# COMPASS RHO0 ANALYSIS

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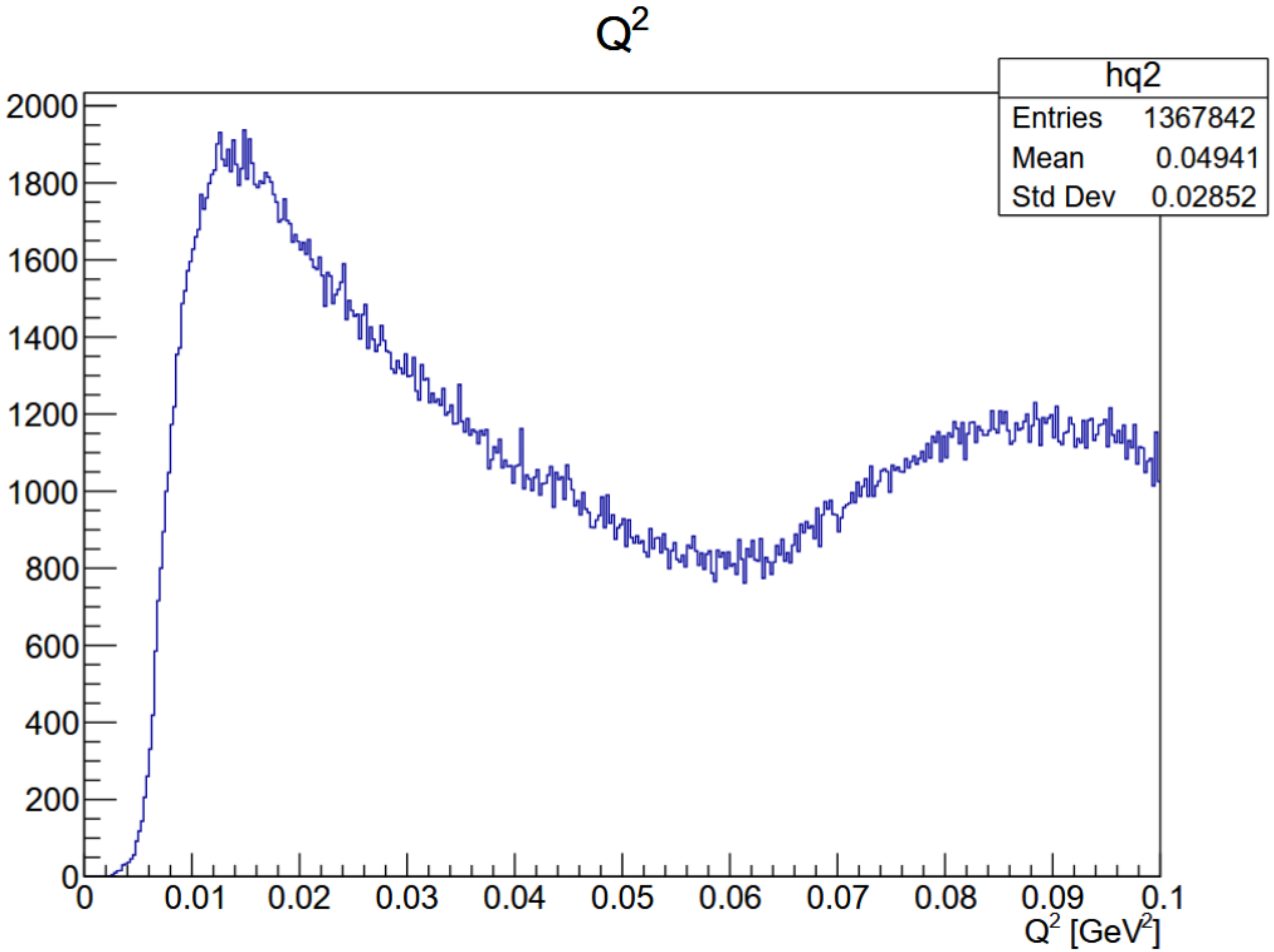
# COMPASS DATA AND MC

- Year 2016, and period 04,05,06,07,09
  - P09 is used for the Monte Carlo comparison and SDME extraction
- COMPASS is using two different Monte Carlo for their 2012 analysis:
  - HepGEN – For the exclusive ρ0 reaction
  - LEPTO –For the SIDIS Background

# Small Q2 events

1. Low Q2 physics
   - A group at COMPASS who looks at the low Q2 physics
   - quasi-real photoproduction
2. Bad reconstruction for small scattering angle
3. Acceptance with the scattered muon trigger
4. For DIS, the kinematic cut of Q2 > 0.8 GeV2 is typically used (Q2 >1 for this analysis)



# Event Selection Muons

Coming from DVCS analysis of 2016 data
(J. V. Giarra, Deeply Virtual Compton Scattering at COMPASS, PhD thesis, 2022.)

**Incoming muon track ($\mu$):**

- first measured before the target ($Z_{tgt,min.}$=-318.5 cm)
- track crosses the full target length
- momentum: $140\,\mathrm{GeV/c} < p_\mu < 180\,\mathrm{GeV/c}$
- momentum error: $\Delta p_\mu \leq 0.025 \cdot p_\mu$
- meantime: $-2\,\mathrm{ns} < t_{track} < 2\,\mathrm{ns}$
- hits in Beam Momentum Station (BMS): $\geq 3$
- hits in Scintillation Fibre detectors (SCIFI): $\geq 2$
- hits in Silicon strip detectors (SI): $\geq 3$

**Outgoing charged track ($\mu'$):**

- same charge as incoming muon
- rel. radiation length: $X/X_0 > 15$
- first measured before and last after SM1: $Z_{first} < 350\,\mathrm{cm}$ and $Z_{last} > 350\,\mathrm{cm}$
- track extrapolations are in the active hodoscope areas (PaHodoHelper::iMuPrim())

**Vertex requirements:**

- in target
  - $-318.5\,\mathrm{cm} < Z_{vtx} < -78.5\,\mathrm{cm}$
  - $R_{vtx} < 1.9\,\mathrm{cm}$
  - $Y_{vtx} < 1.2\,\mathrm{cm}$
- exactly one outgoing charged track

The common UCONN script and common to all of COMPASS

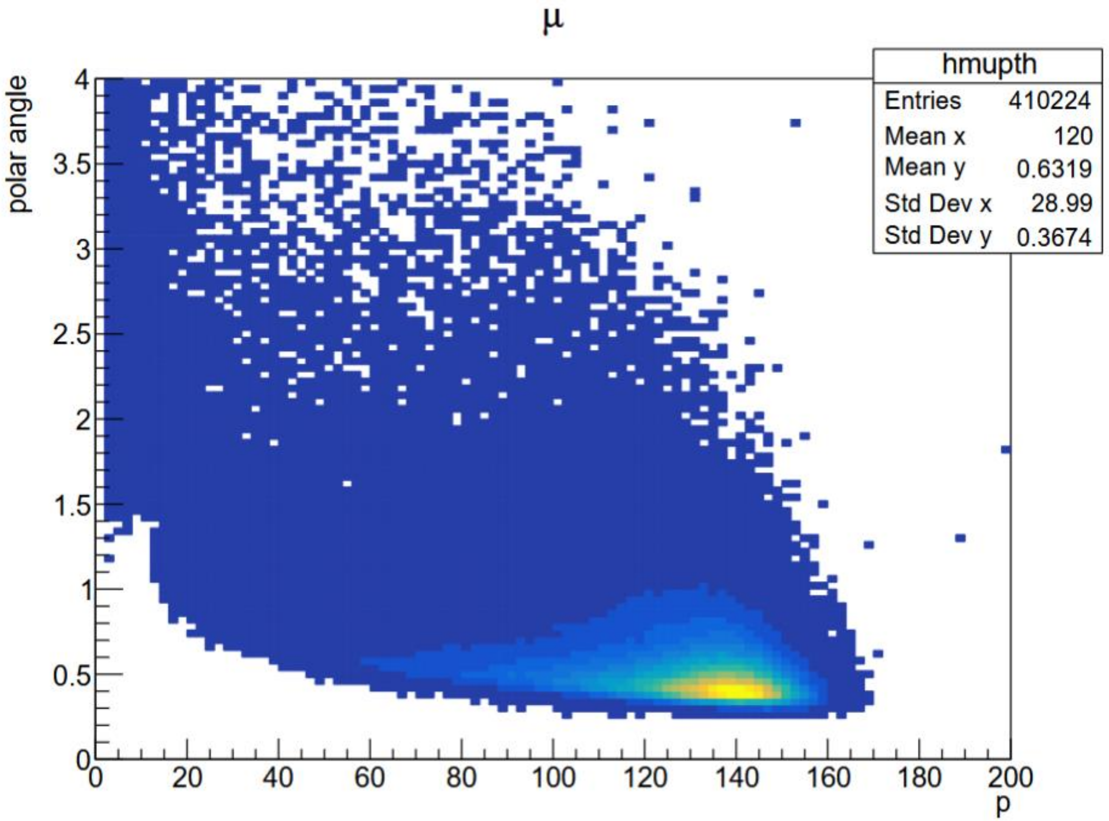
# Event Selection Hadrons

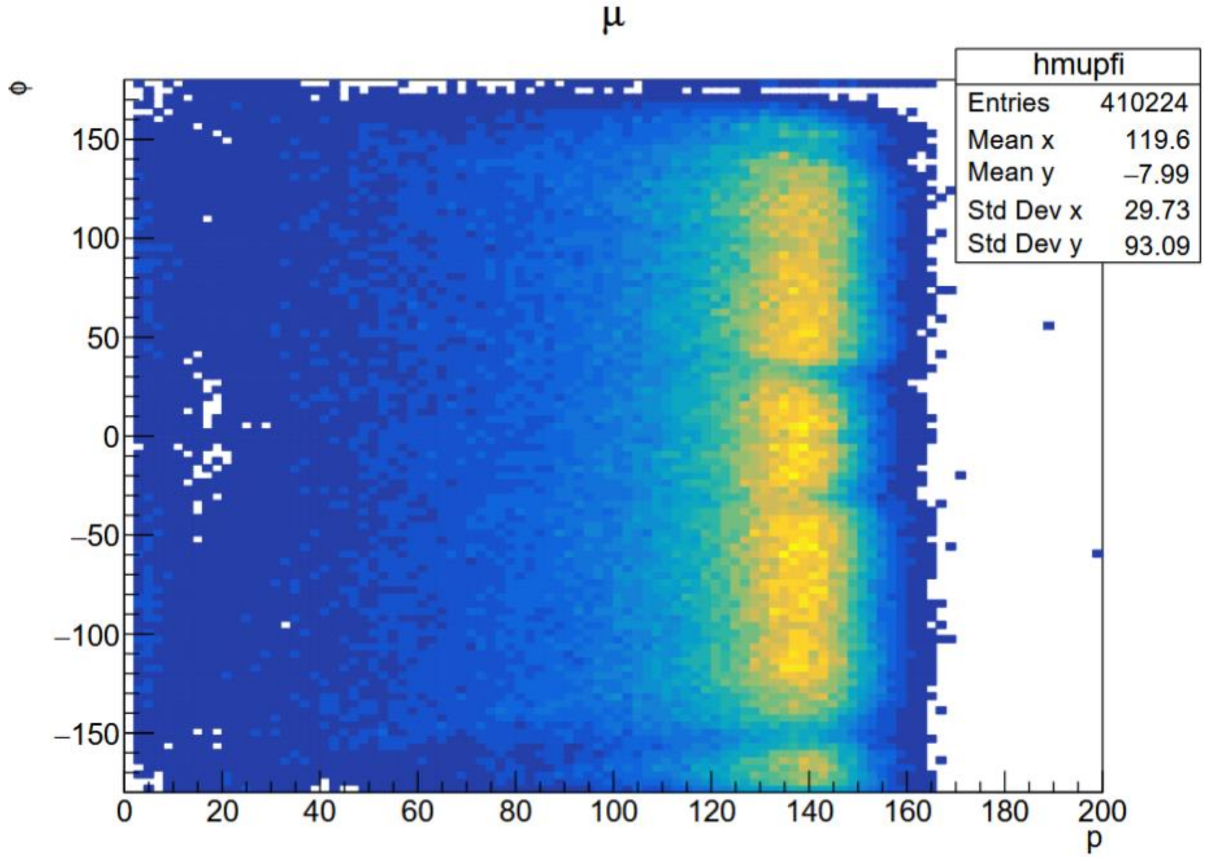
Coming from 2012 Rho analysis (W. Augustyniak, et al. ,Spin Density Matrix Elements for exclusive ρ0 meson production using the 2012 COMPASS data,internal note, 2021.)

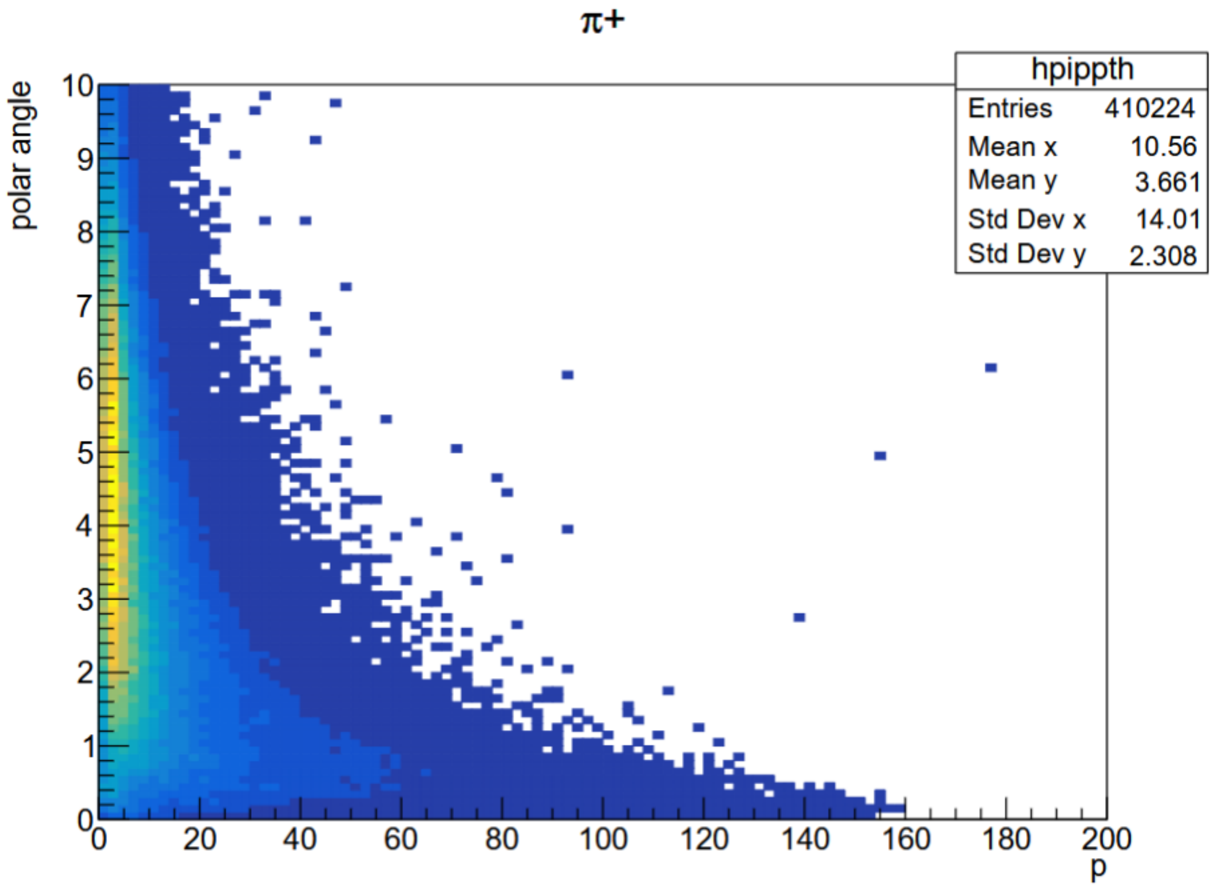
- Hadrons
  - Good fit quality of scattered hadron ($\pi^+, \pi^-$ reconstruction, given by reduced $\chi^2$ is required to be smaller than 10 ($\chi^2$ <10).
    Track reconstruction quality $\chi^2$ <10.
  - Penetration length of hadron track should be smaller than 10 radiation lengths.
  - Track starts before SM1, i.e. $Z_{first} < 350.0$ cm .

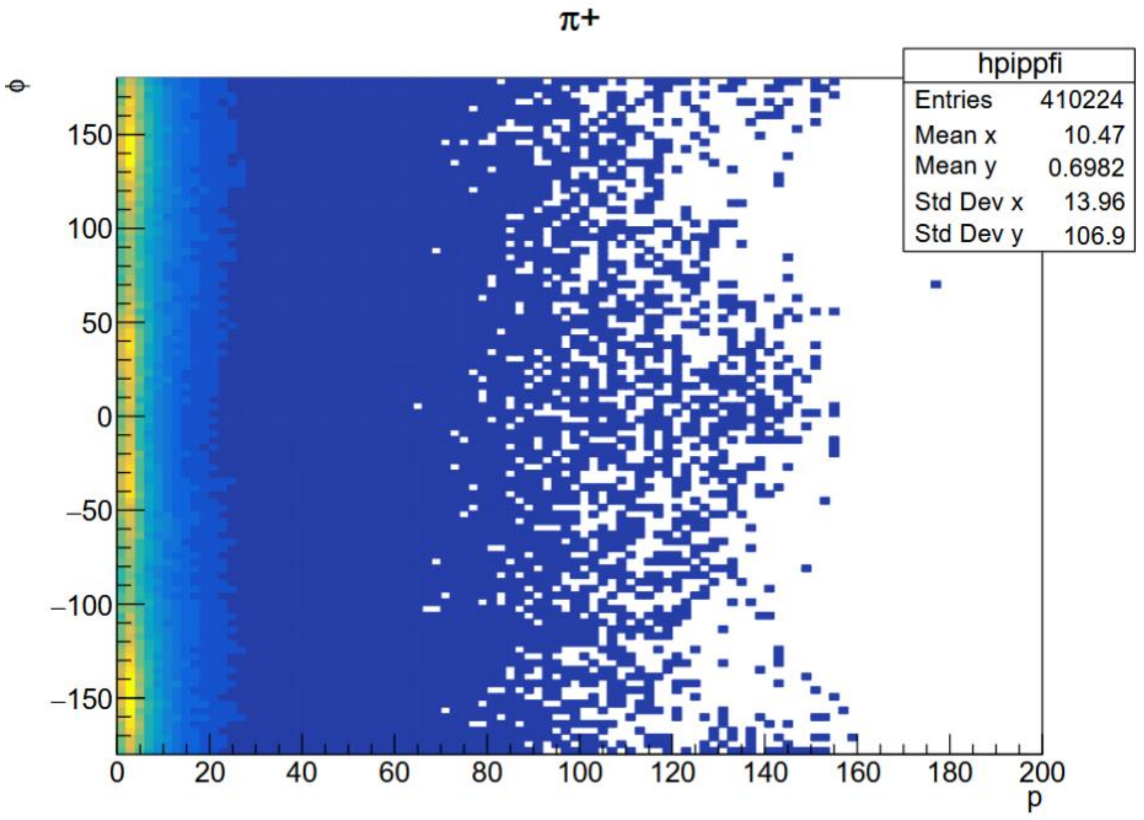
- Fit is on the track of the pions
- Also required both hadrons to have opposite charge
- Proton was identified using Missing Mass (2012 pre-CAMERA)

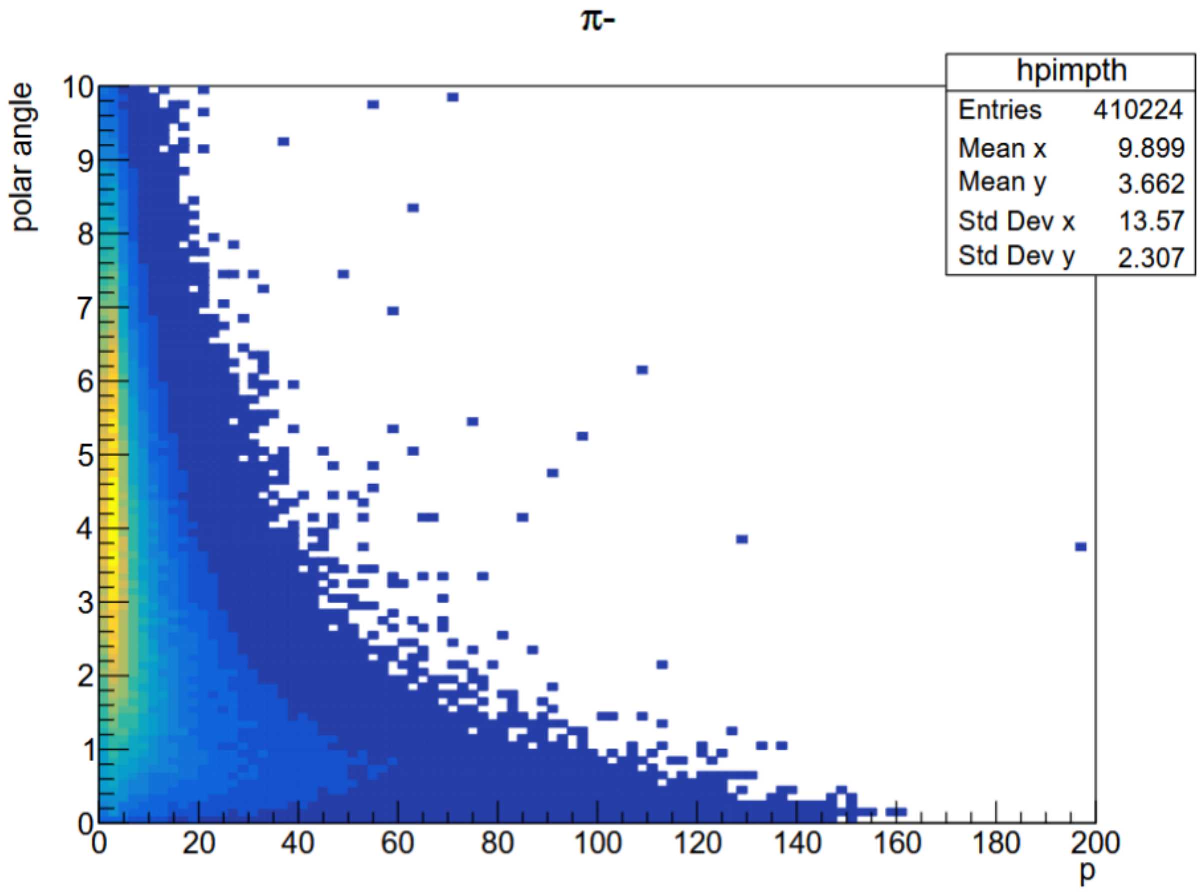
# DATA PARTICLE KINEMATICS NO EXCLUSIVE CUTS ($Q2 > 0.8$ GEV2)

