Constraints on Measurements in a Muon Cooling Exp.

J. Norem
HEP/Argonne
11/10/00

Muon Collaboration

Muon Cooling Instrumentation Workshop

This talk covers three unrelated subjects:

1) The effects of beam correlations in an emittance exchange channel seem to be large and difficult to understand.

2) Dark currents and x rays from rf cavities produce an environment where it is difficult to operate sensitive instrumentation.

3) Faraday Cups and Secondary Emission Monitors have many desirable features.

PART 1: Emittance Exchange Issues / Correlations

There are a number of Emittance Exchange options . .

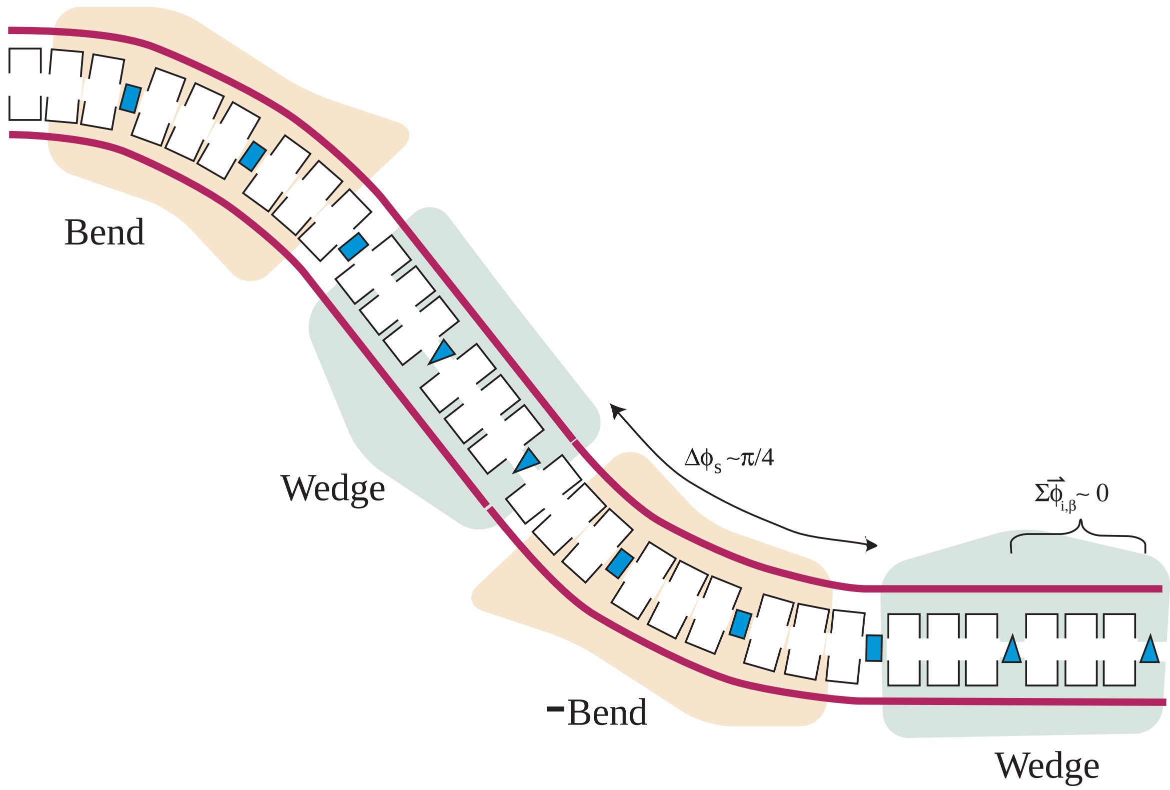
- Bent Solenoid
  - Tight bend w/o rf
  - Gentle Bend with RF
- Helical Channel
- Ring Coolers
- . . .

. . and a lot of people are concerned with these problems.

