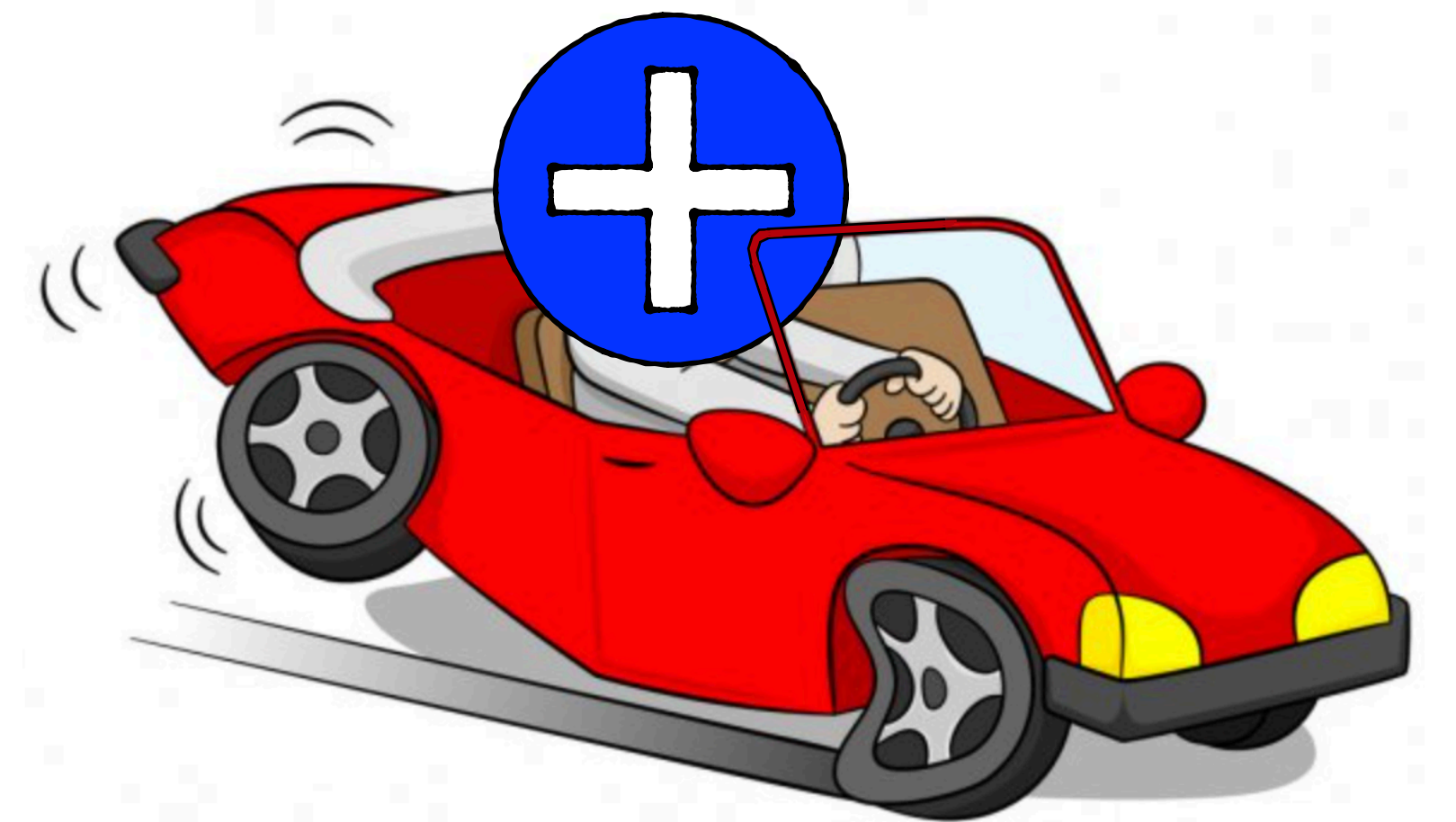


Proton calorimetric reconstruction

Mattia Fani, 2021-10-07

Outline

- Calorimetric reconstruction discrepancy
- Simulated data Prod4
- Run 5387
- Review on reconstruction parameters
- Remarks

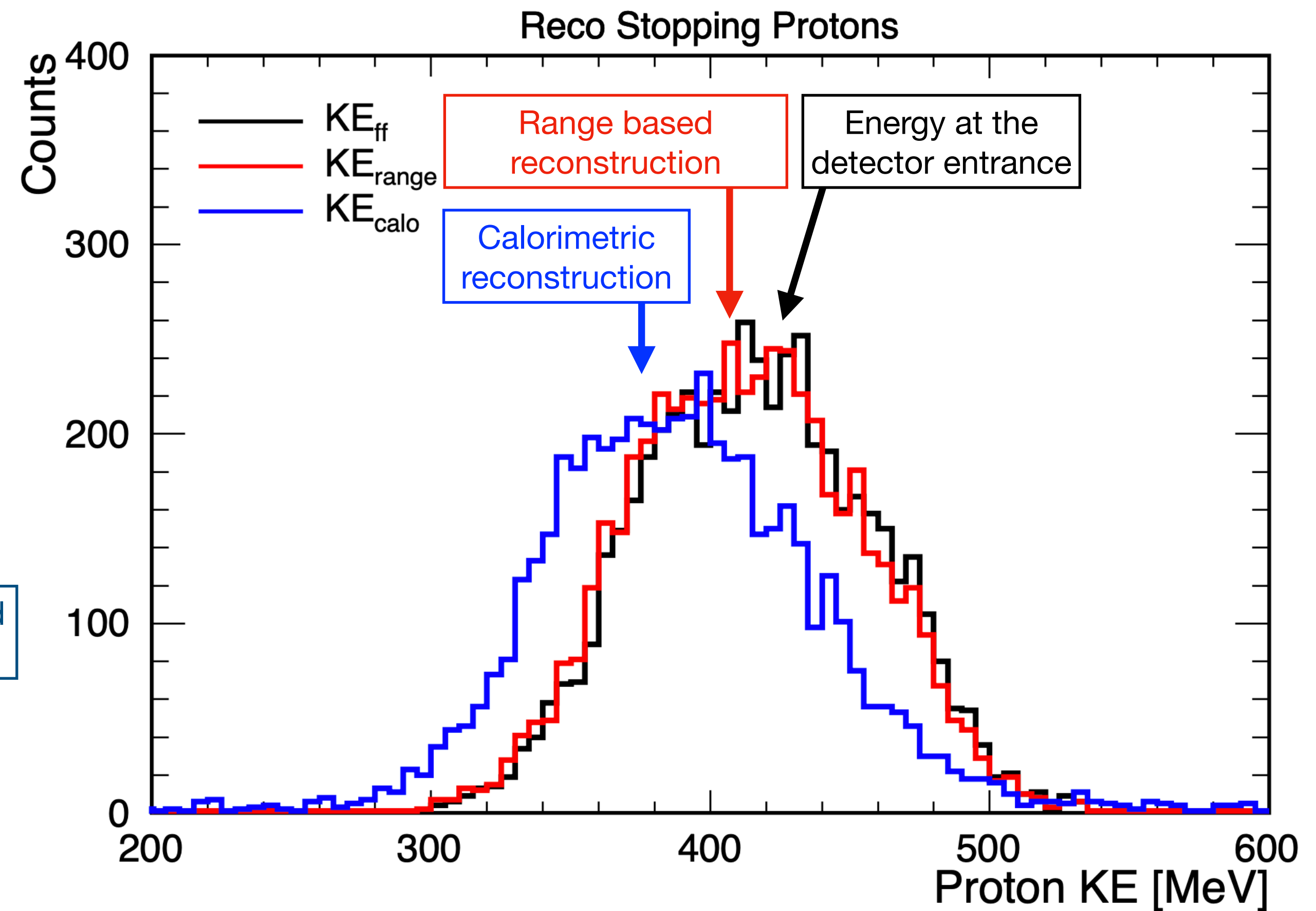
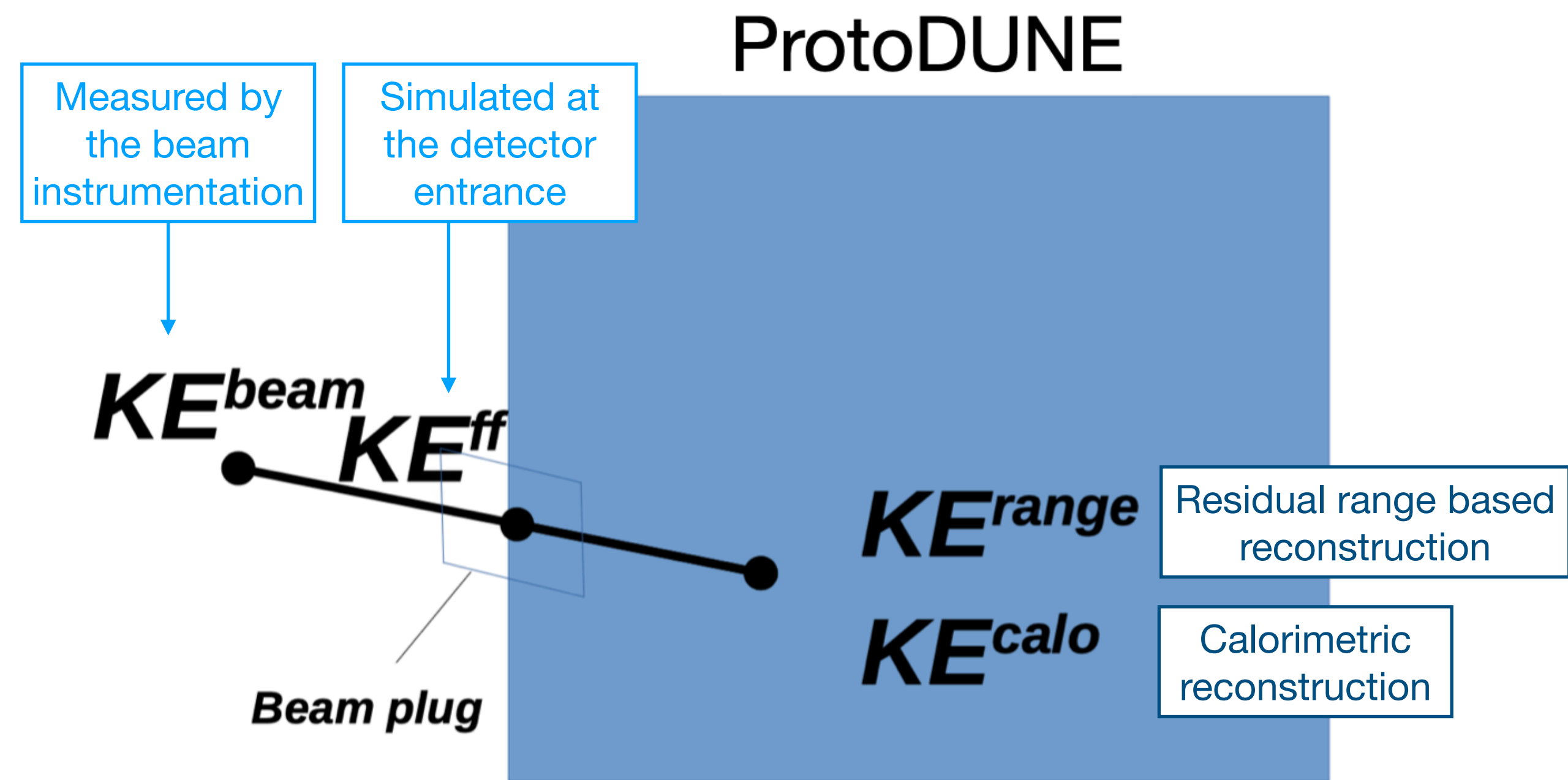


Stopping protons are only considered in this study

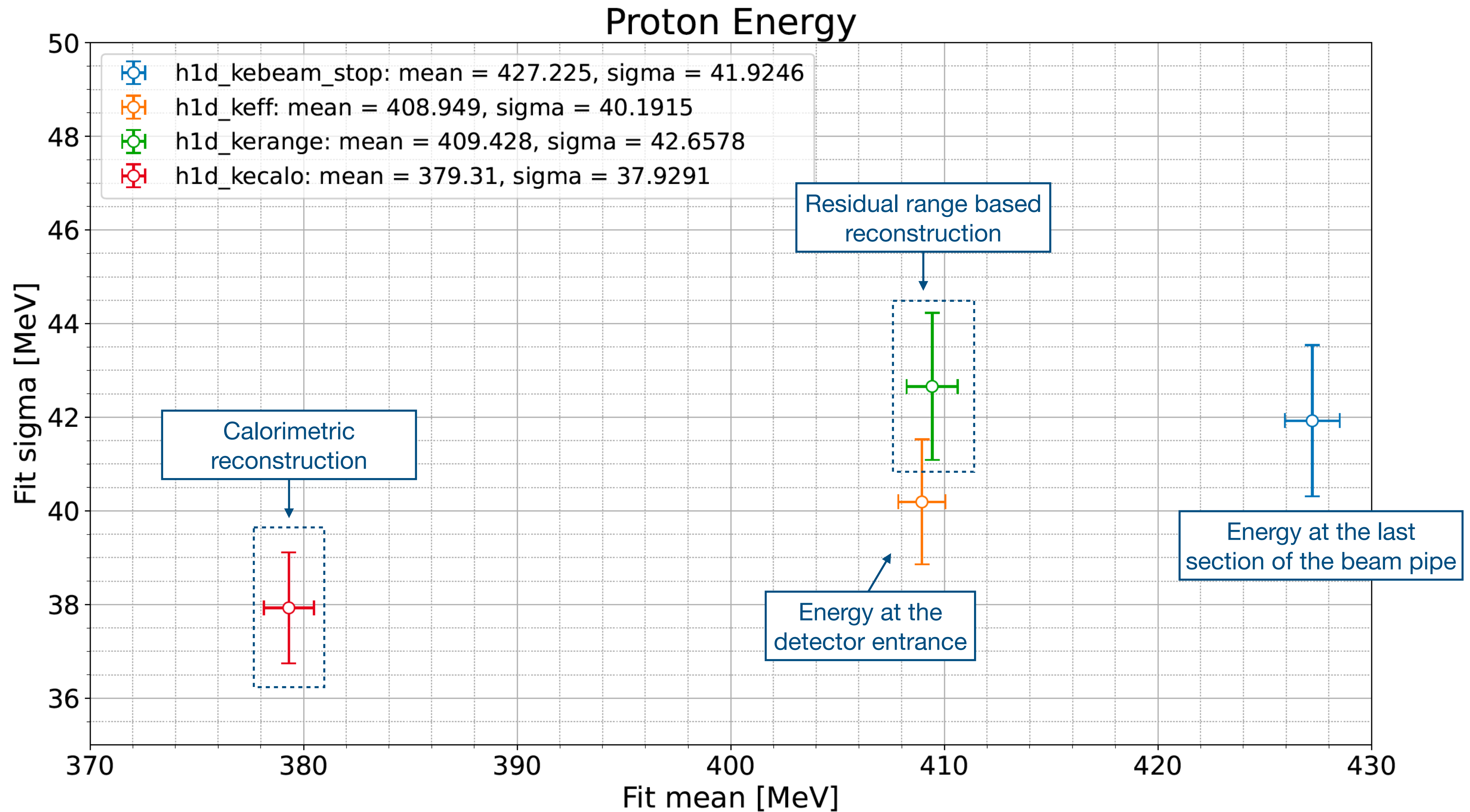
Calorimetric vs Range-based reconstruction

- Two reconstruction methods
- The deposited energy inside the detector should match the energy at the detector entrance

Simulated data
Prod4



~30 MeV discrepancy Range vs Calorimetric

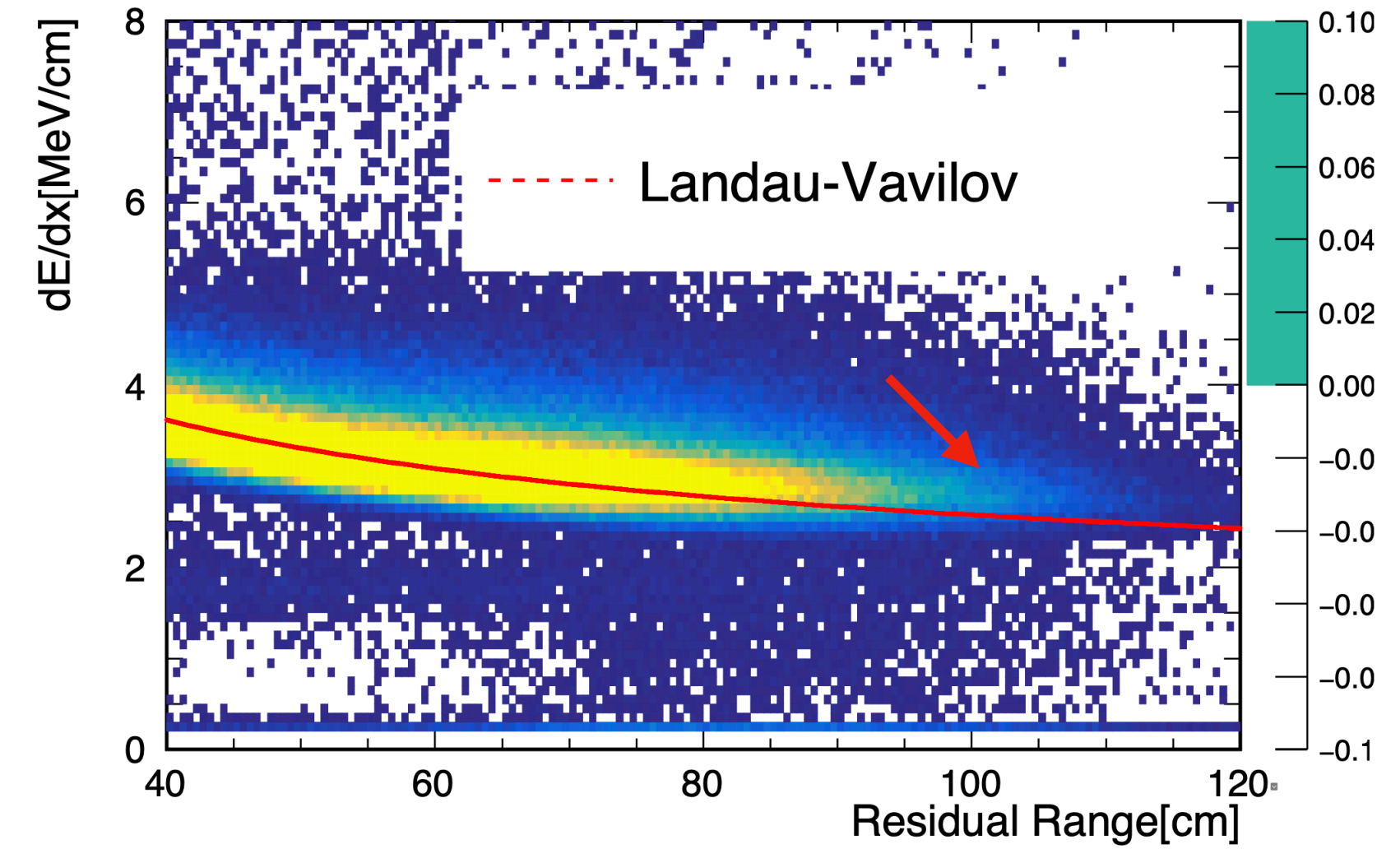
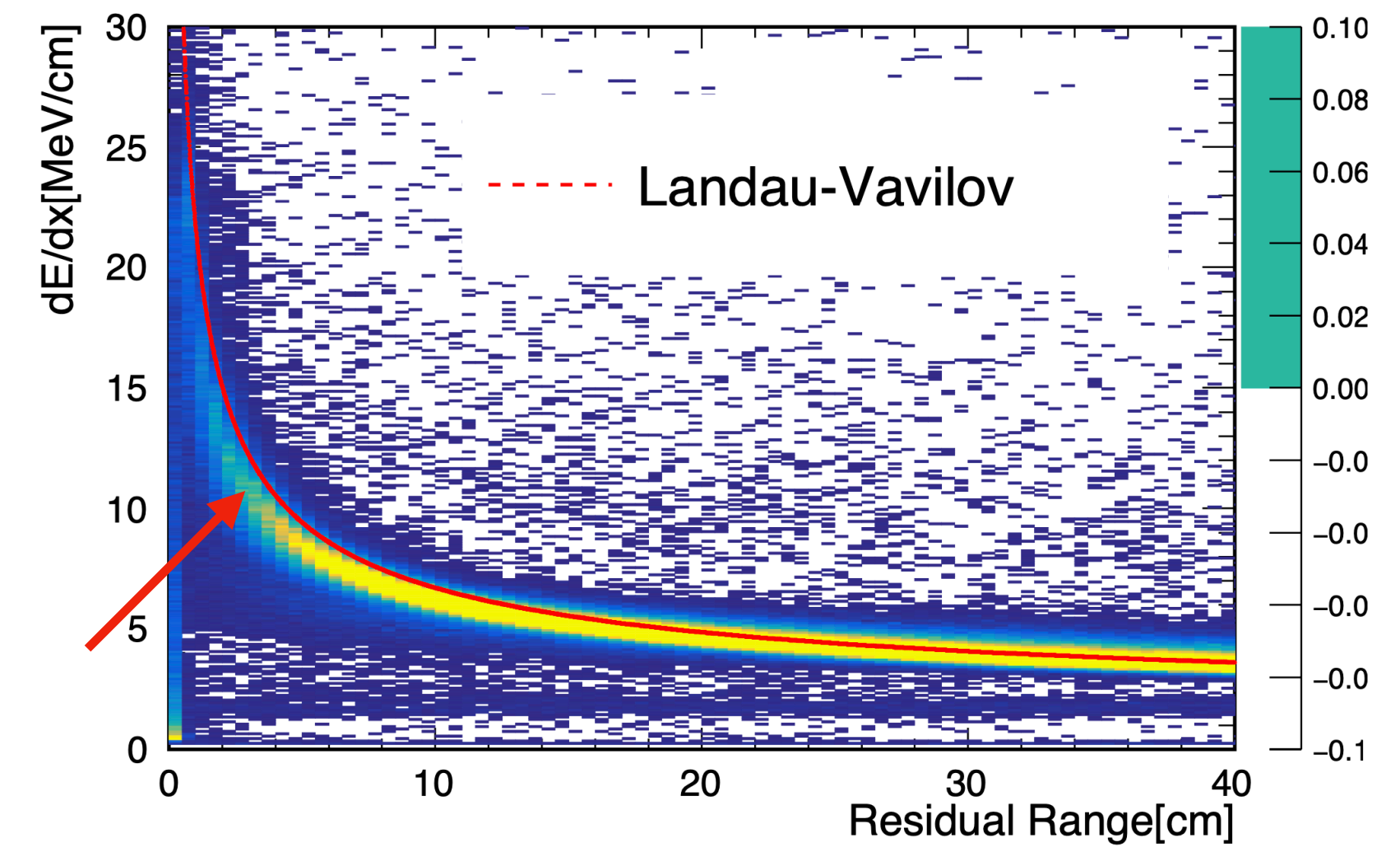
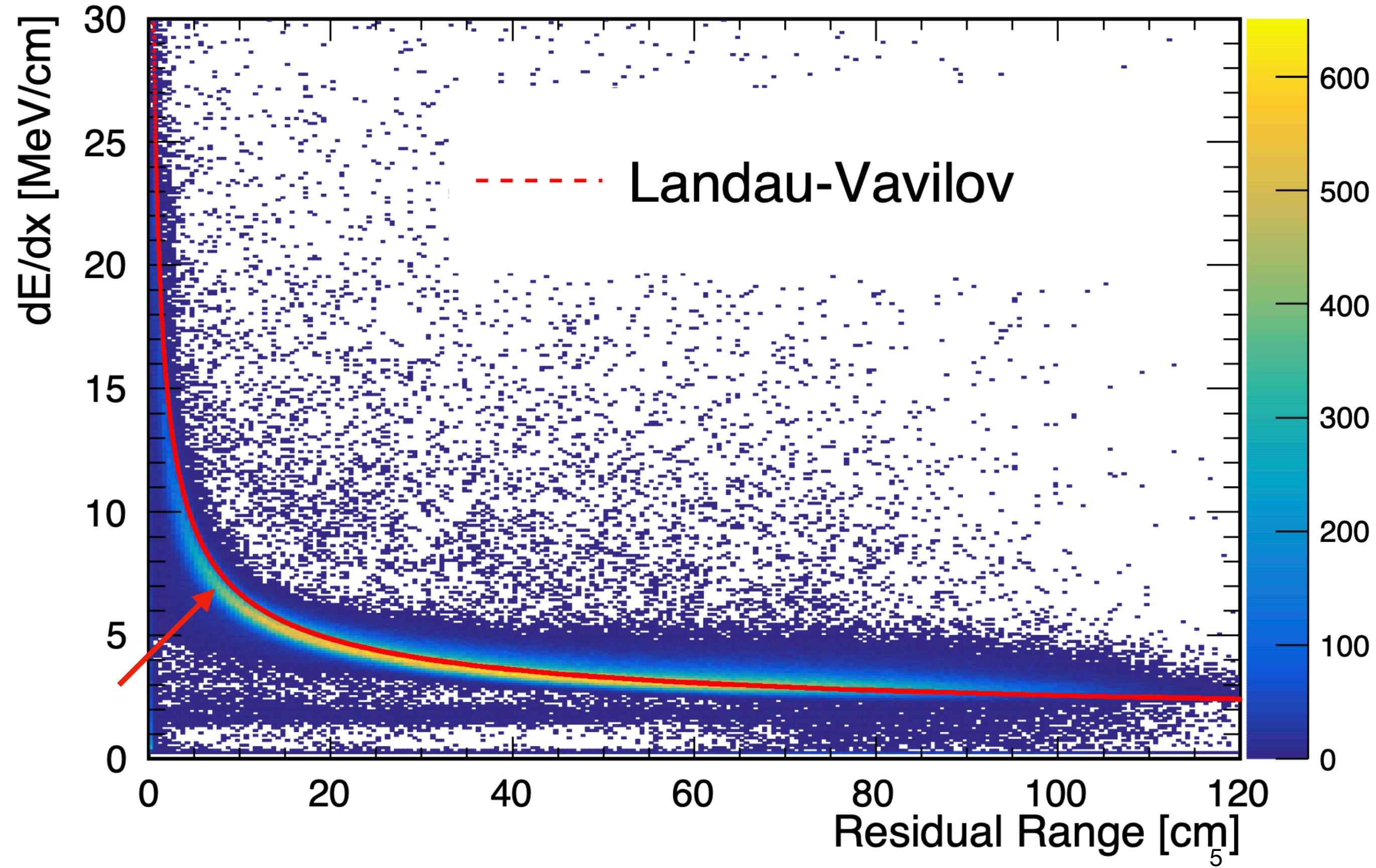


Simulated data
Prod4

Comparison with predictions

Low RR, high RR regions
show the highest discrepancy from theory

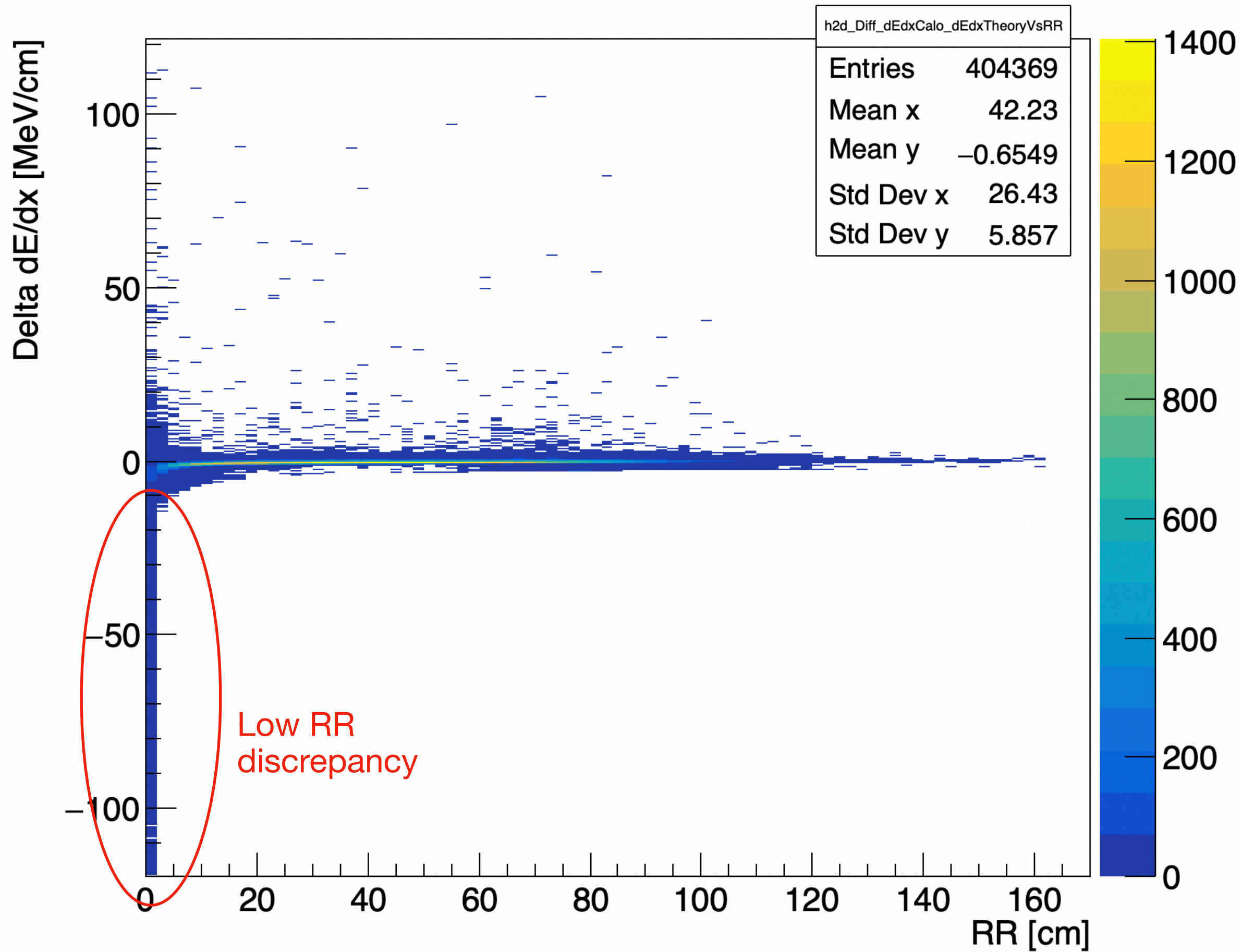
Simulated data
Prod4



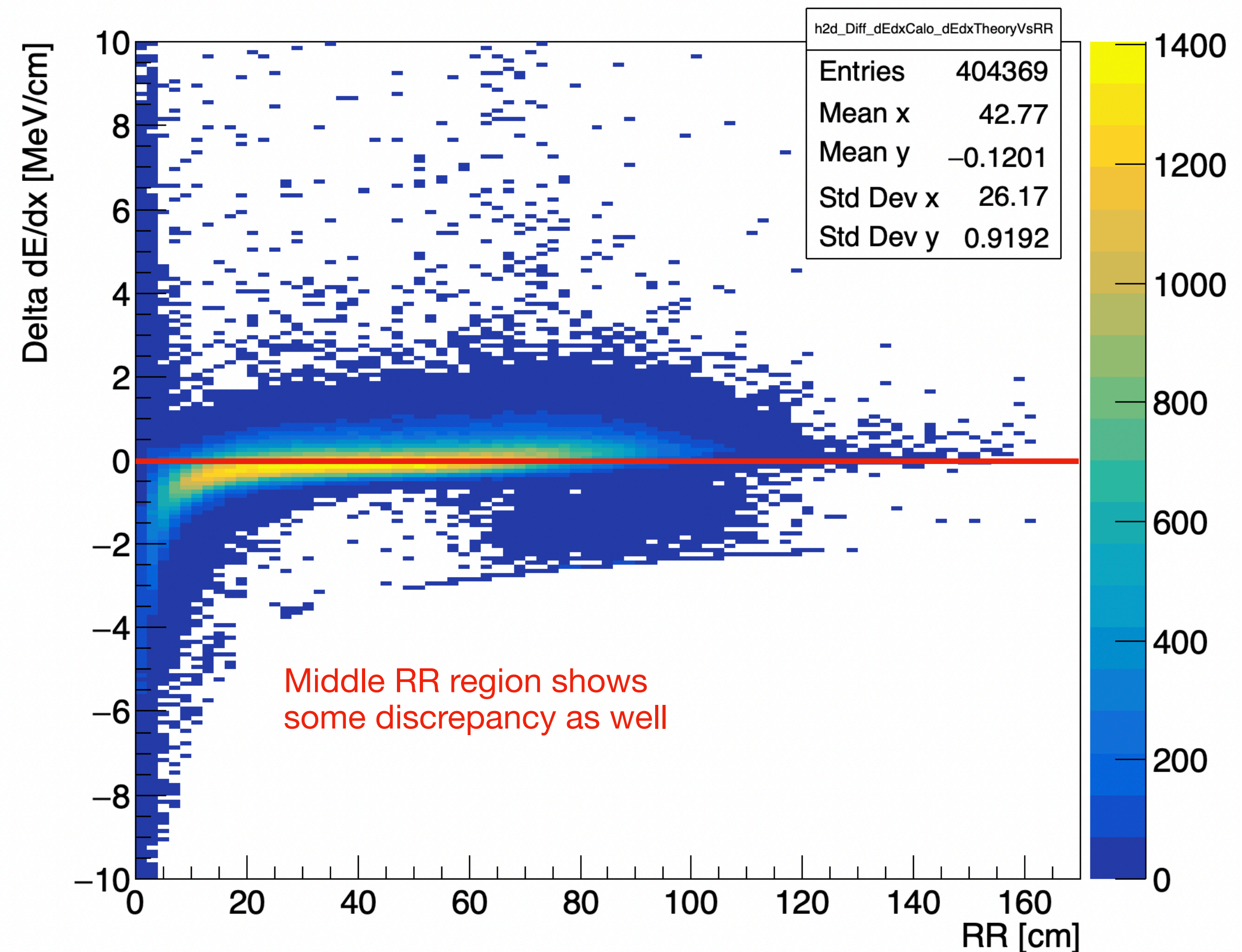
Direct comparison with prediction

Simulated data
Prod4

dE/dx(calor)-dE/dx(theory) Vs RR



dE/dx(calor)-dE/dx(theory) Vs RR



Reco parameters

From A. Waldron's talk, CM May 2021

```
double corrected_dqdx=dqdx*Cx*Cyz*normalisation_factor/calib_factor;
return (exp(corrected_dqdx*(betap/(Rho*Ef)*Wion))-alpha)/(betap/(Rho*Ef));
```

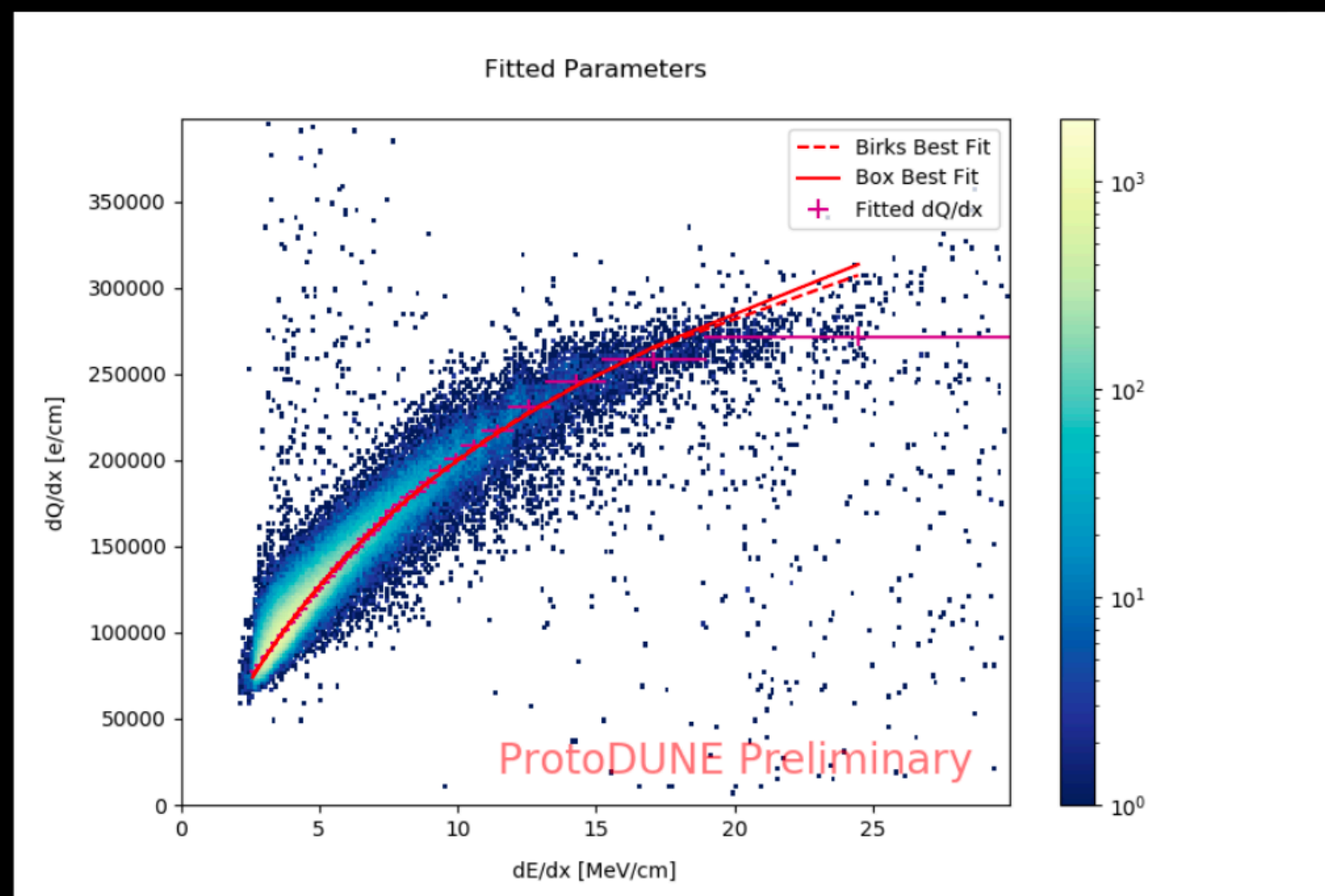
Modified Box Model

$$\frac{dQ}{dx} = \frac{1}{[\rho\epsilon\beta'] W_{ion}} \ln\left([\rho\epsilon\beta'] \frac{dE}{dx} + \alpha\right)$$

Where $\beta = \rho\epsilon\beta'$ and α and β' are free parameters to be fit. Other parameters from nature or detector:

- ▶ $W = 23.6$ MeV/electron (energy to ionise argon atom)
- ▶ $\epsilon = 0.4867$ kV/cm (drift electric field)
- ▶ $\rho = 1.383$ g/cm³ (density of liquid argon at 124.106 kPa)

Fit Results (Data)



Fitted Parameters (MC)

Modified Box Model:

- ▶ $p0 = 0.947 \pm 0.022$ (ArgoNeuT: 0.93 ± 0.02)
- ▶ $p1 = 0.213 \pm 0.005$ (ArgoNeuT: 0.212 ± 0.002) (kV/cm)(g/cm²)/MeV
- ▶ $\chi^2/ndof = 0.24$

Birks Model:

- ▶ $p0 = 0.851 \pm 0.019$ (ICARUS: 0.800 ± 0.003)
- ▶ $p1 = 0.061 \pm 0.004$ (ICARUS: 0.0486 ± 0.0006) (kV/cm)(g/cm²)/MeV
- ▶ $\chi^2/ndof = 0.45$

Results consistent with input parameters to MC (ArgoNeuT modified box model)

```
cali_dqdx=dqdx*Cx*Cyz*normalisation_factor/calib_factor
```

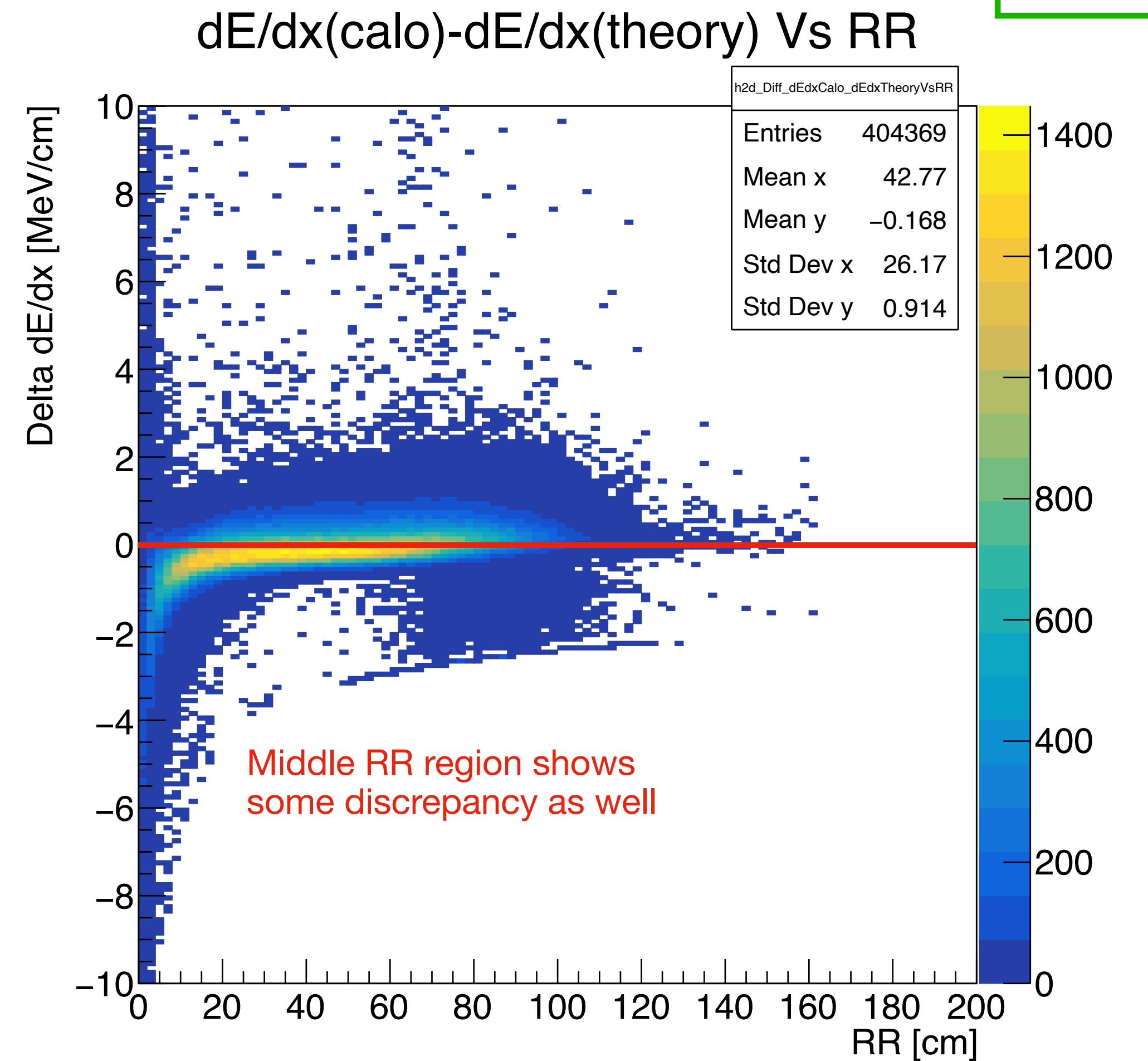
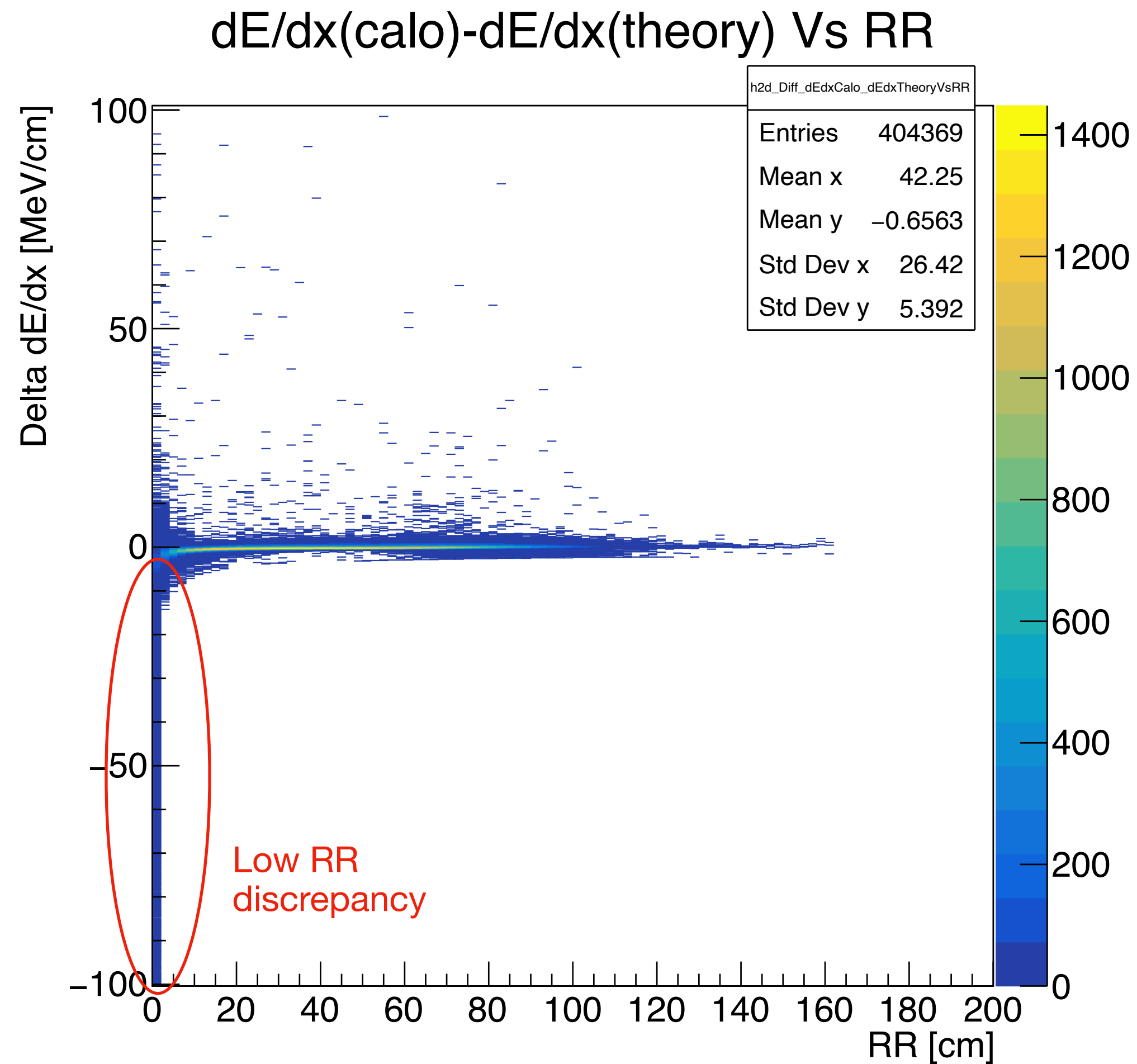
- ▶ Cx and Cyz space charge corrections
- ▶ normalisation_factor ? model independent
- ▶ calib_factor assumes Box + ArgoNeuT THIS IS BAD

