Small-angle pp scattering track reconstruction

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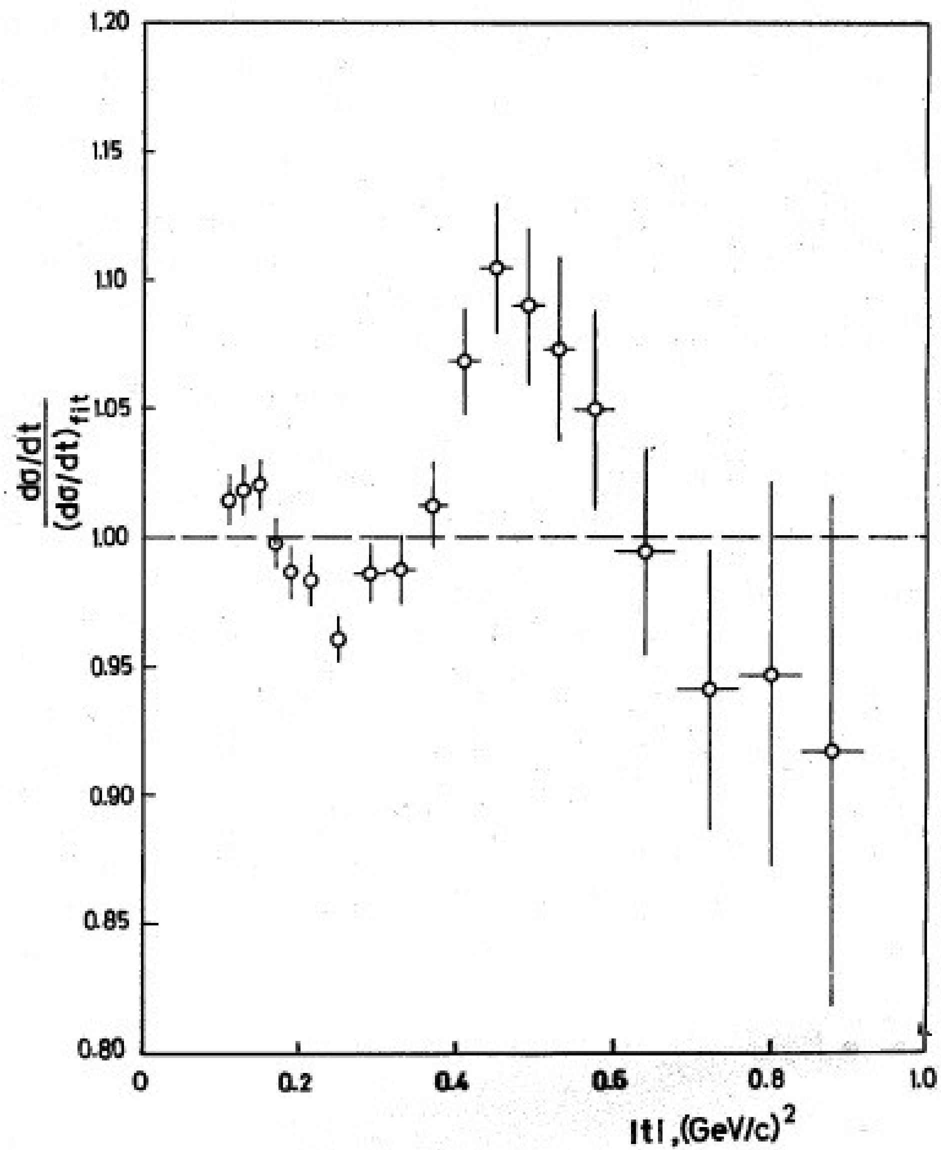


A. Lvov's presentation:

https://indico.jinr.ru/event/1373/

range of interest in t:
-0.1 -0.2 -0.3 -0.4 -0.5 -0.6 -0.7 -0.8 $(GeV/c)^2$

problems:
small t → small polar angle → small # of hits in tracker (vertex, barrell and endcup)

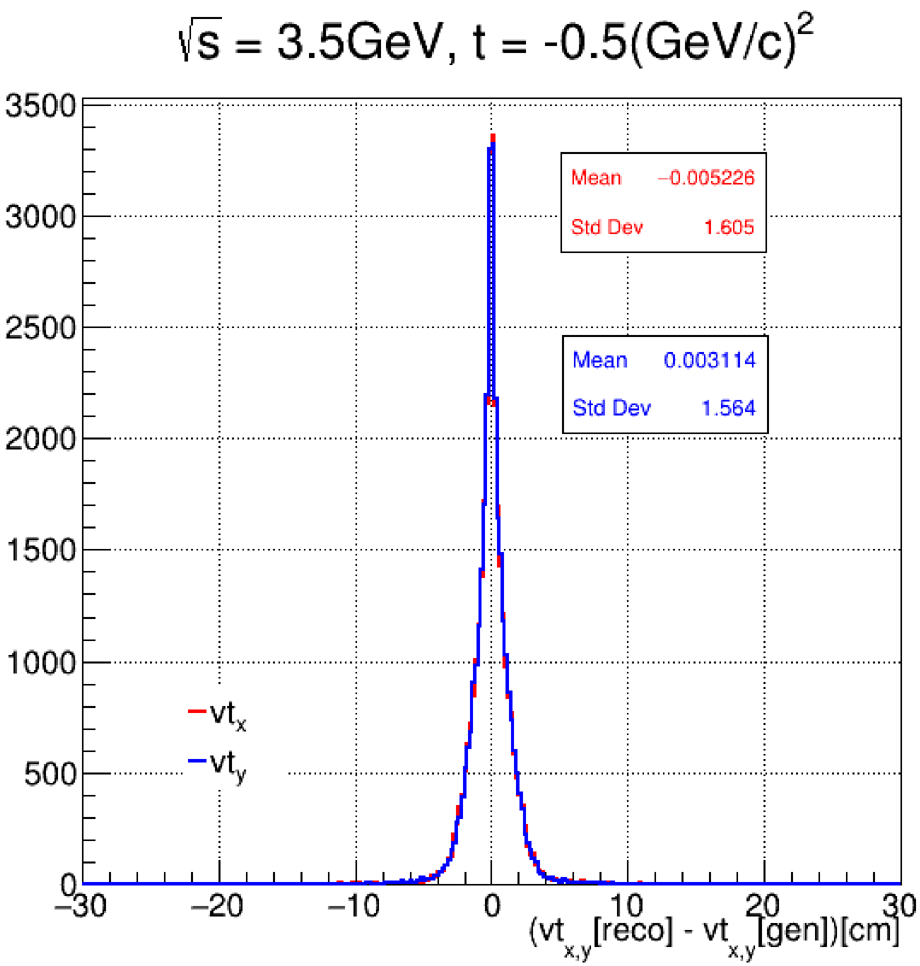
special generator, which generates 2 protons in opposite directions with fixed √s and t,
polar angle generates according with t,
azimuthal randomly inside 2π.
Vertex generation with σ_z = 30cm
and $\sigma_{x,y}$ = 0.1cm

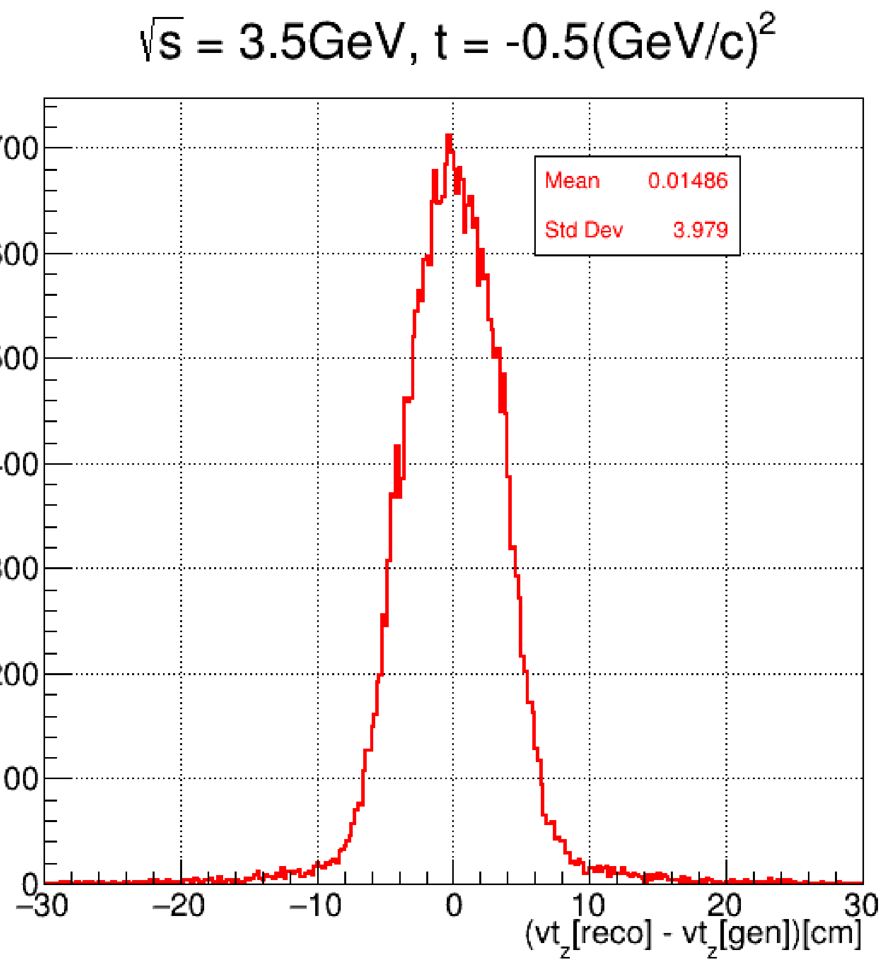
√s: 3.5, 5.0, 6.0, 7.0, 8.0 GeV

t: -0.1, -0.2, -0.3, -0.4, -0.5, -0.6, -0.7, -0.8 $(GeV/c)^2$

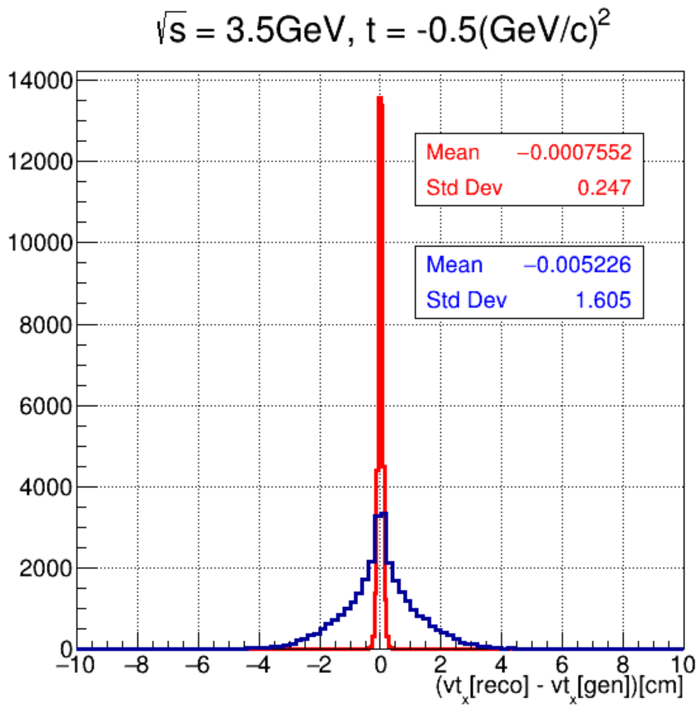
track selection: 2 tracks, each track is fitted and has fit parameters,
for each track at least one hit in vertex part of tracker

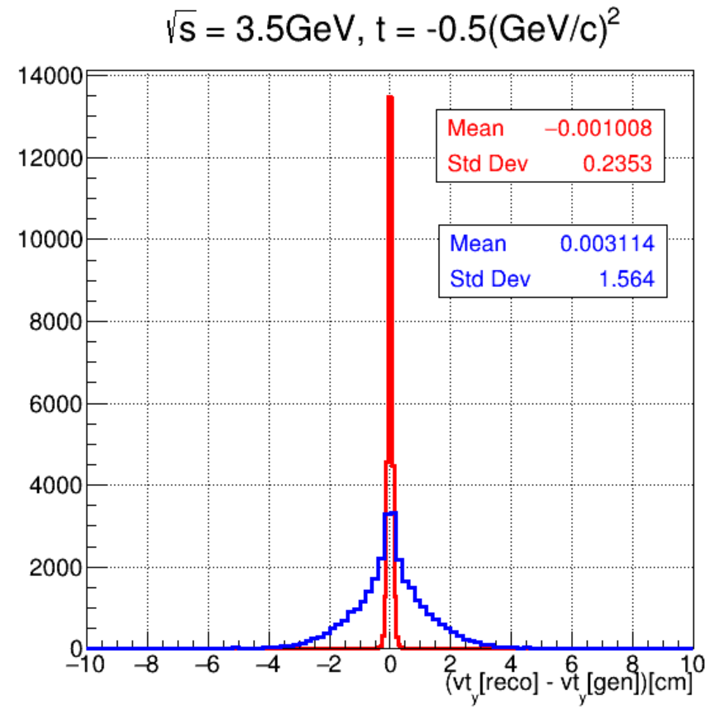
√s = 3.5 GeV and t = -0.5(GeV/c)^2 vertex reconstruction

