G4LBNF Simulation

Adding NuMi Decay Pipe Field Map to LBNF Decay Pipe

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BIWG Meeting

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Goal

- g4LBNF simulation has no geomagnetic field within decay pipe
- Shielding of decay pipe will alter earth’s magnetic field within decay pipe
- Asked to take field map in decay pipe volume from g4NuMI simulation code and put in g4LBNF simulation
- Plot neutrino flux with and without decay pipe field map

Decay Pipe Field Map in g4NuMI

- Decay pipe magnetic field measured by Jim Hylen in 2003
- Average field values: $B_x = 0.1G$, $B_y = -0.3G$, $B_z = -0.07G$
- Average magnetic field of earth = 0.5 G [1]

[1]. Harvard Natural Sciences Lecture Demonstrations. OHP Magnetic Lines Force. URL https://sciencedemonstrations.fas.harvard.edu/presentations/ohp-magnetic-lines-force

Decay Pipe Field Map in g4NuMI

- In /src/NumiDecayPipeMagneticField.cc

```
//magnetic field inside the decay pipe ====================================================
NumiDecayPipeMagneticField::NumiDecayPipeMagneticField()
{
  NumiData=NumiDataInput::GetNumiDataInput();//set initial values

}
NumiDecayPipeMagneticField::~NumiDecayPipeMagneticField(){;}
void NumiDecayPipeMagneticField::GetFieldValue(const double Point[3],double *Bfield) const
{
  static bool first = true;
  G4Navigator* numinav=new G4Navigator(); //geometry navigator
  G4Navigator* theNav=G4TransportationManager::GetTransportationManager()-
>GetNavigatorForTracking();
  numinav->SetWorldVolume(theNav->GetWorldVolume());
  G4ThreeVector Pos=G4ThreeVector(Point[0],Point[1],Point[2]);
  G4VPhysicalVolume* myVol = numinav->LocateGlobalPointAndSetup(Pos);
  G4TouchableHistoryHandle touchable = numinav->CreateTouchableHistoryHandle();
  G4ThreeVector localPos = touchable->GetHistory()->GetTopTransform().TransformPoint(Pos);

  delete numinav;

  //Average values measured by J. Hylen 2003: Z=beam dir, X=beam left, Y=Up
  Bfield[0] = 0.1*gauss;
  Bfield[1] = -0.3*gauss;
  Bfield[2] = -0.07*gauss;
if ( first )  first = false;
}
```

The positions are not actually being used to calculate the magnetic field

Instead, these measured avg. values are being used

- How metal in decay pipe affects field is not known
- Can not use model prediction for field values
- Instead used a constant magnetic field as average of what Jim measured

Decay Pipe Field Map in g4LBNF

- Added a class LBNEMagneticFieldDecayPipe

```
LBNEMagneticFieldDecayPipe::LBNEMagneticFieldDecayPipe()
{
}
LBNEMagneticFieldDecayPipe::~LBNEMagneticFieldDecayPipe(){;}


void LBNEMagneticFieldDecayPipe::GetFieldValue(const double
Point[3], double *Bfield) const
{
  static bool first = true;
//Average values measured by J. Hylen 2003: Z=beam dir,
X=beam left, Y=Up


  Bfield[0] = 0.1*CLHEP::gauss;
  Bfield[1] = -0.3*CLHEP::gauss;
  Bfield[2] = -0.07*CLHEP::gauss;
  if ( first )  first = false;
}
```

- Added field values measured by Jim
- Details of code implementation in backup

Comparison Flux plots with & w/o new NuMi Field map in Nominal Simulation

- Generated flux ntuples and histograms running on grid in **neutrino mode**

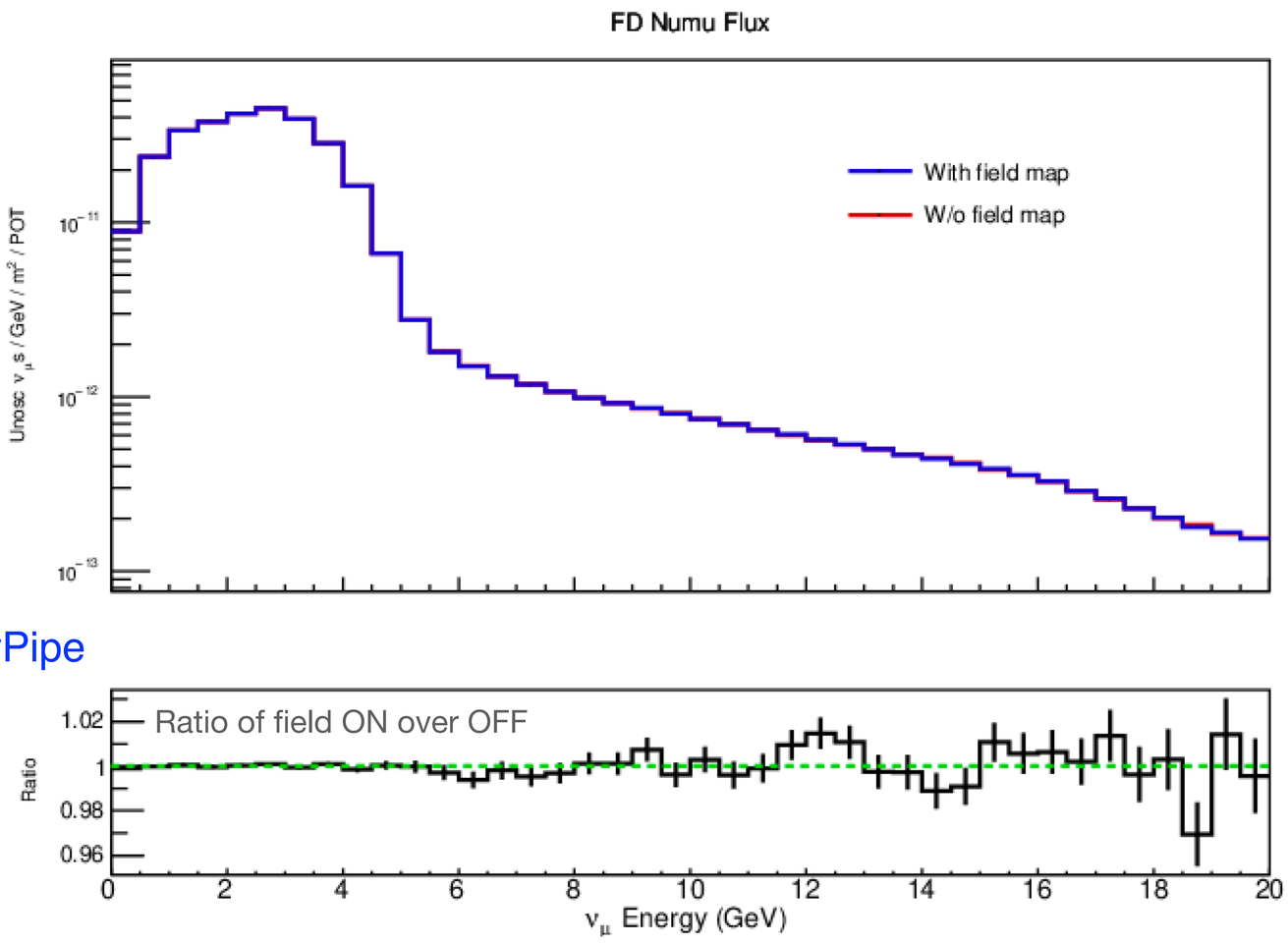
- Geant4 version v3r5p7 simulation with **250,000** POT

