. Some refurbishing will be required.
- All components and devices need to be leak checked to a sensitivity of 2×10^{-10} atm·cc/s with helium prior to installation into the beamline.
- All components should be ultrasonically cleaned prior to welding and again prior to installation.
- Assembly shall be performed using ultra-high vacuum handling practices.
- All components must be oil-free.
- Beam tubes shall be steam cleaned, blown dry, then the ends capped to maintain cleanliness until installation.
- Bake-out of the beamline is not necessary.

M4 Beamline Vacuum Design & Layout

- The M4 line is broken into 3 vacuum sectors that can be isolated by vacuum valves.
- Initial VAC CALC estimates that 10^{-8} torr in the beamline can be achieved. Known outgassing rates for devices like multiwires were used.
- 270 Liter/sec ion pumps are mainly placed ~ 40' apart & more around high vacuum load component. (Instrumentation)
- Interfaces: AC dipole, extinction collimators and protection collimator have been given accelerator vacuum requirements.

(Vac Calc plot from R. Lebeau)



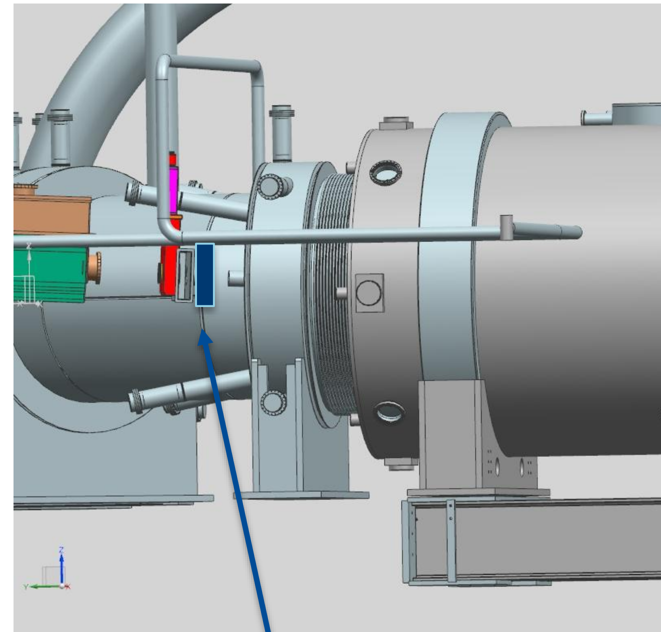
Vacuum Device	Location
Beam Valve	902
Ion Pump	902
TC	902
CC	902
TCV	904
Ion Pump	906
TC	906
CC	906
Beam Valve	907
Ion Pump	907
TC	907
CC	907
Ion Pump	910
Ion Pump	914
Ion Pump	918
TCV	918
Ion Pump	921
TC	921
CC	921
Ion Pump	923
Ion Pump	926
TC	926
CC	926
Beam Valve	927
Ion Pump	928
TC	928
CC	928
Ion Pump	929
Ion Pump	931
Ion Pump	933
Ion Pump	934
Ion Pump	939
Ion Pump	941
TC	941
CC	941

TC = Thermocouple
CC = Cold Cathode
TCV = Turbo Cart Valve

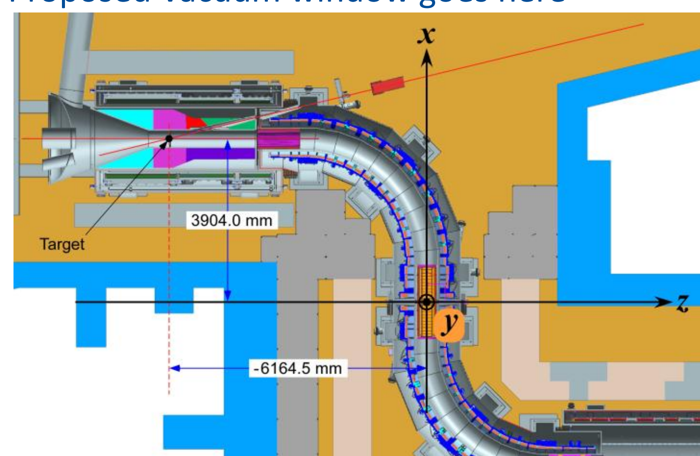
Initial specs for vacuum window at M4BL-PS

Vacuum Window Parameters

- Beamline Vacuum pressure ~ 10^{-8} torr
- TS/PS vacuum pressure 10^{-5} torr
- Material – Titanium (Ti-6Al-4V)
- Thickness – 0.002”
- TS Beam pipe is 4.75” ID, 5” OD.
- There will only be 1 window to reduce material budget.
- Scattering from window produces losses into TS. Estimates for heat load into cryo TS magnet at first estimate are ok. Simulations are being recalculated. (R. Coleman)
- PS needs a port near vacuum window to view the target (w/ bore scope)



Proposed Vacuum window goes here



Beamline Vacuum Components & Controls

- Vacuum Controls will repurpose the AP30 Accumulator vacuum station.
- All ion pump valve controllers , CIA crate (programmable valve interface), and controls interface cards will be reused.
- These will use standard practice vacuum controls items.

Row Labels	Needed
New:	**879**
5.5" to 4' beam tube reducer	20
Beamtube, large, special, transitional	20
Fittings:	21
Flange Gaskets:	150
Flanges:	99
Gauges:	14
KF40	10
Stands:	28
Valves:	17
Beamtube, 4" round, laser welded, 316L SS (ft)	400
Beamtube, 6" round, laser welded, 316L SS (ft)	100
Repurposed:	**250**
Gauges:	14
Ion Pumps: (270 L/sec & 30 L/sec)	18
Rough Pumps: (20 CFH scroll pump	4
Stands:	47
Valves: (4” remote and manual)	16
Windows: (titanium)	3
Bellows:	48
Beamtube, 5-1/2" round, 316L SS (ft)	100
Grand Total	**1129**

Vacuum Controls at AP30 service building will be repurposed

Low Conductivity Water (LCW)

Requirements:

- Provide LCW to the M4 tunnel for magnet cooling & generic use
- Provide LCW to the MC-1 and Mu2e service buildings for power supply & general use water cooling.
- LCW systems for M4 tunnel, MC-1 & Mu2e service building will tie into the existing standard LCW for the accelerator sourced from the Central Utility Building (CUB).
- Provide LCW to the Production Solenoid (PS) Heat and Radiation Shielding (HRS)
- Provide Compressed Air System to the tunnel for control of pneumatic systems like beam value and tools used in the tunnel.
- Standard expectable LCW parameters are:

Supply Temp (F)	Flow (GPM)	Conductivity (MΩ-cm)	Supply Pressure (PSI)	Return Pressure (PSI)
90	1610	15	215	45

