Muon Fast Simulation & Z' Study

Chawon Park (SKKU)

Sep. 26th, 2009

Korea CMS Collaboration Meeting

at KNU

- contents

I. Introduction to Fast Simulation in Muon Detector

II. How to implement the Energy Loss at Calorimeters

    I. Using Simple Cylinder and Disk

        I. Performances

    II. Using Calorimeter Manager

        I. Performances

III. Short Plan for Z' Study

IV. Summary

I. Introduction to Muon FastSimulation

- Parameterized muons
  - Efficiency and p_T resolution determined as a function of eta and p_T from full simulation (look-up tables)
    - Used at L1
    - Recommended for global muons
      - But no hits in the muon chambers
      - Only hits in the tracker
- Muons with hits
  - Muons propagated from the tracker to the 1st muon station, to the second, the third, …
    - <dE/dx> and Multiple scattering are applied at each step
    - Hits used to reconstruct stand-alone and global muons
      - Used at L2 (STA) and L3 (Matched with tracks)

II. How to implement the Energy Loss at Calorimeter

(1) Using Simple Cylinder and Disk

- Steps:

  1) Create cylinder (barrel) and disk(endcap) for outside of ECAL

  2) Divide muon propagation in 3 steps:

     -from outer surface of tracker to ECAL

     -from outer surface to outer surface of HCAL

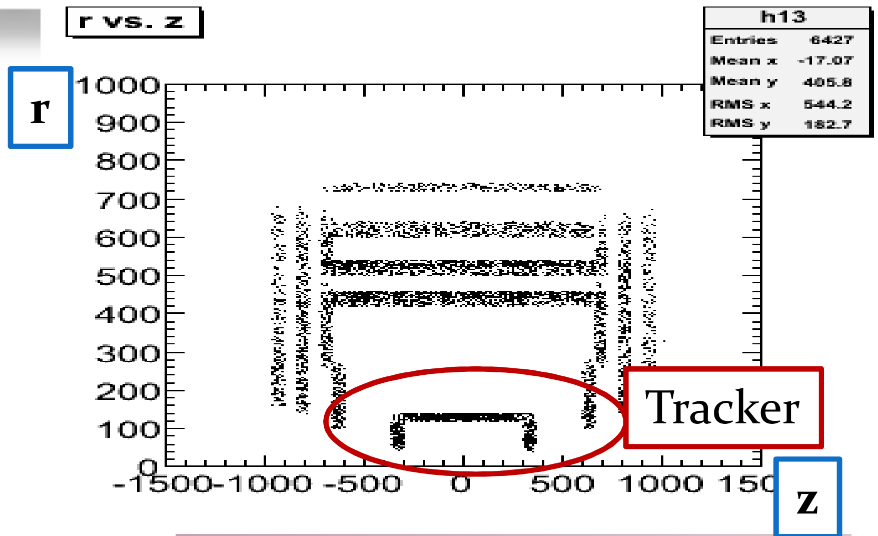
     -To Muon Systems

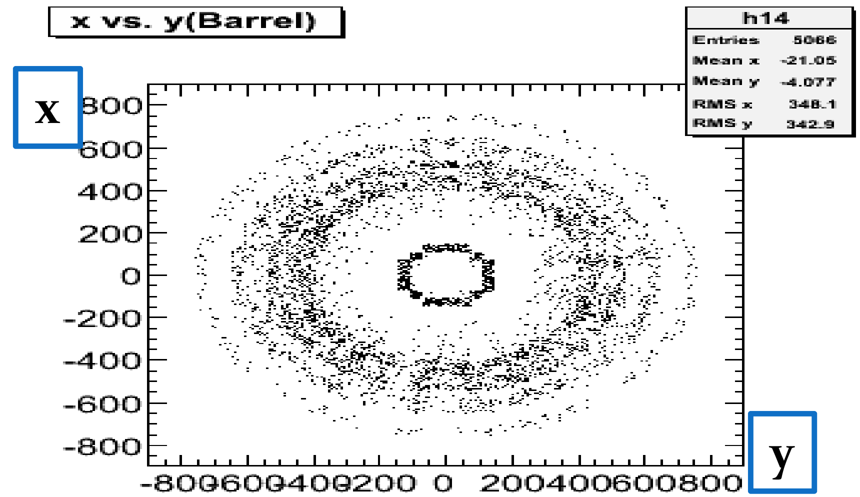
  3) Apply material effects (including dE/dx) separately

  4) Put energy in ECAL and HCAL

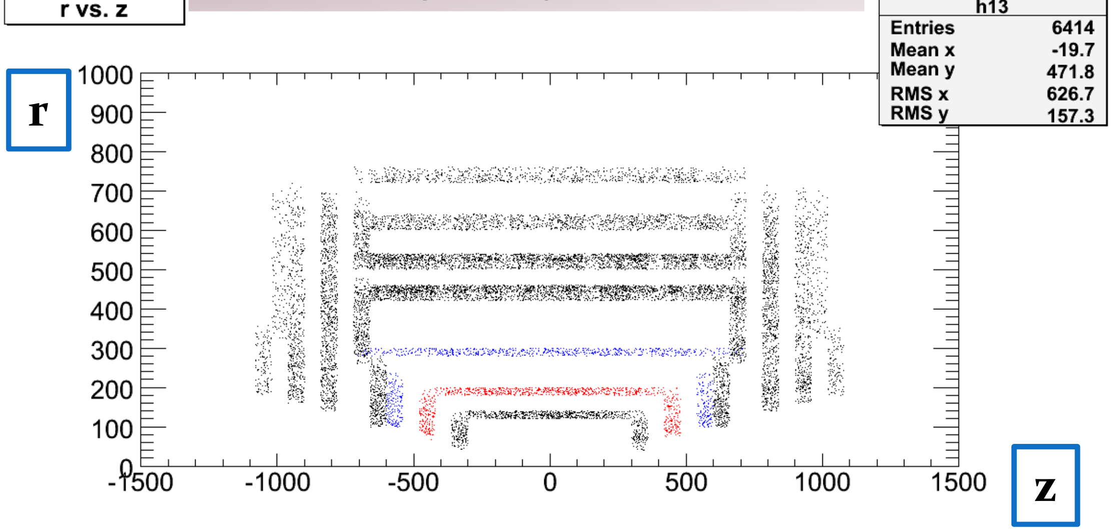
Propagated State on Each Det's (w/ Particle Gun $P_T = 10$ GeV/c)