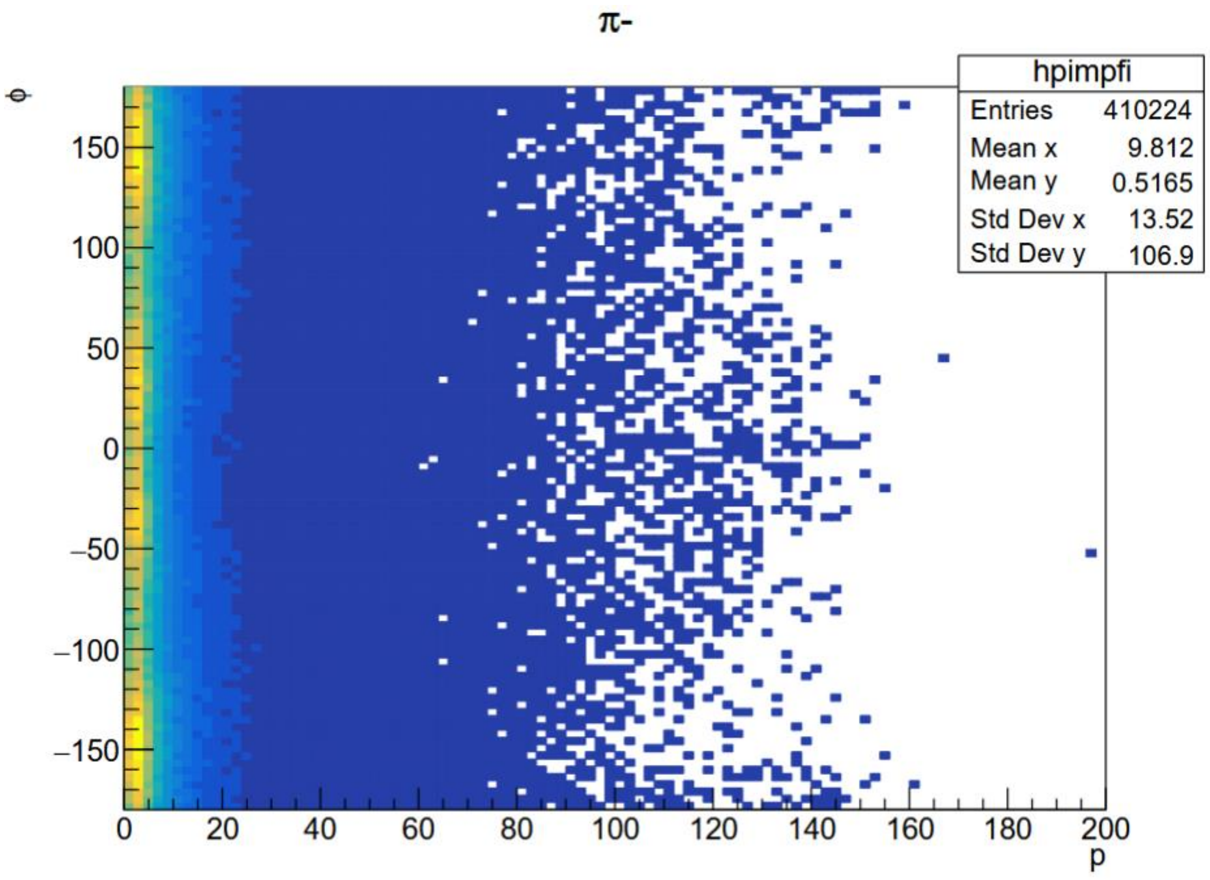

μ
hmupth
Entries 410224
Mean x 120
Mean y 0.6319
Std Dev x 28.99
Std Dev y 0.3674
polar angle
p
0 20 40 60 80 100 120 140 160 180 200
0 0.5 1 1.5 2 2.5 3 3.5 4


μ
hmupfi
Entries 410224
Mean x 119.6
Mean y −7.99
Std Dev x 29.73
Std Dev y 93.09
φ
p
0 20 40 60 80 100 120 140 160 180 200
−150 −100 −50 0 50 100 150


π+
hpippth
Entries 410224
Mean x 10.56
Mean y 3.661
Std Dev x 14.01
Std Dev y 2.308
polar angle
p


π+
hpippfi
Entries 410224
Mean x 10.47
Mean y 0.6982
Std Dev x 13.96
Std Dev y 106.9
φ
p


π-
hpimpth
Entries 410224
Mean x 9.899
Mean y 3.662
Std Dev x 13.57
Std Dev y 2.307
polar angle
p

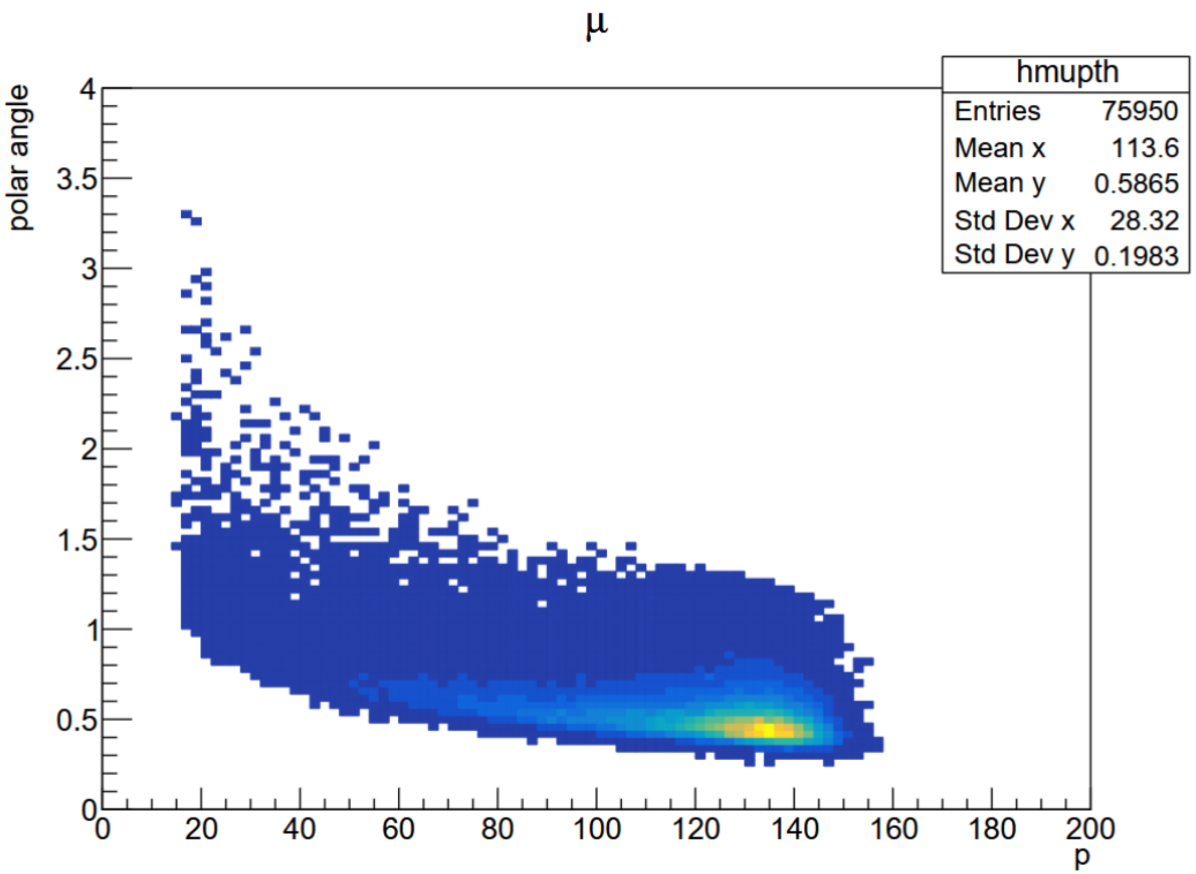

π-
hpimpfi
Entries 410224
Mean x 9.812
Mean y 0.5165
Std Dev x 13.52
Std Dev y 106.9
ϕ
p

Coming from 2012 Rho analysis (W. Augustyniak, et al. ,Spin Density Matrix Elements for exclusive ρ0 meson production using the 2012 COMPASS data,internal note, 2021.)

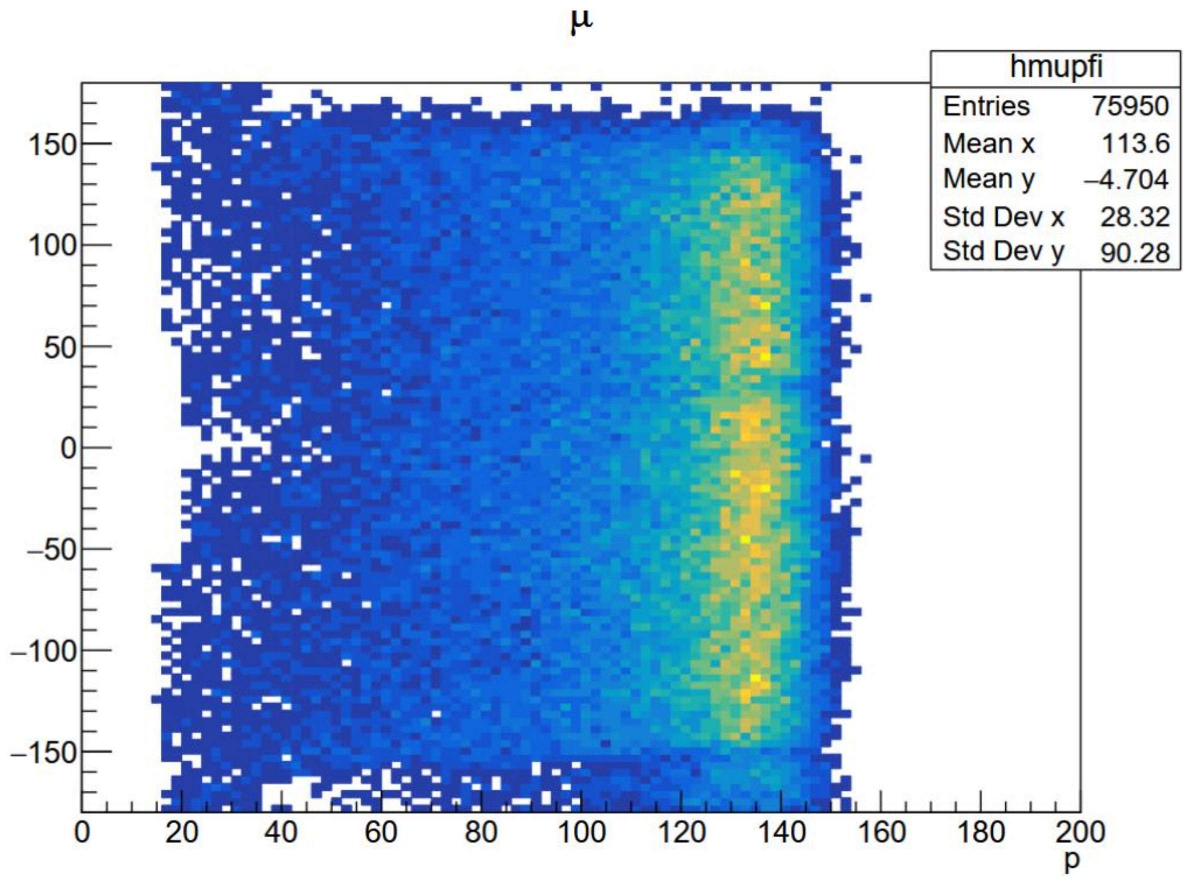
# KINEMATIC CUTS

- $W > 5.0$ GeV to remove the kinematic region where the cross section for the semi-inclusive reactions changes rapidly due to a resonances production.
- $0.1 < y < 0.9$, lower cut suppresses events with a poorly reconstructed kinematics. The upper cut on $y$ remove events with large radiative corrections.
- $1.0 < Q^2 < 10.0$ (GeV/c)$^2$, lower cut on virtuality $Q^2$ ensures hard processes regime and the upper one suppresses background due to the hadron production in DIS which hereafter is referred to as "SIDIS background".
- $\nu >$ 16 GeV    0.1 < y ----> 160*0.1 -----> 16 < nu
- squared transverse momentum of $\rho^0$ with respect to the virtual photon: $0.01 < p_T^2 < 0.5$ (GeV/c)$^2$.
- $0.5 < M_{\pi^+\pi^-} < 1.1$ GeV/c$^2$ invariant mass of two pions.
- $-2.5 < E_{miss} < 2.5$ GeV . $E_{miss} = \frac{M_X^2 - M_p^2}{2M_p}$, with $M_p$ the proton mass and $M_X^2 = (p + q - p_{\pi^+} - p_{\pi^-})^2$ - the missing mass squared, where $p$, $q$, $p_{\pi^+}$ and $p_{\pi^-}$ are the four-momenta of target nucleon, virtual photon, and each of the two pions, respectively.
- momentum of $\rho^0$ $P_{\rho^0} > 15$ GeV/c. To reduce the semi-inclusive background contribution.

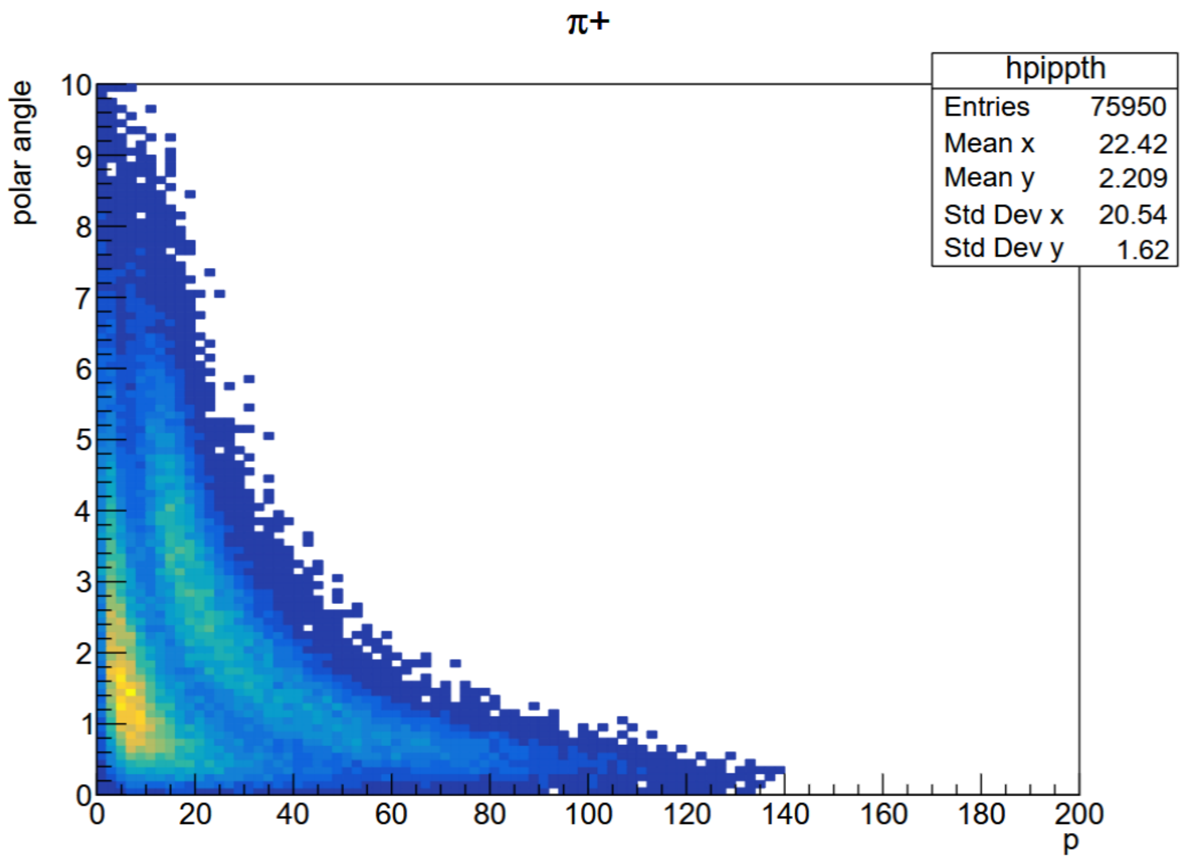
# DATA PARTICLE KINEMATICS WITH CUTS

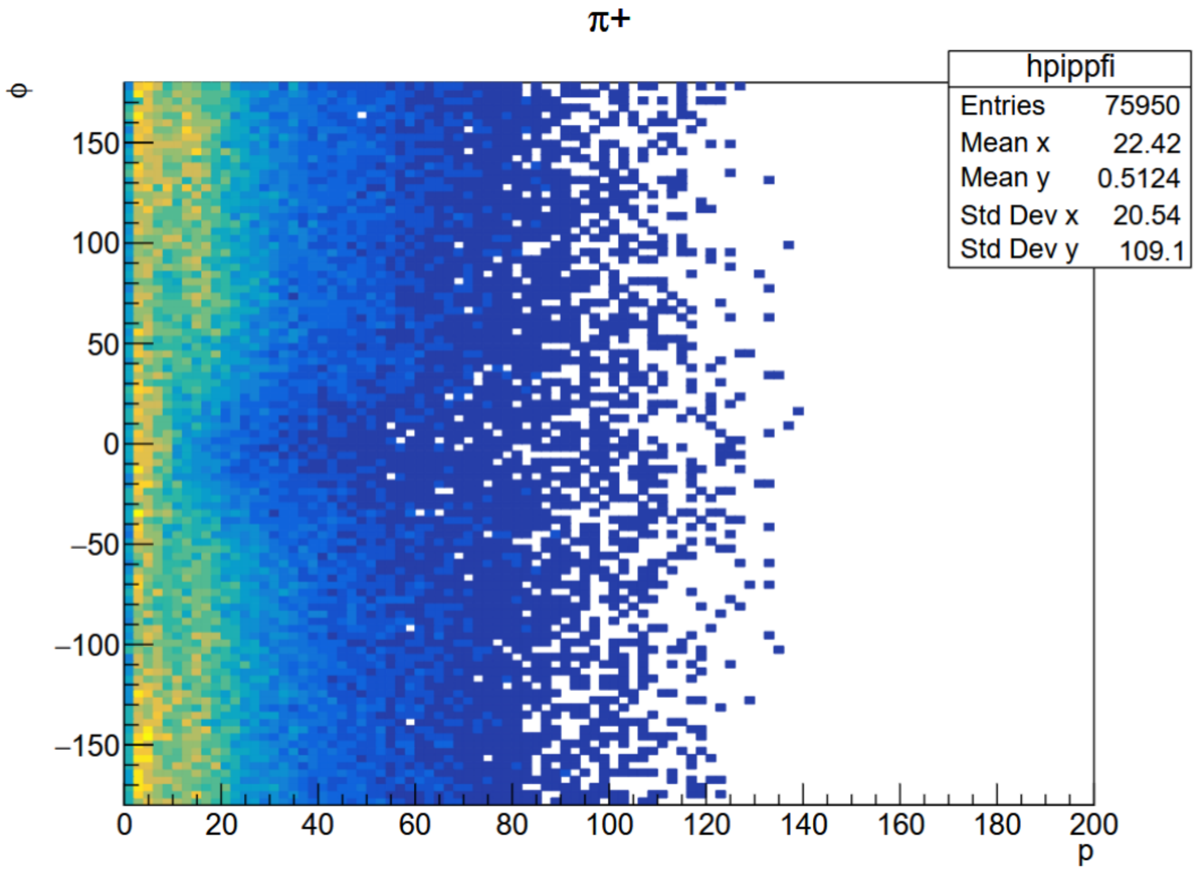


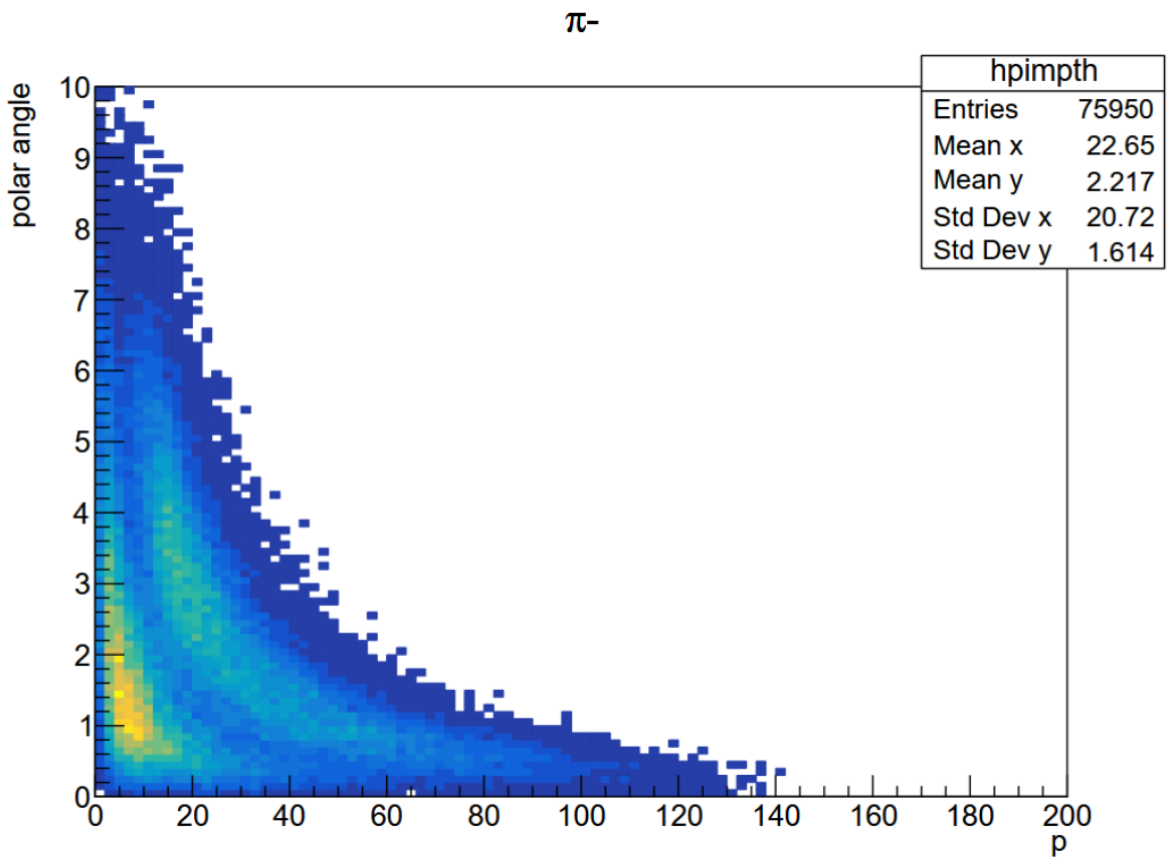
μ
hmupth
Entries 75950
Mean x 113.6
Mean y 0.5865
Std Dev x 28.32
Std Dev y 0.1983
polar angle
p

