An Analysis of Missing Transverse Momentum Triggers for Improving Efficiency at the ATLAS Experiment at CERN

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The LHC

- Circumference 27km
- Design energy of 7TeV per proton
- Expected number of proton-proton collisions is $10^9\mathrm{s}^{-1}$

ATLAS

- $1\mathrm{Gbs}^{-1}$ is collected
- Trigger system is designed to run at about 1kHz (retain this number of events per second)
- Many events need to be rejected

The Trigger System

- A trigger is a system that uses simple criteria in order to rapidly decide which events to keep when only a small fraction are acceptable
- The triggers are divided into levels so that each level selects data that becomes and input for the next level which has more time and information to make better decisions
- There is the **L1** level, which relies on custom electronics, and the **High Level Trigger** (HLT) system that relies on commercial processors.

Missing Transverse Momentum

- There is “true” missing transverse momentum, and missing transverse momentum due to the detector
- Momentum in the plane transverse to the beam pipe.
- Transverse momentum is conserved (protons collided approximately head on)
- True missing transverse momentum is due to particles that escape the detector without being measured (neutrinos, super symmetric particles, etc.)
- Therefore, we use missing transverse momentum as a measure to see if interesting particles escaped the detector

Why Do We Want Efficient Triggers

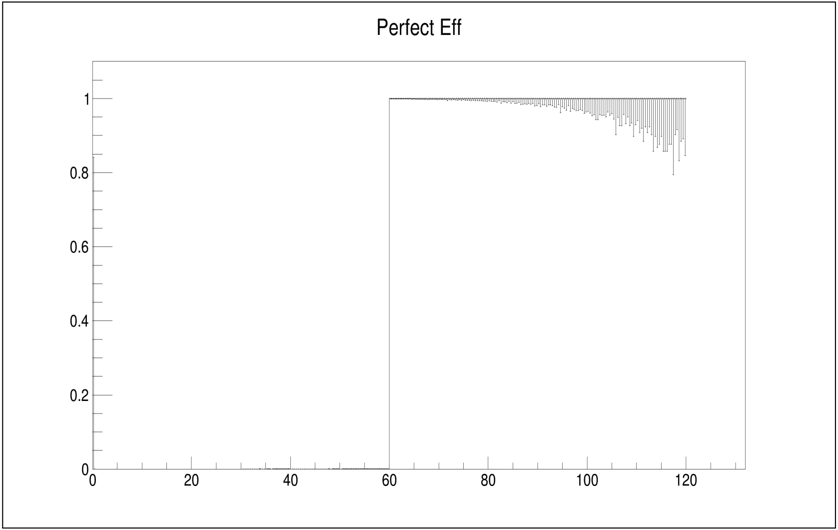
- We want to have a trigger that is efficient at picking events with true missing transverse momentum
- We know that neutrinos escape the detector and therefore are a source of true missing transverse momentum
- Because a W boson is known to decay into a muon and a neutrino, we test how efficient our algorithms are at selecting events with true missing momentum on W boson decays. This is because we can measure muons in the detector, and we can roughly cut on a range of transverse mass that increases the probability of containing a W boson. The presence of an event with the correct transverse mass and a muon produced has a higher likelihood of containing a neutrino, which we can use to test efficiency of our algorithms

Efficiency

- Efficiency is a measure of the classification accuracy of one algorithm, relative to another algorithm
- We usually consider the efficiency of cutting on one of the algorithms, as a function of the value given by another algorithm
- A perfect efficiency curve looks like a step function, centered on the value of the cut

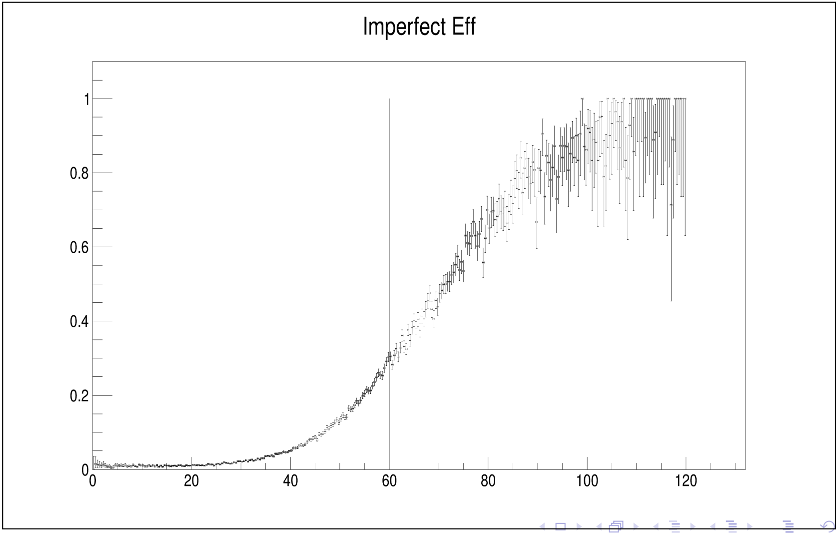
Perfect Efficiency Curve

Here is a plot of the efficiency of $\mathrm{L1} > 60.0\mathrm{GeV}$ as a function of L1 MET



Imperfect Efficiency Curve

Here is a plot of the efficiency of $\mathrm{L1} > 60.0\mathrm{GeV}$ as a function of CELL MET

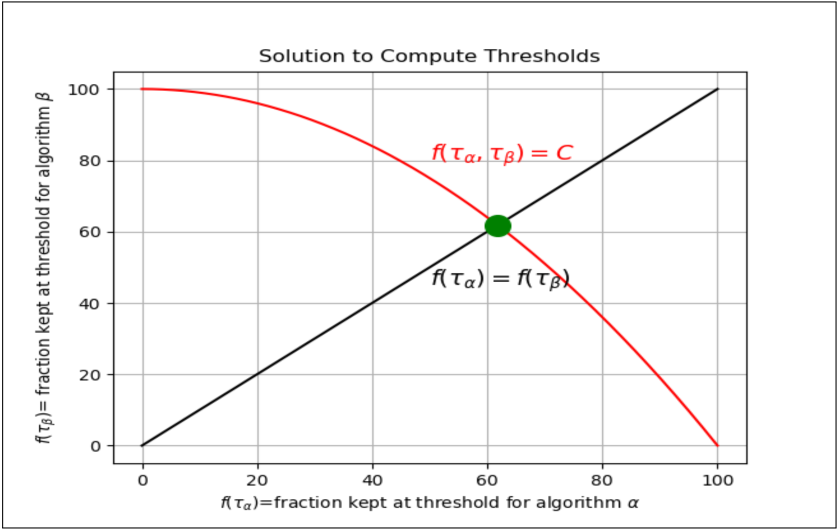


- We would like to improve the efficiency of event selection by combining algorithms
- Combine two uncorrelated algorithms such that they keep the trigger rate when combined
- The trigger rate is determined by the fraction of background events that are kept by the trigger system
- We computed the trigger rate to be the fraction of zerobias events that passed an L1 cut of 50 GeV and a CELL cut of 100 GeV

Bisection

- In order to simplify the problem, we also constrained the algorithms to individually keep the same trigger rate when used alone
- After doing this, our problem was essentially one-dimensional and we used a popular root-finding method (bisection) in order to find a solution, subject to the equal fraction constraint, of the equation:

$$f(\tau_\alpha, \tau_\beta) = \text{trigger rate} \tag{1}$$



Solution to Compute Thresholds
$f(\tau_\alpha, \tau_\beta) = C$
$f(\tau_\alpha) = f(\tau_\beta)$
$f(\tau_\beta)$= fraction kept at threshold for algorithm β
$f(\tau_\alpha)$=fraction kept at threshold for algorithm α
0
20
40
60
80
100

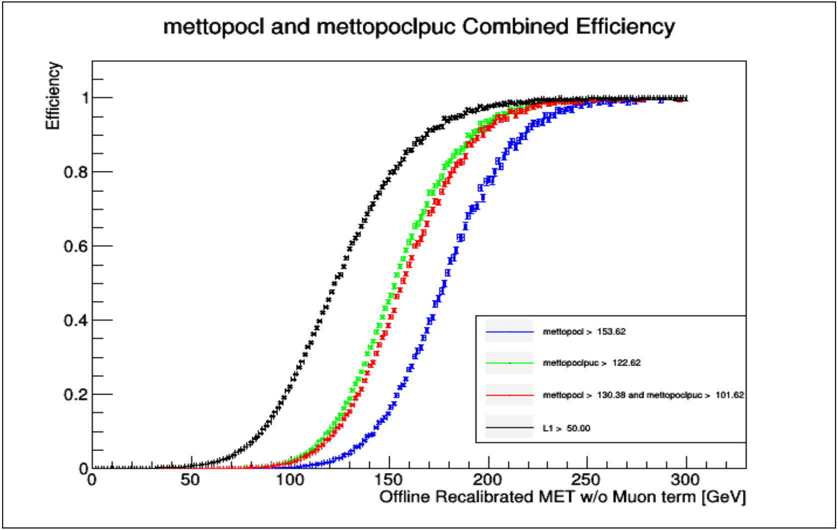
Combined Efficiency

- After solving the problem of figuring out what thresholds are needed to keep the trigger rate when the algorithms are used together, we then compute the efficiency of this new algorithm on signal events
- In order to determine efficiency, we use events known to produce true missing transverse momentum.
- To select events known to produce true missing transverse momentum, we add a cut on the transverse mass for W bosons, and we require the muon trigger to fire (indicates the presence of a muon created)

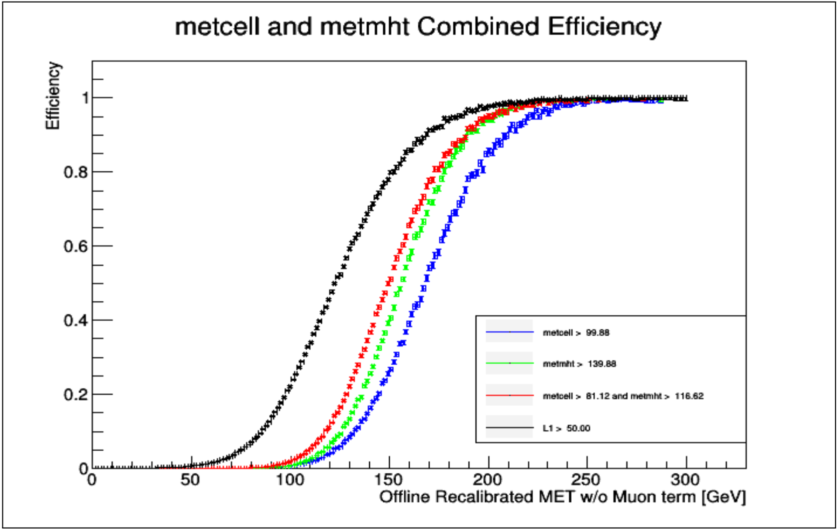
Results

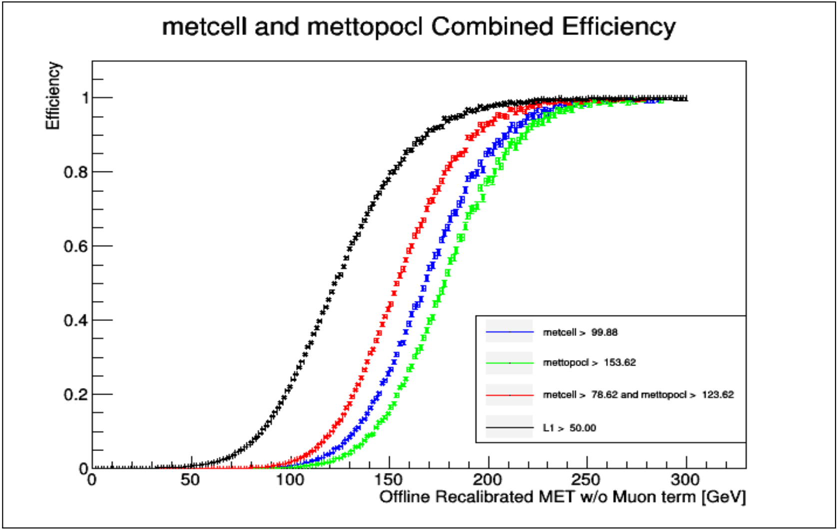
- For some pairs of algorithms, we found no increase in overall efficiency by using combined algorithms
- However, for other pairs, we did find an increase in efficiency by using the combined algorithms
- During the summer of 2018, the pufit and cell combined algorithm trigger was the main trigger that was used for the second part of Run 2.

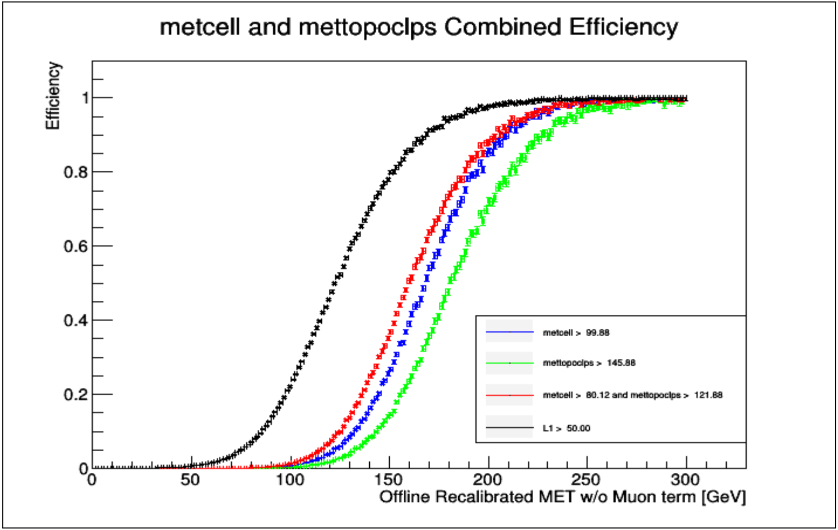
Algorithms that Don't Do Better Together

