GlobalMuon/HLT efficiency for close-by muons

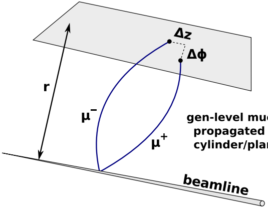
Jim Pivarski

Texas A&M University

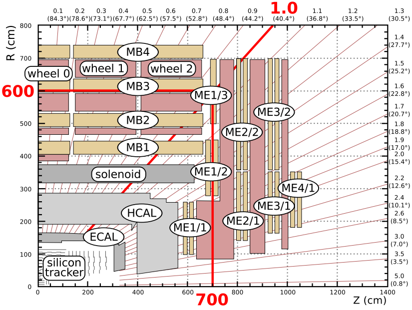
4 October, 2010

Reminder of method

- Generated a sample of dimuons with uniformly distributed mass: $2m_\mu$–50 GeV/c^2 (each dimuon has a different mass) and pair-p_T: 0–100 GeV/c
- Not a realistic physics process: the point is to find variables that quantify nearby-muon efficiency in a model-independent way
- First, detector-based variables: propagate generator-level muons to the muon system and plot efficiency as a function of
  - $\Delta\phi$ and $\Delta z/r$ on a cylinder with $r = 600$ cm
  - $\Delta\phi$ and $\Delta r/z$ on a plane with $z = 700$ cm



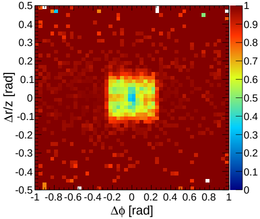
Cylinder for $|\eta| < 1$, plane for $|\eta| > 1$



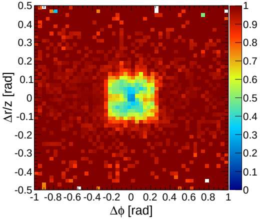
Endcap efficiency

- CMSSW_3_8_4 with ideal conditions; both muons must have $p_T > 5$ GeV$/c$ and $1 < |\eta| < 2.4$ (denominator of efficiency)
- "Quality TrackerMuons:" ≥ 2 arbitrated segments, ≥ 8 tracker hits, $\chi^2/N_{\mathrm{dof}} < 4$

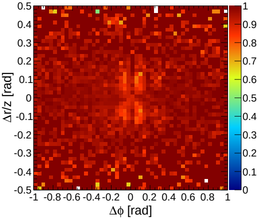
StandAloneMuons



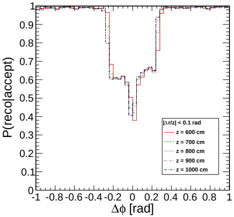
GlobalMuons



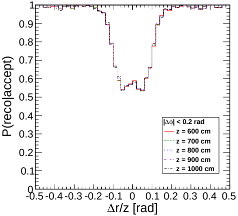
quality TrackerMuons



$\Delta\phi$ projection



$\Delta r/z$ projection

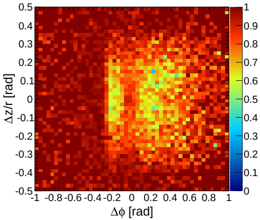


Left: two projections through the most inefficient region for StandAloneMuons

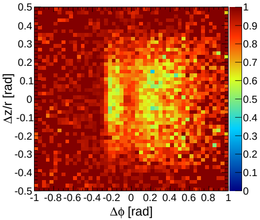
Independent of z of plane (shown here) and momentum (backup)

Barrel efficiency ($|\eta| < 1$)

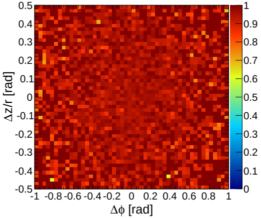
StandAloneMuons



GlobalMuons



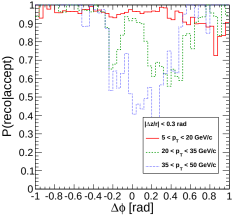
quality TrackerMuons



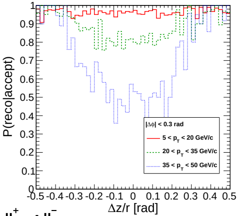
Right: two projections through the most inefficient region for StandAloneMuons

