g4beamline Simulations of Parametric Resonance Ionization Cooling of Muon Beams

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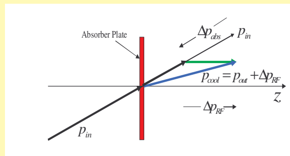
Abstract

The technique of using a parametric resonance to allow better ionization cooling is being developed to create small emittance beams so that high collider luminosity can be achieved with fewer muons. While parametric resonance ionization (PIC) cooling of muons has been shown to work in matrix-based simulations when the system is properly tuned, doing the same using a much more detailed GEANT-based **g4beamline** simulation has been more difficult.

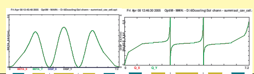
The starting point for this work is a the linear channel; a half integer resonance is induced such that the normal elliptical motion of particles in x-x' phase space becomes hyperbolic, with particles moving to smaller x and larger x' as they pass down the channel. Thin absorbers placed at the focal points of the channel then cool the angular divergence of the beam by the usual ionization cooling mechanism where each absorber is followed by RF cavities to replenish the energy. Thus the phase space of the beam is compressed in transverse position by the dynamics of the resonance and its angular divergence is compressed by the ionization cooling mechanism.

The **g4beamline** and **OptiM** simulations show the importance of synchrotron motion as averaging mechanism for chromatic detuning. Multiple scattering and energy straggling play a significant role that must be addressed via further optimizations and additional compensation solutions.



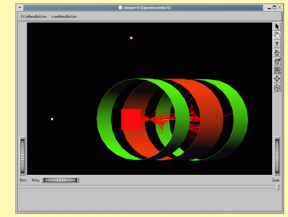
Schematic of angular divergence cooling

Ideal beta function and phase advance from **OptiM**



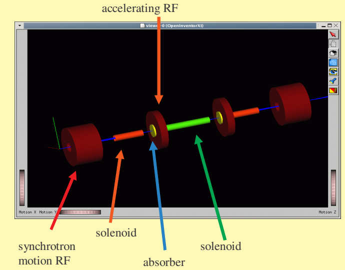
After a muon beam is initially cooled *(please see poster by K.Yonehara et al)*, it may be possible to further cool it using a periodic lattice with a parametric resonance. To find the proper parameters, analytic models and matrix based **OptiM** (*http://wwwbdnew.fnal.gov/pbar/organizationalchart/lebedev/OptiM/optim.htm*) were used initially. Now **g4beamline** (*http://www.muonsinc.com/g4beamline.html*), a new very user-friendly GEANT-based simulation tool, is being used to put in much more detailed tracking, realistic RF cavities, and interaction physics. A special CERNLIB **MINUIT**-based optimization (**kmimf**) is used to with **g4beamline** to determine the proper parameters by iteratively adjusting them and rerunning the simulation.

typical values:
KE= 200 MeV μ+ $\varepsilon_{nx}=\varepsilon_{ny}$=30 mm-mrad ε_L=0.8mm L_{cell}=7.2m absorber: 32.8 mm Be
90º off-crest (Vsyn) RF: 13.08 MV/m on-crest RF (Vacc): 57.28 MV/m
~100% transmission w/o stochastic processes, ~65% w/ stochastic processes



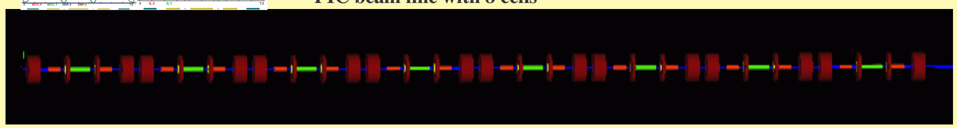
Solenoid triplet and muon beam as viewed in g4beamline with no RF present.

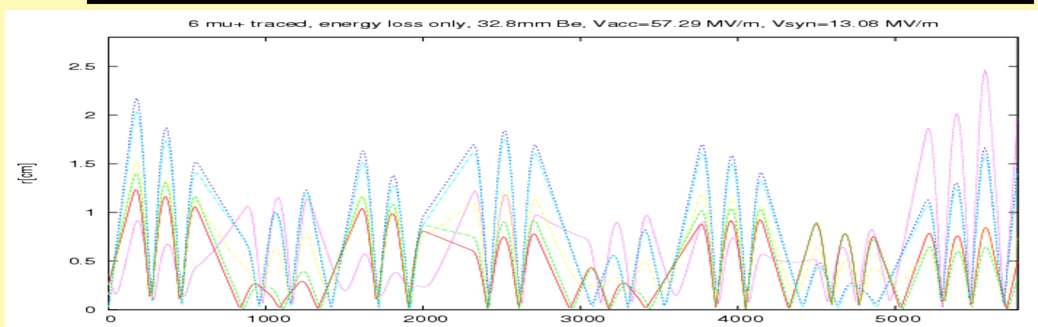
Single Solenoid Triplet Cell



One solenoid triplet cell with absorber with dE/dX RF and offcrest RF to induce synchrotron motion

PIC beam line with 8 cells



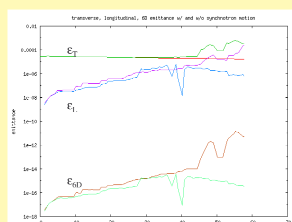


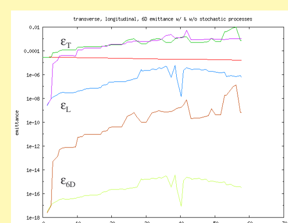
Particle tracking by **g4beamline**, collated by **retrack**.

As a first step, all energy straggling, multiple scattering, and muon decay was disabled to enable a comparison with the previous **OptiM** work. The improvement due to induced synchrotron motion is in qualitative agreement with the earlier work. **ECALC9** is used to calculate the emittances. The Be absorbers are 32.8mm thick in these examples.

The figure immediately to the right shows the improvement in emittance due to synchrotron motion **when only energy loss is enabled.**

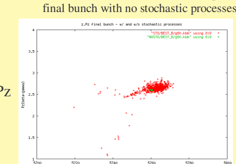
One ca note two orders of magnitude better cooling in the case of synchrotron motion averaging.





The final bunch with all stochastic processes enabled is shown in red, while the final bunch with no stochastic processes enabled is shown in green.

Pz



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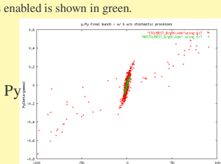
Py



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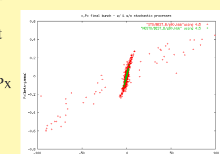
When multiple scattering, energy straggling, and other processes are enabled the emittances increases enormously as shown in the figure to the left. No attempt has been made yet to optimize the parameters in the presence of these stochastic processes.

The final bunch with stochastic processes enabled is shown in red; the final bunch without stochastic processes is shown in green.

Px



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