ILLINOIS INSTITUTE OF TECHNOLOGY

Inroduction to muon monitor simulation

YIDING YU

AI MEETING

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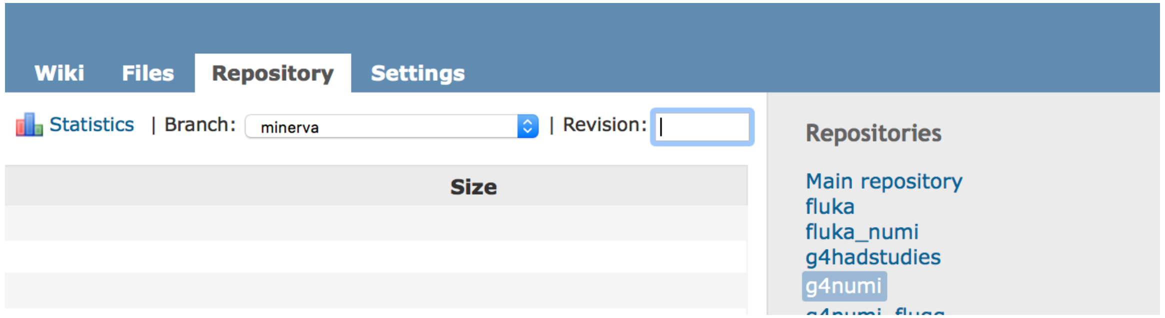
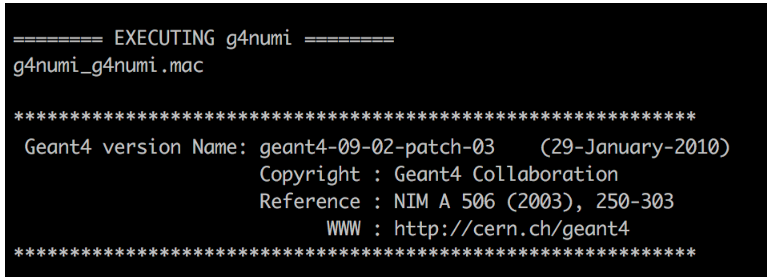
Introduction to G4NuMI



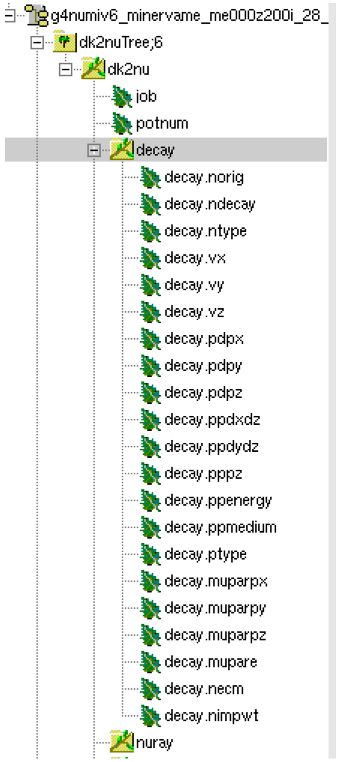
- Checking out, building, and running g4numi:
  - Minerva branch: https://cdcvs.fnal.gov/redmine/projects/minerva-sw/wiki/Flux_MC_Production
  - Numix branch: https://cdcvs.fnal.gov/redmine/projects/numi-beam-sim/wiki/How_to_build_the_Geant4_code
  - Repository: https://cdcvs.fnal.gov/redmine/projects/numi-beam-sim/repository/g4numi?utf8=✓&rev=Minerva

- G4NuMI is based on geant4 9.2 patch 3.
- G4NuMI is suitable for large number of POT. And we can submit a large number of jobs on grid.



Introduction to muon monitor simulation

- The work of Tyler in 2019: https://cdcvs.fnal.gov/redmine/projects/numi-beam-sim /wiki/Muon_Monitors_g4numi
- Procedure muon monitor simulation:
  - Generate files in the format g4numiv6_*.root.(g4numi)
  - Convert the neutrino .root files back to their muon parent particles.
  - Generate the muons based on their parent particles and neutrinos.
  - Feed those muons into g4numi so we can simulate the particles at the monitors.



nu2mubatch.C

- Location: g4numi/dk2nu_local/src/nu2mubatch.C
- How to generate muons:

1. Get decay branch of dk2nu(g4numiv6_*.root)
2. For certain detector location, generate the muons

```
evtno = dk2nu->potnum;
muvx = dk2nu->decay.vx;
muvy = dk2nu->decay.vy;
muvz = dk2nu->decay.vz;
mupx = (Float_t)(dk2nu->decay.pdpx - dk2nu->nuray[0].px);
mupy = (Float_t)(dk2nu->decay.pdpy - dk2nu->nuray[0].py);
mupz = (Float_t)(dk2nu->decay.pdpz - dk2nu->nuray[0].pz);
```

