A first look at the decay $\pi^0 \to e^+e^-\gamma$

University of Athens

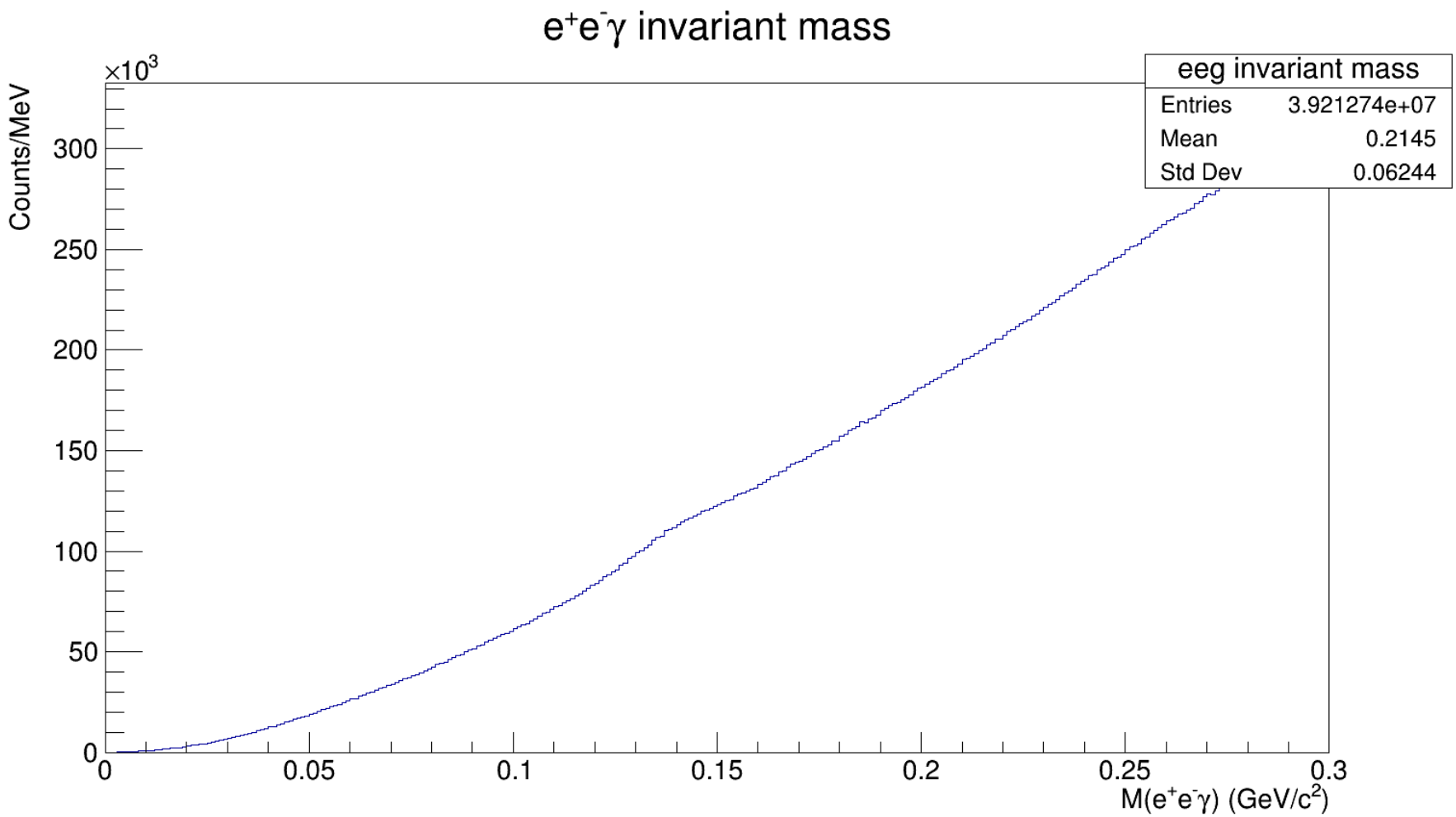
December 15, 2016

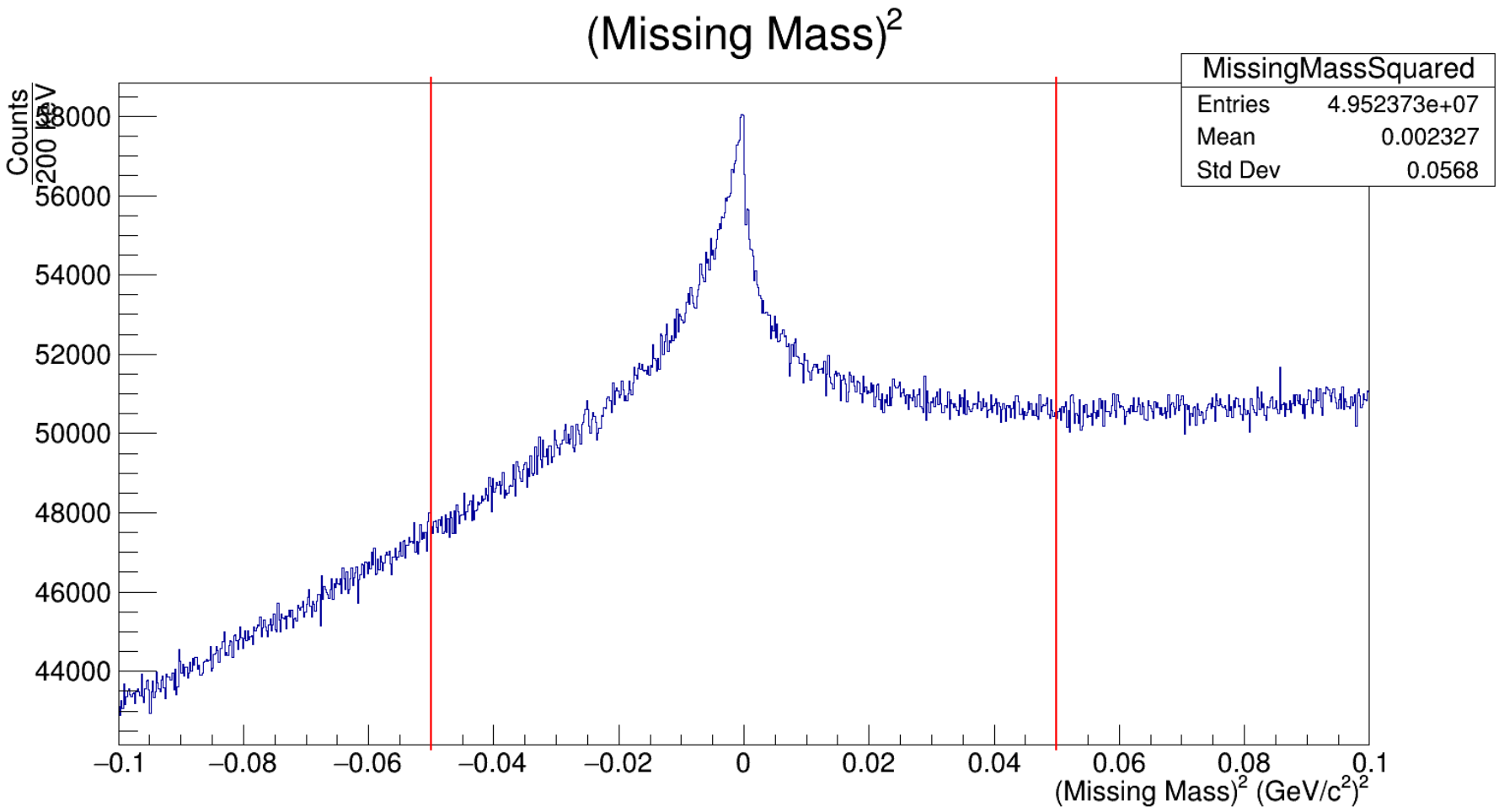
Goals

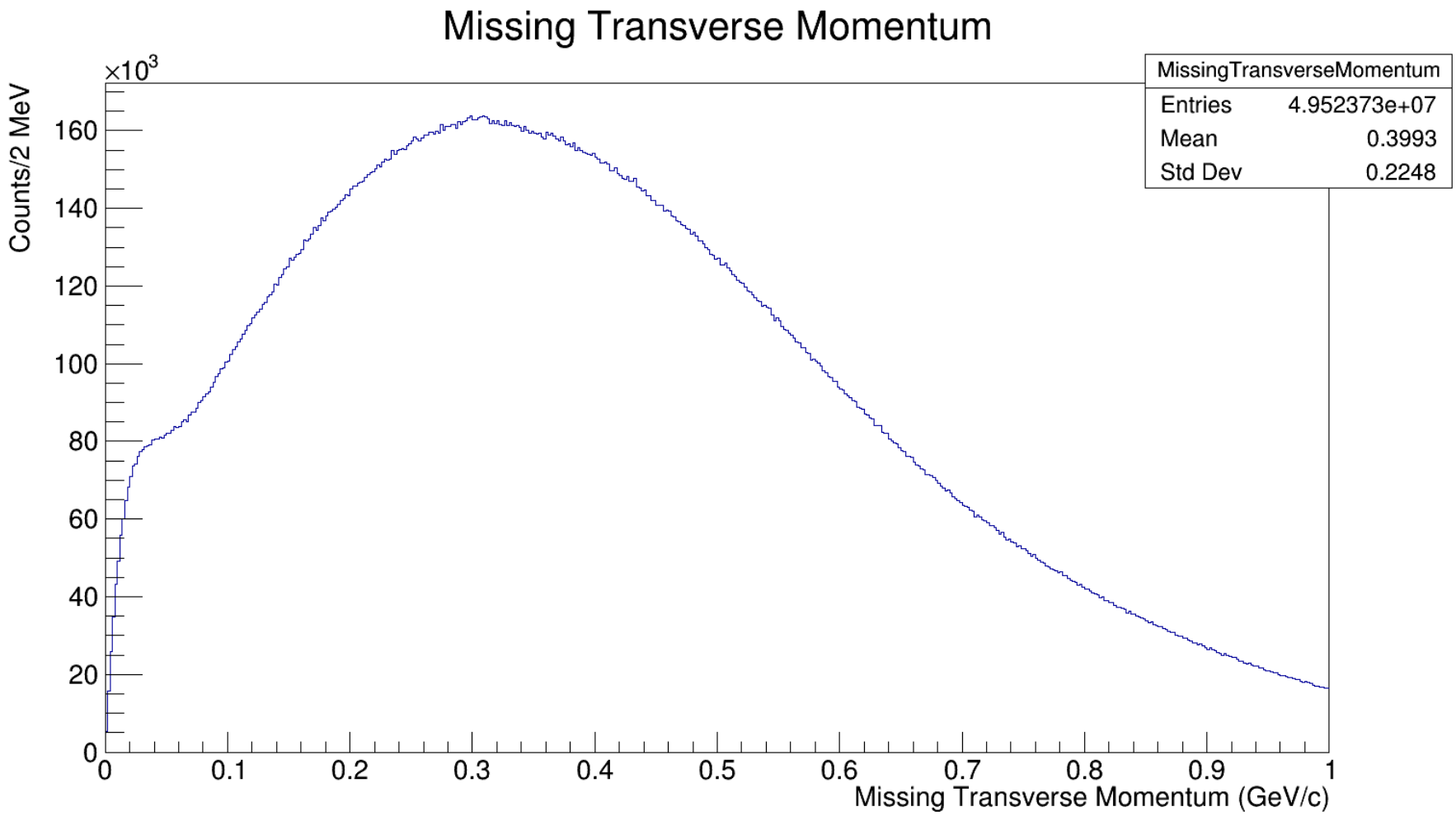
- Isolate "clean" $\pi^0 \to e^+e^-\gamma$ events from the exclusive reaction $\gamma p \to \pi^0 p$
- Use the bachelor photon from these events to determine the single-photon energy resolution of the detector
- Dataset: "Golden Runs", spring 2016

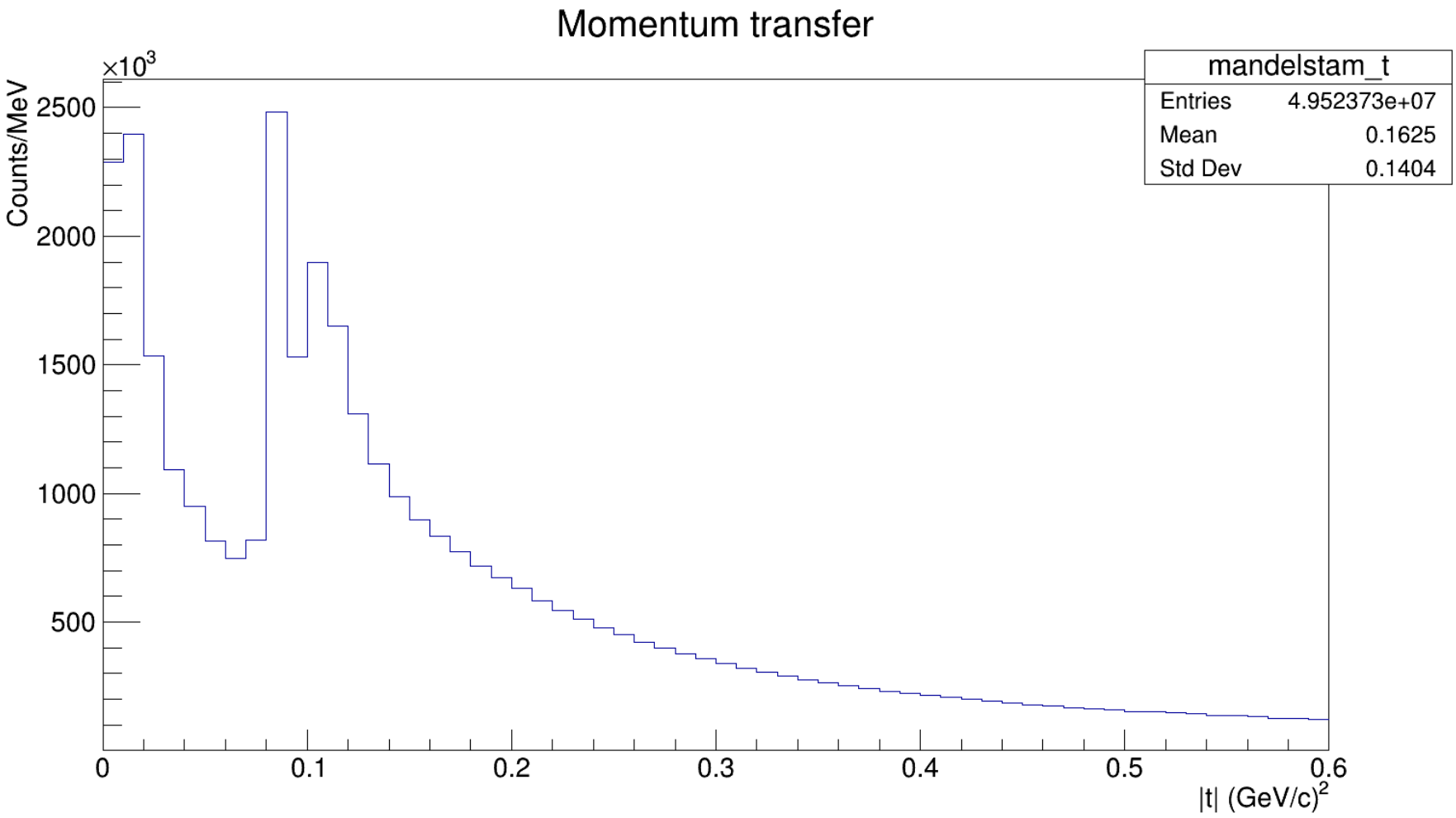
Loose plugin cuts

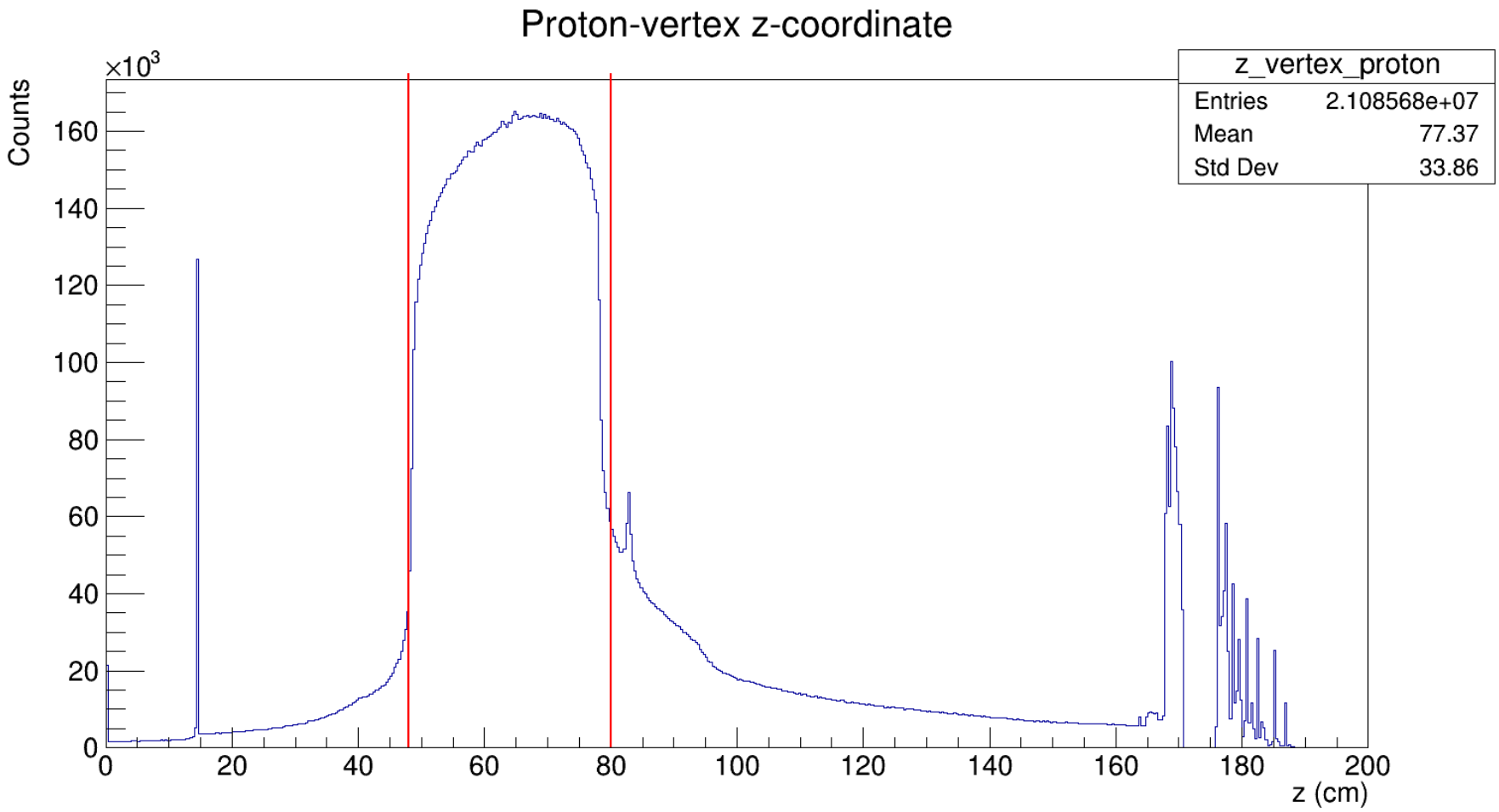
- Type of Kinematic Fit performed: P4 and Vertex fit
- $MaxPhotonRFDeltaT = \frac{BeamBunchPeriod}{2}$
- $MaxExtraGoodTracks = 5$
- π^0 Invariant Mass cut: [0.0, 0.3] GeV
- $(MissingMass)^2$ cut: [-0.1, 0.1] $(\frac{GeV}{c^2})^2$
- PID Δt, protons, TOF: $\pm 3ns$
- PID Δt, protons, BCAL: $\pm 3ns$
- PID Δt, protons, FCAL: $\pm 3ns$
- PID Δt, positrons, TOF: $\pm 1ns$
- PID Δt, positrons, BCAL: $\pm 2ns$
- PID Δt, positrons, FCAL: $\pm 3ns$
- PID Δt, electrons, TOF: $\pm 1ns$
- PID Δt, electrons, BCAL: $\pm 2ns$
- PID Δt, electrons, FCAL: $\pm 3ns$
- PID Δt, photons, BCAL: $\pm 3ns$
- PID Δt, photons, FCAL: $\pm 3ns$
- dEdx cut in CDC