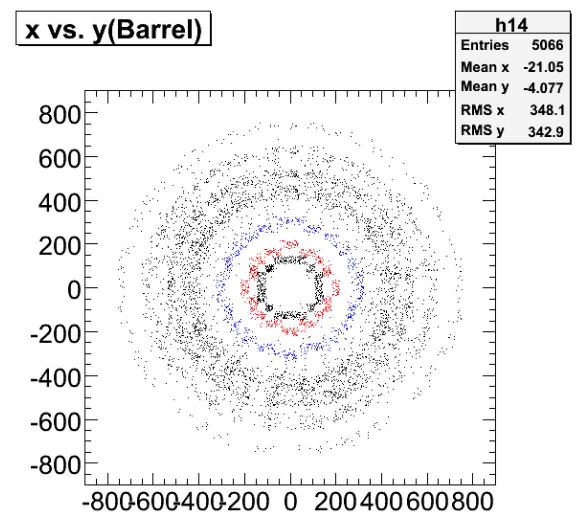
Before applying propagated calorimeters





After applying propagated calorimeters

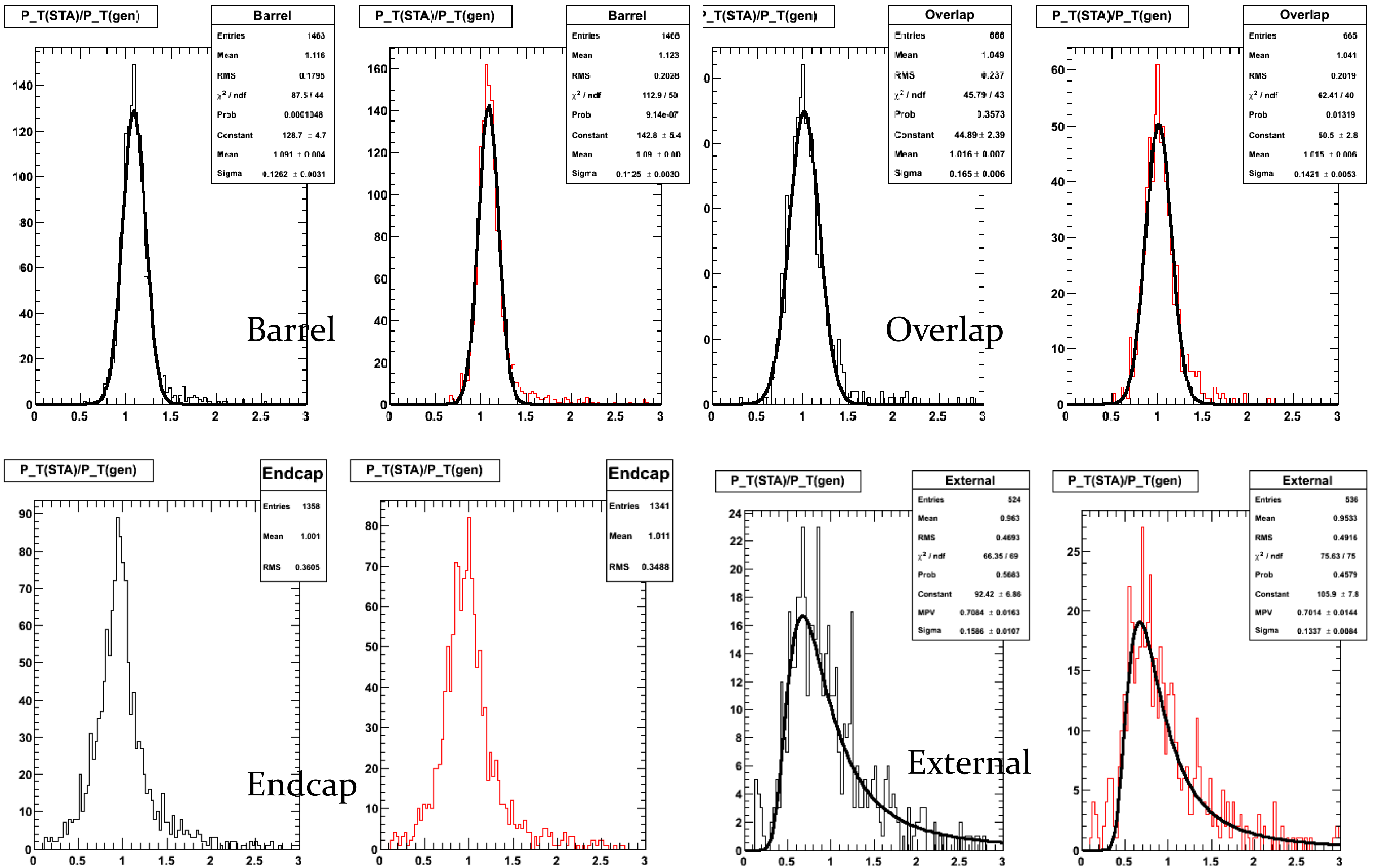




-WithoutMaterial Effects

-With Material Effects at Ecal/HCal

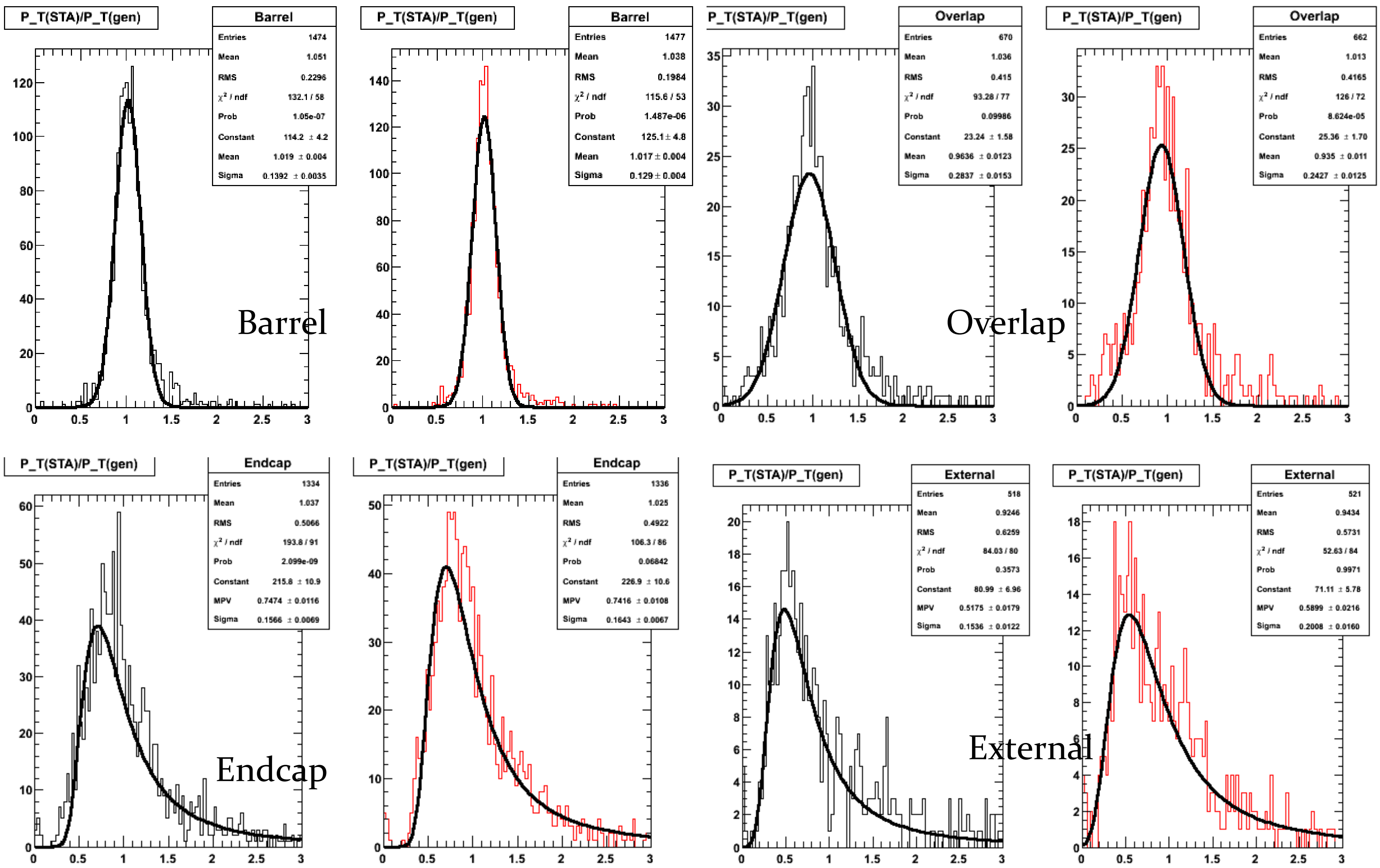
P_T = 10 GeV/c



-WithoutMaterial Effects

-With Material Effects at Ecal/HCal

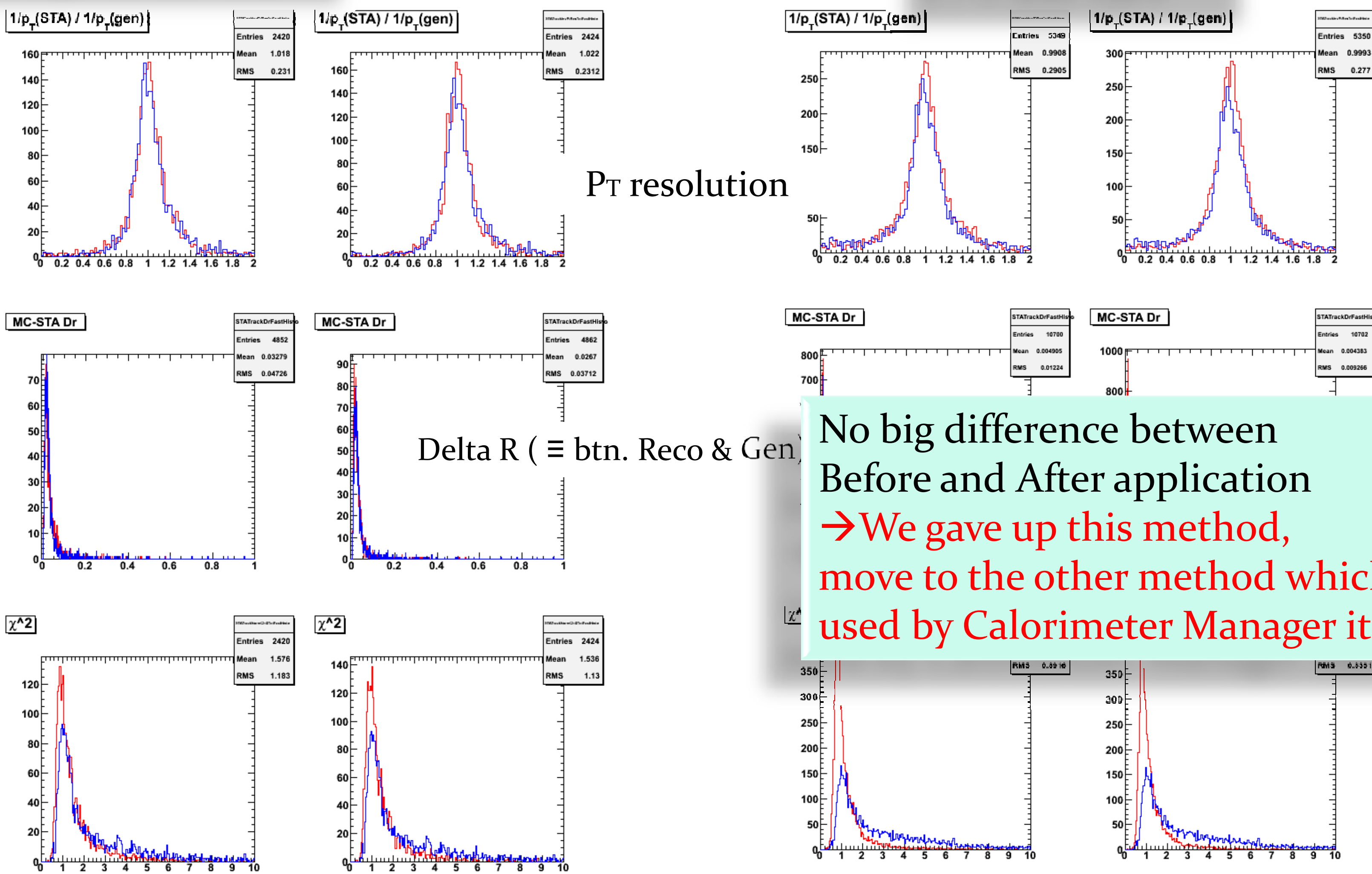
P_T = 100 GeV/c



P_T Resolution, Delta R (at P_T = 10 GeV/c)

--- FastSim
--- FullSim

P_T = 100 GeV



P_T resolution

Delta R (≡ btn. Reco & Gen)

No big difference between Before and After application
→We gave up this method, move to the other method which is used by Calorimeter Manager itself

Before applying a 3 step (Current Version)

After applying a 3 step (New Version)

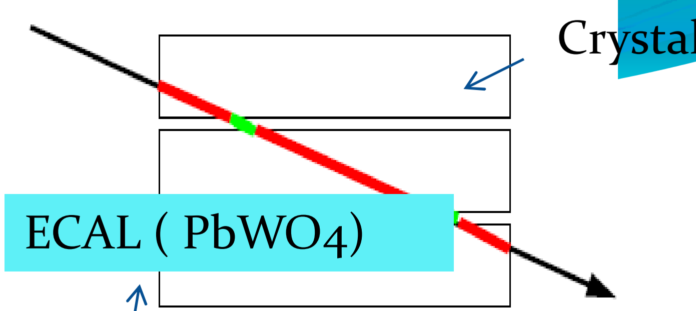
II. How to implement the Energy Loss at Calorimeter

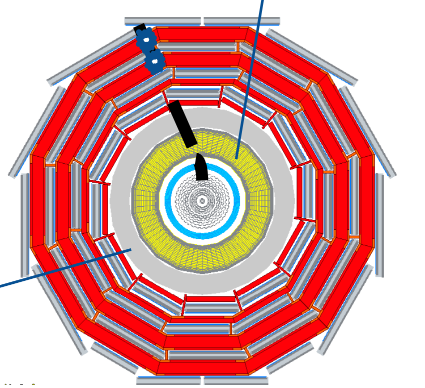
(2) Using Calorimeter Manager

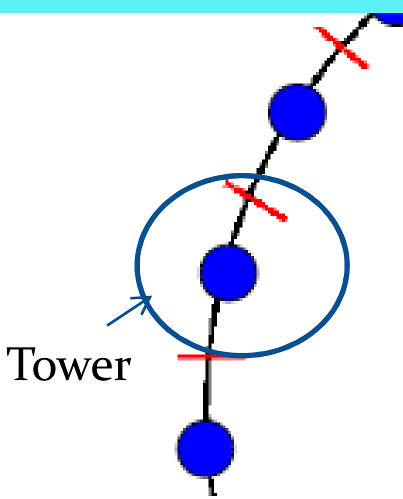
- The calorimeter simulation is done within famosSimHit in the CalorimeterManager class
- The best place to insert the muon energy deposits simulation
  - Direct access to the energy deposits in the calorimeter
  - The geometry tools developed for the calorimeter simulation are easily available from there

How to apply at ECAL/HCAL

- Straight line extrapolation should be sufficient in the ECAL
- The "EcalHitMaker" is computing all the intersections between the track and the crystals
- It is then used to add the muon energy deposit to the cell content