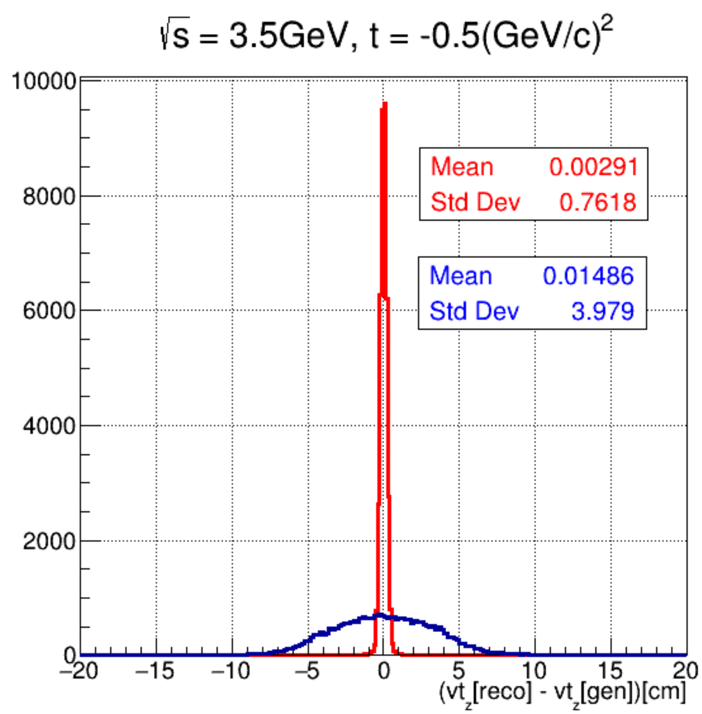




for interaction point $\sigma_{x,y}$ = 0.1cm → extrapolate each track to z axis and find nearest points to this axis (x_1,y_1,z_1) (x_2,y_2,z_2) and take average


√s = 3.5GeV, t = -0.5(GeV/c)^2
Mean −0.0007552
Std Dev 0.247
Mean −0.005226
Std Dev 1.605
(vt_x[reco] - vt_x[gen])[cm]


√s = 3.5GeV, t = -0.5(GeV/c)^2
Mean −0.001008
Std Dev 0.2353
Mean 0.003114
Std Dev 1.564
(vt_y[reco] - vt_y[gen])[cm]


√s = 3.5GeV, t = -0.5(GeV/c)^2
Mean 0.00291
Std Dev 0.7618
Mean 0.01486
Std Dev 3.979
(vt_z[reco] - vt_z[gen])[cm]

Kinematic fit

$$\chi^2 = (Y - Y_0)^T \cdot V^{-1} \cdot (Y - Y_0) \quad V = \begin{bmatrix} \sigma_1^2 & cov(y_1, y_2) & \dots & \dots \\ cov(y_2, y_1) & \sigma_2^2 & \dots & \dots \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \sigma_n^2 \end{bmatrix} \quad Y = \begin{bmatrix} y_1 \\ y_2 \\ \dots \\ y_n \end{bmatrix}$$

V – covariance matrix

y – vector of variables

kinematic fit: https://www.roma1.infn.it/~didomeni/MEPP/MEPP1900/14_MEPP1900_kinefit_4.pdf

apply additional constrains for our variables in form: $H(Y)=0$ where H is vector $H = \begin{bmatrix} H_1(Y)=0 \\ H_2(Y)=0 \\ \dots \\ H_k(Y)=0 \end{bmatrix}$

new equation: $\chi^2 = (Y - Y_0)^T \cdot V^{-1} \cdot (Y - Y_0) + 2 \cdot \lambda^T \cdot H$

linearization: $H(Y) = H(Y_0) + \partial H(Y_0)/\partial Y \cdot (Y - Y_0) = H(Y_0) + D \cdot (Y - Y_0)$

where $D = \begin{bmatrix} \partial H_1/\partial y_1 & \partial H_1/\partial y_2 & \dots & \dots \\ \partial H_2/\partial y_1 & \partial H_2/\partial y_2 & \dots & \dots \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \partial H_k/\partial y_n \end{bmatrix}$ is $k \times n$ matrix

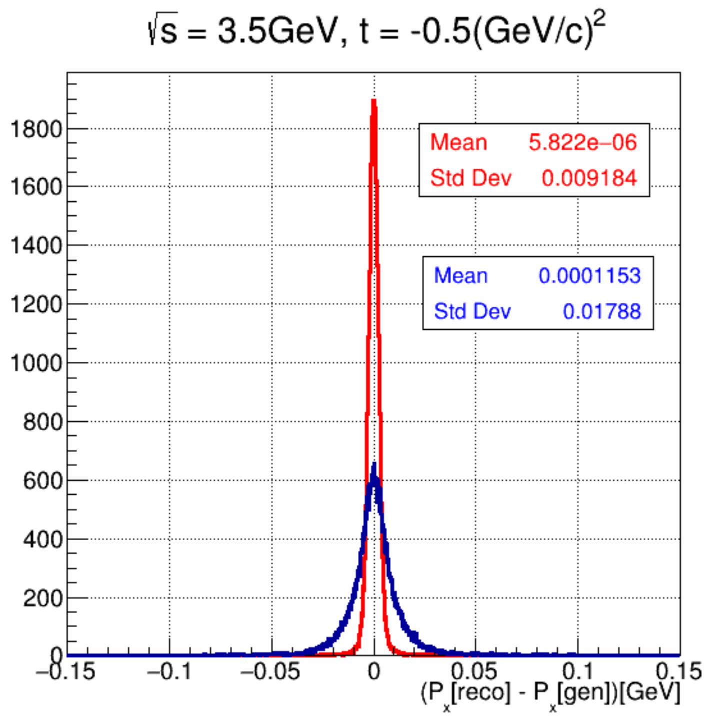
after minimization χ^2 ► $Y = Y_0 - V \cdot D^T \cdot (D \cdot V \cdot D^T)^{-1} \cdot d$ with $d = H(Y_0)$

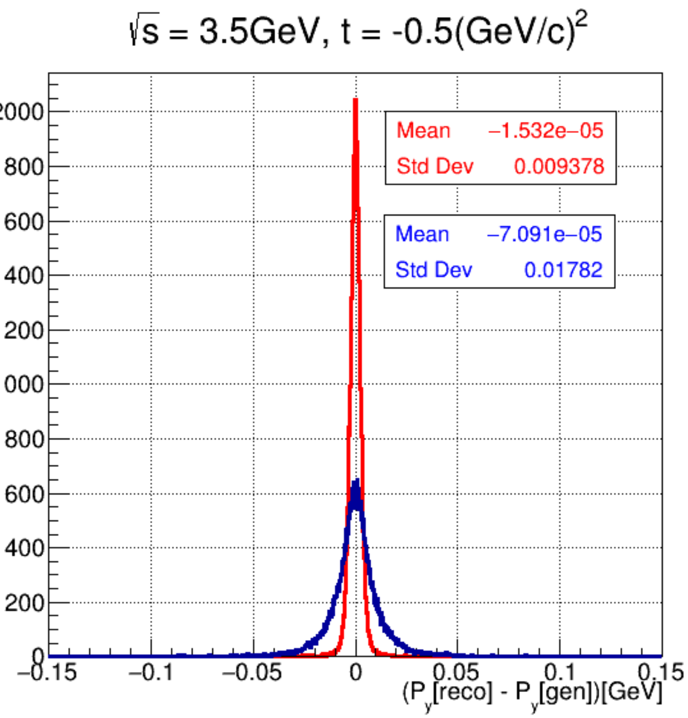
our case:

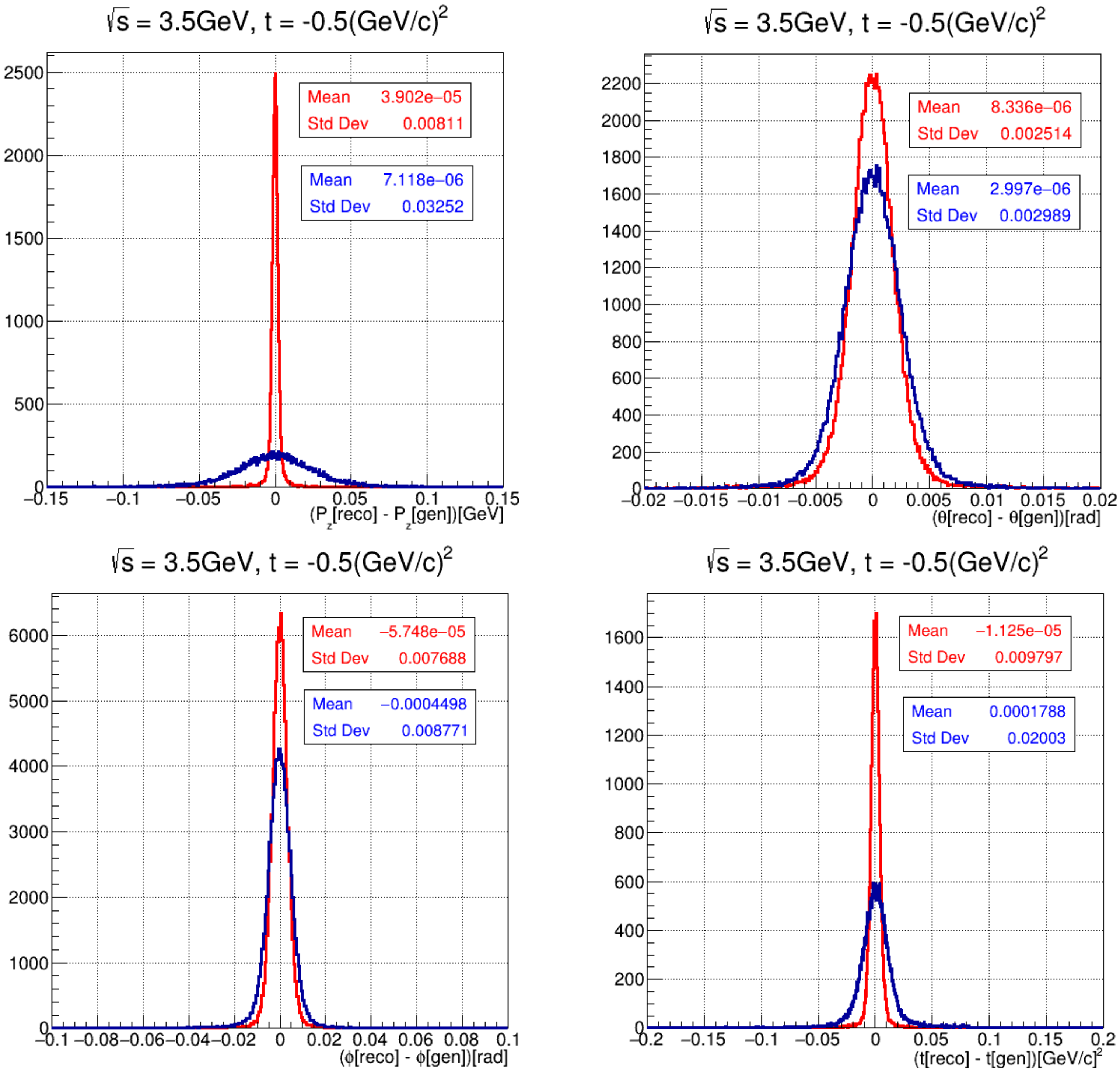
$$Y = \begin{bmatrix} P_{x1} \\ P_{y1} \\ P_{z1} \\ P_{x2} \\ P_{y2} \\ P_{z2} \end{bmatrix} \qquad H = \begin{bmatrix} P_{1x} + P_{2x} = 0 \\ P_{1y} + P_{2y} = 0 \\ P_{1z} + P_{2z} = 0 \\ 2 \cdot P_0 - P_1 - P_2 = 0 \end{bmatrix}$$

P_0 → beam impulse

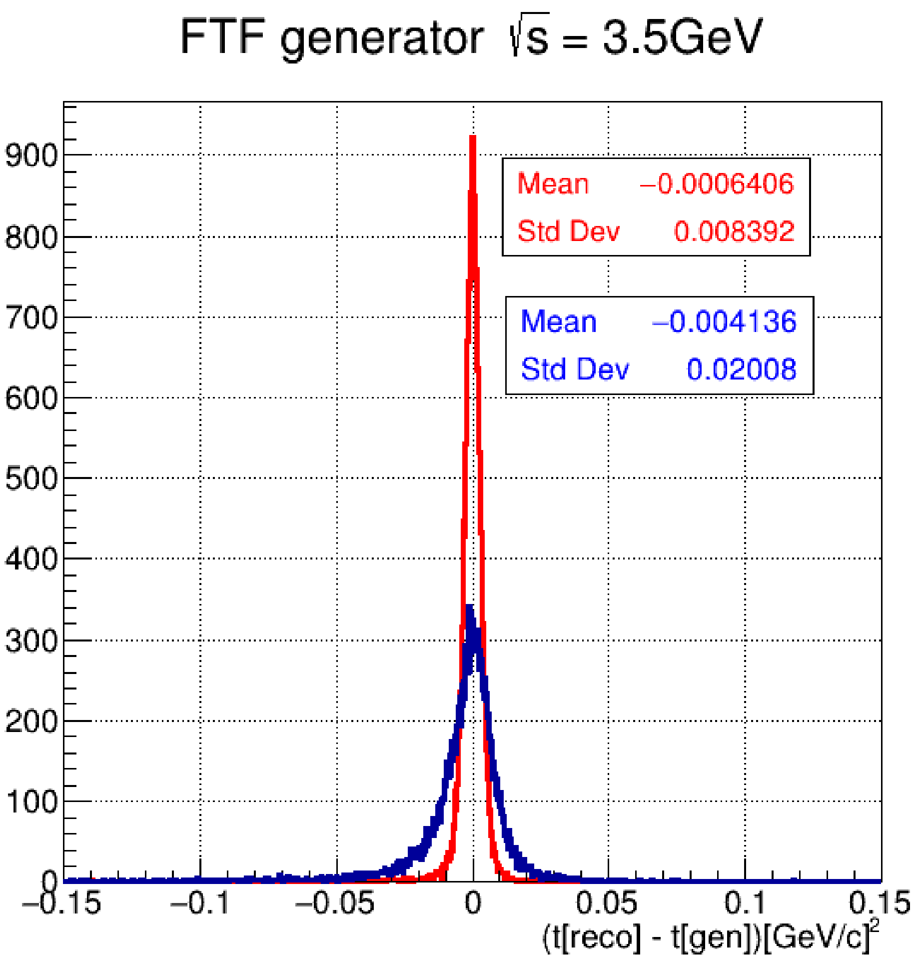
fixed √s = 3.5GeV t = -0.5(GeV/c)^2 kinematic fit

