DPG-Frühjahrstagung 2013 in Dresden:

T78.9: Investigations of Final States with Light Anti-Nuclei at the Belle Experiment

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II. Physikalisches Institut

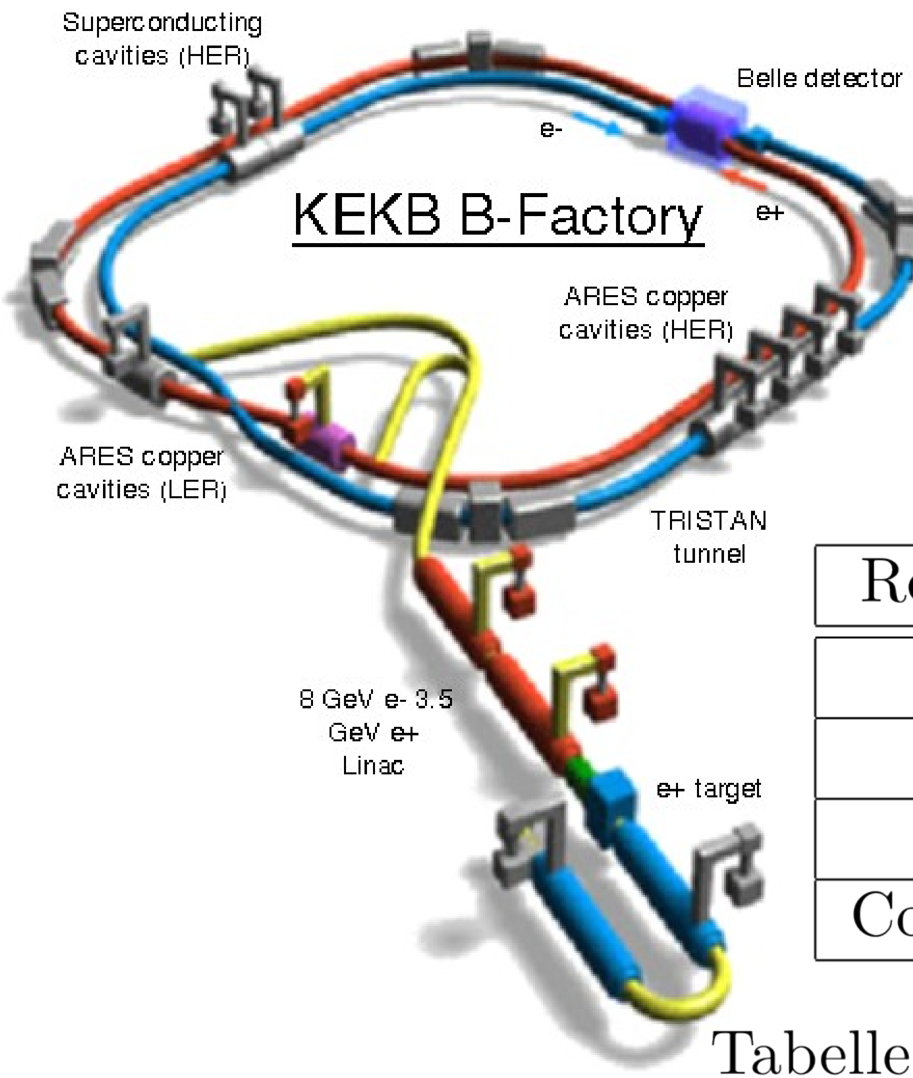
Belle Collaboration

BELLE

Investigations of Final States with Light Anti-Nuclei at the Belle Experiment

- The Belle Detector
- The Basic Idea
- Υ-Decays into $\bar{d}$
  - ➔ Continuum production
  - ➔ Resonant production
- Conclusion

Asymmetric e^+e^--collider



Resonance	L_{int}	Decays
$\Upsilon(1S)$	5.75 fb^{-1}	120 million
$\Upsilon(2S)$	6.57 fb^{-1}	42 million
$\Upsilon(3S)$	2.92 fb^{-1}	11 million
Continuum	79.37 fb^{-1}	-

Tabelle 1: Analyzed data and number of decays

Charge Drift Chamber
Momentum (p),
Energy loss ($\frac{dE}{dx}$)

Calorimeter
Energy (E)

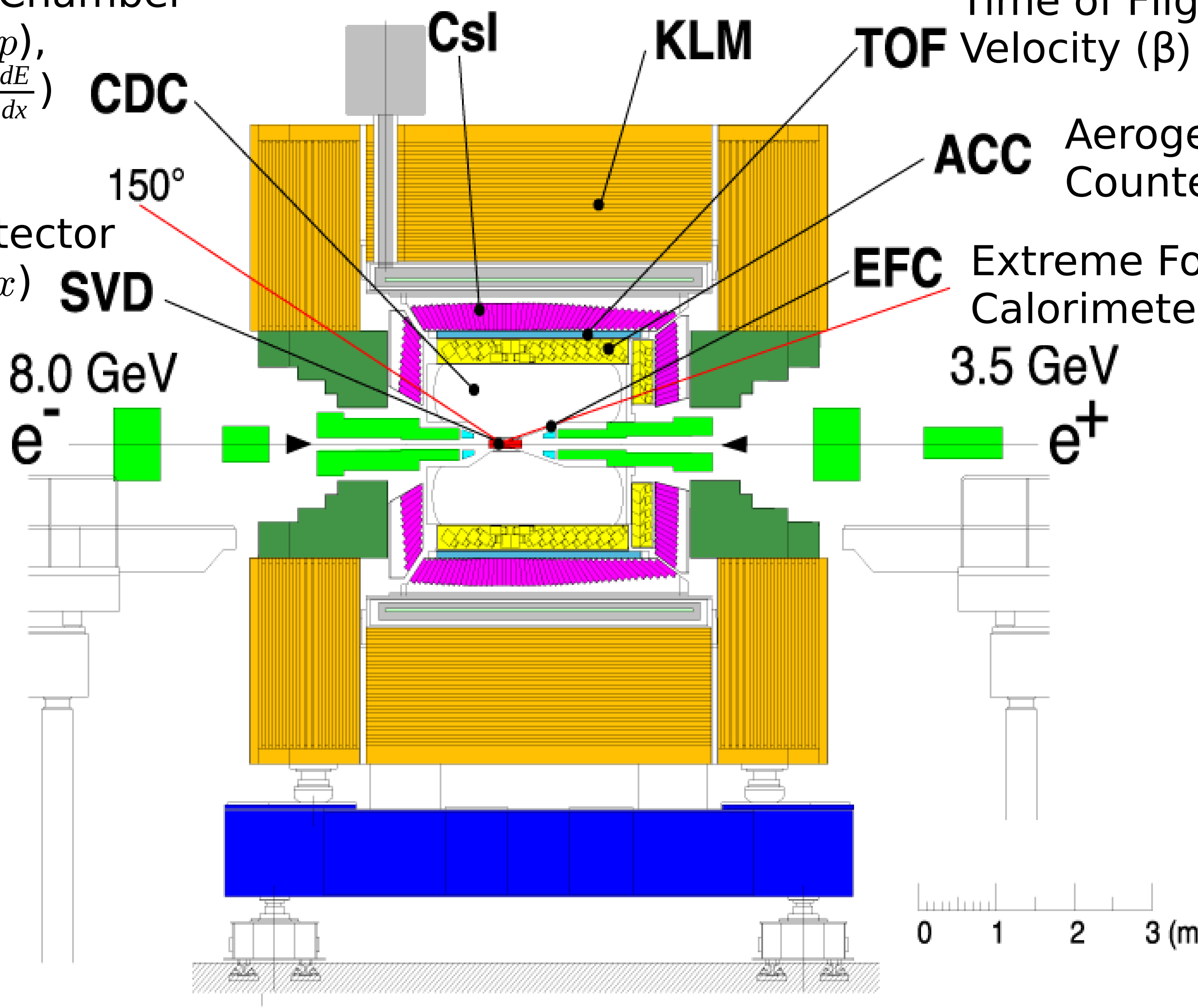
Resistive Plate Chambers
Permeation Ability

Time of Flight Detector
Velocity (β)

Aerogel Cerenkov
Counter β > 0,97

Silicon Vertex Detector
Vertex- Position (x)

Extreme Forward
Calorimeter

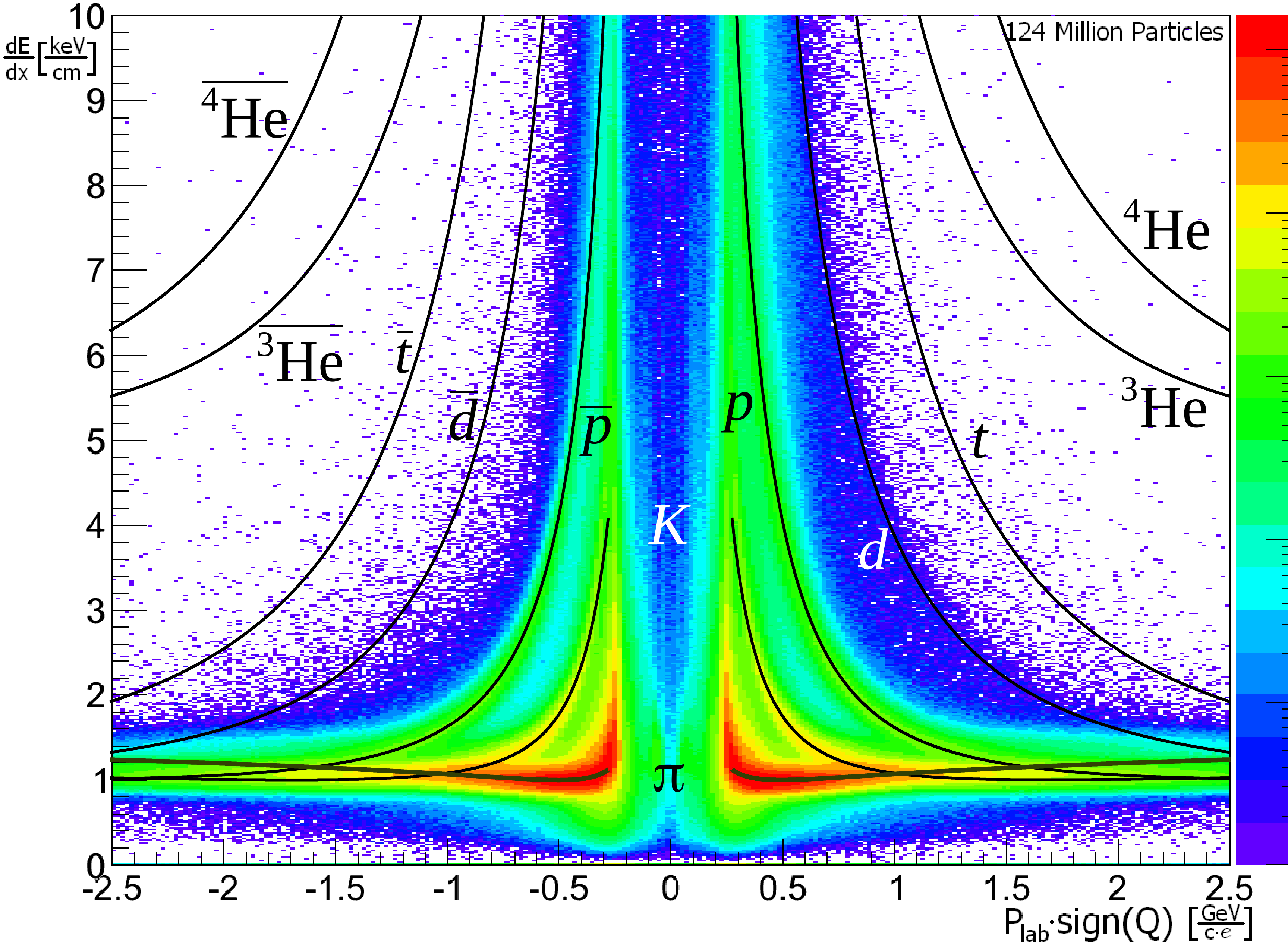


The Basic Idea

- Studying formation of anti-nuclei in e^+e^--collisions
  - Antimatter cleaner than matter
  - Cleaner than nucleus-nucleus collisions
- Inclusive decays
  - $\Upsilon(1S), \Upsilon(2S) \rightarrow \bar{d} + anything$
  - $\Upsilon(3S) \rightarrow \bar{d} + anything$ **(new)**

Processes

- Problem:
  Momentum distribution a priori unknown
  - → **No Monte Carlo simulation available**
    - Solution will be presented
- Too much background by identification via Bethe Bloch plot
  - → Identification via charge-mass-plot



10
9
8
7
6
5
4
3
2
1
0
dE/dx [keV/cm]
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
P_lab·sign(Q) [GeV/c·e]
124 Million Particles
$\overline{^4He}$
$\overline{^3He}$
$\bar{t}$
$\bar{d}$
$\bar{p}$
p
K
π
d
t
^4He
^3He
10^5
10^4
10^3
10^2
10
1

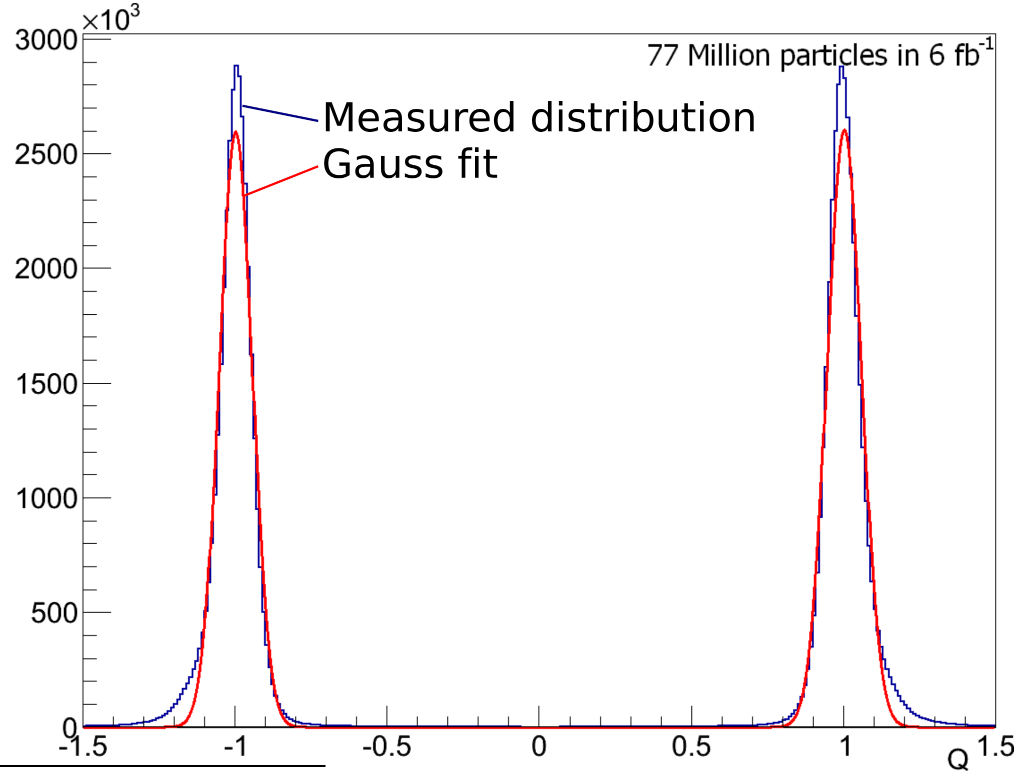
Calculate Charge

- Calculate $\frac{dE}{dx}$ from the Bethe-Bloch-formula:

$$\frac{dE}{dx} = \frac{dE}{dx}_{\text{Bethe Bloch}} \left(\beta ; Q=1\right) \cdot Q^2$$

- Solve for Q:

$$Q = e \cdot \sqrt{\frac{\frac{dE}{dx}_{\text{measured}}}{\frac{dE}{dx}_{\text{Bethe Bloch}} \left(\beta ; Q=1\right)}}$$



$$\Delta Q = \frac{Q}{2} \sqrt{\left(\frac{\Delta \frac{dE}{dx}_{\text{measured}}}{\frac{dE}{dx}_{\text{measured}}}\right)^2 + \left(\frac{\partial \frac{dE}{dx}_{\text{Bethe Bloch}}}{\partial \beta} \frac{\Delta \beta}{\frac{dE}{dx}_{\text{Bethe Bloch}}}\right)^2}$$

Calculate Mass

- Magnetic rigidity R_M measured instead of momentum p:

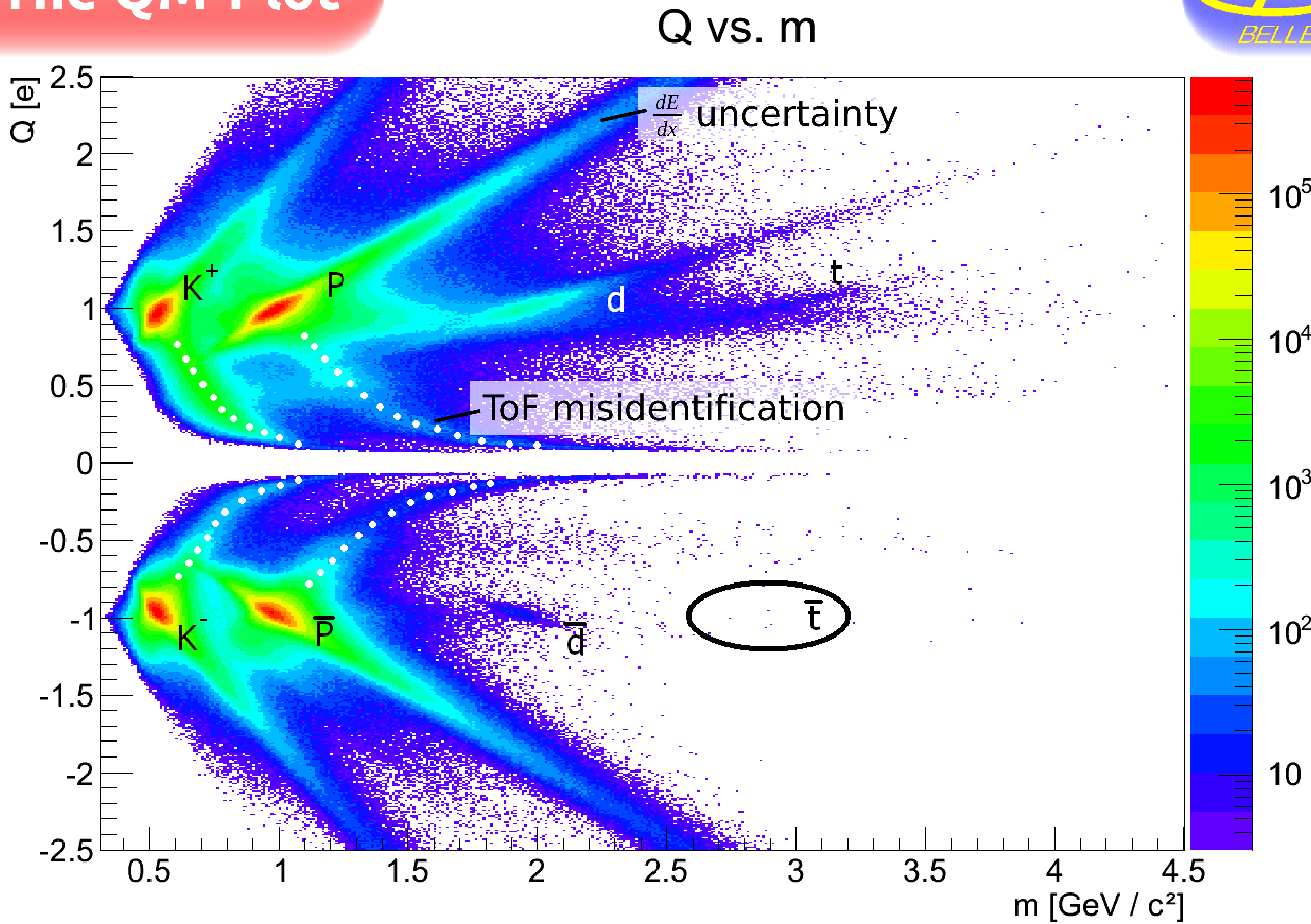
$$R_M \equiv \frac{p}{Q}$$

$$m(R_M, \beta) = \frac{R_M}{c} \cdot \frac{Q}{1e} \cdot \sqrt{\frac{1}{\beta^2} - 1}$$

$$\Delta m = m\sqrt{\left(\frac{\Delta R_M}{R_M}\right)^2 + \left(\frac{\Delta \beta}{\beta}\frac{1}{1-\beta^2}\right)^2 + \left(\frac{\Delta Q}{Q}\right)^2}$$

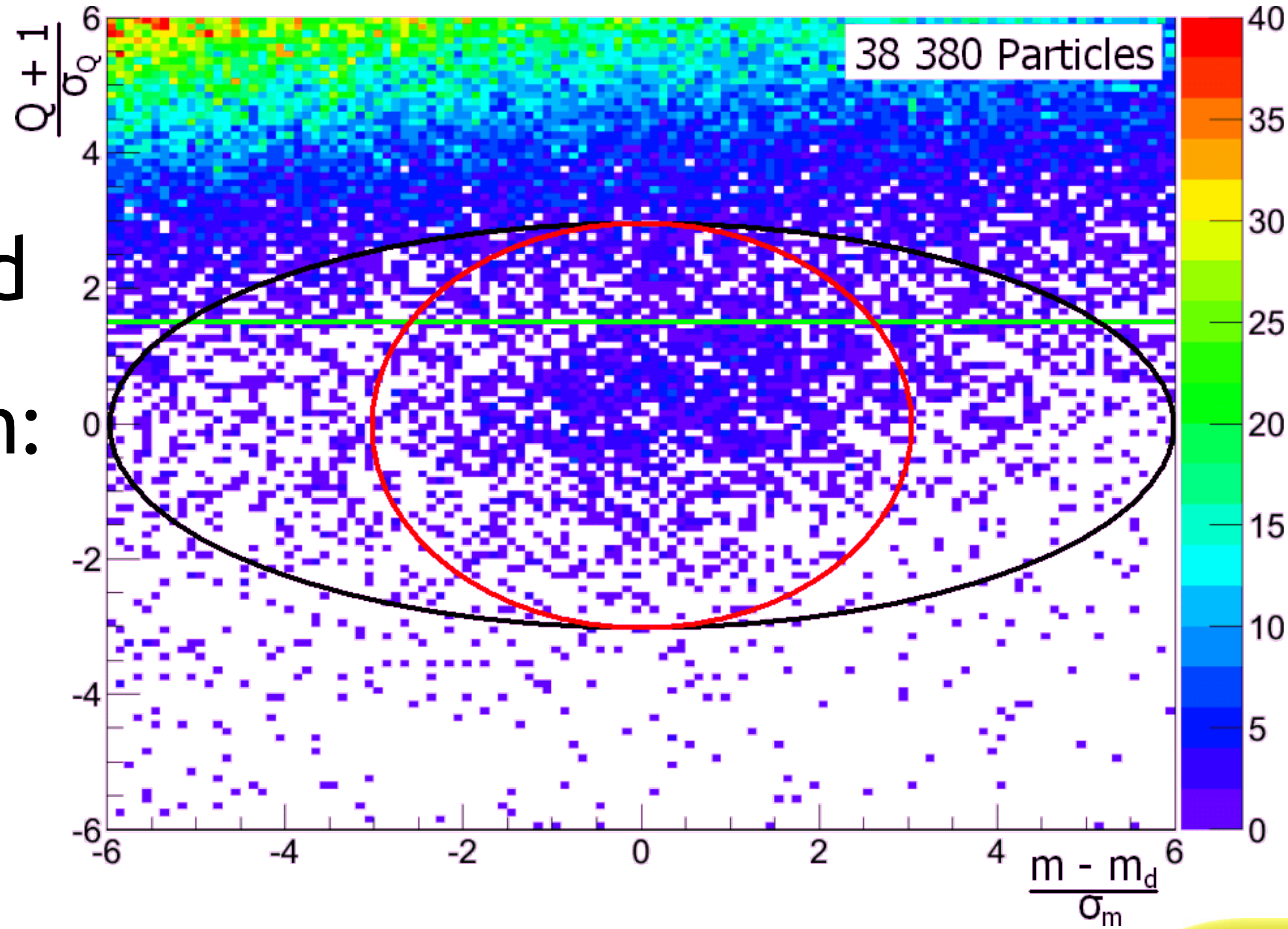
- For β ≈ 1 $\Delta m \rightarrow \infty$
  - ➔ Just applicable for slow particles

The QM-Plot


Q vs. m
Q [e]
m [GeV / c²]
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0.5
1
1.5
2
2.5
3
3.5
4
4.5
10⁵
10⁴
10³
10²
10
dE/dx uncertainty
ToF misidentification
K+
P
d
t
K-
P̄
d̄
t̄

ϒ Decays

- Within 3σ in mass and charge (red circle)
  - ➔ $\bar{d}$ candidate
- Within 6σ in mass and 3σ in charge (black ellipse)
  - ➔ Background
    - Will be subtracted
- For continuum:
  - ➔ Additional cut at +1.5σ of charge (green line)



$\bar{d}$ Identification

- $e^+e^- \rightarrow \bar{d} + anything$ vs.
  $e^+e^- \rightarrow \Upsilon \rightarrow \bar{d} + anything$
- Procedure

1. Subtract Background
   - Estimated in a side band
2. Subtract continuum data
   - Receive resonant fraction
3. Momentum dependent efficiency correction

$\bar{d}$ Identification

- Procedure (continued)

4. Certain range of momentum covered
   - ➔ Make an estimation about uncovered part
   - ➔ Momentum distribution agrees with fireball model
     - Maxwell Boltzmann distribution
5. Calculate total yield
6. Calculate branching ratio

$\bar{d}$ Identification

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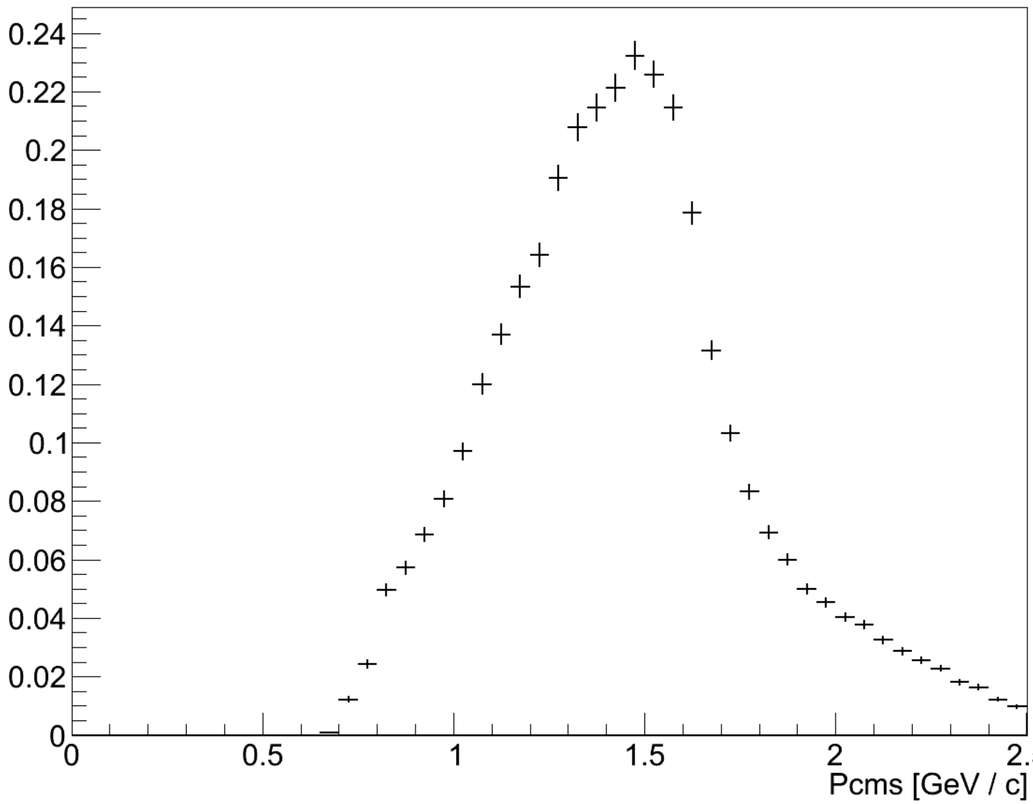
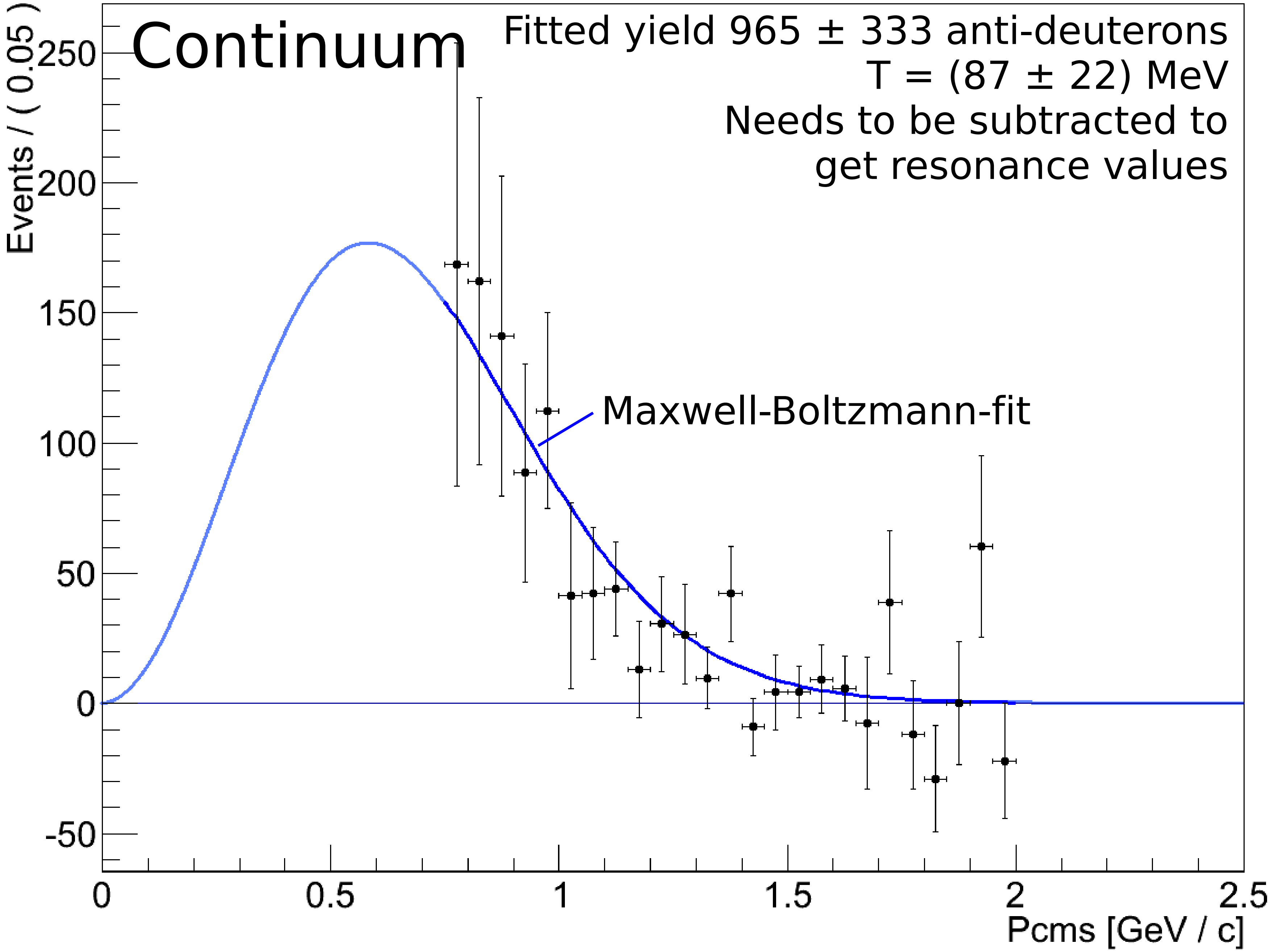
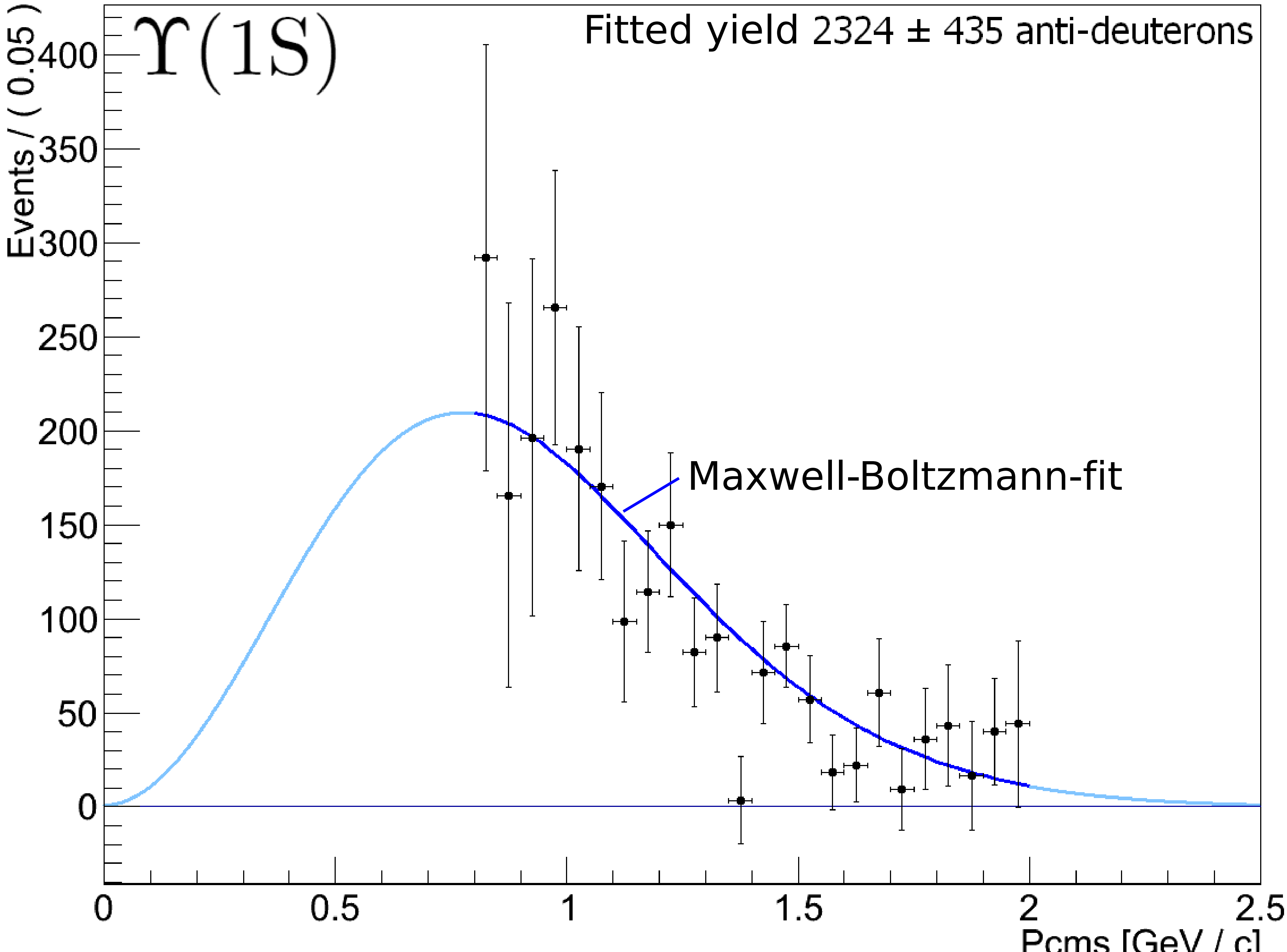
- Calculate p_{cms} depended efficiency of deuterons
  1. Simulate $\Upsilon \rightarrow d + \bar{p} + \bar{n}$
  2. Count simulated events per bin
  3. Count correct identified deuterons per bin
  4. Efficiency is ratio



