

The RPC Hits in the CMS muon reconstruction

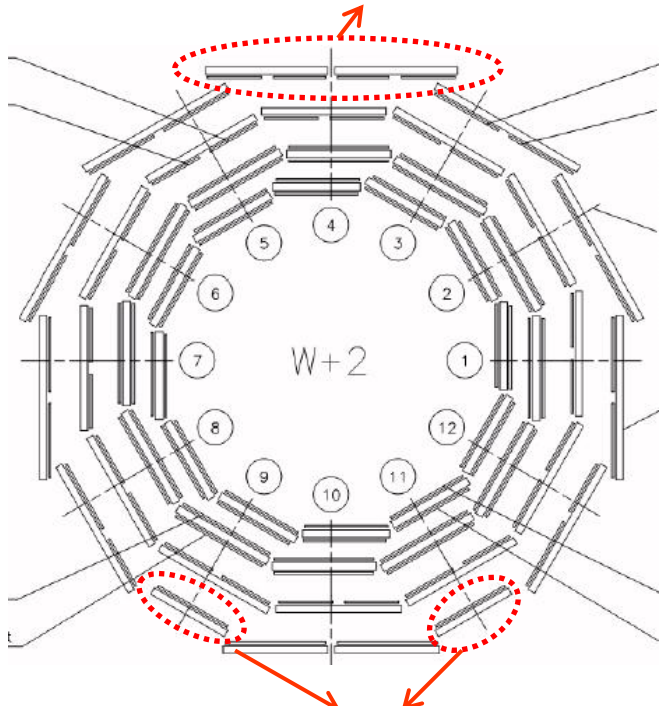
Hyunkwan Seo

Department of Physics, Sungkyunkwan University, Korea

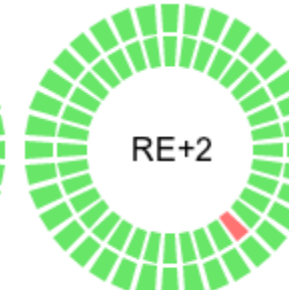
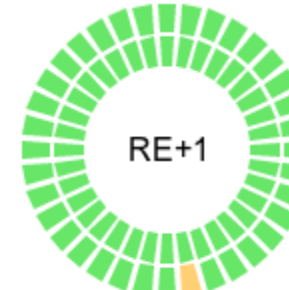
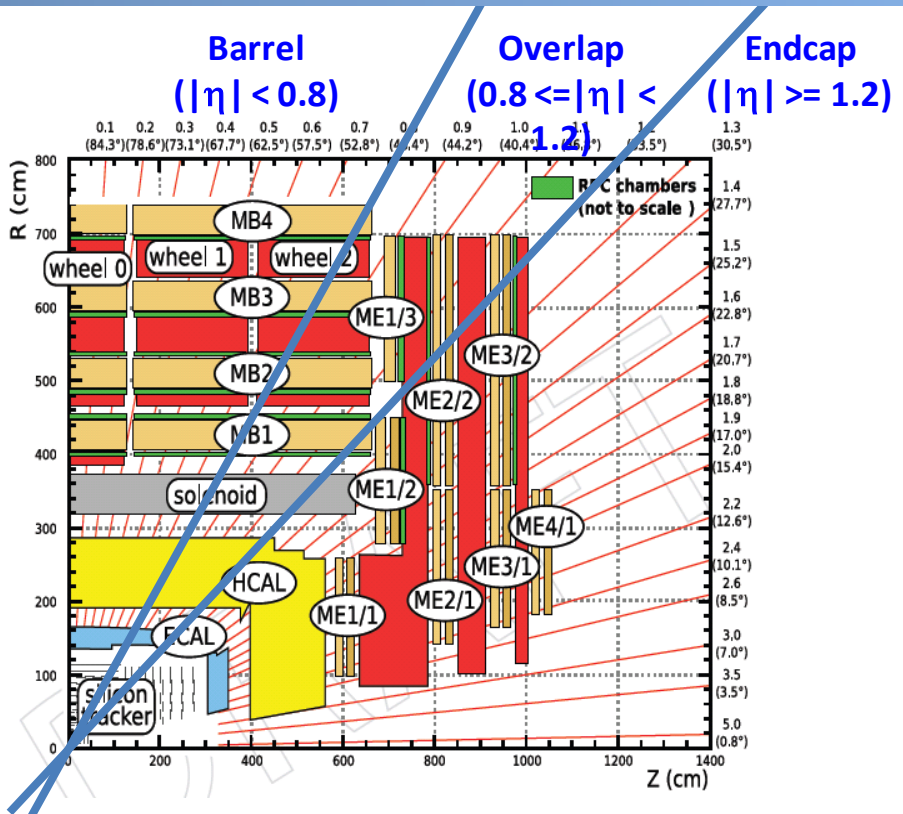
KCMS Seminar, 11.Nov.2011

Layout of RPC chambers in CMS

Sector 4 in layer 6 has 4 rolls



Sector 9 and 11 in layer 6 has 1 rolls, respectively



Comparison 2011 data-MC on RPC hits in muon reconstruction

Outline

- Dataset and selection criteria
- Missing Hits in global muons caused by RPC
- Implementation of RPC efficiencies to MC
- Distribution of number of RPC rechits (STA, GLB muons)
- Occupancy of RPC hits
- Average number of RPC hits
- Summary

Skim & Cuts

- **Z skim** (based on `DPGAnalysis/Skims/python/WZMuSkim_cff.py`)

- HLT : "HLT_Mu9","HLT_Mu11","HLT_Mu15","HLT_Mu15_v*"
 - Two good muons with opposite charges and Z mass cut
 - `pt > 20 && abs(eta)<2.4 && isGlobalMuon = 1 && isTrackerMuon = 1 && isolationR03().sumPt<3.0 && abs(innerTrack().dxy)<1.0 && innerTrack().numberOfValidHits(>10 && globalTrack().normalizedChi2(<10.0 && globalTrack().hitPattern().numberOfValidMuonHits(>0`
 - `Zmass (mu+,mu-) > 60 GeV`
 - Good vertex: `|zVtx|<24 cm, |rVtx|<2 cm, and Ndof>4`

- **Analysis cuts**

- `NgeneralTracks>2 && 3dAngle<3.05 && d0<0.2`
 - `isGlobalMuon && isStaMu && abs(eta)<1.6`
- To remove cosmic muons

To make GLB and STA comparable

Dataset used

Dataset name		# of events after the Z skim	remark
2011 DATA	<code>/SingleMu/Run2011A-ZMu-May10ReReco-v1/RAW-RECO</code>	101,602	Run range: 160413 ~ 163869
Summer11 MC	<code>/DYToMuMu_M-20_TuneZ2_7TeV-pythia6/Summer11-PU_S3_START42_V11-v2/GEN-SIM-RECO</code>	383,177	-

Missing hits in global muon reconstruction

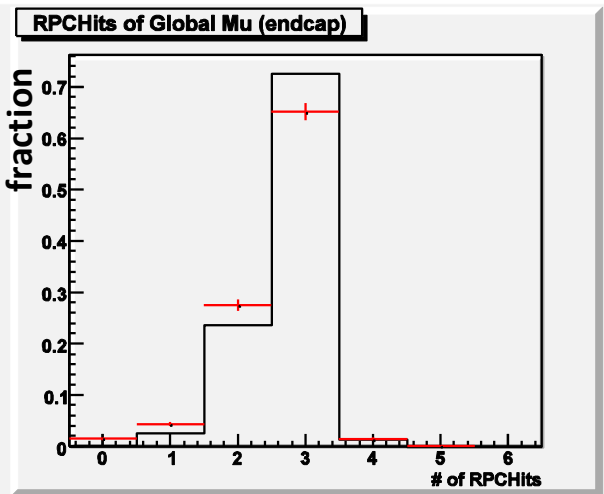
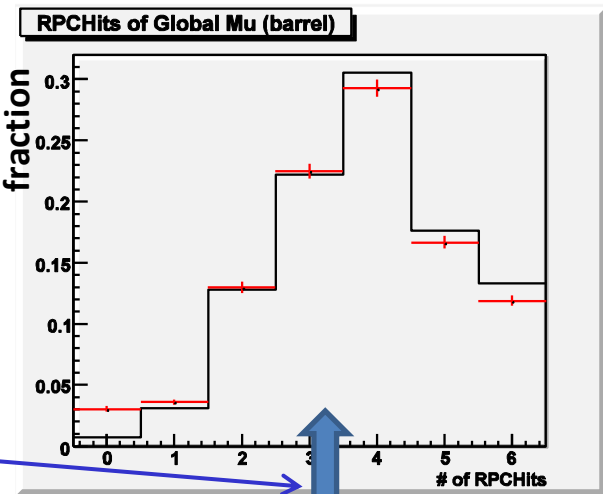
RPCHits distribution

— MC
— Data

Barrel ($|\eta| < 0.8$)

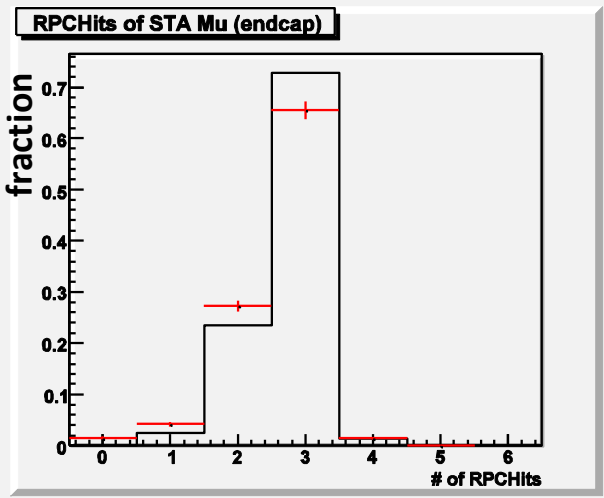
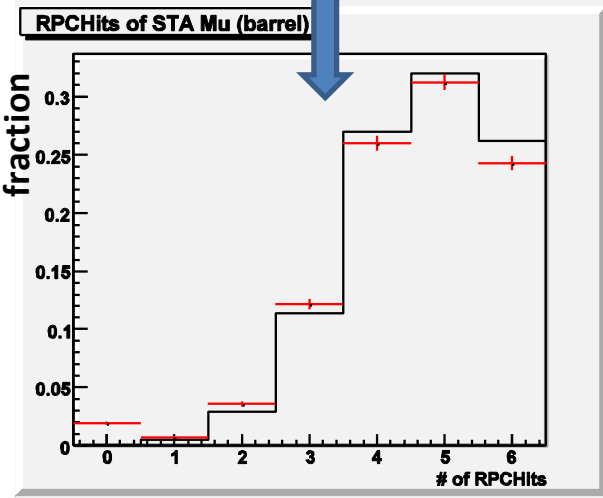
Endcap ($|\eta| \geq 1.2$)

Global muons



Clear difference

Standalone muons



Bug fix

<https://indico.cern.ch/getFile.py/access?contribId=4&resId=0&materialId=slides&confId=130897>



Missing Hits in Global Muon Fits

Adam Everett
March 14, 2011

PURDUE
UNIVERSITY.



Let's look at the sorts

We do an initial sort

```
// check order of muon measurements
if ( (muonRecHits.size() > 1) &&
     ( muonRecHits.front()->globalPosition().mag() >
       muonRecHits.back()->globalPosition().mag() ) ) {
  LogTrace(theCategory)<< "  reverse order: ";
  stable_sort(muonRecHits.begin(),muonRecHits.end(),RechitLessByDet(alongMomentum));
}
```

Then we do a second sort:

```
stable_sort(muonRecHits.begin(),muonRecHits.end(),ComparatorInOut())
```




ComparatorInOut

```
struct ComparatorInOut {  
  
    bool operator()(const TransientTrackingRecHit::ConstRecHitPointer& a,  
                   const TransientTrackingRecHit::ConstRecHitPointer& b) const {  
        bool barrel_a = ( a->det()->subDetector() == GeomDetEnumerators::DT ||  
                          a->det()->subDetector() == GeomDetEnumerators::RPCBarrel );  
  
        bool barrel_b = ( b->det()->subDetector() == GeomDetEnumerators::DT ||  
                          b->det()->subDetector() == GeomDetEnumerators::RPCBarrel );  
  
        if ( barrel_a && barrel_b ) return a->det()->surface().position().perp() < b->det()->surface().position().perp();  
  
        else if ( !barrel_a && !barrel_b ) return fabs(a->globalPosition().z()) < fabs(b->globalPosition().z());  
        else if ( barrel_a && !barrel_b ) return true;  
        else if ( !barrel_a && barrel_b ) return false;  
        //shouldn't really get here in any case (there's some sense to throw here )  
        return false;  
    }  
};
```



Concrete Example

We look at an event with missing DT hits

- **This muon has 17 Tracker Hits and 38 Muon Hits**
 - It should have 55 total hits, but instead has 36



Muon Hits Before First Sort

```

r = 416.708 z = -204.85 dimension = 2 2 8
r = 452.206 z = -204.85 dimension = 2 2 8
r = 499.005 z = -184.85 dimension = 2 2 8
r = 502.58 z = -190.317 dimension = 1 2 7
r = 503.896 z = -190.787 dimension = 1 2 7
r = 505.21 z = -191.258 dimension = 1 2 7
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r = 523.553 z = -197.804 dimension = 1 2 7
r = 524.867 z = -198.261 dimension = 1 2 7
r = 526.33 z = -198.824 dimension = 1 2 7
r = 527.649 z = -199.295 dimension = 1 2 7
r = 528.954 z = -199.765 dimension = 1 2 7
r = 530.279 z = -200.236 dimension = 1 2 7
r = 534.183 z = -204.85 dimension = 2 2 8
r = 607.122 z = -204.85 dimension = 2 2 8
r = 610.769 z = -231.099 dimension = 1 2 7
r = 612.092 z = -231.642 dimension = 1 2 7
r = 613.397 z = -232.184 dimension = 1 2 7
r = 614.708 z = -232.727 dimension = 1 2 7
r = 629.105 z = -238.69 dimension = 1 2 7
r = 630.418 z = -239.232 dimension = 1 2 7
r = 631.731 z = -239.692 dimension = 1 2 7
r = 633.044 z = -240.327 dimension = 1 2 7
r = 634.511 z = -240.904 dimension = 1 2 7
r = 635.818 z = -241.446 dimension = 1 2 7
r = 637.139 z = -241.989 dimension = 1 2 7
r = 638.444 z = -242.531 dimension = 1 2 7
r = 710.984 z = -326.5 dimension = 2 2 8
r = 714.604 z = -267.755 dimension = 1 2 7
r = 715.92 z = -267.755 dimension = 1 2 7
r = 717.236 z = -267.755 dimension = 1 2 7
r = 718.543 z = -267.755 dimension = 1 2 7
r = 738.342 z = -267.755 dimension = 1 2 7
r = 739.66 z = -267.755 dimension = 1 2 7
r = 740.969 z = -267.755 dimension = 1 2 7
r = 742.287 z = -267.755 dimension = 1 2 7

```

38 Hits

Pay attention to this one





Muon Hits Before Second Sort

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r = 416.708 z = -204.85 dimension = 2 2 8
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r = 740.969 z = -267.755 dimension = 1 2 7
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```

38 Hits

Pay attention to this one





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```

38 Hits

Pay attention to
this one



It Moved out of order!



