The top mass at the ttbar threshold with CEPC

Update after Internal Review

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on behalf of

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Q1: Which mass scheme is used in the analysis setup?

In both the CEPC and FCC-ee analysis setups, the top quark mass is defined using the PS (Potential-Subtracted) mass scheme, which is well-suited for threshold measurements due to its reduced sensitivity to renormalon ambiguities.

- To avoid IR renormalon ambiguities, the PS shift (PSS) mass scheme is applied by default in the package

$$\boxed{m_t^{\mathrm{PS}} = 171.5\,\mathrm{GeV}, \qquad \alpha_s(m_Z) = 0.1184}$$

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A detailed study on the prospects for a $\mathrm{t\bar{t}}$ threshold scan in $\mathrm{e^+e^-}$ collisions

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Abstract: A scan of the beam energy across the top quark pair ($\mathrm{t\bar{t}}$) production threshold is part of the program of future Higgs, top, and electroweak factory projects. In this paper, we provide projections for the achievable precision in the top quark mass (m_t), width (Γ_t), and Yukawa coupling (y_t) at the electron-positron ($\mathrm{e^+e^-}$) stage of the Future Circular Collider (FCC-ee). The study includes a detailed assessment of parametric and systematic uncertainties, as well as a rigorous estimate of the effect of point-to-point correlations. We project that m_t and Γ_t can be determined with an experimental precision of about 6.8 and 11.5 MeV, respectively, when m_t is defined in the potential-subtracted (PS) scheme. The

Q2: Ensure that the Luminosity Spectrum width matches the CEPC TDR and has not changed

At CEPC, LS is modeled by a Gaussian distribution and its width σ_{LS} is a function of centre-of-mass energy:

$$\sigma_{LS} = 0.51 \times \left(\frac{\sqrt{s}}{360}\right)^2$$

We have verified this formula in consultation with the CEPC accelerator team and confirmed its consistency with the CEPC TDR, so no modification is needed.

Q3: How do the uncertainties scale when increasing the luminosity from 100 fb^{-1} to 410 fb^{-1}, compared to the FCC-ee

CPEC result L = 100 fb^{-1}

Source	m_{top} precision (MeV) Optimistic	Conservative
Statistics	7.4	7.4
Theory	8	24
Quick scan	2	2
α_S	16	16
Top width	5	5
Experimental efficiency	4	44
Background	1	3
Beam energy	2	2
Luminosity spectrum	3	6
Total(without theory)	19	48
Total	21	54

CPEC result L = 410 fb^{-1}

Source	m_{top} precision (MeV) Optimistic	Conservative
Statistics	3.6	3.6
Theory	8	24
Quick scan	2	2
α_S	16	16
Top width	5	5
Experimental efficiency	4	44
Background	1	3
Beam energy	2	2
Luminosity spectrum	3	6
Total(without theory)	18	47
Total	20	53

Fcc-ee 2D fit result L = 410 fb^{-1}

Uncertainty source	m_t^{PS} [MeV]	Γ_t [MeV]	Input values
Experimental (stat. ×1.2)	4.3	10.4	$L = 410\,\text{fb}^{-1}$ (FCC-ee)
Parametric y_t	4.2	3.6	$\delta y_t = 3\%$
Parametric α_S	2.2	1.7	$\delta\alpha_S(m_Z^2) = 10^{-4}$
Luminosity calibration (uncorr.)	0.5	1.0	$\delta L/L = 0.1\%$
Luminosity calibration (corr.)	0.4	0.4	$\delta L/L = 0.05\%$
Beam energy calibration (uncorr.)	1.2	1.8	$\delta\sqrt{s} = 5\,\text{MeV}$ [36, 37]
Beam energy calibration (corr.)	1.2	0.1	$\delta\sqrt{s} = 2.5\,\text{MeV}$
Beam energy spread (uncorr.)	0.3	0.8	$\delta\Delta E = 1\%$ [36]
Beam energy spread (corr.)	0.1	1.1	$\delta\Delta E = 0.5\%$
Total profiled	6.8	11.5	
Theory, unprofiled (scale)	35	25	N^3LO NR-QCD [11]

- From our likelihood function, it is evident that changes in luminosity only affect the statistical uncertainty.
- The results at 410 fb^{-1} show a twofold improvement compared to those at 100 fb^{-1}, slightly outperforming the FCC-ee expectations.

$$\mathcal{L} = \prod_{i=1}^{N} P(D|\sigma_{t\bar{t}}(m_{top}, \Gamma_{top}, \alpha_S, \sqrt{s_i}) \times L_i \times \epsilon)$$

Q4: try to use full-sim sample to do the analysis

- use FinalPIDSvc 98% WP to get pid_ele & pid_muon
- get p4 D_0 Z_0 D_0_err Z_0_err from leptons in PFO
- reconstruct ele (pid == 11) muon (pid == 13)

```
const edm4hep::ReconstructedParticleCollection* PFO = nullptr;
try {
  PFO = m_PFOColHdl.get();
} catch (GaudiException& e) {
  debug() << "Collection " << m_PFOColHdl.fullKey()
          << " is unavailable in event " << _nEvt << endmsg;
  return StatusCode::SUCCESS;
}
```

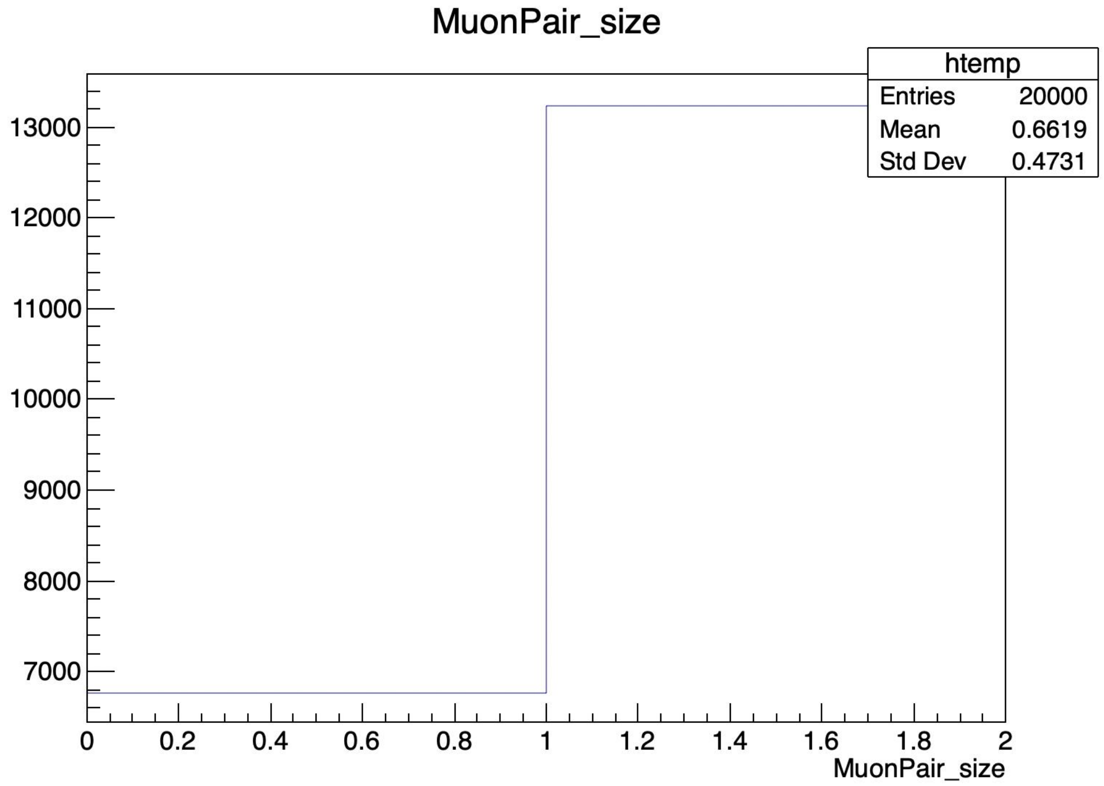
- use this variables to do lepton preselection like fast-sim
  - 1. Select events with: E = p4.E( ) > 12 IPS = $\mathrm{sqrt}\{ (D_0 / D_0\_err)^2 + (Z_0 / Z_0\_err)^2 \} < 3.3$
  - 2. Select the maximum E lepton per event as the isolated lepton in sl final state , if it satisfies Condition 1.
  - 3. Events without any lepton satisfying Condition 1 are classified as hh final state candidates.