Talks at BNL workshop on Emittance Exchange 9/00

Bob Palmer	Introduction to exchange theory
Rick Fernow	Bent solenoid simulations
Dave Neuffer	Exchange theory
Jim Norem	Bent solenoid tracking results
Rick Fernow	ICOOL Background feature
Yasuo Fukui	Transverse bunch stacking
Scott Berg	Impact of exchange on neutrino factory
Don Summers	Stacking bunches
Bob Palmer	s-FOFO with dipoles
Dejan Trbojevic	Ring cooler lattice
Juan Gallardo	Bent rf cavity fields
Bruce King	Longitudinal focusing without rf
Jim Norem	Status: gentle bend dynamics
Rick Fernow	Summary of week 1
Yaroslav Derbenev	Helical channel theory
Paul Lebrun	Bent solenoids in GEANT 4
Daniel Elvira	Helical channel simulations
Dave Neuffer	Buncher demo
Gregg Penn	Helical channel simulations
Valeri Balbekov	Helical channel simulations
Gail Hanson	s-FOFO + dipole simulations
Bob Palmer	r-fofo + bend + wedges
Scott Berg	Emittance exchange without wedges
Valeri Balbekov	Exchange in ring coolers
Chun-xi Wang	Status report
Yaroslav Derbenev	Cooling energy spread of initial beam
Allen Caldwell	Low energy muon cooling
Paul Lebrun	Low energy muon cooling
Dave Cline	Use of friction cooling in a plasma

My Experience is with one Emittance Exchange Option



- A cooling line in a homogeneous solenoid, with rf confinement, is bent to produce dispersion, and LH2 wedges are positioned to reduce the energy spread.

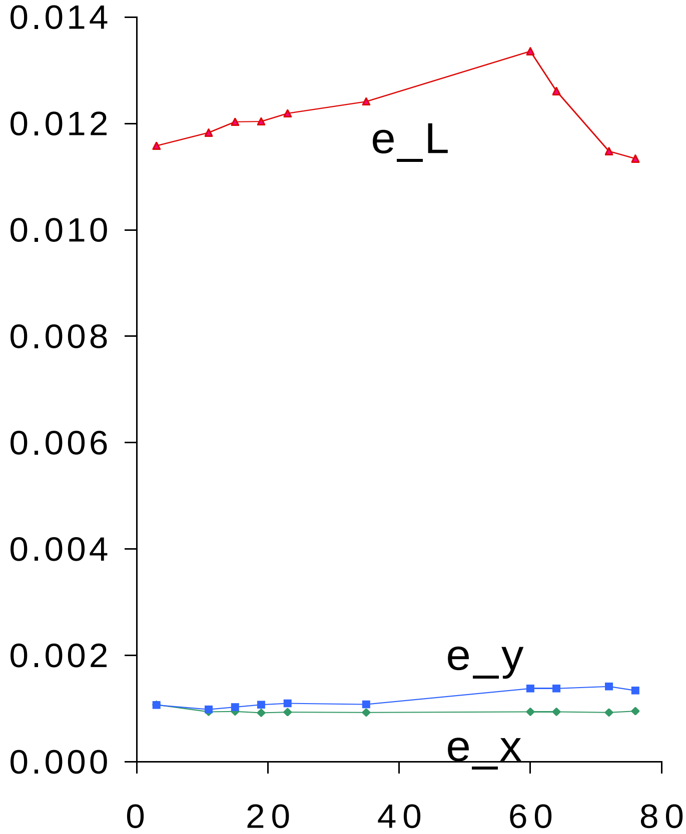
- This system cools in 4 dimensions, (p_x, p_y, E, t), so that ε_x, ε_y, and ε_L are simultaneously cooled.

- Synchrotron motion limits the dispersion that can be induced by the bends, and generally complicates things.

- <u>Discontinuities heat beams</u>, and this method may be the most gentle - but it's not optimized yet.

The correlations affect results.

The graph shows the results of passing a beam, optimized for demonstrating problems rather than emittance exchange, through this channel in ICOOL.