Depends strongly on momentum of muons: most inefficient for high-momentum (blue)

$\Delta\phi$ projection

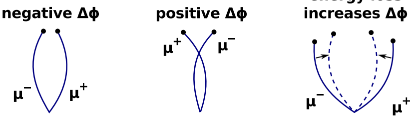


$\Delta z/r$ projection



Asymmetry from muon energy loss (always positive in $\Delta\phi$), double-trough from the two topologies

$$\Delta\phi = \phi^{\mu^+} - \phi^{\mu^-}$$

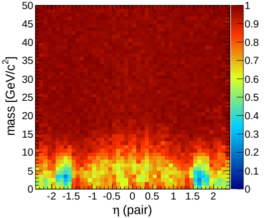


Efficiency vs. physics variables

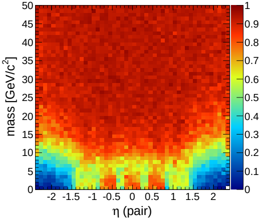
Jim Pivarski

- How does reconstruction/trigger efficiency depend on kinematics?
- Important question because we want to be sensitive to a wide range of kinematics ("mass ~ 1 GeV/c^2" with any integer spin, momenta)

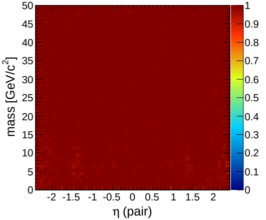
two GlobalMuons



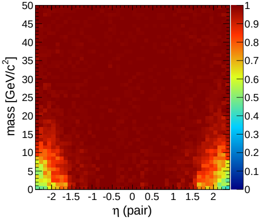
HLT_DoubleMu3



only one GlobalMuon



HLT_Mu5

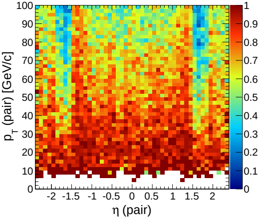


- Offline reconstruction can use $\sim$95% efficient TrackerMuons, but triggers rely on GlobalMuons
- Trigger simulation: /dev/CMSSW_3_8_1/GRun/V17
- DoubleMu triggers are inefficient in exactly the regions we need

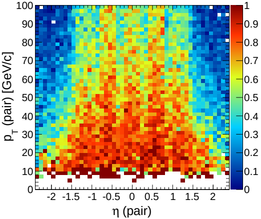
Efficiency vs. physics variables

- How does reconstruction/trigger efficiency depend on kinematics?
- Important question because we want to be sensitive to a wide range of kinematics ("mass ~ 1 GeV/c^2" with any integer spin, momenta)

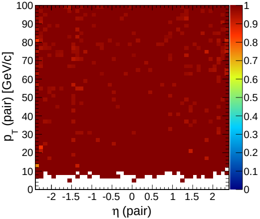
two GlobalMuons



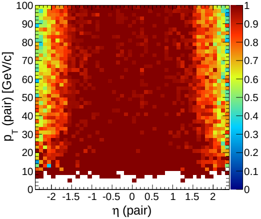
HLT_DoubleMu3



only one GlobalMuon



HLT_Mu5

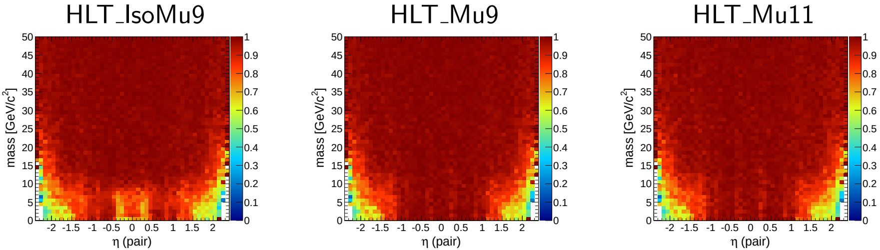


- Offline reconstruction can use $\sim$95% efficient TrackerMuons, but triggers rely on GlobalMuons
- Trigger simulation: /dev/CMSSW_3_8_1/GRun/V17
- DoubleMu triggers are inefficient in exactly the regions we need