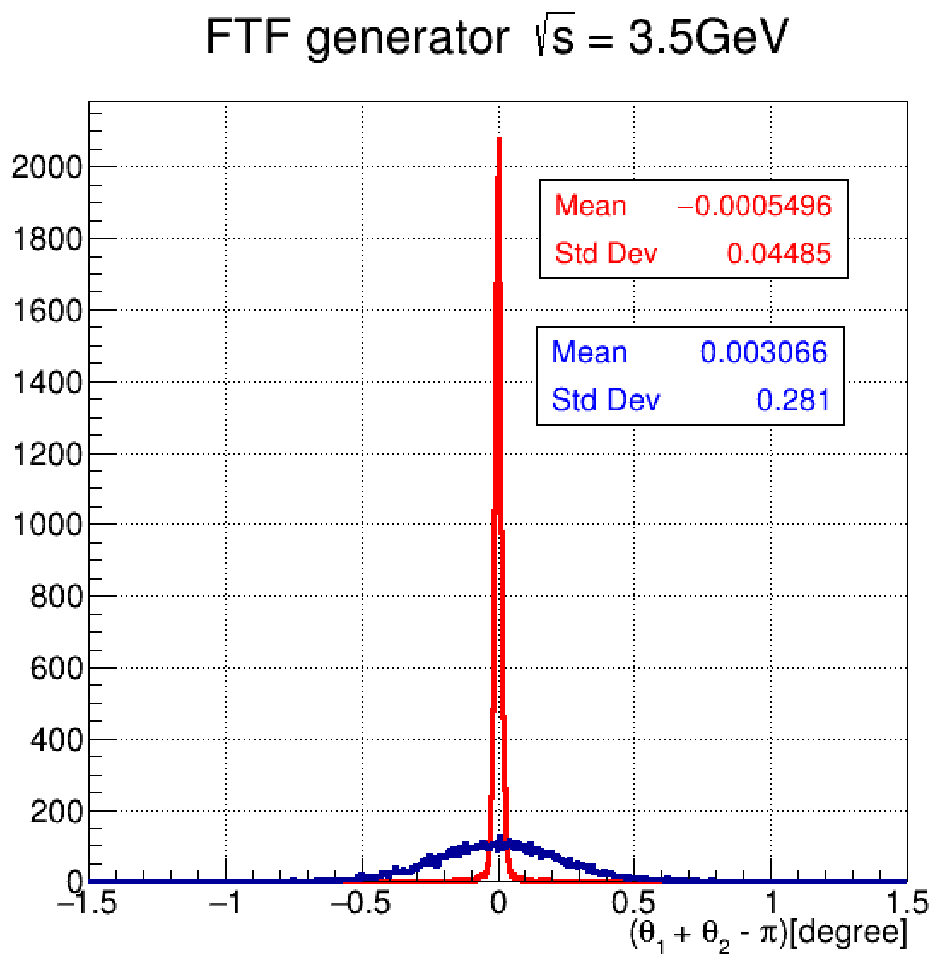





√s = 3.5GeV, t = -0.5(GeV/c)2
Mean 3.902e−05
Std Dev 0.00811
Mean 7.118e−06
Std Dev 0.03252
(Pz[reco] - Pz[gen])[GeV]
√s = 3.5GeV, t = -0.5(GeV/c)2
Mean 8.336e−06
Std Dev 0.002514
Mean 2.997e−06
Std Dev 0.002989
(θ[reco] - θ[gen])[rad]
√s = 3.5GeV, t = -0.5(GeV/c)2
Mean −5.748e−05
Std Dev 0.007688
Mean −0.0004498
Std Dev 0.008771
(ϕ[reco] - ϕ[gen])[rad]
√s = 3.5GeV, t = -0.5(GeV/c)2
Mean −1.125e−05
Std Dev 0.009797
Mean 0.0001788
Std Dev 0.02003
(t[reco] - t[gen])[GeV/c]2

FTF generator $\sqrt{s}$ = 3.5GeV

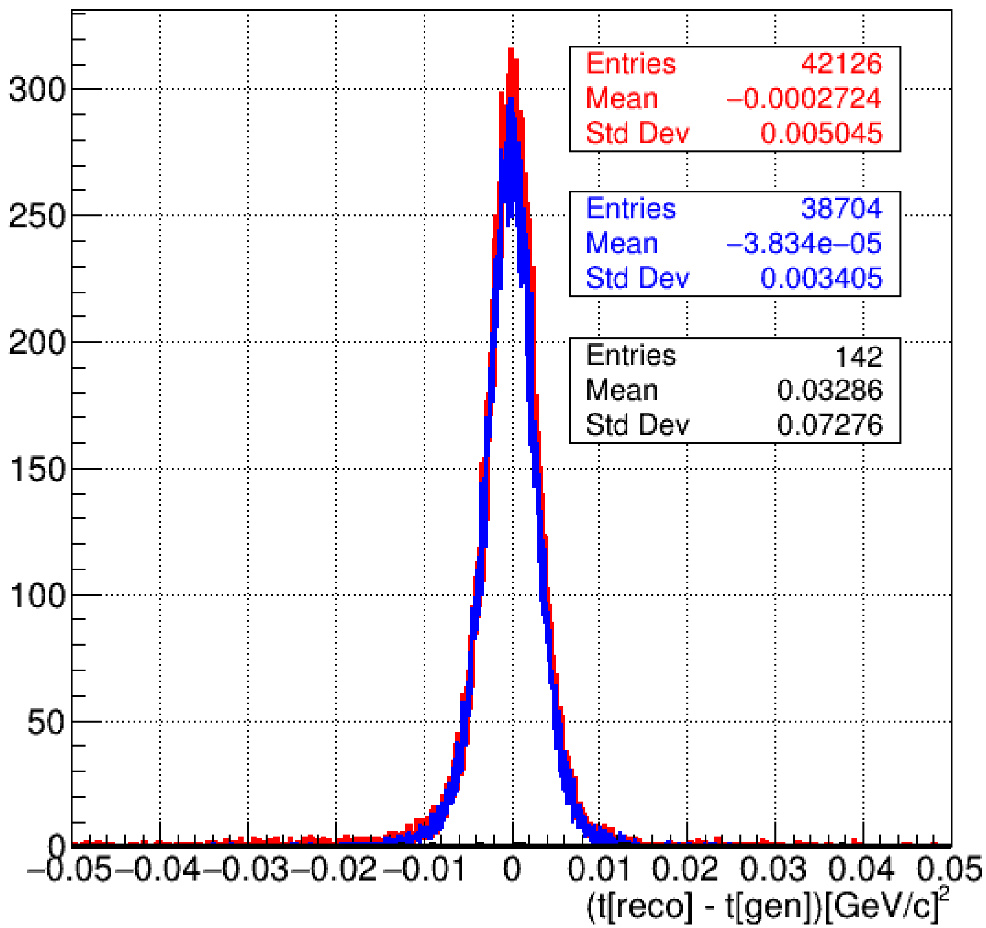




take for analysis elastic events only

for elastic events should be $\theta_1 + \theta_2 = \pi$

FTF generator $\sqrt{s} = 3.5$GeV

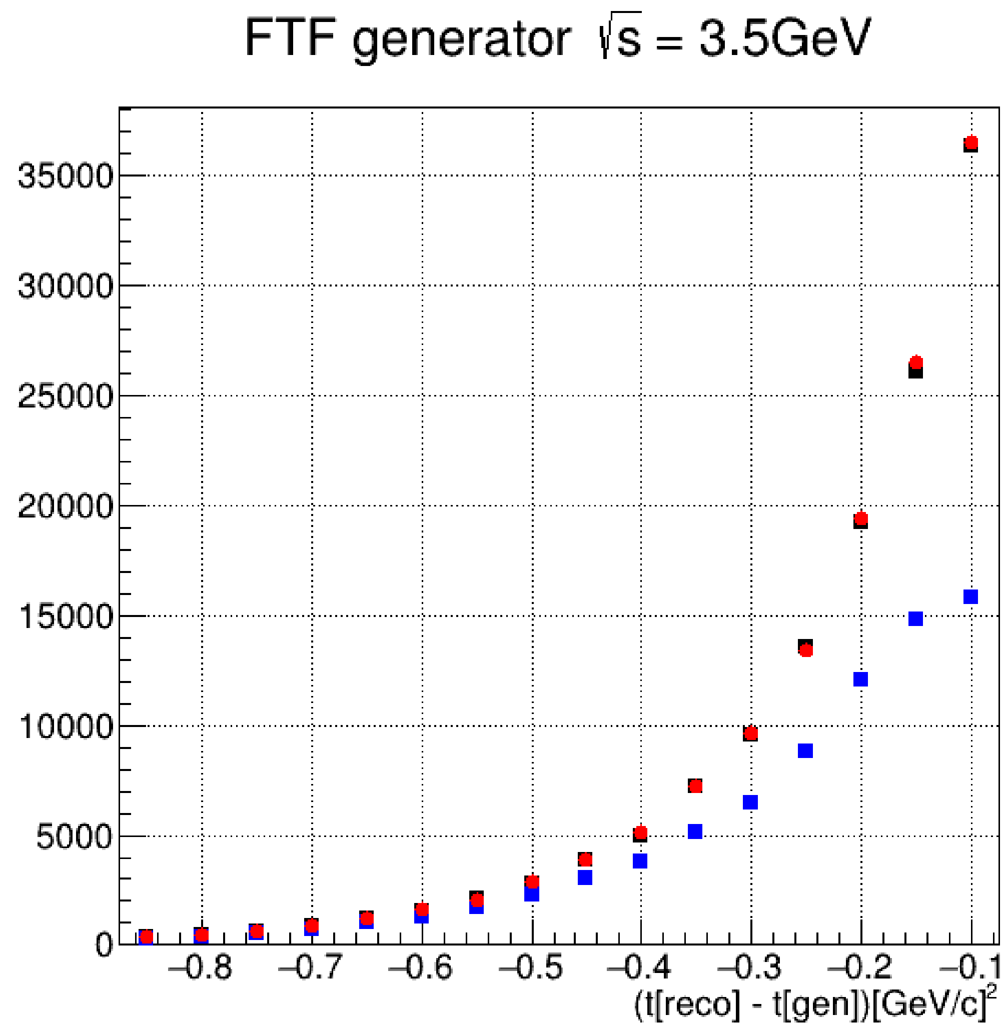


2 tracks, each track is fitted and has fit parameters, for each track at least one hit in vertex part of tracker, and event is elastic

2 tracks, each track is fitted and has fit parameters, for each track at least one hit in vertex part of tracker, fit gives for particle proton type, fabs($\theta_1 + \theta_2 - \pi$)<$1^0$

$0.95*E_{beam} < E_1 < 1.05*E_{beam}$ and $0.95*E_{beam} < E_2 < 1.05*E_{beam}$

cuts like in blue, but nonelastic events



generated elastic events

2 tracks, each track is fitted and has fit parameters, for each track at least one hit in vertex part of tracker, fit gives for particle proton type, fabs(θ_1+ θ_2- π)<1^0
$0.95*E_{beam} < E_1 < 1.05*E_{beam}$ and $0.95*E_{beam} < E_2 < 1.05*E_{beam}$