Three free parameters: **alpha**, **betap**, **calib_factor**

Direct comparison with prediction

Abbey's parameters
calib_factor = 1.011e-3
alpha = 0.947
betap = 0.213

Simulated data
Prod4

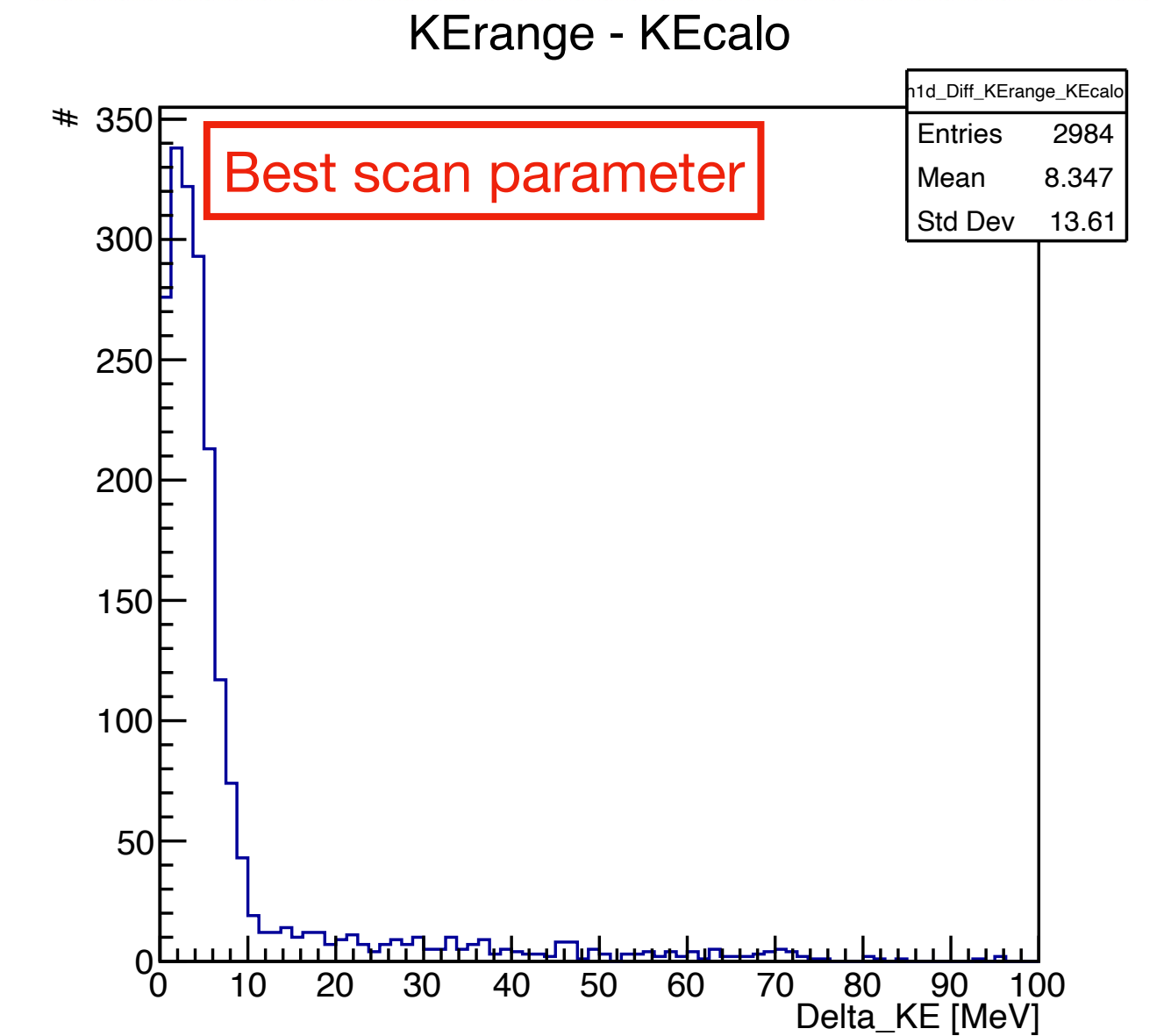
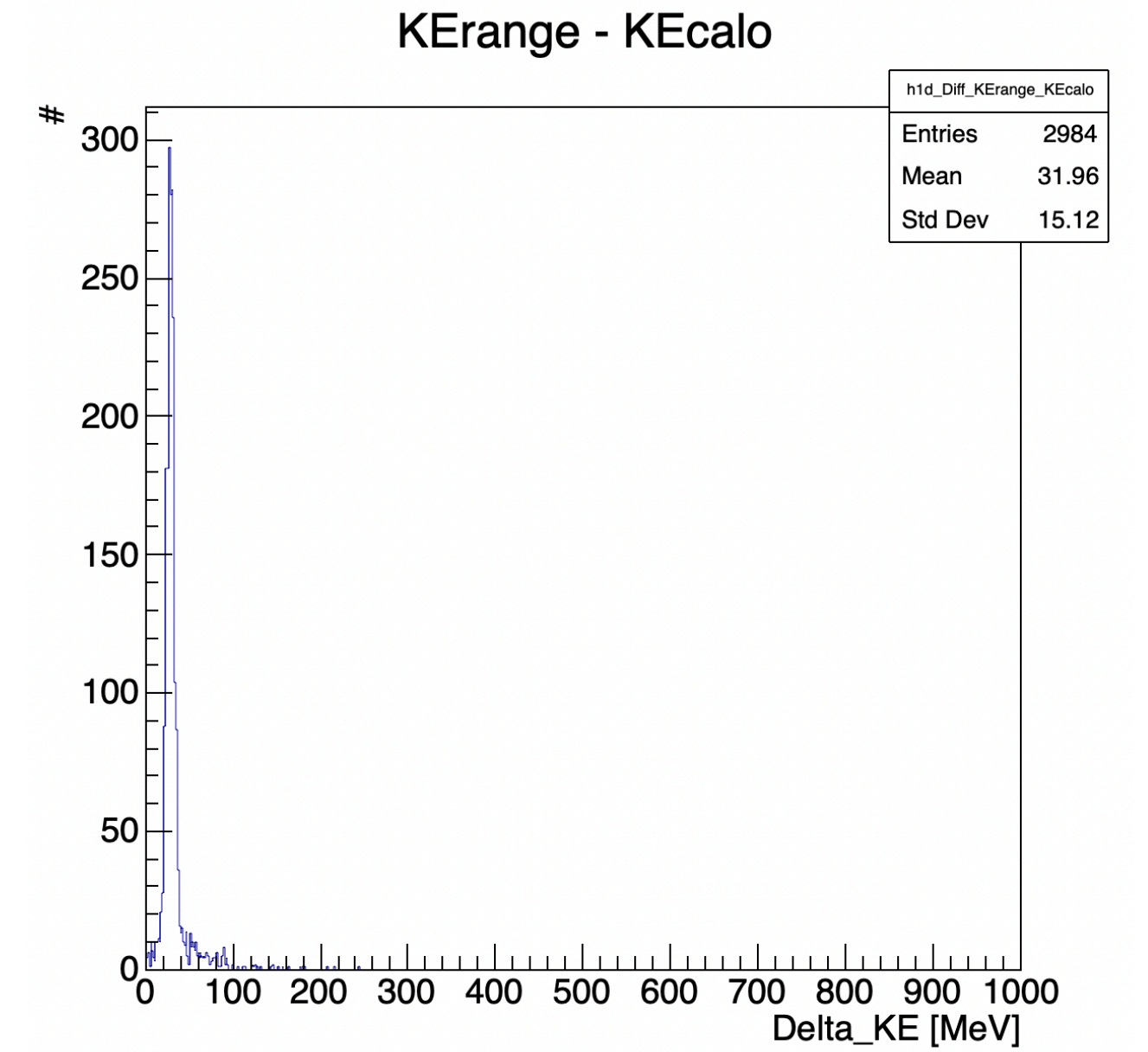
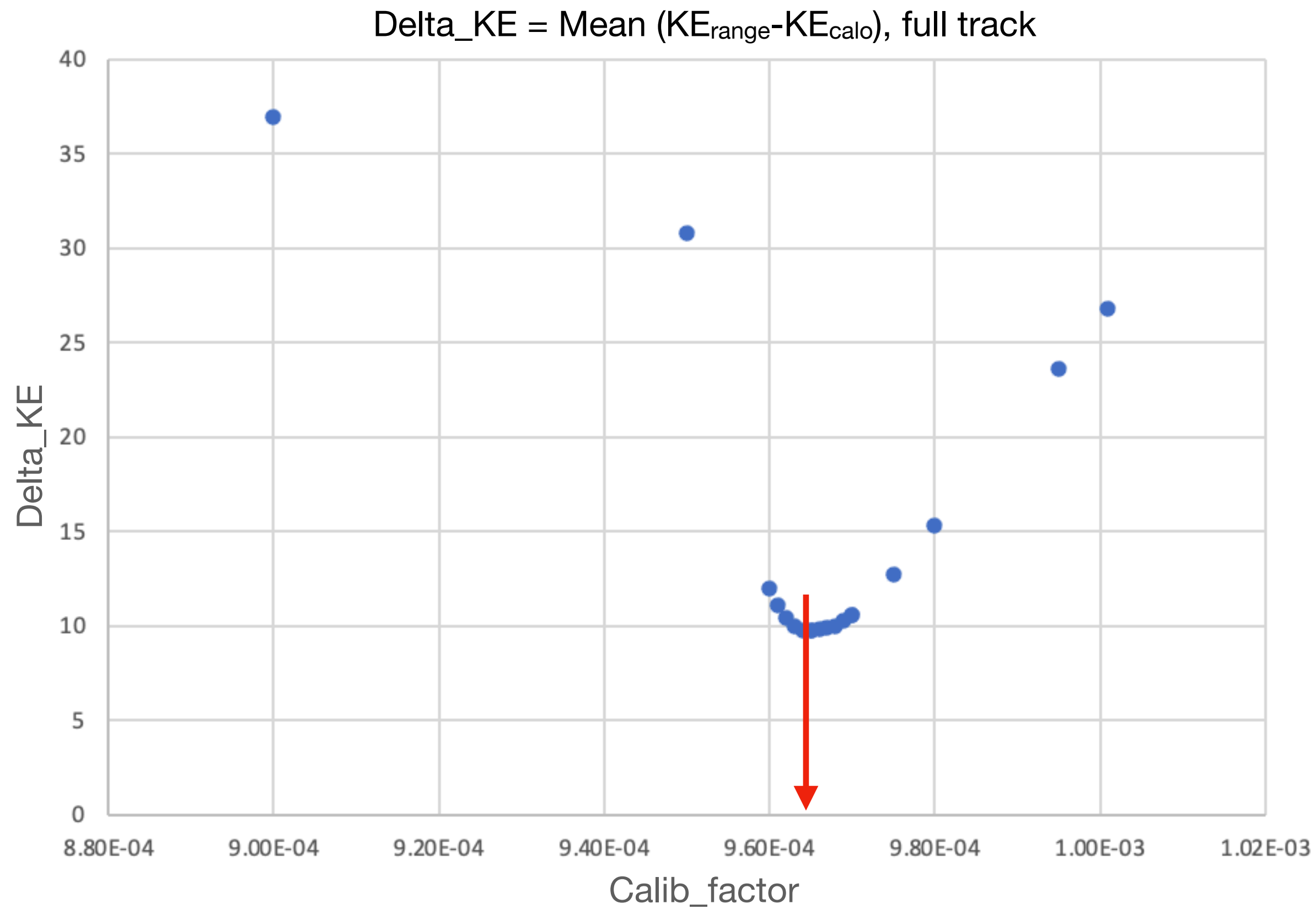


Scan on calib_factor

About 1-sigma from central fit parameter

Calib_factor Delta_KE

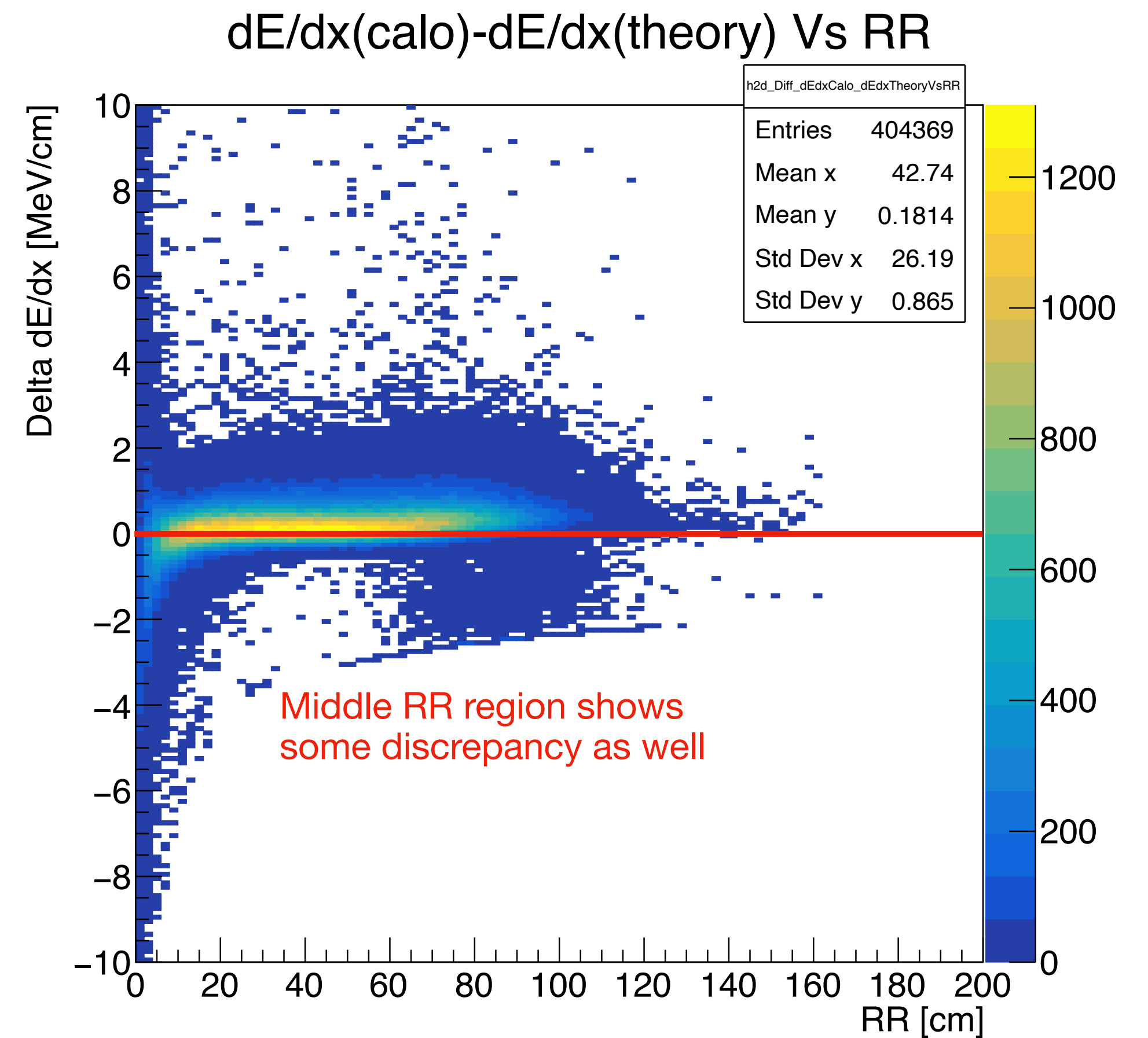
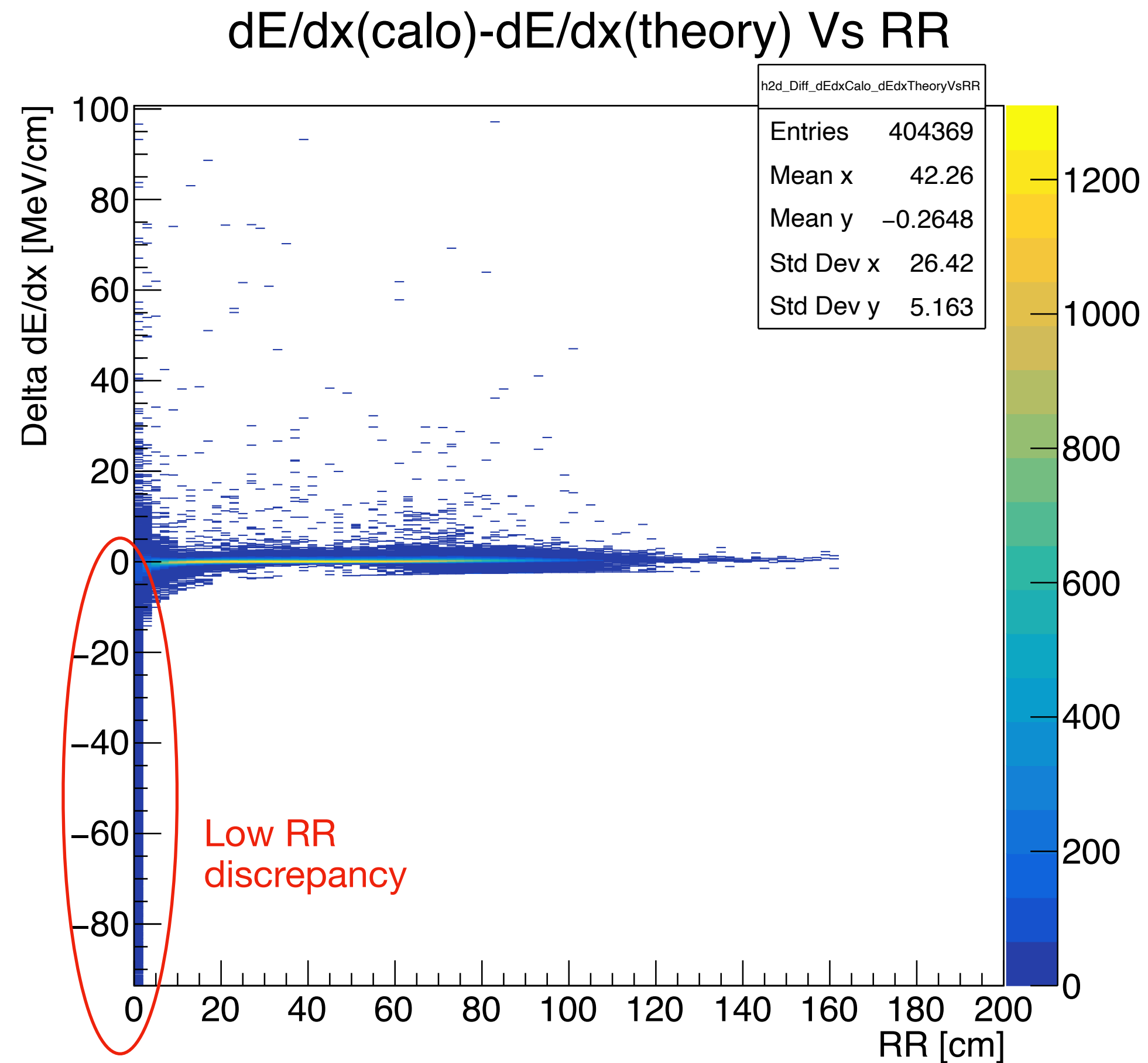
1.00E-03	26.84
9.95E-04	23.62
9.00E-04	36.99
9.50E-04	30.79
9.80E-04	15.32
9.70E-04	10.54
9.75E-04	12.71
9.65E-04	9.75
9.60E-04	11.9671
9.61E-04	11.094
9.62E-04	10.3891
9.63E-04	9.97907
9.64E-04	9.78562
9.65E-04	9.74876
9.66E-04	9.83932
9.67E-04	9.87982
9.68E-04	10.0143
9.69E-04	10.2474
9.70E-04	10.5449



Direct comparison with prediction

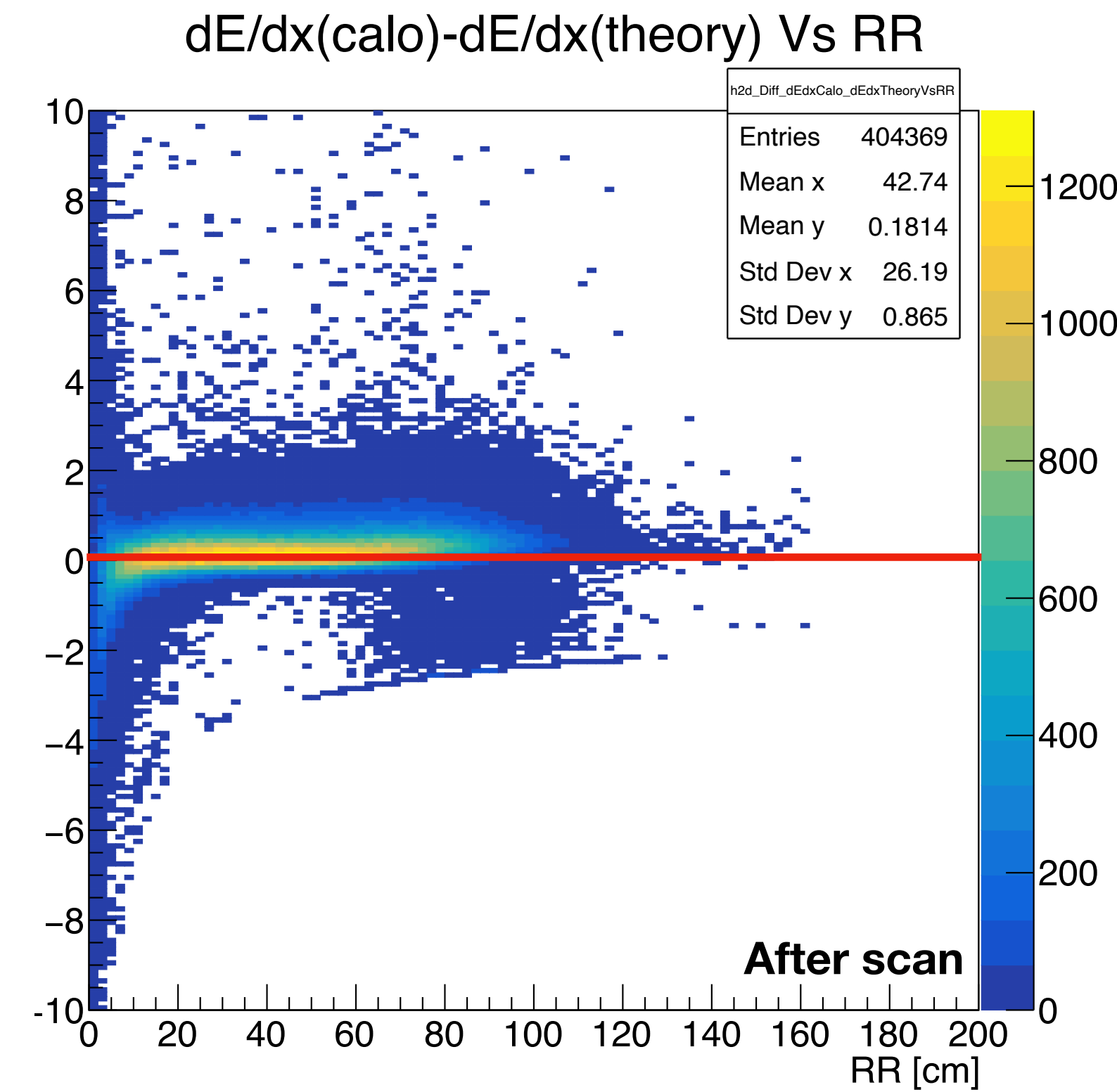
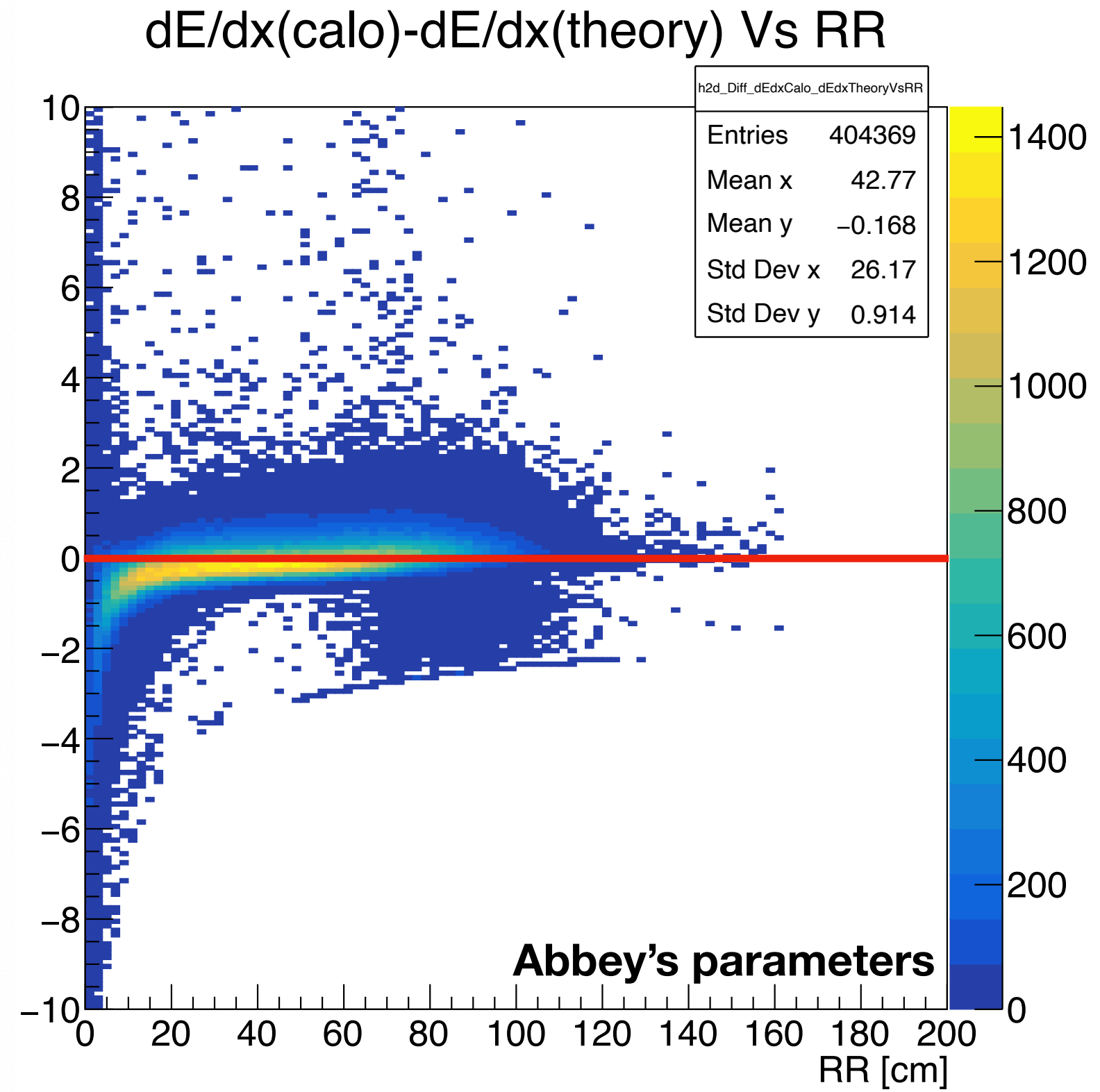
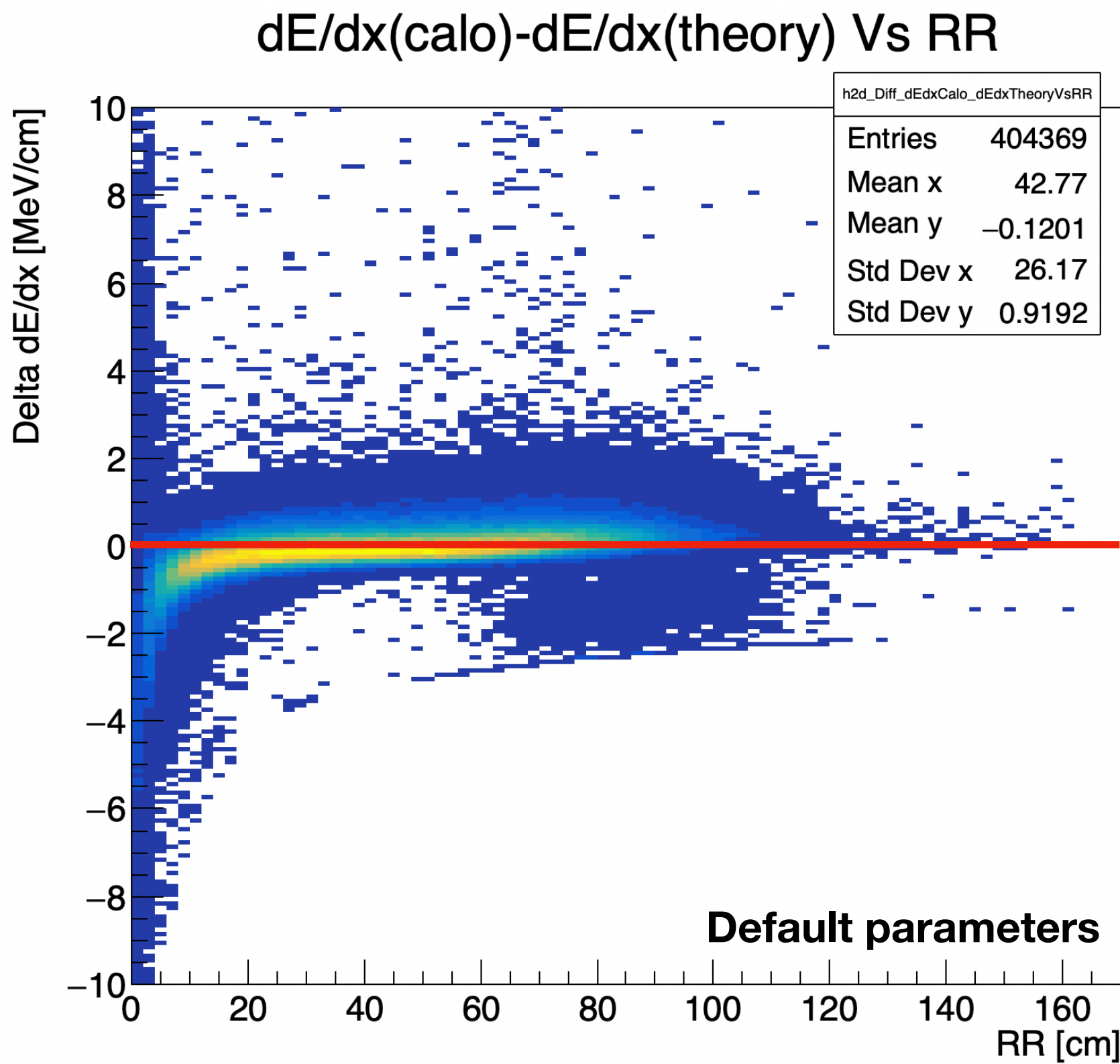
After scan
calib_factor = 9.65e-4
alpha = 0.947
betap = 0.213

Simulated data
Prod4



Comparison for the three sets of parameters

Simulated data
Prod4



calib_factor doesn't seem to play a determinant role

Scan on alpha, betap

Fit on modified box model, about 1-sigma

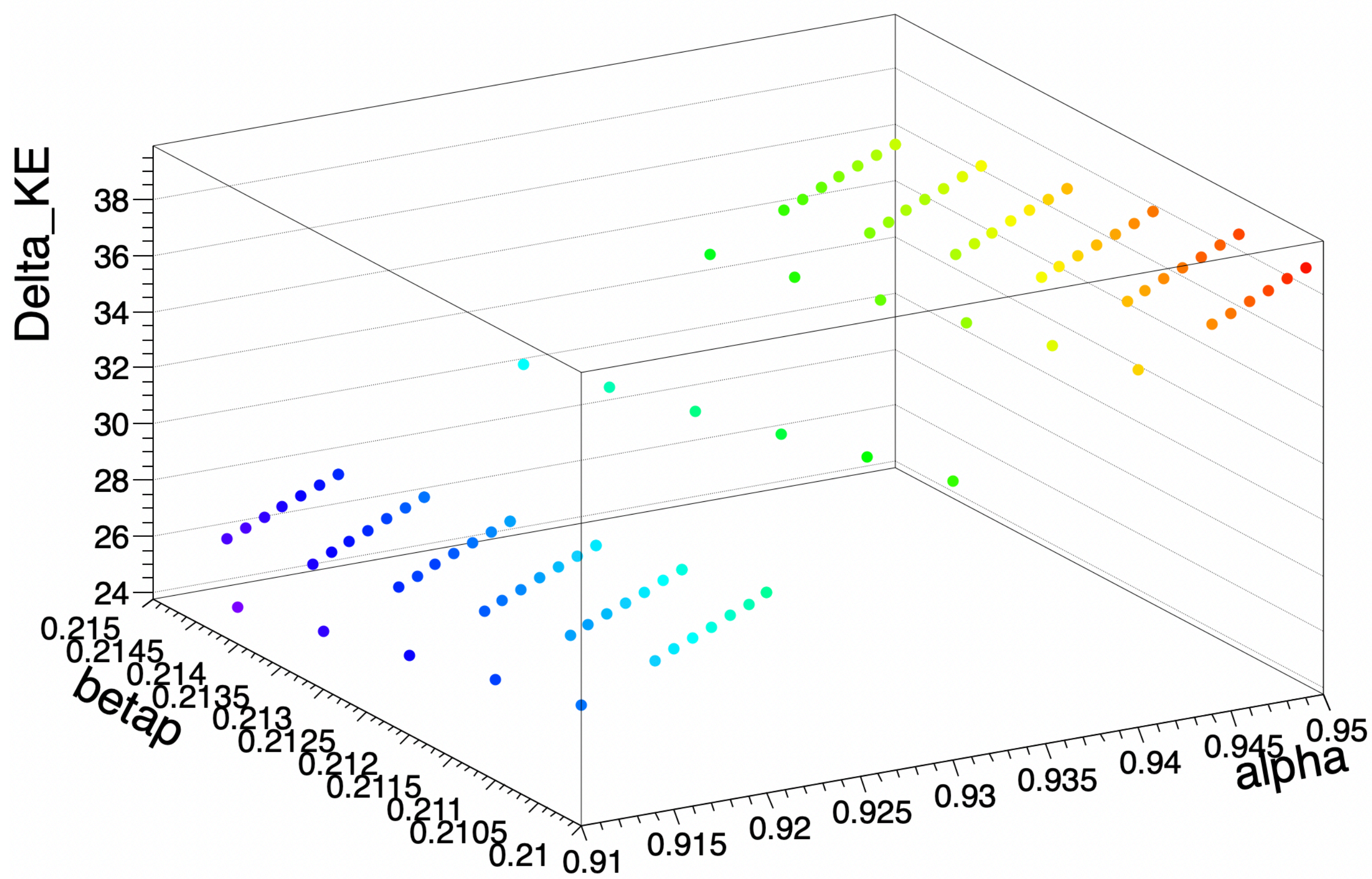
No evident minimum region

▶ $p0 = 0.947 \pm 0.022$ (ArgoNeuT: 0.93 ± 0.02)
▶ $p1 = 0.213 \pm 0.005$ (ArgoNeuT: 0.212 ± 0.002)

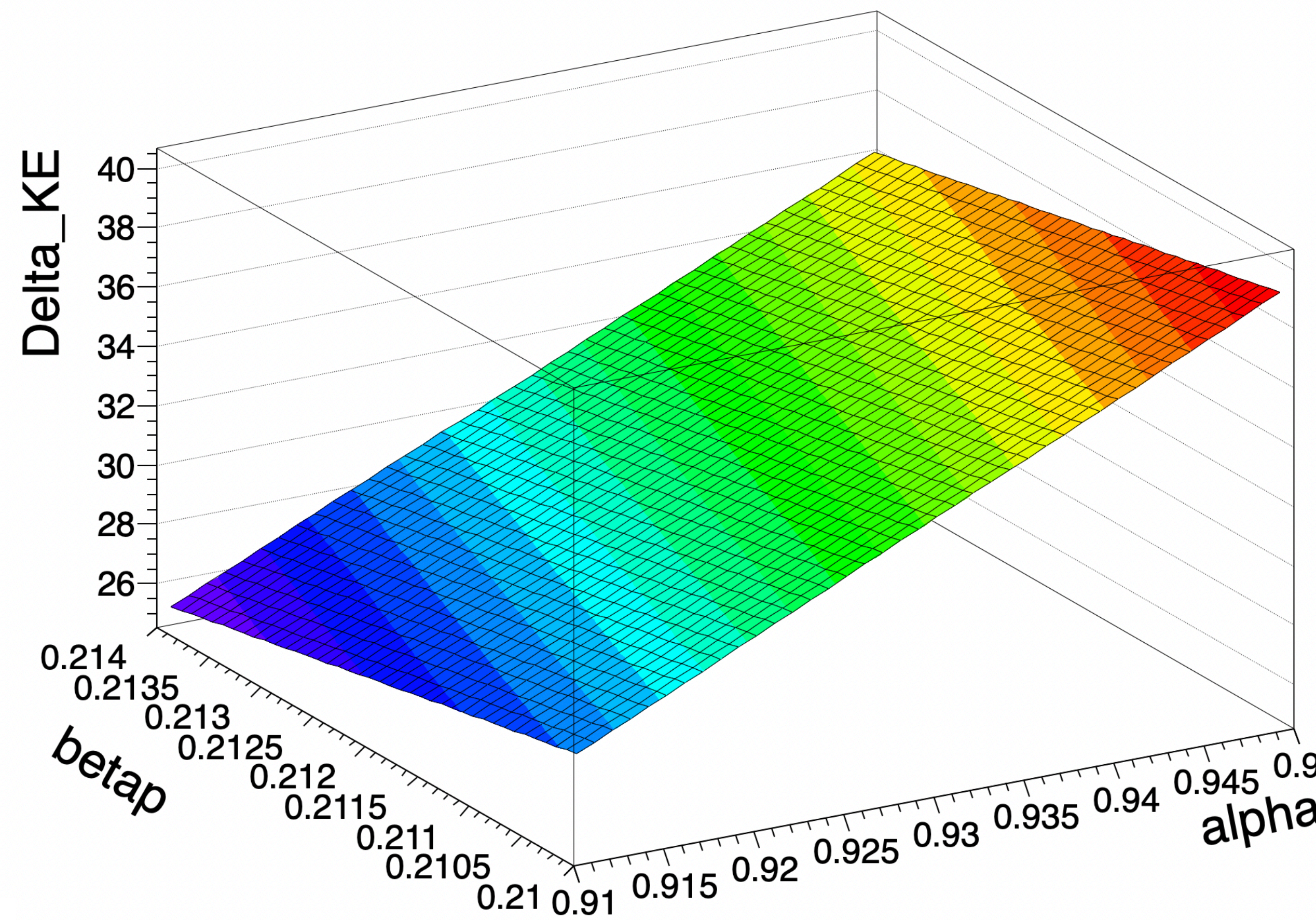
Use $KE_{range} - KE_{calo}$ as a benchmark
for the (alpha, beta) scan

Simulated data
Prod4

KE_range - KE_calo



KE_range - KE_calo



Scan on alpha, betap

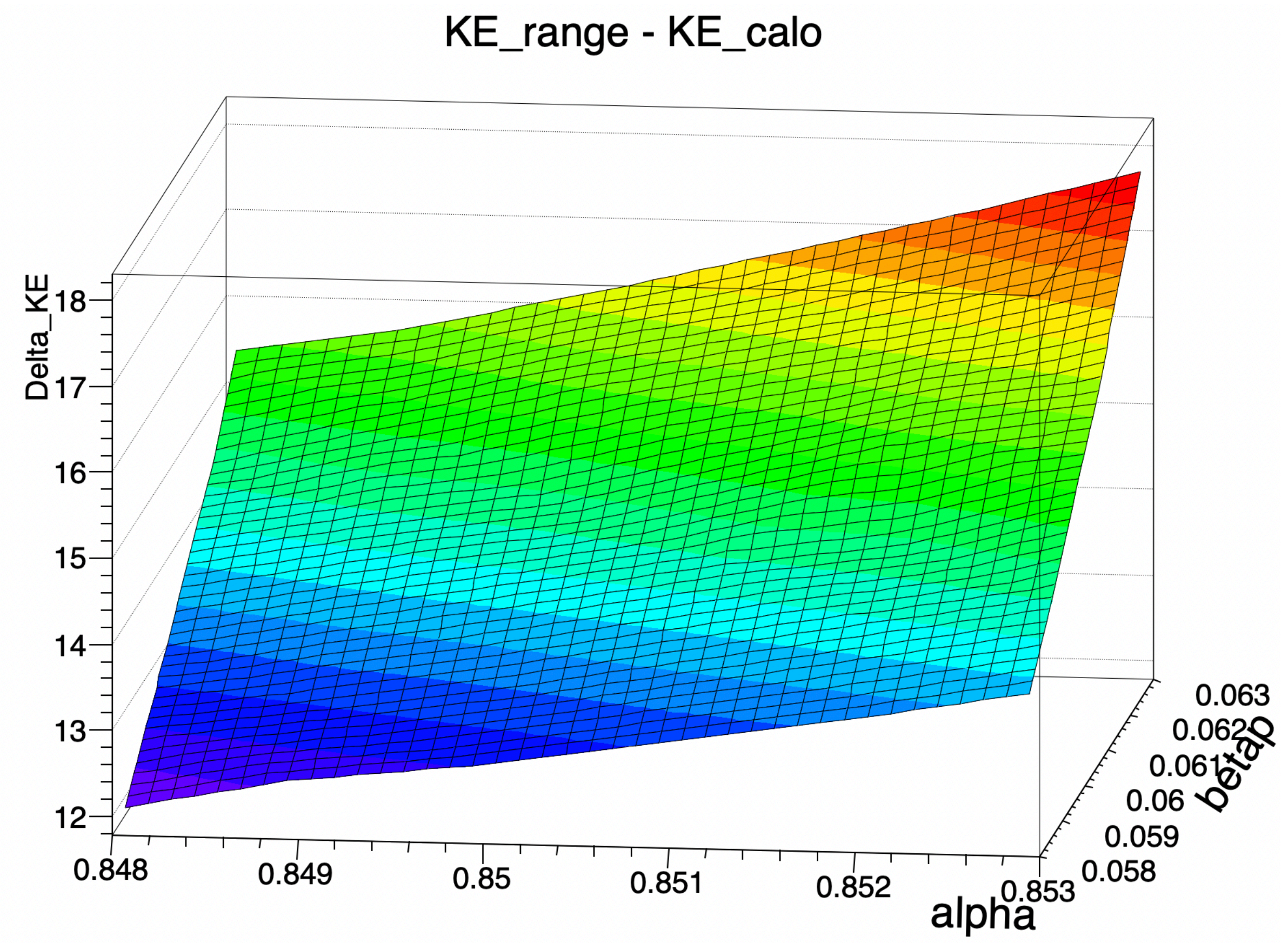
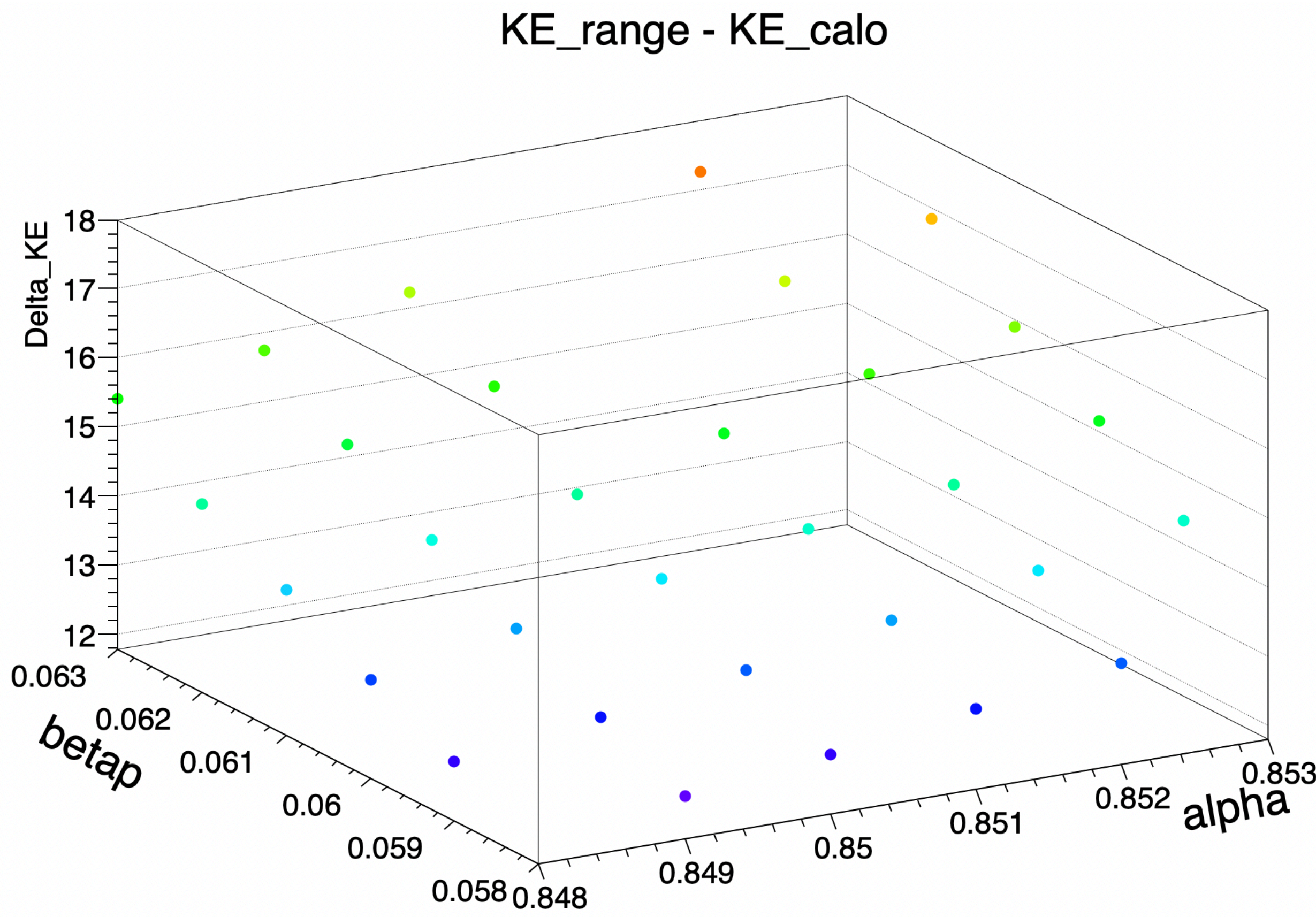
Fit on Birks model, 1-sigma

No evident minimum region

▶ $p0 = 0.851 \pm 0.019$ (ICARUS: 0.800 ± 0.003)
▶ $p1 = 0.061 \pm 0.004$ (ICARUS: 0.0486 ± 0.0006)

Use $KE_{range} - KE_{calo}$ as a benchmark
for the (alpha, beta) scan

Simulated data
Prod4



ProtoDUNE Run 5387

Parameter scan

Scan of alpha, betap parameters (Modified Box Model)
within **1-sigma** from Abbey's central fit parameters

Abbey's parameters

calib_factor = 1.000e-3
alpha = 0.912
betap = 0.195

Default parameters

calib_factor = 1.029e-3
alpha = 0.93
betap = 0.212

Best scan parameters

calib_factor = 1.000e-3
alpha = 0.892
betap = 0.198

Scan on alpha, betap

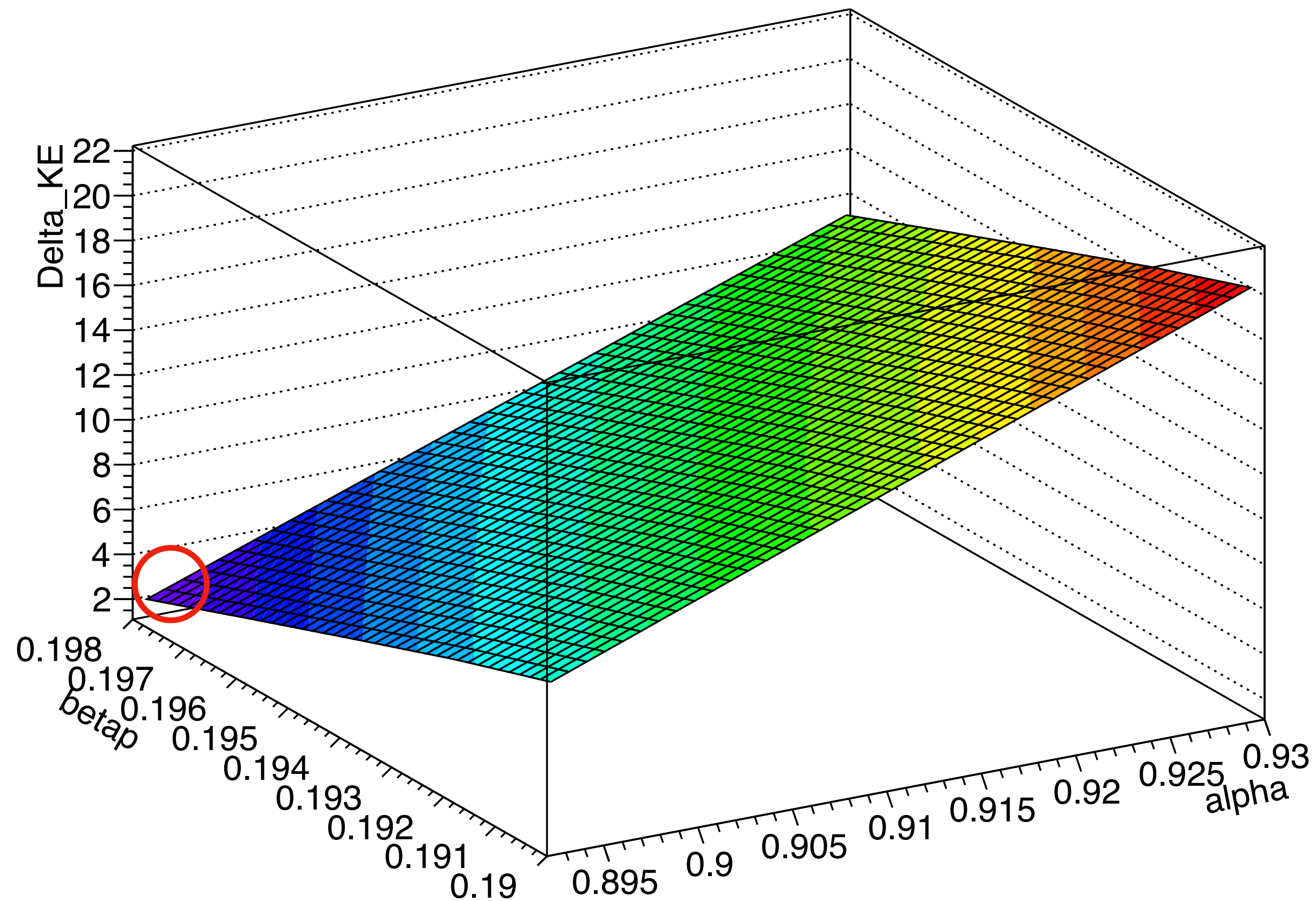
Abbey's fit on modified box model, 1-sigma

No evident minimum region

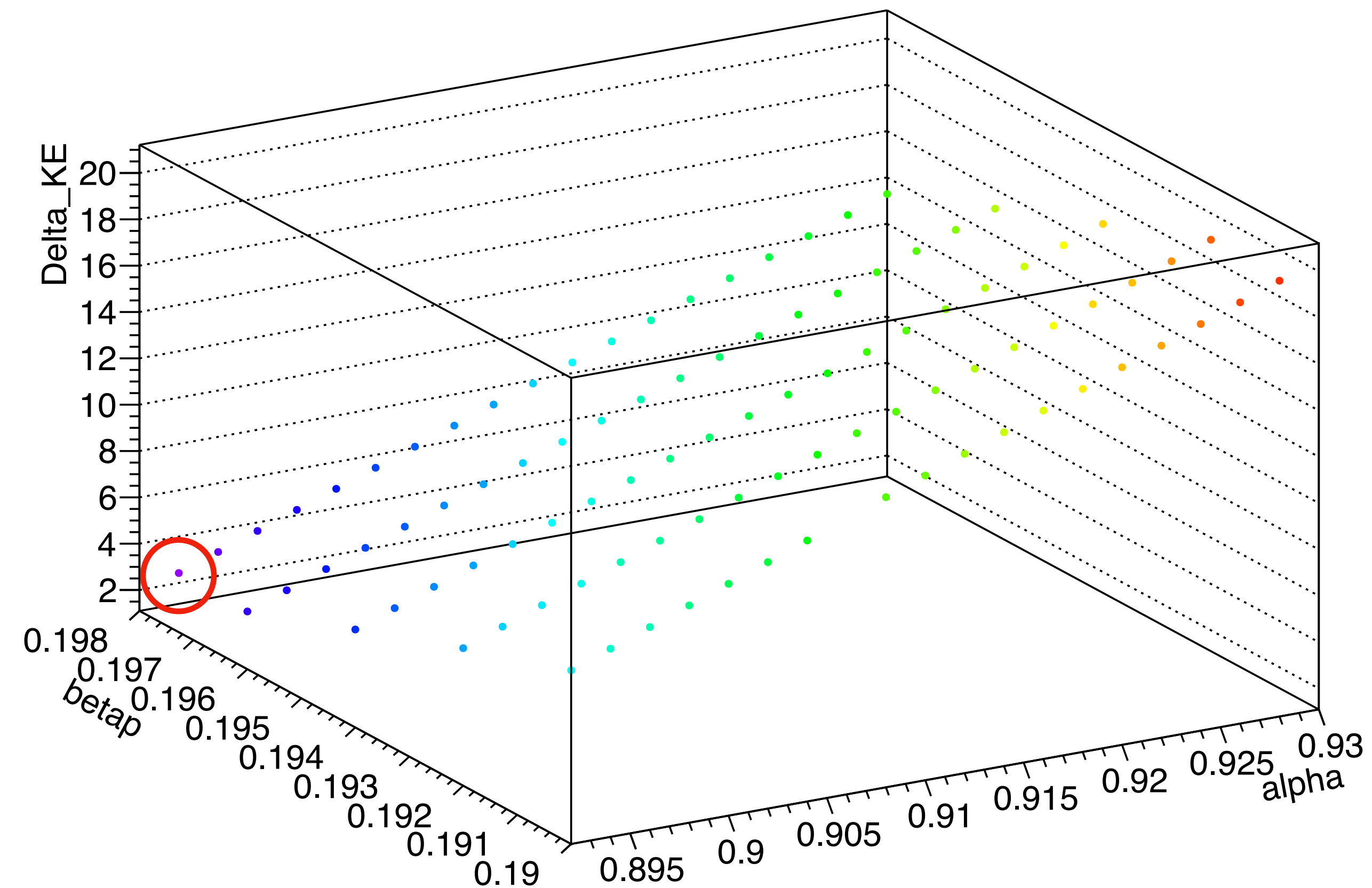
Best scan parameters:
alpha = 0.928, betap = 0.212
 $|\Delta KE_{Track}| = 1.824 \text{ MeV}$