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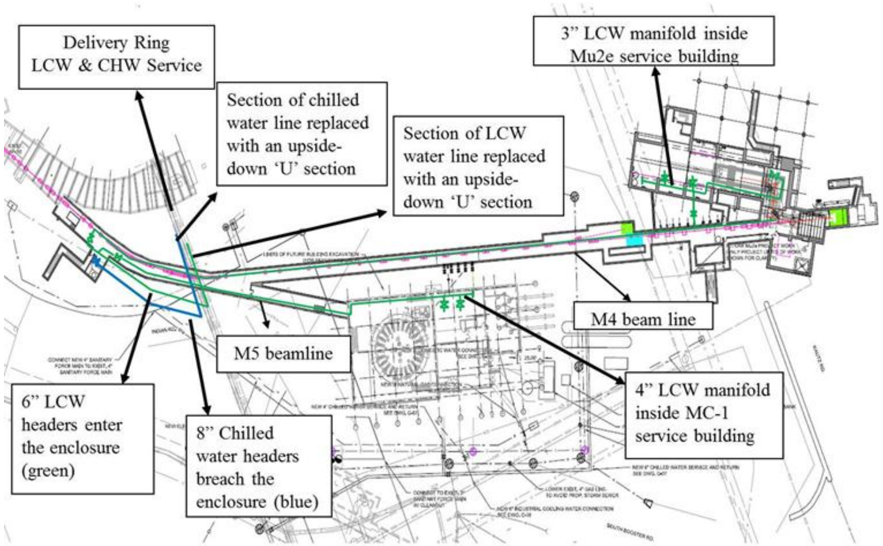
Low Conductivity Water (LCW) Design



*Only the supply lines are shown here

Layout of LCW Headers to the Muon Campus source from CUB

Location	Cooling Demands (kW)
M4 beamline	710
M5 beamline	190
MC-1 Building	370
Mu2e Building	50
M2 beamline	115
M3 beamline	220
Delivery ring	1160

Estimated LCW Cooling Demands

Simulated flow and heat load summary for the Muon Campus LCW cooling system

Heat Load Component	Inlet Temp. (°F)	Outlet Temp. (°F)	Temp. Difference (°F)	Avg. Temp. (°F)	Flow Rate (gpm)	Heat Load (kW)
Delivery Ring Loads						
MAN 1[3]	86.6	103.54	16.94	95.07	56.68	139.80
MAN 2	86.6	101.80	15.20	94.20	41.90	92.73
MAN 3	86.63	104.38	17.75	95.505	56.78	146.74
MAN 4	86.64	103.72	17.08	95.18	50.19	124.81
MAN 5	86.62	101.73	15.11	94.175	41.34	90.95
MAN 6	86.63	103.61	16.98	95.12	76.11	188.17
MAN 7	86.62	105.19	18.57	95.905	55.7	150.60
MAN 8	86.6	97.79	11.19	92.195	35.26	57.45
MAN 9	86.6	104.25	17.65	95.425	64.2	164.98
Delivery Ring Summary					**478.16**	**1156.23**
Remaining Loads						
M2 Line[1]	86.64	92.85	6.21	89.74	127.54	115.32
M3 Line	86.62	97.15	10.53	91.88	142.48	218.45
M4 Line	86.59	103.85	17.26	95.22	279.69	702.88
M5 Line	86.58	93.91	7.33	90.24	178.72	190.74
AP10[2]	86.63	98.82	12.19	92.72	28.23	50.10
AP30[2]	86.65	96.58	9.93	91.61	69.17	100.01
AP50[2]	86.63	100.22	13.59	93.42	101.31	200.46
MC-1 Bldg	86.70	104.21	17.51	95.45	144.98	369.62
Mu2e Bldg	86.79	92.72	5.93	89.75	57.84	49.94
Total Summations					**1608.12**	**3153.75**
P-Bar HX	99.08	86.57	12.51	92.82	1609.35	-2931.36[1]

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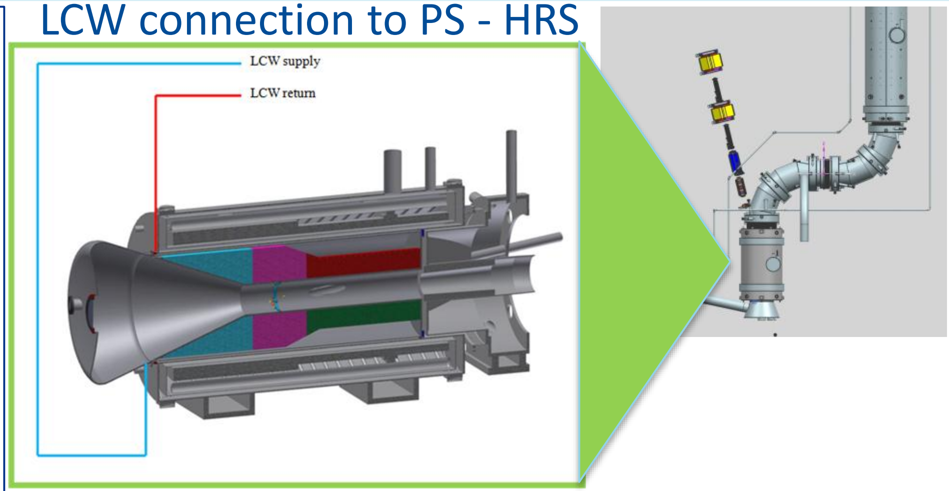
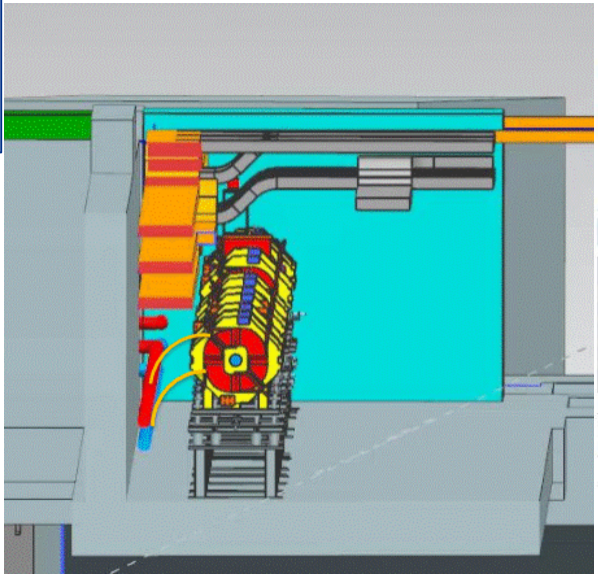
LCW & Compress Air Design

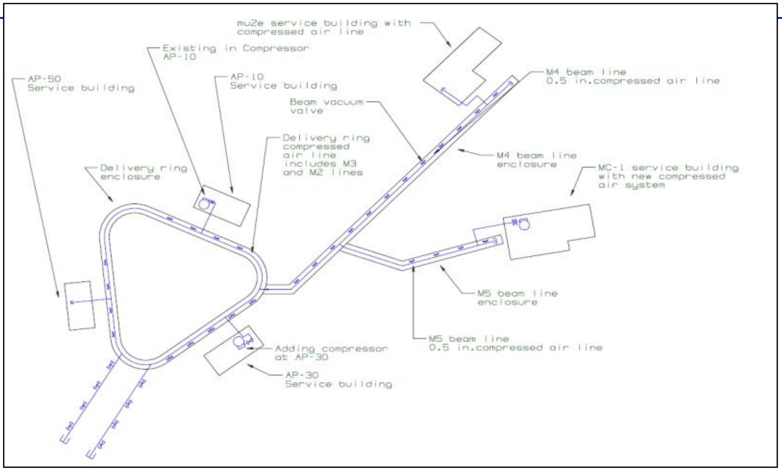
- PS HRS LCW Supply and Return Connections
- These will tap directly into the S&R headers. It will not have a stand alone system.
- Compressed air system will be new for the new tunnels and will tie into the existing DR system.
- LCW hoses from manifold to magnet will be upgraded to a more rad resistive hose with good operational reliability.

