PSI Low Energy Muon Source Study and its Possibility for Acceleration Test

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Abstract

1 Introduction

1.1 Motivation

The anomalous magnetic moment of muon $a_\mu = (g-2)/2$ and the muon electric dipole moment (EDM) d_μ will be measured at the J-PARC muon facility. The E34 experiment at J-PARC introduced a new method with a very different technique, using a 300 MeV reaccelerated thermal muon beam with 50% polarization. Now the preparation of the E34 experiment is actively ongoing.

Previously, a preliminary study of thermal re-accelerated muon production was conducted. Several new muonium target geometry designs were proposed and positive results on the enhancement of muonium production was achieved. More Mu could be hopefully ionized and accelerated further[**1**].

Currently, however, the re-accelerated thermal muon by laser ionization method won't be ready soon. Instead, we are using muon source generated from Al plate for muon LINAC component test. But muon source by this method is way too small to carry out high-intensity characterization on SOA, RFQ and IH-DTL components of muon LINAC.

The estimated Muonium Mu^- Event rate at the final detector now are:

- 6.8×10^{-4}/sec at 300kW for D2 area (surface muon intensity 2.5×10^6/sec), efficiency 10^{-10}[**2**]
- 2×10^{-2}/sec at 1MW for H area

Considering current situation, the Low Energy Muon (LEM) source at PSI may be a temporal choice. They are currently applied on PSI muon precision physics study and have a higher event rate. Thus they will become useful as a future commissioning tool until Ultra-low emittance muon became available. PSI Low Energy Muon source and its possibility for acceleration test will be studied in the following sections.

1.2 PSI Low Energy Muon (LEM) source

The Paul Scherrer Institute (PSI) low-energy μSR spectrometer is an instrument dedicated to muon spin rotation and relaxation measurements.

The Low Energy Muon (LEM) beam line at PSI shown in Figure 1 is delivering μ^+ with tunable kinetic energy between 0.5 and 30 keV[**3**].

The low-energy μ^+ are obtained by moderating a surface μ^+ beam (4 MeV energy) from the μE4 beam line with a 125 μm thickness Ag foil coated with a 200-300 nm thick layer of solid Ar-N_2. The moderated μ^+ leaving the solid Ar-N_2 surface have mean kinetic energy of 15 eV. As the moderator is placed at high voltage (typically V_{mod} = 15 kV), after leaving the moderator the μ^+ are accelerated to about 15 keV kinetic energy. Using various electrostatic elements, the μ^+ are transported from the moderator to the sample region.

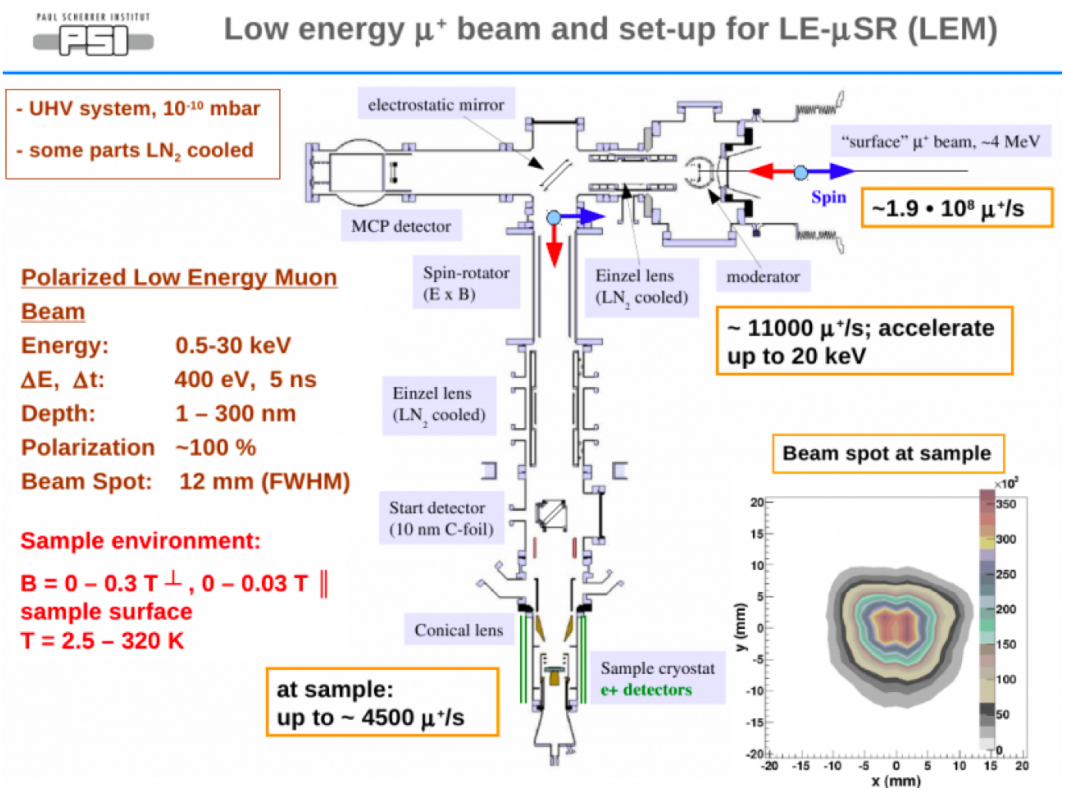

Figure 1. Schematic of the new LEM beam line[**4**]. The 4 MeV surface μ^+ is moderated at an efficiency of about 0.01% to an energy of about 15 eV before being re-accelerated again to energies up to 20 keV. The μ^+ beam is then bent by a 45 degree electrostatic mirror before going through the spin rotator and the start detector and arriving at the sample plate mounted on the cold finger of the cryostat.

2 Acceleration using the default voltage settings

2.1 Simulation Setup

In order to simulate the PSI muon source accelerated by current SOA lens, I used Opera software[**5**] to generate the E field. In the Opera, using .comi file we can specify the SOA size for its components and the voltages applied on each lens.

Then the .comi file was inputed into the Opera 3D modeller program, which can simulate the Electric field. And then another set of .comi command was used to extract the E field into the .table file, which can be easily converted into .txt file. In the .table file, the recorded variables can be specified. For example, here we need the (X, Y, Z, Ex, Ey, Ez) in the file:

```
39        39        120       m         0.00000100
\%nx      ny        nz        length_unit       norm_fact
\%
  −0.700000000000E−01 −0.700000000000E−01 −0.280000000000      −7565.39122113      −8879.10120255      −25309.8596359
  −0.700000000000E−01 −0.700000000000E−01 −0.275000000000      −7804.12057005      −9351.99893486      −26759.4239567
  −0.700000000000E−01 −0.700000000000E−01 −0.270000000000      −8086.94807733      −9776.76049226      −28247.8916534
  −0.700000000000E−01 −0.700000000000E−01 −0.265000000000      −8369.77558461      −10201.5220496      −29736.3593501
  −0.700000000000E−01 −0.700000000000E−01 −0.260000000000      −8613.24114186      −10558.5629489      −31175.4331586
  −0.700000000000E−01 −0.700000000000E−01 −0.255000000000      −8800.10788804      −10857.3707137      −32536.0200539
  −0.700000000000E−01 −0.700000000000E−01 −0.250000000000      −8948.31552088      −11108.2977136      −34289.0383480
  −0.700000000000E−01 −0.700000000000E−01 −0.245000000000      −9244.31309233      −11687.7350389      −36124.1940343
  −0.700000000000E−01 −0.700000000000E−01 −0.240000000000      −9618.89182892      −12282.6779251      −37844.4137946
  −0.700000000000E−01 −0.700000000000E−01 −0.235000000000      −9993.57691109      −12877.4109328      −39563.3098742
```

Now that we have the E-field, we can apply it to freshly ionized thermal re-accelerated muon MC events. These muon events comes from the MC simulations using H-line beam distributions and diffusion model.[**6**] They are saved in the tree in the root file.

Combined E-field with the MC events, we could use the muSR simulation package[**7**] to simulate the initial acceleration test, where we can also specify the size and other key parameters of SOA and also the E-field (.txt file).

Input of .txt files are needed for muSR program, both on E-field (X, Y, Z, Ez, Ey, Ez) and the muon events. For muon event, we should use .root file to specify the following information: (X, Y, Z, X', Y', E), where the position, velocity and energy are all from the laser ionization area and not accelerated yet.

Then run the muSR program we could get the muon events that are accelerated by SOA to the entrance of the RFQ.

Moreover, in the muSR program, we can also put several virtual detectors along the z axis of the beam direction. The emittance and the E field would be monitored along the way to seek the focusing position relating to the different E-feild (voltage) setups.

The details of these files and commands could be found in the Appendix.

2.2 Acceleration using current SOA field

Applying these setup, we firstly tried the PSI muon source accelerated by the TDR SOA E-field[**6**]. At this stage, we only replace the thermal muon by PSI muon source.

For thermal re-accelerated muons by laser ionization, the mean energy is about 0.02 eV ($\Delta E = 0.01eV$), while PSI LEM is about 15 eV (ΔE is about the same order of E). Also, because of the laser ionization process, the thermal muons have a spatial