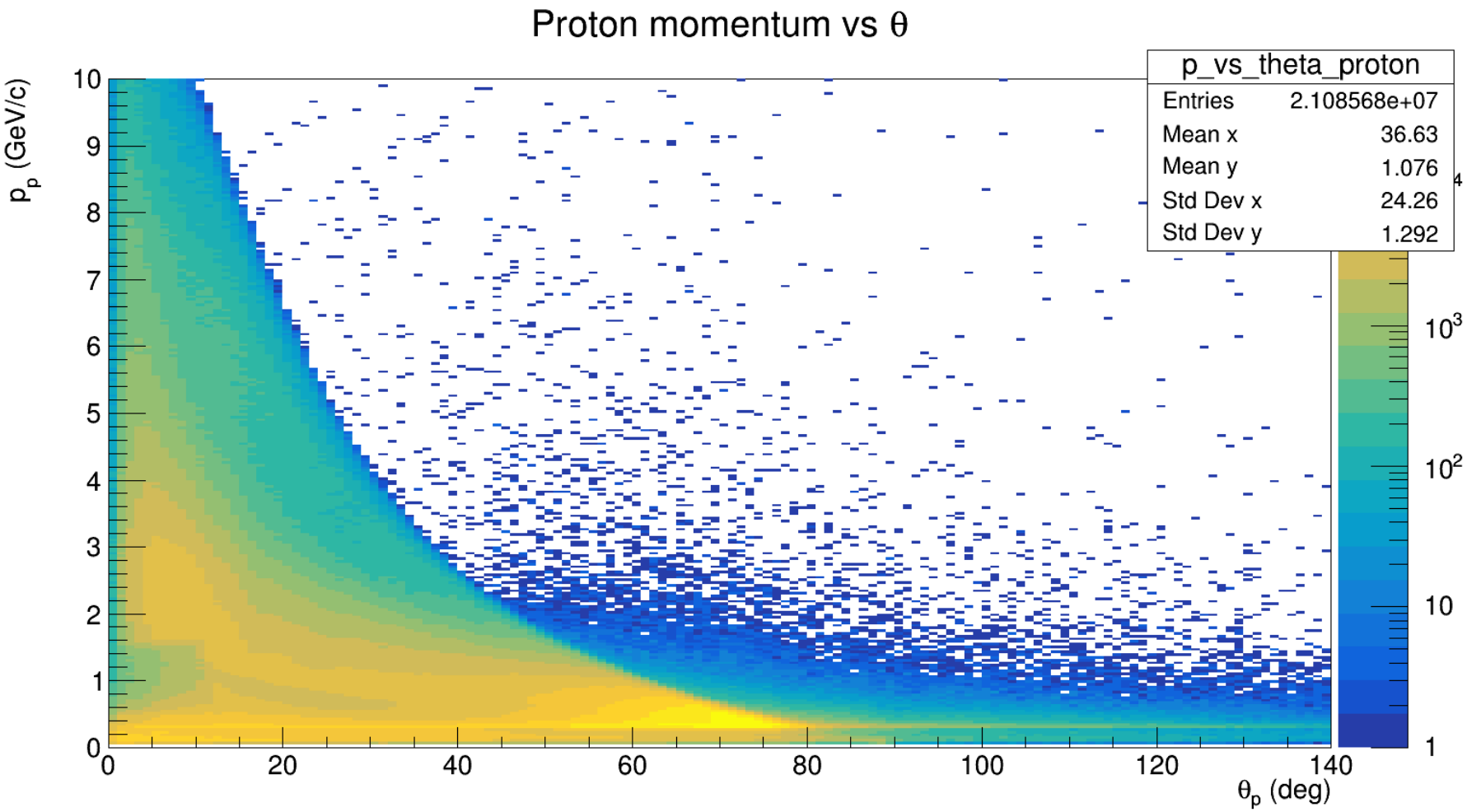

e+e-γ invariant mass
eeg invariant mass
Entries 3.921274e+07
Mean 0.2145
Std Dev 0.06244
×10^3
Counts/MeV
300
250
200
150
100
50
0
0
0.05
0.1
0.15
0.2
0.25
0.3
M(e+e-γ) (GeV/c^2)

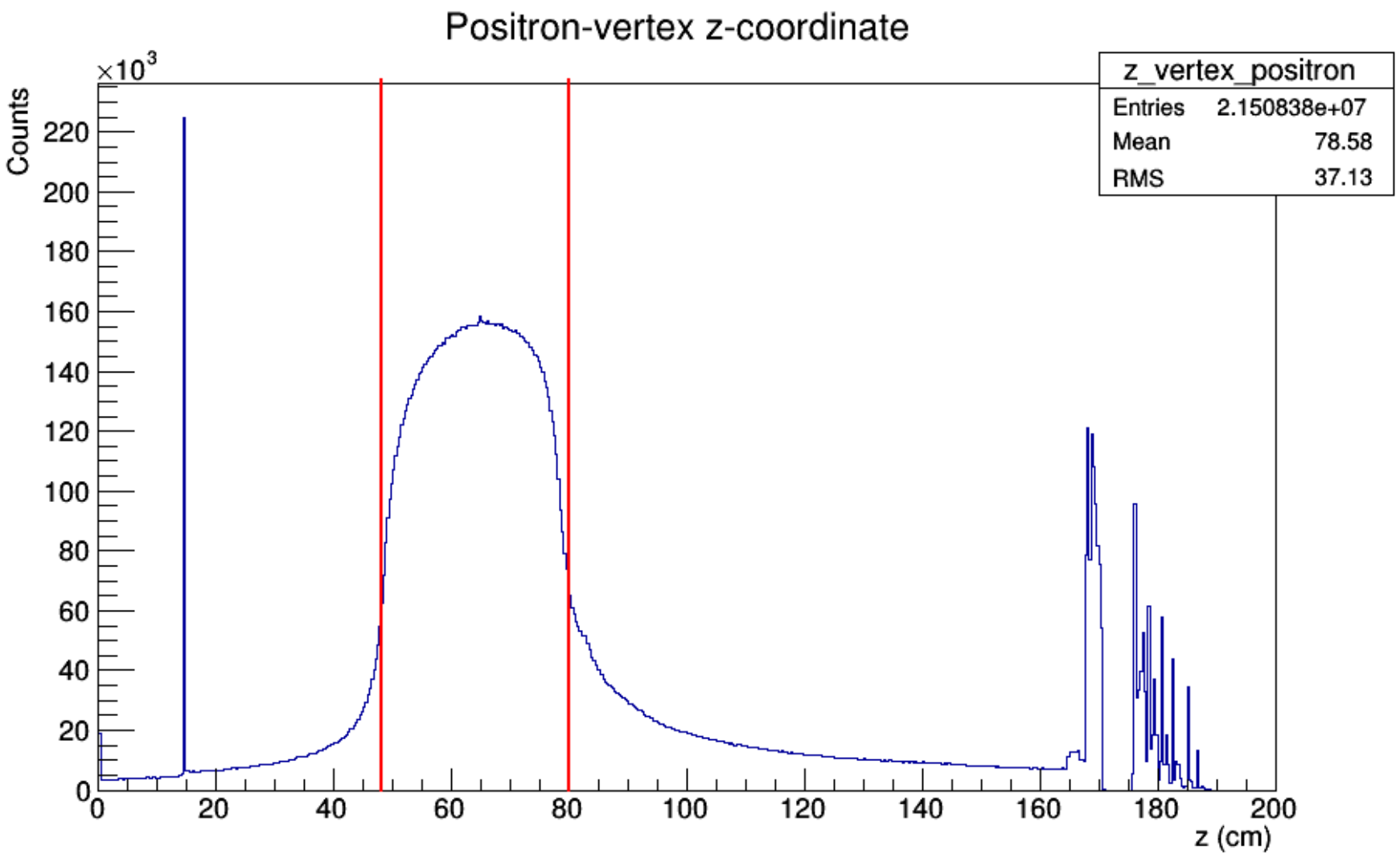

(Missing Mass)^2
MissingMassSquared
Entries 4.952373e+07
Mean 0.002327
Std Dev 0.0568
Counts
200 keV
58000
56000
54000
52000
50000
48000
46000
44000
−0.1
−0.08
−0.06
−0.04
−0.02
0
0.02
0.04
0.06
0.08
0.1
(Missing Mass)^2 (GeV/c^2)^2

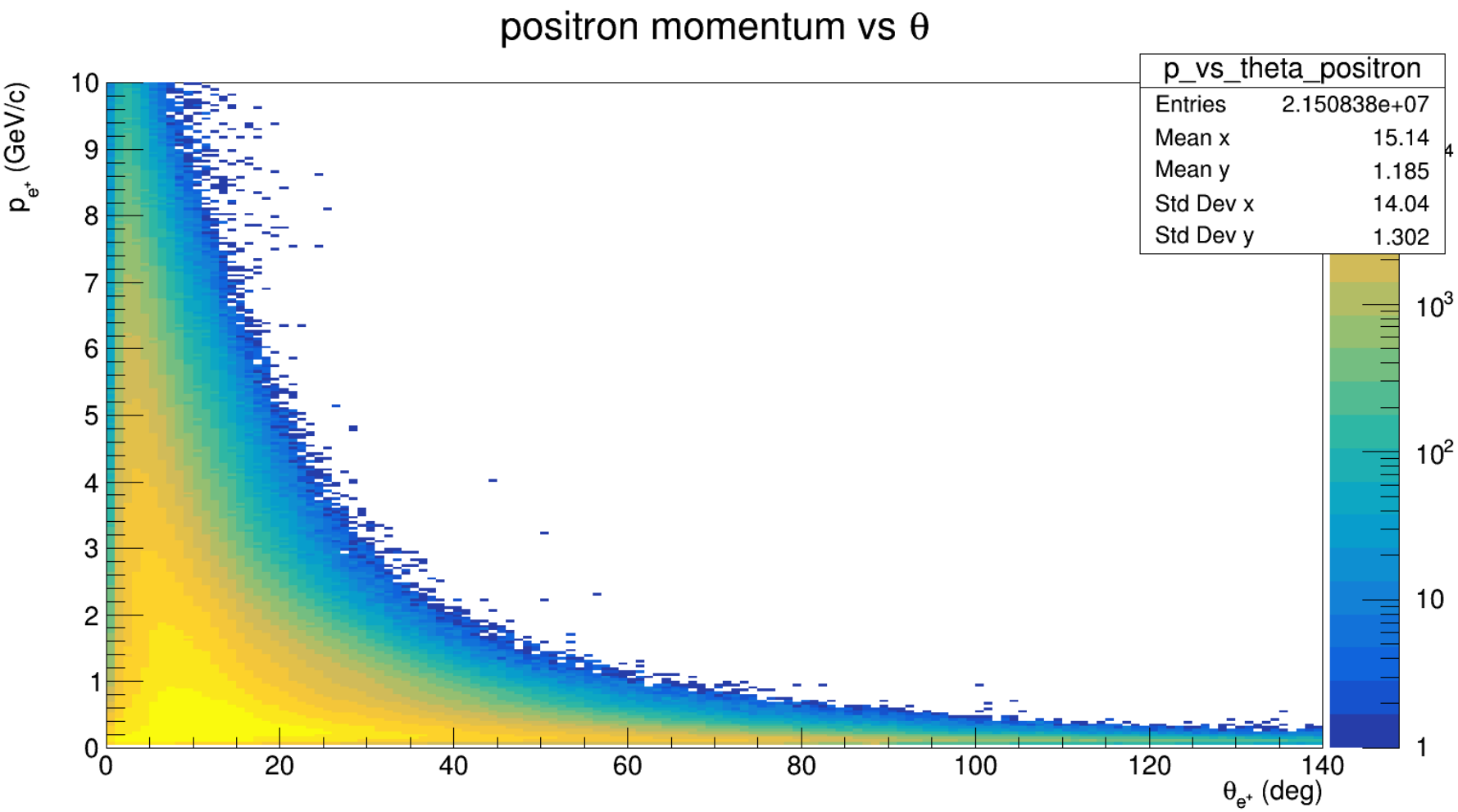

Missing Transverse Momentum
MissingTransverseMomentum
Entries 4.952373e+07
Mean 0.3993
Std Dev 0.2248
×10^3
Counts/2 MeV
0
20
40
60
80
100
120
140
160
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Missing Transverse Momentum (GeV/c)

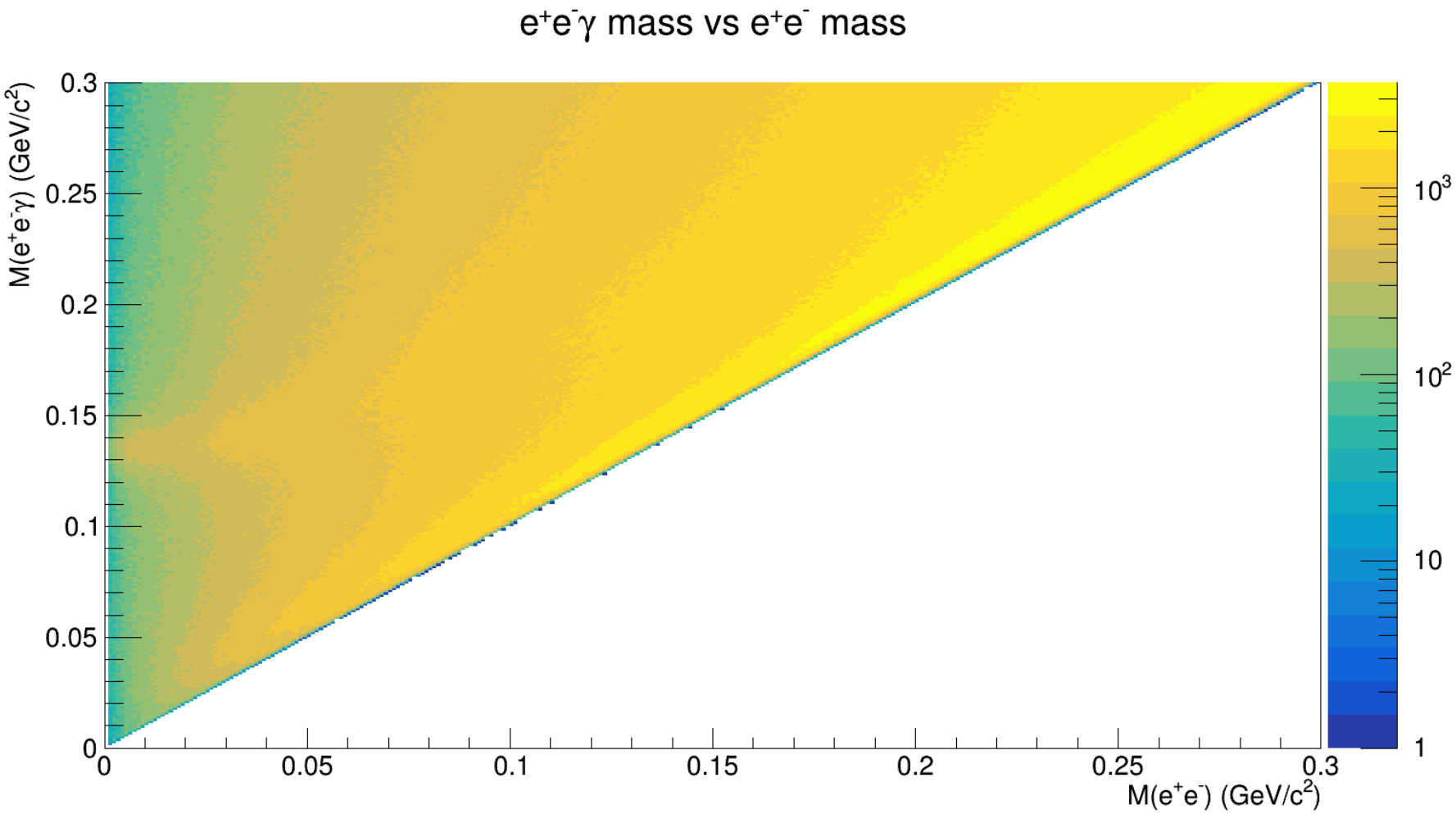

Momentum transfer
mandelstam_t
Entries 4.952373e+07
Mean 0.1625
Std Dev 0.1404
×10^3
Counts/MeV
2500
2000
1500
1000
500
0
0.1
0.2
0.3
0.4
0.5
0.6
|t| (GeV/c)^2

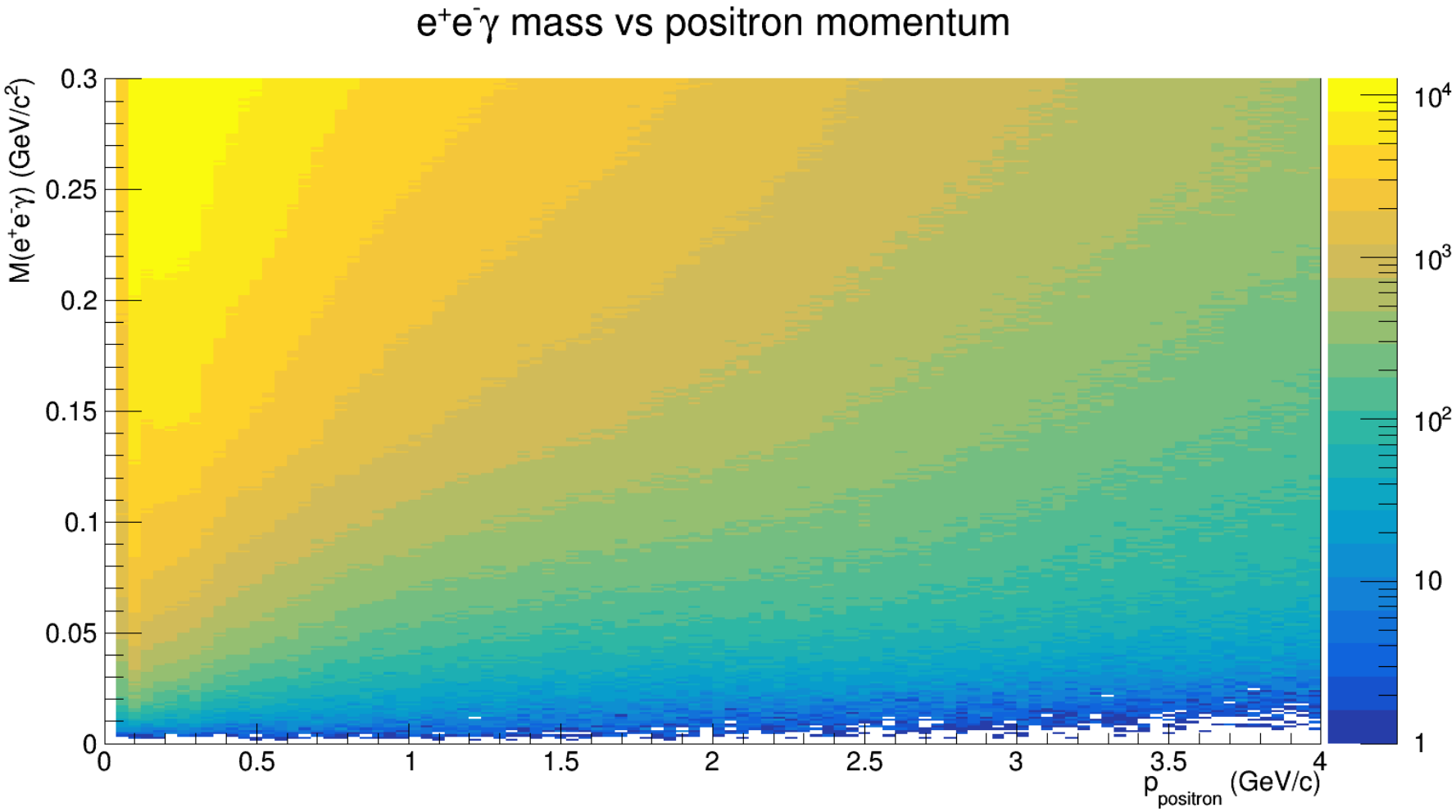

Proton-vertex z-coordinate
z_vertex_proton
Entries 2.108568e+07
Mean 77.37
Std Dev 33.86
Counts
×10^3
0
20
40
60
80
100
120
140
160
0
20
40
60
80
100
120
140
160
180
200
z (cm)

