Transfer line design from Recycler Ring to the P150 line for the Mu2e- project at Fermi National Accelerator Laboratory

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ABSTRACT

The ongoing Mu2e- project requires that 8-GeV protons be transferred from the Booster to the Antiproton source (Pbar). Described is a solution to achieve this via a transfer line between the recycler ring and the P150 line, which negates the need for new civil construction. The original design, created by Meiqin Xiao, faced engineering difficulties due to the interferences between the designed magnets in the transfer line and the beam pipe on the existing recycler ring as well as the magnet in the P150 line. This project remedied the problem by decreasing the distances between the elements of the FODO-cell, allowing for sufficient space between the magnetic elements. Once implemented with the revised design, the line will enable the antiproton source to become a set of proton storage rings to be used in the Mu2e- project.

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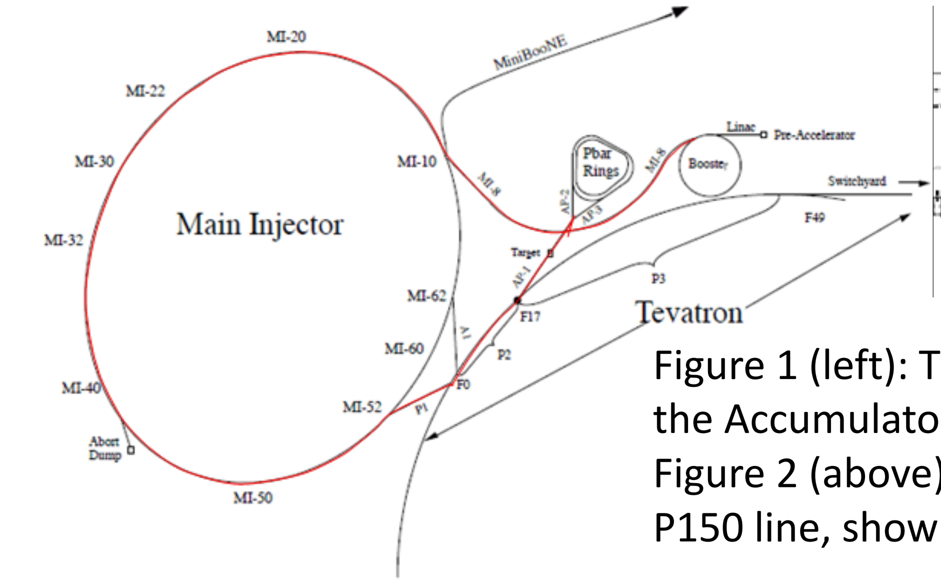
INTRODUCTION

- With CERN's Large Hadron Collider, the Tevatron will cease to be useful to scientists.
- Research with high intensity proton beams will play a key role in Fermilab's physics program
- Ankenbrandt, Harding, Johnson, McGinnis, and Popovic (2007) planned to guide an 8-GeV proton beam from the Booster to the Accumulator/Debuncher via the Recycler ring (Figure 1).
- A previous design by Xiao (2010) described a solution to transport the proton beam from the Recycler Ring to the antiproton source, by building a transfer line between the Recycler Ring and the P150 (RR2P150) line, as shown in the diagram (Figure 2).
- This design did not offer sufficient clearance between the elements of the line, which necessitated a redesign of the transfer line.



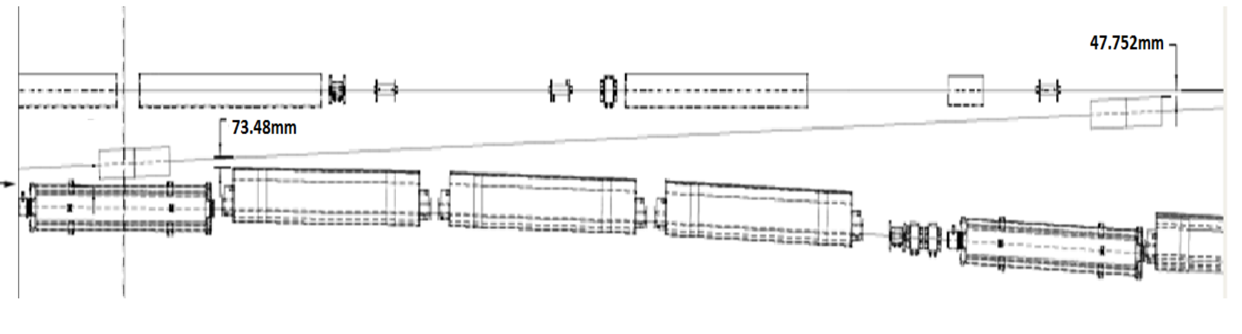


Figure 1 (left): The path developed for an 8-GeV proton beam from the Booster to the Accumulator and Debuncher via the Recycler Ring