	fast-sim	full-sim
no cut	20000	20000
1 isolated lepton	13242	13184

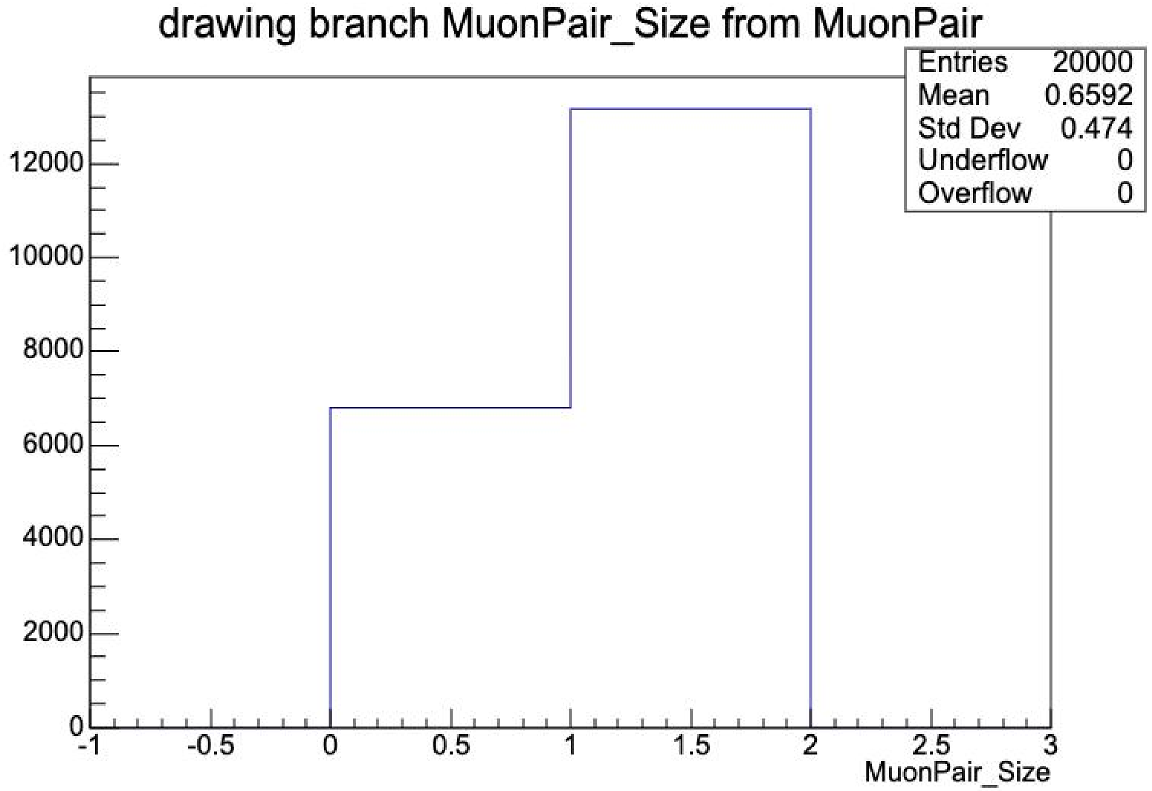
- same lepton preselection (~66%) eff

Q4: try to use full-sim sample to do the analysis

fast-sim

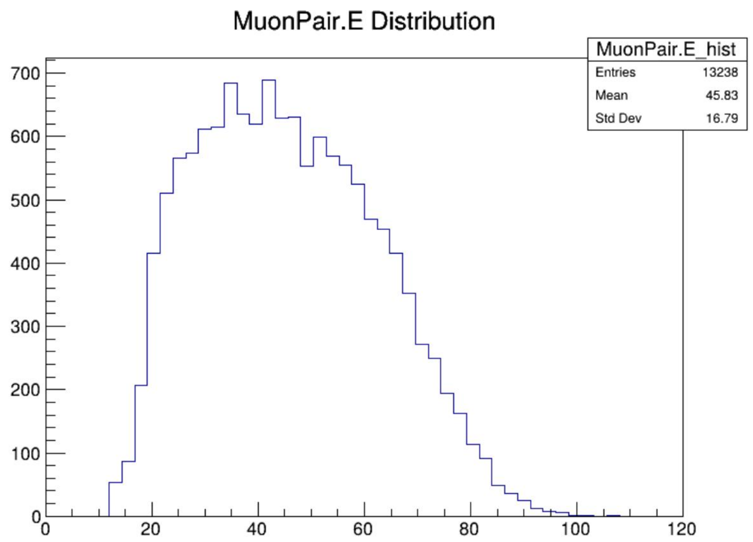


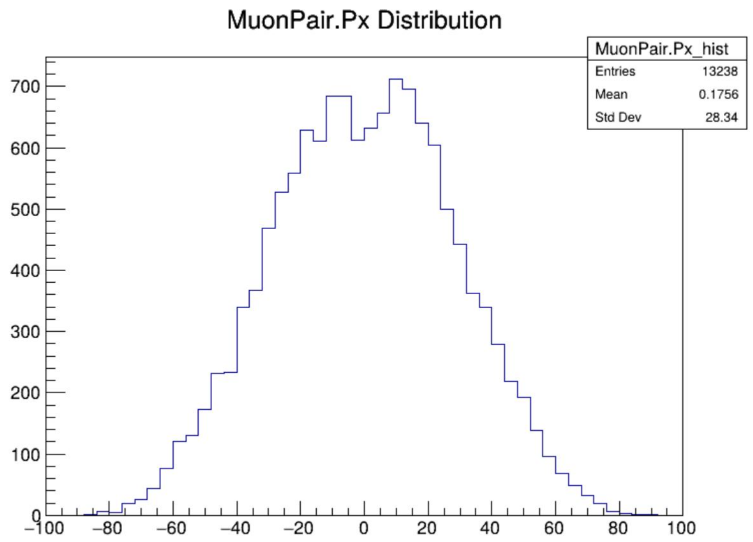
full-sim



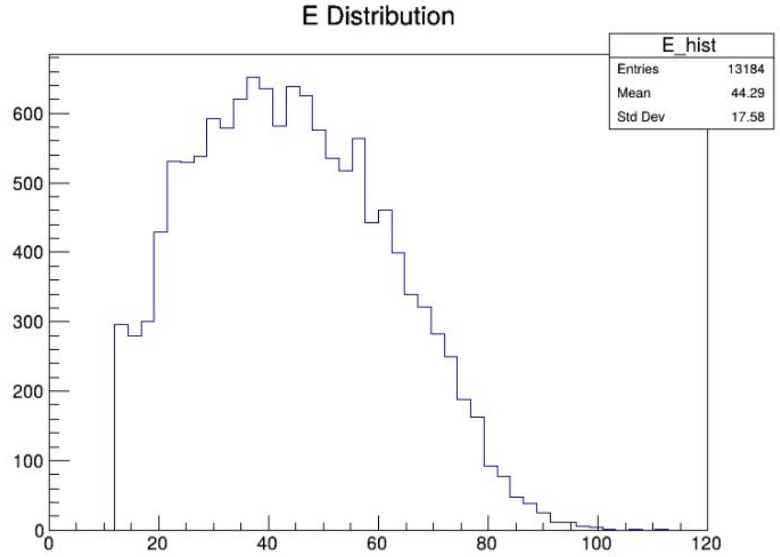
Base kinematic variables of reco ele & muon after preselection

