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dE/dx Particle ID at the TESLA-TPC

- estimated dE/dx resolution
  (based on running detectors experience)
- toy Monte Carlo results
  (study by Magali Gruwe)
- particle separation power

Do we need Particle ID ?

- Physics studies show
  - only "weak" physics cases, e.g.
    background reduction at heavy flavor tags
  - no need for dedicated particle ID detector

↪ dE/dx of TPC sufficient ("for free")
↑ not compromizing other detector performances

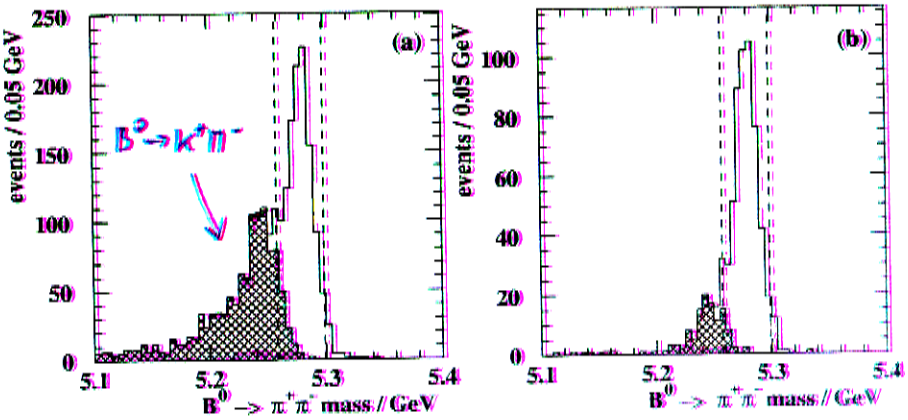
- Different situation at "Giga Z" option
  = 10^9 Z^0 at 2x 45 GeV

↪ Z^0 physics largely profits from particle ID

e.g. CP violation studies in b decays
(Richard Hawkings)

reconstruction of $B^0 \to \pi^+\pi^-$ decays

no dE/dx	with dE/dx (moderate res.)
S/B = 10:1	S/B = 40:1



Estimated dE/dx Resolution

(based on running detectors experience)

- Lehraus 1983:

$$\frac{\sigma\, dE/dx}{dE/dx} = 5.7\,\% * L^{-0.37}$$

↖ "total detector depth" = track length * pressure

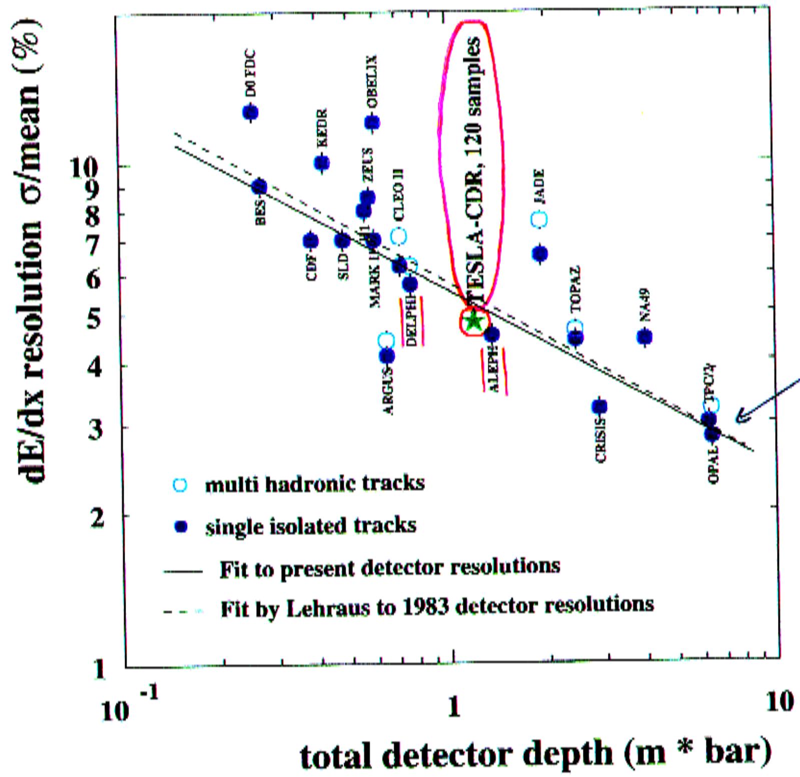
- with present detectors:

$$\ldots = 5.5\,\% * L^{-0.36}$$

← very similar

- do interpolation between DELPHI (= 5.7%) ALEPH (= 4.5%)

