Polyethylene Wedge Absorber in MICE

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Using the wedge absorber in place of the flat absorber would allow demonstrating emittance exchange and simultaneous reduction of the transverse and longitudinal emittance in MICE. The only issue is that the initial distribution upstream of the absorber should have a certain dispersion. There is no mechanism to generate the required dispersion in the MICE beam line and cooling channel, so the desired dispersion must be generated by particle selection or beam reweighting.

Reverse emittance exchange can be demonstrated as well using the wedge absorber [1, 2, 3] with a cut on the energy spread. No further particle selection is required in this case.

Since the LiH wedge could not have been fabricated, it is proposed to use a polyethylene (ultra-high molecular weight, UHMW) wedge. Polyethylene is readily available, inert, and easily machinable. Two slabs of size 24" $\times$ 24" $\times$ 5" will be used to fabricate two identical half-wedges along with the outer disk that matches the geometry of the currently installed LiH disk so that the plastic wedge could be used as a drop-in replacement for the disk.

A wedge with the opening angle of 45 degrees was selected for the following reasons:

- it shows more transverse emittance reduction than the wider 60-degree wedge, while the longitudinal emittance reduction is still significant;
- the wedge is lighter and more compact, which is important given that polyethylene ($\rho = 0.945$ g/m^3) is denser than LiH (measured $\rho = 0.69$ g/m^3) [4];
- covers more aperture, the apex offset with respect to the beam centerline is 63 mm compared to 45 mm for the 60-degree wedge.

Plastic wedge as rendered in Autodesk Fusion 360 is shown in Fig. 1. The simplified MICE lattice as simulated in G4beamline [5] is shown in Fig. 2.

The fact that one of the coils generating a solenoidal magnetic field was rendered inoperable in September 2015 (the so-called Match 1 coil downstream of the absorber, M1D) adds a layer of complexity, given that the lattice is necessarily asymmetric, and there are limits imposed on the other magnet currents. In

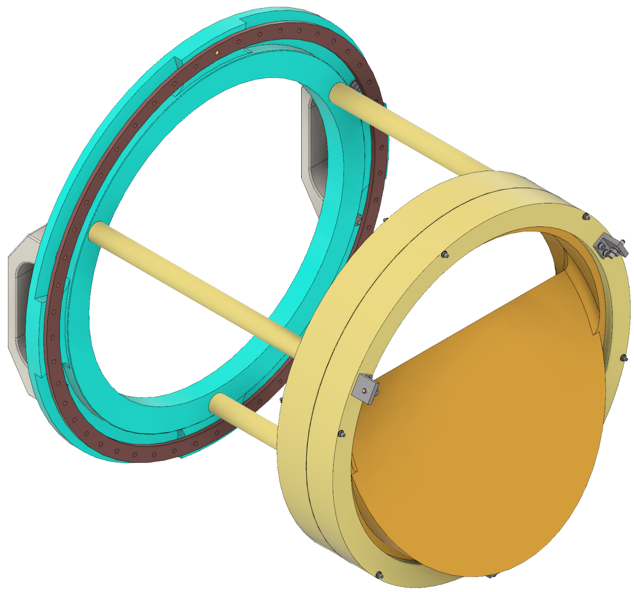


Figure 1: 45-degree opening angle polyethylene wedge engineering drawing. The support structure currently used for the LiH disk absorber is also shown.