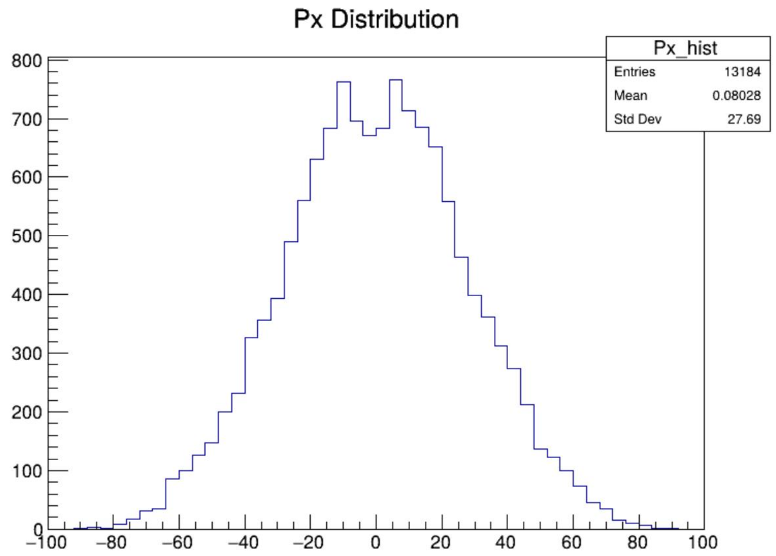
fast-sim





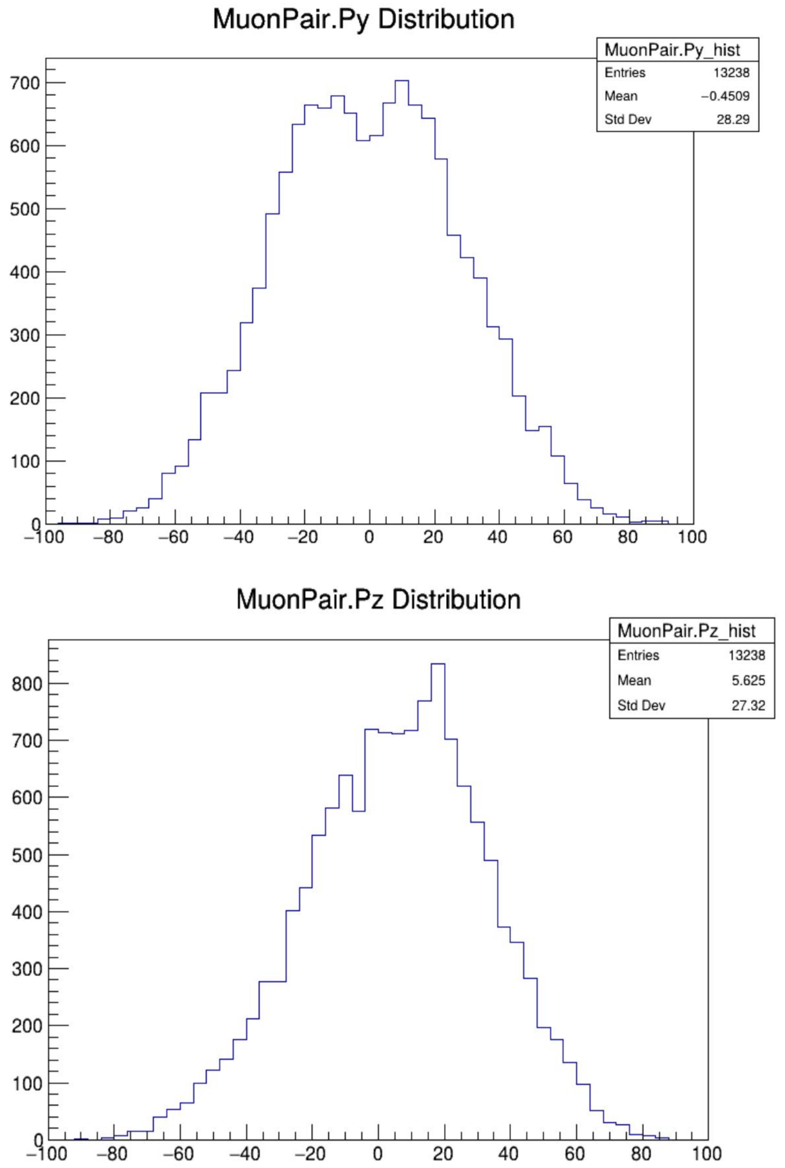
full-sim



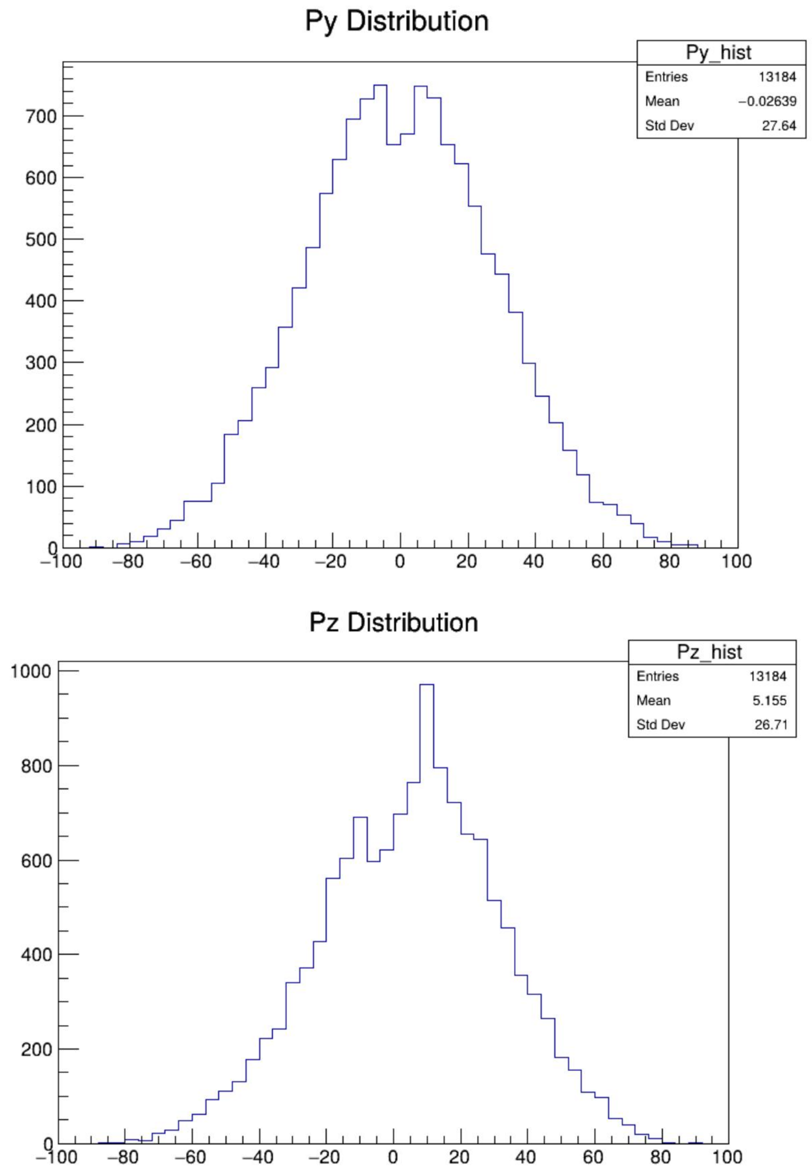


Base kinematic variables of reco ele & muon after preselection

fast-sim

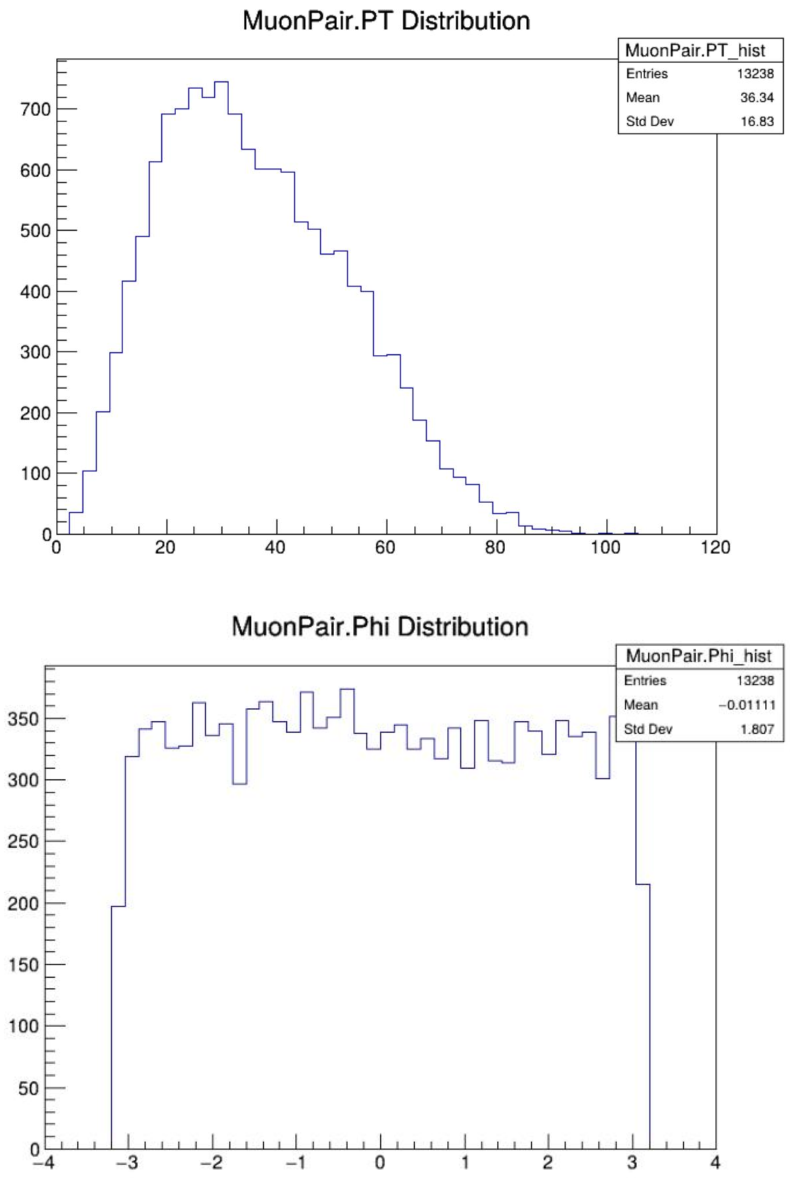


full-sim

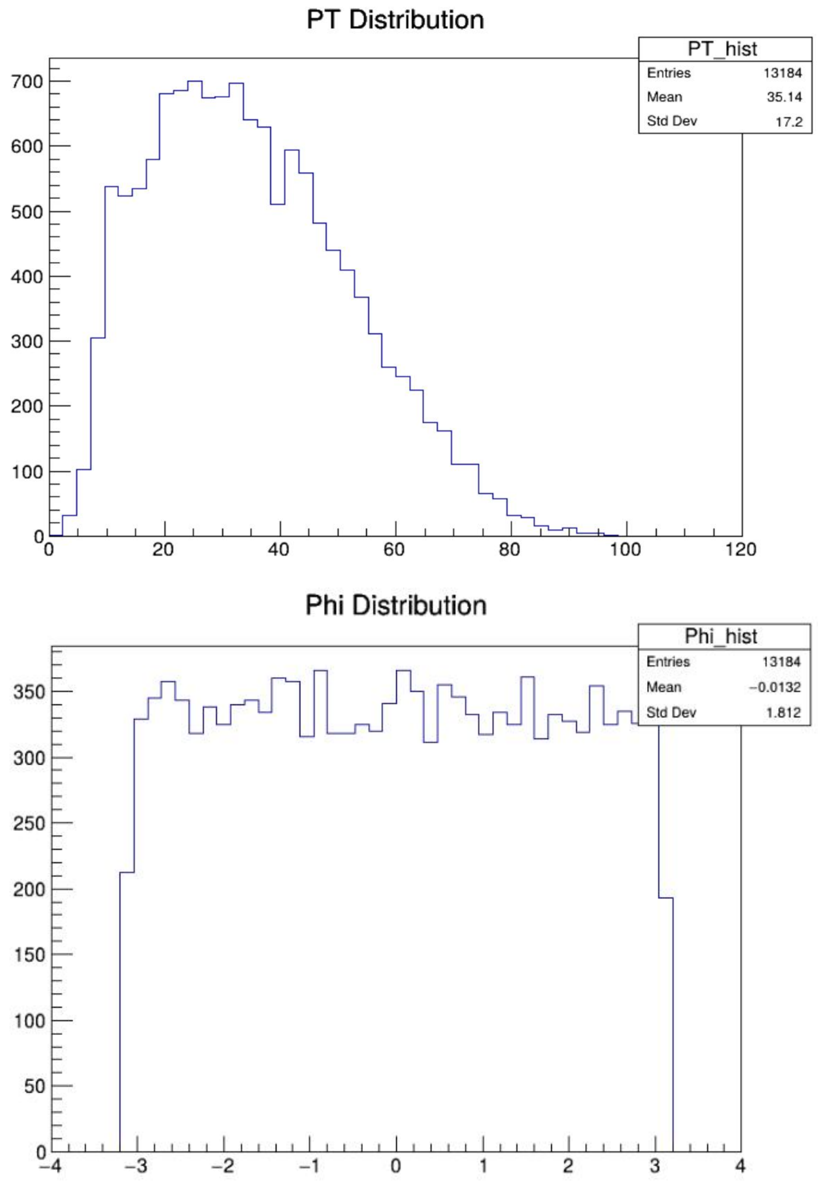


Base kinematic variables of reco ele & muon after preselection

fast-sim

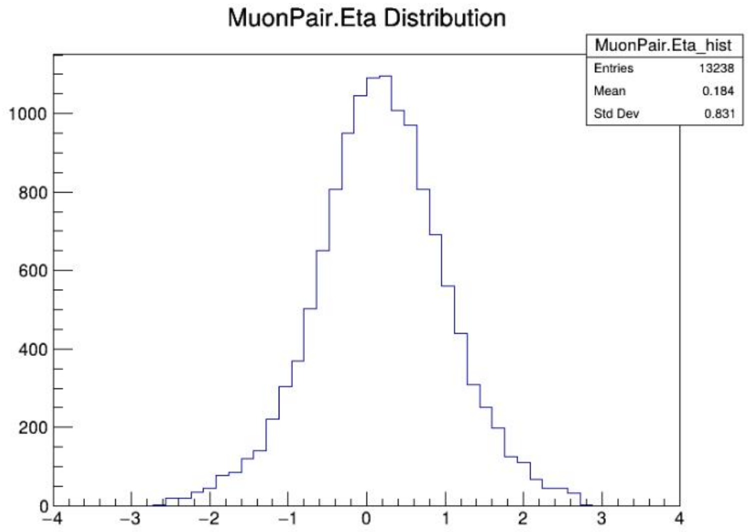