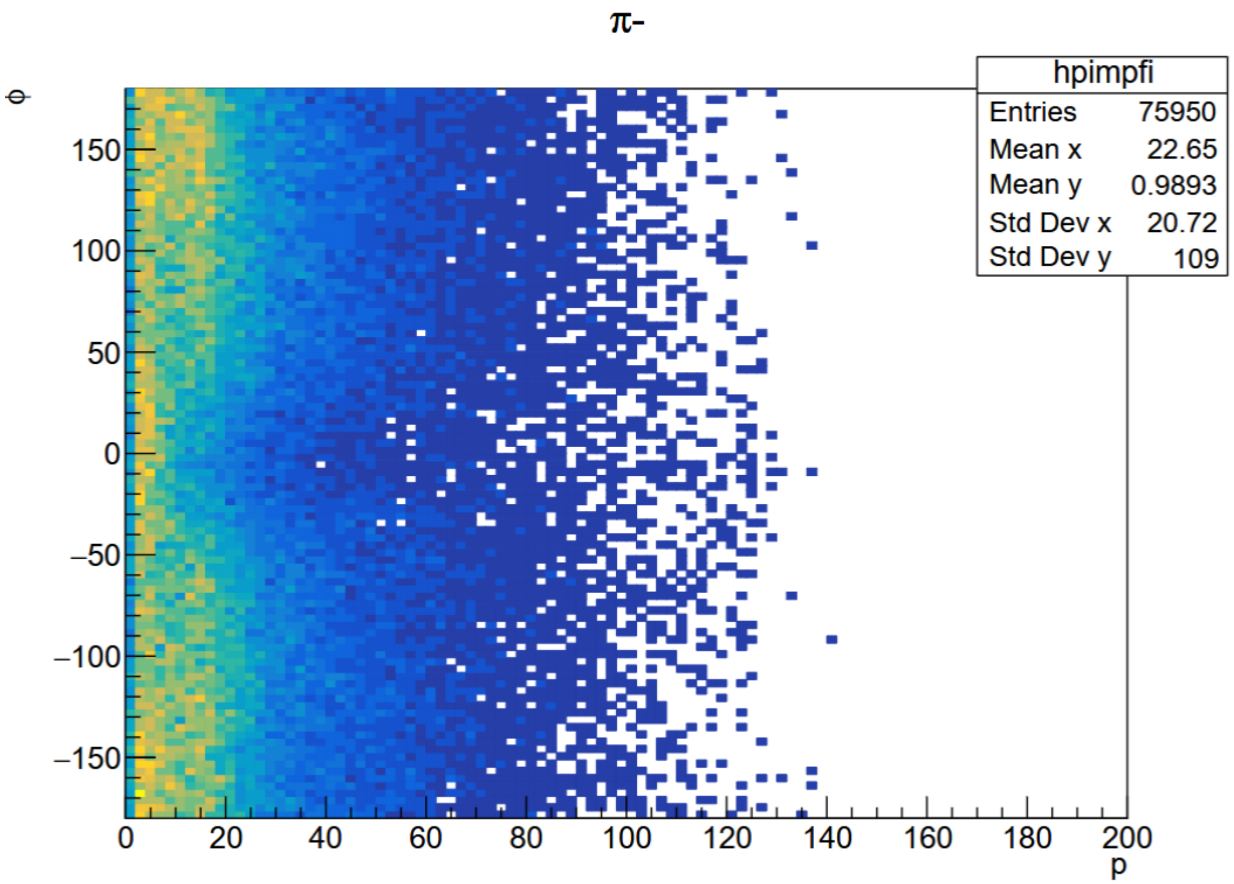



μ
hmupfi
Entries 75950
Mean x 113.6
Mean y −4.704
Std Dev x 28.32
Std Dev y 90.28
p

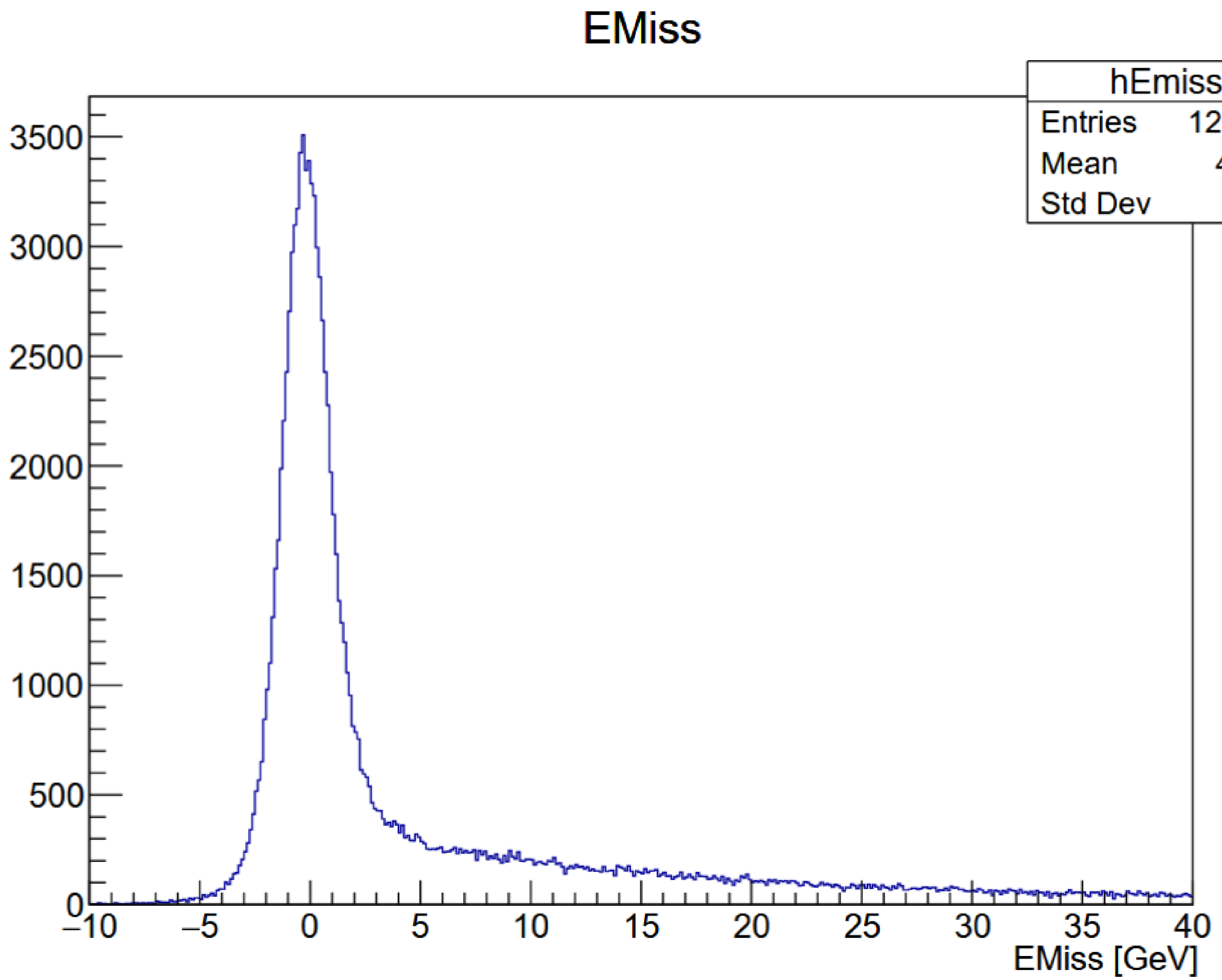

π+
hpippth
Entries 75950
Mean x 22.42
Mean y 2.209
Std Dev x 20.54
Std Dev y 1.62
polar angle
p
0
1
2
3
4
5
6
7
8
9
10
0
20
40
60
80
100
120
140
160
180
200


π+
hpippfi
Entries 75950
Mean x 22.42
Mean y 0.5124
Std Dev x 20.54
Std Dev y 109.1
φ
p
150
100
50
0
−50
−100
−150
0
20
40
60
80
100
120
140
160
180
200

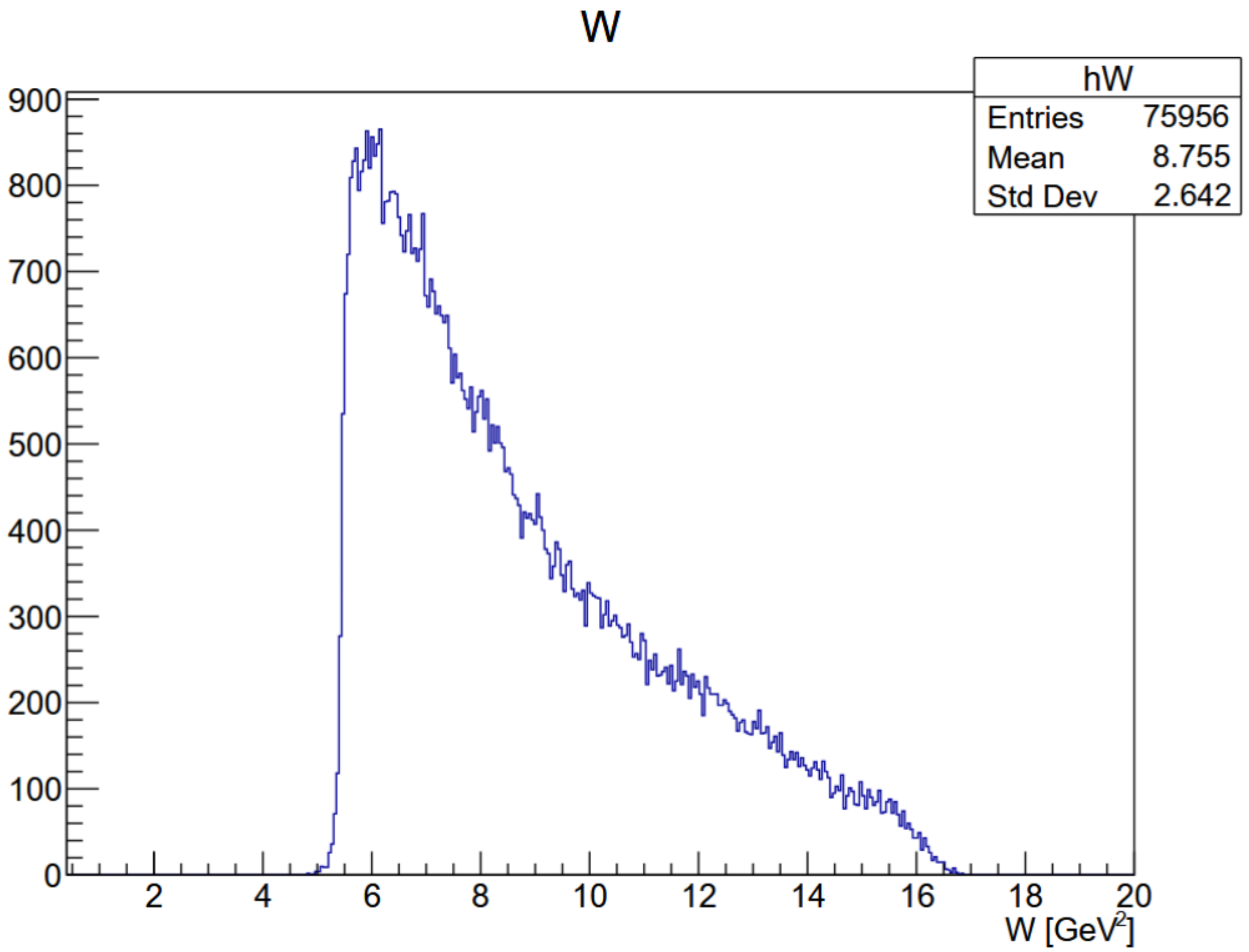

π-
polar angle
hpimpth
Entries 75950
Mean x 22.65
Mean y 2.217
Std Dev x 20.72
Std Dev y 1.614
0 1 2 3 4 5 6 7 8 9 10
0 20 40 60 80 100 120 140 160 180 200
p


π-
φ
hpimpfi
Entries 75950
Mean x 22.65
Mean y 0.9893
Std Dev x 20.72
Std Dev y 109
150 100 50 0 −50 −100 −150
0 20 40 60 80 100 120 140 160 180 200
p