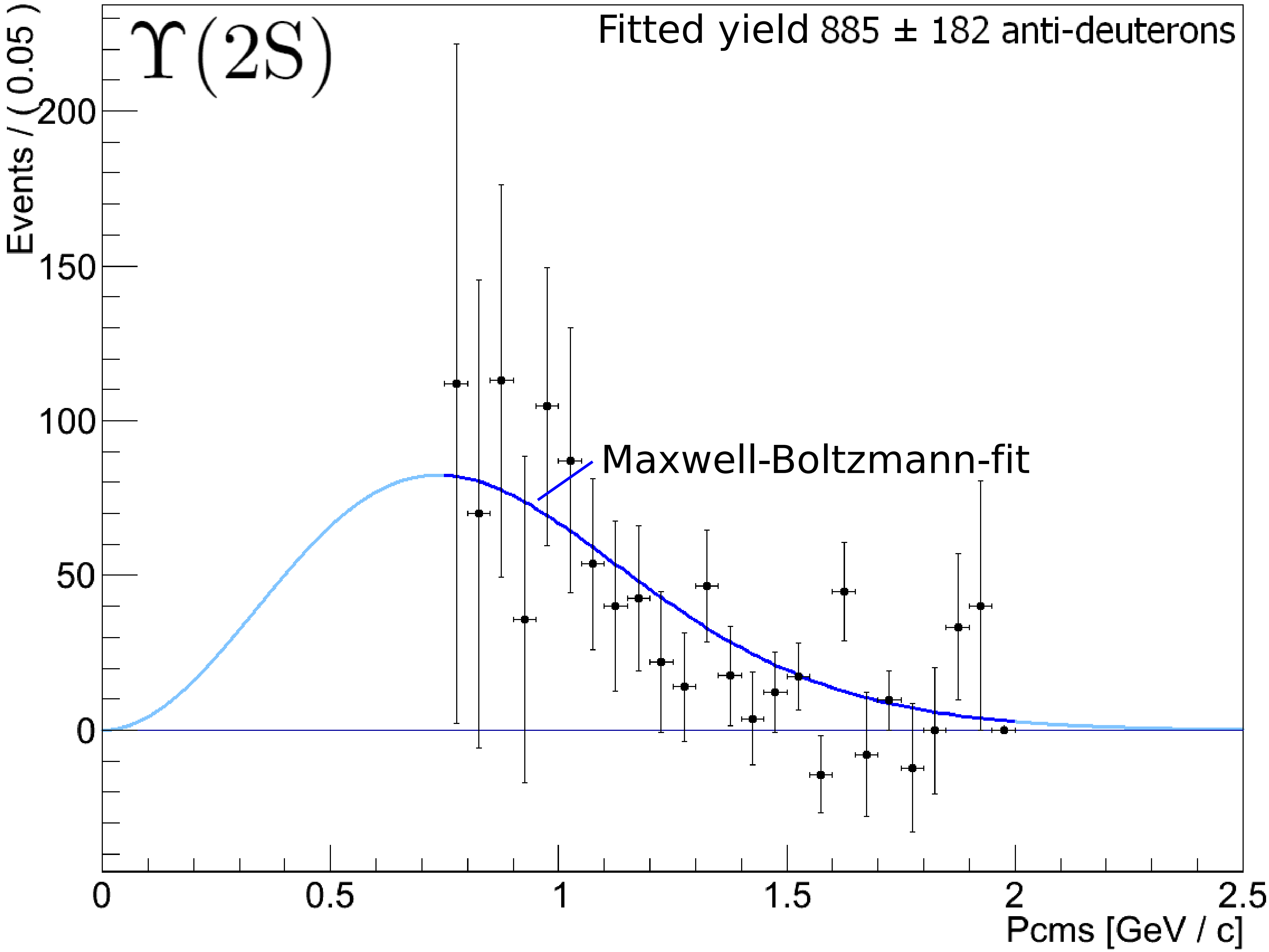
Momentum Distribution of $\bar{d}$



Cross Check


ϒ(1S)
Fitted yield 2324 ± 435 anti-deuterons
Maxwell-Boltzmann-fit
Events / (0.05)
400
350
300
250
200
150
100
50
0
0
0.5
1
1.5
2
2.5
Pcms [GeV / c]

Cross Check


ϒ(2S)
Fitted yield 885 ± 182 anti-deuterons
Maxwell-Boltzmann-fit
Events / (0.05)
200
150
100
50
0
0
0.5
1
1.5
2
2.5
Pcms [GeV / c]

Conclusion

- The QM-Plot is an “All-In-Once”-Method to find light nuclei and anti nuclei
- p, $\bar{p}$, d, $\bar{d}$ and t have been identified
- $\bar{d}$ from continuum, $\Upsilon(1S)$- and $\Upsilon(2S)$-decays have been observed.
- Goal: Get the branching ratio for $\Upsilon(3S) \rightarrow \bar{d} + \mathit{anything}$
- Belle II will have a factor 50 higher statistics

Thanks for your attention

Also thanks to my work group, especially Milan Wagner and Sören Lange for supporting me.

BELLE

- Formulas: Q M
- General plots: P_{Lab}-dEdx QMexp7
- Extended: Sources History Y(4S) Y(5S)
- Cuts: Vertex Muon Momentum Cherenkov ß vs. m Beta
- Vertex plots: Vertex ß-dEdxDetail
- Energy plots: Gamma1 Gamma2 Energy Energy vs. m
- More plots: ß-dEdx dE/dx vs. m
- Other Cut order: Beta Vertex Momentum Muon Cherenkov

Sources

[FH73] S. C. Frautschni, C. J. Hamer:
Effective Temperature of resonance Decay in the statistical Bootstrap Model
Il Nuovo Cimento Vl. 13 A N. 3 (01.02.1973)

[ARG89] ARGUS Collaboration:
Study of Antideuteron Production in e+e− Annihilation at 10 GeV Center-of-Mass Energy
Physics Letters B, Volume 236, Issue 1, p 102–108 (08.02.1990)

[FOP05] Norbert Herrmann:
Search for ppnK− deeply bound states with FOPI
EXA05, Vienna

[CLE07] CLEO Collaboration:
Antideuteron production in Υ(nS) decays and the nearby continuum
Physical Review D 75 (2007), arXiv: hep-ex/0612019

[STA10] STAR Collaboration:
Observation of an Antimatter Hypernucleus
arXiv:1003.2030v1 [nucl-ex] (10.03.2010)

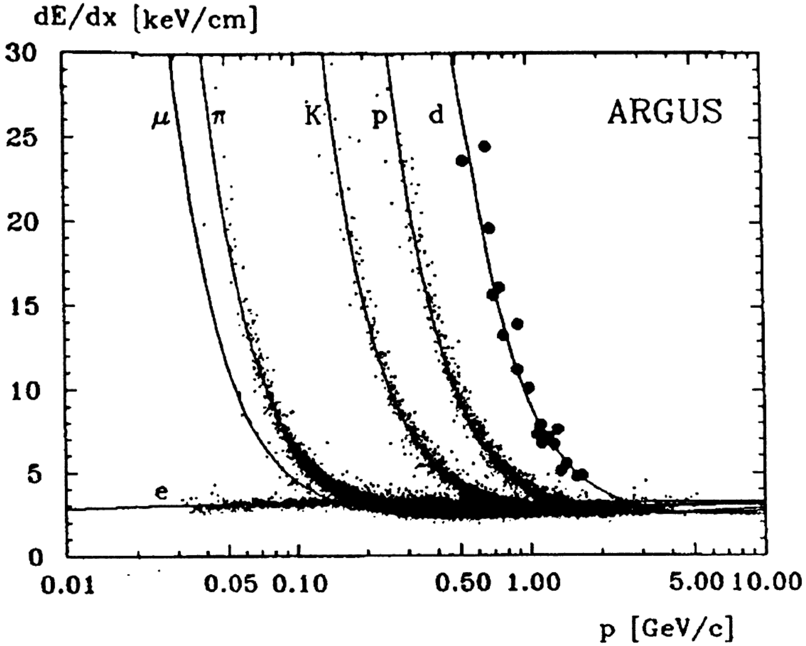
[PDG10] Particle Data Group:
Particle Physics Booklet (2010)

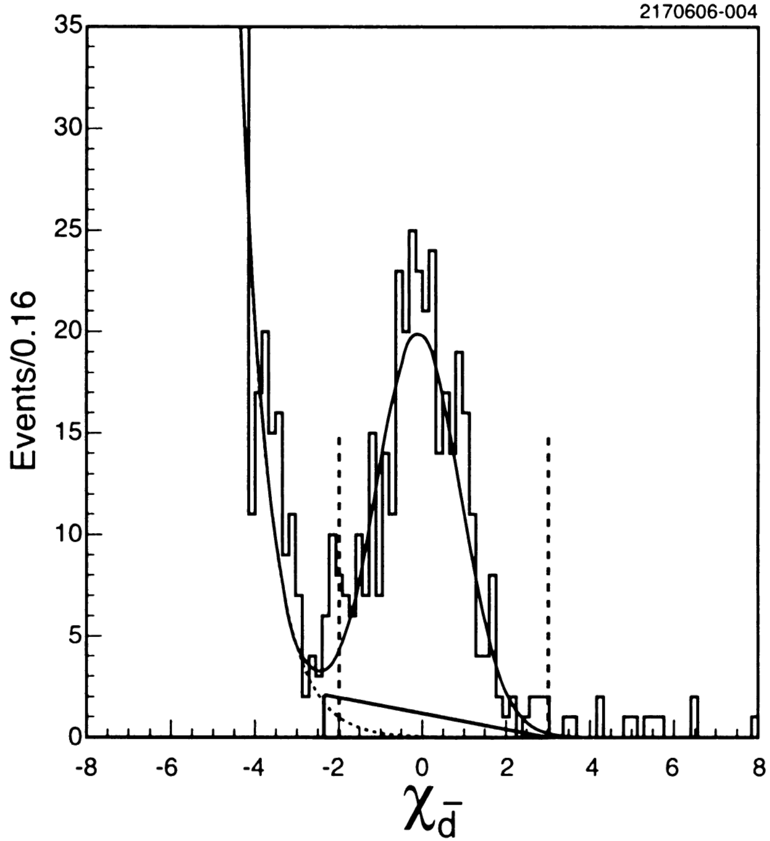
Light Anti-Nuclei

- Are the anti-deuterons produced by certain decays?
- Identify decays into anti-deuterons with an invariant mass plot
- Interesting physics may happen in different decays:
  - ➔ Look for states seen in normal matter:
    - Kaonic cluster with 3.159 GeV at FOPI
    - Hyper-^{3}H seen in Au-Au-collisions at Star
    - Exited ^{3}He