full-sim

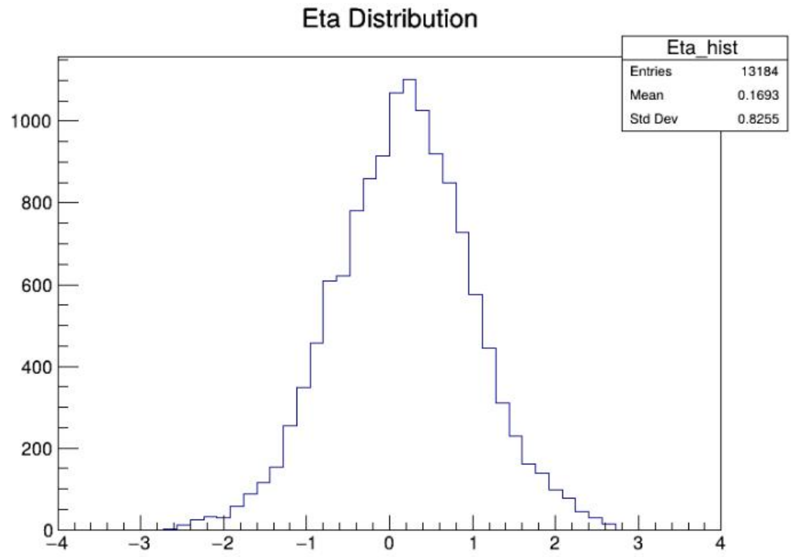


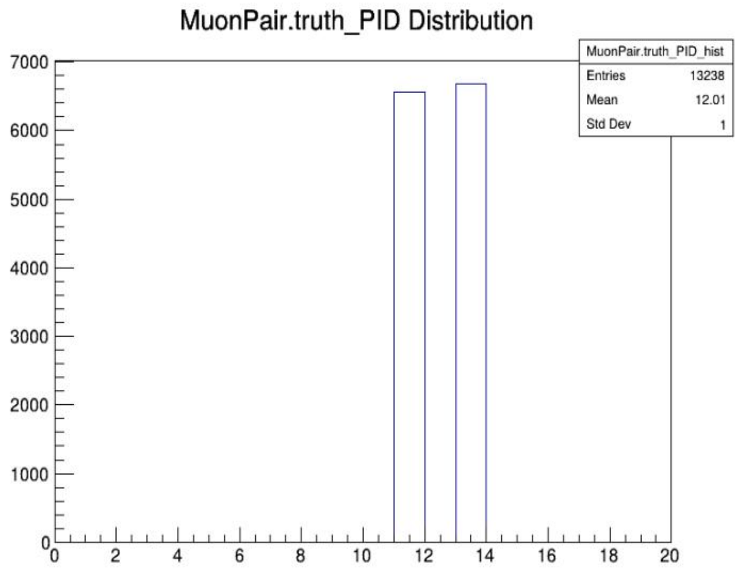
Base kinematic variables of reco ele & muon after preselection

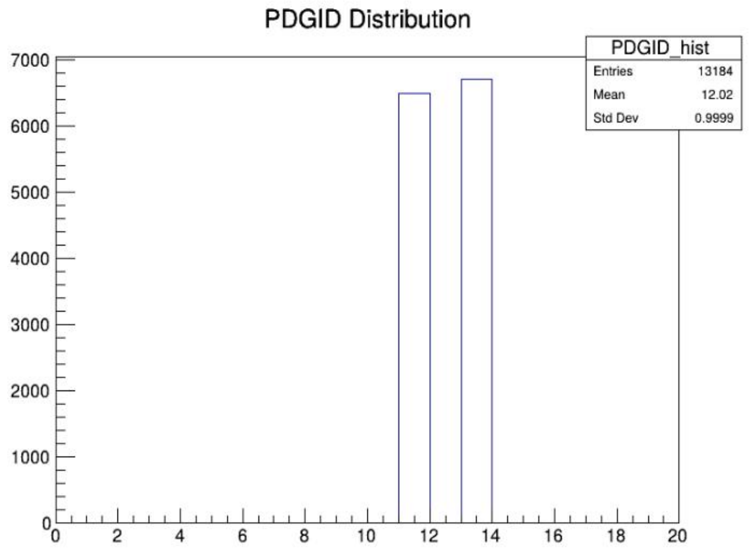
fast-sim



full-sim







Q4: try to use full-sim sample to do the analysis

Lepton Preselection Comparison

- Base kinematic distributions and effciency after lepton preselection agree well between