ATLAS NOTE

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Use of Tracks to Reconstruct Jets in Damaged Calorimeter Regions

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Abstract

We study the use of tracks to reconstruct jets when part of the ATLAS Calorimeter is damaged. We first examine the purity and efficiency of reconstructing truth-level jets as track jets in different scenarios of calorimeter damage. We then combine information from the operational part of the calorimeter and the tracks to estimate the hadron-level momentum of jets reconstructed from tracks. Finally, we examine the effects of calorimeter damage on $E_{\mathrm{T}}^{\mathrm{miss}}$, and try to ameliorate them by using jets reconstructed from tracks. Only Monte Carlo events are used in this study.

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Contents

1 Introduction

During operation, portions of the ATLAS Calorimeter may be non-functional. For example, the readout of a Tile Calorimeter [1] module ($\Delta\phi = \frac{\pi}{32}$) or a low voltage power supply in the Liquid Argon Calorimeter [2] ($\Delta\phi = \frac{\pi}{8}$) could fail. Such a scenario would negatively impact both the reconstruction efficiency of a hadronic jet in the problematic region as well as the measurement of its momentum.

One possible solution is to identify jets by clustering tracks from the Inner Detector [3]. This has the advantage of being independent of the calorimeter. In this article we demonstrate the efficiency and purity of track jets with respect to truth jets, comparing their performance to that of calorimeter jets. We also use the track jets to estimate the hadron-level ("true") jet momentum. However, while the constituent track momenta carry information about the true jet momentum, the calorimeter is much better at measuring the total energy of the jet. This is because the Inner Detector does not record neutral particles and its p_{T} resolution deteriorates at high momentum. Consequently we combine information from both tracks and calorimeter cells to estimate the true jet momentum. The negative impact of calorimeter failures on the quality of momentum reconstruction is characterized.

We use Monte Carlo events to study two separate damage scenarios:

1. A low voltage power supply of LAr fails, creating a "blind spot" in LAr that spans $0 < \eta < 1.4$ and $\frac{\pi}{4} - \frac{\pi}{16} < \phi < \frac{\pi}{4} + \frac{\pi}{16}$ (i.e. $\Delta\phi = 22.5°$).

2. The super-drawer reading out TileCal module LBC13 fails, causing a "blind spot" that spans $-1 < \eta < 0$ and $\frac{12\pi}{32} < \phi < \frac{13\pi}{32}$ (i.e. $\Delta\phi = 5.6°$).

In Section 2 we describe the Monte Carlo datasets and the software used to simulate the effect of the defective calorimeter regions. The algorithms used to reconstruct truth jets, calorimeter jets, and track jets are discussed in Section 3; the resulting efficiency and purity are shown in Section 4. Section 5 describes a way to estimate the true jet momentum based on track jets and surviving information from the damaged calorimeter. The performance of track jets and calorimeter jets are compared in each of the aforementioned damage scenarios. Finally in Section 6 we investigate the effects of calorimeter damage on $E_{\mathrm{T}}^{\mathrm{miss}}$, and try to ameliorate them by using track jets.

2 Datasets and Software

For this study we used approximately 400K events from each of the dijet ESD datasets listed in Table 1. These were generated using Pythia 6.415.2 in Athena release 14.2.0.1 as part of the `mc08` production at $\sqrt{s} = 10$ TeV. They were simulated, digitized, and reconstructed in release 14.1.0.3 with detector geometry `ATLAS-CSC-05-01-00`.

Re-reconstruction from ESD was performed using `RecExCommon-00-09-57` (`Reconstruction/RecExample/RecExCommon`) in the AtlasProduction-14.2.20.3 cache of Athena. In addition, it was patched with updated versions `CaloRec-02-08-37` (`Calorimeter/CaloRec`) and `MissingET-03-01-19-01` (`Reconstruction/MissingET`) that contain needed fixes for cluster, jet, and $E_{\mathrm{T}}^{\mathrm{miss}}$ rebuilding. The ESD re-reconstruction was run via distributed analysis jobs on PanDA [4].

Calorimeter cells (`CaloCells`) in the defective LAr or TileCal region were assigned zero energy. Then 4-2-0 `CaloTopoClusters` were rebuilt on-the-fly from the modified `CaloCells` and calibrated using the H1 calibration scheme. Calorimeter (`Cone4H1TopoJets`) jets were rebuilt from the new topoclusters using the "standard" ATLAS fixed cone jet finder with a radius of 0.4. Lastly the $E_{\mathrm{T}}^{\mathrm{miss}}$ (`MET_RefFinal`) was rebuilt using the new clusters and jets, although it was not studied in this note.

As a consistency check of the re-reconstruction, negligibly small differences were observed between the pre-existing topoclusters stored in the ESD and those rebuilt from unmodified ESD `CaloCells`.

These minute differences were traced to the fact that the pre-existing topoclusters were built during reconstruction from the original `CaloCells` in the RDO, whereas the cluster rebuilding was performed with `CaloCells` in the ESD that have been compressed with a lossy algorithm that only stores cells above a given threshold. [5]

3 Jet Finding

3.1 Truth Jets

The truth jets considered in this study are taken from the `Cone4TruthJets` container. These were built from `TruthParticles` in the `INav4MomTruthEvent` container using the "standard" ATLAS fixed cone jet finder [6], an iterative seeded cone algorithm with seed $p_T > 1$ GeV. A radius $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$ was used along with a split-merge fraction of 0.5.

3.2 Calorimeter Jets

The calorimeter jets are taken from the `Cone4H1TopoJets` container. These jets were reconstructed using the same ATLAS cone jet finder with radius $\Delta R = 0.4$ that was used to create the truth jets above. However, these calorimeter jets were built from uncalibrated 4-2-0 `CaloTopoClusters`, whose energies were subsequently corrected according to cell energy density using the H1 global calibration [7]. Each uncalibrated 4-2-0 topocluster is seeded by a cell whose energy exceeds 4 times the cell-level noise (signal significance greater than 4); all of the seed's nearest neighbors are added; next-to-nearest neighbors with a signal significance greater than 2 are added; and finally a ring of guard cells is added as well. [8]

3.3 Track Jets

In this study we built track jets by clustering tracks using an iterative seeded cone algorithm of radius $\Delta R = 0.4$, similar to that used for truth jets and calorimeter jets. However, no split-merge was performed.

A simple preselection was imposed on tracks from the `TrackParticleCandidate` container before clustering them together. Tracks constructed exclusively from Transition Radiation Tracker (TRT) hits are assigned disingenuous pseudorapidity (η), since drift tubes in the TRT barrel are aligned longitudinally along the z axis.[1] Consequently we removed such tracks by requiring at least 4 silicon hits, which

[1] In the TRT Barrel, the assigned η is determined by the geometric center of the middle straw with respect to the reconstructed vertex. In the endcaps, the first or last straw can be used.

Dataset	p_T bin	Events used
`mc08.105009.J0_pythia_jetjet.recon.ESD.e344_s456_r456`	8-17 GeV	395K
`mc08.105010.J1_pythia_jetjet.recon.ESD.e344_s456_r456`	17-35 GeV	391K
`mc08.105011.J2_pythia_jetjet.recon.ESD.e344_s456_r456`	35-70 GeV	389K
`mc08.105012.J3_pythia_jetjet.recon.ESD.e344_s456_r456`	70-140 GeV	383K
`mc08.105013.J4_pythia_jetjet.recon.ESD.e344_s456_r456`	140-280 GeV	379K
`mc08.105014.J5_pythia_jetjet.recon.ESD.e344_s456_r456`	280-560 GeV	379K
`mc08.105015.J6_pythia_jetjet.recon.ESD.e344_s456_r456`	560-1120 GeV	380K
`mc08.105016.J7_pythia_jetjet.recon.ESD.e344_s456_r456`	1120-2240 GeV	301K

Table 1: Dijet ESD datasets listed along with p_T cut on leading two partons.

may come from either the Pixel Detector or the Silicon Central Tracker (SCT). No cuts on d_0 nor on $z_0 \sin\theta$ were imposed to remove secondaries and conversions.

The clustering of preselected tracks into track jets proceeds according to the following algorithm. First, all tracks are sorted descending by p_{T}. Tracks with $p_{\mathrm{T}} > 1$ GeV may be used as seeds. The algorithm starts from the highest-p_{T} seed available, and goes through the p_{T}-ordered list of tracks that have not yet been clustered. A track is clustered with the seed at hand if it lies within $\Delta R < 0.4$ from it and its associated reconstructed vertex is within $\Delta z < 1$ mm from the vertex of the seed. The momentum of the cluster is recalculated each time a new track is added to it, and the next track to be added must lie within $\Delta R < 0.4$ of the direction of the updated cluster momentum. Once the list of tracks is exhausted, the cluster is complete and is defined as a reconstructed track jet. The algorithm then repeats the process with the next highest p_{T} seed available, iterating until there are no seeds left. Track jets with fewer than 3 tracks or that have $\sum p_{\mathrm{T}} < 5$ GeV are discarded.

3.4 Angular Resolution

Fig. 1 demonstrates that track jets are reconstructed closer to truth jets than calorimeter jets do, namely track jets offer superior angular resolution. Fig. 2 shows the same effect, but focuses on the problematic regions (Sec. 1) to demonstrate the effect of calorimeter damage on angular resolution. The angular resolution of track jets is not affected by calorimeter damage, but that of calorimeter jet is slightly deteriorated. The deterioration is greater in the scenario of LAr damage than in the one of TileCal damage, because in the former the damaged region is larger, pushing calorimeter jets to be reconstructed farther away from the center of the damaged region where the axes of truth jets may point.