Simple test

- **Test: We remove the second sort and re-reco**
- **Result: no lost hits (see next slide)**



Remove the Sort

I remove the second sort
and redo the fit:
Now there are no missing
hits

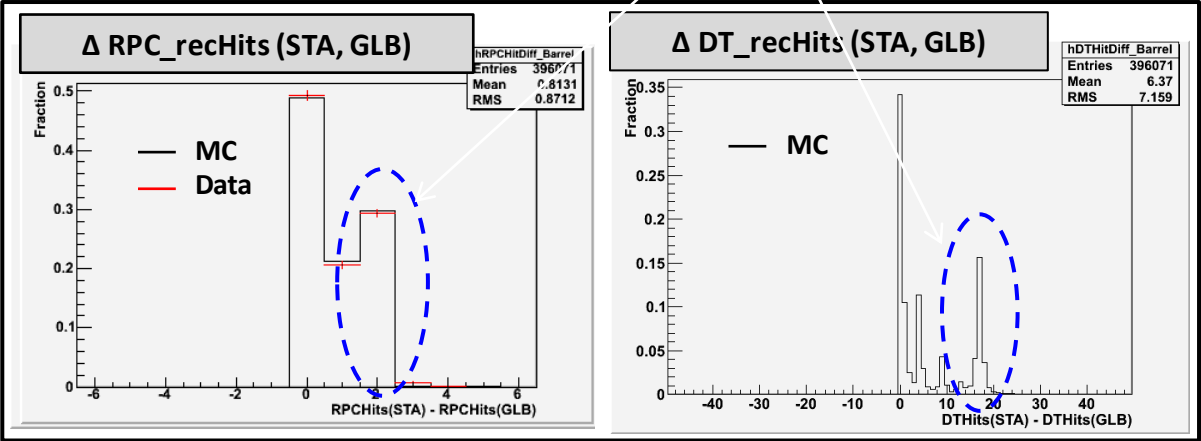
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r = 739.66 z = -267.755 dimension = 1 2 7
r = 740.969 z = -267.755 dimension = 1 2 7
r = 742.287 z = -267.755 dimension = 1 2 7
```

Problem in global muon reconstruction & Solution

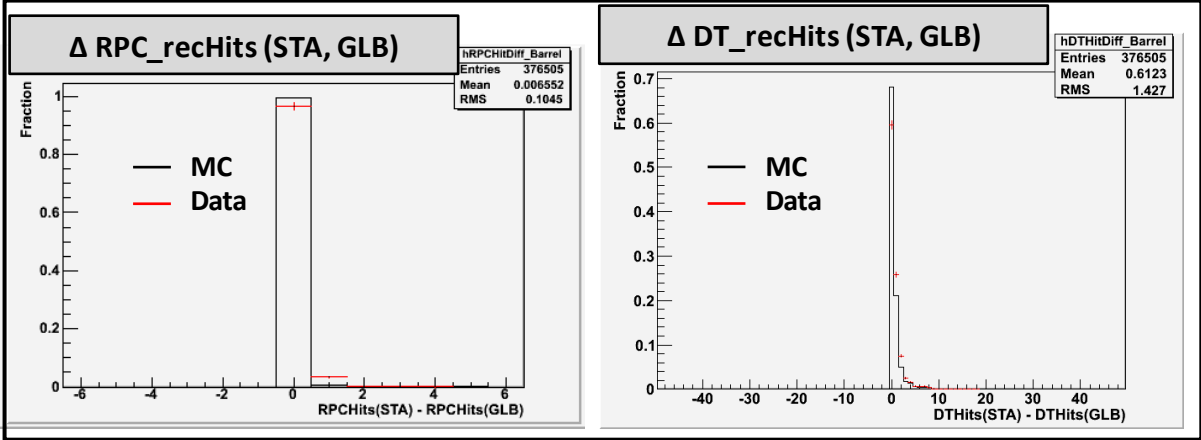
- From Z skimmed samples
- For barrel ($|\eta| < 0.8$)

Loss of RPC and DT hits in global muons

Don't use RPC hits in muon reco



Remove the 2nd sorting



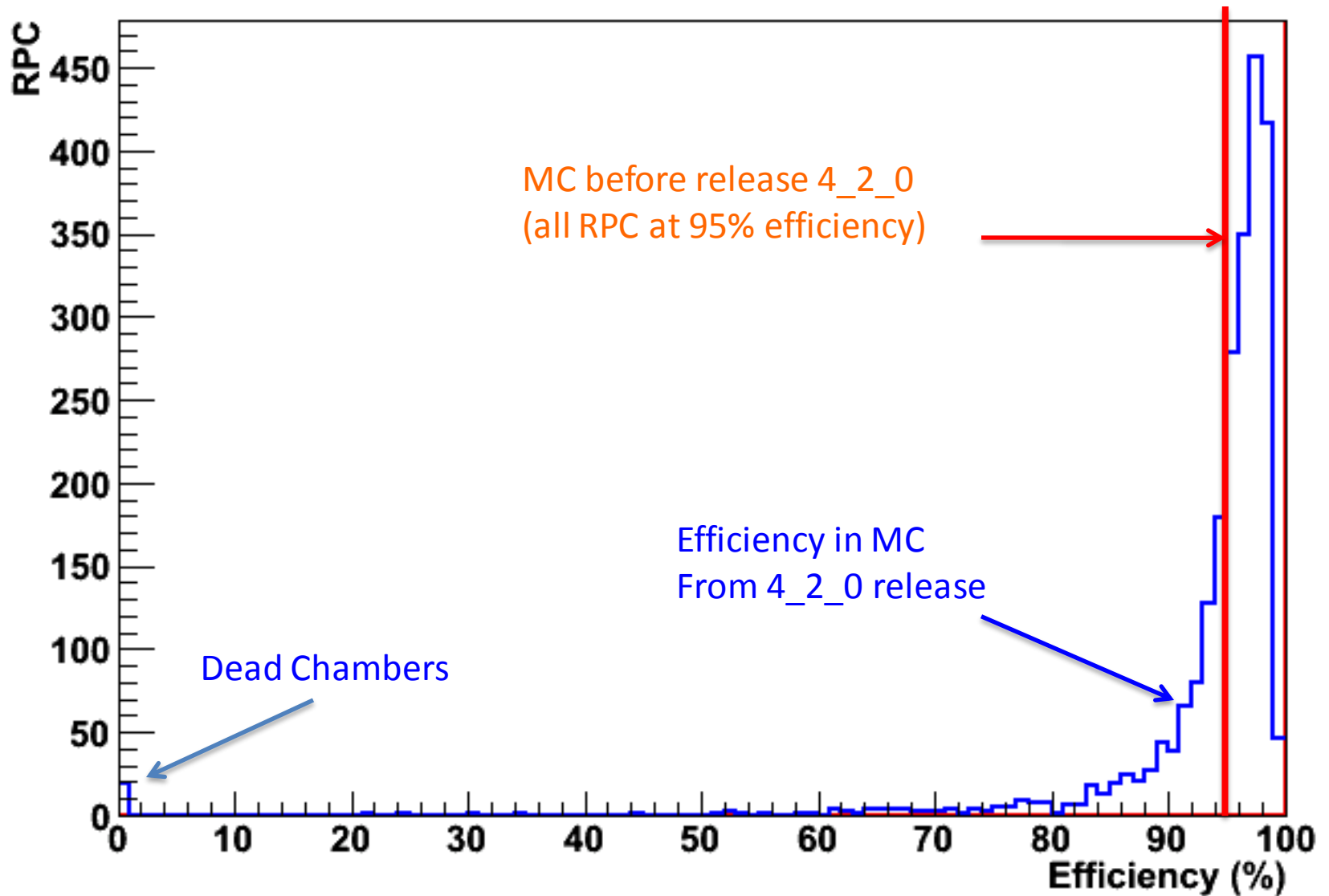
Implementation of RPC efficiencies to MC

☐ Realistic RPC efficiencies are applied on MC

- It was enabled from `CMSSW_4_2_0` and used for `Summer11 MC` production
- In previous MC, RPC efficiencies were assigned as 95% for all the chambers
- Details on the realistic RPC efficiencies
 - ✓ We use analysis of 2010B data
 - ✓ HV Barrel 9350, HV Endcap 9550
 - ✓ DT (or CSC) segment extrapolation onto an RPC surface is used for RPC efficiencies measurement with fiducial cut 8 cm at the border
 - ✓ RPC efficiencies are assigned roll by roll (that is, all the strips belonging to the same roll get the same efficiencies)
 - ✓ Rolls not illuminated for DT/CSC dead have 95 % efficiency assigned

(RPC efficiencies distribution can be seen on the next page)

RPC Efficiency

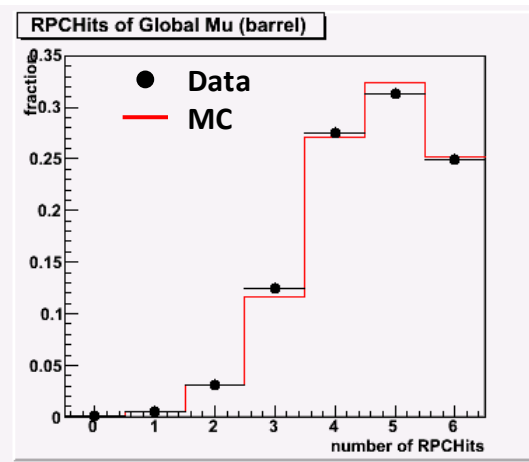


Distribution of # of RPC hits associated with muons