- The Stepping helix propagator is used
  - Dividing the helix arc into several segments
  - Compute the energy deposit in each of them
  - Make a spot (global position, energy)
  - Use the "HcalHitMaker" to put the spot in the proper cell

CalorimetryManager::MuonMipSimuation(const FSimTrack& myTrack)

On ECAL

```
float totalXoEcal=myGrid.ecalTotalXo();
 int ifirstHcal=-1;
 int ilastEcal=-1;
 EnergyLossSimulator* energyLossECAL = 0;
 if (theMuonEcalEffects) energyLossECAL = theMuonEcalEffects-
    >energyLossSimulator();
 for(unsigned iseg=0;iseg<nsegments&&ifirstHcal<0;++iseg)    {
    // in the ECAL, there are two types of segments: PbWO4 and GAP
    float segmentSizeinXo=segments[iseg].X0length();
    // Insert computations here
    float energy=0.0;
    if (segmentSizeinXo>0.001 &&
    segments[iseg].material()==CaloSegment::PbWO4 ) {
      // The energy loss simulator
      float charge = (float)(myTrack.charge());
      ParticlePropagator theMuon(moment,trackPosition,charge,0);
      theMuon.setID(-(int)charge*13);
      if ( energyLossECAL ) {
        energyLossECAL->updateState(theMuon, segmentSizeinXo);
        energy = energyLossECAL->deltaMom().E();
        moment -= energyLossECAL->deltaMom();
       ..........................
```

CalorimetryManager::MuonMipSimuation(const FSimTrack& myTrack) cont'd

On HCAL

```
EnergyLossSimulator* energyLossHCAL = 0;
 if (theMuonHcalEffects) energyLossHCAL = theMuonHcalEffects-
    >energyLossSimulator();
 if(ifirstHcal>0 && energyLossHCAL){
  for(unsigned iseg=ifirstHcal;iseg<nsegments;++iseg)
    {
     float segmentSizeinX0=segments[iseg].X0length();
     if (segmentSizeinX0>0.001 &&
    segments[iseg].material()==CaloSegment::HCAL ) {
       // The energy loss simulator
      float charge = (float)(myTrack.charge());
      ParticlePropagator theMuon(moment,trackPosition,charge,0);
      theMuon.setID(-(int)charge*13);
      energyLossHCAL->updateState(theMuon, segmentSizeinX0);
      mipenergy = energyLossHCAL->deltaMom().E();
      moment -= energyLossHCAL->deltaMom();
      myHcalHitMaker.setSpotEnergy(mipenergy);
      myHcalHitMaker.addHit(segments[iseg].entrance());
     }
     if(segments[iseg].material()==CaloSegment::HCAL)
      {
       ilastHcal=iseg;
      }
    }
 }
```

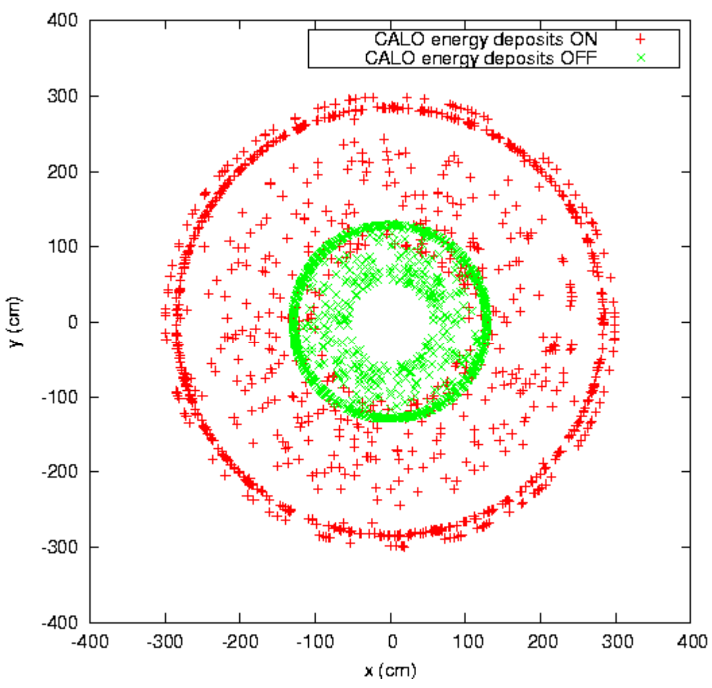
MaterialEffects_cfi.py (for HCAL)

```
MaterialEffectsForMuonsInHCALBlock =
    cms.PSet(
  MaterialEffectsForMuonsInHCAL = cms.PSet(
     # Material Properties (BRASS - this is for
    muons)
     # A
     A = cms.double(64.0),
     # Z
     Z = cms.double(29.0),
     # Density in g/cm3
     Density = cms.double(8.5),
     # One radiation length in cm
     RadiationLength = cms.double(1.44),
     # GEneral switches
     # Enable photon pair conversion
     PairProduction = cms.bool(False),
     # Smallest photon energy allowed for
    conversion
     photonEnergy = cms.double(0.1),
     # Enable electron Bremsstrahlung
     Bremsstrahlung = cms.bool(False),
     # Smallest bremstrahlung photon energy
     bremEnergy = cms.double(0.1),
     # Smallest bremsstrahlung energy fraction
    (wrt to the electron energy)
     bremEnergyFraction = cms.double(0.005),
     # Enable dE/dx
     EnergyLoss = cms.bool(False),
     # Enable Multiple Scattering
     MultipleScattering = cms.bool(False),
     # Smallest pT for the Mutliple Scattering
     pTmin = cms.double(0.3),
     # Enable Nuclear Interactions
     NuclearInteraction = cms.bool(False)

   )
)
```

Performances

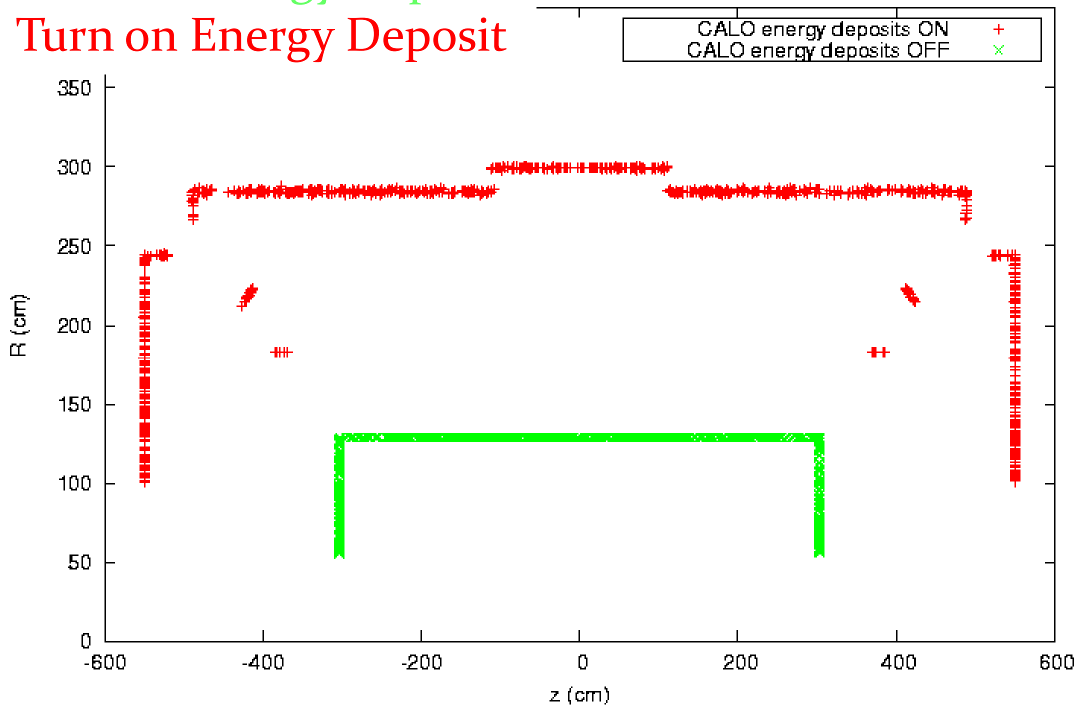
Starting Point
of SteppingHelix propagation in MuonSimHitProducer



x-y plane

Turn off Energy Deposit

Turn on Energy Deposit

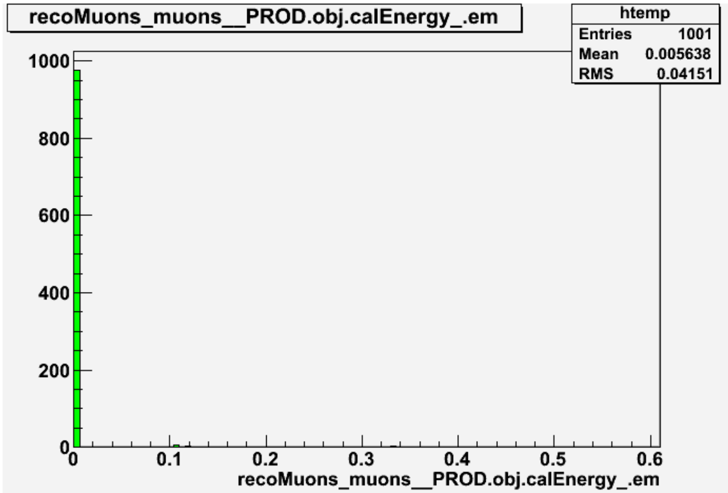


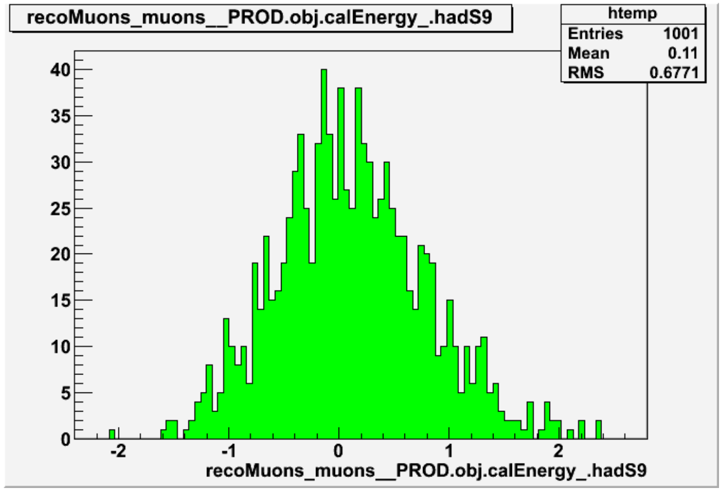
R-z plane

Used samples: P_T = 10 GeV/c Muon

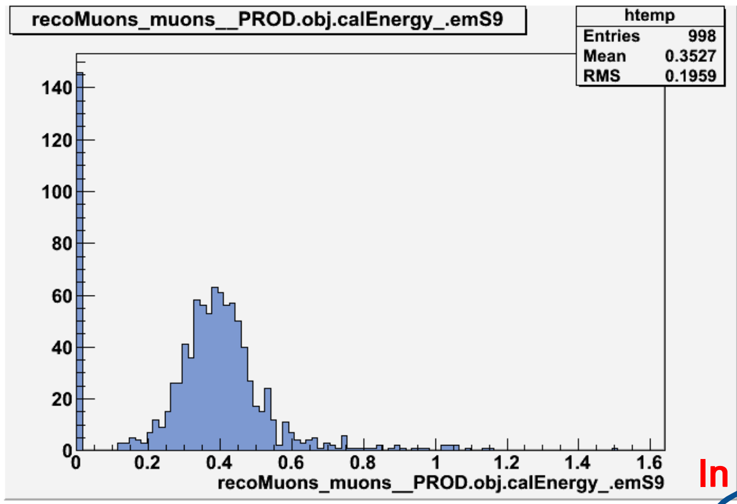
EM energy associated in Muon ID (crossed crystal)

