Wedge Absorber Simulations for the Muon Ionization Cooling Experiment

Chris Rogers, Rutherford Appleton Laboratory
Pavel Snopok, Linda Coney, University of California Riverside

February 25, 2010

History in the making

- EPAC'08, Chris Rogers, Weighting algorithm article.
- NFMCC Meeting, Jan 2009, first open discussion.
- MICE CM24, Jun 2009, two approaches discussed.
- COOL'09, Aug 2009, presentation, article.
- NFMCC Meeting, Jan 2010, people asking about progress and more information.
- MICE VC, Feb 2010, this presentation.
- MAP Friday Phone Meeting, summary of the MICE VC talk.
- MICE CM26, Mar 2010, presentation, seeking approval from MICE to "get official".

Longitudinal cooling + emittance exchange

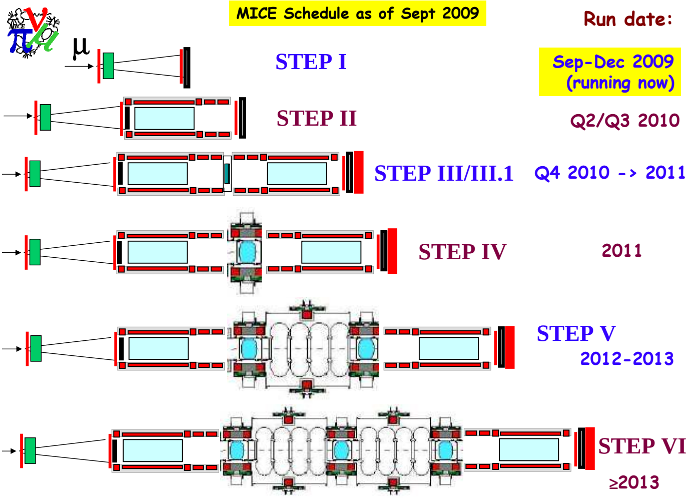
- In emittance exchange, a dispersive beam is passed through wedge-shaped absorbers.
- Muons with higher energy pass through more material, resulting in a reduction in longitudinal emittance as well as transverse emittance.
- Emittance exchange is a vital technology for a Muon Collider and may be of use for a Neutrino Factory.

Wedge absorber in MICE Step IV

Current situation with MICE

- In the Muon Ionization Cooling Experiment (MICE), muons are cooled by ionization cooling.
- Muons are passed through material, reducing the total momentum of the beam.
- Decrease in transverse emittance + slight increase in longitudinal emittance, but overall reduction of 6D beam emittance.
- MICE Step IV absorber is not meant for demonstrating longitudinal cooling and emittance exchange.

MICE Schedule



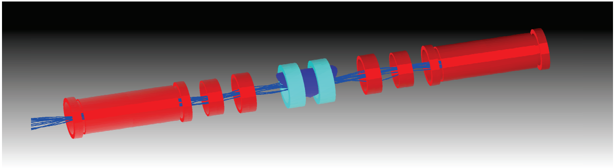
Wedge absorber in Step IV

- In addition to demonstrating ionization cooling, using the wedge absorber will demonstrate emittance exchange.
- Cooling in both transverse and longitudinal directions can be achieved.
- Careful choice of the beam parameters is important.

Assume we have the freedom to choose the beam

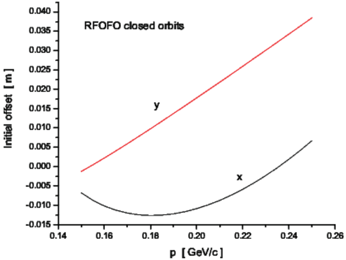
Simple Wedge

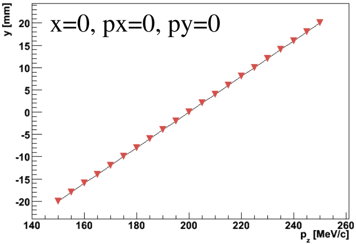
- Simple wedge
  - Induce dispersion in input beam
  - Measure (reverse) emittance exchange
- To what purpose?
  - “Proof-of-principle” - demo for wider community
  - Test material physics model in a different geometry
- Open questions
  - Which material?
  - What opening angle?
  - Can we measure an effect?