Figure 2 (above): The diagram for the proposed line from the Recycler Ring to the P150 line, showing the limited clearance (47.752 mm) between the elements.

FOCUSING QUESTION

The SIR seeks to investigate and understand the basic concepts and theories of particle accelerator technology and physics, with a focus on linear beam dynamics, and its applications in transfer line design from the Recycler ring to the P150 line for Mu2e project.

METHODS

- The proposed transfer line is a FODO cell that successfully transforms the initial lattice function to the final lattice function.
- The FODO cell maintains its effect if its elements are moved in tandem.
- The two magnet pairs - Q901 and Q902 – are the main components of the FODO cell (Figure 3, Table 2).
- To maintain the focusing effect of the FODO cell, Q901 was moved downstream by a distance of delta L meters, and Q902 was moved upstream by a distance of delta L meters.
- The MAD program was used to match the initial lattice functions, at Q522B, with the lattice functions required at the end of the line, at Q703.
- When using MAD's VARY command, the field strength of the magnets are calculated based on the constraints. We used α and β matching, as these are the most important parameters.
- The best delta L value was decided on based on the deviation from the lattice functions (delta L = 0m values). The solution was required to 0.6 π emittance growth

Element Name	Type
M_RRLAM	Marker
DRRLAM1	Drift
RRLAMUS	Marker
LAMEND	Drift
MRKRRLAM	Marker
LAMEND	Drift
RRLAMDS	Marker
DRRLAM2	Drift
QEND	Drift
Q901A1	Quadrupole
QEND	Drift
QEND	Drift
Q901A2	Quadrupole
QEND	Drift
DSS01	Drift
MRK901	Marker
DSS1	Drift
QEND	Drift
Q902A1	Quadrupole
QEND	Drift
QEND	Drift
Q902A2	Quadrupole
QEND	Drift
DSS11	Drift
MRK902	Marker
D902VUP2	Drift
VUP2	r-bend
D902VUP2	Drift
MQ703BE	Marker
Q84U_END	Drift
M_Q703	Marker
Q703	Quadrupole
Q84D_END	Drift
DQ703Q70	Drift
Q84U_END	Drift
M_Q704	Marker
Q704	Quadrupole
Q84D_END	Drift
DQ704Q70	Drift
Q84U_END	Drift
M_Q705	Marker
Q705	Quadrupole
Q84D_END	Drift
DQ705Q70	Drift
Q84U_END	Drift
M_Q706	Marker
Q706	Quadrupole
Q84D_END	Drift

Table 1. Sequential list of elements in the RR2P150 line as specified in the lattice file. The RR2P150 transfer line begins at RRAM0 and ends at Q703.The lengths of the highlighted elements were adjusted as the experimental variables.