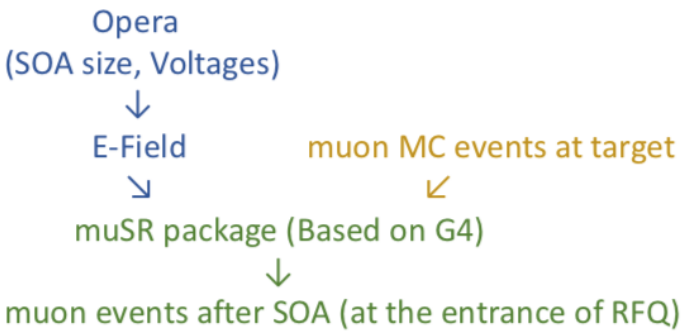

Figure 2. Simulation Setup

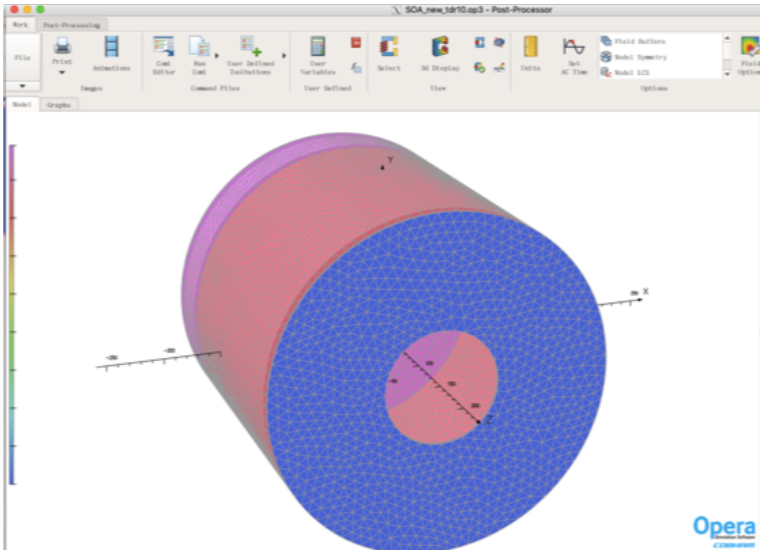

Figure 3. Opera Software

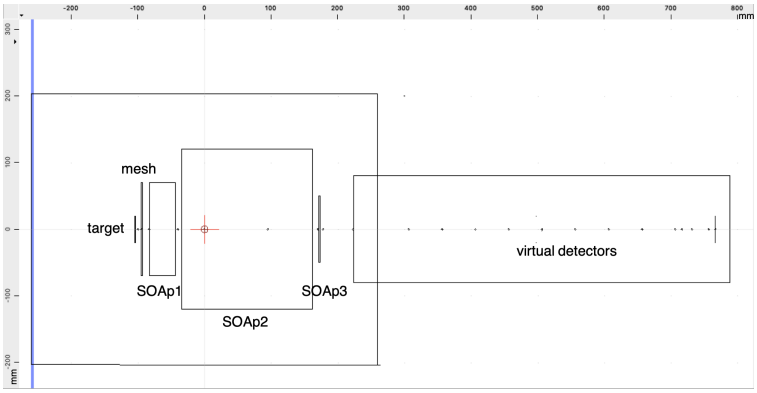

Figure 4. SOA lens and virtual detectors

distribution along z axis (1 - 6 mm away from the surface), while we assume PSI LEM follows the disk-source distribution (at z = 0 plane). Table 1 listed major difference between two sources.

Table 1. Difference between two sources

	thermal muon	**PSI muon**
Energy	0.02 eV	20 eV
ΔE	0.01 eV	5 eV
Spatial Distribution	z = 1 - 6 mm	z = 0 (Disk source)
Initial angular Distribution	$\cos(\theta)$	$\cos(\theta)$

The distributions on two sources are plotted on Figure 5.

Figure 6 shows the currently well-tuned SOA field ready to accelerate the TDR muon.

Figure 7 shows the results for PSI LEM to be accelerated by current SOA E-field. The number left within the RFQ acceptance is quite small, about 2%, while the thermal re-acc. muon on TDR 70%.

To find out the reason, we did the Energy scan from 0 eV to 20 eV. Fig. shows the Number of muon left within RFQ acceptance after SOA acceleration as the function of initial energy of muon.

Here we may conclude that under our current E-field applied on the SOA lens, the initial acceleration ($\Delta V = 100V$) may be not enough for PSI muon. Thus the higher voltage setup is needed.

For reference, the initial acceleration component used in PSI is not SOA lens, but the Einzel lens, where we can only apply voltage on the middle lens among the three[**3**].

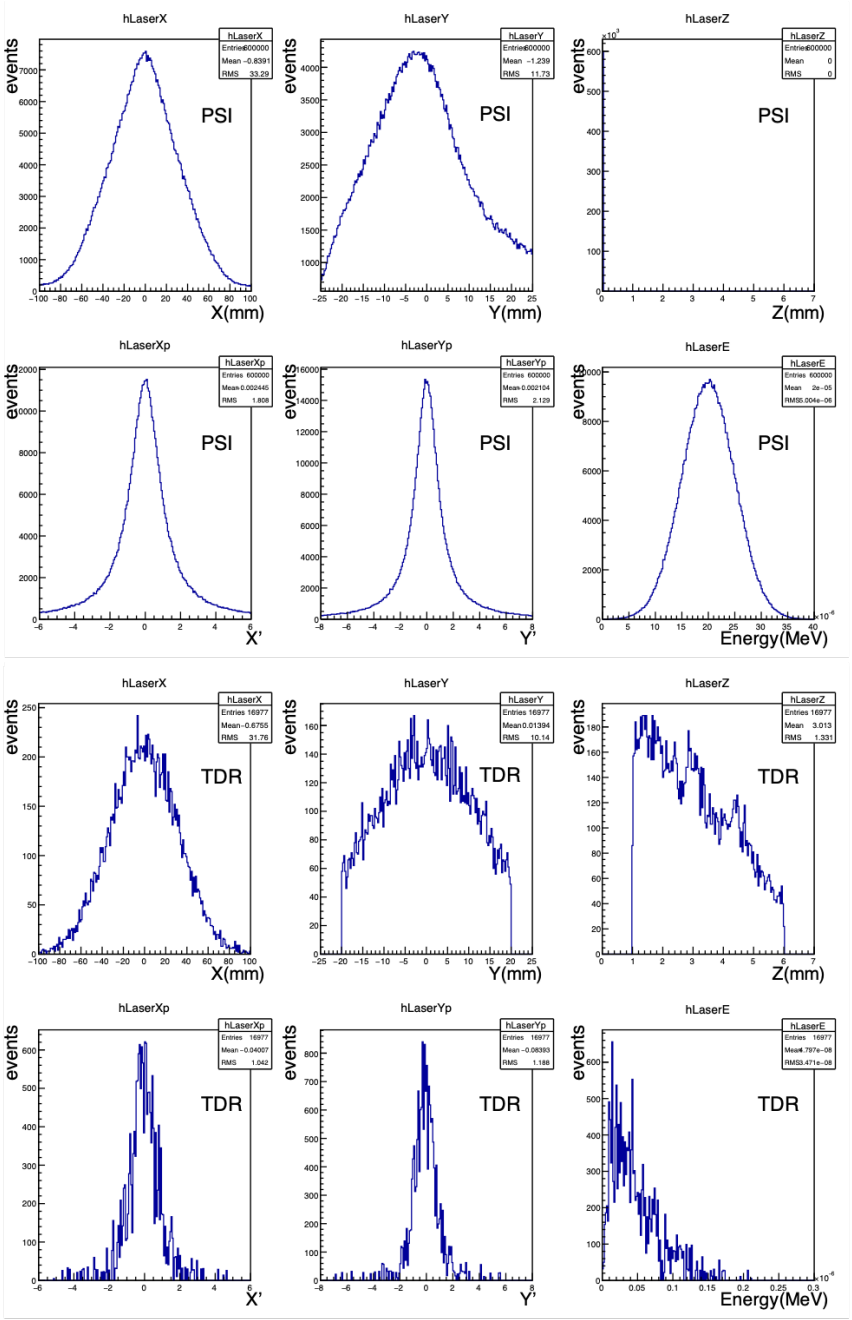

Figure 5. Comparison of distribution on two different muon sources, including the beam structure (x, y, x', y'), energy and the different initial spatial distribution. Top part is TDR thermal re-acc. muon and botton is PSI muon. For PSI source, there's no ionization process.

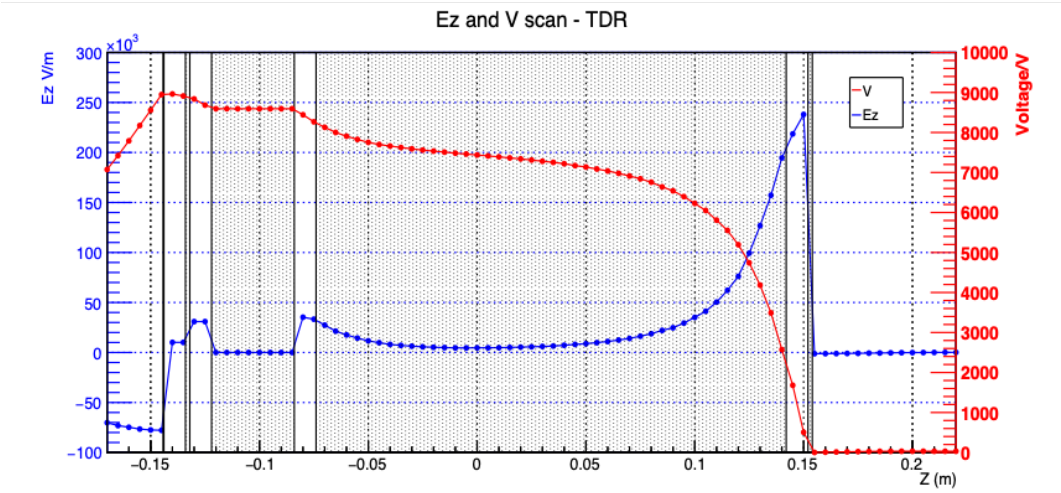

Figure 6. current SOA field for the TDR design

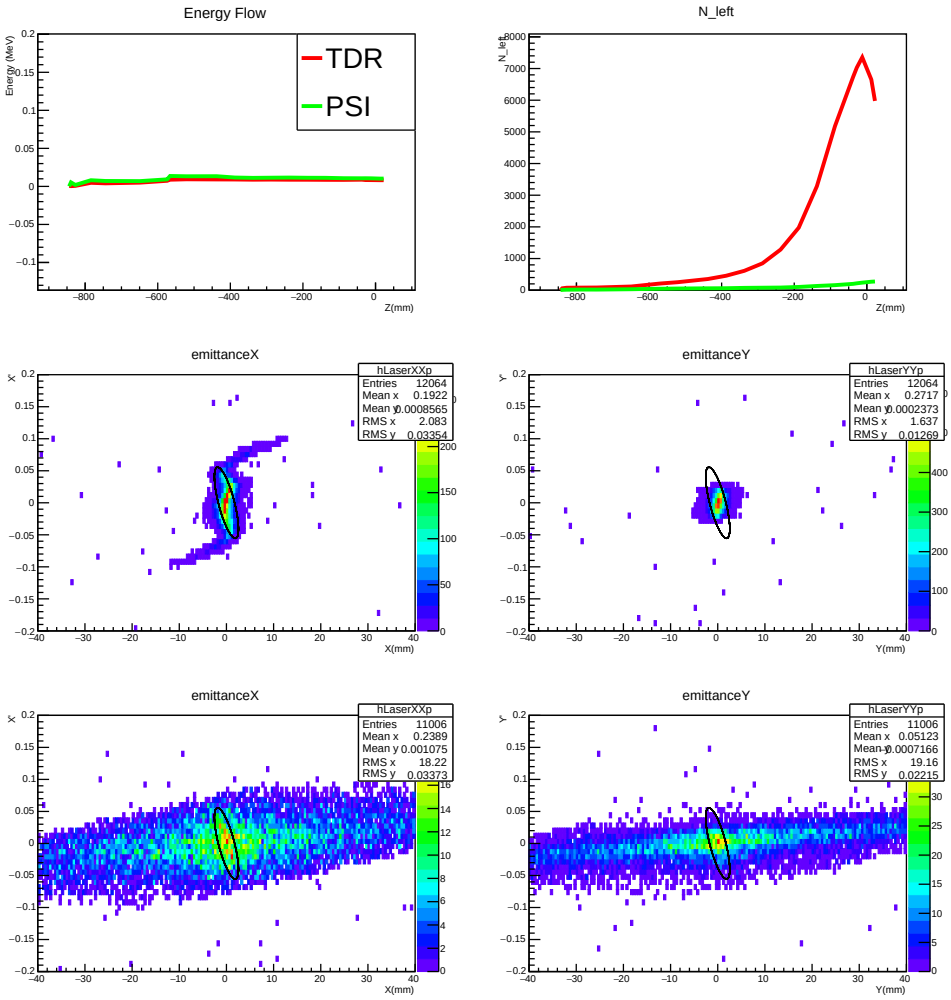

Figure 7. Results of particle tracking simulations for the PSI LEM by the current SOA E-field. Upper plots are the energy and number of muon left with z axis. For PSI muon (green), the number are quite lower than the TDR thermal re-acc. muon (red). The lower part are the emittance comparison. The first row is the PSI source's emittance while the second row the TDR source. Both are at the focusing position.