The p_T plots have a mass $<$ 10 GeV/c^2 cut applied

Efficiency vs. physics variables

- Redefine acceptance as: two muons with $p_T > 5$ GeV/c, $|\eta| < 2.4$, *and* one muon with $p_T > 15$ GeV/c, $|\eta| < 2.1$



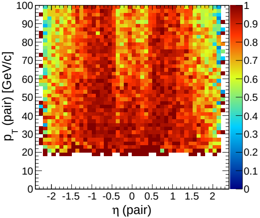
- Isolation (HLT_IsoMu9) gives us a low-mass, high-momentum inefficiency in the barrel: our signal region
- Could get ∼100% trigger efficiency by requiring the high-p_T muon to be in the barrel ($|\eta| < 1$)

Efficiency vs. physics variables

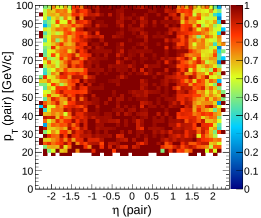
- Redefine acceptance as: two muons with $p_T > 5$ GeV/c, $|\eta| < 2.4$, *and* one muon with $p_T > 15$ GeV/c, $|\eta| < 2.1$

All of the following plots have a mass < 10 GeV/c^2 cut applied

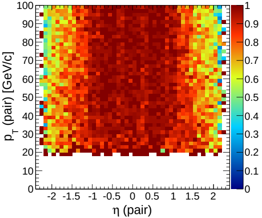
HLT_IsoMu9



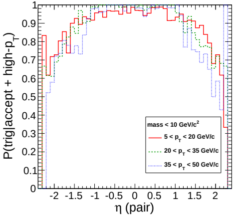
HLT_Mu9



HLT_Mu11

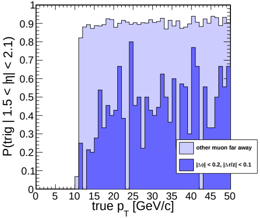


- Isolation (HLT_IsoMu9) gives us a low-mass, high-momentum inefficiency in the barrel: our signal region
- Could get $\sim$100% trigger efficiency by requiring the high-p_T muon to be in the barrel ($|\eta| < 1$)

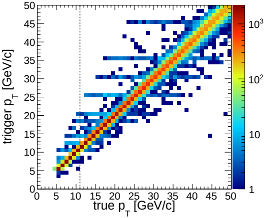


- Why do single-muon triggers fail at high η when single-GlobalMuon efficiency is good out to $|\eta| = 2.4$?
- Check trigger efficiency and p_T resolution in $1.5 < |\eta| < 2.1$, with and without requiring muons to be close to each other
  - left: turn-on curve has a lower plateau for close-by muons
  - middle and right: p_T resolution is not bad enough to bring muons below threshold, even in close-by case (right)

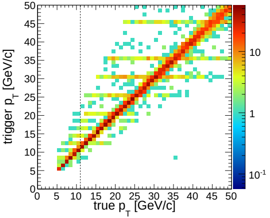
HLT_Mu11 turn-on curves ($p_{T2} < 9$ GeV/c)



p_T resolution with other muon far away



$|\Delta\phi| < 0.2$, $|\Delta r/z| < 0.1$



- Triggers are not failing because close-by muons fall below p_T threshold
- By process of elimination: they're lost at Level-1? (untested guess)

Conclusions

- Updated close-by efficiency study to recent reconstruction
  (CMSSW_3_8_4, which has trigger table /dev/CMSSW_3_8_1/GRun/V17)
- Quality TrackerMuons do have small inefficiencies for close-by muons, but still in the 90–95% range (well-controlled)
- Preferred trigger: single-muon, non-isolated (so we should anticipate a rising threshold)
- Simulated HLT has large inefficiencies starting at $|\eta| = 1$ to 1.5, beyond what is expected from requiring a single GlobalMuon: is it Level-1?
- Proposed update to cuts:
  - at least four quality TrackerMuons with $p_T > 5$ GeV/c, $|\eta| < 2.4$
  - at least one with $p_T > 15$ GeV/c, $|\eta| < 1$ $\leftarrow$ note!
  - must form at least two standard mu-jets (mass < 5 GeV/c^2)

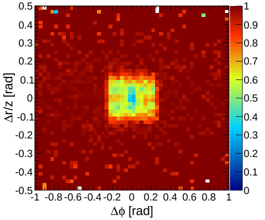
(Replaces detector-specific inefficiencies for kinematics, which would be easier for a theorist to plug into his/her simulation. . .)