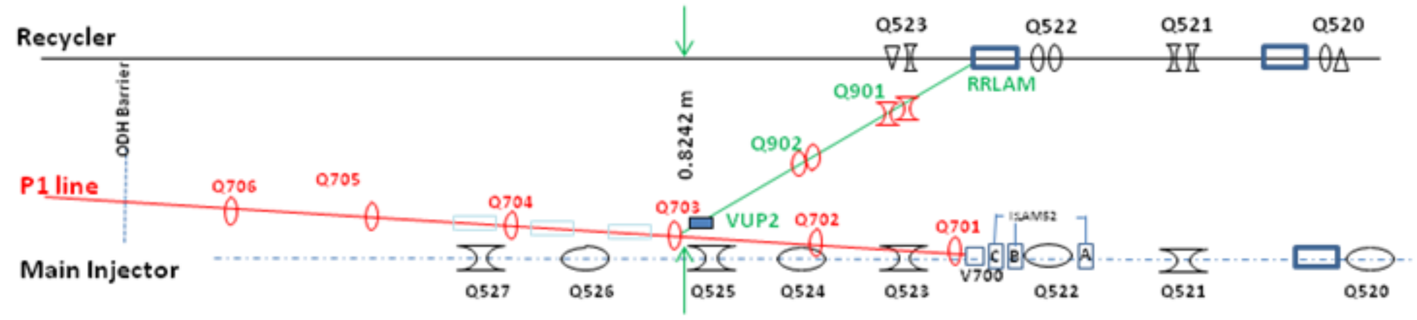


Figure 3. A diagram of the current plan for the RR2P150 transfer line, including existing infrastructure. The line is contains a FODO-cell, with the first magnet pair, Q901, being defocusing elements, and the second magnet pair, Q902, being focusing elements. Element Q703 is the injection point, at which the transfer is complete (Xiao, 2010).

RESULTS AND DISCUSSION

- ΔL = 0.25m is the best solution obtained
- Allowed sufficient space: 80.68mm (Table 2).
- Created a solution using existing magnets in a crowded location
- Redesigned without affecting the other parts of the project
- No new civil construction required

△L(m)	Gained space (mm)	Total space (mm)
0	0.000	47.752
0.25	32.886	80.638
0.5	65.771	113.523
0.75	98.657	146.409
1	131.542	179.294

Table 2. Table displaying space gained between the recycler ring and the RR2P150 transfer line. ΔL is the distance in meters that the first magnet pair Q901 is moved downstream, and the second magnet pair Q902 is moved upstream.

	ΔL = 0m	ΔL = 0.25m		ΔL = 0.50m		ΔL = 0.75m	
	Control	Matched	Percent difference	Matched	Percent difference	Matched	Percent difference
βx	11.115	12.11	-8.952	13.826	-24.390	17.541	-57.814
αx	0.618	0.618	0.000	0.618	0.000	0.618	0.000
βy	66.278	64.513	2.663	63.032	4.898	61.503	7.205
αy	-2.915	-2.915	0.000	-2.915	0.000	-2.915	0.000
μx	0.75	0.243	67.600	0.239	68.133	0.231	69.200
μy	0.75	0.34	54.667	0	100.000	0.371	50.533
Dx	0.013	0.108	N/A	0.115	N/A	0.129	N/A
Dpx	0.001	-0.005	N/A	-0.004	N/A	-0.003	N/A
Dy	-0.043	0.615	N/A	0.575	N/A	0.527	N/A
Dpy	0.007	0.004	N/A	0.002	N/A	-0.001	N/A

	ΔL = 0m	ΔL = 0.25m		ΔL = 0.50m		ΔL = 0.75m	
	Control	Matched	Percent difference	Matched	Percent difference	Matched	Percent difference
βx	11.115	11.115	0.000	11.115	0.000	11.115	0.000
αx	0.618	0.604	2.265	0.568	8.091	0.526	14.887
βy	66.278	66.278	0.000	66.278	0.000	66.278	0.000
αy	-2.915	-3.028	-3.877	-3.094	-6.141	-3.145	-7.890
μx	0.75	0.246	67.200	0.251	66.533	0.256	65.867
μy	0.75	0.344	54.133	0.357	52.400	0.367	51.067
Dx	0.013	0.103	N/A	0.103	N/A	0.102	N/A
Dpx	0.001	-0.005	N/A	-0.005	N/A	-0.005	N/A
Dy	-0.043	0.616	N/A	0.568	N/A	0.559	N/A
Dpy	0.007	0.004	N/A	0.003	N/A	0.001	N/A

Table 2. Tables of alpha (left) and beta (right) matched values. Each match occurs for three values of ΔL, including 0.25m, 0.5m, and 0.75m. ΔL = 0 is the control, as it defines the ideal values of the beam, under the current plan (Xiao, M., personal communication, August 11th, 2010). The "matched" column indicates the beam's values at the injection point, Q703. Dx, Dpx, Dy, and Dpy's percent differences are not included in the table because the range for this value is absolute, and thus its change from the original ΔL = 0 is not important.

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