- With decay pipe field **OFF**: Jan2020_OptEngNov2017_150cmTargetCone (standard for beamline focusing uncertainty studies)
- Horn Current: 300 kA

- With decay pipe field **ON**:
  - Jan2020_OptEngNov2017_150cmTargetCone_withDecayPipe Field
  - Horn current: 300 kA
  - **Contains value for G4UI card:**

#apply decay pipe magnetic field from Numi Field map
/LBNE/det/ApplyDecayPipeMagneticField True

Macro file contains this Geant User Interface card input which sets decay pipe magnetic field to true



No significant difference observed b/w decay pipe field ON vs OFF cases
Is the field being turned on?

• Check if DecayPipe Magnetic Field is ON
• Add a Tune Parameter to tune up/down DecayPipe Magnetic Field

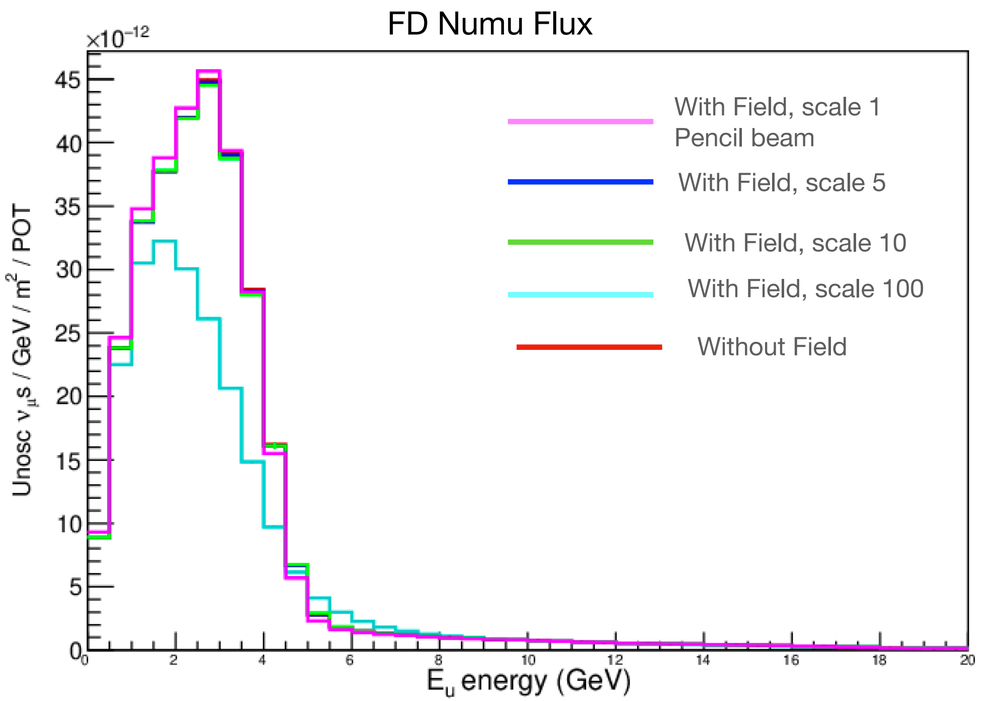
- To confirm field is ON, added “print outs” to code (details in backup)
- Added a tune parameter to tune up/down the applied magnetic field in decay pipe
- In src/LBNEVolumePlacements.cc:

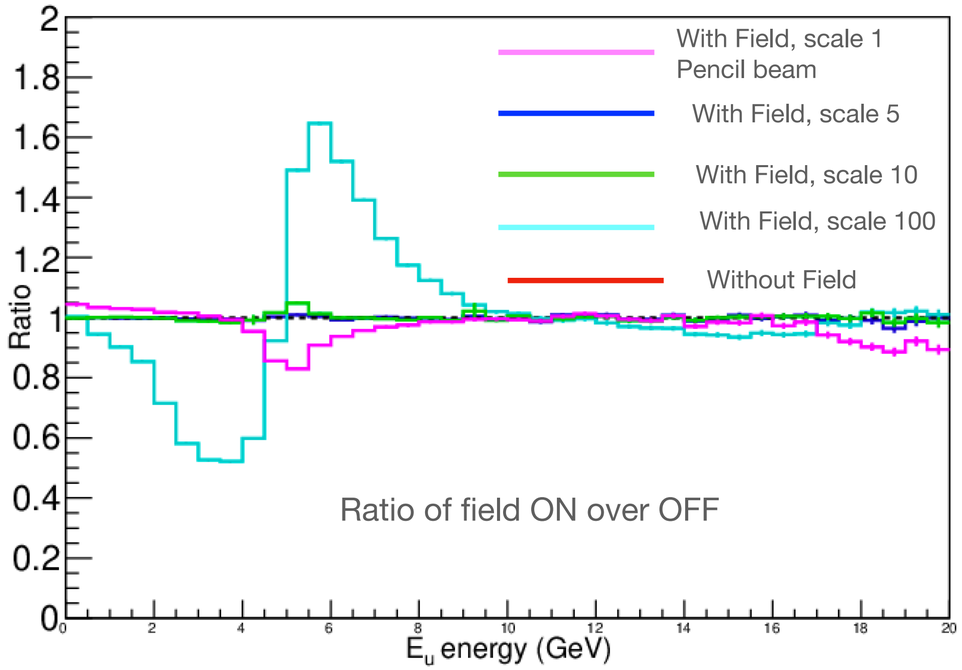
```
fApplyDecayPipeMagneticField = false;
fDecayPipeMagneticFieldScale = 1.0; // No units
```

Scale factor set to 1 by default, can be changed within macro

Comparison Flux plots Neutrino Mode

- Generated flux ntuples and histograms running on grid in **neutrino mode**
- Geant4 version v3r5p7 simulation with **250,000** POT
- With decay pipe field **OFF**:
- Jan2020_OptEngNov2017_150cmTargetCone (standard for beamline focusing uncertainty studies)
- With decay pipe field **ON (with different scale factors)**:
  - Jan2020_OptEngNov2017_150cmTargetCone_withDecayPipeField_**scale1_pencilbeam**.mac **(beamSigmaX = 0.001 mm, beamSigmaY = 0.001 mm)**
  - Jan2020_OptEngNov2017_150cmTargetCone_withDecayPipeField_**scale5**.mac
  - Jan2020_OptEngNov2017_150cmTargetCone_withDecayPipeField_**scale10**.mac
  - Jan2020_OptEngNov2017_150cmTargetCone_withDecayPipeField_**scale100**.mac
  - Horn current: 300 kA