BACKUP

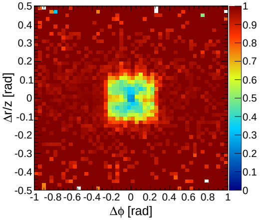
(a complete collection of plots with annotations)

- Distribution: uniform in dimuon mass (0–50 GeV/c^2), dimuon p_T (0–100 GeV/c), at the beamspot, no pileup
- Denominator: both muons $p_T > 5$ GeV/c, $1 < |\eta| < 2.4$
- Numerator: reconstructed

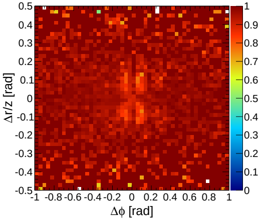
StandAloneMuons



GlobalMuons



quality TrackerMuons



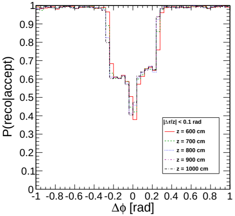
Efficiency vs. crossing (endcap)

Jim Pivarski 13/10

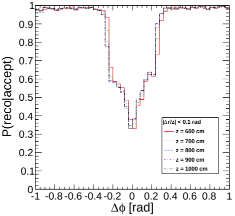
- **Denominator:** both muons $p_T > 5$ GeV/c, $1 < |\eta| < 2.4$,

  $\Delta\phi$ plots: $|\Delta r/z| < 0.1$ rad $\Delta r/z$ plots: $|\Delta\phi| < 0.2$ rad

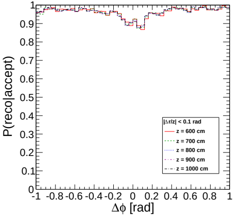
StandAloneMuons



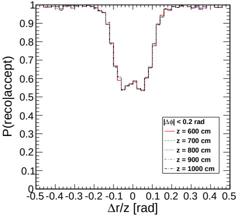
GlobalMuons



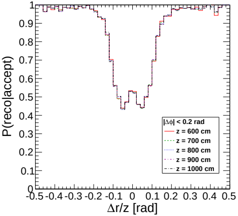
quality TrackerMuons



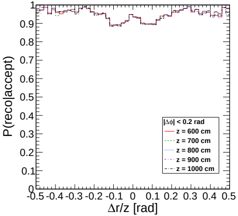
StandAloneMuons



GlobalMuons



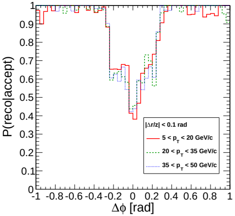
quality TrackerMuons



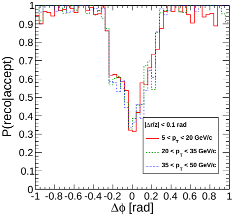
Efficiency vs. crossing (endcap)

- **Denominator:** both muons in selected p_T region, $1 < |\eta| < 2.4$,
  $\Delta\phi$ plots: $|\Delta r/z| < 0.1$ rad $\Delta r/z$ plots: $|\Delta\phi| < 0.2$ rad