LCW connection to PS - HRS





Tunnel cross section showing LCW header and hose connection

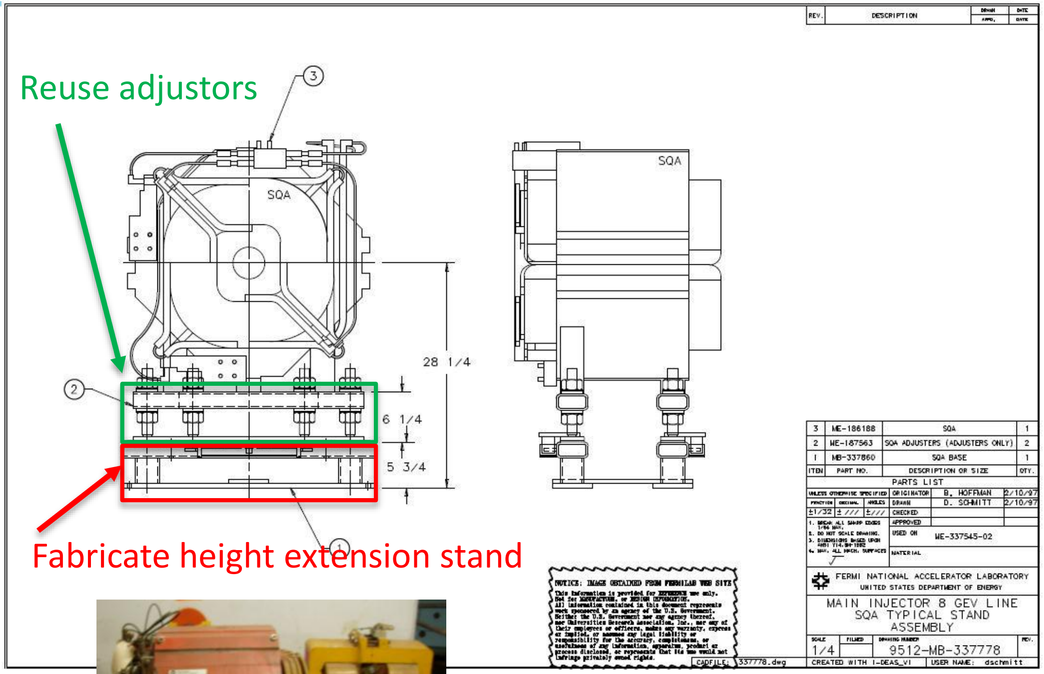


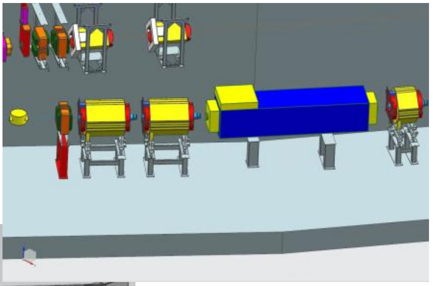
Muon Campus compressed air system

Fixed Magnet Supports

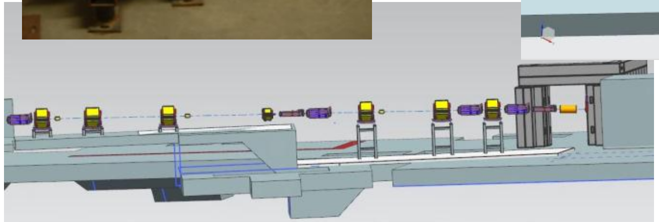
Requirements

- All fixed magnet supports will have 2" of adjustment travel.
- Majority of stands will be reused from the Antiproton Source with some modifications.
- Reused stands will keep the adjustors and fabricated a new stand extension due to the height difference in the Accumulator (29.5") and the M4 height (46.4" and ~ 8').





beamline	M4
Row Labels	**Count of Magnet**
new Motorized Stand	3
New Instrumentation	14
repurposed adjustors with heigth modification	29
new stand & adjustors	42
Grand Total	**88**



Height of beam line varies from ~4' to 8'

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Target Scan Requirements that Force Movable Magnet Supports

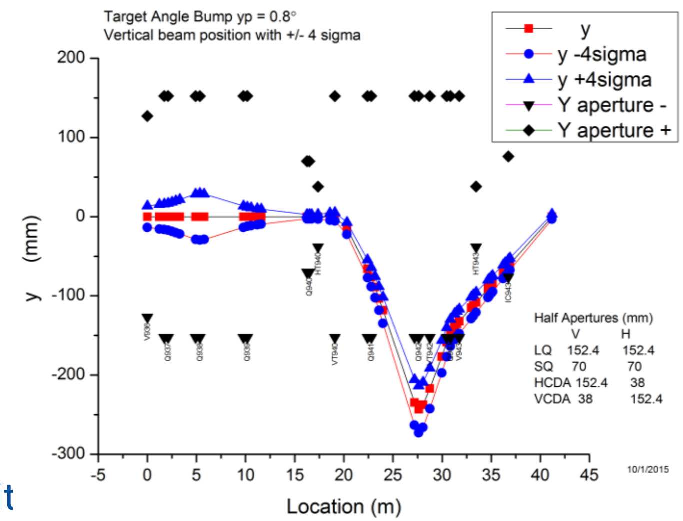
Target Scan Requirements:

- Horizontal and Vertical Position Scans up to 1 cm
- Horizontal and Vertical Angle Scans up to 0.8 °

Reasons for Scans:

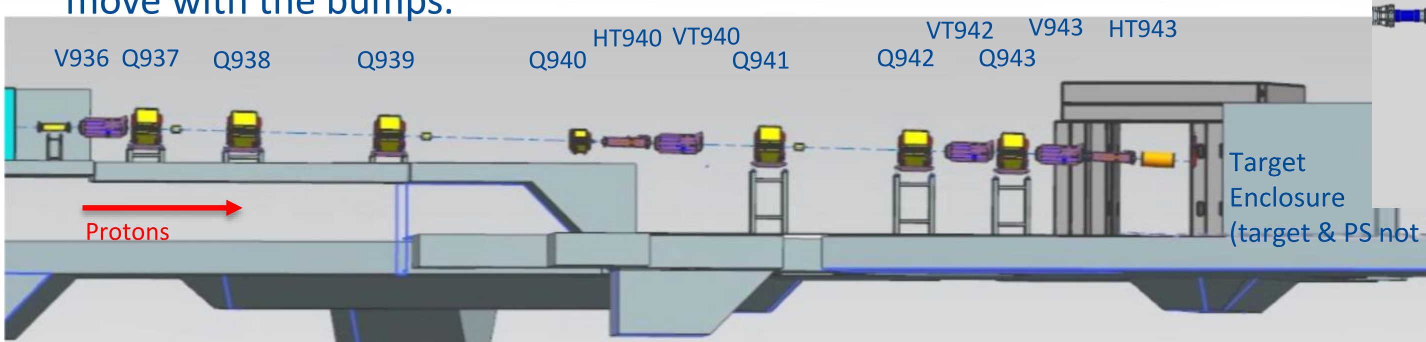
- Initial alignment of beam with the target.
- Diagnose unexplained reduction of yield from proton target.
- Periodic fine tuning of beam to target alignment.

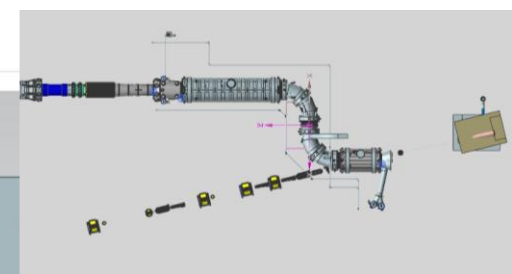
Lattice Results from E. Gianfelice



Vertical Angle Scans of to 0.8 ° too large and requirement Polarity inverse

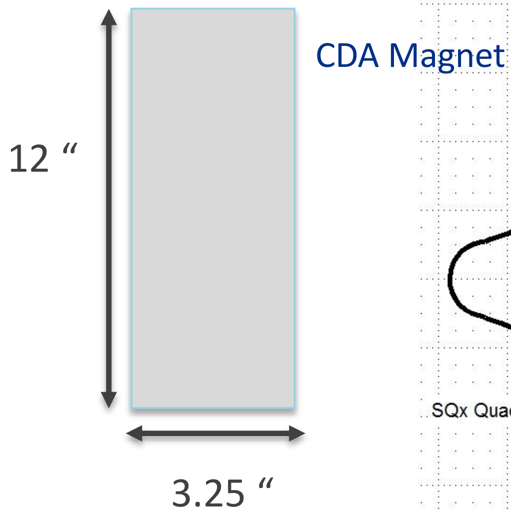
- The vertical angle bump produces a large transverse that extend outside the magnets.
- Therefore, the lattice in y plane must be inverted (need for polarit switches)
- Even with the lattice inverted, there are still large transverse offsets in some of the downstream magnets that require the magnets to move with the bumps.

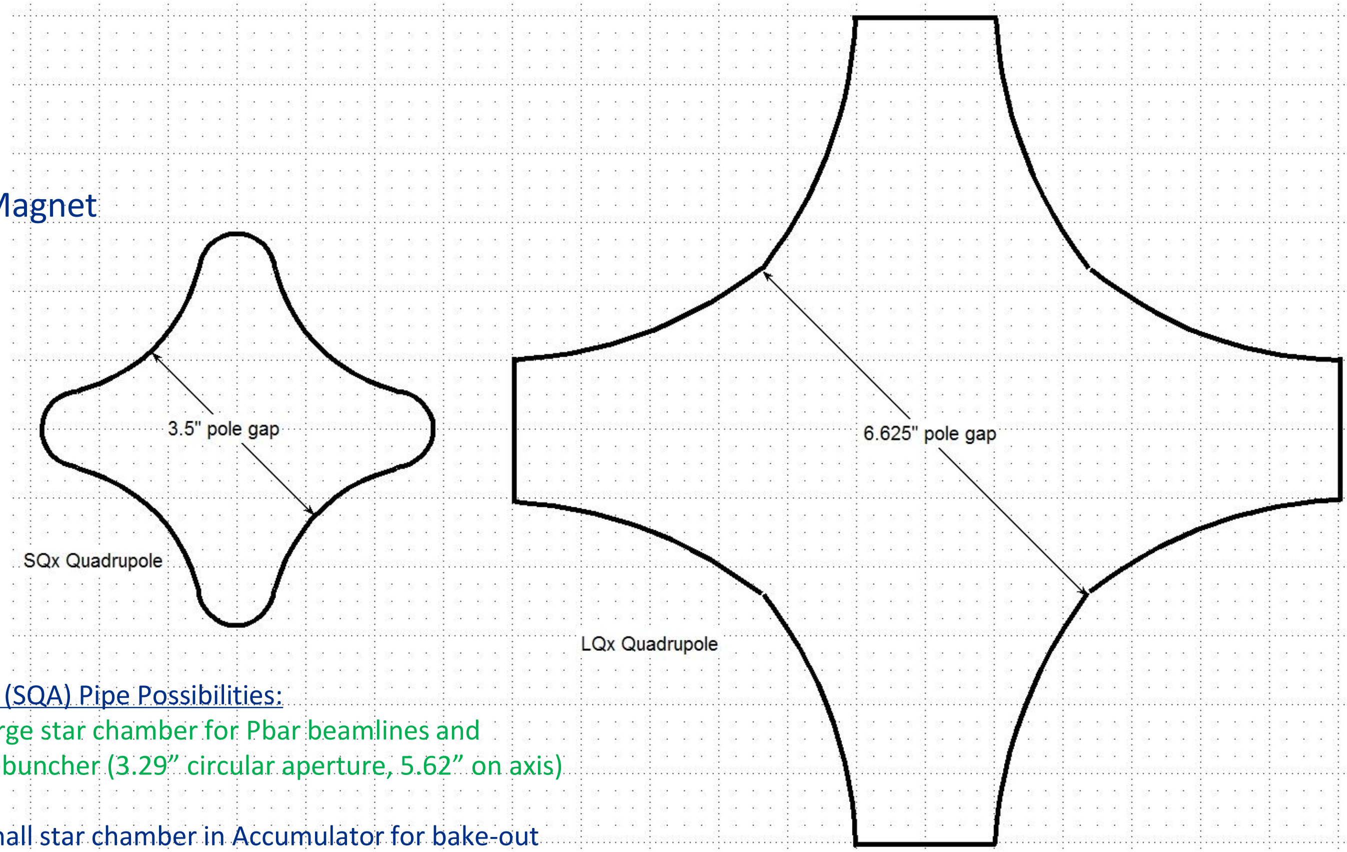




Elevation View of Final Focus

CDA, SQ and LQ aperture





Q940 (SQA) Pipe Possibilities:

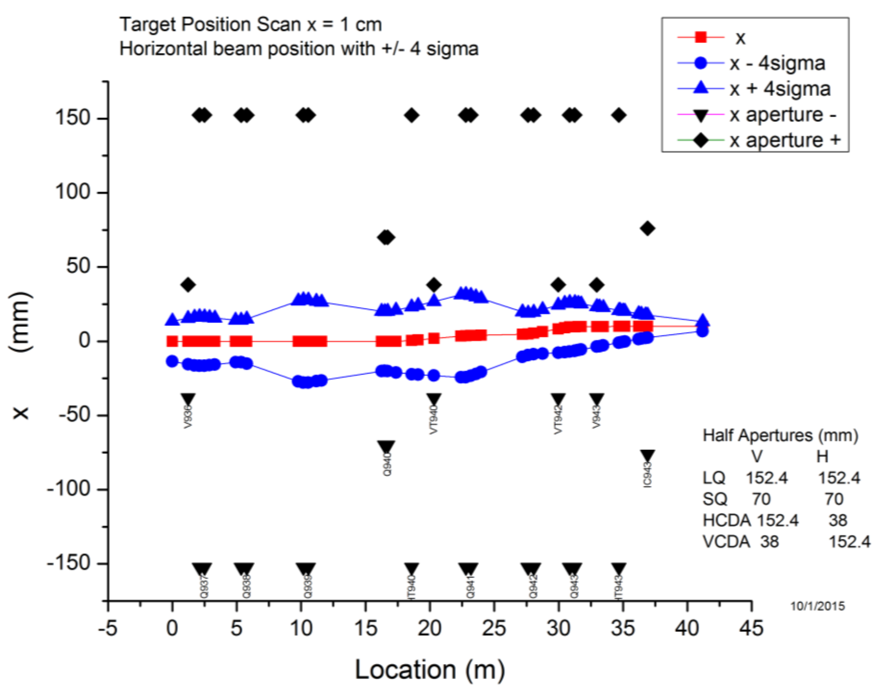
- Large star chamber for Pbar beamlines and Debuncher (3.29" circular aperture, 5.62" on axis)
- Small star chamber in Accumulator for bake-out insulation (2.81" circular aperture, 4.02" on axis)
- Large star chambers can be installed in Accumulator quads (but would need to be built)

LQ Pipe Possibilities:
6.5" round
12" elliptical (only in one plane)
Star Chambered (~ 12" in each plan)

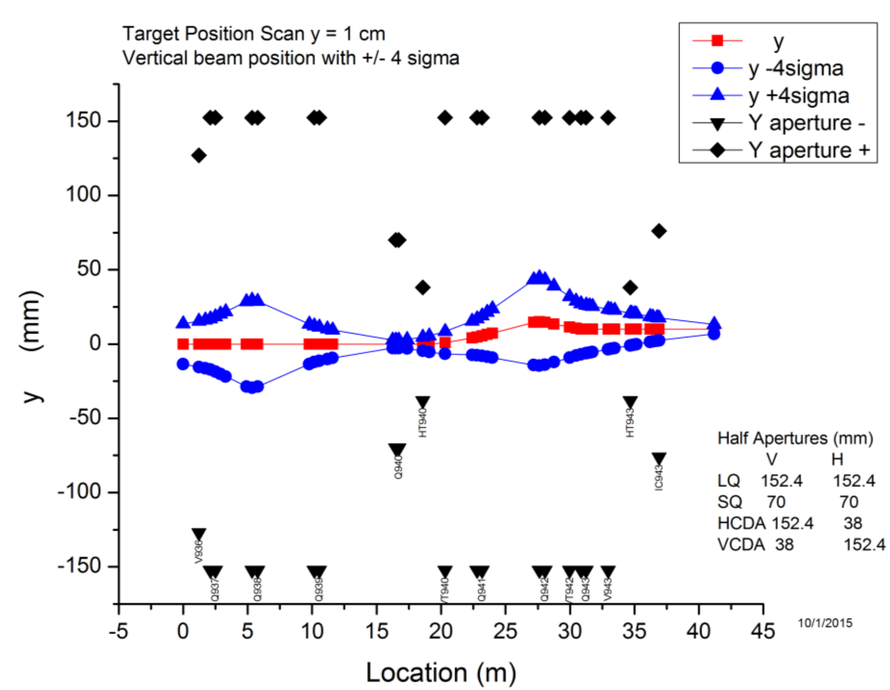
Target 1 cm Position Scans

Horizontal and Vertical Position Scans require no movement of magnets

Horizontal Scan



Vertical Scan



Lattice Results from E. Gianfelice

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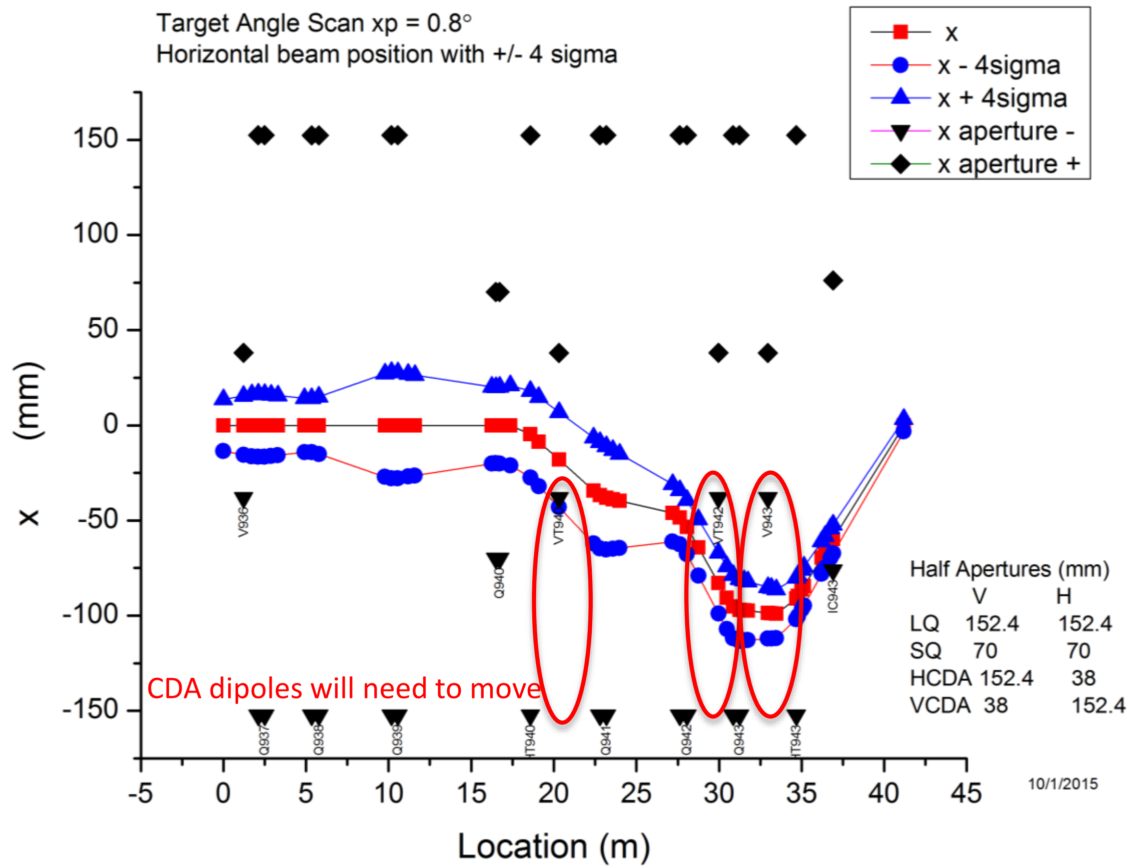
Horizontal Target Angle Scan of 0.8°

