Beam halo filter at HLT

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Introduction

Beam halos:

- Machine induced particles flying with the beam, at large radius (up to 5m)
- Produced through beam-gas/ beam-pipe /... interactions
- Due to the beam optics, mostly produced in the LHC plane.
- High energy halo muons have a non negligible probability to interact in the calorimeters $\rightarrow$ cluster of up to several hundreds of GeV.

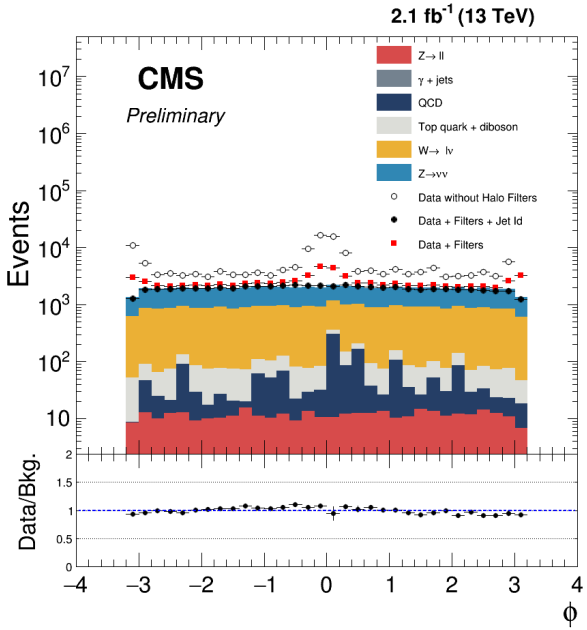
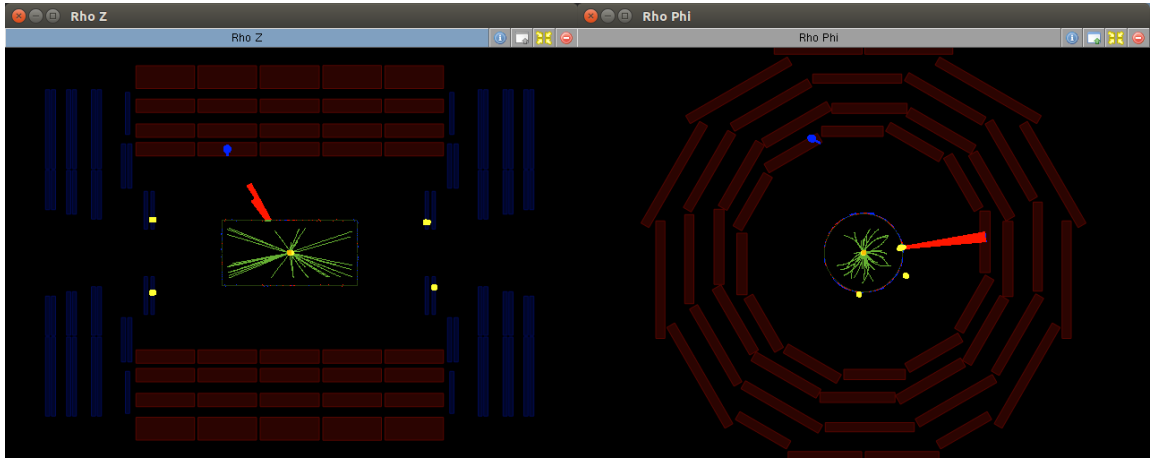
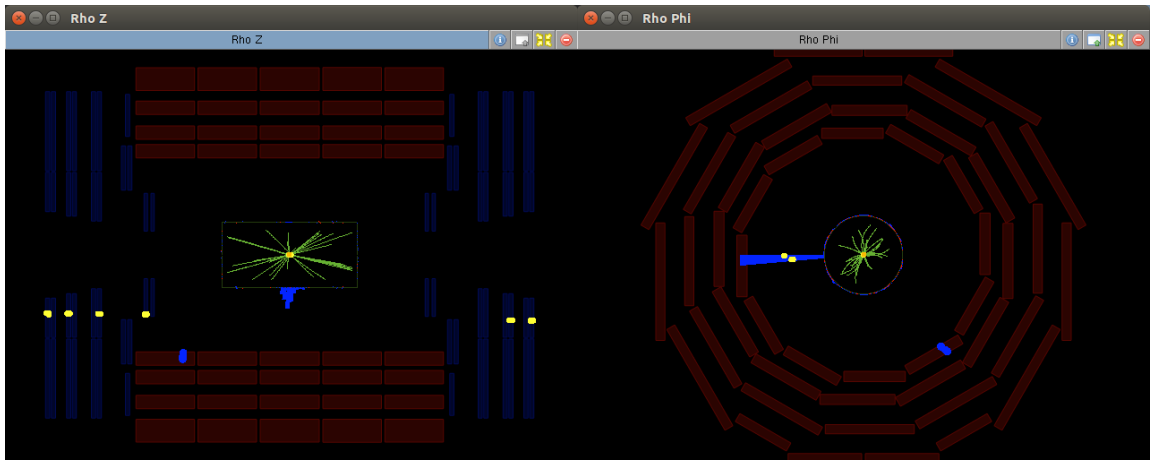


