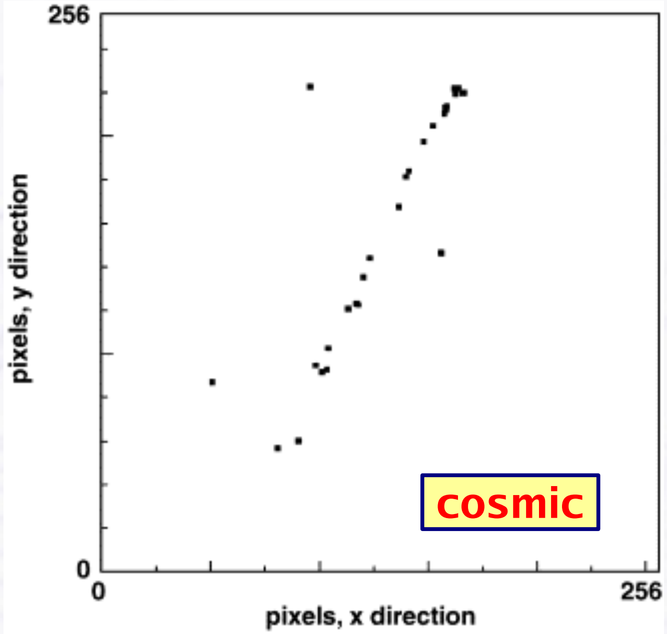
dE/dx and Particle ID Performance with Cluster Counting

- Some basics and reminders
- Bethe-Bloch functions and Particle Separation Power
  - for dE/dx by charge measurement and cluster counting
- Full simulation and reconstruction studies
  - full length ILC tracks with 3-GEM + MediPix
- Efficiencies and more...

Reminder: Cluster "Counting"...

- ...has been successfully demonstrated some years ago
  - MicroMegas + MediPix (NIKHEF)
    - cosmics
  - triple-GEM + MediPix (Freiburg)
    - ^{106}Ru source + DESY testbeam (Sep/Oct 2006)
- MicroMegas/MediPix sensitive to individual electrons
  - small single electron spots (few pixels)
    - low diffusion between MicroMegas and MediPix
    - ~90% efficiency for single electrons
- triple-GEM/MediPix integrates over larger areas
  - larger "blobs"
    - larger diffusion in GEM stack
    - ~20% efficiency for single electrons



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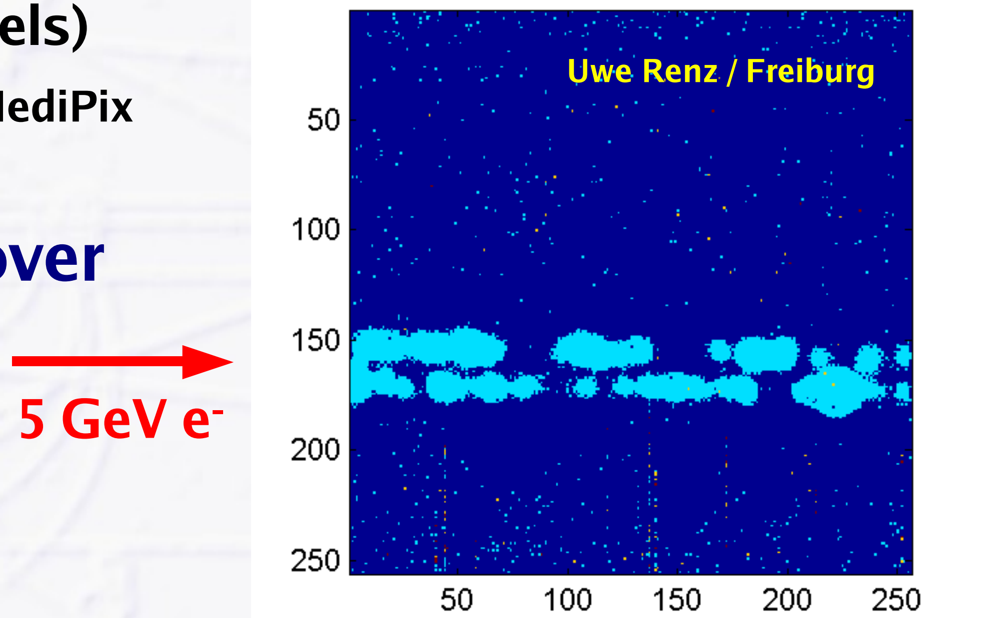
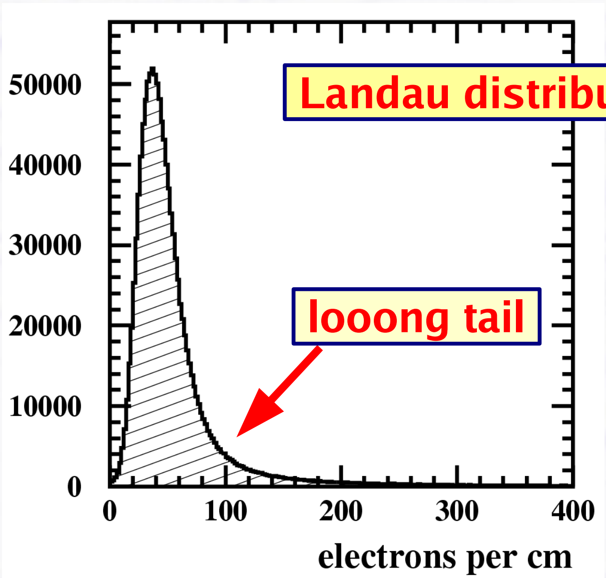


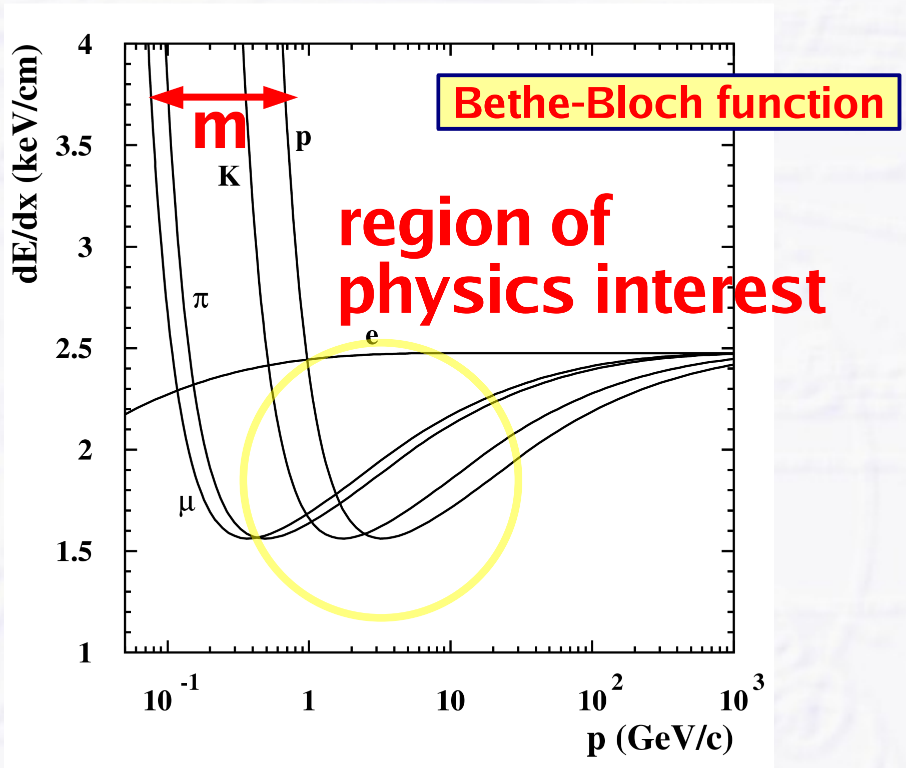
Why Cluster Counting (Prospects)

- Does allow to resolve individual ionisation clusters
= the most basic piece of information along a track
  - unprecedented potential for pattern (track) recognition and track fitting in dense track environments
    - better double hit/track resolution
    - get rid of delta rays/electrons
  - dE/dx measurement by cluster counting provides factor two better resolution compared to classical charge determination
    - get ~4.3% dE/dx resolution by classical charge measurement (TESLA-TDR)
    - cluster counting should give <2% resolution at LC-TPC (from pure ionization statistics)
- Lots of promises...
  - ...however, no proof-of-principle yet
- Needs more study
  - Estimate cluster counting power using cluster generator (HEED)
  - Study performance by detailed simulation/reconstruction of full length ILC tracks

dE/dx basics

- **Typical classical dE/dx measurement**
  - measure n charge samples along track (~200 at LC-TPC) and get "average" charge/energy loss per cm track length
    - charge = primary ionization + secondary electrons (delta electrons)
  - delta electrons lead to large fluctutions of the measured charge
    - reduce this by taking "truncated mean" as average
    - take only those x % (typically 60-80%) of the samples with the lowest charges