VT940 needs to move by 0.5 cm or 0.2”

VT942 needs to move by 6.1 cm or 2.4”

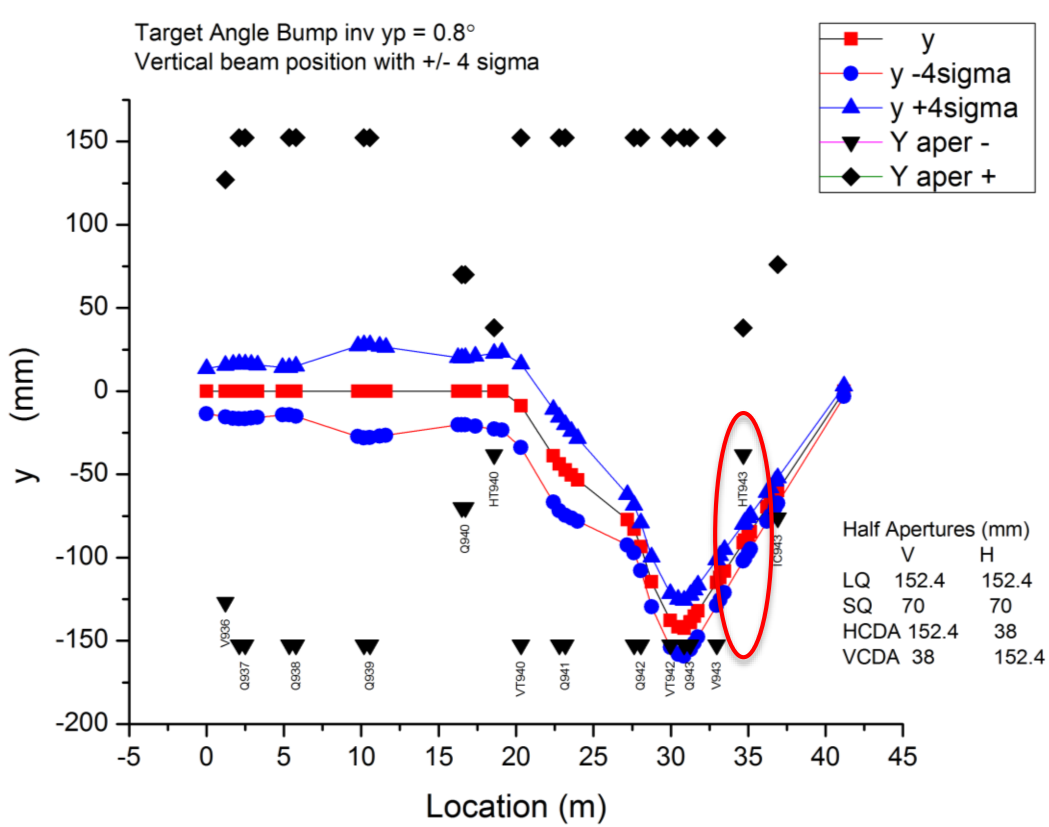
V943 needs to move by 7.4 cm or 2.9”



Lattice Results from E. Gianfelice

Vertical Target Angle Scan of 0.8° with Inverted Polarity

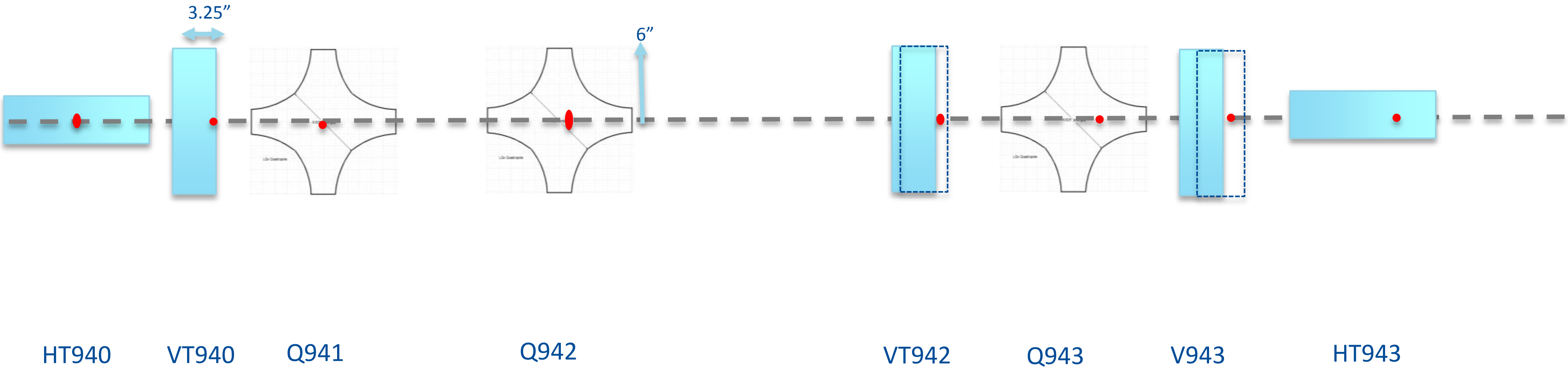
HT943 needs to move by 6.4 cm or 2.5”