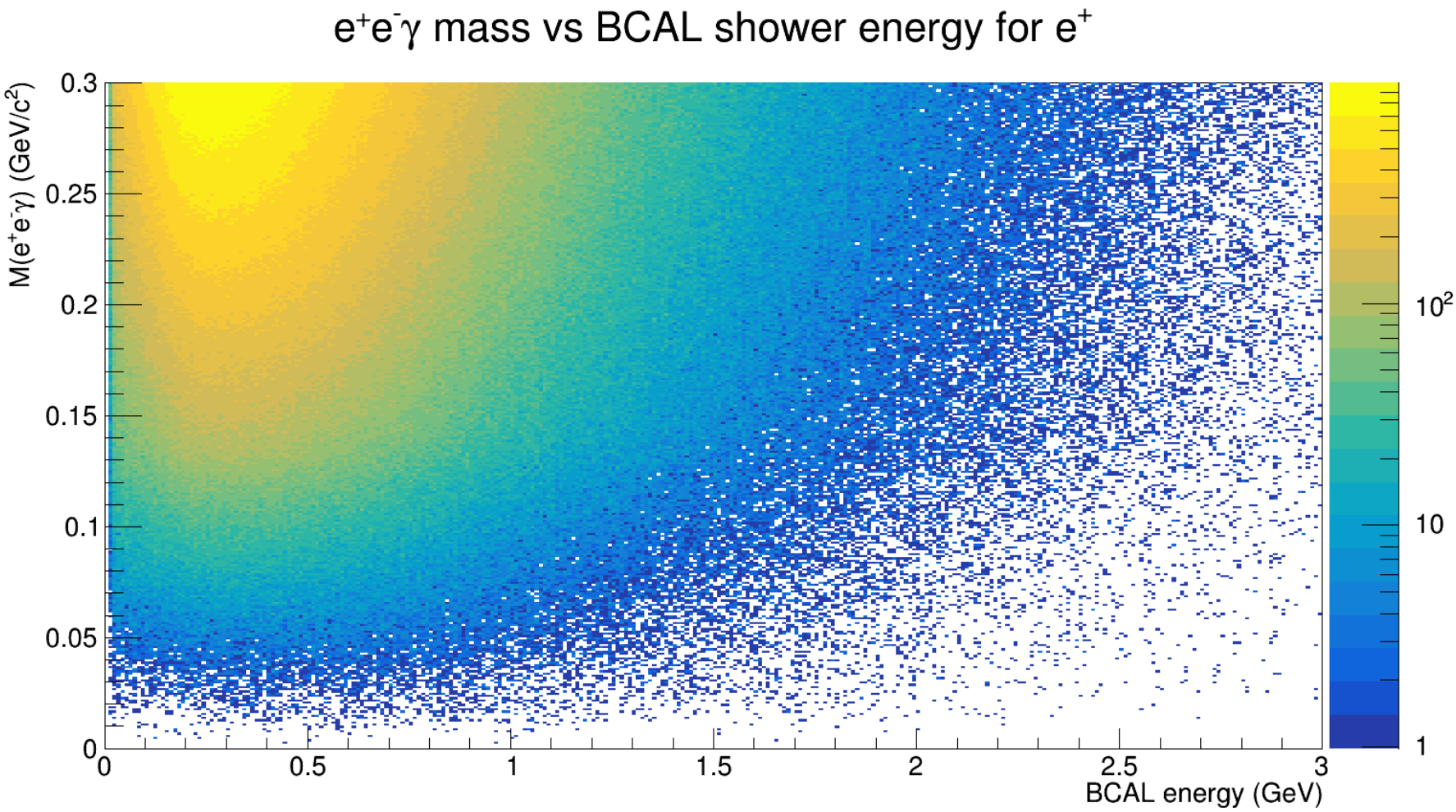

Proton momentum vs θ
p_vs_theta_proton
Entries 2.108568e+07
Mean x 36.63
Mean y 1.076
Std Dev x 24.26
Std Dev y 1.292
p_p (GeV/c)
θ_p (deg)
0
20
40
60
80
100
120
140
1
2
3
4
5
6
7
8
9
10
1
10
10^2
10^3

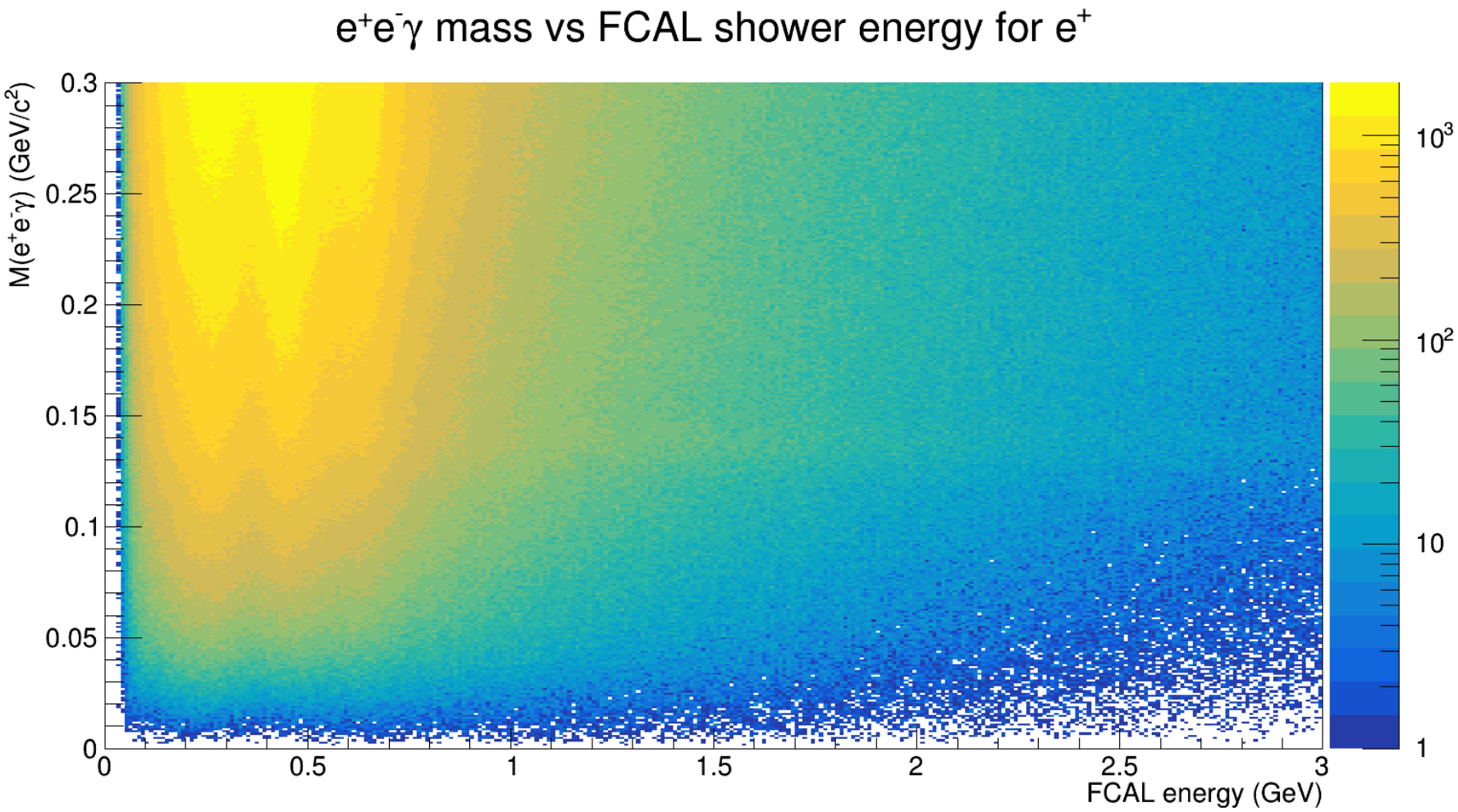

Positron-vertex z-coordinate
z_vertex_positron
Entries 2.150838e+07
Mean 78.58
RMS 37.13
Counts
×10^3
z (cm)

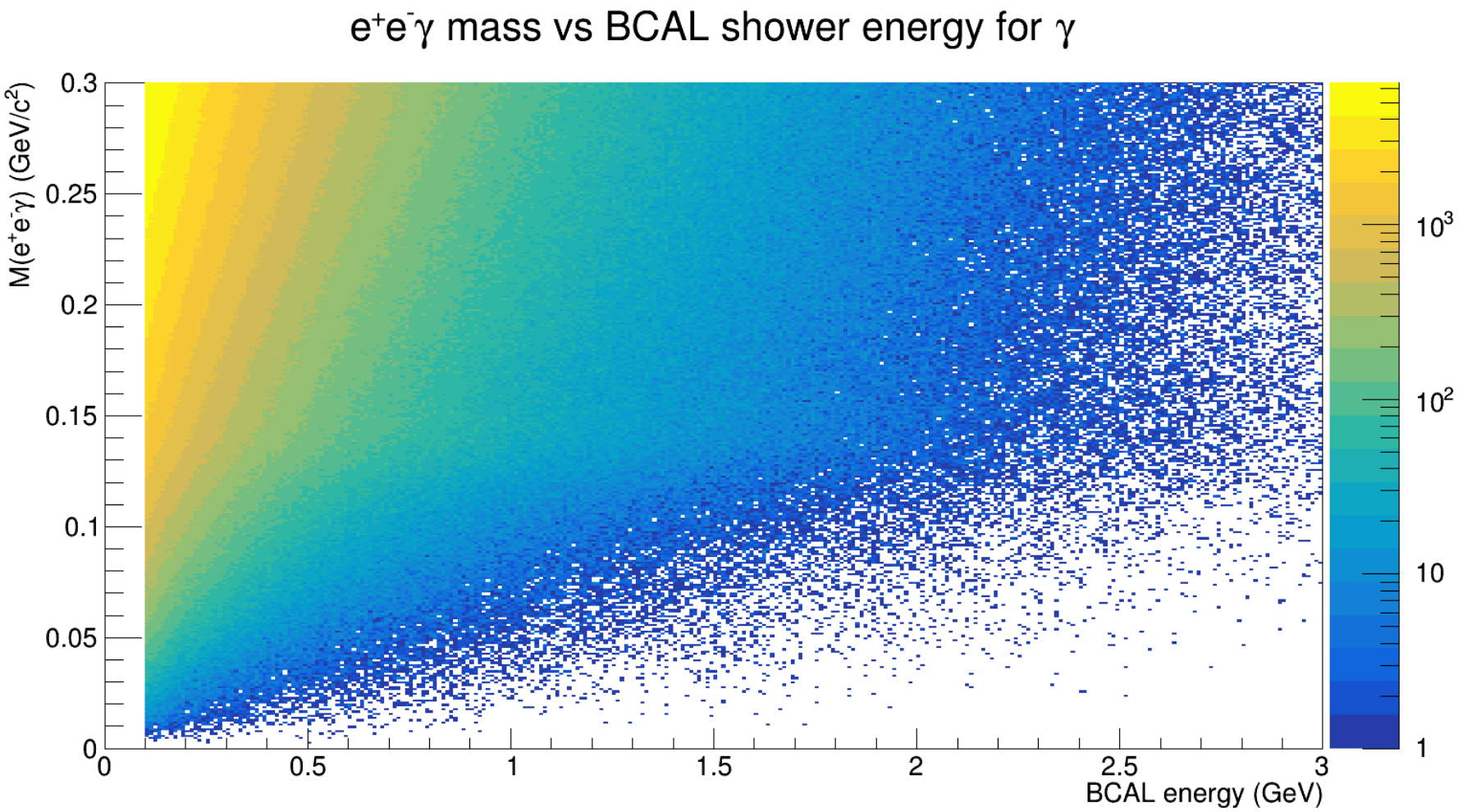

positron momentum vs θ
p_vs_theta_positron
Entries 2.150838e+07
Mean x 15.14
Mean y 1.185
Std Dev x 14.04
Std Dev y 1.302
p_e+ (GeV/c)
θ_e+ (deg)
0
20
40
60
80
100
120
140
1
2
3
4
5
6
7
8
9
10
1
10
10^2
10^3

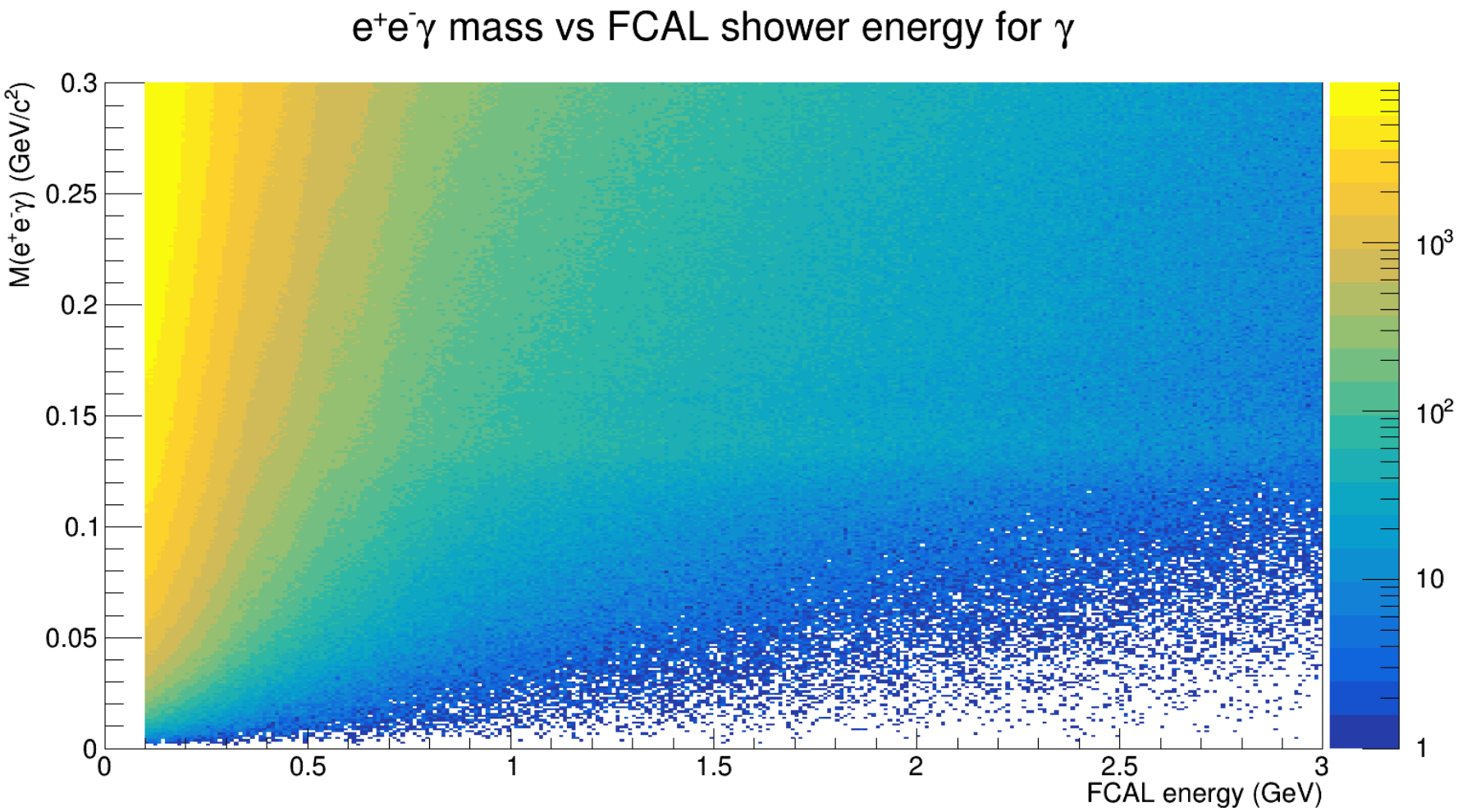

e+e-γ mass vs e+e- mass
M(e+e-γ) (GeV/c2)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3
M(e+e-) (GeV/c2)
10^3
10^2
10
1

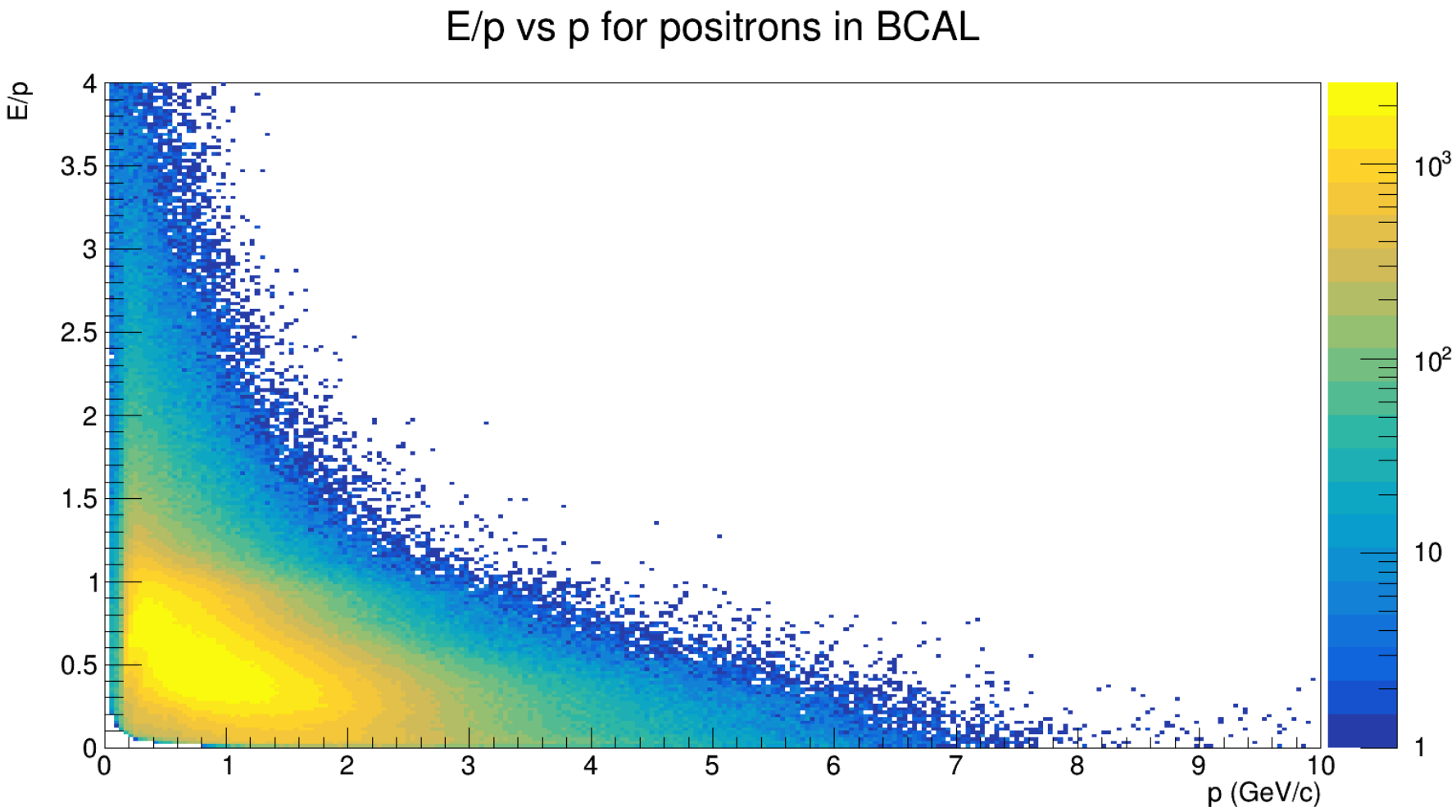

e+e-γ mass vs positron momentum
M(e+e-γ) (GeV/c2)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4
ppositron (GeV/c)
10^4
10^3
10^2
10
1