3. The output of nu2mubatch.Cwill be muon_*.root files.

muon.mac in g4numi

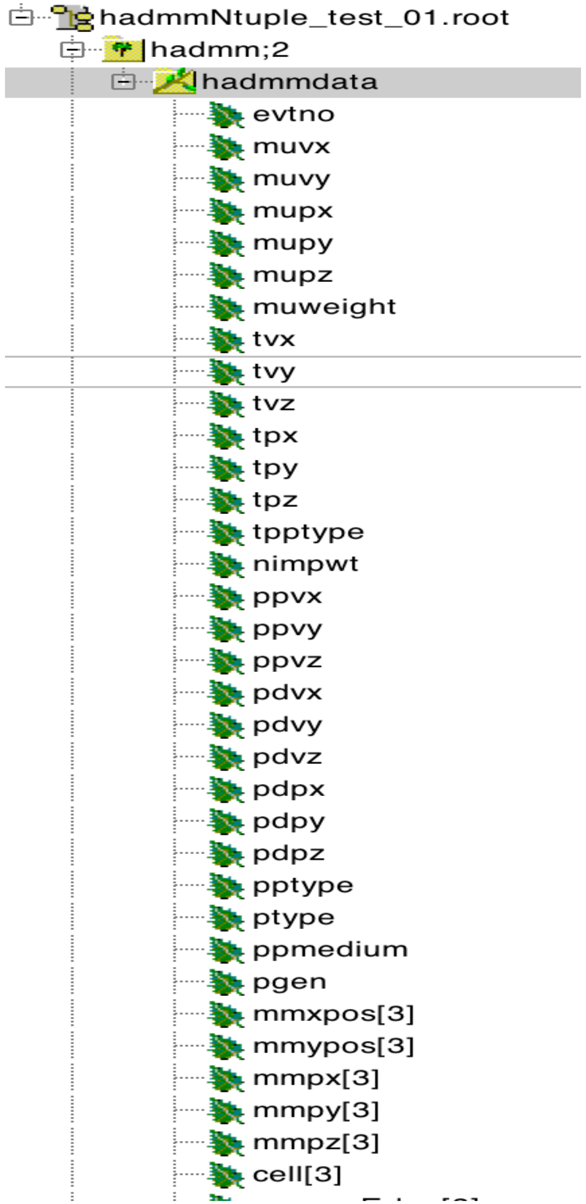
- Location:
  g4numi/macros/template_muon.mac
- Input the muon_*.root files from before into g4numi and output hadmmNtuple_*.root files with data from the muon monitors.

```
#To use the muon beam useMuonBeam
#must be set to true here
/NuMI/run/useMuonBeam true

#When using muon beam tracking threshold
#must be low. Value must be set here.
/NuMI/run/KillTrackingThreshold 0.001 GeV

#To use input from "muon_XXXXX" files
#useMuonInput must be set to true here
/NuMI/run/useMuonInput true
```

```
/NuMI/det/constructTarget false
/NuMI/det/applyDecayPipeMagneticField ture
/NuMI/det/update
```

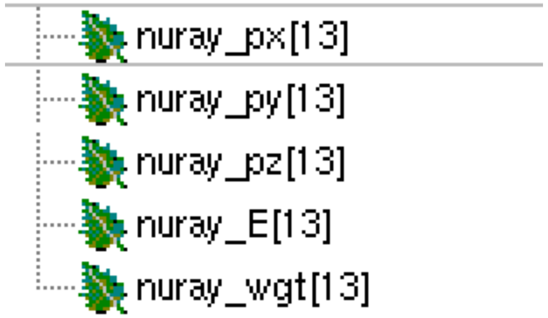
hadmmNtuple.root

- evtno: event number
- muvx,muvy,muvz: production position of muons
- mupx,mupy,mupz: production momentum of muons
- muweights: weights of muons
- tvx,tvy,tvz: position of the events exit the target
- tpx,tpy,tpz: momentum of events exit the target
- tpptype: paticle ID of events exit the target
- ppvx,ppvy,ppvz: production position of parent particles
- pptype: parent particle ID
- ptype: particle ID
- pgen: generation of particle
- mmxpos[3]: x position of muons at MM1~3
- mmypos[3]: y position of muons at MM1~3
- mmpx[3]: x momentum of muons at MM1~3
- mmpy[3]: y momentum of muons at MM1~3
- mmpz[3]: z momentum of muons at MM1~3



hadmmNtuple.root

- nuray_px[13]: neutrino x momentum at 13 locations
- nuray_py[13]: neutrino y momentum at 13 locations
- nuray_pz[13]: neutrino z momentum at 13 locations
- nuray_E[13]: neutrino energy at 13 locations
- nuray_wgt[13]: neutrino wgt at 13 locations



