RA4 Muon Cuts

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Where the muons come from?

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 π and K),
   (d) punch-through of hadronic showers.

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

3. Cosmic rays.

Often called

Prompt muons

Fake muons

- 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')

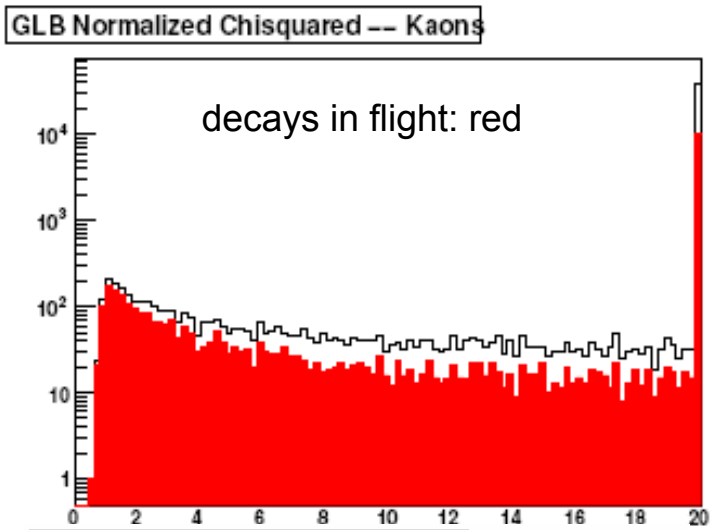
Track quality cuts:

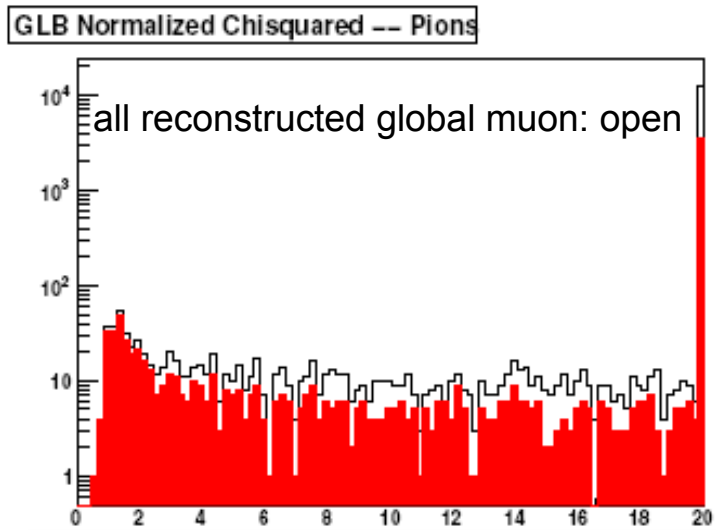
- Normalized-chi2 of the silicon fit.
- Impact parameter of the silicon or global fit.
- Number of hits of the silicon fit.

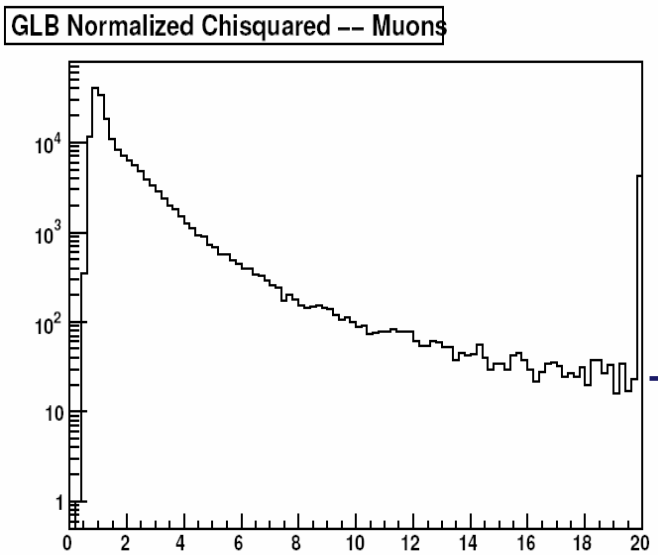
More detailed in: CMS Trigger TDR - Chapter 8 - Muon Trigger Introduction (15/12/2000)