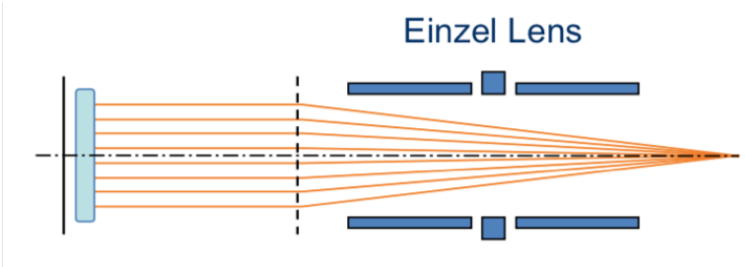

Figure 8. Einzel lens for PSI[**4**]

3 Different Voltage Setup

3.1 Voltage setup 1: to increase the voltage between target and mesh only

Our first strategy is to only increase the voltage between target and mesh. So that the thermal re-acc. muon would be expected to have a higher initial acceleration. The number of muon within the RFQ acceptance, however, are still very unsatisfied. The emittance also disperses all the way after four SOA lens and we could not find the focusing point. These are shown in the Table 5.

Table 2. Voltage setups - 1

label	target	mesh	SOA p1	SOA p2	SOA p3
Voltage - TDR /V	9003	8903	8594	7484	0
Voltage - PSI - 2 /V	9003	8003	7694	6584	0
Voltage - PSI - 5 /V	19003	8903	8594	7484	0

3.2 Voltage setup 2: Scaled Voltage

Thus we switched to strategy No. 2: to increase the voltage on all four lens equally. The setups are shown in the Table 3.

Table 3. Voltage setups - 2

label	target	mesh	SOA p1	SOA p2	SOA p3
Voltage - TDR - 100 /V	9003	8903	8594	7484	0
Voltage - PSI - 1k /V	90030	89030	85940	74840	0
Voltage - PSI - 2k /V	180060	178060	171880	149680	0
Voltage - PSI - 3k /V	270090	267090	257820	224520	0
Voltage - PSI - 10k /V	900300	890300	859400	748400	0
Voltage - PSI - 20k /V	1800600	1780600	1718800	1496800	0
Voltage - PSI - 30k /V	2700900	2670900	2578200	2245200	0

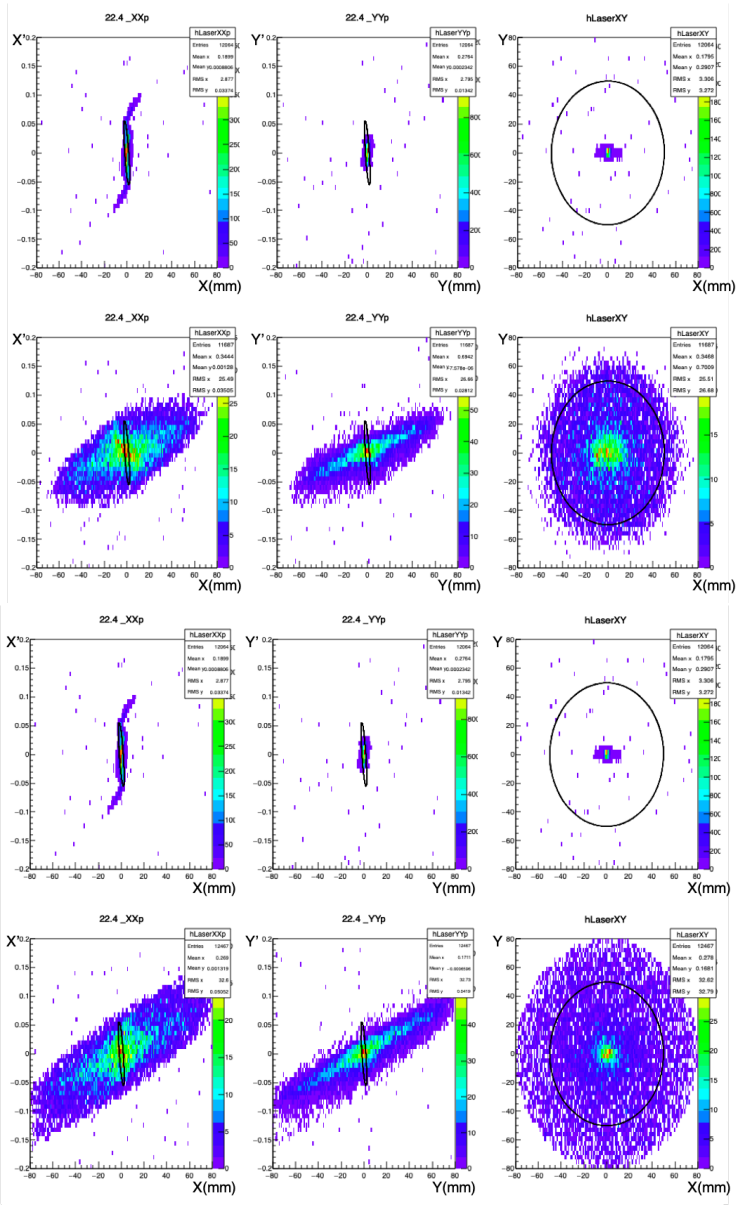

Figure 9. Results on Voltage setup - 1. The upper plots are results from voltage set PSI-2, where the voltage between the target and the mesh is 1000 V. The bottom part is PSI-5, where the voltage 10000 V. For each plot, first row is the TDR source on emittance X, Y and (X, Y) position distribution at the focusing position. The second row is the PSI source counterpart distribution at the same position.

Take for example the voltage setup labeled '3k', which means the voltage between the target and the mesh increased from 100 V to 3000 V, and the same proportion to other lens. This is also a reasonable choice based on the Energy difference between two sources:

$$\sqrt{\frac{E_{PSI}}{E_{thermalre-acc.}}} = \sqrt{\frac{20}{0.02}} \approx 30 \tag{1}$$

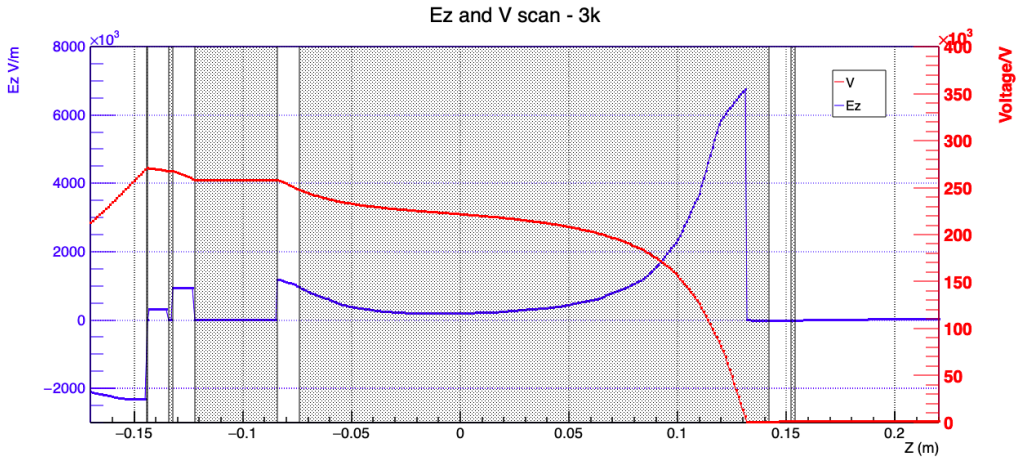

Figure 10. Labeled '3k' E-field

Under this voltage setup as shown in Figure 10, the emittance of PSI source performed significantly better and the focusing point could be found. Details are shown in the Figure 11.

Also, the radius change along the z-axis are shown in the Figure 12.

If we choose to increase even higher voltages, the emittance keeps shrinking and the number of muon left keeps increasing, as shown in the Figure 13. In practice, however, we should note that very high voltage setup may not be realistic.

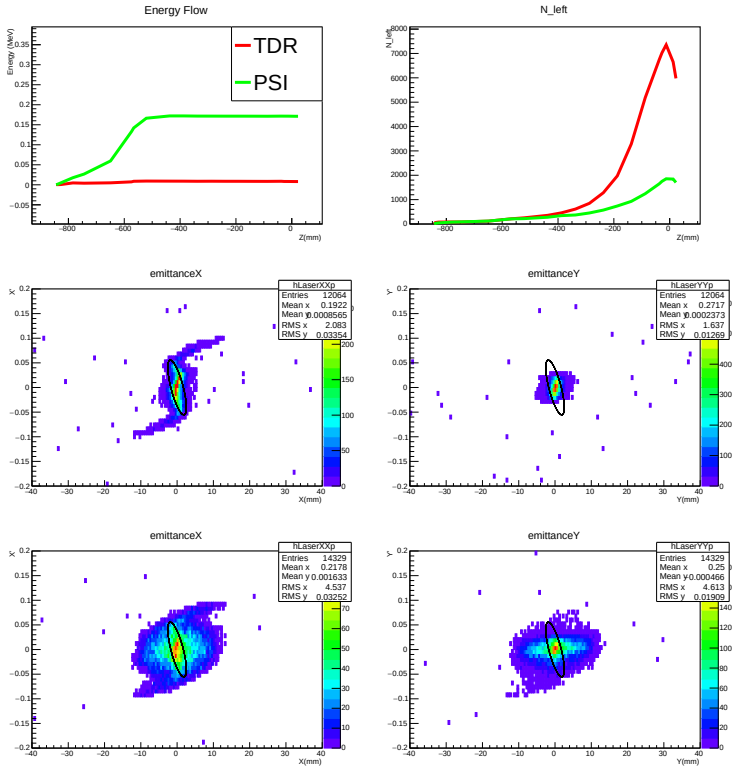

Figure 11. Results under the '3k' labeled voltage setup. The upper plots are the energy and the number flow on z-axis. Then final energy for PSI muon is much higher with the better result on the number left. The lower plots are the emittance comparison where the first row is the TDR source for reference while the second row is the PSI source.