~4.8% at TESLA-TPC



high pressure detectors:

TPC/2γ : 8.5 bar

OPAL : 4 bar

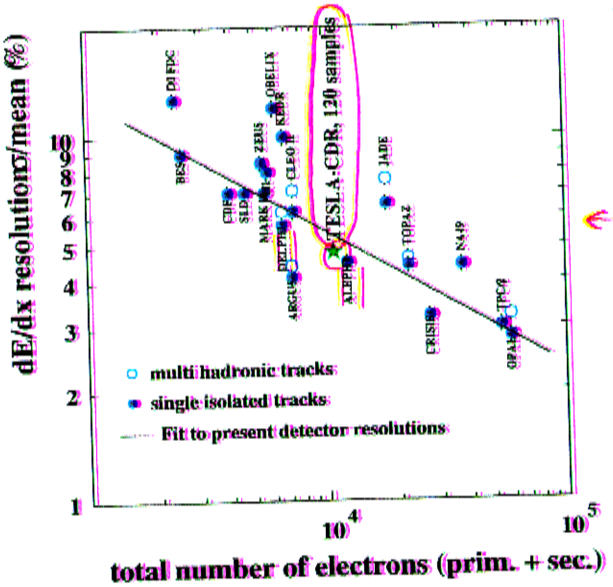
↑

not feasible for TESLA

Estimated dE/dx Resolution II

- Slightly better correlation using
  - total number of electrons (primary + secondary)
  - number of clusters (primary electrons only)

this is what we want to measure by dE/dx



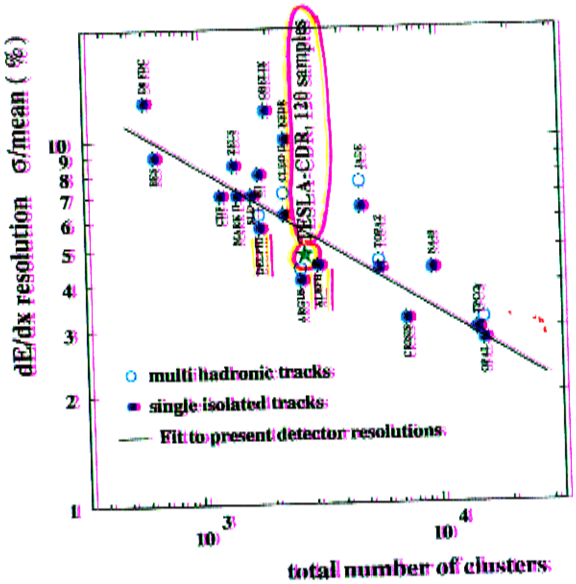
TESLA-TPC:

Ar/CH_4 (90:10)