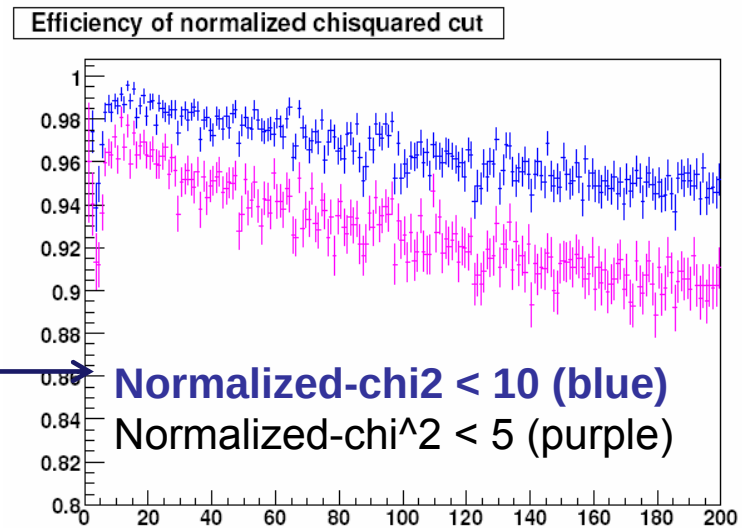
Muon ID: normalized-chi^2 cut

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





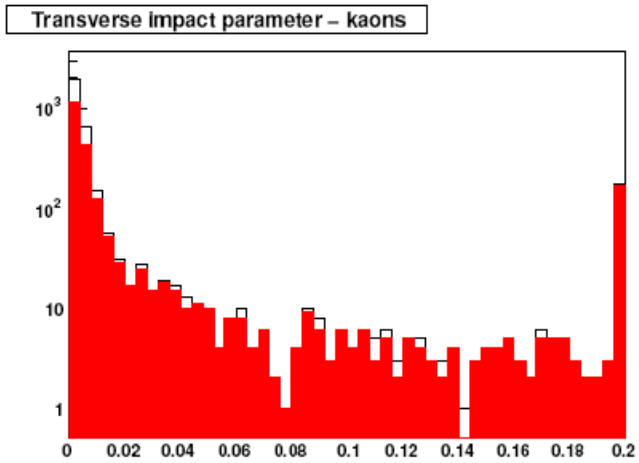


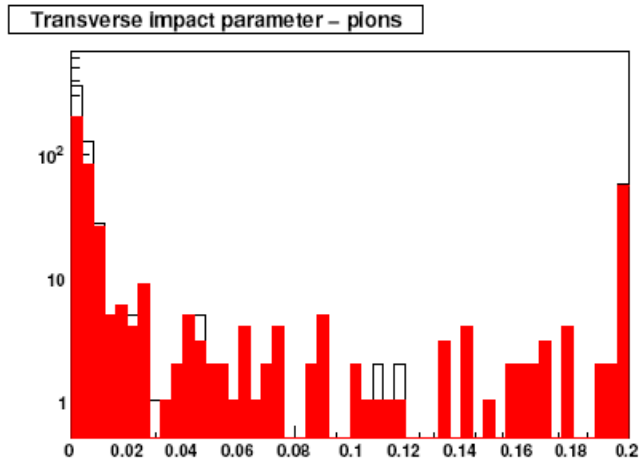


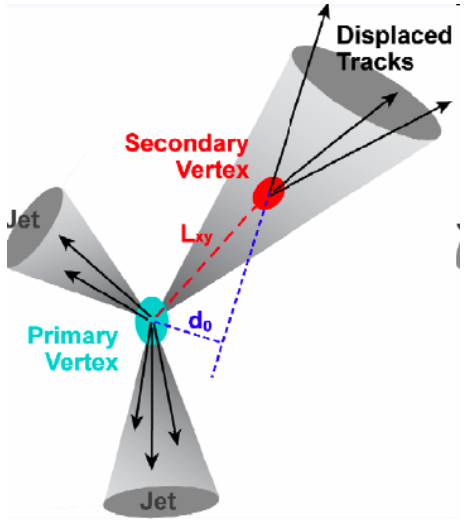
More detailed in: Muon Identification in CMS (03/11/2008), Muon Reconstruction in the CMS Detector (04/12/2008)

