

# RA4 Muon Cuts

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## 1. Proton-proton interactions

- (a) decays of heavy objects like W, Z, top, higgs, etc.,
- (b) b- and c- quark decays,
- (c) decays of hadrons composed with quarks u, d and s (mainly  $\pi$  and K),
- (d) punch-through of hadronic showers.

Often called

**Prompt muons**

**Fake muons**

## 2. Beam losses because of the limited LHC aperture (sometimes called *beam halo muons*).

## 3. Cosmic rays.

- In fact, the definitions depend on the analysis!  
(sometimes only 1.(a) are the Prompt muons)

- Need for muon identification due to the presence of fake muons!
- Goal: use cuts to decrease the **rate of the fake muons** ('fake rate')

### Track quality cuts:

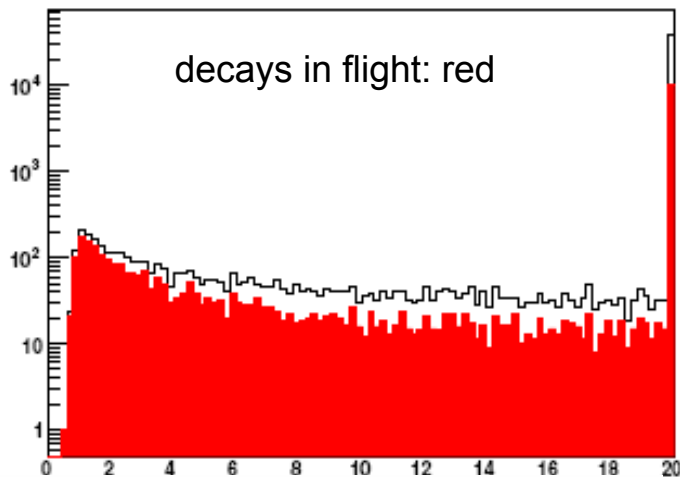
- Normalized-chi2 of the silicon fit.
- Impact parameter of the silicon or global fit.
- Number of hits of the silicon fit.

More detailed in: [CMS Trigger TDR - Chapter 8 - Muon Trigger Introduction \(15/12/2000\)](#)

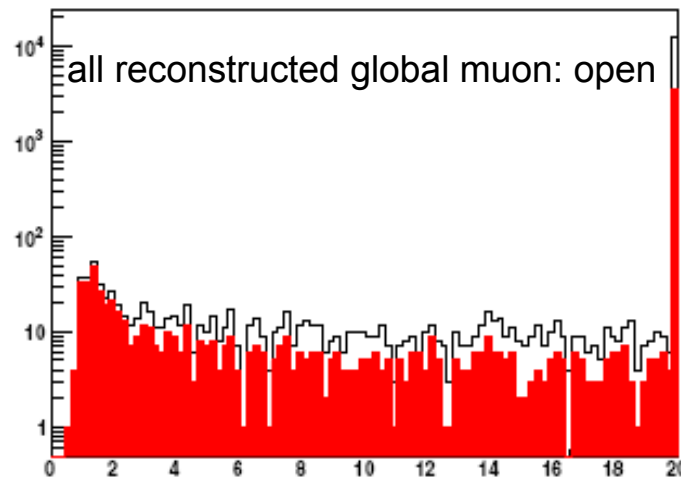


- Global muon normalized-chi<sup>2</sup> (of the track match) is a powerful tool to reject both decays in flight and punch through:

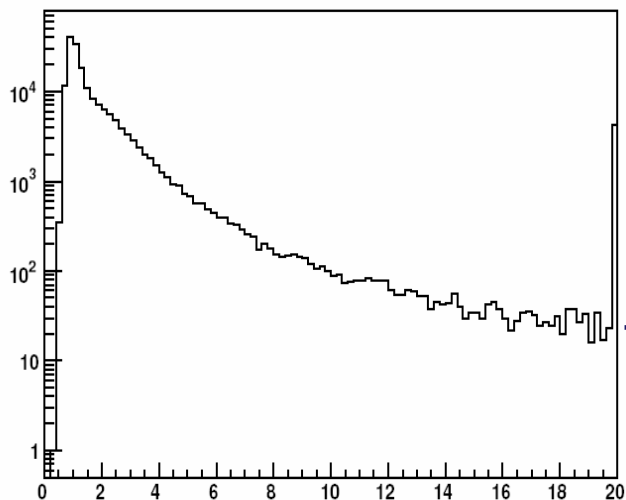
GLB Normalized Chisquared -- Kaons



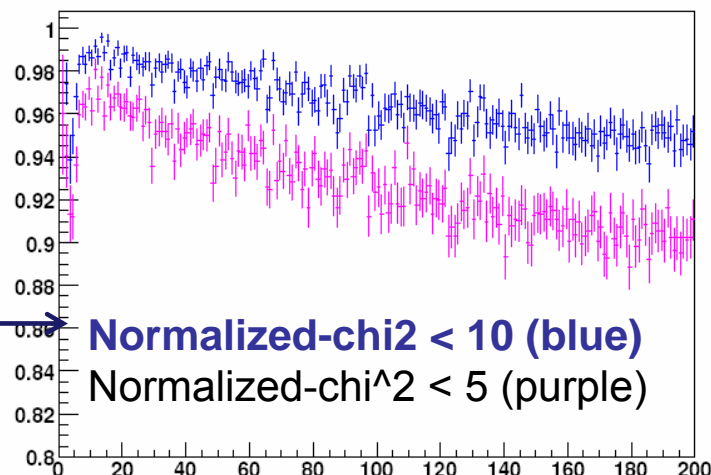
GLB Normalized Chisquared -- Pions



GLB Normalized Chisquared -- Muons



Efficiency of normalized chisquared cut

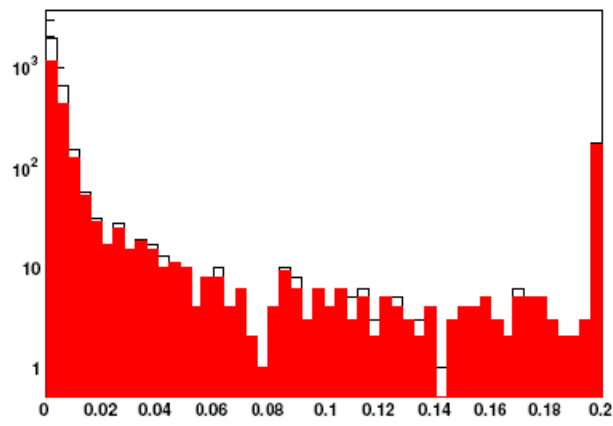


More detailed in: [Muon Identification in CMS \(03/11/2008\)](#), [Muon Reconstruction in the CMS Detector \(04/12/2008\)](#)

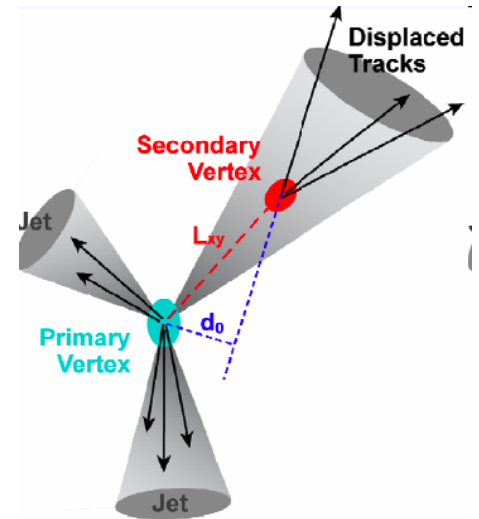
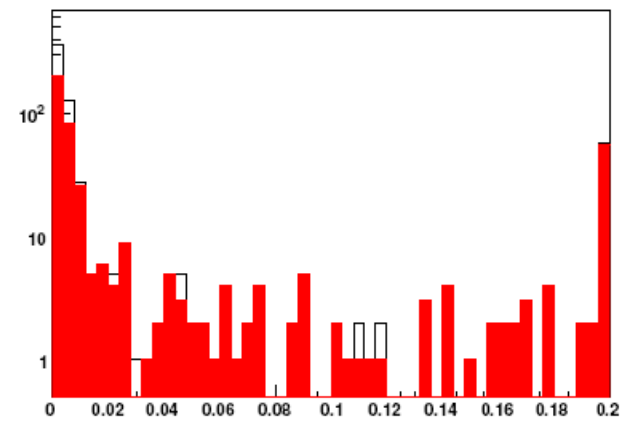


- $d_0$ , Impact parameter of the silicon fit (distance between the track and the primary vertex)