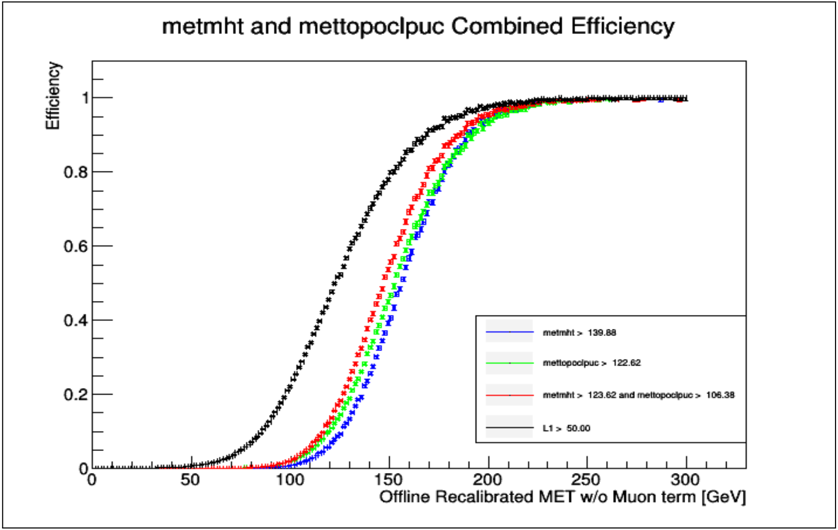


Algorithms that Do Better Together

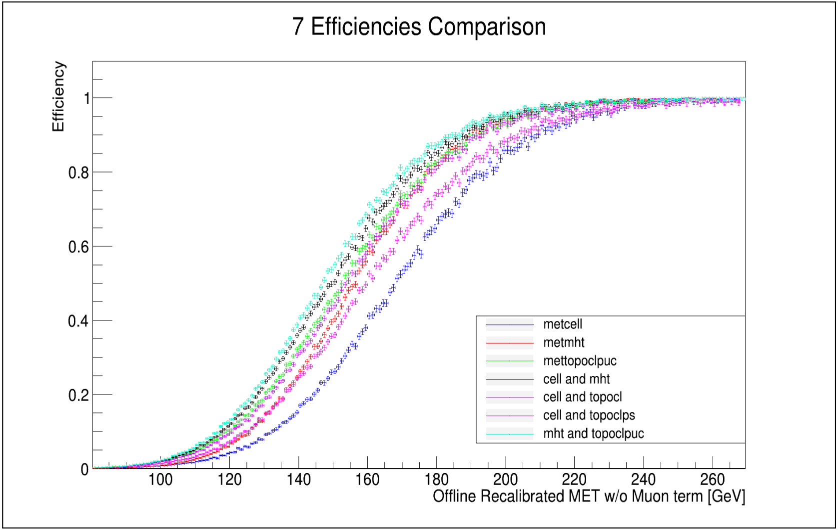



metcell and mettopocl Combined Efficiency
Efficiency
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
Offline Recalibrated MET w/o Muon term [GeV]
metcell > 99.88
mettopocl > 153.62
metcell > 78.62 and mettopocl > 123.62
L1 > 50.00


metcell and mettopoclps Combined Efficiency
Efficiency
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
Offline Recalibrated MET w/o Muon term [GeV]
metcell > 99.88
mettopoclps > 145.88
metcell > 80.12 and mettopoclps > 121.88
L1 > 50.00


metmht and mettopoclpuc Combined Efficiency
Efficiency
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
Offline Recalibrated MET w/o Muon term [GeV]
metmht > 139.88
mettopoclpuc > 122.62
metmht > 123.62 and mettopoclpuc > 106.38
L1 > 50.00

Plot of Best Individual and Best Combined Algorithms



Reconstructing the Unbiased CELL Distribution

- Determine CELL MET Distribution as a function of μ
- Zerobias events run out of statistics above about 80 GeV
- Use `HLTnoalg_L1XExx` triggered events to extend to higher MET.
- Correct the HLTnoalg Data Using Efficiency determined from lower threshold triggers.
- Determine errors including statistical and those due to determination of efficiency.

Method

For each bin of actual number of interactions per bunch crossing (actint/InTimePileup):

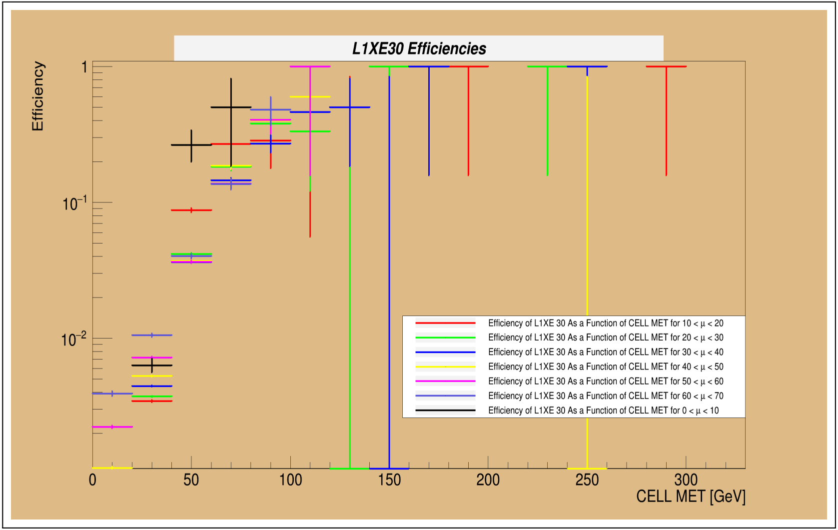
1. Compute the Efficiency of L1XE 30 for `HLTzb_L1ZB` events as a function of cell met
2. Obtain an unbiased (with respect to L1) CELL MET distribution from the `HLTnoalg_L1XE30` data by multiplying by the prescale and dividing by efficiency computed previously
3. Compute efficiency of L1XE50 for `HLTnoalg_L1XE30` data as a function of cell met
4. Obtain an unbiased (with respect to L1) CELL MET distribution from the `HLTnoalg_L1XE50` data by multiplying by the prescale and dividing by both of the previously computed efficiencies.

Data Used

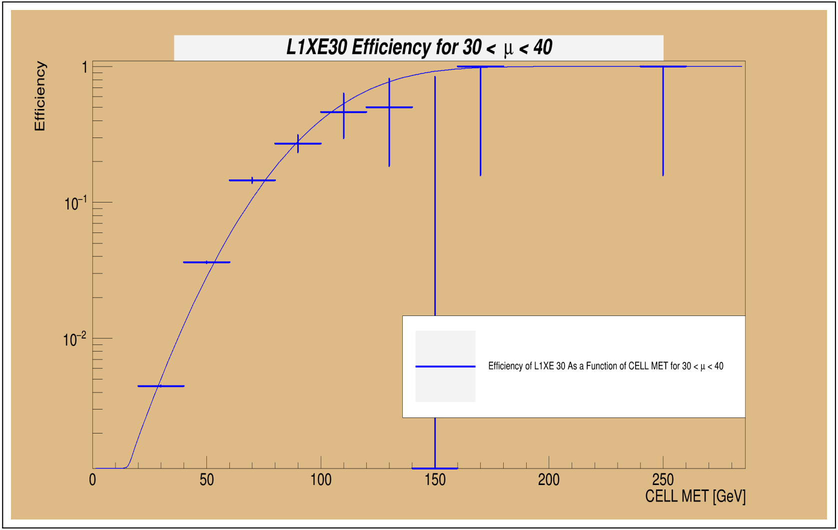
- Used 2015, 2016 and 2017 combined `HLTnoalg_L1ZB`, `HLTnoalg_L1XE30`, and `HLTnoalg_L1XE50` data produced by Jonathan Burr dated 2017-11-17 from ZB and JETM10 trees
- Removed events from Runs 330203, 331975 and 334487. These had large MET events without jets and logbook says there were calorimeter noise problems in these runs

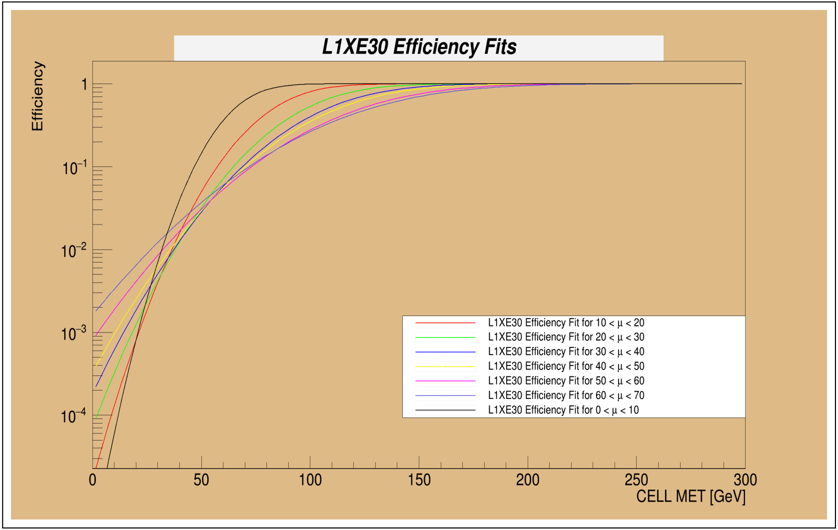
Efficiency Fits

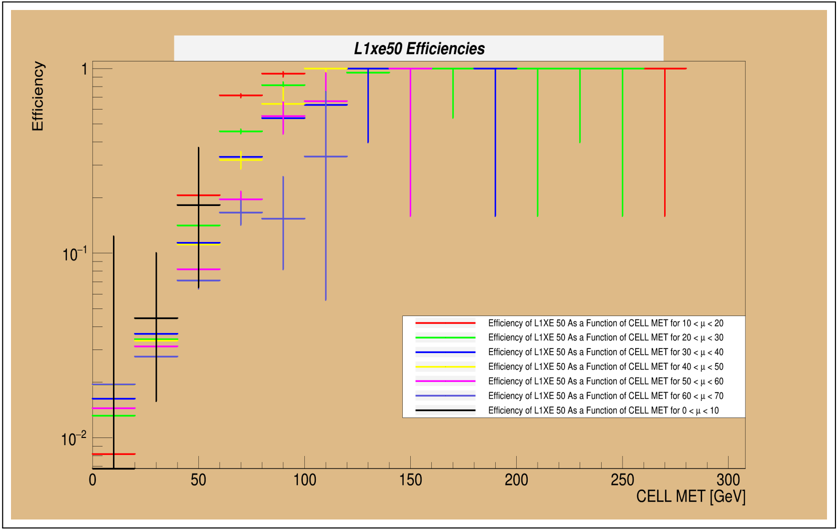
- Assume the distribution of L1 MET, given the value of CELL MET, is gaussian.
- Fitted an error function to the efficiency to evaluate a continuous function when correcting the distribution of `HLTnoalg` data.
- Fit function we used has 4 parameters: a, b, σ, and L1XE.
- $f(x) = \frac{1}{2}\left(1 + \mathrm{Erf}\left(\frac{ax+b-\mathrm{L1XE}}{\sigma\sqrt{2}}\right)\right)$.
- Fit in actint bins of $0-10, \ldots, 60-70$.

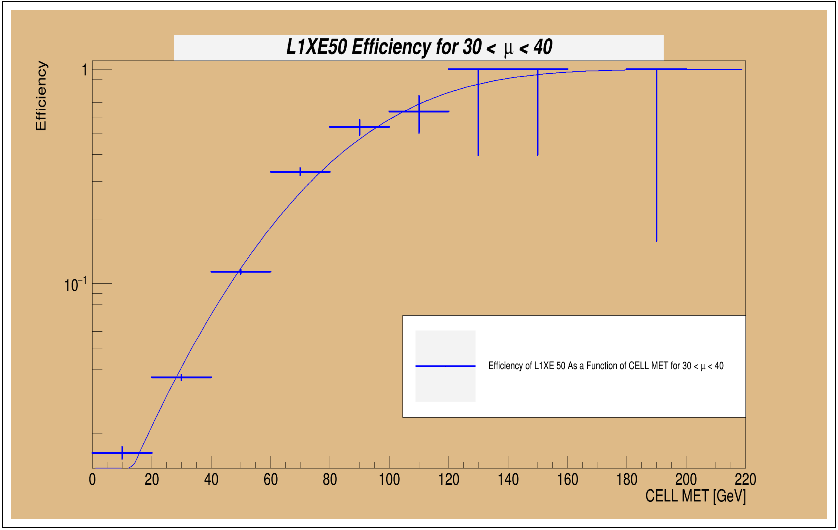


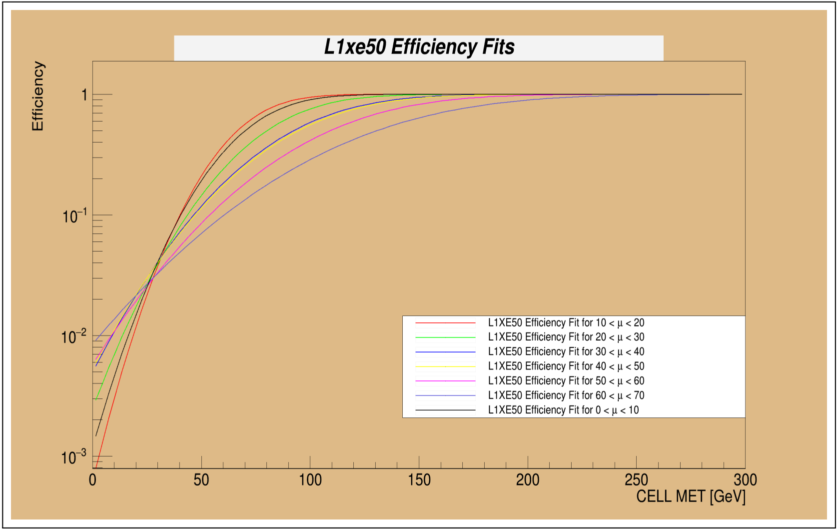
L1XE30 Efficiencies
Efficiency
1
10^{-1}
10^{-2}
0
50
100
150
200
250
300
CELL MET [GeV]
Efficiency of L1XE 30 As a Function of CELL MET for 10 < μ < 20
Efficiency of L1XE 30 As a Function of CELL MET for 20 < μ < 30
Efficiency of L1XE 30 As a Function of CELL MET for 30 < μ < 40
Efficiency of L1XE 30 As a Function of CELL MET for 40 < μ < 50
Efficiency of L1XE 30 As a Function of CELL MET for 50 < μ < 60
Efficiency of L1XE 30 As a Function of CELL MET for 60 < μ < 70
Efficiency of L1XE 30 As a Function of CELL MET for 0 < μ < 10


L1XE30 Efficiency for 30 < μ < 40
Efficiency
1
10^{-1}
10^{-2}
0
50
100
150
200
250
CELL MET [GeV]
Efficiency of L1XE 30 As a Function of CELL MET for 30 < μ < 40


L1XE30 Efficiency Fits
Efficiency
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
50
100
150
200
250
300
CELL MET [GeV]
L1XE30 Efficiency Fit for 10 < μ < 20
L1XE30 Efficiency Fit for 20 < μ < 30
L1XE30 Efficiency Fit for 30 < μ < 40
L1XE30 Efficiency Fit for 40 < μ < 50
L1XE30 Efficiency Fit for 50 < μ < 60
L1XE30 Efficiency Fit for 60 < μ < 70
L1XE30 Efficiency Fit for 0 < μ < 10


L1xe50 Efficiencies
Efficiency
1
10^{-1}
10^{-2}
0
50
100
150
200
250
300
CELL MET [GeV]
Efficiency of L1XE 50 As a Function of CELL MET for 10 < μ < 20
Efficiency of L1XE 50 As a Function of CELL MET for 20 < μ < 30
Efficiency of L1XE 50 As a Function of CELL MET for 30 < μ < 40
Efficiency of L1XE 50 As a Function of CELL MET for 40 < μ < 50
Efficiency of L1XE 50 As a Function of CELL MET for 50 < μ < 60
Efficiency of L1XE 50 As a Function of CELL MET for 60 < μ < 70
Efficiency of L1XE 50 As a Function of CELL MET for 0 < μ < 10