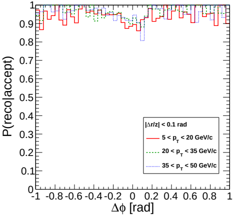
StandAloneMuons



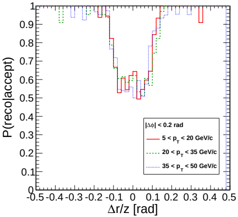
GlobalMuons



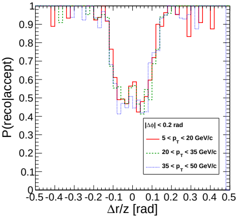
quality TrackerMuons



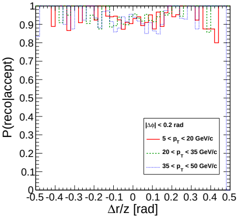
StandAloneMuons



GlobalMuons

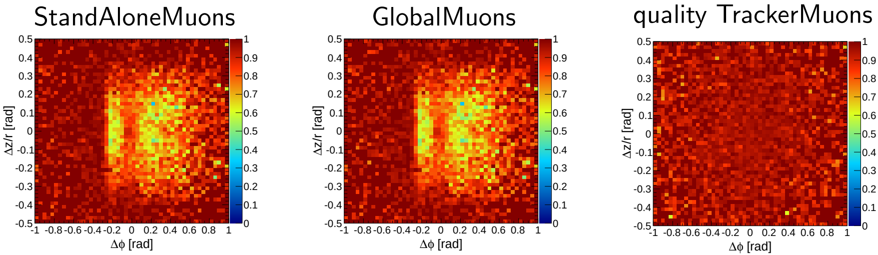


quality TrackerMuons



Efficiency vs. crossing (barrel)

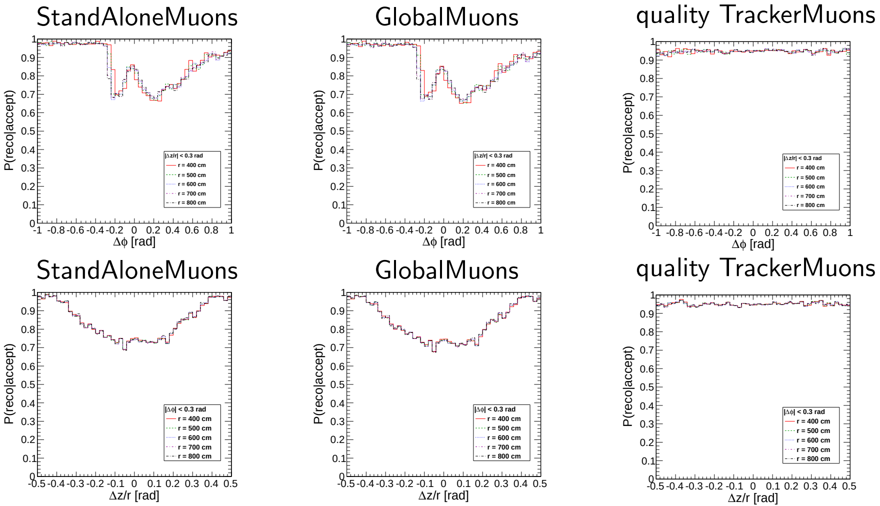
- Distribution: uniform in dimuon mass (0–50 GeV$/c^2$), dimuon p_T (0–100 GeV$/c$), at the beamspot, no pileup
- Denominator: both muons $p_T > 5$ GeV$/c$, $1 < |\eta| < 2.4$
- Numerator: reconstructed



Efficiency vs. crossing (endcap)

- Denominator: both muons $p_T > 5$ GeV$/c$, $1 < |\eta| < 2.4$,

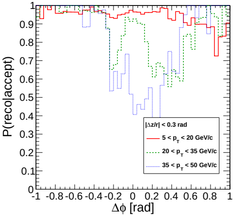
  $\Delta\phi$ plots: $|\Delta z/r| < 0.3$ rad $\quad\quad$ $\Delta z/r$ plots: $|\Delta\phi| < 0.3$ rad



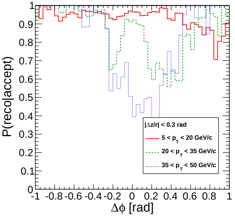
Efficiency vs. crossing (endcap)

- **Denominator:** both muons in selected p_T region, $1 < |\eta| < 2.4$,
  $\Delta\phi$ plots: $|\Delta z/r| < 0.3$ rad $\quad$ $\Delta z/r$ plots: $|\Delta\phi| < 0.3$ rad