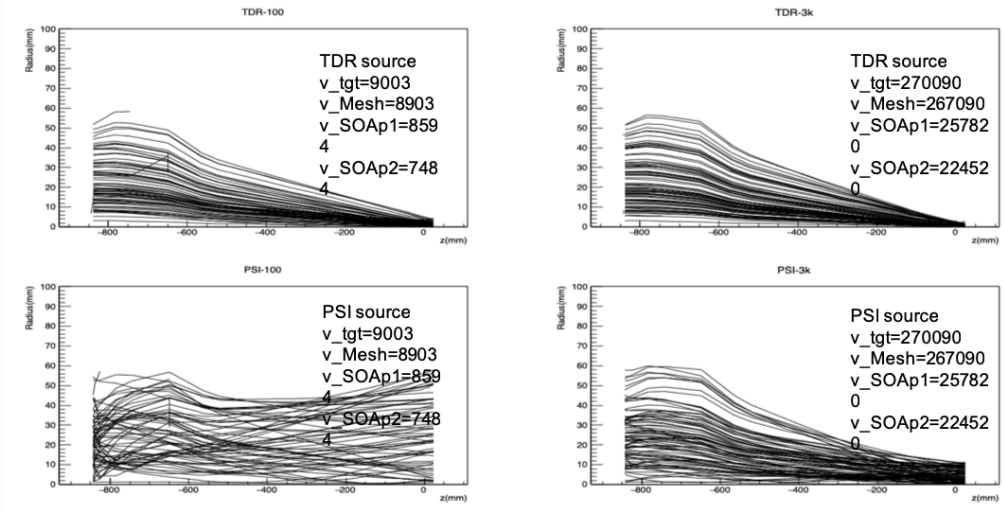

Figure 12. Radius change along the z axis on the '3k' voltage setup. The first row is the TDR thermal re-acc. muon and the second row the PSI muon. The increased voltage helps significantly to focus the muon source.

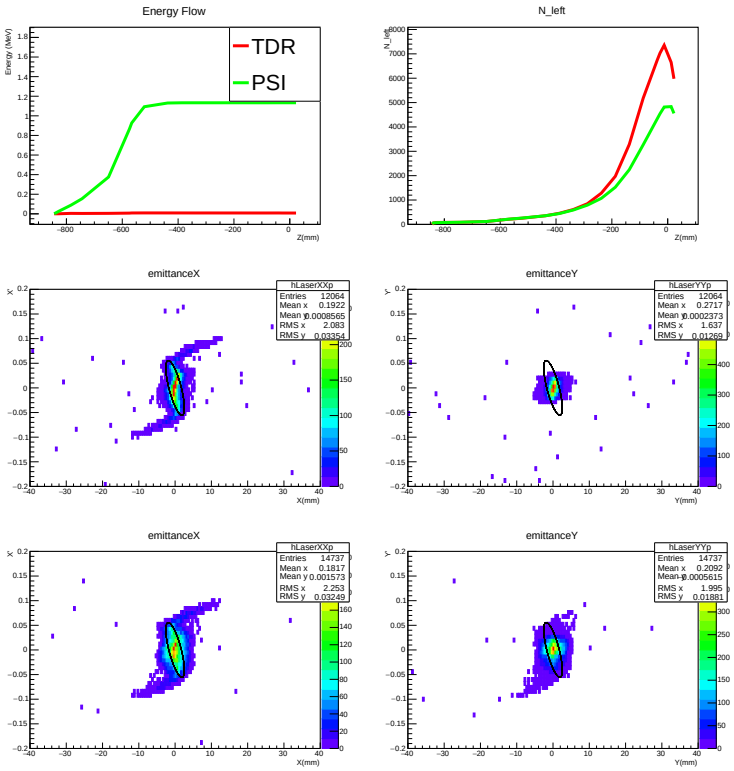

Figure 13. Results on the very high voltage labeled '20k'. We could reach very high number of muon left in the price of very high final energy. Also the emittance becomes much close to the TDR thermal muon case.

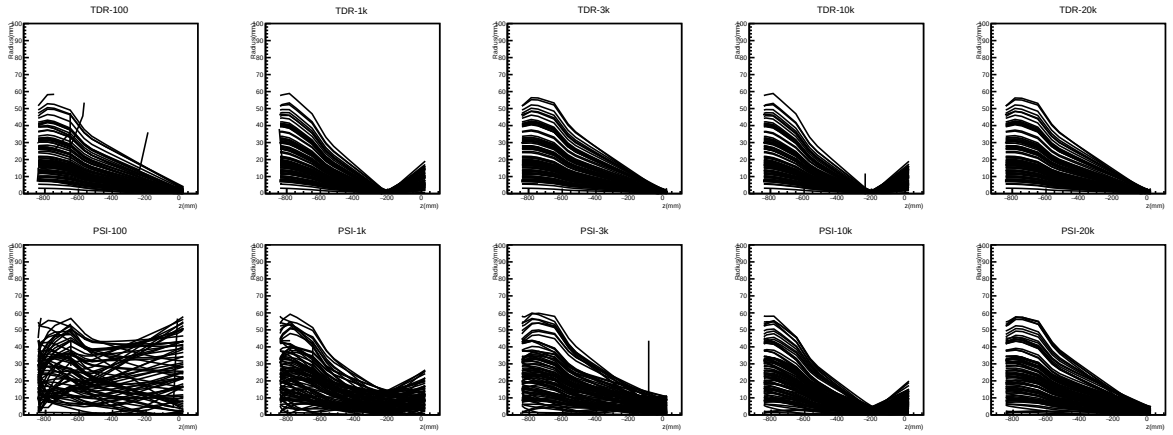

Figure 14. Results on the radius change for different voltage setups.

4 Summary

In summary, possibility of acceleration for PSI LEM source for E34 experiment was studied. Using our current SOA E-field, PSI low energy muon source cannot be well-accelerated.

Table 4. Number flow of muon on different acceleration strategy

Number flow	**thermal muon by TDR field**	**PSI muon by TDR field**	**PSI muon by '3k' field**
Number of total input	16977	16977	16977
Number left within RFQ acceptance	7354 (43%)	335 (2%)	1855 (12%)

Table 5. Efficiency comparison on different acceleration strategy

	thermal muon	**PSI muon by Einzel lens**	**PSI muon by SOA lens (TDR field)**	**PSI muon by SOA lens (3k)**	**Mu^- from Al**
Production Efficiency	3.8×10^{-3}[**8**]	2.0×10^{-4}	0.7×10^{-4}	0.7×10^{-4}	1.1×10^{-6}
Transport Efficiency to RFQ	0.393	?	0.02	0.12	3.0×10^{-3}
Event rate at RFQ (/sec)	2.3×10^5	?	2.5×10^2	1.4×10^3	5.0×10^{-1}

In the table, the transport efficiency for thermal re-acc. muon comes from TDR. Also, the muon production efficiency for PSI source is estimated according to the difference of momentum bite of the H-line and PSI $\mu E4$ beam line. And event rate at the RFQ are calculated based on the incident surface muon at H-Line ($1.6 \times 10^8/sec$).

To modify the SOA field, to equally increase the voltages on SOA lens should be used to focus PSI source (but with much higher energy) and obtain the comparable number of events within the RFQ acceptance.

In the future, PSI source accelerated by Einzel lens will be further studied.

Acknowledgements

I would like to thank my supervisor, Tsutomu Mibe-san, who guided me all the way to this simulation program. Also would like to thank M.Otani-san, who helped me a lot in the Geant-4 simulation and muSR and Opera.

References

[1] C.Zhang, Muonium Target Geometry Design Study for g-2/EDM Experiment, The 17th muon g-2/EDM collaboration meeting.

[2] Technical Design Report for the Measurement of the Muon Anomalous Magnetic Moment $g2$ and Electric Dipole Moment at J-PARC, Version 3.

[3] arXiv:1506.01779v2

[4] Antognini, A., Crivelli, P., Prokscha, T., Khaw, K. S., Barbiellini, B., Liszkay, L., ... Salman, Z. (2012). Muonium emission into vacuum from mesoporous thin films at cryogenic temperatures. Physical review letters, 108(14), 143401.

[5] https://operafea.com/

[6] Report on 'Muonium Target Geometry Design Study for g-2/EDM Experiment', The 17th muon g-2/EDM collaboration meeting

[7] Manual of musrSim - Paul Scherrer Institut, https://www.psi.ch/lmu/DevGeant4SimulationEN/musrSim.pdf