processG4NuMInu2mu.py

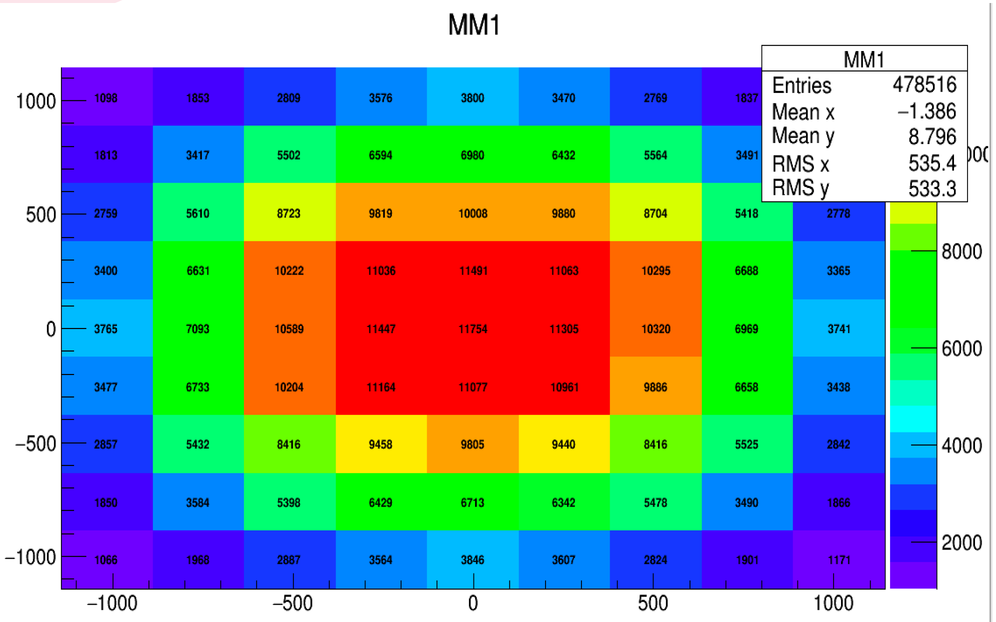
- This script do all the procedure at one step:
  - Include g4numi and muon monitor simulation
- Options:
  - You could change most of the beam parameters in this script

    python processG4NuMInu2mu.py –h

```
Grid Options:
  --outdir=OUTDIR       Output flux histograms location. Default = /pnfs/miner
                        va/persistent/users/yyu/muonmonitor/hornoff/.
  --n_jobs=N_JOBS       Number of g4numi jobs. Default = 1.
  --run_number=RUN_NUMBER
                        Tag on the end of outfiles. Doubles as random # seed.
                        Default = 1.
  --pot=POT             Number of protons on target to simulate. Default =
                        400000.
  --filetag=FILETAG
```

2D-histograms at MMs

simulation



There are 81 pixels at each muon monitor

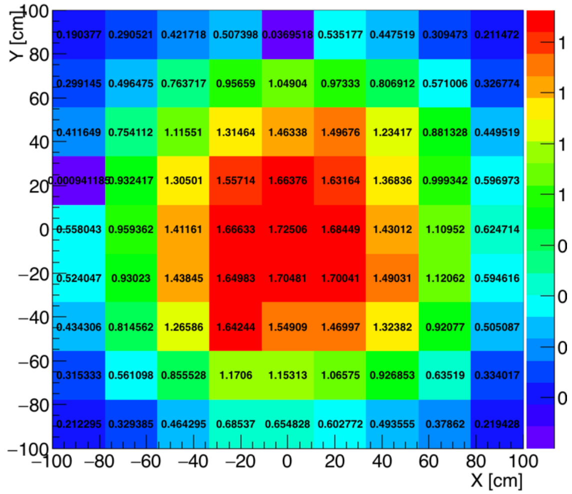
The number on each pixel is the number of muons hitting that area

What we have for muons

- Horizonal position
- Vertical position
- Momentum at MMs in x, y and z directions
- Production Momentum in x, y and z directions