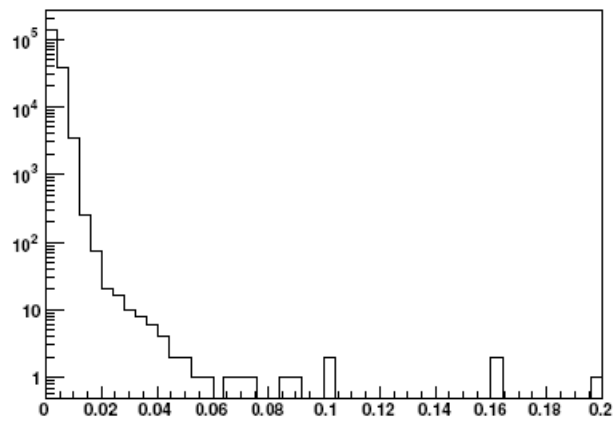
Transverse Impact parameter – kaons



Transverse Impact parameter – pions



Transverse Impact parameter – muons

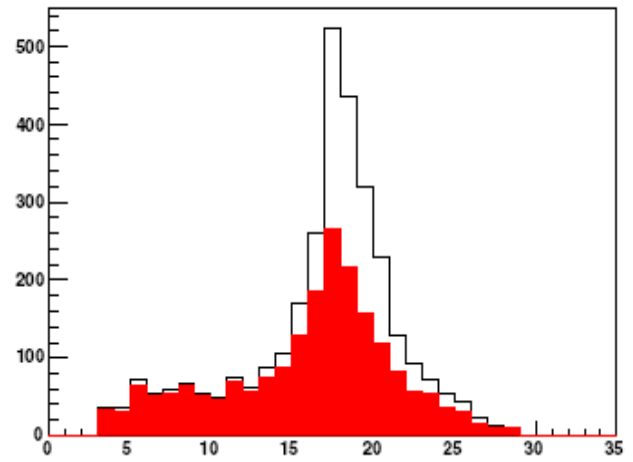


Useage of  $|d_0| < 2\text{mm}$   
 can be reject muons from b and c-quark  
 decays also!

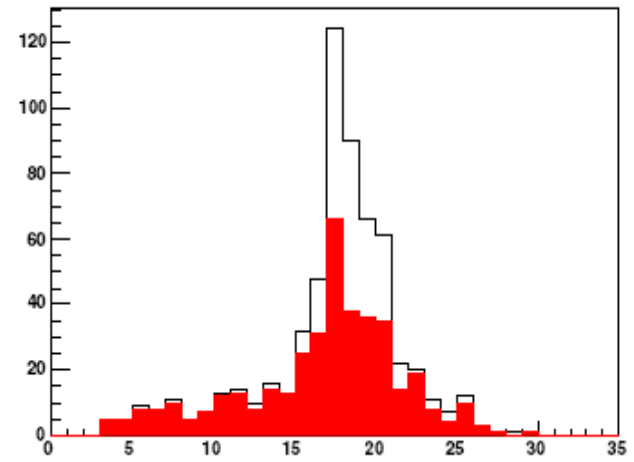
More detailed in: [Muon Identification in CMS \(03/11/2008\)](#), [Muon Reconstruction in the CMS Detector \(04/12/2008\)](#)

- The number of valid hits also has discriminating power

nhits Silicon fit - Kaons

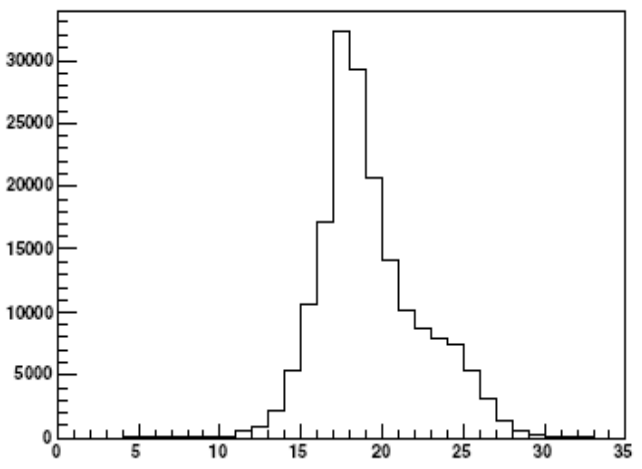


nhits Silicon fit - Pions



After apply previous cuts!

nhits Silicon fit - Muons



Use  $N\_hits > 11$  for loose cut

More detailed in: [Muon Identification in CMS \(03/11/2008\)](#), [Muon Reconstruction in the CMS Detector \(04/12/2008\)](#)



- Isolation criteria can be applied to the muon candidates to provide additional rejection
- suppress non-prompt muons from b, c,  $\pi$ , and K decays.

Three isolation techniques have been studied:

- *Calorimeter isolation*: based on the standard technique of summing the calorimeter energy in a cone around the muon. (in HCAL+ECAL)
- *Pixel isolation*: based on the partial reconstruction of tracks in the silicon pixel detector isolation is determined on the basis of the sum of the transverse momenta of the tracks in a cone around the muon.
- *Tracker isolation*:  $\Sigma$ PT of tracks reconstructed in a cone around the direction of the muon, neglecting the contribution from the muon itself.