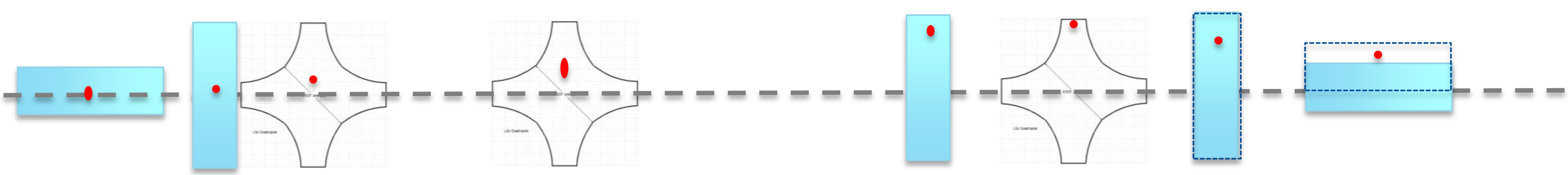
Lattice Results from E. Gianfelice

Beam inside each aperture due to bumps

Horizontal DX bump of 0.8°



Vertical DY-INV bump of 0.8°

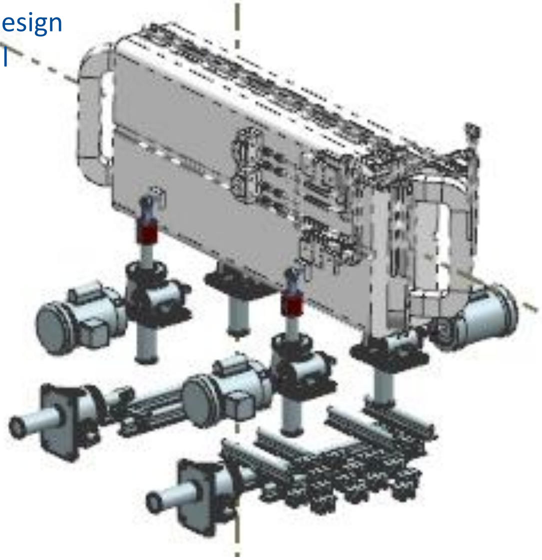


Motorized Magnet Support & Bellows Requirements

Support Requirements:

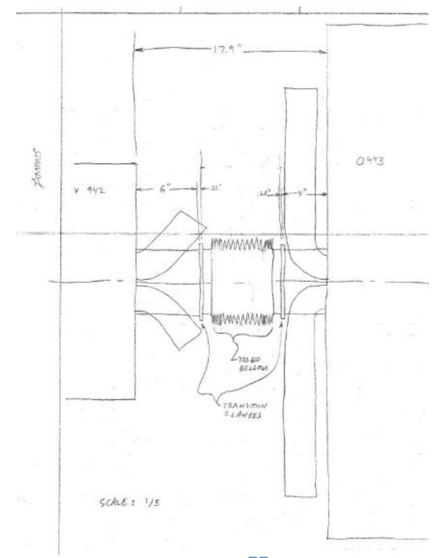
- Magnets that need motorized supports: HT943, VT940, VT942, V943
- Travel = +/- 3" (+/- 76.2 mm)
- Planes of travel: horizontal & vertical
- Speed of travel 7.3 inches /min
- Radiation hard LVDT
- Frequency of moving stands: 5 times /year
- Magnet weight = 2500lb
- Magnet Type: HCDA & VCDA

Motorized support design
R. Rielly & M. Sawtell



Bellows Requirements:

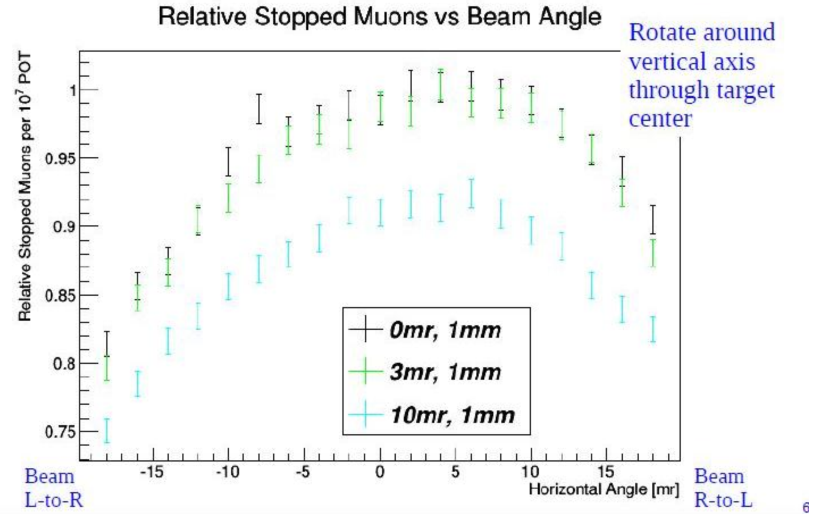
- Vacuum pressure: $1x10^{-8}$ torr
- Match LQ star pipe to CDA pipe.(various combinations of pipe)
- Large Aperture transitions ~ 14"
- Bellows will be "slinky" style.
- Allow for +/- 3" of travel.
- Distance between bellows is short ~2ft



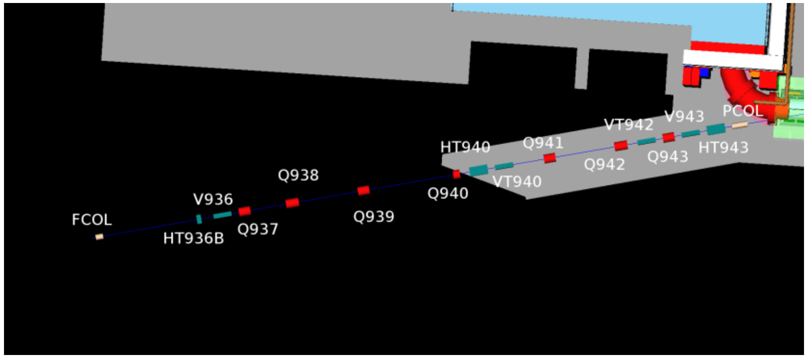
Comments on Target Scans

- The 0.8 angle requirement is challenging to put into practice.
- The design work is not complete for items like bellows and interfaces in the Final Focus.
- We have 2 people from City University (Kevin Lynch and Jim Popp running G4BL simulations to look at production yields with the target scans to see if the angular requirement can be relaxed. This work is not complete. Mu2e-doc-5706

Angular Scan (Kevin Lynch Mu2e-doc-4130 May,2014)