fast and full simulation, with no significant discrepancies.

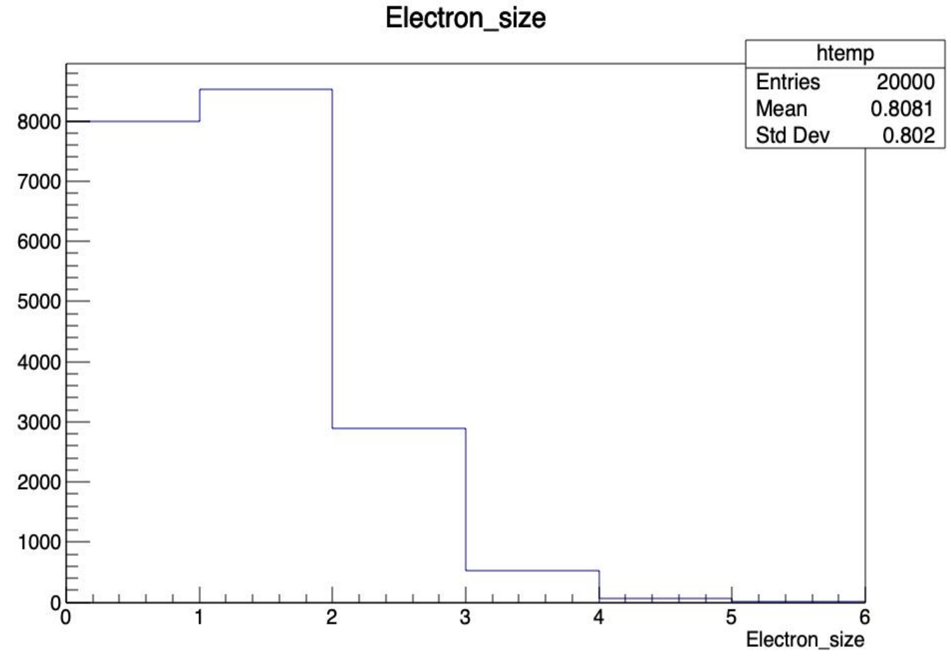
Jet Reconstruction

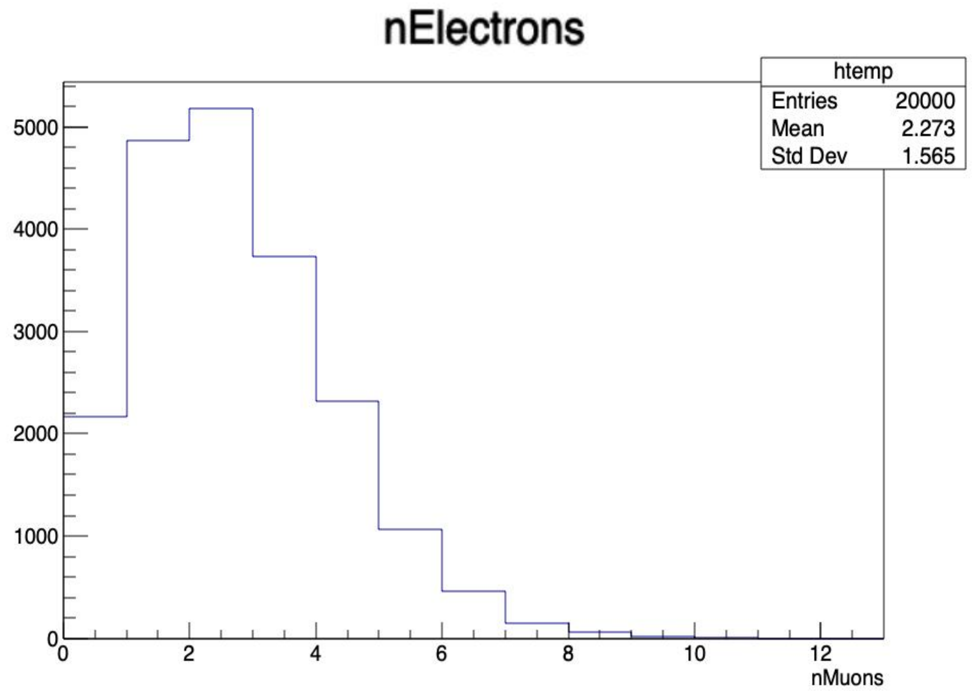
- The semi-leptonic (sl) channel requires 4-jet final states
- The full hadronic (hh) channel requires 6-jet final states
- The current 2-jet framework requires substantial modification to handle more complex final states, which may be time-consuming.