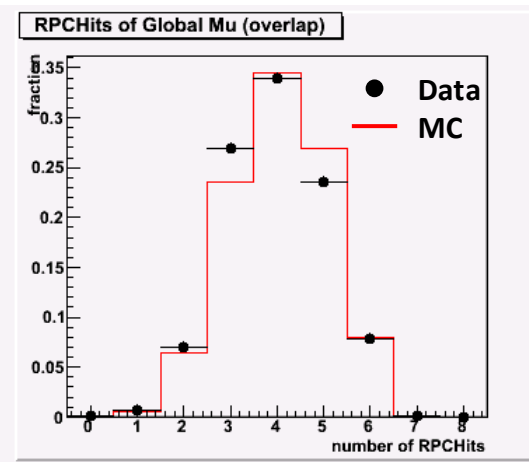
(Muon selection: `isGlobalMuon && isStaMu`)

Run > 163233 ← *RPC conditions are reliable for run > 163233*

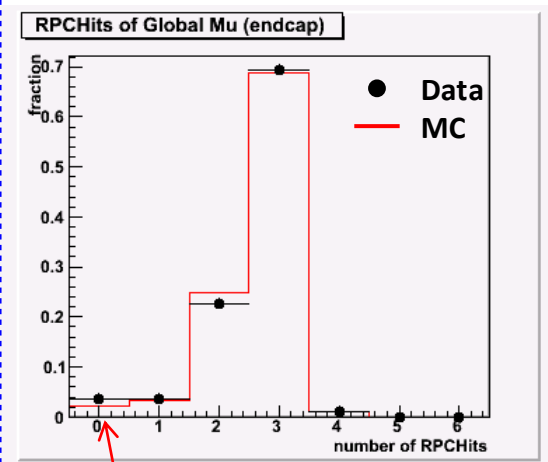
Barrel ($|\eta| < 0.8$)



Overlap ($0.8 \leq |\eta| < 1.2$)

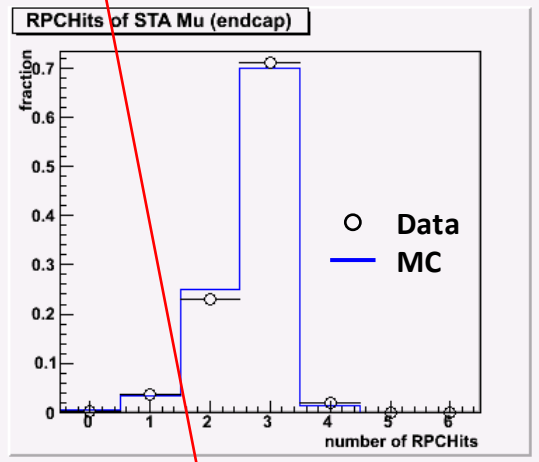
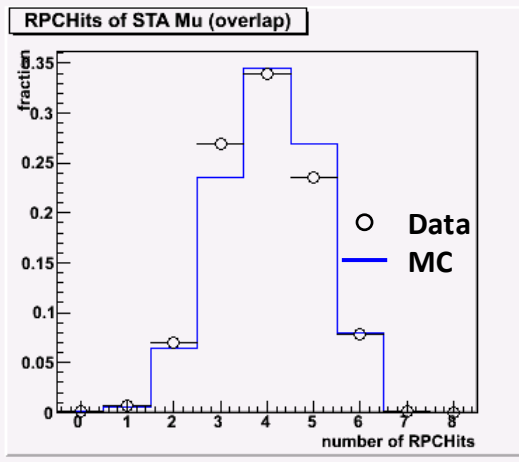
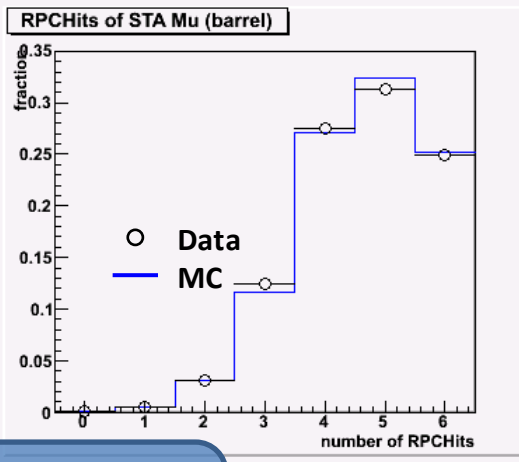


Endcap ($|\eta| \geq 1.2$)



GLB

STA



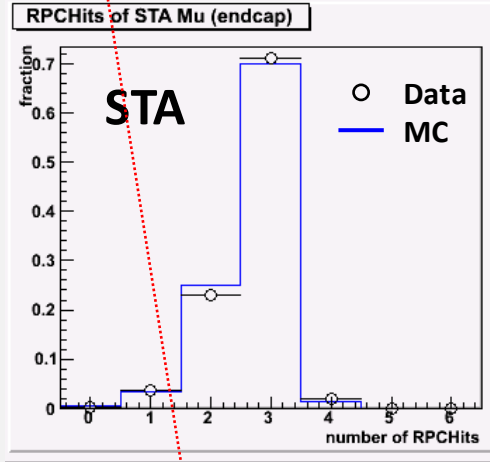
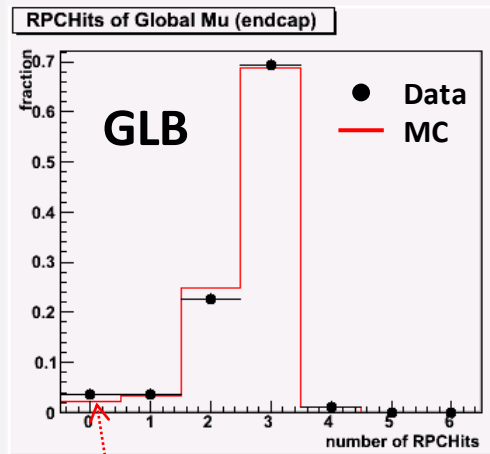
After Adam's fix, global muons agree with standalone muons

Global muons have some 0 hit muons in Endcap

There is a little discrepancy between MC and data in overlap region

Missing hits in global muons in Endcap

Distribution of # of RPC hit in Endcap ($1.2 \leq |\eta| < 1.6$)

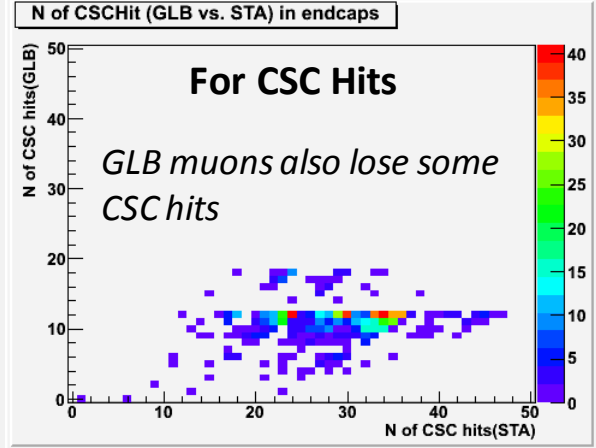
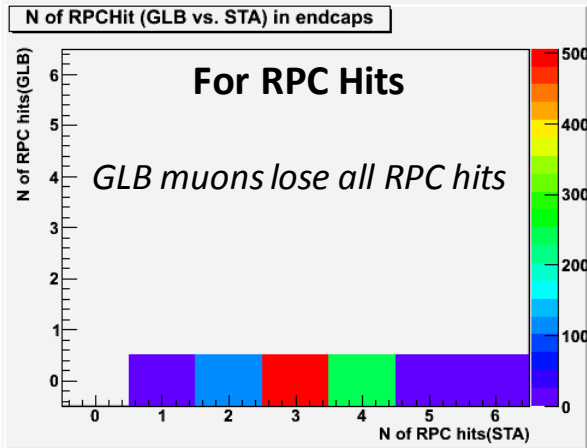


~2 % of global muons have 0 hit in Endcap

Muon selection losing RPC hits in endcaps

- 1) Start from Z skim samples
- 2) isGlobalMuon & isStaMuon
- 3) $1.2 \leq |\eta| < 1.6$
- 4) global muons losing RPC hits

recHits(GLB) vs. recHits(STA) in endcaps (2011A data)



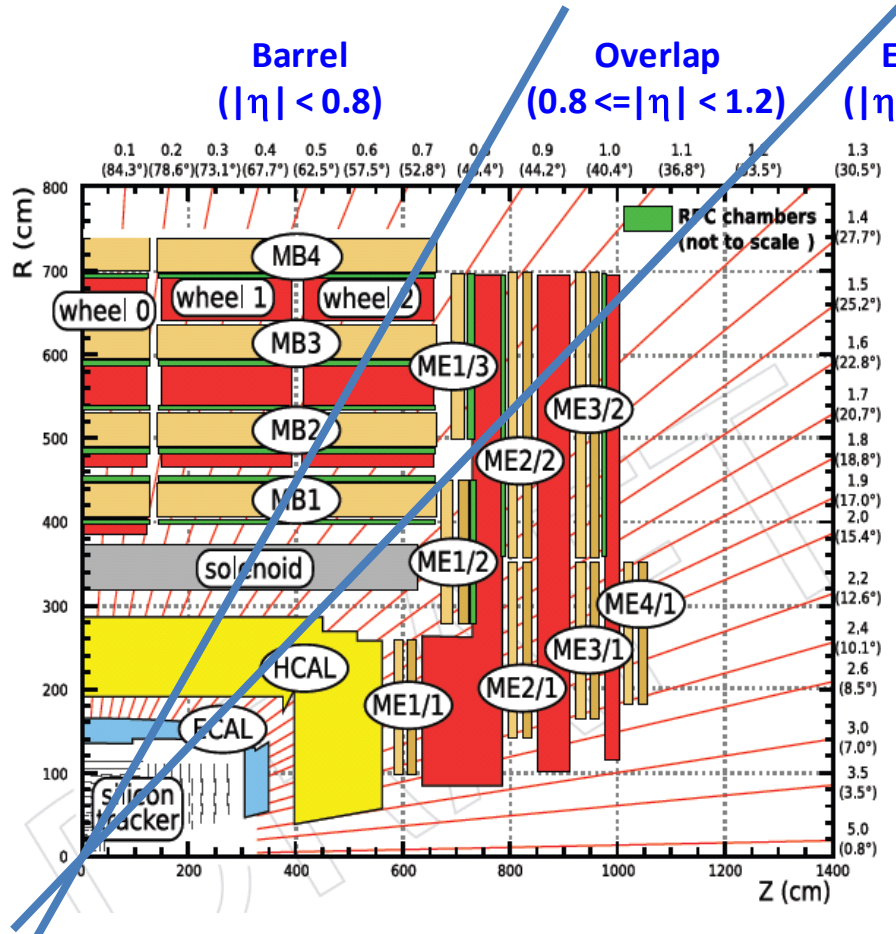
❖ Once GLB lose hits in endcaps, they always lose all RPC hits and some CSC hits (5~24)

Summary (after Adam's investigation)

- This is similar to a hit sorting issue we have seen in barrel (fixed months ago)
- RPC hit is still out of order in endcap as retrieved from the standalone muon
- An endcap navigation expert should investigate that the hits are properly ordered and that the r and z position are proper