Comparison Flux plots Antineutrino Mode

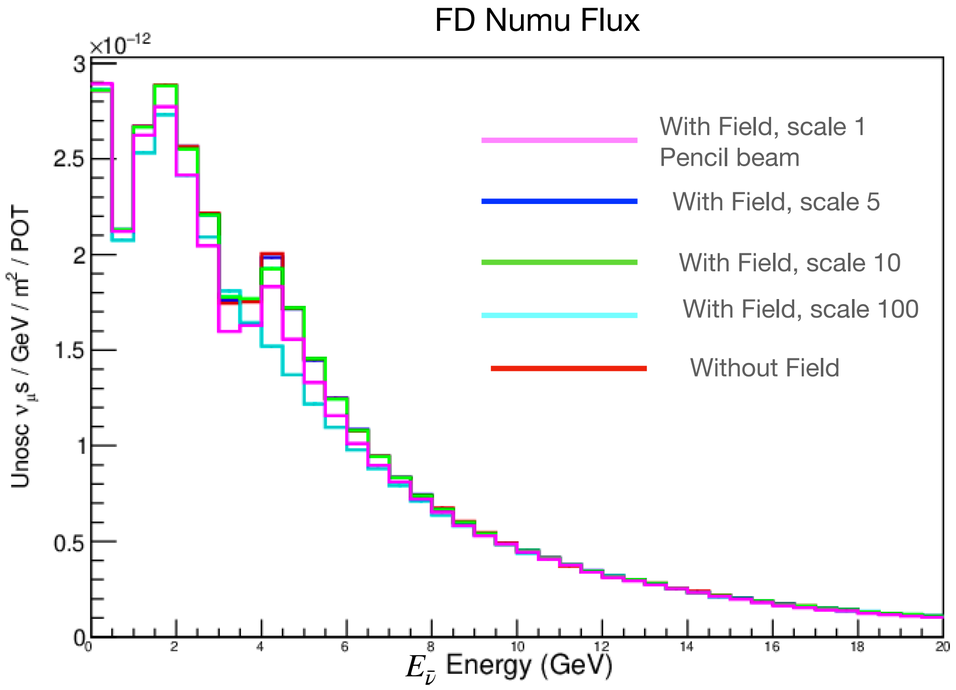
- Generated flux ntuples and histograms running on grid in **antineutrino mode**

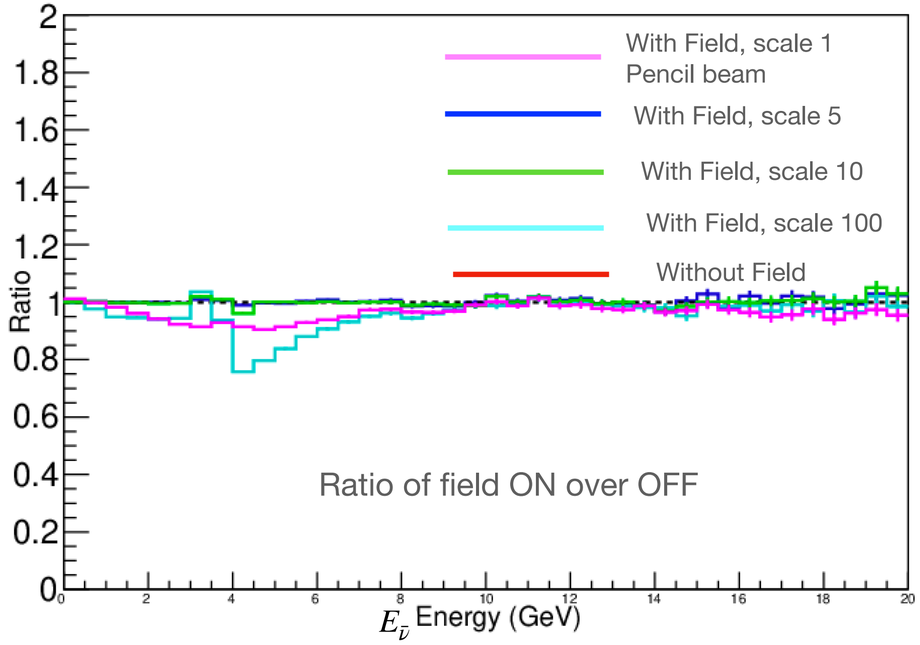
- Geant4 version v3r5p7 simulation with **250,000** POT

- With decay pipe field **OFF**:
- Jan2020_OptEngNov2017_150cmTargetCone (standard for beamline focusing uncertainty studies)

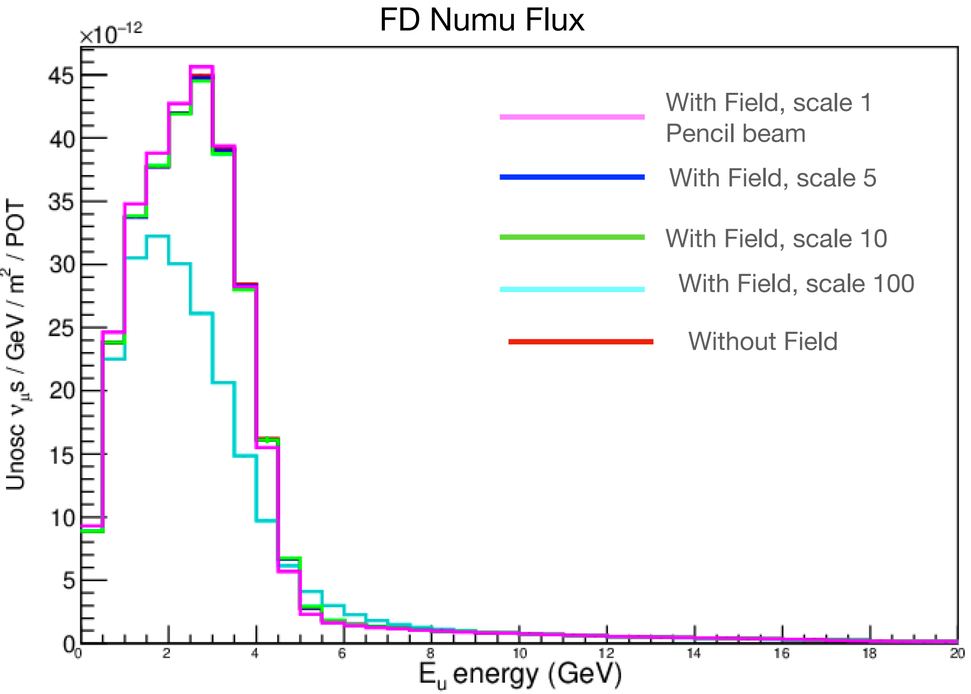
- Macro used for with decay pipe field **ON (with different scale factors)**:
  - Jan2020_OptEngNov2017_150cmTargetCone_withDecayPipeField_**scale1_pencilbeam**.mac **(beamSigmaX = 0.001 mm, beamSigmaY = 0.001 mm)**
  - Jan2020_OptEngNov2017_150cmTargetCone_withDecayPipeField_**scale5**.mac
  - Jan2020_OptEngNov2017_150cmTargetCone_withDecayPipeField_**scale10**.mac
  - Jan2020_OptEngNov2017_150cmTargetCone_withDecayPipeField_**scale100**.mac