Abbey's parameters
calib_factor = 1.000e-3
alpha = 0.912
betap = 0.195

KE_range - KE_calo

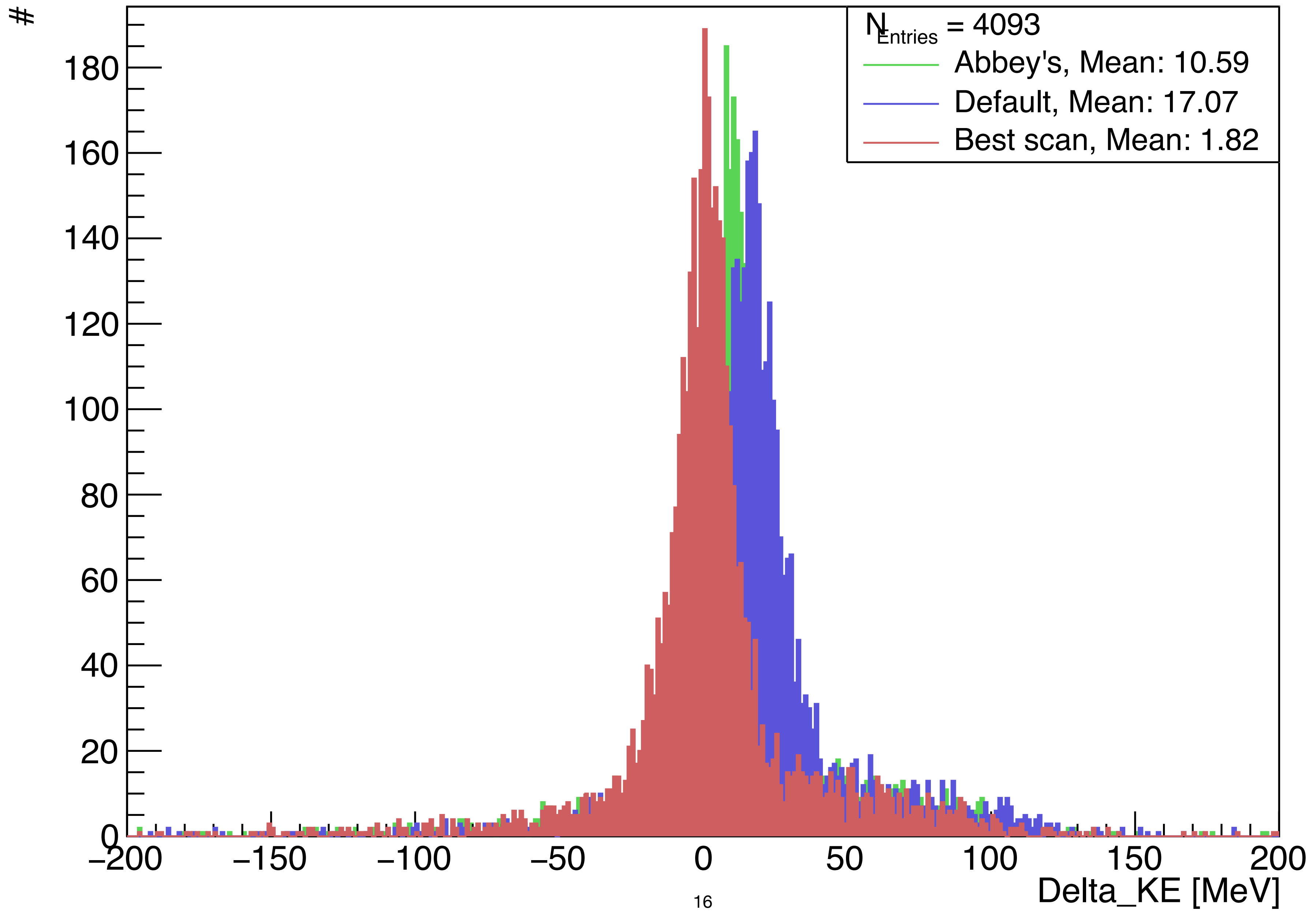


KE_range - KE_calo



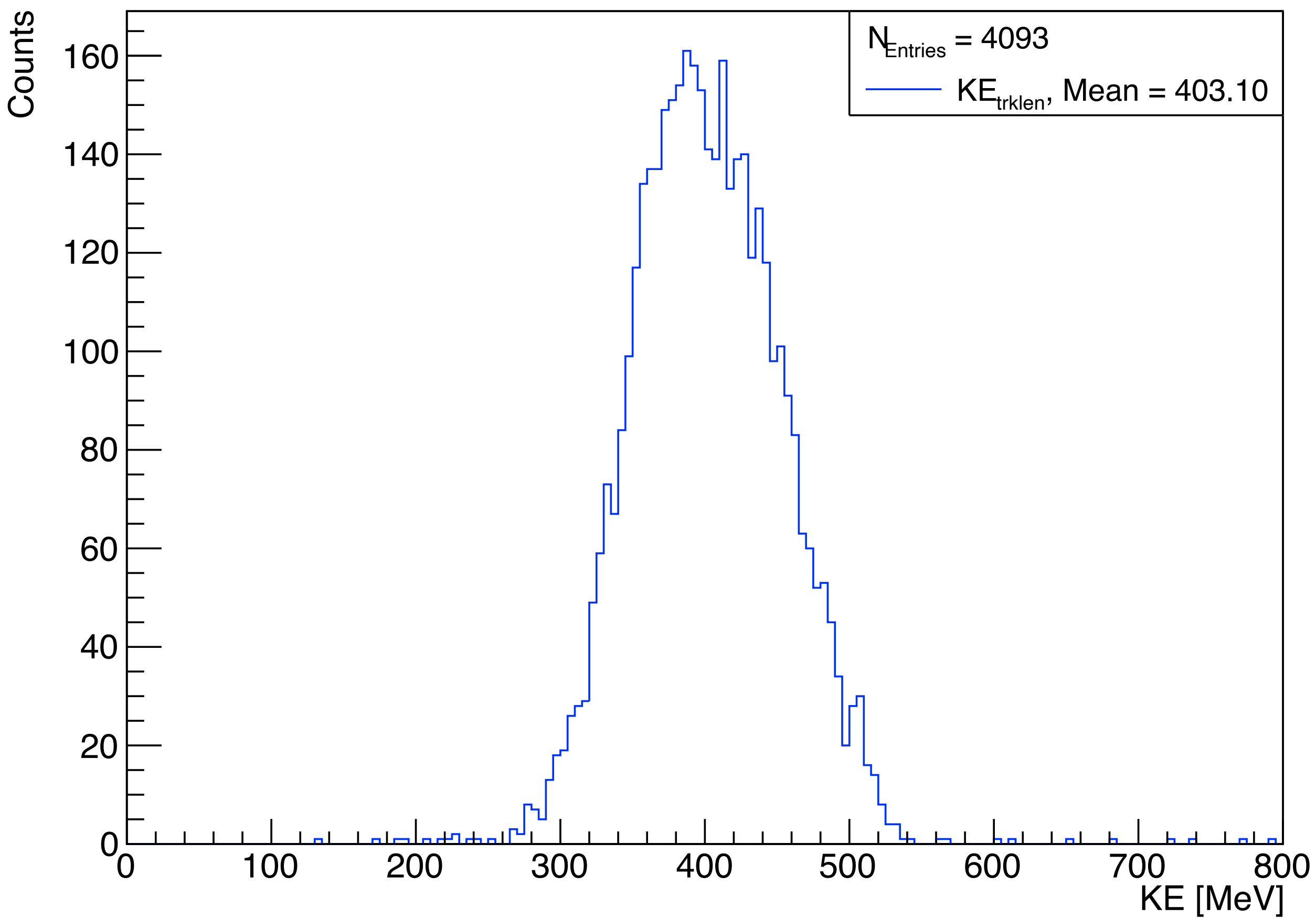
1-sigma range

$KE_{\text{range}} - KE_{\text{calo}}$ per track

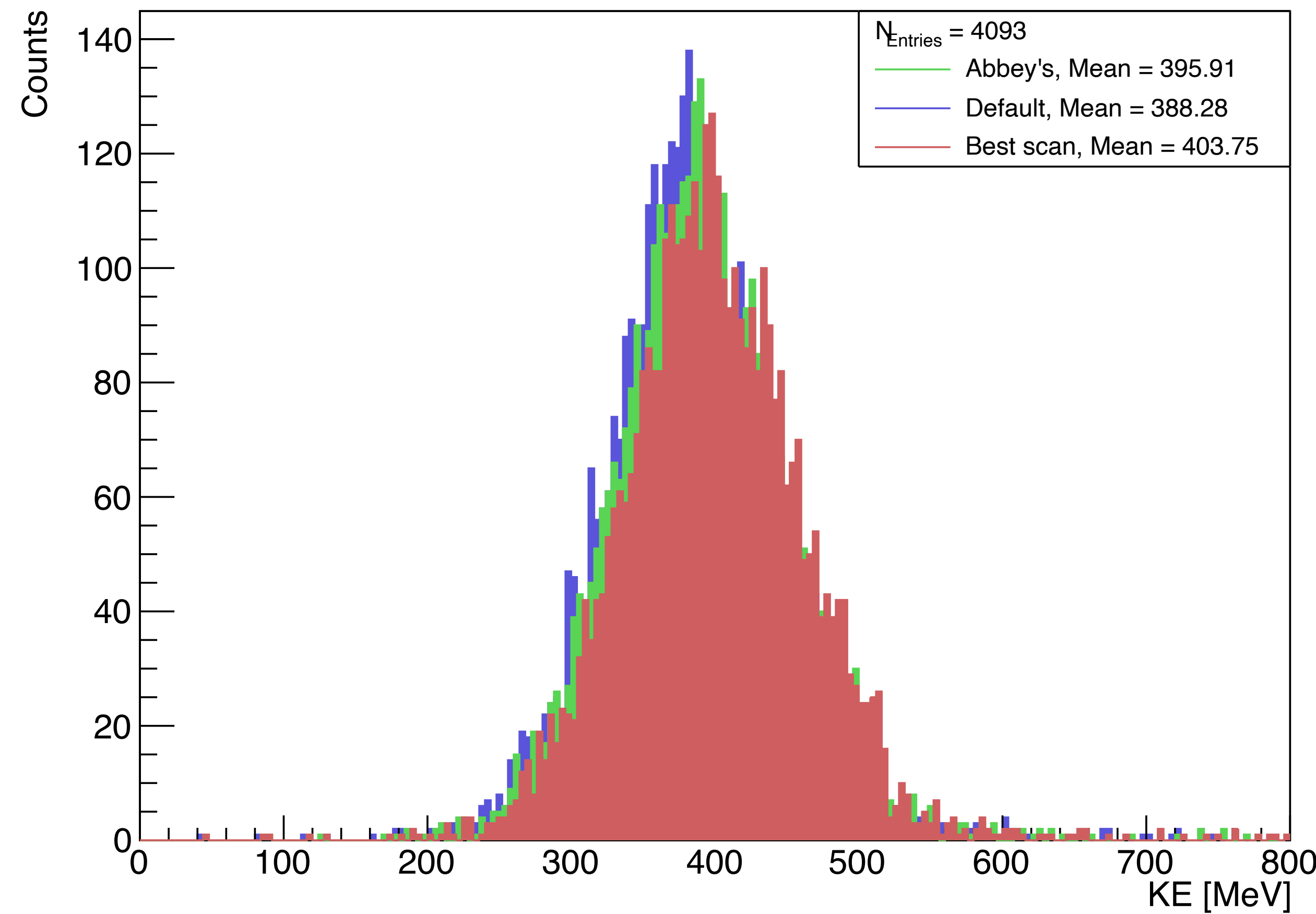


Calorimetric vs range-based reconstruction

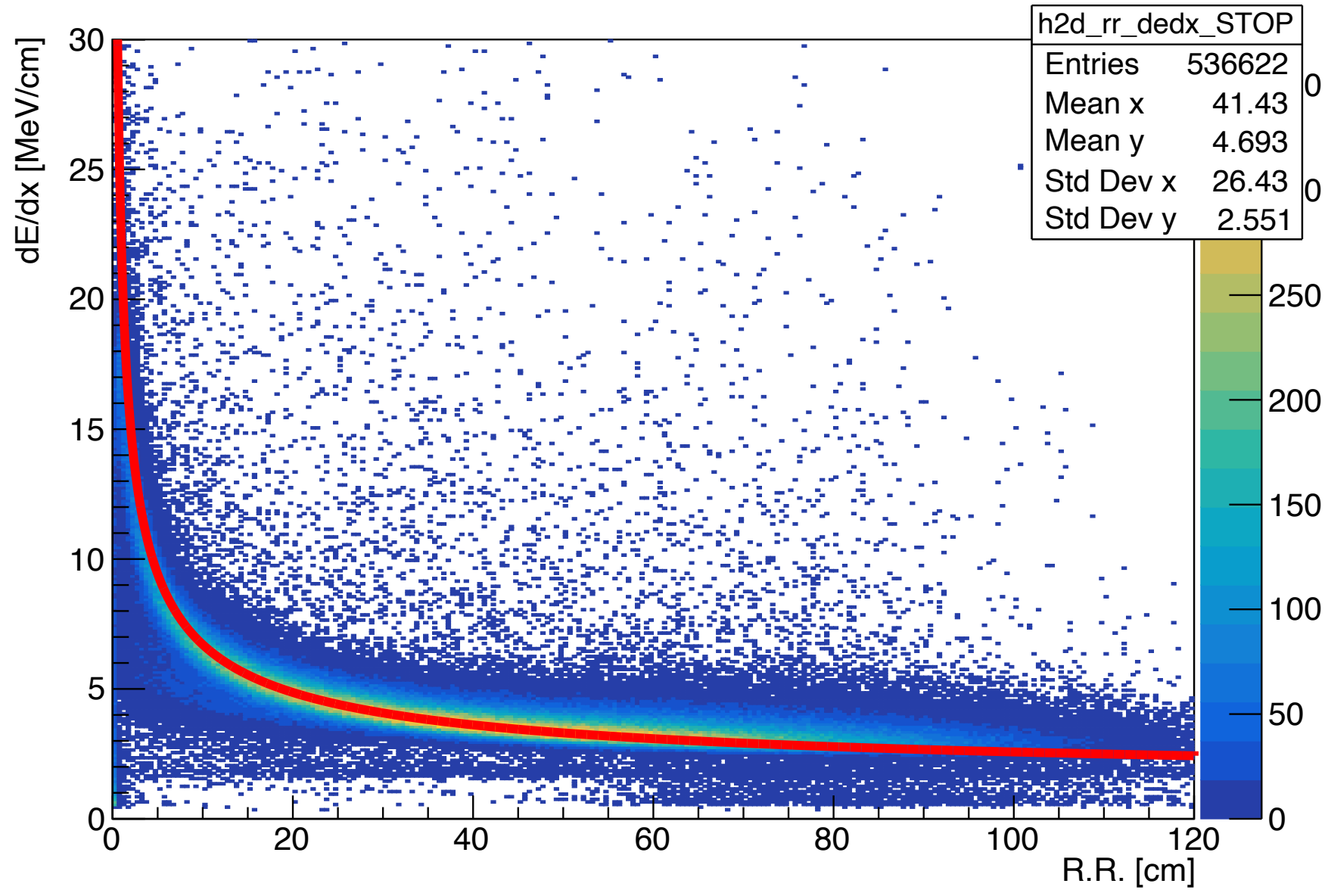
KE_{trklen} per track



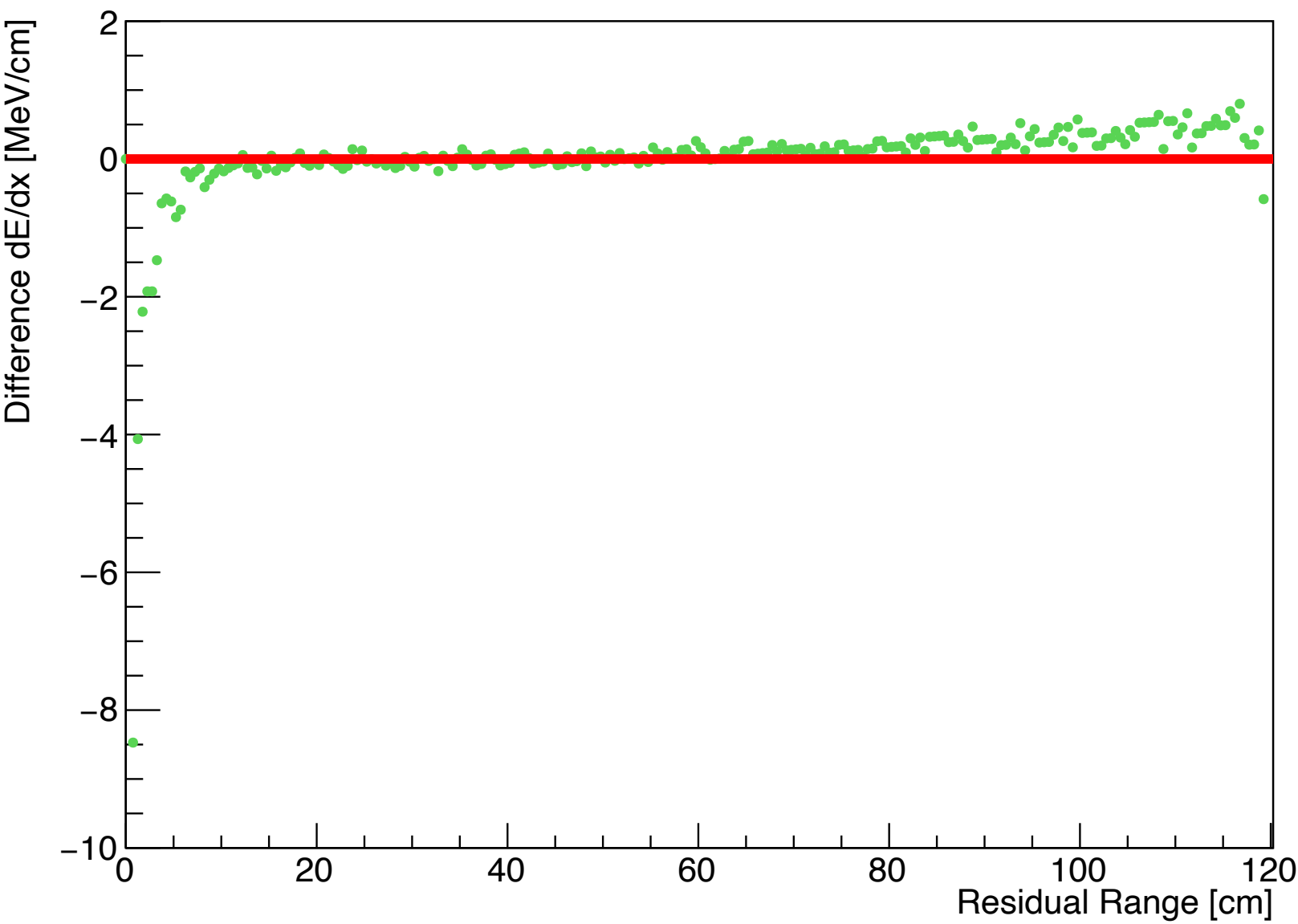
KE_{calo} per track



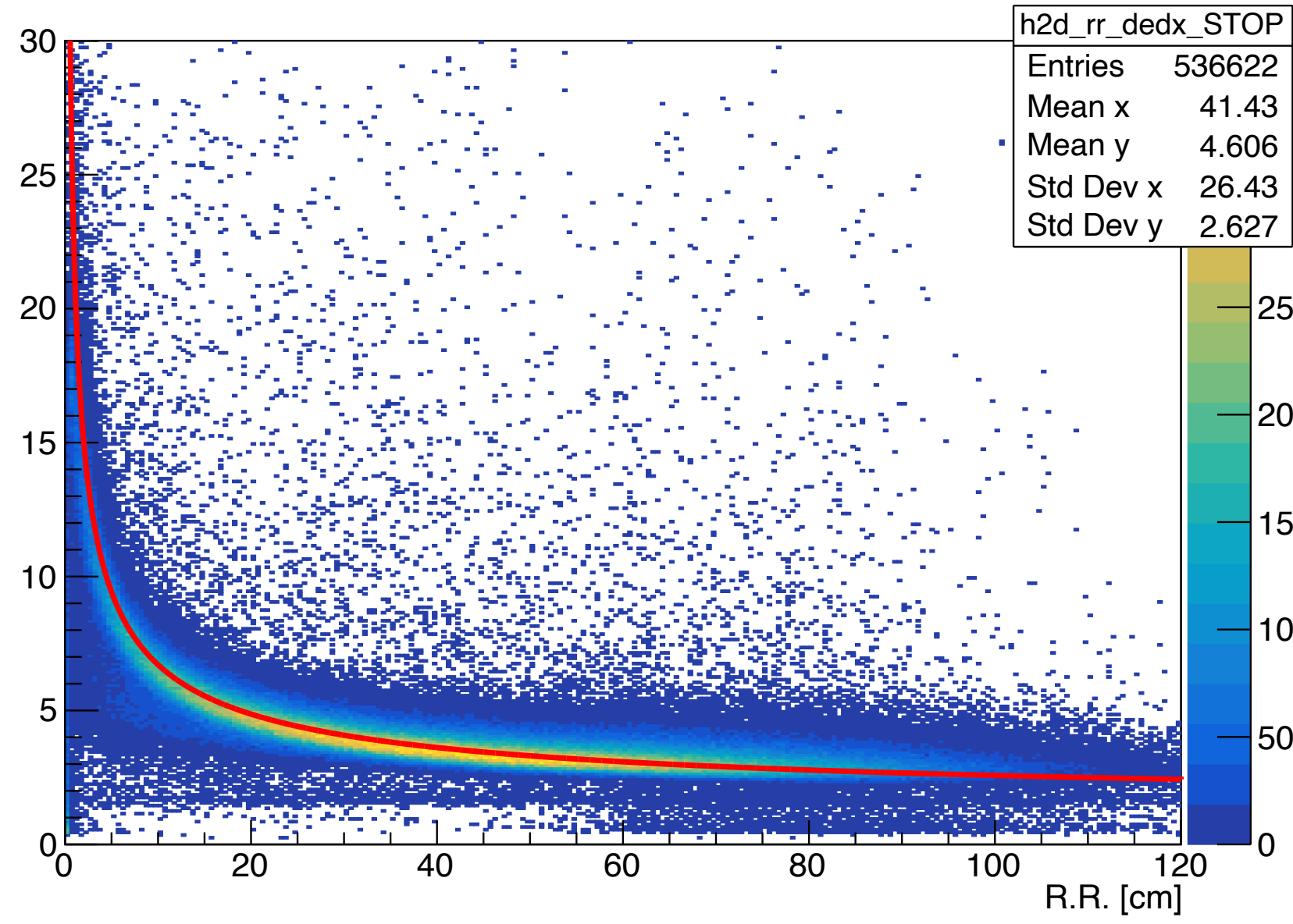
h2d_rr_dedx_STOP, Abbey's parameters



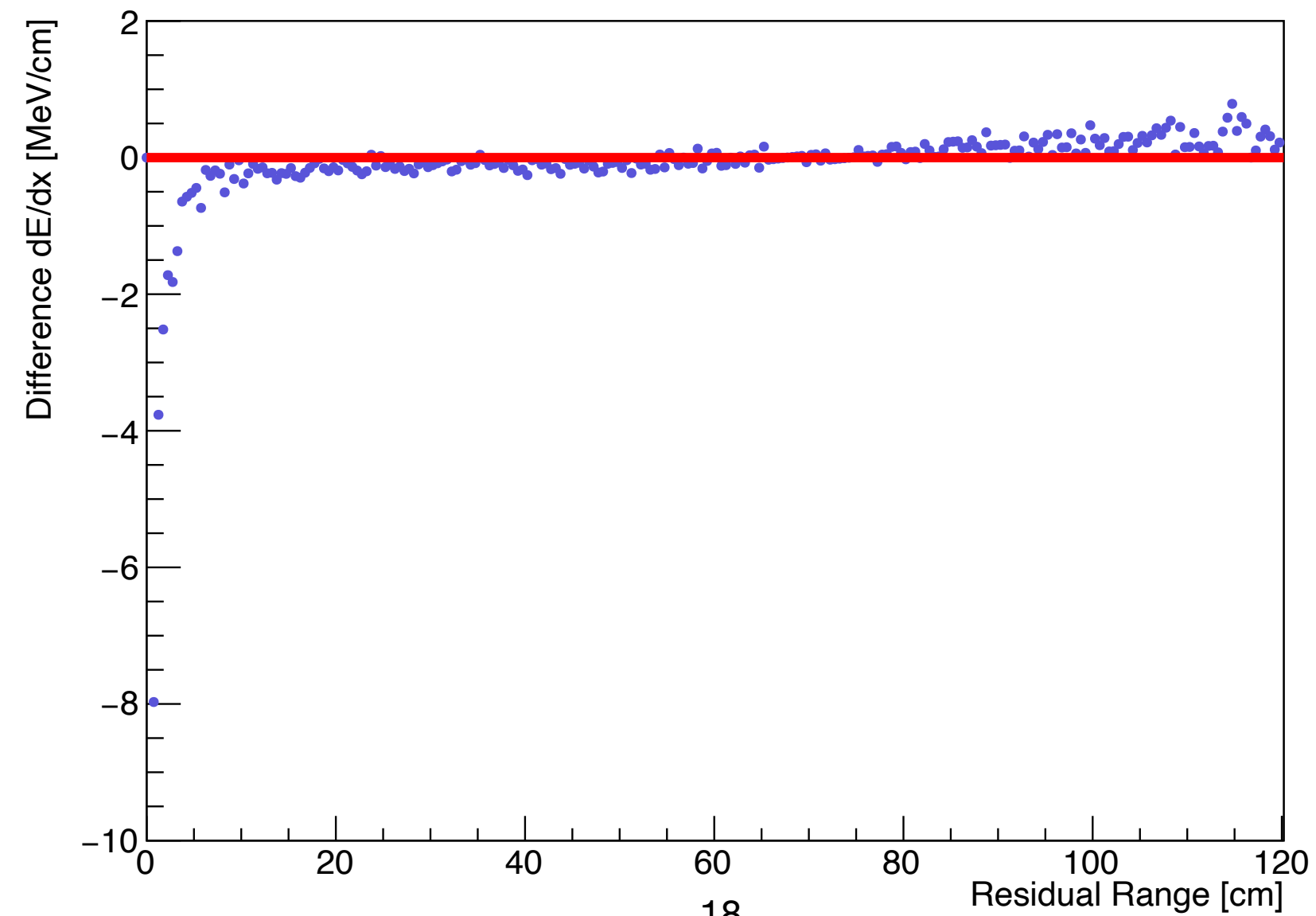
dEdxVsRR(Abbey's) - LV



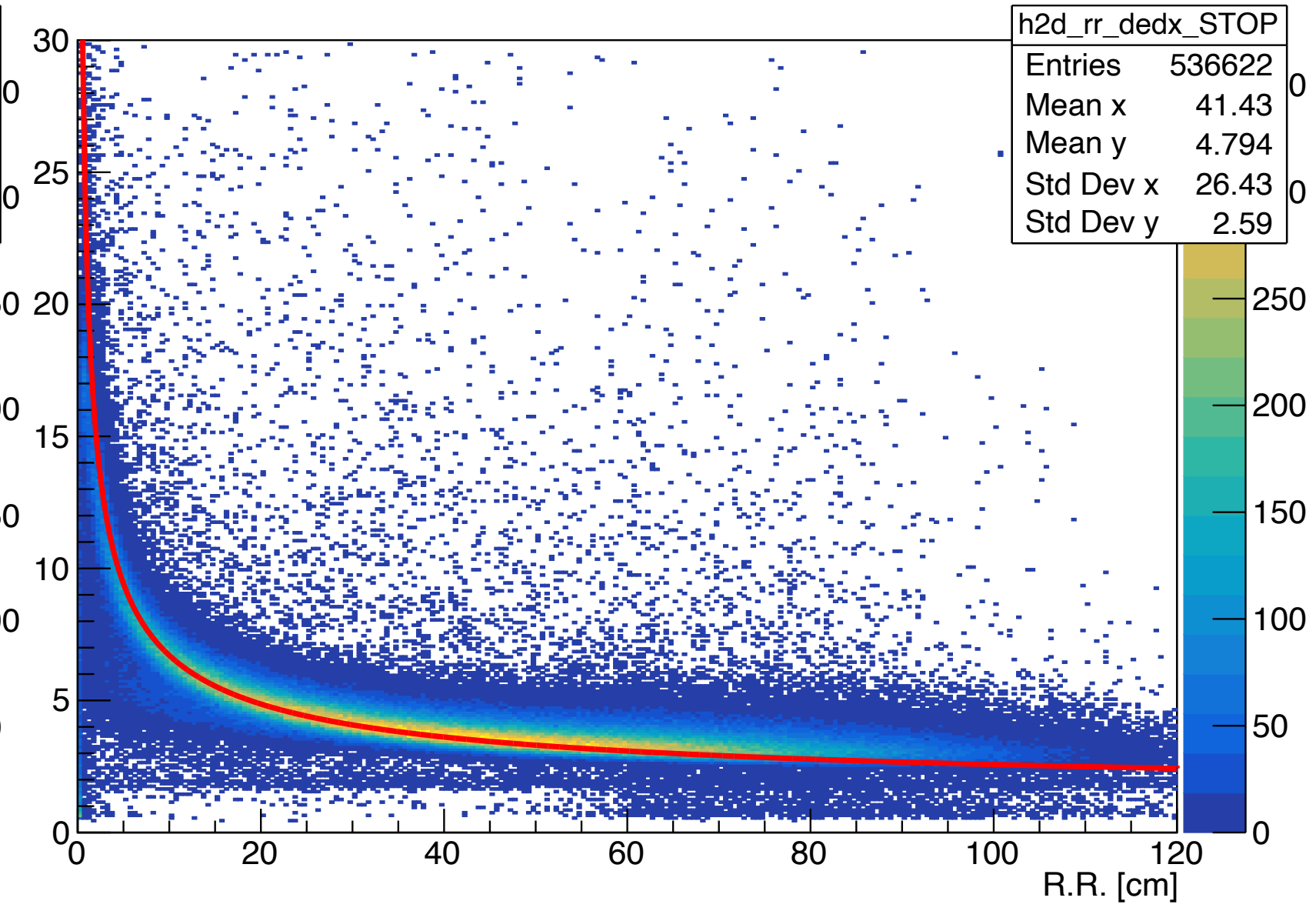
h2d_rr_dedx_STOP, Default parameters



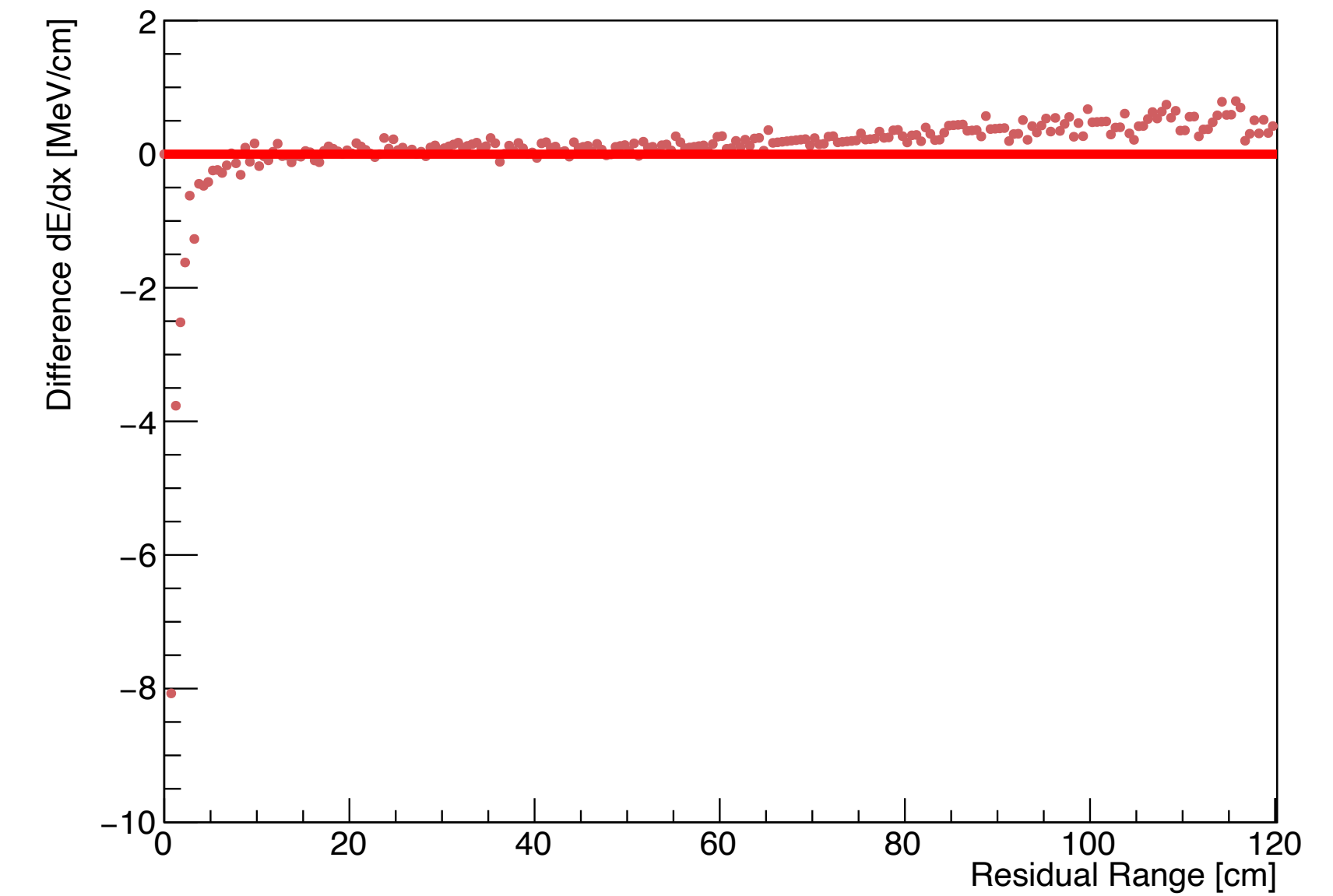
dEdxVsRR(Default) - LV



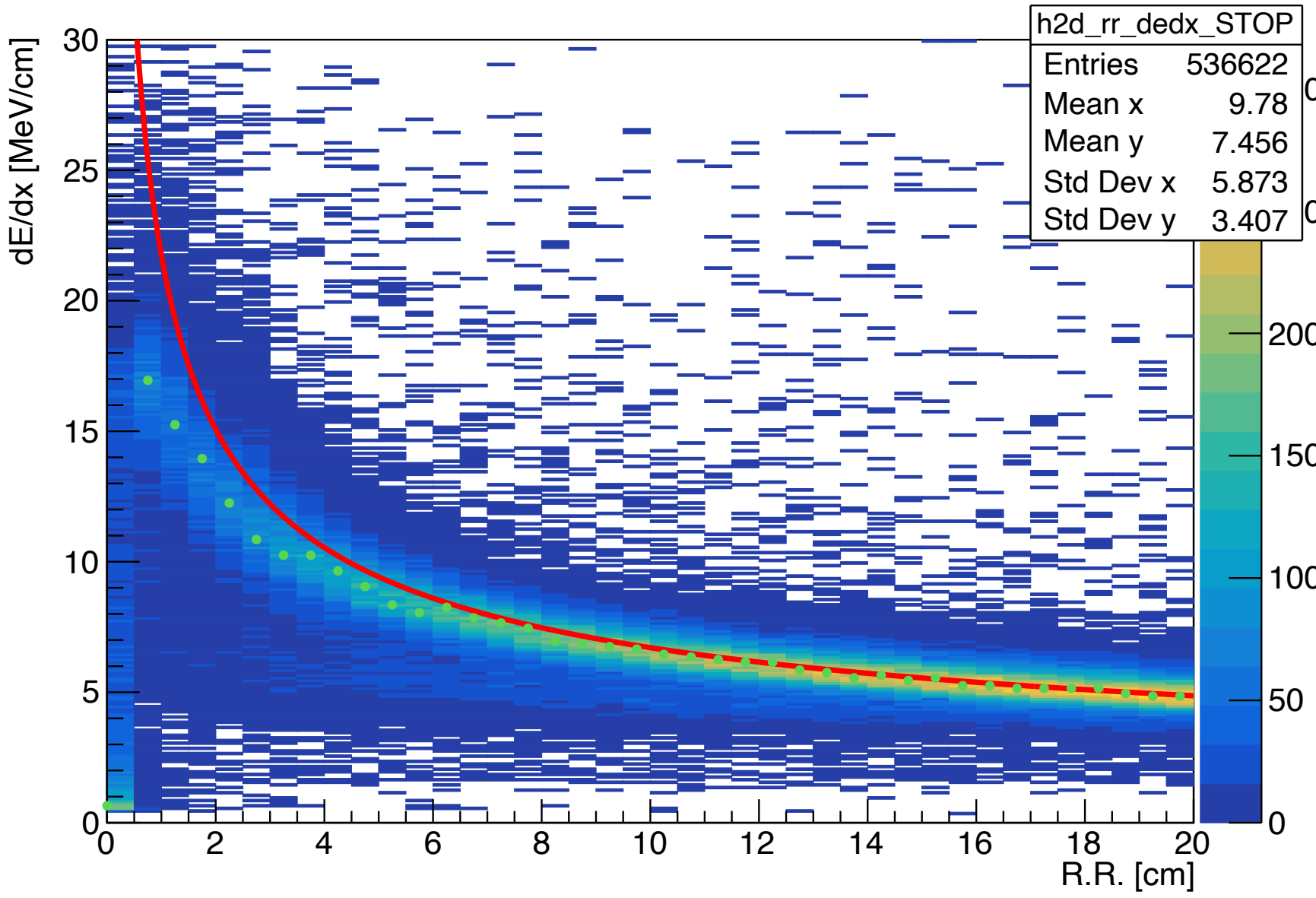
h2d_rr_dedx_STOP, Best scan parameters



dEdxVsRR(Best scan) - LV

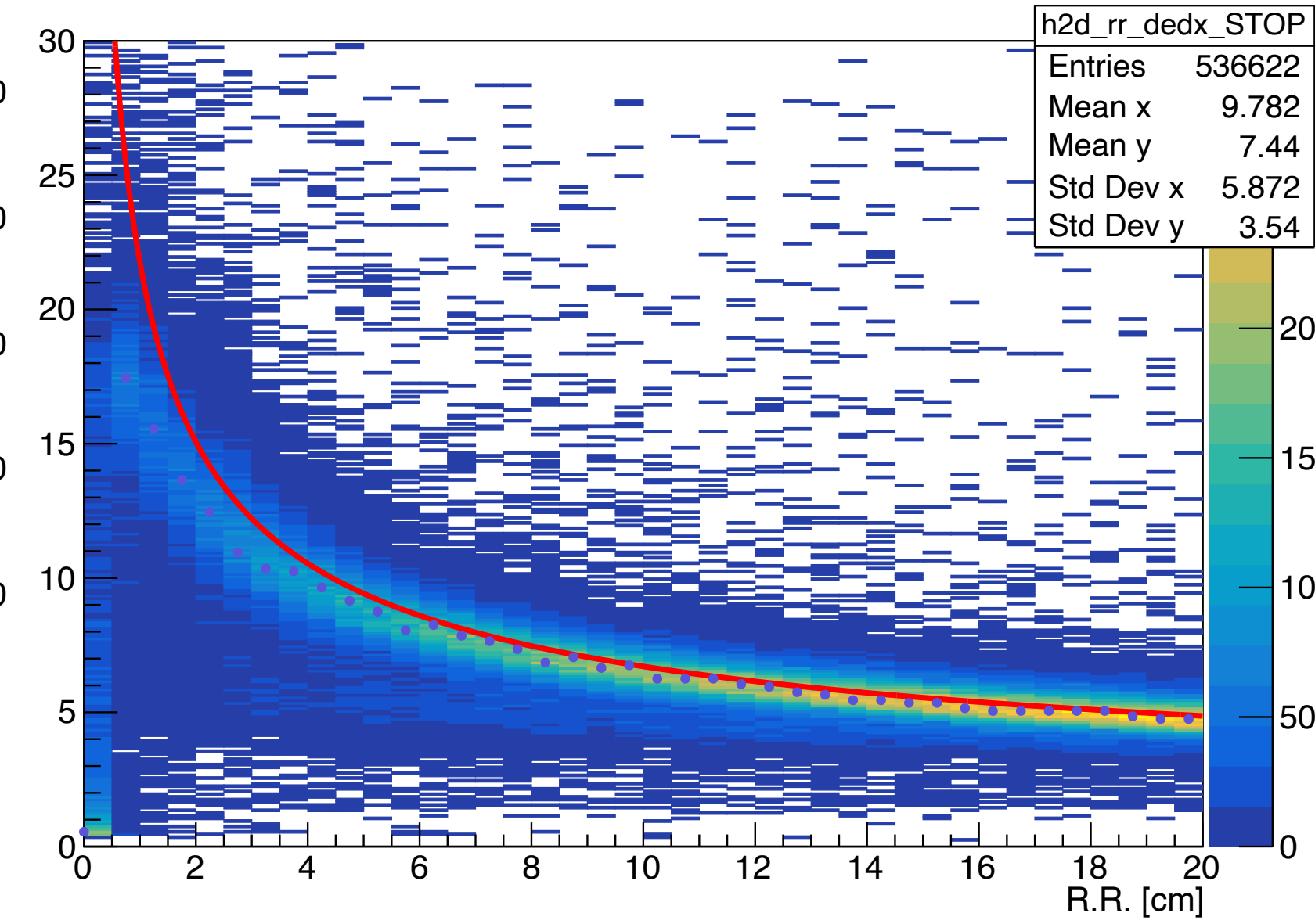


h2d_rr_dedx_STOP, Abbey's parameters



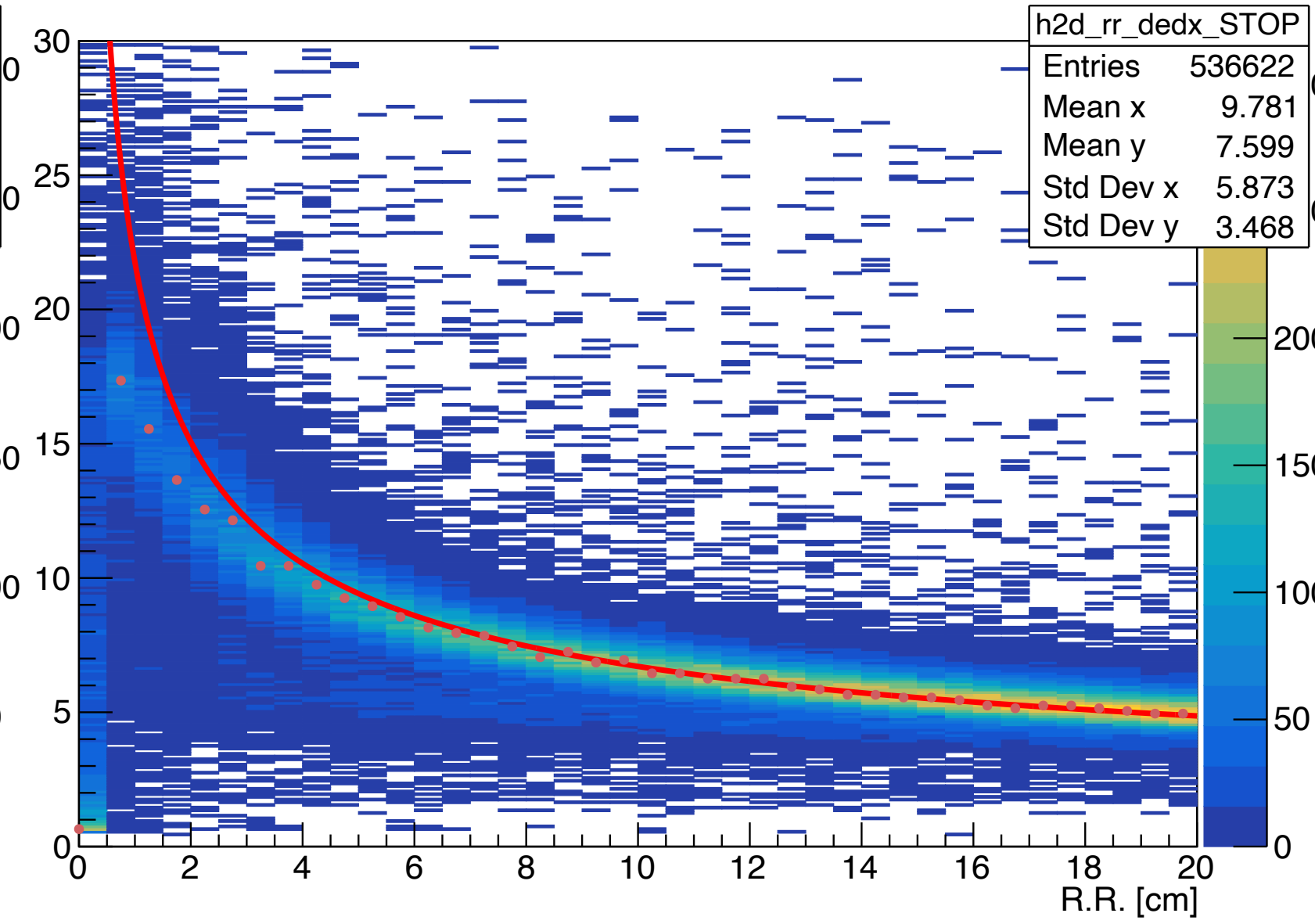
dEdxVsRR(Abbey's) - LV

h2d_rr_dedx_STOP, Default parameters

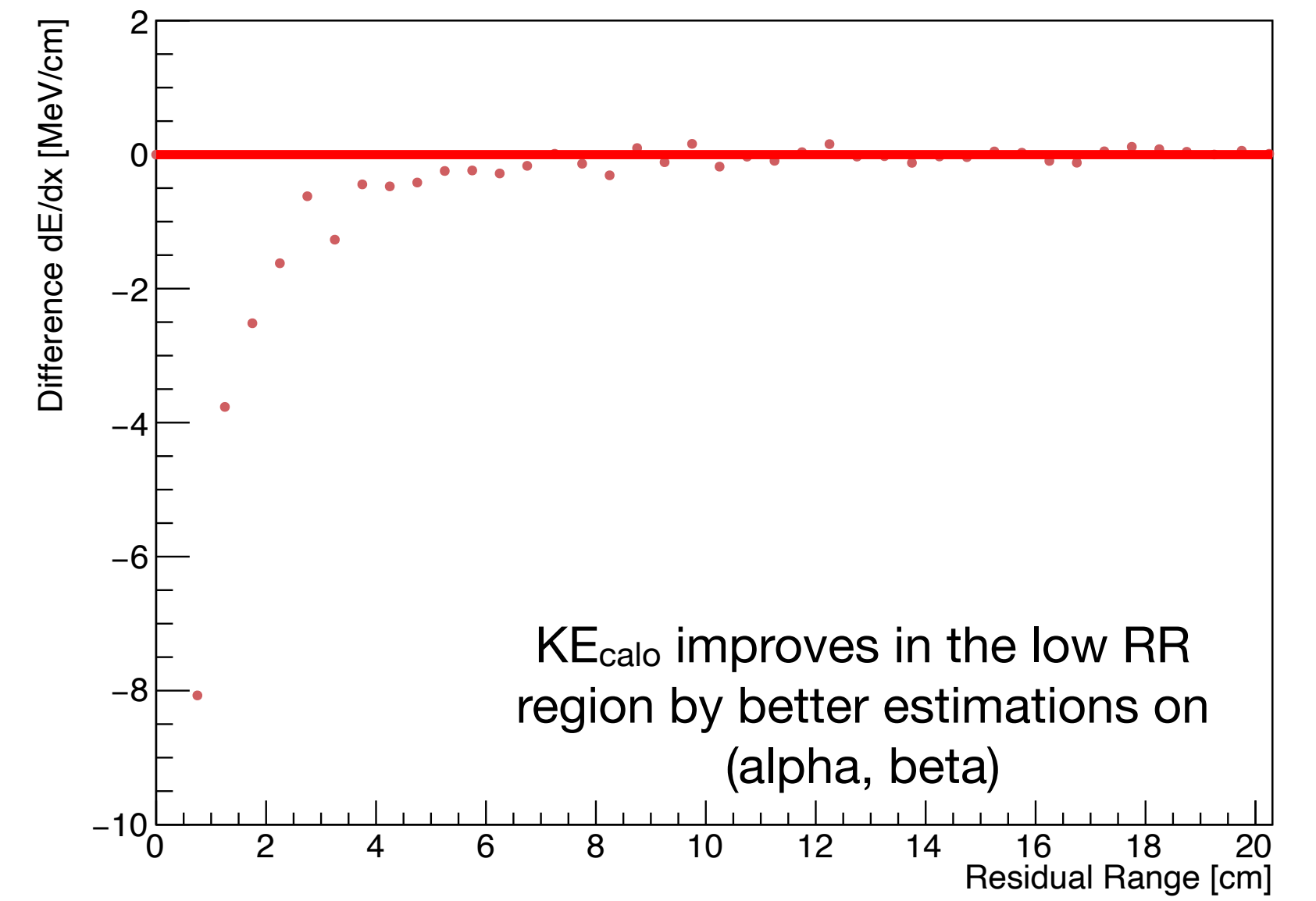
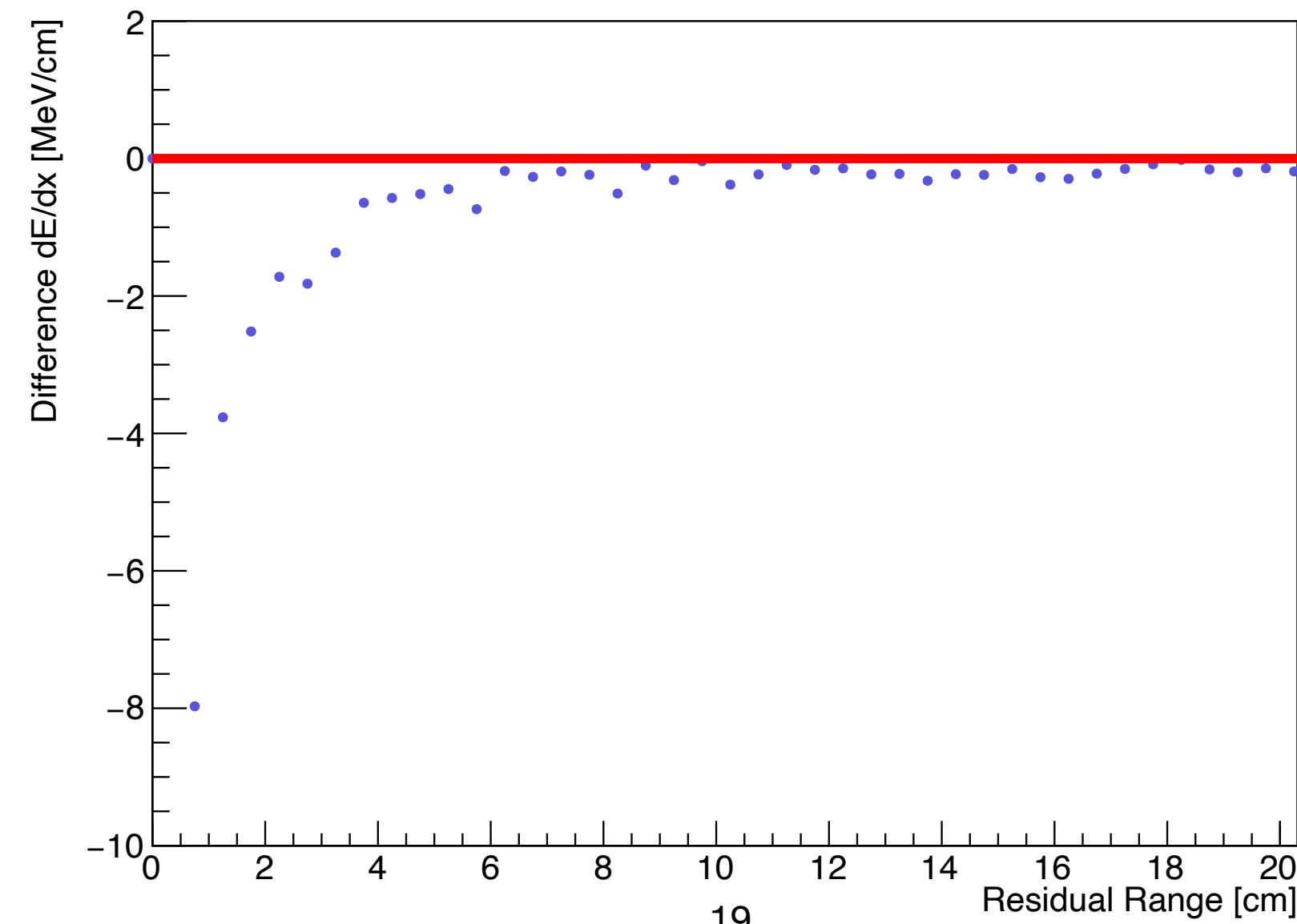
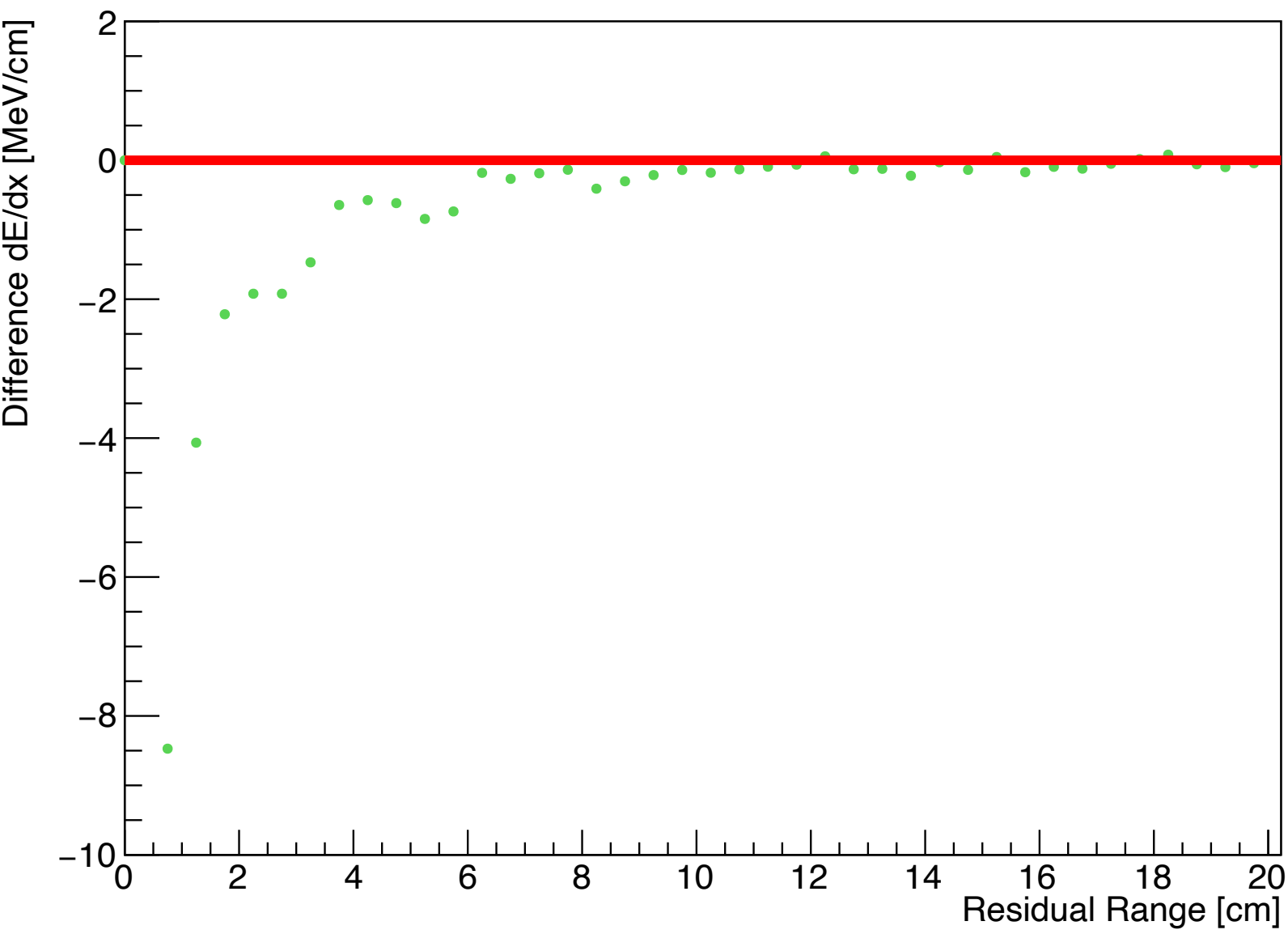


