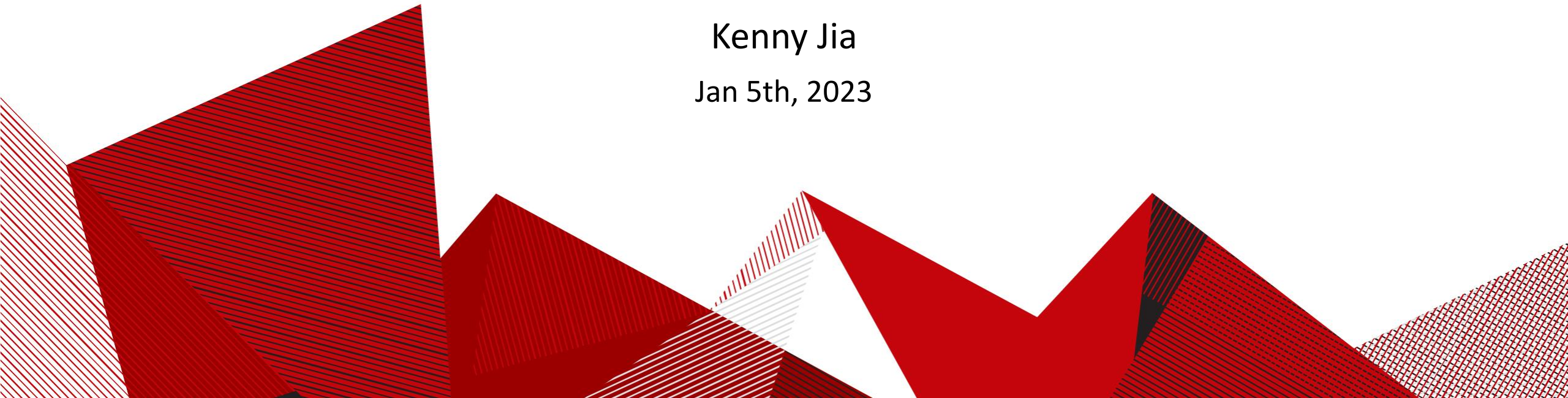




Measuring the Higgs Self-coupling Using the Muon Collider

Kenny Jia

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New BIB module

- Change both Delphes/allParticles and Delphes/stableParticles.
- Need input of several histograms from a provided root file (the file will be inside the Delphes directory when running on cluster).

```
#####  
# BIB Module  
#####  
  
module BIBModule BIBModule {  
    set InputArray Delphes/allParticles  
    set StableInputArray Delphes/stableParticles  
  
    set OutArray allParticles  
    set StableOutArray stableParticles  
  
    set NumParticles 30000000  
    set FileName histograms_MCPar_muComb_files1To8_Allevts.root  
    set PositionHistName xyz  
    set AngPosHistName etaphi  
    set EnergyHistName energy  
    set MomentumHistName pxpypz  
    set PdgIDHistName pdgid  
}
```



BIBModule

- Relationship between particle kind on energy and position?
 - Random generate energy and position follows histograms provided then assign mass, charge and pid randomly following the particleID distribution
 - Or, we treat different kinds of particle differently. Need multiple histograms for each kind.
- Dependency of all these variables:
 - x, y, z
 - Eta, phi
 - Energy
 - p_x, p_y, p_z
 - pdgid



BIBModule

- Dictionary of PdgID, mass, and charge?

```
for (UInt i = 0; i < fNumParticles; i++)
{
    fEnergyHist -> GetRandom(energy);
    fAngPosHist -> GetRandom2(eta, phi);
    fPositionHist -> GetRandom3(x, y, z);
    fMomentumHist -> GetRandom3(px, py, pz);
    fPdgIDHist -> GetRandom(pdgid);

    if(energy <= 0.0) continue;
    x = bib.X;
    y = bib.Y;
    z = bib.Z;
    eta = bib.Eta;
    phi = bib.Phi;
    energy = bib.E;
    px = bib.Px;
    py = bib.Py;
    pz = bib.Pz;

    pdgid = bib.PID;

    //assign mass and charge by pdgID here

    fOutputArray->Add(bib);
    fStableOutputArray->Add(bib);
}
```