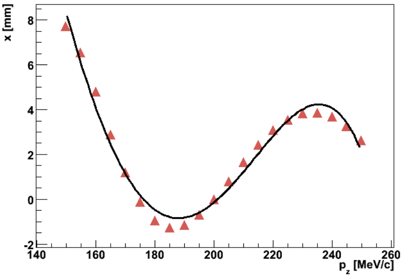
RFoFo Model

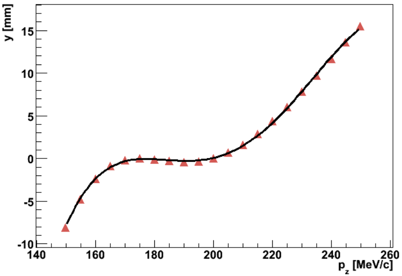
- Induce some y-pz correlation in particles at the wedge
  - Working to approximately follow RFoFo lattice - MUCOOL Note 314





Distribution at the downstream detector

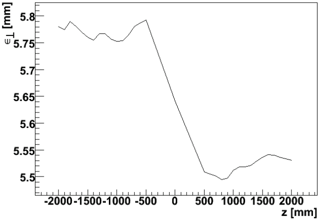


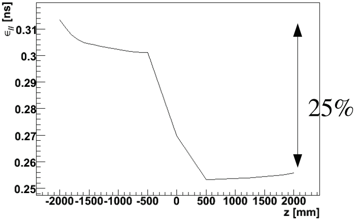


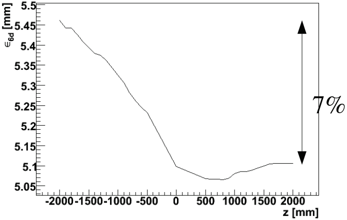
- Pretty nonlinear (4th order polynomial fit is shown).
- By applying (t,px,py)⇒(-t,-px,-py) obtain the distribution we need at the upstream detector to generate linear dispersion at the wedge symmetry plane.

Emittances 90º LiH Wedge

- D_y=200 mm this time
- ~ 25% longitudinal emittance reduction
- 6D emittance reduction
  - 7 % in mm
  - 20 % in mm³
  - lH2 is much worse
  - Plastic is similar

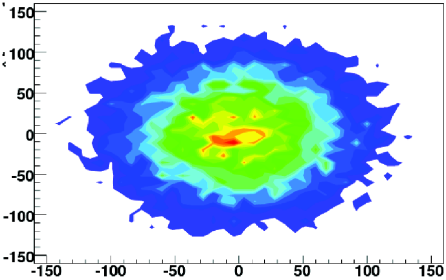




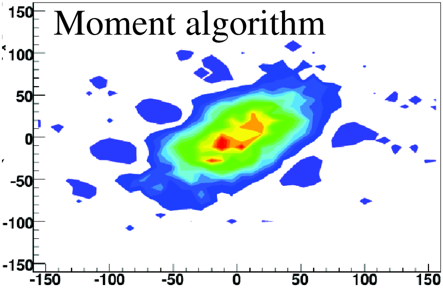


Machine beam vs matched beam

Machine beam vs matched beam



Machine beam



Desired distribution

- Apply a set of statistical weightings that map the input beam distribution from the beamline to the ideal input beam distribution:
- Events that sit in an area of phase space that is statistically depleted relative to the matched distribution would receive a larger weight; and those that sit in an area of phase space that is statistically enriched relative to the matched distribution would receive a smaller weight.