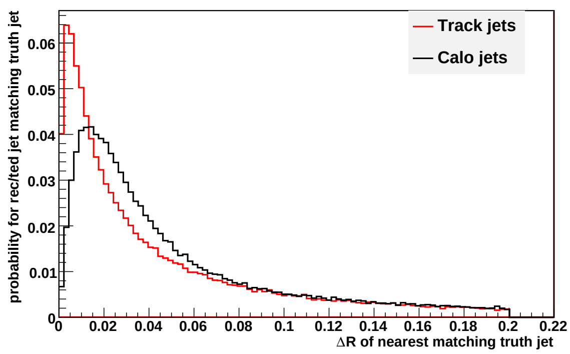
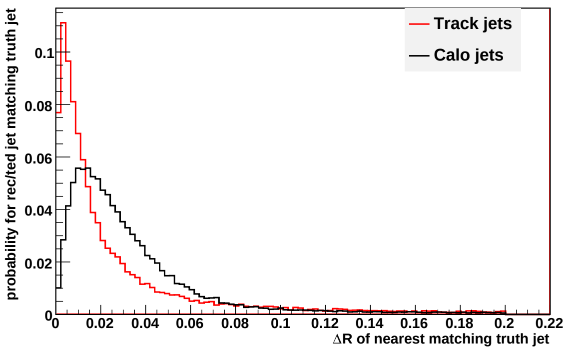


Figure 1: Probability distribution (normalized to 1) of the angular separation ΔR between a reconstructed jet and the nearest truth jet within $\Delta R < 0.2$. Both track jets (red) and calorimeter jets (black) are considered from the whole $|\eta| < 2.5$ region where tracking is possible. The calorimeter is fully functional. Calorimeter jets are required to have $p_T > 7$ GeV, and track jets $p_T > 5$ GeV from tracks (see text). The probability distribution peaks at smaller ΔR for track jets than for calorimeter jets. That means that the direction of true jets is better resolved by track jets than by calorimeter jets.



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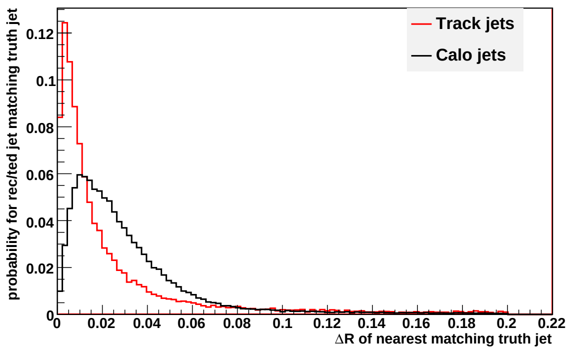

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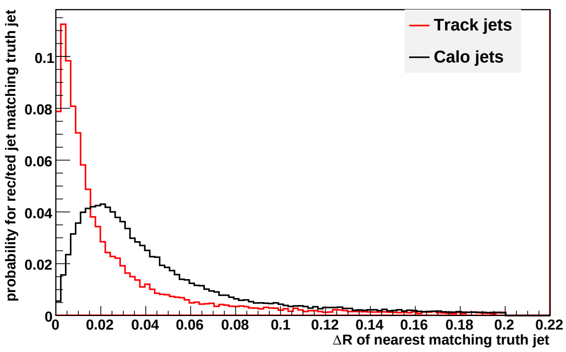

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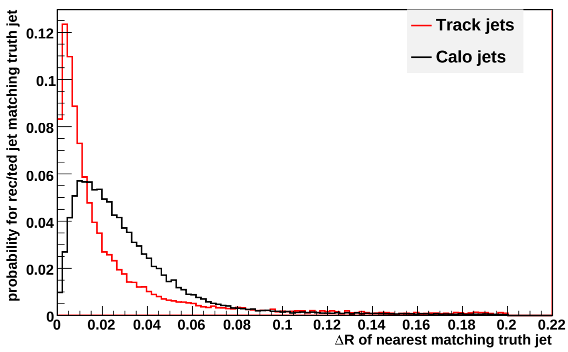


(d)

Figure 2: Same as Fig. 1, but here we isolate reconstructed jets whose axis lies within the problematic LAr Calorimeter region (2(a) and 2(c)) or TileCal region (2(b) and 2(d)) defined in Sec. 1. Fig. 2(a) and 2(b) assume fully functional calorimeter. Fig. 2(c) and 2(d) assume damaged LAr and TileCal respectively. In all cases track jets are reconstructed nearer truth jets than calorimeter jets do. Calorimeter damage does not affect the distance of track jets from truth jets, whereas calorimeter jets are pushed slightly farther away from truth jets, and their distance distribution spreads out. The effect is much more noticeable In the damaged LAr Calorimeter scenario than in the damaged TileCal one.

4 Efficiency and Purity

To assess how well track jets and calorimeter jets perform with respect to truth-level jets, we use the standard definitions of purity and efficiency:

$$\text{purity} \equiv \frac{\text{Reconstructed jets that match a truth jet}}{\text{Reconstructed jets}}, \tag{1}$$

$$\text{efficiency} \equiv \frac{\text{Truth jets matched by a reconstructed jet}}{\text{Truth jets}}, \tag{2}$$

where a reconstructed jet and a truth jet "match" if their momenta point within $\Delta R < 0.2$ of each other. Track jets are compared to calorimeter jets within the Inner Detector acceptance of $|\eta| < 2.5$.

Fig. 3 shows the purity and efficiency of track and calorimeter jets as a function of momentum p and detector η and ϕ in the case of a fully functional calorimeter. Track jets perform as well as calorimeter jets in terms of purity, while they become less efficient at $|\eta| > 1.5$.

A calorimeter failure does not affect the track jet efficiency and purity because they do not rely on the calorimeter. However calorimeter jet performance will be degraded. In the rest of this section we compare calorimeter jet efficiency and purity to those of track jets in the damage scenarios described in Section 1.

Fig. 4 shows the first scenario described in Section 1, in which a LAr low voltage power supply (LVPS) fails. In the defective region, calorimeter jets are less efficient but more pure than with the healthy detector. This is because the damage greatly lowers their reconstruction efficiency, but also somewhat reduces the likelihood of reconstructing a spurious jet. Fig. 5 shows the same scenario of a dead LAr LVPS, but where purity and efficiency are now calculated using only jets whose axis is within the damaged LAr region. Isolating the problematic region better illustrates the effect of the damage. Note that the calorimeter jet efficiency rises with increasing true jet momentum due to the larger fraction of energy deposited in TileCal behind the defective LAr region.

Fig. 6 shows the second scenario described in Section 1, in which a TileCal barrel module fails. This is a less serious case because the $\eta-\phi$ area of this Tile defect is approximately $\frac{1}{6}$ the size of the LAr damage in the previous scenario. Furthermore, TileCal records the tail-end of showers, thus providing less critical information than LAr. For these reasons the efficiency and purity of calorimeter jets in the harmed region are not affected much.

5 Jet Momentum Estimation

We would like to calibrate the momentum of the track jets that we have reconstructed in Section 3.3 to use as an estimator for the true jet momentum. An elaborate scheme analogous to H1 global calibration could be invented and tuned specifically for problematic detector regions, but this would likely be overkill in the case of a damaged calorimeter. Instead we have developed a simple calibration scheme that is tuned for local use in the damaged region. It exploits only two observables of the track jet (listed below) without any cell-level optimization.

The calibration first selects track jets centered in the problematic region that match a truth jet. We correlate the momentum of the truth jet to the following observables of the corresponding track jet:

1. The EM-scale calorimeter energy within a cone of $\Delta R < 0.4$ around the track jet's momentum.
2. The magnitude of the tracks momentum, namely $|\sum \vec{p}|$ where the summation is taken over the constituent tracks belonging to the track jet.