dEdxVsRR(Default) - LV

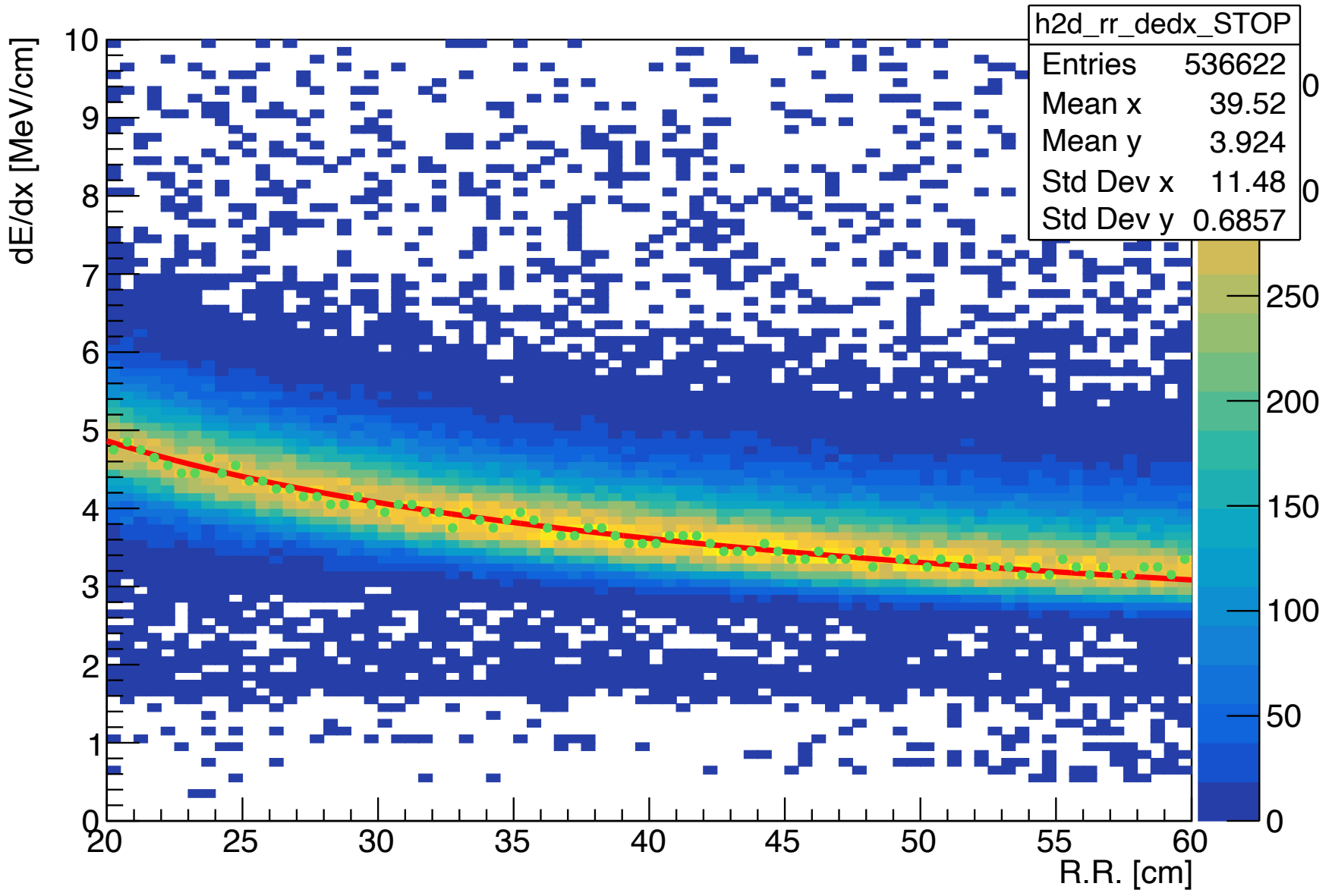
h2d_rr_dedx_STOP, Best scan parameters



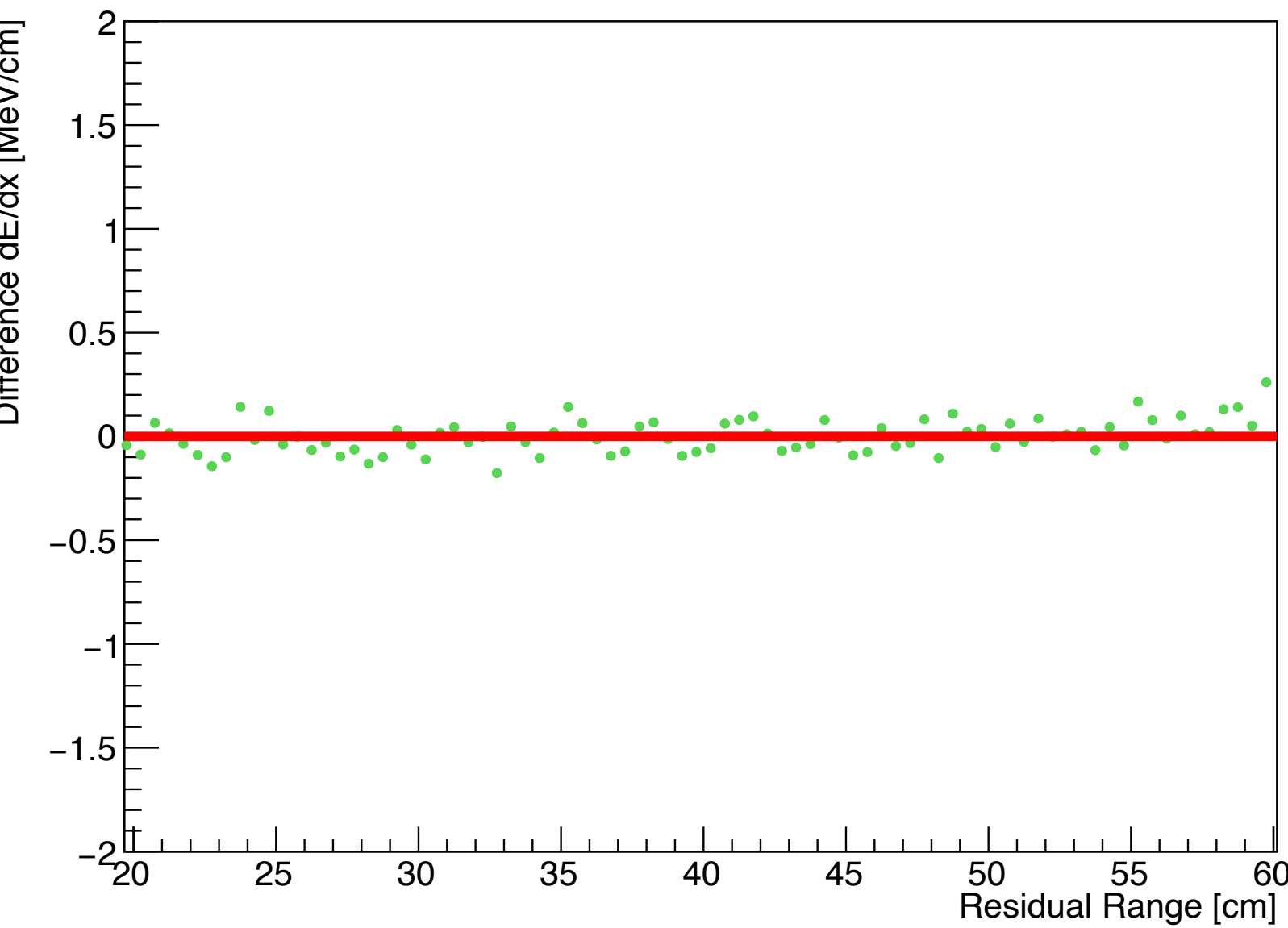
dEdxVsRR(Best scan) - LV



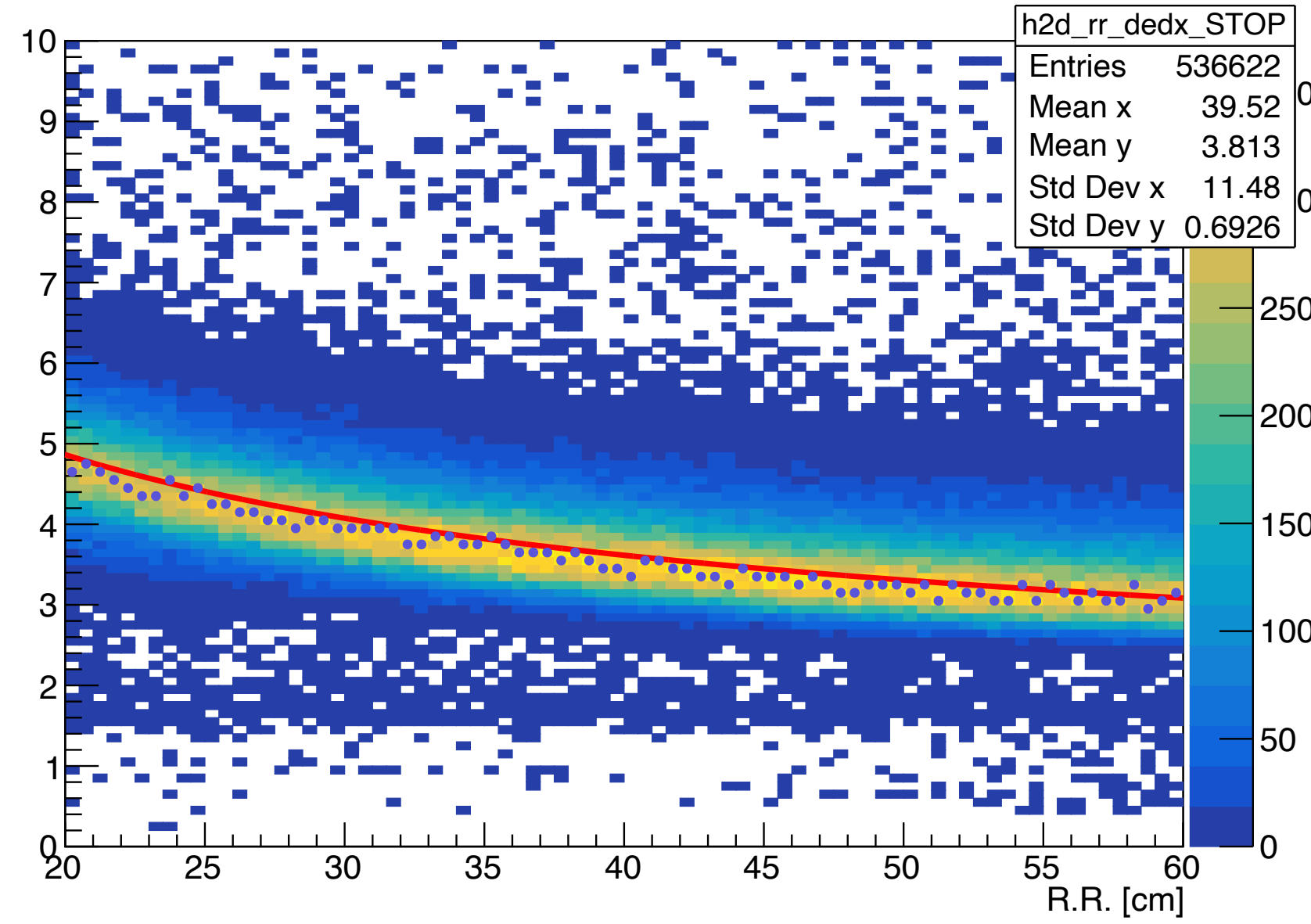
h2d_rr_dedx_STOP, Abbey's parameters



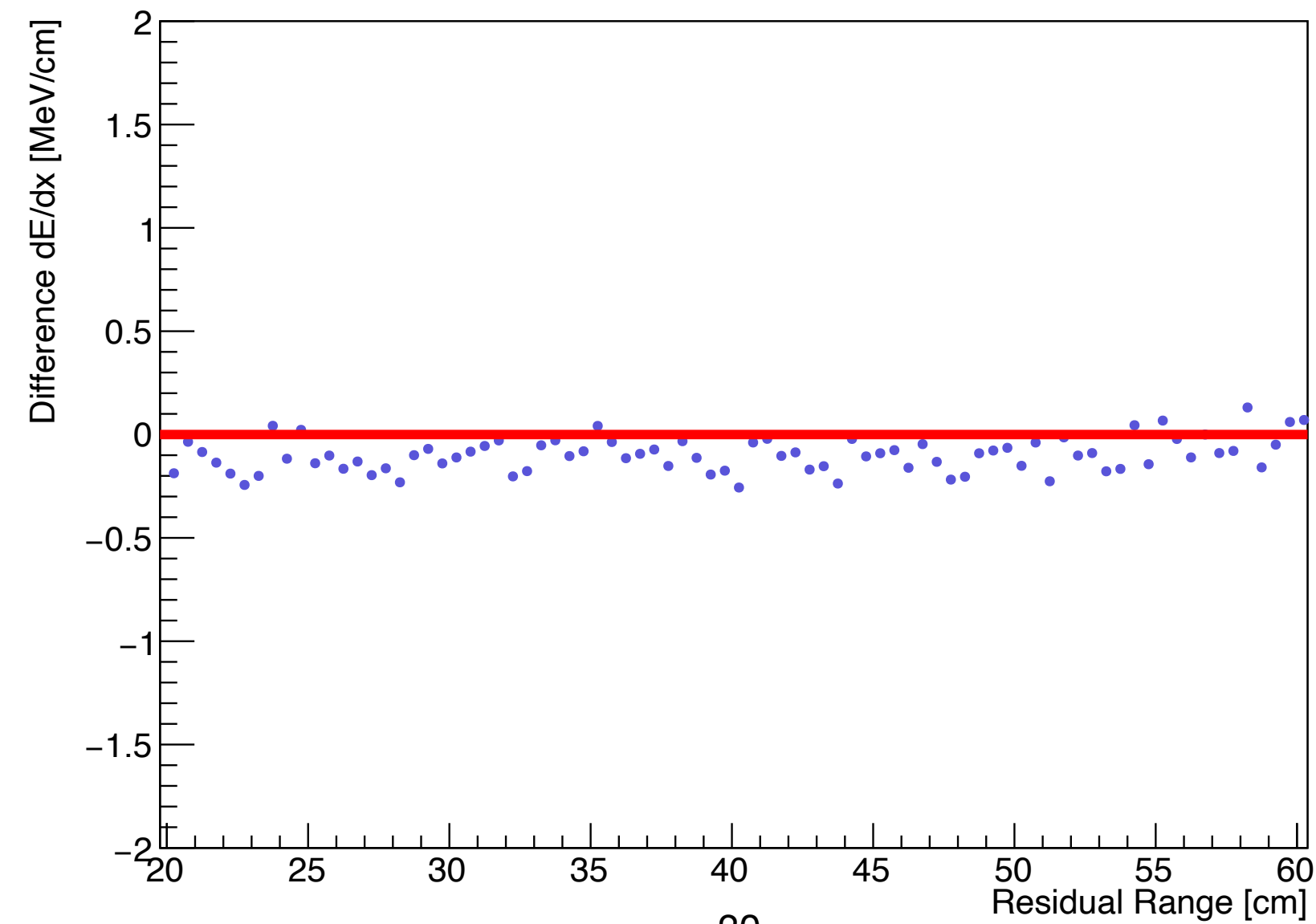
dEdxVsRR(Abbey's) - LV



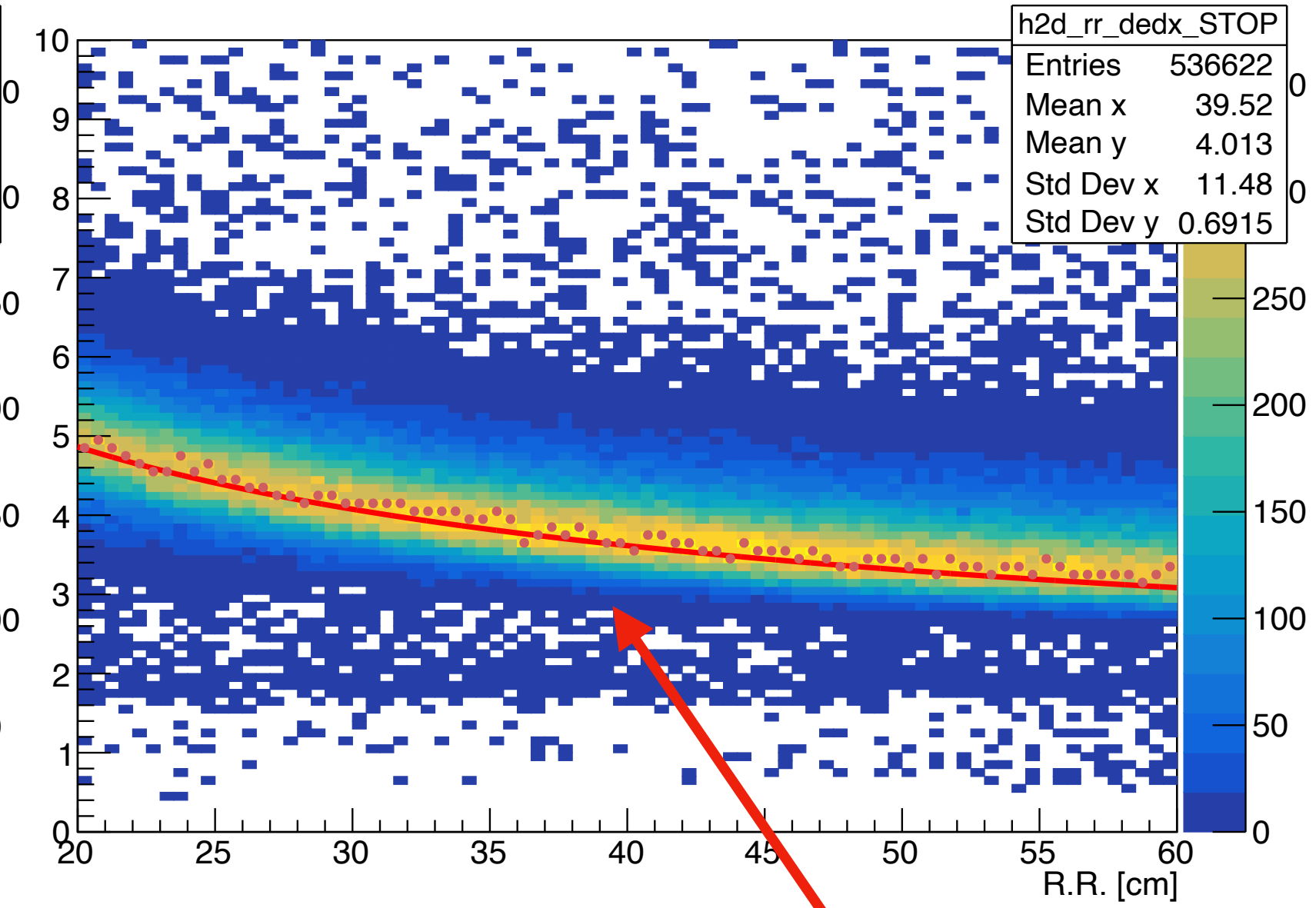
h2d_rr_dedx_STOP, Default parameters



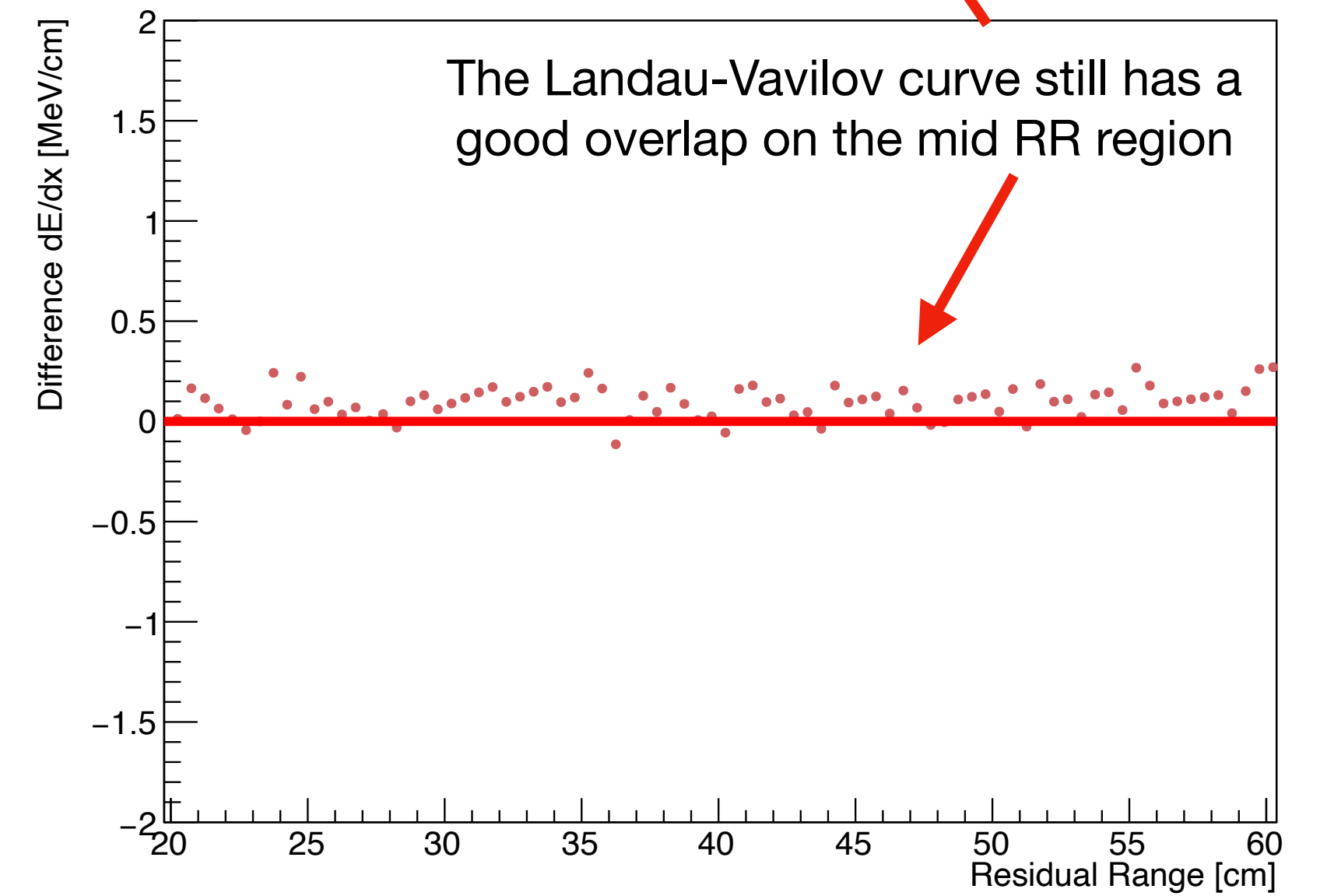
dEdxVsRR(Default) - LV



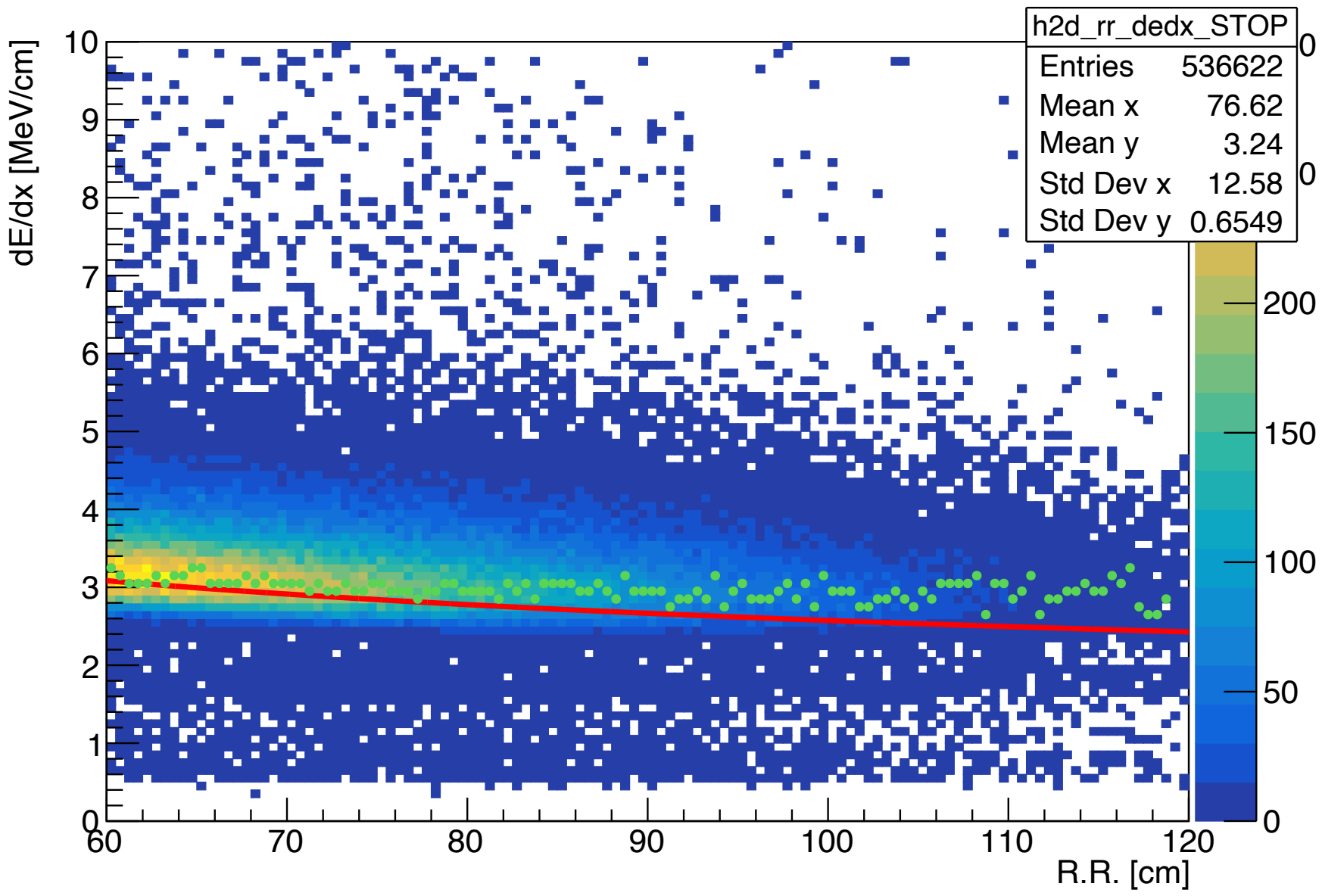
h2d_rr_dedx_STOP, Best scan parameters



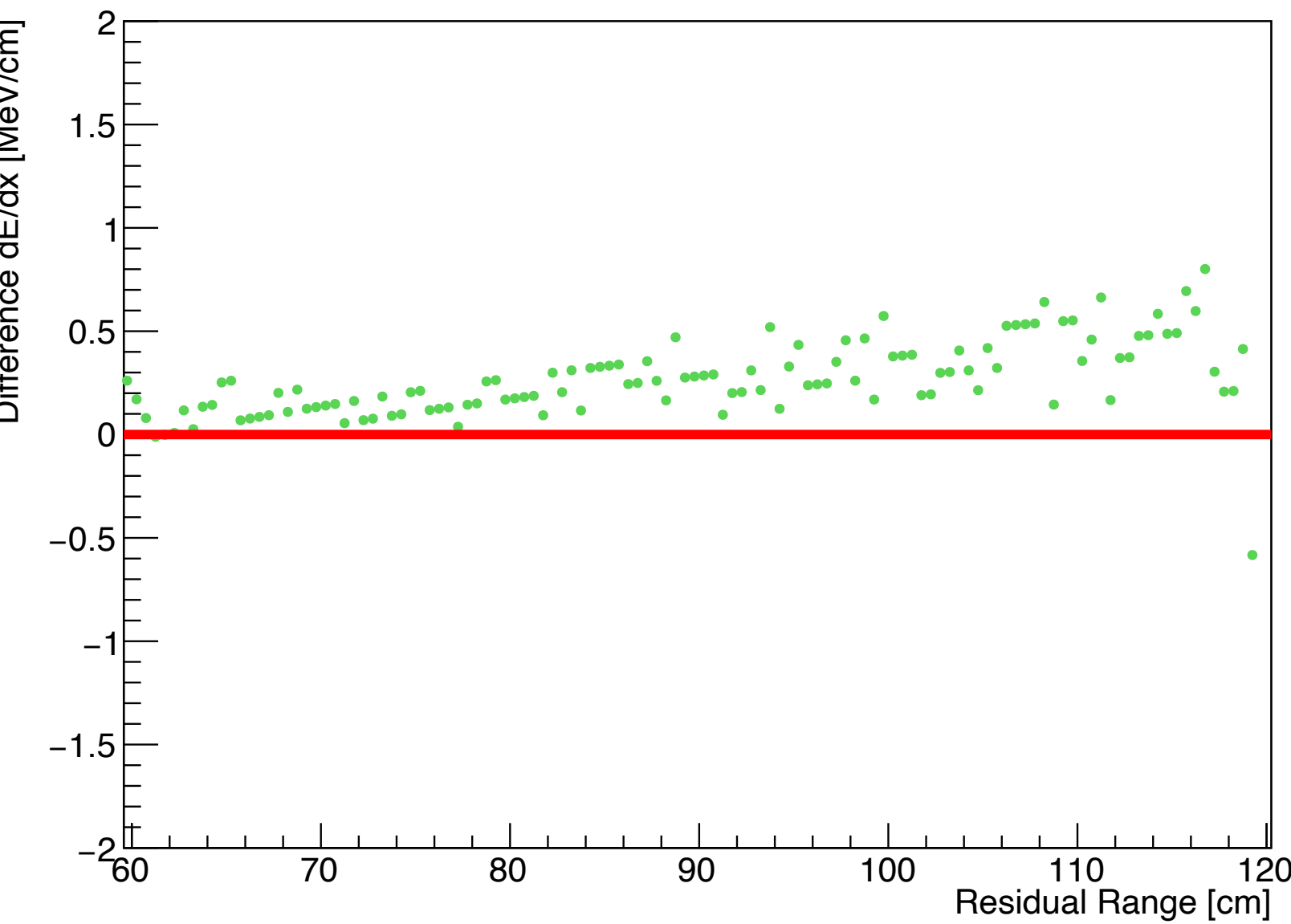
dEdxVsRR(Best scan) - LV



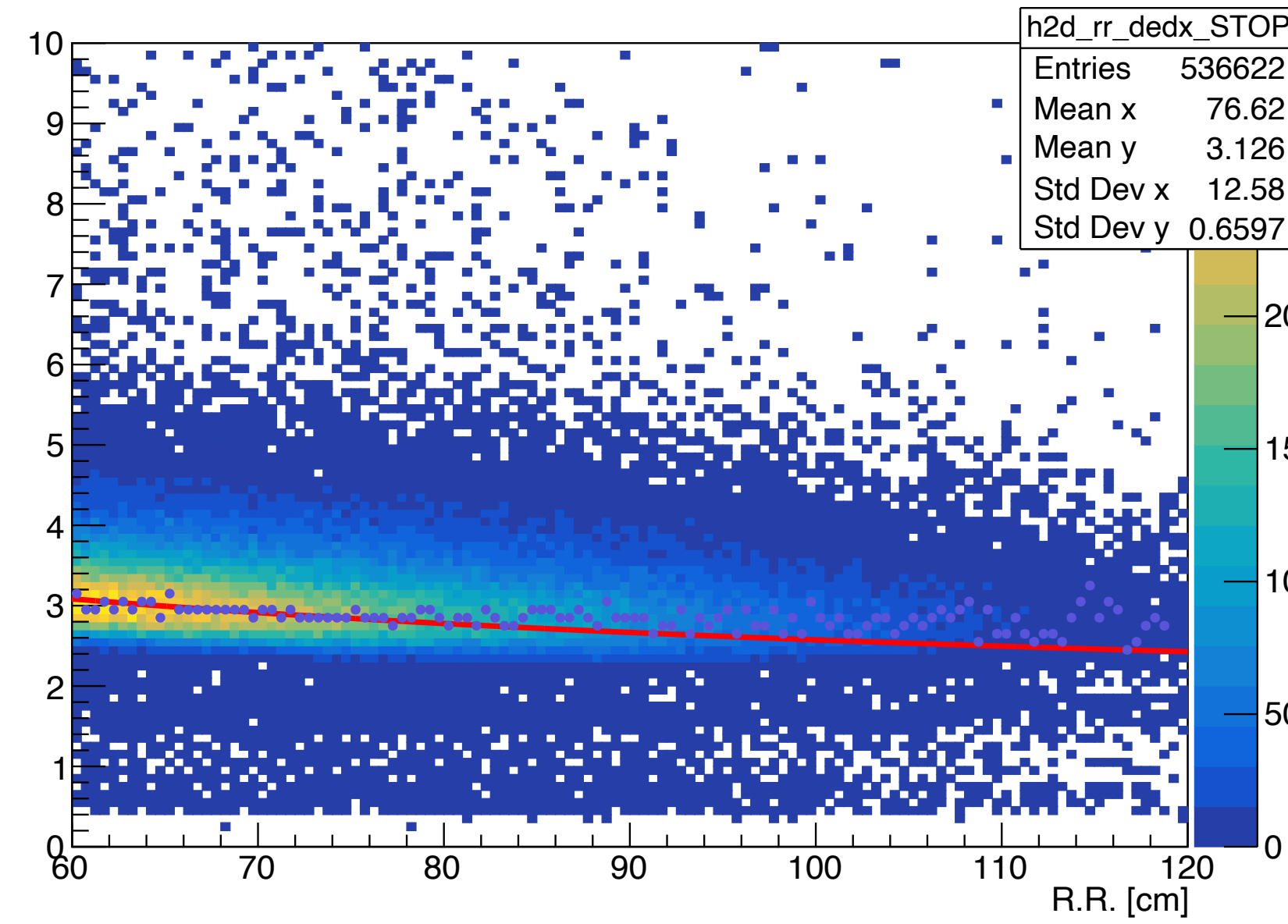
h2d_rr_dedx_STOP, Abbey's parameters



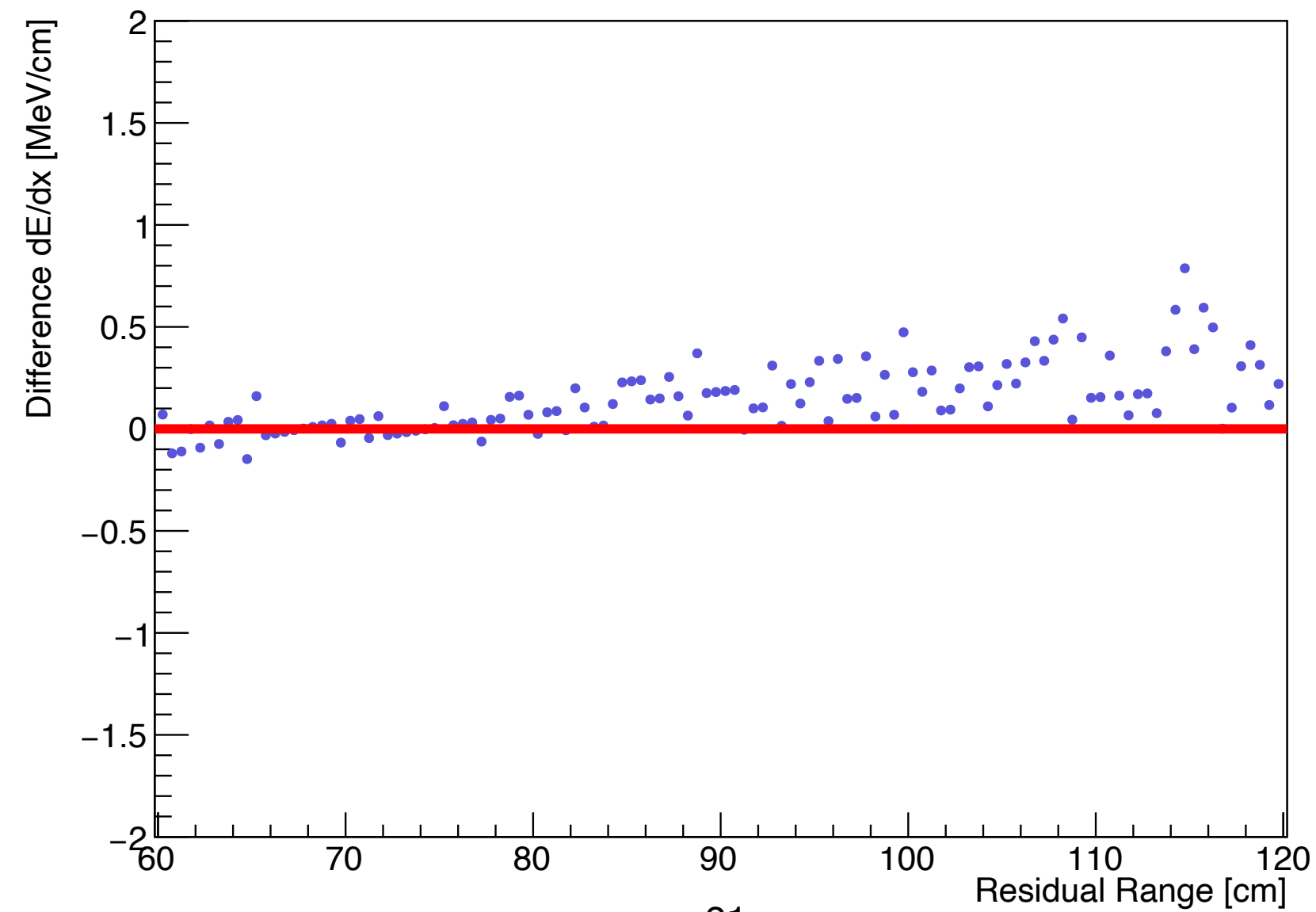
dEdxVsRR(Abbey's) - LV



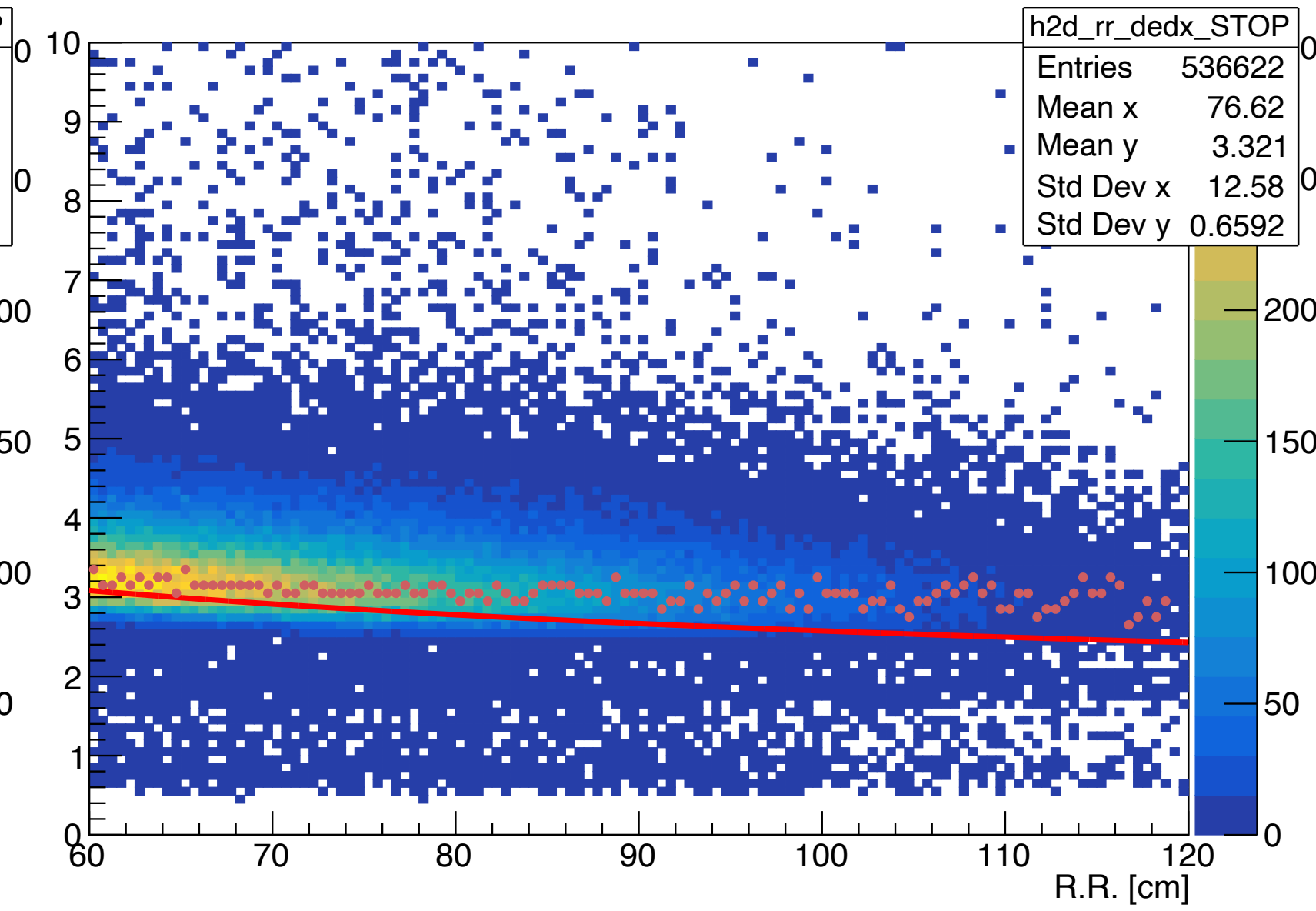
h2d_rr_dedx_STOP, Default parameters



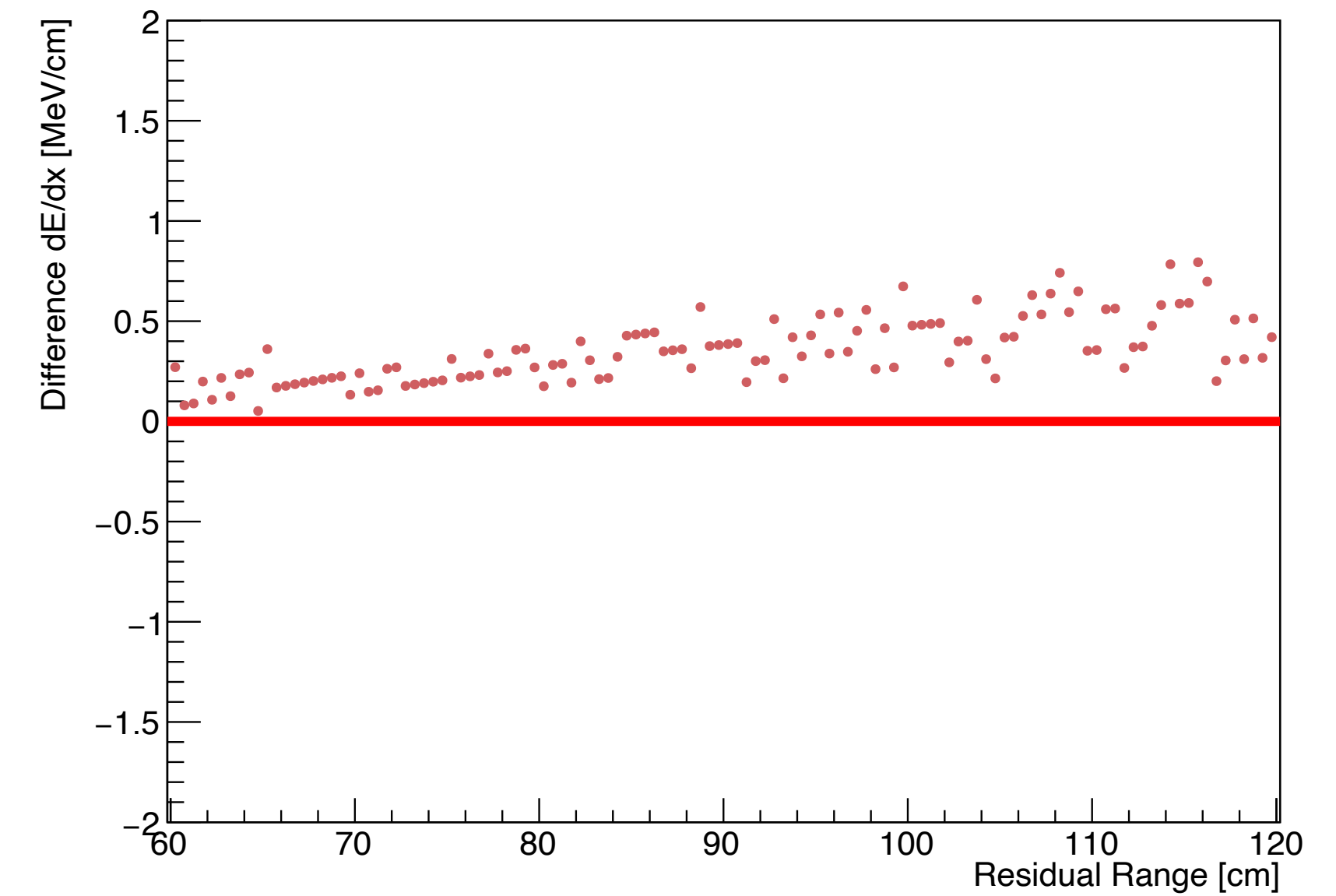
dEdxVsRR(Default) - LV



h2d_rr_dedx_STOP, Best scan parameters



dEdxVsRR(Best scan) - LV



ProtoDUNE Run 5387

Wider Parameter scan

Scan of alpha, betap parameters (Modified Box Model)
within **10-sigma** from Abbey's central fit parameters

Abbey's parameters

calib_factor = 1.000e-3
alpha = 0.912
betap = 0.195

Default parameters

calib_factor = 1.029e-3
alpha = 0.93
betap = 0.212

Best scan parameters

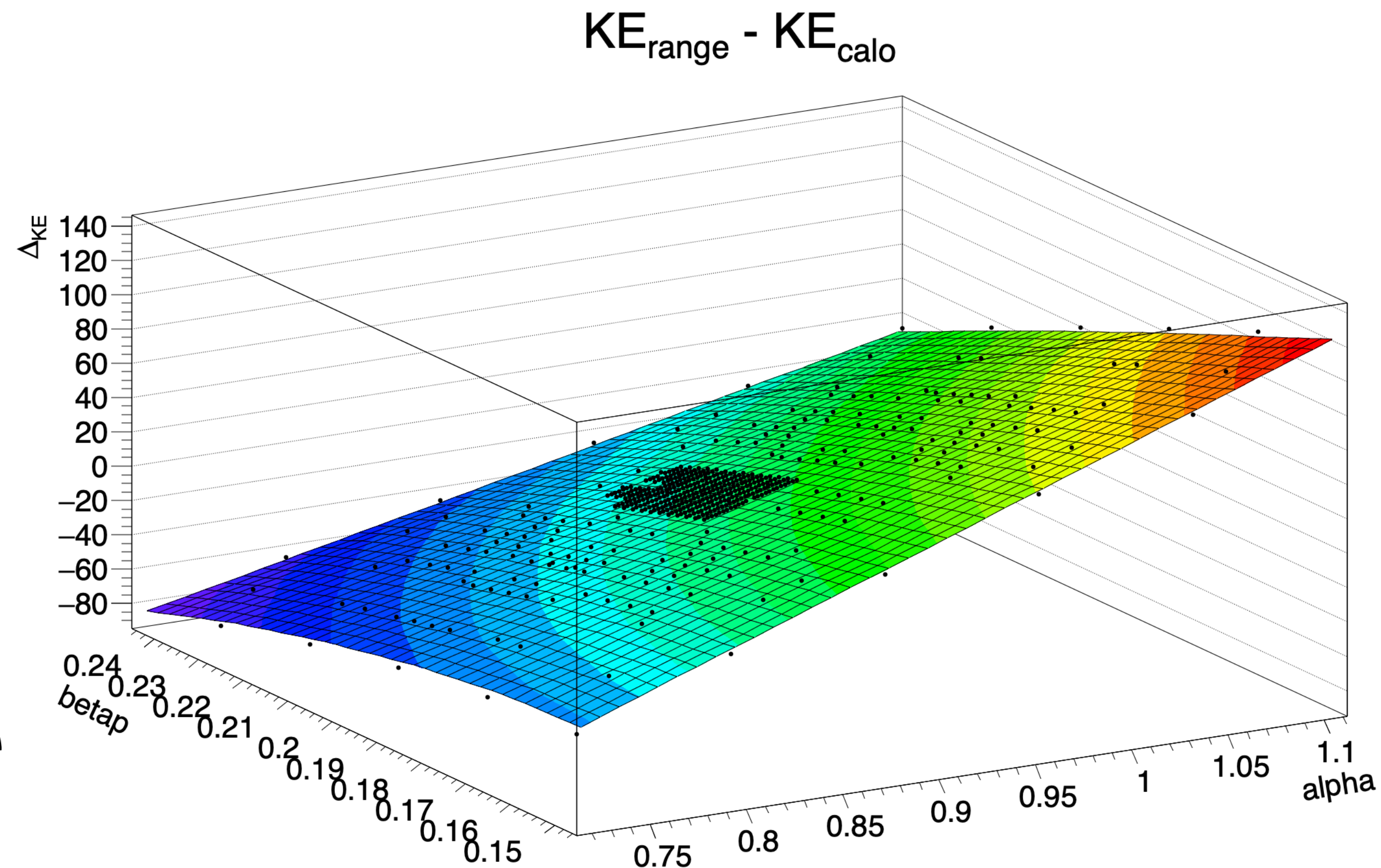
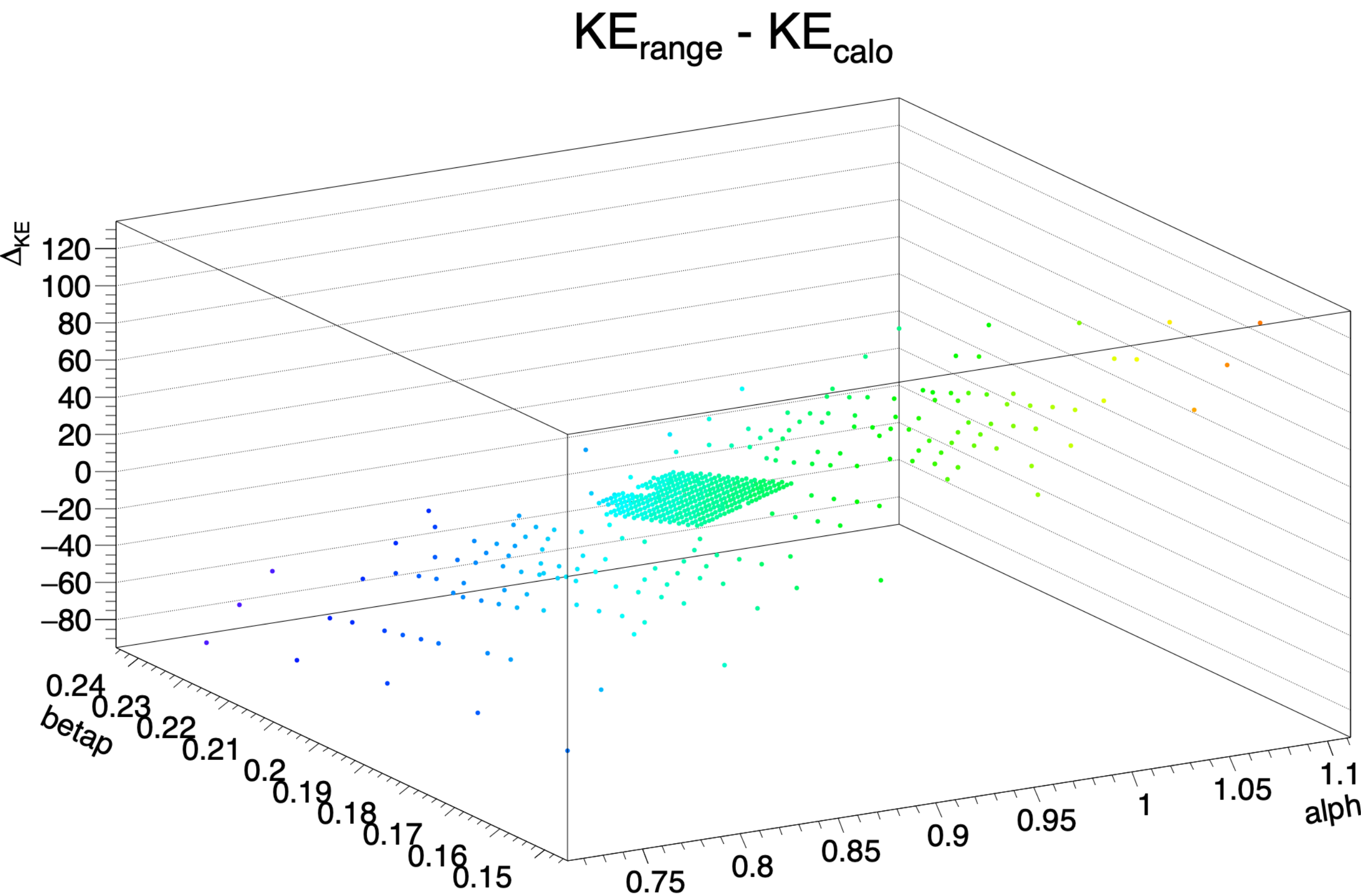
calib_factor = 1.000e-3
alpha = 0.928
betap = 0.212