Occupancy per layer

Motivation : to identify the chambers causing MC and data not to agree



Occupancy = N of RPCHits / N of muons

where RPC rechits are the associated ones with muons

Occupied layers for each three region

- Barrel: $W_0, W_{\pm 1}, W_{\pm 2}$ (station 3,4)
- Overlap : $W_{\pm 2}$ (station 1,2), $RE_{\pm 1,2,3}$ (ring 3)
- Endcap: $RE_{\pm 1,2}$ (ring 2), $RE_{\pm 3}$ (ring 2,3)

**Only the result from standalone muons are shown in this talk (the result from global muons are almost same)*

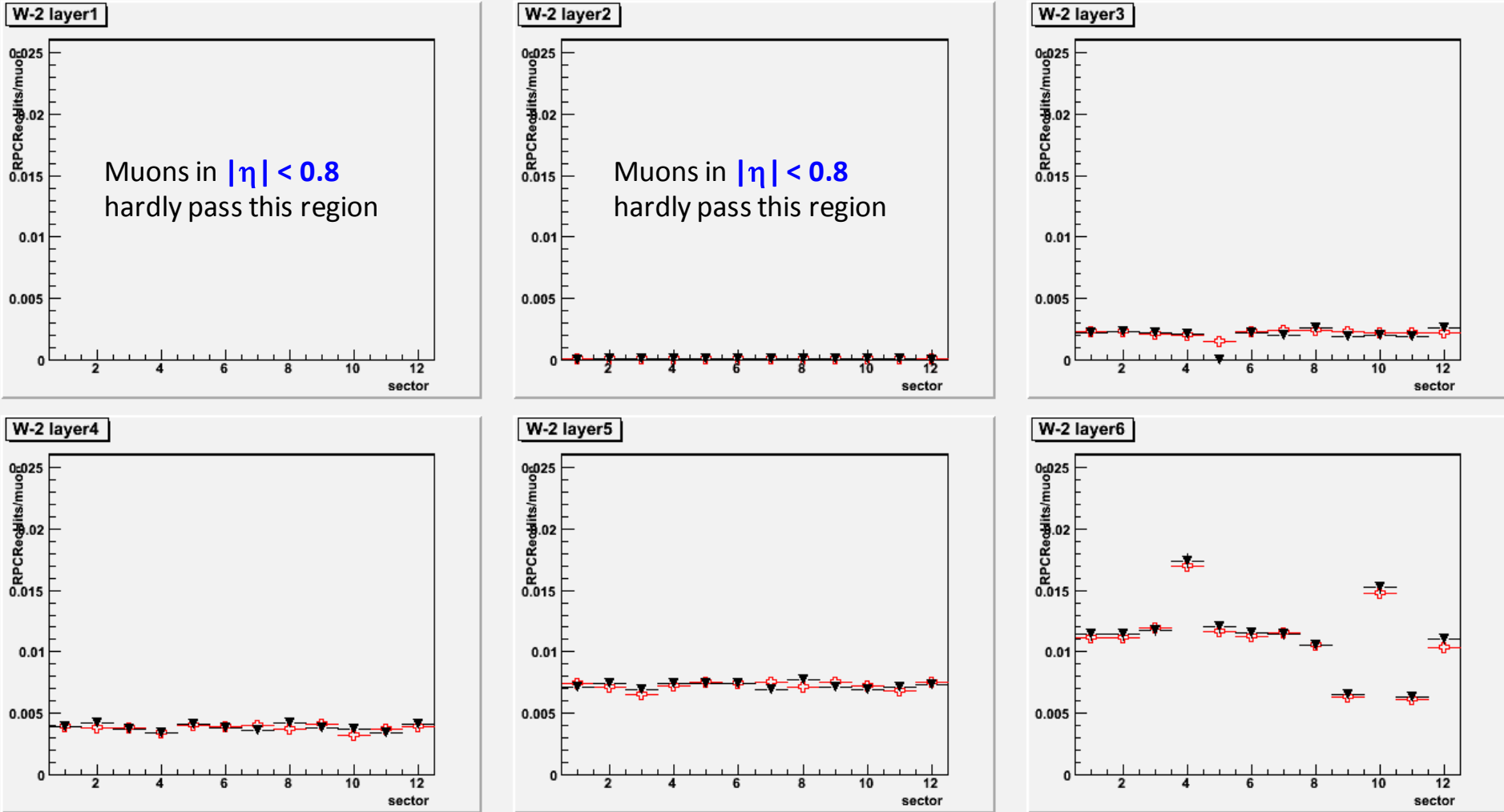
Occupancy

by the muons in $|\eta| < 0.8$

Occupancy of RPCRecHits (W-2)

RPCRecHits/muon vs. Sector

▼ Data
+ MC

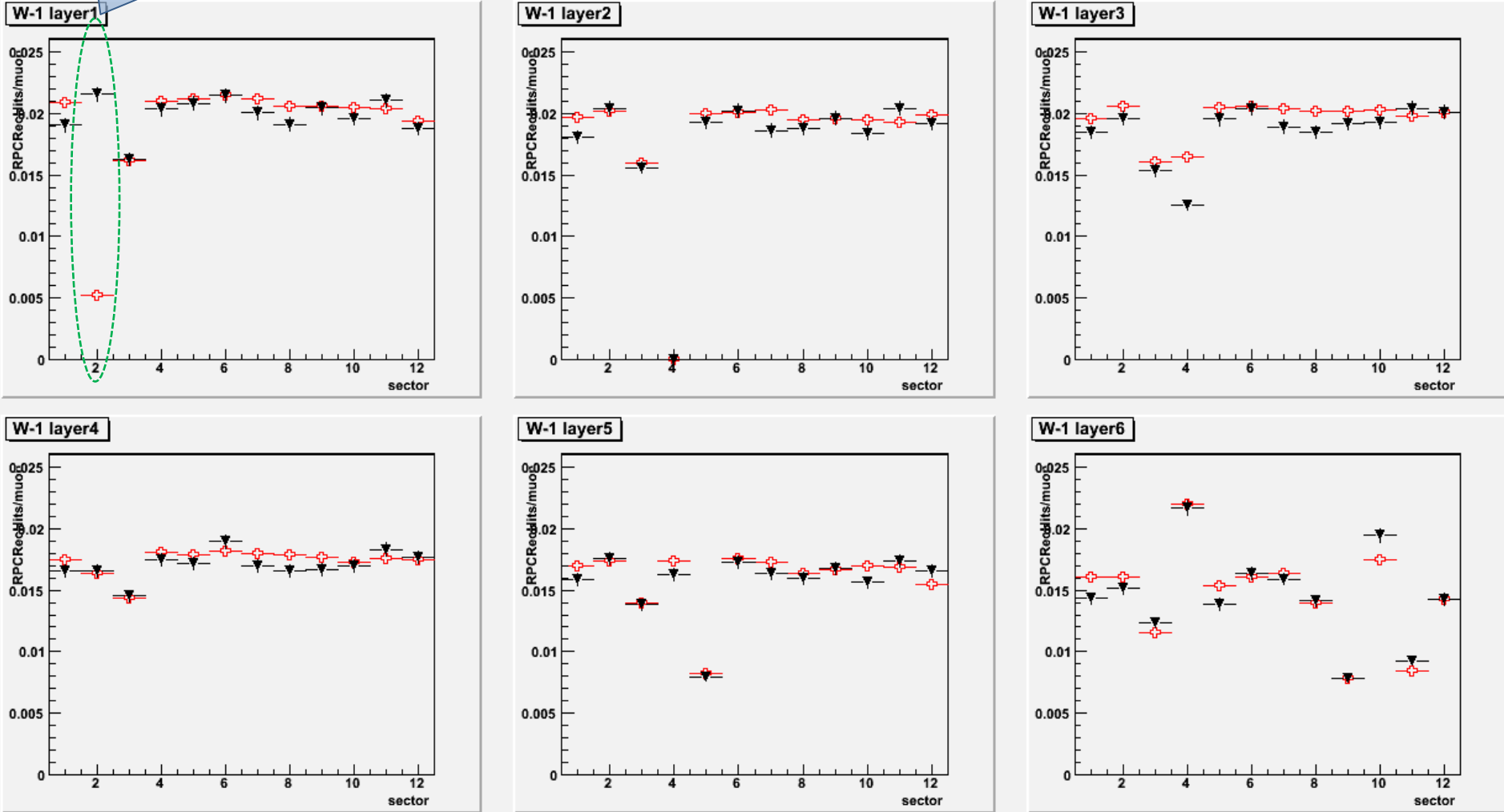


Occupancy of RPCRecHits (W-1)

Clearly MC assign wrong efficiency on W-1 layer1 sector2

RPCRecHits/muon vs. Sector

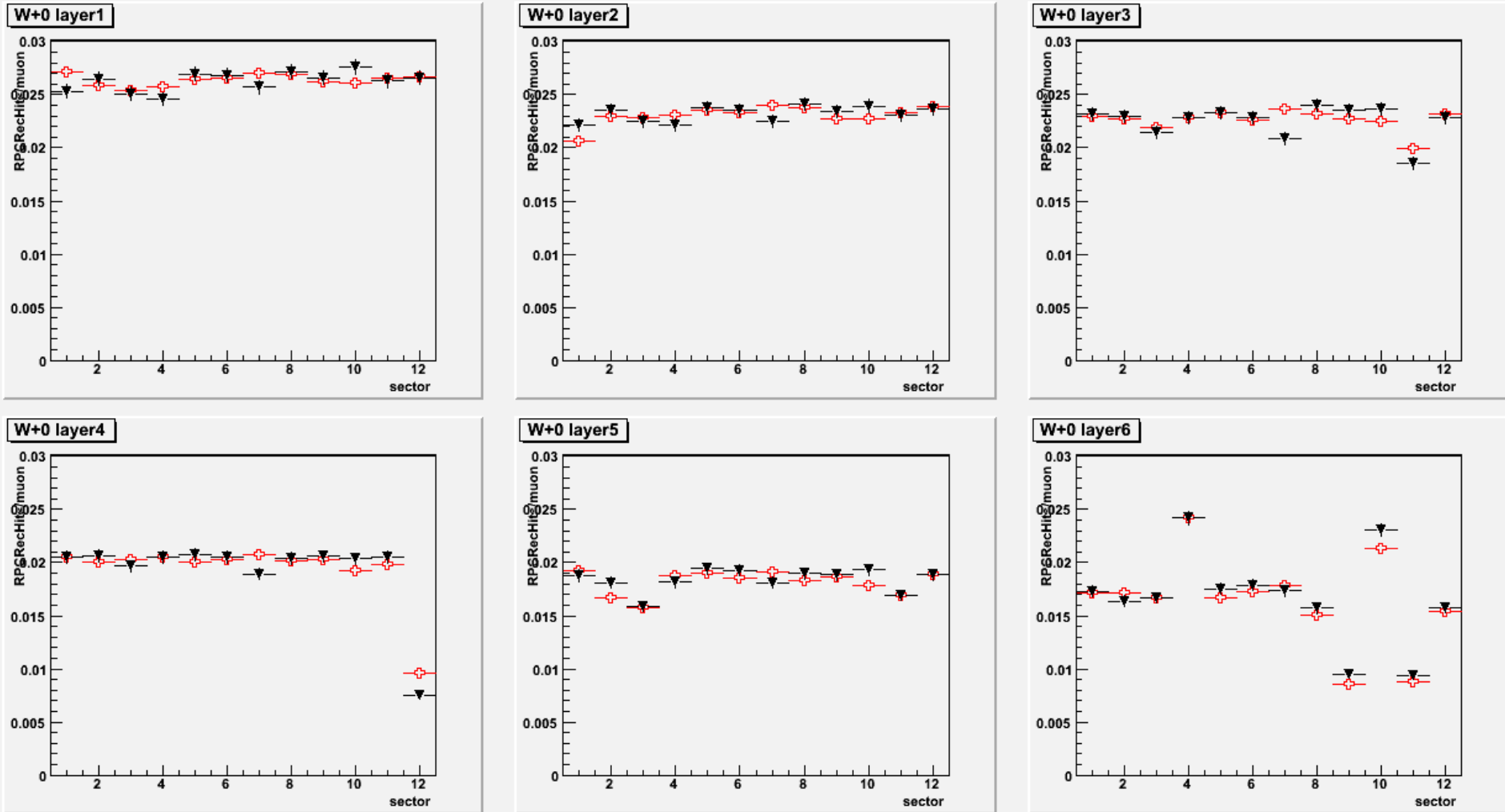
▼ Data
+ MC



Occupancy of RPCRecHits (W00)

RPCRecHits/muon vs. Sector

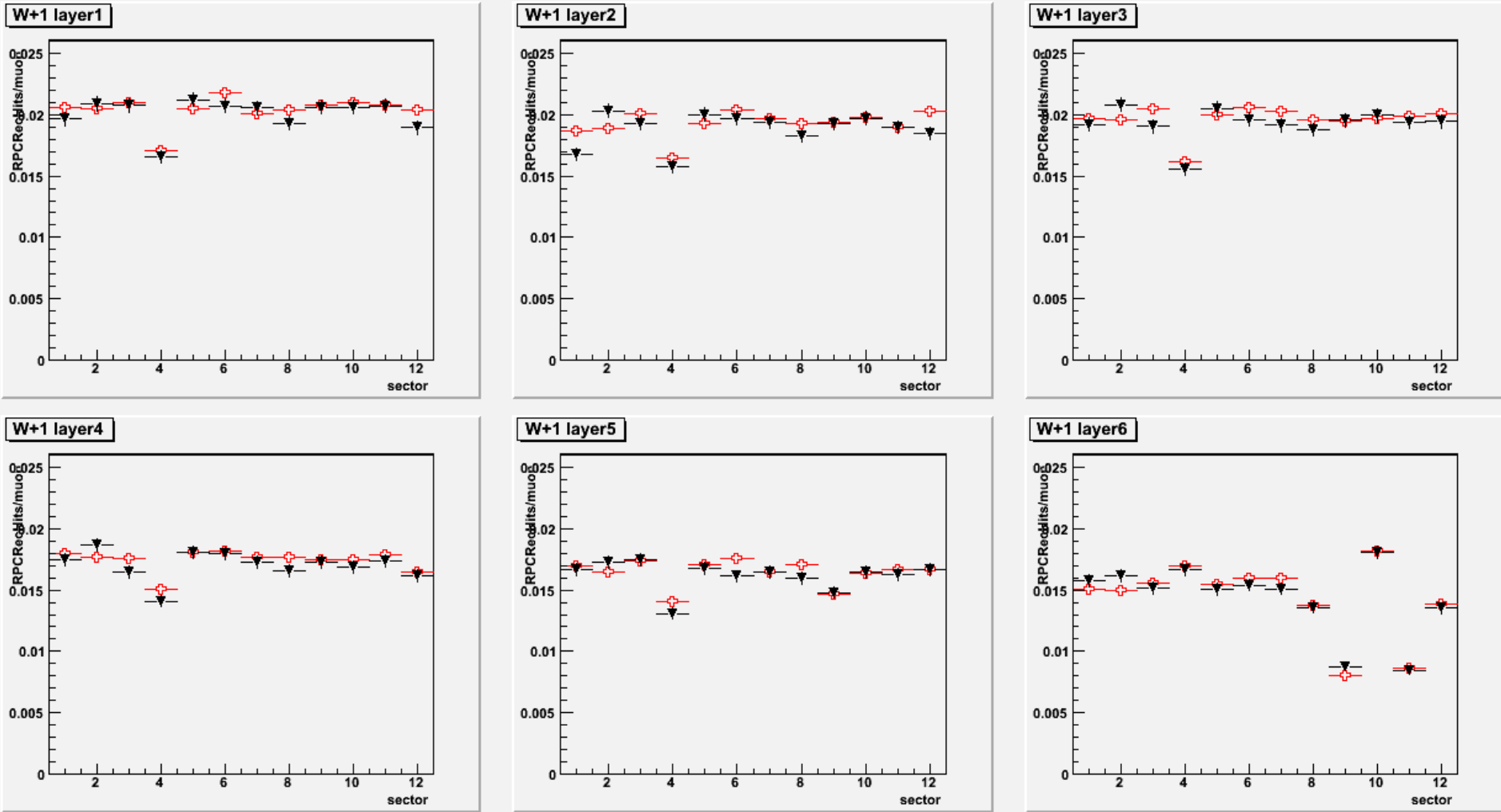
▼ Data
+ MC



Occupancy of RPCRecHits (W+1)

RPCRecHits/muon vs. Sector

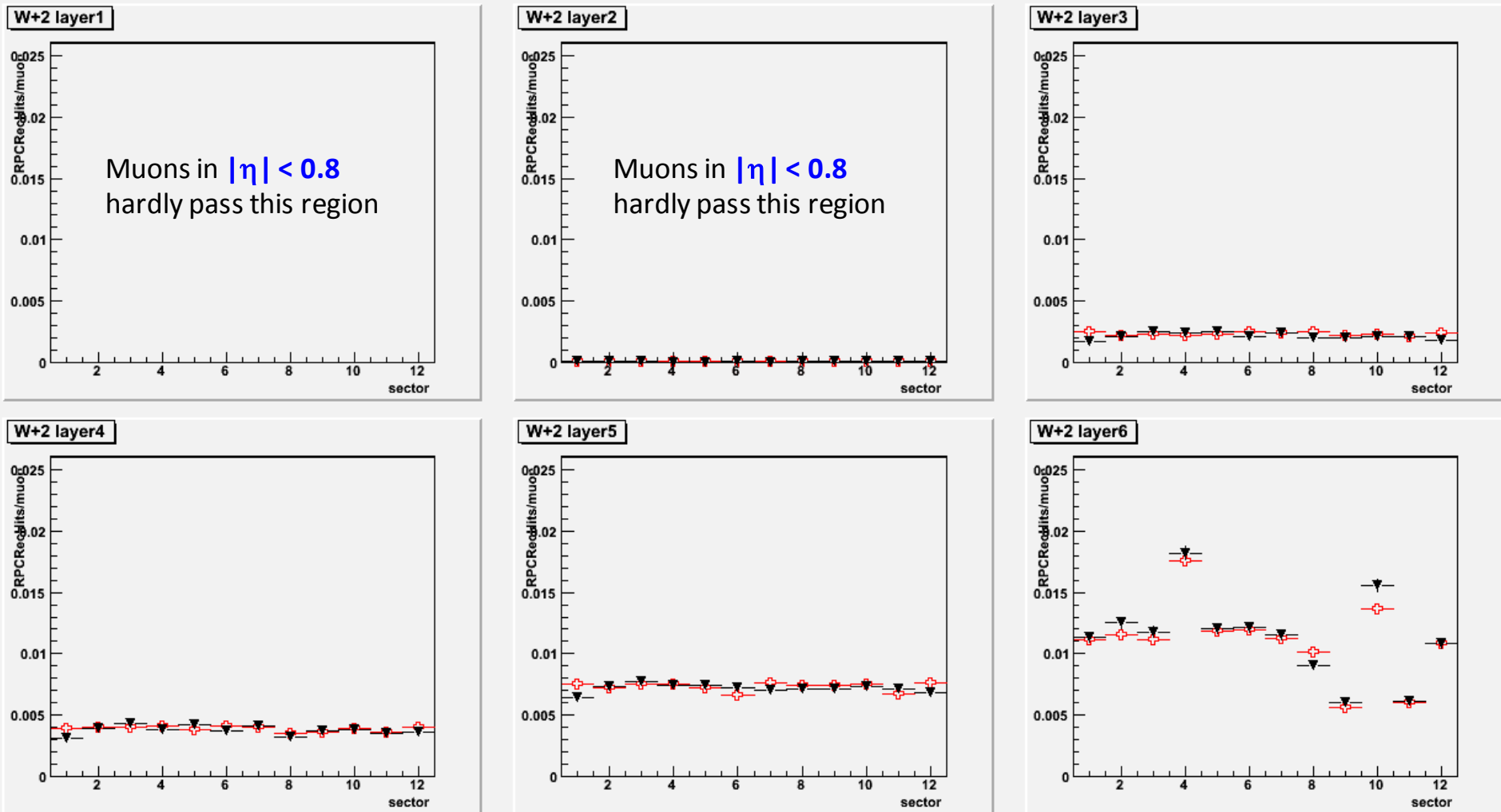
▼ Data
+ MC



Occupancy of RPCRecHits (W+2)

RPCRecHits/muon vs. Sector

▼ Data
+ MC



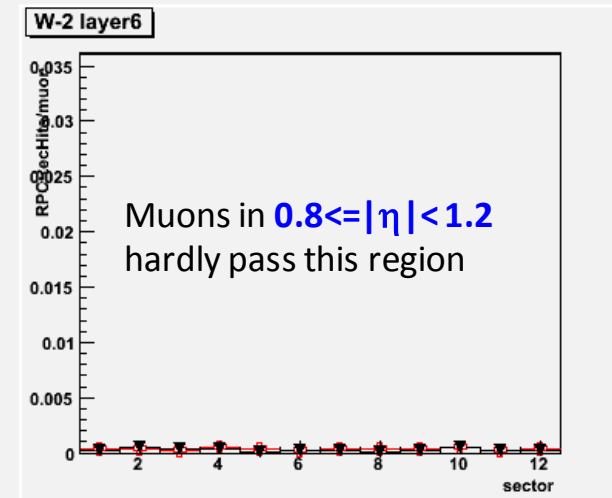
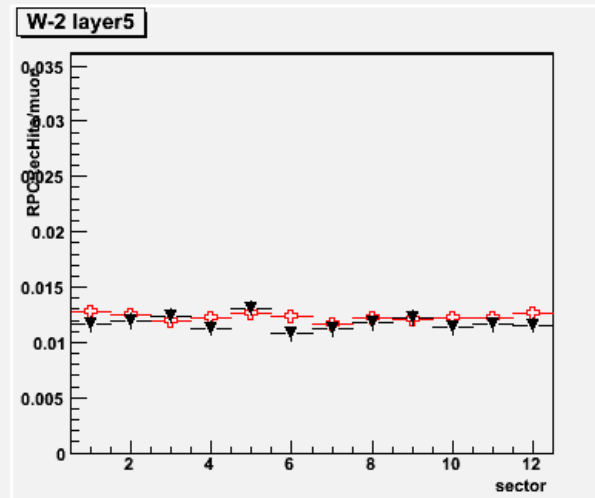
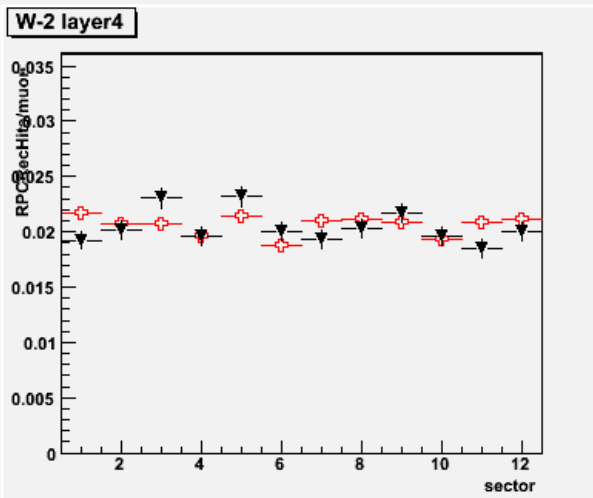
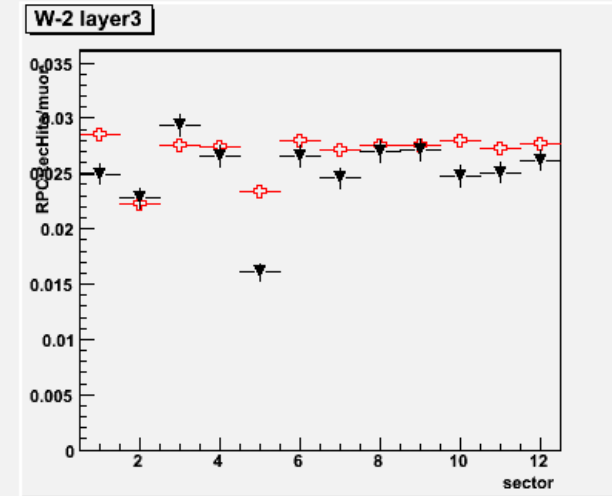
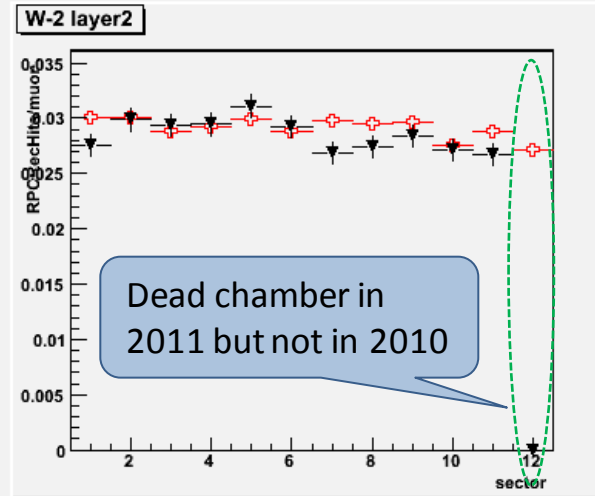
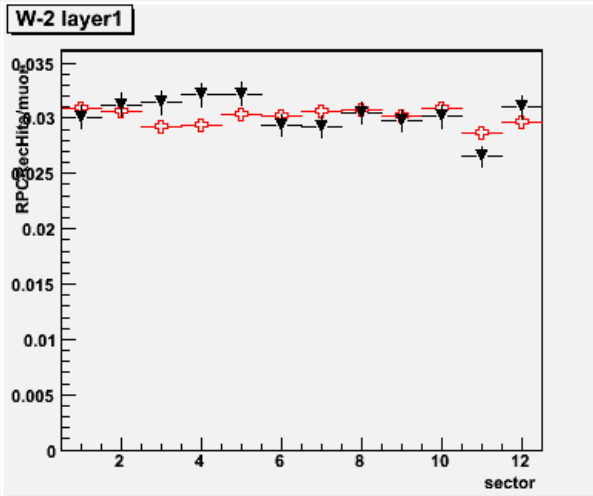
Occupancy

by the muons in $0.8 \leq |\eta| < 1.2$

Occupancy of RPCRecHits (W-2)

RPCRecHits/muon vs. Sector