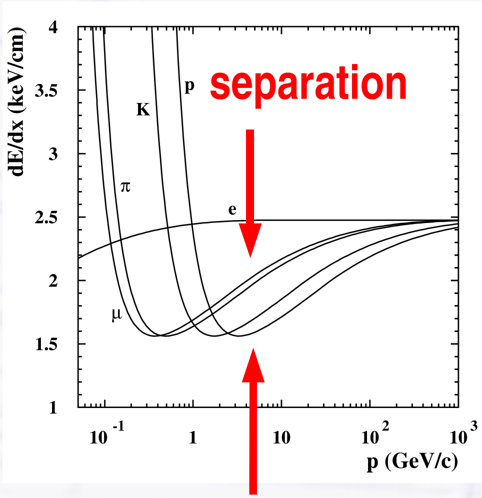


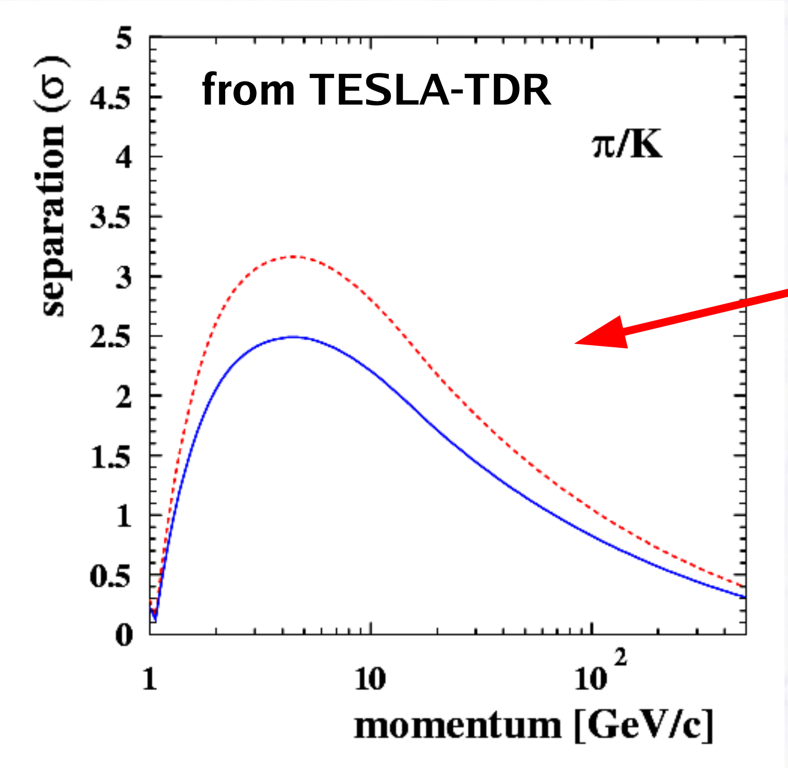


Particle Separation Power

- After all, it's not the dE/dx resolution that counts but the Particle Separation Power
  - Separation of two particle species in dN/dx in units of the dN/dx resolution

$$\text{separation power} = \frac{\text{separation}}{\text{resolution}}$$





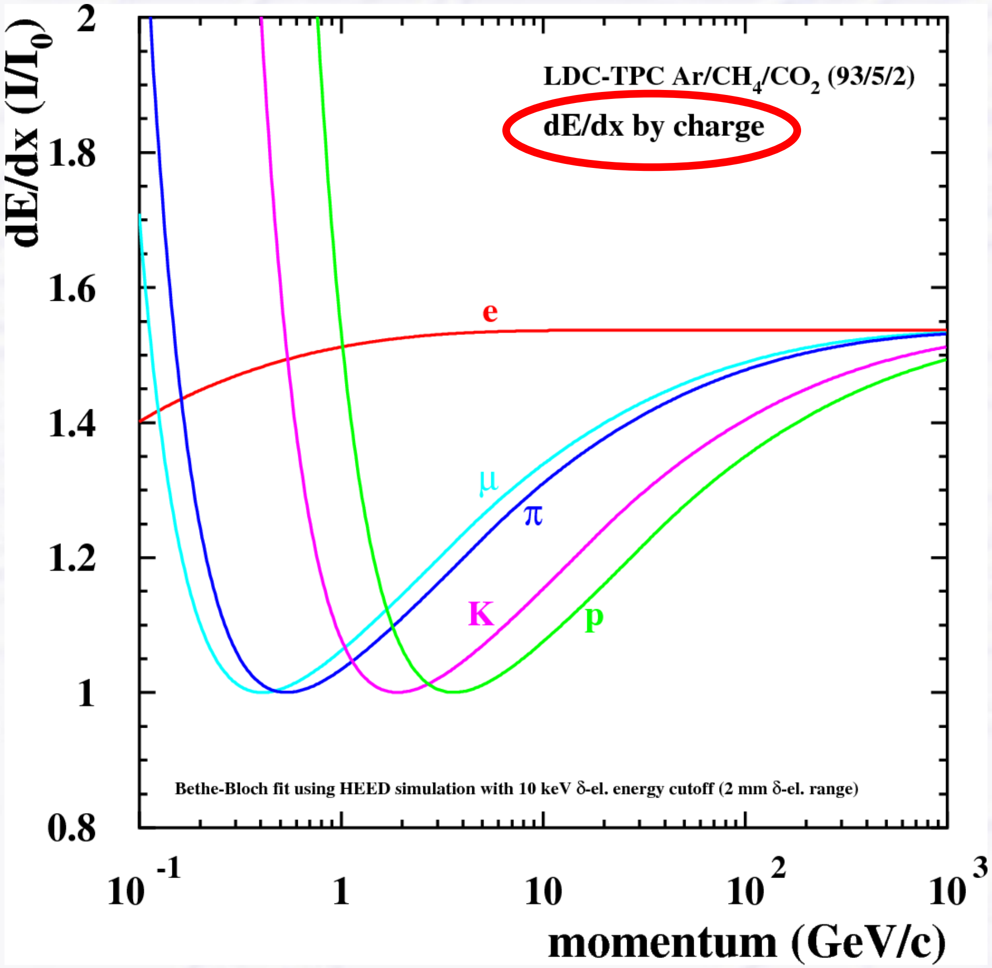
this is the relevant plot for physics

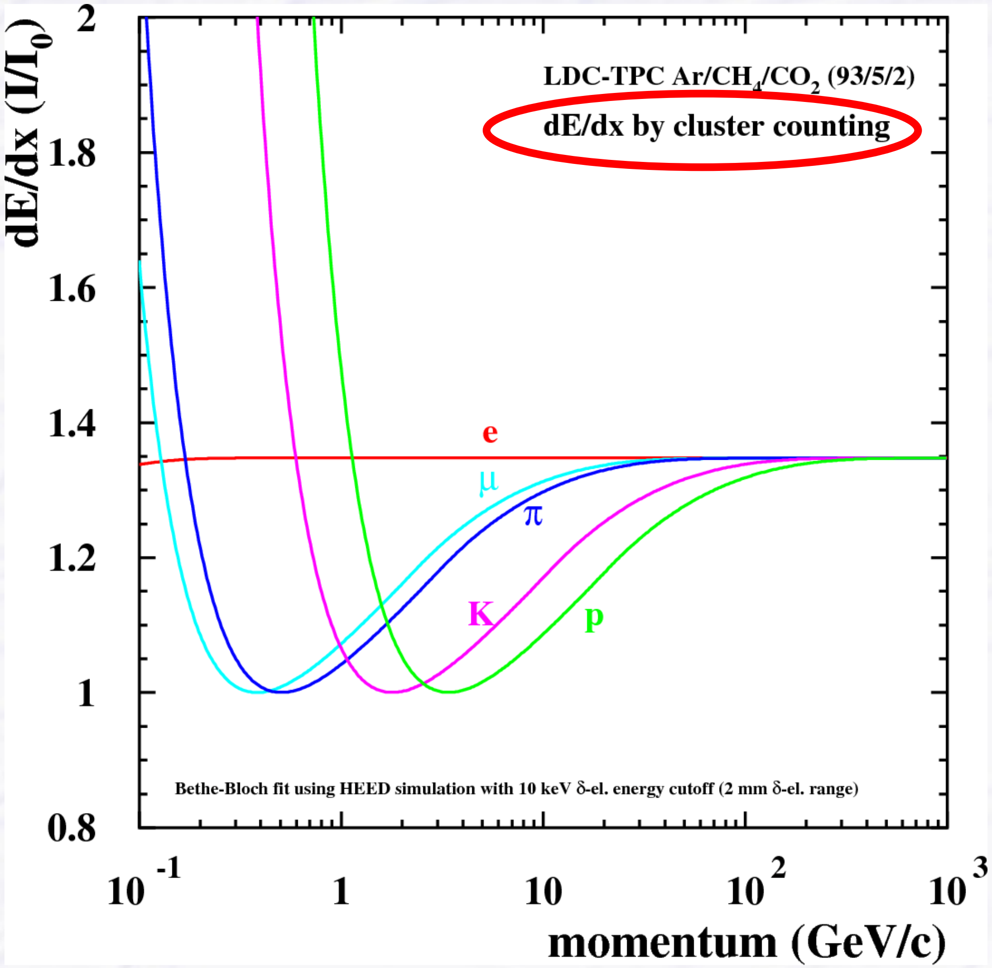
how does it look for cluster counting???

use HEED cluster generator (by I. Smirnov) to get some answers

Bethe-Bloch
(charge measurement + cluster counting)