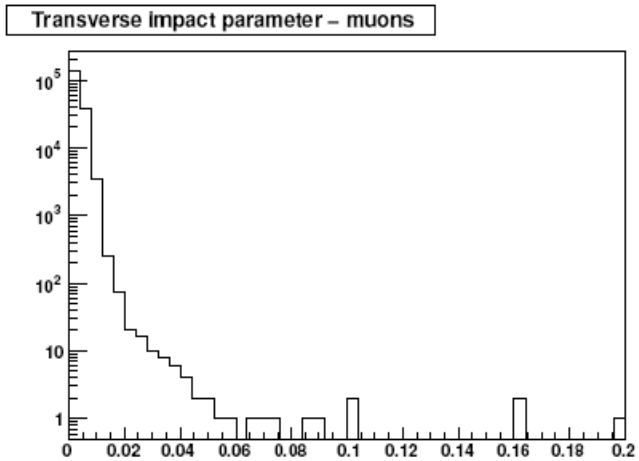
Muon ID: impact parameter

• d0, Impact parameter of the silicon fit (distance between the track and the primary vertex)









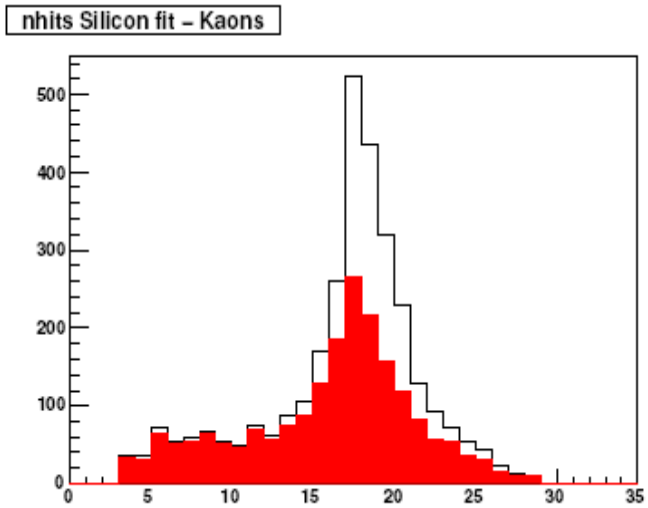
→ Useage of |d0| < 2mm

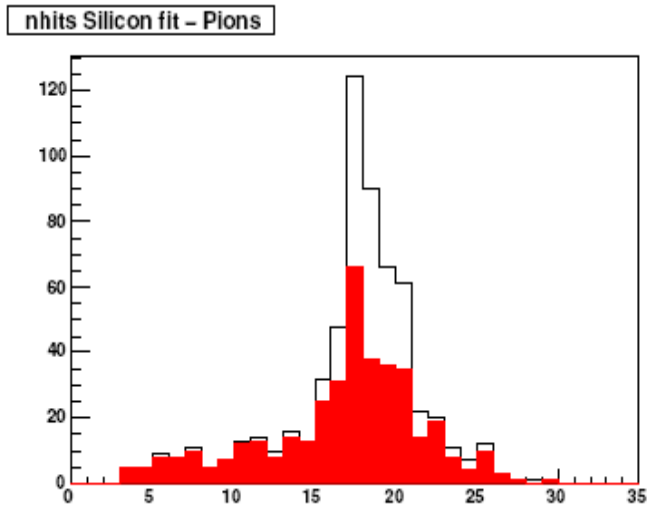
can be reject muons from b and c-quark decays also!

