FastSim dE/dx parameters

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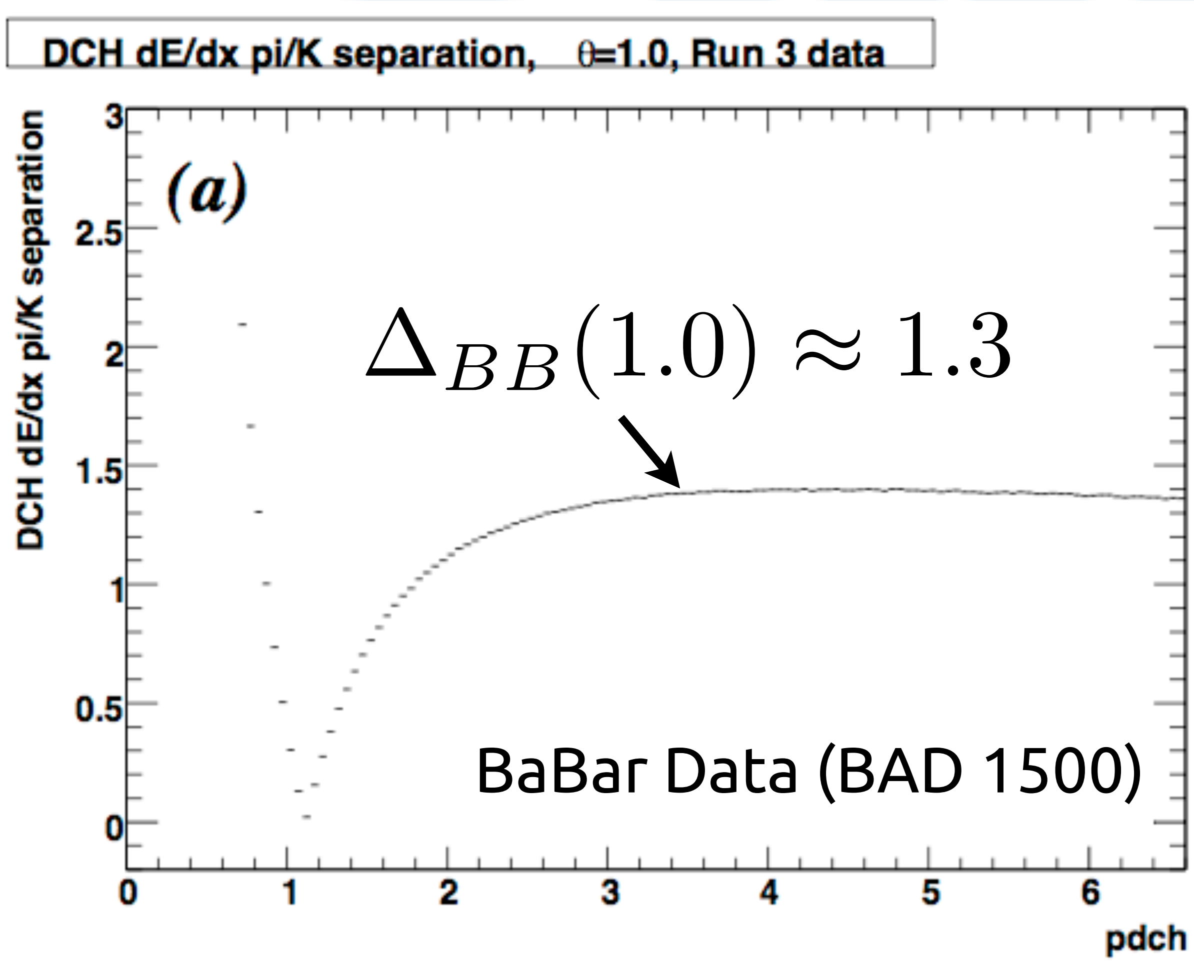
Introduction

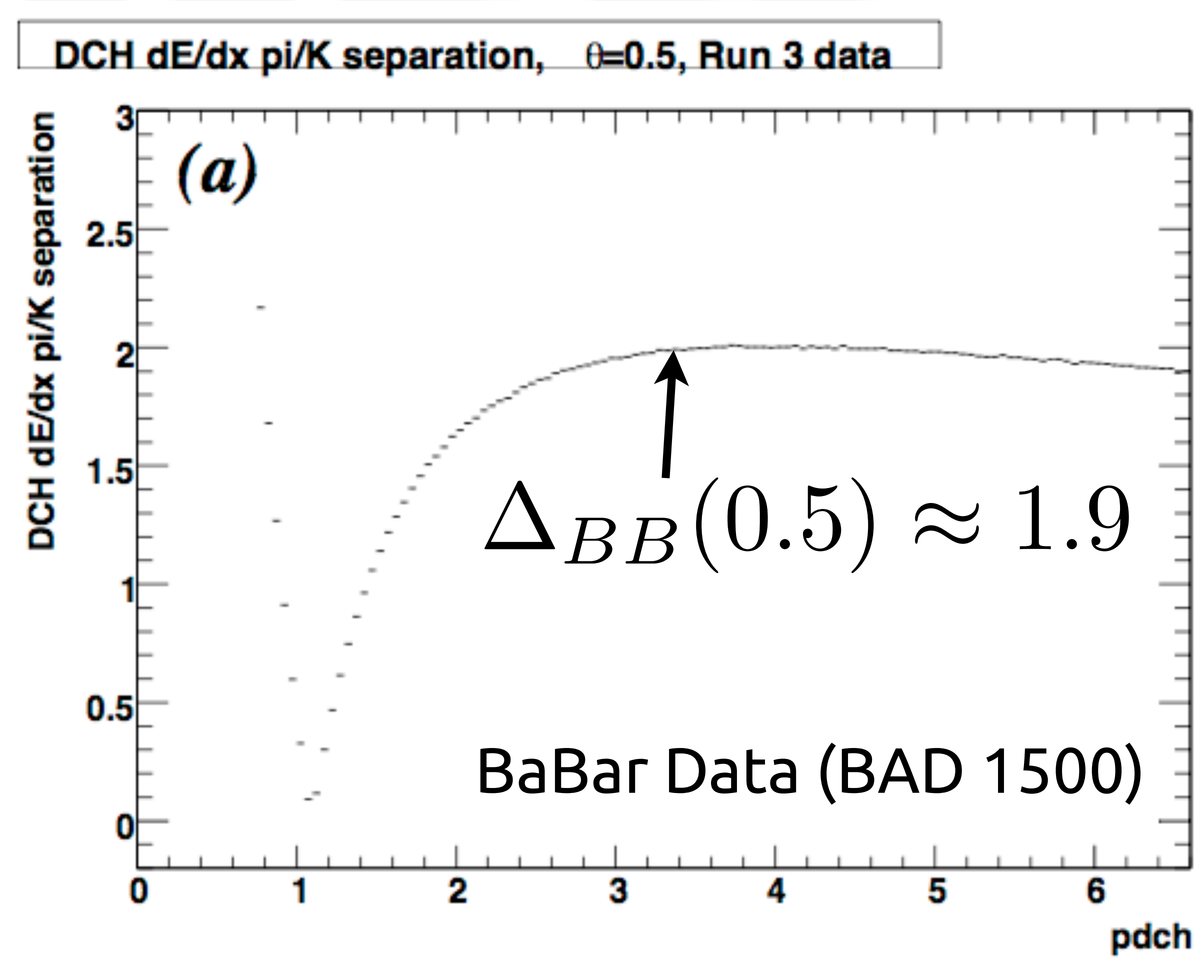
- The goal is to choose suitable dE/dx parameters in FastSim to correctly match the behaviour from BAD 1500.
- We cannot match both dE/dx resolution and K/pi separation, so we focus on K/pi separation.
- Also we wish to choose suitable dE/dx parameters to implement “effective cluster counting” without modifying code.