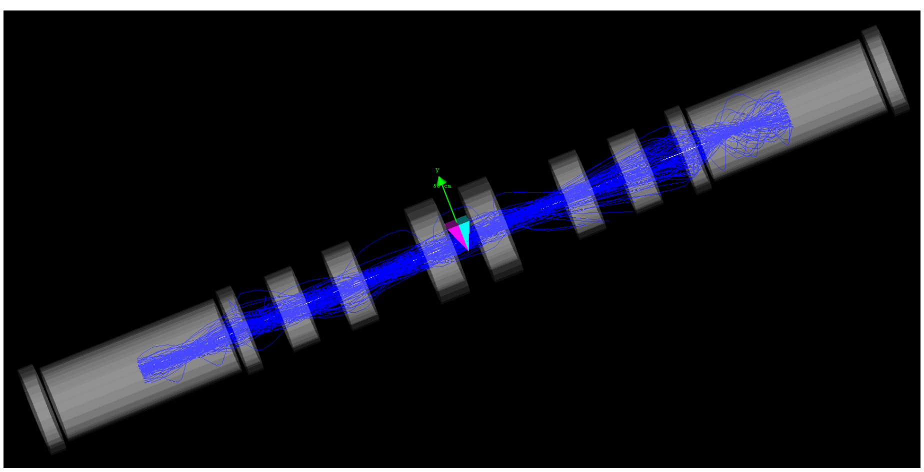


Figure 2: MICE coils (gray), two half-wedge absorbers (magenta and cyan), and particle tracks (blue). The effect of the turned-off M1D and M2D coils is clearly visible as a drift-like expansion of the beam downstream of the absorber.

Table 1: MICE coil geometry parameters and currents for the polyethylene wedge run. Both M1D and M2D are off.

Coil name	Position [mm]	Length [mm]	Inner radius [mm]	Outer radius [mm]	Current [A]	Current density [A/mm^2]
E2U	-3200.28	110.642	258	325.783	208.5	110.33
CU	-2450.28	1314.300	258	280.125	208.5	110.26
E1U	-1700.29	110.642	258	318.905	208.5	110.94
M2U	-1300.29	199.492	258	288.925	170.0	88.03
M1U	-860.65	201.268	258	304.165	142.8	74.16
FCU	-202.20	213.300	267.6	361.900	160.0	89.12
FCD	202.20	213.300	267	361.800	-160.0	-89.14
M1D	860.65	201.268	258	304.483	0.0	0.00
M2D	1300.29	199.492	258	288.608	0.0	0.00
E1D	1700.29	110.642	258	319.638	-208.5	-110.94
CD	2450.28	1314.300	258	280.416	-208.5	-110.26
E2D	3200.28	110.642	258	326.220	-208.5	-110.33

particular, the desired configuration has a 3 T uniform field in the spectrometer solenoids instead of 4 T. In addition to that, it is better not to have current in another downstream coil immediately adjacent to the faulty M1D, the so-called Match 2 coil, M2D). This study shows that even under these constraints one can still observe a significant reduction in both the longitudinal and transverse emittances.

The selection process to obtain particles with the desired dispersion is only applied upstream of the absorber, while the downstream distribution is not manipulated in any way. This requires a larger statistics to be gathered than in other typical MICE runs since we are generating dispersion by selecting a sample of a larger distribution.

MICE coil geometry parameters and currents (as simulated) are summarized in Table 1. A case with no M1D/M2D is illustrated. A number of beam configurations were simulated, with the one presented here producing the best results.

The simulation procedure is set up as follows:

- Start with a prescribed distribution at the center plane (the symmetry plane of the absorber perpendicular to the beam axis), initially without the absorber. Beam parameters are summarized in Table 2. The beam travels nominally in the upstream direction ($-z$), the time is increasing from zero as the particles travel backwards. Flip the polarity of all the magnets.

- Backtrack the distribution up to the center of the upstream Center coil

Table 2: Initial beam parameters and wedge absorber parameters.

Parameter	Unit	Value
initial p_z	[MeV/c]	140
dispersion at the absorber	[mm]	400
$\varepsilon_\perp$	[π mm·rad]	6
$\beta_\perp$	[mm]	420
$\varepsilon_\parallel$	[π mm·rad]	90
$\beta_\parallel$	[mm]	2320
wedge on-axis length	[mm]	52
wedge apex displacement	[mm]	62.77
wedge opening angle	[deg]	45
wedge outer radius	[mm]	195
wedge weight w/support ring	[g]	9788

Table 3: Six-dimensional, transverse, and longitudinal emittance reduction, longitudinal momentum reduction between upstream and downstream reference planes.