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

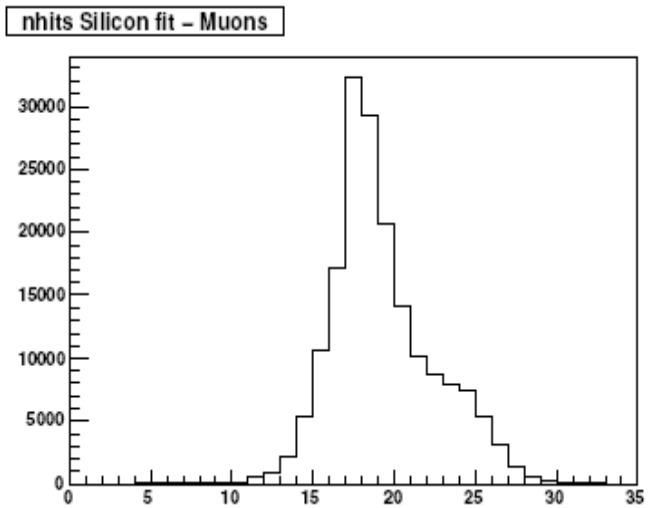
Muon ID: valid hits for the silicon fit

- The number of valid hits also has discriminating power





After apply previous cuts!



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)

Muon isolation

- Isolation criteria can be applied to the muon candidates to provide additional rejection
- suppress non-prompt muons from b, c, π, 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*: ΣPT 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

$$(Cal\_Iso+Pixel\_Iso+Tracker\_Iso)\ /PT$$

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^2<10
p_T	pat::Muon => pt()	$\geq$ 20 GeV	
abs(eta)	pat::Muon => eta()	$\leq$2.1	
Rel. Isolation	pat::Muon => hcalIso(), ecalIso(), trackIso(), pt()	< 0.1	
chi^2/dof	pat::Muon => combinedMuon()–>chi2(), combinedMuon() –>ndof()	< 10	
abs(d_0)	pat::Muon => track()–>d0 *	< 0.2 cm	
N hits	pat::Muon => track()–>numvalhits()	$\geq$ 11	
HCal Iso Deposit E	pat::Muon => hcalIsoDeposit–>candEnergy()	< 6	
ECal Iso Deposit E	pat::Muon => ecalIsoDeposit–>candEnergy()	< 4	

Requirement	Comment
Global normalized-$\chi^2 < 10$	Watch out for long tails in real data
$\lvert d_0 \rvert < 2$ mm	From beamspot; could be tighter; careful about b-quarks
$N_{hits} \geq 11$	Could be made as function of η
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

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()	≥ 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

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

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

RA4 Muon selection (baseline cuts)

selectedLayer1Muons

„Loose" : track chi and hits

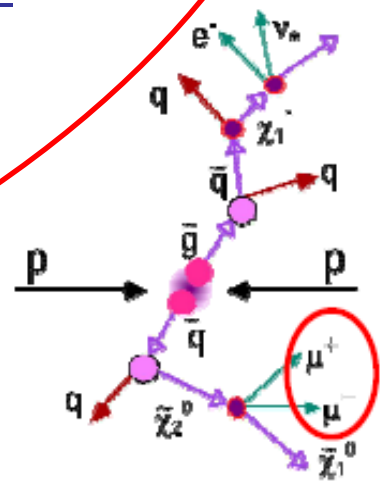
Truthl ?
(stable truth muon)

No truthl ?
(stable truth muon)

Both Fakes!

Prompt ?
(in decay chain of hard interaction)