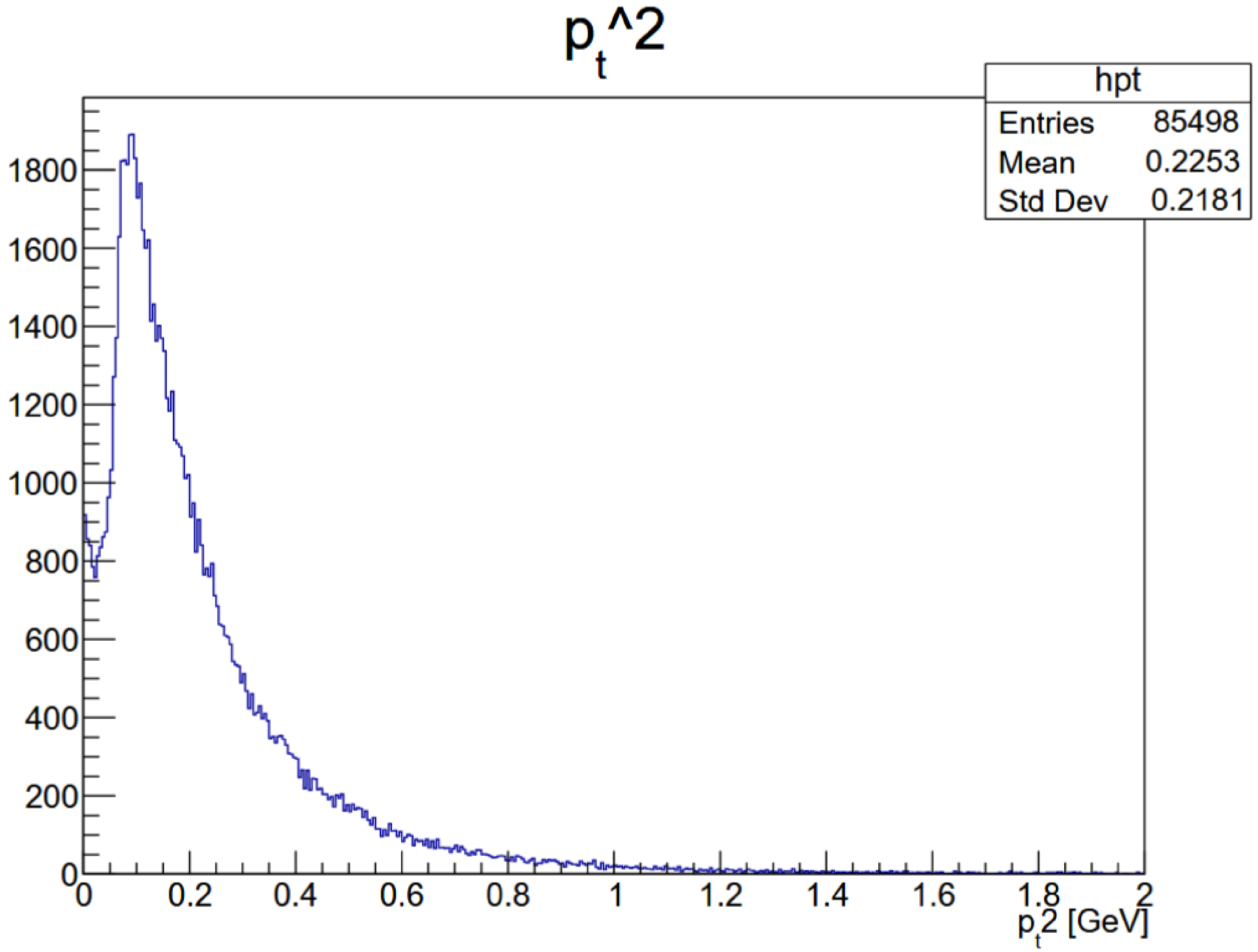
# DATA EXCLUSIVE KINEMATICS WITH CUTS



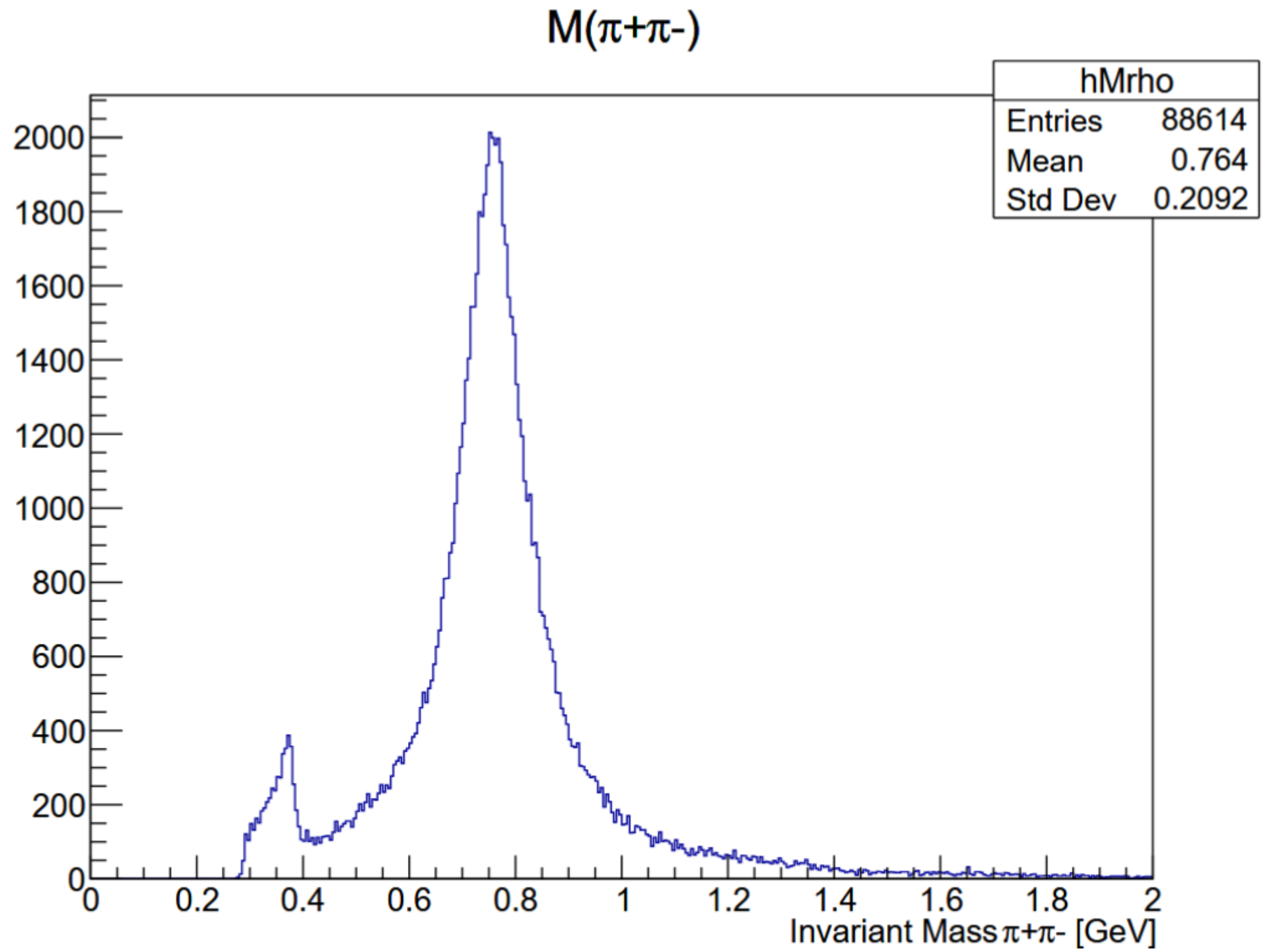

Cuts:W,y,Q2,nu,Pt2, Invariant Mass, Momentum of rho0



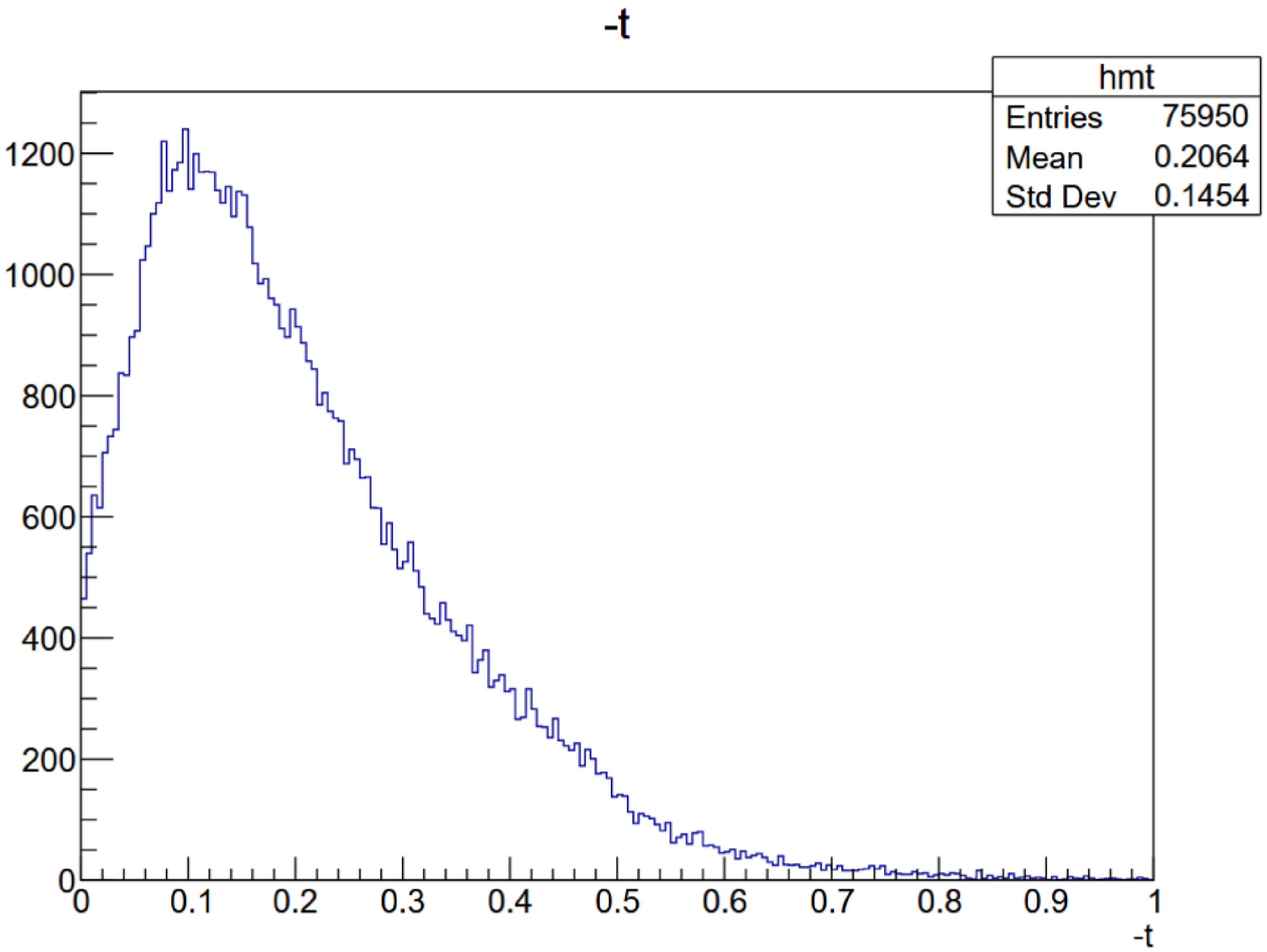

Cuts:y,Q2,nu,Pt2, Invariant Mass
Missing Energy, Momentum of rho0



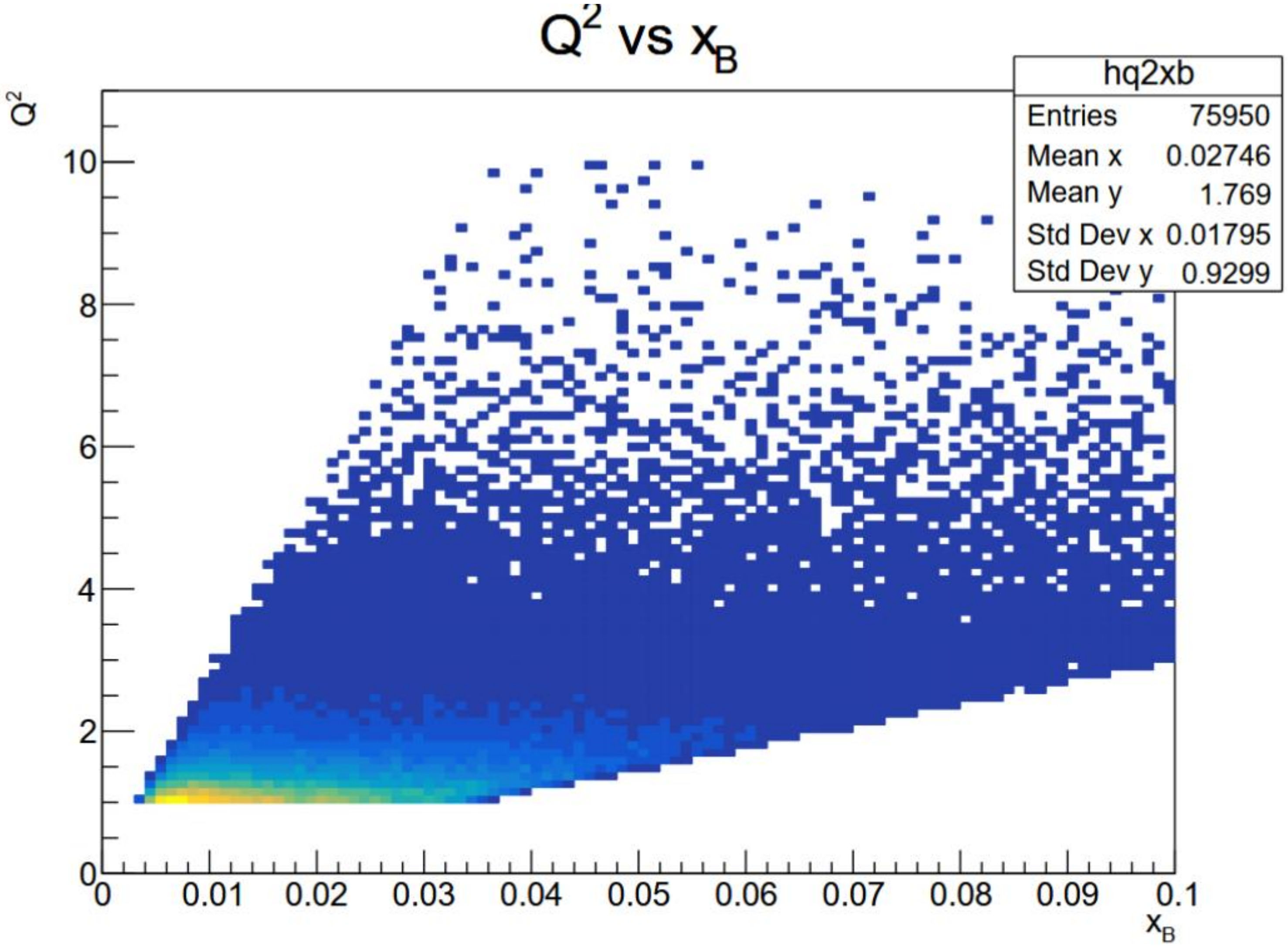

Cuts:W,y,Q2,nu, Invariant Mass
Missing Energy, Momentum of rho0



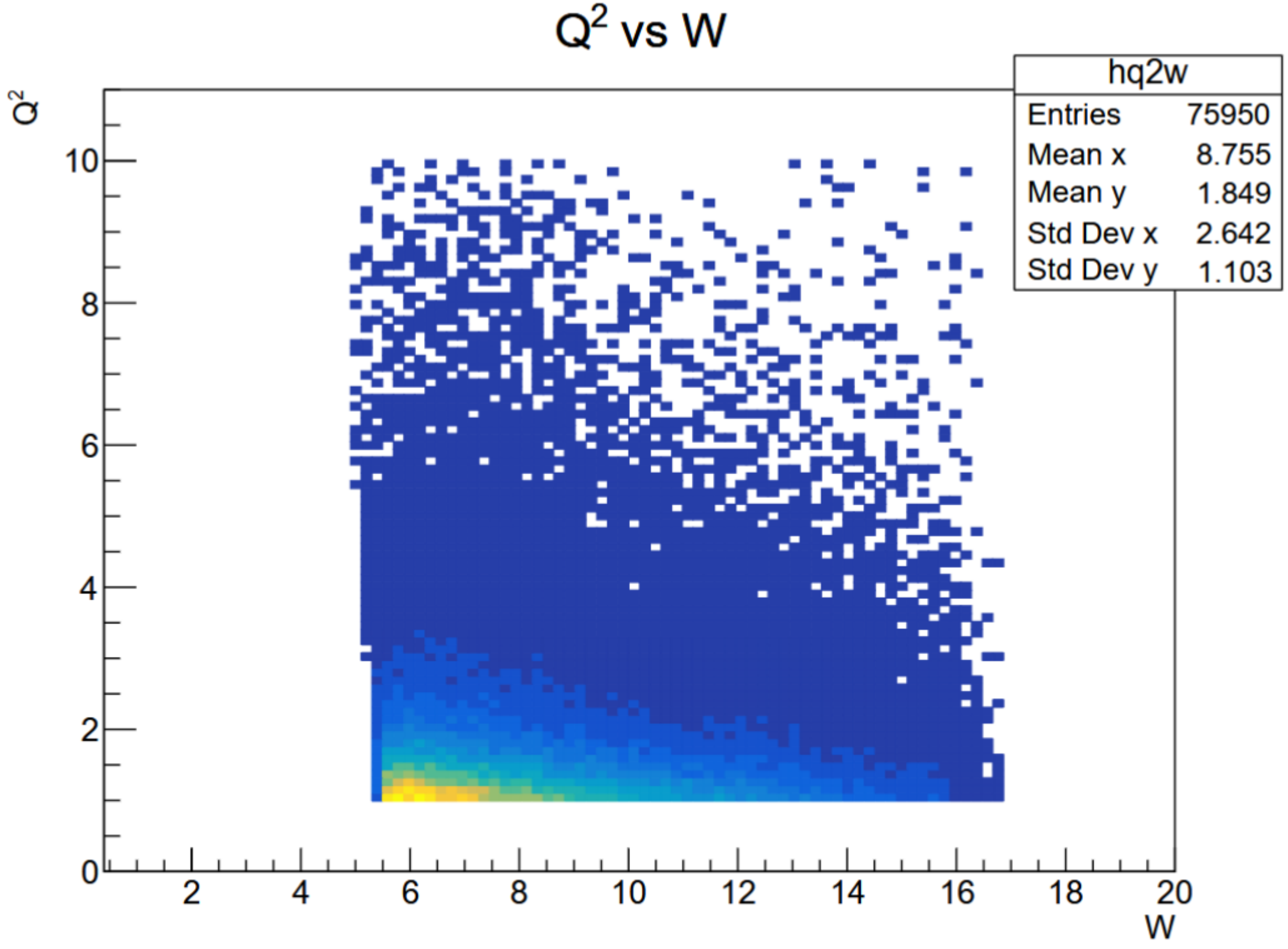

Cuts:W,y,Q2,nu,Pt2, Missing Energy, Momentum of rho0




Cuts:W,y,Q2,nu,Pt2, Invariant Mass
Missing Energy, Momentum of rho0

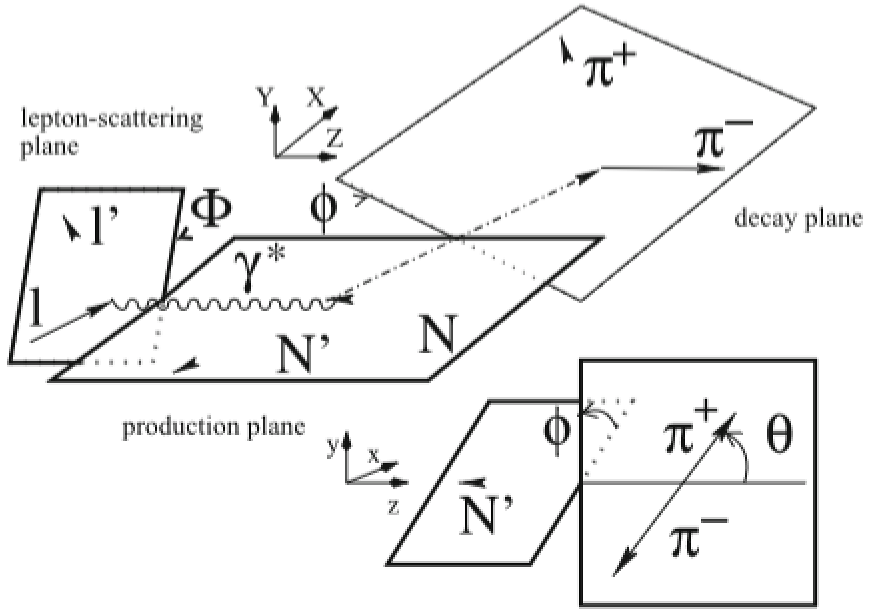



Cuts:W,y,Q2,nu,Pt2, Invariant Mass
Missing Energy, Momentum of rho0



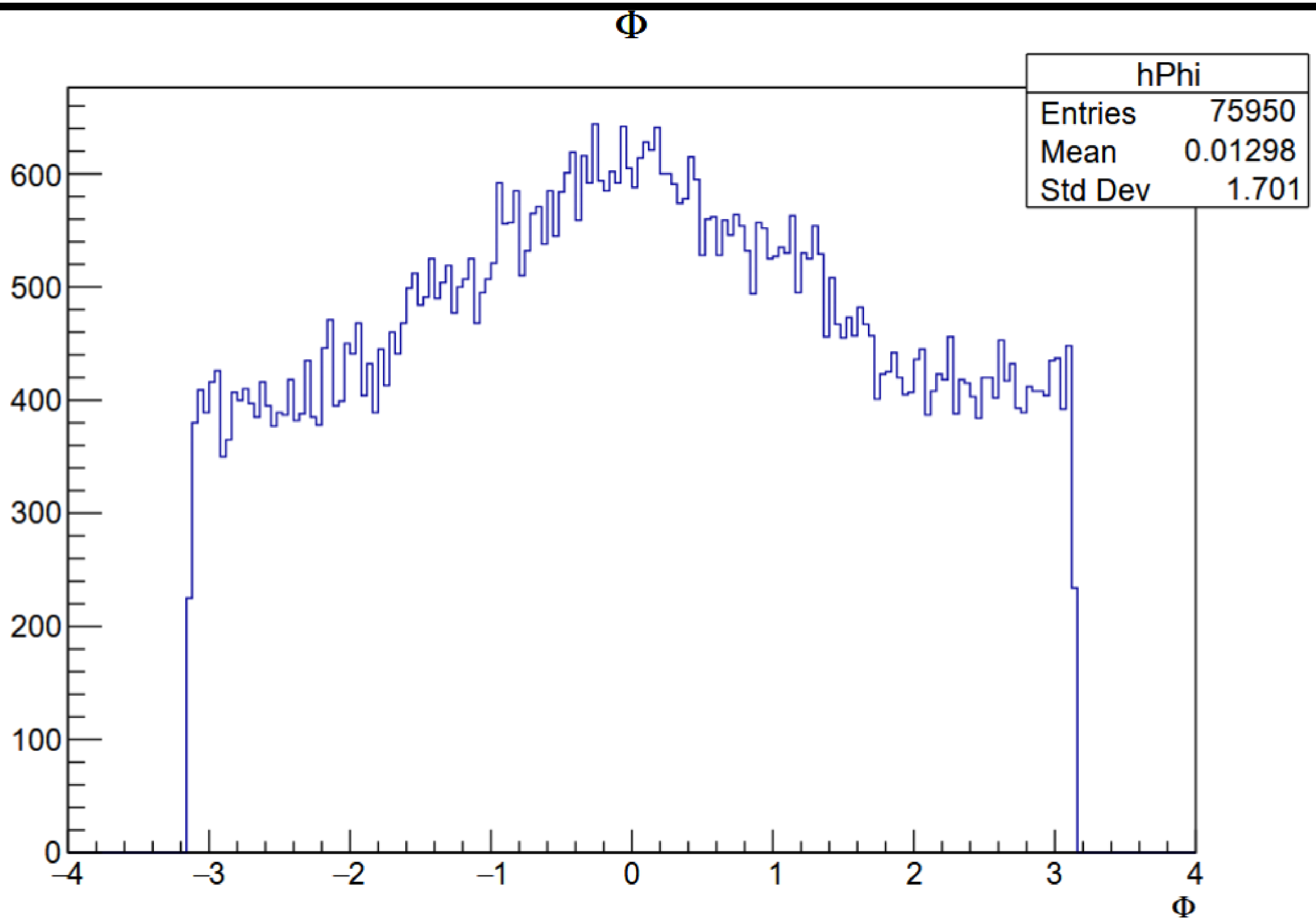

Cuts:W,y,Q2,nu,Pt2, Invariant Mass
Missing Energy, Momentum of rho0

# ANGLES FOR SDME

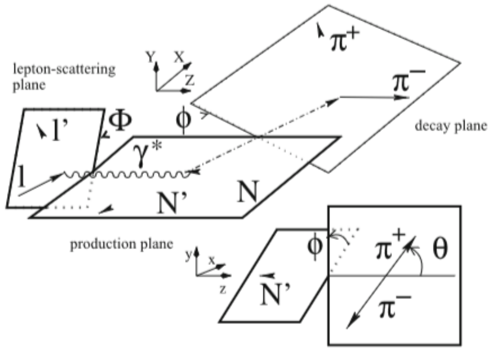



W. Augustyniak, et al. ,Spin Density Matrix Elements for exclusive ρ0 meson production using the 2012 COMPASS data,internal note, 2021.

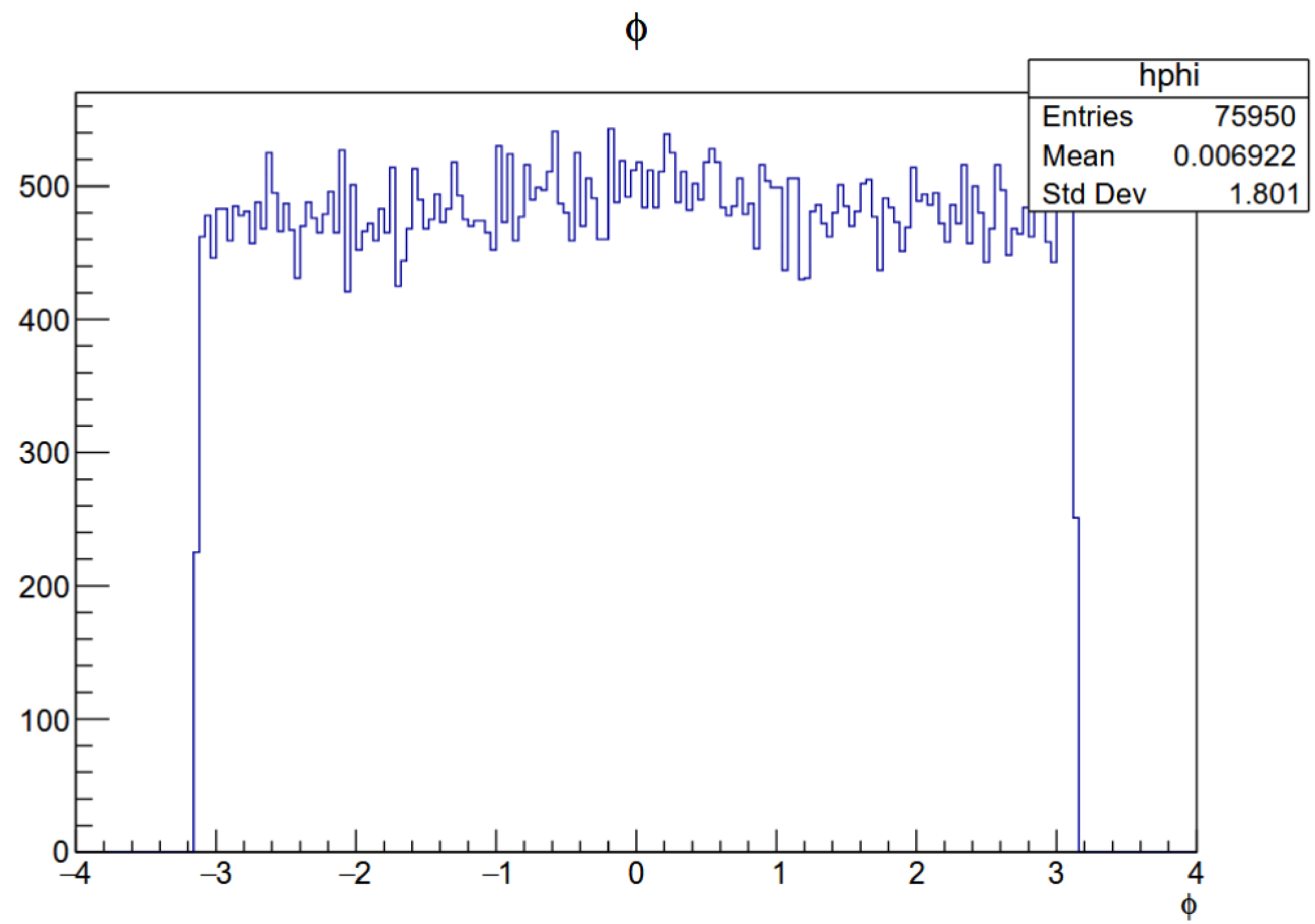
All Exclusive Cuts



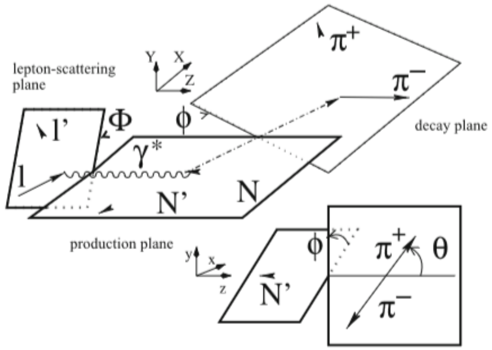

Angle between the lepton scattering plane and rho production plane (phi trento)