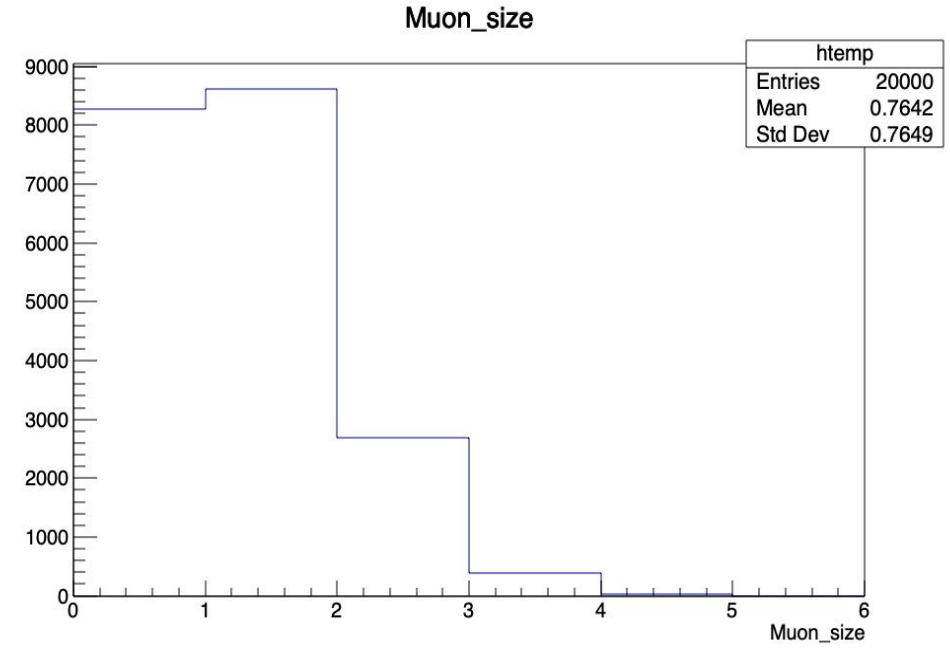
Status of Full Simulation Samples

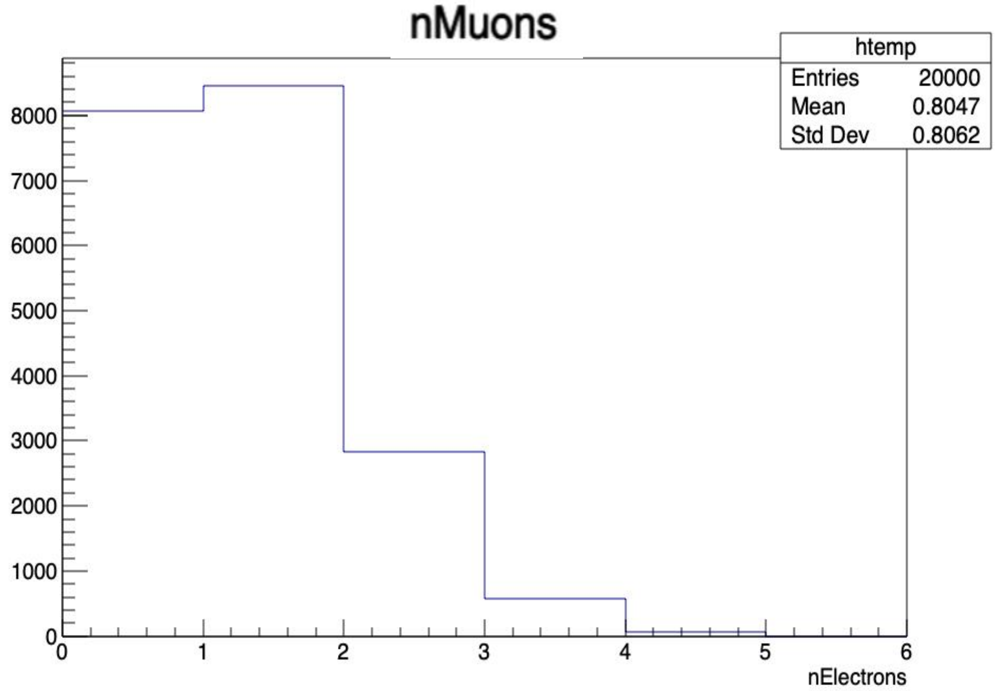
- Currently available full-sim signal sample: 342.75 GeV, ~600k events ($t\bar{t}$ semi-leptonic).
- Background samples are not yet produced; generating sufficient statistics would require significant resources.
- Given that the analysis is signal-driven, it may be reasonable to focus on signal samples for studying the differences between fast-sim and full-sim.