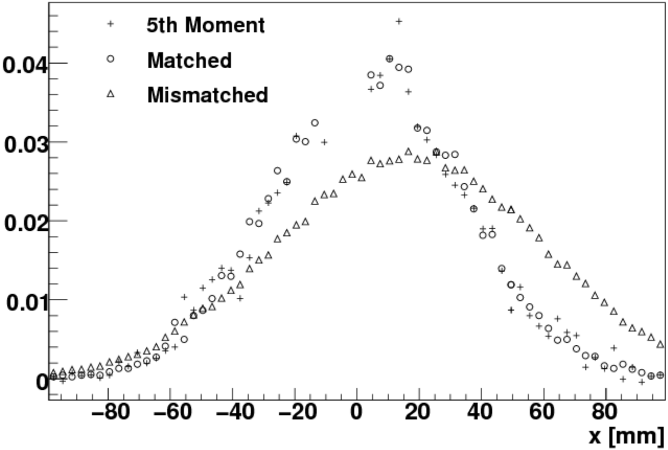
Statistical weighting

- Statistical weights are found by comparing the moments of the realistic beam with the moments of the ideal beam.
- w^i—weighting function, $w(\vec{u})$ is a polynomial in the six-dimensional phase space vector, such that for the i^{th} particle with phase space vector $\vec{u}^i = (x^i, y^i, t^i, p_x^i, p_y^i, E^i)$

$$w^i = a_0 + \sum_j a_j u_j^i + \sum_{k_1 k_2} a_{k_1 k_2} u_{k_1}^i u_{k_2}^i + \dots \qquad (1)$$

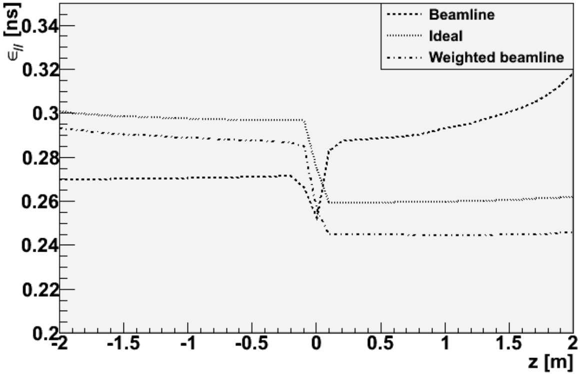
- Applying this weighting to each particle gives us a set of weights that maps the moments of the realistic beam to the moments of the ideal beam, and by extension the distribution of the realistic beam to the distribution of the ideal beam.

Weight distribution



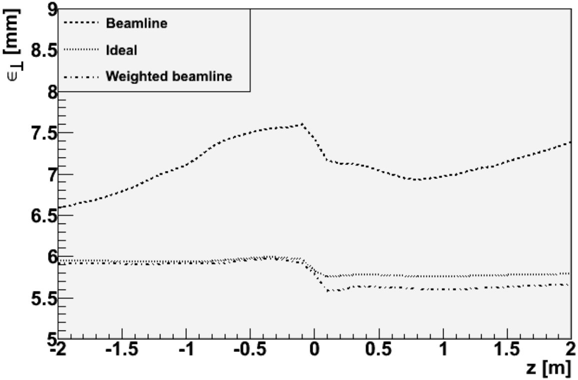
- The ideal distribution and the mismatched distribution before and after weighting up to 5th moment.

Longitudinal emittance



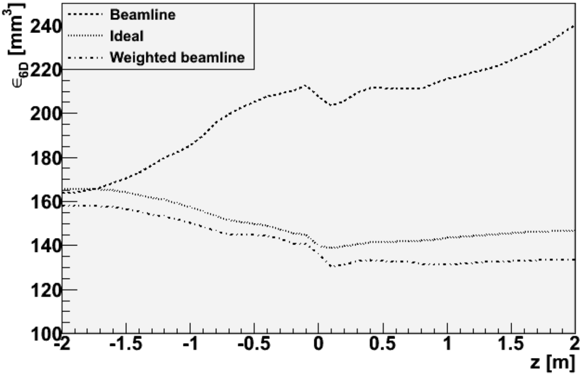
- Longitudinal emittance: the machine beam (dashed line), the ideal beam (dotted line), and the beam matched up to the 5th order using statistical weighting (dash-dotted line).