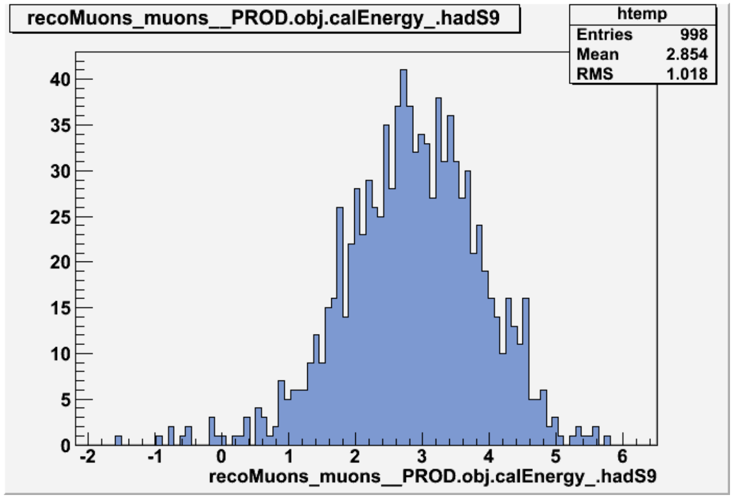
HADS9 energy associated in MuonID (3x3 towers)





Off



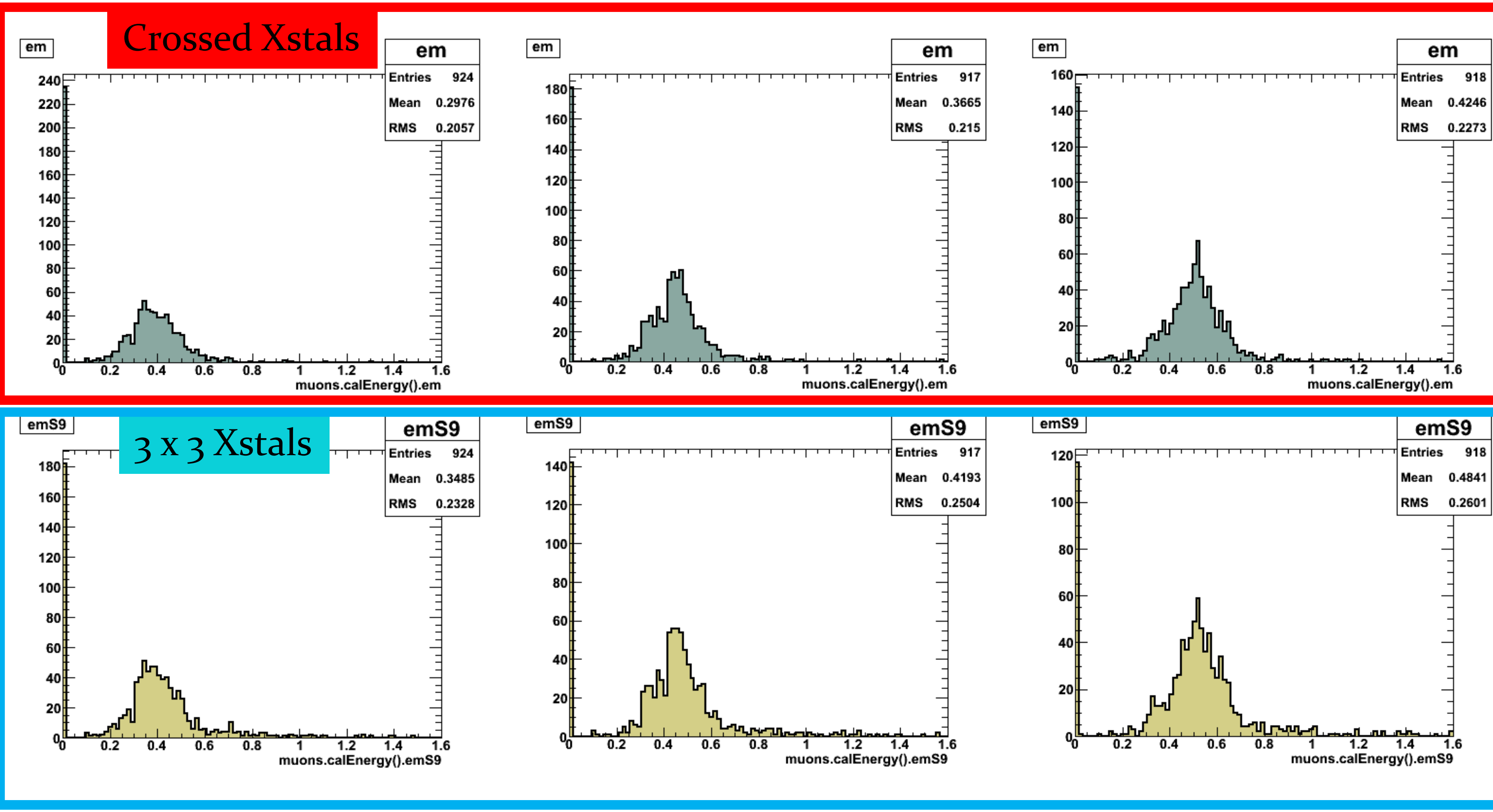


On

In case Off

the option "EnergyLoss = cms.bool(False)" at MaterialEffectsForMuonsInECALBlock and MaterialEffectsForMuonsInHCALBlock in MaterialEffects_cfy.py