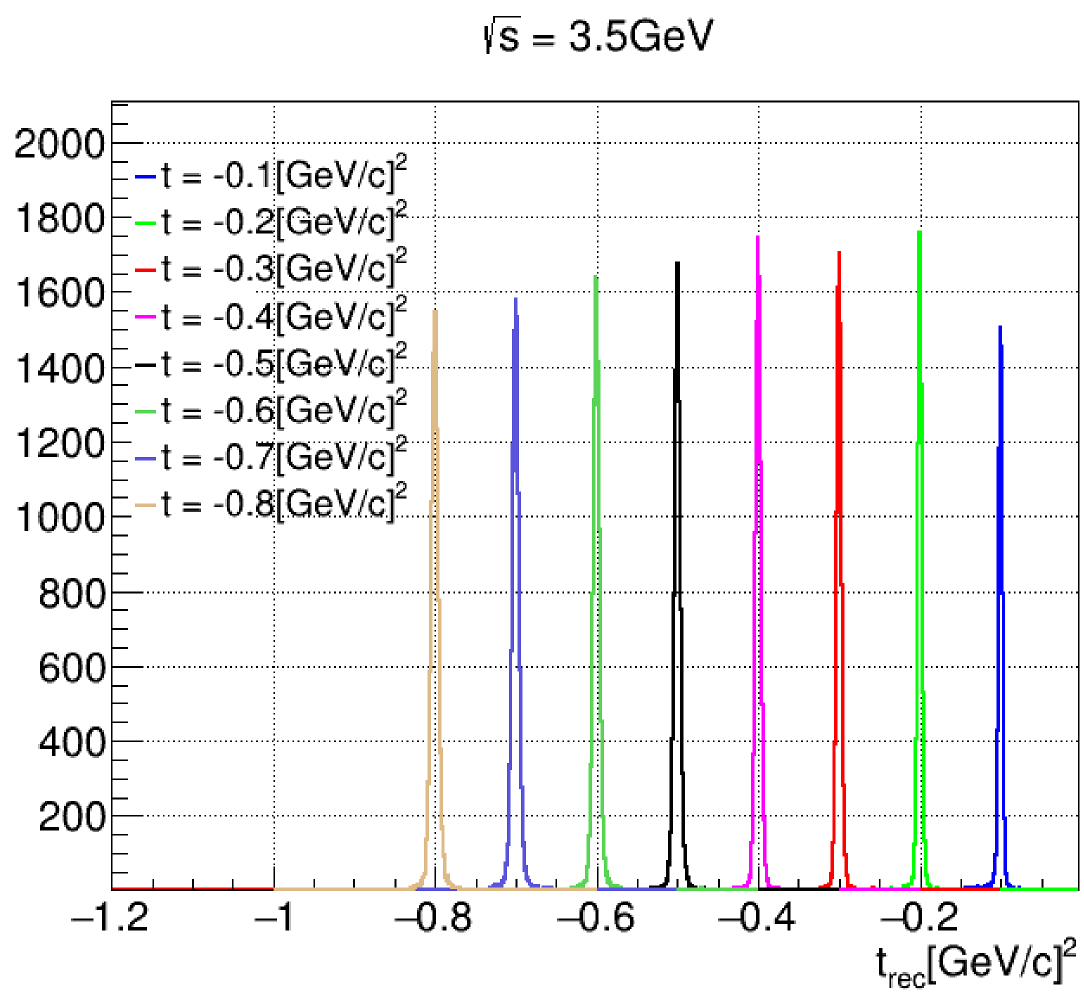
cuts like in blue, corrected for efficiency and acceptance

$\sqrt{s}$ = 3.5 Gev

$t (GeV/c)^2$	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8
efficiency	0.45	0.62	0.68	0.75	0.8	0.83	0.85	0.87

efficiency for: 2 tracks, each track is fitted and has fit parameters, for each track at least one hit in vertex part of tracker, fit gives for particle proton type, $fabs(\theta_1 + \theta_2 - \pi) < 1^0$ and

$0.95 * E_{beam} < E_1 < 1.05 * E_{beam}$ and $0.95 * E_{beam} < E_2 < 1.05 * E_{beam}$

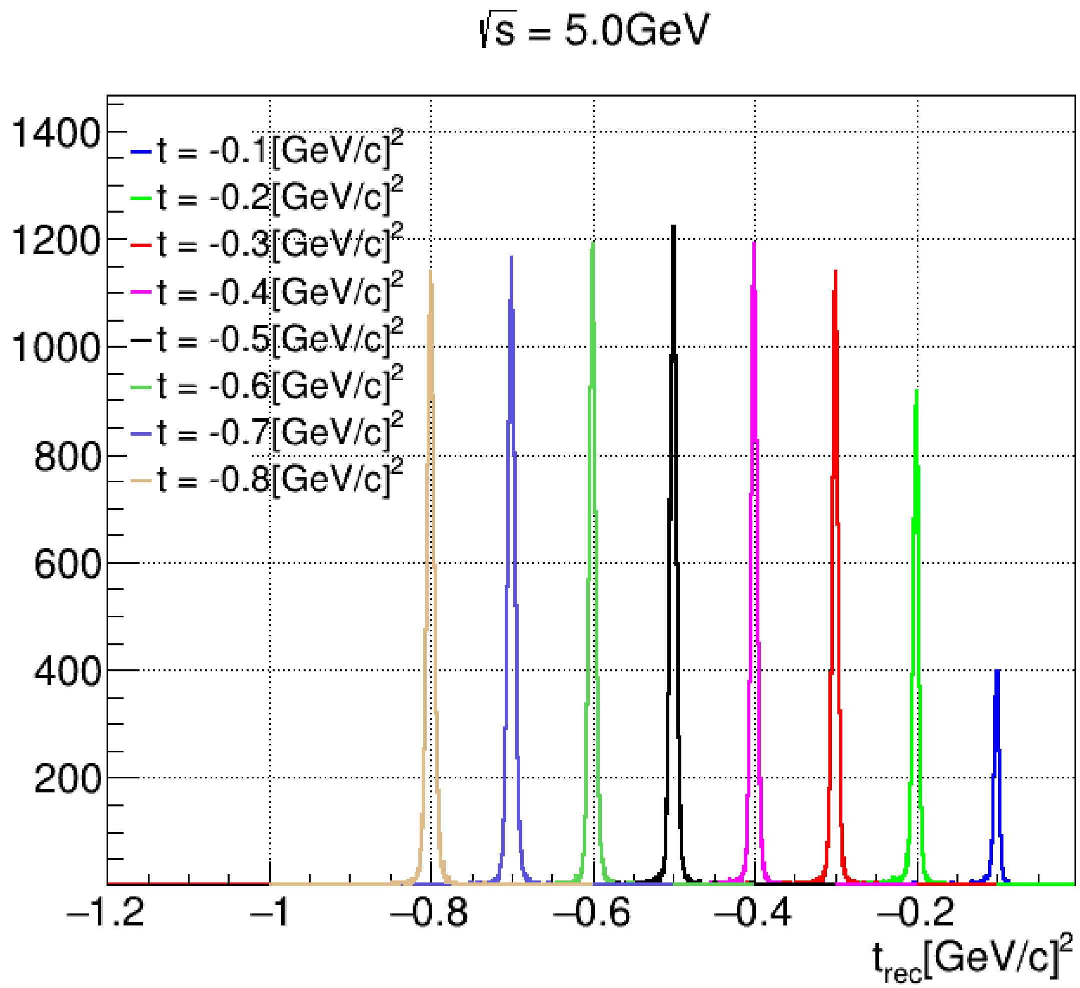


√s = 5.0 Gev

$t (GeV/c)^2$	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8
efficiency	0.13	0.37	0.52	0.58	0.63	0.65	0.67	0.7

efficiency for: 2 tracks, each track is fitted and has fit parameters, for each track at least one hit in vertex part of tracker, fit gives for particle proton type, $fabs(\theta_1 + \theta_2 - \pi) < 1^0$ and

$0.95 \cdot E_{beam} < E_1 < 1.05 \cdot E_{beam}$ and $0.95 \cdot E_{beam} < E_2 < 1.05 \cdot E_{beam}$

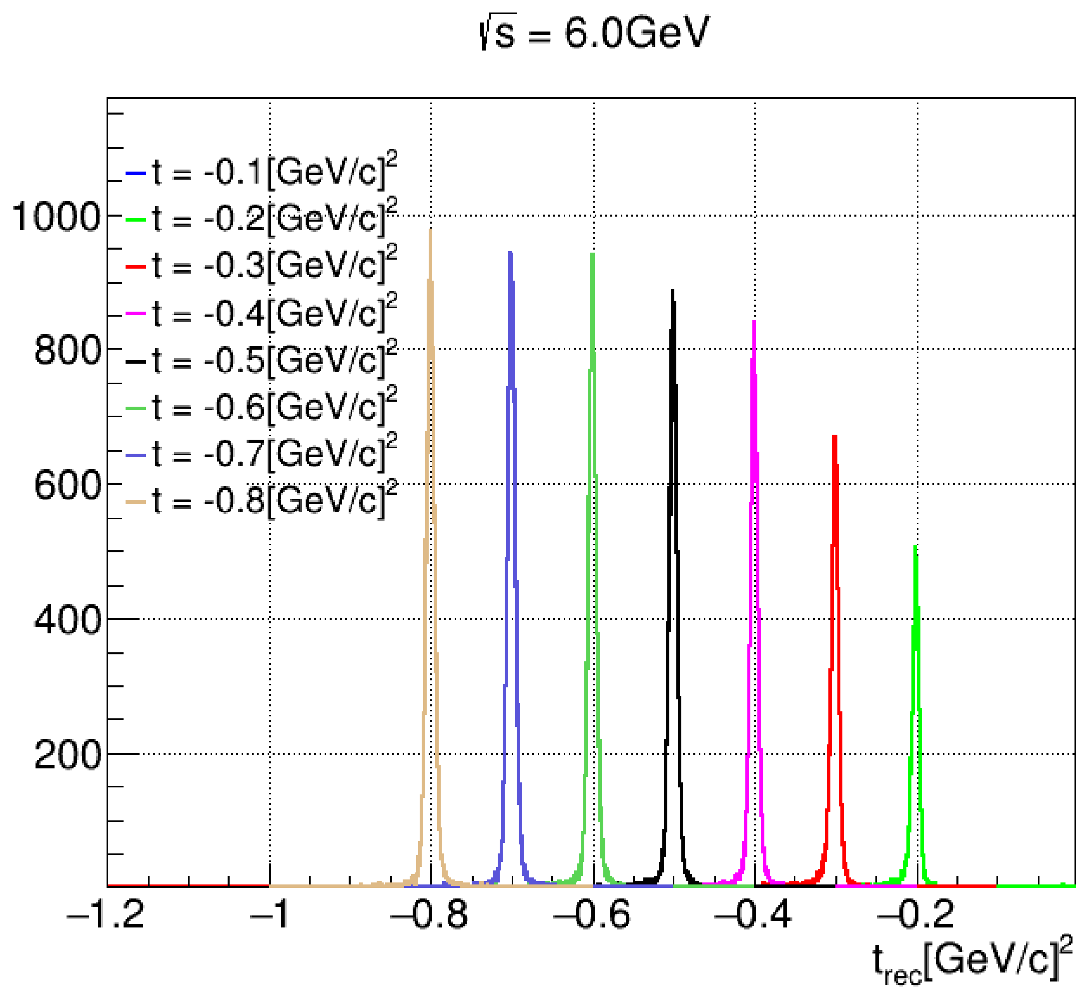


$\sqrt{s}$ = 6.0 Gev

t(GeV/c)^2	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8
efficiency	0.004	0.23	0.37	0.48	0.54	0.58	0.61	0.63

efficiency for: 2 tracks, each track is fitted and has fit parameters, for each track at least one hit in vertex part of tracker, fit gives for particle proton type, fabs($\theta_1 + \theta_2 - \pi$)<$1^0$ and

$0.95 \cdot E_{beam} < E_1 < 1.05 \cdot E_{beam}$ and $0.95 \cdot E_{beam} < E_2 < 1.05 \cdot E_{beam}$

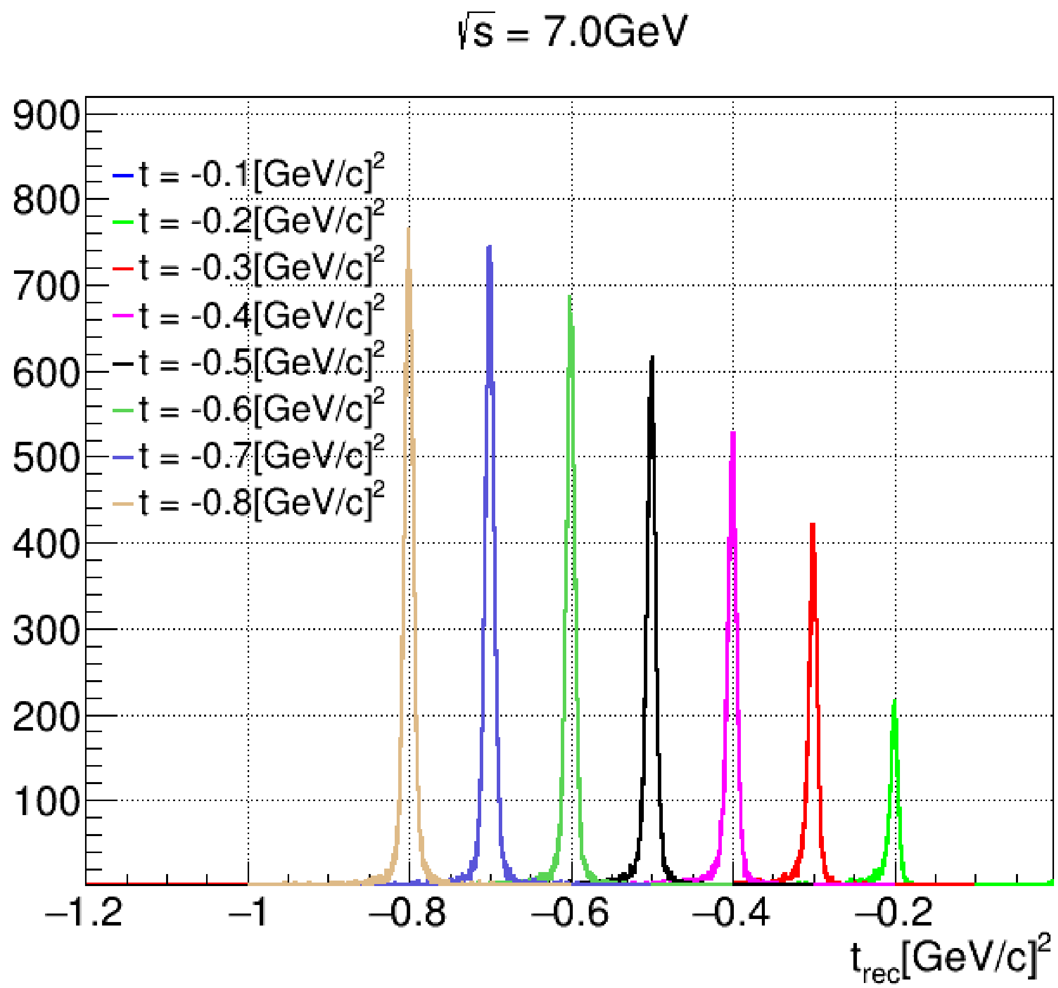


$\sqrt{s}$ = 7.0 Gev

t(GeV/c)^2	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8
efficiency	0.0	0.11	0.26	0.35	0.44	0.5	0.54	0.57

efficiency for: 2 tracks, each track is fitted and has fit parameters, for each track at least one hit in vertex part of tracker, fit gives for particle proton type, fabs($\theta_1 + \theta_2 - \pi$) < 1^0 and