Fig: ϕ_{jet} in Single Jet + MET selection (Z. Demiragli).

Affects physics analyses (mostly Jet+MET, Photon +MET) but also trigger rates.

Typical beam halo events





Features:

- CSC track parallel to the beam axis.
- For halo from the same BX (main case): The outgoing part of track is in time
- For halo from the same BX (main case): The ingoing part is around 50 ns too early ($2 \times |z_{CSCs}|/c$)
- When the halo is interacting: single deposit (ECAL or HCAL), aligned in ϕ, R with the CSC track
- Cluster spread narrow in ϕ, spread in η
- For interacting halos from the same BX (main case): $t_{rh} < 0$

The offline CSC beam halo filter

In 2015, consists of three alternative conditions:

- Halo trigger fired and 2 flat CSC segments are matching in $\Delta\phi$,ΔR.
- 2 flat CSC segments are matching in $\Delta\phi$, ΔR, Δt in opposite endcaps.
- 1 flat CSC segment matched to a large ($>$ 10 GeV) ECAL or HCAL deposit ($\Delta\phi$, ΔR, Δt).

Current 2016 version almost ready and will contain sizeable changes:

- Halo trigger bits not available anymore.
- Focus on interacting beam halo: non negligible rate ($\approx$ 1% in 2015) of non interacting halo on top of a good collision event.
- Uses calo-CSC matching and pure calo based information (cluster shape and timing).

The trigger issue

- In 2015, MET and SinglePhoton triggers were recording a lot non collision events (90% of events recorded by HLT_PFMET_170 were beam halo or HCAL noise).
- Beam halo rate estimated to be $\approx$ 5 Hz in 2015.
- Situation even worse this year since we expect the beam halo rate to increase by a factor 4.

$\rightarrow$ Need for cleaning at trigger level.

Substantial contribution to the following paths:

- HLT_PFMETXXX_(HBHECleaned/JetIdCleaned/NoiseCleaned)
- HLT_PFHTXXX_DiPFJetAveXX_PFAlphaT0pXX
- HLT_PFMETXXX_PFMHTXXX_IDTight
- HLT_PhotonXXX
- HLT_PhotonXXX_PFMETXXX

The halo filter at trigger level

Principle: remove calo rechits associated to a halo cluster from the MET calculation / Photon reconstruction.
Code details: use the same classes as offline:

- CSCHaloAlgo (RecoMET/METAlgorithms) finds all calorechits compatible with halo hypothesis (CSC matEtching or cluster shape pattern recognition) and stores them in CSCHaloData (DataFormats/METReco)
- CSCHaloAlgo needs the following inputs: hltCsc2DRecHits,hltCscSegments, hltMuons,hltHbhereco,hltEcalRecHit,hltDt4DSegments,hltRpcRecHits
- For HLT, calotiming information dropped as it's much less accurate than at RECO level.
- The offline decision is made by the BeamHaloSummaryProducer (RecoMET/METProducers) which combines the various information stored in CSCHaloData.
- A new class, CaloRecHitsBeamHaloCleaned (not in official CMSSW yet), produces a collection of beam halo cleaned rechits that can be used at HLT or RECO.