BaBar

- BaBar NIM Paper: 7.5% dE/dx resolution
- Sasha Telnov's BAD 1500: It's complicated, but around 7.5%
- More importantly, K/pi separation (at 3-4 GeV):

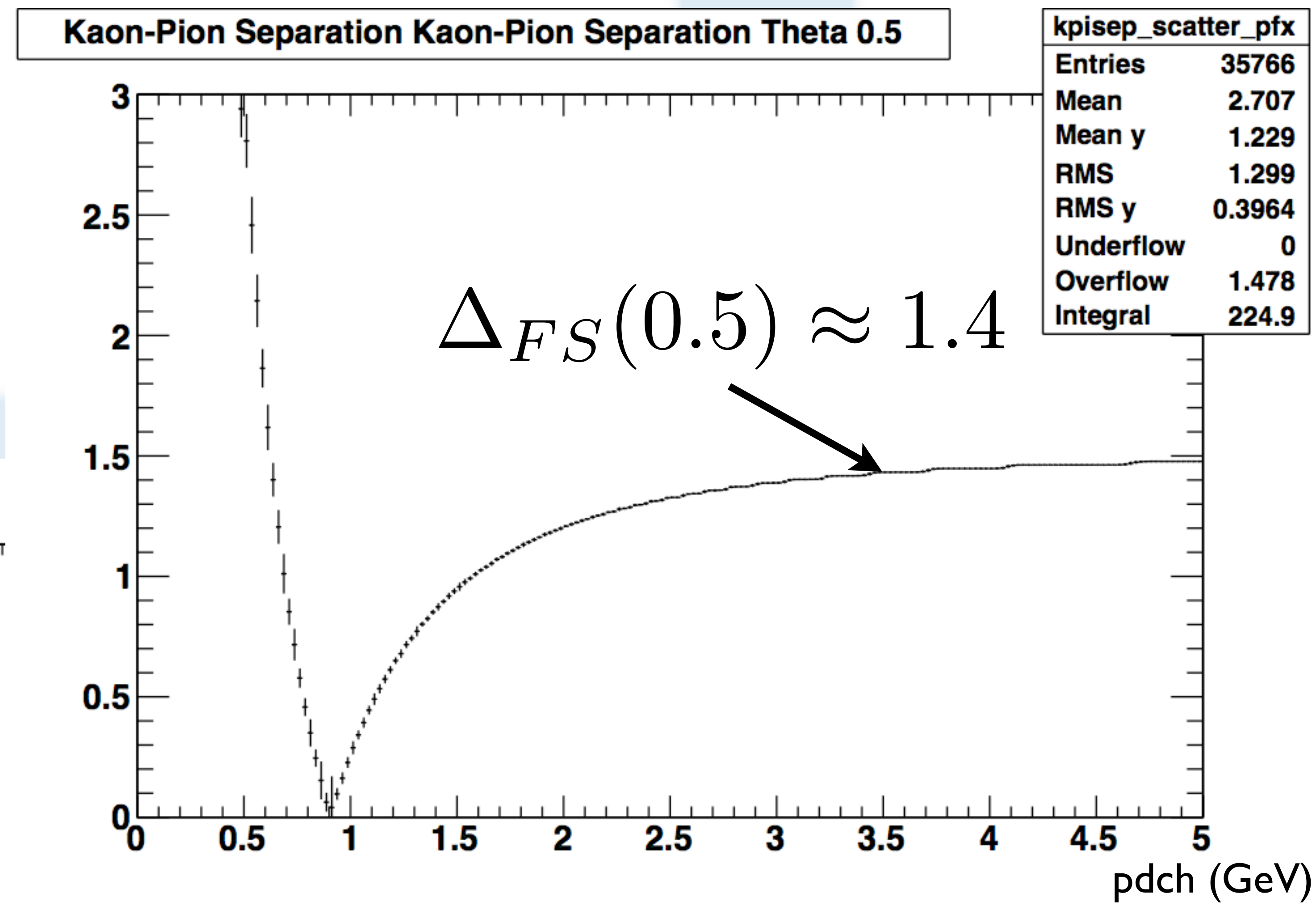
$$\Delta(\theta) = \frac{\left| \left[\frac{dE}{dx}\right]_\pi - \left[\frac{dE}{dx}\right]_K \right|}{(\sigma_\pi + \sigma_K)/2}$$



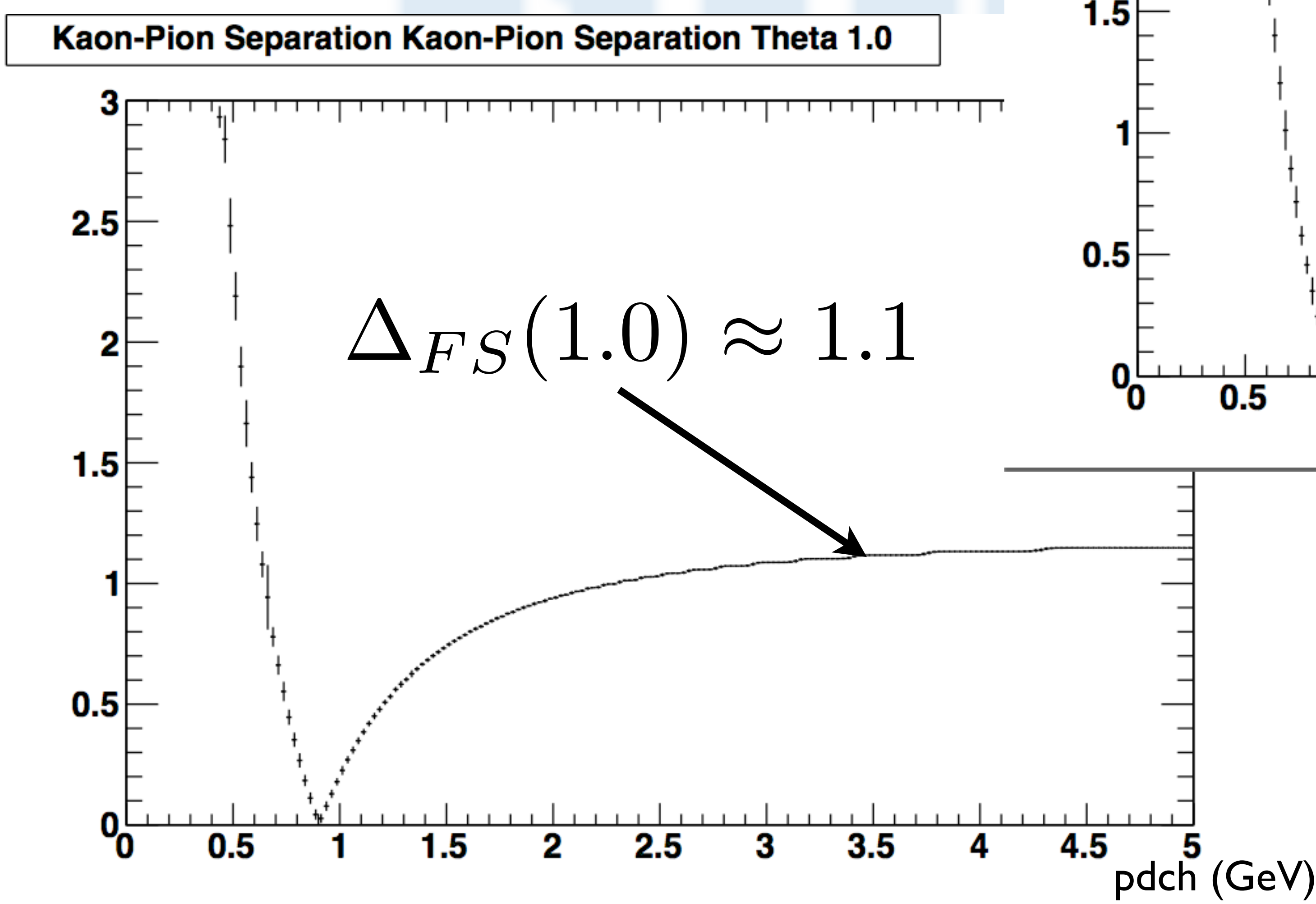


K/pi separation in FastSim

Combined samples of single Kaons and Pions, using the dedx_error from width of Gaussian fit to dEdx measurements in momentum range 3-4 GeV. Standard FastSim parameters.



$$\Delta_{FS}(0.5) \approx 1.4$$



$$\Delta_{FS}(1.0) \approx 1.1$$

$$A = \frac{\Delta_{FS}(0.5)}{\Delta_{BB}(0.5)} \approx 0.7$$

$$B = \frac{\Delta_{FS}(1.0)}{\Delta_{BB}(1.0)} \approx 0.80$$

Fixing K/pi separation to BAD 1500

- Recall that the dE/dx resolution is determined by a 3-parameter formula:

$$\sigma_0 = p_1 \left(\frac{\mu_0}{C}\right)^{p_2} L^{p_3}$$

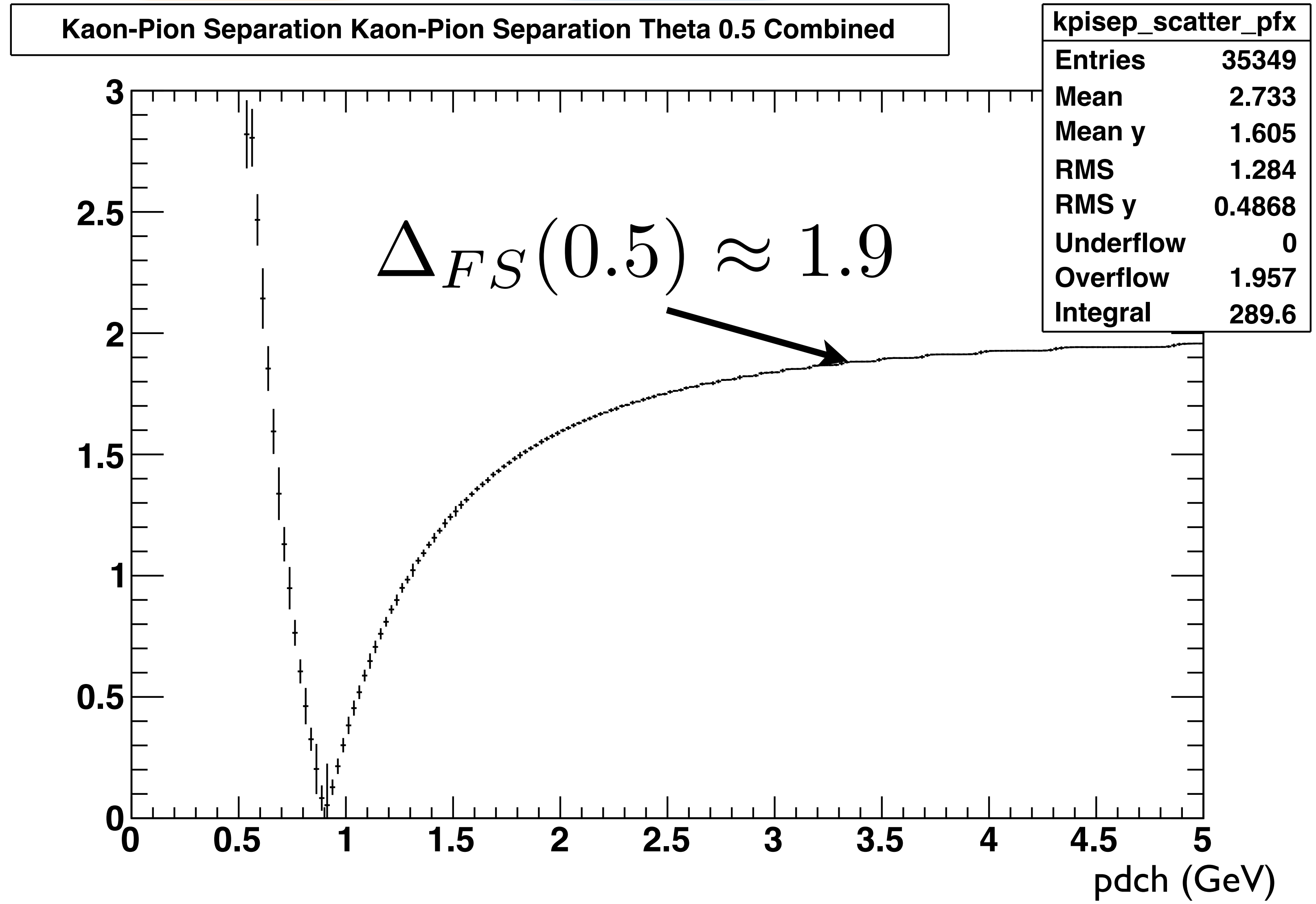
- We keep p2 the same, then tune p1 and p3 to match the BAD 1500 results at theta = 0.5 and 1.0 in the momentum range 3-4 GeV

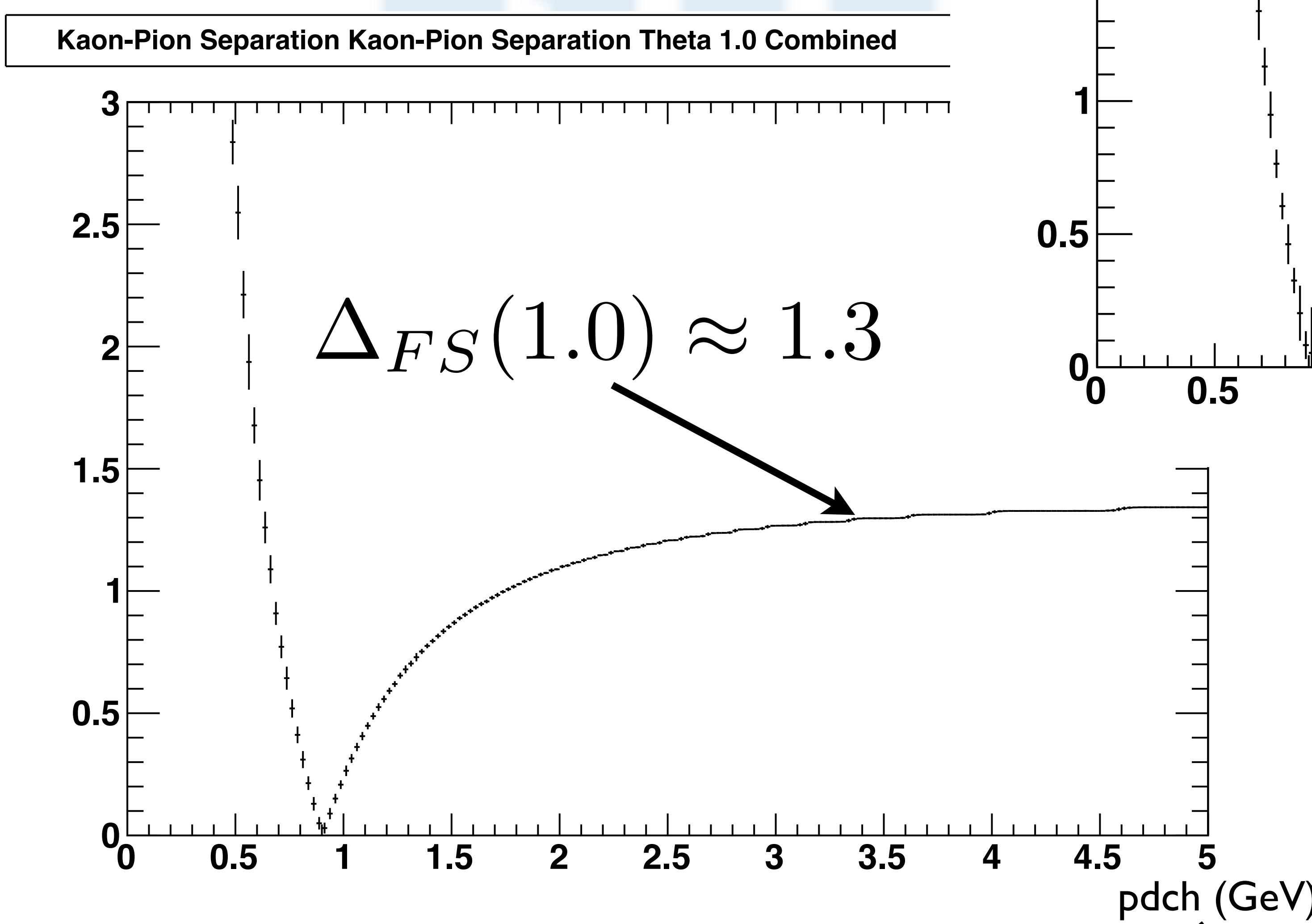
$$p_1' \approx 0.00140$$

$$p_3' \approx -0.565$$

K/pi separation with new parameters

Combined samples of single Kaons and Pions, using the dedx_error from width of Gaussian fit to dEdx measurements in momentum range 3-4 GeV.