$0.95*E_{beam} < E_1 < 1.05*E_{beam}$ and $0.95*E_{beam} < E_2 < 1.05*E_{beam}$



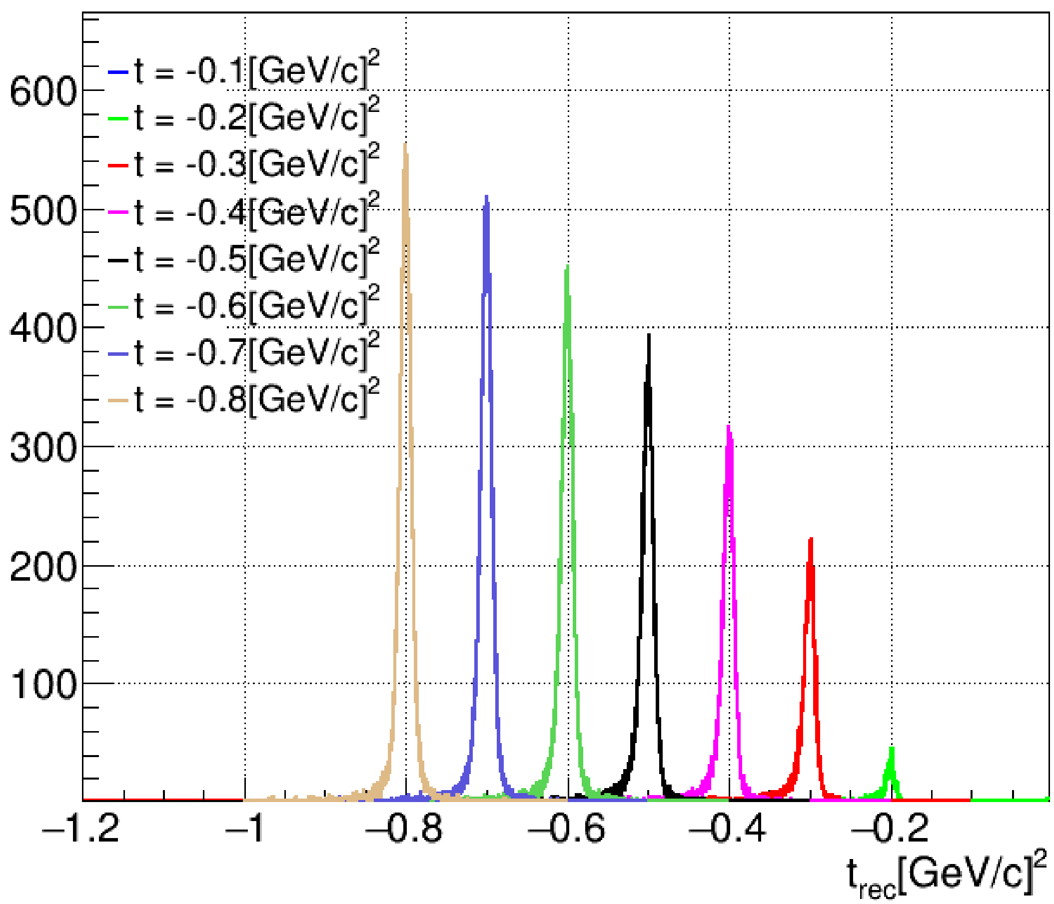
$\sqrt{s}$ = 8.0 Gev

$t (GeV/c)^2$	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8
efficiency	0.0	0.02	0.15	0.25	0.33	0.4	0.45	0.5

efficiency for: 2 tracks, each track is fitted and has fit parameters, for each track at least one hit in vertex part of tracker, fit gives for particle proton type, $fabs(\theta_1 + \theta_2 - \pi) < 1^0$ and

$0.95*E_{beam} < E_1 < 1.05*E_{beam}$ and $0.95*E_{beam} < E_2 < 1.05*E_{beam}$

$\sqrt{s}$ = 8.0GeV



Summary

1. Kinematic fit improves resolution for all variables and gives possibility study elastic scattering for small angles at the first stage

Backup

$\sqrt{s}$ = 3.5GeV t = -0.1$(GeV/c)^2$ $\theta = 12^0$

$\sqrt{s}$ = 6.0GeV t = -0.2$(GeV/c)^2$ $\theta = 9^0$

$\sqrt{s}$ = 8.0GeV t = -0.3$(GeV/c)^2$ $\theta = 8^0$

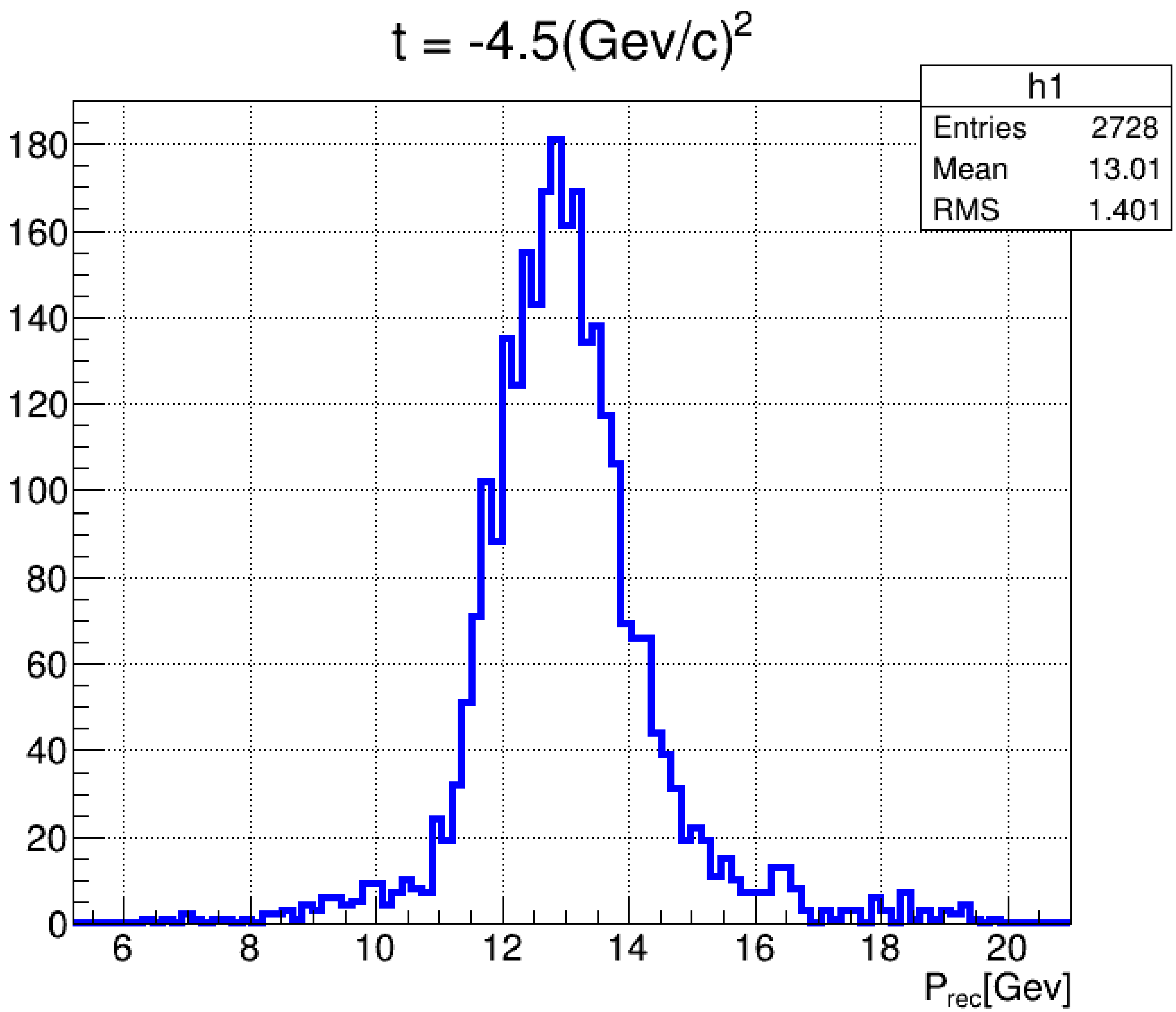
Proton with P=13Gev, vertex = (0,0,0)

azimutal φ: uniform distribution from 0 to 2π

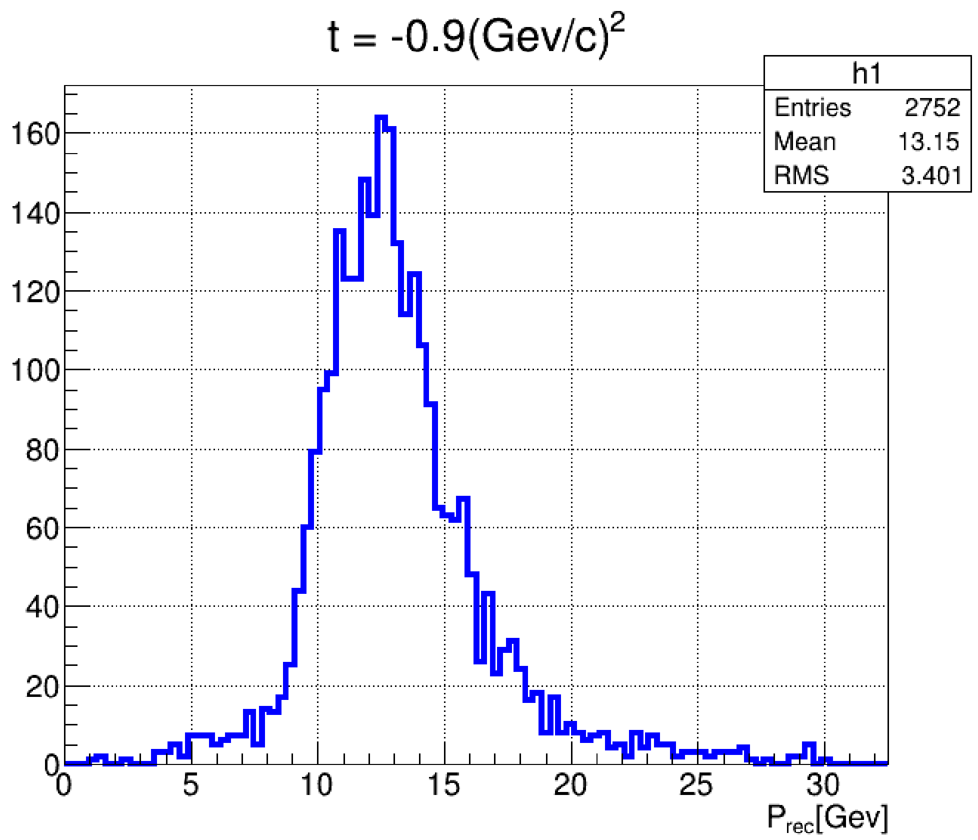
$t = -0.5(Gev/c)^2$ → polar angle 3^0

$t (Gev/c)^2$	hits in vertex tracker	hits in barrel tracker	hits in endcap tracker
-0.1	0	0	0
-0.2	0	0	2 - 4
-0.3	0	0	16
-0.4	0	0	21
-0.5	1	0	25 - 30
-0.9	3	0	30 - 32
-4.5	5	0	48

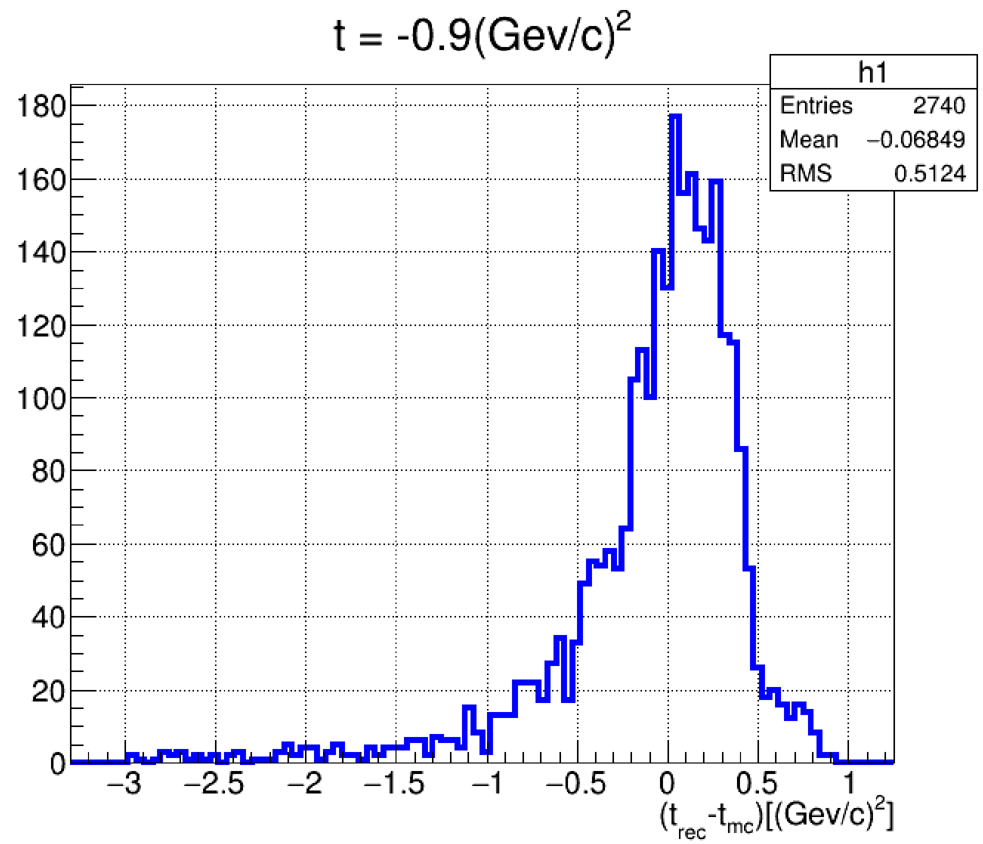
Kalman fit


t = -4.5(Gev/c)^2
h1
Entries 2728
Mean 13.01
RMS 1.401
0
20
40
60
80
100
120
140
160
180
6
8
10
12
14
16
18
20
P$_{rec}$[Gev]