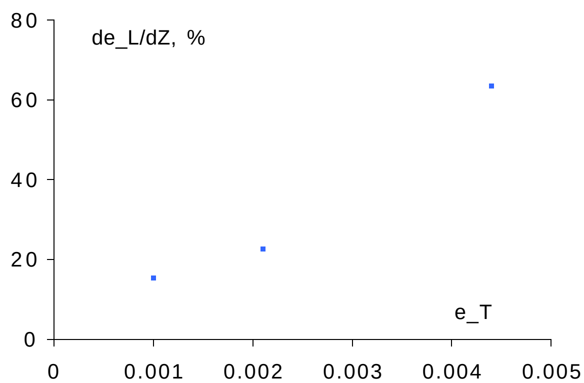
- The ε_L and ε_y both rise in both the bends.
- The ε_L drops only in the second wedge.

Growth in ε_L

In addition to the emittance exchange effects, there is emittance growth of ε_L due to:

Momentum dependence of dE/dx	(real)
Straggling	(real)
Path length differences around bends	(tunable)
Divergence $\Rightarrow$ velocity effects	(tunable)
(Synchrotron motion complicates this.)	
Dispersion	(real)
Transverse emittance	. . .
. . .	

The growth can be very large



Sorting out these effects takes time.

Emittance Calculations

- Its not clear the emittance is now being calculated in an optimum way. The transverse emittance, exclusive of correlations, can be calculated from the 4D covarience matrix, $\varepsilon_T \sim (\det M)^{0.25}$.
  - For ε_x use a 2 x 2 matrix (x, p_x).
  - For ε_6 use a 6 x 6 matrix (x, p_x y, p_y ct, E).

  - Except in special cases, $\varepsilon_6 \neq \varepsilon_L \varepsilon_x \varepsilon_y$, if different matricies are used.

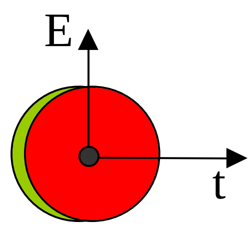
- With dispersion and synchrotron motion, the beam may be aligned in 6D phase space that in a way that is not neatly described relative to normal coordinates. In principle it may be possible to define three orthogonal emittance numbers, but these may have limited physical usefulness.

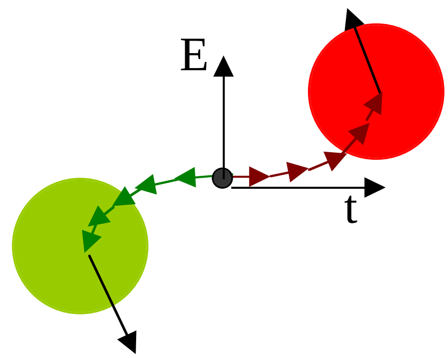
- It would be desirable to use a geometry which will avoid messy correlations.

- It may also be necessary to experimentally look for correlations.

An Example:

- Bending Solenoids introduce correlations.
  With beam at **+dX** and **–dX** have different path lengths around a bend. This gives a offset in synchrotron space (and an increase in ε_L).





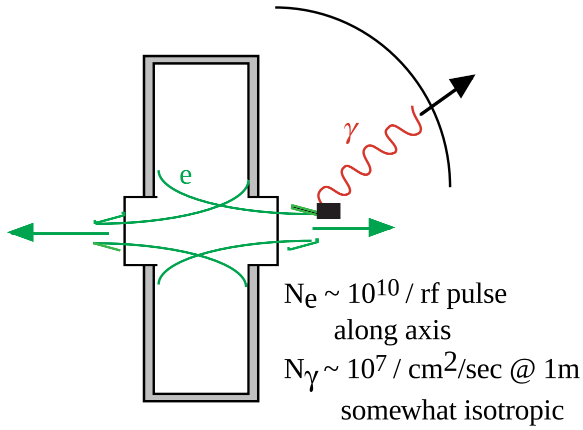
- In principle these correlations can be removed, however synchrotron motion in, and between, bends complicates this.

- If all particles circulate around a common axis, the path length effects cancel. Wedge operation is also cleaner because fluctuations due to Larmor motion can be averaged out.

- A particularly good environment for emittance exchange using this method should be the downstream end of a single flip channel.

PART 2: X Rays and Dark Currents from RF Cavities.

- Large fluxes of x rays and electrons are produced.