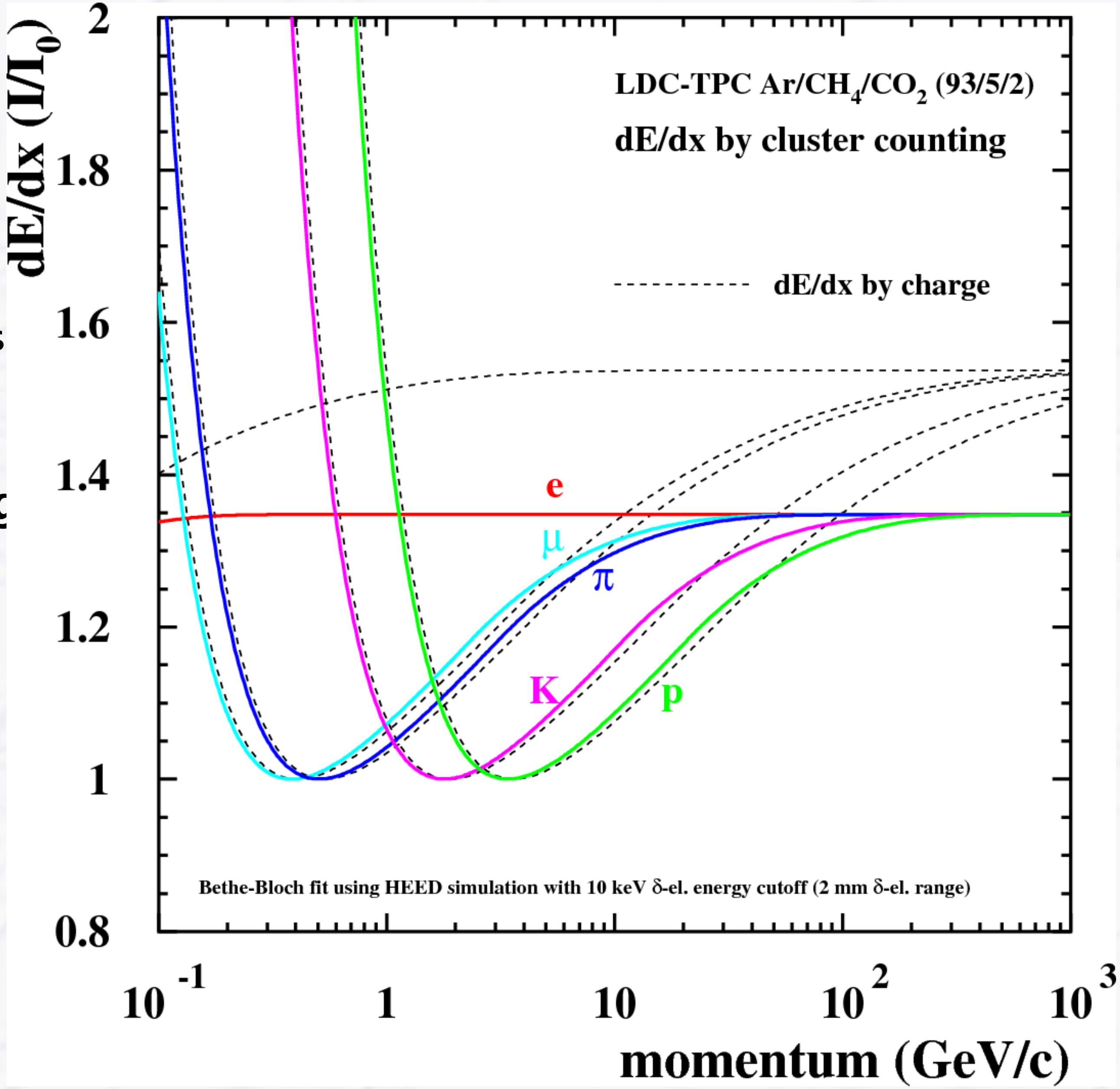
- Relativistic rise looks quite different
  - Fermi plateau reached much earlier with cluster counting
    - particle separation for cluster counting stops at lower momenta





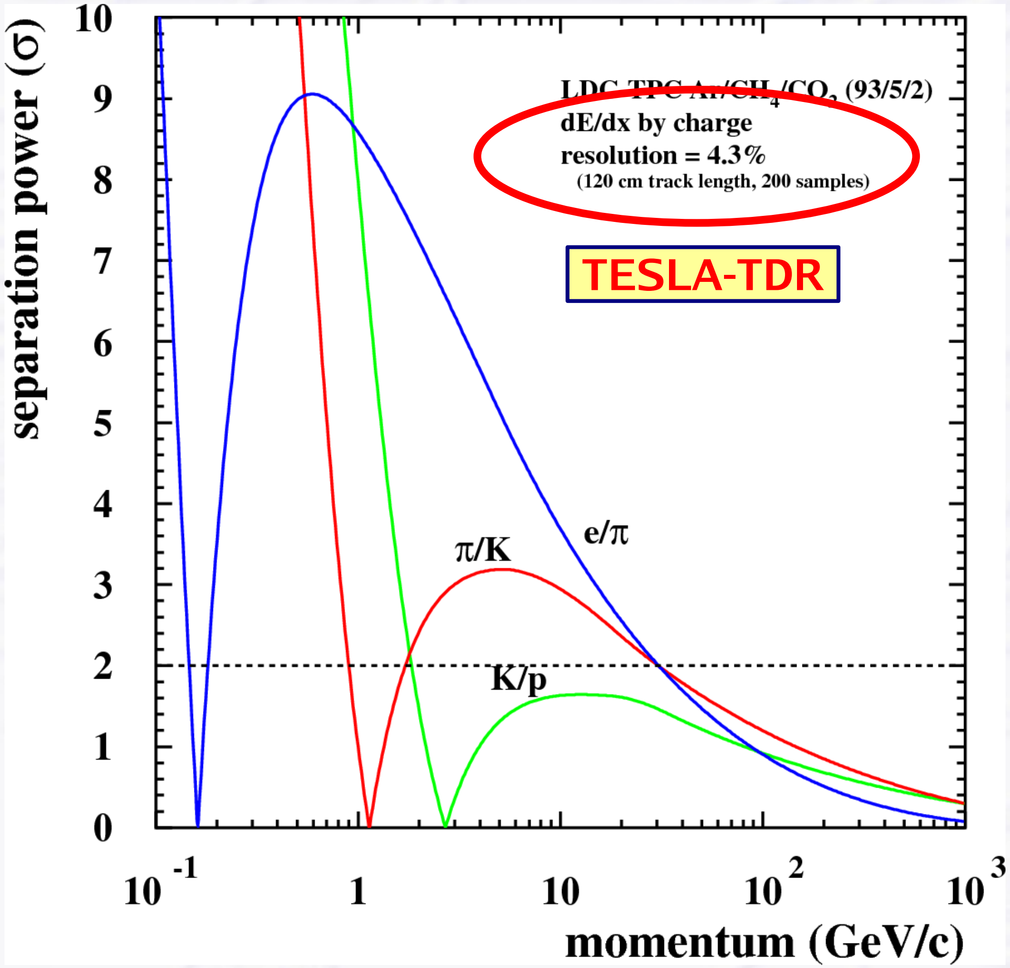
Bethe-Bloch Differences

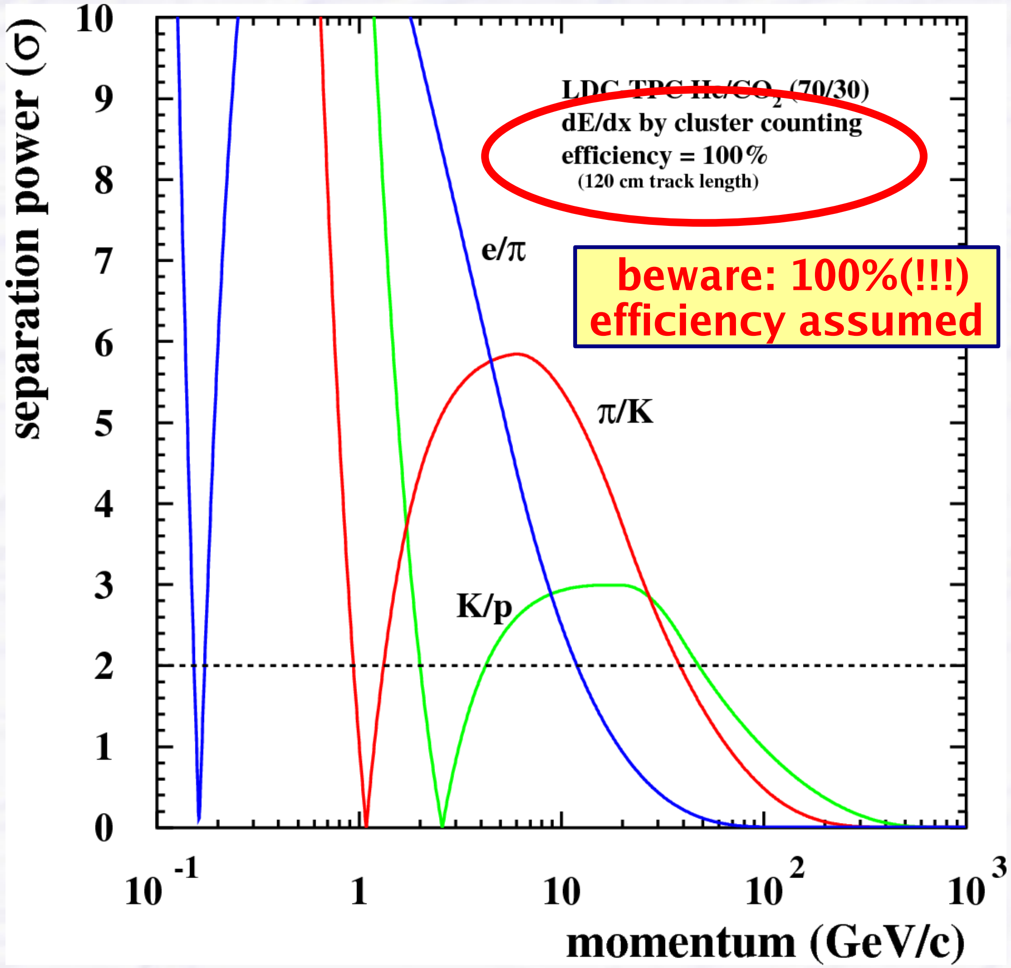
- **Why do they differ?**
  - charge measurement is highly sensitive to secondary electrons
    - there are more and more secondary electrons (deltas at higher momenta
    - Landau tail gets larger
  - (perfect) cluster countinç ignores them
    - relativistic rise “truncated”