EM energy associated in MuonID

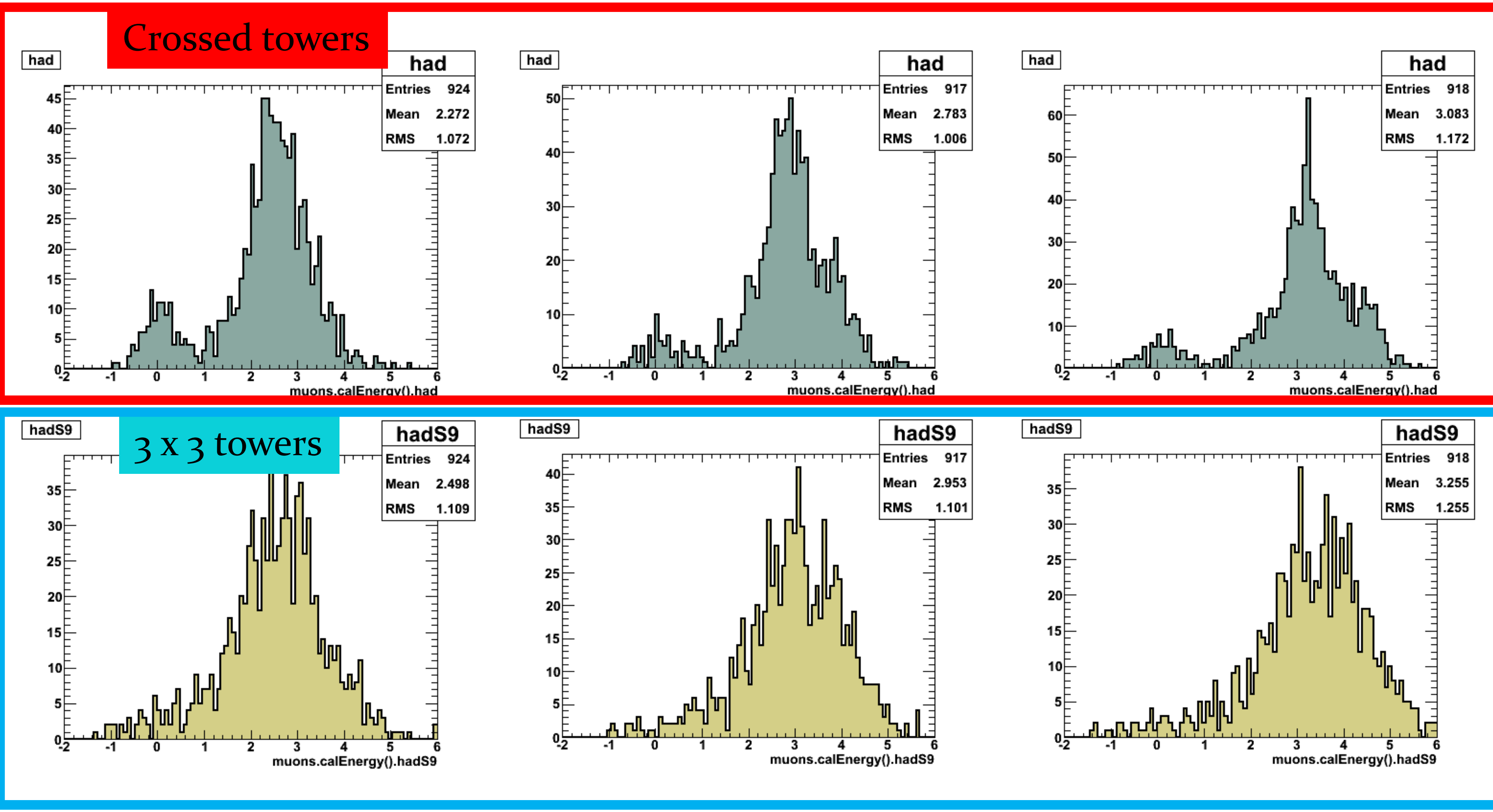


P_T = 10 GeV/c

P_T = 100 GeV/c

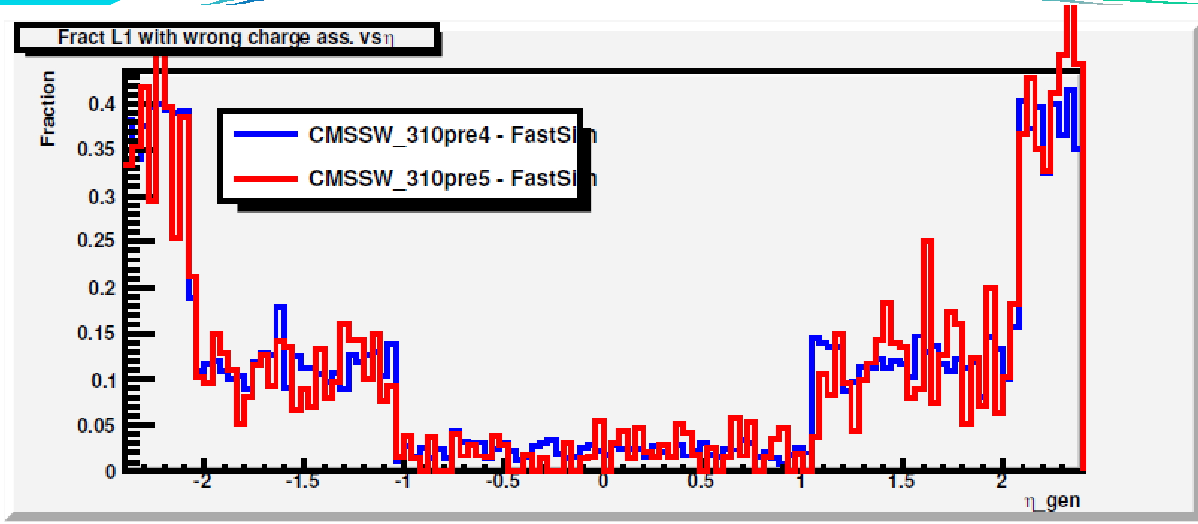
P_T = 1000 GeV/c

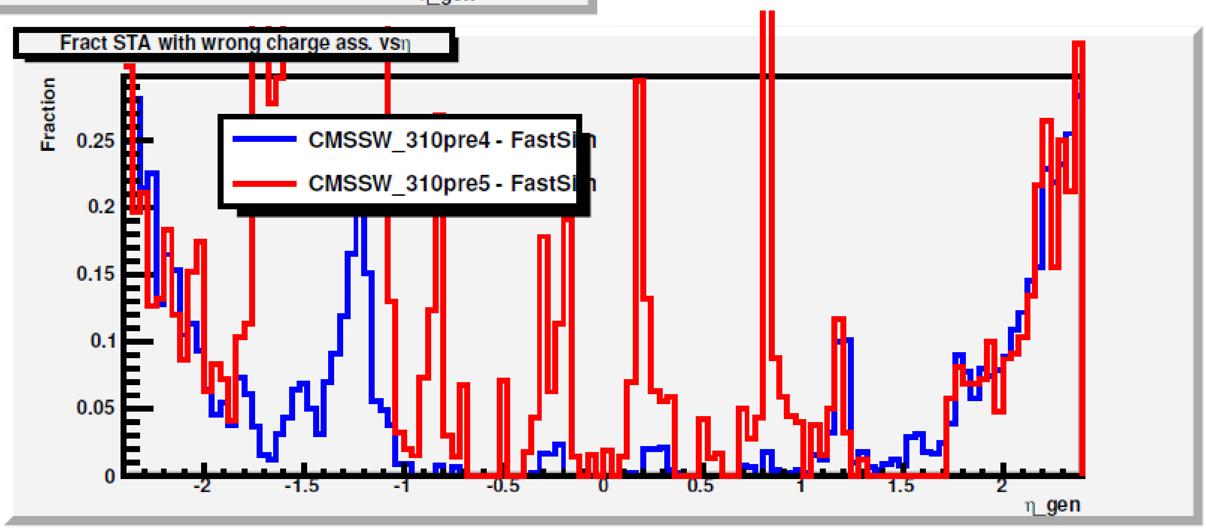
HAD energy associated in MuonID



P_T = 10 GeV/c | P_T = 100 GeV/c | P_T = 1000 GeV/c

Charge Mis-identification

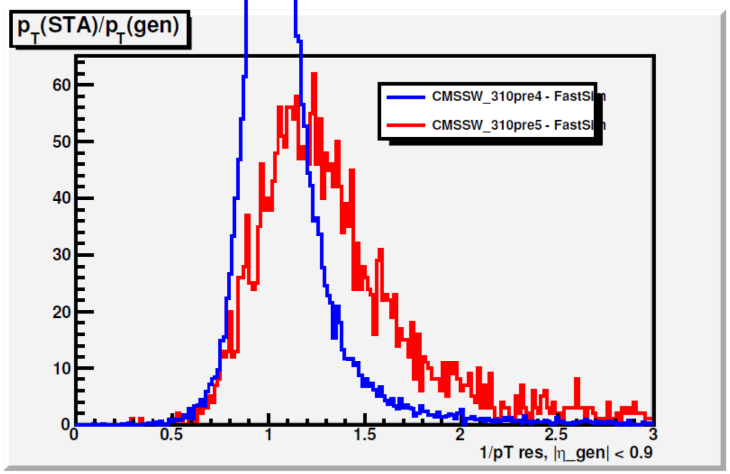


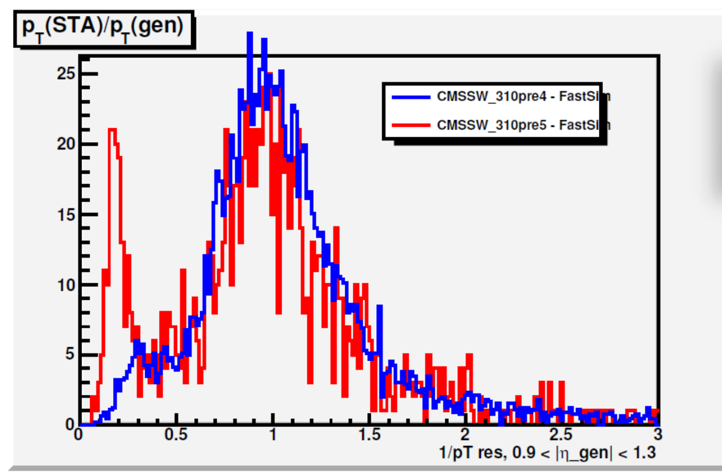


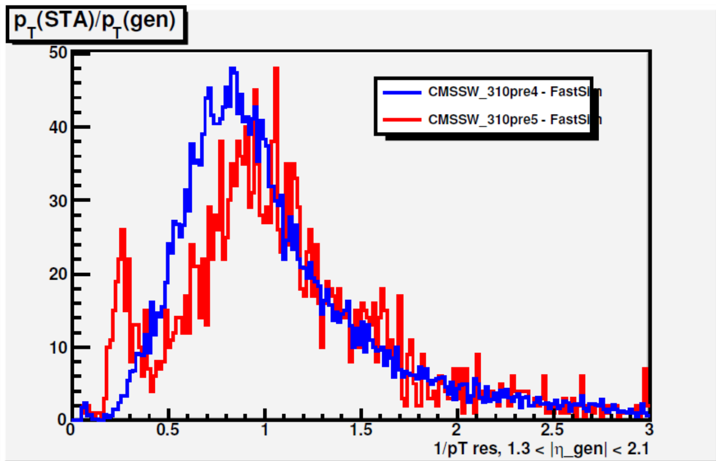
STA muons in New are far worst than in Old:

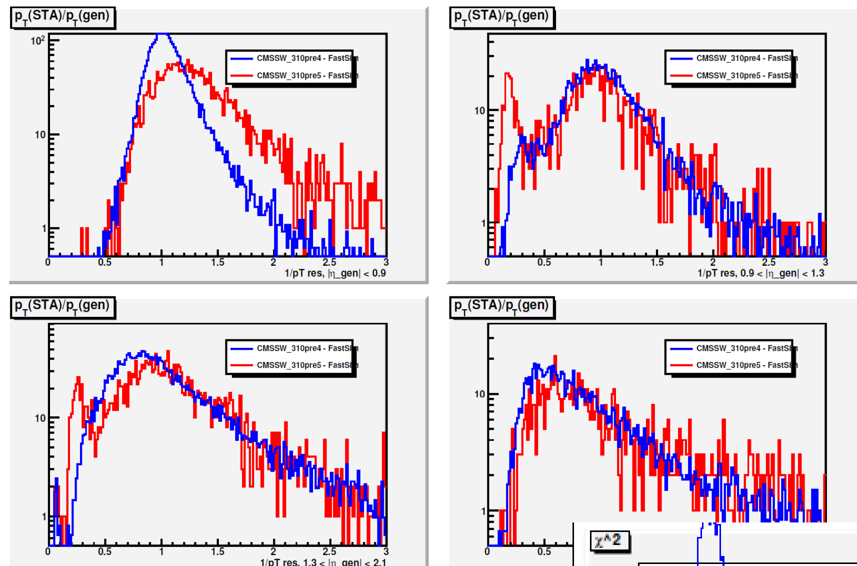
✓ **much larger charge misidentification;**

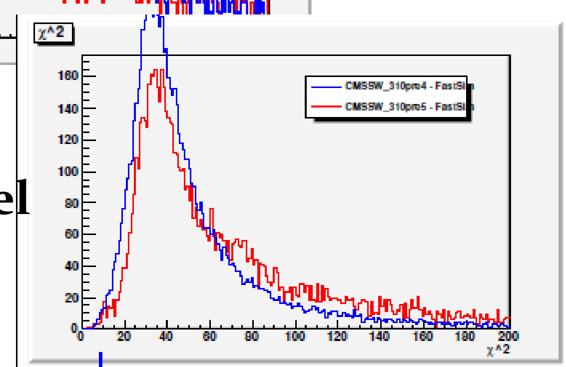
P_T Resolution (at P_T = 10 GeV/c)







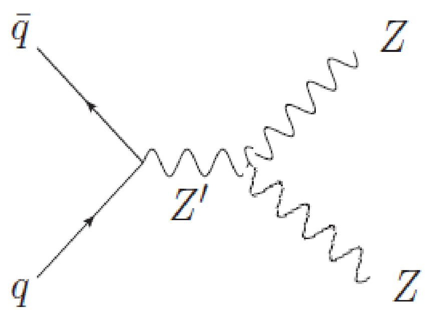




- ✓ **New born peak of very low pt STA muon reconstructed**
- ✓ **larger mean value of the reconstructed STA pt in the barrel**
- ✓ **The chi-square got a bit larger**

III. Plan for Z' Study

Z' → ZZ -> 4 muons



- Theoretical model: Extended Landau-Yang theorem
- Needs lots of luminosity ~ 100 fb^{-1}
- After discovery, measure the azimuthal angular distribution and the phase shift

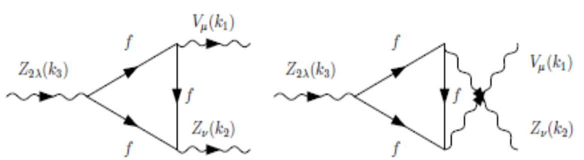
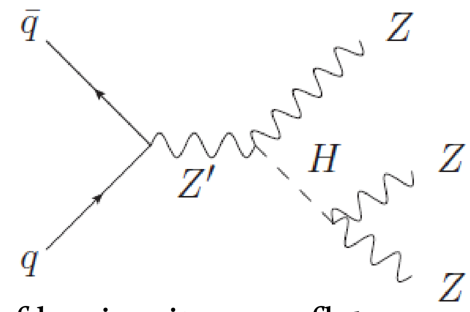


FIG. 1: Feynman diagrams contributing to the anomaly-induced $Z_2 \to Z_1 V$ decay, with $V = \gamma$ or Z_1.