L1XE50 Efficiency for 30 < μ < 40
Efficiency
1
10^{-1}
0
20
40
60
80
100
120
140
160
180
200
220
CELL MET [GeV]
Efficiency of L1XE 50 As a Function of CELL MET for 30 < μ < 40



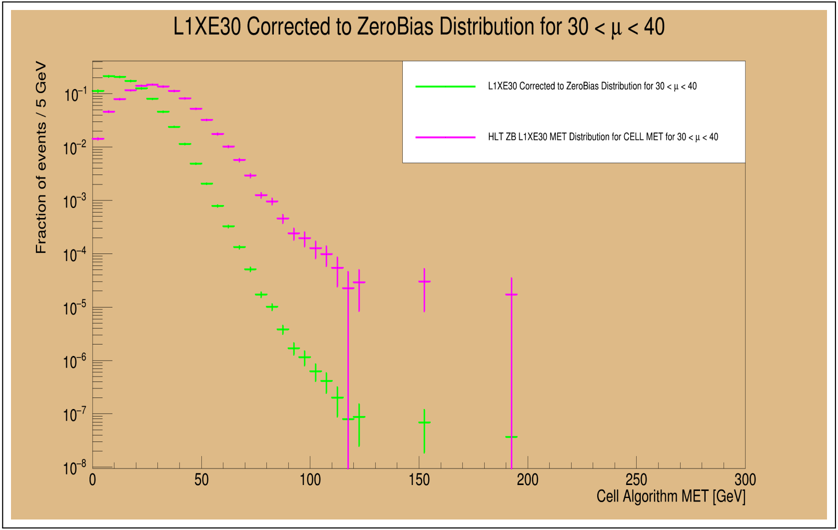
L1xe50 Efficiency Fits
Efficiency
1
10^{-1}
10^{-2}
10^{-3}
0
50
100
150
200
250
300
CELL MET [GeV]
L1XE50 Efficiency Fit for 10 < μ < 20
L1XE50 Efficiency Fit for 20 < μ < 30
L1XE50 Efficiency Fit for 30 < μ < 40
L1XE50 Efficiency Fit for 40 < μ < 50
L1XE50 Efficiency Fit for 50 < μ < 60
L1XE50 Efficiency Fit for 60 < μ < 70
L1XE50 Efficiency Fit for 0 < μ < 10

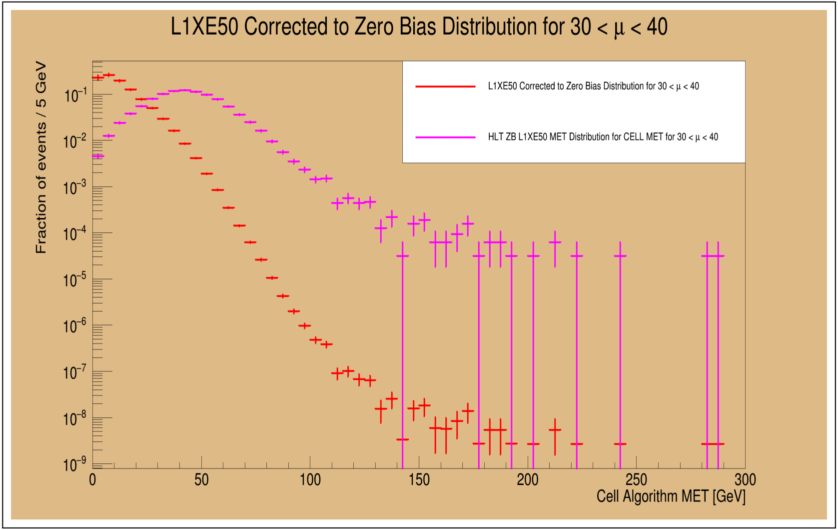
Correcting the HLTnoalg Distribution

- After computing the efficiency curves for the cuts on L1, the curves were used to correct the HLTnoalg distributions that are biased with respect to L1 so that they replicate the unbiased distribution
- In order to do this, it was necessary to multiply by the recorded prescale, and divide by the efficiency used to correct the data
  - For the `HLTnoalg_L1XE30` data, we used the `L1XE30` efficiency curve to correct the distribution
  - For the `HLTnoalg_L1XE50` data we used the `L1XE30` efficiency of the zerobias data, as well as the L1XE50 efficiency of `HLTnoalg_L1XE30` data to correct the distribution

Error Propagation

- The error in each efficiency value is determined by propagating the errors on the parameters of the respective fit function.
- The reconstructed MET distribution includes both the error determined above, and the statistical error.
- Since prescales vary for each bin, must keep track of errors event by event, rather than using ROOTs built-in errors.
- Kept track of the errors on the `L1XE30` corrected curves, as well as the `L1XE50` corrected curves, for each of the mu bins
- There is no error included to reflect the fact that the error function may not be a perfect model. Therefore, in final distribution, zerobias data is kept to as high an MET as possible and similarly for keeping `HLTnoalg_L1XE30` versus `HLTnoalg_L1XE50`

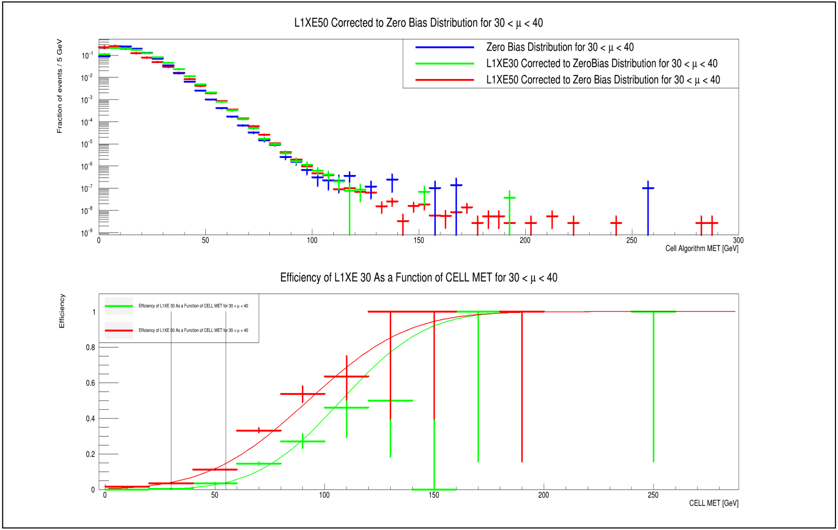

L1XE30 Corrected to ZeroBias Distribution for 30 < μ < 40
L1XE30 Corrected to ZeroBias Distribution for 30 < μ < 40
HLT ZB L1XE30 MET Distribution for CELL MET for 30 < μ < 40
Fraction of events / 5 GeV
Cell Algorithm MET [GeV]
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
0
50
100
150
200
250
300

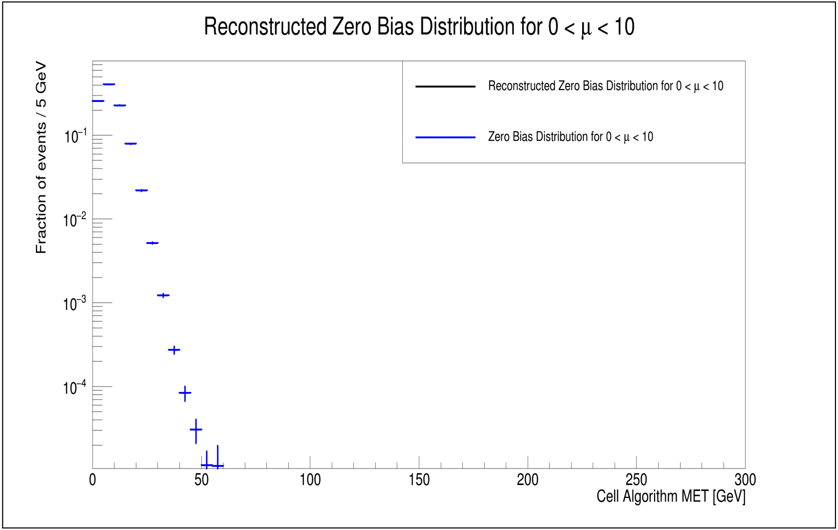


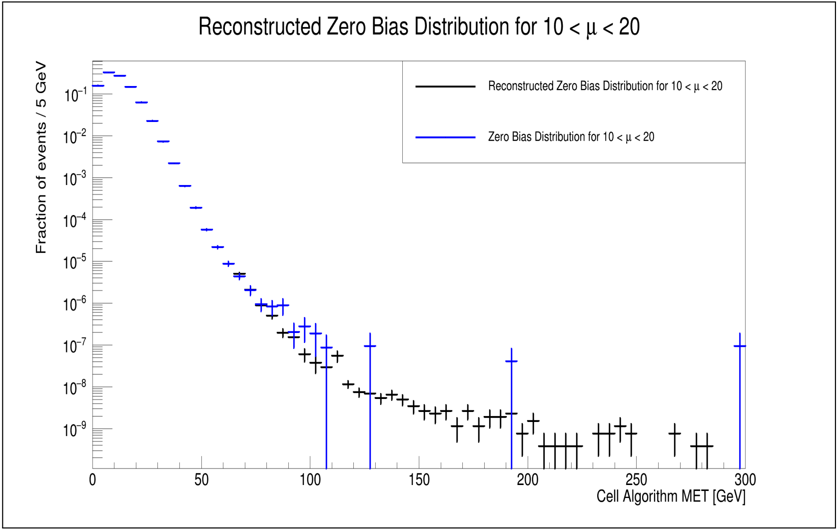
L1XE50 Corrected to Zero Bias Distribution for 30 < μ < 40
L1XE50 Corrected to Zero Bias Distribution for 30 < μ < 40
HLT ZB L1XE50 MET Distribution for CELL MET for 30 < μ < 40
Fraction of events / 5 GeV
Cell Algorithm MET [GeV]

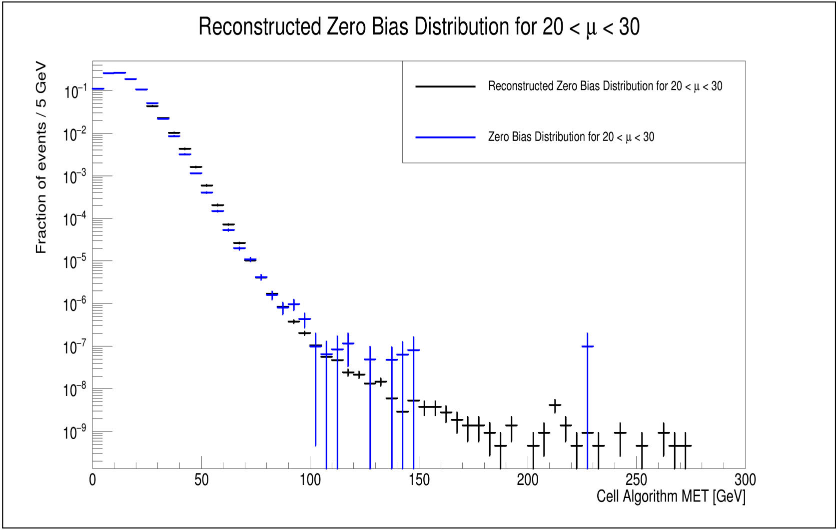
Relative Normalization

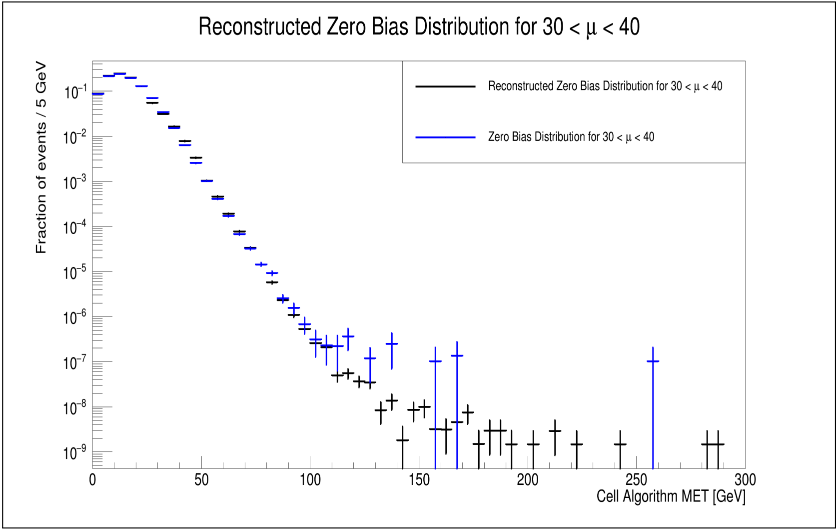
- Because the error bars are larger at low values of MET, it is not sufficient to normalize the entire curve to one. Instead, it was necessary to perform a relative overall normalization between the original zerobias distribution and the corrected curves in order to be able to compare the shapes more easily.
- The relative normalization factor was computed by taking a weighted average of ratios computed in the region where the slopes look most parallel.
- The following slides show all 3 sets of data points after all corrections and the relative normalization (from the corrected HLTnoalg data to the unbiased distribution) have been done.
- The vertical black lines on the bottom efficiency curve plots show where I've stopped using the zerobias data and started using the `HLTnoalg_L1XE30` and `HLTnoalg_L1XE50` data, respectively.