Particle Separation Power
(charge measurement + cluster counting)

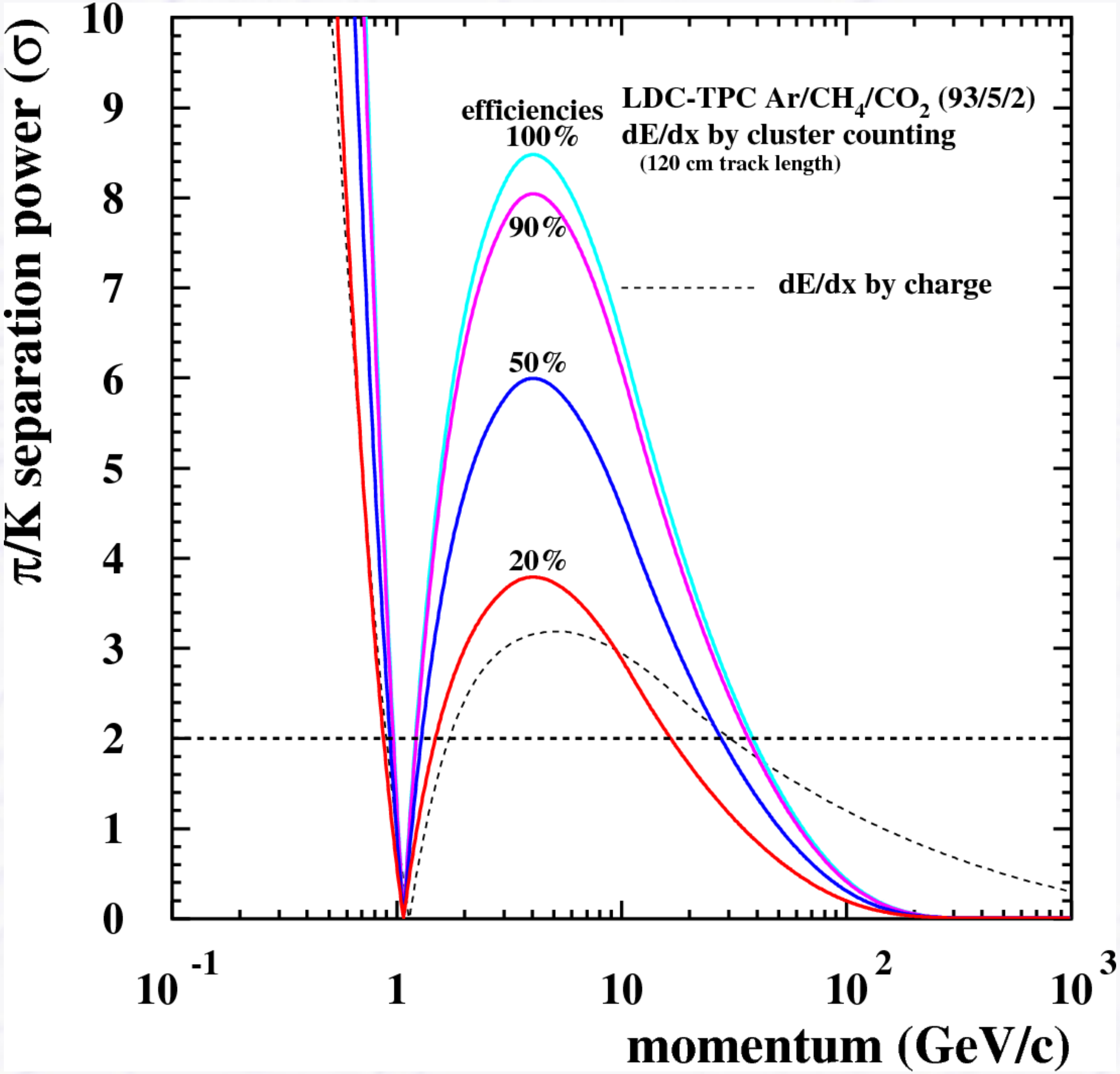
- Shape of particle separation power differs
  - maximum separation at somewhat higher momenta for cluster counting
    - more separation below, less separation above certain momentum for cluster counting





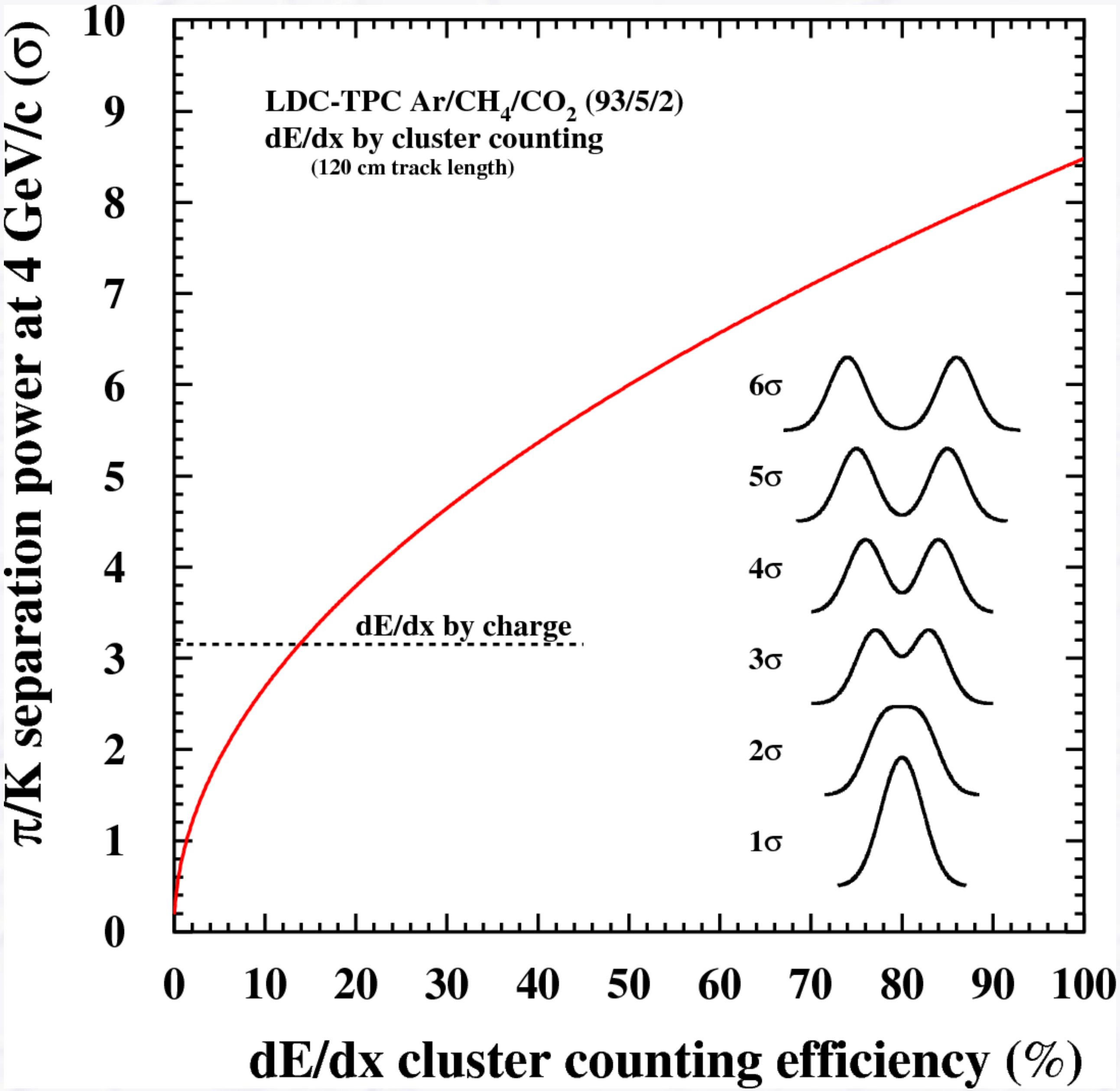
Particle ID
+ Cluster Counting Efficiency

- **Separation power with 100% cluster counting efficiency much better than with classical charge measurement**
  - for pions/kaons ~8 sigma vs. ~3 sigma at 4 GeV/c
  - similar performance at about 20% cluster counting efficiency
    - obtained with triple-GEM system
    - MicroMegas has ~90% efficiency for single electrons(!), cluster finding algrorithm still needed