Scan on alpha, betap

Abbey's fit on modified box model, 1-sigma

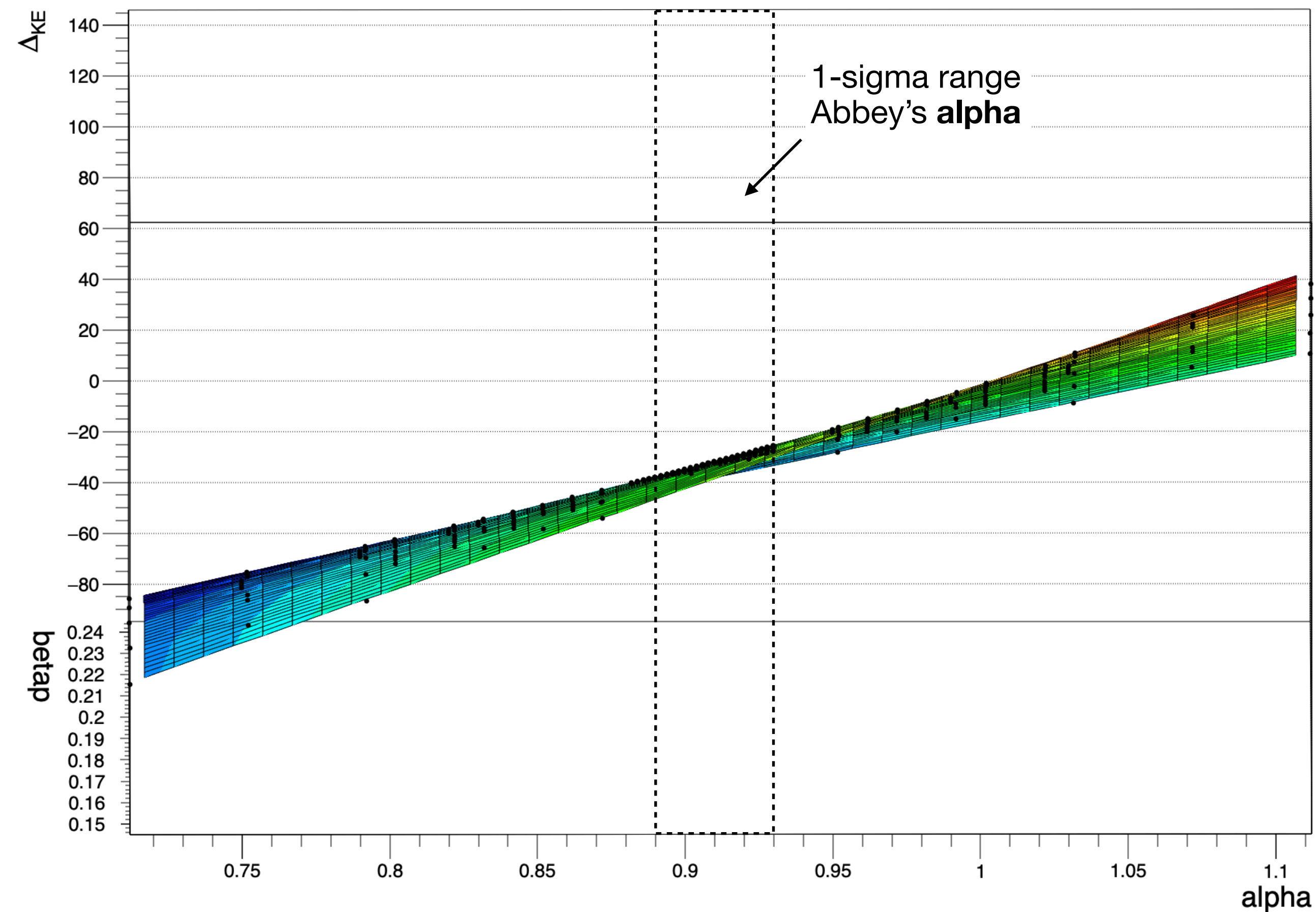
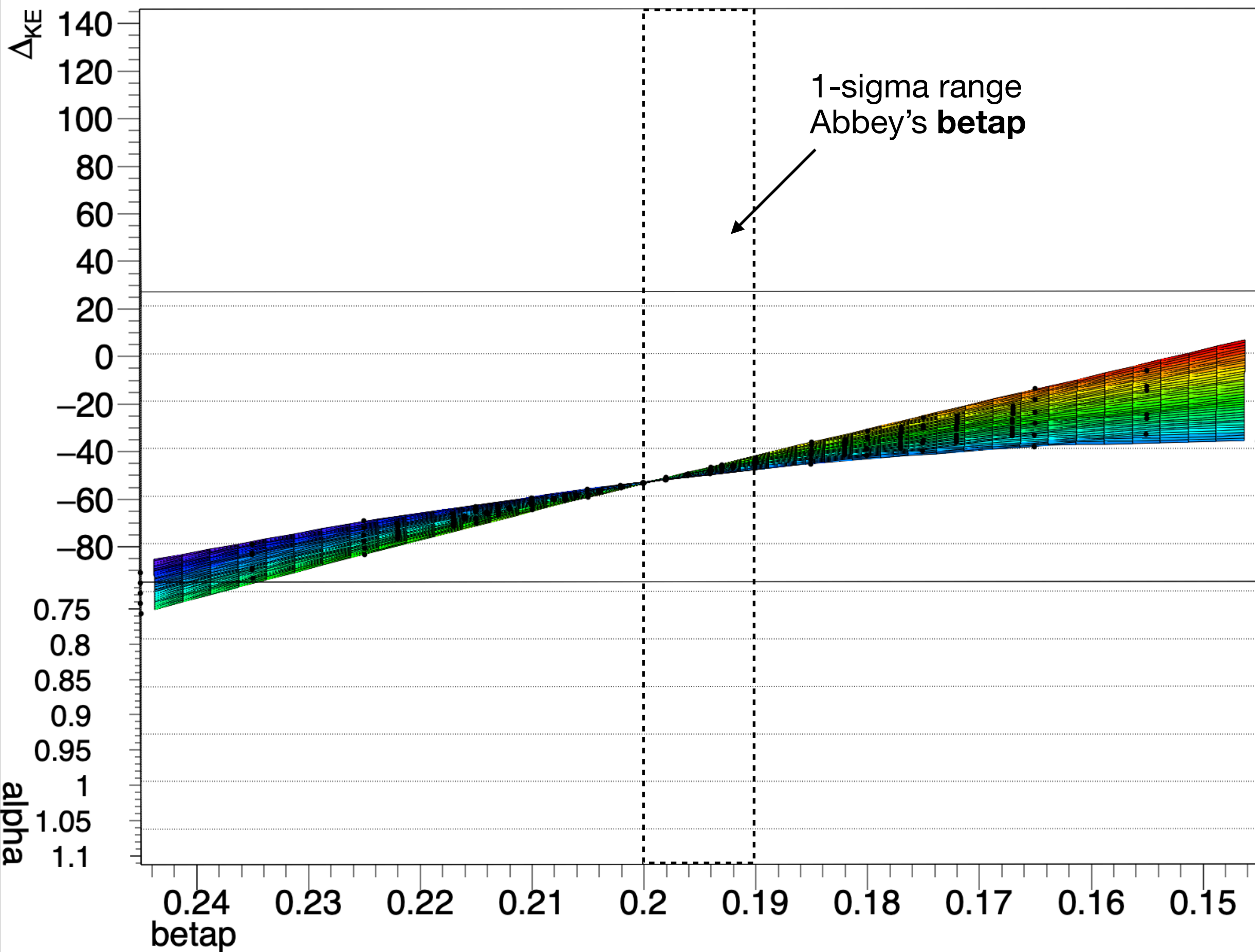
No evident minimum region

Abbey's parameters
calib_factor = 1.000e-3
alpha = 0.912
betap = 0.195

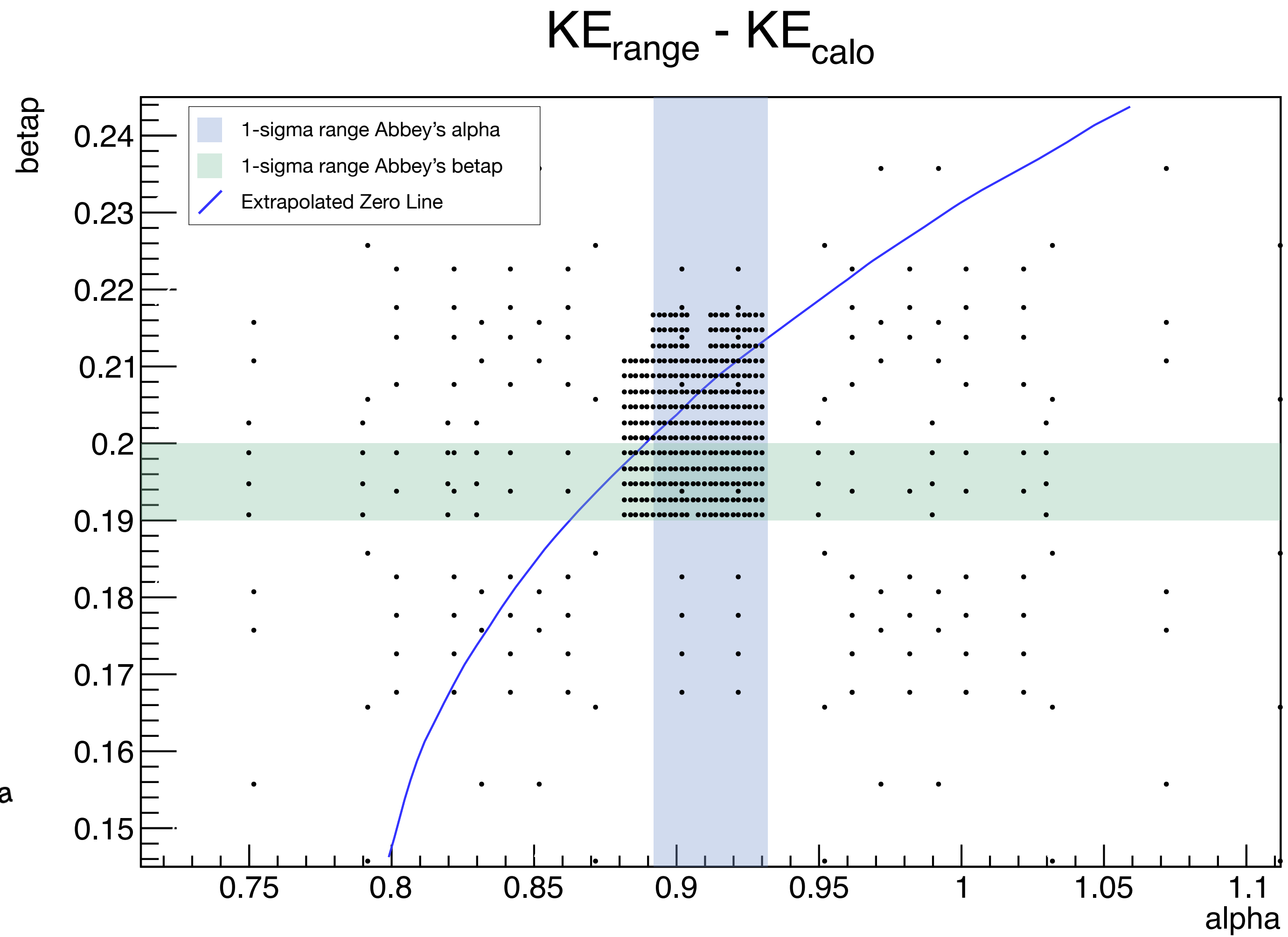
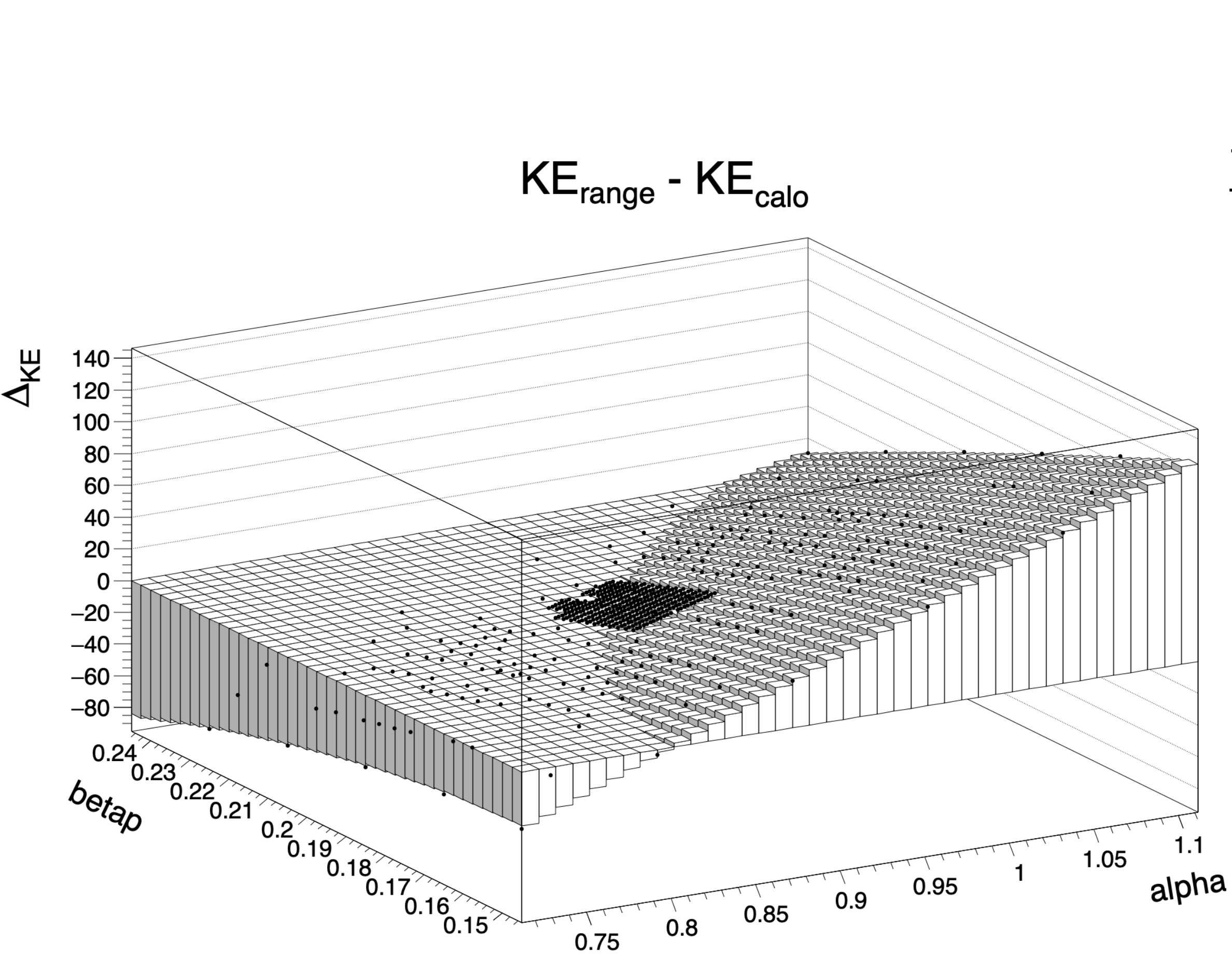


Detail of Δ_{KE} surface in the parameters space

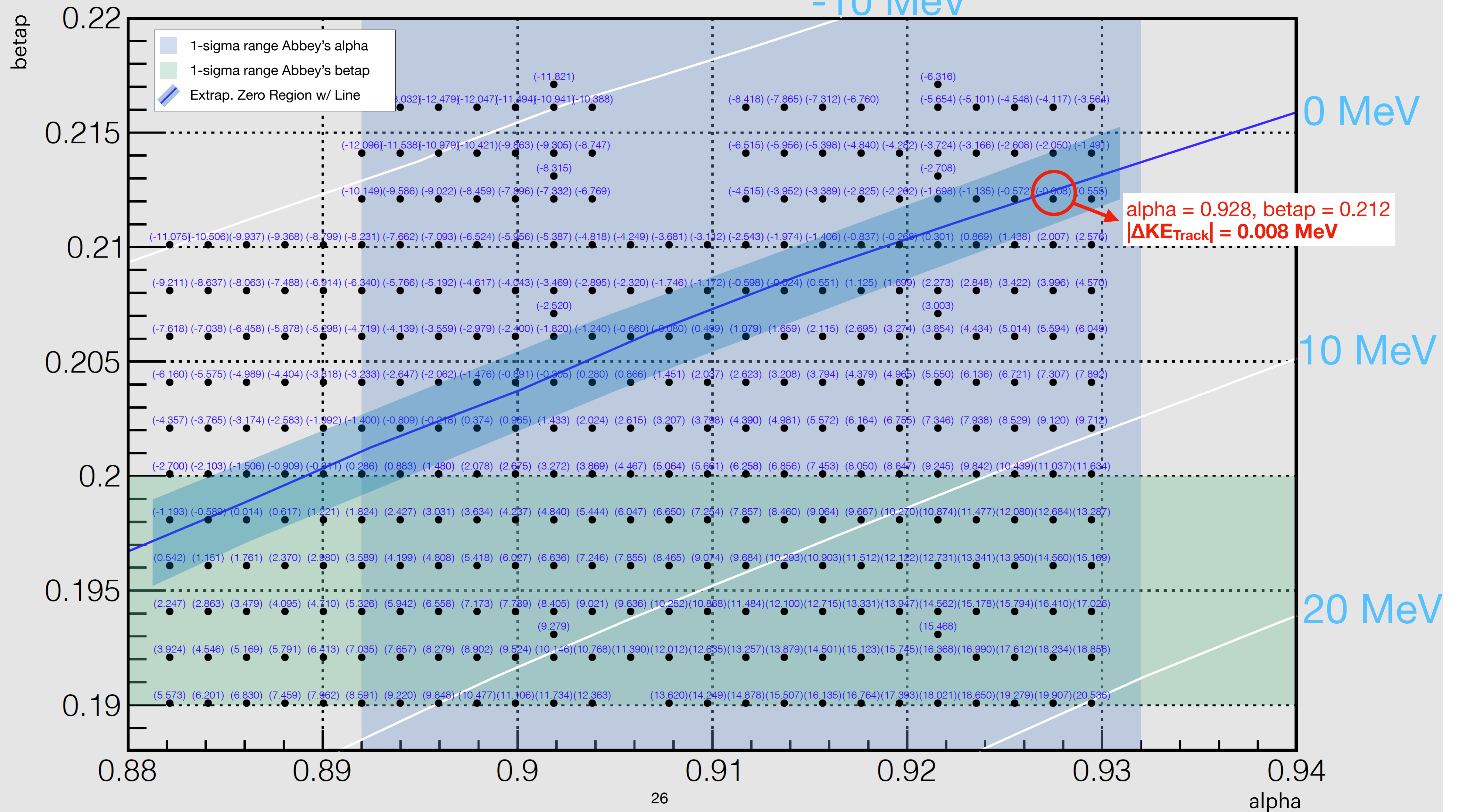
Inflection points visible in the 1-sigma region from central fit parameters



The $\Delta_{KE} = 0$ line

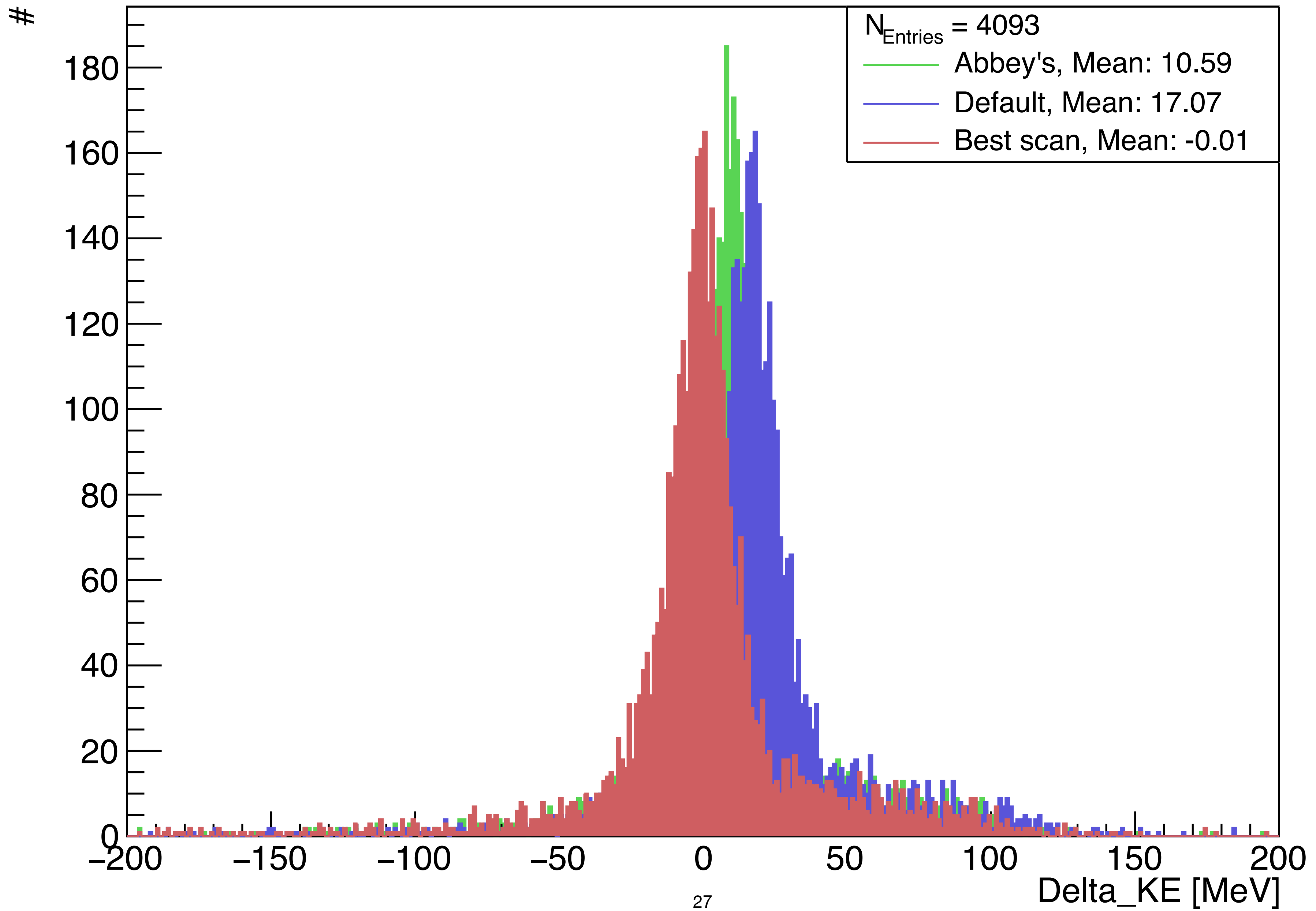


KE_range - KE_calo

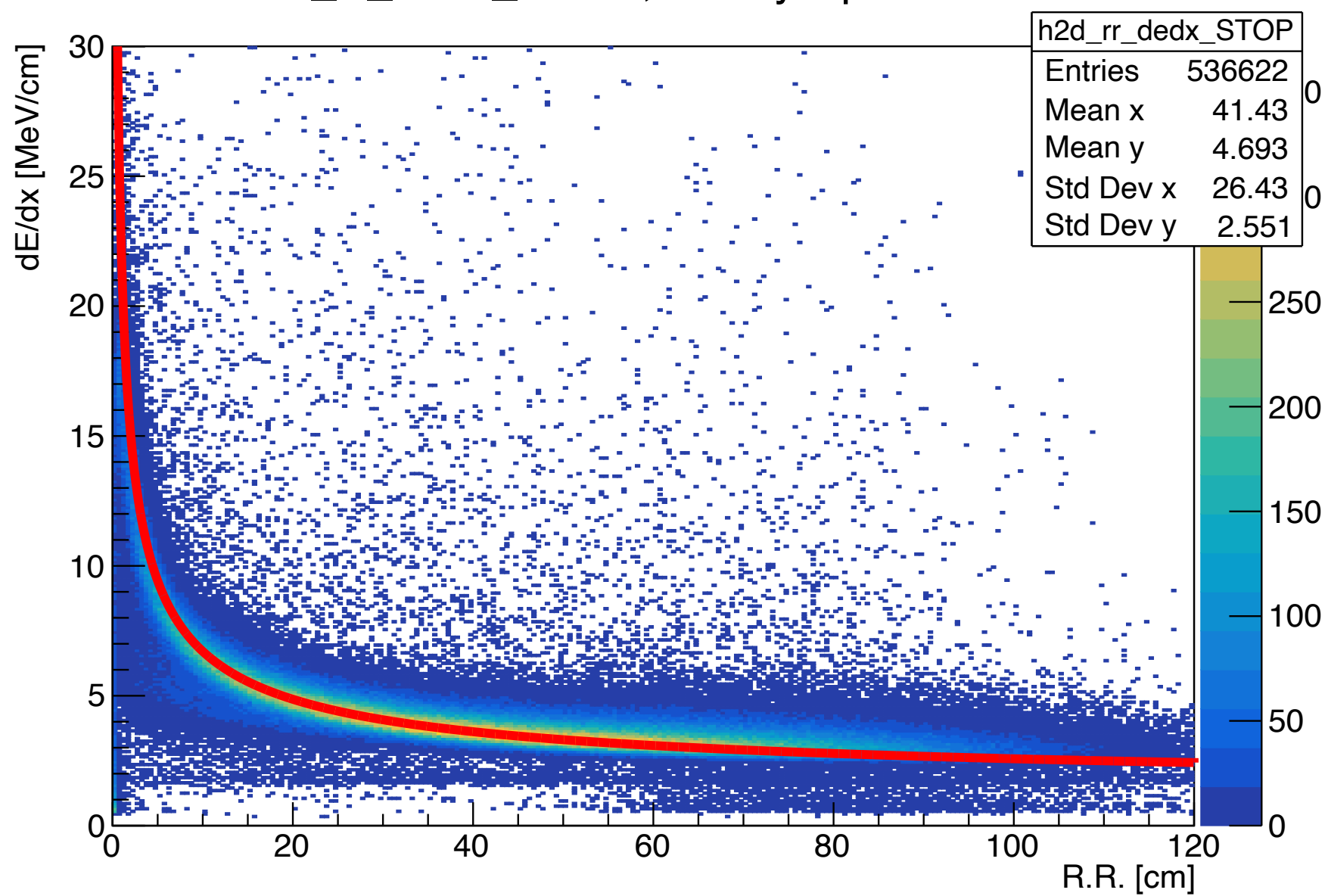


10-sigma range

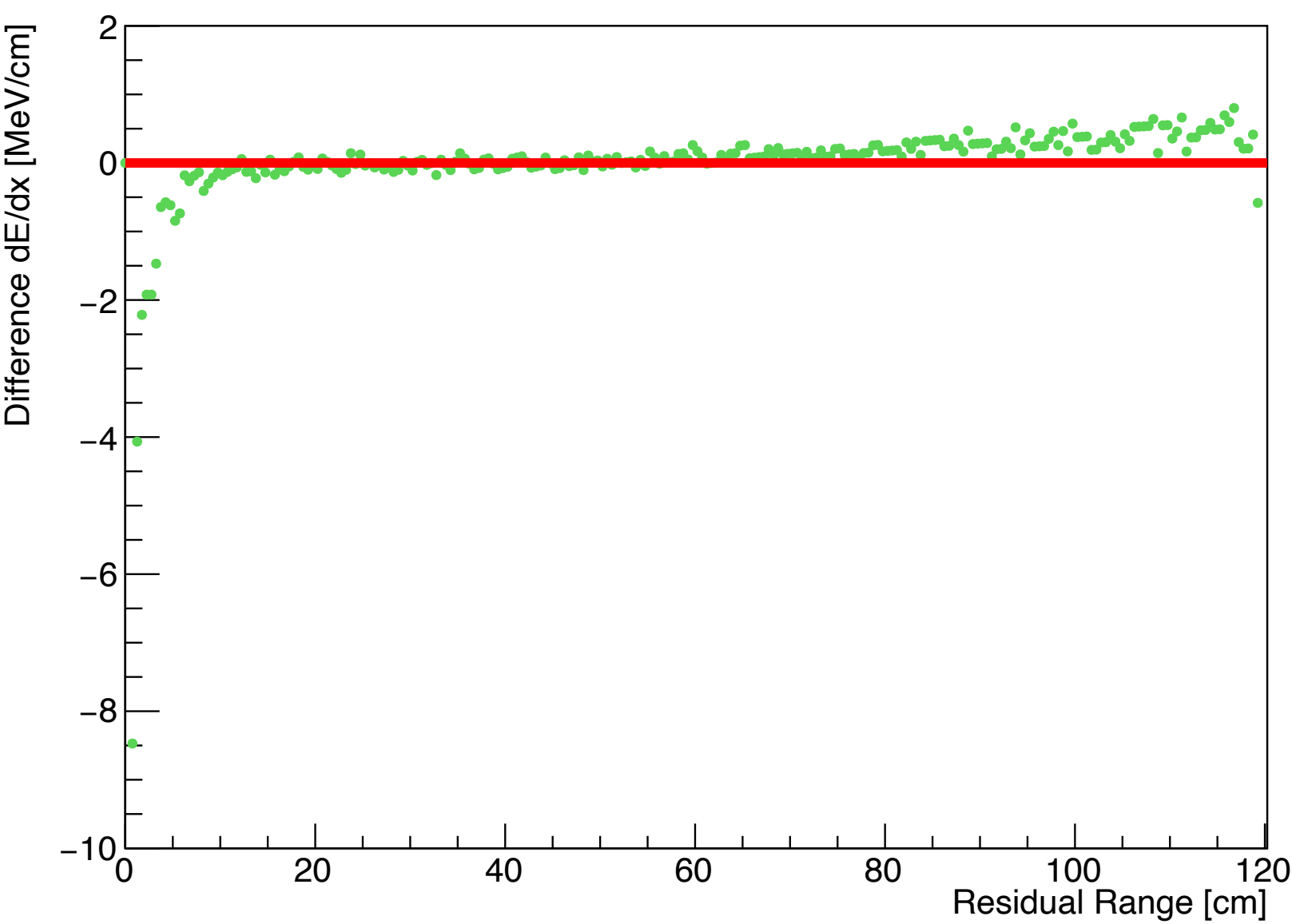
$KE_{\text{range}} - KE_{\text{calo}}$ per track