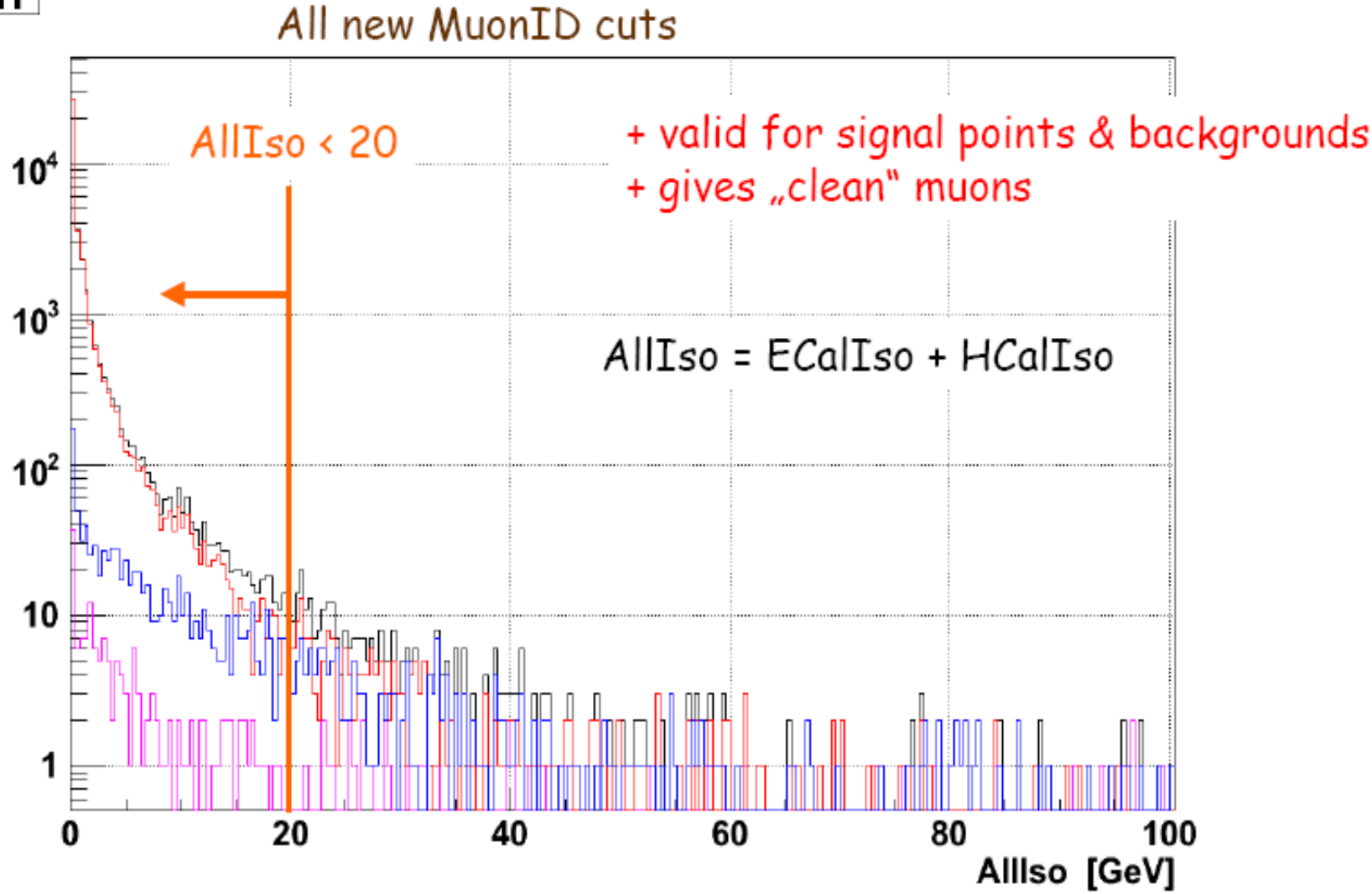
Non-prompt ?
(in decay chain of hadrons)



Are we efficiently selecting prompt muons ?