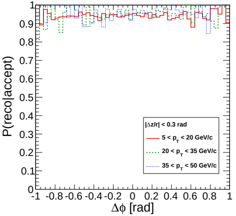
StandAloneMuons



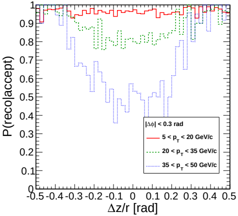
GlobalMuons



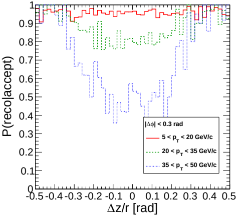
quality TrackerMuons



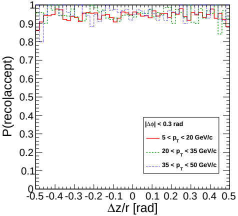
StandAloneMuons



GlobalMuons



quality TrackerMuons

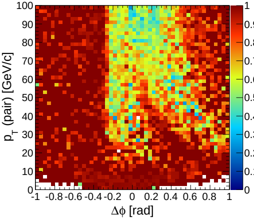


Efficiency vs. crossing and p_T

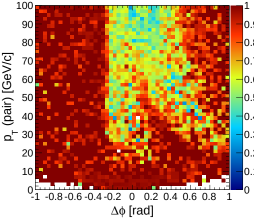
- Denominator: both muons $p_T > 5$ GeV$/c$, $1 < |\eta| < 2.4$,

barel plots: $\Delta z/r < 0.3$ rad endcap plots: $\Delta r/z < 0.1$ rad

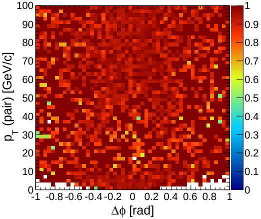
StandAloneMuons



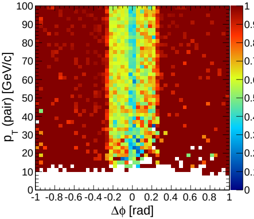
GlobalMuons



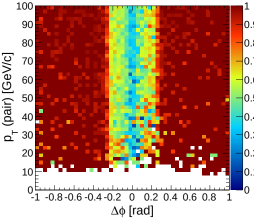
quality TrackerMuons



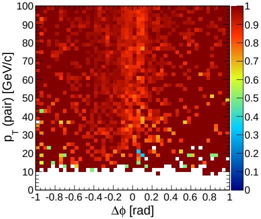
StandAloneMuons



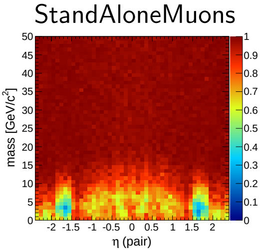
GlobalMuons

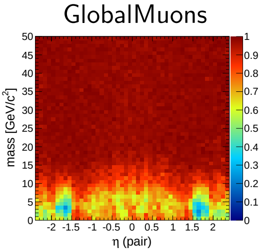


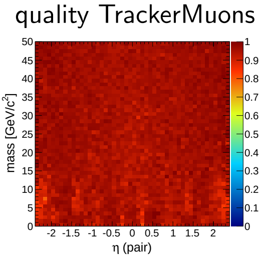
quality TrackerMuons



- **Distribution:** uniform in dimuon mass (0–50 GeV/c^2), dimuon p_T (0–100 GeV/c), at the beamspot, no pileup
- **Denominator:** both muons $p_T > 5$ GeV/c, $1 < |\eta| < 2.4$
- **Numerator:** reconstructed

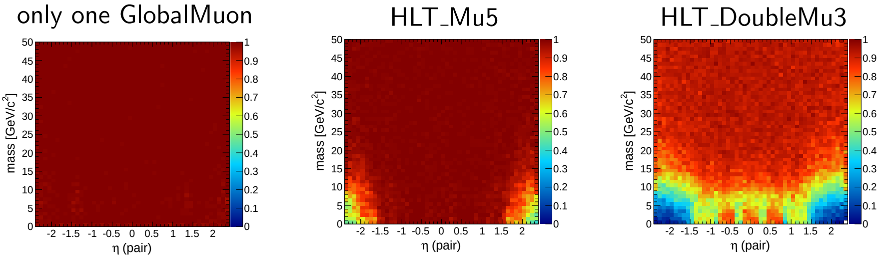






Efficiency vs. mass and η

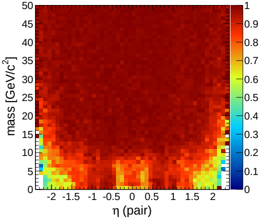
- Distribution: uniform in dimuon mass (0–50 GeV$/c^2$), dimuon p_T (0–100 GeV$/c$), at the beamspot, no pileup
- Denominator: both muons $p_T > 5$ GeV$/c$, $1 < |\eta| < 2.4$
- Numerator: reconstructed/triggered