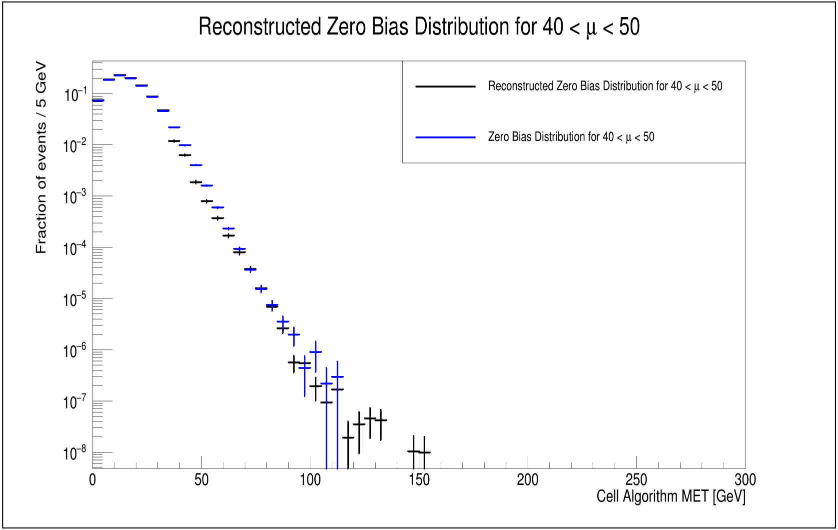

L1XE50 Corrected to Zero Bias Distribution for 30 < μ < 40
Zero Bias Distribution for 30 < μ < 40
L1XE30 Corrected to ZeroBias Distribution for 30 < μ < 40
L1XE50 Corrected to Zero Bias Distribution for 30 < μ < 40
Fraction of events / 5 GeV
Cell Algorithm MET [GeV]
Efficiency of L1XE 30 As a Function of CELL MET for 30 < μ < 40
Efficiency of L1XE 30 As a Function of CELL MET for 30 < μ < 40
Efficiency of L1XE 50 As a Function of CELL MET for 30 < μ < 40
Efficiency
CELL MET [GeV]

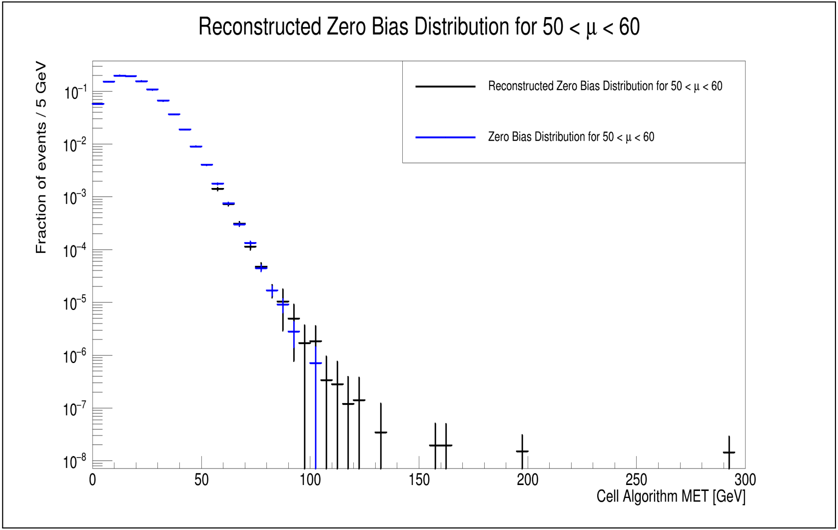

Reconstructed Zero Bias Distribution for 0 < μ < 10
Fraction of events / 5 GeV
Reconstructed Zero Bias Distribution for 0 < μ < 10
Zero Bias Distribution for 0 < μ < 10
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
50
100
150
200
250
300
Cell Algorithm MET [GeV]

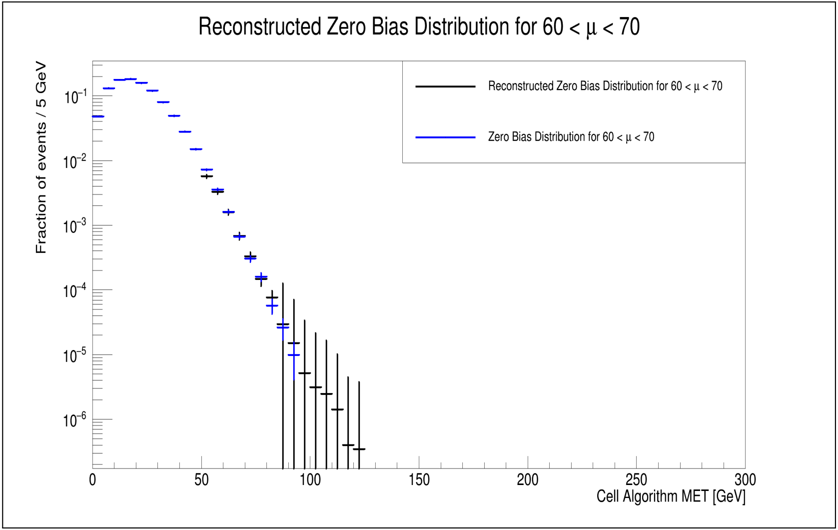

Reconstructed Zero Bias Distribution for 10 < μ < 20
Fraction of events / 5 GeV
Reconstructed Zero Bias Distribution for 10 < μ < 20
Zero Bias Distribution for 10 < μ < 20
Cell Algorithm MET [GeV]


Reconstructed Zero Bias Distribution for 20 < μ < 30
Fraction of events / 5 GeV
Reconstructed Zero Bias Distribution for 20 < μ < 30
Zero Bias Distribution for 20 < μ < 30
Cell Algorithm MET [GeV]
0
50
100
150
200
250
300
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9


Reconstructed Zero Bias Distribution for 30 < μ < 40
Fraction of events / 5 GeV
Reconstructed Zero Bias Distribution for 30 < μ < 40
Zero Bias Distribution for 30 < μ < 40
Cell Algorithm MET [GeV]
0
50
100
150
200
250
300
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}

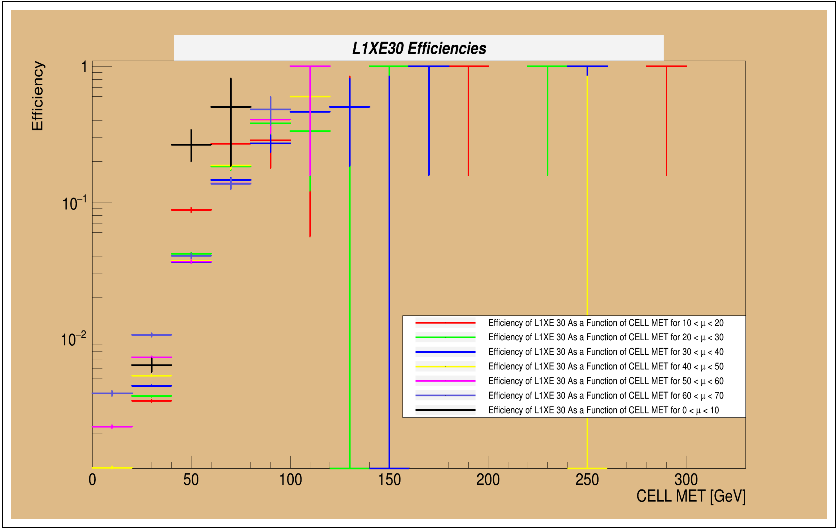

Reconstructed Zero Bias Distribution for 40 < μ < 50
Fraction of events / 5 GeV
Reconstructed Zero Bias Distribution for 40 < μ < 50
Zero Bias Distribution for 40 < μ < 50
Cell Algorithm MET [GeV]
0
50
100
150
200
250
300
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}


Reconstructed Zero Bias Distribution for 50 < μ < 60
Fraction of events / 5 GeV
Reconstructed Zero Bias Distribution for 50 < μ < 60
Zero Bias Distribution for 50 < μ < 60
Cell Algorithm MET [GeV]

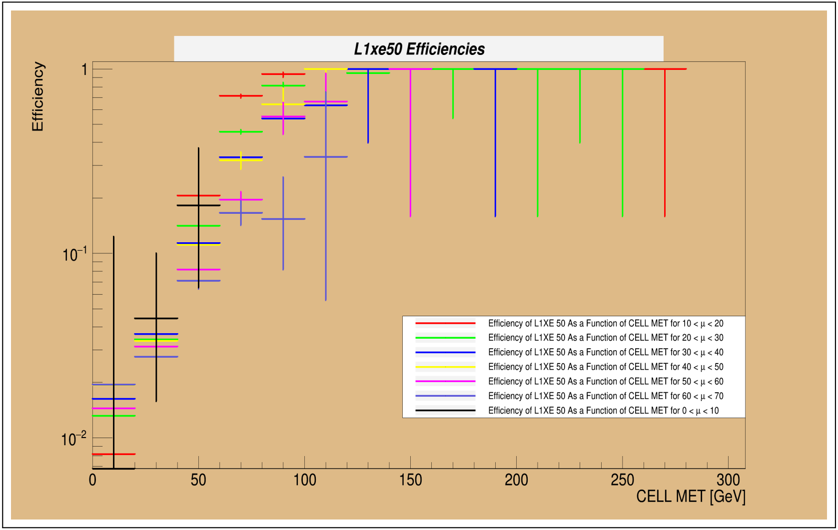

Reconstructed Zero Bias Distribution for 60 < μ < 70
Fraction of events / 5 GeV
Reconstructed Zero Bias Distribution for 60 < μ < 70
Zero Bias Distribution for 60 < μ < 70
Cell Algorithm MET [GeV]
0
50
100
150
200
250
300
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6

Appendix

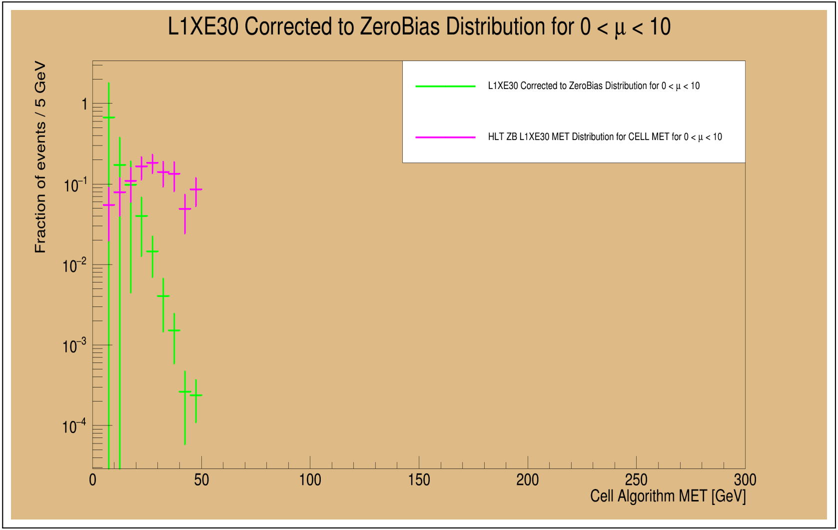
L1XE30 Efficiencies with respect to HLTnoalg_L1ZB Data



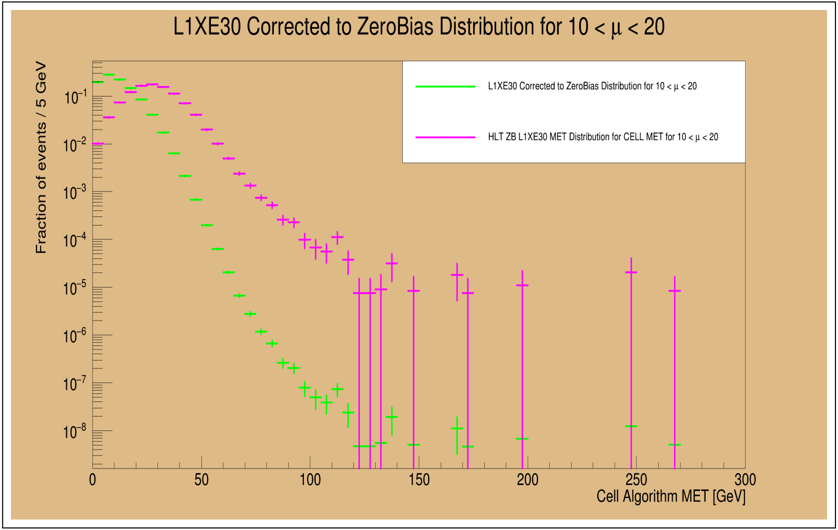
L1XE50 Efficiencies with respect to HLTnoalg_L1XE30 Data



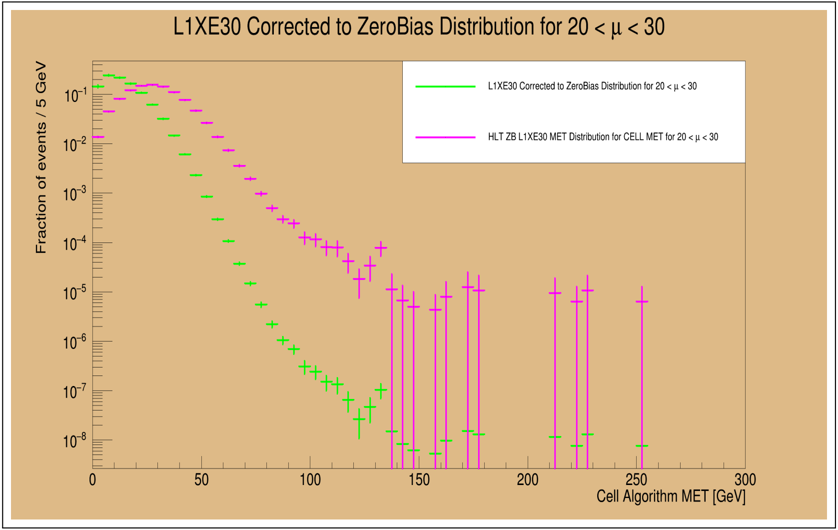
HLTnoalg_L1XE30 Plot for $0 < \mu < 10$



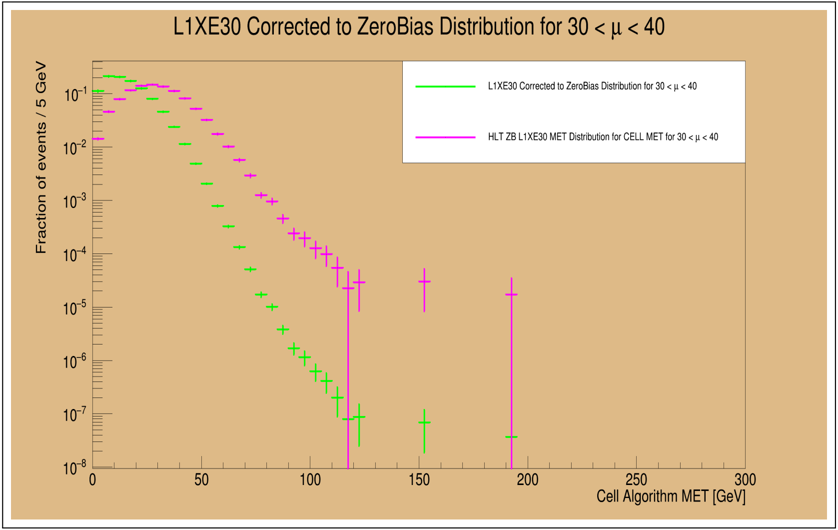
HLTnoalg_L1XE30 Plot for $10 < \mu < 20$