**Commonly used cut**: let the relative isolation (or its reciprocal) above (below) a given threshold

$$(\text{Cal\_Iso} + \text{Pixel\_Iso} + \text{Tracker\_Iso}) / \text{PT}$$

More detailed in: [Technical Design Report, Volume 2: \(15/12/2002\)](#)



# RA4 Muon selection (baseline cuts)

Quantity	PAT Object and Member Function	Cut	Comment
Mu type	pat::Muon => isGood("GlobalMuonPromptTight")	GlobalMuonPromptTight	Chi <sup>2</sup> <10
p <sub>T</sub>	pat::Muon => pt()	≥ 20 GeV	
abs(eta)	pat::Muon => eta()	≤ 2.1	
Rel. Isolation	pat::Muon => hcallIso(), ecallIso(), trackIso(), pt()	< 0.1	
chi <sup>2</sup> /dof	pat::Muon => combinedMuon()->chi2(), combinedMuon() ->ndof()	< 10	
abs(d <sub>0</sub> )	pat::Muon => track()->d0 *	< 0.2 cm	
N hits	pat::Muon => track()->numvalhits()	≥ 11	
HCal Iso Deposit E	pat::Muon => hcallIsoDeposit->candEnergy()	< 6	
ECal Iso Deposit E	pat::Muon => ecallIsoDeposit->candEnergy()	< 4	

Requirement	Comment
Global normalized- $\chi^2 < 10$	Watch out for long tails in real data
$ d_0  < 2$ mm	From beamspot; could be tighter; careful about b-quarks
$N_{hits} \geq 11$	Could be made as function of $\eta$
Reject fits ending in 1st barrel station	Watch out for low $p_T$
Reject fits ending in 1st endcap station	Must wait for fix in CMSSW 2.2.0

Table 1: Summary of baseline global muon requirements. Only the first requirement is implemented in GlobalMuonPromptTight.

More detailed in: [https://twiki.cern.ch/twiki/bin/view/CMS/SusyRA4SingleMuonProjectTable#Muon\\_Selection](https://twiki.cern.ch/twiki/bin/view/CMS/SusyRA4SingleMuonProjectTable#Muon_Selection)

Quantity	PAT Object and Member Function	Cut	Comment
Mu type	pat::Muon => isGood("GlobalMuonPromptTight")	GlobalMuonPromptTight	OK
p_T	pat::Muon => pt()	≥ 20 GeV	
abs(eta)	pat::Muon => eta()	≤ 2.1	OK
Rel. Isolation	pat::Muon => caloIso(), ecalIso(), trackIso(), pt()	< 0.1	
chi^2/dof	pat::Muon => combinedMuon()->chi2(), combinedMuon()->ndof()	< 10	OK
abs(d_0)	pat::Muon => track()->d0 *	< 0.2 cm	OK
N hits	pat::Muon => track()->numvalhits()	≥ 11	OK
HCal E	pat::Muon => hcalIsoDeposit->candEnergy()	< 6	
ECal E	pat::Muon => ecalIsoDeposit->candEnergy()	< 4	