120 cm track length

1 bar

very similar pictures



best correlation

Toy Monte Carlo Studies

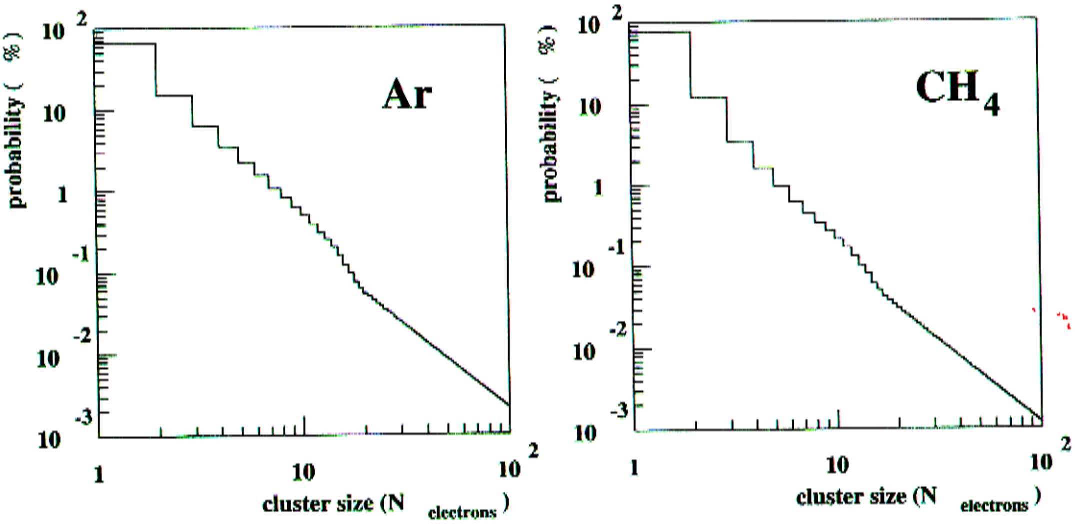
- More detailed studies needed (toy MC)
  - Various theoretical models on dE/dx available:

    e.g. Allison, Cobb
    Sternheimer, Peierls
    Bethe, Landau ...

    ↪ not always consistent picture
    + some complicated + difficult to use

→ try to avoid any dE/dx model

- use measured cluster size distributions
  (Fischle, Heintze, Schmidt NIM A301, 102, 1991)
- generate # of clusters along track (Poisson)
  + generate cluster size according to measured distributions



Measured Cluster Size Distributions

(also available: He, CO_2)

Toy Monte Carlo

- Add:
  - diffusion (~ 1m)
  - gas gain fluctuations (10^4)
  - electronics noise
  - crosstalk between samples

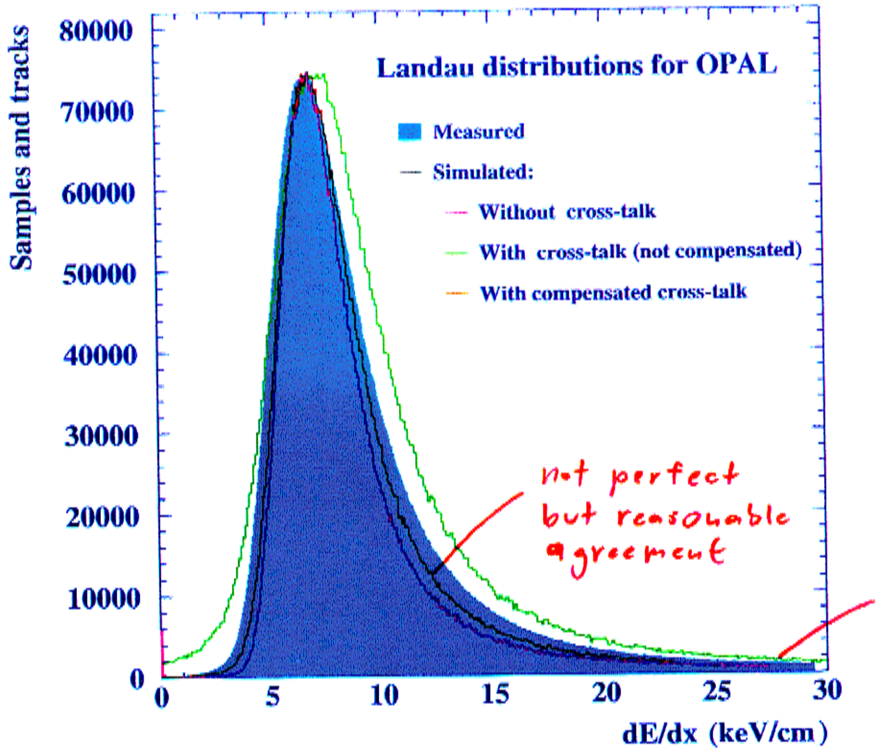
} vary + check influence

↑ correlations between samples !