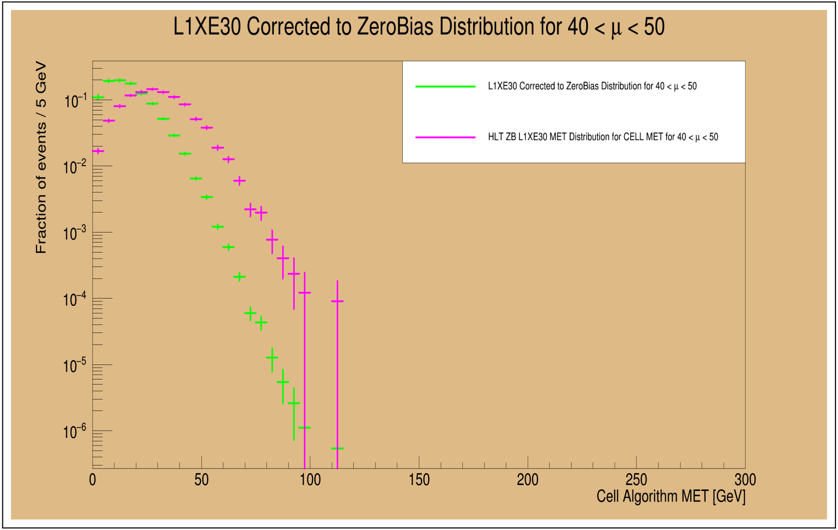
HLTnoalg_L1XE30 Plot for $20 < \mu < 30$



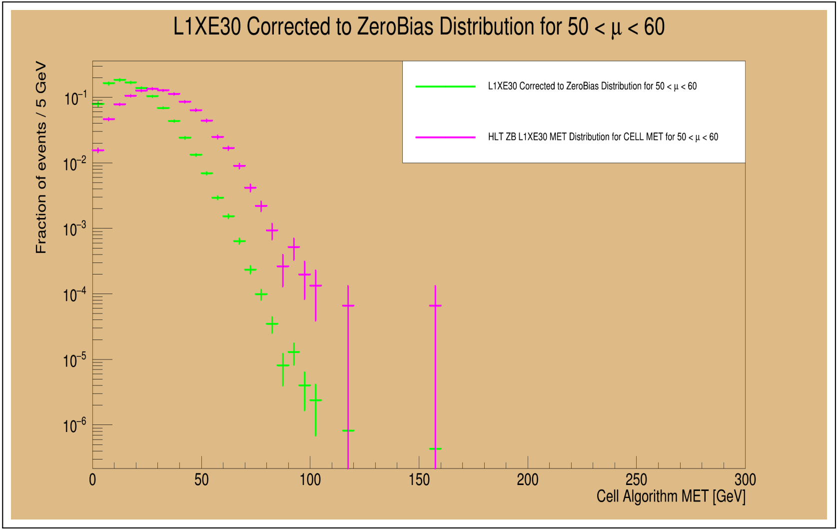
HLTnoalg_L1XE30 Plot for $30 < \mu < 40$



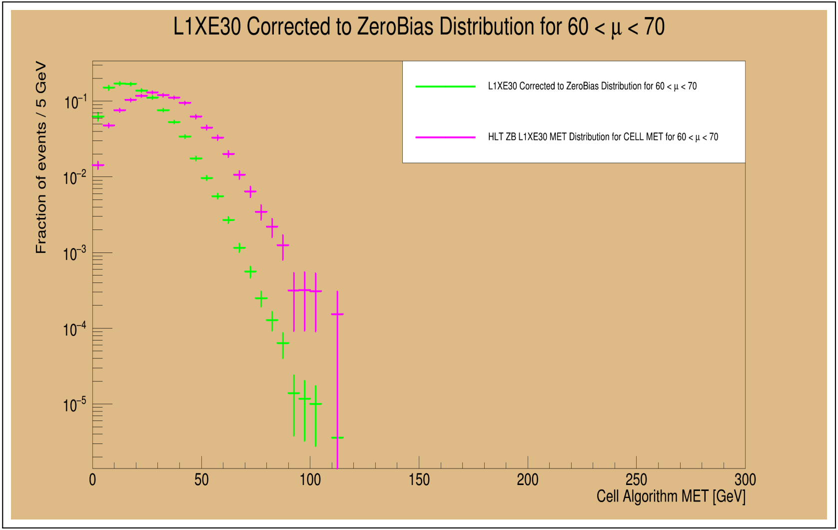
HLTnoalg_L1XE30 Plot for $40 < \mu < 50$



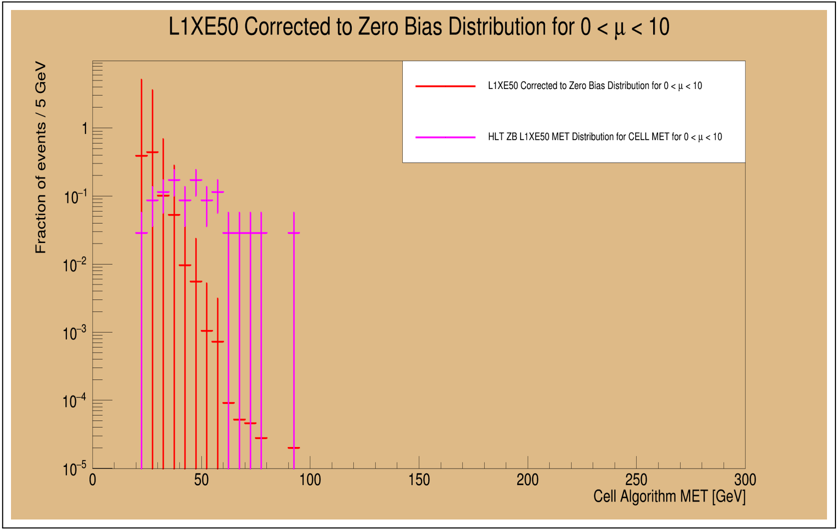
HLTnoalg_L1XE30 Plot for $50 < \mu < 60$



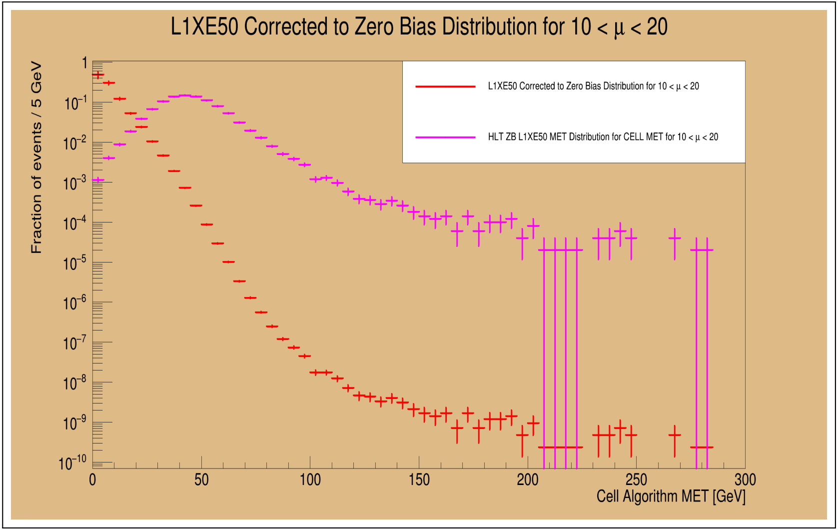
HLTnoalg_L1XE30 Plot for $60 < \mu < 70$



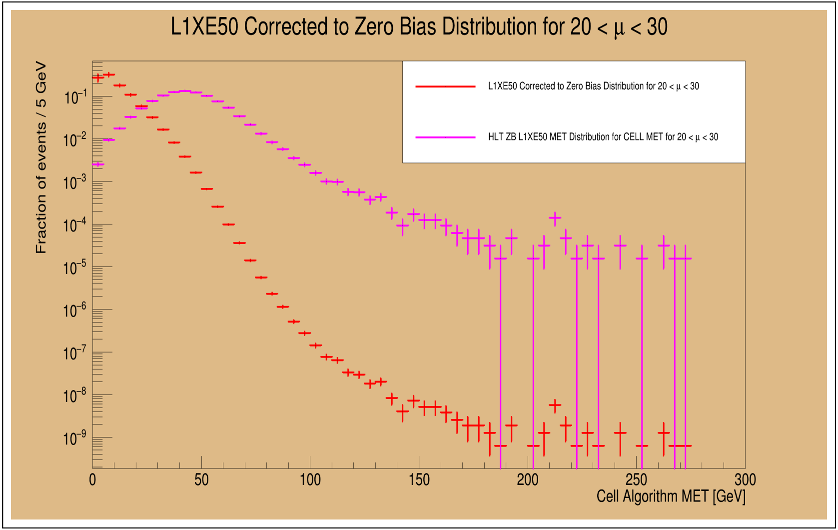
HLTnoalg_L1XE50 Plot for $0 < \mu < 10$



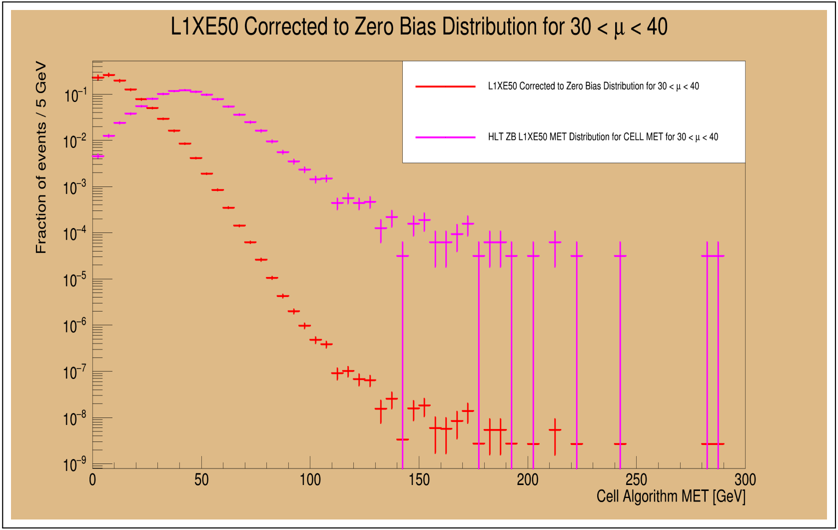
HLTnoalg_L1XE50 Plot for $10 < \mu < 20$



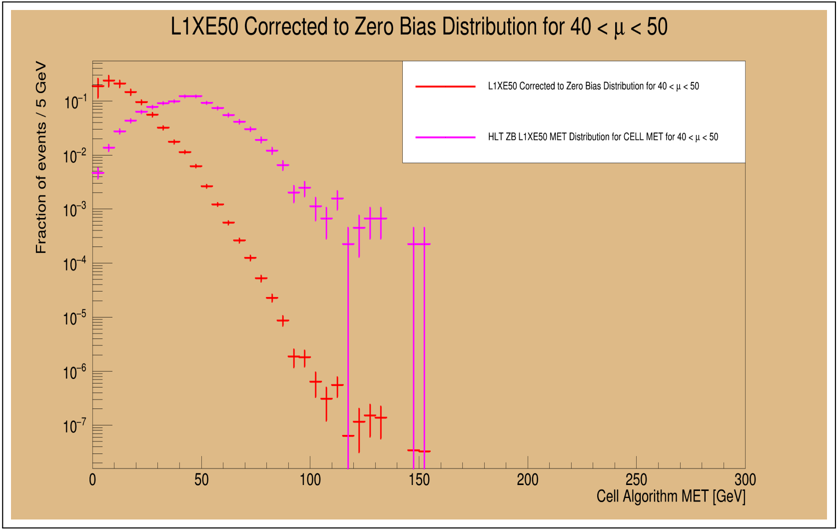
HLTnoalg_L1XE50 Plot for $20 < \mu < 30$



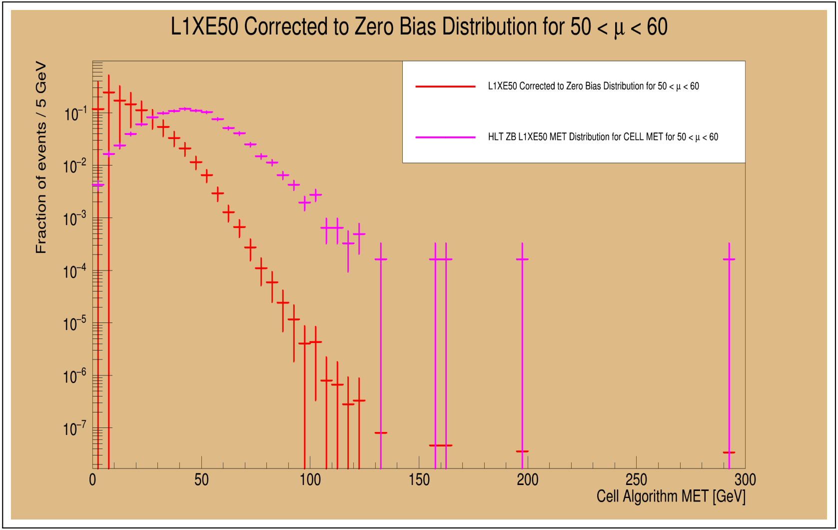
HLTnoalg_L1XE50 Plot for $30 < \mu < 40$



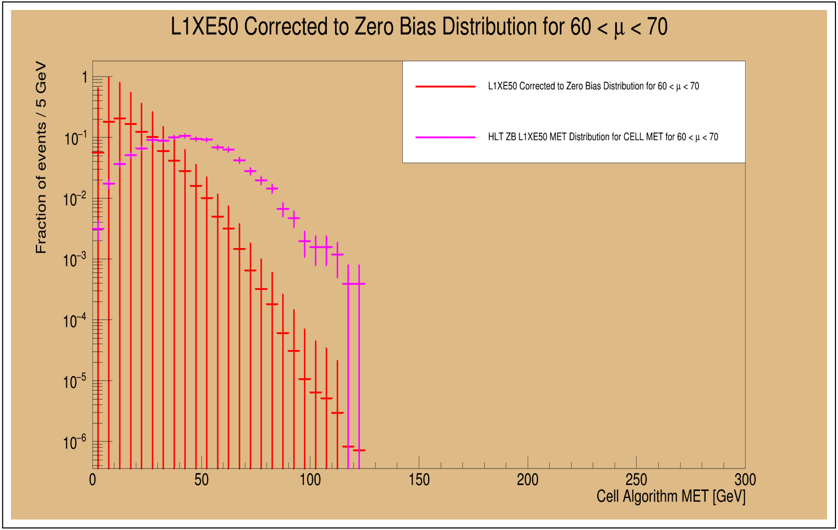
HLTnoalg_L1XE50 Plot for $40 < \mu < 50$



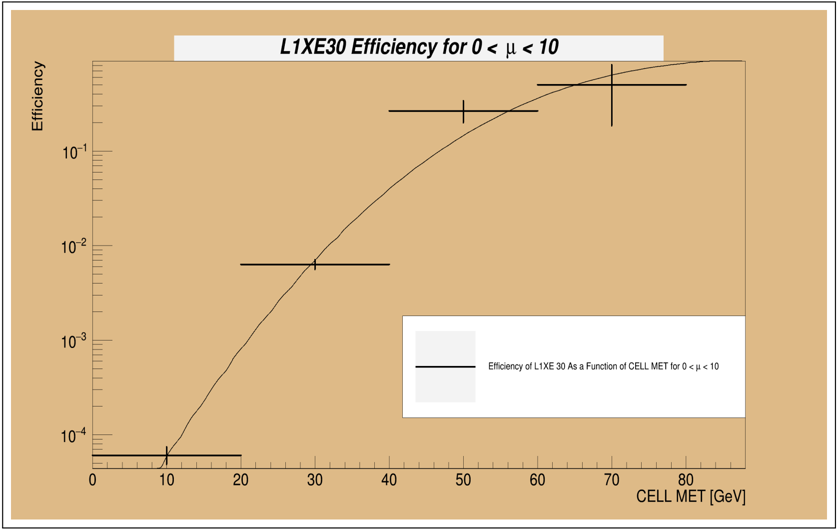
HLTnoalg_L1XE50 Plot for $50 < \mu < 60$