The halo filter at trigger level (2)

Implementation in trigger menu:

- So far, only implemented for MET triggers:

  fragment.HLT_PFMET170_HBHECleaned_v2 = cms.Path(fragment.HLTBeginSequence + fragment.hltL1sL1ETM60ORETM70 + fragment.hltPrePFMET170HBHECleaned + fragment.HLTRecoMETSequence + fragment.hltMET90 + fragment.HLTHBHENoiseCleanerSequence + fragment.hltMetClean + fragment.hltMETClean80 + fragment.HLTAK4PFJetsSequence + fragment.hltPFMETProducer + fragment.HLTBeamHaloCleaningSequence + fragment.hltMetCleanBH + fragment.hltMETCleanBH80+ fragment.hltPFMET170Filter +fragment.HLTEndSequence)

  where:

  fragment.HLTBeamHaloCleaningSequence = cms.Sequence(fragment.CaloRecHitsBeamHaloCleaned + fragment.hltTowerMakerForAllBeamHaloCleaned)

- Note: the sequence needs to come after the PFMETProducer, as some of the input collections to CSCHaloAlgo are created by this producer.
- Still need to translate this to SinglePhoton paths.

Performances

Performances of the filter tested on run 260532 (good physics run).
N.B.: These numbers do not use the most recent version of the BH filter and are therefore expected to improve.

MET dataset (aka Beam Halo dataset):

- 48% of the events pass the HLT_PFMET170_HBHECleaned_v2 in CMSSW 74X (no bh cleaning)
- This ratio goes down to 16.6 % in CMSSW80X (no bh cleaning) due to the HBHECleaning update
- Further reduced to 10.6% after the bh filter
- Half of the remaining events are still not collisions: beam halo or HCAL tower noise

MuonEG dataset (collisions datasets, allows to test the filter in EM enriched environment):

- 0.1% have some hits removed by CaloRecHitsBeamHaloCleaned.

JetHT dataset (collisions datasets, allows to test the filter in high HT environment):

- 0.5% have some hits removed by CaloRecHitsBeamHaloCleaned.
- out of which 0.15% are actual beam halo events (obvious from event displays).