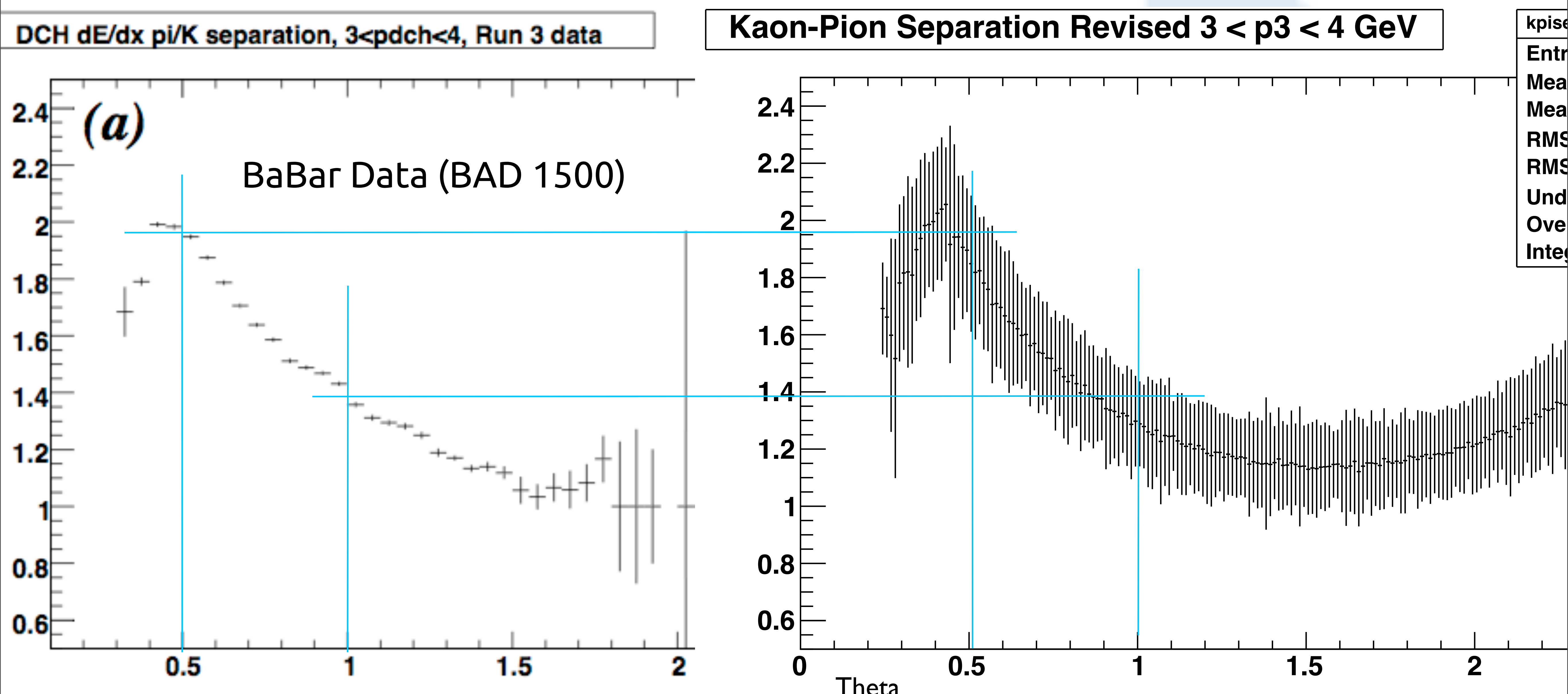




K/pi separation has been matched to BAD 1500 at two angles, what about the whole angular range?

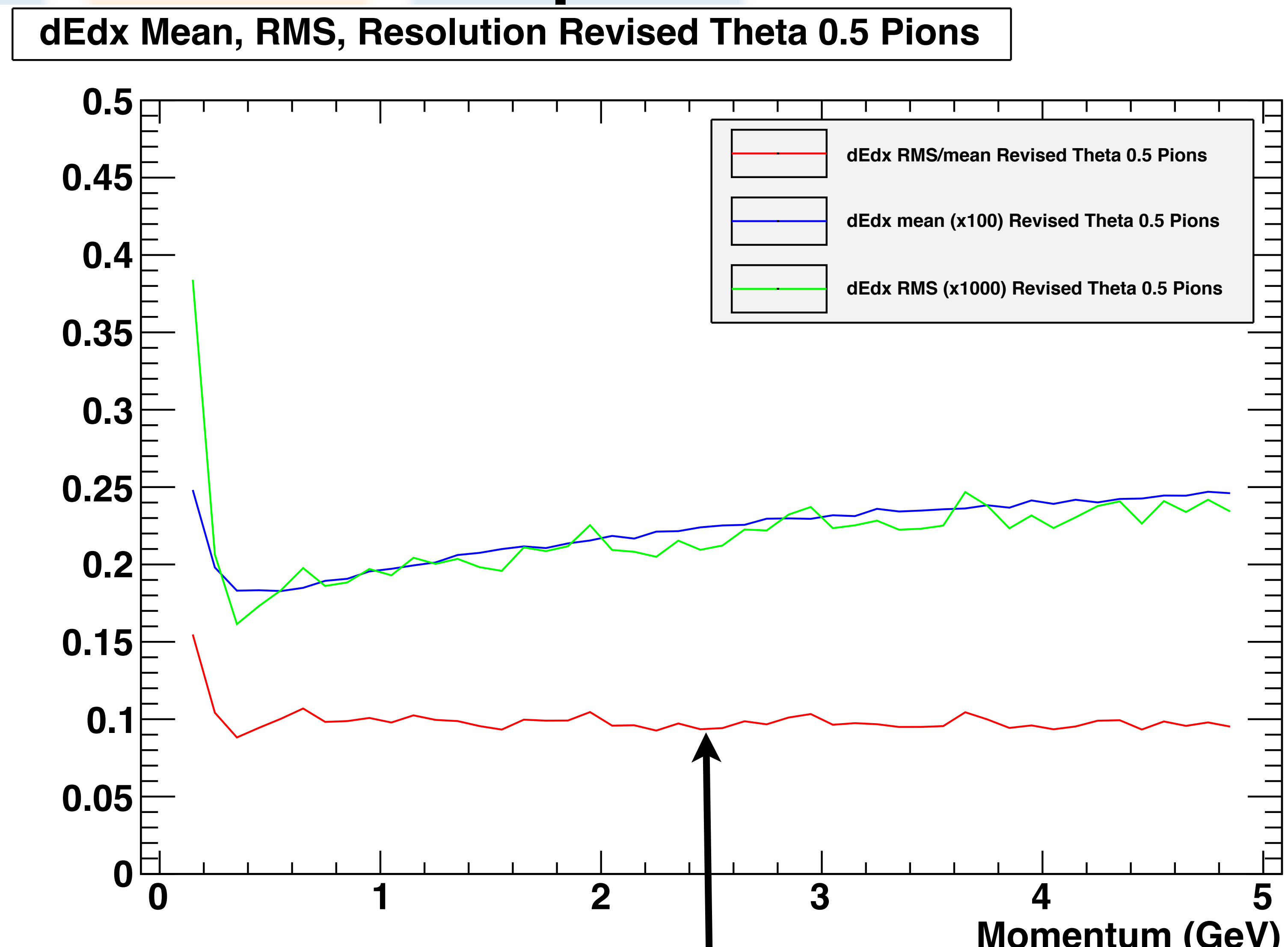
Angular dependence

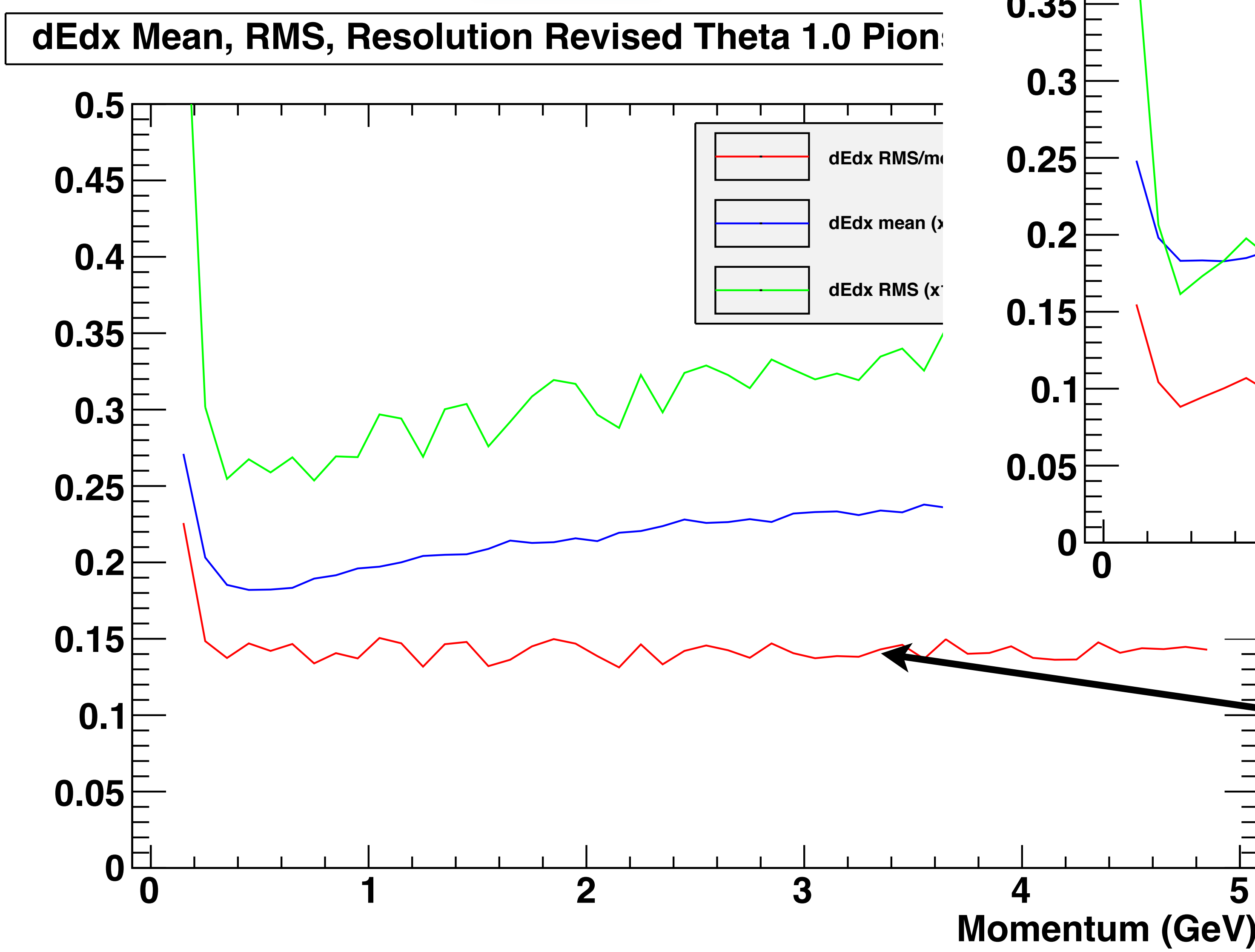
The two points are better matched than before, and the overall shape seems to agree.



dE/dx resolution with new parameters

From FastSim V0.3.1,
revised parameters,
single pions





Constant at ~9%
Constant at ~14%
Similar numbers for Kaons.
This is much greater than 7.5%, but not as large as standard FastSim (13%, 17% respectively).