History

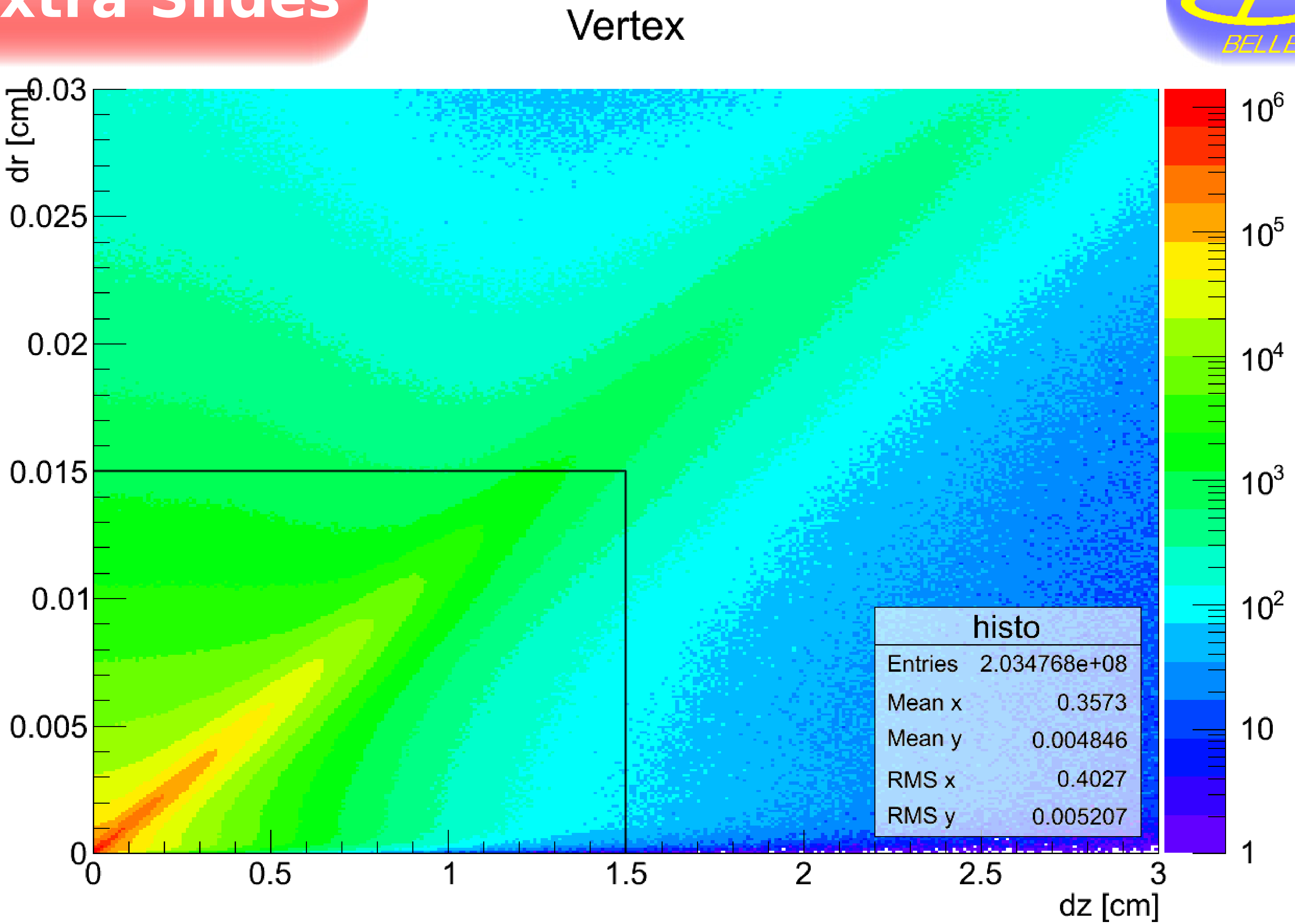
Searches for anti-deuterium in the past

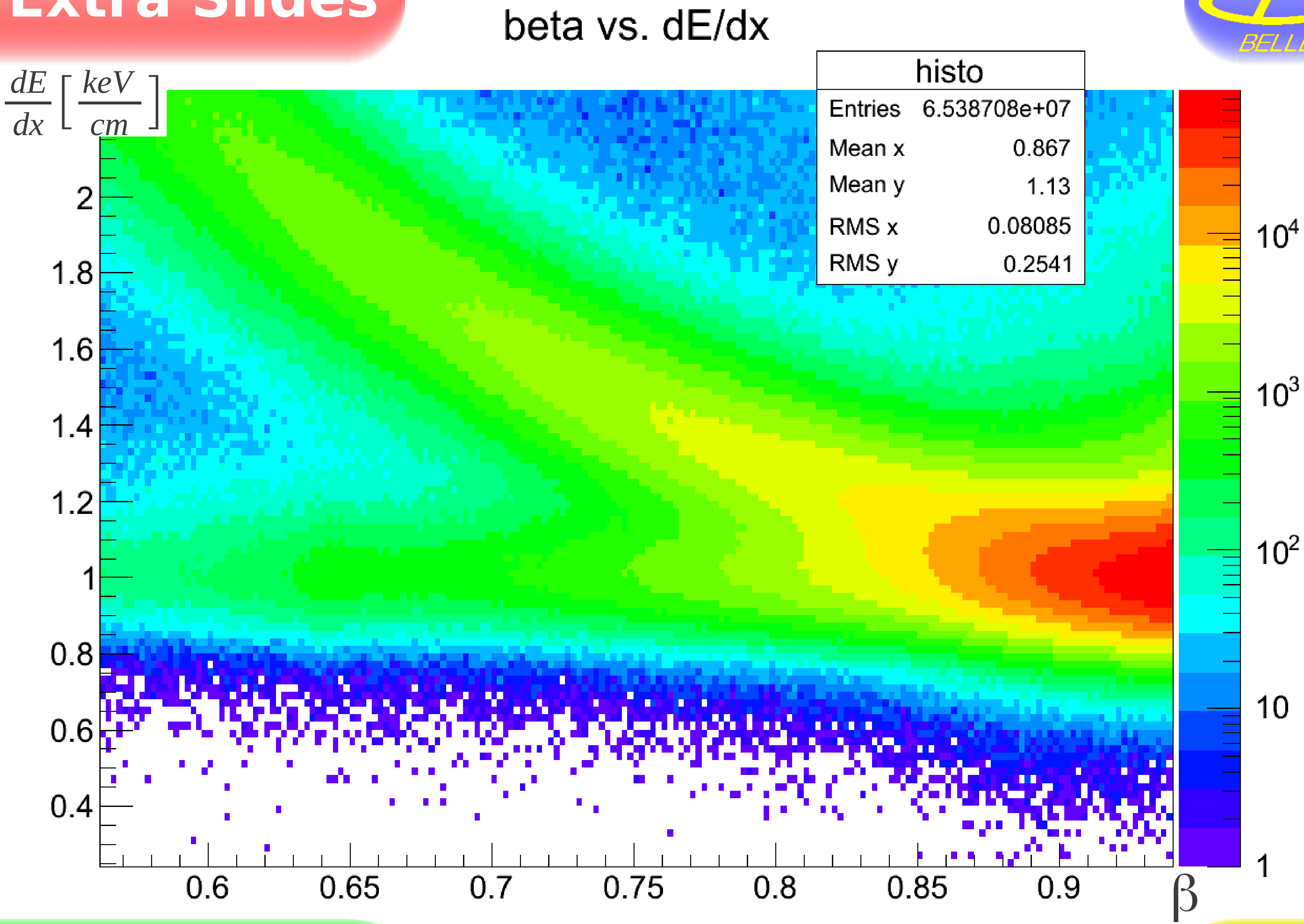




1989: ARGUS found 21 $\bar{d}$ candidates at DESY

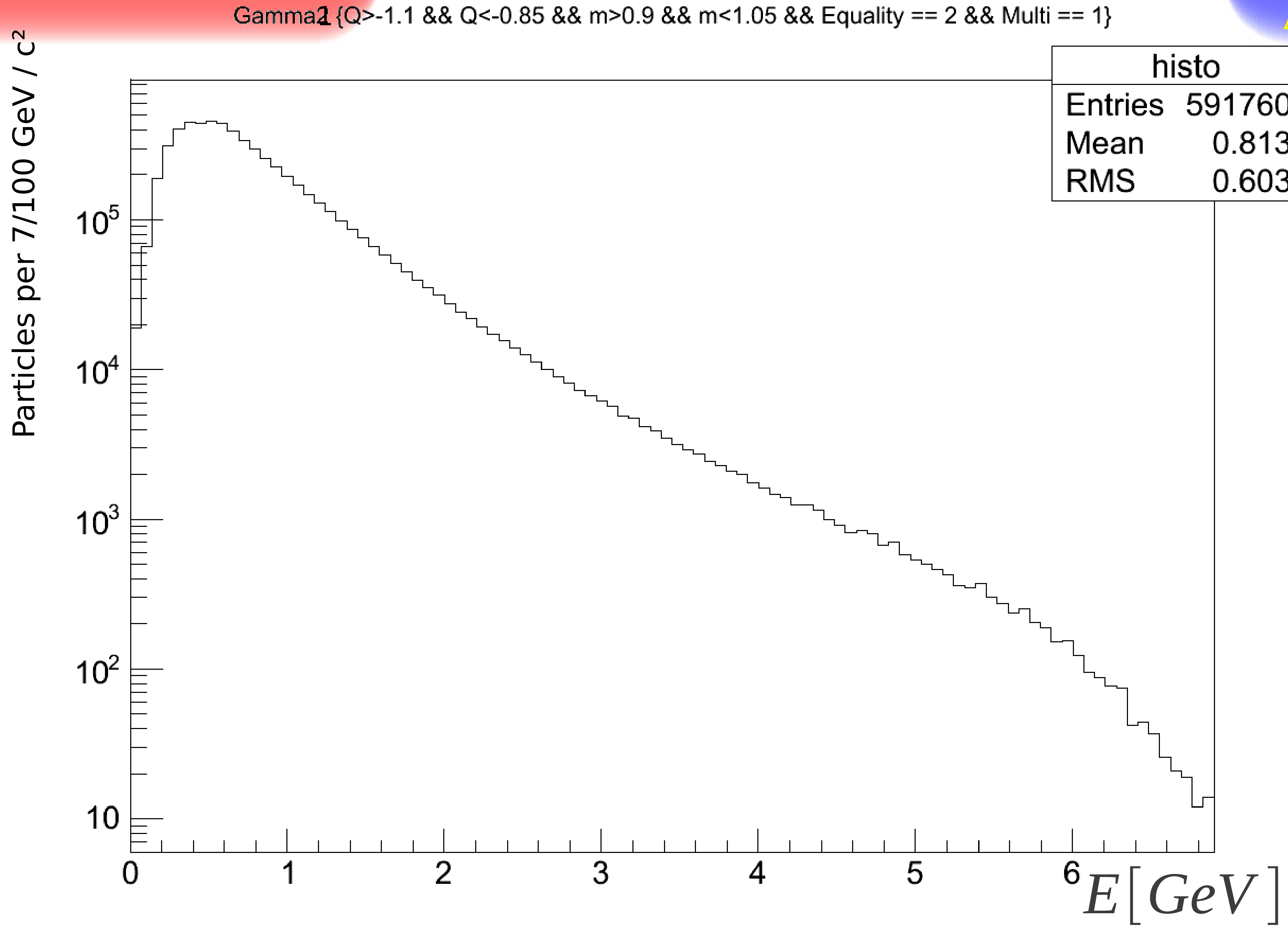
2006: CLEO found 338 $\bar{d}$ candidates at the Cornell Electron Storage Ring

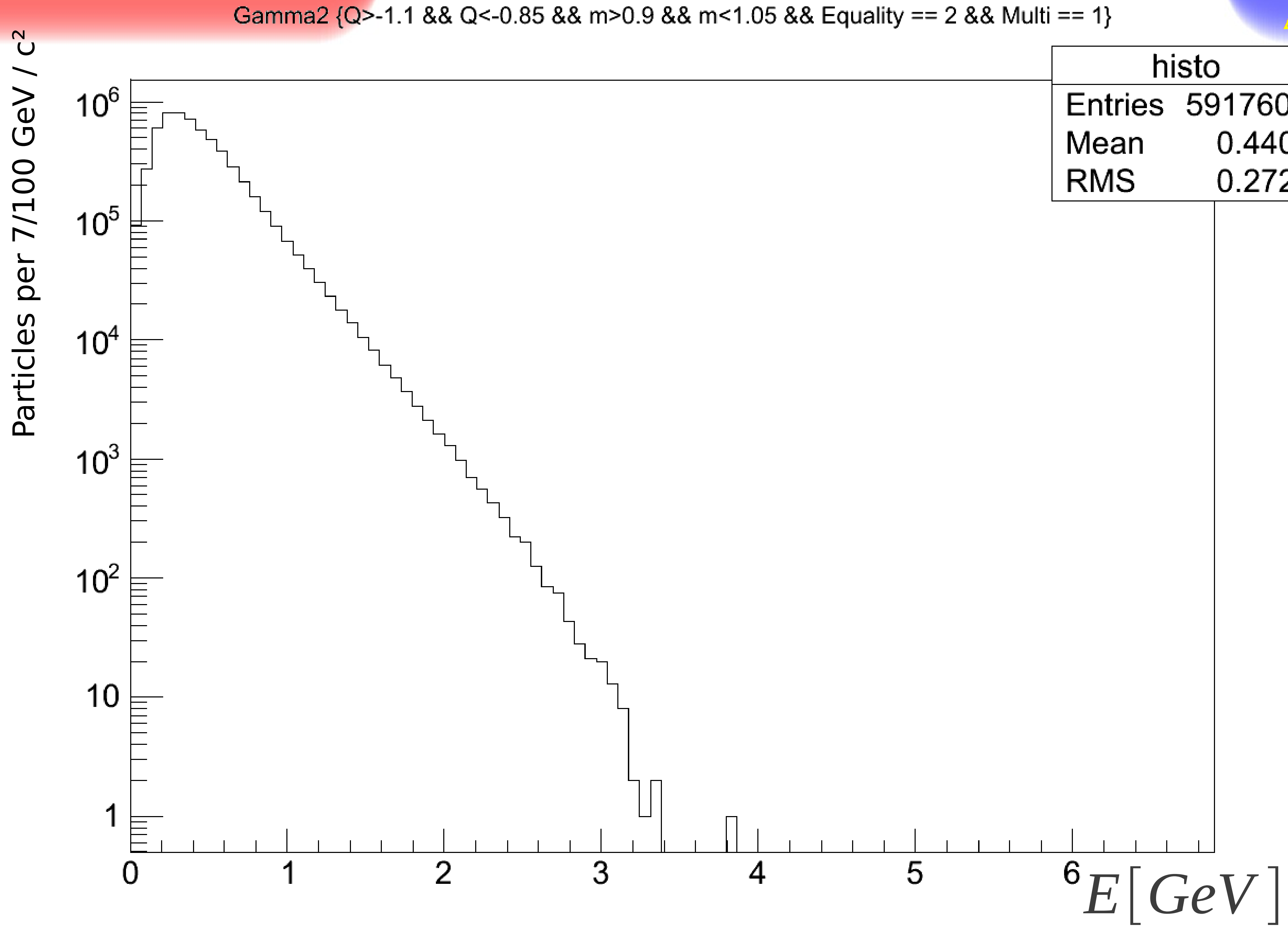

Vertex
dr [cm]
0.03
0.025
0.02
0.015
0.01
0.005
0
0
0.5
1
1.5
2
2.5
3
dz [cm]
10^6
10^5
10^4
10^3
10^2
10
1
histo
Entries 2.034768e+08
Mean x 0.3573
Mean y 0.004846
RMS x 0.4027
RMS y 0.005207



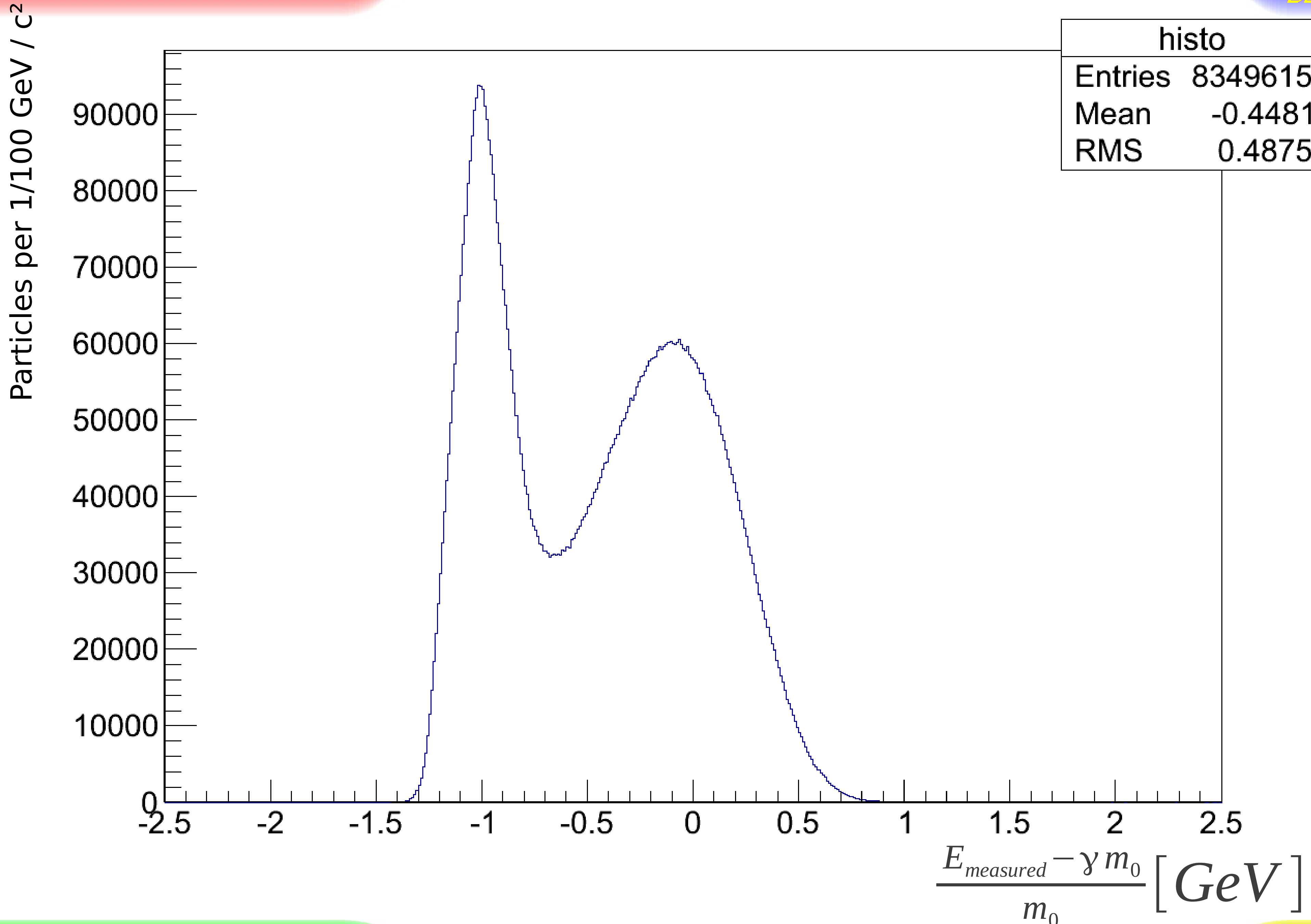
beta vs. dE/dx
histo
Entries 6.538708e+07
Mean x 0.867
Mean y 1.13
RMS x 0.08085
RMS y 0.2541
$\frac{dE}{dx}\left[\frac{keV}{cm}\right]$
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.6
0.65
0.7
0.75
0.8
0.85
0.9
β
10^4
10^3
10^2
10
1

Extra Slides

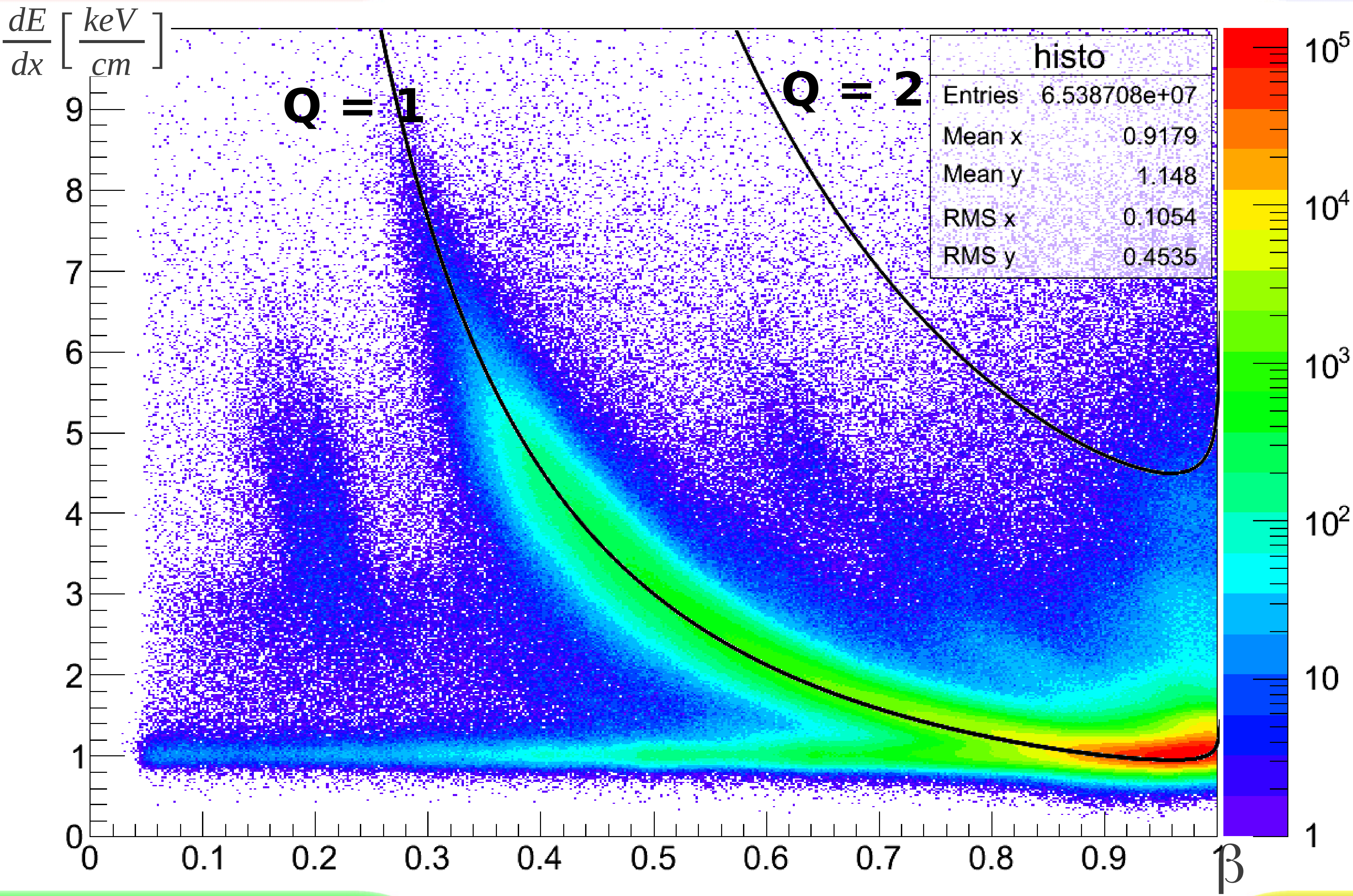



Gamma2 {Q>-1.1 && Q<-0.85 && m>0.9 && m<1.05 && Equality == 2 && Multi == 1}
histo
Entries 5917602
Mean 0.4401
RMS 0.2721
Particles per 7/100 GeV / c²
$E[GeV]$
0
1
2
3
4
5
6
1
10
10²
10³
10⁴
10⁵
10⁶