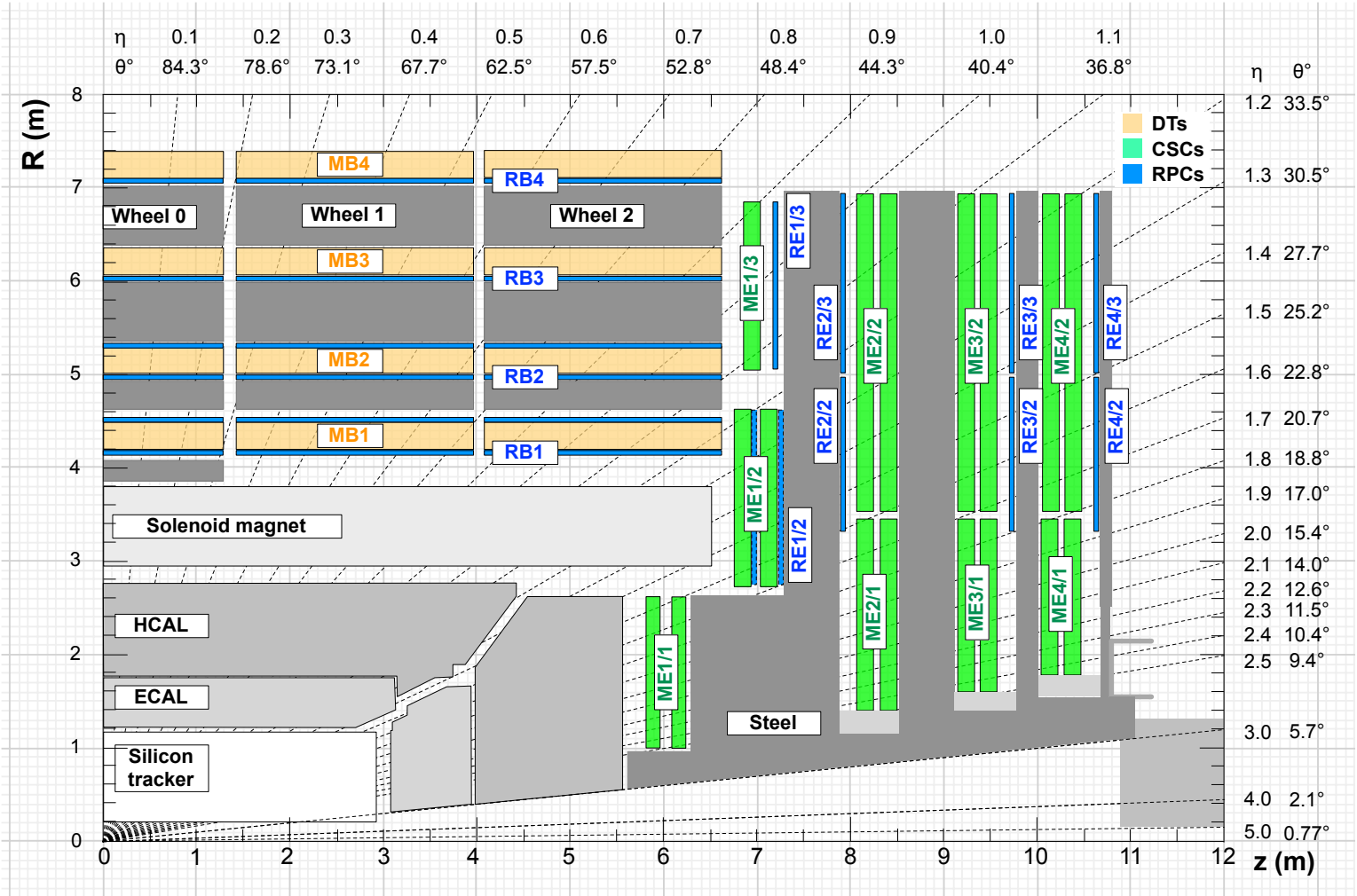
$\rightarrow$ The filter is quite efficient at finding beam halo and would lead to a rejection of fake events probably well below 0.1%.

Conclusions

- Beam halo muons interacting in the calorimeters are responsible for a significant fraction of MET/SinglePhoton rate in 2015.
- Things expected to get worse this year.
- Very specific signature that allows to kill most of them at trigger level without loss of collisions events.
- Proper cleaning of these events at HLT might actually allow the MET/Photon pt thresholds to be lowered down by a significant amount.
- Code almost finalized for MET triggers

Still to do:

- Add a sequence for Photon triggers
- Timing study (probably fine for MET triggers, things maybe worse for SinglePhoton).