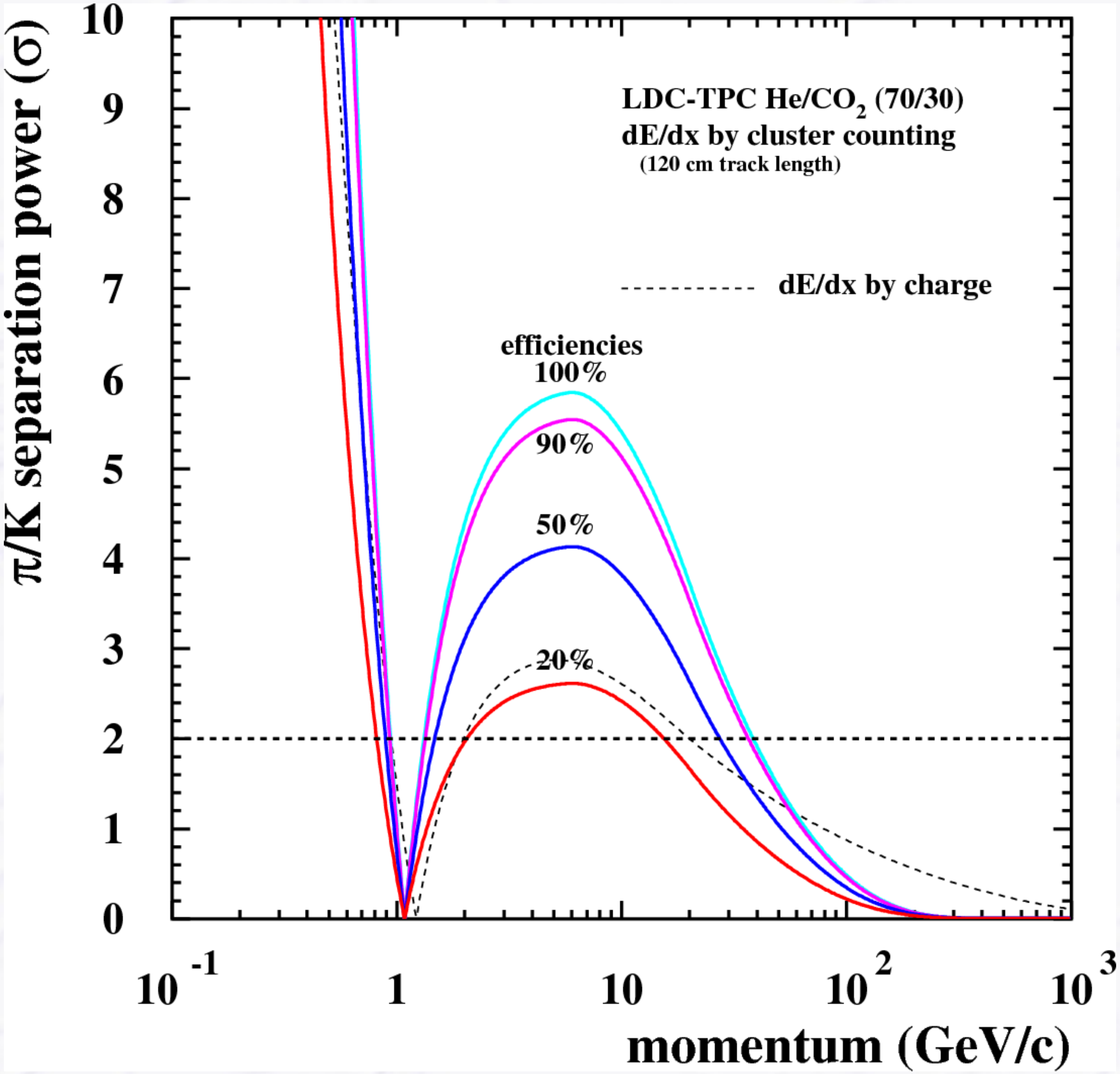
Cluster Counting Efficiencies

- **Need better efficiency to beat charge measurement**
- **Could go to gas with lower diffusion(?)**
  - TESLA-TDR gas has large diffusion in GEM stack
    - = large blobs, difficult to resolve
- **Helium mixtures seem promising**
  - lower diffusion
  - lower cluster density
    - clusters better resolved
    - but no saturated drift vel.(!)



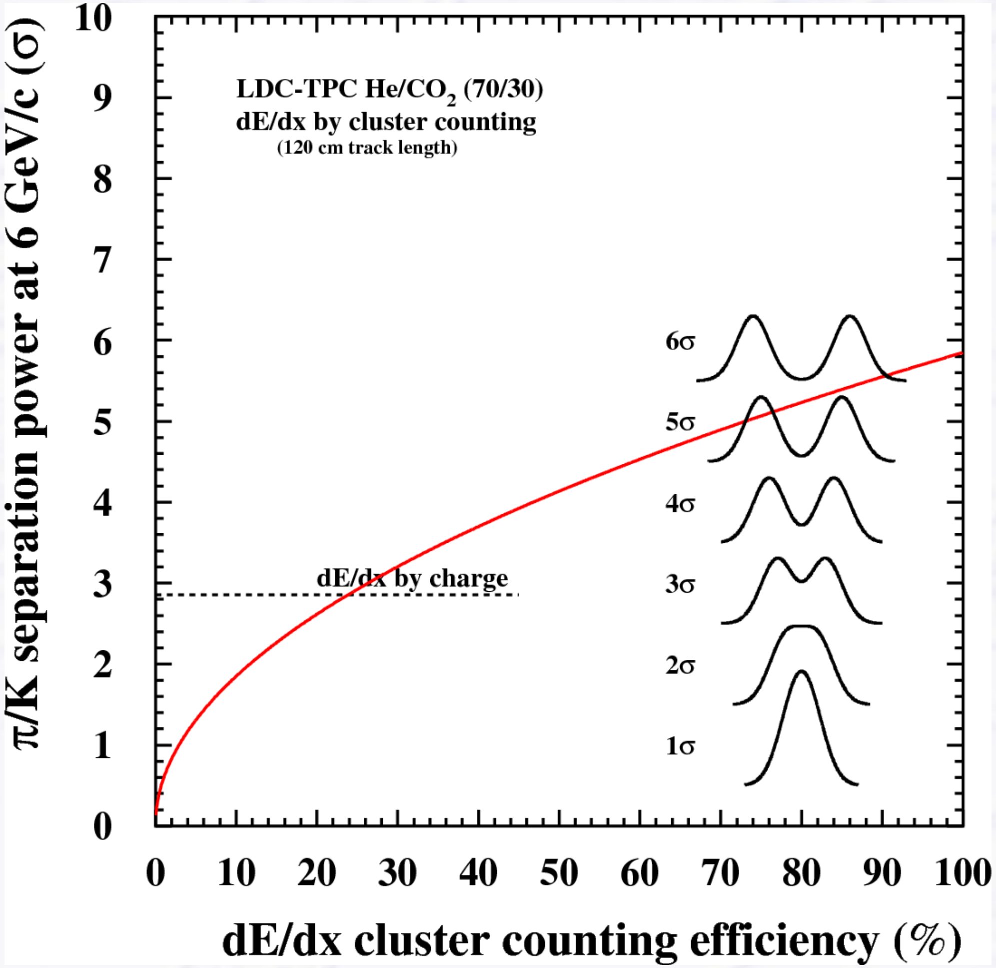
Helium Mixture, e.g. He/CO_2 (70/30)

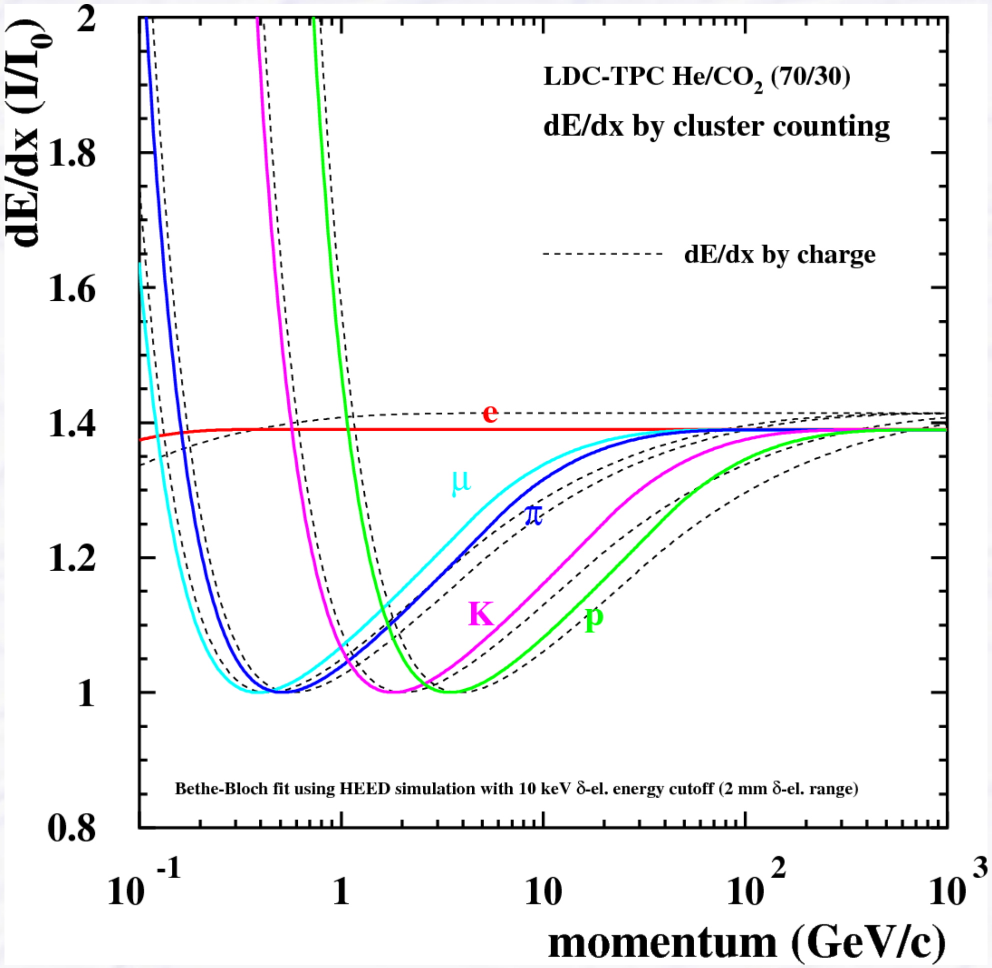
- **Performance NOT better than for Argon mixture**
  - less separation power at 100% cluster counting efficiency
  - typical efficiencies ~30-35% better (measured with Freiburg set-up)
  - but less primary ionization
- **overall number of reconstructed clusters similar than for Argon**



Bethe-Bloch for Helium

- **Need higher efficiency to beat charge measurement for Helium mixtures**
  - **Bethe-Bloch for charge measurement and cluster counting also more similar at Helium than at Argon (fewer secondary electrons in Helium)**