A APPENDEX

A.1 .pl file to generate ./comi command for Opera

```
#!/usr/bin/perl
use Math::Trig;
$filename = "SOA_command_new_1126_1.comi";
#$op_name  = "SOA_new.op3";
#$op_name  = "SOA_new_180828_4.op3";
$op_name  = "SOA_test_1126_1.op3";
open(IN, ">$filename");
$pi           = atan2(1,1)*4;

### ------ parameters ------ ###
$z_offset = -127.8-11.9-4.3;
#length
#$len_Tgt  = -0.3;
$len_Tgt  = 0.3;
$len_S1   = 2;
$len_S2   = 38;
#$len_S3   = 196;
$len_S3   = 216;
$len_S4   = 2;
#front position of Z
$z_Tgt    = -1.0*$len_Tgt;
#$z_S1     = $z_Tgt + $len_Tgt + 9.9; #IDR
$z_S1     = $z_Tgt + $len_Tgt + 50; #2018/8/27, Cedric study
$z_S2     = $z_S1  + $len_S1  + 10;
$z_S3     = $z_S2  + $len_S2  + 10;
$z_S4     = $z_S3  + $len_S3  + 10;
#outer radius
#$oR_Tgt   = 170/2;
#$oR_S1    = 170/2;
#$oR_S2    = 170/2;
#$oR_S3    = 170/2;
#$oR_S4    = 170/2;
#$oR_Tgt   = 170/2;
$oR_Tgt   = 300/2;
$oR_S1    = 300/2;
$oR_S2    = 300/2;
$oR_S3    = 300/2;
$oR_S4    = 300/2;
#inner radius
#$iR_Tgt   = 63/2;
#$iR_S1    = 76/2;
#$iR_S2    = 76/2;
#$iR_S3    = 140/2;
#$iR_S4    = 76/2;
$iR_Tgt   = 120/2;
$iR_S1    = 140/2;
$iR_S2    = 140/2;
$iR_S3    = 240/2;
#$iR_S4    = 120/2; #v1
$iR_S4    = 100/2;
#chamber(GND)
$iR_MC    = 251;
$oR_MC    = 252;
$len_MC   = 400;
$z_MC     = -0.5*$len_MC;
#$iR_muport= 121;
#$oR_muport= 122;
$iR_muport= 160;
$oR_muport= 161;
#$len_muport= 650;
#$len_muport= 850; #for field calcluation
$len_muport= 1550;
$z_muport  = -300;
#origin X, Y
$X = 0;
$Y = 0;
### ------ voltage setting ------ ###
$V_GND= 0;
#IDR
#$V_Tgt= 9003;
#$V_S1 = 8903;
#$V_S2 = 8594;
#$V_S3 = 7484;
#2018/8/27, Cedric study
#$V_Tgt= 9003;
#$V_S1 = 8003;
#$V_S2 = 7730;
#$V_S3 = 6730;
#2018/8/28, Cedric study
$V_Tgt= 9003;
$V_S1 = 7428;
#$V_S2 = 7170;
#$V_S3 = 6244;
#108028_2
#$V_S2 = 6800;
#$V_S3 = 6000;
#108028_3
```

```
#$V_S2 = 7300;
#$V_S3 = 6000;
#108028_4
$V_S2 = 7300;
$V_S3 = 5500;

#$V_S3 = 5484;#v3
$V_S4 = 0;


### ------- start to construct model ------- ###

$line = $line."ANALYSISDATA_OPTION=ACTIVATE_PROGRAM=TOSCAELEC \n";
print IN "$line"; $line="";
#Tgt
$name="Tgt";
$line = $line."CYLINDER_Name='$name' X0=$X_Y0=$Y_Z0=$z_Tgt_X1=$X_Y1=$Y_Z1=$z_Tgt+$len_Tgt_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$oR_Tgt_MINORR
#$line = $line."CYLINDER_Name='${name}_' X0=$X_Y0=$Y_Z0=$z_Tgt_X1=$X_Y1=$Y_Z1=$z_Tgt+$len_Tgt_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$iR_Tgt_MINO
#$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=$name \n";
#$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=${name}_ \n";
#$line = $line."COMBINE_OPERATION=SUBTRACT_+REGULAR \n";
$line = $line."PICK_OPTION=RESET \n";
print IN "$line"; $line="";



#S2
$name="S2";
$line = $line."CYLINDER_Name='$name' X0=$X_Y0=$Y_Z0=$z_S2_X1=$X_Y1=$Y_Z1=$z_S2+$len_S2_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$oR_S2_MINORRADIUS
$line = $line."CYLINDER_Name='${name}_' X0=$X_Y0=$Y_Z0=$z_S2_X1=$X_Y1=$Y_Z1=$z_S2+$len_S2_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$iR_S2_MINORRAD
$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=$name \n";
$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=${name}_ \n";
$line = $line."COMBINE_OPERATION=SUBTRACT_+REGULAR \n";
$line = $line."PICK_OPTION=RESET \n";
print IN "$line"; $line="";

#S3
$name="S3";
$line = $line."CYLINDER_Name='$name' X0=$X_Y0=$Y_Z0=$z_S3_X1=$X_Y1=$Y_Z1=$z_S3+$len_S3_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$oR_S3_MINORRADIUS
$line = $line."CYLINDER_Name='${name}_' X0=$X_Y0=$Y_Z0=$z_S3_X1=$X_Y1=$Y_Z1=$z_S3+$len_S3_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$iR_S3_MINORRAD
$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=$name \n";
$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=${name}_ \n";
$line = $line."COMBINE_OPERATION=SUBTRACT_+REGULAR \n";
$line = $line."PICK_OPTION=RESET \n";
print IN "$line"; $line="";

#S4

$name="S4";
$line = $line."CYLINDER_Name='$name' X0=$X_Y0=$Y_Z0=$z_S4_X1=$X_Y1=$Y_Z1=$z_S4+$len_S4_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$oR_S4_MINORRADIUS
$line = $line."CYLINDER_Name='${name}_' X0=$X_Y0=$Y_Z0=$z_S4_X1=$X_Y1=$Y_Z1=$z_S4+$len_S4_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$iR_S4_MINORRAD
$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=$name \n";
$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=${name}_ \n";
$line = $line."COMBINE_OPERATION=SUBTRACT_+REGULAR \n";
$line = $line."PICK_OPTION=RESET \n";
print IN "$line"; $line="";



#MC
$name="MC";
$line = $line."CYLINDER_Name='$name' X0=$X_Y0=$Y_Z0=$z_MC_X1=$X_Y1=$Y_Z1=$z_MC+$len_MC_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$oR_MC_MINORRADIUS
#$line = $line."CYLINDER_Name='${name}_' X0=$X_Y0=$Y_Z0=$z_MC_X1=$X_Y1=$Y_Z1=$z_MC+$len_MC_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$iR_MC_MINORRA
#$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=$name \n";
#$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=${name}_ \n";
#$line = $line."COMBINE_OPERATION=SUBTRACT_+REGULAR \n";
#$line = $line."PICK_OPTION=RESET \n";
$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=$name \n";
$line = $line."TRANSFORM_OPTION=APPLY_KEEP=YES_TYPE=ROTATE_ROTU=1_ROTV=0_ROTW=0_ANGLE=90 \n";
$line = $line."PICK_OPTION=RESET \n";
#MC TOP
#$line = $line."CYLINDER_Name='${name}_top'  X0=$X_Y0=$Y+$len_MC/2_Z0=0_X1=$X_Y1=$Y+$len_MC/2+1_Z1=0_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$oR_M
#$line = $line."CYLINDER_Name='${name}_bottom'  X0=$X_Y0=$Y-$len_MC/2_Z0=0_X1=$X_Y1=$Y-$len_MC/2-1_Z1=0_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$oR

#MC slow mu port
$name="muport";

$line = $line."CYLINDER_Name='${name}' X0=$X_Y0=$Y_Z0=$z_muport_X1=$X_Y1=$Y_Z1=$z_muport+$len_muport_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$oR_
#$line = $line."CYLINDER_Name='${name}_' X0=$X_Y0=$Y_Z0=$z_muport_X1=$X_Y1=$Y_Z1=$z_muport+$len_muport_-TUBE_SHAPECONTROL=SIMPLE_MAJORRADIUS=$iR
#$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=$name \n";
#$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=${name}_ \n";
#$line = $line."COMBINE_OPERATION=SUBTRACT_+REGULAR \n";
#$line = $line."PICK_OPTION=RESET \n";


$line = $line."PICK_OPTION=RESET \n";
$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=MC \n";
$line = $line."PICK_OPTION=ADD_|_PICK_PROPERTY=Name_LABEL=muport \n";
```

```
$line = $line."COMBINE_OPERATION=UNION -REGULAR \n";
$line = $line."PICK_OPTION=RESET \n";
#$line = $line."CYLINDER Name='${name}_up'  X0=$X Y0=$Y Z0=$z_muport X1=$X Y1=$Y Z1=$z_muport-1 -TUBE SHAPECONTROL=SIMPLE MAJORRADIUS=$oR_muport
#$line = $line."CYLINDER Name='${name}_down'  X0=$X Y0=$Y Z0=$z_muport+$len_muport X1=$X Y1=$Y Z1=$z_muport+$len_muport+1 -TUBE SHAPECONTROL=SIM

print IN "$line"; $line="";



#surface
$line = $line."FILTER TYPE=FACE \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='Tgt' IDENTIFIER=A.00001 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='Tgt' IDENTIFIER=A.00002 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='Tgt' IDENTIFIER=A.00003 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='Tgt' IDENTIFIER=A.00004 \n";
$line = $line."FACEDATA_OPTION=MODIFY BOUNDARYLABEL='Tgt' LEVEL=50 ELEMENTTYPE=Linear FORMETHOD=NONE BACKMETHOD=NONE \n";
print IN "$line"; $line="";

#S1
$name="S1";
$line = $line."CYLINDER Name='$name' X0=$X Y0=$Y Z0=$z_S1 X1=$X Y1=$Y Z1=$z_S1+$len_S1 -TUBE SHAPECONTROL=SIMPLE MAJORRADIUS=$oR_S1 MINORRADIUS
#$line = $line."CYLINDER Name='${name}_' X0=$X Y0=$Y Z0=$z_S1 X1=$X Y1=$Y Z1=$z_S1+$len_S1 -TUBE SHAPECONTROL=SIMPLE MAJORRADIUS=$iR_S1 MINORRA
#$line = $line."PICK OPTION=ADD  | PICK PROPERTY=Name LABEL=$name \n";
#$line = $line."PICK OPTION=ADD  | PICK PROPERTY=Name LABEL=${name}_ \n";
#$line = $line."COMBINE OPERATION=SUBTRACT -REGULAR \n";
$line = $line."PICK_OPTION=RESET \n";

#S1
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='S1' IDENTIFIER=A.00004 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='S1' IDENTIFIER=A.00001 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='S1' IDENTIFIER=A.00002 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='S1' IDENTIFIER=A.00003 \n";
$line = $line."FACEDATA_OPTION=MODIFY BOUNDARYLABEL='S1' LEVEL=50 ELEMENTTYPE=Linear FORMETHOD=NONE BACKMETHOD=NONE \n";
$line = $line."PICK_OPTION=RESET \n";
print IN "$line"; $line="";
#S2
$name="S2";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00004 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00001 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00002 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00003 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=B.00001 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=B.00002 \n";
$line = $line."FACEDATA_OPTION=MODIFY BOUNDARYLABEL='$name' LEVEL=50 ELEMENTTYPE=Linear FORMETHOD=NONE BACKMETHOD=NONE \n";
$line = $line."PICK_OPTION=RESET \n";
print IN "$line"; $line="";

#S3
$name="S3";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00004 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00001 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00002 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00003 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=B.00001 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=B.00002 \n";
$line = $line."FACEDATA_OPTION=MODIFY BOUNDARYLABEL='$name' LEVEL=50 ELEMENTTYPE=Linear FORMETHOD=NONE BACKMETHOD=NONE \n";
$line = $line."PICK_OPTION=RESET \n";
print IN "$line"; $line="";

#S4
$name="S4";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00004 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00001 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00002 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=A.00003 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=B.00001 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='$name' IDENTIFIER=B.00002 \n";
$line = $line."FACEDATA_OPTION=MODIFY BOUNDARYLABEL='$name' LEVEL=50 ELEMENTTYPE=Linear FORMETHOD=NONE BACKMETHOD=NONE \n";
$line = $line."PICK_OPTION=RESET \n";
print IN "$line"; $line="";

#GND

$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='MC' IDENTIFIER=A.00002 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='MC' IDENTIFIER=A.00001 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='MC' IDENTIFIER=A.00003 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='MC' IDENTIFIER=A.00004 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='MC' IDENTIFIER=C.00002 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='MC' IDENTIFIER=C.00001 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='MC' IDENTIFIER=C.00003 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='MC' IDENTIFIER=C.00004 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='MC' IDENTIFIER=B.00003 \n";
$line = $line."PICK_OPTION=TOGGLE TYPE=FACE UNIQUEBODYNAME='MC' IDENTIFIER=B.00004 \n";

$line = $line."FACEDATA_OPTION=MODIFY BOUNDARYLABEL='GND' LEVEL=50 ELEMENTTYPE=Linear FORMETHOD=NONE BACKMETHOD=NONE \n";
$line = $line."PICK_OPTION=RESET \n";
print IN "$line"; $line="";