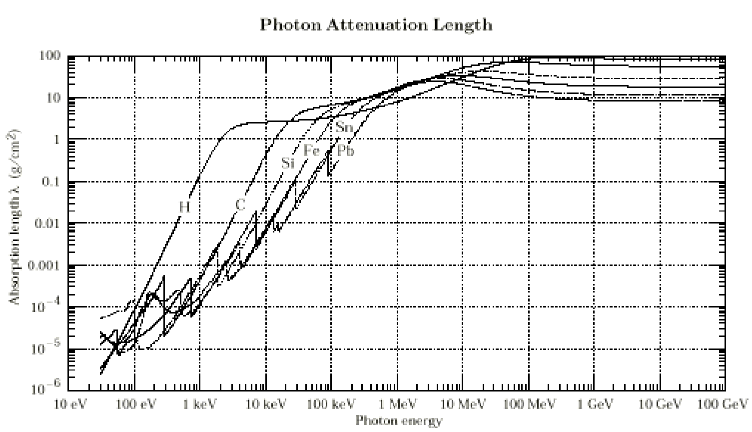


- Three mechanisms are involved:

  1) Dark currents, evidently produced by field emission, have a $I \sim E^{9.6}$ dependence on the electric field.

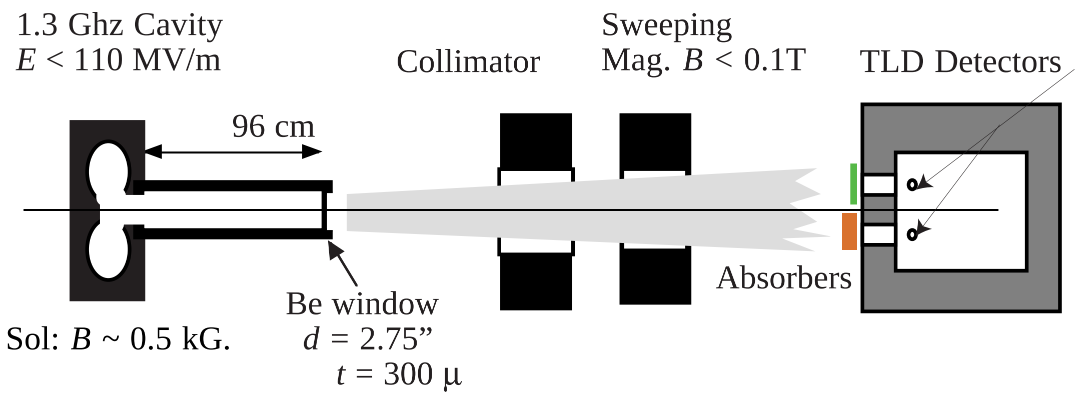
  2) Normal Bremstrahlung produces photons from low energy (short range) electrons.

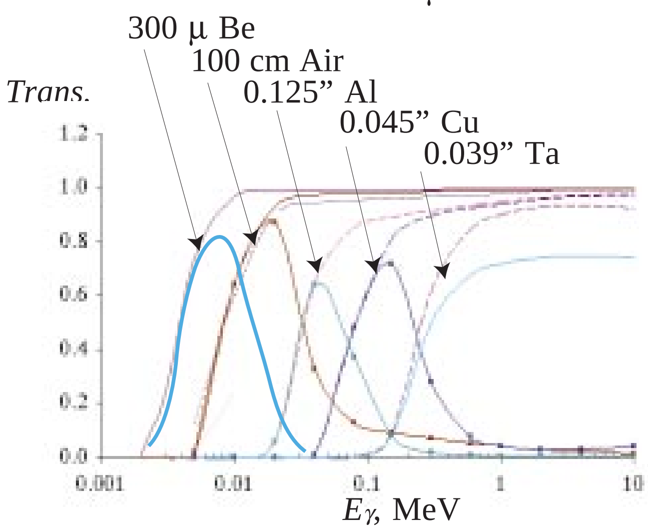
  3) Absorption of photons occurs below ~100 keV. ~1 MeV photons just scatter.

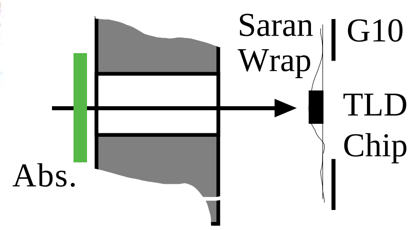


Measurements at Argonne

We measured X rays with the absorption method.