Kalman fit

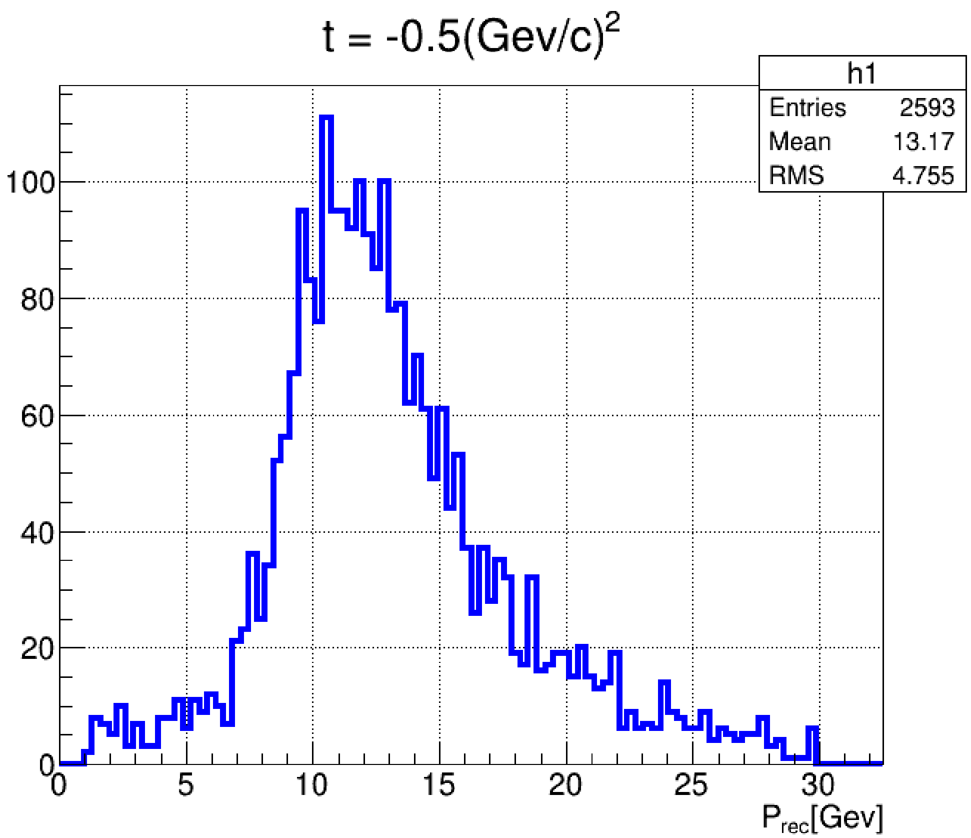


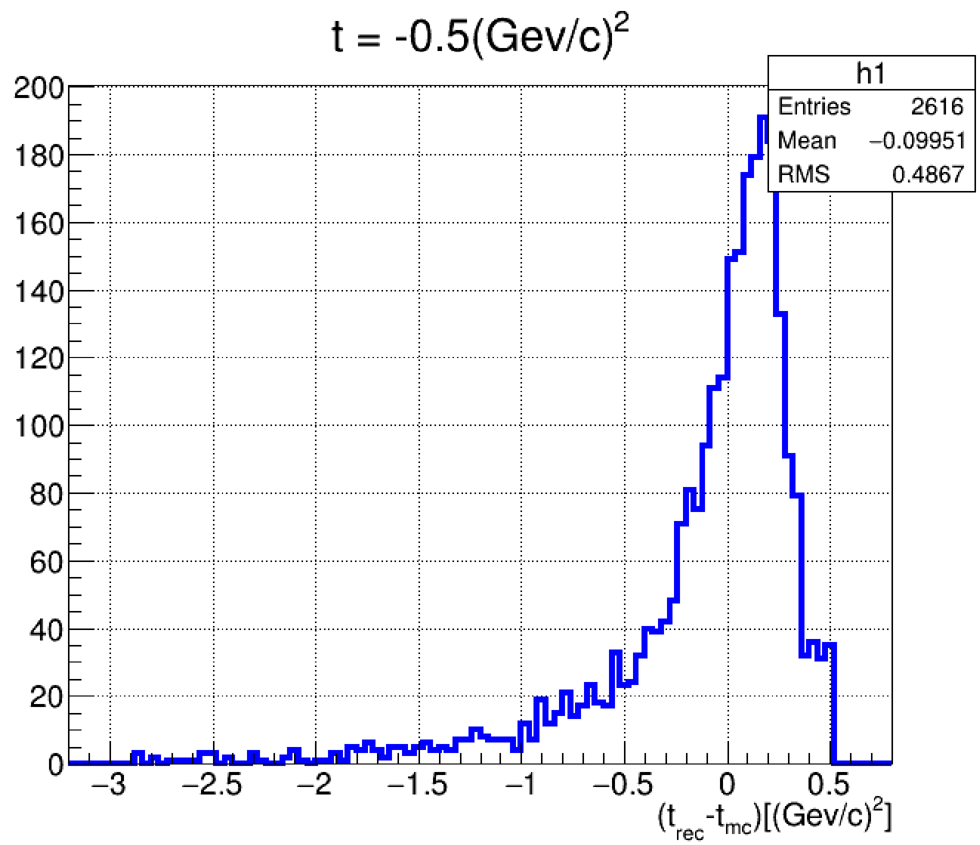
t = -0.9(Gev/c)^2
h1
Entries 2752
Mean 13.15
RMS 3.401
P_{rec}[Gev]



t = -0.9(Gev/c)^2
h1
Entries 2740
Mean −0.06849
RMS 0.5124
$(t_{rec}-t_{mc})[(Gev/c)^2]$

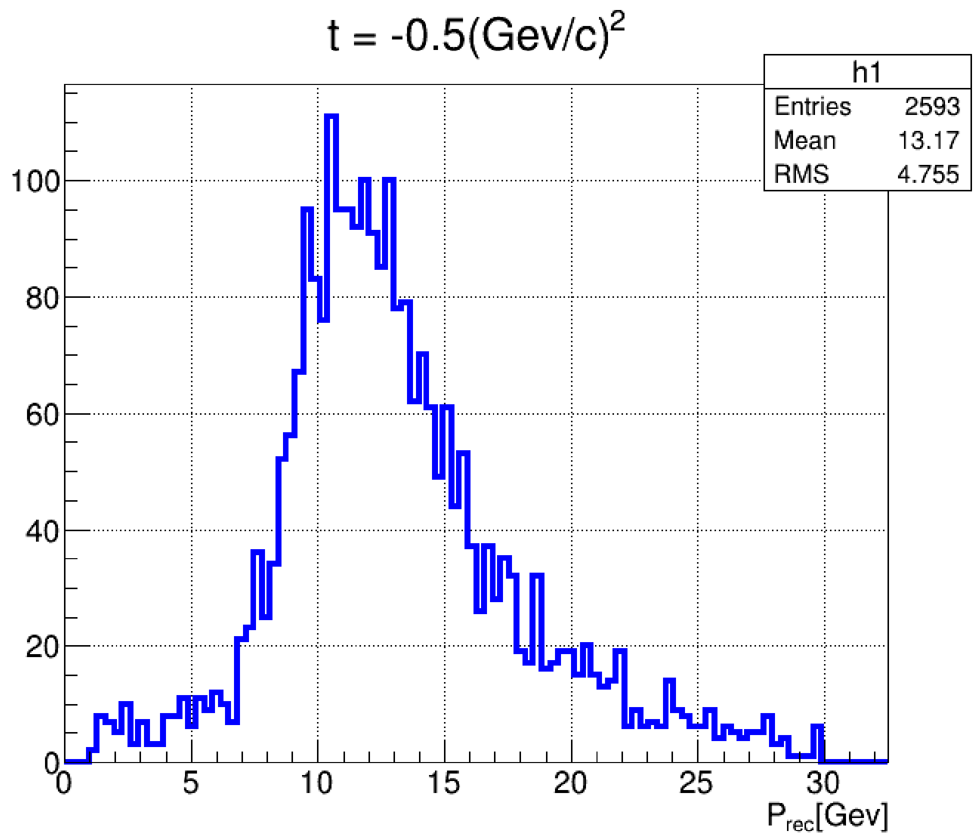
Kalman fit


t = -0.5(Gev/c)^2
h1
Entries 2593
Mean 13.17
RMS 4.755
0 20 40 60 80 100
0 5 10 15 20 25 30
P_{rec}[Gev]

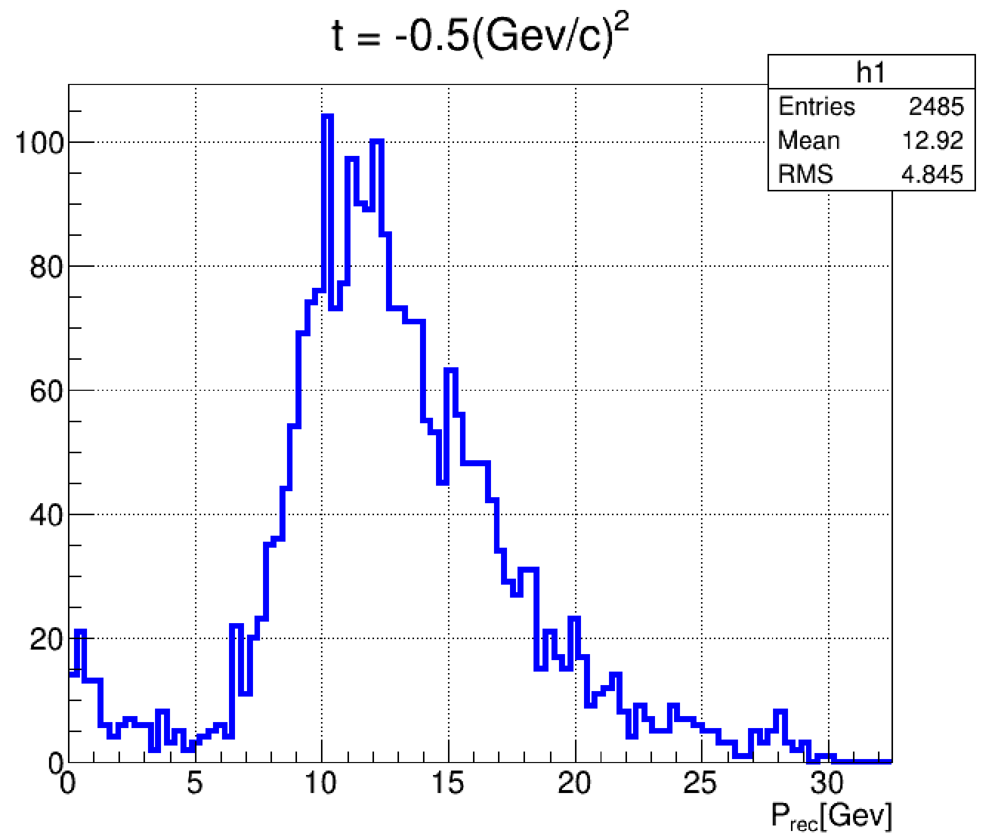

t = -0.5(Gev/c)^2
h1
Entries 2616
Mean −0.09951
RMS 0.4867
0 20 40 60 80 100 120 140 160 180 200
−3 −2.5 −2 −1.5 −1 −0.5 0 0.5
$(t_{rec}-t_{mc})$[(Gev/c)^2]