```

```
264
265 $line = $line."BOUNDARY␣PICK␣'GND'␣\n";
266 $line = $line."BOUNDARY␣OPTION=MODIFY␣CONDITION=VOLTAGE␣VOLTAGE=$V_GND␣\n";
267 $line = $line."BOUNDARY␣UNPICK␣'GND'␣|␣BOUNDARY␣PICK␣'S1'␣\n";
268 $line = $line."BOUNDARY␣OPTION=MODIFY␣CONDITION=VOLTAGE␣VOLTAGE=$V_S1␣\n";
269 $line = $line."BOUNDARY␣UNPICK␣'S1'␣|␣BOUNDARY␣PICK␣'Tgt'␣\n";
270 $line = $line."BOUNDARY␣OPTION=MODIFY␣CONDITION=VOLTAGE␣VOLTAGE=$V_Tgt␣\n";
271 $line = $line."BOUNDARY␣UNPICK␣'Tgt'␣|␣BOUNDARY␣PICK␣'S2'␣\n";
272 $line = $line."BOUNDARY␣OPTION=MODIFY␣CONDITION=VOLTAGE␣VOLTAGE=$V_S2␣\n";
273 $line = $line."BOUNDARY␣UNPICK␣'S2'␣|␣BOUNDARY␣PICK␣'S3'␣\n";
274 $line = $line."BOUNDARY␣OPTION=MODIFY␣CONDITION=VOLTAGE␣VOLTAGE=$V_S3␣\n";
275 $line = $line."BOUNDARY␣UNPICK␣'S3'␣|␣BOUNDARY␣PICK␣'S4'␣\n";
276 $line = $line."BOUNDARY␣OPTION=MODIFY␣CONDITION=VOLTAGE␣VOLTAGE=$V_S4␣\n";
277 $line = $line."BOUNDARY␣OPTION=MODIFY␣CONDITION=VOLTAGE␣VOLTAGE=0␣\n";
278 print IN "$line"; $line="";
279
280 #center is more finer
281 #$line = $line."CYLINDER␣Name='calTMP'␣X0=$X␣Y0=$Y␣Z0=$z_Tgt-2␣X1=$X␣Y1=$Y␣Z1=$z_S4+$len_S4+2␣-TUBE␣SHAPECONTROL=SIMPLE␣MAJORRADIUS=$oR_S3␣MINOR
282 $line = $line."CYLINDER␣Name='calTMP'␣X0=$X␣Y0=$Y␣Z0=$z_Tgt-20␣X1=$X␣Y1=$Y␣Z1=$z_S4+$len_S4+20␣-TUBE␣SHAPECONTROL=SIMPLE␣MAJORRADIUS=$oR_S3␣MINO
283 #$line = $line."CYLINDER␣Name='calTMP'␣X0=$X␣Y0=$Y␣Z0=$z_Tgt-20␣X1=$X␣Y1=$Y␣Z1=$z_S4+$len_S4+50␣-TUBE␣SHAPECONTROL=SIMPLE␣MAJORRADIUS=100␣MINORR
284 $line = $line."PICK␣OPTION=RESET␣\n";
285 $line = $line."PICK␣OPTION=ADD␣␣|␣PICK␣PROPERTY=Name␣LABEL=calTMP␣\n";
286 $line = $line."CELLDATA␣OPTION=MODIFY␣MATERIALLABEL='Air'␣POTENTIAL=Default␣ELEMENTTYPE=Linear␣LEVEL=100␣SIZE=10␣NORMALTOL=5␣SURFACETOL=5␣ELEMSH
287 print IN "$line"; $line="";
288
289 #move for field map
290 print IN
291 "PICK␣OPTION=RESET
292 PICK␣OPTION=TOGGLE␣␣|␣PICK␣PROPERTY=Name␣LABEL=calTMP
293 PICK␣OPTION=TOGGLE␣␣|␣PICK␣PROPERTY=Name␣LABEL=MC
294 PICK␣OPTION=TOGGLE␣␣|␣PICK␣PROPERTY=Name␣LABEL=S1
295 PICK␣OPTION=TOGGLE␣␣|␣PICK␣PROPERTY=Name␣LABEL=S2
296 PICK␣OPTION=TOGGLE␣␣|␣PICK␣PROPERTY=Name␣LABEL=S3
297 PICK␣OPTION=TOGGLE␣␣|␣PICK␣PROPERTY=Name␣LABEL=S4
298 PICK␣OPTION=TOGGLE␣␣|␣PICK␣PROPERTY=Name␣LABEL=Tgt
299 TRANSFORM␣OPTION=APPLY␣KEEP=YES␣TYPE=DISPLACE␣DU=0␣DV=0␣DW=$z_offset
300 PICK␣OPTION=RESET␣\n";
301 #material properties
302 $line = $line."MATERIALS␣GUIINIT␣\n";
303 $line = $line."MATERIALS␣PICK␣'SUS'␣\n";
304 $line = $line."MATERIALS␣OPTION=RESET␣\n";
305 $line = $line."MATERIALS␣OPTION=MODIFY␣EPSANISOTROPY=ISOTROPIC␣EPSILON=1.0␣SIGANISOTROPY=ISOTROPIC␣SIGMA=1.37E+06␣\n";
306
307 $line = $line."MODEL␣CREATE␣\n";
308 $line = $line."MESH␣SIZE=30␣NORMALTOL=20␣SURFACETOL=0.0␣TOLERANCE=1.0E-06␣TYPE=PREFERTETRA␣\n";
309 $line = $line."FILL␣TOL=1.0E-06␣\n";
310 $line = $line."SOLVERS␣SOLVENOW=YES␣SAVEMODEL=YES,␣␣|␣SOLVERS␣OPTION=TEST␣FILE='$op_name'␣UNITS=MM␣ELEMENT=MIXED␣SURFACE=CURVED␣␣|␣COMMENT␣CLEAR=Y
311
312 print IN "$line"; $line="";
```

A.2 .comi command for Opera to read the field

```
1 UNITS␣LENGTH=METRE␣FLUX=TESLA␣FIELD=AM␣SCALAR=AMPERE␣VECTOR=WBM␣DISPLACEMENT=CM2␣ELECTRIC=VM␣CONDUCTIVITY=SMM␣EPOTENTIAL=VOLT␣CURD=AMM2␣CHARGED
2 GRID␣X0=-0.07␣Y0=-0.07␣Z0=-0.28␣DXG=0.005␣DYG=0.005␣DZG=0.005␣NXG=29␣NYG=29␣NZG=120␣FILE='/home/cedric/test_field_1126'␣BINARY=NO␣FORMAT=2␣F1=X
```