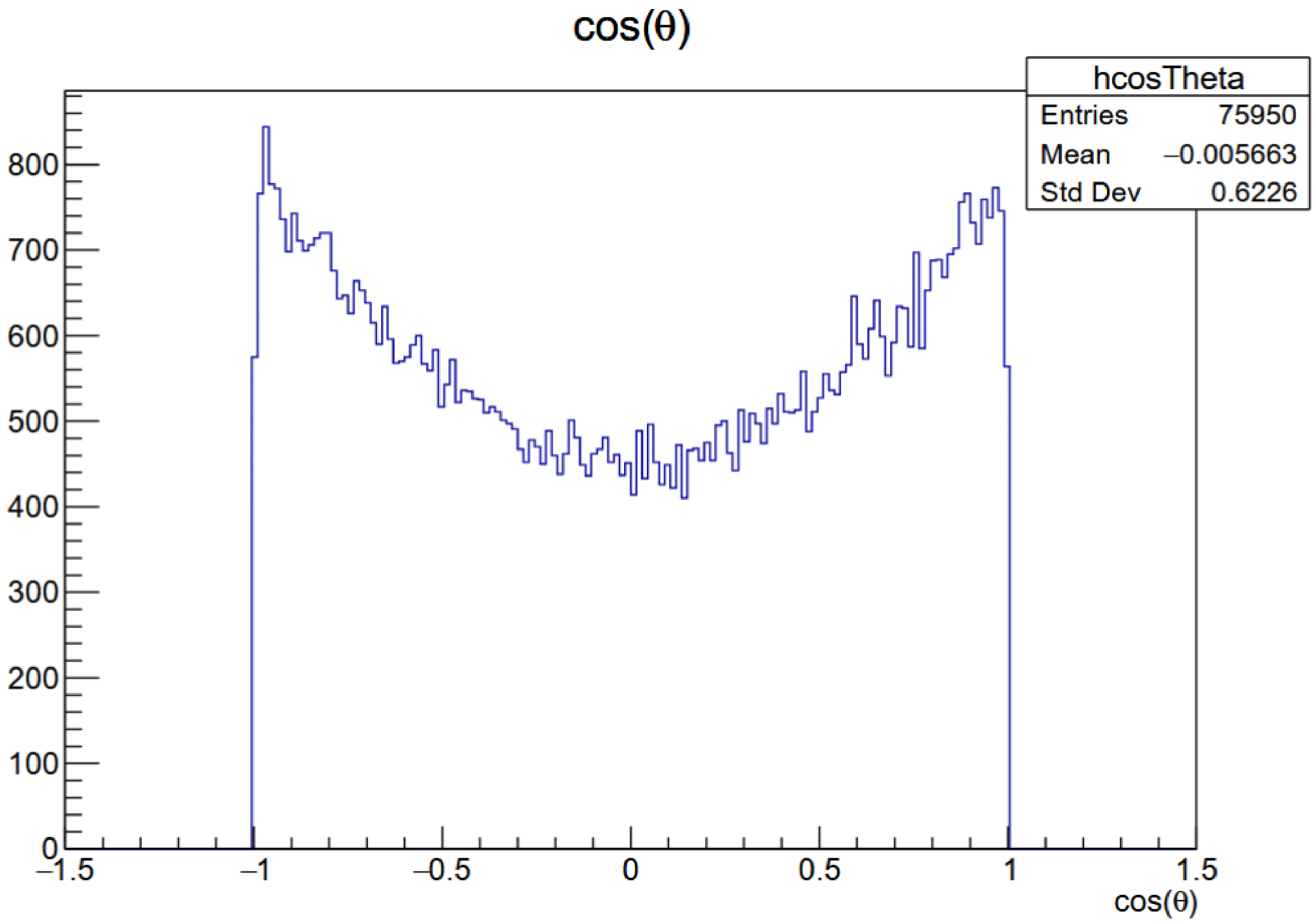
# All Exclusive Cuts



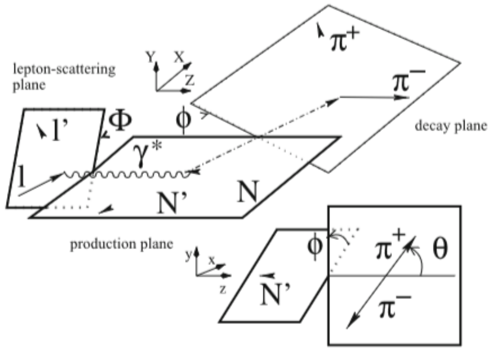

Angle between the rho production plane and the rho decay plane



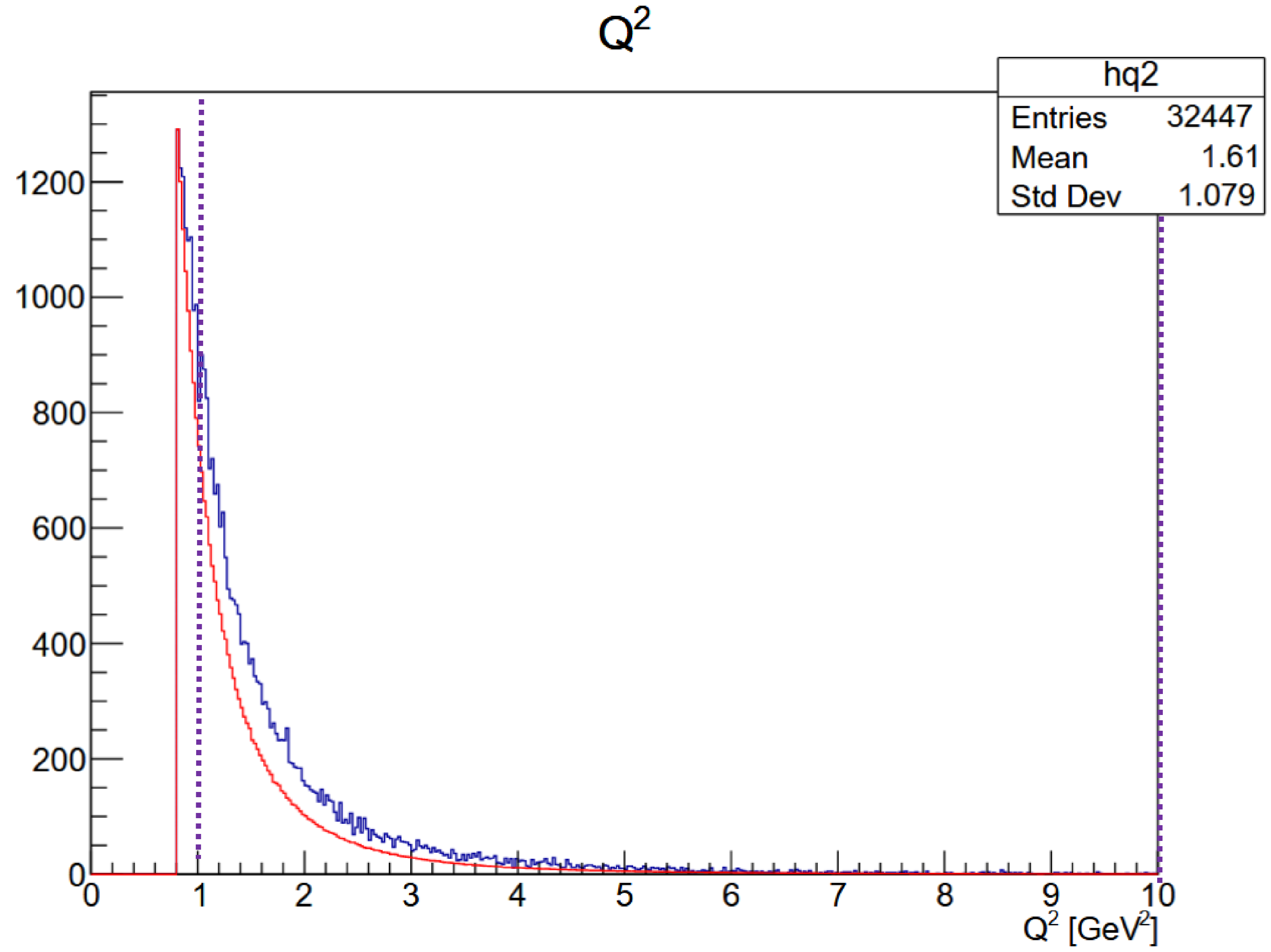
# All Exclusive Cuts




The polar angle of the pi+ in the vector meson decay frame



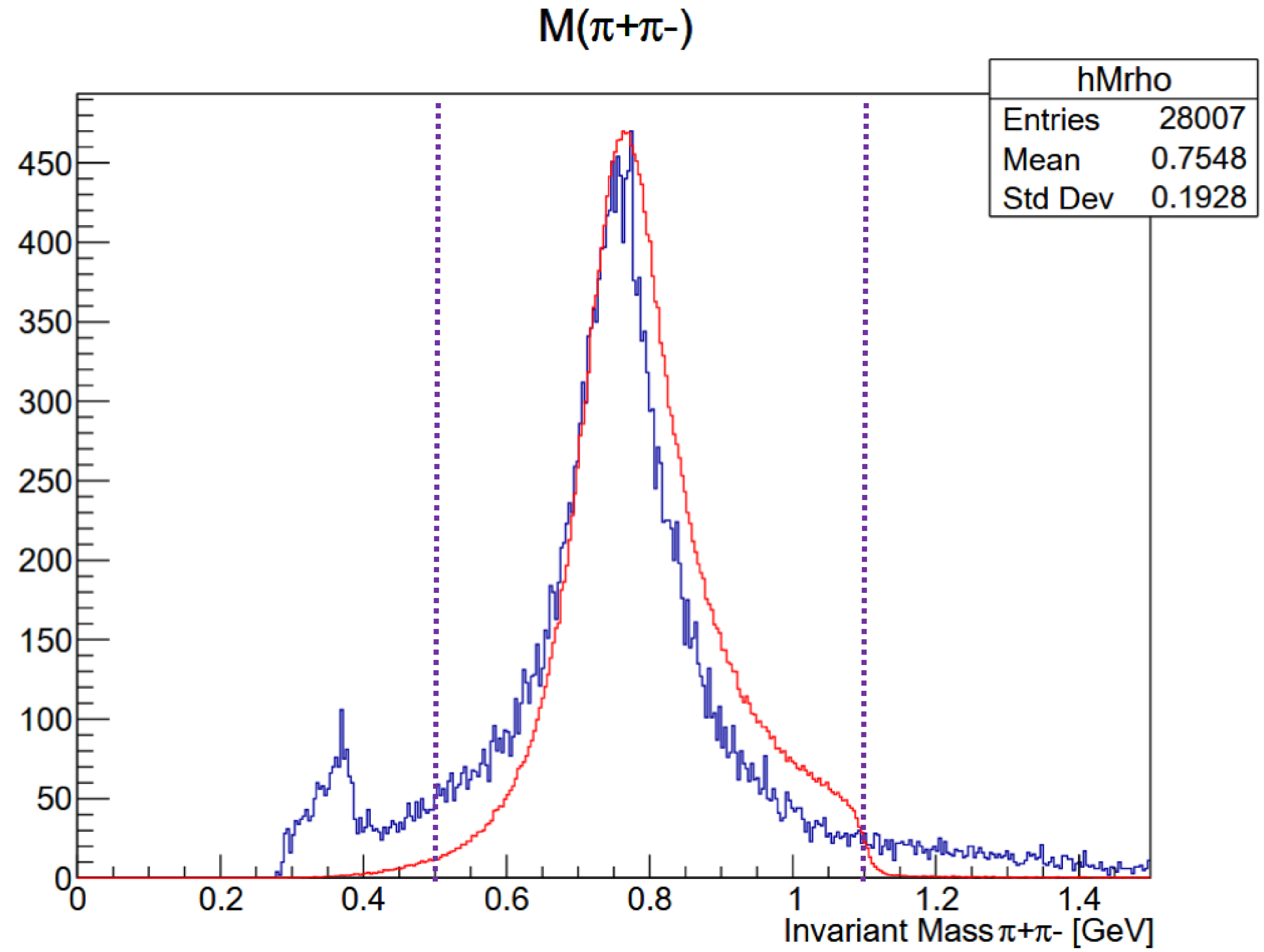
# DATA VS MONTE CARLO (HEPGEN)



Q2
hq2
Entries 32447
Mean 1.61
Std Dev 1.079
1200
1000
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10
Q2 [GeV2]


Data

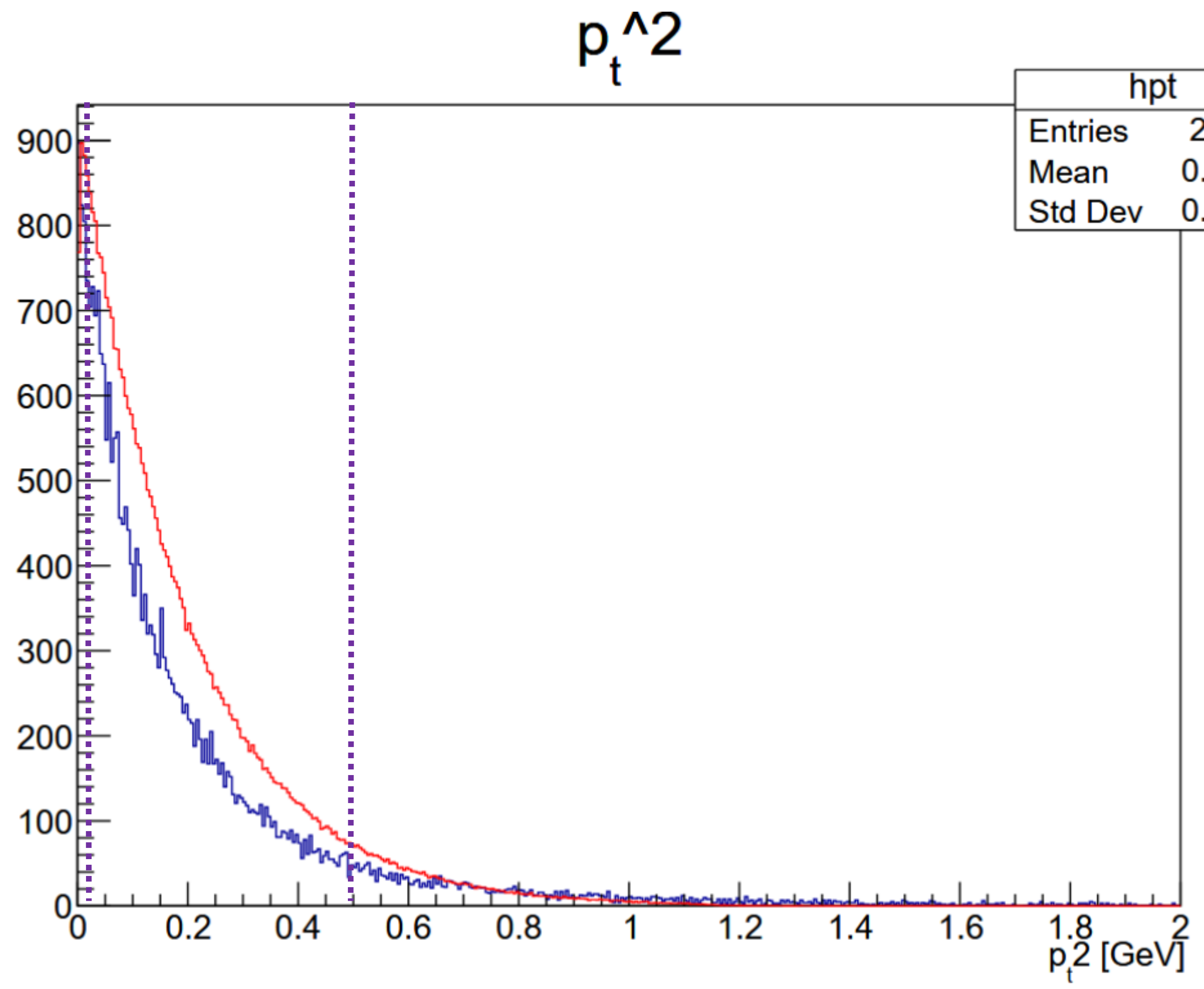
HepGen



M(π+π-)
hMrho
Entries 28007
Mean 0.7548
Std Dev 0.1928
450
400
350
300
250
200
150
100
50
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Invariant Mass π+π- [GeV]


Data

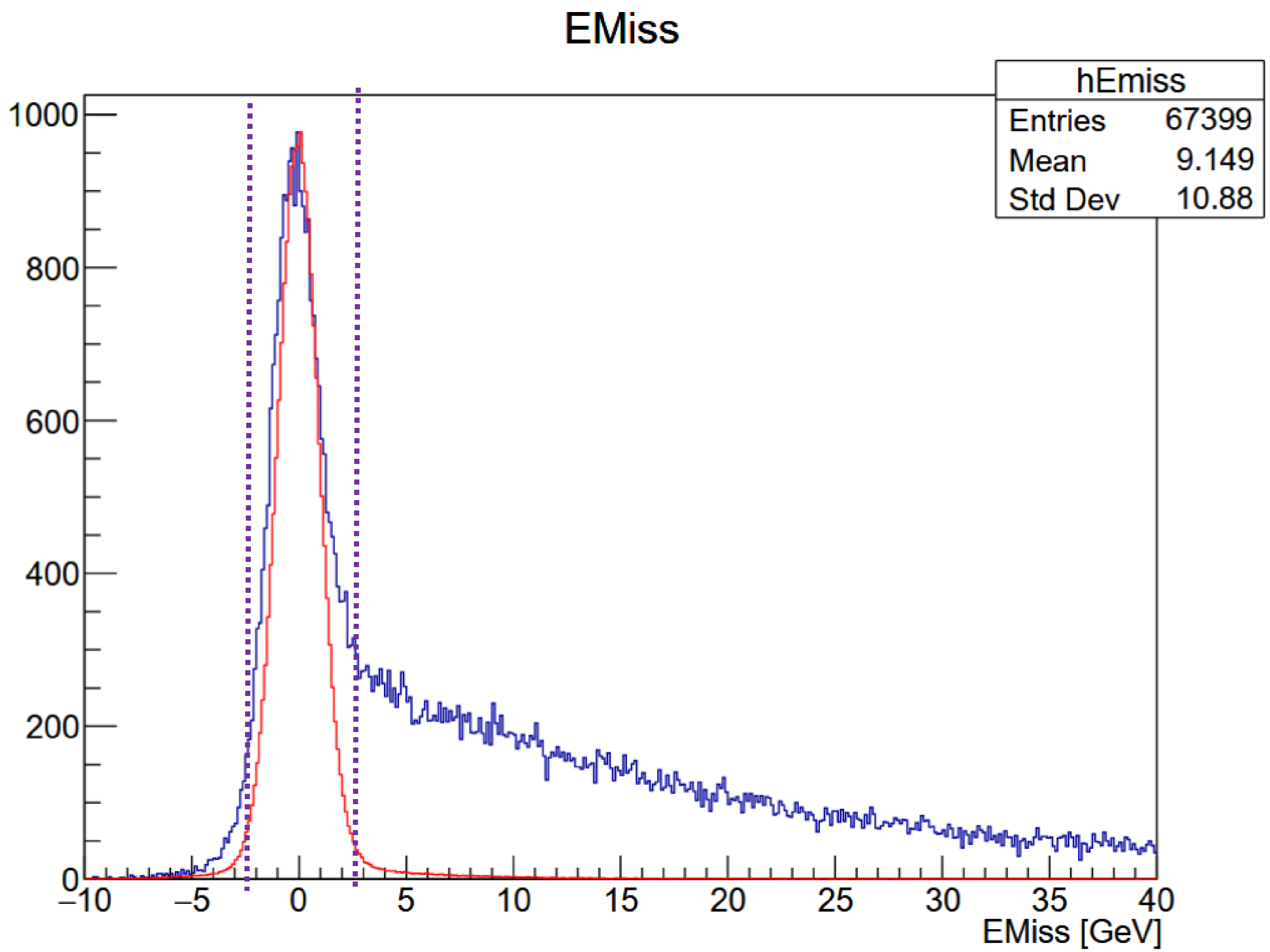
HepGen



p_t^2
hpt
Entries 28082
Mean 0.2127
Std Dev 0.2674
900
800
700
600
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
p_t2 [GeV]


Data

HepGen



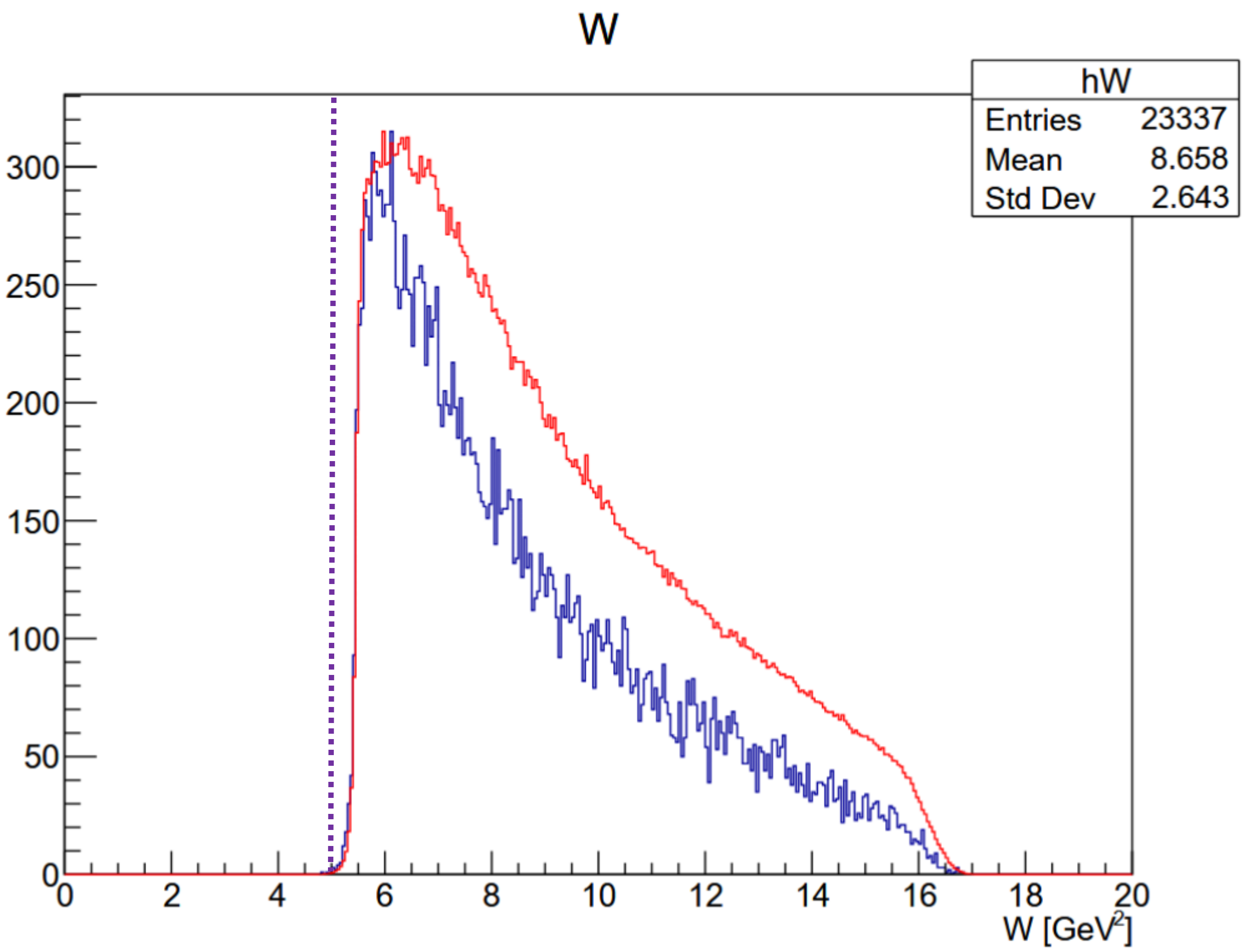
EMiss
hEmiss
Entries 67399
Mean 9.149
Std Dev 10.88
1000
800
600
400
200
0
−10
−5
0
5
10
15
20
25
30
35
40
EMiss [GeV]


Data

HepGen

Some Suggestions:

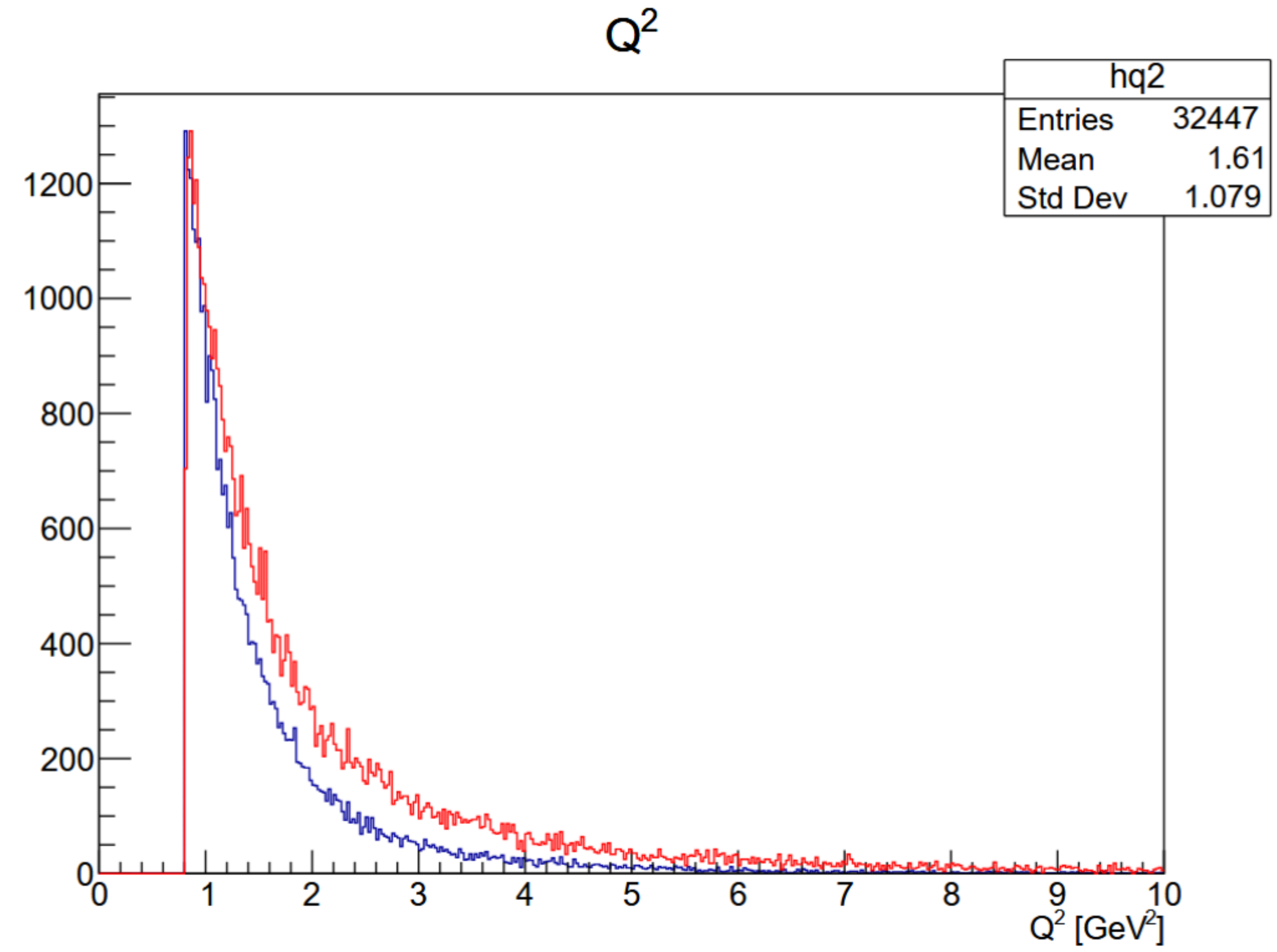
- Get rid of background with lepto
- Reweight the MC to the data