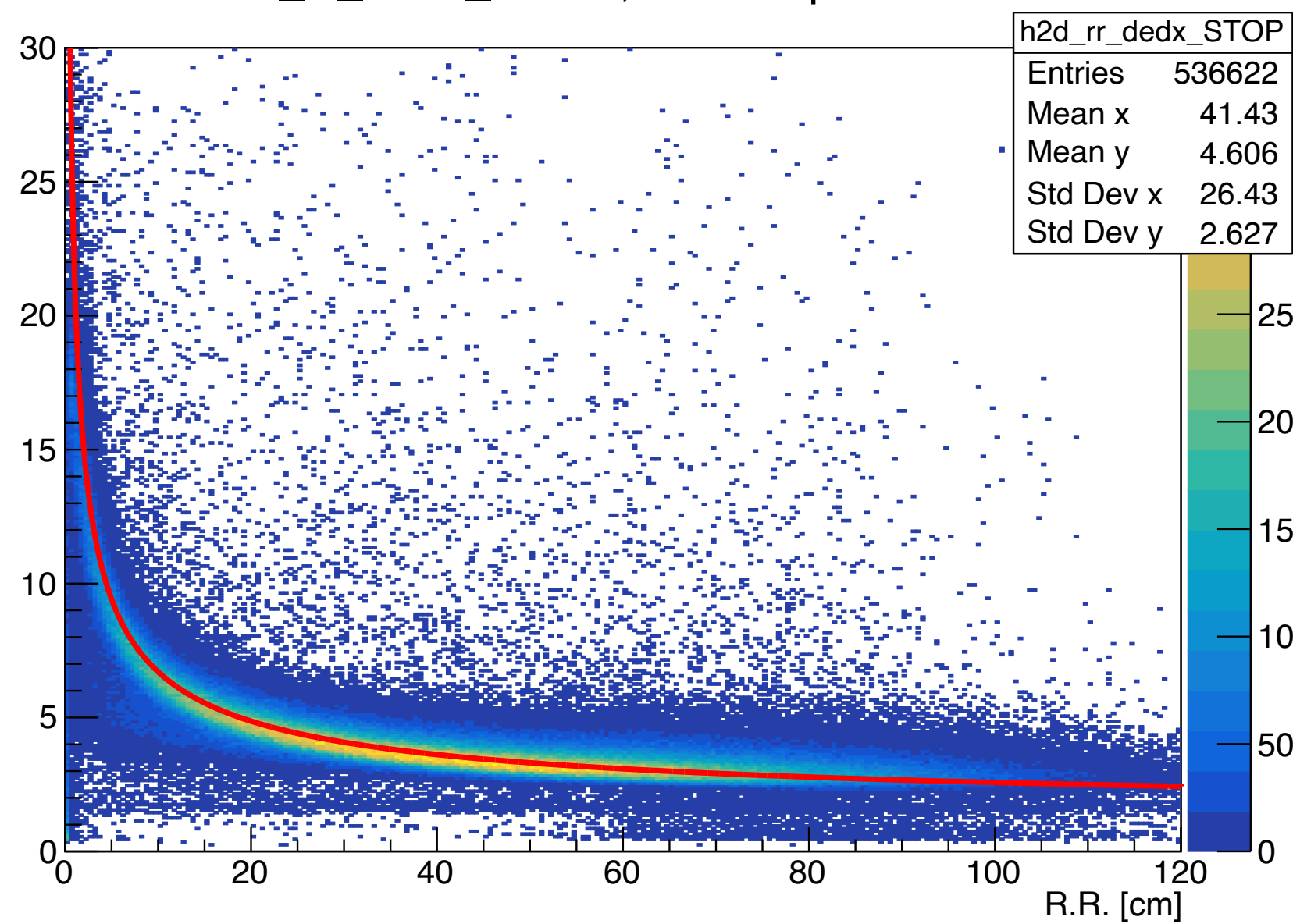
h2d_rr_dedx_STOP, Abbey's parameters



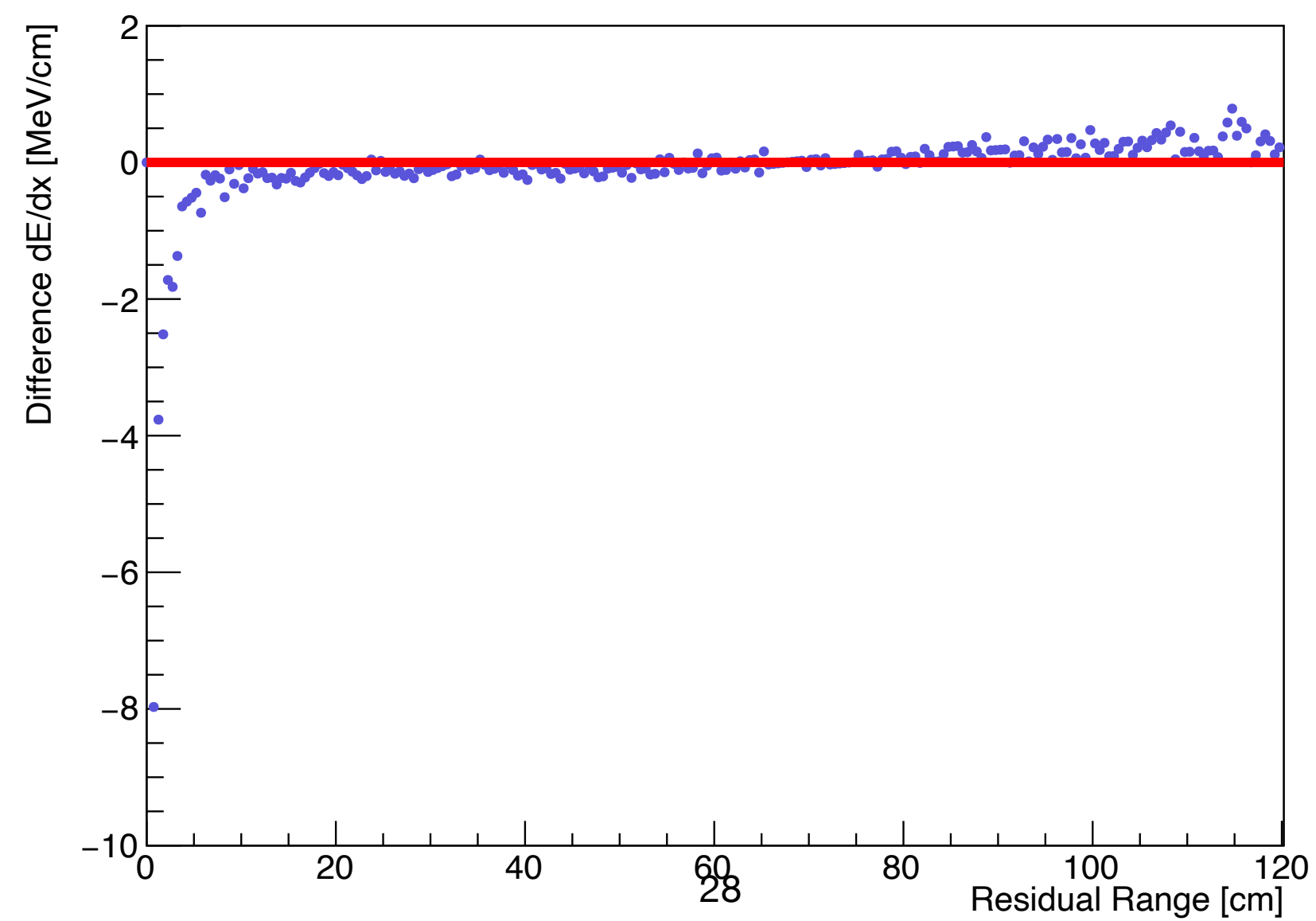
dEdxVsRR(Abbey's) - LV



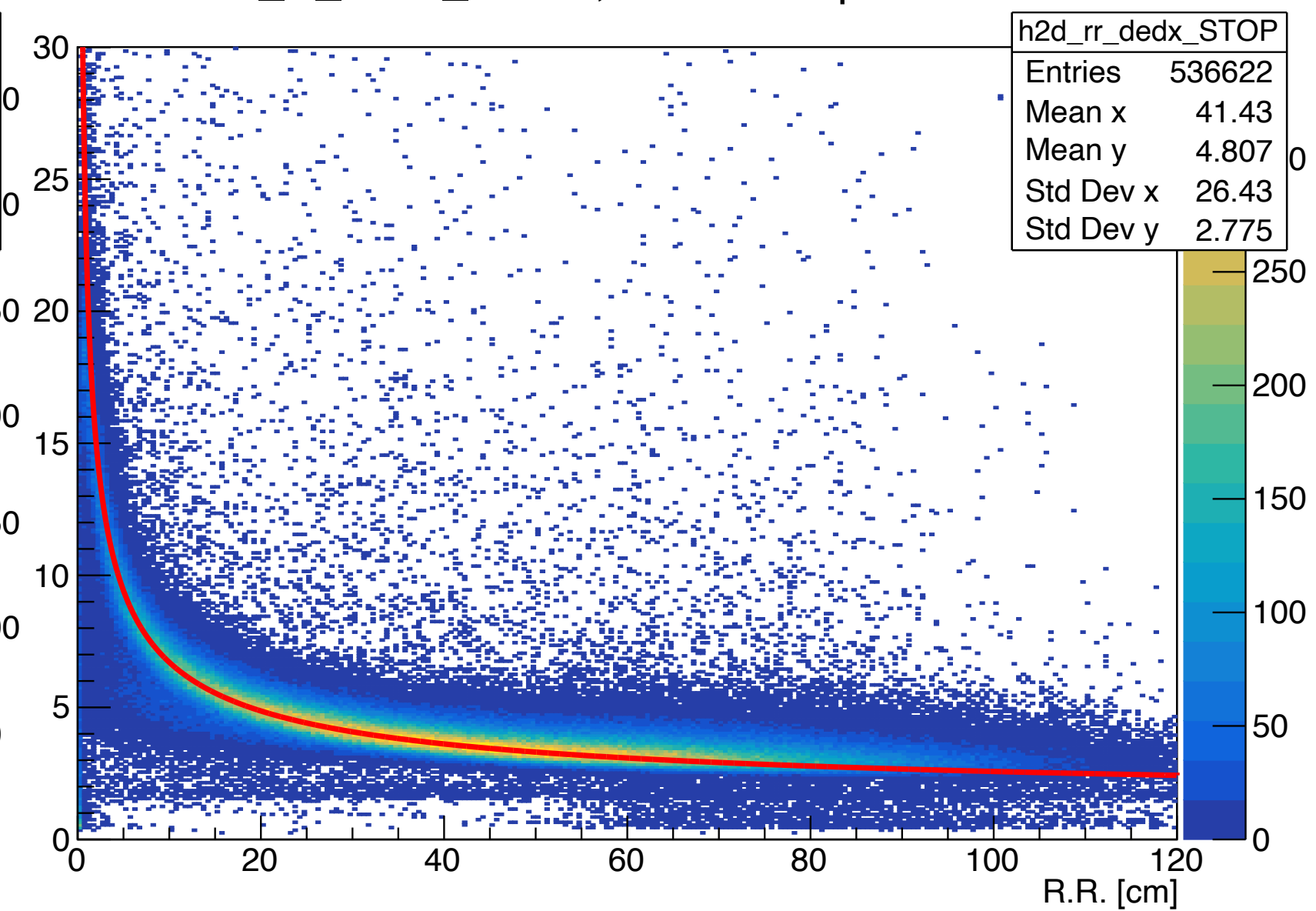
h2d_rr_dedx_STOP, Default parameters



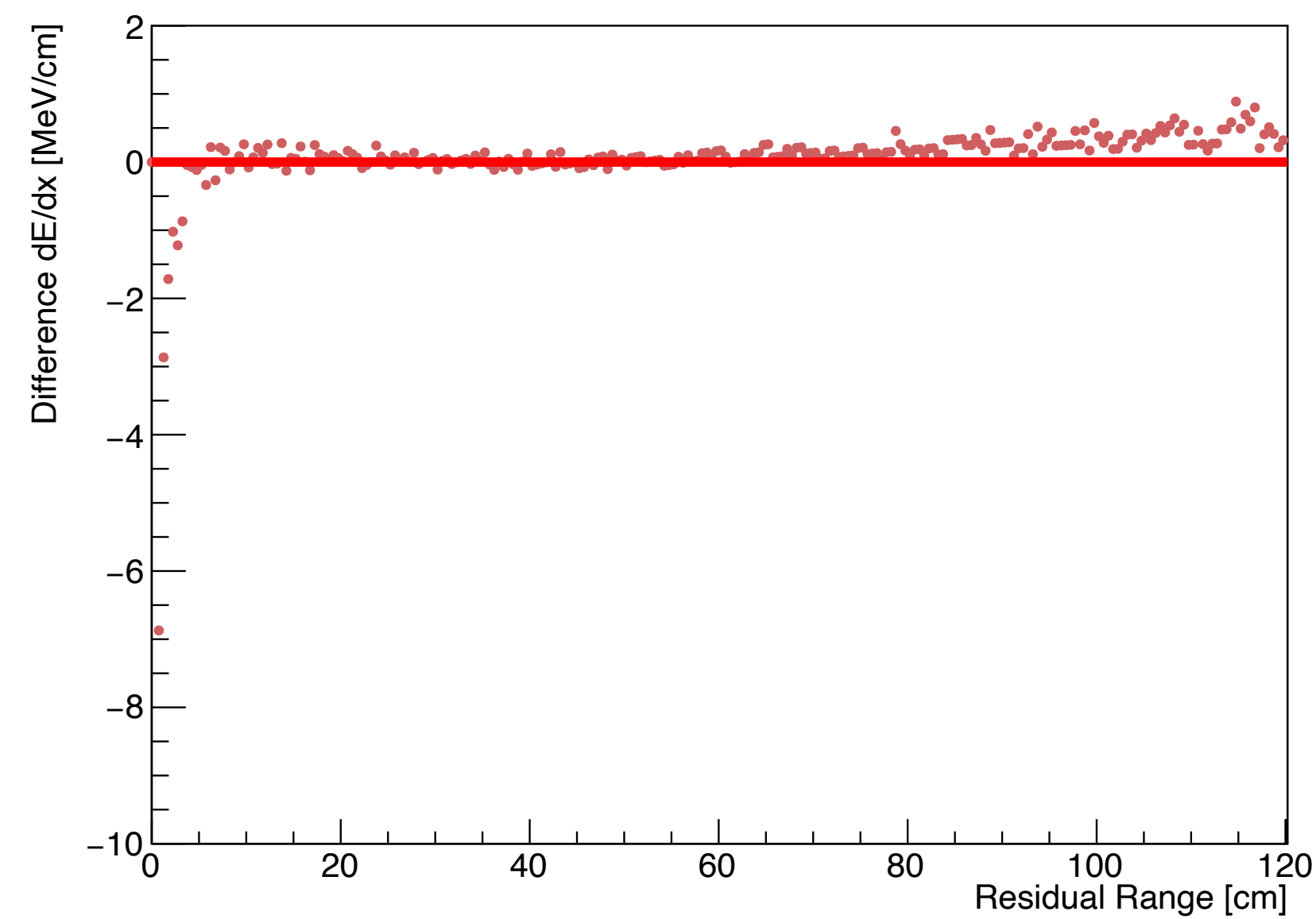
dEdxVsRR(Default) - LV



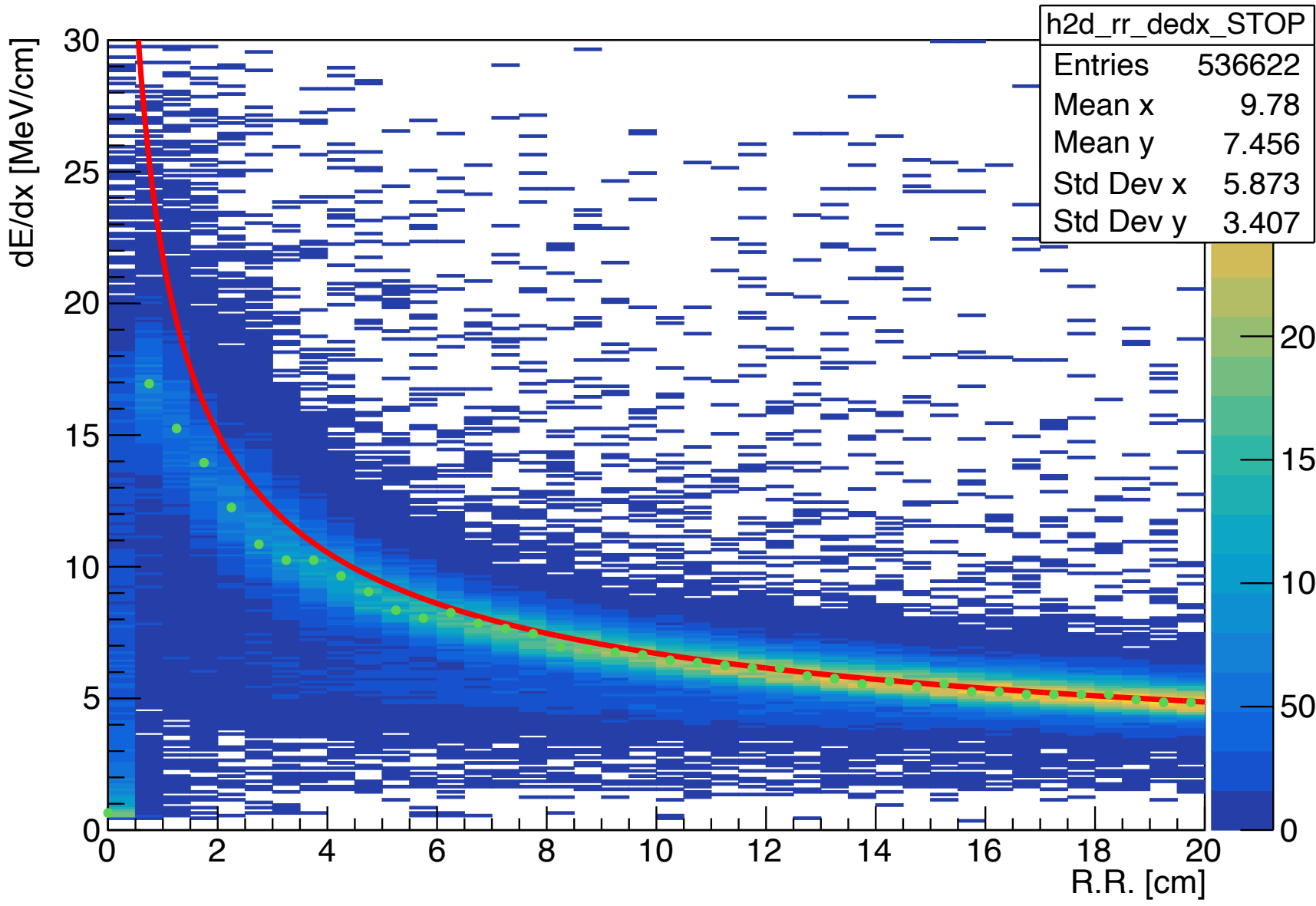
h2d_rr_dedx_STOP, Best scan parameters



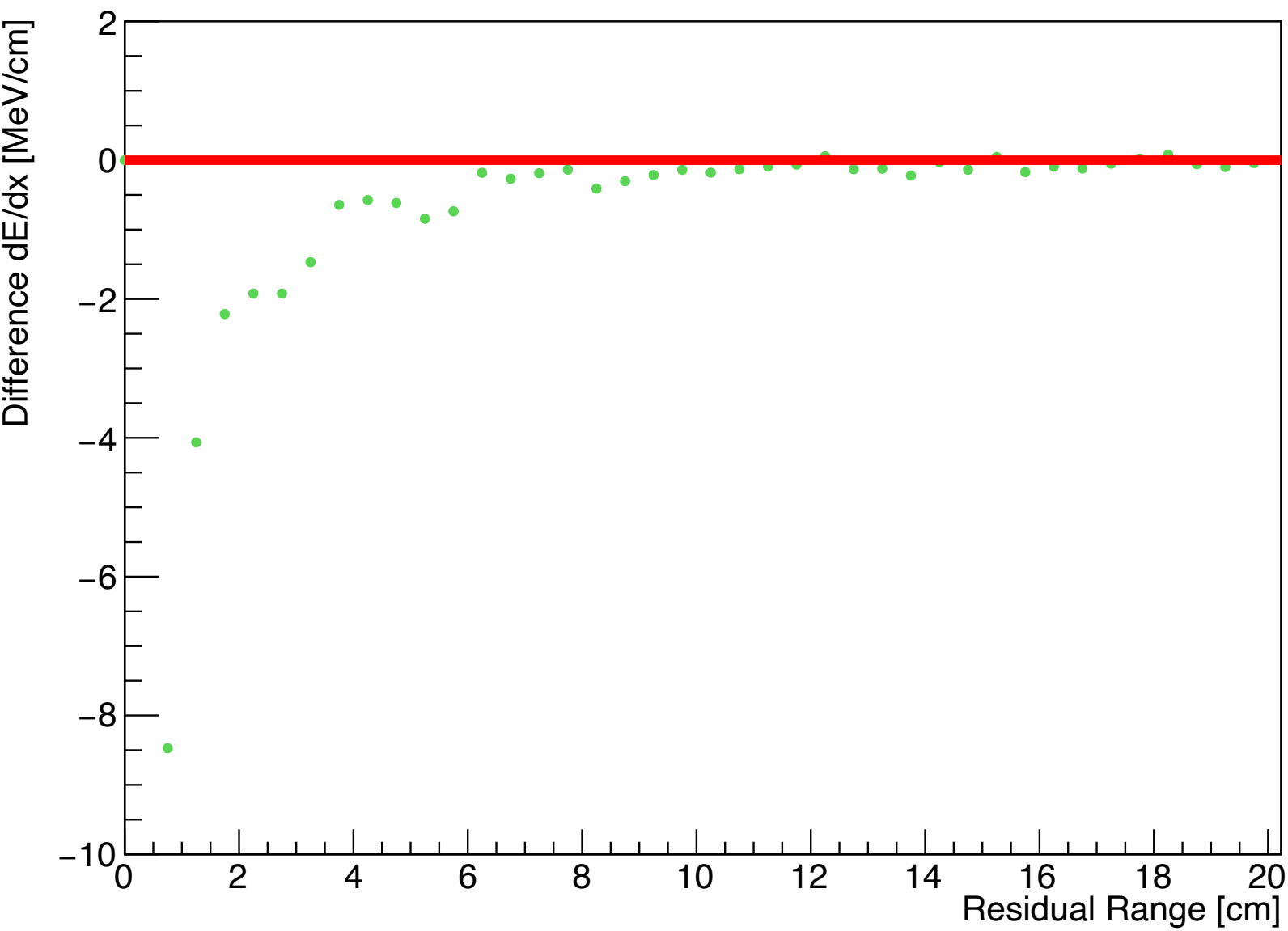
dEdxVsRR(Best scan) - LV



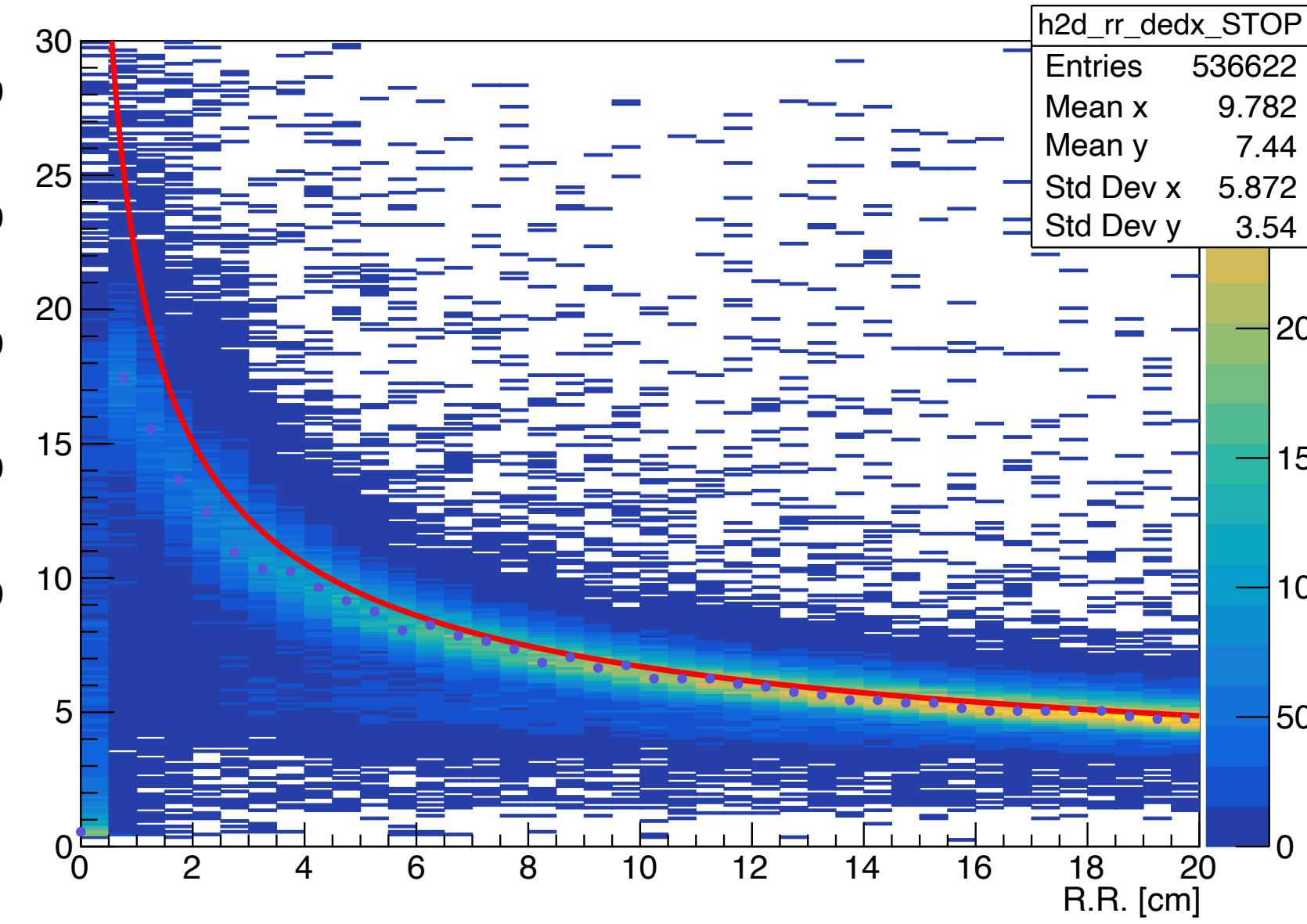
h2d_rr_dedx_STOP, Abbey's parameters



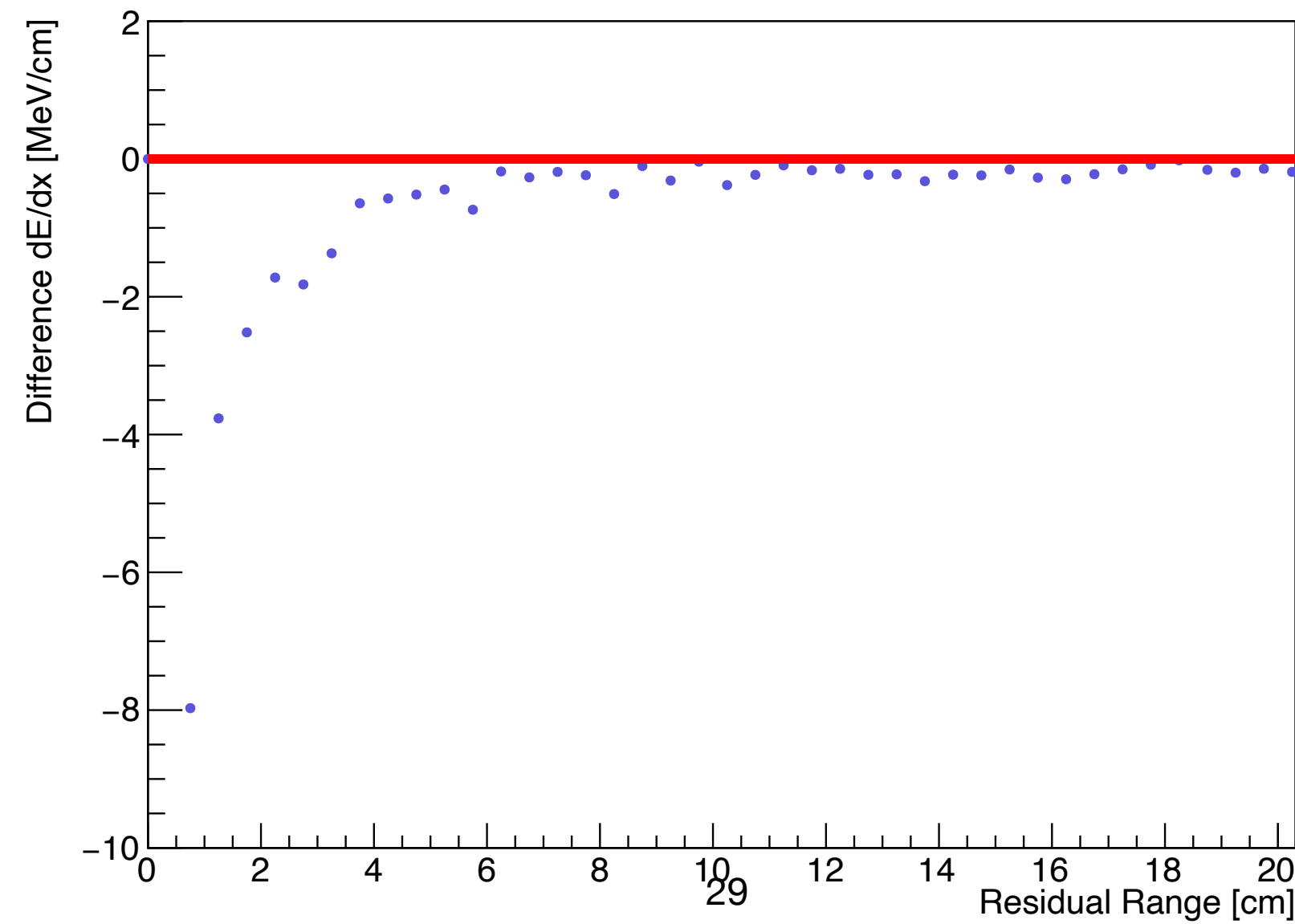
dEdxVsRR(Abbey's) - LV



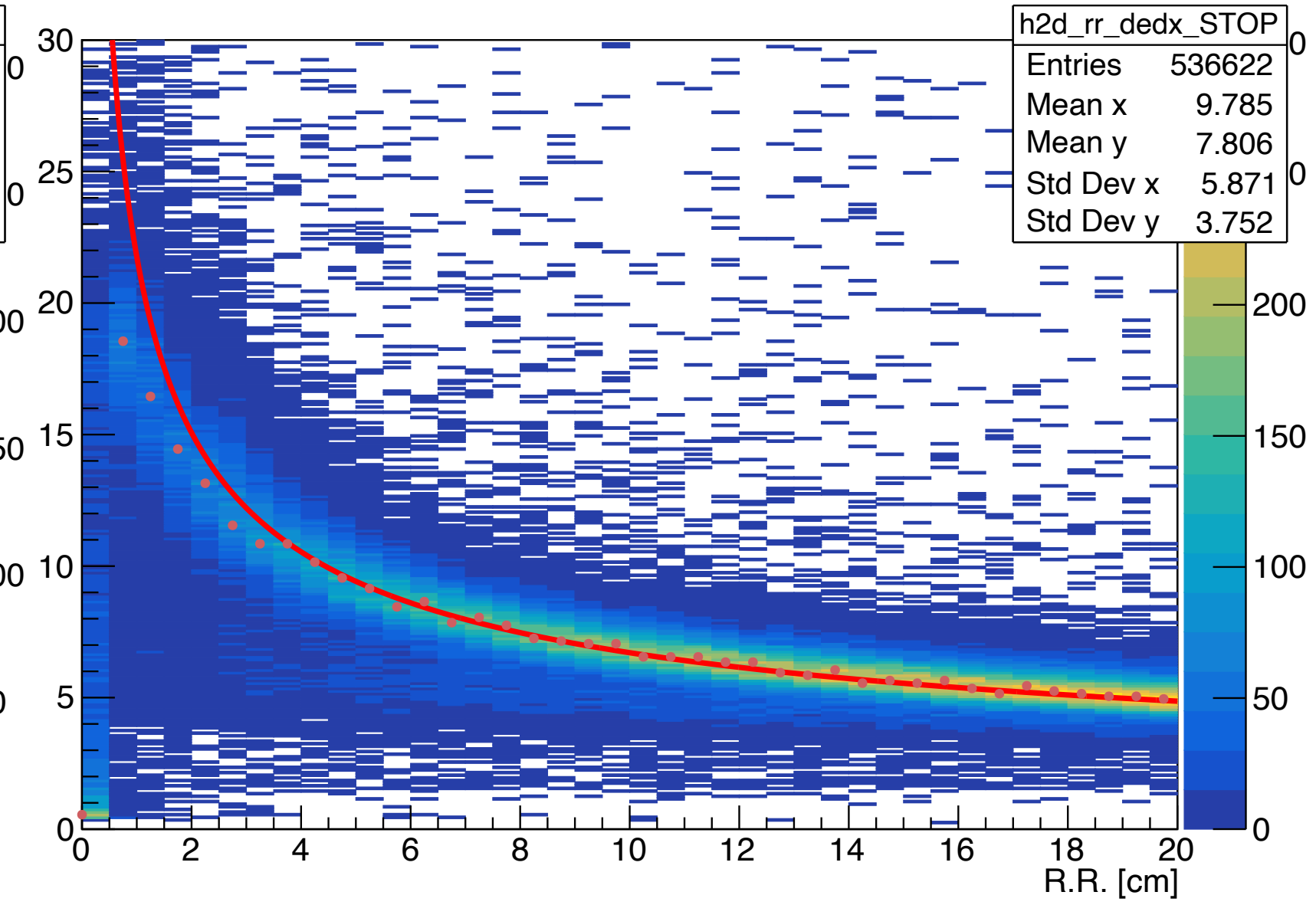
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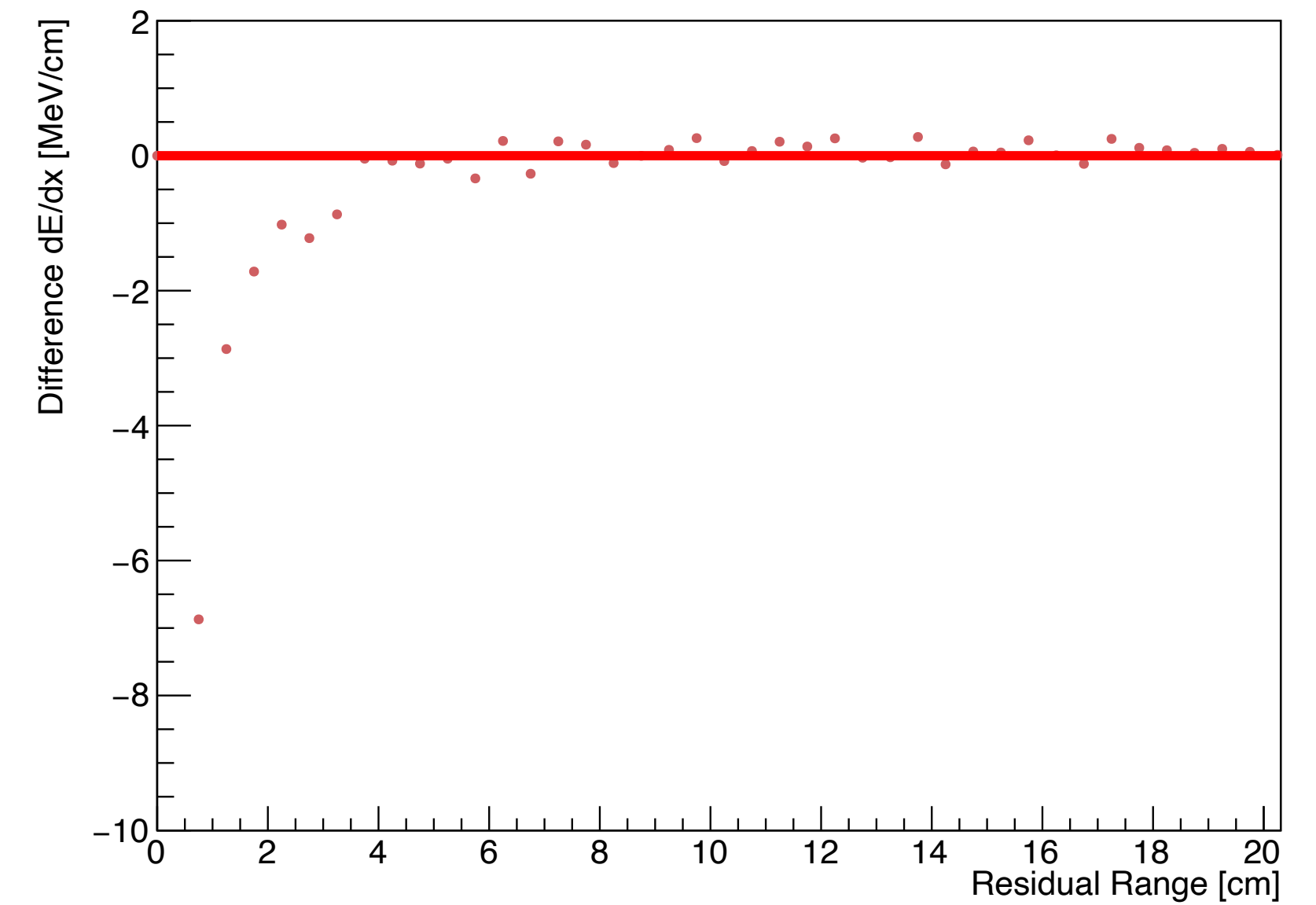
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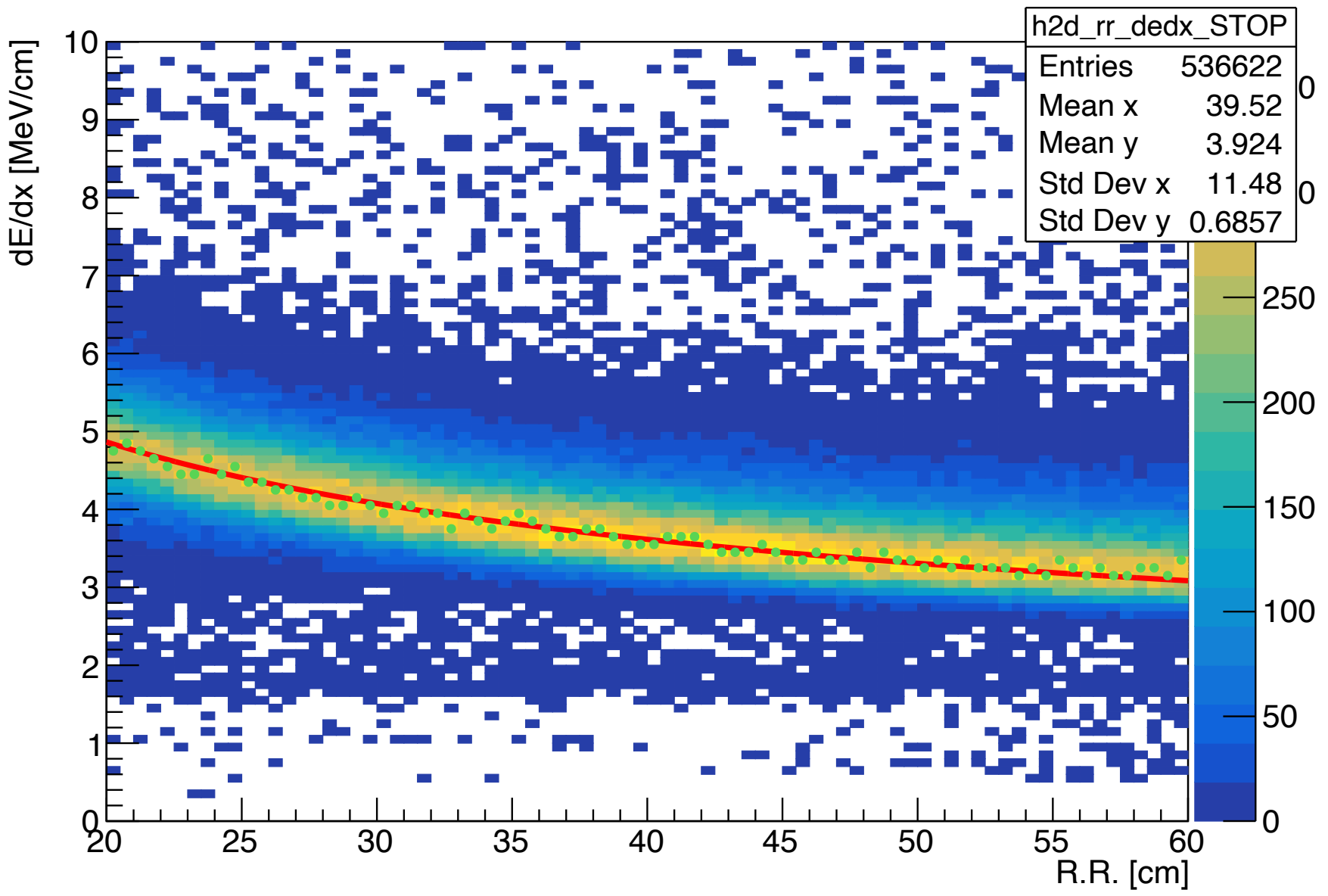
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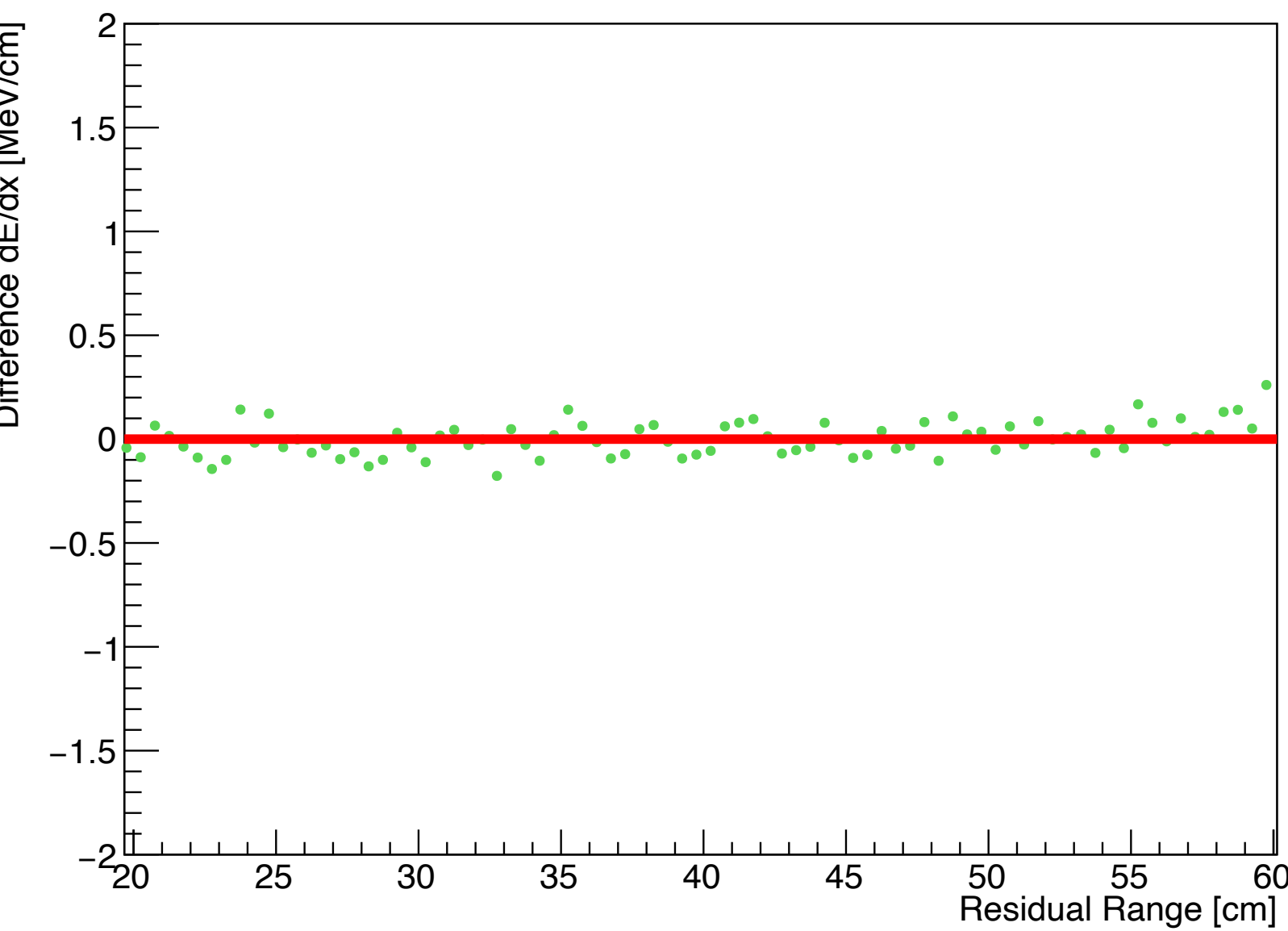
dEdxVsRR(Best scan) - LV



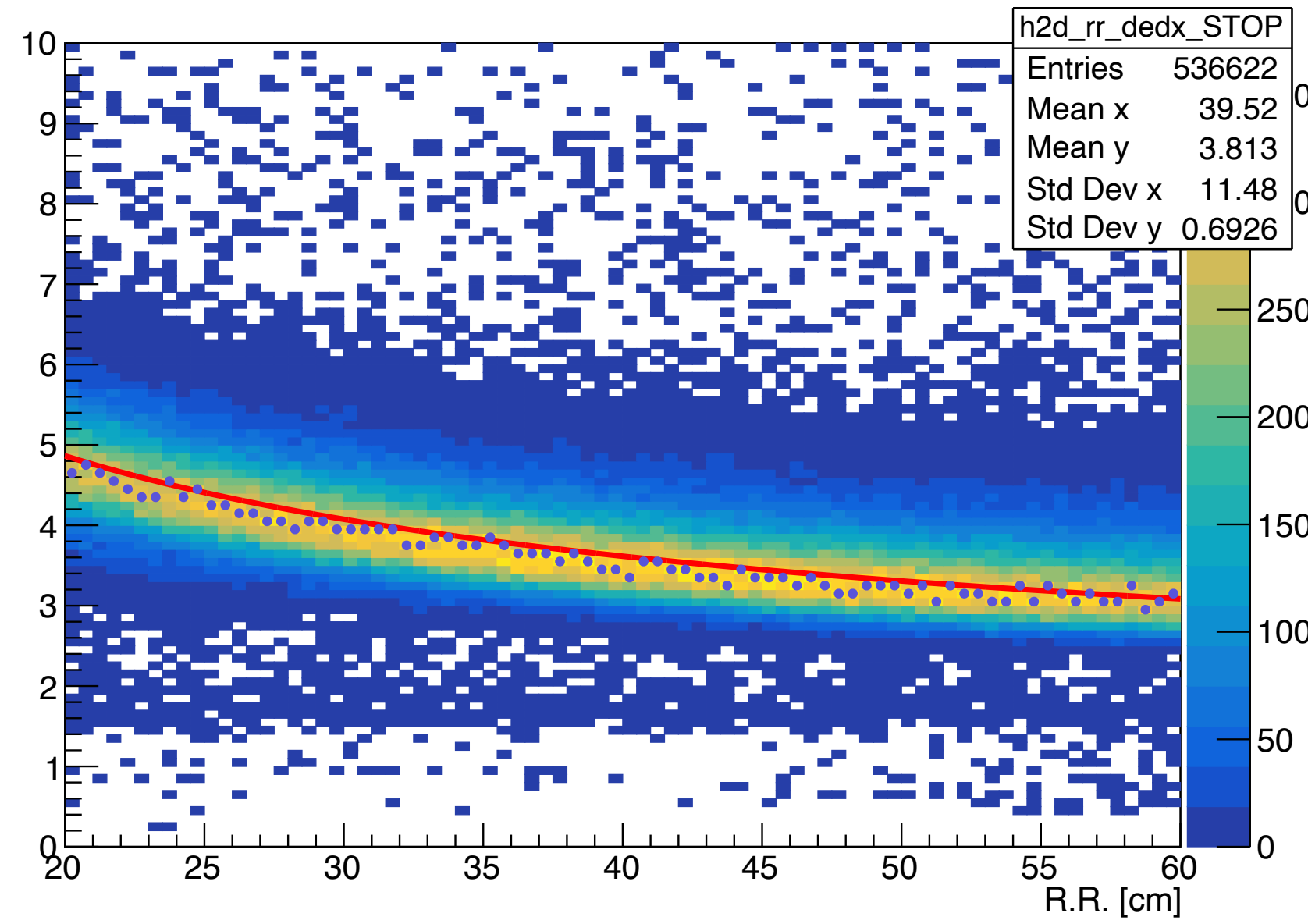
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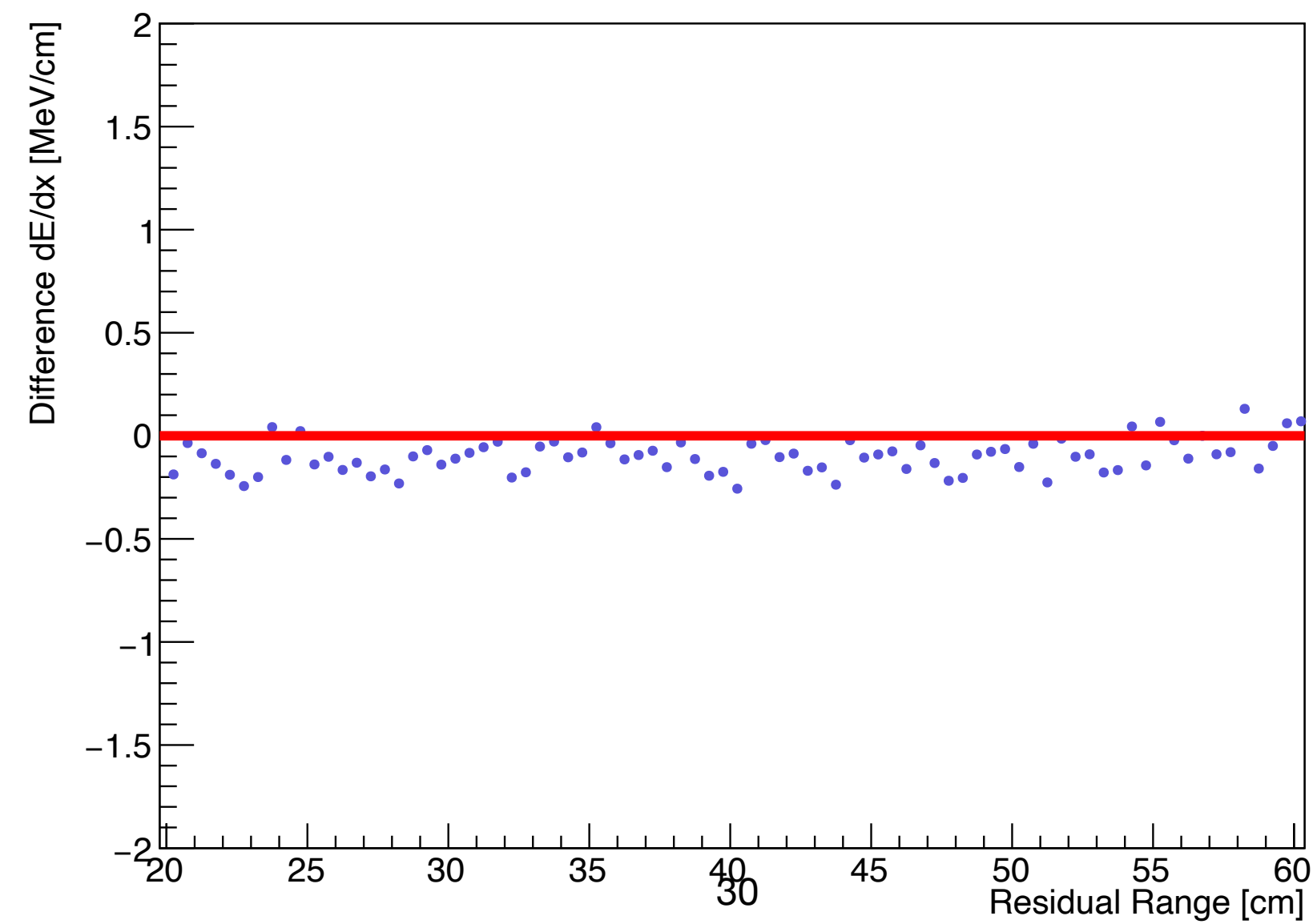
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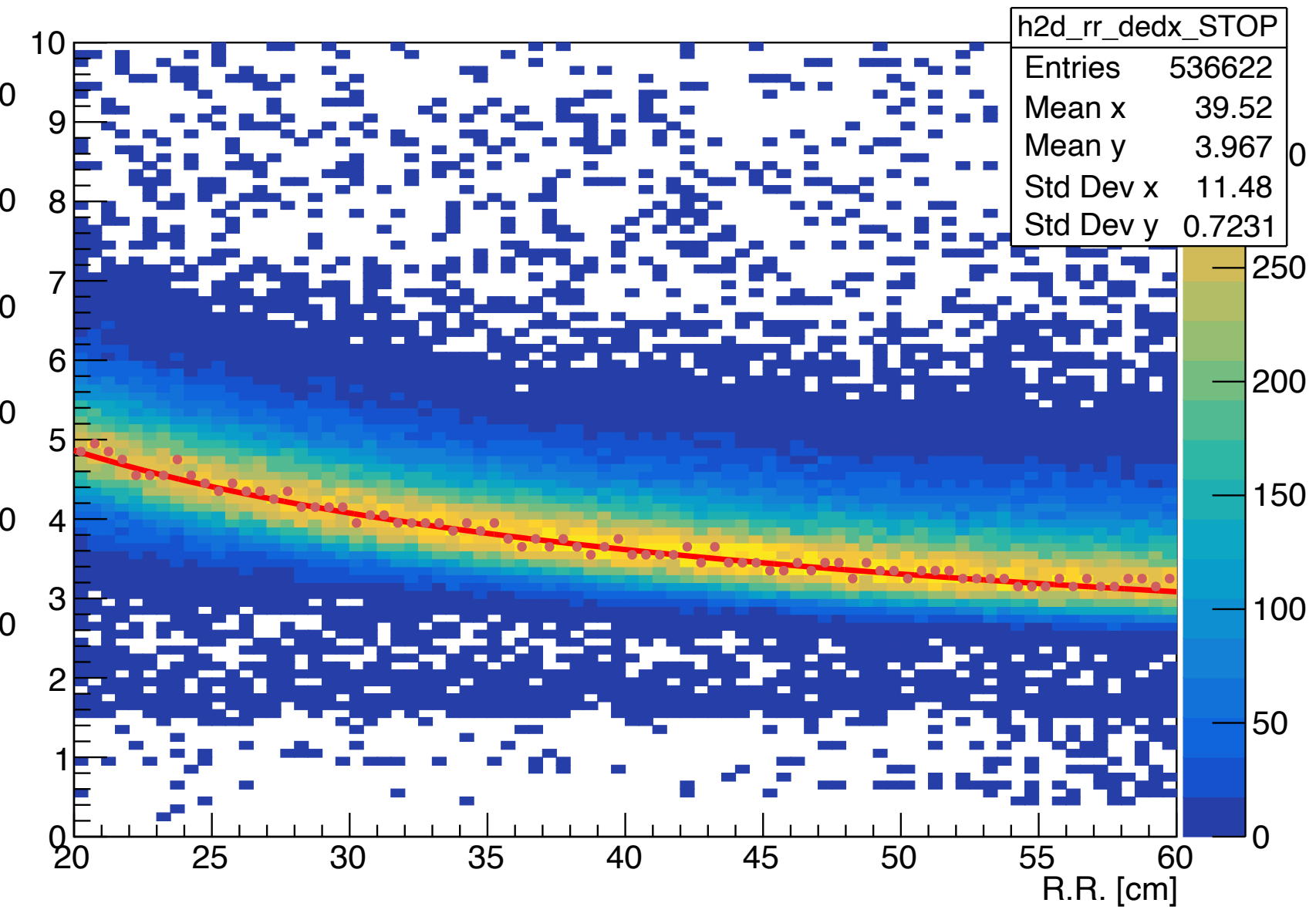
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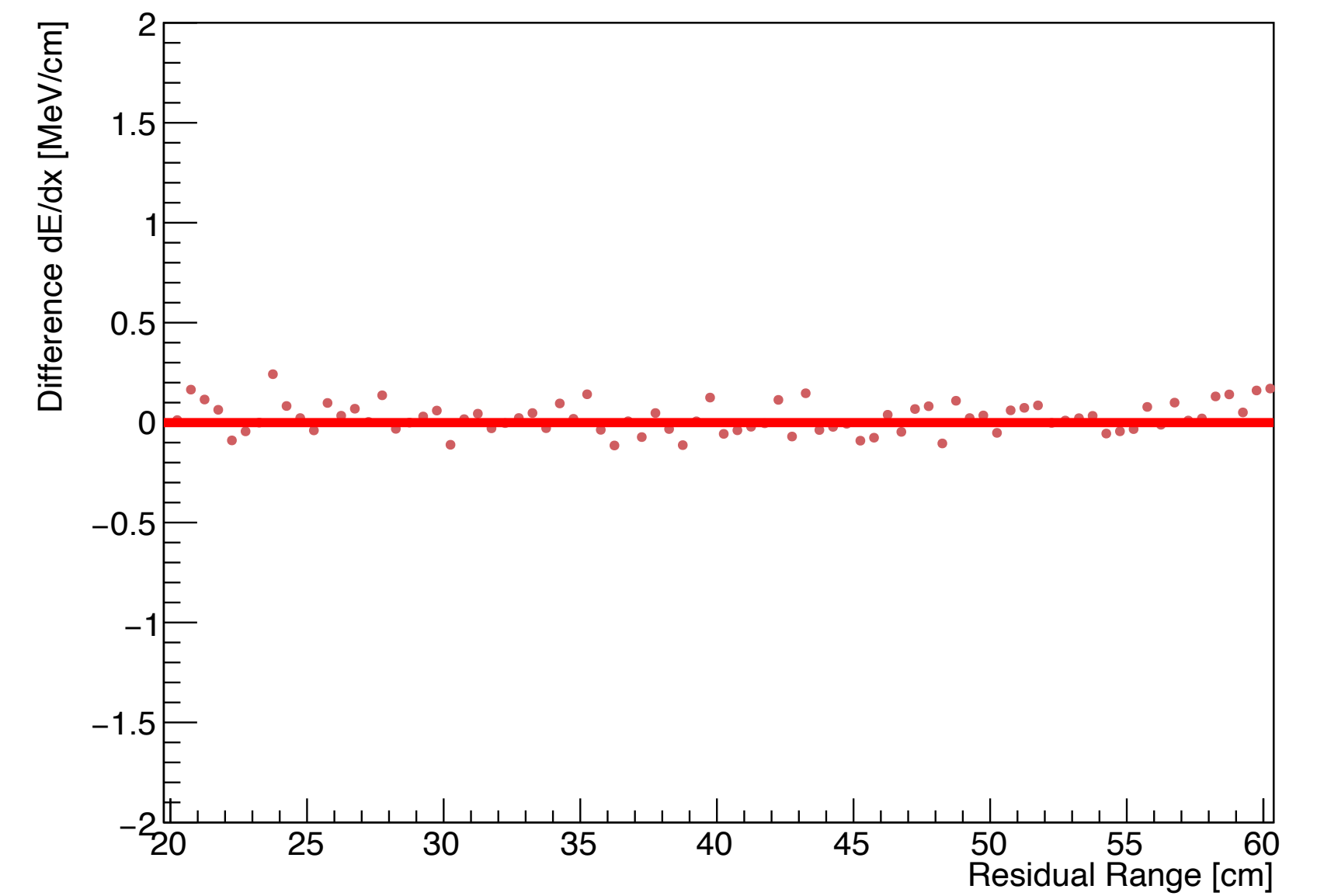
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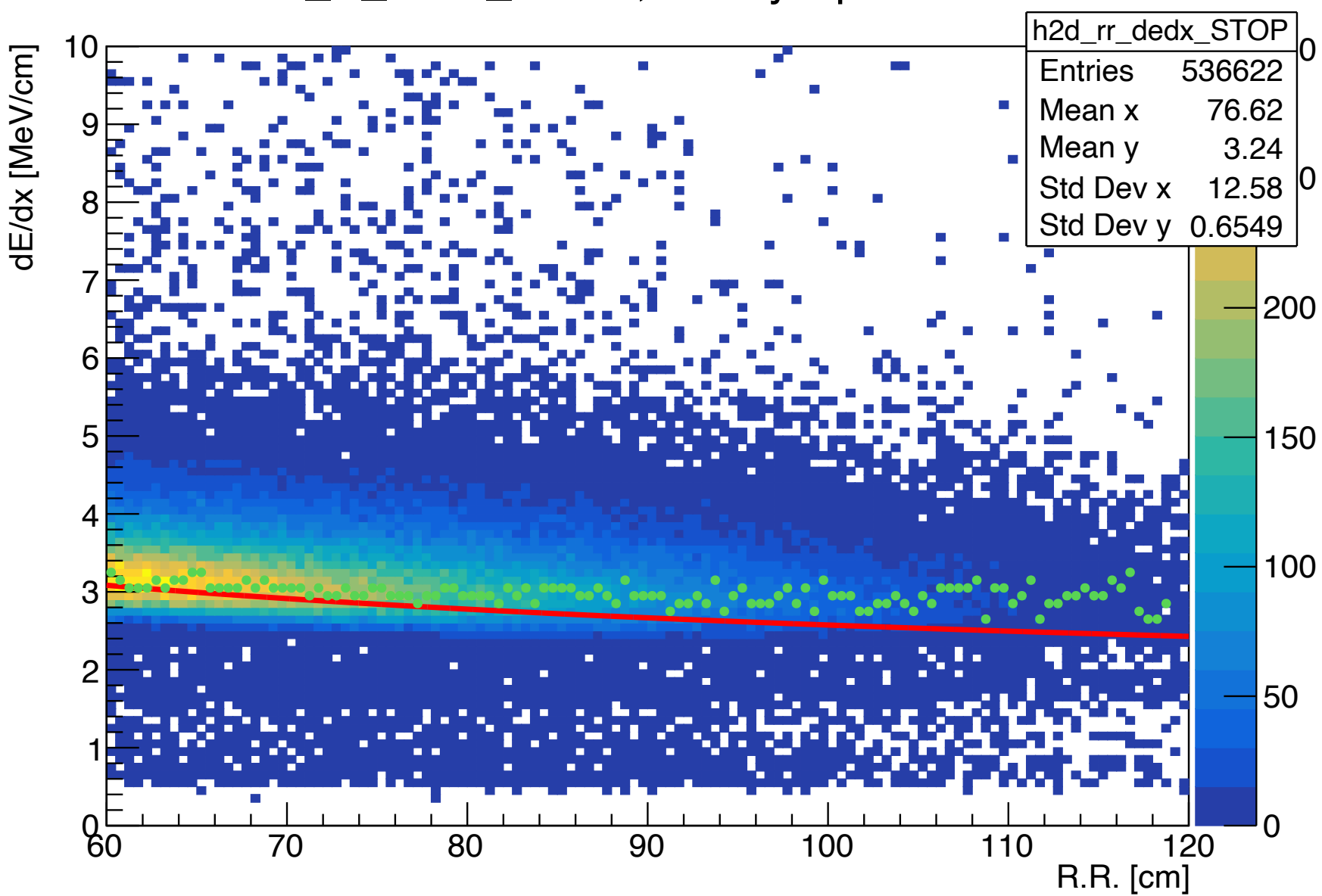
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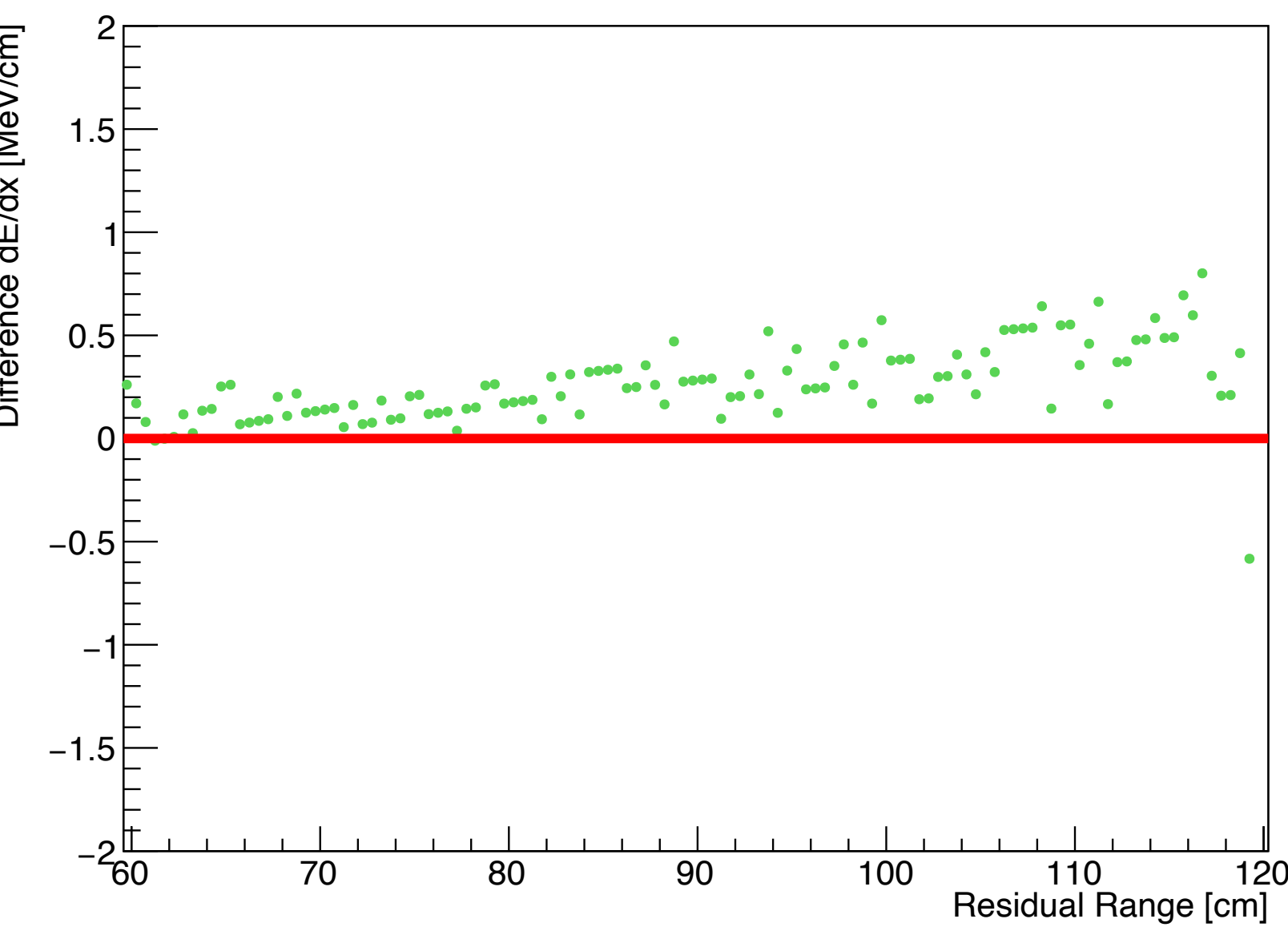
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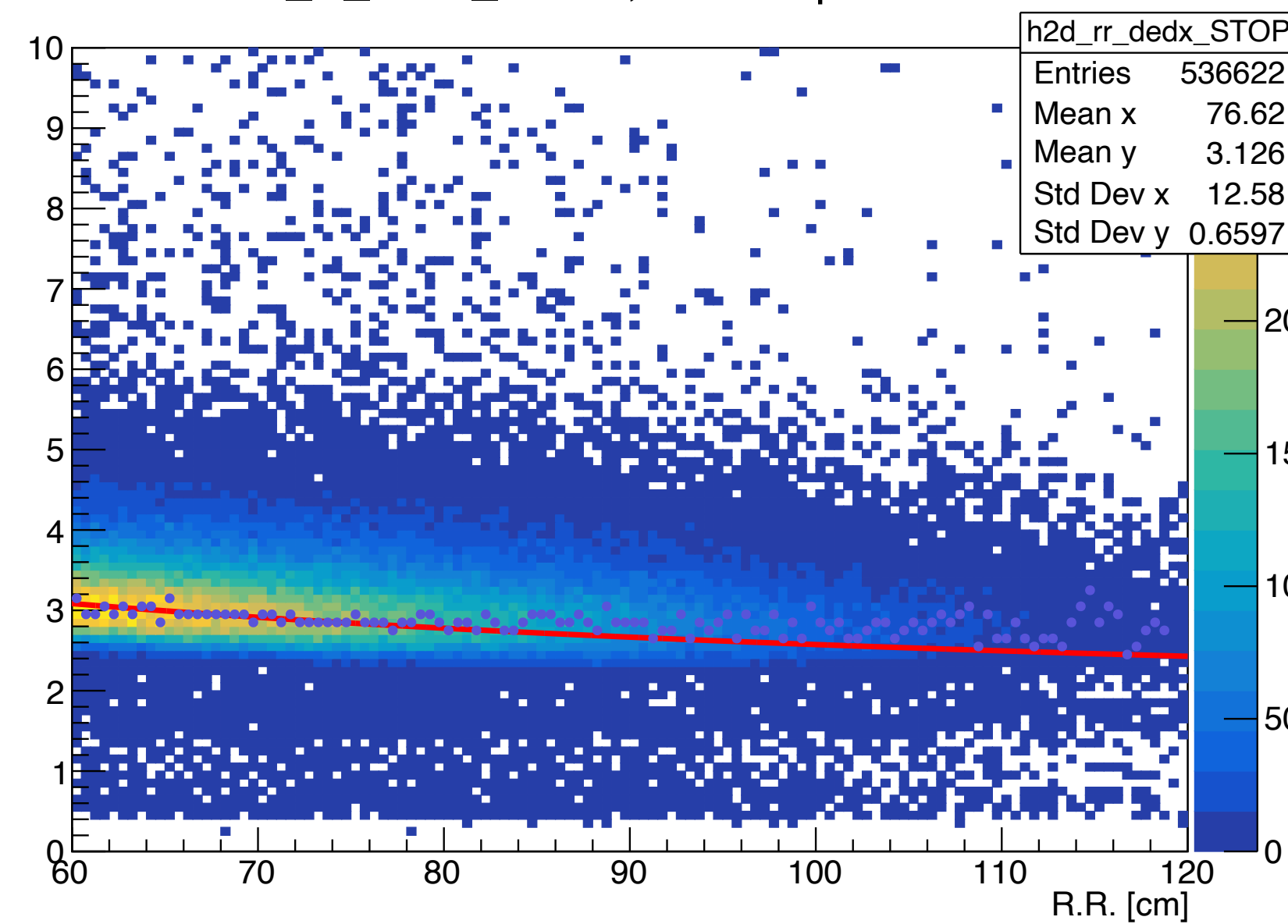
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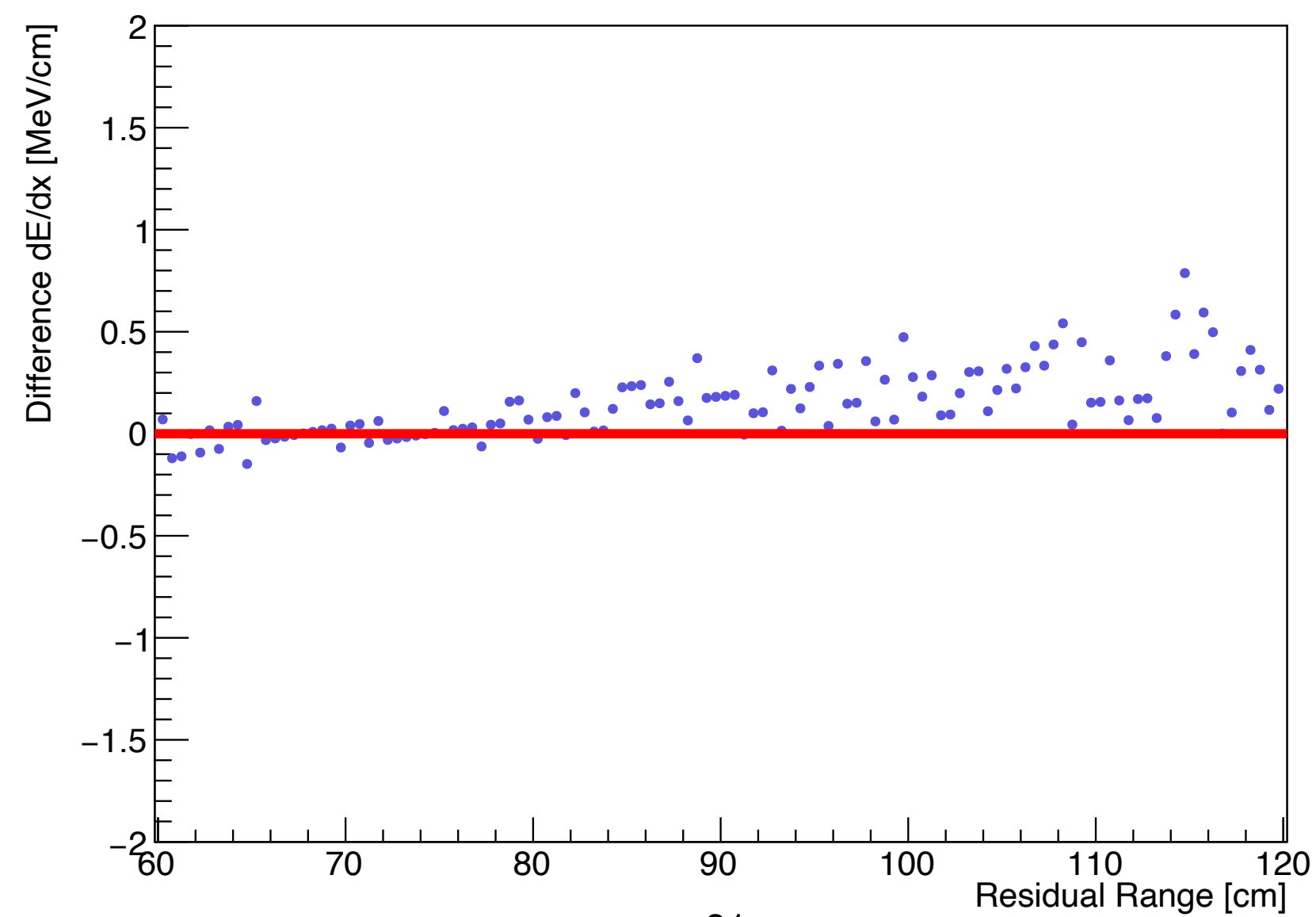
dEdxVsRR(Abbey's) - LV