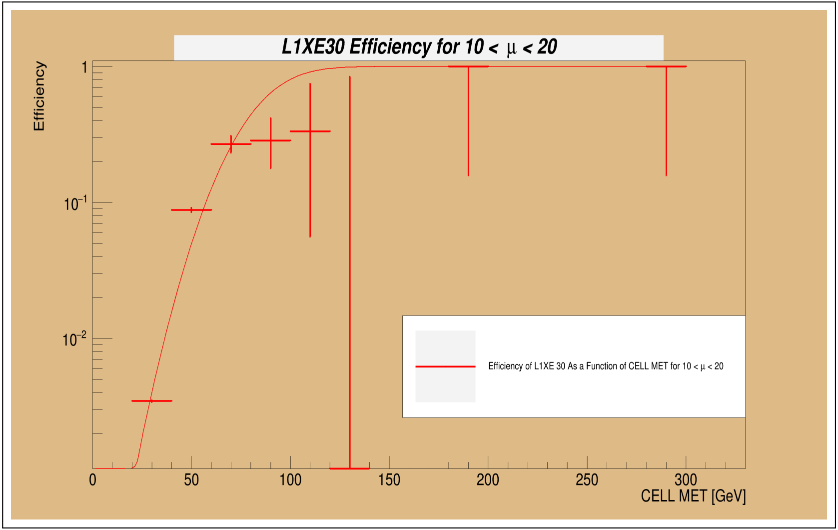
HLTnoalg_L1XE50 Plot for $60 < \mu < 70$



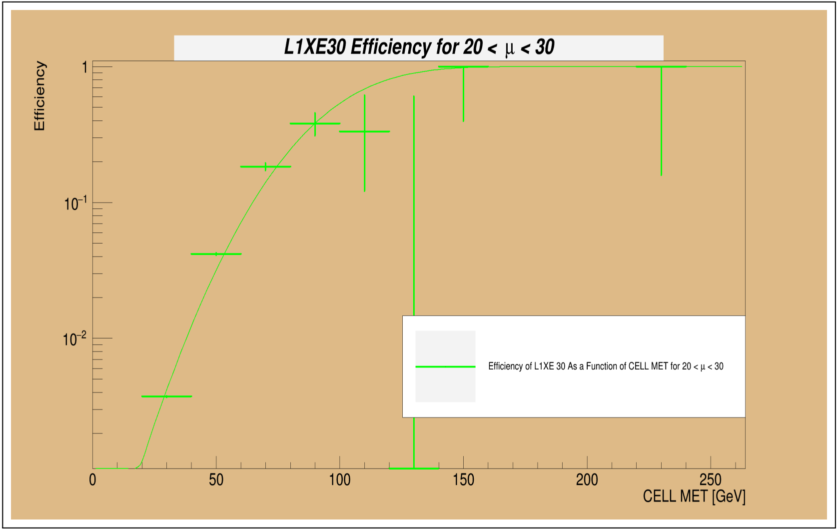
L1XE30 Efficiency Curve Plot for $0 < \mu < 10$



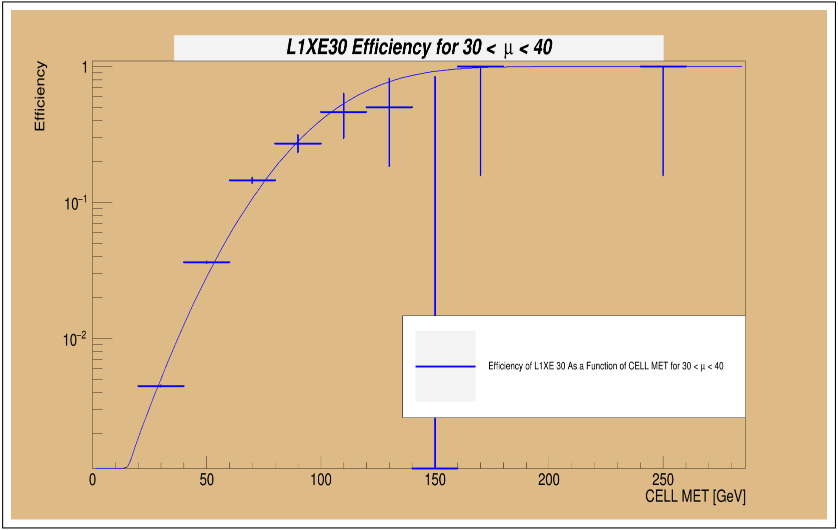
L1XE30 Efficiency Curve Plot for $10 < \mu < 20$



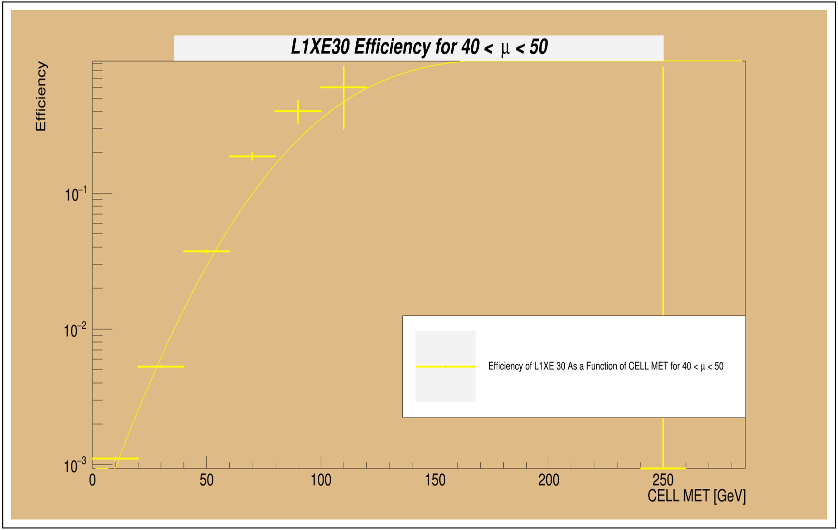
L1XE30 Efficiency Curve Plot for $20 < \mu < 30$



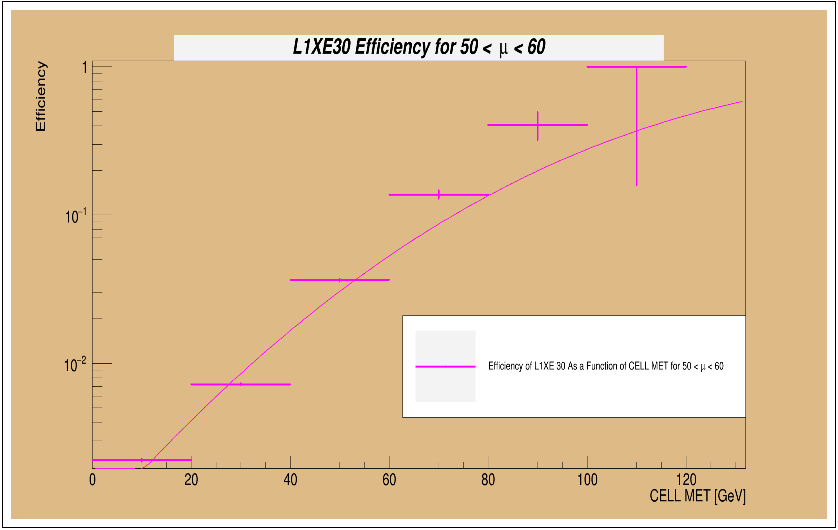
L1XE30 Efficiency Curve Plot for $30 < \mu < 40$



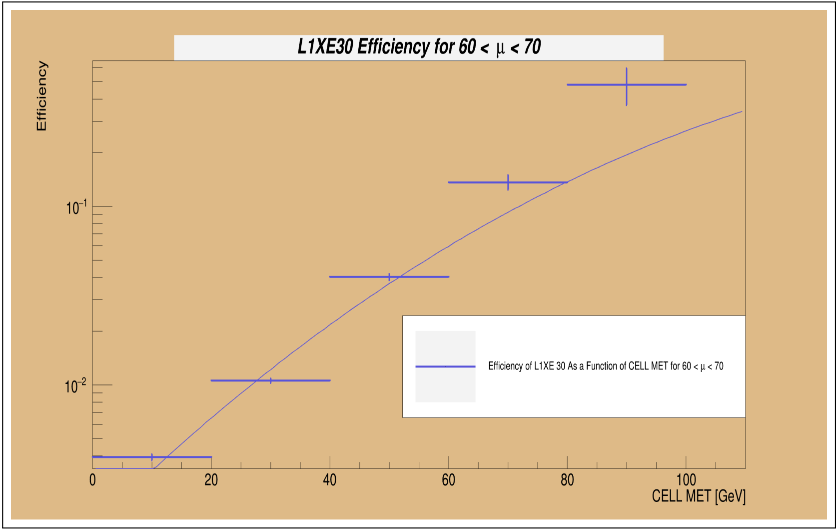
L1XE30 Efficiency Curve Plot for $40 < \mu < 50$



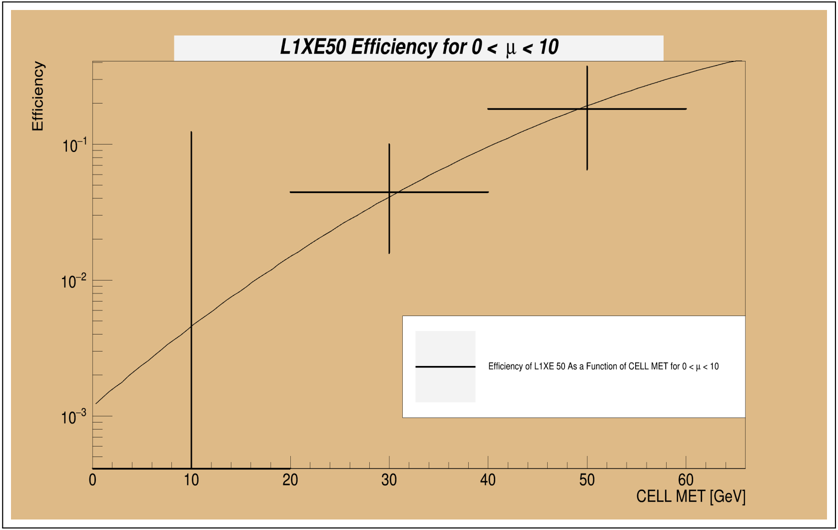
L1XE30 Efficiency Curve Plot for $50 < \mu < 60$



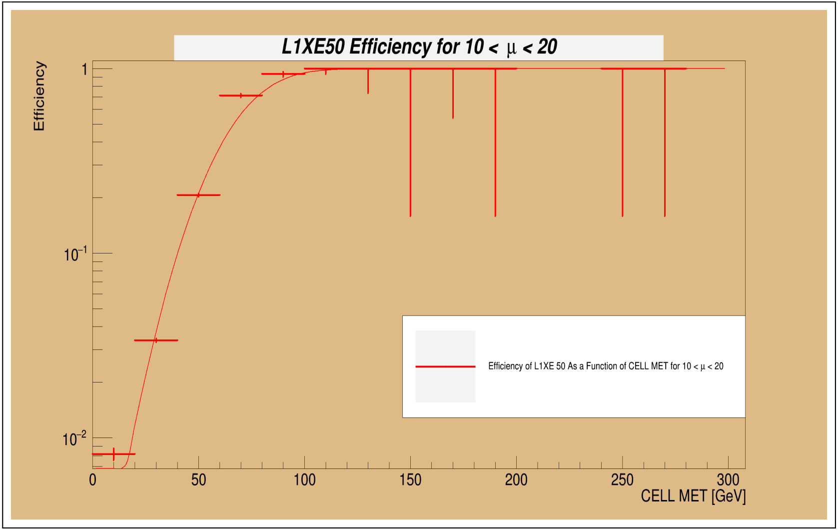
L1XE30 Efficiency Curve Plot for $60 < \mu < 70$



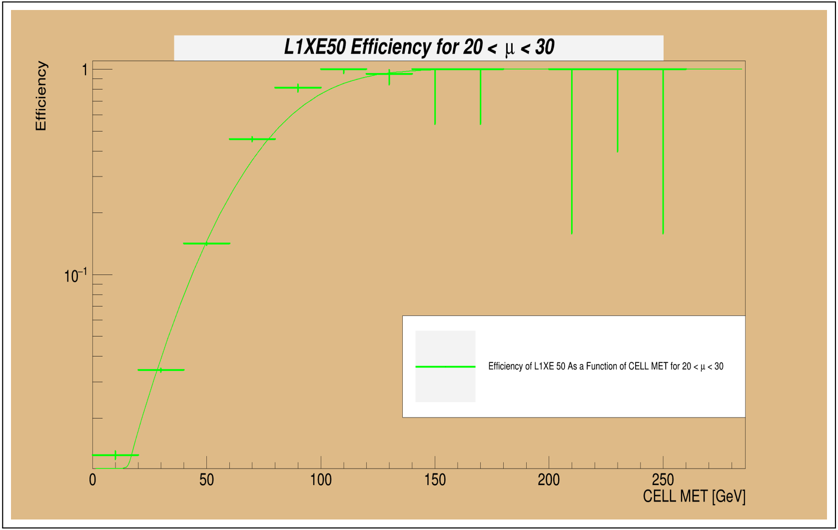
L1XE50 Efficiency Curve Plot for $0 < \mu < 10$



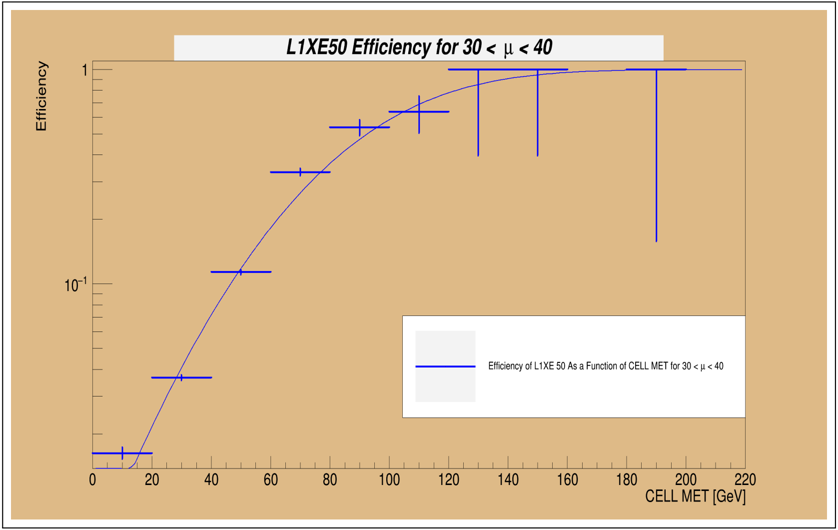
L1XE50 Efficiency Curve Plot for $10 < \mu < 20$