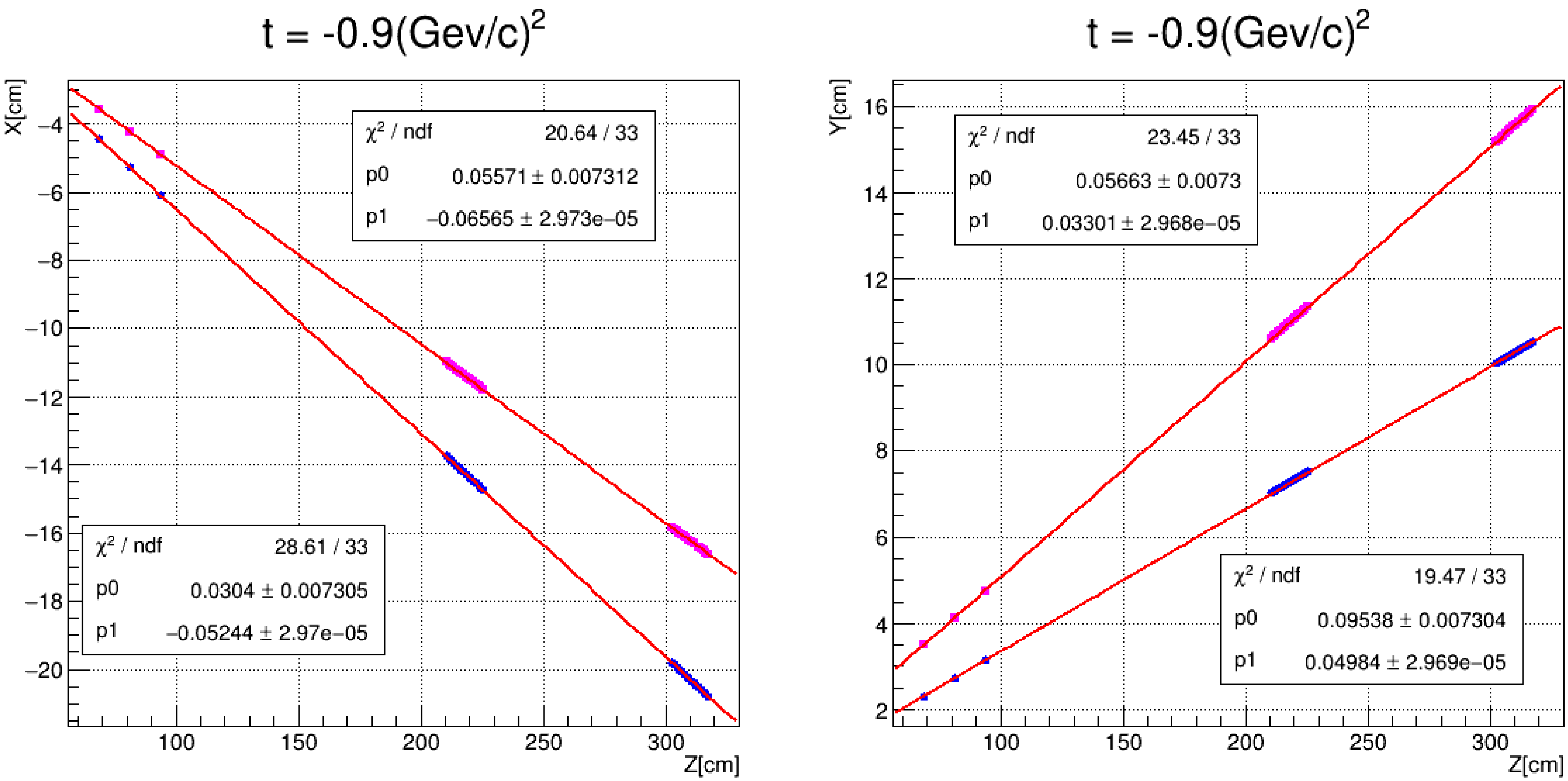
Kalman fit

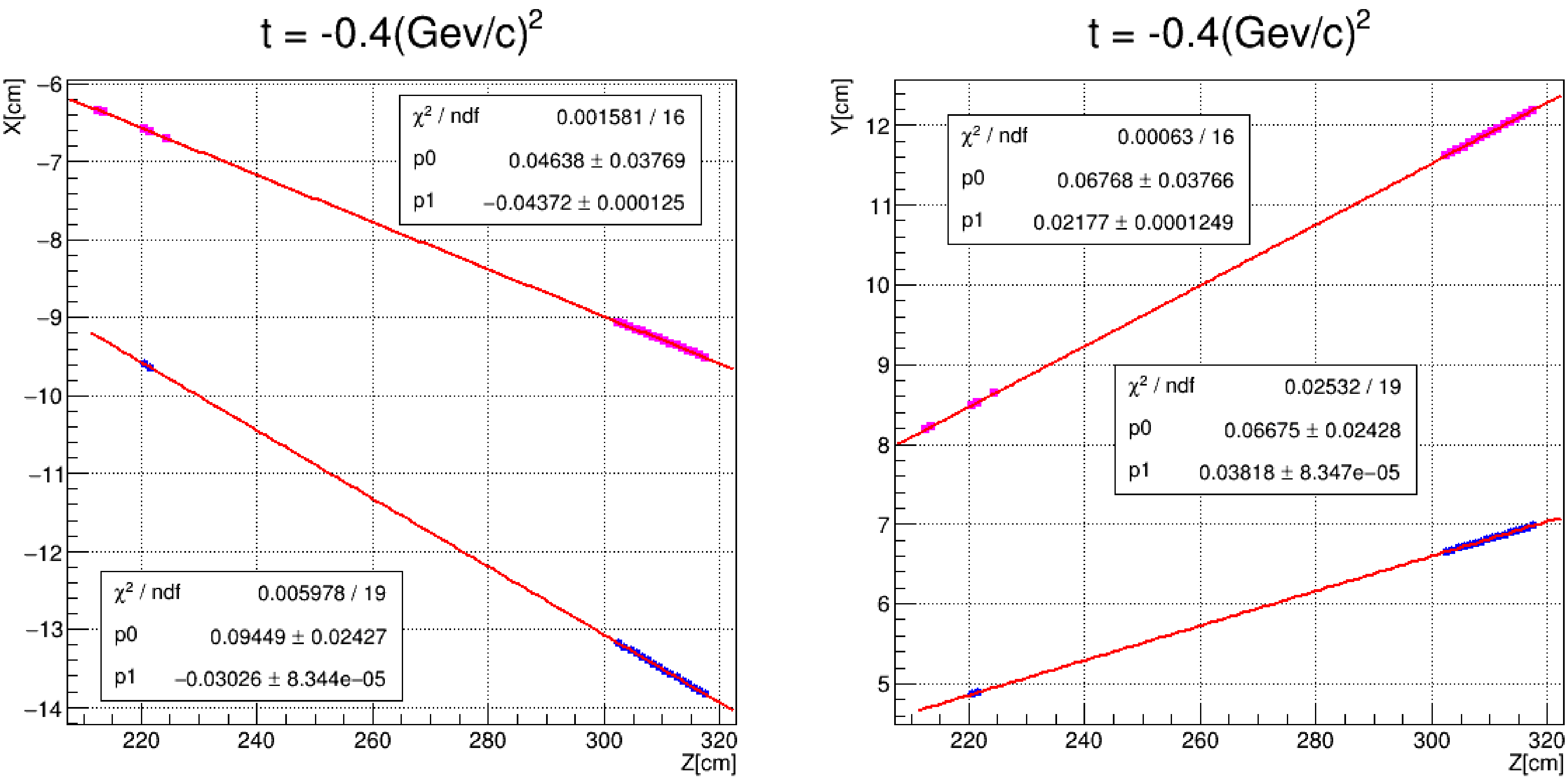
fit start P = 13Gev



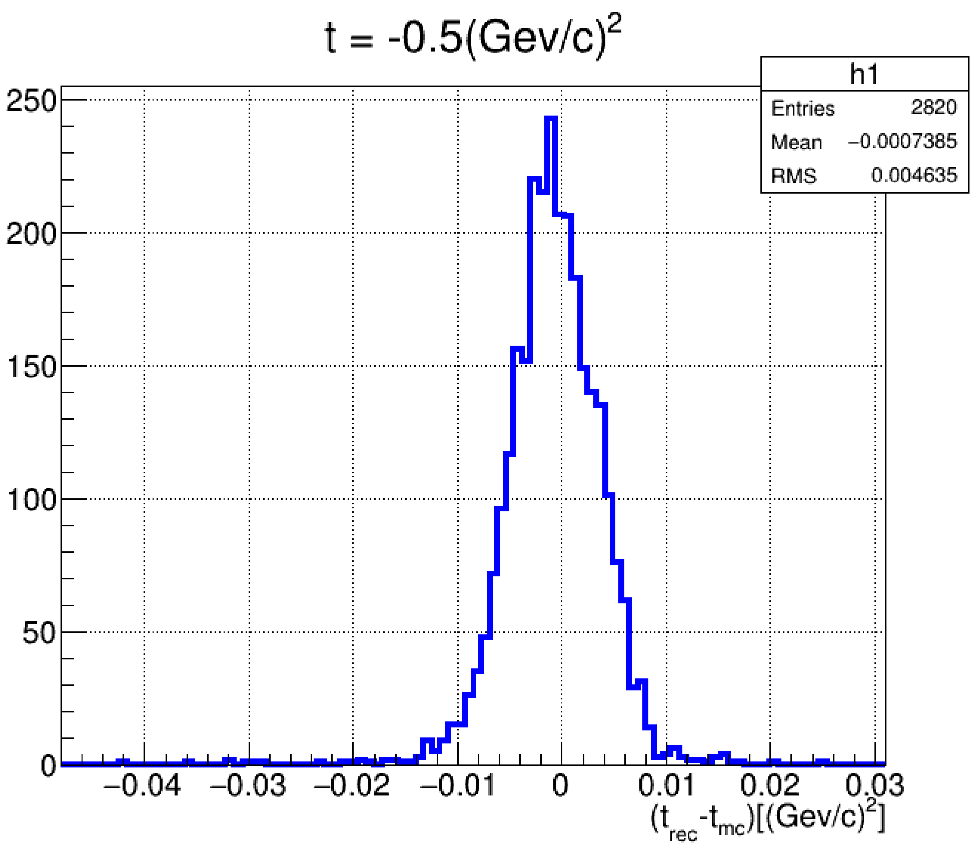
fit start P = 1Gev

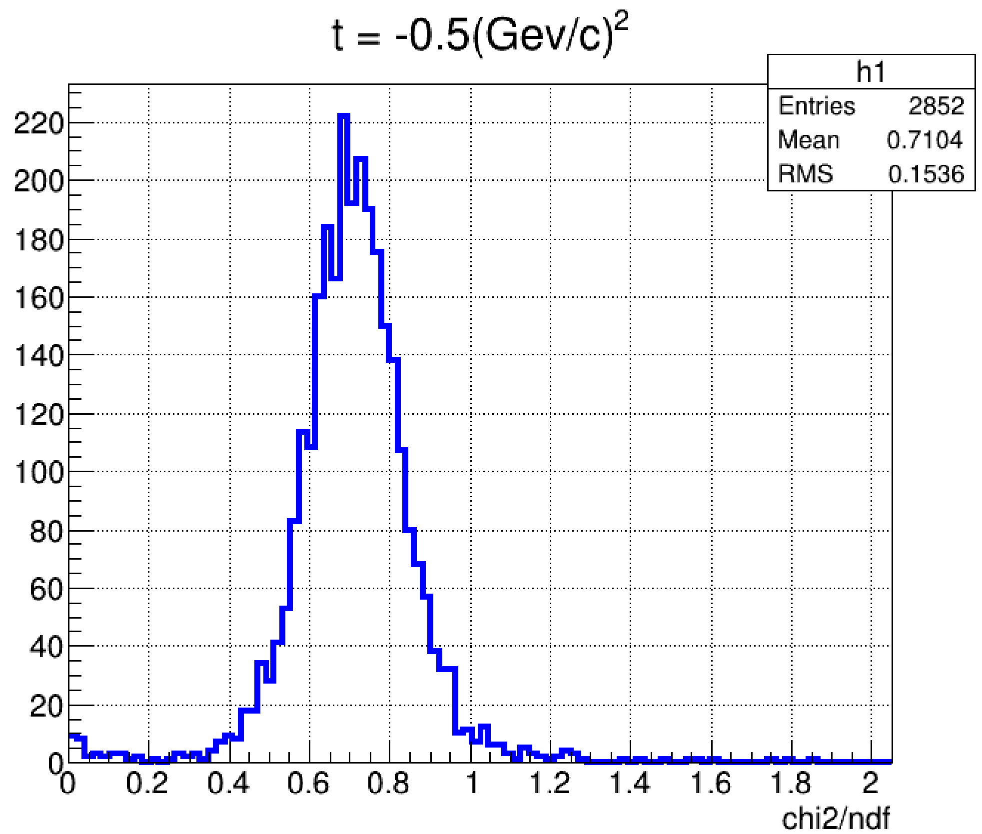



t = -0.9(Gev/c)^2
X[cm]
Z[cm]
χ^2 / ndf 20.64 / 33
p0 0.05571 ± 0.007312
p1 −0.06565 ± 2.973e−05
χ^2 / ndf 28.61 / 33
p0 0.0304 ± 0.007305
p1 −0.05244 ± 2.97e−05
t = -0.9(Gev/c)^2
Y[cm]
Z[cm]
χ^2 / ndf 23.45 / 33
p0 0.05663 ± 0.0073
p1 0.03301 ± 2.968e−05
χ^2 / ndf 19.47 / 33
p0 0.09538 ± 0.007304
p1 0.04984 ± 2.969e−05