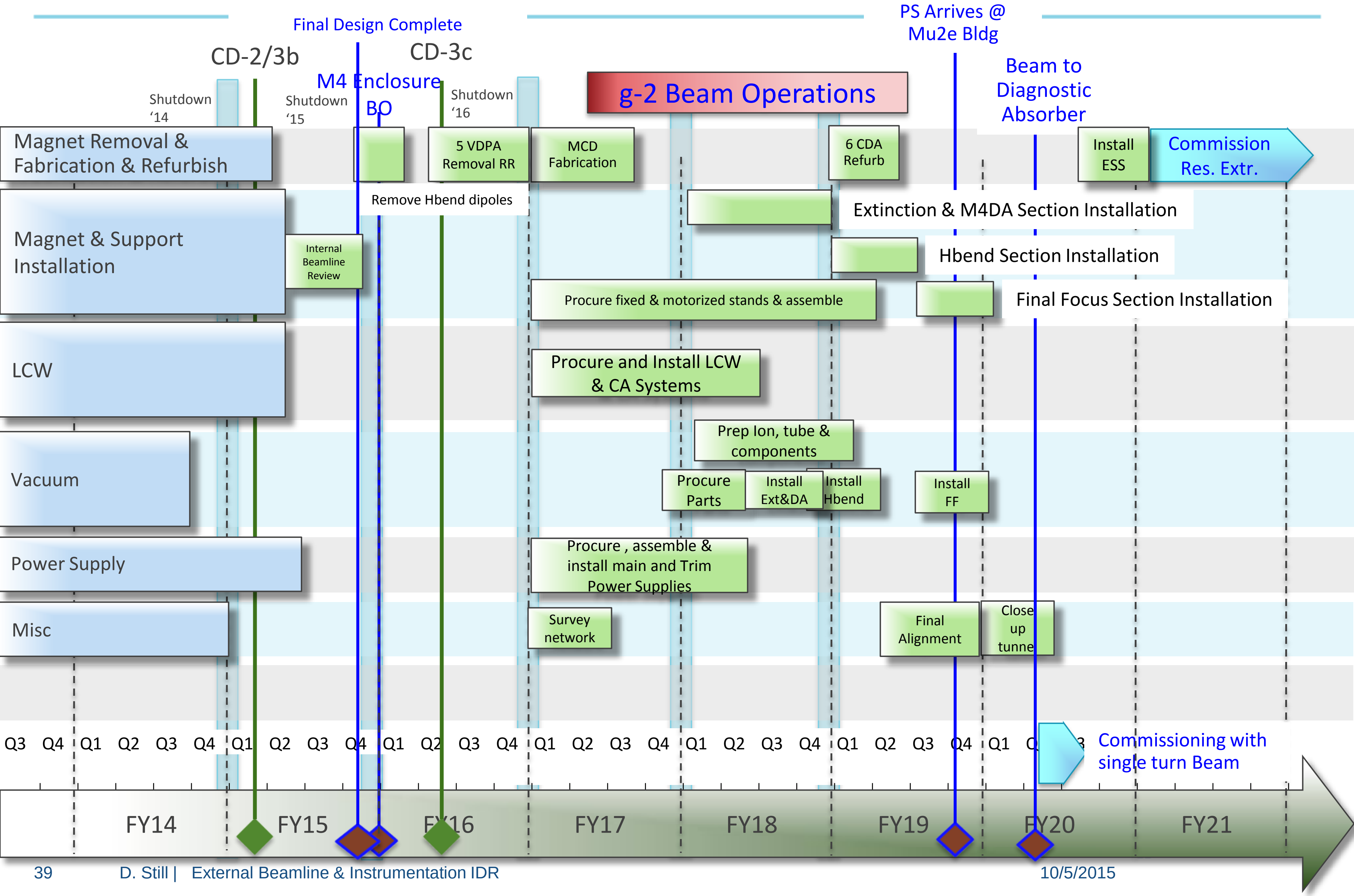


Original simulated estimate for angular requirement



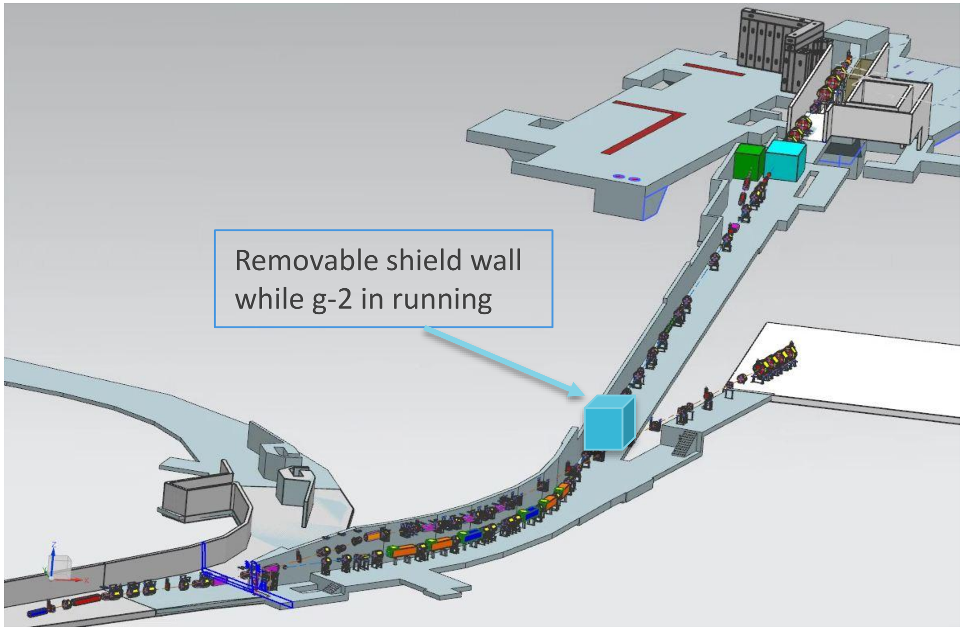
Recent G4BL to simulate target scans and yield.

Schedule – External Beamline



Commissioning

- Beam commissioning is off project but it does occur in the schedule before the end of the project.
- Install removable upstream shield wall 2Q FY17
- Commission signal turn beam to diagnostic absorber 2Q FY20
- Commission resonant extraction 1Q FY21 to diagnostic absorber.
- Commission beam to target may have 2 different scenarios: Commission beam to PS without a target (provide background rates) or Commission beam to PS with target installed.



Risks (All for External Beamline)

Registry contains 2 risks:

- ACCEL-200 - Mu2e-doc-4589 : Additional power supply circuits needed for modified optics for the change in the extinction section due to extinction design change.
  - High probability with up to $400K cost impact
- ACCEL-201 - Mu2e-doc-4590: Additional magnet needed to be fabricated for modified optics for the change in the extinction section due to extinction design change.
  - Moderate probability with $200K cost impact.

1 to be added to Risk Registry:

- ACCEL---- - : Cannot procure appropriate bellows for the bellows design for movable devices in final focus.
  - Moderate probability with $60K cost impact.

Registry contains 1 risk removed where a Threat is Avoided:

- ACCEL-033 Mu2e-doc-3832: Inability to stage magnets in the Accumulator enclosure during g-2 operation

Registry contains 1 opportunity:

- ACCEL-202 - Mu2e-doc-4591: Replace current MDC magnet for diagnostic absorber line with an existing SDC magnet.
  - Moderate probability with $110K cost impact.

Summary

- The magnet selection for the M4 beamline is near a final design and achievable with the selection of available magnets.
- Serial numbers of reused magnets have been assigned to specific locations.
- Complete value engineering to confirm that an existing SDC magnet can replace the need to manufacture an MDC.
- The design of the beamline vacuum and LCW systems are at final design with work still needed to complete drafting.
- The diagnostic absorber is built and installed.
- There is still work to complete a final design for target scans which use movable supports. Work to see if the angle scan requirement of 0.8° can be relaxed is in progress.