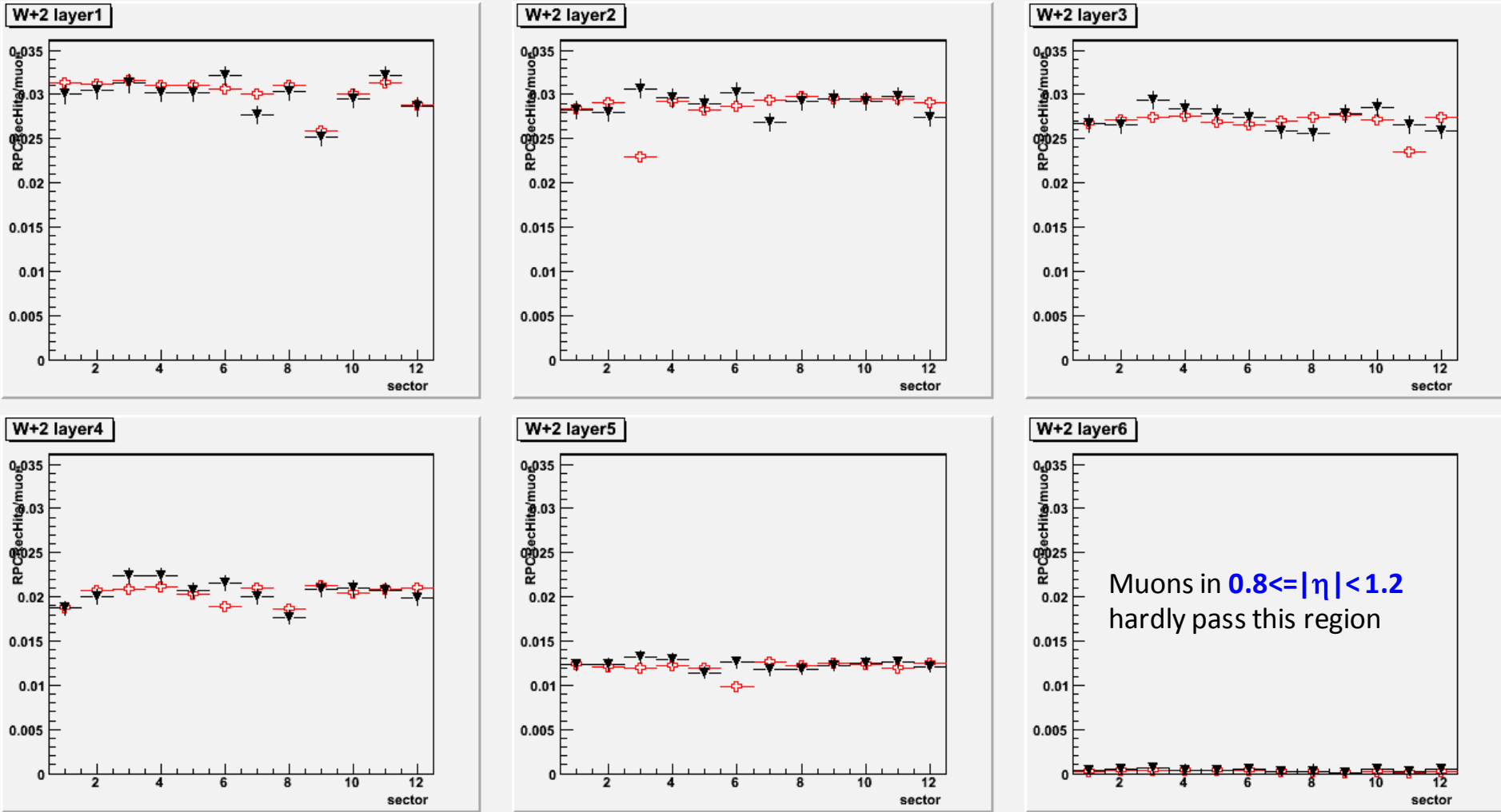
▼ Data
+ MC



Occupancy of RPCRecHits (W+2)

RPCRecHits/muon vs. Sector

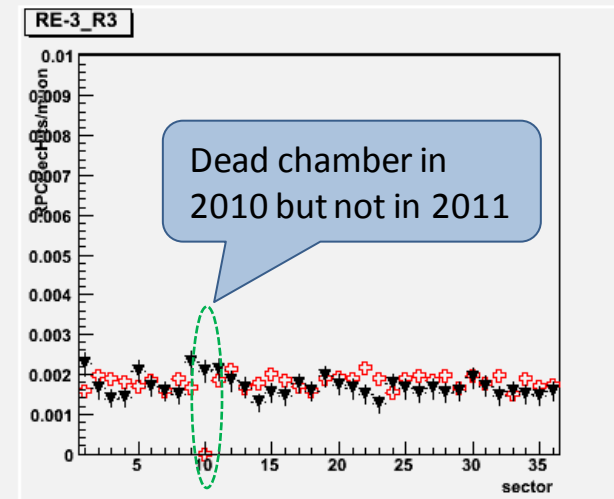
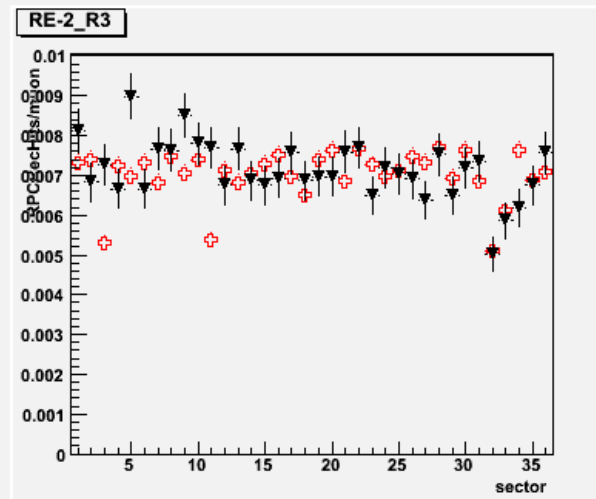
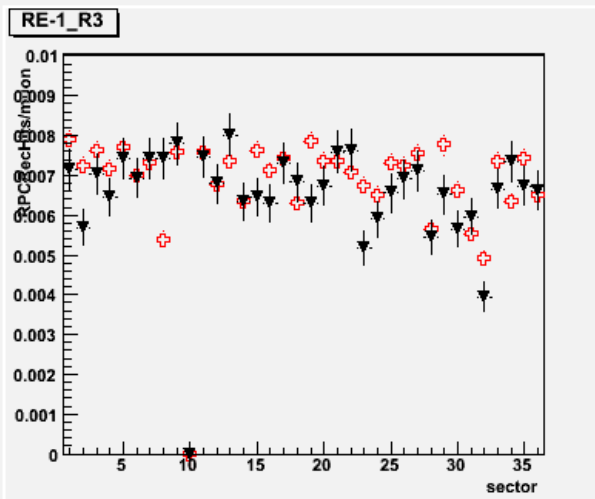
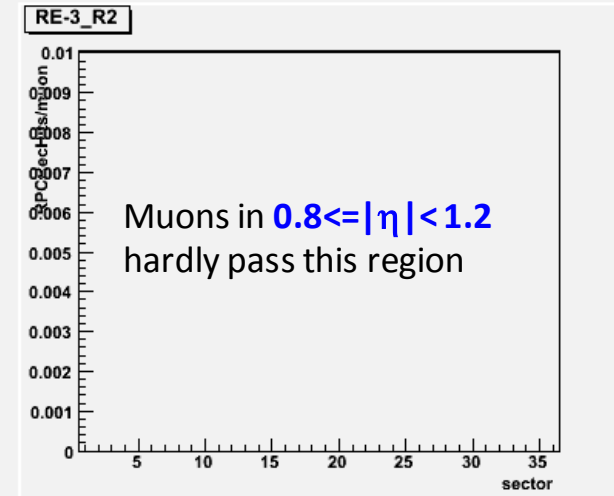
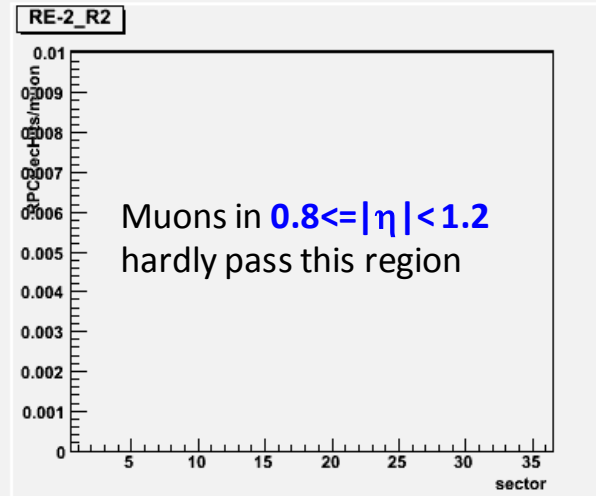
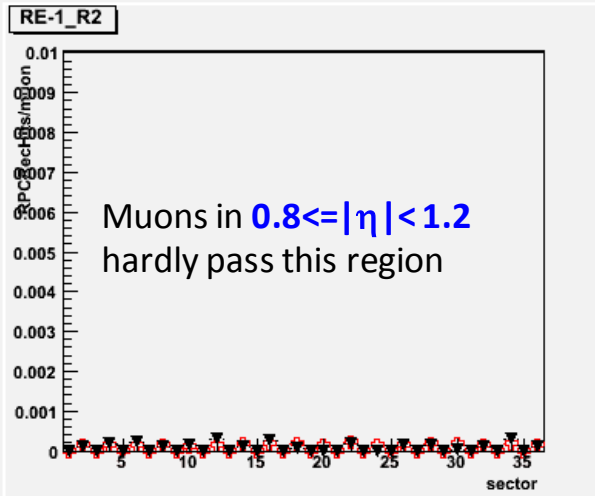
▼ Data
+ MC



Occupancy of RPCRecHits (Endcap-)

RPCRecHits/muon vs. Sector

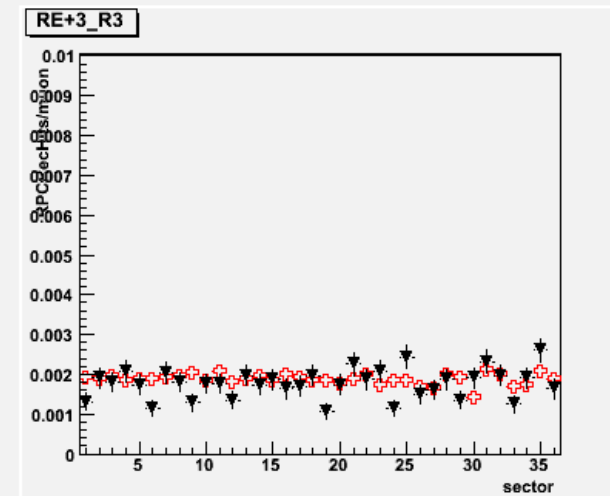
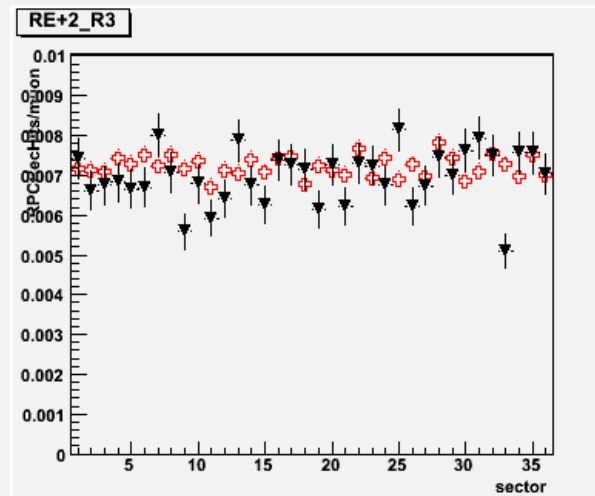
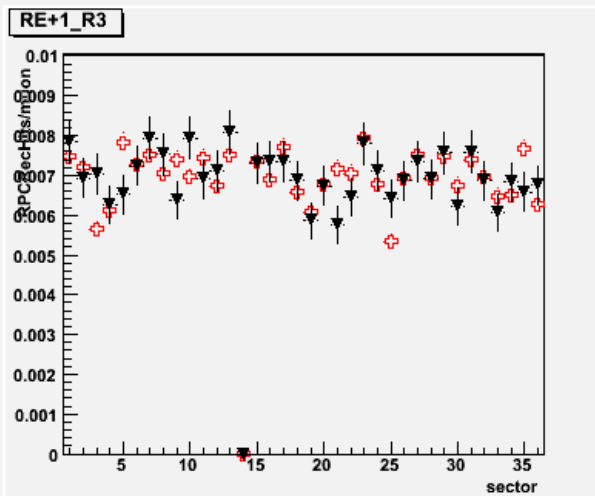
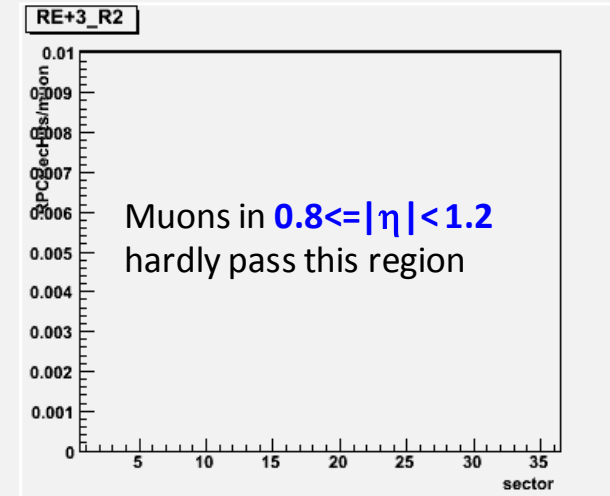
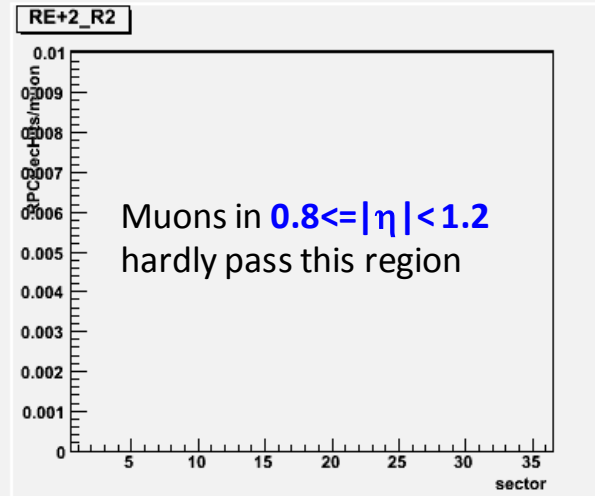
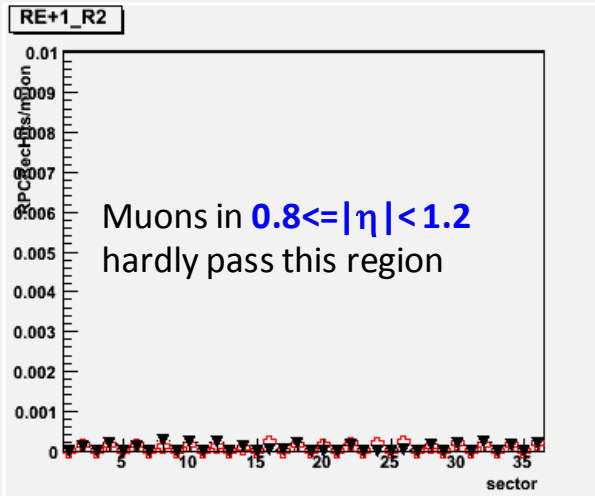
▼ Data
+ MC



Occupancy of RPCRecHits (Endcap+)

RPCRecHits/muon vs. Sector

▼ Data
+ MC



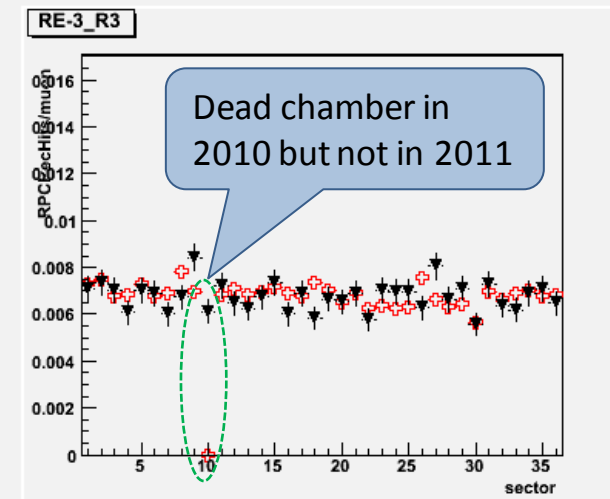
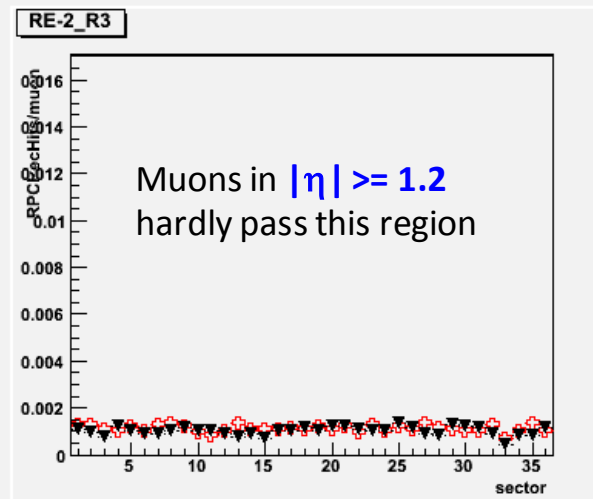
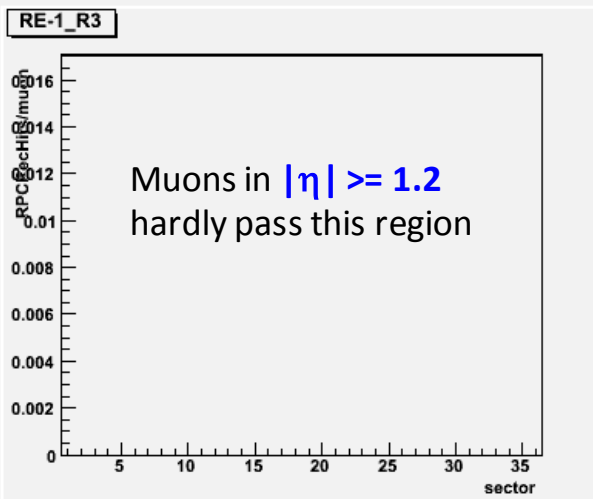
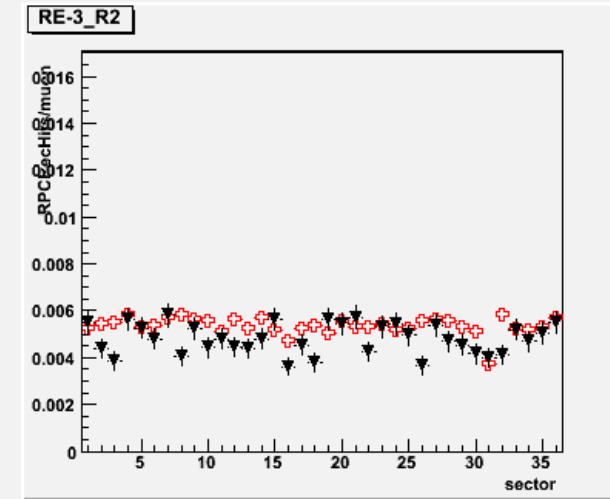
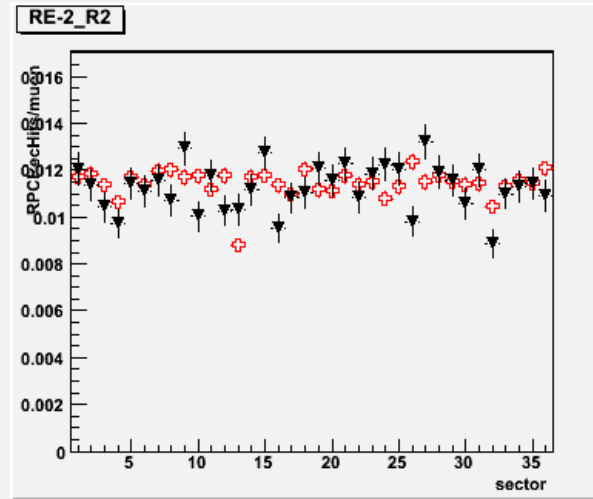
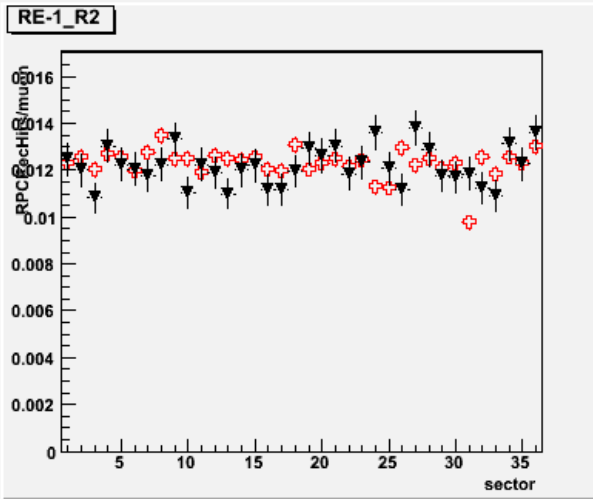
Occupancy

by the muons in $|\eta| \geq 1.2$

Occupancy of RPCRecHits (Endcap-)

RPCRecHits/muon vs. Sector

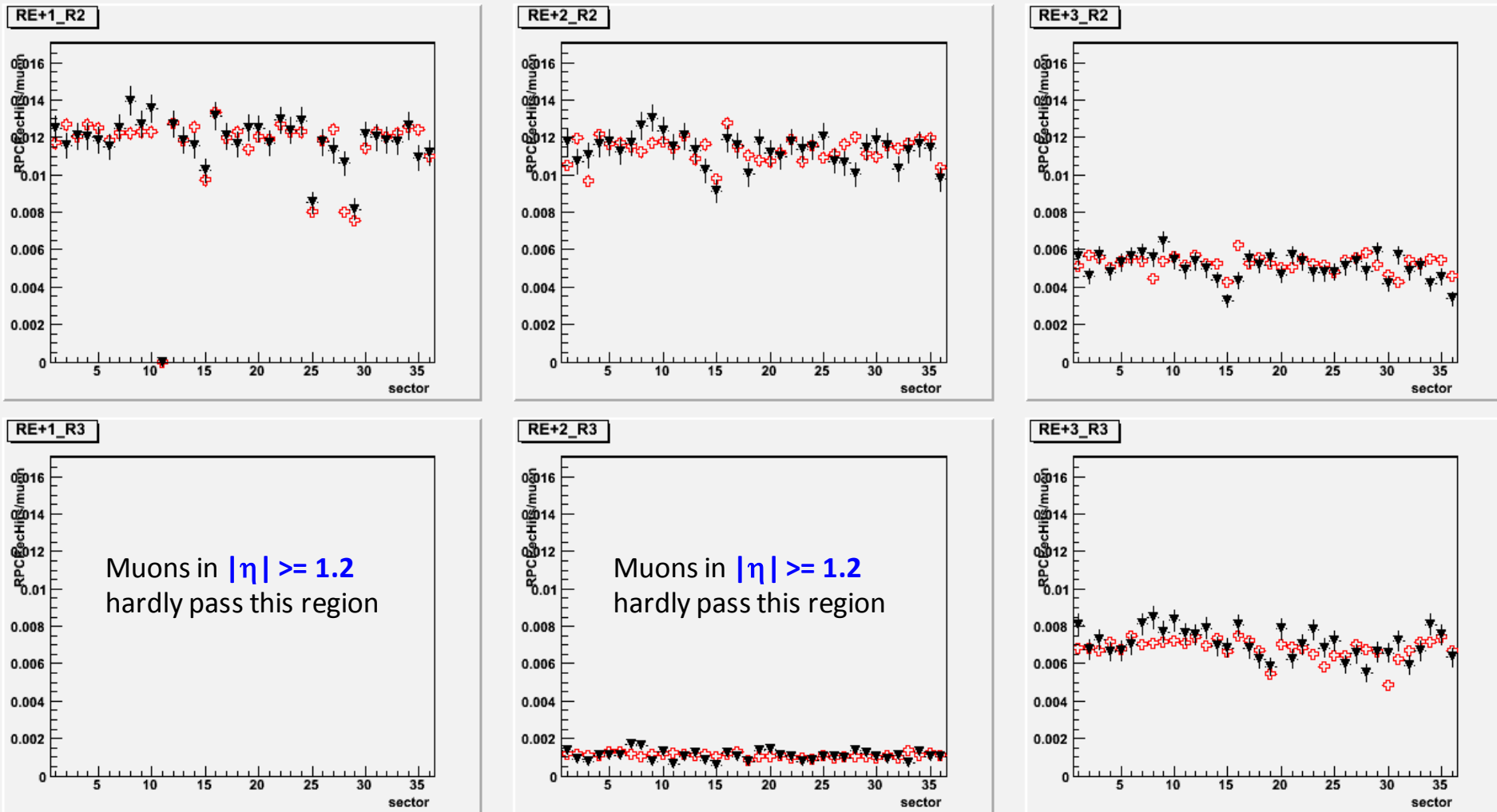
▼ Data
+ MC



Occupancy of RPCRecHits (Endcap+)

RPCRecHits/muon vs. Sector

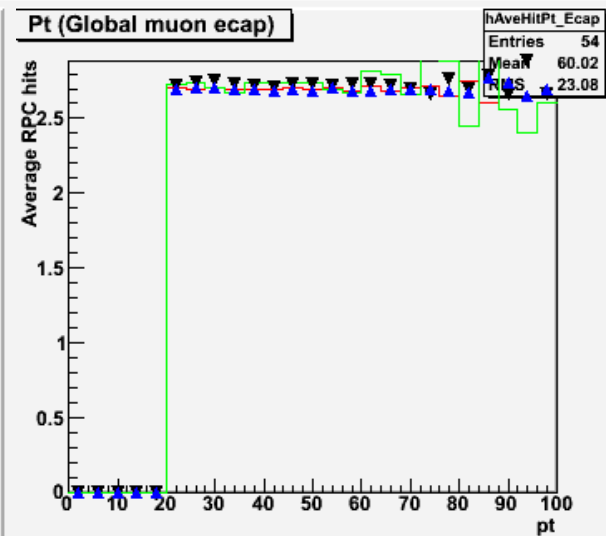
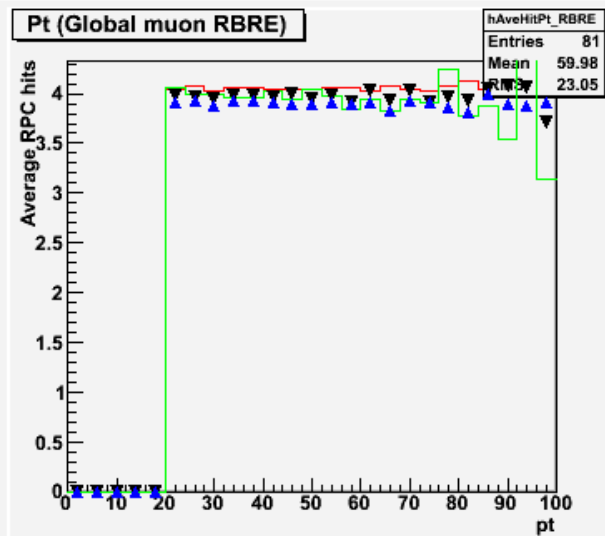
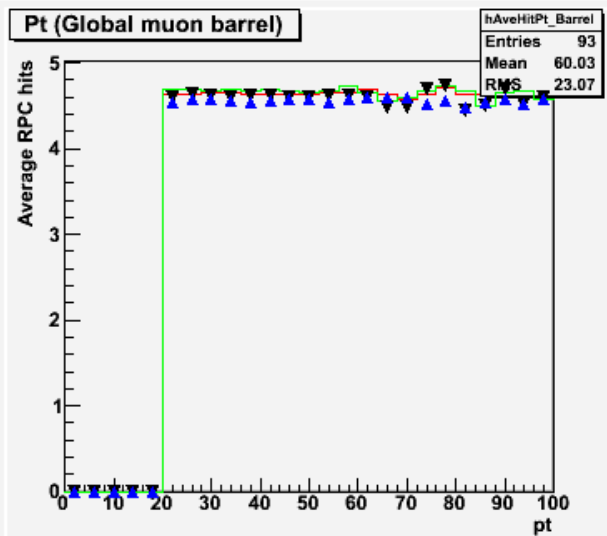
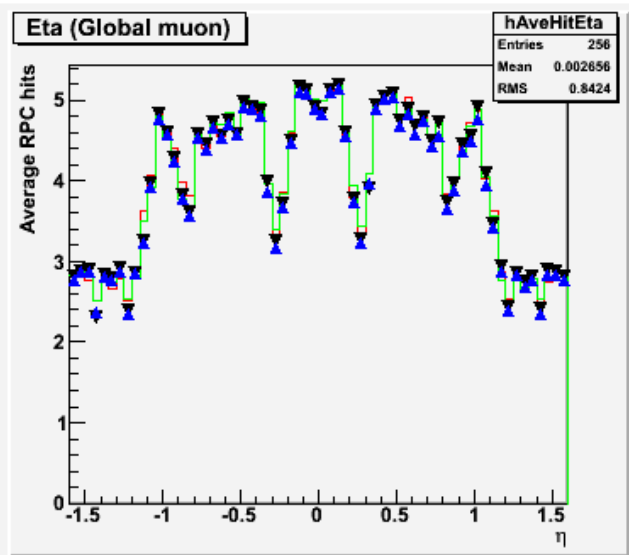
▼ Data
+ MC



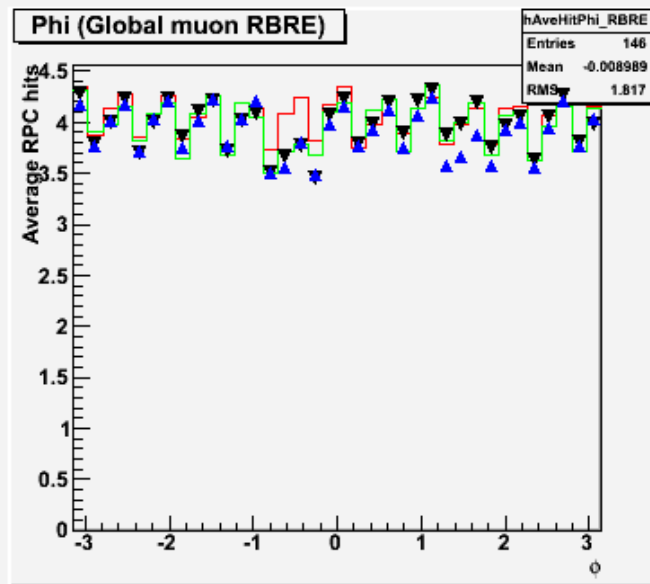
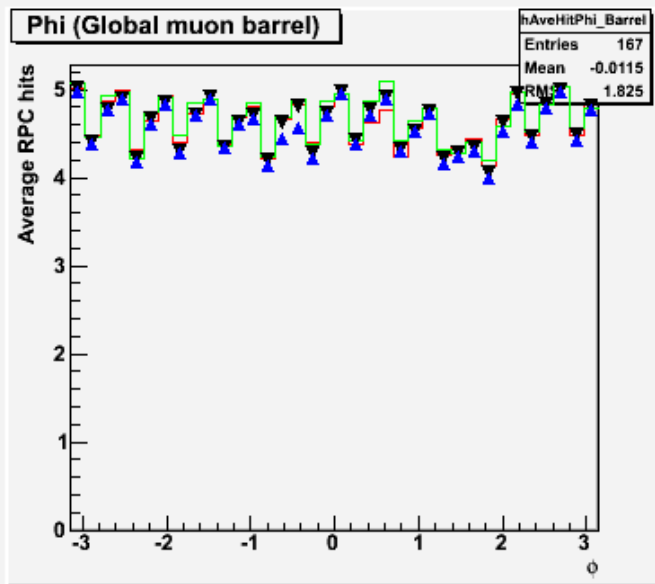
Average # of RPC hits

vs. eta, phi and pt

