

# COMPUTATIONAL MODELING OF MUONS PASSING THROUGH GAS PRESSURED RF CAVITIES

A. Samolov, A. Godunov, Old Dominion University, Norfolk, USA

## Abstract

Using high-pressure RF cavities for muon colliders would provide higher accelerating gradients, that is crucial for fast acceleration of short-living muons. This approach requires a good evaluation for mechanisms of muon - low-Z gas interaction, including such effects as multiple scattering and space charge effects. Most present simulation tools (*GEANT4*, *G4beamline*) for muon beams are based on single particle tracking, where collective effects are not taken into account. We use a modified molecular dynamic simulation technique to study effects of both multiple scattering and space charge screening by the gas on scattering, energy loss, and propagation of muons during both ionization cooling and acceleration.

## INTRODUCTION

Muon cooling is necessary for both a neutrino factory and a muon collider. The need to fit a diffuse muon beam inside the typical accelerating aperture, and at the same time to fit it longitudinally into an RF cavity for acceleration, affects the design of the both facilities. Recently a new approach has been suggested, namely to use high pressure RF cavities to achieve extreme muon cooling. To support these new ideas and developments, and to validate a technical design of these new accelerating facilities, accurate and comprehensive simulations are required long before their construction. Since muon cooling is achieved by passing a muon beam through some low-Z absorbing materials, the interaction between the two must be accounted for in the supporting simulations. The *GEANT4* [1] and *G4beamline* [2], are able to simulate particle passing through matter, and as such are among the best candidates for muon tracking. However the needs of muon accelerating facilities simulations require the upgrade of these tool kits with some new physics processes and features that include, but are not limited to, multiple scattering and collective effects in matter, space charge, etc [3]. The objective of this work is to evaluate the multiple-scattering model in *GEANT4*, and to study the effects of both multiple scattering and space charge screening effect on propagation of muons through matter, utilizing a modified molecular dynamics simulation technique.

## MULTIPLE SCATTERING

Multiple Coulomb Scattering model in *GEANT4* is based on the *Lewis's theory* [4]. The theory offers the solution of the diffusion equation of the multiple scattering problem without using small angle approximation [5].

The solution requires however the scattering cross sections for each particular absorbing material. In *GEANT4* cross sections are not used directly, rather the spatial and angular distributions are described by some model functions that are fitted with number of parameters. Recent reports on Muscat [6] experiment showed that *GEANT4* has a tendency to overestimate the tails in low-Z materials that would affect the design of the cooling channel. Here with our modified molecular dynamic simulation method we want to test the relevant models in *GEANT4*, as well as to study the collective effects using initially a simple model of muons passing through matter.

## PHYSICAL MODEL

We start our study with a classical scattering of muons on multiple centers. Centers are described by realistic potentials, which are calculated quantum mechanically from the first principles. We use *Hartree-Fock* for atomic targets and *Molecular Orbital* method for molecular targets. Target particles are populated randomly to simulate either a gas in a pressure RF cavity with particular material density, or liquid hydrogen. At this simulation stage the centers were kept fixed. The muons were propagated through the target one by one, or as a bunch with the interaction between them described by the Coulomb force.

## SIMULATION RESULTS

Preliminary simulation results are presented for a  $100 \frac{MeV}{c} \mu^+$  passing through liquid hydrogen target of arbitrary size  $L$ . The computational time is strongly dependent on the number of particles in a bunch (solving a system of  $4n$  or  $6n$  differential equations for 2D or 3D cases correspondingly), and the size of the target. At this stage of the simulation we kept the longitudinal size as small as 350 a.u.

First, we compare effects of Coulomb's (Fig.1) and Hydrogen Screened potential (Fig.4) on particles' spatial and angular distributions. In these simulations there was no interaction between the particles in a bunch (a single particle plus multiple scattering centers approximation). For the fast moving muons the spatial distribution for the Coulomb potential is wider comparing to the screened potential. The angular distribution reveals less difference.

The space charge results (Fig.2) compared to the results with single particle tracking results (Fig.4) show that the space charge broadens the distributions despite the fact that the interaction between particles is partly screened by the scattering centers. The spatial distribution is more affected by the space charge effect comparing to the angular distribution.