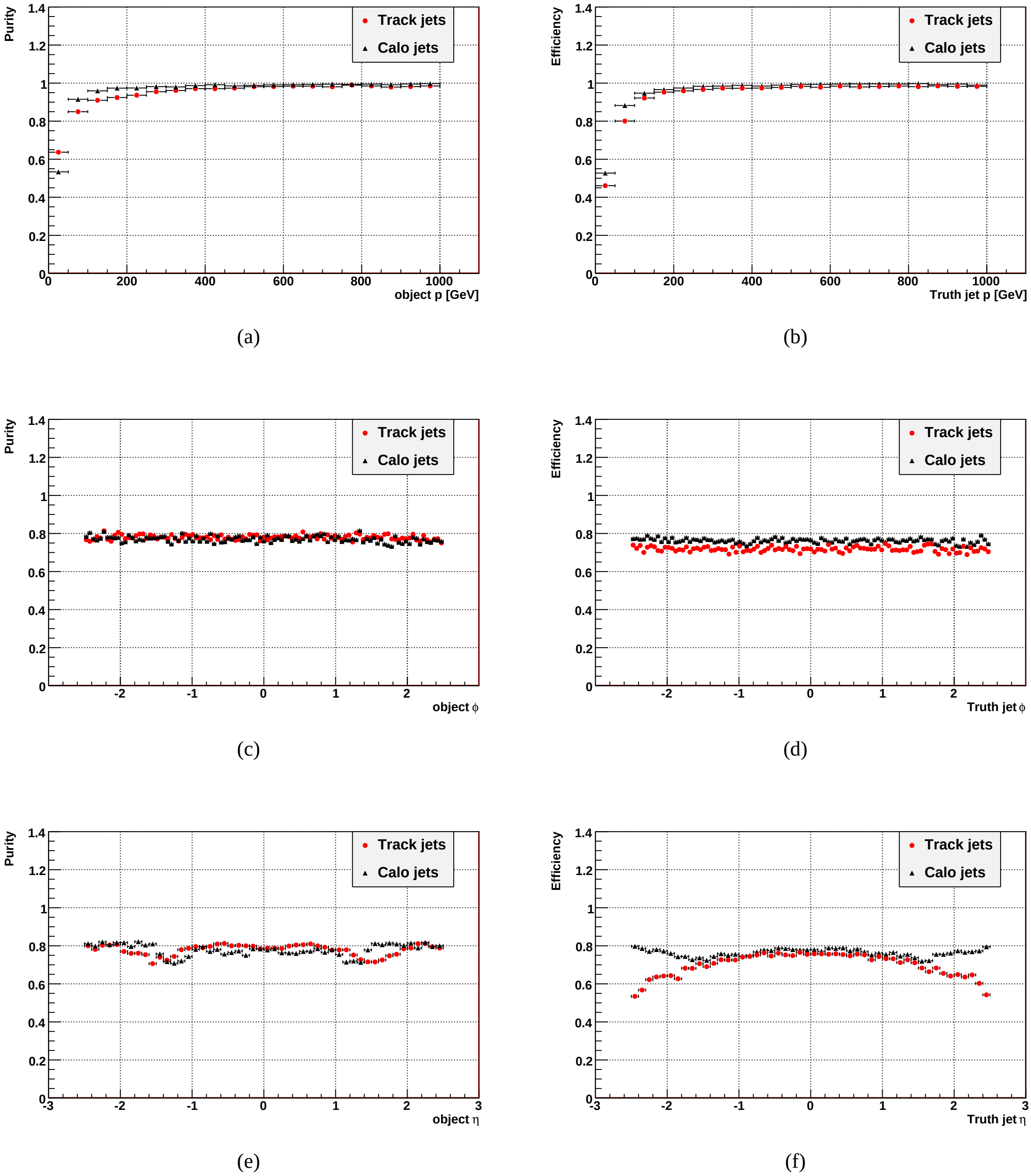
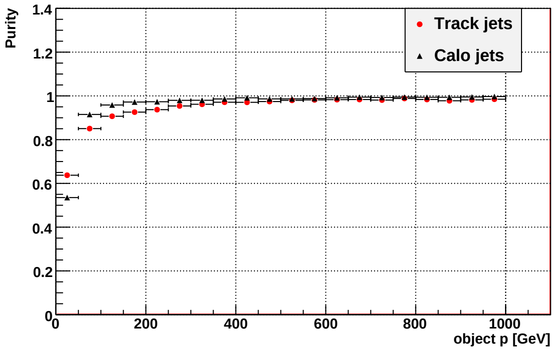
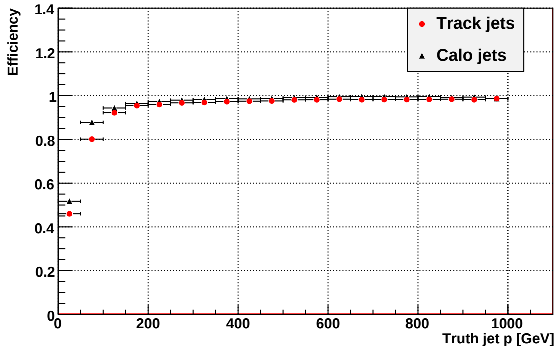


Figure 3: Purity and efficiency of track and calorimeter jets in the absence of calorimeter damage as a function of momentum p (3(a) and 3(b)), of ϕ (3(c) and 3(d)), and of detector η (3(e) and 3(f)). Note that Fig. 3(a) and 3(b) involve p, not p_T. Calorimeter jets are required to have $p_T > 7$ GeV, and track jets $p_T > 5$ GeV from tracks (see text). In Fig. 3(a), "object p" corresponds to H1 corrected momentum for calorimeter jets, while for track jets it is simply the total track momentum. Hence the two plots in 3(a) are not directly comparable, although plotted together for convenience. Fig. 3(c), 3(e), 3(d) and 3(f) show averages over a non-realistic truth momentum spectrum, hence the absolute values of efficiency and purity as functions of η and ϕ should not be taken literally; these plots are meant to show merely the dependence of efficiency and purity on η and ϕ.



(a)



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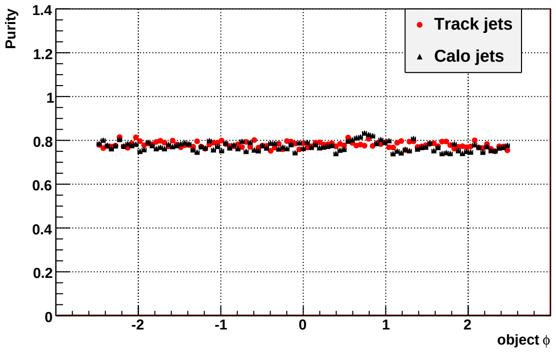

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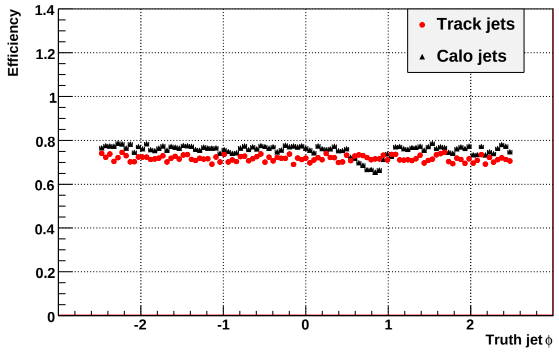

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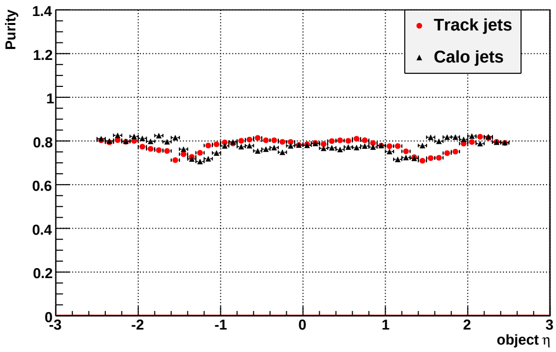

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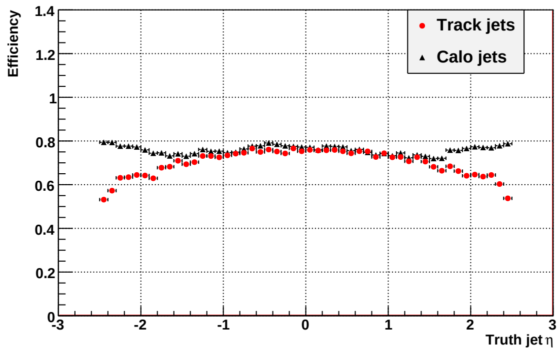


(f)

Figure 4: Same as Fig. 3, but with the LAr LVPS failure described in Section 1. All true and reconstructed jets within $\eta < 2.5$ and at any ϕ are included, not just those in the damaged region.

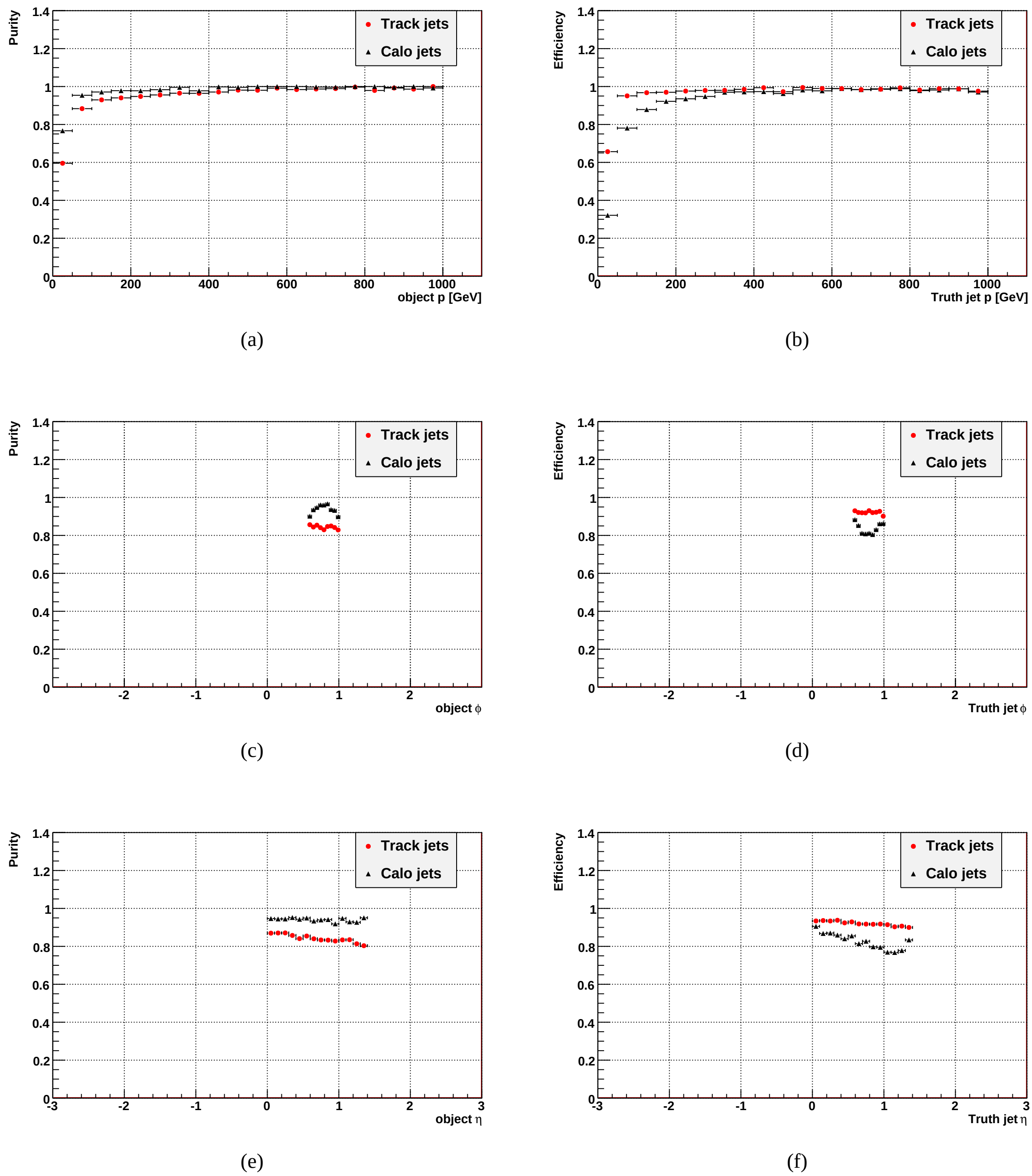


Figure 5: Same as Fig. 3, but with the LAr LVPS failure described in Section 1. Only true and reconstructed jets from the damaged region are considered, which is why the effect of the damage appears more clearly than in Fig. 4. For example, in Fig. 5(d) and 5(f) we see that the efficiency of calorimeter jets is reduced more when the axis of the jet points closer to the center of the damaged region, in which case a larger fraction of the jet energy goes undetected.