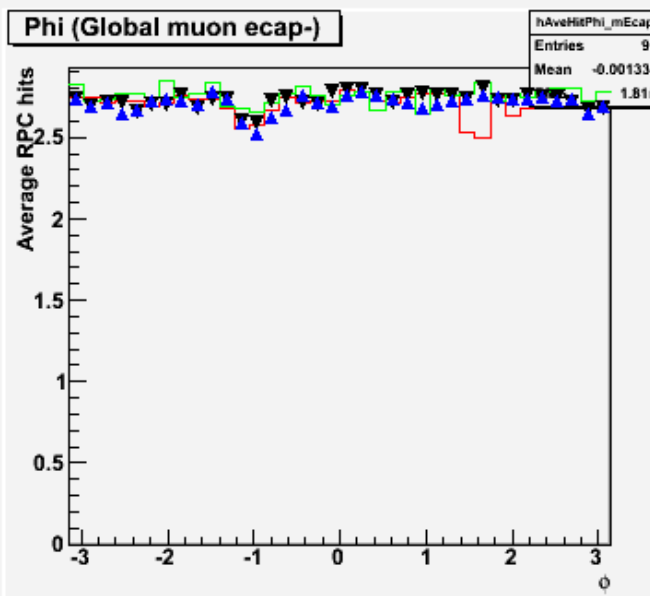
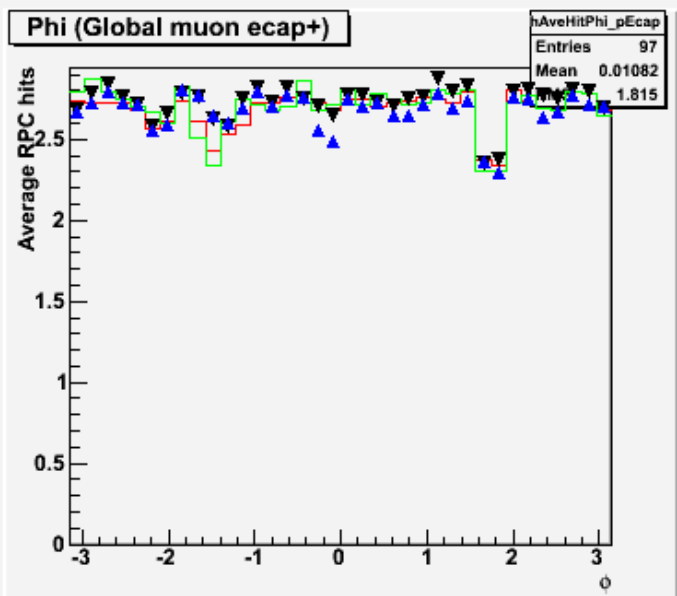
Average # of RPCRecHits vs. eta and pt



Average # of RPCRecHits vs. phi



- ▼ Data_163233-163869
- ▲ Data_170053-172619
- Summer11 MC
- New Summer11 MC



Impact of RPC Hits on Global Muon Reconstruction in CMS

Introduction

■ The condition for global muon reconstruction

- '2 DT/CSC segments' or '1 DT/CSC segment + 1 RPC hit'

■ The purpose of this study

- Get muon reconstruction inefficiency when RPC is removed

If RPC hits are removed in global muon reconstruction, these muons will be lost

■ Method

- Use official TagAndProbe tool & Z resonance
- Dataset

- MC (Summer11-RECO)

DYToMuMu_M-20_TuneZ2_7TeV-pythia6

- Data (Run2011A-ZMu)

/SingleMu/Run2011A-ZMu-05Aug2011-v1/RAW-RECO

(run 170053 – 172619, 15.Jul.2011 - 4.Aug.2011)

Tag and Probe Selection

■ Tag muons

good muons used for Z skim

- isGlobalMuon && isTrackerMuon
- isolationR03().sumPt<3.0
- abs(innerTrack().dxy)<1.0
- pt > 20 && abs(eta) < 2.4

■ Probe muons

Any global muon

- isGlobalMuon

■ Passing Probe

Match to global muons that are reconstructed without RPC hits

■ PDF for S/B

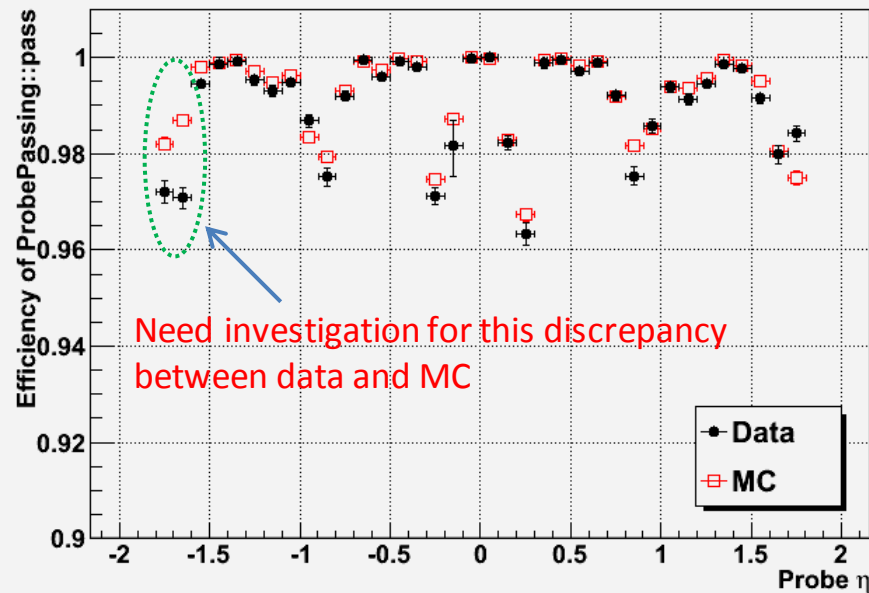
- Voigtian for signal
- Exponential for background

Muon reconstruction efficiency

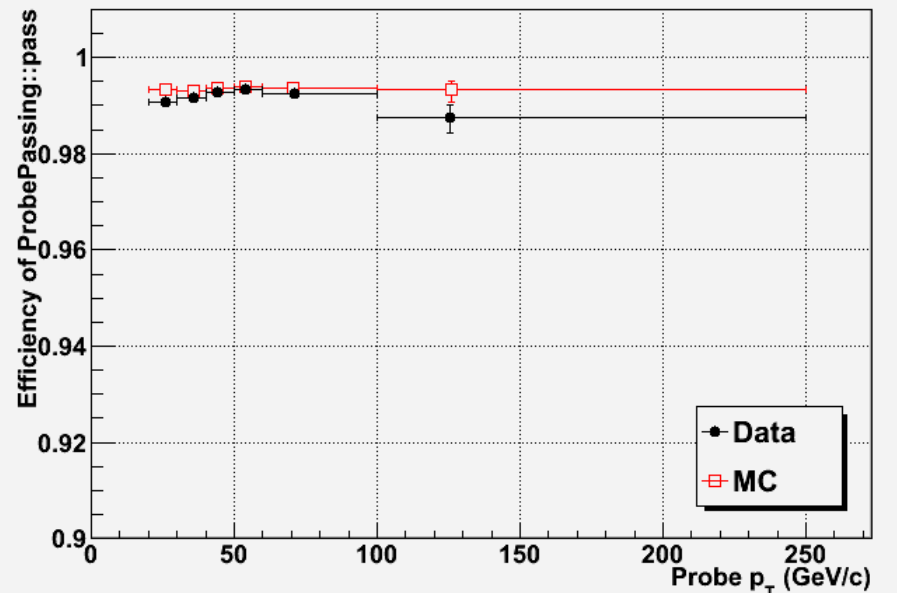
Probes: globalMuons

Passing Probes: match to globalMuonsNoRPC

A RooPlot of "Probe η "



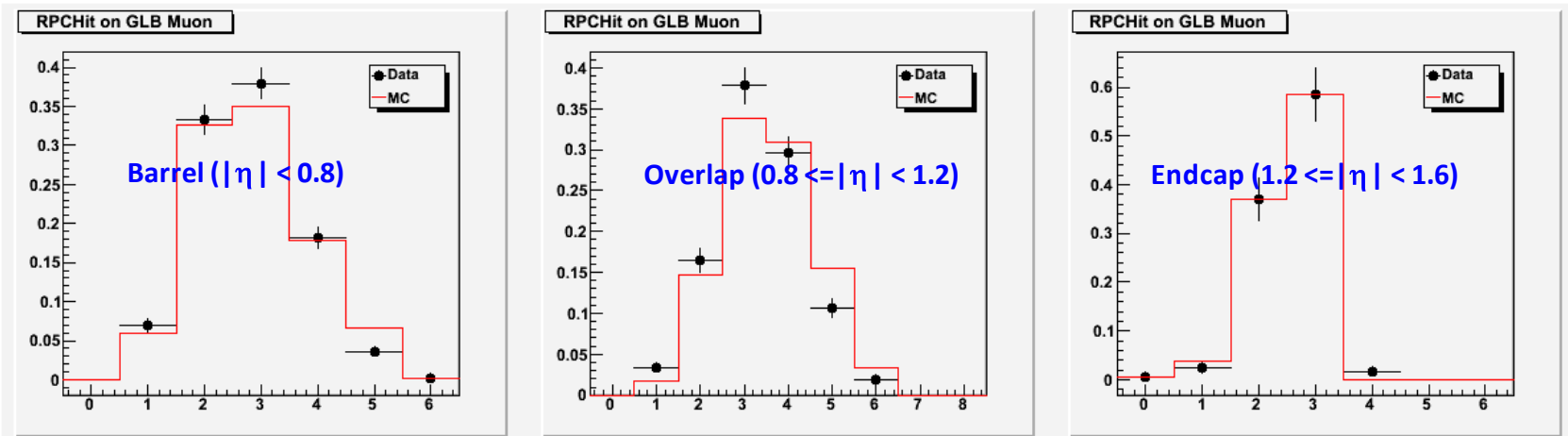
A RooPlot of "Probe p_T "



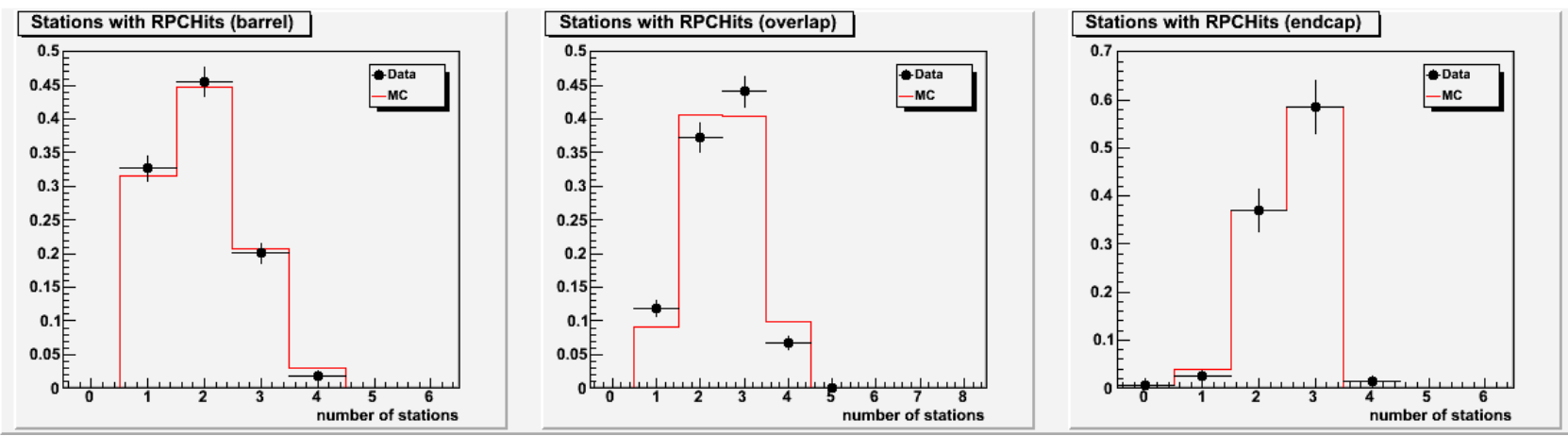
- Increased η range up to 1.8 because a single RPC hit in RE3 can give a contribution in muon reconstruction