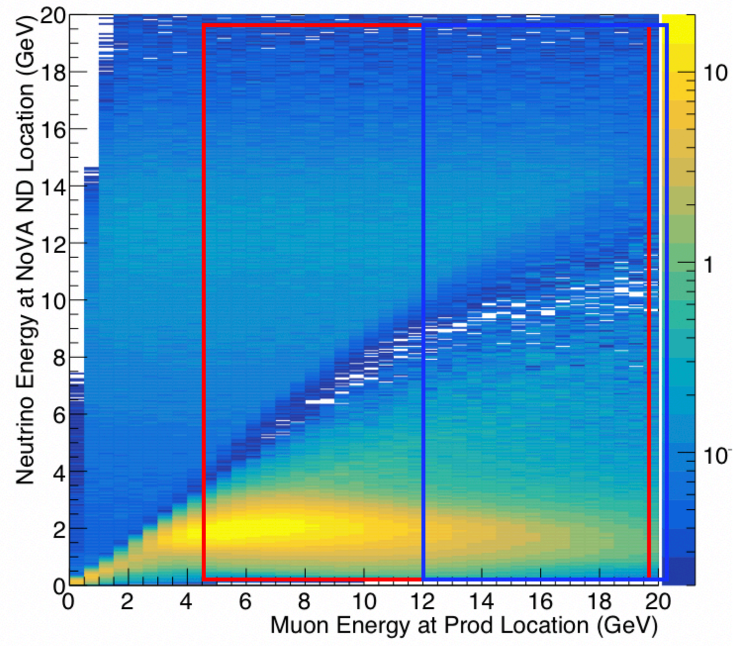
Signal voltage at MM1

data

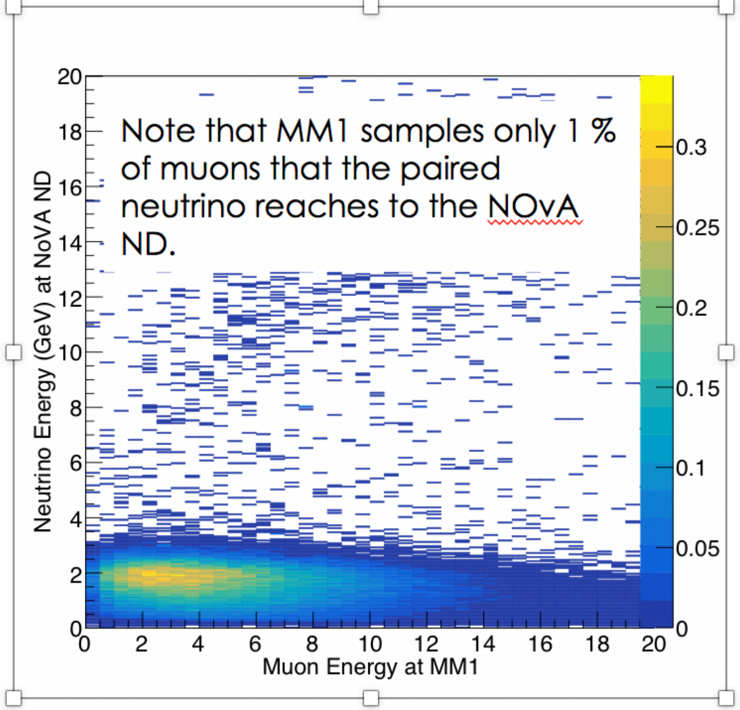


Correlation between muons and neutrinos

MM1 can see a core part of muons

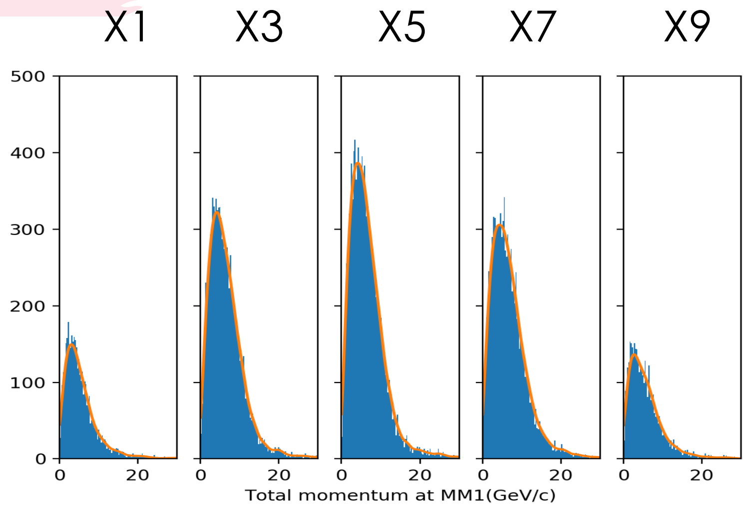


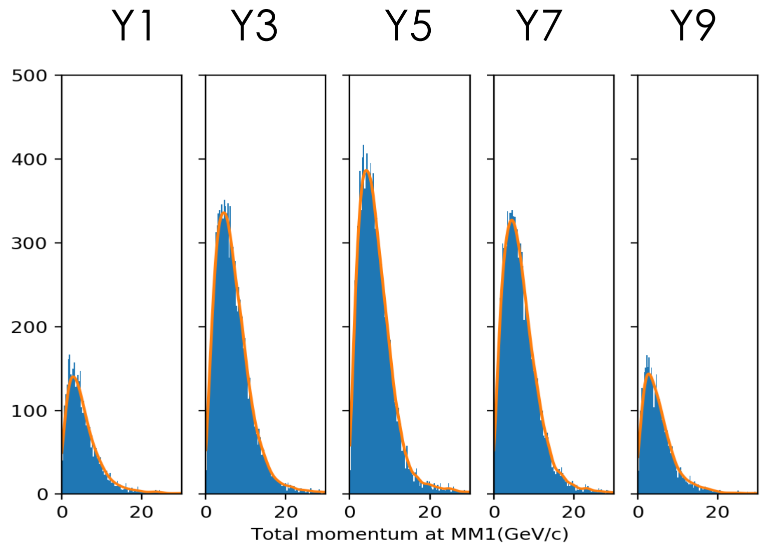
Range of detectable muons in MM1 (MM2)

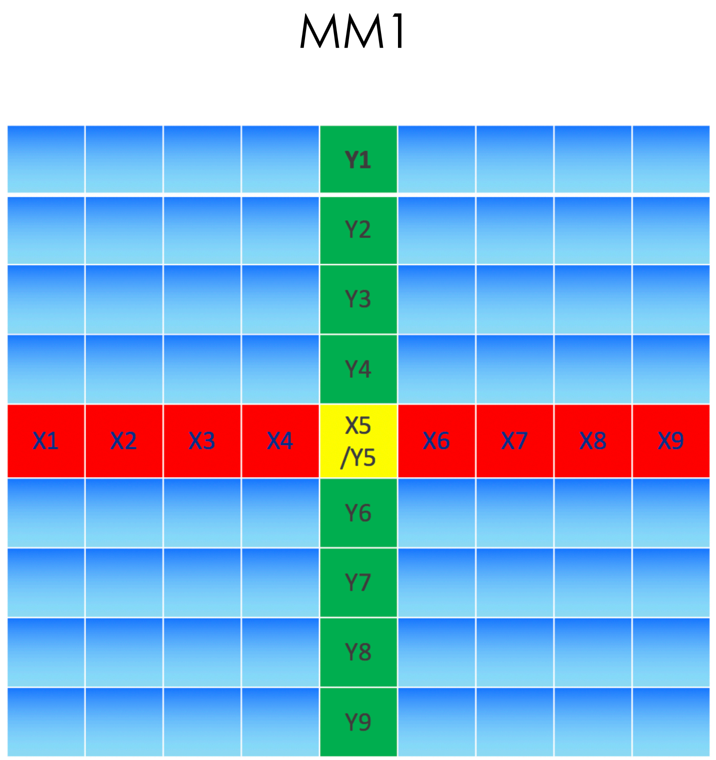


Note that muon energy at MM1 is 5 GeV less than energy at production due to energy loss in Hadron Absorber