- Get Landau distributions

↘ Compare with measured ones (here: OPAL)

↑ the hard case:
- 4 bars
- large crosstalk (4m long wires)
- hardware crosstalk compensation (partially)



not perfect but reasonable agreement

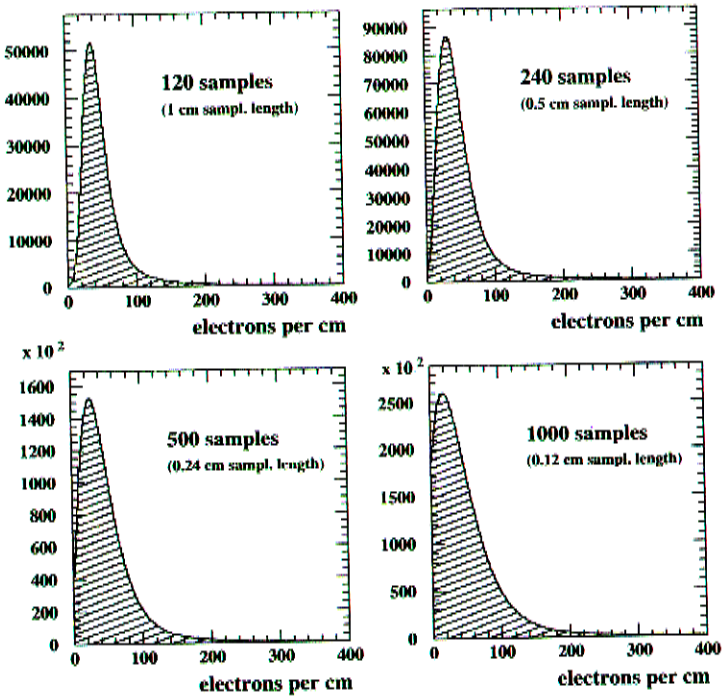
tail well described

Landau Distributions

- Keep track length constant (120 cm = TESLA-TPC)

  ↳ vary sampling length (or number of samples)

track length = 120 cm, Ar/CH$_4$ (90/10)



Landau distributions, 600 e$^-$ noise, Cross-talk

↖ ALEPH pre-amps

- More (shorter) samples → better resolution ?

  e.g. $\sigma(dE/dx) \sim N^{-0.43}$?

  ↖ valid for constant sampling length only

  ↳ Not true in general !

  ↳ Many empty samples if sampling length too short

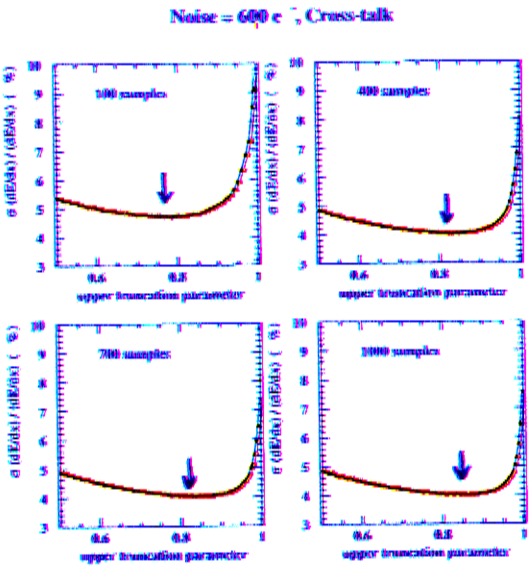
  ↖ difficult to handle in later dE/dx reconstruction

→ Sampling length needs optimization

Truncated Mean

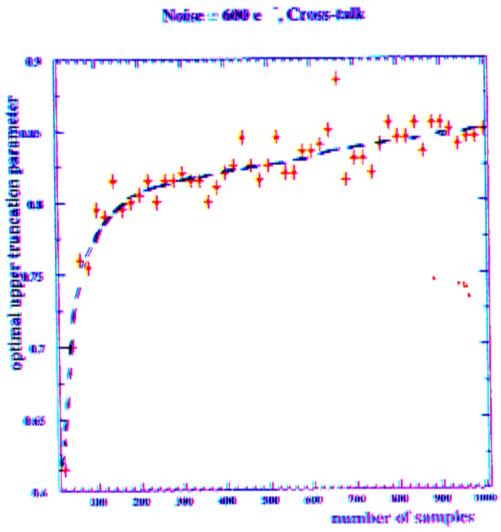
- Use standard truncated mean method ← get rid of Landau tail
  to reconstruct dE/dx per track
  (max. likelihood might be better
  but less robust) ← nowhere used at any running detector

- Resolution depends on upper truncation
  (where to cut the Landau tail ?)