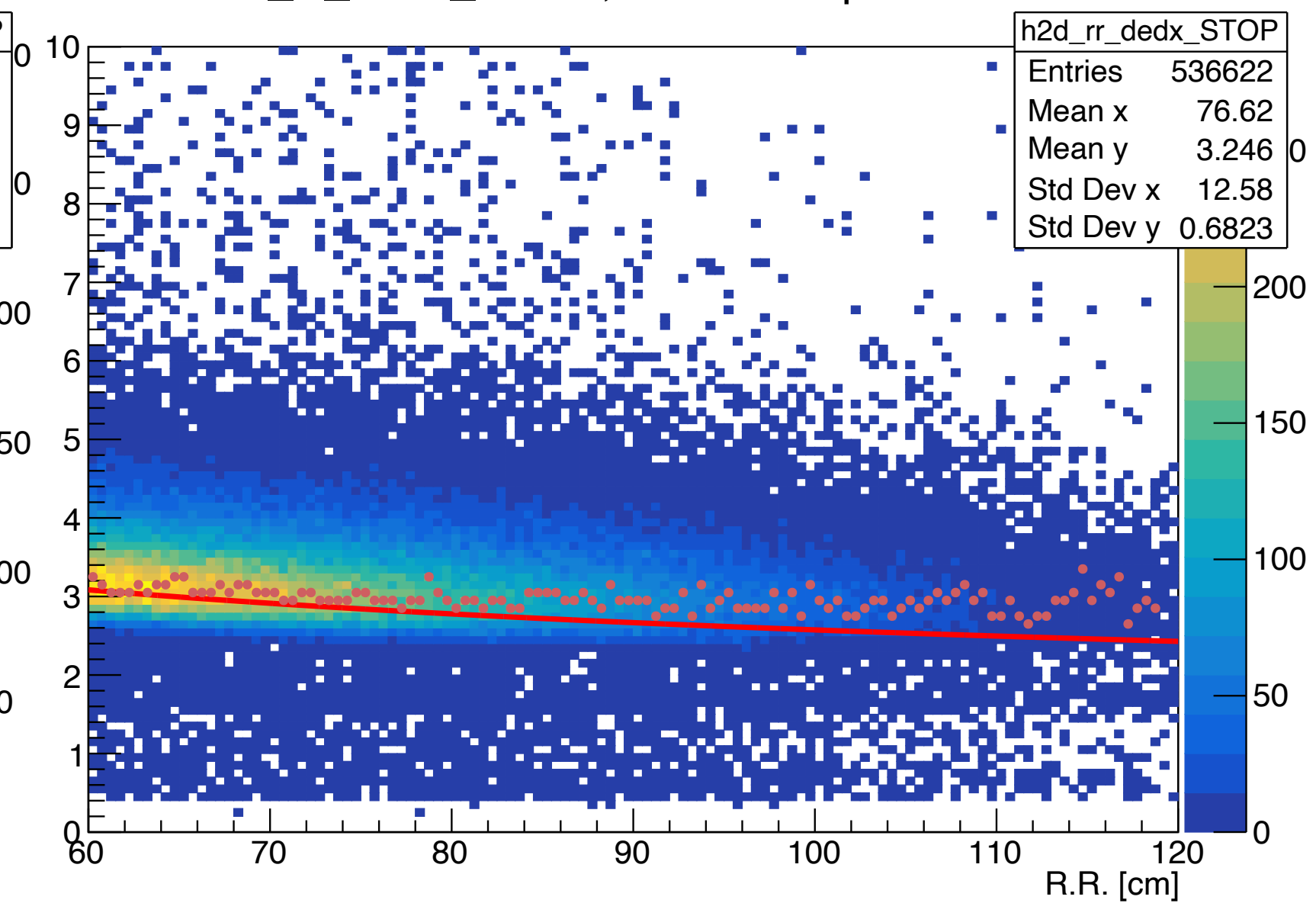
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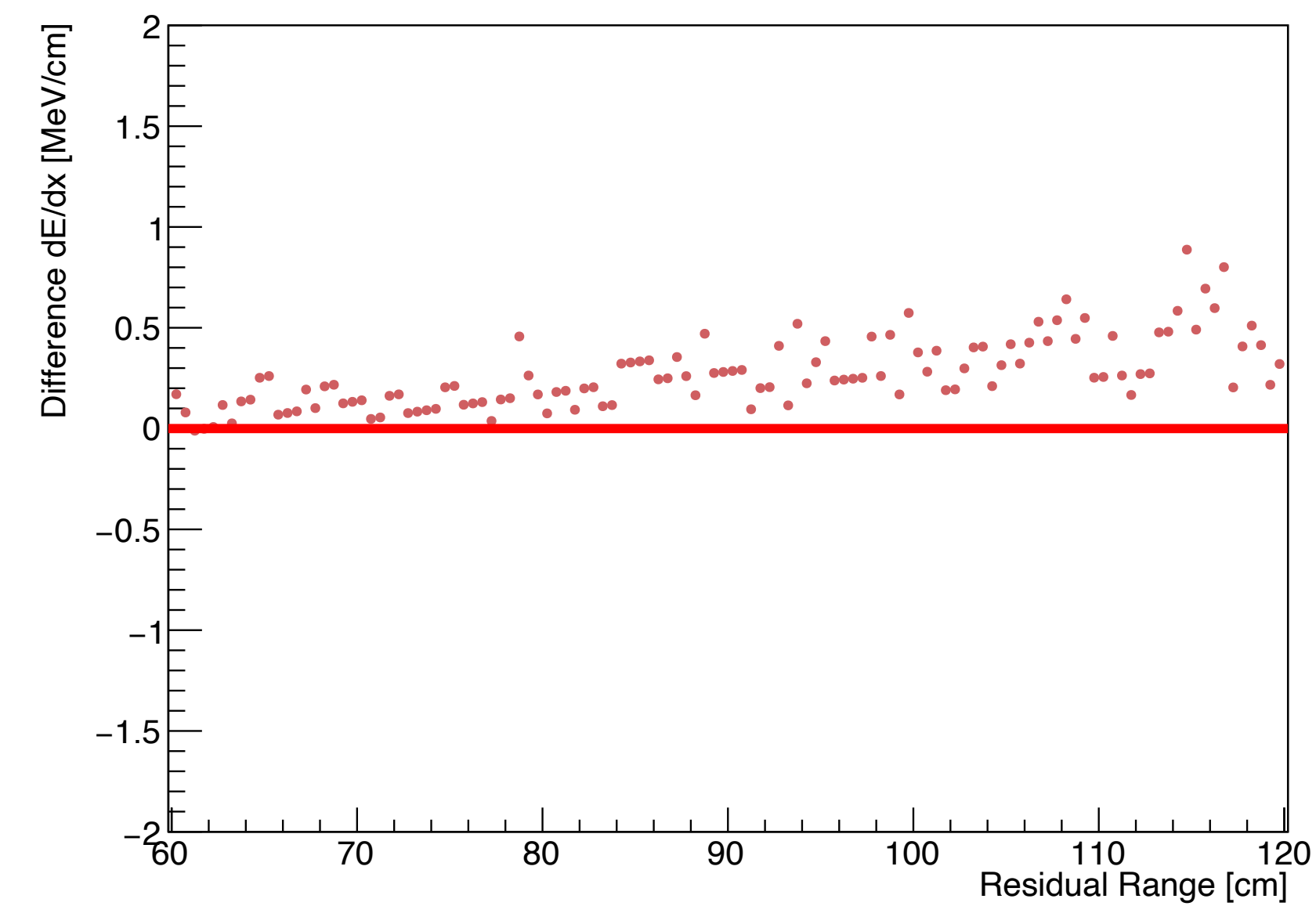
dEdxVsRR(Default) - LV



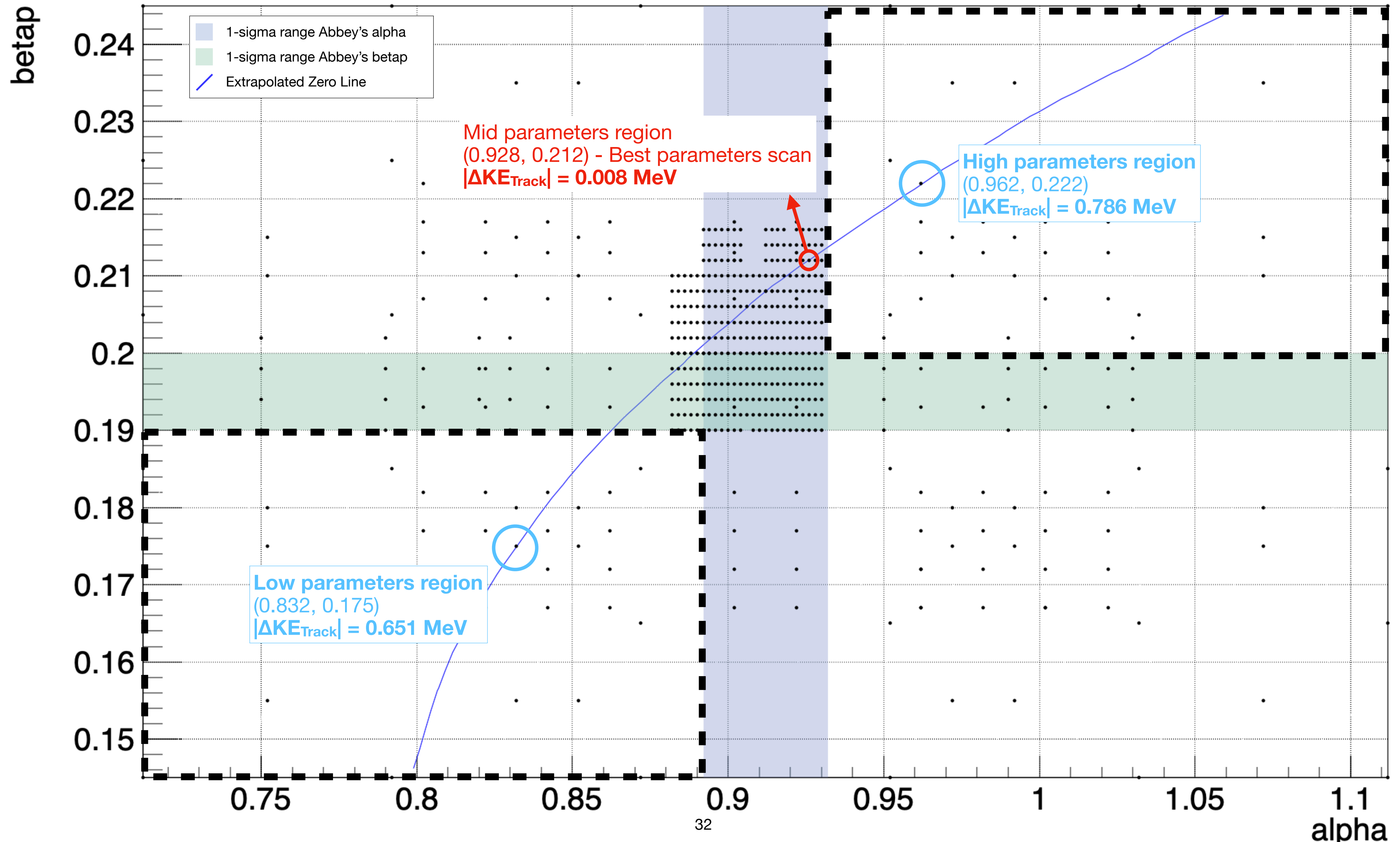
h2d_rr_dedx_STOP, Best scan parameters



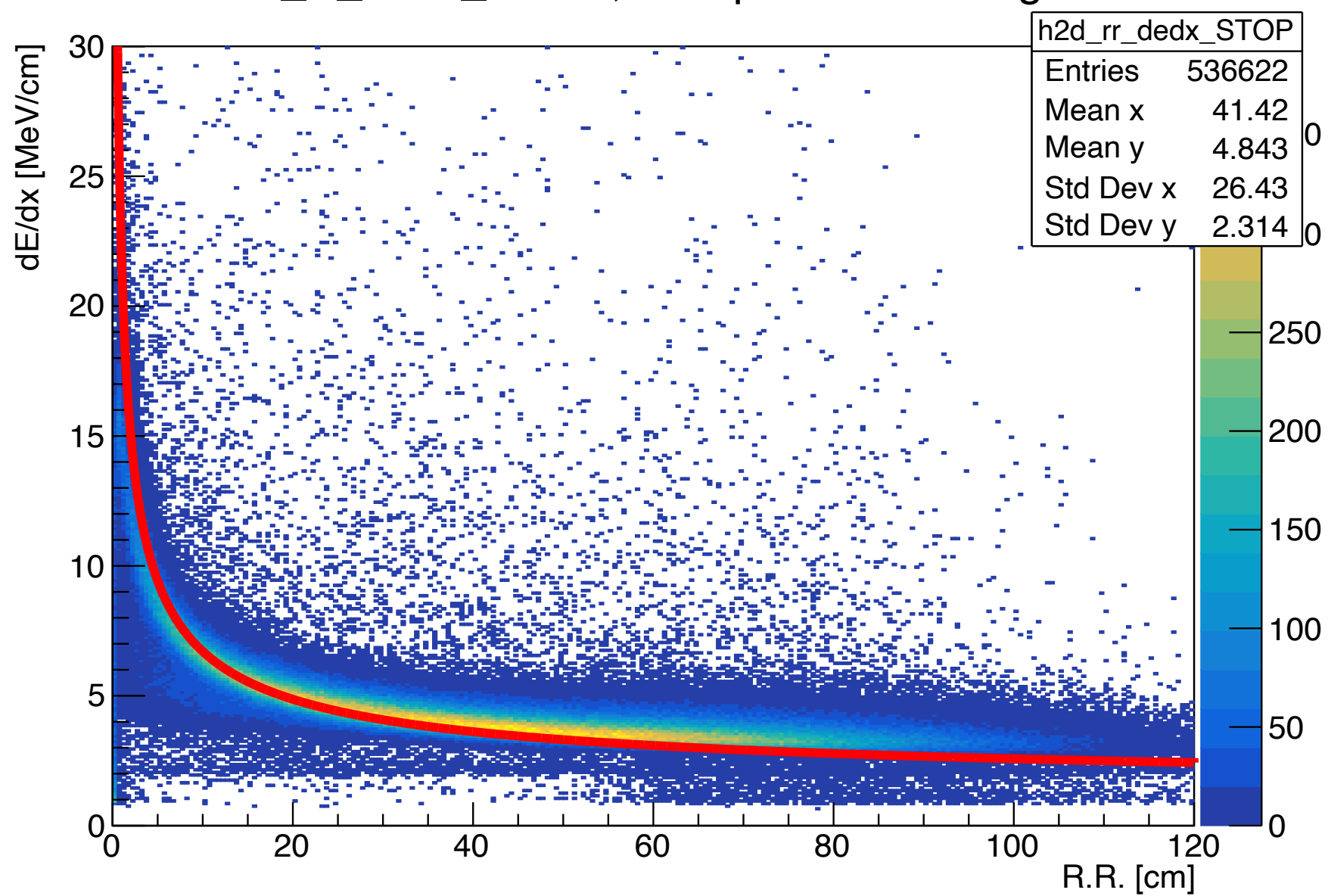
dEdxVsRR(Best scan) - LV



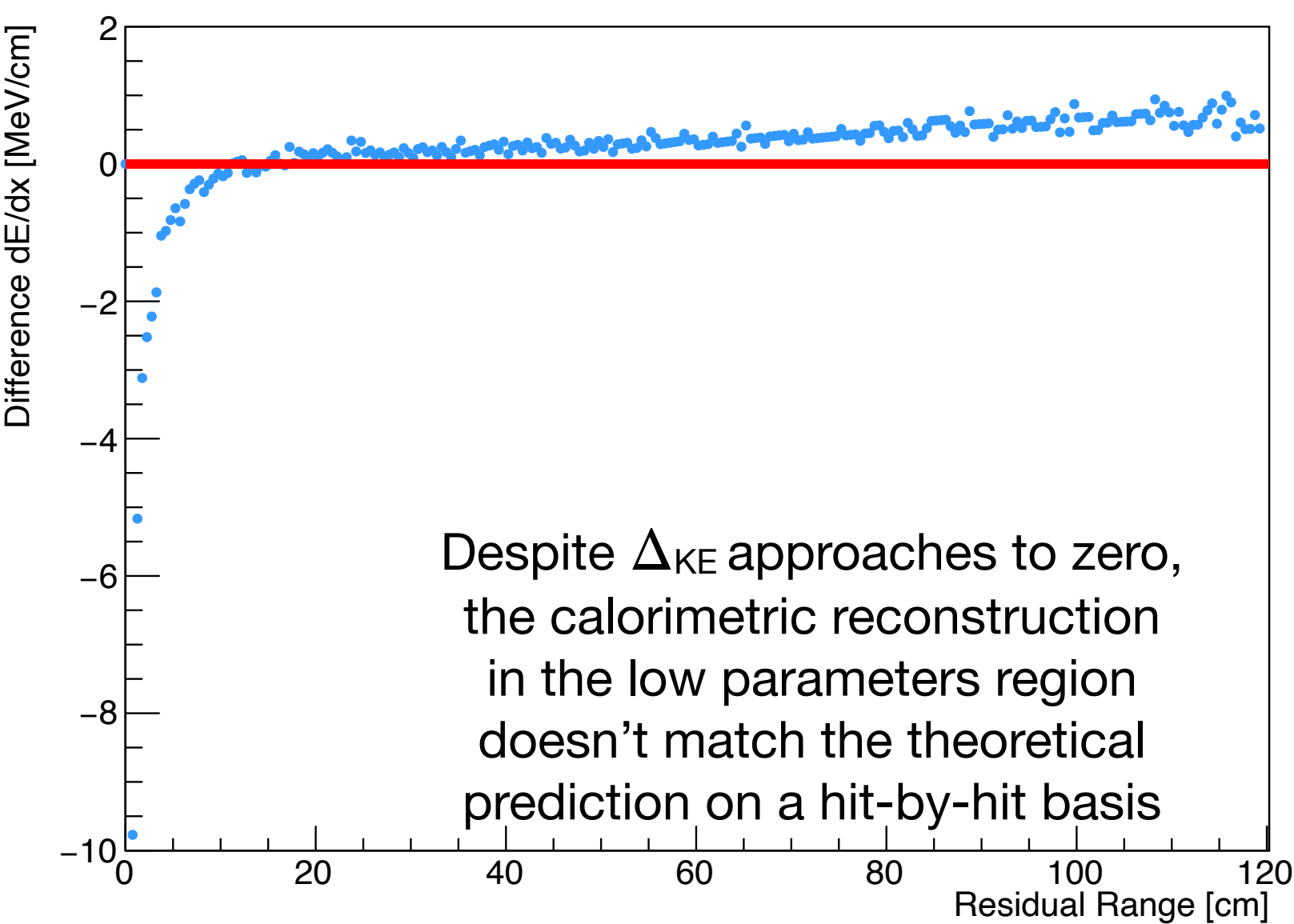
Three regions on the $\Delta_{KE} = 0$ line



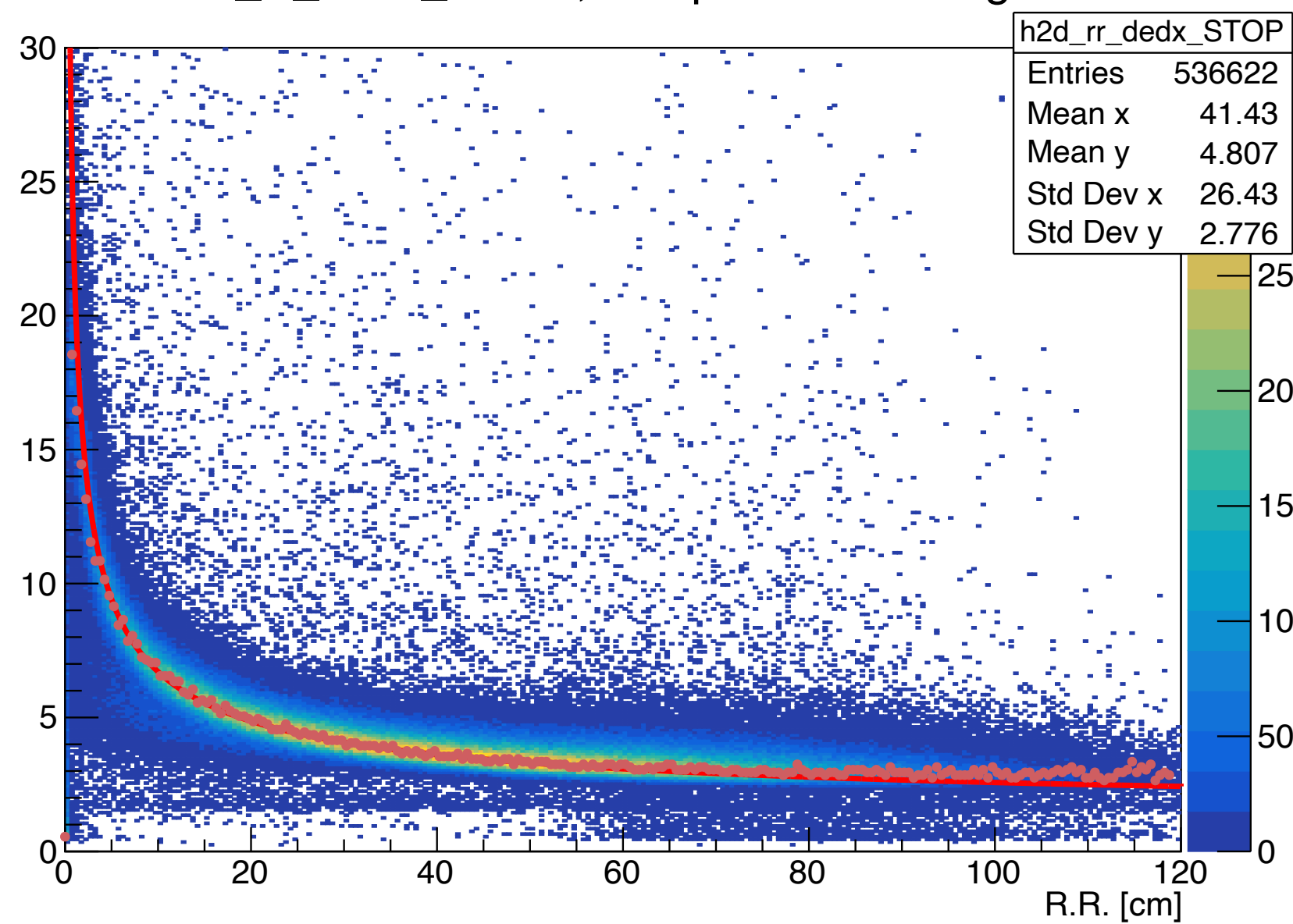
h2d_rr_dedx_STOP, Low parameters region



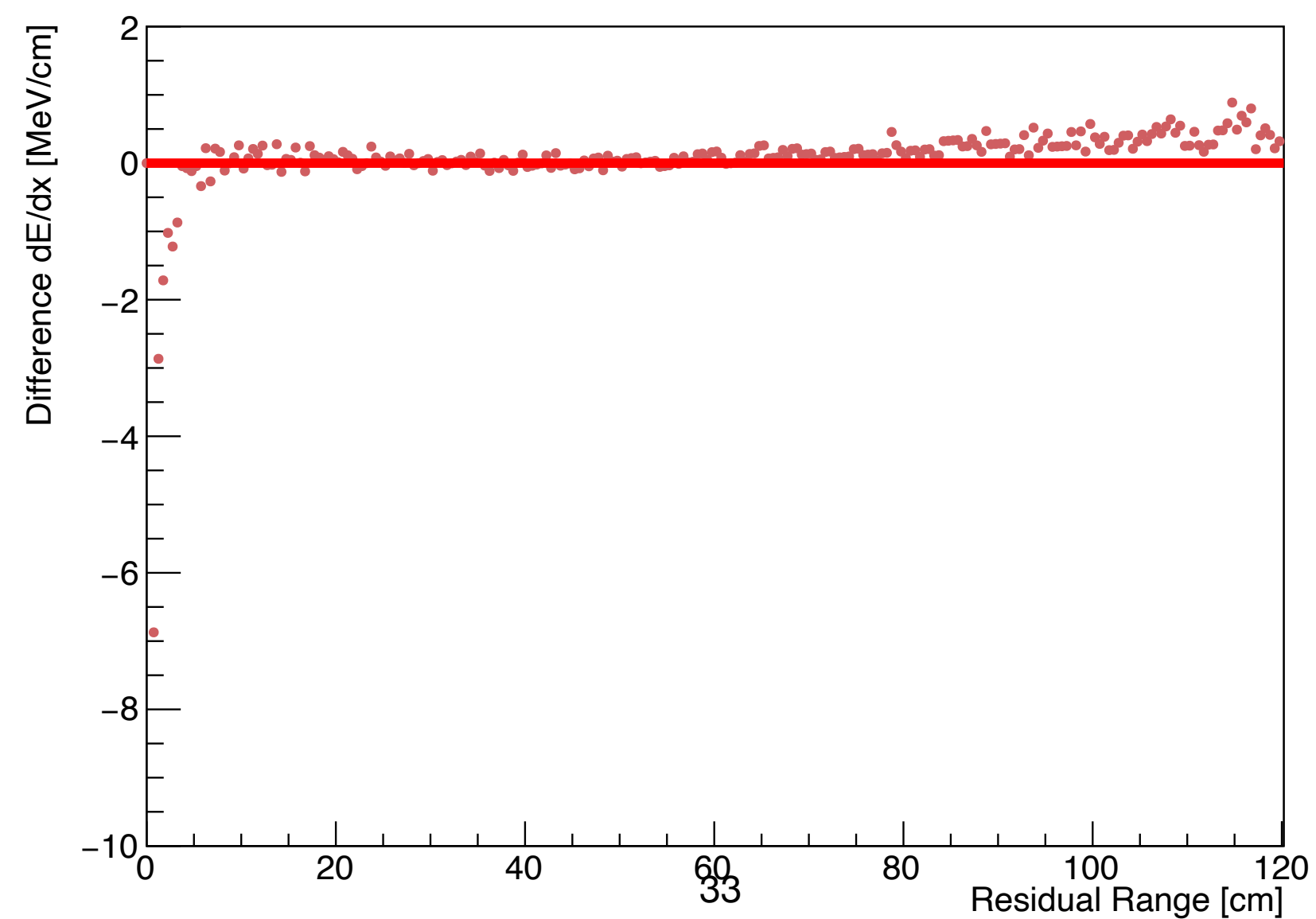
dEdxVsRR(Low parameters region) - LV



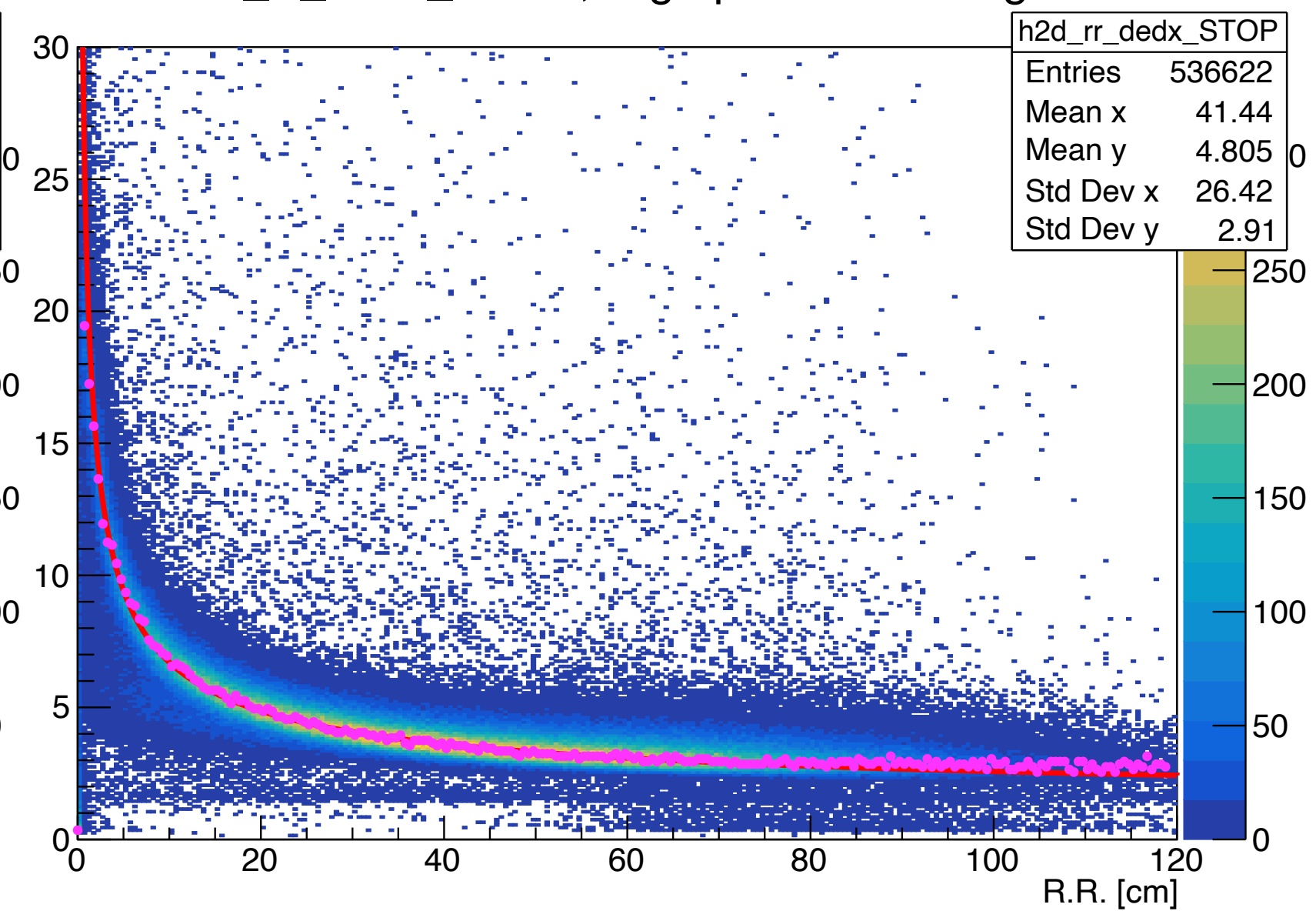
h2d_rr_dedx_STOP, Mid parameters region



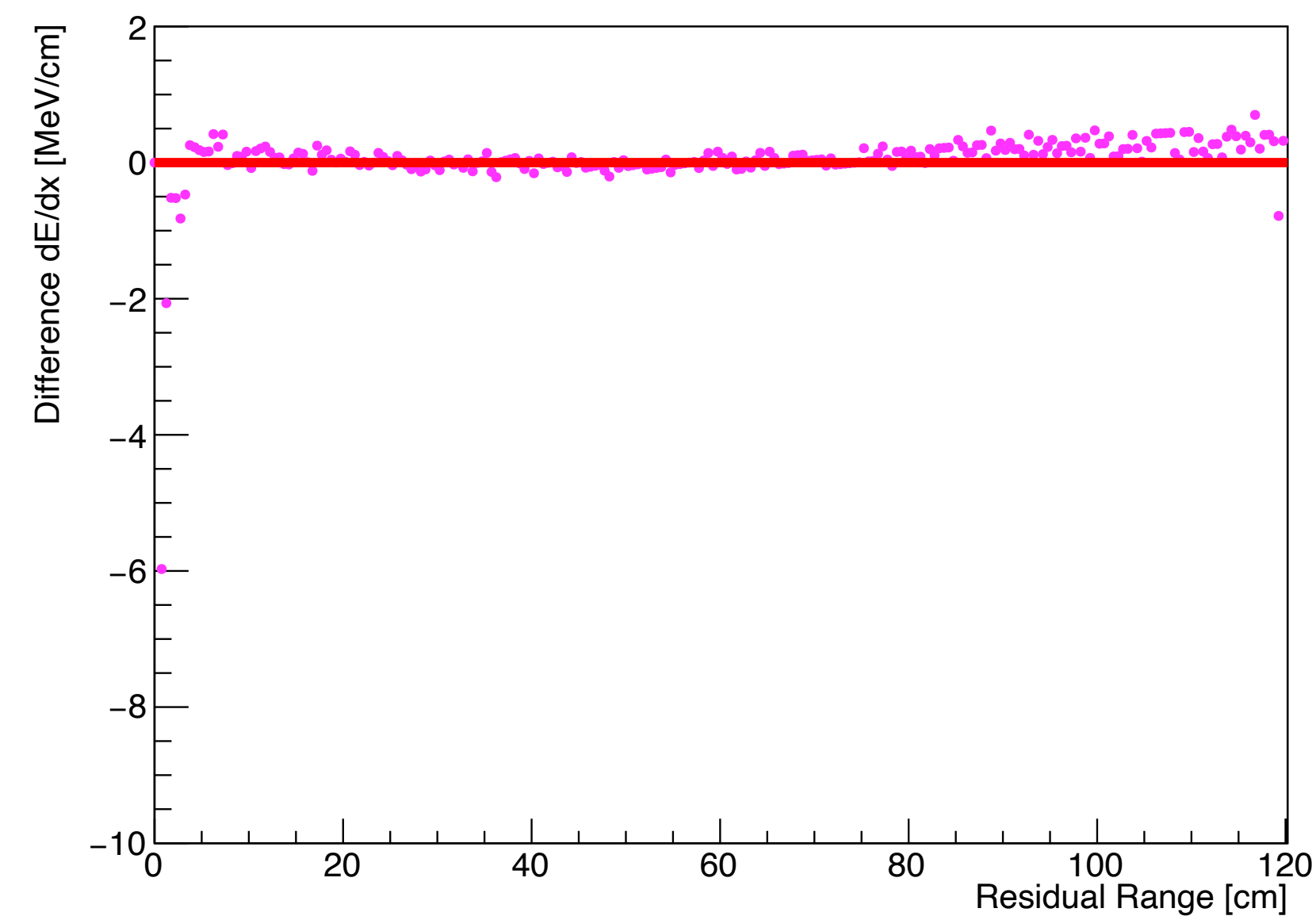
dEdxVsRR(Mid parameters region) - LV



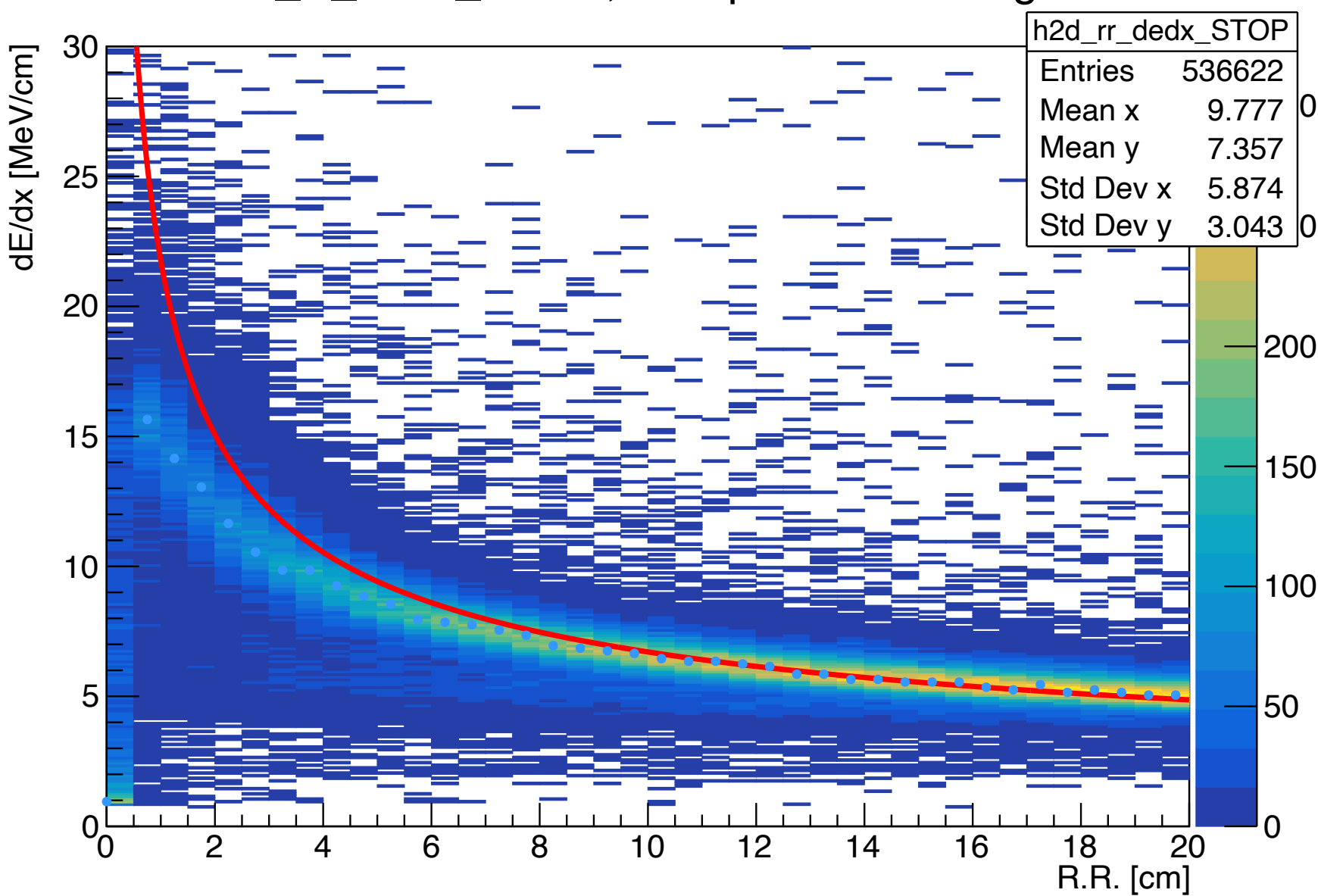
h2d_rr_dedx_STOP, High parameters region



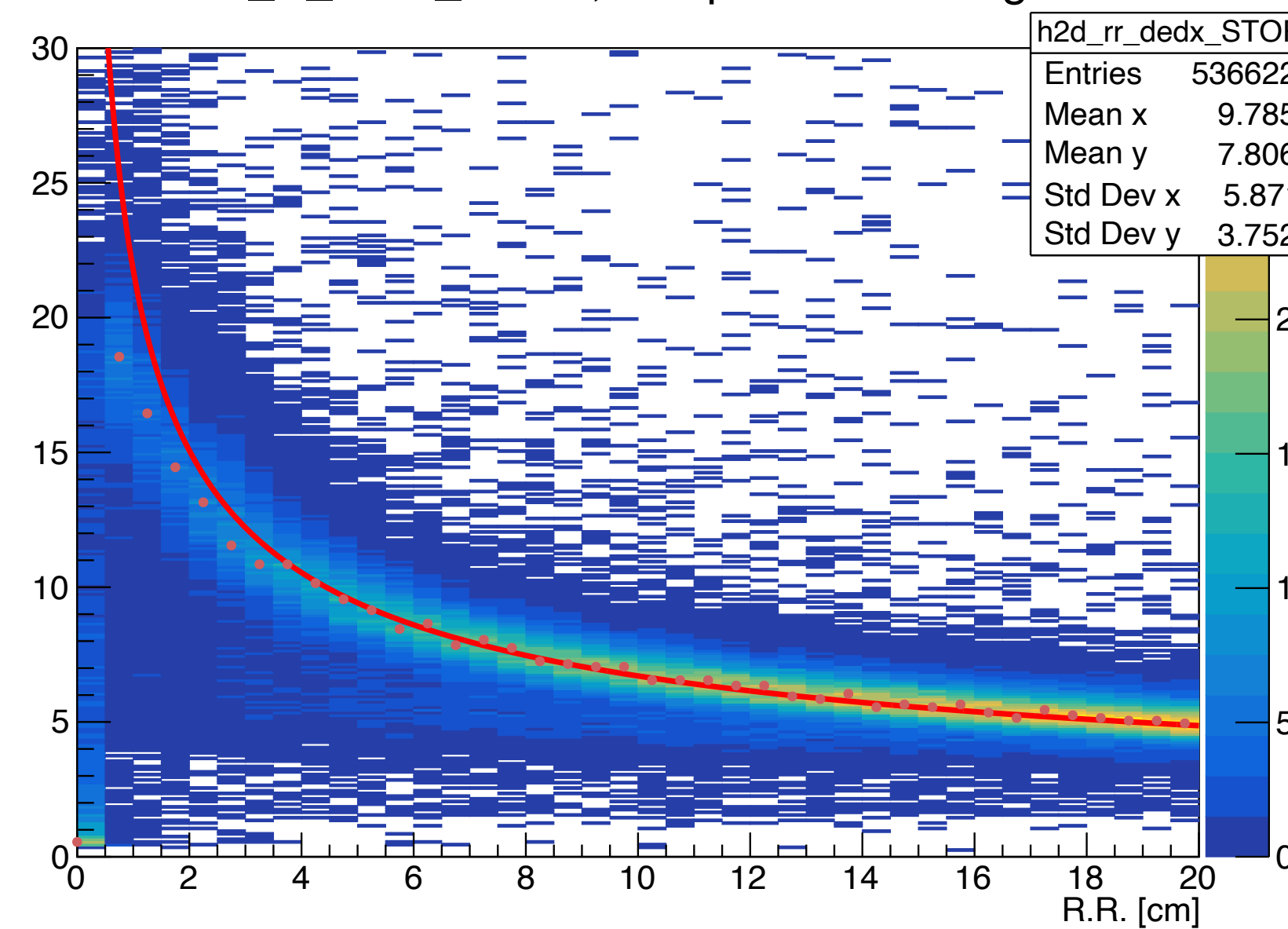
dEdxVsRR(High parameters region) - LV



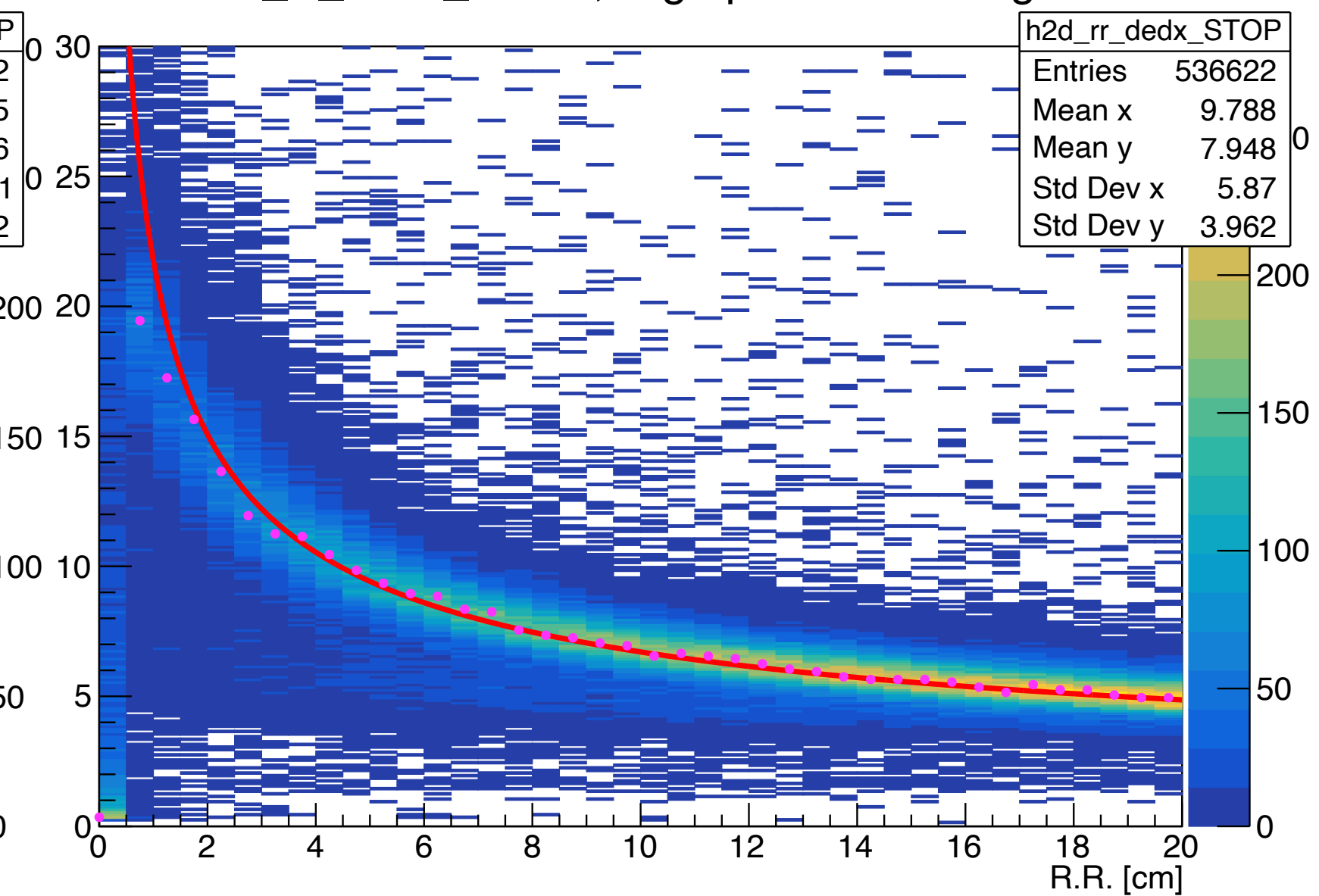
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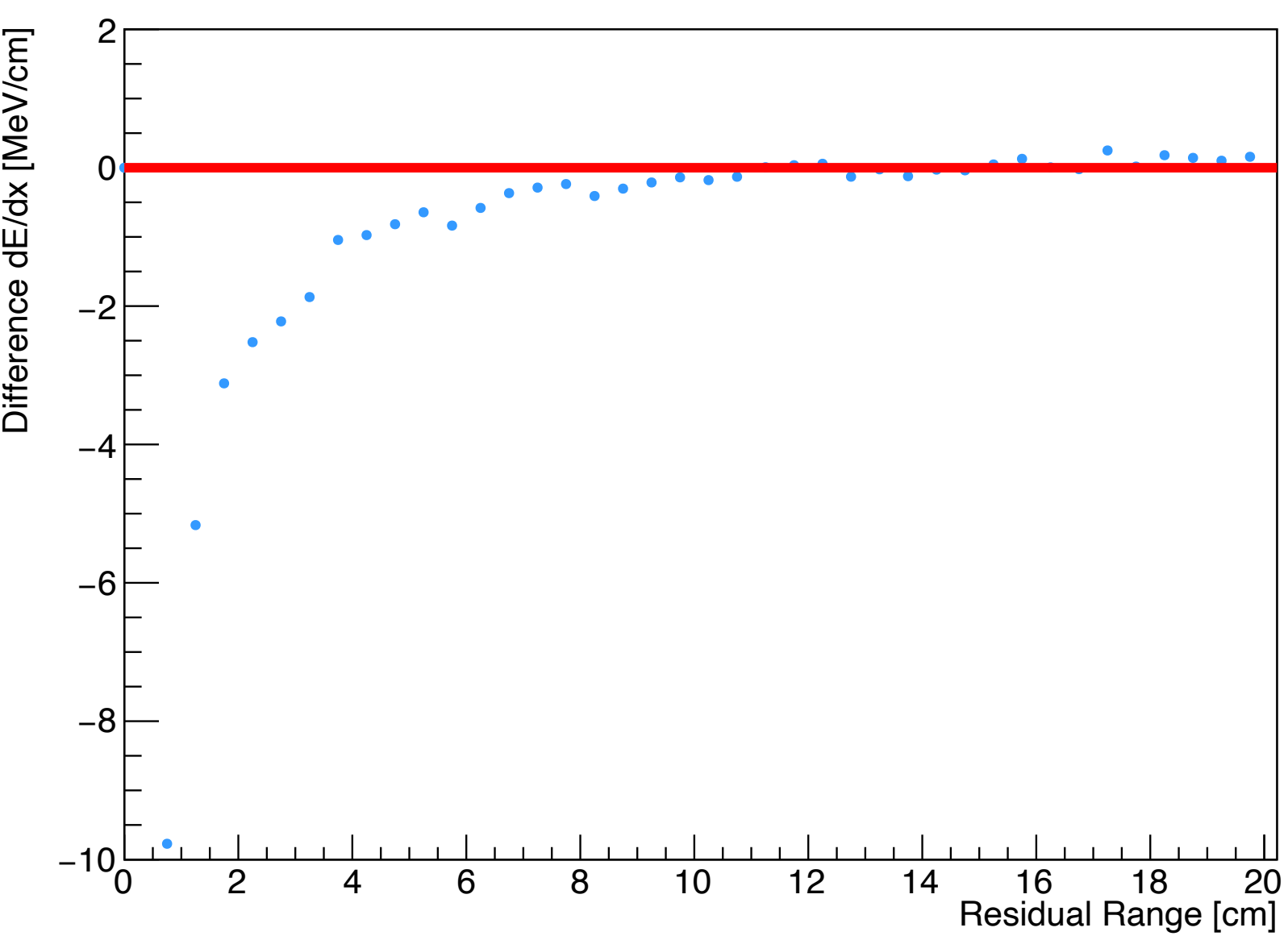
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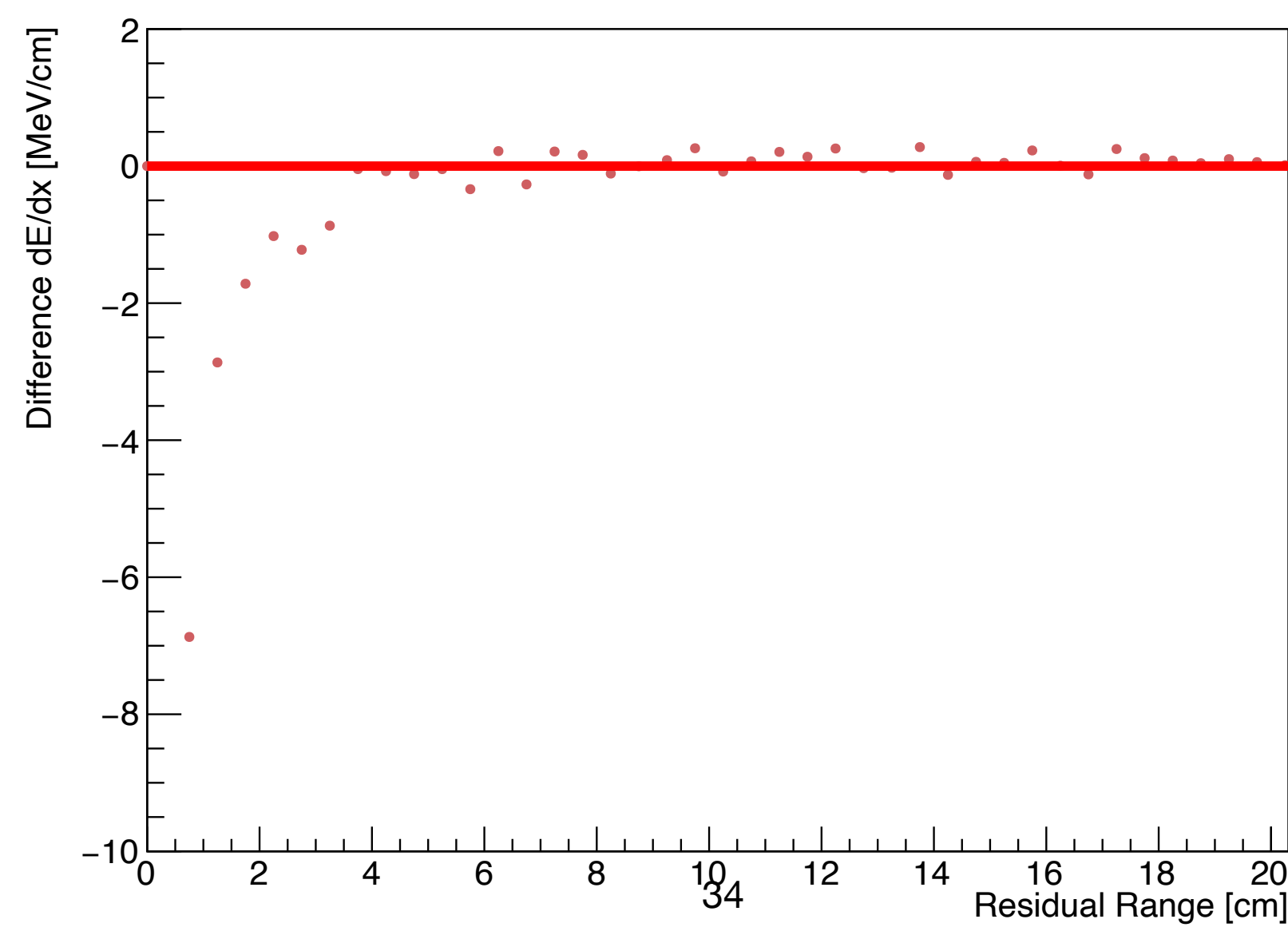
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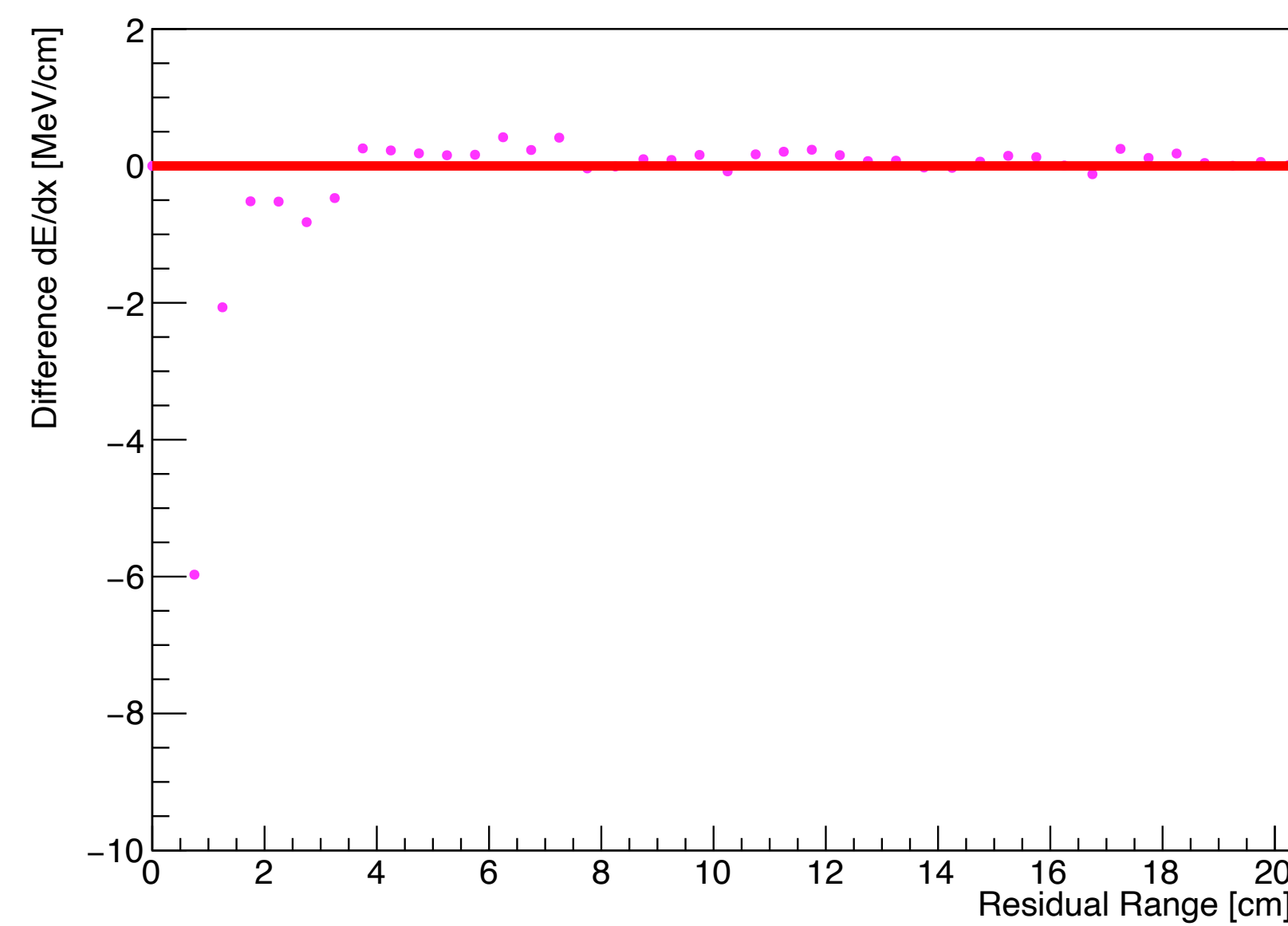
dEdxVsRR(Low parameters region) - LV