Transverse emittance



- Transverse emittance: the machine beam (dashed line), the ideal beam (dotted line), and the beam matched up to the 5th order using statistical weighting (dash-dotted line).

6D emittance



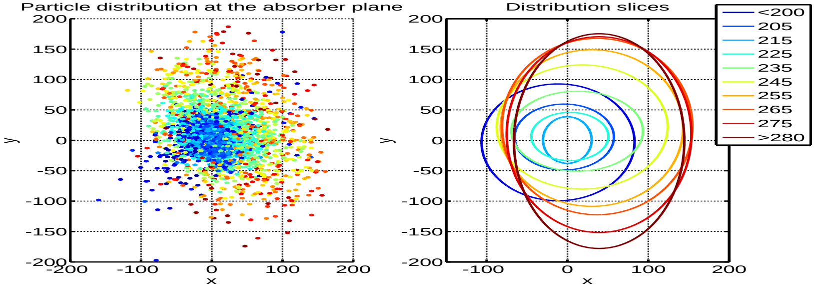
- 6D emittance: the machine beam (dashed line), the ideal beam (dotted line), and the beam matched up to the 5th order using statistical weighting (dash-dotted line).

No control on the beam, changing the shape of the absorber

Alternative approach: use existing beam and carefully shaped absorber

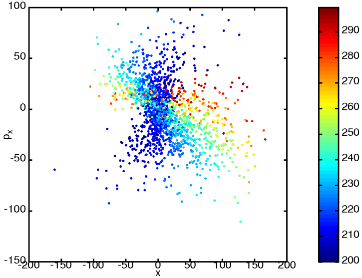
- Start with whatever distribution comes from the beamline to the experiment.
- Track the distribution to the absorber plane.
- Analyze the resulting distribution.
- Decide on the shape of the absorber required.

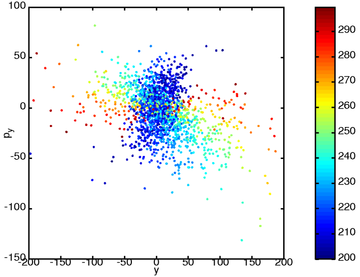
Shape of the distribution at the absorber plane



There is a strong overlap of the regions with different longitudinal momenta.

Shape of the distribution at the absorber plane



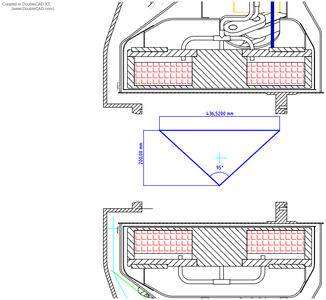


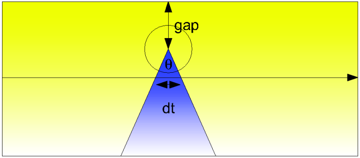
- The transverse components of the momentum are quite large.
- We cannot assume that this is the distribution we get when the experiment runs.
- Main concern: “fancy” absorber only works with one particular beam distribution.

Recent progress

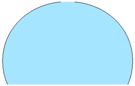
- Decided not to pursue “fancy” absorber.
- Discussing engineering issues with Wing Lau, John Cobb and others, mainly the issue of supporting the solid absorber (plastic or LiH).
- Discussing exact parameters of the cylindrical wedge: angle, radius, orientation.
- Expected weight of the wedge is 10-12 kg.
- Getting ready for MICE CM26 with the hope of becoming an official part of MICE experiment.