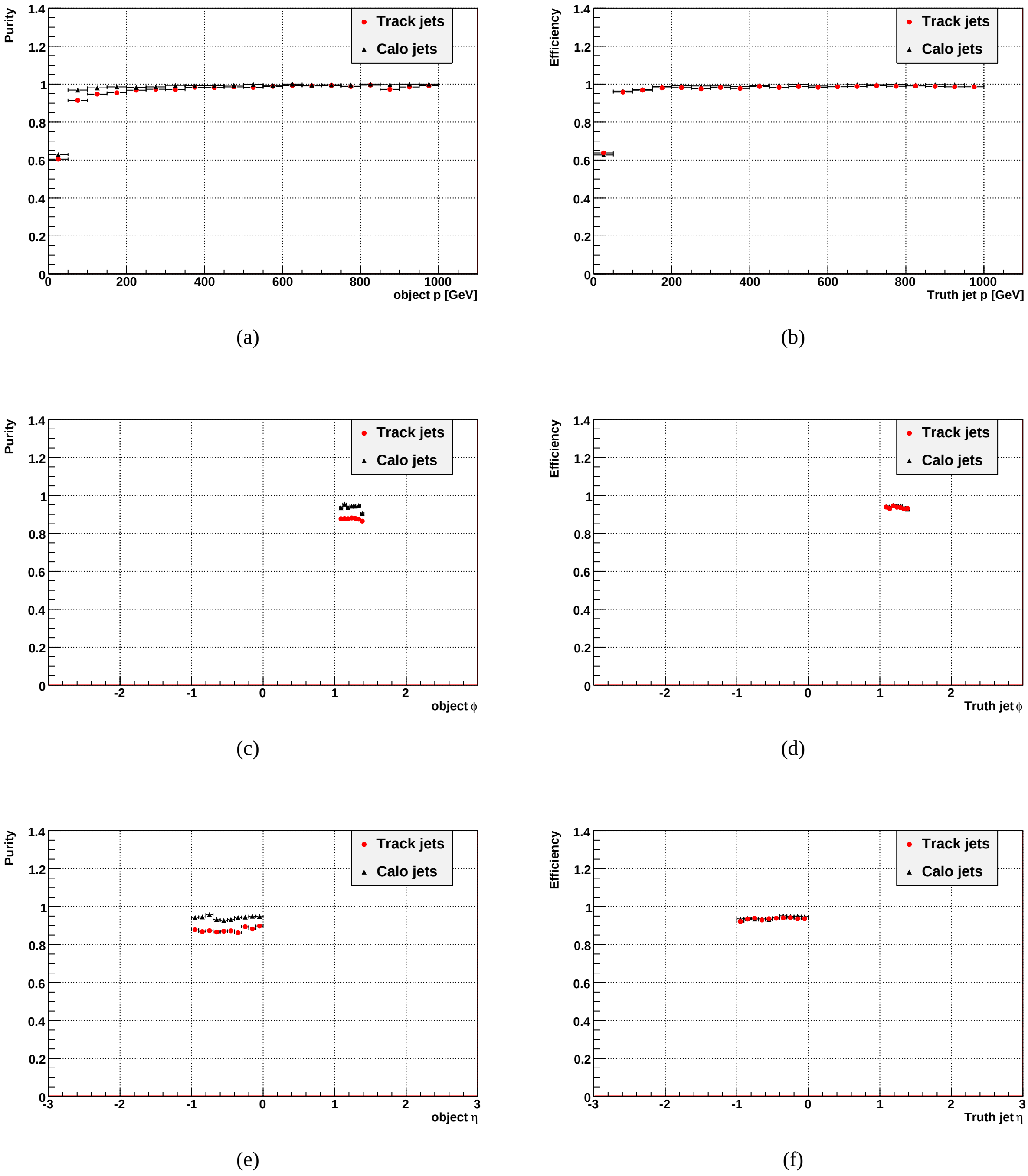


Figure 6: Same as Fig. 3, but with the Tile barrel module failure described in Section 1. Only true and reconstructed jets from the damaged region are considered. The damage is not serious enough to significantly reduce the efficiency of calorimeter jets.

This list of observables is not exhaustive. For example, we also considered as a third observable the angular separation between the two highest p_T tracks in the track jet (ΔR_{12}). However, we found that ΔR_{12} had a negligible effect on the performance of the estimator we were trying to construct. One could also consider counting the hits in the muon chambers aligned with the track jet, although we did not involve the Muon Spectrometer [9] in this study.

From the calorimeter energy within a track jet, we obtain from Monte Carlo a prediction of the true jet momentum along with its uncertainty. The $|\sum \vec{p}|$ of the track jet provides a separate prediction of the true momentum. To obtain a final estimator of the truth-level momentum, we average the above two predictions, weighting them inversely to their respective variances under the assumption that they are uncorrelated.[2]

Fig. 7 shows the dependence of true momentum on the two observables used. Comparing for example Fig. 7(a) to 7(b) for a healthy detector, we see that the prediction from the calorimeter energy has a smaller uncertainty than that from the tracks momentum.[3] Since we use the weighted average of the two predictions as our final estimate, the prediction from the calorimeter energy dominates. This changes when the calorimeter is sufficiently damaged that it contributes about as much precision as the Inner Detector. Such an example is the scenario in which a dead LAr low voltage power supply dies, which is shown in Fig. 7(c) and 7(d). An intermediate case is the scenario when a Tile barrel module fails.

The bias (reconstructed p − true p) and resolution (σ_p/p) of the track jet estimator with respect to truth jets is shown in Fig. 8 for the different scenarios of calorimeter damage. They are compared to calorimeter jets under the same conditions. Fig. 8 is constructed using the means and standard deviations found from Gaussian fits such as those shown in Fig. 9 (healthy detector), 10 (dead LAr LVPS), and 11 (dead Tile module).

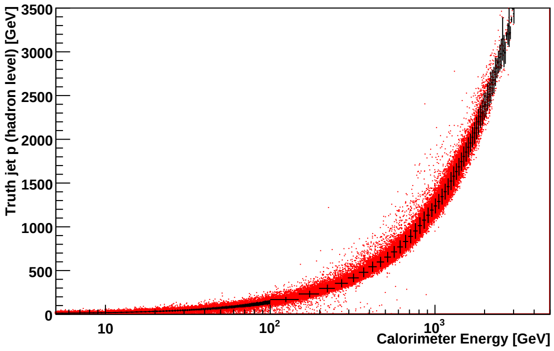
Fig. 8(b), which corresponds to a healthy detector, shows that the momentum predicted by track jets is slightly less precise than that of the H1 calibrated topocluster jets. This is not surprising since the H1 calibration scheme exploits cell-level information via dedicated corrections for each cell, whereas the estimator introduced here uses only two observables (calorimeter energy and tracks momentum within the track jet) that are averaged over the whole $\eta - \phi$ region to translate them to true jet momentum.

Fig. 8(c) and 8(d) show that, in the region of a LAr LVPS failure, the momentum estimated from track jets is less biased and has better resolution at high true jet momentum. At low and intermediate true jet momentum, calorimeter jets appear to have better resolution than track jets despite the detector damage. That is especially true in the damaged LAr scenario, Fig. 8(d). However, it should be noted that, as shown in Fig. 5, track jets are more efficient at identifying jets in that region in the presence of LAr damage. As shown in Fig. 8(c) and 10, the truth jets that are successfully reconstructed as calorimeter jets have H1 calibrated momentum that is heavily biased (underestimated), though its distribution is not very widely spread. In other words, the reconstructed momentum of calorimeter jets in the presence of damage is relatively precise (better resolution than track jets) but inaccurate (heavy bias).

Fig. 8(f) indicates that if a TileCal barrel module fails, the momentum resolution using track jets is comparable to that of calorimeter jets, providing a slight improvement above ~ 1 TeV. Because the damage is not severe enough to degrade the calorimeter jet reconstruction efficiency lower than that of track jets (see Fig. 6), in this scenario there is less benefit to using track jets.

[2]The correlation between calorimeter energy and tracks momentum $|\sum \vec{p}|$ was found to be less than 2% on average, so we ignore it. This non-trivial point was given the necessary attention. For instance, before deciding to use the calorimeter energy within the track jet as an observable, we experimented with using separately LAr and TileCal energies. However, as expected those two observables were found to be strongly anti-correlated for a given true jet momentum. Due to this anti-correlation, the calorimeter energy provides a truth-level momentum estimator of much smaller variance than if we used the average of LAr and TileCal energy.

[3]This is expected, otherwise one wouldn't need a calorimeter to measure jet energy.