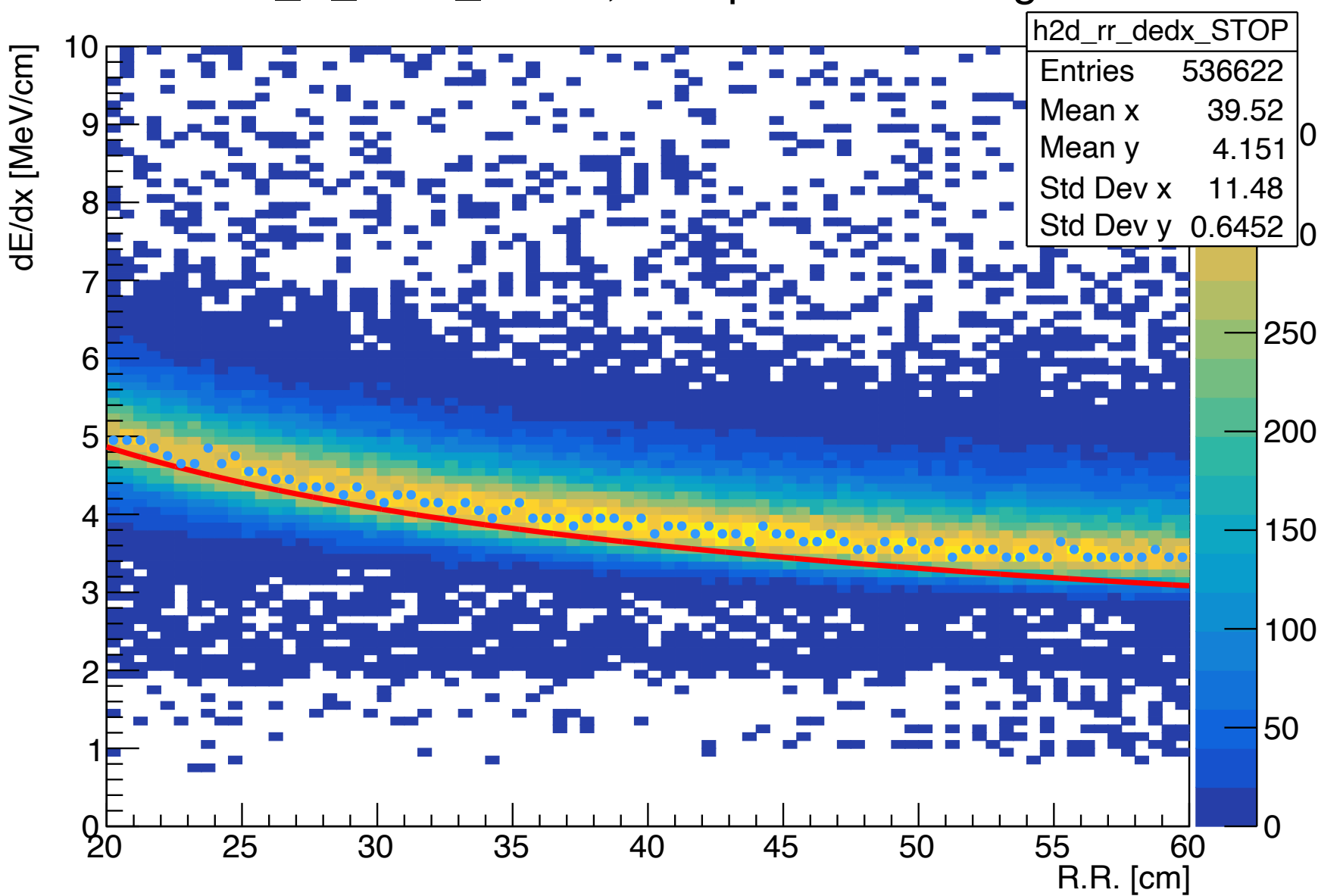
dEdxVsRR(Mid parameters region) - LV



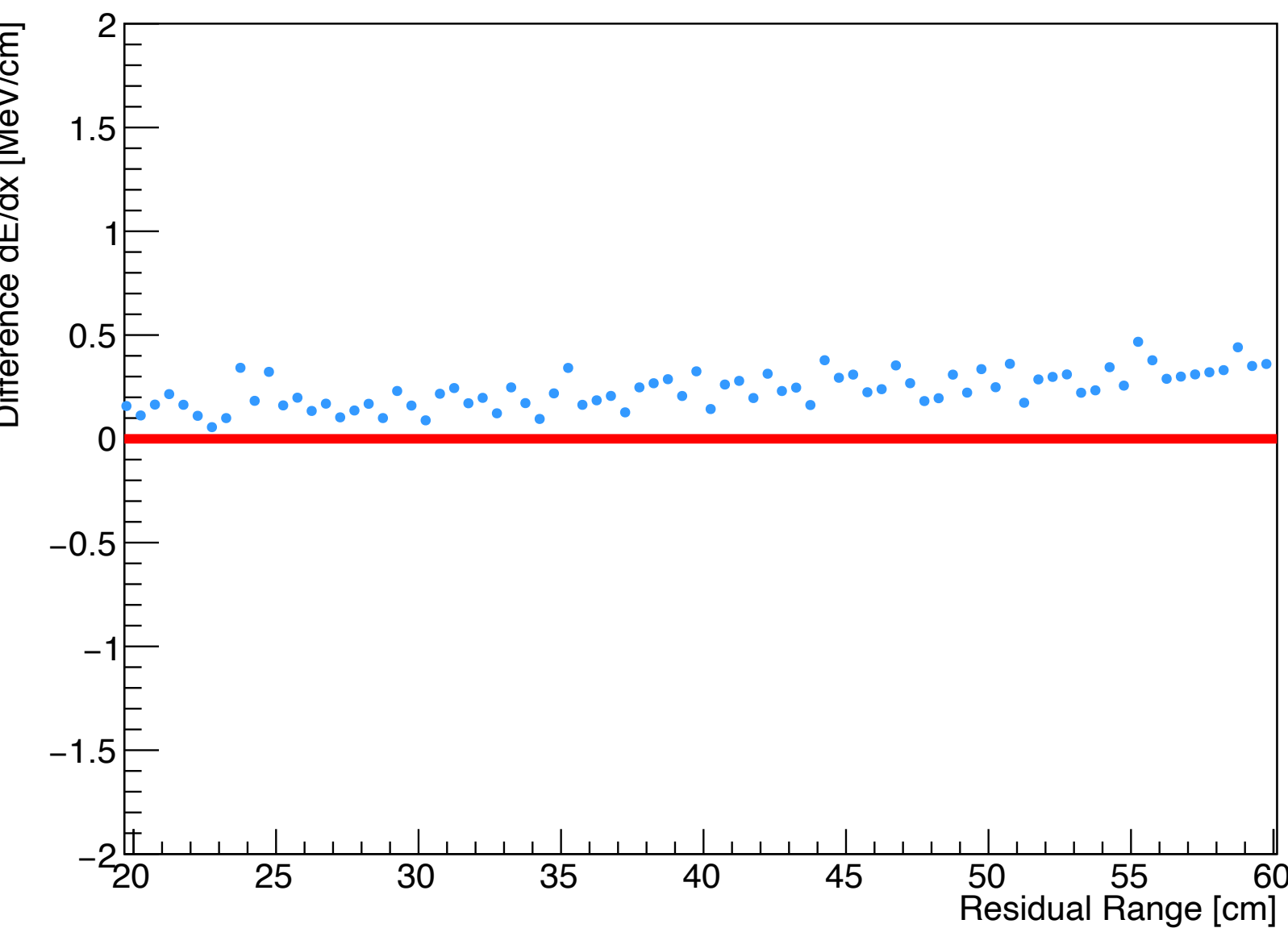
dEdxVsRR(High parameters region) - LV



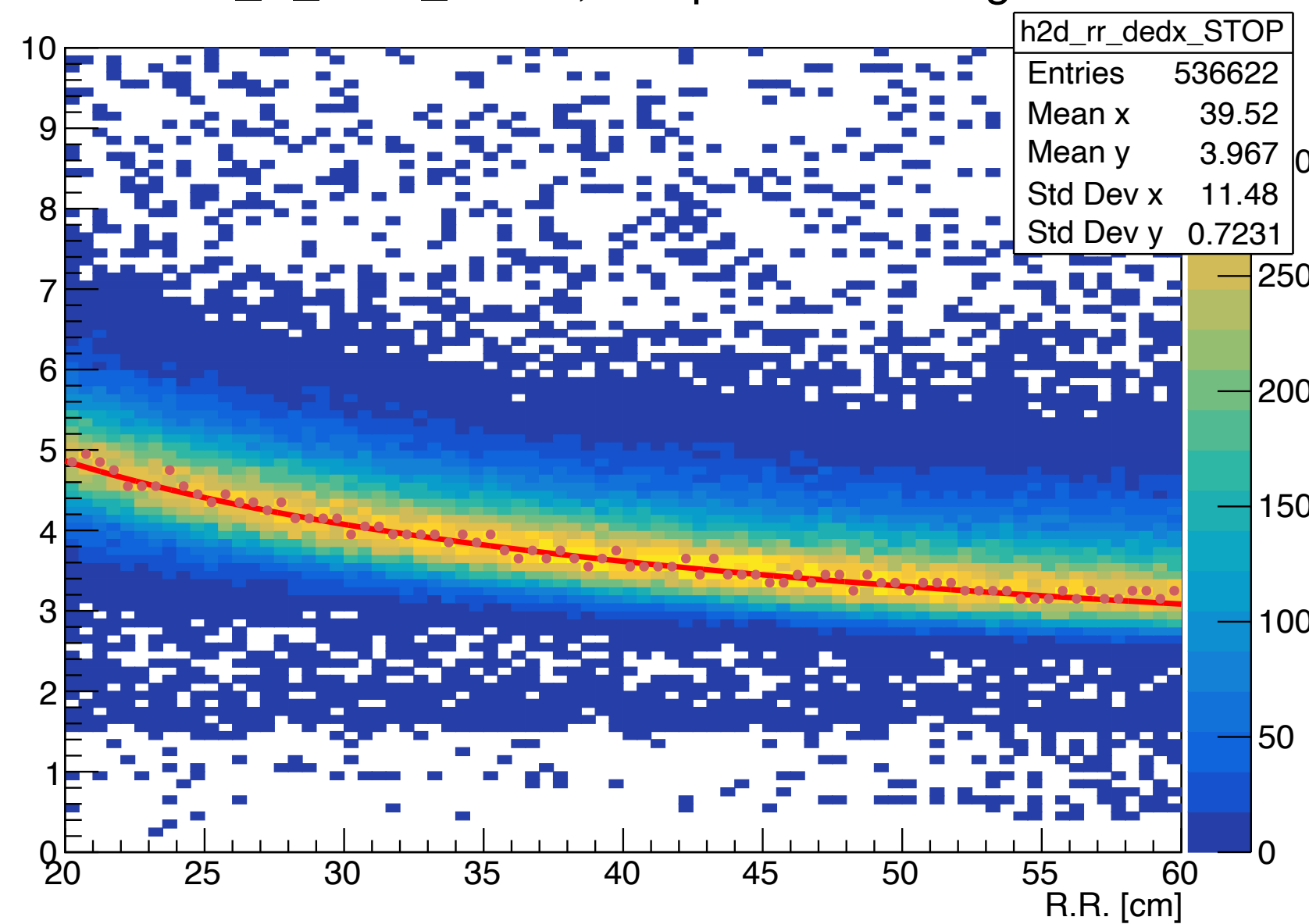
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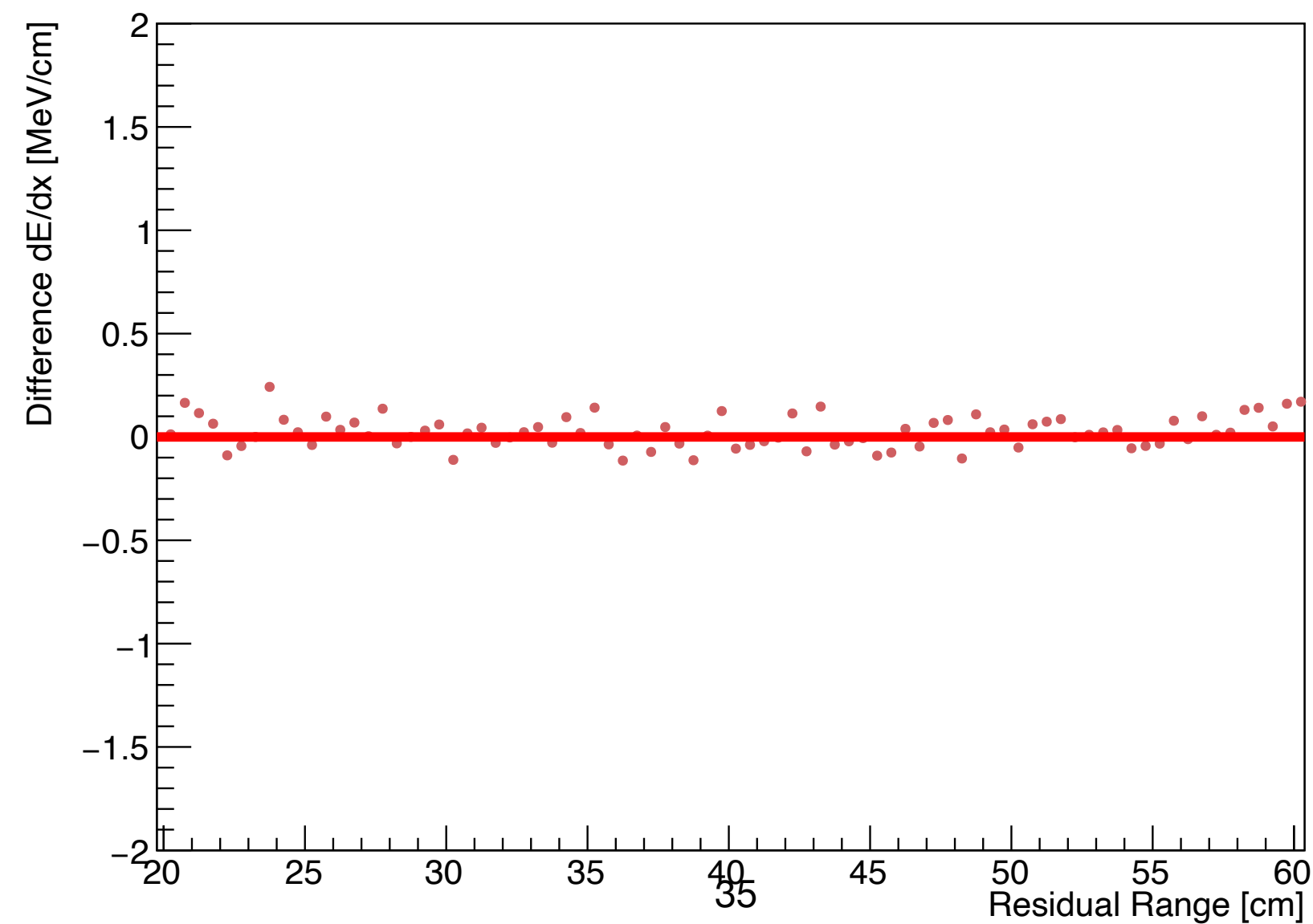
dEdxVsRR(Low parameters region) - LV



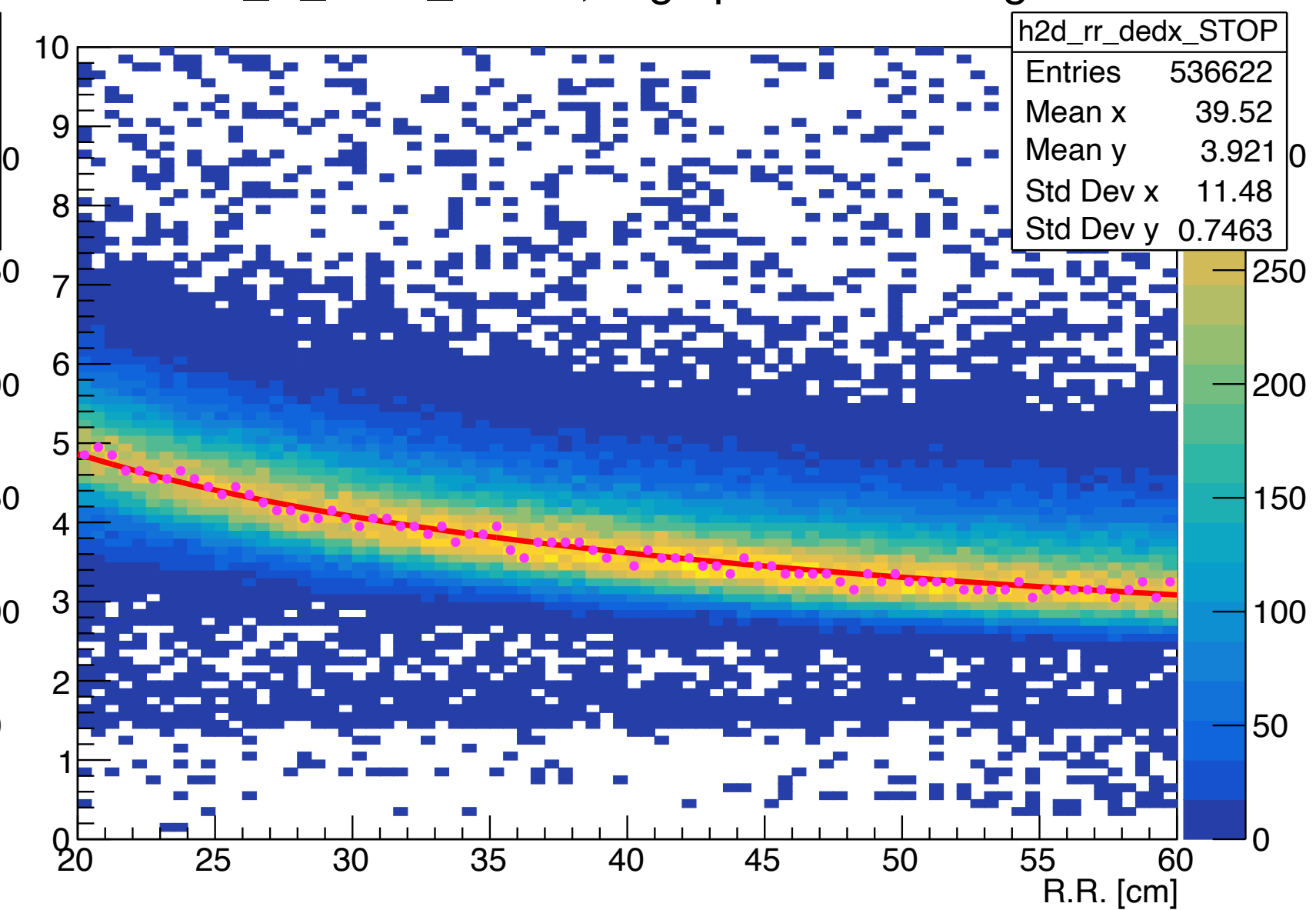
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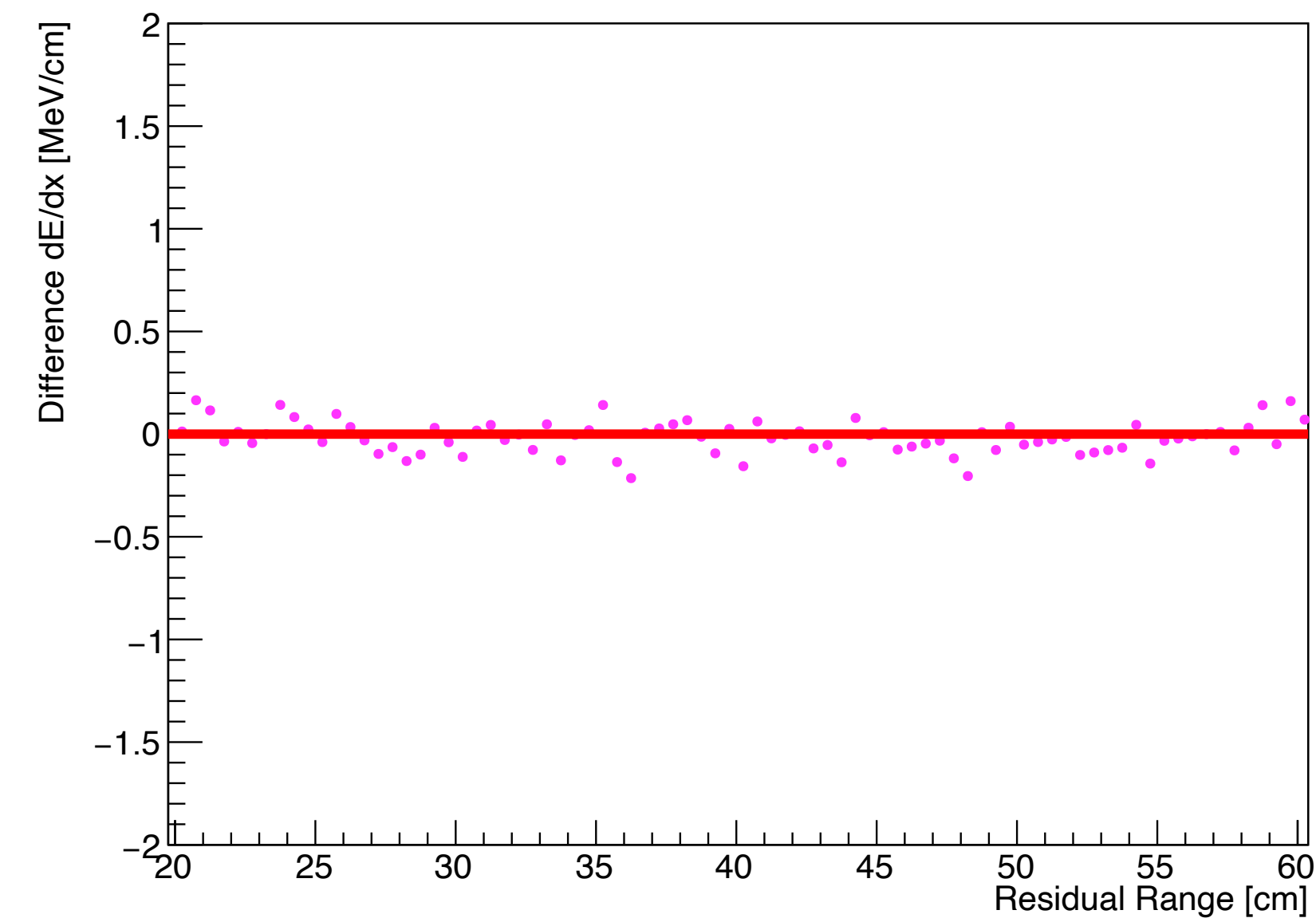
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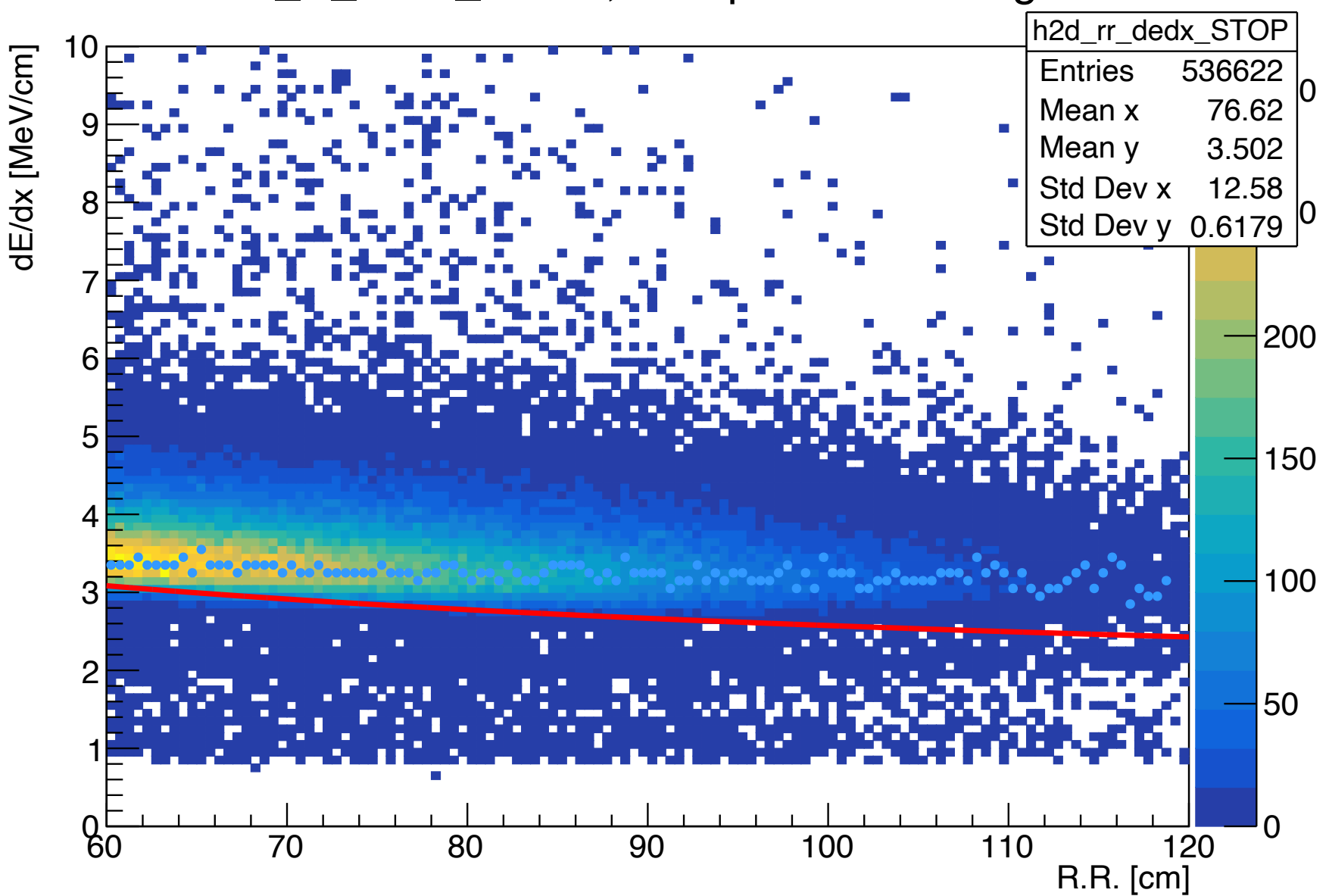
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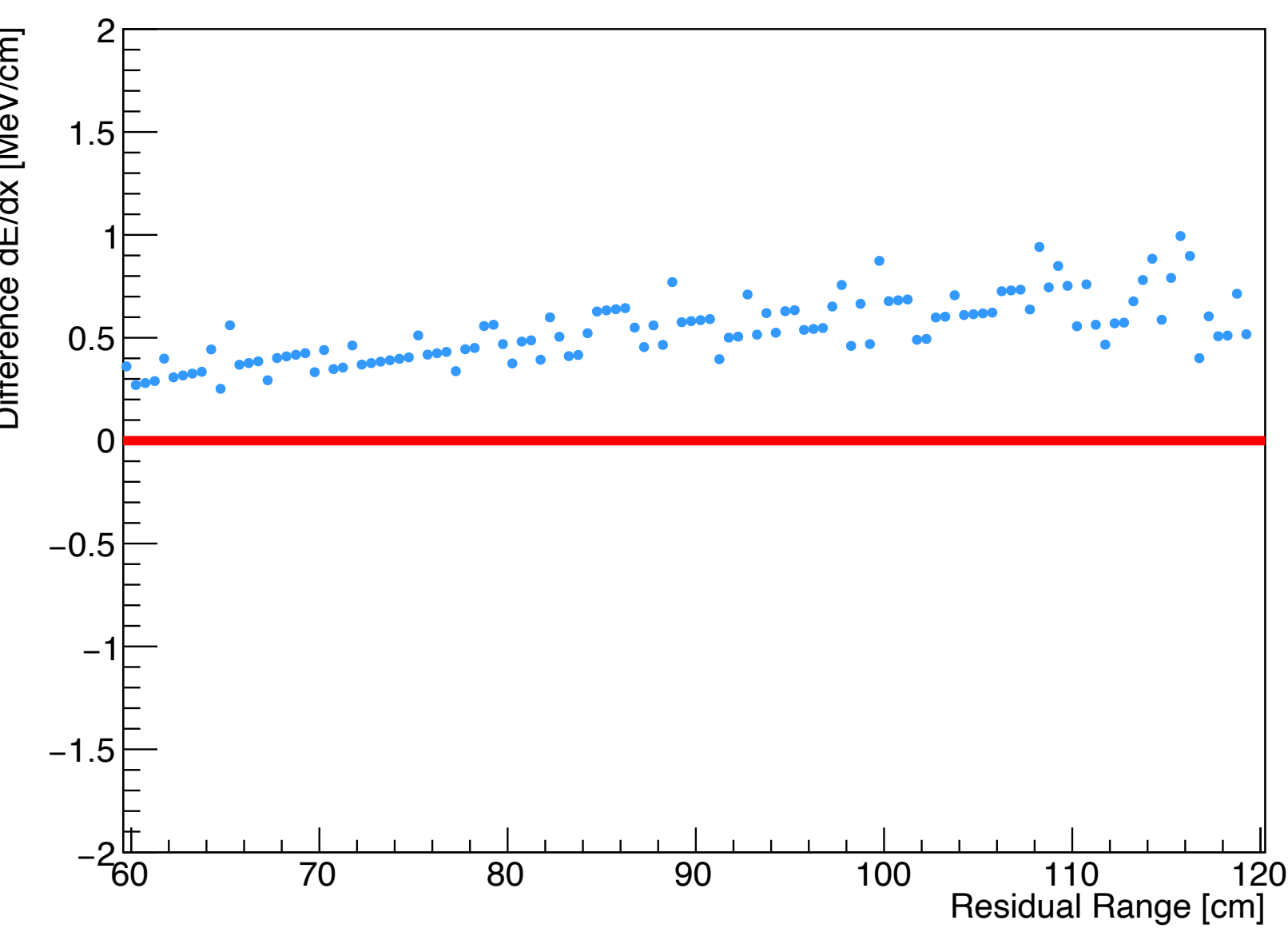
dEdxVsRR(High parameters region) - LV



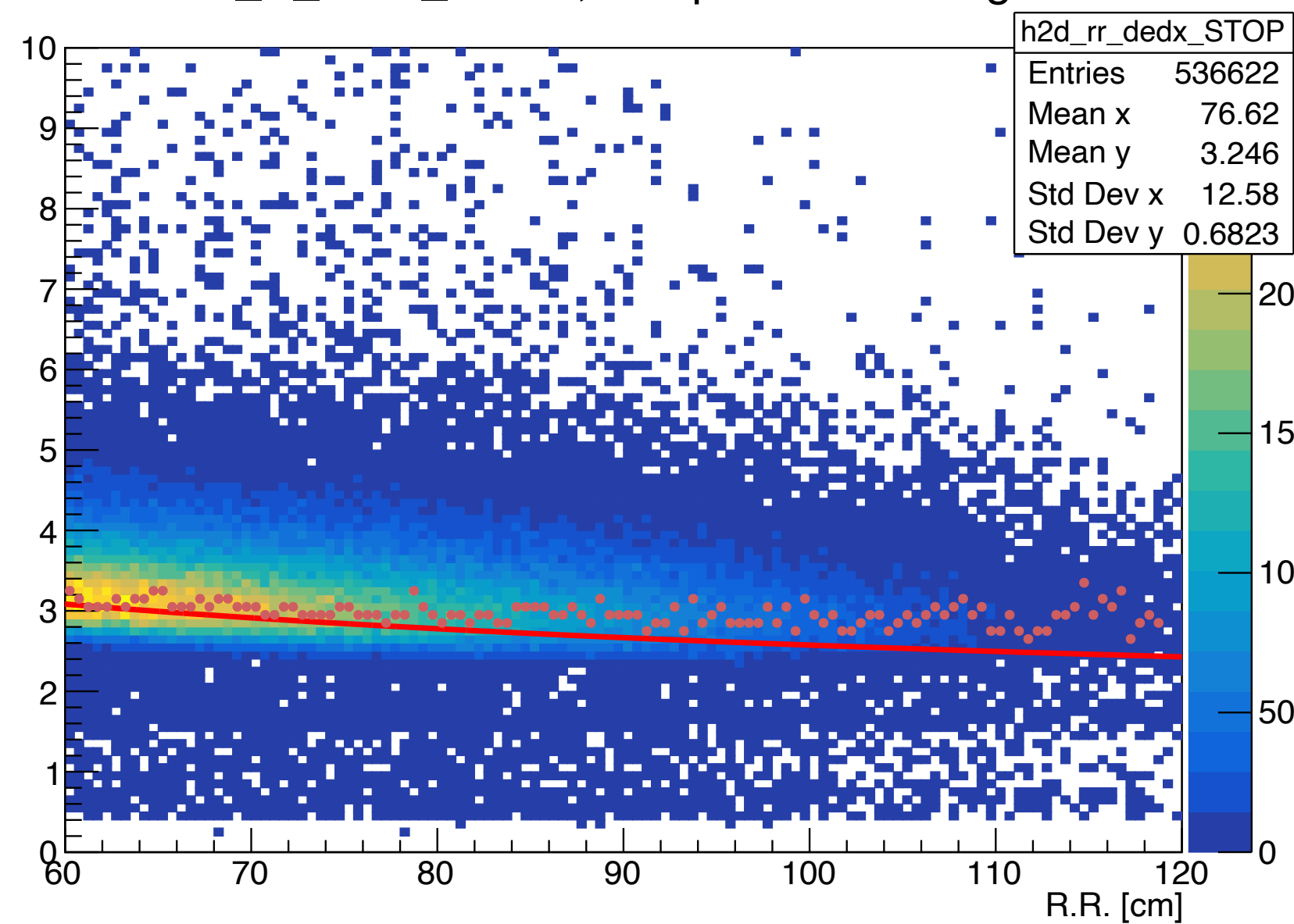
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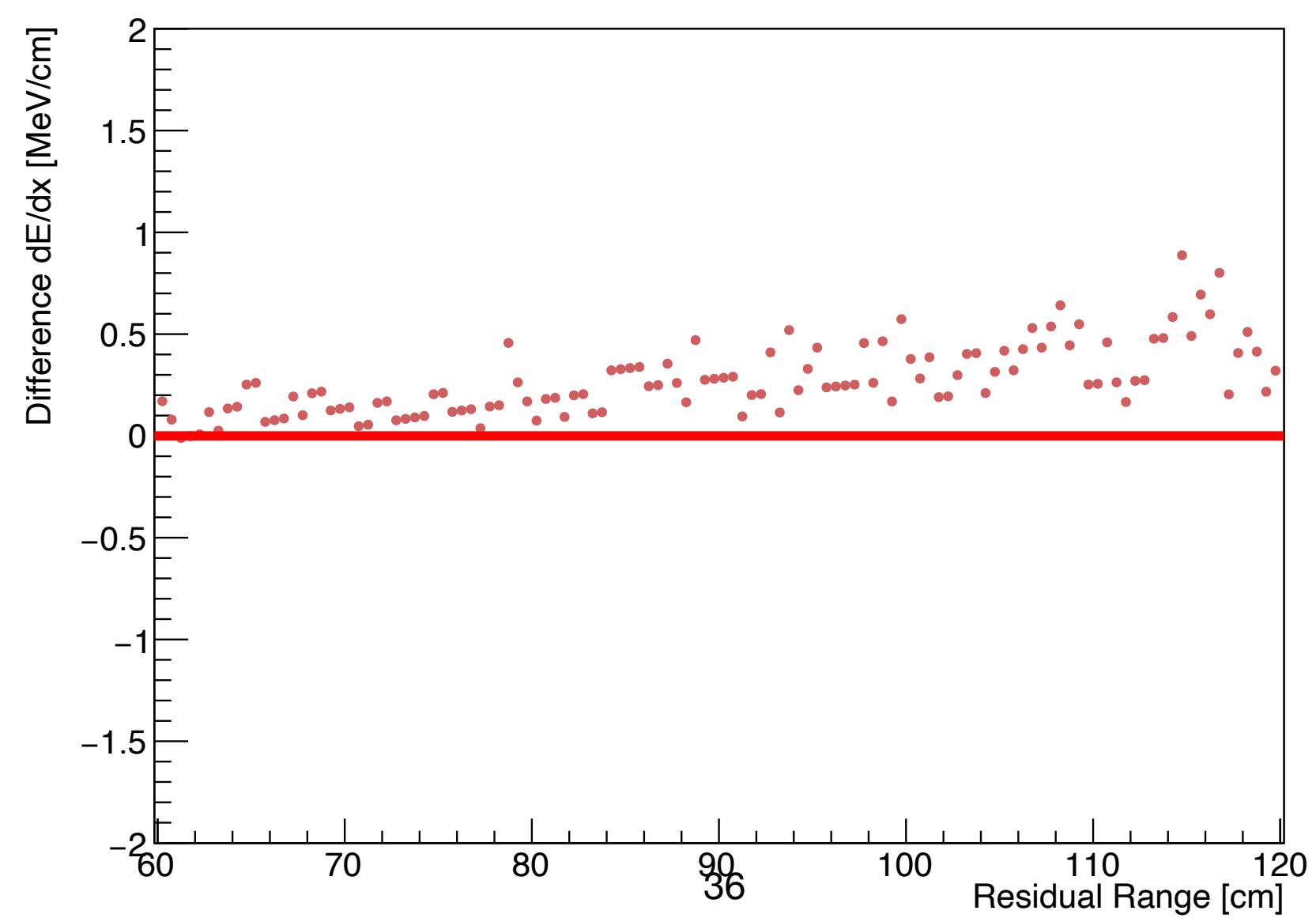
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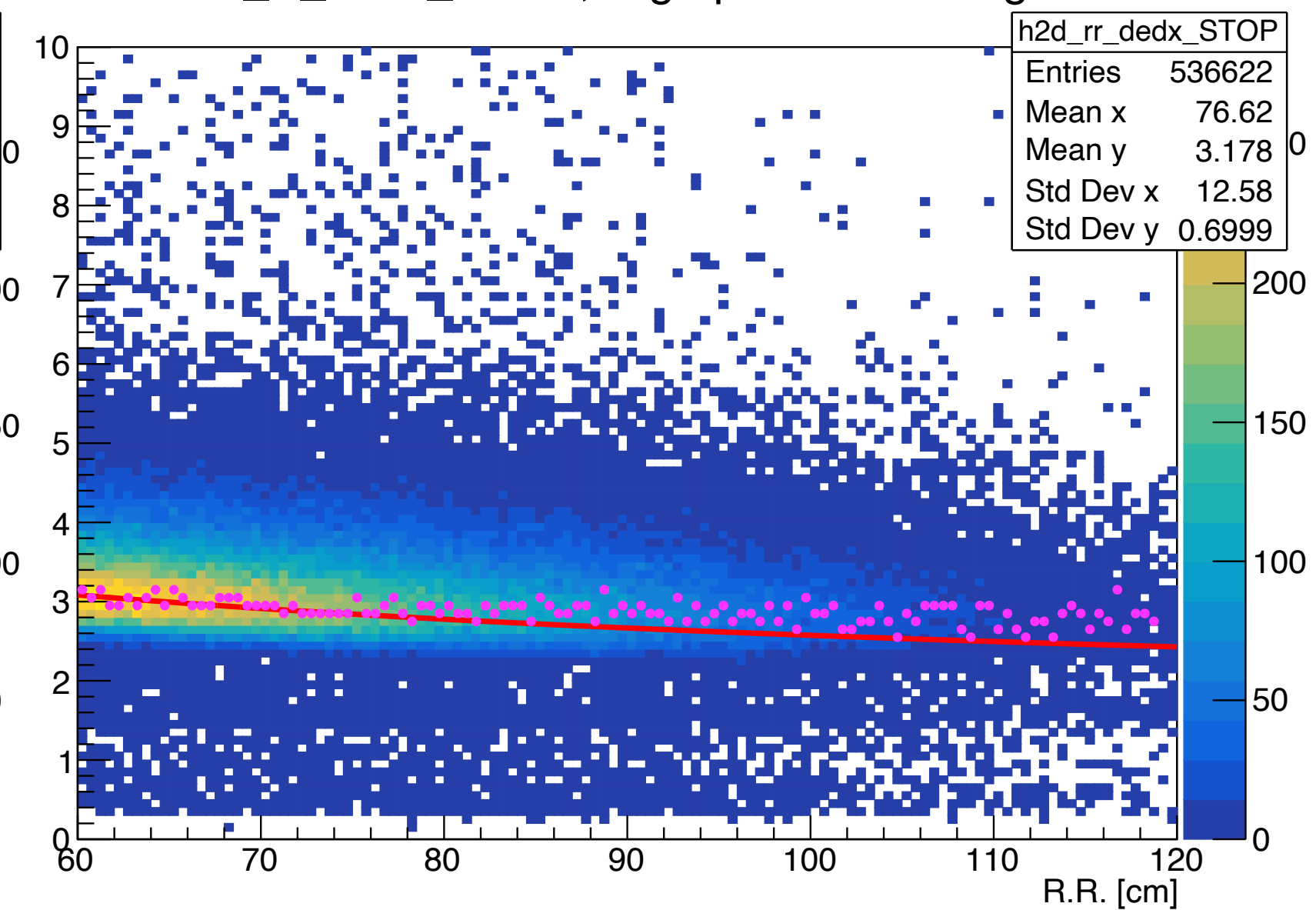
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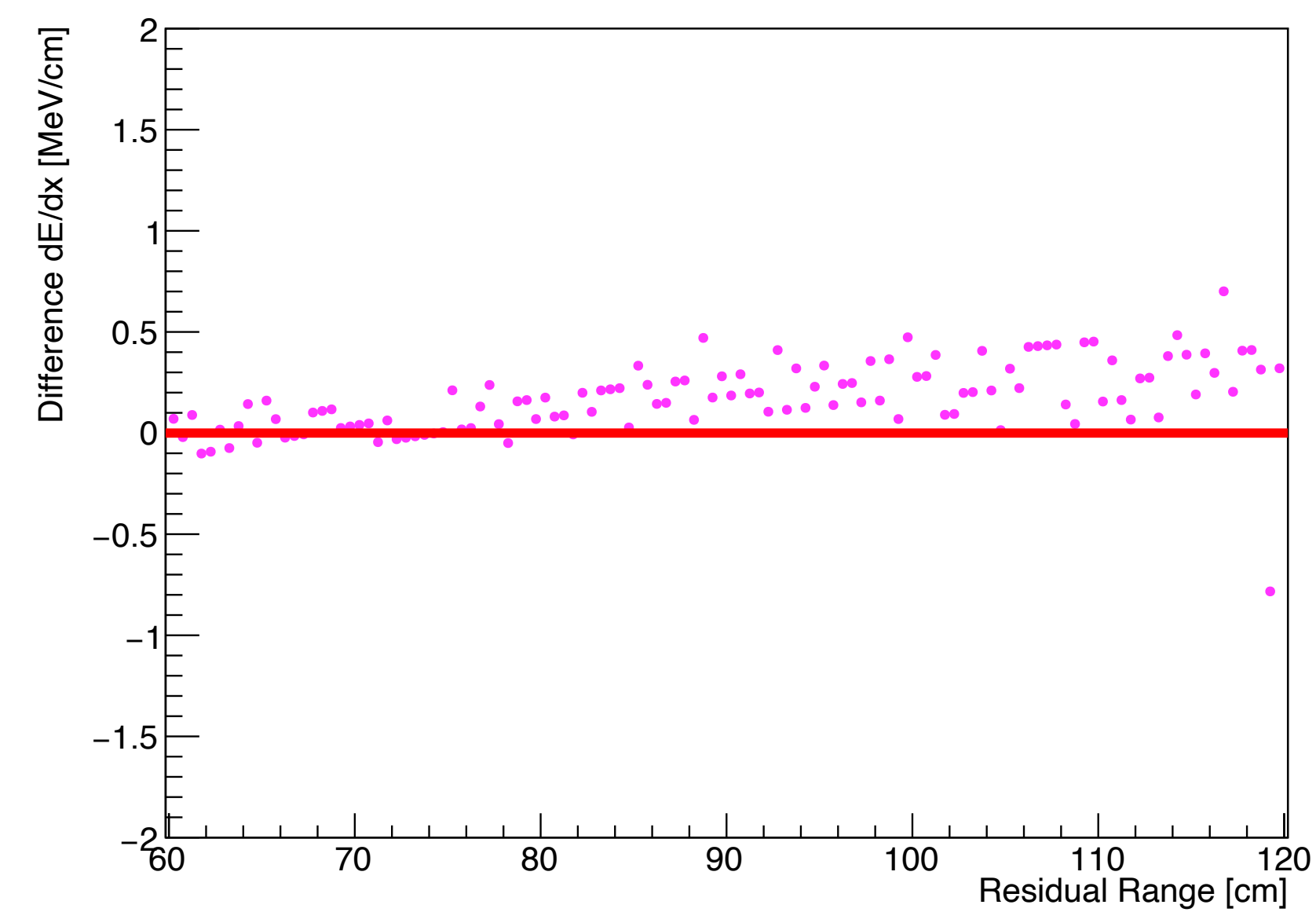
dEdxVsRR(Mid parameters region) - LV



h2d_rr_dedx_STOP, High parameters region



dEdxVsRR(High parameters region) - LV



Remarks

- This work improved the proton calorimetric reconstruction providing better sets of parameters that minimize the discrepancy with the range-based reconstruction and the theoretical prediction
- The difference between range-based and calorimetric reconstructed tracks calculated for the entire track approaches zero on a line in the alpha, betap plan. The high parameters region seems to match better the theoretical predictions on a hit-by-hit basis
- The discrepancy at very low RR hasn't been fully reabsorbed. This indicates that there are possible issues at different steps of the track reconstruction for stopping protons.
Candidates can be the Space Charge Effect and the Bragg Peak reconstruction
- A new determination of reconstruction parameters might be needed at that point