Proposal

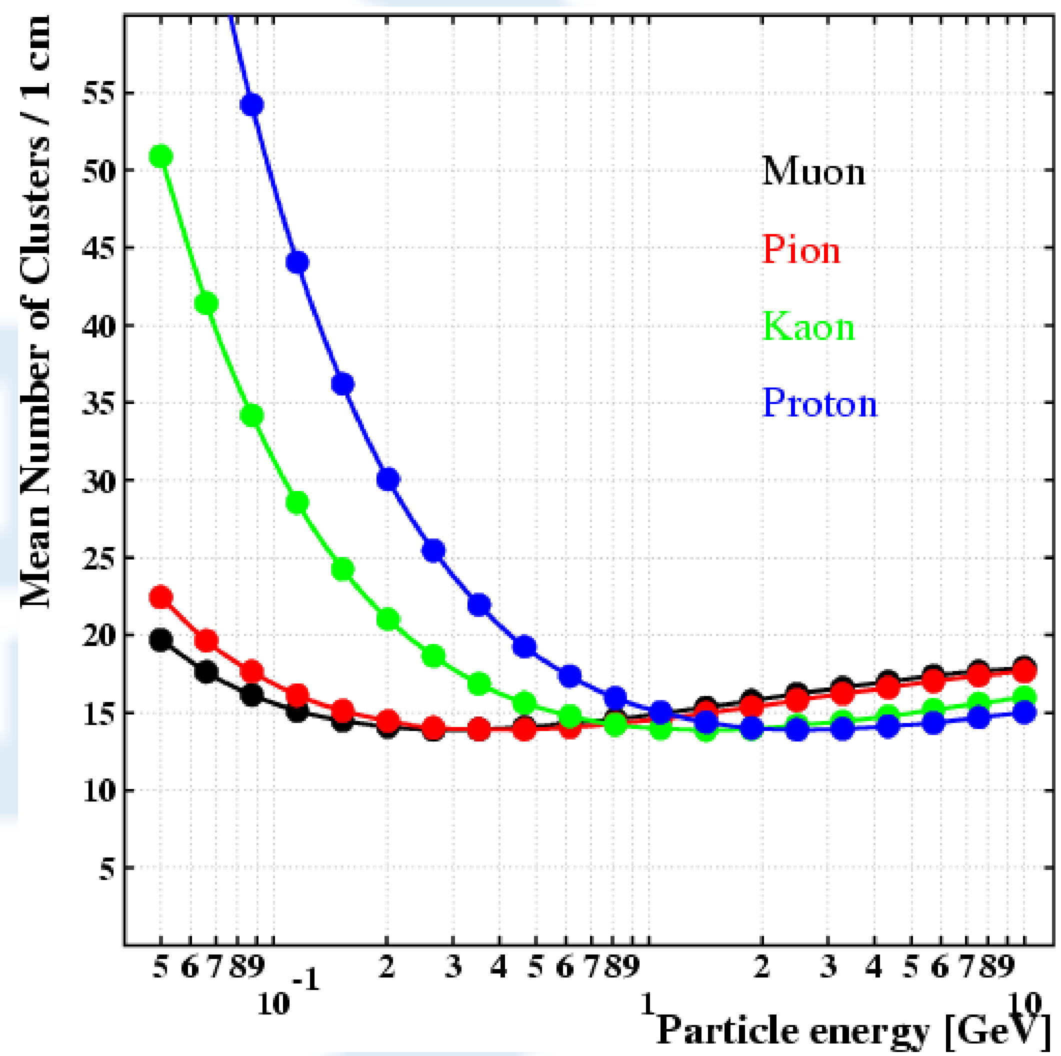
- Change the p1 dE/dx parameter to 0.00140 (from 0.00154)
- Change the p3 dE/dx parameter to -0.565 (from -0.34)
- These choices can be fine-tuned with more precise comparison to BAD 1500 data (here the values were taken from graphs with a ruler)

Cluster Counting

It would be difficult to implement microscopic simulation of cluster counting in FastSim, so instead we would use "parametrized" cluster counting. A certain amount of dE/dx would correspond to a cluster

The uncertainty in counting follows simple Poisson statistics, reflected in a choice of
p2 = 1/2

Cluster-counting efficiency is reflected in the choice of p1. Expected efficiency is around 60%



From Garfield in
He:Isobutane 90:10

Cluster counting parameters

From Poisson statistics, we get p2 = 0.5, p3 = -0.5

By fixing the ratio of ionization to clusters at the minimally-ionizing point, we determine p1 to be 5.81e-4

This choice of p1 would correctly model the dE/dx resolution, however the more important quantity is the K/pi separation.

We have seen that in FastSim, in order to get the correct K/pi separation, the dE/dx resolution is overstated by a factor of ~2 using the standard parameters, and slightly less using my revised parameters shown on slide 7.

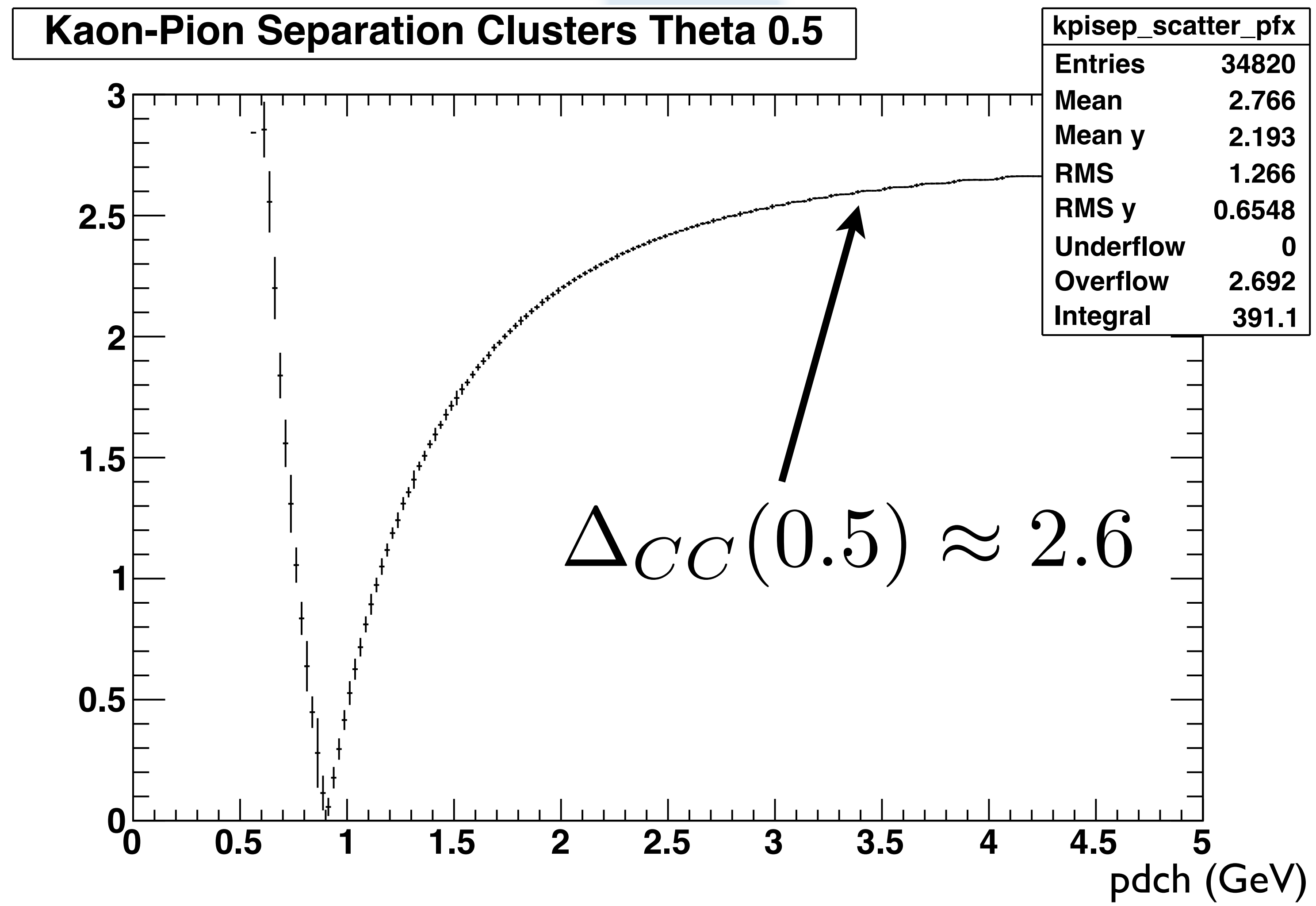
Thus for cluster counting, we would multiply the p1 parameter by the same factor of 2, in order to obtain the correct K/pi separation behavior.