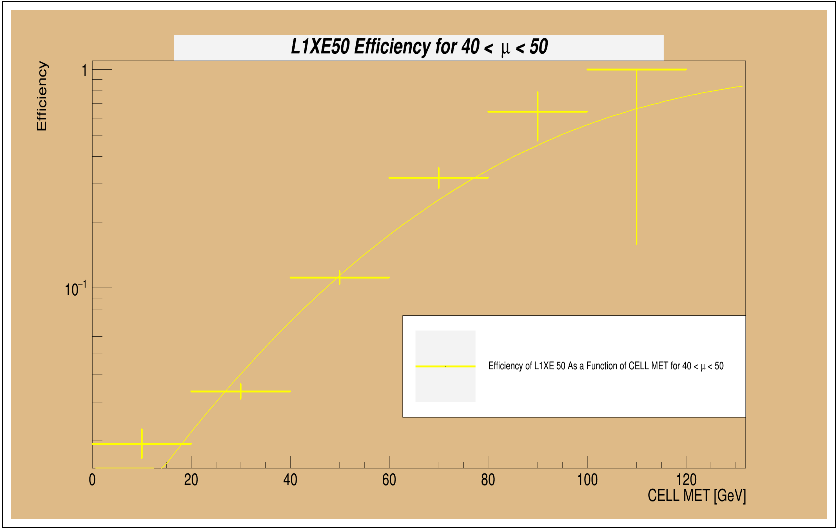
L1XE50 Efficiency Curve Plot for $20 < \mu < 30$



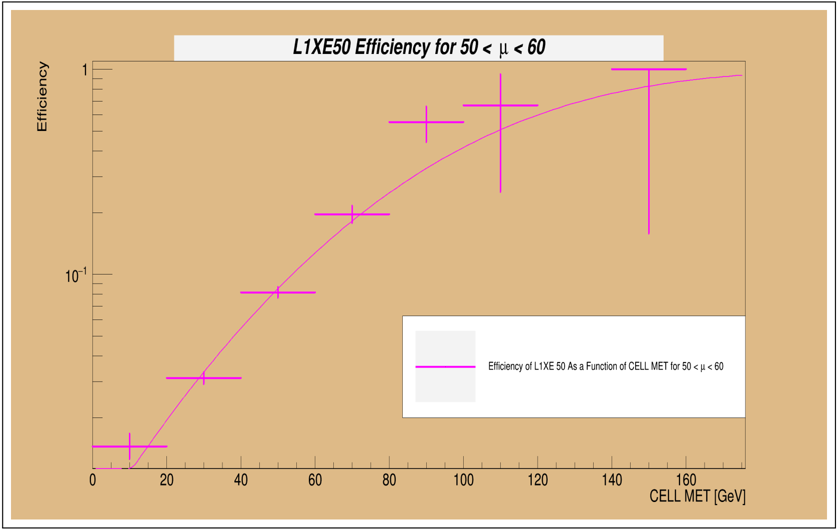
L1XE50 Efficiency Curve Plot for $30 < \mu < 40$



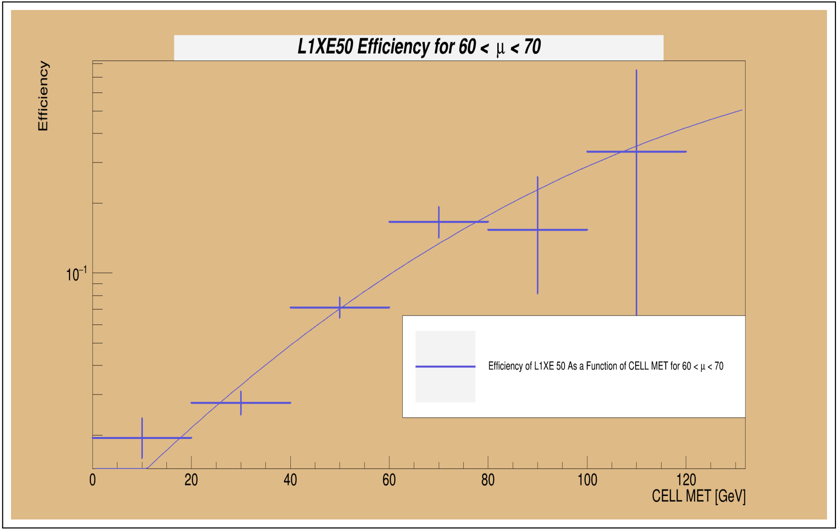
L1XE50 Efficiency Curve Plot for $40 < \mu < 50$



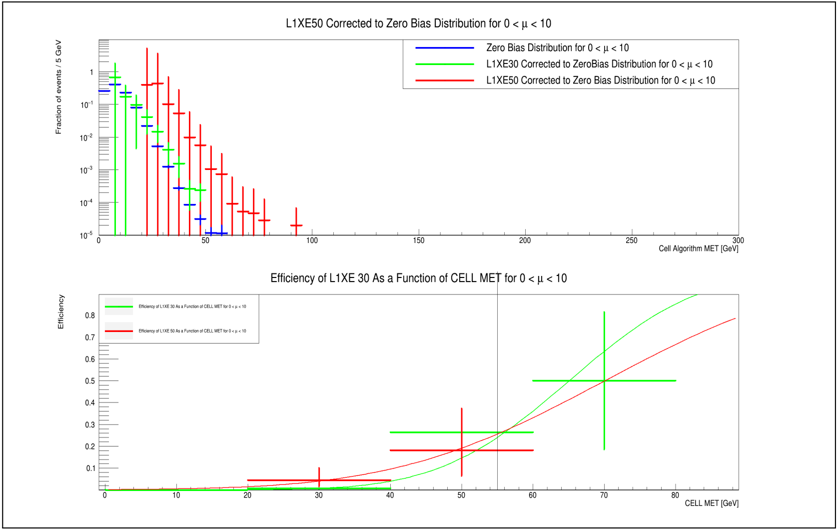
L1XE50 Efficiency Curve Plot for $50 < \mu < 60$



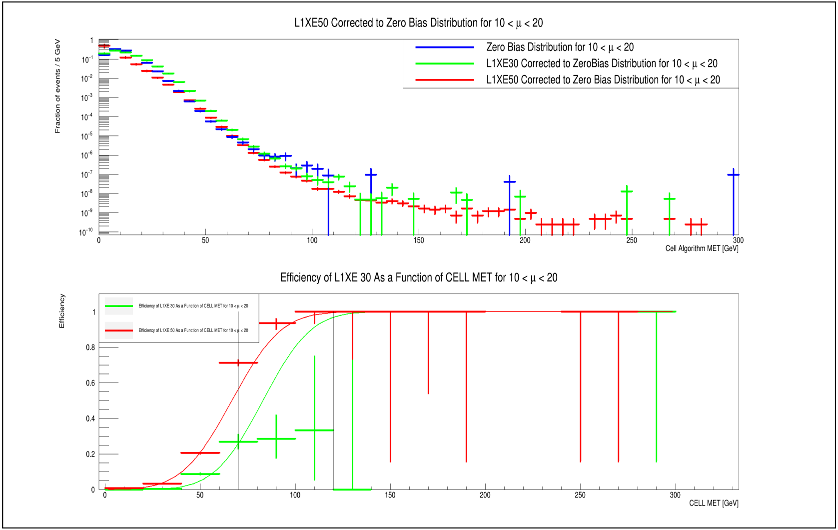
L1XE50 Efficiency Curve Plot for $60 < \mu < 70$



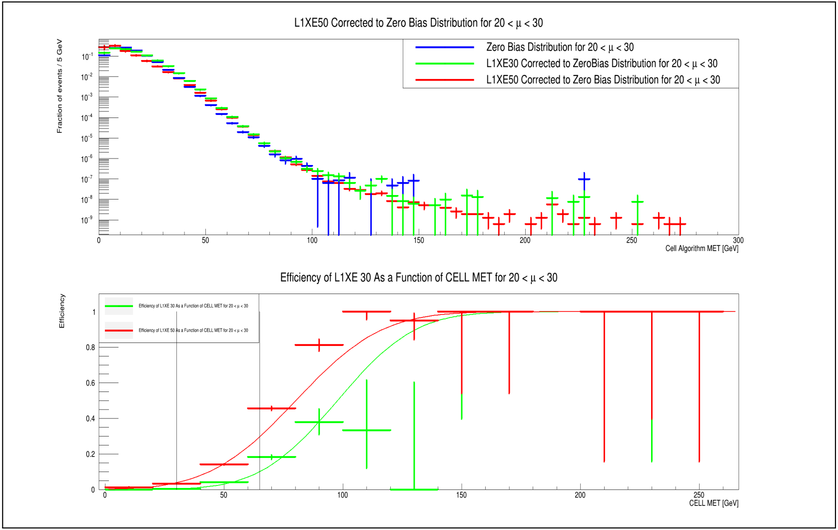
Unbiased Distributions for $0 < \mu < 10$



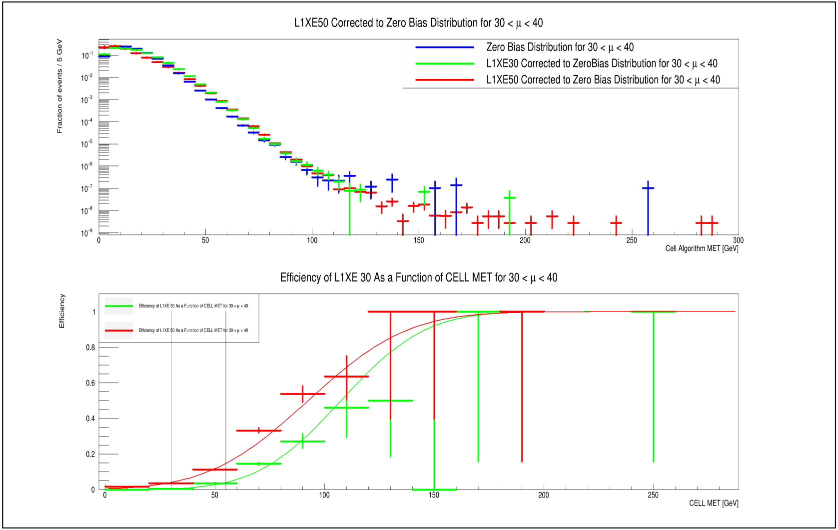
Unbiased Distributions for $10 < \mu < 20$



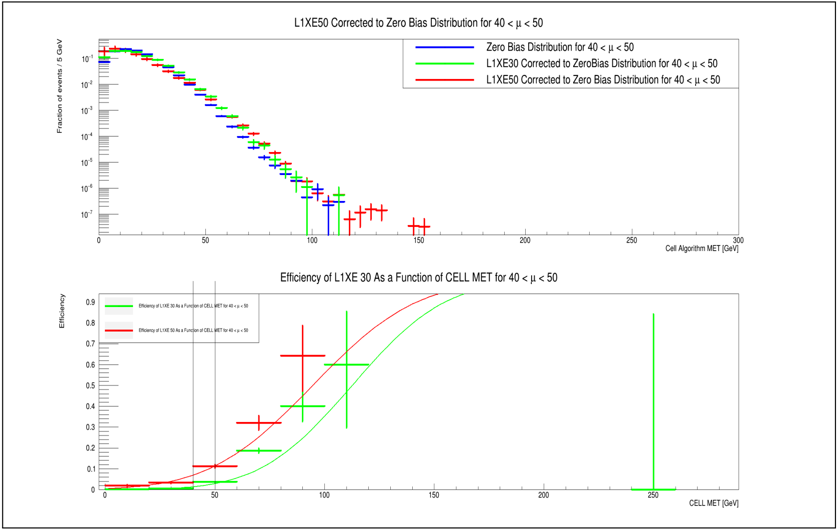
Unbiased Distributions for $20 < \mu < 30$



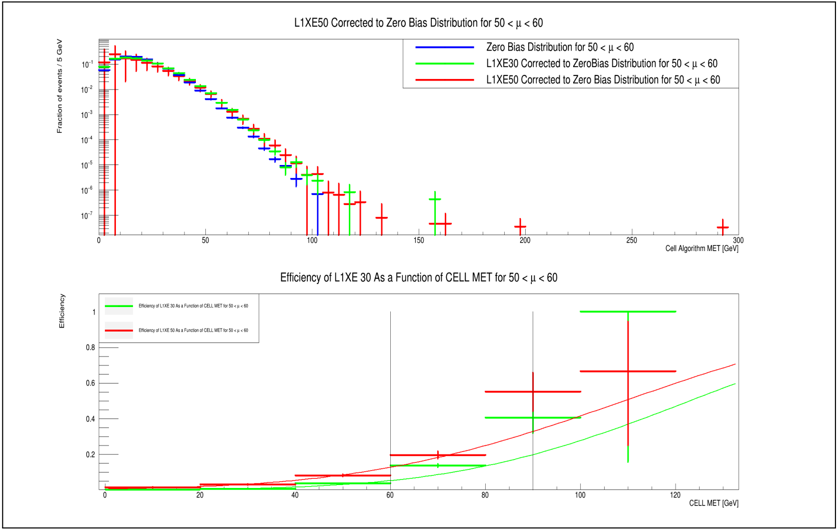
Unbiased Distributions for $30 < \mu < 40$



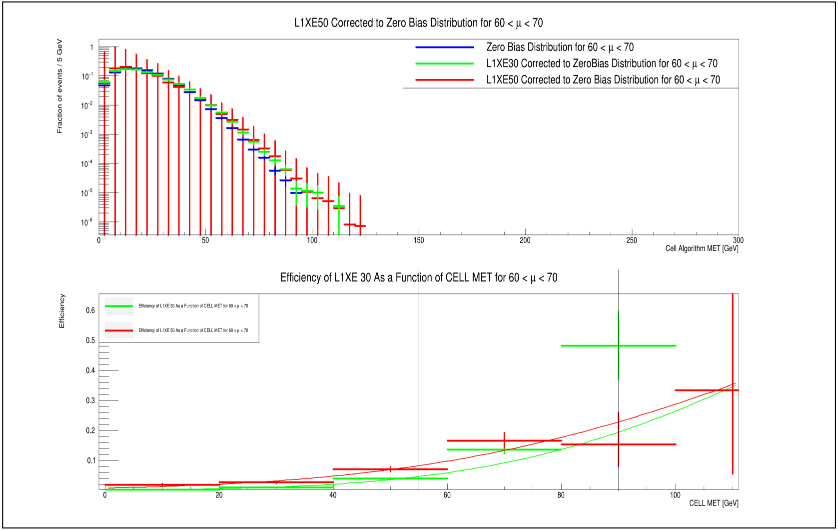
Unbiased Distributions for $40 < \mu < 50$