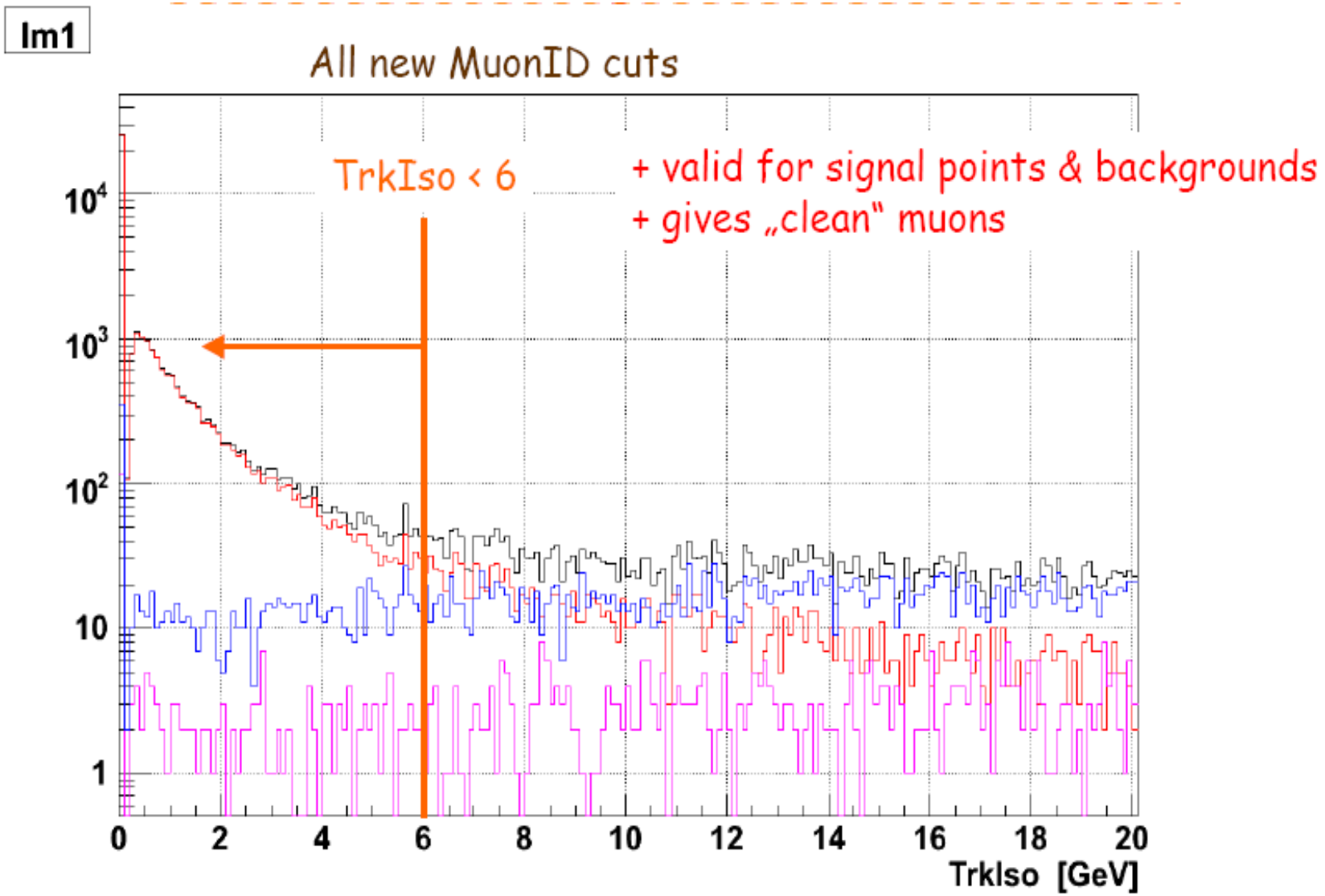
More detailed in: Selection status report for SUSY Muon Id (12/02/2009)

RA4 Muon selection (baseline cuts)