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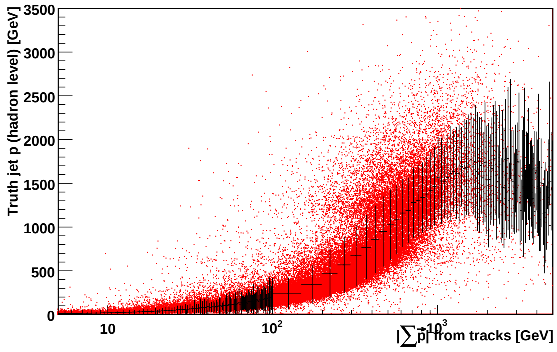

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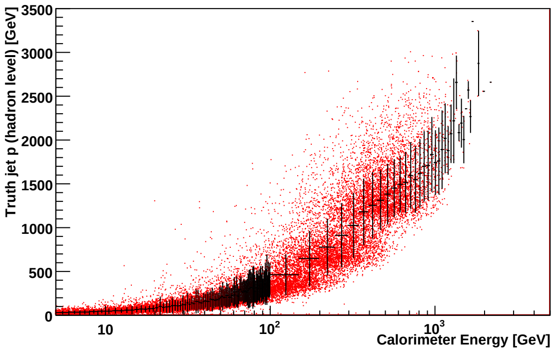

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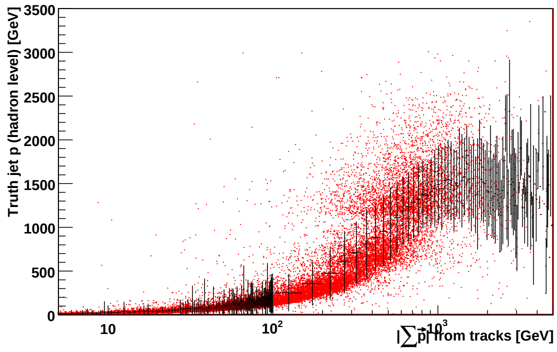

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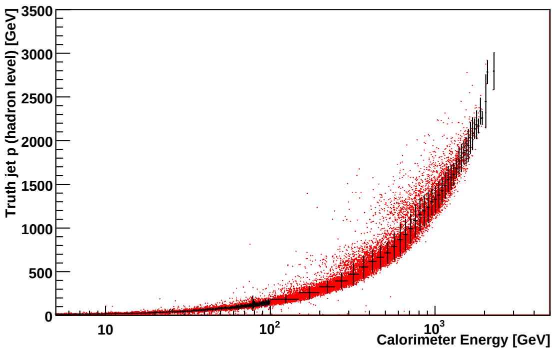

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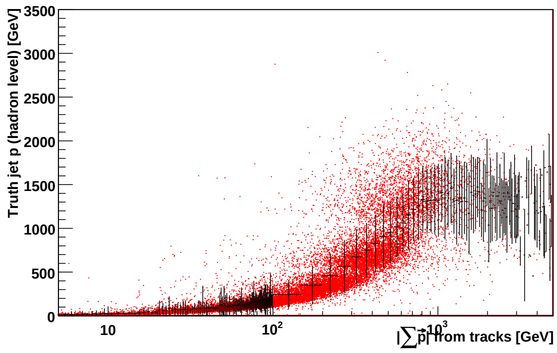
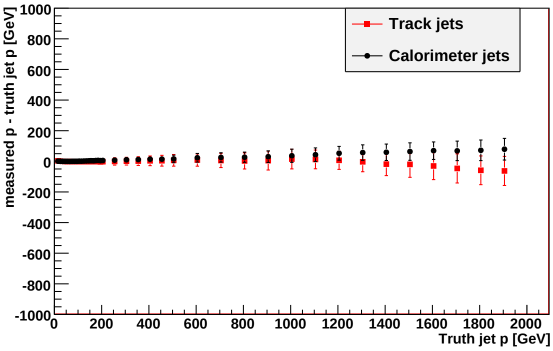
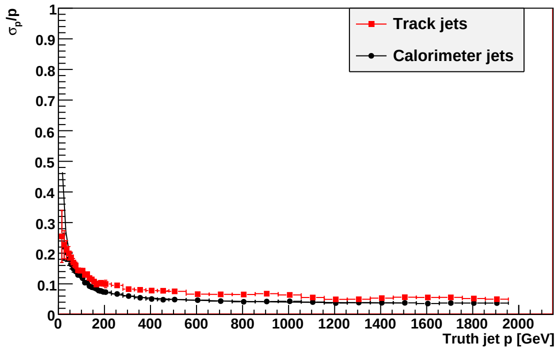


(f)

Figure 7: The momentum of the matching truth jet is shown as a function of the calorimeter energy within $\Delta R < 0.4$ from the reconstructed track jet axis (left) and as a function of $|\sum \vec{p}|$ of tracks in the track jet (right). Notice only the horizontal axis is logarithmic, which causes the apparent non-linearity. In 7(a) and 7(b) the calorimeter is fully functional and the whole $|\eta| < 2.5$ region is included. In 7(c) and 7(d) a LAr LVPS is dead and only jets from the damaged region are used. In 7(e) and 7(f) a Tile barrel module is dead and only jets from the damaged region are used. The red points illustrate the 2D scatter plot; the black points and error bars indicate the mean and RMS, respectively, of the associated profile obtained by averaging over the y-axis bins for each x-axis bin.



(a)



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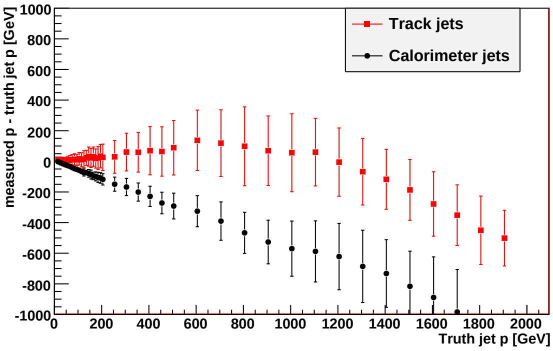

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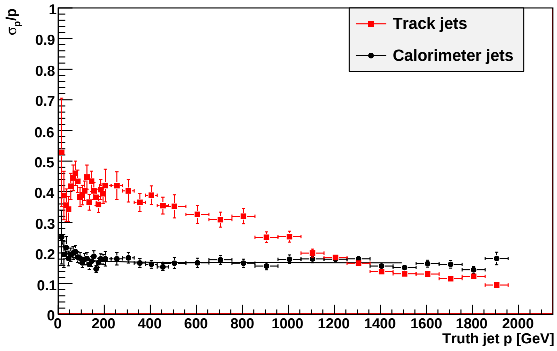

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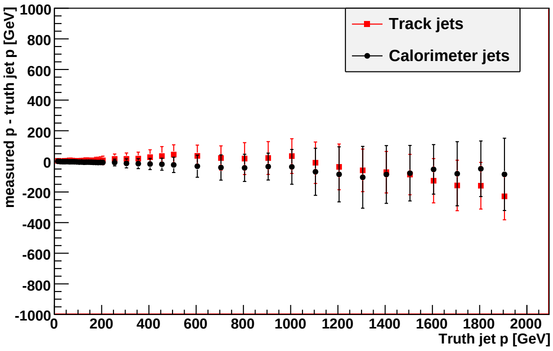

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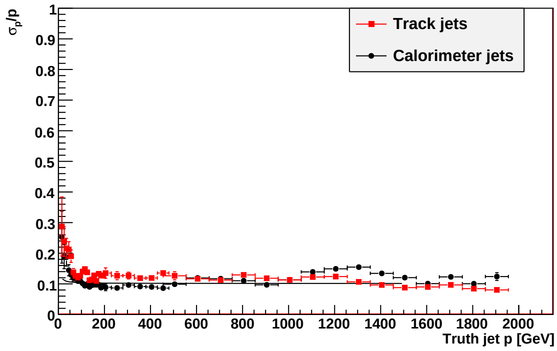


(f)

Figure 8: Difference between predicted and true momentum (left) and resolution $\frac{\sigma_p}{p}$ (right). The prediction described in the text (red) is compared to that of calorimeter jets derived with the H1 calibration. 8(a) and 8(b) correspond to no damage, and include reconstructed jets from the whole $|\eta| < 2.5$ region that match a truth jet. 8(c) and 8(d) correspond to the case of a dead LAr LVPS, and include reconstructed jets whose axis is within the damaged region and that match a truth jet. The same applies to 8(e) and 8(f), only they correspond to the case of a dead Tile module.