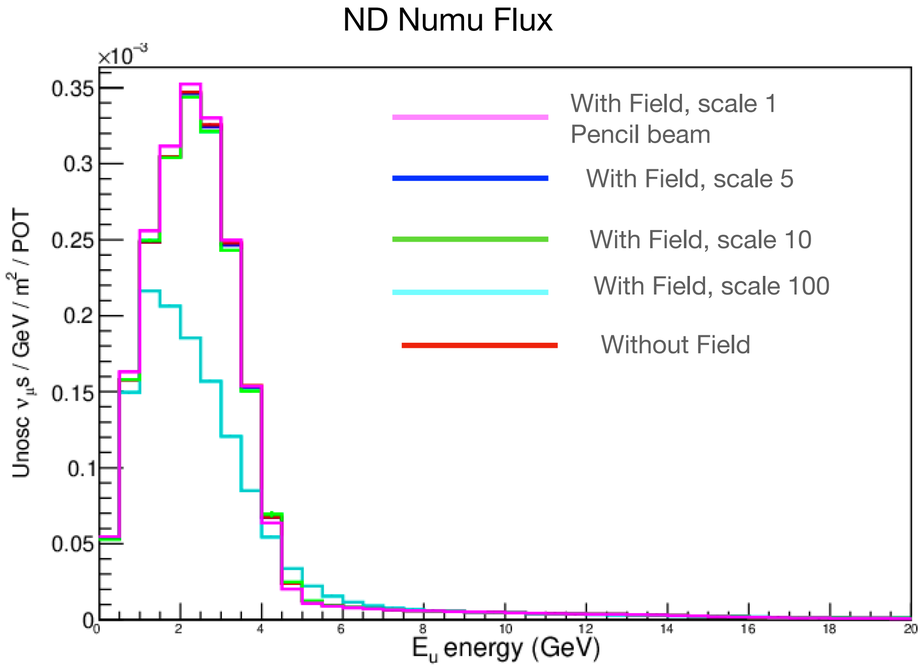
DecayPipe Magnetic Field is ON
Field can be tuned up/down by scale factor