→ Improvement possible & necessary

Higher efficiency, lower fake rate

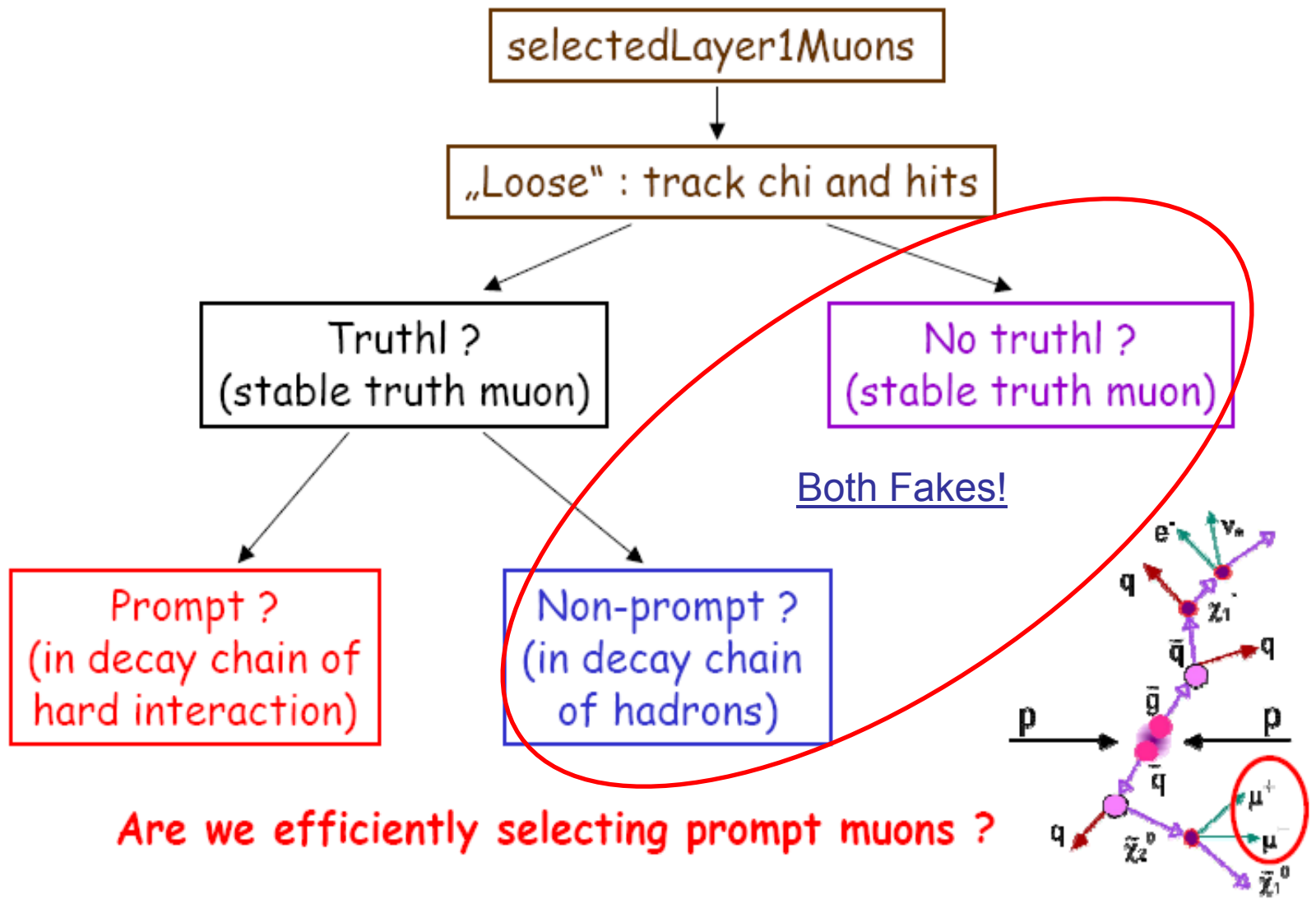
Note: relative isolation is calculated as

$$Isol = (\sum_{\Delta R < 0.3} E_T(ICAL) + \sum_{\Delta R < 0.3} E_T(HCAL) + \sum_{\Delta R < 0.3} p_T(tracker)) / p_T(\mu)$$

More detailed in: [Muon Id for RA4 – Follow up \(02/07/2009\)](#)







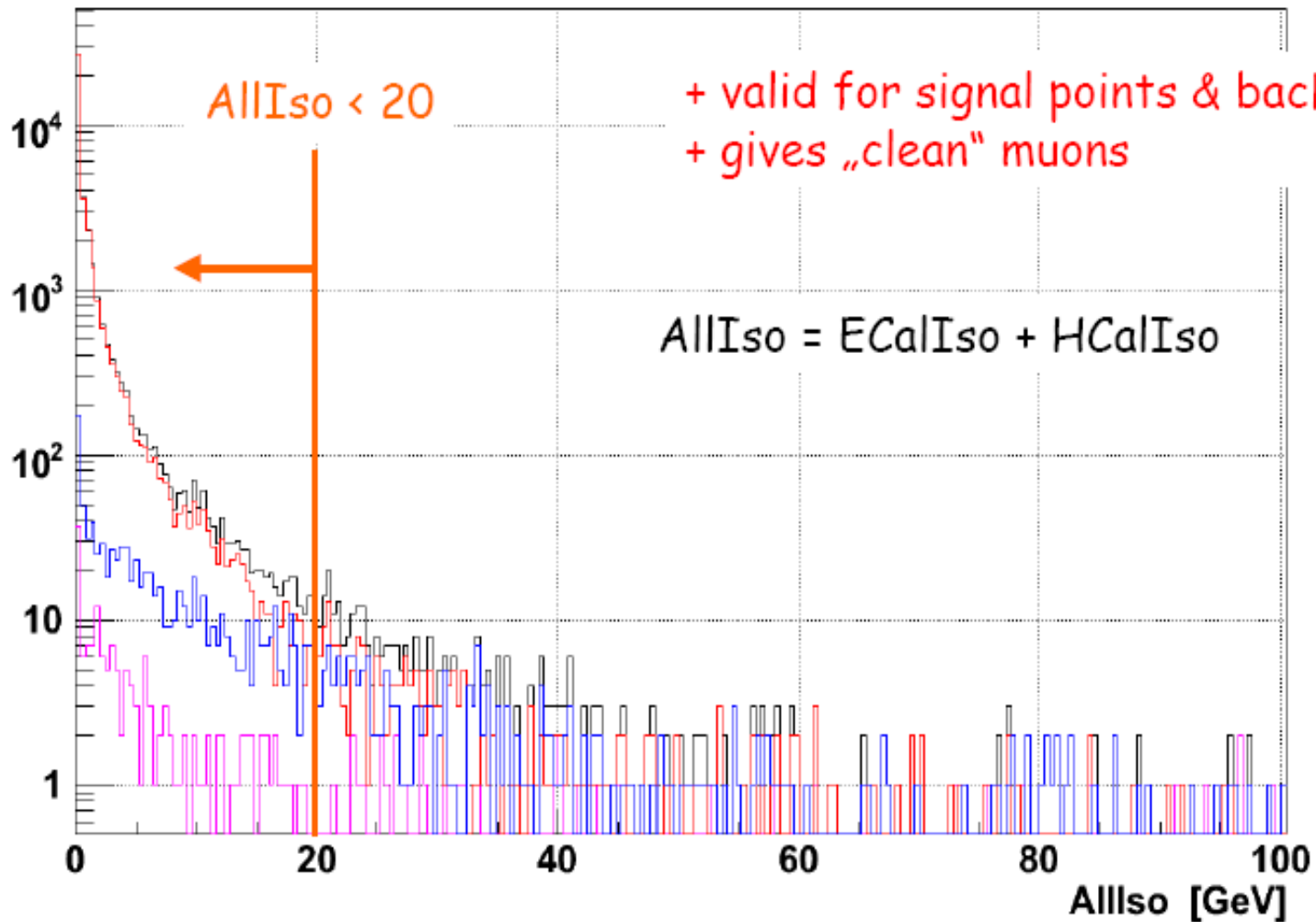
More detailed in: [Selection status report for SUSY Muon Id \(12/02/2009\)](#)