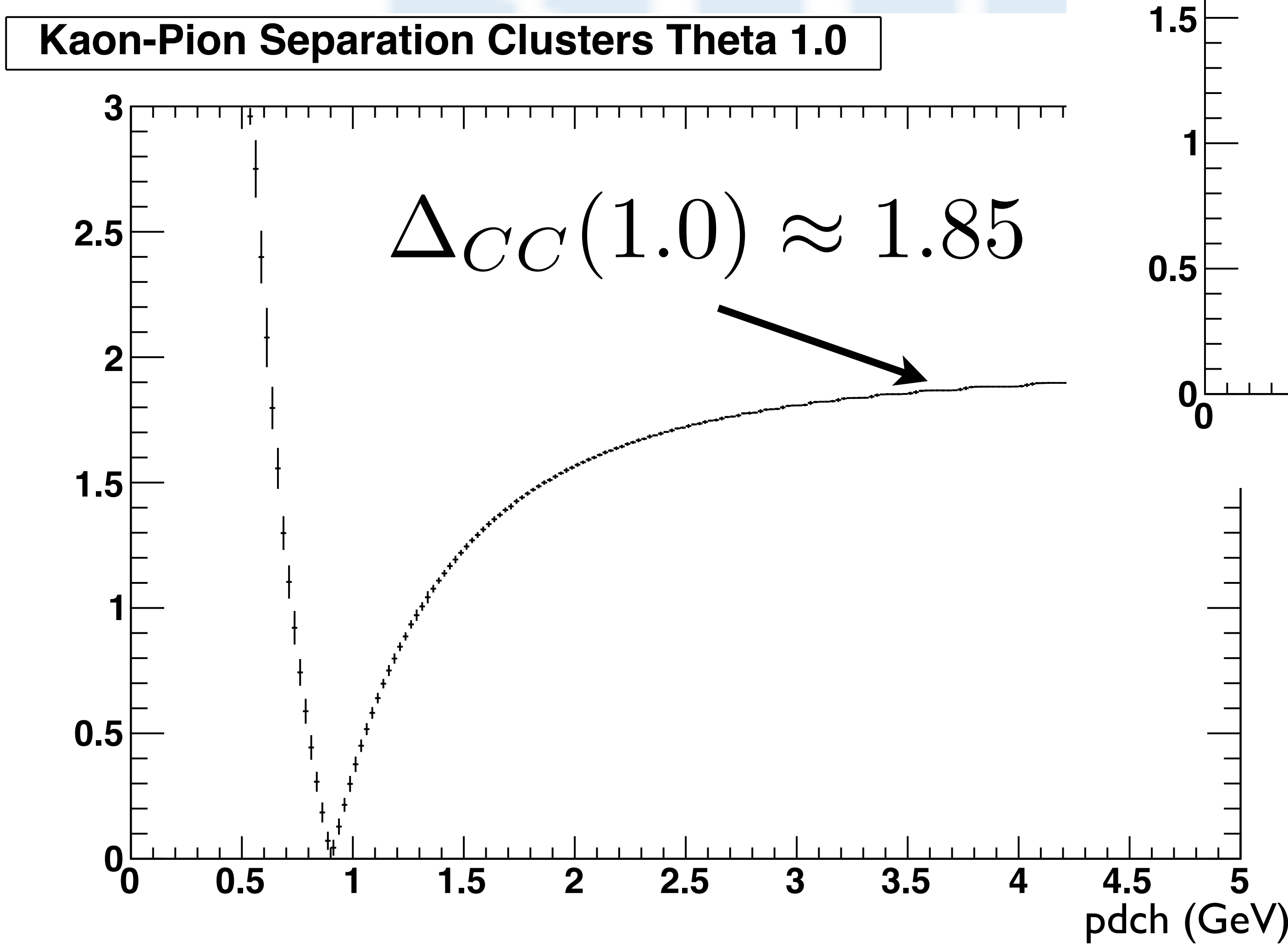
Proposal for cluster counting

- Change p1 to 0.00116 (from 0.00154), using a factor of 2 for the inflated dE/dx resolution.
- Change p2 to 1/2 (from 1).
- Change p3 to -1/2 (from -0.34).
- Note that the exact value of p1 can be tuned with better estimates of Nmin, better estimate of counting efficiency, and more precise comparison with non-cluster counting FastSim.

K/pi separation with cluster counting

Combined samples of single Kaons and Pions, using the dedx_error from width of Gaussian fit to dEdx measurements in momentum range 3-4 GeV.