Data

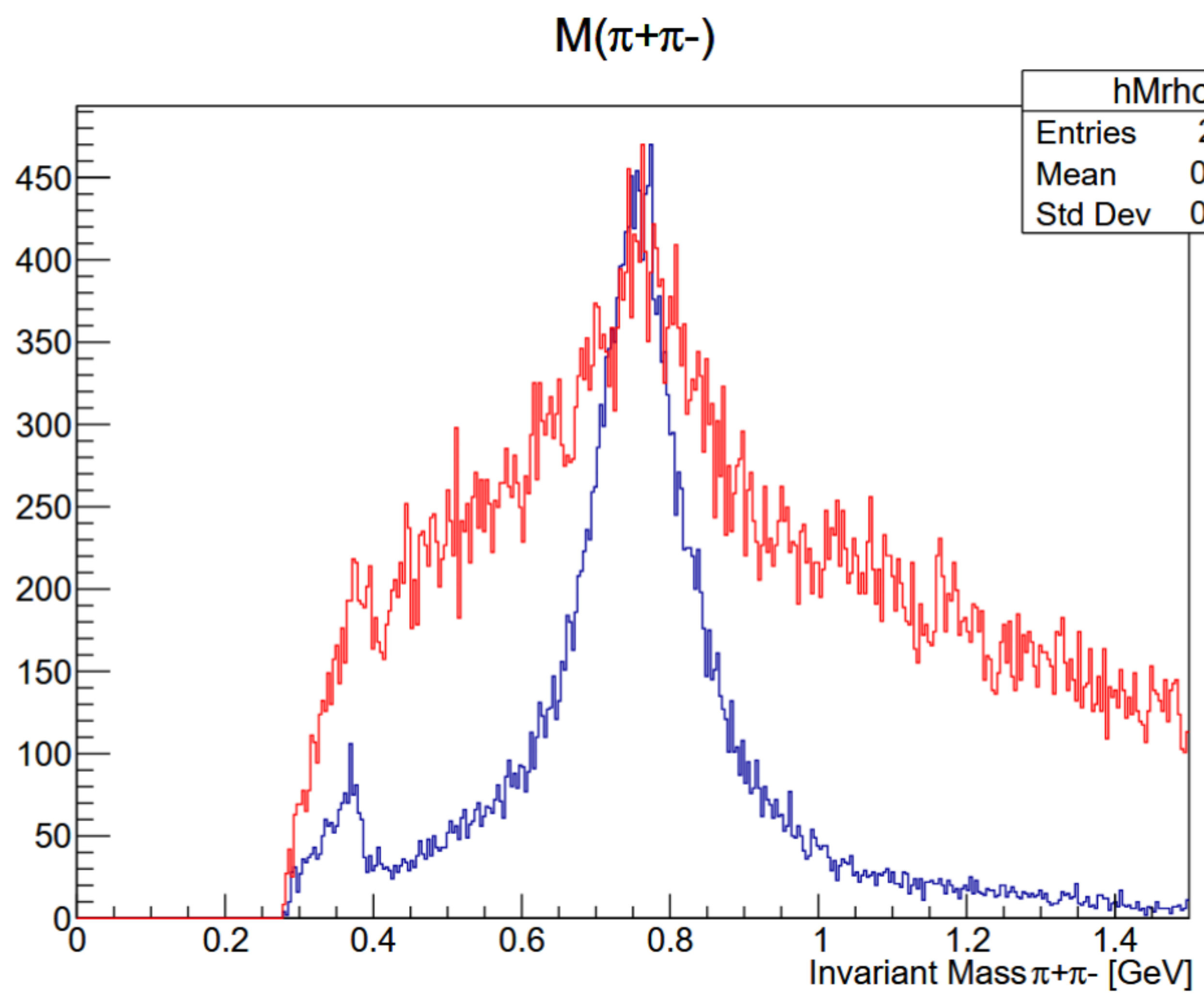
HepGen

# DATA VS MONTE CARLO ( NONWEIGHTED LEPTO)


Q2
hq2
Entries 32447
Mean 1.61
Std Dev 1.079
1200
1000
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10
Q2 [GeV2]

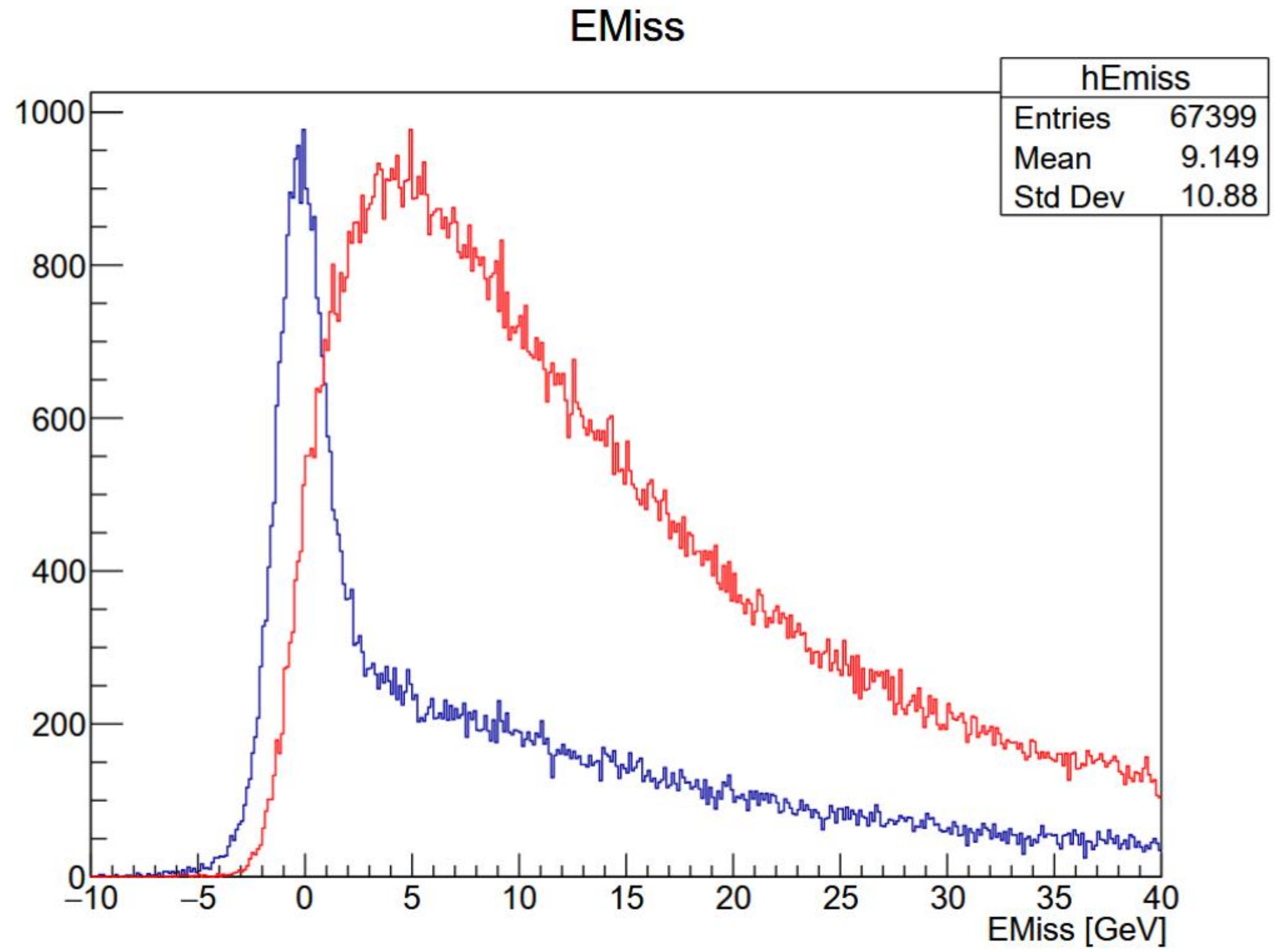
Data

Lepto


M(π+π-)
hMrho
Entries 28007
Mean 0.7548
Std Dev 0.1928
0
50
100
150
200
250
300
350
400
450
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Invariant Mass π+π- [GeV]

Data

Lepto


EMiss
hEmiss
Entries 67399
Mean 9.149
Std Dev 10.88
0
200
400
600
800
1000
−10
−5
0
5
10
15
20
25
30
35
40
EMiss [GeV]

Data

Lepto

# BACKGROUND SUBTRACTION

# BACKGROUND SUBTRACTION USING MISSING ENERGY

- Missing Energy should be centered around zero so background events should be subtracted
  - weight Monte Carlo to match data so we can subtract those events

$$w(E_{\text{miss}}) = \frac{N^{sc}_{rd}(E_{\text{miss}})}{N^{sc}_{MC}(E_{\text{miss}})}.$$

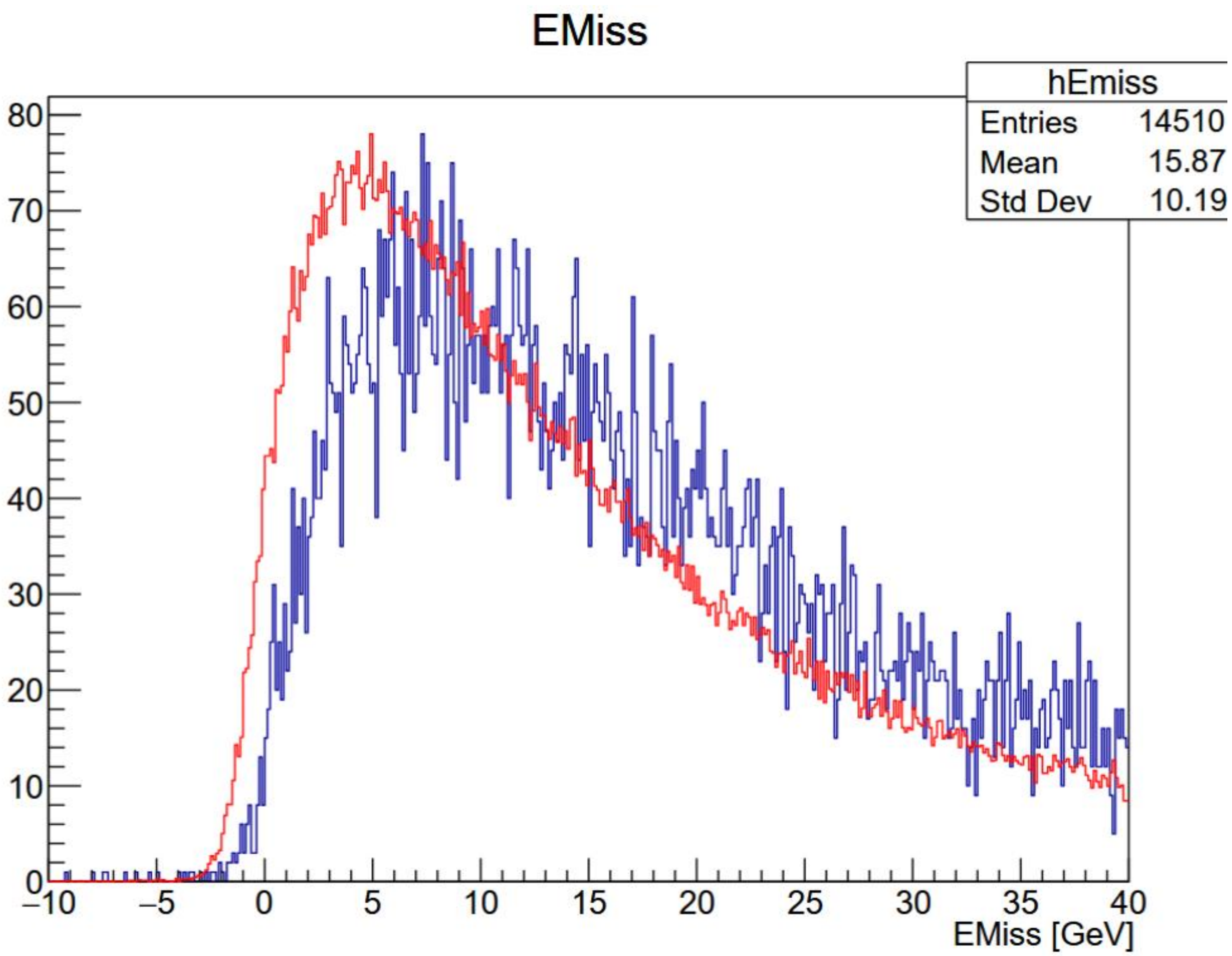
- Here N is the number of events with same charged pions found in the data (numerator) and the Monte Carlo (denominator)

- The factional background, $f_{bkg}$,is calculated
  - Find the number of events of the Monte Carlo and data in our missing energy region

- The plots are for events where we have hadron pairs with the same charge
  - Pi+ Pi+
  - Pi- Pi-
- Using all other exclusive cuts
- The weight is determined by finding the number of events in each histogram

$$w(E_{\text{miss}}) = \frac{N_{rd}^{sc}(E_{\text{miss}})}{N_{MC}^{sc}(E_{\text{miss}})}.$$

- Weight = 0.0662282181000562

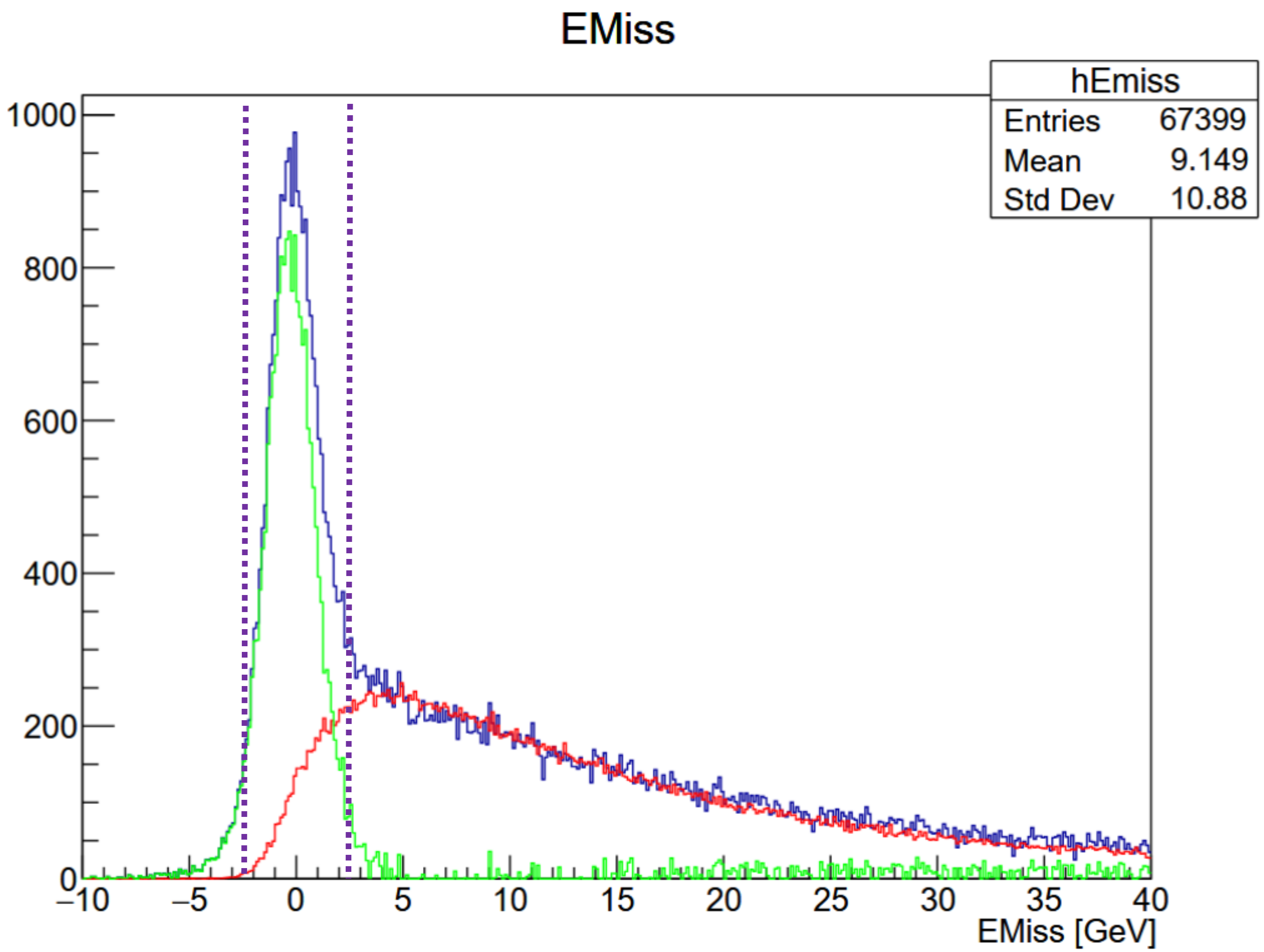



Data

Lepto

# DATA VS MONTE CARLO (WEIGHTED LEPTO)

- The Monte Carlo is normalized to the region 7 < Emiss < 20
- The fraction background is calculated in the region of -3 < Emiss < 3
    - F_bkg = N_bkg/N_T
    - F_bkg = 0.11827684042426548



# EXTRACTING SDME WITHOUT BACKGROUND

- Introduce 23 more SDME for just the background events:

$$-\ln L(\mathcal{R}) = -\sum_{i=1}^{N} \ln\Big[\frac{(1-f_{bg}) * \mathcal{W}^{U+L}(\mathcal{R};\Phi_i,\phi_i,\cos\Theta_i)}{\widetilde{\mathcal{N}}(\mathcal{R},\mathcal{B})} + \frac{f_{bg} * \mathcal{W}^{U+L}(\mathcal{B};\Phi_i,\phi_i,\cos\Theta_i)}{\widetilde{\mathcal{N}}(\mathcal{R},\mathcal{B})}\Big]$$

$$\widetilde{\mathcal{N}}(\mathcal{R},\mathcal{B}) = \sum_{j=1}^{N_{MC}} [(1-f_{bg}) * \mathcal{W}^{U+L}(\mathcal{R};\Phi_j,\phi_j,\cos\Theta_j) + f_{bg} * \mathcal{W}^{U+L}(\mathcal{B};\Phi_j,\phi_j,\cos\Theta_j)]$$

- Here R is the 23 SDME for the signal, and B is the 23 SDME for the background. MLM has to fit 46 parameters
- Fbg is the fractional background

# SPIN DENSITY MATRIX ELEMENTS

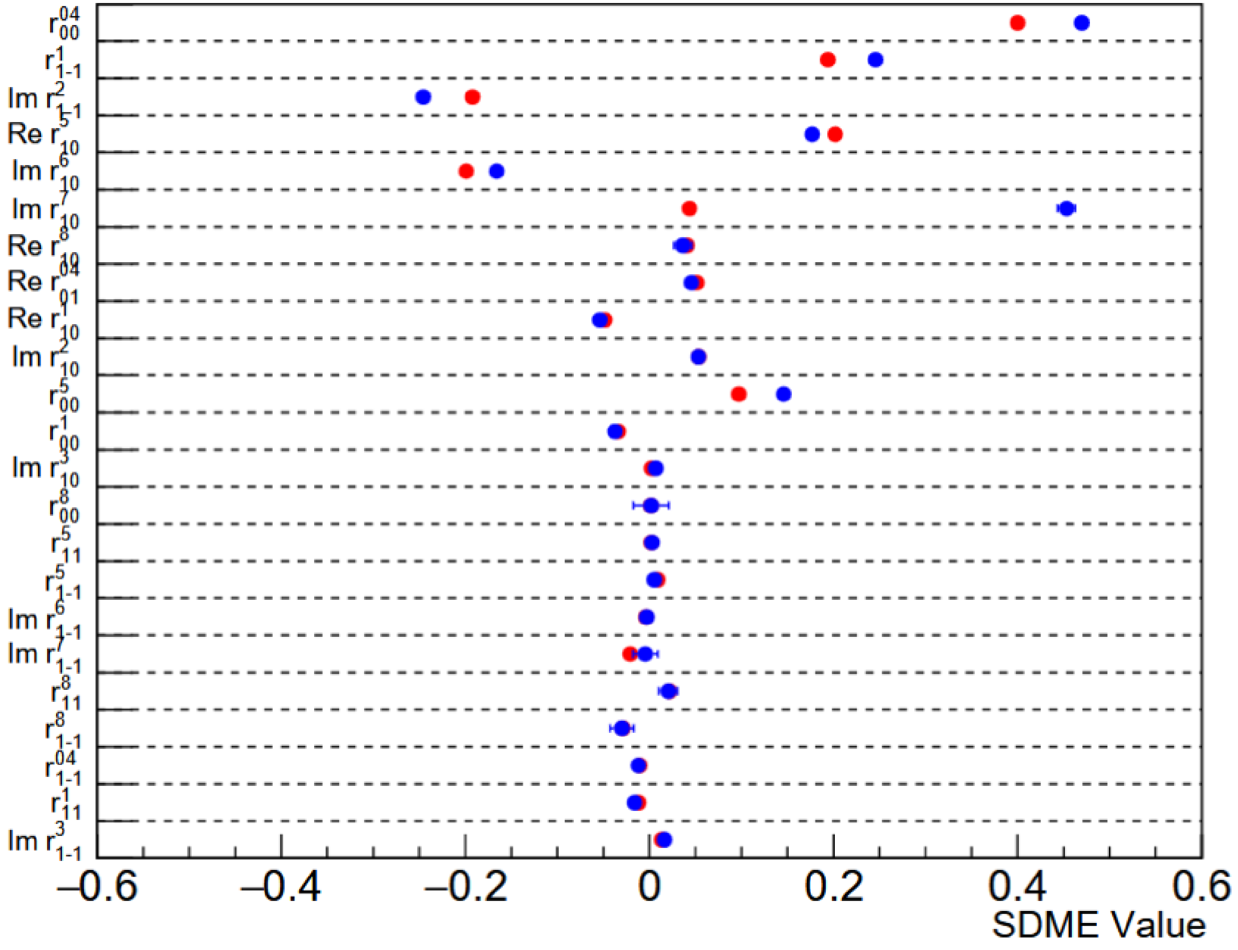
# SDME CODE

```python
import ROOT.Math as rm
import numpy as np
#log sum function (the one we are minimizing)
class logsum(object):
    def __init__(self, cosTheta, phi, Phi, eps, n_Data, cosTheta_sim, phi_sim, Phi_sim, eps_sim, n_sim):
        self.cosTheta = cosTheta
        self.phi = phi
        self.Phi = Phi
        self.eps = eps
        self.n_Data = n_Data

        self.cosTheta_sim = cosTheta_sim
        self.phi_sim = phi_sim
        self.Phi_sim = Phi_sim
        self.eps_sim = eps_sim
        self.n_sim = n_sim

    def __call__(self, x):
        N = 0.0
        for i in range(self.n_Data):
            cT = self.cosTheta[i]
            ph = self.phi[i]
            Ph = self.Phi[i]

            sin2Theta = 2 * cT * rm.sqrt(1 - cT * cT)
            sinTheta2 = (1 - cT * cT)

            N_u = (1/2 * (1 - x[0]) + 1/2 * (3 * x[0] - 1) * cT * cT
                   - rm.sqrt(2) * x[1] * sin2Theta * rm.cos(ph)
                   - x[2] * sinTheta2 * rm.cos(2 * ph))
            N_u += (-self.eps[i] * rm.cos(2 * Ph) * (x[3] * sinTheta2 + x[4] * cT * cT
                    - rm.sqrt(2) * x[5] * sin2Theta * rm.cos(ph)
                    - x[6] * sinTheta2 * rm.cos(2 * ph)))
            N_u += (-self.eps[i] * rm.sin(2 * Ph) * (rm.sqrt(2) * x[7] * sin2Theta * rm.sin(ph)
                    + x[8] * sinTheta2 * rm.sin(2 * ph)))
            N_u += (rm.sqrt(2 * self.eps[i] * (1 + self.eps[1])) * rm.cos(Ph) * (x[9] * sinTheta2
                    + x[10] * cT * cT - rm.sqrt(2) * x[11] * sin2Theta * rm.cos(ph)
                    - x[12] * sinTheta2 * rm.cos(2 * ph)))
            N_u += (rm.sqrt(2 * self.eps[i] * (1 + self.eps[1])) * rm.sin(Ph) * (rm.sqrt(2) * x[13] * sin2Theta * rm.sin(ph)
                    + x[14] * sinTheta2 * rm.sin(2 * ph)))

            N_p = (rm.sqrt(1 - self.eps[i] * self.eps[i]) * (rm.sqrt(2) * x[15] * sin2Theta * rm.sin(ph)
                    + x[16] * sinTheta2 * rm.sin(2 * ph)))
            N_p += (rm.sqrt(2 * self.eps[i] * (1 + self.eps[1])) * rm.cos(Ph) * (rm.sqrt(2) * x[17] * sin2Theta * rm.sin(ph)
                    + x[18] * sinTheta2 * rm.sin(2 * ph)))
            N_p += (rm.sqrt(2 * self.eps[i] * (1 + self.eps[1])) * rm.sin(Ph) * (x[19] * sinTheta2
                    + x[20] * cT * cT - rm.sqrt(2) * x[21] * sin2Theta * rm.cos(ph)
                    - x[22] * sinTheta2 * rm.cos(2 * ph)))

            N += 3 / (8 * rm.pi * rm.pi) * (N_u + Pb * N_p)

        NF = 0.0
        for i in range(self.n_sim):
            cT = self.cosTheta_sim[i]
            ph = self.phi_sim[i]
            Ph = self.Phi_sim[i]

            sin2Theta = 2 * cT * rm.sqrt(1 - cT * cT)
            sinTheta2 = (1 - cT * cT)

            N_u = (1/2 * (1 - x[0]) + 1/2 * (3 * x[0] - 1) * cT * cT
                   - rm.sqrt(2) * x[1] * sin2Theta * rm.cos(ph)
                   - x[2] * sinTheta2 * rm.cos(2 * ph))
            N_u += (-self.eps_sim[i] * rm.cos(2 * Ph) * (x[3] * sinTheta2 + x[4] * cT * cT
                    - rm.sqrt(2) * x[5] * sin2Theta * rm.cos(ph)
                    - x[6] * sinTheta2 * rm.cos(2 * ph)))
            N_u += (-self.eps_sim[i] * rm.sin(2 * Ph) * (rm.sqrt(2) * x[7] * sin2Theta * rm.sin(ph)
                    + x[8] * sinTheta2 * rm.sin(2 * ph)))
            N_u += (rm.sqrt(2 * self.eps_sim[i] * (1 + self.eps_sim[1])) * rm.cos(Ph) * (x[9] * sinTheta2
                    + x[10] * cT * cT - rm.sqrt(2) * x[11] * sin2Theta * rm.cos(ph)
                    - x[12] * sinTheta2 * rm.cos(2 * ph)))
            N_u += (rm.sqrt(2 * self.eps_sim[i] * (1 + self.eps_sim[1])) * rm.sin(Ph) * (rm.sqrt(2) * x[13] * sin2Theta * rm.sin(ph)
                    + x[14] * sinTheta2 * rm.sin(2 * ph)))

            N_p = (rm.sqrt(1 - self.eps_sim[i] * self.eps_sim[i]) * (rm.sqrt(2) * x[15] * sin2Theta * rm.sin(ph)
                    + x[16] * sinTheta2 * rm.sin(2 * ph)))
            N_p += (rm.sqrt(2 * self.eps_sim[i] * (1 + self.eps_sim[1])) * rm.cos(Ph) * (rm.sqrt(2) * x[17] * sin2Theta * rm.sin(ph)
                    + x[18] * sinTheta2 * rm.sin(2 * ph)))
            N_p += (rm.sqrt(2 * self.eps_sim[i] * (1 + self.eps_sim[1])) * rm.sin(Ph) * (x[19] * sinTheta2
                    + x[20] * cT * cT - rm.sqrt(2) * x[21] * sin2Theta * rm.cos(ph)
                    - x[22] * sinTheta2 * rm.cos(2 * ph)))

            NF += 3 / (8 * rm.pi * rm.pi) * (N_u + Pb * N_p)

        tot = ROOT.TMath.Log(N) - ROOT.TMath.Log(NF)
        return -tot
```