Rewrite MuCol card for Delphes with BIBsim

- “Copied” the original execution path of the Delphes card but added BIB particles at the very beginning.
- Two set of execution paths gives us two set of variables to compare with.

```
module TreeWriter TreeWriter
# add Branch InputArray BranchName BranchClass
add Branch Delphes/allParticles Particle GenParticle
add Branch BIBModule/allParticles BIBParticle GenParticle

add Branch GenJetFinder/jets GenJet Jet
add Branch BIBGenJetFinder/jets BIBGenJet Jet
add Branch GenR02JetFinder/R02jets GenR02Jet Jet
add Branch BIBGenR02JetFinder/R02jets BIBGenR02Jet Jet

add Branch FastJetFinderAKt/AKTjets AKTjet Jet
add Branch BIBFastJetFinderAKt/AKTjets BIBAKTjet Jet
add Branch FastJetFinderAKtR02/AKTRO2jets AKTRO2jet Jet
add Branch BIBFastJetFinderAKtR02/AKTRO2jets BIBAKTRO2jet Jet
add Branch FastJetFinderAKtR01/AKTRO1jets AKTRO1jet Jet
add Branch BIBFastJetFinderAKtR01/AKTRO1jets BIBAKTRO1jet Jet

add Branch GenMissingET/momentum GenMissingET MissingET
add Branch BIBGenMissingET/momentum BIBGenMissingET MissingET

add Branch TrackMerger/tracks Track Track
add Branch BIBTrackMerger/tracks BIBTrack Track
add Branch Calorimeter/towers Tower Tower
add Branch BIBCalorimeter/towers BIBTower Tower

add Branch HCal/eflowTracks EFlowTrack Track
add Branch BIBHCal/eflowTracks BIBEFlowTrack Track
add Branch ECal/eflowPhotons EFlowPhoton Tower
add Branch BIBECal/eflowPhotons BIBEFlowPhoton Tower
add Branch HCal/eflowNeutralHadrons EFlowNeutralHadron Tower
add Branch BIBHCal/eflowNeutralHadrons BIBEFlowNeutralHadron Tower

add Branch UniqueObjectFinder/photons Photon Photon
add Branch BIBUniqueObjectFinder/photons BIBPhoton Photon
add Branch UniqueObjectFinder/electrons Electron Electron
add Branch BIBUniqueObjectFinder/electrons BIBElectron Electron
add Branch UniqueObjectFinder/muons Muon Muon
add Branch BIBUniqueObjectFinder/muons BIBMuon Muon
add Branch ForwardMuonMomentumSmearing/muons ForwardMuon Muon
add Branch BIBForwardMuonMomentumSmearing/muons BIBForwardMuon Muon

add Branch MissingET/momentum MissingET MissingET
add Branch BIBMissingET/momentum BIBMissingET MissingET
add Branch ScalarHT/energy ScalarHT ScalarHT
add Branch BIBScalarHT/energy BIBScalarHT ScalarHT
```



Questions about the card modifications

- 1. Does the BIB particles get involve in the “Delphes/partons” array?
 - JetFlavorAssociation and Tagging

```
module JetFlavorAssociation BIBAKT_JetFlavorAssociation_R05_inclusive {  
  
  set PartonInputArray Delphes/partons  
  set ParticleInputArray BIBModule/allParticles  
  set ParticleLHEFInputArray Delphes/allParticlesLHEF  
  set JetInputArray BIBFastJetFinderAKt/AKTjets  
  
  set DeltaR 0.5  
  set PartonPTMin 1.0  
  set PartonEtaMax 2.5  
  
}
```