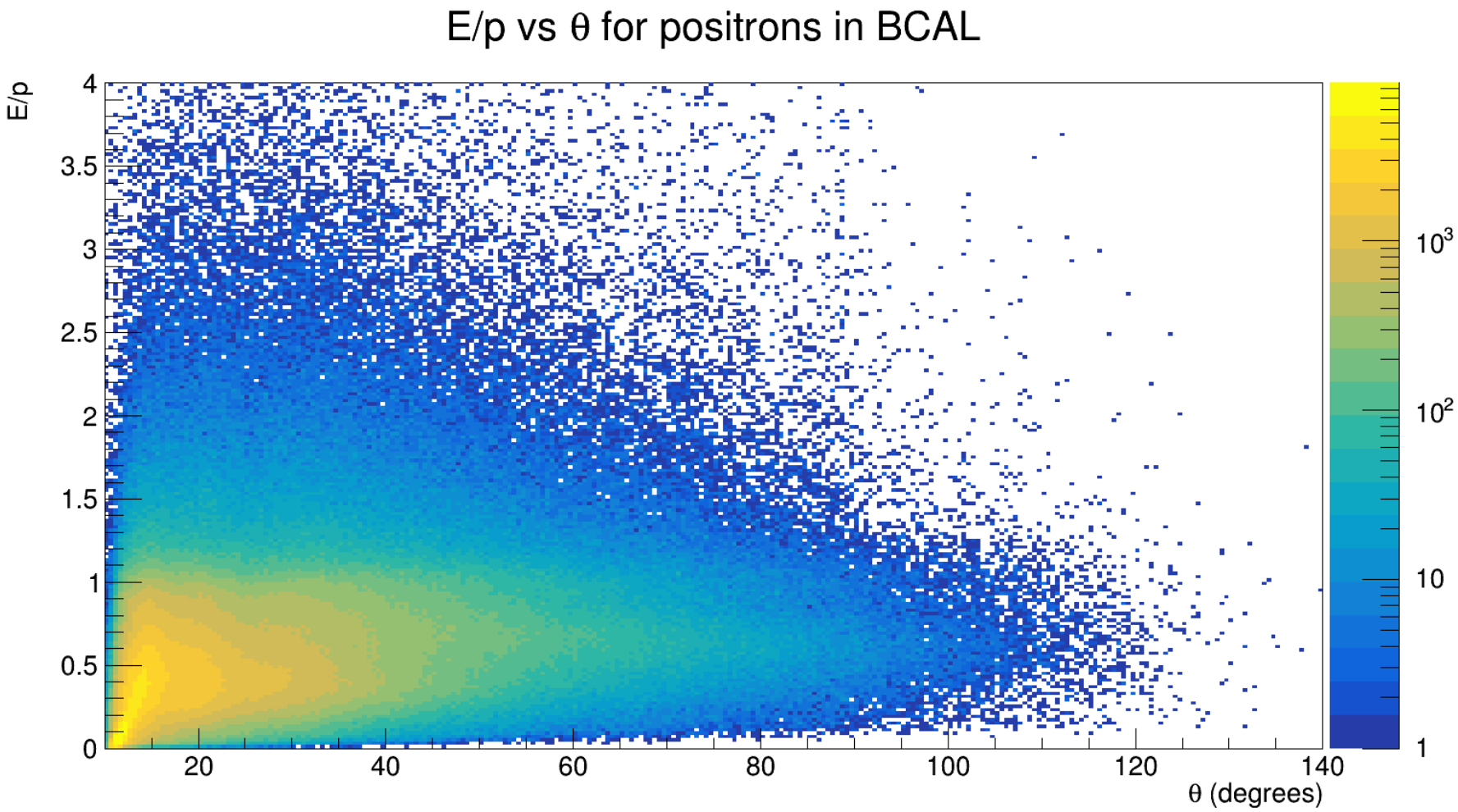

e+e-γ mass vs BCAL shower energy for e+
M(e+e-γ) (GeV/c2)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
BCAL energy (GeV)
10^2
10
1

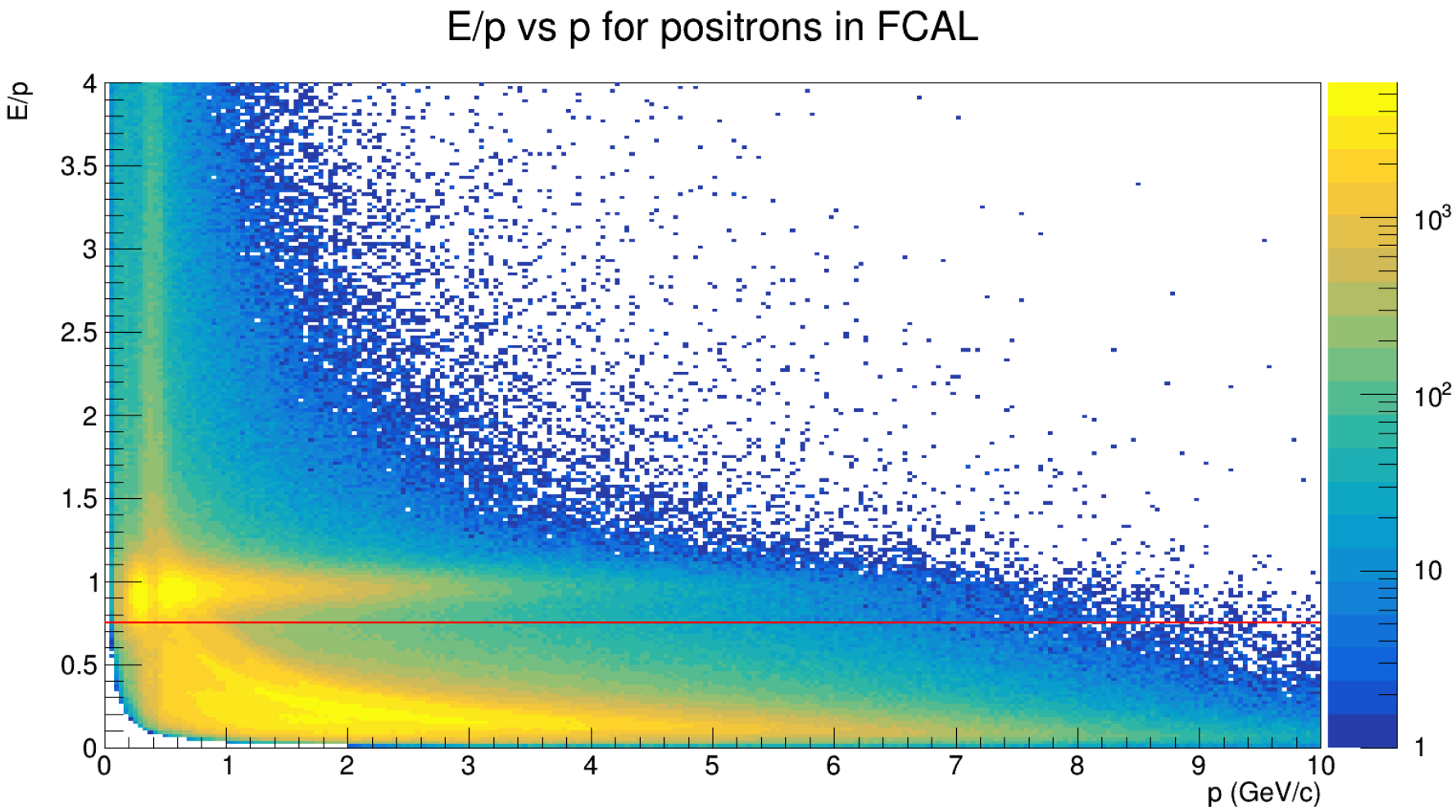

e+e-γ mass vs FCAL shower energy for e+
M(e+e-γ) (GeV/c2)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
FCAL energy (GeV)
10^3
10^2
10
1

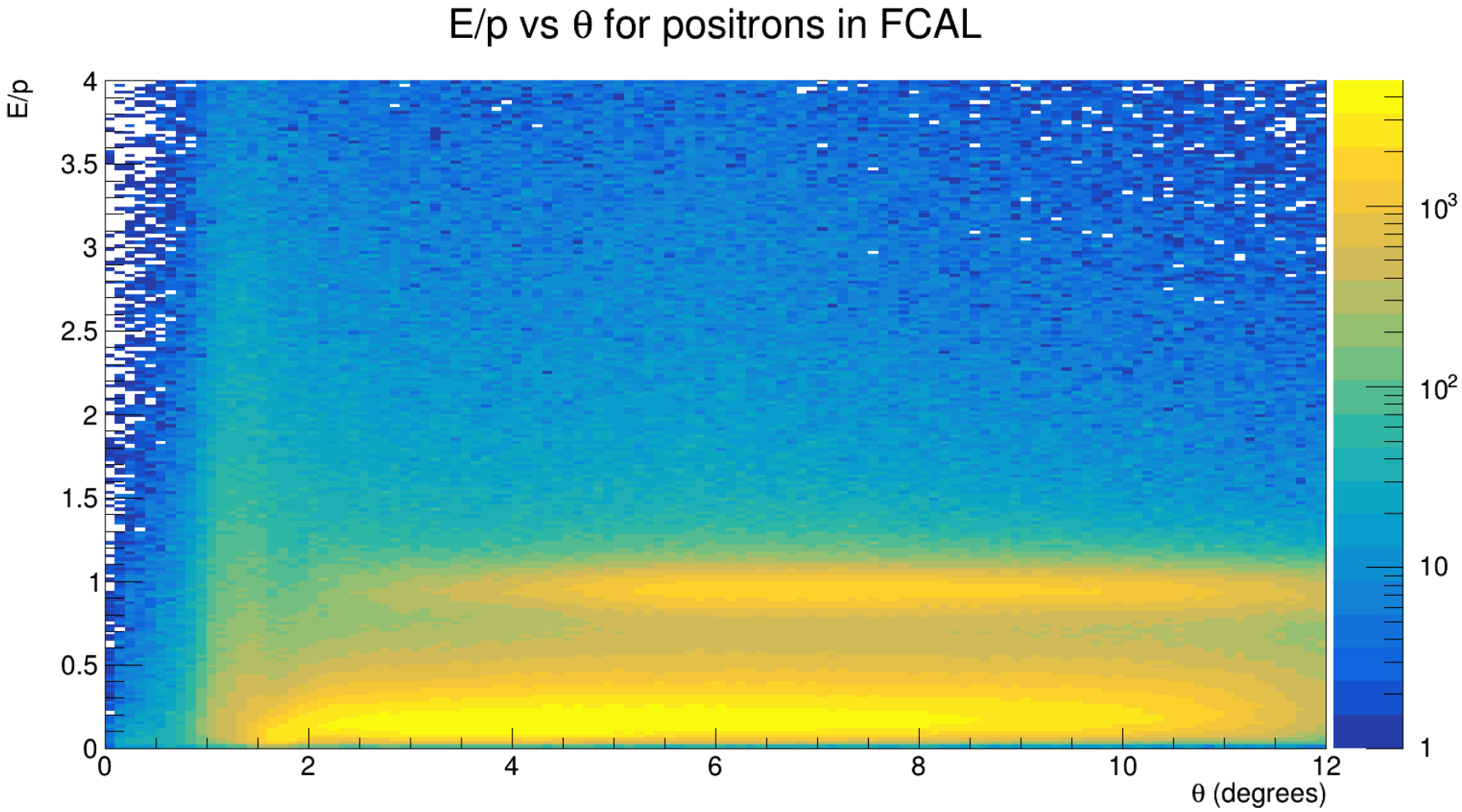

e⁺e⁻γ mass vs BCAL shower energy for γ
M(e⁺e⁻γ) (GeV/c²)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
BCAL energy (GeV)
10³
10²
10
1


e+e-γ mass vs FCAL shower energy for γ
M(e+e-γ) (GeV/c2)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
FCAL energy (GeV)
10^3
10^2
10
1


E/p vs p for positrons in BCAL
E/p
p (GeV/c)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
5
6
7
8
9
10
1
10
10^2
10^3

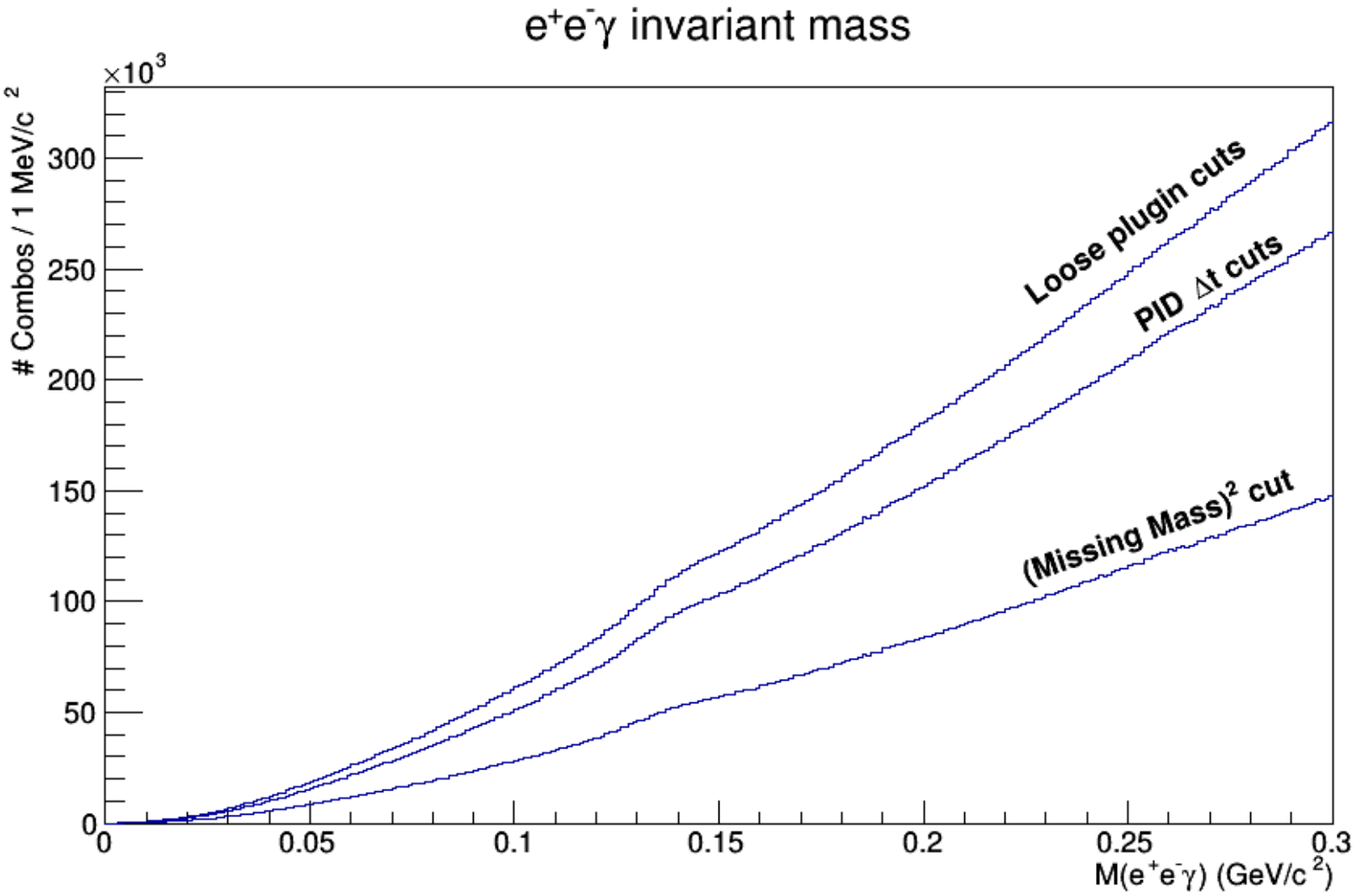

E/p vs θ for positrons in BCAL
E/p
θ (degrees)
0
0.5
1
1.5
2
2.5
3
3.5
4
20
40
60
80
100
120
140
1
10
10^2
10^3

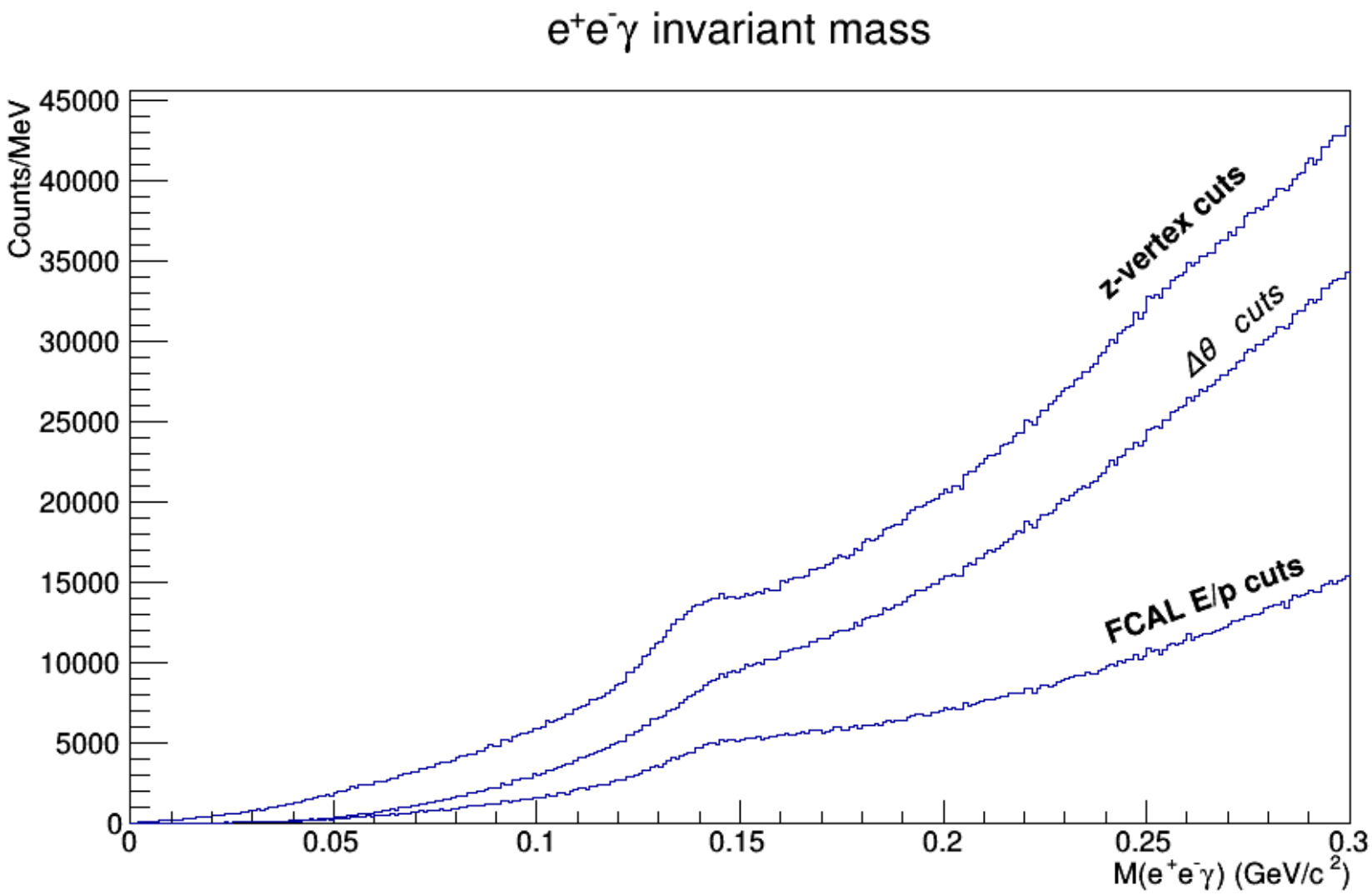

E/p vs p for positrons in FCAL
E/p
p (GeV/c)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
5
6
7
8
9
10
10^3
10^2
10
1


E/p vs θ for positrons in FCAL
E/p
θ (degrees)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
2
4
6
8
10
12
1
10
10^2
10^3

Further cuts

- PID Δt, protons, TOF: $\pm 1 ns$
- PID Δt, protons, BCAL: $\pm 1.5 ns$
- PID Δt, positrons, TOF: $\pm 0.6 ns$
- PID Δt, positrons, BCAL: $\pm 1.5 ns$
- PID Δt, electrons, TOF: $\pm 0.6 ns$
- PID Δt, electrons, BCAL: $\pm 1.5 ns$
- $(MissingMass)^2$ cut: [-0.05, 0.05] $(\frac{GeV}{c^2})^2$
- z-vertex proton/positron/electron cut: [48, 80] cm
- $\Delta\theta(e^+e^-) > 2^\circ$
- $\Delta\theta(e^+\gamma) > 2^\circ$
- $\Delta\theta(e^-\gamma) > 2^\circ$
- $\Delta\theta(e^+e^-, \gamma) > 2^\circ$
- FCAL $\frac{E}{p} > 0.75$ for positrons
- FCAL $\frac{E}{p} > 0.75$ for electrons


e+e-γ invariant mass
×10^3
Combos / 1 MeV/c^2
300
250
200
150
100
50
0
0
0.05
0.1
0.15
0.2
0.25
0.3
M(e+e-γ) (GeV/c^2)
Loose plugin cuts
PID Δt cuts
(Missing Mass)^2 cut


e+e-γ invariant mass
Counts/MeV
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
0.05
0.1
0.15
0.2
0.25
0.3
M(e+e-γ) (GeV/c2)
z-vertex cuts
Δθ cuts
FCAL E/p cuts