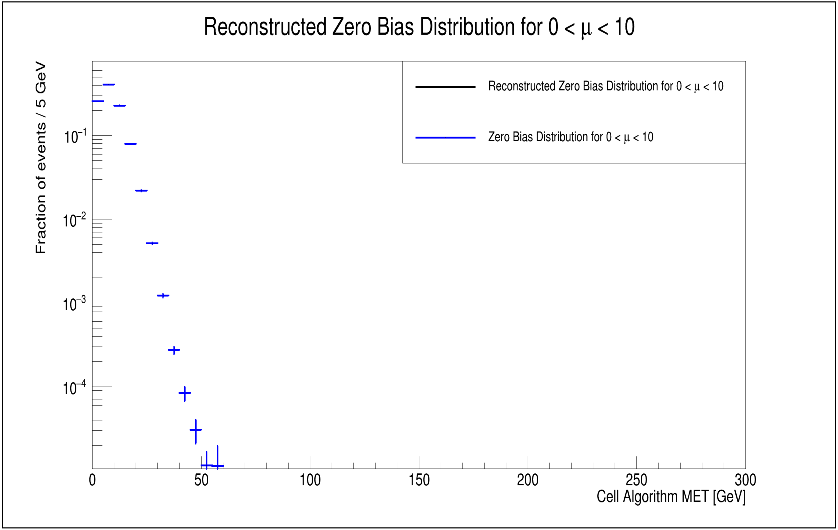
Unbiased Distributions for $50 < \mu < 60$



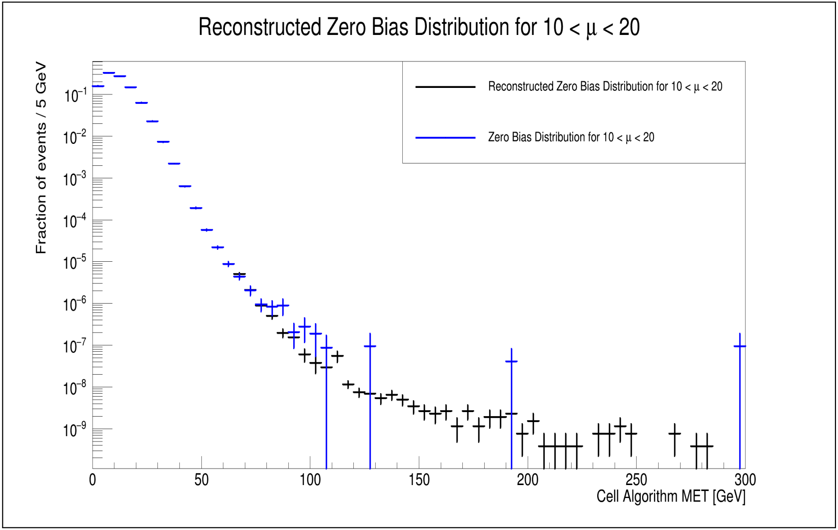
Unbiased Distributions for $60 < \mu < 70$



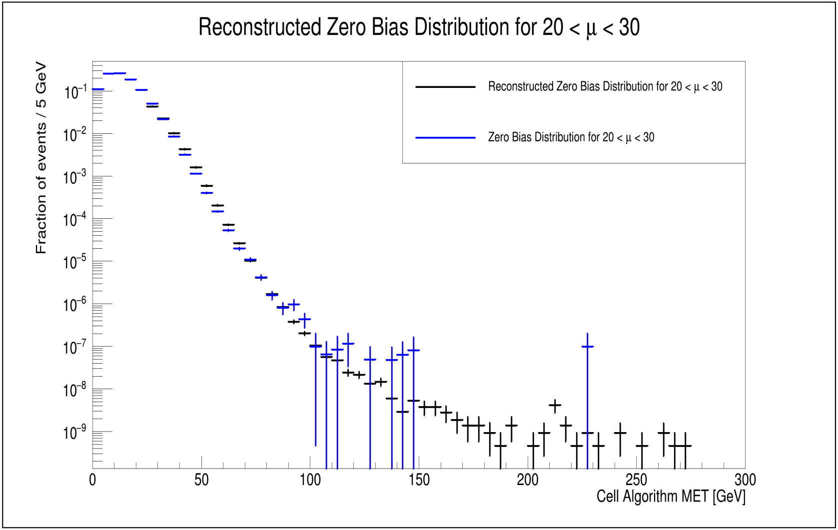
Reconstructed Unbiased CELL MET Distribution for $0 < \mu < 10$



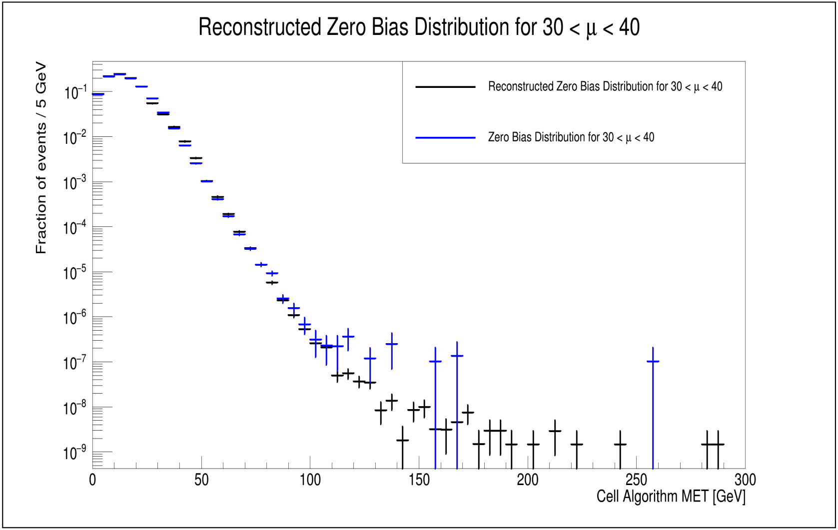
Reconstructed Unbiased CELL MET Distribution for $10 < \mu < 20$



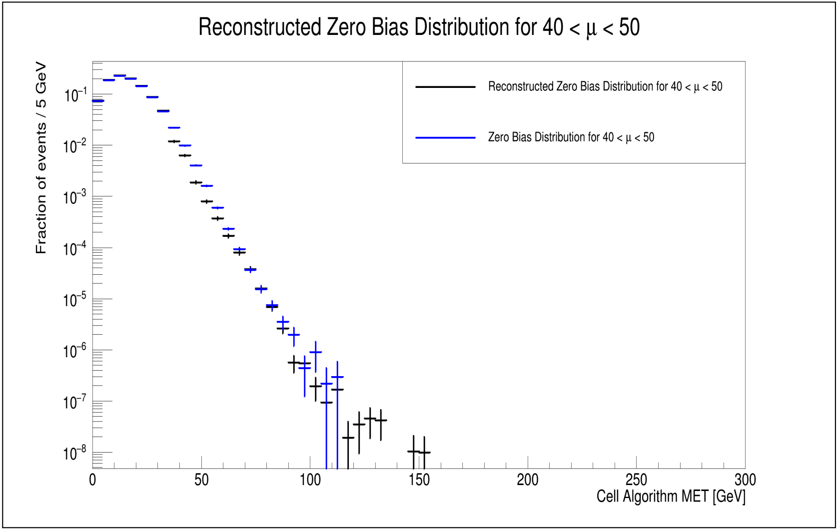
Reconstructed Unbiased CELL MET Distribution for $20 < \mu < 30$



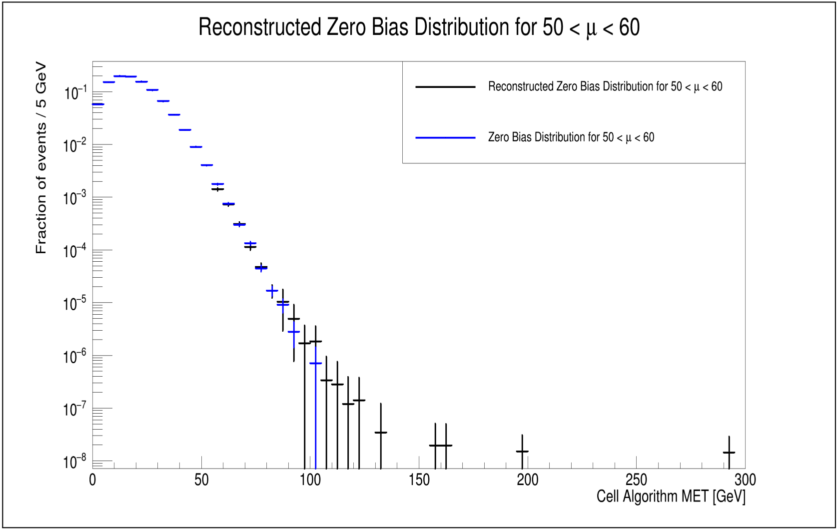
Reconstructed Unbiased CELL MET Distribution for $30 < \mu < 40$



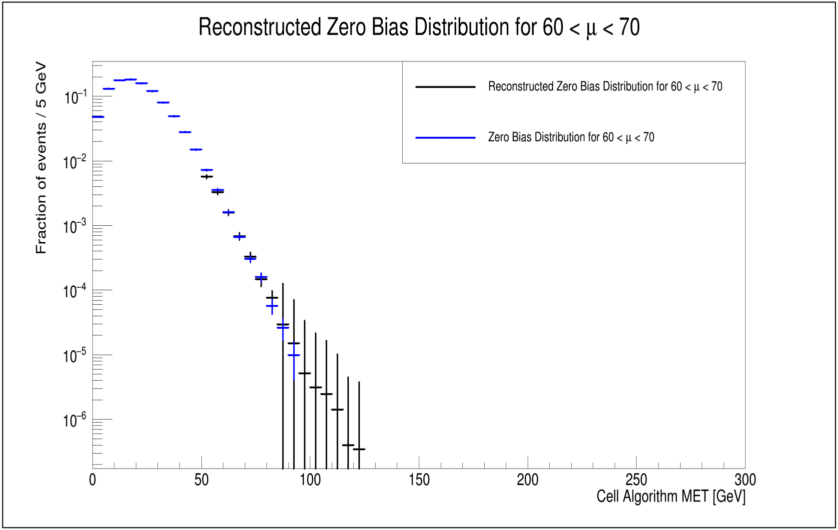
Reconstructed Unbiased CELL MET Distribution for $40 < \mu < 50$



Reconstructed Unbiased CELL MET Distribution for $50 < \mu < 60$



Reconstructed Unbiased CELL MET Distribution for $60 < \mu < 70$



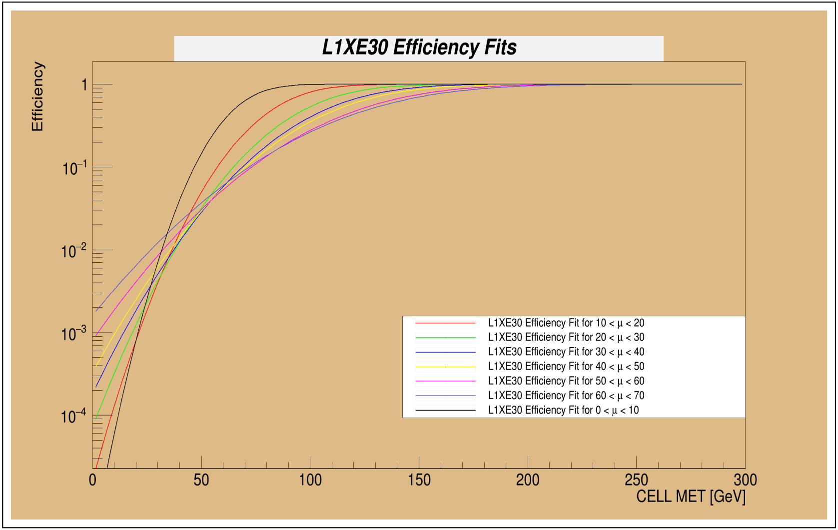
Efficiency Fit Functional Form

$$f(x) = \frac{1}{2}\left(1 + \mathrm{Erf}\left(\frac{ax + b - \mathrm{L1XE}}{\sigma\sqrt{2}}\right)\right) \tag{2}$$

Relative Normalization Functional Form

$$\hat{f}_{MLE} = \frac{\sum_{i=1}^{k} \frac{1}{\sigma_i^2} f_i}{\sum_{i=1}^{k} \frac{1}{\sigma_i^2}} \quad (3)$$

L1XE30 Efficiency Fits with respect to HLTnoalg_L1ZB Data



L1XE50 Efficiency Fits with respect to HLTnoalg_L1XE30 Data

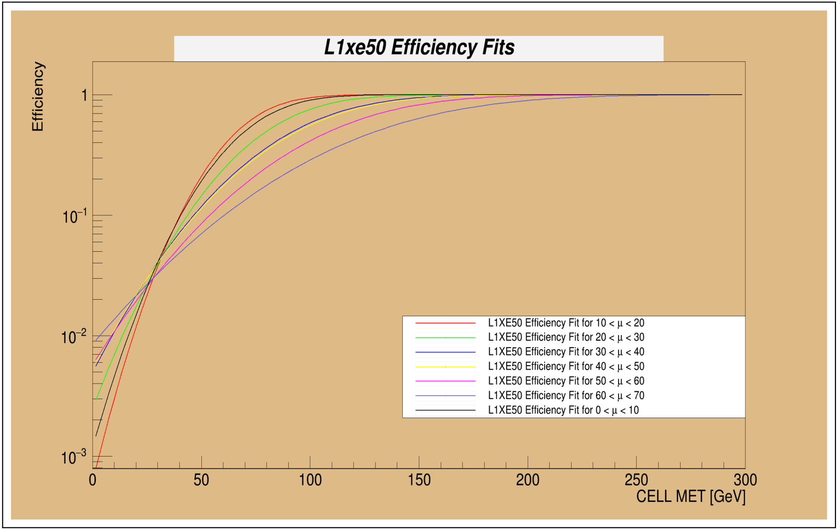


Table: Fit Parameter Table

a	b	σ	L1XE	μ bin
0.536043	-4.88401	7.63437	30	0
0.449818	18.4754	10.3507	50	0
0.40883	-3.87341	8.13195	30	1
0.505088	16.3944	10.3677	50	1
0.336915	-2.90115	8.63962	30	2
0.345437	22.3296	9.83129	50	2
0.29943	-2.17211	9.01473	30	3
0.277972	24.32	9.94887	50	3
0.281092	-1.63701	9.27598	30	4
0.289215	22.6488	10.6932	50	4
0.2487	-0.58147	9.68806	30	5
0.230607	24.8226	9.95501	50	5
0.231716	0.541431	9.99171	30	6
0.183126	26.0774	10.0148	50	6