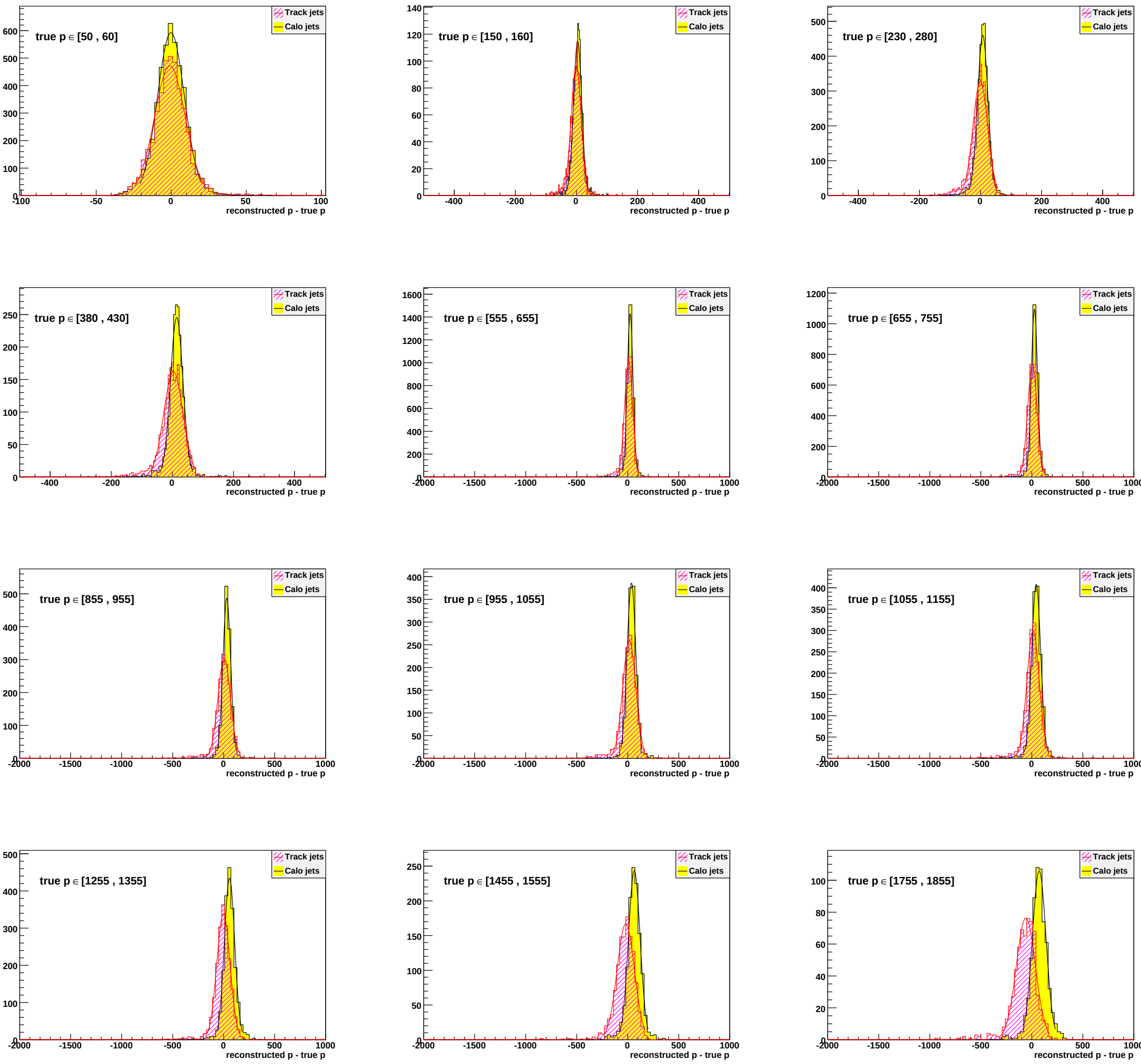


Figure 9: Difference between predicted and true momentum for reconstructed jets (track and topocluster jets) matching a truth jet, shown in various bins of true momentum. The distributions correspond to a healthy detector with jets from the whole $|\eta| < 2.5$ region. Units are GeV/c.

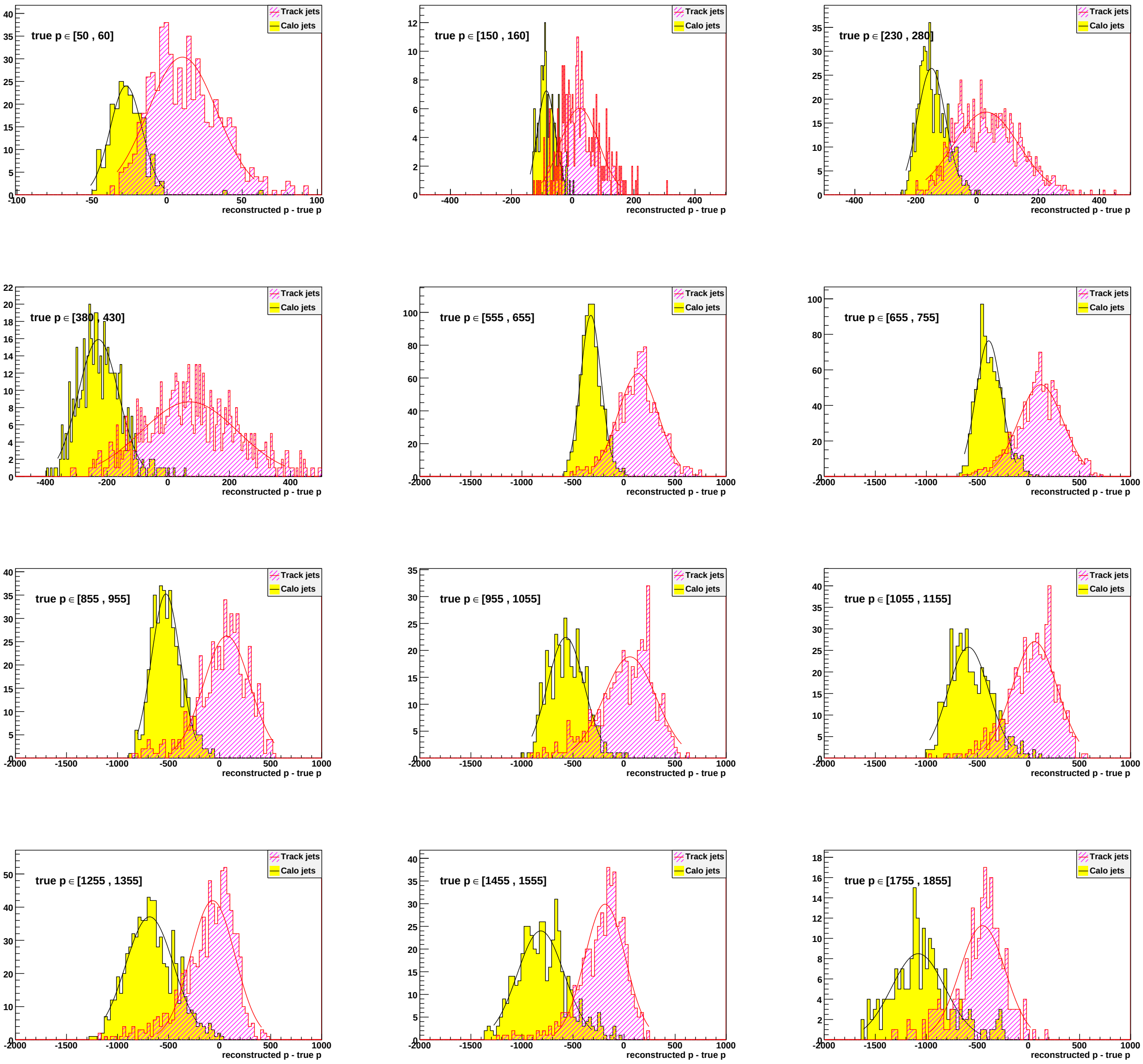


Figure 10: Same as Fig. 9. The distributions correspond to a dead LAr LVPS and consider only jets from the damaged region.

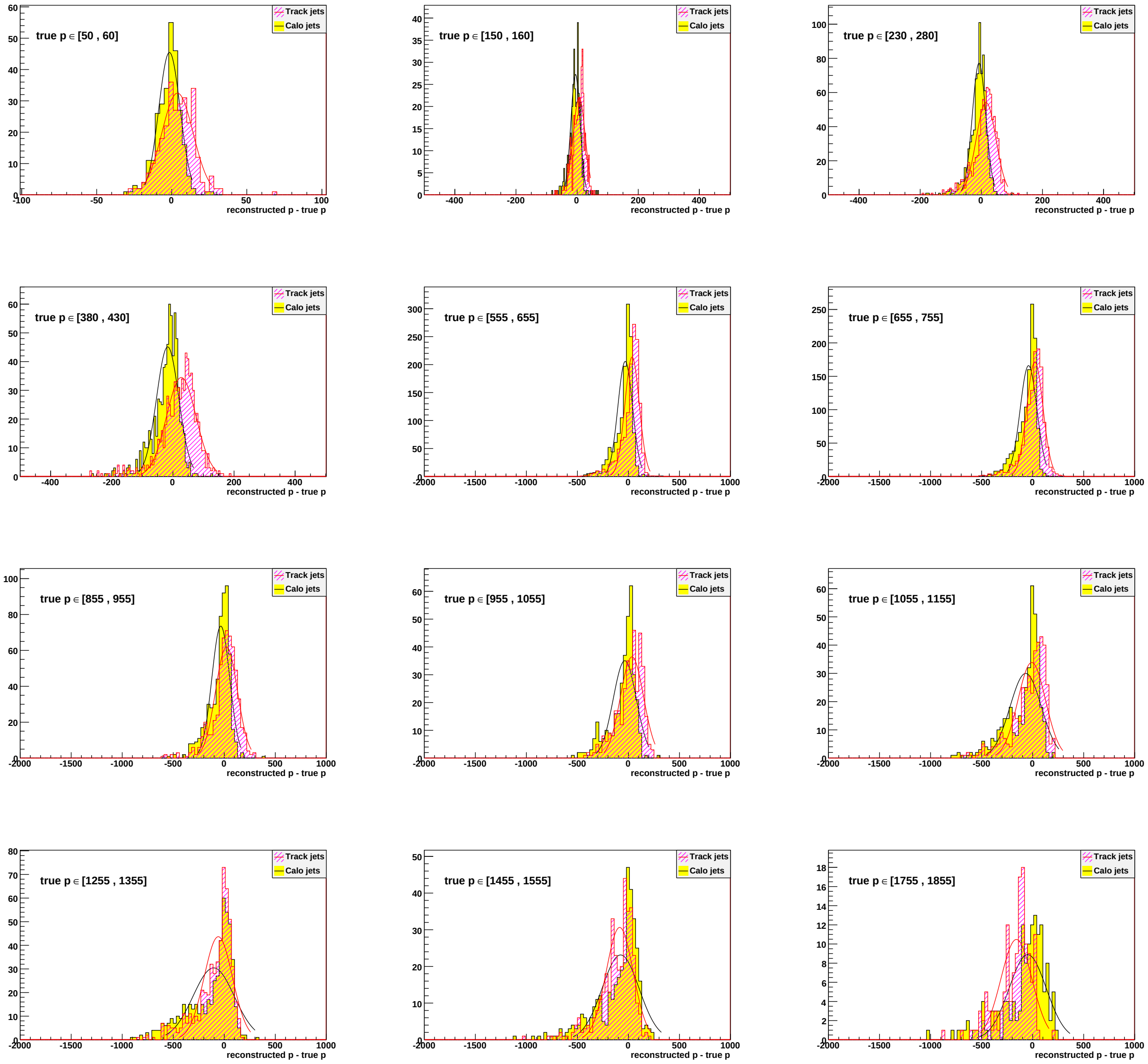
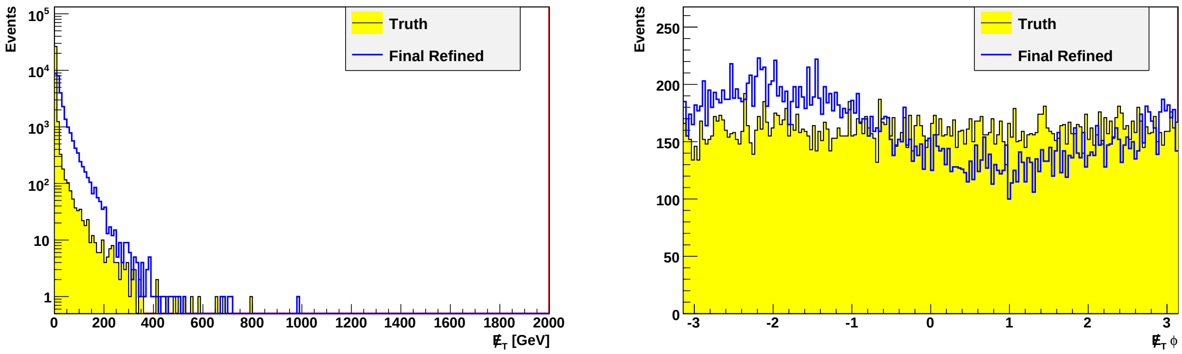