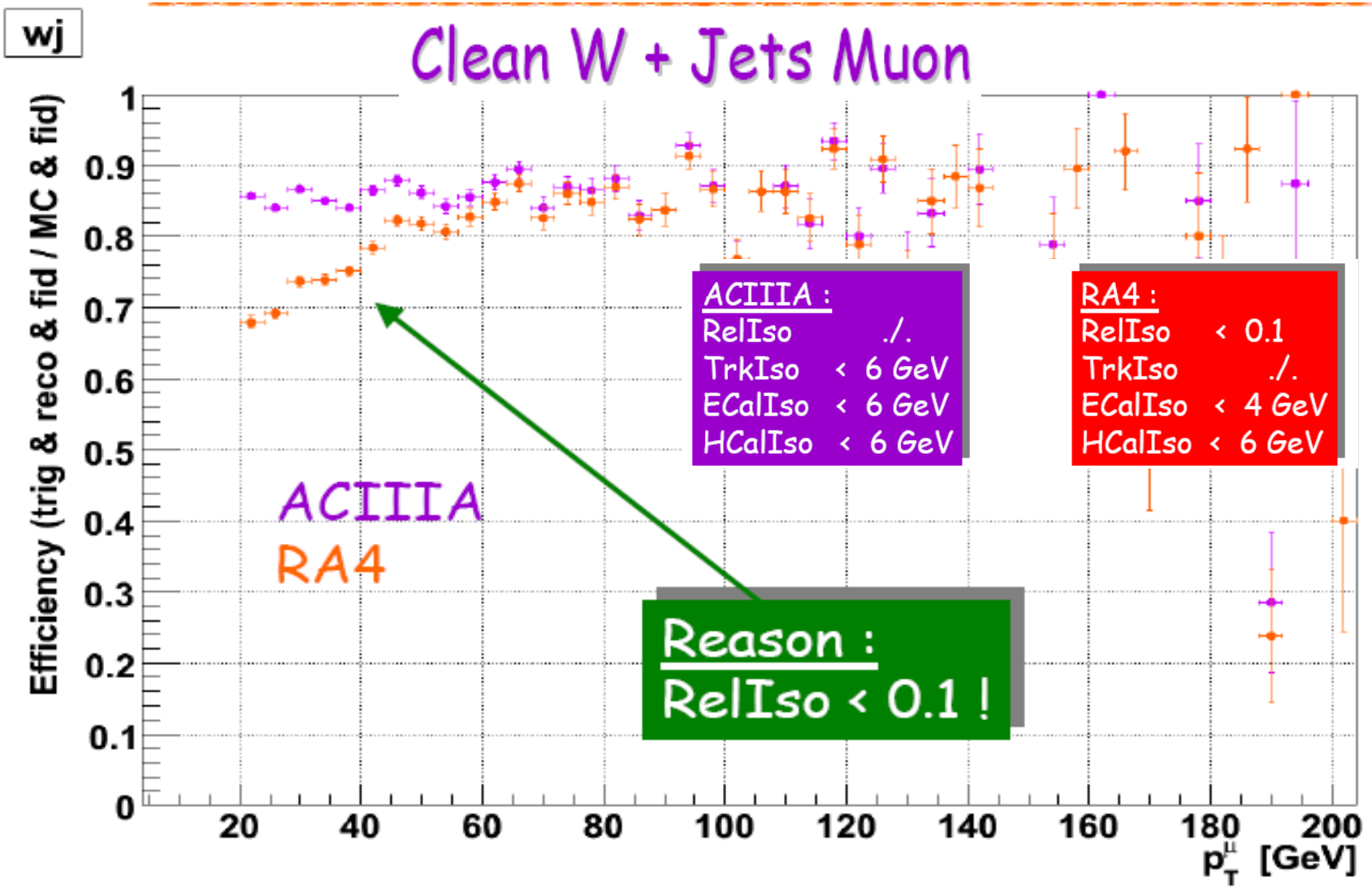
More detailed in: [Baseline Muon Id for SUSY selection (26/02/2009)]

RA4 Muon selection (baseline cuts)



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

RA4 Muon selection (baseline cuts)



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)

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Mu type	pat::Muon => isGood("GlobalMuonPromptTight")	GlobalMuonPromptTight	OK
p_T	pat::Muon => pt()	~~≥ 20 GeV~~ > 10 GeV	
abs(eta)	pat::Muon => eta()	≤ 2.1	OK
~~Rel. Isolation~~	~~pat::Muon => calolso(), 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->sandEnergy()~~	~~< 6~~	
~~ECal E~~	~~pat::Muon => ecalIsoDeposit->sandEnergy()~~	~~< 4~~	

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

TO DO

- 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…

Backup slides

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://cmslxr.fnal.gov/lxr/source/DataFormats/MuonReco/src/MuonSelectors.cc?v=CMSSW_2_2_9#485