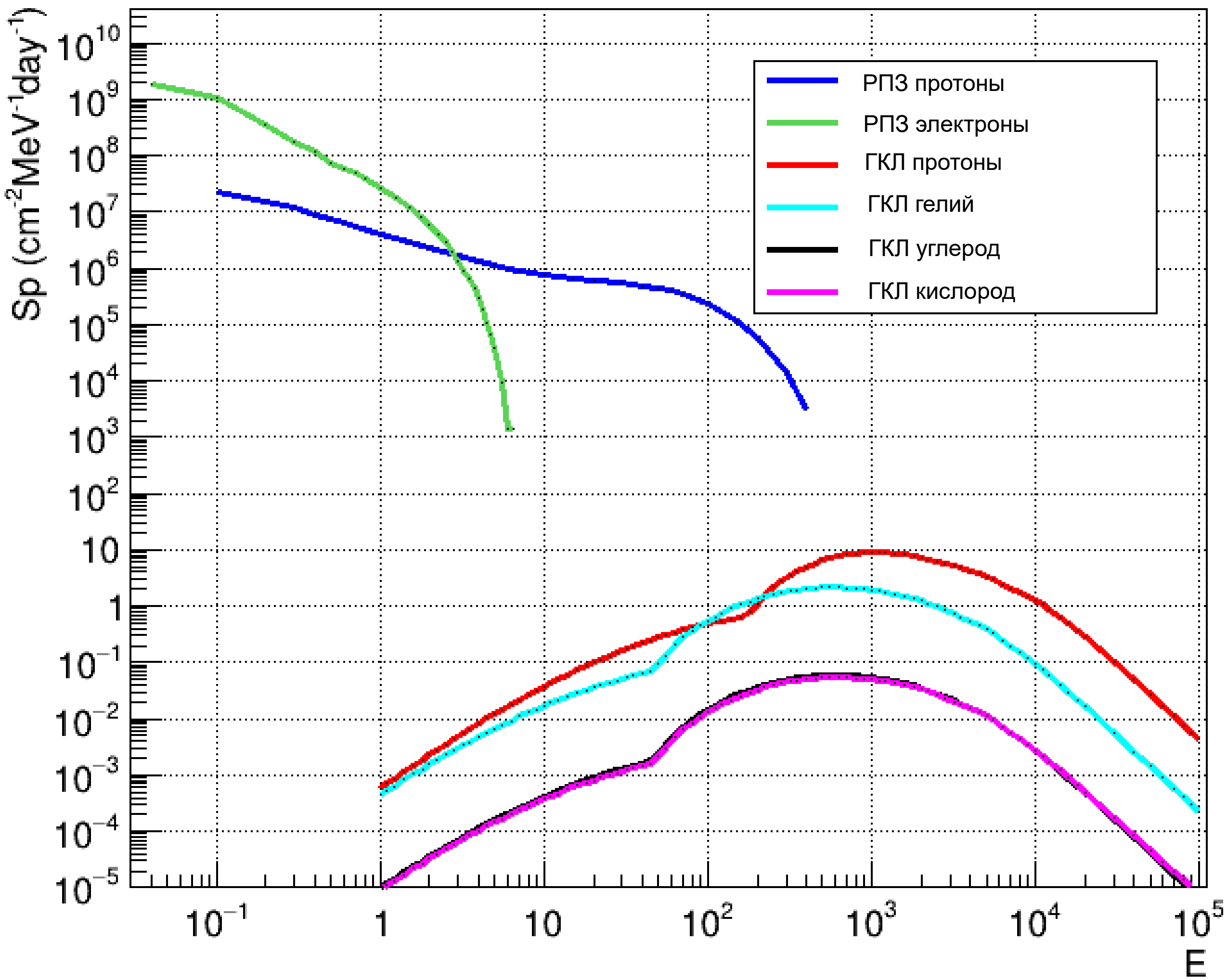

t = -0.4(Gev/c)^2
X[cm]
Z[cm]
χ^2 / ndf 0.001581 / 16
p0 0.04638 ± 0.03769
p1 −0.04372 ± 0.000125
χ^2 / ndf 0.005978 / 19
p0 0.09449 ± 0.02427
p1 −0.03026 ± 8.344e−05
t = -0.4(Gev/c)^2
Y[cm]
Z[cm]
χ^2 / ndf 0.00063 / 16
p0 0.06768 ± 0.03766
p1 0.02177 ± 0.0001249
χ^2 / ndf 0.02532 / 19
p0 0.06675 ± 0.02428
p1 0.03818 ± 8.347e−05

fit by straight line, no Kalman fit



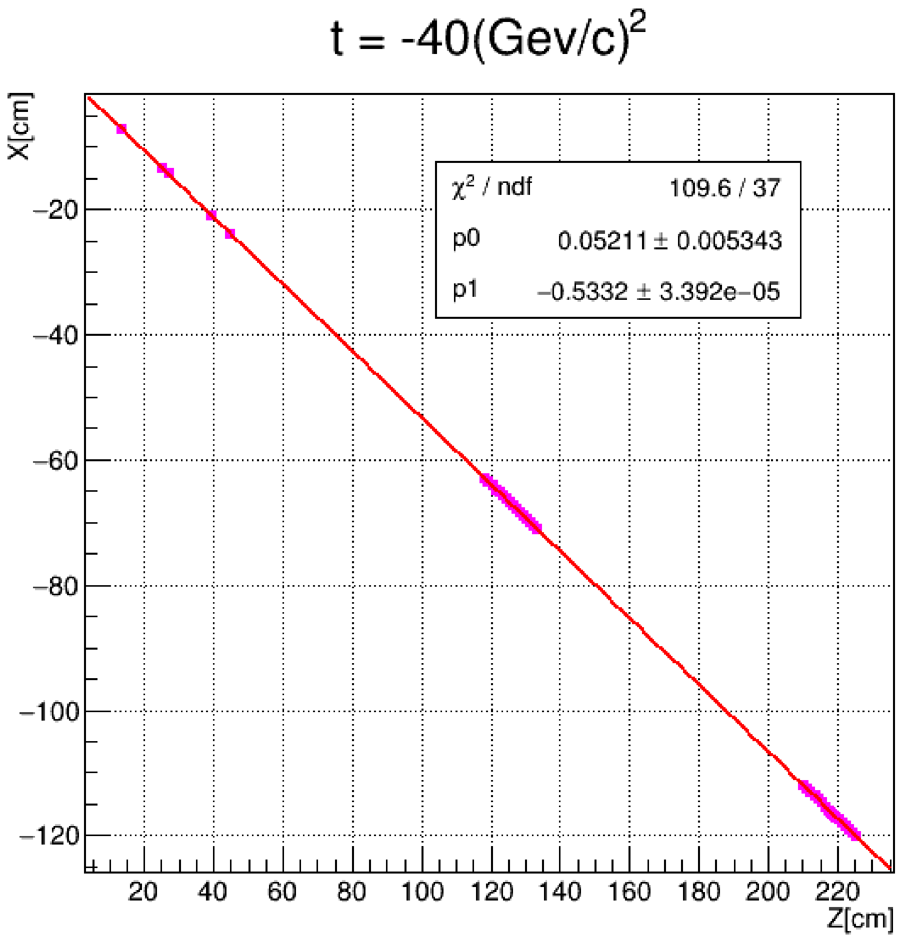


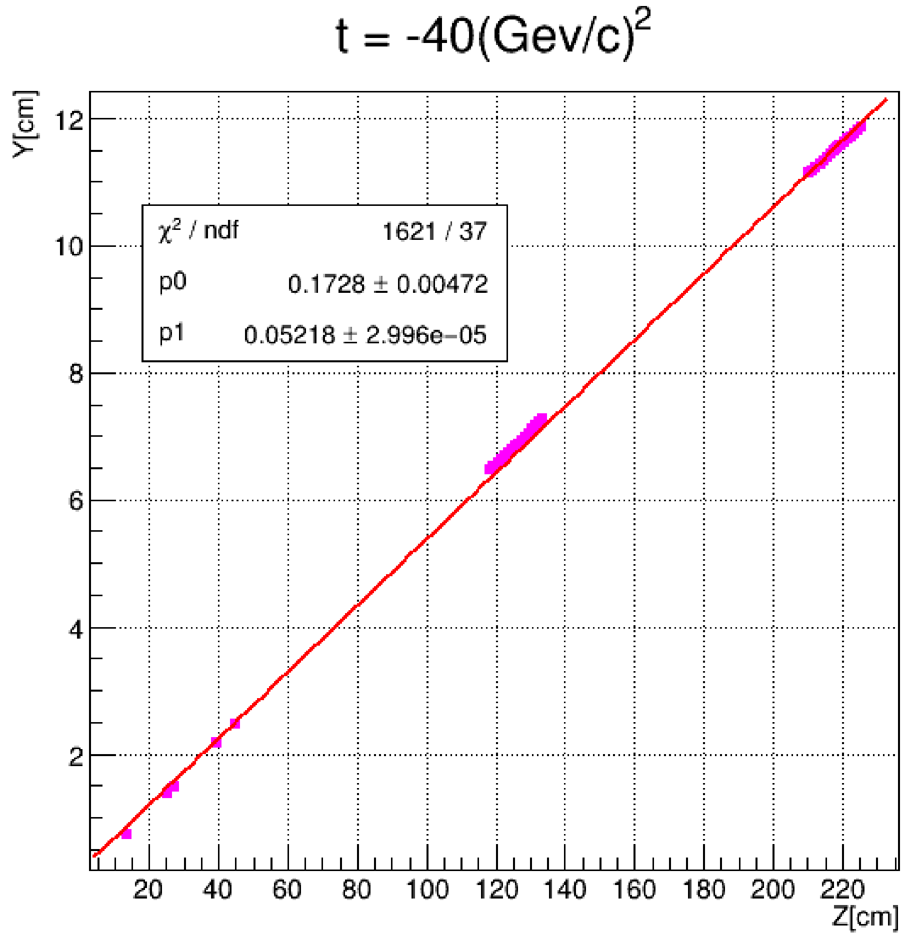
Backup

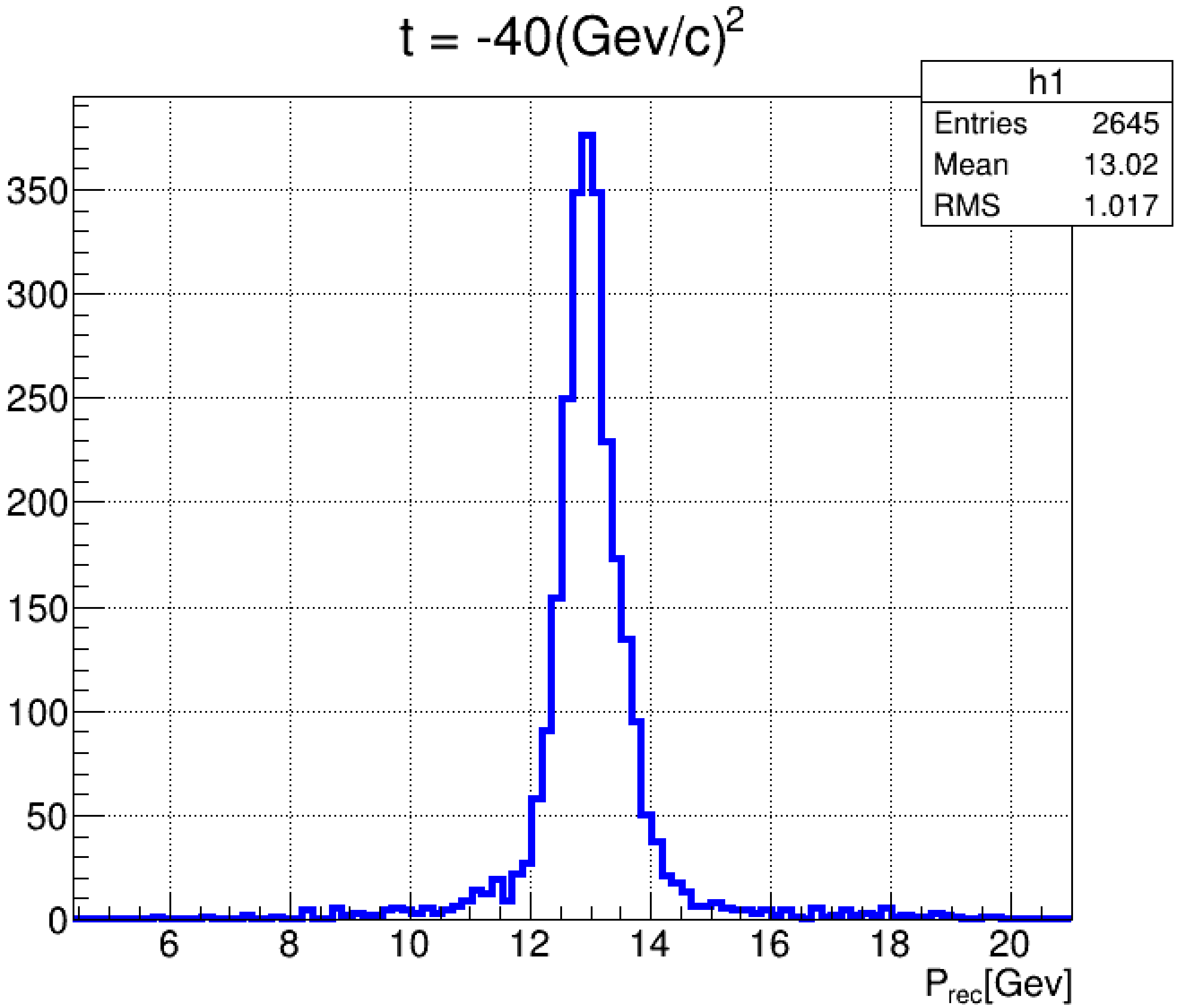


Sp (cm^{-2}MeV^{-1}day^{-1})
E
РПЗ протоны
РПЗ электроны
ГКЛ протоны
ГКЛ гелий
ГКЛ углерод
ГКЛ кислород

polar angle 28^0






t = -40(Gev/c)^2
h1
Entries 2645
Mean 13.02
RMS 1.017
0
50
100
150
200
250
300
350
6
8
10
12
14
16
18
20
P_rec[Gev]