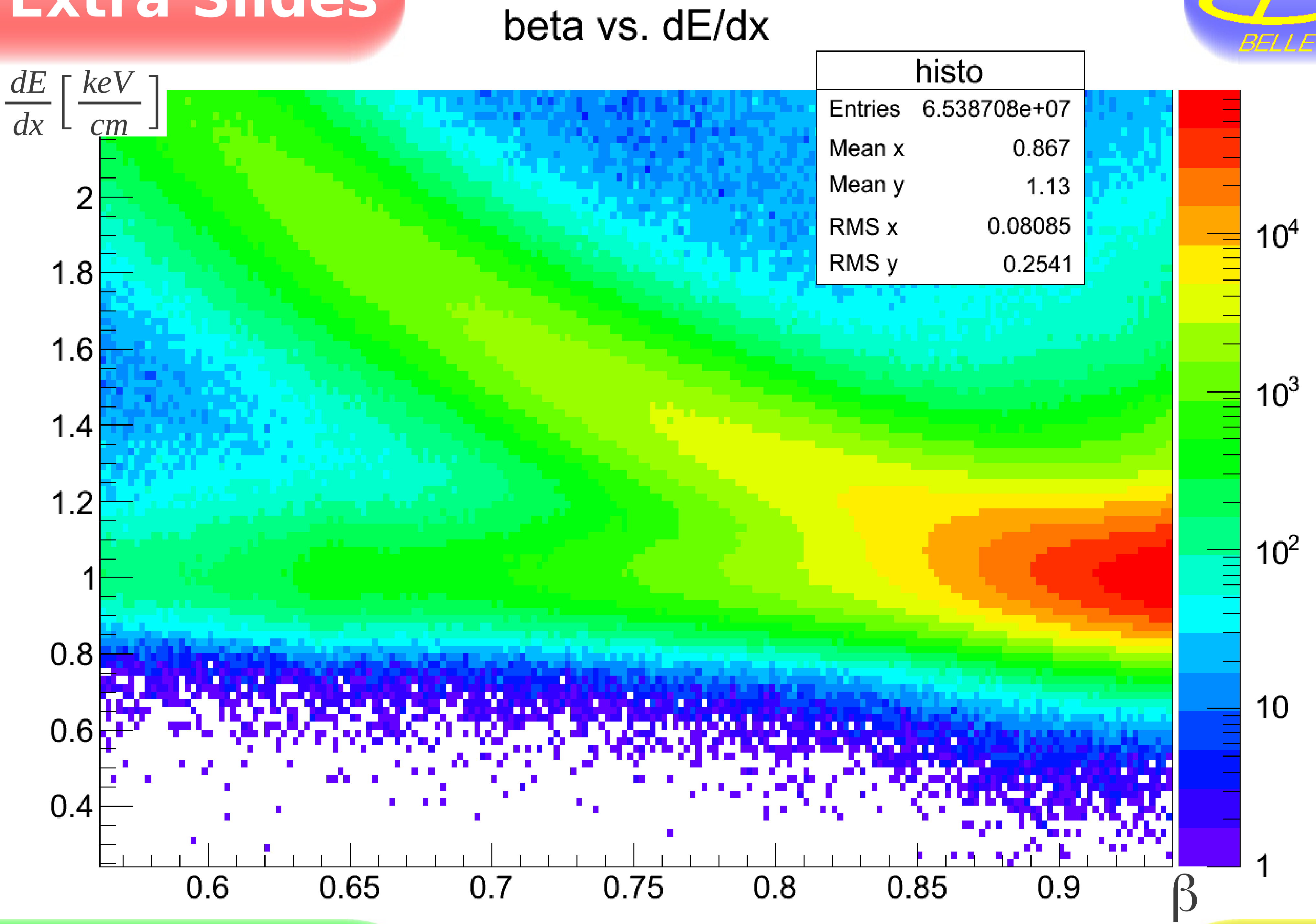
Extra Slides



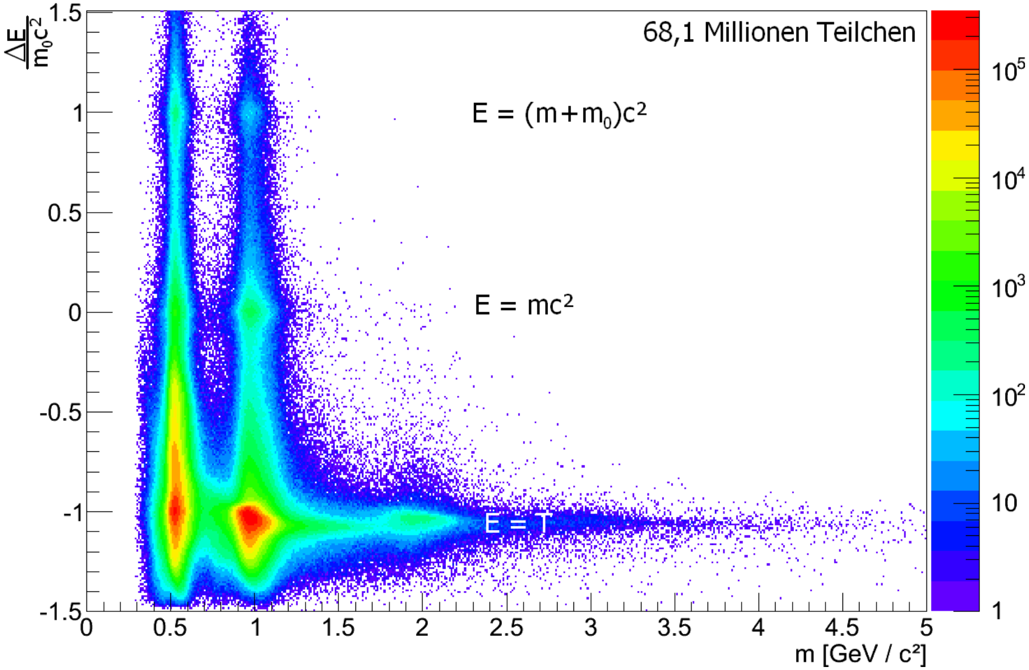
beta vs. dE/dx



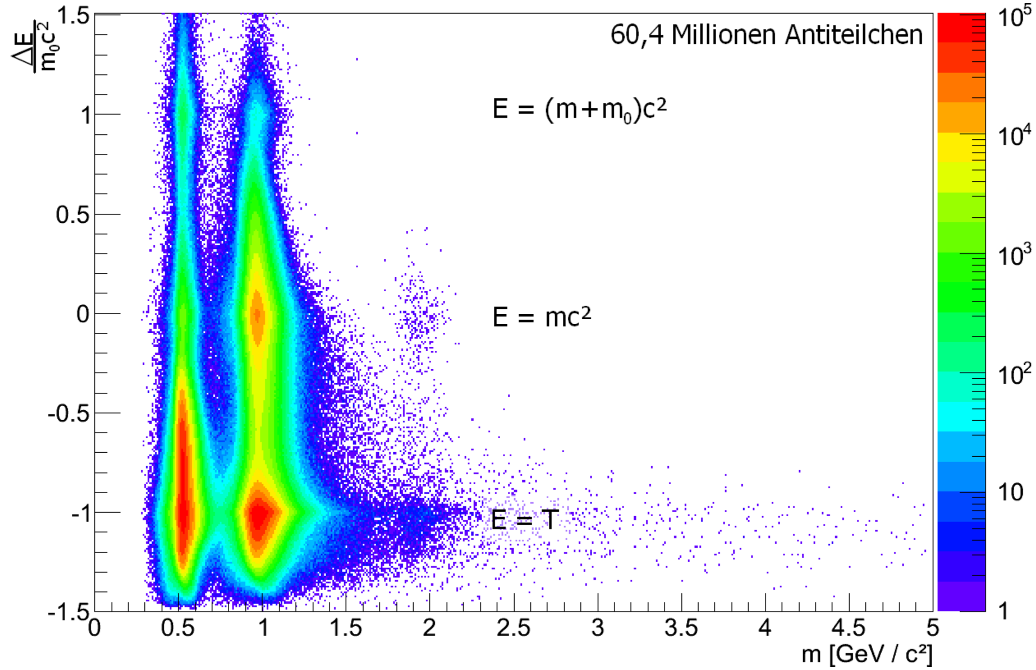
dE/dx [keV/cm]
Q = 1
Q = 2
histo
Entries 6.538708e+07
Mean x 0.9179
Mean y 1.148
RMS x 0.1054
RMS y 0.4535
0 1 2 3 4 5 6 7 8 9
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
β
1 10 10^2 10^3 10^4 10^5


beta vs. dE/dx
histo
Entries 6.538708e+07
Mean x 0.867
Mean y 1.13
RMS x 0.08085
RMS y 0.2541
dE/dx [keV/cm]
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.6
0.65
0.7
0.75
0.8
0.85
0.9
β
10^4
10^3
10^2
10
1
BELLE