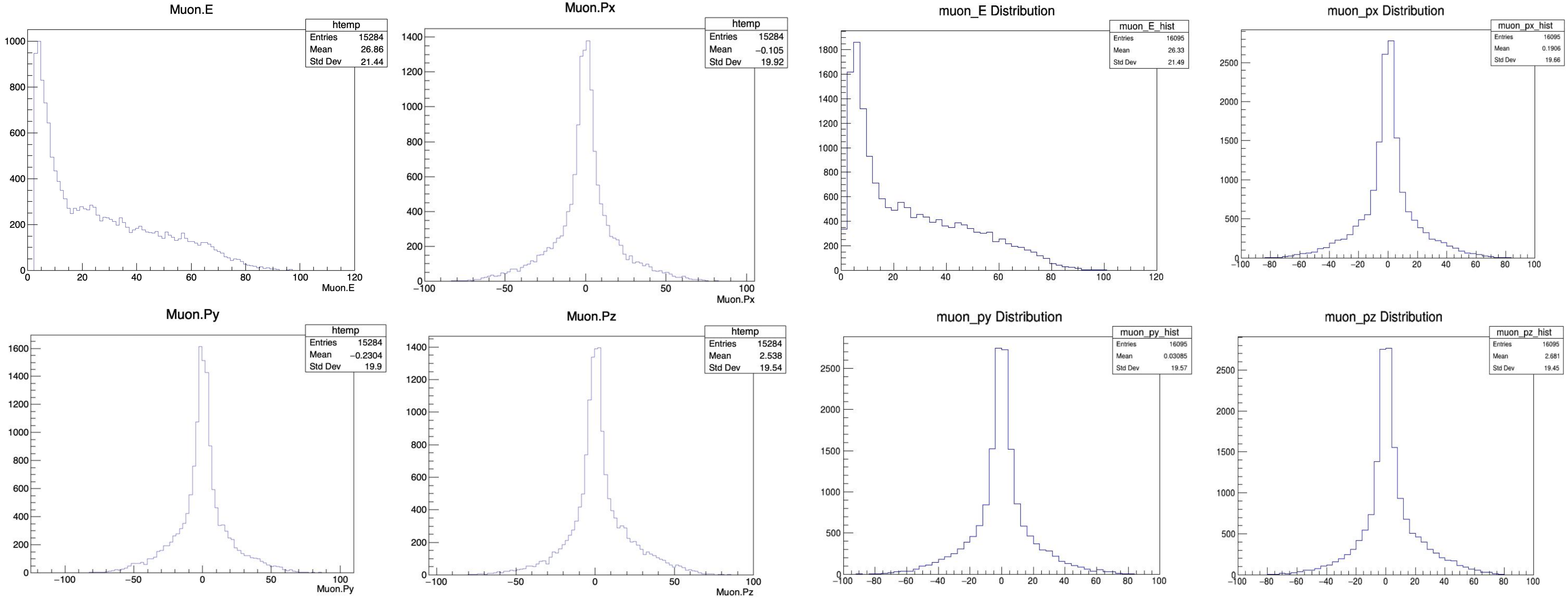
Back Up


Electron_size
htemp
Entries 20000
Mean 0.8081
Std Dev 0.802
Electron_size

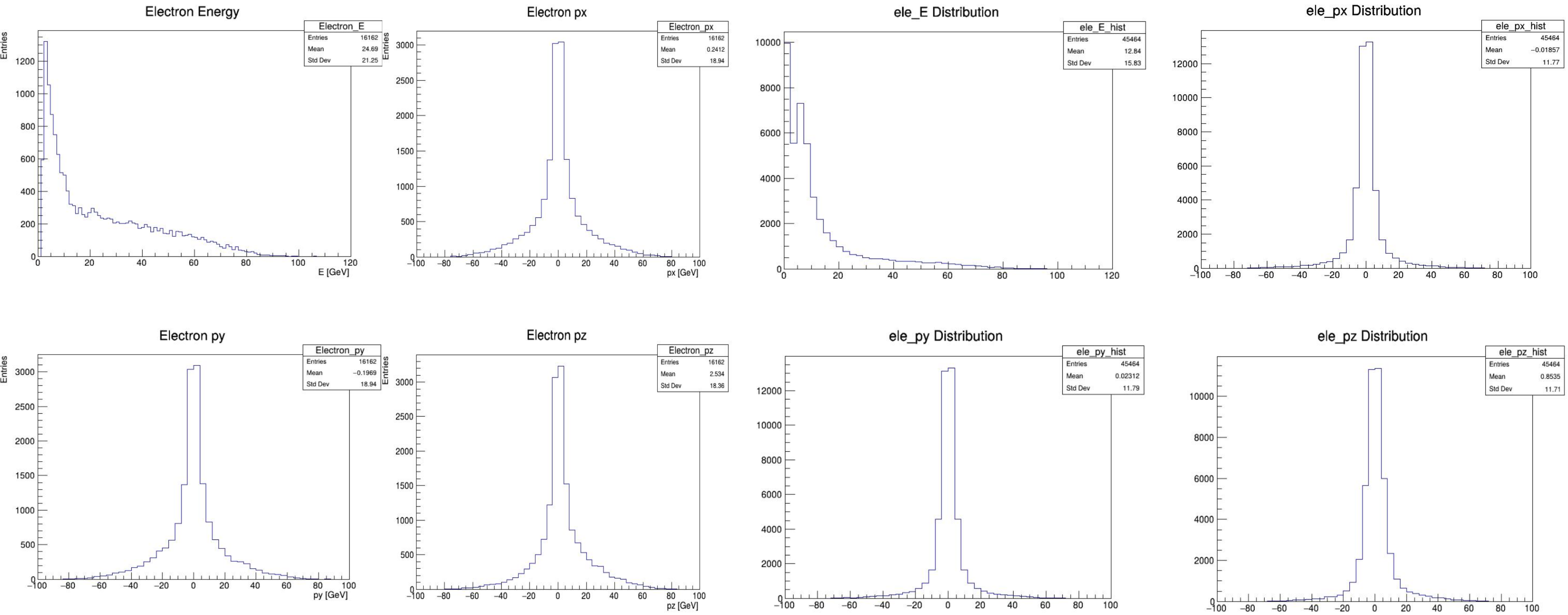

nElectrons
htemp
Entries 20000
Mean 2.273
Std Dev 1.565
nMuons


Muon_size
htemp
Entries 20000
Mean 0.7642
Std Dev 0.7649
Muon_size


nMuons
htemp
Entries 20000
Mean 0.8047
Std Dev 0.8062
nElectrons

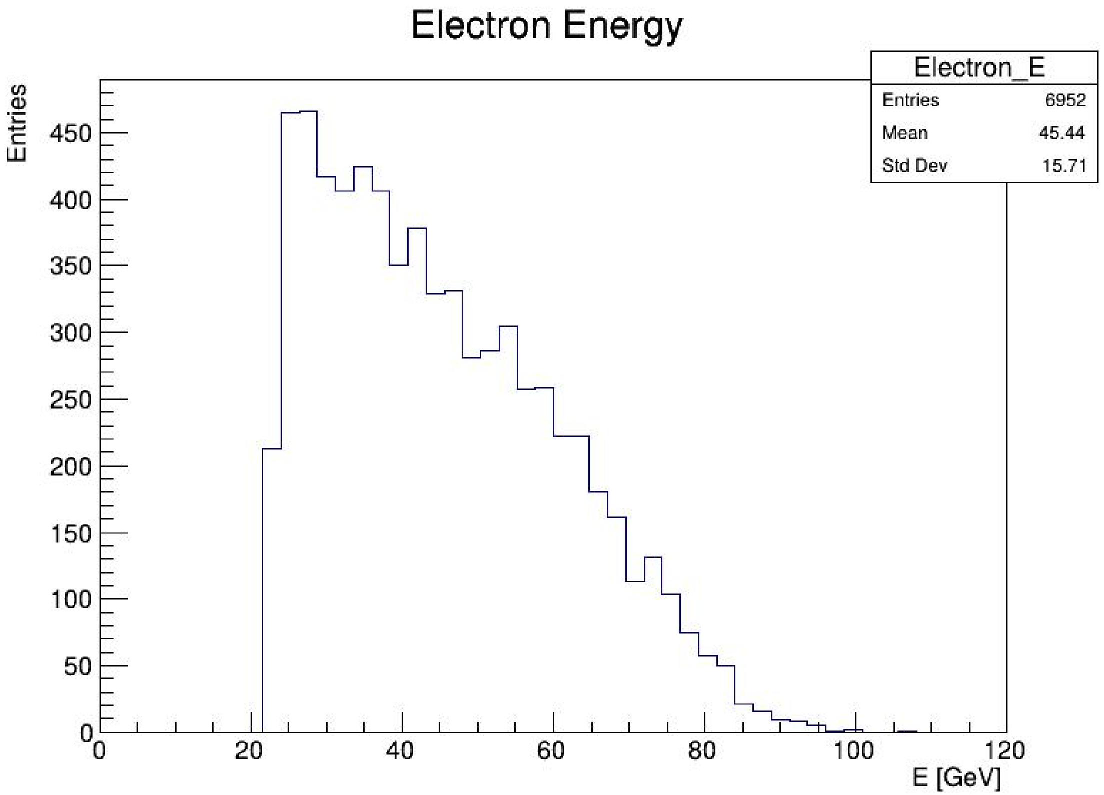


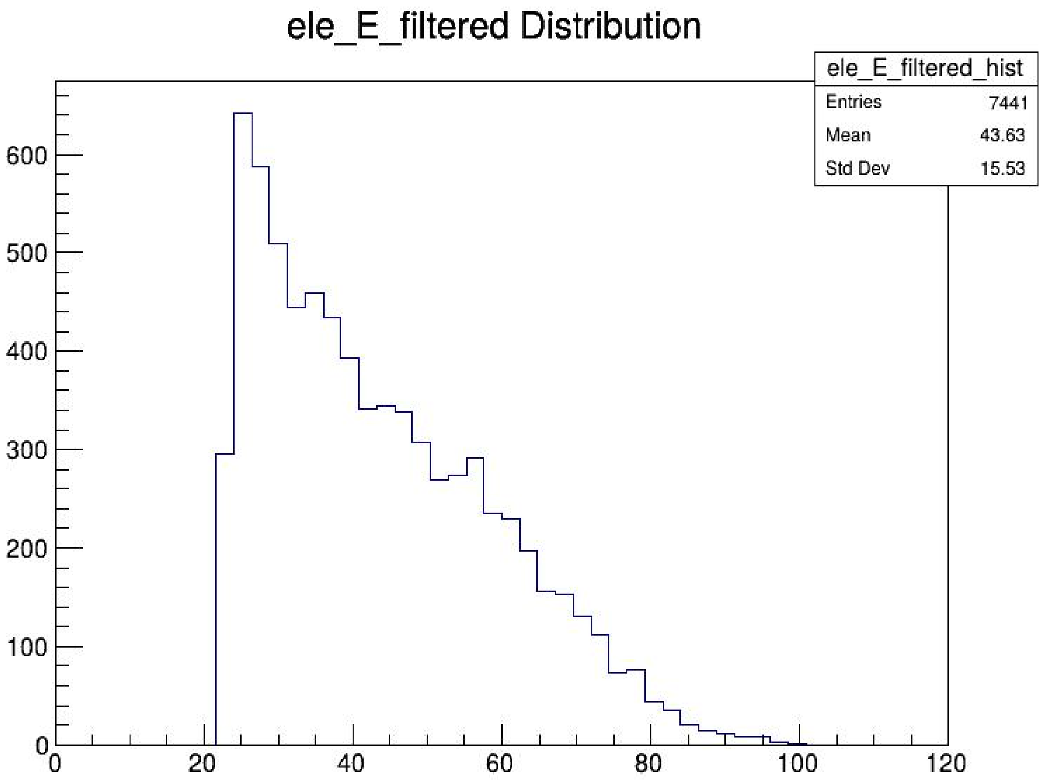
Muon.E
htemp
Entries 15284
Mean 26.86
Std Dev 21.44
Muon.E
Muon.Px
htemp
Entries 15284
Mean −0.105
Std Dev 19.92
Muon.Px
muon_E Distribution
muon_E_hist
Entries 16095
Mean 26.33
Std Dev 21.49
muon_px Distribution
muon_px_hist
Entries 16095
Mean 0.1906
Std Dev 19.66
Muon.Py
htemp
Entries 15284
Mean −0.2304
Std Dev 19.9
Muon.Py
Muon.Pz
htemp
Entries 15284
Mean 2.538
Std Dev 19.54
Muon.Pz
muon_py Distribution
muon_py_hist
Entries 16095
Mean 0.03085
Std Dev 19.57
muon_pz Distribution
muon_pz_hist
Entries 16095
Mean 2.681
Std Dev 19.45