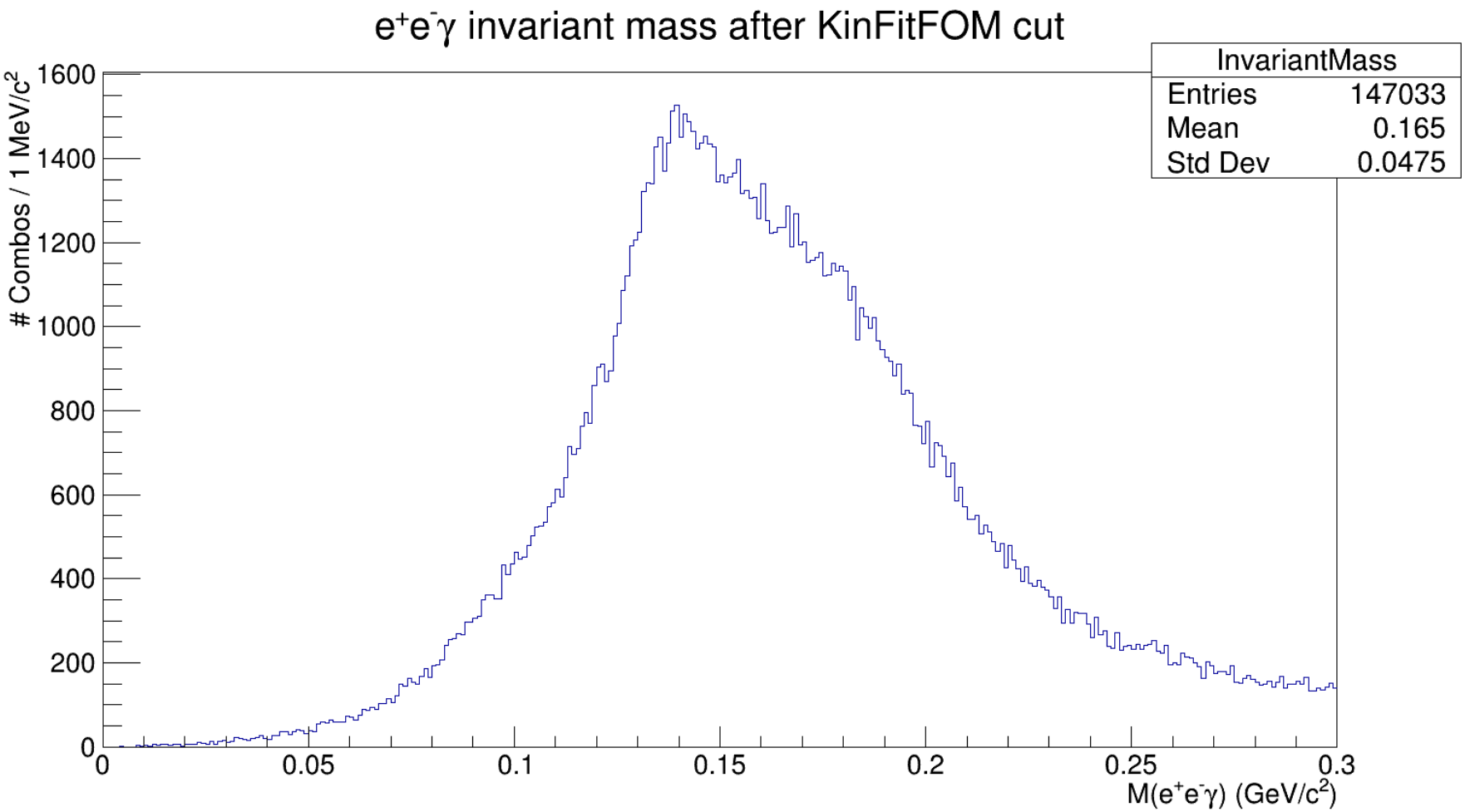
Final cut selection

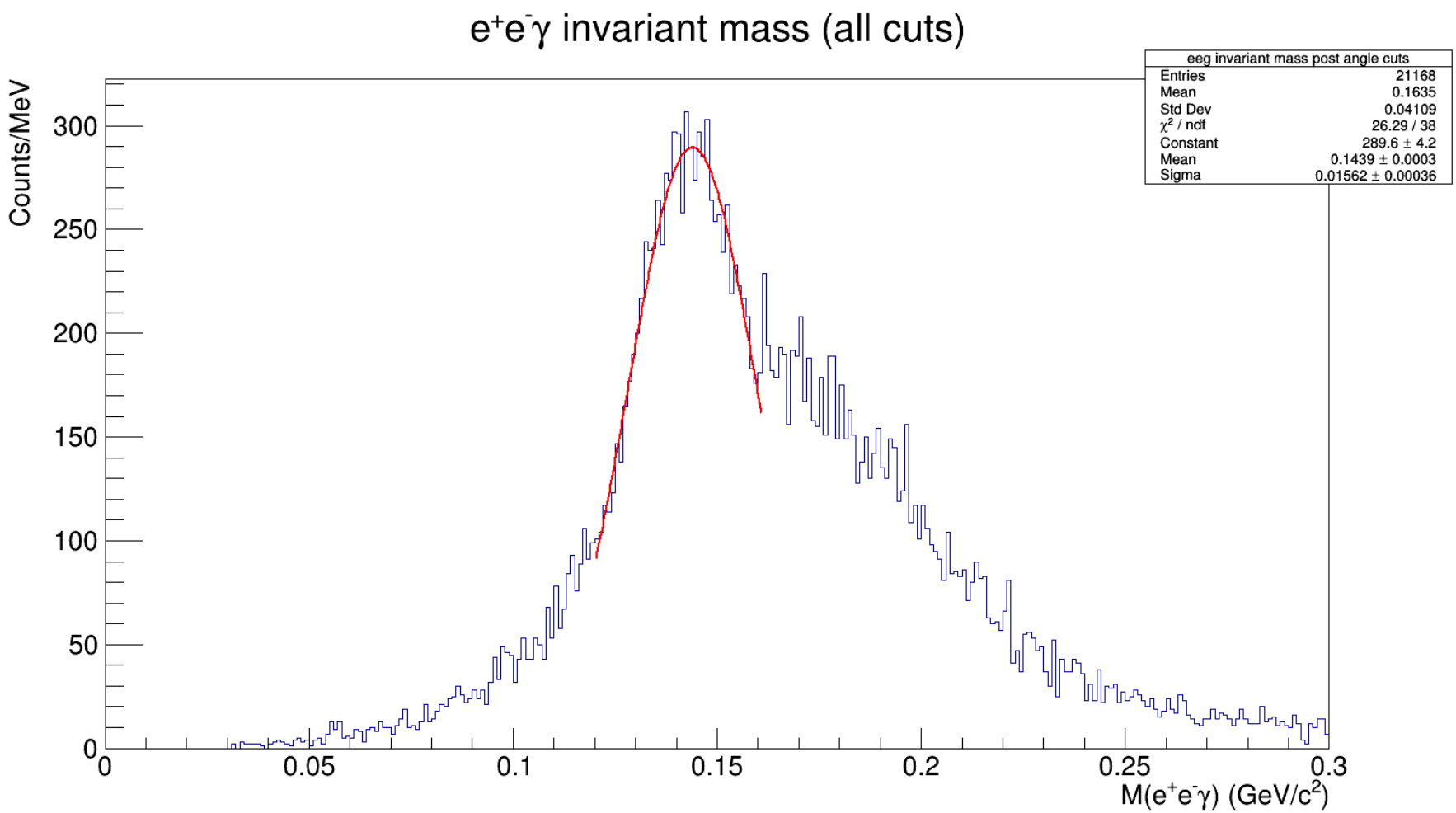
- Add KinFitFOM(0.0) cut (kinematic fit convergence)

- Include all aforementioned cuts

- Tighten $(MissingMass)^2$ cut: [-0.03, 0.03] $(\frac{GeV}{c^2})^2$

- Tighten all $\Delta\theta$ cuts: $\Delta\theta > 1^\circ$


e⁺e⁻γ invariant mass after KinFitFOM cut
InvariantMass
Entries 147033
Mean 0.165
Std Dev 0.0475
# Combos / 1 MeV/c²
M(e⁺e⁻γ) (GeV/c²)
0
200
400
600
800
1000
1200
1400
1600
0.05
0.1
0.15
0.2
0.25
0.3


e⁺e⁻γ invariant mass (all cuts)
eeg invariant mass post angle cuts
Entries 21168
Mean 0.1635
Std Dev 0.04109
χ² / ndf 26.29 / 38
Constant 289.6 ± 4.2
Mean 0.1439 ± 0.0003
Sigma 0.01562 ± 0.00036
Counts/MeV
0
50
100
150
200
250
300
0
0.05
0.1
0.15
0.2
0.25
0.3
M(e⁺e⁻γ) (GeV/c²)

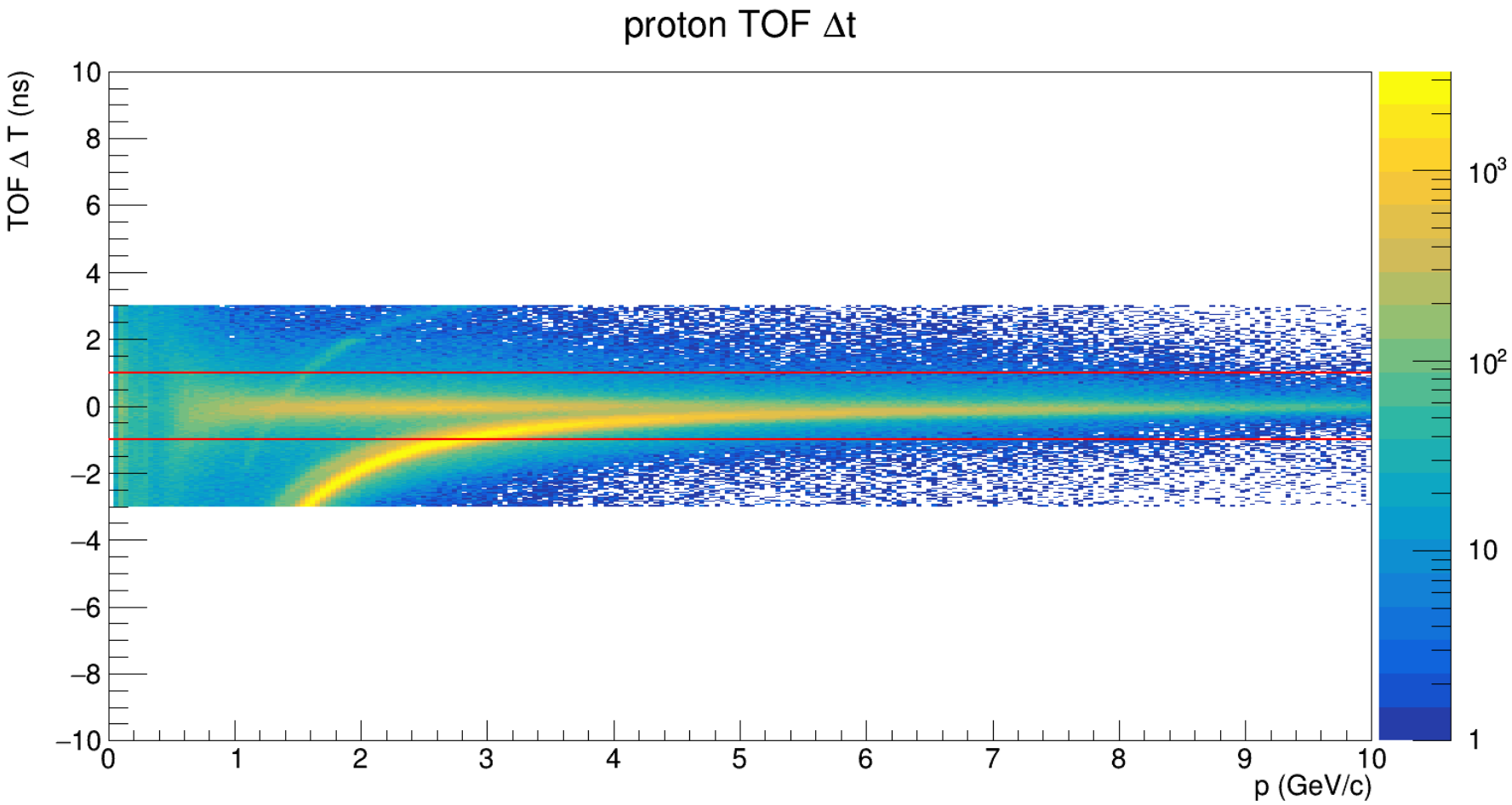
To Do:

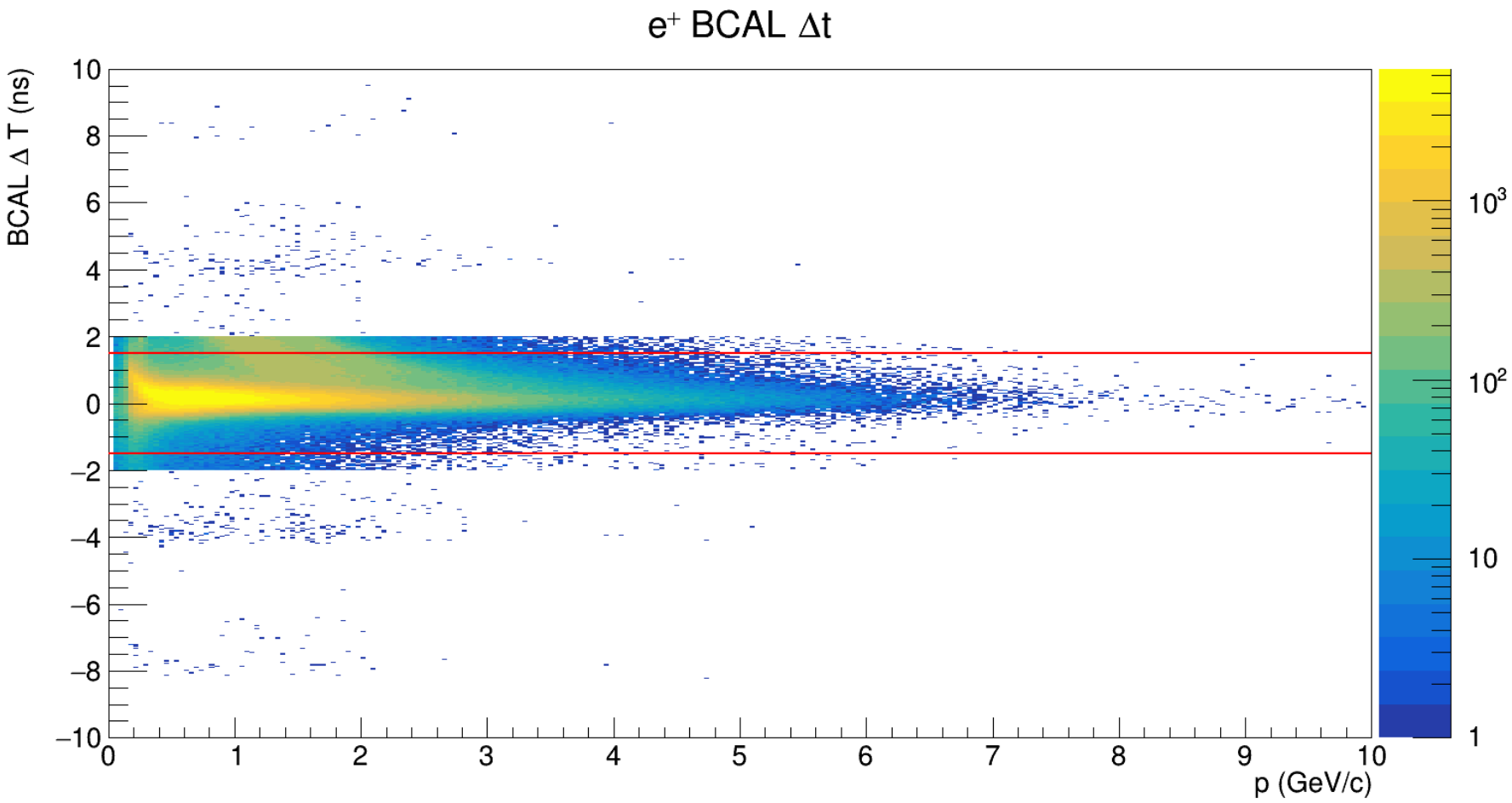
- Add more cuts / Improve current cuts

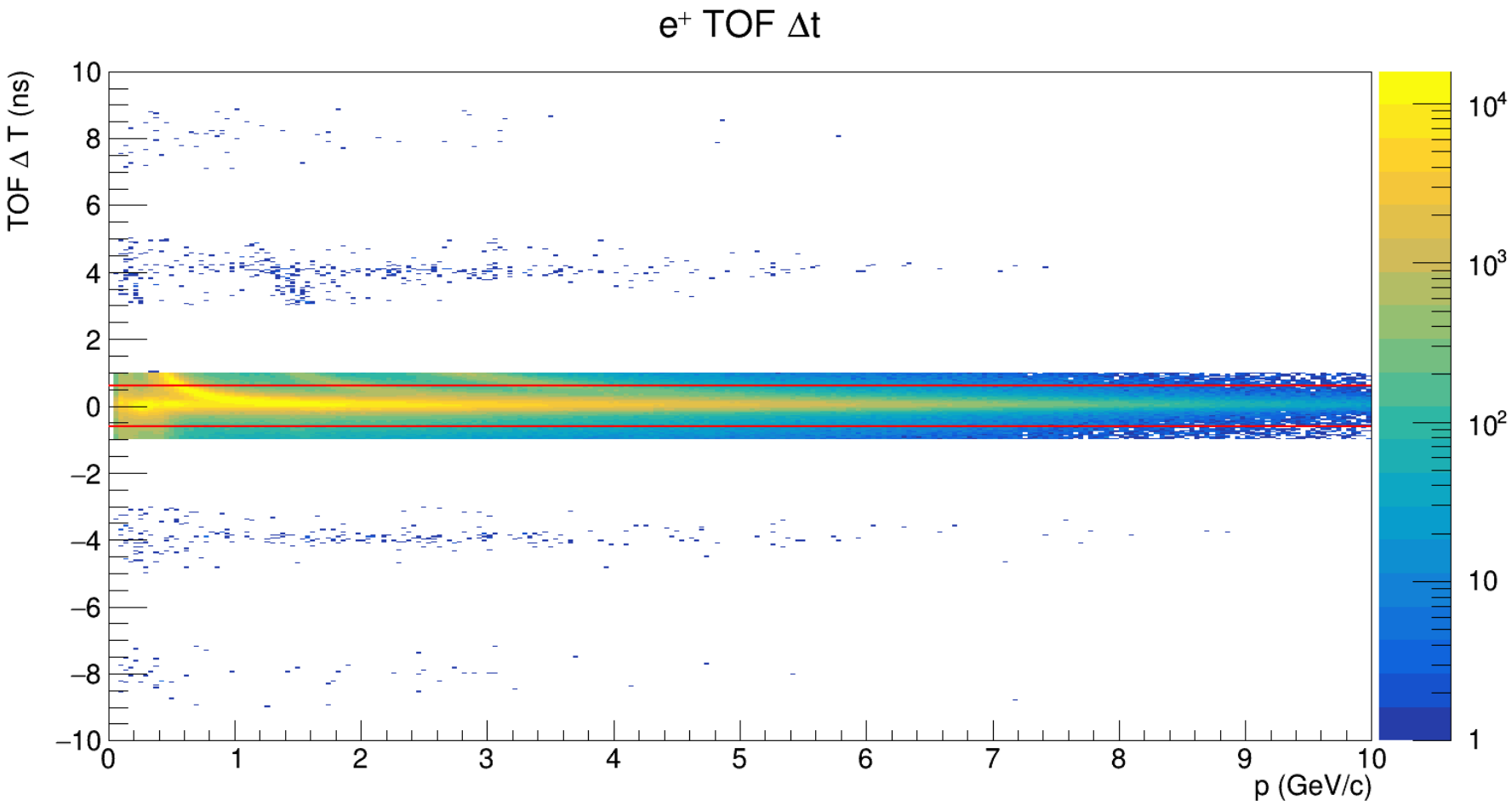
- Run over the full Spring 2016 dataset if needed