Different spectra for different pixels

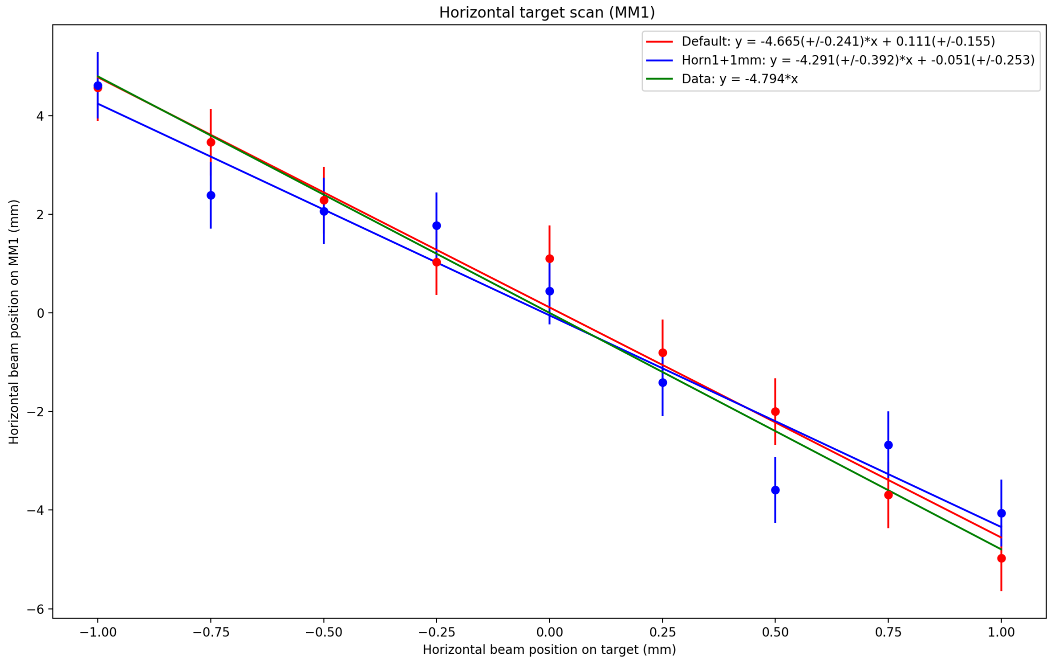




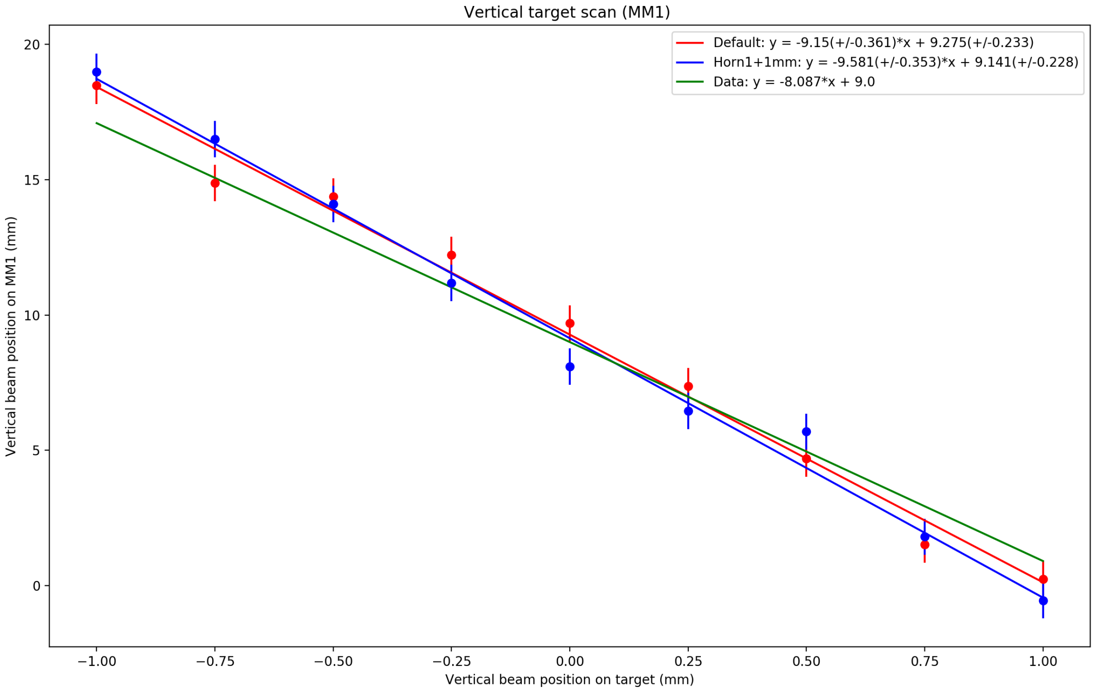


Beam scan simulation for different horn1 z position(MM1)