arXiv:hep-ph/0402156v1

Z' → HZ → ZZZ -> 6 muons



- Needs lots of luminosity ~ 100 fb^{-1}
- Should look also to smaller masses than the current Z' limits

arXiv:0909.2641v1

Six-lepton Z' resonance at the LHC

Vernon Barger,[1] Paul Langacker,[2] and Hye-Sung Lee[3]

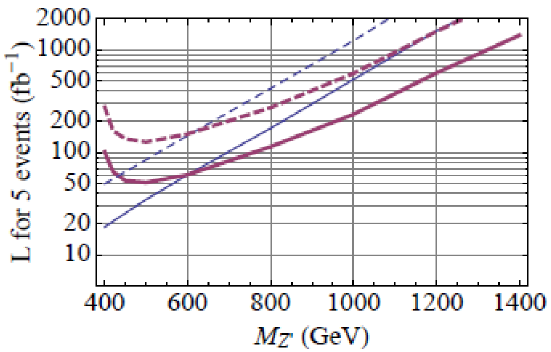


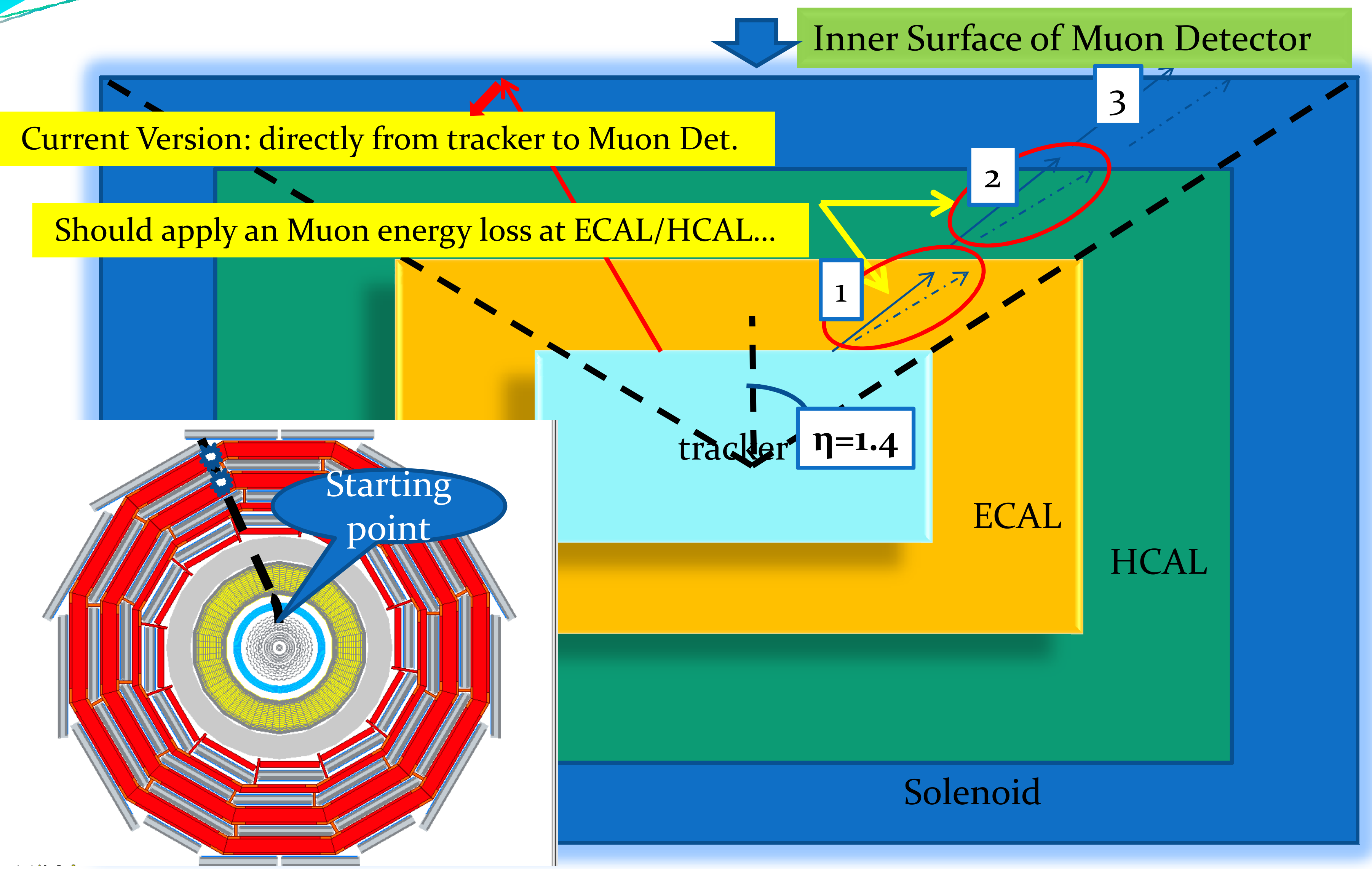
FIG. 3: Required luminosity for five 6-lepton resonance events at the LHC (with $\sqrt{s}$ = 14 TeV) for m_H = 200 GeV (thin blue) and 300 GeV (thick red) when SM-like couplings (dashed) and leptophobic couplings (solid) are assumed.

IV. Summary

- Apply the Muon energy Loss effect at the CAL's
  - The skeleton to compute and simulate the energy deposits in the calorimeters is applied
  - In Validation, we found the far worst cases at STA muon performance comparing with before application
    - Much larger charge mis-identification
    - New born peak of very low pt STA muon
    - Larger mean value of the reconstructed STA pt in the barrel
    - The chi-square got a bit larger
- Go back to the method which use the linear propagation by SteppinHelix propagation at this moment
- Start to study Z' physics

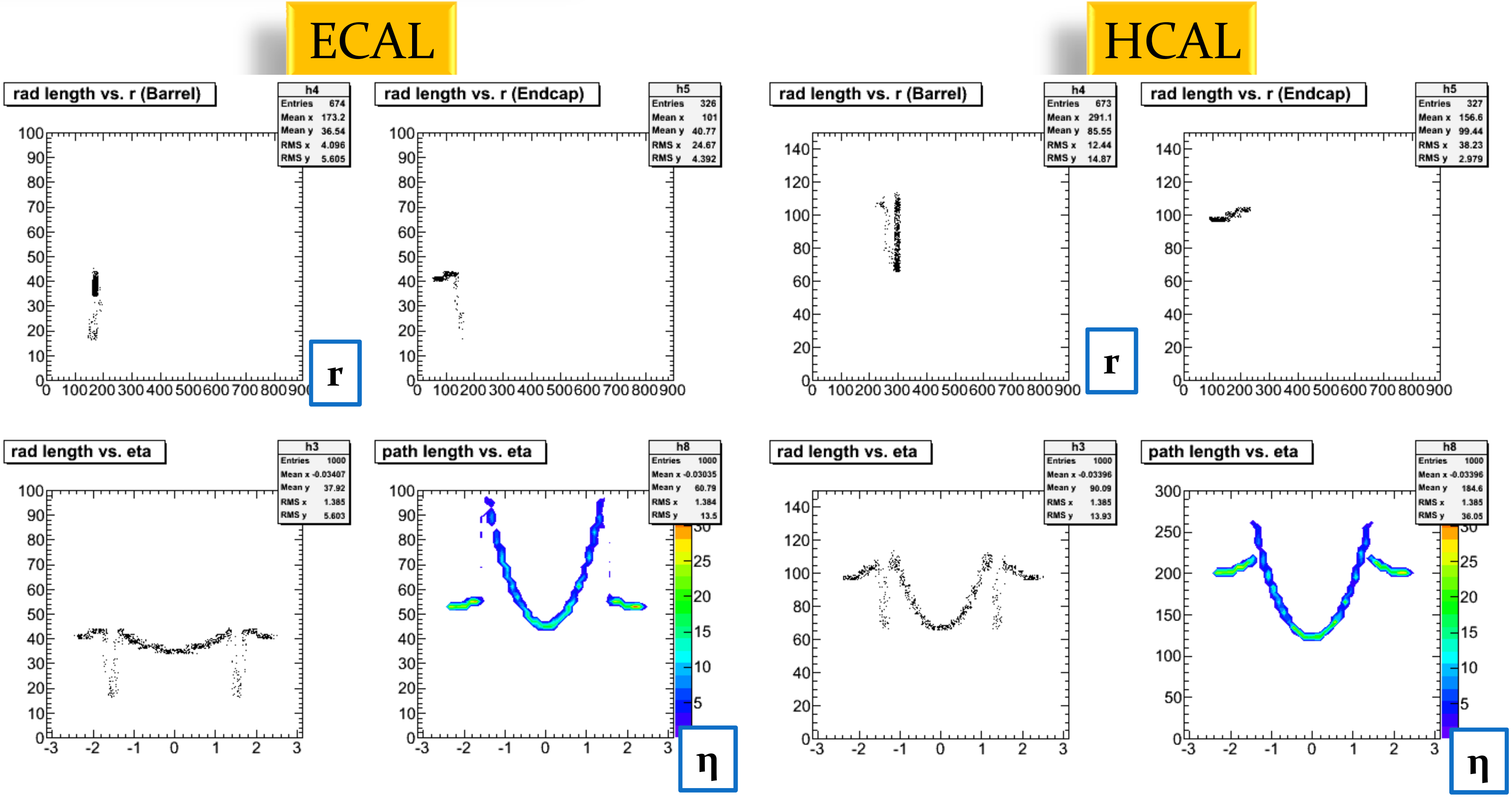
Back up

Divide muon propagation with 3 steps (Simple Cylinder/Disk)



Radiation Length at ECAL/HCAL (w/ Particle Gun P_T = 10 GeV/c)