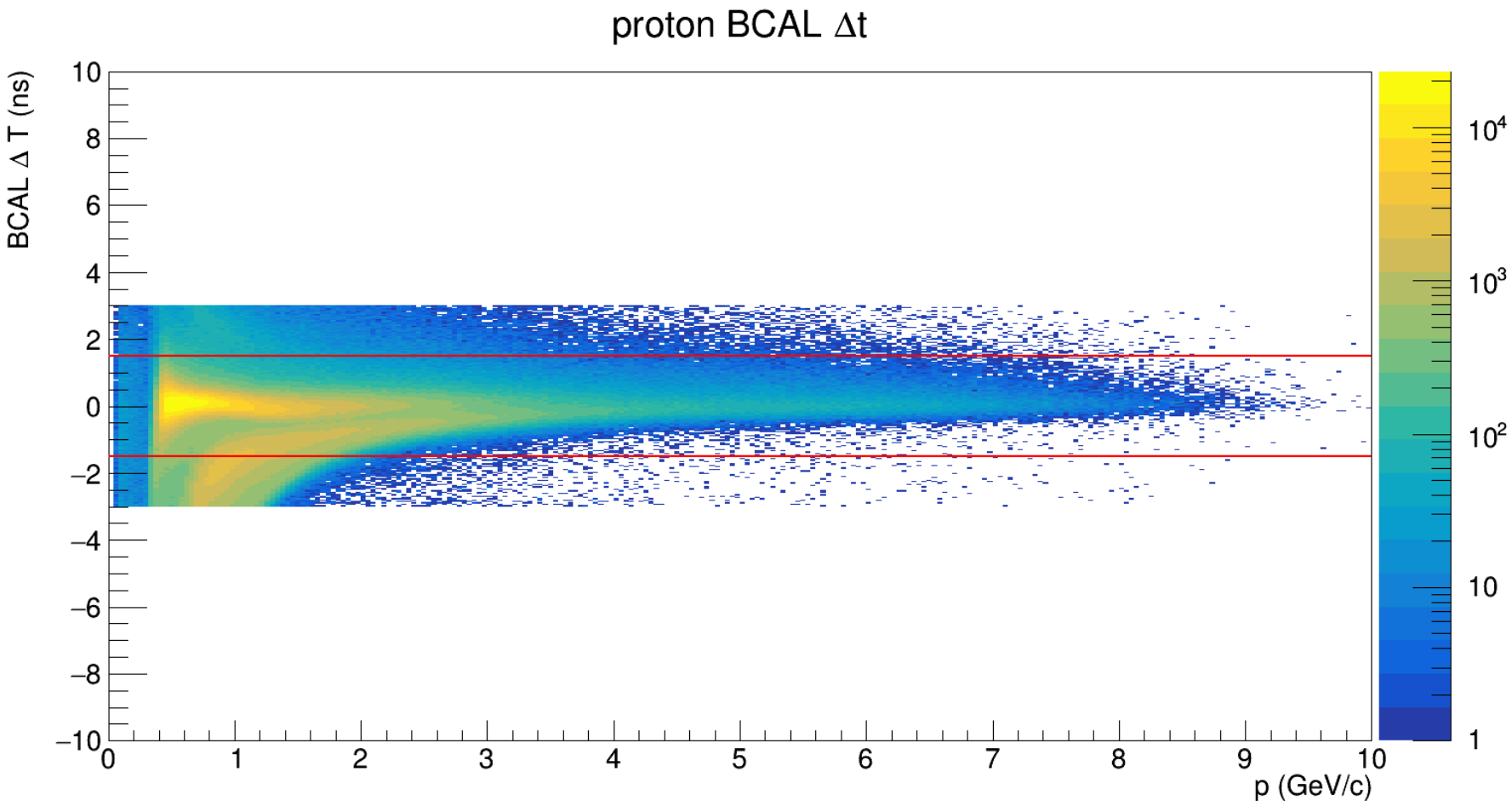
- Determine the energy resolution using the single photon from $\pi^0 \to e^+e^-\gamma$

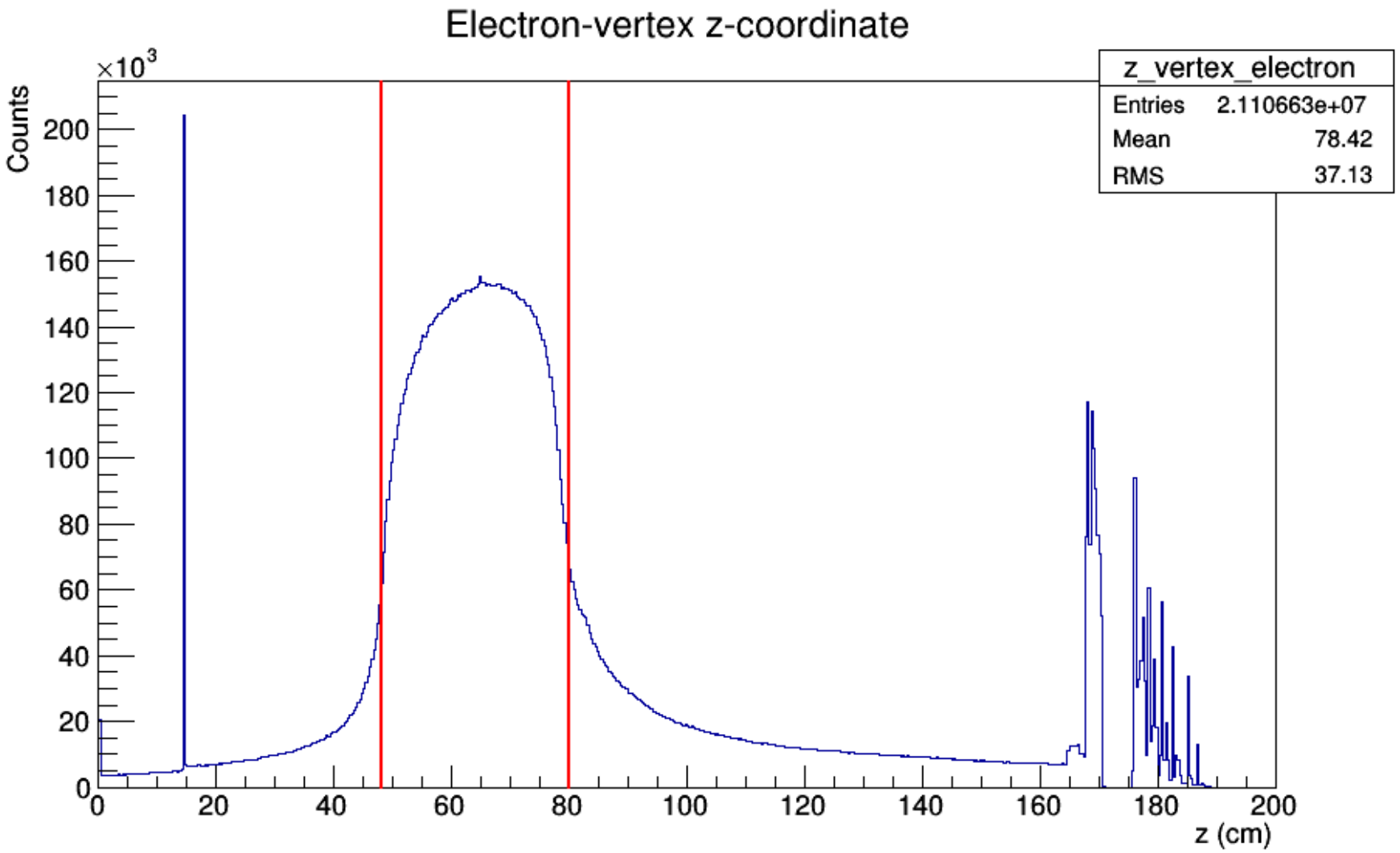
Back Up Slides

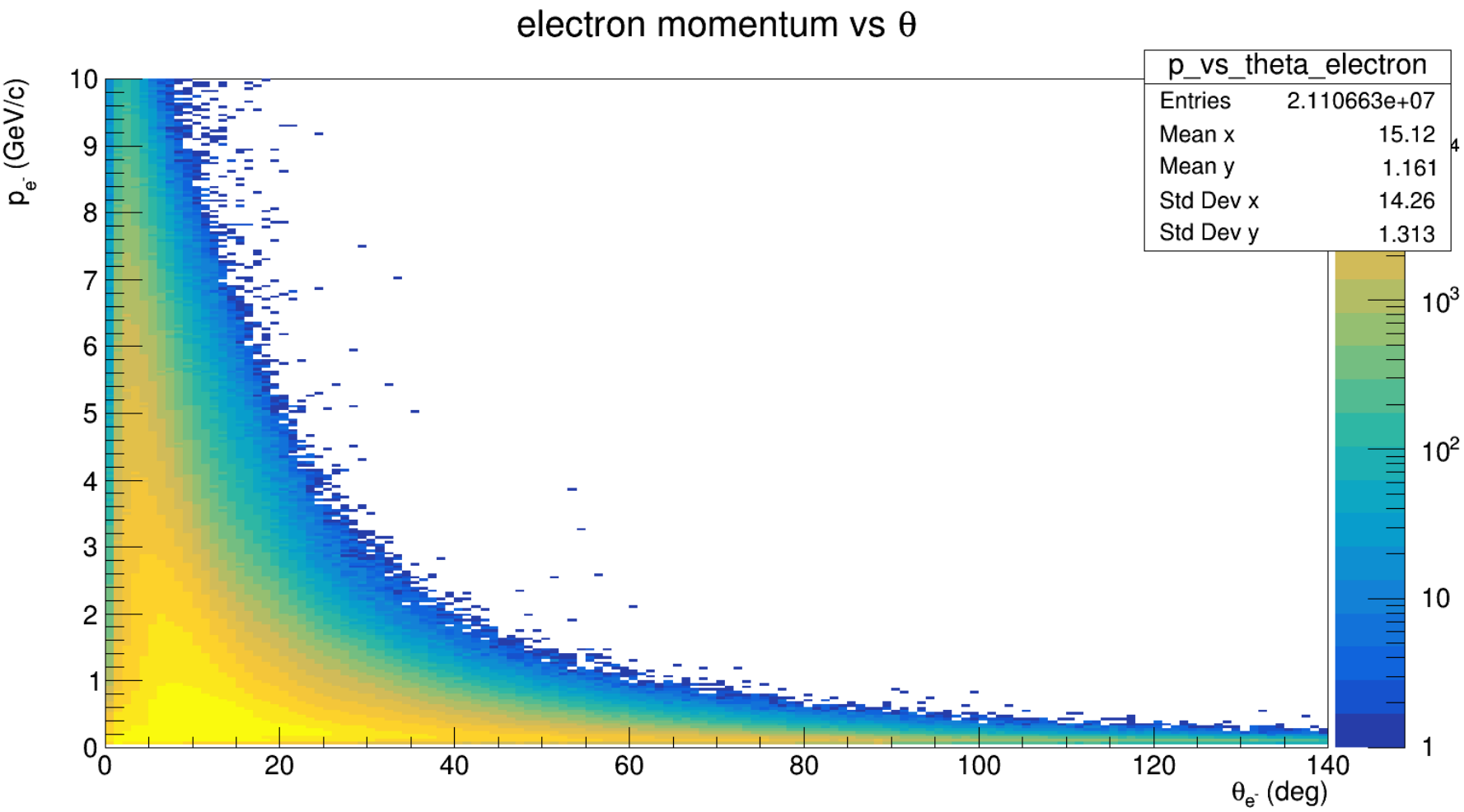

proton TOF Δt
TOF Δ T (ns)
10
8
6
4
2
0
−2
−4
−6
−8
−10
0
1
2
3
4
5
6
7
8
9
10
p (GeV/c)
10^3
10^2
10
1

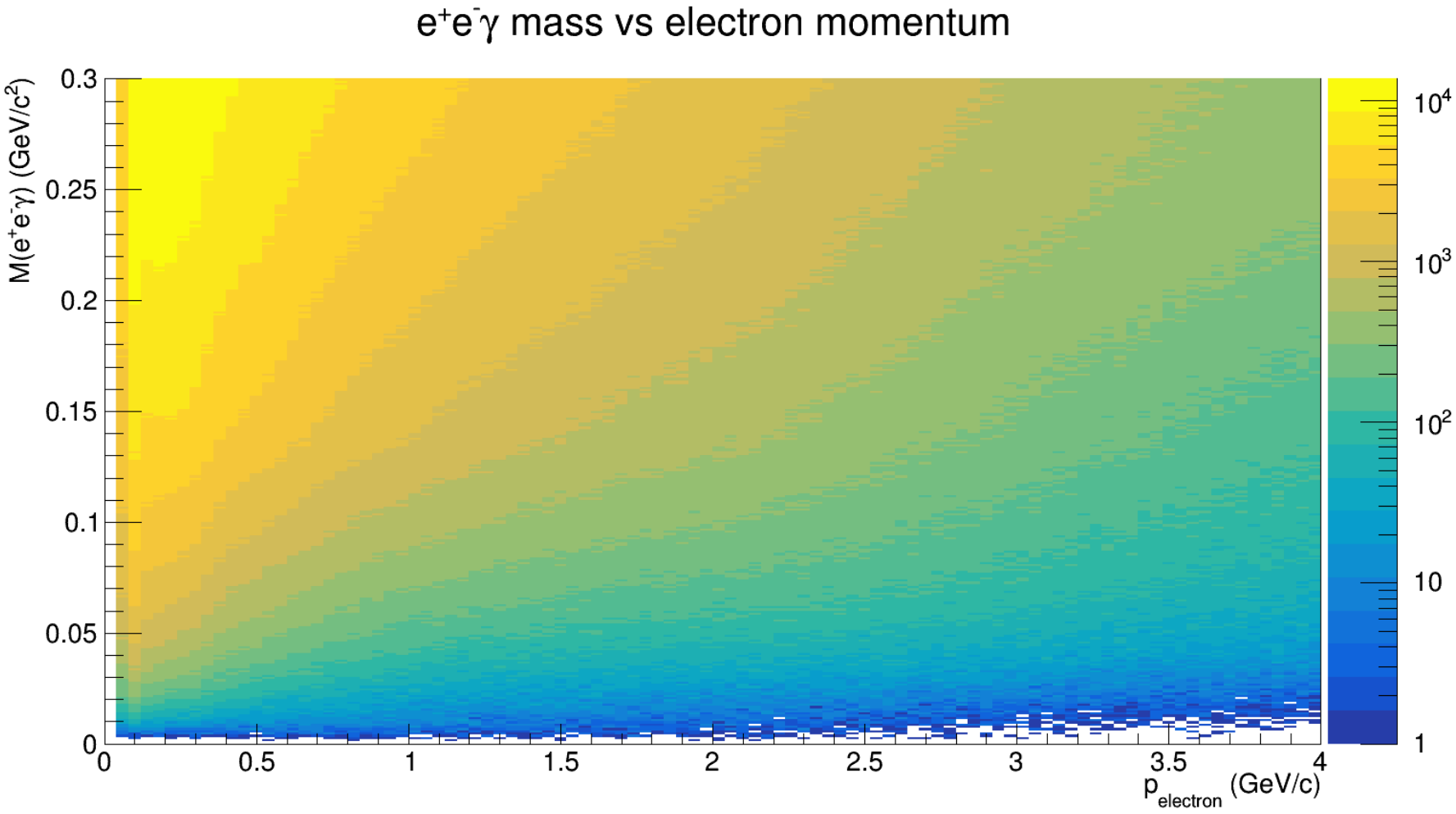

e+ BCAL Δt
BCAL Δ T (ns)
10
8
6
4
2
0
−2
−4
−6
−8
−10
0
1
2
3
4
5
6
7
8
9
10
p (GeV/c)
10^3
10^2
10
1

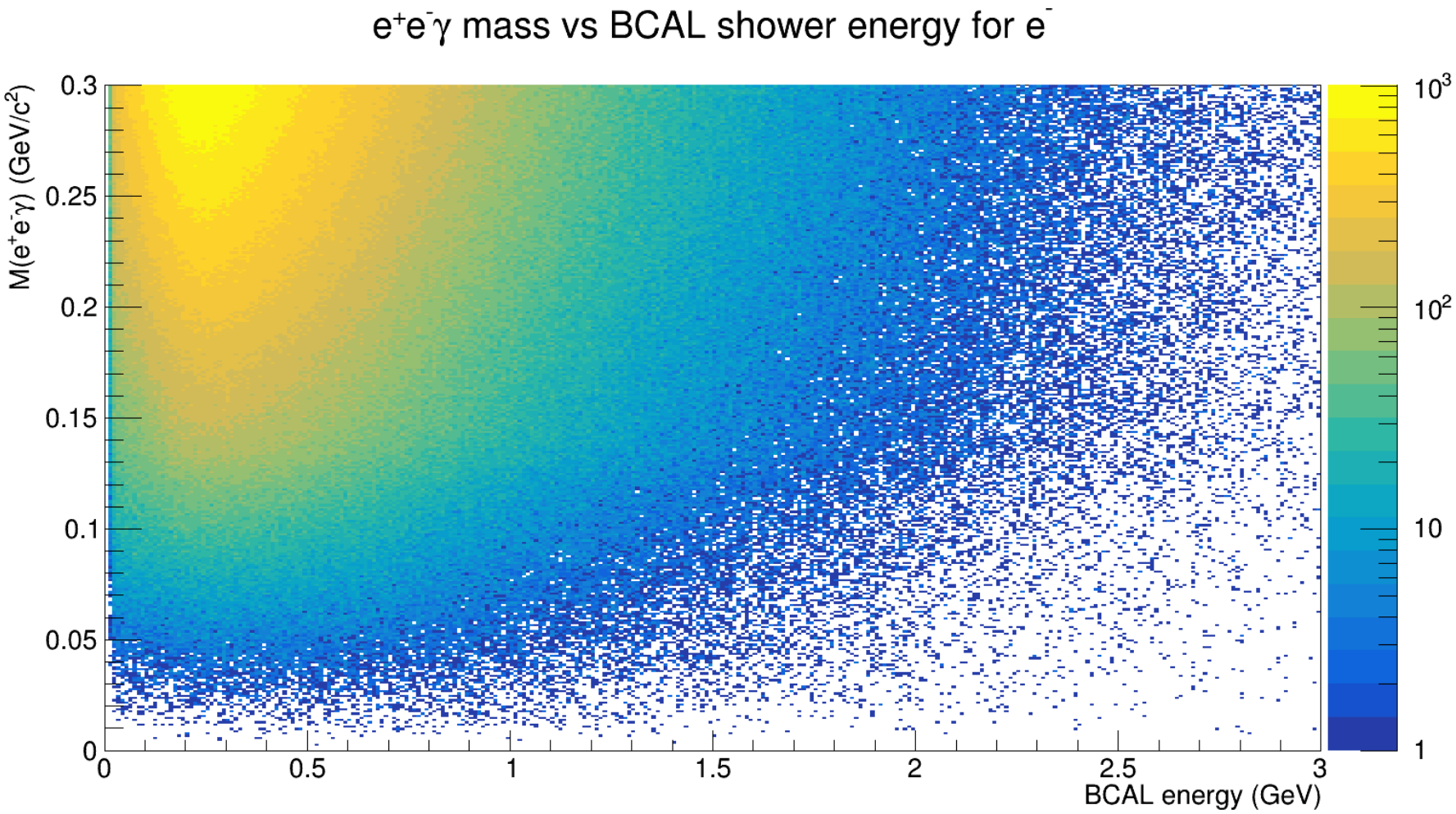

e+ TOF Δt
TOF Δ T (ns)
p (GeV/c)
10
8
6
4
2
0
−2
−4
−6
−8
−10
0
1
2
3
4
5
6
7
8
9
10
10^4
10^3
10^2
10
1