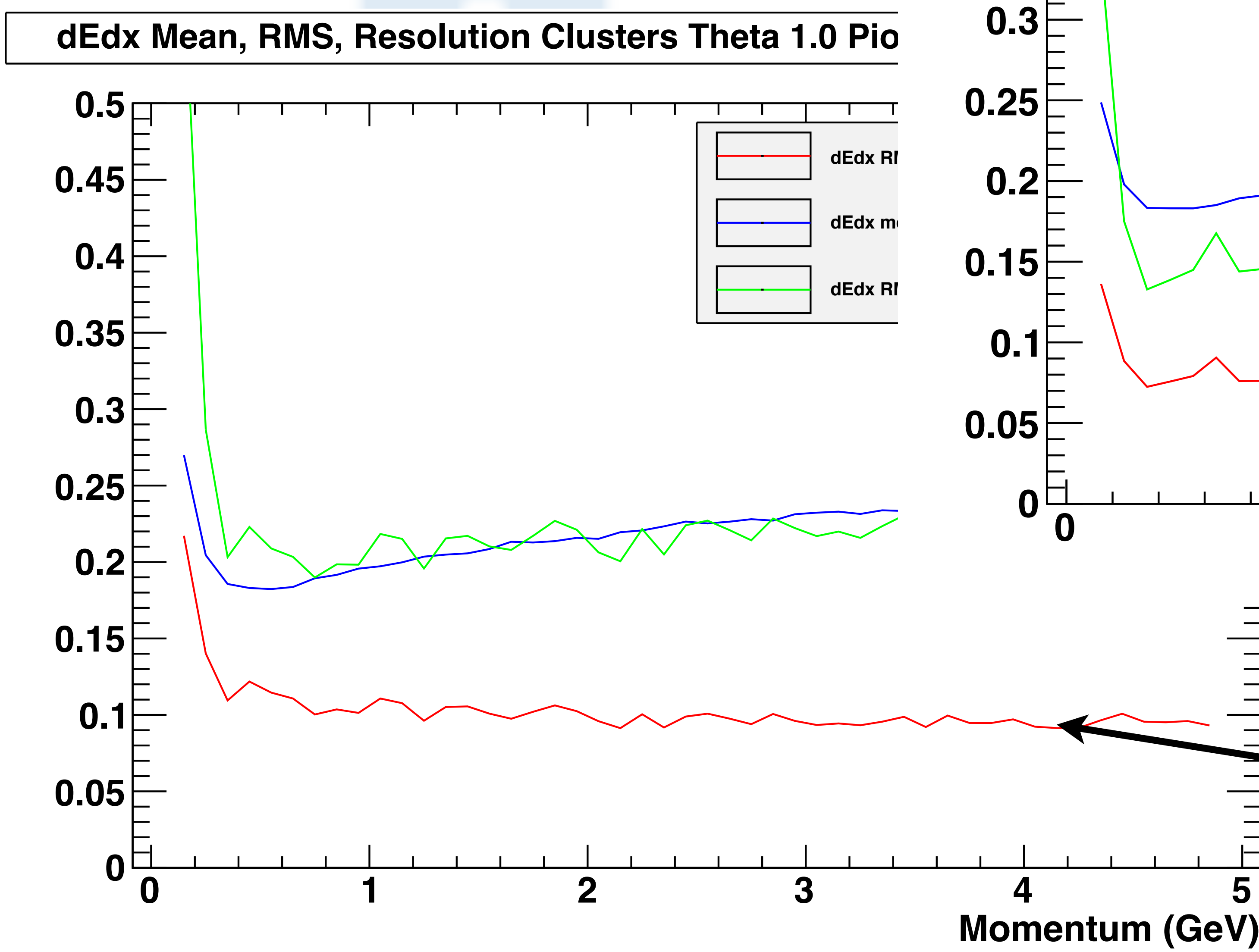


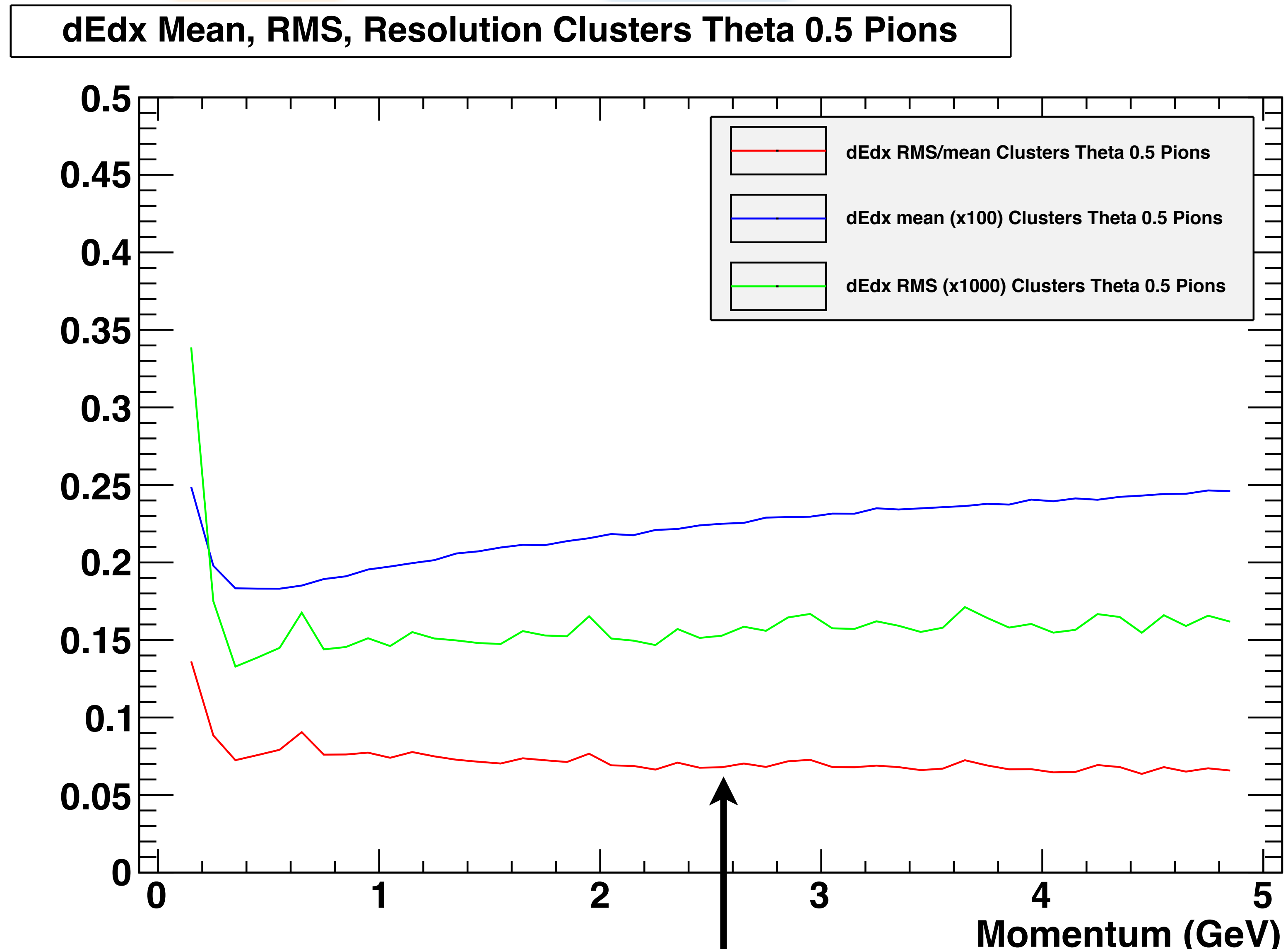


The resulting separation is ~40% better than with the revised parameters on slide 11.

dE/dx resolution with cluster counting

From FastSim V0.3.1, cluster counting parameters, single pions





Gentle slope at ~7%
Gentle slope at ~11%
Similar numbers for Kaons

Cluster counting evaluation

The cluster counting configuration can be used on its own, but the main purpose is to have a large production made of $B \to K\nu\bar{\nu}$ with full backgrounds. The semileptonic analysis of this process can reveal the quantitative gains to be had from a cluster-counting drift chamber.

Analysis code already exists for this, both from previous FPID studies and developed myself.

A more detailed proposal is in preparation.

Backup Slides

SuperB DCH in FastSim

dE/dx measurements for each cell hit by a track are drawn from a Gaussian distribution with mean given by the Bethe formula and standard deviation given by:

$$\mu_0 = \left[\frac{dE}{dx}\right]$$

Bethe formula result normalized to material density, per unit length

$$\sigma_0 = p_1 \left(\frac{\mu_0}{C}\right)^{p_2} L^{p_3}$$

Track segment length in cm (cell_thickness/sin(theta) at large momentum

Bethe formula result for minimum ionizing particles in appropriate units (1.622e-3)

A fraction of the individual measurements are used to form a truncated mean, which is then fed to the normal reconstruction code.

This being identically 1 is important

trunc_frac="0.7"
p1="0.00154"
p2="1"
p3="-0.34"

dE/dx resolution in FastSim

For a track crossing M layers, with a T truncated mean fraction, you get k = MT samples. Model a straight uniform track, then the truncated mean will also be a Gaussian variable with the same mean, and reduced standard deviation

$$\mu = \mu_0$$

$$\sigma = \frac{\sigma_0}{\sqrt{k}}$$

The resolution we use is the RMS/mean of the truncated mean measurements:

$$\Gamma = p_1 \frac{\mu_0^{p_2 - 1}}{\sqrt{k} C^{p_2}} L^{p_3}$$

Given that the second parameter is identically 1, this reduces to a constant function of the track segment length:

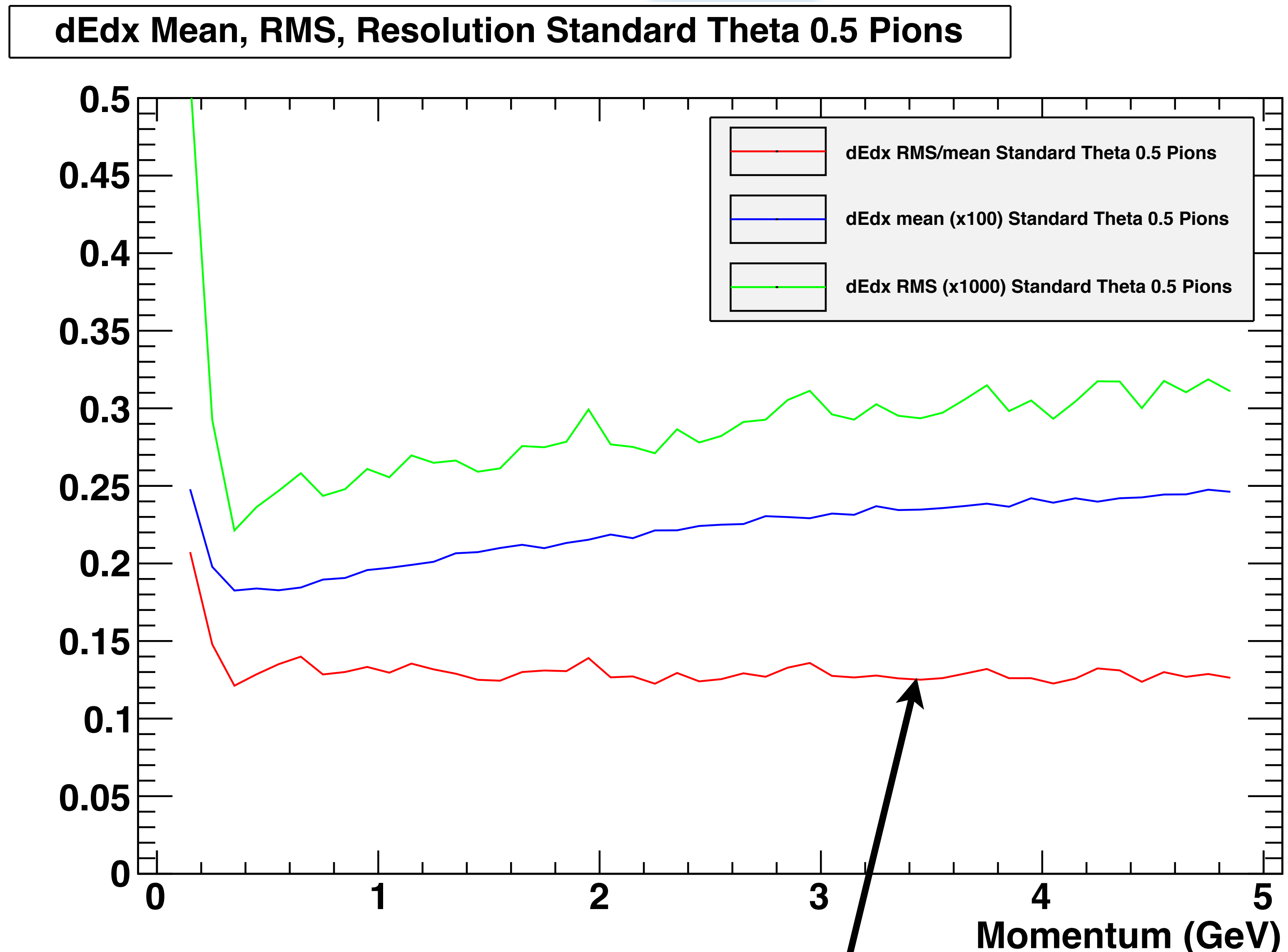
$$\Gamma = \frac{p_1 L^{p_3}}{\sqrt{k} C}$$