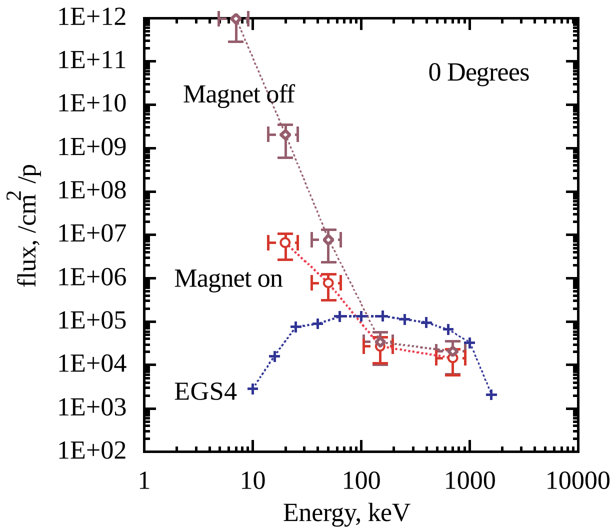




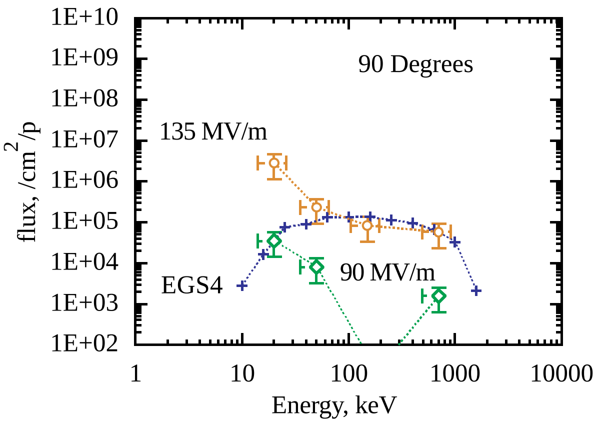
Measurements of a 1.3 GHz cavity at Argonne

- If all radiation is assumed to be from x rays, and an EGS4 spectrum is included for comparison, One sees:

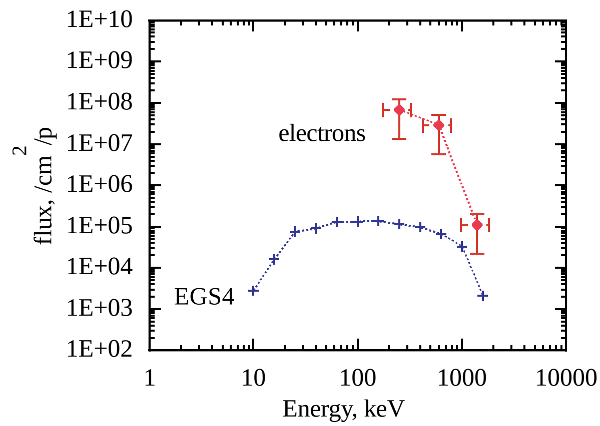
at 0 degrees



at 90 degrees



If the low energy rates are assumed to be electrons,



We still need measurements of:

- the dark currents and x-rays from multicelled cavities
  These fluxes should go to higher energies, but many dark current electrons may interact with the cavity walls.

- the effects due to B Field.
  The B field should affect the dark current orbits.

- measurements of emission vs. rf phase.
  Can we measure muons between bunches?

- measurements of the electron energy spectrum.

In addition, it would be useful to know if reducing the rf field or introducing coatings will reduce the fluxes.

- These measurements will be made in Lab G after the test facility is assembled. This will probably be after the New Year.

- Everyone is welcome (Bring your sampling scope).

Summary

Measurement of muon cooling is straightforward in principle. One should be able to look at cooling effects with high precision by doing differential measurements, with the cooling system on and off.

It may be experimentally difficult to interpret these measurements due to correlations in the beam, which complicate the measurment of emittance, and backgrounds produced in the rf cavities.