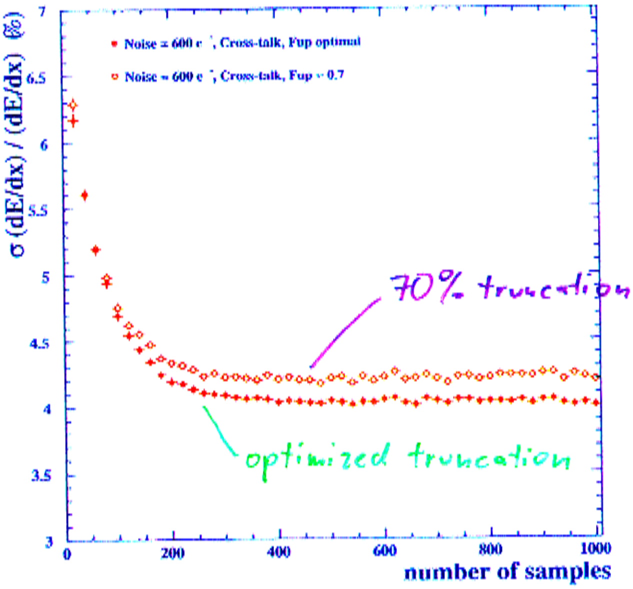
optimal truncation
depends on
sampling length

best resolution
at 75% - 80%
truncation for
100 ... 300 samples



dE/dx Resolution (cont.)

- Saturation reached at ~ 200 - 300 samples
  (~ 4 - 5 mm sampling length)

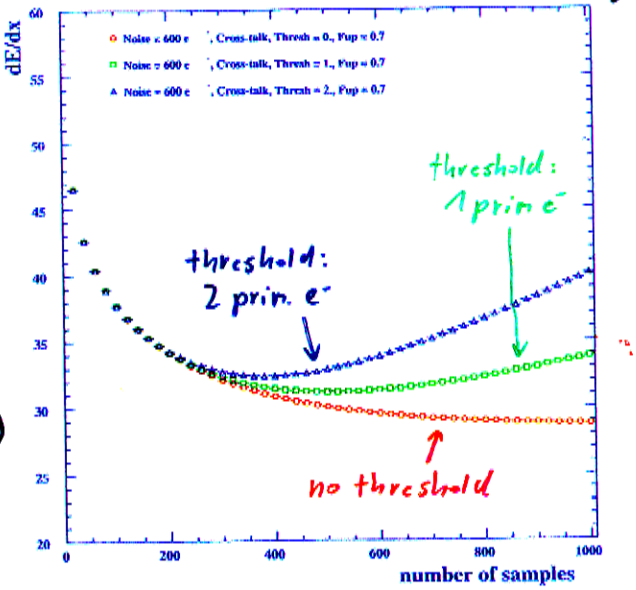


gain up to 0.2% resolution using optimized truncation

- Again: Do not use too many samples (too short sampling length)

reconstructed dE/dx becomes very sensitive to hit detection threshold for > 300 samples (< 4 mm sampling length)

BIAS!