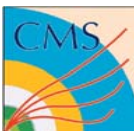
# RA4 Muon selection (baseline cuts)

Im1

All new MuonID cuts



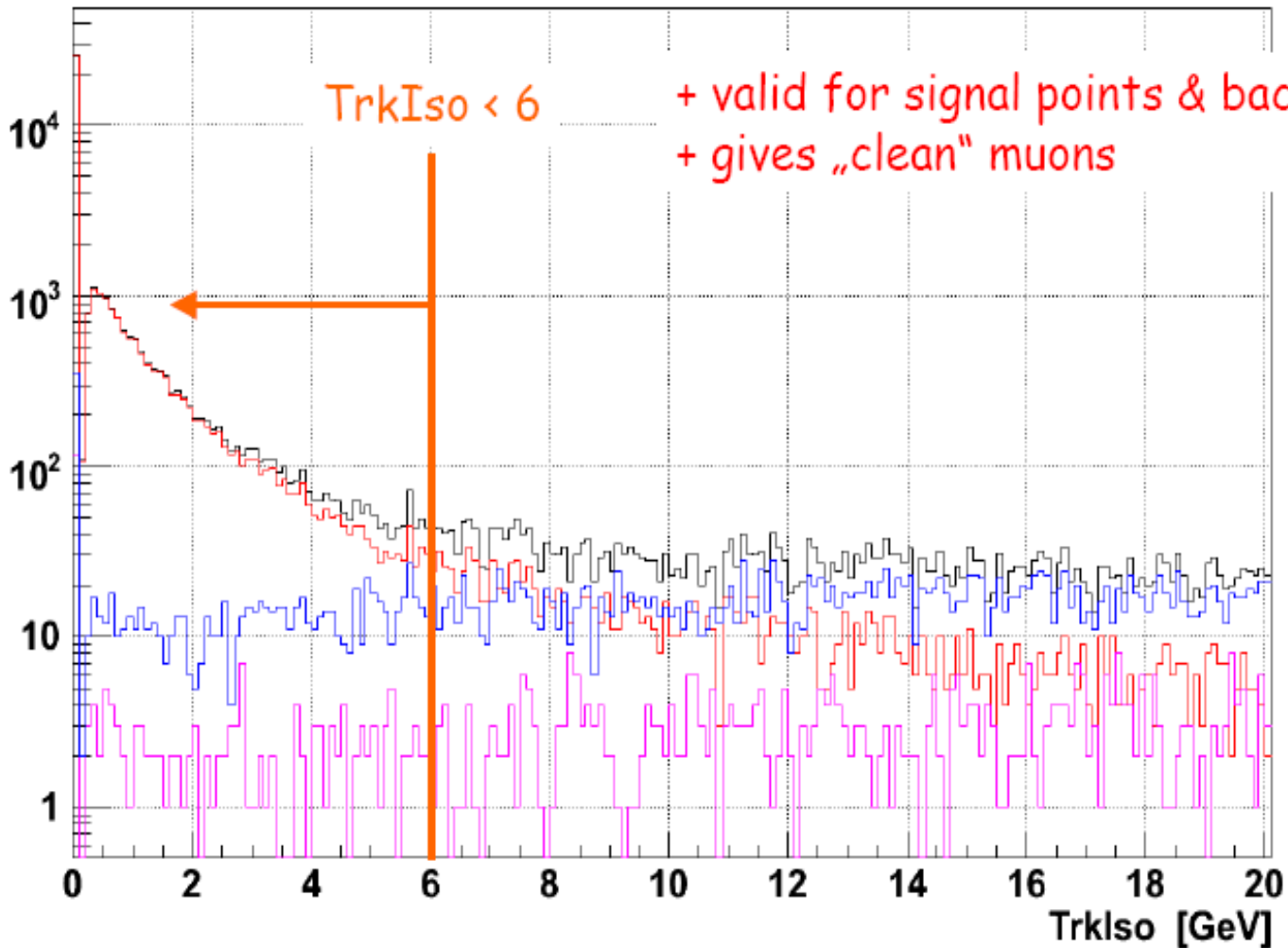
More detailed in: [Baseline Muon Id for SUSY selection \(26/02/2009\)](#)