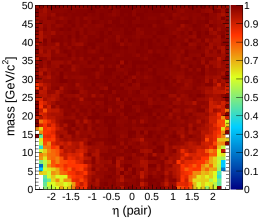
Efficiency vs. mass and η

- Distribution: uniform in dimuon mass (0–50 GeV/c^2), dimuon p_T (0–100 GeV/c), at the beamspot, no pileup
- Denominator: both muons $p_T > 5$ GeV/c, $1 < |\eta| < 2.4$, and one muon with $p_T > 15$ GeV/c, $|\eta| < 2.1$
- Numerator: triggered

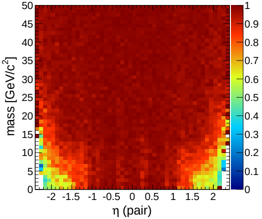
HLT_IsoMu9



HLT_Mu9

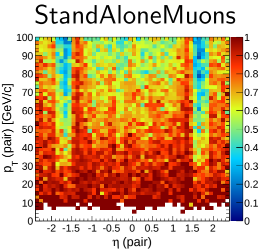


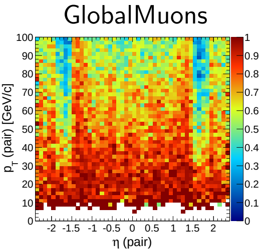
HLT_Mu11

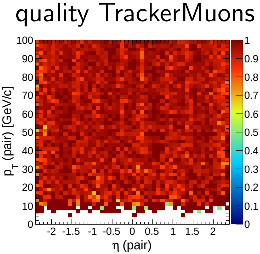


Efficiency vs. p_T and η

- Distribution: uniform in dimuon mass (0–50 GeV/c^2), dimuon p_T (0–100 GeV/c), at the beamspot, no pileup
- Denominator: both muons $p_T > 5$ GeV/c, $1 < |\eta| < 2.4$, dimuon mass < 10 GeV/c^2
- Numerator: reconstructed



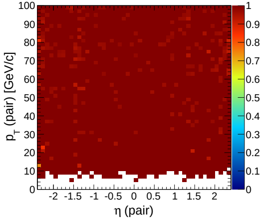




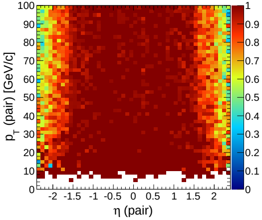
Efficiency vs. p_T and η

- Distribution: uniform in dimuon mass (0–50 GeV$/c^2$), dimuon p_T (0–100 GeV$/c$), at the beamspot, no pileup
- Denominator: both muons $p_T > 5$ GeV$/c$, $1 < |\eta| < 2.4$, dimuon mass < 10 GeV$/c^2$
- Numerator: reconstructed/triggered

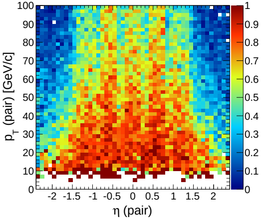
only one GlobalMuon



HLT_Mu5



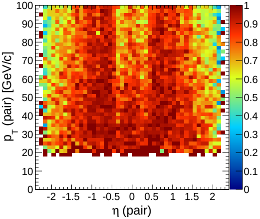
HLT_DoubleMu3



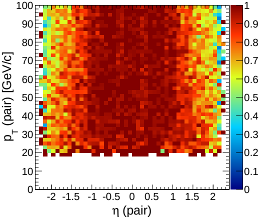
Efficiency vs. p_T and η

- Distribution: uniform in dimuon mass (0–50 GeV/c^2), dimuon p_T (0–100 GeV/c), at the beamspot, no pileup
- Denominator: both muons $p_T > 5$ GeV/c, $1 < |\eta| < 2.4$, dimuon mass < 10 GeV/c^2, and one muon with $p_T > 15$ GeV/c, $|\eta| < 2.1$
- Numerator: triggered