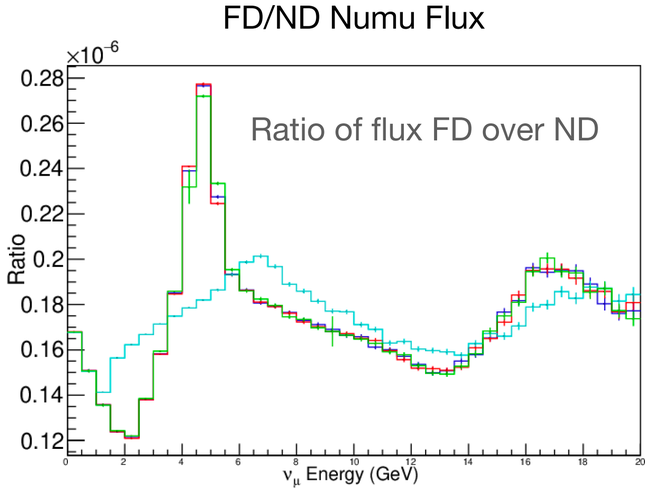


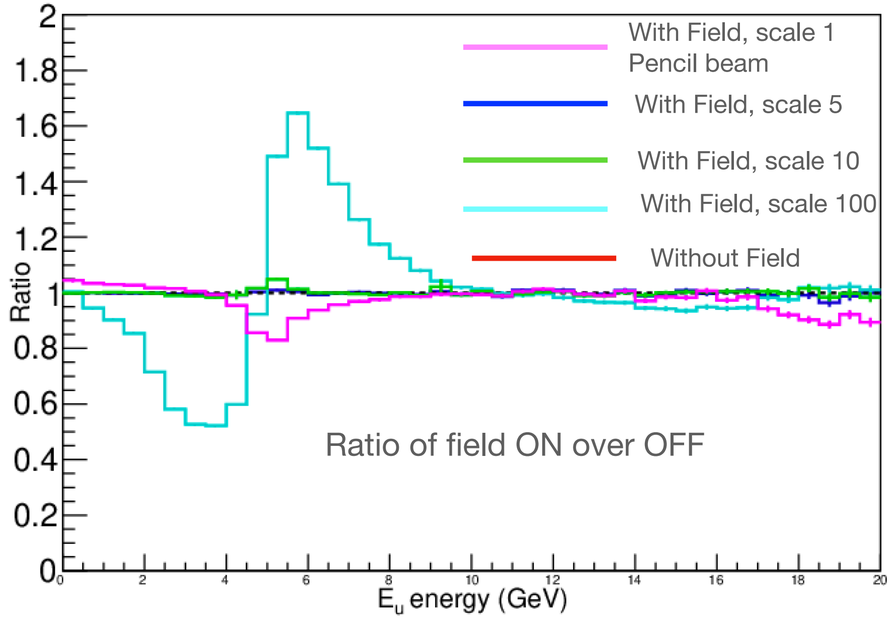


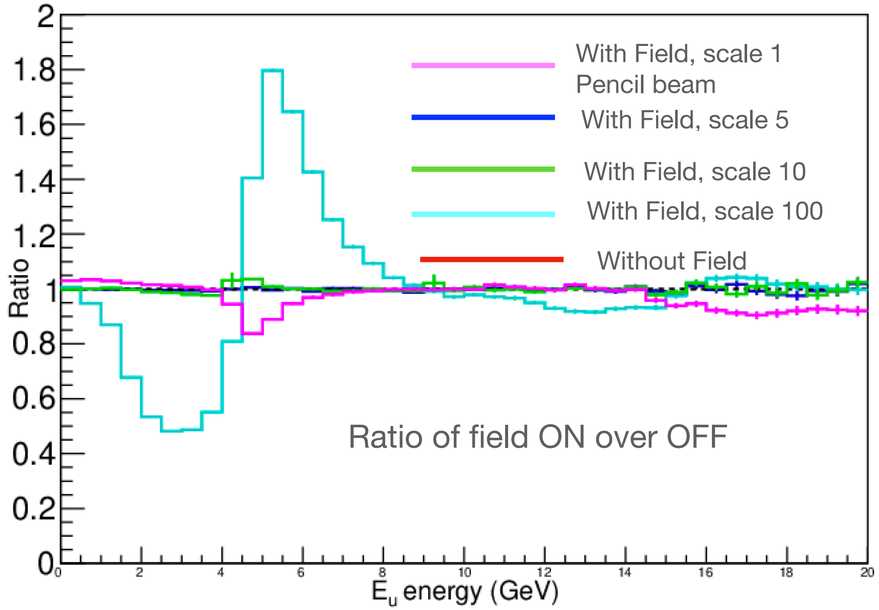
Neutrino Mode



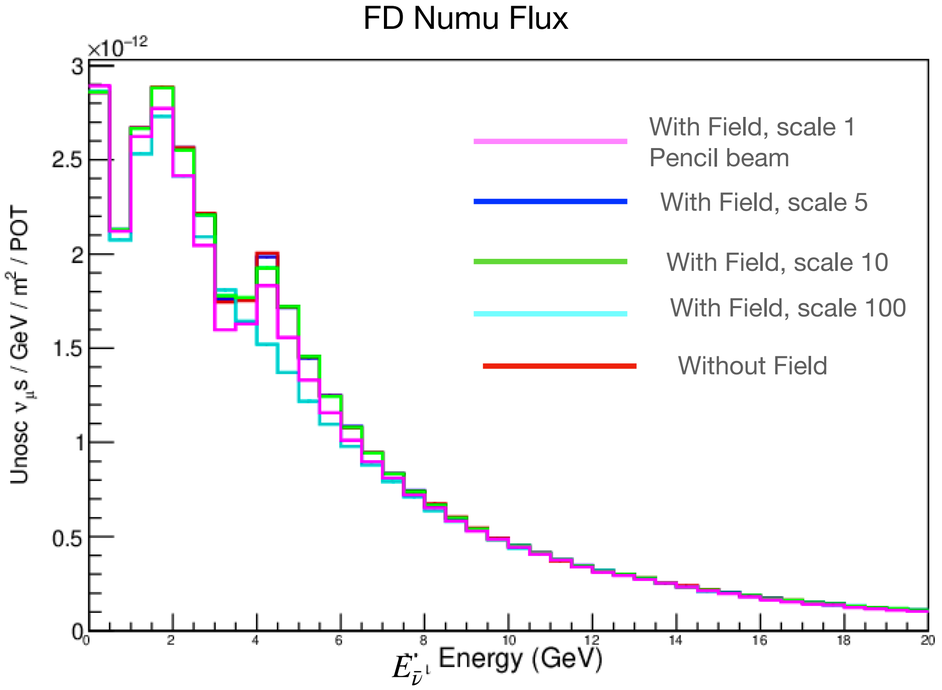


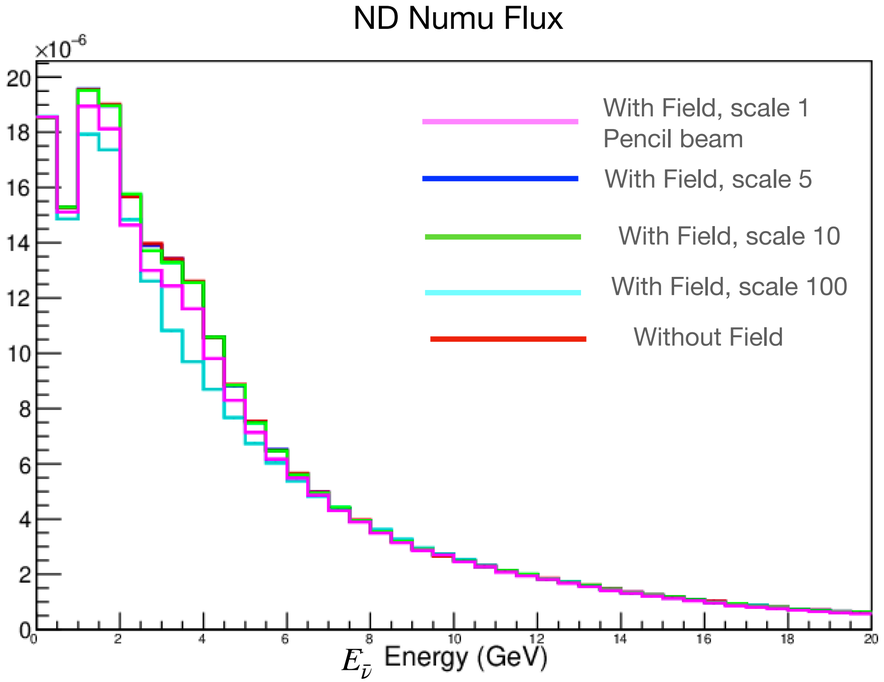


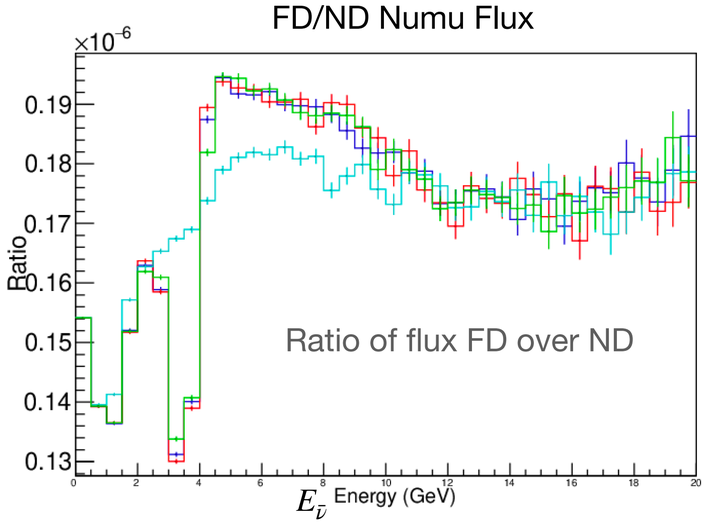


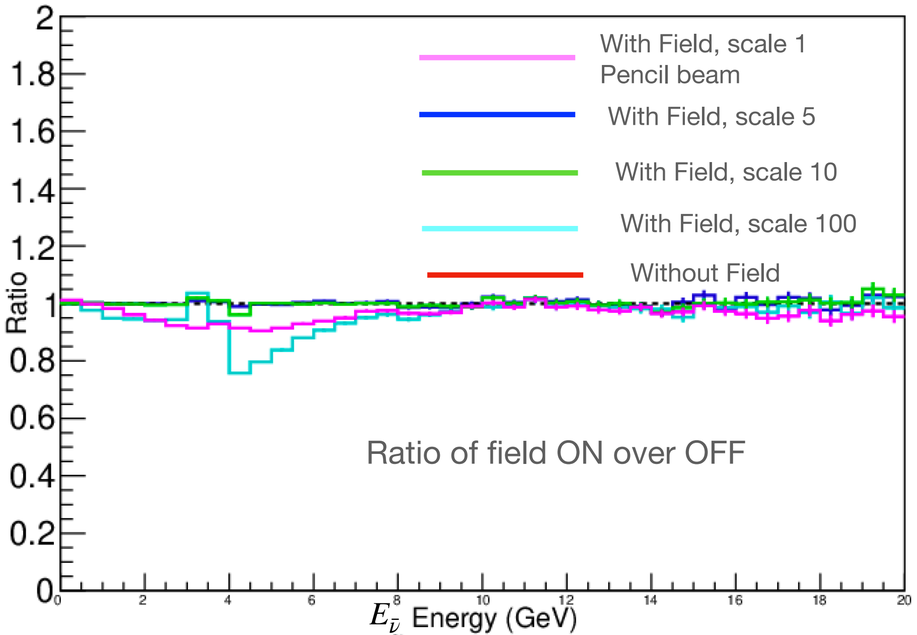


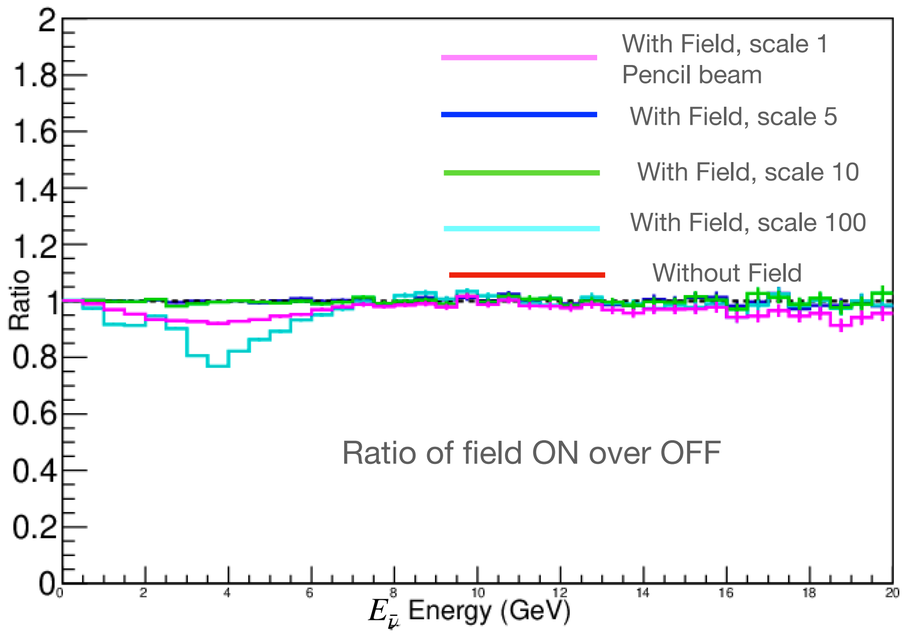
Antineutrino Mode











BACKUP

Details of code implementation

Aim: Get g4NuMi Geomagnetic field in Decay Pipe into g4LBNF Decay Pipe

- g4NuMi
  - Starting with class NuMiDecayPipeMagneticField
  - **In /include/ NumiDecayPipeMagneticField.hh**

```
class NumiDecayPipeMagneticField : public
G4MagneticField //class NuMiDecayPipeMagneticField inherits
all methods and member variables from class G4MagneticField
{
  public:
  NumiDecayPipeMagneticField();
~NumiDecayPipeMagneticField();
virtual void GetFieldValue( const double Point[3],  double
*Bfield ) const;
private:
  NumiDataInput* NumiData;
};
#endif
```

- **In /src/NumiDecayPipeMagneticField.cc (contains function definition for the class members)**

```
//magnetic field inside the decay pipe ==================================================
NumiDecayPipeMagneticField::NumiDecayPipeMagneticField()
{
  NumiData=NumiDataInput::GetNumiDataInput();//set initial values

}
NumiDecayPipeMagneticField::~NumiDecayPipeMagneticField(){;}
void NumiDecayPipeMagneticField::GetFieldValue(const double Point[3],double *Bfield) const
{
  static bool first = true;
  G4Navigator* numinav=new G4Navigator(); //geometry navigator
  G4Navigator* theNav=G4TransportationManager::GetTransportationManager()-
>GetNavigatorForTracking();
  numinav->SetWorldVolume(theNav->GetWorldVolume());