- In some eta region, RPC hits give a contribution up to 3-4%

Number of RPC hits associated with Failing Probes

RPC Hits Distributions



Stations with RPC Hits



The muons that are not reconstructed as global muons without RPC usually are composed by many RPC hits and many RPC stations

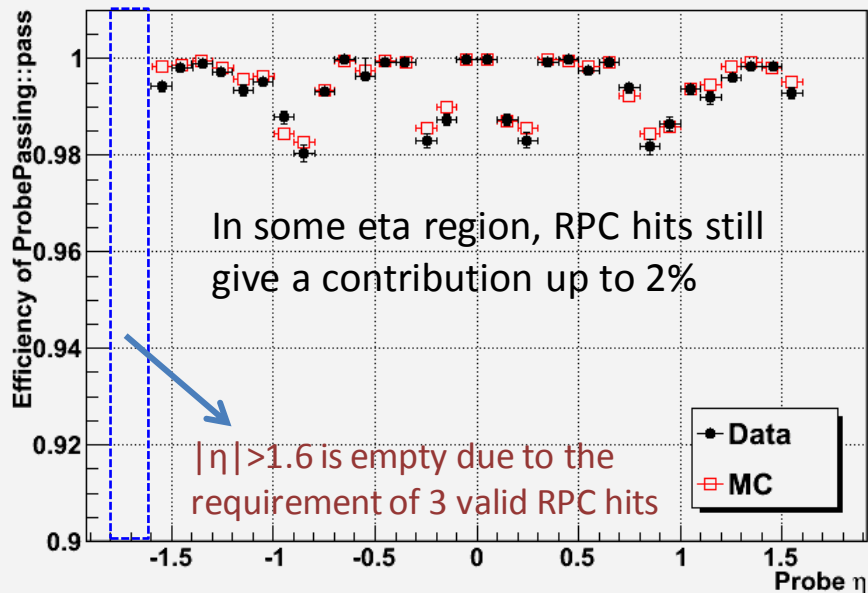
Muon reconstruction efficiency (with ≥ 3 valid RPC hits)

■ Motivation

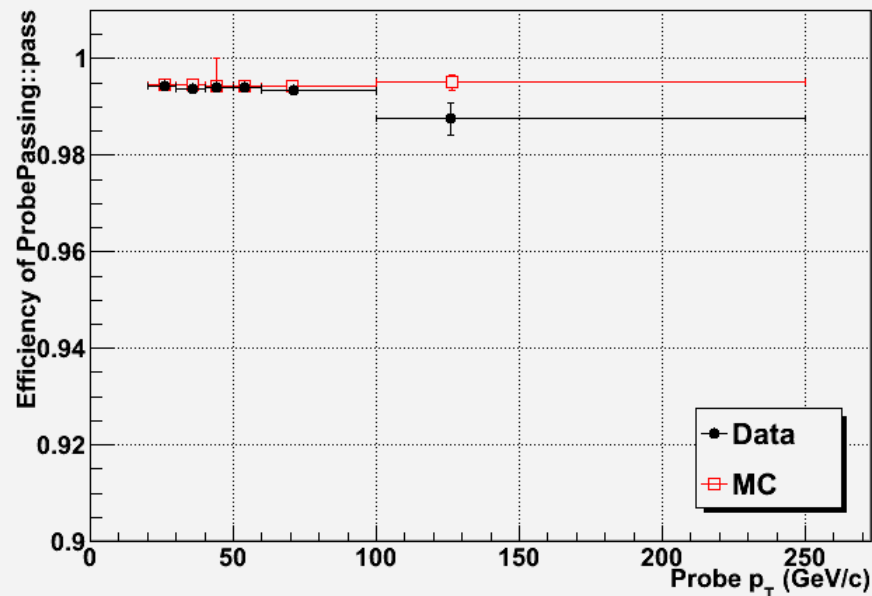
- Usually the selection in PAGs is such to require a tight muon (muons with at least 2 DT/CSC segments). For these events, the RPC contribution is very low.
- To convince that there is a small fraction of muons that have no 2 DT/CSC segments but still are good muons because flagged by at least 3 RPC hits.

Probes: globalMuons **with ≥ 3 valid RPC hits**
Passing Probes: match to globalMuonsNoRPC

A RooPlot of "Probe η "



A RooPlot of "Probe p_T "



Features of failing probes (by event display)

■ 3 categories for the failing probe muons

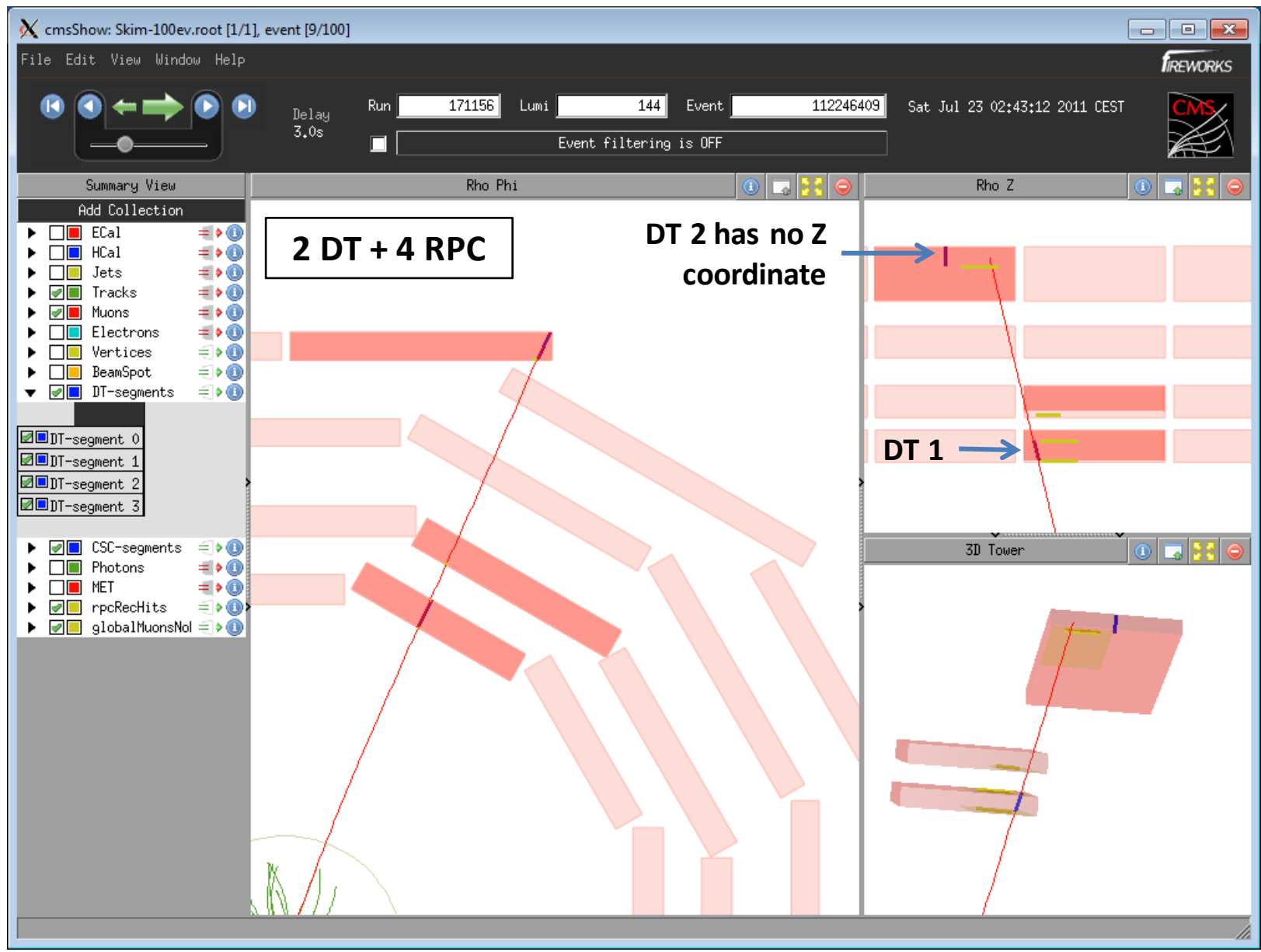
Category	DT/CSC	RPC	Features in DT/CSC	N event (%)
1	2	≥ 2	One of 2 DT segments has no z coordinate (usually MB4), which causes matching failure between 2 segments	~14 %
2	2	≥ 2	2 DT (or CSC) segments are not well matched	~34 %
3	1	≥ 1	Usually in crack regions between sectors and/or wheels	~52 %

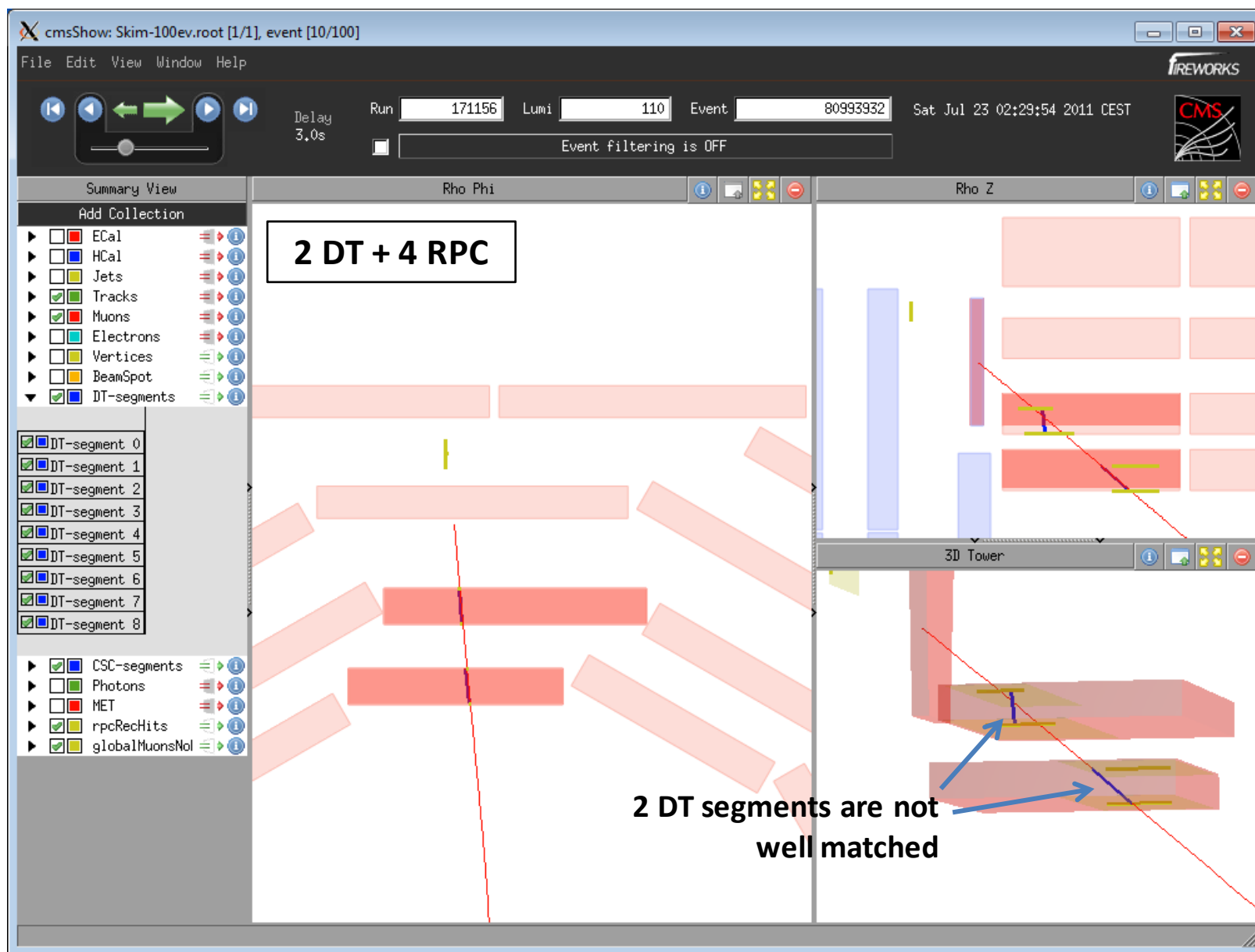
*scanned 100 muons with Run2011A data

■ 3 categories for the failing probe muons with ≥ 3 valid RPC hits

Category	DT/CSC	RPC	Features in DT/CSC	N event (%)