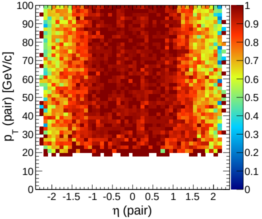
HLT_IsoMu9



HLT_Mu9



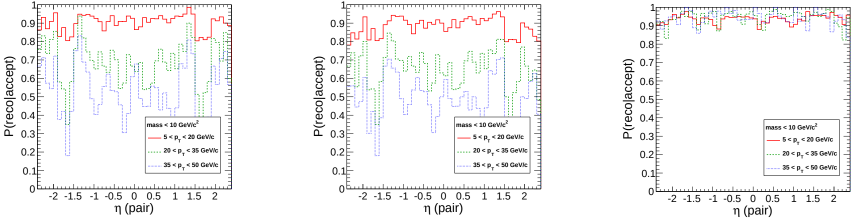
HLT_Mu11



Efficiency vs. η

- Distribution: uniform in dimuon mass (0–50 GeV$/c^2$), dimuon p_T (0–100 GeV$/c$), at the beamspot, no pileup
- Denominator: both muons $p_T > 5$ GeV$/c$, $1 < |\eta| < 2.4$, dimuon mass < 10 GeV$/c^2$
- Numerator: reconstructed

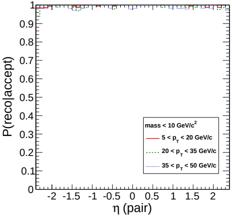
StandAloneMuons | GlobalMuons | quality TrackerMuons



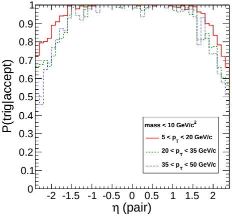
Efficiency vs. η

- Distribution: uniform in dimuon mass (0–50 GeV/c^2), dimuon p_T (0–100 GeV/c), at the beamspot, no pileup
- Denominator: both muons $p_T > 5$ GeV/c, $1 < |\eta| < 2.4$, dimuon mass < 10 GeV/c^2
- Numerator: reconstructed/triggered

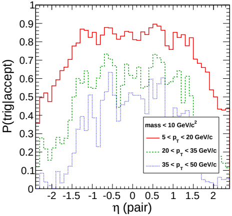
only one GlobalMuon



HLT_Mu5



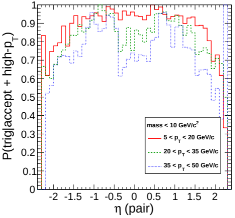
HLT_DoubleMu3



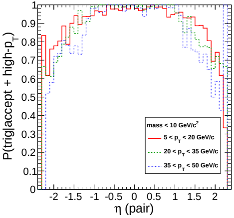
Efficiency vs. η

- Distribution: uniform in dimuon mass (0–50 GeV/c^2), dimuon p_T (0–100 GeV/c), at the beamspot, no pileup
- Denominator: both muons $p_T > 5$ GeV/c, $1 < |\eta| < 2.4$, dimuon mass < 10 GeV/c^2, and one muon with $p_T > 15$ GeV/c, $|\eta| < 2.1$
- Numerator: triggered

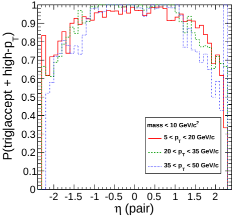
HLT_IsoMu9



HLT_Mu9



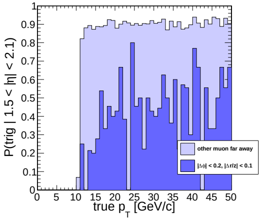
HLT_Mu11



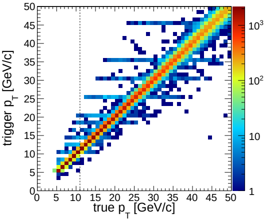
Investigating high-η inefficiency

- Distribution: only μ^+ (antimuons)
- Denominator: $1.5 < |\eta| < 2.1$, μ^- outside or inside of $|\Delta\phi| < 0.2$, $|\Delta r/z| < 0.1$ (evaluated at plane 700 cm from beamspot)
- Numerator (left plot only): HLT_Mu11 acceptance
- Resolutions: trigger p_T vs. true p_T for trigger-matched muons (matched to HLT_Mu5)

HLT_Mu11 turn-on curves ($p_{T2} < 9$ GeV/c)



p_T resolution with other muon far away



$|\Delta\phi| < 0.2$, $|\Delta r/z| < 0.1$