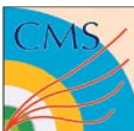
# RA4 Muon selection (baseline cuts)

Im1

All new MuonID cuts



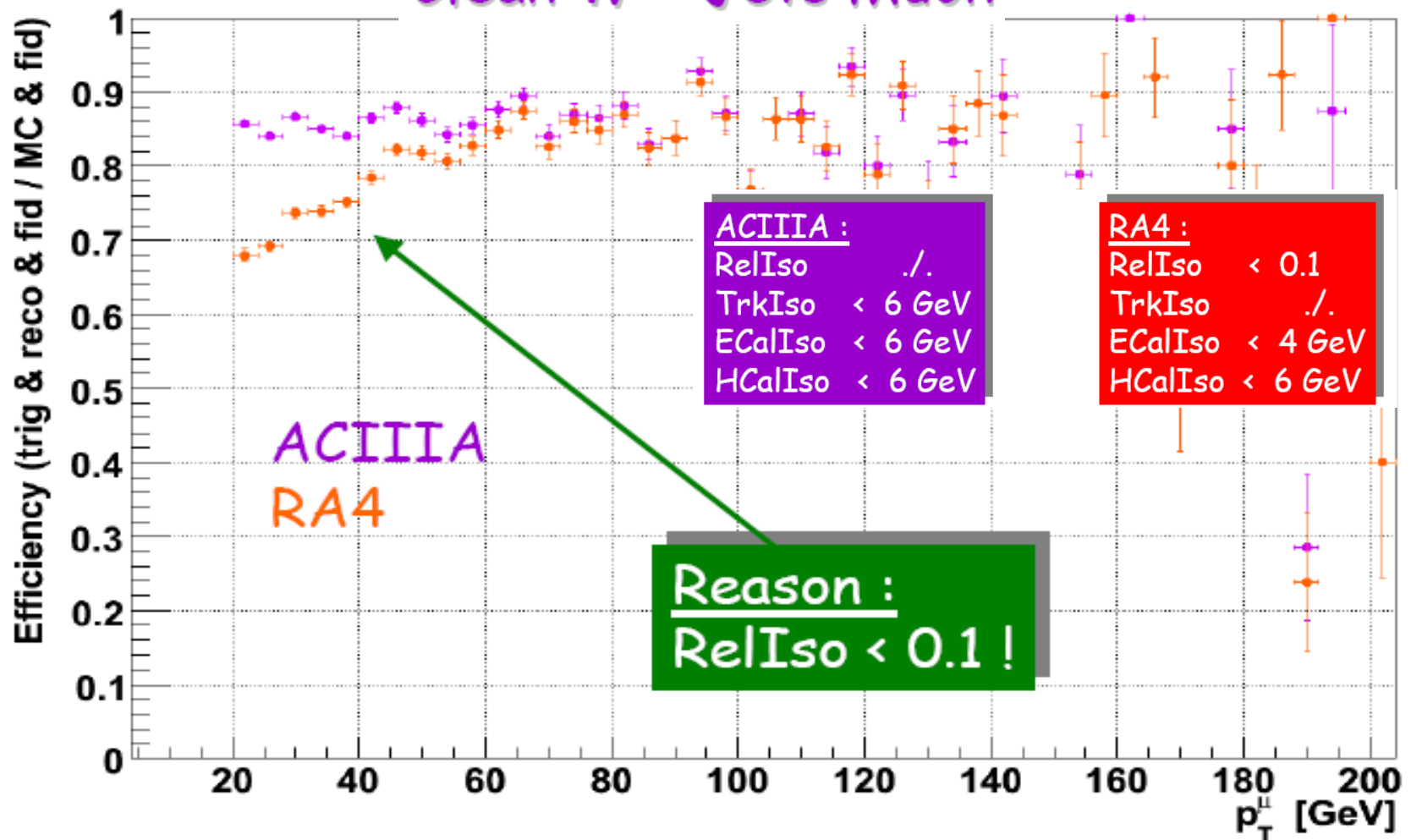
More detailed in: [Baseline Muon Id for SUSY selection \(26/02/2009\)](#)