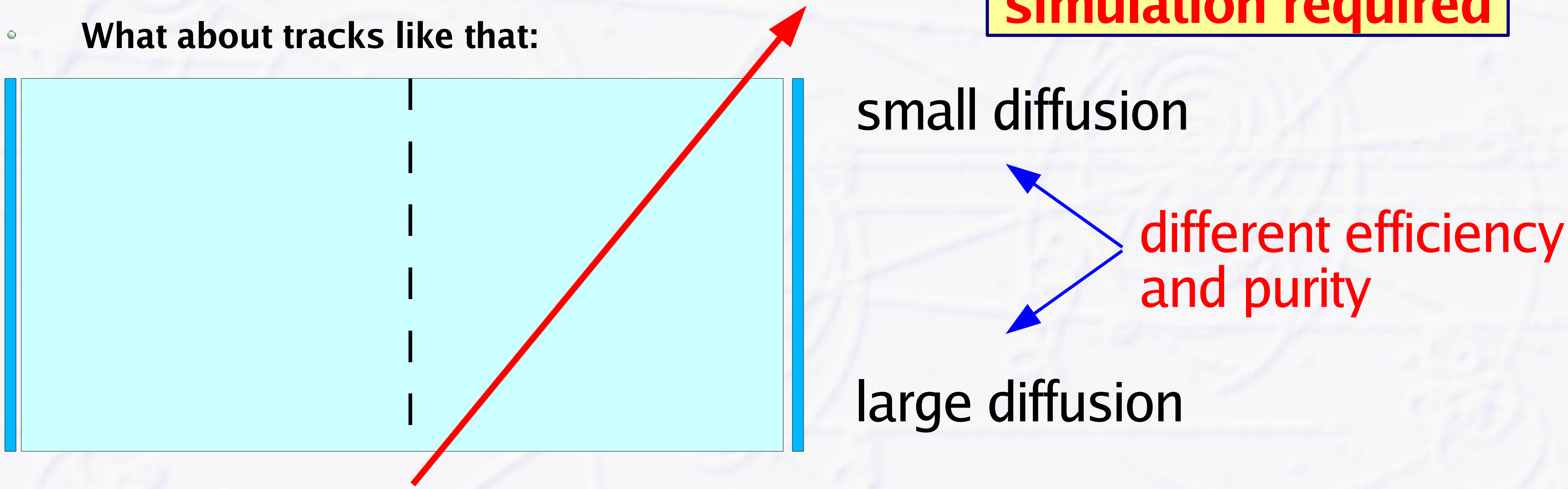




Intermediate Summary

- Particle separation power with cluster counting depends strongly on efficiency of cluster finding and thus DEPENDS ON MANY PARAMETERS
- Calibration/systematics could become rather clumsy
  - Number of reconstructed clusters sensitive to MediPix threshold
  - Efficiency/purity depends on primary cluster density
    - = this is what we want to measure!
  - And on diffusion = drift length
    - What about tracks like that:

Full + detailed simulation required

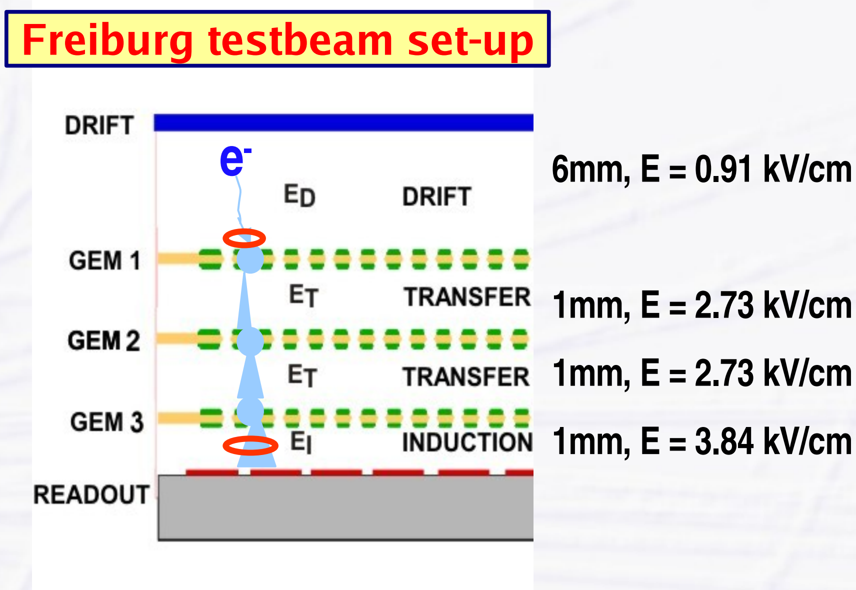


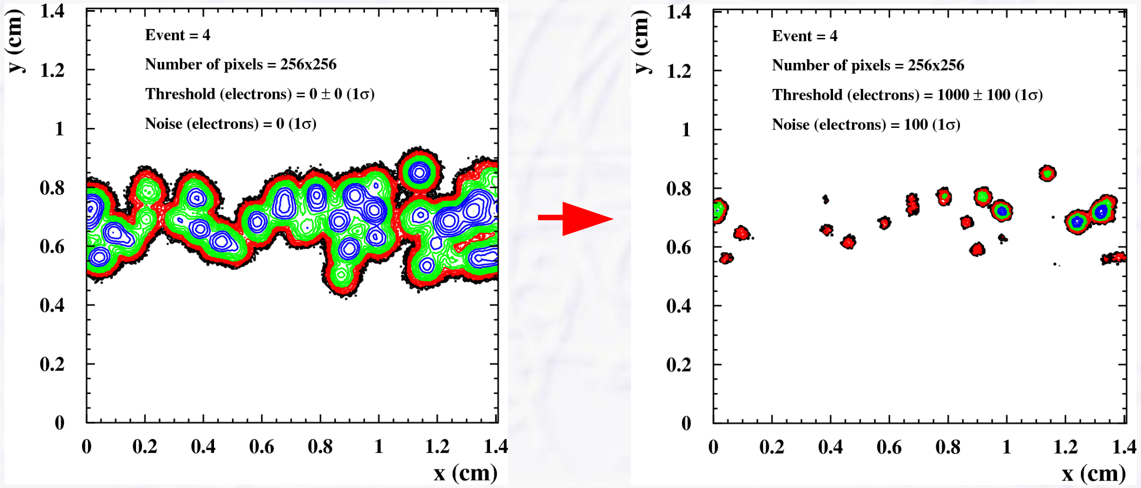
Full Simulation

- Simulate full length ILC tracks using CLUSCO simulation tool
  - 125cm long tracks, 90 MediPix in a row = 5.9 Mill. 55 x 55 μm^2 pixels
  - 4 GeV/c pions and Kaons (separation power at maximum)
- CLUSCO
  - Generates ionization clusters/electrons along tracks and drifts electrons towards GEMs/MicroMegas structures
    - HEED (I. Smirnov) for cluster generation (incl. δ-electrons, mult. scat.)
    - MAGBOLTZ (S. Biagi) for gas properties (diffusion, drift velocity)
  - "Squeeze" electrons through GEM/MicroMegas holes and perform gas amplification
    - simple geometric transformations used, no detailed E-field simulation
    - exponential gas gain distribution (for low gas gain)
  - Drift ALL electrons created in gas amplification to next GEM or MediPix (can be several Millions in total)
  - Count electrons collected on MediPix, generate noise + apply detection thresholds (digitization step)

Freiburg DESY Testbeam Set-up

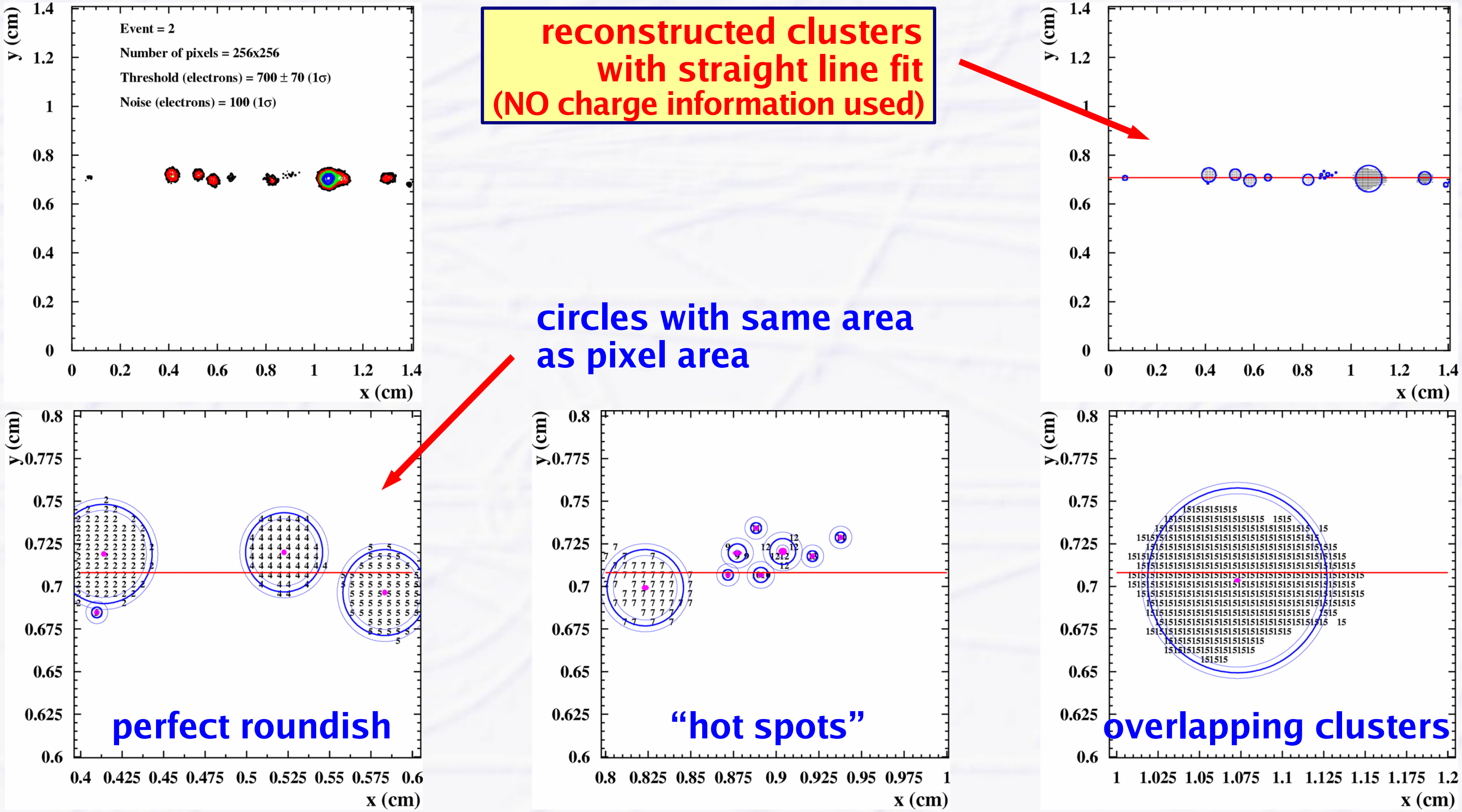
- Take Freiburg set-up for DESY testbeam as follows
- Gas $Ar/CH_4/CO_2$ (93/5/2)
  - = TESLA-TDR gas
  - diffusion param. for 4 T magnetic field
- Gaps between GEMs
  - 1mm – 1mm – 1mm
- Total gas gain = 60'000
  - gain per GEM = 39.15
    - exponential gas gain distr.
- MediPix
  - threshold = 1000 ± 100 e^-
  - noise = 100 e^-