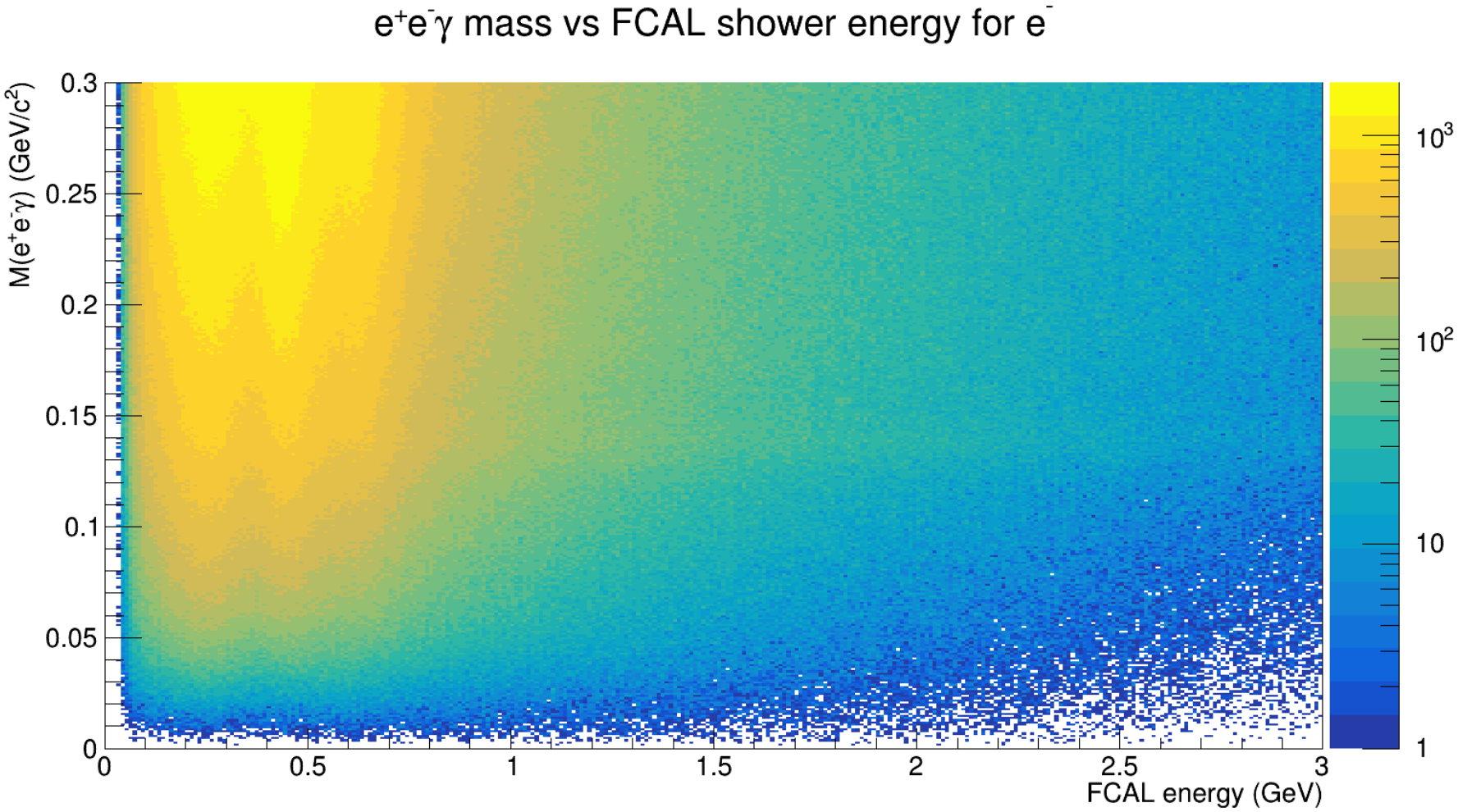

proton BCAL Δt
BCAL Δ T (ns)
10
8
6
4
2
0
−2
−4
−6
−8
−10
0
1
2
3
4
5
6
7
8
9
10
p (GeV/c)
10^4
10^3
10^2
10
1

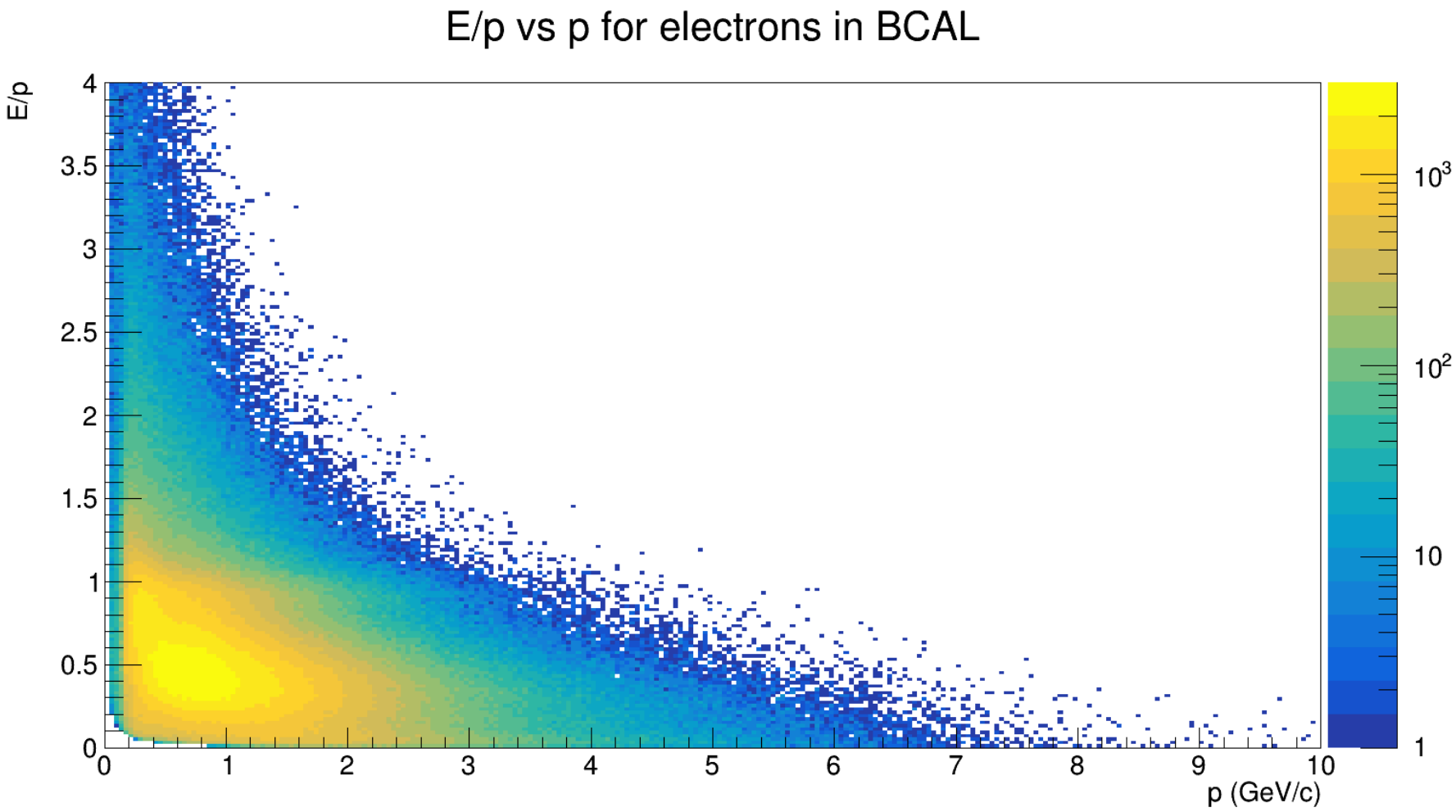

Electron-vertex z-coordinate
z_vertex_electron
Entries 2.110663e+07
Mean 78.42
RMS 37.13
Counts
×10^3
z (cm)
0
20
40
60
80
100
120
140
160
180
200

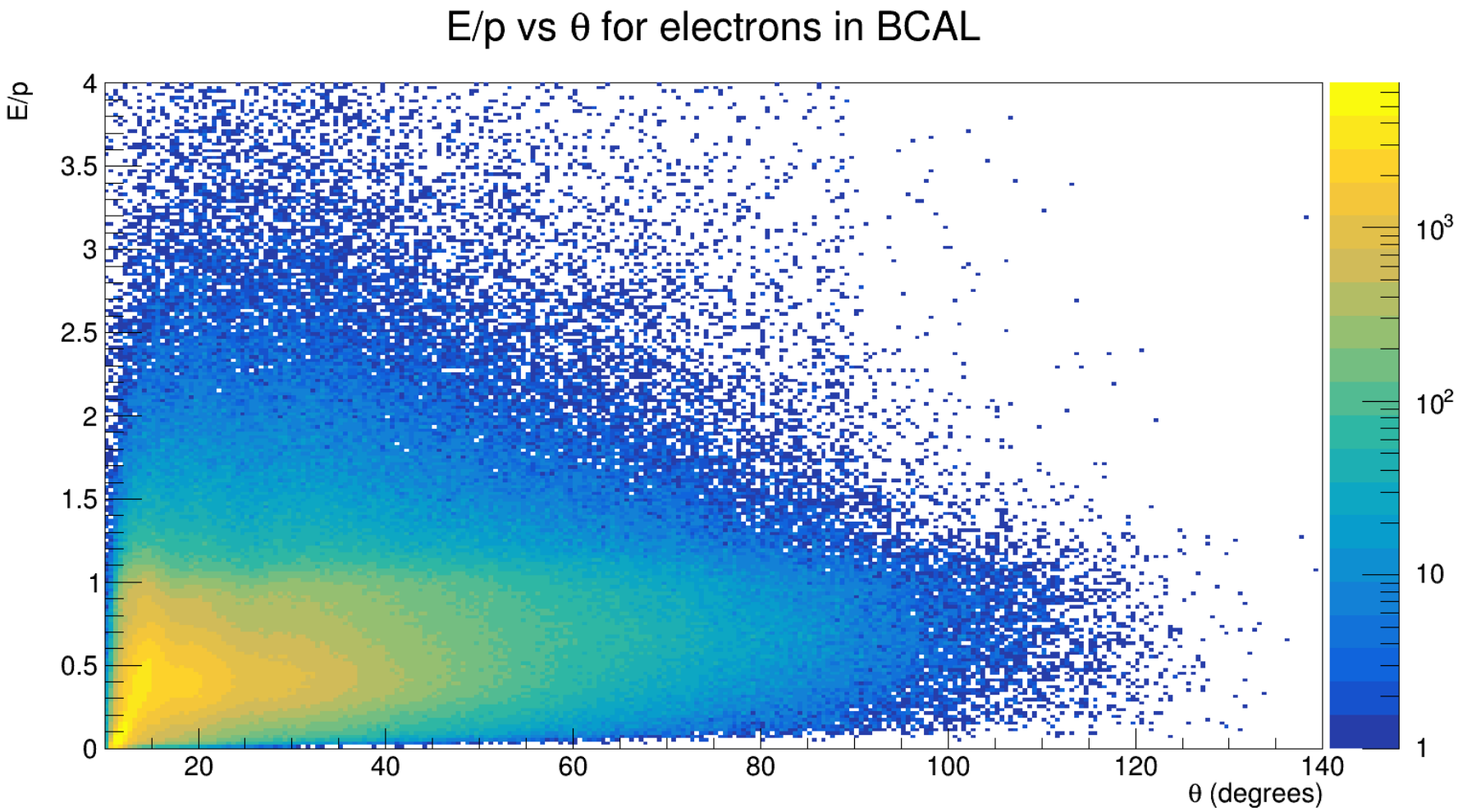

electron momentum vs θ
p_vs_theta_electron
Entries 2.110663e+07
Mean x 15.12
Mean y 1.161
Std Dev x 14.26
Std Dev y 1.313
p_e⁻ (GeV/c)
θ_e⁻ (deg)
0
20
40
60
80
100
120
140
1
2
3
4
5
6
7
8
9
10
1
10
10²
10³

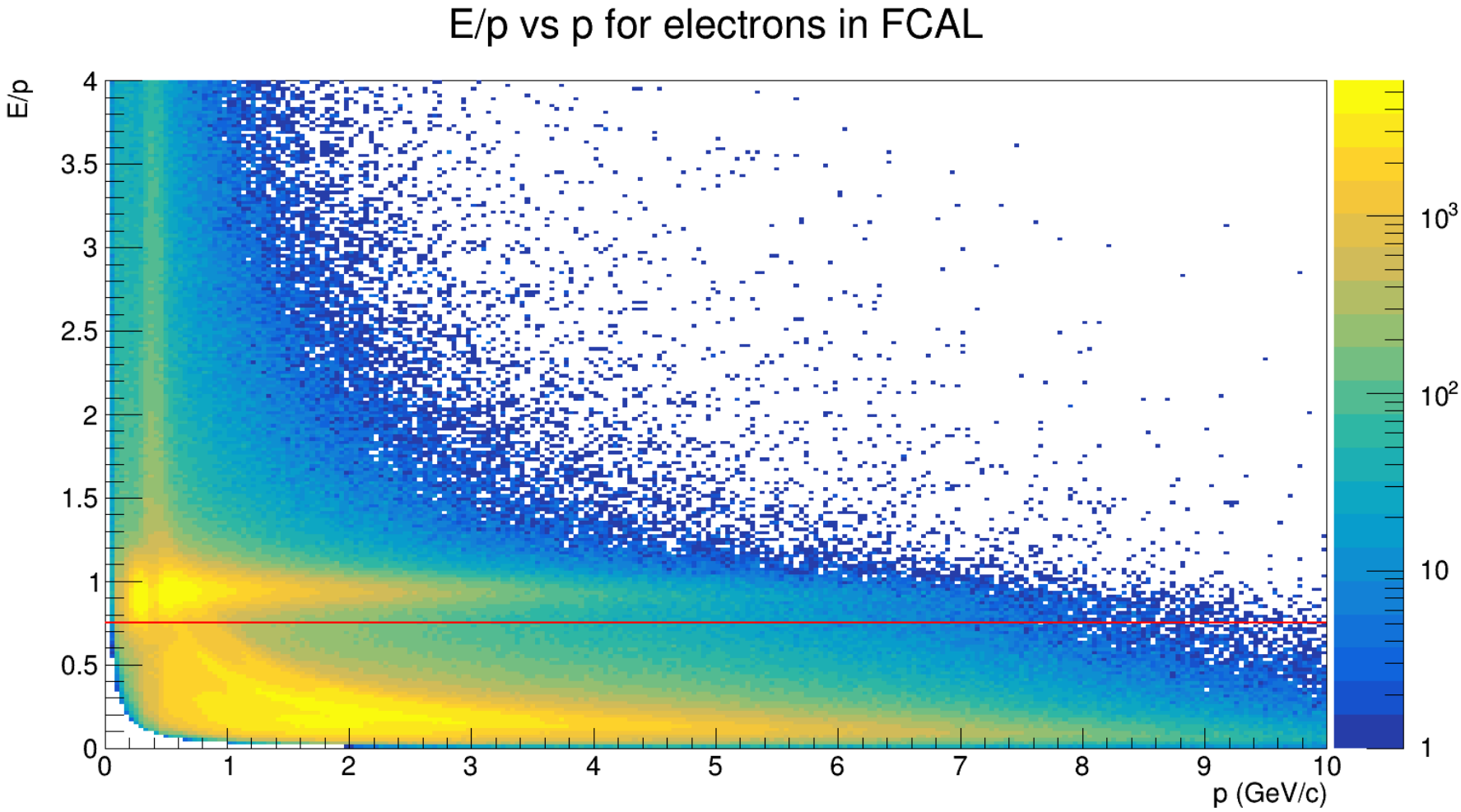

e+e-γ mass vs electron momentum
M(e+e-γ) (GeV/c2)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4
pelectron (GeV/c)
10^4
10^3
10^2
10
1

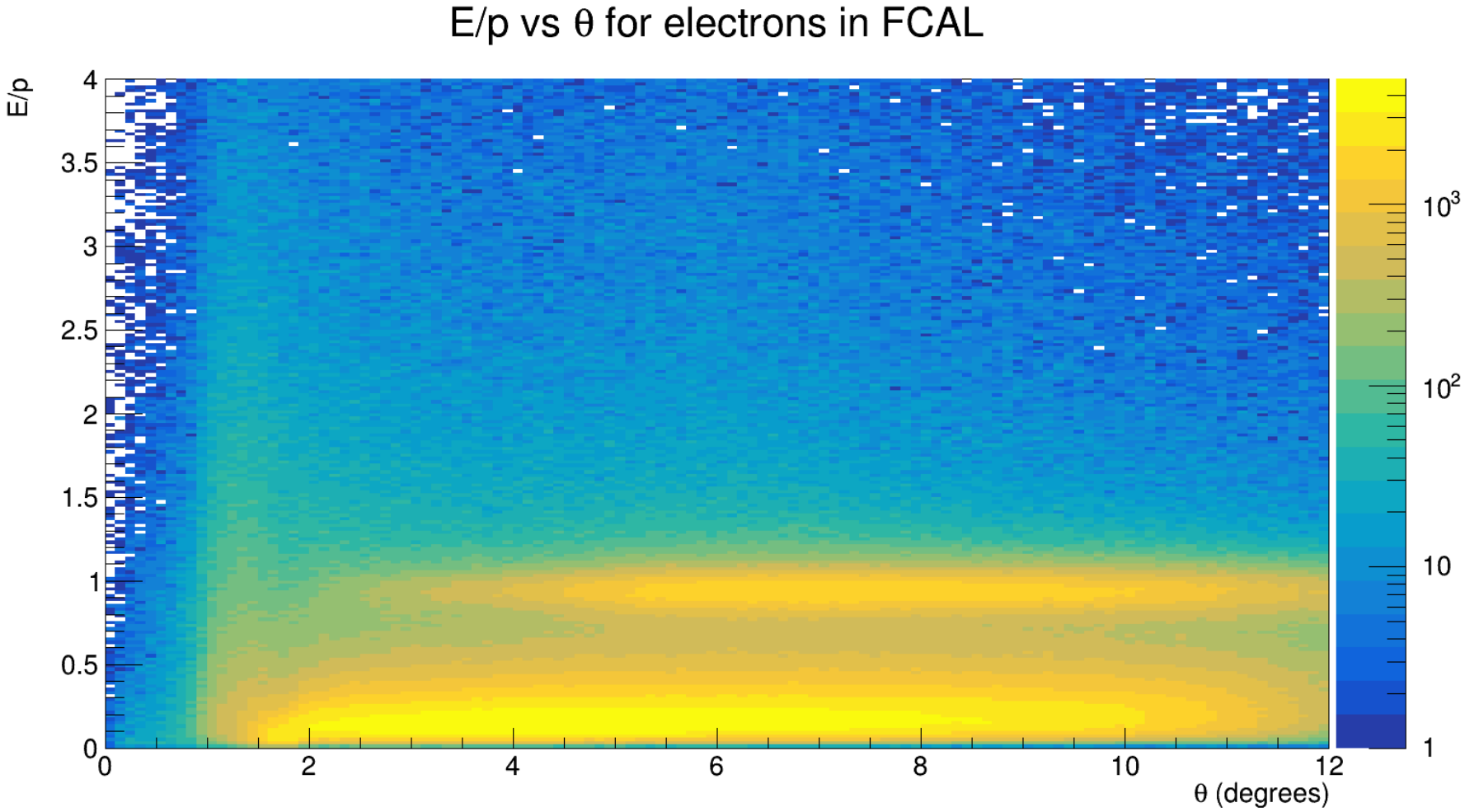

e+e-γ mass vs BCAL shower energy for e-
M(e+e-γ) (GeV/c2)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
BCAL energy (GeV)
10^3
10^2
10
1