Wedge absorber parameter studies





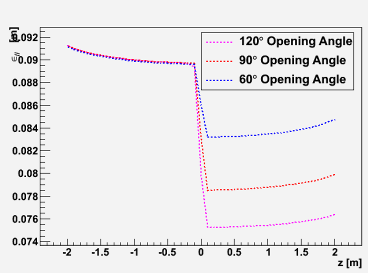
Side On

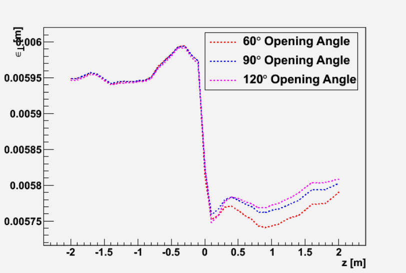


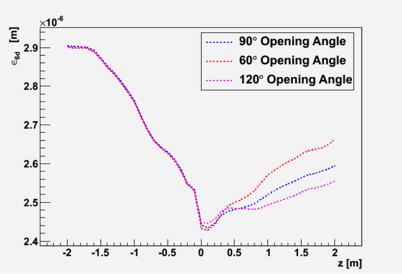
End On

Left: wedge absorber inside the coupling coil, right: schematic wedge geometry.

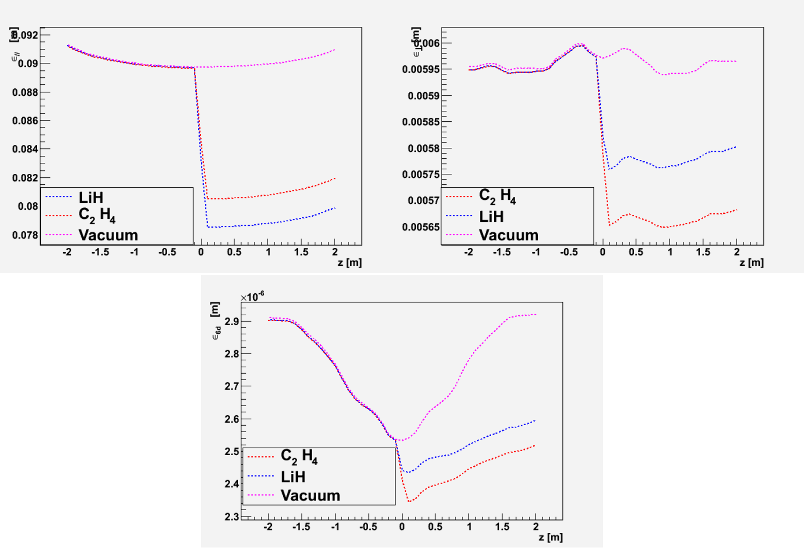
Absorber angle



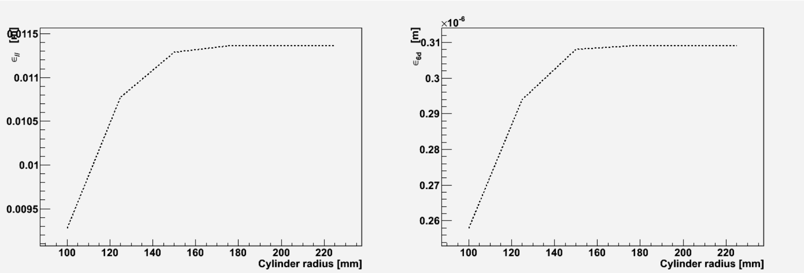




Absorber material



Absorber radius



Difference between the upstread and downstream emittances (emittance reduction).

Feedback from the community

- People at the last NFMCC meeting were very interested in the topic and progress, and were complaining about how little they hear on the subject.
- Bob Palmer expresses his interest in talking to us before MICE CM26 and making a presentation at the meeting.
- There was a discussion on the material choice: should we decide in favor of a plastic wedge (cheap and immediately available) or explore more on the LiH wedge cost and fabrication issues.

Summary

- Emittance exchange is a powerful technique that may be of use for a Neutrino Factory and is vital to a Muon Collider.
- Observation of this phenomenon in the MICE setup would normally be impossible due to the presence of catastrophic beam blow up from non-linearities in the beam optics.
- The use of beam selection or statistical weighting presents us with the opportunity to make measurements over a wider range of parameters than can be generated with the MICE beam.
- Emittance exchange can be demonstrated using a wedge-shaped absorber in MICE Step IV.
- Preliminary wedge parameter studies are underway.
- The project generated a lot of interest from the community.