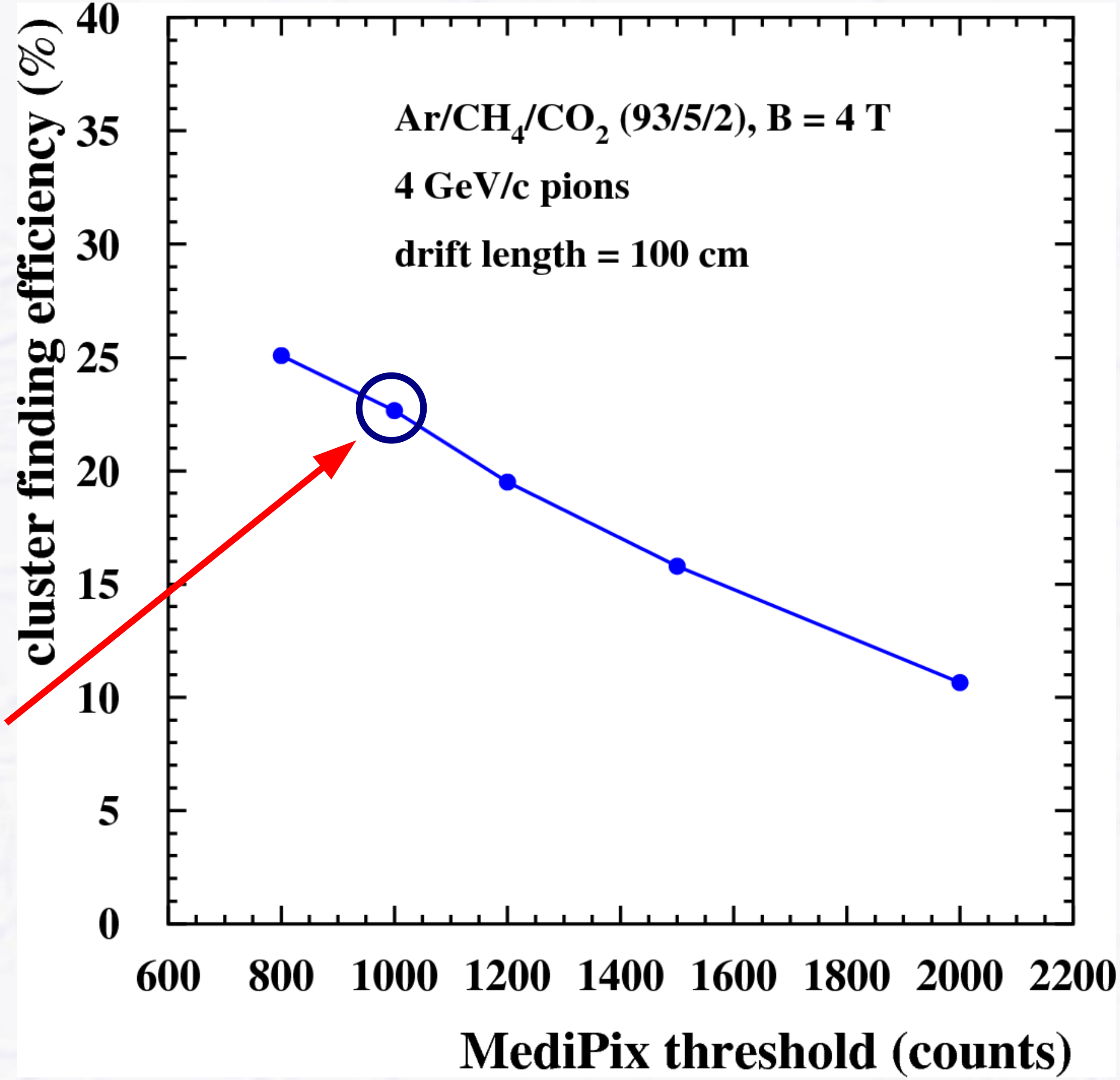
Cluster Finding

- **Apply simple cluster finding algorithm, get efficiency**
  - **search for simply connected areas, use center-of-gravity as position**
    - **sophisticated cluster finder to resolve near-by clusters still missing**



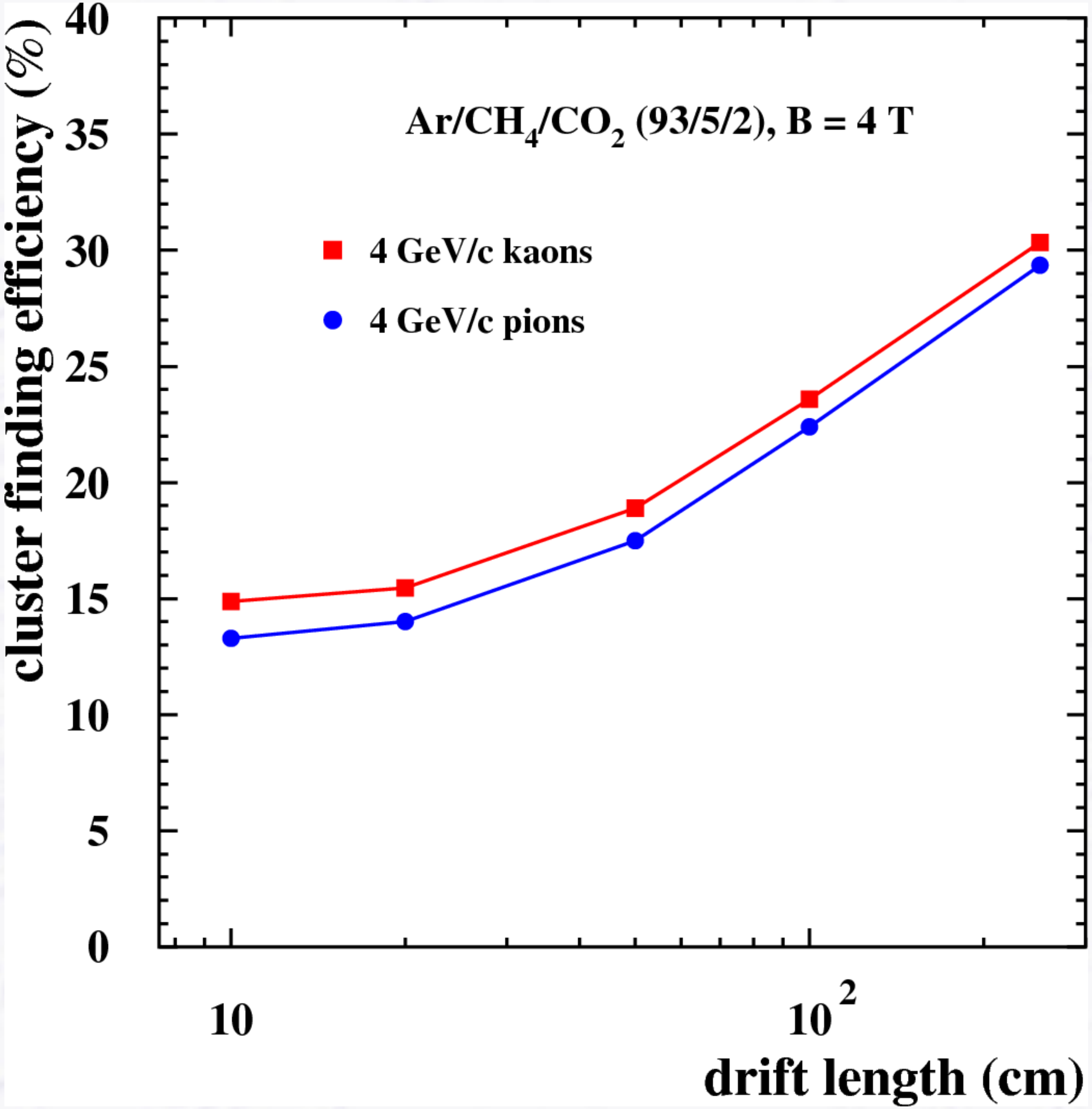
Efficiency vs. MediPix Threshold

- 4 GeV/c pions with 100 cm drift length
- Strong dependence on threshold (as expected)
  - variations by factor 2 from 800 e$^-$ to 2000 e$^-$
- Efficiency at default threshold ~22%