η 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1
θ° 84.3° 78.6° 73.1° 67.7° 62.5° 57.5° 52.8° 48.4° 44.3° 40.4° 36.8°
η θ°
1.2 33.5°
1.3 30.5°
1.4 27.7°
1.5 25.2°
1.6 22.8°
1.7 20.7°
1.8 18.8°
1.9 17.0°
2.0 15.4°
2.1 14.0°
2.2 12.6°
2.3 11.5°
2.4 10.4°
2.5 9.4°
3.0 5.7°
4.0 2.1°
5.0 0.77°
R (m)
z (m)
DTs
CSCs
RPCs
Wheel 0
Wheel 1
Wheel 2
MB4
MB3
MB2
MB1
RB4
RB3
RB2
RB1
Solenoid magnet
HCAL
ECAL
Silicon tracker
Steel
ME1/3
ME1/2
ME1/1
ME2/2
ME2/1
ME3/2
ME3/1
ME4/2
ME4/1
RE1/3
RE2/3
RE2/2
RE1/2
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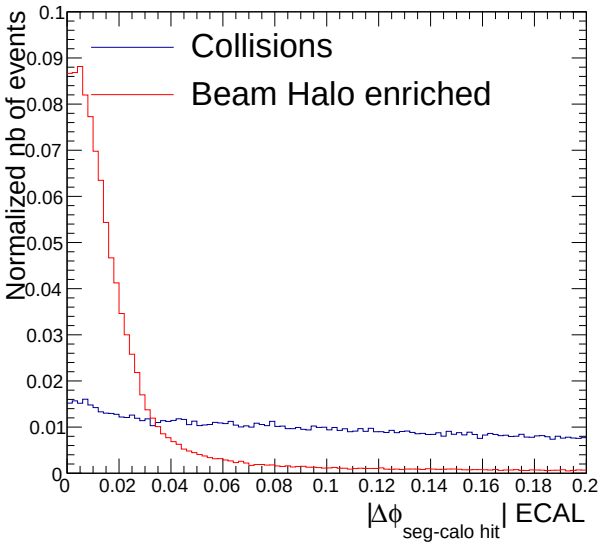
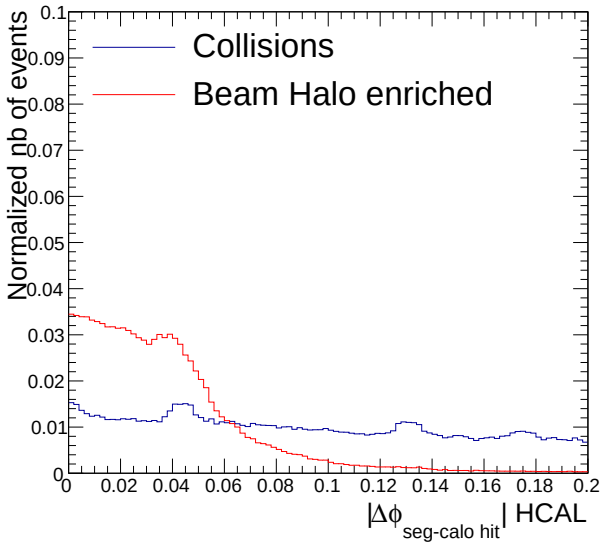
RE3/2
RE4/3
RE4/2

CSC segment - calo matching variables (1) (offline)

ECAL



HCAL

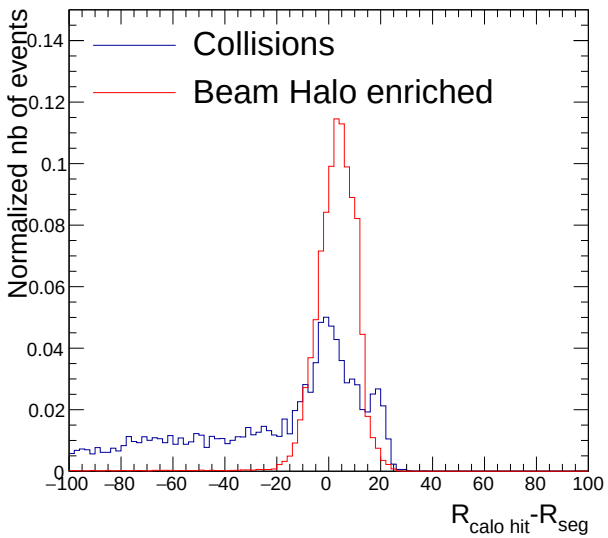


Current cuts:

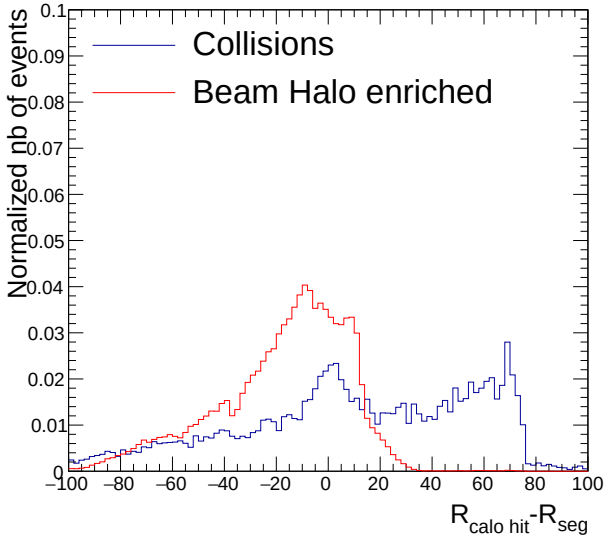
< 0.05 < 0.05

CSC segment - calo matching variables (2) (offline)