  G4ThreeVector Pos=G4ThreeVector(Point[0],Point[1],Point[2]);
  G4VPhysicalVolume* myVol = numinav->LocateGlobalPointAndSetup(Pos);
  G4TouchableHistoryHandle touchable = numinav->CreateTouchableHistoryHandle();
  G4ThreeVector localPos = touchable->GetHistory()->GetTopTransform().TransformPoint(Pos);

  delete numinav;

  //Average values measured by J. Hylen 2003: Z=beam dir, X=beam left, Y=Up
  Bfield[0] = 0.1*gauss;
  Bfield[1] = -0.3*gauss;
  Bfield[2] = -0.07*gauss;
if ( first )  first = false;
}
```

The positions are not actually being used to calculate the magnetic field?

Instead, these measured avg. values are being used

Aim: Get g4NuMi Geomagnetic field in Decay Pipe into g4LBNF Decay Pipe

- g4lbne
  - In /include/LBNEMagneticField.hh (I added the class LBNEMagneticFieldDecayPipe)

```
class LBNEMagneticFieldDecayPipe : public G4MagneticField
{
  public:
  LBNEMagneticFieldDecayPipe();

  ~LBNEMagneticFieldDecayPipe();
virtual void GetFieldValue( const double Point[3], double
*Bfield ) const;
};

#endif
```

- In /src/LBNEMagneticField.cc

```
LBNEMagneticFieldDecayPipe::LBNEMagneticFieldDecayPipe()
{
}
LBNEMagneticFieldDecayPipe::~LBNEMagneticFieldDecayPipe(){;}


void LBNEMagneticFieldDecayPipe::GetFieldValue(const double
Point[3], double *Bfield) const
{
  static bool first = true;
//Average values measured by J. Hylen 2003: Z=beam dir,
X=beam left, Y=Up


  Bfield[0] = 0.1*CLHEP::gauss;
  Bfield[1] = -0.3*CLHEP::gauss;
  Bfield[2] = -0.07*CLHEP::gauss;
  if ( first )  first = false;
}
```

Aim: Get g4NuMi Geomagnetic field in Decay Pipe into g4LBNF Decay Pipe

- g4NuMi

- In /include/NuMiDataInput.hh:

```
In class NumiDataInput
 public:
 // Magnetic Field in decay pipe
  G4bool applyDecayPipeMagneticField;
```