A.3 .mac file for muSR command

```
1  # using this mac., RFQ input was created and the results are described in TDR
2  # Macro file for musr.cc - Construct detector, set fields and other parameters.
3  # Last modified by T. Shiroka: 17.03.2008
4  # PB MACRO TEST 20 Feb 2009
5  #
6
7  # How to run from run directory: ../bin/Linux-g++/musrSim xxxx.mac  (append "idle" for prompt after running)
8  #              ../bin/Linux-g++/musrSim xxxx.mac > fname.txt (stores output on a txt file)
9
10 ##############################################################################################
11 # New commands: /gun/starttime
12 #               /gun/starttimesigma
13 # New solids:   cylpart
14 ##############################################################################################
15
16 ##############################################################################################
17 #                                                                                            #
18 # Specify the geometry parameters in this file (all dimensions in mm)                        #
```

```
# a. Lines starting with hash marks "#" are comments                                                    #
# b  Lines starting with #* are temporary comments. Remove/modify to change the configuration          #
# c. Lines starting with /lem4/command are commands for the executable program                         #
# d. Lines starting with /vis, /gun, etc. are common macro commands                                    #
# e. Beam-line components are ordered from MCH to sample                                               #
# f. z axis of MCH is at x=-780 mm  ; z axis of sample is at x=+780 mm                                 #
# g. z position of the center between T and S1 is z=-845 mm                                            #
# h. positions are always relative to the mother volume !!!                                            #
#------------------------------------------------------------------------------------------------------#
# Syntax example (following /lem4/command):                                                            #
# construct solid_type volume_name parameters_defining_solid  material position mothers_name          #
#                                                             (mothers_name starts with log_)          #
########################################################################################################

# For the meaning of the acronyms see also the original G3 file ugeom.F at:
# http://savannah.psi.ch/viewcvs/trunk/simulation/geant3/src/lemsr/ugeom.F?root=nemu%2Flem&rev=2964&view=markup

########################################################################################################
# --- ROTATION MATRICES ---
########################################################################################################

# 3 parameters -> Define Euler angles (the 4th par. is set to zero).
# 4 parameters -> Define axis + rotation.
# HEP computations ordinarily use the active rotation viewpoint (object is rotated NOT axes).
# Therefore, rotations about an axis imply ACTIVE COUNTER-CLOCKWISE rotation in this package.
# Rotation around a specified axis means counter-clockwise rot. around the positive direction of the axis.

# Define rotations for the field maps of Trigger and Ring Anode:
/musr/command rotation rotU    0   0   1   180
/musr/command rotation rotD    0   0   1     0
/musr/command rotation rotR    0   0   1    90
/musr/command rotation rotL    0   0   1   -90
/musr/command rotation rotMB   0   1   0    45
/musr/command rotation rot90   0   1   0    90
/musr/command rotation rot180  0   1   0   180
/musr/command rotation rotEB   1   0   0    90
/musr/command rotation rotEBe 0 90 90

########################################################################################################
# --- BEAMLINE GEOMETRY ---
########################################################################################################

# WORLD = Laboratory reference frame, the origin is in the centre of the MCH top flange
#/musr/command construct box World 1100 300 1030 G4_Galactic 0 0 0 no_logical_volume norot dead -1
/musr/command construct box World 1100 300 1430 G4_Galactic 0 0 0 no_logical_volume norot dead -1
# MINIMUM WORD HALF LENGTH 1250 mm!
#/musr/command construct box World 2000 2000 4000 G4_Galactic 0 0 0 no_logical_volume norot dead -1

# World visual attributes (optional)
/musr/command visattributes log_World lightblue


#=======================================================================================================
# MAIN CHAMBER                          Rmin Rmax  D/2                      x0 y0 z0
#=======================================================================================================
/musr/command construct tubs MCH    199.2 203.2 260    0 360 Steel          780 0 -744   log_World   norot dead 100
#/musr/command construct tubs MCH    252   253   200    0 360 Steel          780 0 -744   log_World   rotEB dead 100


/musr/command construct tubs MCHvac   0   199.2 243    0 360 G4_Galactic   780 0 -744   log_World   norot dead 101
#/musr/command construct tubs MCHvac   0   122 260    0 360 G4_Galactic   780 0 -744   log_World   norot dead 101

/musr/command construct tubs FLvac    0    98.6  20.5 0 360 G4_Galactic   780 0 -480.5 log_World   norot dead 102

#=======================================================================================================
# SOA LENS
#-------------------------------------------------------------------------------------------------------
#/musr/command construct tubs Grid    38.0    85.0     1 0 360 Steel          0 0  -93   log_MCHvac norot dead 110
#/musr/command construct tubs SOAp1   38.0    85.0    19 0 360 Steel          0 0  -63   log_MCHvac norot dead 111
#/musr/command construct tubs SOAp2   70.0    85.0    98 0 360 Steel          0 0   64   log_MCHvac norot dead 112
#/musr/command construct tubs SOAp3   38.0    85.0     1 0 360 Steel          0 0  173   log_MCHvac norot dead 113
/musr/command construct tubs Grid    70.0   130.0     1 0 360 Steel          0 0  -93   log_MCHvac norot dead 110
/musr/command construct tubs SOAp1   70.0   130.0    19 0 360 Steel          0 0  -63   log_MCHvac norot dead 111
/musr/command construct tubs SOAp2  120.0   130.0    98 0 360 Steel          0 0   64   log_MCHvac norot dead 112
/musr/command construct tubs SOAp3   50.0   130.0     1 0 360 Steel          0 0  173   log_MCHvac norot dead 113


#=======================================================================================================
#  Spacer 1
#-------------------------------------------------------------------------------------------------------
#TDR
#/musr/command construct tubs SP1     80    82   282.5 0 360 Steel          780 0  -237.5 log_World norot dead 120
#/musr/command construct tubs SP1vac   0    80   282.5 0 360 G4_Galactic   780 0  -237.5 log_World norot dead 121

/musr/command construct tubs SP1     80    82   482.5 0 360 Steel          780 0  -37.5 log_World norot dead 120
/musr/command construct tubs SP1vac   0    80   482.5 0 360 G4_Galactic   780 0  -37.5 log_World norot dead 121

#/musr/command construct tubs SP1     80    82   222.5 0 360 Steel          780 0  -237.5 log_World norot dead 120
```

```
#/musr/command construct tubs SP1vac   0    80   222.5 0 360 G4_Galactic   780 0  -237.5 log_World norot dead 121


#flange on the end of MCP
#/musr/command construct tubs Flg1    99   126.6  12.5 0 360 Steel          0 0  364.5  - dimensions relative to MCHVAC but this is already outsi
# Beam spot (just for having a visual idea!)
#/musr/command construct tubs saveBSpot1    0   20    0.1  0 360  G4_Galactic   0 0  -87.5 log_SP1vac  norot musr/ScintSD 650
#/musr/command construct tubs saveBSpot1    0   20    0.1  0 360  G4_Galactic   0 0  70 log_SP1vac  norot musr/ScintSD 651
#/musr/command construct tubs saveBSpot2    0   20    0.1  0 360  G4_Galactic   0 0  75 log_SP1vac  norot musr/ScintSD 651
#/musr/command construct tubs saveBSpot3    0   20    0.1  0 360  G4_Galactic   0 0  80 log_SP1vac  norot musr/ScintSD 652
#/musr/command construct tubs saveBSpot4    0   20    0.1  0 360  G4_Galactic   0 0  85 log_SP1vac  norot musr/ScintSD 653

#/musr/command construct tubs saveBSpot6    0   20    0.1  0 360  G4_Galactic   0 0  95 log_SP1vac  norot musr/ScintSD 654

#150310 14:26
#/musr/command construct tubs saveBSpot    0   20    0.1  0 360  G4_Galactic   0 0  90 log_SP1vac  norot musr/ScintSD 654
#/musr/command construct tubs saveBSpot    0   20    0.1  0 360  G4_Galactic   0 0  190 log_SP1vac  norot musr/ScintSD 654
#ADR
#/musr/command construct tubs saveBSpot    0   20    0.1  0 360  G4_Galactic   0 0  260 log_SP1vac  norot musr/ScintSD 654
#Cedric, (before modifiyinng origin z)
#/musr/command construct tubs saveBSpot    0   20    0.1  0 360  G4_Galactic   0 0  380 log_SP1vac  norot musr/ScintSD 654
#/musr/command construct tubs saveBSpot    0   20    0.1  0 360  G4_Galactic   0 0  260 log_SP1vac  norot musr/ScintSD 654
/musr/command construct tubs saveBSpot    0   20    0.1  0 360  G4_Galactic   0 0  420 log_SP1vac  norot musr/ScintSD 654


/musr/command visattributes log_saveBSpot    darkred


# One can set visible attrib. also on a MATERIAL basis, rather than on log_VOL.
/musr/command visattributes Steel blue



#=============================================================================================
#    Applying fields
#=============================================================================================
#/musr/command construct tubs MCHvac2   0    199.2 243 0 360 G4_Galactic   0 0 0 log_World  norot dead 101
#/musr/command globalfield SOA_field  0 0 0 fromfile 3DE SOA_3D_map.map log_MCHvac2 1.00
#/musr/command globalfield SOA_field  780 0 -708  fromfile 3DE SOA_3D_map.map log_MCHvac 1.00
#/musr/command globalfield SOA_field  780 0 -708  fromfile 3DE SOA_3D_map.map log_MCHvac 0.639
#/musr/command globalfield SOA_field  780 0 -708  fromfile 3DE newSOA_3D_map.map log_MCHvac 1.00
#/musr/command globalfield SOA_field  780 0 -835.8  fromfile 3DE newSOA_3D_map.map log_MCHvac 1.00
#/musr/command globalfield SOA_field  780 0 -835.8  fromfile 3DE newSOA_3D_map.map log_MCHvac 0.628
#/musr/command globalfield SOA_field  780 0 -708  fromfile 3DE newSOA_3D_map.map log_MCHvac 0.635
#/musr/command globalfield SOA_field  780 0 -708  fromfile 3DE newSOA2_3D_map_v3.map log_MCHvac 0.635
#/musr/command globalfield SOA_field  780 0 -708  fromfile 3DE newSOA2_3D_map_v3_180827.map log_MCHvac 0.635
#/musr/command globalfield SOA_field  780 0 -708  fromfile 3DE newSOA_cedric.map log_MCHvac 0.635
#/musr/command globalfield SOA_field  780 0 -708  fromfile 3DE SOA_new_180828.map log_MCHvac 0.635
#/musr/command globalfield SOA_field  780 0 -708  fromfile 3DE SOA_new_180828_3.map log_MCHvac 0.635
/musr/command globalfield SOA_field  780 0 -708  fromfile 3DE SOA_new_180828_3.map log_MCHvac 0.635

# gaussmeter probe point:
#/musr/command globalfield printFieldValueAtPoint  -410 0 745



# Set parameters for particle tracking in an EM field
/musr/command globalfield setparameter SetLargestAcceptableStep 0.5
/musr/command globalfield setparameter SetMinimumEpsilonStep 5e-5
/musr/command globalfield setparameter SetMaximumEpsilonStep 0.001
/musr/command globalfield setparameter SetDeltaOneStep 0.1
/musr/command globalfield setparameter SetDeltaIntersection 0.01
/musr/command globalfield printparameters


###############################################################################################
############################  P H Y S I C S     P R O C E S S E S  ###########################
###############################################################################################
# ---- Low Energy (default) ----
#*/musr/command process addDiscreteProcess gamma G4LowEnergyPhotoElectric
#*/musr/command process addDiscreteProcess gamma G4LowEnergyCompton
#*/musr/command process addDiscreteProcess gamma G4LowEnergyGammaConversion
#*/musr/command process addDiscreteProcess gamma G4LowEnergyRayleigh
/musr/command process addProcess          e-     G4MultipleScattering -1 1 1
#/musr/command process addDiscreteProcess e-     G4CoulombScattering
#/musr/command process addProcess          e-     G4LowEnergyIonisation -1 2 2
#/musr/command process addProcess          e-     G4LowEnergyBremsstrahlung -1 -1 3
/musr/command process addProcess          e+     G4MultipleScattering -1 1 1
#/musr/command process addDiscreteProcess e+     G4CoulombScattering
/musr/command process addProcess          e+     G4eIonisation     -1 2 2
/musr/command process addProcess          e+     G4eBremsstrahlung    -1 3 3
/musr/command process addProcess          e+     G4eplusAnnihilation 0 -1 4
#
# ---- High Energy ----
#/musr/command process addDiscreteProcess gamma G4PhotoElectricEffect
#/musr/command process addDiscreteProcess gamma G4ComptonScattering
#/musr/command process addDiscreteProcess gamma G4GammaConversion
#/musr/command process addProcess          e-     G4MultipleScattering -1 1 1
```

```
##/musr/command process addDiscreteProcess e-    G4CoulombScattering
#/musr/command process addProcess           e-    G4eIonisation         -1 2 2
#/musr/command process addProcess           e-    G4eBremsstrahlung     -1 3 3
#/musr/command process addProcess           e+    G4MultipleScattering -1 1 1
##/musr/command process addDiscreteProcess e+    G4CoulombScattering
#/musr/command process addProcess           e+    G4eIonisation      -1 2 2
#/musr/command process addProcess           e+    G4eBremsstrahlung     -1 3 3
#/musr/command process addProcess           e+    G4eplusAnnihilation 0 -1 4
#
# --- Penelope ---
#/musr/command process addDiscreteProcess gamma G4PenelopePhotoElectric
#/musr/command process addDiscreteProcess gamma G4PenelopeCompton
#/musr/command process addDiscreteProcess gamma G4PenelopeGammaConversion
#/musr/command process addDiscreteProcess gamma G4PenelopeRayleigh
#/musr/command process addProcess           e-    G4MultipleScattering -1 1 1
##/musr/command process addDiscreteProcess e-    G4CoulombScattering
#/musr/command process addProcess           e-    G4PenelopeIonisation    -1 2 2
#/musr/command process addProcess           e-    G4PenelopeBremsstrahlung -1 -1 3
#/musr/command process addProcess           e+    G4MultipleScattering -1 1 1
##/musr/command process addDiscreteProcess e+    G4CoulombScattering
#/musr/command process addProcess           e+    G4PenelopeIonisation,      -1  2 2
#/musr/command process addProcess           e+    G4PenelopeBremsstrahlung, -1 -1 3
#/musr/command process addProcess           e+    G4PenelopeAnnihilation,     0 -1 4
#
# --- Muons ---
/musr/command process addProcess           mu+   G4MultipleScattering -1 1 1
#/musr/command process addProcess           mu+   MultipleAndCoulombScattering -1 1 1 goulombRegion
#/musr/command process addDiscreteProcess  mu+   G4CoulombScattering
/musr/command process addProcess           mu+   G4MuIonisation         -1 2 2
/musr/command process addProcess           mu+   G4MuBremsstrahlung     -1 3 3
/musr/command process addProcess           mu+   G4MuPairProduction     -1 4 4
/musr/command process addProcess           mu-   G4MultipleScattering -1 1 1
#/musr/command process addDiscreteProcess  mu-   G4CoulombScattering
/musr/command process addProcess           mu-   G4MuIonisation         -1 2 2
/musr/command process addProcess           mu-   G4MuBremsstrahlung     -1 3 3
/musr/command process addProcess           mu-   G4MuPairProduction     -1 4 4
# --- Muonium ---
/musr/command process addProcess           mu+   musrMuFormation      -1 -1 2
#cks - the following line not supported yet, has to be tested (at the moment, musrMuScatter is hard wired in the musrPhysicsList.cc):
#/musr/command process addProcess           Mu    musrMuScatter         -1 -1 1




##############################################################################################################
# --- Setting simulation PARAMETERS ---
##############################################################################################################

# Set the overall range cut (default 0.1 mm)
#*/run/setCut 1 mm

# Set user limits
#/musr/command SetUserLimits log_World ustepMax(mm) utrakMax(mm) utimeMax(ns) uekinMin(MeV) urangMin(mm)
#/musr/command SetUserLimits log_World       -1           -1           -1          1e-7          -1
#/musr/command SetUserLimits log_World       0.01         0.01          1          1e-7          0.01
#/musr/command SetUserLimits log_MCHvac      0.01         0.01          1          1e-9          0.01
#/musr/command SetUserLimits log_World       -0.5         -0.5         -0.5         1e-9          -0.5

# Store ALL the events in a ROOT tree or just the interesting ones? (default is true)
#*/musr/command storeOnlyEventsWithHits false

# abandon all positron tracks to study where muons are stopping
#/musr/command killAllPositrons true

# Set the minimum time separation between two subsequent signals in the same detector (in ns)
/musr/command signalSeparationTime 0.1

# Override runID number
#*/musr/run/runID 21

# Set the frequency of event printing
/musr/run/howOftenToPrintEvent 1

#RANDOM option choices: (specify the random number generator initialisation)
# 0 ... no initialisation (default)
# 1 ... use actual computer time to initialise now                    # Pseudo-random numbers
# 2 ... use event number to initialise at the beginning of each event # Reproducible numbers
# 3 ... read in the random no. initial values for each event from a file
/musr/run/randomOption 2

# VISUALIZATION options
# To enable or disable visualization uncomment one of these lines
# To modify visualization options edit the file vis.mac
#*/vis/disable
/control/execute vis.mac