- The code for extracting the SDMEs using maximum likelihood method (MLM) has been written
  - Extracts all 23 SDMEs
  - Based on the python code used for sig_LT'/sig_0 extraction
  - Minuit2 minimizer used
    - "Minimize" as minimizer

# SDME EXTRACTION

COMPASS 2012




| SDME | |
|---|---|
| $r^{04}_{00}$ | $0.4698 \pm 0.0035 \pm 0.0220$ |
| $r^{1}_{1-1}$ | $0.2457 \pm 0.0037 \pm 0.0064$ |
| $\mathrm{Im}\, r^{2}_{1-1}$ | $-0.2459 \pm 0.0038 \pm 0.0049$ |
| $\mathrm{Re}\, r^{5}_{10}$ | $0.1769 \pm 0.0015 \pm 0.0041$ |
| $\mathrm{Im}\, r^{6}_{10}$ | $-0.1662 \pm 0.0014 \pm 0.0040$ |
| $\mathrm{Im}\, r^{7}_{10}$ | $0.0453 \pm 0.0096 \pm 0.0156$ |
| $\mathrm{Re}\, r^{8}_{10}$ | $0.0362 \pm 0.0095 \pm 0.0121$ |
| $\mathrm{Re}\, r^{04}_{10}$ | $0.0454 \pm 0.0021 \pm 0.0058$ |
| $\mathrm{Re}\, r^{1}_{10}$ | $-0.0539 \pm 0.0029 \pm 0.0040$ |
| $\mathrm{Im}\, r^{2}_{10}$ | $0.0532 \pm 0.0028 \pm 0.0043$ |
| $r^{5}_{00}$ | $0.1456 \pm 0.0033 \pm 0.0129$ |
| $r^{1}_{00}$ | $-0.0376 \pm 0.0062 \pm 0.0114$ |
| $\mathrm{Im}\, r^{3}_{10}$ | $0.0067 \pm 0.0067 \pm 0.0045$ |
| $r^{8}_{00}$ | $0.0019 \pm 0.0194 \pm 0.0253$ |
| $r^{5}_{11}$ | $0.0027 \pm 0.0016 \pm 0.0025$ |
| $r^{5}_{1-1}$ | $0.0050 \pm 0.0020 \pm 0.0025$ |
| $\mathrm{Im}\, r^{6}_{1-1}$ | $-0.0028 \pm 0.0020 \pm 0.0019$ |
| $\mathrm{Im}\, r^{7}_{1-1}$ | $-0.0045 \pm 0.0134 \pm 0.0224$ |
| $r^{8}_{11}$ | $0.0203 \pm 0.0101 \pm 0.0305$ |
| $r^{8}_{1-1}$ | $-0.0300 \pm 0.0128 \pm 0.0091$ |
| $r^{04}_{1-1}$ | $-0.0120 \pm 0.0027 \pm 0.0032$ |
| $r^{1}_{11}$ | $-0.0162 \pm 0.0032 \pm 0.0037$ |
| $\mathrm{Im}\, r^{3}_{1-1}$ | $0.0163 \pm 0.0085 \pm 0.0043$ |

2012 is after background subtraction

2012 Data

2016 Data

# NEXT STEPS

- Create background subtraction MLM to extract SDMEs
    - Look at Lepto for background simulation
- Fix up the errors with this MLM
- Ran for the entire run period 9

# BACKUP SLIDES

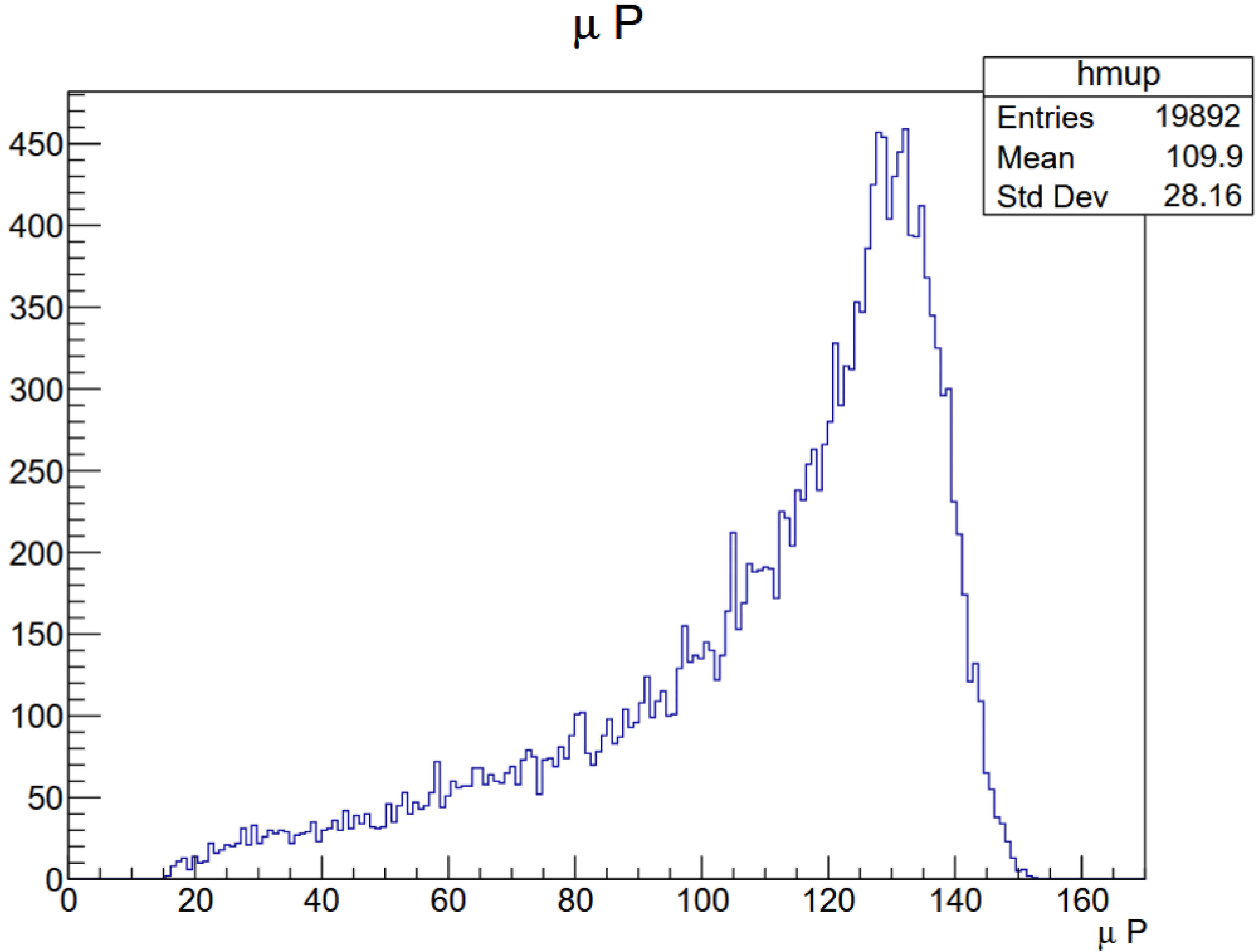
Coming from 2012 Rho analysis (W. Augustyniak, et al. ,Spin Density Matrix Elements for exclusive ρ0 meson production using the 2012 COMPASS data,internal note, 2021.)

# KINEMATIC CUTS

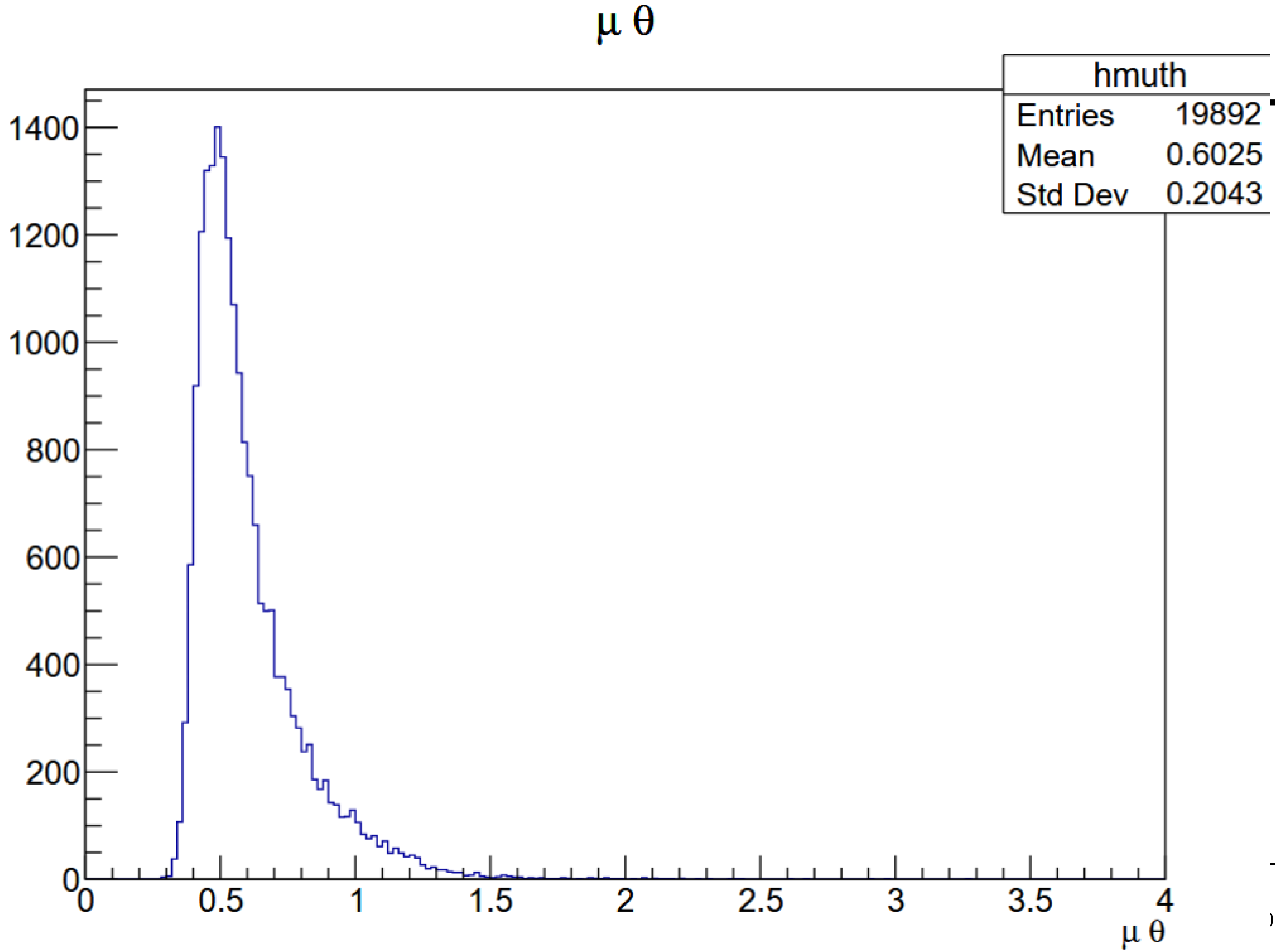
- $W > 5.0$ GeV
- $0.1 < y < 0.9$
- $1.0 < Q2 < 10.0$
- $0.01 < pT2 < 0.5$
- $0.5 < M\pi+\pi- < 1.1$
- P_{ρ0} > 15

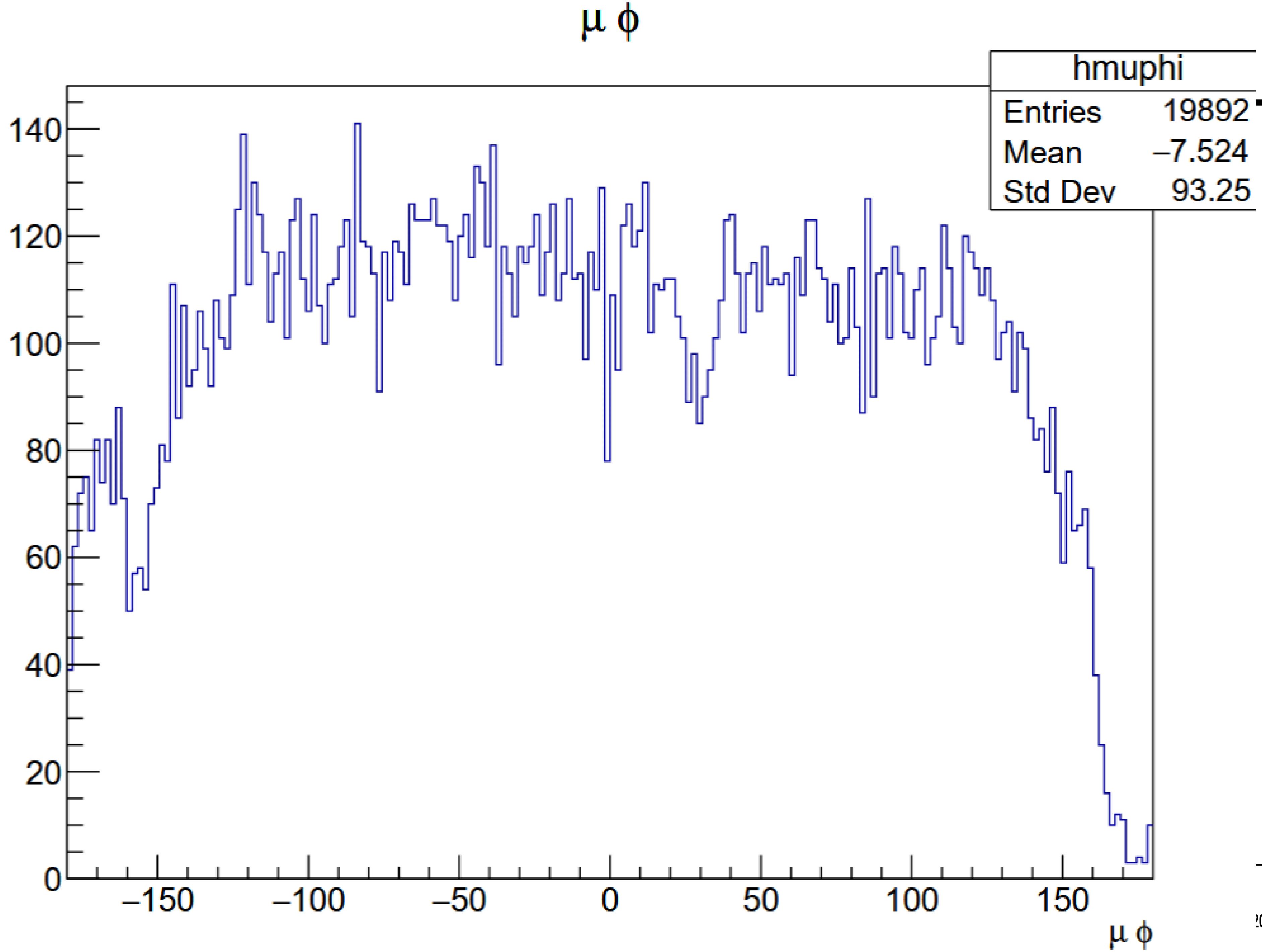
*Each plot is shown without the cut on the variable*

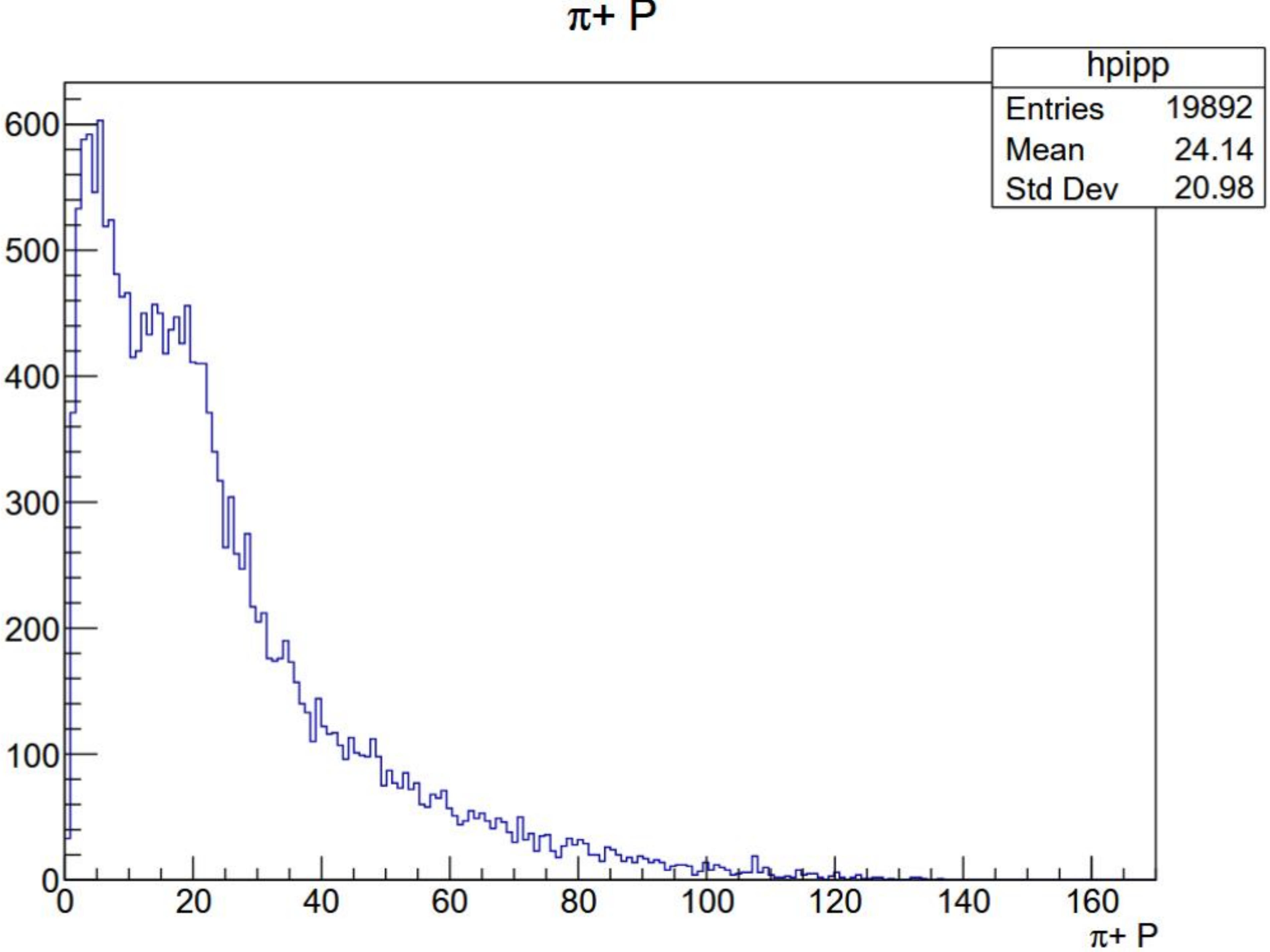
# DATA 1D PARTICLE KINEMATICS WITH CUTS

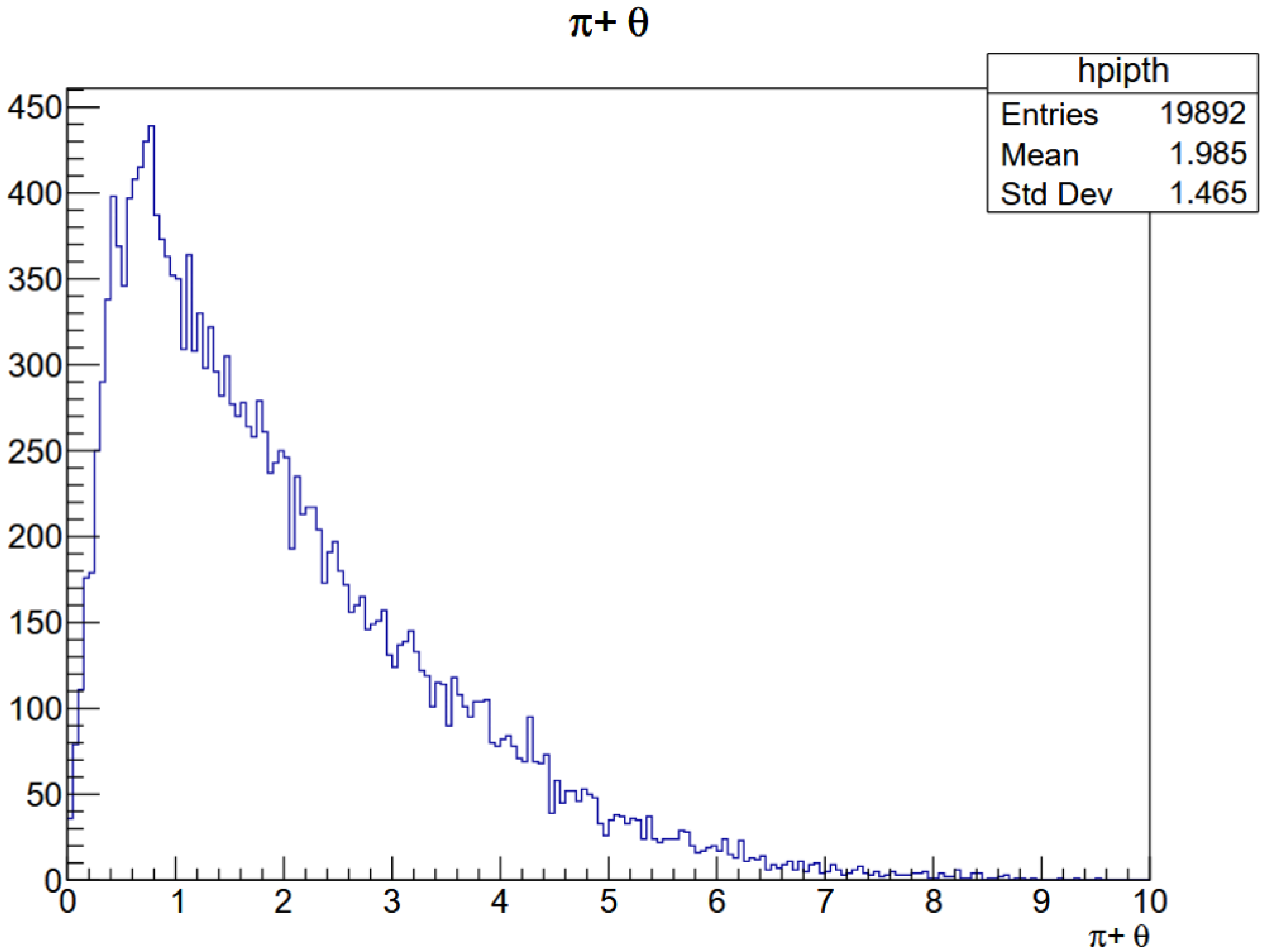


μ P
hmup
Entries 19892
Mean 109.9
Std Dev 28.16
0
50
100
150
200
250
300
350
400
450
0
20
40
60
80
100
120
140
160
μ P