ECAL



HCAL

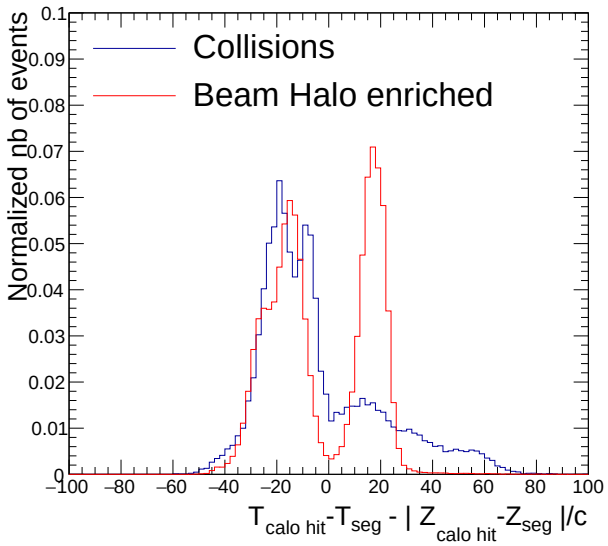


Current cuts:

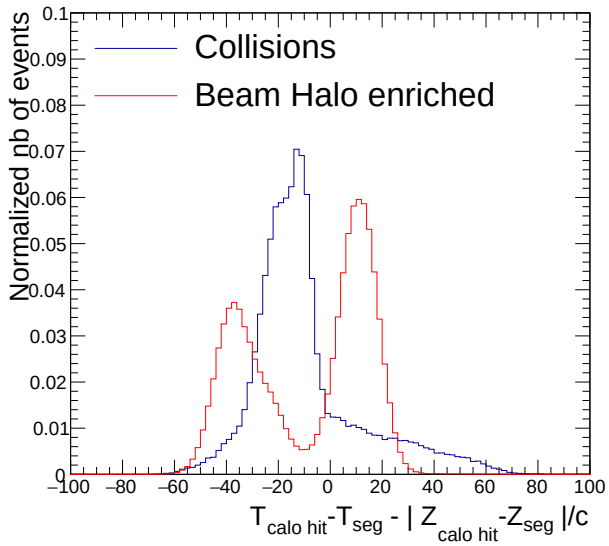
in (-20,20) in (-100,20)

CSC segment - calo matching variables (3) (offline)

ECAL



HCAL



Current cuts:

in (5,30) in (5,30)

Note: We only keep incoming halo tracks

Beam Halo and collisions comparison

The next slides show distributions obtained using MET/Run2015D-PromptReco-v4/RECO dataset.
Two exclusive regions defined:
Beam Halo enriched region:

- Calomet > 70 GeV
- At least one CSC rechit with $\Delta\phi$(CSC rh-MET)< 0.14
- $|\phi_{Calomet}| < 0.2$ or $|\phi_{Calomet}| > PI - 0.2$
- Collision muon veto
- HCAL/ECAL imbalance: $\frac{|HCAL_T - ECAL_T|}{|HCAL_T + ECAL_T|} > 0.9$
  where $HCAL_T = \sum_{HCAL\ dep} E_T$ and $ECAL_T = \sum_{ECAL\ dep} E_T$

Collisions enriched region:

- $|\phi_{Calomet}| > 0.2$ and $|\phi_{Calomet}| < PI - 0.2$
- HCAL/ECAL balance: $0.25 < \frac{|HCAL_T - ECAL_T|}{|HCAL_T + ECAL_T|} < 0.75$