- In src/NumiDataInput.cc:

```
applyDecayPipeMagneticField = false;
```

- In include/NumiDetectorMessenger.hh, class NumiDetectorMessenger contains : G4UIcmdWithABool* applyDecayPipeMagneticField; (Geant User Interface utility for handling the nominal paramtof the geometry)

- In src/NumiDetectorMessenger.cc (add Geant User Interface cards)

```
 applyDecayPipeMagneticField = new G4UIcmdWithABool("/NuMI/det/applyDecayPipeMagneticField",this);
        applyDecayPipeMagneticField->SetGuidance("Apply magnetic field  Bx=0.1, By=-0.3, Bz=-0.07
gauss - on/off");
        applyDecayPipeMagneticField->SetParameterName("applyDecayPipeMagneticField",true);
        applyDecayPipeMagneticField->SetDefaultValue (ND->applyDecayPipeMagneticField);
   applyDecayPipeMagneticField->AvailableForStates(G4State_PreInit,G4State_Idle);


  if ( command == applyDecayPipeMagneticField ) {
      NumiDataInput *NumiData=NumiDataInput::GetNumiDataInput();
      NumiData->applyDecayPipeMagneticField=applyDecayPipeMagneticField->GetNewBoolValue(newValue);
   }
```

- In include/NumiDetectorConstruction.hh (declares variable NumiDecayPipeMagneticField of type pointer to NumiDecayPipeMagneticField class):

```
class NumiDecayPipeMagneticField;
private:

NumiDecayPipeMagneticField* numiDecayMagField;

void ConstructDecayPipe(G4bool=true, G4bool=false);
```

- In src/NumiDetectorConstruction.cc

```
// Pointers for magnetic fields ***
 numiDecayMagField = new NumiDecayPipeMagneticField();
```

In src/NumiDecayPipe.cc (contains function definition for the class member that constitute operations for the class)

```
void NumiDetectorConstruction::ConstructDecayPipe(bool
heInDecayPipe, bool applyDecayPipeMagneticField)
{

 G4cout << "Just to be sure the value is " <<
applyDecayPipeMagneticField  << G4endl;
  // Decay pipe magnetic field
  if (applyDecayPipeMagneticField) {
    G4cout << "And Im in here "<< G4endl;
    G4FieldManager* FieldMngr = new
G4FieldManager(numiDecayMagField); //create a local
field
    FieldMngr->SetDetectorField(numiDecayMagField); //
set the field
    FieldMngr->CreateChordFinder(numiDecayMagField); //
create the objects which calculate the trajectory
    lvDVOL->SetFieldManager(FieldMngr,true); //attach
the local field to logical volume
  }
```

Aim: Get g4NuMi Geomagnetic field in Decay Pipe into g4LBNF Decay Pipe

- g4lbne

- In /include/LBNEVolumePlacements.hh:

```
In class LBNEVolumePlacements
 public:
 // Magnetic Field in decay pipe
 G4bool fApplyDecayPipeMagneticField;

inline void SetApplyDecayPipeMagneticField(bool t){ fApplyDecayPipeMagneticField =
t;}
inline bool GetApplyDecayPipeMagneticField() const { return
fApplyDecayPipeMagneticField;}
```

- In src/LBNEVolumePlacements.cc:

```
fApplyDecayPipeMagneticField = false;
```

- In include/LBNEPlacementMessenger.hh, class LBNEPlacementMessenger contains : G4UIcmdWithABool* fApplyDecayPipeMagneticField; (Geant User Interface utility for handling nominal params of the geometry)

- In src/LBNEPLacementMessenger.cc (add Geant User Interface cards)

```
 {
   fApplyDecayPipeMagneticField = new G4UIcmdWithABool("/LBNE/det/
ApplyDecayPipeMagneticField", this);
   fApplyDecayPipeMagneticField->SetGuidance("Apply magnetic field  Bx=0.1,
By=-0.3, Bz=-0.07 gauss - on/off");
   fApplyDecayPipeMagneticField-
>SetParameterName("ApplyDecayPipeMagneticField",true);
   bool value = volP->GetApplyDecayPipeMagneticField(); //defined in
LBNEVolumePlacements.hh
   fApplyDecayPipeMagneticField->SetDefaultValue(value);
   }


  if (command == fApplyDecayPipeMagneticField) {
     G4UIcmdWithABool* cmdWD = dynamic_cast<G4UIcmdWithABool*> (command);
     volP->SetApplyDecayPipeMagneticField(cmdWD->GetNewBoolValue(newValue));
```

In src/LBNEDetectorConstruction.cc (Contains function definitions for the class members that constitute the *operations* for the class)

```
G4VPhysicalVolume* LBNEDetectorConstruction::Construct() {
   // Decay pipe magnetic field

  if (fPlacementHandler->GetApplyDecayPipeMagneticField()) {
     LBNEMagneticFieldDecayPipe *fieldDecayPipe = new
LBNEMagneticFieldDecayPipe();
     G4FieldManager* FieldMngr = new G4FieldManager(fieldDecayPipe);
     FieldMngr->SetDetectorField(fieldDecayPipe); //set the field

     FieldMngr->CreateChordFinder(fieldDecayPipe); //create the objects
which calculate the trajectory
     const LBNEVolumePlacementData *plDCV =

       fPlacementHandler->Find("FieldDecayPipe", "DecayPipeVolume",
"DetectorConstruction");

     plDCV->fCurrent->SetFieldManager(FieldMngr,true); //attach the local
field to logical volume
   }
  }
```

Replaced this piece of code: using field of a current carrying wire in decay pipe

```
LBNEMagneticFieldDecayPipe *fieldDecayPipe = new LBNEMagneticFieldDecayPipe(true);

G4FieldManager* FieldMngr = new G4FieldManager(fieldDecayPipe); //create a local field

FieldMngr->SetDetectorField(fieldDecayPipe); //set the field

FieldMngr->CreateChordFinder(fieldDecayPipe); //create the objects which calculate the trajectory

const LBNEVolumePlacementData *plDCV =
  fPlacementHandler->Find("FieldDecayPipe", "DecayPipeVolume", "DetectorConstruction");
plDCV->fCurrent->SetFieldManager(FieldMngr,true); //attach the local field to logical volume
```

- **Check if DecayPipe Magnetic Field is ON**
- **Add a Tune Parameter to tune up/down DecayPipe Magnetic Field**

- Added a tune parameter to tune up/down the applied magnetic field in decay pipe

- In include/LBNEVolumePlacements.hh (inline functions are defined here):

```
G4bool fApplyDecayPipeMagneticField;
G4double fDecayPipeMagneticFieldScale;
```

```
inline void SetApplyDecayPipeMagneticField(bool t){ fApplyDecayPipeMagneticField = t;}
inline bool GetApplyDecayPipeMagneticField() const { return fApplyDecayPipeMagneticField;}

inline void SetDecayPipeMagneticFieldScale(double r) {fDecayPipeMagneticFieldScale = r;}
inline double GetDecayPipeMagneticFieldScale() const {return fDecayPipeMagneticFieldScale;}
```