Horizontal



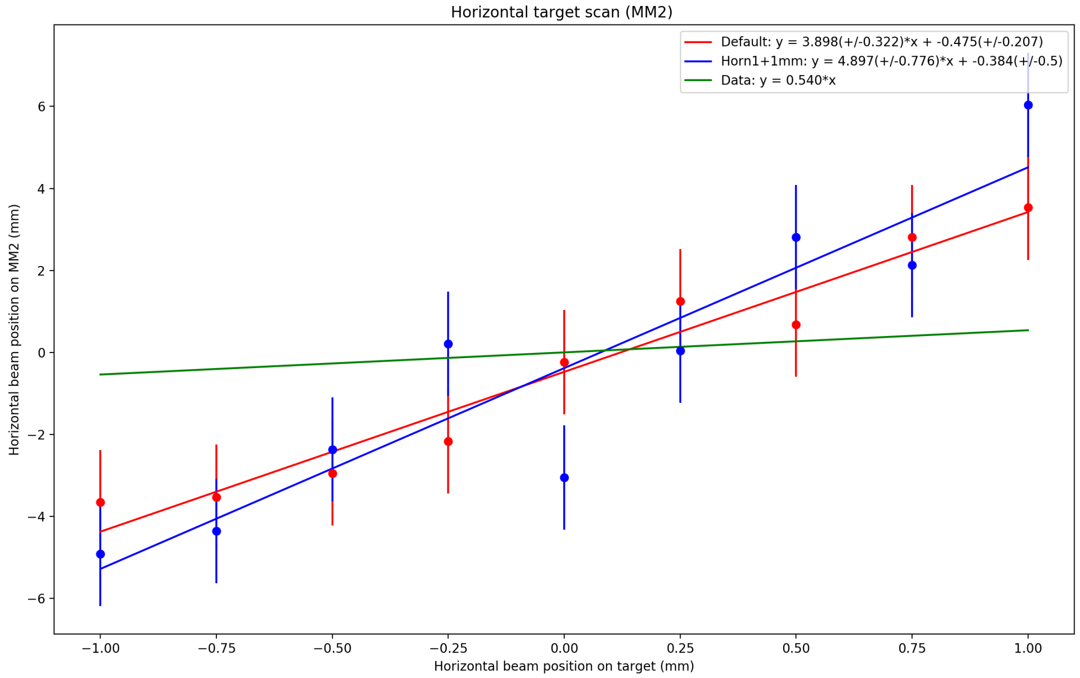
Vertical



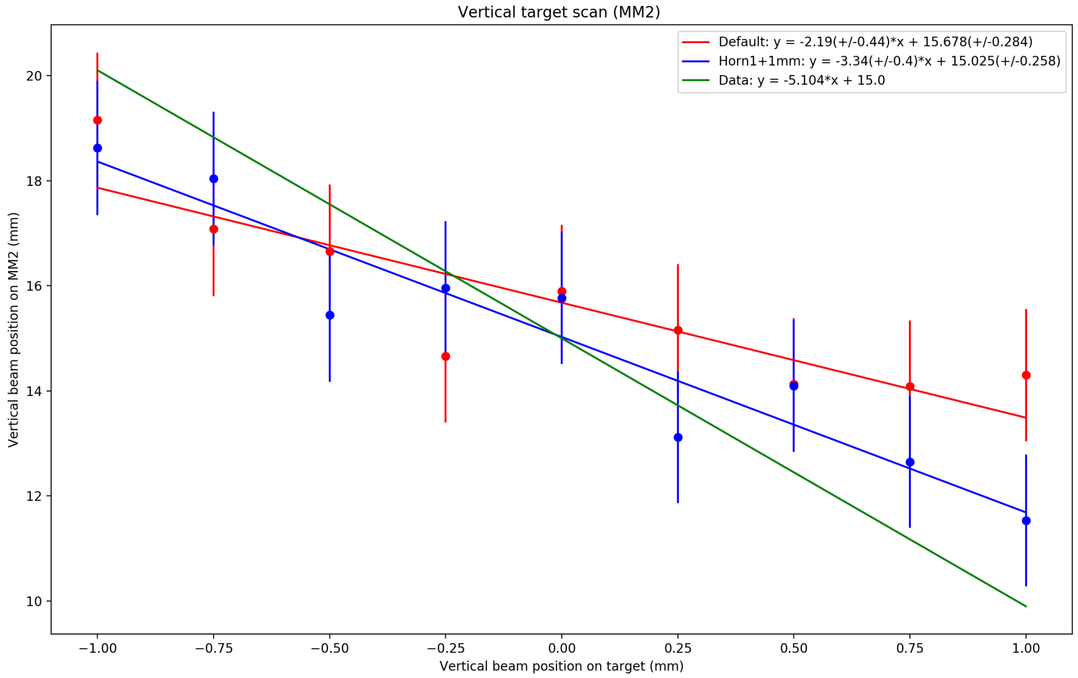
For MM1, horn1 z position do not affect muon signal much.