```

```
283
284
285
286 ##########################################################################################################################
287 # --- Setting PARTICLE GUN parameters ---
288 ##########################################################################################################################
289
290 # Default momentum  direction: 001, i.e. 0z.
291 # Default muon spin direction: 100, i.e. 0x.
292 # Default particle type: mu+ (can be changed to Mu)
293
294 # Set particle type
295 #*/gun/particle Mu
296 /gun/primaryparticle mu+
297
298 # Set beam vertex
299 # CFoil at -1144 mm, acceleration starts at -1154.15 mm
300 #TDR
301 #/gun/vertex  780. 0. -845. mm
302
303 #cedric
304 /gun/vertex  780. 0. -830. mm
305
306 # A point-like uniform beam
307 #/gun/vertexsigma -0.1 -0.1 0 mm
308
309 # Set beam transverse spread (default GAUSSIAN spread)
310 # If FWHM = 10 mm ==> sigma = 10/2.354 = 4.2481 mm (last 0 is a dummy value)
311 # Negative sigma values => random FLAT RECTANGULAR distribution (area 2x.2y)
312 # Use vertexboundary with (vb < sigma_xy) to obtain a CIRCULAR beam spot
313 # /gun/vertexsigma 0 0 0 mm ==> Very SLOW with mag. field ON and centered beam
314 #*/gun/vertexsigma  42.5  42.5  0 mm
315 #/gun/vertexsigma   19. 19.  1  mm
316
317 #                      Rmax    zmin      zmax
318 #/gun/vertexboundary  20.    -845.5     -844.5 mm
319 # /gun/vertexboundary: rMaxAllowed, zMinAllowed, zMaxAllowed # Beam AND gating
320 #*/gun/vertexboundary 7 -1314.4 -1305 mm
321 # Without restrictions in z, but only on r:
322 #*/gun/vertexboundary 3 -1e6 1e6 mm
323
324 #/gun/boxboundarycentre  780 -5 -845 mm
325 #/gun/boxboundary        7  4  0.5 mm
326
327
328 # Set beam momentum (USE only as an ALTERNATIVE to setting energy!)
329 #/gun/momentum 0.00286 MeV
330 #*/gun/momentum 0 0  1.8  MeV
331 # Energy loss at p = 1.2 MeV/c (E =  6.8 keV) => 1.23 +/- 0.2 keV
332 # Energy loss at p = 1.8 MeV/c (E = 15.3 keV) => 1.25 +/- 0.3 keV
333 # 1.2 MeV/c -> 6.8 keV, 1.8 MeV/c -> 15.3 keV
334 # muon rest mass = 105.658 MeV/c2
335
336 # Set muon energy before hitting TD; a constant field in front of the C-foil accelerates the muons
337 # to add 3.73 keV
338 #/gun/kenergy 0.001 keV
339
340 # Set beam momentum direction
341 #/gun/direction 0.0 0.0 1.0 direction command not defined in musrSim version
342 #/gun/momentumsmearing 0.00111 MeV
343 #/gun/momentumsmearing 0 MeV
344 #/gun/tilt 0 0 0 deg
345 #/gun/tiltsigma 90 90 0 deg
346
347 # Set muon spin direction
348 /gun/muonPolarizVector 0 0 -1
349 /gun/muonPolarizFraction 0.5
350
351 # Set time profile of the ionize muonium (muon starting time)
352 #/gun/starttime 100 ns
353 #/gun/starttimesigma 0.425 ns
354 #/gun/starttimesigma 1.7 ns
355
356 # Other useful test parameters:
357 #
358 #FWHM = 3%  ==> sigma = 29.79*0.03/2.354 = 0.37965 MeV/c
359 #*/gun/momentumsmearing 0.37965 MeV
360 #---/gun/momentumboundary: pMinAllowed, pMaxAllowed, dummy
361 #*/gun/momentumboundary 20 40 0 MeV
362 #---/gun/tilt: xangle, yangle, dummy
363 #*/gun/tilt 0  0.5  0 deg
364 #---/gun/tiltsigma: xangleSigma, yangleSigma, dummy  (1 degree at 1 m => 17 mm)
365 #/gun/tiltsigma 45 45 0 deg
366 #*/gun/pitch 0.5 deg
367 #---/gun/decaytimelimits: decayMin, decayMax, decayTime
368 #*/gun/decaytimelimits 10400 10420 2197.03 ns
369 #otani, if want to do without decay
370 #/gun/decaytimelimits 1 1000000000 1000000000 s
```

```
371
372 # Selectively inactivate or activate sensitive detectors
373 #*/hits/inactivate /musr/ScintSD
374
375 # Only for code debugging!
376 #/tracking/verbose 1
377
378 #/gun/turtlefilename test.dat
379 #/gun/turtlefilename 150226_vacMu.txt
380 #/gun/turtlefilename ucmu_v2.dat
381 #/gun/turtlefilename 150310_ucMu_dump_all.dat
382 #/gun/turtlefilename gen_test.dat
383 #/gun/turtlefilename ucMu_v3_zcut_nodecay.dat
384 #/gun/turtlefilename dump_Mu.dat
385 ###/gun/turtlefilename dump_Mu_Cedric.dat
386 ###/run/beamOn    16977
387 ####/gun/turtlefilename dump_Mu_Cedric_D87000_T322_Nrepeat2000000_Xfree1_Thick7.12_NewGeo0_.dat
388 ##/gun/turtlefilename dump_Mu_Cedric_D87000_T322_Nrepeat2000000_Xfree1_Thick7.12_NewGeo0_0827.dat
389 ####/run/beamOn    29949
390 #####/gun/turtlefilename dump_Mu_Cedric_D87000_T322_Nrepeat840000_Xfree1_Thick2.00_NewGeo1_.dat
391 /gun/turtlefilename dump_Mu_Cedric_D87000_T322_Nrepeat840000_Xfree1_Thick2.00_NewGeo1_0827.dat
392 /run/beamOn    100
393 #60997
394 /gun/turtleFirstEventNr 1
395
396
397
398 # BEAM ON
399 #/run/beamOn    101
400 #/run/beamOn    201
401 #/run/beamOn    23716
402 #/run/beamOn    16977
403 #/run/beamOn    1000
404 #/run/beamOn    10000
405 #/run/beamOn    50
406 #/run/beamOn    10
407 #*/run/beamOn 50000
```