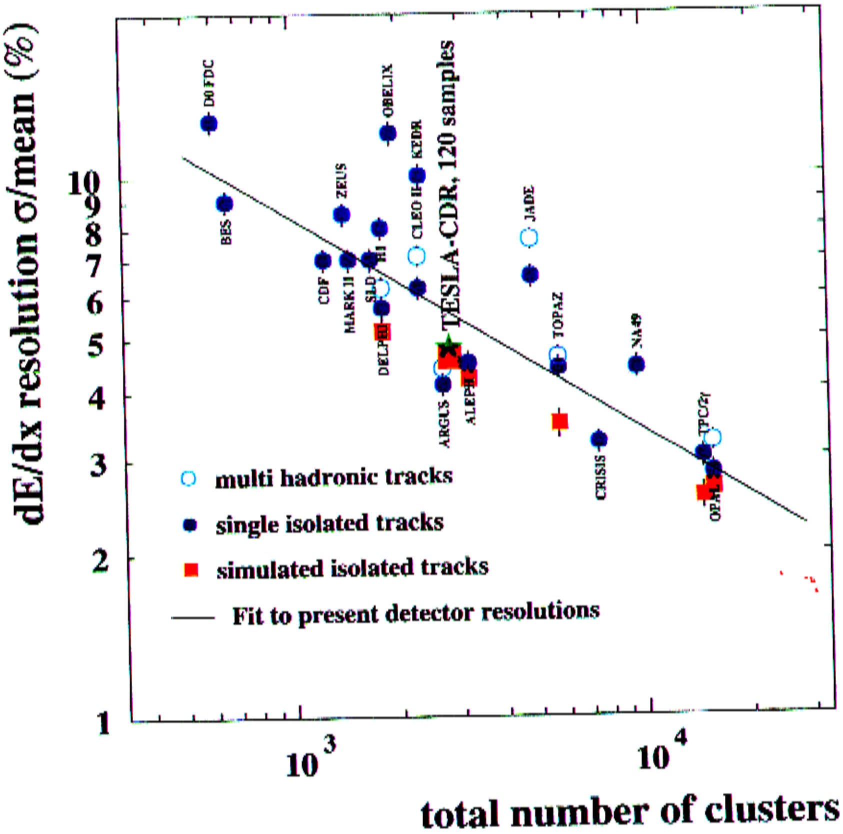


Simulation ⟷ Measurements

	simulated	measured
ALEPH	4.2 %	4.5 %
DELPHI	5.2 %	5.7 %
TOPAZ	3.5 %	4.4 %
TPC/2γ	2.5 %	3.0 %
OPAL	2.6 %	2.8 %
TESLA	4.3 % with 240 samples (0.5 cm) 4.6 % with 120 samples (1 cm)	

good agreement

simulations tends to have ~0.2 - 0.5 % better resolutions (calibration systematics ?)



Particle Separation Power

- Important for physics:

separation

$$\text{particle separation power} = \frac{(dE/dx)_A - (dE/dx)_B}{\sigma(dE/dx)_{A,B}}$$

in relativistic rise ! (> 2 GeV)

resolution

- dE/dx separation depends on
  - gas mixture:

	ionization (resolution)	rel. rise (separation)
light gas (He etc.)	bad	large ✓
hydrocarbons	good ✓	small

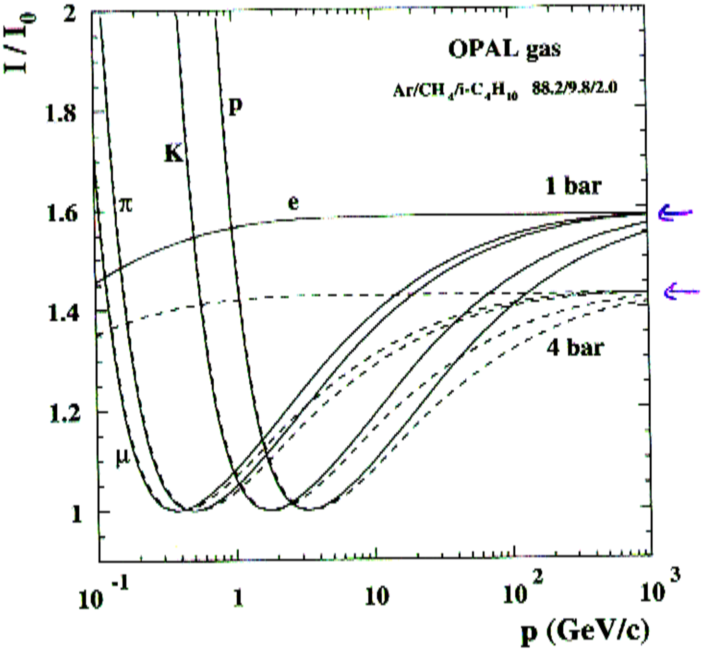
  - gas pressure: high pressure → better resolution, → smaller rel. rise