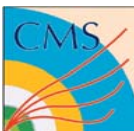
# RA4 Muon selection (baseline cuts)

wj

## Clean W + Jets Muon



More detailed in: [Study of Muon Id for RA4 \(07/05/2009\)](#)



# RA4 Muon selection (baseline cuts)

RA4 Cuts are **not optimal** for RA4/MU analysis

- efficiency not flat, small where signal sits
- difficult to invert cut, since many real muons (small pt) have rather high values of RelIso
- additional ECalIso/HCalIso cuts destroy the advantage of RelIso at high pt

ACIIIA Cuts have same efficiency & fake rate

- flat in pt, significantly higher where signal sits
- allows individual treatment of 3 types of isolation
- no problems with QCD estimation/cut inversion

More detailed in: [Study of Muon Id for RA4 \(07/05/2009\)](#)



# RA4 Muon selection (baseline cuts)

Quantity	PAT Object and Member Function	Cut	Comment
Mu type	pat::Muon => isGood("GlobalMuonPromptTight")	GlobalMuonPromptTight	OK
p_T	pat::Muon => pt()	<del>≥ 20 GeV</del> > 10 GeV	
abs(eta)	pat::Muon => eta()	≤ 2.1	OK
<del>Rel. Isolation</del>	<del>pat::Muon =&gt; isolate(), ecalIso(), trackIso(), pt()</del>	<del>&lt; 0.1</del>	
chi <sup>2</sup> /dof	pat::Muon => combinedMuon()->chi2(), combinedMuon()->ndof()	< 10	OK
abs(d_0)	pat::Muon => track()->d0 *	< 0.2 cm	OK
N hits	pat::Muon => track()->numvalhits()	≥ 11	OK
<del>HCal E</del>	<del>pat::Muon =&gt; hcalIsoDeposit &gt; sandEnergy()</del>	<del>&lt; 6</del>	
<del>ECal E</del>	<del>pat::Muon =&gt; ecalIsoDeposit &gt; sandEnergy()</del>	<del>&lt; 4</del>	

TrkIso pat::Muon->trackIso() < 6 GeV  
 ECalIso pat::Muon->ecalIso() < 6 GeV  
 HCalIso pat::Muon->hcalIso() < 6 GeV

More detailed in: [Muon Id for RA4 – Follow up \(02/07/2009\)](https://twiki.cern.ch/twiki/bin/view/CMS/SusyRA4SingleMuonProjectTable#Muon_Selection),  
[https://twiki.cern.ch/twiki/bin/view/CMS/SusyRA4SingleMuonProjectTable#Muon\\_Selection](https://twiki.cern.ch/twiki/bin/view/CMS/SusyRA4SingleMuonProjectTable#Muon_Selection)



- reconstruct the muon study (all LM samples?)
- recent problem: how to decide whether a particular reco muon has a matched MC muon or not?
- electron study for RA4
  
- expecting advices...

CMSSW/ DataFormats/ MuonReco/ src/ MuonSelectors.cc

```

...
bool muon::isGoodMuon( const reco::Muon& muon, reco::Muon::SelectionType type )
464 {
465   switch (type)
466 {
...
485     case reco::Muon::GlobalMuonPromptTight:
486       return muon.isGlobalMuon() && muon.globalTrack()->normalizedChi2() $<$ 10.;
487       break;
488     // For "Loose" algorithms we choose maximum y quantity cuts of 1E9 instead of
489     // 9999 as before. We do this because the muon methods return 999999 (note
490     // there are six 9's) when the requested information is not available. For
491     // example, if a muon fails to traverse the z measuring superlayer in a station
492     // in the DT, then all methods involving segmentY in this station return
493     // 999999 to demonstrate that the information is missing. In order to not
494     // penalize muons for missing y information in Loose algorithms where we do
495     // not care at all about y information, we raise these limits. In the
496     // TMLastStation and TMOneStation algorithms we actually use this huge number
497     // to determine whether to consider y information at all.
...

```

More detailed in: [http://cmslrx.fnal.gov/lxr/source/DataFormats/MuonReco/src/MuonSelectors.cc?v=CMSSW\\_2\\_2\\_9#485](http://cmslrx.fnal.gov/lxr/source/DataFormats/MuonReco/src/MuonSelectors.cc?v=CMSSW_2_2_9#485)