It seems desirable to eliminate correlations when possible, measure them when possible, and design the measurement to be insensistive to rf induced backgrounds,

Faraday Cups and SEMs **J. Norem/Argonne**

The primary motivation for using these devices is their compatibility with large backgrounds

$$Signal / background = \frac{N_\mu}{f\ \delta t}$$

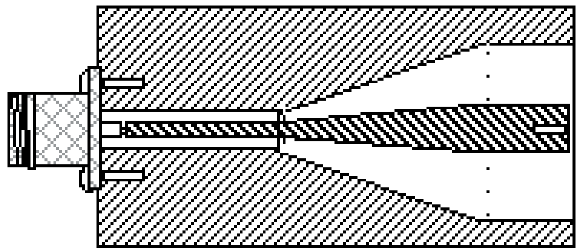
where f, δt and N_μ are the background flux, resolution time and number of muon/bunch. The resolution time, δt, of a charge collector can be much less than an rf period and shorter than any other method.

Faraday cups and Secondary Emission Monitors are:

- simple
- have a very large dynamic range (~10^2 - 10^{12} /pulse)
- very good time resolution (~20 ps measured)
- flexible (exp. and machine use the same system)
- compatible with many geometries
- some momentum / particle sensitivity
- well understood response
- no major R&D program required.

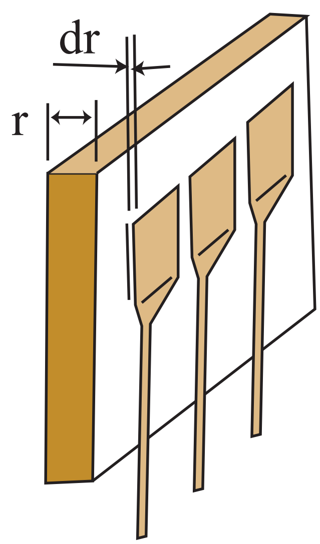
Possible Geometries

A coaxial Faraday cup and a stripline pickup.



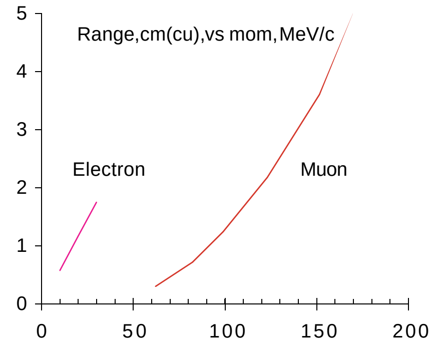
The size of coaxial pickups may be limited by parasitic circumferential modes, however it is unclear how significant these would be in a tapered line.

A planer array could function both in the Faraday cup or SEM mode. One could design for a fairly tight momentum resolution for low energy muons from range.



The limits of this technique are determined by:

- The particle ranges



- The thermal noise

$$V_{noise} = \sqrt{P_{noise} R / N_p} = \sqrt{\Delta f\, kT\, NF\, R / N_p} \sim 0.6\,\mu V,$$

where N_p, NF and Δf are the number of pulses, amplifier noise figure and bandwidth. This parameterization implies that averaging the $N_p \sim 100$ pulses and cooling the detector and preamps to 4 ^{0}K would give a sensitivity of ~4000 μ's/ns

- And the Detector Size.

$\delta t \sim (pickup\ dimensions) / c$

Cooling Lines & Ring Coolers

It is assumed that a real machine with intense beams, 10^{12} μ's/pulse, Secondary Emission Monitors (SEMs) would be used, since they provide a good signal, and signal / noise.

In a cooling test it is difficult to generate more than 10^{6}-10^{7} μ's/pulse, so Faraday cups, which absorb the entire beam, might be more desirable.

If the experiment was done in a ring cooler it seems necessary to use SEMs, which would have a signal reduced by the secondary emission coefficient, i.e. 0.02 - 0.05.

Summary

Although SEMs and Faraday cups are fairly straightforward devices, they have interesting properties which can be easily demonstrated in low energy linacs.
It would be desirable to explore:

- sensitivity to electrons and x rays
- time response
- usefulness of particle range

Electrons at 20 MeV are a good way to explore these issues and beamtime should be available at Argonne over the next few months. Everyone is welcome.