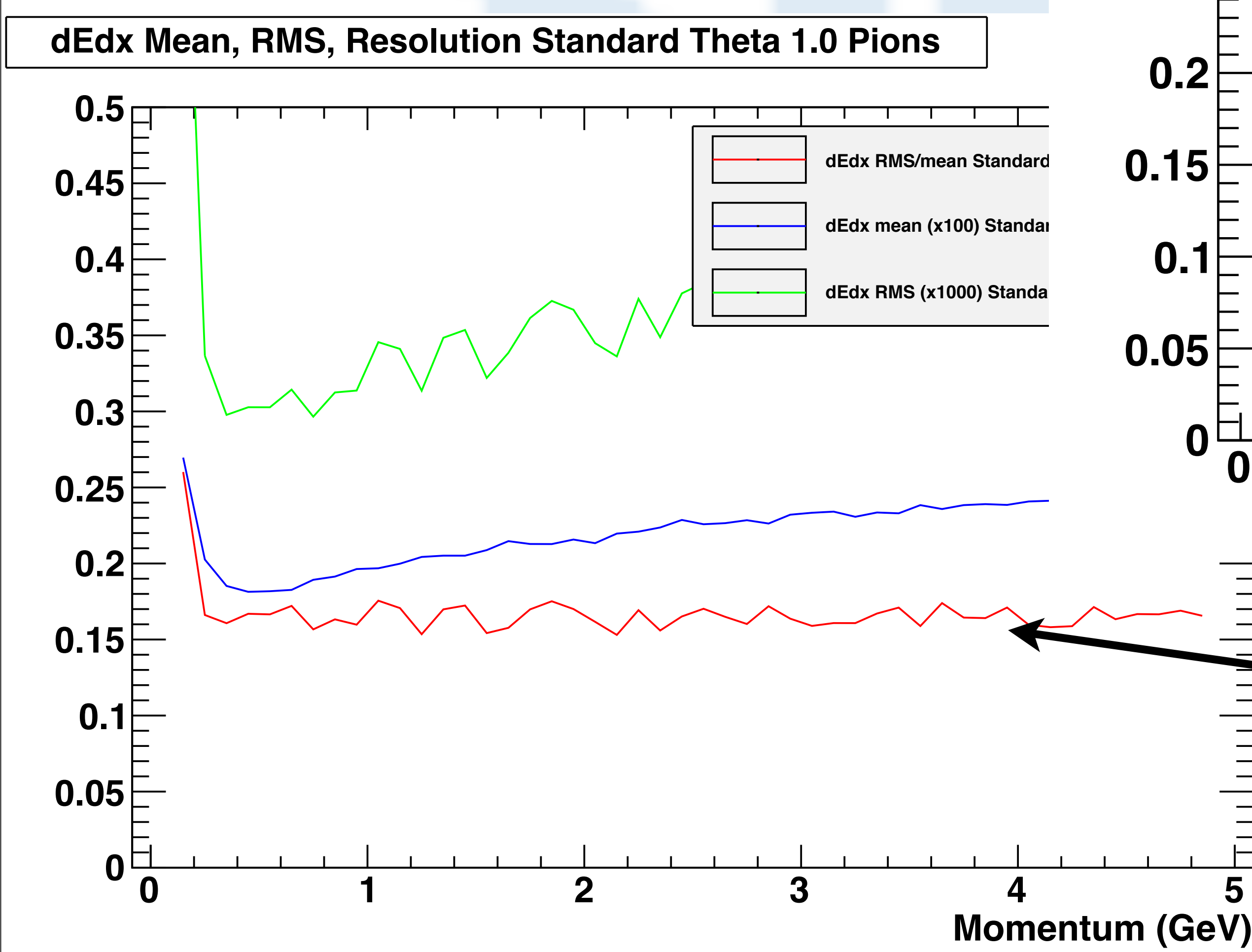
Putting in the numerical factors (k = 28 = 40*0.7, L = 1.375 cm)

$$\Gamma = 0.161$$

Confirmation in simulation

From FastSim V0.3.1, standard configuration, single pions





Constant at ~13%
Constant at ~17%
Similar numbers for Kaons

Fixing K/pi separation to BAD 1500

Separation is inversely proportional to the width of the dE/dx distribution:

$$\Delta_{FS}(\theta) \propto \frac{1}{p_1}\left(\frac{\sin\theta}{L}\right)^{p_3}$$

So we choose two new parameters to match the BaBar separation at the two angles shown in BAD 1500.

$$\frac{1}{p_1'}\left(\frac{\sin\theta_1}{L}\right)^{p_3'} = \frac{1}{A}\frac{1}{p_1}\left(\frac{\sin\theta_1}{L}\right)^{p_3}$$

The two equations uniquely determine the new parameters.

$$\frac{1}{p_1'}\left(\frac{\sin\theta_2}{L}\right)^{p_3'} = \frac{1}{B}\frac{1}{p_1}\left(\frac{\sin\theta_2}{L}\right)^{p_3}$$

$$p_1' = Ap_1\left(\frac{\sin\theta_1}{L}\right)^{p_3'-p_3} \approx 0.00140 \qquad p_3' = \frac{\log\frac{B}{A}}{\log\frac{\sin\theta_1}{\sin\theta_2}} + p_3 \approx -0.565$$

This dependence on L is unfortunate, as geometry changes, the parameter must be updated. Hereon I use 1.375 cm from the non-updated geometry in FastSim.

Deriving Parameters for Cluster Counting

$$\mu_c = \left[\frac{dE}{dx}\right]$$

(1) the mean ionization per unit length normalized by gas density, given by the Bethe formula.

$$\mu_{c_{cell}} = \mu_c L$$

(2) mean ionization in a cell of size L

$$\sigma_c = p_1 \left(\frac{\mu_c}{C}\right)^{p_2} L^{p_3}$$

(3) standard deviation of the ionization per unit length

$$\sigma_{c_{cell}} = \sigma_c L$$

(4) standard deviation of the total ionization in a cell of size L.

$$\mu_{N_{cell}} = \alpha\epsilon\mu_{c_{cell}}$$

(5) mean number of clusters counted in a cell, proportional to the total ionization in that cell.

$$\sigma_{N_{cell}} = \sqrt{\mu_{N_{cell}}}$$

(6) standard deviation of the number of clusters counted in a cell from Poisson statistics.

$$\sigma_{N_{cell}} = \alpha\epsilon\sigma_{c_{cell}}$$

(7) also the standard deviation of the number of clusters counted in a cell, following from equation 5

C ionization per unit length of a minimally-ionizing particle

p_1 parameter with dimension of ionization density$*cm^{-p_3}$

p_2, p_3 dimensionless parameters

α average ionization corresponding to one cluster

ϵ cluster-counting efficiency

N_{min} number of clusters created per cm by a minimally-ionizing particle

Equate (6) and (7), substitute (2),(3), and (5)...

Deriving Parameters for Cluster Counting (2)

$$\sqrt{\alpha\epsilon\mu_c L} = \alpha\epsilon L p_1 \left(\frac{\mu_c}{C}\right)^{p_2} L^{p_3}$$

This holds for all cell sizes L and mean ionization densities, so we immediately get:

$$p_2 = \frac{1}{2}$$

$$p_3 = -\frac{1}{2}$$

The rest of the parameters are globbed up into p1:

$$p_1 = \frac{C^{p_2}}{\sqrt{\alpha\epsilon}} = \sqrt{\frac{C}{\alpha\epsilon}}$$

N_{min} is the minimum number of clusters created, so

$$N_{min}\epsilon L = \alpha\epsilon C L$$

$$\alpha = \frac{N_{min}}{C}$$

$$p_1 = \frac{C}{\sqrt{N_{min}\epsilon}}$$

Deriving Parameters for Cluster Counting (3)

Numerical values for some constants (in appropriate units):

$$C = 1.622 \times 10^{-3}$$

$$\epsilon \approx 0.6$$

$$N_{min} \approx 13$$

$$p_1 = 5.808 \times 10^{-4}$$

This choice of p1 would correctly model the dE/dx resolution, however the more important quantity is the K/pi separation.

We have seen that in FastSim, in order to get the correct K/pi separation, the dE/dx resolution is overstated by a factor of ~2 using the standard parameters, and slightly less using my revised parameters shown on slide 7.

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