1	2	≥ 3	One of 2 DT segments has no z coordinate (usually MB4), which causes matching failure between 2 segments	~9 %
2	2	≥ 3	2 DT (or CSC) segments are not well matched	~28 %
3	1	≥ 3	Usually in crack regions between sectors and/or wheels	~63 %

*scanned 100 muons with Run2011A data





The screenshot displays the cmsShow event viewer interface for event 99678234. The top status bar shows Run 171156, Lumi 130, and Event 99678234. The interface is divided into several panels:

- Summary View:** A tree view on the left showing detector components. Under "DT-segments", segments 0 through 4 are listed. Under "rpcRecHits", there are 3 hits. Other components like ECal, HCal, Jets, Tracks, Muons, Electrons, Vertices, BeamSpot, CSC-segments, Photons, MET, and globalMuonsMol are also visible.
- Rho Phi View:** Shows the detector geometry in the Rho-Phi plane. A box labeled "1 DT + 3 RPC" points to a specific region. A blue arrow points to a single red segment labeled "Only 1 DT".
- Rho Z View:** Shows the detector geometry in the Rho-Z plane, highlighting the vertical structure of the detector.
- 3D Tower View:** Shows a 3D perspective of the detector tower structure.

Summary

- RPC hits give a contribution in global muon reconstruction up to 3-4 % in some η region (crack region)
- Muons with 2 DT/CSC segments reach ~ 50 % among the lost muons without RPC
- The muons that are not reconstructed as global muons without RPC usually are composed of many RPC hits and many RPC stations
- Plan to extend the analysis to J/ψ resonance to cover low p_T range