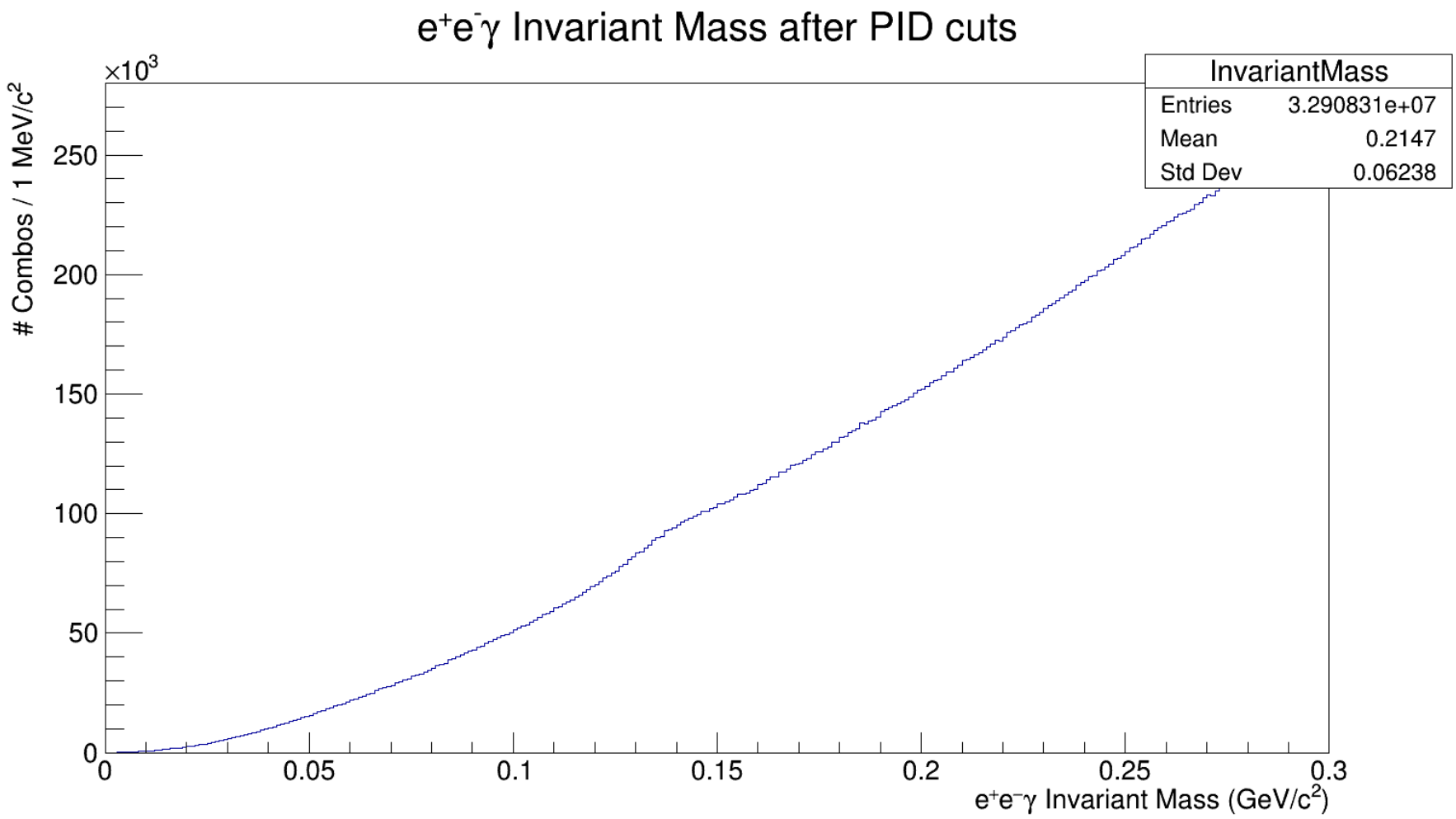

e+e-γ mass vs FCAL shower energy for e-
M(e+e-γ) (GeV/c2)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
FCAL energy (GeV)
10^3
10^2
10
1

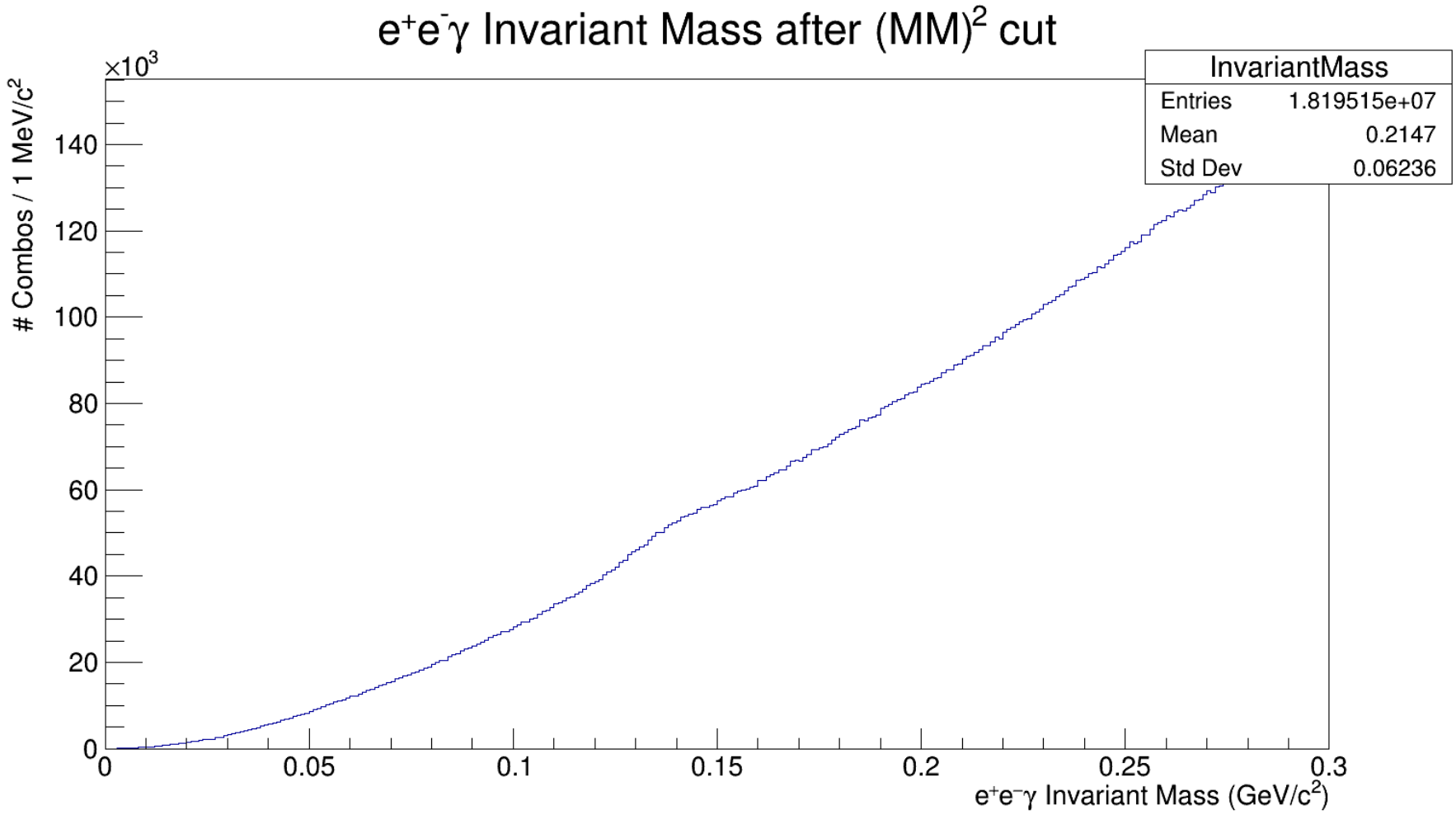

E/p vs p for electrons in BCAL
E/p
p (GeV/c)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
5
6
7
8
9
10
10^3
10^2
10
1

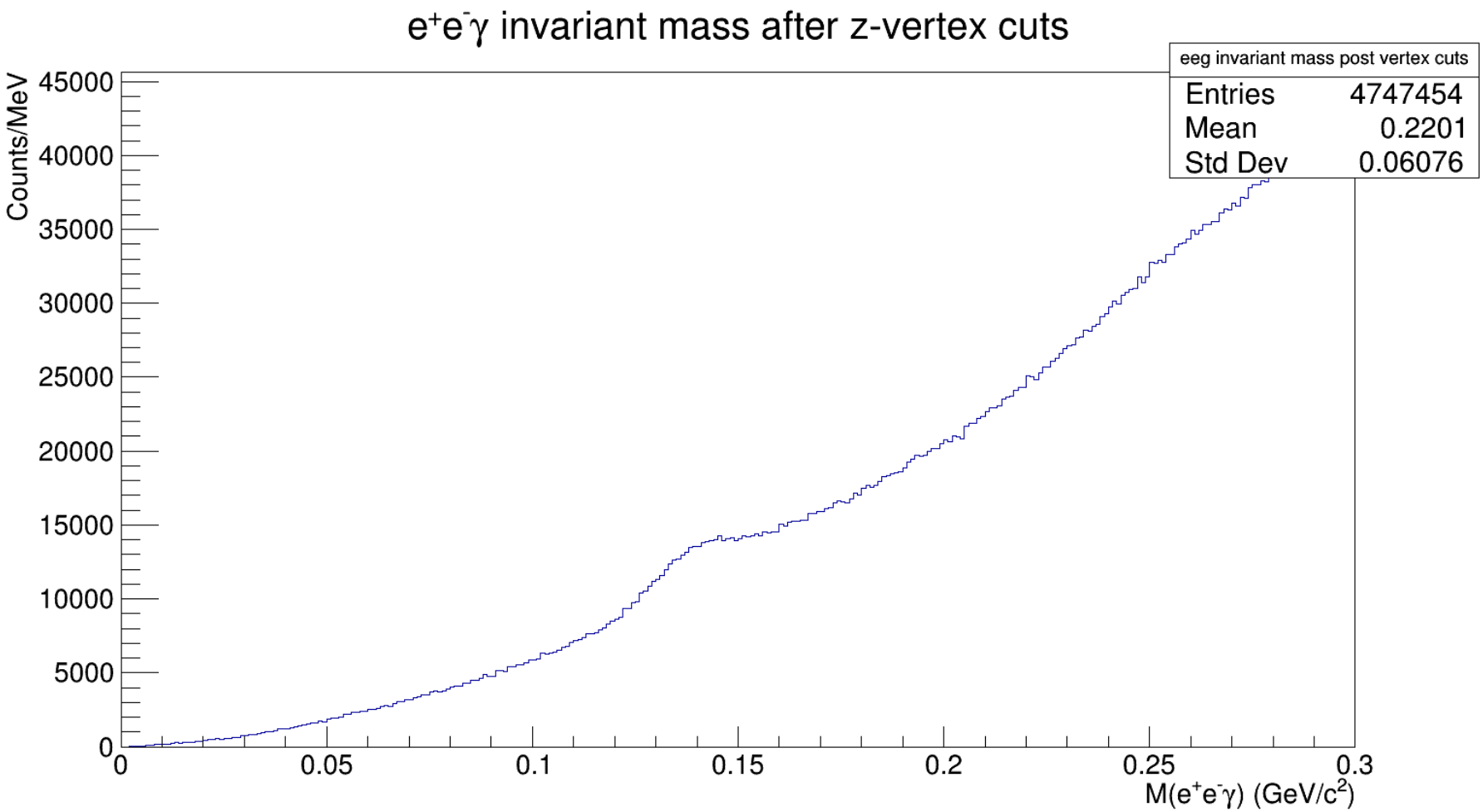

E/p vs θ for electrons in BCAL
E/p
θ (degrees)
0
0.5
1
1.5
2
2.5
3
3.5
4
20
40
60
80
100
120
140
1
10
10^2
10^3

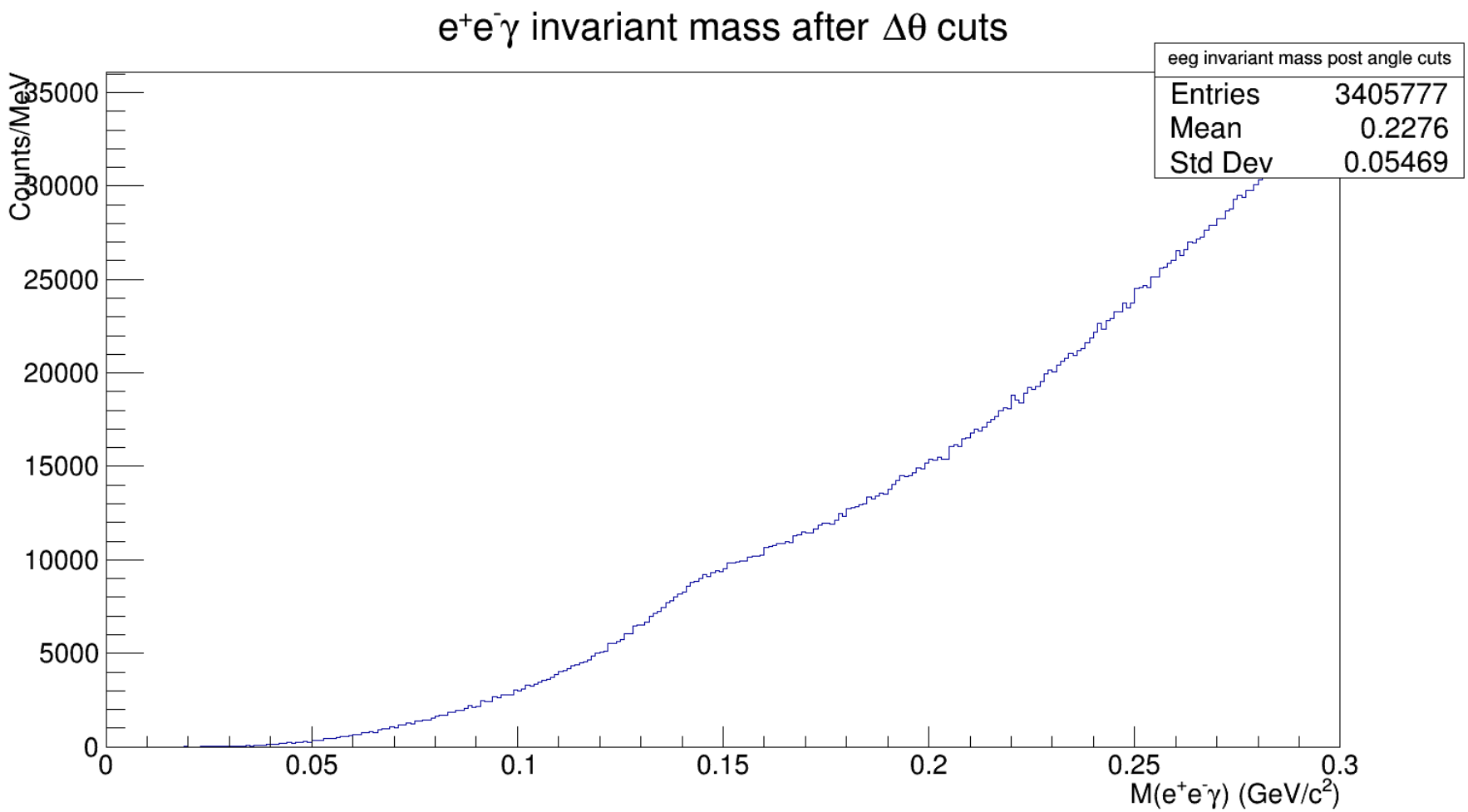

E/p vs p for electrons in FCAL
E/p
p (GeV/c)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
5
6
7
8
9
10
1
10
10^2
10^3

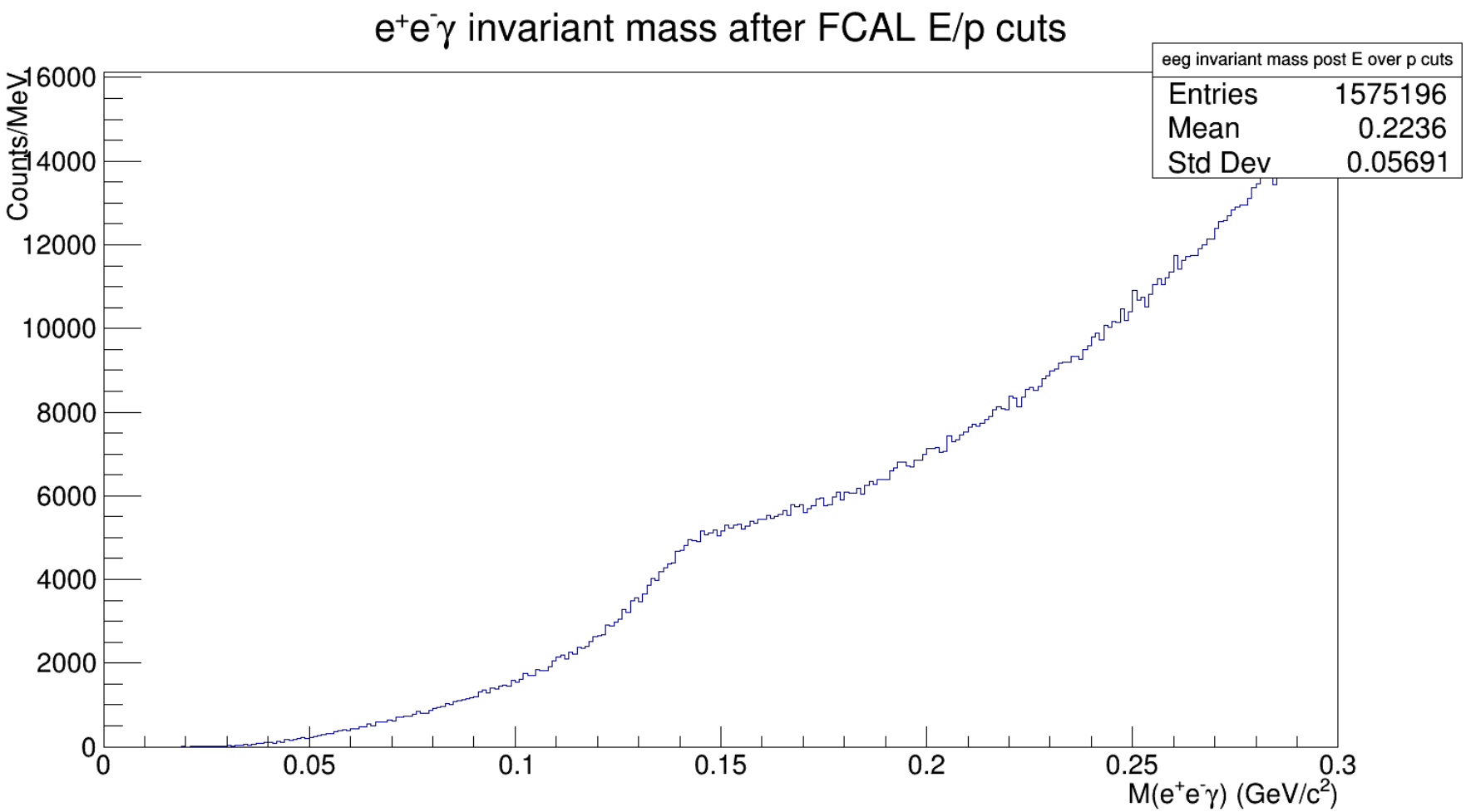

E/p vs θ for electrons in FCAL
E/p
θ (degrees)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
2
4
6
8
10
12
10^3
10^2
10
1


e⁺e⁻γ Invariant Mass after PID cuts
InvariantMass
Entries 3.290831e+07
Mean 0.2147
Std Dev 0.06238
×10³
Combos / 1 MeV/c²
250
200
150
100
50
0
0
0.05
0.1
0.15
0.2
0.25
0.3
e⁺e⁻γ Invariant Mass (GeV/c²)


e+e-γ Invariant Mass after (MM)2 cut
InvariantMass
Entries 1.819515e+07
Mean 0.2147
Std Dev 0.06236
×10^3
Combos / 1 MeV/c2
0
20
40
60
80
100
120
140
0
0.05
0.1
0.15
0.2
0.25
0.3
e+e−γ Invariant Mass (GeV/c2)


e+e-γ invariant mass after z-vertex cuts
eeg invariant mass post vertex cuts
Entries 4747454
Mean 0.2201
Std Dev 0.06076
Counts/MeV
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
0.05
0.1
0.15
0.2
0.25
0.3
M(e+e-γ) (GeV/c2)


e⁺e⁻γ invariant mass after Δθ cuts
eeg invariant mass post angle cuts
Entries 3405777
Mean 0.2276
Std Dev 0.05469
Counts/MeV
35000
30000
25000
20000
15000
10000
5000
0
0
0.05
0.1
0.15
0.2
0.25
0.3
M(e⁺e⁻γ) (GeV/c²)


e⁺e⁻γ invariant mass after FCAL E/p cuts
eeg invariant mass post E over p cuts
Entries 1575196
Mean 0.2236
Std Dev 0.05691
Counts/MeV
0
2000
4000
6000
8000
10000
12000
14000
16000
0
0.05
0.1
0.15
0.2
0.25
0.3
M(e⁺e⁻γ) (GeV/c²)