- In src/LBNEVolumePlacements.cc:

```
fApplyDecayPipeMagneticField = false;
fDecayPipeMagneticFieldScale = 1.0; // No units
```

- **Check if DecayPipe Magnetic Field is ON**
- **Add a Tune Parameter to tune up/down DecayPipe Magnetic Field**

- **Adding Geant User Interface Card**:

- In include/LBNEPlacementMessenger.hh:

```
G4UIcmdWithABool* fApplyDecayPipeMagneticField;
G4UIcmdWithADouble* fDecayPipeMagneticFieldScale;
```

- In src/LBNEPLacementMessenger.cc:

```
{
fApplyDecayPipeMagneticField = new G4UIcmdWithABool("/LBNE/det/ApplyDecayPipeMagneticField", this);
fApplyDecayPipeMagneticField->SetGuidance("Apply magnetic field  Bx=0.1, By=-0.3, Bz=-0.07 gauss - on/off");
fApplyDecayPipeMagneticField->SetParameterName("ApplyDecayPipeMagneticField",true);
bool value = volP->GetApplyDecayPipeMagneticField(); //defined in LBNEVolumePlacements.hh
fApplyDecayPipeMagneticField->SetDefaultValue(value);
}

{
  fDecayPipeMagneticFieldScale = new G4UIcmdWithADouble("/LBNE/det/DecayPipeMagneticFieldScale", this);
  G4String guidance("A unitless scale parameter to tune up decay pipe magnetic field set by default to 1\n  ");
  fDecayPipeMagneticFieldScale->SetGuidance(guidance);
  fDecayPipeMagneticFieldScale->SetParameterName("DecayPipeMagneticFieldScale",true);
  fDecayPipeMagneticFieldScale->SetDefaultValue(1.0);
}
```

```
if (command == fApplyDecayPipeMagneticField) {
  G4UIcmdWithABool* cmdWD = dynamic_cast<G4UIcmdWithABool*> (command);
  volP->SetApplyDecayPipeMagneticField(cmdWD->GetNewBoolValue(newValue));
}
if (command == fDecayPipeMagneticFieldScale) {
  G4UIcmdWithADouble* cmdWD = dynamic_cast<G4UIcmdWithADouble*> (command);
  volP->SetDecayPipeMagneticFieldScale(cmdWD->GetNewDoubleValue(newValue));
}
```

- **Check if DecayPipe Magnetic Field is ON**
- **Add a Tune Parameter to tune up/down DecayPipe Magnetic Field**

In src/LBNEMagneticField.cc :

```
const LBNEVolumePlacements *aPlacementHandler = LBNEVolumePlacements::Instance();
static bool first = true;
//for (size_t k=0; k!=3; ++k) Bfield[k] = 0.;
//average values measured by J. Hylen 2003: Z=beam dir, X=beam left, Y=Up
Bfield[0] = 0.1*gauss*aPlacementHandler->GetDecayPipeMagneticFieldScale();
Bfield[1] = -0.3*gauss*aPlacementHandler->GetDecayPipeMagneticFieldScale();
Bfield[2] = -0.07*gauss*aPlacementHandler->GetDecayPipeMagneticFieldScale();

if ( first ) first = false;

std::cerr << " LBNEMagneticFieldDecayPipe::GetFieldValue X= "<<Bfield[0]<< " LBNEMagneticFieldDecayPipe::GetFieldValue Y= "<<Bfield[1]<<"LBNEMag\
neticFieldDecayPipe::GetFieldValue Z= "<<Bfield[2]<<std::endl;
```

Scale factor set to 1 by default, can be changed within macro

Added 3 print statements

In src/LBNEDetectorConstruction.cc :

```
// Decay pipe magnetic field

G4cout << "Just to be sure the value is " << fPlacementHandler->GetApplyDecayPipeMagneticField()  << G4endl;


G4cout << "The scale factor for decay pipe magnetic field tune " << fPlacementHandler->GetDecayPipeMagneticFieldScale() << G4endl;

if (fPlacementHandler->GetApplyDecayPipeMagneticField()) {

  G4cout << "And Im in here "<< G4endl;

  LBNEMagneticFieldDecayPipe *fieldDecayPipe = new LBNEMagneticFieldDecayPipe();
  G4FieldManager* FieldMngr = new G4FieldManager(fieldDecayPipe);
  FieldMngr->SetDetectorField(fieldDecayPipe); //set the field

  FieldMngr->CreateChordFinder(fieldDecayPipe); //create the objects which calculate the trajectory
  const LBNEVolumePlacementData *plDCV =

    fPlacementHandler->Find("FieldDecayPipe", "DecayPipeVolume", "DetectorConstruction");

  plDCV->fCurrent->SetFieldManager(FieldMngr,true); //attach the local field to logical volume
}
```

- **Check if DecayPipe Magnetic Field is ON**
- **Add a Tune Parameter to tune up/down DecayPipe Magnetic Field**

Running locally:

- `./g4lbnf macros/Jan2020_OptEngNov2017_150cmTargetCone_withDecayPipeField_scale10.mac`

```
#apply decay pipe magnetic field from Numi Field map
/LBNE/det/ApplyDecayPipeMagneticField True
/LBNE/det/DecayPipeMagneticFieldScale 10
```

The scale factor is set to 10, means Bx = 1 Gauss, By = -3 Gauss, Bz = -0.7 Gauss

1 means decay pipe field is on

```
Just to be sure the value is 1
The scale factor for decay pipe magnetic field tune 10
And Im in here
```

Prints from LBNEDetectorConstruction.cc

Prints from LBNEMagneticField.cc

```
LBNEMagneticFieldDecayPipe::GetFieldValue X= 1e-08
LBNEMagneticFieldDecayPipe::GetFieldValue Y= -3e-08
LBNEMagneticFieldDecayPipe::GetFieldValue Z= -7e-09
```

0.1 Gauss *1
-0.3 Gauss *1
-0.07 Gauss *1

```
LBNEMagneticFieldDecayPipe::GetFieldValue X= 1e-07
LBNEMagneticFieldDecayPipe::GetFieldValue Y= -3e-07
LBNEMagneticFieldDecayPipe::GetFieldValue Z= -7e-08
```

0.1 Gauss *10
-0.3 Gauss *10
-0.07 Gauss *10

```
LBNEMagneticFieldDecayPipe::GetFieldValue X= 5e-08
LBNEMagneticFieldDecayPipe::GetFieldValue Y= -1.5e-07
LBNEMagneticFieldDecayPipe::GetFieldValue Z= -3.5e-08
```

0.1 Gauss *5
-0.3 Gauss *5
-0.07 Gauss *5