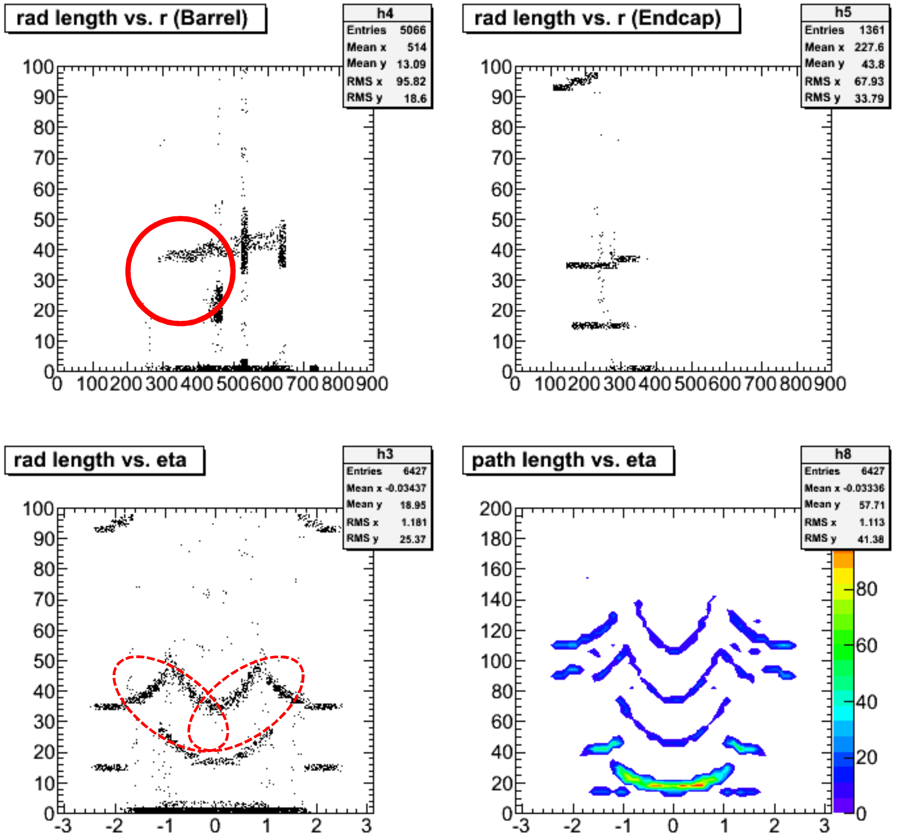
ECAL | HCAL



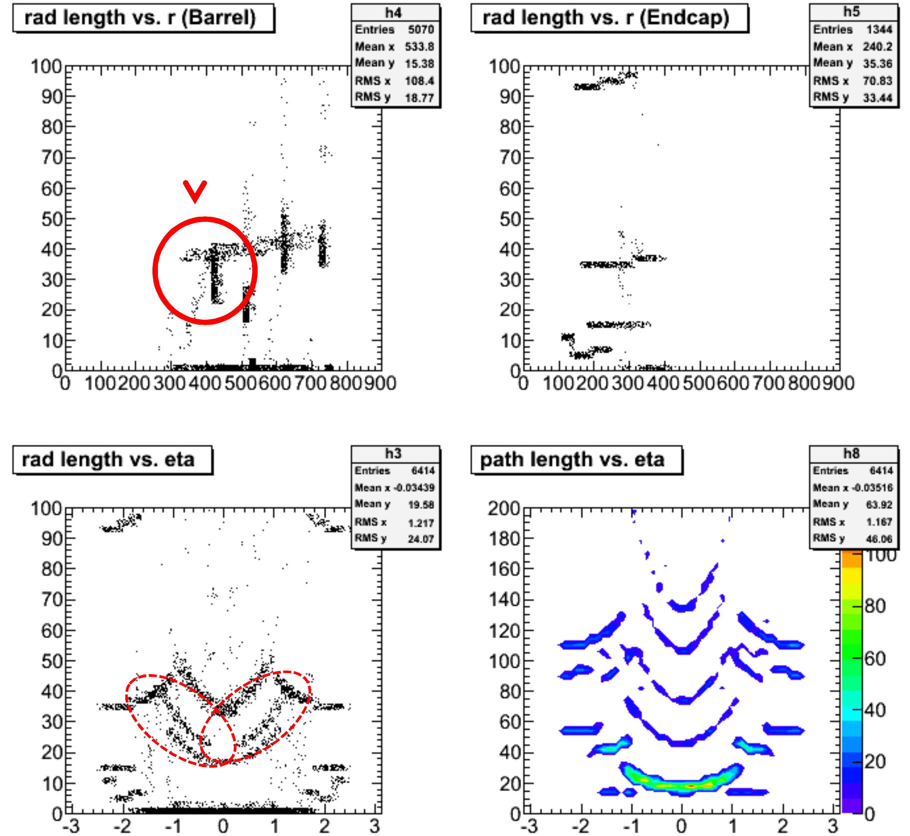
Information of Radiation length get from SteppingHelixStateInfo

Radiation Length at Muon Det's (w/ Particle Gun $P_T = 10$ GeV/c)

Before applying propagated calorimeters

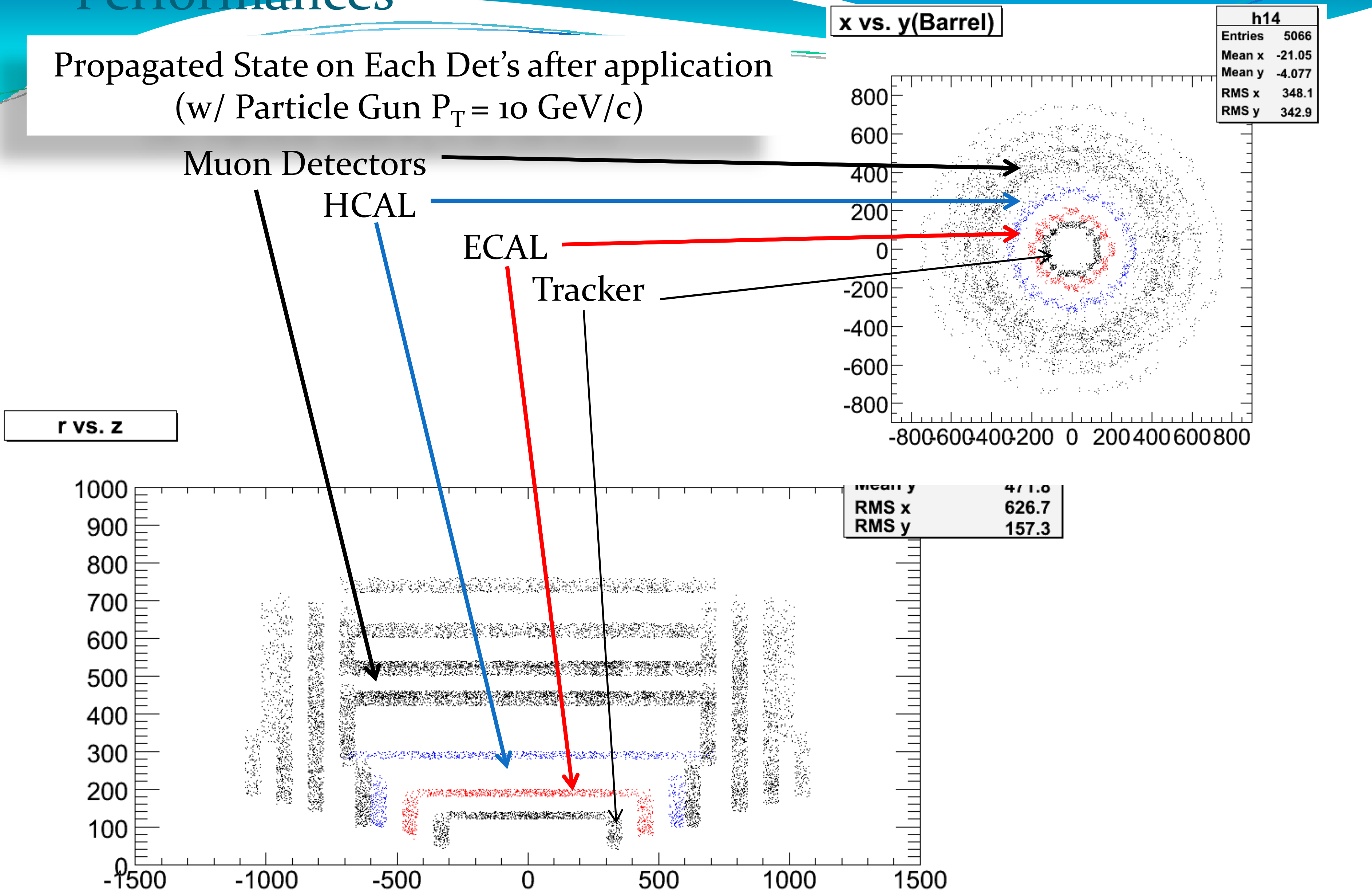


After applying propagated calorimeters



Performances

Propagated State on Each Det's after application
(w/ Particle Gun P_T = 10 GeV/c)



Make a new Simple Cylinders and Disks with bound (at MuonSimHitProducer)

For ECAL

```
Surface::PositionType posecalbd(0.,0.,355.);
  Surface::PositionType posecalbackbd(0.,0.,-355.);
  const BoundSurface *pecalbd= NULL;

//Make a new Simple Cylinder with bound..... as pecalbd
  if (startingState.globalMomentum().eta() > 1.4 ) {
   pecalbd = new BoundDisk(posecalbd, rot1, SimpleDiskBounds(25., 175.0, 396.0, 397.0));
  }
  else if (startingState.globalMomentum().eta() < -1.4 ) {
   pecalbd = new BoundDisk(posecalbackbd, rot1, SimpleDiskBounds(25., 175.0, 396.0, 397.0));
  }
  else if ( startingState.globalMomentum().eta() < 1.4 && startingState.globalMomentum().eta() > -1.4){
   pecalbd = new BoundCylinder(pos, rot1, SimpleCylinderBounds(173.999, 174.001, -
  }
TrajectoryStateOnSurface propagatedState = startingState;
  // Starting momentum
  double pi = propagatedState.globalMomentum().mag();

  // Propgate with material effects (dE/dx average only)
  SteppingHelixStateInfo shsStart1(*(propagatedState.freeTrajectoryState()));
  const SteppingHelixStateInfo& shsDest1 =
   // Progate by SteppingHelixPropagator
    ((const SteppingHelixPropagator*)propagatorWithMaterial)->propagate(shsStart1,*pecalbd);
  std::pair<TrajectoryStateOnSurface,double> next1(shsDest1.getStateOnSurface(*pecalbd),
                                   shsDest1.path());
std::vector<const DetLayer *> navLayers;
 if ( fabs(startingState.globalMomentum().eta()) > 4.5 ) {
  navLayers = navigation.compatibleEndcapLayers(*(startingState.freeState()),
                                alongMomentum);
```