Beam scan simulation for different horn1 z position(MM2)

Horizontal



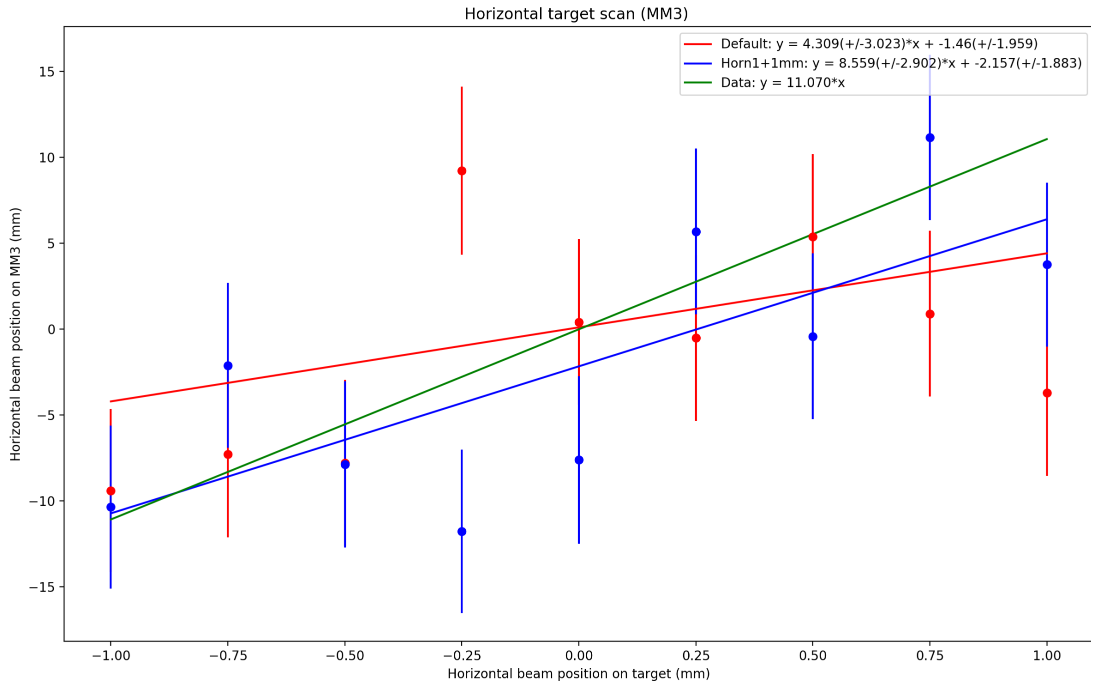
Vertical



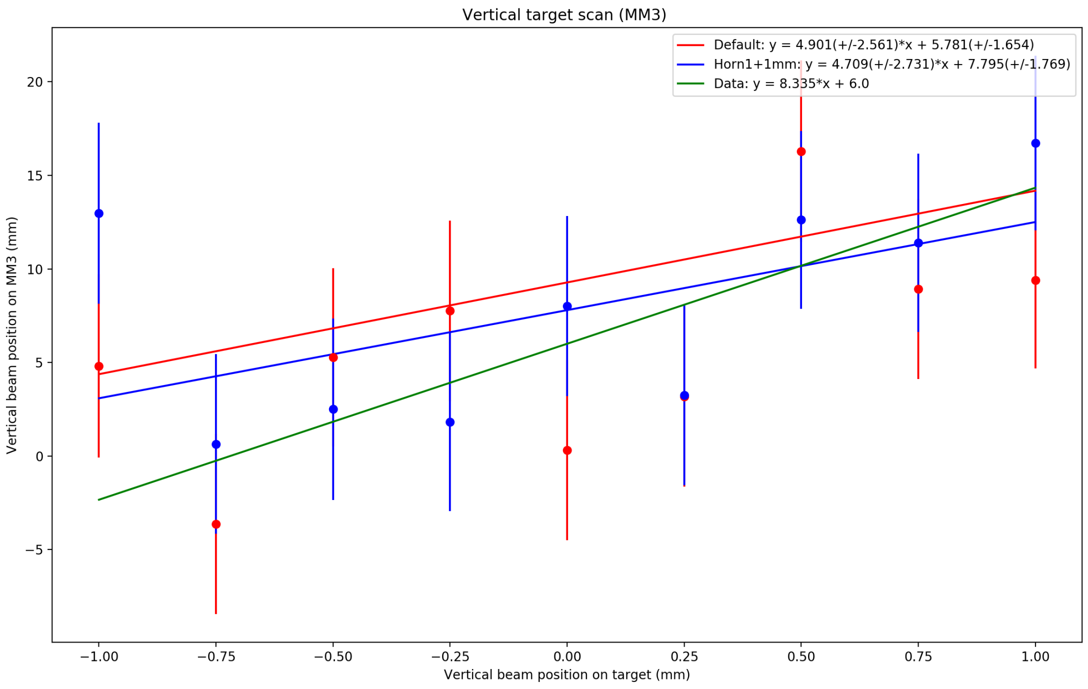
For MM2, both slopes are nit close to experiment data.