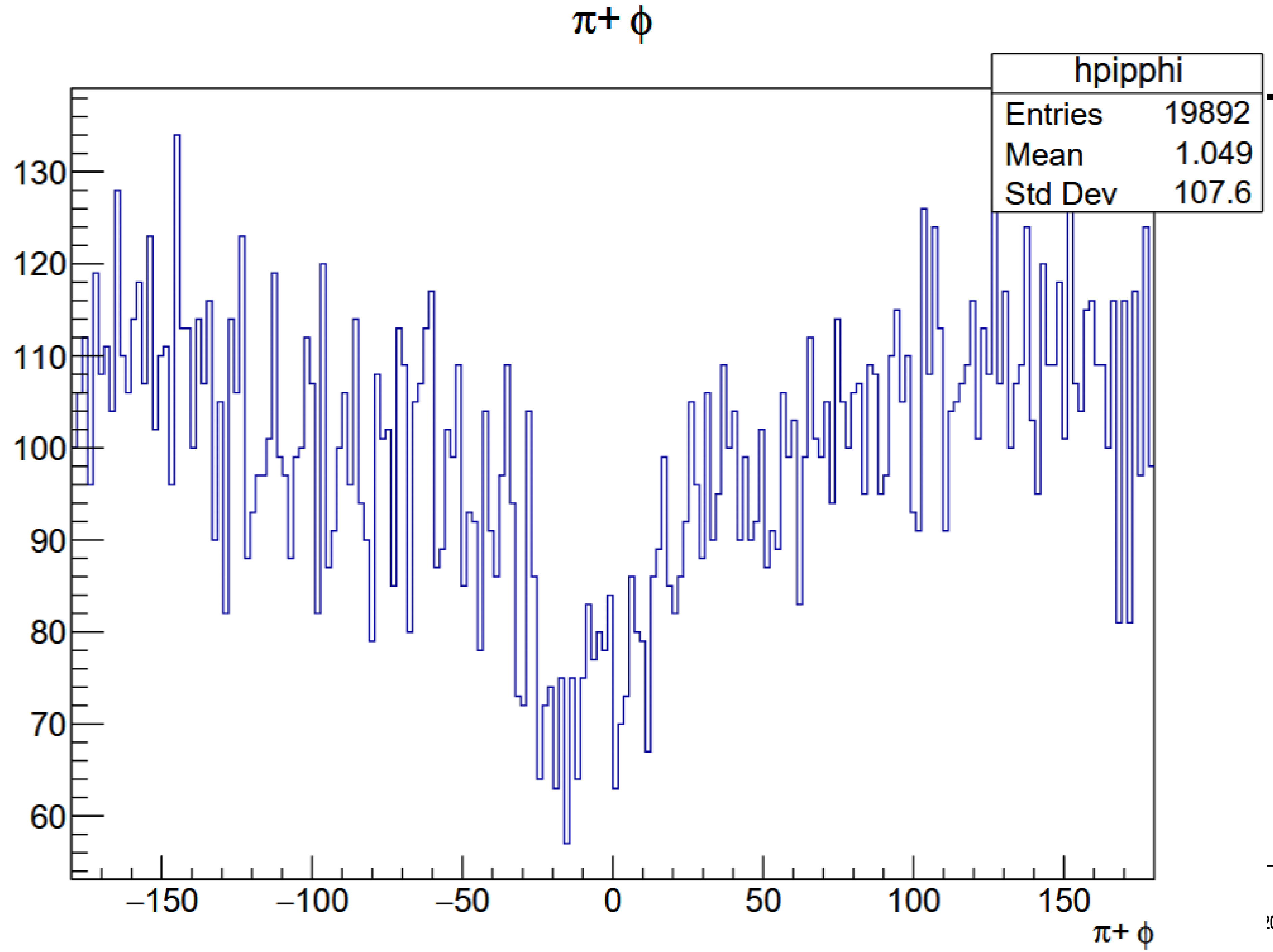

μ θ
hmuth
Entries 19892
Mean 0.6025
Std Dev 0.2043
1400
1200
1000
800
600
400
200
0
0
0.5
1
1.5
2
2.5
3
3.5
4
μ θ

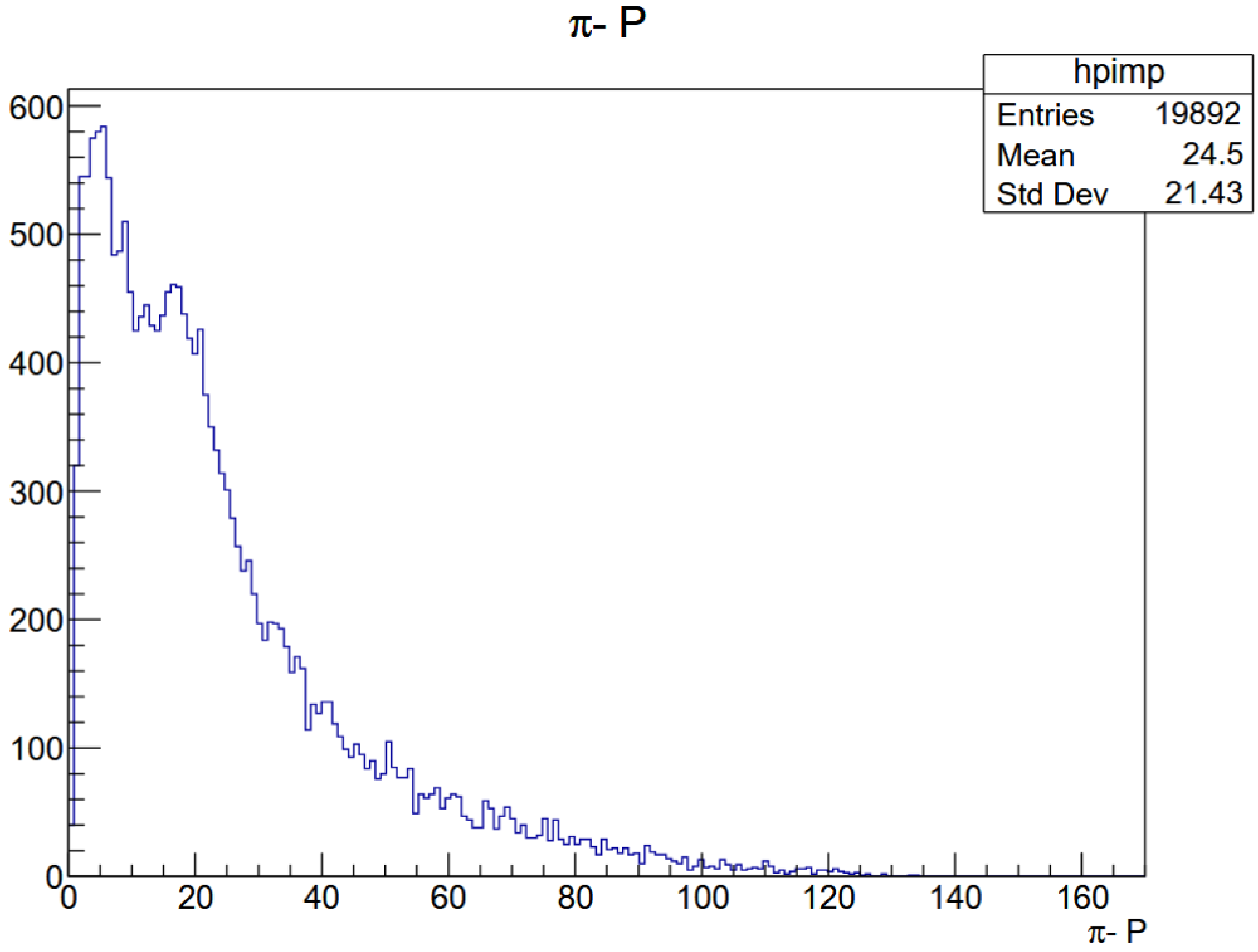

μ φ
hmuphi
Entries 19892
Mean −7.524
Std Dev 93.25
140
120
100
80
60
40
20
0
−150
−100
−50
0
50
100
150
μ φ

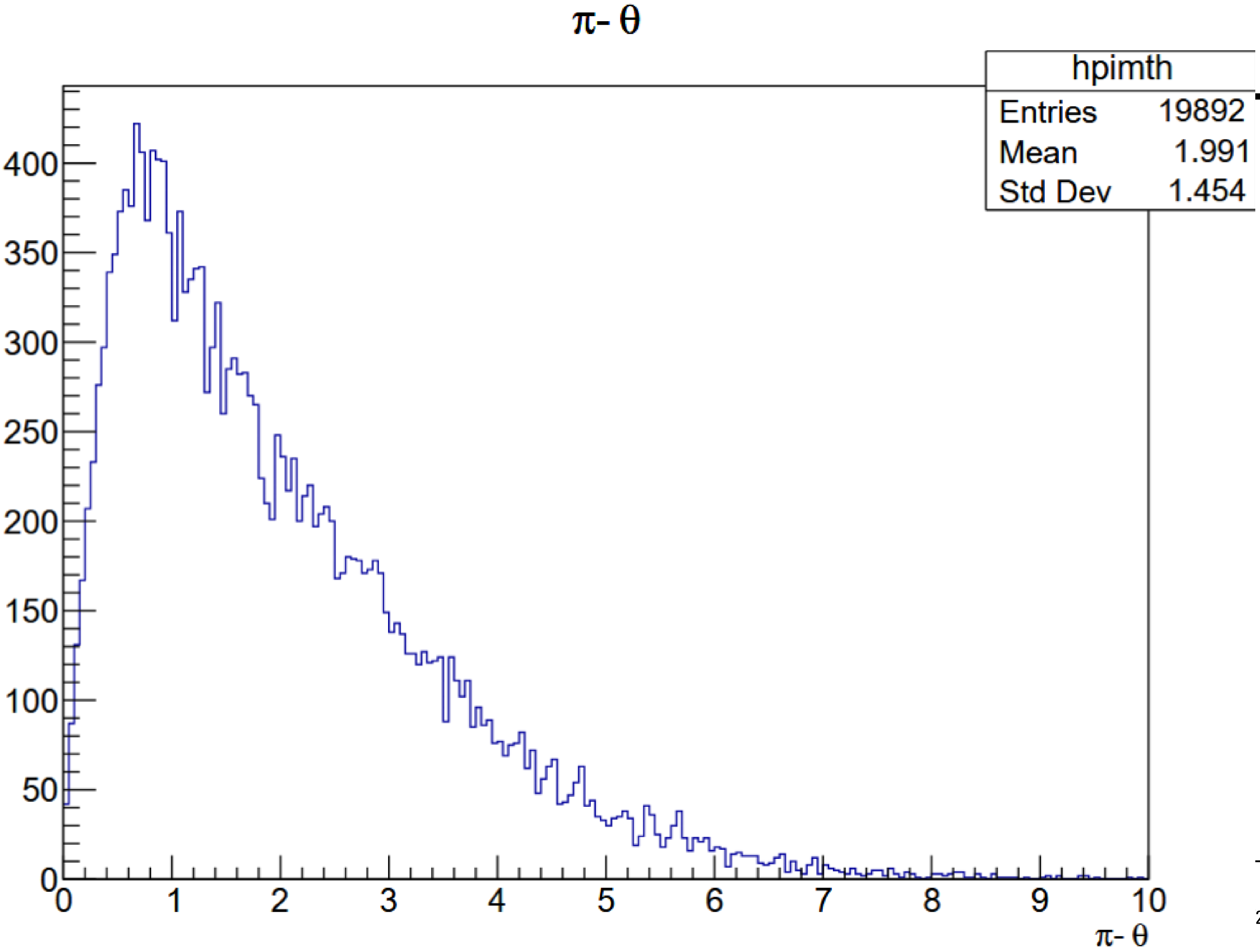

π+ P
hpipp
Entries 19892
Mean 24.14
Std Dev 20.98
0
100
200
300
400
500
600
0
20
40
60
80
100
120
140
160
π+ P



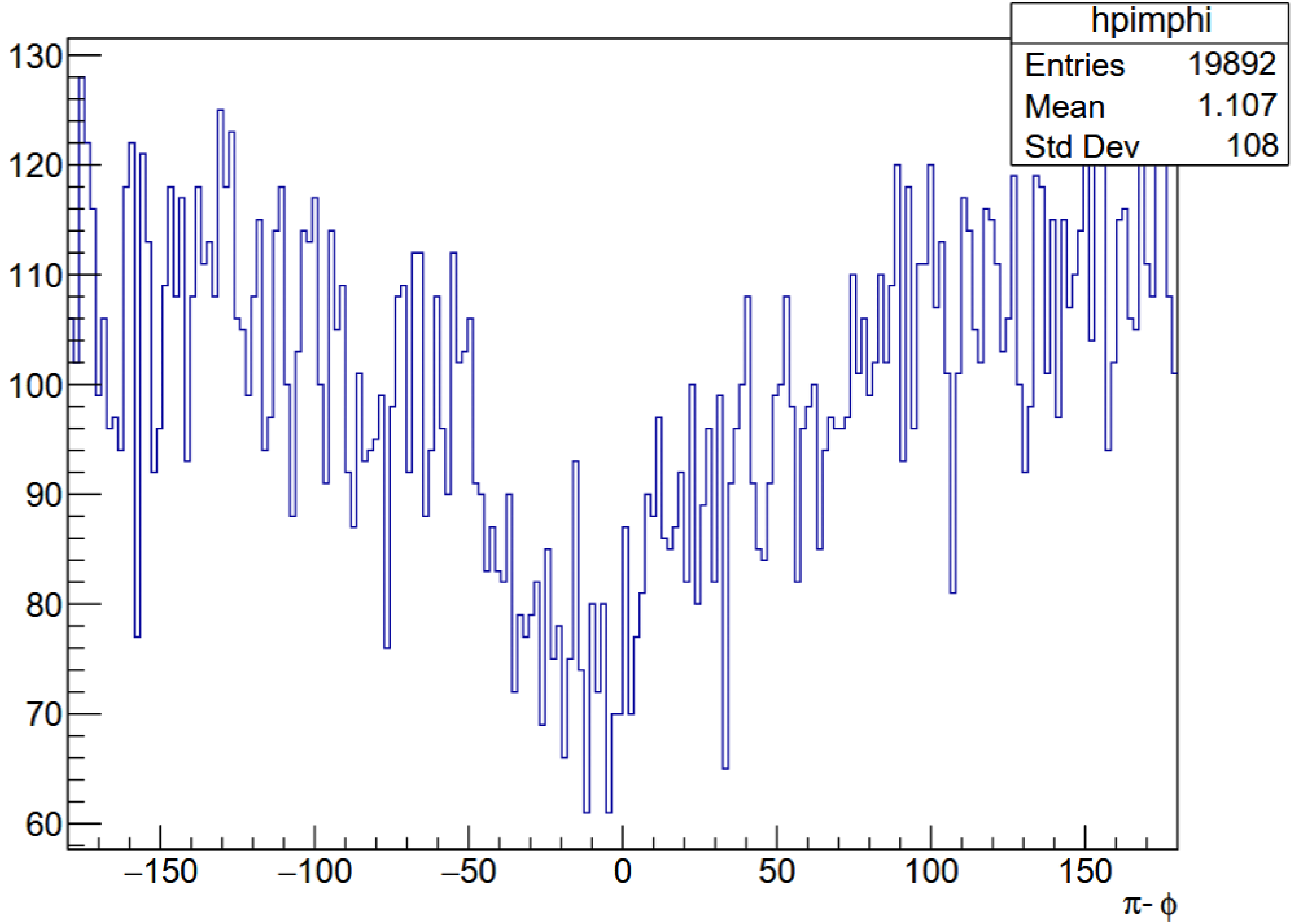
π+ θ
hpipth
Entries 19892
Mean 1.985
Std Dev 1.465
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10
π+ θ

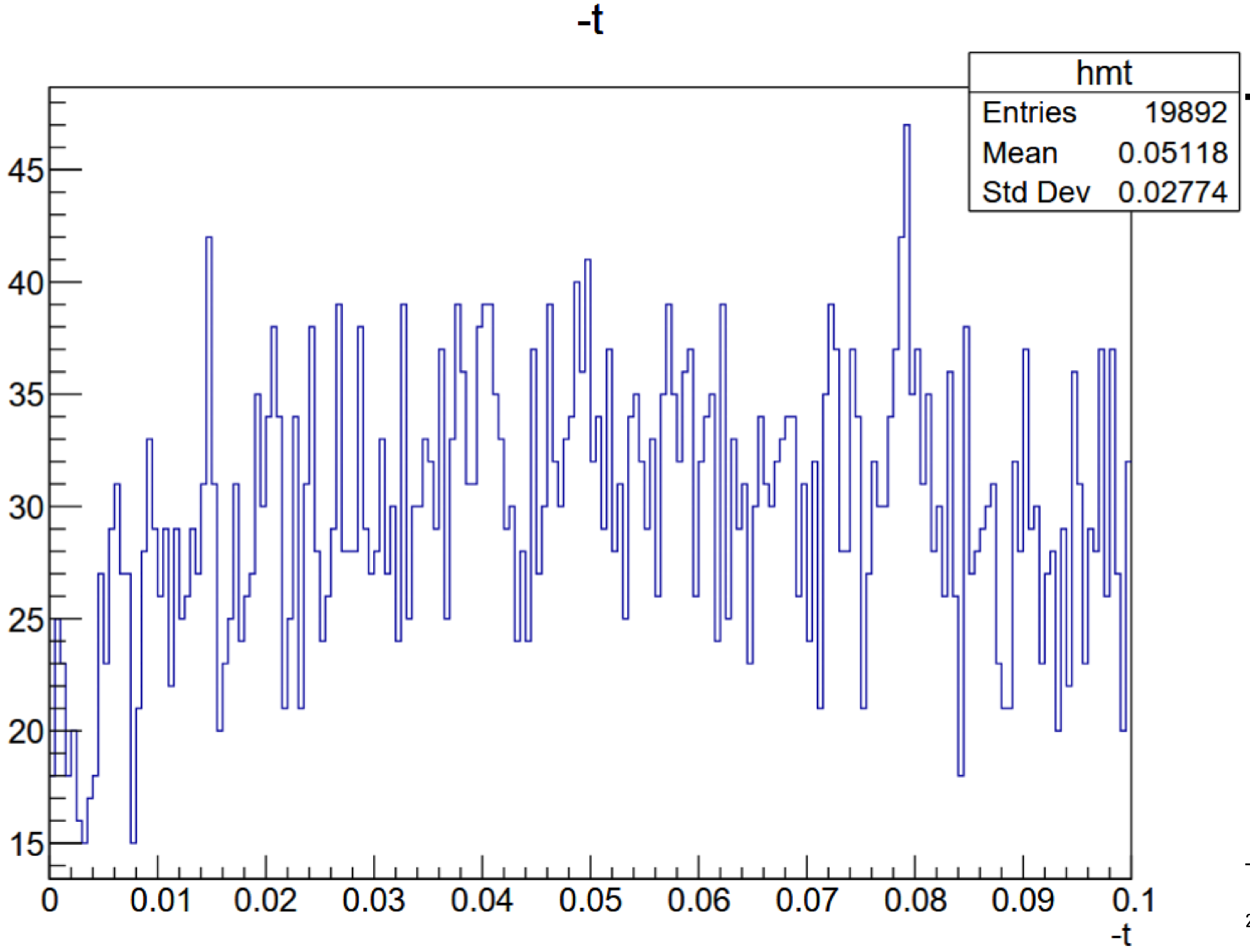

π+ φ
hpipphi
Entries 19892
Mean 1.049
Std Dev 107.6
130
120
110
100
90
80
70
60
−150
−100
−50
0
50
100
150
π+ φ


π- P
hpimp
Entries 19892
Mean 24.5
Std Dev 21.43
0
100
200
300
400
500
600
0
20
40
60
80
100
120
140
160
π- P


π- θ
hpimth
Entries 19892
Mean 1.991
Std Dev 1.454
0
50
100
150
200
250
300
350
400
0 1 2 3 4 5 6 7 8 9 10
π- θ

$\pi$- $\phi$


hpimphi
Entries 19892
Mean 1.107
Std Dev 108
130
120
110
100
90
80
70
60
−150
−100
−50
0
50
100
150
π- φ


-t
hmt
Entries 19892
Mean 0.05118
Std Dev 0.02774
15
20
25
30
35
40
45
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
-t