	Unit	Upstream	Downstream	% reduction
ε_{6D}	[πmm·rad]	11.80	8.12	31.2
$\varepsilon_\perp$	[πmm·rad]	5.54	4.80	13.3
$\varepsilon_\parallel$	[πmm·rad]	76.63	41.08	46.4
average p_z	[MeV/c]	141.4	120.9	14.5

(CU in Table 1), $z = -2451$ mm in the current setup.

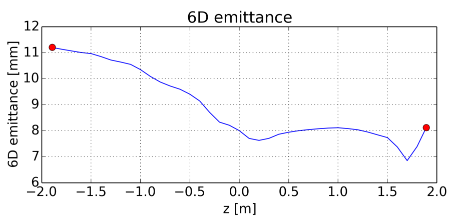
- Perform the coordinate transformation $t \to -t$, $p_x \to -p_x$, $p_y \to -p_y$, flip the polarity of the magnets back to normal. The beam is now ready to be propagated down the cooling channel.

- Run particles through MICE with the polyethylene wedge absorber in place. The absorber parameters are summarized in Table 2.

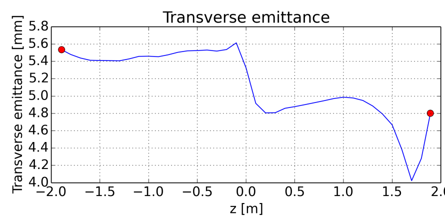
The results are shown in Fig. 3, the emittance change is summarized in Table 3. The transmission in this configuration is 85% (before any momentum cut), the momentum cut applied is $p_z \in [100, 400]$ MeV/c, no other cuts were applied.

Conclusion

Observing simultaneous six-dimensional, transverse, and longitudinal emittance reduction is possible in MICE Step IV using a polyethylene wedge even if the



(a)



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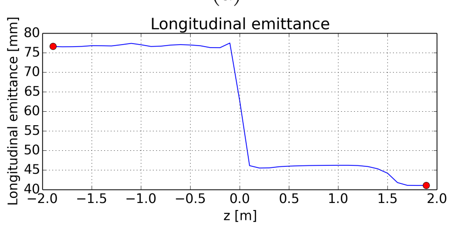
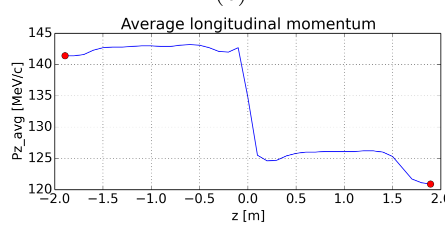
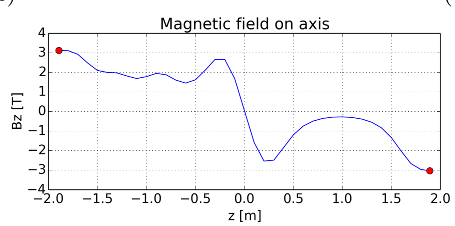


(c)



(d)



(e)

Figure 3: Beam parameter evolution between the upstream and downstream reference planes (marked with a red dot): (a) six-dimensional normalized emittance; (b) transverse normalized emittance; (c) longitudinal normalized emittance; (d) average longitudinal momentum; (e) magnetic field on axis.

two coils, M1D and M2D are inoperable. The dispersion in the beam needs to be generated by particle selection. The best configuration found so far is with the 45-degree wedge opening angle. This wedge generates more transverse cooling than the 60-degree one. At the same time, the longitudinal cooling is not jeopardized. The wedge itself is smaller and lighter and covers more of the beam aperture. On the other hand, the 30-degree wedge requires larger dispersion at the wedge, which complicates particle selection. The fabrication of the absorber is straightforward with short lead time and material readily available.

References

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