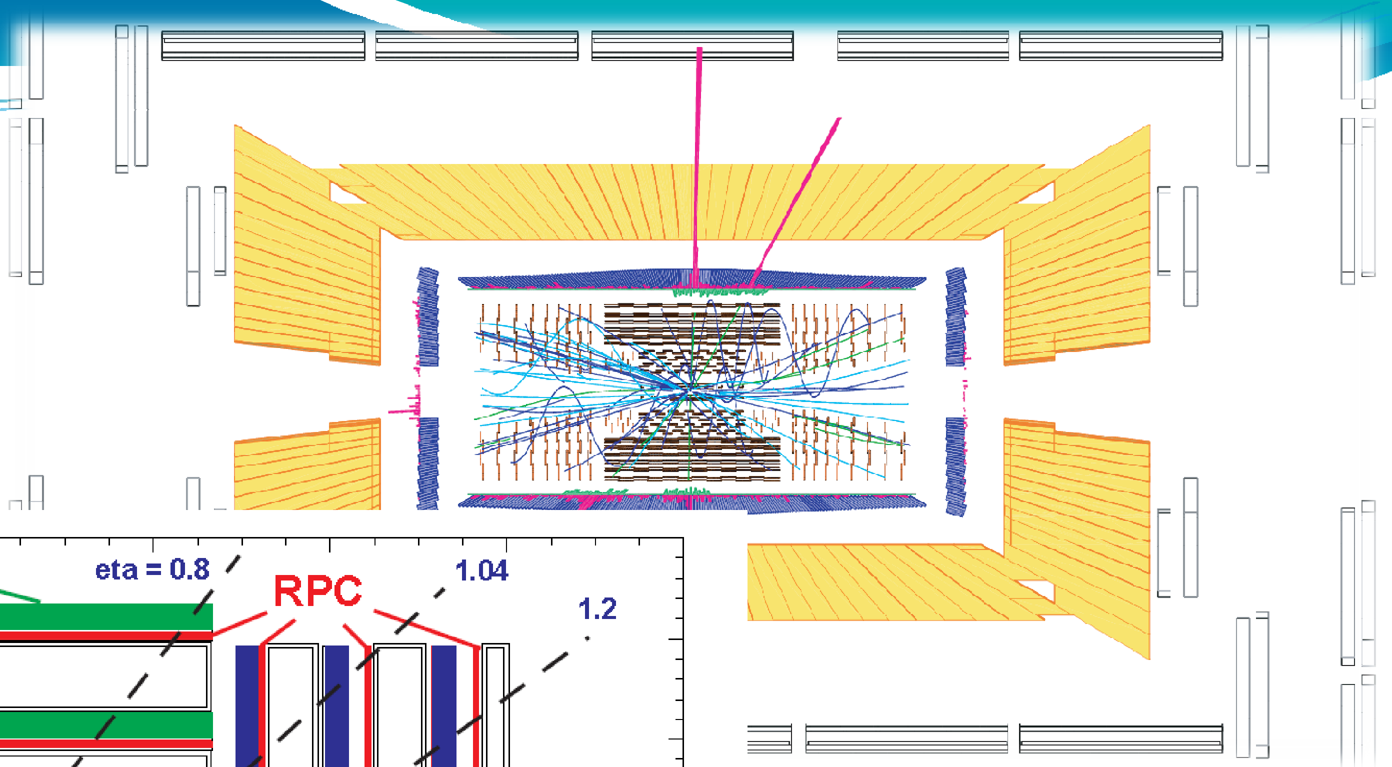
If | η | < 1.4, use simpleCylinder

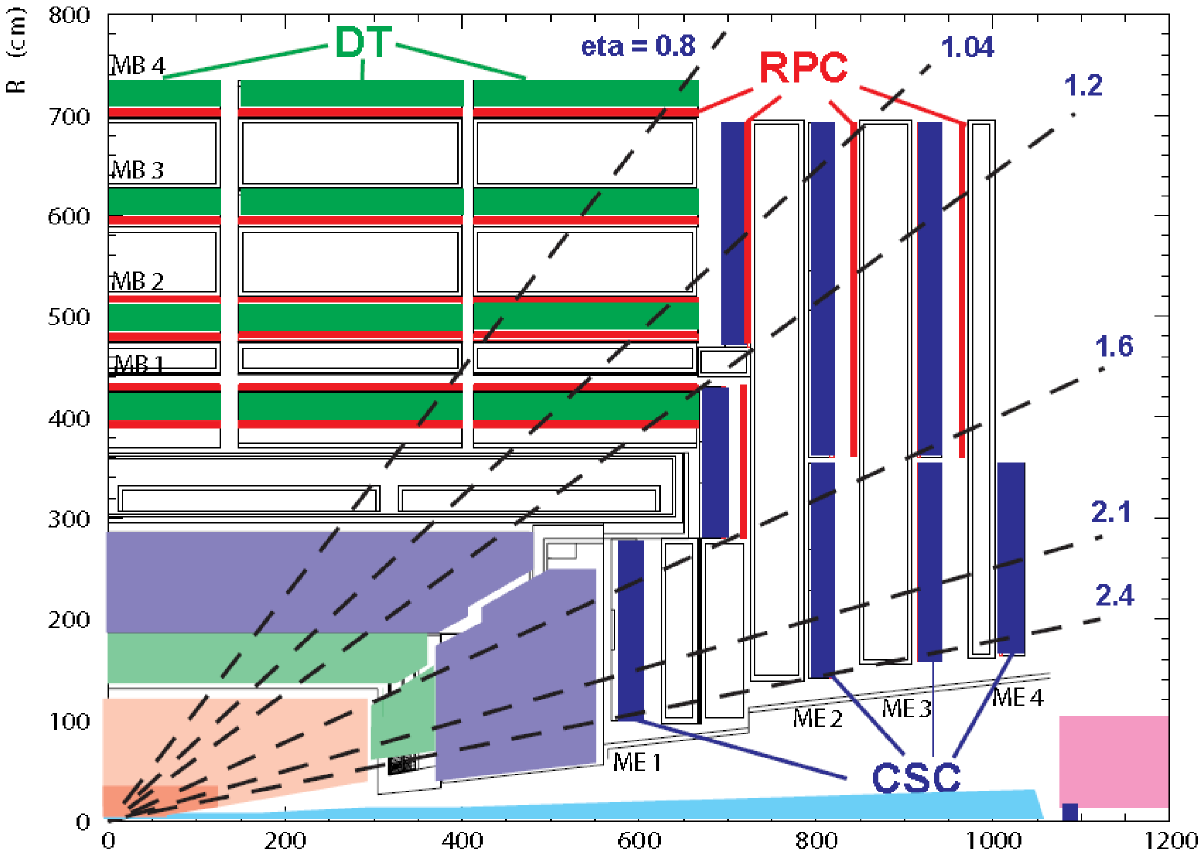
Barrel

If | η | > 1.4, use simpleDisk

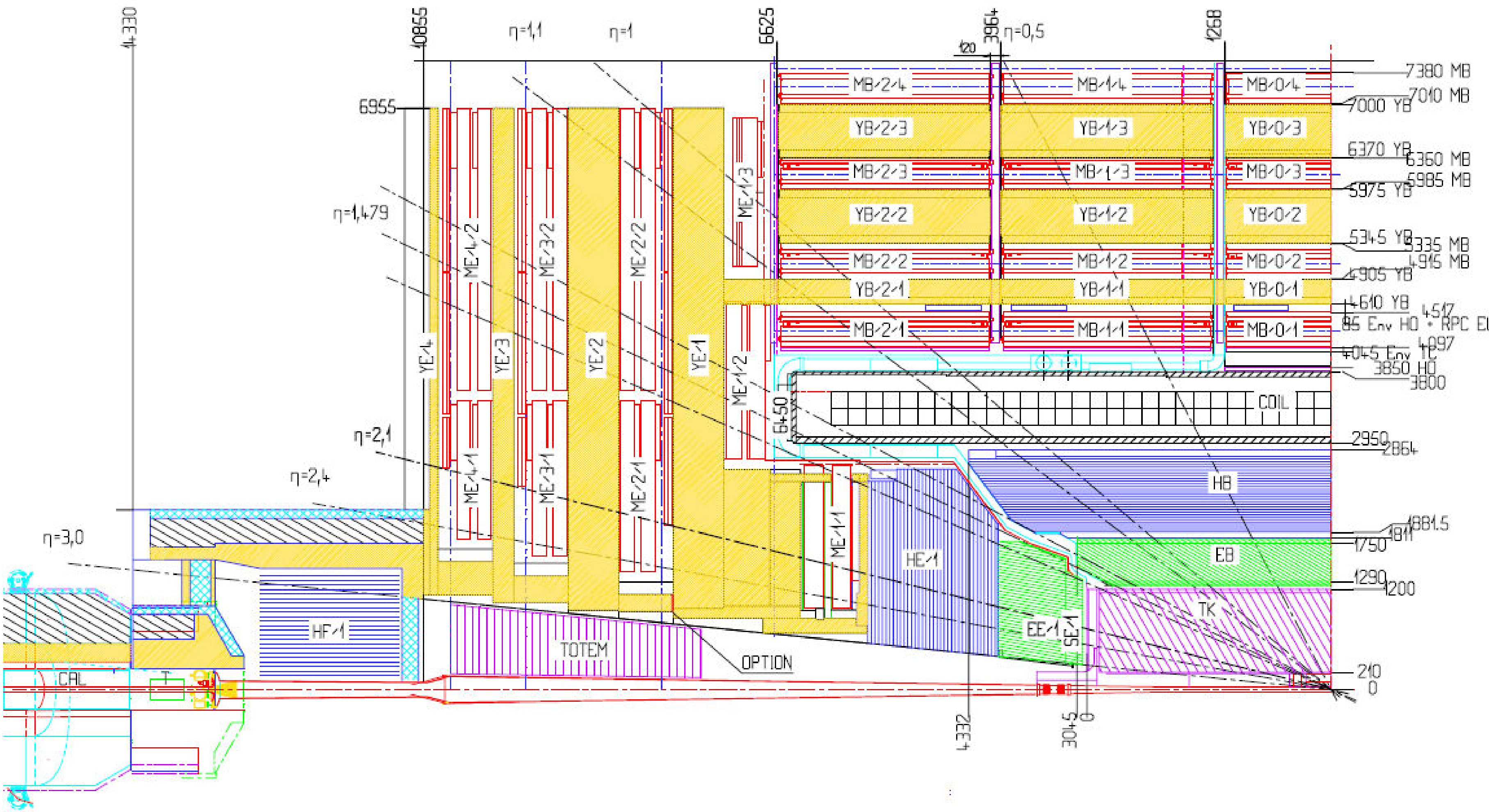
Endcap

And also take a process at HCAL same as ECAL.....





R (cm)
800
700
600
500
400
300
200
100
0
DT
MB 4
MB 3
MB 2
MB 1
eta = 0.8
1.04
1.2
1.6
2.1
2.4
RPC
ME 1
ME 2
ME 3
ME 4
CSC
0
200
400
600
800
1000
1200
Z (cm)


10855
η=1,1
η=1
6625
3964
η=0,5
1268
6955
η=1,479
η=2,1
η=2,4
η=3,0
MB/2/4
MB/1/4
MB/0/4
YB/2/3
YB/1/3
YB/0/3
MB/2/3
MB/1/3
MB/0/3
YB/2/2
YB/1/2
YB/0/2
MB/2/2
MB/1/2
MB/0/2
YB/2/1
YB/1/1
YB/0/1
MB/2/1
MB/1/1
MB/0/1
ME/4/2
ME/3/2
ME/2/2
ME/1/3
YE/4
YE/3
YE/2
YE/1
ME/1/2
ME/4/1
ME/3/1
ME/2/1
ME/1/1
6450
COIL
HB
HE/1
EB
EE/1
SE/1
TK
HF/1
TOTEM
OPTION
CAL
7380 MB
7010 MB
7000 YB
6370 YB
6360 MB
5985 MB
5975 YB
5345 YB
5335 MB
4915 MB
4905 YB
4610 YB
3850 HO
3800
2950
2864
1881.5
1811
1750
1290
1200
210
0
4332
3045

Bethe-Bloch Formula

$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \cdot \frac{n z^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1-\beta^2)}\right) - \beta^2\right]$$

- $\beta = v / c$
- v : velocity of the particle
- E : energy of the particle
- x : distance travelled by the particle
- c : speed of light
- Ze : particle charge
- e : charge of the electron
- m_e : rest mass of the electron
- n : electron density of the target
- I : mean excitation potential of the target