Figure 11: Same as Fig. 9. The distributions correspond to a dead Tile module and consider only jets from the damaged region.

6 Missing Transverse Energy

The measurement of $E_{\mathrm{T}}^{\mathrm{miss}}$ depends most significantly on the calorimeter [10]. The energy of particles falling into damaged calorimeter regions is expected to not be fully measured, hence contributing to fake $E_{\mathrm{T}}^{\mathrm{miss}}$.



(a)

(b)

Figure 12: $E_{\mathrm{T}}^{\mathrm{miss}}$ with a fully functional calorimeter, at truth and reconstruction level after final refinement (a.k.a. `MET_RefFinal`). The samples listed in Table 1 are not mixed in proportions consistent with QCD, therefore the spectrum of $E_{\mathrm{T}}^{\mathrm{miss}}$ in Fig. 12(a) and subsequent figures is not realistic; figures like 12(a) simply demonstrate how reconstruction smears the given truth level $E_{\mathrm{T}}^{\mathrm{miss}}$ spectrum. Reconstructed $E_{\mathrm{T}}^{\mathrm{miss}}$ in Fig. 12(b) seems to reflect some transverse displacement of the interaction point, but to confirm that it would take some further study.

Fig. 12 shows the distribution of $E_{\mathrm{T}}^{\mathrm{miss}}$ with fully functional calorimeter, at truth and reconstruction level after final refinement (a.k.a. `MET_RefFinal`) [10]. One sees the smearing of the truth level $E_{\mathrm{T}}^{\mathrm{miss}}$ spectrum without any calorimeter damage.

Fig. 13 isolates events that have at least one jet (true or reconstructed) in the problematic LAr Calorimeter region. That introduces a strong bias in the direction of reconstructed $E_{\mathrm{T}}^{\mathrm{miss}}$, even without any detector damage. When detector damage is introduced, $E_{\mathrm{T}}^{\mathrm{miss}}$ points predominantly towards the problematic region, and is often overestimated.

In an attempt to ameliorate the effect of calorimeter damage on $E_{\mathrm{T}}^{\mathrm{miss}}$, we try a correction that exploits track jets. We subtract from the event's total p_{T} the p_{T} of any calorimeter jets whose axis is in the damaged detector region, and add in its place the total p_{T} of track jets in the same region. Said differently, we substitute some calorimeter jets with track jets. More specifically,

$$\vec{E}_{\mathrm{T}}^{\mathrm{miss}} \to \vec{E}_{\mathrm{T}}^{\mathrm{miss}} + \Big(\sum_{\text{calo jets}} \vec{p}_{\mathrm{T}} \Big) - \Big(\sum_{\text{track jets}} \vec{p}_{\mathrm{T}} \Big), \tag{3}$$

where we treat energy and momentum as interchangeable, which is a fair approximation at high-energy.

First remark regarding this correction is that we do not expect it to be very accurate, since it uses high-level reconstructed jets, which it treats as if they were single, well-measured particles; however $E_{\mathrm{T}}^{\mathrm{miss}}$ calculation normally involves sophisticated cell-by-cell p_{T} contributions and corrections[4]. A second remark is that the track jets, with which we substitute calorimeter jets, have momentum that is also

[4] An obvious consequence of adding and subtracting the momenta of whole jets to correct $E_{\mathrm{T}}^{\mathrm{miss}}$ is that this correction does not account for out-of-cone jet energy, apart from the effort that has been made to include it in the reconstructed jet energy.

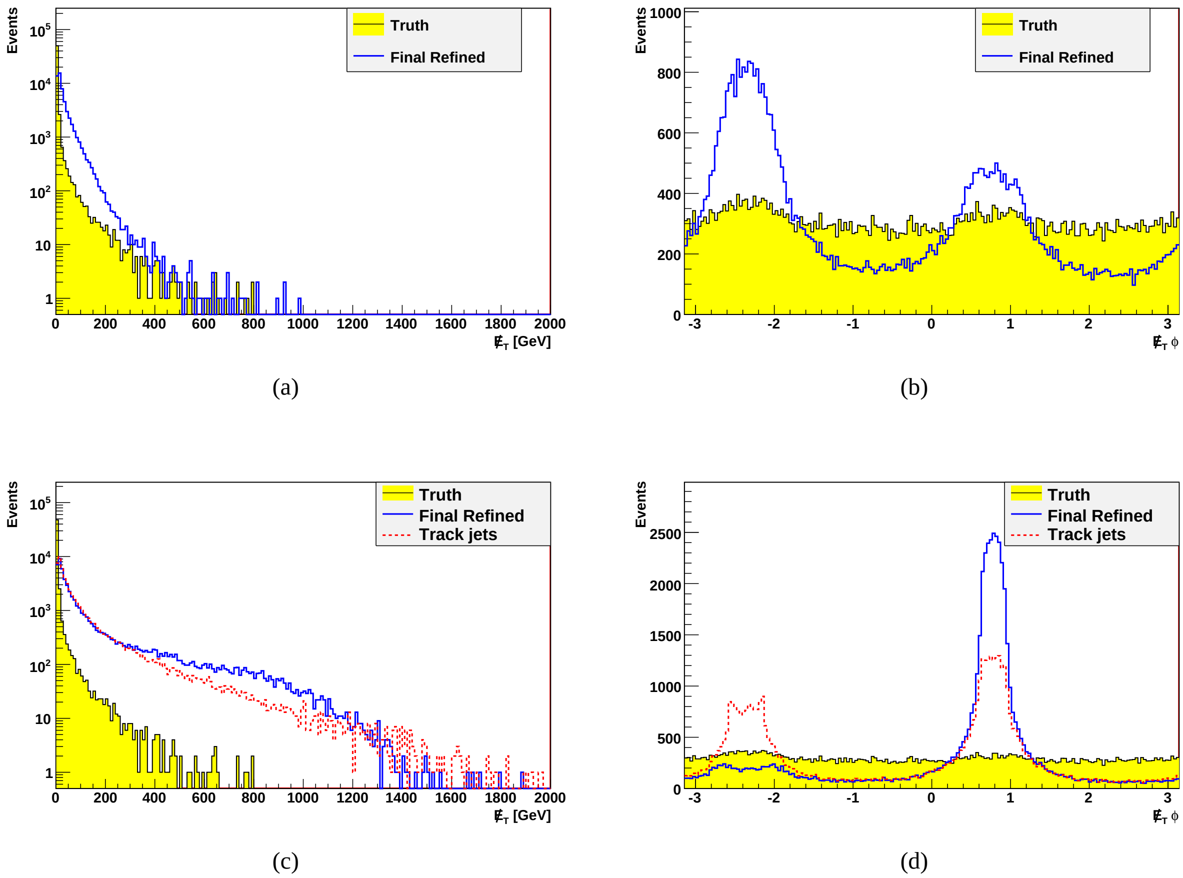


Figure 13: E_T^{miss} for events with at least one jet (true or reconstructed) whose axis lies in the problematic region of LAr defined in Sec. 1. In Fig. 13(a) and 13(b) the calorimeter is functional, whereas in 13(c) and 13(d) LAr is damaged. In 13(c) and 13(d) appears (dashed line) the E_T^{miss} obtained by substituting calorimeter jets in the damaged region with track jets (see Sec. 6). Fig. 13(b) shows that reconstructed E_T^{miss} is biased to point towards or away from the problematic LAr region, even when there is no calorimeter damage. That bias is due to the imposed event selection, which forces jets to point towards that LAr region, hence any mismeasurement of the energy of those jets appears as fake E_T^{miss} along jet axis. The variation shown in Fig. 12(b) contributes to the asymmetry of the two peaks in 13(b). Comparing Fig. 13(b) to 13(d) shows that when LAr Calorimeter fails the reconstructed E_T^{miss} points predominantly in the direction of the damage. That effect is ameliorated by the use of track jets. Comparing Fig. 13(a) to 13(c) shows that the size of reconstructed E_T^{miss} is overestimated significantly more in the presence of detector damage. The overestimation is reduced by the use of track jets.