Efficiency vs. Drift Length

- 4 GeV/c pions and kaons
- Strong dependence on drift length
  - about 2 better efficiency at 250 cm drift length compared to short drift
  - (lateral) diffusion spread much larger at larger drift length
  - easier to find clusters
- Slight differences between pions and kaons
  - lower primary cluster density for kaons



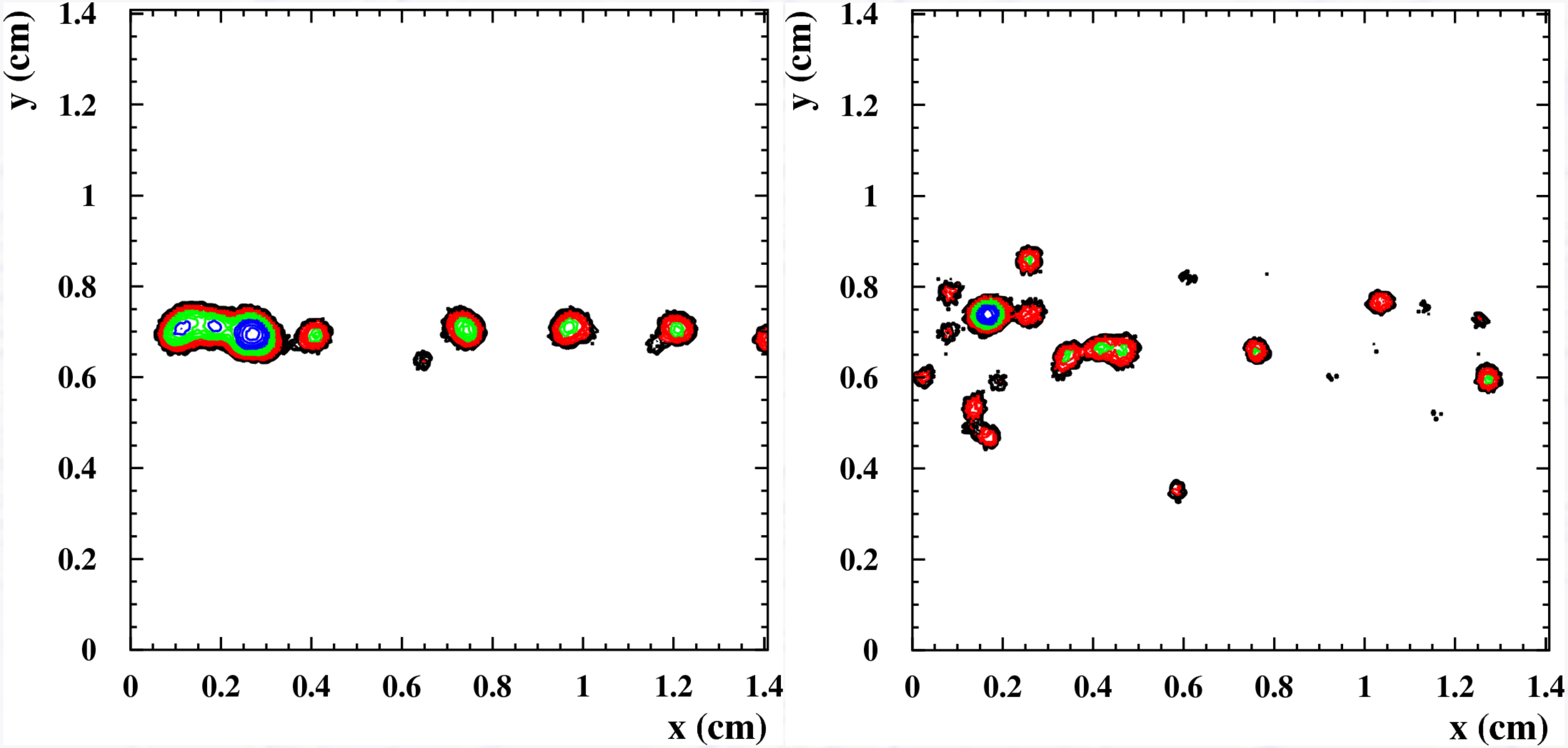
Diffusion Spread

10 cm drift length

efficiency = 13.5%

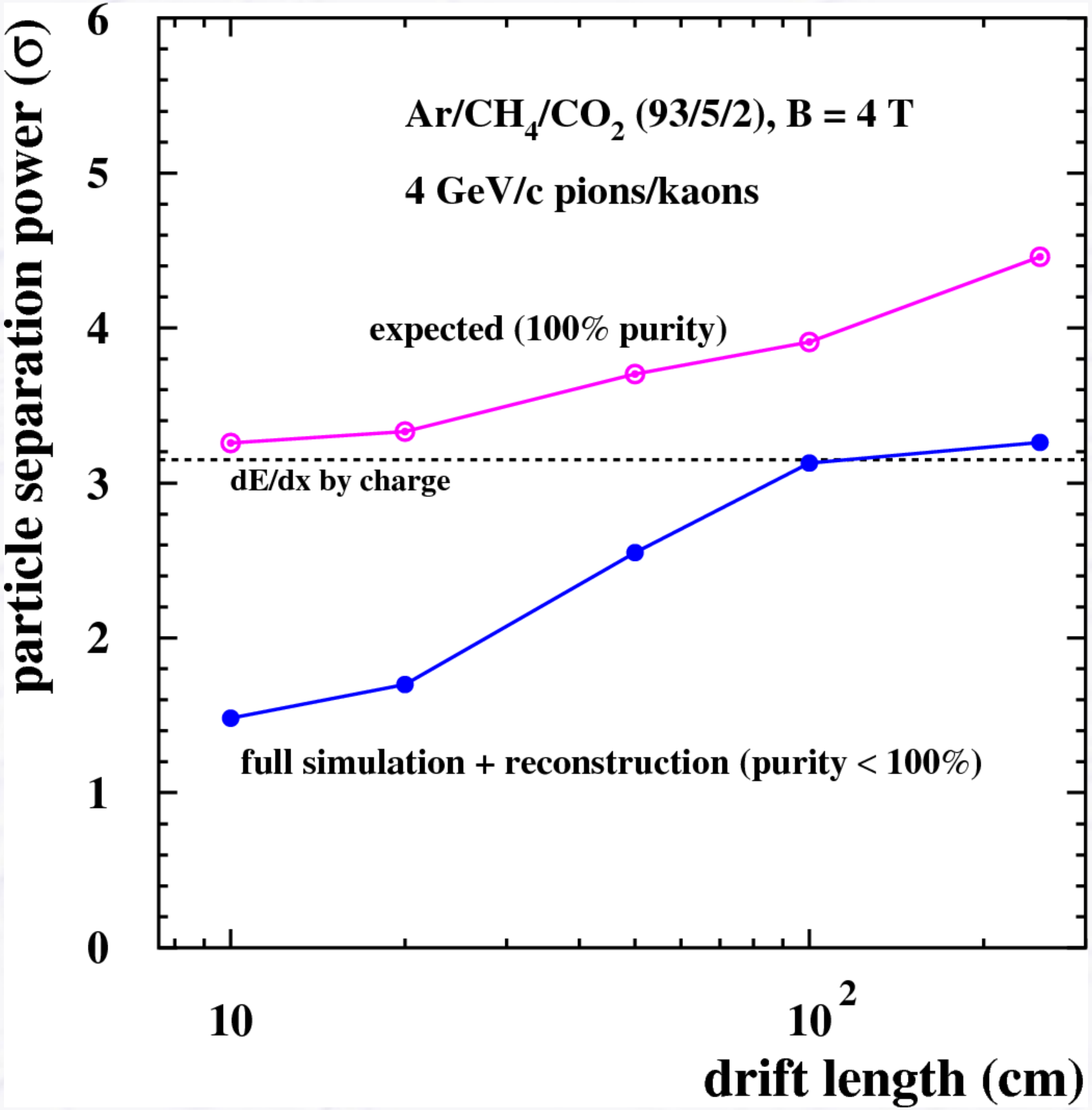
250 cm drift length

efficiency = 29.5%



Separation Power

- Expected separation power (at a given efficiency) always better than for dE/dx measurement by charge
  - assumes 100% purity of found clusters = no unresolved close primary clusters
- Full simulation and reconstruction gives worse results
  - purity < 100%
  - unresolved primary clusters



Cluster Counting Conclusions (prel.)

- dE/dx measurement by cluster counting has large potential
  - dE/dx resolution < 2% under perfect conditions (100% efficiency/purity)
- Bethe-Bloch function and particle separation power looks different compared to charge measurement
  - relativistic rise "truncated"
    - not sensitive to increase of secondary (delta) electrons at higher momenta
- Efficiency and purity is key to success
  - Helium mixtures do not really help
    - higher efficiency but less primary cluster density (no improvement as net effect)
  - at ~20% efficiency (with 100% purity) compatible to classical dE/dx measurement by charge
  - strong dependence on MediPix threshold and drift length (systematics!)
- Full simulation and reconstruction
  - separation power worse than expected for 100% purity
  - need better cluster reconstruction to resolve close-by primary clusters!!!

...will we see something like that...?
(the good old bubble chamber)