Beam scan simulation for different horn1 z position(MM3)

Horizontal



Vertical



Geometry in g4numi

```
absbkgtuple_t.cc                NA49StackingAction.cc            NumiNuWeight.cc
CVS                             NA49TrackInfo.cc                 NumiParticleCode.cc
data_t.cc                       NA49TrackingAction.cc            NumiPrimaryGeneratorAction.cc
dk2nu.cc                        NtpMuon.cc                       NumiPrimaryMessenger.cc
dkmeta.cc                       NumiAnalysis.cc                  NumiRunAction.cc
draytupleMIB_t.cc               NumiBaffle.cc                    NumiRunActionMessenger.cc
draytupleSPB_t.cc               NumiDataInput.cc                 NumiRunManager.cc
Edep_t.cc                       NumiDecayPipe.cc                 NumiSecMonitors.cc
g4numiCint.cc                   NumiDecayPipeMagneticField.cc    NumiStackingAction.cc
g4numiCint.h                    NumiDetectorConstruction.cc      NumiSteppingAction.cc
hadmmtuple_t.cc                 NumiDetectorMessenger.cc         NumiTarget.cc
NA49Analysis.cc                 NumiEventAction.cc               NumiTargetHall.cc
NA49Config.cc                   NumiHadronAbsorber.cc            NumiTrackInformation.cc
NA49DetectorConstruction.cc     NumiHorn1.cc                     NumiTrackingAction.cc
NA49DetectorMessenger.cc        NumiHorn2.cc                     NumiTrajectory.cc
NA49EventAction.cc              NumiHorns.cc                     NumiVisManager.cc
NA49EventActionMessenger.cc     NumiHornSpiderSupport.cc         ProdTuple_t.cc
NA49PhysicsList.cc              NumiImpWeight.cc                 store
NA49PhysicsListMessenger.cc     NumiMagneticField.cc             target_exit_t.cc
NA49PrimaryGeneratorAction.cc   NumiMaterials.cc                 TrackInfo_t.cc
NA49RunAction.cc                NumiNOvATarget.cc                zptuple_t.cc
```

numiDataInput.cc

- For simple change in geometry, you can use the parameters in numiDataInput.cc.

```
// Target   1
//===================================================================
TargetX0              = 0.0;
//TargetY0              = 0.067*cm;
TargetY0              = 0.0;
TargetFinX0           = 0.0;
TargetFinY0           = 0.0*cm;
//TargetZ0              = -0.35*m + TargetConfigZ;
TargetZ0              = fTargetZ0_ref; // this is LE000 position
TargetDxdz            = 0.0; // doesn't
//TargetDydz            = 0.000786;
TargetDydz            = 0.0; // work properly yet
TargetSLength         = 20.*mm;
TargetSWidth          = 6.40E-03*m;
TargetSHeight         = 18.0E-03*m;
TargetCPGRadius       = 3.2*mm; // Cooling pipe groove
TargetCPGPosition     = 10.7*mm;
TargetEndRounded      = true;
TargetSegmentNo       = 47;
TargetSegmentPitch    = 0.3*mm;
TargetA               = 12.01*g/mole;
TargetZ               = 6.;
TargetDensity         = 1.78*g/cm3; //1.815*g/cm3;//1.754*g/cm3;
TargetRL              = 25.692;
TargetGEANTmat        = 18;
```

Add commands in macros

- You can also use commands in macros to change the geometry.

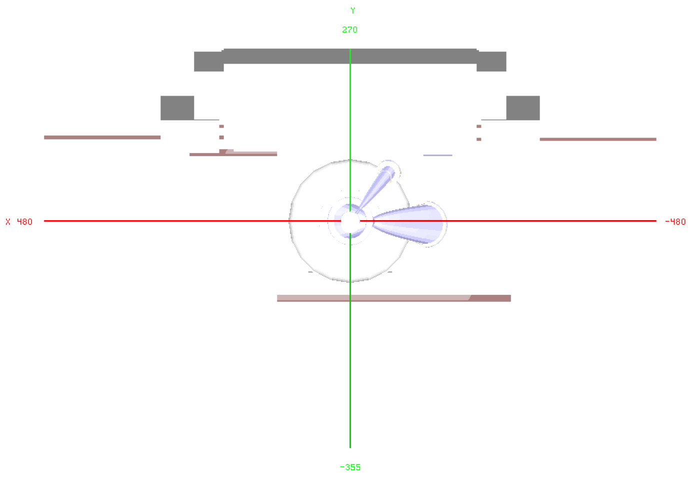
```
/NuMI/det/set/horn1Position 0 0 3 cm
/NuMI/det/set/horn2Position 0 0 1918 cm
/NuMI/det/set/bafflePosition 0 0 -380 cm
/NuMI/det/set/targetPosition 0 0 -143.3 cm

/NuMI/det/set/deltaOuterThickness 0.9525 cm
/NuMI/det/set/duratekShift 4.5 m
/NuMI/det/set/thblockShift 4.5 m

/NuMI/det/set/baffleInnerRadius 6.5 mm
```

Change the geometry in detail

- If there is no command and parameters to change the geometry, we have to change the source file in detail.

```
if (NumiData->constructTarget)
{
    if (fBeamType.find("me") != std::string::npos &&
        !fForcedOldTarget) ConstructNOvATarget();
    else ConstructTarget();
}

ConstructHadronAbsorber();
ConstructSecMonitors();
```

gdml file



- For Minerva branch:
  we can not generate the gdml file

- For numix branch:
  to extract a GDML file add the following lines to the .mac file just before the /run/beamOn line:

  /NuMI/output/GDMLref false

  /NuMI/output/writeGDML myfile.gdml