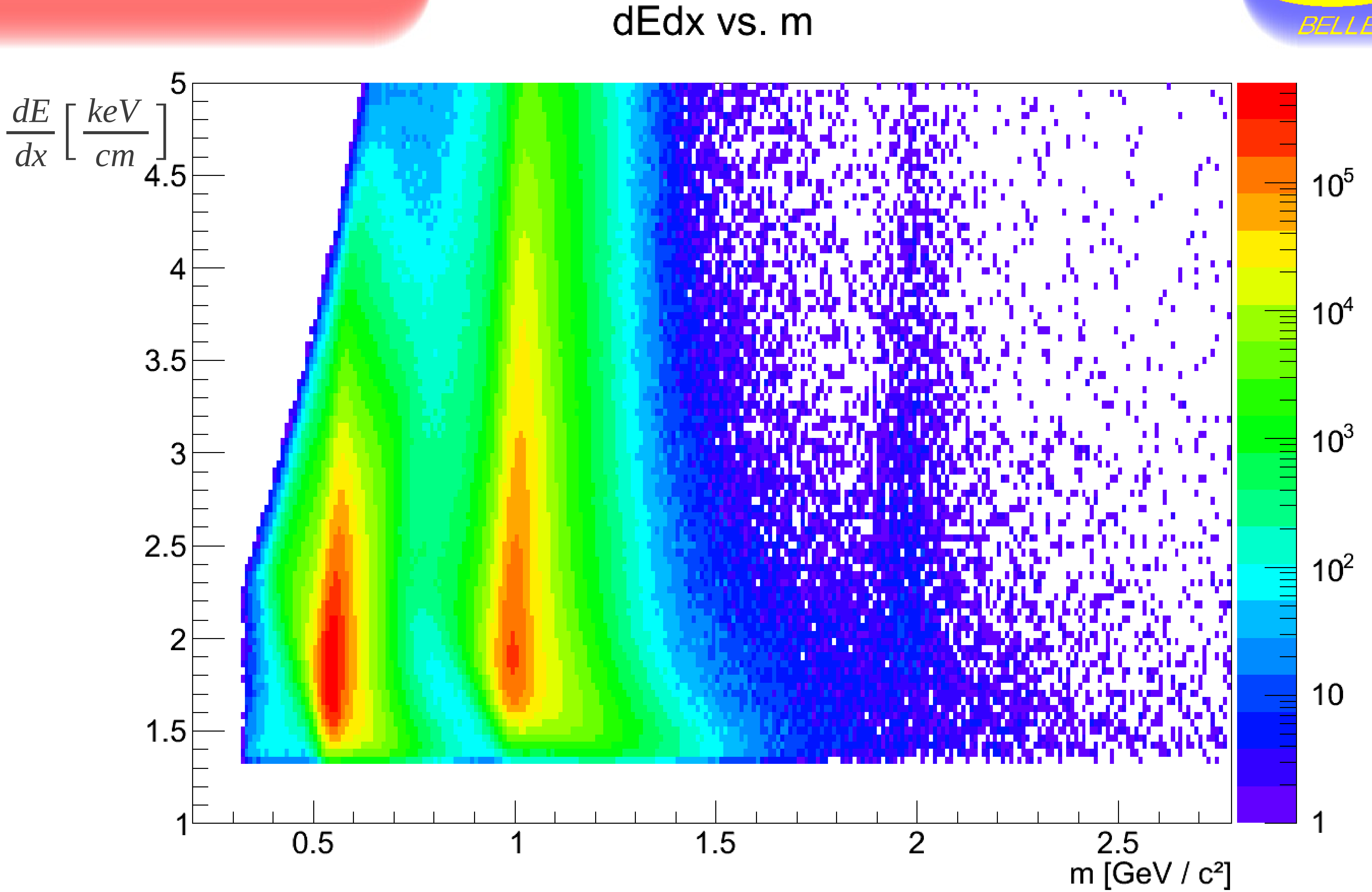
Matter

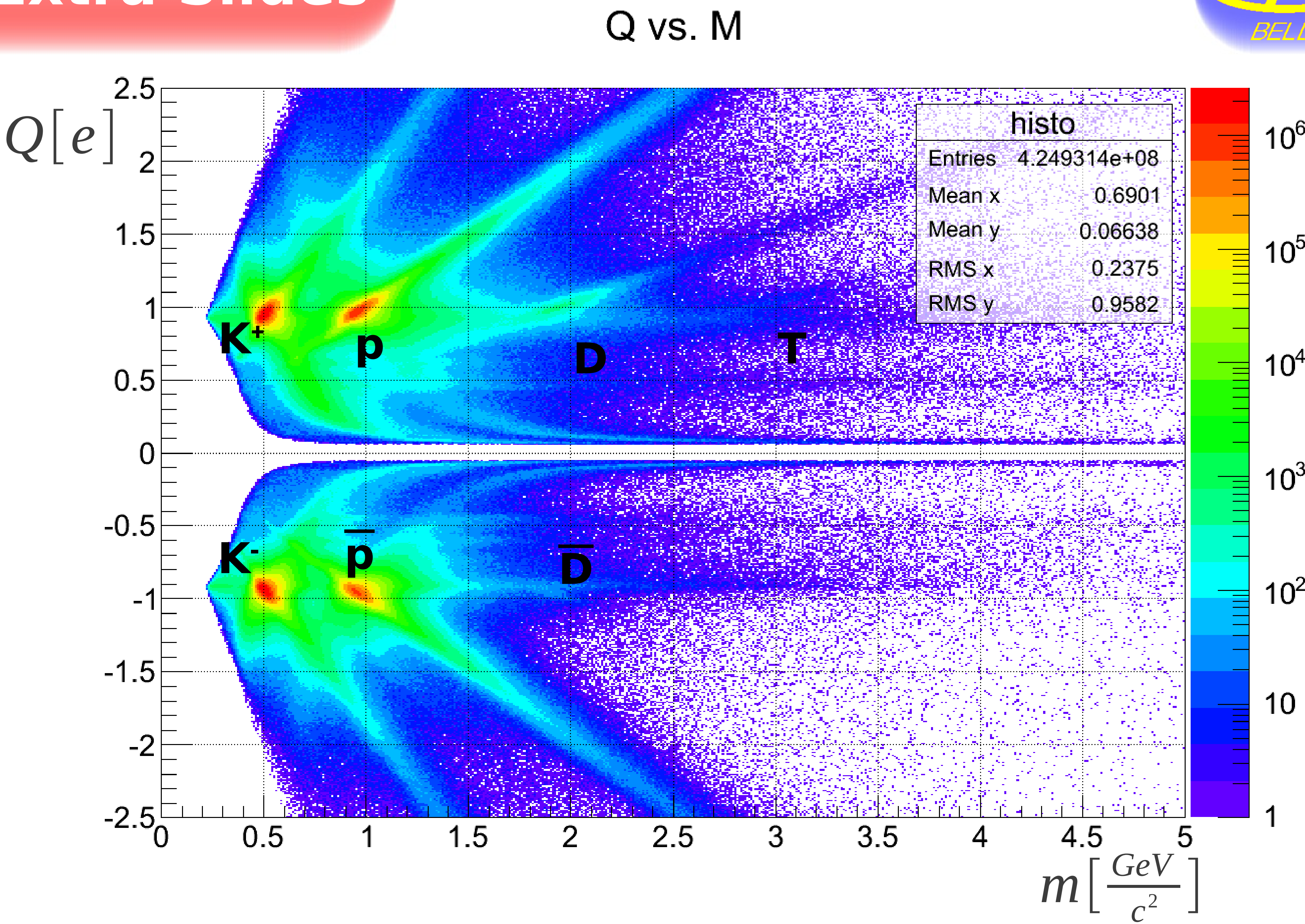


Antimatter

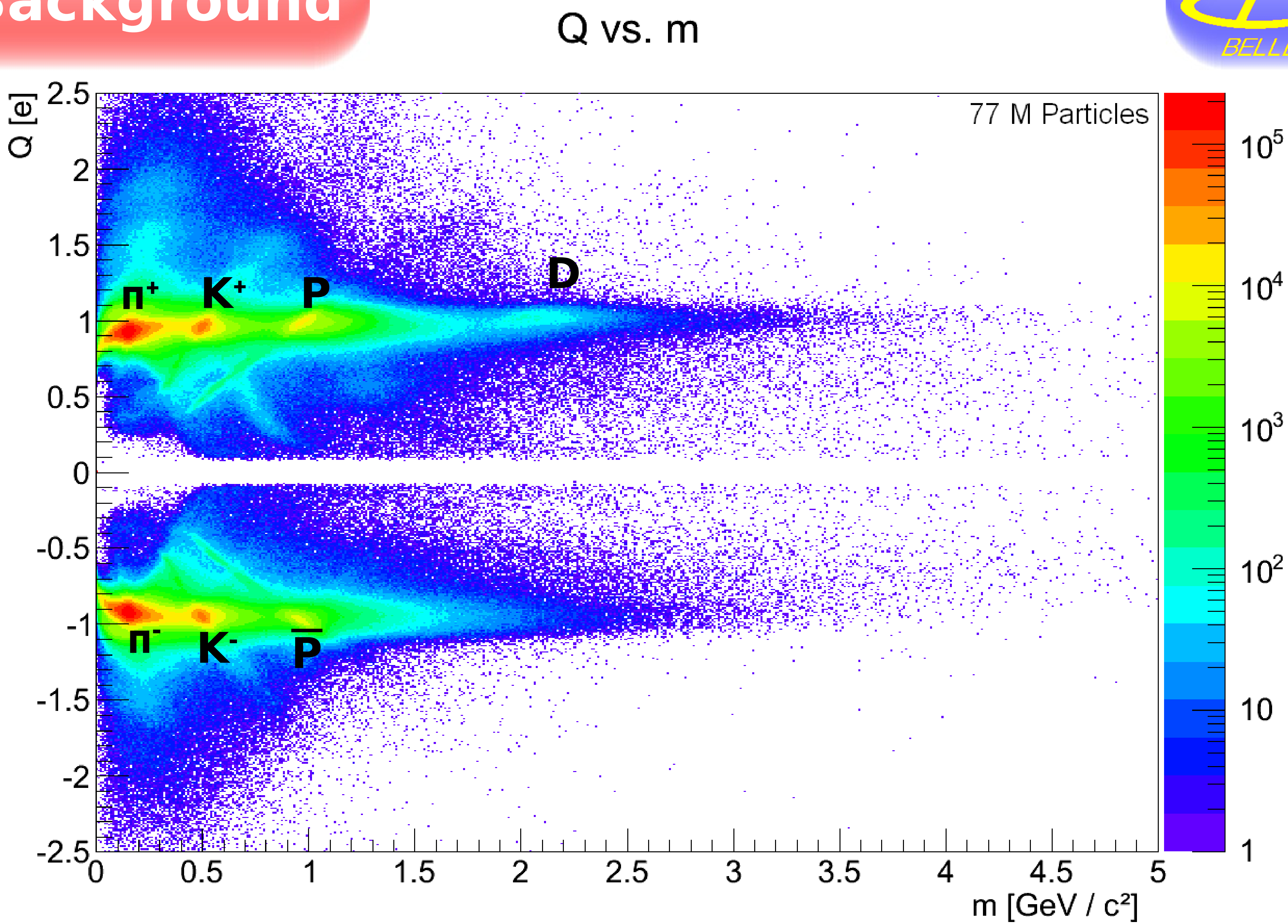


Peaks are artificially generated.


dEdx vs. m
$\frac{dE}{dx}\left[\frac{keV}{cm}\right]$
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
1
1.5
2
2.5
m [GeV / c²]
10^5
10^4
10^3
10^2
10
1

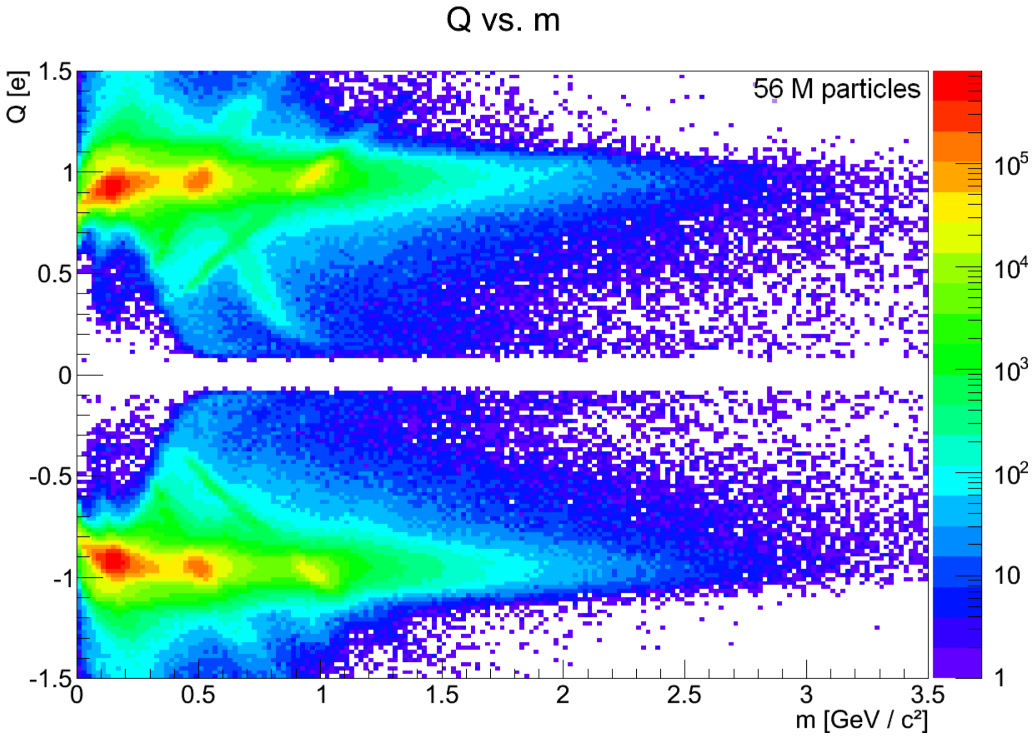

Q vs. M
histo
Entries 4.249314e+08
Mean x 0.6901
Mean y 0.06638
RMS x 0.2375
RMS y 0.9582
Q[e]
m [GeV/c²]
K+
p
D
T
K-
p̄
D̄

Background

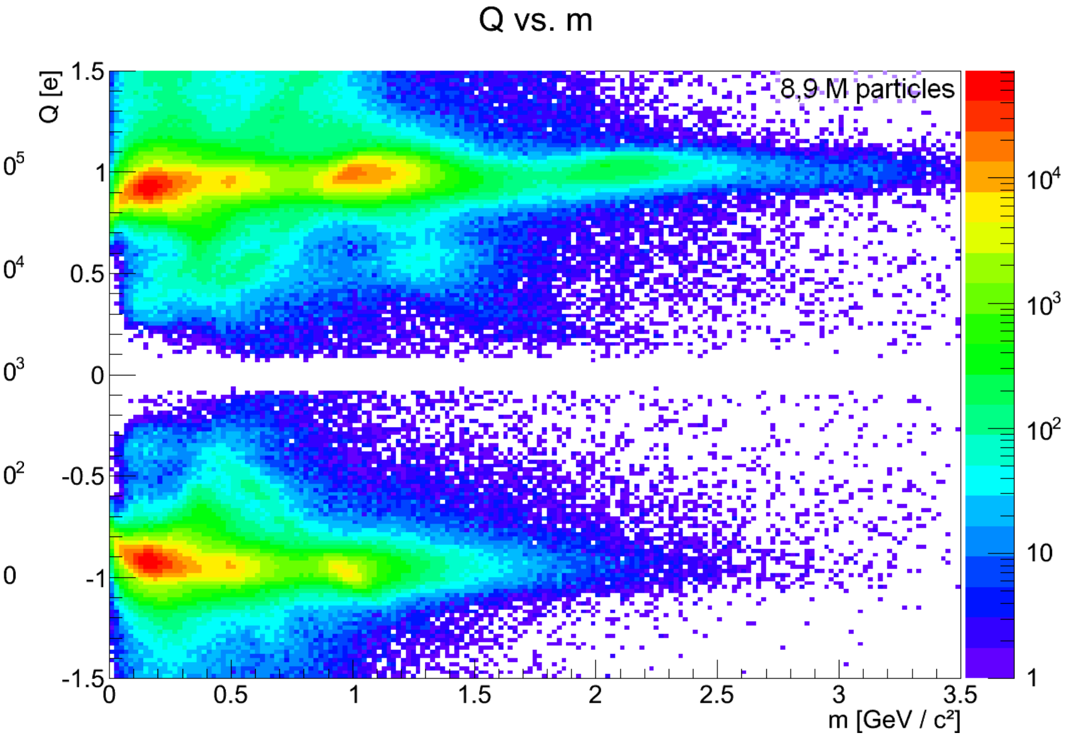

Q vs. m
77 M Particles
Q [e]
m [GeV / c²]
π+
K+
P
D
π-
K-
P̄
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
10^5
10^4
10^3
10^2
10
1

Vertex Cut

After the cut:



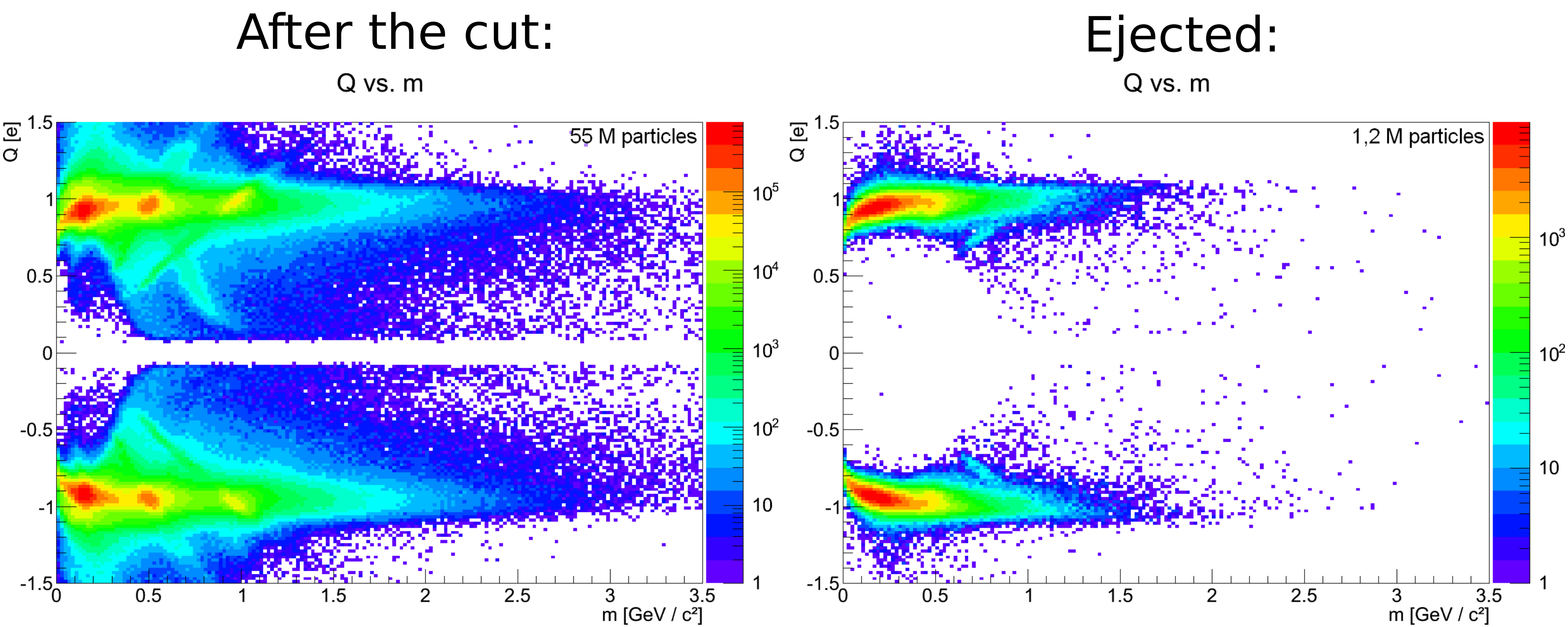
Ejected:



Reason: Eject particles from beam pipe interactio

Keeping condition: dr < 0,15 mm and dz < 15 mr

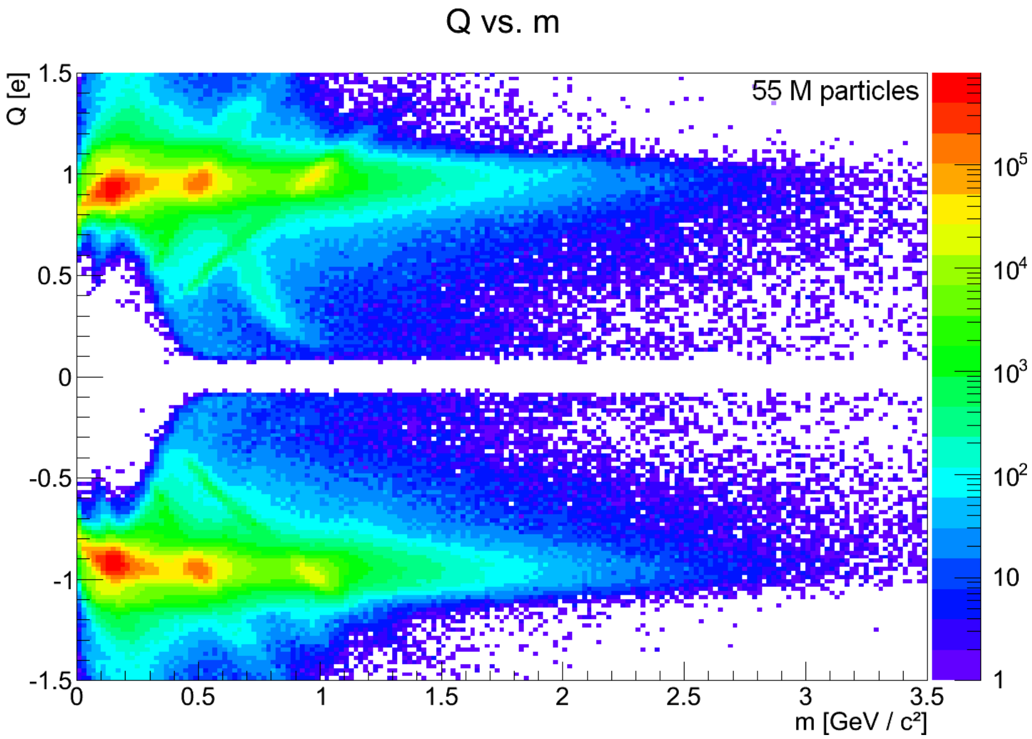
Muon-Veto



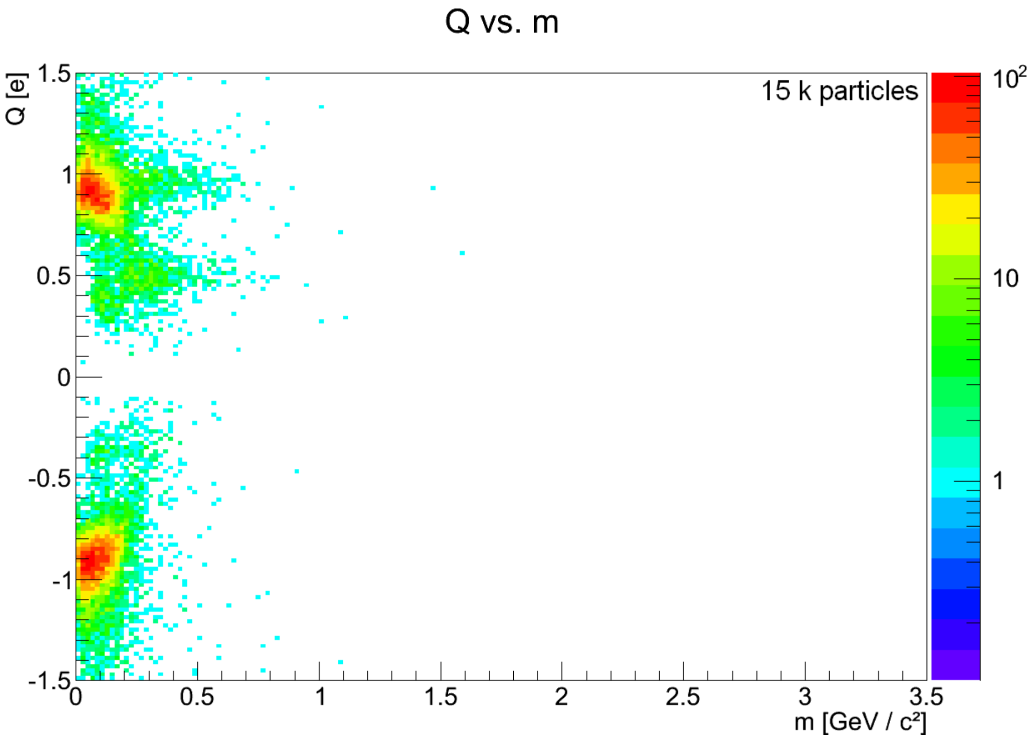
- Reason: Eject muons very cleanly
- Keeping condition: No correlated hit in the KLM-detector

Momentum Cut

After the cut:



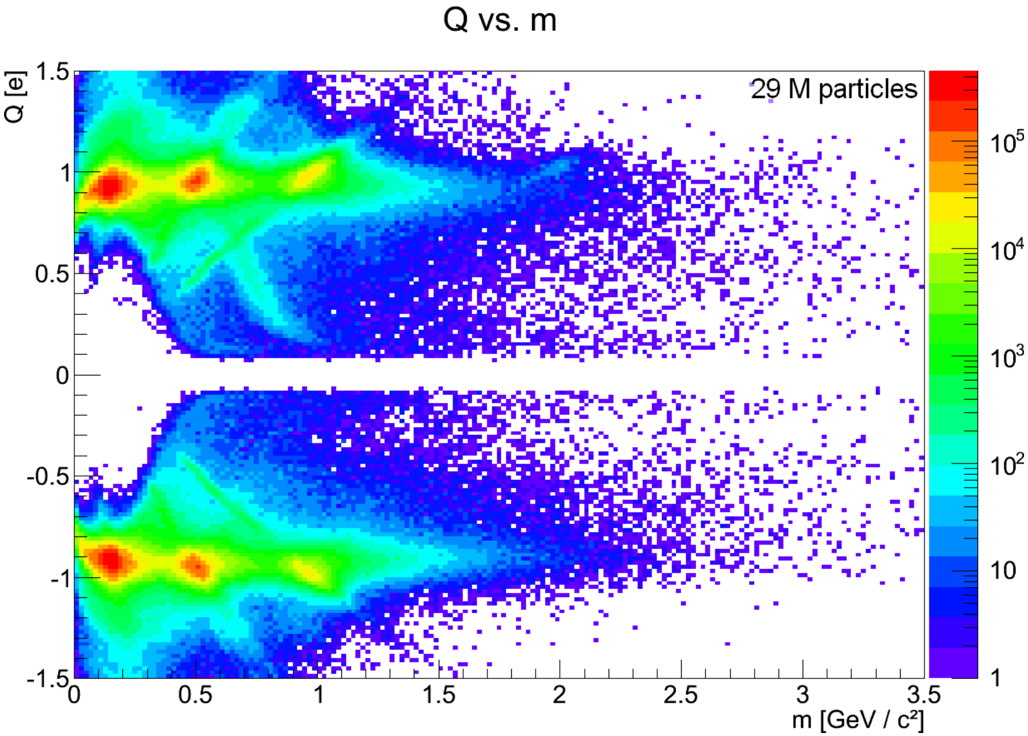
Ejected:



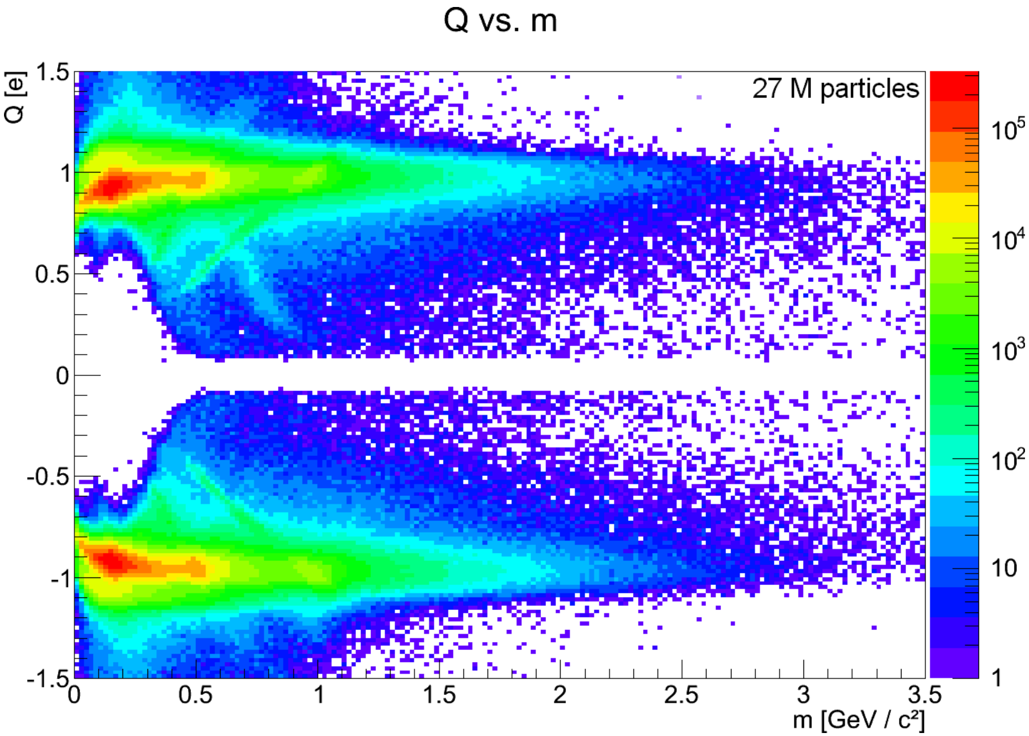
- Reason: Particles with too small p' can't hit the TOF
- Keeping condition: $p_{lab} > 0{,}3\,\frac{GeV}{c}$

Cherenkov-Veto

After the cut:

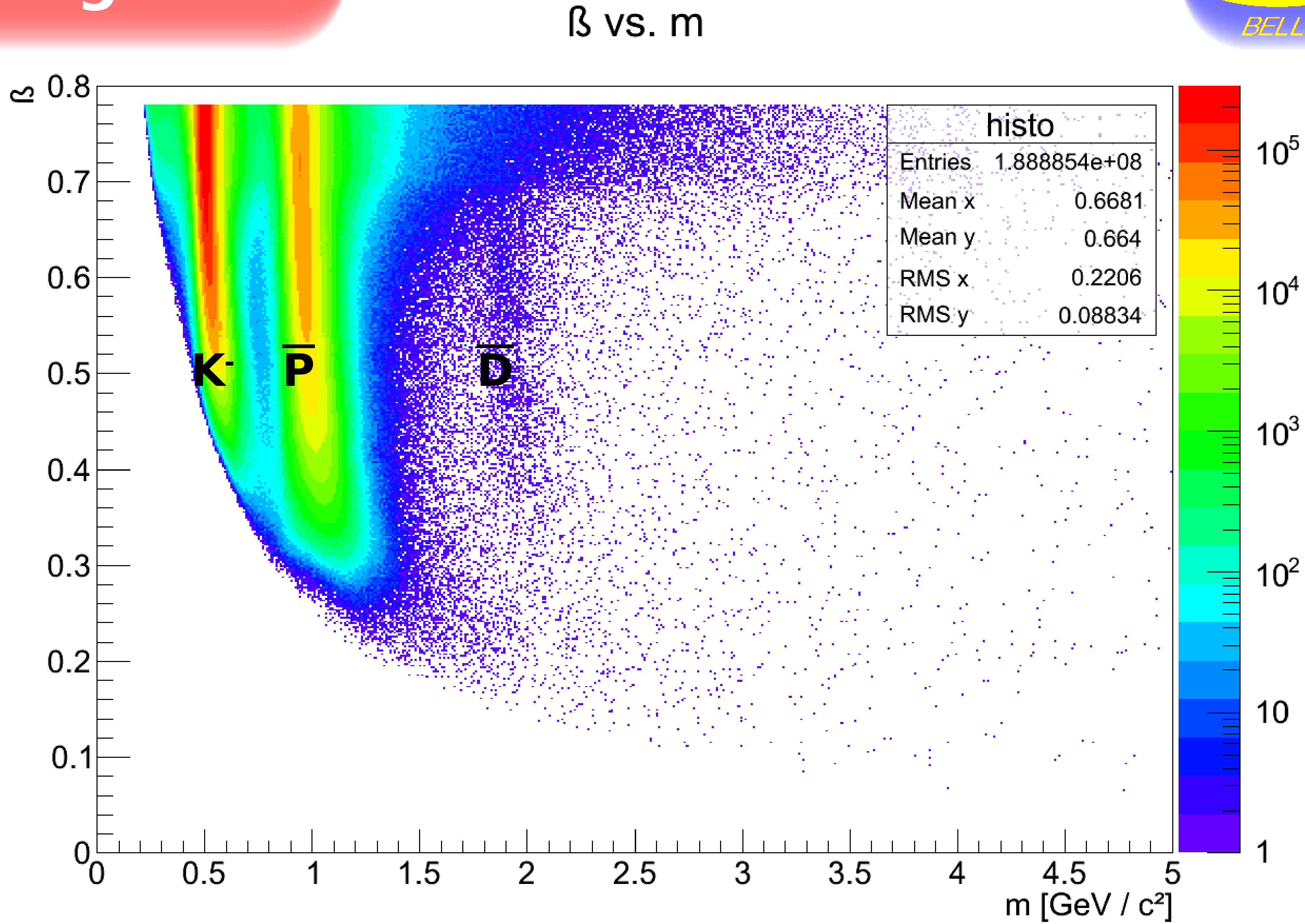


Ejected:



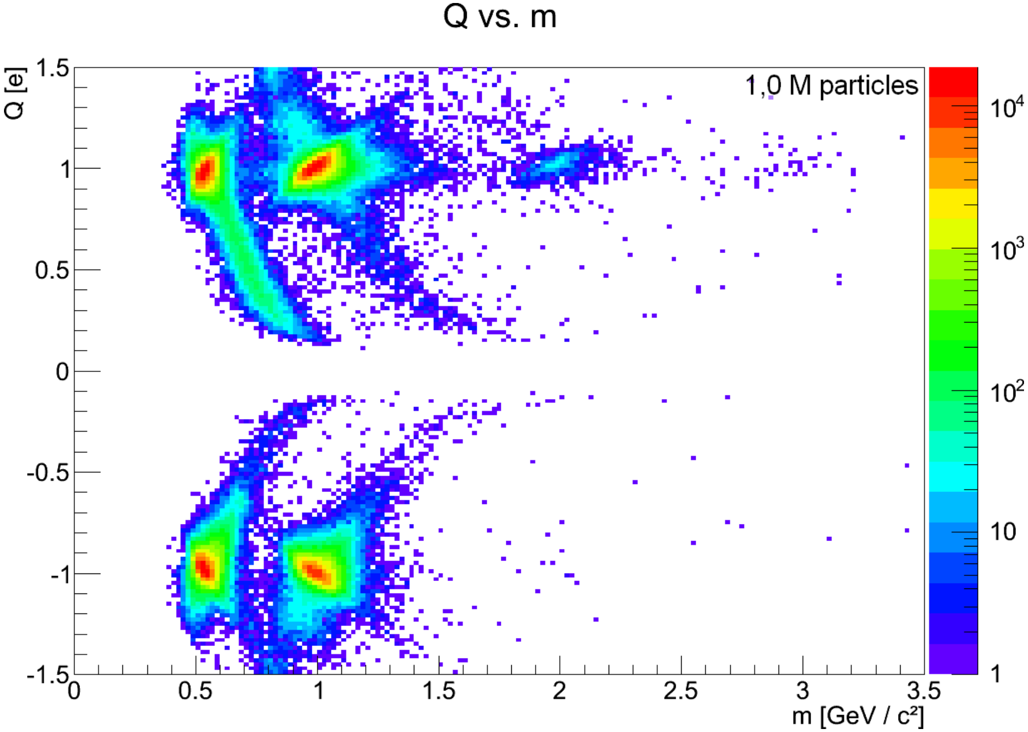
- Reason: Particles with Cerenkov radiation are too fast
- Keeping condition: No correlated signal in the Cerenkov-detector

Background

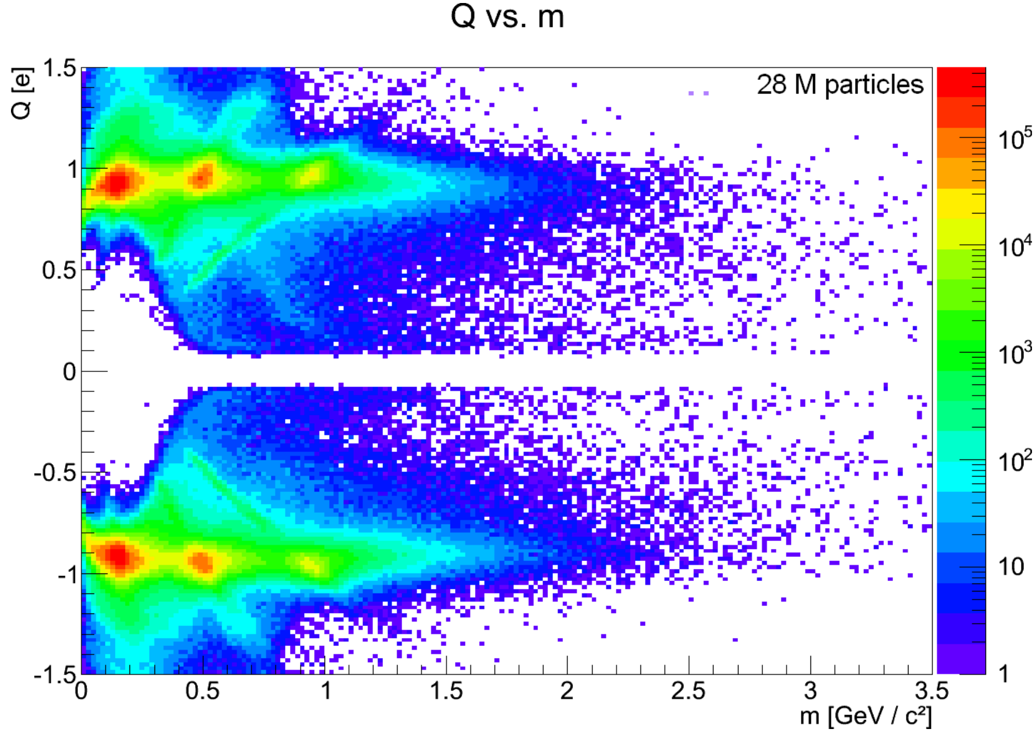

ß vs. m
ß
m [GeV / c²]
histo
Entries 1.888854e+08
Mean x 0.6681
Mean y 0.664
RMS x 0.2206
RMS y 0.08834
K-
P̄
D̄

$\frac{dE}{dx}$-β-Cut

After the cut:



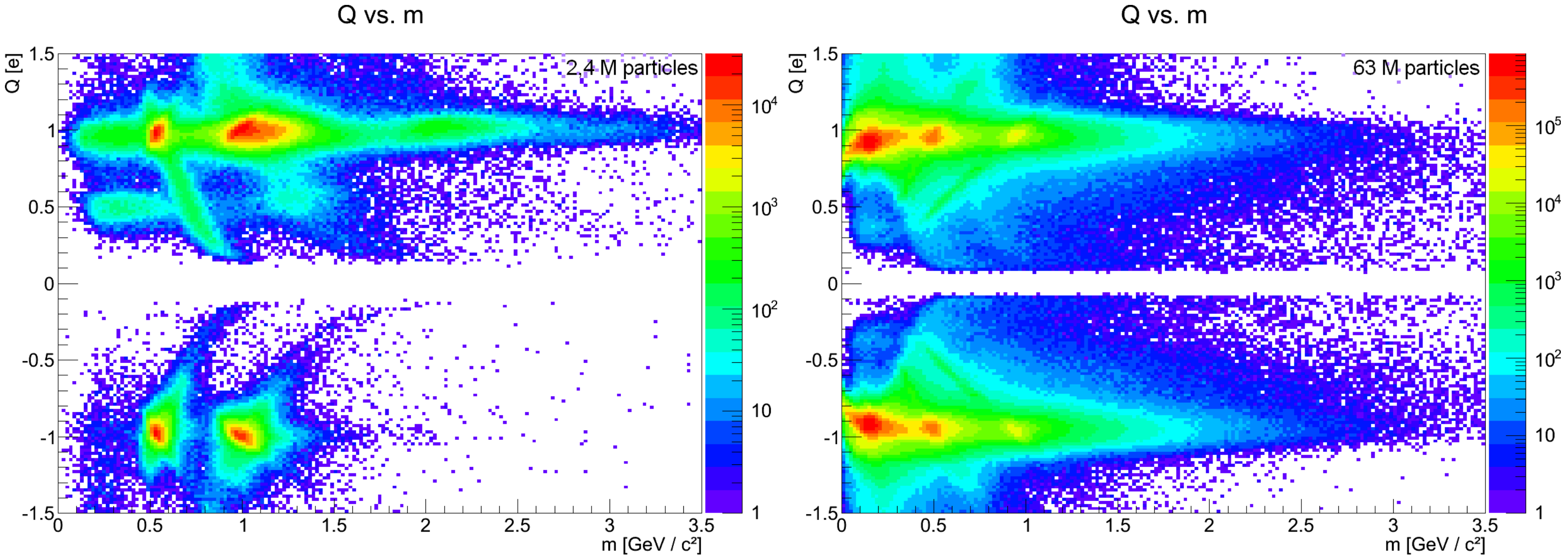
Ejected:



- Reason: Fast particles have a large error
- Keeping condition: $\beta < 0{,}68$ and $\frac{dE}{dx} > 1{,}85 \frac{keV}{cm}$