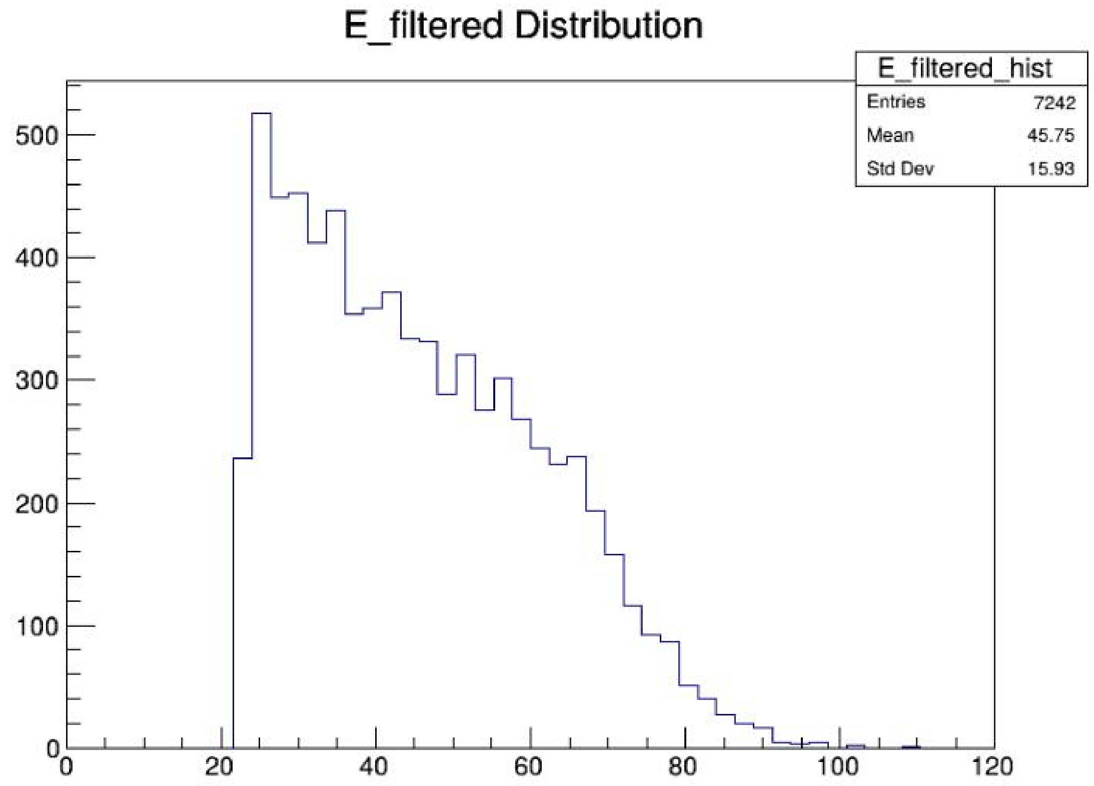


Electron Energy
Electron_E
Entries 16162
Mean 24.69
Std Dev 21.25
Entries
E [GeV]
Electron px
Electron_px
Entries 16162
Mean 0.2412
Std Dev 18.94
Entries
px [GeV]
ele_E Distribution
ele_E_hist
Entries 45464
Mean 12.84
Std Dev 15.83
ele_px Distribution
ele_px_hist
Entries 45464
Mean −0.01857
Std Dev 11.77
Electron py
Electron_py
Entries 16162
Mean −0.1969
Std Dev 18.94
Entries
py [GeV]
Electron pz
Electron_pz
Entries 16162
Mean 2.534
Std Dev 18.36
Entries
pz [GeV]
ele_py Distribution
ele_py_hist
Entries 45464
Mean 0.02312
Std Dev 11.79
ele_pz Distribution
ele_pz_hist
Entries 45464
Mean 0.8535
Std Dev 11.71

E > 23


Electron Energy
Electron_E
Entries 6952
Mean 45.44
Std Dev 15.71
Entries
0
50
100
150
200
250
300
350
400
450
0
20
40
60
80
100
120
E [GeV]


ele_E_filtered Distribution
ele_E_filtered_hist
Entries 7441
Mean 43.63
Std Dev 15.53
0
100
200
300
400
500
600
0
20
40
60
80
100
120


E_filtered Distribution
E_filtered_hist
Entries 7242
Mean 45.75
Std Dev 15.93
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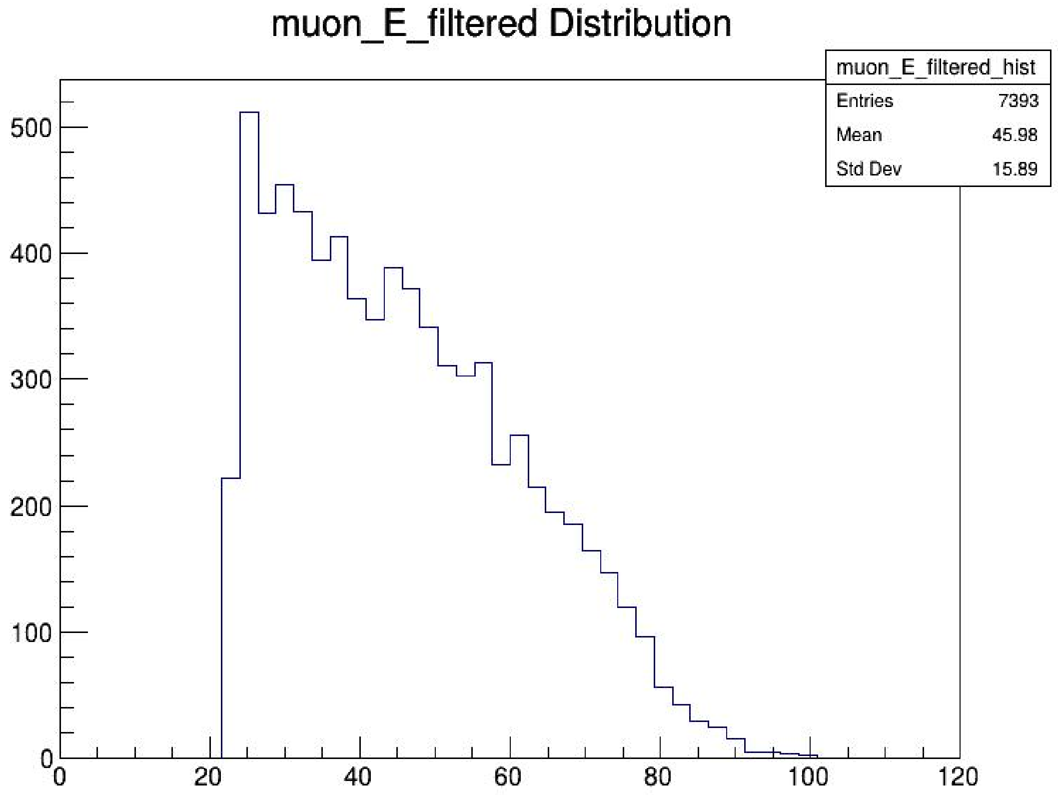
100
200
300
400
500
0
20
40
60
80
100
120


muon_E_filtered Distribution
muon_E_filtered_hist
Entries 7393
Mean 45.98
Std Dev 15.89
0
100
200
300
400
500
0
20
40
60
80
100
120