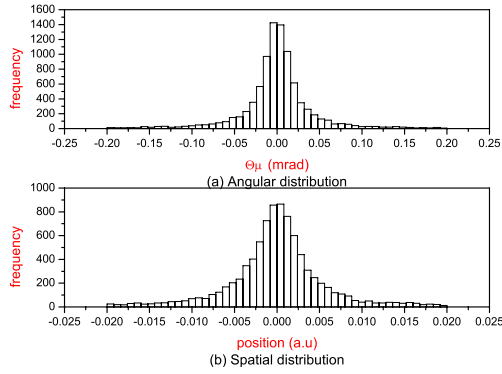


Figure 1: Distributions for the Coulomb's potential in the target

bution. This indicates that the space charge modeling needs more careful treatment as it may affect the design of muon accelerator facilities.

We also compare the effects of the size of the target on a beam spatial and angular distribution (Fig.3). Obviously the larger the size of a target, the broader the angular distribution of the scattered muons.

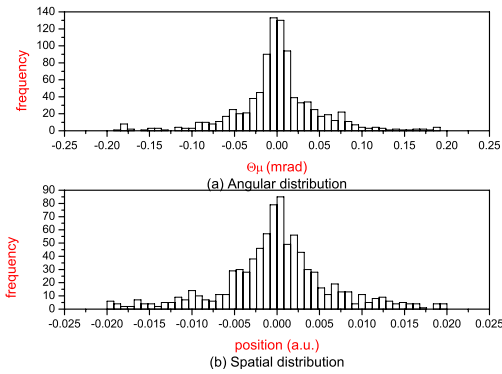


Figure 2: Distributions for the Screened potential in the target with space charge

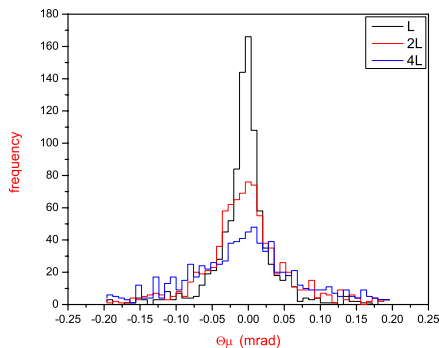


Figure 3: Angular distributions for the different target sizes

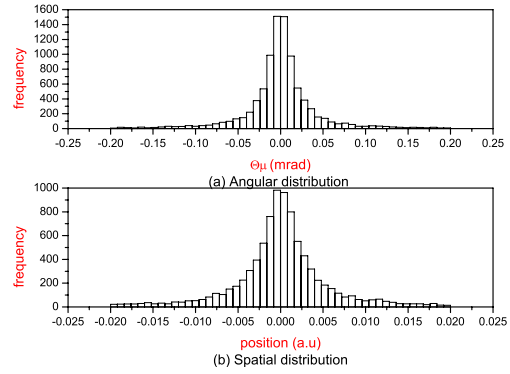


Figure 4: Distributions for the Screened potential in the target

## DEVELOPMENT PLANS

The objective of the first phase of our computer simulation was to test the basics of the model (calculations for the potentials, the numerical model). On the next phase we plan to implement the following features into the simulations: a) increase the size of the target to compare with *G4beamline* calculations provided to us, b) increase the number of muons in a bunch to decrease the surface effects on MD simulation, c) include energy straggling in target material, d) simulate low energy electron production from materials, e) include effects of magnetic field on multiple scattering.

## SUMMARY

The simulation based on a modified molecular dynamic technique has been developed to study the multiple scattering and collective effects of muon passing through matter. Preliminary results show that the choice of the target potential (calculated by *Hartee-Fock* vs. Coulomb potential) affects the particles' distributions. The effect of the space charge also influences the results, however the spatial distributions of the scattered muons are more sensitive the the potential choice comparing to the angular distributions. We plan to develop the model to include more physics that may affect the results on simulations. One of the main challenges would be to keep the computational time as reasonable as possible.

## REFERENCES

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