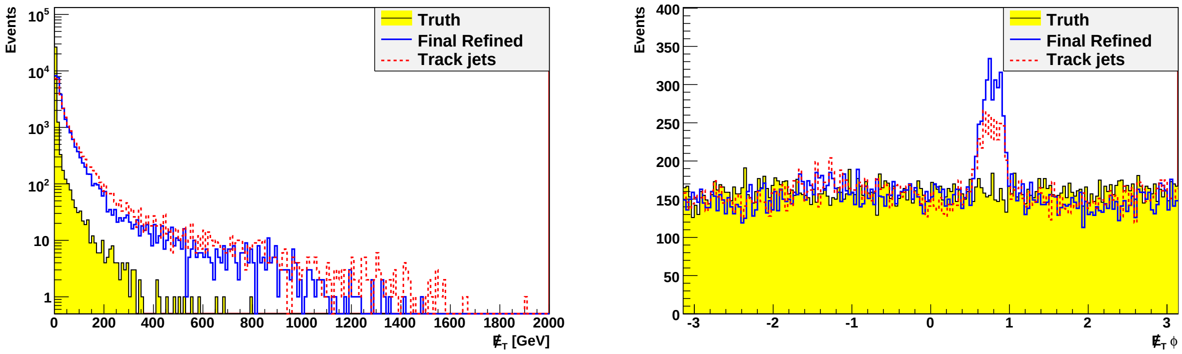


Figure 14: Similar to Fig. 12, with the difference that the LAr damage described in Sec. 1 is present. As opposed to Fig. 13(c) and 13(d), here all events are included, not only those with a jet in the damaged region. Fig. 14(b) shows an excess of events with the reconstructed $E_{\mathrm{T}}^{\mathrm{miss}}$ pointing in the direction of the damage. That effect is ameliorated by the use of track jets. Comparing the shape of reconstructed $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution in Fig. 14(a), 12(a) and 13(c) indicates that, as one would expect, the events with a jet in the problematic region are mostly responsible for the high $E_{\mathrm{T}}^{\mathrm{miss}}$ tail in 14(a).

affected by calorimeter damage, as explained in Sec. 5. Therefore, the substitute to calorimeter jets is not itself immune to the damage that renders calorimeter jets less reliable in the first place. A third remark is that there can be several variations to this $E_{\mathrm{T}}^{\mathrm{miss}}$ correction. For example, we could substitute calorimeter jets with track jets only if they are significantly overlapping; or we could expand this substitution to include calorimeter and track jets that may simply overlap with the damaged region, as opposed to having their axes within it. Such alternatives were investigated to some degree, showing small variation in the outcome, but more detailed studies could be conducted.

Fig. 14 shows the effect of the studied LAr Calorimeter damage, but, in contrast with Fig. 13, all events are included. The impact of the damage is diluted by showing in the same distribution events that have no jets in the damaged region. Still, we see how clear the effect would be, even if we didn't know where the damage was – the fake $E_{\mathrm{T}}^{\mathrm{miss}}$ would point us to it.

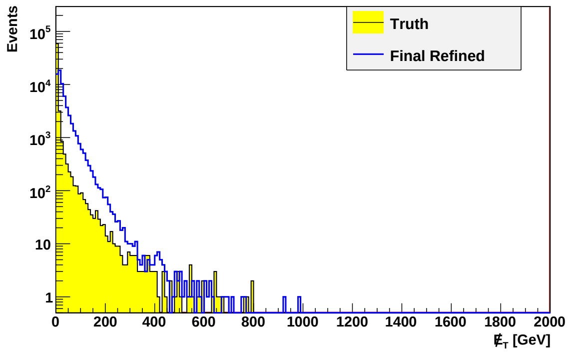
Fig. 15 is analogous to Fig. 15, but focuses on the problematic TileCal region defined in Sec. 1, and the corresponding TileCal damage. Compared to the scenario of LAr Calorimeter damage, the TileCal damage has a much smaller impact on $E_{\mathrm{T}}^{\mathrm{miss}}$, since it results in less energy undetected per event.

7 Conclusion

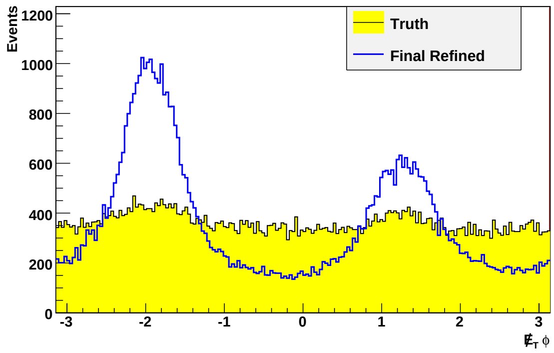
We have investigated the option of reconstructing jets using tracks to address local calorimeter damage. Two examples are studied: one where a Tile Calorimeter module ($\Delta\phi = \frac{\pi}{32}$) fails, and one where a low voltage power supply in the Liquid Argon Calorimeter ($\Delta\phi = \frac{\pi}{8}$) fails. Similar Monte Carlo studies could be repeated in the event of an actual calorimeter damage.

It was found that in the case of significant LAr damage, such as the failure of a power supply, the reduced efficiency of topocluster jets in the damaged region could be improved by using track jets. By contrast, the loss of a superdrawer in TileCal would not be serious enough to render topocluster jets less efficient than track jets.

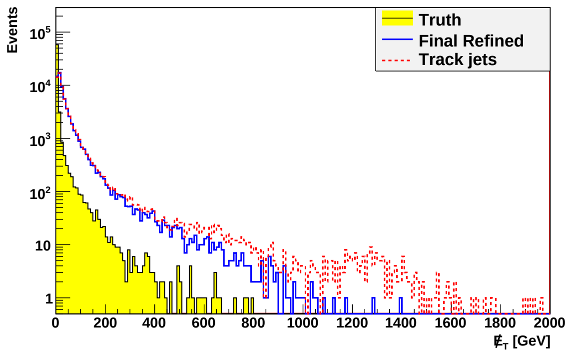
A simple, Monte Carlo based calibration scheme was developed, which was tuned and applied lo-



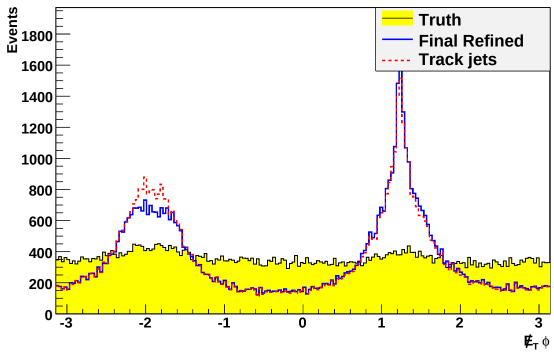
(a)



(b)



(c)



(d)

Figure 15: Same as Fig. 13, with the difference that events are required to have at least one jet (true or reconstructed) whose axis lies in the problematic region of Tile Calorimeter defined in Sec. 1. In Fig. 15(a) and 15(b) the calorimeter is functional, whereas in 15(c) and 15(d) TileCal is damaged. Fig. 15(b) shows analogous behavior to 13(b). Fig. 15(d) is analogous to 13(d), though the effect of damage in 15(d) is less intense, as TileCal damage affects a narrower region and less energy reaches TileCal than LAr Calorimeter. The $E_{\mathrm{T}}^{\mathrm{miss}}$ direction bias is slightly ameliorated by the use of track jets. Comparing Fig. 15(c) to 13(c) shows, as expected, that the simulated TileCal damage causes less fake $E_{\mathrm{T}}^{\mathrm{miss}}$ than the simulated LAr Calorimeter damage. In this case the effect of the damage is so little that it is not beneficial to substitute calorimeter jets with track jets.

cally in the damaged region to estimate truth-level jet momentum from two observables: the calorimeter energy within a cone around the track jet, and the total momentum of the tracks constituting the track jet. In the case of LAr damage studied, the momentum linearity is improved by the use of track jets calibrated with this scheme (Fig. 8(c)). In either scenario of LAr or Tile damage, momentum resolution of jets above approximately 1 TeV is improved (Fig. 8(d), 8(f)). For momentum below 1 TeV, it seems preferable to use calorimeter jets, which provides better resolution (Fig. 8(d)), but rescale their momentum with the appropriate multiplicative factor to correct for the bias caused by the detector damage (Fig. 8(c)).

The effects of calorimeter damage on $E_{\mathrm{T}}^{\mathrm{miss}}$ were found to be significant, especially in the scenario of LAr damage. A simple $E_{\mathrm{T}}^{\mathrm{miss}}$ correction, which exploits track jets, was used to ameliorate the effect. Especially in the scenario of LAr damage, the improvement was noticeable. Still, complete recovery of the energy lost in the damaged region is not possible.

8 Related Studies

The tools are now available to repeat this study for any kind of calorimeter damage that may affect the real data.

There has been a related study [11] of the effect of calorimeter damage on trigger.

Regarding $E_{\mathrm{T}}^{\mathrm{miss}}$, there has been a similar study to assess the impact of calorimeter damage on $E_{\mathrm{T}}^{\mathrm{miss}}$ [12]. The addition made here is the use of track jets to reduce some of the effects of damage. There have also been studies [13] about measuring $E_{\mathrm{T}}^{\mathrm{miss}}$ exclusively from tracks, without relying on the calorimeter at all.

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