Questions about the card modifications

- 2. Should those efficiency and smearing formula works the same on BIB particles?

```
module Efficiency BIBElectronEfficiency {
  set InputArray BIBElectronFilter/electrons
  set OutputArray electrons

  # set EfficiencyFormula {efficiency formula as a function of eta and pt}

  set EfficiencyFormula {
    (energy < 3.0 ) * ( 0.00 ) +
    (abs(eta) > 2.50) * ( 0.00 ) +
    ( energy >=3 && energy < 8 ) * (abs(eta) > 1.95 && abs(eta) < 2.50) * (0.58 ) +
    ( energy >=3 && energy < 8 ) * (abs(eta) <= 1.95 && abs(eta) > 1.22) * ( 0.7 ) +
    ( energy >=3 && energy < 8 ) * (abs(eta) <= 1.22 && abs(eta) > 1.1 ) * ( 0.6 ) +
    ( energy >=3 && energy < 8 ) * (abs(eta) <= 1.1 && abs(eta) > 0.91 ) * ( 0.7 ) +
    ( energy >=3 && energy < 8 ) * (abs(eta) <= 0.91 && abs(eta) > 0.69) * ( 0.8 ) +
    ( energy >=3 && energy < 8 ) * (abs(eta) <= 0.69) * (0.84 ) +
    ( energy >=8 && energy < 13 ) * (abs(eta) > 1.95 && abs(eta) < 2.50) * ( 0.6 ) +
    ( energy >=8 && energy < 13 ) * (abs(eta) <= 1.95 && abs(eta) > 1.22) * ( 0.76 ) +
    ( energy >=8 && energy < 13 ) * (abs(eta) <= 1.22 && abs(eta) > 1.1 ) * ( 0.67 ) +
    ( energy >=8 && energy < 13 ) * (abs(eta) <= 1.1 && abs(eta) > 0.91 ) * ( 0.78 ) +
    ( energy >=8 && energy < 13 ) * (abs(eta) <= 0.91 && abs(eta) > 0.69) * ( 0.86 ) +
    ( energy >=8 && energy < 13 ) * (abs(eta) <= 0.69) * ( 0.88 ) +
    ( energy >=13 && energy < 18 ) * (abs(eta) > 1.95 && abs(eta) < 2.50) * ( 0.6 ) +
    ( energy >=13 && energy < 18 ) * (abs(eta) <= 1.95 && abs(eta) > 1.22) * ( 0.8 ) +
    ( energy >=13 && energy < 18 ) * (abs(eta) <= 1.22 && abs(eta) > 1.1 ) * ( 0.68 ) +
    ( energy >=13 && energy < 18 ) * (abs(eta) <= 1.1 && abs(eta) > 0.91 ) * ( 0.84 ) +
    ( energy >=13 && energy < 18 ) * (abs(eta) <= 0.91 && abs(eta) > 0.69) * ( 0.88 ) +
    ( energy >=13 && energy < 18 ) * (abs(eta) <= 0.69) * ( 0.9 ) +
    ( energy >=18 && energy < 23 ) * (abs(eta) > 1.95 && abs(eta) < 2.50) * (0.64 ) +
    ( energy >=18 && energy < 23 ) * (abs(eta) <= 1.95 && abs(eta) > 1.22) * (0.82 ) +
    ( energy >=18 && energy < 23 ) * (abs(eta) <= 1.22 && abs(eta) > 1.1 ) * ( 0.7 ) +
    ( energy >=18 && energy < 23 ) * (abs(eta) <= 1.1 && abs(eta) > 0.91 ) * (0.84 ) +
    ( energy >=18 && energy < 23 ) * (abs(eta) <= 0.91 && abs(eta) > 0.69) * ( 0.9 ) +
    ( energy >=18 && energy < 23 ) * (abs(eta) <= 0.69) * ( 0.92 ) +
  }
```



- New Delphes card and BIBModule uploaded to github:
 - https://github.com/cvuosalo/MuonCollider/blob/main/runMGjobs/runMG_job/src/delphes_card_MuonColliderDet_HHstudy_BIB.tcl
 - https://github.com/cvuosalo/MuonCollider/blob/main/runMGjobs/runMG_job/src/BIBModule.cc
 - https://github.com/cvuosalo/MuonCollider/blob/main/runMGjobs/runMG_job/src/BIBModule.h
- Test with given histograms