$\frac{dE}{dx}$-β-Cut

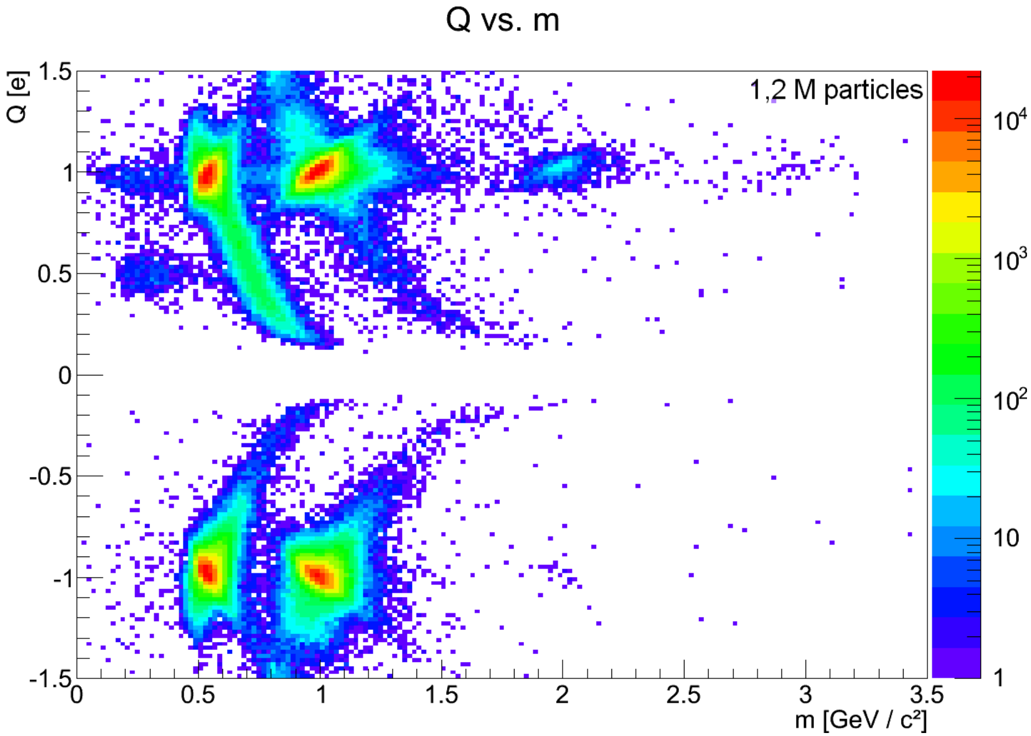
After the cut: Ejected:



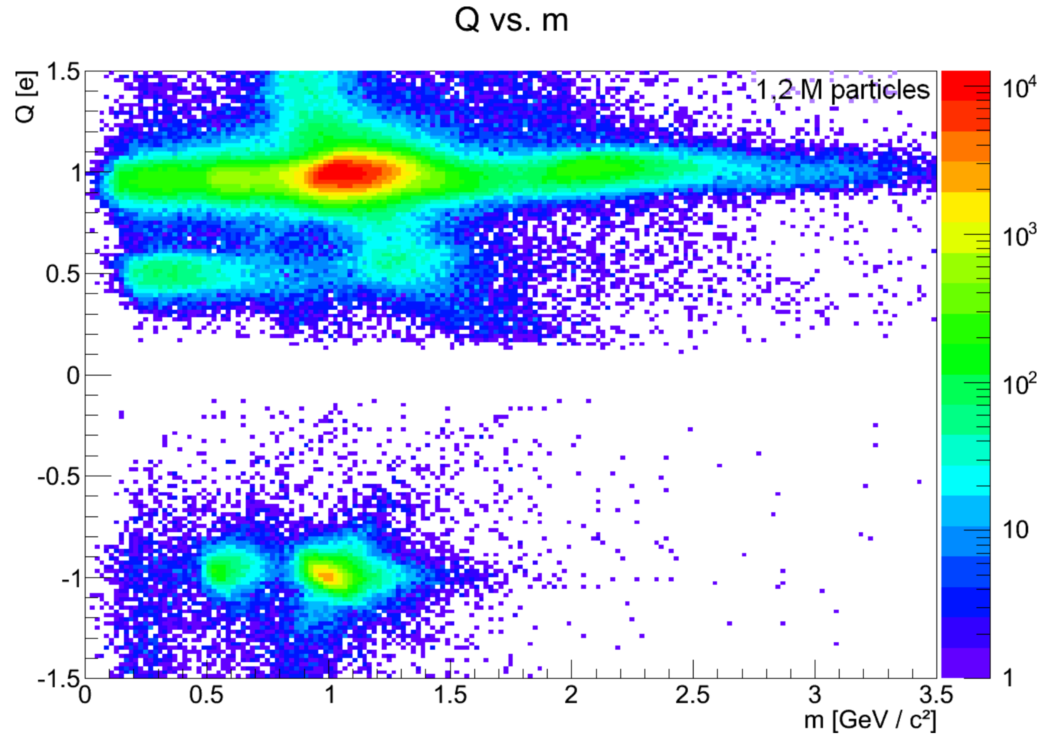
- Reason: Fast particles have a large error
- Keeping condition: $\beta < 0{,}68$ and $\frac{dE}{dx} > 1{,}85\,\frac{keV}{cm}$

Vertex Cut

After the cut:



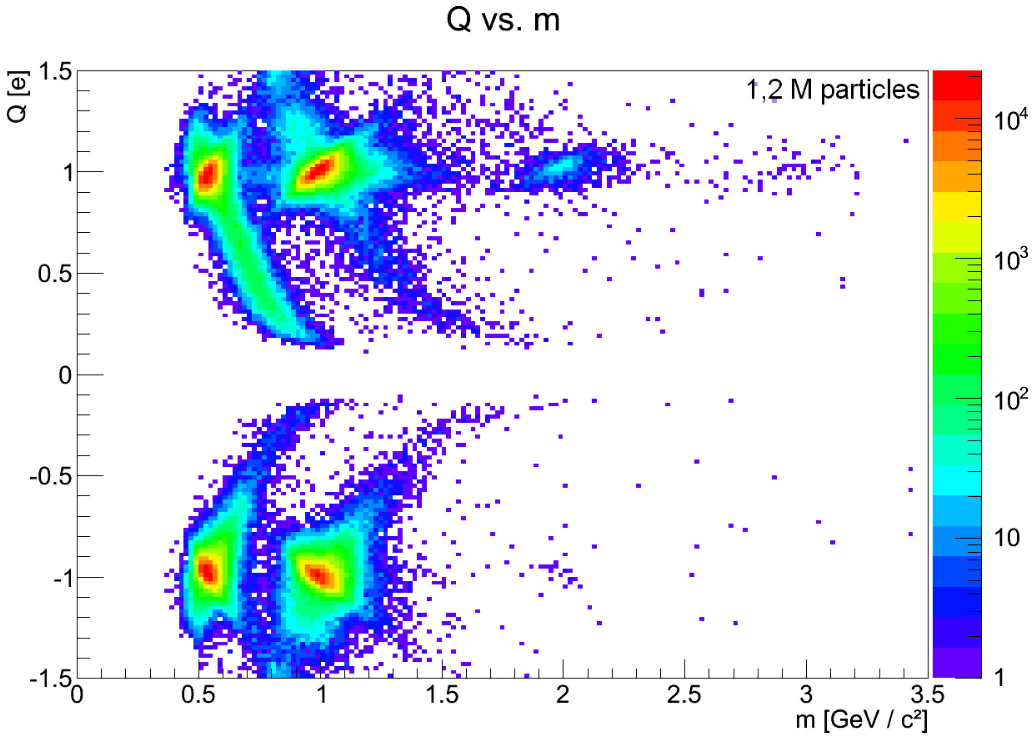
Ejected:



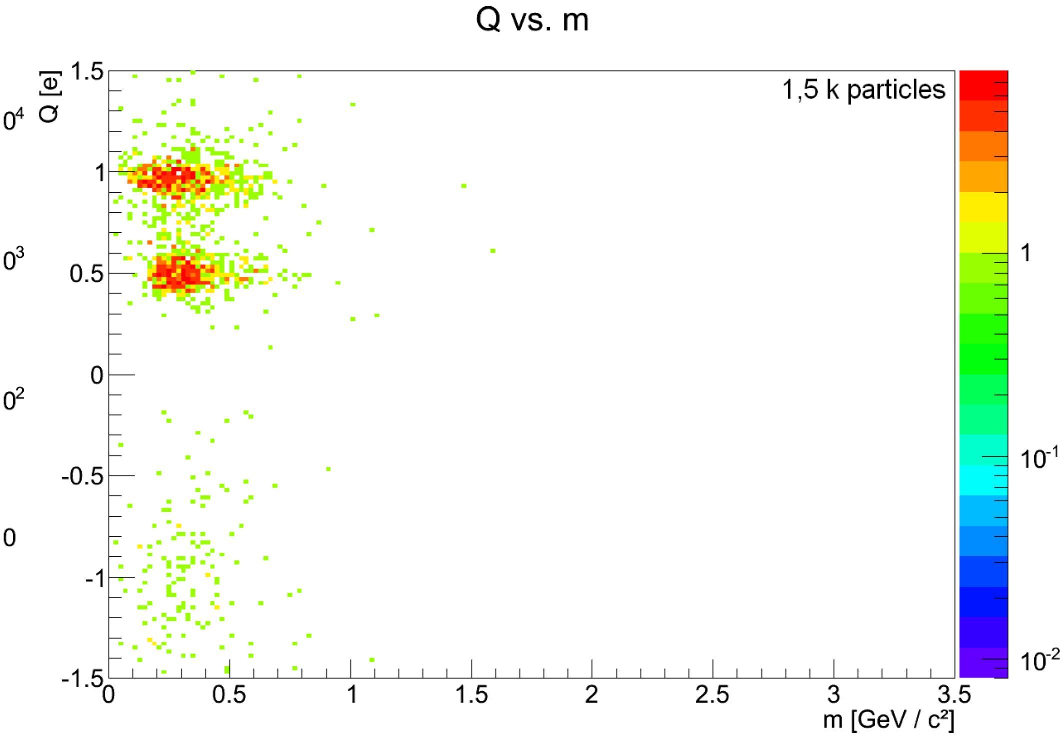
- Reason: Sort out particles from beam pipe interaction
- Keeping Condition: dr < 0,15 mm and dz < 15 mm

Momentum Cut

After the cut:



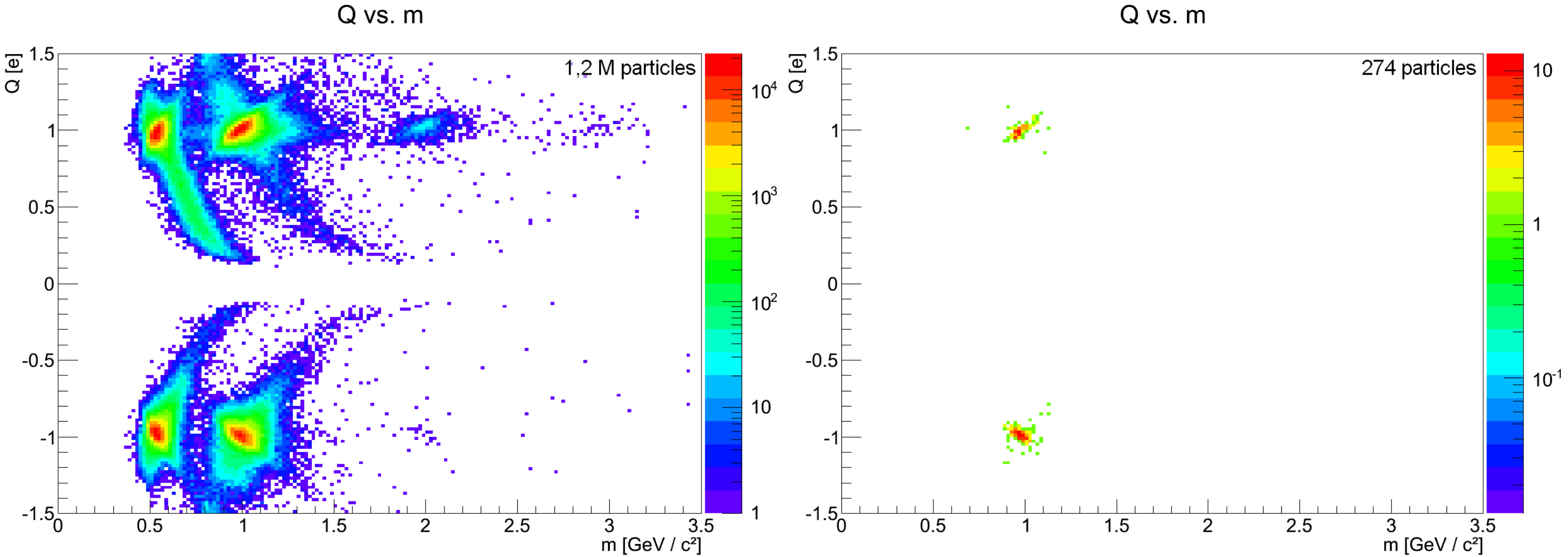
Ejected:



- Reason: Particles with too small p can't hit the TOF
- Keeping Condition: $p_{lab} > 0{,}3\,\frac{GeV}{c}$

Muon-Veto

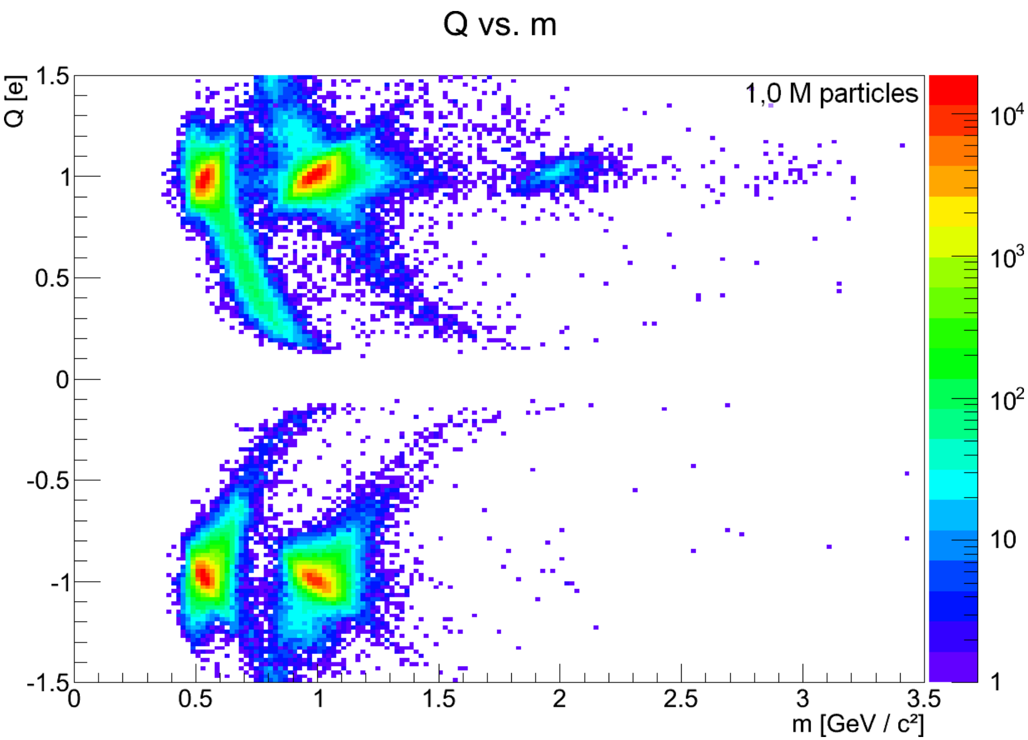
After the cut: Ejected:



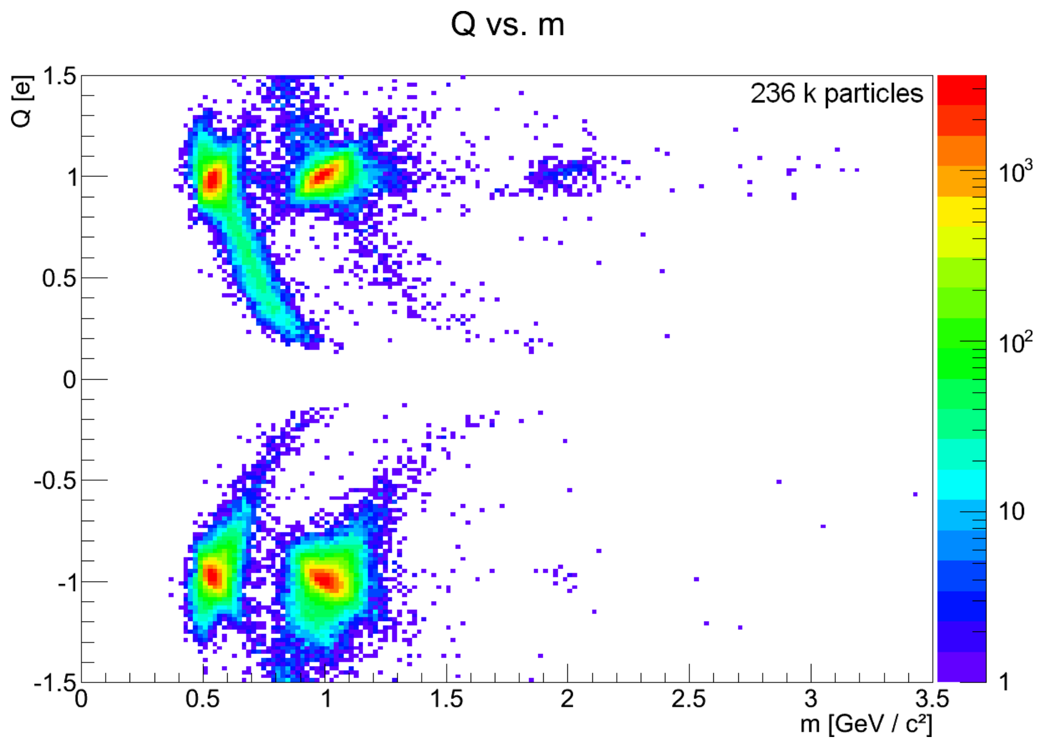
- Reason: Sort out muons very cleanly
- Keeping Condition: No correlated hit in the KLM-Detector

Cherenkov-Veto

After the cut:



Ejected:



- Reason: Particles with Cerenkov radiation are too fast
- Keeping Condition: No signal in the Cerenkov-Detector

End