↓

better resolution dominates, best separation power at 3-4 bar

↑

but high pressure detector not feasible



← 1.58

← 1.43

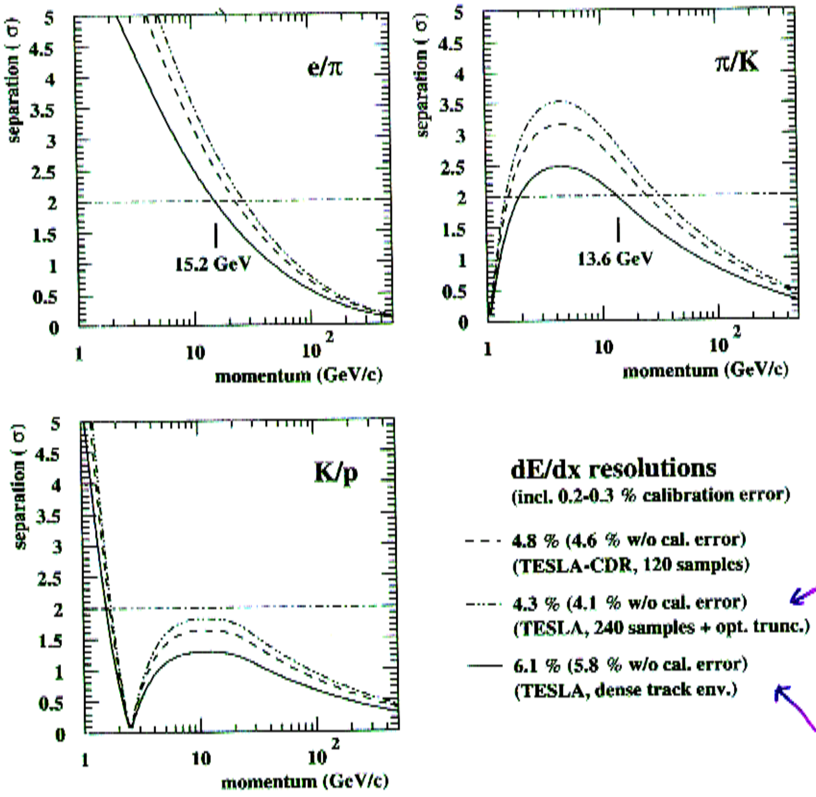
Expected Separation Power

- Simulation + measured dE/dx resolutions based on
  - isolated, clean tracks, full number of samples
    → "testbeam like"

- Particle ID in physics analysis use tracks in dense track environments (multihadronic jets)
  - reduced no. of samples (limited by double hit res.)
  - samples less clean (additional corrections)
    → at ALEPH, DELPHI, OPAL typically ~ 60 - 70 % of full no. of samples used

↓

$\sigma(dE/dx)_{AVERAGE} \approx \sqrt{2} * \sigma(dE/dx)_{150}$



4.3 % best

6.1 % average

dE/dx particle separation power

Conclusions

- dE/dx in TPC only tool for (hadronic) particle ID at TESLA
- results of detailed toy MC study (Magali Gruwe)
  - able to reproduce measured detector resolutions (with small offsets, calibration ?)
  - optimal resolution with ~ 5 mm sampling length (240 samples)
  - some improvements possible using optimized truncation
- estimated separation power (based on 6.1 % average dE/dx resolution in multihadrons)

  $e/\pi > 2\sigma$ up to 15.2 GeV

  $\pi/K > 2\sigma$ up to 13.6 GeV

  $K/p \sim 1.2\sigma$ max. in rel. rise
- Continue studies
  - different gases
  - influence of pad structure (mixture of different sampling lengths at GEM pads)
  - double hits / dense track environment
  - realistic dE/dx reconstruction